EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2014-2020

Operational Programme Competitiveness

Extreme Light Infrastructure – Nuclear Physics (ELI-NP) – Phase II

Project co-financed by the European Regional Development Fund

Ultra-intense laser and gamma beam systems at ELI-NP

Kazuo A. Tanaka and N. Victor Zamfir

for the ELI-NP researchers and collaborators

eli Nuclear Physics

Prof T Tajima's 70th Birthday Symposium

UC Irvine,

Jan. 26, 2018

Extreme Light Infrastructure: Nuclear Physics at Bucharest Romania

Outline of My Talk

- Introduction
- Team Structure
- High Power Laser System
  Gamma Beam System
- Proposed Experiments
- Nuclear Photonics 2018
- Summary

Extreme Light Infrastructure: ELI ？

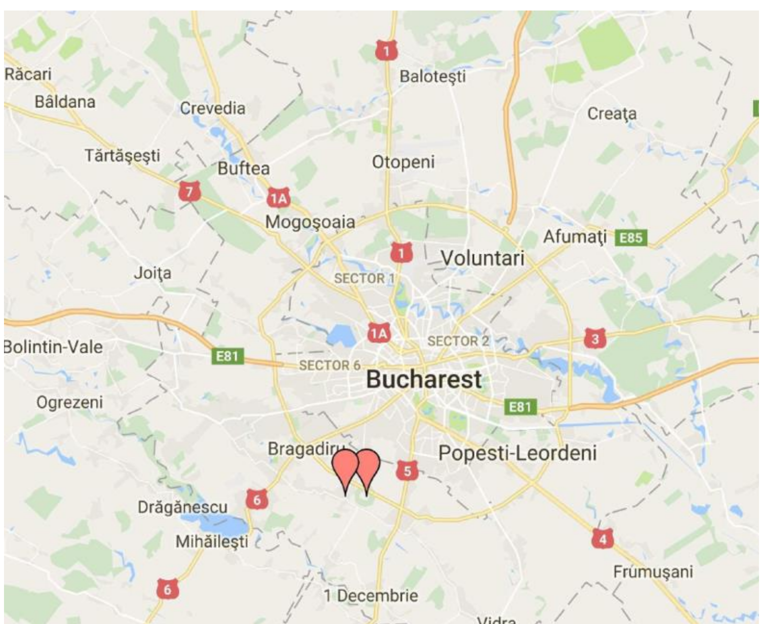
- Three laser labos are being constructed with 300 MEuro each.
- Those are planned in Romania, Czeco, and Hungary.
- Each has its own characteritics.

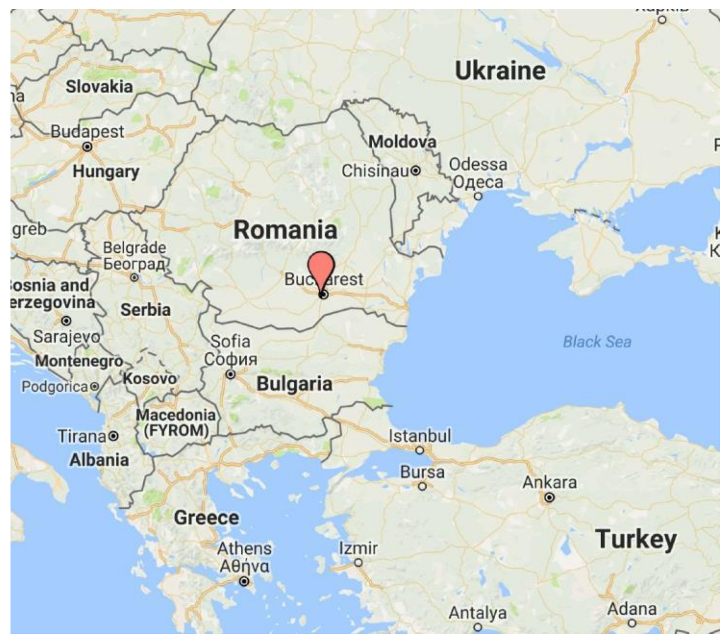
Hungary/ELI-ALPS

Romania/ELI-NP

Czech/ELI-Beamlines

We are located in Bucharest.





Introduction

Laser System with Highest Focused Intensity

The wavelength, pulse width, energy, and beam diameter are 820 nm, 25 fsec, 250 J, and 50 cm.
Focused laser intensity may reach 10^{23} W/cm^2.
The laser light will accelerate electrons up to the speed of light.

Gamma Beam System with Highest Photon Number

The Gamma Beam photon energy is 19.5 MeV with 2 psec pulse width.
The number of photons may reach 10^9 photons/sec.
The gamma light will interact directly with nuclei for excitation and fission.

Laser system can be operated as stand alone or combined with Gamma beam system.

- Experiments under extreme conditions, so far not possible, can be conducted.

For example, we will perform

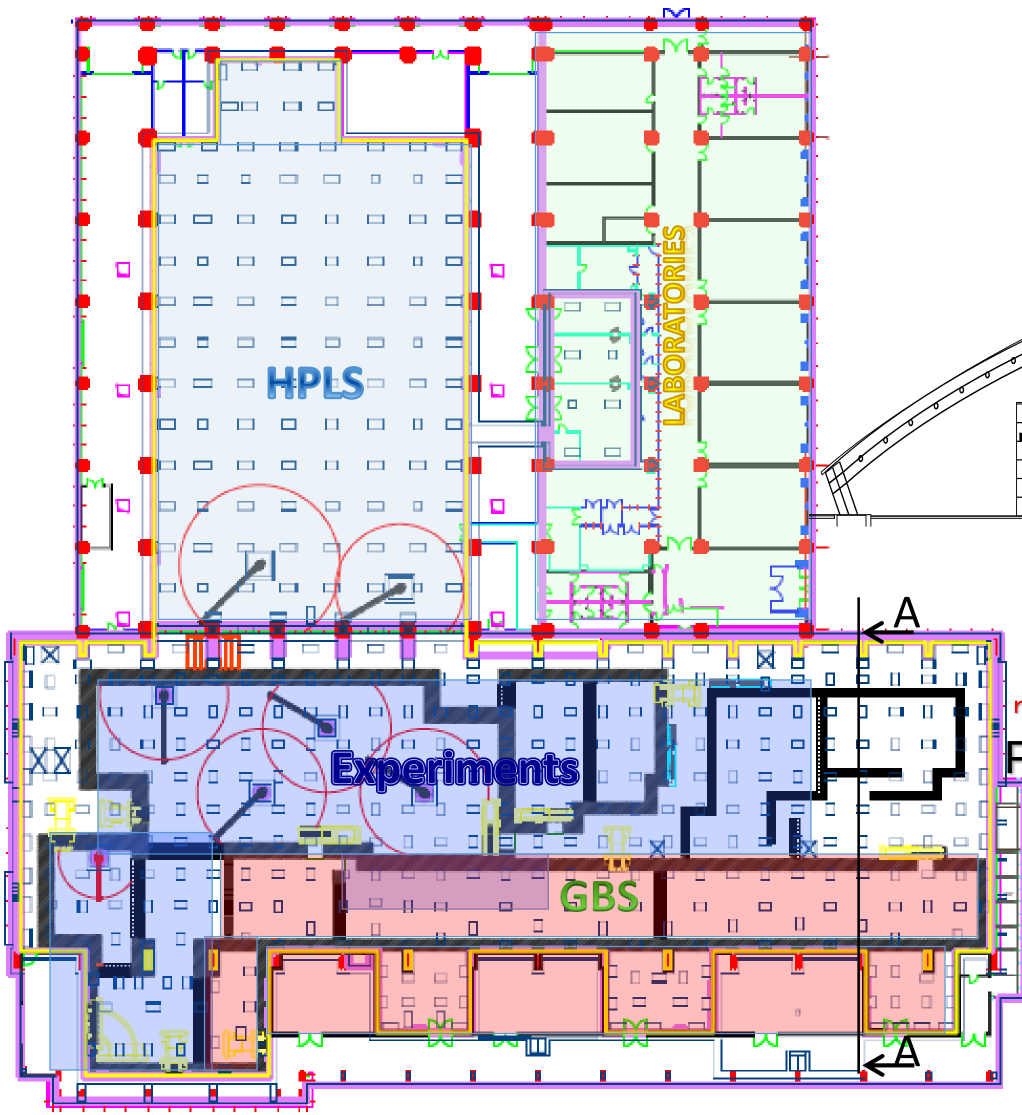
- Electron acceleration more than 10 GeV
- Nuclear fission and fusion
- Head-on collision of the laser and relativistic electron beam

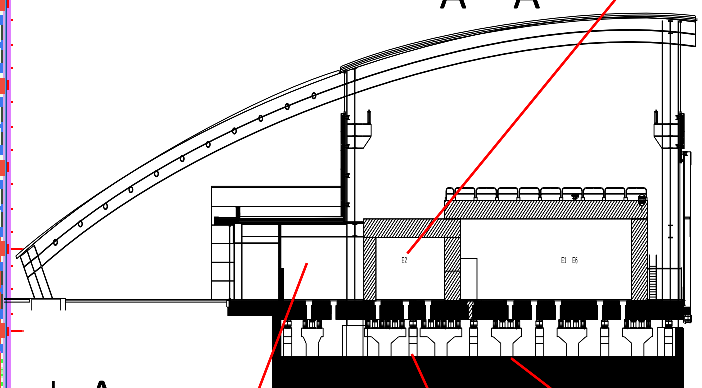
Then these experiments will clarify

- History of the Universe
- Important Issues on nonlinear QED
- Isotope production for medical use

These achievements may lead to the Nobel prize and/or realistic outcomes for our society.

ELI–NP Building





Platform supported on dampers

Anti-vibration platform

±1 μm @ < 10 Hz

Team Structure

General Director of IFIN/HH & Project Director

Prof Dr Nicolai Victor Zamfir (US-Romania)

Scientific Director

Prof Dr Kazuo A Tanaka (US-Japan)

Technical Director

Dr Dan Gabriel Ghita (Rom)

RA1 Laser Group	Dr Daniel Ursescu (Germany Rom)
RA2 Gamma Beam Grp.	Dr Calin Ur (Italy Rom)
RA3 Laser plasma nuclear physics Grp.	Dr Dan Stutman (US Rom)
RA4 Gamma Beam nuclear Physics Grp.	Dr Dimiter Balabanski (Bulgaria)
RA5 Combined Laser and Gamma Beam Grp.	Dr Ovidiu Tesileanu (Italy Rom)

Currently 130 members (20 Senior Sci., 60 Junior Sci. Rest Eng.)

Will boost up to 250 members.

High intensity laser system has started from these two.

When they were at Laboratory for Laser Energetics, Univ. of Rochester in early 80's.

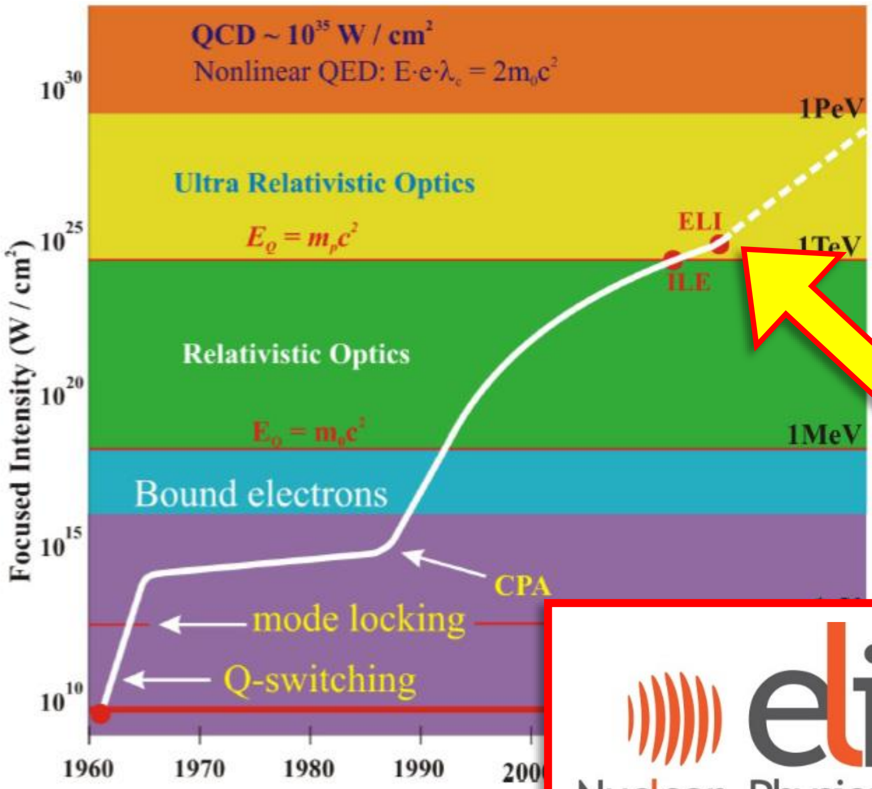
Gerard Mourou

IZEST France

Dana Strickland

University of Waterloo in Ontario, Canada

Intensity could reach 10^{22}-10^{23} W/cm^2



Nuclear Physics

10^{23} W/cm^2

Laser system sits in a 70 x 70 m² clean room.

Nuclear Physics

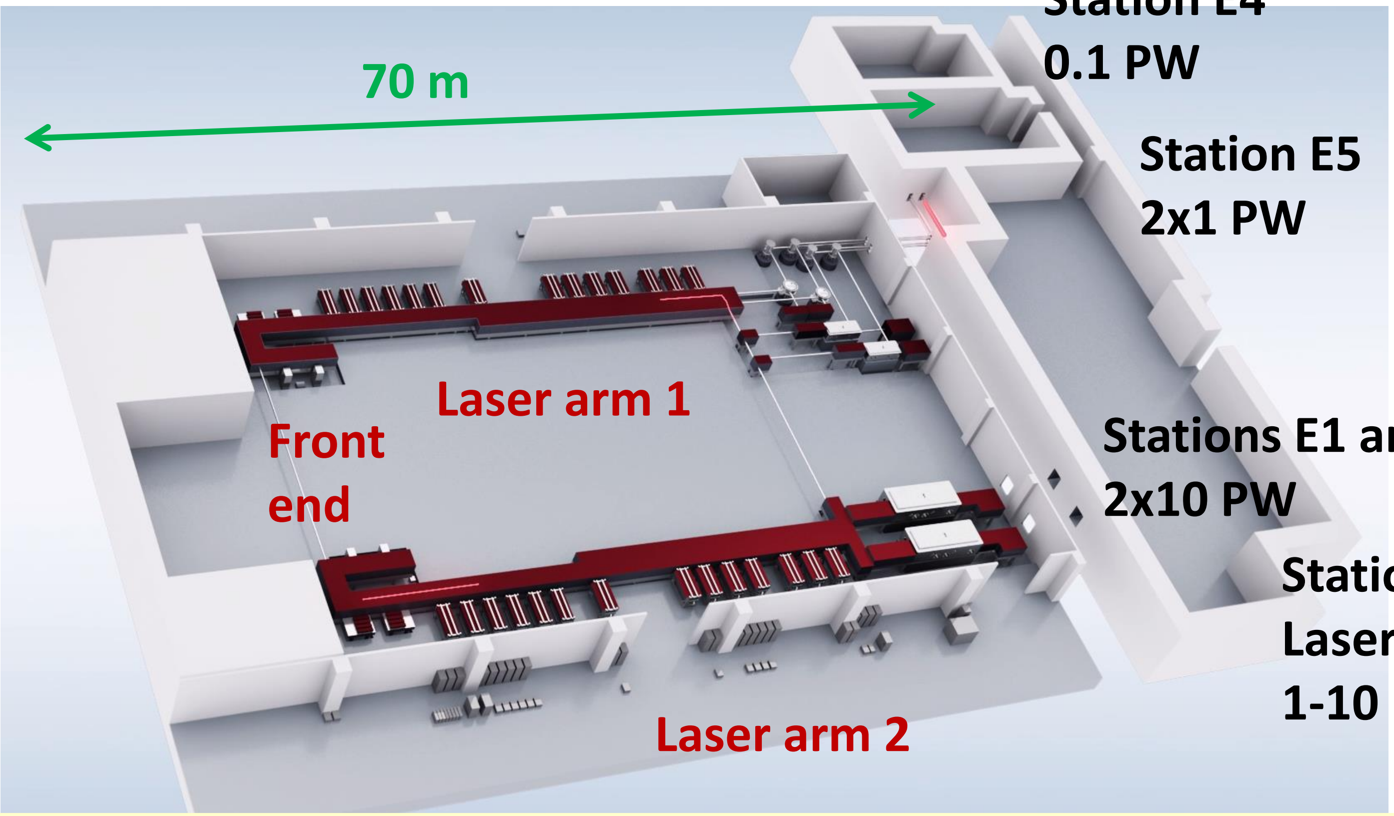
IFIN-HH

Installation in progress.

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

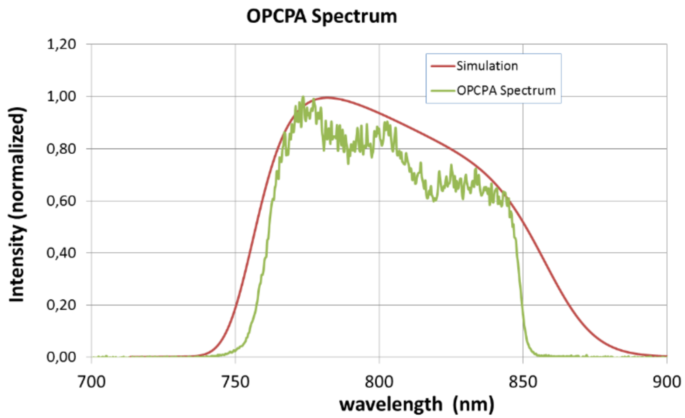
10 PW Laser System Layout

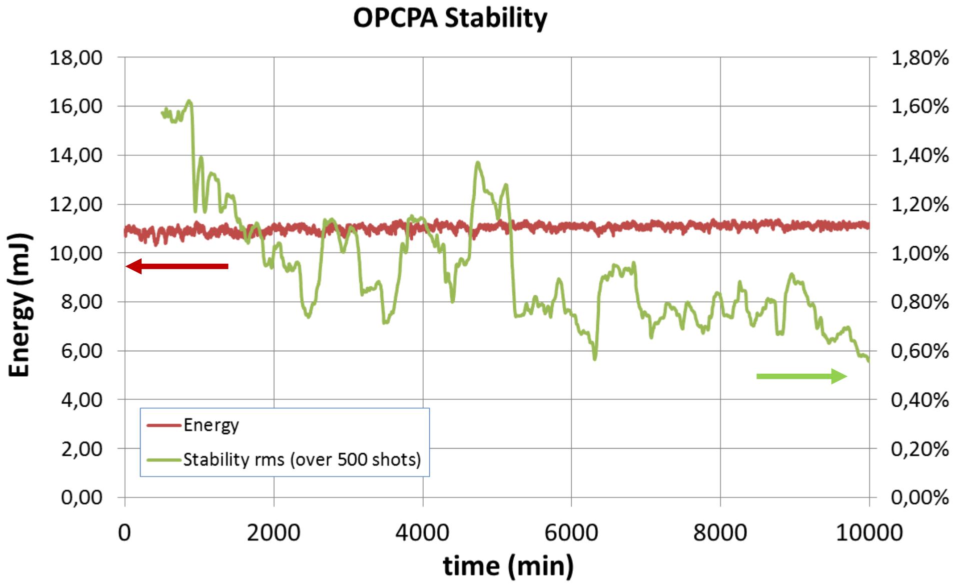


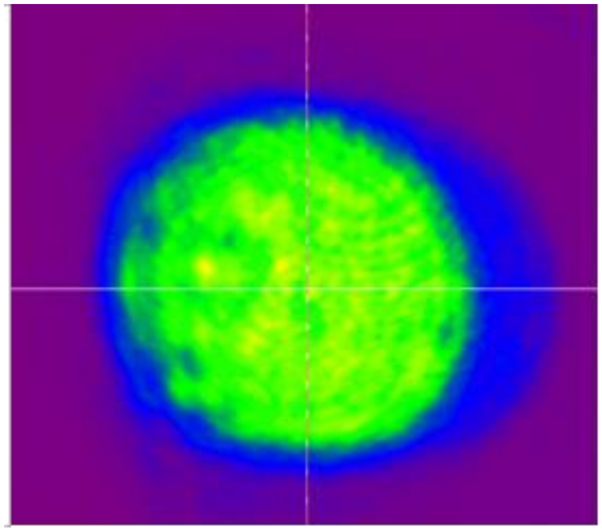
- **High performance parameters :** 250 J in 25fs, 0.9 Strehl ratio, $<10^{-13}$ contrast
- **Outputs:** 2x 10 PW/min
  2x 1 PW/1 Hz
  2 x 0.1 PW/10 Hz

Thales at Elancourt France has reported the performance.

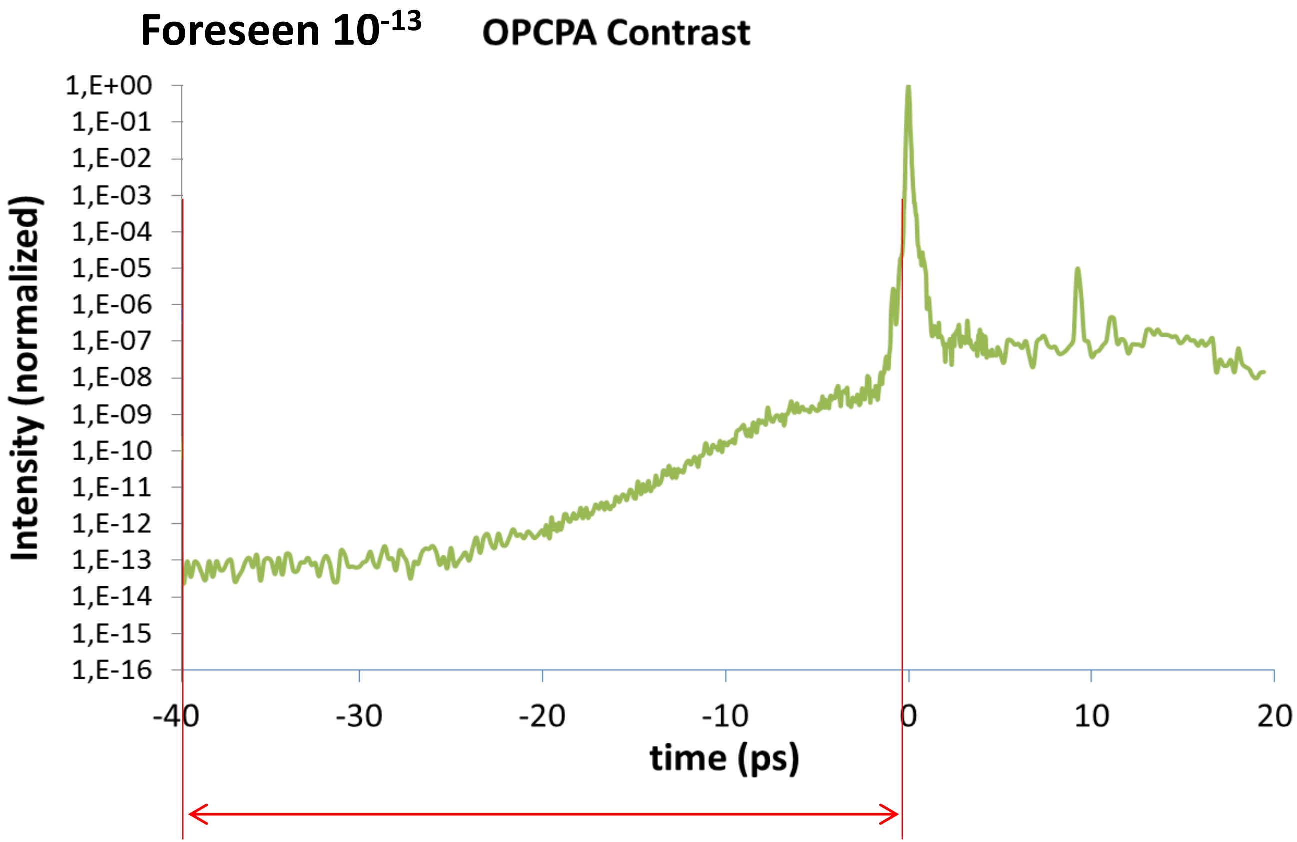
- Simulation and Results
  - Simulation result:
    - 16mJ
    - 77nm FWHM
  - Experimental result:
    - 11,6mJ (< 1,6% rms over 500 shots)
    - 67nm FWHM







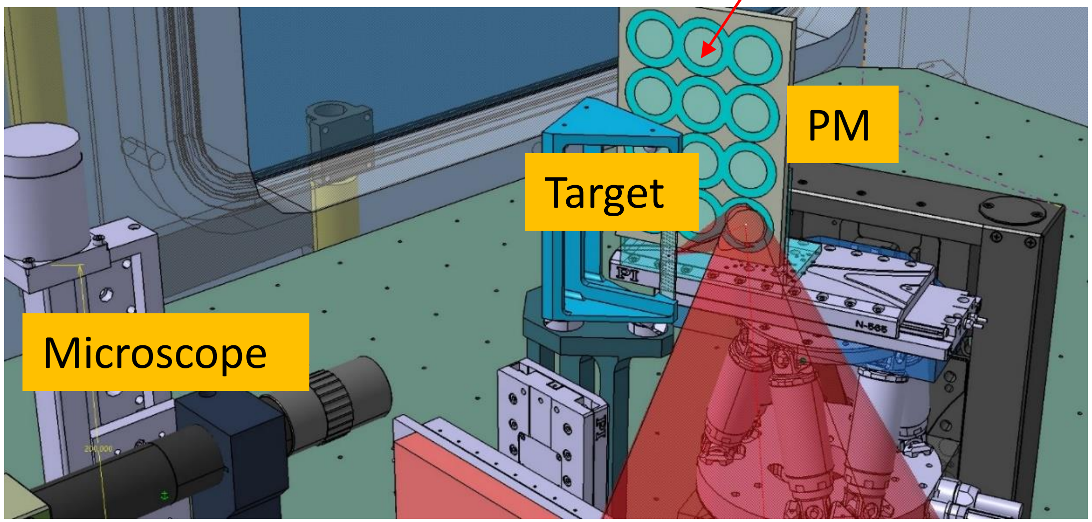
We expect to have 10^{13} contrast ratio.



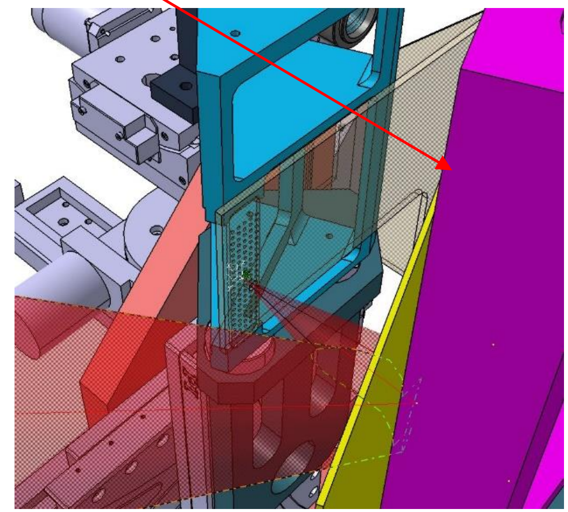
$E_{-40ps:-0.4ps} = 30mJ$

Back reflection?
Plasma mirror is tested for optics protection.

- Silver coated glass slab

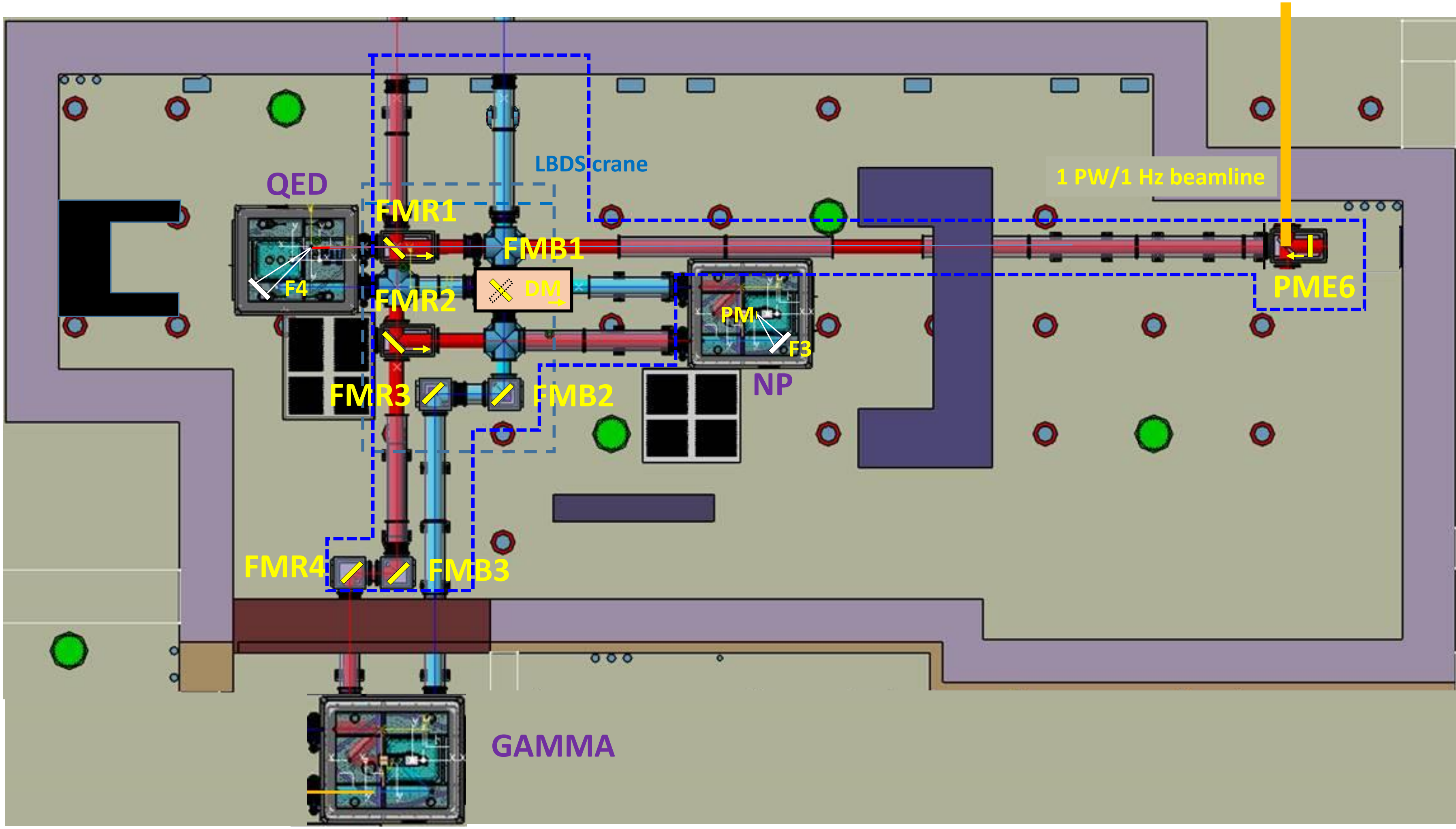


PM @ 50mm away from target



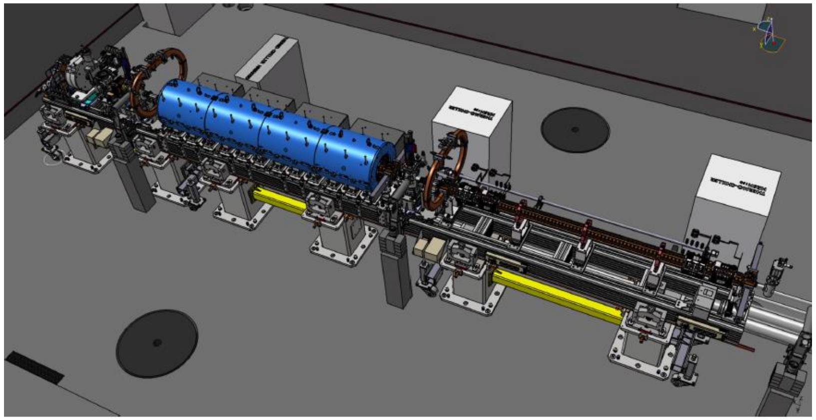
Typically the peak intensity is set at 10^{15} – 10^{16} W/cm^{2} on the plasma mirror.

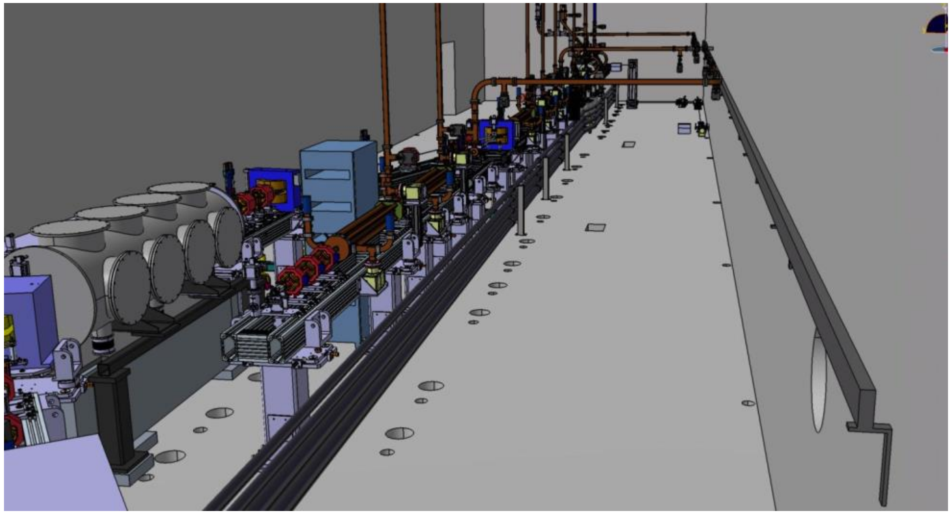
New 10 PW LBTS design



Gamma Beam System

RF Photoinjector





Components of Gamma Beam System

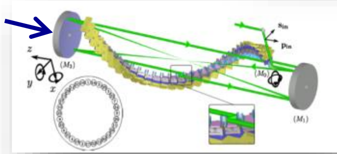
1) Warm electron RF Linac (innovative techniques)

- 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

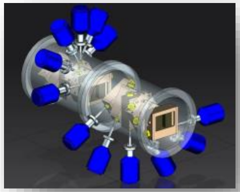
- state–of–the–art cryo–cooled Yb:YAG (200 mJ, 2.3 eV, 3.5 ps)
- two lasers (one for low–$E\gamma$ and both for high–$E\gamma$)

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



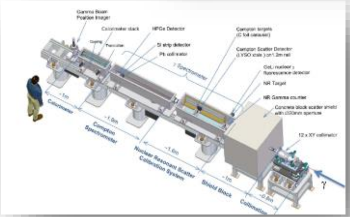
- complex opto/mechanical system
- two interaction points: $E\gamma < 3.5$ MeV & $E\gamma < 19.5$ MeV

4) Gamma beam collimation system



- complex array of dual slits
- relative bandwidths $< 5 \times 10^{-3}$

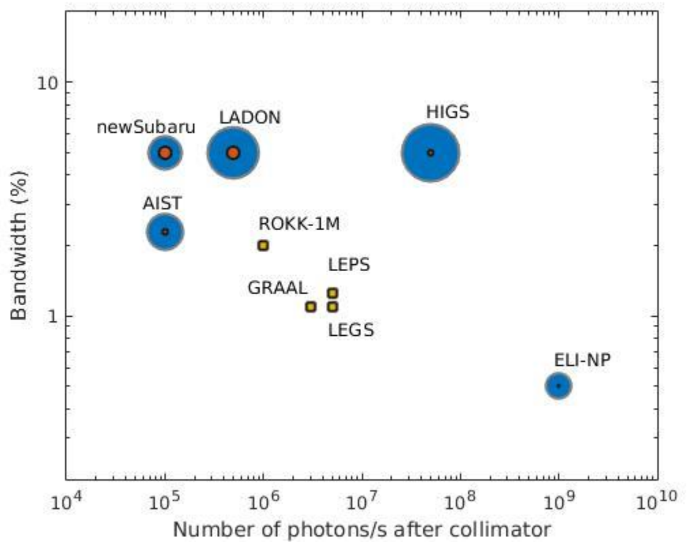
5) Gamma beam diagnostic system

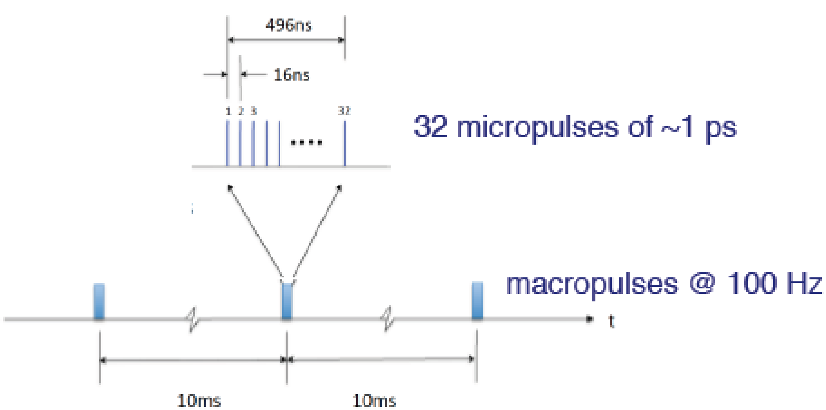


- beam optimization and characterization: energy, intensity, profile

GBS Specification

Parameter [units]	Value
Photon energy [MeV]	0.2 – 19.5
Spectral density [ph/s/eV]	> 0.5 x 10^4
Bandwidth	< 0.5 %
# photons / shot FWHM bdw.	1.0 – 4.0·10^5
# photons/sec FWHM bdw.	2.0 – 8.0·10^8
Source rms size [µm]	10 – 30
Source rms divergence [µrad]	25 – 250
Peak brill. [N_{ph}/sec·mm^2mrad^2·0.1%]	10^{22}– 10^{24}
Radiation pulse length [ps]	0.7 – 1.5
Linear polarization	> 95 %
Macro repetition rate [Hz]	100
# of pulses per macropulse	>31
Pulse–to–pulse separation [ns]	16





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^{22} W/cm^2
- Electron acceleration > GeV
- Proton acceleration > 200 MeV

Gamma Beam System

- Gamma photon energy calibration-Nuclear excitation 3.5 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-excitation of isomers

Etc.

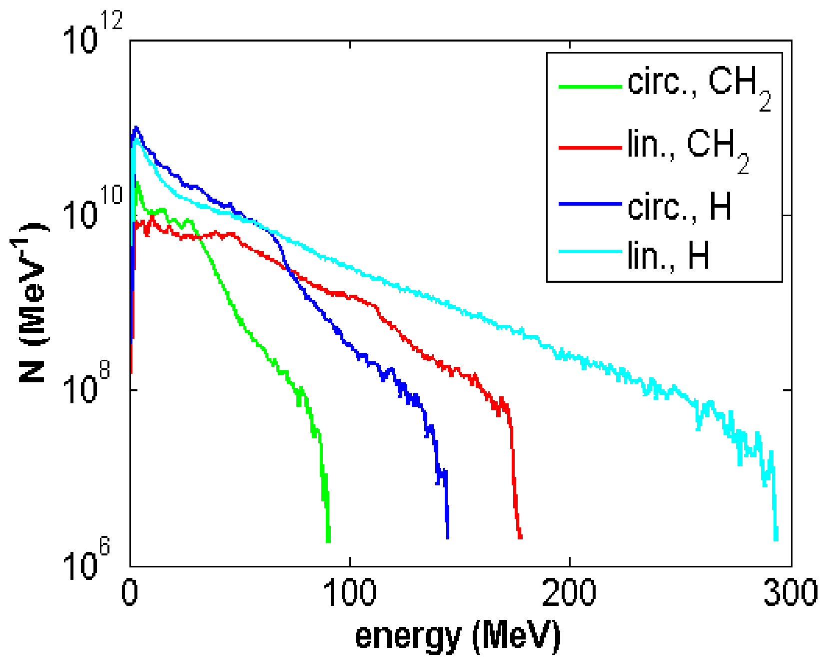
Romanian Report in Physics 68 Supplimment 2016

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**

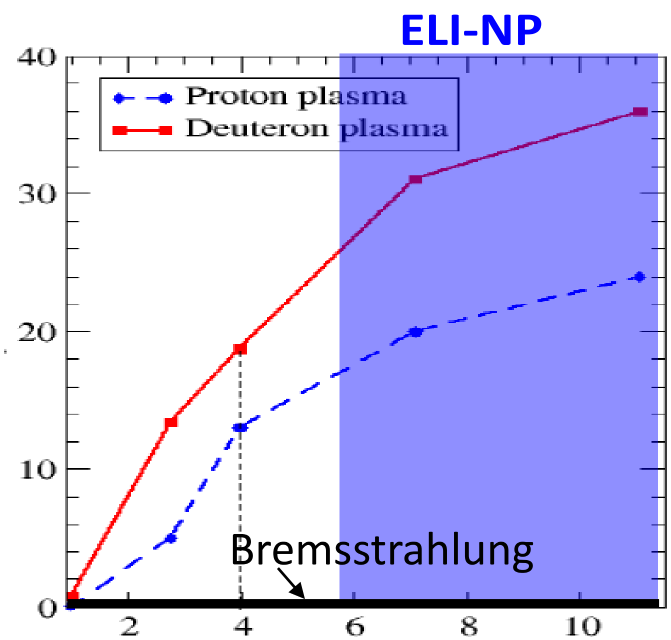
Proton >200 MeV is possible.

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)



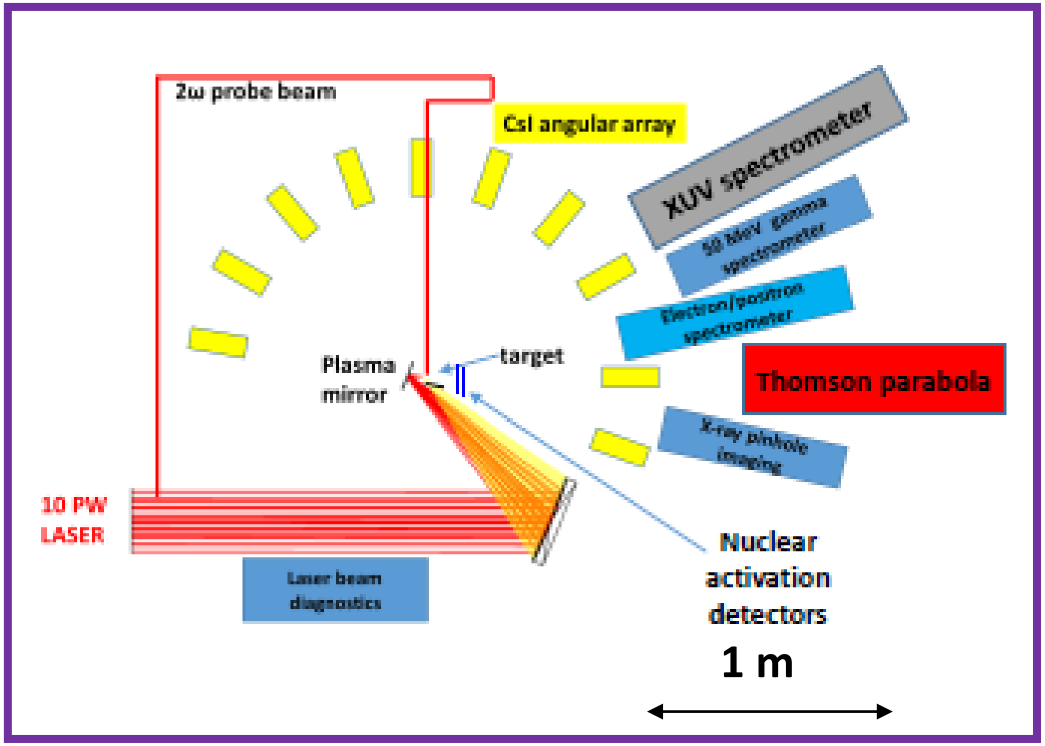
Commissioning experiment: Demonstration of extreme laser intensity through efficient laser-γ conversion

Laser-γ conversion efficiency (%)



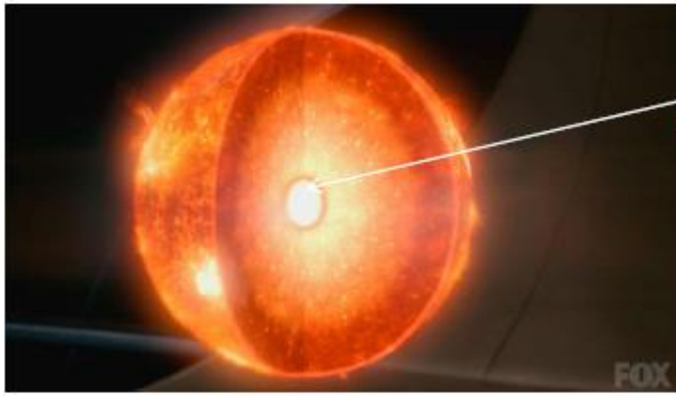
Focal intensity (10^{22} W/cm^2)

Capdessus et al RRP 2016



- ❑ Tens of % gamma conversion efficiency in µm-thick plastic or dense gas targets
- ❑ GeV dense ion bunch acceleration using same setup with thinner targets
- ❑ Plasma mirror + baffle for protection against <u>laser back-reflection</u>, debris
- ❑ We consider also membrane protection for the parabola

Path to Extreme pressures by irradiation of aligned nanowire arrays

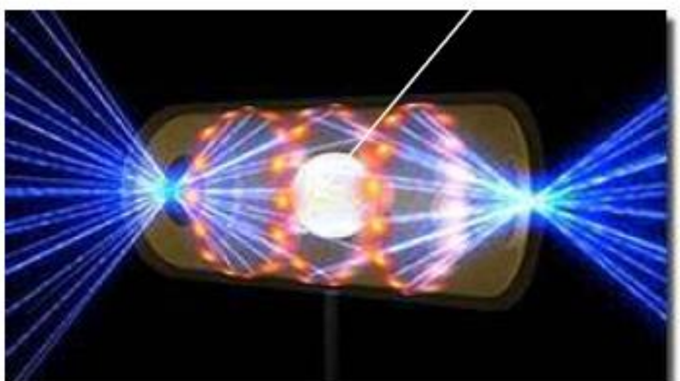


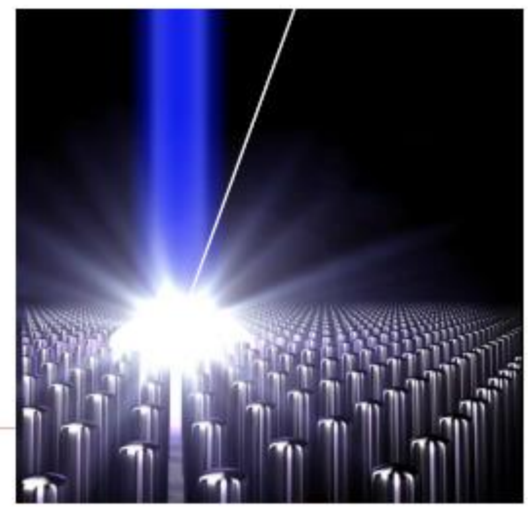
Sun Core
240 Gbar

Nanowire array plasma

I = 1 x 10 ^{22} W cm^{-2}

NIF Implosion
150 Gbar





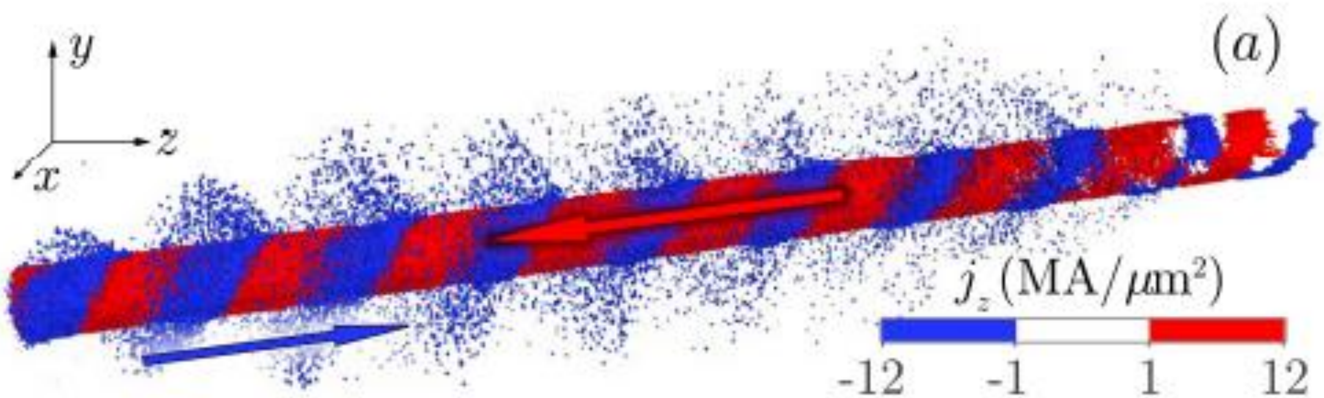
A Pukhov Heinrich Heine Univ., Germany

Kaymak et al, PRL **117**, 035004 (2016)

HEINRICH HEINE
UNIVERSITÄT DÜSSELDORF

Nanoscale Ultradense Z -Pinch

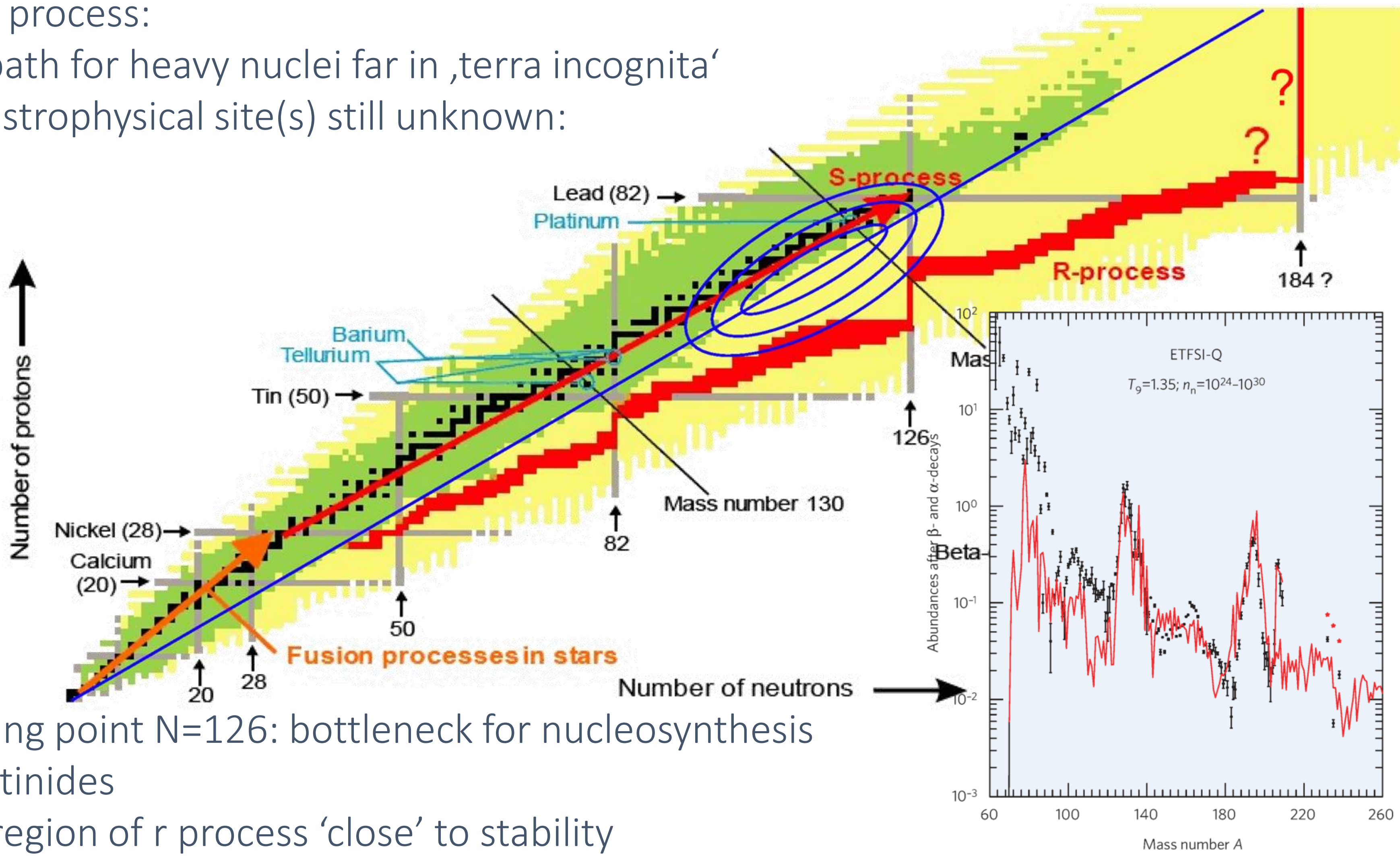
Longitudinal current distribution



A Pukhov Heinrich Heine Univ., Germany

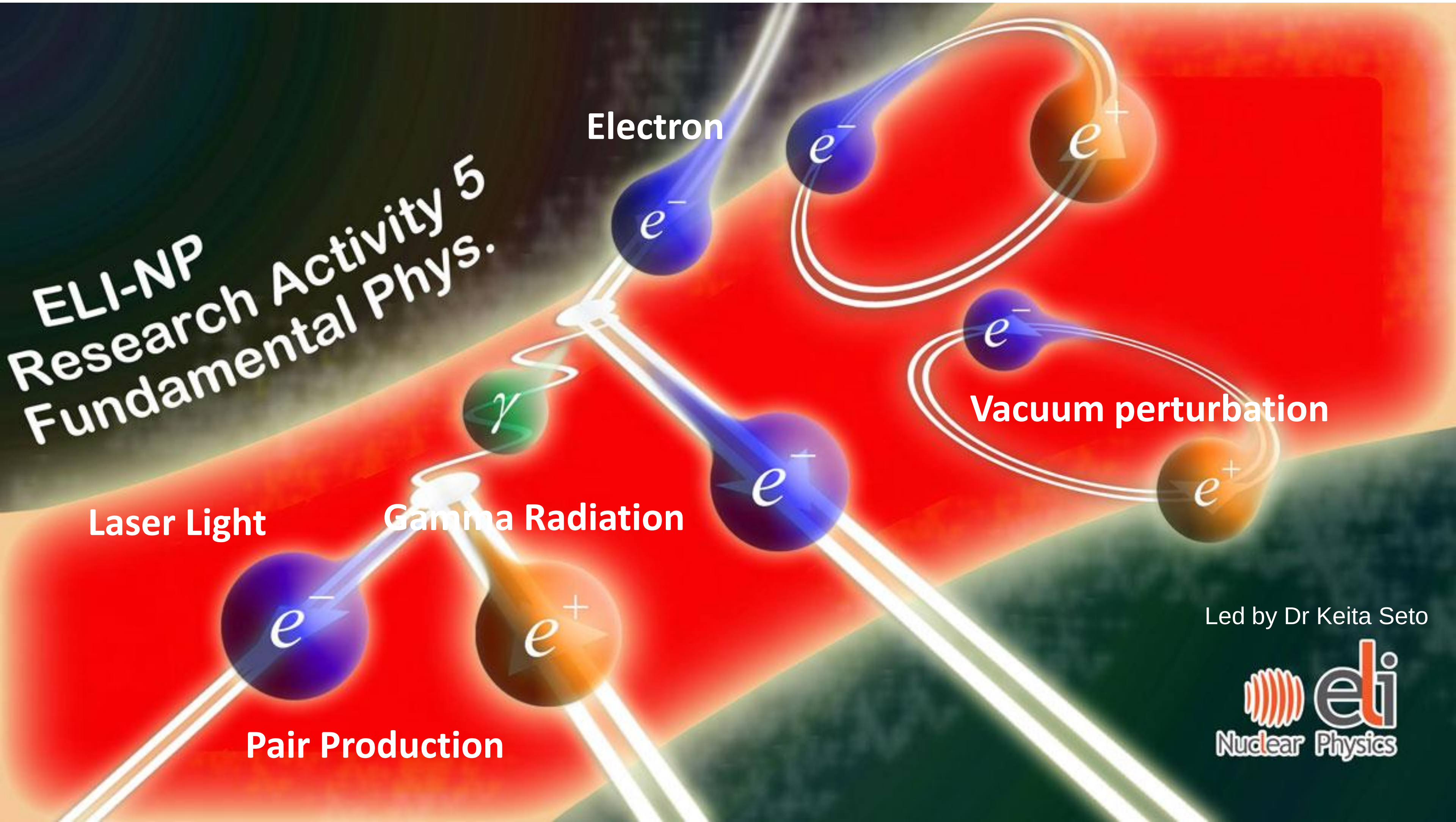
Astrophysical r process: waiting point N=126
-P. Thirolf (LMU)-

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

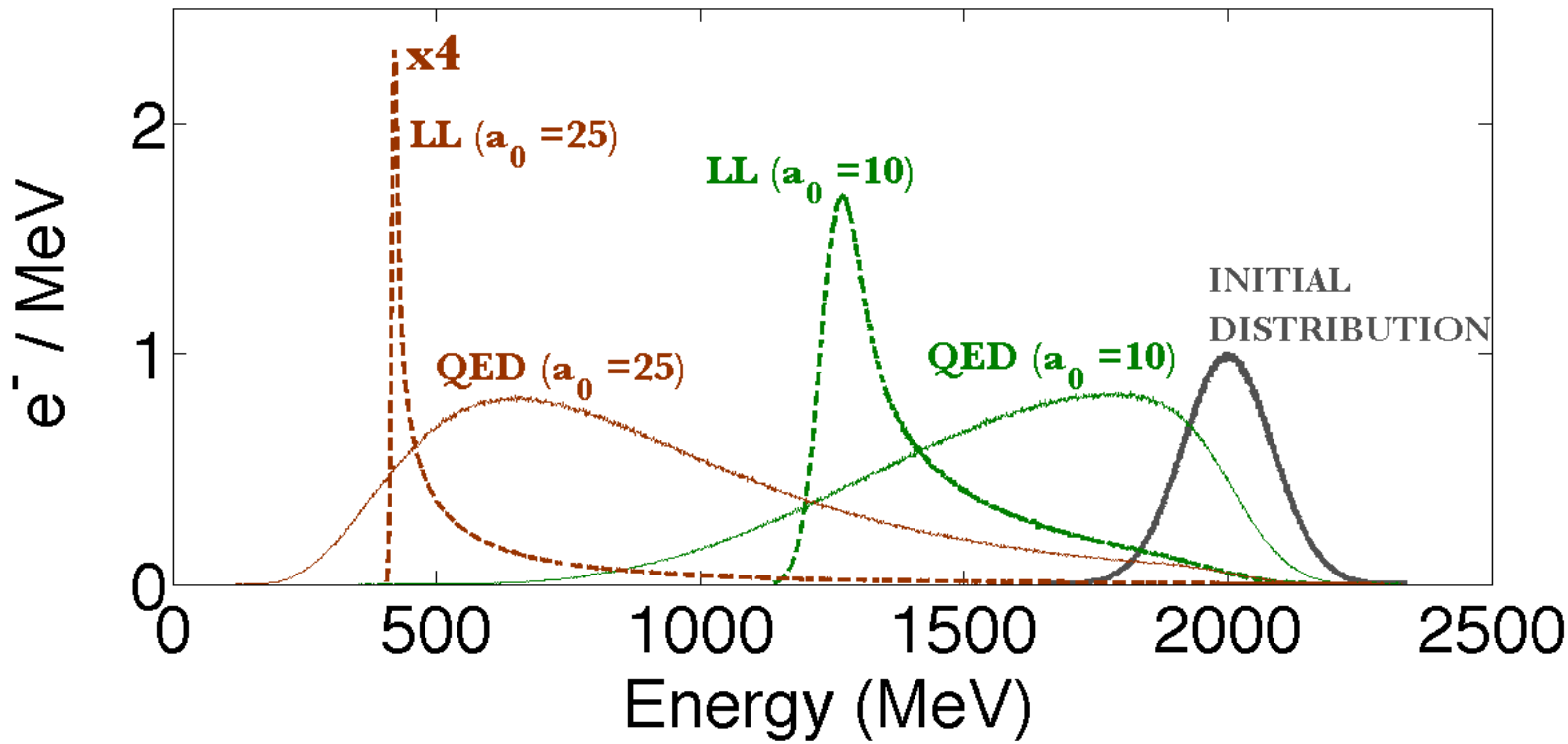


- waiting point N=126: bottleneck for nucleosynthesis of actinides
- last region of r process ‘close’ to stability

Nonlinear QED may be confirmed.

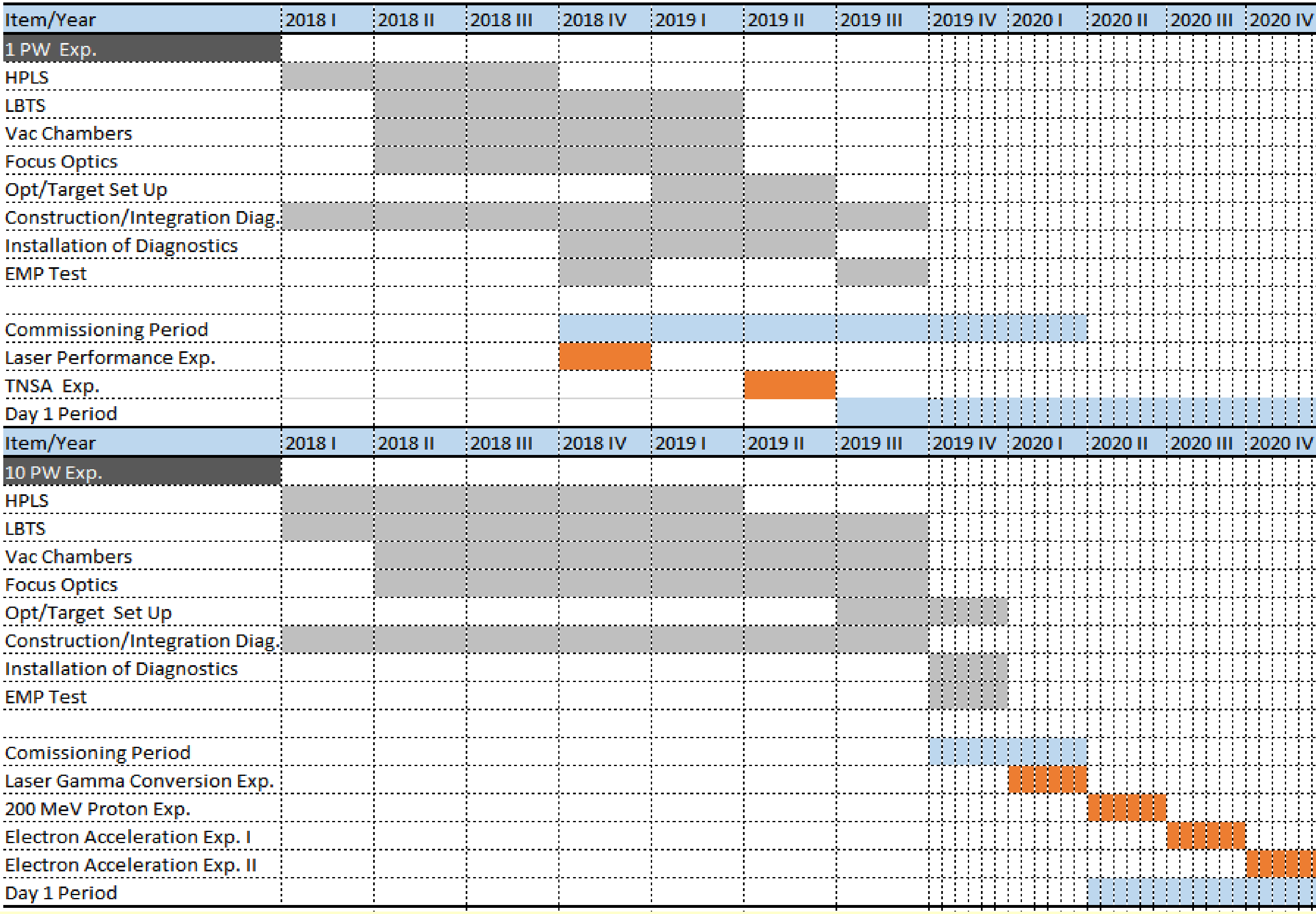


We may expect to see the drastic down shift in Electron spectrum.



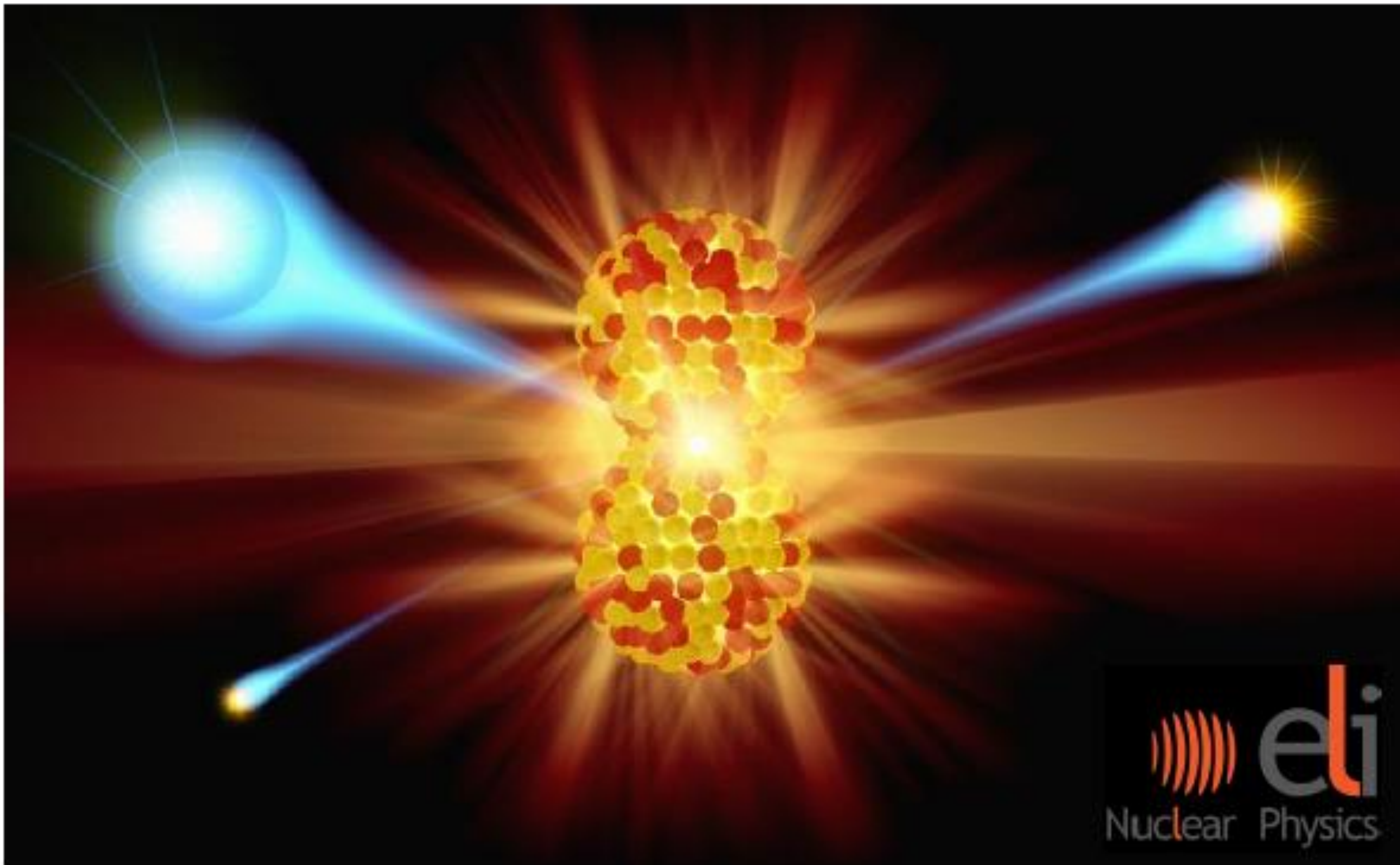
G Sarri, Queens’ Univ. Belfast, UK.

Commissioning laser experiment schedule



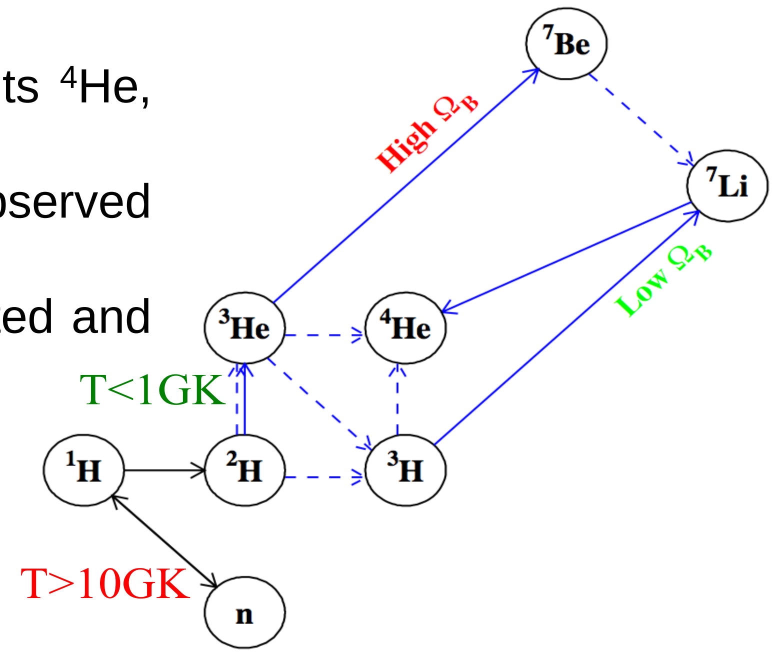
- **Assumes 10 PW LBTS commissioning by Q3 2019**
- **1 PW “Laser performance ” experiment in Q4 2018**
- **10 PW experiments paced by LBTS delivery and installation to ~Q1 2020**

Gamma Beam System Experiments

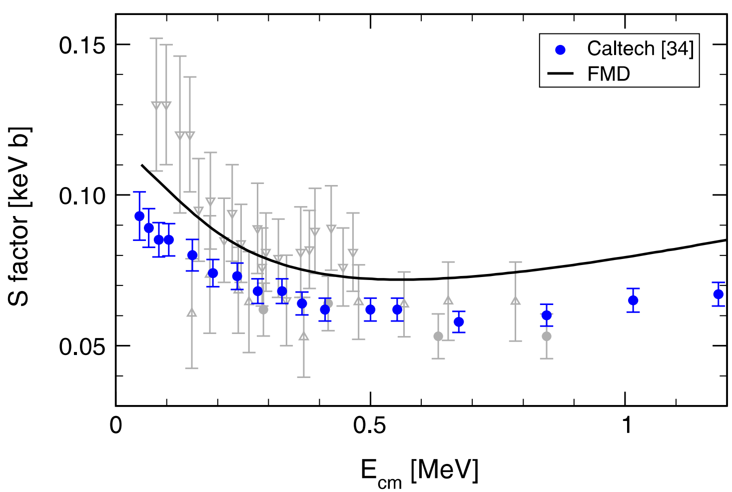


Li problem : cosmological & theoretical

- BBN predicts the abundances of light elements ^4He, D, ^3He and ^7Li
- good agreement between calculated and observed abundances for all light nuclei except for ^7Li
- factor of 3-4 discrepancy between the calculated and the observed abundance of ^7Li.



- Li-7 made by the mirror alpha capture reactions $^3He(\alpha,\gamma)^7Be$ and $^3H(\alpha,\gamma)^7Li$
- theoretical models could provide the capture cross section at lower energies where experiments are not possible
- good agreement with measurements of $^3He(\alpha,\gamma)^7Be$
- no agreement with measurements of Brune et al for $^3H(\alpha,\gamma)^7Li$

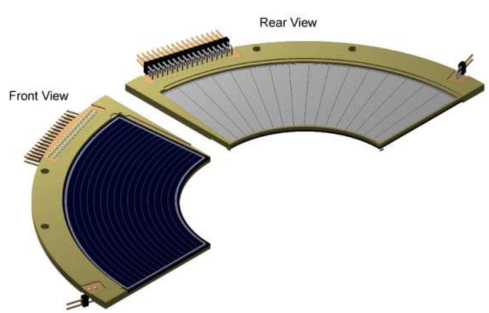


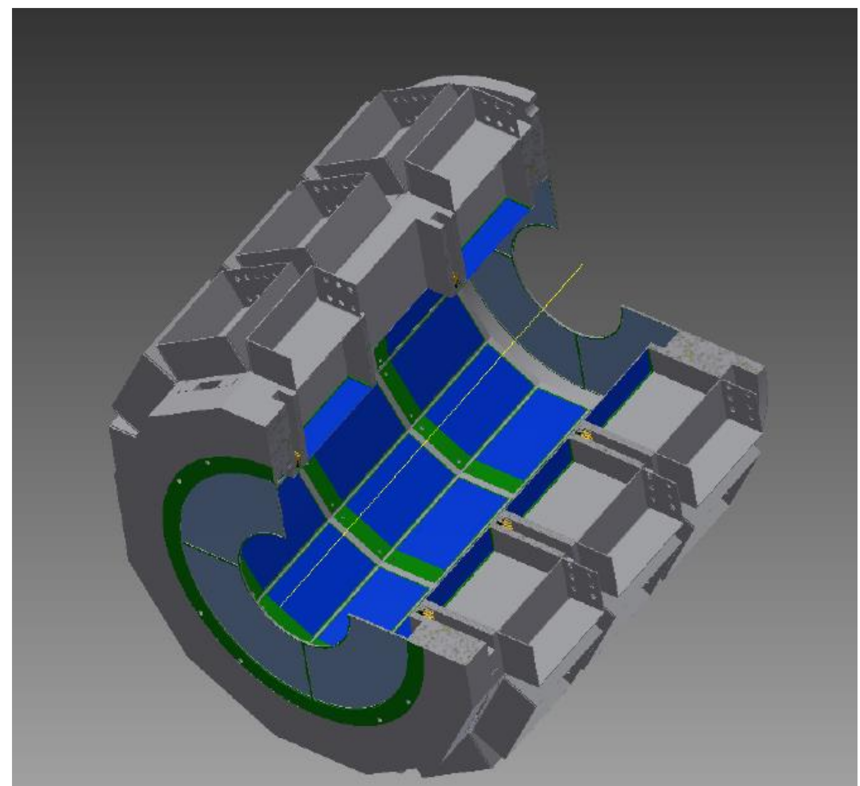
from Neff et al, PRL 106, 042502 (2011)

ELISSA – ELI Silicon Strip Array

- silicon array would make it possible to measure reactions on solid targets
- good energy resolution, almost 100% efficiency, small thresholds
- successfully designed and applied to nuclear astrophysics, e.g. ORRUBA
- array developed in collaboration with INFN-LNS, Catania

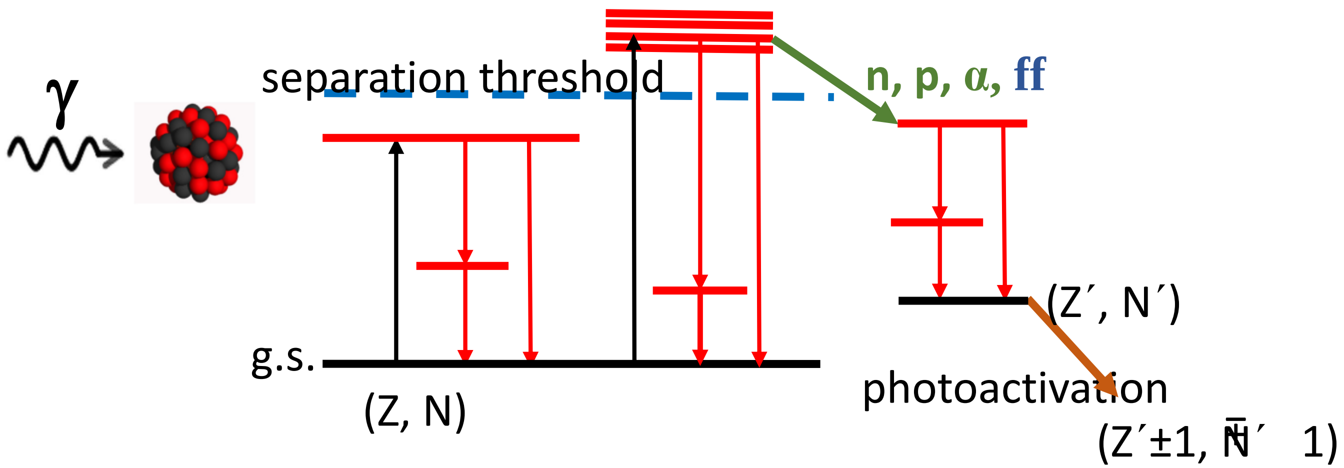
- 3 rings of 12 position sensitive X3 silicon-strip detectors (1000 μm) by Micron
- 2 end cap detectors from 4 QQQ3 segmented detectors by Micron (300 μm)
- 512 channels readout with standard DAQ or GET electronics





Experiments with high-brilliance gamma beams at ELI-NP

S. Gales et al., Phys. Scr. 91, 093004 (2016)



Nuclear Resonance Fluorescence (NRF) – **Rom. Rep. Phys. 68, S483 (2016)**

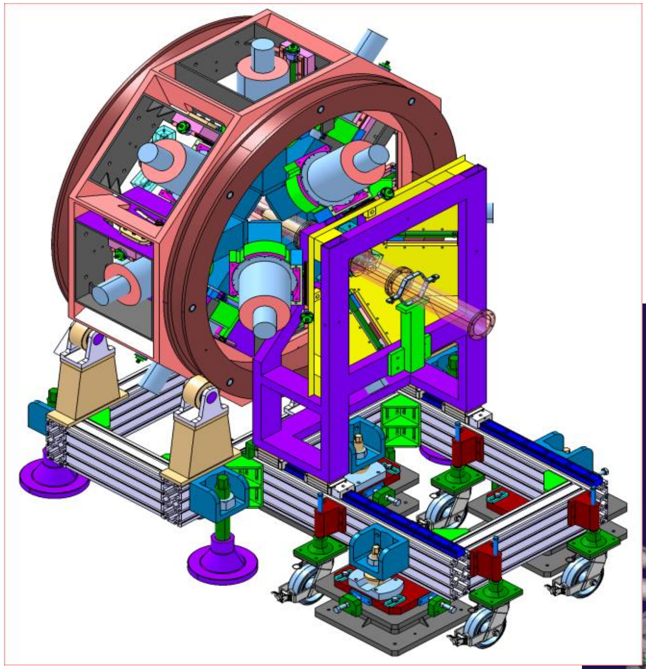
Giant/Pigmy Resonances (GANT) **– Rom. Rep. Phys. 68, S539 (2016)**

Photodisintegration (γ,n), (γ,p), (γ,α) – **Rom. Rep. Phys. 68, S699 (2016)**

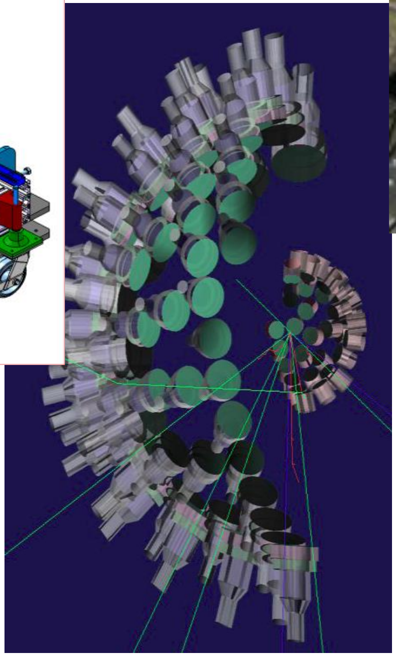
Photofission (γ,ff) – **Rom. Rep. Phys. 68, S621 (2016)**

Applications **– Rom. Rep. Phys. 68, S735 (2016), *ibid* 68, S799 (2016), *ibid* 68, S847 (2016)**

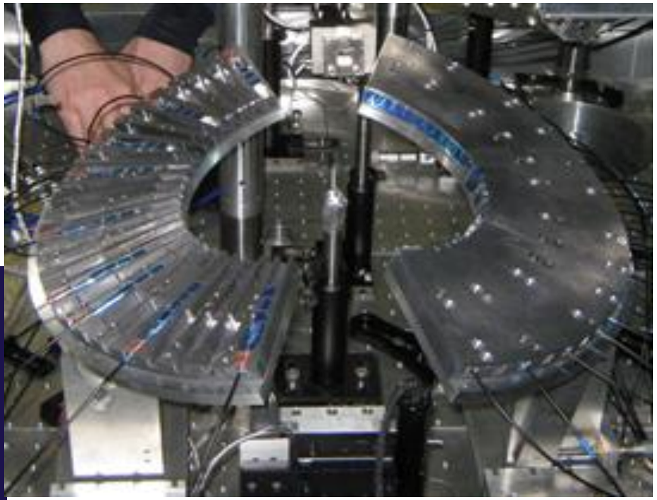
Instrumentation for Physics



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

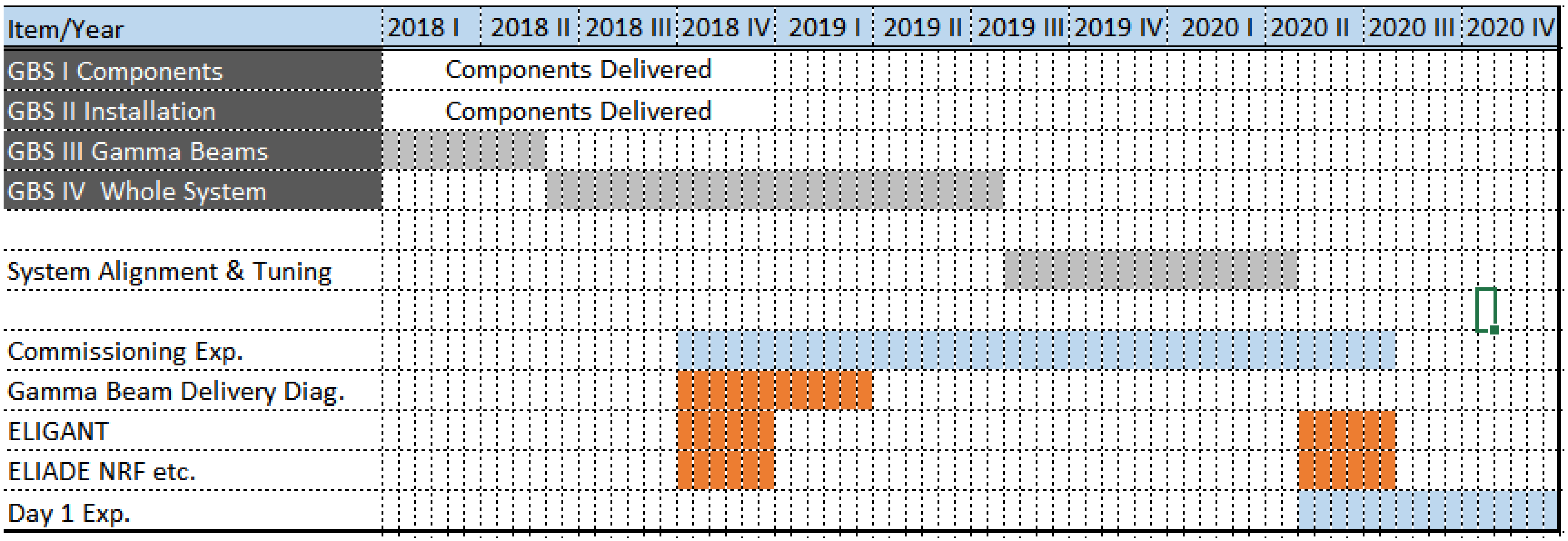


Gamma above neutron threshold (GANT)



CsI array for angle resolved calorimetry

Commissioning GBS experiment schedule



Actual Issues in Medical Isotope Production

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).

An 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 the big cities.

Alternative technologies are a necessity

Could High Power Lasers play a role in this field ?

Lasers provide a flexible way for reaching different characteristics of the accelerated particle beam (type of particle, energy spectrum, etc) based on different targets.

Laser-based particle beams have big density ☞ many activations/shot produced.

Acceleration field more intense than at accelerators and less shielding against radiation is needed ☞ potential for size reducing.

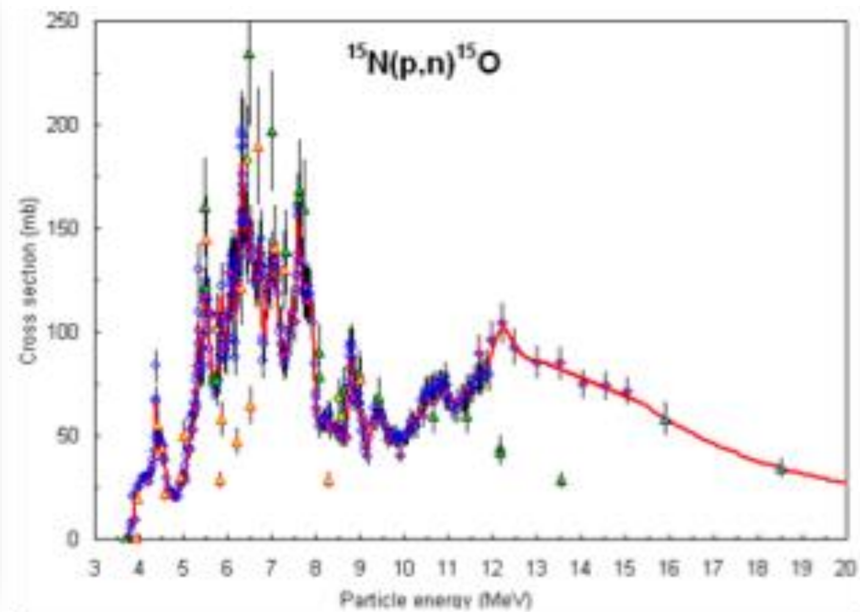
The actual challenges are related to the "quality" of the proton beam, the repetition rate and the size minimization.

Many synergies with cyclotron- related isotope production and with laser-related physics experiments.

The Production Next Door

In laser based systems the shielding against radiation is needed only after laser-target interaction, in a much smaller volume/space than in the case of cyclotrons. ▯ possibility of producing short-live isotopes with small laser-based accelerators and deserving hospitals far away from the big cities.

Very short lived isotopes such as ^{15}O ($\tau_{1/2}$ = 122s !!) from $^{15}N(p,n)^{15}O$ are hardly accessible by conventional cyclotrons. They could be produced in the future with "table-top" lasers at dedicated production centers inside clinics.



Be part of this great adventure, join out team!

HORIZON 2020

Acknowledgment

- A Pukhov Heinrich Heine University
- A Zilges University of Cologne
- M LaCognata INFN-LNS, Catania
- All the co-authors from Technical Design Report and Romanian Report in Physics 2016

Summary

- ELI-NP is under active implementation.
  10 PW laser beam will be available in June 2019.
  3 MeV and 19.5 MeV gamma beams in June 2019.

- Fission-fusion, Non linear QED, Plasma Physics, Dark Matter Physics, and Applications to Bio and Medical fields are to be tested.

- This experimental platforms can offer excellent opportunities to young scientists to test their original ideas.

- Your proposal is welcome. You can talk to me first.

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Structural Instruments 2007-2013

Thank You Very Much for Your Listening

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

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