ELI Beamlines: the high-energy, high-average-power pillar of the Extreme Light Infrastructure

***ELISS summer school**, ELI Beamlines, August 29th, 2023*

Daniele Margarone *(on behalf of the ELI BL team)*

Director of Research and Operations
ELI Beamline Facility, The Extreme Light Infrastructure ERIC

Outline

- **ELI Beamlines mission and facility overview**
- **ELI BL current user offer** *(secondary sources and end-stations)*
- **ELI BL future capabilities** *(ramp-up and upgrades)*

From Nobel Prize to ELI

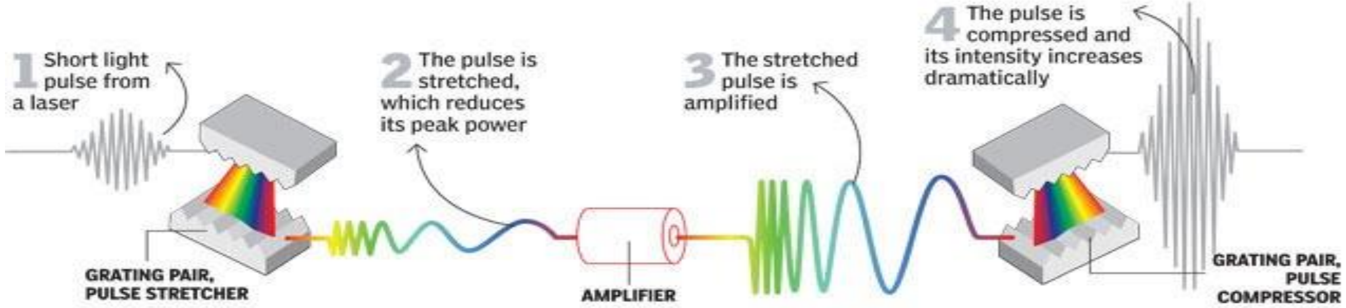
from ELI to Nobel Prize?

***Gérard Mourou and Donna Strickland** won the **2018 Nobel Prize for Physics** for proposing **"Chirped Pulse Amplification"** for high-power, ultrafast, extremely intense lasers.*

SEVENTH FRAMEWORK PROGRAMME

Mourou, et al proposed ELI in 2004, and from 2007-2010 initial research including 15 institutions and € 7.9M from the Seventh Framework Programme.

Chirped Pulse Amplification (CPA)



ELI Beamlines High-Energy Beam Pillar of the Extreme Light Infrastructure

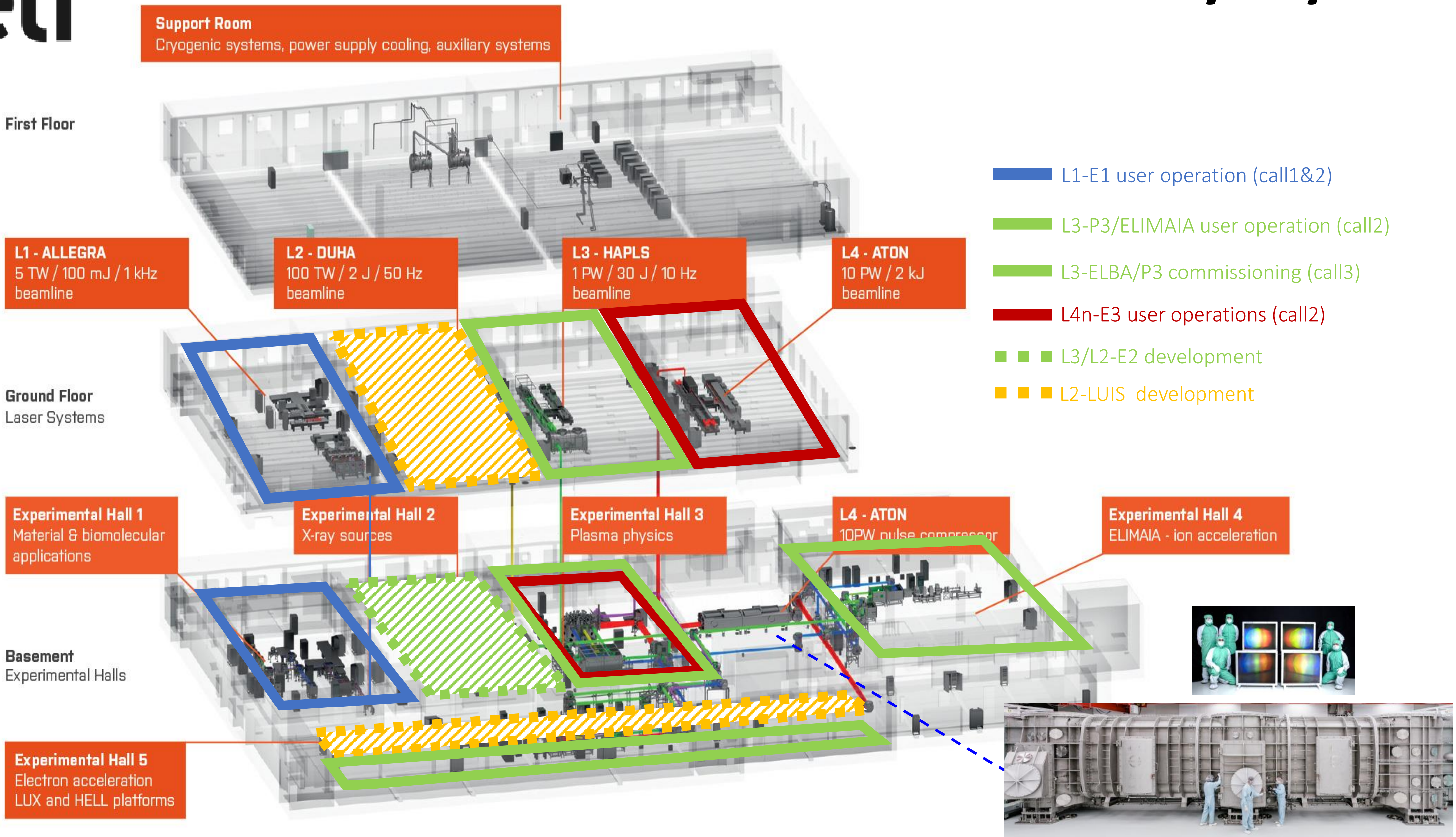
ELI Beamlines

Dolní Břežany, Czech Republic

ELI Beamlines mission profile

- Operate cutting edge, **high-peak power femtosecond laser** systems with **high energy**, **high repetition-rate** capability
- Explore interaction of **light with matter (plasma) at ultrahigh laser intensities**
- Offer **secondary sources (X-rays and accelerated particles)** with unique capabilities to users
- Enable **pioneering research** not only in plasma physics, high-field physics, nuclear fusion and laboratory astrophysics, but also in material science, biology, chemistry, medicine and other disciplines with strong **multidisciplinary application** potential

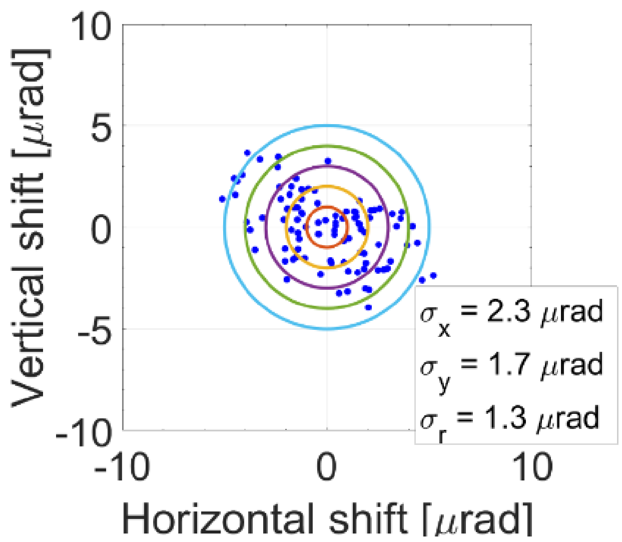
ELI Beamlines Facility Layout

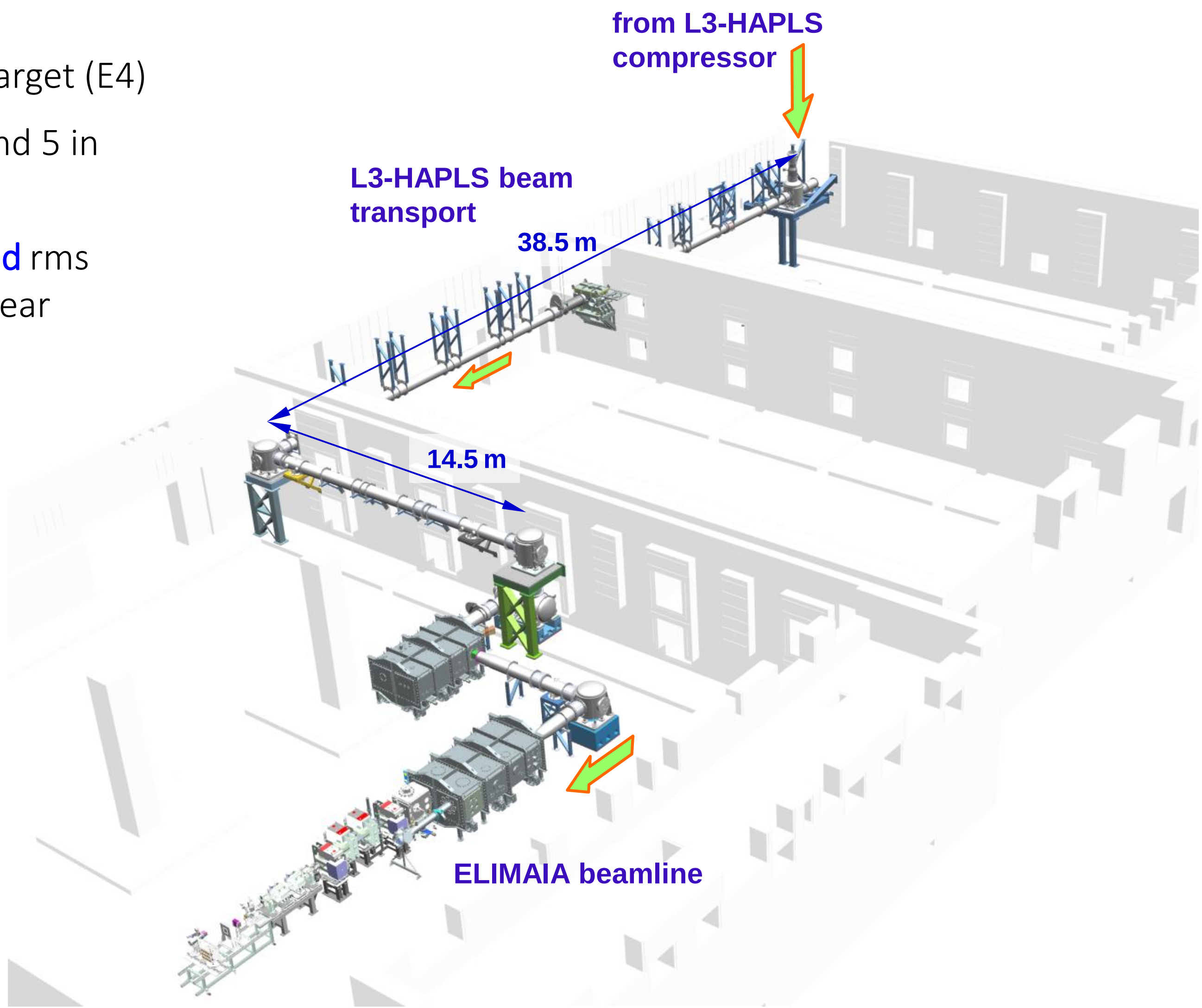


Laser beam transport

example: L3-to-E4

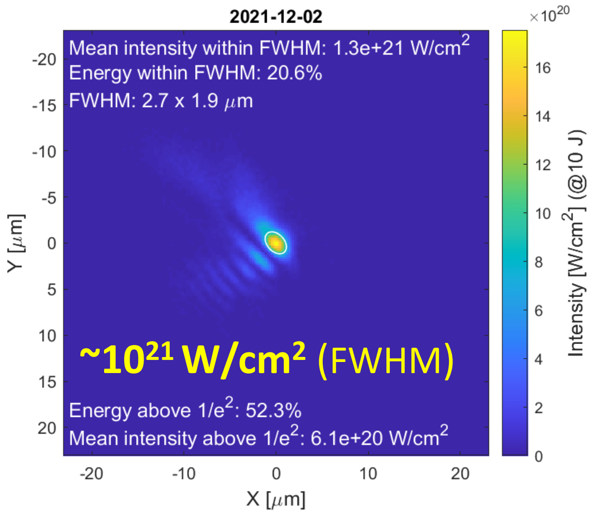
- ✓ 78 m beam path: from L3 compressor output to ELIMAIA target (E4)
- ✓ Optical beam path: 13 turning mirrors (8 in L3-BT section and 5 in ELIMAIA chambers)
- ✓ Excellent pointing stability of the integrated system: 1.3 µrad rms jitter over 54 min of continuous operation (shot-to-shot linear fluctuation on target <1 µm rms)



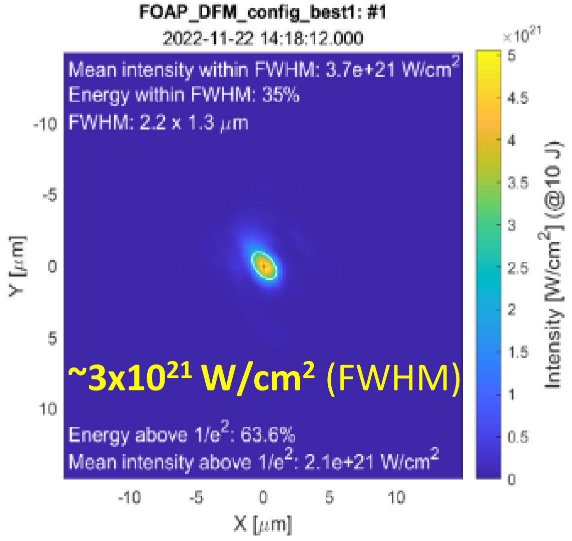


L3-HAPLS focusability and pulse width

wavefront, focal spot quality and pulse width on target



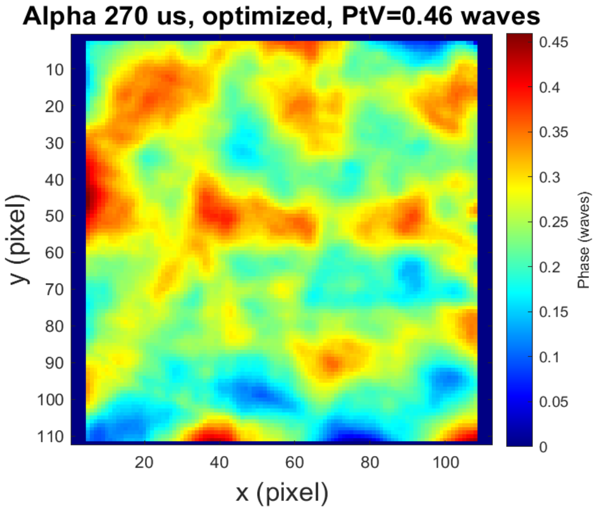
1st DFM

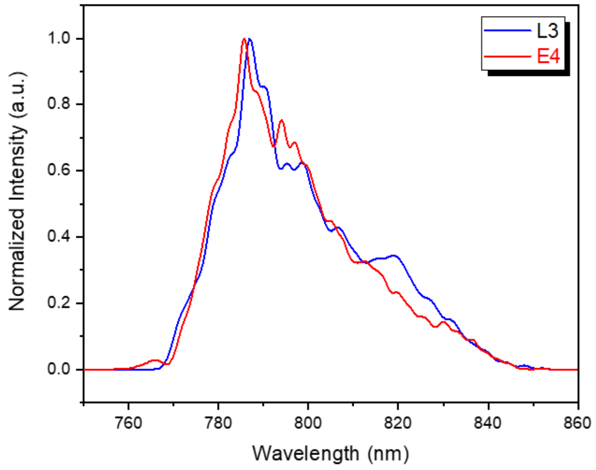


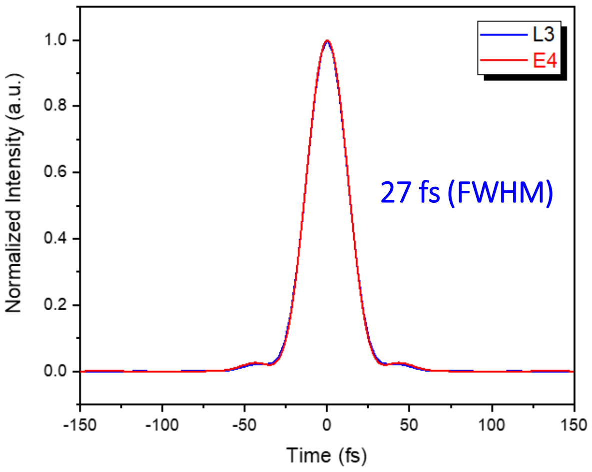
✓ 2nd DFM

✓ 10J → 30J

~10^{22} W/cm^2 ?







ELI Beamlines

current user offer

- Mid-IR to Hard X-rays @1kHz
- Pump-Probe techniques for
- fs-ms dynamics

- Ultrahigh intensity laser-matter interaction (>10^{21}W/cm^2)
- Laser-plasma p acc. (>35MeV)
- Tertiary sources (pitcher-catcher)

- kJ-class (2w), ns, high rep-rate, pulse-shaping capability
- Platform for HEDP, ICF, shock physics
- Dedicated targetry & diagnostics

Laser systems @ELI BL

including ramp-up/upgrades

Laser parameters	L1 - ALLEGRA	L2-DUHA	L3 - HAPLS	L4 - ATON
Description	OPCPA, Yb:YAG thin disks, diode pumping	OPCPA, Yb:YAG slabs,diode-pumped	CPA, Ti:Sa, diode pumping	CPA/OPCPA, Nd:glass, flash lamps pumping
Energy	**55 mJ** (100 mJ)	3 J	**13 J** (30 J)	**0.3 kJ @2w** (1.5 kJ @1w)
Pulse width	**15 fs**	**25 fs**	**27 fs**	**2-10 ns** (150 fs)
Peak Power	**>3 TW** (>6 TW)	>100 TW	**0.5 PW** (1 PW)	NA (10 PW)
Wavelength	840 nm	820 nm *(2.2 μm)*	800 nm	530 nm (1060 nm)
Repetition rate	**up to 1 kHz**	50 Hz *(1 kHz)*	**up to 3.3 Hz** (10 Hz)	**1/3min** (1/min)
Intensity contrast	10^{-10}	10^{-11}	10^{-11}	NA (10^{-11})

Talk by R. Antipenkov (Tuesday, 13:30)

E1 Experimental Hall

kHz Appl. in AMO, Bio, and Material Sci.

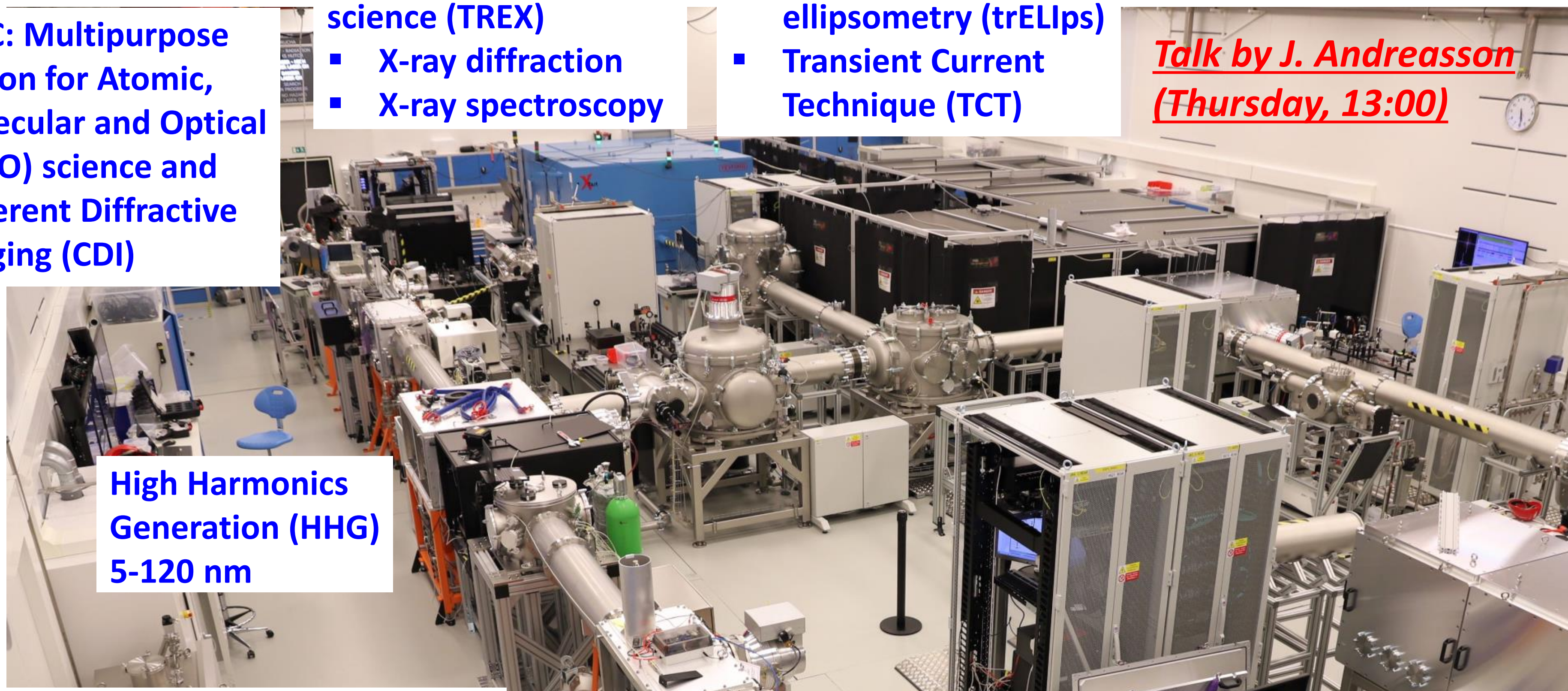
Plasma X-ray source (PXS), 3-30 keV, 8 keV End station for X-ray science (TREX)
- X-ray diffraction
- X-ray spectroscopy

E1 Ultrafast Optical spectroscopy
- Time resolved spectroscopic ellipsometry (trELIps)
- Transient Current Technique (TCT)

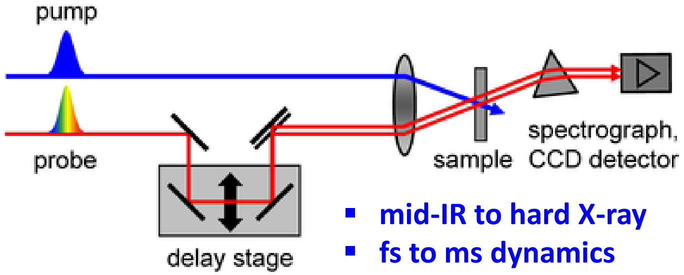
Talk by J. Andreasson (Thursday, 13:00)

- Drive laser XUV and X-ray: L1: 4-25 mJ (40 mJ), 15 fs, 1 kHz
- Support laser XUV and X-ray: Legend: 12 mJ, 35 fs, 1 kHz
- Drive laser E1 optical: Astrella: 7 mJ, 35 fs, 1 kHz
- Drive laser Biolab optical: Femtopower/Solstice doublet: 4.5/7 mJ, 20/35 fs, 1 kHz

MAC: Multipurpose station for Atomic, Molecular and Optical (AMO) science and Coherent Diffractive Imaging (CDI)

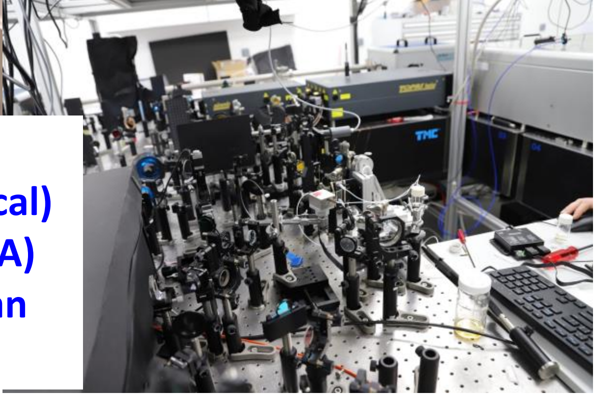


High Harmonics Generation (HHG) 5-120 nm



- mid-IR to hard X-ray
- fs to ms dynamics

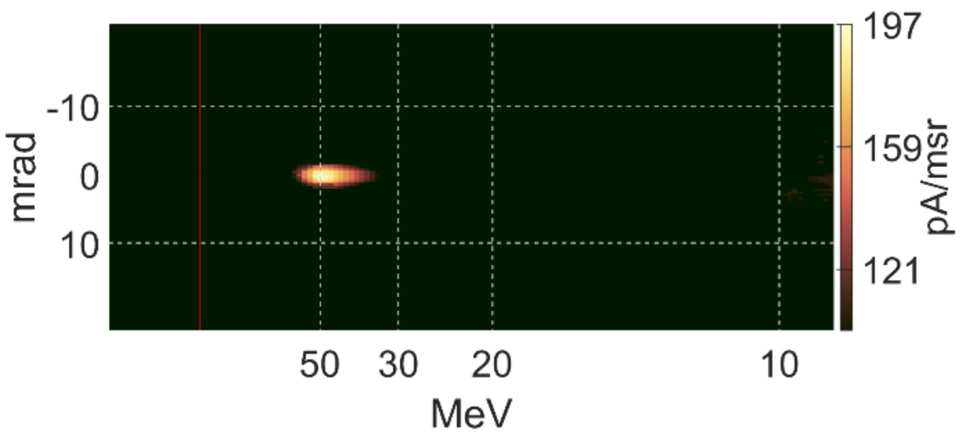
Satellite laboratory for Ultrafast Optical spectroscopy (Biolab Optical)
- Transient optical Absorption (TA)
- Femtosecond Stimulated Raman Scattering (FSRS)



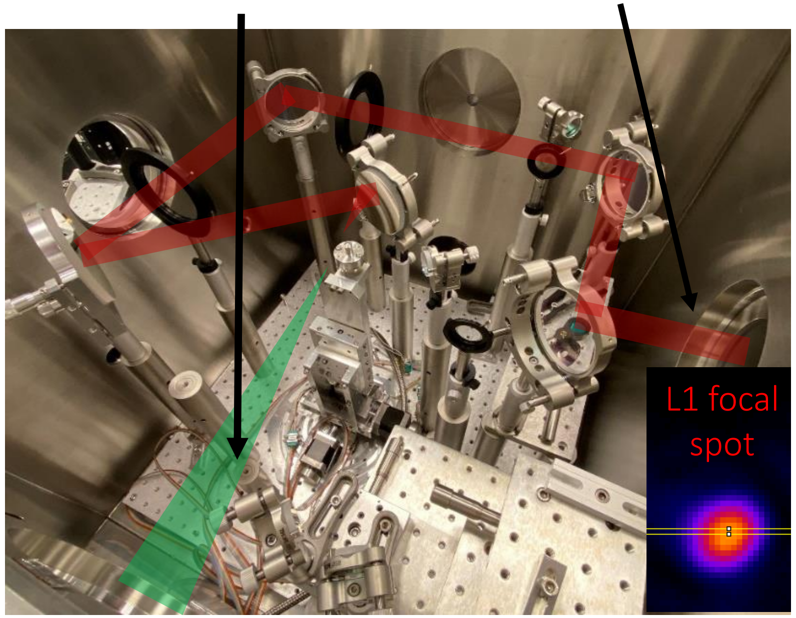
ALFA kHz Laser-Plasma Accelerator (L1 Hall)

- L1-ALLEGRA laser focused down to enable laser-matter interaction at **relativistic intensities (kHz experimental platform)**
- L1-ALLEGRA drives the ALFA plasma accelerator which delivers ultra-short **electron beams** (~fs) with tuneable energy (up to 50 MeV)
- In-air **end station** for user **sample irradiation**

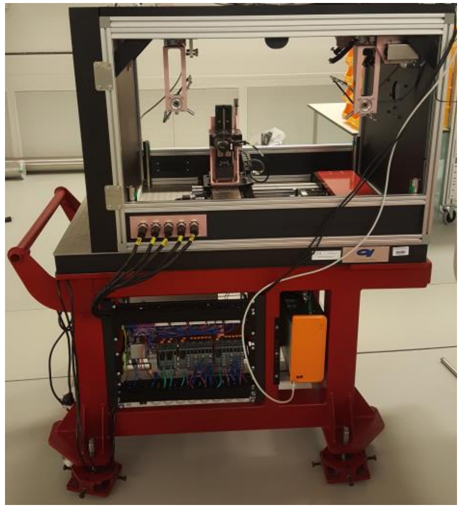
C. Lazzarini et al.



Electron Beam **L1 Laser**



End station for sample irradiation

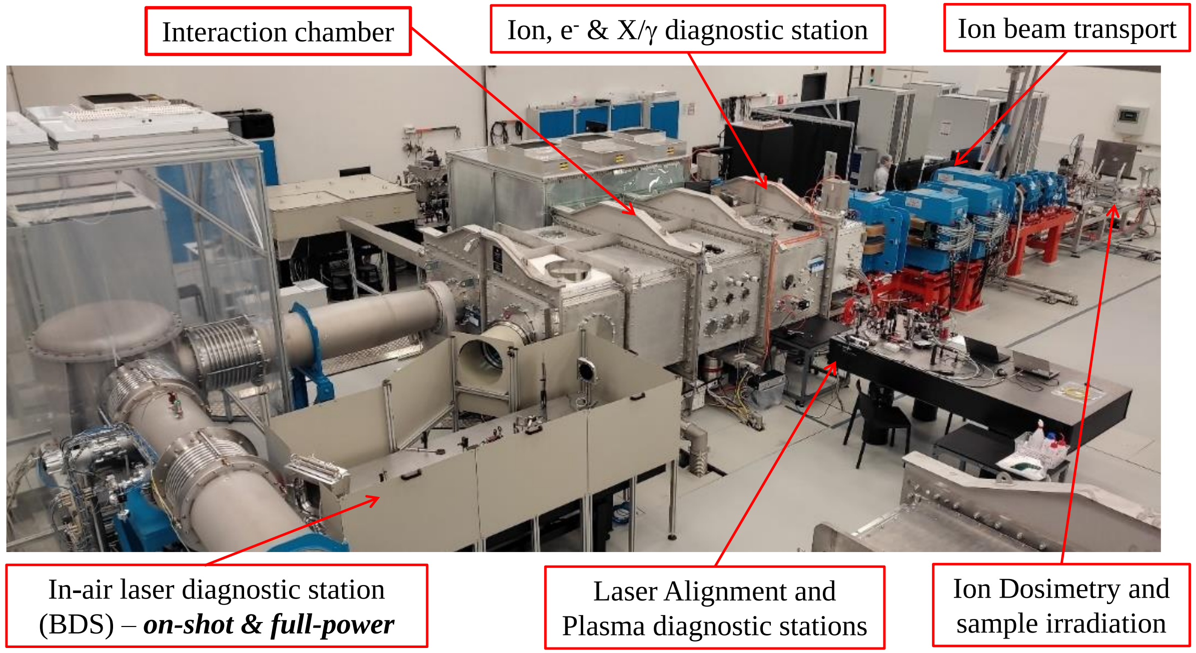


L1-ALFA (Call 2)	Laser beam	Electron beam
Intensity	$6 \cdot 10^{18}$ W/cm^2	-
Energy	55 mJ	30±5 MeV
Pulse width	15 fs	~fs
Repetition rate	up to 1 kHz	up to 1 kHz
Current	-	10-300 pA
Divergence	-	2-8 mrad

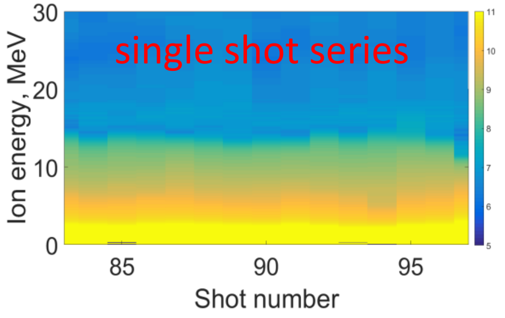
ELIMAIA-ELIMED Laser-Plasma Ion Accelerator (E4)

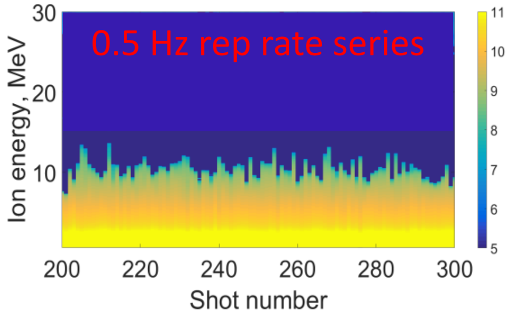
ELI Multidisciplinary Applications of laser-Ion Acceleration (1 Hz)

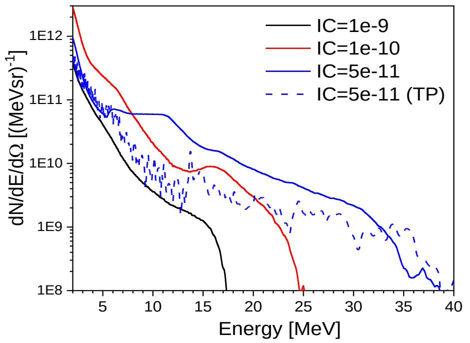
Talk by L. Giuffrida (Thursday, 15:10)



L3 - Ion Accelerator (user call)	Demonstrated	Design parameters
Laser intensity	$3\cdot10^{21}$ W/cm^2	10^{22} W/cm^2
Laser energy	>10 J	30 J
Laser pulse width	<30 fs	<30 fs
Repetition rate	~ 1 Hz	10 Hz
Proton energy cutoff	~ 40 MeV	100 MeV
Proton flux (>3 MeV)	~ $1\cdot10^{11}$/sr	> $1\cdot10^{11}$/sr



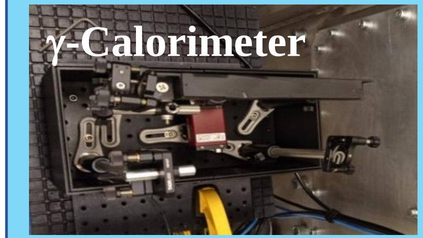


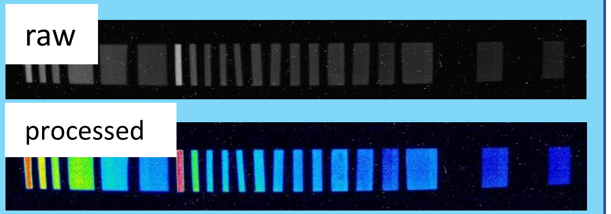


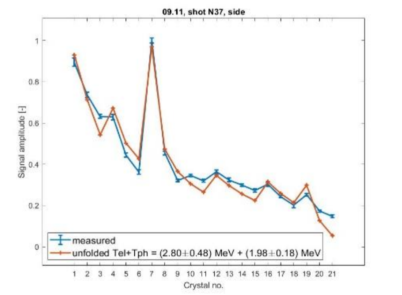
ELIMED end station (commissioning)	Design parameters @ user sample
Ion energy	**5-60 MeV/nucleon**
Energy spread	**<10%**
Ions/shot	$1\cdot10^8$-$1\cdot10^{10}$/sr
Bunch duration	1-10 ns (>10^9 Gy/s)
Ion beam aperture	**~ 1deg** (FWHM)
Ion beam spot size	0.1-10 mm (FWHM)
Repetition rate	Active modulation (1Hz)

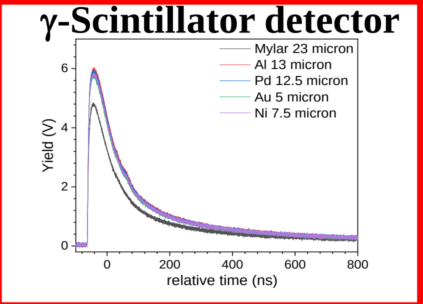
On-Shot Laser, Plasma, and Ion Diagnostics

X/γ-ray diagnostics

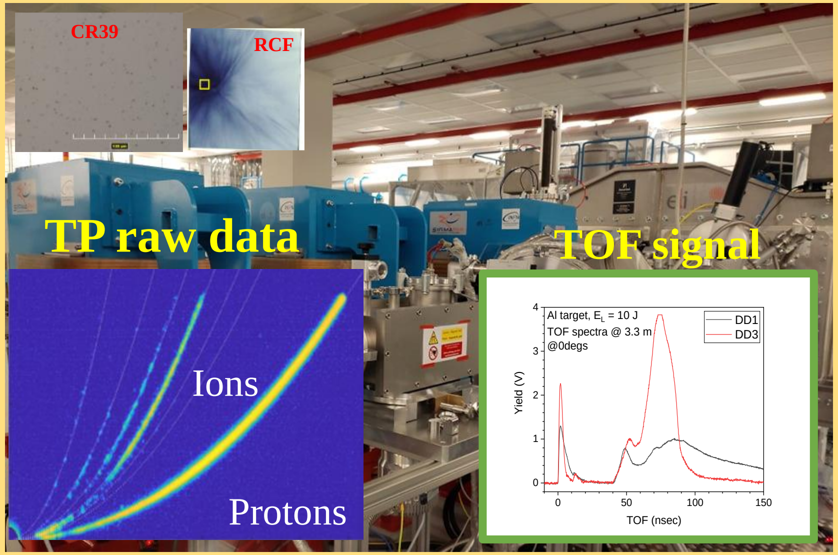




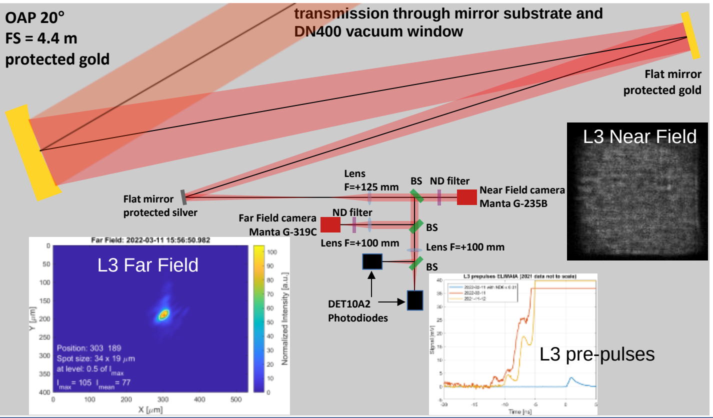




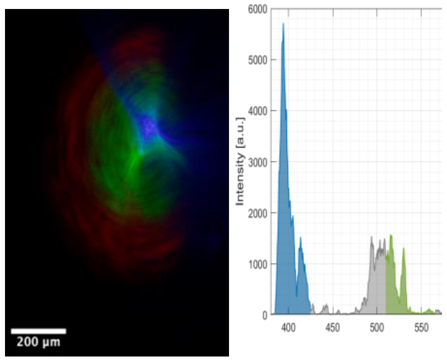
Ion diagnostics



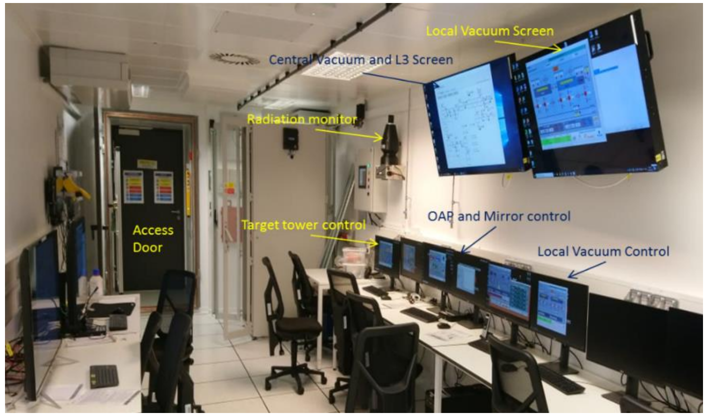
On-shot laser diagnostics



Plasma imaging/ spectroscopy



Online data analysis (1-10 Hz)

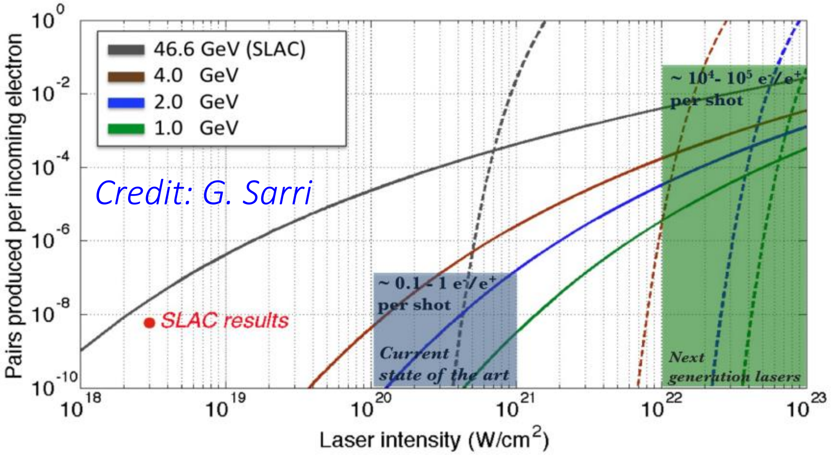


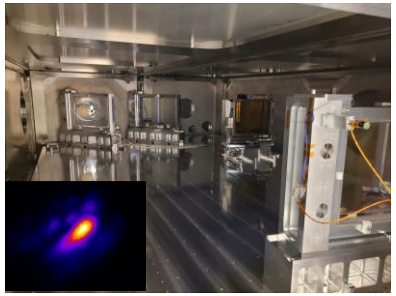
ELBA Electron Accelerator and Collider (E5)

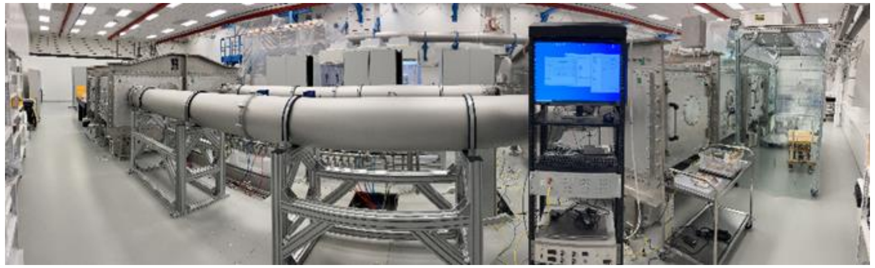
multi-GeV electron beams and PW-class photon-electron collider (3-10 Hz)

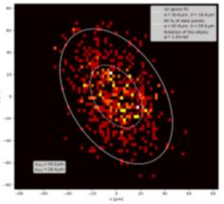
Talk by G. Grittani (Thursday, 15:40)

- Electron Accelerator basic commissioning: conducted
- Electron Accelerator advanced commissioning: user-assisted commissioning call
- Counter Propagation setup: installation in summer 2023 (L3 laser beam splitting ratio can be varied)



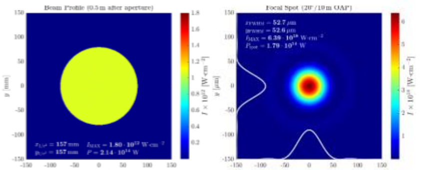




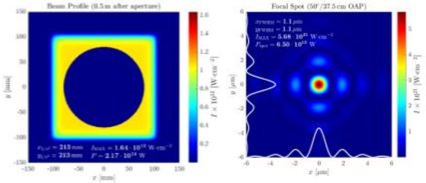


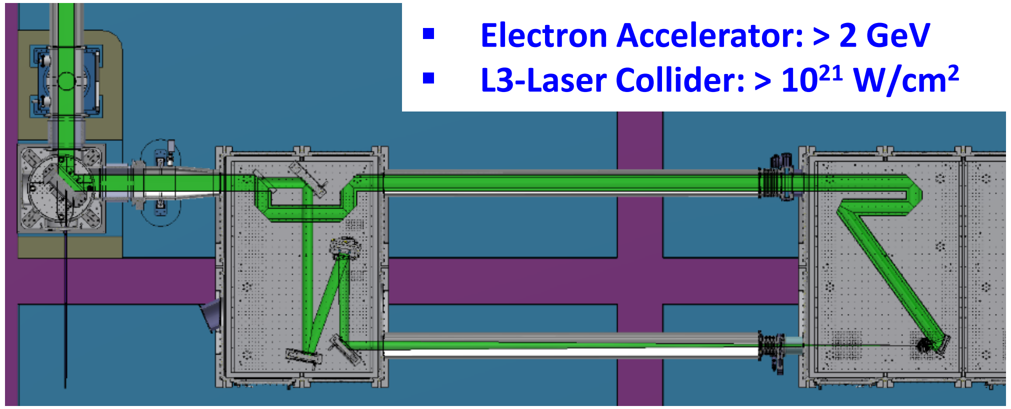
e⁻ pointing (~1mrad)

electron acceleration laser beam



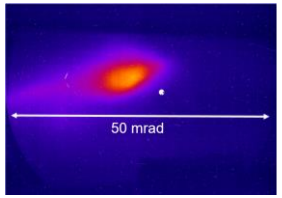
counter-propagating laser beam

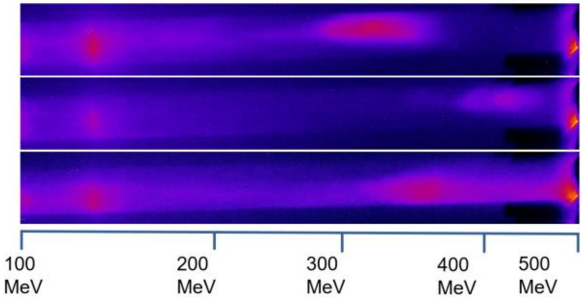




- Electron Accelerator: > 2 GeV
- L3-Laser Collider: > 10^{21} W/cm²

ELBA basic commissioning results

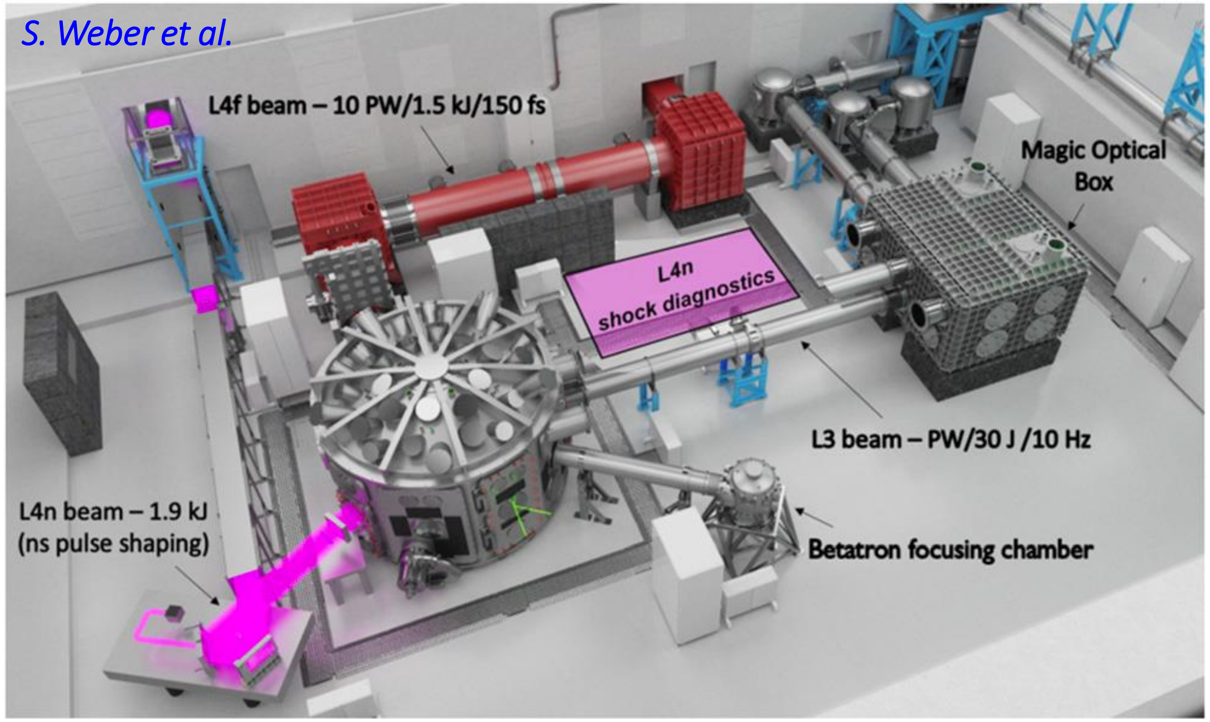




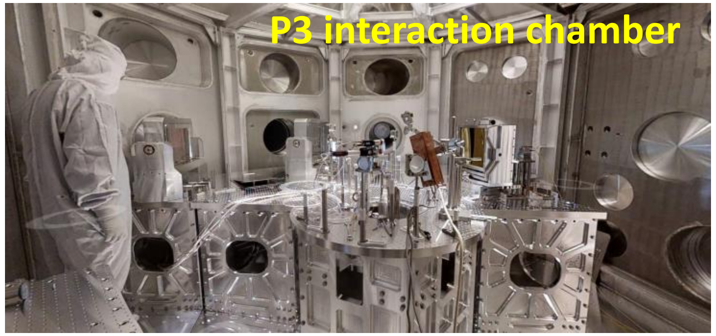
P3 Plasma Physics Platform (E3)

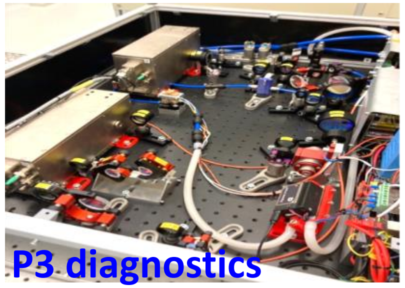
1-10PW (L3+L4) & kJ-ns class lasers (1 shot/min)

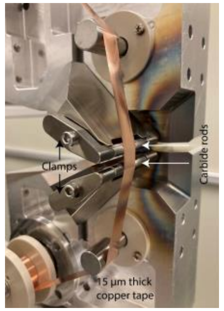
Talk by F. Condamine (Thursday, 14:10)



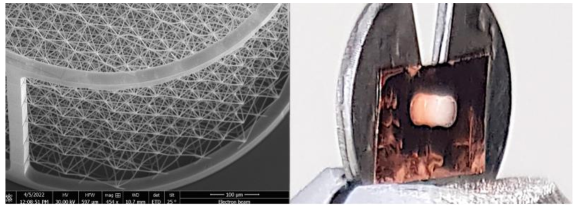
- ➔ L4n-P3 as experimental platform for **HEDP**, including **ICF/IFE** and shock physics
- ➔ High rep. rate capability at kJ level 1 shot/3min (up to 1shot/min)
- ➔ L4 pulse width tuneability (2-10 ns), **temporal shaping** capability (150 ps resolution) and narrow-band/**broadband** option (~5 nm)
- ➔ time-resolved diagnostics for **LPI** (Raman, Brillouin, TPD) and **shock physics**, including VISAR/SOP (commissioning)
- ➔ Hard **X-ray diagnostics** available
- ➔ **Targetry**: solid, gas, multi-layer and foam on tape & raster







P3 targetry

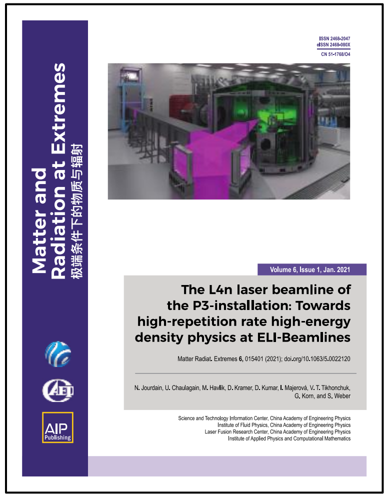


What can ELI do for ICF & IFE?

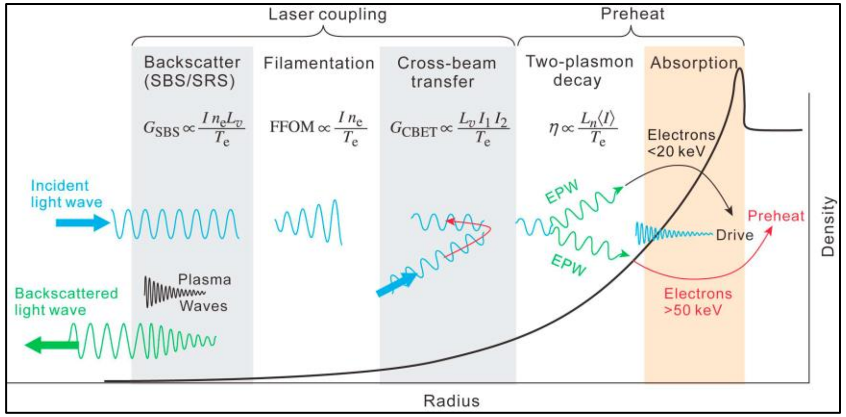
eli

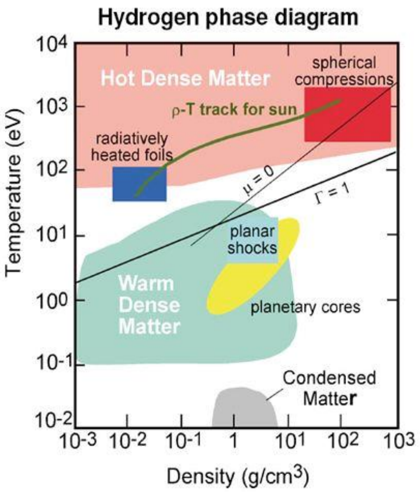
fusion-related research (1 shot/min)

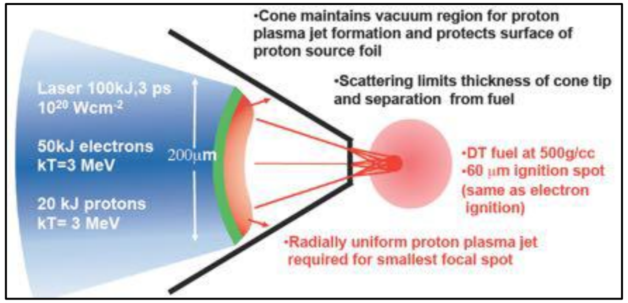
[*Talk by V. Tikhonchuk (Wednesday, 10:00)*]

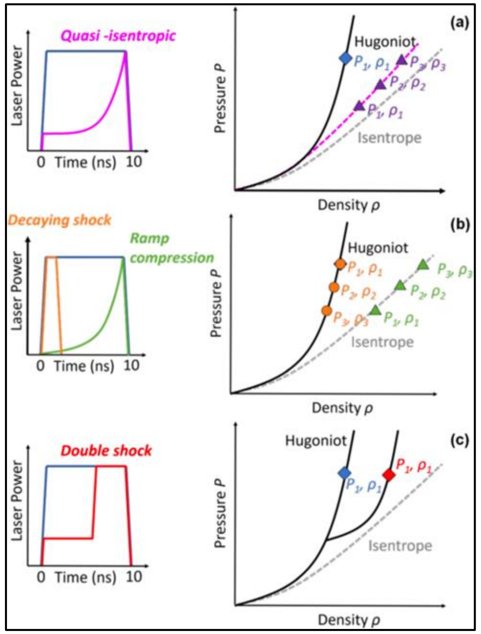


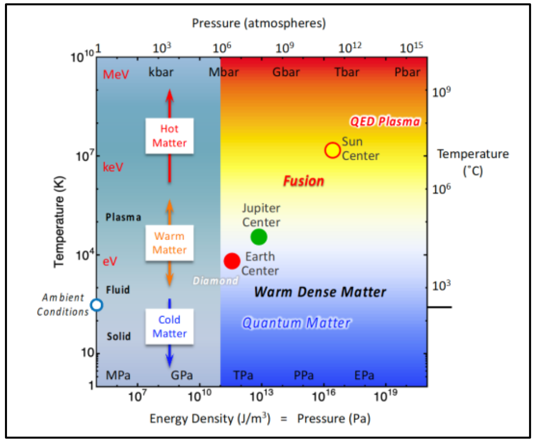
- **Physics studies**
  - LPI, transport, hot electrons, stopping power
  - Opacities, EoS (also off-Hugoniot)
  - WDM (now), HDM (a bit later)
  - Neutron-related studies (D-D or pitcher-catcher)
  - Proton-related studies
  - Magnetized laser-plasma interaction
- **Technology studies**
  - Secondary issues: debris, emp
  - Repetion-rate related issues
  - Targetry
- **Laser-related studies**
  - 2-omega operation (1-omega in the future)
  - Broadband operation (~5 nm)
  - Temporal pulse shaping (150 ps)
- **Development of dedicated simulation tools**

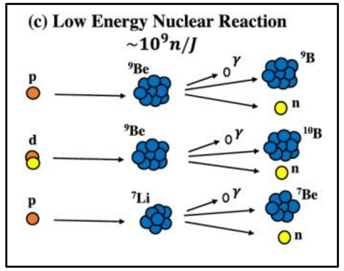










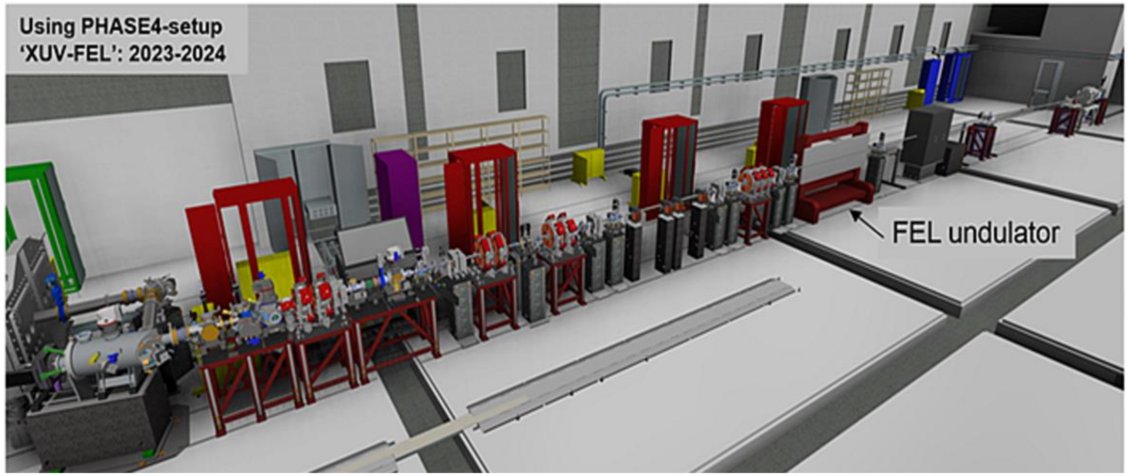


LUIS beamline in E5 driven by L2-DUHA (R&D)

high quality LWFA electron beams for FEL

A. Molodozhentsev et al.

Biomolecular imaging with fs, coherent XUV pulses *(compact approach)*



L2-DUHA Laser

- 3J / 25fs (> **100TW**) @**50Hz**
- Pump laser uses diode-pumped Yb:YAG slabs (cryogenic cooling)
- OPCPA short-pulse chain (**ultrahigh ps-contrast**)
- Auxiliary MID-IR (2.2 µm) beam @ 1kHz

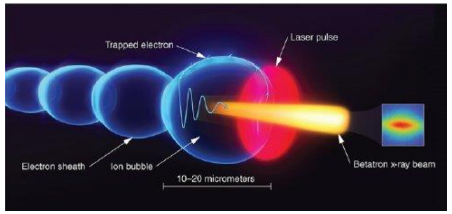
Gammatron beamline in E2 (R&D)

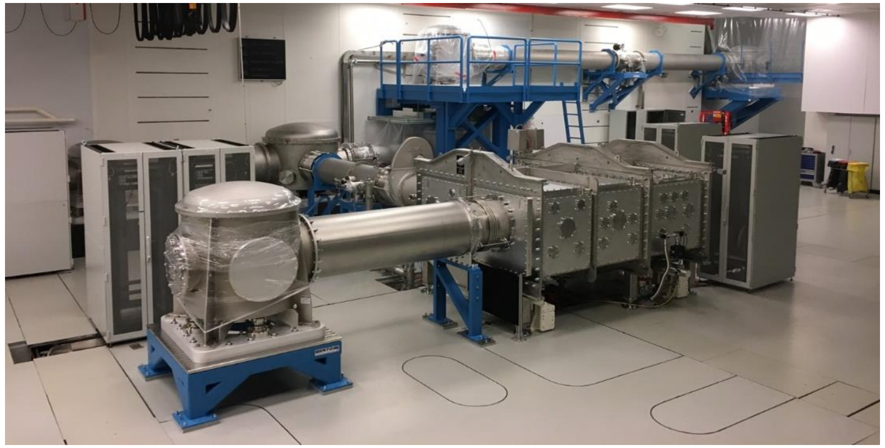
Betatron/Compton X-ray sources in E2/E3

[*Talk by U. Chaulagain (Thursday, 13:40)*]

Driven by L3 (or L2) @ 10Hz (or 50Hz)

	Betatron	Compton
photon energy	10- 100 keV	50 – 5000 keV
photons/shot	> 1E9	> 1E8
Source size	< 5 µm	< 5 µm
pulse duration	~30 fs	< 30 fs





ELI Beamlines User Opportunities

- ✓ ELI expert teams
- ✓ User access (open)
- ✓ Young scientists
- ✓ Unique technologies

→

Unlimited
User Science
Opportunities

→

IDEA

EXPLORATION

TEAM WORK