Experimental Topics for ELI Nuclear Physics Pillar

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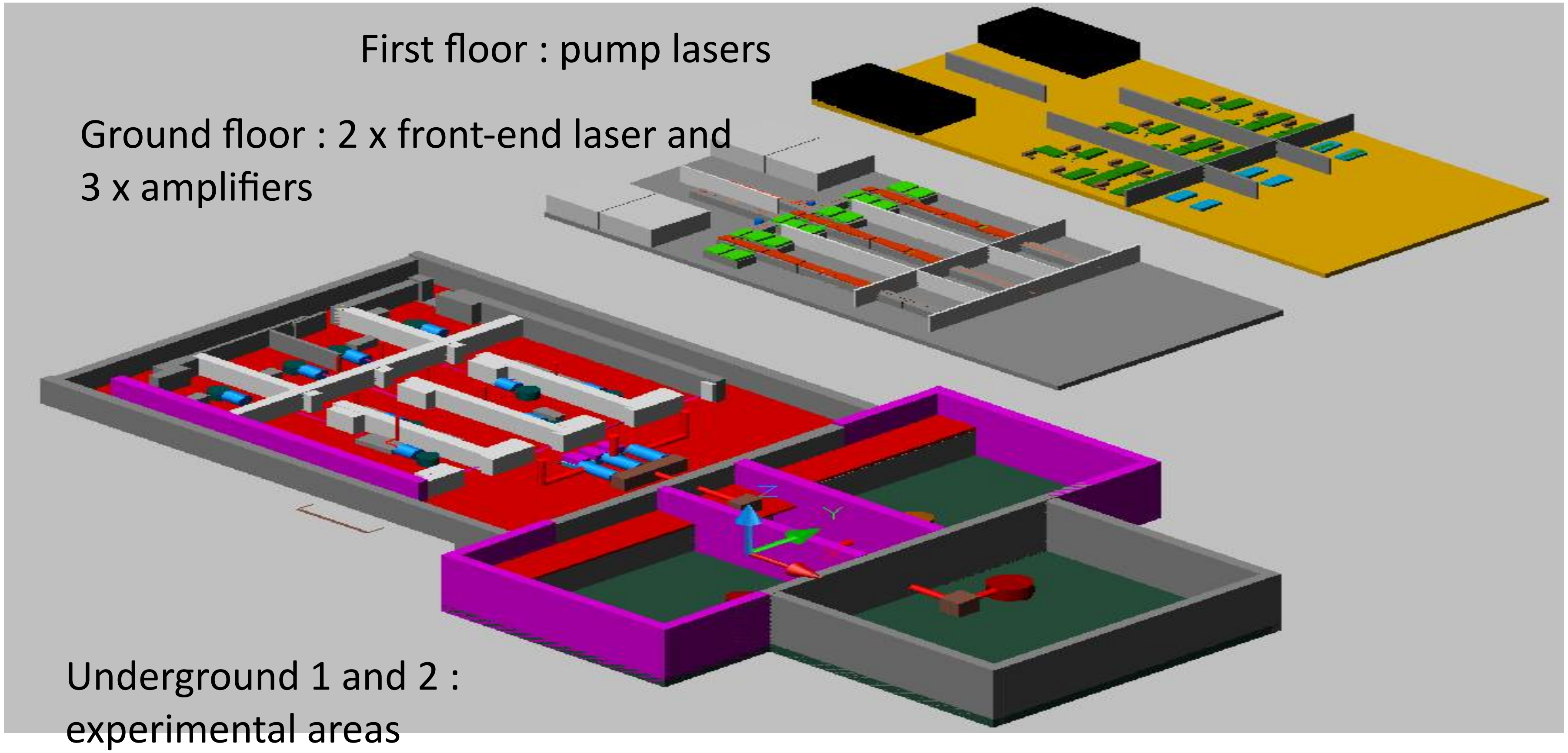
ELI Nuclear Physics : High Intensity Laser System

3 APPOLON 10 PW (150 J/15 fs)
10^{24} W/cm^2



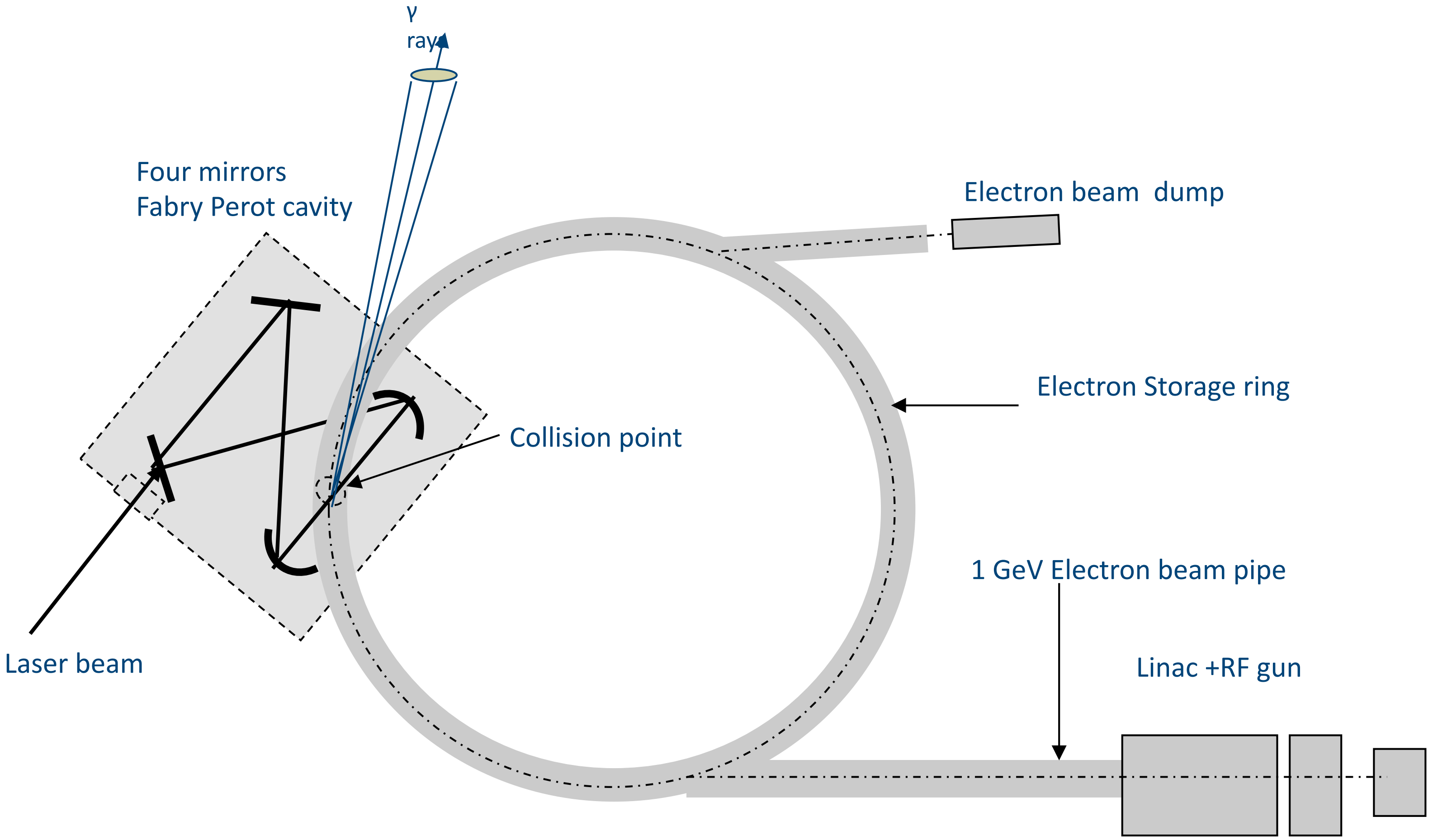
First floor : pump lasers

Ground floor : 2 x front-end laser and
3 x amplifiers

Underground 1 and 2 :
experimental areas

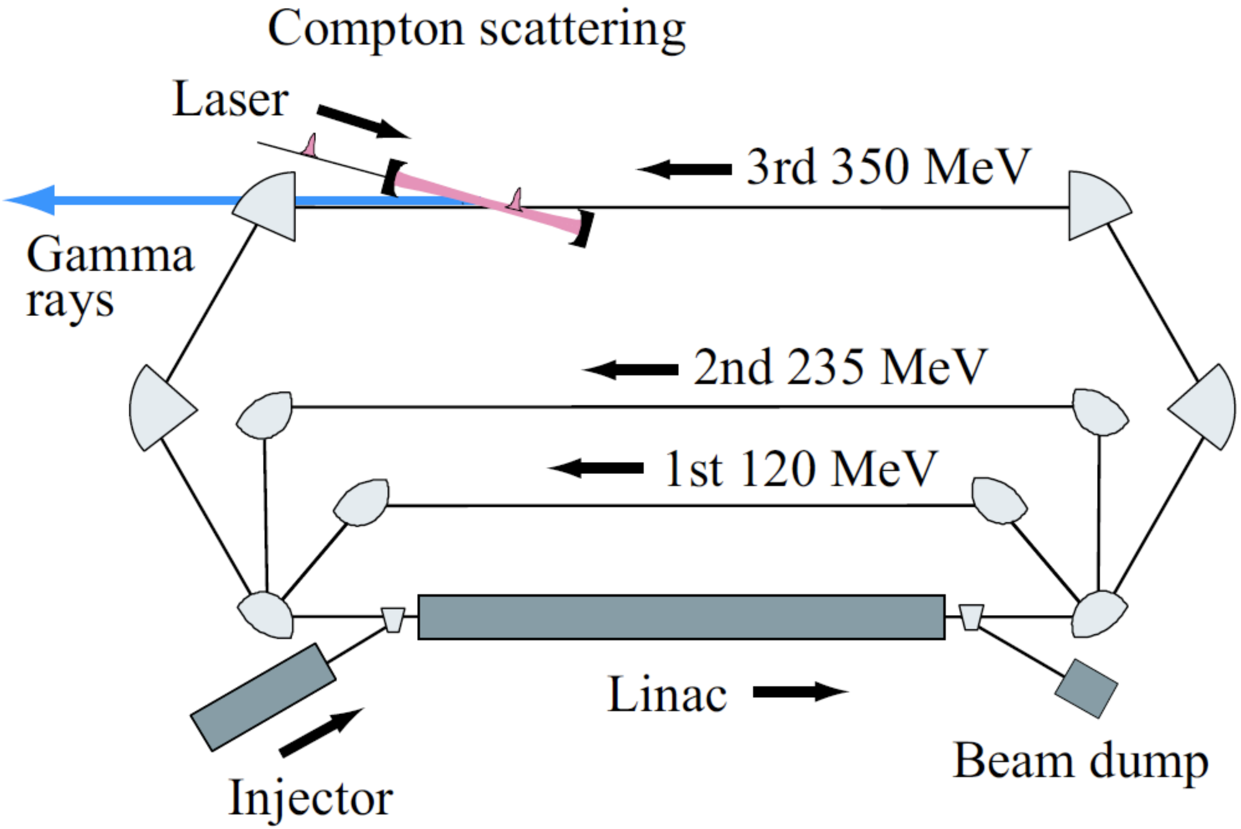
ELI Nuclear Physics – γ source

Option 1: storage ring (high intensity, bandwidth: 1%)



ELI Nuclear Physics – γ source

Option 2: Energy Recovery Linac (lower intensity , bandwidth: >10^{-3} BW)



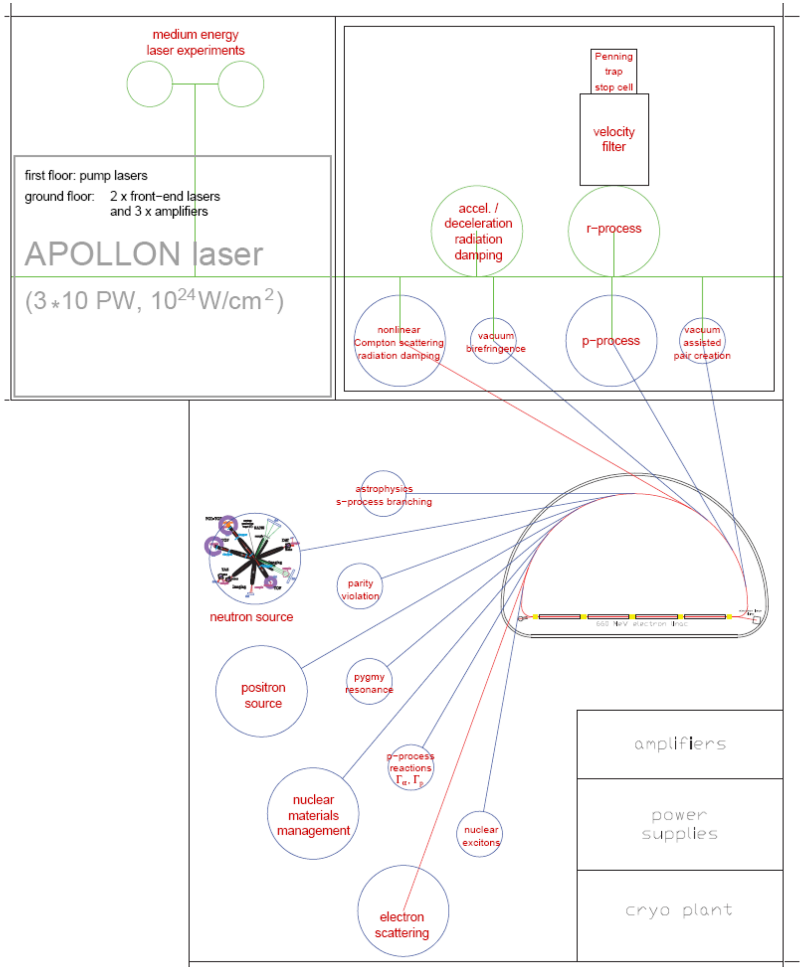
ELI Nuclear Physics Facility

The facility will contain :

- One high-intensity laser system
  - *10-30 PW, ~10^{24} W/cm^2*
  - *0.1-1 Hz repetition rate*

and

- One high-frequency Compton based gamma source
  - ERL or Storage Ring electron beam coupled with high-repetition lasers
  - will produce $10^{13} – 10^{15}$ photons/second



Laser acceleration schemes : TNSA

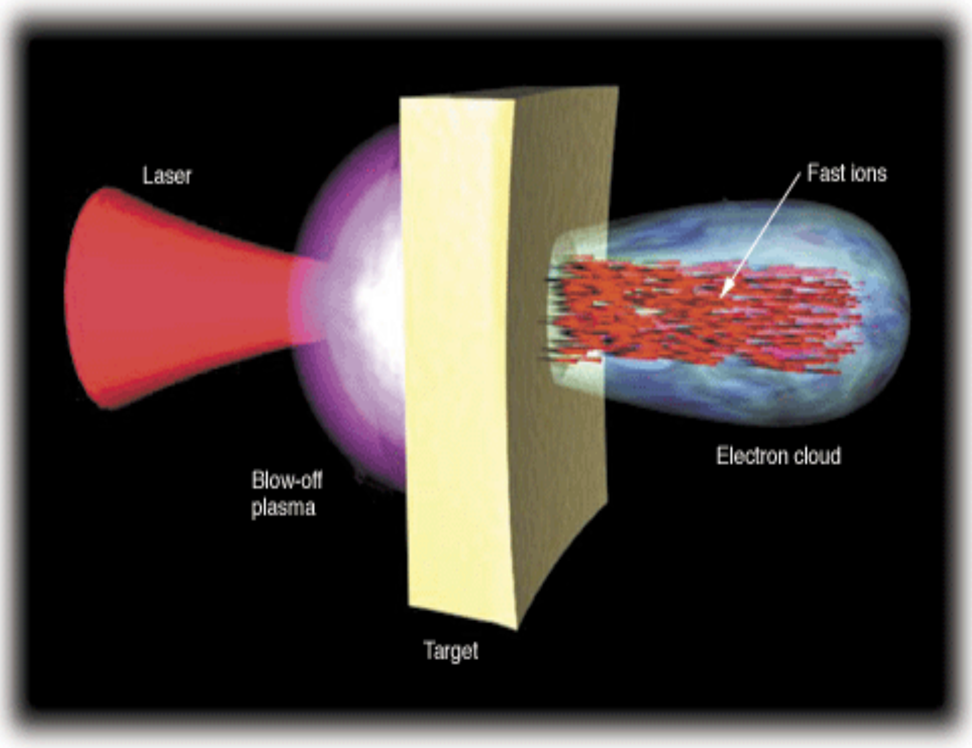
Ion acceleration

TNSA

(target-normal sheath acceleration)

- **Low conversion efficiency**
- **Huge lasers are required**

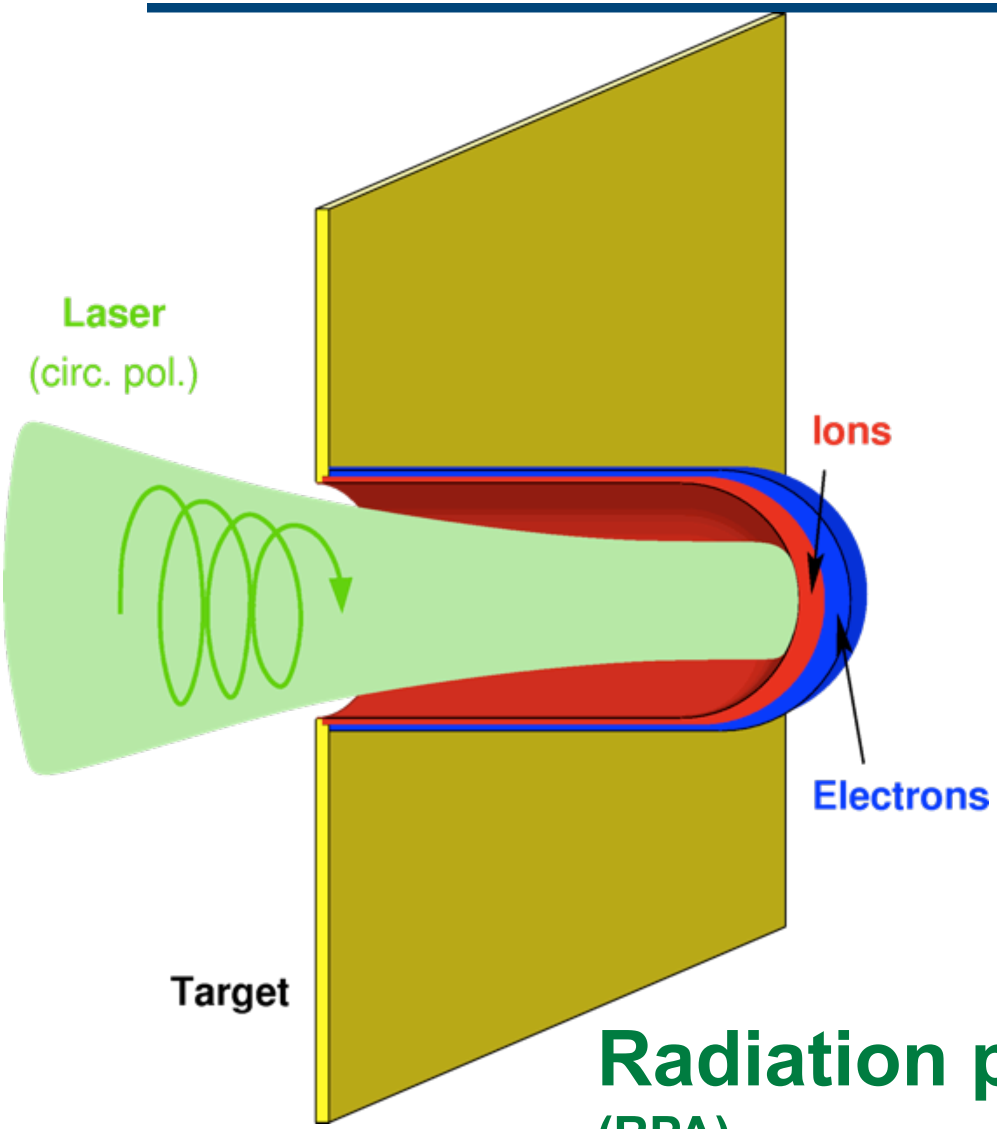
$$E_{\text{ion}} \propto \sqrt{I_{\text{Laser}}}$$



In laboratory experiments, the Petawatt laser's tremendous power produced intense beams of protons, proving the laser to be a powerful ion accelerator.

S.C. Wilks et al., Phys. Plasmas **8**, 542 (2001).

Laser acceleration schemes : RPA



Cold compression of electron sheet.

Rectified dipole field between electrons and ions.

Neutral bunch of ions + electrons accelerated.

Solid-state density: 10^{24} e cm^{-3}

Classical bunches: 10^{8} e cm^{-3}

$$E_{\text{ion}} \propto I_{\text{Laser}}$$

Very efficient!

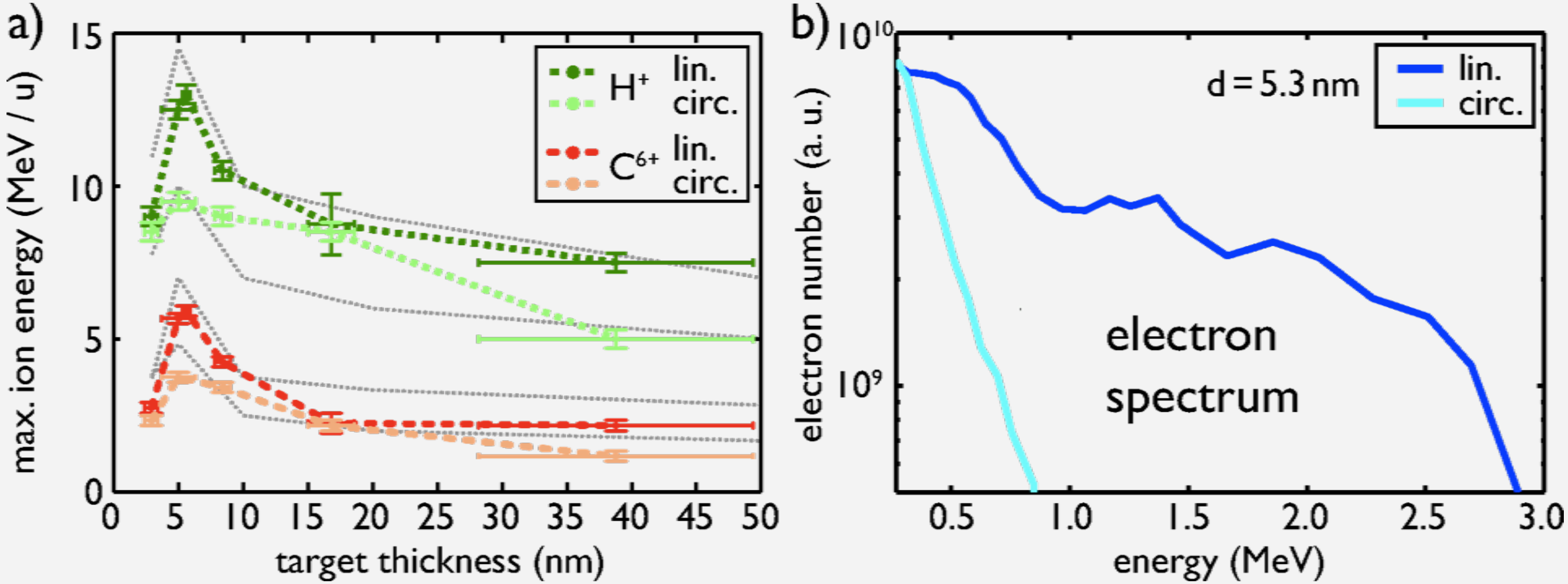
Radiation pressure acceleration

(RPA)

RPA ion accel. + DLC foils (I)

Max-Born Institute (MBI),
Berlin

Laser Power: 15 TW (700 mJ in 45 fs)
Focused Intensity: $a_L = 5$, **Contrast:** $> 10^{11}$



Peak at very low target thickness of 5.6 nm

Cold target for circular polarization

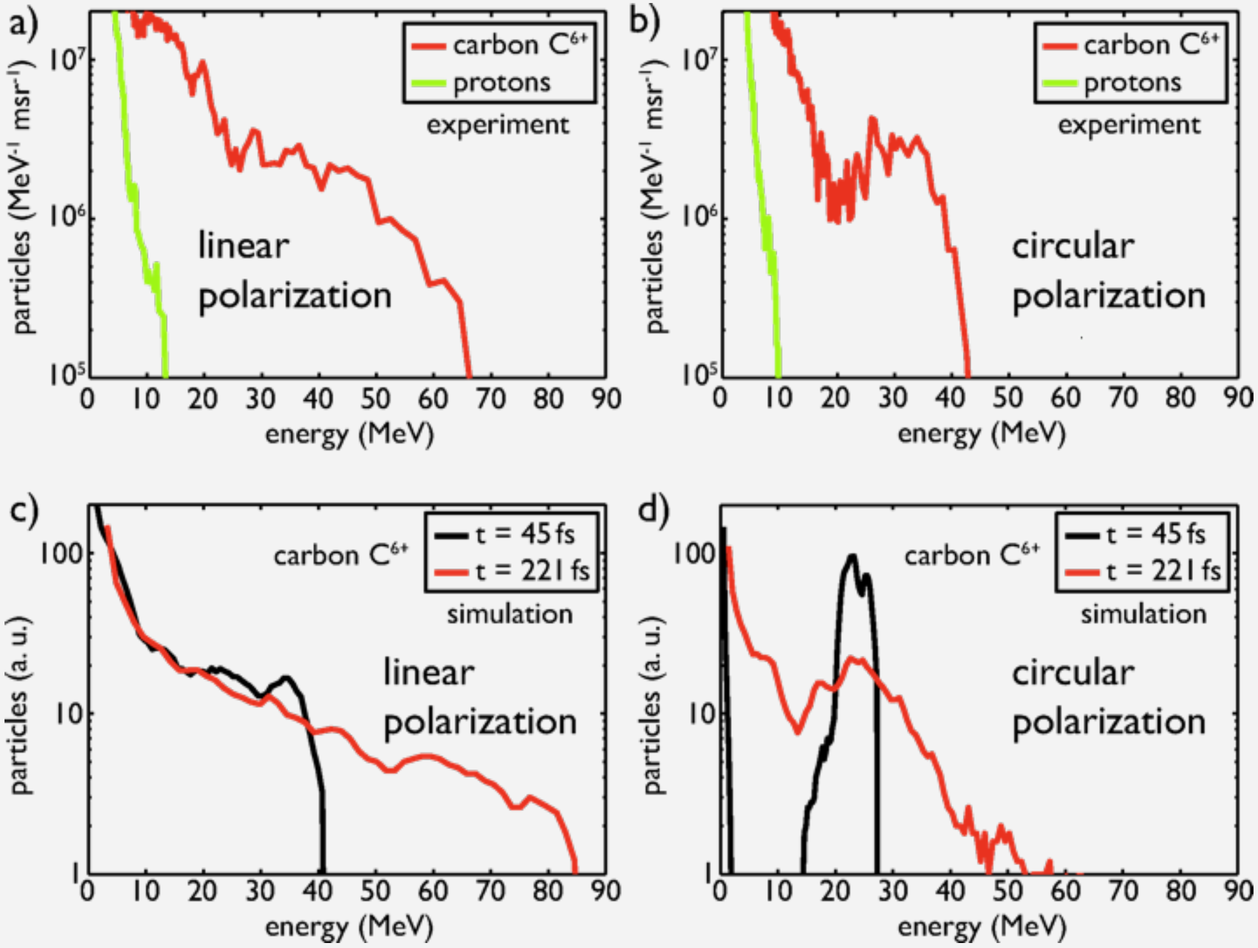
$$a_L \approx \sigma\,, \qquad \sigma = \left(\frac{n_e}{n_c}\right)\cdot\left(\frac{D}{\lambda}\right), \qquad a_L = \sqrt{I_L \cdot \lambda^2}$$

A. Henig et al.,*“Radiation pressure acceleration of ion beams driven by circularly polarized laser pulses”*, Phys. Rev. Lett. **103**, 245009 (2009).

RPA ion accel. + DLC foils (II)

Hot electrons

cold electrons

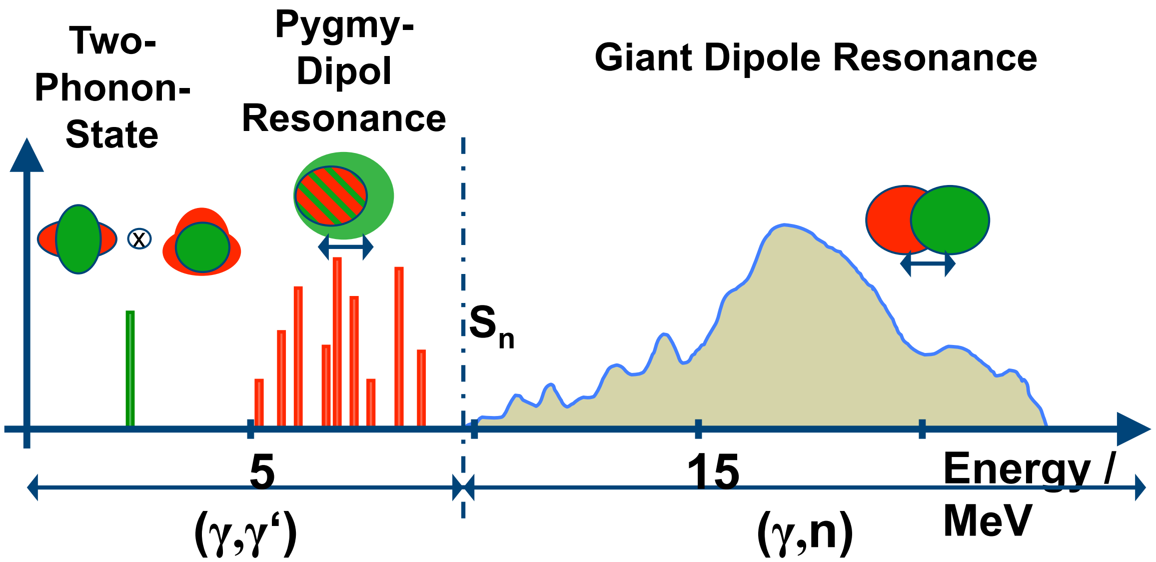


Experiment

Theory

2D PIC simulations

Realm of photonuclear structure physics



- Electric Dipole strength concentrated in GDR above and in PDR below particle separation threshold

- Photonuclear reaction useful tool for investigation of dipole strength

Experiment classes

1. Stand-alone experiments with the 3*10 PW APOLLON lasers
2. Stand-alone experiments with the new gamma beam facility
3. Combined experiments using synergies of the APOLLON system and the gamma-beam facility
4. More visionary future experiments

(1) Experiments with the PW APOLLON lasers

a) **Characterization of the Acceleration mechanism**
(in particular Radiation Pressure Acceleration (RPA) mechanism) with intensities up to 10^{24}W/cm^2.
[scaling with normalized amplitude, production of monoenergetic beams, study of angular distributions, ...]

b) **Study of deceleration properties of very dense, high energy ion bunches**

c) **Nuclear Physics and Astrophysics studies**:
Characterization of the ***novel fission-fusion reaction mechanism*** through laser-ion acceleration of dense ion bunches via the radiation pressure acceleration - ***spectroscopy of very neutron rich isotopes around the N=126 waiting point*** of the astrophysical r process (not possible to be produced at FAIR or SPIRAL2/EURISOL)

d) **pump-probe experiments (streaking and other types)**

e) **Induced Gamma Emission (IGE) and gamma laser**

Experimental issues …

For high-resolution spectroscopy one must use **event-based detection** instead of track detectors

Experimental problems:

- Large radiation flux in a very short amount of time, less than 1 ns, and may **overload the detectors**
- The low repetition rate for the laser pulse **would not allow to accumulate enough statistics**
- Several types of radiations are produced simultaneously (electrons, heavy ions, gamma and X rays) and require **complex detection systems**

Similar problems exist at nuclear physics facilities

… and possible solutions

- High granularity detection systems (arrays)
  - More difficult to overload since every individual element cover a small solid angle
  - The statistics accumulates faster because many detectors give signal after one laser shot
- Reduction of dead time
  - Digital electronics
  - “Trigger-less” data acquisition, keeping the detection system continuously active
- Separate different types of radiations before detection
  - Beam transportation

(2) Experiments with the gamma beam facility (part 1)

a) Astrophysics Studies: Study the Pygmy dipole resonance via NRF for s-process waiting point nuclei

b) Pygmy resonance studies for the transition to deformed nuclei

c) Spectroscopy of M1+E1 transitions in the Fe-Ni region [seeding nuclei in nucleosynthesis]

d) Measure (γ,n) and (γ , γ) for Sn nuclei [compare to Coulex measurements]

e) Parity violation experiments

f) Photofission studies

g) High intensity pulsed micro-neutron source [proposal available including many application]

h) Self-absorption measurement with notch detectors (using NRF)

i) applications in radioactive waste management [study 235U, 239 Pu]

j) measurements of (γ,α) and (γ,p) above the separation energy [special detectors like time-projection chambers have to be developed]

(2) Experiments with the gamma beam facility (part 2)

k) Cross section at reaction threshold for nuclear astrophysics

l) Intense brilliant positron source [proposal available including many application]

m) (e,e’) and (e,e’g) spectroscopy

n) Nuclear excitons

o) Gamma tomography

p) Production of Mo-99 (used in medical applications)

(3) Combined experiments: APOLLON system and the gamma-beam facility

a) **Measurement of magnetic moments of excited nuclear states** by measuring the change in width with the gamma beam, when applying the high magnetic field of the APOLLON lasers of $3*10^{7}$ T.
[requirement: keep the nuclei sufficiently cold, though the APPOLON lasers have electric fields $E=10^{16}$ V/m]

b) **Pygmy resonance studies for radioactive nuclei**
e.q. proton rich p-process nuclei produced with APOLLON in very dense small spot and probe these nuclei with the intense brilliant gamma beam

c) **Vacuum pair creation at 10^{24} W/cm^{2} with g catalysis**

d) **Vacuum birefringence at 10^{24} W/cm^{2} with g probe and NRF detection**

e) **Damping of high energy electrons in 10^{24} W/cm^{2}**

(4) More visionary future experiments

a) collision of 500 MeV electron bunches with the 10^{24} W/cm^2 APPOLON laser bunches.

[with the Lorentz-factor =1000 we reach in the inner rest frame of the electron bunch 10^{30} W/cm^2 which is beyond the Schwinger limit]

b) 10 GeV/u heavy ion collider with solid state density

c) Production of ultrashort multi-MeV photon pulses (10^{-16} - 10^{-21} s) via Thomson backscattering off laser-accelerated electron bunches

Study the time dependence of compound nuclear resonances in order to test random matrix theory in nuclei around the neutron threshold. [measure dipole absorption cross section and/or use streaking technique to probe ultrashort time range, for this we need ultra-short electron bunches?]

Working groups for ELI Nuclear Physics

- Laser
- Gamma source
- Experiments
- Civil Engineering

The short-term objectives are :

- Define the facility
- Define the experimental highlights, and writing of *“ELI Nuclear Physics White Book”*
- Prepare the funding application