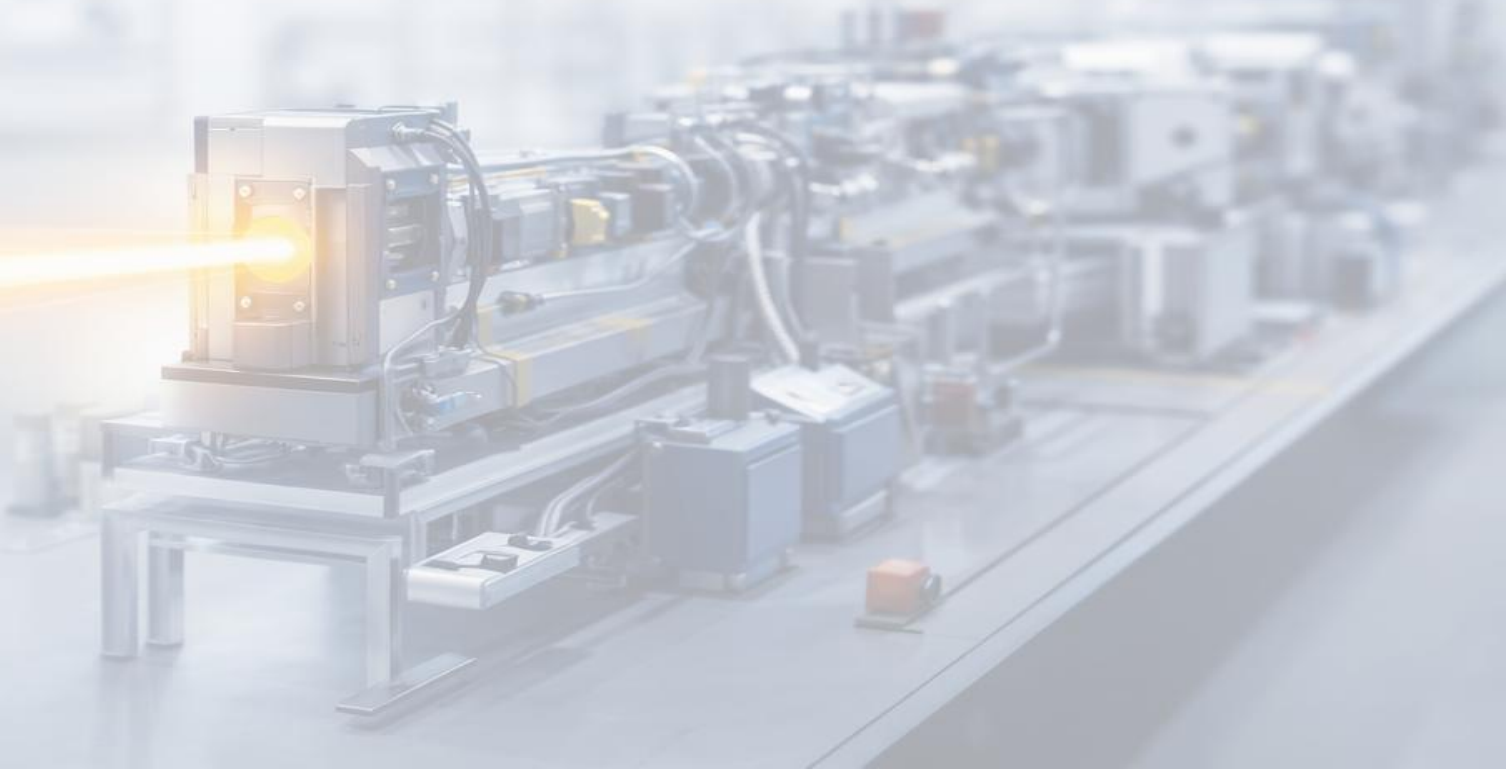
ELIMAIA-ELIMED: Present Achievements and Future Perspectives for high -repetition rate Laser Driven Ion Accelerators

Lorenzo Giuffrida
Head of department of Ion Acceleration and Application
ELI Beamlines Facility. The Extreme Light Infrastructure ERIC
Email: Lorenzo.Giuffrida@eli-laser.eu



eli
EXTREME LIGHT INFRASTRUCTURE

ELI Membership Enlargement

The Extreme Light Infrastructure (ELI) is an **international research infrastructure** with the world's largest and most advanced collection of high-power and high-repetition-rate lasers.

ELI is dedicated to **multi-disciplinary science** and research applications of ultra-intense and ultra-short laser pulses and offers unprecedented capabilities in intense light-matter interactions.

MEMBERS

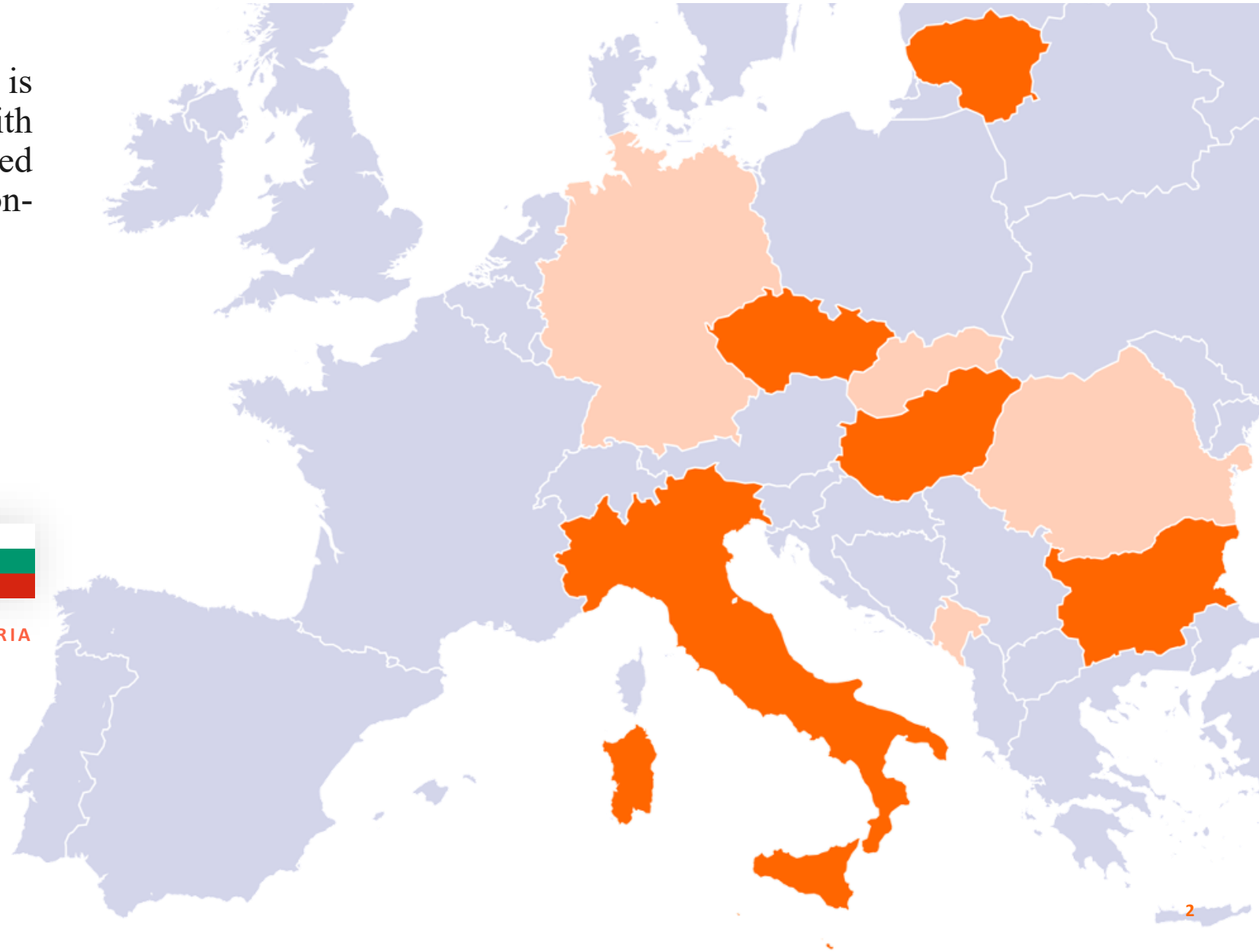


CZECH REPUBLIC* HUNGARY* ITALY LITHUANIA BULGARIA

OBSERVERS



ROMANIA* GERMANY SLOVAKIA MONTENEGRO



* Host Countries

Integration of the ELI Facilities

Consistent excellence across three facilities



ELI Beamlines Facility

High-Energy Beam facility, develops and applies ultra-short pulses of ultra-intense radiation to explore extreme conditions or produce high-energy particles and radiation.

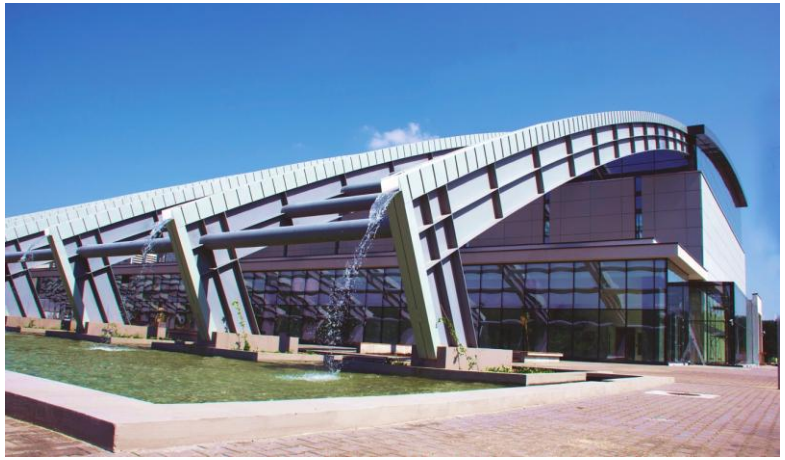
DOLNÍ BŘEŽANY, CZECH REPUBLIC
SINCE 1 JANUARY 2023



ELI Attosecond Light Pulse Source Facility

Attosecond Light Pulse Source, offers unique time-resolved investigation possibilities for both nonrelativistic and relativistic interaction of light with all the four states of matter.

SZEGED, HUNGARY
SINCE 1 JANUARY 2024



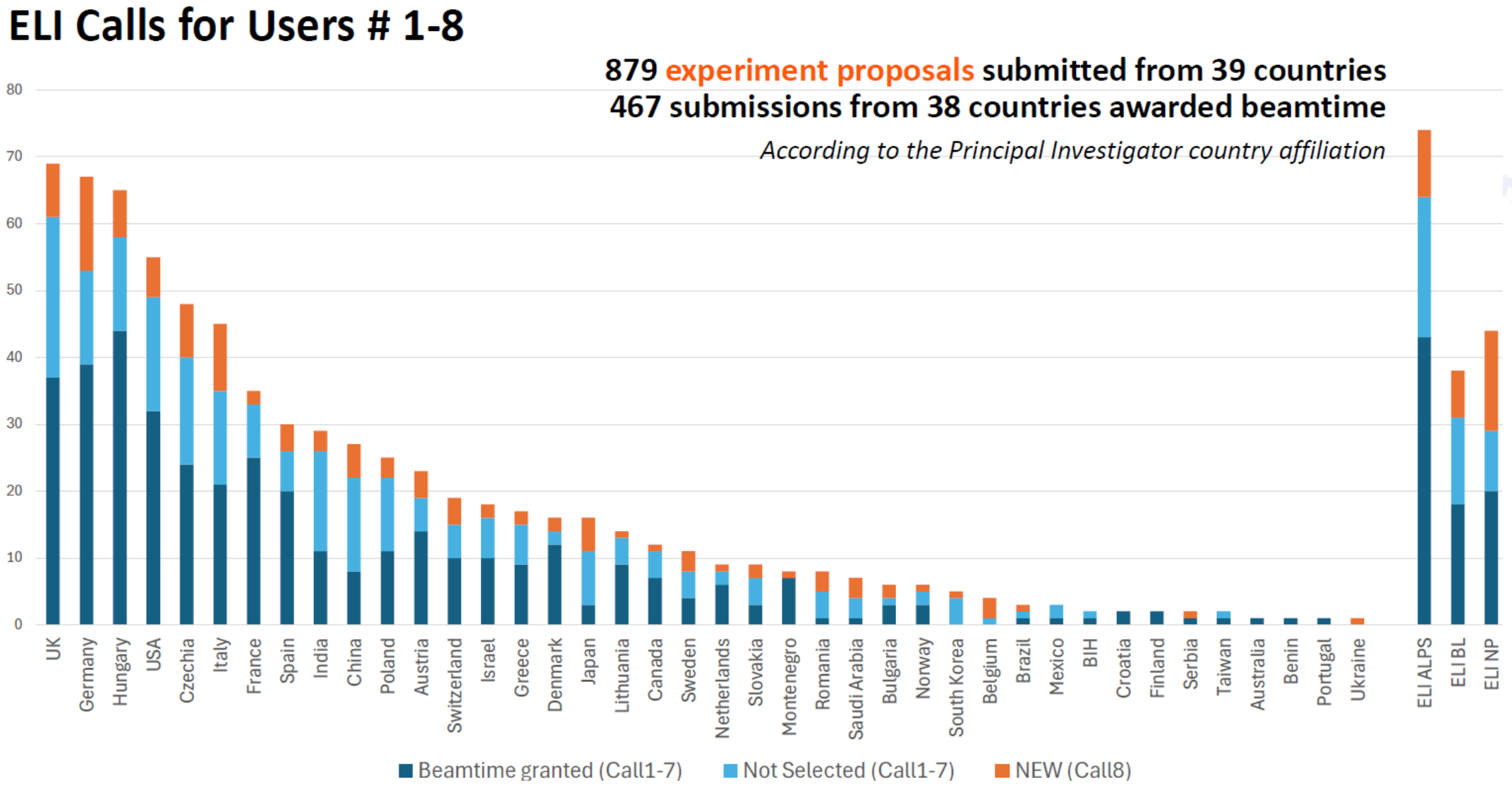
ELI Nuclear Physics Facility

Nuclear Physics facility with ultra-intense lasers and brilliant gamma beams (up to 19 MeV) to produce and explore new nuclear states or generate neutron beams.

MĂGURELE, ROMANIA

A growing user community

Submitted vs Granted ***Proposals***




eli
ELI Beamlines
Dolní Břežany,
Czechia

ELI BL Primary Sources (Lasers)

high-energy, high-rep-rate laser systems (0.01-1 kHz)

B. Rus et al.

L1-ALLEGRA 100mJ/12fs/1kHz (>5TW) laser system

(in operation – 50mJ/15fs/1kHz)



Thin disk Yb:YAG (diode-pumped) pump, ps OPCPA

Auxiliary 15 mJ /12 fs beam (Q4 2024)

L2-DUHA: 3J/20fs/50-100Hz (>100TW) laser system

(under development)



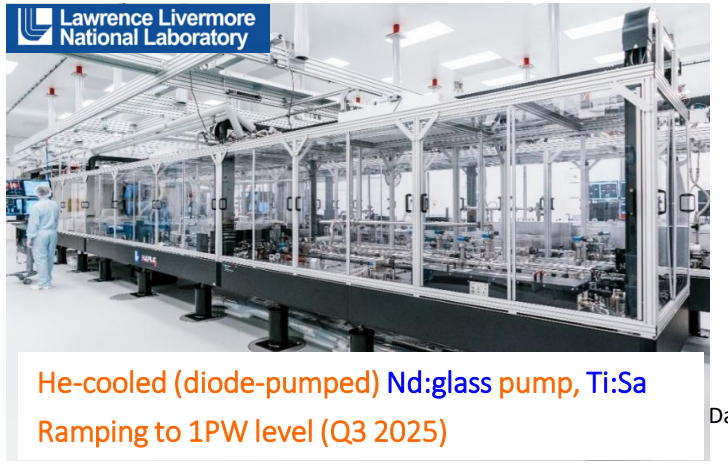


Cryogenic He-cooled slab Yb:YAG (diode-pumped) pump, ns OPCPA

Expected availability for experiments: Q3 2025

L3-HAPLS: 30J/30fs/10Hz (1PW) laser system

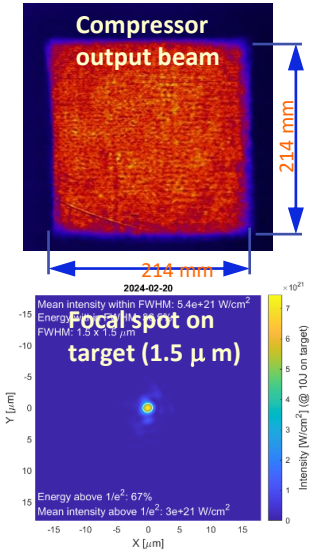
(in operation – 15J/27fs/3.3Hz)



He-cooled (diode-pumped) Nd:glass pump, Ti:Sa

Ramping to 1PW level (Q3 2025)

Date:



L4-ATON: 1.5kJ/150fs/1shot/min (10PW) laser system

(long pulse in operation – 1.2kJ (0.6kJ @2w)/2-10ns/1shot/min)





Mixed Nd:glass (>15nm spectral bandwidth)

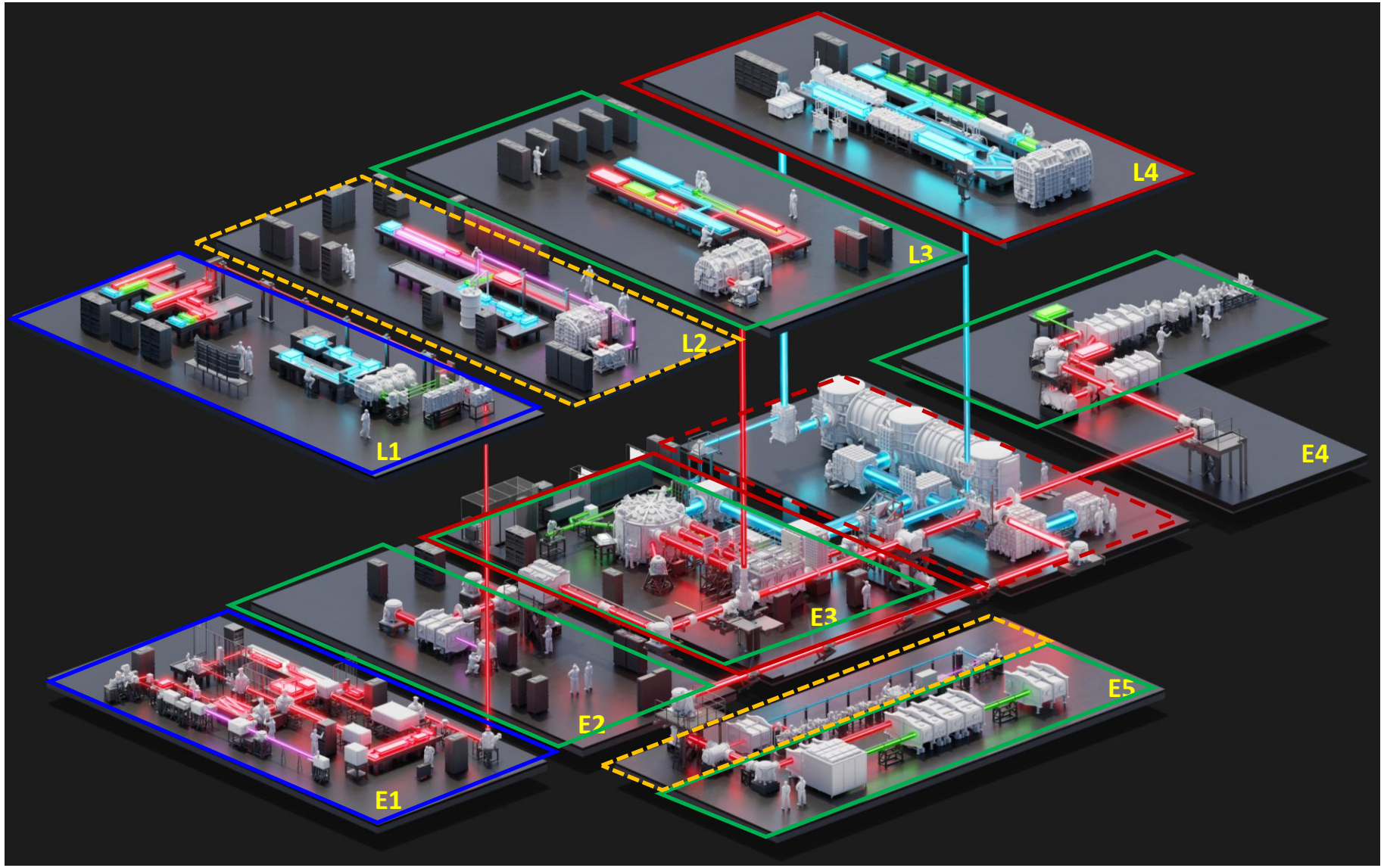
ns-kJ pulses with programmable temporal shaping (150ps steps)

10PW commissioning on target: Q3 2025

Facility Layout (2026)

user operations, commissioning, development

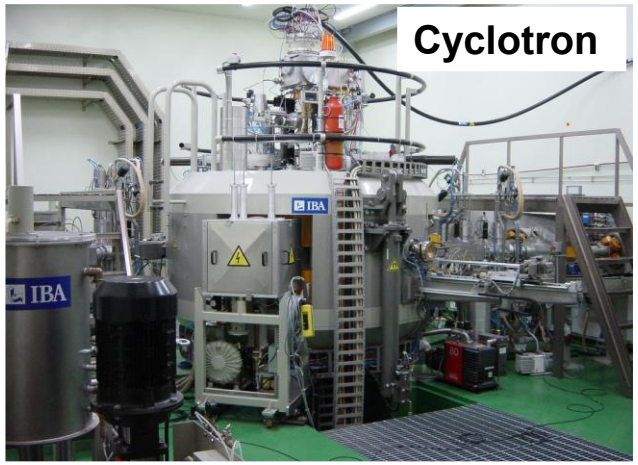
- L1-E1 user operation (Call1)
- L3-ELIMAIA user operation (Call2)
- L3-ELBA/ELIMED user operation (Call3)
- L3-Gammatron (Call5)
- L4n-P3 user operations (Call2)
- L4f 10PW (Call7)
- L2-LUIS (R&D)

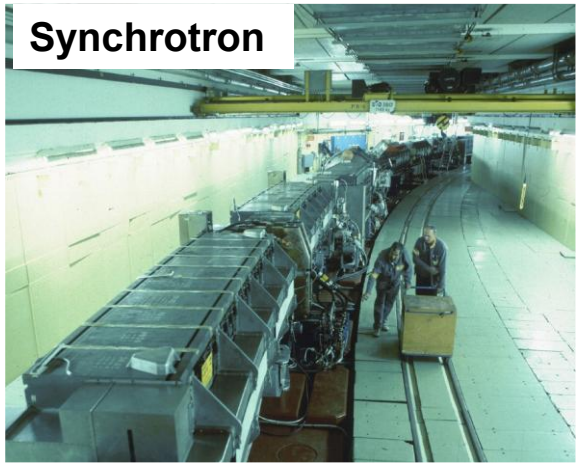


Laser Plasma Accelerators

ion acceleration

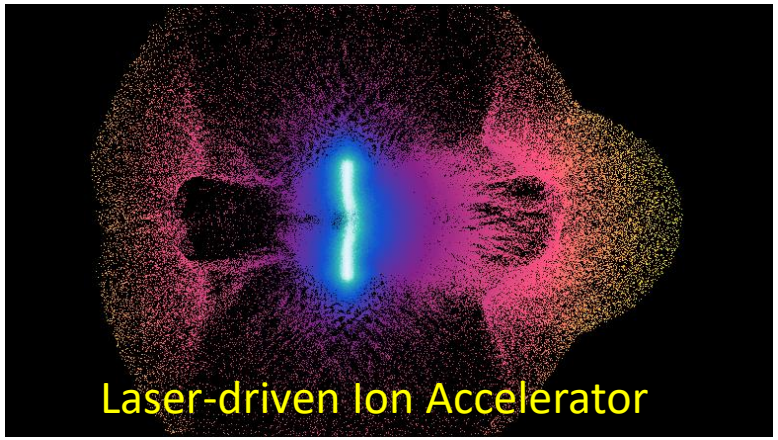






E_{max} ~ 50 MV/m
L_{acc} ~ 1-10 m

a few micrometres to reach 100 MeV



E_{max} ~ 1-10 TV/m
L_{acc} ~ 1 μm

100,000 smaller!

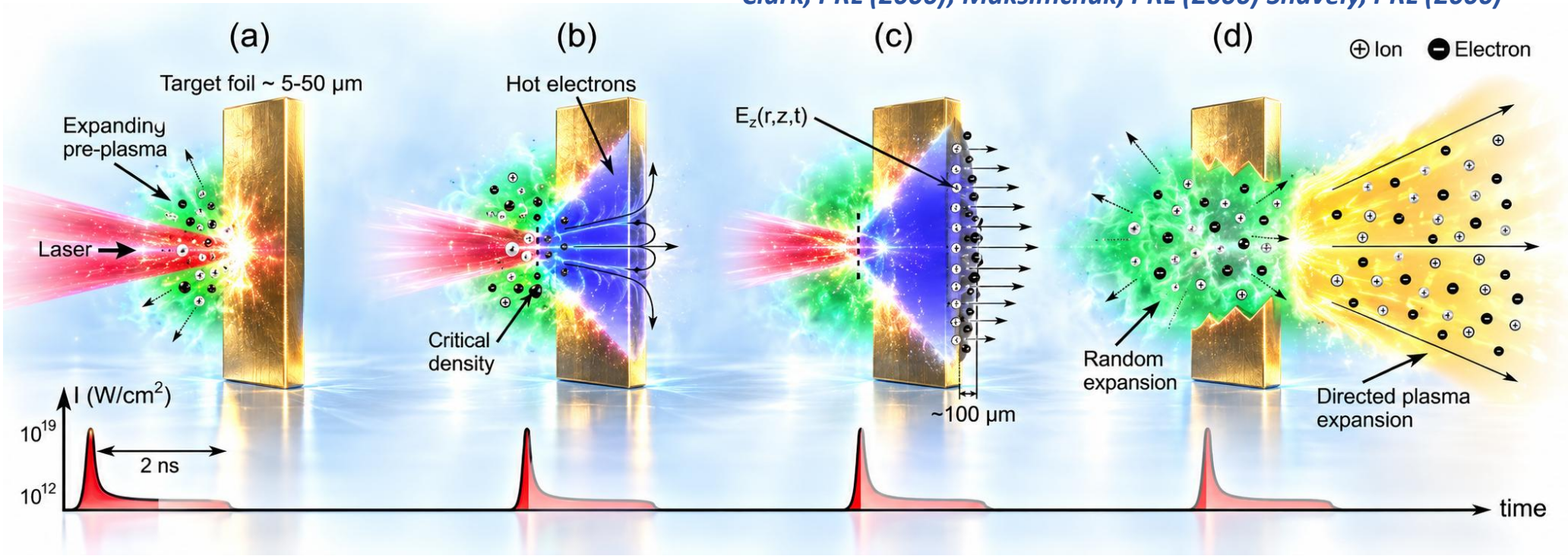
The ELIMAIA Ion Accelerator at ELI BL



Target Normal Sheath Acceleration (TNSA)

a robust and experimentally well-established mechanism

Clark, PRL (2000); Maksimchuk, PRL (2000) Snavely, PRL (2000)



TNSA mechanism

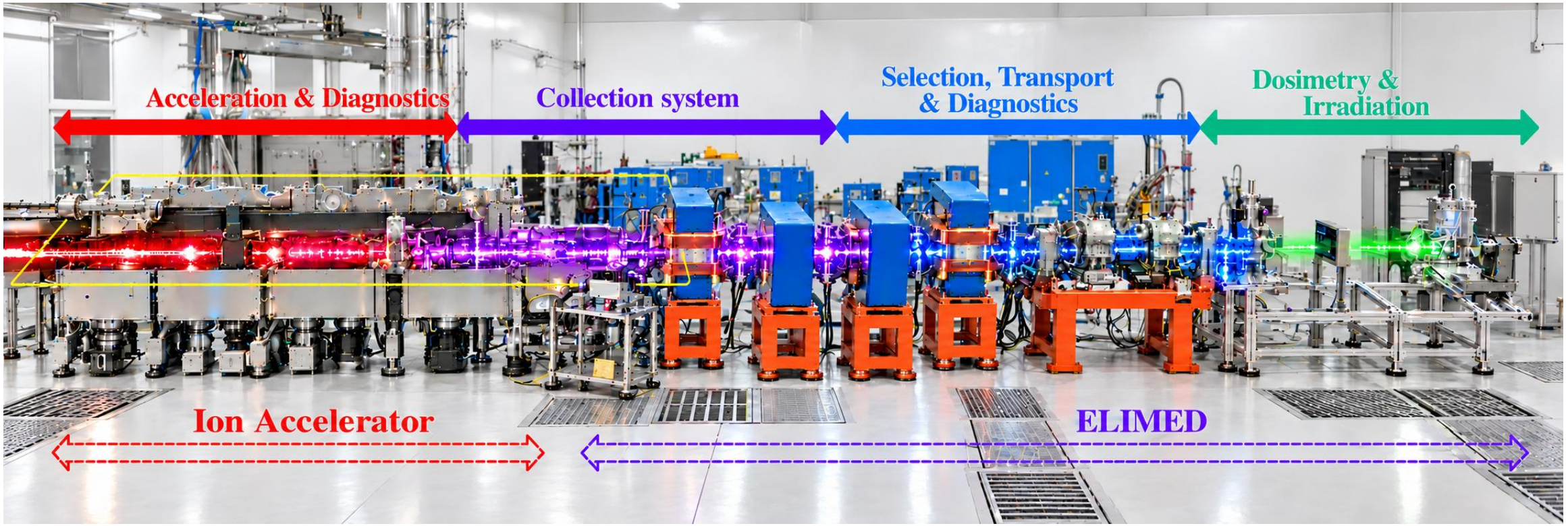
- Typical Laser Intensity (**10^{18}-10^{20} W/cm^2**)
- Accelerated **Relativistic Electrons** (multi MeV) traverse the thin target (0.1÷100 μm).
- H-ultrathin rear-side layer is ionized by the electron beam and **protons** are generated.
- Fast electron cloud builds up a **quasi-electrostatic field** exceeding ~10 TV/m accelerating protons in the forward direction to 10s-MeV energies.

TNSA features

- Protons/ions are accelerated along the **target normal**
- Ions with the highest charge-to-mass ratio **(protons) dominate the acceleration**, gaining the most energy (electric field screening effect)
- **Exponential ion energy distribution** (large energy spread)

ELIMAIA user beamline

ELI Multidisciplinary Applications of laser-Ion Acceleration



- *D. Margarone et al., "**ELIMAIA: A Laser-Driven Ion Accelerator for Multidisciplinary Applications**", Quantum Beam Science 2 (2018) 8*
- *G.A.P. Cirrone et al., "**ELIMED-ELIMAIA: The First Open User Irradiation Beamline for Laser-Plasma-Accelerated Ion Beams**", Frontiers in Physics 8 (2020) 564907*
- *F. Schillaci et al., "**The ELIMAIA Laser-Plasma Ion Accelerator: Technology Commissioning and Perspectives**", Quantum Beam Sci. 2022, 6(4), 30*
- *L. Giuffrida et al., **"The ELIMAIA laser-plasma Ion Accelerator: a platform for open-access user experiments",** submitted to PRAB*
- *P. Blaha et al., "**ELIMAIA-ELIMED: A new user platform for radiobiological research utilizing laser-driven protons**". Front. Phys. 13:1567622*

Scientific & Societal Impact of laser-driven sources

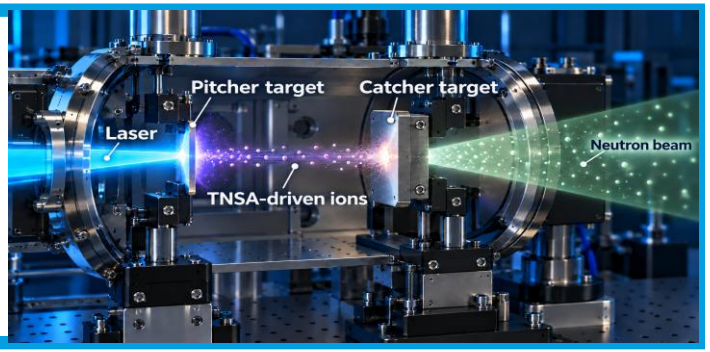
Scientific Applications in ELIMAIA:

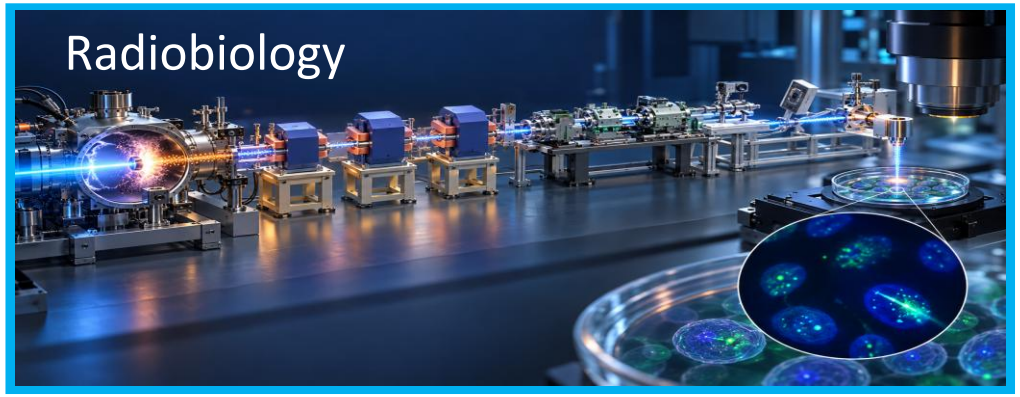
- ✓Advanced laser-driven ion mechanisms
- ✓Laser-driven nuclear reactions
- ✓ion pump-probe experiments (e.g. isochoric proton heating and ion stopping power with all-optical energy selected proton beam)
- ✓Machine learning studies

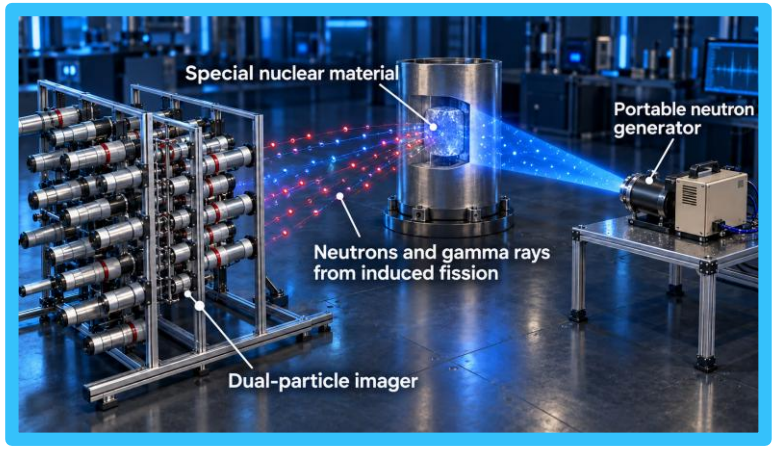
Multidisciplinary user applications in ELIMED

- ✓Radiobiology, cancer treatment (hadrontherapy & BNCT), medical imaging
- ✓Radiation chemistry with protons & neutrons (pulsed radiolysis of water, management of nuclear waste)
- ✓Space radiation (electronics, radiobiology in space)
- ✓Material analysis for cultural heritage (PIXE, XRF, DPAA)
- ✓Non-destructive inspection of massive objects with proton & neutron radiography

Secondary particles from Pitcher-catcher



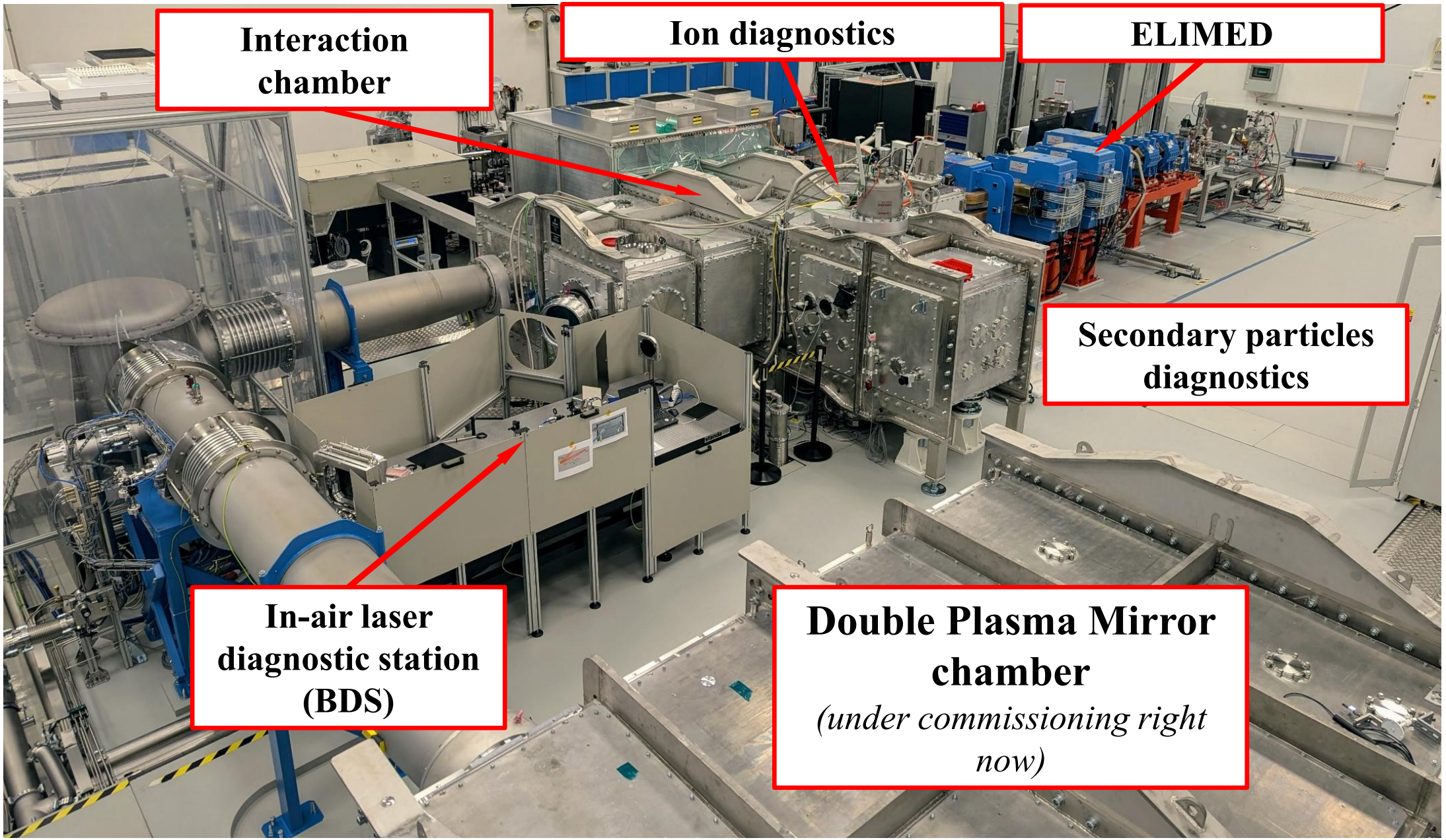




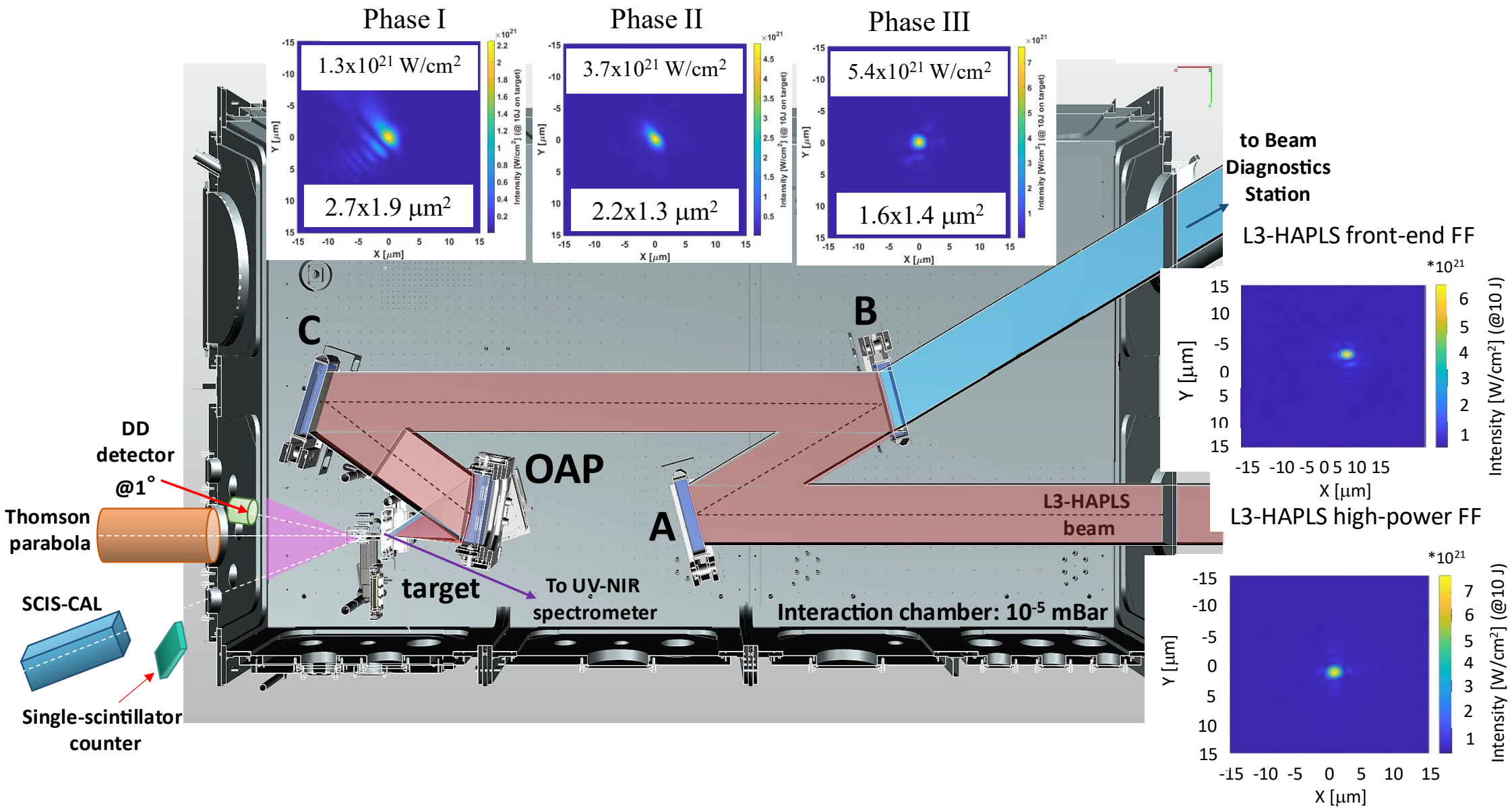
ELIMAIA: Setup overview



ELIMAIA: Setup overview



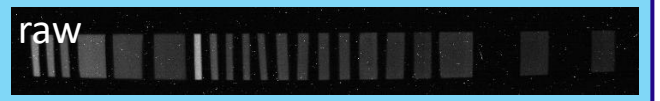
ELIMAIA: Setup sketch



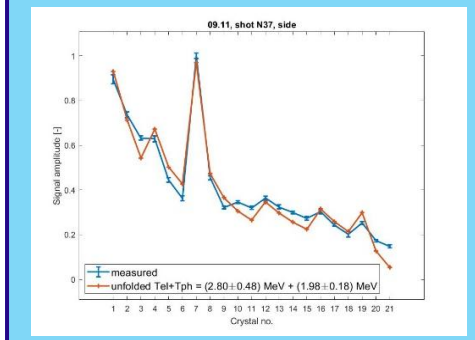
ELIMAIA : Online laser/plasma/ion diagnostics

X/γ-ray diagnostics

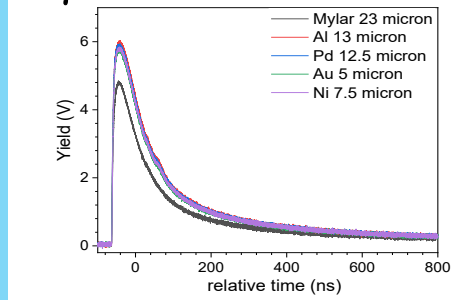




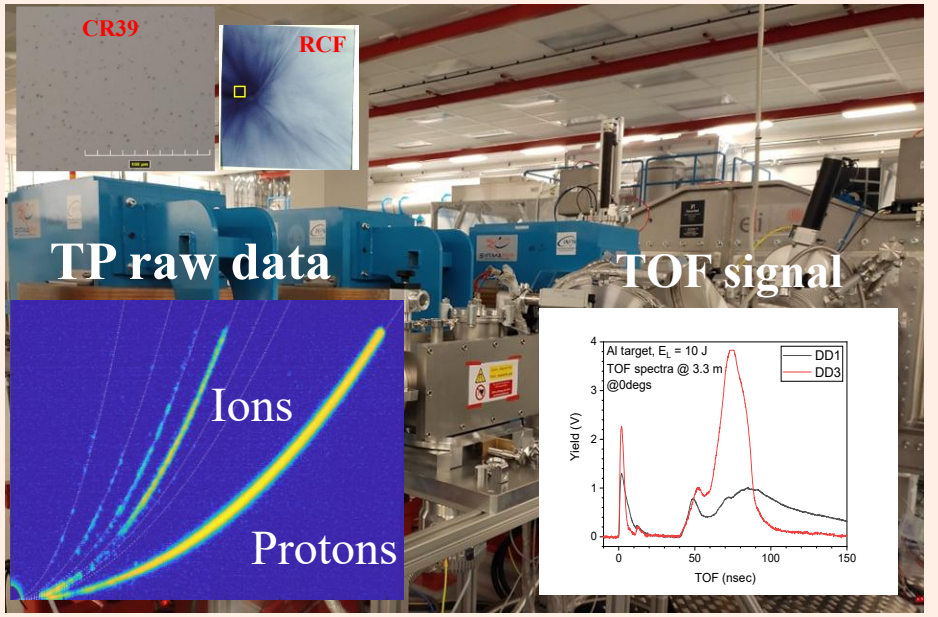




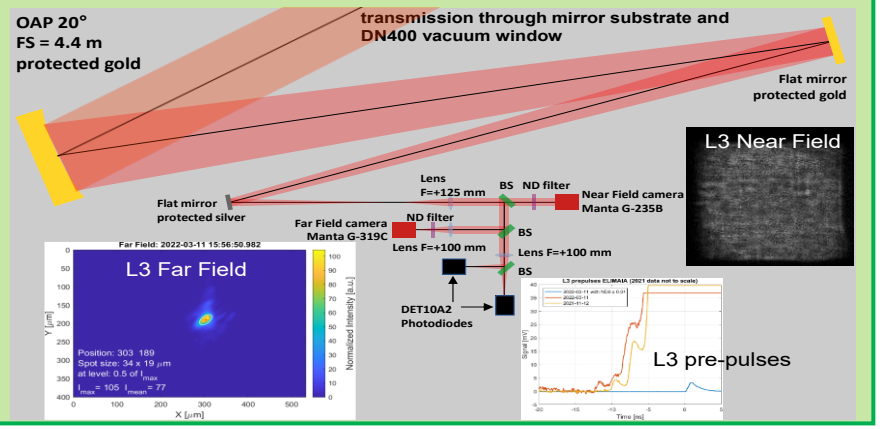
γ-Scintillator detector



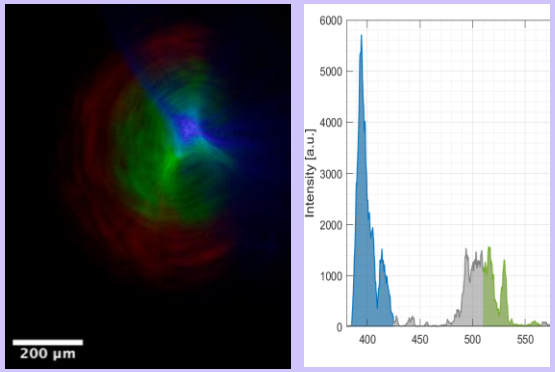
Ion diagnostics



On-shot laser diagnostics



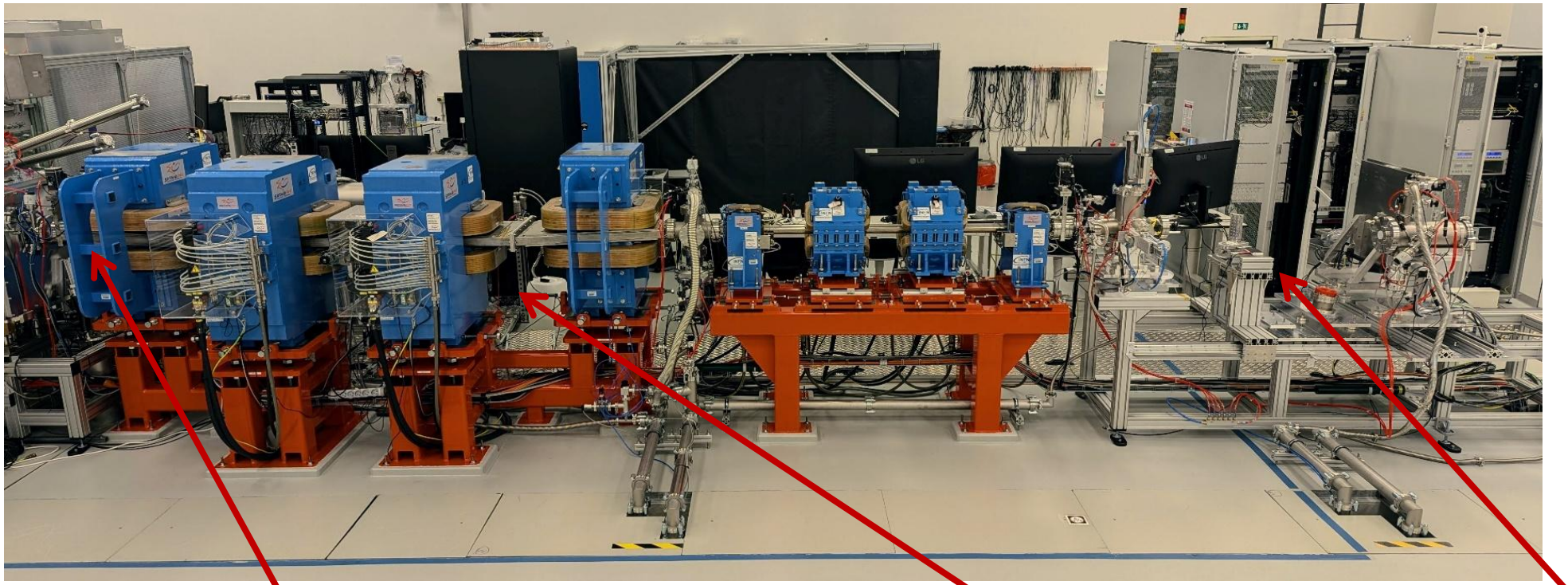
Plasma imaging/ spectroscopy

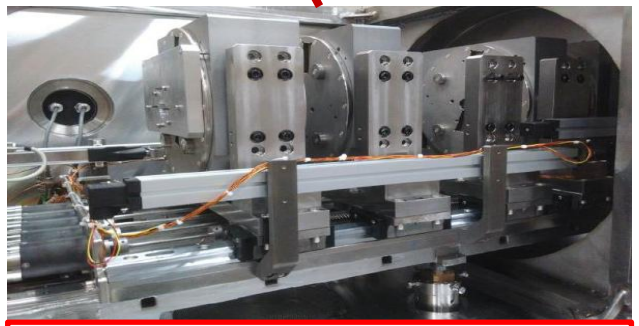


Online data analysis (1-10 Hz)

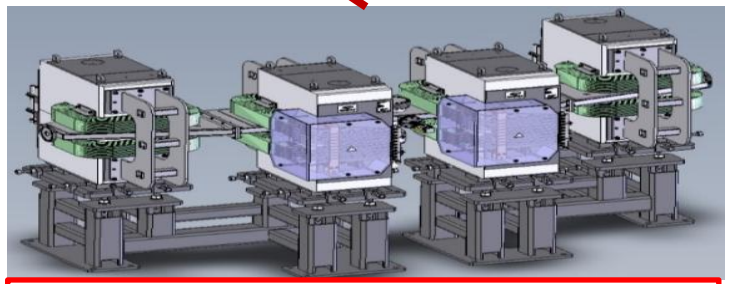


ELIMED: Setup overview

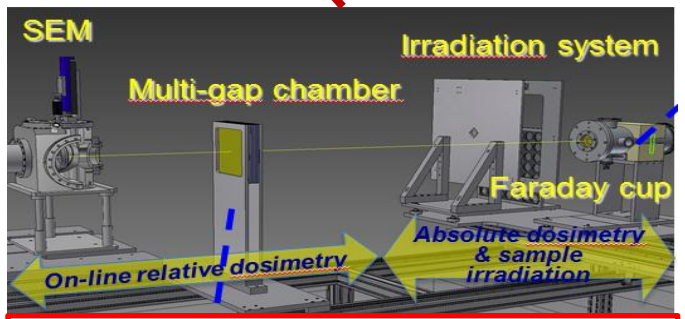




Collection System: 5 PMQs, 36mm magnetic bore, 100 T/m gradient with 2% uniformity



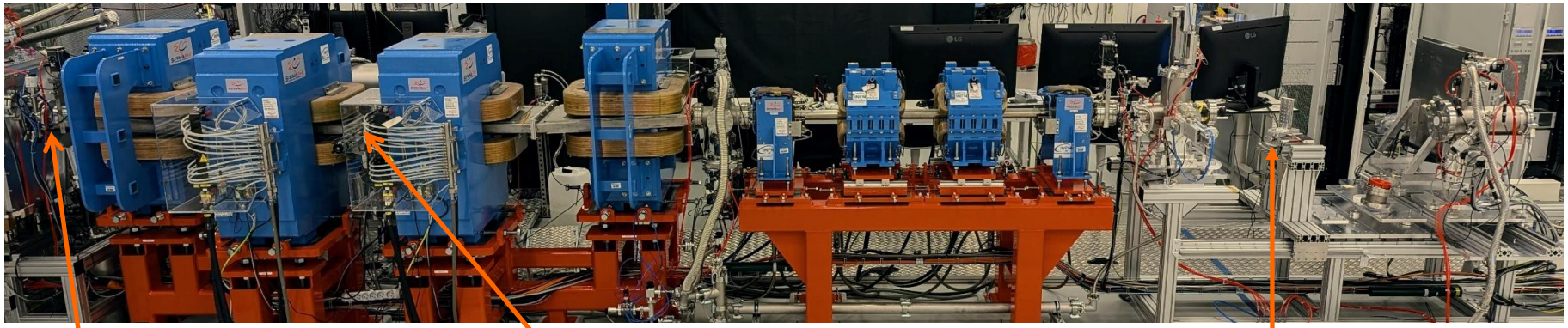
Energy Selection system: 4 electro-dipoles, 55mm bore, 0.06 – 1.226 T with 0.5% uniformity, linear resolution with slit aperture size, active energy modulation.



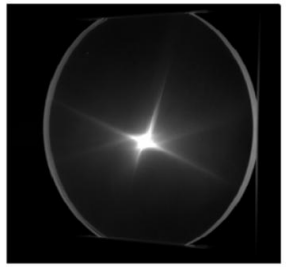
Dosimetry and Irradiation System

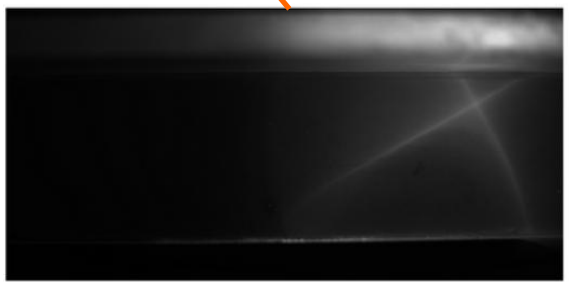
Date:

ELIMED: Online diagnostics



3 beam viewers are used to verify and correct the beam position

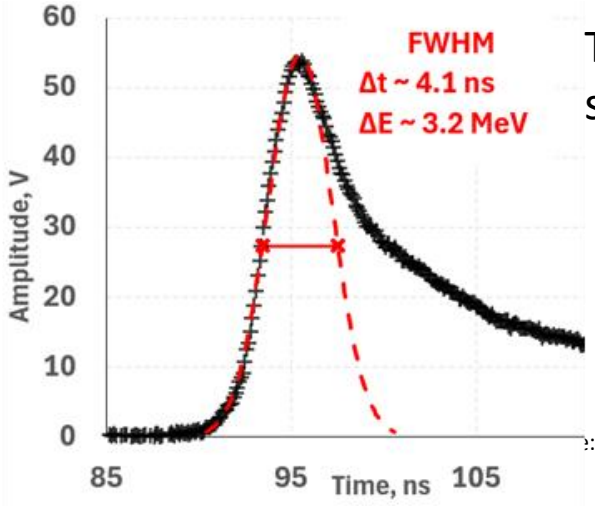




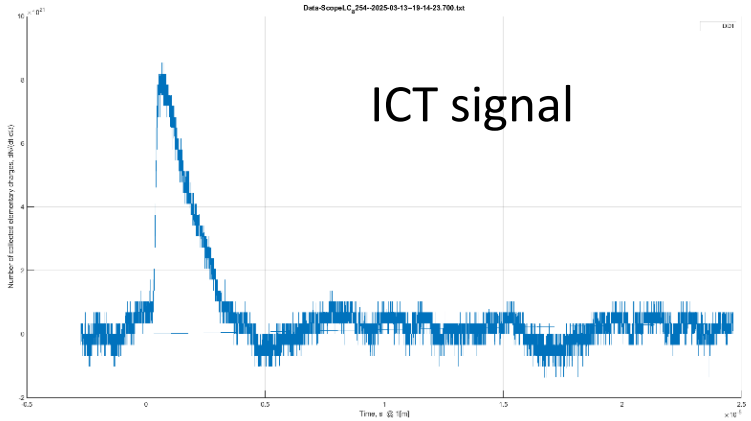


Several online diagnostics:

- **TOF1 after PMQs;**
- **TOF2 and ICT at the end of the beamline;**
- **RCF at the end of the beamline.**

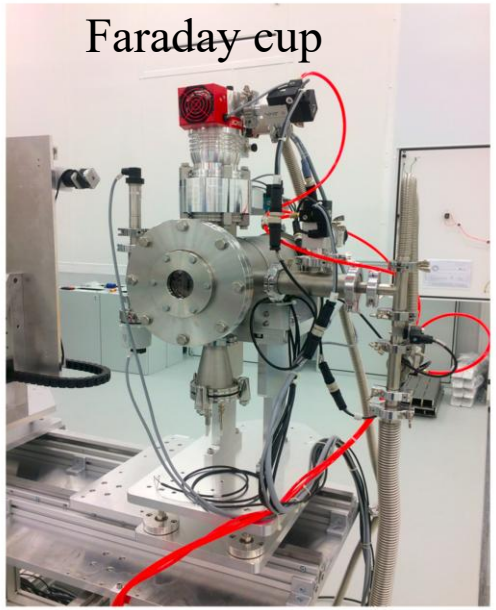


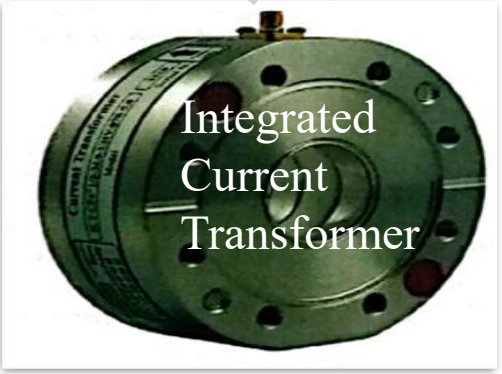
TOF2 signal

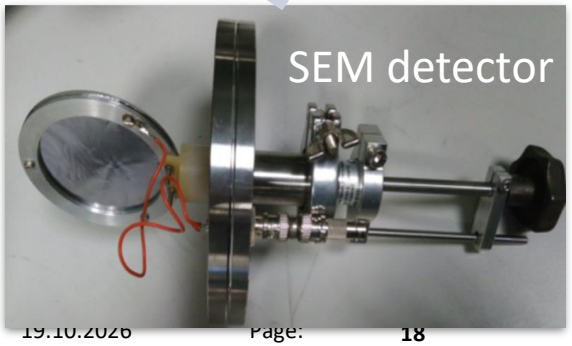


ELIMED: Dosimetric diagnostics

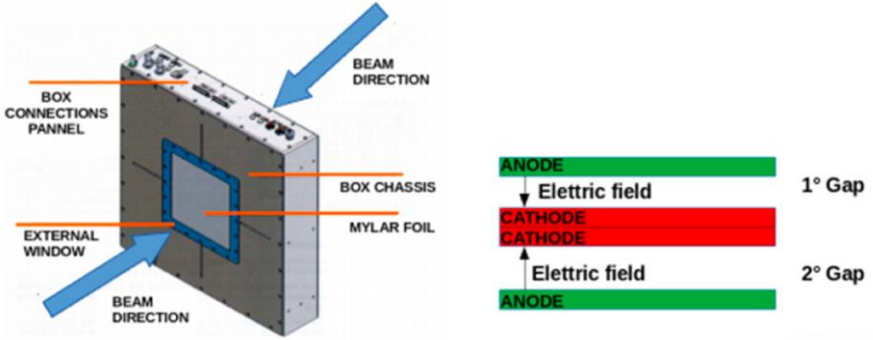






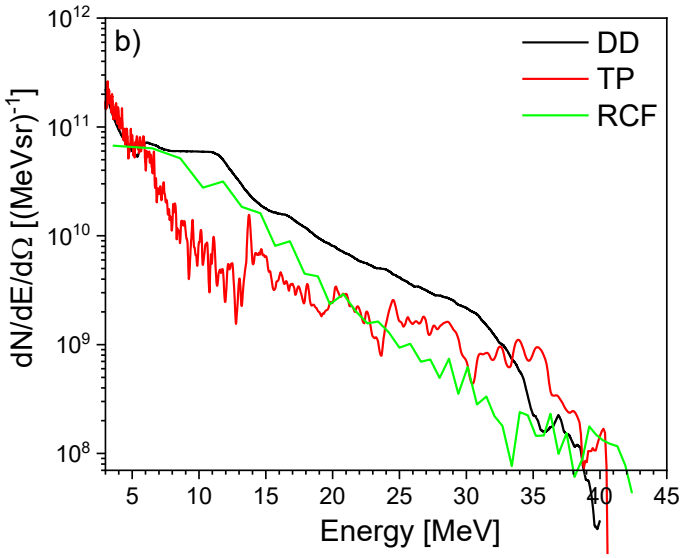


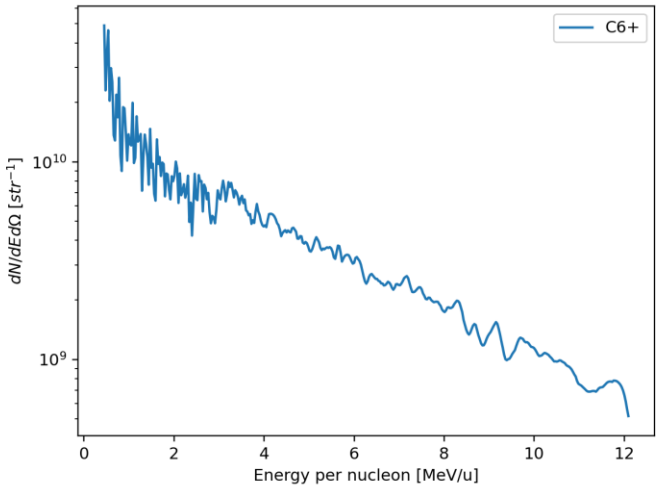
Multi-gap ionization chamber

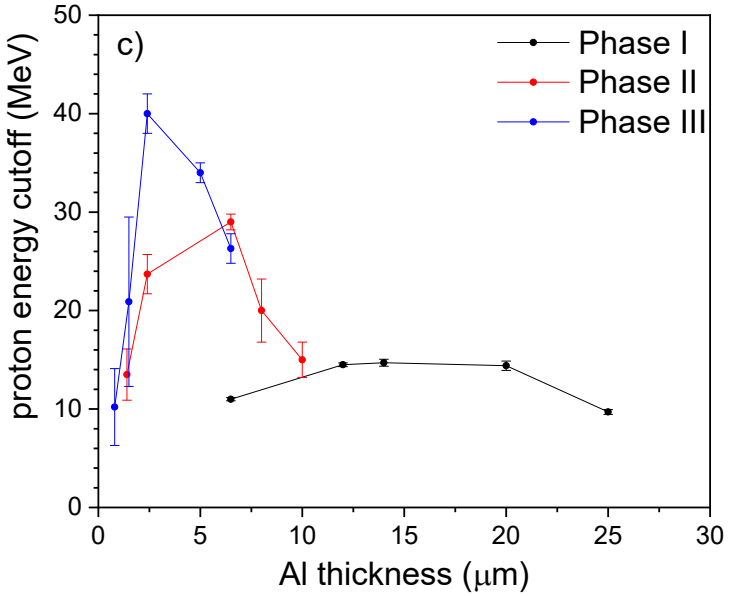


ELIMAIA Beamline: accelerator performances I

L. Giuffrida et al., Phys. Rev. Acc. Beams (subm 2026)





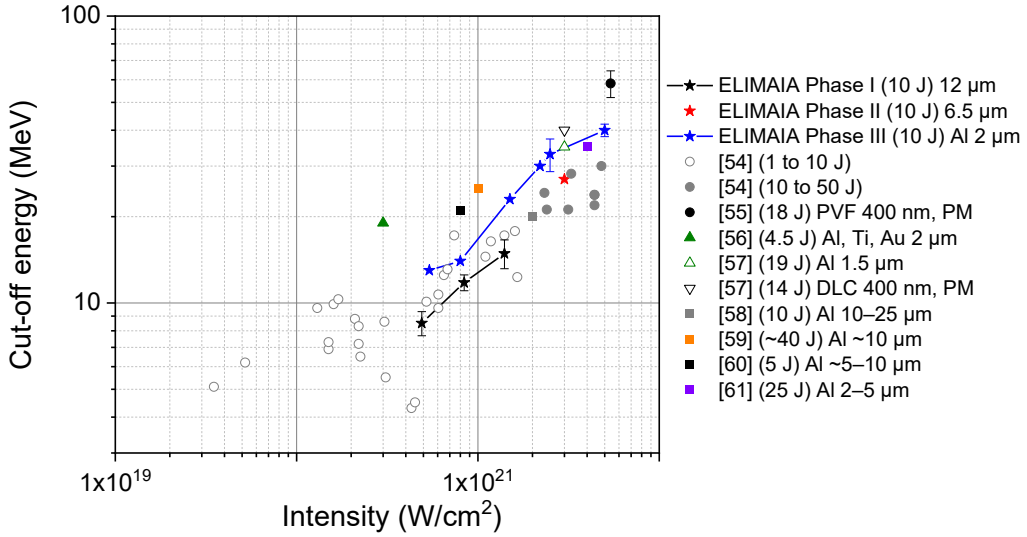


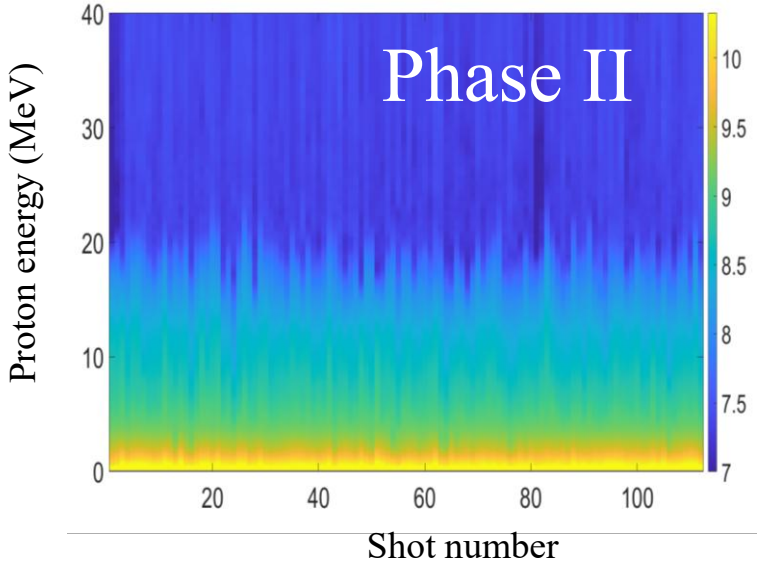
Proton/Ion Accelerator	Available	Target
Laser intensity	**$5 \cdot 10^{21}$ W/cm^2**	**10^{22} W/cm^2**
Laser energy	~10 J	30 J
Laser pulse width	<30 fs	<30 fs
Repetition rate	**3.3 Hz**	**10 Hz**
Proton/Ion energy (max)	**~40 MeV / ~12 MeV/u ($C6^+$)**	**100 MeV / 60 MeV/u ($C6^+$)**
Proton/Ion flux (>3 MeV)	~10^{10}/sr / ~10^9/sr	~10^{11}/sr

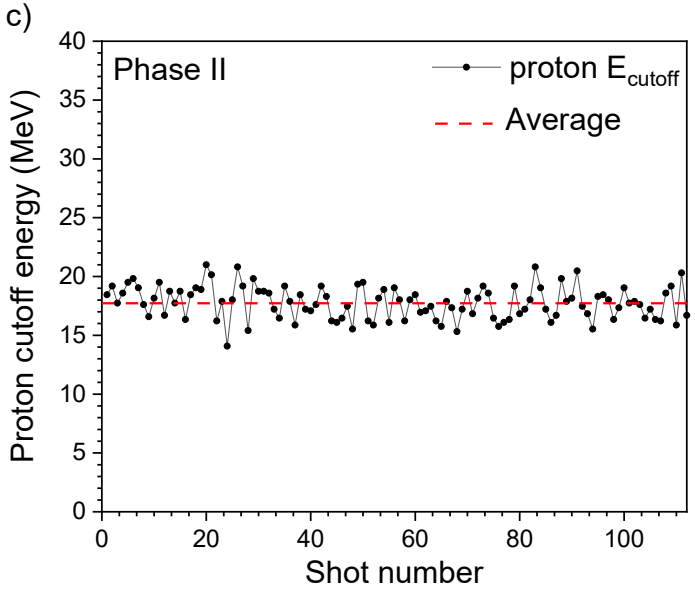
Moving to 20 J laser energy on target

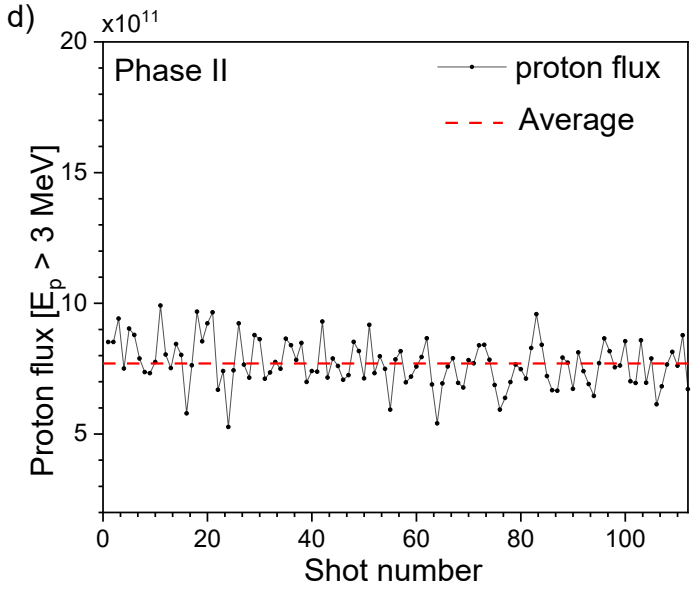
Intensity close to 1x10^{22} W/cm^2

ELIMAIA Beamline: accelerator performances II









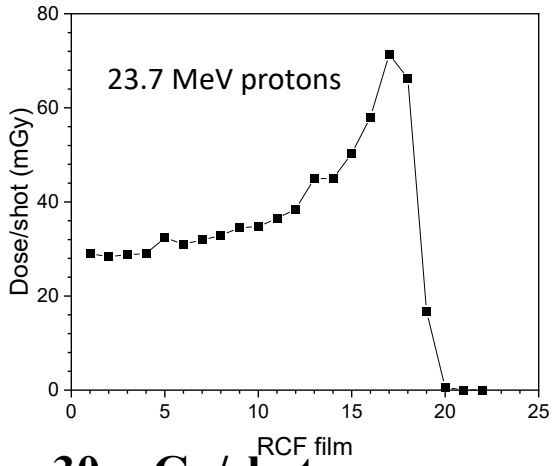
Fluctuations below 10%

ELIMED: *From commissioning phase …*

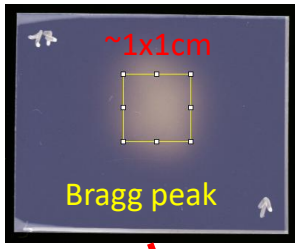
Successful ELIMED commissioning

ELIMED BT proton beam transmission improvement: from ~0.6% (Q4 2024) to ~5% (Q1 2025)

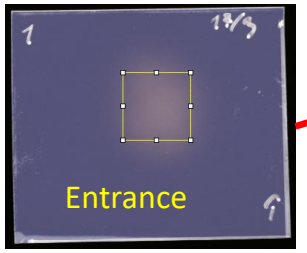
Selected proton beam from ELIMED

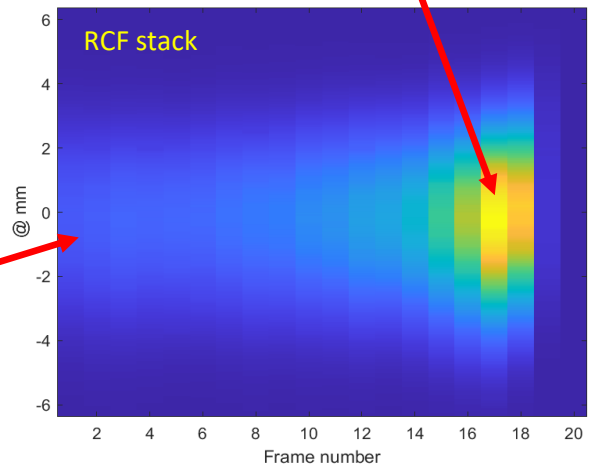


~ 70 mGy/shot



~ 30 mGy/shot



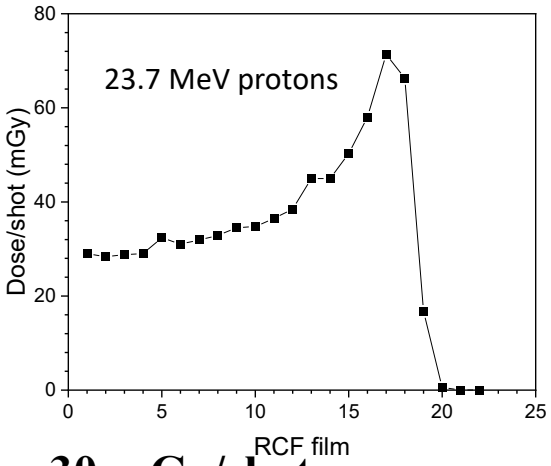


… To *user operations*

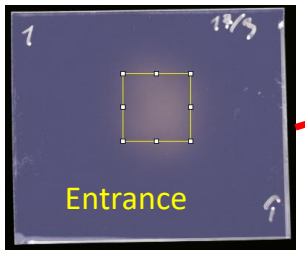
Successful ELIMED commissioning

ELIMED BT proton beam transmission improvement: from ~0.6% (Q4 2024) to ~5% (Q1 2025)

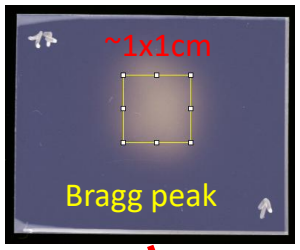
Selected proton beam from ELIMED

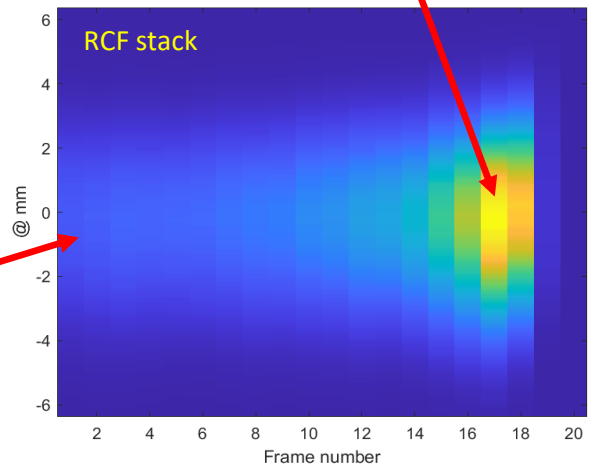


~ 30 mGy/shot



~ 70 mGy/shot

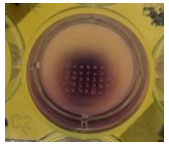


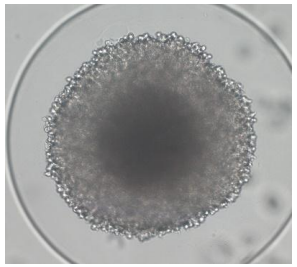


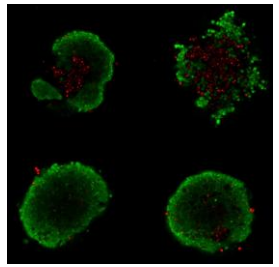
3 experiments with L3 in 3 weeks (>5000 shots)

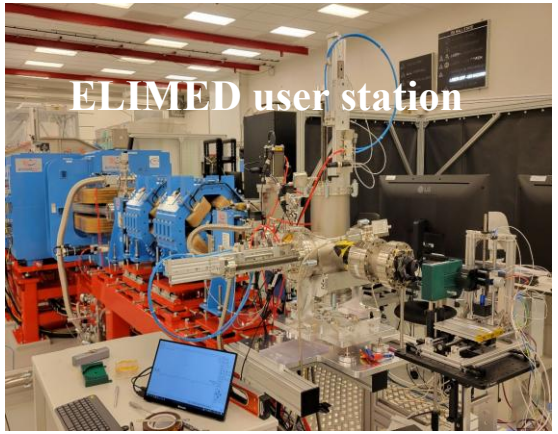
ELIUPM4-117 (Bláha, ELI BL)

Laser-driven proton (LDP) effects on **3D cancer cell spheroids**: an intermediate step **between in vitro and in vivo** research



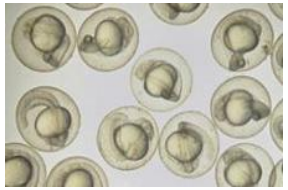


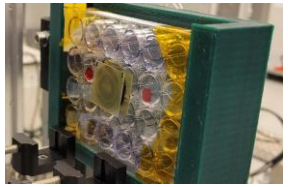




ELIUPM3-58 (Hideghéty, ELI ALPS)

Biological effects of LDP beams using a **Zebrafish embryo** model (**in vivo**)





ELIUPM4-100 (Zahradníček, CAS)

LDP beam irradiation effects on **chicken** development in early **embryonic cells (in vitro)**



P. Blaha et al., ELIMAIA-ELIMED: a new user platform for radiobiological research utilizing laser-driven protons. Front. Phys. 13:1567622. doi: 10.3389/fphy.2025.1567622

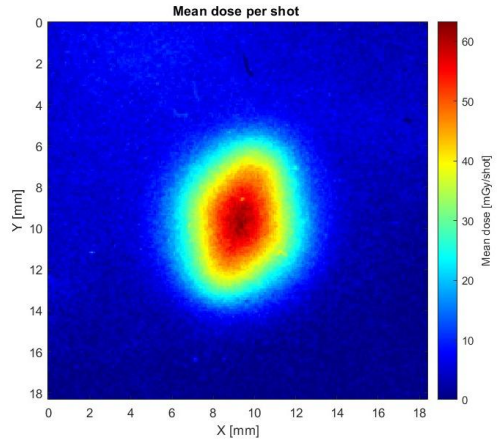
Improvement on the transport section

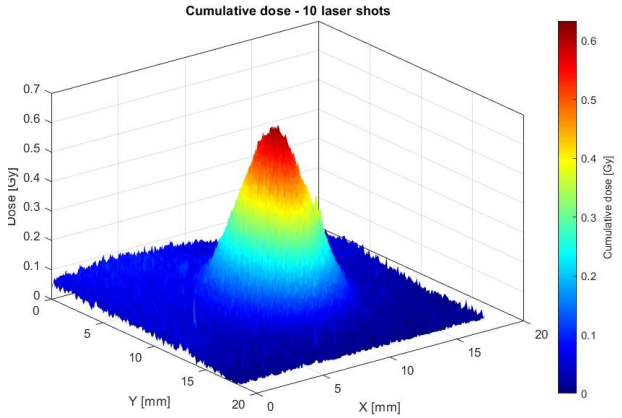
… recent achievements

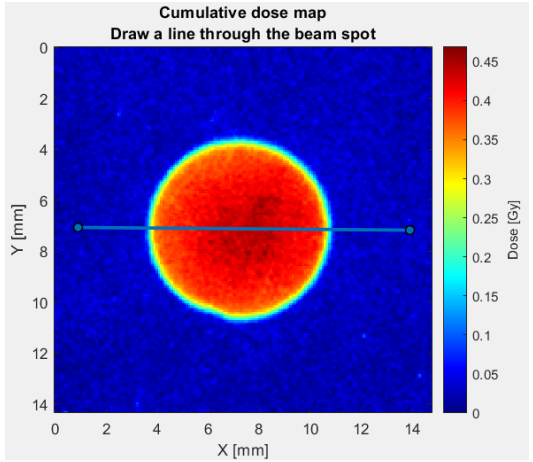
In-air Proton beam

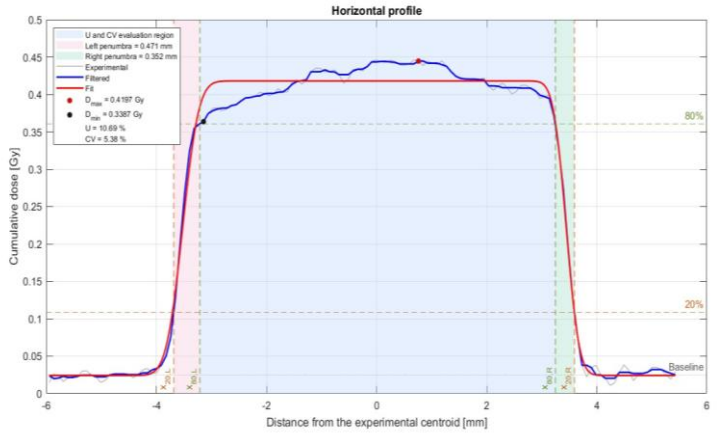
4x4mm gaussian-like beam
~60 mGy/shot @ Bragg peak

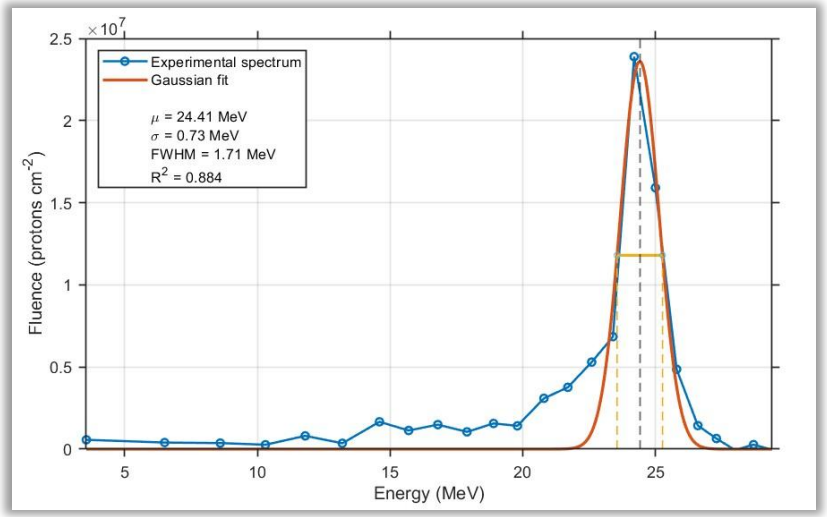
Homogenized proton beam 7,4x7,4 mm
~40 mGy/shot @ Bragg peak











$$U(\%) = 100\frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}}$$

Full Width 10% maximum: 7,44 mm

Proton beam useful for rabiological experiments

Improvement on the transport section

… recent achievements

NEXT STEPS

Increase the dose/shot of the proton beam

Using ELIMED @ 3.3 Hz

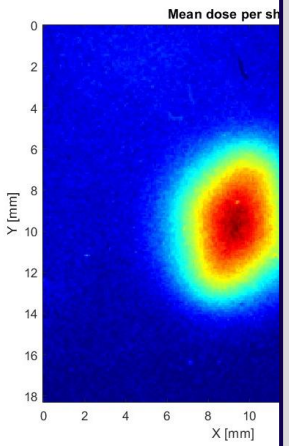
Improve the source quality:

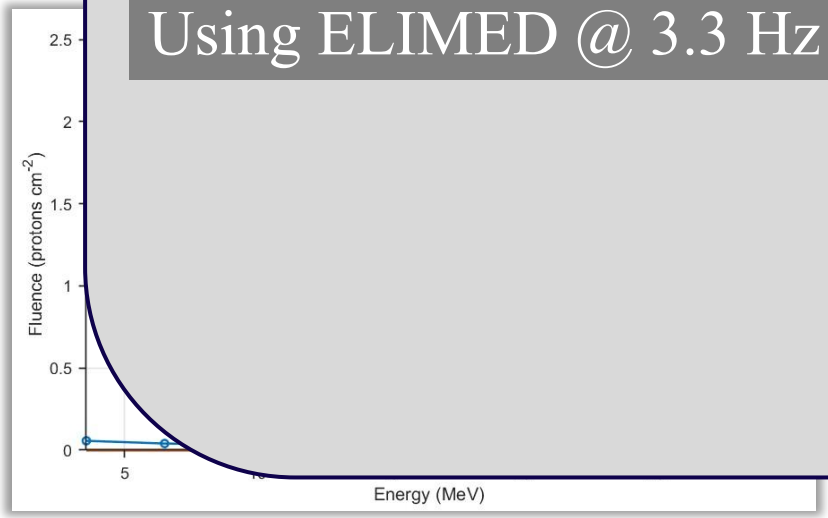
- Point stability of the proton beam
- Fluctuations of energy and flux

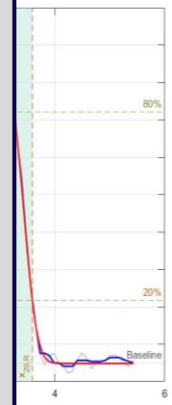
Improve the proton injection quality:

- Directionality of the beam
- Beam divergence

Use of water jet target system







experiments

L. Giuffrida, F. Grepl, F. Schillaci, P. Blaha, T. Chagovets, N. Gamaniuova, M. Greplova Zakova, V. Istokskaia, V. Kantarelou, H. Lefebvre, J. Novak, P. Szotkowski, M. Tryus, A. Velyhan, B. Rus, D. Margarone.



G.A.P. Cirrone, R. Catalano, M. Guarnera, G. Petringa, A. Pappalardo.



M. Borghesi, S. Kar, K. Prise, G. Schettino, P. Chaudhary, A. McCay

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Thank you

EXTREME LIGHT
INFRASTRUCTURE

