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"

Upcoming High Power Laser Facility ELI-NP: Over-view and strategy

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

ICTS Laser Plasma Accelerator
Ramanujan Lecture Hall, ICTS Bangalore

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€)*

Connection to India

ASHULA Grand Seminar with Prof PK Kaw GR Kumar

ASHULA Project

I met Ashula through collaboration.

Prof Predhiman K Kaw
Inst. Plasma Physics, India

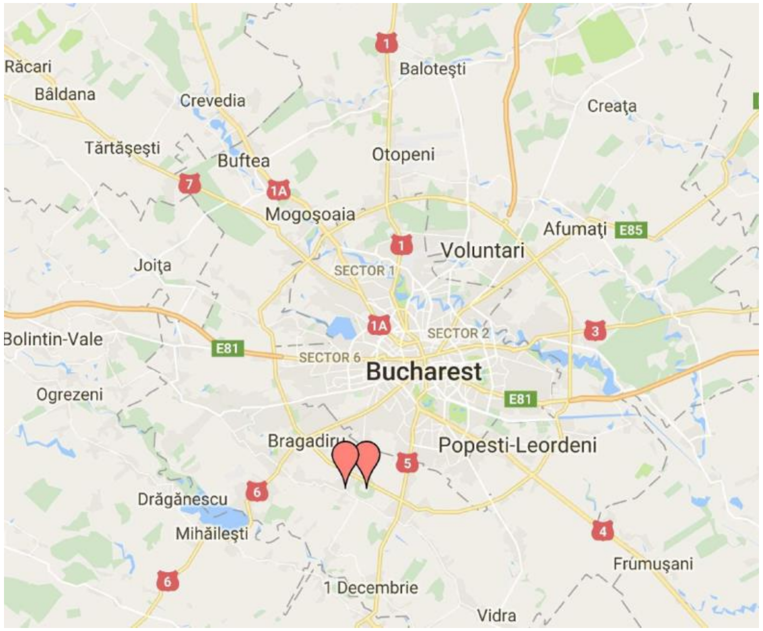
Move to Romania

New assignment on

Scientific Director of

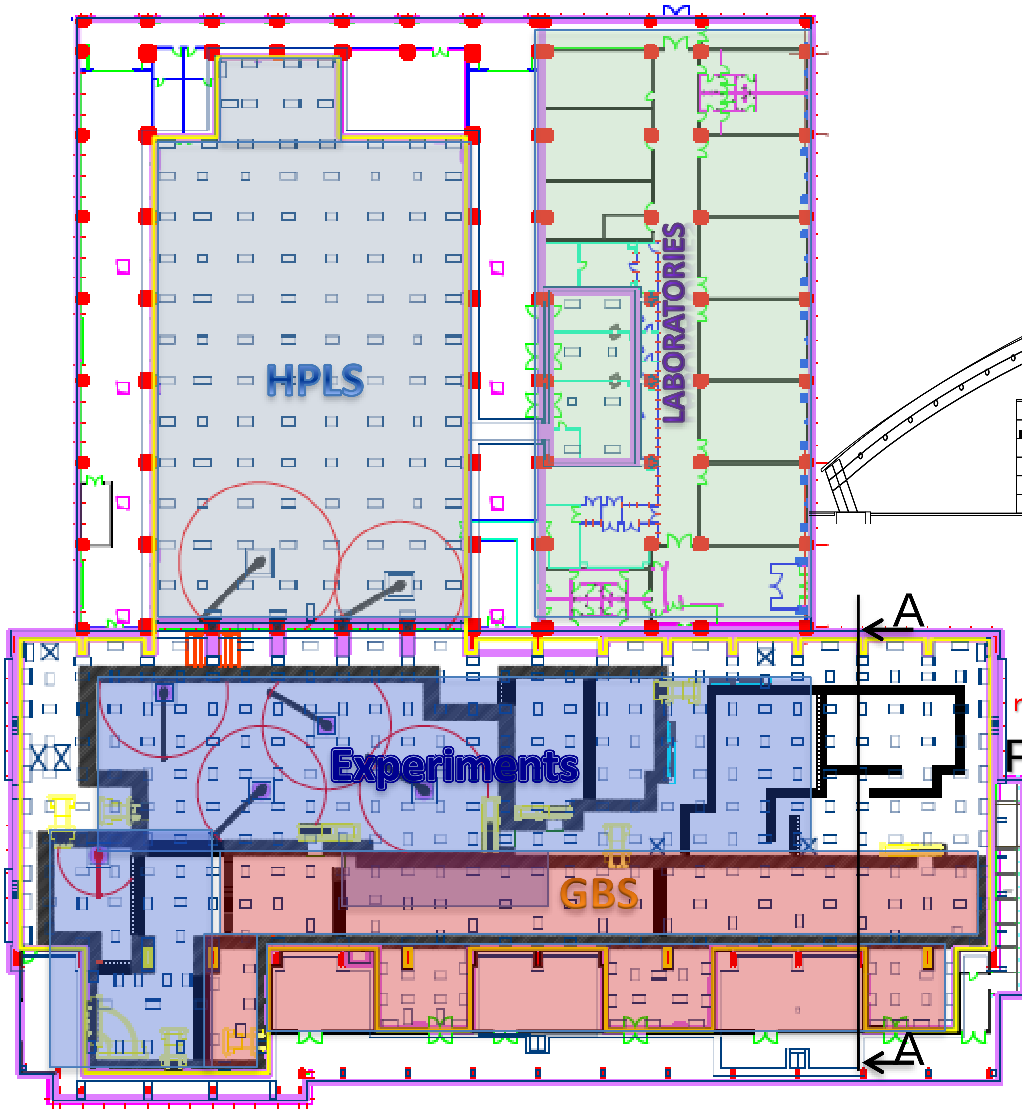
Extreme Light Infrastructure-Nuclear Physics

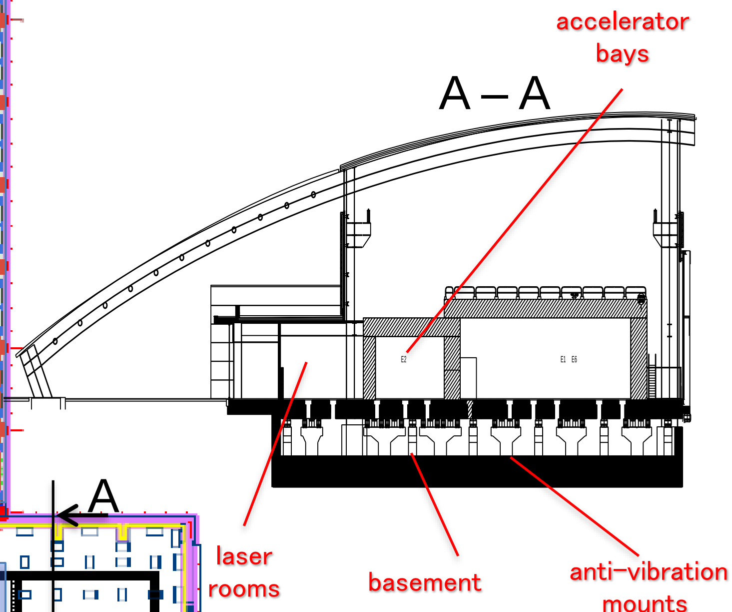
Our buildings are completed.



ELI-ALPS(Hungary) & ELI Beamlines (Czech)

ELI–NP –Building Status

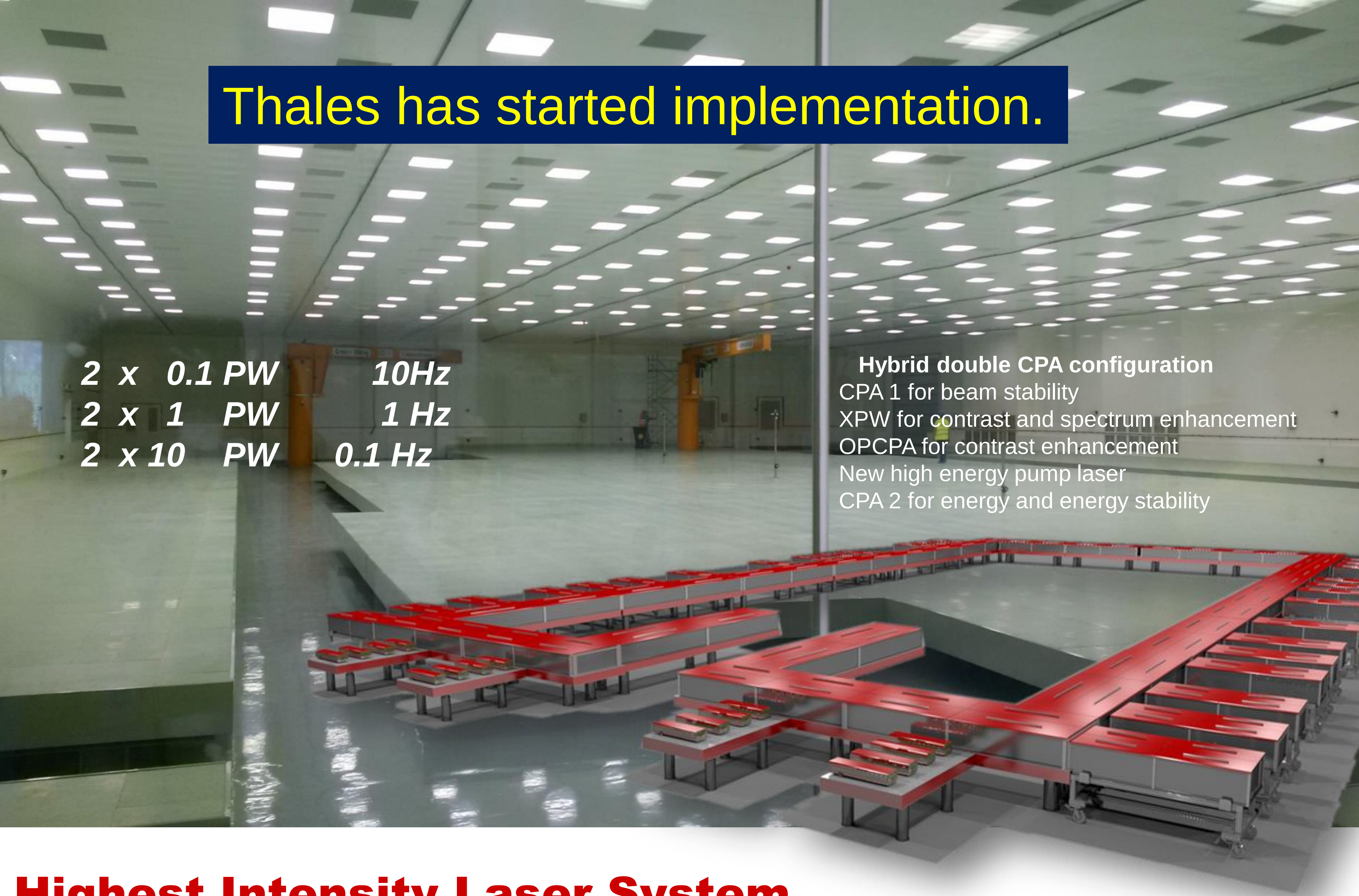




Platform supported on dampers

Anti-vibration platform

±1 μm @ < 10 Hz



Highest Intensity Laser System
Large Clean Room

Laser Bay as of Mar. 3, 2017

Dana Strickland and Gerard Mourou

the University of Waterloo in Ontario, Canada

IZEST France

High Power Laser System

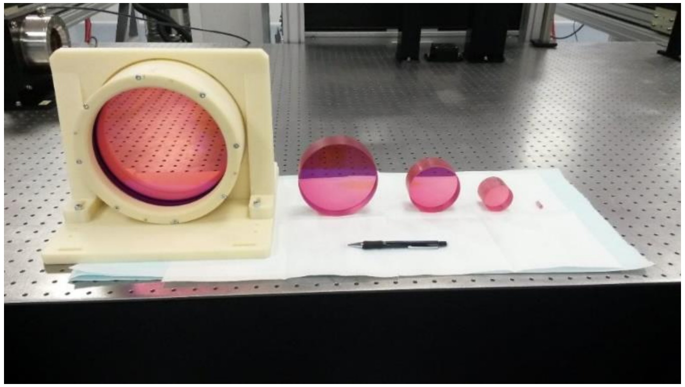
	min	max	unit
Energy/pulse	150	225	J
Central wavelength	814	825	nm
Spectral bandwidth (FWHM)	55	65	nm
Spectral bandwidth (at nearly zero level of intensity)	120	130	nm
Pulse duration (FWHM)	15	22.5	fs
FWHM beam diameter/Full aperture beam diameter	450/550		mm
Repetition rate	1		pulse /min
Strehl ratio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

eli Nuclear Physics

Each component has been tested on time

Couple of technical issues have been solved.

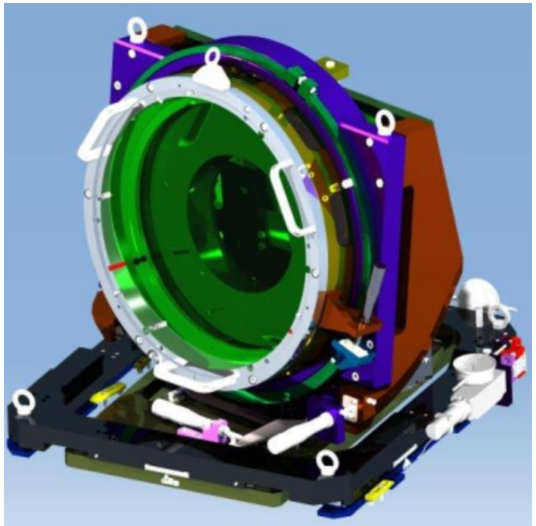
- Stable ps OPCPA demonstrated
- 12/16 Pump lasers 100J@ 527nm tested
- 20cm useful aperture Ti:Sa crystal available
- First large diffractive grating for 10PW compressor produced



Optical componets are ready? Yes.

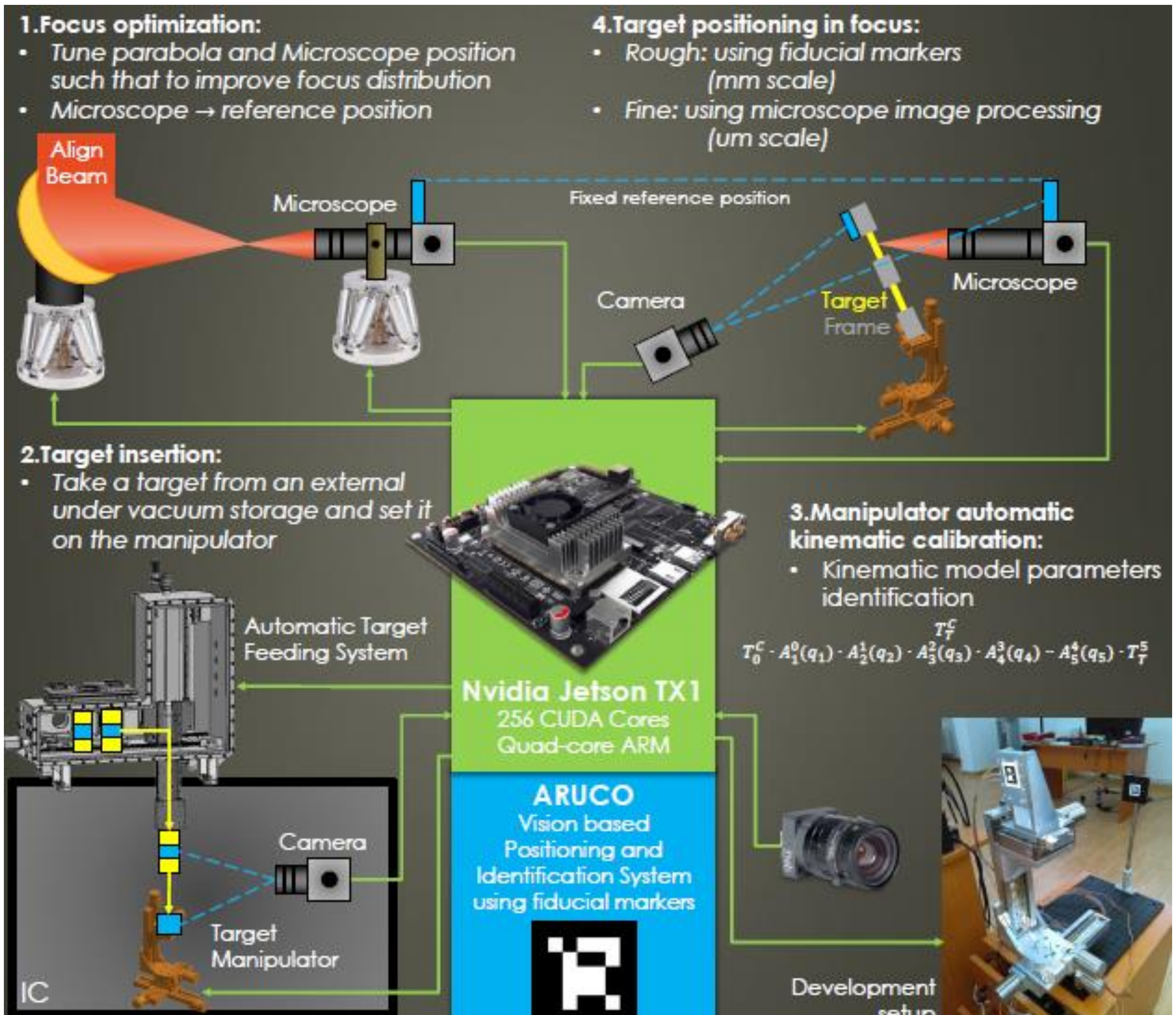
Heavy duty (1 ton) hexapod
Resolution 0.8 μm / 0.5 μrad

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?
Automatic target alignment is planned



Laser shot cycle
1 mint.-10 Hz

1.Optimize the focus using the off-axis parabola

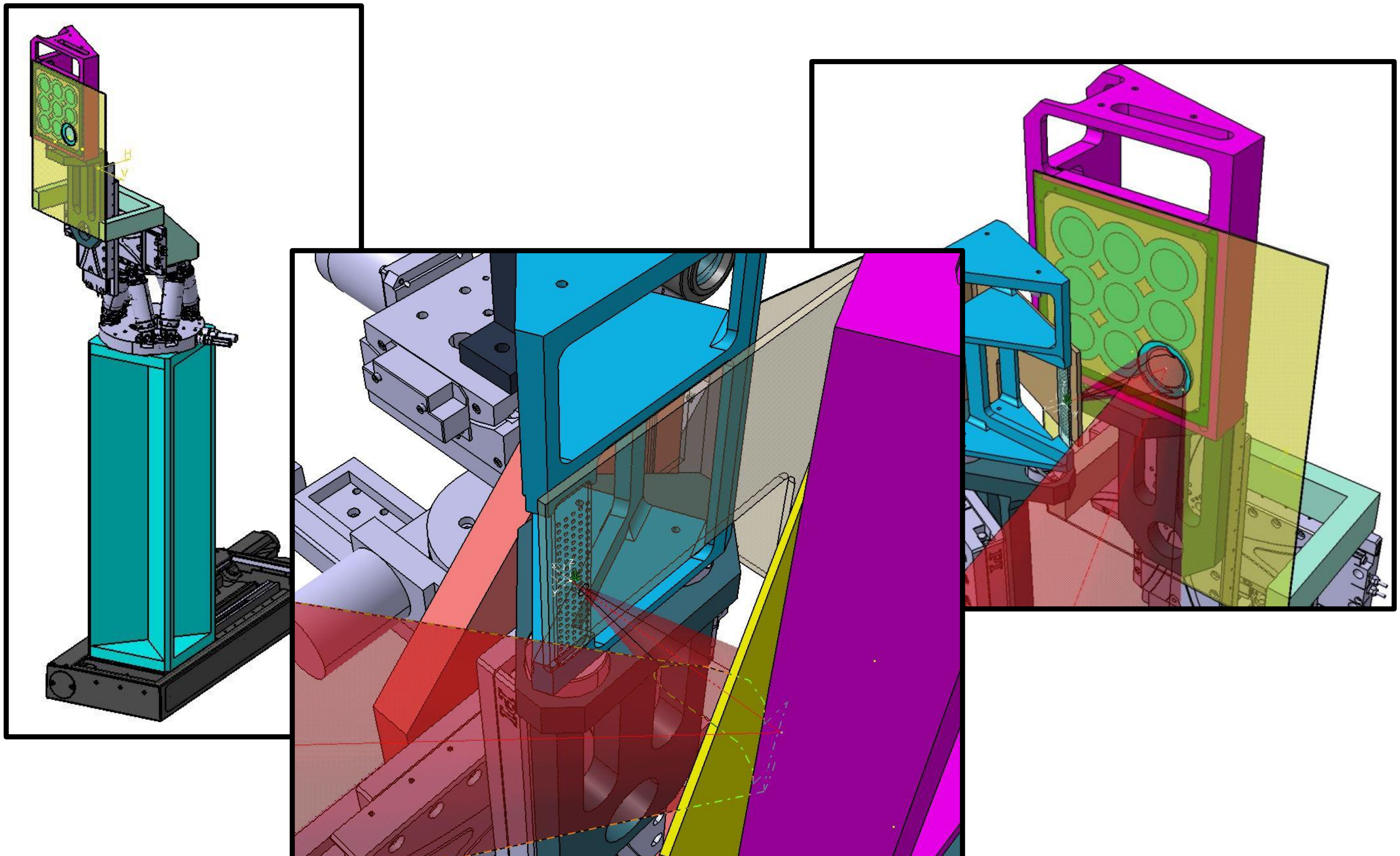
2.Insert the first target frame using the target insertion system

3.Align roughly the frame in focus

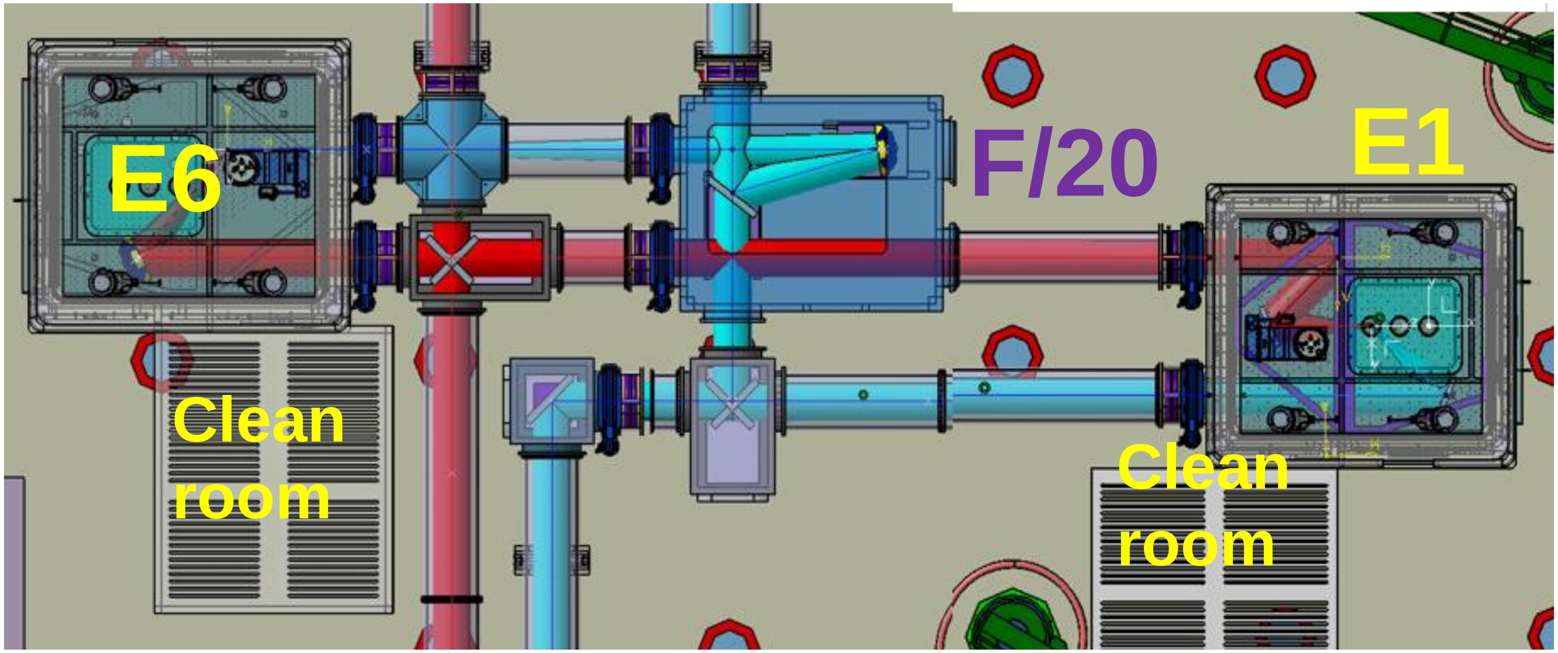
4.Align finely the frame in focus

5.Move the frame to the first target

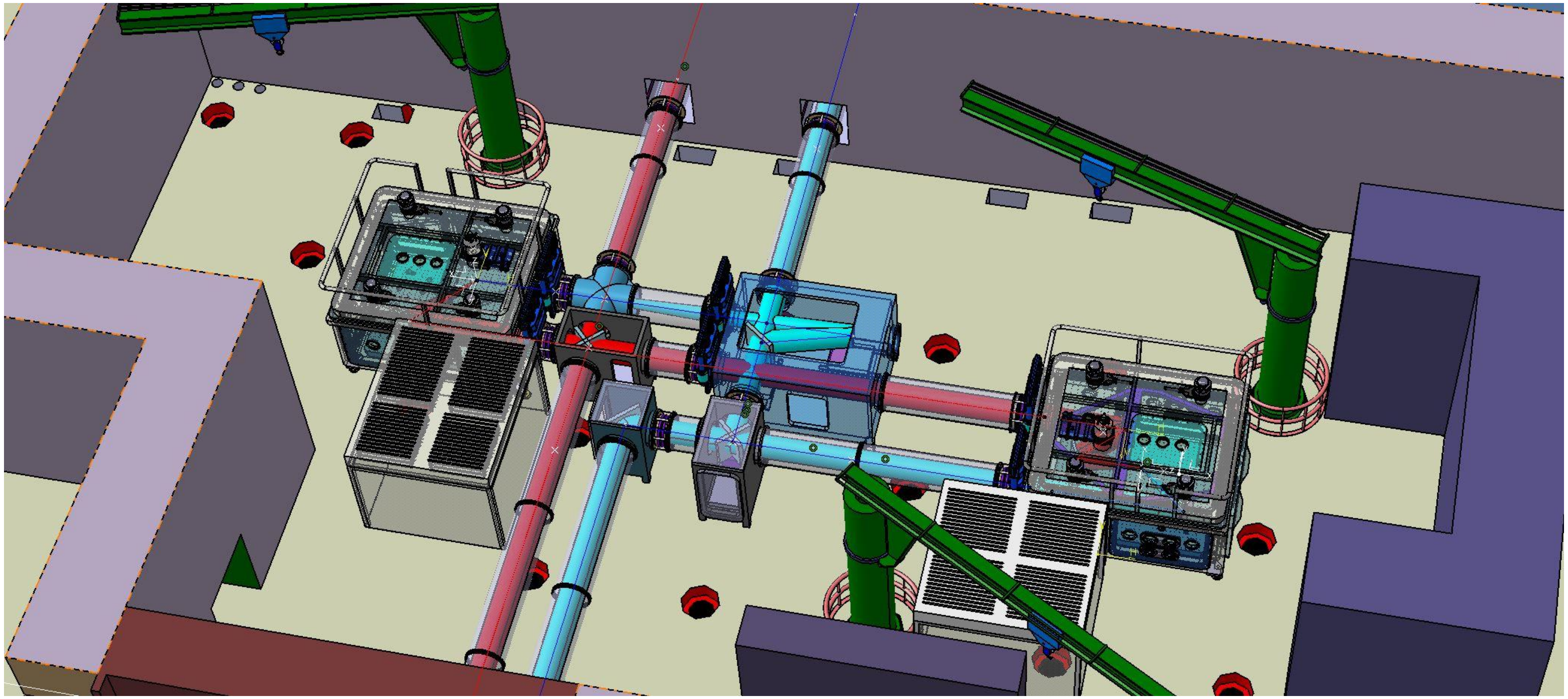
Back reflection?
Plasma mirror is tested for optics protection.



2x10 PW Laser Exp. Area Design

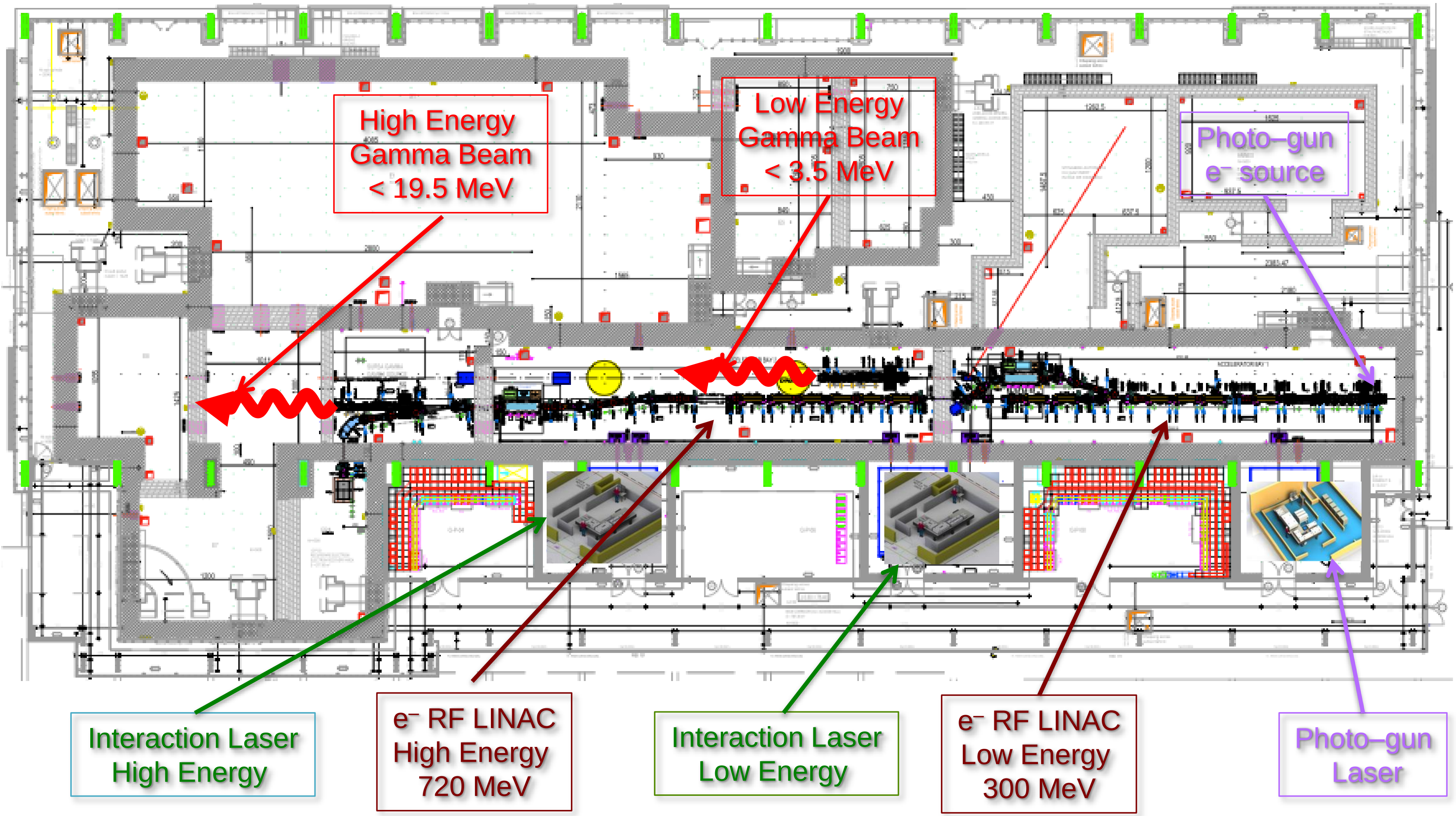


2x10 PW Laser Exp. Area Design II

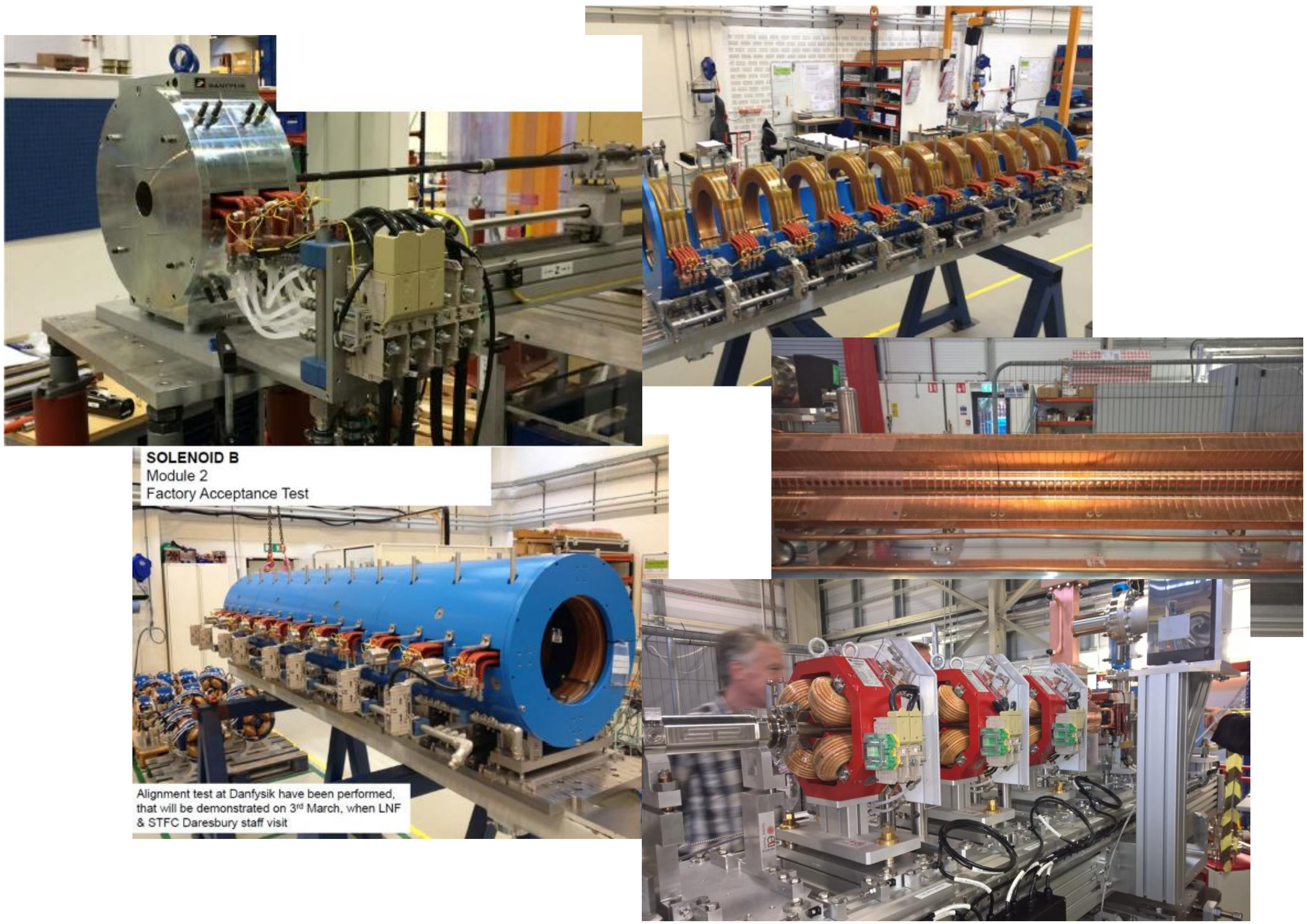


- ❑ Adaptive mirrors will be available later.
- ❑ Long-pulse heating beam at E1 (plasma production with ~250 J / ns pulse)
- ❑ Circular Polarization system will be available.

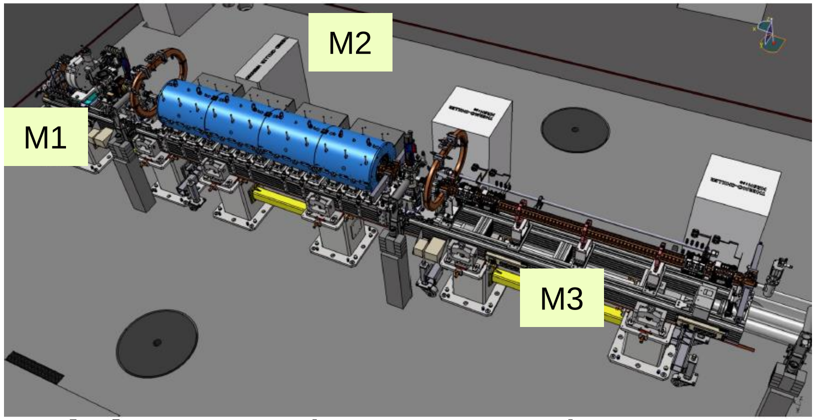
Gamma Beam Layout



Gamma Beam System Components

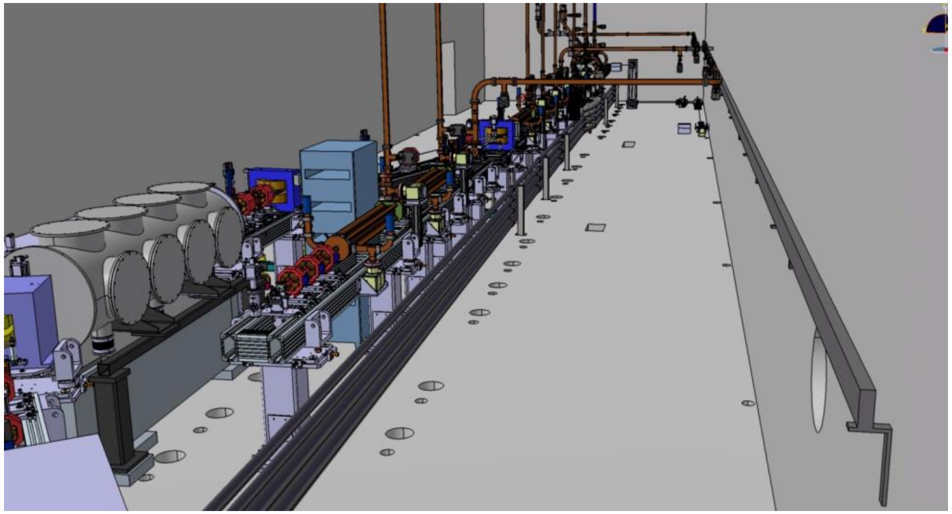


Gamma Beam System Layout



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

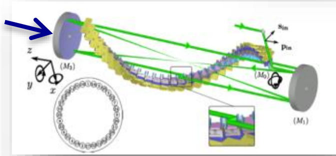
1) *Warm electron RF Linac* (innovative techniques)

- 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*

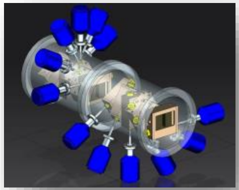
- state–of–the–art cryo–cooled Yb:YAG (200 mJ, 2.3 eV, 3.5 ps)
- two lasers (one for low–E_γ and both for high–E_γ)

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



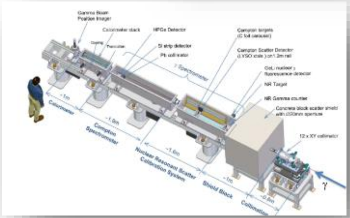
- complex opto/mechanical system
- two interaction points: E_γ < 3.5 MeV & E_γ < 19.5 MeV

4) *Gamma beam collimation system*



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

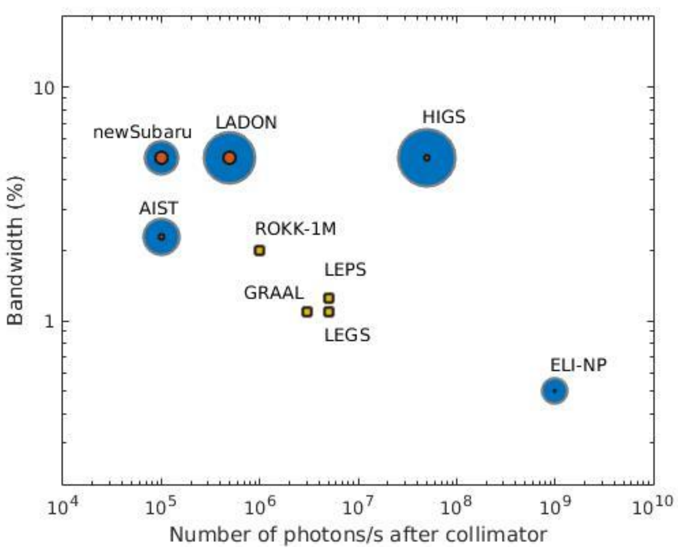
5) *Gamma beam diagnostic system*

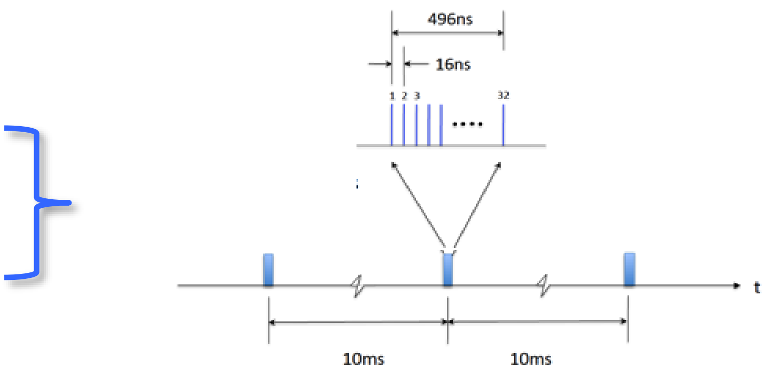


- beam optimization and characterization: energy, intensity, profile

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) x 10^{-4}
Source rms diameter		[m]	(0.01 - 0.03) x 10^{-3}
Average diametral Full Width Half Maximum of beam spot	σ_r	[m]	≤ 1.0 x 10^{-3}
Average bandwidth of the gamma-ray beam	W		≤ 5.0 x 10^{-3}
Time-average spectral density at the peak energy	F	[1/(s eV)]	(0.8 - 4.0) x 10^{4}
Time-average brilliance at peak energy	B_{av}	[1/s mm^2 mrad^2 0.1%W]	≥ 1.0 x 10^{13}
Peak-brilliance at peak energy	B	[1/s mm^2 mrad^2 0.1%W]	10^{20} - 10^{23}
Average spectral off-peak gamma-ray background density	$\Phi_{\gamma,bkgr}$	[1/(s eV)]	≤ 1.0 x 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 in 2019.

- 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%

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.

Day 1 Experiments with Gamma Beams

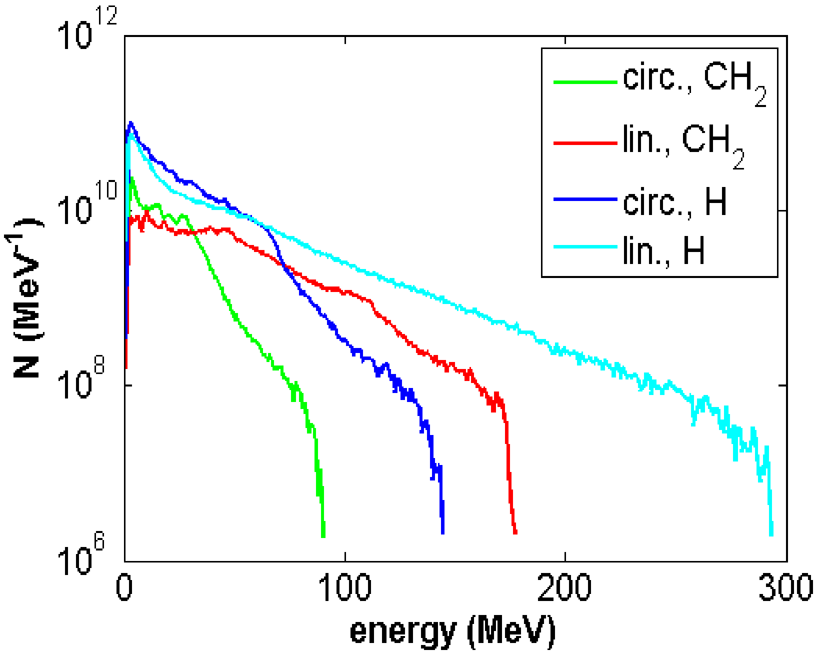
- Nuclear Resonance Fluorescence
- Giant/Pigmy Resonace
- Photodisintegration
- Photofission
- Etc.

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**

Proton >200 MeV is possible.

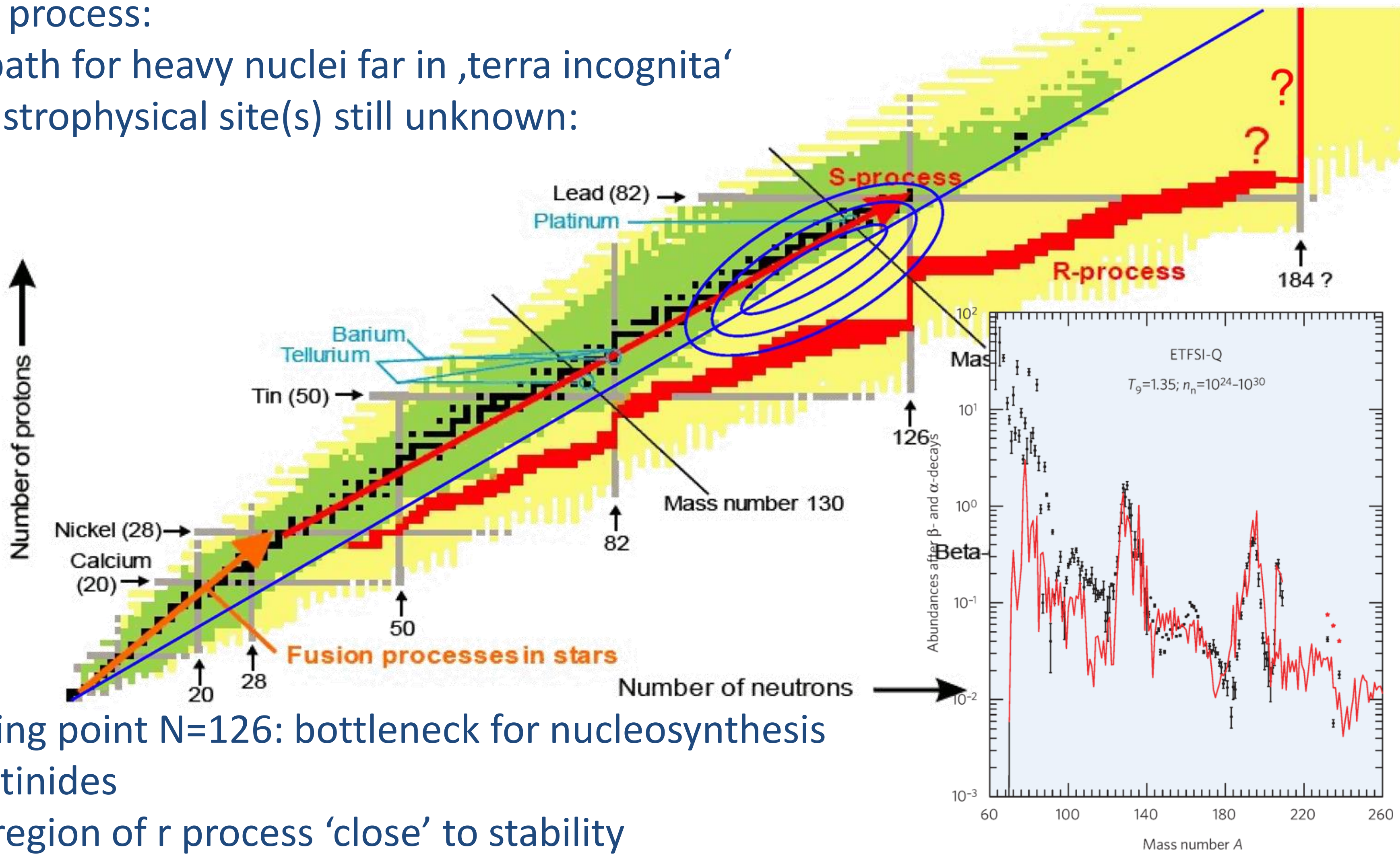
Predicted proton energy for LP and CP I=10^{22} W/cm2, 0.2 µm CH_2 target
(Psikal et al J Phys Conf 2016)



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

Nuclear Physics

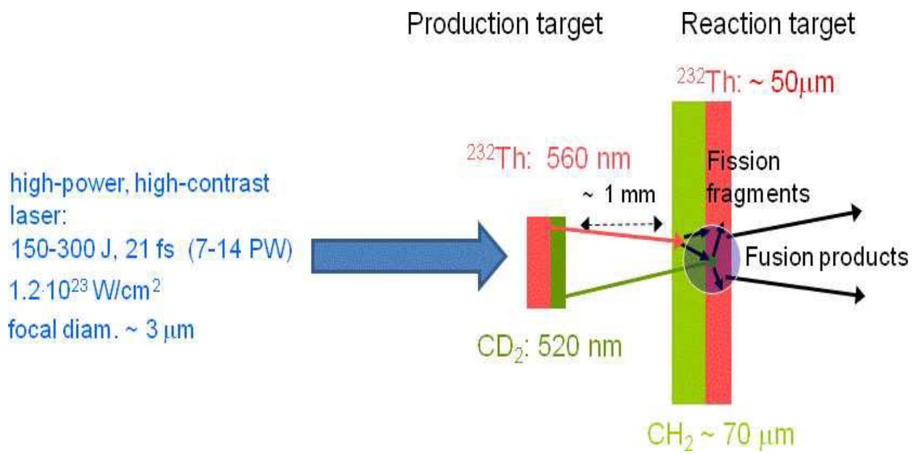
- r process:
  - path for heavy nuclei far in ‚terra incognita'
  - astrophysical site(s) still unknown:



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

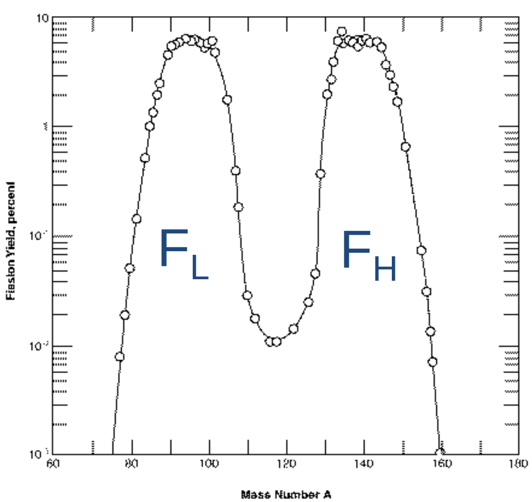
Nuclear Physics

Fission – Fusion Mechanism



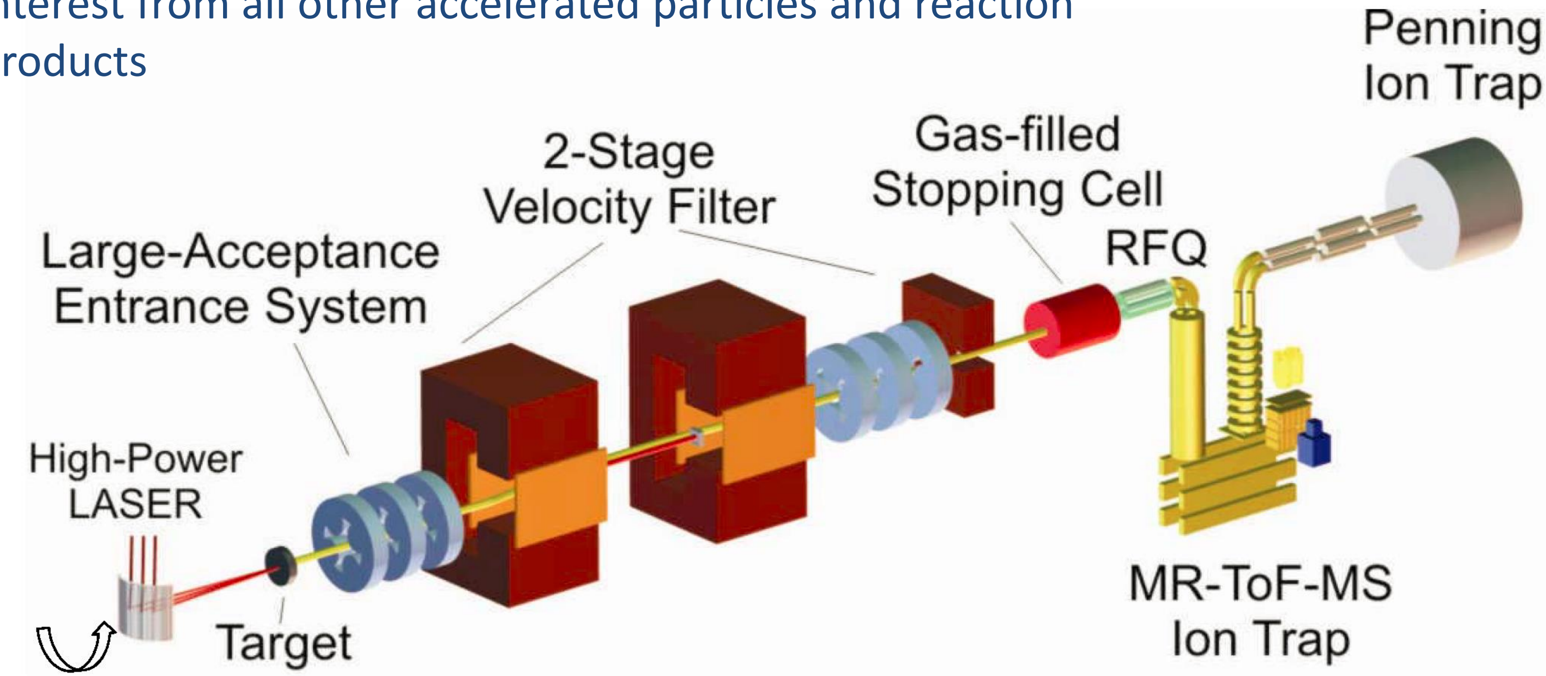
	Normal stopping	Reduced stopping
Production target:		
^{232}Th	560 nm	560 nm
CD_2	520 nm	520 nm
Accelerated Th ions	1.2×10^{11}	1.2×10^{11}
Accelerated deuterons	2.8×10^{11}	2.8×10^{11}
Accelerated C ions	1.4×10^{11}	1.4×10^{11}
Reaction target:		
CH_2	70 µm	–
^{232}Th	50 µm	5 mm
Beam-like light fragments	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
<u>the running coupling</u>
between
an electron & radiation

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

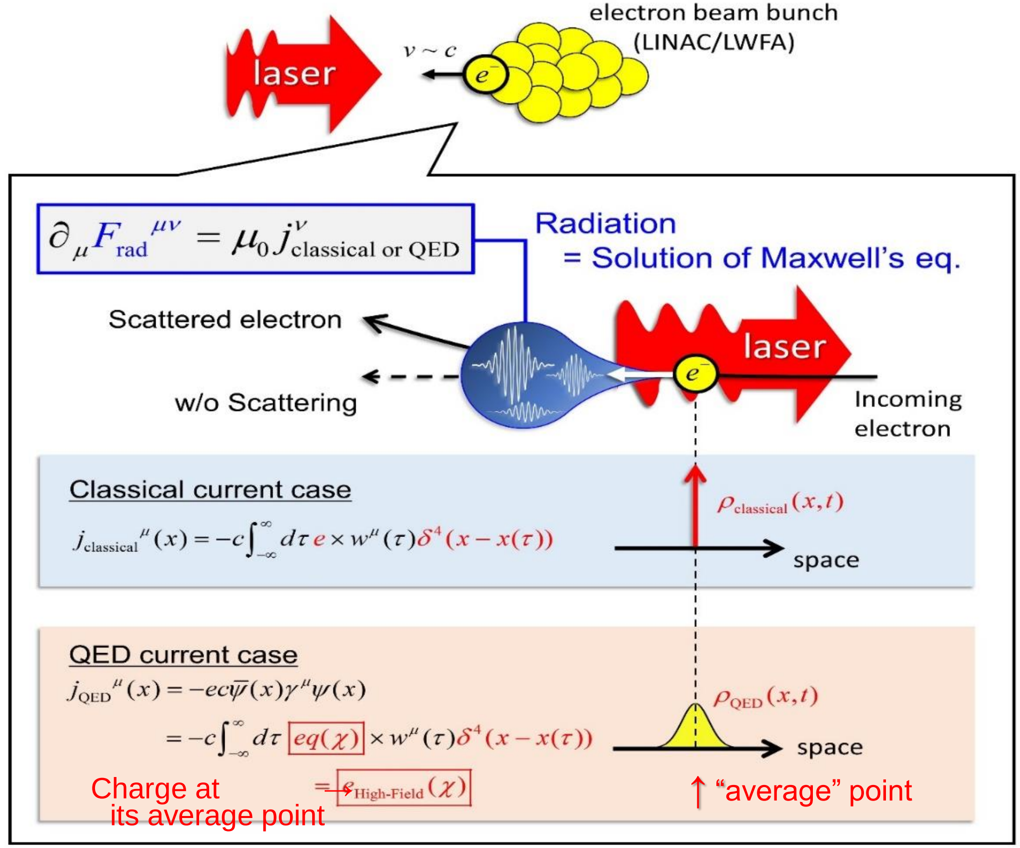
Solving dynamics ⇩

Radiation formula:

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

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

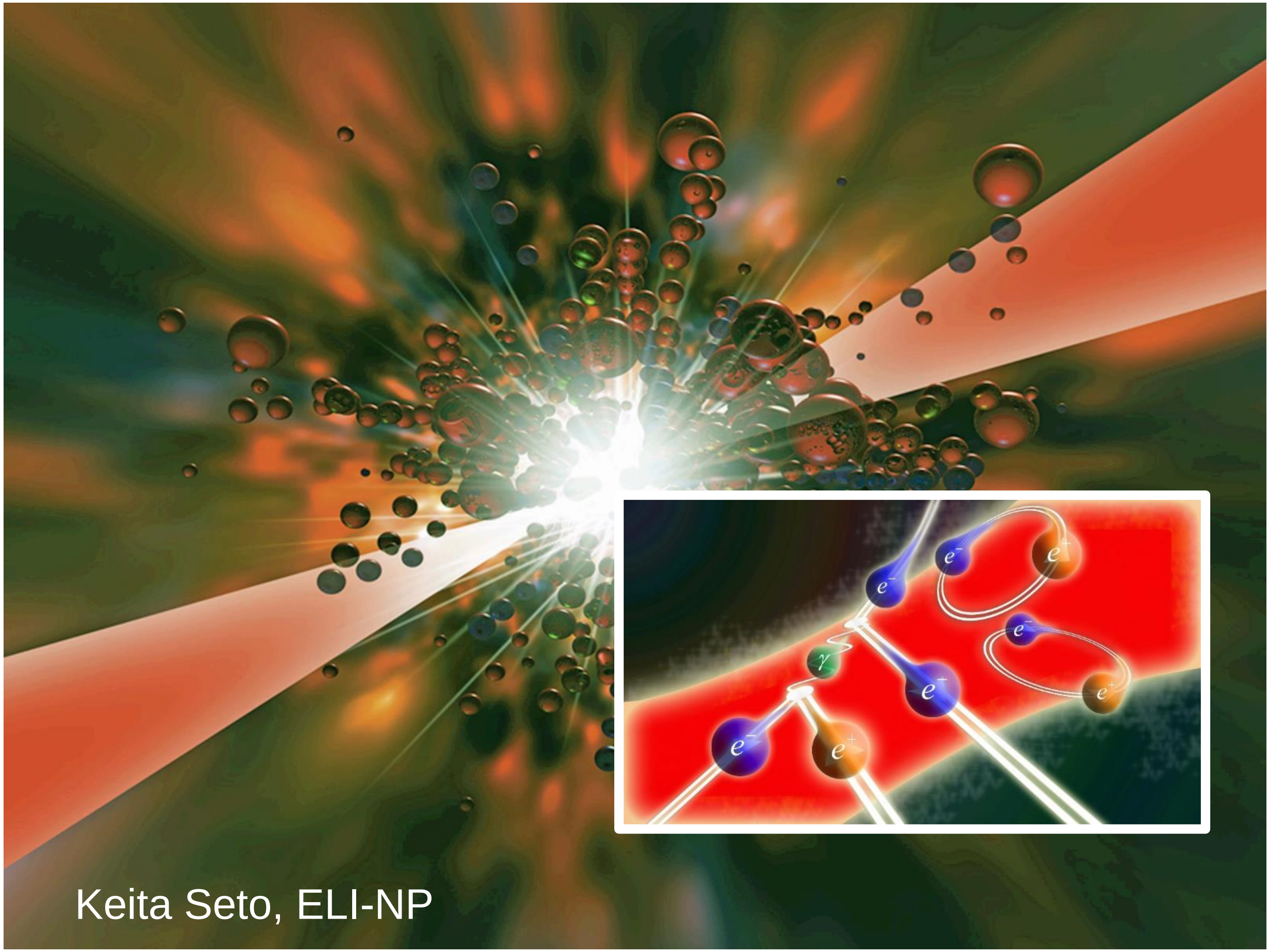
(Laser intensity dependence)



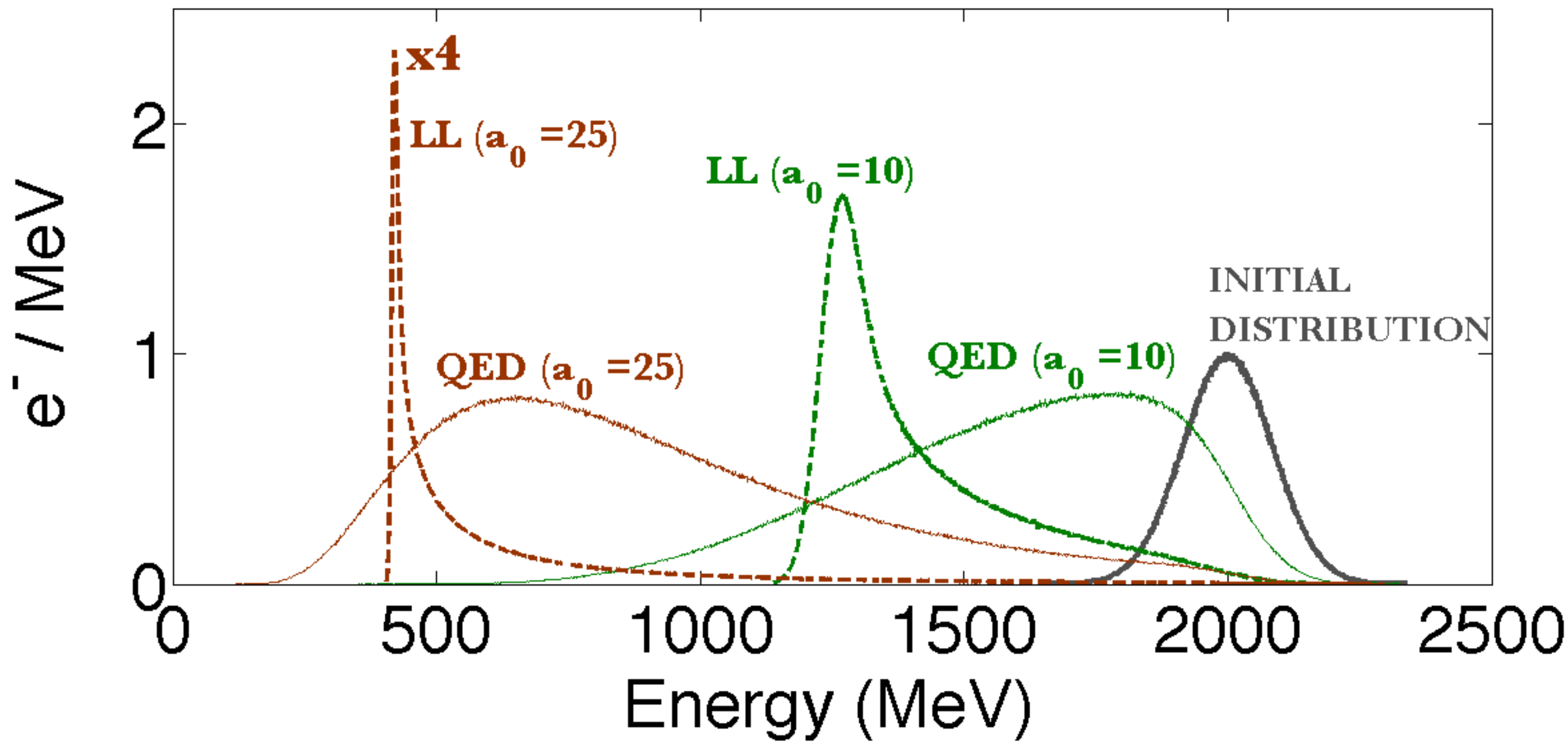
By Keita Seto (ELI-NP/IFIN-HH)

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

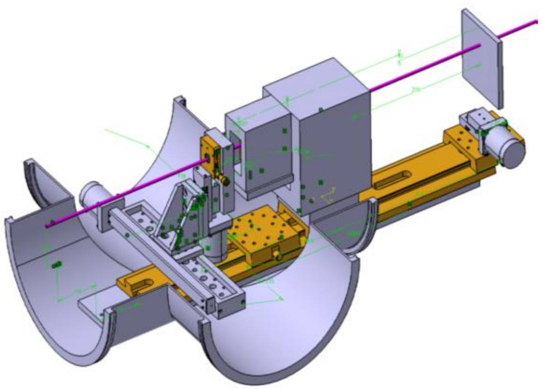


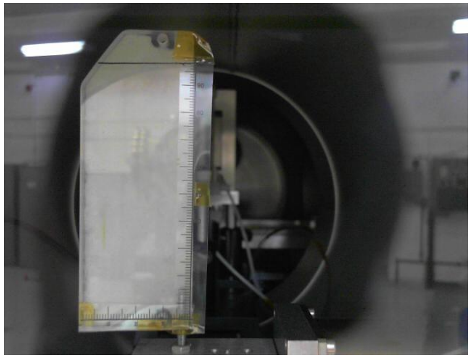
We may expect to see the drastic down shift in Gamma spectrum.

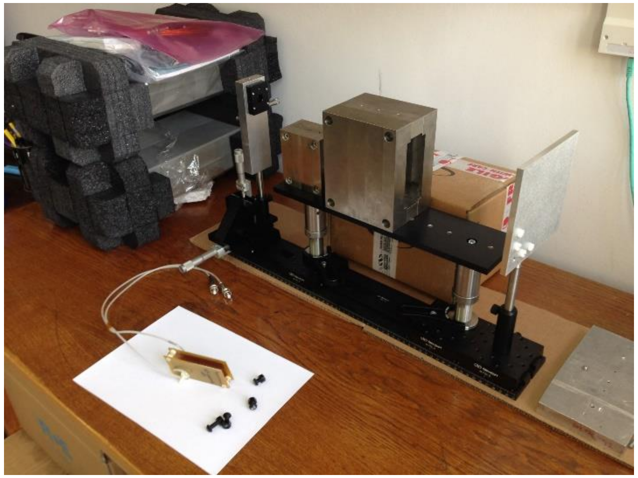


G Sarri, Queens' Univ. Belfast, UK.

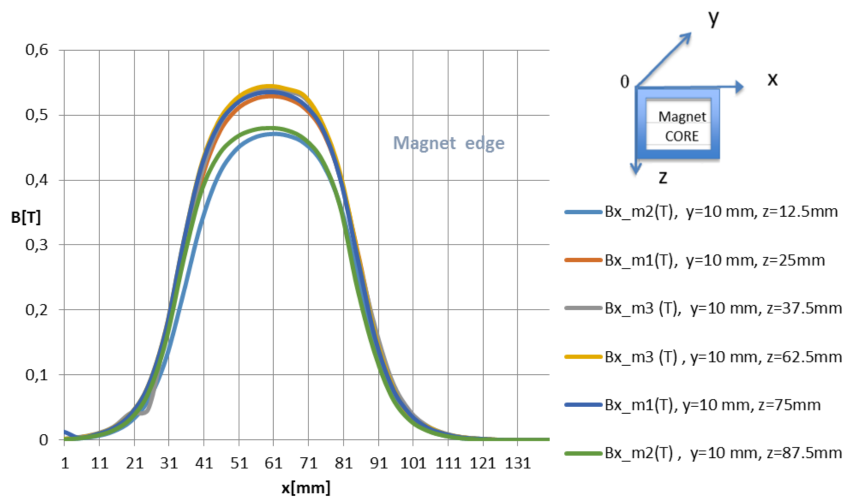
Marriage of Plasma and Nuclear Physics



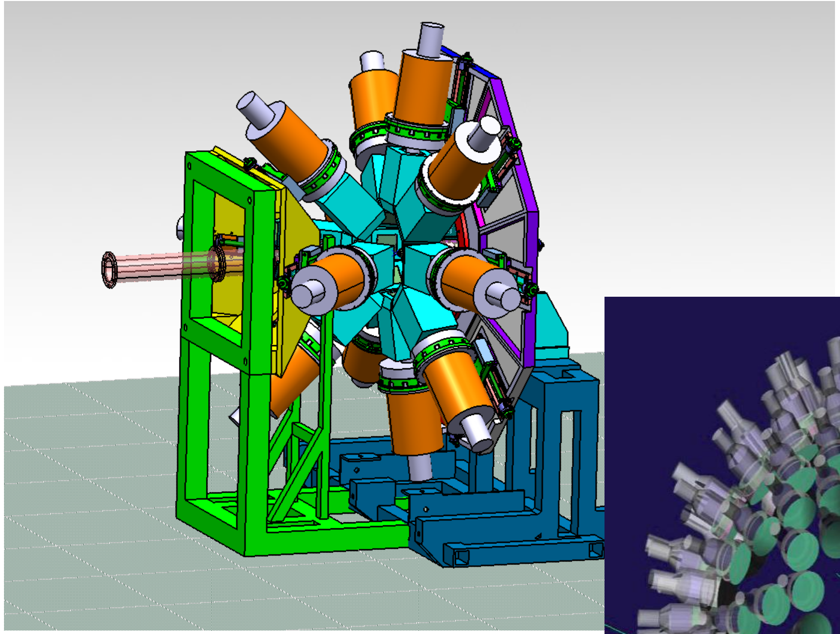


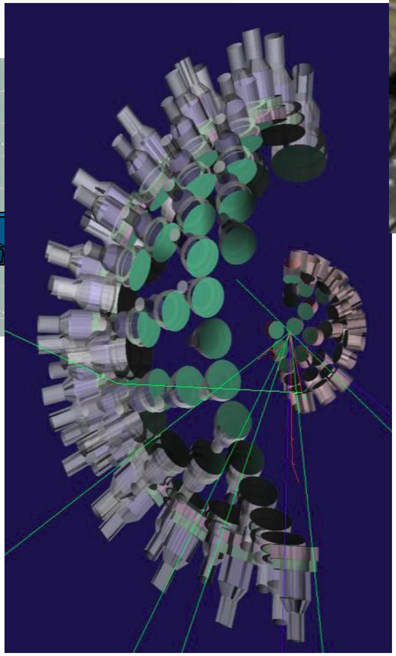


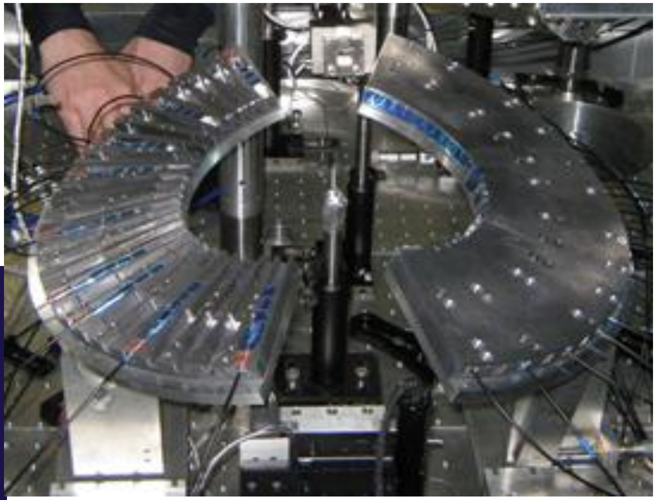
In beam test and calibration at 9 MV Tandem of IFIN-HH



Diagnostics being developed







CsI array for angle resolved calorimetry

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

Gamma above neutron threshold

Application towards Medical Field

- **Foreseen experiments at high power lasers** (even before the finishing of the ELI-NP construction), **having as aim the optimization of the beam parameters for isotope production.** **Many synergies with the foreseen ELI-NP experiments.**

- Collaboration with IFIN-HH/Cyclotron group, specialized in medical isotope production.

A.S. Cucoanes, P. Cuong, K.A.T. D.Balabanski, F. Negoita, F. Canova, F. Puicea

Present Issues in Medical Radioisotopes Production

Nuclear Physics

- **Radioisotopes play a crucial role in nuclear medicine**, being used for the diagnosis and the treatment of ones of the most spread diseases: **the cancer and the cardiovascular disease.**

- **Medical radioisotopes have a limited lifetime** ➔ **the production centers and the clinics should be placed relatively close one to each other.**

- **The main medical radioisotopes are produced in nuclear reactors** (ex.^{99m}Tc). ➔ **the production could be affected by long maintenance periods, safety issues, etc.** (see the Tc crisis from 2009).

- **Another important part of medical radioisotopes are produced in cyclotrons** (ex. ^{11}C, ^{13}N, ^{15}O, ^{18}F). Cyclotrons have big dimensions (and price) -> **they could deserve a relatively small amount of hospitals concentrated in big cities.**

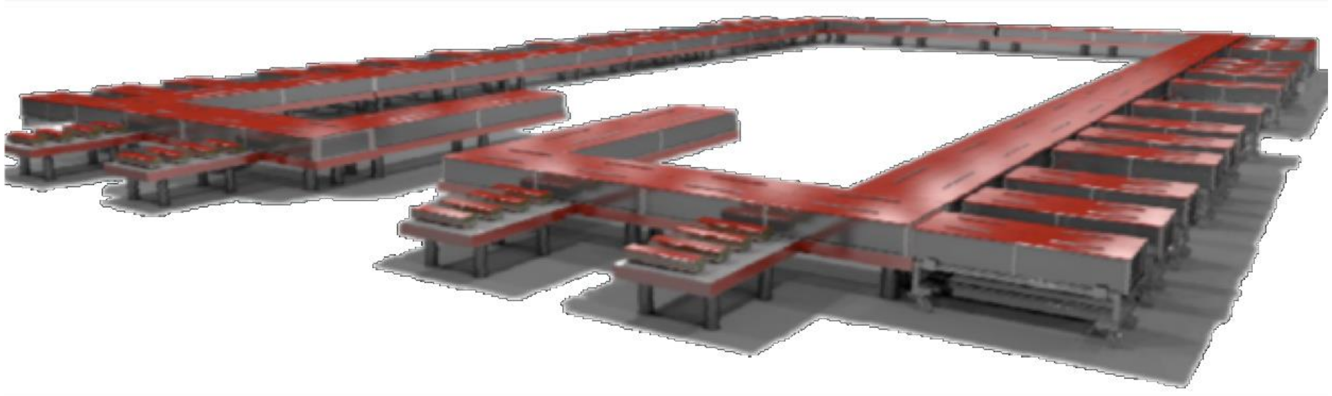
Compact high intensity laser could represent an alternative in the near future.

A.S. Cucoanes, P. Cuong, K.A.T. D.Balabanski, F. Negoita, F. Canova, F. Puicea

Are Lasers an alternative for medical radioisotopes production ?

- **Lasers** (like accelerators, unlike reactors) **are a green technology.**
- **Lasers could produce accelerated particle beams with a big density → potential for costs reducing.**
- **Acceleration field more intense than at accelerators → potential for small dimension.**

The actual challenges are related to the "quality" of the accelerated proton beam, the laser repetition rate and the minimization of the dimensions.



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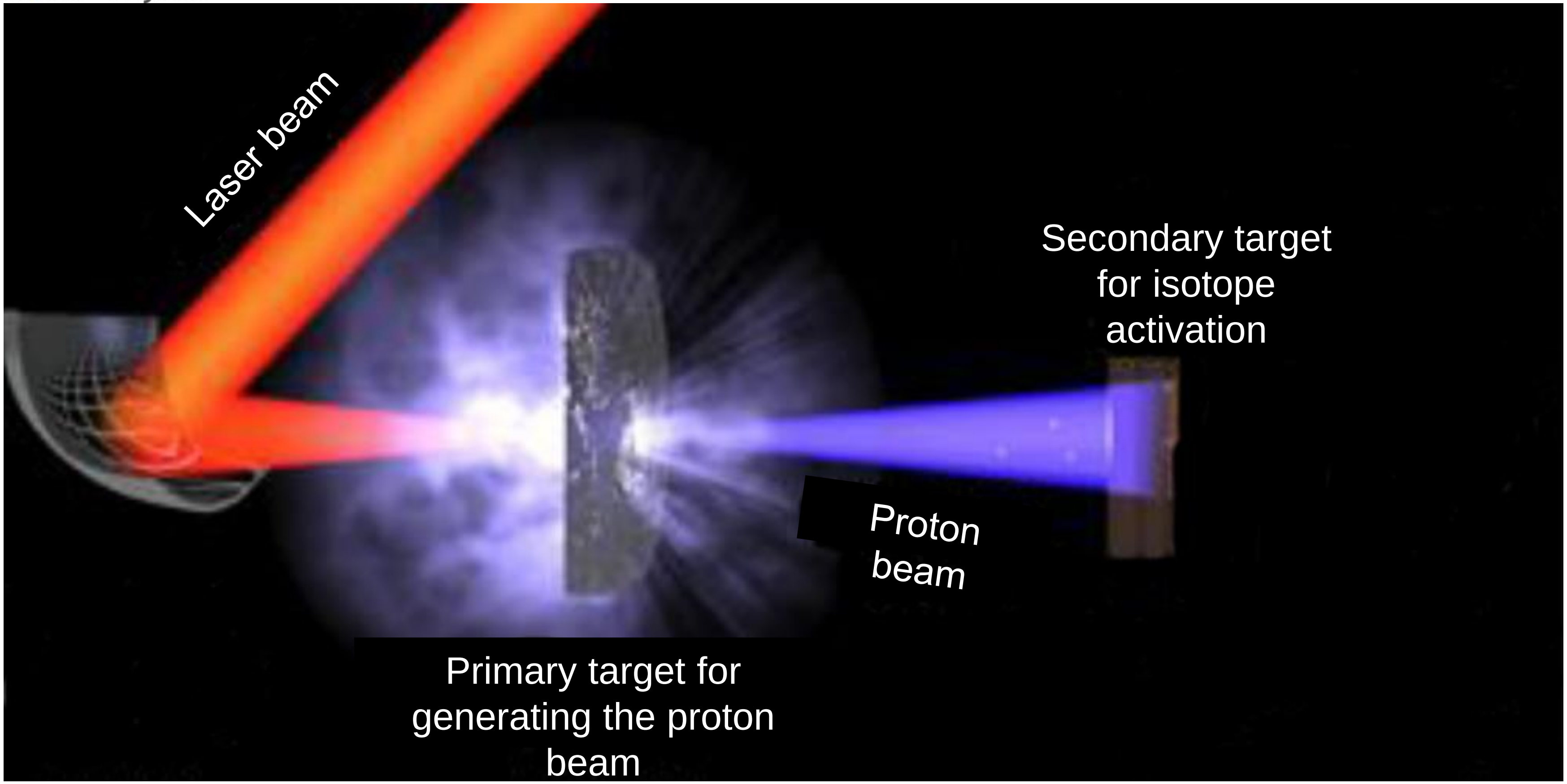
Isotope Activation using Laser



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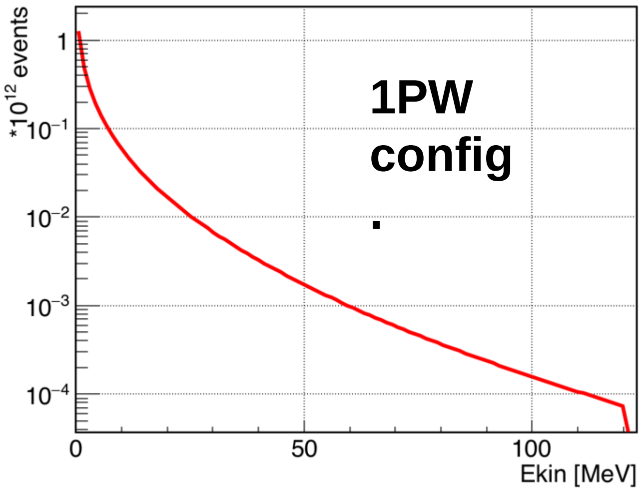
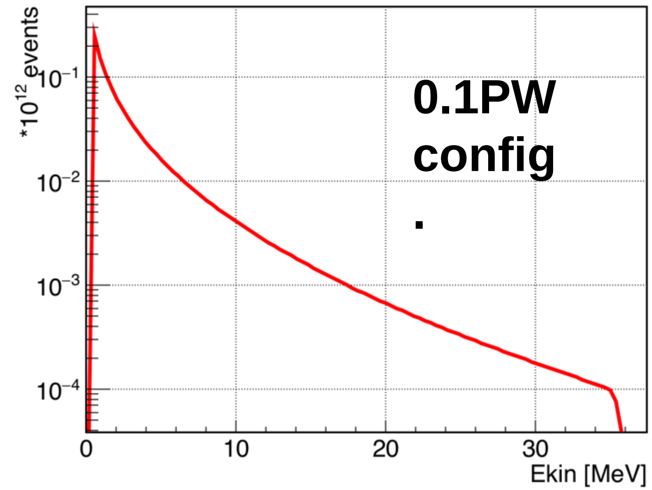
Foreseen proton spectrum at ELI-NP





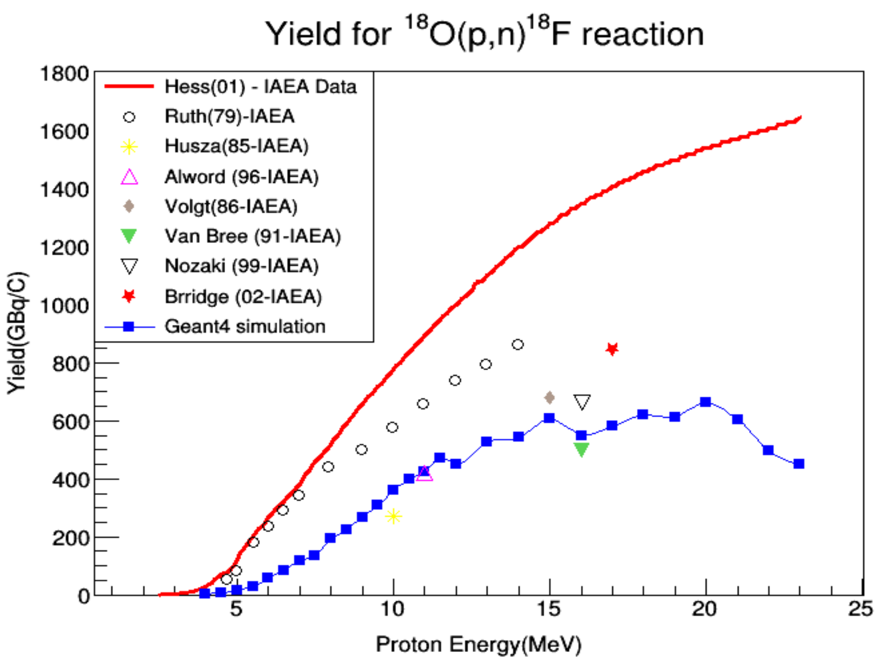
$P_L[PW]$	$I_{18}[W/cm^2]$	$T_e[MeV]$	$E_{max}[MeV]$	$\int_1^{E_{max}} \phi * 10^{12}$
1	2546	4.1	121	2.4
0.1	398	1.6	35	0.25

- **2 analyzed configurations: 1PW@1Hz and 100TW@10Hz.**
- **Analytical estimation of the proton flux generated in TNSA process based on P.Mora, PRL 90 185002 (2003), analytical estimation of the beam divergence based on Z.Lecz, PhD Thesis TUD (2013).**
- **PIC simulations are ongoing for increasing the precision of estimations.**

A.S. Cucoanes, P. Cuong, K.A.T. D.Balabanski, F. Negoita, F. Canova, F. Puicea

Simulation of the secondary target physics

- The proton propagation in the secondary target simulated with Geant4 software (CERN).
- Since this software does not handle very well inelastic interactions at <200MeV, a new package has been developed inside Geant 4 in order to model (p,n) reaction at low energy. This package uses evaluated data bases for handling inelastic interactions.



The reaction yields computed with Geant4 agree with experimental data but not so well with old predictions which look overestimated.

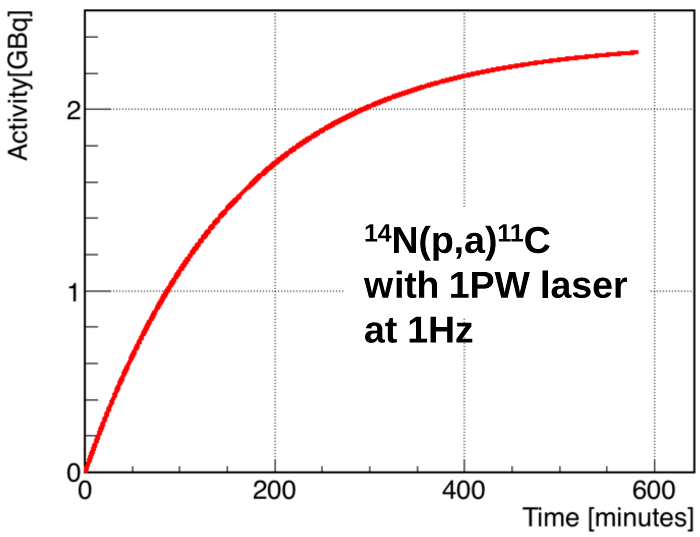
Simulation of the yield vs. target radius and source-target distance is ongoing.

Optimization of the beam-target interaction follows.

A.S. Cucoanes, P. Cuong, K.A.T. D.Balabanski, F. Negoita, F. Canova, F. Puicea

Isotope Activation

Activation curves are obtained by convoluting the proton spectrum generated by the laser interaction with reaction yields for isotope production and the isotope decay during irradiation. "Per-shot" activity delivered too.



Activities "per-shot"

Reaction	Activ.@1PW[kBq]	A@0.1PW[kBq]
$^{18}O(p,n)^{18}F$	164.2	10.5
$^{14}N(d,n)^{15}O$	3949.7	298.8
$^{15}N(p,n)^{15}O$	3775.4	218.9
$^{14}N(p,a)^{11}C$	547.4	27.8
$^{16}O(p,a)^{13}N$	151.8	8.0
$^{nat}Ne(d,x)^{18}F$	3818.1	255.2

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Nuclear Physics

Buildings are ready now.

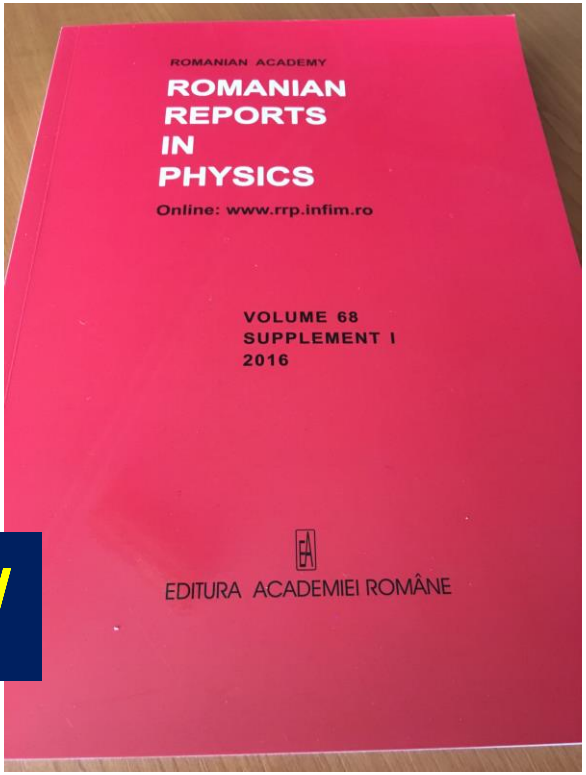
- HPLS 2000 **m²**
- GBS
- Workshops and Laboratories
- Experiments 7000 **m²**
- Office Building
- Guest House
- Cantine

Buildings, 33000 m² tot

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/



Summary

- 10 TW, 200 J Ultra-high Intensity Laser &
- 19.5 MeV Gamma Beam systems will start their operations in early 2019.
- Collaboration is welcome to consider attaractive experimental designs.
- Many job opportunity.
- PhD students are accepted.

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Thanks for your attention