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”

ELI-NP: Over-view and strategy

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Extreme Light Infrastructure-Nuclear Physics (ELI-NP)
Bucharest-Magurele, *Romania*

Extreme Light Scientific and Socio-Economic Outlook
IZEST
Embassy of the Czech Republic in Paris France
Nov. 28, 2016

eli Nuclear Physics

IFIN-HH

ELI-NP Project

310 M € *2013-2018*

Large equipment:

- High power laser system, 2 x 10PW maximum power (2013-2018)

  Thales Optronique SA and SC Thales System Romania (~62 M€)

- Laser Beam Transport System (2016-2018) *(~18M€)*

  Under Tender Procedure

- High intensity gamma beam system (2014-2018)

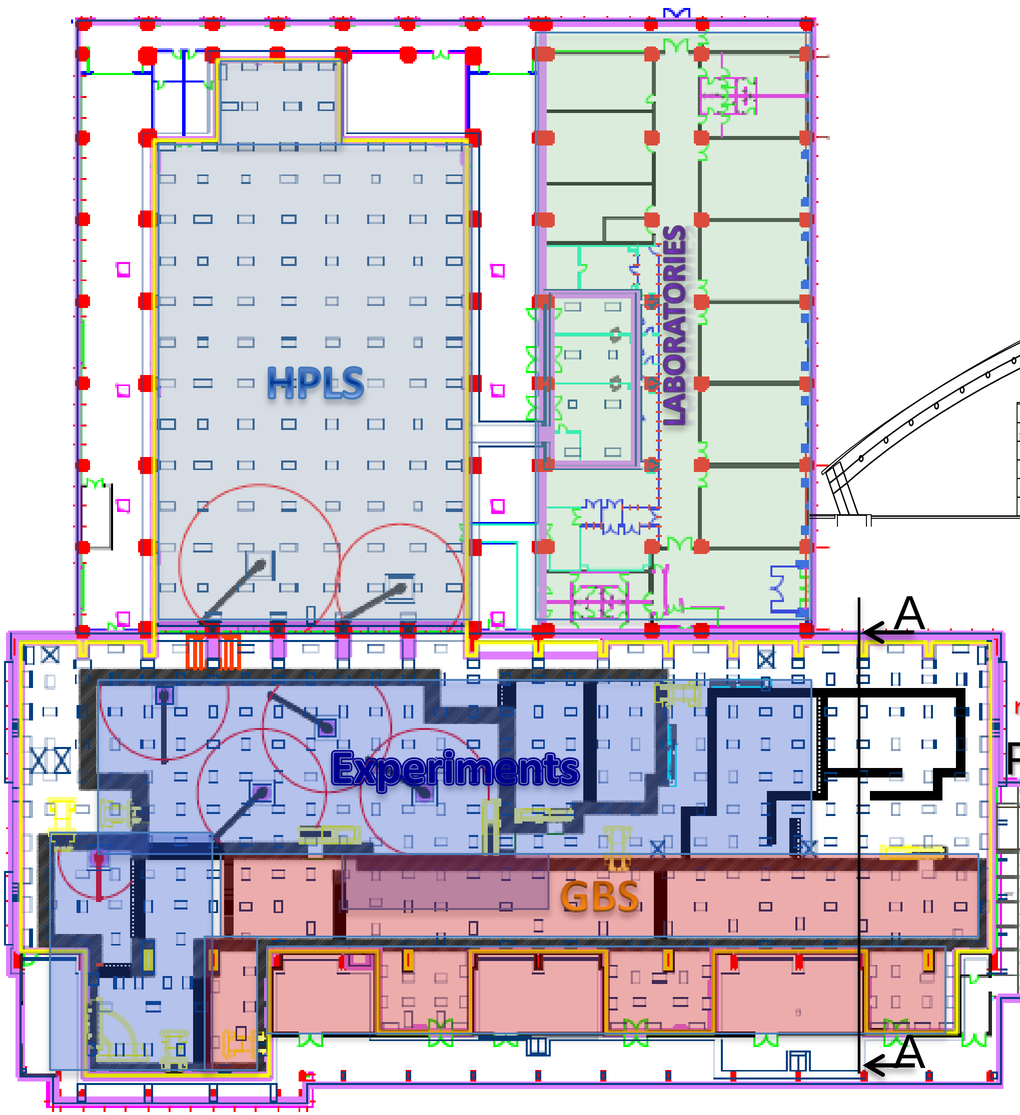
  European Consortium EuroGammaS led by INFN Rome (~67 M€):
  INFN (Italy), University "La Sapienza" Rome (Italy), CNRS (France), ALSYOM (France), ACP Systems S.A.S.U. (France), COMEB Srl (Italy), ScandiNova Systems (Sweden)
  Subcontractors: MENLO SYSTEMS GmbH, RI Research Instruments GmbH(Germany), DANFYSIK (Denmark), STFC(UK), Instrumentation Technology, Cosylab D.D. (Slovenia), M+W SrL (Italy), CELLS(Portugal), Amplitude Technologies (France)

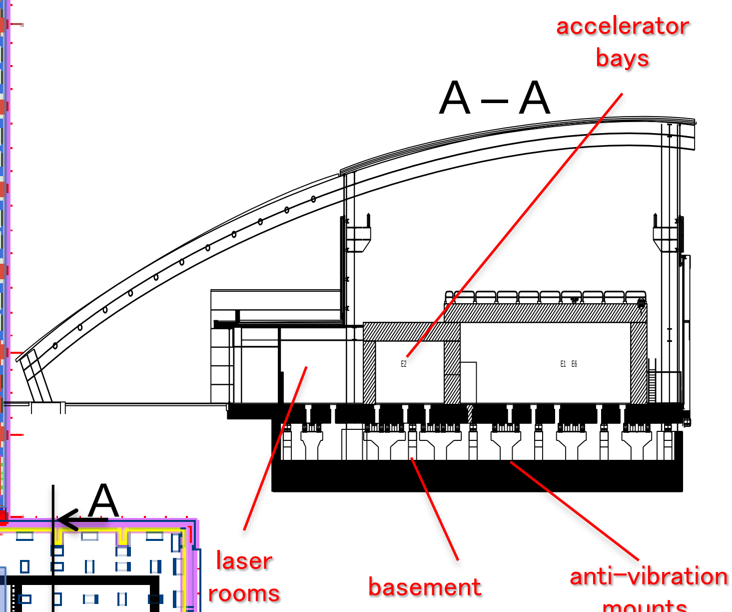
Experiments:

- 8 experimental areas, for gamma, laser, and gamma+laser (~33M€)
- Workshops and laboratories *(~7M€)*

Buildings (2013-2016) : 33000sqm total – *STRABAG (~80M€)*

ELI–NP –Building Status





Platform supported on dampers

Anti-vibration platform

±1 μm @ < 10 Hz

Highest Intensity Laser System
Large Clean Room

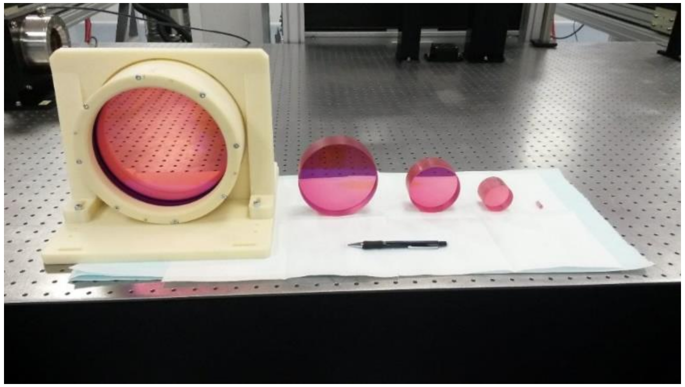
High Power Laser System

	min	max	unit
Energy/pulse	150	225	J
Central wavelength	814	825	nm
Spectral bandwidth (FWHM)	55	65	nm
Spectral bandwidth (at nearly zero level of intensity)	120	130	nm
Pulse duration (FWHM)	15	22.5	fs
FWHM beam diameter/Full aperture beam diameter	450/550		mm
Repetition rate	1		pulse /min
Strehl ratio	0.8	0.95	
Pointing stability	2	5	µrad
Beam height to the floor	1500	1510	mm

Each component has been tested on time

Couple of technical issues have been solved.

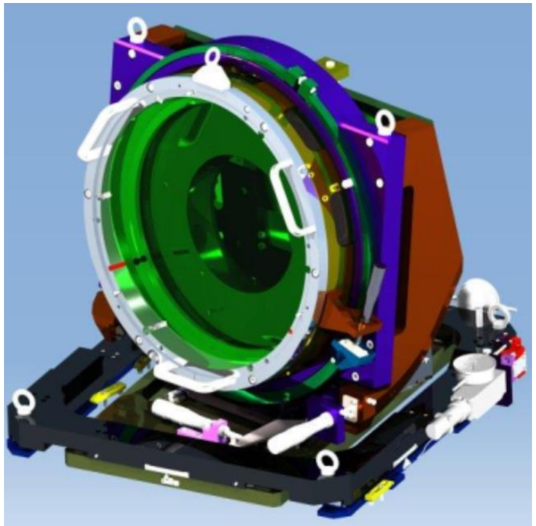
- Stable ps OPCPA demonstrated
- 12/16 Pump lasers 100J@ 527nm tested
- 20cm useful aperture Ti:Sa crystal available
- First large diffractive grating for 10PW compressor produced



Optical componets are ready? Yes.

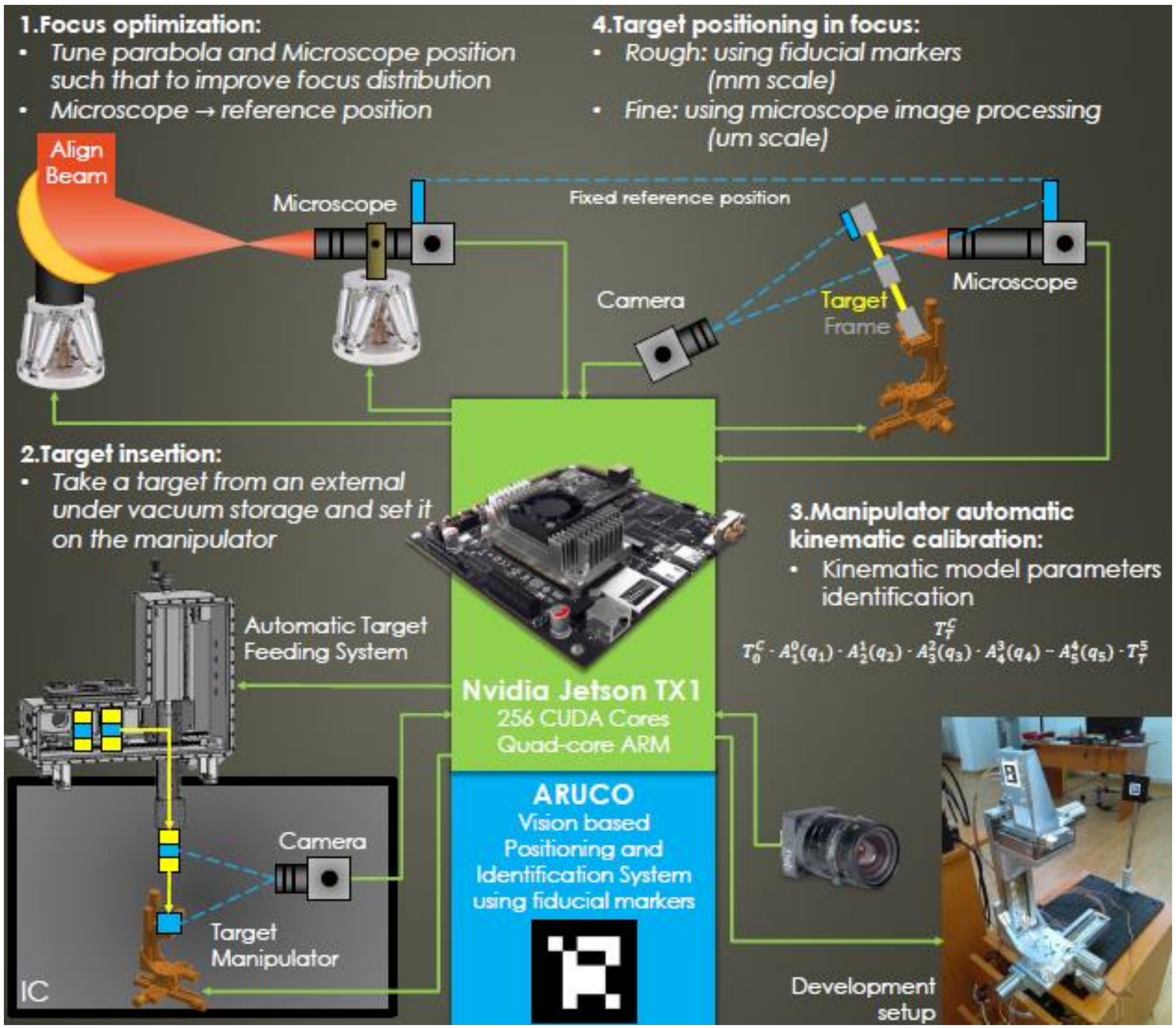
Heavy duty (1 ton) hexapod
Resolution 0.8 µm / 0.5 µrad

Apollon parabola design (45 cm beam)



- 300 kg mirrors must be positioned over 6-degrees of freedom with 1 µm and 1.2 µrad resolution
- Hexapods our initial choice, but decided to let manufacturer propose

High repetition shooting?
How about automatic target alignment?



Laser shot cycle
1 mint.-10 Hz

1.Optimize the focus using the off-axis parabola

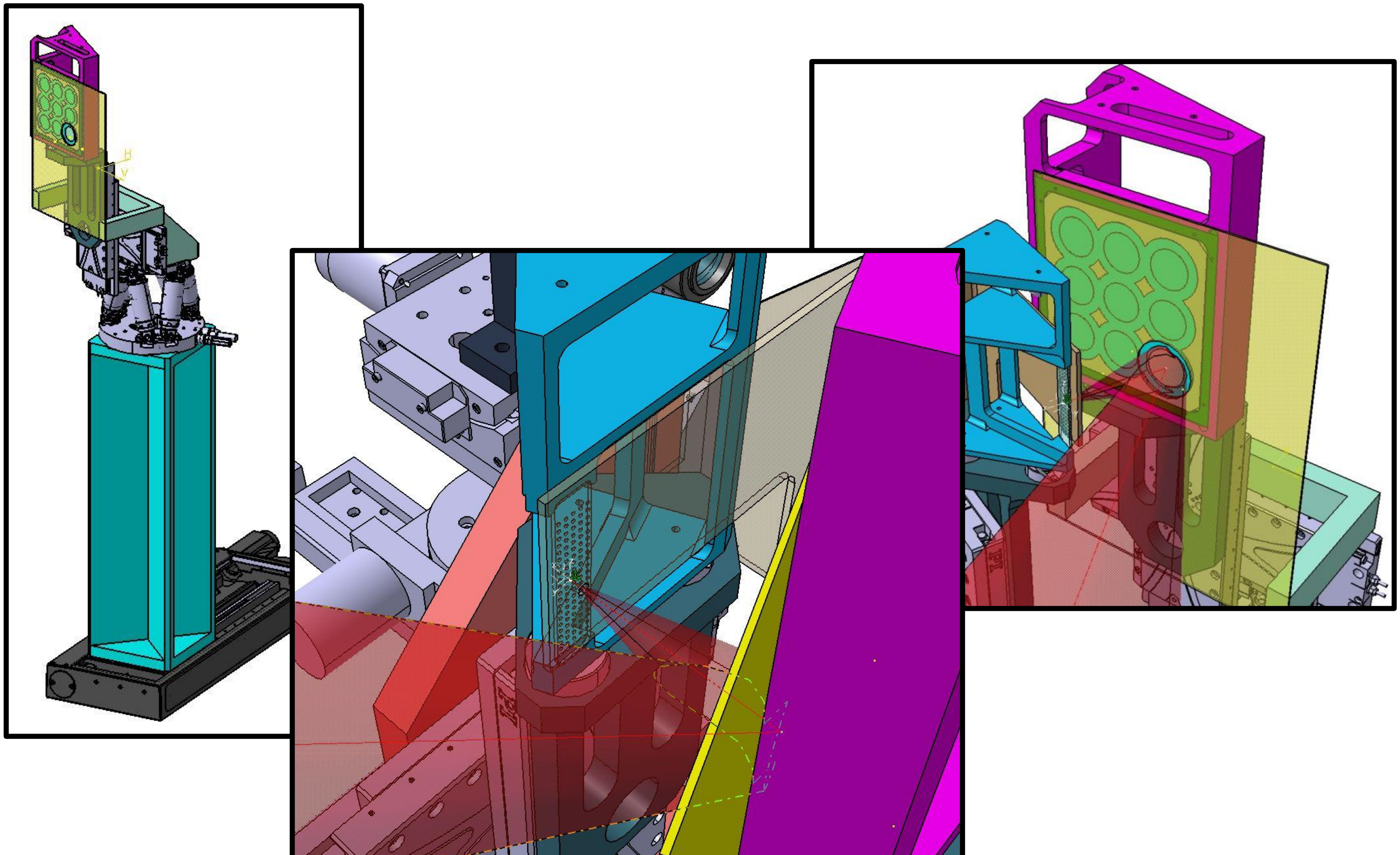
2.Insert the first target frame using the target insertion system

3.Align roughly the frame in focus

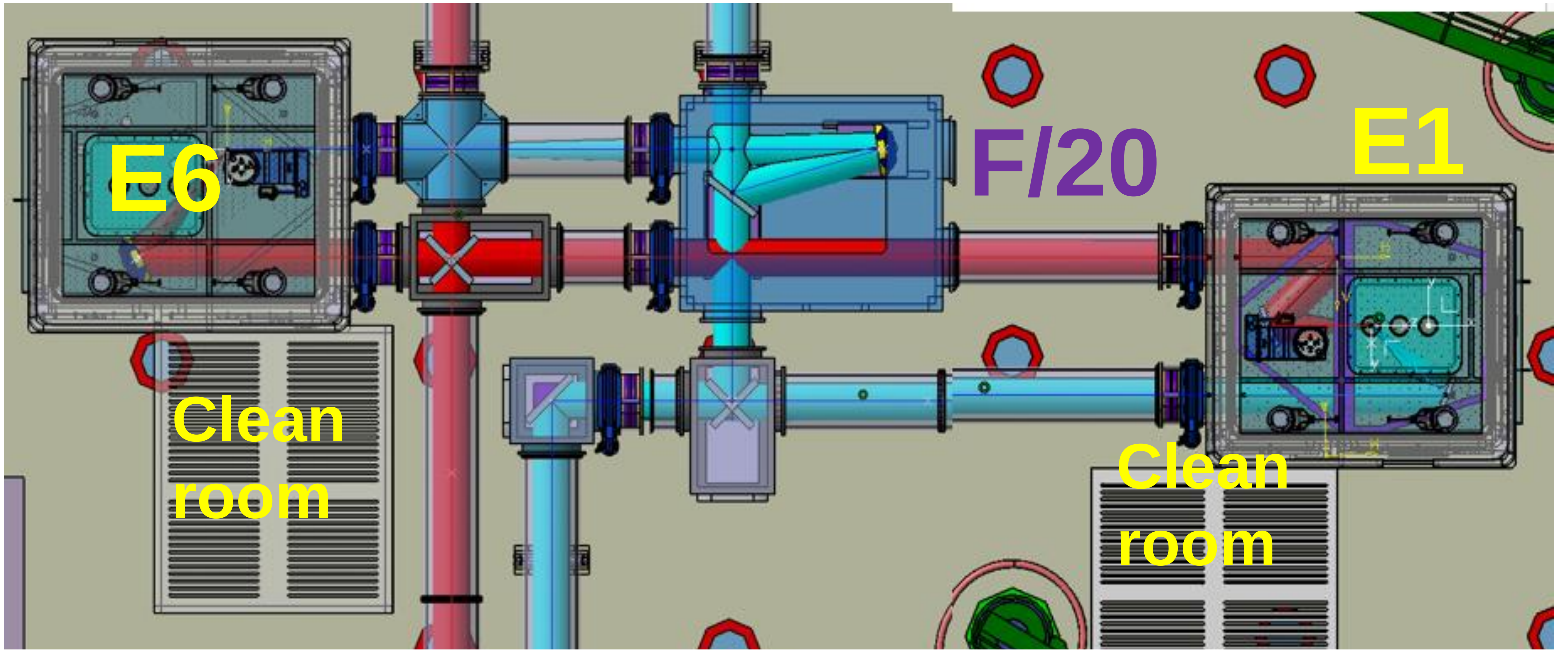
4.Align finely the frame in focus

5.Move the frame to the first target

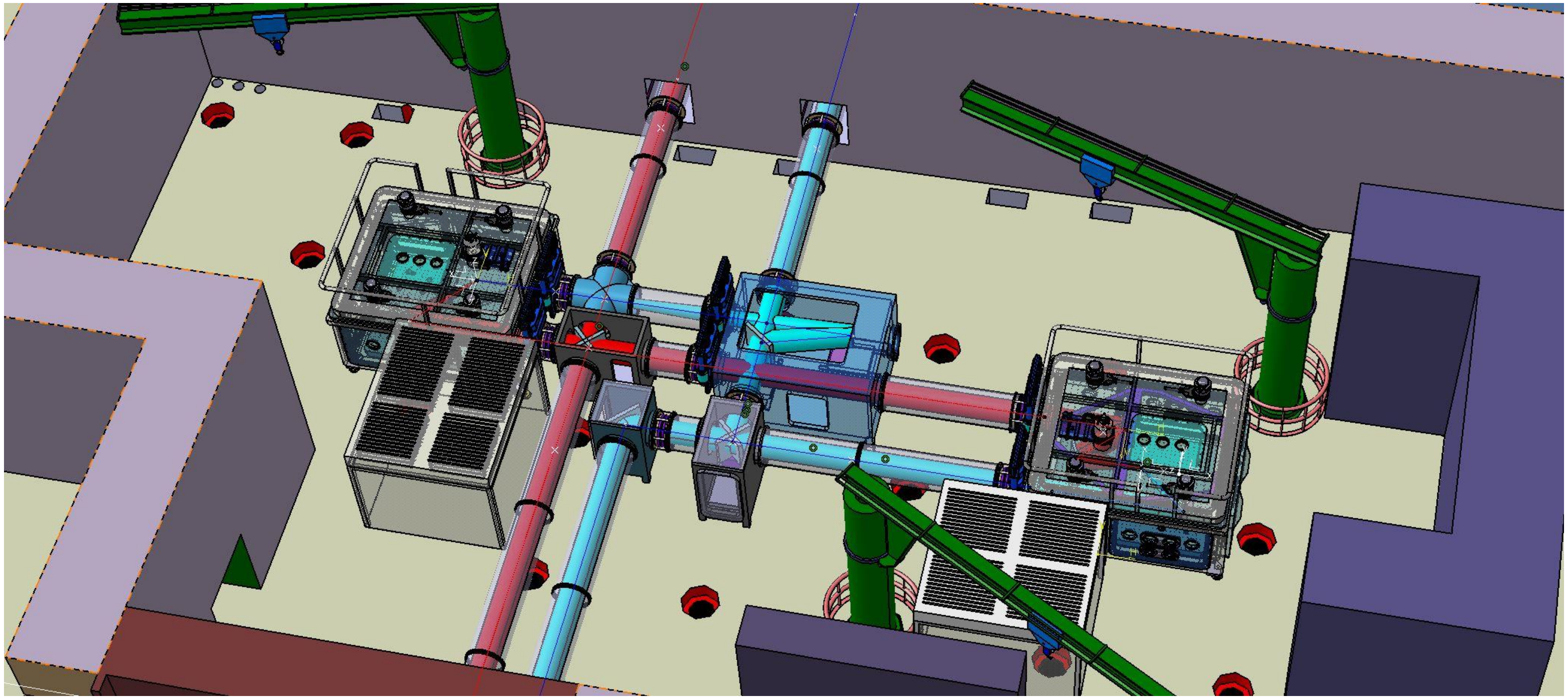
Back reflection? How about plasma mirror?



2x10 PW Laser Exp. Area Design

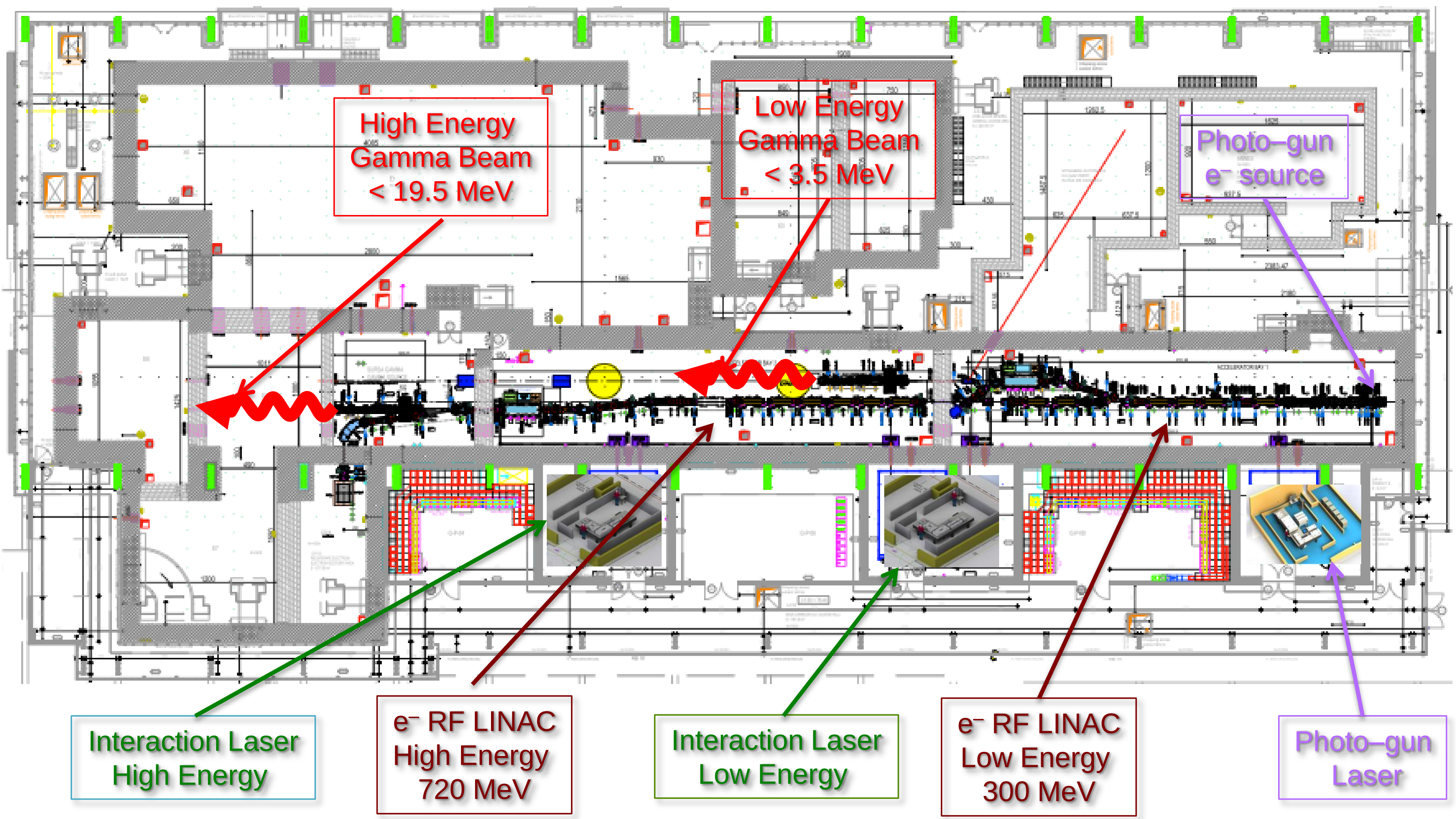


2x10 PW Laser Exp. Area Design II

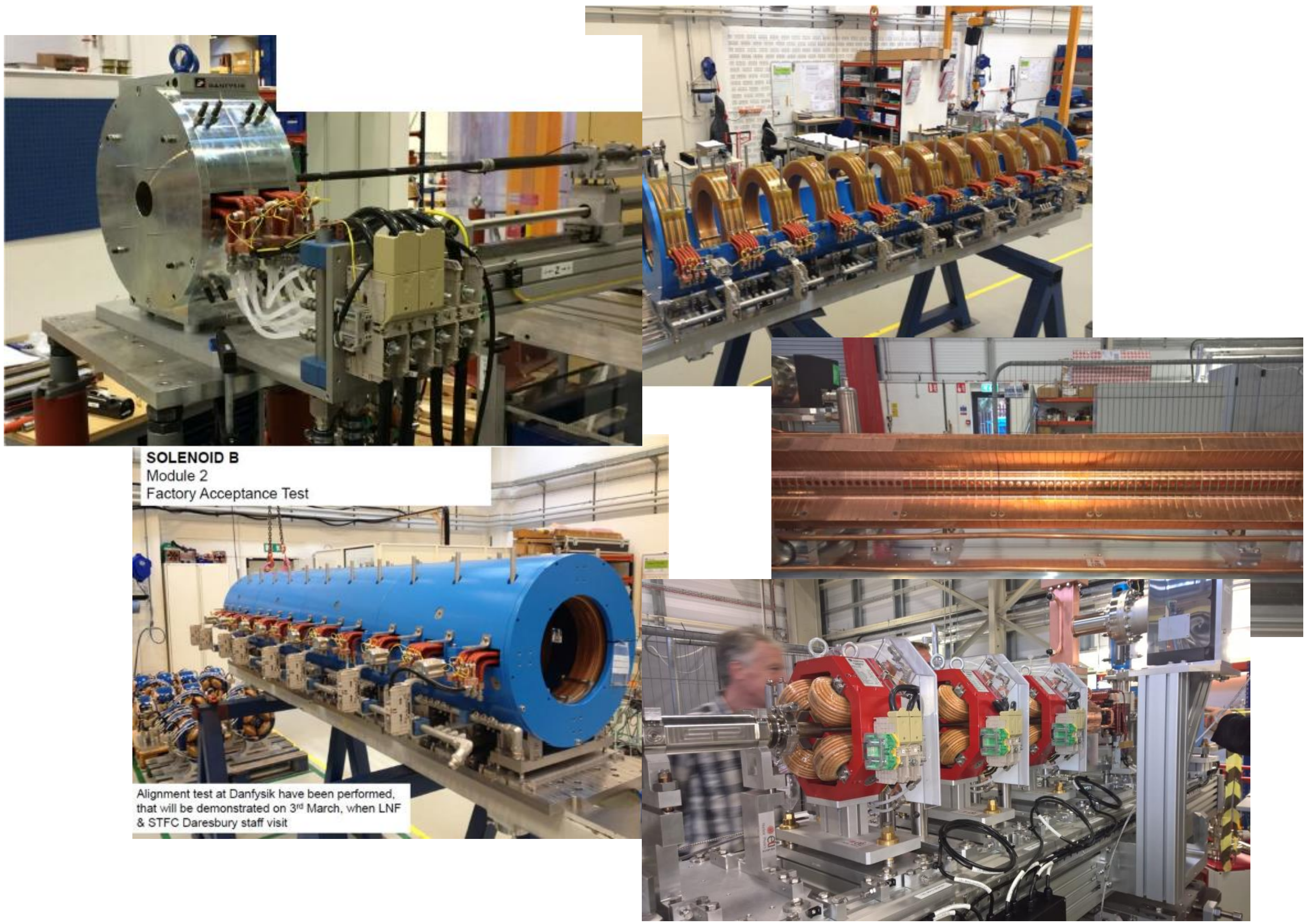


- ❑ Adaptive mirrors will be available later.
- ❑ Long-pulse heating beam at E1 (plasma production with ~250 J / ns pulse)
- ❑ Circular Polarization system will be available.

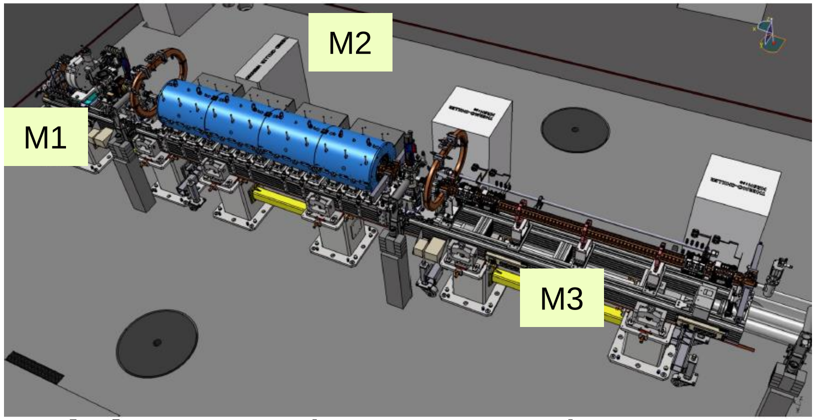
Gamma Beam Layout



Gamma Beam System Components

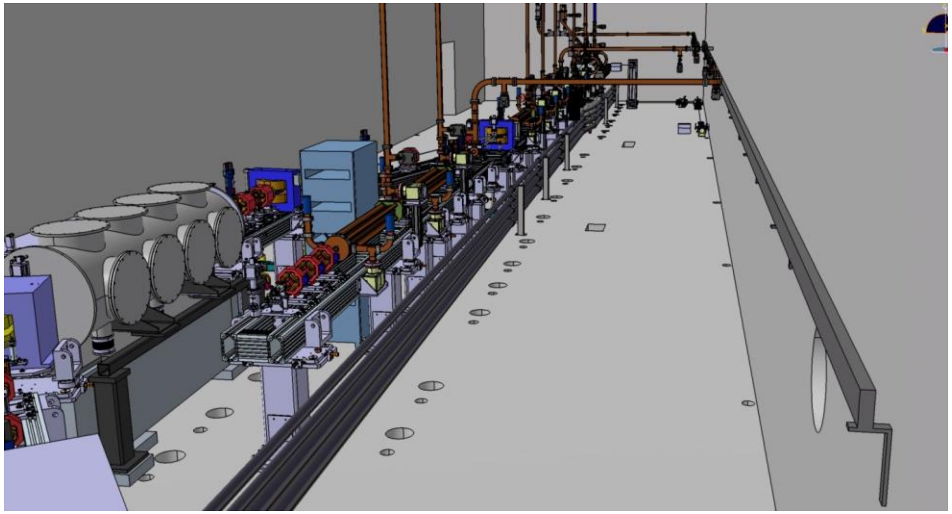


Gamma Beam System Layout



module M1 – photogun and electron beam extraction components (solenoid A)
module M2 – the first S–band accelerating structure and the solenoid B surrounding the S–band structure
module M3 – the second S–band accelerating structure

RF waveguides layout in Accelerator Bay 1



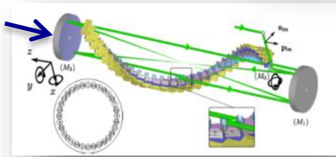
Components of Gamma Beam System

1) ***Warm electron RF Linac*** (innovative techniques)

- multi–bunch photogun (32 e^- microbunches of 250 pC @100 Hz RF)
  - 2 x S–band (22 MV/m) and 12 x C–band (33 MV/m) acc. structures
  - low emittance 0.2 – 0.6 mm·mrad
  - two acceleration stages (300 MeV and 720 MeV)

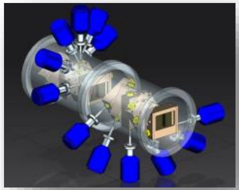
2) ***High average power, high quality J–class 100 Hz ps Collision Laser***

  - state–of–the–art cryo–cooled Yb:YAG (200 mJ, 2.3 eV, 3.5 ps)
  - two lasers (one for low–E_γ and both for high–E_γ)



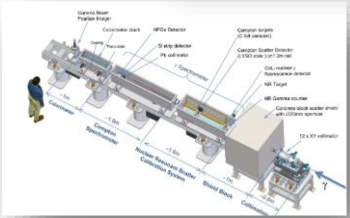
3) ***Laser circulation with μm and μrad and sub–ps alignment/synchronization***

  - complex opto/mechanical system
  - two interaction points: E_γ < 3.5 MeV & E_γ < 19.5 MeV



4) ***Gamma beam collimation system***

  - complex array of dual slits
  - relative bandwidths < 5×10^{-3}

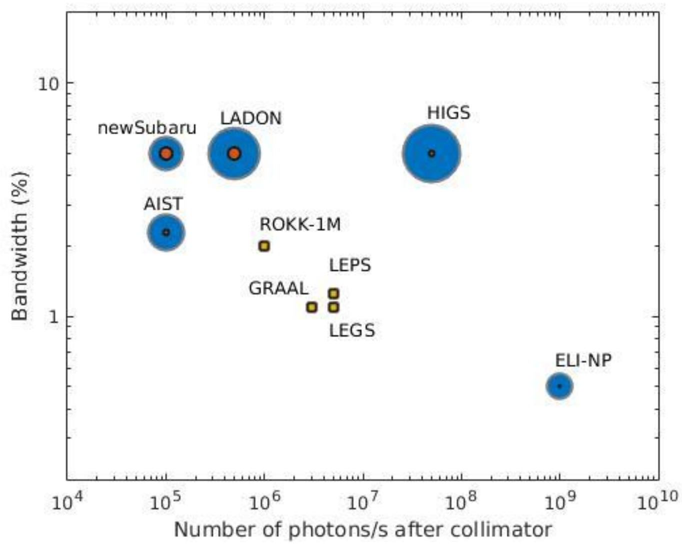


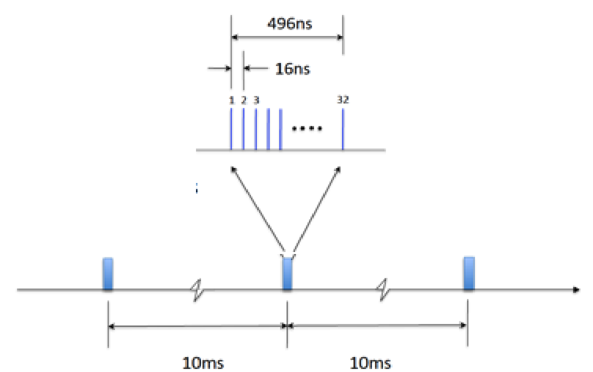
5) ***Gamma beam diagnostic system***

  - beam optimization and characterization: energy, intensity, profile

GBS Specification

Quantity	Symbol	Units	Specification
Minimum Photon Energy	E_γ	[MeV]	0.2
Maximum Photon Energy	E_γ	[MeV]	19.5
Tunability of the photon energy			Continuously variable
Linear polarization of the gamma ray beam	P_γ	[%]	≥ 99
Divergence	$\Delta\theta$	[rad]	$(0.25 - 2.0) \times 10^{-4}$
Source rms diameter		[m]	$(0.01 - 0.03) \times 10^{-3}$
Average diametral Full Width Half Maximum of beam spot	σ_r	[m]	$\leq 1.0 \times 10^{-3}$
Average bandwidth of the gamma-ray beam	W		$\leq 5.0 \times 10^{-3}$
Time-average spectral density at the peak energy	F	[1/(s eV)]	$(0.8 - 4.0) \times 10^{4}$
Time-average brilliance at peak energy	B_{av}	[1/s mm² mrad² 0.1%W]	$\geq 1.0 \times 10^{13}$
Peak-brilliance at peak energy	B	[1/s mm² mrad² 0.1%W]	$10^{20} - 10^{23}$
Average spectral off-peak gamma-ray background density	$\Phi_{\gamma,bkgr}$	[1/(s eV)]	$\leq 1.0 \times 10^{-2}$
Frequency of the gamma-ray macropulses	$\Omega_{\gamma,M}$	[Hz]	100
Number of gamma-ray micropulses per macropulse			32
Micropulse-to-micropulse separation		[ns]	16





Diagnostics List

- A full range of detectors employed by high-power laser experiments at other facilities and adapted to ELI-NP:
  - proton or ion spectrometers
    - passive: Thomson parabola + IPs, RCF stacks
    - active: Thomson parabola + scintillator
  - gamma detectors:
    - prompt spectrum
    - short lived states with in-situ LaBr3 scintillators
    - off-line (activation) detectors
  - neutron detectors: scintillators, bubble detectors
  - plasma diagnostics and electromagnetic fields (Optical, THz, XUV) including fast probe beams

Commissioning Phase

- We will focus on the characterization of each machines: 10PW laser and 19 MeV Gamma beam systems.

10 PW Laser System

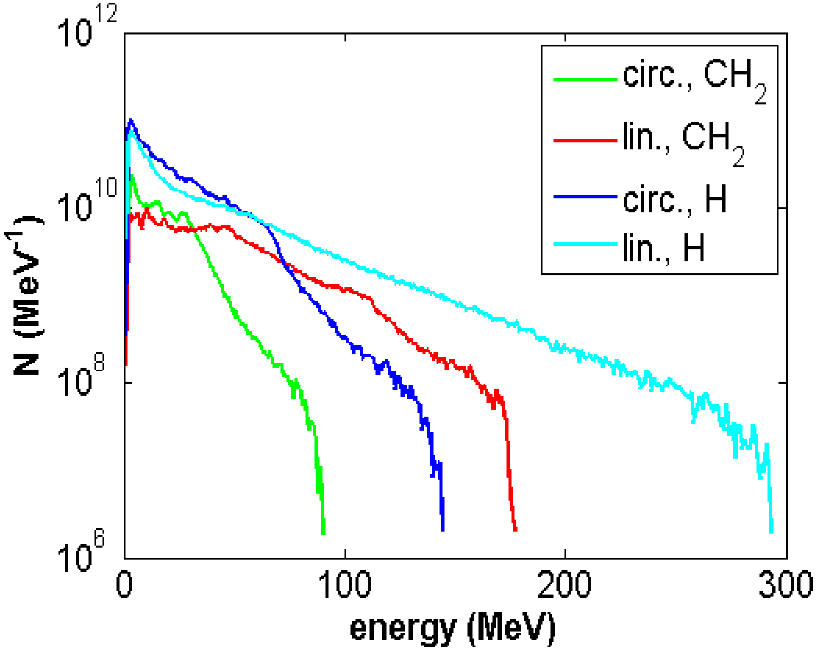
- Laser intensity: 10^{23} W/cm^2
- Electron acceleration > GeV
- Proton acceleration > 200 MeV

Gamma Beam System

- Gamma photon energy calibration-Nuclear excitation 3 or 19.5 MeV
- Polarization > 95%

Proton >200 MeV is possible.

Predicted proton energy for LP and CP I=10^{22} W/cm2, 0.2 µm CH_2 target
(Psikal et al J Phys Conf 2016)



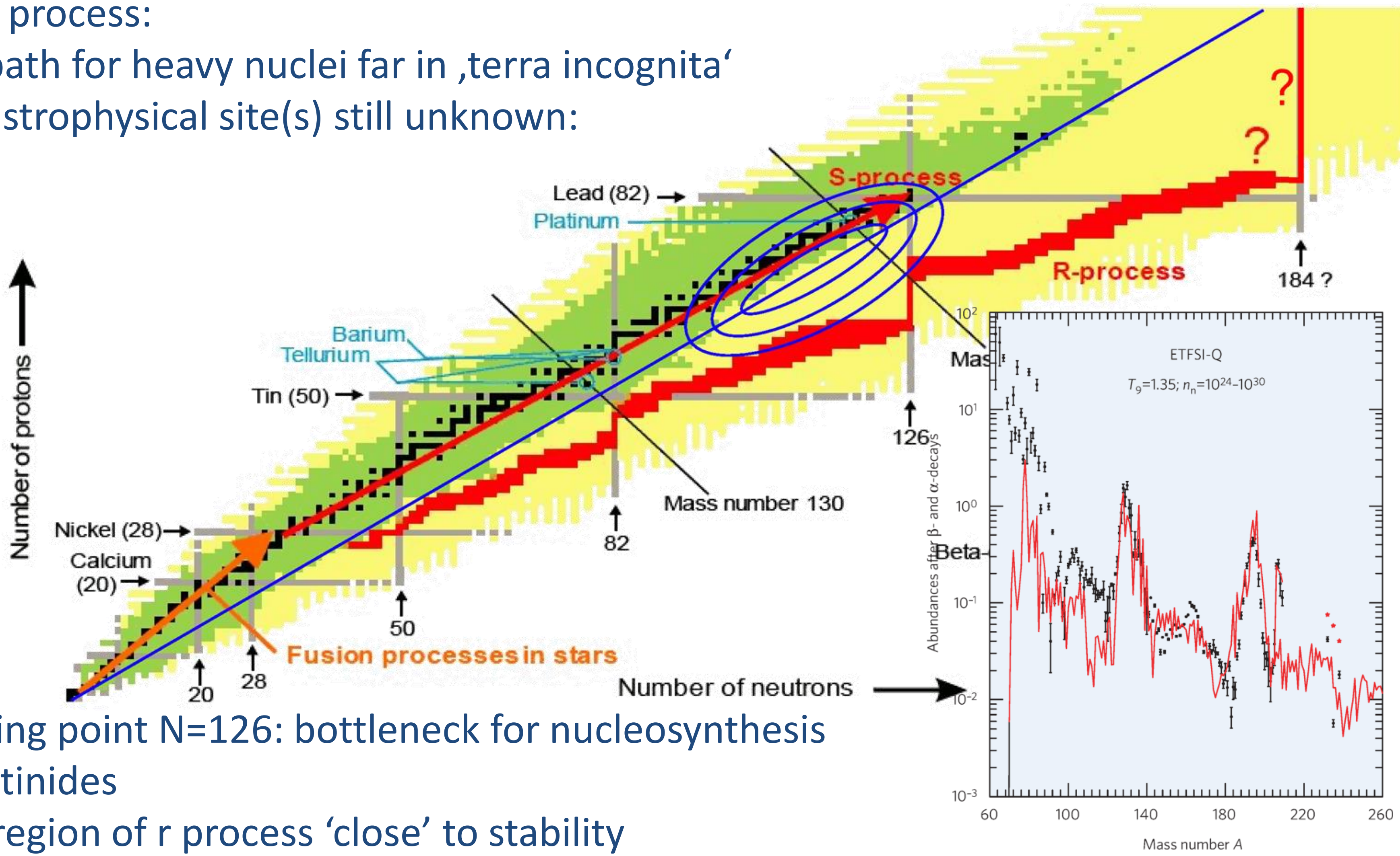
Day 1 Experiments with 10 PW

- Radiation Reaction: Classical to QED
- Photo Nuclear Reaction
- Ion Stopping & Excitation in Plasmas
- Fission Fusion Mechanism: r process ^{232}Th
- Dark Matter Physics
- Vacuum Birefringence
- Photo-excitatin of isomers

Etc.

Astrophysical r process: waiting point N=126
-P. Thirolf (LMU)-

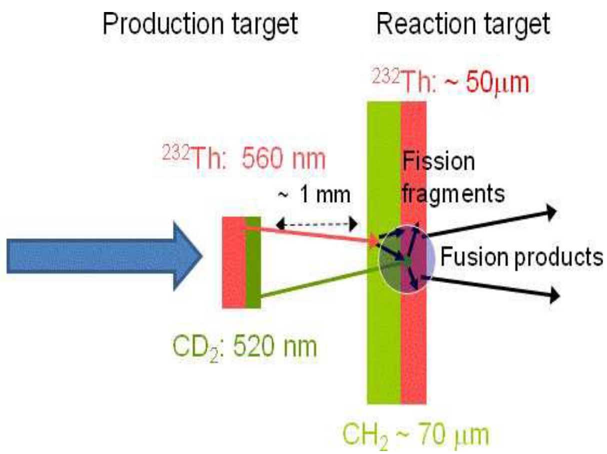
- r process:
  - path for heavy nuclei far in ‚terra incognita‘
  - astrophysical site(s) still unknown:



- waiting point N=126: bottleneck for nucleosynthesis of actinides
- last region of r process ‘close’ to stability

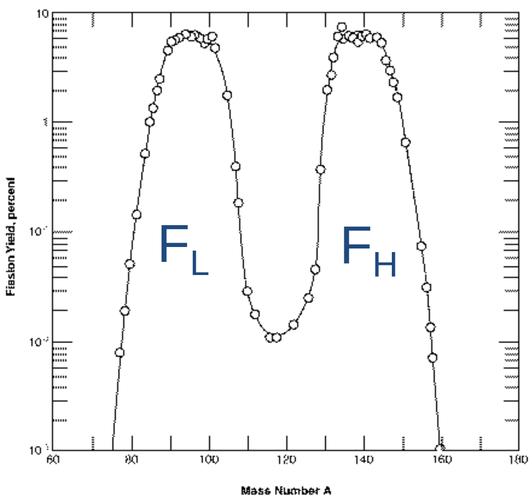
Fission – Fusion Mechanism

high-power, high-contrast laser:
150-300 J, 21 fs (7-14 PW)
$1.2 \cdot 10^{23}$ W/cm^2
focal diam. ~ 3 μm



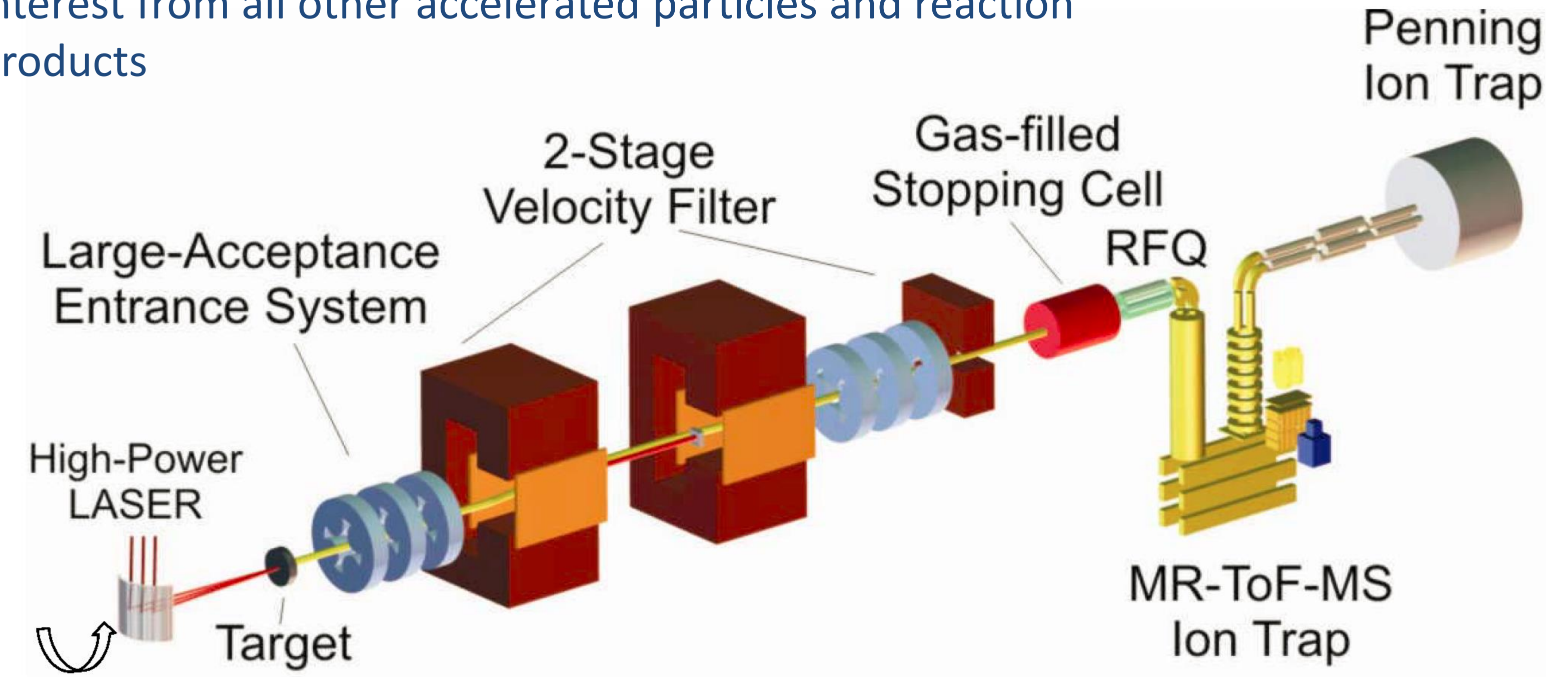
	Normal stopping	Reduced stopping
Production target:		
^{232}Th	560 nm	560 nm
CD_2	520 nm	520 nm
Accelerated Th ions	1.2×10^{11}	1.2×10^{11}
Accelerated deuterons	2.8×10^{11}	2.8×10^{11}
Accelerated C ions	1.4×10^{11}	1.4×10^{11}
Reaction target:		
CH_2	70 μm	–
^{232}Th	50 μm	5 mm
Beam-like light fragments	3.7×10^{8}	1.2×10^{11}
Target-like fission probability	2.3×10^{-5}	2.3×10^{-3}
Target-like light fragments	3.2×10^{6}	1.2×10^{11}
Fusion probability	1.8×10^{-4}	1.8×10^{-4}
Fusion products	1.5	4×10^{4}

Mass distribution in Th fission



In-flight Separator for ELI-NP

H. Geissel (GSI/U Giessen) proposed separation of nuclei of interest from all other accelerated particles and reaction products



Measuring basic properties of N~126 nuclei: **masses**
lifetimes
decay modes

Radiation Reaction

Investigation of
the running coupling
between
an electron & radiation

$$e_{\text{High-Field}} = q(\chi) \times e_{\text{classical}}$$

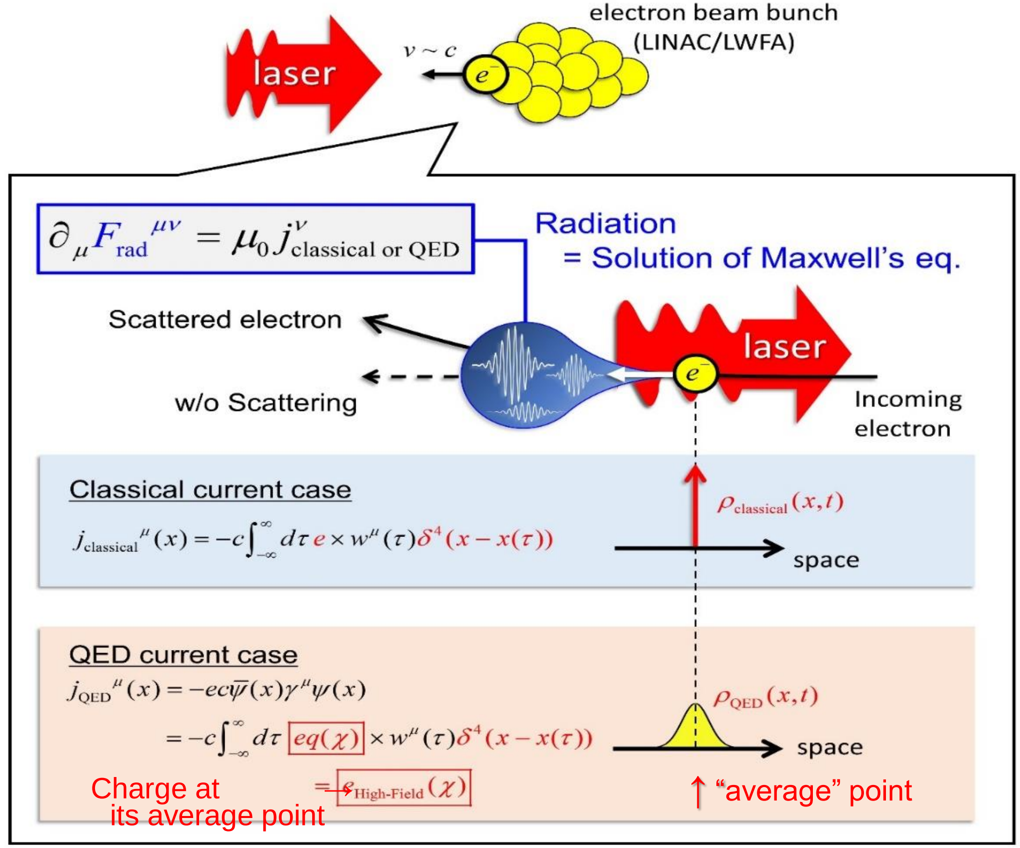
Solving dynamics ⇩

Radiation formula:

$$\frac{dW_{\text{High-intensity}}}{dt} = q(\chi) \times \frac{dW_{\text{classical}}}{dt}$$

$$\chi \propto E_{\text{electron}} \sqrt{I}$$

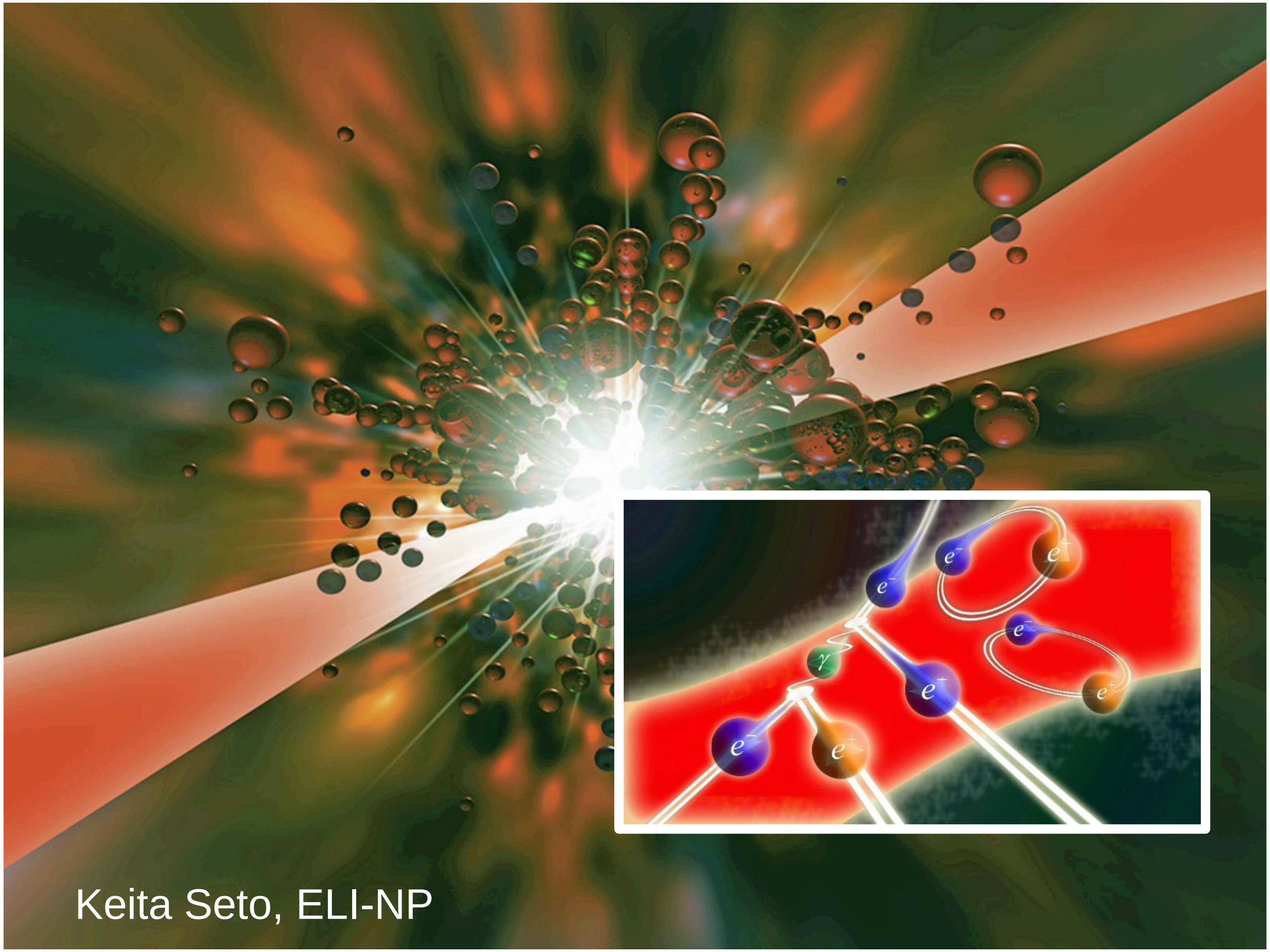
(Laser intensity dependence)



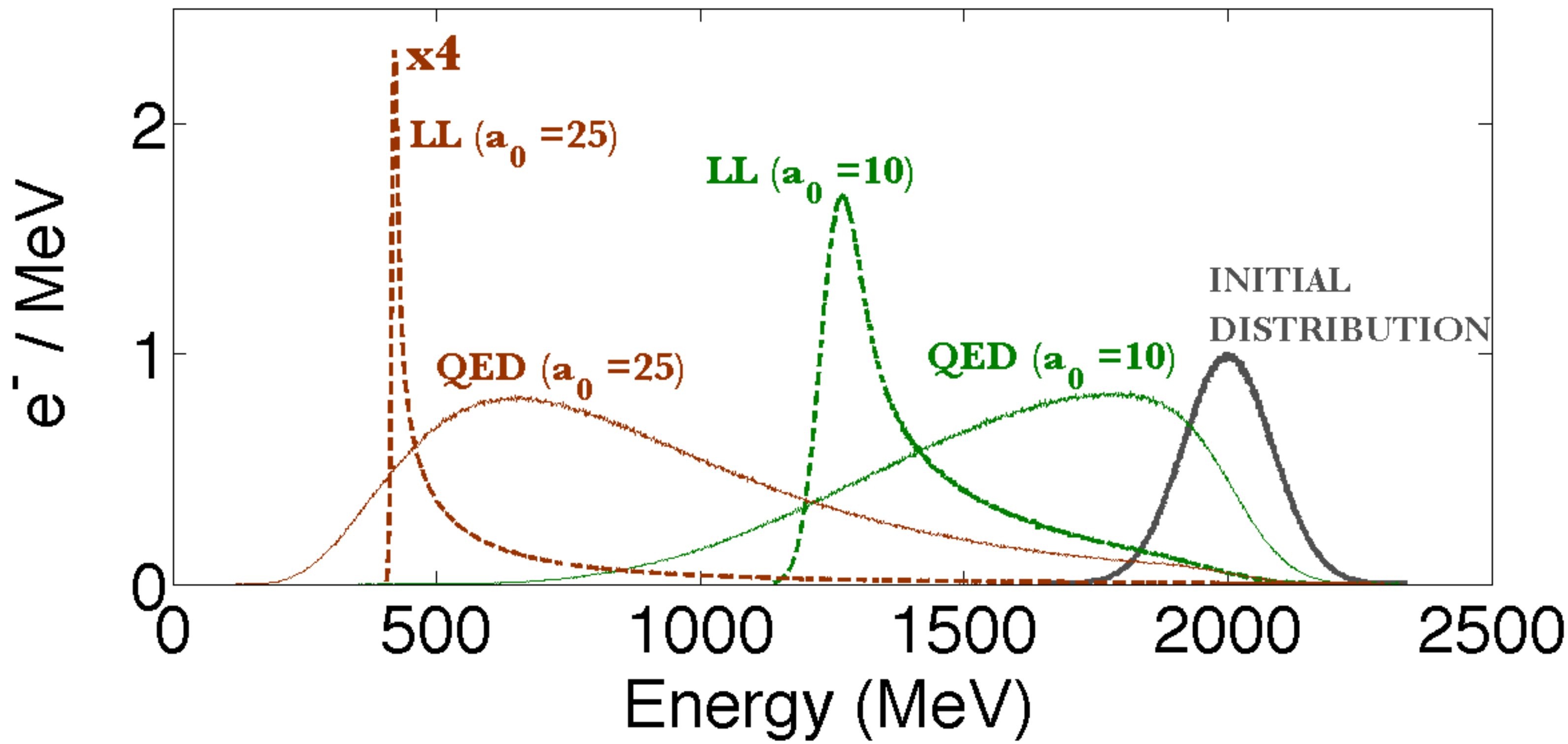
By Keita Seto (ELI-NP/IFIN-HH)

K. Seto, PTEP **2015**, 103A01 (2015).
K. Homma, et. al, Rom. Rep. Phys. **68 Supp.**, S233 (2016).
K. Seto, arXiv: 1603.03379v4 (2016) [under upgrading].

QED exp. is performed at both facilities

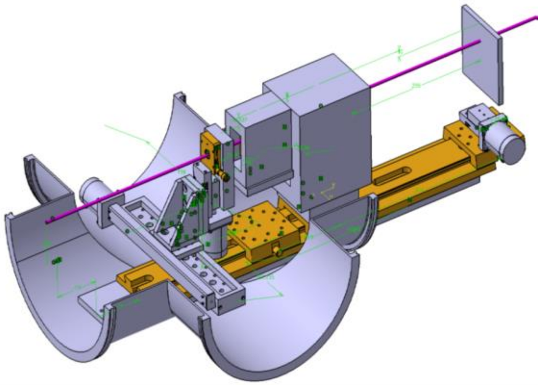


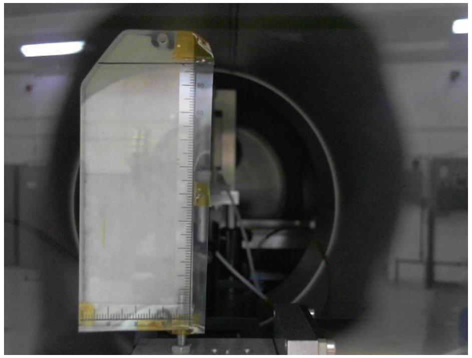
We may expect to see the drastic down shift in Gamma spectrum.



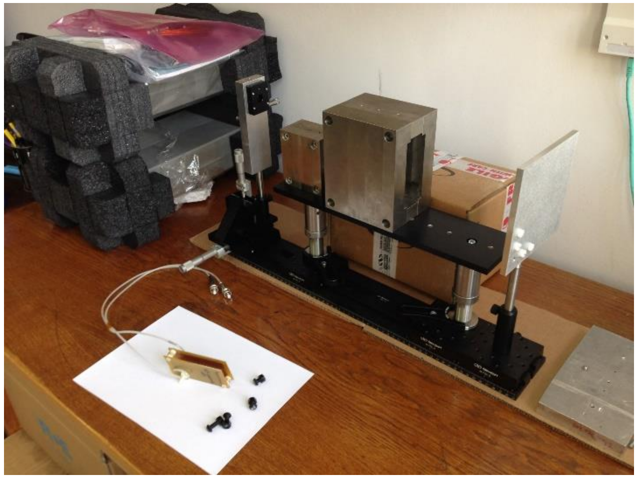
G Sarri, Queens' Univ. Belfast, UK.

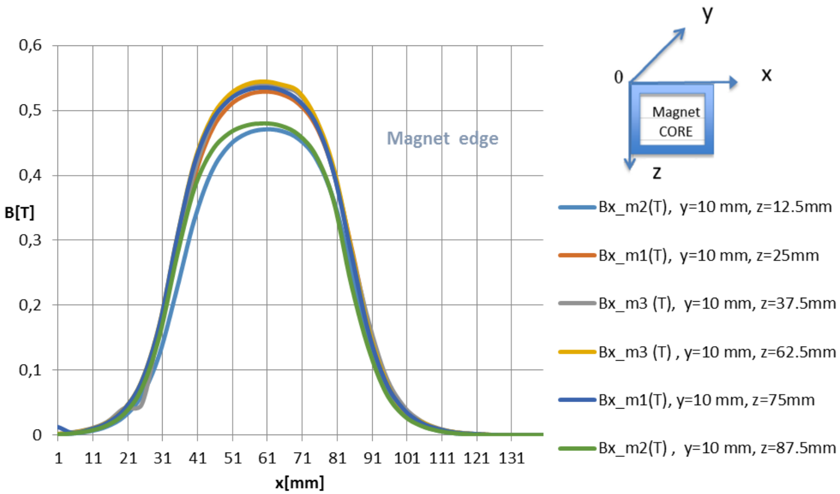
Thomson Parabola being tested.



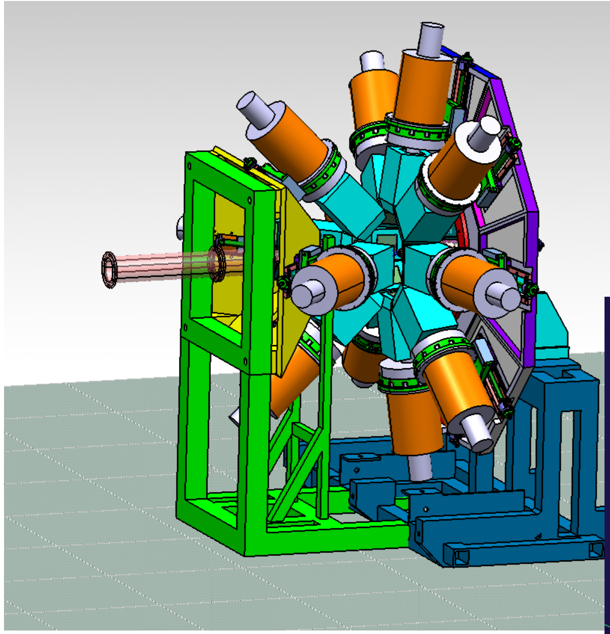


In beam test and calibration at 9 MV Tandem of IFIN-HH

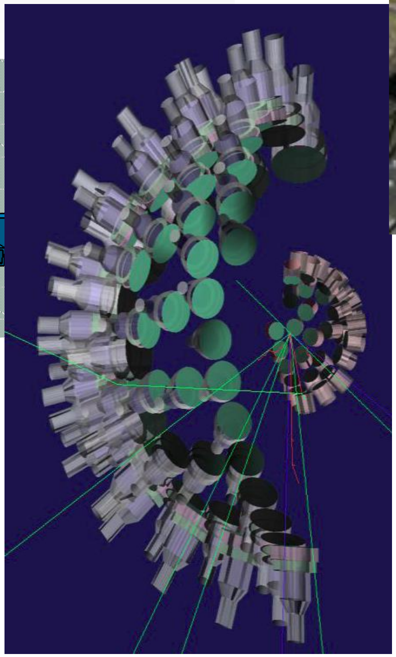




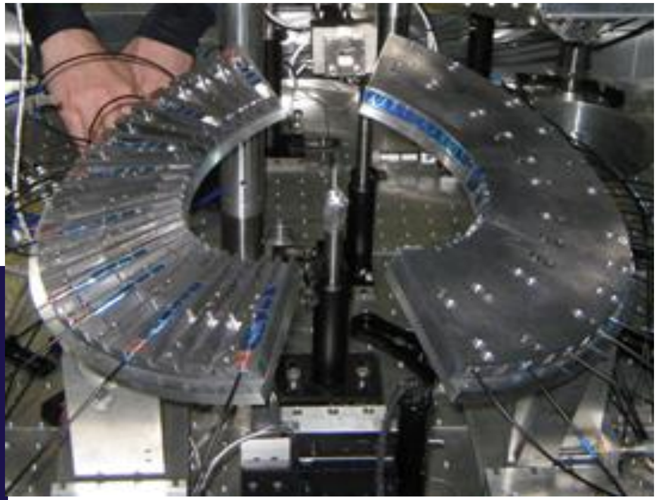
Diagnostics being developed



ELIADE array: 8 segmented HPGe Clover detectors with anti-Compton shields + 4 LaBr3 detectors



Gamma above neutron threshold



CsI array for angle resolved calorimetry

New horizons

Fission-fusion	**Astrophysics**
Dark matter	**Astrophysics**
Radiation effect	**Biology**
Nuclear Resonance	**Nuclear Physics**
Gamma Imaging	**Nuclear Security**
Material Science	**Fusion Reactor Eng.**
Medical Isotopes	**Cancer Therapy**

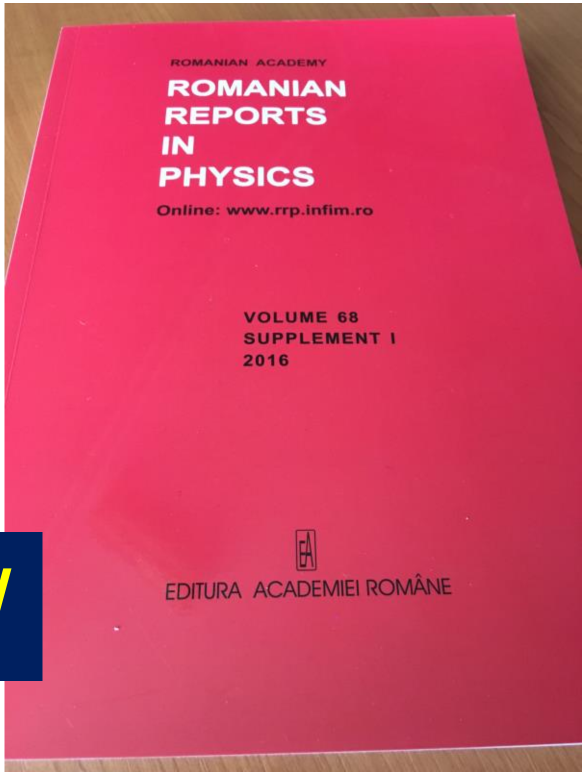
Nuclear Physics

Buildings are ready now.

Nuclear Physics eli

Romanian Reports in Physics, 68, S3-S349, 2016

In this among more than 300 pages, you can find the proposals and system details.



http://www.rrp.infim.ro/

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"Investments for Your Future!"

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

IFIN-HH

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Thanks for your attention