



Project co-financed by the European Regional Development Fund
Sectoral Operational Programme
„Increase of Economic Competitiveness”
“Investments for Your Future”

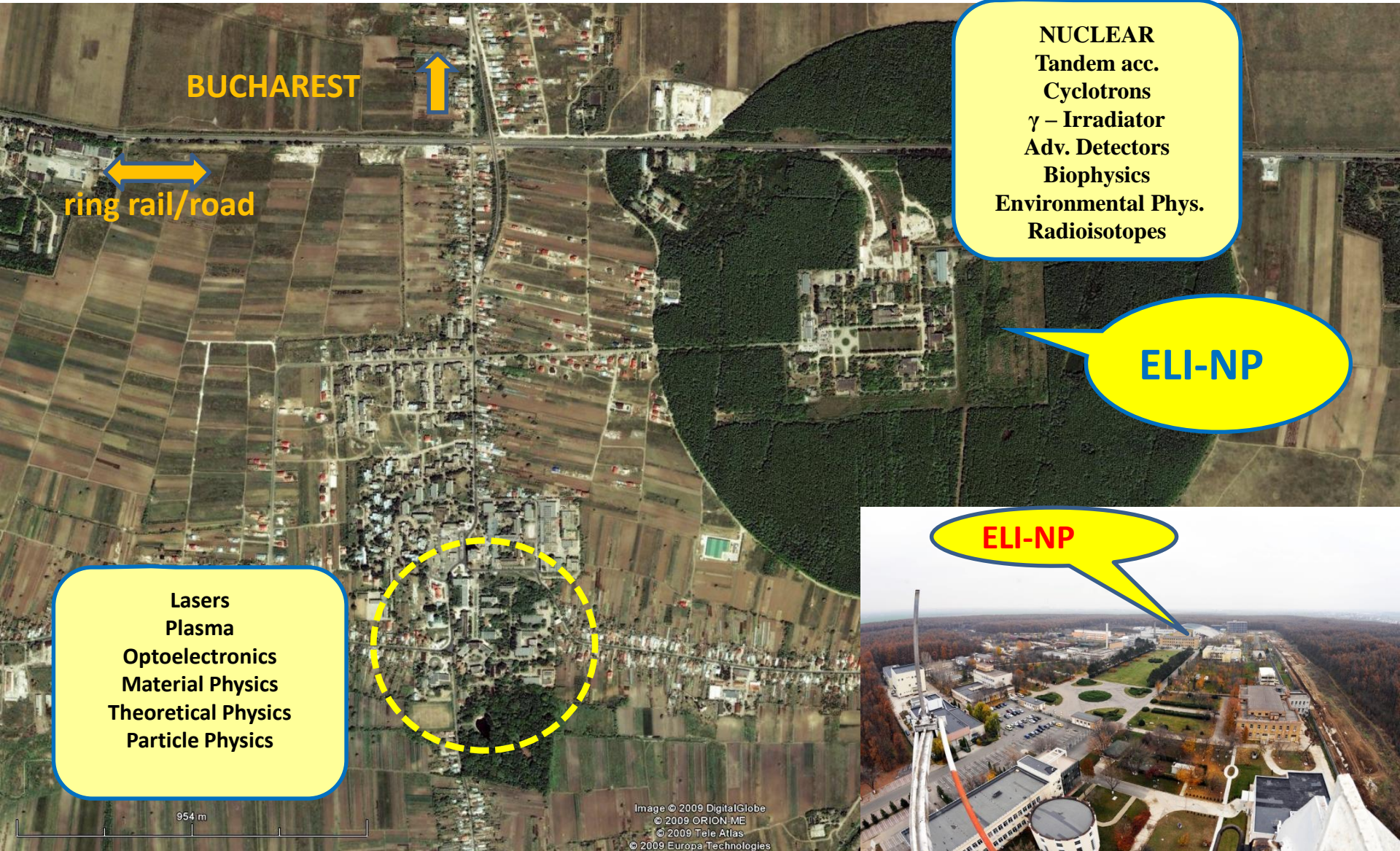
Extreme Light Infrastructure – Nuclear Physics ***(ELI-NP)***



ISOLDE Workshop 2015, CERN



Bucharest-Magurele National Physics Institutes



BUCHAREST

ring rail/road

NUCLEAR
Tandem acc.
Cyclotrons
 γ - Irradiator
Adv. Detectors
Biophysics
Environmental Phys.
Radioisotopes

ELI-NP

**Lasers
Plasma
Optoelectronics
Material Physics
Theoretical Physics
Particle Physics**

ELI-NP

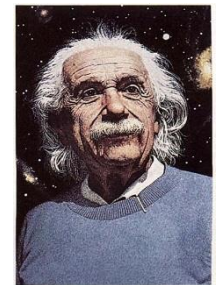
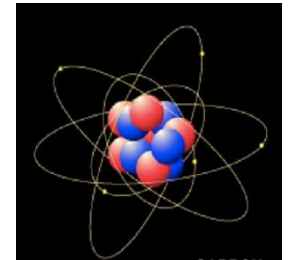
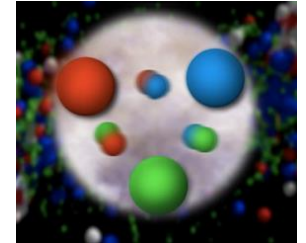
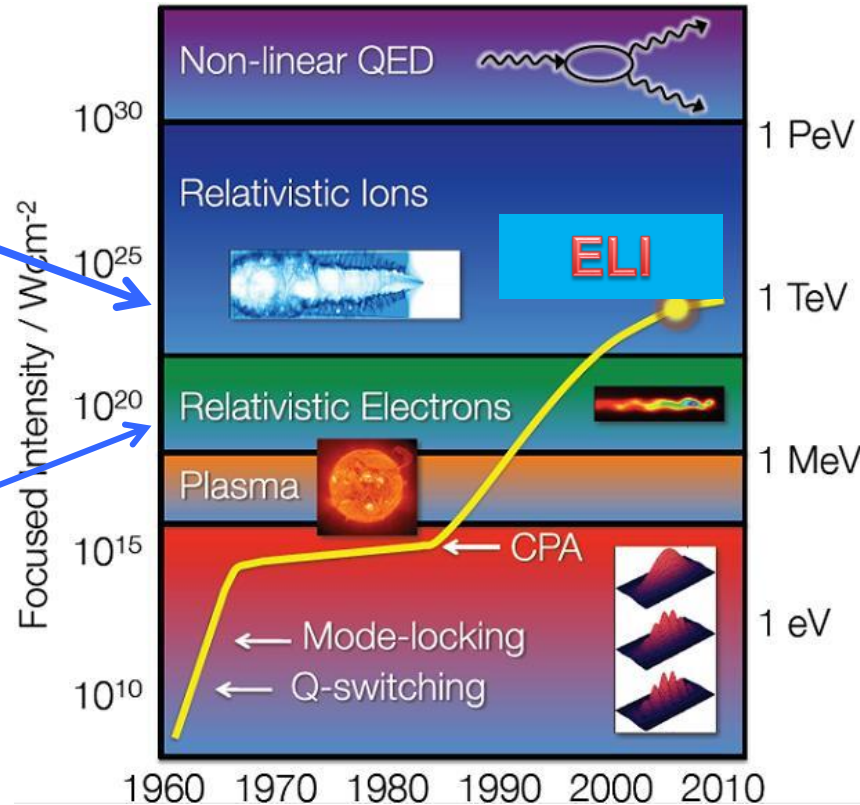
954 m

Image © 2009 DigitalGlobe
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Extreme Light Infrastructure (ELI)

$10^{24} \text{W} \sim 10\%$ of Sun's total power on 1 cm^2

$1 \text{ PW} \sim$ Highest Power today



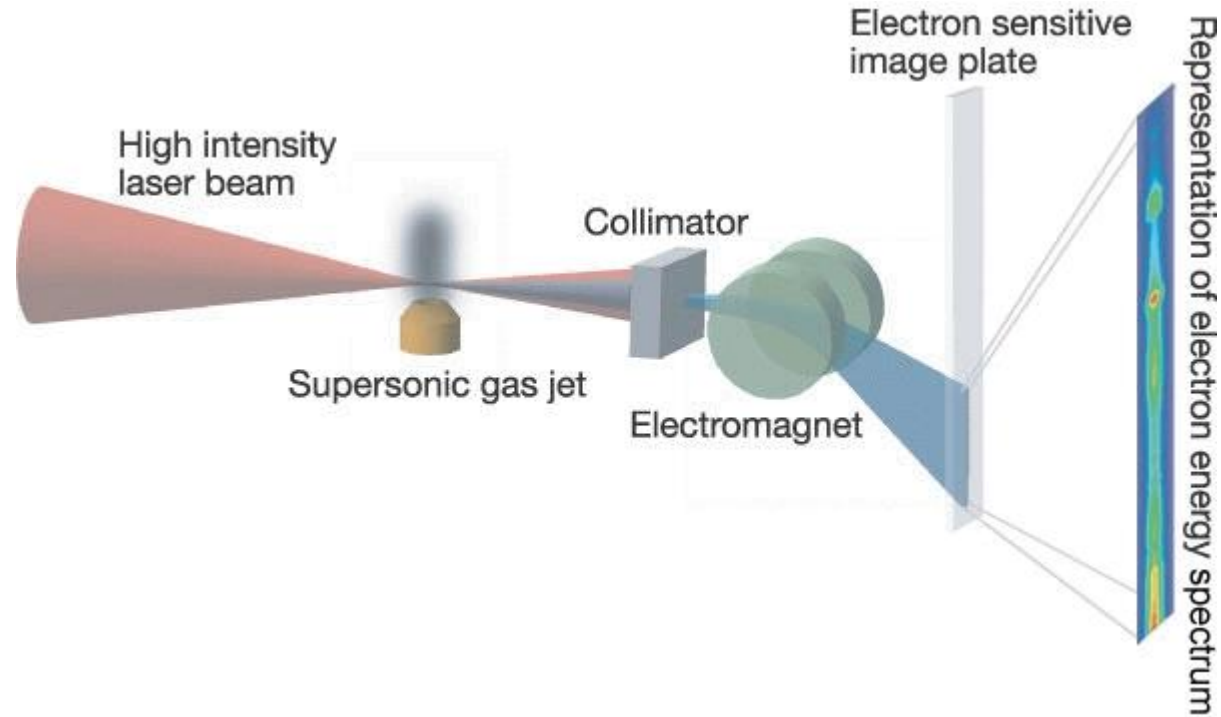
Laser-Acceleration of Electrons

Pioneering work:



Nature 431 (Sept. 2004):
3 groups report on laser acceleration of (low-emittance) electron beams with (quasi-monochromatic) 70-200 MeV

typical setup for electron laser acceleration studies:

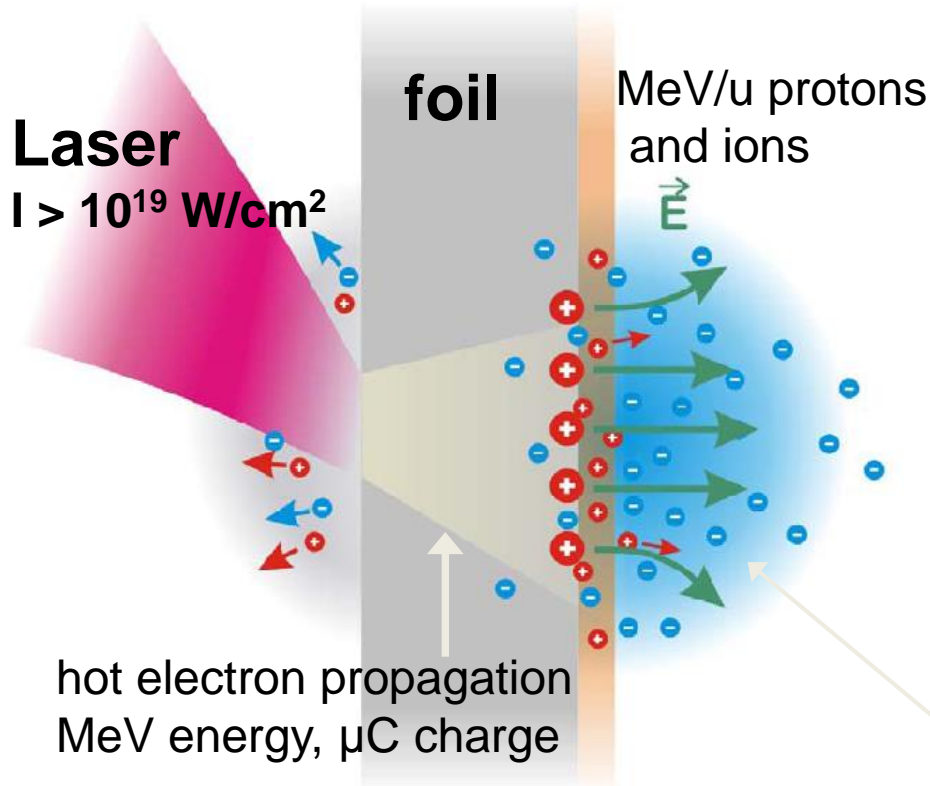


rapidly expanding field :
since 2000 : >150 x PRL
> 10 x Nature

Today ~3 GeV electrons

Laser-Ion Acceleration

Target Normal Sheath Acceleration (TNSA)



- electron acceleration
- hot (MeV) electrons penetrate the (μm) foil
- quasi-static field forms normal to target surface

- use thick (metallic) foil targets ($\sim\mu\text{m}$)

proton source: CH contamination on foil surfaces (typically $\sim 50\text{\AA}$)
ion source: foil bulk material

- space charge field:

$$E \sim T_{\text{hot}} / \lambda_{\text{Debye}} \sim \text{MeV}/\mu\text{m} = 10^{12} \text{ V/m}$$

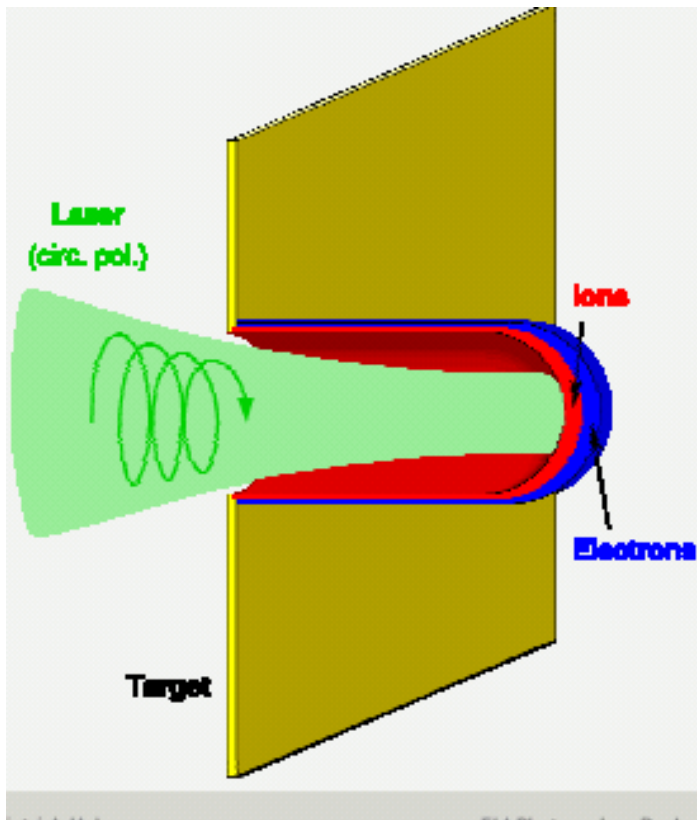
- conversion efficiency:
(from laser to ions)

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

Laser-Ion Acceleration

Radiation Pressure Acceleration RPA

- thin targets (~ nm thick diamond-like carbon foils)



Electrons and ions accelerated

at solid state densities 10^{24}e cm^{-3} **never reached before**

(Classical beam densities 10^8e cm^{-3})
on very short distance (μm -mm)

$$E \sim I_{\text{laser}}$$

Energy reached equal to a 400m up-to-date accelerator (reduction of scale of 10^9)

ELI-NP Project

300 M € 2013-2018

Large equipment:

- High power laser system, 2 x 10PW maximum power (2013-2018)

Thales Optronique SA and SC Thales System Romania (~65 M€)

- High intensity gamma beam system (2014-2018)

European Consortium EuroGammaS led by INFN Rome (~65 M€):

INFN (Italy), University “La Sapienza” Rome (Italy), CNRS (France), ALSYOM (France), ACP Systems S.A.S.U. (France), COMEB Srl (Italy), ScandiNova Systems (Sweden)

Subcontractors: MENLO SYSTEMS GmbH, RI Research Instruments GmbH(Germany), DANFYSIK (Denmark), STFC(UK), Instrumentation Technology, Cosylab D.D. (Slovenia), M+W SrL (Italy), CELLS(Portugal), Amplitude Technologies (France)

Experiments:

8 experimental areas, for gamma, laser, and gamma+laser

Buildings (2013-2015) : 33000sqm total – *STRABAG (~65M€)*

ELI-NP High Power Laser System

THALES – France

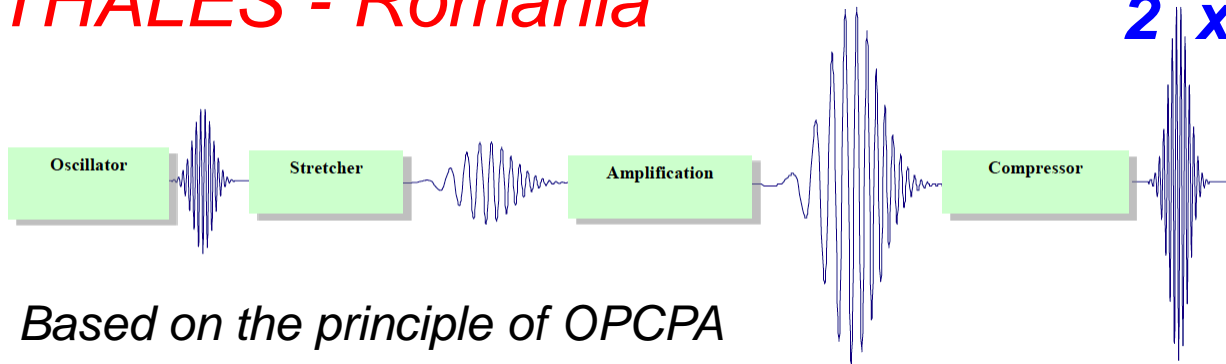
2013-2018

2 x 0.1 PW 10Hz

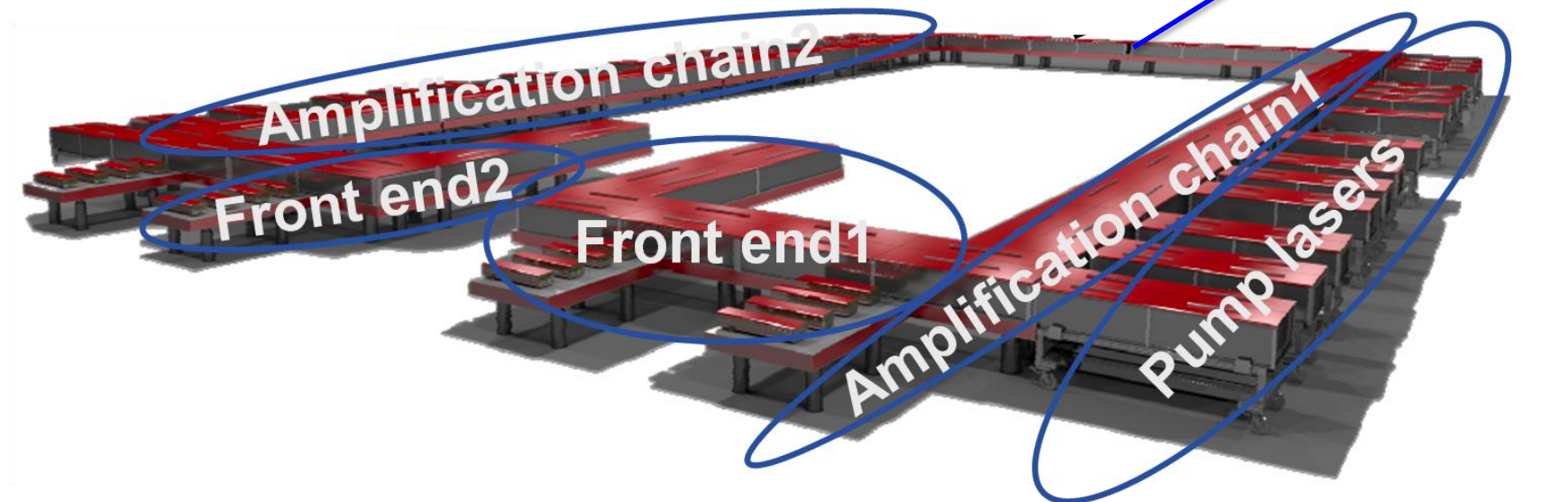
THALES - Romania

2 x 1 PW 1 Hz

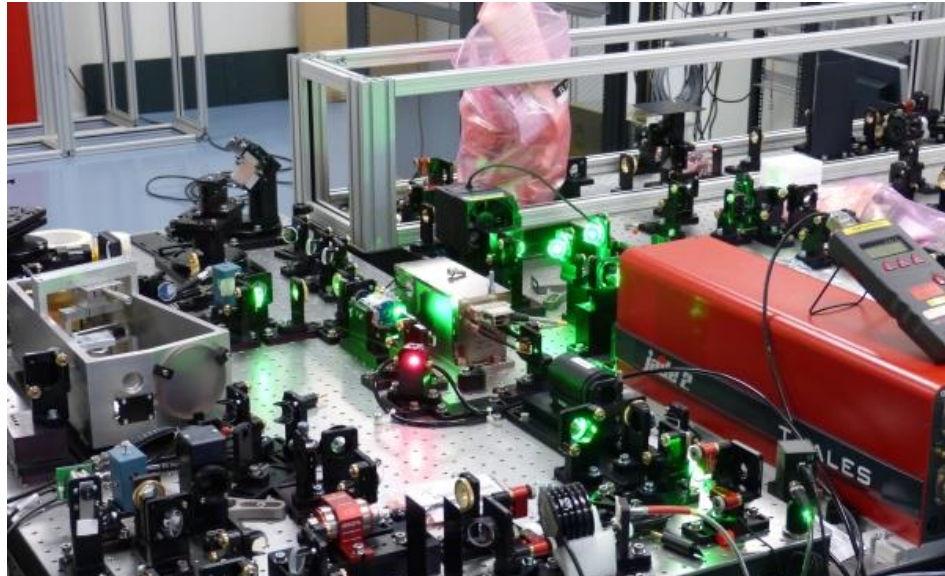
2 x 10 PW 0.1 Hz



Based on the principle of OPCPA

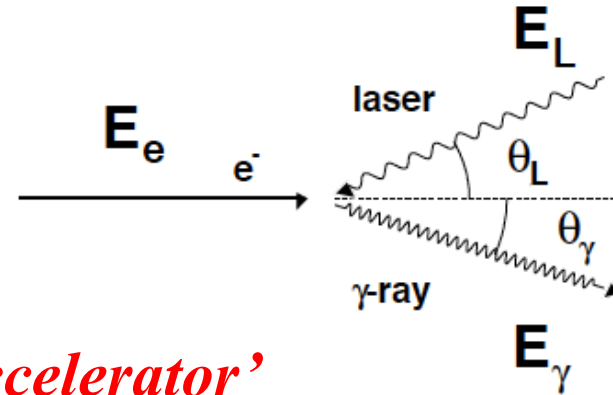


High Power Laser System



ELI-NP Gamma beam production

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



Compton backscattering: ***‘Photon accelerator’***

$$E_\gamma = 4\gamma_e^2 E_L$$

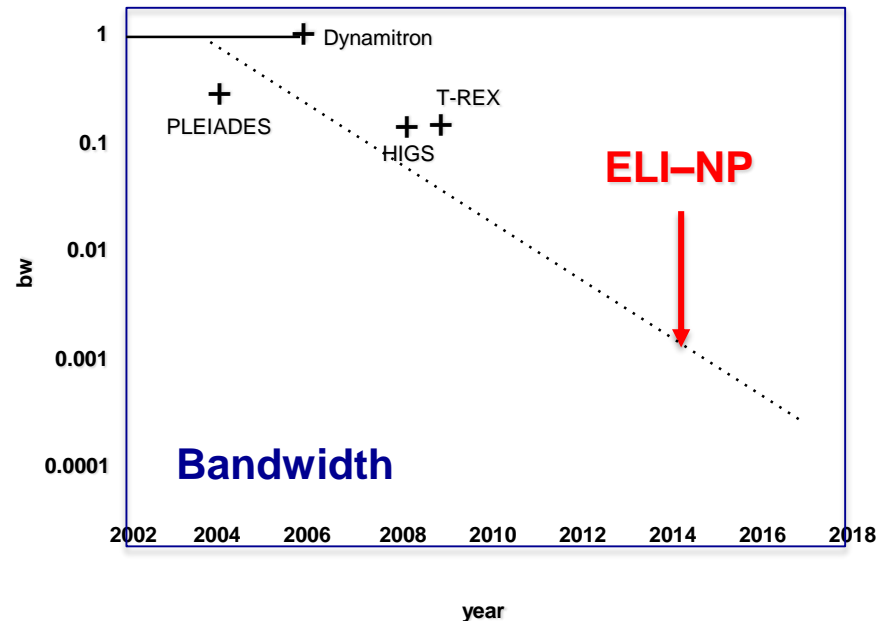
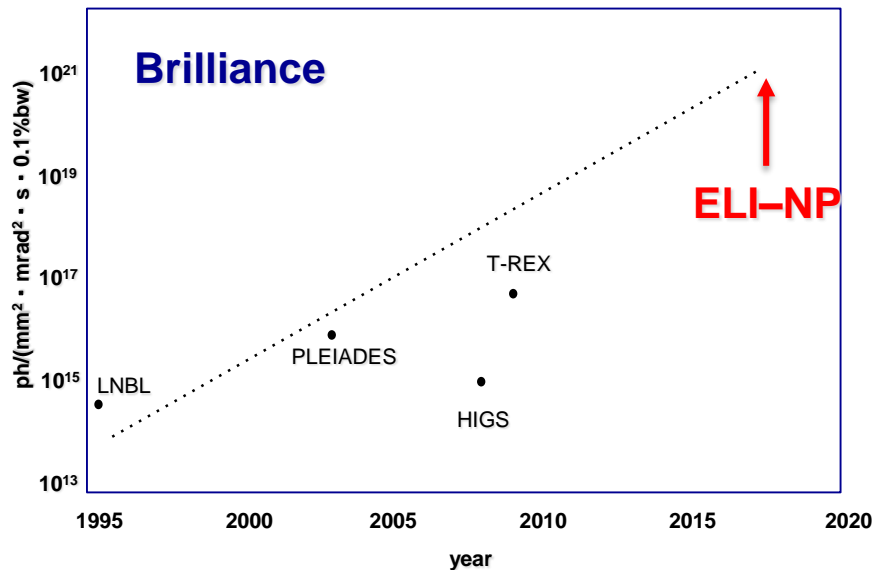
$$E_e = 720 \text{ MeV} \Rightarrow \gamma_e \sim 700 \Rightarrow E_\gamma \sim 20 \text{ MeV}$$

but very weak cross section: $6.6 \cdot 10^{-25} \text{ cm}^2$

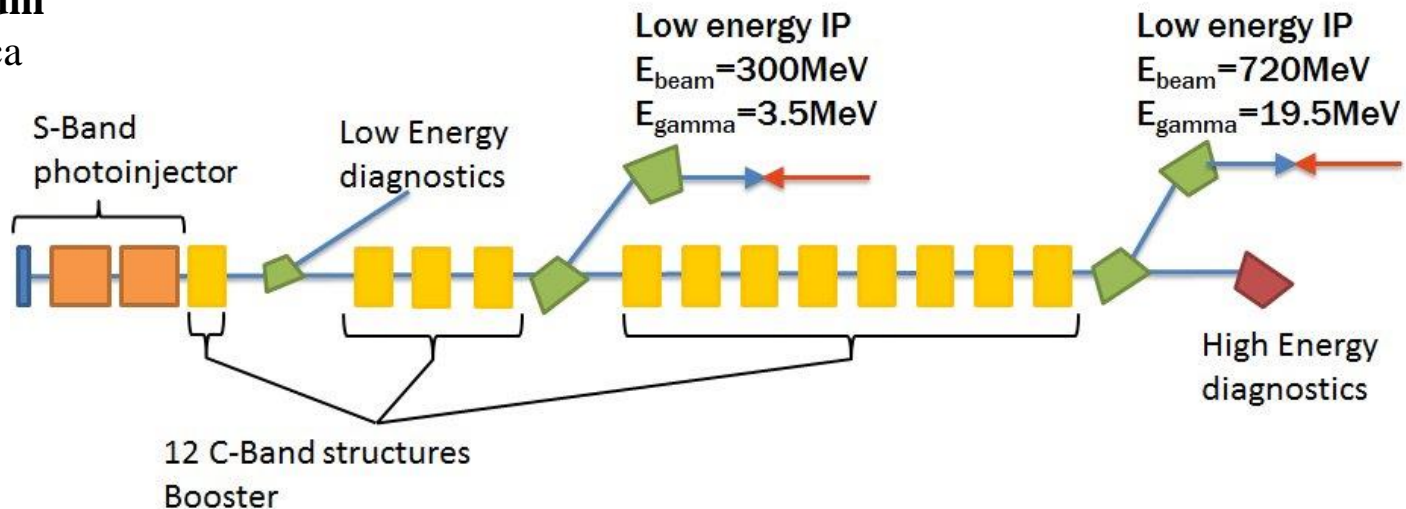
Therefore for a powerful γ beam, one needs:

- high intensity electron beams
- very brilliant optical photon beams
- very small collision volume
- very high repetition frequency

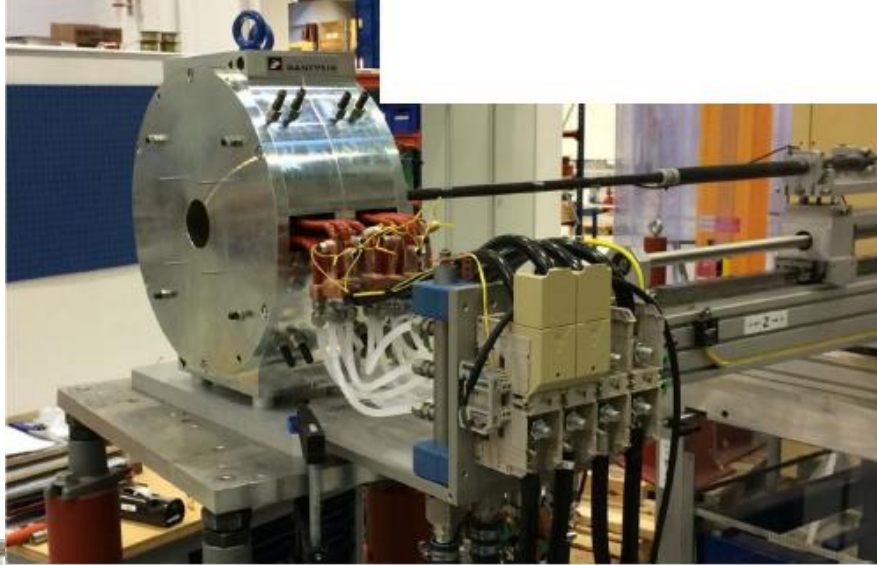
ELI-NP Gamma Beam System



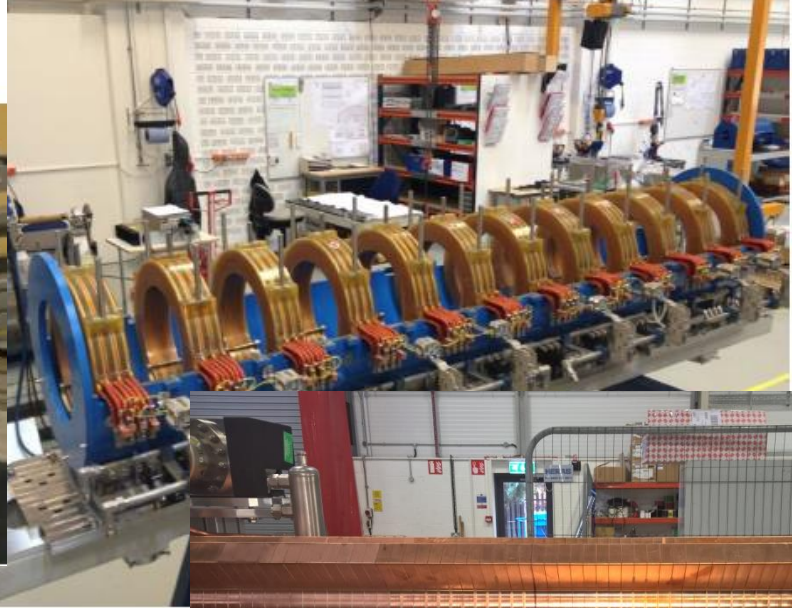
EuroGammas Consortium
Istituto Nazionale di Fisica Nucleare, INFN Italy
Research Institutes and HighTech Companies from 8 Countries



Gamma Beam System



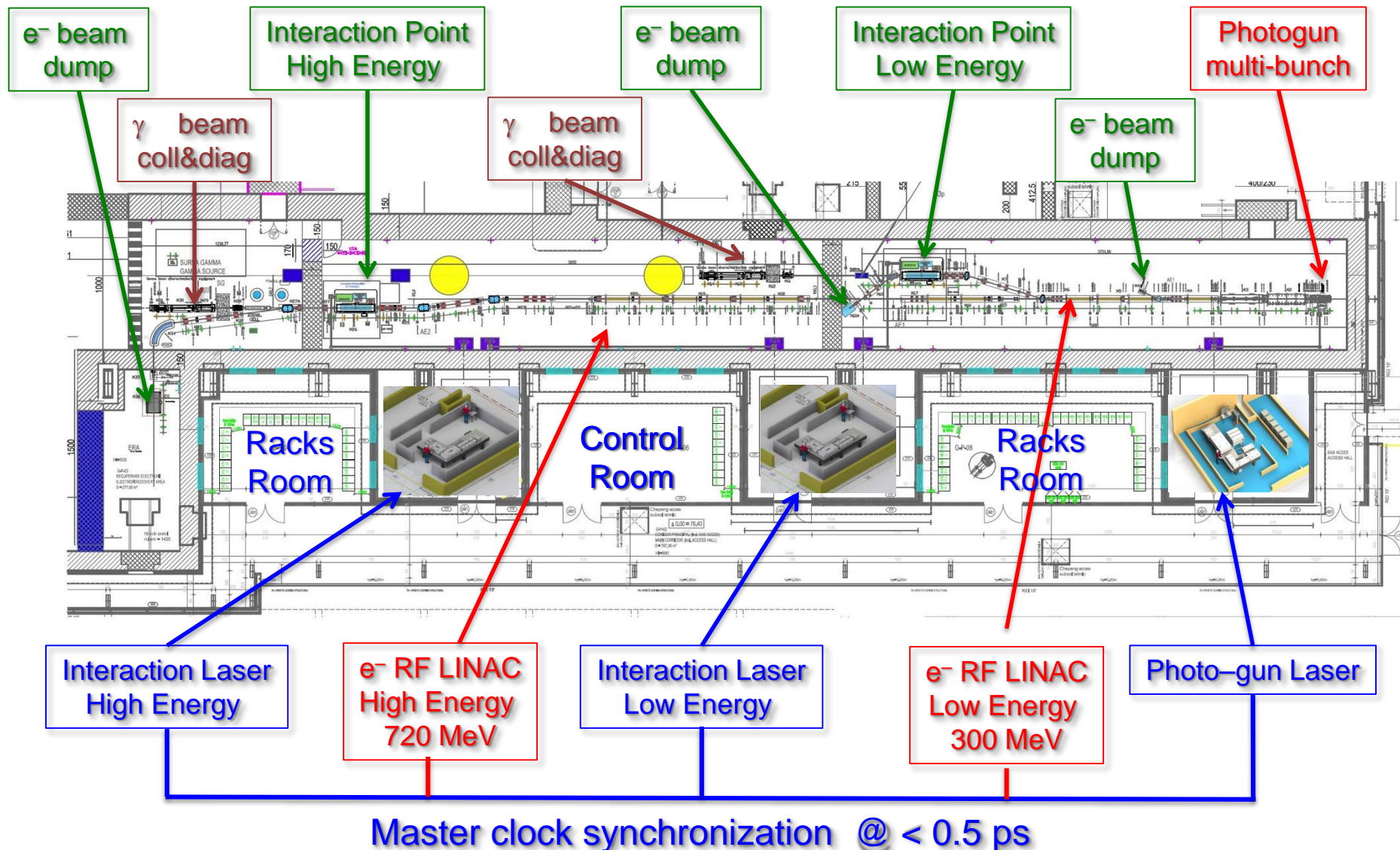
SOLENOID B
Module 2
Factory Acceptance Test



Alignment test at Danfysik have been performed, that will be demonstrated on 3rd March, when LNF & STFC Daresbury staff visit



Gamma Beam System – Layout



High-Energy Stage: γ rays up to 19.5 MeV

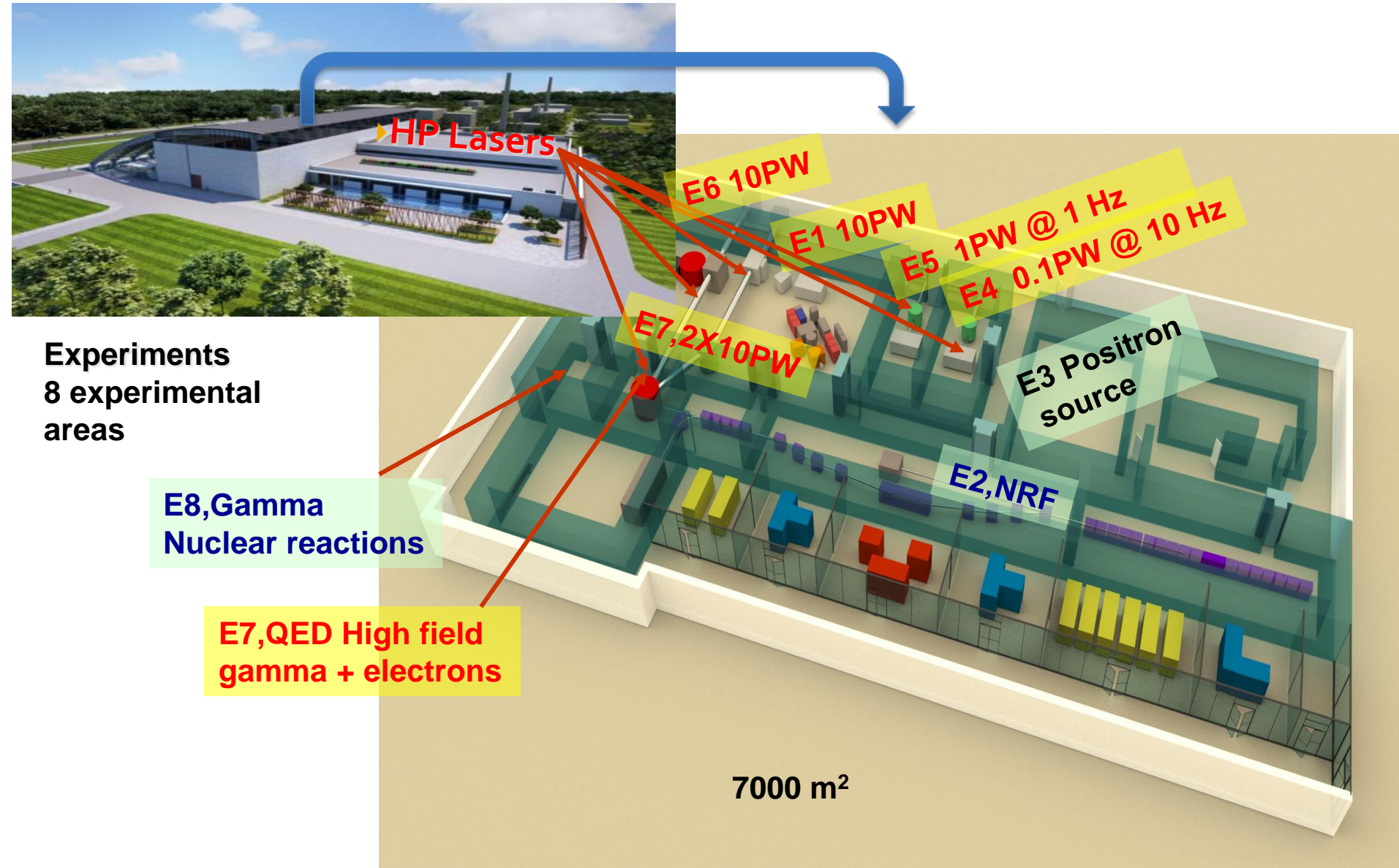
Low-Energy Stage: γ rays up to 3.5 MeV

Buildings, 33000 m² total

- HPLS 2000 m²
- GBS
- Workshops and Laboratories
- Experiments 7000 m²
- Office Building
- Guest House
- Cantine



ELI-NP Experiment Building



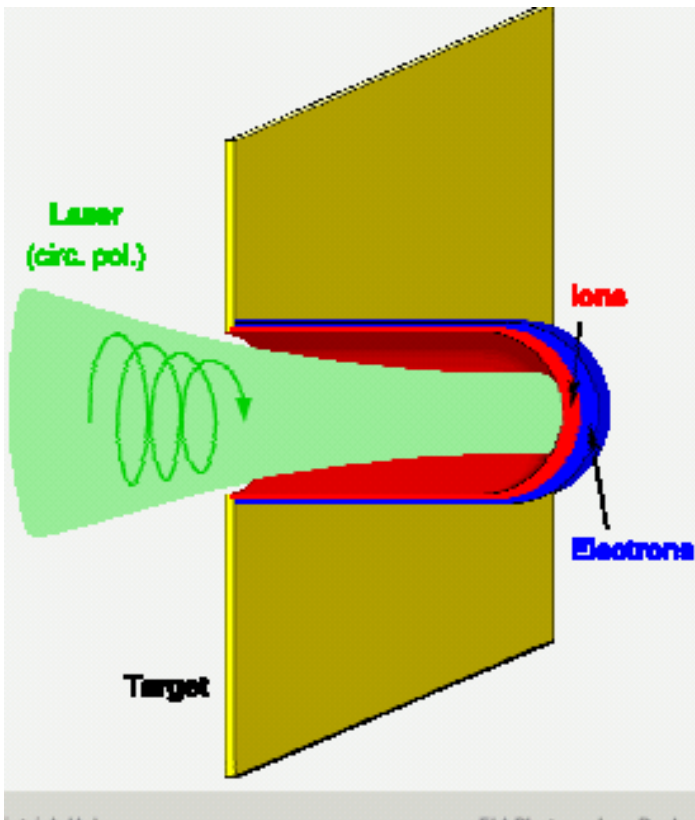
Scientific program:

- *Nuclear Physics experiments to characterize laser – target int.*
- *Photonuclear reactions*
- *Exotic Nuclear Physics and astrophysics*
- *Applied Research*

Laser-Ion Acceleration

Radiation Pressure Acceleration RPA

- thin targets (\sim nm thick diamond-like carbon foils)



Electrons and ions accelerated

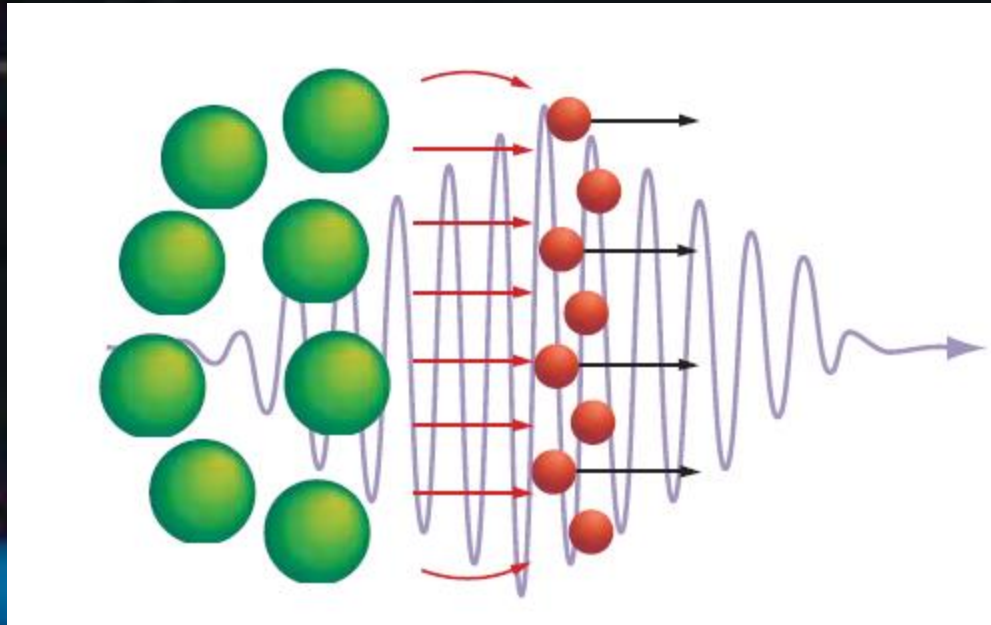
at solid state densities 10^{24}e cm^{-3} **never reached before**

(Classical beam densities 10^8e cm^{-3})
on very short distance (μm -mm)

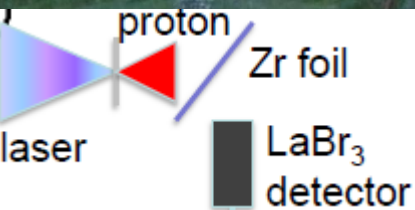
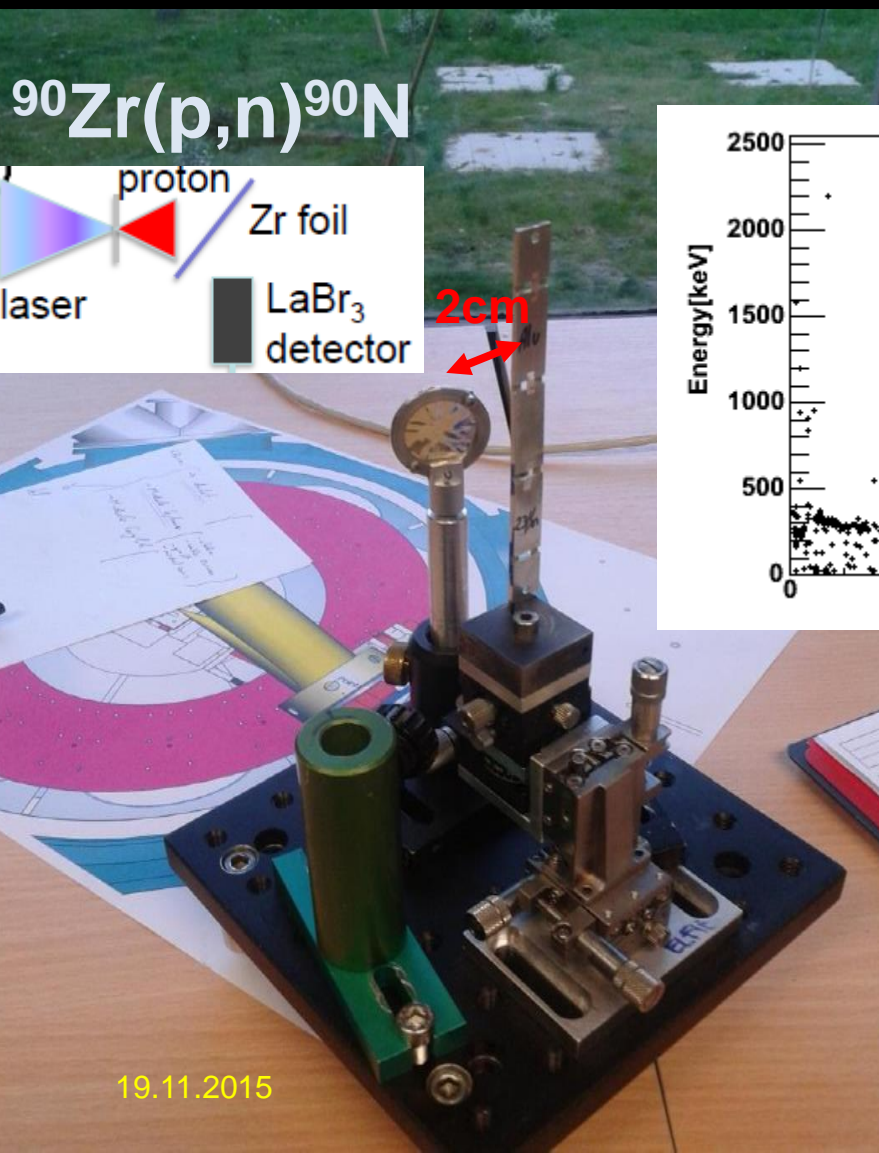
$$E \sim I_{\text{laser}}$$

Energy reached equal to a 400m up-to-date accelerator (reduction of scale of 10^9)

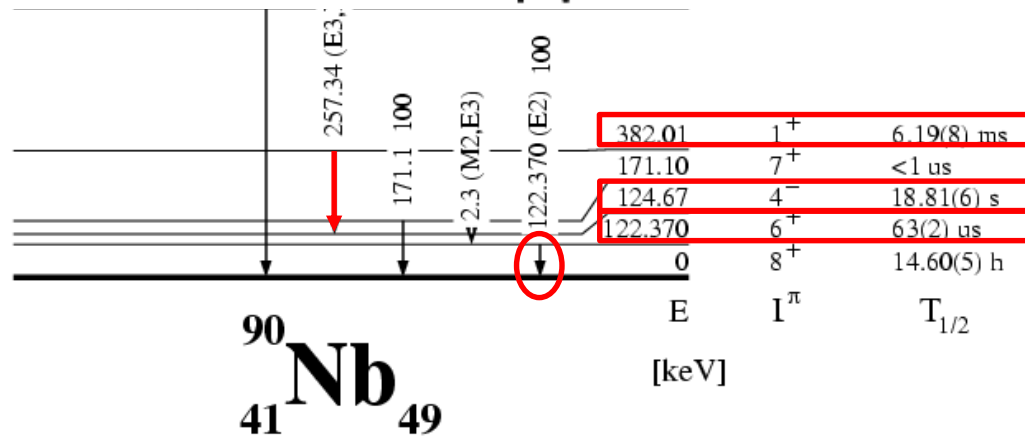
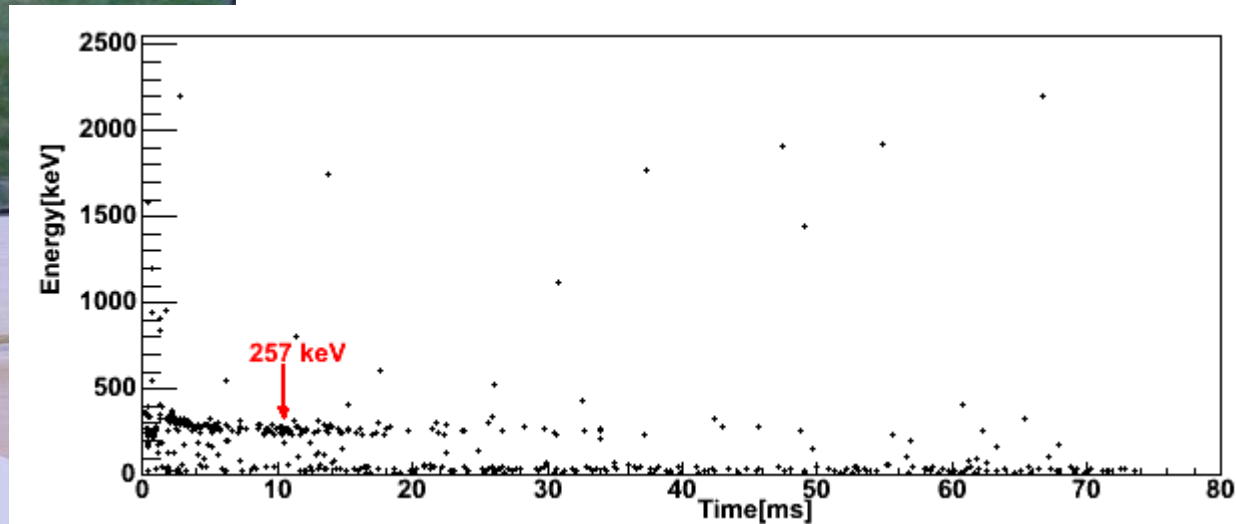
Electrons and ions accelerated at solid state densities 10^{24}e cm^{-3} never reached before



Nuclear isomer spectroscopy



experiment of Florin Negoita @ L

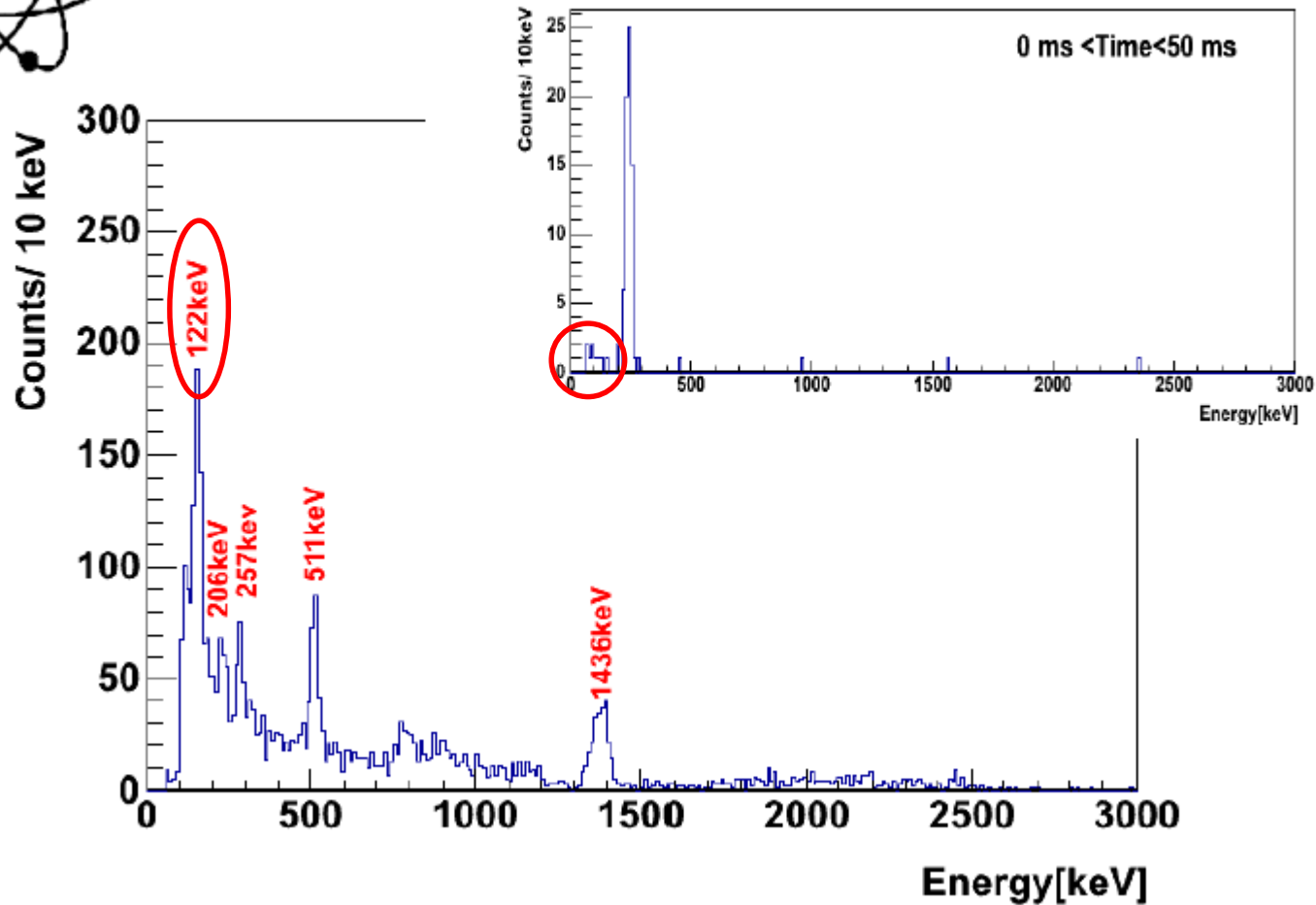


19.11.2015

γ -ray spectra



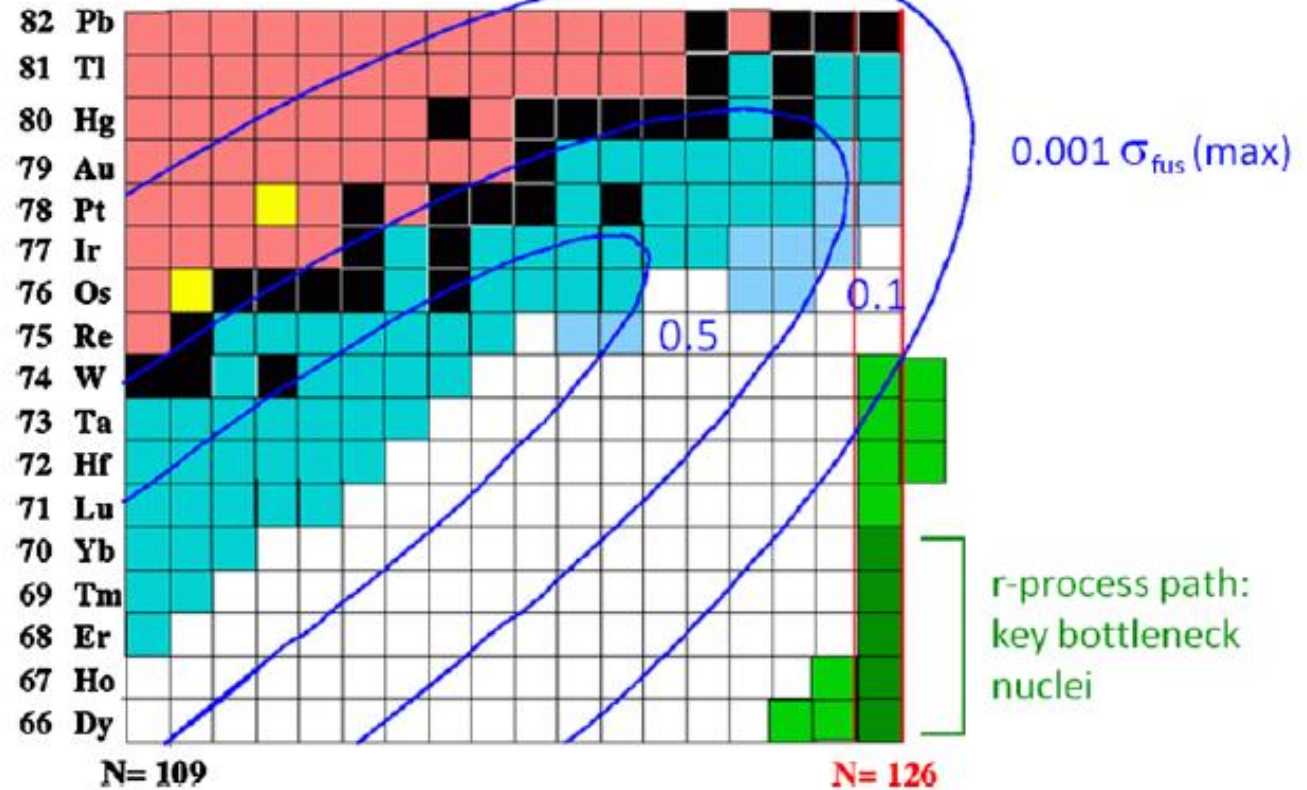
F. Negoita et al. (2015) AIP Conf. Proc. 1645 22



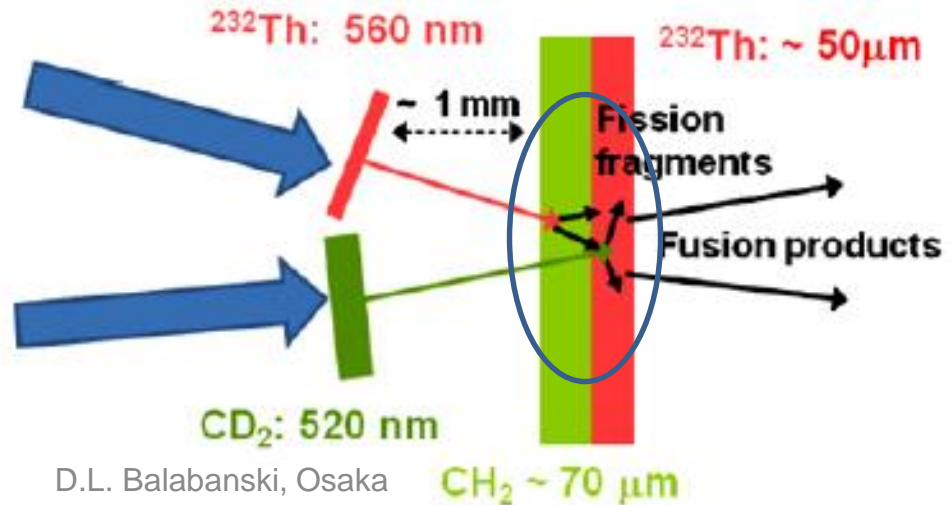
$F_L + F_L \rightarrow \langle AZ \rangle \approx {}^{192}\text{Re}$

Introducing the first laser-accelerated heavy ion towards the $N = 126$ shell

D. Habs · P.G. Thirolf · M. Grunert · A. Henig · D. Kiefer · W. Ma · ...

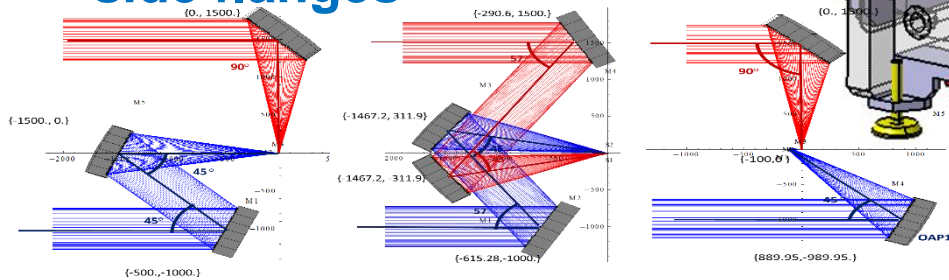
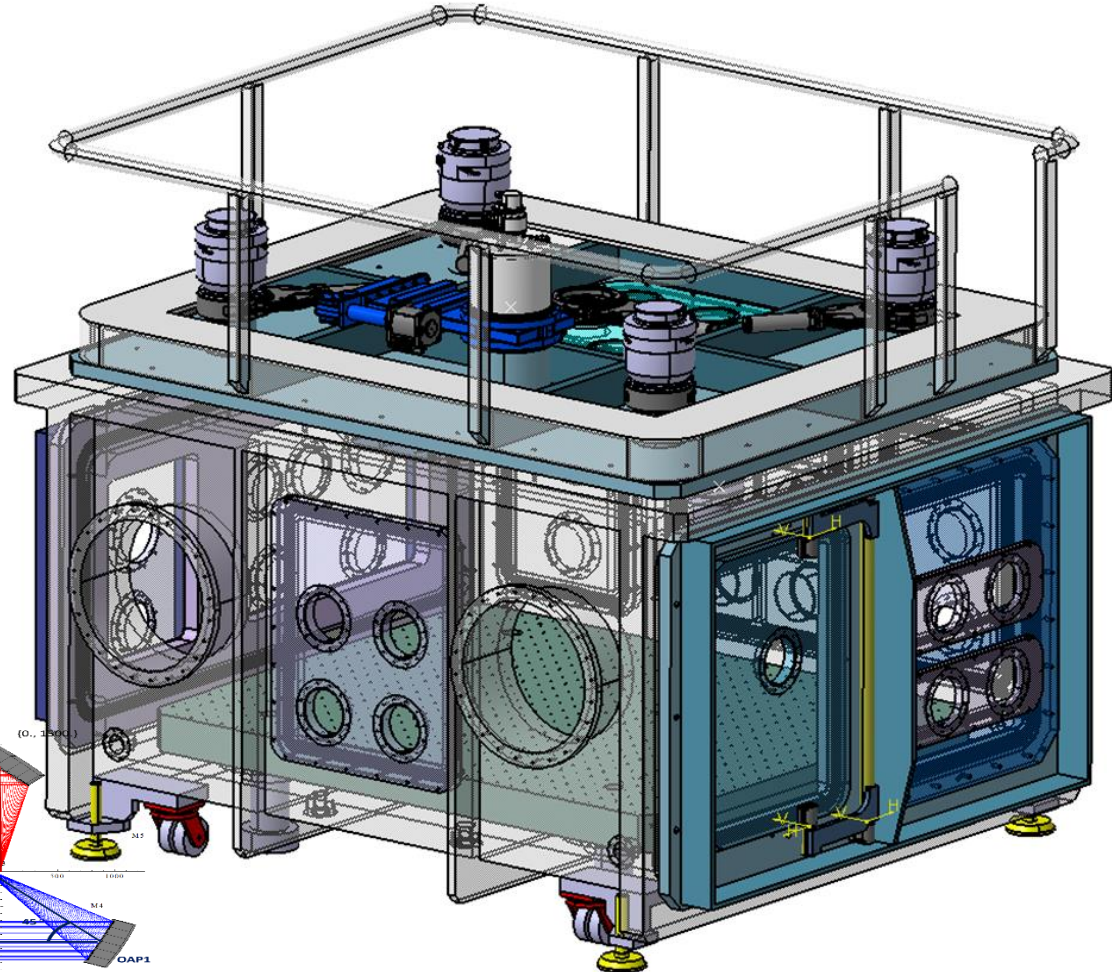


$1.2 \cdot 10^{23} \text{ W/cm}^2$
 32 fs, 273 J, 8.5 PW
 high-power, high-contrast APOLLON laser :
 focal spot: diam. $\sim 3 \mu\text{m}$
 $1.0 \cdot 10^{22} \text{ W/cm}^2$
 32 fs, 23 J, 0.7 PW



E1 Interaction Chamber (under construction)

- Shape: Rectangular
- Material: aluminium
- Volume: $3 \times 4 \times 2 (=24) \text{ m}^3$
- Vacuum: 10^{-6} mbar (empty chamber)
- Pump-down to 5×10^{-6} mbar: 45 min.
- Multiple flanges and ports
- Isolation of optical table
- Removable roof and side flanges



Focal length for all parabolas: 1500 mm

- Access on top for target exchange system
- Internal crane for heavy equipment (mirrors) manipulation
- Door for access inside through a cleanroom attached to the chamber (not shown)

Electromagnetic dipole response of nuclei

Nuclear structure

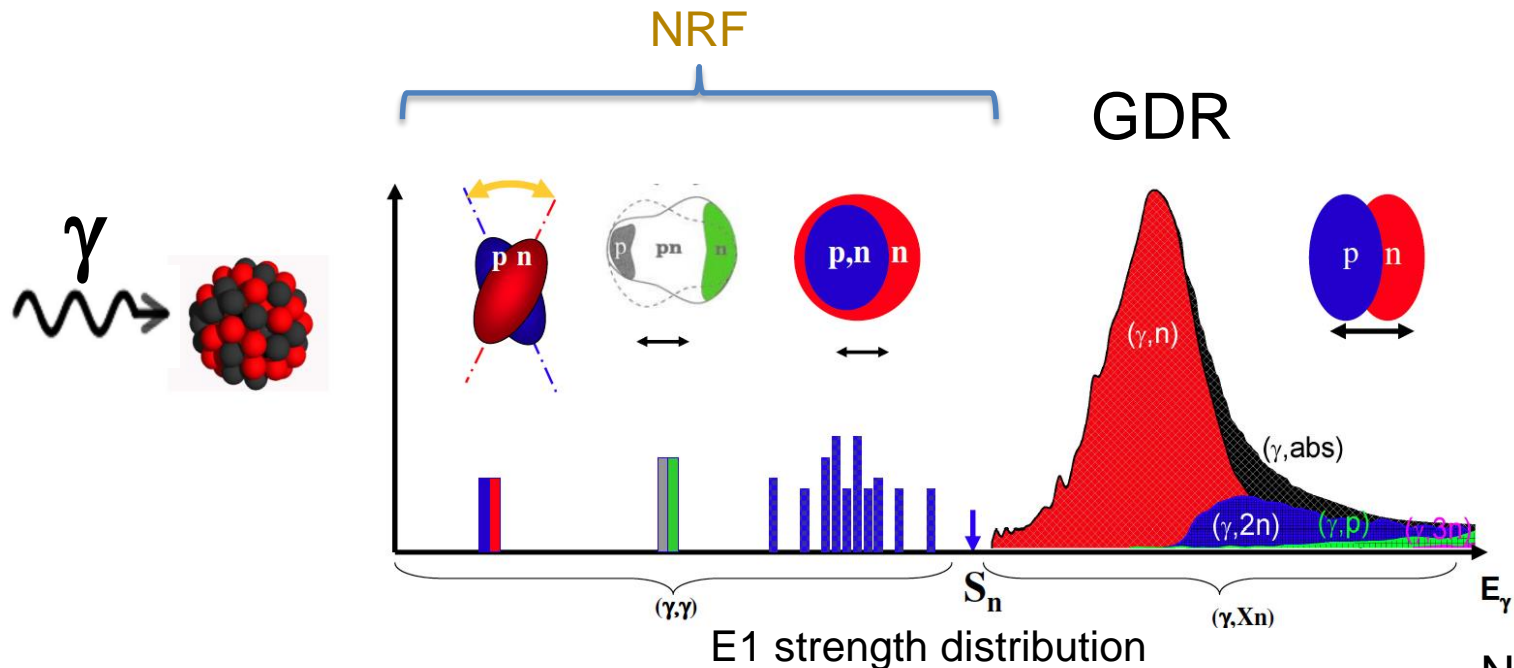
- Modes of excitation below the Giant Dipole Resonance (GDR)

Impact on nucleosynthesis

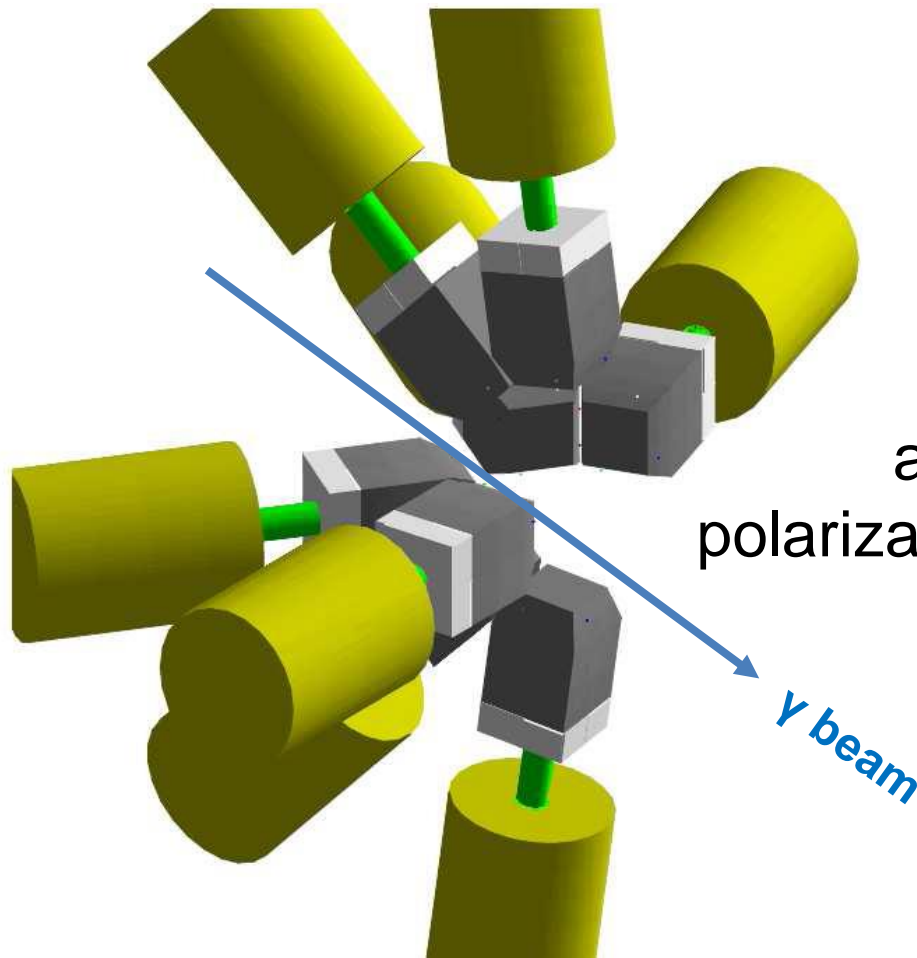
- Gamow window for photo-induced reactions in explosive stellar events

Understanding exotic nuclei

- E1 strength will be shifted to lower energies in neutron rich system

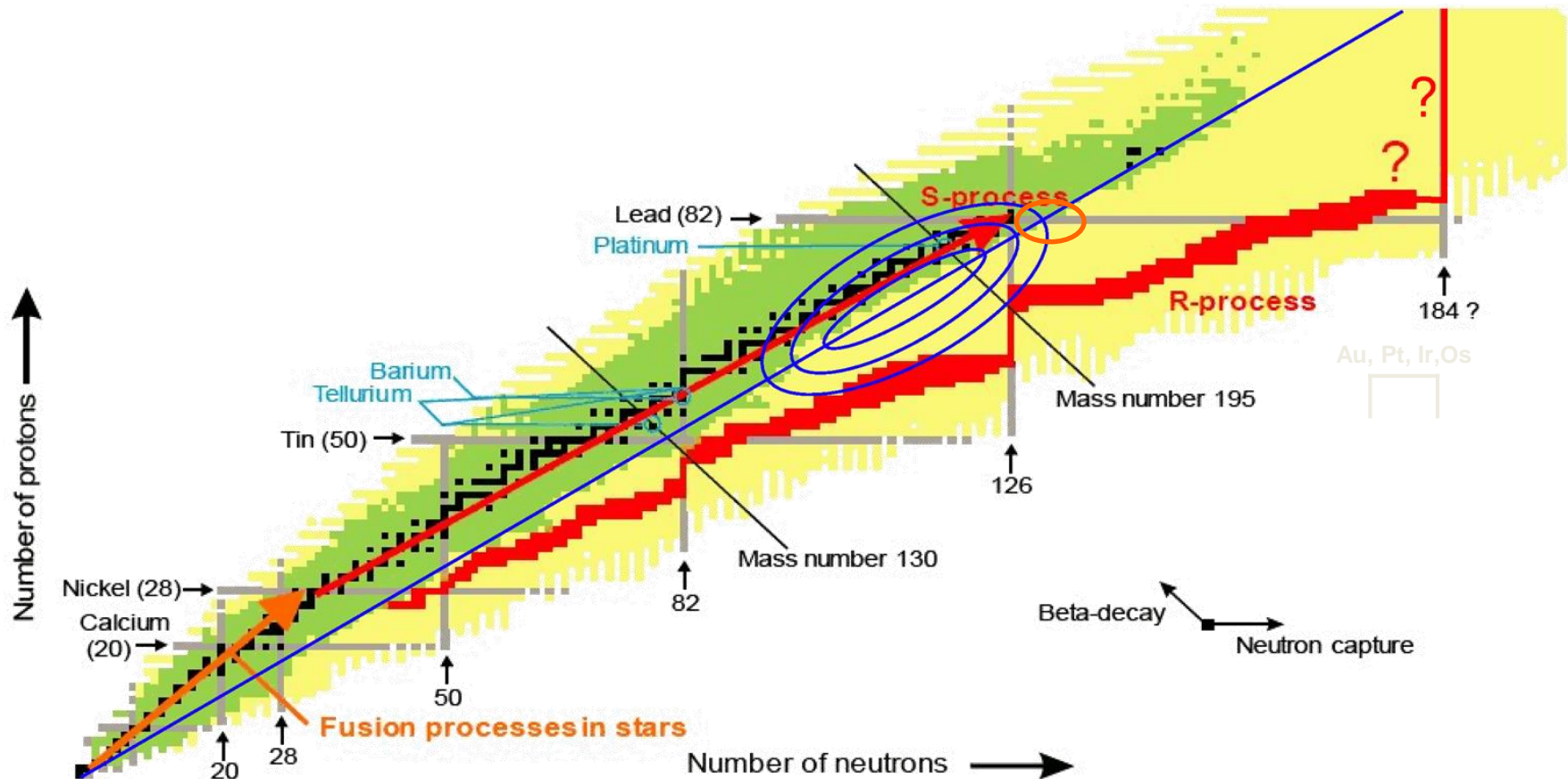


ELIADE array



$\gamma\gamma$ coincidences
angular distributions
polarization measurements

- s Process: (γ, n) reactions
- p process (γ, p) and (γ, α) Reactions
- r process: $N=126$, bottleneck for understanding nucleosynthesis of actinides





HEU Grand Challenge
detection of shielded material



Nuclear Fuel Assay
100 parts per million per isotope



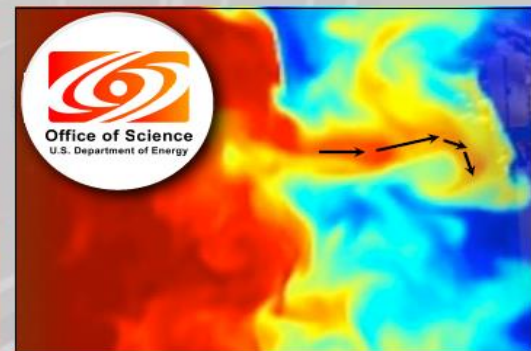
Waste Imaging & Assay
non-invasive content certification



Precision Imaging
micron-scale & isotope specific



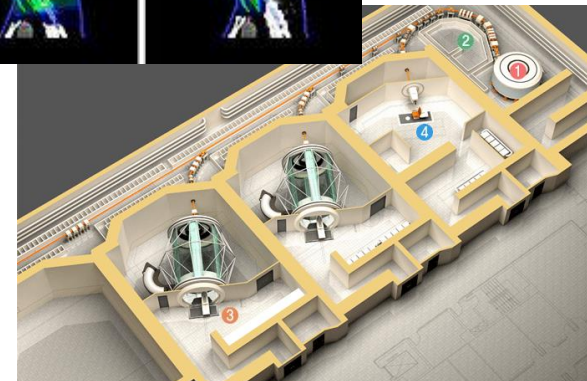
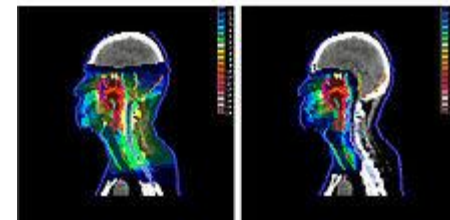
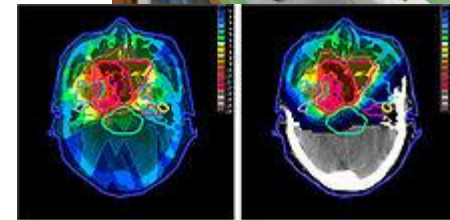
Medical Imaging
low density & isotope specific



Dense Plasma Science
isotope mass, position & velocity

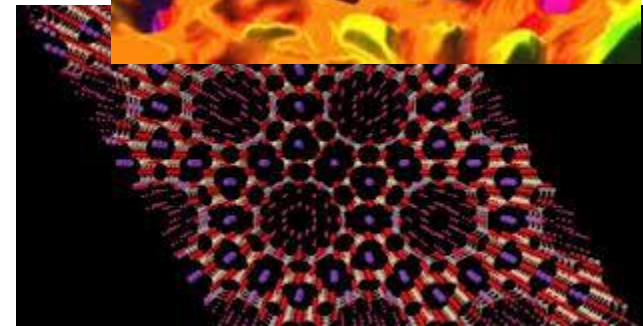
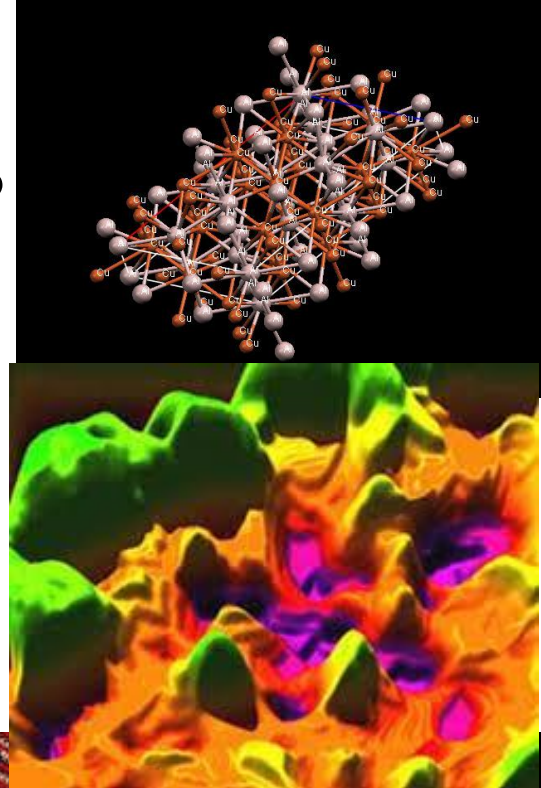
Radioisotopes for medical use

- New approaches and methods for producing radioisotopes urgently needed
- *Mo-99 and other medical isotopes used globally for diagnostic medical imaging and radiotherapy*
- ^{195m}Pt : In chemotherapy of tumors it can be used to exclude "non responding" patients from unnecessary chemotherapy and optimizing the dose of all chemotherapy

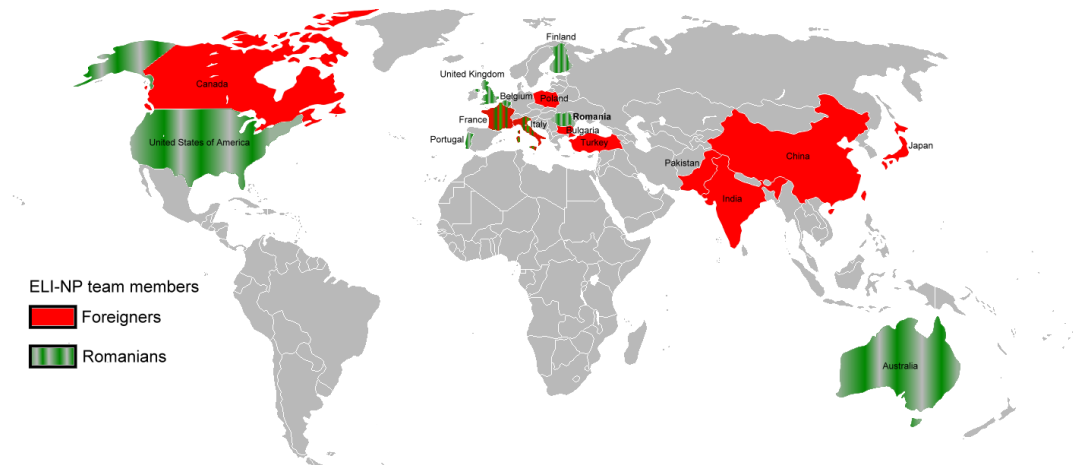
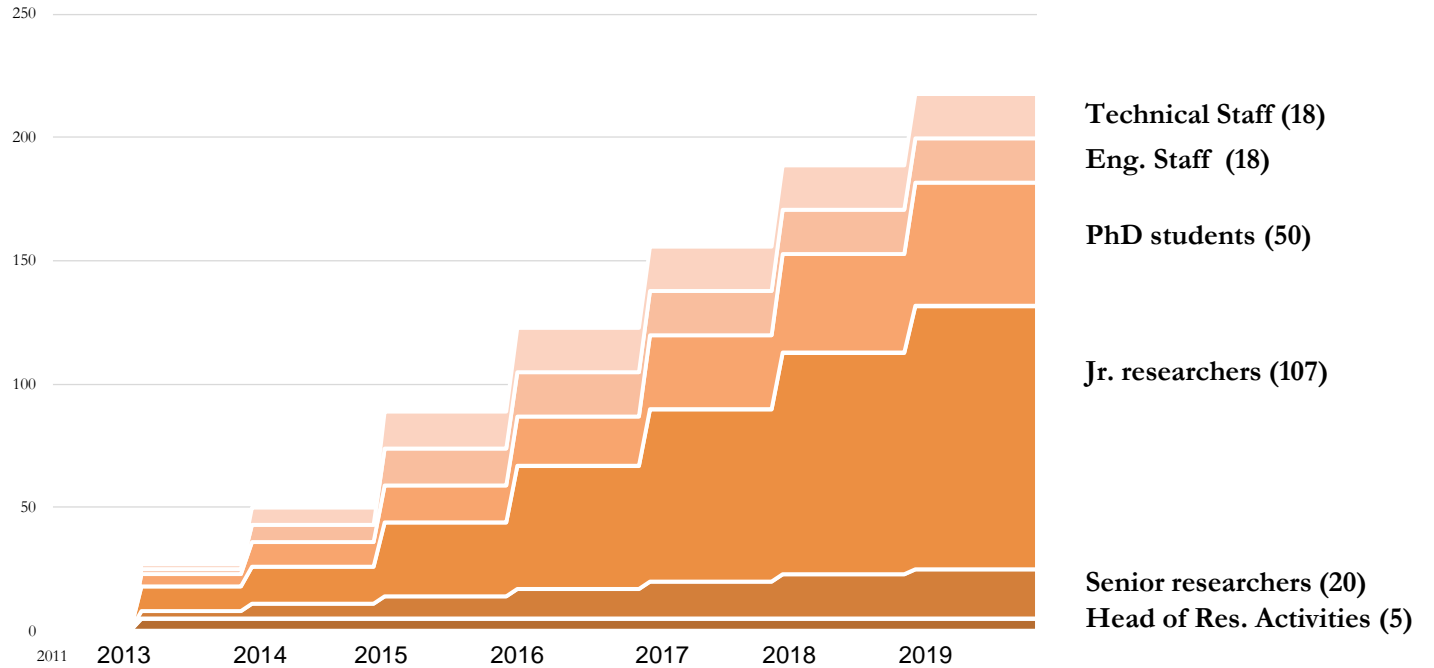


Materials Science and Engineering

- **study of materials on the nano- and femto-scales**
- novel experimental studies of material behavior – thanks to extreme fields intensity provided by the laser and gamma-ray beams
- understand, at the atomic scale, the behavior of materials subject to extreme radiation doses and mechanical stress
- **polarized positron beam – new microscopy**



Human Resources



ELI-NP Industrial Forum

*Body promoting relationships, for mutual benefits,
with local and foreign companies*

- *Consulting in elaborating the TDRs for experiments
and auxiliary equipment*
- *Promotion of contractual research, technology transfer, etc.*
- *Consulting services provided by ELI-NP experts*
- *Creation of a cluster of high-tech companies in Magurele*

“Măgurele High Tech Cluster”

ELI-NP Academic Forum

- *to secure the fulfillment of ELI-NP needs in terms of PhD students, junior researchers, engineers, and technicians (training programs, specific MSc and PhD programs, etc.);*
- *to assure the education of engineers for the companies part of the high-tech cluster at Magurele;*
- *to support the ELI-NP Project in the achievement of its objectives in terms of scientific excellence;*



EUROPEAN UNION



GOVERNMENT OF ROMANIA



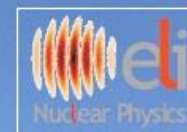
Structural Instruments
2007-2013

Sectoral Operational Programme “Increase of Economic Competitiveness”
“Investments for Your Future!”



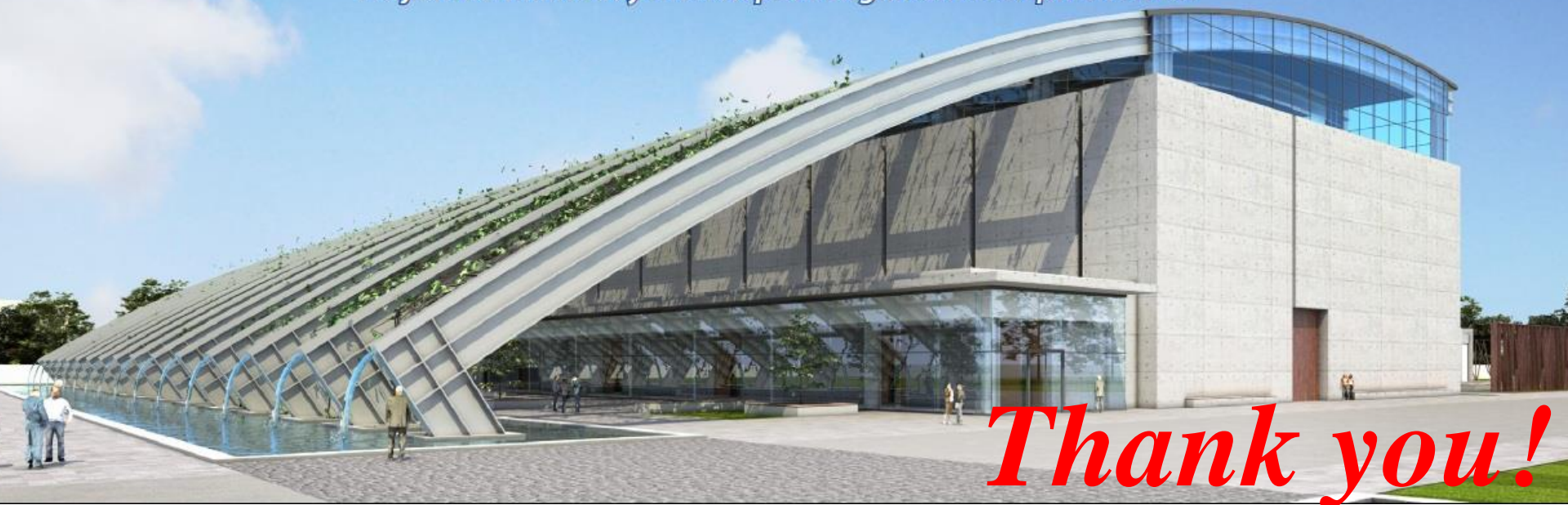
Extreme Light Infrastructure - Nuclear Physics

(ELI-NP) - Phase I



www.eli-np.ro

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Thank you!