EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments
2007-2013

Project co-financed by the European Regional Development Fund

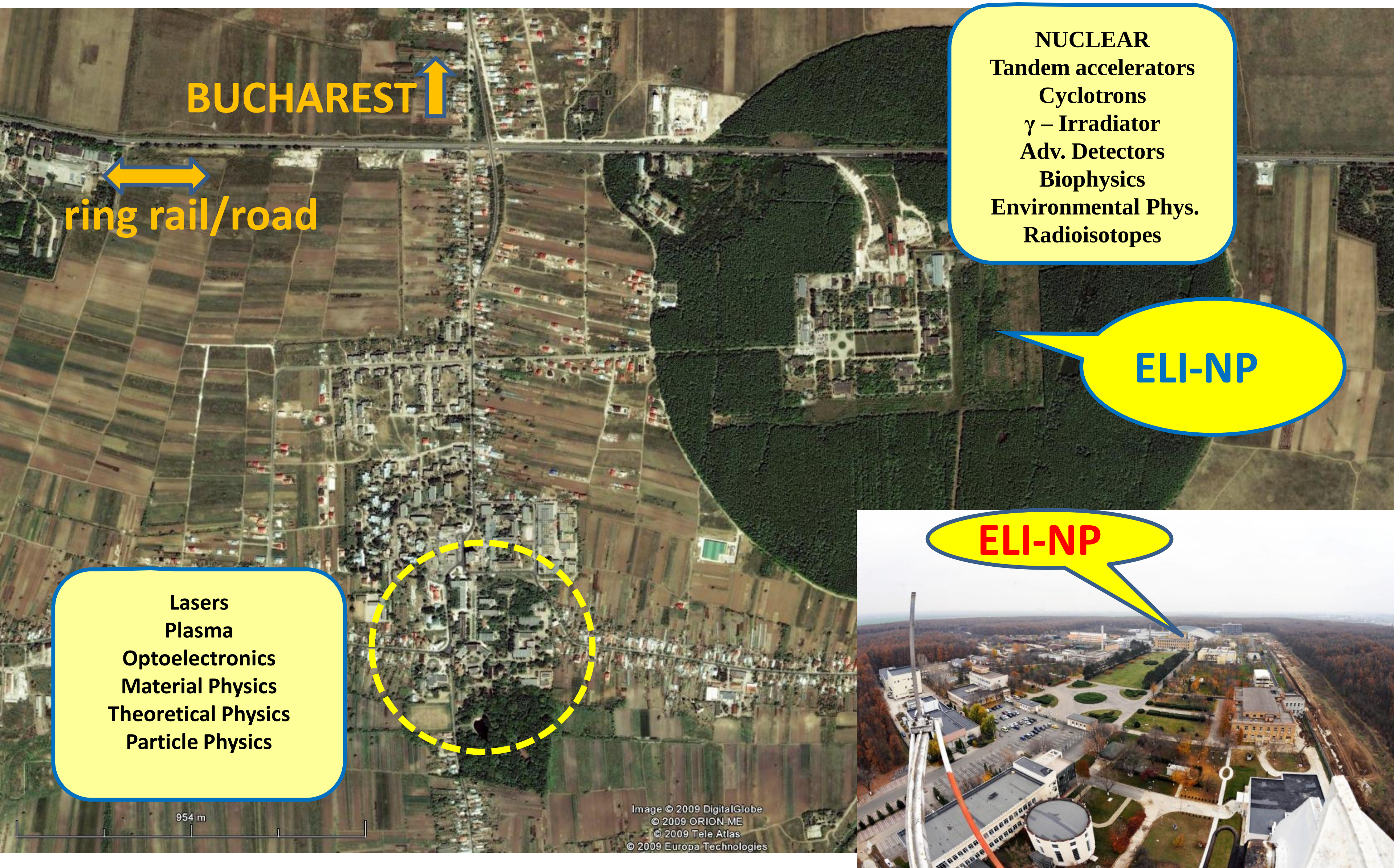
Sectoral Operational Programme
„Increase of Economic Competitiveness”
“Investments for Your Future”

Extreme Light Infrastructure – Nuclear Physics (ELI-NP)
Status and Perspectives

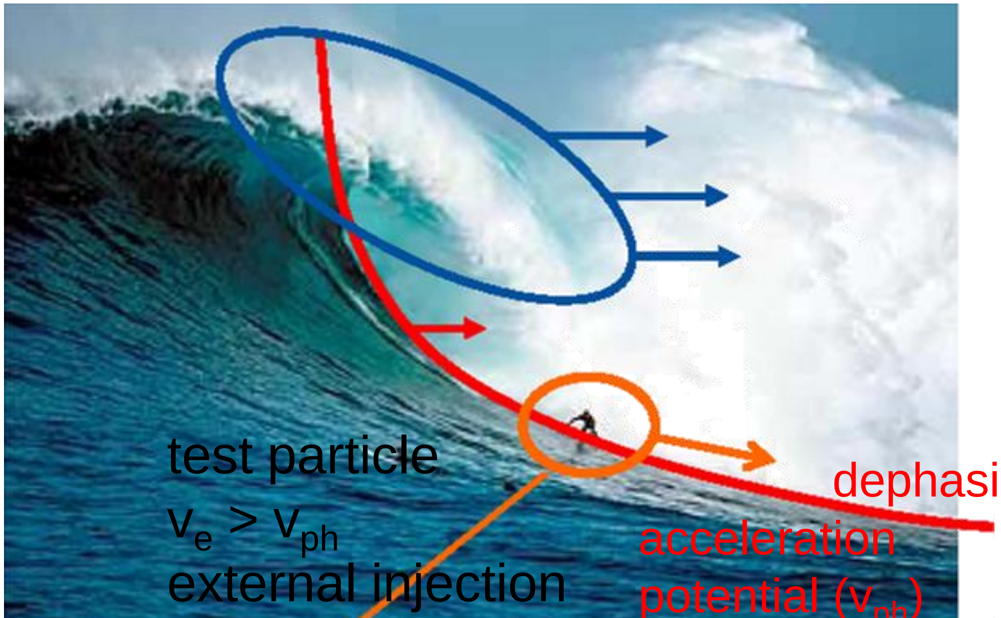
eli Nuclear Physics

IFIN-HH

Bucharest-Magurele
National Physics Institutes



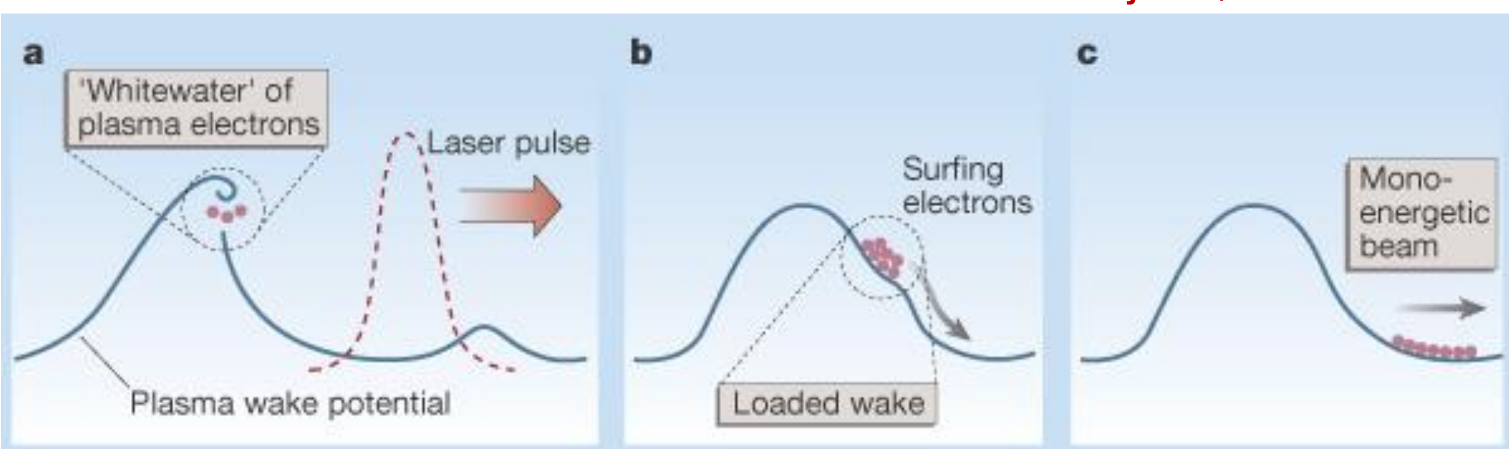
Laser wake field acceleration of electrons



Wake field: radiation pressure of intense laser pulse excites plasma wave with high amplitude

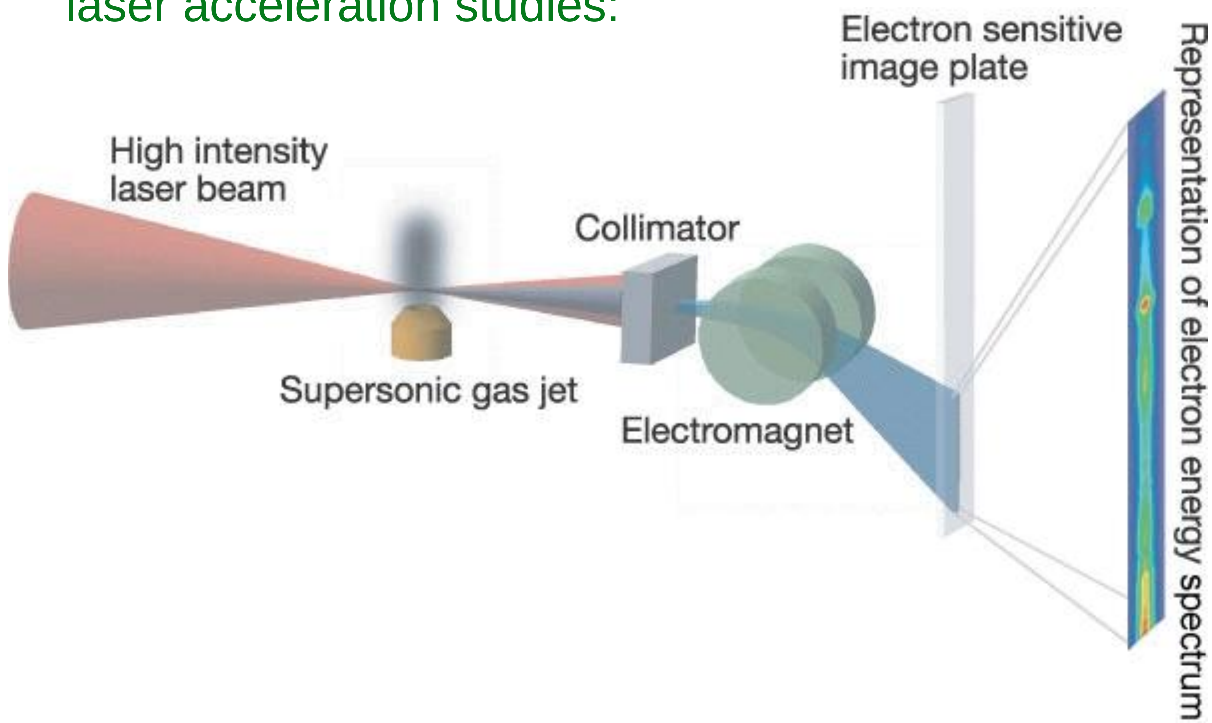
- electron acceleration by 'surfing' on the plasma wave
- efficient for laser pulses shorter than plasma wavelength

T. Tajima, J.M. Dawson PRL 43 (1979)



Laser-Acceleration of Electrons

typical setup for electron laser acceleration studies:



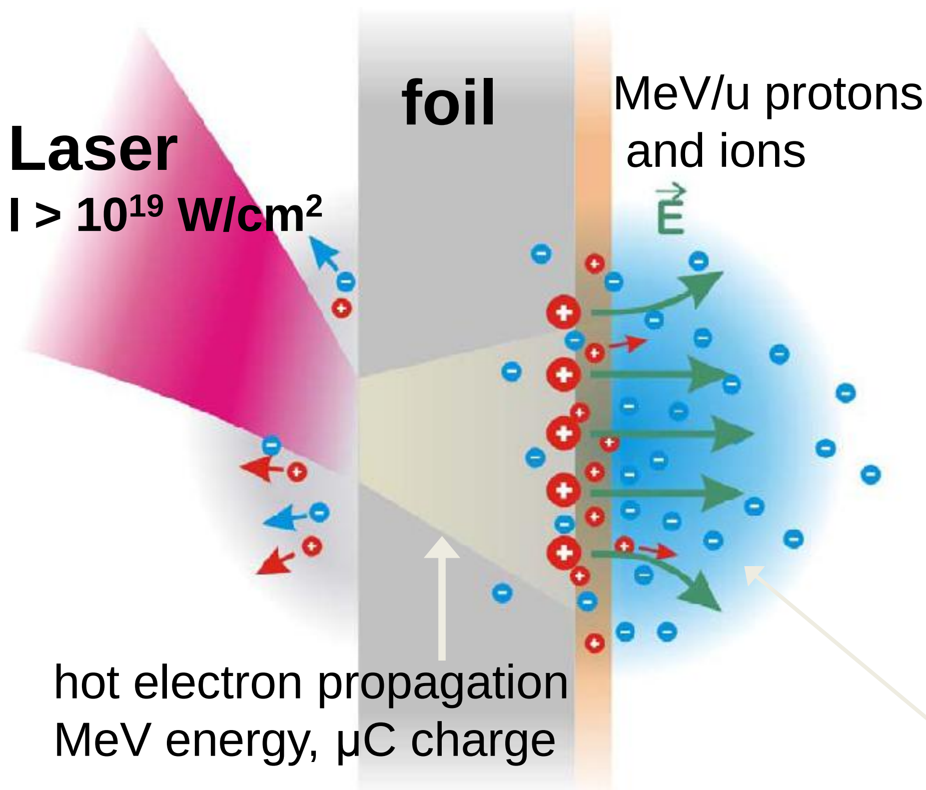
Nature 431 (Sept. 2004):
3 groups report on laser acceleration of (low-emittance) electron beams with (quasi-monochromatic) 70-200 MeV

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

Today ~3 GeV electrons

Laser-Ion Acceleration

Target Normal Sheath Acceleration (TNSA)

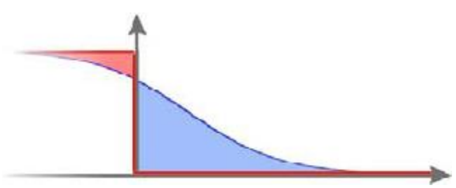


- electron acceleration
- hot (MeV) electrons penetrate the (µm) foil
- quasi-static field forms normal to target surface

- use thick (metallic) foil targets (~µm)

proton source: CH contamination on foil surfaces (typically ~50Å)

ion source: foil bulk material



- space charge field:
  $E \sim T_{hot}/\lambda_{Debye} \sim \mathrm{MeV}/\mu\mathrm{m} = 10^{12}\,\mathrm{V/m}$

- conversion efficiency: (from laser to ions)

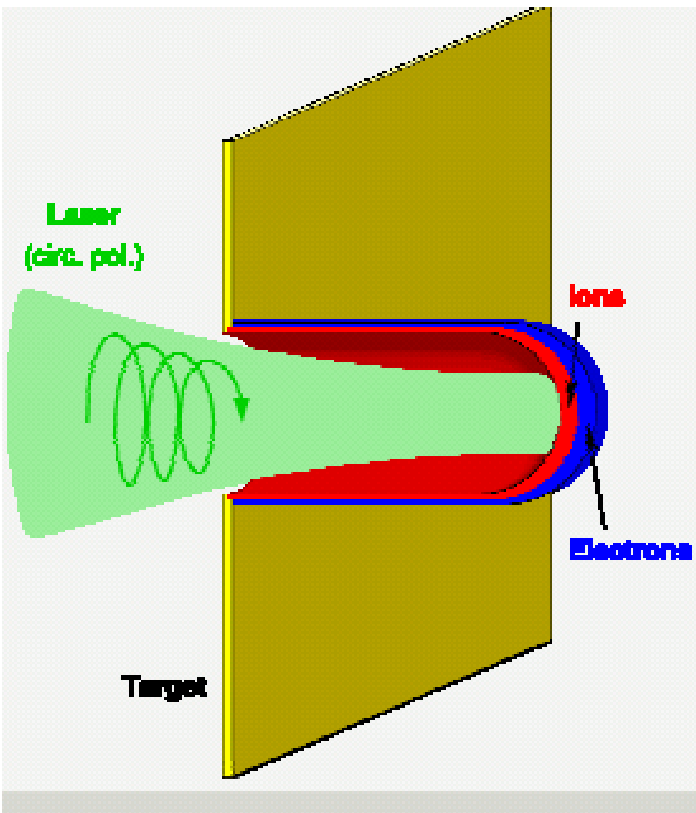
$$E_{ion} \propto \sqrt{I_{Laser}}$$

E.L. Clark et al., PRL 84 (2000) 670
R. Snavely et al., PRL 85 (2000) 2945

Nuclear Physics

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^{8}e 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})

Infrastructure

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 (~50 *M€)*

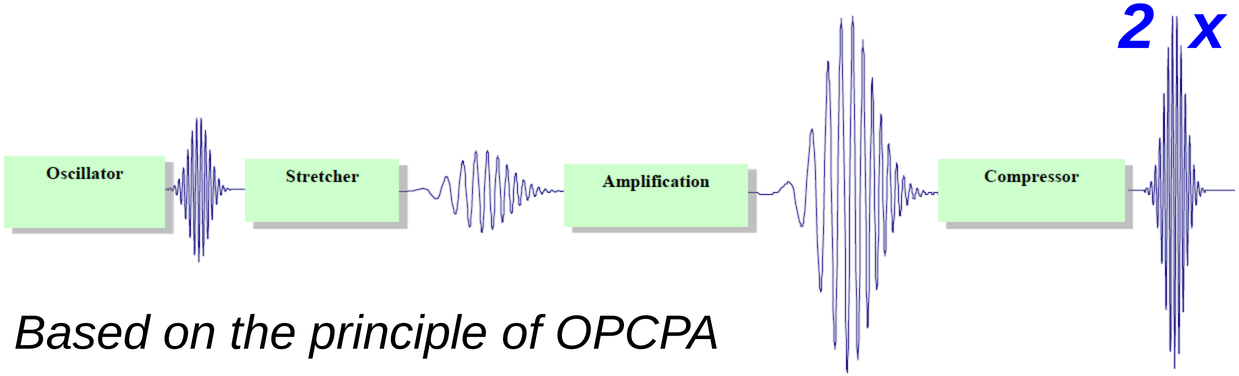
Buildings (2013-2015) : 33000sqm total – *STRABAG (~65M€)*

High Power Laser System

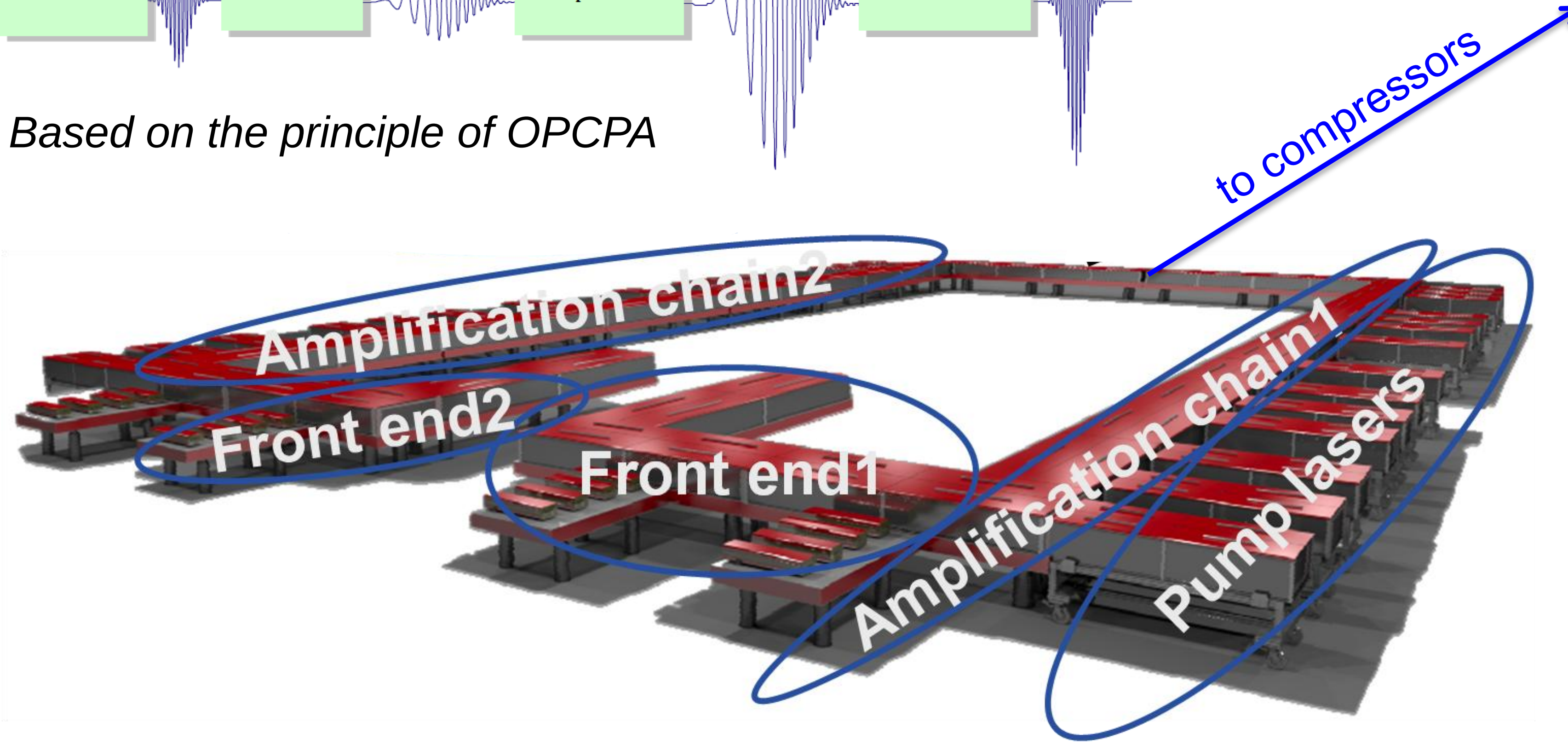
Nuclear Physics

THALES Optronique 2013-2018

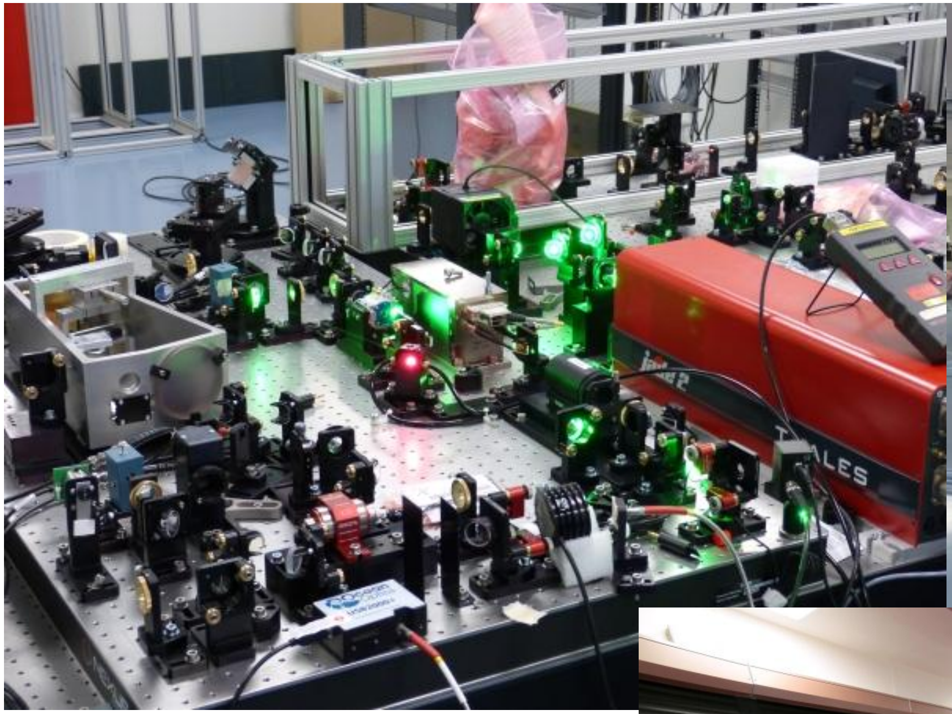
2	x	0.1 PW	10Hz
2	x	1 PW	1 Hz
2	x	10 PW	0.1 Hz



Based on the principle of OPCPA

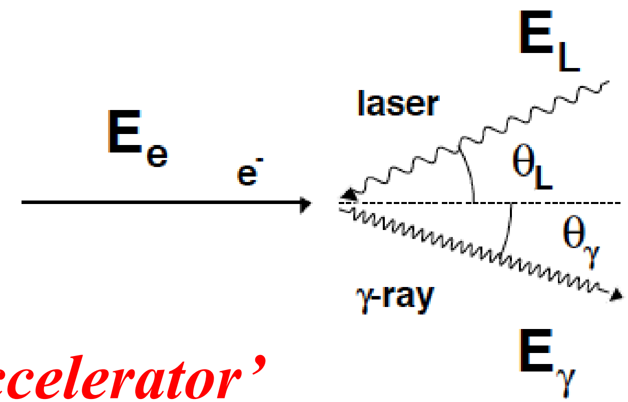


High Power Laser System



Gamma Beam System

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



Compton backscattering: ***'Photon accelerator'***

$$\mathbf{E_\gamma = 4\gamma_e^2\, E_L}$$

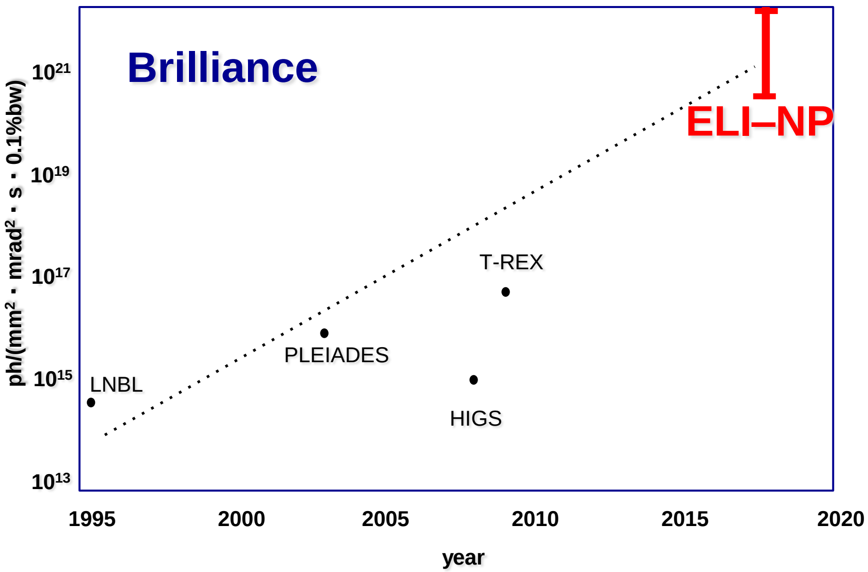
E_e=720 MeV => γ_e~ 700 => E_γ ~20 MeV

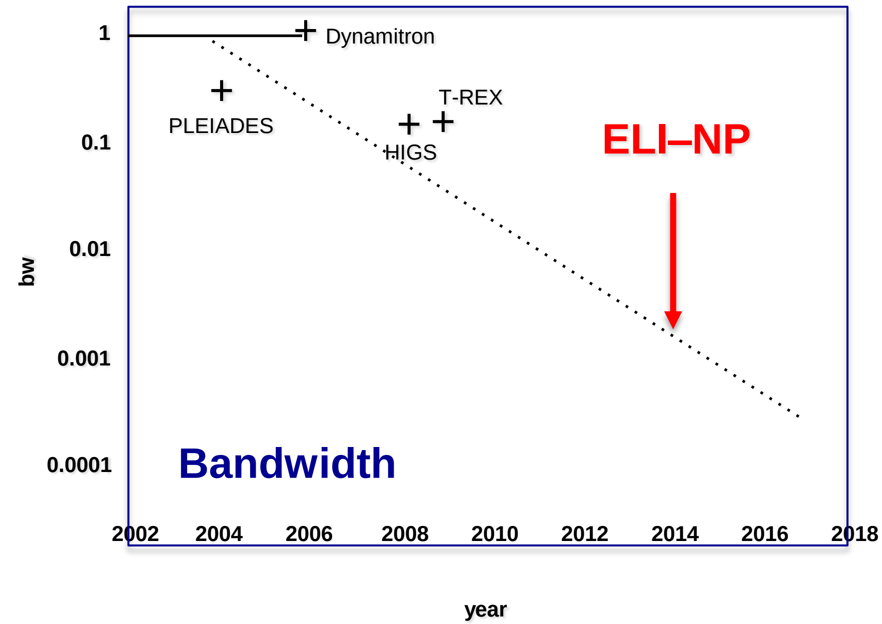
but very weak cross section: 6.6 10^{-25} cm^2

Therefore for a brilliant γ beam, one needs:

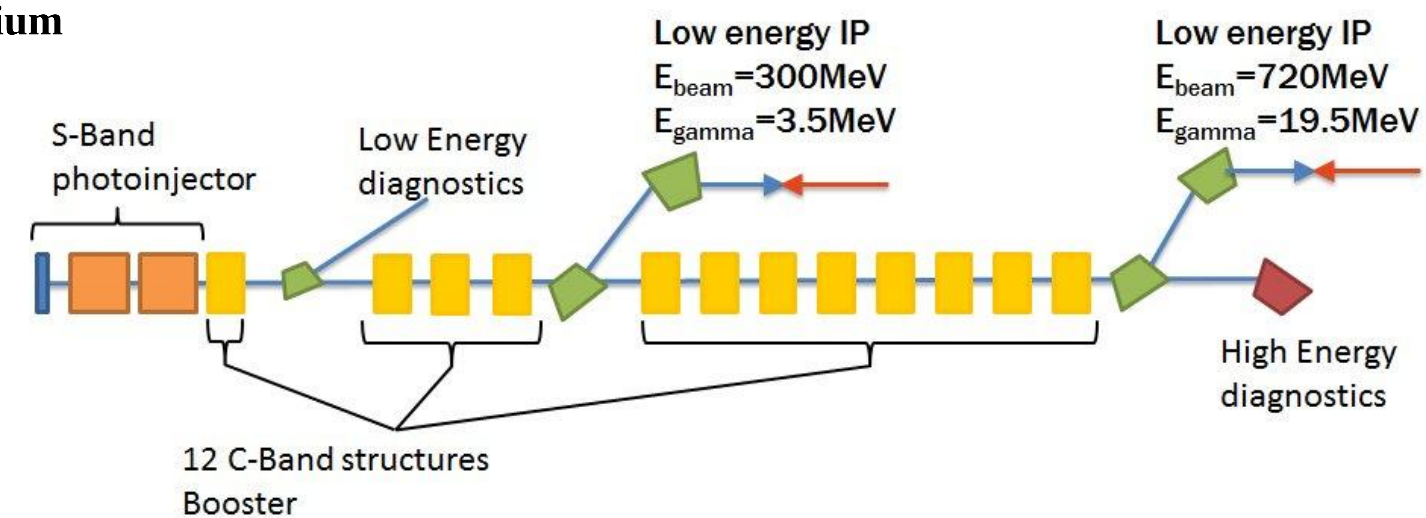
- high intensity electron beams
- very brilliant optical photon beams
- very small collision volume
- very high repetition frequency

Gamma Beam System





EuroGammas Consortium
Lead by INFN Italy

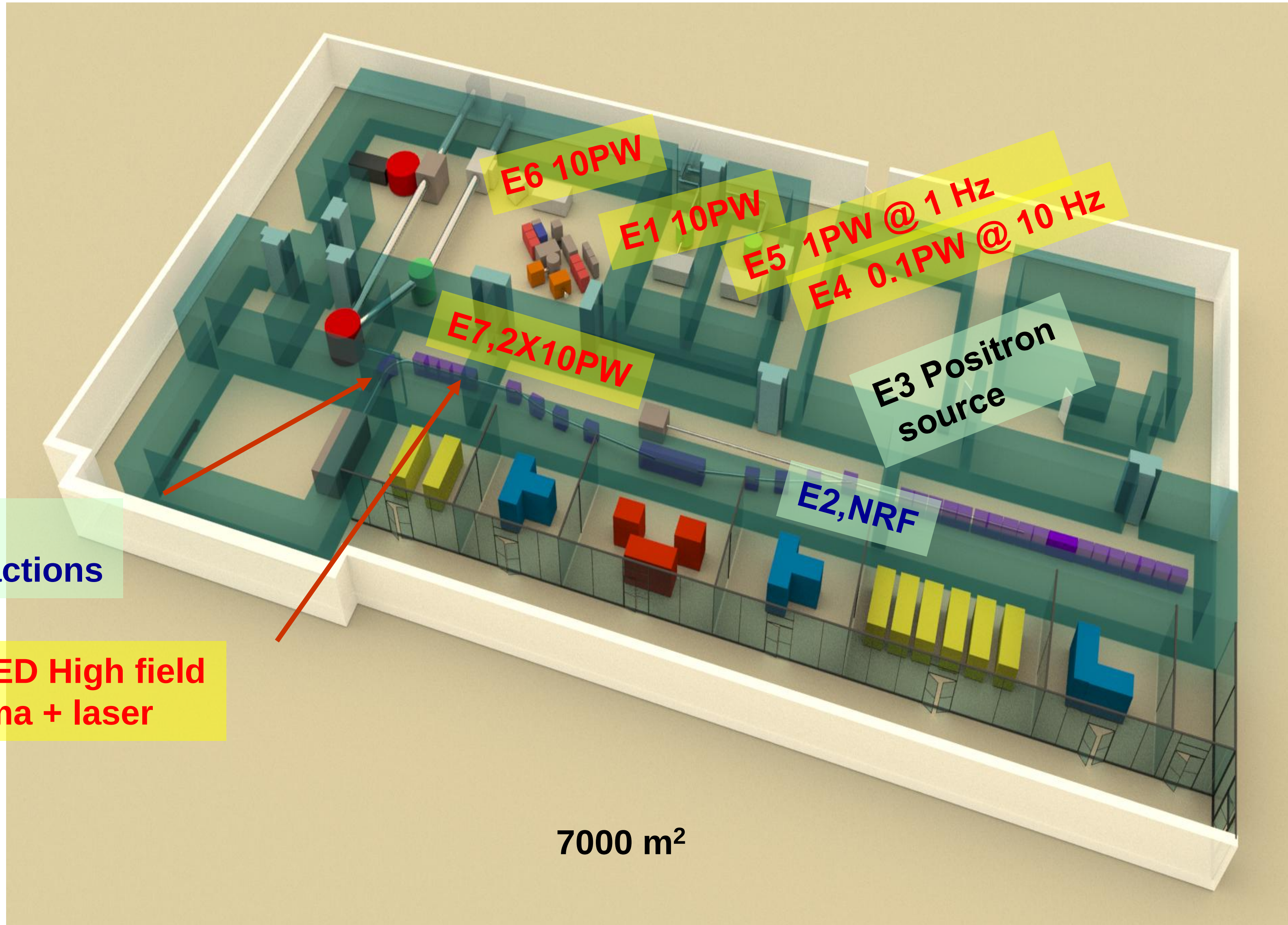


Gamma Beam System

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

Experiment Building



Buildings, 33000 m² total

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

Research Program

- **Nuclear Physics experiments to characterize laser – target interaction**

- **Exotic Nuclear Physics and astrophysics**

  complementary to other ESFRI Large Scale Physics Facilities (FAIR, SPIRAL2)

- **Applications based on high intensity laser and very brilliant γ beams**

Scientific Program

Gamma Beams System

- NRF Experiments and applications
- Photo–fission experiments
- (γ,n) experiments
- (γ,p) experiments
- Positron source for material science

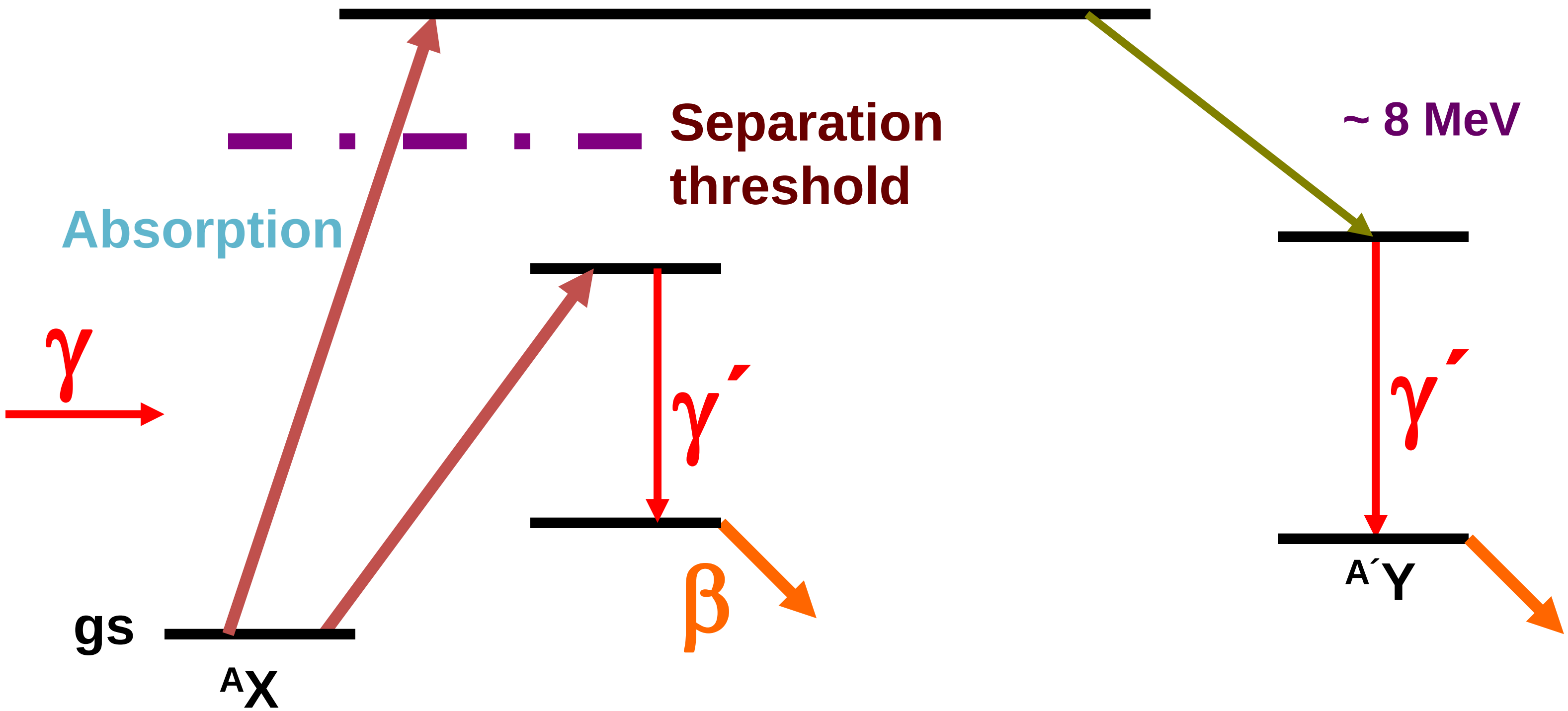
High–Power Laser System

- Laser delivery and beam lines
- Fission–fusion experiments
- Strong field QED
- Laser + Gamma interaction
- Applications

International Workgroups

25 MoU with major
Laser and Nuclear Physics
labs and Institutions

Gamma Beam System
Photonuclear Reactions



Nuclear Resonance Fluorescence (NRF)

Photoactivation

Photodisintegration (–activation)

Photo–fission

Nuclear Photonics

Electromagnetic dipole response of nuclei

Nuclear structure

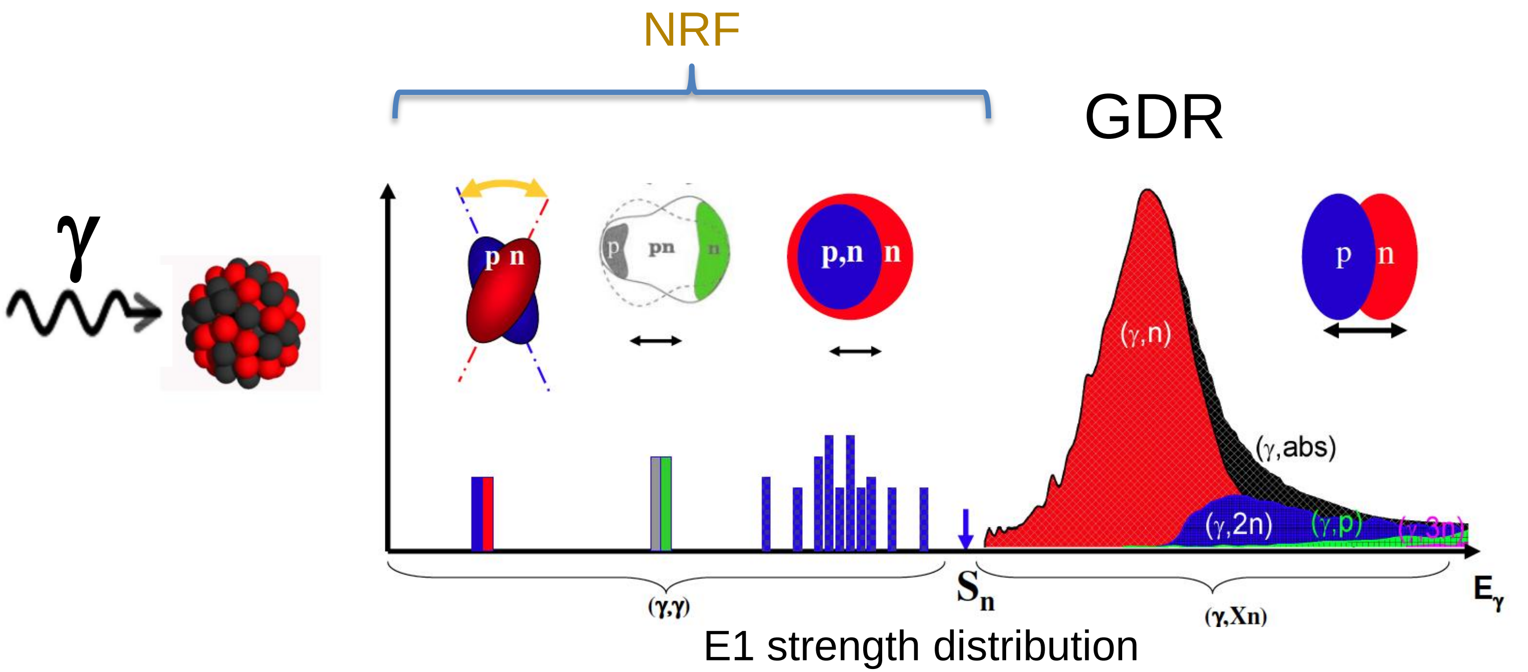
- Modes of excitation below the Giant Dipole Resonance (GDR)

Impact on nucleosynthesis

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

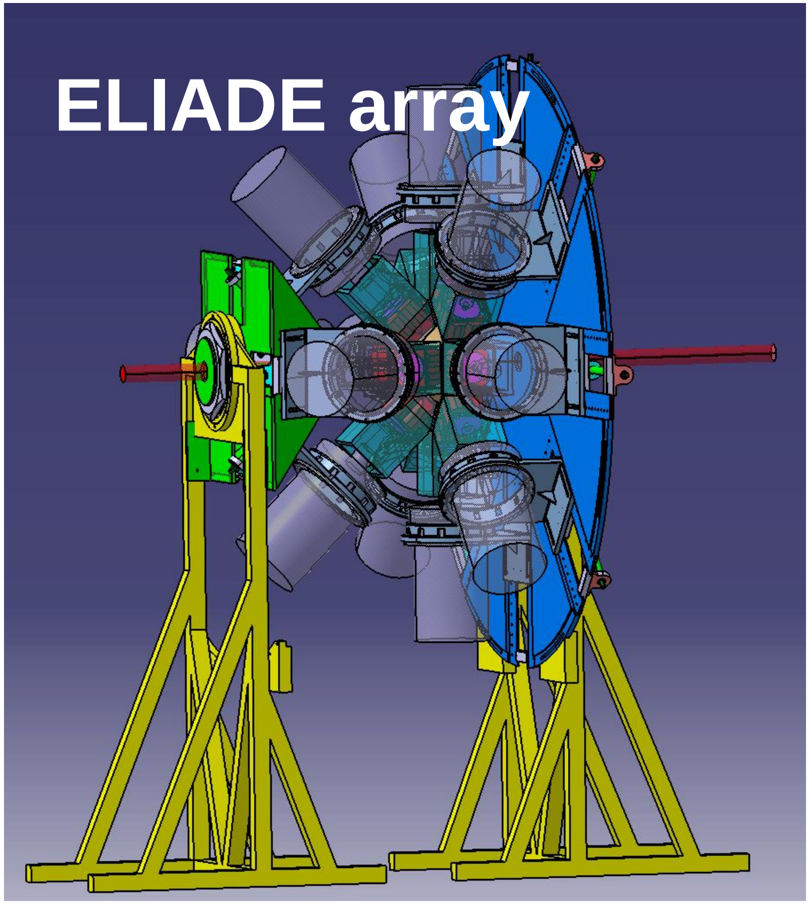
Understanding exotic nuclei

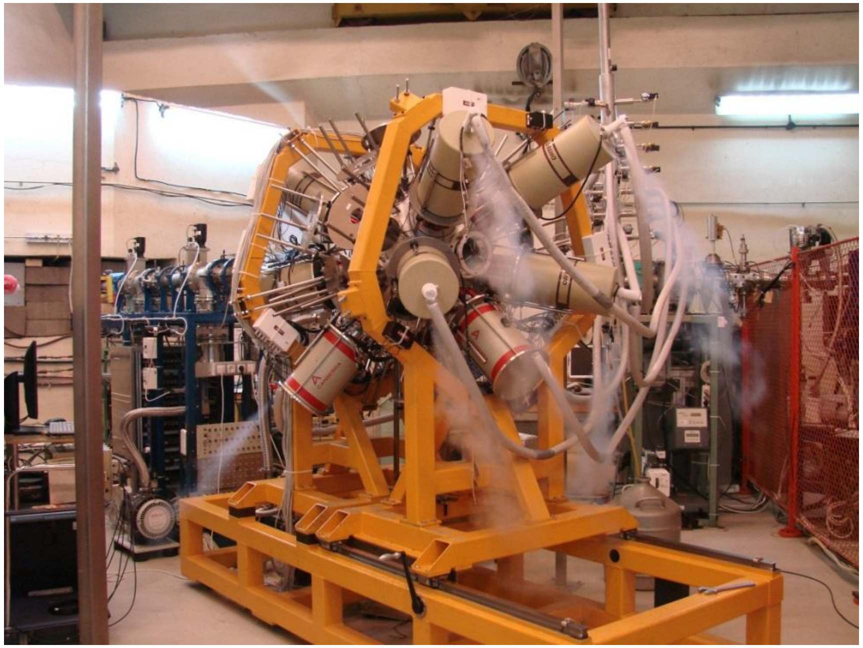
- E1 strength will be shifted to lower energies in neutron rich system

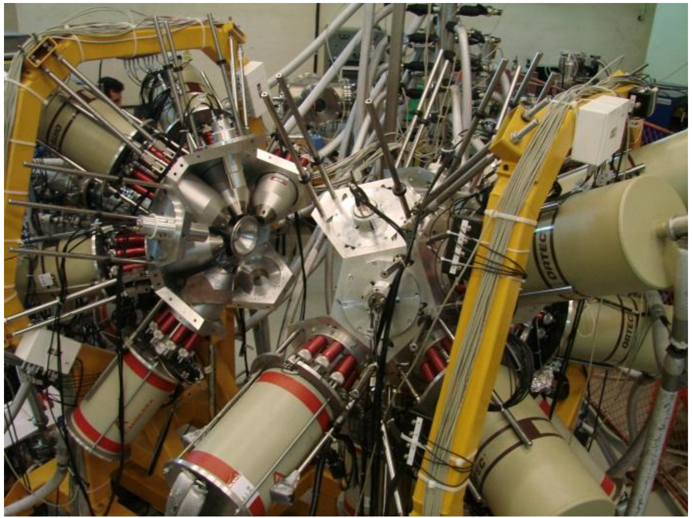


N. Pietralla

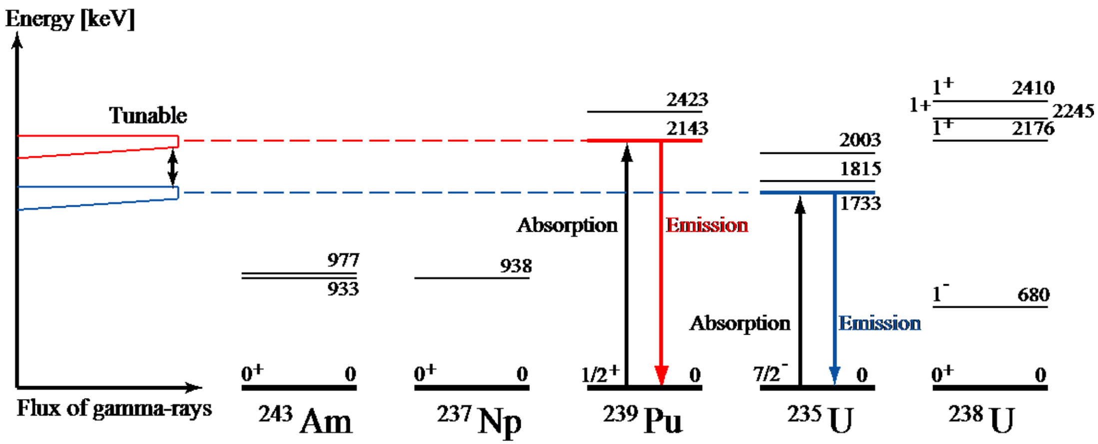
NRF γ-ray spectroscopy

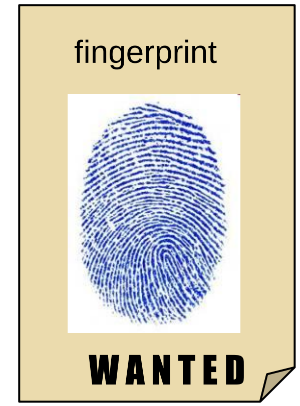




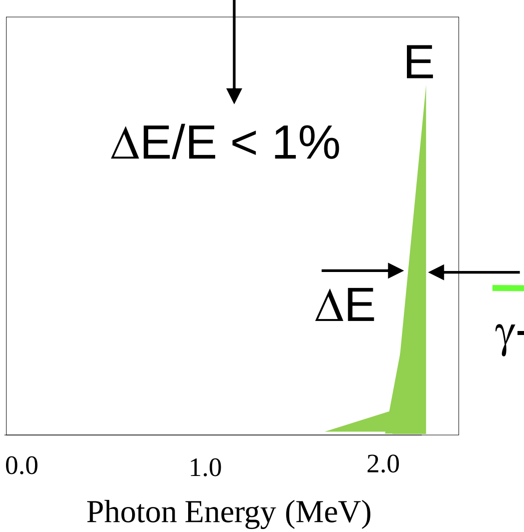


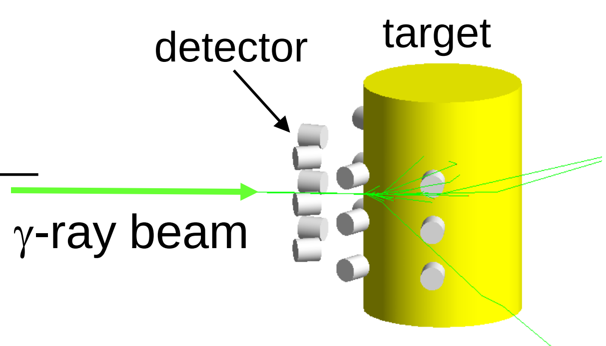
Applications of NRF to Nuclear Materials



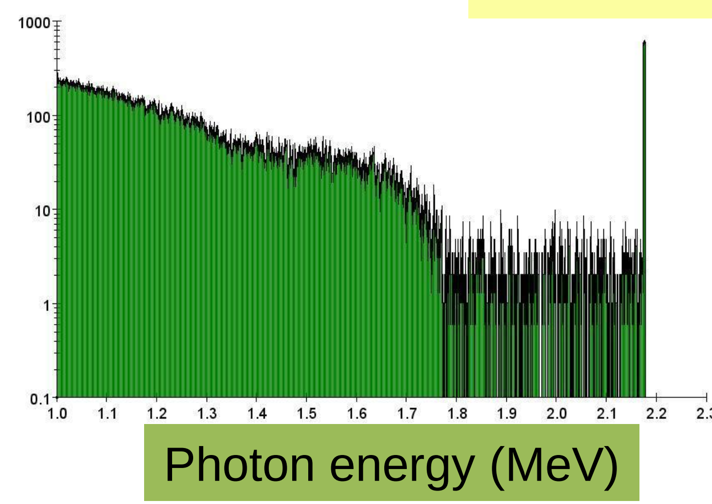


2.176 MeV for U-238





NRF signal
U-238
2.176 MeV

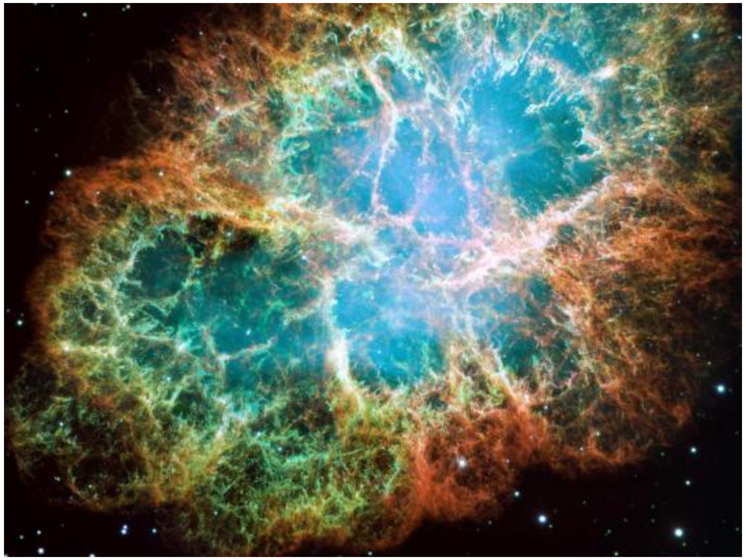


Astrophysics: s- and p - process

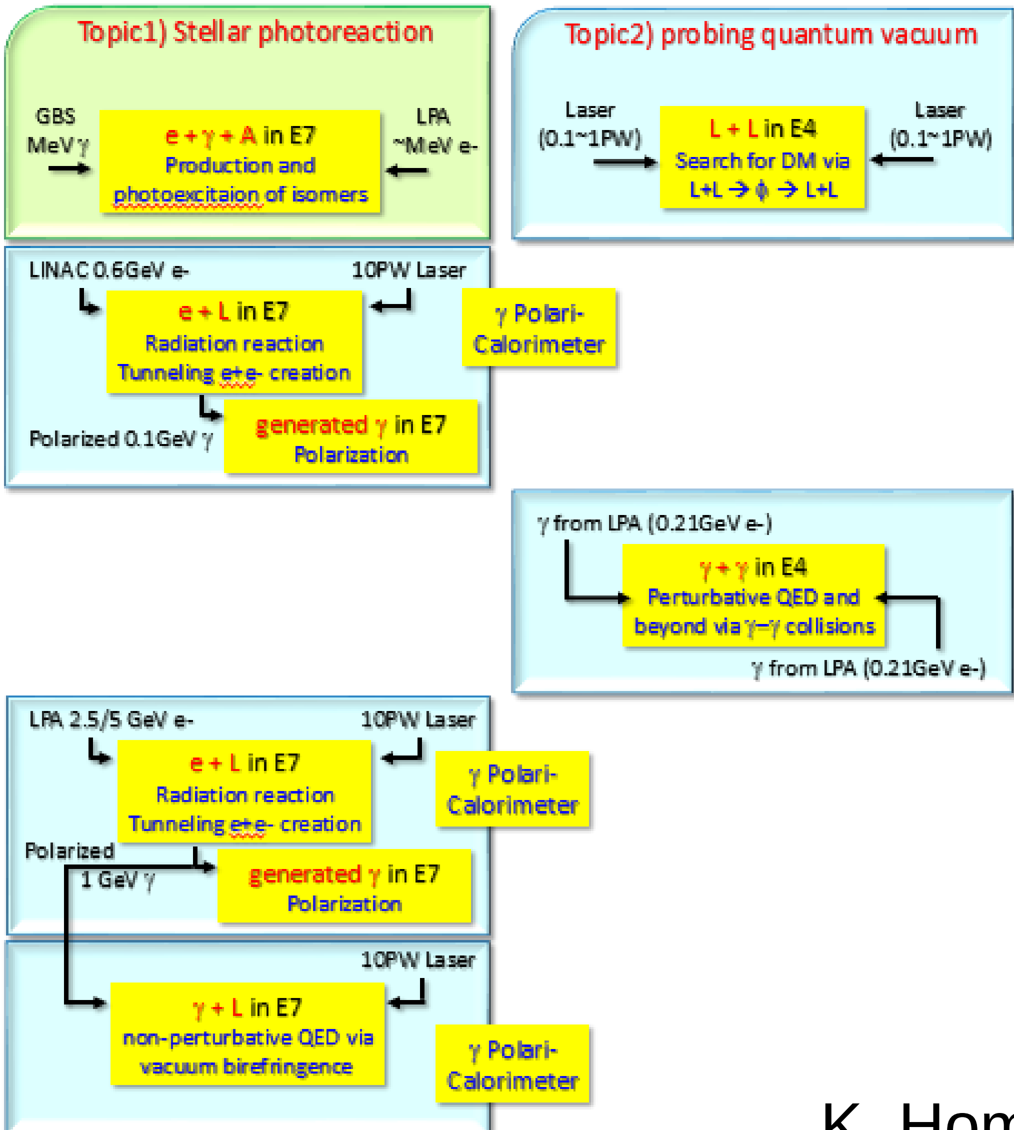
- Neutron Capture Cross Section of s-Process Branch in Inverse Reactions (γ, n)

- Measurements of (γ, p) and (γ, α) Reaction Cross Sections for p –process-Nucleosynthesis

key reaction $\gamma + ^{16}O \rightarrow ^{12}C + \alpha$

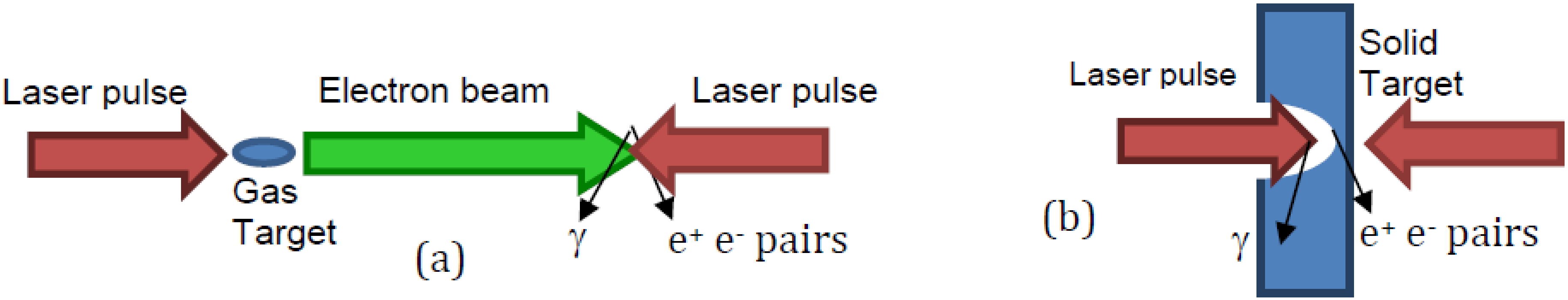


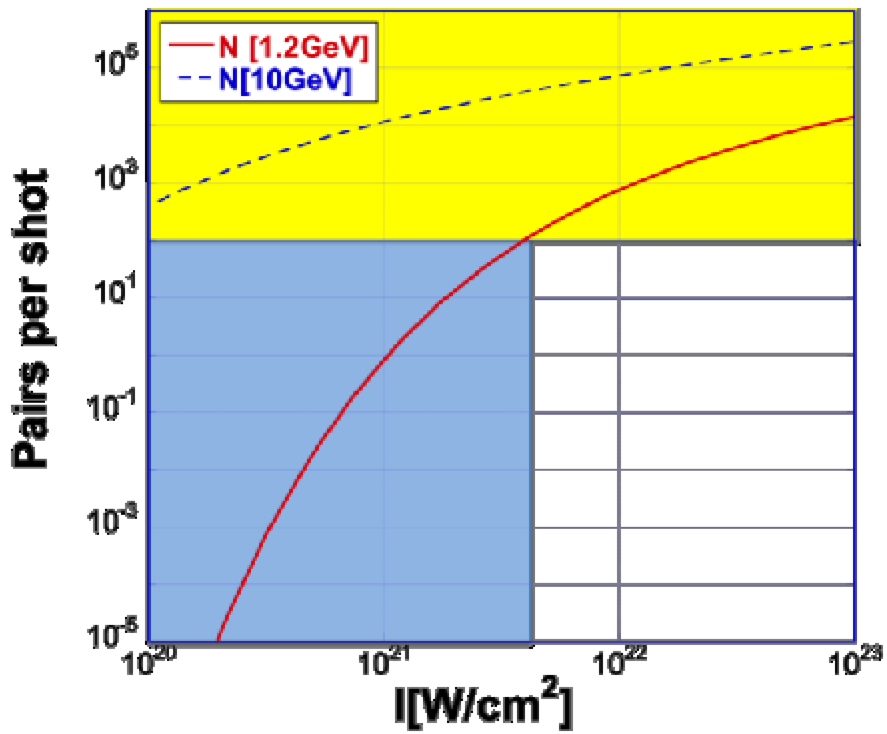
Combined Laser Gamma Experiments



K. Homma, Keita Seto, O.

High Field Physics and QED Experiments

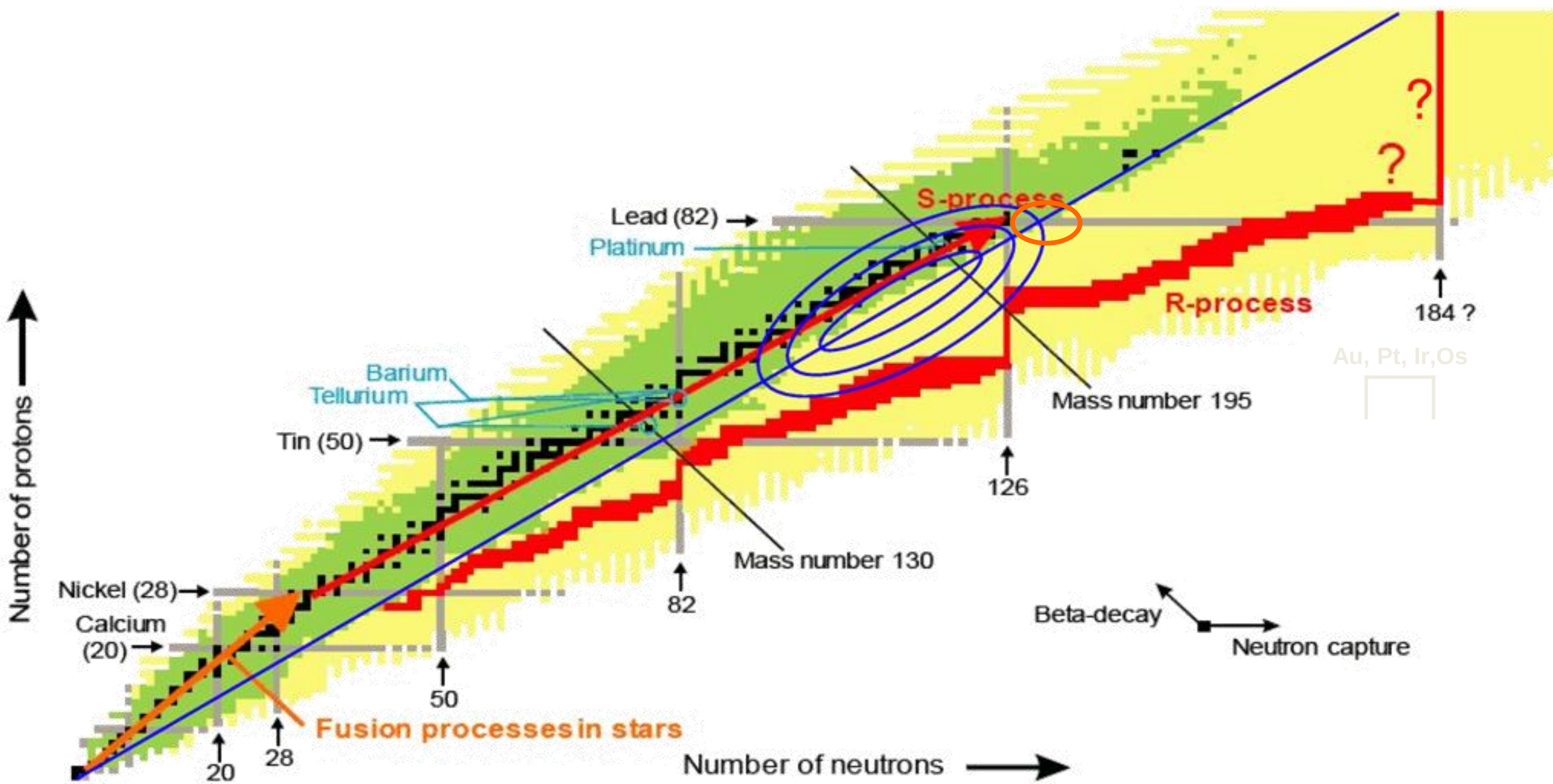




D. Jaroszynski et

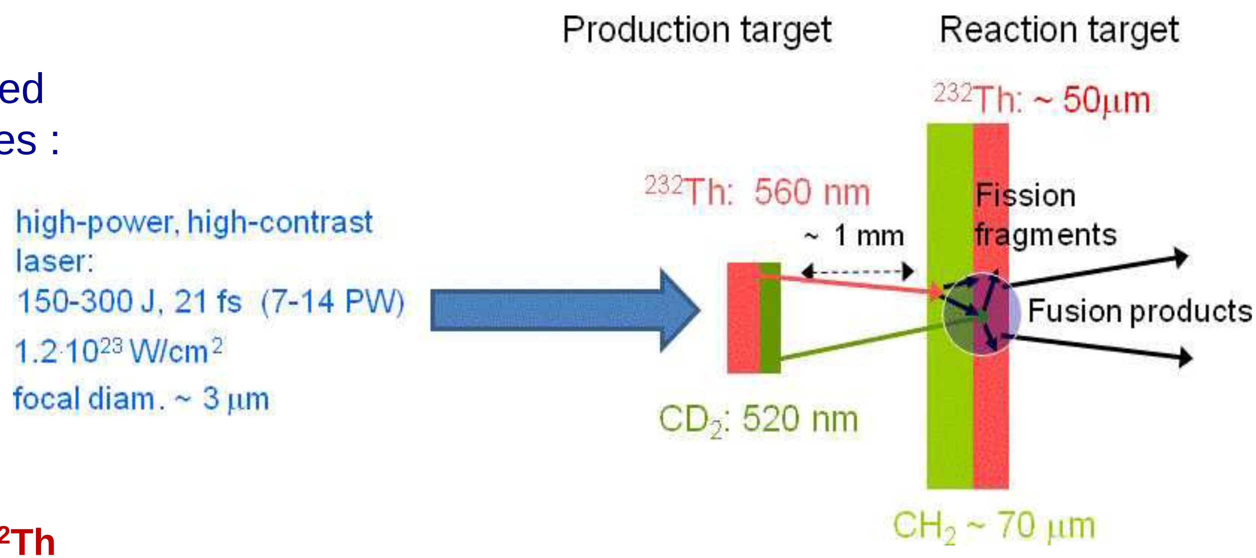
Astrophysics

- **s-process:** (γ, n) reactions
- **p-process** (γ, p) and (γ, α) Reactions; key reaction $\gamma + {}^{16}O \rightarrow {}^{12}C + \alpha$
- **r-process:** N=126, bottleneck for understanding nucleosynthesis of actinides

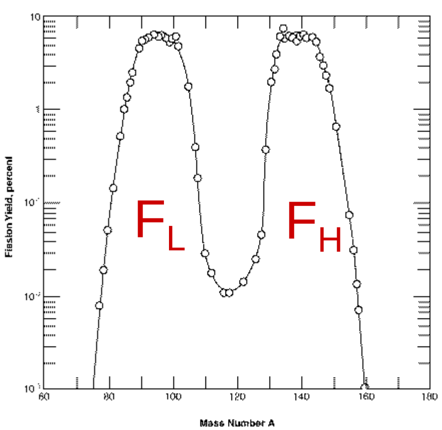


Laser Nuclear Physics Experiment

Study of exotic nuclei of astrophysical interest produced using high density ion bunches :
fission–fusion reactions.
n–rich nuclei
around N = 126 waiting point



Mass distribution of fission of ^{232}Th



$\langle A_L \rangle$ ~ 91, ΔA_L ~ 14 amu (FWHM)

ΔAL ~ 22 amu (10%)

$\langle Z_L \rangle$ ~ 37.5 (Rb,Sr)

Fusion of (light) fission products :

$F_L + F_L$ => (A~200, Z~70, N ~ 126)

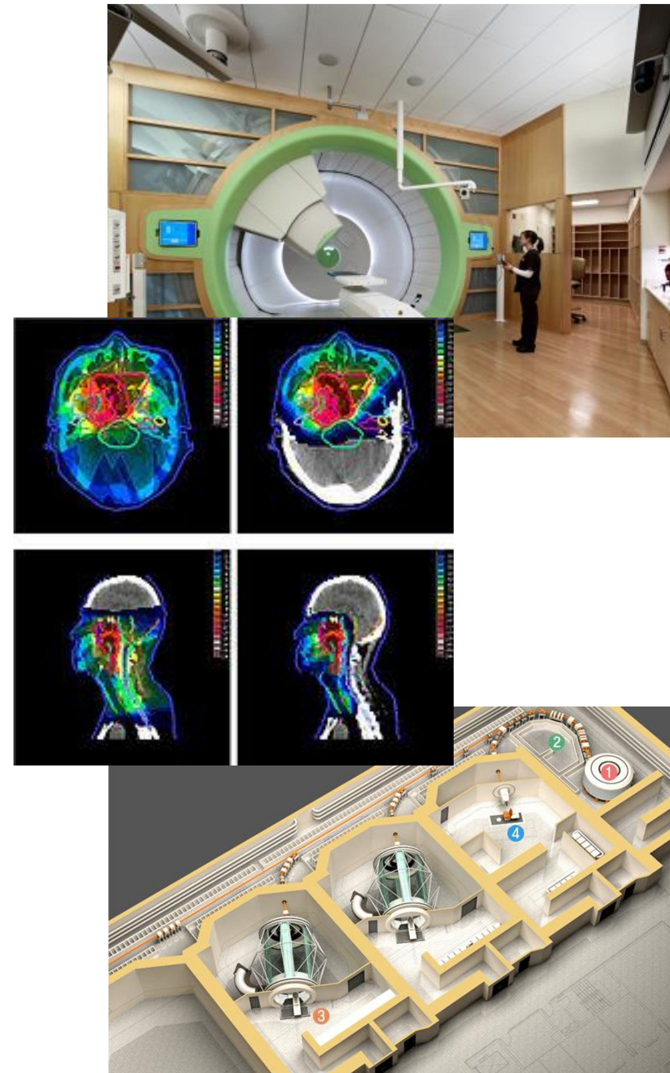
Proposal of D. Habs, P.Thirolf – LMU (Germany)

Nuclear Photonics Applications

from C. Barty (Lawrence Livermore National Laboratory)

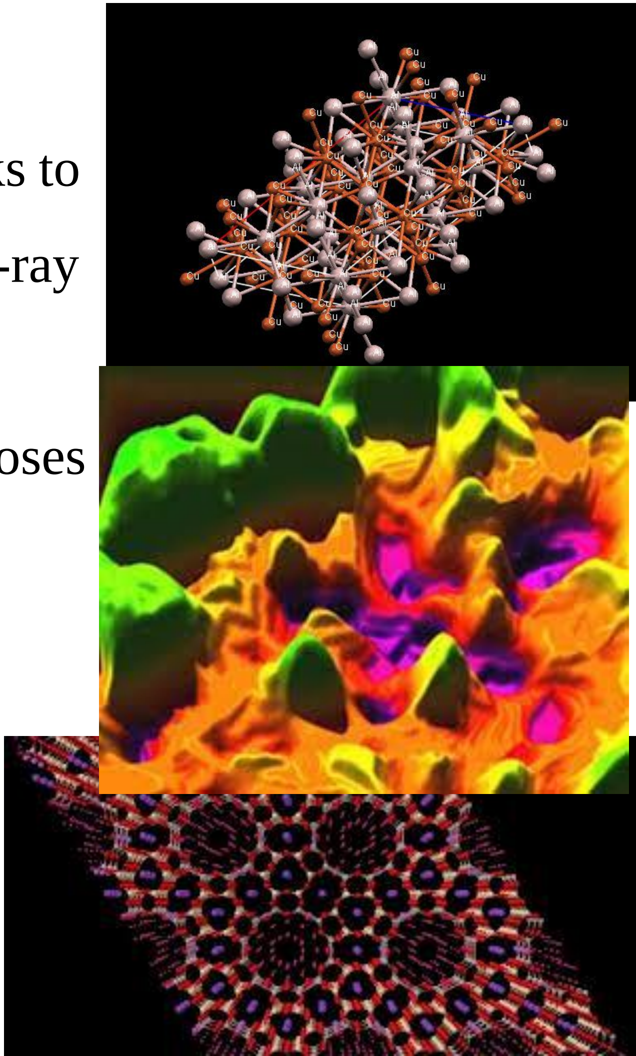
Radioisotopes for medical use

- **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

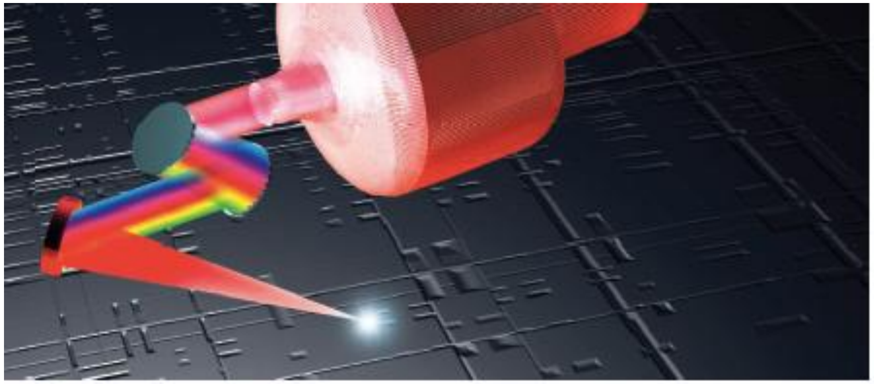


Materials Science and Engineering

- novel experimental studies of material behavior – thanks to extreme fields intensity provided by the laser and gamma-ray beams
- the behavior of materials subject to extreme radiation doses
- **polarized positron beam – new microscopy**



Exciting Perspectives in Accelerators field



Enormous reduction in scale

PARTICLE PHYSICS

Europe Aims for a Cut-Rate Superlaser To Power Future Particle Accelerators

Could the light at the end of high-energy physics' increasingly long tunnels be ... light? The field's appetite for ever more powerful accelerators is running up against society's willingness to pay. The Large Hadron Collider (LHC) at CERN, the European particle physics laboratory near Geneva, Switzerland, with its 27-kilometer circular tunnel and detectors the size of cathedrals, cost close to $10 billion. Next, physicists want to build the 31-kilometer-long International Linear Collider at up to $25 billion, and they are talking about even bigger machines and longer tunnels. Sooner or later, these ambitions will be stymied—unless some new, radically cheaper accelerator technology succeeds. A team of European physicists sees hope in the light of simple fiber-optic lasers.

"People said it was crazy."
—GÉRARD MOUROU
ÉCOLE POLYTECHNIQUE, PALAISEAU, FRANCE

Researchers have known for decades that laser pulses can accelerate charged particles, but only in the past few years have they produced beams of high enough quality for particle physics. The remaining stumbling block is quantity: Lasers that can produce sufficiently intense pulses at high enough repetition rates with reasonable efficiency just don't exist.

Now, a consortium of European physics labs says that it can meet the necessary spec without building a new superlaser. The trick is to take fiber lasers—a workhorse of the telecommunications industry—and combine their output into a superbeam. In an 18-month pilot project funded by €500,000 from the European Union, the labs coaxed 64 fiber lasers to merge their beams smoothly. If the European Union's next 7-year research budget allows—it is now being finalized—they hope to scale up to a full-size demonstrator with thousands of fibers.

Physicists are reaching the limits not only of national budgets, but also of technology. To search for new physics, they would ultimately like to accelerate leptons, such as electrons and positrons, to energies in excess of 5 trillion electron volts (5 TeV). But doing so with today's technology would consume hundreds of megawatts (MW) of electricity—the entire output of a medium-sized power station. "There is no technology for over-5-TeV lepton colliders," says Roy Aleksan of France's Atomic Energy Commission lab at Saclay. The problem is that the radio-frequency waves now

cles: ions, and elect
If a high-powered p
into a plasma, the t
the light pushes the
out of the way but
heavier ions, leavin
deficient bubble of
by a region of nega
electrons rush back
ful electric field pa
tion of travel. This
huge boost in speed
from the plasma or
cially injected to ta

When Dawson
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however, Gérard
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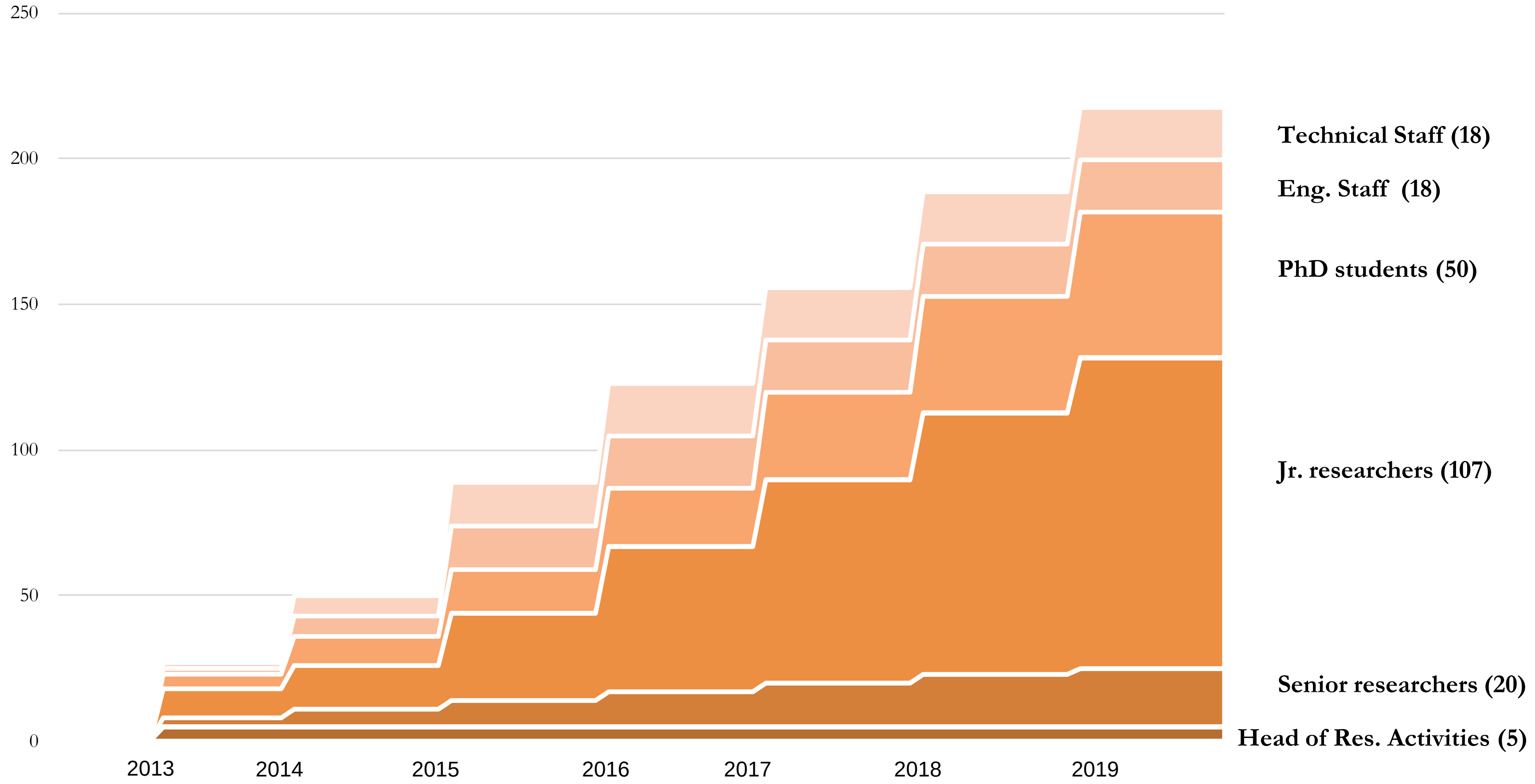
devised chirped pu
This takes a mod
laser pulse and str
ger, lower-powered
gated pulse throug
its energy, and so
to its original lengt
power. Almost all
power lasers use C
(10^{15} watt) pulses.

With such pulse
duce accelerating
10 billion to 100
(GV/m), three ord
than conventional

Human Resources



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GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

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"Investments for Your Future!"

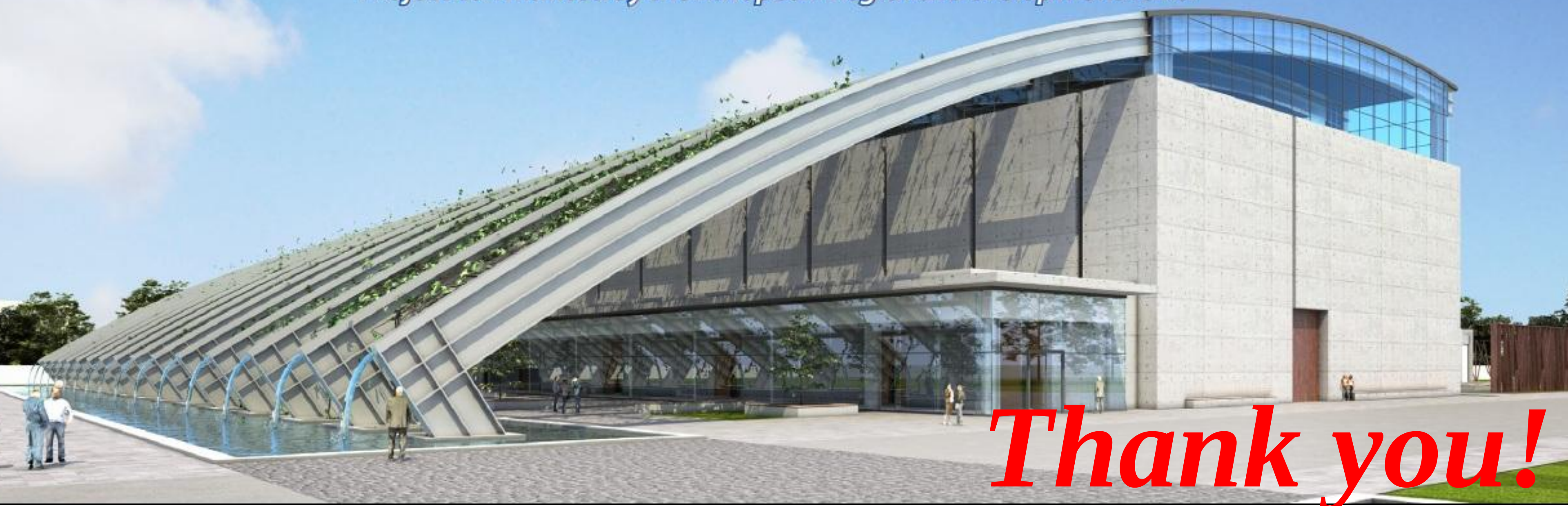
IFIN-HH

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) - Phase I

eli Nuclear Physics

www.eli-np.ro

Project co-financed by the European Regional Development Fund



Thank you!