ELI - Nuclear Physics

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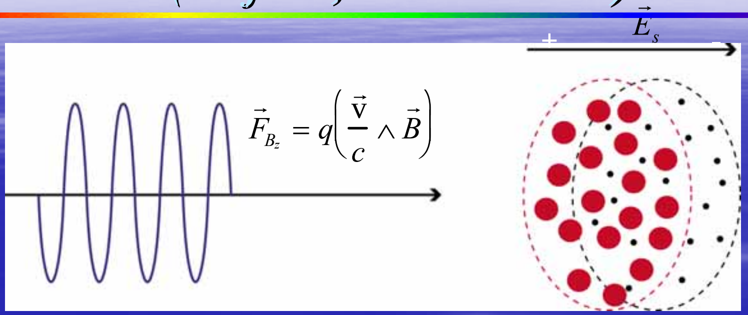
Wake-Field acceleration
(Tajima, Dawson 1979)



$$\vec{F}_{B_z} = q\left(\frac{\vec{\mathrm{v}}}{c} \wedge \vec{B}\right)$$

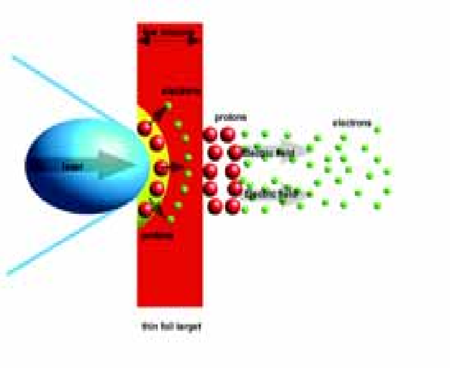
1) $\vec{\mathrm{v}} \wedge \vec{B}$ pushes the electrons.

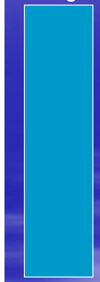
2) The charge separation generates an electrostatic longitudinal field. (Tajima and Dawson: Wake Fields or Snow Plough)

$$E_s = \frac{c\gamma m_o \omega_p}{e} = \sqrt{4\pi\gamma m_o c^2 n_e}$$

3) The electrostatic field $E_s \approx E_L$

Target Normal Sheath Acceleration (TNSA)





Secondary target

Secondary radiations
- electrons bremssstrahlung
- gamma rays, neutrons

Primary radiations

Electrons are expelled from the target due to the ponderomotive force

Heavy ions are accelerated in the field created by the electrons

$E \sim I_{laser}^{1/2}$

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

Electrons

Laser intensity **~ 10^{19} W/cm^2**

- Collimated beams were obtained, even of the size of the incident laser beam
- The energies up to hundreds of MeV at ~ 1PW lasers (VULCAN, etc.)
- Intensities may go up to 10^{12} particles/laser pulse

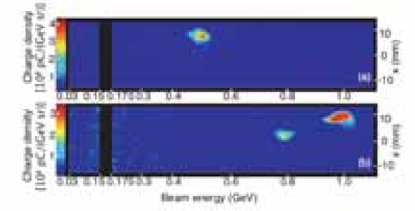


FIG. 43. (Color) Single-shot electron bunch spectra of the capillary-guided LWFA (Leemans, Nagler, et al., 2006; Nakamura et al., 2007). Examples are shown of bunches at (a) $0.50^{+0.02}_{-0.015}$ GeV (5.6% rms energy spread, 2.0 mrad divergence rms, ~50 pC charge) and (b) $1.0^{+0.06}_{-0.05}$ GeV (2.5% rms energy spread, 1.6 mrad divergence rms, ~30 pC). The 0.5 GeV (1.0 GeV) bunch was obtained in a 225 (310) μm capillary with a density of 3.5×10^{18} (4.3×10^{18}) cm^{-3} and input laser power of 12 TW (40 TW). The black stripe denotes the energy range not measured by the spectrometer. In (b) a second bunch at 0.8 GeV is also visible.

Esarey, Schroeder, and Leemans

Rev. Mod. Phys., Vol. 81, No. 3, 2009

Protons, Heavy Ions

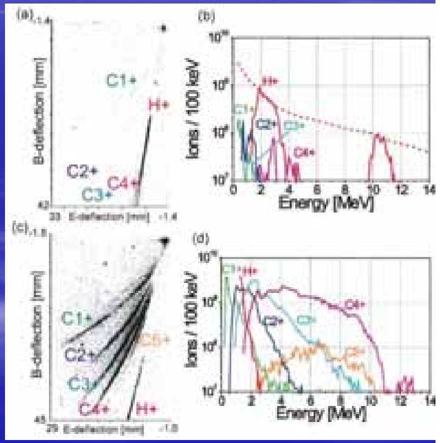
Heavy ion beams at LULI (France)

Laser pulses:
30 J, 300 fs, 1.05 *μm* => 5x10^{19} W/cm^2.

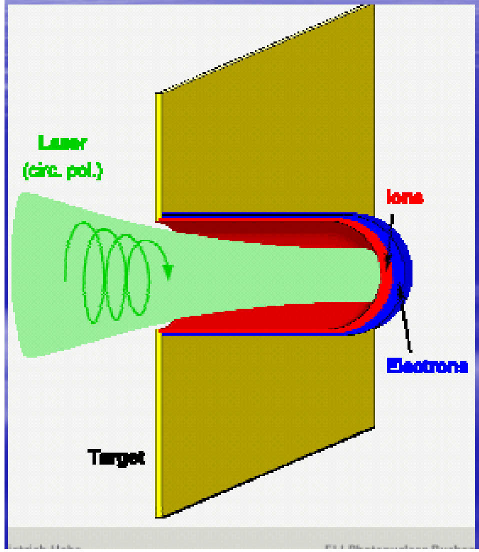
Target: 1 μm C
on rear side of 50 μm W foils

Detection: Thomson parabola spectrometers
+ CR-39 track detectors

- Protons come from surface contamination
- Heating the target the protons are removed and heavy ions are better accelerated



Radiation Pressure Acceleration RPA



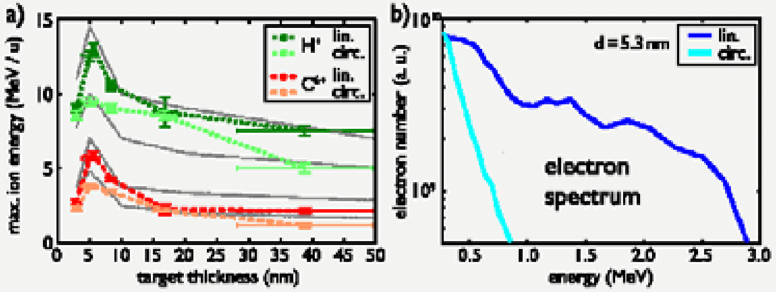
Electrons and ions accelerated
at solid state densities 10^{24}e cm^{-3}
(Classical beam densities 10^8e cm^{-3})

$E \sim I_{laser}$

RPA DLC foils

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).

Bucharest-Magurele National Physics Institutes

NUCLEAR
Tandem acc.
Cyclotron
γ – Irradiator
Adv. Detectors
Life & Env.
Radioisotopes

Lasers
Plasma
Optoelectronics
Material Physics
Theoretical Physics
Particle Physics

ELI-NP Scientific Case

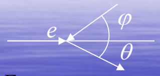
February – April 2010,
"White Book" (100 scientists, 30 institutions) (www.eli-np.ro)
editors: D. Habs et al.

August 2010 Feasibility Study 280 Meuro w/o VAT

"Extreme Light" :

- *two 10 PW APOLLON-type lasers*
- *the most brilliant γ beam, up to 20 MeV, BW:10-3 produced by Compton scattering on a 700 MeV electron beam*

ELI-NP Gamma Beam production



$$E_\gamma = n \cdot 2\gamma_e^2 \cdot \frac{1+\cos\varphi}{1+(\gamma_e\theta)^2 + a_0^2 + \frac{4\gamma_e E_0}{mc^2}} \cdot E_0$$

$$n = \text{harmonic number}; \quad \frac{4\gamma_e E_0}{mc^2} = \text{recoil parameter}; \quad a_0 = \frac{eE}{m\omega_0}; \quad E_0 = \hbar\omega_0$$

Compton backscattering is the most efficient « frequency amplifier »

$\omega_{diff} = 4\gamma_e^2 \omega_{laser}$

E_e=300 MeV <=> γ_e~ 600 => E_γ > 1 MeV with optical laser

but very weak cross section: 6.6524 10^{-25} cm^2

Therefore for a powerful light source, one needs
- -lots of electrons
- -lots of photons
- -very small collision volume
- -very high repetition frequency

ELI-NP γ beam

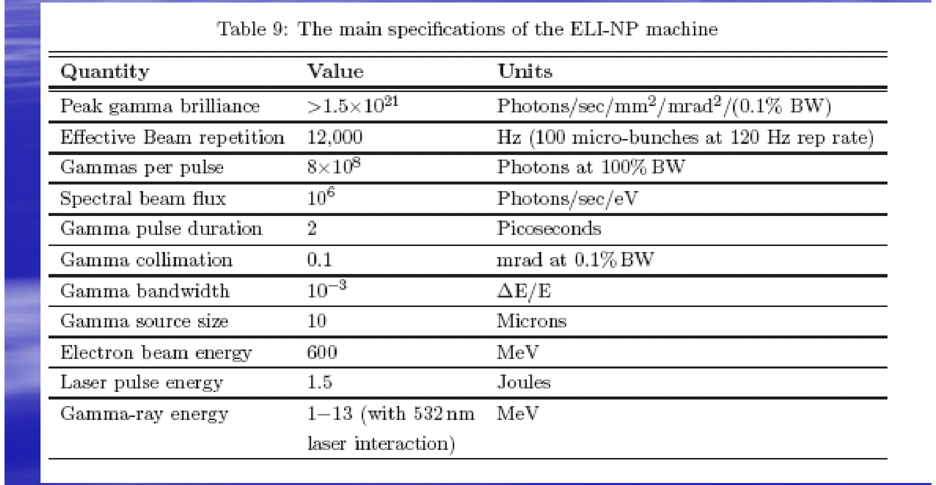
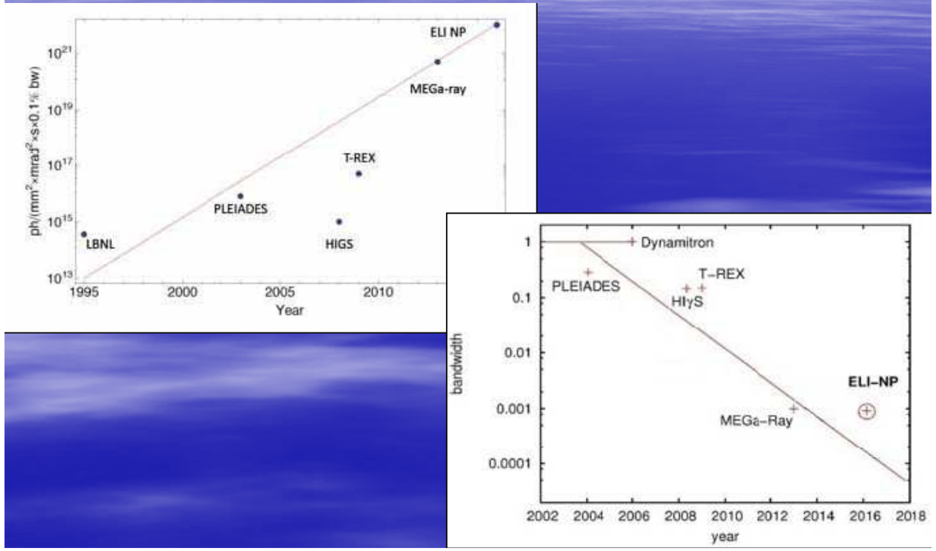


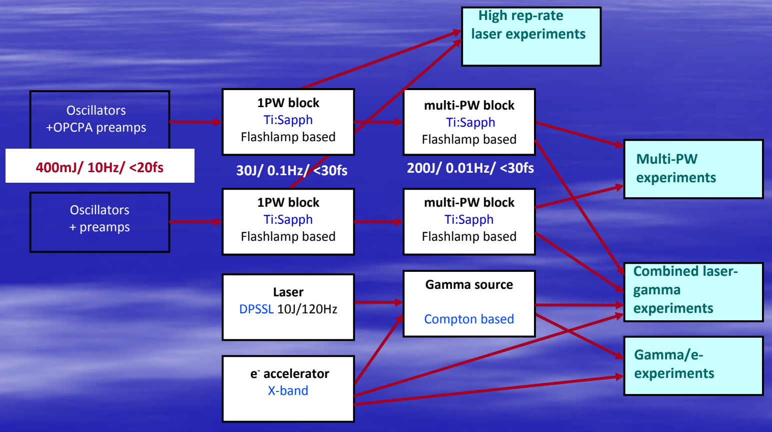
Table 9: The main specifications of the ELI-NP machine

Quantity	Value	Units
Peak gamma brilliance	$>1.5\times10^{21}$	Photons/sec/mm^2/mrad^2/(0.1% BW)
Effective Beam repetition	12,000	Hz (100 micro-bunches at 120 Hz rep rate)
Gammas per pulse	8×10^8	Photons at 100% BW
Spectral beam flux	10^6	Photons/sec/eV
Gamma pulse duration	2	Picoseconds
Gamma collimation	0.1	mrad at 0.1% BW
Gamma bandwidth	10^{-3}	ΔE/E
Gamma source size	10	Microns
Electron beam energy	600	MeV
Laser pulse energy	1.5	Joules
Gamma-ray energy	1–13 (with 532 nm laser interaction)	MeV

ELI-NP γ beam



ELI-NP Facility Concept



Oscillators
+OPCPA preamps

400mJ/ 10Hz/ <20fs

Oscillators
+ preamps

1PW block
Ti:Sapph
Flashlamp based

30J/ 0.1Hz/ <30fs

1PW block
Ti:Sapph
Flashlamp based

Laser
DPSSL 10J/120Hz

e⁻ accelerator
X-band

multi-PW block
Ti:Sapph
Flashlamp based

200J/ 0.01Hz/ <30fs

multi-PW block
Ti:Sapph
Flashlamp based

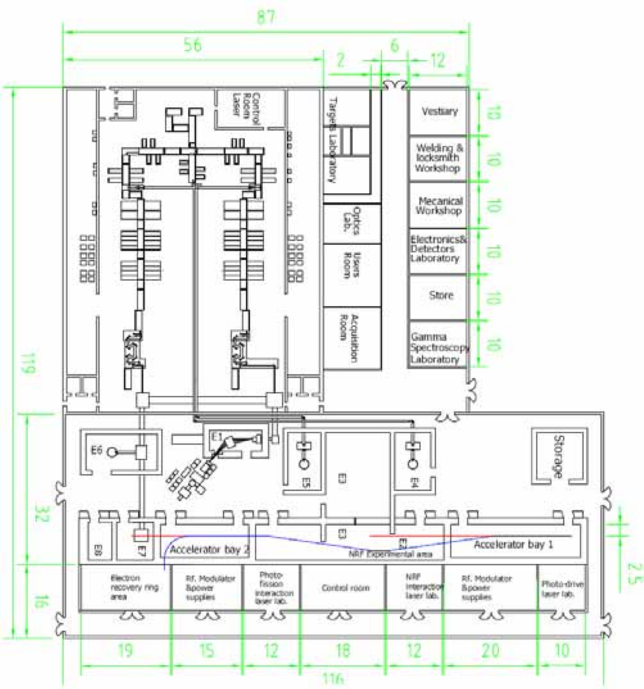
Gamma source
Compton based

High rep-rate laser experiments

Multi-PW experiments

Combined laser-gamma experiments

Gamma/e- experiments



ELI – Nuclear Physics Research

- *Nuclear Physics experiments to characterize laser – target int.*
- *Photonuclear reactions.*
- *Exotic Nuclear Physics and astrophysics complementary to other NP large facilities (FAIR, SPIRAL2).*
- *Applications based on high intensity laser and very brilliant γ beams. Complementary to the other pillars*

ELI-RO Nuclear Physics

*in '**Nuclear Physics Long Range Plan in Europe**' as a major facility*

Nuclear Resonance Fluorescence Applications

- Management of Sensitive Nuclear Materials and Radioactive waste
  - isotope-specific identification 238U/235U , ^{239}Pu,
  - scan containers for nuclear material and explosives

- Burn-up of nuclear fuel rods
  - fuel elements are frequently changed in position to obtain a homogeneous burn-up
  - measuring the final ^{235}U, ^{238}U content may allow to use fuel elements 20% longer
  - more nuclear energy without additional radioactive waste

- Medical applications– new radioisotopes and radiopharmaceuticals

  Producing of medical radioisotopes via the (γ, n) reactions

  ex. 100Mo(g, n) 99Mo

- \- Extremely BRIlliant Neutron-Source produced via the (γ ,n) Reaction without Moderation

ELI-NP Next Steps

- *December 2011: Submission of the Application to DG-Regio*
- *December 2011: Technical Design*
- *June 2012: Tender Procedures*
- *September 2012- September 2014 Civil Construction*
- *July 2015 : Lasers and Gamma Beam – Phase 1*
- *December 2016 : Lasers and Gamma beam Phase 2*

www.eli-np.ro

Thank You !