ELI-NP: Nuclear Science and applications with the next generation of High Power Laser and Gamma beams: Project Status and Roadmap

The world's first international laser Research Infrastructure
Pan–European distributed research infrastructure based initially on 3 facilities in CZ, HU and RO

ELI–Beamlines, Prague, CZ

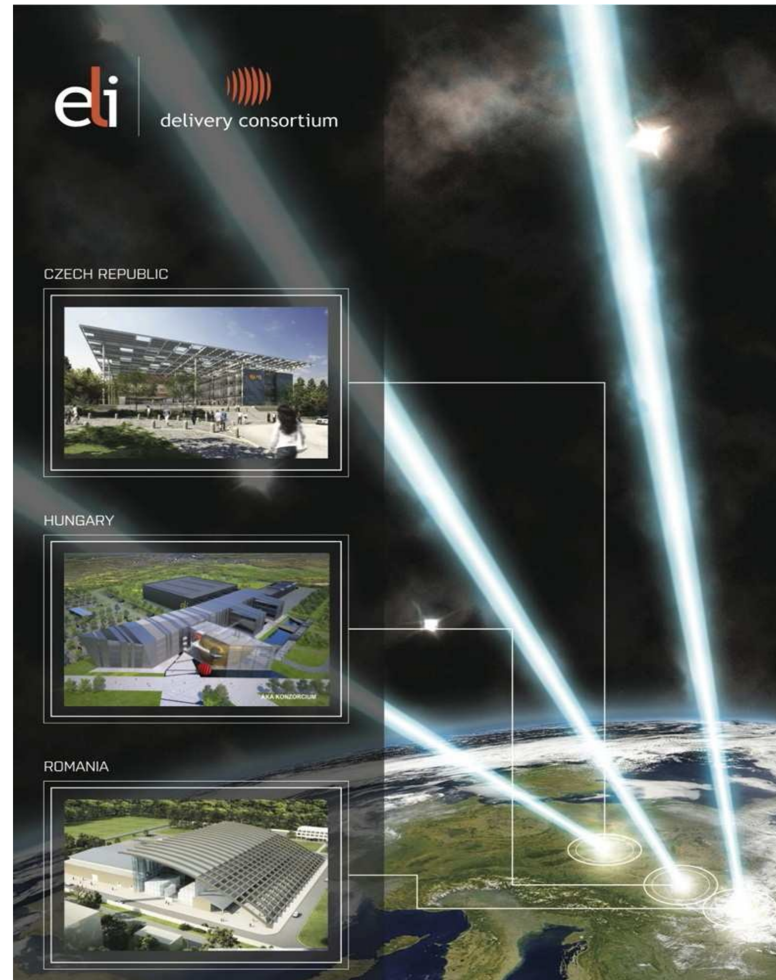
High–Energy Beam Facility
development and application of ultra–short pulses of high–energy particles and radiation

ELI–ALPS, Szeged, HU

Attosecond Laser Science Facility
new regimes of time resolution

ELI–NP, Magurele, RO

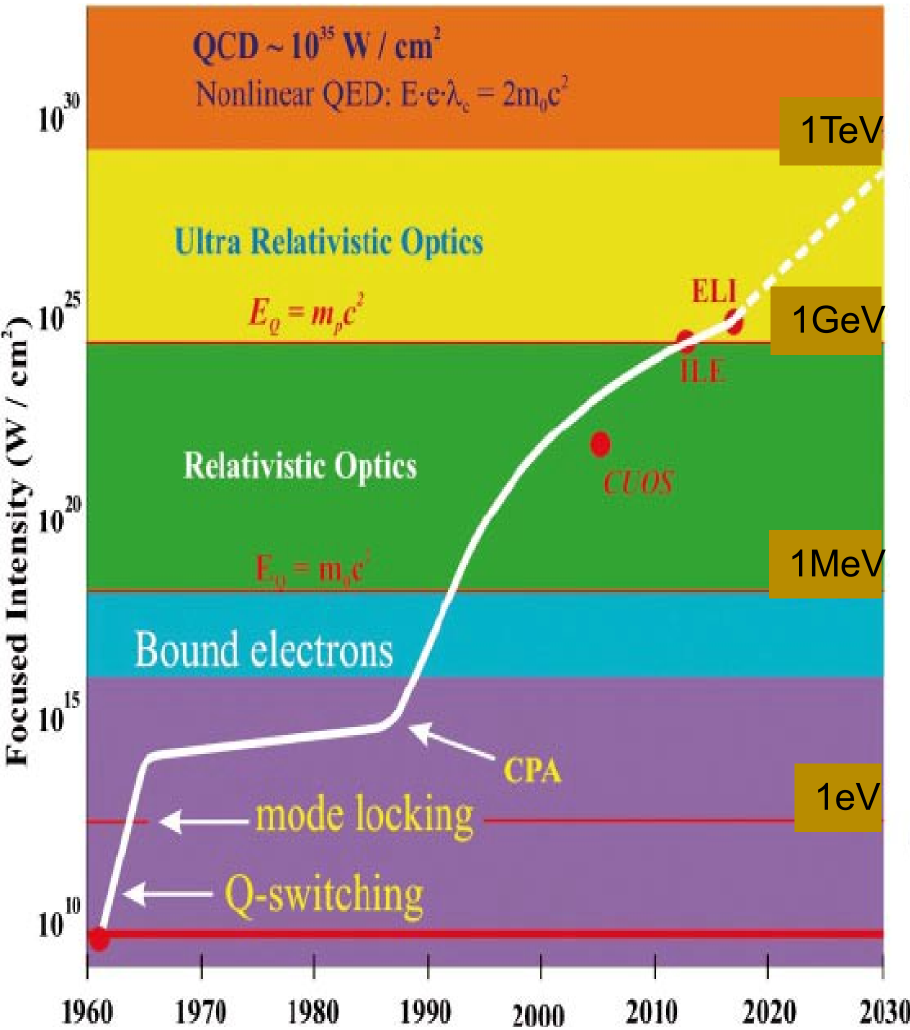
Nuclear Physics Facility with ultra–intense laser and brilliant gamma beams (up to 20 MeV)
novel photonuclear studies

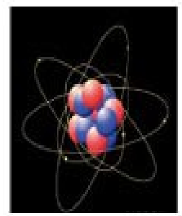


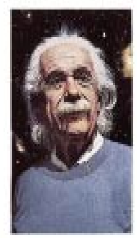
Extreme Light Infrastructure
A world laser roadmap

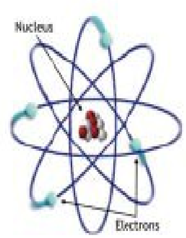
Nuclear Physics

Gerard Mourou 1985: Chirped Pulse Amplification (CPA)









Electric field in the laser focus is function of laser intensity:

$E(V/cm) = 27.4 \times \sqrt{I(W/cm^2)}$

$I = 10^{23}\ W/cm^2$

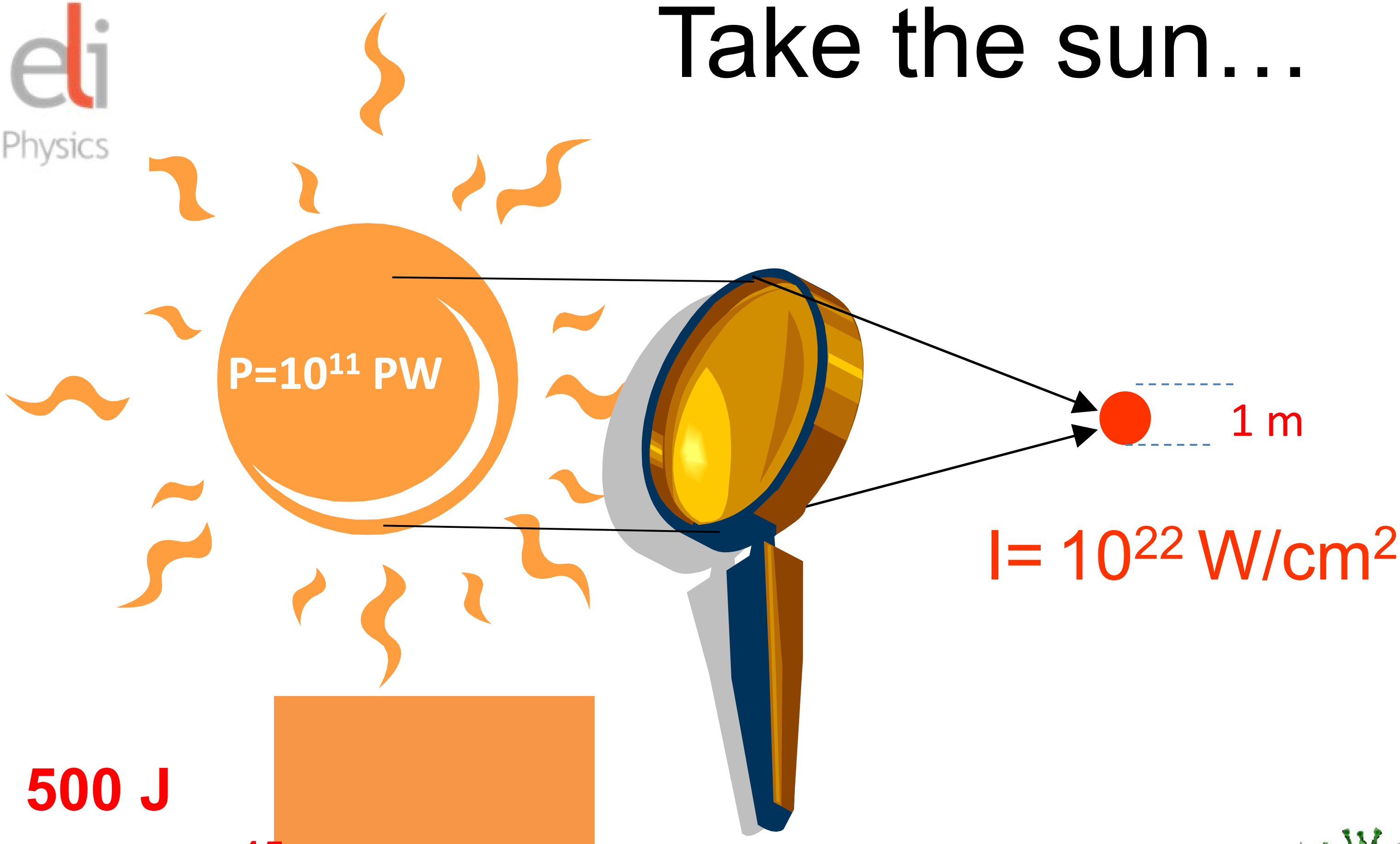
$E = 8.7 \times 10^{12}\ V/cm =$

$= 8.7 \times 10^{6}\ MV/cm$

$I(\text{Schwinger}) = 2.3 \times 10^{29}\ W/cm^2$

$E_s = 1.3 \times 10^{16}\ V/cm$

Take the sun…



500 J

50 fs = **50x10^-15s**

P= 10 PW

I > 10^22 W/cm^2 ! 10micron

Taken from P.Martin

ELI Nuclear Physics in Romania

Structural Funds approved in Sept. 2012
Start construction June 2013

Projected completion date: spring 2018-
Fully operation facility +1-2 years

Building under construction
(Completed June 2015)

staff hiring in progress (~60→>240)

Major equipment:
two 10PW lasers under construction

Gamma Beam System under construction

293 Meuro 83% EC , 17% Romania

Budget break-down 2012 – 2017:

Building	**66 M€**
Stafff	**34 M€**
Scientific equipment	**169 M€**
Others	**24 M€**
Total	**293 M€**

ELI-NP

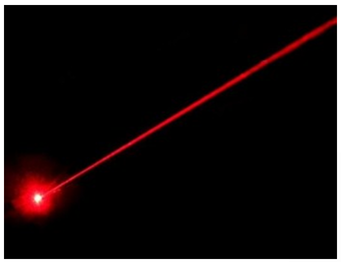
Observation of matter with new powerful probes

Two machines of extreme performances

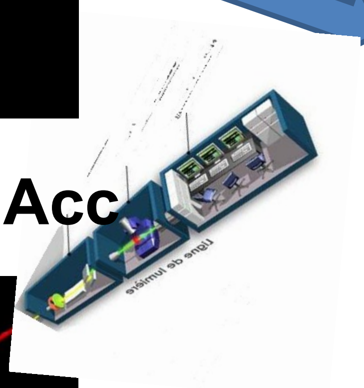
Large discovery potential

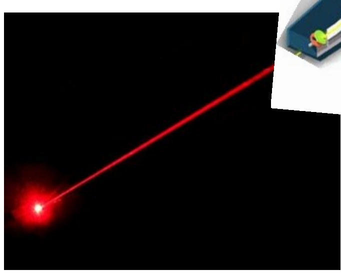
Two 10 PW lasers, 10^{23} w/cm^2

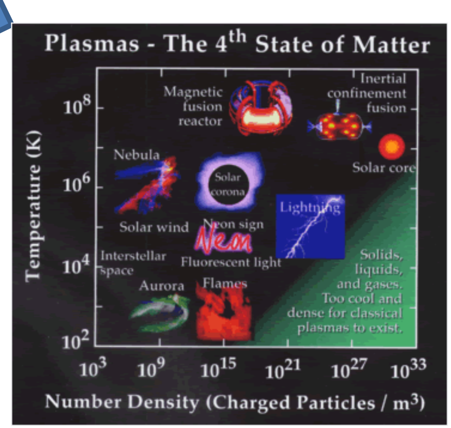
Extreme E-M fields



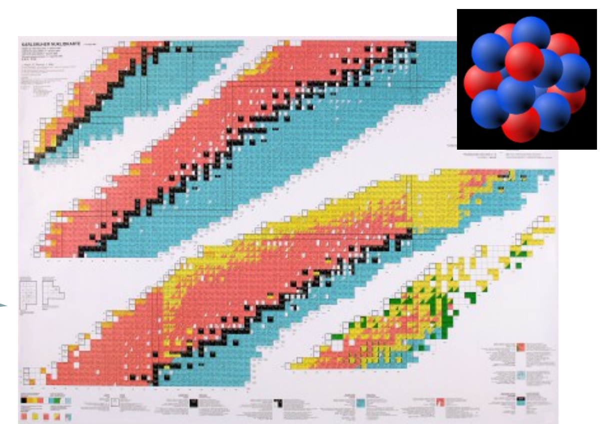
Laser +e- Acc





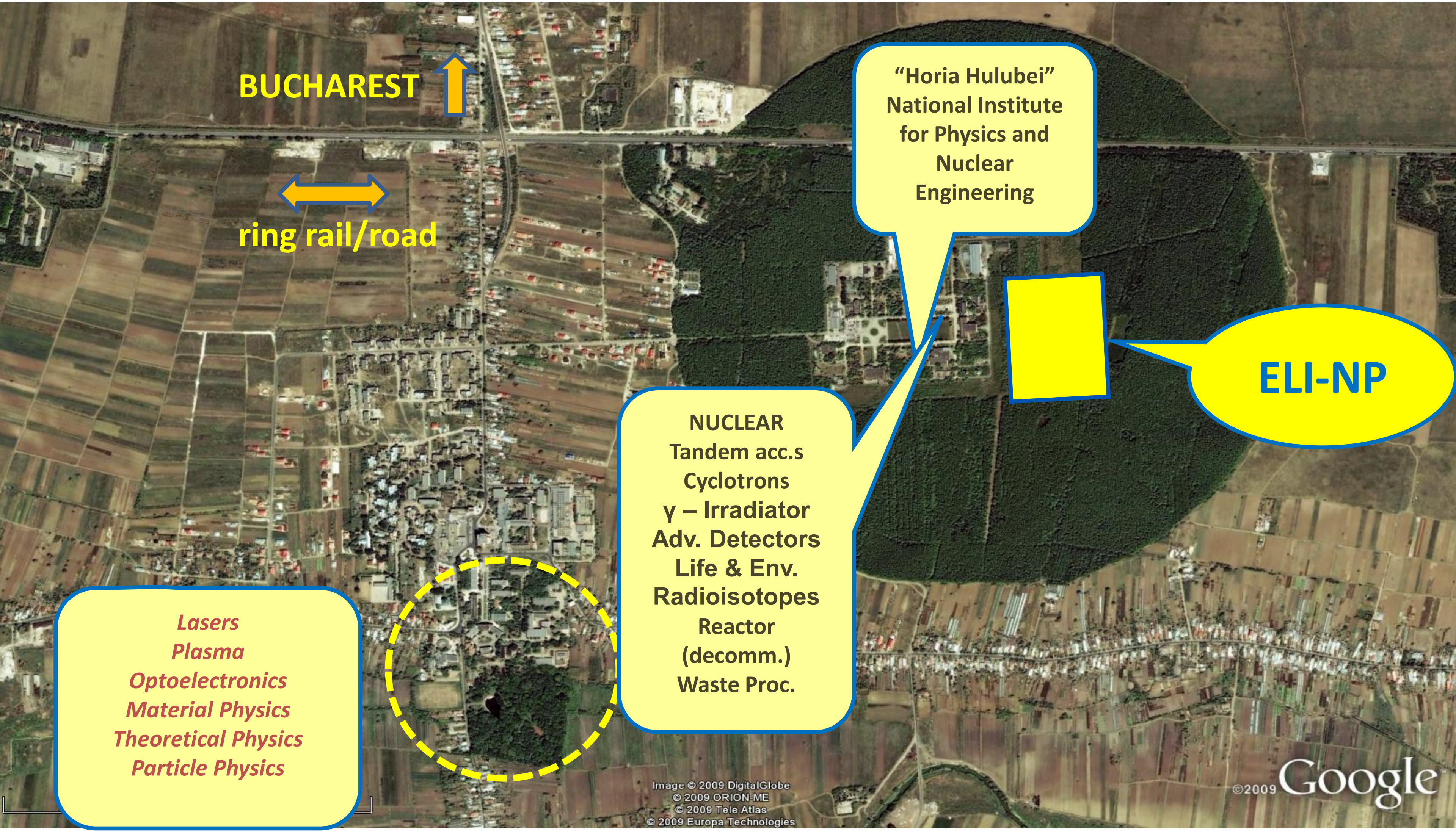


Femto scale



BCS Brillant Gamma Beams
0,2-19 MeV, $10^{11}\gamma$/s, 0,3% BW

Bucharest-Magurele Physics Campus
National Physics Institutes



ELI-NP Milestones –Facility Construction

Buildings – one contractor, 33000 m^2 total

Ready by June 2015

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

1st October 2014

ELI–NP Nuclear Physics Research

- **Nuclear Structure**

  Nuclear Photonics (NRF)

  Photo–disintegration, Photo–fission & Exotic Nuclei

  Nuclear Astrophysics

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

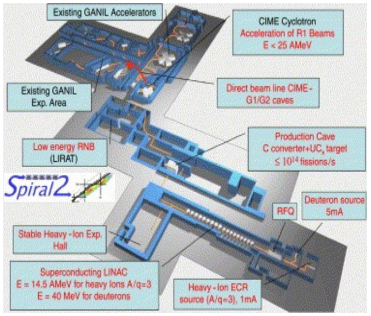
  Laser–Target interaction characteristics : NP diagnostics

  Laser Ion driven nuclear physics : fission–fusion

  Laser – Extreme E-M Fields–Acceleration – Beyond QED

- 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, in the ‘**Nuclear Physics Long Range Plan in Europe’** as a major facility*



ELI–NP Scientific Coordination

Research Activities

20 MoU With major Laser and NP labs and Institutions

- HPLS
- GBS
- Experiments with HPLS
- Experiments with GBS

Experiments with HPLS

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

Experiments with GBS

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

Engineering office Interface (building,safety RP ,Vacuum,C&C, labs, workshops)

ELI–NP Scientific Coordination

TDR's Workshops June 2013& April 2014

The workshop "Towards Technical Design Reports (TDR) of experiments with intense **laser beams** at ELI-NP" was held in Bucharest-Magurele, on June **June 27th - 28th,** adjacent to a workshop "Towards Technical Design Reports (TDR) of experiments with brilliant **gamma-ray beams** at ELI-NP" held at the same location **on June 25th - 26th,** 2013.

Next ELI–NP International Workshop

- **"ELI–NP Science Program and Instruments"**

Technical Design Reports-*February 18 – 20, 2015*

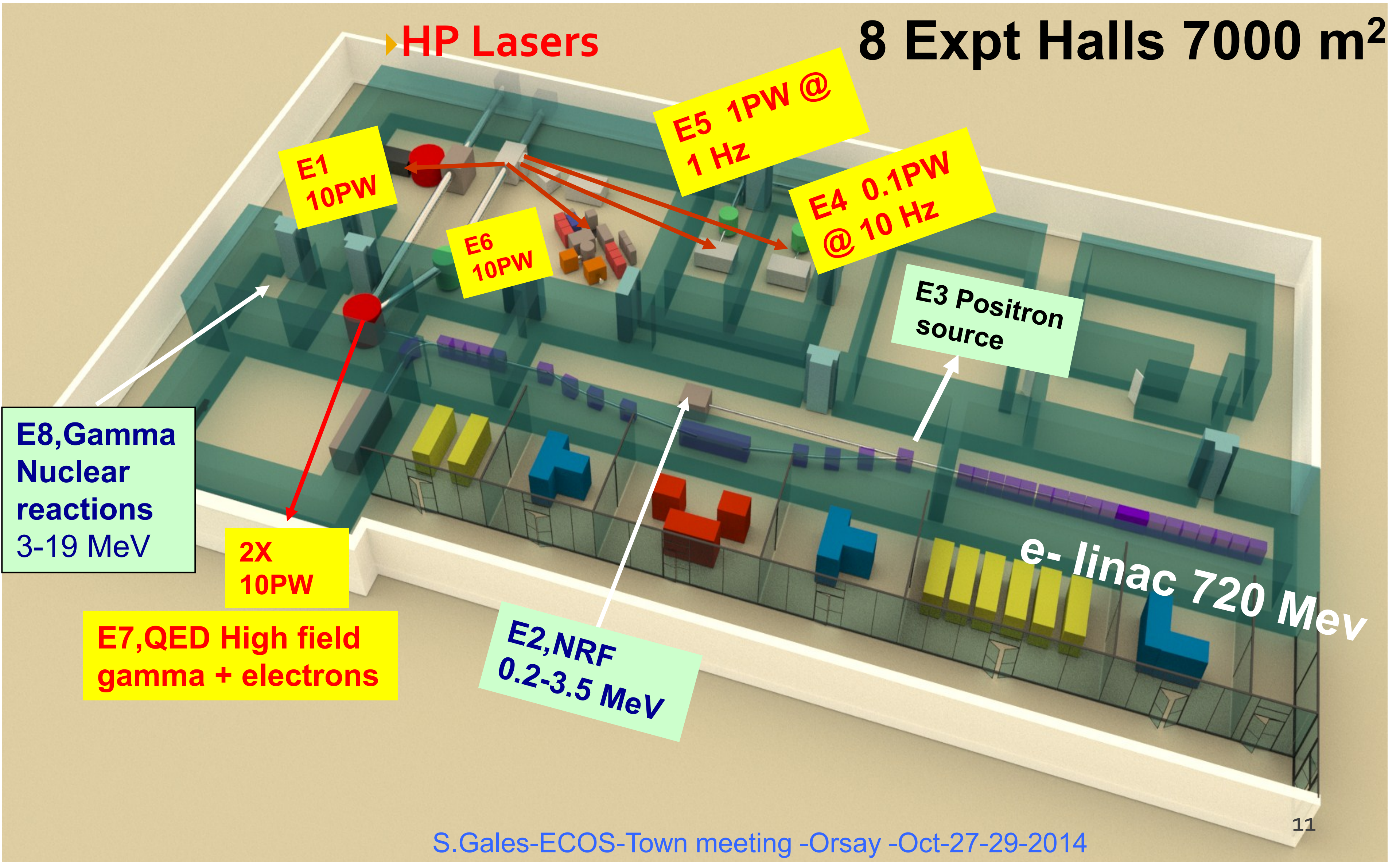
External reviews March-May 2015

International Scientific Advisory Board (20 members)

2nd Trimester of 2015

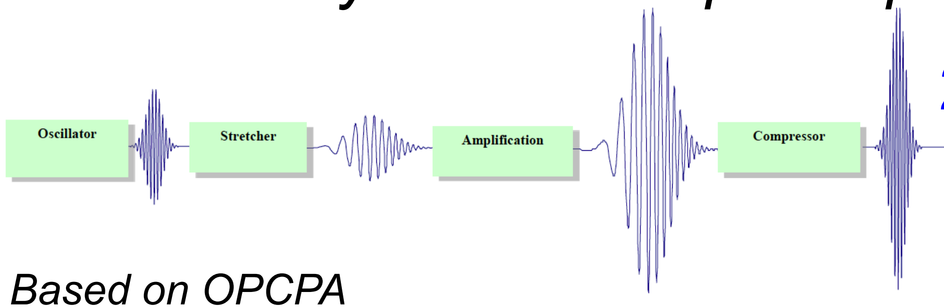
ANR proposals FR-RO dedicated to ELI-NP (18/11/2014)

ELI–NP Experiment Building



ELI–NP HPLS

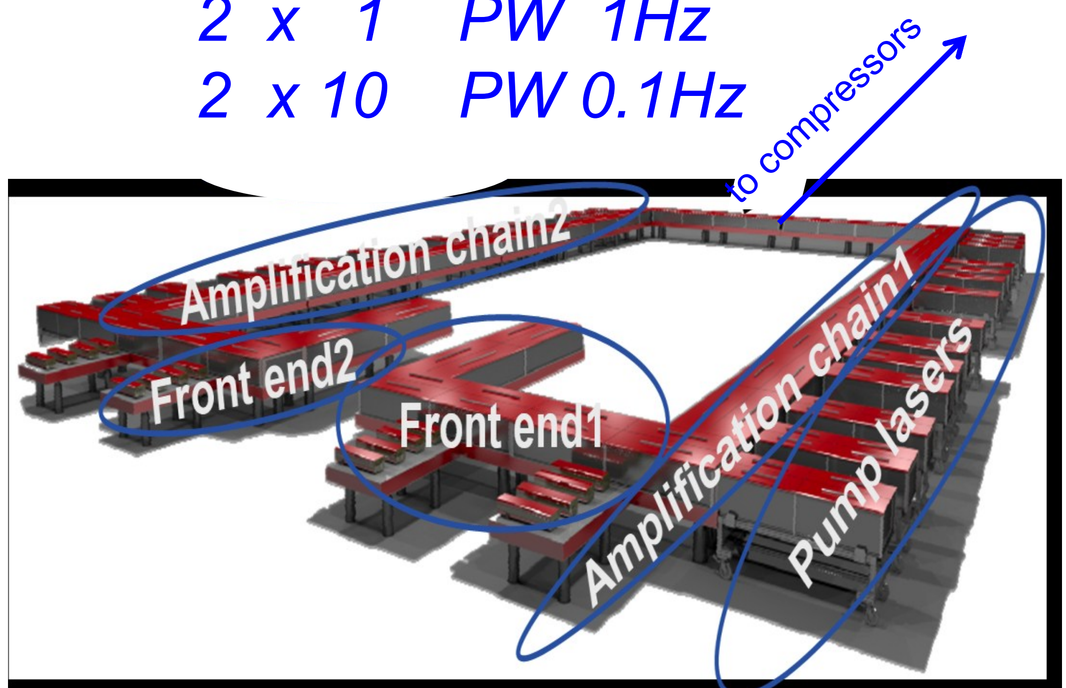
Provided by THALES Optronique – France



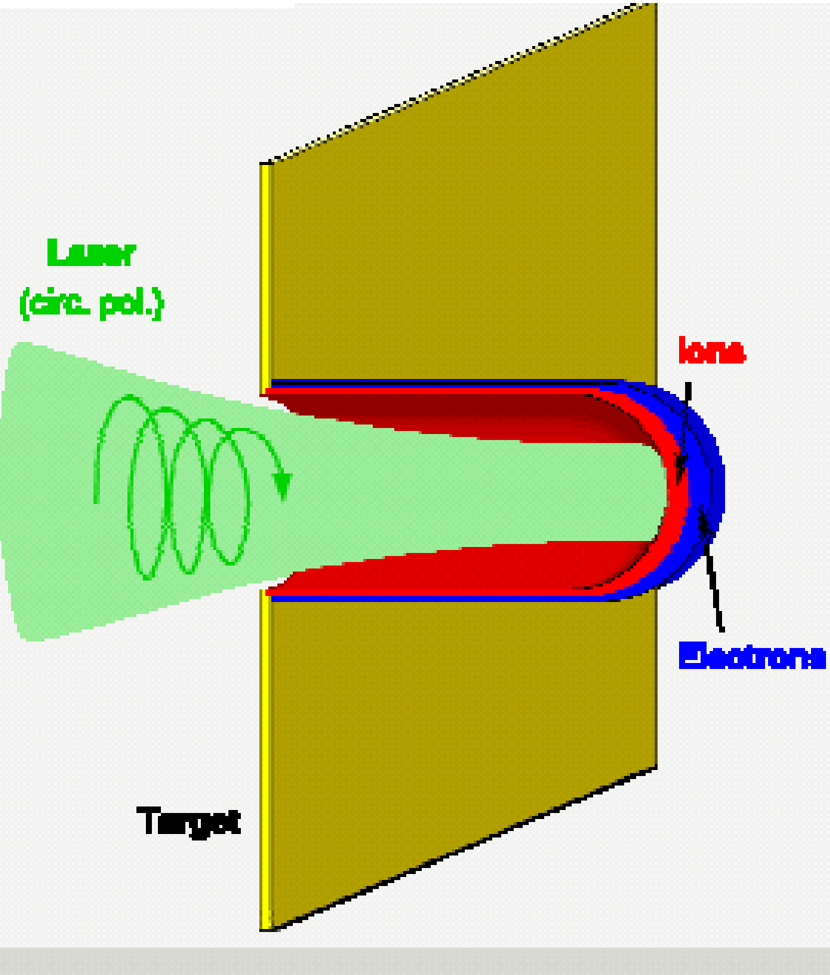
Based on OPCPA

2 HPLS up to 10 PW – 6 outputs

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



Interaction of High Power Laser with Matter will suffer this :



GIGANTIC TSUNAMI !!

Electrons are expelled from the target due to the chock wave induced by the powerful laser .Heavy ions are accelerated in the field created by the electrons

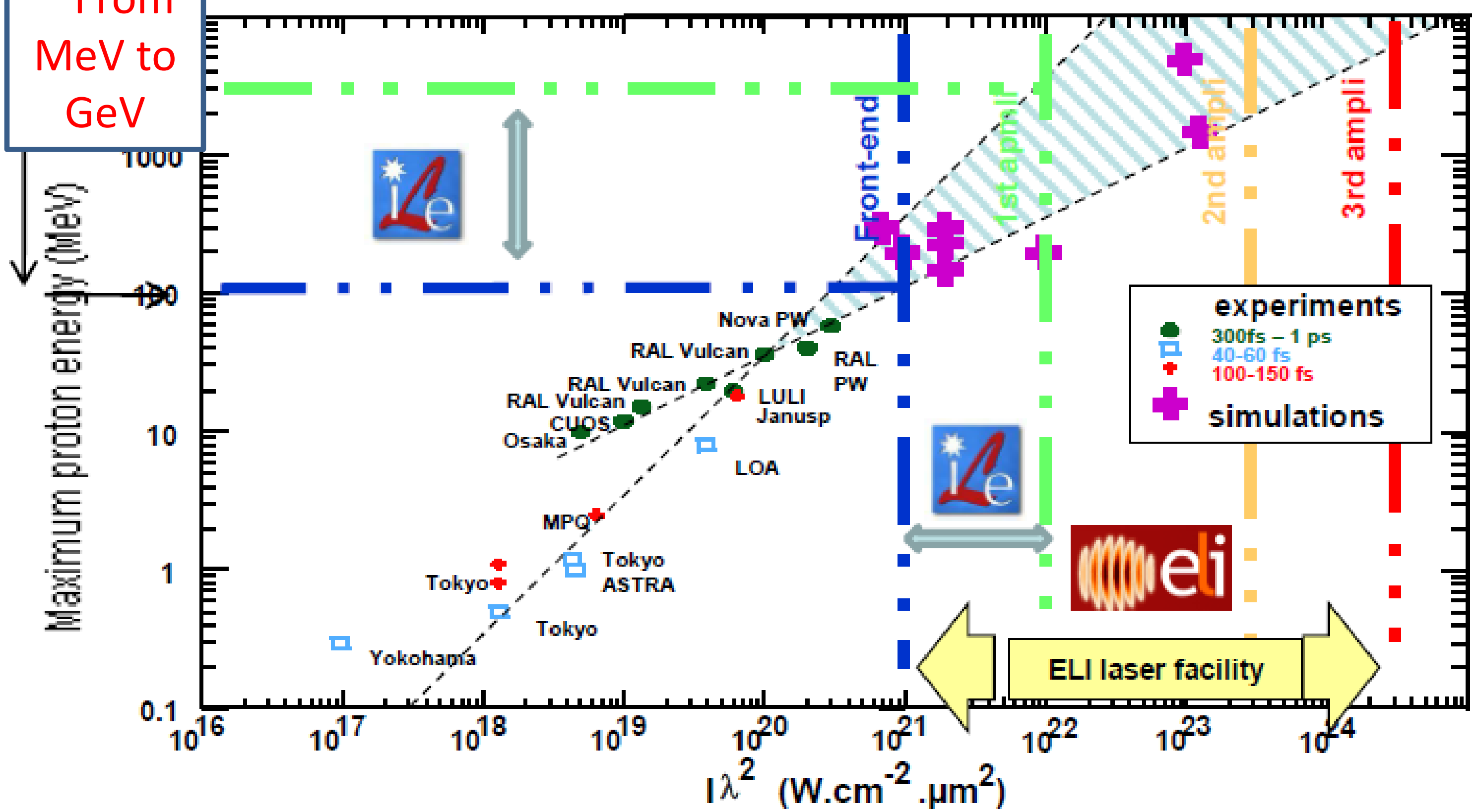
Accelerations of Electrons and Ions

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)

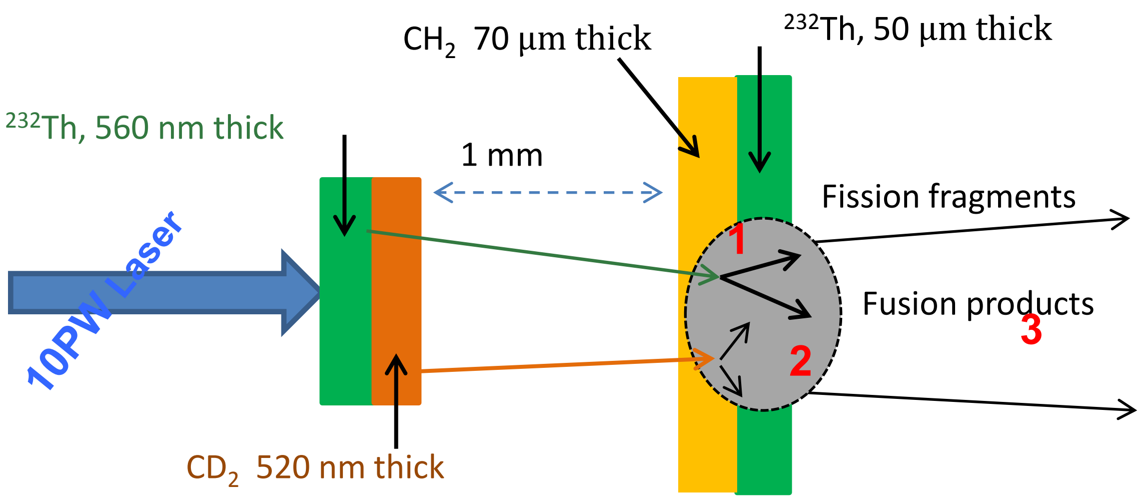
E~ I_{laser}

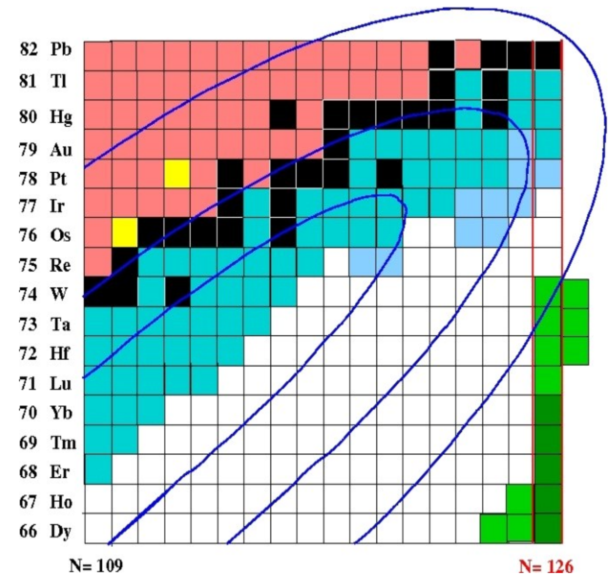
Energy reached equal to a 400m up-to-date accelerator (up to GeV reduction of scale of 10^{9})

From MeV to GeV



LASER DRIVEN NUCLEAR PHYSICS EXPTS: Nuclear Astrophysics





1. **Circular polarized Laser beam** incident on production target produces a beam of ^{232}Th, ^{12}C and ^{2}D ions through the Radiation Pressure Acceleration.

2 **Fission reactions:** a) ^{232}Th interacts with ^{12}C (or ^{1}H) in the 1st layer and b) ^{12}C and ^{2}D nuclei interacts with ^{232}Th in the 2nd layer of reaction target. One light and another heavy fragments are produced:

^{232}Th + (^{12}C , ^{1}H) -> $X_L + X_H$

^{12}C (or ^{2}D) + ^{232}Th→ $Y_L + Y_D$

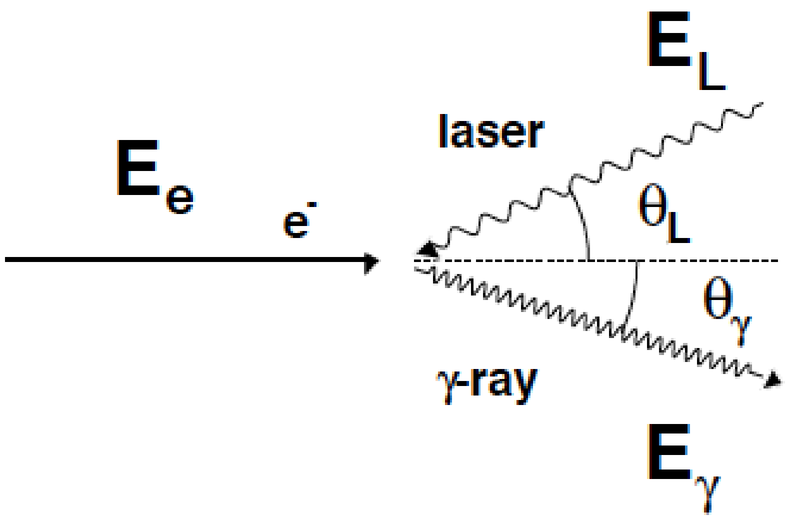
3 **Fusion:Two light fission fragments (X_L, Y_L)** fuse in the reaction target. Neutron rich nuclei (close to N=126) are produced.

fission–fusion reactions.
n–rich nuclei around
N = 126 Z=66,70 waiting point

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*

The Gamma Beam System (GBS)



Laser Compton Back–scattering (LCB)

- **the most efficient frequency amplifier**

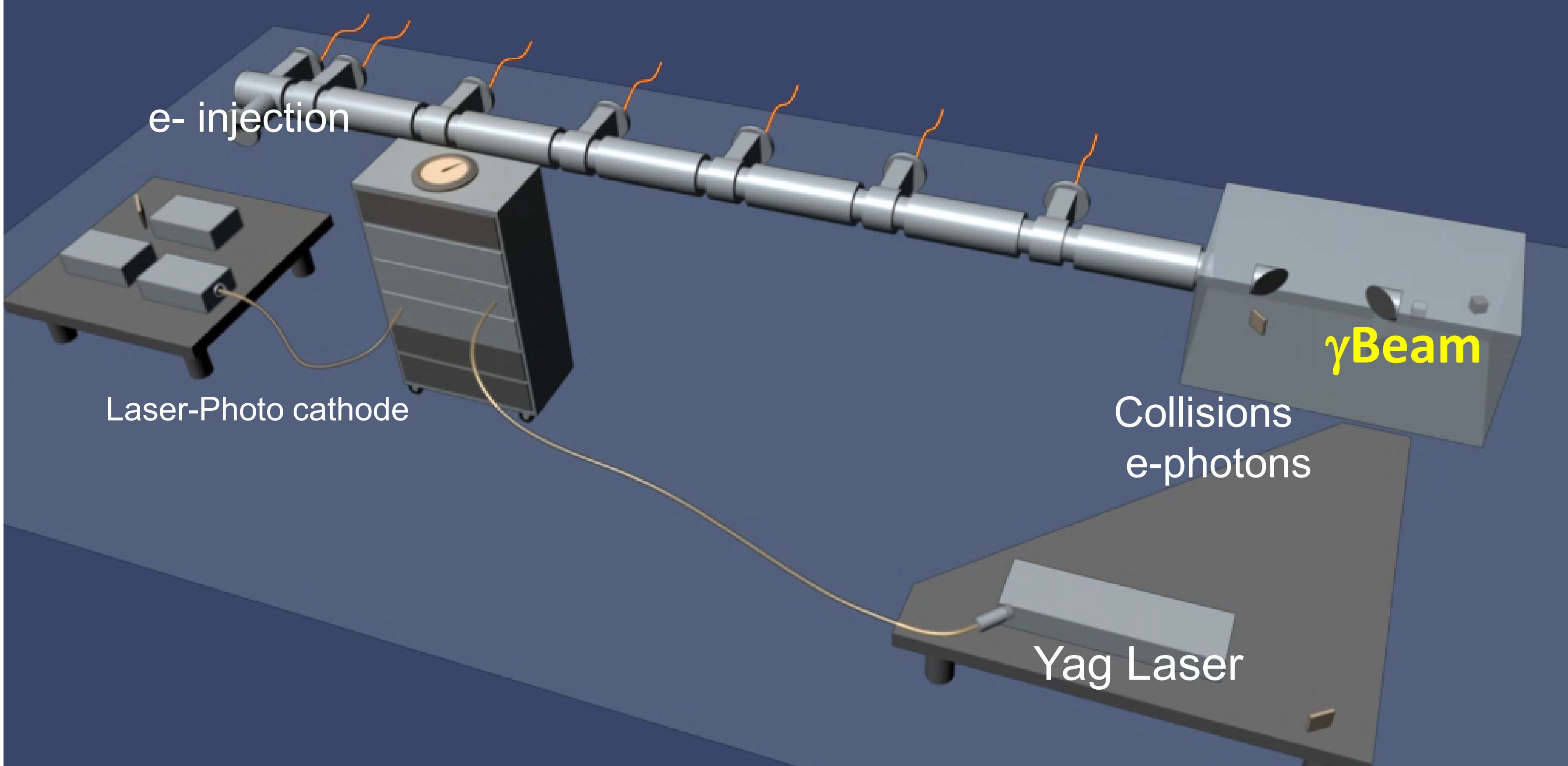
'Photon accelerator'

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

Maximum upshift

- head–on collision (θ_L=0) & backscattering (θ_γ=0) $E_\gamma \sim 4\gamma_e^2 E_L$

Electron Linac



-
- $E_L \sim 2.4$ eV (green)

$E_e \sim 300$ MeV $E_\gamma < 3.5$ MeV

$E_e \sim 720$ MeV $E_\gamma < 20$ MeV

The GBS of ELI–NP

Provider – EuroGammaS Association

Academic Institutions
Sapienza University (Italy), INFN (Italy), CNRS (France), IN2P3 (France)
Industrial Partners
ACP (Amplitue Group, France), Alsyom (Alcen Group, France),Comeb (Italy), ScandiNova Systems (Sweden)

and several Sub-Contractors:
Alba (Spain), Cosylab (Slovenia), Danfysik (Denmark), IT (Slovenia), M+W Group (Italy), Menlo Systems (Germany), RI (Germany)

The Challenges :

- **design the *most advanced* *Compton* Gamma Beam Source based on *state–of–the–art* components**
- **combining electron accelerator physics with a photon–electron collider**

ELI–NP Gamma Beam Source: Bright, Monochromatic (≲0.5%), High Spectral Flux (~10^4 ph/s·eV), Tunable (0.2–19.5 MeV), Polarized (≳99%)

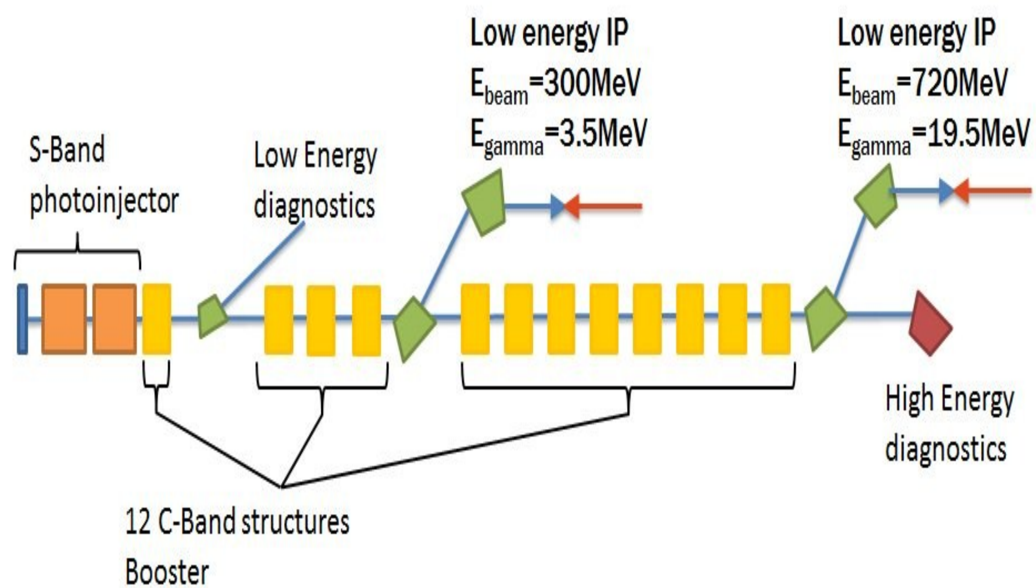
TDR – arXiv:1407.3669 [physics.acc-ph]

GBS – Beam Specifications

Energy (MeV)	0.2 – 19.5
Spectral Density (ph/s·eV)	$0.8 – 4 \cdot 10^4$
Bandwidth rms (%)	≤ 0.5
# photons per shot within FWHM bdw.	$\leq 2.6 \cdot 10^5$
# photons/sec within FWHM bdw.	$\leq 8.3 \cdot 10^8$
Source rms size (μm)	10 – 30
Source rms divergence (μrad)	25 – 200
Peak brilliance (N_{ph}/sec·mm²·mrad²·0.1%)	$10^{20} – 10^{23}$
Radiation pulse length rms (ps)	0.7 – 1.5
Linear polarization (%)	> 99
Macro rep. rate (Hz)	100
# pulses per macropulse	32
Pulse–to–pulse separation (nsec)	16

Low–energy stage: Eγ < 3.5 MeV
March 2017

High–energy stage: Eγ < 19.5 MeV
September 2018



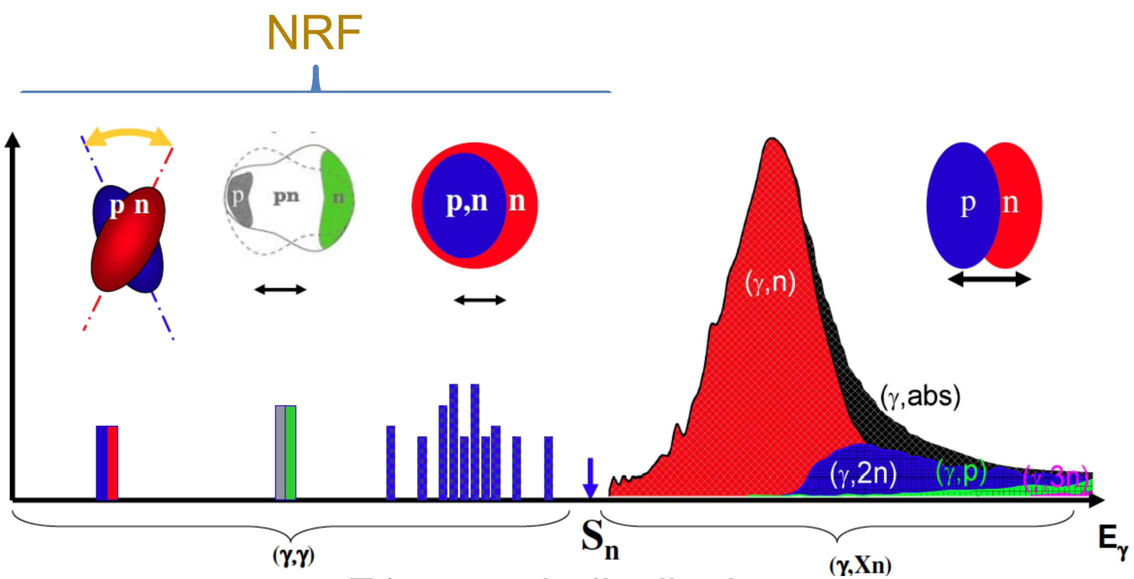
NRF Physics cases @ ELI-NP
Physics above the neutron threshold
Nuclear Astrophysics

Nuclear structure

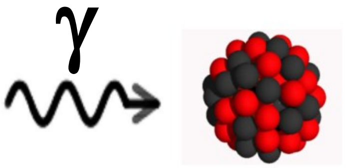
- Modes of excitation below the GDR ,Scissor modes, Parity Violation, M1
- Decay of PDR ,GDR ,
- Impact on nucleosynthesis
- Gamow window for photo–induced reactions in explosive stellar events
  p process(γ,n) (γ,π), (γ,α) rections

Understanding exotic nuclei

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



E1 strength distribution

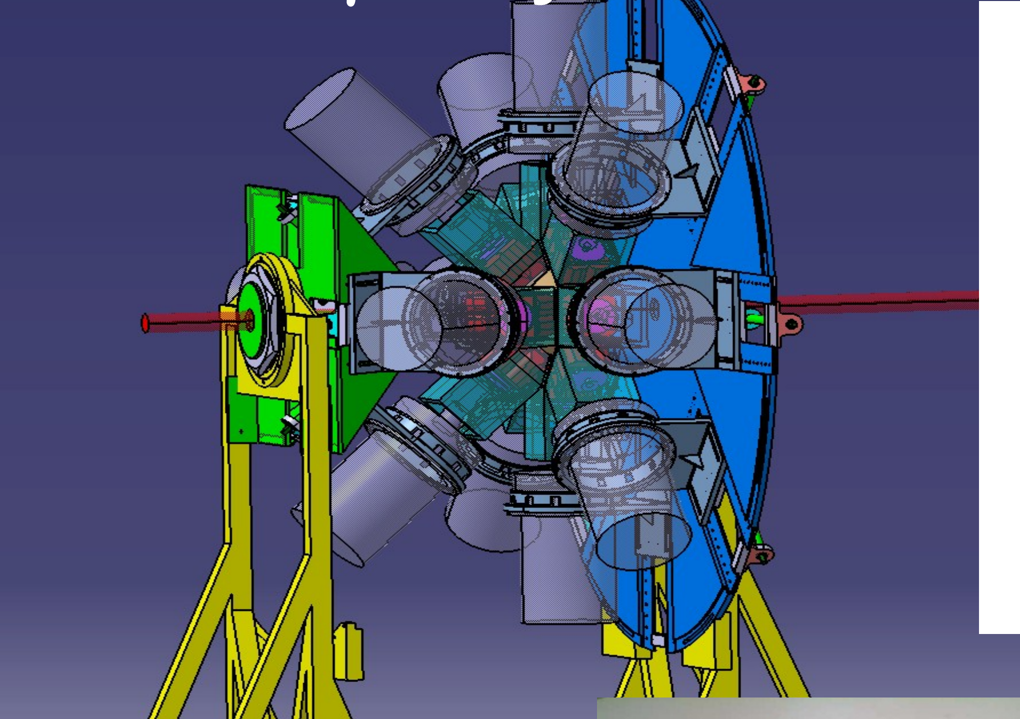


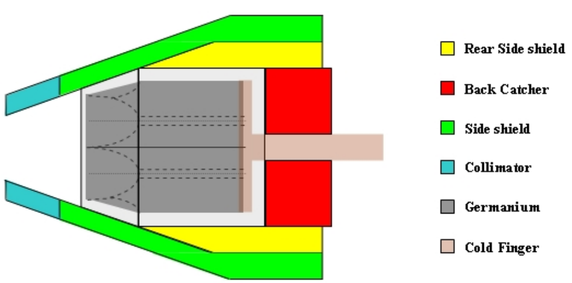
ELI–NP NRF Working group
ELI-NP above Threshold WG
ELI-NP Charged Particles WG

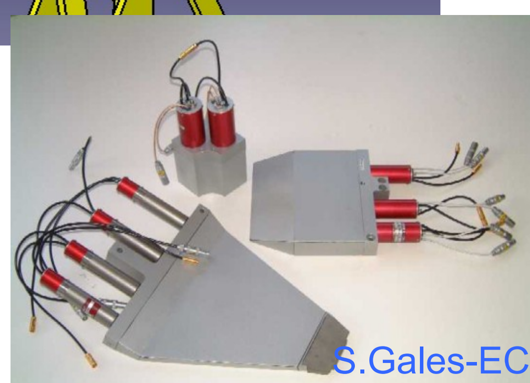
S.Gales-ECOS-Town meeting -Orsay -Oct-27-29-2014

Instruments

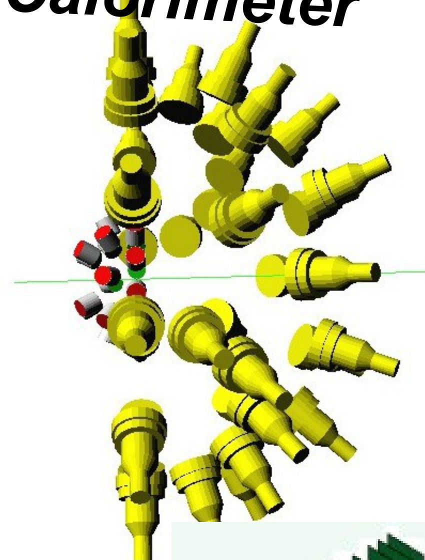
ELIADE γ array

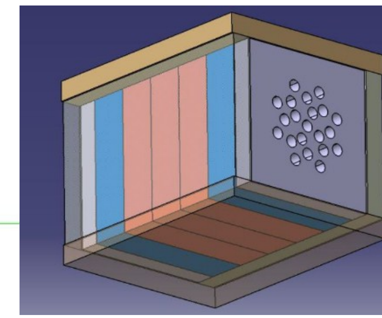


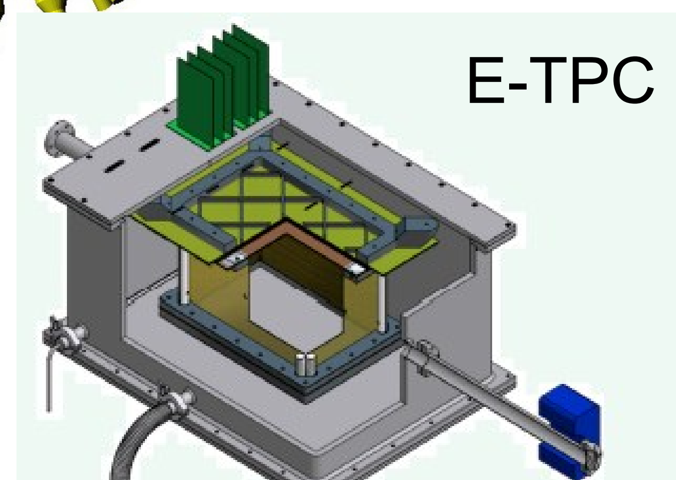




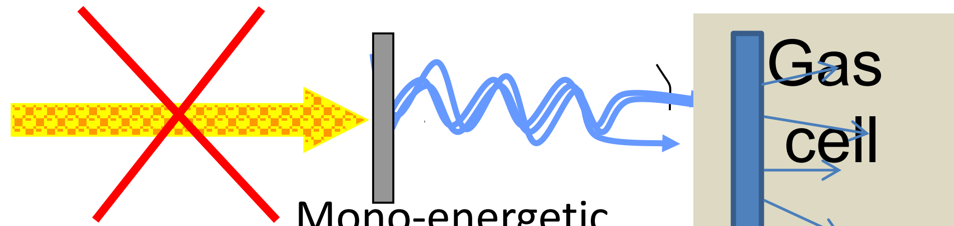
BaF3 + neutron array & Calorimeter



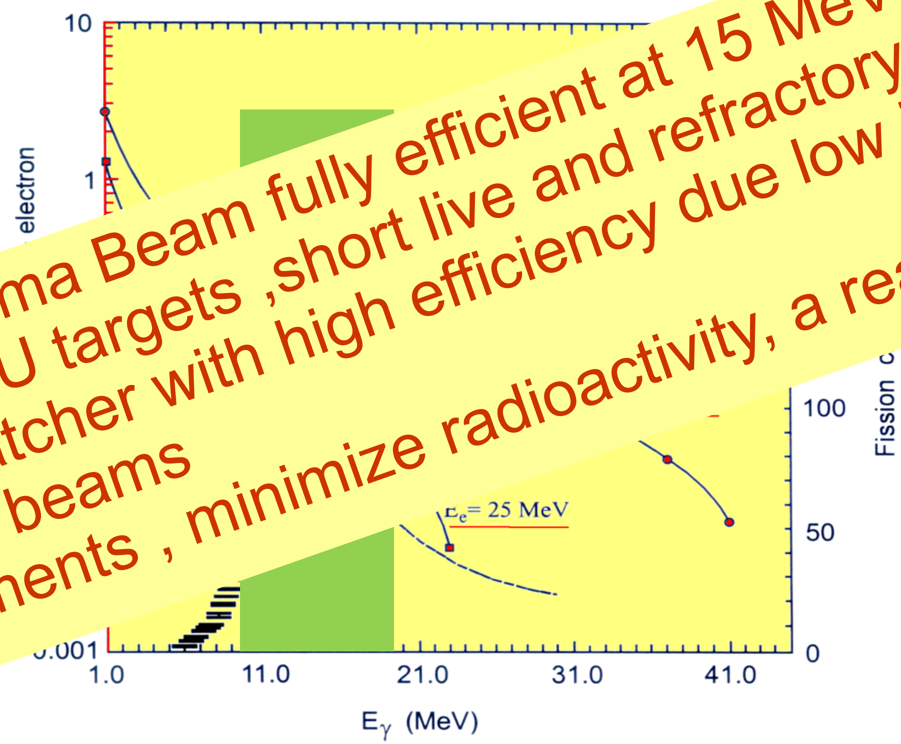




Production of neutron rich fission fragments by photo-fission at ELI-NP



$\Phi = 1.4 \cdot 10^{11}$ γ/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!! 10^9 fiss/s

Coll IPN Orsay, Leuven,GSI,Giessen,JYVL

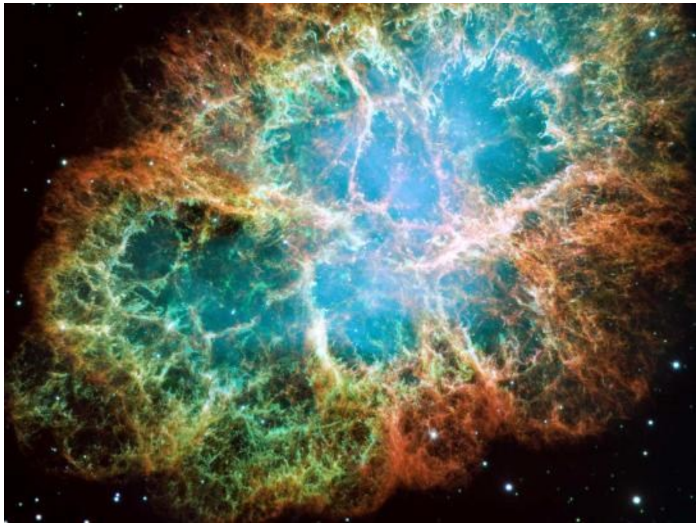
Φ. s. N= Φ.6,4 10^{-3} f/s

S.Gales-ECOS-Town meeting -Orsay -Oct-27-29-2014

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)

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-N**

Tremendous advance to measure these rates directly- very high intense γ beam needed

Potential Nuclear Photonics Applications

eli Nuclear Physics

Perspectives

- *a new research facility, open to the European and International community is being under construction at Bucharest with state of art instruments 2X10 PW HPLS and 0.2-19 MV brilliant ,monochromatic GBS*

- *Research opportunities*
  - *nuclear astrophysics*
  - *Nuclear physics*
    - *Nuclear photonics*
    - *HP laser driven nuclear physics*
  - *strong field QED*
  - *Large Spectrum of Applications*
- *we are open for collaboration*
- *young researchers are invited to join the fun!*

ELI-NP Core Team

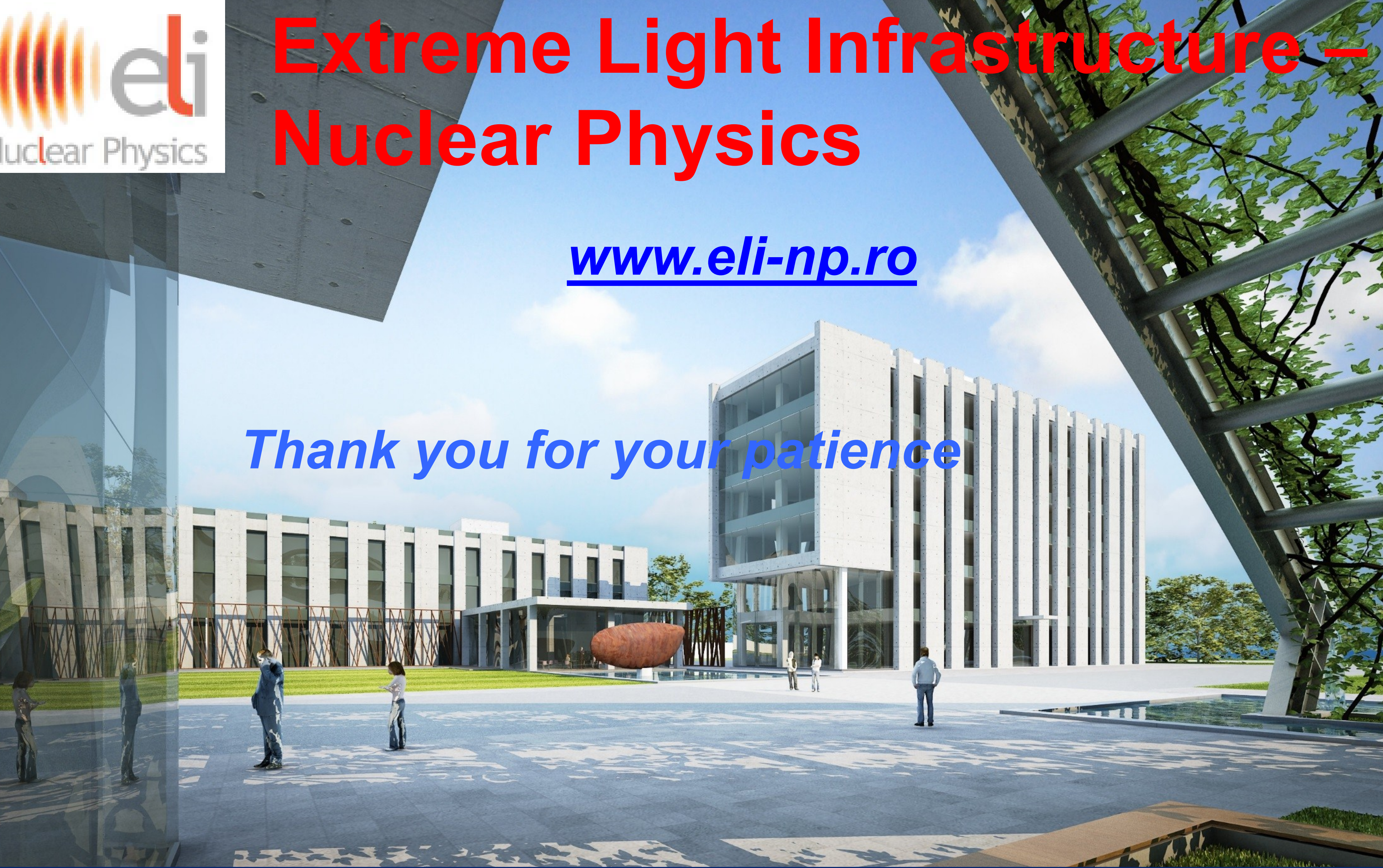
Board of Directors

N.V. Zamfir ,G. Cata–Danil,S. Gales,C. Ivan, A.Popescu, R. Stoicea, I.I. Ursu

Research Activities *Assistant G.I. Apetrei*

Gamma Beam	High PowerLasers	Engineering	Radioprotection,EMP
C.A.Ur (GBS)	D.Urcescu (Expts)	M. Toma	*M. Gugiu,* I.Mitu
D. Balabanski	R. Dabu	C. Petcu	S. Bercea,H.Stancu
O. Tesileanu	F. Negoita	M. Risca	D.Aranghel, E. Iliescu
D. Filipescu	E. Turcu	M. Cernaianu	
A.Oprisa	I. Dancus	B. De Boisdeffre	+ IFIN-HH
N. Ivanov	S. Balascuta	B. Tatulea	+ International TDR's working groups
V.Leca	L. Neagu	M. Tataru	
K.Sato	T. Asavei	M. Conde	
P.Constantin	G.G Acbas	D. Popa	
G.Sullivan	M.Bobeica	V.Buznea	
V. Iancu	I.Morjan (HPLS)	C.Paun	
		I. Garagaianu	

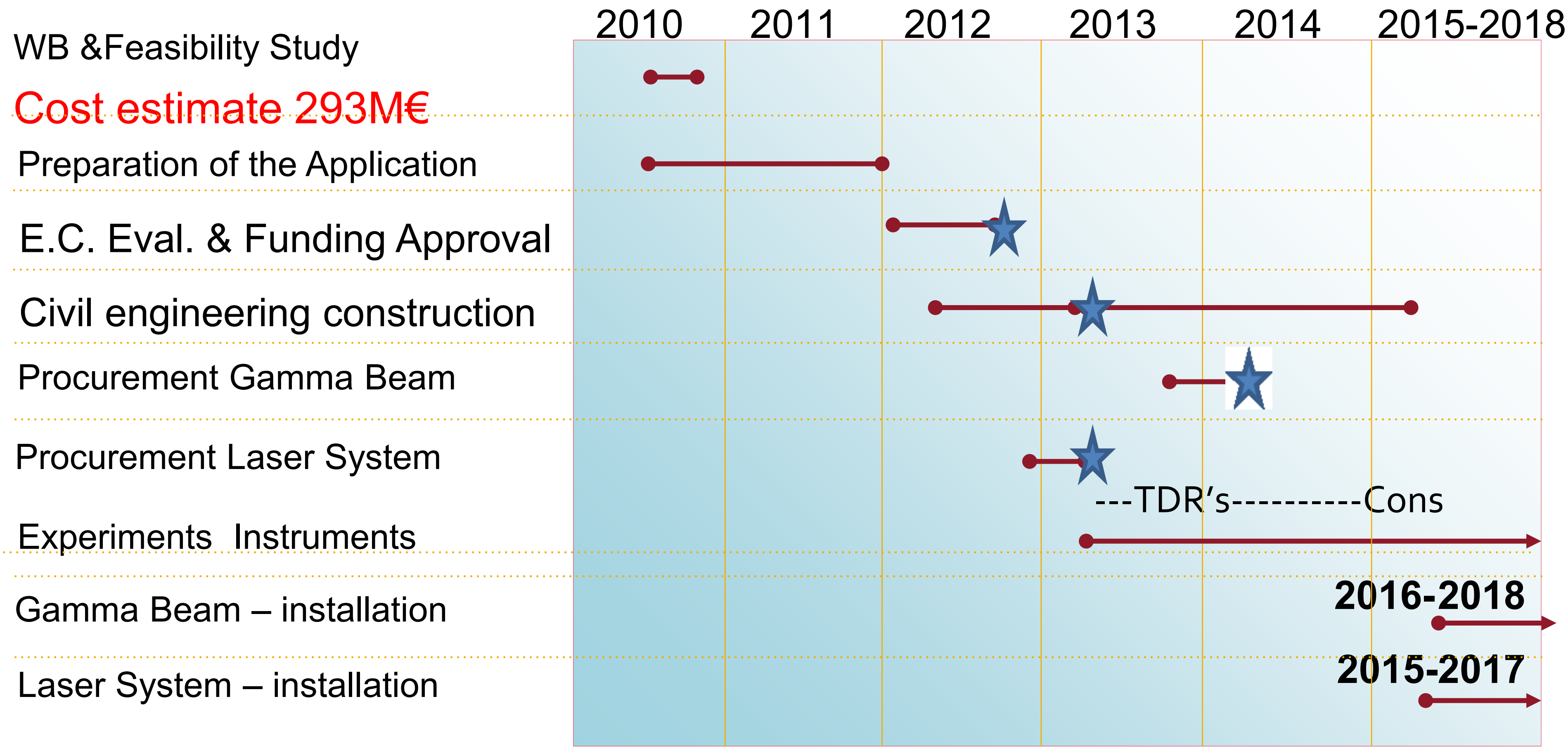
Extreme Light Infrastructure – Nuclear Physics



www.eli-np.ro

Thank you for your patience

ELI–NP Project Timeline



ELI-NP Academic Forum

International Collaborations

MoU's signed with the following entities (May 2014)

Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Daniel Ursescu

Research Cluster "Matter and Radiation Science" Technische Universität Darmstadt, Germany ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Calin A. Ur

Institute of Laser Physics, Siberian Branch Russian Academy of Sciences, Novosibirsk, Russia ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Razvan Dabu

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Poland ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Ovidiu Tesileanu

Institute for Nuclear Research of the Hungarian Academy of Sciences (MTA-Atomki) ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Dimiter Balabanski

Konan University, Kobe, Japan ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Dan Mihai Filipescu

University of Connecticut, USA ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Ovidiu Tesileanu

Institute of Nuclear Physics, University of Cologne, Germany ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Calin A. Ur

University of California - Irvine, USA ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Nicolae Zamfir

INFN LNS Catania, Italy ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Nicolae Zamfir

Triangle Universities Nuclear Laboratory, Durham, NC, USA ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Sydney Gales

Friedrich Schiller University, Jena, Germany ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Daniel Ursescu

"II. Physikalisches Institut" of Justus-Liebig University, Gießen, Germany ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Sydney Gales

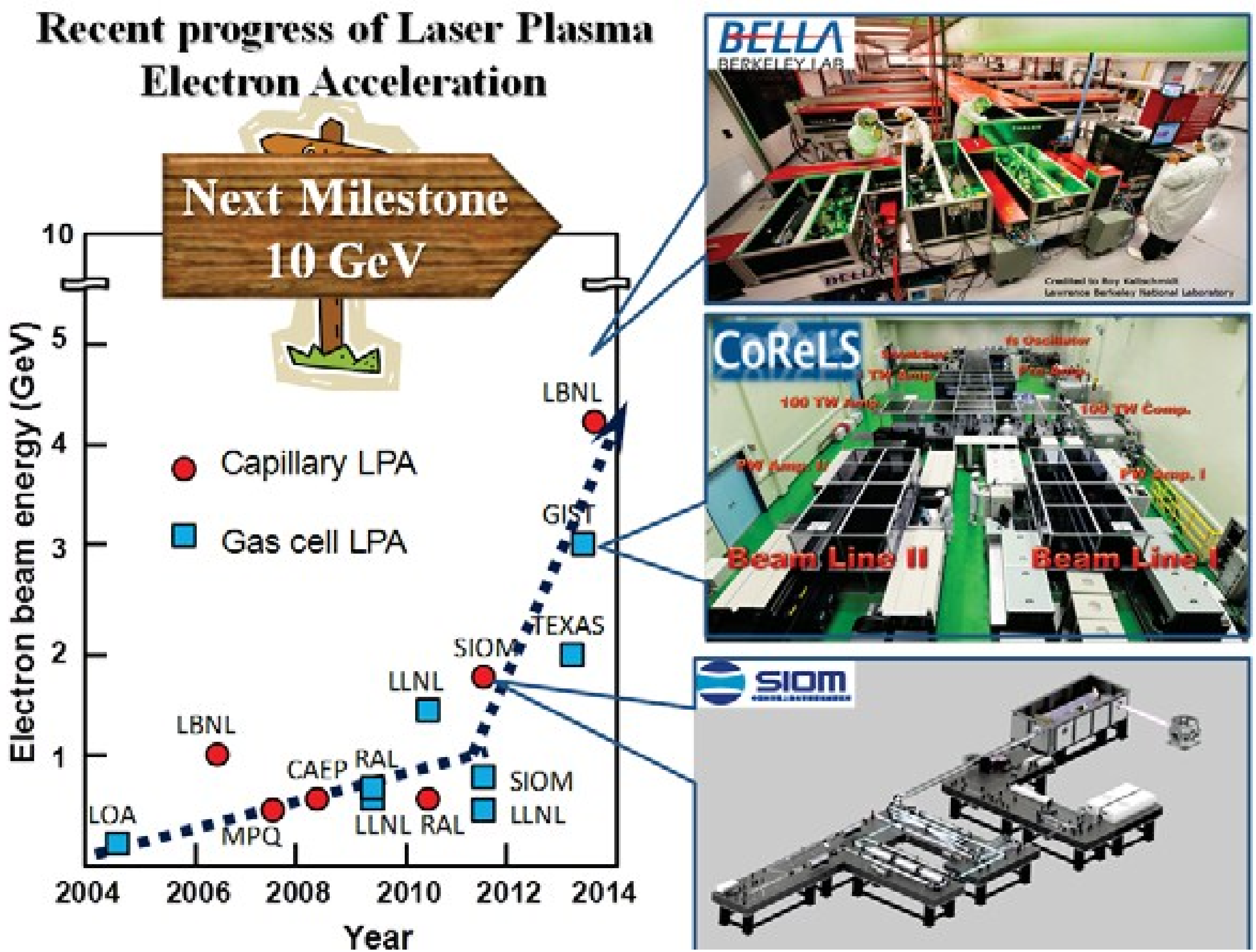
Institut de Physique Nucléaire, Orsay, France ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Sydney Gales

Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physics, Russia ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Dan Filipescu

Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Science, Poland ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Ovidiu Tesileanu

The University of Strathclyde, Glasgow, UK ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Edmond Turcu

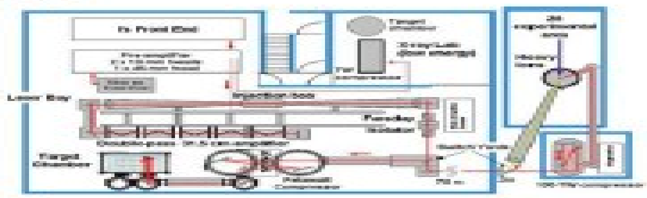
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany ↔ IFIN-HH/ELI-NP [website]
Responsible: Dr. Sydney Gales



S.Gales-ECOS-Town meeting -Orsay -Oct-27-29-2014

SCAPA

SIOM



PHELIX – GSI Germany

Gwangju Institute of Science and Technology (GIST), Gwangju, South Korea

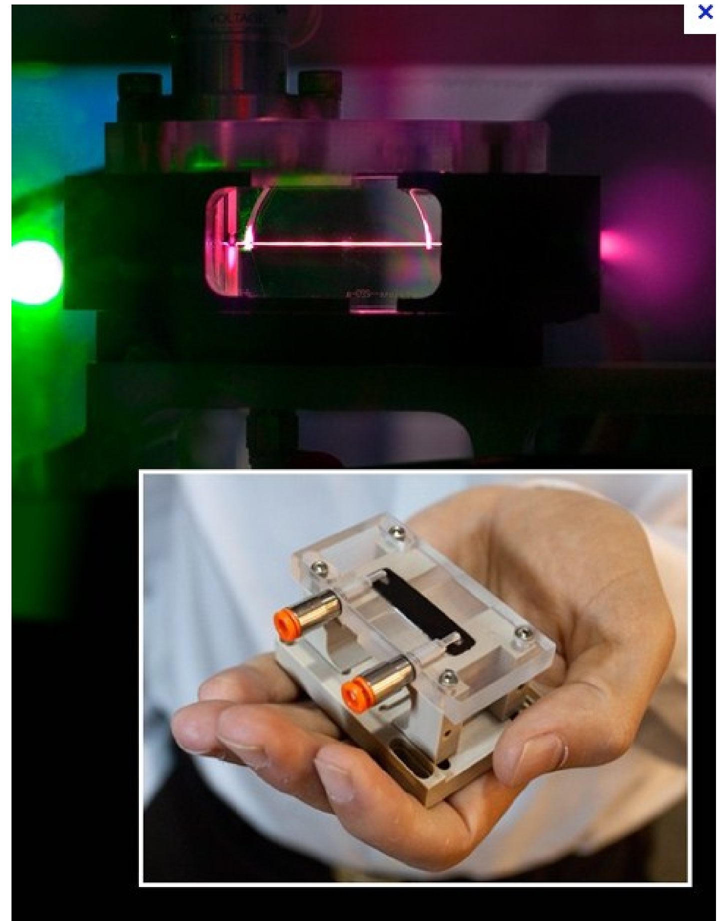
Name	Country	#Beams	10^{15} W
SCAPA	UK	3	< 0.3
UHI 100	France	1	0.1
ELPHIE	France	3	< 0.1
ALLS	Canada	1	0.2
PHELIX	Germany	2	0.5
Texas	USA	1	1
SIOM	China	1	> 1
GIST	S. Korea	2	> 1
PETAL	France	1	> 1
LFEX	Japan	4	1
ELI-NP	Romania	2	10
ELI-Beams	Czech	5	10
XCELS	Russia	12	15

Table 1: A sample of the laser installations associated with the IZEST partnership.

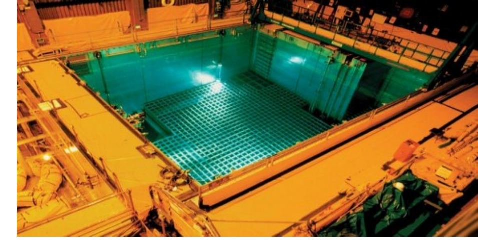
Nuclear Physics

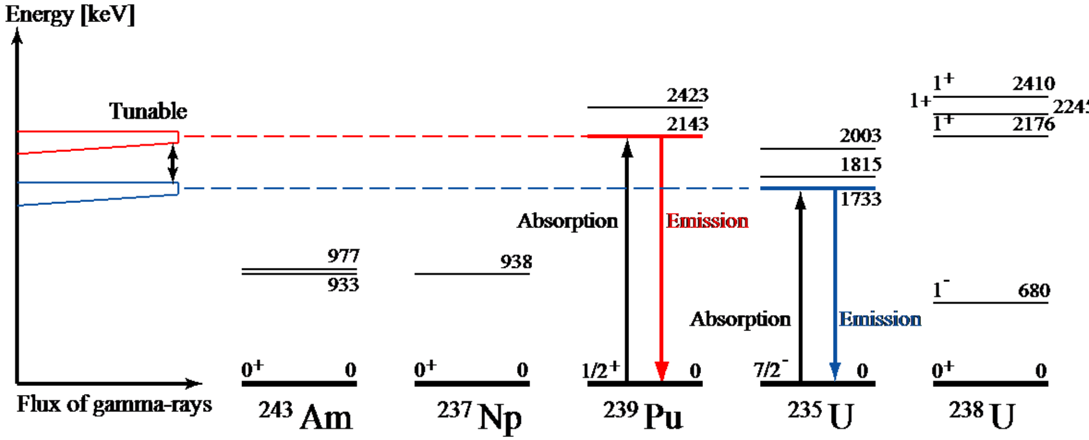
Laser acceleration
Exciting Perspectives

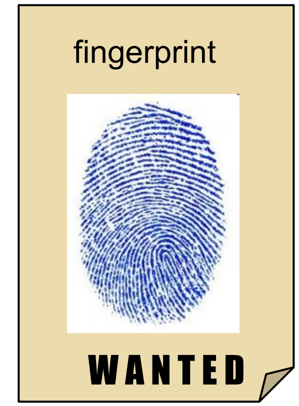
Enormous reduction in scale



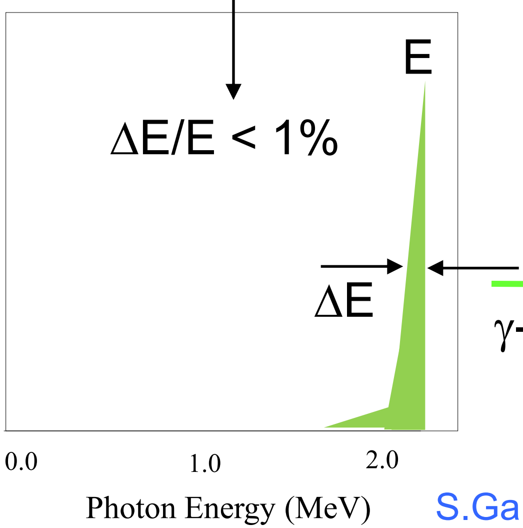
Applications of NRF To Nuclear Materials

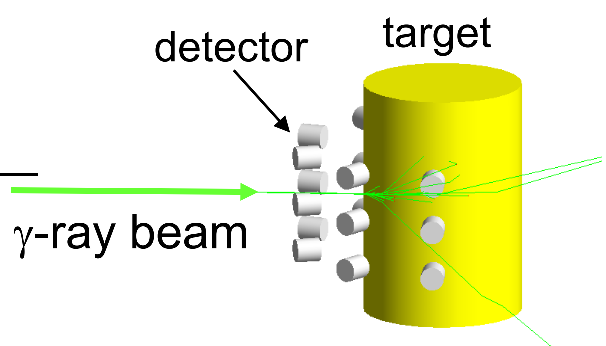




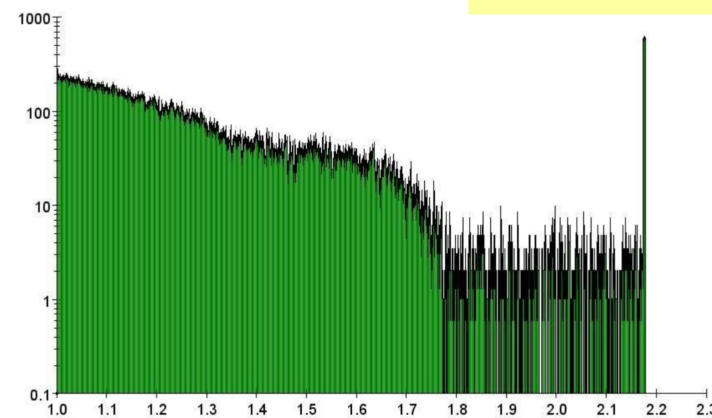


2.176 MeV for U-238





NRF signal U-238 2.176 MeV

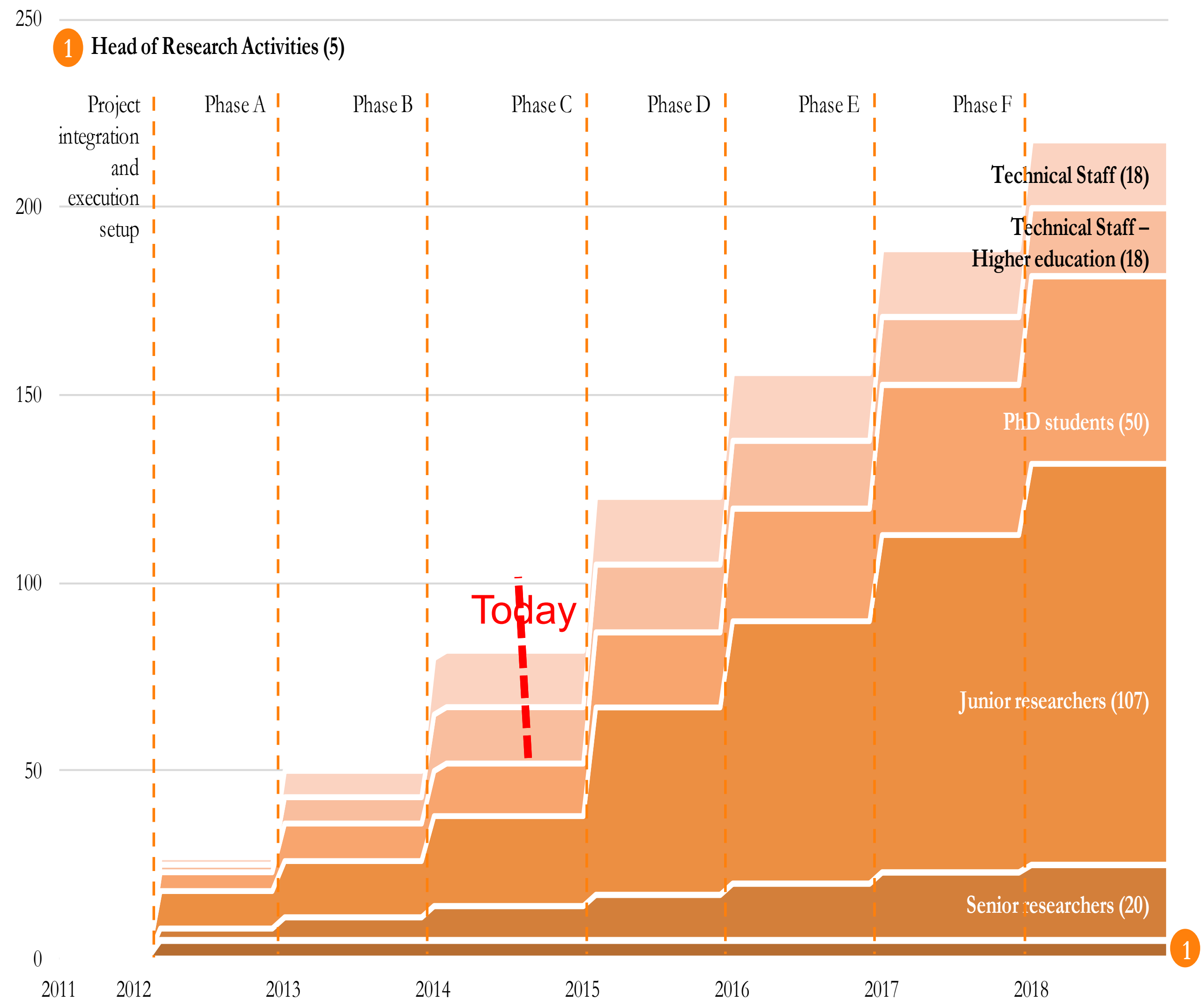


Photon energy (MeV)

Human Resources

Attracting the best competencies:

- public announcements
- international recruitment
- head–hunting for management positions
- junior researchers specializing in a unique and top-level field of research
- PhD students will benefit of a very high specialization with enormous possibilities



HPLS -Applications

Materials in Extreme Environments for Energy, Accelerators and Space

materials for fusion reactors

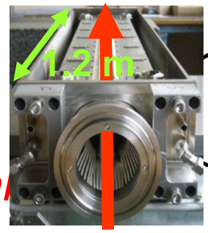
- testing of new materials for ***accelerator components***

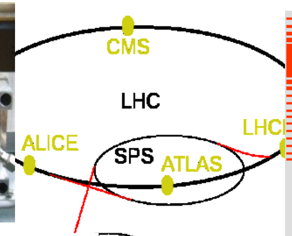
high power targets: for RIB production, spal

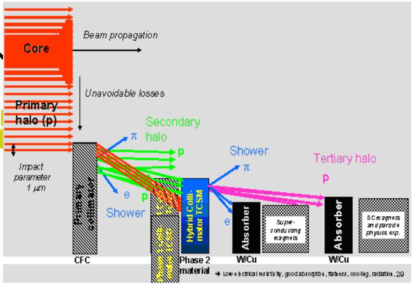
new materials are needed for accelerato

collimator jaws for the upgrade of the LHC

Collimators





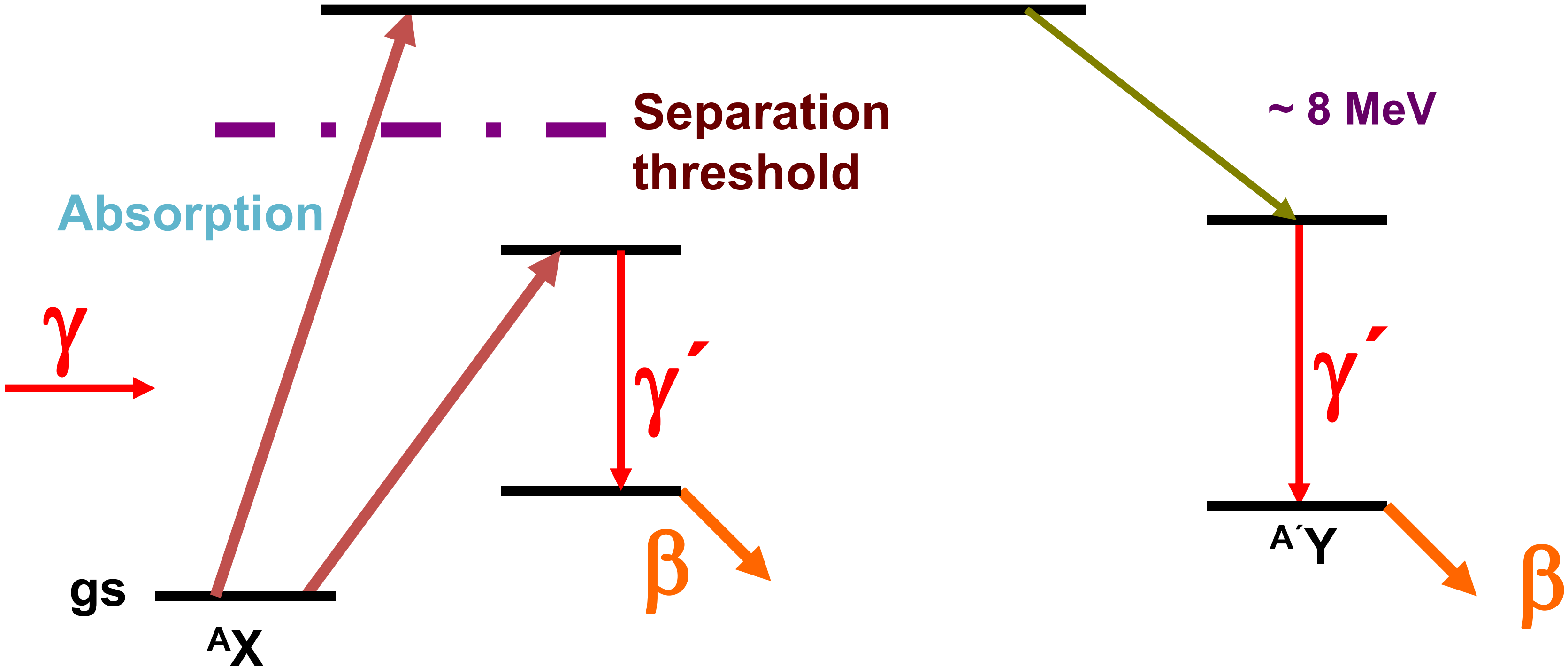


360 MJ proton beam

- testing materials for space science (electronics components,
- hypervelocity impacts)
  - *the radiation environment used for ground testing should ide*
    the natural environment probed by the satellite

- biological science research (effects on bio-molecules, cells)
- testing radiation hardness and developments of detectors
- irradiated optical components testing

GBS – Photonuclear Reactions

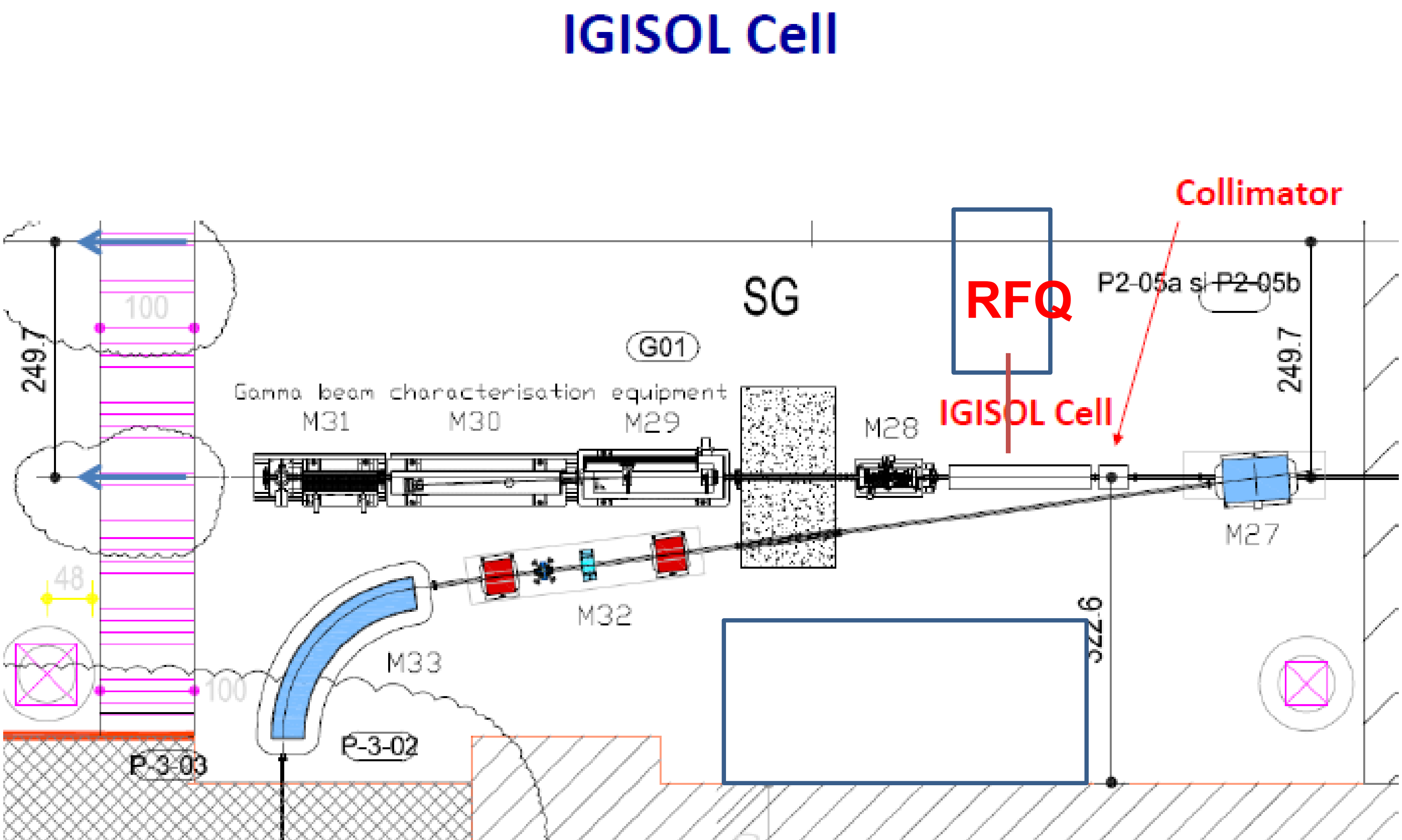


Nuclear Resonance Fluorescence (NRF)
Photoactivation
Photodisintegration (–activation)

Photo–fission

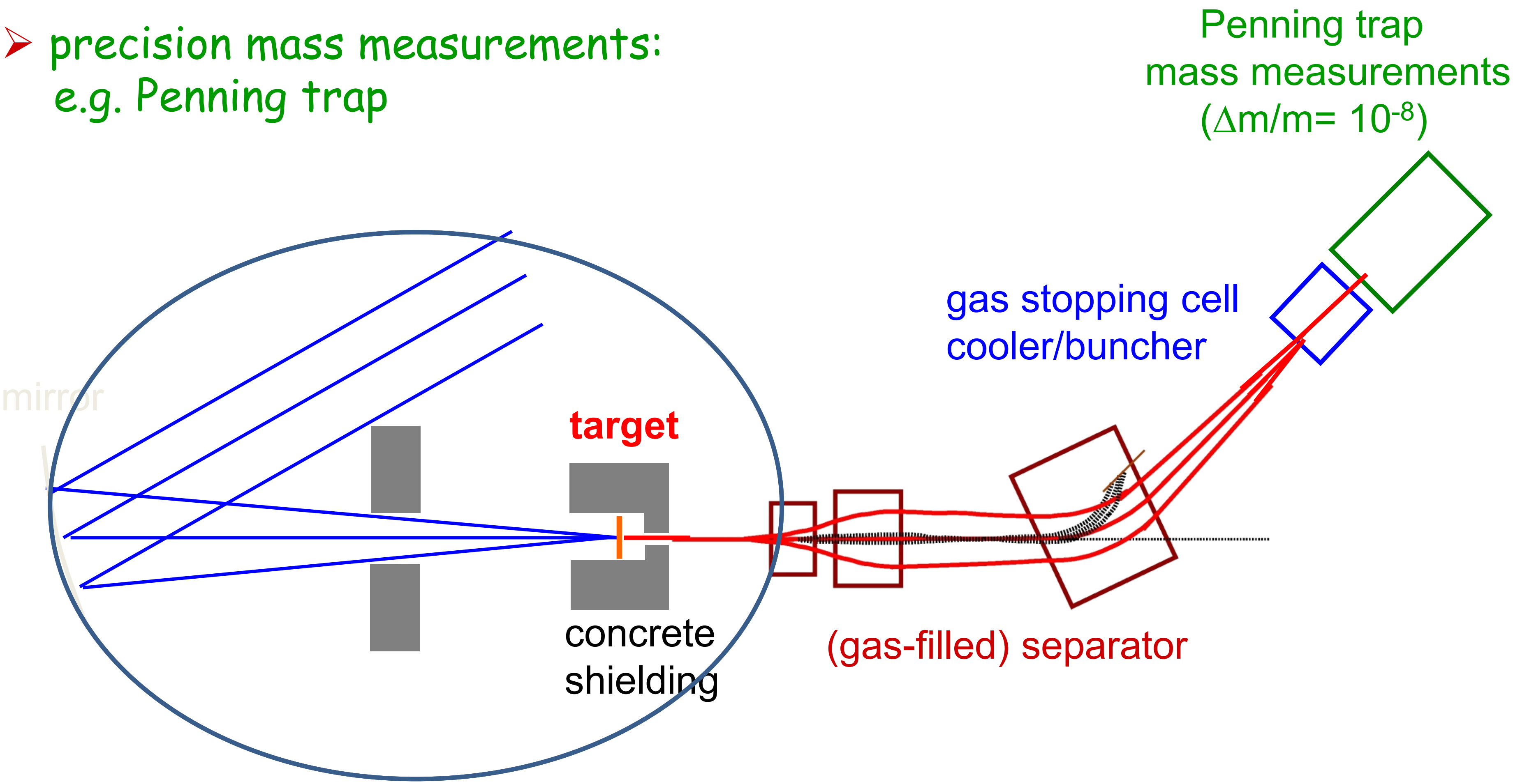
N. Pietralla

Location of the IGISOL gas catcher



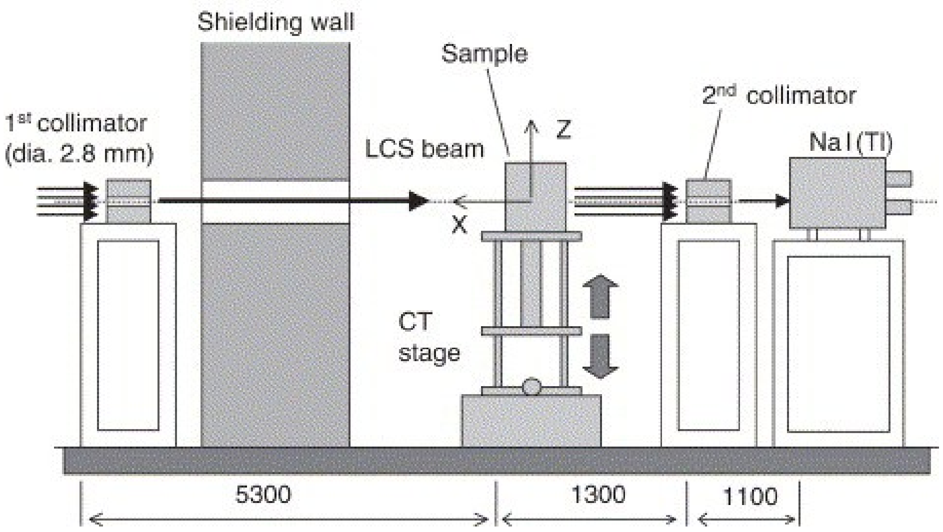
Laser driven Fusion-Fission Experimental layout

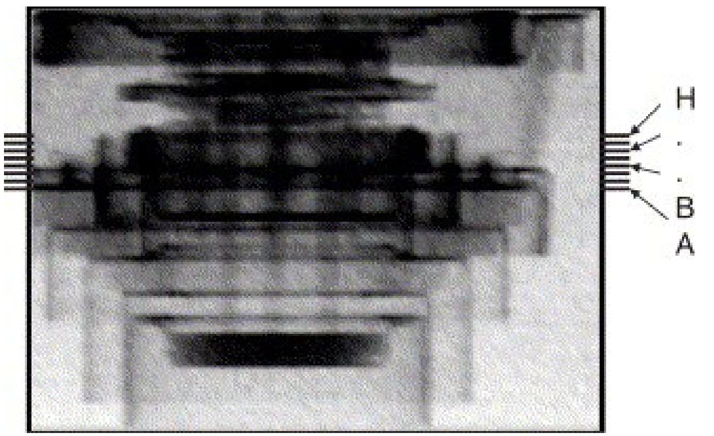
- characterization of reaction products
  - decay spectroscopy
- precision mass measurements: e.g. Penning trap



NRF – Applications

Non–destructive computerized tomography of objects





electrode of the TH571A tetrode tube

CT setup @ AIST, Tsukaba, Japan

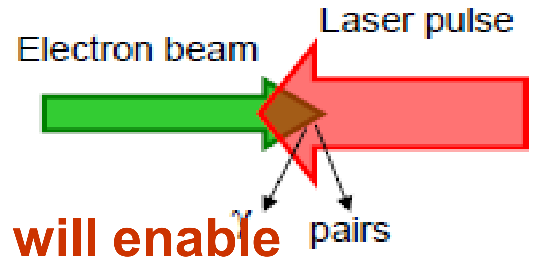
- 10 MeV LCB gamma–ray beam
- off–line reconstruction of the object image with the filtered–back–projection method
- less prone to artifacts due to radiation hardening
- need of high intensity to reduce scanning time

H. Toyokawa, NIM 545, 469 (2005)

Strong field QED physics…

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



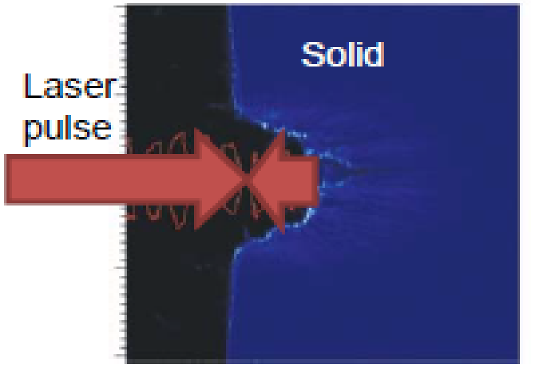
ELI-NP Delivering 20fs pulse at > 10^{23} W/cm^2 will enable this exciting new regime to be investigated

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

Reaction rates are high due to high electron density

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

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

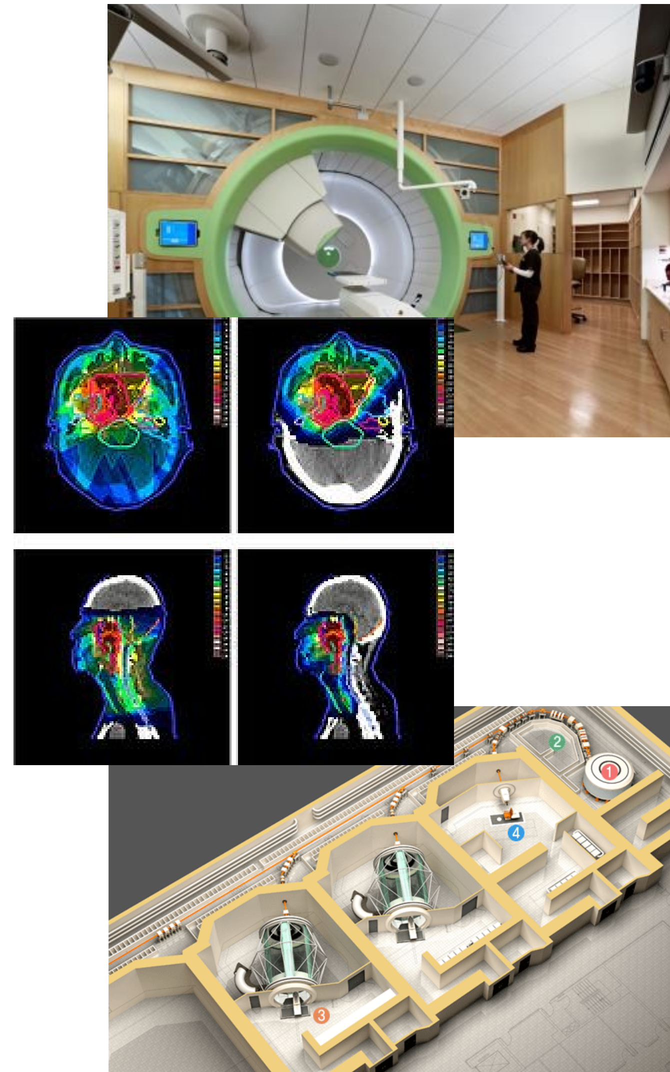


Radioisotopes for medical use

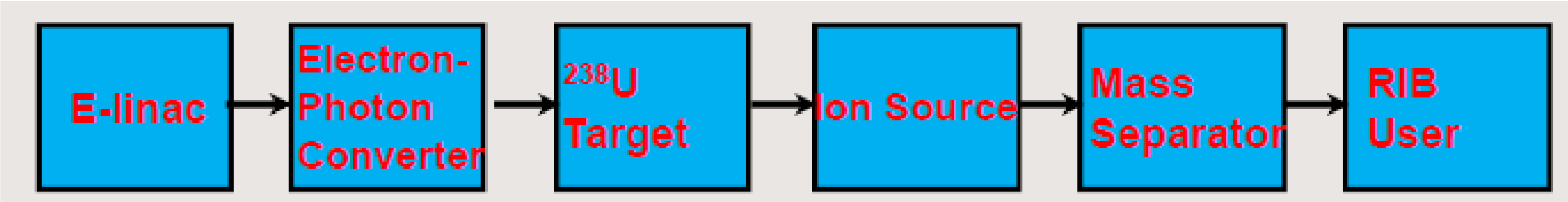
- **New approaches and methods for producing radioisotopes urgently needed**

•Mo-99 and other medical isotopes used globally for diagnostic medical imaging and radiotherapy

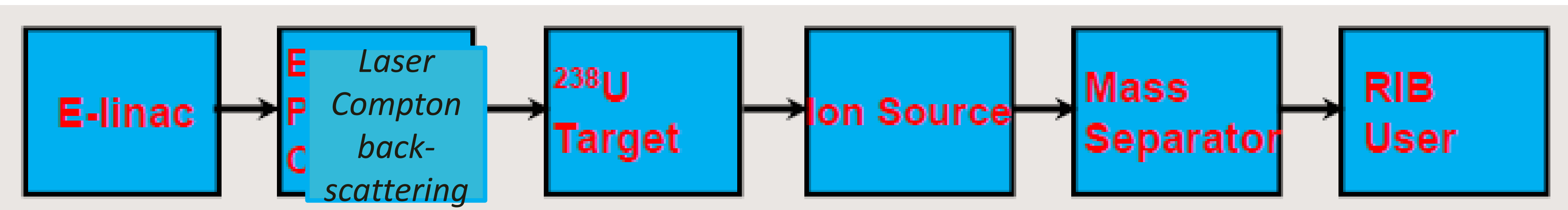
- **^{195m}Pt**: In chemotherapy of tumors it can be used to exclude ”non responding” patients from unnecessary chemotherapy and optimizing the dose of all chemotherapy

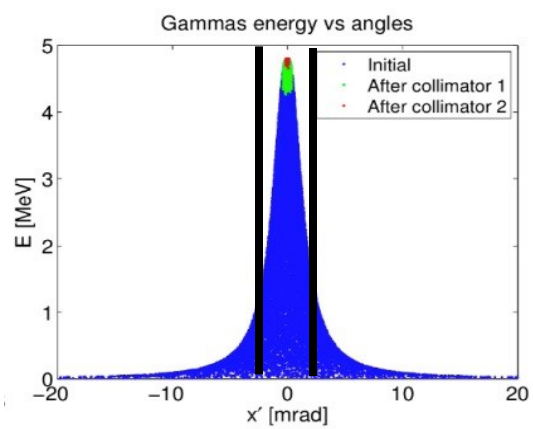


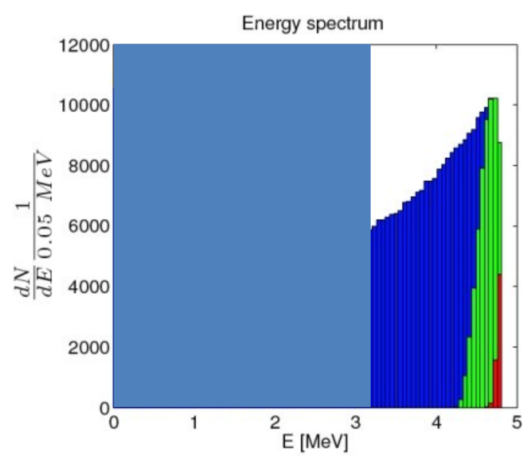
ALTO, ARIEL, etc.



ELI-NP



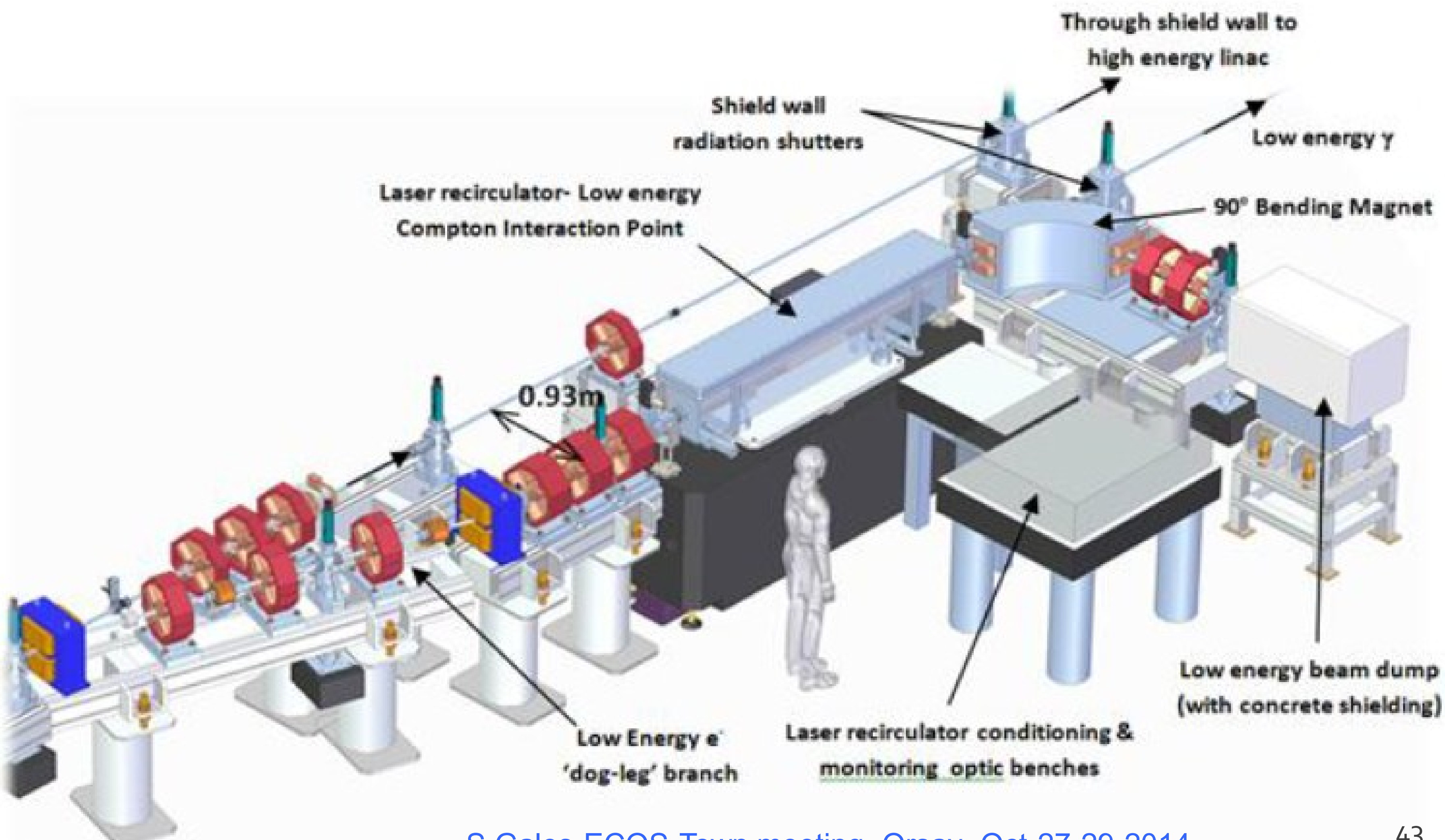


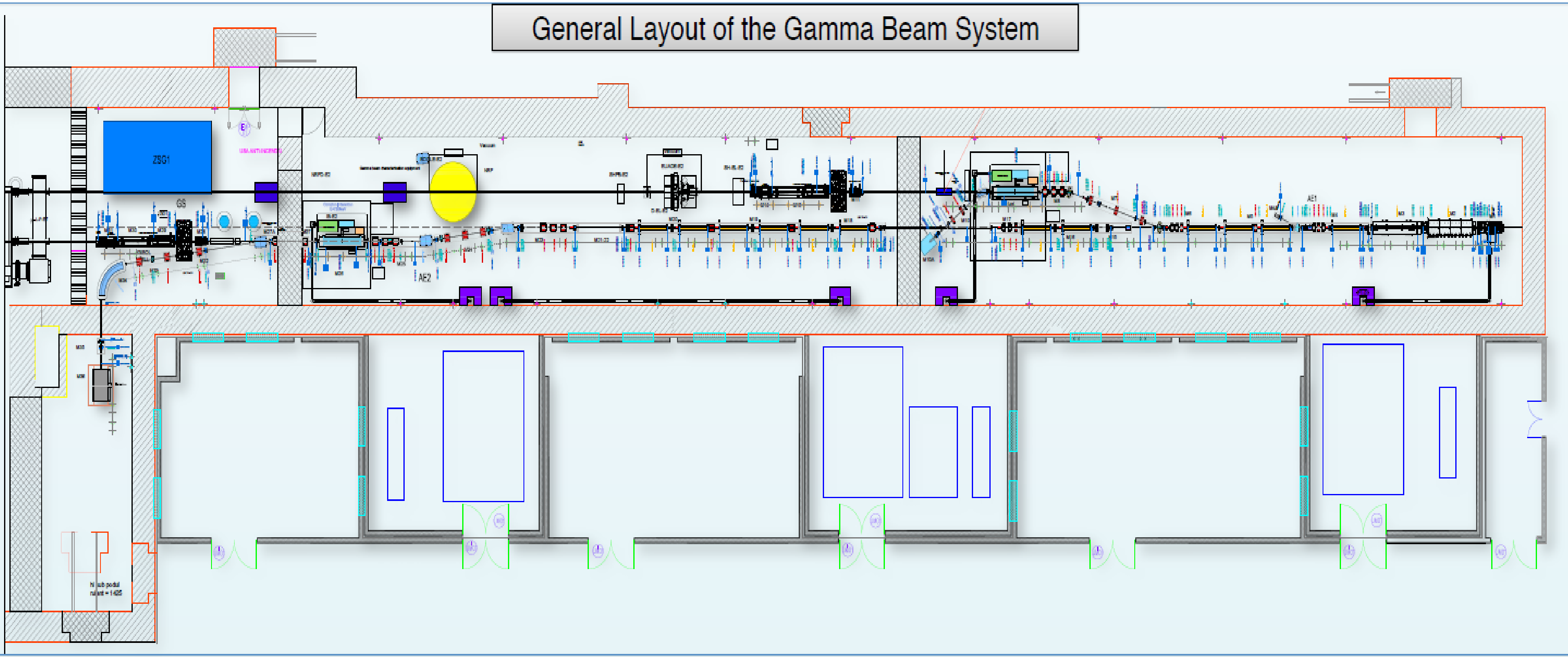


γ–beam spectrum at t
(without collima

~ 10^{11} γ/s

Laser Recirculation at IP




General Layout of the Gamma Beam System
ZSG1
GS
AE2
AE1

POWER : 10 PW = 10^{16} W

1 Million Billions light bulbs!

10 Millions !

DURATION : 50 fs = 50×10^{-15}s

1 Thousandth Billionth blink eyes !