XFEL Accelerator R&D
RP-419: ASPECT Laser R&D (ALRD) Status Report

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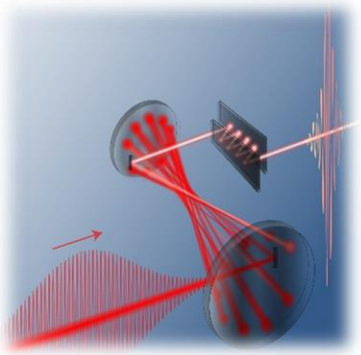
12th September 2025

HELMHOLTZ

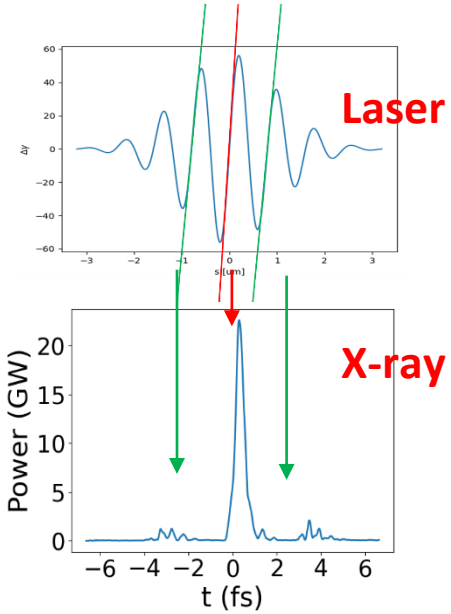
Scope of the R&D activity

Phase	Rep. rate	Pulse Energy	Pulse duration	Stability
User	100 kHz	5 mJ (on target)	4-5 fs	Carrier-envelope phase (CEP) stable

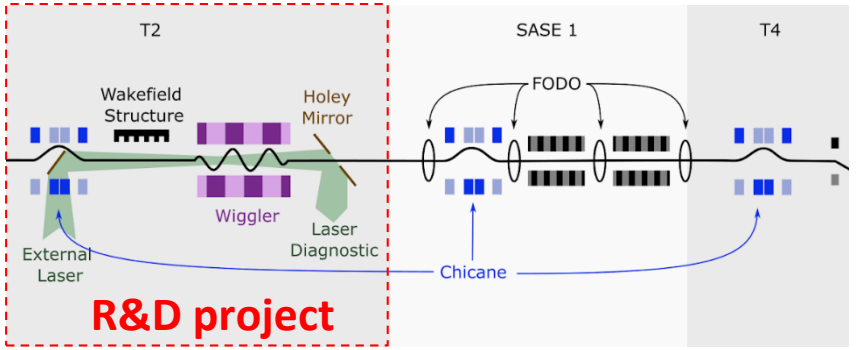


- **Post-compressed Ytterbium laser system** is the only viable option to generate **CEP stable multi-mJ few-cycle** pulses at **100 kHz or higher.**

- **R&D Goals:**
  (1) Develop the missing laser technology for ASPECT.
  (2) Deliver a 1 mJ 5 fs CEP stable laser synchronized to EuXFEL (sufficient for eSASE)



Future laser enabled attosecond generation.



Scope of the R&D activity.

ALRD I – Oscillator + Front-end development

- Develop **a CEP stable oscillator, front-end** and **power amplifier (100W)**.
- **Synchronization** and timing with EuXFEL facility.

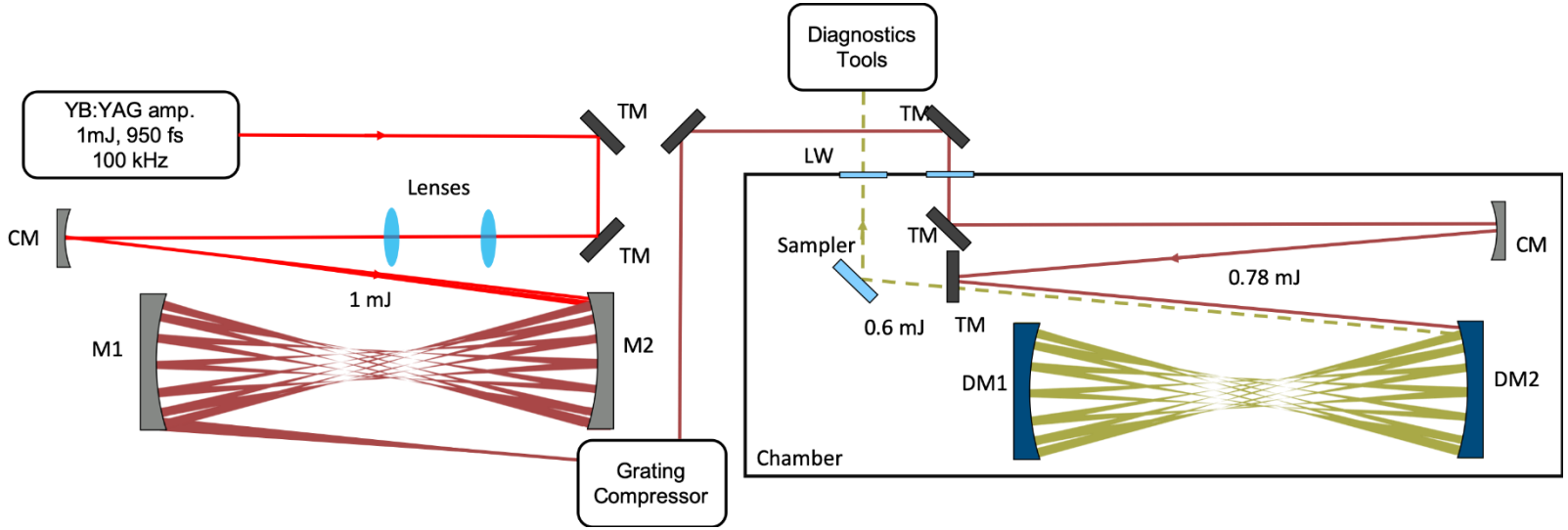
ALRD II – Post-compressed Ytterbium laser system

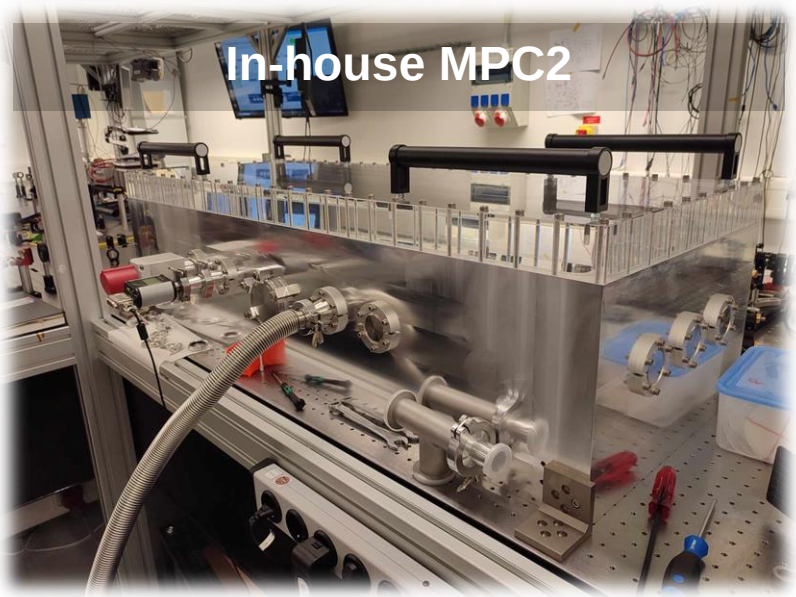
- **Multi-mJ,** compressed to **sub-5 fs** (not achieved yet).
- Develop **broadband mirrors** with suitable **dispersion control** (beyond state-of-the-art).
- **CEP** drift **control**.

ALRD II – Beam transport

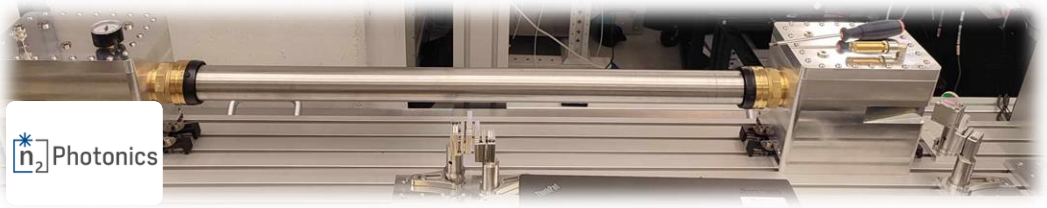
- Develop **large bandwidth** laser transport.
- Solve **spatio-temporal overlaping** problems with e-beam.
- **Thermal and fluence management** on mirrors**.**

Achievements from the past year.

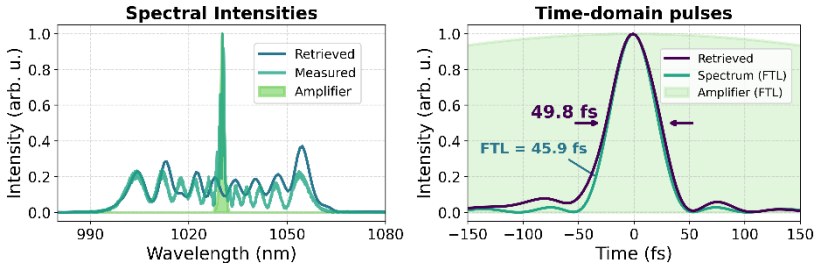


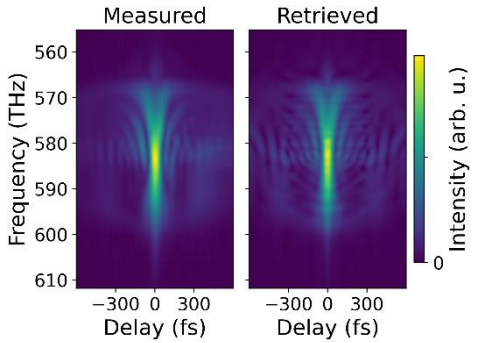


Achievements from the past year.



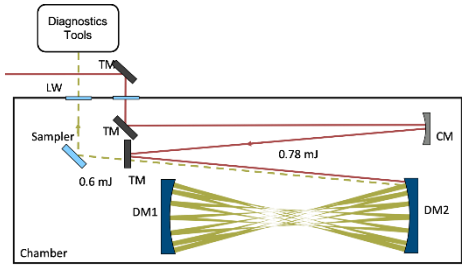
First stage compression

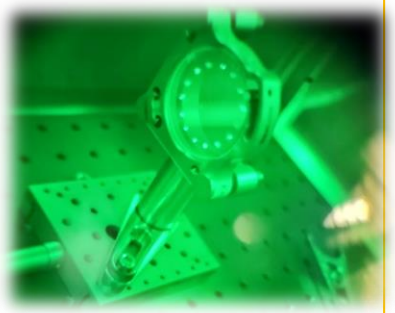




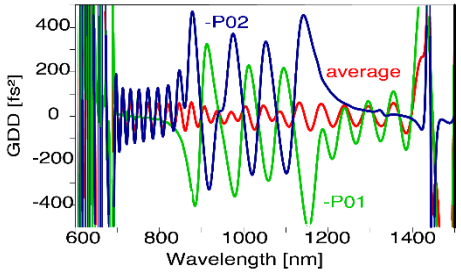
- **Drift-free** and **stable** output power.
- **Throughput** of the MPC **>90%.**
- Output: **0.8 mJ** pulses with **50 fs** pulse duration.

Second stage compression

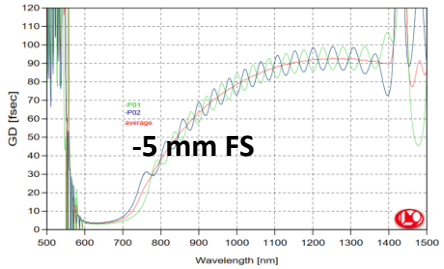




Cell mirror coating: HR700-1400nm



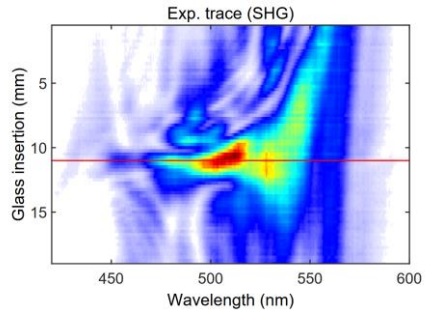
Compression mirrors: HR700-1400nm

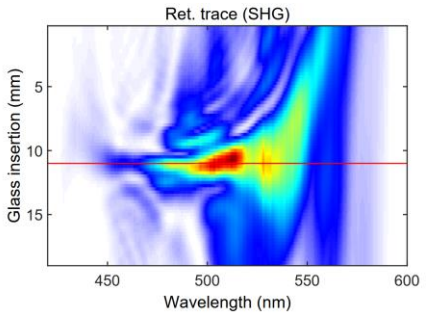


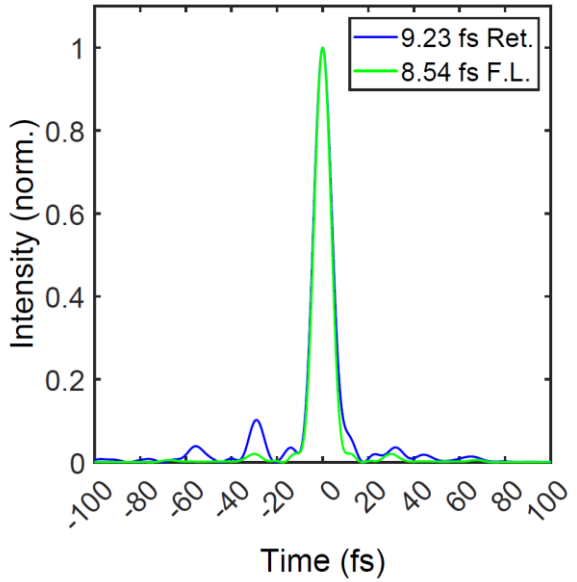
- **New mirror set** tested in the designed configuration
- **Alignment** and characterization was performed across **several parameters**.
- The MPC exhibits a **transmission** of over **>80%.**
- **High beam quality** was measured, **comparable** with the input.

Achievements from the past year.

D-scan measurements

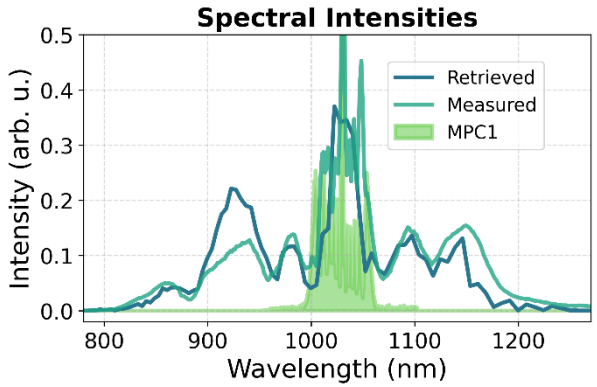


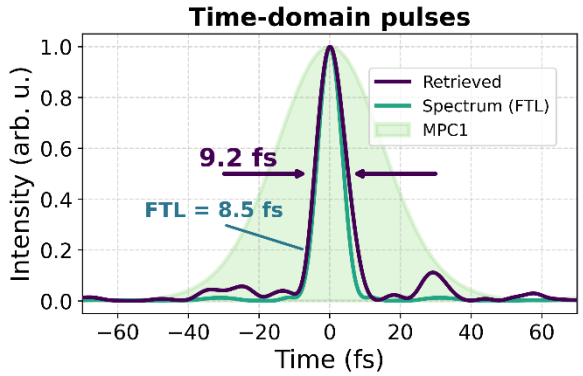


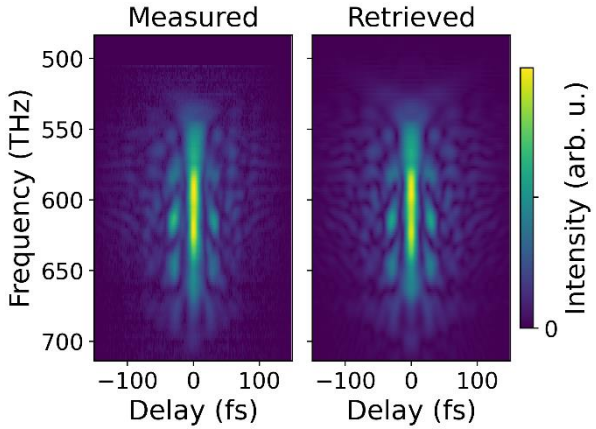


- **In-house device** and **software** used for characterization.
- **Sub-10 fs** pulse duration measured achieving one of the goals.

FROG reconstruction

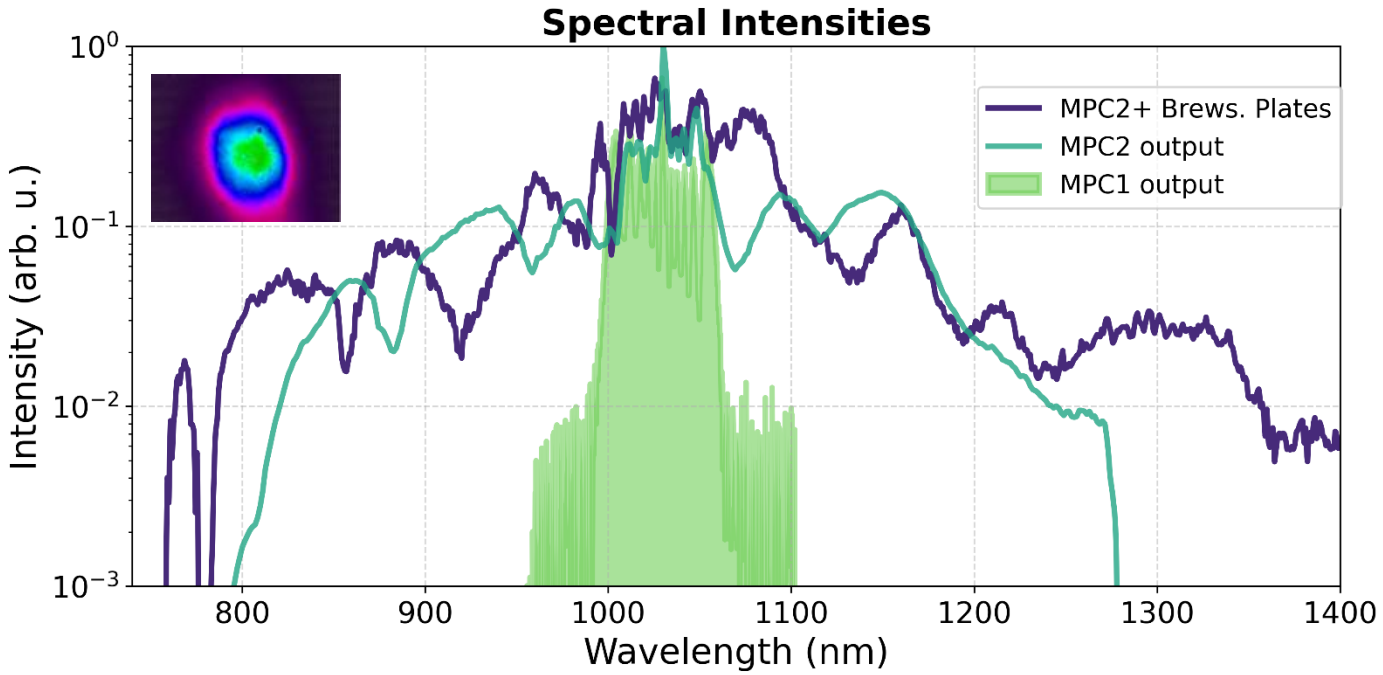


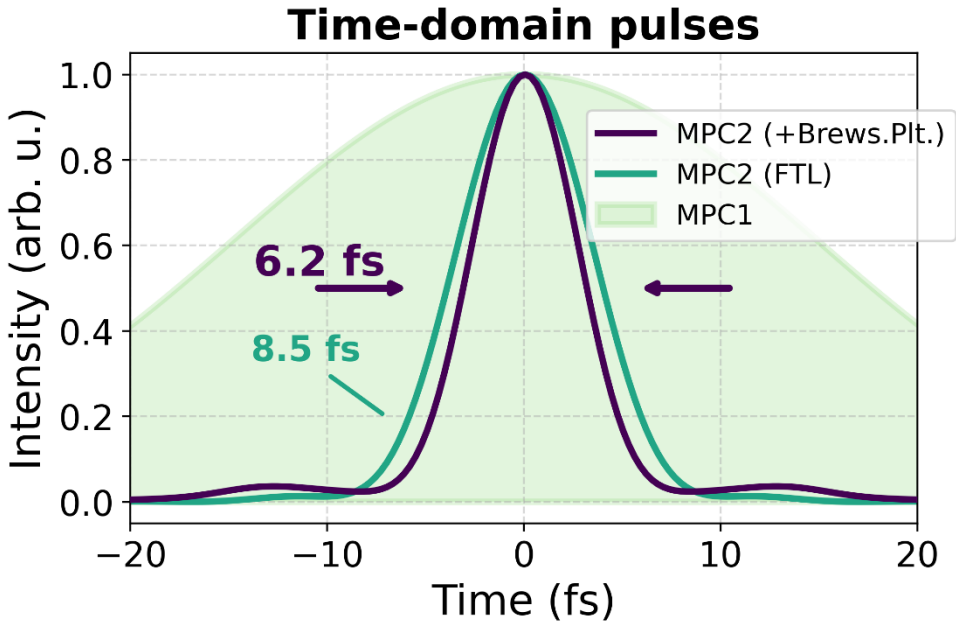




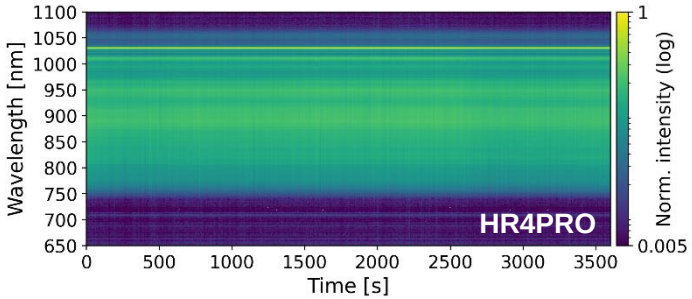
- **Compression factor** of over **100x** confirmed with a different tool.
- Similar pulse (sub-10 fs) duration retrieved.

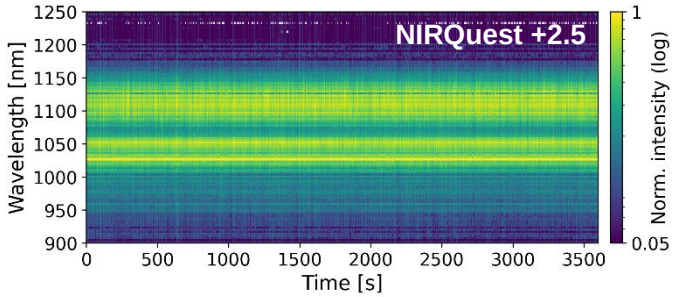
Achievements from the past year





Spectrum is stable in the hour time-scale.





- Further broadening of the spectrum was achieved, supporting **6.2 fs FTL pulses**.
- **Spectral stability** measured over hours.
- Compression of this bandwidth **still to be performed**.

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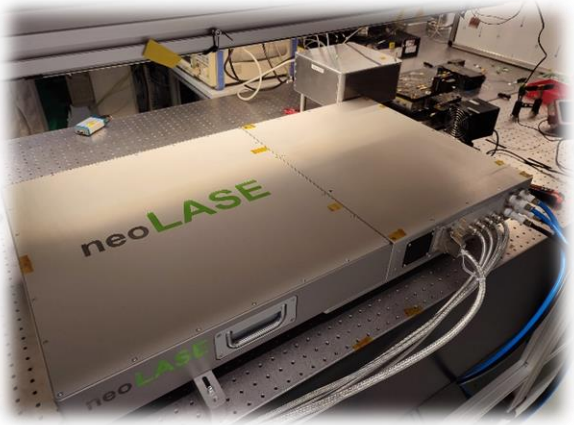
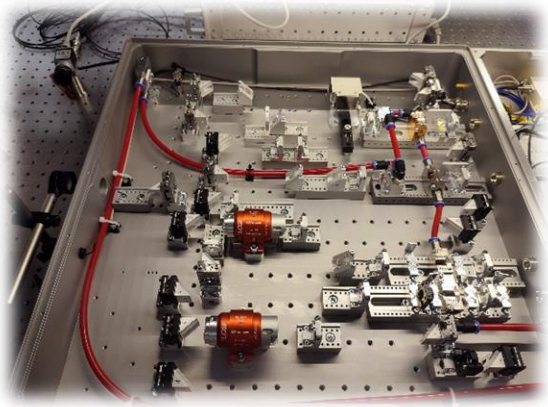
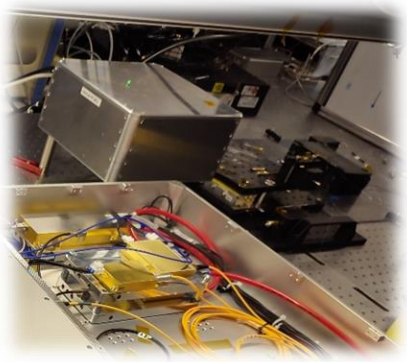
Achievements from the past year.

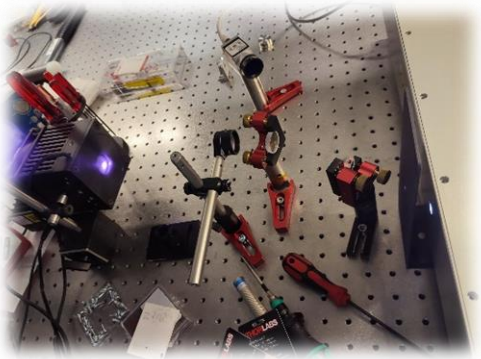


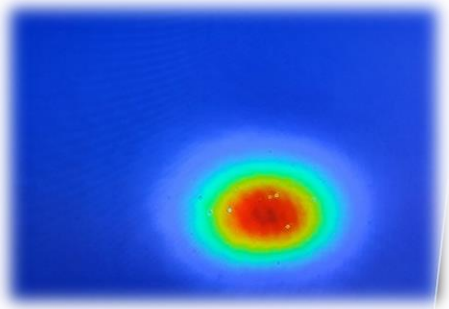


- **High power** system was delivered on **March 2025**.
- **Preliminary** installation was **successful**.

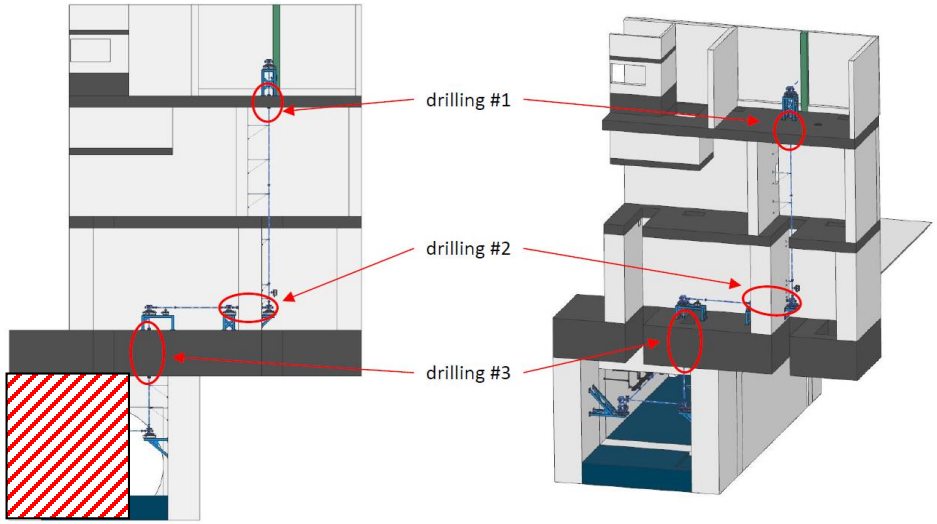
- **cNALM** (inhouse oscillator) used as seed.
- **Good beam profile** was measured at **170 W**.
- Front-end **still to be finished** and integrated.
- Pulse energy scaling (to >1mJ) **still to be done.**
- **CEP** stabilization not yet started.

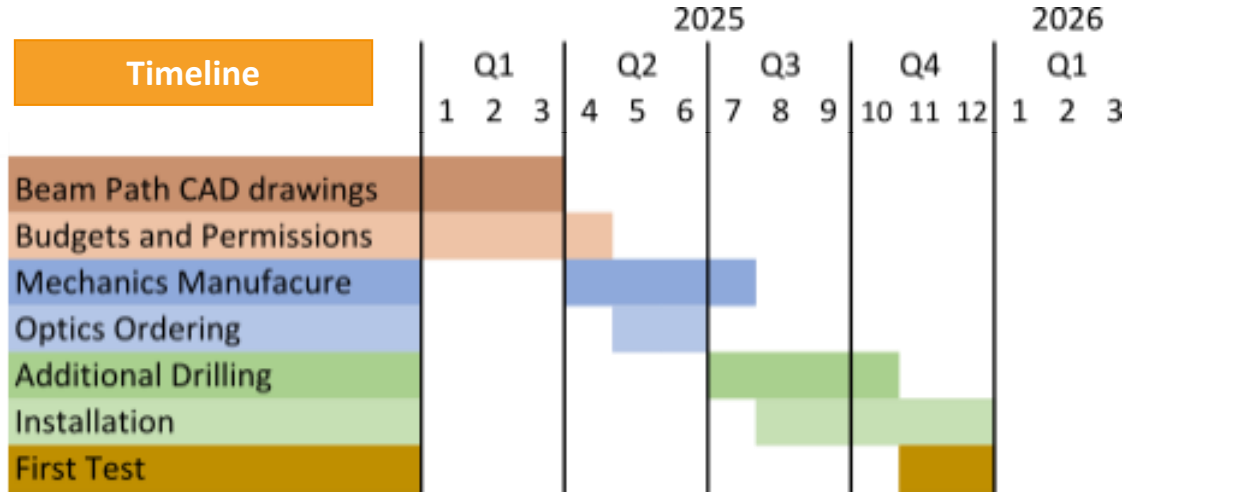






Achievements from the past year

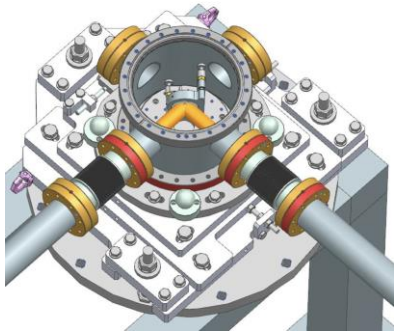


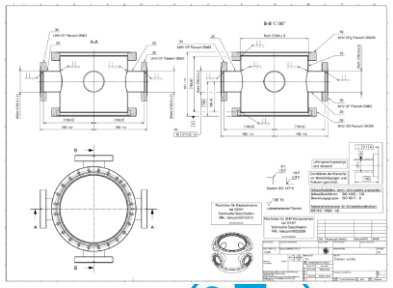


ASPECT

- Work in **collaboration** with **ZM1** team **(Peter Talkovsky).**
- Additional **involved groups contacted** and **in communication** (MKK2, D3, MEA, MVS, Laser safety office…).
- First design of the beam transport line finished.
- **LIMP25** - duration 6 months - opportunity for larger installation works
- **ASPECT beam transport**:
  - Utilize chance to do laborious works (drilling).
  - Install functional test beamline to evaluate noise, drifts, CEP stability

drilling #1





Drilling started and parts ordered

Deviations from the plan

- **Pillar I (Laser Compression)**
  - Sub-2 cycle compression proved more difficult than expected.
  - Dispersion mitigation needs further study.
  - Scaling the 100 W system to 1 mJ delayed → milestone shifted to 12/2025.
- **Pillar II (NEOPRENE & CEP Stabilization)**
  - NEOPRENE front-end construction delayed due to technical setbacks and loss of a key team member - Victor. New member training in progress.
  - CEP stabilization investigations not yet started.
  - Milestones shifted to 12/2025.
- **Pillar III (Beam Transport System)**
  - Progress slowed by synchronization with facility shutdowns and limited personnel availability.
  - Final installation milestone shifted to 02/2026.

Milestones of this R&D Activity

Milestone Description	Target MTH
Simulations for 5fs compression performed, ready for MPC-2 coating	done
Packaged oscillator complete	done
>= 1mJ, < 10 fs FWHM pulses (burst mode, 100kHz using NEPAL-D)	done
Beam transport and in-coupling design ready for review	done
Packaged front-end ready	11/2025
CEP stabilization of oscillator completed	12/2025
~~Beam transport and focusing validated~~	~~04/2025~~
~~5fs, 500µJ measured after transport and focus (burst-mode, using NEPAL-D + validation beamline)~~	~~04/2025~~
CEP stable 1mJ, dual-stage compressed, 100kHz (100W)	06/2026
5fs, 1mJ, 100kHz (100W)	07/2026
CEP stable, 5fs, 1mJ, 100kHz laser	12/2026

Risks to R&D Project

- **Technical Risks**
  - Achieving stable sub-2 cycle (≤5 fs) pulses remains highly challenging.
  - CEP stabilization across the full chain not yet demonstrated → possible delays in integration.
  - Dispersion control strategies not fully validated.
- **Resource & Personnel Risks**
  - New member training (team member departure - Victor) impacts timeline.
  - Limited staff availability during facility shutdowns may cause further delays.
- **Infrastructure Risks**
  - Potential procurement and delivery delays for large vacuum components.
  - Facility shutdown coordination may limit available installation windows.
- **Timeline Risks**
  - Multiple milestones shifted into late 2025–2026, creating pressure on final goals.

Outlook / Summary

- Technical Strong progress across all three pillars despite technical and resource challenges.
- **Laser System (Pillar I):** Sub-2 cycle regime within reach; further work on dispersion control and scaling to 1 mJ ongoing.
- **NEOPRENE (Pillar II):** Design validated; front-end construction underway; CEP stabilization targeted for end of 2025.
- **Beam Transport (Pillar III):** Design finalized; procurement ongoing; finalize installation by beginning of 2026.
- Project delays mainly due to technical complexity, staff training, and facility shutdown constraints.
- Risks identified (technical, resource, timeline) but manageable with current mitigation strategies.
- With sustained effort and team reinforcement, **major milestones remain achievable within revised timeline.**