Nuclear Physics

ELI-NP
Nuclear Science and applications with the next generation of High Power Lasers and Gamma beams

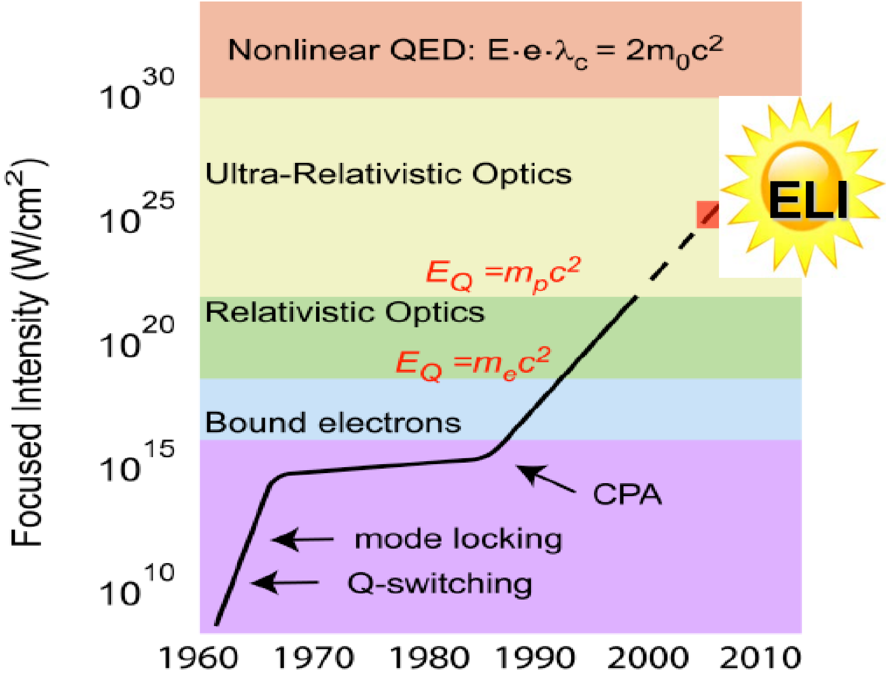
EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

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

S. Gales for the ELI-NP team



Europe has decided
to build the highest
intensity laser ELI
For
Extreme Light Infrastructure

1PW, 1µm~highest power laser today

2006 – ELI on ESFRI Roadmap

ELI-PP 2007-2010 (FP7)

Three Pillars ***(1B€)***

ELI-Beamlines (Czech Republic)
ELI-Attoseconds (Hungary)
ELI-Nuclear Physics (Romania)

Project Approved by the European Competitiveness Council (December 2009)

ELI-DC (Delivery Consortium): April 2010

S.Gales for the ELI-NP team

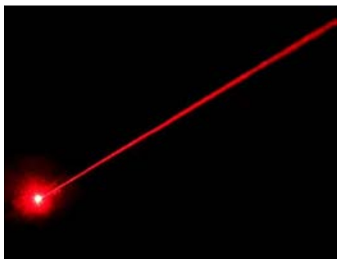
ELI-NP

Observation of matter with new powerful probes

Two machines of extreme performances

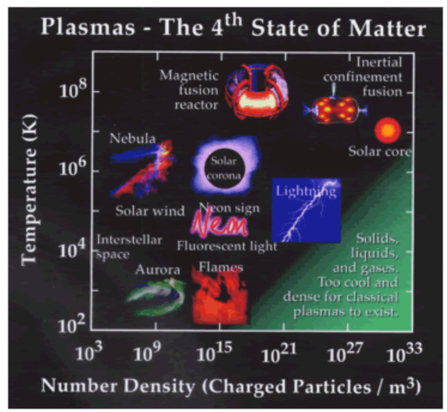
Large discovery potential

Light



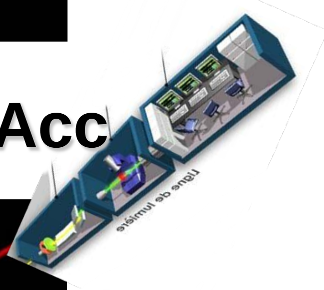
Two 10 PW lasers,10^{23} w/cm^2

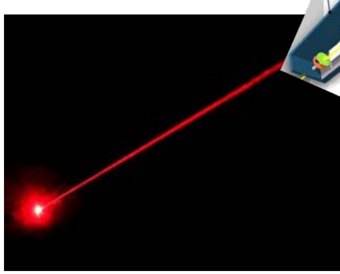
Extreme E-M fields

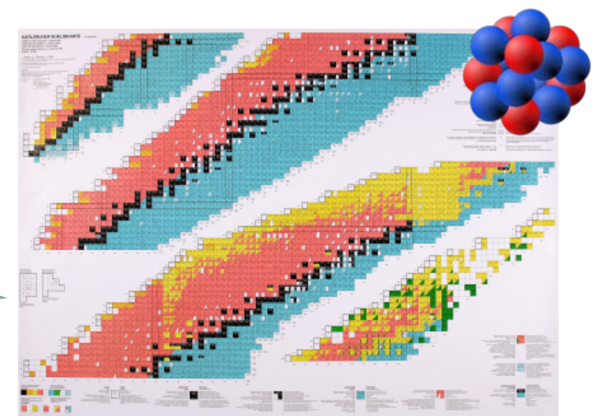


Femto scale

Laser +e- Acc



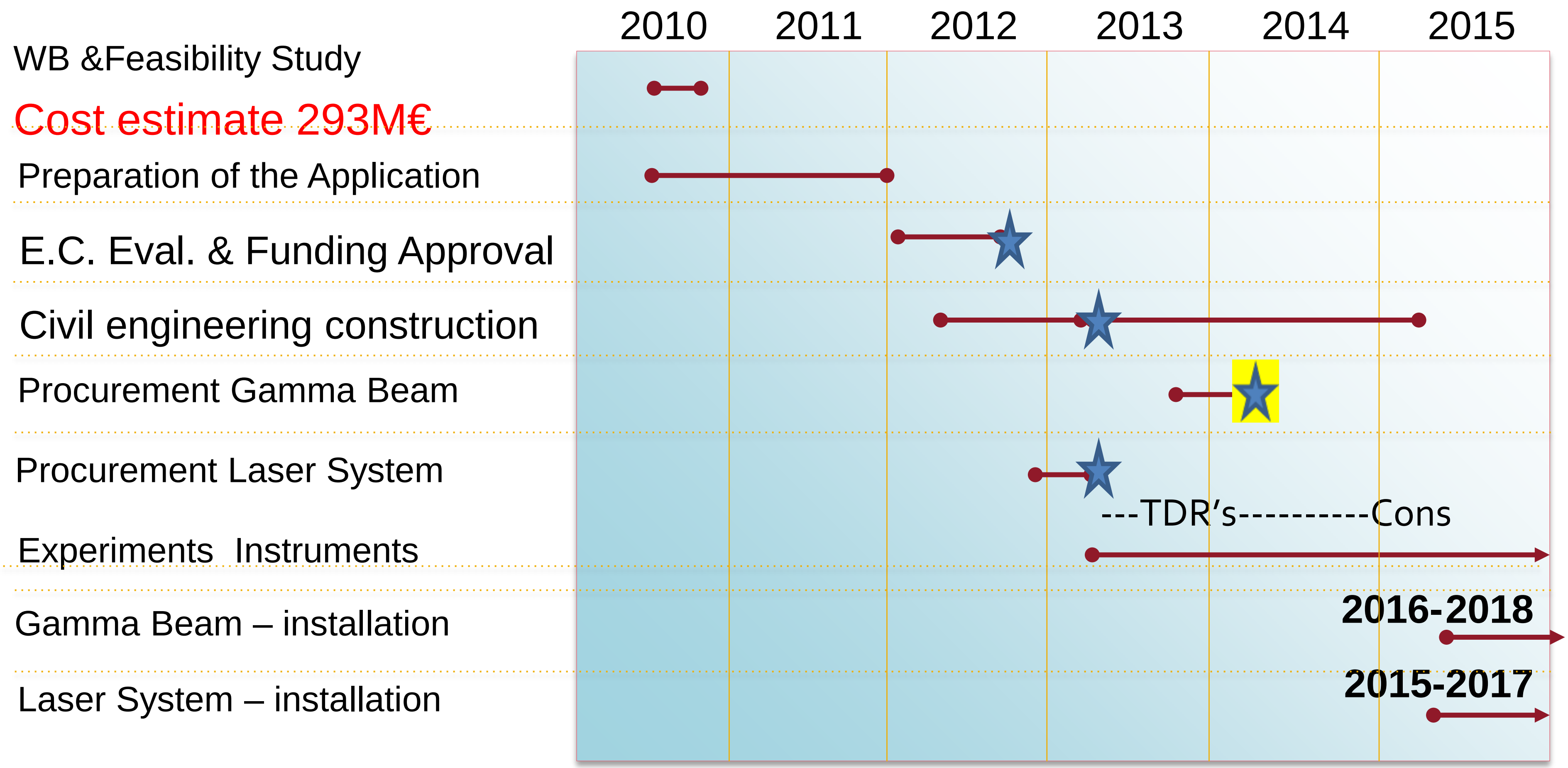




BCS Brillant Gamma Beams
0,2-19 MeV ,$10^{13}\gamma$/s ,0,3% BW

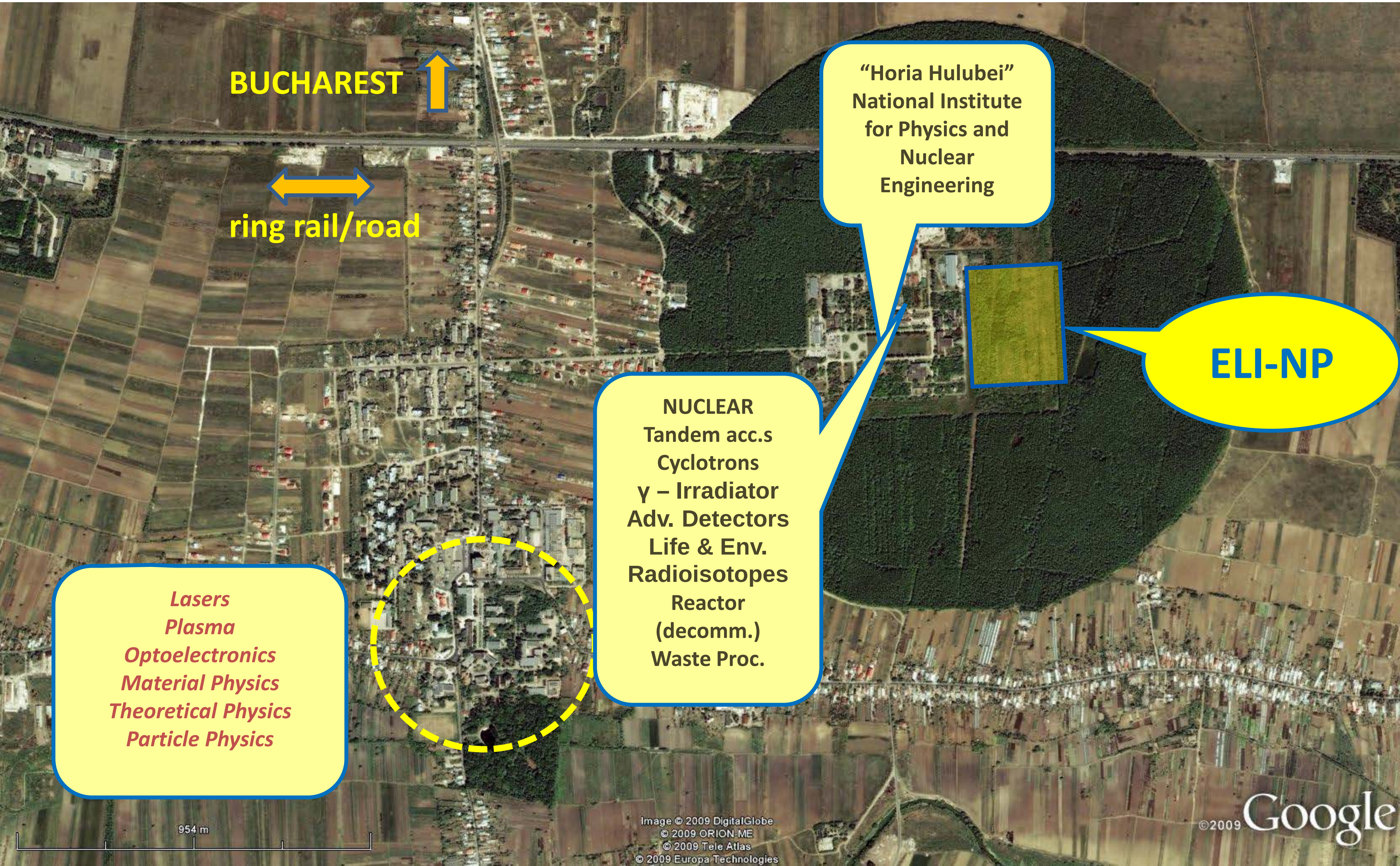
S.Gales for the ELI-NP team

ELI–NP Project Timeline



S.Gales for the ELI-NP team

Bucharest-Magurele Physics Campus
National Physics Institutes



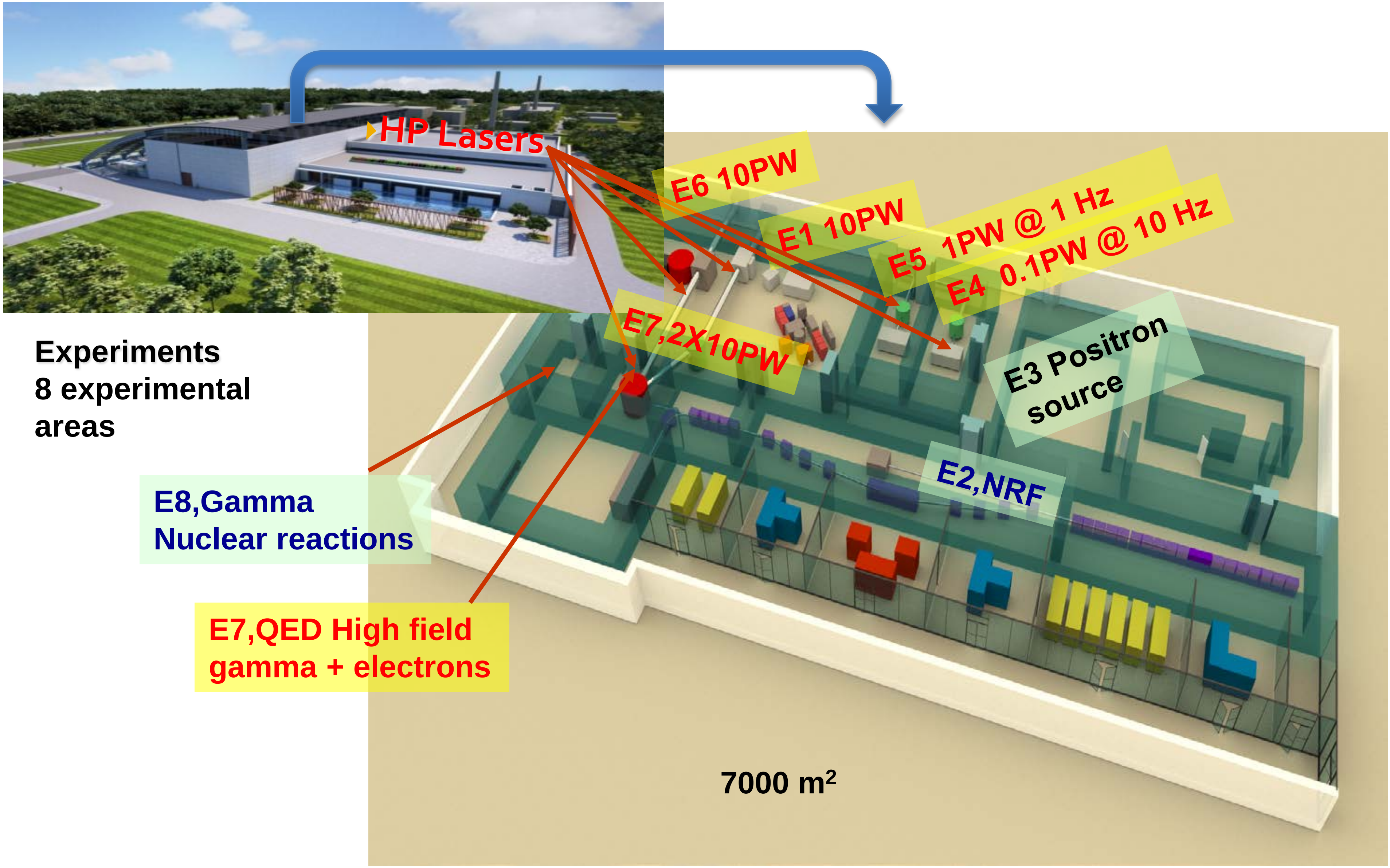
ELI-NP Milestones –Facility Construction

Buildings – one contractor, 33000 m² total

Feb 2014

- Experimental area building
- Office building
- Guest house
- Canteen

ELI–NP Experiment Building



ELI–NP Nuclear Physics Research

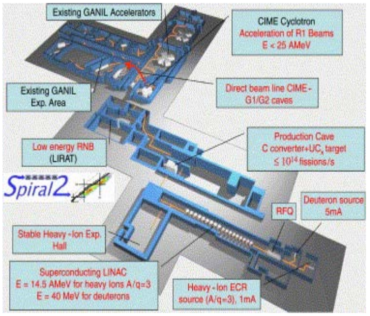
- Nuclear Physics experiments

  Photo–fission & Exotic Nuclei

  Nuclear Photonics (NRF)

  Photo–disintegration, Nuclear Astrophysics

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



- **Laser–Target interaction characteristics : NP diagnostics**
- **Laser Ion driven nuclear physics : fission–fusion**
- **Strong fields QED. Towards High field (Laser + Gamma) and Plasma**

- **Applications based on HPLS and High intensity laser and very brilliant ©beams complementary to the other ELI pillars**

ELI–NP in Romania selected by the most important science committees in Europe – ESFRI and NuPECC, in the ***'Nuclear Physics Long Range Plan in Europe'*** ***as a major facility***

ELI–NP Scientific Coordination

Scientific Director

International Workgroups

Gamma Beams System

1. Gamma Beam Delivery & Diagnostics
2. NRF Experiments and applications
3. Photo–fission experiments
4. (γ,n) experiments
5. (γ,p) experiments
6. Positron source for material science

Convener ⟷ local liaison

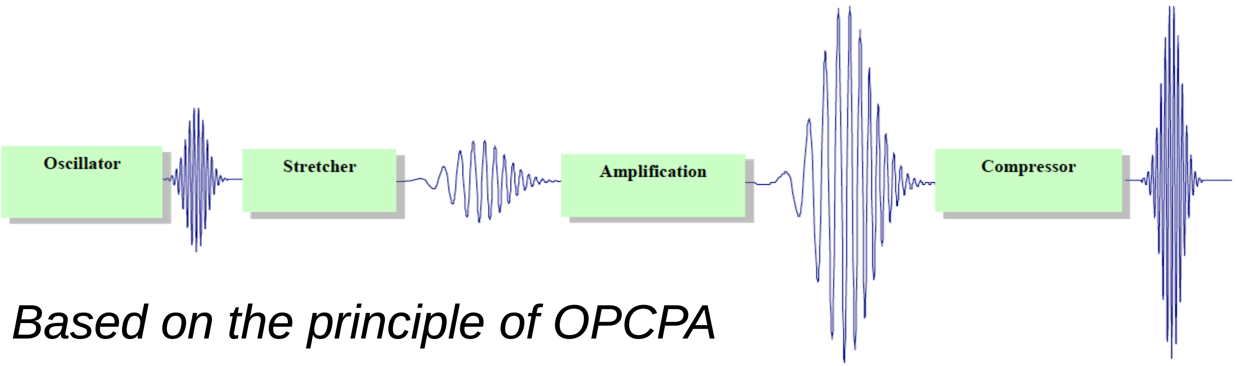
High–Power Laser System

1. Laser delivery and beam lines
2. Fission–fusion experiments
3. Strong field QED
4. Laser + Gamma interaction
5. Applications

Convener ⟷ local liaison

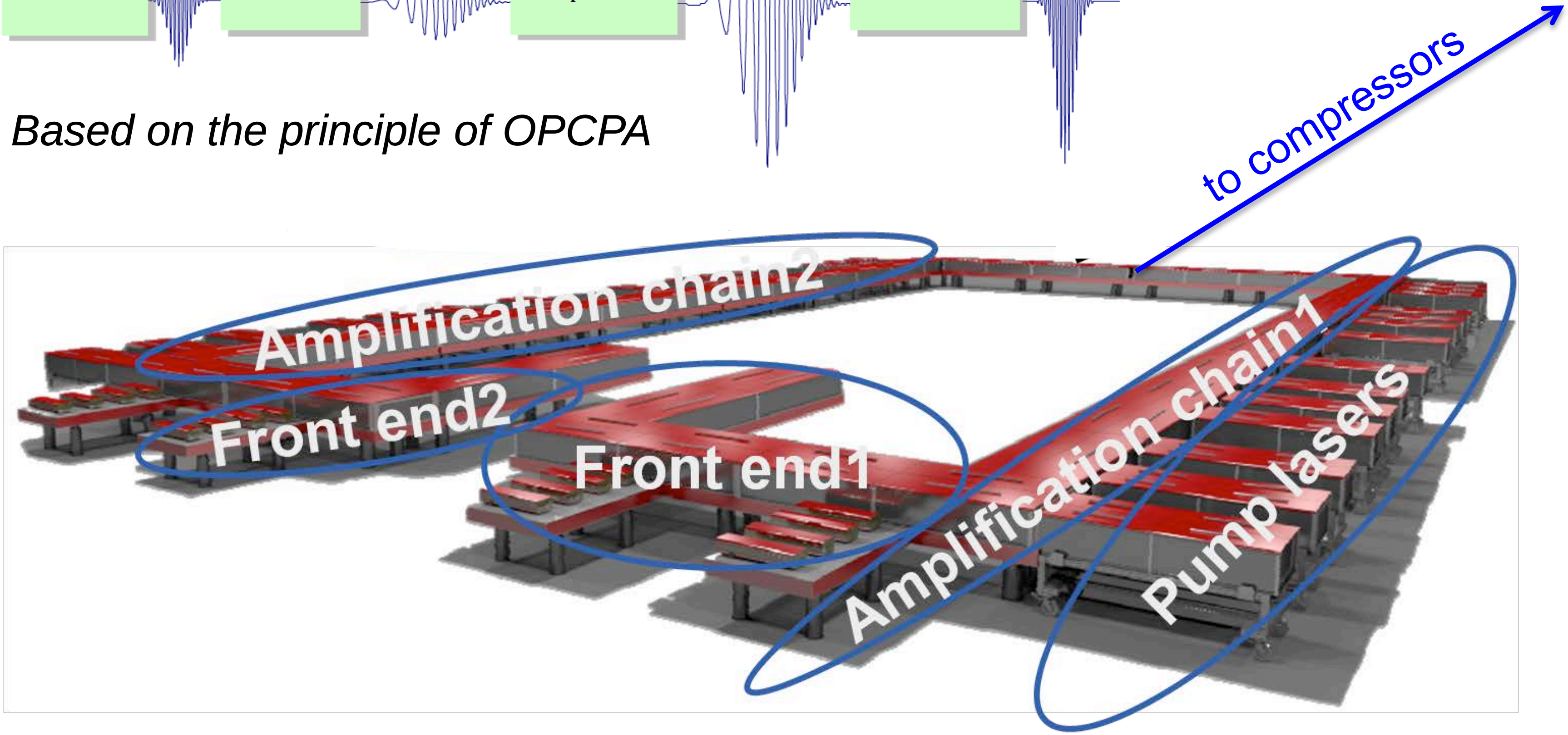
ELI–NP HPLS

Provided by THALES - France

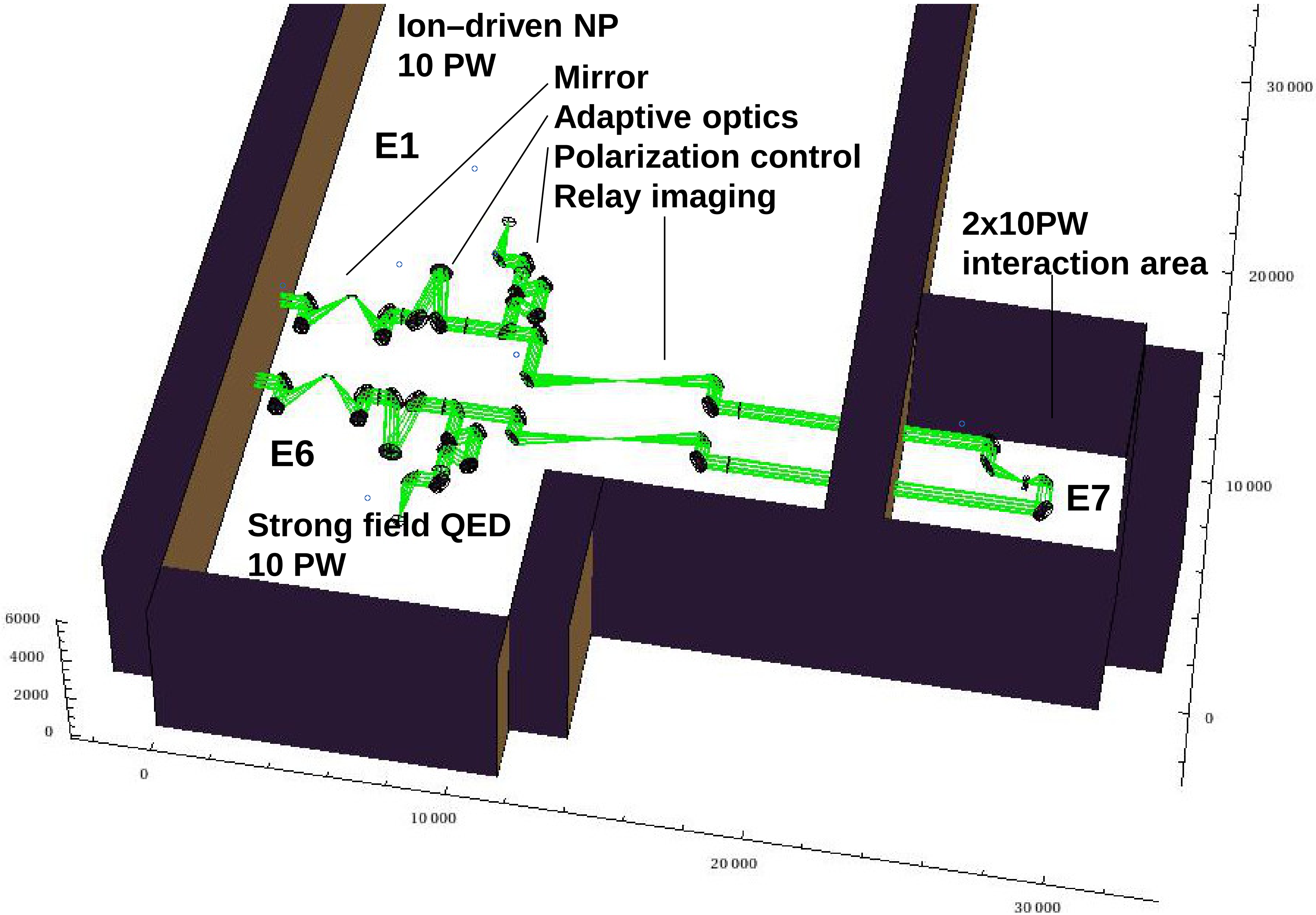


Based on the principle of OPCPA

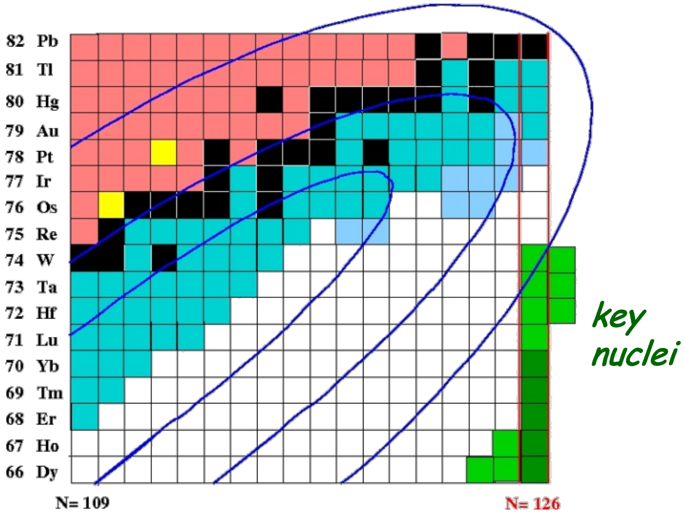
2 x 0.1 PW
2 x 1 PW
2 x 10 PW



HPLS Delivery



Laser Driven NP at ELI–NP

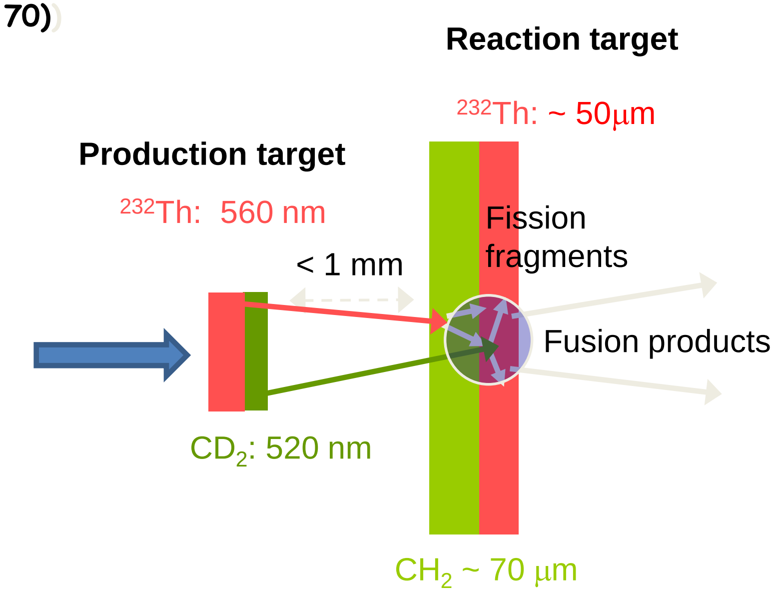


15 neutrons away
from r process path (Z≈ 70)

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

high-power, high-contrast laser:

- **300 J, ~30 fs (10 PW)**
- **~10^{23} W/cm^2**
- **focal diam. ~ 3 μm**



D.Habs, P.Thirolf et al., Appl. Phys. B 103, 471 (2011)

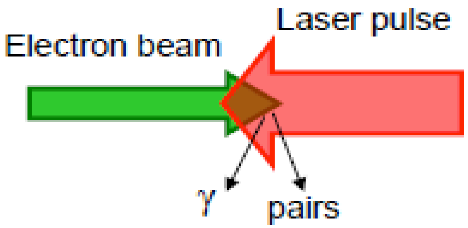
- ***Study of heavy ions acceleration mechanism at laser intensities > 10^{23} W/cm^2***
- ***Deceleration of very dense electron and ion beams***
- ***Understanding influence of screening effect on stellar reaction rates using laser plasma***
- ***Nuclear techniques for characterization of laser–induced radiations***

Strong Field QED

ELI–NP delivering pulse at > 10^{23} W/cm^2 will enable this exciting new regime to be investigated

Require electrons with a large Lorentz factor (γ) interacting with strong electromagnetic fields.
Ultra-intense lasers should be able to provide both the Lorentz factor and the fields

(1) Interaction of GeV electron beam (Wakefield) with TW-PW laser

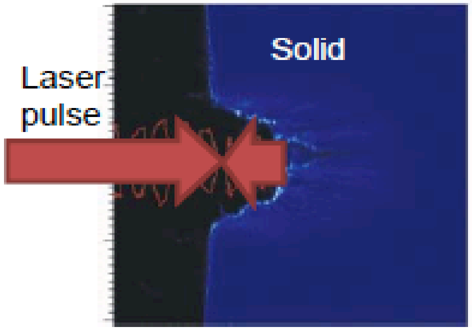


(2) >10PW laser pulse interactions with dense plasma

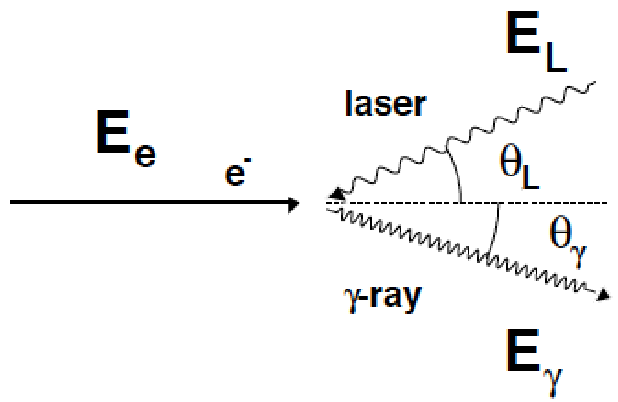
Reaction rates are high due to high electron density

10PW=10^{23} Wcm^{-2} $\rightarrow$ γ=300 $\rightarrow$ $\eta\approx0.2$

A.R. Bell & J.G. Kirk, Phys Rev Lett, 101, 200403 (2008)



The Gamma Beam System



Laser Compton Back–scattering (LCB)

- **the most efficient frequency amplifier**

'Photon accelerator'

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

$\frac{4\gamma_e E_L}{mc^2}$ = recoil parameter ;

$a_L = \frac{eE}{m\omega_L c}$ = normalized potential vector of the laser field;

E = laser electric field strength; $E_L = \hbar\omega_L$

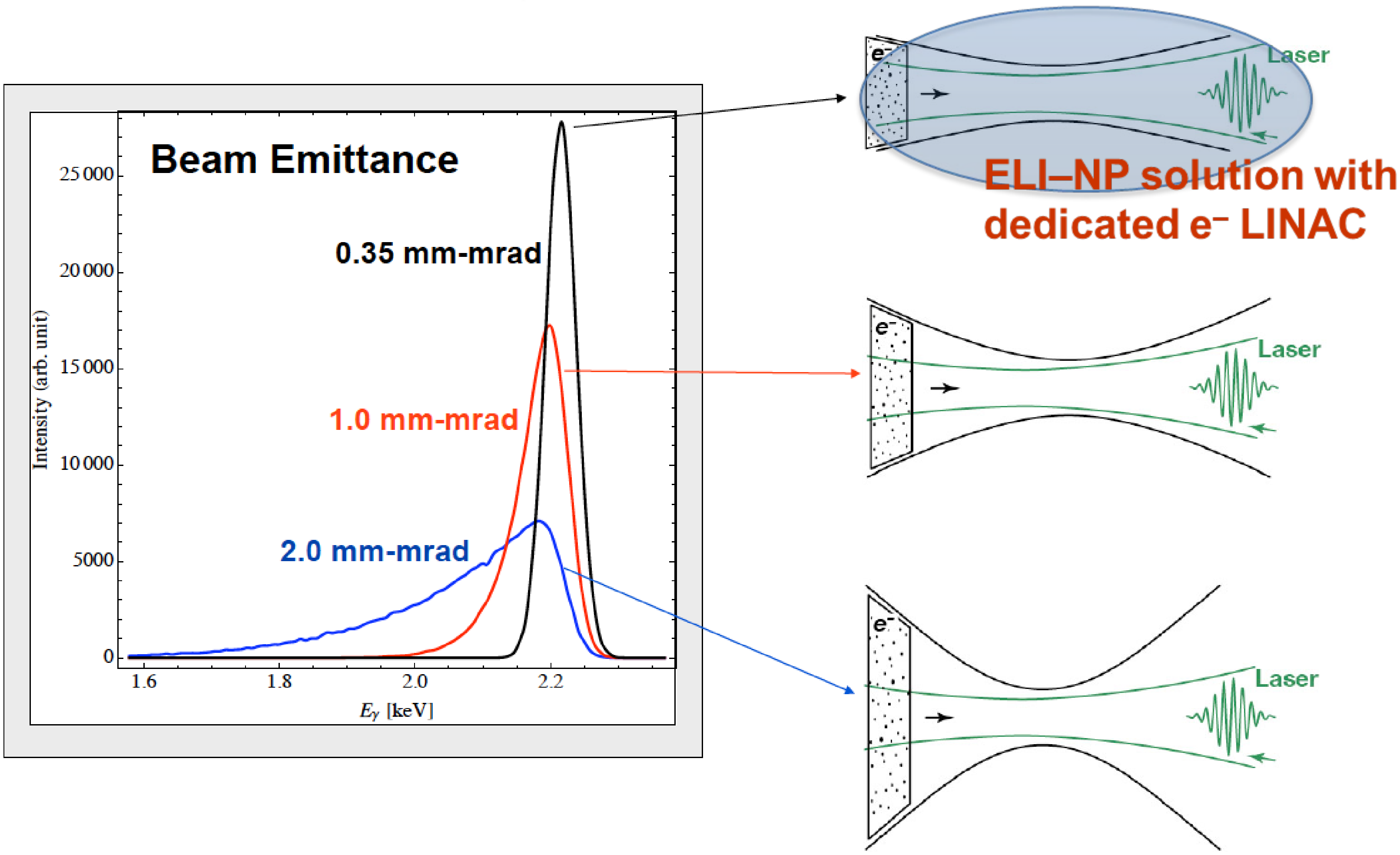
Low cross section (~10^{-25} cm^2) ➡ need of high photon and electron densities

Maximum upshift

- head–on collision (θ_L=0) & backscattering (θ_γ=0) $E_\gamma \sim 4\gamma_e^2 \cdot E_L$
- **E_L ~ 2.4 eV (green)**
  - **E_e ~ 300 MeV** ➡ **E_γ < 3.5 MeV**
  - **E_e ~ 720 MeV** ➡ **E_γ < 20 MeV**

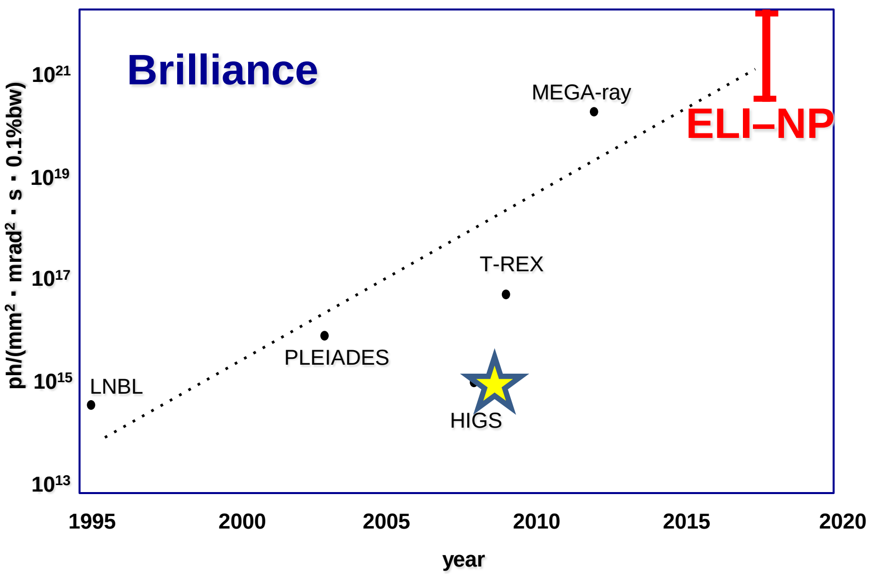
GBS – Bandwidth & Brilliance

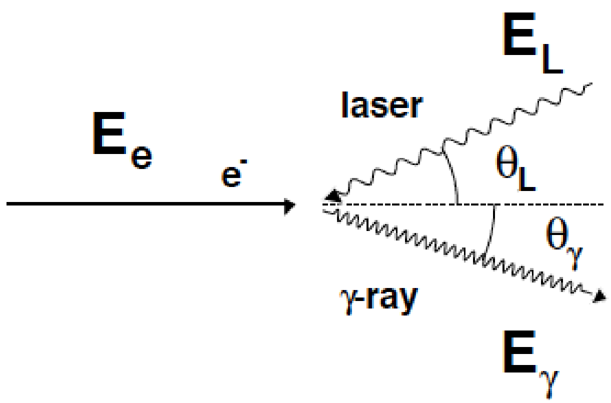
Low emittance e⁻ beam → improve gamma beam bandwidth & brilliance



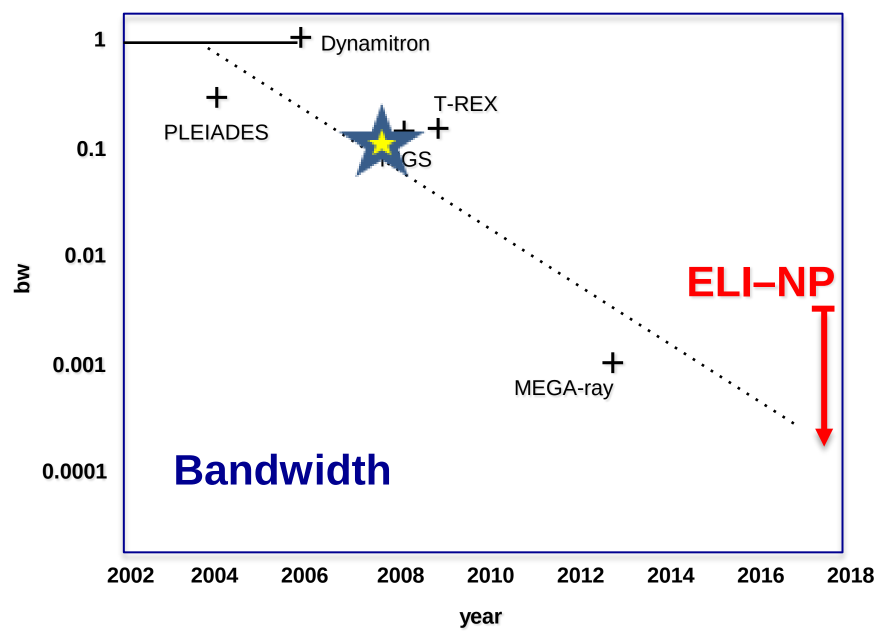
C.Barty – ELI–NP Gamma Source Meeting, Bucharest, August 18, 2011

ELI–NP Gamma Beam System



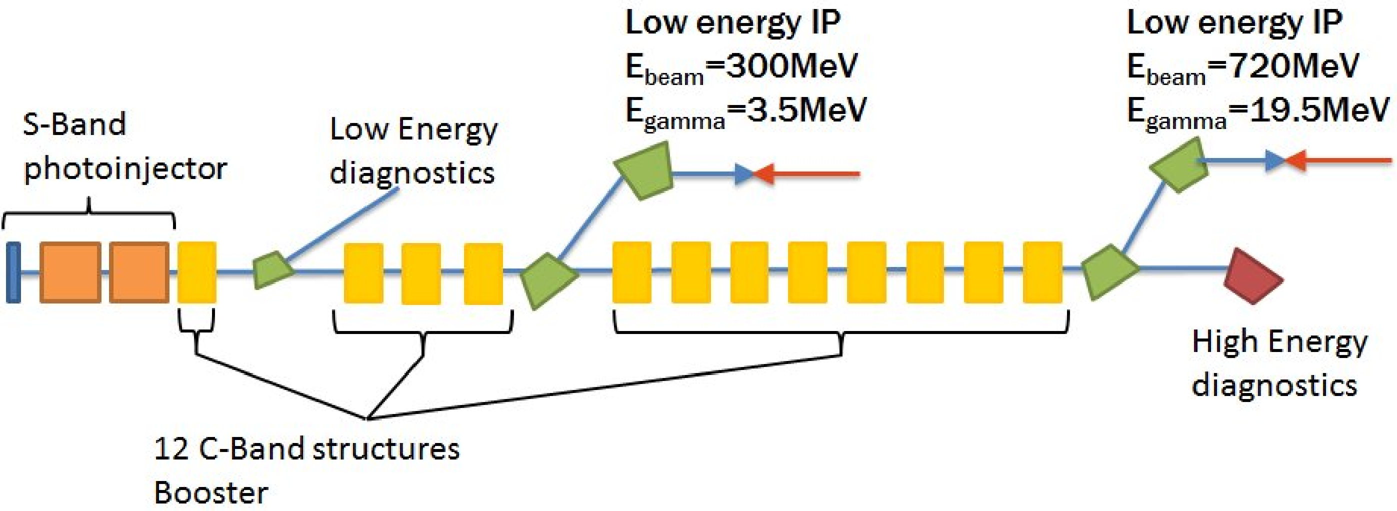


- high intensity / small emittance e⁻ beam from a warm LINAC
- very brillant high rep./rate int. laser
- small collision volume



GBS – The Eurogammas Proposal

In the **context of the ELI-NP Research Infrastructure**, to be built at Magurele (Bucharest, Romania), an advanced Source of Gamma–ray photons is planned, capable to produce beams of mono-chromatic and high spectral density gamma photons. The **Gamma Beam System is based on a Compton back–scattering** source. Its main specifications are: photon energy tunable in the range 1–20 MeV, rms bandwidth smaller than 0.5% and spectral density larger than 10^4 photons/s/eV, with source spot sizes smaller than 10–30 microns.



Bunch charge	250 pC
Number of bunches	32
Bunch distance	16 ns
C-band average accelerating gradient	33 MV/m
Norm. emittance	0.2-0.6 mm·mrad
Bunch length	<300 μm
RF rep Rate	100 Hz

GBS – Experimental Setups

E3: Positron spectroscopy

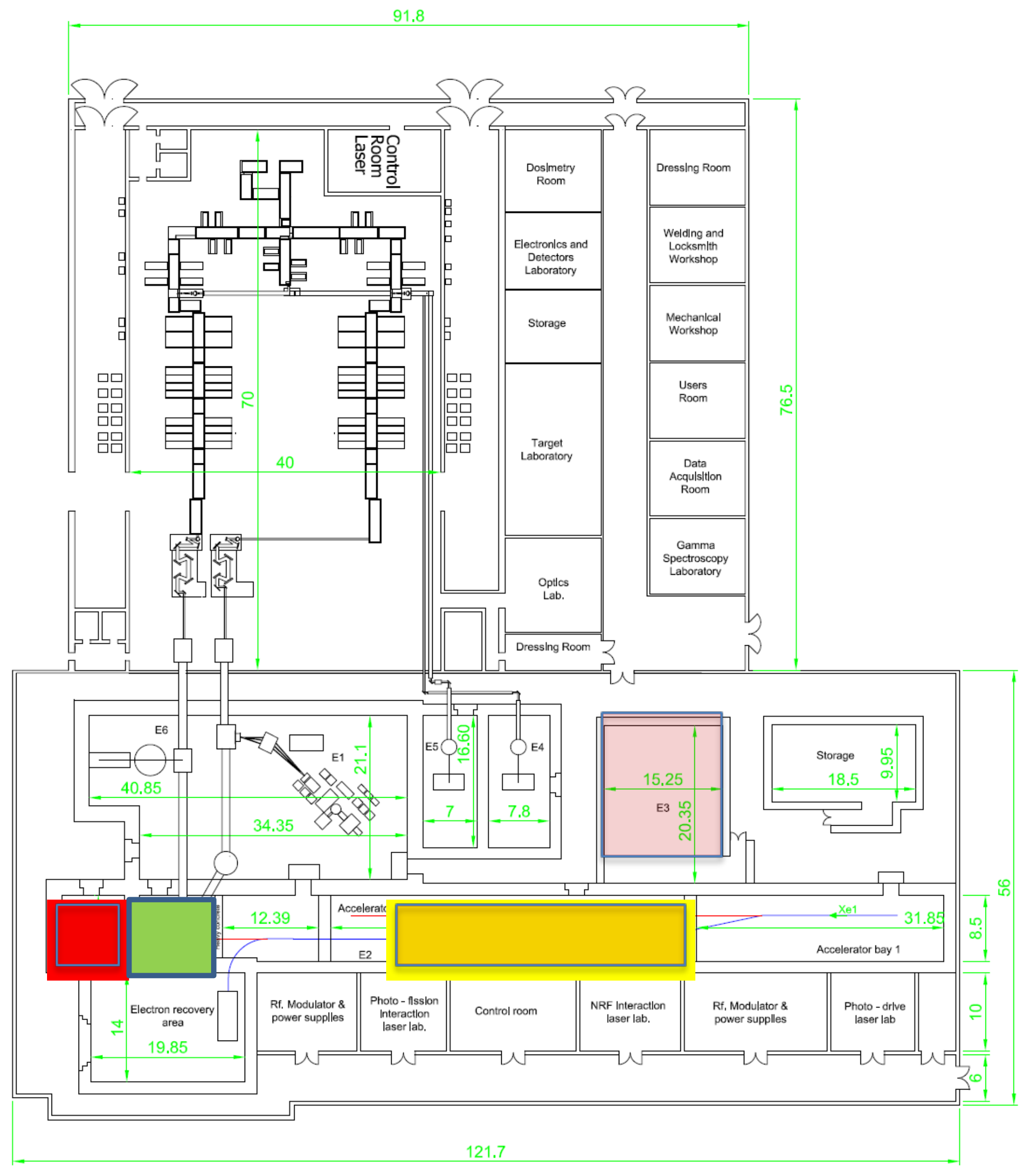
E2: Low energy gamma vault

- Nuclear Resonance Fluorescence
- Isotope-specific material detection, assay and imaging
- Photofission
- Medical isotopes

E8: High energy gamma vault

- (γ,*n*) cross sections
- NRF
- Photofission

E7: Experiments with combined laser and gamma beams



NRF – Physics case

Electromagnetic dipole response of nuclei

Nuclear structure

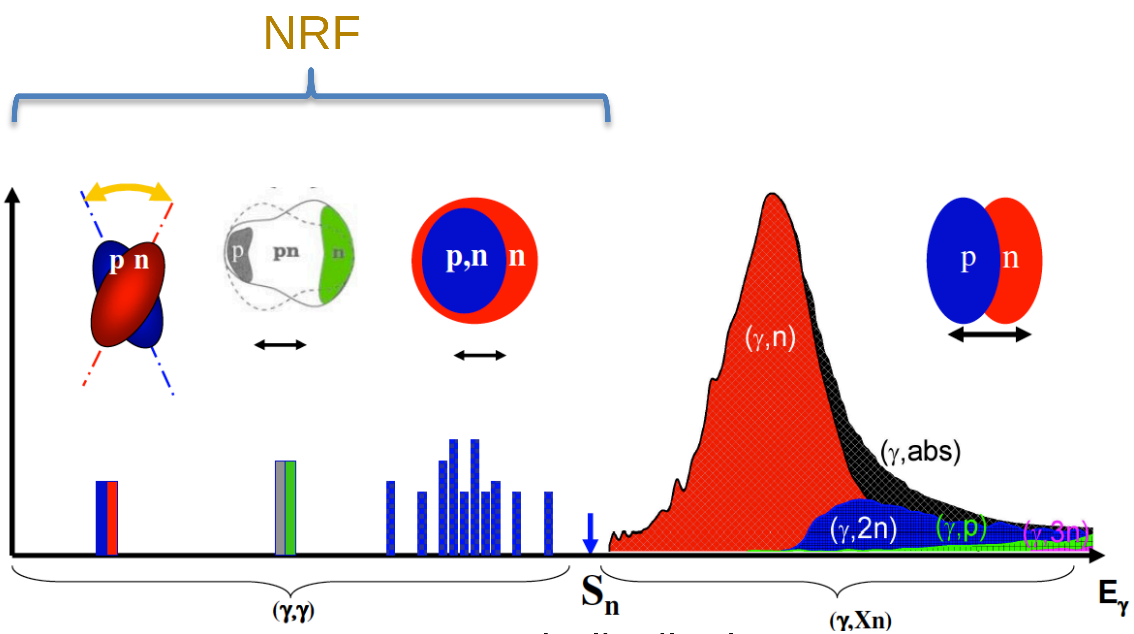
- Modes of excitation below the GDR

Impact on nucleosynthesis

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

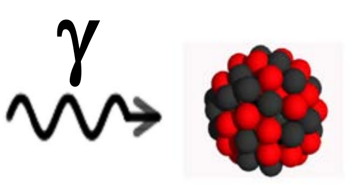
Understanding exotic nuclei

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



A. Tonchev

E1 strength distribution



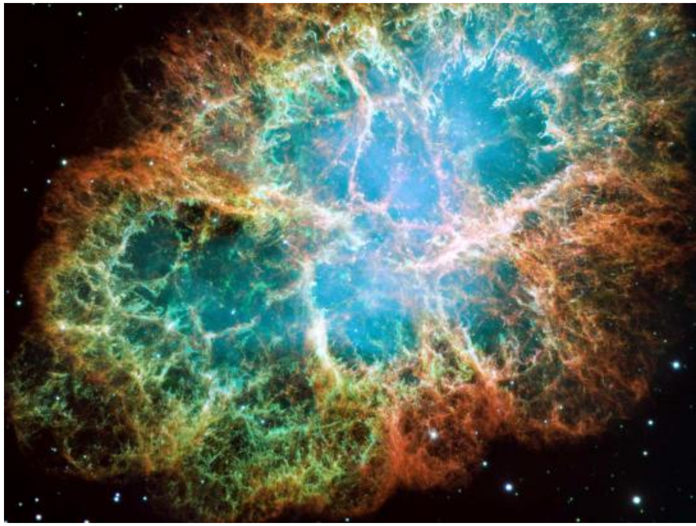
ELI–NP NRF Working group

Jacob Beller	IKP, TU Darmstadt
Vera Derya	IKP, Universitat zu Koeln
Bastian Loehner	EMMI, GSI Darmstadt
Norbert Pietralla	TU Darmstadt
Cristopher Romig	IKP, TU Darmstadt
Andreas Zilges	IKP, Universitat zu Koeln

Astrophysics – related studies

- **Production of heavy elements in the Universe –a central question for Astrophysics**

- **Neutron Capture Cross Section of s-Process Branch - Nuclei with Inverse Reactions (γ, n)**
  - **neutron capture cross sections in the models differ by up to 50% from the experimentally determined values**



Measurements of (γ, p) and (γ, α) Reaction Cross Sections for p – Process-Nucleosynthesis :Key reaction $\gamma + {}^{16}O \rightarrow {}^{12}C + \alpha$

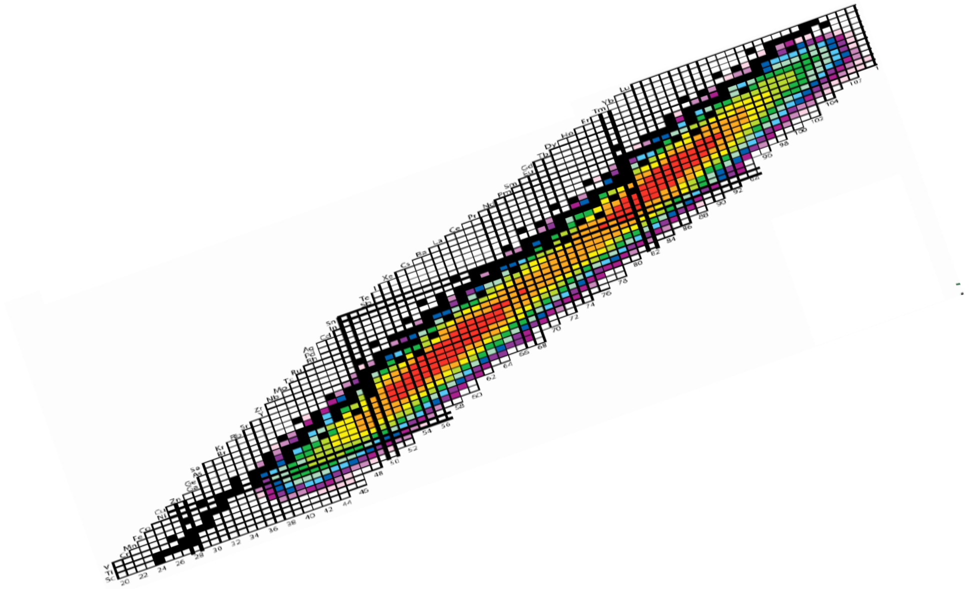
Determination of the reaction rates by an absolute cross section measurement is possible using **mono-energetic photon beams produced at ELI-NP**

tremendous advance to measure these rates directly

broad database of reactions – high intense γ beam needed

S.Gales for the ELI-NP team

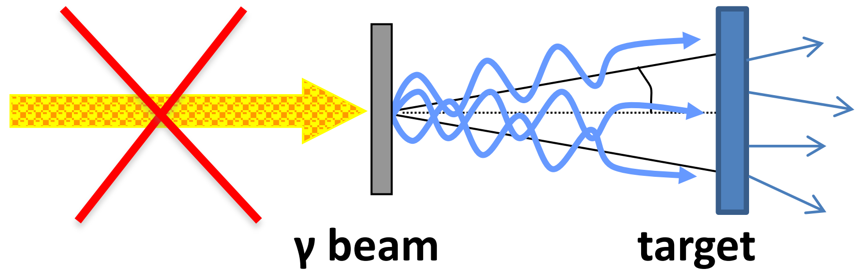
A new ISOL-Photofission concept based on Brillant and Mono-energetic Gamma Beams



- (1) ISOLDE @ CERN
- (2) GANIL,SPIRAL1,2…
- (2) ALTO @ Orsay
- (3) TRIUMF and ARIEL
- (4) CARIBU @ Argonne
- (6) IGISOL @ Jyvaskyla
- + Many projects at SPES (LNL) RIBF(RIKEN) , DESIR(GANIL), NSCL, IThema lab, JINR Dubna……
- ***All these laboratories possess huge expertise. Is there really a niche to compete?***

S.Gales for the ELI-NP team

Production of fission fragments by photo-fission at ELI



First calculation says that the yield is ≈10^{9}-^{10} f/s.

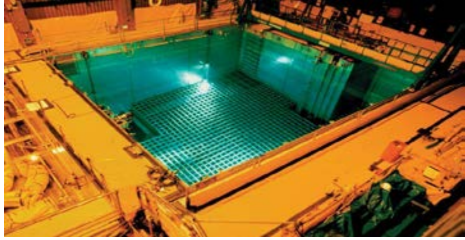
Low Energy Gamma Beam fully efficient at 15 MeV for producing in thin U targets ,short live and refractory elements using gas cell catcher with high efficiency due low ionizing power of pure γ beams

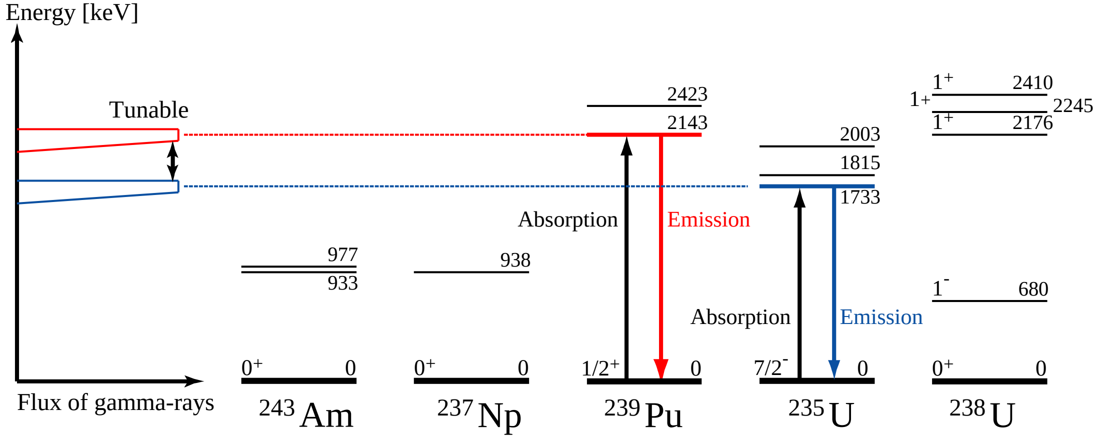
Limited investments , minimize radioactivity, a real niche!!

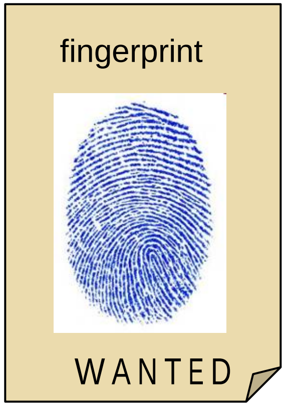
Potential Nuclear Photonics Applications from C.P.J. Barty (LLNL)

S.Gales for the ELI-NP team

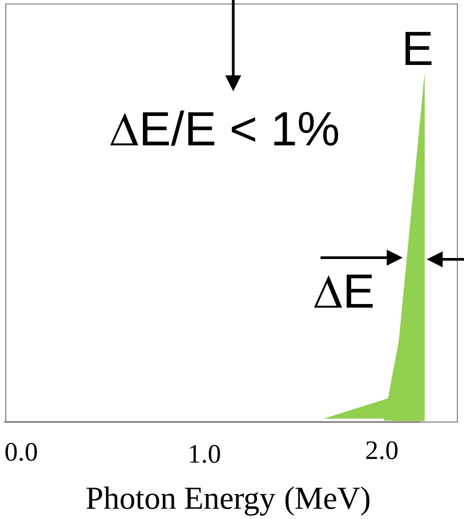
Applications of NRF To Nuclear Materials

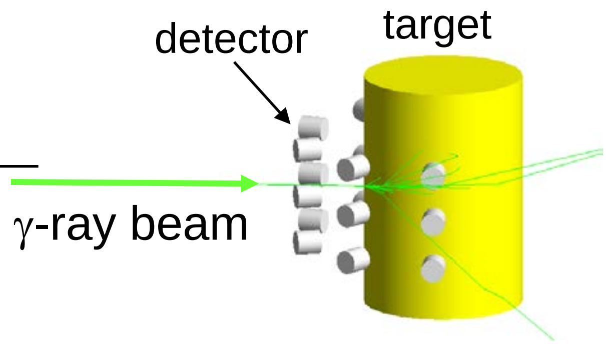




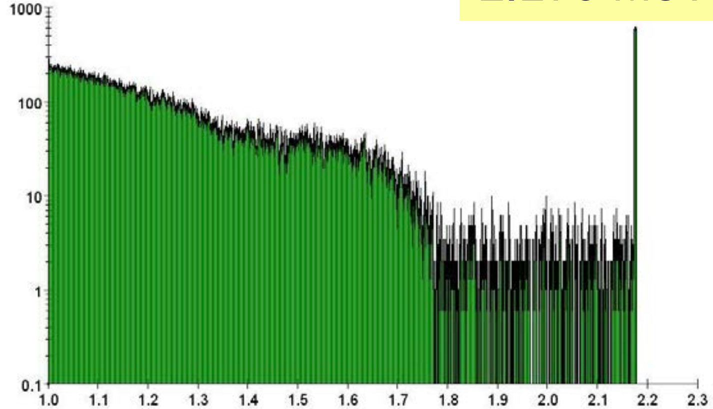


2.176 MeV for U-238





NRF signal U-238 2.176 MeV



Photon energy (MeV)

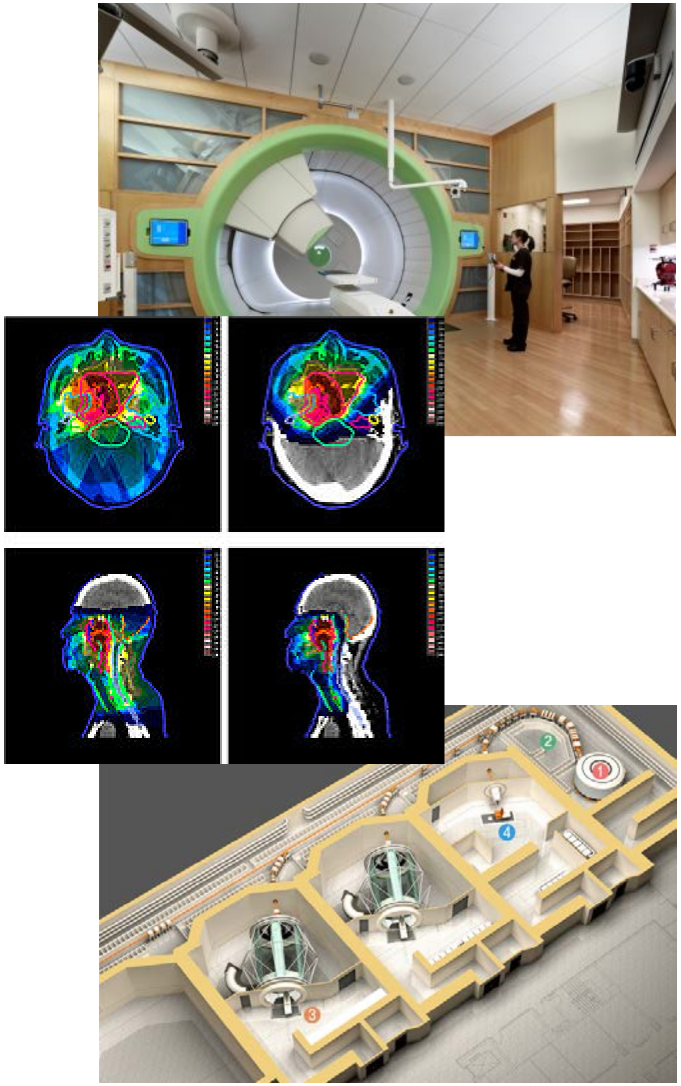
S.Gales for the ELI-NP team

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



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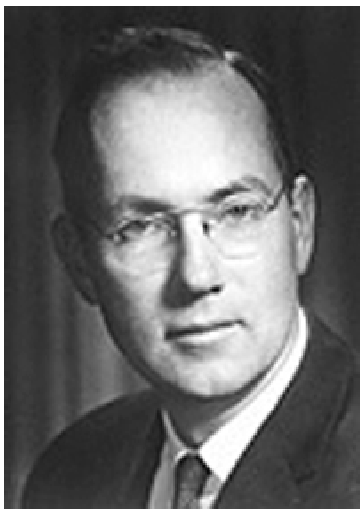
Perspectives

- a new research facility is being under construction at Bucharest
  - HPLS
  - GBS
- research opportunities
  - nuclear physics
    - nuclear photonics
    - HP laser driven
  - strong field QED
- we are open for collaboration
- young researchers are invited to join the fun !

21st Century; the Photon Century
Could basic research be driven
by the massless and chargeless Photons??

Large Scale Lasers: Could they become the Next Large Scale Fondamental Research Infrastructures?



The First exemple is the Extreme Light Infrastructure ELI.

S.Gales for the ELI-NP team

ELI–NP Core Team

Management
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G. Cata–Danil
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I. Ursu

Head of Research Activities
C.A. Ur
D. Balabanski
D. Ursescu

GBS
O. Tesileanu
D. Filipescu
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M. Toma
C. Petcu
M. Risca
M. Cernaianu

Radioprotection
S. Bercea
E. Iliescu
I. Mitu

EMP
M. Gugiu

+ IFIN–HH

EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

You are welcome to join us!!
Thank you for your patience

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

Project Co-financed by the European Regional Development Fund