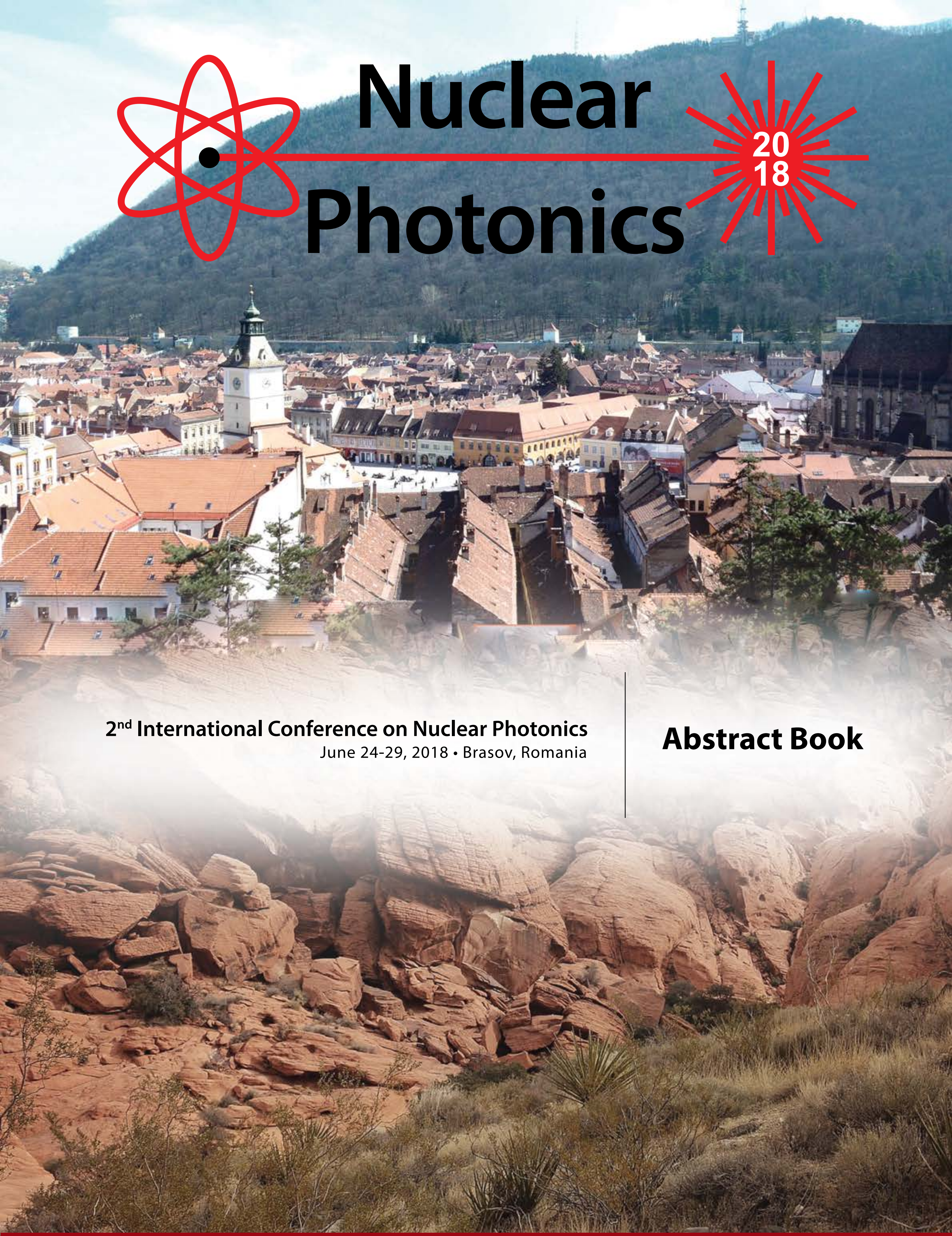

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Monday, June 25, 2018

02. Tutorial talks

10:40 – 13:00

Chair: C. A. Ur

Ultrahigh intensity laser technologies and worldwide capabilities

C. Barty

University of California, Irvine

This tutorial will review the basic concepts and architectures of ultrahigh intensity lasers systems capable of producing ultra-relativistic intensities of relevance to nuclear photonics applications, i.e. intensities significantly above 10^{21} W/cm^2. A world survey of existing and planned capabilities will also be presented.

Laser-driven ion acceleration

P. McKenna

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Ever since the first measurements in 2000 of multi-MeV/nucleon ions accelerated in the interaction of ultra-intense laser pulses with solid targets, there has been intense interactional research activity on this topic. This is motivated by the potential to produce compact sources of energetic ions with unique beam properties, with envisaged applications in nuclear physics (fusion and nuclear excitation), medicine (e.g. oncology and radioisotope generation) and high energy density physics (e.g. isochoric heating of matter, radiographic density diagnosis and probing highly transient fields in plasmas). This topic has also provided significant motivation for the development of lasers with increasing peak power, towards the multi-petawatt regime.

In this tutorial talk, I will provide an overview of laser-driven ion acceleration. The basic acceleration processes will be briefly reviewed, together with novel concepts and hybrid mechanisms. The experimental state of the art will be summarized and recent progress discussed. The use of target engineering and all-optical methods for ion beam control will also be discussed.

Accelerator-based gamma sources: review and perspectives

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Electron accelerators have been utilized for generation of gamma-ray beams for decades. The accelerator-based gamma sources can be categorized according to the principle of photon generation, Bremsstrahlung and Compton scattering. The Bremsstrahlung, emission of high-energy photons by electrons decelerating in a metal target, has a long history since the discovery of X-ray by Röntgen but it still plays an important role in scientific and industrial applications of gamma-ray beams because it can generate a gamma-ray beam with a simple apparatus. The second category, Compton scattering gamma-ray source, emerged after the invention of the laser in 1960's. In the Compton source, high-energy photons are generated via the collision of relativistic electrons and laser photons. Since the Compton source provides energy-tunable quasi-monoenergetic gamma-ray beams with linear and circular polarization, it has expanded the range of gamma-ray applications.

The Compton source itself has continuously evolved in its performance, the photon flux and the energy width, following the progress of laser and accelerator technologies. The photon flux can be increased by increasing the density or the frequency of collision of electron and photon beams. The energy width can be narrowed by improving electron beam emittance and energy purity. In most of the gamma-ray applications, the figure of merit of a gamma source is measured by spectral density and bandwidth of the gamma-ray at an experimental station. The spectral density is directly connected to the event rate of interest and the bandwidth limits the total count rate of gamma-ray detectors. Combining modern accelerator and laser technologies, one can design Compton sources to achieve a spectral density of 10^5-10^7 ph/s/eV and a bandwidth of $\leq 1\%$ at a wide range of gamma-ray energies.

In this tutorial talk, we review the accelerator-based gamma-ray sources and discuss future perspectives.

This work was supported in part by JSPS KAKENHI Grant Number 17H02818.

Photonuclear Physics

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Photons in the range of several MeV are an ideal tool to investigate the atomic nucleus. The pure electromagnetic interaction leads to a very selective population of excitations with low multipolarity and large electromagnetic transition strengths to the ground state, various nuclear properties can be derived in a model independent way [1].

This tutorial will start with an overview about the history of photonuclear physics and photon sources. The mechanism for the excitation by photons below and above the particle threshold will be explained. Some highlights of photonuclear research in the last decades will be discussed [2, 3].

Supported by the BMBF (05P2015 ELI-NP).

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Monday, June 25, 2018
03. Keynote lecture
14:20 – 15:10
Chair: N.V. Zamfir

Getting beyond the laser field horizon:
the single cycle high energy pulse short cut

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For several years EP and UCI have been pursuing a new technique based on high energy single cycle pulses compression in the X-ray regime beyond forecasted level set by the today’s ELI program. This regime, will lead to revolutionary applications such as TeV accelerator on the chip, compact relativistic proton accelerator, sources of muon, neutrino and compact free electron laser that could reshape, fundamental science, medicine, material and environment ambits. This ambitious task warrants the creation of a task force formed by the most advanced laboratories eager to explore the regime beyond today’s intensity horizon.

Monday, June 25, 2018
04. ELI facilities and research programs
15:10 – 16:00
Chair: D. Stutman

Where does ELI–NP stand now?

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Since chirped pulse amplification scheme [1] has changed the game in high energy density physics, the available laser intensity has kept increasing, can reach 10^{23} W/cm^2 or even higher, and can deliver radiation higher than the previously used in nuclear facilities. In order to make use of this capability in full depth, ELI-NP has been funded to come up with both high intensity laser and high briliance gamma beam systems through the European Light Infrastructure (ELI) project for the state of the art and beyond.

High Power Laser System (HPLS): The high power laser system (HPLS) consists of OPCPA, Ti Sapphire configuration at the central wavelength 820 nm with 60 nm bandwidth, the output energy 250 J, the pulse width 25 fs, the contrast ratio10^{13} with 50 cm beam diameter. This may enable to create a focused laser intensity 10^{22}–10^{23} W/cm^2 on target. 3 PW performance test is planned in April 2018.

Gamma Beam System (GBS): The output of gamma–ray beams comes up with continuously tunable energy in the range from 200 keV to 19.5 MeV. The production of quasi–monochromatic gamma beams is based on the Inverse Compton Scattering (ICS) process of green laser light pulses off relativistic electron bunches up to 700 MeV. The resulting GBS is based on a high–quality electron–photon collider with luminosity at the level of about 2 x 10^{35} cm^{-2} s^{-1}, that is almost one order of magnitude better than what was achieved at LHC in CERN [2].

Planned Experiments: The commissioning phase may be expected to start as early as in 2018. A number of experiments have been proposed for the Day–1 phase and has been recommended by the International Scientific Advisory Board (ISAB). For example gamma ray conversion efficiency, high–energy electron acceleration, and non–linear QED [3] are being prepared for the HPLS. First–phase experiments for the GBS involve studies of the distribution of the E1 strength in the region of the Pigmy Dipole Resonance (PDR) and the Giant Dipole Resonance (GDR). Delbrück Scattering is also considered. These experiments will take advantage of the narrow–bandwidth pencil–size beams at ELI–NP, which provide the possibility for studies low–abundance targets, e.g. NRF studies in the actinide nuclei. Call for further proposal will be announced from ELI–DC [4] organization.

Acknowledgement: This project work has been cooperated with the entire staffs, groups and management of ELI–NP. The efficient and speedy installation of HPLS by Thales is commended. Excellent technical and scientific suggestions have been made by ISAB chaired by Prof. T. Tajima, UC Irvine. Work supported by the Extreme Light Infrastructure – Nuclear Physics (ELI–NP) Phase II, a project co–financed by the Romanian Government and the European Union through the European Regional Development Fund and the Competitiveness Operational Programme (1/07.07.2016, COP, ID 1334).

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3. N.V. Zamfir *et al*., *Romanian Reports in Physics*, Vol. **68**, Supplement I & II, (2016).
4. ELI-DC: https://eli-laser.eu/

Figure1. ELI-NP Experimental and Office Buildings

News from ELI-ALPS

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The Attosecond Light Pulse Source (ALPS) of the Extreme Light Infrastructure (ELI) is currently implemented in Szeged, Hungary. The central mission of the ELI-ALPS facility is to develop and provide access to a wide range of “beyond the state of the art”, laser driven, radiation and particle secondary sources, to the international scientific community [1, 2].

The first laser systems of ELI-ALPS are installed in 2017 together with a THz facility. Commissioning experiments of external expert groups in collaboration with ELI-ALPS researchers started being implemented in January 2018. Overall 10 commissioning experiments will be conducted in 2018.

In this presentation I will give an overview of the ELI-ALPS Infrastructure, with emphasis to the commissioning and the future planed experiments utilizing unique parameters of the ELI-ALPS sources.

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2. D. Charalambidis *et al*. in „Progress in Ultrafast Intense Laser Science XIII“, *Springer Series in Chemical Physics* **116**, p. 181-215 (2017).

Monday, June 25, 2018

05. Fundamental Nuclear Structure and Low-Energy QCD physics

16:30 – 18:40

Chair: D. Balabanski

Low-energy QCD research at HIγS

C. R. Howell[1,3] and Mohammad W. Ahmed[2,3]

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The mechanisms by which nucleon structure and the residual strong nuclear force emerge from color interactions in QCD remain mysteries. These phenomena are consequences of quarks and gluons interacting at confinement-scale distances where color forces are strong, i.e., in the non-perturbative regime of QCD at low energies and distances of order the size of nucleons. Effective field theories (EFT), e.g., chiral perturbation theory, and Lattice QCD calculations provide theoretical frames that connect low-energy nuclear phenomena to QCD. The photon is a theoretically well-understood probe of nuclear and nucleon structure over wide distance and energy ranges. The angular-momentum selectivity in gamma-ray (γ-ray) induced reactions enable strategic investigations of the collective motion response of the internal degrees of freedom associated with electric charge and current distributions inside nuclei and nucleons.

The High Intensity Gamma-ray Source (HIγS) at TUNL delivers the most intense nearly mono-energetic γ-ray beam to nuclear physics experiments in the world. The beam at HIγS is produced by Compton backscattering of electrons from photons inside the optical cavity of a storage-ring based free electron laser. Circularly and linearly polarized γ-ray beams are available with beam polarization greater than 95%. Beams are delivered to experiments with energies from 1 to 100 MeV with energy spread selectable down to about 1% by collimation. The nuclear physics research program at HIγS includes nuclear structure, nuclear fission, nuclear astrophysics and low-energy QCD. The low-energy QCD program is described in this presentation.

The focus of the low-energy QCD program at HIγS is to measure data that are sensitive to the long-range structure of nucleons and details of two- and three-nucleon interactions in few-nucleon systems. The main thrust of this effort is to reduce uncertainties in low-energy nucleon-structure parameters in effective field theory calculations and to evaluate ab-initio few-nucleon calculations for different models of two- and three-nucleon interactions. The electric (α) and magnetic (β) polarizabilities of the proton and neutron are determined via Compton scattering from proton, deuteron and few-nucleon targets at beam energies from about 50 to just above 100 MeV and analysis of these data with EFT calculations. High accuracy exclusive cross-section measurements of photo-disintegration of few-nucleon systems at energies below 30 MeV are used to investigate effects of three-nucleon interactions. Recent results, current activities and plans for new experiments will be summarized.

This work is supported in part by the U.S. Department of Energy Office of Nuclear Physics under grant no. DE-FG02-97ER41033 and DE-SC000536.

Investigation of the Pygmy Dipole Resonance with photon beams

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Beside the Giant Dipole Resonance (GDR), many nuclei show the feature of additional low-lying electric dipole (E1) strength below and around the particle separation energies, which is usually denoted as Pygmy Dipole Resonance (PDR) [1]. The existence of the PDR in nearly every studied nucleus and the smooth variation of its properties lead to the assumption that the PDR is a newly discovered collective mode. While some of the gross characteristics are reproduced by different theoretical model descriptions, its detailed structure and the degree of collectivity are a matter of ongoing discussions.

An excellent tool to investigate bound E1 excitations is the method of nuclear resonance fluorescence (NRF) [2], which has been used in the last years to perform systematic studies of E1 strength below the neutron separation energy in nuclei of different mass regions [1]. Besides the possibility to perform systematic studies of the gross features of low-lying E1 strength this experimental method allows the investigation of the fine structure or of individual states using high-purity Germanium (HPGe) detectors in the γ-ray spectroscopy. Modern photon sources for this kind of experiments are bremsstrahlung and laser-Compton-backscattering (LCB). While experiments with bremsstrahlung allow to investigate a large energy region within one experimental run and to identify single photo-excited states, the mono-energetic and highly polarized character of LCB is ideal to investigate certain energy regions or individual states in detail. In addition, experiments with mono-energetic photons provide the possibility to get insight into the decay properties of the PDR [3]. To further increase the sensitivity to certain decay channels and to investigate in detail the decay behavior of the PDR we recently performed γ-γ coincidence spectroscopy in combination with the LCB beam at the High-Intensity Photon Source (HIγS) using the new installed γ^3 setup [4]. An overview on the available experimental data on low-lying E1 strength obtained with the NRF method will be presented with a focus on experiments using LCB photons.

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Decay characteristics of the nuclear scissors mode from Compton-back-scattering

V. Werner[1], J. Kleemann[1], U. Gayer[1], N. Pietralla[1], T. Beck[1], M. Bhike[2], V. Derya[3], S. Finch[2], J. Isaak[1], Krishichayan[2], B. Löher[1], H. Pai[1,4], O. Papst[1], P.C. Ries[1], C. Romig[1], D. Savran[5], M. Schilling[1], W. Tornow[2], M. Weinert[3], J. Wilhelmy[3], M. Zweidinger[1]

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The use of near-monoenergetic, polarized gamma-ray beams has great advantages over conventional beams from bremsstrahlung. The latter allow easily to survey broad energy regions for the nuclear dipole (and to a lesser extent quadrupole) response, but are hampered by large background toward lower energies from non-resonant scattering processes. Beams from Compton-back-scattering (CBS), such as provided at the HIGS facility at TUNL, Duke University, overcome this limitation to some degree. The monoenergecity of CBS beams allows to search for decay branches from dipole-excited states to lower-lying states which would be below the sensitivity limit of a bremsstrahlung experiment. The polarization, on the other hand, makes it easy to assure the parities of excited states with an appropriate polarimeter setup [1].

We made use of this approach in a study of the decay behavior of the nuclear scissors mode [2,3] in nuclei which are mother or daughter isotopes of double-beta decay events. In particular, we concentrate on isotopes which are candidates in the ongoing search for neutrino-less double-beta ($0\nu\beta\beta$) decay. Recently, the $0\nu\beta\beta$ decay from ^{150}Nd into ^{150}Sm has been proposed to be dominated by the decay into the first excited 0^+ state of ^{150}Sm [4]. This can be seen as a consequence of shape coexistence, which is known to be a dominant feature in the lowest structures of the N = 90 isotones [5], hence, of ^{150}Nd [6]. Also in neighboring isotopes at N = 88, such as ^{150}Sm, shape coexistence may still occur, with the spherical configuration dominating the ground state.

Since $2\nu\beta\beta$ and $0\nu\beta\beta$ decay would be strongest between states with like configurations, the mixing of spherical and deformed configurations into both, the ground and first excited 0^+ states, should enhance the decay into the 0_2^+ state of ^{150}Sm. Since photo-excitation is particularly sensitive to dipole-excited states, we use the decay behavior of the nuclear scissors mode as a probe for the occurrence of shape coexistence. In a spherical nucleus, the decay of the scissors mode into the first excited 0^+ state is typically enhanced over the ground state decay, and in deformed nuclei the ground-state decay is enhanced over the excited-state decay. Hence, similar M1 decay strengths into both 0^+ states present a signature for shape coexistence, complementary to the more difficult to measure E0 strength connecting the 0^+ states. The decays of interest have been observed for both, ^{150}Nd and ^{150}Sm. In addition, the location of the energy of the scissors mode allows to fix isovector operators, and along with the structural classification of the nuclei of interest the new data serves as a new constraint for structure calculations which ultimately predict nuclear matrix elements for $0\nu\beta\beta$ decay.

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Spectral Features of Electric and Magnetic Dipole and Quadrupole Modes

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Electric and magnetic dipole excitations reflecting the dynamics of the nuclear skin are in the focus of our studies. The theoretical approach is based on density functional theory as the appropriate theoretical scheme of high predictive power for systematic investigations of nuclear ground and excited states and advanced quasiparticle-random-phase approximation and multi-phonon techniques [1].

New evidences on the existence of pygmy quadrupole resonance in tin isotopes, predicted theoretically a while ago in our approach [2], and now being confirmed by three independent experiments in ^{124}Sn [3, 4], will be also discussed. In particular, novel systematic data in tin isotopes indicate clearly the presence of a multitude of discrete low-energy 2^+ excitations of neutron type, following closely the predicted pygmy quadrupole resonance mode. The independent measurements with different probes of E2 transitions associated with pygmy quadrupole resonance confirm the theoretically prediction of their dominant isoscalar nature. The measured γ-decay branching ratios clearly distinguish between PQR neutron skin excitations and multi-phonon states.

Furthermore, of special interest is the description of the fine structure of pygmy dipole resonance and the relation between the pygmy dipole resonance and the neutron skin [5]. Presently, a direct method to extract experimentally the neutron skin thickness from the pygmy dipole resonance does not exist. This could be related to the fact that at excitation energies below the neutron separation energy the pygmy resonances of different multipolarity coexist with a variety of modes, such as the tail of the giant resonances and multi-phonon excitations. The distinction between pygmy and other modes could be obtained theoretically in our microscopic theory [1]. Recently, new aspects of nuclear dynamics below and around the neutron threshold has been explored in studies on the fine and gross spectral features of electric and magnetic dipole modes up to giant resonance energies in ^{206}Pb [5]. These studies provide a precise determination of the nuclear dipole polarizability and its relation to the nuclear skin thickness and symmetry energy.

The importance of the pygmy resonances for understanding of fundamental properties of the nucleus and nuclear matter such as neutron and proton root-mean-square radii, nuclear skin thickness and symmetry energy, respectively are discussed.

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Electric Dipole Response of Nuclei Studied by Proton Scattering

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The responses of nuclei against external electromagnetic fields are of fundamental importance. Among various external fields, the electric dipole (E1) field induces isovector responses that are sensitive to the symmetry energy of the nuclear equation of state. The knowledge of the symmetry energy is indispensable for the study of the neutron-star properties, like radius-mass relation, internal structure and cooling process, as well as the dynamical processes of core-collapse supernova, neutron-star mergers and their gravitational waves [1]. The density dependence of the symmetry energy has also a strong correlation with the neutron-skin thickness of heavy neutron-rich nuclei. The *E1* response of nuclei was widely studied by gamma-ray induced reactions. The full *E1* response was, however, not fully obtained especially at around the neutron separation energy. Recent finding of the low-energy dipole strength, often called pygmy dipole resonance (PDR), arose in the situation.

We have developed a new experimental method [2] employing high-resolution proton inelastic scattering at very forward angles that is suitable for extracting the full *E1* response across the neutron separation energy, covering fully the PDRs and the giant dipole resonances (GDRs). The missing mass spectroscopy method enabled us to probe the total strength independently of the decay channels. Multipole decomposition and spin-transfer analyses allowed the extraction of the full *E1* strength distribution including contributions from unresolved small strengths. The method is complementary with the high-resolution gamma-ray-induced reactions planned at ELI-NP.

The method has been applied to ^{208}Pb [2], ^{120}Sn [3], ^{48}Ca [4] and other representative stable nuclei. The full E1 strength distributions were extracted for the excitation energies from 5 to ~20 MeV. The static electric-dipole-polarizabilities were precisely determined by applying the inversely-energy-weighted sum-rule of the *E1* strength. Constraints on the symmetry energy parameters was determined with a help of the mean-field model calculations [5]. The method has been expanded for the studies of PDRs [6], gamma-strength functions, and nuclear level-densities [7]. Coincidence measurements of the gamma decay are progressing.

I will report on the recent studies on the electric dipole response of nuclei from the proton inelastic scattering and on the projects in near future.

1. See *e.g.* J.M. Lattimer and M. Prakash, "Neutron star observations: Prognosis for equation of state constraints," *Phys. Rep*. **442**, 109 (2007).
2. A. Tamii *et al*., "Complete Electric Dipole Response and the Neutron Skin in ^{208}Pb," *Phys. Rev. Lett.*, **107**, 062502 (2011).
3. T. Hashimoto *et al.*, "Dipole polarizability of ^{120}Sn and nuclear energy density functionals," *Phys. Rev. C*, **92**, 031305(R) (2015).
4. J. Birkhan *et al*., "Electric Dipole Polarizability of ^{48}Ca and Implications for the Neutron Skin, " *Phys. Rev. Lett.*, **118**, 252501 (2017).

5. X. Roca-Maza *et al*., "Neutron skin thickness from the measured electric dipole polarizability in ^{68}Ni, ^{120}Sn, and ^{208}Pb," *Phys. Rev. C*, **92**, 064304 (2015).
6. See *e.g.*, I. Poltoratska *et al*., "Pygmy dipole resonance in ^{208}Pb," *Phys. Rev. C*, **85**, 041304 (2012).
7. D. Martin *et al*., "Test of the Brink-Axel Hypothesis for the Pygmy Dipole Resonance," *Phys. Rev. Lett.*, **119**, 182503 (2017) and the references therein.

Study of photon strength functions via (γ,γ'γ'') reactions using quasi-monochromatic γ-ray beams

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The photon strength function (PSF) serves as an essential input for nuclear astrophysical model calculations. It plays an important role in capture and photo-disintegration reactions as well as in astrophysical scenarios describing the nucleosynthesis. In the past, different experimental methods and approaches have been used to study the PSF. However, many of these methods are model dependent either in the reaction mechanism itself or in the data analysis. In this contribution, we present a model-independent approach to extract the PSF in real- photon scattering experiments using quasi-monochromatic photon beams provided by the High Intensity γ-ray Source [1] at Duke University, Durham, NC, USA. After the nuclear excitation via resonant photoabsorption, the subsequent deexcitation via γ-emission from the target nuclei is measured with the γ-γ coincidence setup γ^3 [2]. This experiment allows to determine the PSF in two different ways. On the one hand side, it is possible to measure the photoabsorption cross section as a function of the excitation energy, which can be linked to the PSF build on the ground state. On the other hand, by extracting intensities from primary transitions to low-lying excited states, the PSF can be determined as a function of the γ-ray energy for different excitation energy regions. These two independent approaches enable to separately study the PSF in the excitation and the decay channel, respectively. The comparison of experimental data measured with ^{128}Te to statistical model calculations provides evidence, that the PSF extracted from the photoabsorption cross section is not in an overall agreement with the PSF determined from direct transitions to low-lying excited states. The corresponding methods and results are presented and discussed.

This work is supported by the Alliance Program of the Helmholtz Association (HA216/EMMI), the Deutsche Forschungsgemeinschaft under Grant Nos. SFB 634, SFB 1245 and ZI 510/7-1, and the U.S. Department of Energy, Office of Nuclear Physics, under Grant No. DE-FG02-97ER41033.

1. H. R. Weller *et al*., *Prog. Part. Nucl. Phys*., **62**, 257 (2009).
2. B. Löher *et al*., *Nucl. Instr. Meth. Res. A*, **723**, 136 (2013).

Tuesday, June 26, 2018

06. High Intensity laser-plasma interaction

08:30 – 10:20

Chair: P. McKenna

Performance and Applications of Multi-PW Laser at CoReLS

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Ultrahigh intensity lasers have been developed for the exploration of high field science in a number of institutes around the world. At Center for Relativistic Laser Science (CoReLS) of Institute for Basic Science one of the two PW laser beamlines has been upgraded to a 20 fs, 4 PW laser in 2016 [1]. With the completion of the upgrade a series of commissioning experiments have been performed using the target chambers since 2017. From the performance test of a double plasma mirror system an overall throughput efficiency of 70% was measured, which greatly exceeds the previous result, about 40%, obtained with the 1 PW beamline. It is a good indication of the improved contrast ratio achieved by installing XPW and OPCPA stages in the frontend of the 4PW laser. In the conference experimental results obtained with the 4PW laser, relevant to the research programs of ELI facilities, will be presented.

1. J. H. Sung *et al*., “4.2 PW, 20 fs Ti:Sapphire Laser at 0.1 Hz,” *Opt. Lett.* **42**, 2058 (2017).

Hybrid OPCPA/Glass 10 PW laser at 1 shot a minute

G. Chériaux[1], E. Gaul[1], R. Antipenkov[2], F. Batysta[2], T. Borger1, G. Friedman[1], J.T. Greene[2], D. Hammond[1], J. Heisler[1], D. Hidinger1, A. Jochmann[1], M. Kepler1, A. Kissinger[1], D. Kramer[2], J.C. Lagron[2], A. Meadows[2], B. Rus[2], P. Trojek[2], S. Vyhlídka[2], T. Ditmire1

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State-of-the-art physics experiments are pushing the development of lasers with ultra-high peak power pulses. 4 PW pulses have been produced with Titanium Sapphire [1] and 10 PW with the same medium is scheduled at LULI (Apollon) [2] and at ELI Nuclear Physics in Romania.

Another approach is to use Nd-doped glass, whose interest is in its capability of delivering higher energy albeit at longer pulse duration. Based on this gain material, the 10 PW laser will be delivered by National Energetics to ELI-Beamlines in Prague. This is a hybrid laser configuration based on OPCPA for large spectral bandwidth and contrast management and on actively liquid-cooled mixed Nd:glass amplifiers for thermal and spectral management. The laser architecture is described in Figure 1.

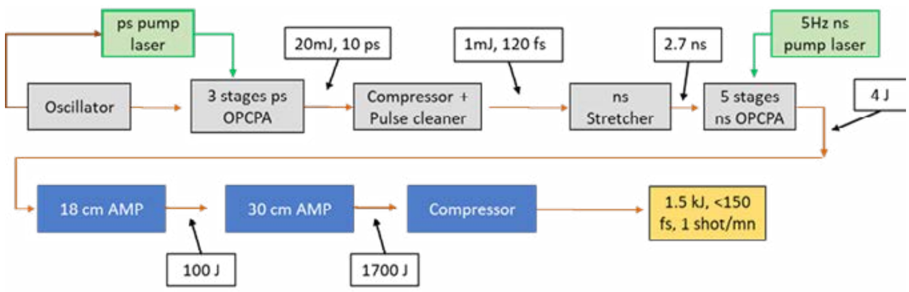


Figure 1: Layout of 10 PW laser system

The system can be divided into 3 main sections; Front-End, Power Amplifiers and compressor.

The Front End consists of a 5 Hz three-stage BBO picosecond OPCPA delivering 20 mJ pulses that are subsequently compressed down to 120 fs before entering a non-linear pulse cleaner [3, 4] based on Optical Parametric Amplification in a degenerated configuration.

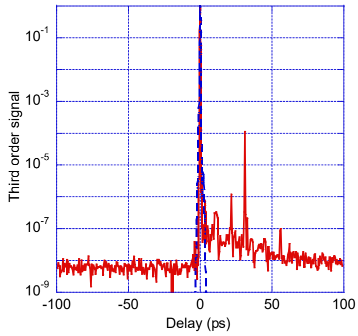


Figure 2: measured third order correlation after the pulse cleaner (solid line). Calculated $I_{signal}(t)^3$ (dashed line)

In the pulse cleaner, the compressed ps OPCPA pulse is split in two; 90% is converted to the second harmonic that will be the pump pulse in the parametric process and the remaining 10% will be the signal. With appropriate balancing between the different waves, an idler with an energy of 2 mJ at the same wavelength and bandwidth as the signal is generated. Thanks to this three waves process, the output pulse goes as $I_{signal}(t)^3$. Figure 2 shows a third order correlation measurement of the pulse after the pulse cleaner. The actual noise level of the third order correlator is $7x10^{-9}$. The solid line curve is the experimental one and the dashed curve is the calculated $I_{signal}(t)^3$. The cleaned pulses are then stretched with a ratio of 214 ps/nm and transported to the nanosecond OPCPA section consisting of 5 stages. Thanks to temporal shaping of the EKSPLA 5 Hz Nd:YAG lasers, the spectral shape of the amplified output pulses can be tailored to pre compensate for gain narrowing in the PA. Figure 3 shows the output beam profile of the 4 Joules amplified pulses. Beam shaping and relay imaging throughout the 5 stages allows obtaining a square and flat energy distribution.

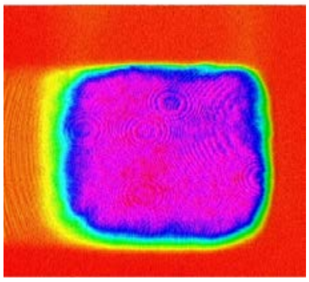
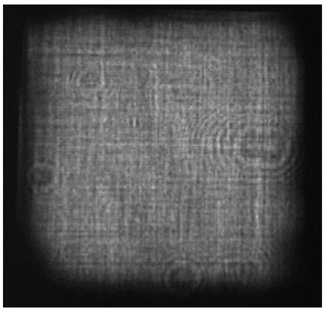


Figure 3: 4 Joules, 5 Hz, output spatial beam profile of Front End

The power amplifier section is composed of 2 multi-pass amplifiers (PA1 and PA2) leading to an amplified energy of more than 1500 Joules. Each amplifier consists of a full reflective relay imaging system allowing four passes in the amplification modules. Silicate and phosphate glass are used for bandwidth management and high energy amplification. The thermal management to allow operation at one shot a minute is obtained by using a split-disk arrangement with liquid coolant in between glass slabs. We are currently ramping up the energy in PA1. Up to 2.35 Joules pulses with shaped spectrum have been seeding the amplifier. The amplified energy is 38.1 Joules. Figure 4 shows results in terms of output beam profile and spectrum.



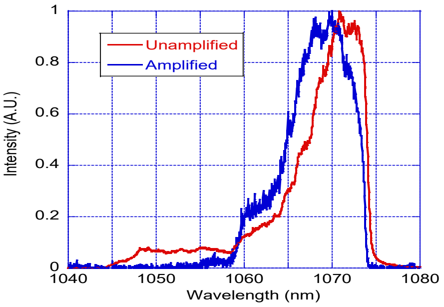


Figure 4: 38 Joules output beam profile of PA1 (left). Input and output spectrum (right)

PA2 is in process of being assembled and thereafter activated. Full results on energy, spectrum and beam quality will be shown.

The amplified beam will be transported to the optical compressor through the Compressor Imaging System (CIS). Reflective optics are used for relay imaging and up collimating the square beam to 620 mm. A deformable mirror will ensure a flat wavefront for optimal pulse compression. Four 1136 lines/mm dielectric coated gratings are used. The distance between gratings is 15 meters. The beam dimension on gratings 3 and 4 is more than 1 meter. Monolithic gratings of the required size do not exist, so alternative methods must be implemented. One option is phasing smaller gratings. The approach we have selected to solve this problem is to phase the grating with a mirror at 90° [5]. This solution is easier to implement as the line-density variation, angular tip, and longitudinal piston errors within a tiled grating no longer exist. The number of degrees of freedom to consider are then lowered. The CIS and optical compressor will be implemented in a large vacuum vessel.

1. J. Hee Sung, H. W. Lee, J. Y. Yoo, J. W. Yoon, C. W. Lee, J. M. Yang, Y. J. Son, Y. H. Jang, S. K. Lee, and C. H. Nam; *Opt Let*, p. 2058, Vol. **42**, No 11, June 2017.
2. D. Papadopoulos, J. Zou, C. Le Blanc, G. Chériaux, P. Georges, F. Druon, G. Mennerat, P. Ramirez, L. Martin, A. Fréneaux et al., *High Power Laser Science and Engineering*, **4** (2016).
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4. R. C. Shah, R. P. Johnson, T. Shimada, K. A. Flippo, J. C. Fernandez, and B. M. Hegelich, *Opt Let*, p. 2273, Vol. **34**, No 15, August 2009.
5. Z. Li, G. Xu, T. Wang, and Y. Da; *Opt Let*, Vol. **35**, No. 13, July 1, 2010.

Radiation-dominated particle and plasma dynamics

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Upcoming large-scale laser facilities aim to produce ultra-strong electromagnetic fields that will be capable of accelerating electrons to high energies and causing the emission of gamma quanta. This opens up opportunities for the creation of a new kind of gamma-ray source that can potentially reach extraordinarily high densities and energies of photons, giving new opportunities for experimental studies in nuclear physics. However, finding ways to create such sources and controlling their properties is dependent on understanding the dynamics of particles in the presence of strong radiation losses.

Recent numerical studies have revealed that strong radiation losses can dramatically alter the particle dynamics, and lead to counterintuitive phenomena, such as radiation-reaction trapping in travelling waves, as well as normal and anomalous radiative trapping in standing electromagnetic waves. One may therefore ask if there exists a universal behaviour that lies behind these types of phenomena. Here we unveil such a universal behaviour and, using this, develop a new general theoretical approach for analysing particle and plasma dynamics under strong radiation losses [1].

Consider the motion of a charged particle in a strong electromagnetic field of arbitrary configuration. We demonstrate that for sufficiently high field strengths, radiation losses lead to a general tendency of the particle to move along the direction that locally yields zero lateral acceleration. The relativistic motion along such a direction results in no radiation losses, according to both the classical and quantum descriptions of radiation reaction. We demonstrate that this radiation-free direction (RFD) exists at each point of an arbitrary electromagnetic field, while the time-scale of approaching this direction decreases with the increase of field strength. Note that in the ultra-relativistic case the radiation reaction force is orientated opposite to the motion and thus cannot directly alter the direction of motion. Thus, radiation reaction affects the particle's dynamics indirectly through reducing the particle's energy so that the Lorentz force can alter the direction of motion over shorter timescales. Such alterations have the universal property of converging to the RFD. Our estimates and numerical studies show that already at intensities of the order of 10^{23}W/cm^2 the time-scale of approaching the RFD becomes comparable with the time-scale of the field evolution. This enables a specific type of dynamics: at each point of space, the particles mainly move and form currents along the local RFD, while the deviation of their motion from the RFD can be calculated in order to account for their incoherent emission. By deriving an explicit expression for the RFD, we develop a closed description of both particle and plasma dynamics in this regime.

1. A. Gonoskov and M. Marklund, "Radiation-dominated particle and plasma dynamics" *arXiv:1707.05749* (2017).

Planned experiments with Shanghai Super-intense Ultrafast Laser Facility and the Station of Extreme Light

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The Shanghai Super-intense Ultrafast Laser Facility (SULF) with a ten petawatt laser will be completed in the end of 2018. The research platform for Ultrafast Sub-atomic Physics at SULF will be focused on the production of energetic beams and their applications. Laser driven proton acceleration with solid and gas targets is planned [1]. Protons will be polarized and accelerated in a special way. Laser driven electrons will be used to generate positron beams [2] and intense gamma rays, especially in the near QED regime. Nuclear physics by using laser driven protons and gamma rays are considered.

The Station of Extreme Light (SEL) at Shanghai Coherent Light Facility (SCLF) has been approved to be built. The 100 PW laser of SEL will not only be used for exploring vacuum birefringence [3] and other vacuum QED effects with the help of the hard XFEL, but also accelerate protons to more than 10GeV which can be used for anti-proton production [4]. Thanks to the high production efficiency of gamma ray in the QED regime, nuclear photonics will be one of the most important research fields [5, 6].

1. H. Zhang, B.F. Shen *et al*., “Collisionless Shock Acceleration of High-Flux Quasi monoenergetic Proton Beams Driven by Circularly Polarized Laser Pulses,” *Phys. Rev. Lett.*, **119**, 164801 (2017).
2. Tongjun Xu, Baifei Shen *et al*., “Ultrashort megaelectronvolt positron beam generation based on laser-accelerated electrons,” *Physics of Plasmas*, **23**, 033109 (2016).
3. Baifei Shen *et al*., “Exploring vacuum birefringence based on a 100 PW laser and an x-ray free electron laser beam,” *Plasma Phys. Control. Fusion*, **60**, 044002 (2018).
4. Shun Li, Zhikun Pei, Baifei Shen *et al*., *Physics of Plasmas*, **25**, 023111 (2018).
5. L. L. Ji, A. Pukhov, E. N. Nerush, I. Yu. Kostyukov, B. F. Shen, and K. U. Akli, “Energy partition, gamma-ray emission, and radiation reaction in the near-quantum electrodynamical regime of laser-plasma interaction,” *Physics of Plasmas*, **21**, 023109 (2014).
6. Shun Li, Baifei Shen *et al.*, “Ultrafast multi-MeV gamma-ray beam produced by laser-accelerated electrons,” Physics of Plasmas, 24, 093104 (2017).

Quasi-monoenergetic positron beam generation and acceleration based on laser-accelerated electrons

T. Xu, Baifei Shen, Jiancai Xu, Shun Li, Yong Yu, Jinfeng Li, Xiaoming Lu, Cheng Wang, Xinliang Wang, Xiaoyan Liang, Yuxin Leng, Ruxin Li, and Zhizhan Xu

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Experimental generation of ultrashort MeV positron beams with high intensity and high density using a compact laser-driven setup has been reported [1]. A high-density gas jet is employed experimentally to generate MeV electrons with high charge; thus, a charge-neutralized MeV positron beam with high density is obtained during laser-wakefield-accelerated electrons irradiating high-Z solid targets. It is a novel electron–positron source for the study of laboratory astrophysics. Meanwhile, the MeV positron beam is pulsed with an ultrashort duration of tens of femtoseconds and has a high peak intensity of 7.8×10^{21} s^{-1}, thus allows specific studies of fast kinetics in millimeter-thick materials with a high time resolution and exhibits potential for applications in positron annihilation spectroscopy.

Further research is also made based on ultrashort MeV positron beam generation. A novel mechanism to accelerate quasi-monoenergetic positron beams is proposed. Based on a high-density electron beam with high energy, the laser-driven positron beam is further modulated in space distribution and accelerated to a high energy. As a result, a quasi-monoenergetic positron beam is generated. This mechanism is also confirmed in the experiments, where a positron beam with a high energy of 82.5 MeV and a narrow energy spread of 4.4% is generated.

1. Tongjun Xu, Baifei Shen, Jiancai Xu, *et al*, "Ultrashort MeV positron beam generation based on laser-accelerated electrons," *Physics of Plasmas*, **23**, 033109 (2016).

Tuesday, June 26, 2018

07. Physics with Laser Compton Backscattering sources

10:50 – 12:40

Chair: A. Zilges

Dipole Response in Nuclei – Real vs. Virtual Photon Probes

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Despite almost 70 years of experimental studies, the electric dipole response of nuclei is at the focus of present nuclear structure research. This is to a large extent due to the observation of a low-energy structure around neutron threshold, commonly called Pygmy Dipole Resonance (PDR) in nuclei with neutron excess. In many models the PDR strength can be related to the formation of a neutron skin in neutron-rich nuclei. It also contributes to the nuclear polarizability, which has been established as a measure of the neutron skin thickness and a constraint to the parameters of the symmetry energy and the equation of state of neutron-rich matter. The PDR contribution to the Gamma Strength Function also impacts many applications, in particular large astrophysical reaction network calculations aiming at an understanding of the stellar production of heavy elements. Furthermore, recent experiments question many results of the surveys of the Giant Dipole Resonance (GDR) in nuclei with the (γ,xn) reaction.

Using illustrative examples from current research, I will discuss the advantages and limitations of real and virtual (relativistic Coulomb excitation, electron scattering) photon probes for the exploration of the PDR and GDR and identify future areas of research at next-generation photon sources like ELI-NP.

Photonuclear studies with gamma beams

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Photon-induced nuclear reactions with energies higher than the particle binding energy mainly excite collective states like the PDR (Pygmy Dipole Resonance) or the IsoVector Giant Dipole Resonance (IVGDR or simply GDR).

The ground state excited PDR/GDR decays with photon and neutron either to the ground state or to an excited states. This provides information on the decay strength of the PDR/GDR with (in case of photon decay) multipole selectivity and information on the composition of the GDR/PDR wave function. In case of neutron decay, discrepancies have been revealed in the measured partial (γ,xn) cross sections and therefore a new compilation of total and partial photo-neutron cross sections is needed.

The extremely intense and monochromatic gamma-ray beams provided by the ELI-NP facility will permit a new type of experimental photonuclear reaction study. Some of the Physics cases and the experimental setup addressed by the ELI-NP Working Group “Gamma Above Neutron Threshold” (ELIGANT) will be presented, discussed and the feasibility shown.

Characterization of Giant Dipole Resonance excitation mode using photon probes at ELI-NP

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The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) is a facility dedicated to nuclear physics research with extreme electromagnetic fields. It will host a system of two high power 10 PW lasers and a very brilliant gamma-beam system. The expected gamma-ray beams with energies up to 20 MeV, 0.5% relative energy resolution and ~10^8 photons per second intensity will be employed for precise photonuclear measurements [1].
Here we report on the status of the experimental setups dedicated to studies of the nuclear Giant Dipole Resonance excitation mode using the high energy resolution and high intensity ELI-NP gamma-ray beams. We present the feasibility studies performed using extensive Geant4 simulations, results of detector tests, the status of the data acquisition system, details on the implementation of the mechanical frames.
Nuclear structure experiments will involve photo-excitations of mainly low-spin collective states and the observation of the radiation emitted in the subsequent decays. Energy and angular differential photoneutron reactions and elastic and inelastic photon scattering are proposed to be recorded using a mixed gamma-neutron detection system.
Photoneutron (g,xn) with x=1,2 reactions cross sections measurements will be performed with a 4π flat efficiency neutron detection system dedicated for neutron multiplicity sorting experiments. The detection system is comprised of ^{3}He neutron counters embedded in a moderator block and has ~36% efficiency flat within 2 % for neutrons with kinetic energies up to 5 MeV.

1. D. Filipescu, “Perspectives for photonuclear research at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) facility” *Eur. Phys. J. A*, **51**, 185 (2015).

Renewed database of GDR parameters of ground-state photoabsorption

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K.M. Solodovnyk[1]

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[2]*NAPC-Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria*
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A comprehensive experimental database with reliable data for the GDR parameters and their uncertainties is very important for the reliable modeling of E1 gamma-ray cascades in highly excited nuclei, for the study of nuclear reaction mechanisms as well as for verifying different theoretical approaches used to describe the GDR and other nuclear structure properties (deformations, contribution of velocity-dependent forces, shape-transitions, etc), and forms an integral part of all nuclear reaction computer codes.

A revised database with updated values of Giant Dipole Resonance (GDR) parameters with uncertainties for 144 isotopes from Li-6 to Pu-239 is presented and discussed. It improves and extends previously published databases [1-5].

The experimental data on the photoabsorption cross- section in the GDR region that are available in the EXFOR database are used for GDR parameters extraction. These data are fitted in an energy interval near the peak by Lorentz-shape curves that are parametrized within the Standard Lorentzian (SLO) model and Simplified version of the modified Lorentzian (SMLO) approach [4-6]. The theoretical photoabsorption cross section is taken as a sum of the components corresponding to excitation of the GDR and quasideuteron photodisintegration. The fitting is done by a least-square method with the GDR peak parameters treated as variables. The approximation of axially-deformed nuclei with two normal modes of GDR excitation is used. The extracted parameters include the resonance energies, widths and strength with associated uncertainties.

This work is partially supported by the IAEA through a CRP on Updating the Photonuclear Data Library and generating a Reference Database for Photon Strength Functions (F41032).

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6. V.A.Plujko, O.M.Gorbachenko, R.Capote, P. Dimitriou, “Giant Dipole Resonance Parameters of Ground-State Photoabsorption: Experimental Values with Uncertainties,” *At. Data Nucl. Data Tables,* (submitted, 2017).

Photoneutron measurements for IAEA CRP on updating the current photonuclear data library

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Photonuclear data are used both in fundamental nuclear studies and in a wide variety of applications. A large fraction of the data were measured at the Lawrence Livermore National Laboratory (USA) and the Centre d'Etudes Nucleaires de Saclay (France) facilities [1], with systematic discrepancies between (g,n) and (g,2n) cross sections from the two laboratories [2]. It is now considered that the reason could be shortcomings of the photoneutron multiplicity sorting method used in both of them. The International Atomic Energy Agency (IAEA) has launched a new Coordinated Research Project (IAEA CRP F41032) on Updating the Photonuclear Data Library and generating a Reference Database for Photon Strength Functions [3].

We have established an experimental collaboration for (g,xn) with x=1-4 measurements performed in the γ-ray beam line GACKO (Gamma Collaboration hutch of KOnan university) of the NewSUBARU synchrotron radiation facility in Japan. We will present our newly developed direct neutron multiplicity (DNM) sorting method based on a high-and-flat efficiency neutron detection system comprised of ^{3}He counters embedded in polyethylene moderator [4]. We committed to apply the DNM sorting method on ^{9}Be, ^{59}Co, ^{89}Y, ^{103}Rh, ^{139}La, ^{159}Tb, ^{165}Ho, ^{169}Tm, ^{181}Ta, ^{197}Au, ^{209}Bi, and provide the (γ, 1–3n) reaction cross sections to the IAEA CRP F41032. The excitation functions have been investigated between the neutron separation threshold up to ~40 MeV incident photon energy. We aim to resolve the historical discrepancies between the Livermore and Saclay data sets by providing new and reliable photoneutron cross section data.

We report here on the preliminary results of our investigations.

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Tuesday, June 26, 2018

08. Laser plasma nuclear physics

14:00 – 16:10

Chair: C.H. Nam

Progress towards calculating higher order Delbrück scattering and prospects for measurements

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We have previously shown that a precise nearly isolated measurement of Delbrück Scattering, the scattering of gamma rays by virtual electron-positron pairs in vacuum, is possible using high flux polarized gamma ray sources [1]. Since the cross section increases as $(Z\alpha)^4$ where α is the fine structure constant, it is desirable to perform experiments with high Z materials such as lead and uranium. However, for large Z higher order corrections, Coulomb corrections, to the scattering amplitude can become large and only empirical estimates exist [2,3]. Even though experimental data shows that higher order corrections are necessary [3], theoretical calculations of these corrections have not been done due to the large number of terms [4]. After summarizing previous work, we present our progress towards calculating higher order corrections using software developed for high energy physics to compute integrals from the Feynman diagrams.

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Nuclear excitations in plasma

F. Hannachi

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The development of high intensity lasers is opening up new opportunities for nuclear physics studies. Lasers are unique tools to produce hot and dense plasma and very high fluxes of photon and particle bunches in very short duration pulses. The possibility to combine in the same reaction chamber different high intensity laser beams makes it possible to study nuclear properties in extreme conditions which cannot be reached with conventional particle accelerators. It is for example possible to create nuclei in isomeric states (IS) and investigate their decay properties in such hot and dense plasmas. In these new media, the interaction between the nuclei and their electronic cloud may modify nuclear properties such as apparent decay lifetimes. In a plasma, the interaction between a nucleus and its electronic cloud can be influenced by its environment and unusual excitation processes such as nuclear excitation by electronic capture (NEEC) and nuclear excitation by electronic transition (NEET) should be observed. Indeed, NEEC and NEET (observed in 197Au [1], 189Os [2,3], 193Ir [4] and 93Mo[5] in accelerator based experiments) are exotic processes relevant to astrophysics, which can be dominant in particular plasma conditions of temperature and density. It is therefore very important to study them. We have undertaken joint experimental and theoretical programs to investigate NEET in laser produced plasma [6]. The present status of this program will be presented.

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Day-1 laser driven nuclear experiments at ELI-NP

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Foreseen Day-1 nuclear experiments at the ELI-NP PW systems are intended to measure the magnitude and scaling of the achievable intensity *I via* the laser-γ conversion efficiency, followed by studies of proton acceleration aimed to enhance the understanding and control of high intensity laser-driven ion sources [1]. The associated nuclear diagnostic systems to characterise the complex laser-solid target interaction will be depicted. Only recently, near 100 MeV protons were produced by the use ultra-thin production target foils enabling a RPA/TNSA hybrid acceleration scheme pointing out the importance of the chosen target thickness for a given *I* [2]. Theoretical 2D EPOCH PIC calculations underpin the crucial influence of the target dimensions since they govern the coupling of laser energy into the intended acceleration of ions. With the eventually foreseen use of ultra-thin targets (d < 100 nm) at $I \sim 10^{23}$ Wcm^{-2}, efficient laser plasma acceleration regimes are expected to be reached and kinetic proton energies well above 100 MeV are predicted. Henceforth the design, production, alignment and debris mitigation associated with thinnest, mass limited targets play an important role in the successful progression of our field. An overview on the special challenges regarding the realisation of the experiments will be given. First measurements will focus on the characterization of the obtainable intensity *I* and proton energy as function of target thickness and laser power for different primary target materials.

1. F. Negoita *et al*., "Laser driven nuclear physics at ELI-NP", *Rom. Rep. in Physics* **68**, S37-S144 (2016).
2. A. Higginson *et al.*, "Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme", *Nature Communications*, **9** 724 (2018).

Near threshold photonuclear reactions with high intensity lasers

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The paper is devoted to the feasibility study of photonuclear reactions at photon energies below 10 MeV. Significant results could be obtained, especially on pigmy resonance excitation in soft nuclei measured with real and virtual photons through excitation of spin isomers. The experimental study of low-lying collective excitations of nuclei is now an actual problem, because it allows us to investigate toroidal and compression modes of excitations of nuclei of different multipolarity (M1, M2, E2, etc.), to obtain additional information on the neutron halo in nuclei, to promote the development of microscopic nuclear models. This implies measurements of the total cross sections of photoabsorption, yields and cross sections of photoneutron reactions. Preliminary comparative results obtained with the electron linear accelerator LUE-8 MeV at INR and terawatt femtosecond laser complex of Moscow State University are presented. Mutual use of two different systems provides high accuracy measurements and the development of new technologies. Based on numerical simulation and targeted experiments new methods for the study of photonuclear reactions are under development.

Experimental & numerical studies of interaction of femtosecond laser radiation with intensity up to $5x10^{18}$ W/cm^2 with dense plasma, conducted recently using terawatt femtosecond laser facility at MSU, are discussed. Main stress was on the control of plasma parameters (luminosity in X-ray and gamma ranges, generation of bunches of relativistic electrons and fast multicharged ions) and their optimization by choosing interaction regime and preplasma parameters. The pre-plasma extent was controlled by changing time delay between the pulses and energy density of the nanosecond pulse. We studied two specific set of parameters then electron heating is very efficient and gamma quanta as high as 7-10 MeV appeared at intensities of 2000 PW/cm2.

In the last part of the paper we are also considering applicability of our approaches for large scale modern laser installations such as the ELI-NP facility that can be used for efficient production of “monochromatic” gamma beam within sub10 MeV range for nuclear studies not only with stable but also isomeric nuclei.

This study was supported by RSF (grant # 16-12-10039, nuclear reaction studies) and by RFBR (grant#16-02-00263, gamma & electron detection techniques).

Laser-induced radioisotope production at L2A2

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The Laser Laboratory for Acceleration and Applications (L2A2) at the University of Santiago de Compostela is a new infrastructure for the investigation of laser-plasma particle acceleration and the use of this new technology in several fields of application. One of the main research programs at L2A2 aims at developing alternative technologies for the production of medical radiotracers using laser-plasma accelerated beams of protons and ions.

Laser-plasma acceleration could be the enabling technology to produce on-demand doses of PET probes of interest at low cost, in an automated, user-friendly device. However, the realization of such a single-dose radiotracers production devices still requires important progress in many different areas. L2A2 is working in some of these technologies, in particular:

- High-power laser pulse focusing and characterization systems.
- Multi-shot laser-plasma acceleration targets.
- Diagnostics of laser-plasma accelerated beams of protons and ions.

The core of the L2A2 infrastructure is a compact ultra-short pulse laser system built by Thales (Alpha 10/XS) with two beam lines. The main laser line produces ultra-short pulses (25 – 50 fs) with moderate energy (~ 1.5 J) and high-contrast (1:10-10 ASE) with a 10 Hz repetition rate. The second beam line will produce also ultra-short pulses but with lower energies (~ 1 mJ) and higher repetition rate (1 kHz).

We will present the L2A2 facility, the radioisotope production research program, the main developments in terms of focusing, multi-shot targets and sensors, and the first results concerning proton acceleration.

Nano-structure for advanced laser-plasma X-ray source

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Advanced laser-plasma X-ray sources produced by ultra-intense laser have potential applications in many fields for their promising merits, including high brightness, short duration and small spot. The novel laser-plasma X-ray sources are proposed by utilizing the targets with Nano-structure. The Nano-structure benefits for the laser absorption and unique electromagnetic field generation inside the target. As a result, several times enhancement of the laser absorption and the corresponding X-ray yields are suggested by our particle-in-cell simulations. Meanwhile, the spot of the X-ray source is also reduced for the guidance of the fast electrons in the unique electromagnetic fields. The recent experiments conducted at Xingguang-III Laser Facility (Three beams consisted of ns/ps/fs laser, ns laser 500J/1ns, ps laser 300J/1ps, fs laser 30J/30fs) confirm the conclusions from our simulations. Finally, some radiography results of the dynamic process by utilizing of these sources are represented.

Tuesday, June 26, 2018

09. High intensity lasers and QED

16:40 – 18:30

Chair: K. Krushelnick

Leveraging extreme laser-driven magnetic fields for efficient generation of gamma-ray beams

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Currently constructed laser facilities are expected to deliver on-target intensities approaching 10^{23} watt/cm^2, which would enable experiments in a qualitatively new regime of light-matter interactions. In this regime, quantum effects will change the individual dynamics of charged particles through radiation reaction, but, even more importantly, collective effects will alter the optical properties of otherwise opaque matter through relativistically induced transparency. By performing computational and theoretical research in anticipation of experimentally achieving this novel regime, we found that the performance of laser-driven particle and radiation sources can be dramatically improved by leveraging new physics. These improvements go well beyond the incremental improvement expected from simply upsacaling the laser intensity.

The relativistically induced transparency allows the laser pulse to propagation through material with an electron density that would normally be prohibitively high. We found that the resulting volumetric interaction of the laser pulse with the dense electron population generates an unprecedented slowly-evolving magnetic field that is coiled around the pulse [1,2]. Its strength can be at the mega tesla level and comparable to that in the laser pulse itself. This magnetic field is shown to enhance the energy gain by laser-accelerated electrons by more than an order of magnitude. A combination of the high energy possessed by the electrons and an extreme acceleration induced on these electrons by the magnetic field leads to a strong emission of directed beams of energetic photons. The number of multi-MeV photons exceeds 10^{12} even at 510^{23} watt/cm^2, which accounts for more than 3% of the incoming laser energy [1]. The generation of a strong magnetic field is critical for this mechanism since the energy enhancement is a threshold process.

The novelty of the discussed regime is that the extreme magnetic field couples three key aspects of laser-plasma interactions at high intensities: relativistic transparency, direct laser acceleration, and synchrotron photon emission. Multiple applications that require a dense beam of gamma-rays, including advanced nuclear and radiological detection, can directly benefit from the development of such a photon source.

This work was supported by the National Science Foundation (No. 1632777), AFOSR (No. FA9550-17-1-0382), and XSEDE.

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New routes to high-energy photon generation in laser-matter interactions

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Intense laser-plasma and laser-beam interactions are promising routes for producing high-energy photons from compact setups, through, e.g. Compton scattering and bremsstrahlung [1]. The small time and space scales associated with these emission mechanisms give such sources unique properties. However, there are longstanding discussions as to the limit on the achievable photon energies. Over the last decade, rigorous efforts in the development of particle-in-cell (PIC) schemes with corrections from quantum electrodynamics (QED) have resulted in many new and exciting predictions of high-energy photon generation. It has become clear that many earlier concerns regarding the limitations of laser-plasma and laser-beam systems as sources were unwarranted. Here, we will present results based on state-of-the-art QED-PIC and analytical calculations on the generation of high-energy photons from laser-plasma [2] and laser-beam systems [3].

Closely connected to the emission of high-energy photons are electromagnetic cascades of electron-positron pairs. The latter have the potential to act as high-energy photon sources of unprecedented brightness. In the cascade process, radiation reaction and rapid electron-positron plasma production seemingly restrict the efficient production of photons to sub-GeV energies, in line with the long-standing discussion mentioned above. Here, we show how the interplay between the pair cascade and radiation reaction effects results in the possibility to emit GeV photons. The possibility to use tailored laser fields as well as particular particle sources promises not only the generation of high-energy photons, but also of controlled pair production at very high densities. Such matter—anti-matter/radiation systems could be of importance for laboratory astrophysics.

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Launching QED cascades in high-intensity laser pulses

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A cascade of quantum electrodynamical (QED) processes is launched when a high-energy electron or photon enters a region of strong electromagnetic fields, distributing the energy of the primary particle into a shower of photons and electron-positron pairs [1]. Such cascades play an important role in neutron star magnetospheres as they efficiently convert particle energy to escaping radiation [2], and they will dominate the plasma dynamics explored in the next generation of high-intensity laser experiments [3]. Experimental investigation of the same dynamics is possible with existing laser facilities, as it is possible to accelerate electrons with laser wakefields to multi-GeV energies and to focus laser pulses to intensities > 10^{21} $\mathrm{Wcm^{-2}}$. In combination, these 'all-optical' designs allow us to study the physics of elementary particles in electromagnetic fields of unprecedented strength. Here we consider two possible experimental geometries for observation of a QED cascade: one in which the accelerated electron beam collides directly with an ultraintense laser pulse, producing photons via nonlinear Compton scattering (as accomplished in [4]); and one in which the electron beam instead collides with a high-*Z* foil, producing bremsstrahlung photons that go on to collide with the laser pulse [5].

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Probing vacuum birefringence with 10 PW laser and 1 GeV gamma-rays at ELI-NP

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The vacuum birefringence is expected to appear if it is exposed by linearly polarized strong electromagnetic field [1-4]. Head-on collision system with 10 PW laser and 1 GeV gamma-ray has capabilities of deforming the vacuum and making the birefringent vacuum visible. The vacuum birefringence can be probed by the change of polarization state of gamma-rays [5,6].

The polarimetry of photons at the GeV energy can be performed via electron-positron pair production. The electron-positron pair topology in Bethe-Heitler process has information about relative phase shift of probed photons inside the birefringent vacuum.

We proposed the way to extract relative phase shift via electron-positron pairs and discussed measurability by PW class laser system in the publication [7]. We will present the capability of the experiment and current status of gamma-ray polarimeter at ELI-NP.

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Dense pair plasma generation and nonlinear QED physics with 10PW scale lasers

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With the development of ultraintense laser facilities, laser plasma interaction enters a completely new regime, where new phenomena related to nonlinear QED processes are expected to occur, such as copious γ-photon generation, electron-positron (e^-e^+) pair production and QED cascade, etc. Several 10PW scale laser facilities currently under construction, such as ELI and Apollo in Europe and SULF in China, will provide the possibility for experimental test of these predicted phenomena in the near future. Moreover, these ultra-high power laser facilities may allow one to study some extreme astrophysical phenomena in lab, such as relativistic e^-e^+ jets formation. They are ubiquitously found in black holes (BHs), pulsars and quasars, and are associated with violent emission of short-duration (milliseconds up to a few minutes) gamma-ray bursts.

We investigate the QED cascade and consequent relativistic e^-e^+ formation from counter-propagating laser-irradiated ultrathin foils. We present a scaling law of QED cascade growth with laser intensity, which shows that QED cascade saturation occurs at laser intensities just exceeding 10^{24} W/cm^2. QED cascade saturation results in highly efficient conversion from laser photons to e^-e^+ pairs with a conversion efficiency of the order of 10%. A high-yield ($\geq 10^{13}$) ultradense (10^{24} cm^{-3}) e^-e^+ bunch is produced, causing the plasma to become opaque to incident lasers. This finally leads to the emergence of a new high-field phenomenon, which is different from early-discovered radiative trapping and we call it QED pair plasma compression. Consequent relativistic e^-e^+ jet formation along the transverse direction and high-harmonic generation (HHG) along the longitudinal direction have been observed as the plasma squeezing effects become significant. The laser-driven relativistic jets formation opens up the opportunity to study energetic astrophysical phenomena in laboratory, and the HHG discovered here provides a promising way to experimentally identify these phenomena.

Wednesday, June 27, 2018

10. High intensity laser-plasma interaction

08:30 – 10:20

Chair: C.J. Barty

Relativistic laser plasma interaction experiments at the University of Michigan

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High intensity laser plasma interaction experiments have been performed using the 300 TW Hercules laser facility at the University of Michigan to investigate laser driven electron acceleration and x-ray radiation generation. The flux of radiation has been optimized through increasing the length of the interaction showing that the electron beam hosing instability increases the x-ray flux significantly. We have also used electron accelerators to diagnose warm dense matter (using the x-ray beam) and measure magnetic fields related to laboratory astrophysics (using the electron beam). Laser wakefield accelerators have also been critical to make measurements of the flux of back scattered gamma rays from inverse Compton scattering experiments. The implications of these experiments will be discussed as will the results from further experiments at the Laboratory for Laser Energetics (Rochester NY, USA) and at the Rutherford Appleton Laboratory (Oxfordshire UK). In addition to researchers from the University of Michigan, scientists from Queen's University Belfast, Imperial College London, Lawrence Livermore National Lab, the Laboratory for Laser Energetics as well as the Princeton Plasma Physics Laboratory were involved in designing and conducting these experiments.

Development of electron accelerator and gamma-ray sources with 4-PW laser

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Since intense lasers have reached the intensity for relativistic laser-plasma interactions, laser wakefield acceleration (LWFA) have paved routes to develop compact electron accelerators and radiation sources. LWFA can provide high-energy femtosecond electron bunches for the generation of ultra-short high-brightness x-rays and gamma-rays, which are useful light sources for high-resolution imaging, nondestructive inspection, and nuclear spectroscopy. As intense lasers reaching PW peak power, the LWFA has been progressed to produce multi-GeV electron beams and support the generation of 100s-of-MeV gamma-rays. We have developed two PW Ti:Sapphire laser beamlines [1], and successfully applied to generate a 3-GeV electron beam [2]. Furthermore, we upgraded one of our PW lasers to a 20-fs, 4-PW laser [3], which has generated 4.5-GeV high-charge electron beams. Here, we present our recent progress in LWFA research with multi-PW laser pulses, and the plan for developing 10-GeV electron beam and gamma-ray sources driven by the 4-PW laser. These developments of high energy electron beam and femtosecond γ-rays with multi-PW lasers will open gateways to investigate nonlinear QED phenomena and nuclear processes.

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Advancements in extreme laser pulse compression with applications for Nuclear Photonics

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High power laser facilities capable of generating petawatt (10^{15} W) level pulses are producing peak intensities that are approaching the threshold of a wide range of applications for high energy physics; vacuum physics; as well as medical imaging and treatments. State-of-the-art in high power laser systems, such as those being built at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) are expected to consistently produce large diameter beams on the order of tens of centimeters with nearly flat-top spatial modes and low divergences that suggest efficient nonlinear techniques for pulse post-compression and thus extending the intensities achievable within existing and planned PW facilities. The basic sketch of the Thin Film Compression (TFC) concept is shown in Figure 1 [1]. Simulations and experimental work based on self-phase modulation (SPM) within an often sub-millimeter amount of material demonstrate the potential for such a system to efficiently compress a pulsed laser toward its wavelength-defined fundamental limit of a few femtoseconds while efficiently maintaining Joule-level energy within the pulse [2, 3]. Here we report novel results relevant to the TFC method from recent experiments conducted at the Laserix facility located in U. Paris-Sud, Orsay, France through the collaborative efforts of members coming from several laser research laboratories. The intense laser interacted with several thin film materials -- fused silica, PMMA, Cyclic Olefin Polymer (COP: Zeonor) -- under vacuum conditions with formats of simple millimeter-thickness plates as well as continuously renewable rolls of 100 micron thick film. The prime goal being to test the equipment (see, for example, figure 2) and conditions required to scale from the 20mm diameter beam up by an order of magnitude or more to the aperture sizes expected at PW laser facilities and to gain insight on the challenges that will arise coupling within a laser beamline.

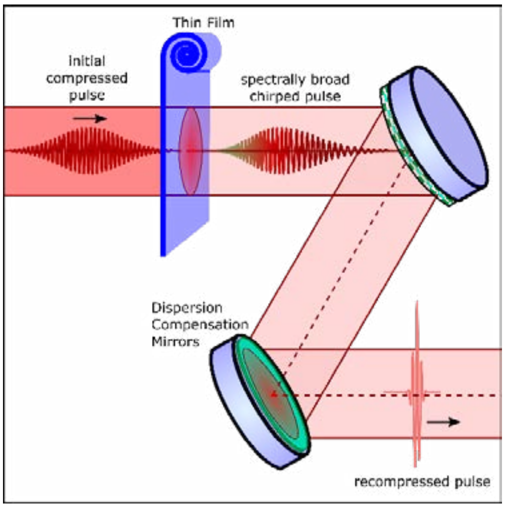

Figure 1. Basis for compression technique. Interaction of an amplified short pulse with a thin film whose exact thickness is determined by laser parameters produces additional spectral content through SPM. The resultant pulse is further recompressed to its new fourier limit using a series of bounces on negative-dispersive mirrors.

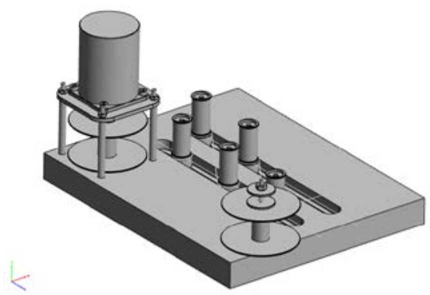

Figure 2. Design for roller assembly designed to manage under vacuum 100 micron thick plastic film and advancement to new material in case of damage.

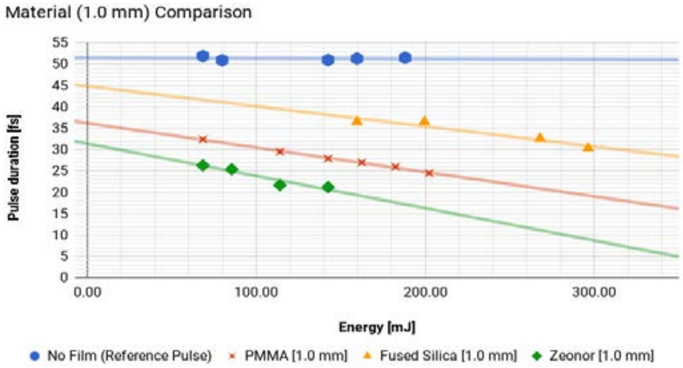

Figure 3. The optimized pulse duration as measured for increasing input pulse energy after interaction with 1.0 mm of fused silica, PMMA, and Zeonor (COP).

To this end, diagnostics monitored the beam profile in the near and far fields to verify the resultant beam quality while both an autocorrelator and WIZZLER device confirmed the duration after recompression of the resultant broadened pulse using a combination of negative-dispersion mirrors and glass plates. The preliminary results, as shown in figure 3, demonstrate the ability to optimally compress the initial pulse of 50 fs for the range of energies available down to 30 fs in the case of fused silica glass, 25 fs in the case of PMMA, and 20 fs in the novel case of COP (Zeonor) with further detailed analysis of the experimental campaign on-going.

An early application of these shorter, energetic pulses is as a compact ultrashort (10 fs pulse resulting from 25 fs) plasma probe. This becomes an attractive feature to introduce within laser facilities due to the easy alignment, efficient energy transmission, and compact size of the thin film / negative-dispersion mirror combination as compared to a more traditional fiber-based compression scheme. In addition, such high energy, eventually single-cycle, ultrashort pulses offer access to new physical processes and show great promise as drivers of secondary sources for improved laser-driven ion acceleration, as well as coherent, hard X-ray pulses from solid targets capable of producing atto/zeptosecond-scale pulses at the exawatt level (10^{18} W).

This research was supported through Laserlab-Europe EU-H2020 654148 as well as by Extreme Light Infrastructure - Nuclear Physics (ELI-NP) - Phase II, a project co-financed by the Romanian Government and the European Union through the European Regional Development Fund through the Competitiveness Operational Programme "Investing in Sustainable Development" (1/07.07.2016, COP ID 1334).

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Electron beam and plasma monitors for staging laser acceleration experiments at LAPLACIAN

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Laser wake field acceleration (LWFA) [1] is now conceived as the future for compact accelerators after several break-through experiments done over 20 years [2]. We are developing such system based on staging laser acceleration at LAPLACIAN, RIKEN SPring-8 center aiming for future compact X-ray free-electron lasers (XFELs). In staging acceleration, several separate-function stages are employed as standard radio-frequency linear accelerators. We start experiments with two-stages: an electron injector and a booster accelerator.

Because the beam quality even with state-of-art LWFA is not sufficient for XFELs, we need further improvement as well as reproducibility. To mitigate this issue we consider beam matching between stages as indispensable. We are developing plasma monitors and electron beams monitors. For plasma monitors we developed sub-10 fs probe beams and frequency domain holography (FDH) to observe laser wake waves in real time. With a 10 TW laser system, shadowgrams and schliren images were successfully taken showing the nonlinear structure of the wake waves.

To observe the electron beam pulse duration and timing between the drive laser, we have developed an electro-optical decoding system. We have derived a modified formulation suited for LWFA and succeeded in measuring the electron beam duration and timing [3].

For alignment error detection in the second stage we are developing a betatron X-ray spectrograph based on a curved crystal. The calibration test has been done using a standard X-ray source. We will install the device to detect betatron X-rays during the staged LWFA process.

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Measurement of the sheath field strength by the charge state of heavy ions as a probe

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It is well known that an extraordinary strong electric field is established by the interaction between the high peak power laser pulse and the solid density target. This strong field has attracted the attention of many researchers all over the world as a source of energetic ion beams.
Recent development of high peak power laser systems has resulted in short-pulse petawatt-class laser systems with peak intensities of ~10^{22} Wcm^{-2} for real experiments. For such high intensity laser pulse interaction especially with solid density targets, the real laser matter interaction is not simply a single idealized high peak power laser pulse with a Gaussian-like temporal and spatial distribution interacting with an idealized solid density target. In particular, the temporal distribution of the laser pulse significantly alters the target condition and the maximum achievable sheath field strength is lowered. The J-KAREN-P laser system at the Kansai Photon Science Institute can, uncommonly for high power laser systems [1-5], provide real high laser intensity pulses on target of ~$10^{22}Wcm^{-2}$ with good laser contrast conditions and an almost diffraction limited spatial distribution. Over the commissioning phase of the last few years, ion acceleration experiments have been extensively carried out [3,4-7]. We have measured the sheath field strength by using the charge state of the heavy ions as a probe. We have clarified how the temporal distribution of the laser pulse affects the laser matter interaction, thus, how it severely affects the formation of the sheath field on the rear side of the target.
At KPSI, a project is currently going on to establish a laser-driven carbon injector for a compact medical accelerator system which we call the “Quantum scalpel” system. The current status of the project will be also briefly introduced.
A part of the work is supported by Japan Society for the Promotion of Science (JSPS) (KAKENHI JP 16K05506 15K13410 and 15F15772, and Japan Science and Technology Agency (PRESTO JPMJPR16P9 16813804).

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Wednesday, June 27, 2018
11. Laser plasma nuclear physics
10:50 – 12:45
Chair: K.A. Tanaka

Laser-driven plasmas, particle and radiation beams @ CLPU
"The first User access on VEGA"

L. Volpe[1,2], G. Gatti[1] and L. Roso[1,2]

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The Centro de Lasers Pulsados (USAL) is one of the Power-full Laser facility currently in operation. It is placed in Salamanca Spain and it's main system VEGA consist in two high power Arms: VEGA 2 (200 TW/ 30 fs) already in operation and VEGA 3 (1 PW / 30 fs) which operation has started recently. Here we report the first experimental results of the 200 TW system which combine both high intensity physical processes at high repetition rates.

Pulsed high-brightness neutrons delivered by multi-PW lasers for neutron interactions investigations

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We will present a project that will be based on the Apollon and ELI-NP laser facilities to develop a compact and high-brightness source of pulsed neutrons. The project is aimed at being a flexible experimental platform to uniquely study neutron interactions in the plasma state (for e.g. the nucleosynthesis of heavy elements in plasmas), which is not possible at conventional facilities where additional particle beams and energy sources to drive high-energy-density plasmas are usually missing. For this, the project will take advantage of new laser-ion acceleration regimes accessible at the multi-PW level (namely shock acceleration and radiation-pressure acceleration) compared to the standard regime (Target Normal Sheath Acceleration) used so far. These alternative regimes have a high potential for yield improvement (i.e. the laser-to-ion conversion efficiency can be increased from a fraction of a % to tens of %), and strategies exist for exploiting them in an optimized way. The project also aims to investigate the transition from the current methods that are used to generate neutrons with high-power lasers, i.e. nuclear reactions (e.g. (p,n) in Li), to the spallation method. Nuclear reactions are well assessed to produce the neutron beam, but their efficiency is low, so to attain higher yields, one obvious possibility, as exploited in high-end conventional sources (SNS, ESS), is to trigger spallation neutrons. However, this requires higher-energy accelerated ions (typically above 100 MeV/nucleon) to produce significant neutron yields, which will be aimed at by the project.

High–energy density science applications x-ray and gamma-ray sources from laser-wakefield acceleration

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This talk will review the development and applications of x-ray and gamma-ray sources based on laser-wakefield acceleration (LWFA) to the field of high energy density (HED) sciences. HED science laser facilities are now uniquely able to create conditions of temperature and pressure that were thought to be only attainable in the interiors of stars and planets. To diagnose such transient and extreme states of matter, the development of efficient, versatile and fast (sub-picosecond scale) x-ray and gamma-ray probes has become essential for HED science experiments.

We will present recent experiments on the production of LWFA-based radiation, with photon energies from a few keV to a few MeV, using picosecond laser pulses. Using the Titan laser (LLNL), we demonstrated evidence of betatron, Compton scattering, and bremsstrahlung emission in the self-modulated regime of laser wakefield acceleration (SMLWFA), for laser intensities around 10^{18} W/cm^2 [1]. For each radiation generation mechanism, we will go over detailed experimental properties and characterization of the sources, as well as supporting Particle In Cell simulations [2].

Finally, we will discuss the prospects of developing LWFA-based x-ray and gamma-ray sources for probing high energy density science experiments at large-scale laser facilities.

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344, supported by the LLNL LDRD program under tracking code 16-ERD-041, and supported by the DOE Office Science Early Career Research Program under SCW 1575-1.

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Demonstration of neutron radiography driven by a single laser pulse

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Laser-driven neutron sources are attracting attention as a new neutron source to replace nuclear reactors and accelerators. However, because of its low efficiency on the neutron generation yield, the laser-driven neutron source still remains at the stage of basic research at present. Recently, efficient ion acceleration has been achieved with picosecond (ps) relativistic-intensity laser [1]. Here, we report on the efficient neutron generation boosted by efficient acceleration of MeV-energy deuterons with the ps laser pulse. The high neutron yield allows us for the first time to obtain radiographic image by neutrons with a single laser shot.

The laser pulse with a duration of 1.5 ps (FWHM) are focused onto a few-micron-thick foil of deuterated polystyrene (CD) with the intensity of 5×10^{18} or 1×10^{19} $\mathrm{Wcm^{-2}}$, corresponding to the laser energy of 500 J or 1 kJ, respectively. Deuterons are accelerated toward the laser propagation direction up to 20 MeV with the 1-kJ laser, when the laser energy conversion efficiency is evaluated as 3.5% for deuterons over 5 MeV. Detailed mechanism of the ion acceleration will be discussed in the presentation. The accelerated ions bombard a solid beryllium block and converted into neutrons via nuclear reactions. Using CR-39 track detectors and bubble detectors, we confirm that 4×10^{11} neutrons are generated with the 1-kJ mode in 4π direction, which corresponds to the generation rate per laser energy of 1×10^{8} $\mathrm{sr^{-1}J^{-1}}$ in the laser propagation direction. The fast neutrons are decelerated by a polystyrene block having a thickness of 10 cm down to thermal or epithermal energy region and used for neutron radiography. In order to obtain background-free neutron images, we utilize the neutron capture process of ^{164}Dy. A shadow of boron carbide (B_2C), which is a neutron absorber used in a control rod of nuclear reactor, is clearly monitored on the Dy detector, while the B_2C shadow is not recorded on an Imaging Plate detector that is sensitive to plasma-induced x-ray. This fact is the evidence that our radiographic image on the Dy detector is attributed to neutrons, not x-rays.

The single-shot burst of neutrons achieved here leads to several advanced applications including high-speed imaging of fast phenomena, turbulence in piping for instance, and time-of-flight neutron absorption analysis of matters with higher resolution. The feasibility for future applications will also be discussed.

This work was funded by Grants-in-Aid for Scientific Research (Nos.25420911 and 26246043) from MEXT, A-STEP (AS2721002c), and PRESTO (JPMJPR15PD) organized by JST.

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Laser acceleration of charged particles from low-density targets for nuclear and gamma sources

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Laser-driven particle acceleration by femtosecond high-power pulses is a topic of extraordinary interest for fundamental research and nuclear applications. These issues motivated a worldwide search for different mechanisms of electron and ion acceleration with the aim to maximize both the yield and the energy of the generated particles. In this context, an important role is played by low-density targets with an electron density close to the relativistic critical density that is discussed here on the basis of the 3D particle-in-cell (PIC) simulations and theoretical models.

We have extended recently published results of so-called SASL (synchronized acceleration by slow light) simulations [1] to other schemes of laser-plasma interaction for proton acceleration involving manipulation of laser polarization and low-density targets which are available in practice [2,3]. In all cases, the main idea is to capture the protons from a target front side in laser pulse ponderomotive electric field sheath and keep them synchronized with the latter due to specific nonlinear propagation and laser-target design. We have performed optimization study for given laser pulse energy to find the target which may produce protons with maximum possible energy.

The 3D PIC simulations have also demonstrated effective acceleration of electrons from low-density targets in terms of the increased electron yield [4]. The electron charge per shot with energies in excess of 100 MeV reaches multi-nC level for current femtosecond lasers, that is not available for LWFA-based accelerators with a standard gas density and electron acceleration from planar solid targets with step-like density.

Our findings constitute an important approach to laser-based nuclear sources for deep gamma-radiography of dense samples and isotope production. This approach is demonstrated on some examples.

This work was supported by the Russian Science Foundation (Grant No. 17-12-01283).

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Thursday, June 28, 2018

12. New perspectives for gamma beam systems

08:30 – 10:20

Chair: C. Howell

An overview of the activities of inverse compton scattering sources in China

C. Tang

Tsinghua University, China

For ICS sources can supply mono-energetic photon beams from x-ray to very high energy gamma-ray, with a relatively small scale and low cost, more and more institutes are evolved in the ICS source studies. The TTX (Tsinghua Thomson Scattering X-ray Source) is still the only one can supply regular x-ray lights for users until now. The advanced x-ray imaging and polarization studies with the x-ray from TTX will be introduced in this talk, together with the upgrading design of TTX. There are two designs of the TTX upgrading, high average flux upgrading with the electron bunch being stored in a mini-storage ring colliding continuously with a laser pulse in an optic cavity, high photon energy upgrading design of using x-band linac instead of the 3-m SLAC S-band structure, to enhance the electron energy to about 150MeV, and the photon energy of 0.5-1MeV. And there are several other ICS source projects are under construction or design, based on electron linacs and Ti:Sa Lasers.

Other kinds of ICS sources, such as the all-optic experiments, ICS gamma-ray beamlines based on synchrotron sources, will also be mentioned here.

New opportunities in nuclear physics with multi PW high power lasers and multi-MeV monochromatic and brilliant gamma beams

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The nuclear physics pillar of the European Extreme Light Infrastructure, ELI-NP, is currently under construction at Magurele, Bucharest, Romania. Its mission covers scientific research at the frontier of knowledge involving two domains. The first one is laser-driven experiments related to nuclear physics. The second is based on a Compton–backscattering high-brilliance and intense low-energy gamma beam (<20 MeV), a marriage of laser and accelerator technology which will allow us to investigate nuclear structure and reactions as well as nuclear astrophysics with unpreceded resolution and accuracy.

Ultra-intense laser fields, reaching up to 10^{22} W/cm2, are now able to produce typical radiation formerly used in nuclear facilities, as demonstrated in laboratories across the globe. Such power densities are comparable to stellar environment conditions. High power laser probes will allow to study isomer properties in plasmas, to investigate laser induced multi step reactions, such as fission-fusion, to reach extremely neutron rich nuclei, and shed new light in the understanding of the r-process.

The new brilliant gamma beam facility at ELI-NP will be used to study key questions in Nuclear Structure and Reactions like detailed structure of the dipole response in very heavy nuclei, search for new low-spin modes or to investigate reactions relevant to nucleosynthesis. One of them is the fusion reaction rate between alpha particles and carbon nuclei to produce oxygen ($^{4}He + ^{12}C \rightarrow ^{16}O$) which lies at the root of life on earth. Brilliant Multi-MeV Gamma Beams may also be used to develop new imaging technics. Nondestructive investigations based on brilliant gamma rays can be successfully applied to nuclear security and counter terrorism. In this paper the research domain at reach with these new probes as well as the related applications will be illustrated through selected examples.

Simulation of a brilliant betatron gamma-ray source from a two-stage wakefield accelerator

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Thanks to the recent progress in laser-driven plasma acceleration of electrons, the ultra-short, compact and spatially coherent X-ray betatron sources generated in a wakefield accelerator have been successfully applied to high-resolution imaging or ultra-fast probing of matter evolution in the last few years. Here, based on three-dimensional particle-in-cell simulations, we propose an original hybrid scheme in which an electron beam produced in a first stage of laser-driven wakefield, interacts in a second stage with a higher plasma density to generate a beam-driven wakefield and undergo strong betatron oscillation. This second stage acts as an efficient plasma radiator: we show that this scheme greatly improves the energy efficiency of the source, with about 1% of the laser energy transferred to the radiation, and that the gamma-ray photon energy exceeds the MeV range when using a 15 J laser pulse. This new scheme opens the way to a wide range of applications requiring high-brilliance MeV photon source, such as photo-nuclear reaction study, radiography of dense objects, probing in nuclear physics or electron-positron pair production.

High intensity monoenergetic Compton Backscattered gamma-ray source at Fermilab FAST facility

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The construction and commissioning of the 300~MeV superconducting linac at Fermilab Accelerator Science and Technology (FAST) facility have recently been completed. Our goal is to build a gamma-ray source based on inverse Compton scattering between intense IR laser pulses and the electron bunches. The low energy spread of the electron beam (< 0.1%), allows the selection of very narrow bandwidth gamma photons. The low energy spread, in addition to the high photon flux, ensured by the high repetition rate of the electron bunch generation (up 15,000/second) and high IR laser intensity (>1 mJ/pulse) makes these gamma-rays suitable for nuclear physics research and for active probing of special nuclear materials.

We present the main parameters of the FAST linac, the design of the proposed experiment and the evaluation of the gamma-ray source performances. Based on conservative assumptions we estimate the flux of the 1.2 MeV gamma-ray in the range 10^6 – 10^7 photons/s, the brightness of the order 10^{21} photons/[s-(mm-mrad)^2 -0.1%BW] and radiation bandwidth below 0.5%.

This work was sponsored by the DNDO award 2015-DN-077-ARI094 to Northern Illinois University and US DOE contract DE-AC02-07CH11359 to Fermilab.

Optical energy recovery Linac ICS gamma-ray source

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We propose to develop a novel, compact, and very high average power Inverse Compton Scattering (ICS) Gamma-ray source, where electron beam generated by a photoinjector, is accelerated with the Inverse Free Electron Laser (IFEL), and after the ICS interaction point, is decelerated in the IFEL operated in reverse (TESSA), resulting in a full optical energy recovery of the laser pulse, as well as much reduced radiation footprint. The resultant capability to recirculate the laser energy yields up to a factor of 100 enhancement of the flux compare to a more conventional ICS source; thus, a proposed device can achieve the total flux of as much as 10^{13} photons/second in a compact (8-meter footprint) configuration. In this paper we present the initial design of the system, preliminary simulations and anticipated performance.

Thursday, June 28, 2018

13. Laser plasma nuclear physics

10:50 – 12:40

Chair: J. Fuchs

Toward a burning plasma state using diamond ablator inertially confined fusion (ICF) implosions on the National Ignition Facility (NIF)

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The potential of nuclear fusion as an efficient source of energy was identified decades ago. However, harnessing fusion for energy production has proven to be a difficult task. Throughout the world, billions of dollars are invested in experimental facilities and programs with the goal of demonstrating ignition - the point at which the amount of energy produced via fusion reactions is equal to or greater than the energy supplied to initiate the process. At Lawrence Livermore National Laboratory, the indirect drive approach for Inertial Confinement Fusion (ICF) is pursued at the National Ignition Facility (NIF). ICF is based on the hot spot ignition concept, where the kinetic energy of an imploding shell is converted, upon stagnation, to internal energy in a central hot spot.

We will present the first implosions in a laser driven system that produced more fusion energy than the peak kinetic energy of the imploding shell. Recent experiments on the NIF using High Density Carbon (HDC) ablators have resulted in a fusion energy output of 54 kJ for the first time exceeding the peak kinetic energy of the shell (by a factor >2).

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Laser-direct-drive inertial confinement fusion research on OMEGA

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The objective of the multi-year, systematic 100-Gbar Campaign on the 30-kJ, 351-nm, 60-beam OMEGA Laser System is to demonstrate and understand the physics for hot-spot conditions and formation relevant for ignition at the MJ scale. Laser-direct-drive (LDD) ignition requires a hot-spot pressure above 120 Gbar for an ion temperature of 4 keV and an implosion convergence ratio above 22. The physics goals and the laser and target requirements of the hydrodynamically scaled DT cryogenic implosions on OMEGA are derived from LDD ignition target designs for a 1.8-MJ laser system (e.g., the National Ignition Facility). The strategy to increase the hot-spot pressure from the current level of ~60 Gbar is to reduce the long-and short-wavelength perturbations, mitigate laser–plasma instabilities, and increase laser-to-target energy coupling. In parallel, a predictive capability that maps the relationship between the 1-D simulations and the experimental results is being used to optimize target performance. This talk will summarize the 100-Gbar Campaign on OMEGA.

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Application and potential of laser–accelerated ion bunches

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One of the most intriguing features of laser-driven ion sources is their potentially short duration and micrometer small source size (low longitudinal and transverse emittance), and their synchronism to multi-modal radiation bursts. The interest in this unique capability is exemplified in various application fields of laser-driven particle acceleration [1].

The talk will impart the most relevant underlying principles of laser ion acceleration and explain recent advances enabled by fully isolated, levitation microscopic targets [2-4]. In addition, technological developments for single-shot ion bunch metrology [5] and repetition rated target supply [6], which we pursue at the chair for medical physics of the Ludwig-Maximillians-University Munich, will be presented. Those key ingredients will facilitate a solid basis for our research using the 3 PW-laser system at the Centre for Advanced Laser Applications (CALA) at the research campus in Garching b. München and can provide valuable additions for activities at large scale extreme light infrastructures.

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5. D. Haffa, R. Yang, J. Bin, S. Lehrack, H. Ding, F. Engelbrecht, Y. Gao, J. Gebhard, J. Götzfried, M. Gilljohann, J. Hartmann, S. Herr, P. Hilz, C. Kreuzer, F.H. Lindner, T.M. Ostermayr, E. Ridente, T.F. Rösch, G. Schilling, M. Speicher, D. Taray, M. Würl, S. Karsch, K. Parodi, P.R. Bolton, W. Assmann, J. Schreiber, "I-BEAT: New ultrasonic method for single bunch measurement of ion energy distribution", (2018, in review).
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New targets for enhancing pB nuclear fusion reaction at the PALS facility

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The interaction of protons with Boron atoms can trigger the nuclear reaction known as proton-boron fusion, thus generating three alpha-particles which carry on a few MeV kinetic energy each. This neutron-less nuclear reaction is currently being actively investigated by various groups to find potential applications. Several papers report on applications in Nuclear Physics (for building an “ultraclean” nuclear-fusion reactor [1]), in Medical Physics (for cancer treatments [2 and 3]) and in Space missions [4].

In 2015, Belyaev et al. [5] demonstrated for the first time that pB fusion can be triggered by using focusing an intense and pulsed laser onto a B-doped target. This method opened a new way for successfully triggering this nuclear reaction.

In this presentation, an experimental campaign carried out at the PALS laser facility in Prague will be described. Based in our previous experimental results [6], we have optimized the target irradiation parameters (both in terms of total concentration of B atoms and target geometry) to enhance the yield of the measured alpha-particles, using the same laser intensity ($3*10^{16}$ W/cm^2).

Results using SiH targets doped with B atoms (SiHB), with overall thickness of 10 micrometers, properly designed as an output of hydrodynamic simulations using the 2D Prague Arbitrary Lagrangian-Eulerian (PALE) code for optimizing the nuclear reaction, will be compared with results obtained with thick NB targets, where the amount of B atoms is higher than in SiHB targets.

The use of several semiconductor detectors (Silicon Carbide and Diamonds) working in Time Of Flight configuration, coupled with an energy spectrometer (Thomson Parabola) and several nuclear track detectors (CR39), placed at different angles, allowed to study alpha-particle emission in terms of energy and amount of generated particles in the space.

In both cases (NB and SiHB targets) an extremely large amount of alpha-particles (more than 10^{11} alphas) was measured. To the best of our knowledge, such a value is more than 1000 higher than any other already published results [6].

Experimental results are in good agreement with theoretical expectations as it will be also described during the presentation.

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Laser-driven acceleration of gold ions in preparation of the fission-fusion reaction scheme

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Heavy elements in the universe are generated following the rapid neutron capture process (rprocess) at astrophysical sites like binary neutron star mergers [1]. A bulk of this process, however, remains largely unexplored, as it runs in fields of the nuclear landscape which are yet inaccessible for conventional accelerator techniques, especially around the waiting point at the magic neutron number of N = 126.

Habs et al. proposed the fission-fusion reaction scheme [2] for the production of neutron-rich elements close to this waiting point at N = 126. The fission-fusion reaction scheme exploits the unprecedented high ion bunch density of laser-accelerated heavy ions with energies of 7 MeV/u. Such ion bunches will come within reach at laser intensities around 10^{23} W/cm^2, as envisaged for the 2x10 PW laser system at ELI-NP, where radiation pressure acceleration (RPA) is expected to become increasingly important [3].

Preparatory work for the realization of this fission-fusion reaction mechanism is already in progress at the Center for Advanced Laser Applications (CALA) in Garching near Munich. We present results from an experiment at the Texas Petawatt Laser (TPW) at the University of Texas at Austin, USA. There, gold ions have been accelerated to the highest energies reported so far with a maximum around 5 MeV/u (and as such five times higher than reported by [4]) in a range of charge states between 45 - 60. Future experiments will aim at the reproduction and further optimization of heavy ion energies and particle numbers as well as at the investigation of the influence of collective effects at high particle bunch densities on a potential stopping power reduction, which would enhance the yield of the fission-fission reaction mechanism radically. Moreover, next-generation high-intensity lasers like the ATLAS-3000 in Garching (3 PW, 20 fs) or the high-power laser beams at ELI-NP will make the RPA regime accessible and experimental efforts will be devoted to establish this new acceleration mechanism.

This work is supported by the BMBF under Contract No. 05P15WMEN9, the DFG Cluster of Excellence MAP (Munich-Centre for Advanced Photonics) and the Centre for Advanced Laser Applications (CALA) in Garching.

1. D. Kasen *et al.*, “Origin of the heavy elements in binary neutron-star mergers from a gravitational-wave event” *Nature*, **551**, 80-84 (2017).
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Thursday, June 28, 2018

14. Laser-driven particle acceleration

14:00 – 16:00

Chair: L. Volpe

Development and application of laser-driven neutron sources

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In the context of developing a compact, high current ion accelerator, the study of intense laser driven acceleration mechanisms and their optimisation, have been, over the past two decades, very active areas of research [1]. An appealing beam of ions will not only be useful for their direct application in science, industry and healthcare, it can be useful towards developing secondary particle sources, such as neutrons. An ultra-short, directional burst of fast neutrons, produced by the high power laser driven compact ion accelerators, would have a wide ranging applications [2], including material testing for fusion energy research, fast neutron radiography, neutron resonance spectroscopy etc.
One of the efficient route to create laser-based neutron sources is by employing laser accelerated ions in nuclear reactions based on low atomic mass nuclei, such as $d(d,n)^3He$, $^7Li(p,n)^9Be$. While protons can be efficiently accelerated by the so-called Target Normal Sheath Acceleration (TNSA) mechanism [1], energetic deuterons can be obtained either by recoating typical foil targets with a deuterated compound [3, 4], or by accelerating deuterons from ultra-thin (sub-micron) targets of deuterated plastics via the radiation pressure of intense lasers. For the later case, recent experimental data not only show production of high flux, forwardly peaked neutron beams, neutron spectroscopy itself proved to be an extremely useful diagnostic to characterise and optimise the acceleration mechanism of the parent ions.
Footprint of a narrow divergence (FWHM divergence of ~70°) beam of neutrons [5], produced by employing TNSA driven ions in pitcher-catcher scenario, was obtained for the first time by using CR39 nuclear track detector close to the catcher target. Such beamed flux of fast neutrons is highly favourable for a wide range of applications, and indeed for further transport and moderation to thermal energies. Possible ways of moderating the neutrons to thermal and epithermal [6] regions will be discussed based on the data obtained from recent experimental campaign at Vulcan laser of Rutherford Appleton Laboratory, UK.

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Deuterium layer laser driven acceleration and neutron production

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High Power Lasers capable of achieving relativistic intensities $>10^{18}$ Wcm^{-2} on target are rapidly developing worldwide and are promising drivers for producing bright sources of multi 10's MeV ion beams. Understanding the mechanisms which control the spectral content is essential, as such ion beams will have many applications from probing electrostatic and magnetic fields through to studies of plasma heating, stopping powers, cellular damage at high flux rates, ion fast ignition and pulsed neutron production etc. Although laser to ion conversion efficiencies of >15% have been achieved using the Target Normal Sheath acceleration scheme, the beams produced tend to have a thermal like energy spectrum which are not ideal for all applications.

Using a recently developed cryogenic target system, an ultra thin layer of deuterium can be readily deposited as a pure low Z surface layer. To ensure that the layer is contaminant free it is deposited ms before the shot and using a combination of coating parameters it can be adjusted from a few nm's to microns in thickness. By controlling the thickness of the deuterium layer it can act as a probe of the acceleration sheath dynamics. Also, as deuterium has a lower charge to mass ratio than hydrogen it can be used to modify the spectral content of the accelerated ions, producing peaked spectra with a $\Delta E/E$ of 30-50%. Measurements taken using the Vulcan ps laser of the range of accessible ion beam properties deliverable will be given and the potential for this method for future experimental campaigns reviewed.

1. G Scott *et al.*, “Dual ion species plasma expansion from isotopically layered cryogenic targets,” *Phys. Rev. Lett (2018*) accepted for publication.

Carbon ion acceleration via ultra-short laser pulse employing ultra-thin foils

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In this work, we present recent experimental results obtained by using the GEMINI laser at the Rutherford Appleton Laboratory. The investigation concerns the acceleration of ions from ultrathin carbon foils (2-100 nm) by laser. The laser delivered ~6 J on target in a 30 fs (λ= 800 nm) pulse providing an intensity of approximately $6x10^{20}$ Wcm^{-2}. A double plasma mirror system was implemented to provide a contrast of 10^{12}.

In this interaction regime, it is known that laser polarization can play an important role in determining the dynamics of the laser-target coupling and of the ion acceleration process [1]. In particular, the use of circular polarization (controlled by a quarter-wave plate) can help to significantly reduce unawanted effects like electron heating and consequently preserve the opacity of the foils during the irradiation. This is key to accessing acceleration regimes where the laser radiation pressure is the dominant mechanism, such as the so-called Light Sail process.

Our results highlight a strong dependence of the maximum ion energies on laser polarisation, with circular polarisation leading to the highest values (>25 MeV/nucleon) for carbon and contaminant protons [2] and higher energies in more recent experiments. For targets thinner than 20 nm, circular polarisation produced energies over double that of linear polarisation. This is consistent with the onset of Light Sail acceleration, also indicated by Particle in Cell simulations.

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2. C. Scullion et al, "Polarization Dependence of Bulk Ion Acceleration from Ultrathin Foils Irradiated by High-Intensity Ultrashort Laser Pulses" Phys. Rev. Lett. 119, 054801 (2017).

Enhanced laser-driven ion sources for nuclear and material science applications

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In this contribution we present a broad range of research activities carried out within the ERC-ENSURE project [1]. ENSURE aims at the study of laser-driven ion acceleration and its foreseen applications in the fields of nuclear engineering and materials science. These sources have a great potential for a number of applications due to their unique properties and the possibility to use compact, table-top laser systems as drivers. Moreover, the development of advanced acceleration strategies based on the adoption of nanostructured target materials poses fundamental issues, since the physical processes at play in this regime are still not completely understood. Here we present a comprehensive overview of these topics, considering both the experimental and the theoretical point of views:

1) Investigations of advanced acceleration strategies based on innovative targetry solutions. Using solid foils coated with a nanostructured low-density foam as a target leads to a considerable enhancement of the properties of the accelerated ions [2,3]. We present an overview of recent experimental activities.

2) Theoretical investigations of laser-plasma interaction with nanostructured low-density materials. Due the ultra-short duration and high contrast of ultra-intense lasers, nanostructure targets can survive long enough to affect the interaction. With in-depth numerical investigations [4,5,6] we show that several observables are influenced by the nanostructure morphology.

3) Development of novel target solutions based on nanostructured low-density materials[7]. We present new insights on the growth process of low-density materials produced by Pulsed Laser Deposition, which allow for a fine control of the target properties.

4) Assessing the feasibility of specific applications in nuclear and materials sciences. We present a thorough feasibility study of laser-driven Proton-Induced X-ray Emission (PIXE) with a table-top laser, proposing a complete, compact experimental setup[8]. We also discuss how enhanced laser-driven ion acceleration could be beneficial both for PIXE and neutron sources.

The ENSURE project aims at investigating these strongly multidisciplinary goals bringing together a diverse expertise in a single team: nuclear engineering, materials science, laser technology, plasma physics, nanotechnology and computer science.

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Prospects for laser-driven ion acceleration through controlled displacement of electrons by standing waves

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During the interaction of intense femtosecond laser pulses with various targets, the natural mechanisms of laser energy transformation inherently lack temporal control and thus commonly provide limited opportunities for a controlled generation of a well-collimated, high-charge beam of ions with a given energy of particular interest. In an effort to alleviate this problem, it was recently proposed that the ions can be dragged by an electron bunch trapped in a controllably moving potential well formed by laser radiation. Such *standing-wave acceleration* (SWA) can be achieved through reflection of a chirped laser pulse from a mirror, which has been formulated as the concept of *chirped-standing-wave acceleration* (CSWA) [1].
In this contribution we further analyze general feasibility aspects of the SWA approach and demonstrate its reasonable robustness against field structure imperfections, such as those caused by misalignment, elliptical polarization and limited contrast. Using this we also identify prospects and limitations of the CSWA concept [2].

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Polarized proton beams from laser-induced plasmas

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Polarized hadron beams are of outstanding importance for nuclear and particle physics. Although the field of laser-driven particle acceleration has undergone impressive progress in recent years, one unexplored issue is how the particle spins are influenced by the huge magnetic fields inherently present in the plasmas. As part of the *Ju*SPARC (Jülich Short-Pulse Particle and Radiation Center) project at Forschungszentrum Jülich, the laser-driven generation of polarized particle beams in combination with the development of advanced target technologies is being pursued.
In order to predict the degree of beam polarization from a laser-driven plasma accelerator, particle-in-cell (PIC) simulations including spin effects have been carried out for the first time. Therefore, the Thomas-BMT equation, describing the spin motion in electromagnetic fields, has been implemented into the VLPL (Virtual Laser Plasma Lab; Univ. Düsseldorf) code. The simulation work focuses at proton acceleration in the bubble regime, where not only GeV protons are expected but also the interaction time between the plasma magnetic fields and the proton beam is significantly boosted to the pico-second level – almost three orders of magnitudes higher than that with other mechanisms like radiation pressure acceleration (RPA) and target normal sheath acceleration (TNSA). Hence, driving laser pulses with a peak power of a few PW would be required. A crucial result of the simulations is that the spins only precess during the acceleration process but they do not flip. Thus, by using a pre-polarized gas target, the chance of producing a highly polarized relativistic proton beam will be strongly enhanced.
For the experimental realization, a pre-polarized HCl gas-jet target promising a high degree of proton polarization is under construction in Jülich. With the help of a Nd:YAG laser system, the HCl bonds are aligned by the fundamental (1064 nm). Simultaneously, circular polarized light of the fifth harmonic (213 nm) is used for photo-dissociation yielding nuclear polarized H atoms. Subsequently, their degree of polarization is measured with a Lamb-shift polarimeter.

Thursday, June 28, 2018

15. Fundamental Nuclear Structure

16:30 – 18:05

Chair: S. Gales

Investigation of the γ-ray strength function of ^{87}Rb

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About half of the elements heavier than iron are produced in the slow neutron-capture process (s-process) and the reaction path is close to the valley of stability. For this production process the beta-decay rate λ_b is usually dominating over the neutron-capture rate λ_N. When $\lambda_b \approx \lambda_N$ the s-process can branch [1]. In the s-process nucleosynthesis such a branching-point nucleus is ^{86}Rb bypassing the s-only nuclei ^{86}Sr/^{87}Sr. Hence, to precisely understand the production of ^{86}Sr/^{87}Sr during the s-process, the radiative neutron-capture rate λ_N of ^{86}Rb is of utmost importance. Since ^{86}Rb has a half-life of only $T_{1/2}$ = 18.7 d, the direct measurement of the neutron-capture cross section ^{86}Rb(n,γ)^{87}Rb is experimentally not feasible [2]. Within the framework of the Hauser-Feshbach Statistical model theoretical calculations of neutron-capture cross sections can be performed [3]. For these calculations a precise knowledge of the γ-ray strength function (γSF) of the product nucleus (^{87}Rb) is crucial.

To experimentally determine the γSF, real photon scattering experiments are a very powerful tool [4]. Several (γ,γ') experiments have been performed on ^{87}Rb so far. Bremsstrahlung experiments with different electron energies have been done at the Stuttgart Dynamitron facility (4 MeV [5]) and the γELBE facility [6] (8 MeV, 11 MeV, and 13 MeV) to investigate photoabsorption cross sections.

The bremsstrahlung measurements have been extended by a complementary measurement at the High Intensity Gamma-ray Source (HIγS) at TUNL, Durham, USA. Here, almost monoenergetic, linear polarized γ-ray beams are provided by the Laser-Compton backscattering technique [7,8]. A complex energy scan from 5 MeV to 15 MeV with 26 energy settings has been performed. Deexciting γ-rays and neutrons were detected with the high-efficiency setup γ^3 (4 HPGe detectors and 4 LaBr detectors) in combination with 8 neutron liquid scintillation detectors [9]. At HIγS, absolute values for elastic and inelastic photoabsorption cross sections are investigated also aggregating unresolved transitions [10].

Moreover, the linear polarized beam enables the direct measurement of electromagnetic type of radiation. For non-zero groundstate-spins, angular distributions are less distinct, but still measurable with high accuracy for the $3/2^-$ groundstate in ^{87}Rb.

In this contribution, the experimental setups will be presented and first results regarding the dipole response of ^{87}Rb will be shown and discussed.

Supported by the BMBF (05P15PKEN9), J.W. is supported by the Bonn-Cologne Graduate School of Physics and Astronomy.

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Study of the dipole response in ^{142}Ce

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The low-lying dipole response of the N = 84 nucleus ^{142}Ce has been studied in photon scattering experiments that selectively excite J = 1 states. ^{142}Ce contains two neutrons more than the well-studied N = 82 isotones [1]. Hence, the experiments provide information about the effect of additional neutrons on pygmy dipole excitations and how the transition strengths evolve beyond the N = 82 shell closure.

Nuclei are excited from the ground state to an excited state and the photons of the subsequent decay are detected. Their angular distribution provides information on spin and parity quantum numbers of the excited states.

To study ^{142}Ce, two complementary nuclear resonance fluorescence (NRF) experiments were performed.

Firstly, the nucleus was measured at the Darmstadt High-Intensity Photon Setup (DHIPS [2]) using bremsstrahlung as photon source with an endpoint energy of 7.35 MeV. With this experiment multipolarities can be assigned to the observed transitions.

Secondly, an NRF experiment was performed with a linearly polarized, quasi monoenergetic photon beam in the entrance channel at ten different beam energies at the High Intensity Gamma-Ray Source (HIγS [3]) facility of Duke University, Durham, USA. Due to the polarization of the photons, the determination of the parity quantum numbers of the J = 1 states is possible.

Within this contribution the experimental setups will be presented and first results will be discussed.

Supported by the BMBF (05P15PKEN9) and the Alliance Program of the Helmholtz Association (HA216/EMMI). J. Wilhelmy is supported by the Bonn-Cologne Graduate School of Physics and Astronomy.

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Precision nuclear structure for 0νββ decay using second-generation gamma-ray beams

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The first nuclear resonance fluorescence (NRF) experiment using an artificial bremsstrahlung gamma-ray beam from a betatron was conducted in the year 1957 [1]. Bremsstrahlung remained the most important gamma-ray source for NRF until around the new millenium, when a second-generation gamma-ray source that employs laser-Compton backscattered (LCB) gamma-rays at the High-Intensity Gamma-Ray Source (HIγS) [2] was first used for fundamental nuclear physics research [3].

Compared to bremsstrahlung at forward angles, LCB-generated gamma-rays are almost completely linearly polarized and quasi-monoenergetic, which makes them a versatile tool to investigate the structure of nuclei.

We apply second-generation gamma-ray beams to investigate the influence of nuclear structure on the hypothetical neutrinoless double-beta (0νββ) decay. Recent theoretical investigations have shown that nuclear shapes and the phenomenon of shape coexistence can have a considerable influence on predicted 0νββ decay rates [4]. An experimental observable which is strongly sensitive to the coexistence of nuclear shapes is the decay of the M1 scissors mode [5], a collective excitation that can be observed in quadrupole-deformed nuclei. Even very weak decay branches of the scissors mode can have a large influence on theoretical calculations, which was shown in an experiment by some of the co-authors of this contribution, where such a decay was observed for the nucleus ^{154}Gd [6].

In our current research program, we are making use of the unique properties of LCB gamma-rays to study the decay behavior of the scissors mode in pairs of nuclides which are candidates for 0νββ decay. This contribution will focus on an experiment on the nuclides ^{82}Se and ^{82}Kr, which are promising candidates for neutrinoless double-beta decay due to the high Q-value, which is why they are considered for use in the SuperNEMO experiment [7]. Using this example, we will show how the quasi-monoenergetic, polarized gamma-ray beam of HIγS can be used to completely characterize the decay behaviour of low-energy magnetic dipole-excited states, the manifestations of the scissors mode. The impact of our new precise measurements on predictions of 0νββ decay rate predictions will be discussed.

Supported by Deutsche Forschungsgemeinschaft (DFG) under research grant SFB 1245

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Probing the E2 properties of the scissors mode with real photons

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The emergence of laser-generated photon beams produced by current (second-generation) γ-ray sources has significantly stimulated [1] the research in nuclear structure physics. Due to the quasi-monochromaticity and linear polarization, they enable the selective investigation of nuclear states in a confined energy region by means of photonuclear reactions [2] with an unprecedented level of precision and efficiency.

Consequently, numerous nuclear resonance fluorescence experiments at facilities such as the High Intensity γ-ray Source (HIγS) [3] have been conducted to study dipole excitations of stable nuclei especially focusing on the Pygmy dipole resonance [4] and the isovector nuclear scissors mode [5]. In the latter case, these measurements complement results from inelastic electron scattering and bremsstrahlung experiments with main focus on strong M1 transitions to the ground-state band. Despite the quadrupole-collective origin of the nuclear scissors mode, the *E*2 properties of the scissors mode were mostly unknown. Recently, first information on the *E*2 transition strength of the scissors mode was extracted [6] from a high-statistics photon-scattering experiment on ^{156}Gd using linearly polarized photon beams provided by HIγS. The data allowed for measuring a finite value of the *E*2/*M*1 multipole mixing ratio and, thus, the first measurement of an *F*-vector *E*2 transition in axially deformed nuclei. Similar experiments have been performed on the well-deformed nuclei ^{162,164}Dy at HIγS. The obtained results yield first distributions of the F-vector *E*2 transition strength of axially deformed nuclei. Furthermore, they indicate that highest precision photon-scattering experiments with quasi-monochromatic, linearly polarized photon beams are highly sensitive to the decay properties of the scissors mode and, hence, provide an essential insight into the nature of the restoring forces between the proton and neutron subsystems.

The obtained results will be presented in detail and discussed in terms of the underlying nuclear physics. An outlook for future research will be given with special focus on research possibilities at the next-generation γ-ray source ELI-NP.

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Validating the Bohr Hypothesis: measuring the energy evolution of fission-product yields from photon-induced fission of ^{240}Pu

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Systematic studies of neutron induced fission-product yields in ^{235}U, ^{238}U, and ^{239}Pu confirmed the progression towards symmetric fission at higher incident neutron energy, i.e., 14.8 MeV. However, at lower energies (E_n < ~4 MeV) the experimental data revealed a peculiar energy dependence of some high-yield fission-products from neutron-induced fission of ^{239}Pu: a positive slope up to about 4-5 MeV which then turns negative as the incident neutron energy increases. This latter finding at low-energy is in conflict with present theoretical predictions.

High-precision measurements of the fission product yields of ^{240}Pu using monoenergetic photons produced at the HIGS facility between 8 and 16 MeV will be performed to study the energy dependence, creating the same compound nucleus and excitation energy as neutron induced fission of ^{239}Pu. Preliminary results of the fission product yields will be presented, with implications for validating the Bohr hypothesis. Additionally, progress in a broader campaign of monoenergetic photon-induced fission cross section measurements will be discussed.

Accreting intermediate mass blackhole in M82 starburst Galaxy: A ZeV linear accelerator for ultra high energy cosmic rays

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M82 is a starburst galaxy, which undergoes a burst of star formation triggered by the encounter with the neighboring galaxy M81. It harbors an intermediate mass black hole, M82 X-1 with the mass of 100 ~ 10,000$M_\odot$. The X-ray luminosity of M82 X-1 is as high as 10^{41} erg s^{-1} , so that its mass must be higher than 1000$M_\odot$, if we assume the sub-Eddington luminosity. According to the bow wake linear acceleration theory developed by Ebisuzaki and Tajima [1,2], charged particles in the relativistic jets are linearly accelerated by the pondermotive force of intense Alfven waves emitted from the magnetic eruption of the accretion disk around the blackhole.

The energies of accelerated protons in the jets can reach well above ZeV $\sim 10^{21}$ eV, while accelerated electrons emits gamma-rays due to the interaction with magnetic disturbances. The protons produced by M82 X-1 by the bow wake linear acceleration can explain the northern hot spot in the sky distribution of Ultra High Energy Cosmic-Rays reported by Telescope Array group [3], if we take into account the deflection by the intergalactic magnetic field between M82 and the Milky Way galaxy. According to the observation by Fermi gamma-ray observatory, M82 is a source of gamma-rays (1-100 GeV), which is also consistent with the bow wake linear acceleration theory.

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Friday, June 28, 2018

16. Applications with gamma beams and high-power lasers

08:30 – 10:30

Chair: M. Roth

Demonstration of NRF-CT imaging by Laser Compton Backscattering gamma-rays in UVSOR

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The imaging technique of a density and nuclide-distribution inside the object is an important for the assay of nuclear materials and nuclear safeguards. Here, we report the first experimental demonstration of two-dimensional isotope imaging using high energy gamma-ray based on nuclear resonance fluorescence computed tomography (NRF-CT) technique which can be one of candidates for the imaging technique of a density and nuclide-distribution.

In this study, a new LCS beamline at UVSOR-III which can generate the maximum energy of 5.4-MeV gamma-rays with a flux of 1×10^7 photons/s [1] was used. Two large Ge detectors and a $LaBr_3$(Ce) scintillation detector were employed as the detection system. Figure 1 shows the experimental set up in UVSOR gamma-ray beamline. A 3-cm-scale CT target (Fig.2 (a)) which consists of an 8-mm lead and a 10-mmn iron rod wrapped in a 30-mm aluminum cylinder and a 34-mm iron cylinder was used. We have measured the 5292-keV NRF gamma-rays from the lead rod (^{208}Pb) to obtain a NRF-CT image by using the NRF absorption method.

After numerical reconstruction processing, we successfully obtained the ^{208}Pb distribution of the sample target, as shown in Fig.2 (b). This could be the first demonstration work of the isotope-specific CT imaging which will be a practical technique when the next generation of extremely intense LCS gamma-rays, like the ELI-NP, will be available [2].

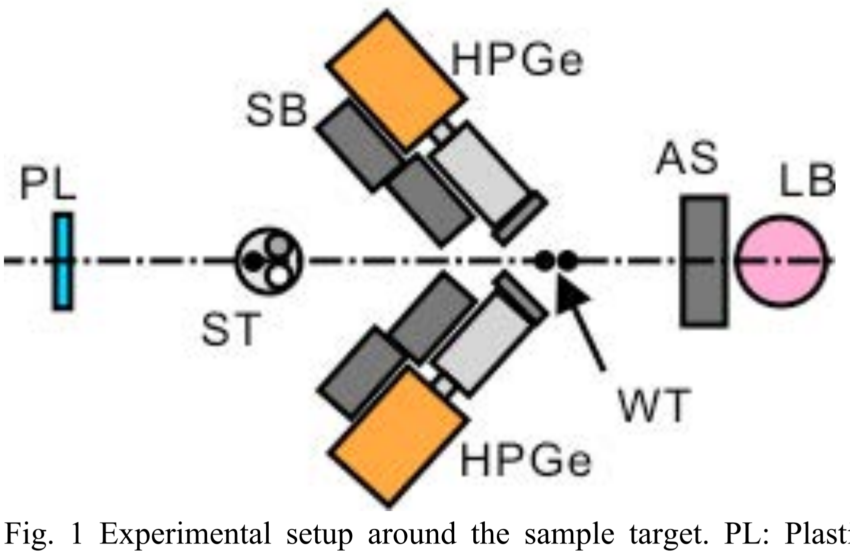

Fig. 1 Experimental setup around the sample target. PL: Plastic Scintillator, ST: Sample Target, WT: Witness Target, HPGe: Ge detector, SB: Shielding Block made from lead, AS: Absorber made from lead, LB: LaBr3(Ce) scintillation detector.

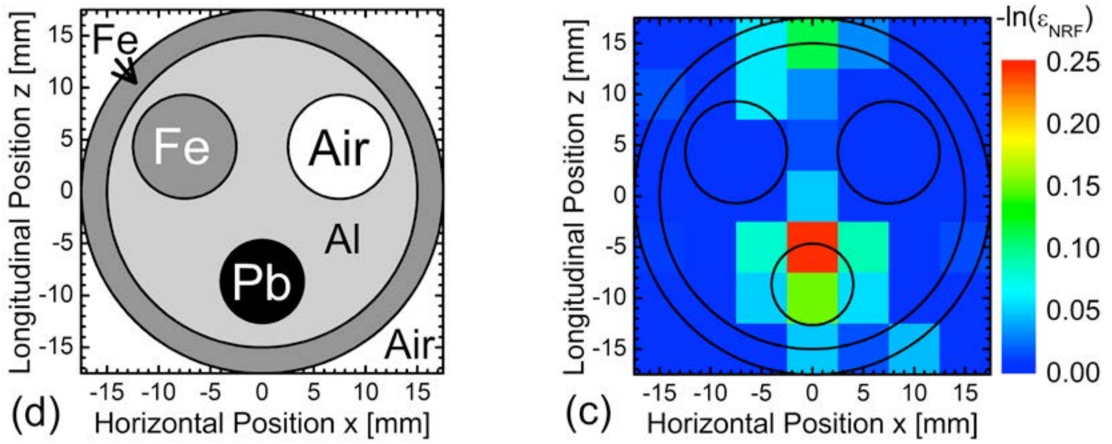

Fig.2 (a) Schematic drawing of the sample target and (b) reconstructed ^{208}Pb distribution.

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Laser-driven x-rays and neutrons for application in nuclear waste management imaging and material inspection

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Recent results from a proof-of-concept experiment as part of an innovation development project, Pulsed Laser Accelerators for The Inspection of NUclear Materials (PLATINUM), will be presented including demonstration of high resolution imaging of cracks surrounding corroded uranium encased in grout and penetrative imaging of a uranium penny through a 50L waste drum simulator.

The principle concern regarding intermediate level waste (ILW) containers is the internal volumetric expansion due to the formation of corrosion products. To tackle this (via non-destructive testing) the development of laser-driven sources to identify problematic containers was initiated via the PLATINUM collaboration, which aims to demonstrate the impact of laser-driven high-energy bremsstrahlung radiation for imaging and laser-driven thermal energy neutrons for isotopic quantification.

The study established the non-destructive imaging capability of a high-energy laser driven x-ray source for identifying fine features such as corrosion products on uranium samples encased in grout and cracks, and for penetrative imaging through large thicknesses of grout. In addition, generation of laser-driven neutrons of thermal energy required for active interrogation of uranium isotopes is demonstrated experimentally and simulations of the neutron inspection method are presented, thus paving the way for criticality testing of ILW containers.

This current study is single pulse exposure acquisition, but the data can be used to predict the potential capability of a diode-pumped laser-driven system operating at, or above, 10Hz by utilising, for example, the DiPOLE laser technology recently delivered by the STFC Central Laser Facility. Such a system will enable 3D tomography of nuclear waste containers and also greatly reduced signal to noise ratio via multiple acquisition and image stacking.

Non-destructive detection of gold in ores using gamma activation analysis

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Mining has been one of most important industries for the Australian economy since the mid-1800s, and today remains a multi-billion dollar industry. Within the past century, the relative concentration of precious metals in ores has been gradually decreasing [1], requiring a larger quantity of ore to be mined in order to produce the same amount of these metals. As such, the importance of extracting a maximum amount of metal from ores is paramount, which in turn requires accurate determination of metal concentration throughout the mining processing chain [2]. Currently, the method mostly used for analysing elemental grades in ore is fire assay. This complex chemical process involves destroying the sample, requires very careful quality control procedures to maintain accuracy and is time consuming [2].

CSIRO Mineral Resources have been developing Gamma Activation Analysis (GAA) as an innovative means to measure gold at sub parts per million levels. GAA has been demonstrated gold assay of individual samples and the same technique is now being applied to bulk gold ore sensing and sorting [3]. GAA utilises high energy X-rays produced by electron beam accelerators to cause photonuclear interactions with the target nuclei, which induces short-lived radioactivity. These activated nuclei will decay back into their stable state through a number of different possible decay paths, each emitting gamma rays of varying energies. These energies are known for a range of elements and can be used to determine the concentration of the desired target element in the sample, thus acting as a remarkably accurate form of non-destructive testing, enabling the rapid analysis of large ore samples in real time, with no matrix effects and is chemical free [4, 5].

This presentation starts with an overview of GAA for rapid non-destructive detection of gold in bulk ore. The importance and difficulty of gold detection will be discussed including the activation mechanisms and the key challenges of using intense high energy X-ray sources. Finally, the practical application in industrial settings are presented.

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γ-ray refractive lens systems for the MeV energy range

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Important for the realization of refractive optics is the knowledge of the index of refraction of the material where the optics are composed. The investigation of the fundamental properties of matter within the visible light is of crucial importance for the development of optics in industrial as well as scientific applications. Since the discovery of X-ray radiation and the forthcoming development of X-ray radiation sources within the last century, made a basis for new optics and applications. The evolution of modern brilliant X-ray radiation sources made the investigation of the optical properties of materials up to about 100 keV possible. Current theory describing the optical behavior of materials is validated experimentally in the X-ray regime (several hundreds of eV up to tens of keV). In the γ-ray energy regime (up to several MeV) no experiments to verify the theory of the index of refraction were performed so far. At γ-ray energies additional other processes occur compared to the X-ray regime during the photon matter interaction. It arises the question for the optical behavior at such energies and the demand for experimental tests. For the first time we have measured the index of refraction for several pure as well as compound and fluid materials with different charge numbers (Z=4 to Z=82) at γ-ray energies from 181 keV up to 2 MeV. The deviation from unity of the refractive index is expected as very tiny (10^{-9} to 10^{-7}). Therefore, it needs a metrology of ultra-high precision and resolution, which is described in detail by Günther et al. [1]. In this contribution we will present the new findings of the refractive index as basis for the knowledge of developing γ-ray refractive optics.

A further aspect is the feasibility of refractive γ-ray optics. In the past the focusing of X-rays was successful demonstrated, which is established in nowadays X-ray imaging applications [2-4]. In the X-ray regime refractive lenses were realized up to 200 keV. In the near future, novel high brilliant and high energy γ-ray sources, such as ELI-NP [5], will be realized. The success of a number of different applications in nuclear physics might be boosted by the capability of γ-beam focusing and collimation. The announced appearance of highly brilliant tunable γ-ray sources [4] motivates studies of the optical properties of materials at higher energies, and therefore the development of special refractive focusing optics. Such sources will provide very intense photon pulses with tunable energies in the range of 0.1-20 MeV and a typical bandwidth of $\Delta E/E \sim 10^{-3}$. One important application for these sources is to be found in the field of nuclear resonance fluorescence (NRF) experiments. Typical resonance energies are in the range of 100 keV up to 8 MeV, where the expected Doppler broadened resonance width is about 1 eV. Therefore, NRF-resonance experiments one would require a very high degree of monochromatization. Via crystal diffraction the source bandwidth can be tuned to NRF-resonance requirements. But, the use of conventional crystal monochromators leads to losses because finite beam divergence of the source. An additional use of refractive optics makes this process sufficiently efficient to decrease the beam divergence compared to what is provided from the source. At such high energies conventional focusing optics based on diffraction, like mirrors, multilayer Laue lenses or Fresnel zone plates [6], are very difficult to operate, mostly because the angular acceptance range for diffraction decreases strongly with photon energy. The main problem is the fast convergence of the value of the refractive index towards unity. Based on our investigation of the refractive behavior of several different materials at γ-ray energies we have pointed out an optimum for the realization of γ-ray refractive optics. The results demonstrate that there is a range where the refractive index becomes maximum for all energies, which means that these materials are suitable candidates for refractive optics. With such materials it is feasible to realize refractive focusing optics within the high photon energy range above 500 keV and up to above 1 MeV.

We have performed optical as well as atomic simulation studies for developing and design new γ-ray refractive optics. These studies are the basis for fabrication of suitable refractive optics for the mentioned photon energy. In the fabrication step of the optics development we pointed out the best method and best choice of materials for the realization of these special optics.

In this presentation we will show the results of our index of refraction measurements with respect to the realization of γ-ray refractive optics. Furthermore, we present results concerning our refractive focusing optics development and fabrication for γ-ray energies. In addition to other aspects the γ-ray refractive focusing optics will be designed for a novel imaging application, which will be also presented.

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Non-destructive inspection of material defect by positron generated by laser compton scattering gamma-ray beam

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We will report the experiments on generating positron beam based on a high brightness gamma-ray facility, which is built on an electron storage ring through Compton scattering of laser light from a high-energy electron beam circulating in the ring. The laser Compton scattering gamma-ray beam source has been developed on NewSUBARU storage ring several years before and became a user facility for the applications from nuclear physics research to industrial imaging [1]. Electron beam is injected from 1 GeV linac at SPring-8 facility and circulates in the ring with bunch length of 30 ps. At the top-up operation, the beam current can be kept as 300 mA. One of the straight sections of the ring where the electron beam collides with the incoming laser light in a head-to-head manner. The Compton backscattering photons are going along the incident electron moving direction and extract from the vacuum chamber and transport to the experimental area through an atmospheric pressure. The laser light with wavelength of 1064nm comes from a Nd:YVO_4 laser, which provides 30 W output. The produced gamma-ray photons have the maximum energy of 16.9 MeV on axis. Quasi-monochromatic gamma-ray beam can be obtained by using a collimator placed on the axis. The actual gamma-ray yield was measured as 250 photons/mA/W/s after a collimator of 3 mm in diameter. The gamma-ray beam is arranged to inject on a thin Pb target to generate positrons and electrons via pair creation reaction and this process is also studied with the Phits Monte Carlo simulation code. A magnet was used to separate the electron-positron beams and retrieve positrons with the required energy to inject into a sample to be measured.

The non-destructive inspection measurements were the spectra width of electron-positron annihilation photons and the lifetime of positron in the material. The spectra width has an information of the electron momentum annihilated with a positron. The lifetime of positron is approximately inversely proportional to the electron density at the annihilation, it has information on the size of the defect [2]. The measurement system and results will be reported.

This work was supported by JSPS Grant-in-Aid for Scientific Research Grant Number JP26289365. This work was performed by using NewSUBARU-GACKO (Gamma Collaboration Hutch of Konan University).

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Friday, June 28, 2018

17. Nuclear photonics and related fields

11:00 – 12:45

Chair: R. Hajima

Nuclear Photonics activities at the Technische Universität Darmstadt

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Nuclear Photonics is a rapidly growing field of basic and applied sciences. It links the physics of ultra-intense lasers and high energy density matter with nuclear physics and enables new tools and new insight in a variety of topics.

At TU Darmstadt, we have embraced this new field and focused on combined research using the strong expertise in nuclear, plasma, laser and accelerator sciences. Eight faculty members have teamed up with their research groups to address this field focussing on two primary topics: the generation of a bright, laser-driven, neutron source and the use of intense, mono-energetic, polarized gamma beams.

Research in this field makes first use of the Darmstadt PHELIX laser system at Helmholtzzentrum für Schwerionenforschung - GSI, and the superconducting energy recovery electron accelerator S-DALINAC at TU Darmstadt, but is ultimately aimed at research at the two ELI pillars NP and BEAMLINE.

We report on our strategy, the recent activities, on latest results in developing a laser driven neutron source and prospects for research at TU Darmstadt.

IAEA activities in support of the accelerator-based research and applications

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Promotion of nuclear applications for peaceful purposes and related capacity building is among the missions of the IAEA. In this context, accelerator applications and nuclear instrumentation is one of the thematic areas, where the IAEA supports its Member States in strengthening their capabilities to adopt and benefit from the usage of accelerators. A number of activities are being implemented focusing on accelerator applications in multiple disciplines, facilitating access to accelerator facilities for the countries without such capabilities, and also development and capacity building in associated nuclear instrumentation.

ELI-NP is going to be a laser-based research facility covering diverse areas of fundamental physics, nuclear physics and astrophysics, and also applied research in materials science, management of nuclear materials and life sciences.

This presentation aims at disseminating the currently running activities of the Physics Section of IAEA and those planned for the near future, implemented through Collaborative Research Projects, Technical Cooperation projects and scientific-technical meetings organized by the IAEA. Some aspects on possible synergies with ELI-NP will be explored and presented.

High-field science platform in X-ray free electron laser SACLA

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X-ray Free Electron Lasers (XFELs) have successfully generated brilliant femtosecond X-ray pulses that opens up new frontiers in various scientific fields. These X-ray short pulses enable us to observe the behavior of molecules and solid materials on the time scales of atomic motion, with a greater fidelity than had been possible with previous techniques. The Linac Coherent Light Source (LCLS) [1] and the SPring-8 Angstrom Compact Free Electron Laser (SACLA) [2] have been utilized as user experiments and produced many kinds of cutting-edge scientific results. Recently the other facilities, such as European-XFEL [3], and XFEL at Pohang Accelerator Laboratory (PAL-FEL) [4] succeeded in the generation of hard X-ray short pulses.

In SACLA, ~0.5-mJ and <10-fs pulses are provided in a range from 4 to 15 keV at 60-Hz repetition rate on hard X-ray beamlines (BL2 and BL3). The beam of the XFEL pulse is typically focused to a spot size of 1 um on a sample with a Kirkpatrick-Baez (KB) mirror set [5] or compound refractive lenses. We have reached the smallest beam spot down to several tens nanometer diameter, which is estimated to be a power density of ~10^{20} W/cm^2, with a two-stage KB focusing system [6]. In addition, we have operated two-color double-pulse generation for pump-probe experiments in a hard X-ray region [7]. That has applications in areas of not only materials science [8], but also high energy density physics [9], planetary science and studies of nonlinear X-ray phenomena [10-13].

We have constructed two types of the high-power optical laser system (short-pulse and long-pulse laser systems) combining with the XFEL pules of SACLA for studies of high-field science. Figure 1 shows a schematic view of the experimental hole in SACLA – SPring-8 experimental facility. The short-pulse laser system provides two beams of 500-TW pulses with ~25 fs (FWHM) pulse duration at 1Hz (Thales). The pulse contrast has been realized to 10^{-10} at a 100-ps range with a double-chirped pulse amplification stage including a cross-polarized wave generator (XPW). We have precisely synchronized these pulses to RF clock of the accelerator by controlling the cavity length of the mode-locked oscillator with a phase-lock loop circuit. The timing jitter between the optical and XFEL pulses have successfully been reduced down to 60 fs (rms). The two beams are directed to the target chamber on the beamline of BL2 in the experimental hutch EH6. By focusing them to 10-μm spots with off-axis parabolic mirrors, we accomplish a peak power density above 10^{20} W/cm^2. Some kinds of studies on plasma state, using the ultrashort-pulse laser and XFEL, are planned as early user experiment in 2018.

The long-pulse laser system generates 5-J pulse energy with 4-ns pulse duration at 0.1 Hz, which have been developed by Hamamatsu Photonics K. K. and will be upgraded to more than a few tens of joules in 2018. The beam of the long-pulse laser has been transported to the target chamber on the beamline of BL3 in the experimental hutch EH5. This apparatus has specifically been designed for diffraction and imaging of high-energy-density materials.

In this session, we will present the recent progress of high-field science studies utilizing these two type optical laser systems and XFEL. As an acknowledgment, a part of this work has been performed in collaboration with Osaka University (Drs. Norimasa Ozaki, Takeshi Matsuoka, Kohei Miyanishi, Keiichi Sueda, Hideaki Habara, and Ryosuke Kodama).

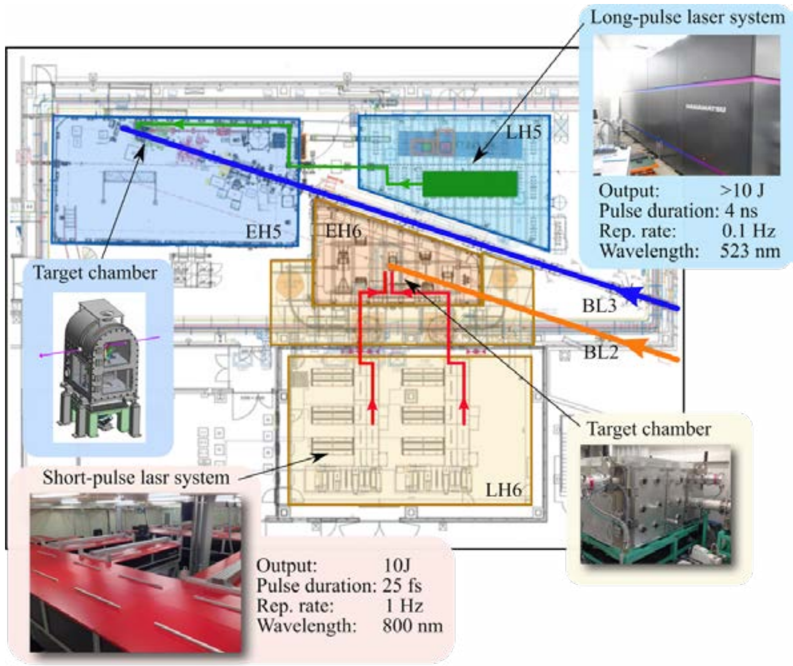

Fig. 1, Schematic view of SACLA – SPring-8 experimental facility. EH5 and EH6 are experimental hutches for the beamlines BL3 and BL2 respectively. LH5 and LH6 are laser hutches for the long-pulse and short-pulse laser systems respectively.

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New biomedical research directions with high-power lasers at ELI-NP

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Laser sources using chirped pulse amplification [1] were shown in the last years to yield secondary pulsed particle and gamma beams with very high dose rates. Doses of the order of Gy can be delivered on time scales faster than microseconds to cells, tissues, and organs. This new type of radiation delivery inflicts damage to tumour cells via different molecular pathways compared to traditional prolonged radiation exposure. The pathways involve, in particular, the generation of bursts of free radicals and the quenching of these radicals. Biomarkers are to be identified in order to follow the radiation effects in cell irradiation experiments [2].

Using lasers as radiation sources, new medical technologies and the research studies associated with these technologies can be projected and developed. These studies will focus on the detection of the effects of radiation with mixed particle and gamma pulsed beams as well as on laser-driven diagnostics using phase contrast imaging. These new medical applications can be further improved using nanoparticles as effective imaging or radio-sensitising agents as well as carriers for radiation markers.

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A comprehensive photon-and-neutron hybrid transmutation study of long-living fission products

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The transmutation of long-living fission products (LLFPs) into stable or short-living fission products is receiving added attention in recent times, as an alternate option of spent fuel waste disposal. In this paper, a systematic transmutation study based on photonuclear (γ,n)-reaction and neutron capture based (n,γ)-reaction is presented. The aim of the study is to devise an efficient way of transmutation for I-129, Cs-135, and Cs-137 using the advantages of both photonuclear and neutron capture transmutation simultaneously. This newly proposed transmutation concept is termed as hybrid transmutation. The basic idea is to utilize the highly energetic photons for giant dipole resonance (GDR) based photonuclear (γ,n)-reactions and the emitted neutrons will be further used for neutron capture based (n,γ) transmutation. The effectiveness of the method depends on the incident photon spectrum for (γ,n)-reaction and emitted neutron spectrum for the (n,γ)-reaction. Therefore, in this paper, an optimized incident photon spectrum which is generated from the laser-Compton scattering (LCS) source is used to maximize the (γ,n) transmutation reaction [1]. Also, the neutron spectrum is adjusted based on the optimization of moderator thickness inside the target material.

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Poster Presentations

P. 01

Feasibility study for the Gamma Above Neutron Threshold experiments at ELI-NP using GEANT4 simulations

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The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) is a facility dedicated to nuclear physics research with extreme electromagnetic fields. It will host a system of two high power 10 PW lasers and a very brilliant gamma-beam system. The gamma-beam system will provide high brilliant and intense gamma-ray beams with energies up to 20 MeV, 0.5% relative energy resolution and ~10^8 photons per second intensity. These gamma-ray beams will be used for precise photonuclear measurements [1].

The ELI-NP Working Group "Gamma Above Neutron Threshold" (ELIGANT) aims to study the physics cases related to: (1) p-process nucleosynthesis, (2) nuclear structure of Giant Dipole Resonance (GDR), (3) new compilation of total and partial photoneutron cross sections, (4) nuclear structure of Pygmy Dipole Resonance (PDR) and spin-flip Magnetic Dipole Resonance (MDR).

For this purpose two dedicated arrays were developed: (1) The ELIGANT-GN array will constitute of $LaBr_3$:Ce and $CeBr_3$ detectors for the gamma detection as well as liquid scintillators and ^{6}Li-glass for fast neutron detection. (2) The ELIGANT-TNF is a 4π flat efficiency neutron detection system dedicated for neutron multiplicity sorting experiments. It is comprised of ^{3}He neutron counters embedded in a moderator block.

Here we report on the status of the feasibility studies performed using extensive Geant4 simulations. Dedicated codes includes many features: simulation of the laser-Compton backscattered (LCB) gamma beams as expected at ELI-NP, response of $LaBr_{3:}$Ce, $CeBr_3$ and BC501A detectors. The expected performance of the arrays will be discussed in terms of timing properties, detection efficiencies, beam-related background and count rates. Predictions concerning the Day1 experiments planned at ELI-NP will be also discussed.

1. D. Filipescu, "Perspectives for photonuclear research at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) facility" *Eur. Phys. J. A*, **51**, 185 (2015).

P. 02

Realising Single Shot Measurements of Radiation Reaction for Inverse Compton Sources

C. D. Baird[1], C. D. Murphy[1], T. G. Blackburn[2], A. Ilderton[3], S. P. D. Mangles[4], M. Marklund[2], and C. P. Ridgers[1]

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Modern, high-intensity laser systems can accelerate electrons to multi-GeV energies in laser-wakefield schemes. By employing a second, counter-propagating laser, those electrons can then be used to drive high-brightness X-ray sources via inverse Compton scattering (ICS). In order to increase the brightness of such sources, it is desirable to increase the intensity of the scattering laser. This leads to nonlinear ICS where multiple photons interact with a single electron and radiation reaction (RR) effects where the motion of the electron is significantly altered by its own emission. At the highest intensities pair production may occur, providing a laboratory analogue for some of the most extreme environments in the universe.

Several models exist to predict the effects of such strong field QED processes but only recently have experiments been possible to benchmark these models [1]. To improve our understanding of both the fundamental physics and the range of sources which might be generated, we must better understand the changes in electron and photon spectra driven by the interaction of an intense laser with a relativistic electron beam.

Recent experiments have shown that high-intensity laser-plasma experiments can reach the RR regime, however shot-to-shot fluctuations in laser pointing and electron beam profiles limit the precision with which RR can be measured. We present a method for measuring RR effects in a single laser shot by comparing different regions of an electron bunch post-interaction. Using the 3D PIC code, EPOCH [2], we simulate the interaction of an electron bunch with a short-pulse, high-intensity laser in a 180° inverse Compton scattering geometry. The figures below show the phase-space representation of a mono-energetic electron bunch before (Fig. 1) and after (Fig. 2) interaction with an intense laser-pulse. The electron bunch is larger than the focused laser spot by design, and so the central region of the bunch loses energy from the interaction, whereas the edge of the bunch remains unaffected allowing direct comparison between the pre- and post-interaction spectra to be made. With the aid of improved detection methods, this may allow detailed, on-shot measurements to be made.

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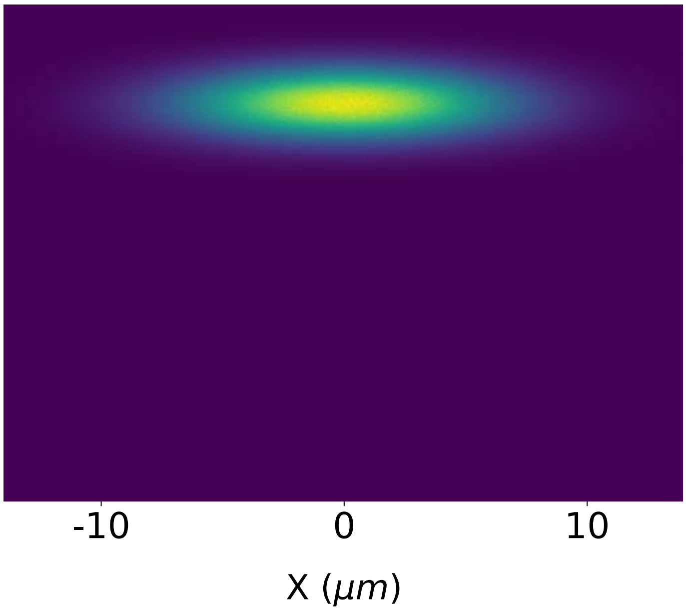

Figure 1: Phase space of electron bunch before interaction with laser pulse.

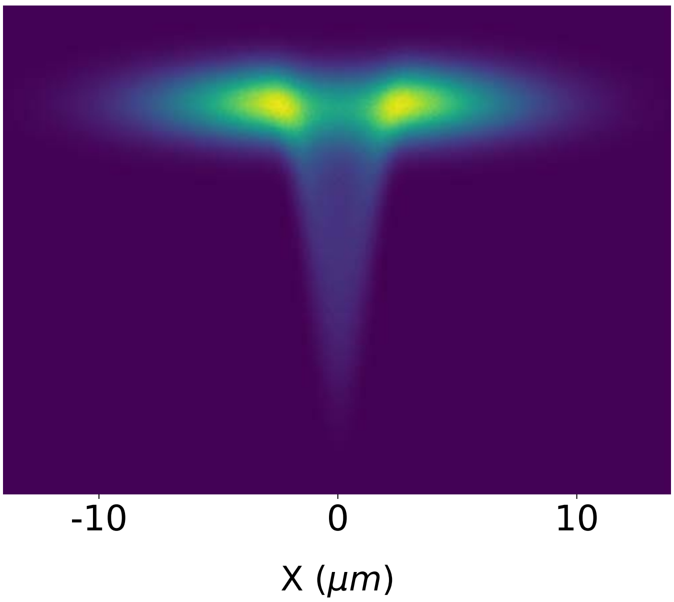

Figure 2: Electron bunch after laser interaction. The central region of the bunch (red) has lost energy due to RR effects; the edges (blue) retain the original spectrum for comparison.

P. 03

Ray-tracing simulation and magneto-hydrodynamic calculations for the design of the probe beam transport for plasma diagnostics in laser wakefield electron acceleration at ELI-NP

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At the ELI-NP facility, a laser pulse, with 20 fs duration and 200 J energy will be focused by a spherical mirror with 30 m long focal length, into a gas cell with adjustable length, located in the ultra-high vacuum of the E6 interaction chamber. The aim is to generate a plasma wakefield with strong electric field gradients which captures and accelerates electrons [1]. One goal is to implement a laser plasma wakefield accelerator with high conversion efficiency from laser to electron energy and a well collimated electron beam, with angular divergence < 0.01 rad and relative energy bandwidth < 1%. To fulfill these requirements, one-shot measurements of the plasma density maps and plasma dynamics will be performed using the techniques of transversal Nomarski interferometry [2] and Faraday rotation polarimetry [3, 4]. The facilitated probe pulse will have an energy up to 10 mJ, duration less than 10 fs and negligible chromatic dispersion. The probe beam has to be synchronized with the 10 PW pulse such that the time delay between the two pulses can be adjusted within a few fs precision.

A complete model of the transport system of the plasma-diagnostic and pre-plasma probe beams was simulated with OpticStudio [5], to calculate the probe pulse energy in the gas cell and on the surface of a metallic tape that reflects the 10 PW laser pulse. The ray-tracing calculations were done to estimate the background contribution of the scattered main laser pulse to the interference image. Based on the 3D models built in Autodesk and OpticStudio, the transport optical lines of the two probe beams and the dipole magnet of the electron spectrometer were integrated in the engineering model of the E6 interaction chamber. Magneto-hydrodynamic calculations of plasma density variation in time and space were performed with Helios [6] to estimate the required thickness of the metallic tape and its position relative to the exit of the gas cell.

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P. 04

Production of isotopes for nuclear medicine via photo-nuclear reactions on 232Th

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Isotopes are a key component in nuclear medicine. They have several applications, from imaging techniques for diagnostic to dose delivery for cancer treatments [1]. One of the main issue in nuclear medicine is the limited availability of isotopes, usually produced in nuclear power plants [2]. In this paper it will be presented a study of photo-irradiation of 232Th with laser plasma accelerator as possible alternative method for the production of radioisotopes. Simulations of the photo-nuclear interaction between high energy bremsstrahlung photons and a solid Thorium target have been performed using the FLUKA Monte Carlo code. A range of photon energies, from 100 MeV up to more than 2 GeV, has been investigated in order to try to maximize the isotopes production yield. .

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P. 05

Optical production of nuclear isomers

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The ELI-NP facility [1] presents a unique opportunity for exploring problems in fundamental physics, combining a 2x10 PW high-power laser system (HPLS) and a high-brilliance gamma-beam system (GBS) with energies of up to 19.5 MeV. The laser system consists of two synchronized arms, each with three optical compressors that allow pulse extraction at different powers, ie. 100 TW at 10 Hz, 1 PW at 1 Hz, and 10 PW at 0.016 Hz, with a pulse duration around 20 fs. The GBS photons are produced by inverse Compton backscattering of laser pulses off electron bunches accelerated by a LINAC up to 720 MeV.

One of the proposed first-phase experiments [2] aims at studying in the laboratory the conditions normally encountered in nuclear astrophysics, namely inducing photoexcitation on a nuclear isomeric state. In a nutshell, electrons are accelerated by the laser pulse to MeV energies, and they hit a tungsten target, producing Bremsstrahlung gamma radiation that impacts a secondary target with the nucleus of interest, producing isomers.

We performed 3D PIC simulations using the codes PIConGPU [3] and EPOCH [4] in order to study the electron beam generated by laser wakefield acceleration (LWFA), as follows. An electron beam is produced from a LWFA source consisting of a 1-mm-long gas cell filled with nitrogen. The relevant parameters of the LWFA can be determined by using the scaling law of nonlinear plasma wakefields in the bubble regime [5-7]. A TW-class laser pulse is focused on a spot with a few μm radius at the entrance of the gas cell, operated at a plasma density of $\sim 10^{18}$ cm^{-3}. As a result, strong nonlinear wakefields can be generated so that the electron bunch could be trapped due to ionization-induced injection [8, 9] and accelerated up to hundreds of MeV [10]. Figure 1 shows results of one such PIC simulation, where we fixed the width of the gas-filled region from the nozzle jet to 1 mm and obtained an accelerated electron beam with an angular divergence of about 6°.

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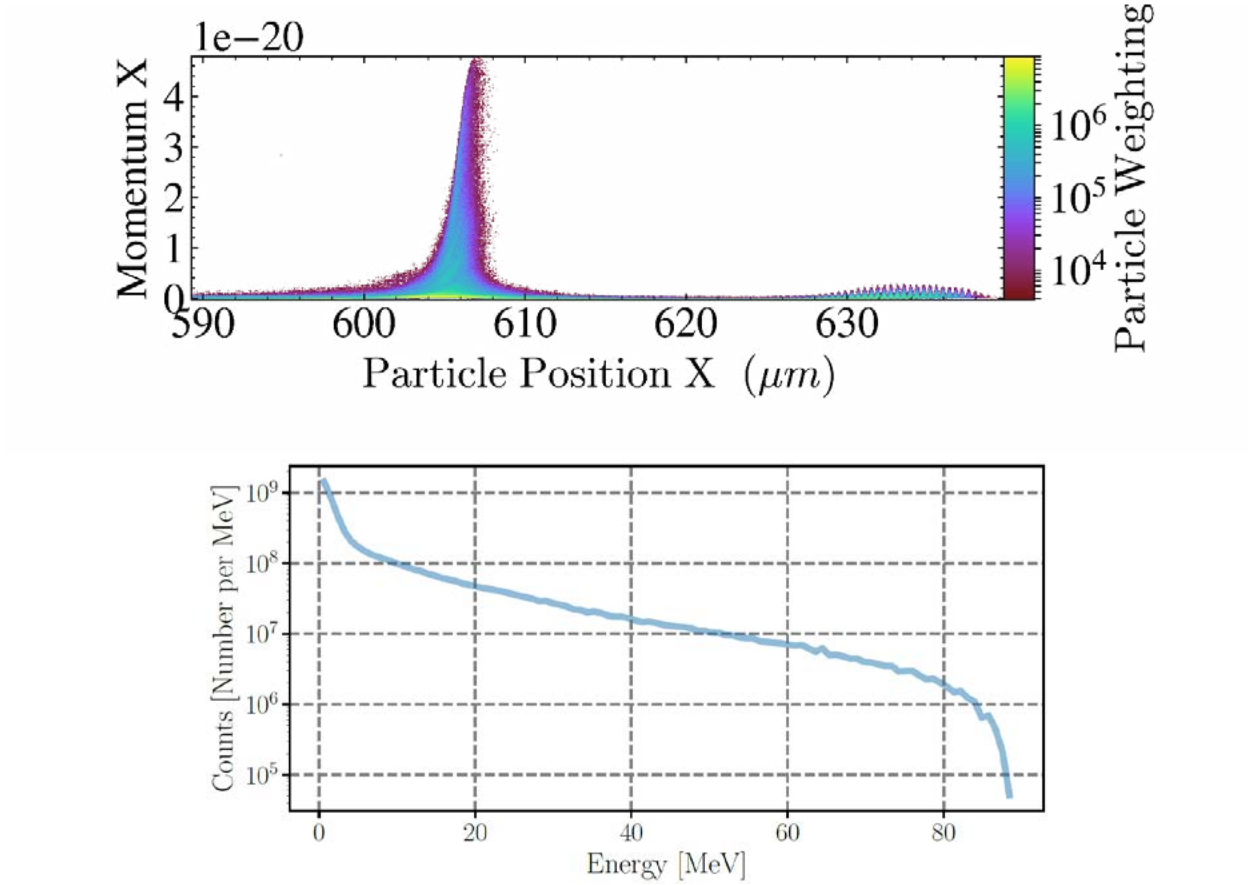

Figure 1: Momentum (top) and energy (bottom) distribution for LWFA electrons from PIC simulations. The driving laser has a Gaussian profile, with a wavelength of 800 nm.

P. 06

Photonuclear Reaction Measurements with an Active Target e-TPC at the GBS facility of ELI-NP

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Photo-induced reactions present an attractive spectroscopic tool for measuring nuclear observables that are pertinent for nuclear structure and nuclear astrophysics interests [1]. The Gamma Beam System facility at ELI-NP will deliver unique opportunities for photonuclear reaction investigations, reuniting high-luminosity, narrow-bandwidth, and mono-energetic gamma photon beams.

In this context, an extended gas target, electronic-readout Time Projection Chamber (ELITPC) is being developed for measuring charged-particle emitting reaction channels [2]. The ELITPC scientific program incorporates seminal physics cases such as the $^{16}O(\gamma,\alpha)^{12}C$ and $^{19}F(\gamma,p)^{18}O$ stellar evolution reactions.

A Geant4 toolkit simulation application, TPC G4App, was developed to accompany these experimental efforts. The application features a modular build, giving users the flexibility to adapt and extend the software capabilities to the specific experiment needs. The first phase of the simulations focused on optimizing ELITPC experiments settings in view of, for instance, the hall location with reference to the gamma source, background, and the detector design.

An overview of the TPC G4App application and key simulation results will be presented in this contribution.

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P. 07

Design of mixed beams radiobiology experiments

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A number of biomedical applications with laser-driven particle beams at ELI-NP will benefit from the radiobiology experiments in the "mixed beams approach" [1]. This could include laser-driven theranostics and mixed beams radiotherapy. In this approach and experimental design, the biological sample are irradiated simultaneously or sequentially with particle beams that can be obtained by different arms of the high power laser or by specially designed targets.

Such mixed beams radiobiology experiments were performed in the past with conventional radiation sources and were reported in the literature [2]. The results showed that the order of irradiations for two different ion beams can produce different effects. The synergistic effect of irradiations depend on the time interval between the exposures.

Laser accelerated particles have special characteristics including ultra-short, pulsed beams, high dose rates. The link between these characteristics and the radiobiological effects for mixed beams need to be studied using dose-controlled, high-throughput irradiations. We present here an experimental design for such studies and Monte Carlo dose calculations for proton beams.

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P. 08

Laser-ion Acceleration at ELI-NP

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We investigate the interaction of an ultra-high intensity laser pulse with plastic foil and flat-top cone targets coated with nanospheres. The laser pulse has the parameters of the 10 PW lasers from ELI-NP. We find the optimal geometric dimensions of the foil, the flat-top cone and the nanospheres to obtain monoenergetic beams of accelerated ions with low angular divergence. This study will allow one to prepare and optimize first laser-ion acceleration experiments on ELI-NP using micro-cone targets.

In the last decade a lot of target geometries were proposed in order to obtain very energetic protons. Some works showed that the interaction of the ultra-high intensity laser pulse with a micro-cone target can generate protons accelerated at energies of tens MeV with low angular divergence and high laser absorption [1] in the Target Normal Sheath Acceleration regime. In this paper we investigate the laser-ion acceleration in the ultra-high intensity regime as the result of the interaction of a circularly polarized ultra-high intensity laser pulse with a foil and a cone target coated with nanospheres. We find that the cone target coated inside with nanospheres irradiated by an ultra-high intensity pulse can generate beams of protons more energetic and with a greater number of protons with energies higher than 800 MeV than with the simple micro-cone target. We obtain the most efficient ratio between nanosphere diameter and the foil target thickness for the lowest energy spread, the lowest divergence and the highest energy of accelerated protons and carbon ions beams.

In our PIC simulations we use the parameters of two high-intensity ELI-NP PW laser beams having central wavelength λ=0.8 μm, intensity on focus I=2.16 x10^{22} W/cm^2, normalized laser amplitude a_0=100, laser focal spot FWHM d=5.6 μm, laser-pulse circular polarized E_z=E_y, E_x=0, laser-pulse duration τ=25 fs, laser-pulse power P=21.3 PW and laser-pulse energy E=532 J.

We performed Particle-in-Cell (PIC) simulations using the 2D PICLS code for the interaction of a high-intensity laser pulse with a plastic foil target coated with the nanospheres. We varied diameter of the nanospheres and the thickness of the foil. In Figure 1 we plot the maximum proton energies versus time of the simulations for different foil targets with nanospheres. We can see that the highest maximum proton energy value, 1235 MeV is obtained for the plastic foil target of 40 nm thickness with nanospheres of 40 nm in diameter.

We performed PIC simulations also for a flat-top micro-cone target coated inside with nanospheres. The height of the cone is 20 μm, the walls thickness is 4 μm. The cone base width is 25 μm and the width of the cone neck is 5 μm. The flat-top cone is coated with nanospheres. We simulate the cones with flat-top foil thicknesses of 20 nm and 40 nm coated with nanospheres with 40, 60 and 80 nm. The maximum proton energy as a function of time graphs are illustrated in Fig. 2.

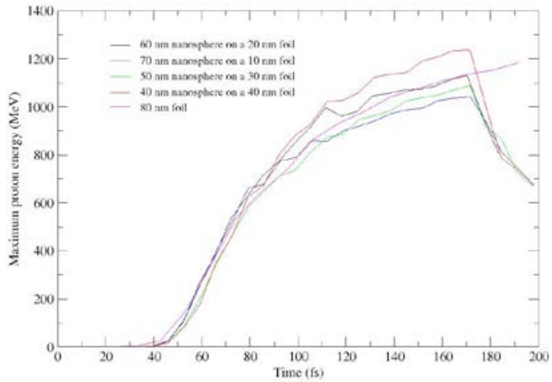

Fig. 1 Maximum proton energy versus time for different foil target geometries.

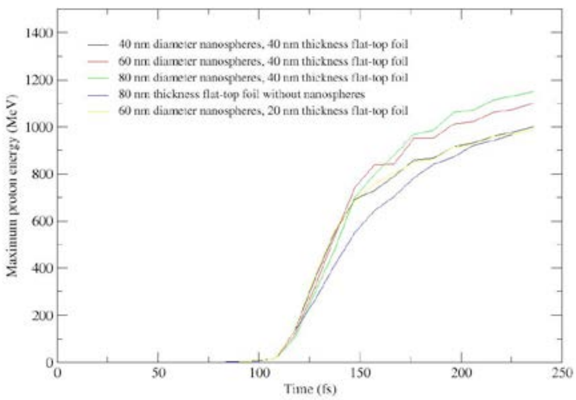

Fig. 2 Maximum proton energy versus time for different

We studied the electromagnetic field distribution in the focal region both from temporal and spatial point of view using FullWave, a package of the commercial software RSoft which solves Maxwell equations using the finite difference time domain (FDTD) method. The flat-top foil has the 40 nm thickness same as the diameter of the nanospheres. We obtained for the case of coated cone a higher value of the electric field intensity in the vicinity of the focal region.

We can conclude that a plastic foil target of 40 nm thickness with nanospheres of 40 nm in diameter has the optimum ratio between the nanospheres diameter and the thickness of the foil for ion acceleration. We notice that the cone target coated with nanospheres is a better structure for ion acceleration than the simple cone target. According to these numerical studies the most efficient target for ion acceleration from the studied cases is the coated cone target with the thickness of the flat-top foil of 40 nm and the diameter of the nanosphere of 80 nm.

This work has been financed by the national project PN III 5/5.1/ELI-RO, No. 16 ELI/2017 (“SIMULATE”), under the financial support of Institute for Atomic Physics – IFA.

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P. 09

Laboratory investigation of magnetized laser plasma expansion into the vacuum at PEARL facility

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The experiments on laser plasma expansion into an ambient magnetic field modeling different astrophysical phenomena have been conducted on a laser-plasma stand [1,2] based on laser facility PEARL [3]. A high-speed dense plasma flow simulating the plasma of the accretion disk was formed by thermal ablation of a substance from the surface of a solid target when it was irradiated with powerful laser pulse. This plasma flux interacted with an external magnetic field directed along the surface of the target, i.e. the plasma flow propagated predominantly across the magnetic field lines. Such formulation of the problem was aimed to modeling the processes of interaction of the accretion disk surrounding the young star with the stars own magnetic field, mainly the region of balance of the accretion disc plasma gas-dynamic pressure and magnetic pressure. The accretion flow moving perpendicular to the magnetic field lines in the direction of the increasing magnetic field of the star reaches the region in which the balance between the gas-dynamic pressure of the flow and the magnetic pressure is satisfied. It and leads to the formation of the internal boundary of the accretion disk. The analog of this in laboratory experiments is the density decrease of the laser plasma moving away from the target. As a result, at some distance from the target surface the gas-dynamic pressure of the laser plasma compares with the magnetic pressure. It simulates the inner region of the accretion disk of interest to us.

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P. 10

Laser driven particle sources for various laser-target conditions

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Particle beam acceleration by high power laser pulses is a research field of rapidly growth covering a wide range of laser-target interactions physics. Due to many practical applications of laser accelerated electron and ion sources extensive research is going on worldwide for improving their physical parameters such as flux, maximum energy, collimation, total charge, etc. In particular, high repetitive rate ion sources of narrow energy spread have attracted great attention.

Here, we present an extensive study of laser driven ion beams in single and double beam experiments performed at the Arcturus Laser System in Düsseldorf. The two almost identical high power beams offer large flexibility of laser pulse parameters and allow generating and controlling different plasma states. Gas, cluster and solid targets were employed in various interaction conditions in order to optimize and control the particle acceleration processes. In particular, it will be emphasized in the presentation on the progress and results on the development of high repetition rate ion sources of narrow energy bandwidth and high stability. In addition, proton imaging was employed to investigate the rapidly evolving plasmas.

P. 11

Single plasma mirror simulations for back-reflection protection in 10 PW laser experiments

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Recent measurements with PW class lasers demonstrates that energies of up to 3% of the incident laser energy can be back-reflected in the laser system [1] and that modulations of the target surface can occur due to the radiation pressure [1, 2]. Given the foreseen intensities in the ELI-NP experiments in the range of 10^{22}-10^{23} W/cm^2, back-reflections of the main laser pulse can occur from the distorted plasma, leading to irreversible damages of the beam transport system optics or even to the laser amplification chain. Moreover, the debris generated from the laser – target interaction can damage the focusing optics and decrease their performance from only a few shots. We are presenting simulated results of the interaction between the ELI-NP 10 PW laser beam and a sacrificial mirror design that yields up to 80% attenuation of the back-reflected light.

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P. 12

Experimental evidence for the enhanced and reduced stopping regimes for protons propagating through hot plasmas

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Our understanding of the dynamics of ion collisional energy loss in a plasma is still not complete, in part due to the difficulty and lack of high-quality experimental measurements. These measurements are crucial to benchmark existing models. In this talk, we will show that such a measurement is possible using high-flux proton beams accelerated by high intensity short pulse lasers, where there is a high number of particles in a picosecond pulse, which is ideal for measurements in quickly expanding plasmas. By reducing the energy bandwidth of the protons using a passive selector, we have made proton stopping measurements in partially ionized Argon and fully ionized Hydrogen plasmas with electron temperatures of hundreds of eV and densities in the range 10^{20} – 10^{21} cm^{-3}. In the first case, we have observed, consistently with previous reports, enhanced stopping of protons when compared to stopping power in non-ionized gas. In the second case, we have observed for the first time the regime of reduced stopping, which is theoretically predicted in such hot and fully ionized plasma. The versatility of these tunable short-pulse laser based ion sources, where the ion type and energy can be changed at will, could open up the possibility for a variety of ion stopping power measurements in plasmas so long as they are well characterized in terms of temperature and density. In turn, these measurements will allow tests of the validity of existing theoretical models.

P. 13

Sub-barrier binary and ternary fission studies with the GBS facility at ELI-NP

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Along with 2 × 10 PW high power laser system (HPLS), the Extreme Light Infrastructure - Nuclear Physics facility (ELI-NP) will host a brilliant gamma beam system (GBS) [1,2] delivering quasi mono-energetic gamma beams with high spectral density (~10^4 photons/s/eV), high resolution (band width ≥ 0.5%) and high degree of linear polarization (>95%) [3]. The high-energy beam will be tunable from 0.2 MeV to 19.5 MeV. All these features of the beam will contribute in overcoming the existing limitations on photo-fission experiments and hence enabling high resolution measurements of sub-barrier transmission resonances in the fission decay channels with cross sections down to $\Gamma\sigma \approx 0.1$ eV b [4,5].

The photo-fission experimental campaign at ELI-NP, aims at high resolution study of transmission resonances as a function of energy, for light actinide nuclei. The important observables to be measured include the absolute photo-fission cross sections, fission fragment characteristics like energy, mass, charge and angular distributions, neutron gamma-ray emission, and de-excitation of fission fragments. Also, the study of ternary photo-fission is aimed at which will become possible for the first time due to the high intensity of the beam. An important goal is to resolve the so-far unobserved fine structure of the isomeric shelf by decomposing it into individual transmission resonances, and to observe the predicted nucleon clusterization phenomena in super- and hyper-deformed states of the actinides [4].

In order to make these measurements possible, new detector arrays based on the existing, well-understood cutting-edge technologies, are being constructed. The first setup, called ELITHGEM, is an array of 12 THick Gas Electron Multipliers (THGEM) inside a low-pressure gas chamber, dedicated to the measurement of fission cross sections as a function of the incoming gamma energy and angular distribution of the fission fragments. This detector array covers almost a full solid angle (80% of 4π) and has an angular resolution of about 5°. The second setup, called ELI-BIC, includes a set of four double-sided Frisch-grid Bragg Ionization Chambers to investigate the fission fragment characteristics, each chamber being coupled with eight ΔE-E detectors (covering a one π solid angle) for the study of ternary fission [4]. For the measurements of prompt fission gamma and neutron spectra, we plan to couple an ionization chamber with gamma and neutron arrays, under construction at ELI-NP.

The present status of development of the above mentioned detector arrays will be reported along with the results from several performance tests carried out till date for the newly constructed detectors. The near future plans for in-beam test experiments at the existing neutron and γ-beam facilities will also be presented along with our future plans for photo-fission experiments with the GBS at ELI-NP.

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P. 14

Measuring energy and polarization of gamma rays at ELI-NP with the Gamma Polari-Calorimeter

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Studying Radiation Reaction and Vacuum Birefringence in the conditions available at ELI-NP will require measuring both energy and polarization of emitted gamma rays. The Gamma Polari-Calorimeter (GPC) is an instrument being designed to measure these parameters for gamma beams of 100 MeV - 2 GeV using the polarization dependent cross-section of the pair production process. Using a combination of pixelated SOI sensors to track the electron and positron trajectories in a magnetic field the kinematic properties of these particles, and by extension those of the interacting photon, can be obtained. Measuring the modulation of the azimuthal distribution of the electron-positron pairs provides a measure for the degree of polarization of the beam. Monte Carlo simulations show that for single incoming photons within the targeted energy range the energy resolution is below 8% and the analyzing power is greater than 0.5. Performance degrades when considering multiple photons arriving at the detector simultaneously but the energy resolution is still kept below 10% for photon energies greater than 500 MeV, while simultaneously reconstructing more than 10 photons per event.

P. 15

PIC simulations for applications at ELI-NP

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In this contribution, we present recent simulation results obtained with EPOCH [1] on the characteristics of the proton beam generated in laser interactions with solid targets. We implemented the parameters of the high power laser system of ELI-NP [2] and we studied the optimization of the proton beam on two parameters: the maximum (cutoff) energy of the beam and the number of high energy protons. We analyzed the variation of these parameters for various types of targets (changing their density, composition and thickness) and for different laser intensities. The results are compared with the requirements of applications foreseen at ELI-NP, including the production of medical radioisotopes [3], new technologies for space applications [4] and the management of nuclear waste disposals [5,6].

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P. 16

Investigating nuclear reactions at astrophysical energies with gamma-ray beams and an active-target TPC

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A new methodology to measure cross-sections for thermonuclear reactions that power the stars is being developed at the University of Warsaw in collaboration with ELI-NP and the University of Connecticut. These reactions take place at different energies according to the respective stellar environment. Such energies are well below the Coulomb barrier and the respective cross-sections are incredibly small, often below the experimental reach. There is a lack of experimental data on cross-sections for low-energies, information that is indispensable for modeling energy production in stars. As a consequence, extrapolations are made, with their unavoidable large uncertainty. Of special interest are (p, γ) and (α, γ) reactions, in particular those, that regulate the ratio of C and O and those that burn ^{18}O and, therefore, regulate the ratio between ^{16}O and ^{18}O in the Universe. One of the benchmark reactions to be investigated in this work is the $^{12}C(\alpha, \gamma)^{16}O$ at energies down to 1 MeV in the center-of-mass reference frame.

We propose to use a gaseous active target detector to study (α, γ) and (p, γ) nuclear reactions of current astrophysical interest by means of studying time-inverse photo-disintegration processes induced by high energy photons. The advantage of such an approach stems from the fact that photons are not subject to the nuclear Coulomb barrier. The Extreme Light Infrastructure-Nuclear Physics facility (ELI-NP) - currently being built near Bucharest, Romania - will deliver monochromatic, high-brilliance and polarized gamma-ray beams. The charged products of photodisintegration reactions will be measured by means of a Time Projection Chamber (ELITPC) with 3-coordinate (u-v-w) planar electronic readout acting as virtual pixels. The detector will be equipped with triple-GEM structure for gas amplification and will work at lower-than-atmospheric pressure. The concept of the detector and the status of the R&D for it will be presented, as well as results from tests using a scaled demonstrator detector.

P. 17

Characterization Methods of Ferrofluids Usable in Plasma Mirror Applications

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In the last years, plasma mirrors (PM) [1] were used extensively in high power laser experiments and also required for ELI-NP operation [2]. We have studied ferrofluid materials which could be used as PM reflectors. As the laser systems at ELI-NP will be operating at a high pulse repetition rate, it is essential to have renewable and conformal thin films that can act as either plasma mirrors, or as sacrificial mirrors, or as low f-number focusing optics.

PMs are based on plasma generation processes after the ionization of a target material surface by an incident laser pre-pulse. Therefore, the high power laser pulse applied shortly after pre-pulse will be reflected by the previously generated plasma whose optical quality follows the optical quality of the initial surface.

We have prepared ferrofluidic suspensions with different compositions. These suspensions consist of ferromagnetic microparticles immersed in a polyphenyl ether matrix, material which is suited for use in ultra-high vacuum conditions due to low vapor pressure. The ferromagnetic micro-powder particles consist of a mixture of iron oxide (Fe_2O_3), polymeric styrene/acrylate and polyolephyne.

Before preparing the ferrofluids, the ferromagnetic micro-powder was characterized by scanning electron microscopy and optical profilometry in order to obtain the statistical size distribution, along with an assessment of particles' surface roughness and morphology. Following the mixture of ferrofluid particles with the matrix material, the roughness of ferrofluid films were then determined by optical profilometry, both in the absence and presence of a magnetic field. The magnetic field was provided by an external permanent magnet. Also optical microscopy data was employed in order to correlate spatial distributions of ferromagnetic microparticles from the ferrofluidic films with the roughness measurement, for different concentrations and in the presence of a magnetic field.

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P. 18

Optimization of the compact gamma-ray source based on inverse Compton scattering design

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Recently a 0.5-4MeV quasi-monochromatic compact gamma-ray source with high peak spectral density based on the inverse Compton scattering (ICS) has been proposed in the Department of engineering physics, Tsinghua University. This type compact gamma-ray source will be used for advanced X/gamma-ray imaging application based on the nuclear resonance Fluorescence (NRF). The machine size and the peak spectral density of scattered photons are the most important parameters for such application. In order to make the source compact enough, a compact commercial narrow bandwidth Nd:Yag laser system with ~25ps FWHM duration and ~1.5J maximum energy per pulse is selected as the scattering laser, and the linac is proposed to combine a photo-injector and an X-band main linac to obtain high quality 200MeV maximum energy electron beam with high charge (~200pC) and low transverse and longitudinal emittance. In ICS, the properties of the generated photons are determined by the parameters of the incident laser and electron beam, and also their interaction geometry. In this paper, we will present the optimization of the linac design. We systematic simulate and optimize the linac design with Astra and Cain. In the simulations, we find that with a velocity buncher after the gun will significantly reduce the uncorrelated energy spread caused by the X-band RF curve in the main linac and then increase the gamma-ray spectral density. Three possible type of photo-injector, S-band photocathode RF gun with S-band booster, C-band photocathode RF gun with C-band booster, X-band photocathode RF gun with X-band booster, are systematically optimized and compared.

P. 19

Machine Learning with Artificial Neural Networks for specific data analysis used in Nuclear Physics

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In the past few years there was a lot of interest in Artificial Neural Networks(ANNs) for machine learning, mainly, because of the increased computational and memory resources. The amount of information that needs to be processed has increased beyond the level of human comprehension both in complexity and volume; this is especially true for the nuclear data that had increased with the technology involved.
The networks are highly dependent on their purpose; there are two main types of networks: regression networks and classification networks. For example, regression networks can be used to extract the magnitude of a given nuclear event and classification networks to search for a given particle or nucleus. A useful type of ANN is deep ANN that has multiple hidden layers of neurons, after each layer, specific features[1] are extracted from the last layer; these features can represent definitory characteristics of a nuclear event or particle, that can be specified if needed. In the training session if the network architecture is not limited to extract real-world features it will find some random-features that might not have meaningful information in the real world. This feature extraction makes the machine learning approach a powerful tool capable of finishing tasks that are hard to describe into a programming language or to find an algorithm for them, opening the path for pattern recognition-based algorithms. In this way nuclear data can be interpreted, extrapolated, interpolated or classified.
A very powerful open-source, cross-platform tool for creating and using ANNs is TensorFlow[2], a library developed by Google Brain written in C++ with APIs in C++/Java and Python where the layers, weights and biases are all represented by tensors and the activation function of the neuron it's applied to the whole tensor. The library also has a very optimal matrix multiplication algorithm witch it's highly used in the tensor approach of the network. Because of the high amount of multiple-but-simple operations needed to train and use the networks, the library can use and work better with the GPU instead of CPU that have a higher level of parallelization.
Even though the machine learning approach can have surprising results once it is well trained, the biggest challenge and the most important part is the training itself. Usually, for machine learning one needs as many data as he can obtain to train the machine. One possible source of trusted nuclear processed data is the National Nuclear Data Center [3].

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P. 20

Day-1 experiments at ELI-NP 10 PW Strong-Field Physics Experimental Area

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The ELI-NP facility will enable, for the first time, dual-beam experiments with laser intensities exceeding 10^{22} W/cm^2. In the Strong-Field Physics experimental station an all-optical setup will be implemented with one beam dedicated for relativistic electron acceleration and the second focused beam submits them to very high electromagnetic fields [1]. A multi-GeV electron spectrometer and diagnostics tools will be available for: gamma-rays, electrons and positrons, plasma characterization and transmitted and reflected laser beam properties. Here we will outline the implementation progress of the first experimental runs.

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P. 21

Comparison of Practical Expressions for E1 Photon Strength Functions

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Different closed-form models for the photon strength functions (PSF) for nuclear photoabsorption of electric dipole (E1) gamma-rays are tested. The following models are used: Standard Lorentzian (SLO); Simplified Modified Lorentzian model (SMLO) [1,2]; Simplified Modified Lorentzian model with constant width after the Giant Dipole Resonance (GDR) energy (SMLOc); Triple Lorentzian Model (TLO) [3,4]. For the SLO, SMLO, SMLOc models, the approximation of axially deformed nuclei is adopted and the approximation of triaxial nuclei is used in the TLO model.

The quality of description of the experimental photonuclear cross-sections below 30 MeV by these theoretical models is analyzed using the least-squares criteria χ^2. The ratios $R_\alpha = <\chi^2_\alpha>/<\chi^2_{SLO}>$ of arithmetical means of least-square deviations for the given model to the SLO model are considered. The calculations are performed for spherical and axially deformed nuclei with the results: $R_{SMLO} = 0.73$; $R_{SMLOc} = 0.83$; $R_{TLO} = 10.15$. It can be seen that the SMLO model is the best one for description of photoabsorption cross sections. But in this model the energy-weighted sum rule is violated due to permanent growing the width with energy. The SMLOc model corrects such defect and leads to smaller values of the PSF in comparison with SMLO approach for the gamma-ray energies higher than 30 MeV. So, SMLOc model can be considered as the best candidate for the modelling of the E1 PSF at the gamma-ray energies above GDR values and for simple overall description of the E1 PSF in nuclear photoabsorption processes.

This work is partially supported by the IAEA through a CRP on Updating the Photonuclear Data Library and generating a Reference Database for Photon Strength Functions (F41032).

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P. 22

Laboratory investigation of collision-less ion-plasma energy exchange

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We will present recent experimental results investigating, in the laboratory, the development of the streaming instability. The streaming instability is driven by energetic ions propagating in a magnetized background plasma. Our goal is to elucidate the effects of the instability on the ion beam and background plasma. The investigation was performed by exploiting the coupling between fast ion beams driven by short-pulse lasers, the generation and characterization of well-controlled background plasma in which the ions will be propagated, and strong external magnetization of this system. Doing so, we have observed very clear collisionless ion energy losses in magnetized plasmas for broadband energy ion beams. Strong thermalization of streaming ion beams are also observed in numerical investigations we are pursuing in parallel using hybrid codes. Beyond its interest as a fundamental phenomenon in plasma physics, electromagnetic streaming instabilities play a key role in the acceleration of particles in astrophysical shocks and are also recognized to be responsible for confining low energy cosmic rays, both effect have potentially important repercussion on the observed anomalous ionization of dense clouds in the inter-stellar medium (ISM), and thus on star formation.

P. 23

Applications of a Novel Laser-Driven X-Ray Source to Nuclear Science

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We discuss the potential nuclear physics applications of a recently-demonstrated all-laser-driven MeV-energy x-ray source [1]. This idea is based on inverse Compton scattering (ICS) of laser light by 0.1-1 GeV energy electrons accelerated in an ultra-high-gradient laser wakefield. ICS x-rays have several advantages over conventional bremsstrahlung x-rays, including, modest bandwidth (10-20%), low divergence angle (1-5 mrad), and large energy tunability range (1-15 MeV). These x-rays beams were previously used to study photodisintegration, and processes such as (γ,xn) and (γ, fission).
Recently, we have used this source to study long-lived isomeric nuclear states that are of interest to efficient energy storage. It is well-known that metastable states such as ^{180m}Ta, which has a half-life $>10^{15}$ years, can be used to store energy with orders of magnitude higher density than conventional chemical storage [2]. Selectively accessing the intermediate states (IS) within the nucleus, energy can either stored (known as isomer *population*) or released (isomer *depletion*). The implications of such energy storage in principle are the creation of either a nuclear battery or even a γ-ray laser. Unfortunately, due to the complexities of the nucleus, only a few metastable isomers have been experimentally depleted. The characteristics of the laser-driven ICS source make it optimal for studies to map energy levels which could be useful for energy storage applications.
To better understand the population and depletion of specific isomeric states, a complete level scheme must be known which includes all IS that lead to the isomeric state from the ground state and subsequently from the isomeric state back to the ground state. Maps of these states can be built by probing the nucleus with x-rays with known energy (on the order of MeV), which has previously been done with x-rays produced at linear accelerators (LINAC). This method, however, has specific drawbacks. Bremsstrahlung x-rays produced at LINACs are polychromatic, which can smear together contributions from different paths through the IS, and the highly monochromatic x-rays produced by using monochrometers can have extremely long scan times if the IS are completely unknown. The laser-driven ICS source with modest bandwidth and large tunability overcomes both drawbacks.
In our first experiments, we have studied population of the well-known 4.6-hour isomer of ^{115}In with the goal of demonstrating the efficacy of the ICS radiation for these types of nuclear physics studies. This was achieved by comparing the isomeric yield's dependence on the ICS source's x-ray beam parameters, to the predicted response [3] as shown in Figure 1. Furthermore, we have recently produced high energy photons (~20MeV) by the mechanism of high-order multiphoton ICS. In these experiments, laser light was focused to a peak intensity $>10^{20}$ W cm^{-2} [4]. It has been predicted that x-ray pulses with attosecond duration can be produced by this novel mechanism, which opens the possibility to study ultrafast nuclear processes.

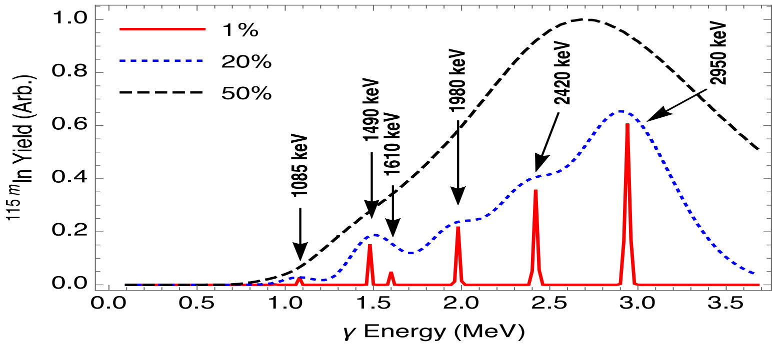

Figure 1: Theoretical production of ^{115m}In and its dependence on ICS beam central energy assuming a Gaussian distribution with 1%, 20%, and 50% spread (FWHM). The marked peaks are the known intermediate states for ^{115}In→^{115m}In as used in Belic et al. [3]. Intermediate states above 2950 keV have yet to be investigated.

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P. 24

Repetitive Laser-Driven Neutron Source Using Diode Pumped Solid State Laser

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We introduce the research project about the development of laser driven compact neutron source. The neutron technology is one of the key technologies for broad range of applications; (a) analyzing materials such as proteins, magnetic materials, metal alloys and secondary batteries, (b) radiographic imaging of thick objects such as automobile engines, buildings and bridges, and (c) treating cancers by BNCT (boron neutron capture therapy). Extensive efforts are undertaken to develop compact neutron sources with linear accelerators and cyclotrons, where the neutrons are generated by Be(p,n)B or Li(p,n)Be reactions by irradiating Be or Li targets with high energy (typically 7-30 MeV) and high current (100mA-1mA) proton beams. However, it is still in scientific research state. The key technology for creating neutron industry is available and affordable compact neutron source.

We are investigating a possibility to develop a compact neutron source with ion beams driven by high-intensity short-pulse laser. The laser-driven neutron source has several unique possibilities; (a) realization of a compact neutron source by closely locating a laser-driven particle source and a neutron generating target, (b) a small size neutron source which is advantageous for high resolution radiography, and (c) neutrons with short pulse duration leading to a possibility for time-of-flight measurements in material analyses and imaging. The most important feature for a practical neutron source is repetitive neutron generation capability. We use the diode pumped ultra-intense laser of Hamamatsu photonics. The laser system can be operated in 10 Hz of repetition rate. The irradiation target supplying system is also important for realizing repetitive neutron generation. Figure 1 shows the irradiation target. This target enables 25 times repetitive irradiation. The target consists of two deuterated polystyrene film and spacer. The thickness of two of films are 5 mm and 50 mm, respectively. It has so-called "Pitcher-Catcher"

Figure 1. Double foil target with "Pitcher-

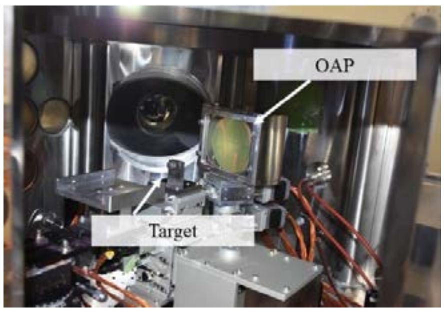


Figure 2. The irradiation chamber

Catcher configuration”

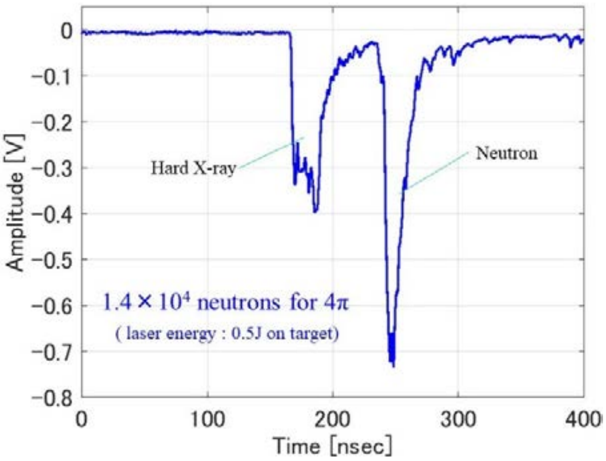
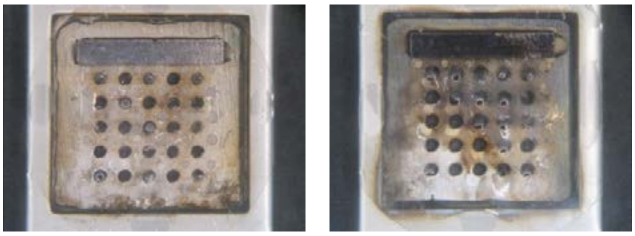


Figure 3. Acquired signal using scintillation type neutron detector.



(a) (b)

Figure 4. Targets after multiple-shots, view from the second target, “Catcher”, side.

configuration. High energy ion beam generated in the first target, “Pitcher”, under intense laser irradiation hits the second target, “Catcher” for neutron generation by nuclear reaction. As the first step, we are testing neutron generation by D-D fusion reaction (D+D→^{3}He+n and T+p), since this reaction takes place with ~1MeV deuterons and the deuterated plastic foil is easy to handle. Since the nuclear reaction cross sections of D-Li or D-Be reactions are higher than those of P-Li or P-Be reactions in low energy regime (<3 MeV), we are exploring deuteron acceleration with a deuterated thin plastic foil [1, 2]. When Li or Be target is adopted as “Catcher”, These reactions can be applied to the laser driven neutron source.

We demonstrated the repetitive laser driven neutron generation. Currently, the repetitive interval is about 1 minute. So, the 25 times of repetitive shots could be executed less than 30 minutes. Figure 2 shows the irradiation chamber. The ultra-intense laser pulses were focused on to the “pitcher” by the off-axis parabola (OAP) mirror. Neutron generation was monitored by the neutron detector, that is installed at 45 degrees from the laser axis. The detector consists of plastic scintillator (BC408) and photo-multiplier tube. The output current was acquired using an oscilloscope. An example of the output signal is shown in Figure 3. These signals were analyzed using Time-of-Flight (ToF) manner. The signal of neutron generation can be observed following that of hard X-ray, because 2.45MeV of DD neutrons are about 10 times slower than the speed of light. In the case of Figure 3, the number of neutron yield can be calculated as 1.4×10^4 neutrons for 4p direction. Figure 4 shows the targets after laser irradiation. The inside of two films were contaminated by carbons. The target film was partially broken. That could be problem for more numbers and faster repetitive shots. We are working to realize continuous target supplying.

We express appreciation to Hamamatsu photonics K.K. for their cooperation in experiments using high-power laser. This work is supported by Japan Science and Technology Agency (JST), Adaptable & Seamless Technology Transfer Program through Target-driven R&D (A-STEP).

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P. 25

Laser Compton scattering gamma-ray generation for Delbrück scattering experiments

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Delbrück scattering, in which a gamma-ray interacting with a Coulomb field creates an electron-position pair, which subsequently annihilates to generate a gamma-ray which energy is almost identical with the incident gamma-ray, is one of important phenomena to study non-linear effects by QED and vacuum polarization. Koga and Hayakawa [1] have presented that it is possible to measure selectively the amplitude of Delbrück scattering using linearly polarized gamma-ray beams. Furthermore, if one uses a linearly polarized beam with energies lower than 1.022 MeV, which is the threshold of the pair creation, it is possible to measure only the virtual process of Delbrück Scattering, namely vacuum polarization. For such a purpose, we have developed a laser Compton scattering (LCS) gamma-ray beam with a CO_2 laser having a wavelength of 10 μm at the UVSOR-III synchrotron radiation facility, in which the energy of the electron beam stored in top-up mode is approximately 750 MeV. We generated a 1-MeV LCS gamma-ray beam. We will also discuss future plans.

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P. 26

Influence of temporal laser pulse profile on the pair production dynamics in ultraintense laser – electron collisions

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Current petawatt laser facilities [1] can generate multi-GeV electron beams [2] from laser wakefield acceleration and achieve focal spot intensities of up to 10^{23} W/cm^2. A high energy electron beam can be scattered from a counter-propagating laser pulse of ultrahigh intensity (10^{22} W/cm^2), producing copious amounts of gamma-ray and electron-positron pairs. Such experiments can open the way to study quantum electrodynamics in the nonlinear regime.

In this work we examined the role played by the temporal laser pulse profile on the production of electron-positron pairs from laser-electron scattering. We systematically investigated the collision of a multi-GeV electron beam with a laser pulse of $I > 10^{22}$ W/cm^2 using the particle-in-cell simulation code EPOCH [3]. We observed that the temporal asymmetry of the pulse played a role in the final number of pairs produced through the Breit-Wheeler and Trident processes and we analyzed the phase space distribution of the pairs. The results obtained here provided significant insights into planning and implementing upcoming experiments.

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P. 27

Collisionless shock acceleration of high-flux quasimonoenergetic proton beams driven by circularly polarized laser pulses

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Laser-driven ion accelerators have the prospects of realizing compact and affordable ion sources for many exciting applications, many of which require ion beams with narrow energy spread as well as high flux. Here, using an 800-nm circularly polarized laser pulse interacting with an overdense plasma that is produced by a laser prepulse ionizing an initially ultrathin plastic foil, we experimentally demonstrate collisionless shock acceleration of quasimonoenergetic proton beams with peak energies up to 9 MeV and extremely high fluxes of 3×10^{12} protons/MeV/sr [1]. Two-dimensional particle-in-cell simulations reveal that collisionless shocks are efficiently launched by circularly polarized lasers in exploded plasmas, resulting in a narrow energy spectrum. Furthermore, this novel scheme predicts the generation of quasimonoenergetic proton beams with peak energies of approximately 150 MeV using current laser technology. These results represent a major step for developing high-flux, high-energy and monoenergetic ion sources for applications such as cancer therapy.

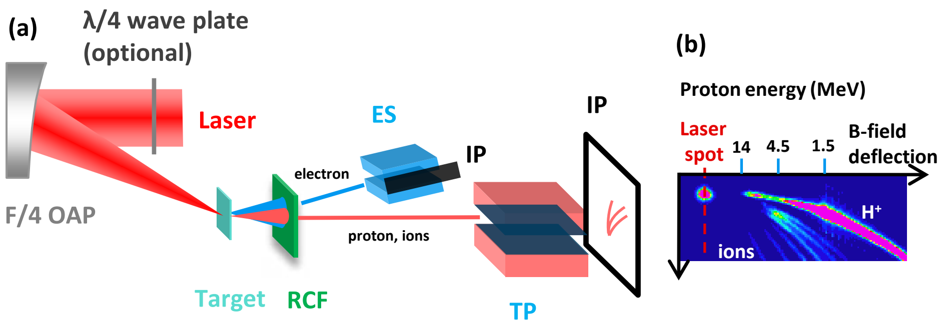

FIG. 1. (a) Schematic of the experimental setup. (b) Image plate data of Thomson parabola spectrometer obtained from 40-nm plastic foils irradiated by circularly polarized laser pulses with a peak intensity of 6.9×10^{19} W/cm^2.

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P. 28

Elemental analyses sensitivities of prospective nondestructive inspections at ELI-NP

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Extreme Light Infrastructure – Nuclear Physics (ELI-NP) facility will provide laser and gamma beams with unprecedented characteristics for nuclear physics research and applications [1-2]. These beams are promising tools for probing the structural and elemental composition of industrial objects with high resolution and high precision. Nuclear resonance spectroscopy (NRF) can be combined with computed tomography to yield 2D/3D maps of elemental/isotopic distributions in industrial objects. CT-NRF mapping done with quasi-monoenergetic gamma beams can be employed in nondestructive and noninvasive inspections of objects of various nature and composition [3], including detection of special nuclear material, assay of spent fuel or elemental analyses of work of arts. The unique features of ELI-NP gamma beam coupled with a high-efficiency gamma array detector will meet criteria for high sensitivity NRF measurements that are crucial in these fields [4]. The future NRF-based assays at ELI-NP will be performed using two methods: backscattering and transmission. Using Monte Carlo simulations that include the nuclear resonance fluorescence process and the complete framework for elastic scattering we estimate the sensitivity of quantitative assays that can be performed at the future ELI-NP LCS gamma beam for several test cases. In addition, two experimental setups specialized in nondestructive analyses based on transmission images or reconstructed tomograms will also be available at ELI-NP to analyze objects up to 150 kg using either pencil or cone beams. Here we discuss the performance of nondestructive inspections foreseen at ELI-NP and the implementation of the experimental setups, which is currently underway at ELI-NP.

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P. 29

The ELIADE Array of Detectors from ELI-NP

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The Gamma Beam System (GBS) that will be installed at Extreme Light Infrastructure Nuclear Physics (ELI-NP) is an advanced high energy (gamma) photon source based on Compton back scattering of laser light on a high energy electron beam provided by a linear accelerator.

The properties of the gamma–ray beams provided by the system are order of magnitude superior in bandwidth and spectral density in comparison to the presently running systems based on inverse Compton scattering.

One of the main goals of the ELI-NP facility is the study of photonuclear physics and its applications. The experiments which will benefit most from the gamma beam characteristics are the nuclear resonance fluorescence (NRF) experiments.

The detector array for these experiments (ELI-NP Array of Detectors, ELIADE) will contain eight HPGe segmented clover detectors and four LaBr3 detectors and will be used to detect with high efficiency the gamma-rays with energies of up to several MeV in the presence of the high radiation background produced by the gamma beams.

The segmented HPGe clover detectors are built by closely packing four single HPGe crystals in the same cryostat. Each of the crystals is electrically divided in eight segments. The CAD design of the ELIADE array [courtesy of C. Petcu], one clover detector and the crystal's geometry are shown in Fig. 1.

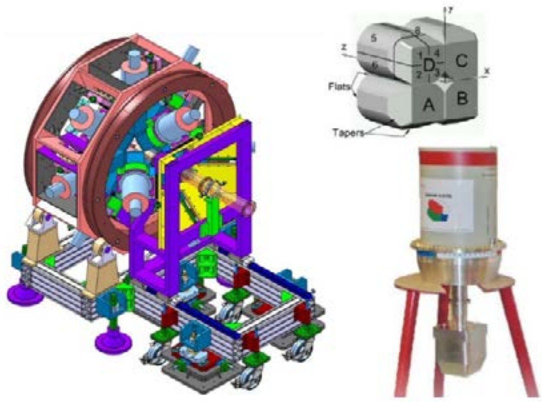

Figure 1. The view of the CAD design of the ELIADE, one clover detector and the crystal's geometry.

The data acquisition used in the experiments is based on 14 bit 250MS/s digitisers (v1725 by CAEN). The DAQ needs to take data from more than 330 channels, making it one of the most complex data acquisition systems in the world. The DAQ is based on the new MIDAS framework [4] coupled to custom made software.

While the development work for the digital system is ongoing, an analog DAQ system consisting of spectroscopic amplifiers (Canberra model 2026) coupled to a Multiport II MCA (Canberra) and Genie2000 data acquisition software is used for comparison and evaluation.

The performance of the ELIADE array relies heavily on the performance of the individual detectors. As a result, one of the main priorities is the testing and characterisation of the segmented clover detectors before the start of the experiments. Energy resolution and efficiency measurements (both absolute and relative) are carried out using both the analog and digital acquisition system and ^{152}Eu, ^{60}Co point-like sources.

The values of the energy resolution and relative efficiency are obtained using the existing ISO standards. The obtained results will be presented in this work.
The existing ISO standards cannot be applied to characterise the gamma beam due to its unique properties, therefore novel or adapted protocols have been proposed which will be developed into procedures once the operation phase of the facility will start.

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P. 30

Virtual Reality at ELI-NP

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The poster will describe a virtual reality application that will be used at the ELI-NP facility. Because of the radiation risk the access to the experimental areas of the building is restricted to a small number of members and they are allowed to be there only for limited periods of time. The application will provide a risk free environment which is available at any time for everybody.

The aim of the app is to allow for: virtual tours of the facility and training activities.

Virtual tours will be available for public. The users will be able to explore the facility, the two machines in operation and the experimental areas connected to the machines. The users will also get the chance to do simple tasks related to the operation of the machine for instance mounting or changing different components.

The exploration will be done in two ways. The first way is a guided tour where the machine and the events will be presented to the users in a predefined sequence, so they can observe and understand every step of the process. The second way of exploration is a free tour where the users will have unrestricted access to every area and will be informed only about the devices that are interesting to them.

Training is related to operation and maintenance of the machines, safety at workplace and space management.

The users will benefit from using this virtual environment which is a detailed copy of the facility, where they will be able to learn and practice the procedures related to operating and maintaining the machines. The application will provide detailed procedures for every operation (detailed view of the machine, detailed explanations of the way the machine works, the tools used for the operations, the risks that can occur), will present the steps to complete each task and will provide visual aid during each operation (details, hints). In addition the app can be used for assessing the employee performance and to evaluate the time required for the operations in order to manage future operations.

The training function will also have a component related to safety at workplace. The users will be able to practice safety drills that will help them be prepared in case of an emergency. They will learn about the risks related to working in such an environment, learn the procedures related to different kind of emergencies, will be able to recognize the different types of alarms and will learn the evacuation routes. The app will challenge the users with different situations where they have to identify the danger and react accordingly.

An emergency alarm can be triggered during normal operating conditions to prepare the employees for these events and also to test their reactions.

The application will also have a component related to space management. There will be some scenarios related to installing different devices. The app will provide measuring tools and collision warnings so that the users can plan ahead the most efficient ways of doing certain tasks.

P. 31

Spatio-temporal analysis of non-collinear femtosecond pulses combination

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Non-collinear coherent combining (NCCC) of ultrashort pulses is investigated in the presence of symmetrical variation of the laser beams propagation angle (α°) in order to determine the optimum conditions to generate higher intensity in the focal region. For this, a 2D model of the electromagnetic field (EMF) distribution of the coherently combined pulses have been elaborated using a commercial software (RSoft, by Synopsys Optical Solutions Group) that implements the finite difference time domain (FDTD) method for solving Maxwell equations. The geometry of the problem is depicted in Figure 1.The study implies two laser sources with the diameter of 20 μm, pulse duration of 25fs and vertical polarization. The laser pulses are focused by two identical optical lenses that have the focal distance f of 50 μm and the diameter of 30 μm. In order to investigate the temporal parameters, units of c·t are used by the model, taking into consideration that 1 μm corresponds to 3.33 fs. The sources are Gaussian both in space and in time. The numerical simulations have been done by varying symmetrically the laser beam propagation angle α in the range of 25°-65° with 5° step. A detailed study concerning the intensity evolution of the EMF distribution in the focal point has been performed under the α variation conditions in air and non-linear media. The results obtained by this method will be presented and discussed.

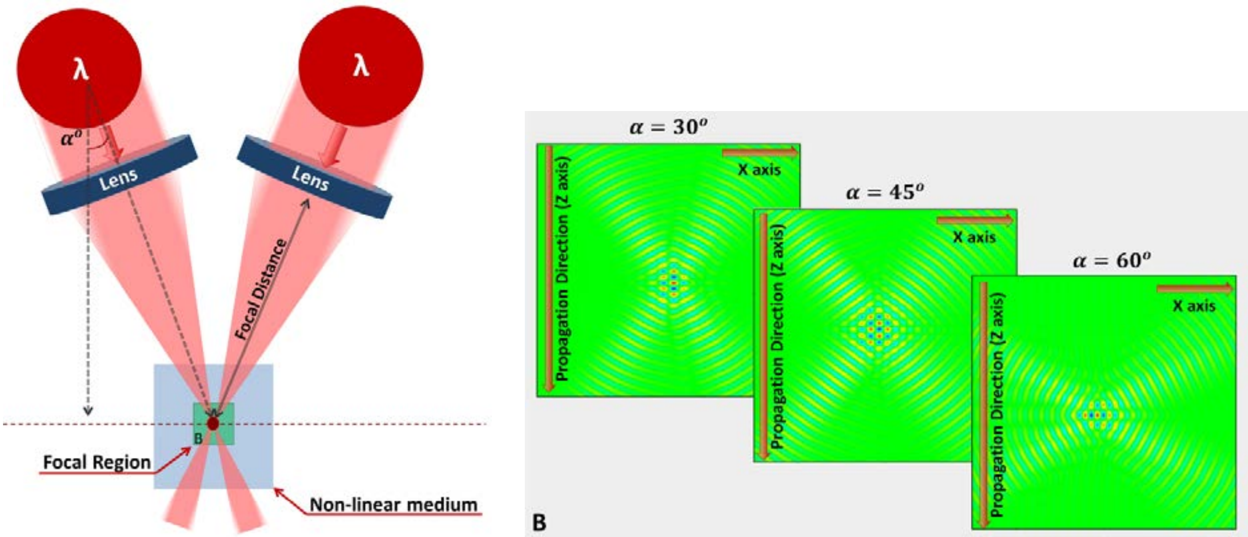

Figure 1*. Schematic design of the optical setup in case of non-collinear coherent combination of two sources at different laser beam propagation angle. Inset - Electromagnetic field distribution in focus in the presence of symmetrical variation of the laser beams propagation angle (α°).*

This method is scalable to a large number of ultrashort pulses and it aims to provide an effective solution to obtain a high power laser for experiments in the extreme fields proposed at the ELI-NP facility [1,2].

This work has been supported by National Authority for Scientific Research, Project LAPLAS V and by the national projects: PNCDI III 5/5.1/ELI-RO_2017_16 ("SIMULATE") and PNCDI III 5/5.1/04-ELI/2016 ("QLASNUC") under the financial support of Institute for Atomic Physics – IFA.

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P. 32

Design and technology development for nanostructured targets at ELI-NP

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One of high power laser capabilities is to produce high charged particles of high kinetic energy, for *e.g.* research in fundamental and nuclear physics [1]; as well as medical physics [2] and space applications [3, 4]. Target design is one of the key elements to promote the field of high power laser driven particle acceleration. As depicted in the ELI-NP TDR, our future research aims to enhance the quality and control of achievable ion acceleration in terms of maximum energy, efficiency and repetition rate. In this regard, the development of advanced target configurations is important for the implementation of the ELI-NP scientific programme. Micro and nanostructured targets have already shown good results in the enhancement of the laser energy absorption [5, 6], and consequently in increasing the maximum achievable ion energy. We present novel target concepts of nanostructured thin foils (carbon/iron based) as preliminary proposed. Their corresponding fabrication methodology sustained by the available technology at ELI-NP target laboratory [7] is also shown. A short overview of the laboratory capabilities will be given.

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P. 33

Support Actions for Industrial Imaging Applications Development at ELI-NP Gamma Beam

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The **ELI-NP** facility will provide laser and gamma beams with unprecedented characteristics for nuclear physics research and applications. The ELI-NP gamma beam system (GBS) will deliver quasi-monochromatic gamma-ray beams (bandwidth < 0.5%) of high spectral density ($\sim 10^4$ photons/s/eV) and high degree of linear polarization (> 95%) in the range of 0.2–19.5 MeV produced by laser Compton scattering technique (LCS) [1]. These gamma beams are promising tools for probing the structural and elemental composition of industrial objects with high resolution [2]. The research program of ELI-NP includes both fundamental research and applied science. Industrial tomography, nuclear waste management, and medical applications are several topics considered at ELI-NP that will take advantage of the unique features of the gamma beam system to create opportunities for industry and medical research.

The experimental setups that are being developed at ELI-NP for industrial applications consist of high-accuracy positioning systems and high-energy gamma detection systems to perform gamma-beam radiography and computed tomography of large objects with high resolution. The **ELITOMO** project aims at providing support for industrial gamma imaging applications development at ELI-NP gamma beam system (GBS). Moreover we intent to combine 2D&3D imaging techniques based on gamma-ray transmission with nuclear resonance fluorescence (NRF) for developing screening/scanning algorithms for large-size objects, like cargo containers, trucks, vans, parcels, etc., in order to accurately detect the most forbidden threatening materials hidden inside, such as: special nuclear materials, shielded gamma sources, various type of explosives or precursors of explosives, contraband materials, flammable liquids, toxic substances, etc.

Here we present the status of the supporting activities undertaken and comment on the improvements they will bring to the final configurations. We will discuss the design, construction and testing of new detection systems developed to overcome the damage and saturation in the conventional detectors due to high intensity photon pulses created by GBS. Using Monte Carlo simulations and modified reconstruction algorithms we have studied the optimal conditions for obtaining high resolution imaging in different beam configurations.

We acknowledge the financial support of the Romanian Government through the ELI-RO projects: ELITOMO and ELI_THREAT_DETECT.

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P. 34

Laser-electron collider within a micro-channel

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We propose a laser-electron collider based on a laser-driven micro-channel-plate target. In this unique geometry, electrons accelerated within a channel can collide head-on with the laser reflected from a foil attached onto the rear target surface. The simple scheme could allow for efficient generation of gamma-photons and most importantly, observation of the renowned radiation-reaction effect. The micro-channel target resolves the aligning and time synchronization challenges for laser-electron colliding scenarios involving two light/electron beams. We perform simulations that predict that a single 5 PW laser is sufficient to make the radiation-reaction effect measurable. A proof-of-principle experiment was conducted at a laser system running at 200 TW. The enhanced acceleration of electrons within the novel micro-channel structure was confirmed, showing enhanced electron cut-off energies and slope temperatures compared to ordinary flat interfaces. The results set forth the basis for a radiation-reaction measurement from laser-electron collisions in upcoming multi-PW laser systems.

P. 35

Parametric Characterization of Laser-Compton Scattering (LCS) Beam in a Multiple LCS Extraction Scheme

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The laser-Compton scattering (LCS) is a well-known method for the production of highly energetic and quasi-monochromatic gamma rays. However, for some specific applications e.g., nuclear waste transmutation and radioisotope production, a much higher photon flux than the existing LCS facilities is needed. Therefore, in this paper, authors present a multiple laser-Compton scattering extraction (MULEX) concept to increase LCS beam intensity for such applications. It can enhance the beam intensity by taking into account multiple collision points aligned with the electron beam path. The characteristics of LCS beam photons depend on the parameters related to the incident electron and laser beams which are well described by the Klein-Nishina cross section. Moreover, the electron beam cross-sectional area is dependent on the beam path-length and its energy spectrum is also affected by the LCS itself. In this paper, both of these effects are considered in detail to quantify the intensity of LCS beam and its properties. It is expected that, with a newly proposed MULEX concept the LCS photon intensity can increase significantly.

P. 36

Nonlinear Electromagnetic Waves in Quantum Vacuum

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We analyze theoretically the properties of two counter-propagating electromagnetic waves within the framework of the long wavelength approximation corresponding to the Heisenberg--Euler formalism in QED. We investigate the generation of higher-order-harmonics during the wave interaction using methods known in nonlinear wave theory.

P. 37

Simulations for diagnostics of protons accelerated in high-power laser experiments based on the population of nuclear isomeric states

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A method to diagnose accelerated protons emerging from high-power laser-solid target interactions is presented. The Geant4 toolkit [1] was used to perform simulations of a prospective experimental setup. The simulations include protons with energies up to 150 MeV as primary particles and a stack of targets on which the protons impinge. Cross sections for (p,n) reactions calculated with the TALYS code [2] were added to the physics processes included in Geant4.

The simulated stack of targets includes layers of Ta, natural Zr, and Ti (enriched to 82.5% ^{46}Ti) placed one behind another. Five $LaBr_3$:Ce scintillators were simulated in order to detect the gamma decays of isomeric states in ^{90}Nb and ^{46}V populated via (p,n) reactions. The relations between the gamma ray yields detected in the scintillators and the energy and spatial properties of the emitted protons which induced reactions are discussed.

Background events which contribute to the gamma spectra of the $LaBr_3$:Ce detectors but are not related to the population of the isomeric states of interest were also simulated. The background level was investigated for several laser shot repetition rates.

The simulated setup and processes are of interest for the diagnostics of particles produced in high-power laser-target interactions in prospective experiments at ELI-NP, as foreseen in the implementation of the facility.

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P. 38

High-energy electroproduction in a strong atomic field

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I will report the recent results of high-energy electroproduction in the strong atomic field. I will consider a cases of e^+e^- pair production by an ultrarelativistic electron and massive charged particles as well as a production of $\mu^+\mu^-$ pair by high-energy electron in an atomic field. The special attention will be paid by exact account of interaction of all particles with the atomic field. It is shown that, in contrast to the commonly accepted point of view, the cross section differential with respect to the final momentum of a particle which emit a virtual photon is strongly affected by the interaction of this particle with the atomic field. However, the cross section integrated over the final momentum of a heavy particle is independent of this interaction.

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Laser-Driven hadron sources for materials science: assessing experimental feasibility

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In this contribution we address several key experimental aspects related to the applications of moderate energy laser-driven hadron sources in materials science.

Ion and neutron sources at moderate energies (few MeVs) are an invaluable tool for a number of scientific and technological applications [1,2]. However, conventional sources usually rely on large particle accelerators, which prevents their widespread availability. High intensity(I>1018W/cm2) lasers can drive ion sources [3] with properties already exceeding the requirements for few applications in this field [4]. The existence of compact 10s TW-class lasers [5] could pave the way for portable hadron sources for materials science applications. However, several experimental challenges should be addressed to achieve this goal.

Here, we consider two specific cases of potential widespread interest: Proton-Induced X-ray emission (PIXE) and neutron generation using compact laser-driven proton sources [6]. PIXE is a powerful technique to probe the composition of complex samples [1] (e.g. cultural heritage artifacts[7], industrial artifacts...), which exploits ion beams in the ~ 1-5 MeV energy range. Neutrons can be generated via the interaction of few MeVs protons with a suitable converter (e.g. Lithium or Beryllium) and could be used for radiography or spectroscopy applications.

In this contribution we discuss in detail the experimental feasibility of Laser-Driven PIXE. Moreover, we investigate the possibility of using advanced target solutions to enhance the energy and the number of laser-accelerated protons, which could be beneficial for both PIXE and neutron generation. In particular we address the following issues:

1) Advanced targetry solutions to enhance laser-driven proton yield. Solid foils coated with a nanostructured low density foam lead to a considerable enhancement of the properties of laser-driven ion sources [8,9]. This is particularly interesting since it could lower the requirements for the laser system. Here we discuss how difficulties concerning the production and the handling of these advanced targets can be overcome.

2) Beam handling components for laser-driven PIXE. Laser-driven ion acceleration schemes also produce an intense electron emission, which could be severely detrimental for laser-driven PIXE. Here we discuss two possible strategies to separate the accelerated ions from the electrons (namely the use of a magnet and of a metal foil).

3) Detector solutions for laser-driven PIXE. Traditional Si-Li detectors are unsuitable for laser-driven PIXE, due to their excessive dead time. Here we discuss two possible alternative solutions, namely a CCD in single photon counting mode [10] and a Von Hamos spectrometer [11].

The strategies outlined here could be generalized also for other non-destructive materials characterization techniques based on hadrons (e.g. Proton Induced Gamma-ray Emission).

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P. 40

Mecanisms of Plasma Formation in Potassium Vapor Excited by Nanosecond Resonant Laser Pulses

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We have studied theoretically formation of molecular ion K_2^+ and the atomic ion K^+ which are created in laser excited potassium vapor at the first resonance transition, 4S - 4P.

A set of rate equations, which describe the temporal variation of the electron energy distribution function(EEDF), the electron density, the population density of the excited states as well as the atomic K^+ and molecular ion K^+_2, are solved numerically. The calculations are carried out at different laser energy and different potassium atomic vapor densities under the experimental conditions of Amin et al[19]. In this instance the potassium number density was varied in the range from 3.5×10^{15} to 9×10^{15} cm 3.5×10^{15} to 9×10^{15} cm $^{-3}$, the vapor temperature was 540 K° and the repetition rate 10 Hz. The intensity of the exciting laser beam is 0.5 mJ, the intensity of the ionizing laser beam was varied in the range from 0.1 to 1 mJ and the laser beam diameter was varied in the range from 230 to 290 mm. The numerical calculations of the electron energy distribution function (EEDF) show that a deviation from the Maxwellian distribution due to the superelastic collisions effect. In addition to the competition between associative ionization(4p-4p), and Molnar –Hornbeck ionization processes for producing K_2^+,the calculations have also shown that the atomic ions K^+ are formed through the Penning ionization and photoionization processes. These results are found to be consistent with the experimental observations. If there are multiple authors from the same organization, only list the organization once, include only the main author email address. References should be included in square brackets within the text [1].

Keywords: Plasma, potassium vapor, laser, collisional ionization, photoionzation, Electron energy distribution function.

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Design of a Rep-rated Proton Imaging Diagnostic for High Energy Density Physics Experiments

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Proton imaging is the predominant technique for visualizing electromagnetic fields in high-energy-density (HED) physics experiments [1]. Due to the complex nature of these systems, other techniques, such as Faraday rotation, are prohibitive or impossible given spatial and temporal constraints of the plasma environment. The detecting medium for proton imaging is typically radiochromic film (RCF) or plastic-track detectors (e.g. CR-39), both of which are single use and require replacement of the detector pack between shots. This methodology is only functional for single-shot operation. However, new HED physics facilities are moving towards rep-rated (>1 Hz) experiments, allowing for unprecedented statistical studies to be performed in the HED regime and opening up whole new areas of HED research. To visualize electromagnetic fields in this new era of rep-rated HED physics experiments, a new method of proton imaging is necessary.

We present the initial design of a scintillator-based proton imaging diagnostic based on a previously successful ion-beam monitoring system [2]. The primary concern for imaging is the spatial resolution and response of the scintillator. Recent results from experiments conducted at the Birmingham Cyclotron to measure intrinsic properties for multiple organic scintillators will be presented. Processing techniques for optimizing the spatial response of the scintillators will be discussed.

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Laser-plasma X-Ray source for high resolution imaging applications

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Development of novel X-ray sources has a significant impact on the society due to its applications on very different fields such as medicine, biology, chemistry, industry. Laser-plasma X-ray sources, produced by an intense infrared laser pulse of femtoseconds interacting with a solid target, have many advantages over conventional ones. On one hand, they can achieve higher imaging resolutions because of the micrometric size of the source. On the other hand, the X-ray beam is pulsed in the picosecond regime with the same repetition rate as the laser radiation. Also, the target engineering allows to produce sophisticated targets for special applications with several materials.

The laser-plasma X-ray source, currently installed at the Laser Laboratory for Acceleration and Applications (L2A2) of the University of Santiago de Compostela (USC), is produced by 1mJ, 35 fs, 1kHz pulses centered at 800 nm wavelength on thick rotatory metallic targets. The X-ray spectra of this source are characterized by the K peaks of the target material and a Bremsstrahlung continuum up to several tens of keV. The L2A2 x-ray source has been optimized and stabilized for imaging applications. We have demonstrated the higher quality of the L2A2 x-ray source against a conventional x-ray tube evaluating the MTF (Modulation Transfer Function) of both sources. We present some imaging applications like high resolution absorption imaging with scintillator-silicon array detectors and 3D reconstruction of biological and non-biological samples.

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Thin Film Compression System for Laser Induced Plasma Diagnostics

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The ELI-NP facility will focus 10 PW laser beams at intensities up to $1\times\times10^{23}$ W/cm^2, enabling the investigation of QED phenomena in the quantum radiation regime and the nuclear reactions of the laser plasma interaction. Laser-based electron acceleration driven by a 10 PW laser beam focused in a gas cell represents one of the main experiments foreseen at the ELI-NP facility in Romania [1]. A 30 meter focal length spherical mirror will be used to focus a 10 PW laser beam into a gas-jet, generating an electron beam through laser wakefield acceleration. As part of the plasma diagnostics experiments required for the optimization of the electron acceleration, an optical probe laser beam will be synchronized with the main laser pulse. This optical probe pulse is required to characterize the density gradients and the formation of micro-cavities within the plasma. A proposed thin film compressor [2] is an attractive method to shorten the duration of this plasma probe pulse below the original pulse length due to its support of high energy density, cheap materials, and ease in alignment.

A small portion of the high intensity main beam used to create plasma is extracted via a mirror with a hole through its substrate, and due to self-phase modulation as it interacts with a thin film material is spectrally broadened. The output is eventually compressed by dispersion compensation mirrors. Few cycle pulse duration can be furtherly obtained by passing the post-compressed pulse to a subsequent stage consisting of thin film and dispersion compensation mirrors. By varying the delay between the thin film probe and main pulse, different stages of the plasma wave evolution can be investigated in subsequent shots.

In this paper, the thin film materials PMMA, Cyclic Olefin Polymer (Zeonor), and fused silica, have been tested to investigate their optical non-linearity response to high intensity femtosecond laser pulses, in vacuum condition at the LASERIX facility, in Orsay, France. A preliminary analysis of the data shows that Zeonor material provides the best response in broadening the spectrum, thus allowing a larger reduction of the pulse duration in comparison with other materials at the same laser intensity. By adjusting the Zeonor target thickness (by introducing multiple layers using an automatic roller machine), a pulse duration of approximately 15-20 fs (compression factor of three) was obtained. At ELI-NP, using the same technique, we expect a pulse duration less than 10 fs, sufficient for using as optical laser probe in the laser-plasma experiments.

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$^{7}Li(\gamma,t)^{4}He$ at HIγS and perspectives for BBN investigations at ELI-NP

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The Extreme Light Infrastructure – Nuclear Physics facility (ELI-NP), under construction in Bucharest-Magurele, Romania, will deliver very intense brilliant γ beams. Several very important nuclear reactions related to Big Bang Nucleosynthesis and other stages of stellar burning have been selected for the first measurement campaigns.

The $^{7}Li(\gamma,^{3}H)^{4}He$ reaction is of interest for the longstanding ”Cosmological Li problem” and for verifying several recent theoretical predictions. Although most measurements over the last 30 years have concentrated in an energy range below 1.5 MeV, measurements at higher energies could restrict the extrapolation to astrophysically important energies.

We have measured the $^{7}Li(\gamma,^{3}H)^{4}He$ reaction between 4 and 11 MeV at the HIγS facility at the Duke Free Electron Laser Laboratory. Tritons and alpha particles were detected in coincidence using the SIDAR array from ORNL. SIDAR was installed in the lamp-shade configuration using twelve YY1 silicon detectors surrounding the LiF target. The beam intensity was monitored using multiple techniques: activation, Compton scattering, and the d(γ,n)p reaction. Details of the experiment, including the challenges of beam normalization and charged-particle measurements with gamma-ray beams, will be presented together with preliminary results.

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A novel ion chamber array for dose measurement in laser accelerated charged particle beams

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For the future applications of the laser accelerated beams (as generated in the ELI and CETAL projects) in beam dose measurements are a definite must. Reliable dosimetric methods have already been set up in the medical and industrial applications and most of them rely heavily on what is seen as the gold standard in dose measurement: the ion chambers. Although ionization measurements remain also in the case of laser accelerated particle beams the most reliable method, there is one marking disadvantage of the method in this case: the large number of corrections to be applied in order to calculate a correct dose from the measured charge. The ELIDOSE project tries to address these problems by proposing an array detector that would allow the simultaneous measurement of the recombination and polarity corrections, and of the dose. The detector consists of 4 identical ion chambers mounted together in a PMMA frame and the project will analyse its response to various charged particle beams and the reciprocal influences of the chambers on each other.

The present paper outlines the first measurements made in order to realise the prototype. Advanced Markus chambers have been used for the initial prototype, the choice being made due to the proton beams available: only the Markus chambers can be used for measurements in the 3 MeV beams generated by the Tandetron™ accelerator at the NIPNE-HH. Measurements have been made in proton beams at the Tandetron accelerator and the TR19 Cyclotron (Horia Hulubei National Institute of Physics and Nuclear Engineering) as well as at various medical electron beams (Clinical Hospital "COLTEA"), in order to establish the best configuration for our detector array. The 2 chamber and 4 chamber configurations used in the well-defined medical electron beams allowed us to compare the recombination and bias corrections determined via the standard method and the array method, and the initial conclusion is that the ion chamber array is a good solution for the laser accelerated beams.

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Advanced multi-stage simulations of laser-driven ion sources for materials science applications

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In this contribution we present in-depth numerical investigations of laser-based ion sources for materials and nuclear sciences applications. These are inherently multi-stage problems, which require the use of different computational tools in cascade.

Laser-driven ion sources [1] at relatively moderate pulse intensities (I < 10^{19}W/cm^2) are appealing for various potential applications, such as Proton Induced X-ray Emission (PIXE) [2] and secondary neutron generation for radiography and spectroscopy [3]. Above all, laser-driven sources could provide a flexible, cost-effective and compact alternative to conventional sources, which rely on large-scale accelerators, especially if a low pulse energy is used. However, several challenges should be faced in order to make these applications a reality. In particular, a reliable numerical modeling of all the physical mechanisms at play is essential to be able to optimize all the different stages of the process, from laser-ion acceleration to the actual applications. In particular, here we consider laser-driven PIXE and neutron generation, addressing the following points:

1) Coupling of 3D Particle-In-Cell (PIC) simulations [4] of the laser-driven ion source with a Monte Carlo code [5] to describe the interaction between ions and matter. Laser-accelerated ions are characterized by a broad energy spectrum with non-trivial angular dependence. Moreover the acceleration process also leads to a copious emission of high energy electrons. PIC codes are a standard tool to simulate laser-plasma interaction. Feeding the ions and electrons spectra, namely the energy and angular distributions obtained with a PIC code, to a Monte Carlo code allows us to assess the feasibility of laser-driven PIXE. A similar approach is used to simulate laser-driven neutron generation through the interaction between laser-driven ions and a low-Z converter (Li and Be).

2) Realistic modeling of advanced targets for enhanced laser-driven ion acceleration. Solid foils coated with a low-density, fractal-like, nanostructured material lead to a significant enhancement of the number and maximum energy of laser-driven ions [6]. This is particularly interesting since it could lower the requirements for the laser system. The morphology and the growth process of these targets are non trivial [7]. A proper modeling of the growth process is important to guide the production of optimized targets and to initialize the plasma configuration in PIC codes. We show that an extension of the Diffusion Limited Aggregation can realistically simulate the structure and morphology of these low-density materials. Moreover, we discuss how the morphology of the nanostructured material may influence the physics at play [8].

3) Laser-driven PIXE theory and feasibility assessment. PIXE allows to retrieve the elemental composition of a sample. By varying the energy of the ion source it is also possible to retrieve the concentration depths profiles (differential PIXE). However, the theory has been specifically developed only for monochromatic sources. We present an extension of PIXE theory for ion sources with a broad energy spectrum, which is an essential step towards laser-driven PIXE [9]. This allows us to perform a feasibility study of laser-driven PIXE, e.g. assessing the sensitivity

of target reconstruction with respect to shot-to-shot fluctuations of the ion source. These activities support that laser-driven PIXE is feasible with compact setups and provide suggestions to guide future experimental campaigns, both of laser-driven PIXE and neutron generation.

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P. 47

Pion Polarizability Status Report

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The electric α_π and magnetic β_π charged pion polarizabilities characterize the induced dipole moments of the pion during $\gamma\pi$ Compton scattering. Pion polarizabilities affect the shape of the $\gamma\pi$ Compton scattering angular distribution. The polarizability dipole moments are induced via the interaction of the γ's electromagnetic field with the quark substructure of the pion. In particular, α_π is the proportionality constant between the γ's electric field and the electric dipole moment, while β_π is similarly related to the γ's magnetic field and the induced magnetic dipole moment. Ref. [1] gives all relevant references for the discussion below. The polarizabilities are fundamental characteristics of the pion. A stringent test of chiral perturbation theory (ChPT) is possible by comparing the experimental polarizabilities with the chiral perturbation theory ChPT two-loop predictions $\alpha_\pi - \beta_\pi = (5.7\pm1.0)\times10^{-4}$ fm^3 and $\alpha_\pi+\beta_\pi = 0.16\times10^{-4}$ fm^3. The pion polarizability combination (α_π-β_π) may be measured by four different methods . These are (1) radiative pion Primakoff scattering (pion Bremsstrahlung) in the nuclear Coulomb field $\pi Z \to \pi Z\gamma$, (2) two-photon fusion production of pion pairs $\gamma\gamma\to\pi\pi$ via the $e^+e^- \to e^+e^-\pi^+\pi^-$ reaction, (3) radiative pion photoproduction from the proton $\gamma p\to \gamma\pi n$, and (4) Primakoff scattering of high energy γ's in the nuclear Coulomb field leading to two-photon fusion production of pion pairs $\gamma\gamma\to\pi\pi$. Methods 1,2,3 experiments have been most recently studied at CERN COMPASS, SLAC PEP Mark-II, and Mainz Microtron MAMI, respectively; while the method 4 experiment is planned at Jefferson Laboratory (JLab). The measured values are: (1) $\alpha_\pi-\beta_\pi = (4.0\pm1.2_{stat}\pm1.4_{syst})\times10^{-4}$fm^3, (2) $\alpha_\pi-\beta_\pi = (4.4\pm3.2_{stat+syst})\times10^{-4}$ fm^3,
(3) $\alpha_\pi-\beta_\pi = (11.6 \pm 1.5_{stat} \pm 3.0_{syst} \pm 0.5_{model}) \times10^{-4}$fm^3.

The COMPASS collaboration at CERN determined $\alpha_\pi-\beta_\pi$ by investigating pion Compton scattering $\gamma\pi \to \gamma\pi$ at center-of-mass energies below 3.5 pion masses. Compton scattering was measured via radiative pion Primakoff scattering (Bremsstrahlung of 190 GeV/c negative pions) in the nuclear Coulomb field of the Ni nucleus: π^- Ni $\to$ π^- Ni γ. Exchanged quasi-real photons are selected by isolating the sharp Coulomb peak observed at lowest four-momentum transfers to the target nucleus, $Q^2 < 0.0015$ GeV^2/c^2. The resulting data are equivalent to $\gamma\pi \to \gamma\pi$ Compton scattering for laboratory γ's having momenta of order 1 GeV/c incident on a target pion at rest. In the reference frame of this target pion, the cross section is sensitive to ($\alpha_\pi-\beta_\pi$) at backward angles of the scattered γ's. This corresponds to the most forward angles in the laboratory frame for the highest energy Primakoff γ's. Assuming $\alpha_\pi+\beta_\pi=0$, the dependence of the laboratory differential cross section on $x_\gamma=E_\gamma/E_\pi$ is used to determine α_π, where x_γ is the fraction of the beam energy carried by the final state γ.

Radiative π^+-meson photoproduction from the proton ($\gamma p \to \gamma\pi^+ n$) was studied at the Mainz Microtron in the kinematic region 537 MeV < E_γ < 817 MeV, $140^\circ \le \theta_{\gamma\gamma'} \le 180^\circ$, where $\theta_{\gamma\gamma}'$ is the polar angle in the c.m. system of the outgoing gamma and pion. The experimental challenge is that the incident γ-ray is scattered from an off-shell pion, and the polarizability contribution to the Compton cross section from the pion pole diagrams is only a small fraction of the measured cross section. The π^+-meson polarizability was determined from a comparison of the data with the predictions of two theoretical models. In the region where the pion polarizability contribution is substantial, $\alpha_\pi-\beta_\pi$ was determined from a fit of the calculated cross section to the data. The quoted model uncertainty $0.5_{model}\times10^{-4}$fm^3 denotes the uncertainty associated with using the two chosen theoretical models. However, it does not take into account that comparisons with other possible models may significantly increase the model error.

Charged pion polarizabilities were determined by comparing MARK-II total cross section data ($\gamma\gamma \rightarrow \pi^+\pi^-$) for $M_{\pi\pi} \leq 0.5$ GeV with a ChPT one-loop calculation. The MARK-II experiment was carried out via the reaction $e^+e^- \rightarrow e^+e^-\pi^+\pi^-$ at a center-of-mass energy of 29 GeV for invariant pion-pair masses $M_{\pi\pi}$ between 350 MeV/c^2 and 1.6 GeV/c^2. Only the region below $M_{\pi\pi} = 0.5$ GeV is considered within the domain of validity of ChPT. A number of theoretical papers subsequently made use of the MARK-II data to deduce pion polarizabilities. The cross section excess below $M_{\pi\pi} = 0.5$ GeV compared to the Born calculation was interpreted as due to pion polarizabilities, with best fit value $\alpha_\pi-\beta_\pi = (4.4\pm3.2_{stat+syst})\times10^{-4}$ fm.

Pion polarizabilities are determined by how the $\gamma\pi\rightarrow\gamma\pi$ Compton scattering amplitudes approach threshold. By crossing symmetry, the $\gamma\pi\rightarrow\gamma\pi$ amplitudes are related to the $\gamma\gamma\rightarrow\pi\pi$ amplitudes. Dispersion relations (DRs) provide the method to continue the $\gamma\gamma$ amplitudes analytically to the Compton scattering threshold. DRs describe how pion polarizabilities contribute to both $\gamma\gamma \rightarrow \pi^+\pi^-$ and $\gamma\gamma \rightarrow \pi^0\pi^0$ reactions. Most recently, Dai and Pennington (DP) carried out DR calculations. In their formalism, the π^0 and $\pi^\pm$ polarizability values are correlated, so that knowing one allows calculating the other. Using the COMPASS value, they find excellent agreement for $\gamma\gamma\rightarrow\pi^+\pi^-$ and reasonable agreement for $\gamma\gamma\rightarrow\pi^0\pi^0$. Using the Mainz value, their DR calculations and Crystal Ball data do not agree at all. DP conclude that the Mainz determination $\alpha_\pi-\beta_\pi = 11.6\times10^{-4}$ fm^3 is excluded by the Crystal Ball $\gamma\gamma\rightarrow\pi^0\pi^0$ data.

The pion is believed to belong to the pseudoscalar meson nonet and to be one of the Goldstone bosons associated with spontaneously broken chiral symmetry. Chiral perturbation theory (ChPT) is therefore expected to successfully describe the electromagnetic interactions of pions. In this framework, the low-energy interactions of the pion are described by a phenomenological effective Lagrangian which stems directly from QCD, with only the assumptions of chiral symmetry $SU(3)_L$ X $SU(3)_R$, Lorentz invariance and low momentum transfer. This method gives a precise prediction for the pion polarizabilities. The COMPASS and Mark-II polarizability values are in good agreement with the two-loop ChPT prediction, thereby strengthening the identification of the pion with the Goldstone boson of QCD.

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Research Project on Laser-Driven Neutron sources and applications at ILE, Osaka University

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Neutron sources are getting important in the various fields of applications as well as nuclear energy developments. Success of the neutron application for the natural science, biology, medicine and engineering at the large facilities, such as J-PARC, stimulated the industrial needs for compact neutron sources. Laser driven neutron sources have unique properties of a tiny, bright pulse source which is suitable for a point projection imaging and Time-of-Flight spectroscopy. Following the preliminary study [1] and basic experiments, we had initiated a project to get a clear perspective of the laser driven neutron sources for the dynamic neutron radiography in 2015. Final goal of the project is to demonstrate the possibility of the compact neutron imaging system using a repetitive high intensity laser.

The tasks of the project are 1) investigation of the scaling and optimization of the neutron generation mechanisms, 2) development of large formatted neutron imager with the 1-mm spatial resolution, 3) development of the continuous and precise targets supplying system, 4) design of the neutron moderators for the system which provide a proper neutron energy distribution.

The neutron generation processes pursued are nuclear fusion of accelerated hydrogen isotopes, proton capture reaction with light elements such as Li and Be, photonuclear reactions of heavy elements. We demonstrated the repetitive generation of photo-neutrons by using the rotating target supply system at T^6 laser of Kyoto University [2,3]. Neutron generation of 3.5×10^4 neutrons/pulse was achieved with optimized laser irradiation conditions. Another important progress was a discovery of an effective acceleration of the deuterons and continuous neutron energy spectrum generated by using the deuterated plastic foil and Be captures [4], which will be reported in another presentation in this conference. As for the development of an imaging device, Neutron imaging was successfully demonstrated by a large scintillation detector with the sensitive area of 40 cm x 60 cm to show the better resolution of 1 mm at the RANS neutron facility of RIKEN [5].

This project is supported by Adaptable Seamless Technology transfer Program through target driven R&D program (A-STEP; AS2721002c) and partly by Precursory Research for Embryonic Science and Technology (PRESTO; JPMJPR15PD) of Japan Science and Technology Agency (JST). This work was also funded by Grant-in-Aids for Scientific Research [Nos. 24244095, 2624043, 23360413, 16H02245], for Young Scientists [Nos. 24686103, 24684044], for Challenging Exploratory Research [Nos. 25630419, 16K13918], for the JSPS fellows [No. 14J06592] under the auspices of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). We also thank to the Joint usage/ joint research scheme of the Institute for Chemical Research, Kyoto University (grant #2017-5).

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Target Deploying Mechanism for „Thin Film Compression" Experiments

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In the recent years, a great deal of interest was manifested towards laser systems which can deliver short pulses with high intensities, in particular on their interaction with plasma [1].

Self-phase modulation is a technique which further enables laser systems to provide even shorter pulses [2]. A femtosecond laser pulse is propagated through thin film target materials; this results in a spectral broadening of the pulse. A recompression of the pulse is carried out afterwards by using chirped mirrors, allowing for a post-compressed shorter pulse. A controlled variation in the thickness of the targets at fixed laser pulse parameters will induce modifications in the spectral bandwidth.

A target deploying mechanism was designed and manufactured at ELI-NP [3] giving the possibility of long term experiments without the need to break vaccuum in the experimental chamber and the corresponding down time. This technique provides a larger time for data aquisition to the user. The new device is designed for a roll with several meters of thin film which can be mounted and guided through the beam path on five rollers. The rolling elements can be arranged in different configurations in order to modify the number of beam passes through the target, hence modifying the thickness through which the laser pulse propagates. In order to preserve the quality of the laser beam profile, the mechanism is equipped with a tension maintaining system which keeps the rolled thin film target straight, without damaging it. One motivation for implementing such a device based on a roll of film is due to the ready availability of such materials in sizes of up to 1 meter width and 100 meter lengths of high optical quality and sophisticated multilayer options for anti-reflection coatings manufactured for use with handheld electronic devices. This suggests the ability to scale a proven device to the size required for the beam diameters planned at ELI-NP.

The functionality of this technique and mechanism was demonstrated in the experimental campaign of the „Thin Film Compression" project, taken in December 2017 at the laser facility LASERIX in Paris [4]. In this campaign pulse energies and power density up to 290 mJ and 1.9 TW/cm^2 were delivered. The device allowed a continuous data taking with many laser shots without interruptions due to the target change in the experimental chamber.

It is expected that future improved versions of this target deploying mechanism will facilitate the usage of self-phase modulation technique to post-compress large beam profiles, possibly at the upcoming laser user facility at ELI-NP.

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P. 50

Characterization of Laser-driven Electro Magnetic Pulses (EMP) with 200 TW 30 fs laser pulses @ CLPU

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This project is executed in collaboration between ELI-ALPS and CLPU.

ELI-ALPS is part of the Extreme Light Infrastructure (ELI) project and located in Szeged Hungary. The ELI project is an integral part of the European plan to build the next generation of large research facilities identified and selected by the European Strategy Forum on Research Infrastructures (ESFRI).

The Centro de Lasers Pulsados (USAL) is one of the Power-full Laser facility currently in operation. It is placed in Salamanca Spain and it's main system VEGA consist in two high power Arms: VEGA 2 (200 TW/ 30 fs) already in operation and VEGA 3 (1 PW / 30 fs) which operation has started recently.

Here we report the first EMP measurements of the 200 TW system, which combine both high intensity physical processes at high repetition rates. At this poster the dependence of the strength of the EMP on the pulse duration, intensity, and pulse energy is reported.

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Quasiparticle vibration coupling description of beta-decay half-lives in superfluid nuclei

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Nuclear β-decay half-lives set the time scale of the rapid neutron capture process (r-process), and hence are important for understanding the origin of heavy elements in the universe.
However, the accurate description of β-decay half-lives is a long-standing hard problem. As a widely used microscopic model, quasiparticle random-phase approximation (QRPA) often overestimates β-decay half-lives.
Our newly established self-consistent QRPA + quasiparticle vibration coupling (QPVC) model will be introduced. With this model, the β-decay half-lives of whole isotopic chains are well reproduced, which overcomes the problems of QRPA model, and shed new light on understanding the r-process.

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New full OPCPA beamline for Vulcan Petawatt target area

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The Vulcan laser is being upgraded with an entire new PW laser beamline. Vulcan will have the ability to conjugate this new beamline with the existing PW beamline. The existing beamline has nominally 600J in 500fs, the new beamline will have similar characteristics to existing Ti:Sapphire lasers PW class lasers, 30J in 30fs. The initial main purpose for this laser is to create betatron radiation but other applications like compton scattering could be envisioned.

This new laser will be done exclusively of OPCPA amplification, and so shifted to the red, it will be centered at 890nm, 280nm bandwidth, which is the optimal wavelength for an LBO crystal. The first stages will be constituted by a ps-OPCPA up to the mJ level to increase the contrast while the ns-OPCPA amplification will be pumped at a repetition rate of 5min by a ns long laser which can be temporally shaped and which will allow us to control the spectral shape. The first few ns stages will be pumped by a nanosecond long pulse in which the temporal shape will be controlled by an arbitrary waveform generator and a EOM. The ns front end will be pumped with doubled Nd:YAG laser at 532nm with a repetition rate of 2Hz and an energy of 4.5J laser. This will allow for a J-level output of the OPCPA maintaining the spectral bandwidth.

Two additional amplification stages B1 and B2 will increase the energy at 50J before the compressor.

From preliminary OPCPA simulation and using frequency double Nd:Glass pump laser at 526.5nm, OPCPA with LBO in non-collinear geometry will provide bandwidth of >220nm around 877nm (Fig. 2a).

The general scheme of the laser is as follows:

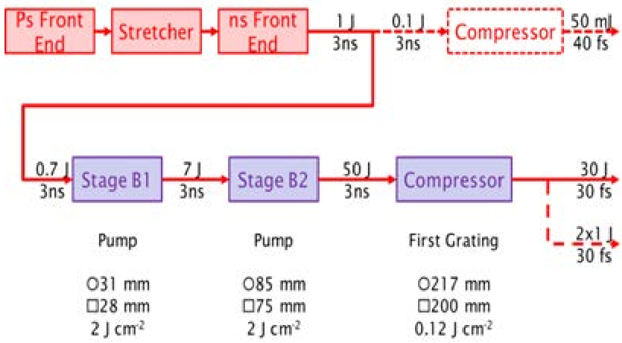

Fig. 1. Schematic of the new beamline

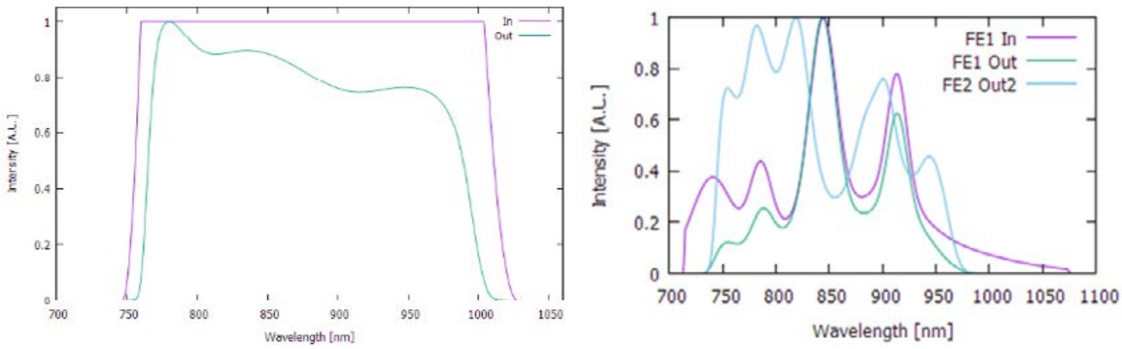

Fig. 2. a) Simulated output spectrum from a LBO crystal pumped at 526.5nm; b) . Simulated spectra after the first (FE1 Out) and the second (FE2 Out) ps OPCPA.

The generation of the ps laser pulse is one of the most critical part of the system and it is where is most focused the current work on the project. The overall schematic is still not fully design but it will include a first dual OPCPA stages pumped by a 2mJ Yb:YAG laser system operating at 100Hz. An additional pump laser of 25mJ will be used to further amplify the pulses to the mJ level.

More in detail, the laser pulse, generated by a broadband TiSa oscillator (Venteon), is stretched by glass block to approximately 5ps and sent to the OPA stages.

The 1030nm of this oscillator are injected into a fibre amplifier which seeds the Yb:YAG based amplifiers. This allows the system to be optically synchronized and so allows the ps OPCPA to be independent of electrical synchronization.

As for the ns OPA stages the gain crystal for the ps stages is LBO. Numerical simulations suggest that the output from the first two stages (pumped by a 600 uJ 515nm laser) should be around 40uJ and with bandwidth of >200nm (Fig. 3).

Two other stages pumped by 8mJ of 515nm laser are configured.

The pump and the signal delivery is designed considering the relay imaging between the stages and the doubling crystal. Particular care is taken to reduce the chromatic aberration on the signal by using a new imaging design that combines lenses and a parabolic mirror.

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The optimum conditions for laser field depletion in laser-electron beam collision

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The laser field depletion in laser-electron beam collision is generally small. It is even worse when the electron undergoes a collision with an ultraintense laser at . At such laser intensity, the laser beam is tightly focused and the ponderomotive force prevents the electron from entering the laser pulse. However, for properly chosen parameters of the laser and electrons, along with the implementation of radiation reaction (RR), the laser field depletion can be significant [1].
The laser and electron parameters are optimized such that the ponderomotive forces are balanced by the RR forces in transverse and longitudinal direction. As a result, the electrons spend a longer time quivering in the laser pulse as compared to the case without RR. Thus, the electrons are able to convert a significant amount of laser energy into radiation emission. The energy conversion efficiency of the laser and electron into radiation emission was expected to be up to 11% for an electron bunch with the charge at the order of 100 nC at .
We will present the results of Particle-in-Cell (PIC) simulations and the outlook for the generation of multiple gamma sources by using a single laser pulse. These gamma-ray sources will be useful in the studies of photonuclear experiments in ELI-NP.

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Slow positron beam and spectrometers at ELI-NP

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The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) project aims to open new dimensions in material sciences applications with γ-beam. The positron source at ELI-NP is designed to deliver slow positrons after moderation of fast positrons produced by pair production via γ-rays [1]. The low energy branch of the γ-beam system will provide γ-rays with a maximum energy of 3.5 MeV produced through Compton backscattering of laser photons on electrons from a warm Linac [2]. With a γ-beam intensity of 2.4×10^{10} s^{-1}, it is expected that the intensity of the slow positron beam can exceed 1×10^{6} s^{-1} [3]. The slow positrons will be used to implement some particular experimental tools based on positron annihilation. Free access for users will allow various material research, for example, to measure sizes and detect variations in the number density of defects and voids, and to extract valuable information also of the chemical composition. The design of the slow positron production at ELI-NP, and the planned spectroscopy instruments are presented.

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P. 55

Status update of the gamma beam monitoring instruments at ELI-NP

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The high brilliance Gamma Beam System (GBS) at ELI–NP will deliver quasi–monochromatic gamma-ray beams (bandwidth < 0.5%) with a high spectral density (>10^4 photons/s/eV) and high degree of linear polarization (> 99%). The gamma-ray beam is produced through Compton backscattering of laser light off an accelerated electron beam. The GBS will be delivered in two phases with two separate beam lines: a low-energy gamma-ray line with gamma energies up to 3.5 MeV and a high-energy gamma line with energies up to 19.5 MeV. The research program with the GBS focuses on fundamental nuclear physics as well as on applied research and development.

Optimization and monitoring of the gamma beam with these characteristics is challenging and requires the proper means for accurately measuring the spatial, spectral and temporal characteristics of the gamma-ray beams.

The gamma beam energy spread will be monitored using a large volume HPGe detector with a NaI(Tl) anti-Compton shield placed in the attenuated beam. Energies above 10 MeV will be monitored using a large volume LaBr3 instead of the HPGe detector

An intensity and polarization monitor is developed based on the d(γ,n)p reaction which could be placed in either the low-energy or the high-energy experimental areas. The choice of neutron detector for the d(γ,n)p setup depends on the beam energy. For beam energies below 4 MeV, Li-glass detectors will be used to detect the outgoing neutrons. These detectors can count low energy neutrons and are not subject to the same threshold effects as the liquid scintillator neutron detectors. For beam energies above 4 MeV, liquid scintillator neutron detectors based on EJ-309 scintillation material will be used. This technique has been tested successfully [1] at the HIγS facility to measure the beam intensity and polarization.

A thin scintillator sheet (with high efficiency) would be placed in the gamma beam and imaged with a CCD camera to give insights into the spatial position of the beam and allow quick experimental instrument alignment.

A fission chamber is foreseen for monitoring the gamma beam intensity on the high-energy beam line at ELI-NP. This instrument will be an ionization chamber [2] with a ^{238}U deposit of a thickness in the range from 100 to 400 μg/cm^2. For a fast ionization chamber the design requires an inter electrode gap of 1 mm and CF_4 as counting gas which has excellent properties in terms of timing. The short charge collection time, smaller than 10 ns, ensures that the temporal micro-pulse structure of the gamma-ray beam at ELI-NP can be resolved.

Details about the development the instruments will be presented.

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Properties of a detector gas with high stopping power for nuclear photonics applications: Ar-CF_4 mixtures as example*

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The use of ionization chambers (IC) for the study of charged particles e.g. in photofission experiments [1] relies on the accurate determination of the energy deposition in the gas. One of the major issues in this respect is the so-called pulse-height defect (PHD). The term is used to summarize effects that cause a non-linear response of the pulse height to highly ionizing particles, such as fission fragments. To our knowledge, the only gas for which the PHD has been directly measured with ions of known energies is P-10 (90%Ar+10%CH_4) [2]. However, evidence exists [3] that these results can be directly applied to pure CF_4. While pure CF_4 has disadvantages due to the very high stopping power, mixing Ar and CF_4 would be more applicable for compact multi-target set-ups employed for detecting fission fragments with increased luminosity as described in [4]. However for Ar+CF_4 mixtures not much is known in terms of electron mobility and PHD. Hence, counting gas properties in different mixtures of Ar+CF_4 have been studied using a twin Frisch-grid IC. The PHD in the different gas mixtures has been determined relative to the reference gas P-10 using the well-known ^{252}Cf(sf) decay.
*Supported by CHANDA and BMBF (05P2015RDENA).

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ELIADE Detectors Array Support

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The GBS of the ELI-NP facility will deliver gamma beams with unprecedented quality as concerns the spectral density and energy resolution. One type of experiments that will benefit most of these beams are the Nuclear Resonance Fluorescence measurements. Such experiments will be performed at ELI-NP using a state of the art HPGe Segmented Clover detector array, ELIADE, using a fully digital data acquisition system.

The ELIADE detector array support structure is one of the key components for the performance of NRF measurements at ELI-NP. It will allow the fine tuning of the experimental conditions through the degrees of freedom of the detectors and their shields, without compromising any of the safety features associated with the operation of such sensitive equipment. The structure will play a direct role in the alignment of the detectors with the small volume where the beam intersects the target.

ELIADE detector array support is a complex structure special designed to host 12 HPGe Segmented Clover detectors and the interaction chamber where reactions between gamma beam and different targets will be performed under vacuum conditions. The interaction chamber will be symmetrically positioned between the frontal faces of the HPGe Clovers. Also, the interaction chamber will be able to accommodate a positioning system, providing an accurate alignment (sub-millimetric) of the target with respect to the gamma beam axis.

Basically, the ELIADE mechanical support structure comprises two independently sub-structures: one for 4 detectors in up-stream position and one for 8 detectors positioned in down-stream relatively to the Interaction point, where the target will be placed. In addition, detectors mounted on the DOWNSTREAM structure may be inclined to the gamma beam propagation direction at angles between +8° and –8° (angles measured in the plane created between the gamma beam axis and the detector axis).

The poster will present a general overview of the structure, its design goals, and will emphasize aspects directly related to the operation of the array by scientists performing NRF experiments at ELI-NP.

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Theoretical Approach on Optical Choppers for Gaussian Laser Beam Distributions

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Optical choppers are widely used in a variety of laser systems, for light modulation or attenuation [1].
The classical configuration of these optical devices is built as rotational wheels with windows with linear margins, which transforms a continuous-wave laser beam into a series of impulses with a certain frequency and profile.
In the present work we present the characteristic cases of classical optical choppers, as we have solved for top-hat (constant intensity) laser beams [2, 3]. The case of eclipse choppers (with windows with semi-circular, inward or outward margins) that we have introduced is also pointed out [4, 5].
Gaussian laser beam distributions of the laser beams to be chopped are also considered and the functions of the transmitted light flux of the device are approached. This allows for the designing calculus of choppers for different applications, taking into account their specific requirements [6, 7].
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Design of a broad energy range (50 MeV-10 GeV) electron spectrometer

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Electron spectrometers are widely used as tools to measure the high energy electrons produced by the laser plasma interactions [1-7]. We are presenting a detailed design of the ELI-NP electron spectrometer as foreseen to be implemented which has a broad energy range (50 MeV - 10 GeV). The ELI-NP spectrometer is made up of permanent dipole magnets of 1 m length with a gap of 20 mm and features a 1.6 T magnetic field at the center. We have carried out Monte Carlo calculations of electron beam transport and interactions using GEANT4 and electron beam trajectory simulations using SIMION and COMSOL.
According to our estimates, we need two Lanex [4] screens for ELI-NP electron spectrometer, one at the horizontal and one at the vertical exit of the spectrometer magnets. The horizontal Lanex covers energies up to 3 GeV and the vertical Lanex up to 10 GeV. We have found that the minimal suitable distance of the vertical Lanex is at least 1 m away from the magnet exit, since for an anticipated beam divergence of ± 1.5 mrad, this position keeps the uncertainty in the measured energies below 10 %. The electron beam divergence is the main source of error in the energy measurement. A possible use of collimator at the spectrometer entrance to improve the energy measurements has also been studied, and it is found that the collimator improves the quality of measurements in case of large beam divergence and large beam pointing.

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Decay behavior of scissors mode states in ^{76}Ge

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The study of the neutrinoless double beta decay (0νββ) is important for fundamental physics. The existence of such a decay would require an extension of the standard model and indicate that the neutrino is a Majorana particle.

Large scale experiments like GERDA [1] and MAJORANA [2] are searching for the 0νββ decay from the mother nucleus ^{76}Ge to the daughter nucleus ^{76}Se.

If they measure a decay rate $\lambda_{0\nu\beta\beta}$ the determination of the effective mass of the neutrino is possible. Precise knowledge of the nuclear matrix elements (NME) $|M^{(0\nu)}|$ is essential, which cannot be measured directly but needs to be provided by nuclear structure theory, for example the interacting boson model (IBM) [3,4]. For a reliable description of the 0νββ-decay in terms of the IBM-2 it is particularly important to verify the proper relative contributions of proton and neutron bosons to the IBM-2 wave functions which makes the precise inclusion of the decay channels of the scissors mode mandatory.

$$\lambda_{0\nu\beta\beta} = G_{0\nu}\left|M^{(0\nu)}\right|^2 \left(\frac{\langle m_\nu \rangle}{m_e}\right)^2 \text{ [4]}$$

Therefore, nuclear resonance fluorescence experiments were conducted at the High Intensity γ-Ray Source in Durham, NC, USA [5]. Polarized quasi monoenergetic γ-rays enable a selective excitation of states in a narrow energy window, such that only states in the region of the scissors mode gets exited. Due to the polarization of the γ-rays an easy assignment of the parities of transitions is possible.

The decay behavior of the scissors mode was measured with the γ^3 setup [6]. This setup is optimized for the analysis of γγ-coincidences and extraction of branching ratios. The transition strength [7] and branching ratio can be compared to theoretical calculations.

First results of the coincidence analysis will be shown.

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Coded Apertures for X-Ray Imaging with Spectral Selectivity

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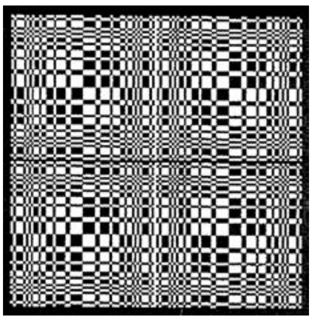
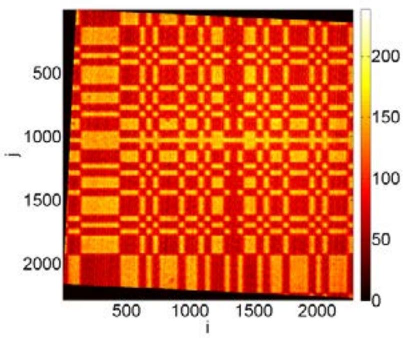
Pinhole apertures are commonplace for x-ray imaging but require high flux sources due to the small angle subtended by the aperture. The poor signal to noise (SNR) ratio may be mitigated by using a pinhole array or 'mask' which can then be used to deconvolve the signal during post-processing[1].

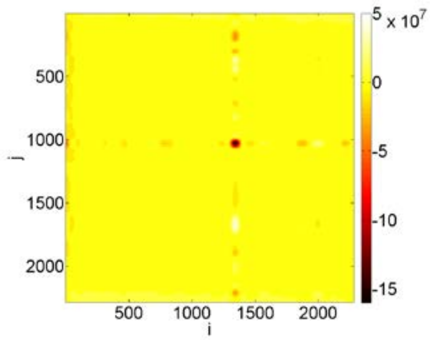
Previously, this technique has been confined to macro-scale imaging of far-off point sources, due to the decoding assumption of 1:1 magnification of the image between the aperture and the detector. However, recently research is being undertaken to extend the use of these apertures to rival the ~microns resolution of many single pinhole systems. Figure 1 shows a typical mask (a), a raw signal (b) and the deconvolved image (c) for a test rig using blue optical light with a magnification of 51x.



(a)



(b)



(c)

Figure 1. A typical mask, (a), constructed using the MURA template[1]. The smallest aperture element was 320 microns, and this was used to image a blue LED onto an Andor Neo camera, (b). This was deconvolved to reconstruct the image of the LED, (c). The scale on (c) is an arbitrary correlation factor, and is inverted due to an error in mask manufacture – an anti mask was instead delivered, and thus the correlation with the mask is negative.

Furthermore, with the increased throughput afforded by coded apertures, spectral selectivity may be feasible. If an aperture were used in conjunctions with a ross pair, spectral information could be gleaned from the image. Multiple detectors could give spatial information of elemental composition.

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Design of a magnetic spectrometer for pulsed X/γ-ray

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High brightness X/γ-ray generated by Inverse-Compton scattering is desirable for many applications especially nuclear photonics. In order to characterize energy spectrum of pulsed X/γ-ray, two main methods are developed up to now. The first one is traditional spectrometry which works on counting mode. Although high energy resolution (<1%) is achievable using HPGe spectrometer, it only suits for stable pulsed radiation with low peak-intensity and high frequency. The other one is magnetic spectrometer based on Compton electrons which is widely used for intense X/γ-ray measurement in fusing research and plasma diagnose. The ability of energy spectrum measurement of a single intense pulse is unique which provides powerful real-time tools to monitor and diagnose facilities.

In order to balance the characteristics of energy resolution and detecting efficiency, we studied the dependence of them on parameters of magnetic spectrometer in [1] including the material and thickness of the Compton converter, the collecting angle of Compton electrons, the configuration of the magnet et. al.. While the simulation shows that the energy resolution varies with the size of X/γ-ray beam. Here we report the further work on the spectrometer design. By adjusting the bending radius and size of electron collimator, a detecting efficiency of 10^{-4} e-/γ and an energy resolution of below 5% (FWHM) for 3MeV X/γ-ray beam with radius 0~5 mm have been achieved. The system response to quasi-monochromatic X/γ-ray beam generated by Inverse-Compton scattering is also studied using Geant4.

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Conceptual Design of Electron Spectrometer for Experiments at CETAL

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An electron spectrometer has been designed and built to measure the angular and energetic spectral distributions of the high-energy electrons generated from ultra-intense laser-plasma interactions. The spectrometer is intended to observe a broad range of energies from a few to 200 MeV per shot, with the possibility of simultaneous measurement of electron beam spectrum on two detectors. An analytical model where the dispersion equation is obtained and numerical simulations of electron trajectories with different energies entering the spectrometer are used to identify the calibration scale for detection of electron bunches. The magnetic system introduces an energy dependent dispersion such that the electron energy is translated to position on each detector plane. The correspondence between the electron energy and the detection position is determined by using a charged particle tracking code. The computation of the detected position and the corresponding divergence angle on detectors allows the estimation of the spectral distribution (energetic and angular) of the electron beam.

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High-Density Gas Capillaries for Betatron X-ray Sources of Laser-Accelerated Electrons

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Recent developments of high-repetition-rate multi-Terawatt few-cycle femtosecond 1030 nm OPCPA system delivering 40-75 mJ 7-20 fs pulses at 1 kHz rate [1], the interest in using betatron hard X-ray sources driven by laser-accelerated electrons for the spectroscopic absorption measurement of the Warm Dense Matter [2] raise the requirement of manufacturing and characterization of high-density gas targets of micrometric dimensions. The characteristic betatron frequency $\omega_\beta=\omega_p/\sqrt{2\gamma}$ is proportional to the plasma frequency ω_p and $\sqrt{n_p}$, where n_p is the plasma density and γ is the Lorentz factor of electrons. The electrons in the plasma wave are efficiently accelerated when the laser pulse duration is approximately equal to the half of plasma wave period. Confining of the laser field inside of the plasma bubble can act as an effective wiggler to produce betatron X-ray radiation with harmonics peaking in the range of tens and hundreds of keV [3]. The frequency of harmonics can be estimated as $\omega_h=n2\gamma_x^2\omega_\beta$, where $\gamma_x=\gamma(1+\frac{a_\beta^2}{2})^{-1/2}$ is the average longitudinal Lorentz factor, n is the harmonic number, $a_\beta=2\pi\sqrt{\gamma/2}\ r_\beta/\lambda_p$ is the normalized transverse momentum, r_β is the amplitude of electron motion and λ_p is the plasma wavelength.

In this report, microcapillaries with the diameter of 100 – 500 µm and length of several millimetres were implemented as nozzles to produce high-density gas targets. The microcapillaries were simulated using analytical calculations and numerical solutions of OpenFOAM® transonic solver rhoSimpleFoam and manufactured from fused silica block using a hybrid laser 3D machining technique. Initially, the samples were shaped using the DPSS nanosecond laser with high material removal rate and accuracy of approximately 200 µm [4]. Then, microcapillaries were inscribed inside the fused silica material using the femtosecond direct laser writing technique and etched in the 10M KOH and/or diluted 10% concentration HF acid for 24-48 hours. In such way, the manufacturing accuracy has been improved up to ± 5-10 µm.

The gas density profiles of microcapillaries were measured using nitrogen, continuous wave 632.8 nm HeNe laser, Mach-Zehnder interferometer and subsequently the interferograms were filtered using Fourier transformation. The phase was retrieved, and the density profiles were reconstructed using the Interferometric Data Evaluation Algorithms (IDEA) [5]. Depending on the valve backup pressure of 10 to 40 bar, the concentration of the gas density in the range of 1.3 - $5\cdot10^{19}$ cm^{-3} was measured. According to the numerical simulations, the gas density at the output of the nozzle is close to the critical density of the gas inside of the capillary at subsonic conditions of the flow. The pressure at the output of the nozzle is typically 0.15 – 0.2 from the input pressure and can be defined as a difference between the total pressure at the input of the capillary and dynamic pressure of the flow. Leaving the capillary, the gas expands quickly, and for the microcapillary with the diameter of 100 µm, reaches the residual pressure within the distance of 150 – 200 µm. The longitudinal profile becomes steeper with increasing of the input pressure and becomes more oblique with increasing the diameter of the capillary. The typical expansion rates of Laval nozzles used as targets for Laser Wake Field Accelerators lead to the pressure at the output being 0.05 – 0.1 from the input pressure of the nozzle. Thus, the gas concentration at the output of the capillary at the 50 bar backup pressure is equal to $2\text{-}6\cdot10^{19}$ cm^{-3}, and is 3 -4 times higher relative to the typical concentration of $5\cdot10^{18}$ - $2\cdot10^{19}$ cm^{-3} at the output of Laval nozzle. The strong dependence of the concentration on the distance from the nozzle output could be a disadvantage if looking for monoenergetic electron acceleration. On the other hand, the steep concentration gradient is in favour if aiming to generate continuous secondary betatron X-ray radiation and use it subsequently as a probe for spectroscopic measurements of the matter. In the Fig. 1, the calculated (a) and measured (b) nitrogen density profiles close to the exit of microcapillary with the diameter of 100 µm at the backup pressure of valve 40 bar are presented.

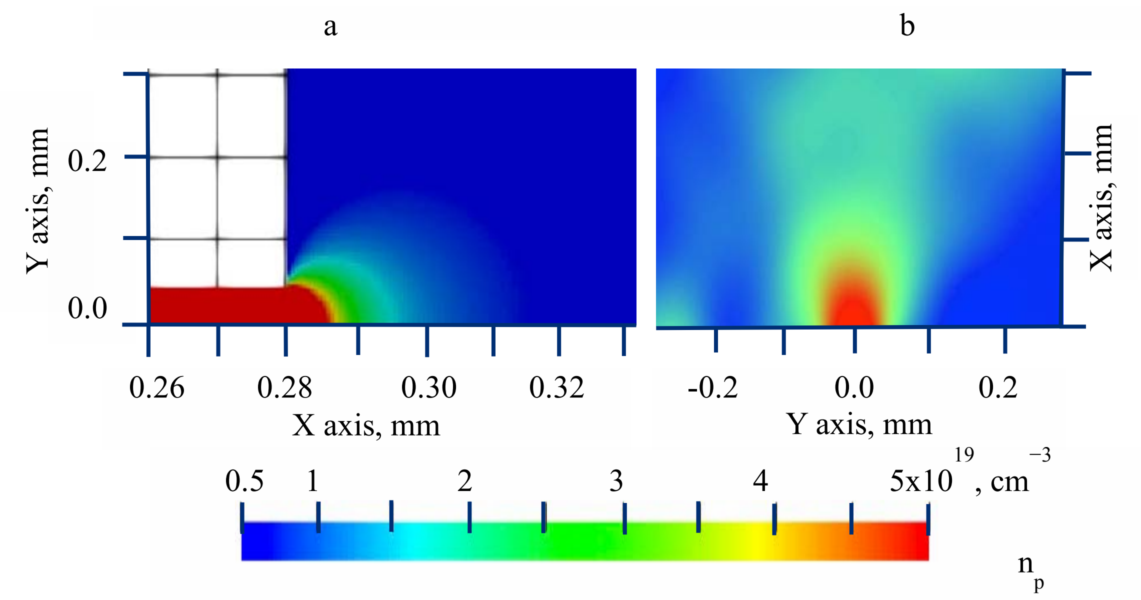

Fig. 1. Calculated (a) and measured (b) nitrogen density profile of microcapillary with 100 µm diameter at the backup pressure of the valve 40 bar.

The measured value of the gas concentration close to the output of the nozzle is $5.2\cdot10^{19}$ cm^{-3}. The combination of the 7-12 fs laser pulses and plasma targets of size 150 – 200 µm with the gas density of $2\text{-}6\cdot10^{19}$ cm^{-3} allows realisation of betatron hard X-ray sources of with the critical energy of tens of keV with a temporal resolution of few femtoseconds.

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Possible interaction between gamma-ray vortex and particles such as electron and nucleus

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Photon vortices caring orbital angular momentum [1] are one of most interesting topics in physics. It can be applied to various fields such as nanotechnology and quantum communications. The energy of photon vortices has been extended to wide regions. To generate gamma-ray vortices in the MeV region, Compton scattering with vortex laser beams [2] and non-linear Compton scattering with highly intense circularly polarized laser [3] have been proposed. Although it is expected to generate gamma-ray vortex in near future, an important consideration in gamma-ray vortex experiments is the verification method of the generated gamma-ray vortex because the optical devise such as holographic phase plates cannot be used. Therefore, we consider the coincidence measurement of photon vortices on rest electron because the angular momentum of the incident gamma-ray vortices should be conserved into the scattered photon-electron system. The differential cross section of the scattered photon measured simultaneously with the scattered electron for the incident photon with wave function of Laguerre Gaussian is calculated in the framework of relativistic quantum mechanics. The result shows that this method is powerful tools to investigate the angular momentum of the wave function of incident gamma-ray vortices. We also discuss the interaction between of the gamma-ray vortices and atomic nuclei. The parity and spin of states exited by photon induced reactions should be limited by the conservation law of the angular momentum. When photon vortices with angular momentum higher then or equal to 2 hbar infract with nuclei, the distribution of the exited states should be different with that with standard photon with plane wave. This may change the abundance pattern of stellar nucleosyntheses such as gamma-process in huge photon bath.

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Thomson Parabola spectrometer design for an 60 MeV – 200 MeV energy range of protons at ELI-NP

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In this work an extended range Thomson Parabola (TP) spectrometer design as foreseen to be implemented for Day-1 experiments at ELI-NP is presented [1]. The design is based on analytical calculations and simulations made with SIMION v7 [2], a specific software for charged particle trajectory simulations. The TP is able to measure the energy distribution of accelerated protons and ions resulting from the interaction of high power laser beams with matter in the TW to PW regime. The spectrometer is highly versatile due to its architecture, which uses a pinhole, one permanent magnetic core, an electrostatic deflector and a detection screen. In the presented configuration the spectrometer is able to measure the energy spectra of proton, oxygen and carbon ions, with high resolution, on a shot by shot basis. The simulations were undertaken for protons in a range from 60 MeV to 200 MeV. The energy resolution varied between 0.5 MeV for 60 MeV protons and 3.7 MeV for 200 MeV protons. The TP spectrometer measures only a small part of particle emission due to the low angular acceptance (1 mrad), but has a large acceptance in terms of energy, and is immune to electromagnetic pulses (EMP) when coupled to passive detectors [3].

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Study of multipole photonuclear excitations near threshold

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The paper is devoted to investigation of photonuclear reactions induced by real and virtual photons (electrons) at photon energies below 10 MeV. A special attention is paid to comparison of real and virtual photon spectra which provide a noticeable difference in the multipolarity of excitation. Namely, E2 excitation in case of virtual photons is in order of magnitude stronger than E1 excitation by real photons.

New experimental results obtained for In and Cd isotopes by the activation method are presented. Experimental method based on GEANT-4 simulation is described. Experiment was performed at the electron linear accelerator LUE-8 MeV at the INR RAS and terawatt femtosecond laser facility of Moscow State University [1].

The obtained data are discussed in frame of the phenomenological model which allows the theoretical evaluation of the isomeric ratio in this energy region. First experimental results on the probability of dipole and quadrupole mode excitations in Cd and In nuclei provide the complementary information about multipolarity of photonuclear excitations obtained in experiments with real photons where the angular distributions were measured. The experimental results are discussed in frame of the existing nuclear models.

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P. 68

Geant4 implementation of photon elastic scattering processes

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The ELI-NP gamma beam system (GBS) will deliver quasi monochromatic gamma-ray beams (bandwidth < 0.5%) of high spectral density (~104 photons/s/eV) and high degree of linear polarization (> 95%) in the range of 0.2–19.5 MeV produced by the laser-Compton backscattering technique (LCS) [1]. These beams are promising tools for active interrogations of special nuclear materials [2] and together with a high efficiency gamma-ray detector array can provide the means for structural and elemental composition investigations of industrial objects. Quantitative assays of spent fuel or low composition materials require good knowledge of elastic background especially when quasi-monoenergetic gamma beams are used as probes. Typical general particle transport codes, Geant4 or MCNP, are limited to the inclusion of Rayleigh scattering, which provides a good approximation for the elastic scattering in the case of low energy photons. However at energies above 1 MeV, the contribution of Rayleigh scattering to the total elastic cross section declines and other processes become more important. Here we discuss the implementation of photon elastic scattering in GEANT4 using the complete theoretical framework for the photon elastic processes. The total elastic cross section is calculated based on scattering amplitudes to account for interferences between coherent processes. Rayleigh scattering amplitudes were obtained by using the S-matrix formalism developed by Kissel *et al.* [3], for which we extended the calculations up to 6 MeV. Delbruck scattering amplitudes were obtained by interpolation and extrapolation procedures based on data calculated by Falkenberg *et al.* [4]. The amplitudes for the last two elastic processes, Thomson scattering and Giant Dipole Resonance scattering, were obtained by using known analytical formulas.

In order to validate the implementation we performed Geant4 simulations for several test cases. We test the agreement between simulation and experimental data by comparing the simulated angular distribution, energy distribution and charge number distribution of elastically scattered gamma rays with existing experimental results. The validation showed good agreement between simulated and experimental data. Further improvements to the accuracy of the simulation can be obtained if a complete description of Delbruck scattering is employed.

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Nonlinear Waves in Free and Magnetized Quasi-neutral Plasmas Excited by External Electromagnetic Radiation

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Starting from the Vlasov-Maxwell equations describing the dynamics of various species in a free quasi-neutral plasma, an exact relativistic hydrodynamic closure for a special type of water-bag distributions satisfying the Vlasov equation has been derived. It has been shown that the set of equations for the macroscopic hydrodynamic variables coupled to the wave equations for the self-consistent electromagnetic field is fully equivalent to the Vlasov-Maxwell system.

In the case of magnetized quasi-neutral plasma the hydrodynamic substitution has been used to derive the hydrodynamic equations for the plasma density and current velocity, coupled to the wave equations for the self-consistent electromagnetic fields.

Based on the method of multiple scales, a system comprising a vector nonlinear Schrodinger equation for the transverse envelopes of the self-consistent plasma wakefield, coupled to a scalar nonlinear Schrodinger equation for the electron current velocity envelope for free plasma, has been derived.

In the case of magnetized plasma, it has been shown that the whistler wave envelopes of the three basic modes satisfy a system of three coupled nonlinear Schrodinger equations.

Numerical examples for typical plasma parameters have been presented, which demonstrate the relevance of the results thus obtained to the so-called shock laser-plasma acceleration. In addition, it has been shown that in the case of magnetized plasma, the whistler waves facilitate the transverse confinement considerably.

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Designs and Static Structural Analysis of the Diagnostic Mechanical Setups for High-Brilliance Gamma Source at ELI-NP facility

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Extreme Light Infrastructure - Nuclear Physics (ELI-NP) is a new nuclear physics research infrastructure that will host a brilliant, high intensity gamma beam system characterized by unique features well beyond the present–day state–of–the–art. New opportunities for both fundamental nuclear physics and applied research are within the reach of the proposed experiments with the gamma beams. The refinement of the proposed physics cases and the implementation of the experimental and diagnostic setups with gamma beams.

In this poster we propose to define the mechanical designs for the experimental and diagnostic setups to create the best condition to perform the study describe in the Technical Design Reports (TDRs). To validate the mechanical designs we perform the static structural analysis to determinate the deformation and stress distribution using the finite element analysis (FEA) tools.

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Simulation of wakefield-accelerated electrons using density-ramp injection for x-ray source generation

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Mono-energetic electron beams are useful for applied physics, especially for the creation of high energy, mono-energetic photons by inverse Compton scattering. Production of mono-energetic electrons via laser wakefield acceleration can be induced by tailoring the plasma density to have a sharp transition between a high and low density. This has been shown experimentally by Schmid [1] where a shock-front is produced by inserting a blade into the supersonic flow from a DeLaval nozzle. In Schmid's experiment the density was calculated from the shadowgraph.

We have shown, with simulations of the gas flow in openFoam [2], how these shocks form and how best to manipulate the setup to have a tuneable electron beam energy from the LWFA. An example density map is shown in Figure 1 below.

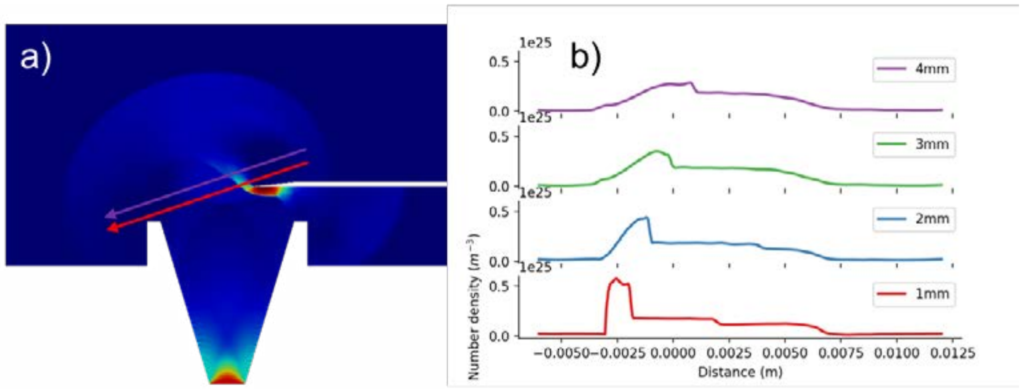

Figure 1: a) Density map showing the shock wave forming at the blade producing the sharp density transition. b) The electron number density across the shockwave along the line from the tip of the blade to the top of the nozzle. As the line out height above the blade and nozzle increases the transition is seen to become less sharp.

The tuning of the electron energy can be done by altering the length of the acceleration region, the lower density section. These simulations, in combination with plasma PIC simulations (EPOCH)[3], produce an in-depth study of how the conditions of the gas target affect the mono-energetic electron beam production, meaning that the targets can be optimised for each laser.

The photon energy of the inverse Compton source scales as $E_{source} = 4\,\gamma_e^2 E_{laser}$ GeV electrons are producible by petawatt lasers through LWFA, and their γ factor is in the thousands. This combined with infrared laser light this produces photon sources up to tens of MeV. A source of this energy can drive photofission and be used for scanning very dense materials.

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Measurement of Energy Spectrum of Betatron X-rays from Laser-plasma Acceleration

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Betatron X-ray radiation is a highlighted hotspot in research of novel radiation sources driven by laser-plasma. It is generated by transverse betatron motion in the laser-plasma wake field. Therefore, it has comparatively small scale and femtosecond duration. By virtue of this, betatron X-ray has great advantage of femtosecond pump detection; meanwhile it has prospective applications in material science and bioscience. Measurement of its energy spectrum is valuable to learn the quality of betatron radiation sources and to get to know the quality of betatron X-rays. To measure its spectrum, we employ the method of estimating spectra by transmission measurements. A detection system was tailor-designed for betatron X-ray source of SIOM(Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences) satisfying the meet that the energy spectrum of each X-ray pulse be acquired for every pulse rays with a small angle of beams. Correspondingly, the reconstruction algorithm to solve the energy spectrum was also well optimized. On Philips X'Unique II current steady X-ray source, comparison measurement experiments were done to test the designed system and the developed algorithm. The measured spectra gained by our detection system fit quite well with the spectrum measured by HPGe as comparison. Furthermore, the energy spectrum detection system was successfully applied in detection of Tesla repetitive frequency X-ray source.

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P. 73

Laser energy absorption and relativistic electron dynamics in intense laser-foil interactions

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Laser energy absorption in dense plasma is fundamental to a range of intense laser-driven particle and radiation generation mechanisms. The coupling of energy to plasma electrons defines the properties of the radiation beams produced and strongly influences the optical properties of the plasma. Using the high power PHELIX laser at the GSI laboratory, we measure the total reflected and scattered laser energy as a function of intensity and target thickness, by using an integrating (Ulbricht) sphere. We correlate these results with measurements of the angular and energy distributions of relativistic electrons escaping from the foils, made using stacked Image-Plate detector surrounding the sphere.

Specifically, we investigate total laser energy absorption into thin foil targets in the transition from surface- to volume-dominated interaction physics. The former is driven by the dynamics of the plasma critical density surface in micron-thick foils and the latter is defined by laser hole-boring into expanding nanometer-thick foils. The total reflected, scattered and transmitted laser energy components are measured to determine the absolute energy absorption. We find that laser absorption only weakly varies with target thickness in the range 40 – 1000 nm. By contrast, an optimum thickness is measured for coupling energy into relativistic electrons which escape the foil and the thinnest targets are found to produce a less divergent electron beam distribution. 2D particle-in-cell (PIC) simulations show that the absorption physic is strongly affected by the onset of relativistic induced transparency in the thinnest foils.

We also distinguish between the influence of pulse energy and focal spot size on total energy absorption. We confirm the scaling of absorption with intensity by variation of laser pulse energy as previously reported in reference [1], but find a slower scaling when changing the focal spot size. The results were recently published in reference [2]. Our 2D PIC simulations show that the differences arise due to relativistic electrons recirculating within the target. These electrons undergo multiple interactions with the laser pulse, enhancing absorption in the case of a large focal spot. This effect is found to be dependent on the laser pulse duration, the target thickness and the divergence of the relativistic electron beam.

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A proposal for verify the Breit-Wheeler process at SINAP

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Quantum electrodynamics (QED) is one of the most successful and accurate theory ever achieved in physics for its extremely accurate prediction in atomic physics has been verified. By contrast, the Breit–Wheeler process, $2\gamma \rightarrow e^{+}+e^{-}$, the simplest mechanism predict in QED to create an electron-positron pair from the collision of two real photons, is still waiting a direct observational verification due to its small scattering cross section and large pair generation energy threshold. The Shanghai X-ray Free-Electron Laser (SXFEL) facility, under construction at Shanghai Institute of Applied Physics (SINAP), provides us an opportunity to learn about the BW process through collision the high energy gamma photons generated by Laser Compton Scattering (LCS) of optical laser off the 1.6 GeV electrons with the X-ray photons generated by the undulator. The maximum energy of the gamma-ray photons could be up to hundreds of MeV. In order to manipulate X-ray to collide with gamma ray better, we propose to adopt beam-drived plasma wakefield acceleration (BPA) technology to boost the electrons energy to 6 GeV to generate the hard X ray based on FEL radiation. We propose to construct a new electron beamline in the SXFEL undulator hall beside the other two radiator undulator lines special to develop a high brightness gamma ray source based on LCS and to research the key techniques involved in BPA. Tuning the gamma energies to the energy corresponding to the maximum of the collision cross section, about 850 electron-positron pairs per second will be generated calculation by Monte Carlo method.

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Recent progress on the gamma-ray generation system of Shanghai Laser Electron Gamma Source(SLEGS)

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Shanghai laser electron gamma source (SLEGS) [1,2] based on laser Compton scattering (LCS), as one of beamlines of SSRF in phase II, has been proposed since 2007. The design of its gamma-ray generation system has changed a lot from the original one. In this paper, a brief summary of the latest design of the gamma-ray generation system is given, including the laser transport system, magnet lattice and the interaction chamber.
In order to inject the 10640nm CO_2 laser into the interaction point from the laser hutch outside the storage ring's shielding wall, A 23 m long laser transport system using relay-imaging telescopes is planned. A pair of 2.3 Tesla room temperature super bending magnet (SB) is designed to save space for the interaction region between them. The interaction chamber mainly inherits the design used in the prototype [3]. It has two operation mode. One is backscattering mode, which will make the laser and electron bunch collide at 175.5° with flux higher than 2×10^6 γ/s. The other mode is named slanting mode, which allow the collision angle between the laser and electron beam consecutively adjustable from 20° to 160°, thus the maximum energy of the generated γ ray can change from 0.7 MeV to 21 MeV, when the energy of electron is fixed to 3.5 GeV. Additional water-cooled structures are designed to compensate the thermal effect of synchrotron radiation of SB and the high-power laser on the interaction chamber. Meanwhile, the influences of SLEGS's gamma-ray generation system on the storage ring are also calculated, including the bunch lifetime, emittance, energy spread.

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P. 76

Ultrafast multi-MeV gamma-ray beam produced by laser-accelerated electrons

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Ultrafast multi-MeV high-flux gamma-ray beams have been experimentally produced via bremsstrahlung radiation of laser-accelerated energetic electrons through millimeter-thick copper targets[1]. By optimizing the electron bunches to the charge of 10 nC in a clustering argon gas target, the obtained gamma-ray beam significantly increases to 10^{10} photons per shot. Figure 1 plots the experimental setup of gamma-ray beam generation and detection and the raw signal of gamma-ray beam in the detectors.

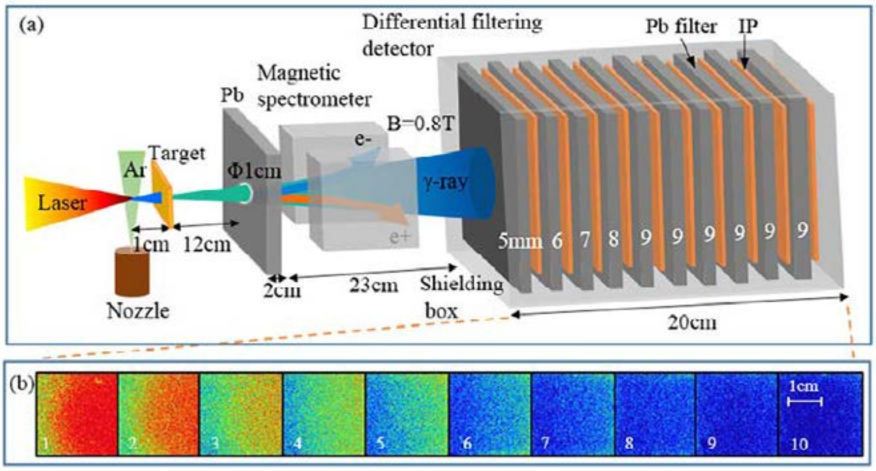

Fig.1 (a) Experimental layout of the ultrafast gamma-ray beam generation and measurement. (b) Raw signal of gamma-ray photon recorded in IPs behind each lead filter.

The gamma-ray beam spectrum has been measured using a differential filtering detector, which contains lead filters with different thicknesses. The image plates are set behind each lead filter. The gamma-ray beam has a broad spectrum up to 15 MeV, which is approximately consistent with the Geant4 simulation. The generated high-flux high-energy gamma-ray beams are promising sources for photonuclear reaction, non-destructive inspection and clinical applications.

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P. 77

The interrogation of high-Z materials with photons and neutrons driven by an electron LINAC

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The fusion of photon-based technologies and neutron-based technologies is necessary for detecting and identifying the concealed special nuclear materials (SNMs). With a low energy electron LINAC, both photons and neutrons, which are the byproducts of photons when a photon-to-neutron converter is used to convert bremsstrahlung photons as neutrons. There are three steps for detecting and identifying the SNMs. (1) The combination of photons attenuation information and that of neutrons helps separate high-Z materials from low-Z and middle-Z materials. (2) The beta-delayed neutrons, which are induced by the penetrating photons via the (gamma, fission) reaction, are measured to confirm the existence of fissionable materials. (3) To evaluate the abundance of ^{235}U or ^{239}Pu, which are the principal isotopes in the SNMs, resonant attenuation of slow neutrons is measured to analyze the isotopic concentrations in the inspected matter. The inspection time of these three steps can be limited to <30 minutes. The underlying principles and experimental results will be presented in this presentation [1].

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Experimental Polarization Control and Measurement of Thomson Scattering X-ray Source

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Thomson scattering of laser beams scattering from relativistic electrons allows us to produce high polarized and brightness X-ray beams. We control the polarization of X-ray beams by changing the polarization of incident laser beam. A quarter-wave plate and a half-wave plate are used to change the polarized state and the polarization direction of incident laser beam separately. We use the Compton scattering effect which X-ray beams irradiate on the scattered target to determine the degree of X-ray polarization. Meanwhile, we make different size of target to observe the effect of target size on polarization measurements. According to the experiment results, we can get the conclusion that the polarization of Thomson scattering X-ray source is controllable. And small size of target improves the polarization measurement accuracy.

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Neutron Generation by Indirect-drive Fast Ignition on SG-II Upgrade Laser Facility

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Compared with central ignition of laser fusion, fast ignition separates compression and ignition thus it can relax the requirements on the implosion symmetry and the driven energy. In this presentation, the progress on fast ignition experiment on SG-II upgrade laser will be introduced. The SG-II upgrade laser facility has been brought into operation in 2015. It is capable to deliver totally 24 kJ nanosecond laser beams for compression and 1 kJ at 10 picosecond heating laser for the generation of hot electrons. The implosion of indirect-drive fast ignition targets with reentrant cone was experimentally researched on SG-II upgrade laser. The small-scale cone-in-shell target was pre-compressed by the SG-II upgrade eight nanosecond laser beams indirectly. The density and areal density distribution of the compressed fuel was obtained by picosecond X-ray backlight. Moreover, integrated fast ignition experiments have been performed and 200-fold neutron generation enhancement was observed. The results confirmed the heating effect of picosecond laser and the heating efficiency can reach ~10%, calculated from the measurement of neutron yield, fuel density and spot size.


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