EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2014-2020

IFIN-HH

eli nuclear physics

NUCLEAR PHOTONICS AT EXTREME LIGHT INFRASTRUCTURE – NUCLEAR PHYSICS

CĂLIN A. UR
ELI-NP / IFIN-HH

May 29, 2025

INPC 2025

INPC 2025 Daejeon, South Korea

Extreme Light Infrastructure – Nuclear Physics @ ELI

High-Energy Beam Facility: application of primary and secondary sources of high-energy radiation and particles (*ELI-Beamlines*, Prague, CZ)

Attosecond Laser Science: new regimes of time resolution in broad spectral ranges (*ELI-ALPS*, Szeged, HU)

Nuclear Physics Facility: ultra-intense lasers and brilliant gamma beams (up to 19 MeV) enabling novel nuclear and photonuclear studies (*ELI-NP*, Magurele, RO)

Dedicated to NUCLEAR PHOTONICS

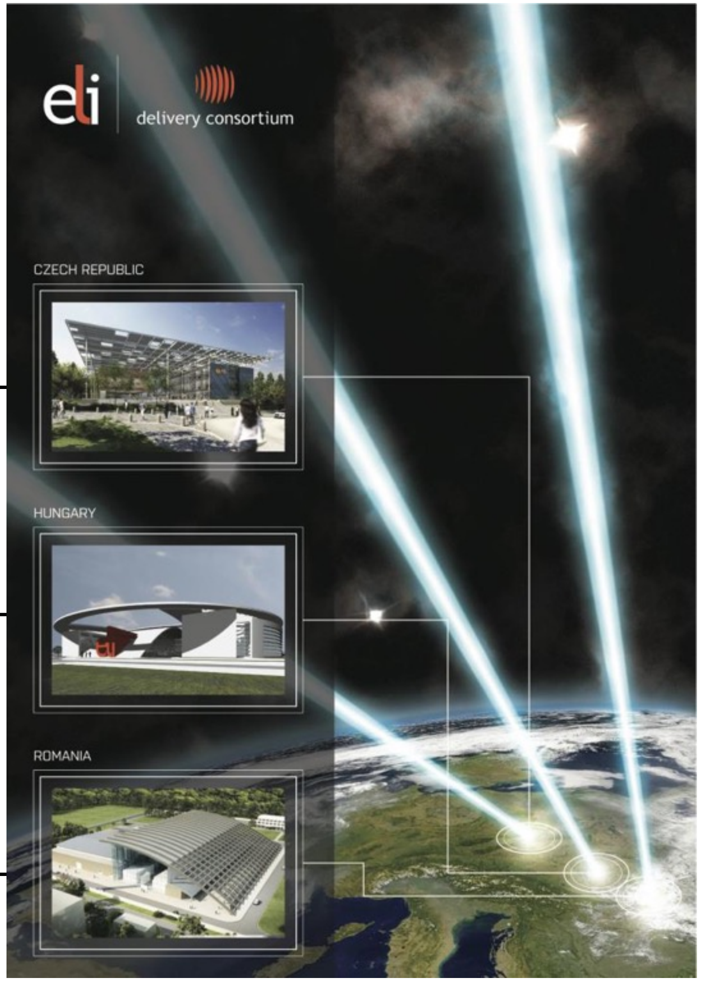
Fundamental physics research ...

- characterizing laser-matter interaction with nuclear methods
- particle acceleration with high power lasers
- nuclear reactions in plasma
- nuclear astrophysics and nucleosynthesis
- quantum electrodynamics

... and applied – developing technologies with potential for:

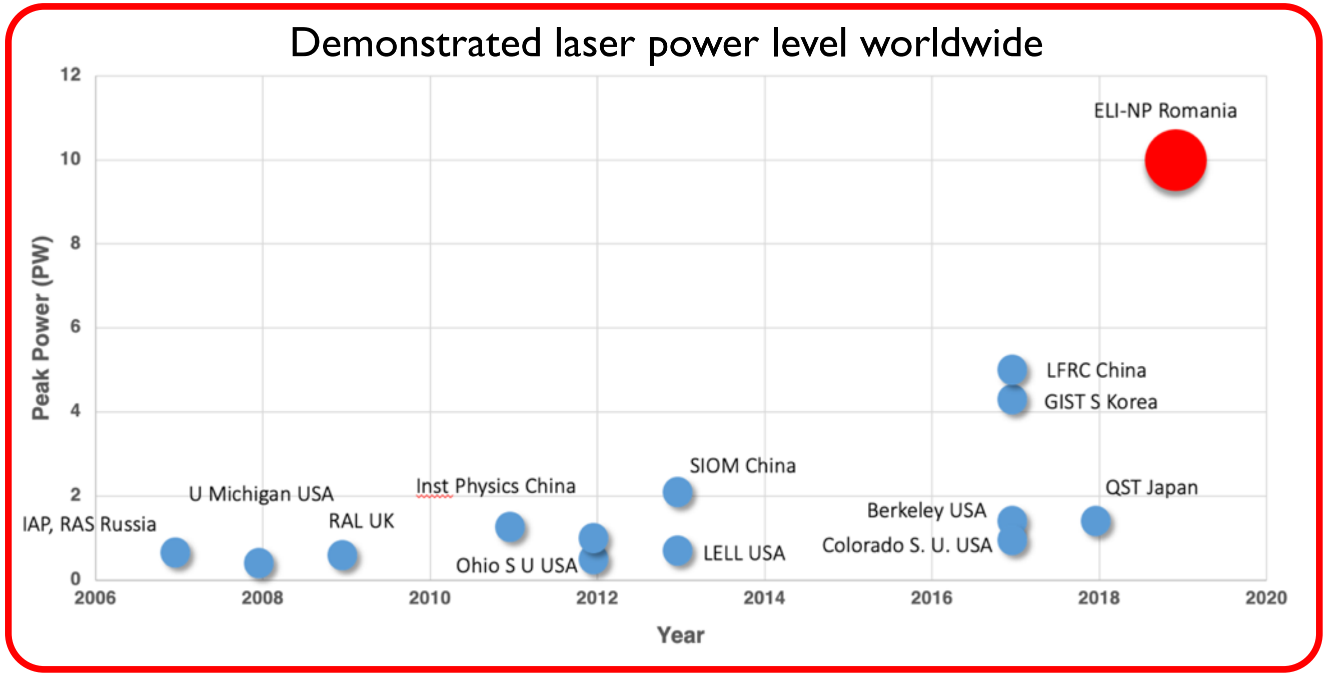
- medical applications (hadron therapy, X-ray imaging, medical use radioisotopes)
- industrial applications (non-destructive gamma ray inspection, active interrogation)
- material studies with positrons

Extreme Light Infrastructure (ELI)



ELI - the largest laser research center worldwide distributed in three countries (RO, HU, CZ)

Most powerful laser system operational in the world @ ELI-NP



- demonstrated **power level 10 PW**
- combination of **2 high-power lasers**
- each arm has three output power levels:

  100 TW@10 Hz

  1 PW@1 Hz

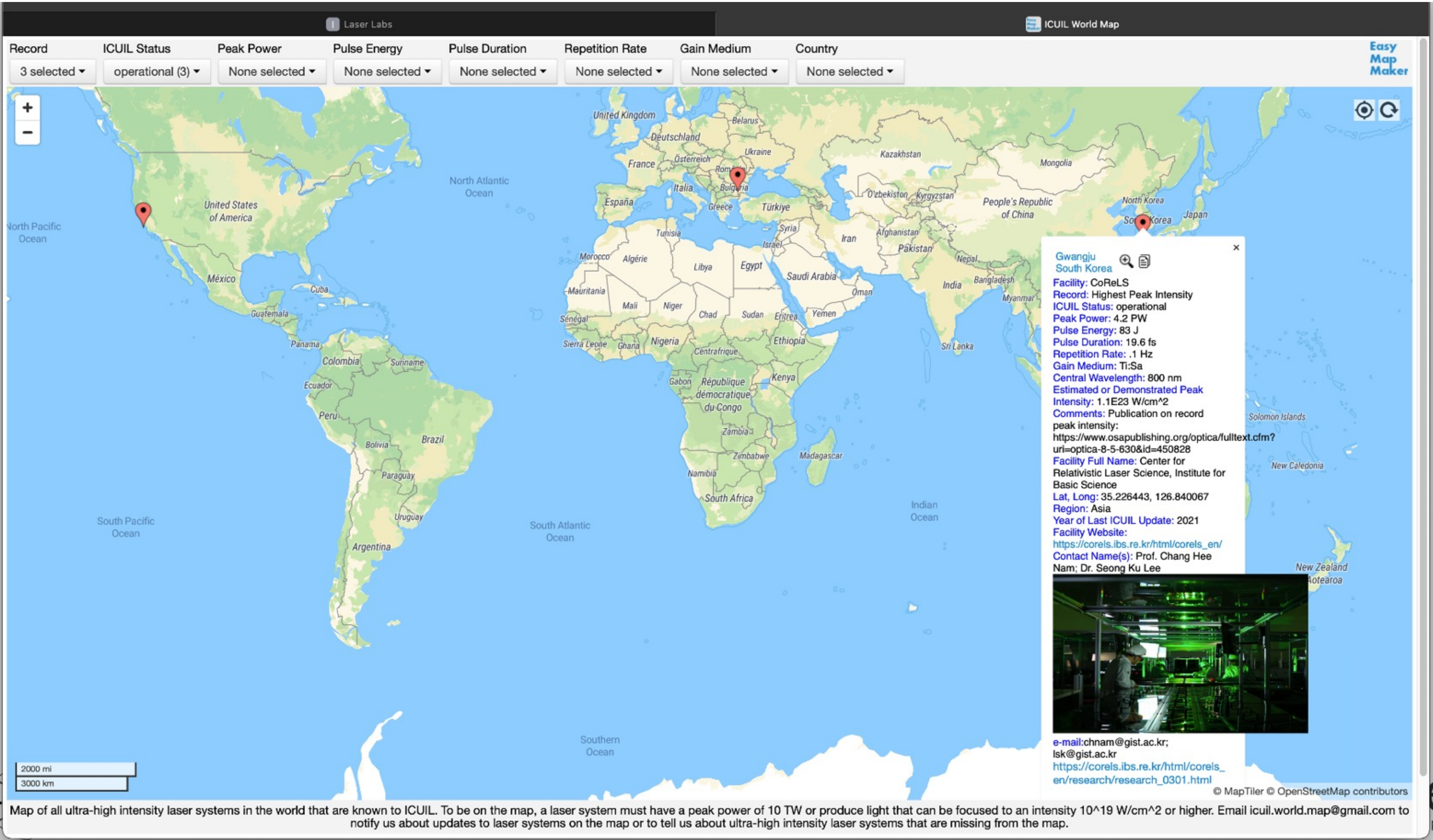
  10 PW@1/minute

High-power lasers the world

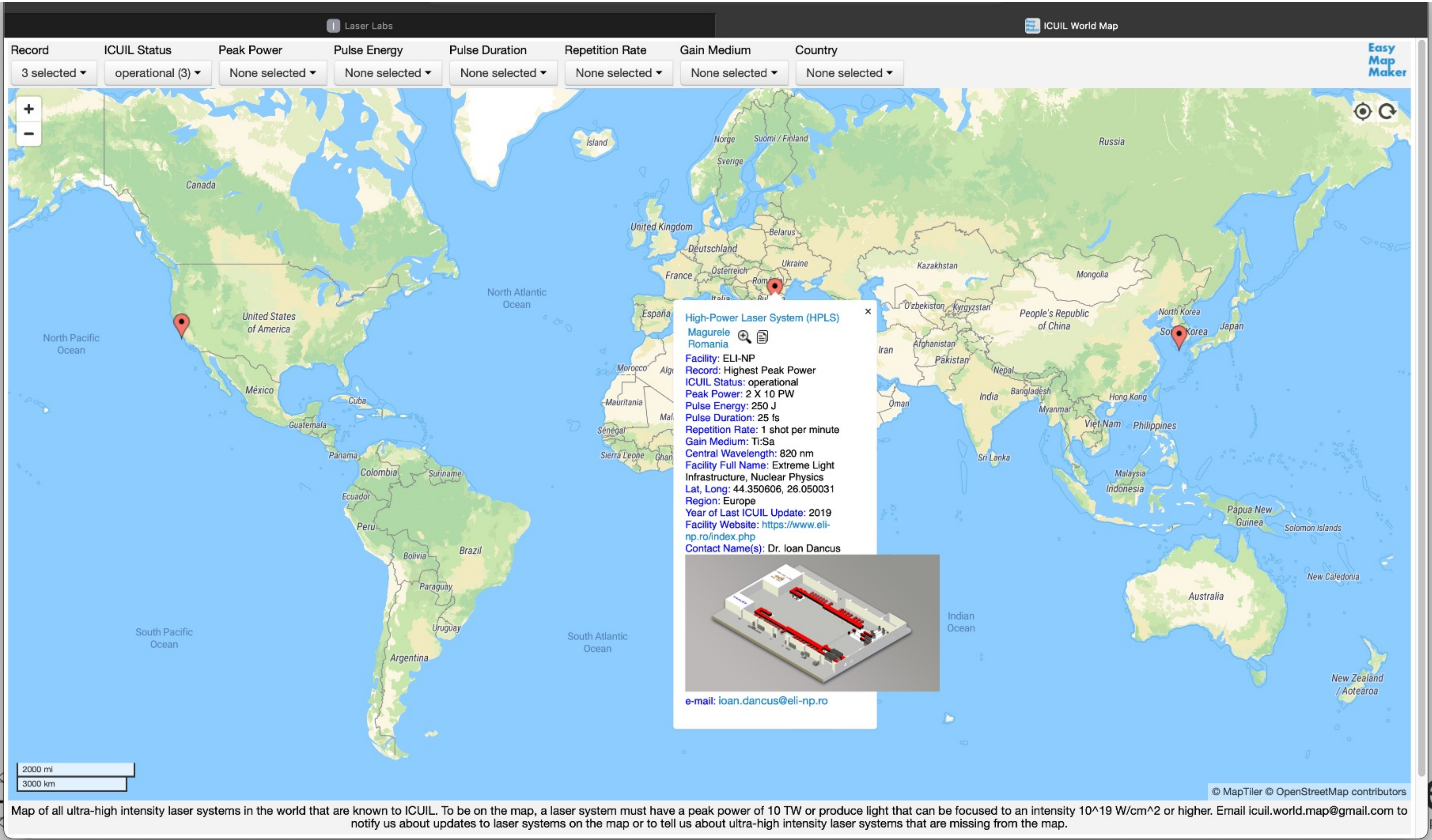
Extreme Light Infrastructures – worldwide records

Highest pulse energy

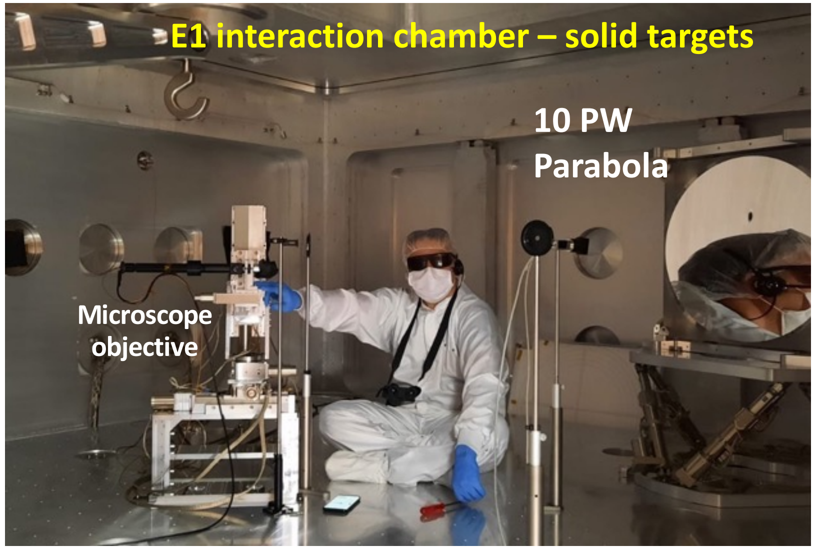
Highest peak intensity



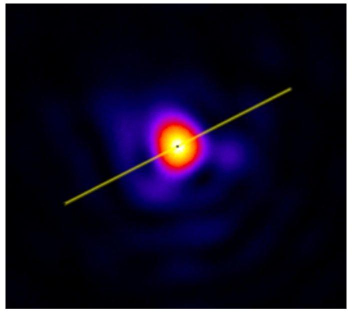
Highest peak power

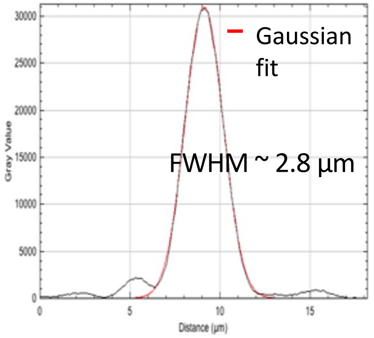


April 13th 2023 – a landmark in the history of plasma physics



First tests show focal spot below ***3 μm***





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

→ $E = 0.86 \times 10^{15}$ V/m

$B = 3 \times 10^{6}$ T

Extreme light intensity (10 PW ⟹ 10^{23} W/cm^2)

Extreme electric fields (10^{15} V/m)

Strong-field QED

10 PW laser + solid target

↓

PW γ-source

10 PW laser + GeV LWFA electrons

↓

Radiation reaction
Breit-Wheeler pairs
QED vacuum

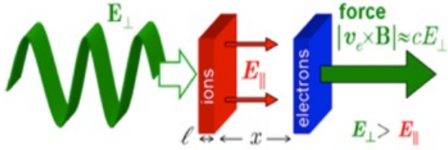
Extreme light pressures (Tbar)

Nuclear Physics with Lasers

10 PW radiation pressure acceleration of *dense* ion beams

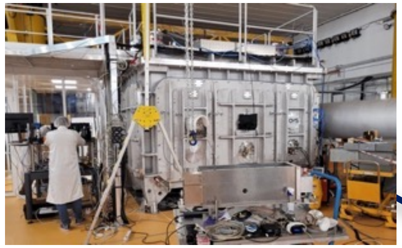
Nuclear reactions in plasma

Ultra-intense neutron source



Laser field sweep away all electrons, forming an electrostatic field

Laser-driven experimental setups – all operational



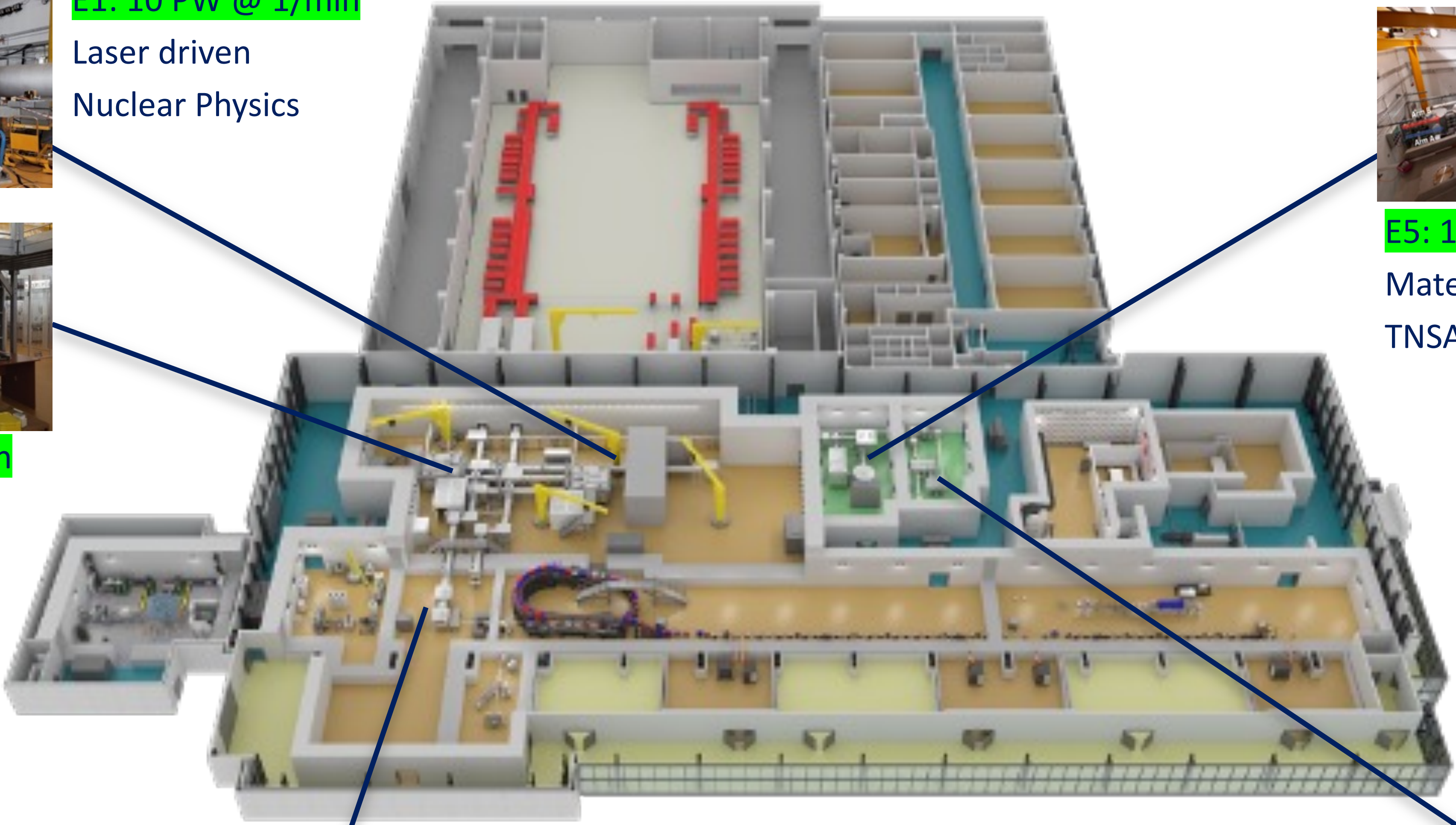
E1: 10 PW @ 1/min

Laser driven

Nuclear Physics

E6: 10 PW @ 1/min

High Field QED



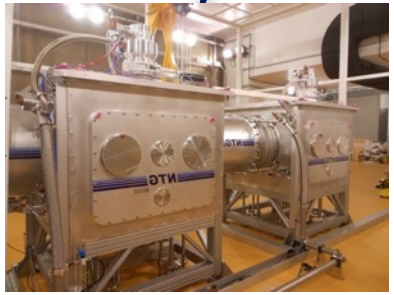
E5: 1 PW @ 1 Hz

Material Studies, LWFA,

TNSA, RPA

E7: 1 PW @ 1 Hz

High Field QED



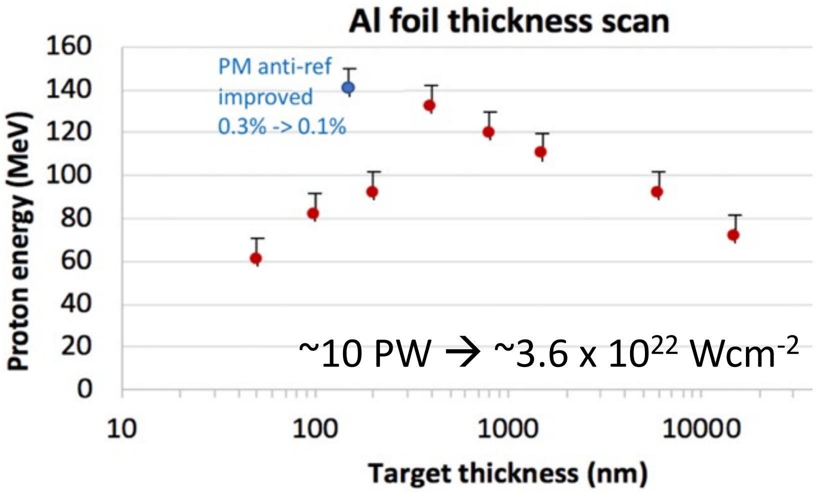
E4: 0.1PW@10 Hz

Photon-photon int.,

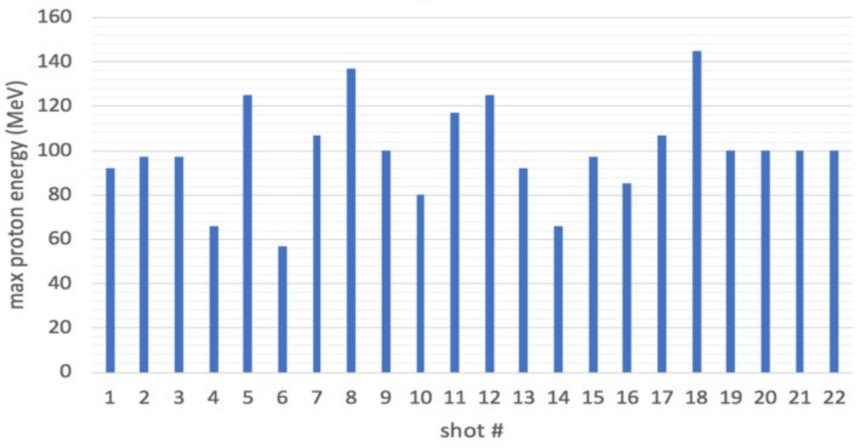
LWFA, X-ray imaging

10 PW Highlights – Ion acceleration

Protons



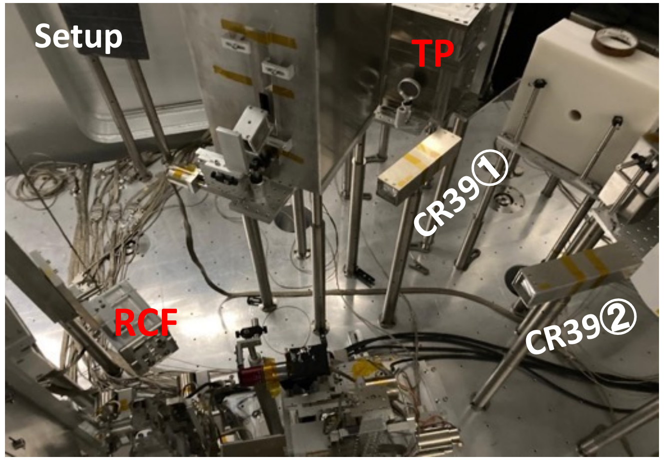
H+ cutoff energy from Al and Au targets < 1.5 µm



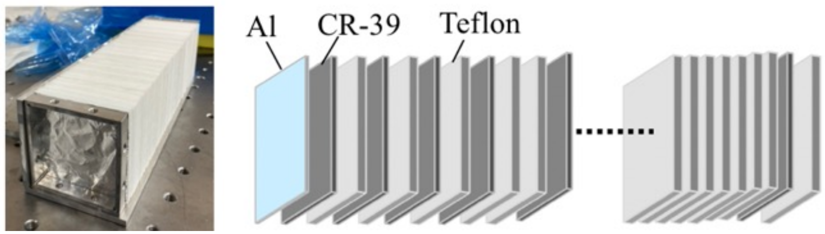
PI: D. Doria (ELI-NP)

Collaboration: CLF-RAL (UK), ELI-BL (CZ), HZDR (DE), Strathclyde Uni. (UK), KPSI and Osaka Uni. (JP), UCSD (US)

Carbon ions

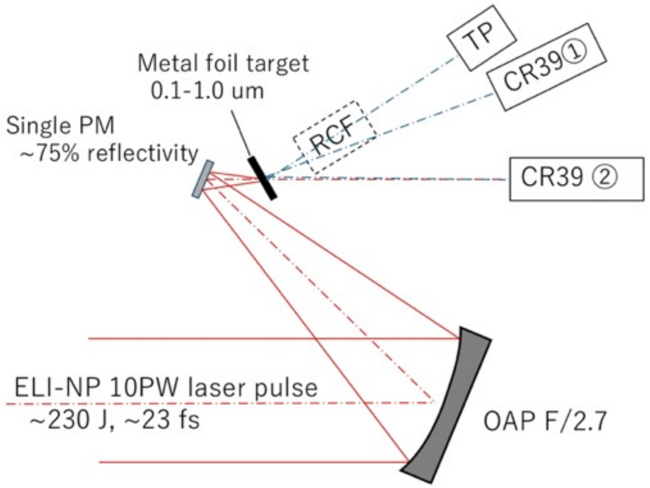


Schematic of the CR-39 Stack

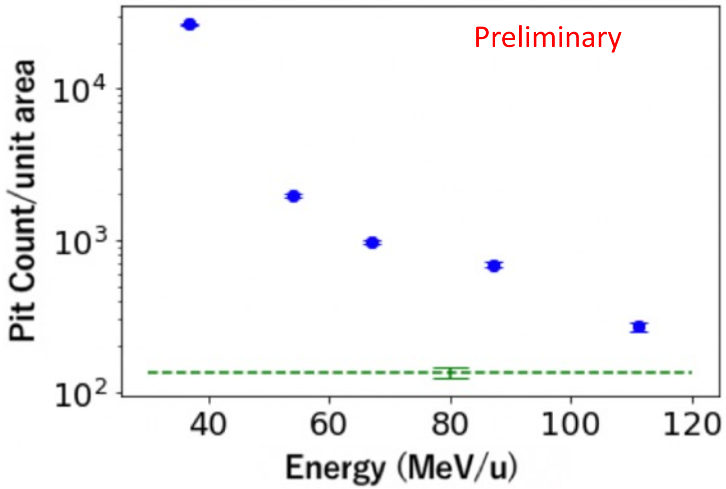


M. Kanasaki et al., in preparation.

T. Sato et al., J. Nucl. Sci. Technol. **55**, 68 (2018).



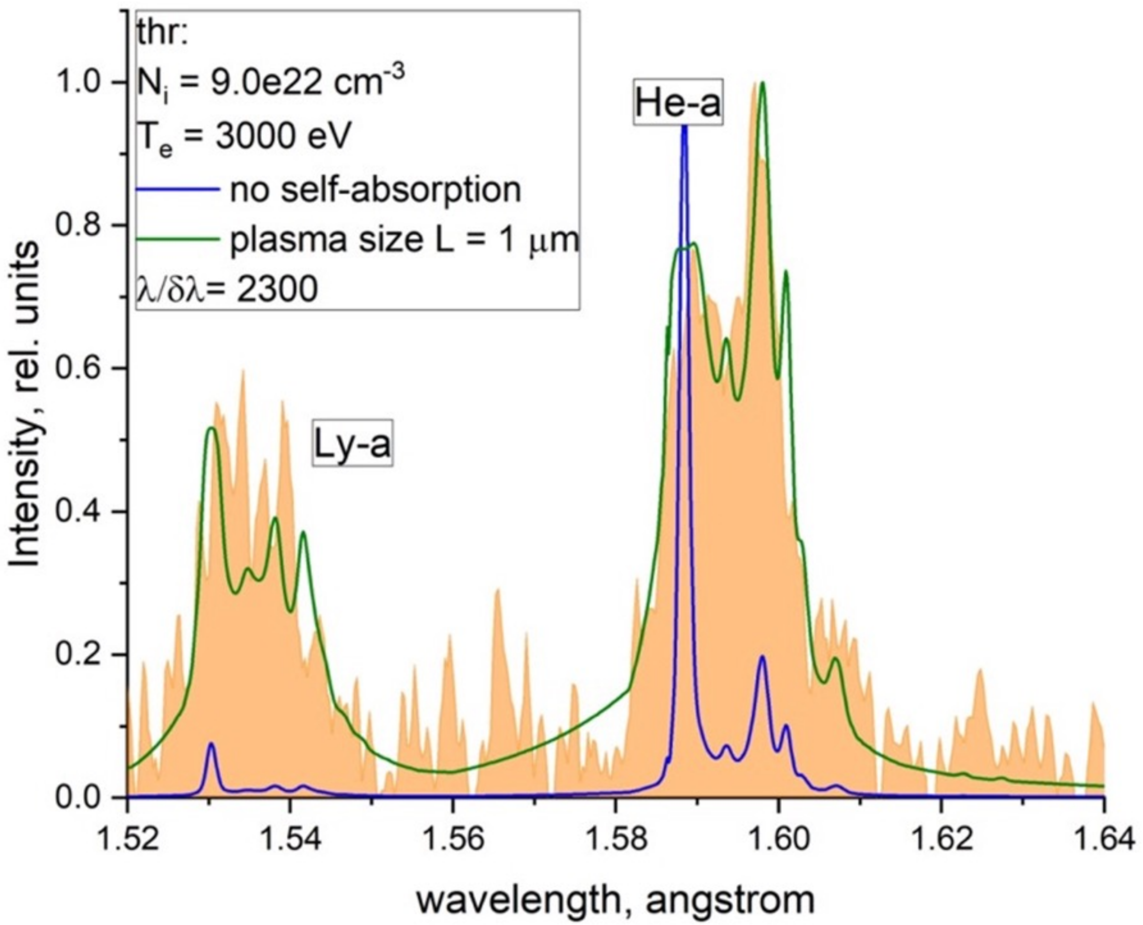
Carbon ion spectrum



Collaboration: Kobe U., KPSI

10 PW Highlights – Fully ionized ions

Experiment at high intensity in E1 interaction chamber



First observation of H-like Ly_α of Ni (Z=28) in laser produced plasma (Collaboration with Osaka University)

High ionization states at solid density are a paramount in plasma physics since it opens the possibility to investigate states of matter that are similar to those existing in stellar environment.

For **the first time a fully ionised plasma of Nickel atoms at solid density has been created** and fully characterised through the measurement of Ly_α line indicating a temperature of 3 keV at a density close to 10^{23} e^-/cm^3

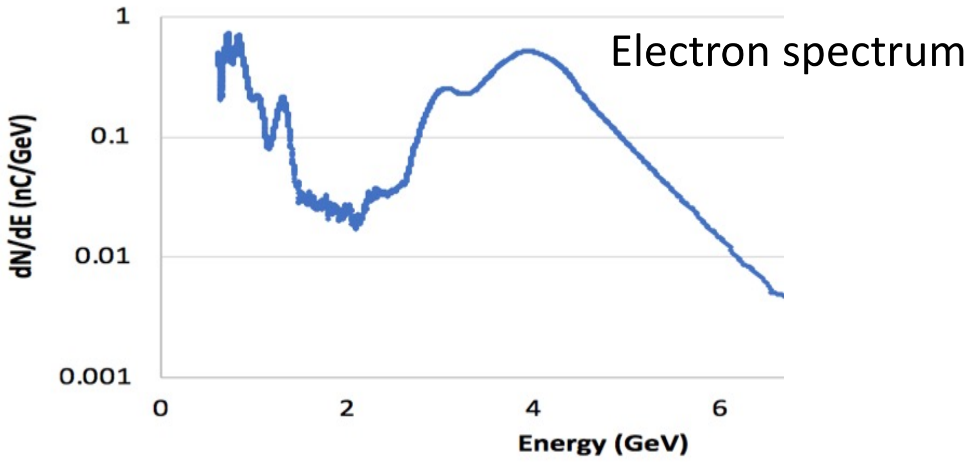
Courtesy of T. Pikuz

10 PW Highlights – High energy electrons and gamma rays

Interaction chamber E6 – gas targets

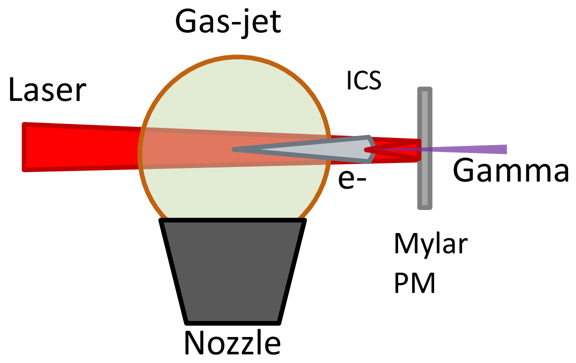
Electron acceleration using 60 mm gas length , He+N2 2% gas

RAW image of the Lanex scintillator screen

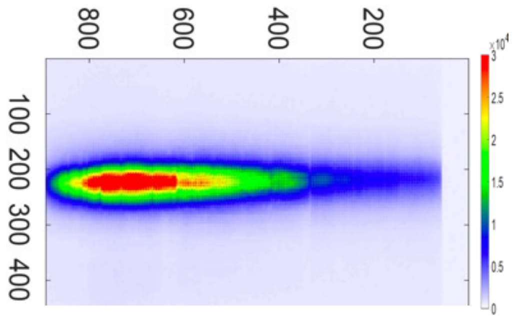


High-energy gamma rays following Inverse Compton Scattering

Sketch of the ICS setup



Gamma from Inverse Compton Scattering – LYSO matrix detector



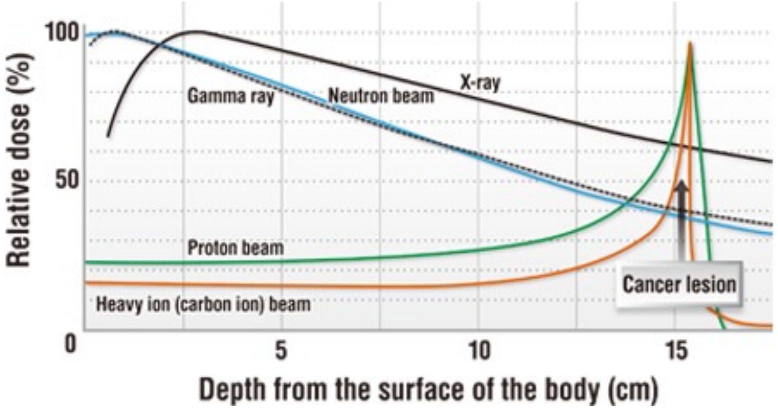
Collaboration with Weizmann Institute, CLF-RAL, QST-KPSI, Osaka University

Courtesy of D. Doria

Laser – driven medical applications research

Dr. LASER

Laser-driven ions for hadron therapy

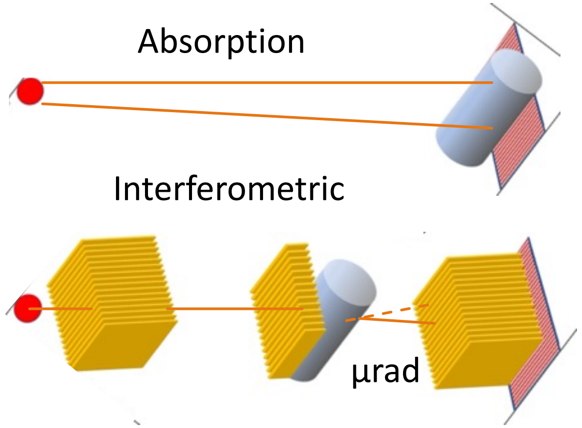


10 PW-class lasers have potential to accelerate particles and heavy-ions (p, α, C, N) to therapeutic energy and dose, at ultrahigh dose rate, in few µm

laser-driven ultra-high dose rate heavy-ion irradiation can enable **the FLASH effect** (healthy tissue sparring) (10^{10} Gy/s)

Proposed medical focus on long term: **start from skin-level cancer, progressing to HNC and breast cancer** (#1 cause of cancer mortality for women)

Interferometric phase contrast X–ray imaging



- **Conventional**, absorption-contrast **X-ray imaging has poor visibility of soft tissue tumors**
- **Phase-contrast X-ray imaging investigated as alternative**
- Method requires intense, directional, short–pulse and spatially coherent X–ray source: **100 TW class lasers can do this**
- Proposed medical focus: **breast cancer and later lung cancer**

Medical interest radioisotopes production

Radioisotopes have a central role in nuclear medicine, for the diagnosis and treatment of cancer (40 million procedures/year)

High power lasers offer an advantageous alternative for producing medical radioisotopes due to their ability to accelerate different types of particles

The "***on-site*** **" production of medically important short-lived radioisotopes, such as ^{11}C, ^{13}N or ^{15}O**, is difficult with conventional accelerators, but **becomes feasible with lasers**

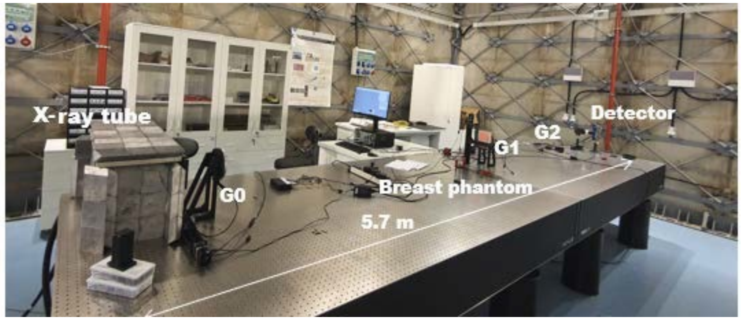
100 TW-class high repetition rate laser sufficient for radioisotope production

Cofinanțat de Uniunea Europeană

Program Sănătate

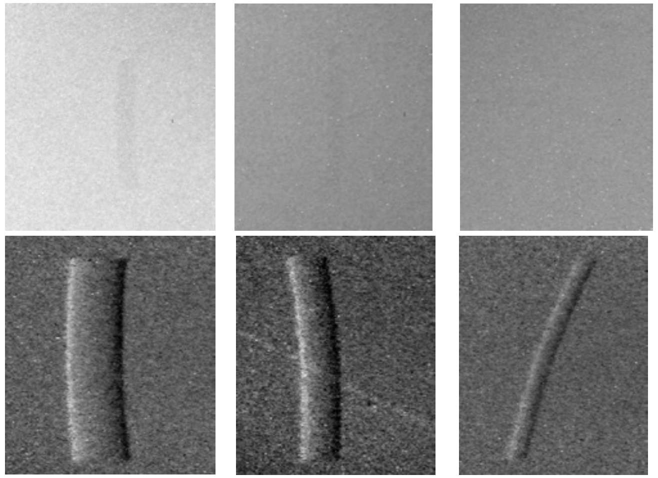
Interferometric phase contrast mammography with laser produced X-rays

6 m length 2.4 µm period grid interferometer at ELI-NP



Predictions confirmed by experiments with conventional X-ray tube – 2 mGy

1120 µm | 750 µm | 400 µm

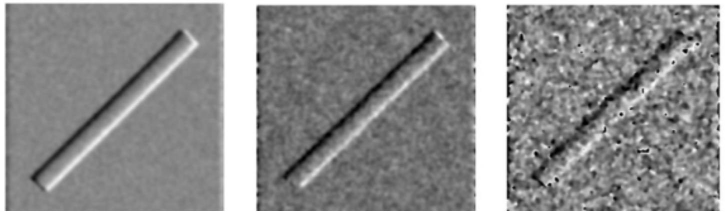


N Safca et al Phys Med Bio 2022

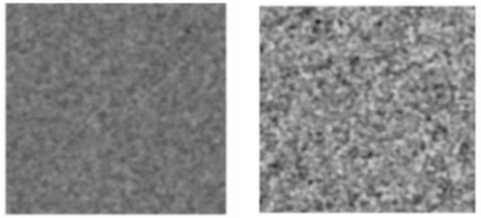
Interferometry with directional and intense laser-based X-ray sources to be developed towards clinical mammography (<1 s exposure)

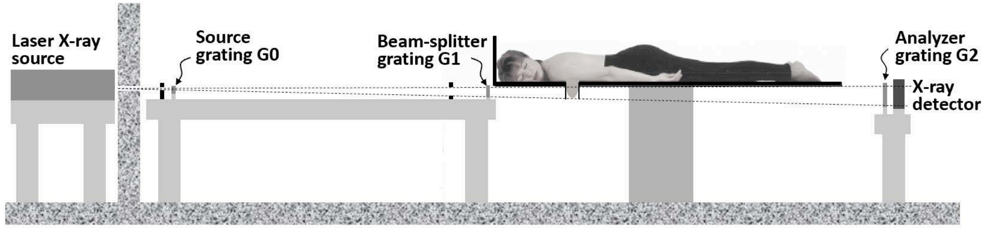
Predicted interferometric images of 400 µm breast glandular tissue in adipose tissue, with 6 m length 2.4 µm period interferometer at 33 keV

2 mGy ($3x10^{10}$ photons/shot) | 0.2 mGy ($3x10^{9}$ photons/shot) | 0.02 mGy ($3x10^{8}$ photons/shot)



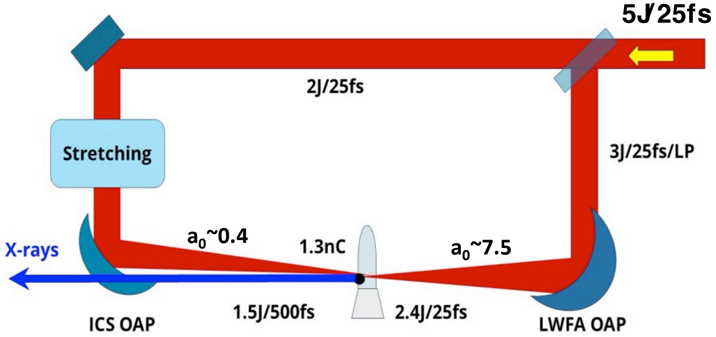
Conventional images



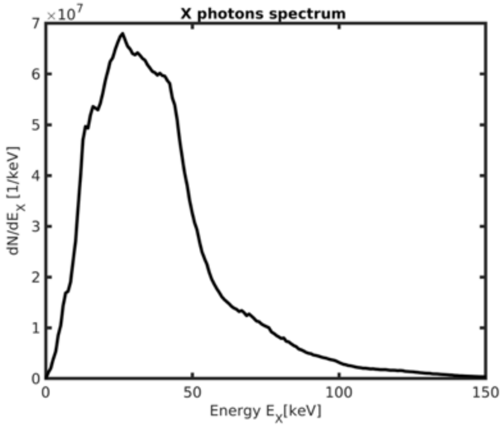


- Strongly enhanced soft tissue contrast at low dose predicted for interferometric phase contrast imaging with multi-m long, µm-period grid interferometers
- Potential for ultrasensitive, low dose mammography

Self-synchronized "all-optical" ICS scheme (P Tomassini, ELI-NP)



10^9 photons/shot in 20-60 keV band, 20 mrad cone, 2.5 µm diameter 5 µm length X-ray spot (coherence)



D Stutman et al SPIE 2023

PIC simulations predict "all-optical" Inverse Compton source with 200 TW laser adequate for clinical interferometric mammography

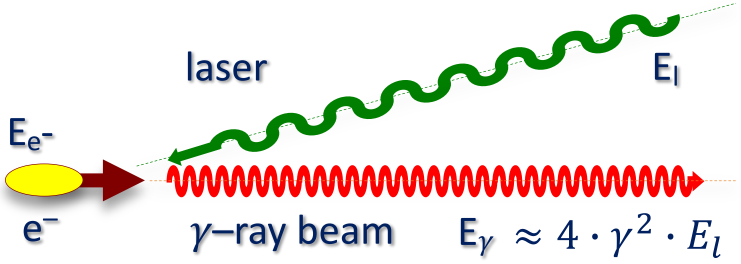
Cofinanțat de Uniunea Europeană

Program Sănătate

Courtesy of D. Stutman

The Gamma beam system

Laser Compton Backscattering off relativistic electrons



Laser – electron collider

$$N_\gamma = L\sigma_T$$

$\sigma_T = 0.67 \cdot 10^{-24}\ cm^2$ – very small

$$L = \frac{N_L N_{e-}}{4\pi\sigma_x^2} f$$ – needs to be very high

To be completed in 2026

Solution

RF electron linear accelerator and optical cavity

$L \sim 10^{35}\ cm^{-2}\ s^{-1}$

Energy up to: **19.5 MeV**

Quasi-monochromatic: **< 0.5% rel. bandwidth**

High spectral density: **> 5000 photons/eV/s**

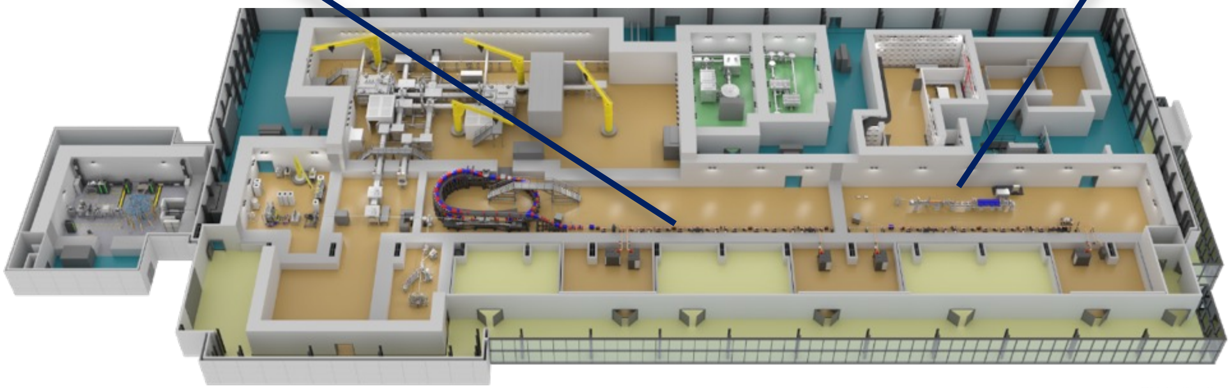
High-degree of linear polarization: **> 95%**

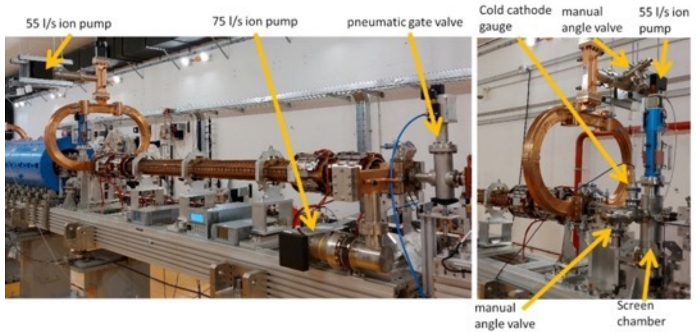
Gamma Beam System

- Commercial contracts
- Local personnel

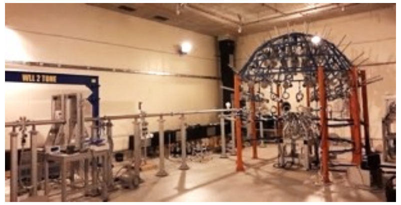
Scalable System for Radioisotopes Production

- Collaboration with INFN and CNRS





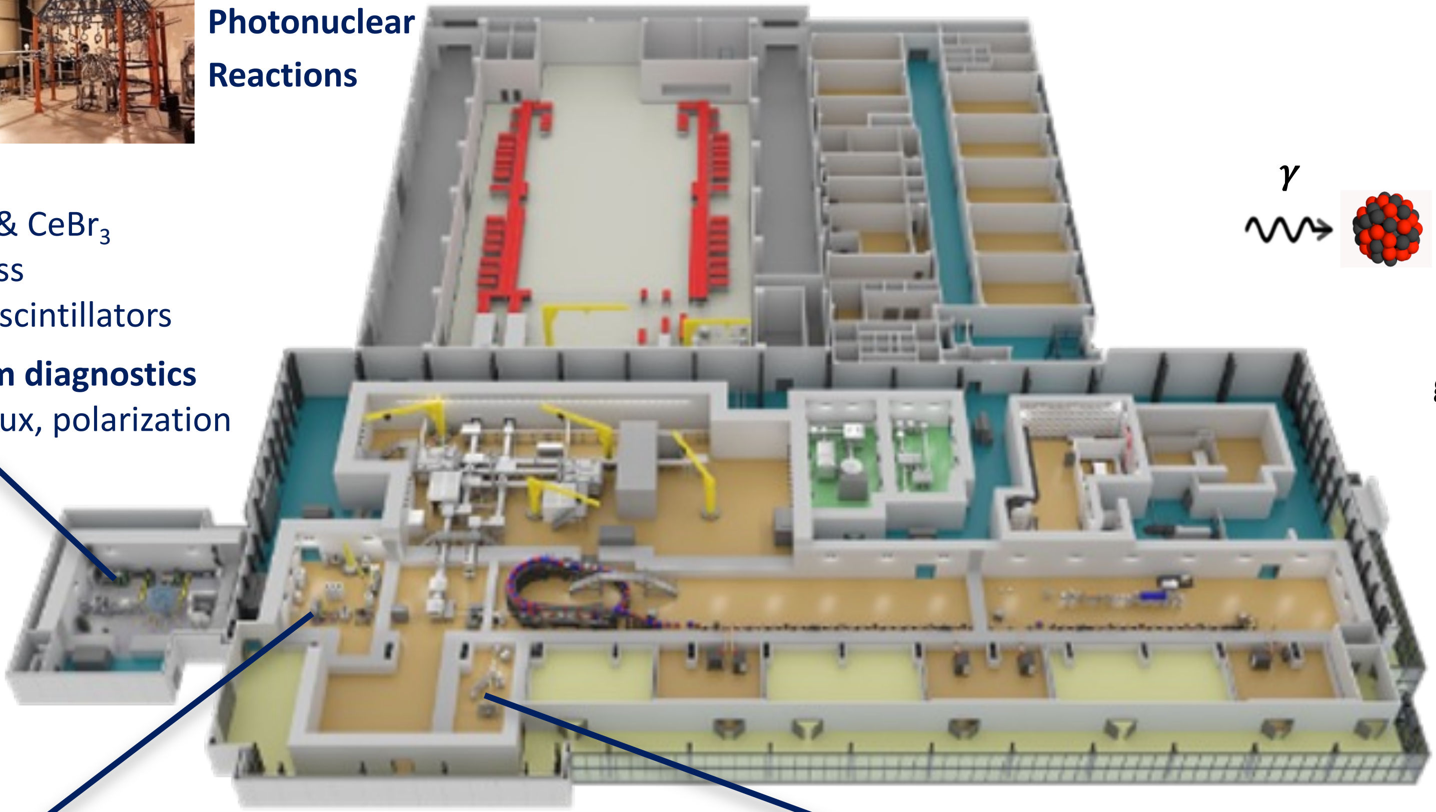
Gamma-driven experimental setups



E9: γ beams
Photonuclear Reactions

ELIGANT-GN
- 34 $LaBr_3$ & $CeBr_3$
- 25 ^{7}Li glass
- 36 liquid scintillators

Gamma beam diagnostics
- energy, flux, polarization

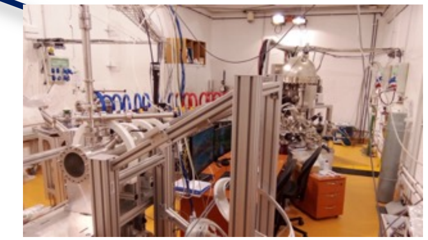


E8: γ beams
Photonuclear Reactions

ELIADE
- 8 HPGe segmented clover
- 4 $LaBr_3(Ce)$

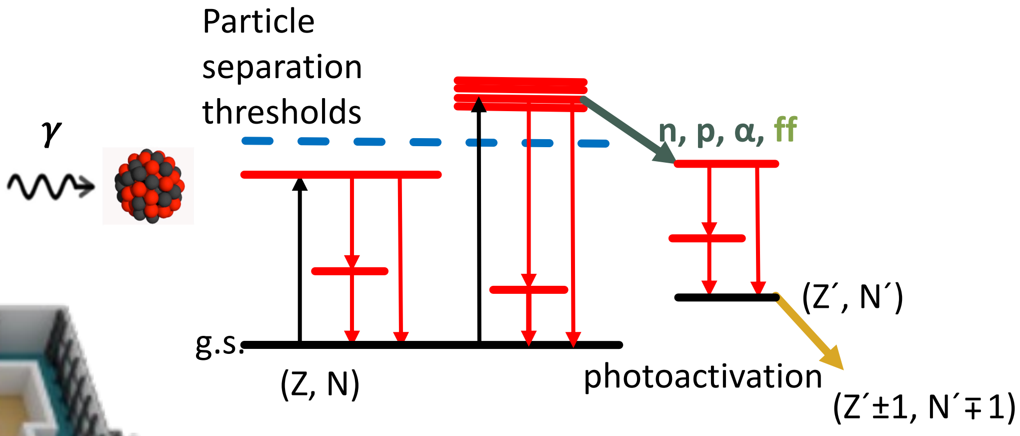
Gamma-Ray Imaging

ELISSA
- DSSSD



ERA: positrons
Material Studies

Physics Case: photonuclear reactions

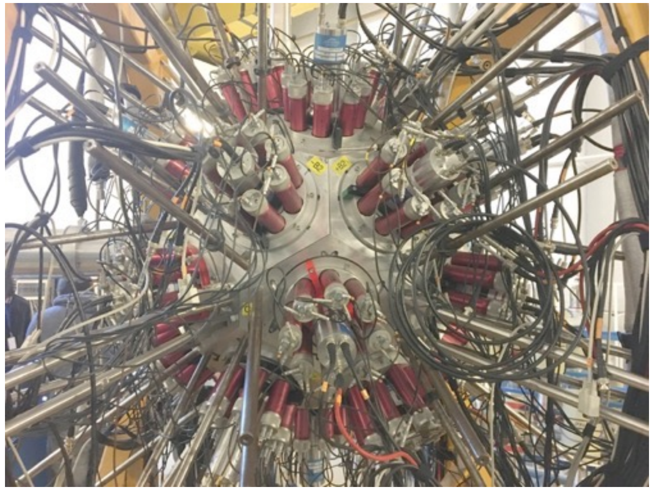


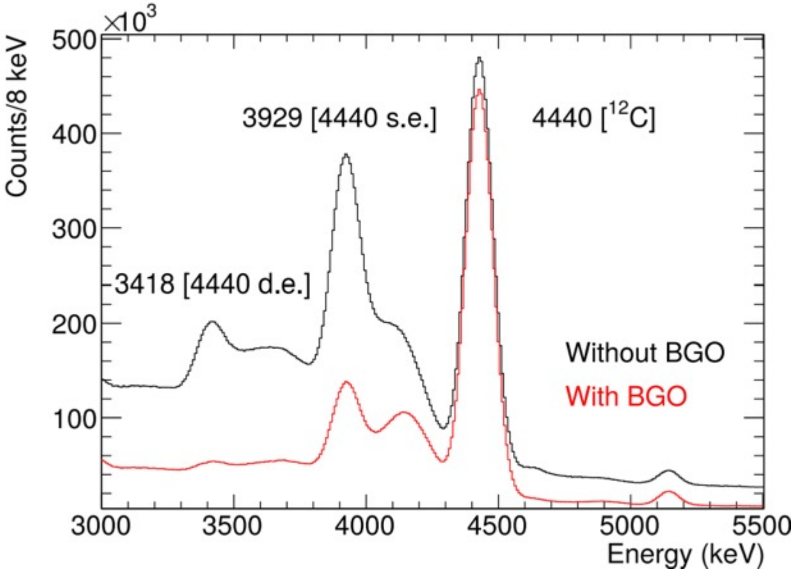
Nuclear physics
- e.m. dipole response of nuclei
- Nuclear structure
- Pygmy and Giant Dipole Resonances
- Photonuclear reactions cross sections
- Nuclear astrophysics
- Photofission and exotic nuclei

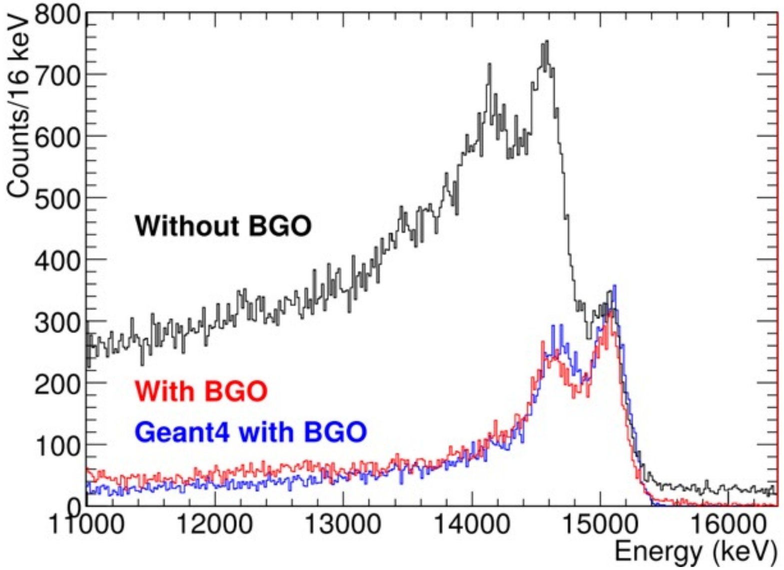
Applications
- Industrial imaging
- Radioisotopes generation
- Material studies with positrons

ELIFANT – Gamma-ray spectroscopy – at IFIN-HH 9 MV Tandem

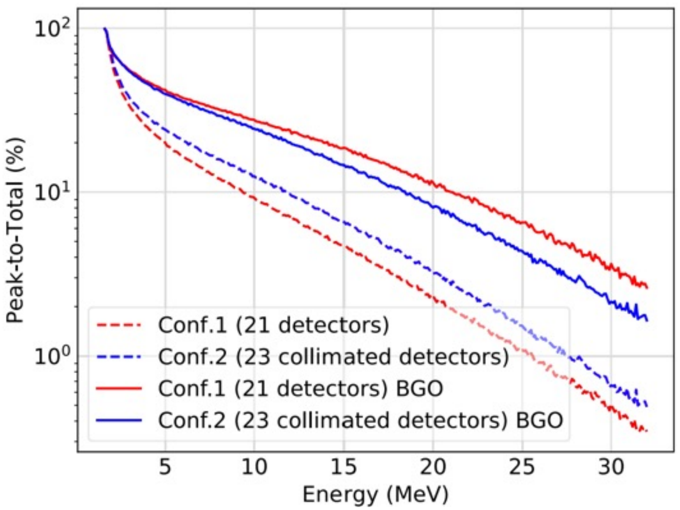
ELIFANT

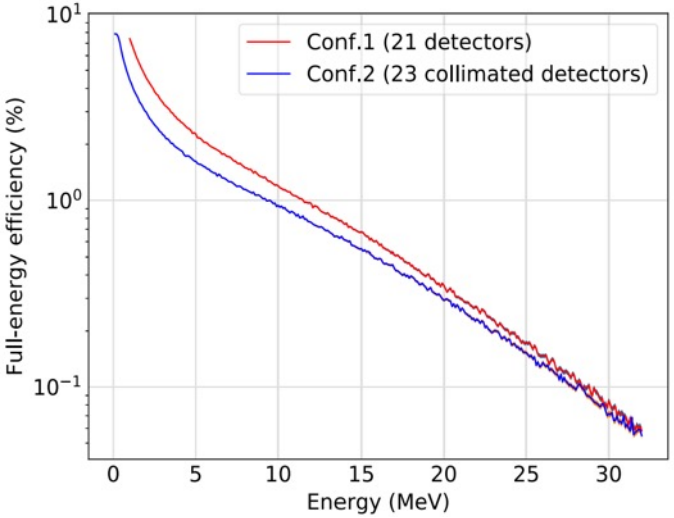






- 23 $LaBr_3$/$CeBr_3$ – used in the ROSPHERE array replacing HPGe detectors in the AC shields
- Three experimental campaigns (2022 – six months; 2023 – three months; 2024 – five months)
- 16 experiments successfully carried out





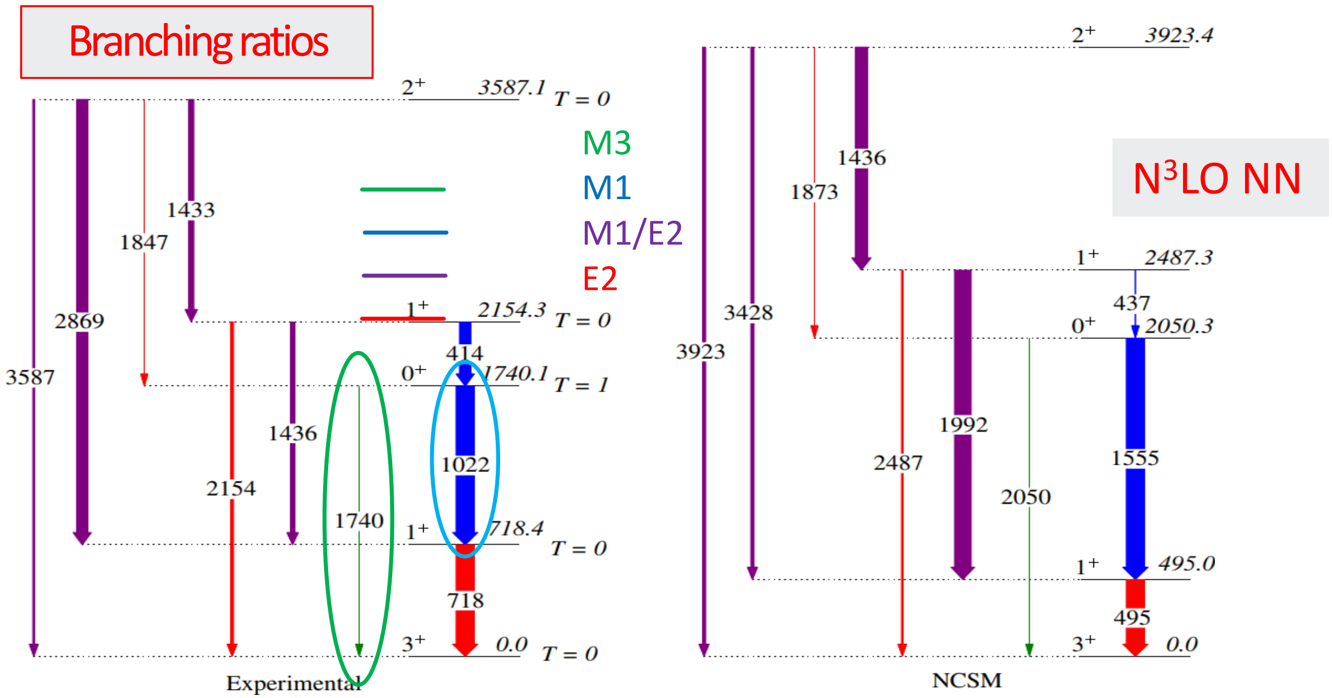
ELIFANT – Gamma-ray spectroscopy

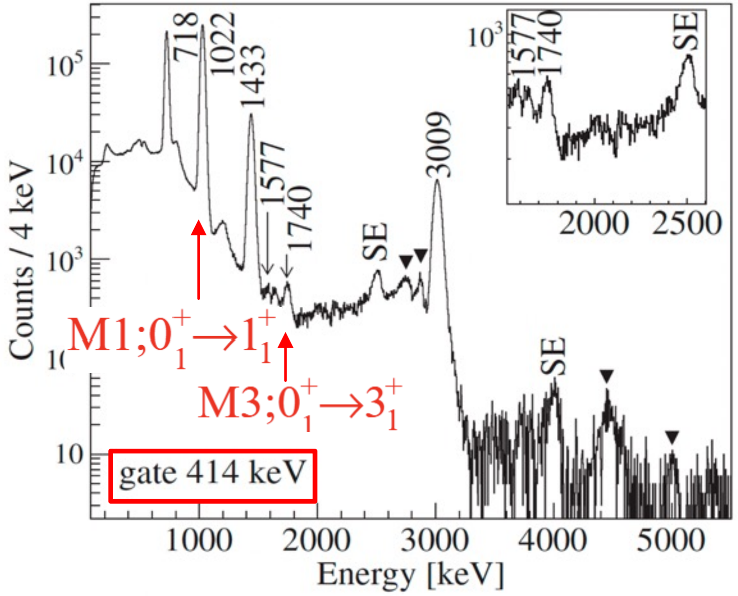
Direct observation of competing M1 and M3 transitions in ^{10}B

$^{10}B(p, p')^{10}B^*$ @ 9 MV Tandem IFIN-HH

- ^{10}B target (99.24% purity) 30 mg/cm^2
- 23 large volume LaBr3:Ce/CeBr$_3$ and 2 HPGe (high efficiency setup)

$\lambda = I_\gamma(M3)/I_\gamma(M1) = 2.5(1) \cdot 10^{-4}$





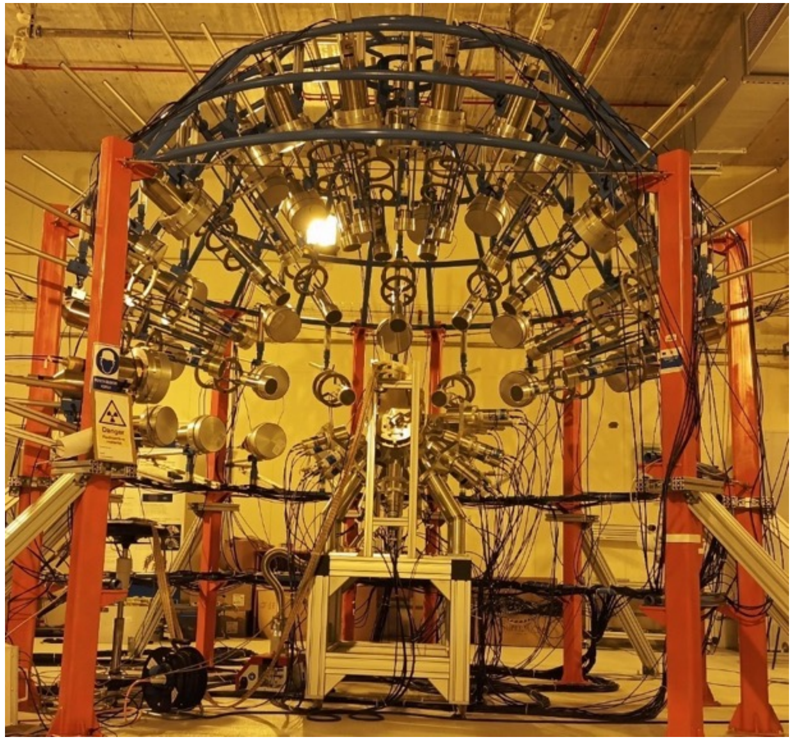
✓ *A. Kuşoğlu, D.L. Balabanski et al., Phys. Rev. Lett. 133, 7 (2024)*

✓ *A. Kuşoğlu, Sci. Bull. 69, 3303 (2024)*

ELIGANT-GN – Triple neutron correlations in spontaneous fission

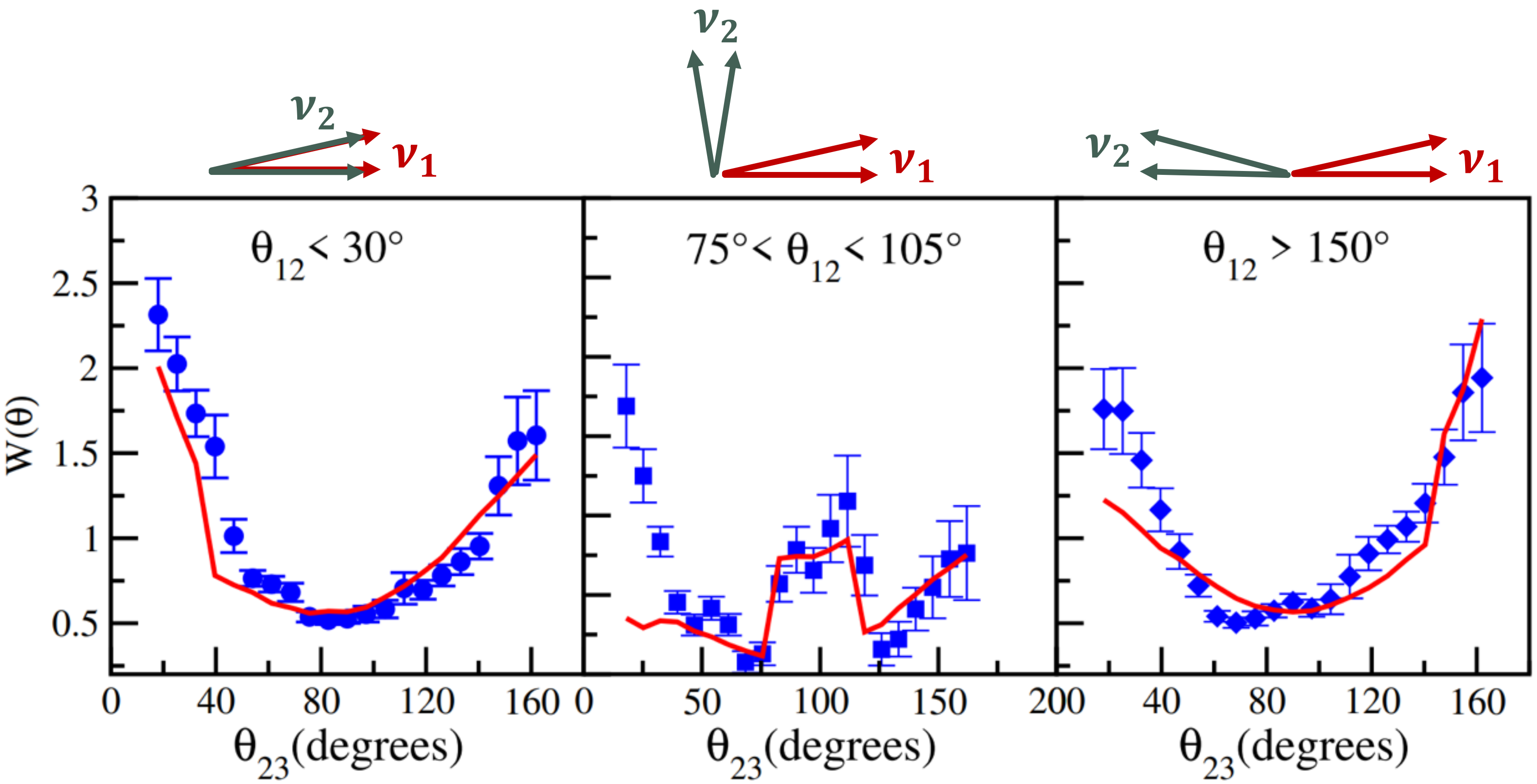
^{252}Cf source

- pioneering results
- FREYA calculations by J. Randrup, LANL



neutron dets:
36 Liquid Scintillators
25 Lithium Glass

gamma dets:
15 LaBr3, 19 CeBr3



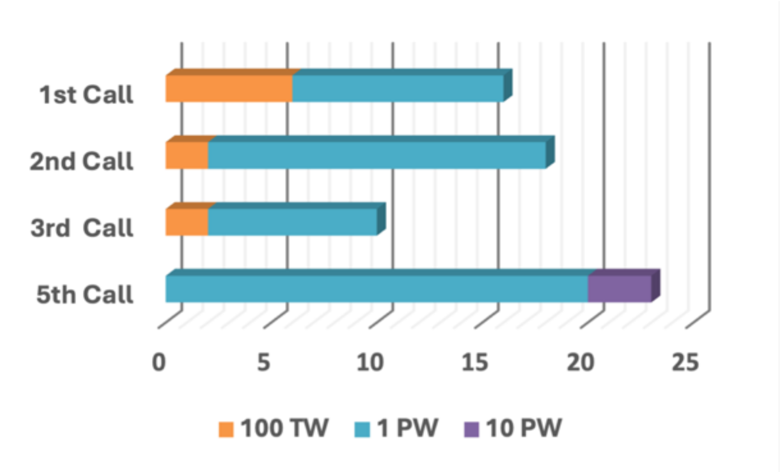
- New measurements ongoing for double and triple neutron correlations with fission fragment vectors
- 16×16 Si strip detector used for the fission fragments

D. Choudhury et al., Phys. Rev. C (2025) to be submitted

ELI-NP as User Facility

Access based on scientific excellence – since 2022 four user calls in comun cu ELI ERIC
ELI-NP Program Advisory Committee (PAC) – international experts

65 Proposals from 12 countries for the period 2022-2024



Mission based access – startegic research in the benefit of society

Approved by ISAB Research for the project Dr. LASER – **medical applications**
Research in the field of inertial confinement fusion – **applications in energy**

Proprietary access

Payed access - Limited to 5% of the total access time

ELI-NP as User Facility

eli
nuclear physics

User Office

Experimental Facilities

Beamtime Application Process

Beamtime Allocation

Beamtime Schedule

Call for Proposals

User's Guide

User Office

ELI-NP website

Welcome to the ELI-NP User Office

The User Office at ELI-NP is a gateway for users to access beam time and to foster the community that relies on the equipment at ELI-NP to further their scientific goals. Whether you are a new user or a returning user, you are invited to access information about the facility and instrumentation, training, proposal submission information, and contact details via the User Office.

Contact Info

Head of User Office: Dr. Sophia CHEN

Secretary: Ms. Cristina HOLEAB

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For further information on conditions of participation in ELI-NP experiments, please contact users@eli-np.ro

https://users.eli-np.ro

Highlights

- 2019 – demonstrated the capability of the lasers to deliver 10 PW pulses
- 2020 – transport of the 10 PW laser pulses to the interaction chamber and characterization
- 2022 – open the gates for worldwide users in collaboration with ELI ERIC – selection of experiments based on scientific merits at 100 TW and 1 PW
- 2023 – first time in the world focusing 10 PW laser beams on target
  – ELI-NP becomes institutional member of NuPECC
- 2024 – Romania becomes becomes Founding Observer of ELI ERIC
  – first experiments at 10 PW
- 2025 – start of project on Medical applications of high-power lasers
- Gamma Beam System under implementation – first beams 2027
- Use of ELI-NP detectors for nuclear physics experiments at the IFIN-HH 9 MV Tandem accelerator

Events

Nuclear Photonics 2025

October 6 - 10, 2025 in Darmstadt, Germany

The 5th Nuclear Photonics Conference

Oct 6 – 10, 2025
TU Darmstadt
Europe/Berlin timezone

Enter your search term

Deadline for early-bird registration is July 18, 2025.

- Overview
- Scope
- Committees
- Keynotes
- Registration
- Conference Fees
- Important Dates
- Practical Information
- Code of Conduct

Local Organizing Committee

np2025@ikp.tu-darmsta…

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

eli nuclear physics

Thank you !

www.eli-np.ro