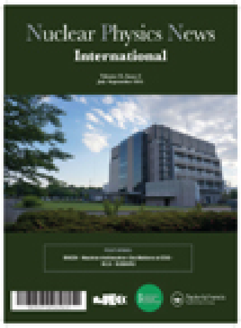

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Extreme Light Infrastructure–Nuclear Physics (ELI–NP)

The project Extreme Light Infrastructure–Nuclear Physics (ELI–NP) [1], to build in Romania a European research center to study ultraintense lasers interaction with matter and nuclear science using gamma and laser beams, ends in December 2014 the second year of its implementation. The new research center will be located in Magurele, a town a few kilometers away from Bucharest, Romania. The project is implemented by "Horia Hulubei" National Institute for Physics and Nuclear Engineering (IFIN-HH). ELI–NP will host two 10 PW lasers and a gamma beam system producing gamma beams with parameters beyond those available at the present state of the art machines. At ELI–NP two well-established scientific communities, high-power lasers and nuclear physics, have joined their efforts to build a new interdisciplinary facility and to define its research program [2–4]. As a result of this collaboration the scientific interest of ELI–NP is covering a broad range of key topics in frontier fundamental physics and nuclear physics. The total cost of the facility will be 300 million euro, without value-added tax (VAT). In September 2012, the project was approved by the European Commission and the first phase was financed with 180 million euro, with 83% financial support from the existing Structural Funds cycle, which ends in 2015 and 17% from the Romanian National Budget. The second phase of financing will be granted in the next Structural Funds cycle which will start in 2015. The entire facility will be operational in 2018.

ELI–NP Buildings Complex and Major Equipment

The ELI–NP main buildings complex, covering more than 15,000 m^2, is dedicated to the experimental activities and it will host the main research equipment, the experimental areas, laboratories and workshops, control rooms, and user area. The high spatial accuracy of the laser and gamma beams requires a special design of the concrete base plate of the building to prevent vibrations. The state of the art equipment will require special clean-room, temperature, and humidity conditions. The architect's vision of the main buildings complex is shown in Figure 1. Other buildings under construction are the office building, a guest house and a canteen. The construction of the building complex started in May 2013 and will be completed in 2015. Figure 2 shows the status of the construction in December of 2014.

Figure 1. *The architect's vision of the main buildings complex at ELI–NP.*

ELI–NP hosts two major research equipment with beyond state-of-the art characteristics: a high-power laser system (HPLS), with two arms—reaching up to 10 PW for each arm—and a gamma-beam system (GBS) that will provide very intense and narrow-band gamma-rays with energies up to 19 MeV.

The high–power laser system of ELI–NP consists of two 10 PW lasers based on Optical Parametric Chirped Pulse Amplification (OPCPA) [5, 6] at about 820 nm central wavelength, with a dual front-end architecture with two parallel amplification arms. Each of the two parallel chains includes Ti: Sapphire amplifiers to bring the final output energy to the level of a few hundreds of Joule. Subsequently, the pulses are compressed to around a 20 fs pulse duration that implies a peak power of 10 PW at a repetition rate of 1 shot per min for each of the two arms [7]. Along the two amplifi-

Figure 2. *View of the construction site of ELI–NP in December 2014.*

cation chains, additional outputs with corresponding optical compressors will be installed. Their corresponding power levels are 0.1 PW and 1 PW at repetition rates of 10 Hz and 1 Hz, respectively. For the two 10 PW outputs an unprecedented level of intensity of about 10^{23}–10^{24} W/cm^2 will be achieved. Out of the six possible outputs on the two arms, two of them, one from each arm, can be provided simultaneously for experiments, combined in the same experimental setup or to be used independently in two different setups. The HPLS is being built by Thales Optronique France and Thales Romania (Figure 3).

The Gamma Beam System (GBS) for ELI–NP was designed to provide a very intense and brilliant gamma beam with tunable energy based on the incoherent inverse Compton scattering of a high repetition pulsed laser beam on a high intensity, low emittance, relativistic electron beam. The electron accelerator will be a warm linac, with two acceleration stages of 360 MeV each [8, 9]. The gamma beam up to 19 MeV will have a bandwidth smaller than 0.5%. The very low cross-section for Compton scattering will be compensated in obtaining high brilliance gamma beam by very intense high repetition rate photon beam, very intense low emittance electron beam and a very small and precise interaction volume. The ELI–NP GBS is being constructed by EuroGammaS [8], a European Consortium of academic and research institutions and industrial partners with expertise in the field of electron accelerators and laser technology from 8 European countries, consortium led by INFN Italy. A layout of the Gamma Beam system is displayed in Figure 4.

The ELI–NP Scientific Program

The scientific case for ELI–NP was elaborated by an international collaboration of more than 100 scientists from 30 countries and published as the ELI–NP White Book [10]. It is based on the unique features of the high–power laser and gamma beams. The main research topics of interest are: laser driven nuclear physics experiments, characterization of the laser–target interaction by the means of nuclear physics methods, photonuclear reactions, exotic nuclear physics and astrophysics. In addition to fundamental themes, applications of HPLS and GBS are under study. Accelerated particles produced by laser-matter interaction radiation-induced damage, and gamma beams–induced nuclear reactions are major active research areas in nuclear physics and engineering. Their applications extend from the nuclear power plants to medicine and from space science to material science.

The ELI–NP team, together with their collaborators from the international scientific community, shaped the future scientific program of ELI–NP in a series of workshops and de-

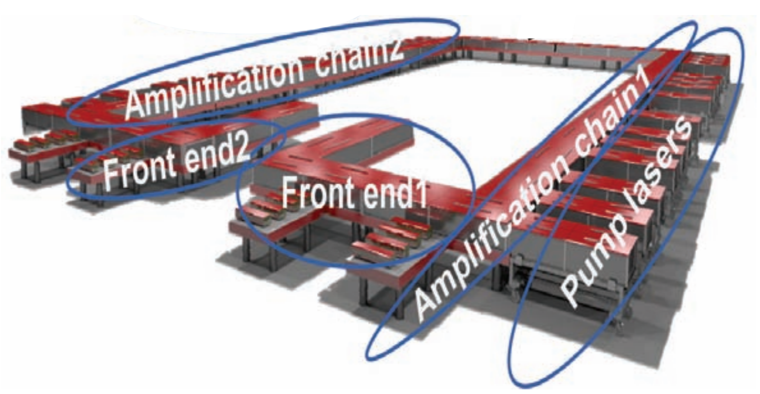

Figure 3. *Schematic layout of the ELI–NP High Power Laser System (HPLS).*

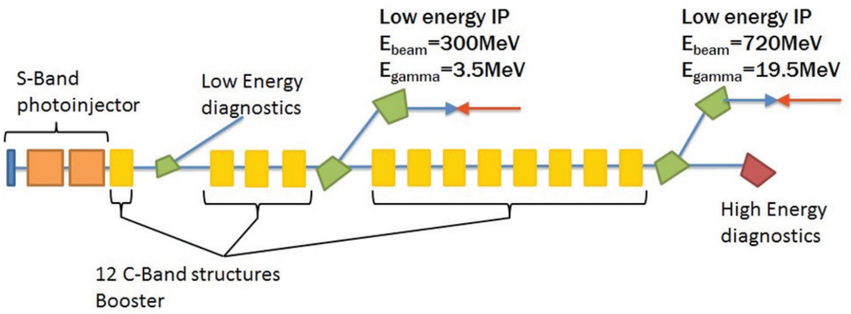

Figure 4. *General layout of the ELI–NP Gamma Beam System (GBS).*

fined ten development directions for the facility. The Technical Design Reports (TDRs) are being finalized and in the first part of 2015 will be approved by the scientific community and by the ELI–NP International Scientific Advisory Board.

Eight experimental areas will be available for performing experiments using the laser beams, the gamma beams or combined.

Laser-Driven Nuclear Physics Experiments

One of the most exciting driving forces behind the studies of the high-intensity laser interaction with matter is the perspective of obtaining laser-driven particles beams with characteristics similar to those obtained with conventional accelerators but, potentially, much less expensive. The present energy frontier of high energy physics is several TeV, but colliders capable of reaching this regime are very costly to build. Relatively expensive are also the accelerators used for science, hadron-therapy, or synchrotrons for material studies. Virtually all of today's accelerators are using the electric field generated between conducting electrodes or electromagnetic cavities. In this approach electrical breakdown limits the maximum field to less than 100 MV/m. Laser-based accelerators have the potential to deliver accelerating gradients more than 1,000 times higher than in conventional accelerator technology, reducing the required accelerator length by the same factor. This large increase in accelerating gradient for laser technology is the key to reducing the size up to a tabletop scale and reducing associated cost over conventional accelerators. It is expected that the compact, high repetition rate, tabletop laser will define the future for laser-driven nuclear and particle phenomena [11]. The observation of high brilliance beams of multi-MeV protons from solid targets has stimulated an enormous amount of studies. However, the laser-driven beams have yet to achieve the quality of conventional accelerator beams and, consequently, systematic studies should be performed in order to obtain mono-energetic particle beams. This novel technology must be followed by the development of diagnostics and suitable detectors for such beams with 10^8–10^{12} particles in 1 ps pulse at 1–200 Hz repetition rate. For this purpose, typical nuclear physics studies, with specific methods and tools, are extremely important for the development of this new field.

As a leading facility in laser-driven nuclear physics, ELI–NP will take advantage of the high intensity laser beams. Acceleration of ions with high–power lasers offers unique features such as production of beams with solid target densities and large acceleration over very short distances. Laser acceleration of heavy ions will be investigated and the possibility to use it for nuclear reactions.

The flagship experiment involves production of neutron rich isotopes using fission of Th and subsequent fusion process [12], to shed light on the formation of heavy elements (beyond Fe) in the universe. The needed data for the formation of heavy elements in the region of lead (Z = 82) and beyond are those related to very neutron-rich isotopes. The fusion cross-section even with secondary beams of radioisotopes is so low that in practice these key measurements are not within reach today. Using HPLS with a CD_2 production target and a very thin Th target, one may reach fusion of two very neutron-rich isotopes originating from the fission of Th (e.g., fusion of Z = 35) leading to this unknown mass region. First circular polarized laser beam incident on production target produces, through Radiation Pressure Acceleration (RPA) mechanism, a high density bunch of ^{232}Th, ^{12}C, and D ions. Then fission reactions will take place. ^{232}Th ion bunches interacts with ^{12}C (or ^{1}H) in the 1st layer and ^{12}C and D nuclei interacts with ^{232}Th in the 2nd layer of reaction target. Following their production, the two light fission fragments fuse in the reaction target and neutron rich nuclei (close to N = 126) are produced. Such experiments require significant experimental development in the field of laser-driven ion acceleration in order to produce intense heavy-ion bunches in the 5–10 MeV/u energy range relevant for fission and fusion reactions.

Experiments related to strong-field quantum electrodynamics are also planned. The tightly focused beams up to 10^{23} W/cm^2 on solid targets will be used for electron positron pair creation studies. The pair production can be enhanced by combining the laser and gamma beams.

The high-repetition rate 0.1 PW and 1 PW beams, where laser pulses produce relatively broadband spectrum of secondary radiation (electrons, gamma, protons, neutrons and positrons), are proposed to study the material behavior under extreme conditions of radiation.

Nuclear Science and Applications with High Brilliance Low-Energy Gamma Beams

The ELI–NP gamma beam experimental program will explore new territory in the field of Nuclear Resonance Fluorescence (NRF) [13] and experiments above the particle separation threshold such as studies of giant resonances, nuclear astrophysics reactions, and photo-fission experiments. The narrow bandwidth beam excites a single excited state, whose decay is studied in the experiment. The excited state can be below or above the particle separation energy. In the former case, the NRF method is applied and, in the latter case, induced reactions, such as (γ, n), (γ, p),

The low-energy gamma experiments ($E_\gamma < 3.5$ MeV) shall be mainly dedicated to NRF experiments and applications. Due to the brilliance of the gamma-ray beam, significantly increased with respect to existing facilities, experiments on isotopes whose availability is very limited will become feasible. This opens up an entire new area of applicability of the NRF method to isotopes that may be available only in quantities of a few mg, like long-lived radioactive isotopes of heavy actinides. The NRF technique allows the measurements of several physical quantities, such as: the excitation energies, level widths, decay branching ratios, or spin quantum numbers and parities of the excited nuclear states.

The high brilliance, small bandwidth, and tunable energy of the low-energy gamma beam may revolutionize the characterization of nuclear materials. The tunable-energy gamma-ray beam can be locked on the known excitation energy of the isotope to be located and identified (each isotope has a unique fingerprint) and the energy response of the detectors will clearly indicate the location and presence or absence of the isotope in the bulk material (e.g., in a nuclear waste container). This technique will be extremely useful in the management of sensitive nuclear materials and radioactive waste for isotope-specific identification such as $^{238}U/^{235}U$ or ^{239}Pu. It will allow the scan of containers for nuclear material and explosives, the inspection of spent fuel elements, and the quantitative measure of the final $^{235}U/^{238}U$ content in order to optimize the geometry toward the longer use (20%) of fuel elements in the reactor core.

An intense and high-energy resolving γ–ray beam from ELI–NP will open up new horizons for the investigation of the nuclear photo-response at and above the separation threshold. Both the GDR and the PDR can be covered within the energy range of the ELI–NP beams. In the experiments the excitation functions for elastic and inelastic scattering will be measured, revealing possible fine-structures/splitting of the Giant Dipole Resonance (GDR) and the Pigmy Dipole Resonance (PDR). The excitation function with high resolution for (γ, n) and (γ, charged-particle) channels, allows the determination of the branching ratios for various decay channels. The polarized beam will also allow the determination of the *E*1 or *M*1 type of excitation for the observed structures.

Photo-fission is also a topic where ELI–NP gamma beam will bring significant advances. So far bremsstrahlung was used to induce fission of actinide nuclei. Two classes of experiments have been identified: investigation of the fission potential barrier and the high efficiency production of neutron rich nuclei through photo-fission of U nuclei. High-resolution photo-fission of the second and third potential minima in actinide nuclei, angular and mass distribution, cross-sections, studies of rare photo-fission events, such as triple fission and highly asymmetric fission will be investigated.

Gamma beams of 15 MeV are highly efficient for producing short-lived and refractory elements in thin U targets using a gas-cell catcher (IGISOL technique). After their separation, the nuclei of interest can be transported to different measurement stations.

The ELI–NP facility provides unique opportunities for nuclear astrophysics research. Gamma-induced nuclear reactions of astrophysical interest still represent a challenge due to their very low cross-sections as the reactions occur deep below the Coulomb barrier. The study of these reactions will benefit from the use of the high intensity gamma beams at ELI–NP. Laboratory astrophysics experiments aiming at explaining the nucleosynthesis processes will be possible, through direct or inverse reactions. To advance the explanation of the formation of a large part of the known elements in the Universe, reactions relevant for the p- and r-processes will be investigated. All *p*-nuclei can be synthesized from the destruction of pre-existing nuclei of the *s*- and *r*-type by a combination of (p, γ) captures and (γ, n), (γ, p) or (γ, *a*) photo-reactions [14]. In particular, charged-particle detector systems, needed to measure nuclear reaction cross-sections of the proton and alpha burning processes and—most importantly—the $^{12}C(\alpha, \gamma)$ reaction cross-section relevant for stellar helium burning, will be investigated.

In order to carry out the scientific program discussed above, a number of different state-of-the-art instruments are being considered. These include: a high-resolution spectrometer of (segmented) large HPGe (clover) detectors, combined with good timing, for example, LaBr3 detectors, a spectrometer with medium resolution of large LaBr3 detectors and a neutron detector array, a tape station and a close-geometry spectrometer for high-resolution decay studies, a 4π charged-particle array of segmented DSSSD detectors and a TPC gas cell for astrophysics reaction measurements.

In addition, a variety of applied research experiments are proposed using low-energy brilliant intense gamma, neutron, and positron beams, which will open new fields in materials science and life sciences. The new production schemes of medical isotopes [15] (e.g., ^{99}Mo currently used in therapies, ^{195m}Pt for nuclear imaging to determine efficiency of chemotherapy, and ^{117m}Sn, an emitter of low-energy Auger electrons for tumor therapy) via (γ, n) processes may also reach socioeconomical relevance. Computerized tomography with gamma-ray beams for non-destructive inspection of objects will also benefit from high-energy quasi-monochromatic and high beam intensity to shorten the scanning time. The gamma beams will also be used to produce pozitrons in a converter foil via the $(\gamma, e^{-}e^{+})$ process. After moderation, the positrons will be used for material science, as probes for defect spectroscopy to depths up to several 100 nm.

Conclusions

The ELI–NP facility combines two major research equipment with beyond state-of-the-art parameters, namely a high power laser system with two amplification arms to deliver 10 PW and intensities on the target in the range of 10^{23} W/cm^2 at least every minute and, a gamma beam system to deliver up to 19 MeV photons with extremely good brilliance and bandwidth. Their outstanding performances will allow the exploration of new frontiers in nuclear physics. Benefiting from the support of a large number of specialists across the globe, the ELI–NP facility is on track with TDR and construction of the experimental areas. Commissioning is expected to take place in 2018.

Acknowledgments

The ELI–NP project is the result of an international collaborative effort of more than 100 scientists from 20 countries and their contribution to the definition and implementation of the project scientific program is gratefully acknowledged. The tremendous work of the ELI–NP scientific team and the essential contribution of my enthusiastic and tenacious colleagues from the Management team in the implementation of the project are also deeply acknowledged.

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IUPAP Young Scientist Prize in Nuclear Physics

This prize was established by IUPAP in 2005 at the time of the General Assembly in Capetown, South Africa. The purpose of this prize, which consists of 1,000€, a medal, and a certificate citing the recipient's contributions, is:

> To recognize and encourage very promising experimental or theoretical research in nuclear physics, including the advancement of a method, a procedure, a technique, or a device that contributes in a significant way to nuclear physics research. Candidates for the prize must have a maximum of eight years of research experience (excluding career interruptions) following the Ph.D. (or equivalent) degree.

Nominations by one or two nominators (and distinct from the nominee) are open to all experimental and theoretical nuclear physicists. The nomination package should contain, other than the nomination letter, at least two additional letters of support, the curriculum vitae of the nominee containing also the list of publications. Three prizes will ordinarily be awarded at the time of the tri-annual International Nuclear Physics Conference.

Nominations are due 1 December 2015 and are valid only until then. The additional letters supporting the nomination should detail the expected significance of the contributions of the nominee to nuclear physics. To underline this, additional material such as published articles can be added to the nomination package. Especially information that allows the selection committee to evaluate the nominee's contribution to and its direct impact on the field.

Nominations for prizes to be awarded at the next International Nuclear Physics Conference, 11–16 September 2016, in Adelaide, Australia, are to be sent by e-mail by 1 December 2015 to the Chair of the IUPAP Commission of Nuclear Physics (C12): Professor Alinka Lépine-Szily, Institut of Physics, University of São Paulo, alinka@if.usp.br, subject "IUPAP prize nomination."

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