Extreme Light Infrastructure - Nuclear Physics ELI - NP

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HG 2013 Workshop, Trieste, June 2013

EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

Sectoral Operational Programme "Increase of Economic Competitiveness"

"Investments for Your Future!"

IFIN-HH

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

eli Nuclear Physics

Project co-financed by the European Regional Development Fund

Extreme Light Infrastructure (ELI)
An European Research Infrastructure

2006 – ELI on ESFRI Roadmap

ESFRI, the European Strategy Forum on Research Infrastructures, is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach

ELI-PP 2007-2010 (FP7)

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

Project Approved by the European Competitiveness Council (December 2009)

ELI-DC (Delivery Consortium):

Founding Members:

IFIN-HH (Romania)

ELI-Hu R&D Non-Profit Ltd. (Hungary)

ELETTRA-Sincrotrone Trieste (Italy) many other to follow

Extreme Light Infrastructure (ELI)
An European Research Infrastructure

- **ELI-Beamlines Facility**

In the **Czech Republic**, Prague, the ELI pillar will focus on providing ultra-short energetic particle (10 GeV) and radiation (up to few MeV) beams produced from compact laser plasma accelerators to users.

- **ELI-Attosecond Facility**

In **Hungary**, Szeged, the ELI pillar will be dedicated to Extremely fast dynamics by taking snap-shots in the attosecond scale of the electron dynamics in atoms, molecules, plasmas and solids. It will also pursue research in ultrahigh intensity laser.

- **ELI-Nuclear Physics Facility**

In **Romania**, Magurele, the ELI pillar will focus on laser-based nuclear physics. For this purpose, an intense gamma-ray source is foreseen by coupling a high-energy particle accelerator to a high-power laser.

- **ELI-Ultra High Field Facility**

The **highest intensity pillar location** is still to be decided. The laser power will reach the 200 PW or 100 000 times the power of the world electric grid. It will depend, among other things, on the laser technology development and validation. It could be built on one of the existing three sites or in a new country. With the possibility of going into the ultra-relativistic regime, ELI will afford new investigations in particle physics, nuclear physics, gravitational physics, nonlinear field theory, ultrahigh-pressure physics, astrophysics and cosmology (generating intensities exceeding 10^{23} W/cm^2). It will offer a new paradigm in High Energy Physics.

ELI-NP: Activities

- **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

- **December 2010** – Romanian Government:

ELI-NP priority project

- **August 2011 – March 2012**

Technical Design

- **January 2012**

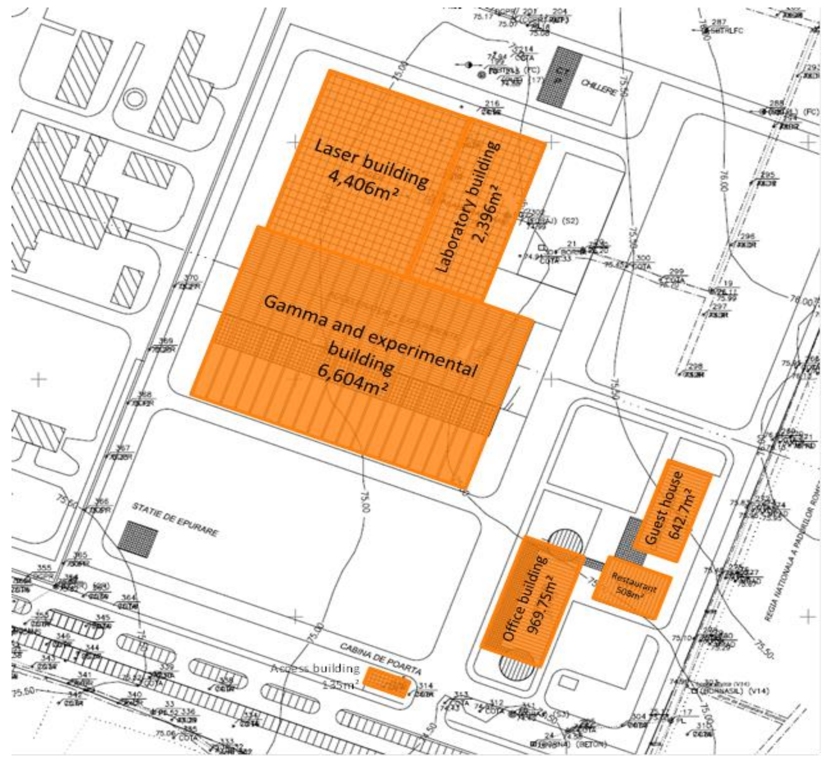
Submission of the application to the E.C.

- **September 2012**

Approval for funding from structural funds

- **October 2012**

Workshop: Experimental program at ELI-NP



ELI-NP: Scope

- ELI-NP facility will generate particle beams with high energies and brilliances suited to studies of nuclear and fundamental processes.
- The core of the facility is a high-power laser system. In order to perform cutting edge photo-nuclear physics experiments, a complementary highly brilliant γ beam, with energies in the 20 MeV range, will be generated via the laser interaction with a brilliant bunched electron beam.
- ELI-NP will allow either combined experiments using the high power laser and the γ beam or stand-alone experiments.
- The modular design of the facility reserves space for further extension of the laser system and allows later extension of the experimental area, if needed.

ELI-NP: Basic Objectives

The basic objectives of the ELI-NP pillar are:

- to proceed to a precise diagnosis of the laser beam interaction with matter with techniques specific to Nuclear Physics.
- to use photonuclear reactions and laser accelerated particles for nuclear structure studies and for applications

ELI-NP: The Probes

Large equipment at the frontier of technology:

- A very high intensity laser beam system, where 2 x 10PW maximum power lasers are coherently added to the high intensity of 10^{23}–10^{24} W/cm^2 or electrical fields of 10^{15} V/m.
- A very intense, brilliant, very low relative bandwidth of 10^{-3} , up to 20 MeV tunable energy γ beam, produced by incoherent Compton backscattering of a laser beam on a 700 MeV energy, very brilliant, intense, classical electron beam. (unique new probe worldwide, going to explore unknown territory)

ELI-NP: The High Power Laser System (HPLS)

HPLS is a dual front-end system with two parallel amplification arms, each with three outputs, as sketched in figure 1. Only one front end will run at a time, while the second front end represents a back-up solution that minimizes the down-time of the facility.

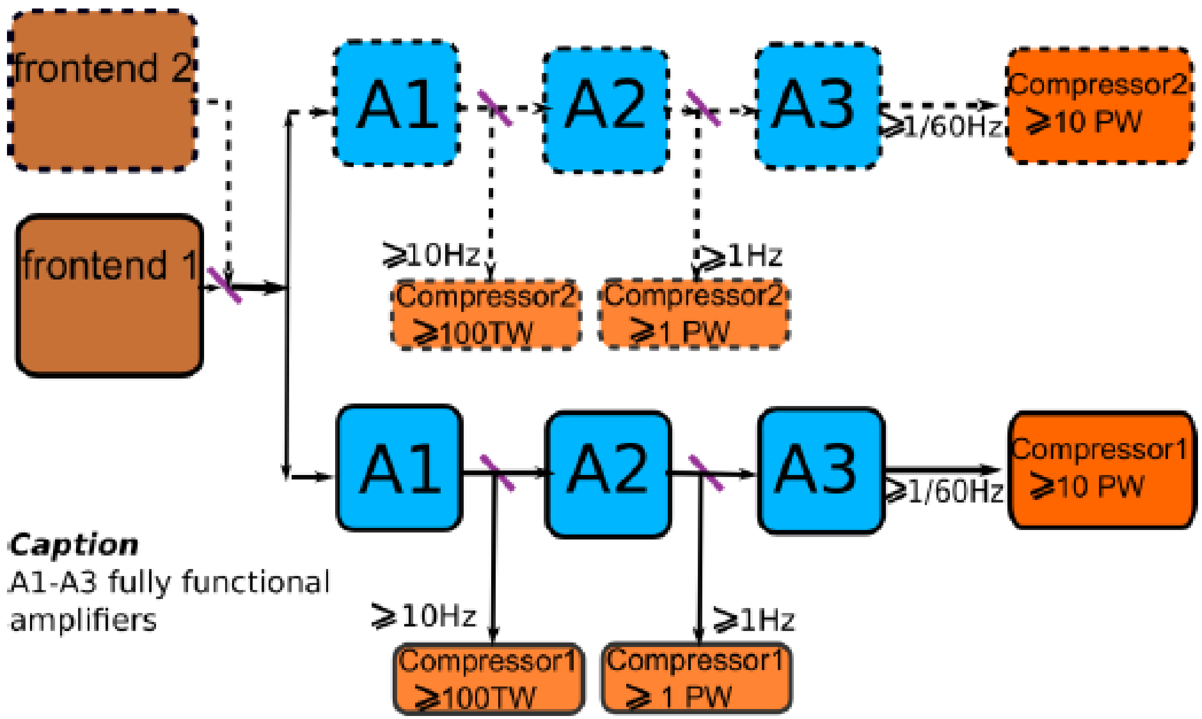


Figure 1. The HPLS architecture

ELI-NP: The High Power Laser System (HPLS)

HPLS will serve several experimental areas in parallel, delivering pulses with different power levels:

- the main two of the outputs, one for each amplification arm, are specified to reach 10PW at a repetition rate of at least one shot/minute;
- two more outputs are extracted at the 1PW level from the amplification chains at the place where the repetition rate of the system is 1Hz;
- two more outputs, at 10Hz and 0.1PW are extracted at earlier amplification stages from the two arms.

Each output will have its optical pulse compressor. The duration of the pulses from each of the 6 outputs of the HPLS shall be tunable from the best compression level to at least 5 ps pulse duration, with both positive and negative chirp.

- The HPLS outputs will be synchronized with accuracy below 200 fs. On the long run, coherent combination of the outputs with the same output power levels is envisaged. The laser system will deliver pulses synchronously with the Gamma Beam System electron and gamma bunches. The synchronization system will be implemented at the HPLS front-end level.

ELI-NP: The Gamma Beam System (GBS)

GBS will enable the production of a brilliant, highly collimated beam of radiation in the gamma ray domain, through the Compton backscattering of a laser beam off a beam of accelerated electrons. This will ensure the possibility to tune with very high precision the energy of the gamma radiation produced in a range that is relevant for the scientific case of ELI-NP. Electrons will be accelerated up to 700MeV by means of a warm Linac.

Table 2. Specified parameters for the gamma beam source:

Type	Units	Range
Photon energy	MeV	0.2 – 19.5
Divergence	Rad	$\leq 2.0 \times 10^{-4}$
Average Relative Bandwidth of Gamma-Ray Beam		$\leq 5.0 \times 10^{-3}$
Time-Average Spectral Density at Peak Energy	1/(s eV)	$\geq 5.0 \times 10^{3}$
Time-Average Brilliance at Peak Energy	$1/(\text{s mm}^2 \text{ mrad}^2 \text{ } 0.1\% \text{ } \eta_{,\gamma})$	$\geq 1.0 \times 10^{11}$
Minimum Frequency of Gamma-Ray Macropulses	Hz	≥ 100

ELI: Extreme Light Infrastructure – Feasibility Study
Appendix x: Detailed description of Research Activity 2
High Brilliance Gamma Source

White book suggested a 450 MeV + 150 MeV = 600 MeV approach

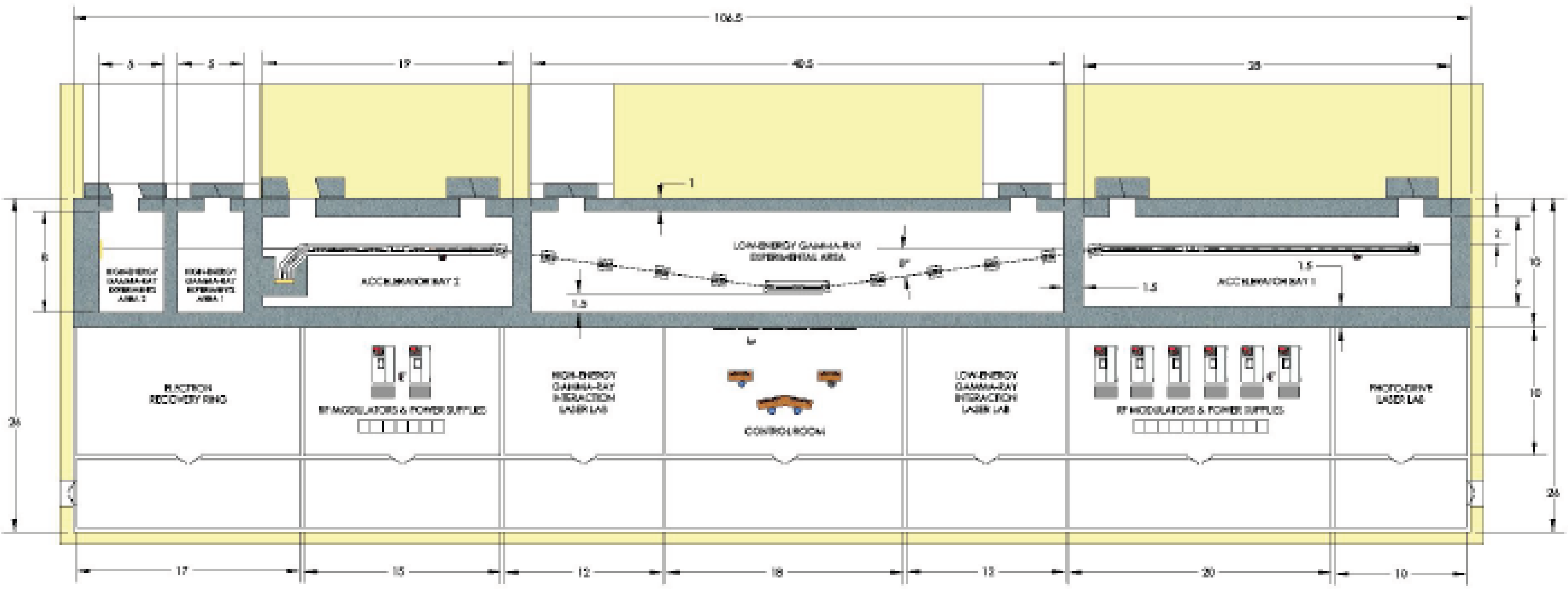


Fig. 14b

Fig. 14a and 14b: Overall view of the proposed ELI-NP γ source

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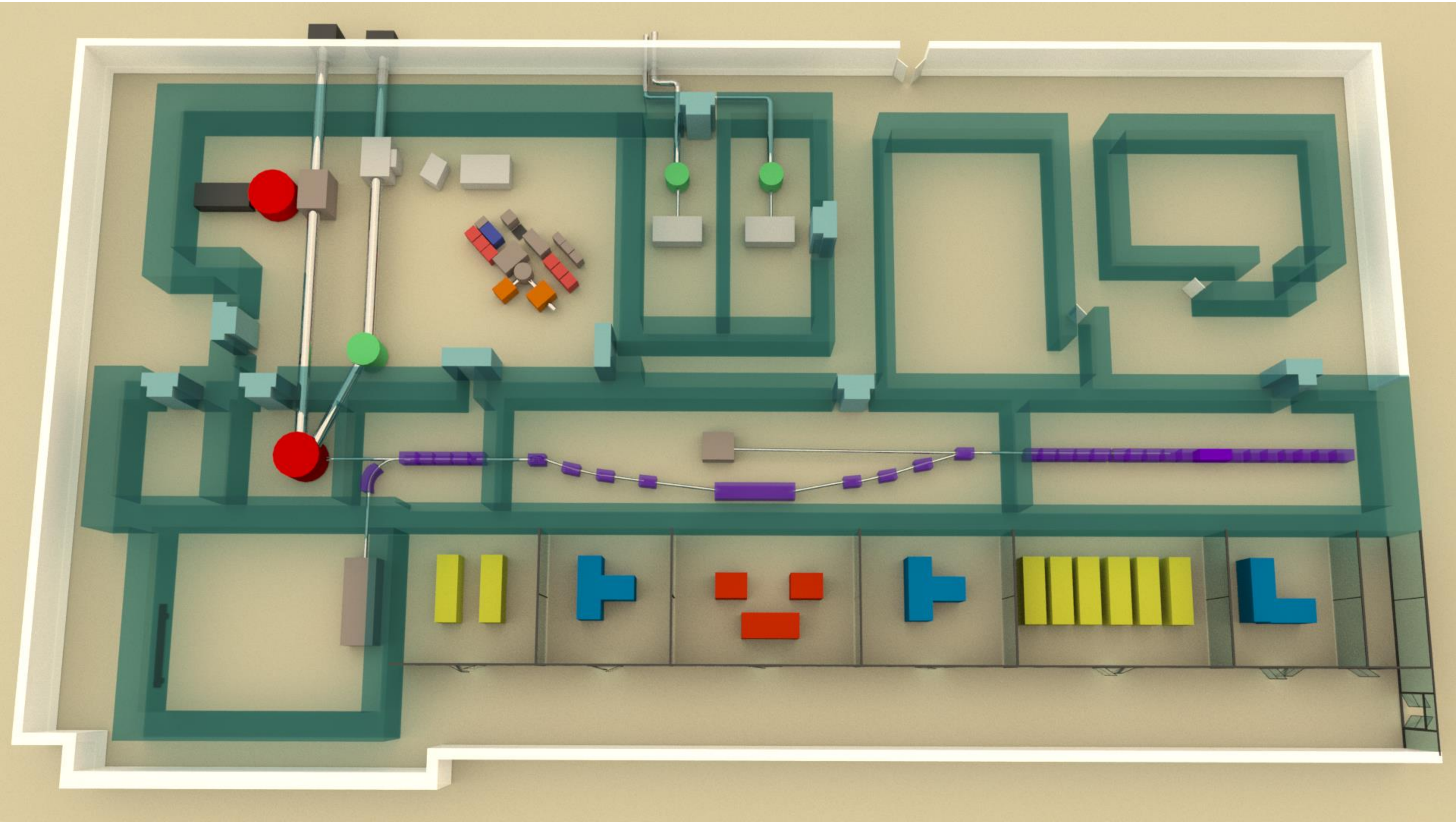


3D view of ELI-NP lasers, linac and experiments rooms

Nuclear Physics

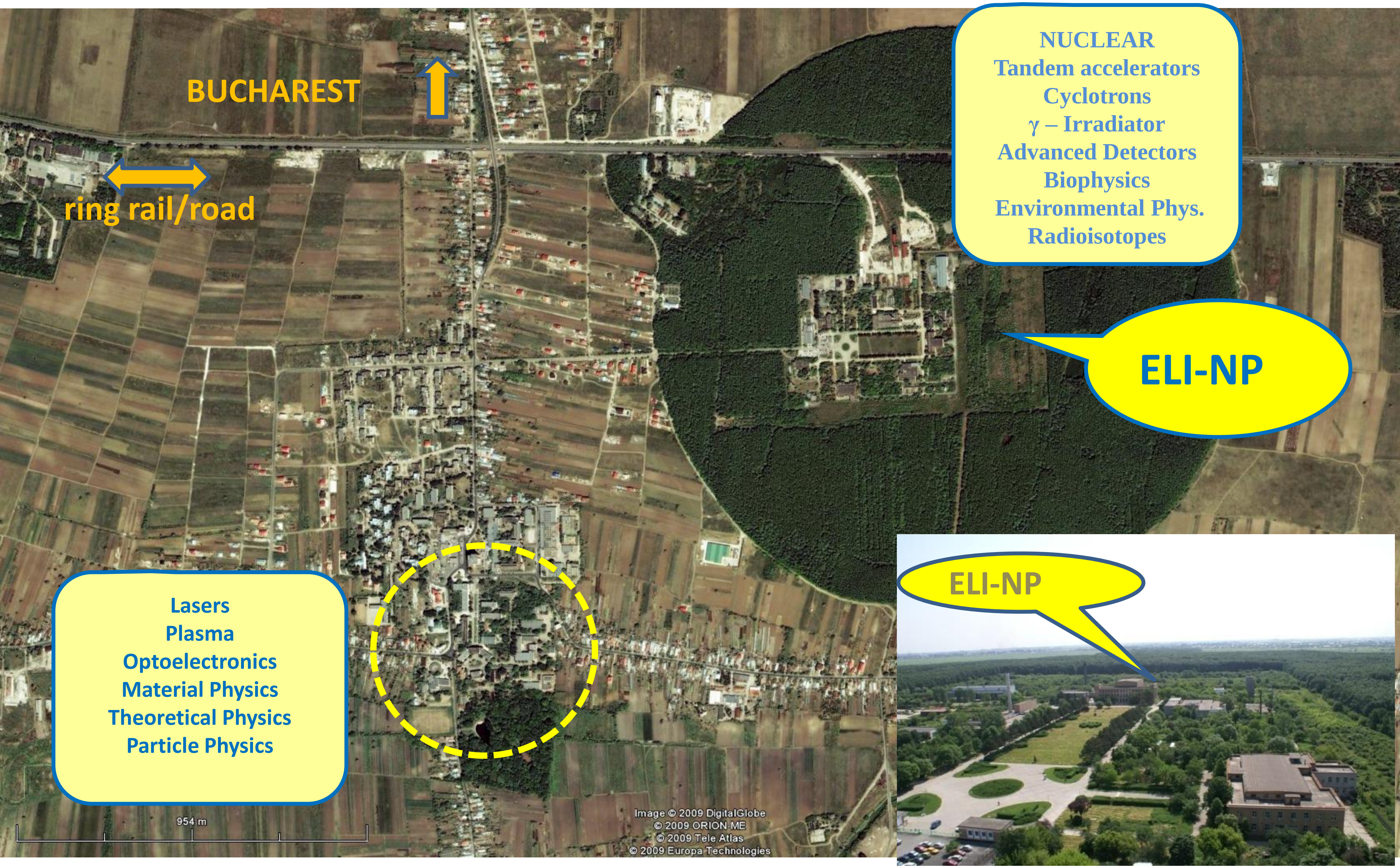
ELI-NP: Site and building

- ELI-NP will be built at Magurele, Ilfov County, on the premises of the "Horia Hulubei" National Institute of Research and Development in Physics and Nuclear Engineering (IFIN-HH). The site is situated Southwest of Bucharest, at 15 km from the center of the town. A circular forest with a radius of 800 meters forms the sanitary protection area for the nuclear activities being performed on the site as shown in the next slide.

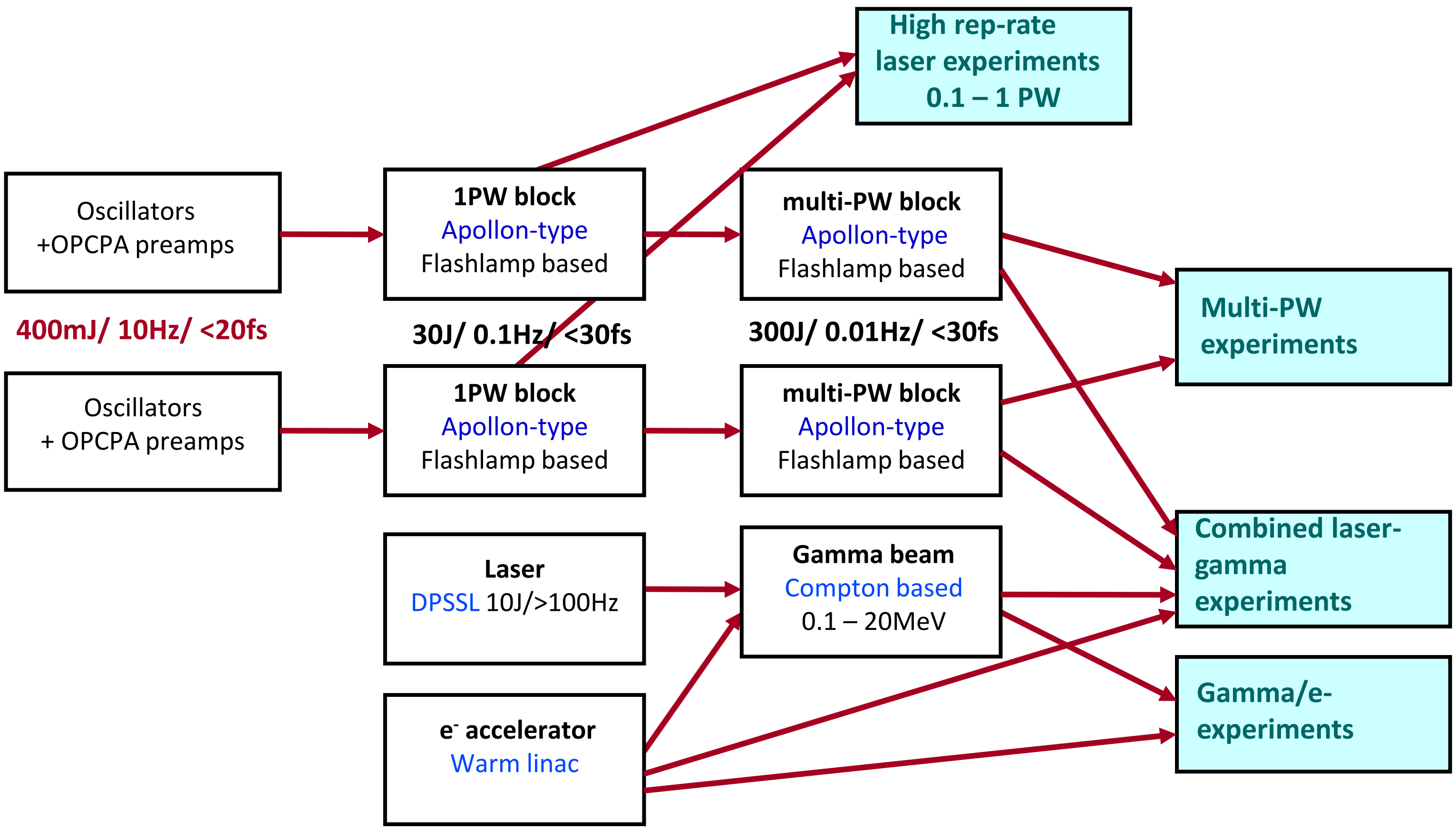
Total cost 293 M€

Duration/phasing: 2 phases (2012-2015/2014-2017)

Bucharest-Magurele National Physics Institutes

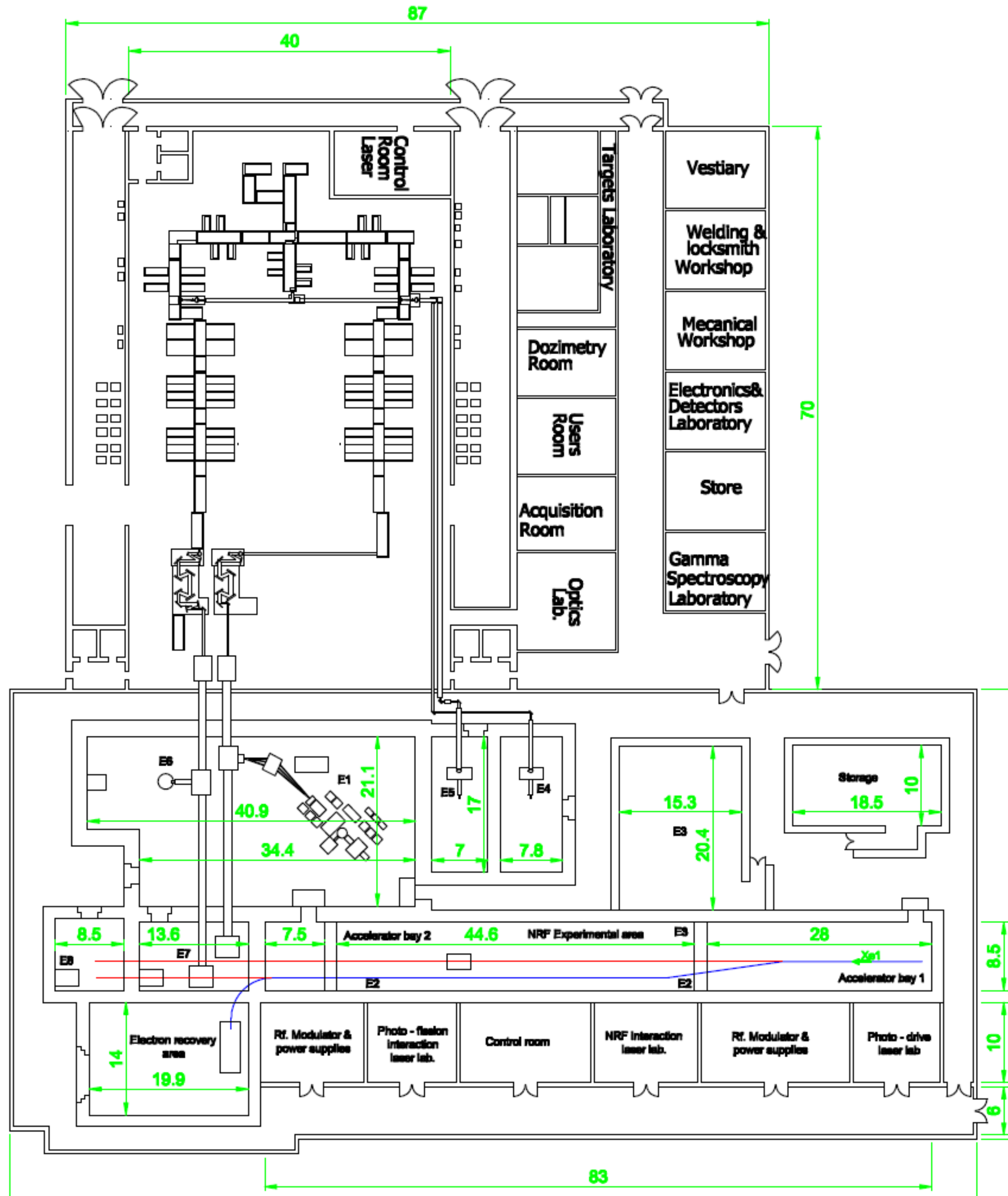


ELI-NP Facility Concept



ELI-NP
Main buildings

- Lasers
- Gamma and experiments
- Laboratories
- Unique architecture



ELI-NP: Site and building

The ELI-NP research infrastructure consists of a major buildings group, which forms the functional and compositional core of the architectural concept, and several adjacent buildings necessary to sustain the main purpose from technical and functional point of view.
The main buildings assembly in the picture is divided into three areas:
“Laser Building”,
“Gamma Beam and Experiments Building” and
“Laboratories and Workshops Building”.

The main adjacent buildings area consists of offices building for research and administrative staff, restaurant, guest-house and the gate access building. All together they amount to about 33,500 m^2 of total built area.

ELI-NP: Site and building

The two arms of the multi-PW laser system are placed in an area of 42×34 m^2 with a 50×50 m^2 area available for further extensions of the laser system and experimental rooms. The laser system is installed in a 10,000 class clean room, thermally stabilized within approx. 0.5^{0}C and controlled humidity of 30–50%. The required very low vibration level is maintained installing all sensitive components on thick concrete slab isolated from the walls and suspended form the basement by a matrix of spring and dampers.

ELI-NP: Site and building

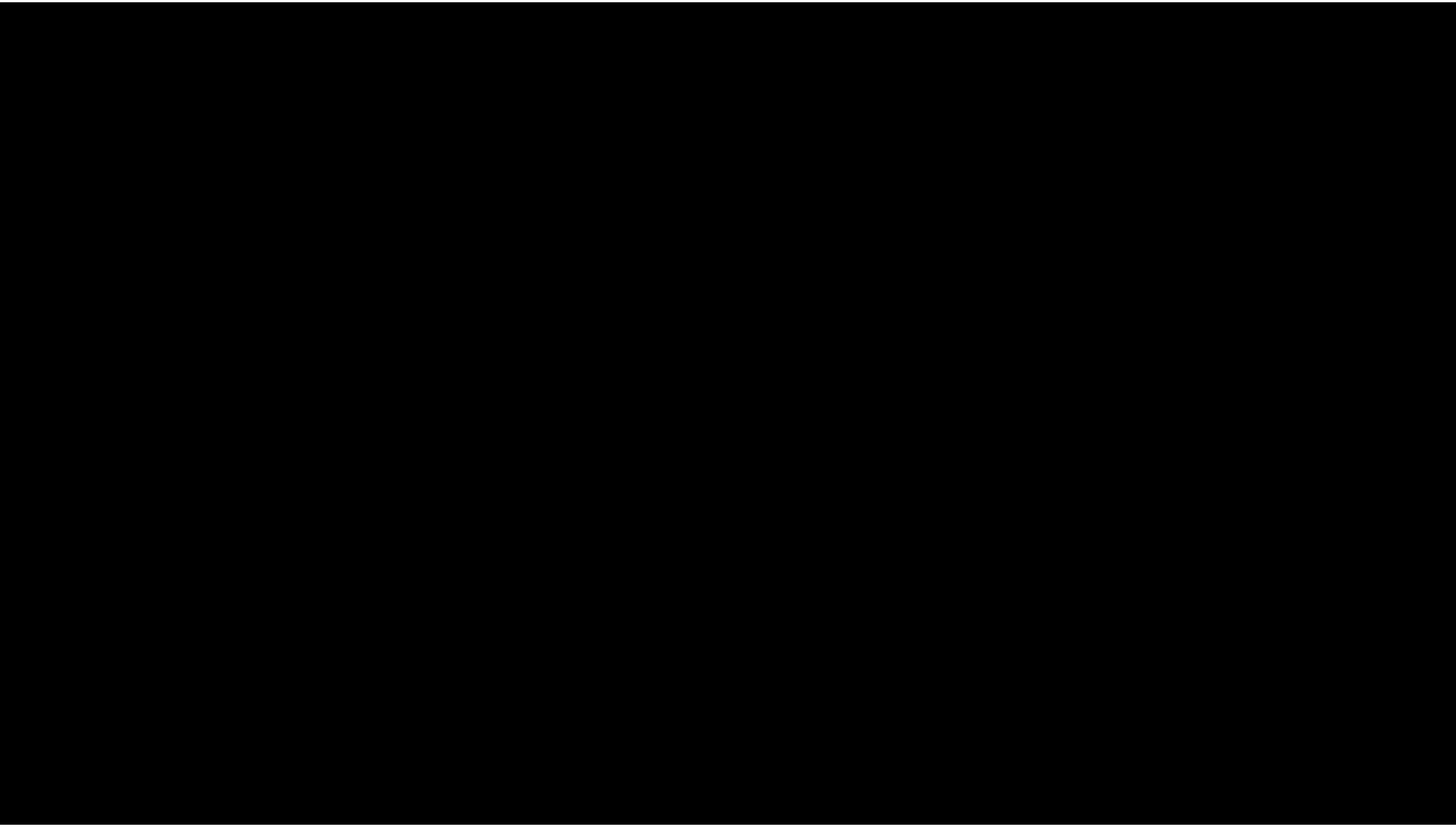
The “Gamma Beam and Experiments Building” will have an external light structure of industrial type and will be equipped with a large crane able to move the concrete blocks defining the experimental rooms and other heavy equipment. The conditions related to temperature, humidity and cleanness are less demanding for this building. Instead, the vibrations has to maintained at the same low level for an even larger area and with much higher load due to the thick biological radioprotection walls defining the various experimental halls.

The same technology will be used with a much dense matrix of spring and dampers. It will assure also highly effective anti seismic protection for all the equipment, the building itself being thoroughly designed taking account the seismic risk according to national relevant regulations and classification of the region where the facility will be built.

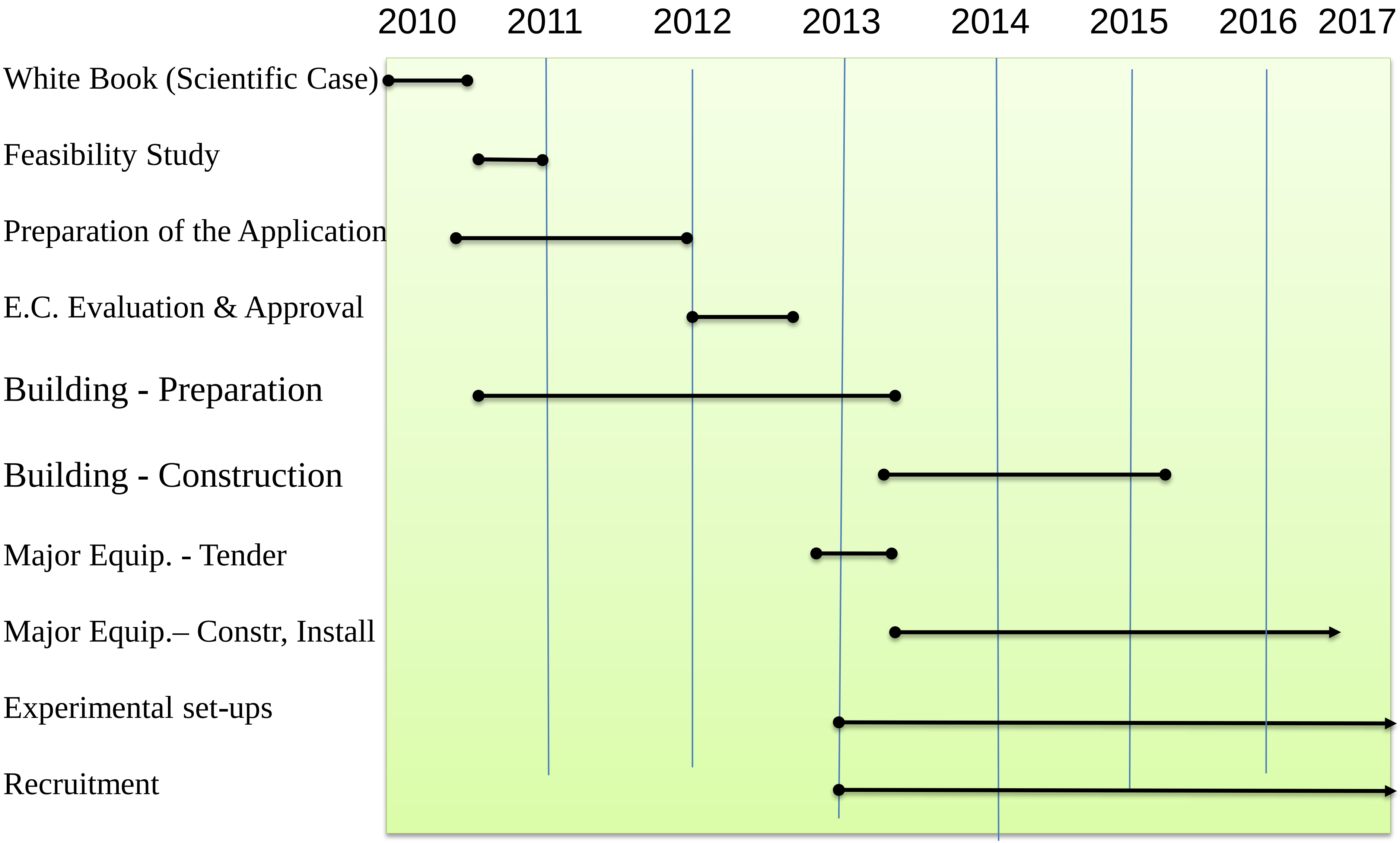
ELI-NP: Site and building

The needs of heating/cooling power for all buildings and equipment may achieve maxima of about 4 MW. A large geo-thermal system is foreseen consisting in about 260 km close-loop liquid circuit (installed in 1000 pits of 130 m each) eliminating completely the gas consumption and compensating rapidly the higher investment cost as compared to a classical system.

ELI-NP ARCHITECTURE 3D RENDERING



ELI-NP Project implementation



ELI-NP: The Experiments

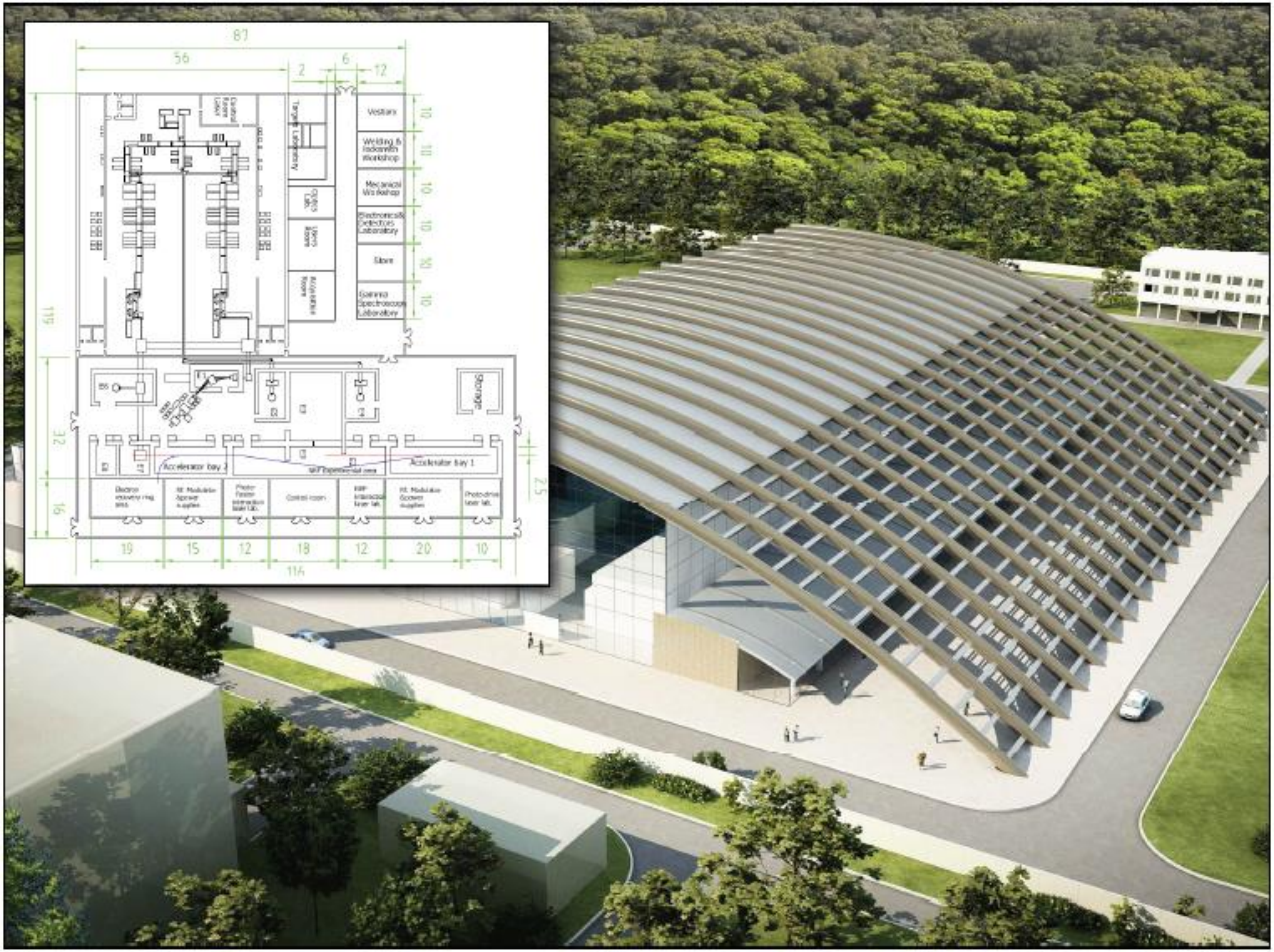
Experimental Halls

Located in between the high-power laser and high brilliance gamma systems 8 experimental halls were proposed, denoted E1–E8, having main primarily thematic assignment as follows:

- E1 – laser induced nuclear reactions;
- E2 – nuclear resonance fluorescence and applications;
- E3 – positrons source and experiments;
- E4/E5 – accelerated beams induced by high repetition laser beams of 1 PW and 100 TW pulse power;
- E6 – intense electron and gamma beams induced by high power laser beams;
- E7 – experiments with combined laser and gamma beams;
- E8 – nuclear reactions induced by high energy gamma beams.

Up to 3 of these halls are supposed to be used simultaneously: one of them receiving multi-PW laser pulses, the second one – 100 TW/1 PW, high repetition rate pulses, and the third one– the gamma beam. Meanwhile the other halls are available for preparation of next experiments.

The use of movable concrete blocks for walls and ceiling allows reconfiguring the experimental area according to the needs expected to evolve very fast in the emerging field of laser driven nuclear physics addressed by ELI-NP facility.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Vestiare
Welding & locksmith Workshop
Mecanical Workshop
Electronics& Detectors Laboratory
Store
Gamma Spectroscopy Laboratory
Target Laboratory
Control Room Linac
Storage
Accelerator bay 2
Accelerator bay 1
Control room
Photo-drive laser lab.
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ELI – NP: Experimental Areas

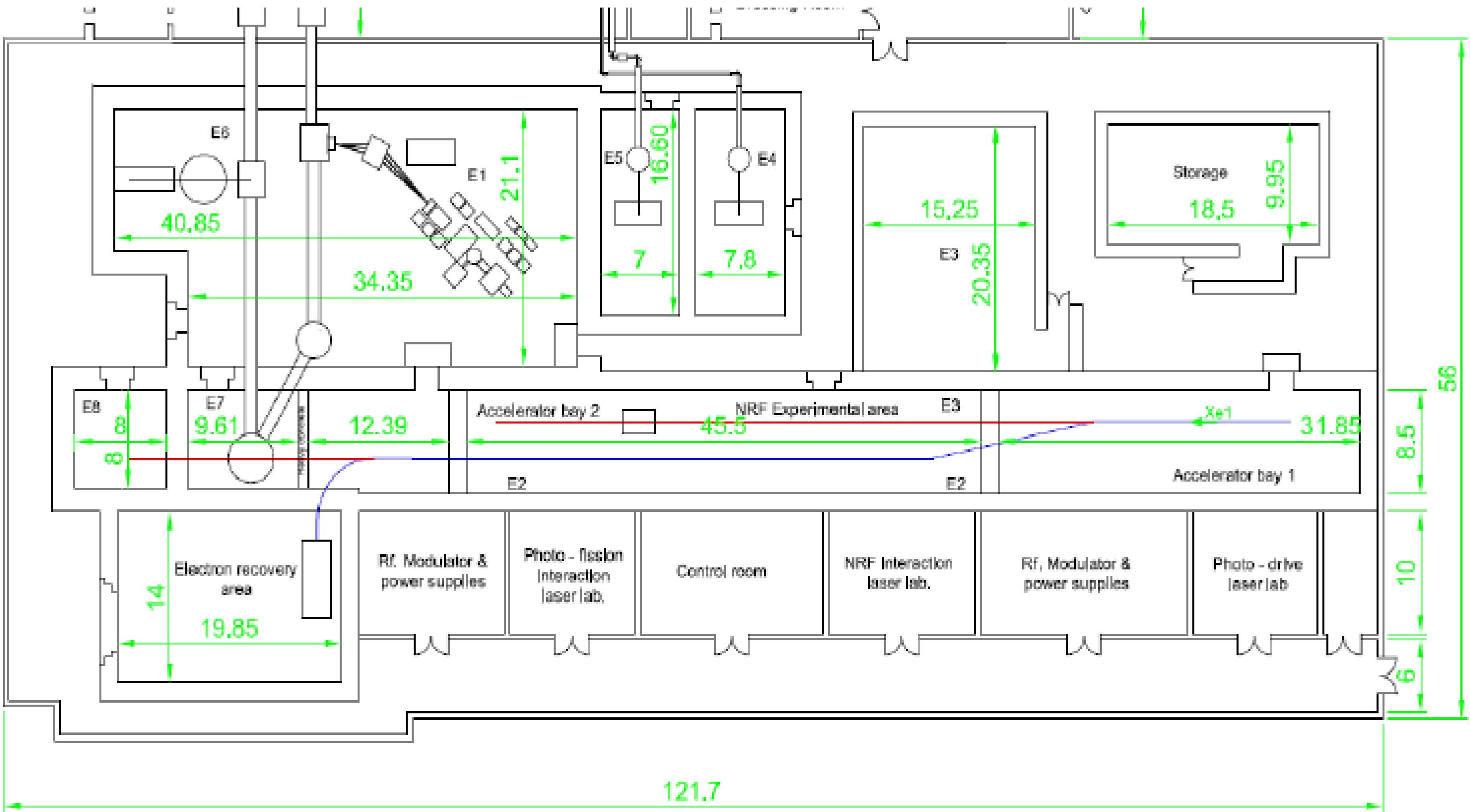


Figure 3: Lay-out of the experimental areas of the ELI-NP facility, as of year 2012, with the dimensions specified in meters.

ELI – NP: Experimental Areas

Table 3. Experimental areas at ELI-NP

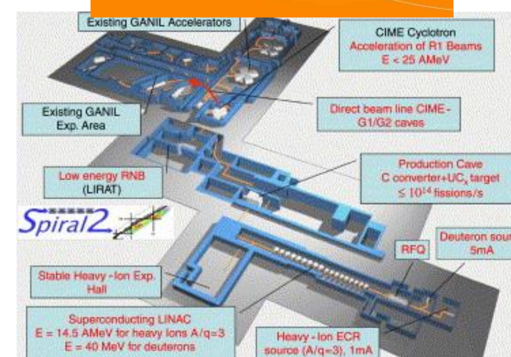
Acronym	Subject	Available beams
E1	Ion acceleration for nuclear science experiments	Laser, 10 PW
E2	Nuclear Resonance Fluorescence Gamma-beam experimental area	Gamma, 4.5 MeV
E3	positron source experimental area	positrons
E4	0.1PW@10Hz, intermediate developments for laser driven experiments	Laser, 2 x 0.1 PW
E5	1PW@1Hz, intermediate developments for laser driven experiments	Laser, 2 x 1 PW
E6	Gamma and electron beams production for QED and nuclear physics studies	Laser, 10 PW
E7	Combined laser-gamma experiments related to vacuum structure	Laser, 2 x 10 PW, electron and gamma beams
E8	Nuclear reactions induced by high energy gamma beams and material science experimental area	Gamma, 19MeV

ELI – Nuclear Physics Research

- 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 complementary to the other ELI pillars



ELI-NP in Romania (selected by the most important science committees in Europe – ESFRI and NuPECC, all fields of science included, from social science to space science)

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

Experimental Program at ELI-NP

International workshop held in Magurele, October 2012

- Invitations to submit Letters of Intents for experiments @ ELI-NP
- Aim: initiate the work at the TDRs of experimental halls
- TDRs to be completed by end 2014
- Participation: >100 researchers
- 2.5-days workshop
- Activity in three workgroups, for laser, gamma, and laser+gamma experiments
- Template for LoIs, containing more technical details than proposals in the WB

ELI – NP Experiments (1)

Stand-alone High Power Laser Experiments

- Nuclear Techniques for Characterization of Laser-Induced Radiations
- Modelling of High-Intensity Laser Interaction with Matter
- Stopping Power of Charge Particles Bunches with Ultra-High Density
- Laser Acceleration of very dense Electrons, Protons and Heavy Ions Beams
- Laser-Accelerated Th Beam to produce Neutron-Rich Nuclei around the N = 126 Waiting Point of the r-Process via the Fission-Fusion Reaction
- A Relativistic Ultra-thin Electron Sheet used as a Relativistic Mirror for the Production of Brilliant, Intense Coherent γ-Rays
- Studies of enhanced decay of ^{26}Al in hot plasma environments

ELI – NP Experiments (2)

Laser + γ /e− Beam

- Probing the Pair Creation from the Vacuum in the Focus of Strong Electrical Fields with a High Energy γ Beam
- The Real Part of the Index of Refraction of the Vacuum in High Fields: Vacuum Birefringence
- Cascades of e+e− Pairs and **γ** -Rays triggered by a Single Slow Electron in Strong Fields
- Compton Scattering and Radiation Reaction of a Single Electron at High Intensities
- Nuclear Lifetime Measurements by Streaking Conversion Electrons with a Laser Field.

ELI – NP Experiments (3)

Standalone γ /e experiments for nuclear spectroscopy and astrophysics

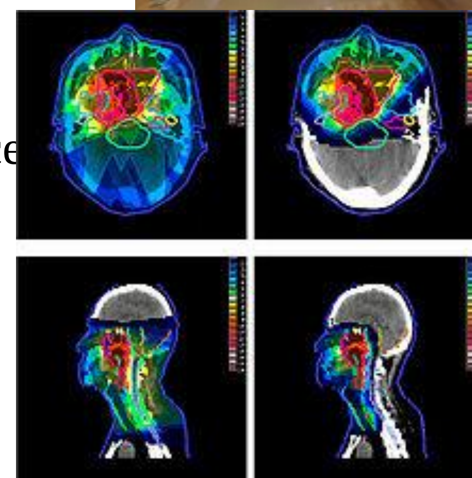
- Measuring Narrow Doorway States, embedded in Regions of High Level Density in the First Nuclear Minimum, which are identified by specific (γ, f), (γ, p), (γ, n) Reactions
- Dipole polarizability with high intensity, monoenergetic MeV γ-radiation for the evaluation of neutron skin
- Nuclear Transitions and Parity-violating Meson-Nucleon Coupling
- Study of pygmy and giant dipole resonances
- Gamma scattering on nuclei
- Fine-structure of Photo-response above the Particle Threshold: the (γ ,α), (γ,p) and (γ ,n)
- Nuclear Resonance Fluorescence on Rare Isotopes and Isomers
- Neutron Capture Cross Section of s-Process Branching Nuclei with Inverse Reactions
- Measurements of (γ, p) and (γ, α) Reaction Cross Sections for p-Process Nucleosynthesis
- High Resolution Inelastic Electron Scattering (e,e')

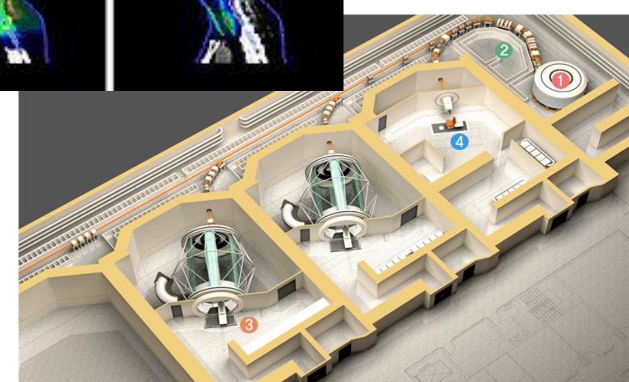
ELI – NP Applications

ELI-NP – new science, new experimental approaches. Considering the audience, we will focus on technological and applications aspects

- Laser produced charge particle beams may become an attractive alternative for large scale conventional facilities
- Laser driven gamma beams
- High Resolution, high Intensity X-Ray Beam
- Intense Brilliant Positron-Source: $10^7 e^+/[s(mm\ mrad)^2]$
- Radioscopy and Tomography
- Materials research in high intensity radiation fields
- Applications to characterization of Nuclear Waste

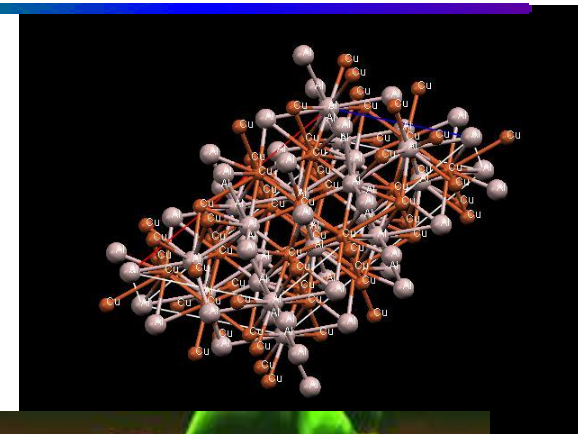
Radioisotopes for medical use

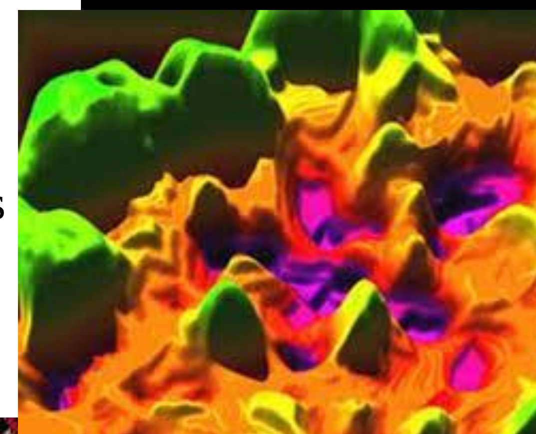


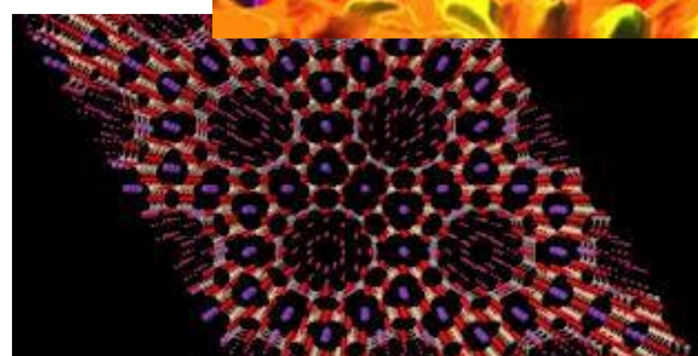


- Ageing nuclear reactors that currently produce medical radioisotopes, growing demand – shortages very likely in the future
- New approaches and methods for producing radioisotopes urgently needed
- Feasibility of producing a viable and reliable source of photo fission / photo nuclear-induced Mo-99 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

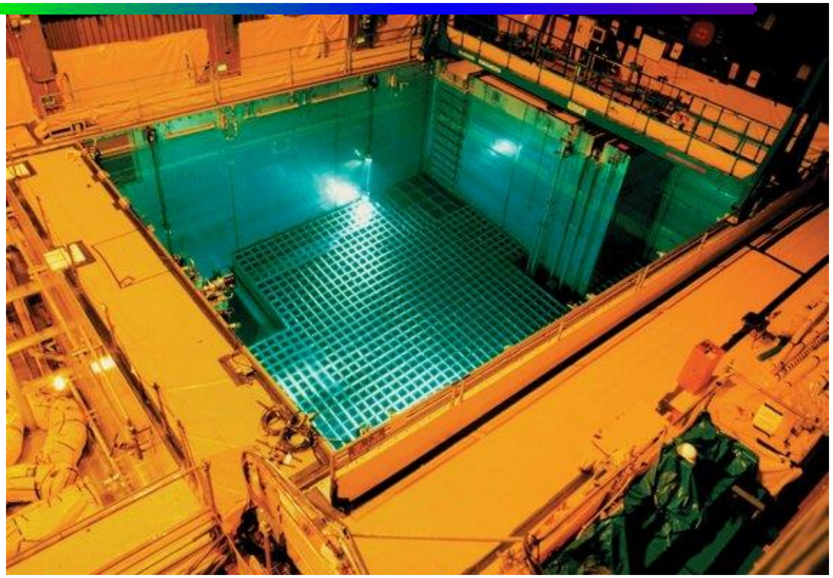






- **manipulating materials on the nano- and femto-scales**
- novel experimental studies of material behavior – extreme fields intensity provided by the laser and gamma-ray beams
- understand, at the atomic scale, the behavior of materials subject to extreme radiation doses and mechanical stress
- structure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

NRF Applications



- **Management of Sensitive Nuclear Materials and Radioactive waste**
  - isotope-specific identification $^{238}U/^{235}U$, ^{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

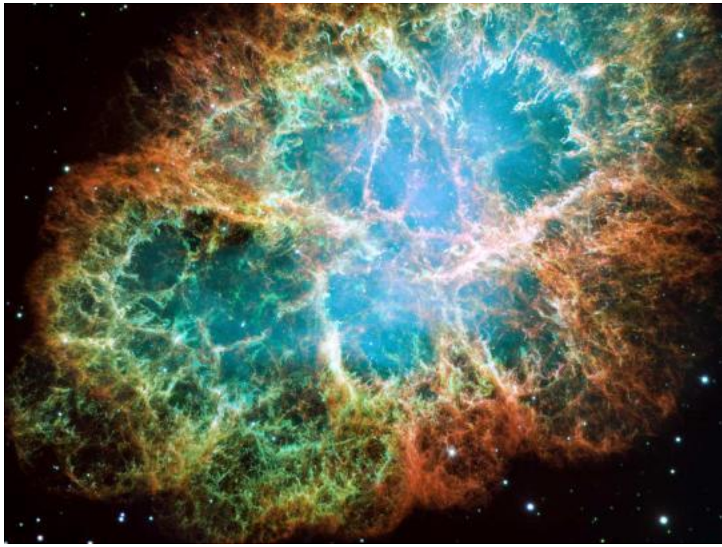
Astrophysics Applications

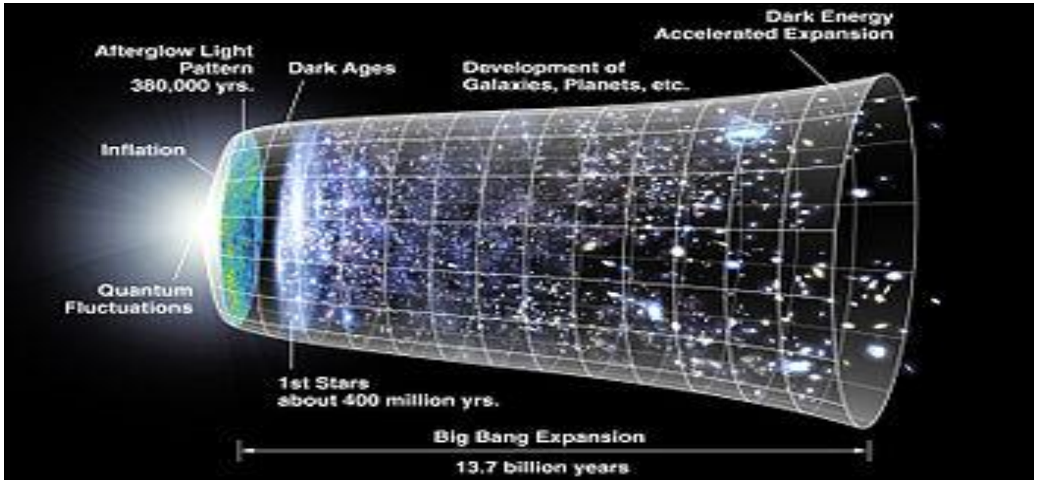
Production of heavy elements in the Universe – a central question for Astrophysics

•Neutron Capture Cross Section of s-Process Branching Nuclei with Inverse Reactions

• Measurements of (γ, p) and (γ, α) Reaction Cross Sections for p-Process Nucleosynthesis

- determination of the reaction rates by an absolute cross section measurement is possible using monoenergetic photon beams produced at ELI-NP
- broad database of reactions – high intense γ beam needed






Thank You !

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