ELISS2023

ELI Summer School | 29 Aug – 1 Sep 2023

Dolní Břežany, Czech Republic

Plasma physics and Ultra-High Intensity laser-matter interaction in the ELI Beamlines' E3 hall

Florian Condamine

ELI Beamlines

31.08.2023

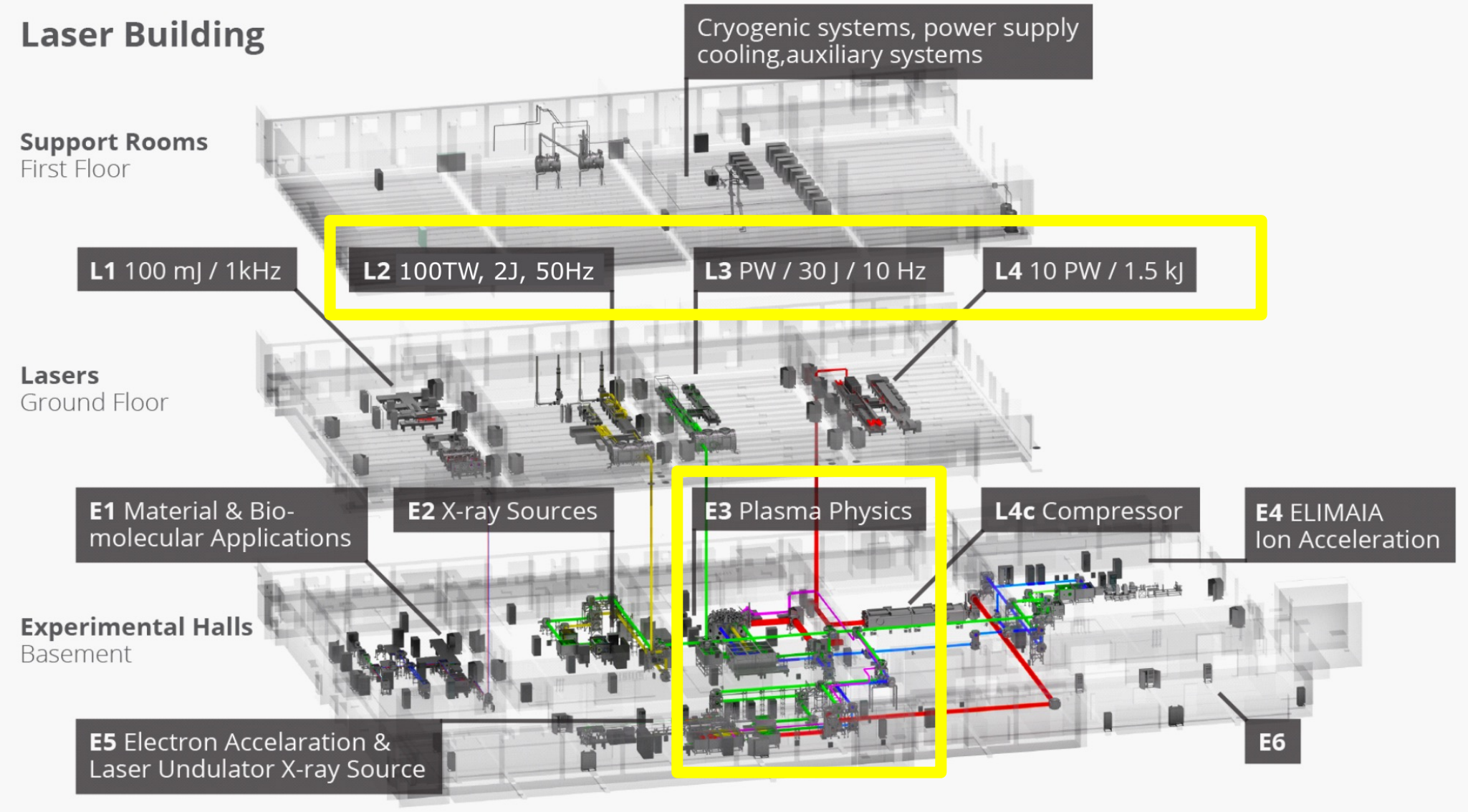
Dolní Břežany, Czech Republic

IMPULSE

IMPULSE is funded by the European Union's Horizon 2020 programme under grant agreement No. 871161

- Lasers and technology
- Example of commissioning campaign (L4n ns-kJ class laser)
- Example of high-repetition rate solid targetry system for UHI interaction

ELI Beamlines



- Long-Pulse interaction :

  - Laboratory astrophysics
  - Inertial Confinement Fusion related studies

- Shot-Pulse interaction at high-intensities :

  - Gamma-ray generation
  - LWFA pump-probe experiments

- Short-Pulse interaction at ultra high-intensities :

  - QED studies

··· Among many others

Current and mid-term future setups

	L3-SFL (Short Focal) - *2024*	L3-LFL (Long Focal) - *2024*	L4n - *2023*	L4n + L3-SFL / LFL - *2024*	L4f
Laser parameters	12 J 27 fs **~ 450 TW**	12 J 27 fs **~ 450 TW**	500 J (2ω) 2 ns to 10 ns		~ 500 J (1ω) 150 fs **~ 3 PW**
Focusing optics	f/3.6 OAP f/1.2 OAP	~f/24 spherical mirror	~f/10 lens DPP available		f/3 OAP
Wavelength	810 nm	810 nm	527 nm or BB		1054 nm
Repetition rate	~0.1Hz (single shots) 3.3 Hz bursts	~0.1 Hz (single shots) 3.3 Hz bursts	1 per 3 min		1 per 3 min
Synchronization				~10 ps	
Actual status	**Commissioned**	*Commissioning 2024*	**Commissioned**	**Sync. Comm.** *1st exp. 2024*	*Commissioning 2024*

Laser technology

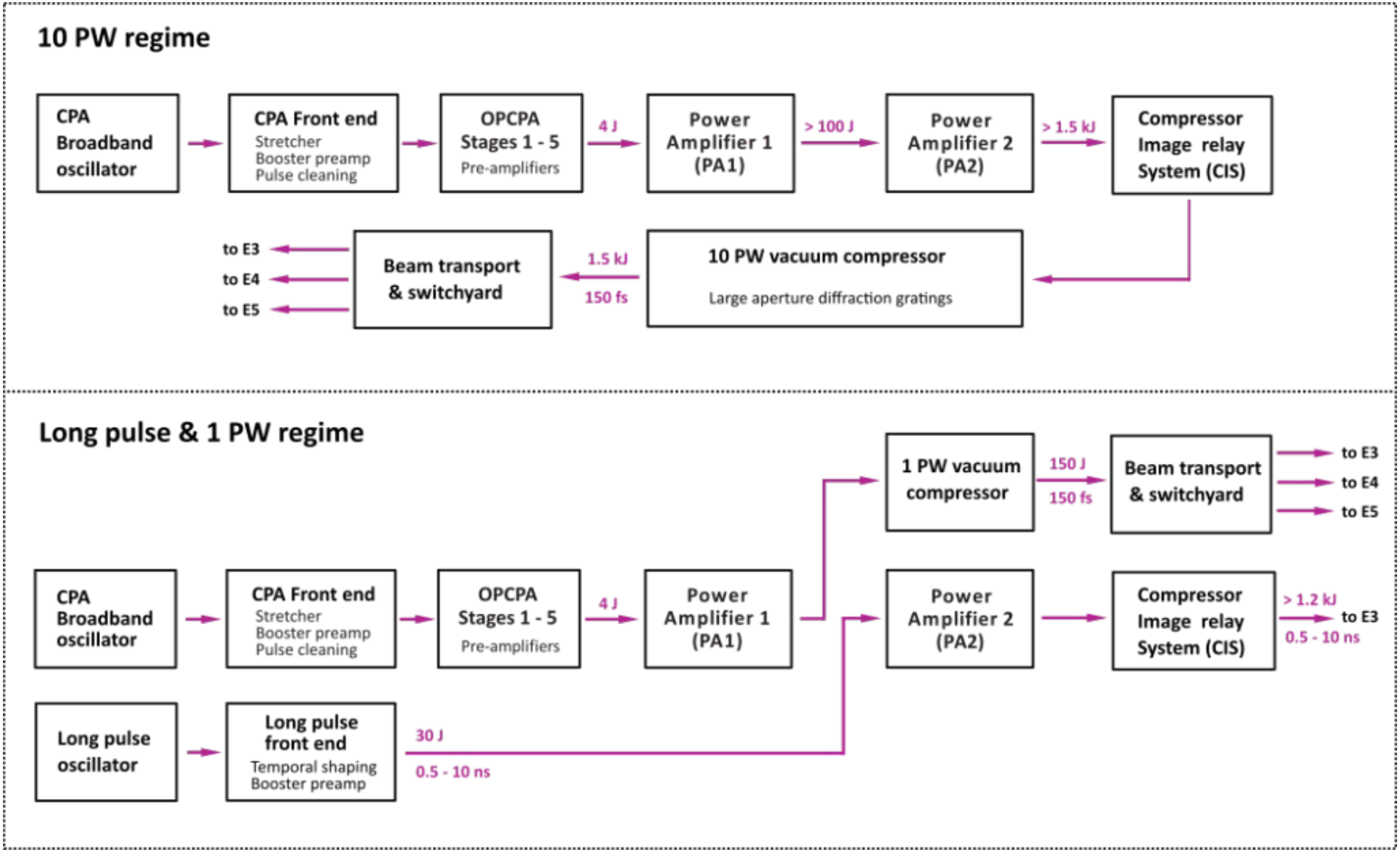
L4n-ATON

- L4 laser can be used uncompressed with **pulse shaping from 0.5 ns to 10 ns.**
  - Long-pulse front-end for narrowband at 527nm.
  - CPA front-end for chirped-broadband operation.
- The maximum energy on target is **~0.6 kJ at 2w (527nm).**
- During the commissioning phase (2022/2023), the repetition rate is limited at 1 shot / 3 min.
- The rate will be increased to **1 shot / min** in mid-term future.

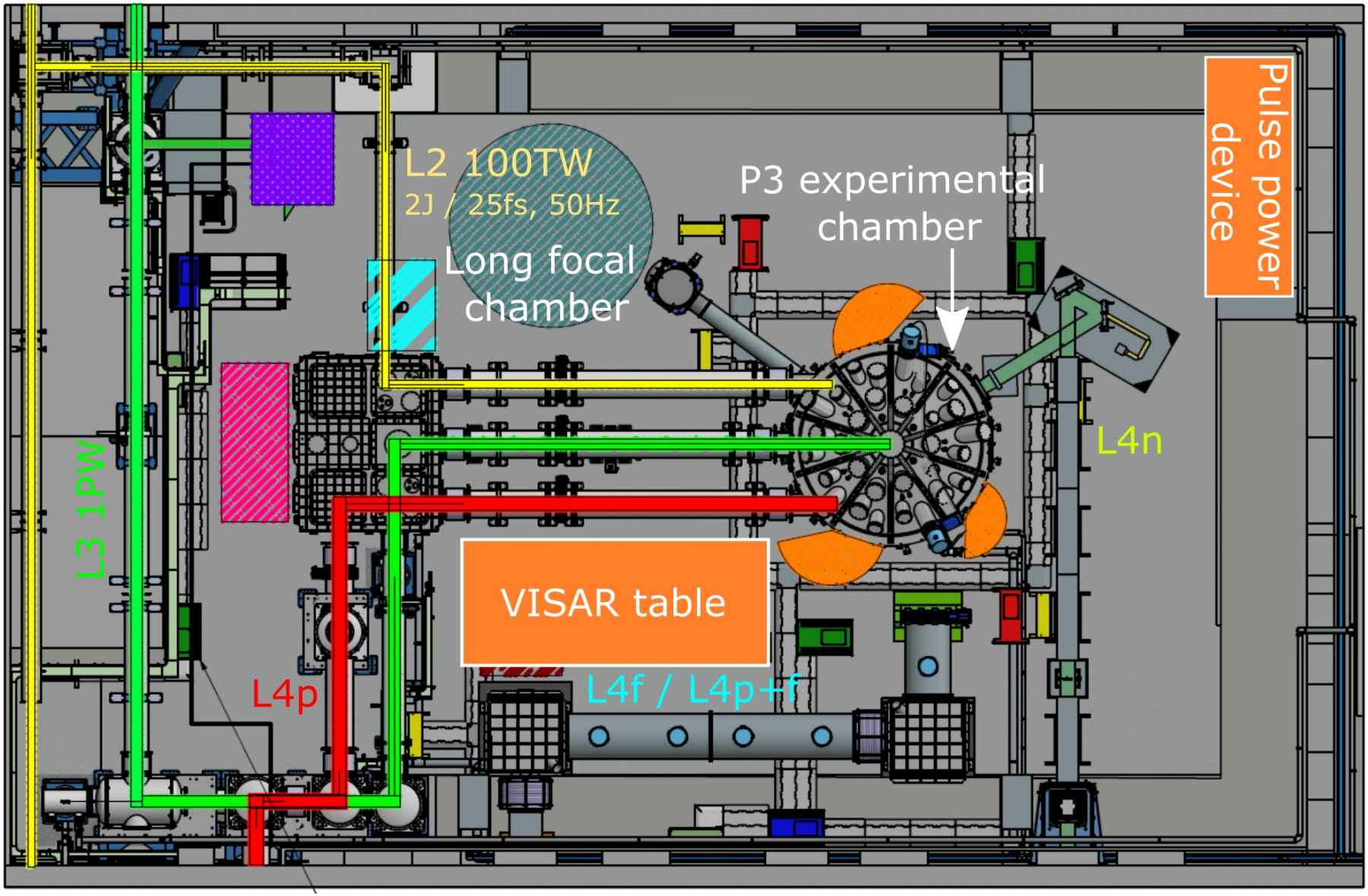
L4f-ATON

- Compressed, L4 will reach a maximum energy of **~1.5 kJ for a ~150 fs pulse duration (~10PW).**
- The repetition rate is also expected to be **1 shot / minute** at full performance.
- Commissioning 2024 (multi-PW).

Laser technology

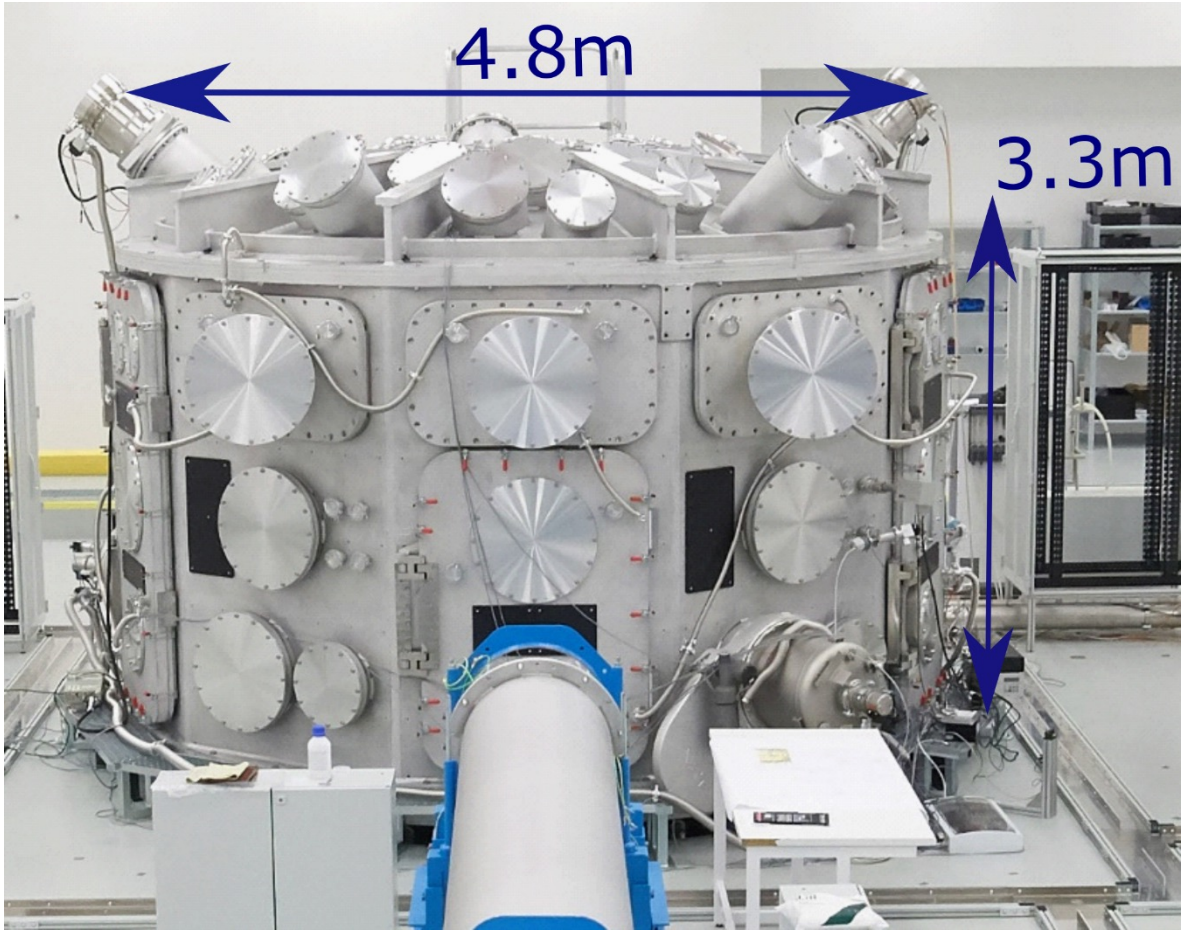


E3 experimental hall



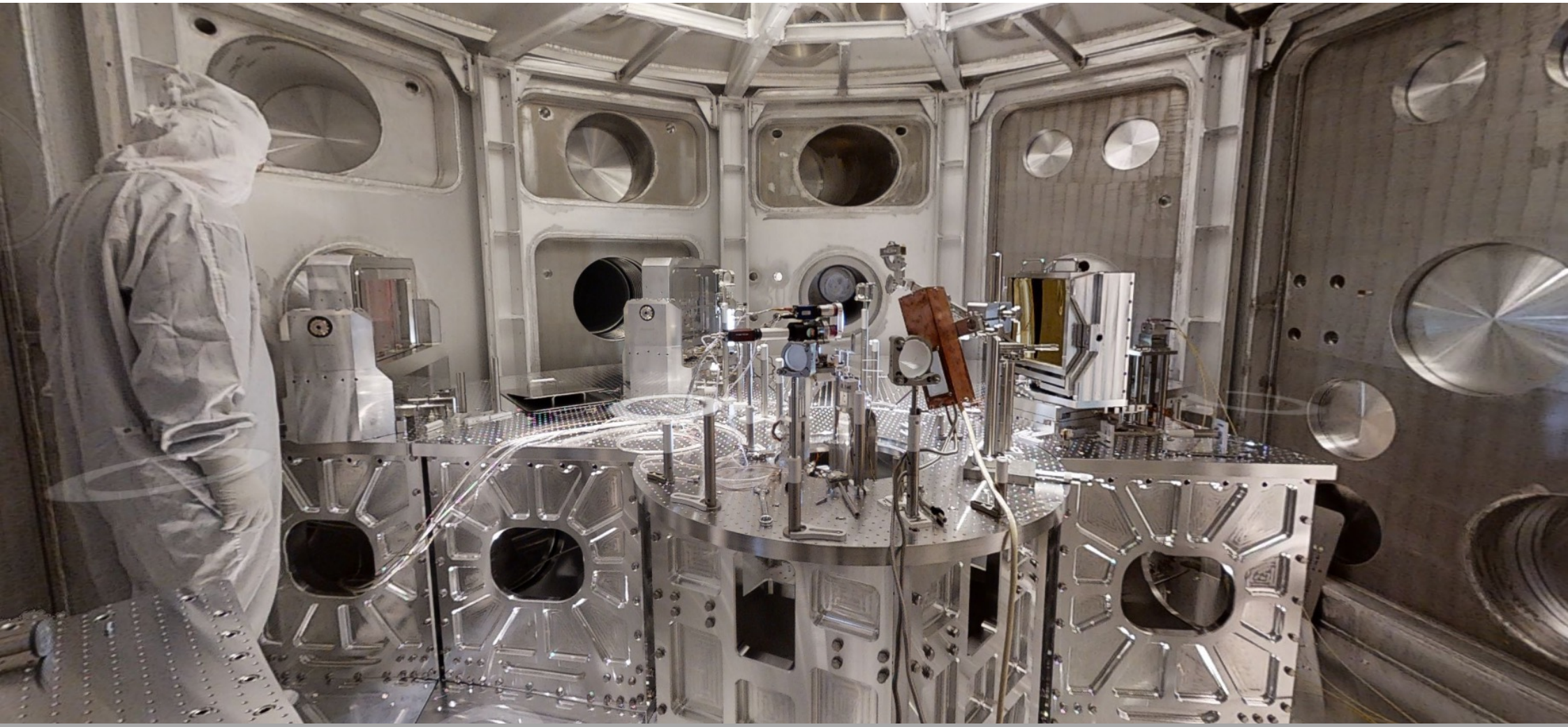
P3 experimental chamber

- E3 hall has one the biggest civil experimental chamber for welcoming these different beams.
- Aluminum chamber for avoiding activation issues.
- Despite the large volume, vacuum reaches the 9E-6 mbar operating pressure in ~1h.



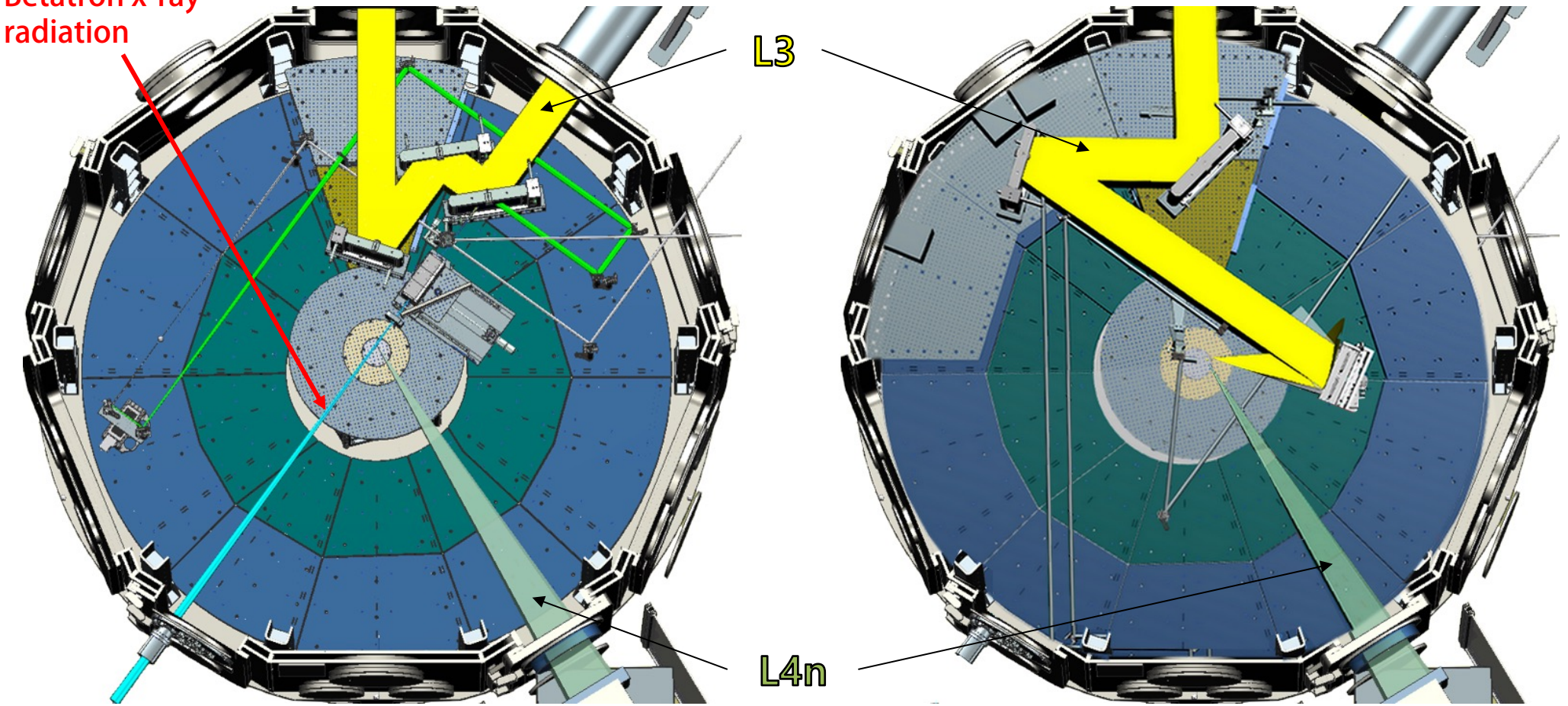
P3 experimental chamber

https://my.matterport.com/show/?m=fkP3VjGbYyq



Long focal length configuration

Short focal length configuration



Angle L4n and x-rays at TCC = 112˚

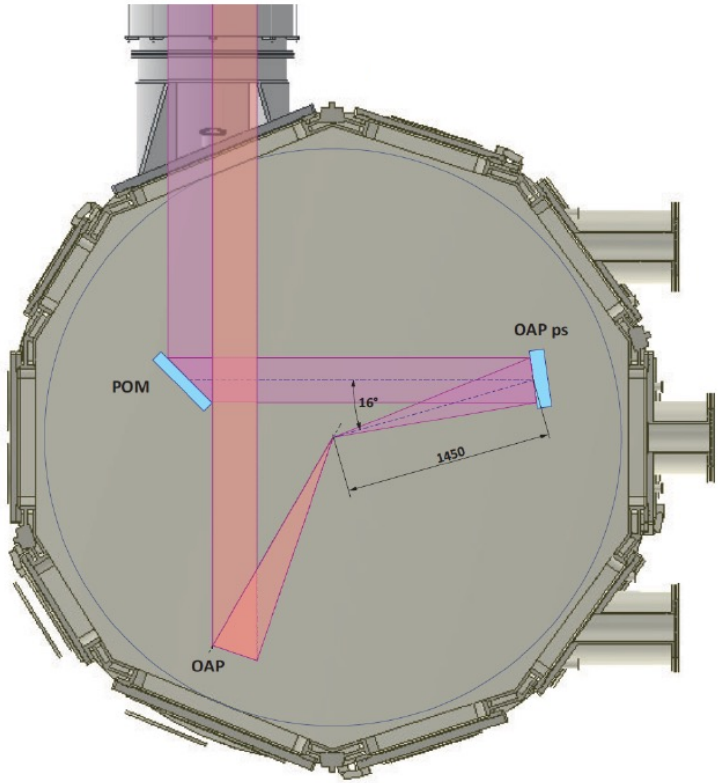
Angle L4n and L3 at TCC = 58˚

L4p/f-ATON - *mid-term future*

- Users will have the possibility to synchronize a ps and a fs version of L4.

- The laser seed will be the same and the square beam will be divided in two sections and separated inside the experimental chamber.

- In this configuration (concept) :
  - **L4f — 1kJ max — 150 fs**
  - **L4p — 1kJ max - 0.7 ps, 1 ps, 2 ps, 5 ps or 10 ps**
  - **Delay between -1 ns and +2.5 ns**



Hands-On activity on Friday

- Velocity Interferometer System for Any Reflector (VISAR)
- Streaked Optical Pyrometer (SOP)

- *X-ray Streak Camera (~0.7ps resolution, ~100eV to ~10keV)*

- Soft X-ray flat crystal spectrometer (~400 to ~800eV)
- Very high-resolution X-ray spherical crystal spectrometer (~800eV to ~10keV)
- *High-reflectivity cylindrical mosaic crystal spectrometer (~4keV to ~20keV)*

- Back-scattering devices for Laser Plasma Instabilities studies

- *Electron and gamma-ray spectrometers (up to ~GeV)*

- *Ion Time Of Flight (TOF)*
- *Thomson Parabola*

Why commissioning campaigns ?

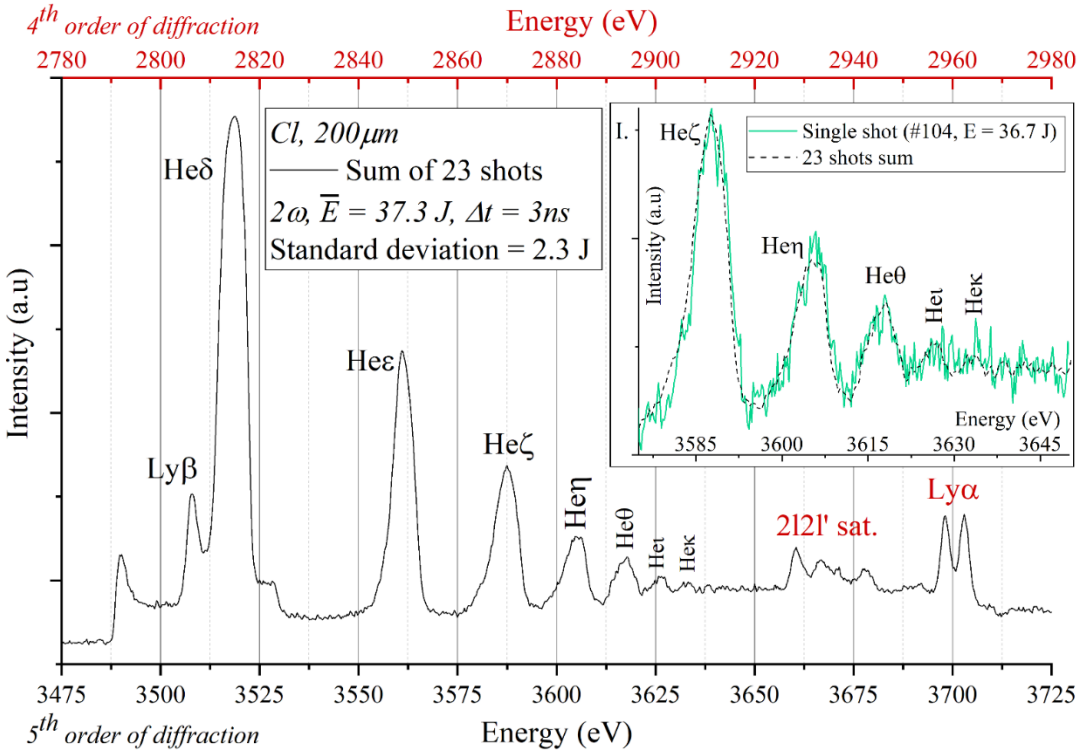
- Need to understand how the machine works (communication with laser scientists, etc.)
- Implement a procedure for safe operation (alignment, ramp-up)
- Fine tuning and test of diagnostics

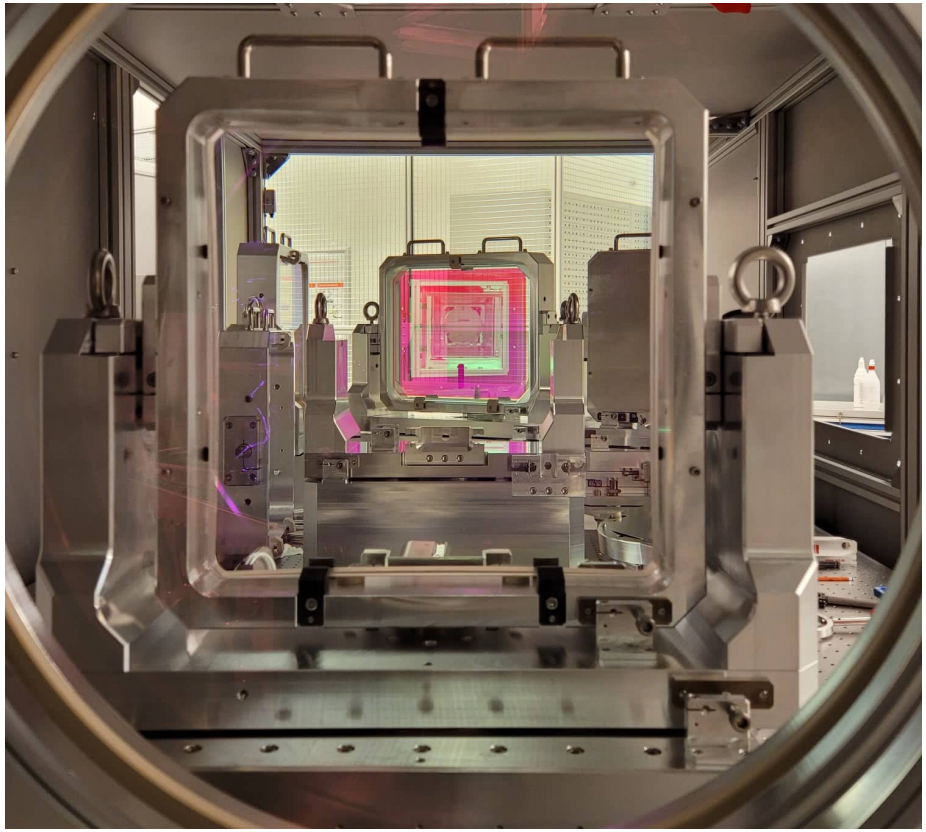
Not a one-day activity. Several weeks runs shared over 1 or 2 years before smooth operation

L4n commissioning campaigns

First commissioning in June 22

➡ First ~100 shots on target



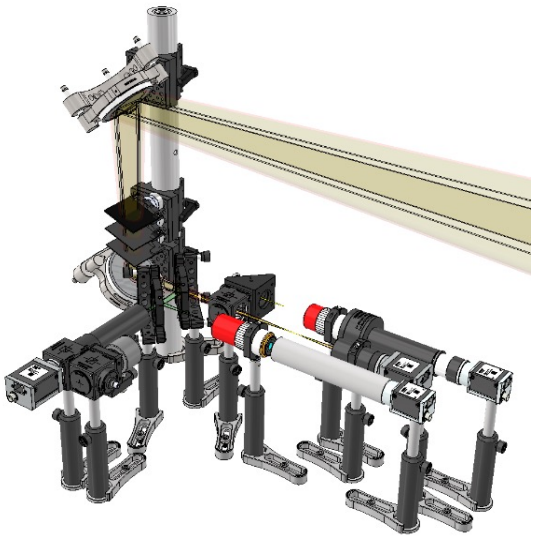


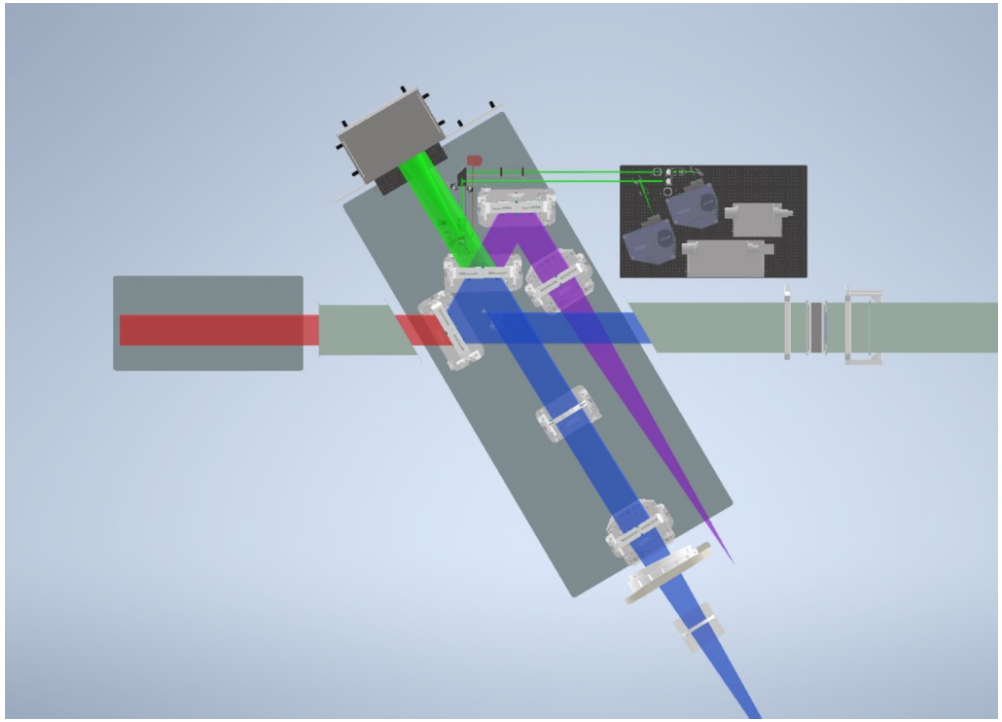
F. P. Condamine et al., *Commissioning results from the high-repetition rate nanosecond-kilojoule laser beamline at the extreme light infrastructure,* Plasma Phys. Control. Fusion **65**, 015004 (2023)

L4n commissioning campaigns

Second commissioning in Nov./Dec. 22

- 709 shots on target in 10 days
- Back-Scattering Diagnostics (SBS, SRS, TPD) commissioned

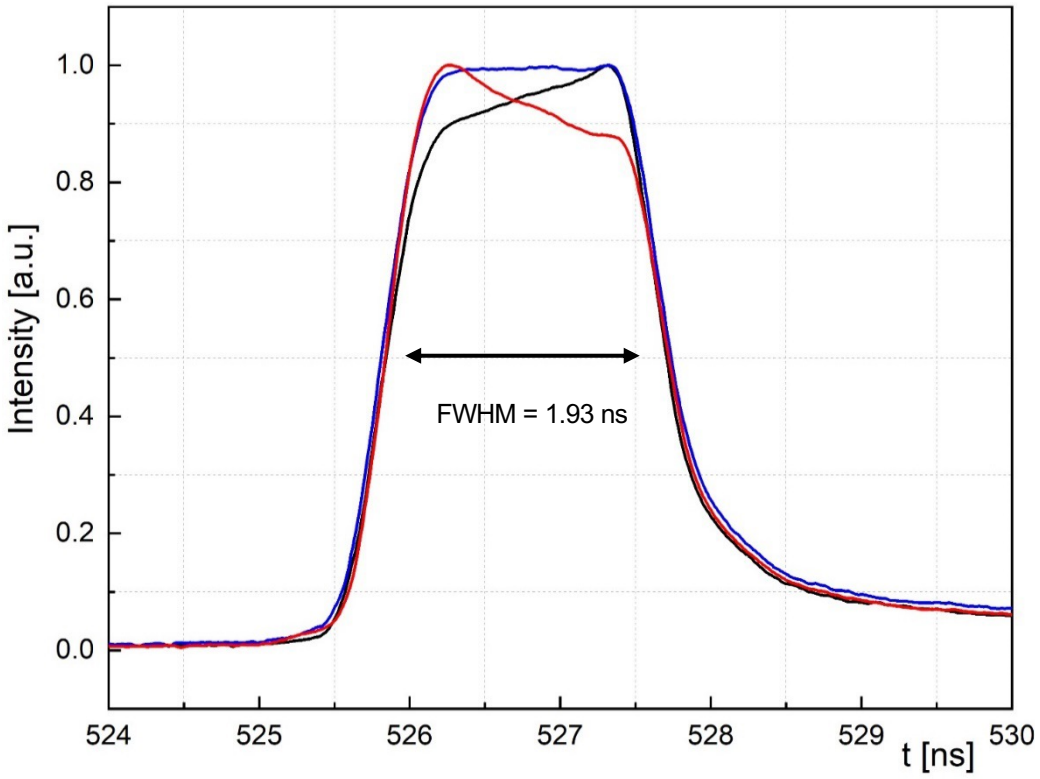




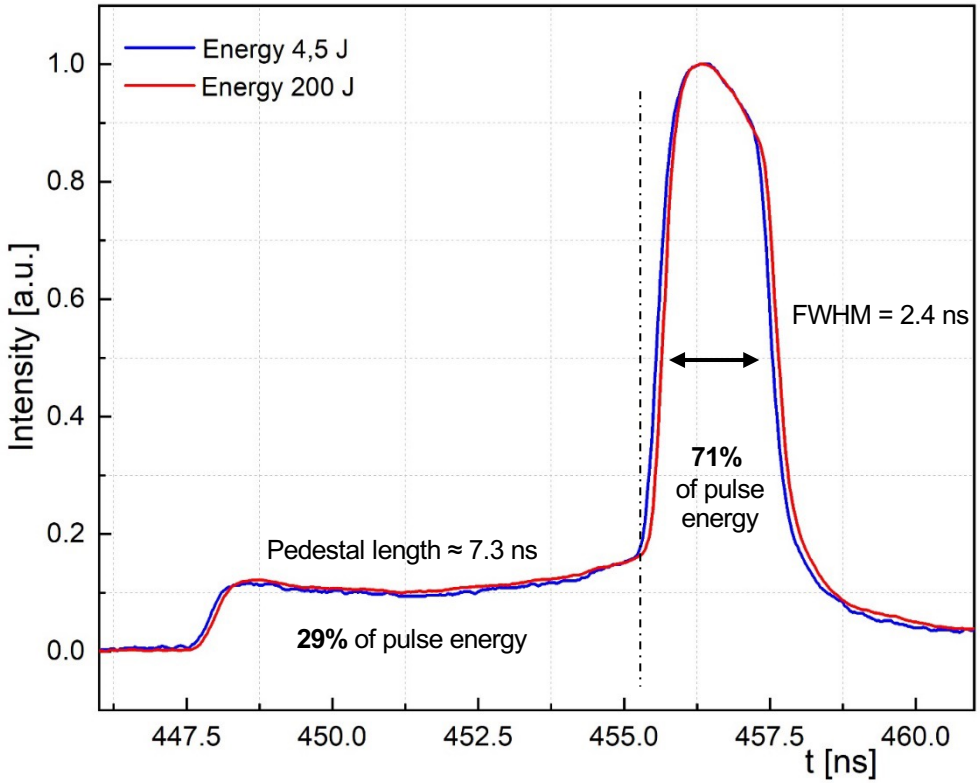
Time	Laser ener
10:43	101,68
10:46	289,28
10:49	337,12
10:52	330,72
10:55	394,56
10:58	460,8
11:01	432,64
11:04	464,64
11:07	455,84
11:10	444,32
11:13	447,04
11:16	430,88
11:19	436,96
11:22	423,36
11:25	456,48
11:28	478,08
11:31	479,84
11:34	472
11:37	479,84
11:40	479,84
11:43	456,96
11:46	503,68
11:49	376,96
11:52	428,32
11:55	510,72
11:58	508,32
12:01	501,76
13:25	295,04
13:28	329,76
13:31	359,2
13:34	499,36
13:40	508
13:43	508,8
13:46	406,56
13:49	486,72

Examples of pulse shaping capabilities (March 23)

2 ns rectangular pulse

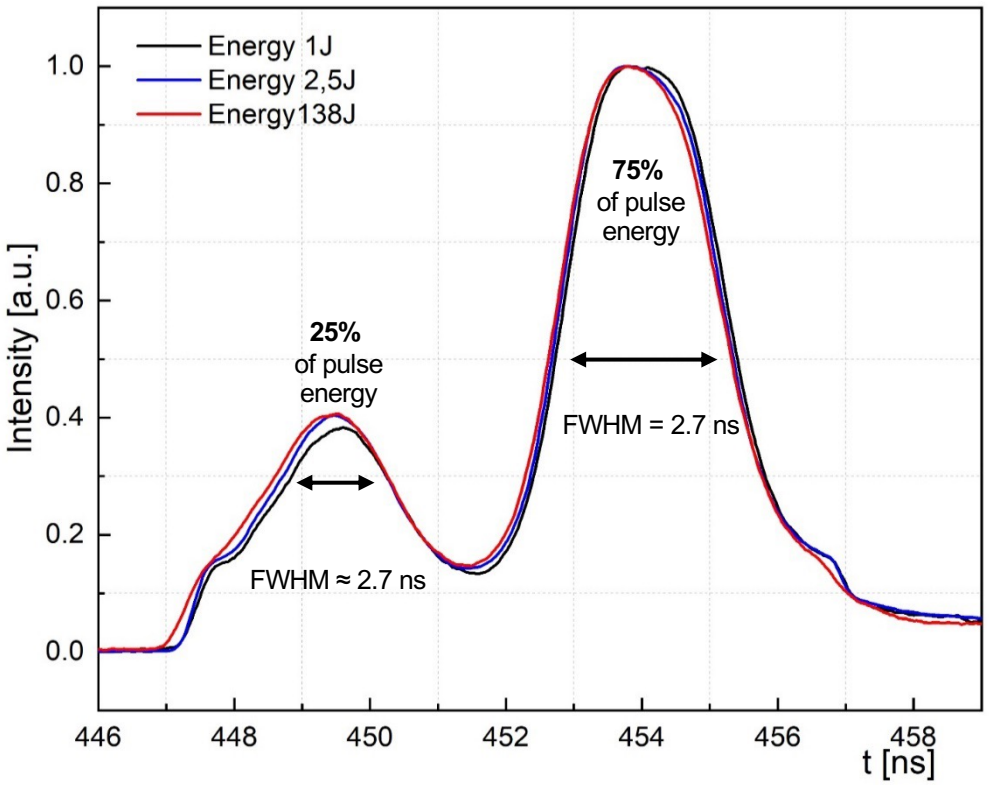


Pulse with pedestal

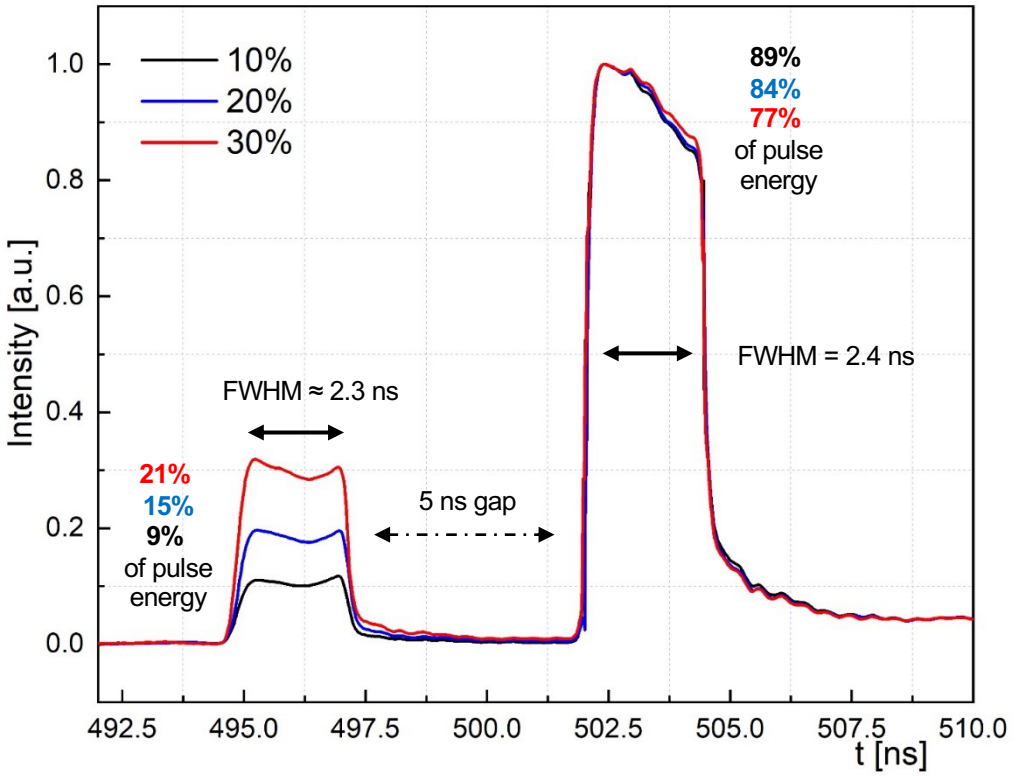


Examples of pulse shaping capabilities (March 23)

Gaussian double pulse



Rectangular double pulse



Solid targetry for UHI and HRR lasers

- High-Repetation lasers = Need for fast targetry

- Ultra High Intensity = Extreme and complex environment

  - EMPs
  - Radiations
  - Stability

Solid targetry for UHI and HRR lasers

- High-Repetation lasers = Need for fast targetry

- Ultra High Intensity = Extreme and complex environment

  - EMPs
  - Radiations
  - Stability

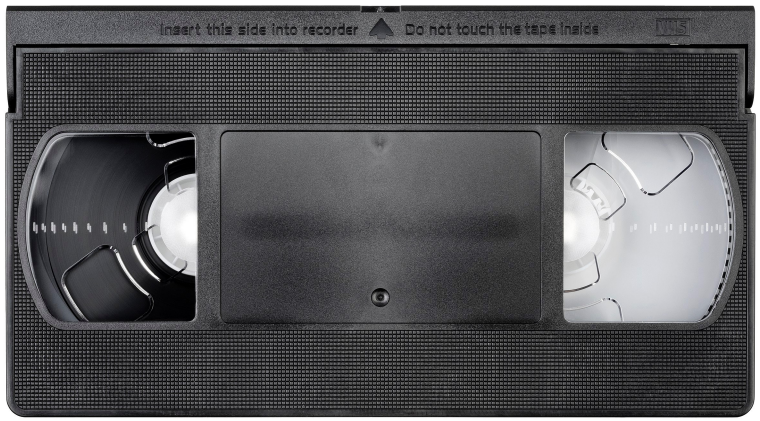
As we are using cutting-edge laser technology,
we can over-engineer a super sophisticated technique that will look amazing

Solid targetry for UHI and HRR lasers

- High-Repetation lasers = Need for fast targetry

- Ultra High Intensity = Extreme and complex environment

  - EMPs
  - Radiations
  - Stability



Tape target system

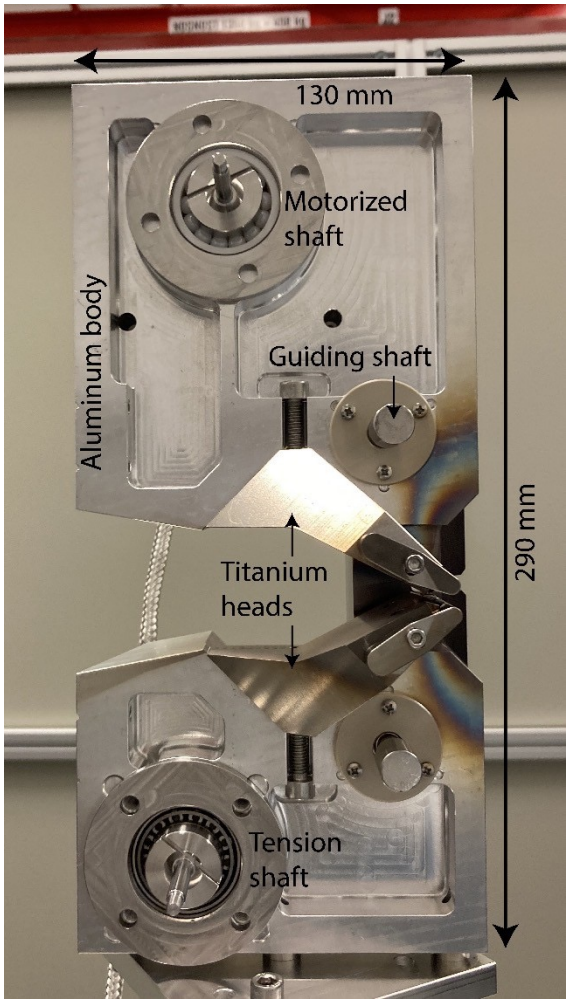
Possible to shoot solid targets for several hours

Hands-On activity on Friday

- One stepper motor pulls the tape.
- The tape is tensed using the non-motorized shaft that applies a resistance to the motor movement.

The system can be used in single shot mode or in burst mode

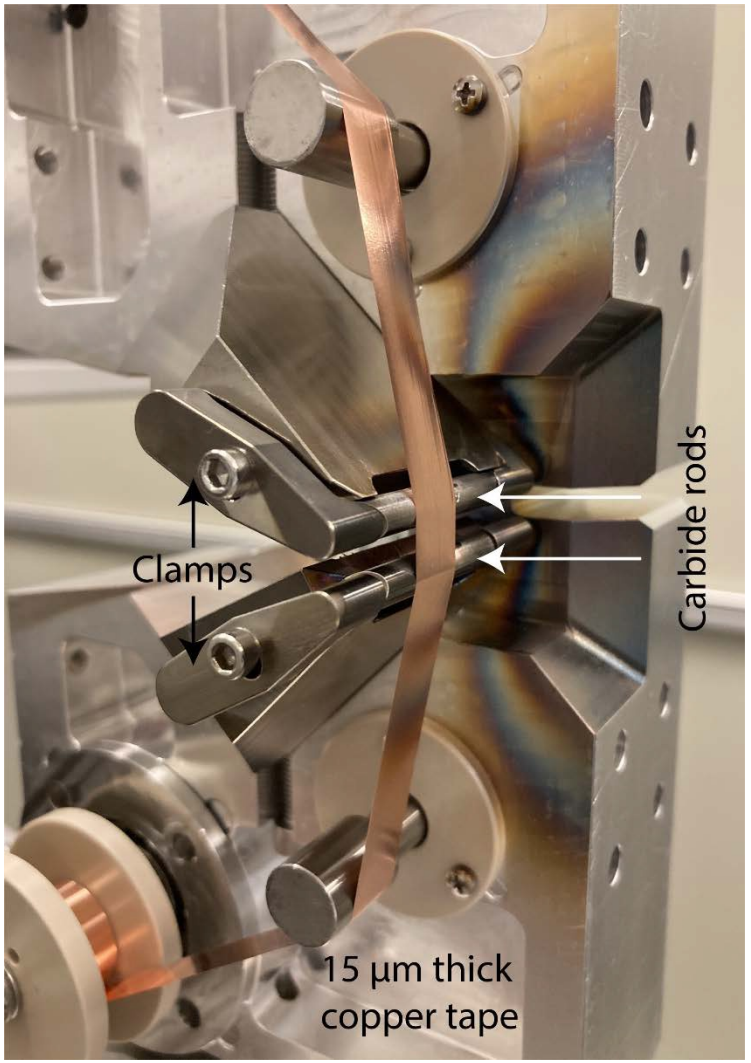
- In single shot mode, the stepper motor keeps tension on the target through its holding torque.
- In burst mode, the stepper motor keeps tension by pulling the tape.



Tape target system

All elements are easily interchangeable

- Two target heads in titanium are used to position the target.
  - Custom design can be made.
  - Easy replacement in case of damage.
- Tape is maintained at TCC with 2 tungsten carbide rods.
  - Very precise machining.
  - Highly resistant in extreme environment.
  - Easy and cheap replacement.

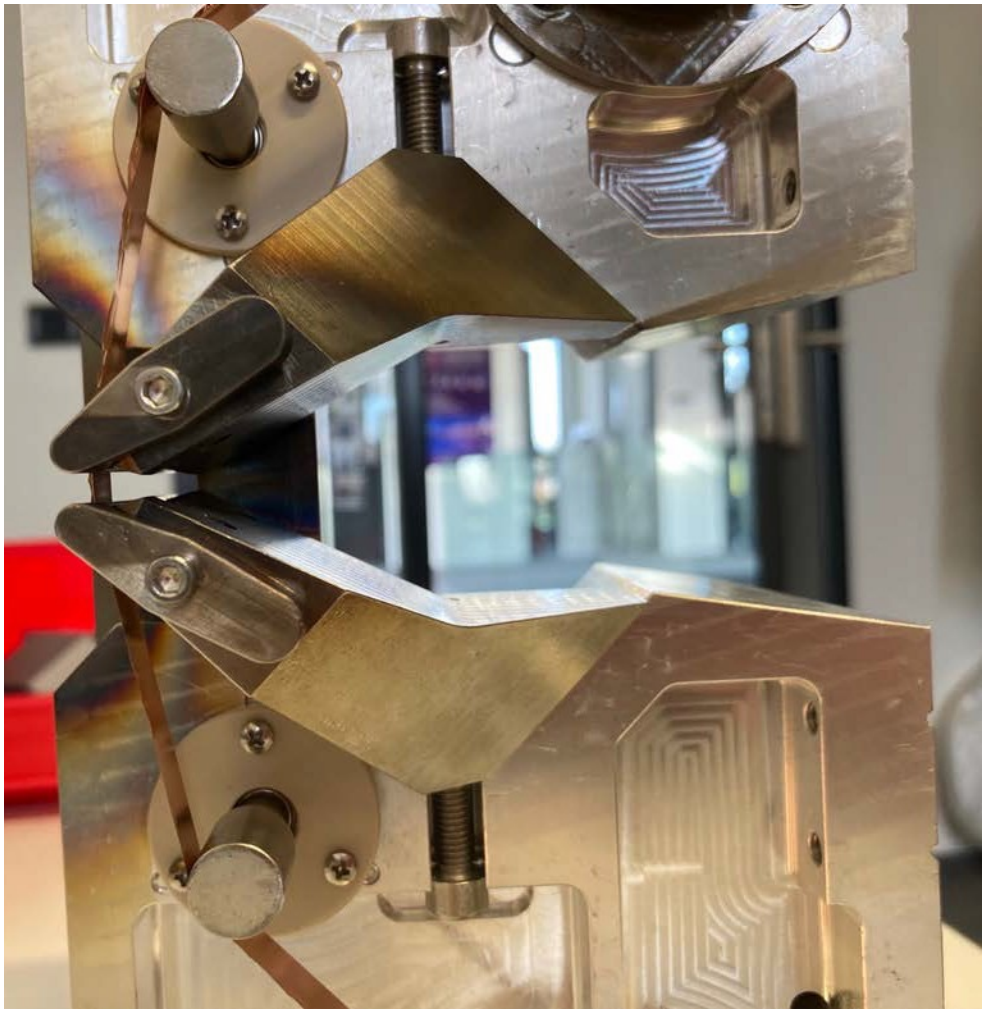


Tape target system

300° angle of view for diagnostics

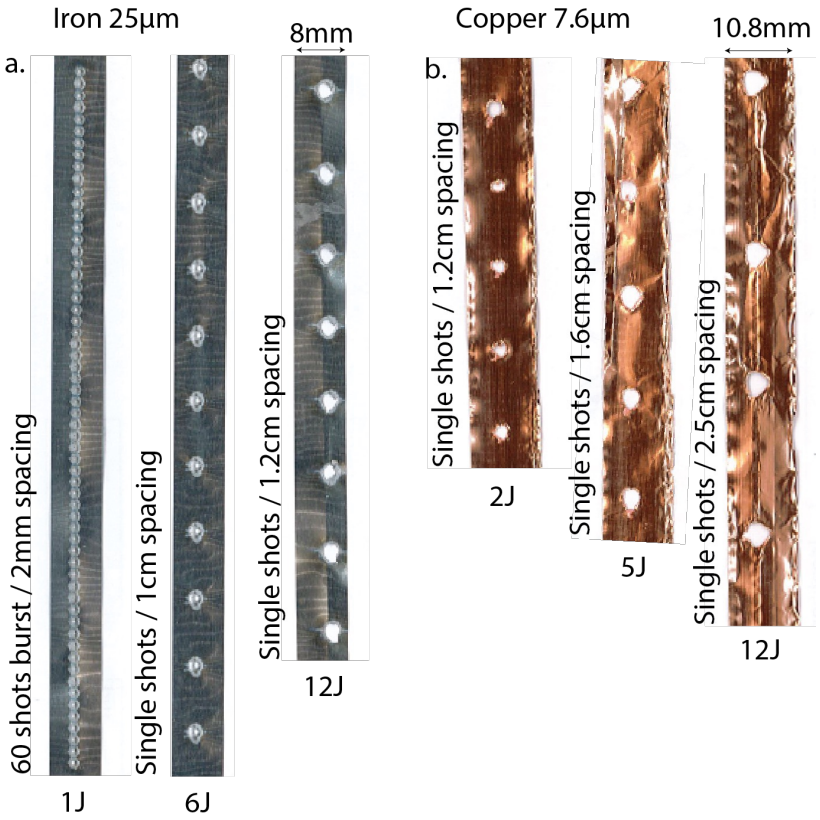
- Large slit at the center to shoot the laser from the rear side
  - Very convenient to place diagnostics close to the target

- A secondary slit gives view on the target from the side
  - More space to put diagnostics in the equatorial plane
  - Convenient for symmetrical diagnostics.



Tape target system

- 2 commissioning experiments have been performed in E3 hall with the L3 laser in 2021.
- L3 shot a total of ~4500 times on target during these two campaigns (3 + 1 weeks).
- Tape target has been successfully used in burst and single shot operation.

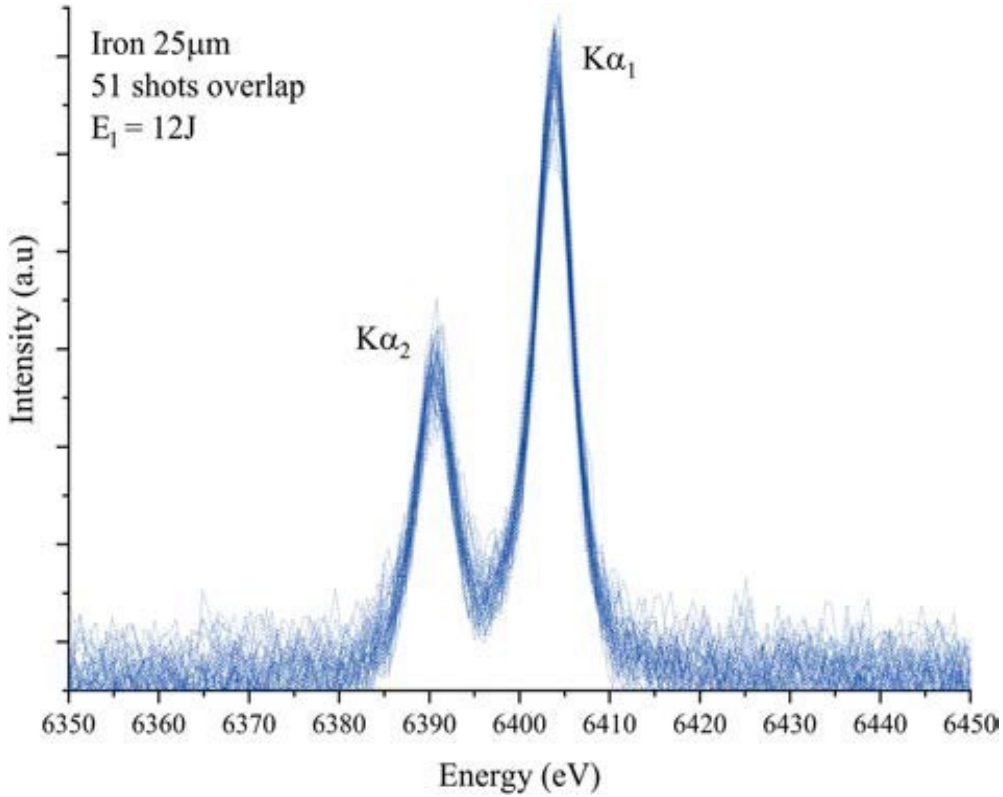


X-ray generation stability

Generation of hot electrons induced X-rays shows a very good shot-to-shot stability

➡ Ka lines are generated when hot electrons generated during the laser-matter interaction are ionizing K-shell of atoms.

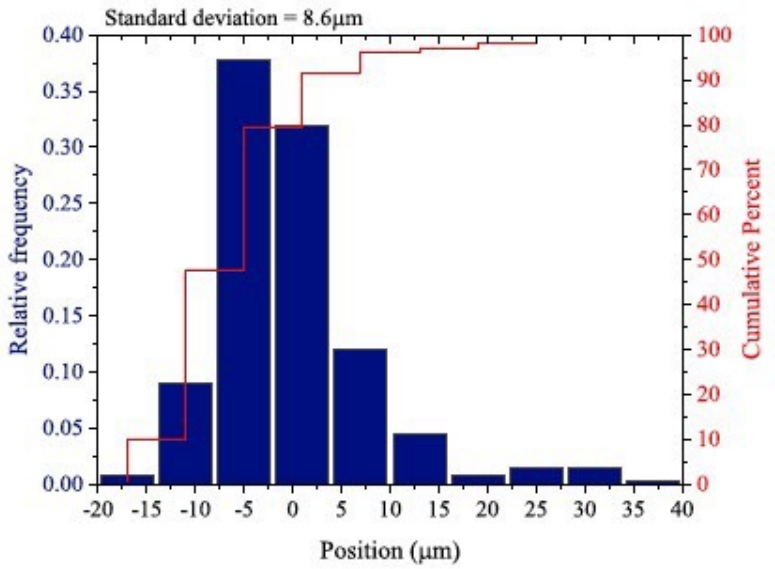
Measuring the Ka yield, the standard deviation is :
- 6.6 +- 0.5% for the 25µm thick iron
- 10.6 +- 3% for the 7.6µm thick copper



After the campaign, the stability of the tape was measured using damaged carbide rods

- All along the campaign, carbide rods have been slowly damaged due to the proximity with the interaction point.
- The standard deviation of the tape in the focal plane using these rods is 8.6 um (for a 15um thick copper tape)
  - Compatible with the L3-HAPLS best confocal parameter (12.3um for an F/3 OAP).

Results discussed and available in:
F.P. Condamine et al. Review of Scientific Instruments ***92****, 063504 (2021)*



Thank you for your attention

PS: We are hiring post-docs / junior scientists.

florian.condamine@eli-beams.eu