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
Project co-financed by the European Regional Development Fund

Extreme Light Infrastructure – Nuclear Physics

Ovidiu Tesileanu and Dan Filipescu,
on behalf of the ELI-NP Team

eli Nuclear Physics

Lomonosov Moscow State University
November 25th, 2013

Extreme Light Infrastructure (ELI)

2006: ELI on ESFRI Roadmap

2007-2010: ELI-PP (FP7)

ELI-Beamlines (Czech Republic)
ELI-Attoseconds (Hungary)
ELI-Nuclear Physics (Romania)
ELI-Ultra-high intensity – TBD

2009: Approved by Competitiveness Council

2010: ELI-DC formation decided, MoU
2013: Establishment of ELI-DC
as a Legal entity: Czech Republic,
Hungary, Romania, Italy, Germany
Mission: Complementarity of the Scientific Programs
ERIC

ELI-NP Milestones

- **February-April 2010**

Scientific case **“White Book”** (100 scientists, 30 institutions) (www.eli-np.ro)
approved by ELI-NP International Scientific Advisory Board

- **August 2010**

Feasibility Study: 293 MEuro

- **August 2011 – March 2012 :** Technical Design
- **January 2012:** Submission of the application to the E.C.
- **July 2012: *Romanian Government Decision***

Construction of the New Research Infrastructure ELI-NP: 293 M€

- **September 2012: EC Project approval**

European Regional Development Fund (ERDF)
Operational Programme Increase of Economic Competitiveness
Financial Support (83%) of the First phase (2012-2015) 180 M€

- **October 2012**

Workshop: Experimental programme at ELI-NP

- **June 2013**

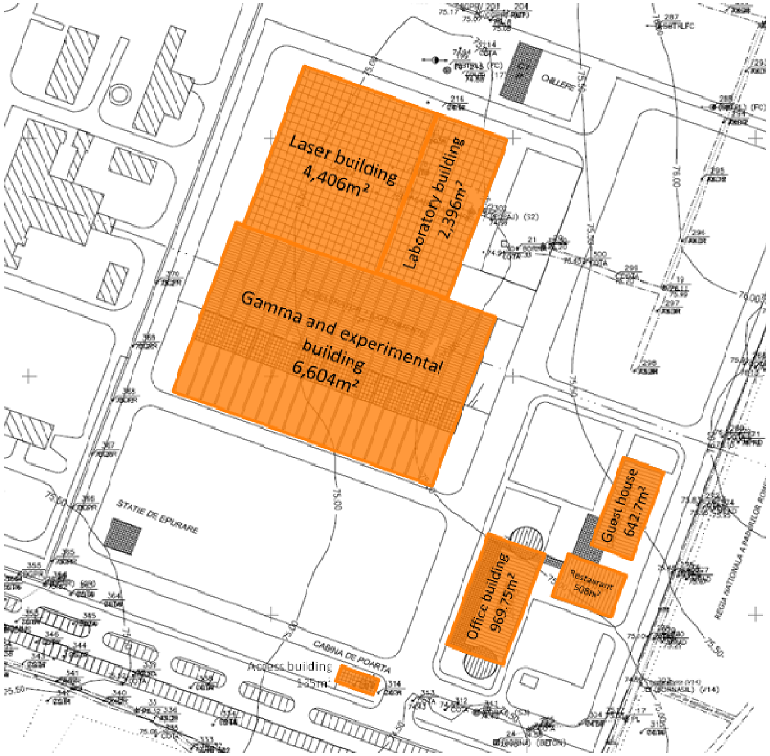
International workshops on TDRs experimental areas
Start of construction works

- **July 2013**

Signing of the laser contract

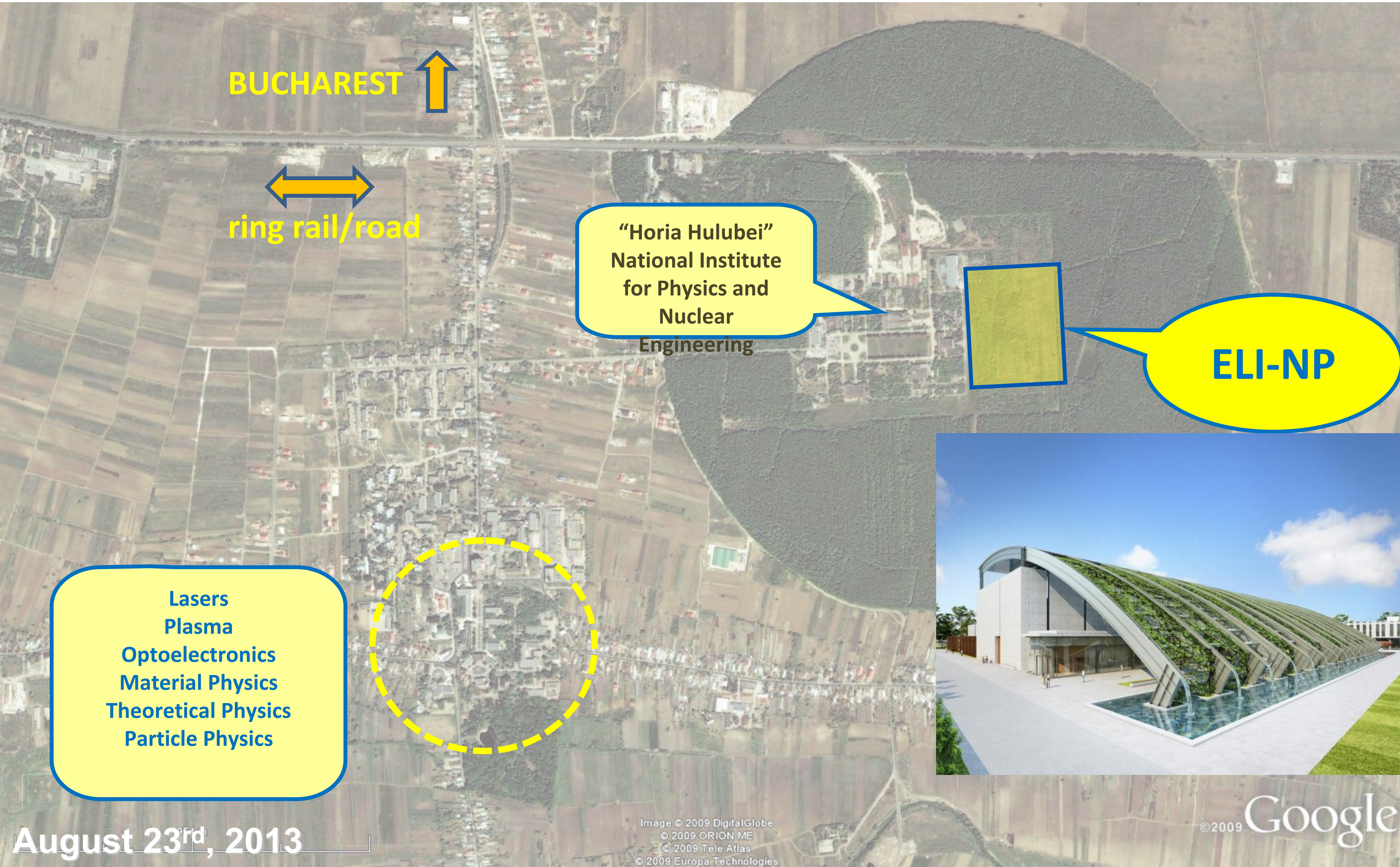
- **October 2013**

End Tender procedure Gamma Beam



Bucharest-Magurele Physics Campus
National Physics Institutes

Nuclear Physics eli




June 14, 2013


August 23, 2013


September 25, 2013

ELI-NP Infrastructure

Large equipment:

- Ultra-short pulse high power laser system, 2 x 10PW maximum power

Thales Optronique SA and SC Thales System Romania

- Gamma radiation beam, high intensity, tunable energy up to 20MeV, relative bandwidth 10^{-3}, produced by Compton scattering of a laser beam on a 700 MeV electron beam produced by a warm LINAC

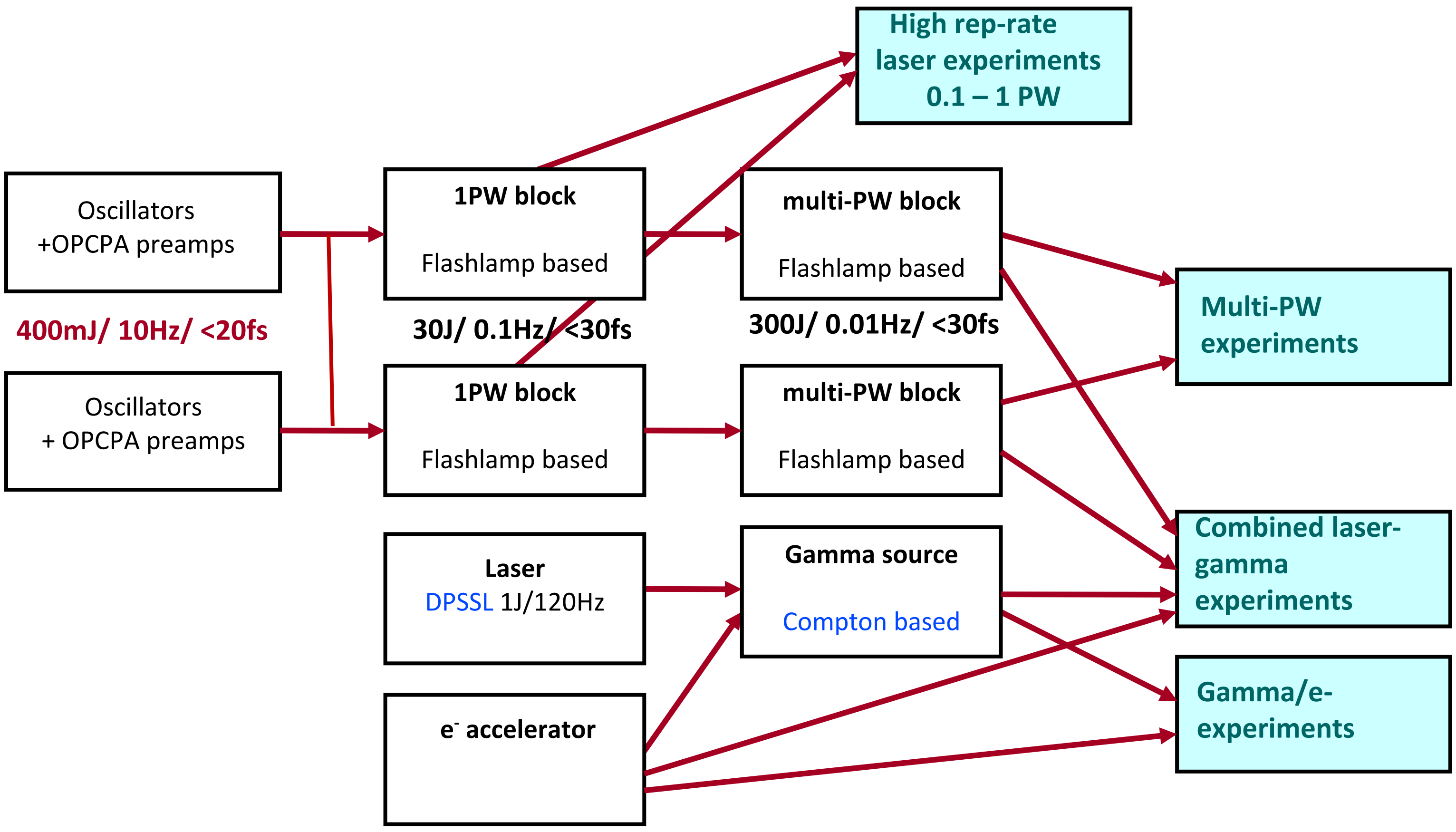
Proposals from an European Consortium and LLNL

Buildings – one contractor, 33000sqm total

Experiments

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

ELI-NP Facility Concept

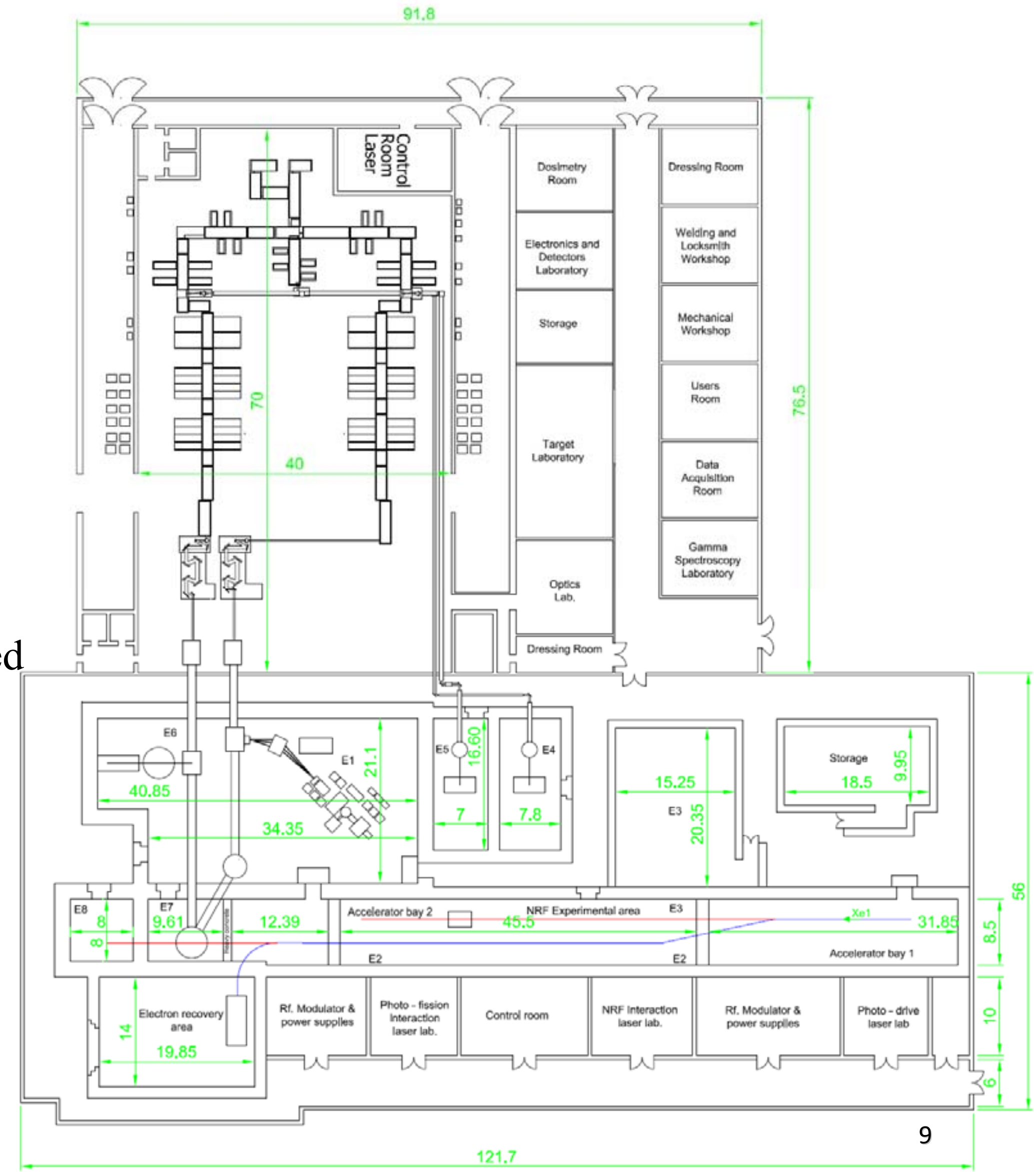


ELI – Nuclear Physics Research

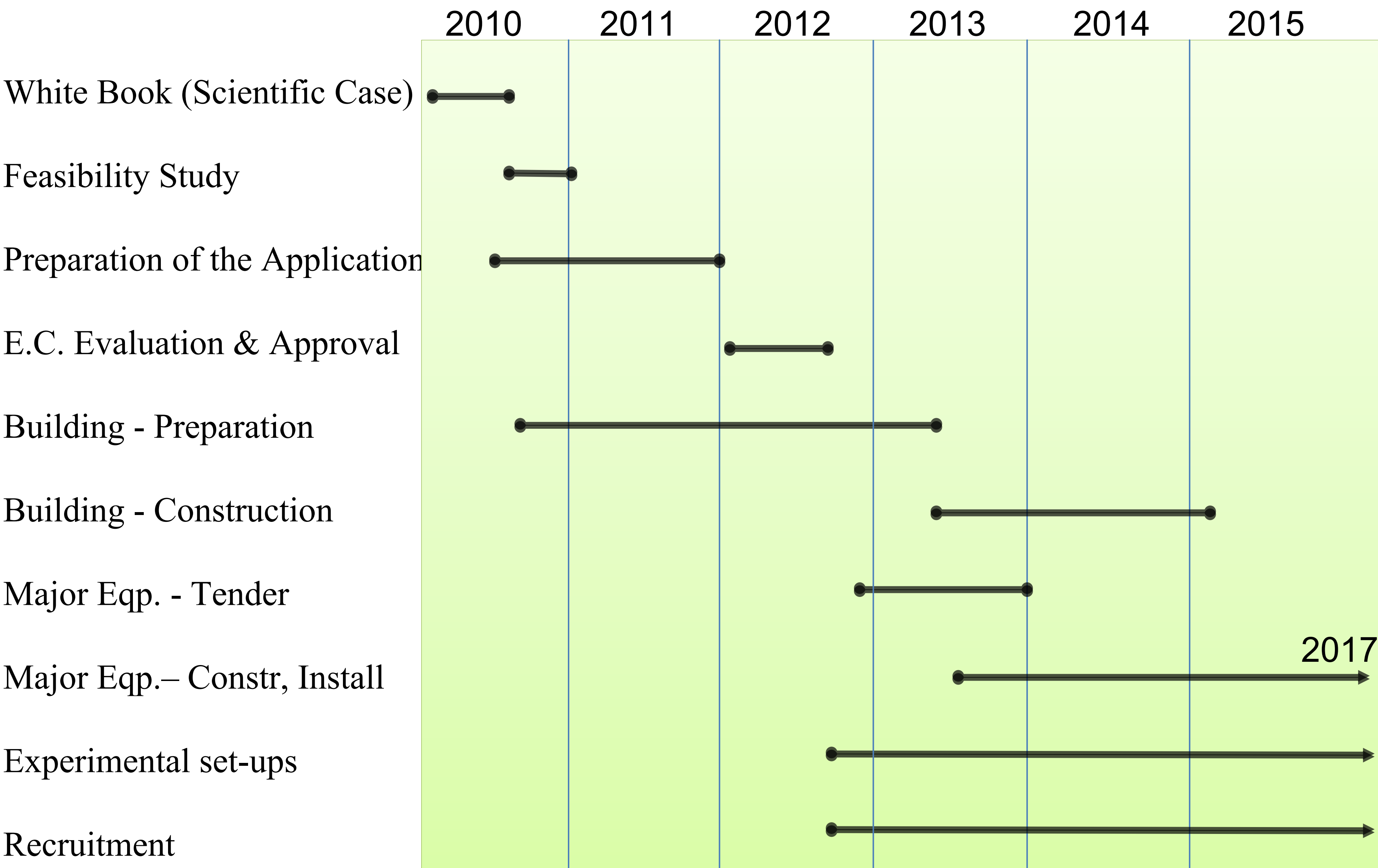
- *Nuclear Physics experiments to characterize laser – target interaction*
- *Photonuclear reactions*
- *Exotic Nuclear Physics and Astrophysics complementary to other NP large facilities (FAIR, SPIRAL2)*
- *Applied Research based on high intensity laser and very brilliant γ beams*

Experimental Areas at ELI-NP

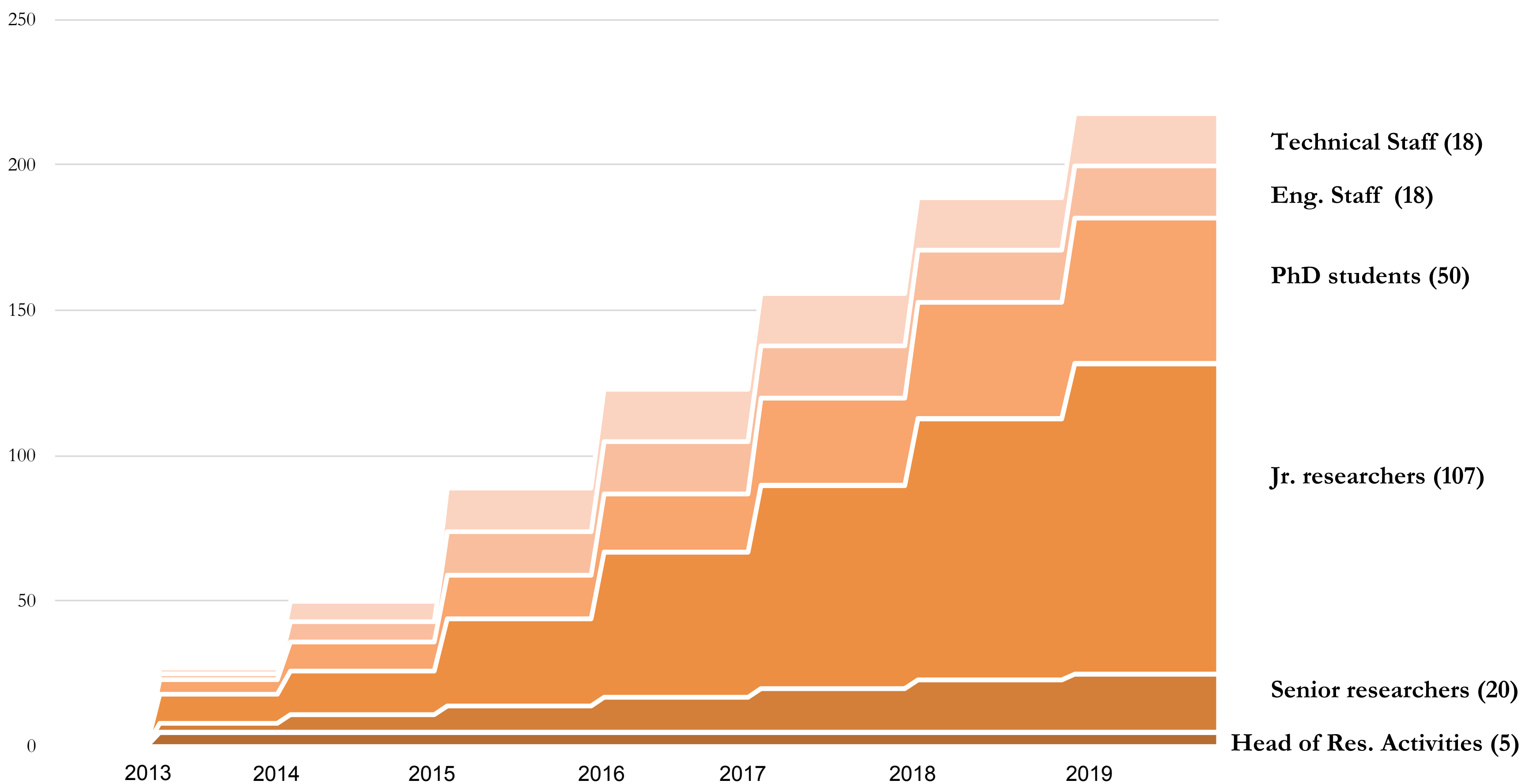
- E1 Laser induced nuclear reactions;
- E2 NRF and applications;
- E3 Positrons source;
- E4/E5 Accelerated particle beams induced by high power laser beams (0,1/1 PW) at high repetition rates;
- E6 Intense electron and gamma beams induced by high power (multi-PW) laser;
- E7 Experiments with combined laser and gamma beams;
- E8 Nuclear reactions induced by high energy gamma beams.



Project implementation



Human Resources



ELI-NP Next Steps

Nuclear Physics

- End 2014: TDRs experiments
- Spring 2015: Construction of buildings
- June 30th, 2015: Lasers and Gamma Beam – end of Phase 1
- 2017: End of second Phase, Beginning operation

ELI-NP TDR Workgroups

- Technical Design Reports for the experiments
- Workshop in June for TDRs;

Gamma WGs:

- Gamma beam preparation, beam lines, diagnostics
- NRF and applications
- Photo fission (production and physics)
- Gamma above Threshold
- Charged particles

+ Positron source for materials science WG

+ Transversal WGs: Vacuum, Control Systems, Dosimetry

Laser WGs:

•Laser delivery and beam lines

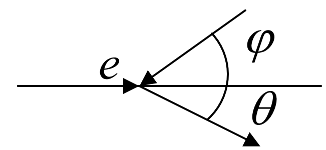
•Ion driven nuclear physics: fission-fusion

•Strong fields QED

•Towards High field (Laser +Gamma) and Plasma

ELI-NP Gamma beam production

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



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

Compton backscattering is the most efficient « frequency amplifier »

$w_{diff}=4g_e^2 w_{laser}$

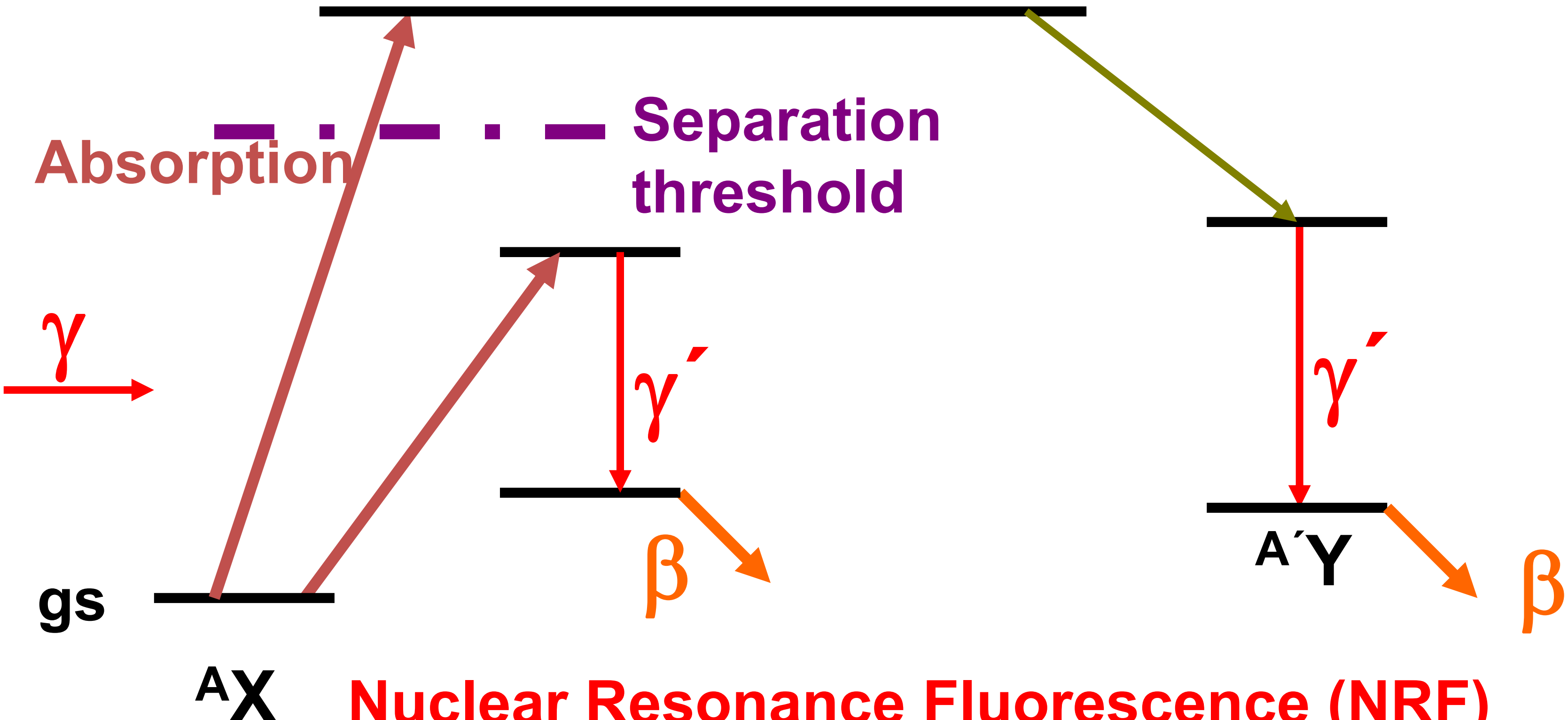
E_e=300 MeV and optical laser <=> g_e~ 600 => E_g > 1 MeV

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

Photonuclear reactions



Nuclear Resonance Fluorescence (NRF)

Photoactivation

Photodisintegration (-activation)

N. Pietralla

Gamma Workgroup

Charged Particles

Convener: Moshe Gai (Yale University)

ELI-NP Liaison: Ovidiu Tesileanu

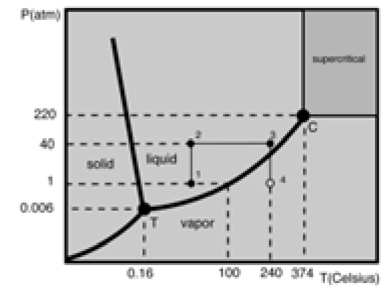
The Charged Particles Working Group

- **Scope: TDR for charged particles detection @ ELI-NP**
- Physics case:
  - nuclear structure – clustering in light nuclei: ^{12}C, ^{16}O;
  - Photodisintegration: $^{16}O(\gamma,\alpha)^{12}C$, $^{22}Ne(\gamma,\alpha)^{18}O$, $^{19}F(\gamma,p)^{18}O$, $^{24}Mg(\gamma,\alpha)^{20}Ne$ (astrophysics, high energy γ, E8);
- International collaboration: Italy (INFN-LNS), Poland (Univ. Warsaw, USA (U. Chicago, U. Yale), Germany (PTB), Romania;

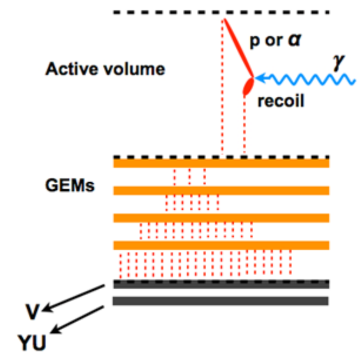
The Charged Particles Working Group

Three detectors proposed:

•**Bubble chamber:** threshold detector, superheated water, computer controlled pressurization, insensitive to gamma beam, neutron background; target: the superheated liquid;



•**Time Projection Chamber:** TPC with electronic readout, active volume 35 x 20 x 20 cm^3, electrodes on internal side of lateral walls, charge amplification structure; charge-collecting electrode plane w/ time-resolved 2D readout; identify reactions with more than 2 particles, background; strip pitch 1.5mm adequate to record tracks of recoiling ion; target: the TPC-compatible gas;



•**Silicon Strip Detector**: allows for particle identification through pulse analysis and TOF; Electrons and positrons not large background in 150µm silicon detector; target: solid.

Gamma Workgroup

Gamma beam preparation, beam lines, diagnostics

Convener: Henry Weller (HIGS, TUNL)

ELI-NP Liaison: Calin Alexandru Ur

Phases of GBS and parameters

ELI Nuclear Physics

Quantity	Symbol	Unit	Specification: Full	Specification: Stage 2	Footnote
Minimum Photon Energy	E_γ	[MeV]	≤ 0.2	≤ 0.2	
Maximum Photon Energy	E_γ	[MeV]	≥ 19.5	≥ 3	
Tunability of the Photon Energy			Steplessly variable	–	b)
Linear Polarization of Gamma-Ray Beam	P_γ	[%]	≥ 95	–	b)
Minimum Frequency of Gamma-Ray Macropulses	$\Omega_{\gamma,M}$	[Hz]	$\geq 1.0 \times 10^2$	–	b)
Divergence	$\Delta\theta$	[rad]	$\leq 2.0 \times 10^{-4}$	$\leq 2.0 \times 10^{-3}$	b)
Average Diametral Full Width Half Maximum of Beam Spot	σ_r	[m]	$\leq 1.0 \times 10^{-3}$	$\leq 1.0 \times 10^{-2}$	a,b)
Average Bandwidth of Gamma–Ray Beam	W		$\leq 5.0 \times 10^{-3}$	$\leq 5.0 \times 10^{-2}$	a,b,c)
Gamma–Ray Beam Time–Average Spectral Density at Peak Energy	F	[1/(s•eV)]	$\geq 5.0 \times 10^3$	–	d)
Time–Average Brilliance at Peak Energy	B_{av}	[1/(s•mm²•mrad² •0.1%W)]	$\geq 1.0 \times 10^{11}$	$\geq 1.0 \times 10^{10}$	a,d)
Peak–Brilliance at Peak Energy	B	[1/(s•mm²•mrad² •0.1%W)]	$\geq 1.0 \times 10^{19}$	–	a,d)
Average Spectral Off–Peak Gamma–Ray Background Density	$\Phi_{\gamma,Mgr}$	[1/(s•eV)]	$\leq 1.0 \times 10^{-2}$	–	a,b,c)

1. Eγ > 1 MeV (*Demonstrator*)
   a. Expandable to the full system
   b. Deadline 31.10.2015
2. Intermediate parameters
   a. Deadline 30.11.2016
3. Full system
   a. Deadline (after 54 months)
   b. Two beams: stage 2 and stage 3

a) At reference–point located at approximately 10 m downstream of the Compton–collision point for gamma–ray production

b) For all gamma–ray energies between minimum and maximum photon energy

c) At all points within the FWHM of the beam spot

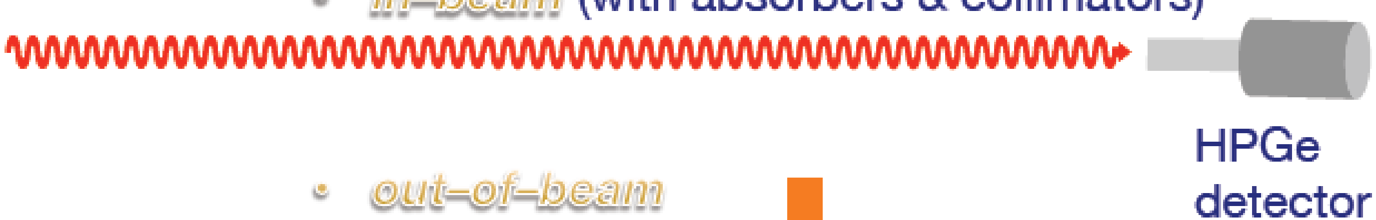
d) At gamma–ray energy of 2 MeV (for the first part of the electron accelerator) and 10 MeV (for the full electron accelerator)

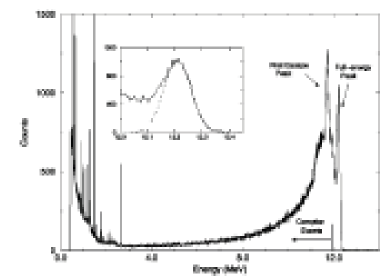
Equipment for GBS diagnostics

Nuclear Physics

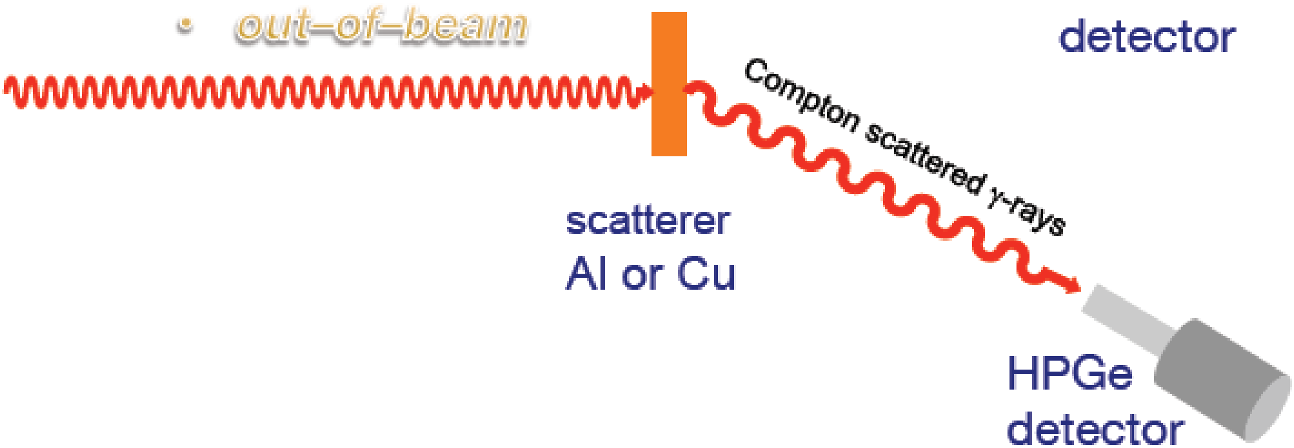
First stage of the project (end of 2015)

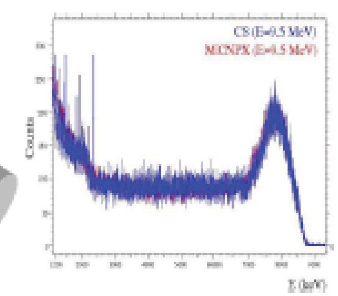
- gamma rays of $\geq$ 1 MeV
- energy profile measurements
  - large volume HPGe detector with anti–Compton shield or large volume $LaBr_3$ detector
  - commercial detectors and simple DAQ
  - to be used
    - *in–beam* (with absorbers & collimators)





- *out–of–beam*





Equipment for GBS diagnostics

Intermediate stage of the project (end of 2016)

- gamma rays of ≥ 3 MeV & BW $\leq 5 \times 10^{-2}$
- beam spot diameter FWHM ≤ 1 cm
- energy profile measurements
  - large volume HPGe detector with anti–Compton shield or large volume $LaBr_3$ detector (available from the previous stage)
  - in–beam
  - out–of–beam
  - precise energy calibration of the detectors can be achieved with standard gamma–ray sources
- flux counter detector
  - e.g. *paddle detector*
  - other solutions are discussed
- spatial profile detector
  - mm resolution
  - e.g. *CCD based detector*

Equipment for GBS diagnostics

Final stage of the project (end of 2017)

- gamma rays of $\geq$ 19.5 MeV & BW $\leq 5 \times 10^{-3}$
- beam spot diameter FWHM $\leq$ 1 mm
- energy profile measurements
  - large volume HPGe detector with anti–Compton shield or large volume $LaBr_3$ detector (available from the previous stage)
  - in–beam
  - out–of–beam
  - define methods for precise energy calibration of the detectors at gamma–ray energies above 3.5 MeV
- flux counter detector
  - from the previous stage
- spatial profile detector
  - need of sub–mm resolution
  - new *CCD based detector*
- characterize the time structure of the gamma beam

Nuclear Physics

Gamma Workgroup

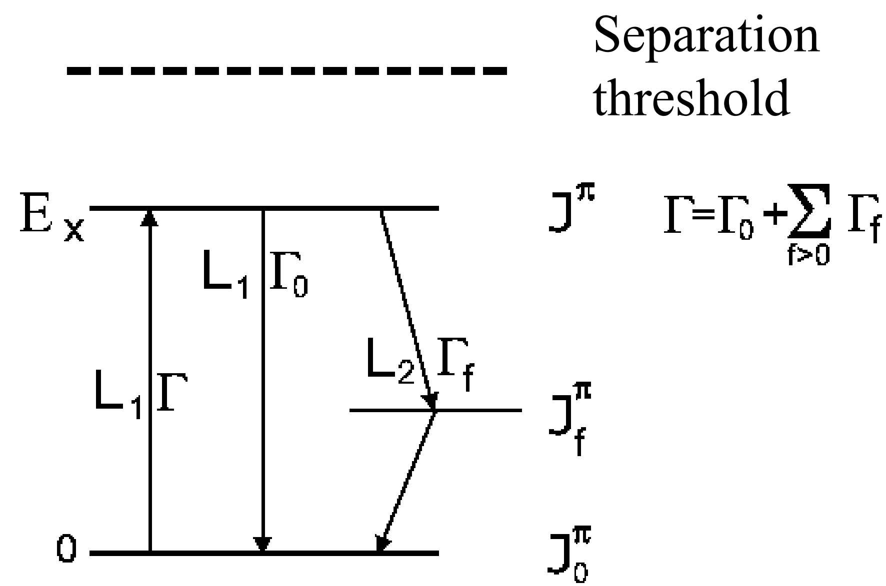
Nuclear Resonance Fluorescence and Applications

Convener: Norbert Pietralle (T.U. Darmstadt)

ELI-NP Liaison: Calin Alexandru Ur

Nuclear Resonance Fluorescence

- **Pure EM-interaction**
  - (nuclear–)model independent
  - "small" cross sections
    → need intense beams
- **Minimum projectile mass**
  - min. angular momentum transfer, spin-selective → excite mainly low–spin modes [E1,M1,E2,(E3?)]
- **Polarisation**
  parity physics
- **Narrow Bandwidth (at ELI)**
  - explore specific excitation energy



Observables

- Excitation Energy E_x
- Spin J
- Parity **p**
- Decay Energies E_g
- Partial Widths Γ_f/Γ_0
- Multipole Mixing d
- Decay Strengths B(pl)
- Level Width Γ (eV)
- Lifetime t (ps – as)

Nuclear Resonance Fluorescence

- **Dipole response and parity measurements in weakly–bound nuclei**
  - low–lying E1 strength in *p–nuclei* having very low natural abundance
  - development of the E1 strength on isotope chains as a function of the neutron number
- **Low–energy dipole response in the actinides region**
  - precise distribution of M1 and E1 transitions
  - small samples of about 10 mg in pencil like configuration with 1 mm diameter → needed to keep low activity levels of the sample
- **Constraints on 0nbb–decay matrix elements from a novel decay channel of the scissors mode of ^{150}Sm**

$$^{150}\mathrm{Nd} \xrightarrow{0\nu\beta\beta} {}^{150}\mathrm{Sm}$$

  - for accurate calculation of the Nuclear Matrix Elements in IBM–2 one needs to know accurately the spectroscopic properties (excitation energy, electromagnetic decay) of the scissors mode states $J^p=1^+$
- **Applications**
  - isotopic and/or elemental information about a sample
  - non–distructive assay applied to nuclear waste management

Gamma Workgroup

Photofission

Conveners: Attila Krasznahorkay (ATOMKI), Fadi Ibrahim (IPNO)

ELI-NP Liaison: Dimiter Balabanski

List of experiments to be considered

1. Studies of transmission resonances through fission decay (White Book case)
2. Photo-fission cross-section measurements
3. Spectroscopic experiments with fission fragments

(TDR WS conclusions)

Photo-fission experiments
Physics goals

- **High-resolution photofission studies in actinides → investigation of 2nd, 3rd potential minima, angular and mass distribution measurements.**

- **measurements of absolute photofission cross sections:**

→ (monochromatic photons with variable energy required)

- **limited photon source intensity:**

→ target thickness limited by finite range of fission fragments (ca. 8 mg/cm^2 in uranium)

→ multiple target-detector arrays needed

Physics- Photofission

Part 2

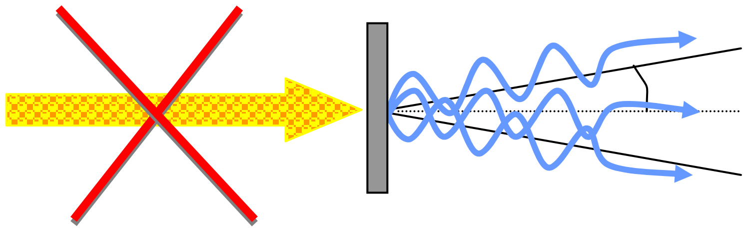
Production of RIB with ISOL target

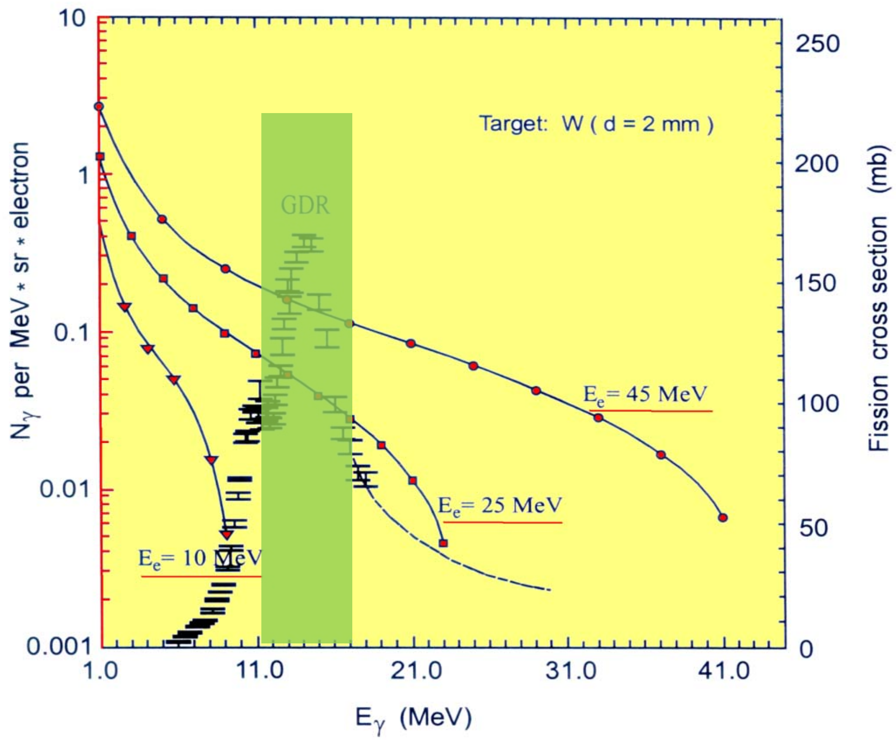
Big investment
Radioprotection
Not really competitive with the existing or future facilities

Production of RIB with IGISOL technique

Big investment (still)
Easy Radioprotection
Competitive : refractory elements and very short lived nuclei
Unique in the world

Production of fission fragments by photo-fission at ELI





With a flux of F γ's at 15 MeV per second ELI can produce F. s. N=F.6,4 10^{-3} f/s in a standard target. If you open the energy window of the γ then F increase and the production increase proportionally

Elements of an IGISOL facility

- Large acceptance ion guide
- Laser ion source
- Mass separator
- Multi-reflection purification trap
- Measurement stations
  - β-decay station (also β-delayed neutrons)
  - collinear laser spectroscopy
  - mass measurements

Gamma Workgroup

Reactions above the particle Threshold

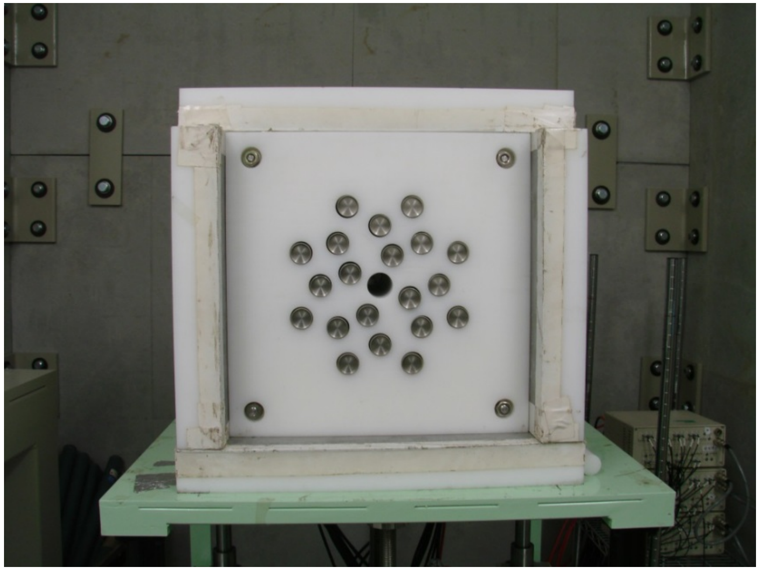
Conveners: Hiroaki Utsunomiya (Konan Univ.), Franco Camera (INFN)

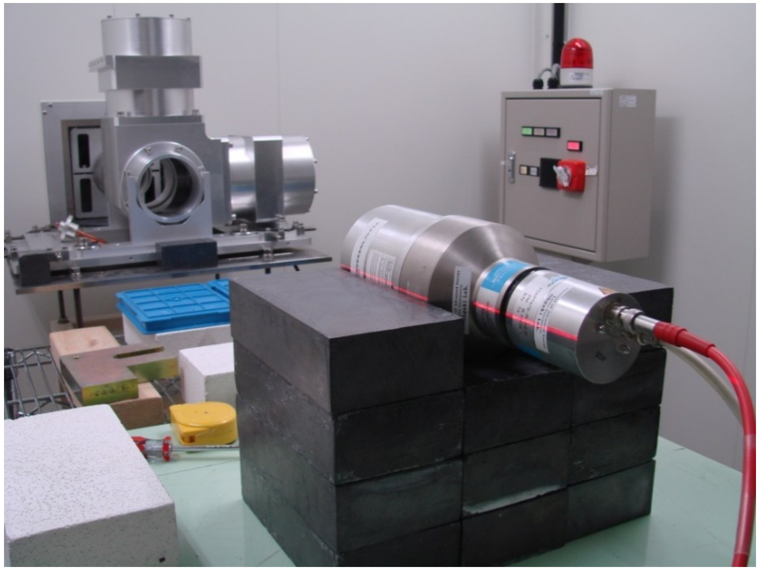
ELI-NP Liaison: Dan Filipescu

Absolute (γ,n) cross section measurements (Hiroaki Utsunomiya)

- 4π high efficiency neutron detector
- [3]He proportional counters arranged in concentric rings, embedded in a parallelepiped polyethylene moderator covered with polyethylene plates with cadmium sheets towards interior;
- Efficiency of neutron detector obtained with ring-ratio technique

- γ beam spectrum measurement
- Large volume $LaBr_3$(Ce) detector
- Accurate beam flux monitor (proper for specific ELI-NP gamma beam properties)





Hiroaki is proposing to measure also (γ,2n) c.s. and the anisotropy of neutrons for separating E1 and M1 (γ,n) using liquid scintillators.

Measurement of GDR strength functions (Franco Camera)

- (γ, n/ γ / γ') measurements (event by event γ and neutron spectroscopy)

- Excitation and decay of PDR-GDR (from 5 to 19 MeV)
  - Direct γ -decay to ground state
    - Two step γ -decay to ground state (measured in coincidence)
    - Neutron and γ decay to ground state (measured in coincidence)
      - measurement of γ -ray energy
      - measurement of neutron energy

Instrumentation:

Array of

- γ detectors
  - large volume scintillators ($LaBr_3$) for high energy gammas (decay of the entry state)
  - HPGe detectors for low energy discrete decays (second γ in two step)
- n detectors
  - liquid scintillators (for neutron anisotropy and γ - n coincidences)
  - plastic scintillators (neutron wall for γ - n coincidences)

arranged in flexible configurations.

Radioisotope production (Ulli Koester)

Gamma ray beams can be an asset to overcome the inherent limitations of Bremsstrahlung, namely the enormous power density required to compensate the relatively meager CS

Specific applications of isotopes otherwise difficult to reach, e.g. ^{195m}Pt produced by (γ, γ ') or ^{225}Ra produced by ^{226}Ra(γ ,n)

Do not need a fancy irradiation station -> one of the principal advantages of narrow bandwidth gamma beams over charged projectiles: the heat dissipation of the sample is much easier realizable; one does not require extremely thin windows and related safety systems as at cyclotrons

Any irradiation station (or simply a place in the beam dump) that can take the full gamma beam it would fully serve the needs.

Perform test irradiations by irradiating briefly thin foils, then measure them with one or two shielded Ge detector.

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