ELIMAIA User Beamline: Dedicated Platform for Applications Using Laser-Driven Ion Beams

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The **Extreme Light Infrastructure (ELI)** is the world's largest and most advanced high-power laser research infrastructure. As an international user facility dedicated to multi-disciplinary science and research applications of ultra-intense and ultra-short laser pulses, ELI provides access to world-class high-power, high-repetition-rate laser systems and enables cutting-edge research in physical, chemical, materials, and medical sciences, as well as breakthrough technological innovations. ELI Beamlines Facility hosts a multitude of laser-driven secondary particle & radiation sources, available for excellence-based access to a wide international user community.

ELIMAIA

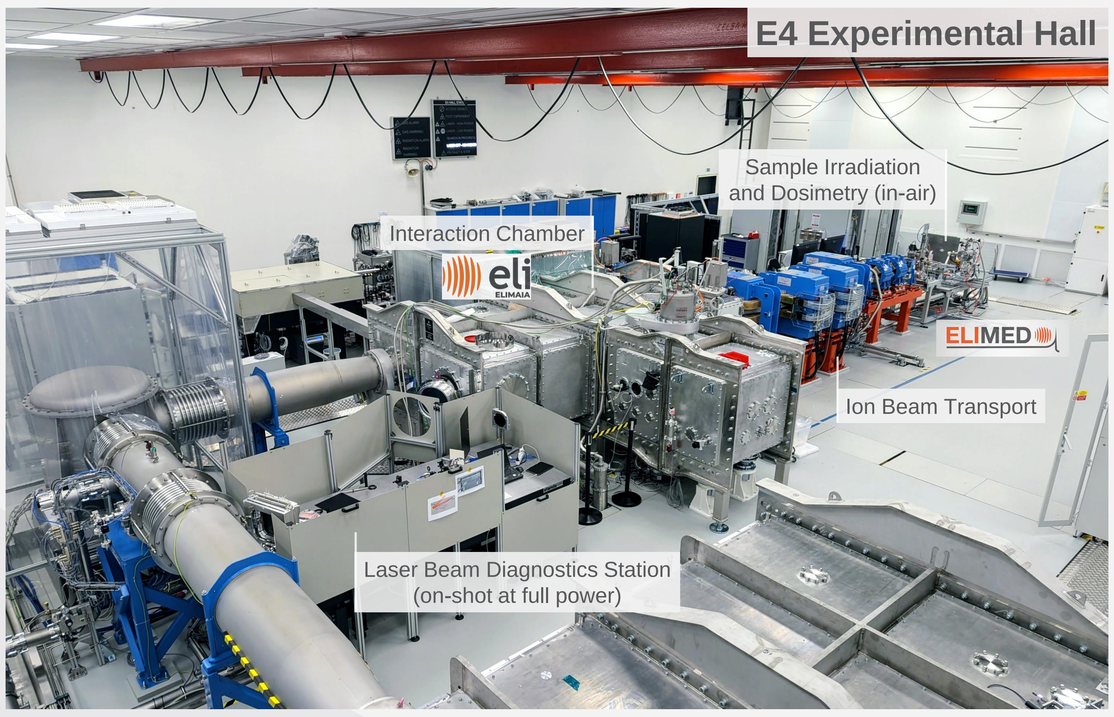
The ELIMAIA (ELI Multidisciplinary Applications of laser-Ion Acceleration) Beamline [1] is an experimental platform focused on laser-driven ion acceleration, driven by the L3-HAPLS PW-class high-repetition-rate Ti:sapphire CPA laser.

Current performance:

- Laser intensity: $5{\cdot}10^{21}$ W/cm^2, current specs: 10 J / 27 fs (~ 350 TW) at 0.2 Hz / single shot
- Proton cutoff energy: up to 40 MeV | σ < 10%
- Proton flux (> 3 MeV): ~ 5 x 10^{11} sr^{-1} | σ < 10%

Potential applications:

- exploring ion acceleration mechanisms
- testing advanced targets
- developing machine learning algorithms
- research of laser-driven nuclear reactions
- electromagnetic pulse studies



ELIMED

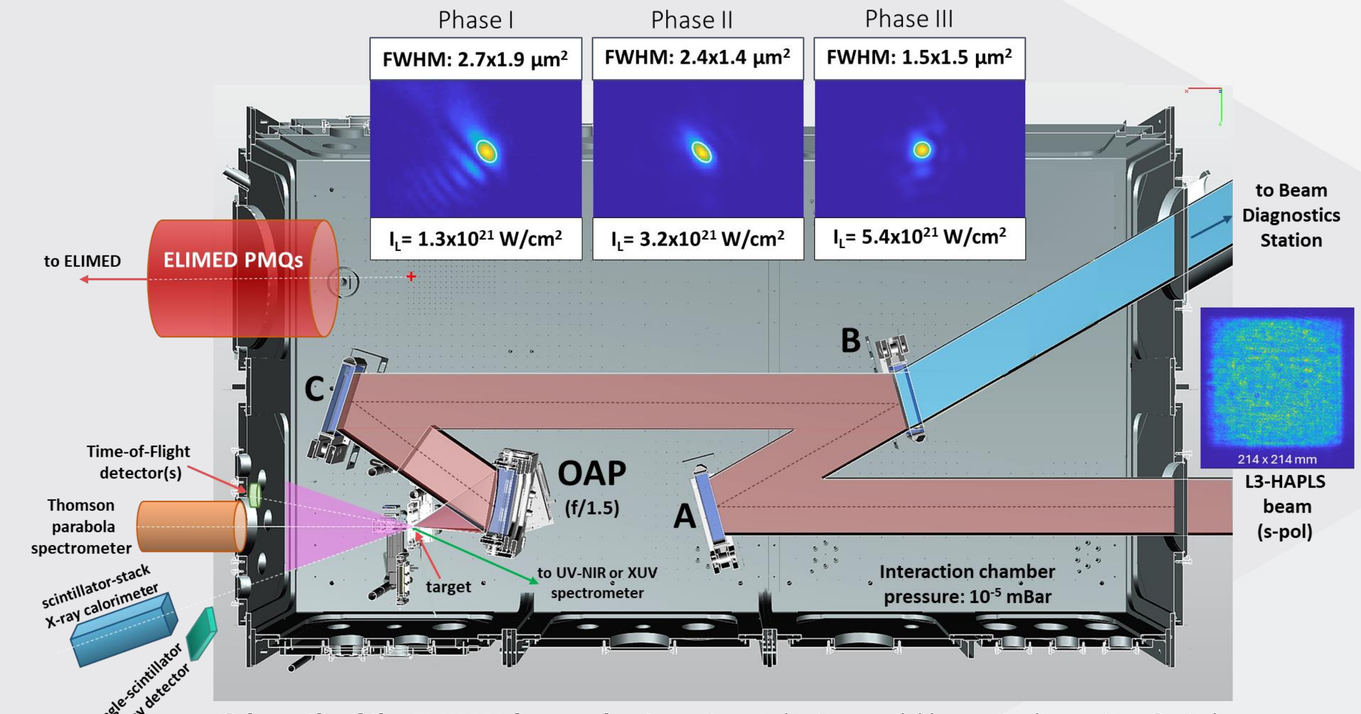
The ELIMED end-station [2] is designed for in-air sample irradiation with a controlled proton/ion beam from the ELIMAIA laser-plasma accelerator.

Current performance:

- Protons from 5 to 25 MeV
- Selectable energy spread: ±1-25%
- Transmission efficiency: 5% (for ±10% spread)
- Output beam size (nominal): 0.1-10 mm
- Ultrashort proton bunch duration (<10 ns)
- Dose: ~10 mGy/shot (peak dose rate 10^6 Gy/s)

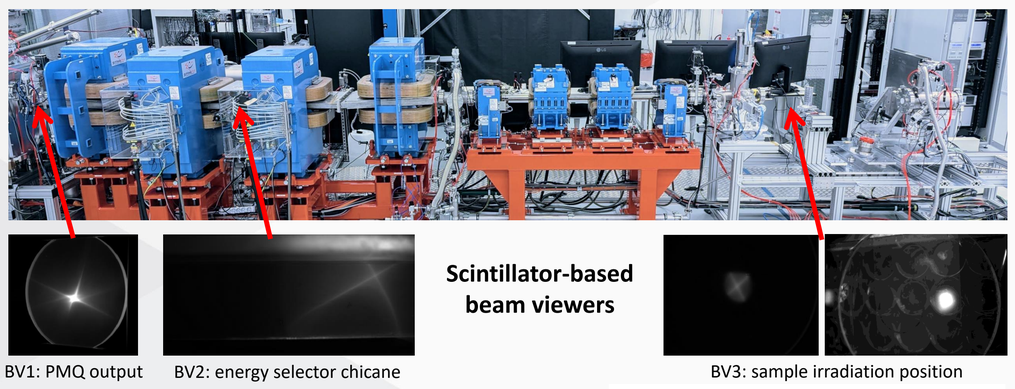
Potential applications:

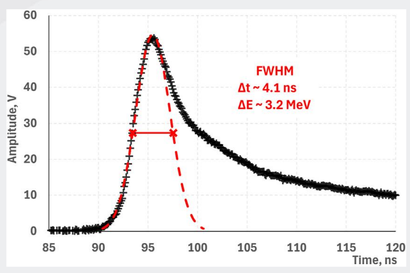
- medical research linked with cancer therapy
- radiobiology in ultra-high dose-rate regime
- material science (PIXE, DPAA, proton imaging)
- cultural heritage studies
- testing of radiation effects on electronics



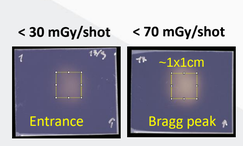
Schematic of the ELIMAIA ion accelerator setup, indicating available on-site diagnostics. Spatial profiles of the laser focal spot with estimated intensity values for three phases of laser development. *Phases II and III also featured reduced levels of the laser ASE (amplified spontaneous emission)*

MAGNETIC ION BEAM TRANSPORT

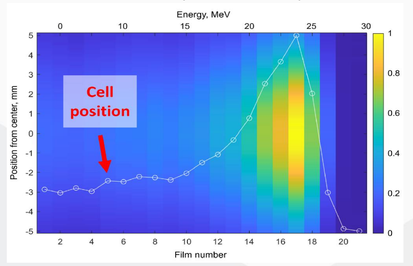




Duration of a typical proton bunch measured by a time-of-flight detector at the output of the ELIMED beamline.

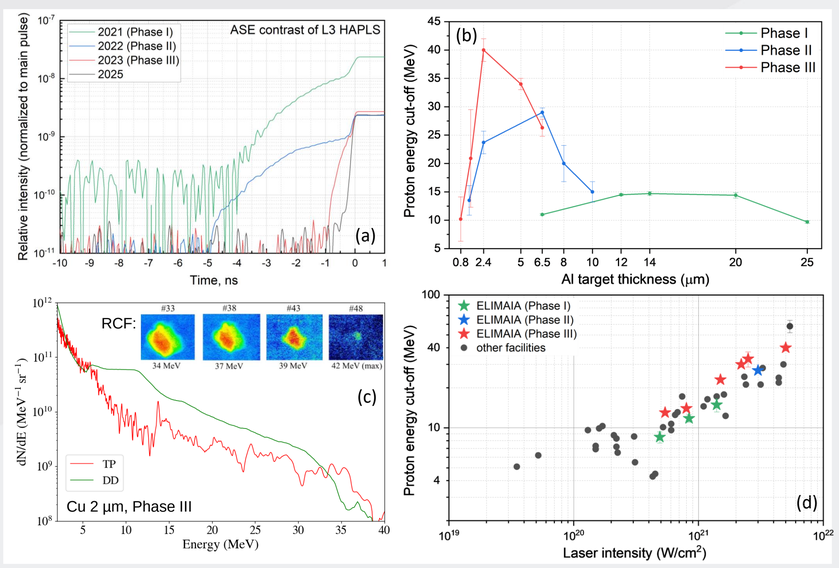


Dose measurement at sample irradiation position (best conditions)



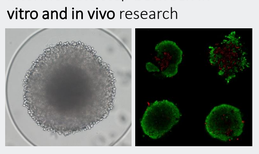
Relative dose deposited on RCF films (EBT3). Bottom x-axis shows the film number in the stack, while the top – the incident proton energy. The y-axis indicates the distance from the center of each film.

ION ACCELERATOR PERFORMANCE

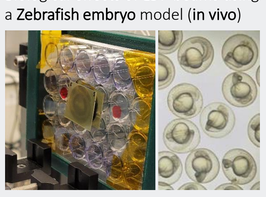


Ion accelerator performance in Phases I-III [3]**: (a)** laser ASE contrast evaluation based on PD measurements; **(b)** Al targets thickness scan; **(c)** proton spectrum obtained with three different diagnostics in Phase III; **(d)** plot of proton cutoff vs laser intensity for pulses of less than 40 fs from various laser facilities.

ELIUPM4-117 (P. 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 (K. Hideghéty, ELI-ALPS)
Biological effects of LDP beams using a Zebrafish embryo model (in vivo)



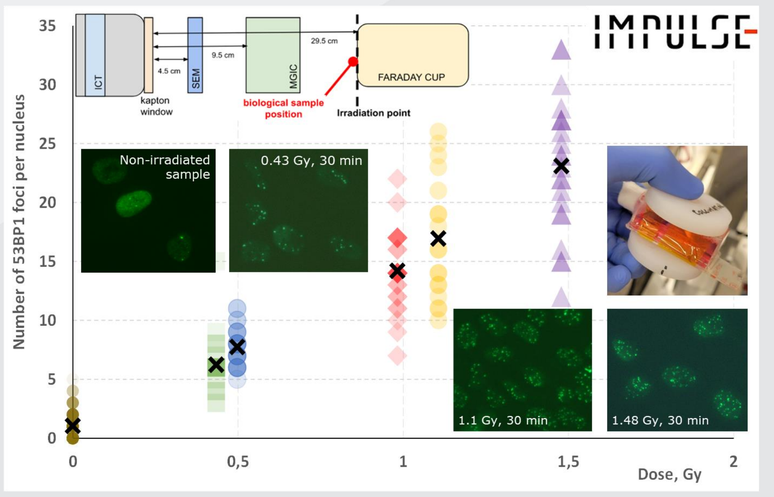
ELIUPM4-100 (O. Zahradníček, CAS)
LDP beam irradiation effects on chicken development in early embryonic cells (in vitro)

USER OPERATION HIGHLIGHTS

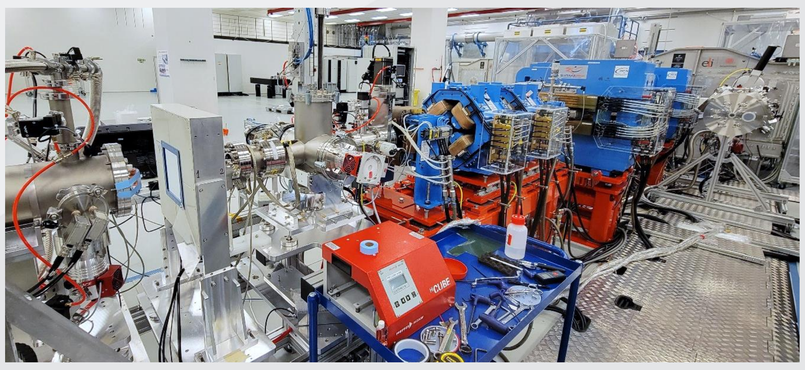
- 12 campaigns from October 2023 to March 2025 (4 at ELIMAIA + 8 at ELIMED)
- 112 days of high power beamtime
- Over 24000 high power shots received
- From 300 to 4500 shots per campaign
- Up to 1000 solid target shots per day
- First radiobiological experiment at ELIMED – published [4]
- 4 more campaigns scheduled for 2025

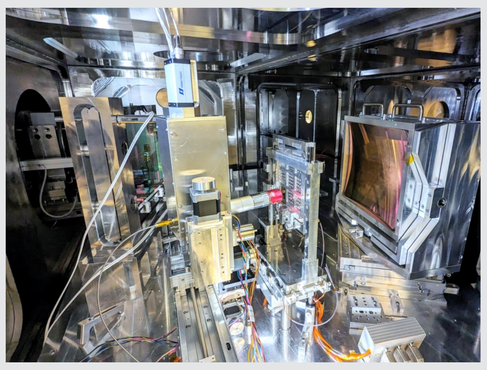
6th Joint ELI Call for Users open: 18 March – 25 April 2025
Apply for beamtime at https://up.eli-laser.eu

RADIOBIOLOGY AT ELIMED



Flagship experiment FLAIM (Flash and ultrahigh dose-rate radiobiology with Laser Accelerated Ions for Medical research) performed **at ELIMED** to irradiate cell cultures (normal skin fibroblasts grown on slide flasks) with laser-accelerated protons [4]. Examples of the induced DNA damage (visualized using a fluorescent stain) shown for different absorbed doses, approximately 30 min after the end of irradiation.





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[1] Schillaci, F., Giuffrida, L., Tryus, M., et al. (2022). The ELIMAIA Laser–Plasma Ion Accelerator: Technological Commissioning and Perspectives. *Quantum Beam Science*, 6(4), 30.
[2] Cirrone, G.A.P., Petringa, G., Catalano, R., et al. (2020). ELIMED-ELIMAIA: The First Open User Irradiation Beamline for Laser-Plasma-Accelerated Ion Beams. *Frontiers in Physics*, 8, 564907.
[3] Giuffrida et al., The ELIMAIA laser-plasma Ion Accelerator: a platform for open-access user experiments (*submitted to Matter and Radiation at Extremes*).
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