Extreme Light Infrastructure – Nuclear Physics

IFIN-HH
eli nuclear physics

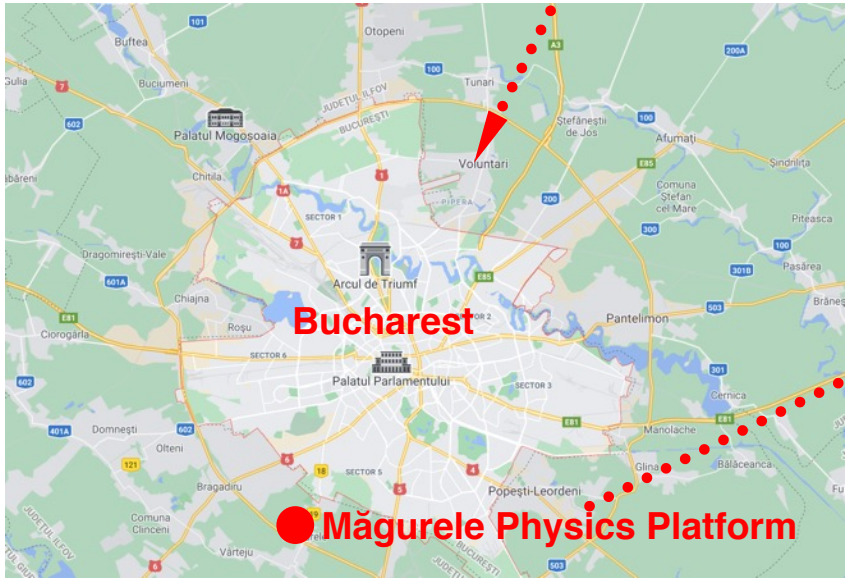
C.A. Ur

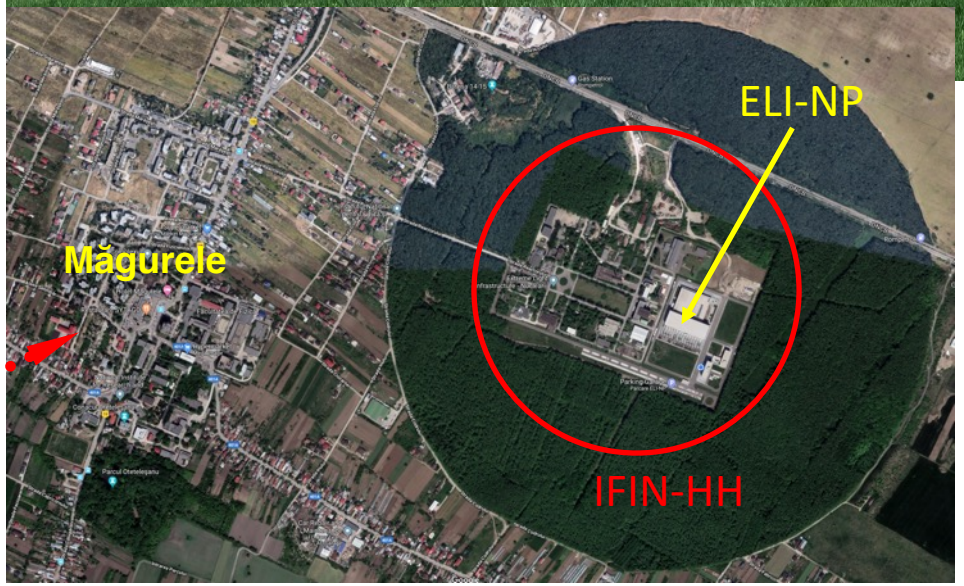
on behalf of the ELI-NP team

SPIN 2021

ELI-NP on the map

Extreme Light Infrastructure (ERDF)





ELI-NP Infrastructure

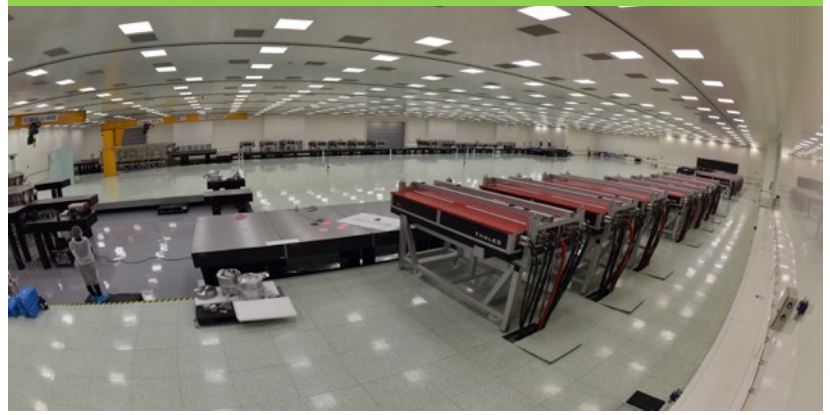
Operational since 2016

- Experiment building
- Office building
- Guest house
- Cantine
- Access control building

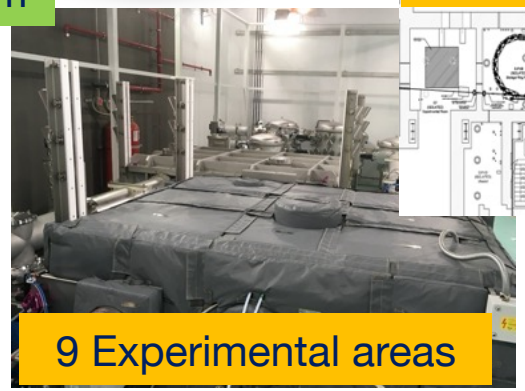
Over 32.000 sqm of built area and 270.000 cubic meter of air to condition

Largest geothermal system in Europe ~ 6 MW

2 x 10 PW High-Power Laser System

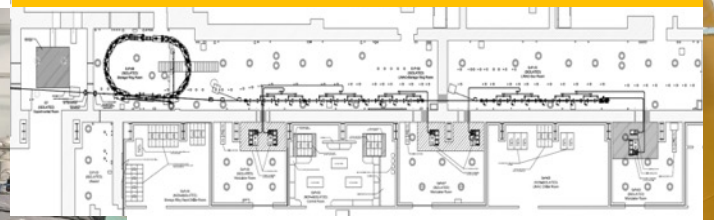


120,000 tons antivibration platform



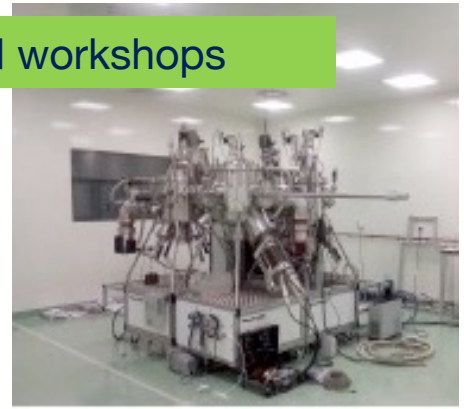
9 Experimental areas

Variable Energy Gamma System

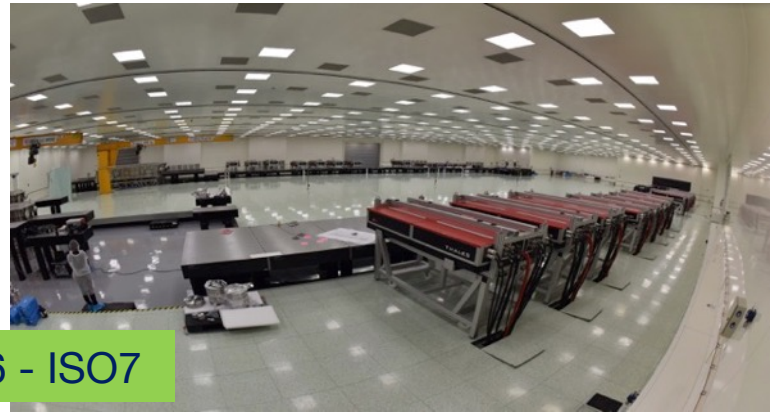


2 x 10 PW + 1 x 1 PW
Laser Beam Transport System

Laboratories and workshops



Clean rooms ISO6 - ISO7



ELI-NP Research Infrastructure

Advanced studies in basic science ...

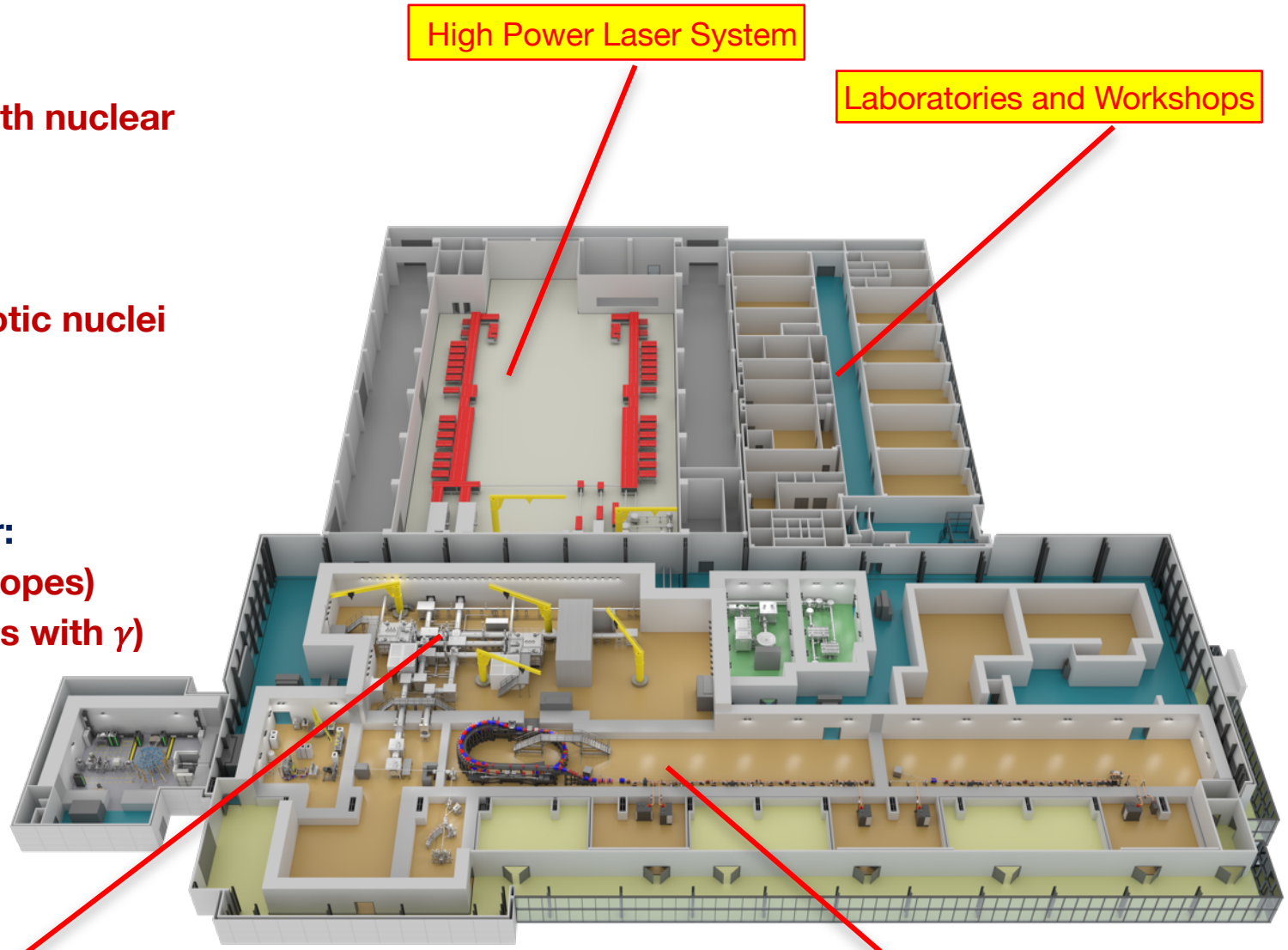
- characterization of laser-matter interaction with nuclear methods
- particle acceleration with high power lasers
- nuclear reactions in plasma
- photonuclear reactions, nuclear structure, exotic nuclei
- nuclear astrophysics and nucleosynthesis
- quantum electrodynamics

... and applications – developing technologies for:

- medical applications (X-ray imaging, radioisotopes)
- industrial applications (non-destructive studies with γ)
- material studies with positrons
- materials in high radiation fields

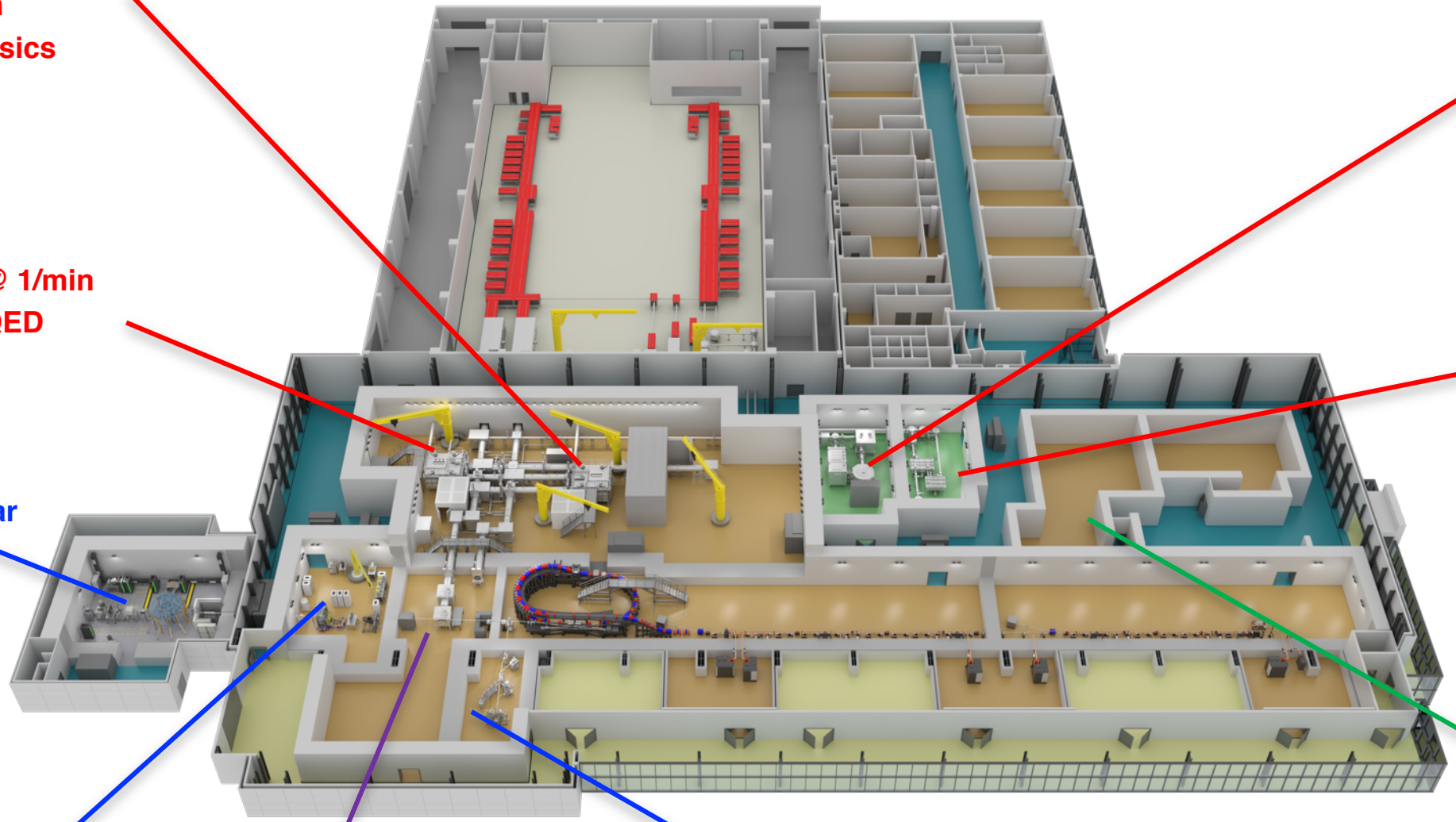
2015

Technical Design Reports



Rom. Rep. Phys. Vol. 68 (2016)

ELI-NP Experimental Areas



E1: 10 PW @ 1/min
Laser driven
Nuclear Physics

E5: 1 PW @ 1 Hz
Material Studies

E6: 10 PW @ 1/min
High Field QED

E4: 0.1PW@10 Hz
Photon-photon
int., LWFA, X-ray
imaging

E9: γ beams
Photonuclear
Reactions

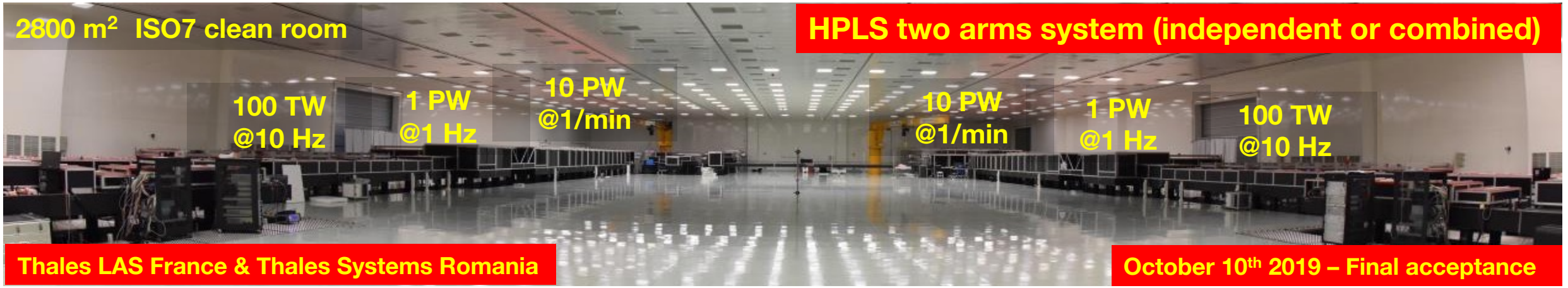
E3: X rays
Test/develop
instrumentation
and technology

E8: γ beams
Photonuclear
Reactions

E7: 10 PW + 1 PW + γ/e^-
High Field QED

ERA: positrons
Material Studies

ELI-NP High Power Laser System (HPLS)



Unique system in the world:

- *demonstrated power level 10 PW*
- *combination of 2 high power lasers*

Premiere achievements:

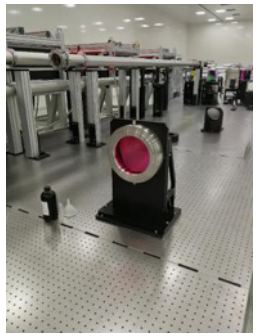
- *large Ti:Sapphire crystals 20 cm*
- *large compressor gratings meter size*
- *ATLAS pump lasers 100 J*
- *10 PW laser beam transport system*
- *10 PW beam-dump*

Laser Beam Transport System (LBTS) 10 PW

Final acceptance:

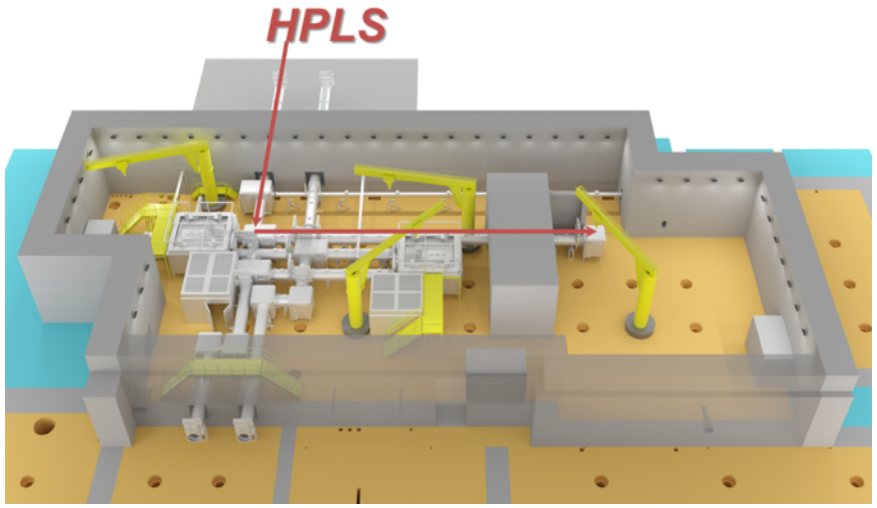
December 2020

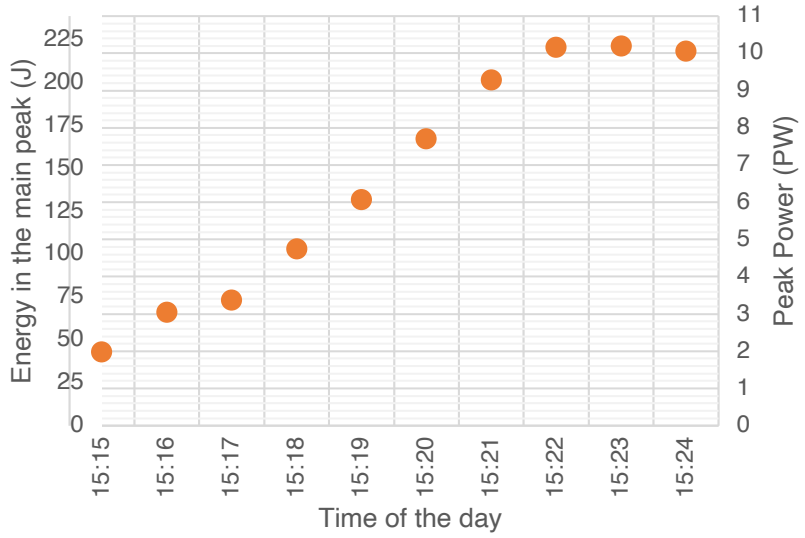
- **2 x 10 PW + 1 PW beams**

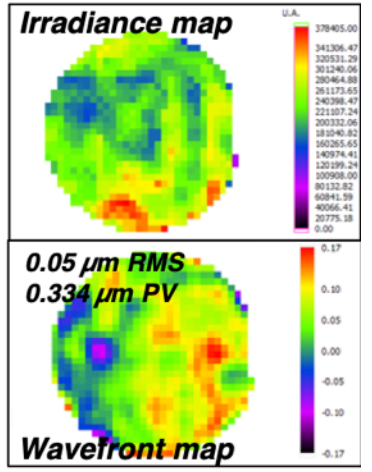


HPLS + LBTS @ 10 PW – November 17, 2020

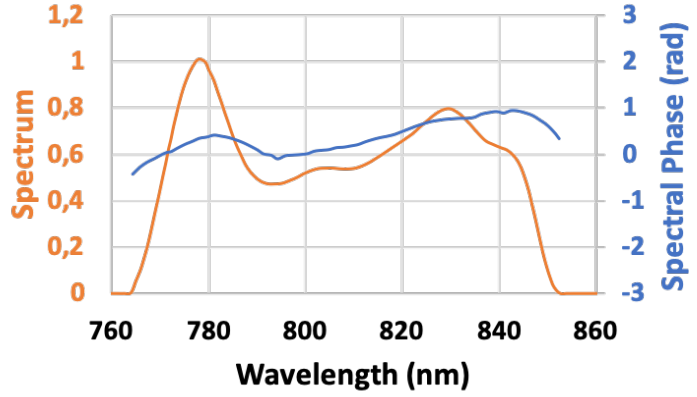
Inaugural 10 PW and User Symposium – Moving into Uncharted Territories online – more than 200 participants



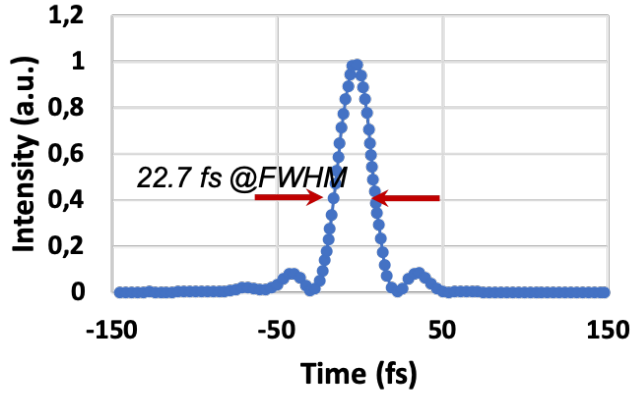




Spatial characteristics



Spectral characteristics



Time characteristics

ELI-NP Light at Extremes

Most powerful lasers in the world

2 x 10 PW

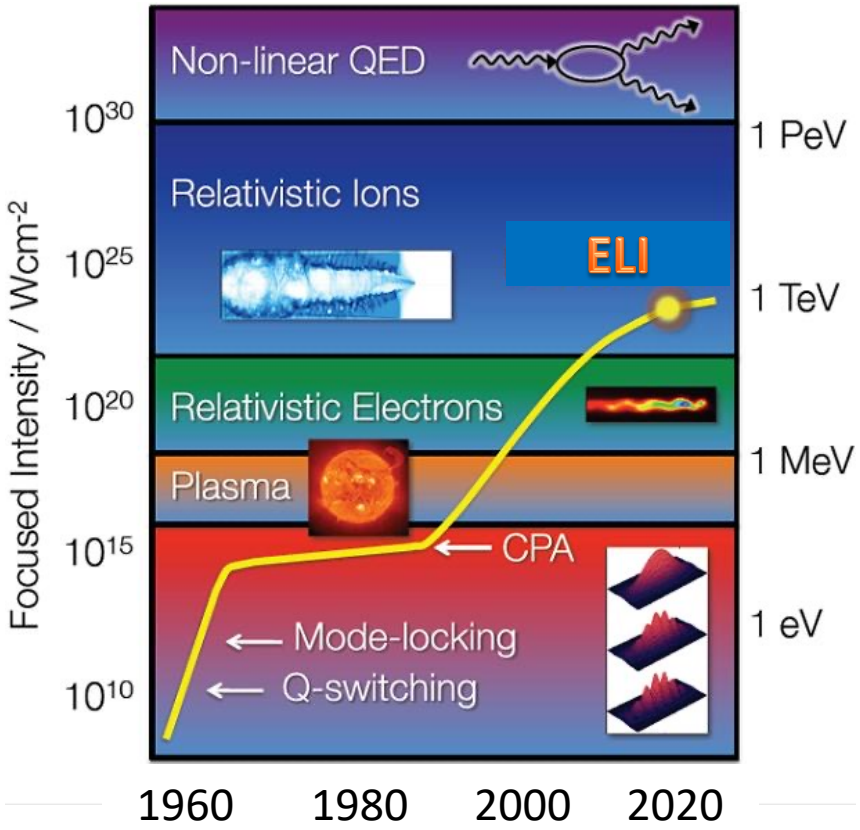
March 2019

Lasers @ ELI-NP – first laser in the world able to deliver 10 PW pulses

August 2020

Lasers @ ELI-NP – world premiere in generating and transporting 10 PW laser pulses

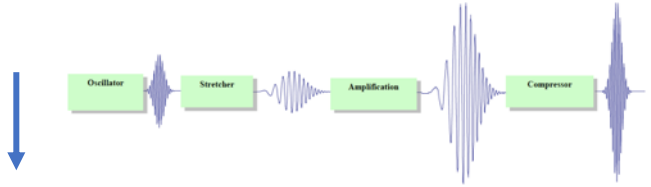
Dedicated to nuclear physics studies !



Gerard Mourou
(France)

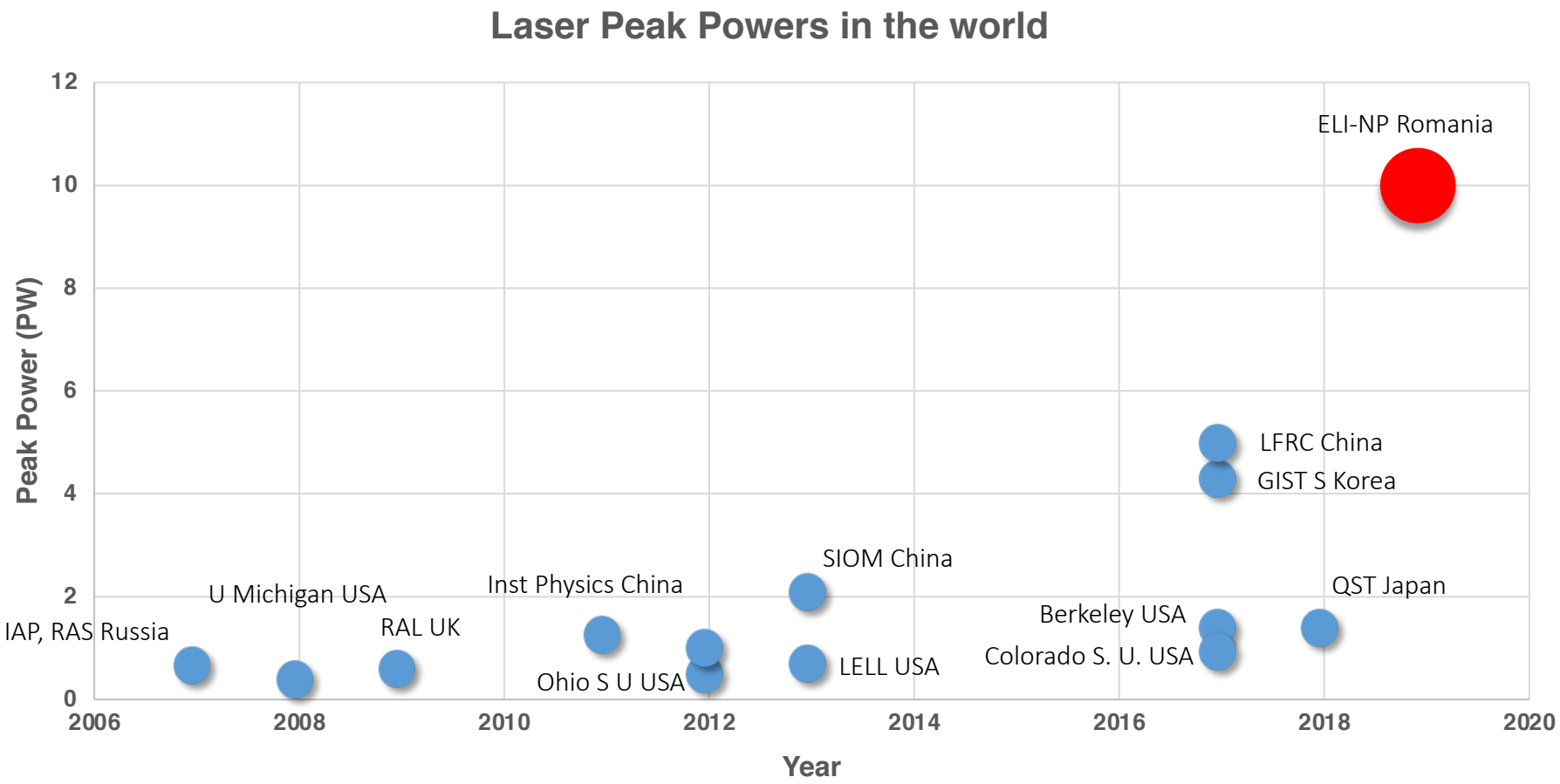
Nobel Prize in Physics 2018 together with Donna Strickland (Canada)

CPA 1985



1985: Chirped Pulse Amplification (CPA)

ELI-NP @ 10 PW


Laser Peak Powers in the world
Peak Power (PW)
Year
0
2
4
6
8
10
12
2006
2008
2010
2012
2014
2016
2018
2020
ELI-NP Romania
LFRC China
GIST S Korea
SIOM China
Inst Physics China
U Michigan USA
IAP, RAS Russia
RAL UK
Ohio S U USA
LELL USA
Berkeley USA
Colorado S. U. USA
QST Japan

ELI-NP Laser–based Commissioning Experiments

Goal: performance test at full power of complete laser driven experimental system

(HPLS + LBTS + focusing optics + experimental setups)

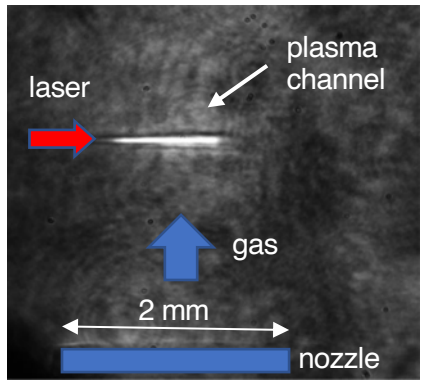
Experiments to be led by ELI-NP researchers together with ***international expert users***

Part of the project implementation - approved by ELI-NP ISAB

- **100 TW (E4):**
  - Four-wave mixing in vacuum, in search of dark matter candidates
  - X ray production through betatron emission
- **1 PW (E5 & E7):**
  - Benchmark TNSA proton acceleration
  - Benchmark LWFA electron acceleration
  - Optimization of high charge, stable electron acceleration
- **10 PW solid target (E1):**
  - Demonstrate extreme focal intensity through laser-γ conversion (“γ-flash”)
  - Demonstrate over 200 MeV proton acceleration (neutron generation add-on)
  - Dense heavy ion beams for nuclear physics
- **10 PW gas target (E6):**
  - 10 PW laser wakefield acceleration of multi-GeV electron beams

First Experiments at 100 TW – 2020

Electron acceleration in gas jet & betatron X-ray emission



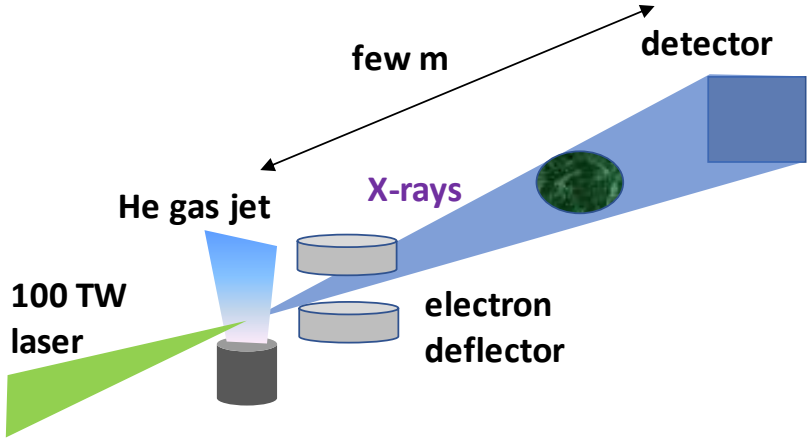
'Shadowgraphy'
The image of the gas jet at the interaction with the 25 fs laser pulse

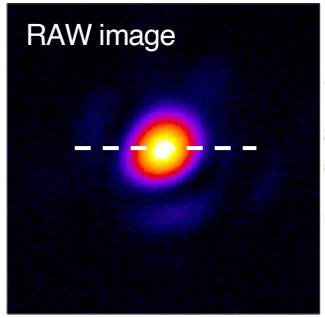
Gas: He or He + 2% N_2
Pressure: 10 - 20 bar

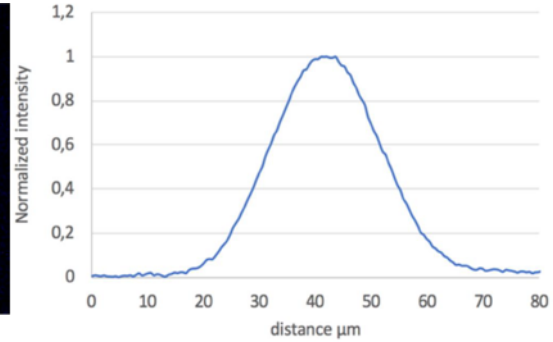
Max Energy: < 2.5 J
Pulse duration: ~ 25 fs
Central wavelength ~ 810 nm
Beam diameter: ~ 54 mm
Laser pointing fluctuation: ~ ±7 µrad

Parabolic mirror: 1.5 m focal length (F# ~28)
Spot size diameter: ~ 22±2 µm at FWHM

$I_0 \sim 10^{19}$ W/cm^2

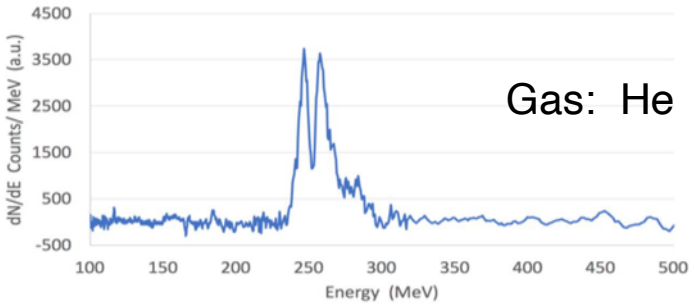




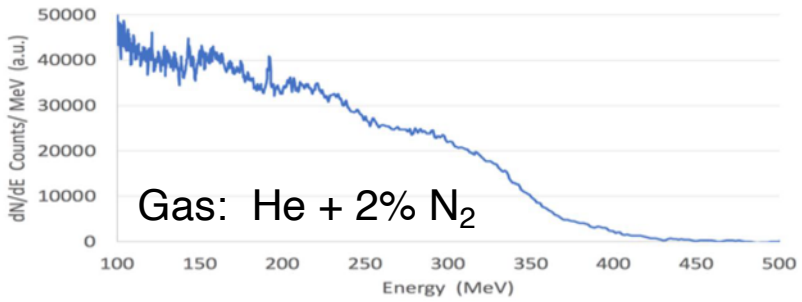


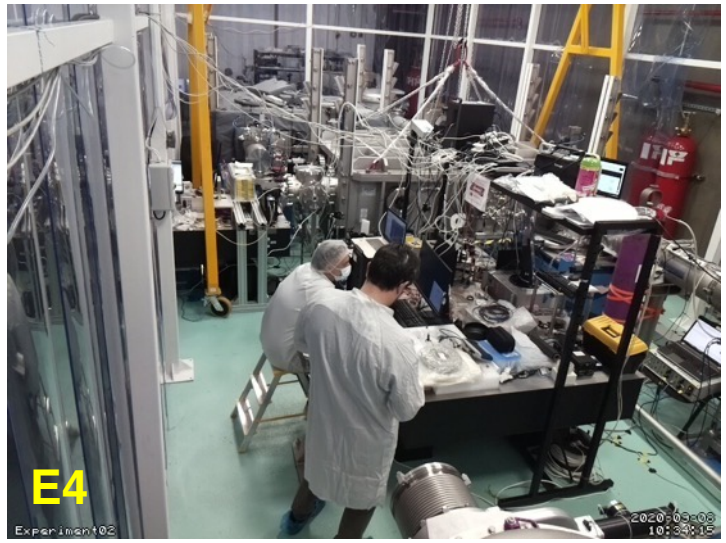
LWFA electron acceleration

courtesy of D. Doria, P. Ghenuche, M. Cernaianu

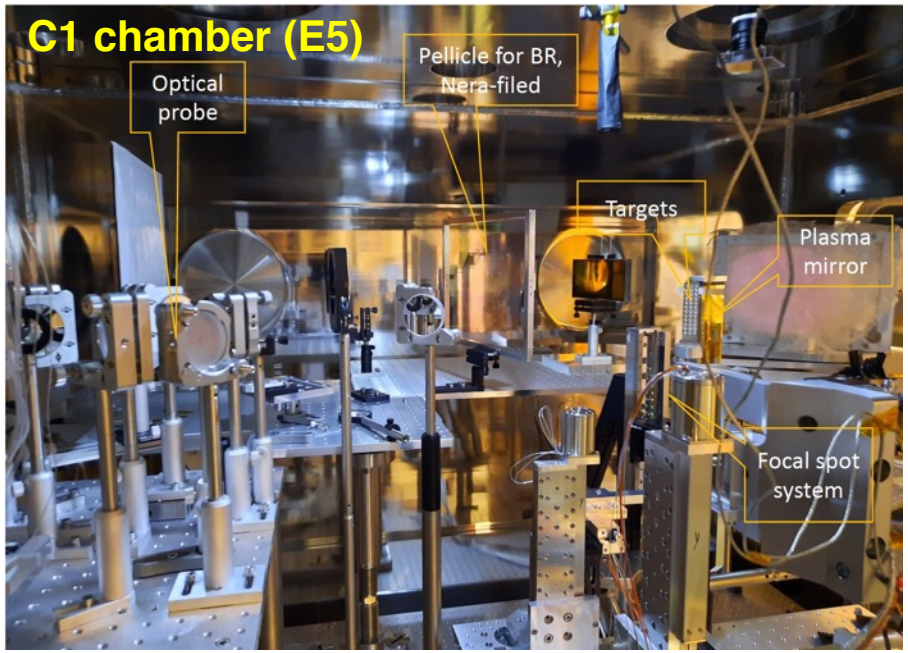


→ acceleration field of ~1 GeV/cm





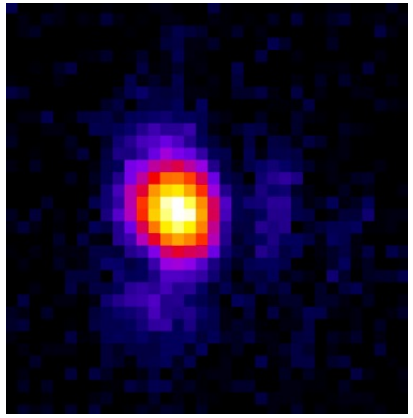
First Experiments at 1 PW – 2021



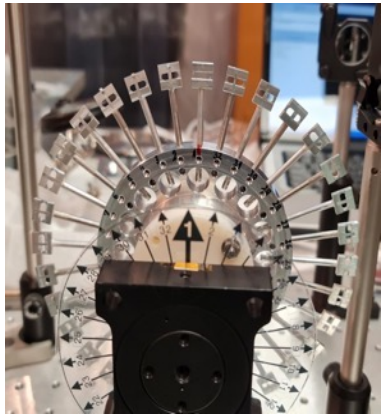
1 PW commissioning experiment: Benchmark of TNSA acceleration at PW class laser and assessment of HPLS performance with solid targets and gas targets

4.5 µm Al target

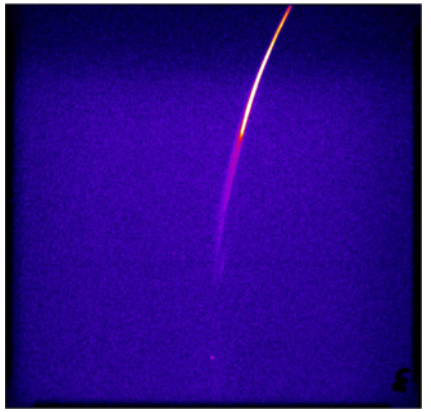
Best focal spot:
3.5 μm at FWHM



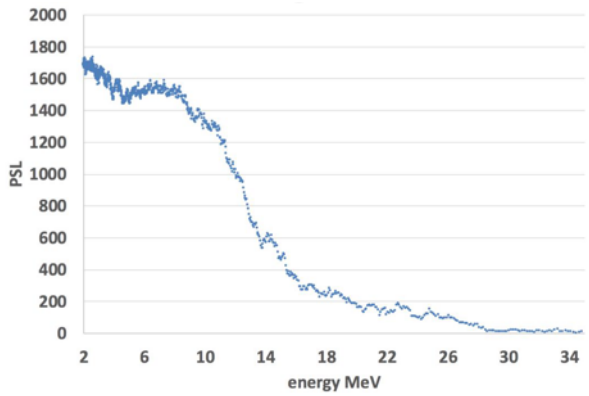
Target wheel:
up to 32 targets



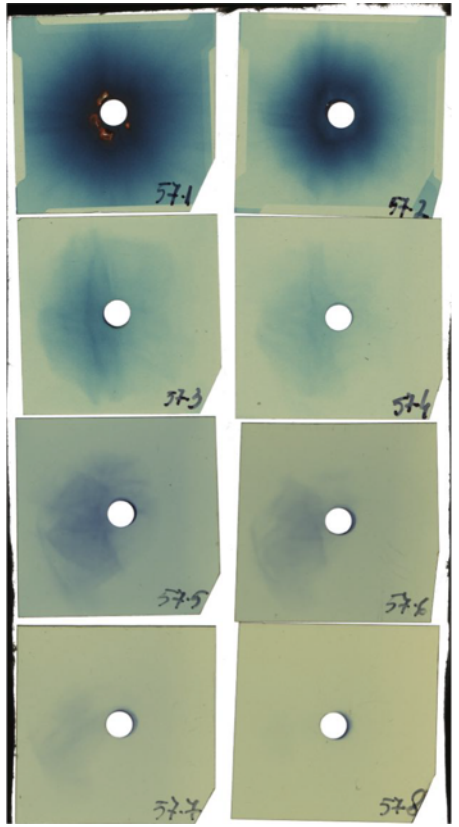
Thomson Parabola



Proton spectrum at 900 TW



Radiochromic film stack

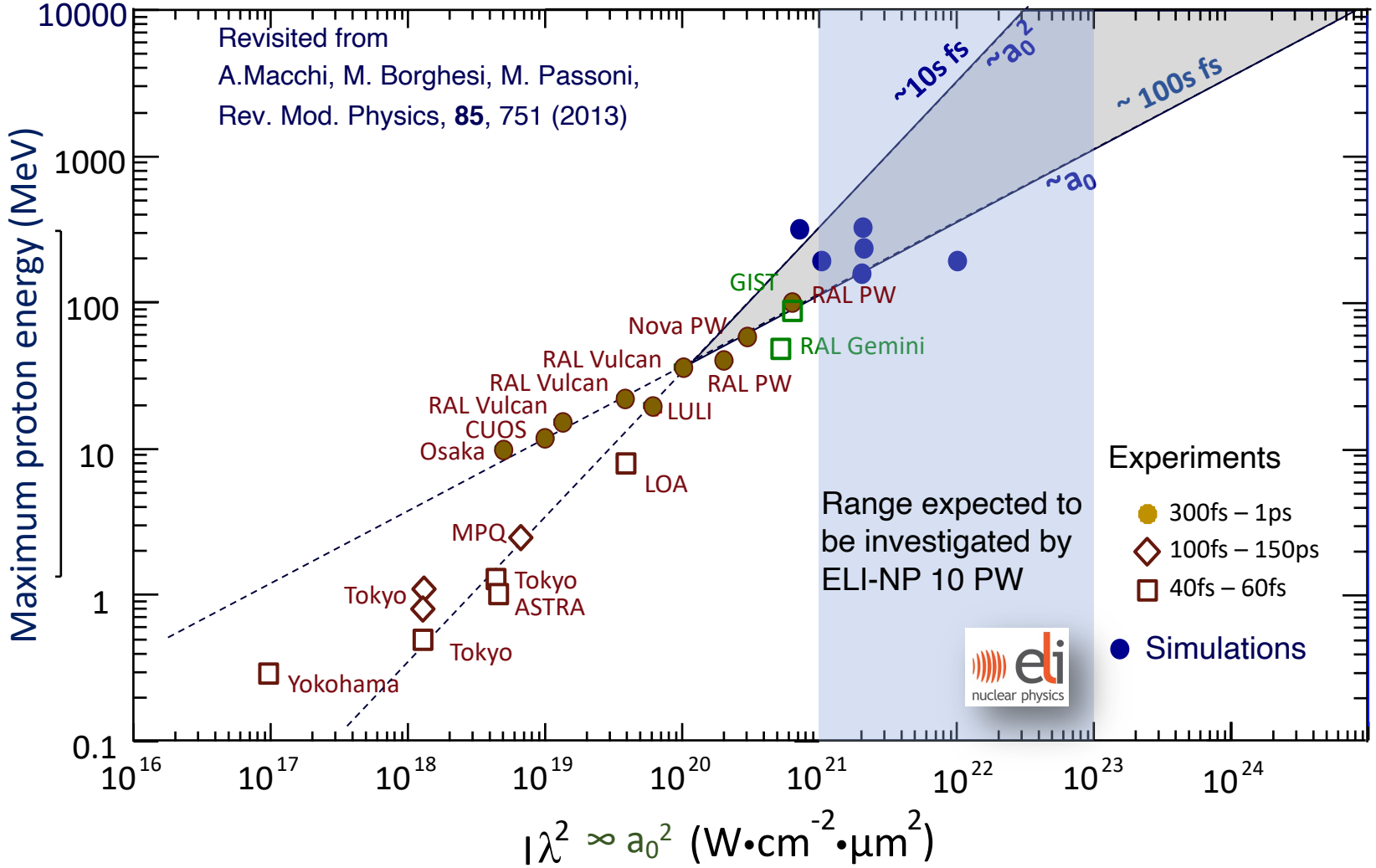


Laser irradiance at 1 PW ~ 4.5 x 10^{21} W/cm^2

First Experiments at 10 PW – 2022

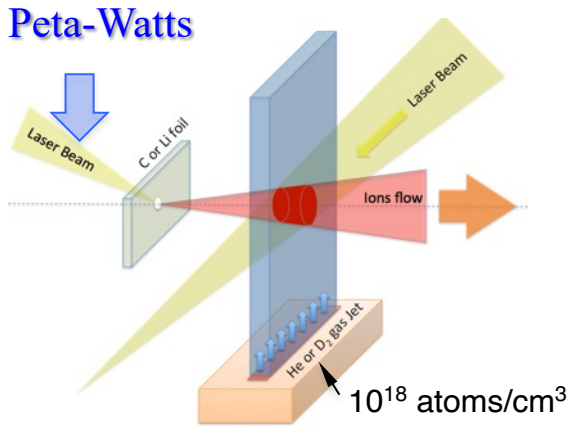
TNSA regim : accelerating protons above 200 MeV
(theory ⇨ sub-GeV proton and 100s MeV/u light ions)

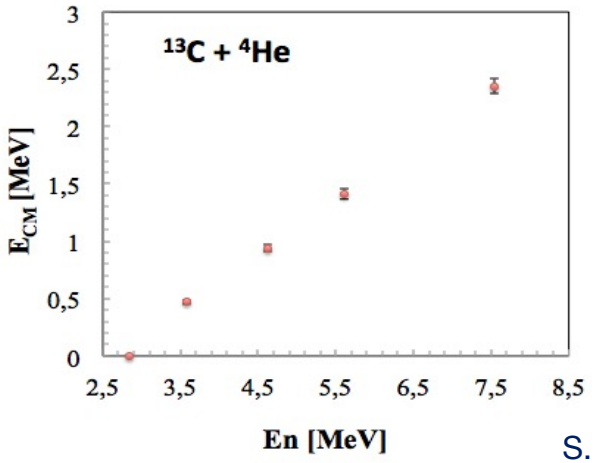
TNSA scaling law and state-of –the-art



Nuclear Reactions in Plasma

Study of electron screening factor in nuclear reactions of astrophysical interest

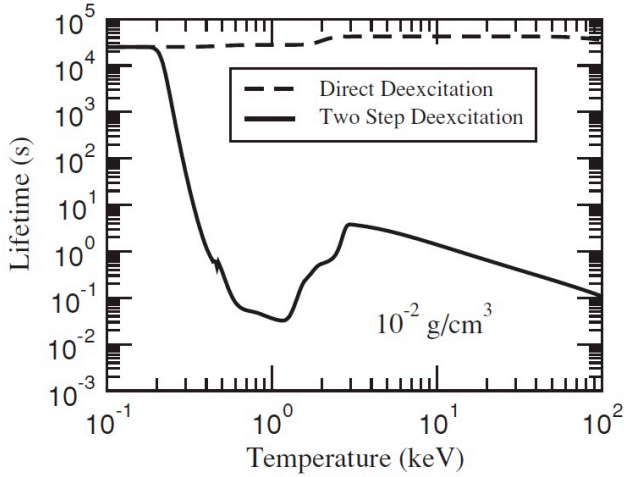




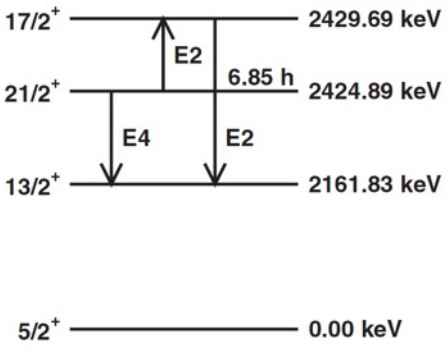
S. Tudisco *et al., INFN*

Nuclear reactions in hot plasma created by laser beams simulating in laboratory the stellar environments

Nuclear de-excitations in plasma

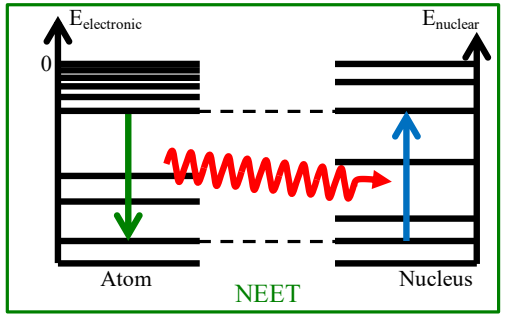


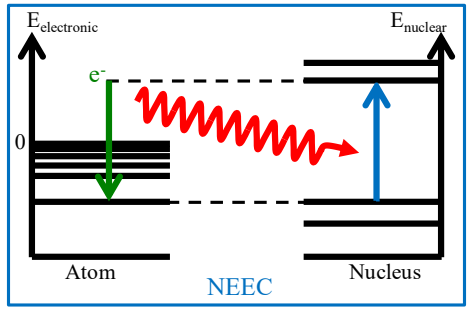
^{93}Nb (p,n) ^{93m}Mo



^{93}Mo

G. Gosselin *et al.*, *Phys. Rev. C (2007) 044611*

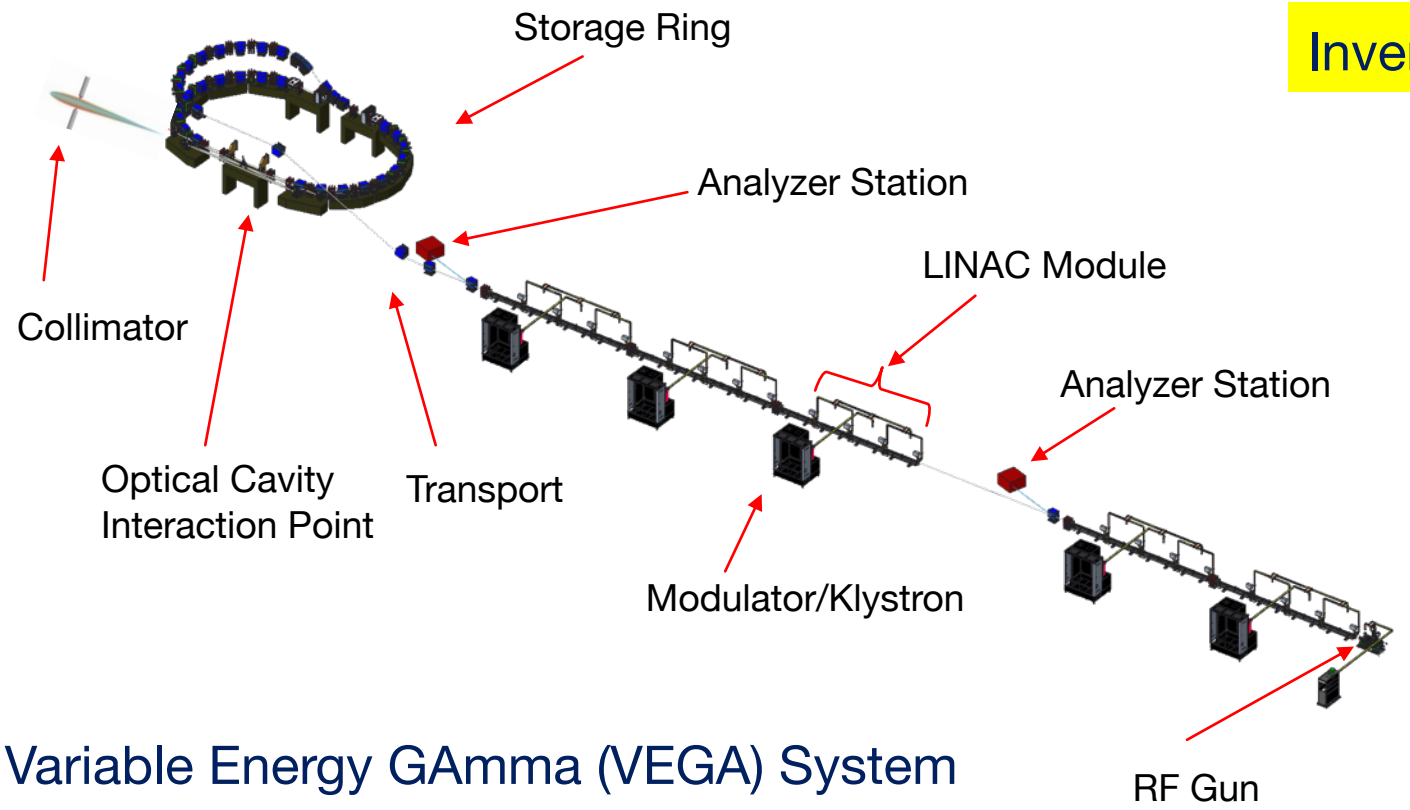




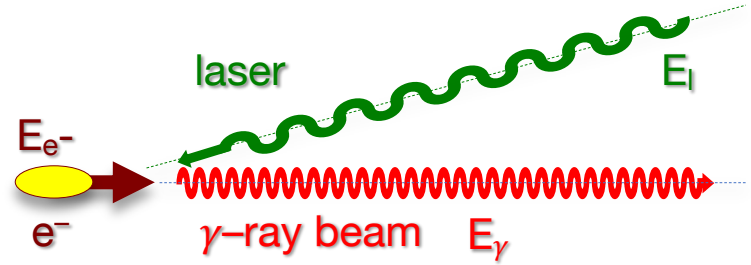
F. Hannachi *et al., CENBG*

Significant changes in lifetimes are predicted in plasma conditions

ELI-NP VEGA System



Inverse Compton Scattering



$$E_\gamma \approx 4 \cdot \gamma^2 \cdot E_l$$

Variable Energy GAmma (VEGA) System

Contract signed
- October 2019

Stage I – accomplished – 2020
Stage II – on-going
- utilities installed
- several components delivered

Stage III – 2023

Start experiments
- 2023 2nd half

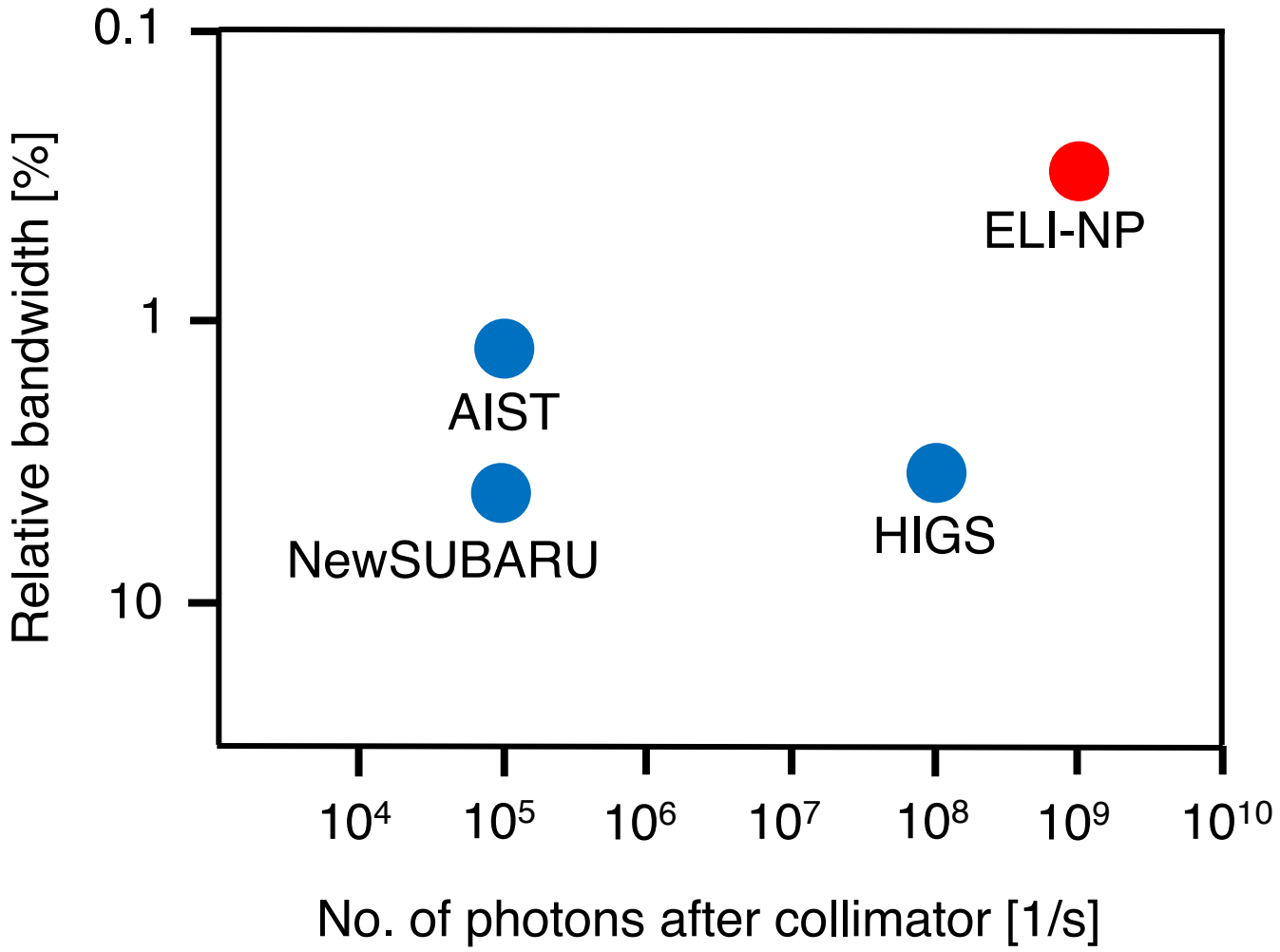
Energy up to:
- 19.5 MeV

Quasi-monochromatic
- < 0.5 % relative bandwidth

High spectral density
- > 5000 photons/eV/s

High-degree of linear polarization
- > 95 %

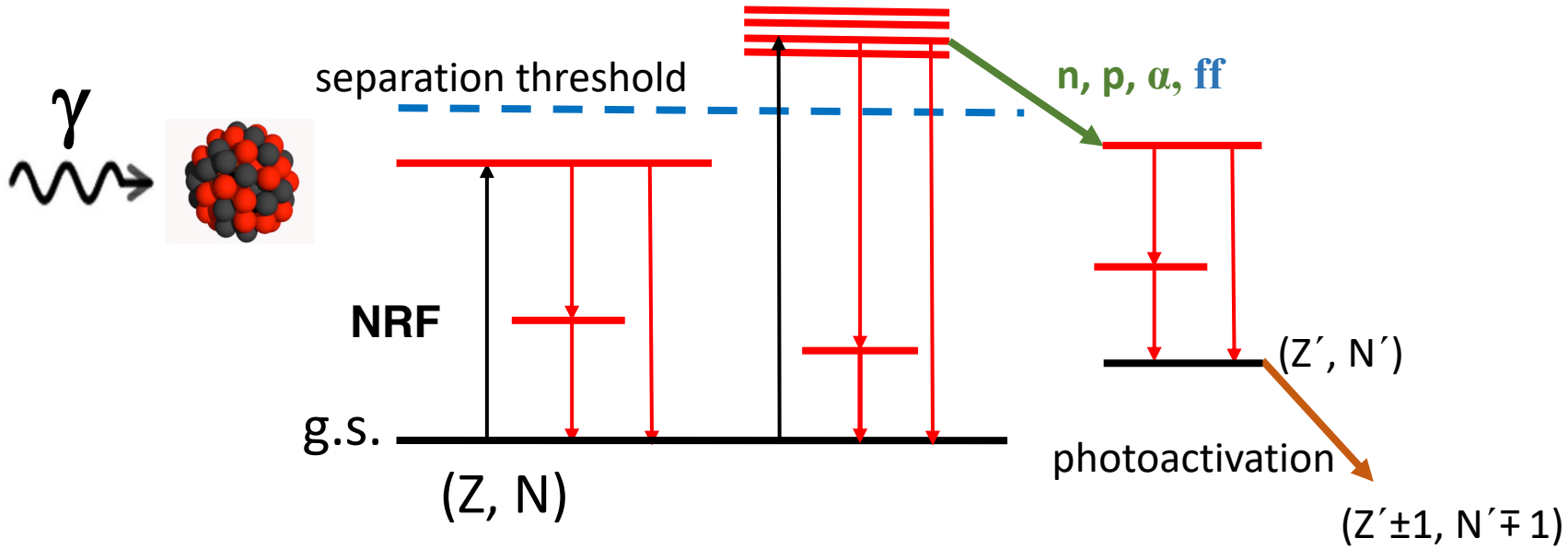
ELI-NP VEGA System



Gamma Beam Experiments

Physics Case: photonuclear reactions

Photons with energy of several MeV are complementary to „standard“ probes in nuclear physics and excite nuclei in a very selective manner

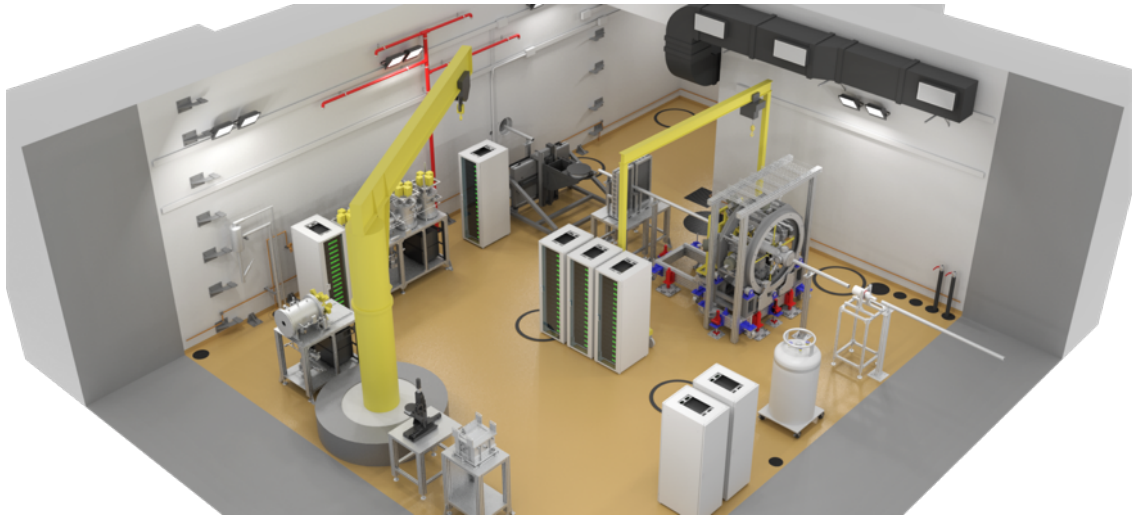


- **Nuclear physics**
  - Nuclear structure
  - E.m. dipole response of nuclei
  - Pygmy and Giant Dipole Resonances
  - Photonuclear reactions cross sections
  - Nuclear astrophysics
  - Photofission and exotic nuclei

- **Applications**
  - Industrial imaging
  - Radioisotopes
  - Material studies with positrons

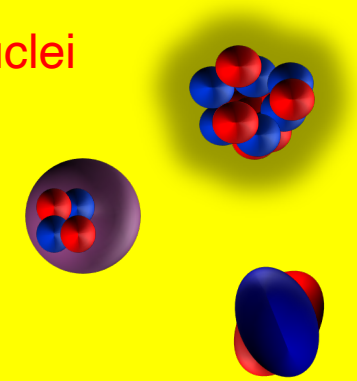
Gamma Beam Experimental Hall E8

ELIADE = ELI-NP Array of DEtectors

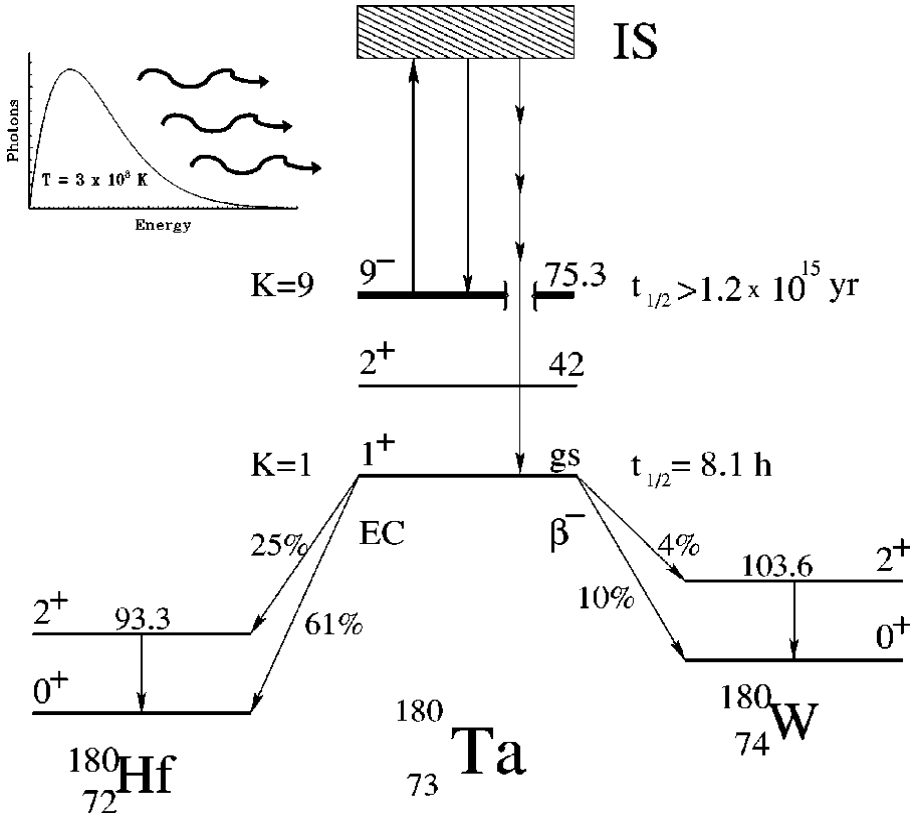


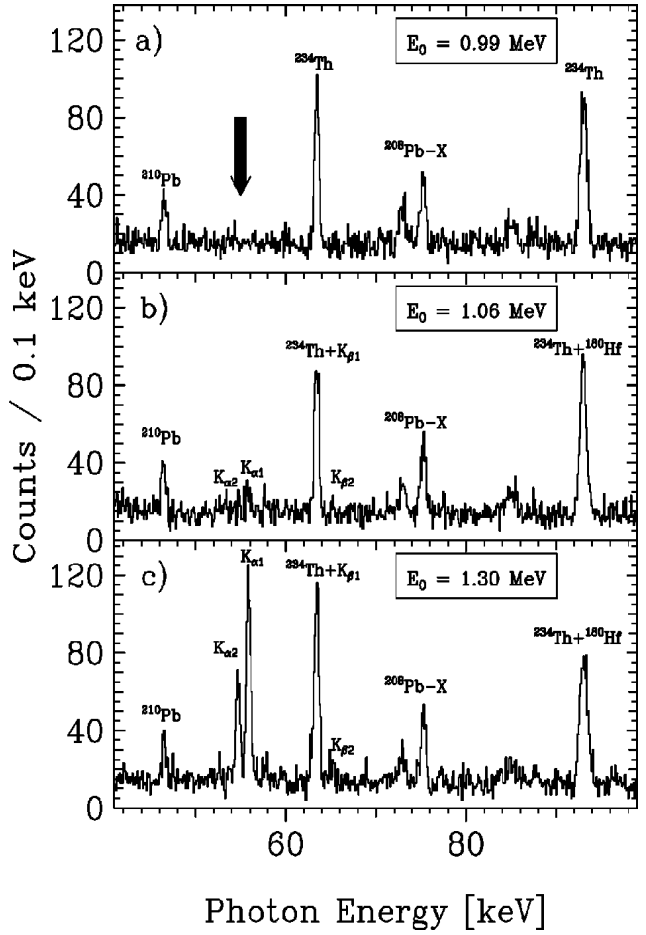
Gamma-ray detection: ***8 segmented Clover Ge det.***
4 det. $LaBr_3(Ce)$

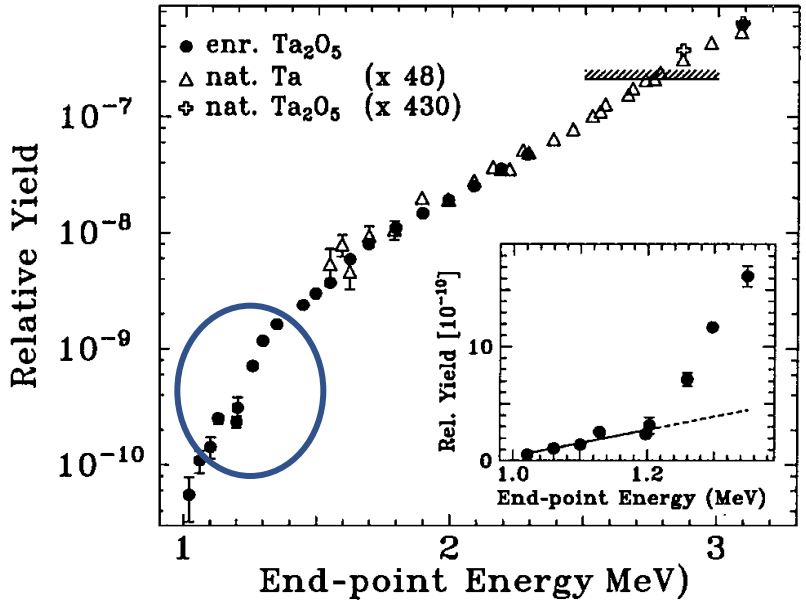
- Determine the decay widths of nuclear states
- Low-energy e.m. dipole response in nuclei
  - (e.g., actinides, rare nuclei – p-nuclei)
- Study of Pygmy Dipole Resonances
- Study of scissors mode nuclear states



Photoactivation of ^{180m}Ta







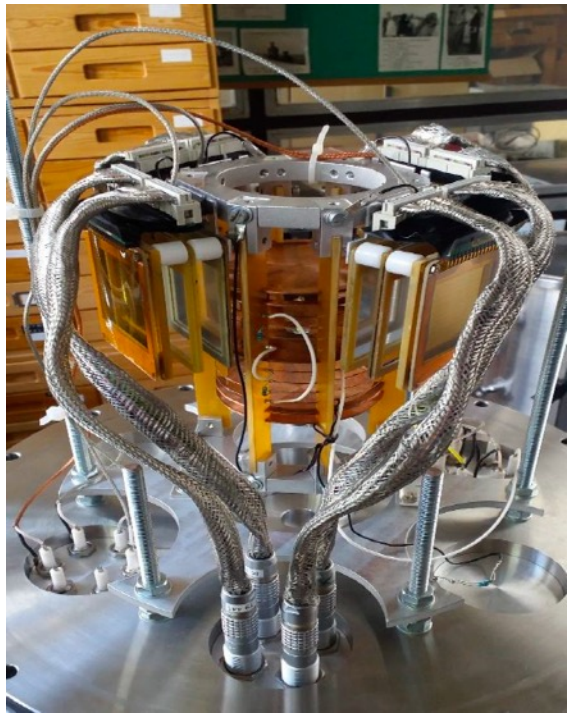
E_{IS} (MeV)		I_D (eV b)		$g_{IS}\cdot\Gamma_{ISO}\cdot\Gamma_{g.s.}/\Gamma$ (meV)	
1.01 [a]	0.057	±0.003	±0.015	0.015	±0.001	±0.004
1.22(2)	0.27	±0.02	±0.07	0.103	±0.008	±0.027
1.43(2)	0.24	±0.04	±0.06	0.126	±0.022	±0.033
1.55(3)	0.70	±0.09	±0.18	0.44	±0.06	±0.11
1.85(5)	1.11	±0.14	±0.29	1.0	±0.1	±0.3
2.16(2)	2.8	±0.3	±0.7	3.3	±0.3	±0.9
2.40(6)	3.5	±0.6	±0.9	5.2	±0.8	±1.4
2.64(3)	13	±1	±3	23	±2	±6
2.80(4)	36	±2	±9	73	±3	±19

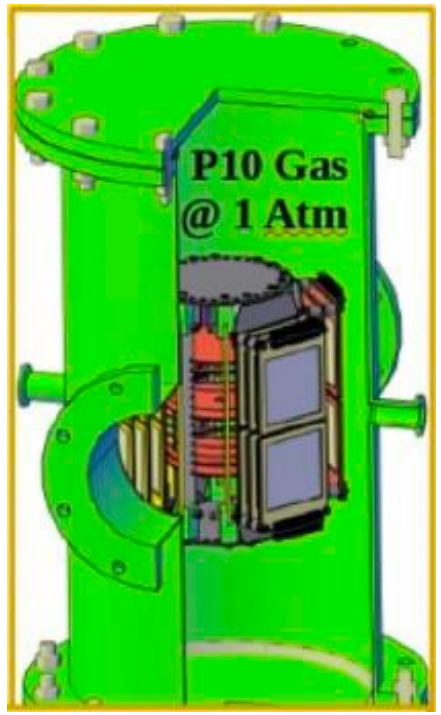
[a]Fixed by the onset of the activation.

Belic D *et al.* 2002 *Phys. Rev. C* **65** 035801

Belic D *et al.* 1999 *Phys. Rev. Lett.* **83** 5242

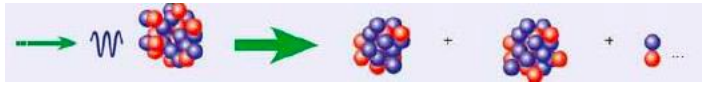
Photofission Experiments

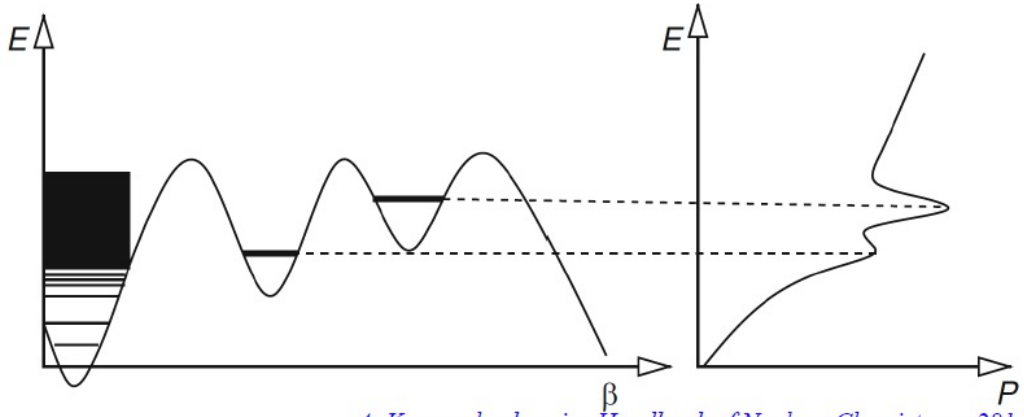




ELI–BIC = 4 x highly efficient Frisch gridded twin ionization chambers (mass, charge, kinetic energy of fission fragments) + 8 E–ΔE telescopes

- study of fission barrier (sub-barrier transmission resonances, states in the SD and HD minima, fine structure of *isomeric shelf)*
- identification of ternary fission





A. Krasznahorkay, in: Handbook of Nuclear Chemistry, p.281 (2011)

Gamma Beam Experimental Hall E9

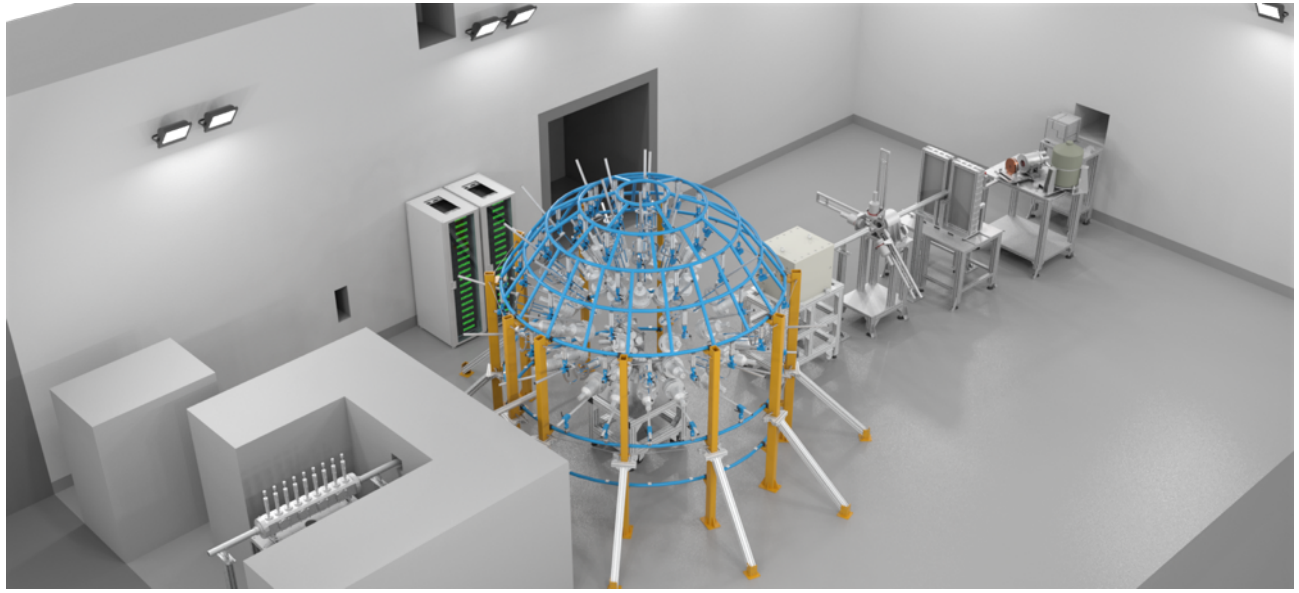
ELIGANT-GN = ELI-NP Gamma Above Neutron Threshold – Gamma Neutron

Gamma rays : 34 $LaBr_3$ and $CeBr_3$

Neutrons: 25 ^{7}Li glass detectors
36 Liquid Scintilator detectors

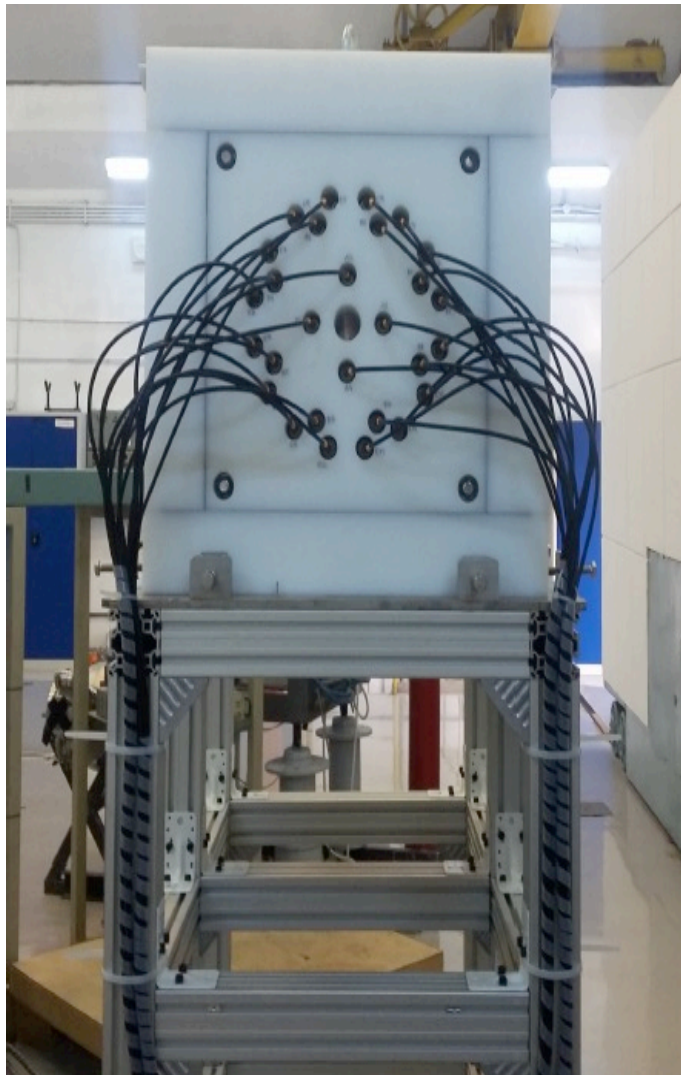
Study of GDR and PDR decay (e.g., ^{90}Zr, ^{208}Pb)

- Data from (γ,n) experiments
- Data from (γ,γ') (*e.g.,* polarization)
- Study of the γ decay to the gs and excited states as a function of excitation energy

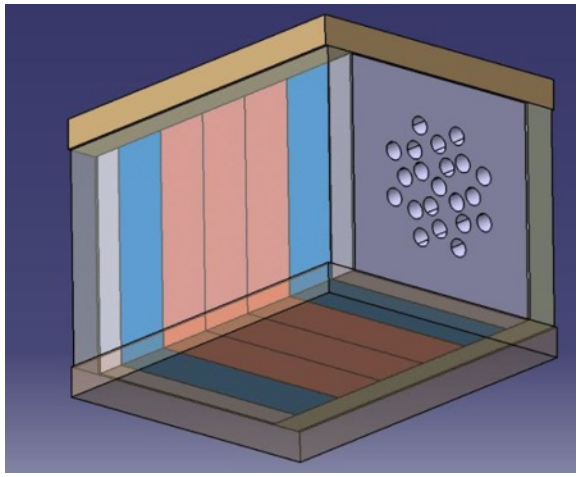


Gamma Beam Experimental Hall E9

ELIGANT-TN = ELI-NP Gamma Above Neutron Threshold – Thermal Neutron

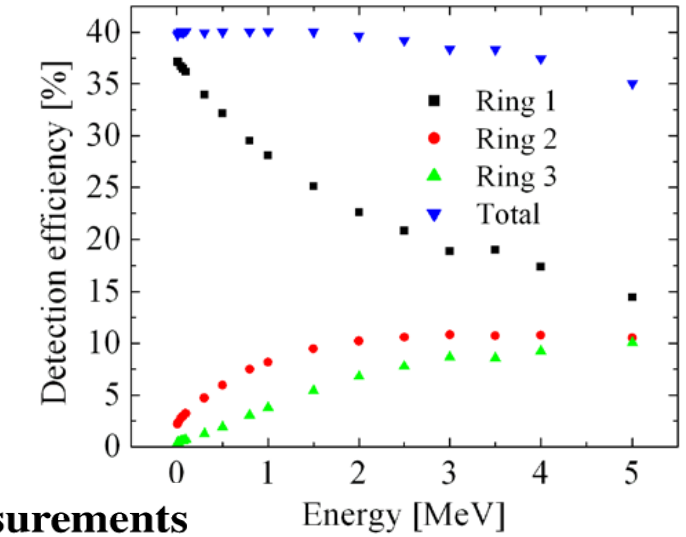


I. Gheorghe, D. Filipescu *et al.*



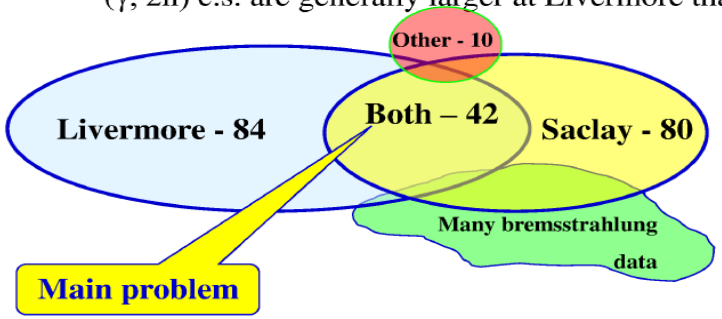
Neutrons:

28 ^{3}He counters



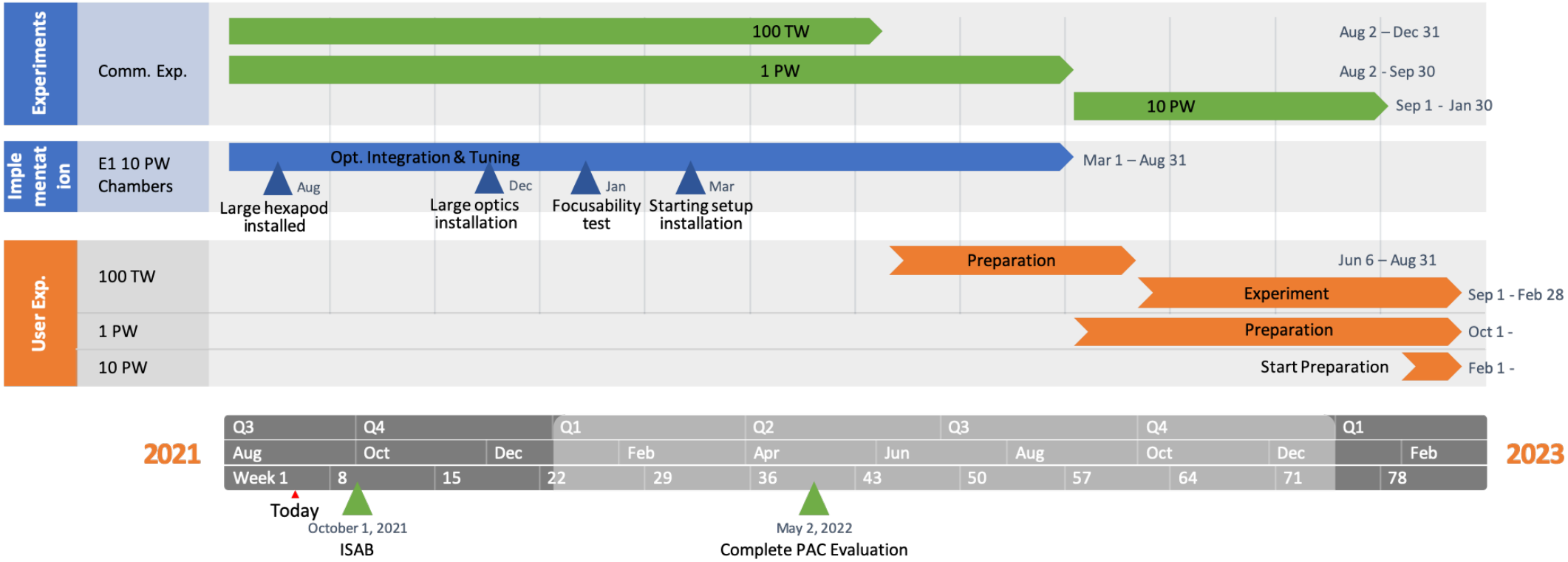
Systematics of the photonuclear C.S. measurements

- Most of the photoneutron cross section measurements were performed in period 1962 – 1986 using quasi-monochromatic annihilation – QMA photons using positron in flight annihilation at two major facilities:
  - Saclay (France) Photonuclear Data Library – IAEA 2000
  - Lawrence Livermore National Laboratory (USA)
- Large discrepancies in (γ,xn) c.s. measured at the two facilities:
  - (γ, 1n) c.s. are generally noticeably larger at Saclay than at Livermore
  - (γ, 2n) c.s. are generally larger at Livermore than at Saclay.



No systematic way to resolve the discrepancies: New and reliable measurements are required!

Transition from implementation to operation



Commissioning experiments

- expert users – they contributed to the definition of TDRs
- experiments approved by ELI-NP ISAB in the TDRs
- ***demonstrate the performance of the systems but also relevant physics***

Open access based on scientific merit/evaluation

- ***evaluation by an international scientific committee***
- additional equipment can be considered

Summary

- Laser system fully operational on all outputs / 10 PW LBTS successfully commissioned
- VEGA system under construction – to be commissioned in 2023
- Experimental areas E4 (100 TW) and E5 (1 PW) installed and under commissioning
  - First results – agree with published data
- Commissioning of experimental areas E1 and E6 (10 PW) will start mid 2022
- User experiments - call for proposals foreseen for beginning of 2022
- The research infrastructure will be installed and fully commissioned by the end of 2023

EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2014-2020

Project co-financed by the European Regional Development Fund through the Competitiveness Operational Programme "Investing in Sustainable Development"

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

Thank you !

www.eli-np.ro