Technical Capabilities; Beamlines

ELI Ultrafast Science Workshop
EUROPEAN XFEL, Schenefeld, Germany
12.02.2026

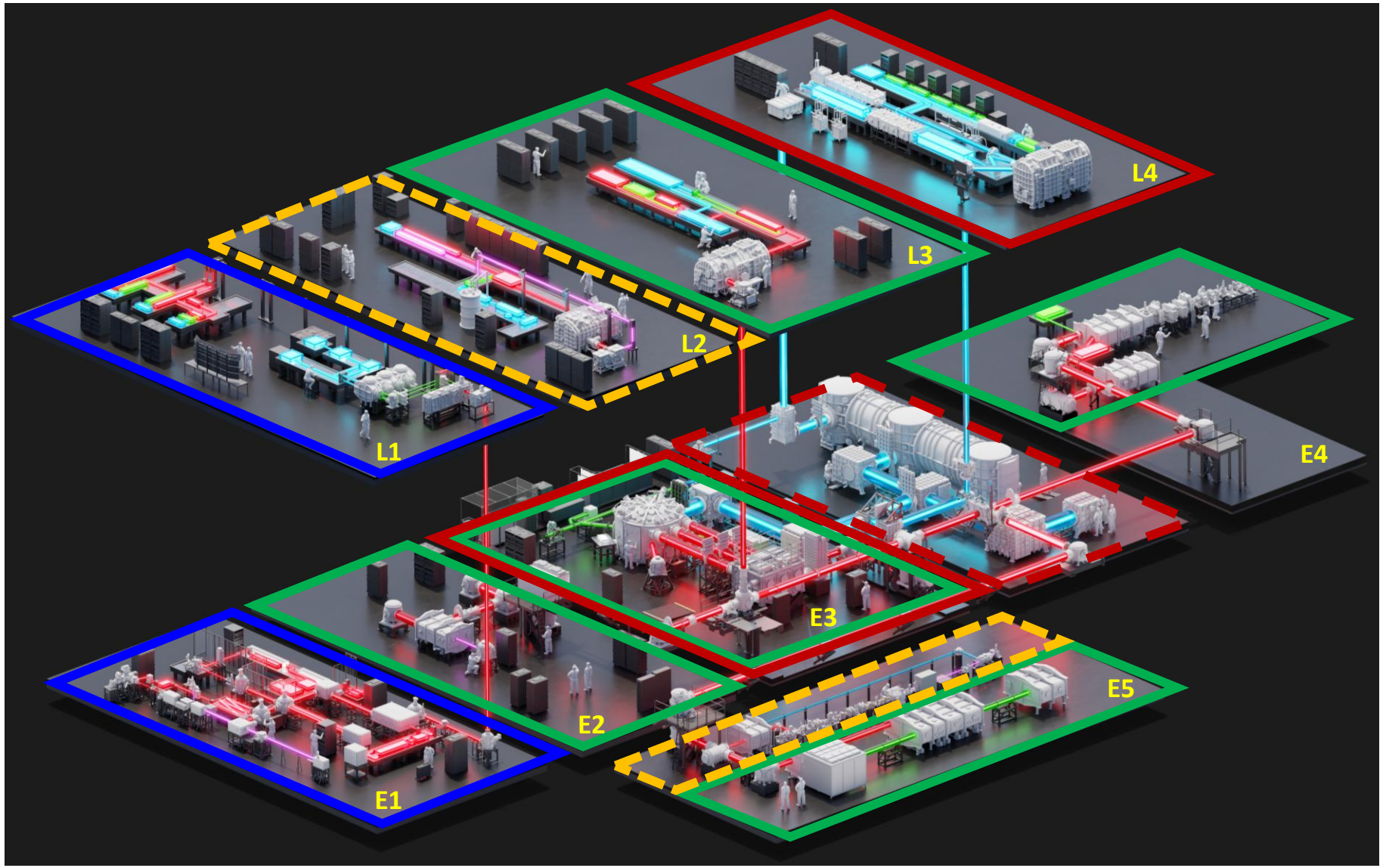
Jakob Andreasson
Head of Department for Structural Dynamics at ELI Beamlines,
The European Extreme Light Infrastructure ERIC

With input from Departments and grops for Laser development, X-ray source development and Electron acceleration.

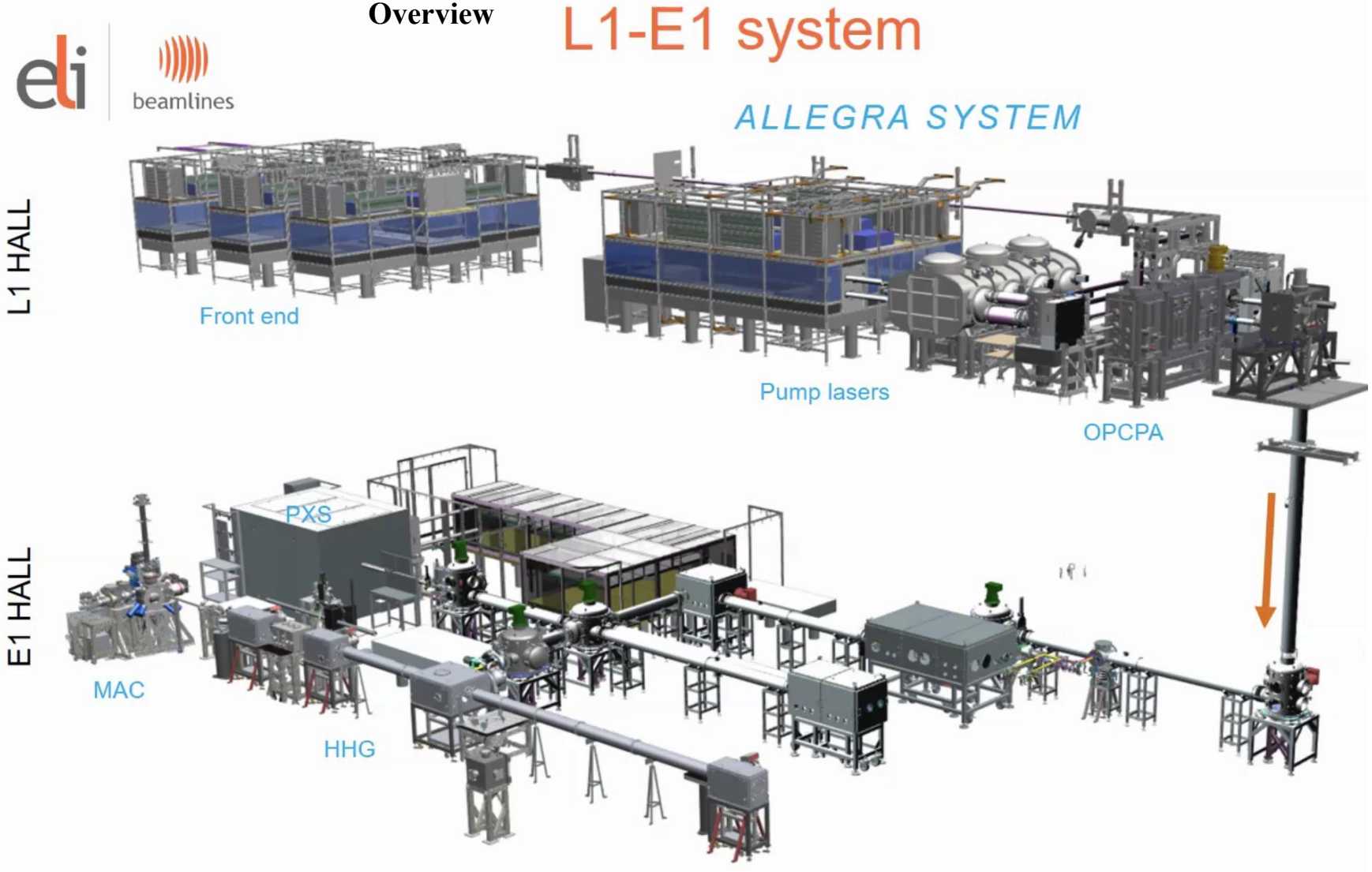
Facility Layout (2025)

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)

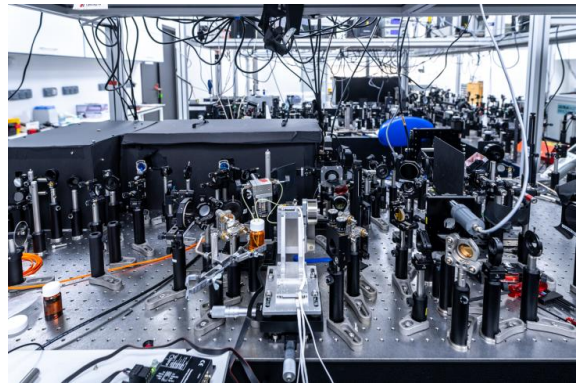


Overview

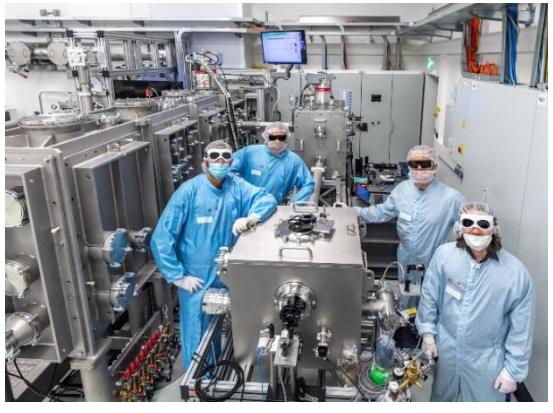


Additional labs/instruments

Biolab optical: Femtosecond Stimulated Raman and Transient Absorption



ALFA station for kHz electron acceleration and applications



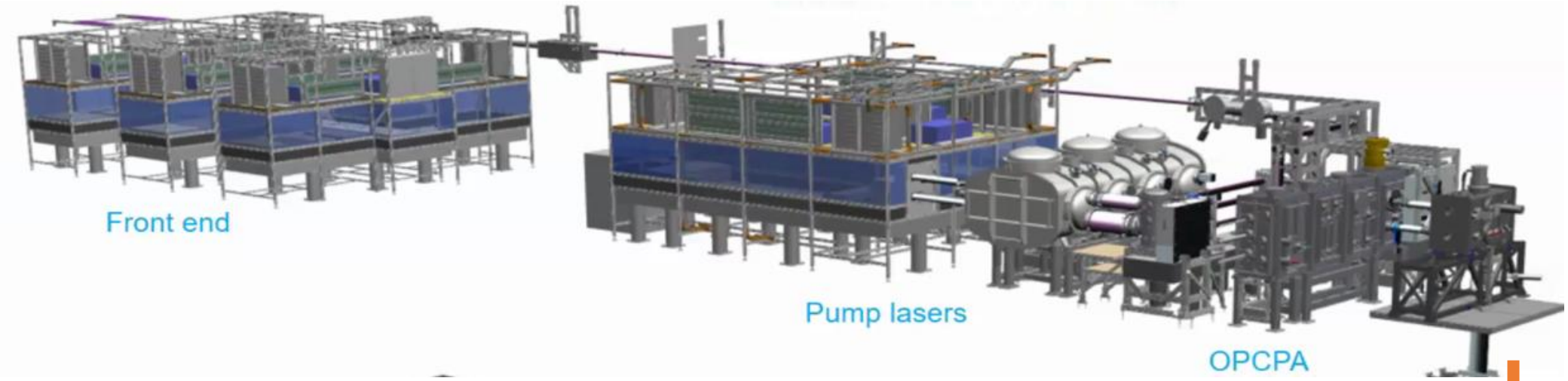
Labs for sample preparation and characterization

https://www.eli-beams.eu/facility/lasers

L1 ALLEGRA System

- The L1 Allegra laser amplifies picosecond pulses in broadband OPCPA and compression to <16 femtosecond using chirped mirrors.
- The pump lasers are based on Yb:YAG thin disk technology.
- The central wavelength is 860 nm, beam profile is Gaussian-like and the polarization is linear s-polarization.
- Pre-pulse temporal contrast (up to 5 ps before pulse) is 10^-10.

Upgrade underway: Independent, synchronized 2nd beam at 12 mJ (FSYNC)



Energy	Compressed pulse @target	Repetition rate
4-55* mJ	<16 fs	1 kHz

User operations in the E1 Experimental Hall and Auxiliary labs (1 kHz, L1 Allegra and support lasers)

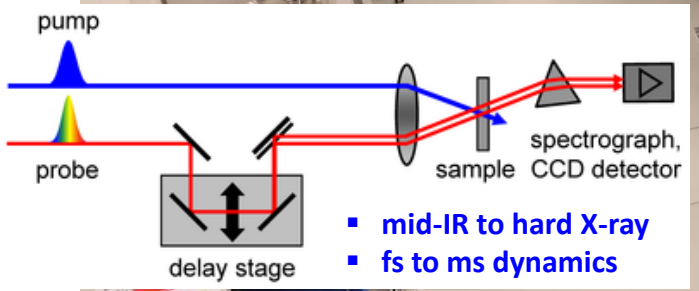
J. Andreasson, J. Nejdl et al.

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

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)

High Harmonics Generation (HHG)
- EUV/XUV, 10-120 nm

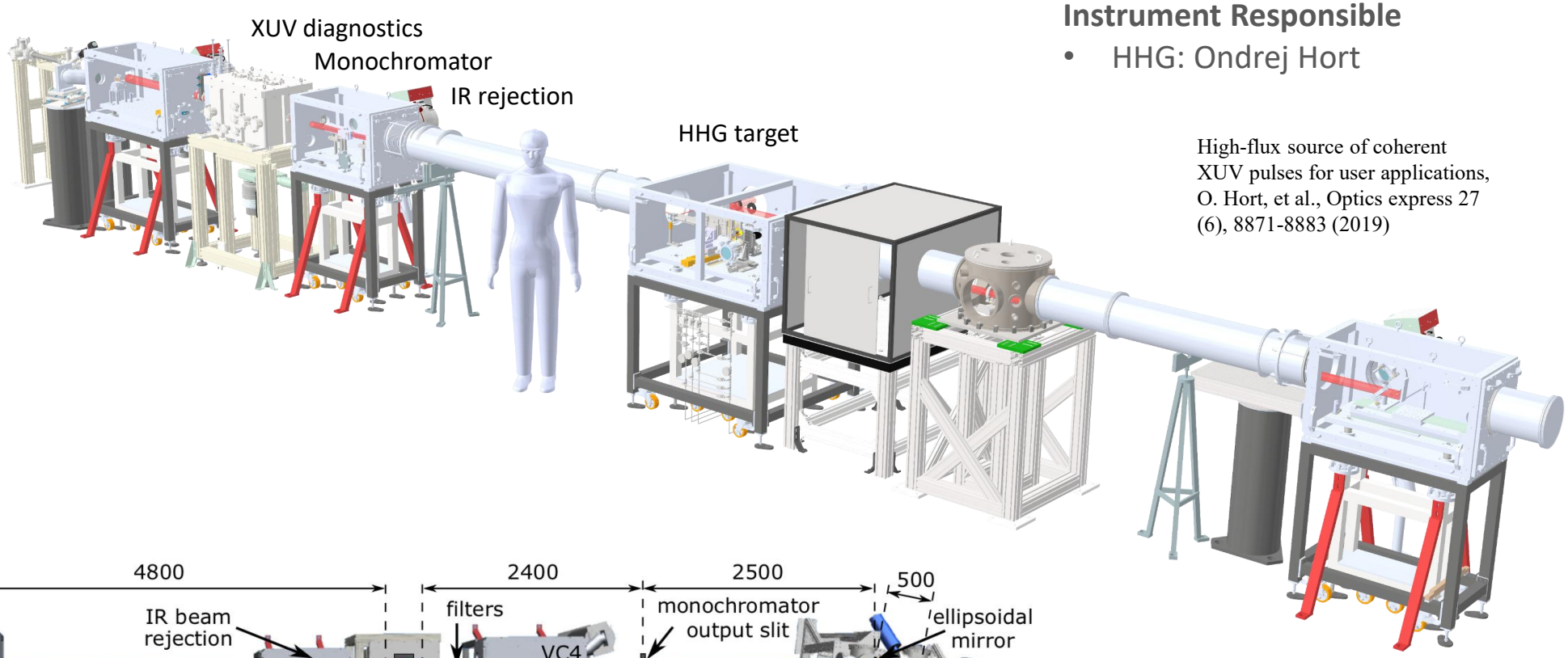


- mid-IR to hard X-ray
- fs to ms dynamics

Support Lasers	Energy	Pulse duration	Repetition rate
Coherent Legend Duo Elite	12 mJ	35 fs	1 kHz
Coherent Hidra	40 mJ	40 fs	10 Hz

XUV science; E1 User oriented HHG beamline

←Towards user chamber



Instrument Responsible

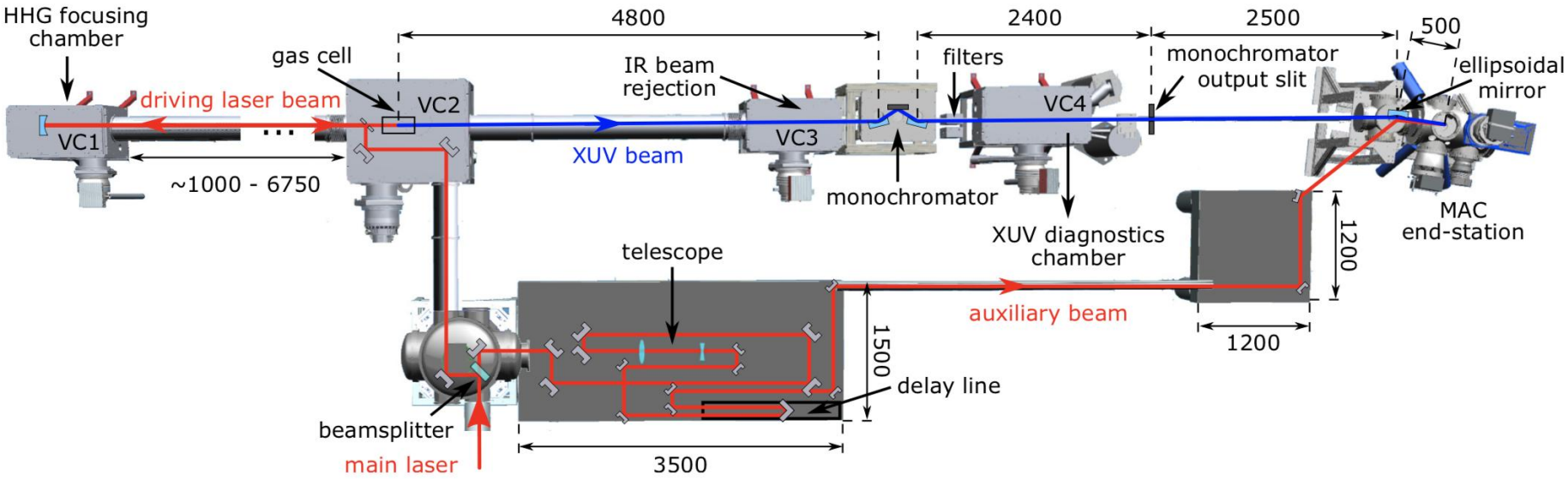
- HHG: Ondrej Hort

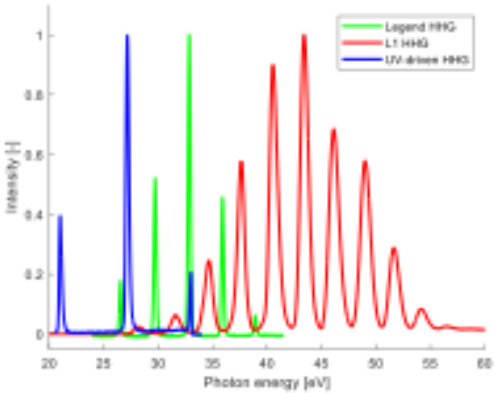
Versatile solution for user needs

High-flux source of coherent XUV pulses for user applications, O. Hort, et al., Optics express 27 (6), 8871-8883 (2019)

Focusing:

- 2.1 m
- 5 m
- 14.5 m





XUV science; MAC user station

MAC: Multi-purpose station for AMO science and Coherent Diffrctive Imaging

Instrument Responsible

- Eva Klimesova

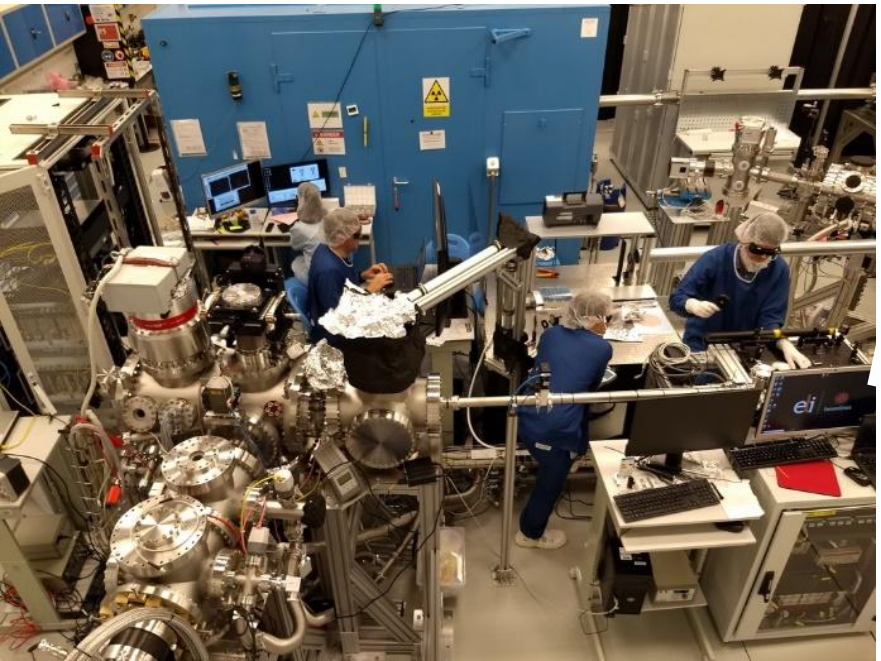
Detectors

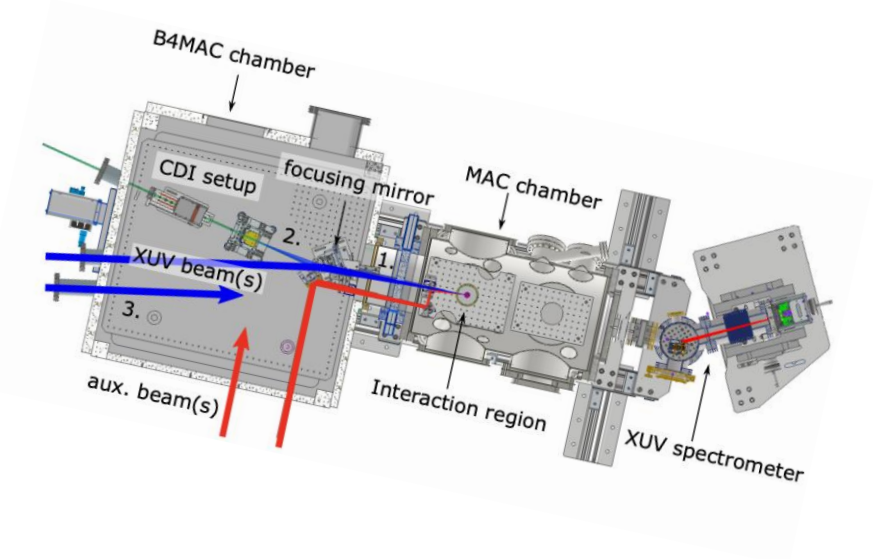
- Ion and electron Time of Flight spectrometers
- Magnetic Bottle Electron Spectrometer
- Velocity Map Imaging (VMI)
- Coincidence and event-driven detection (Tpx3Cam, Amsterdam Scientific Instruments)
- XUV spectrometer
- XUV imaging detector

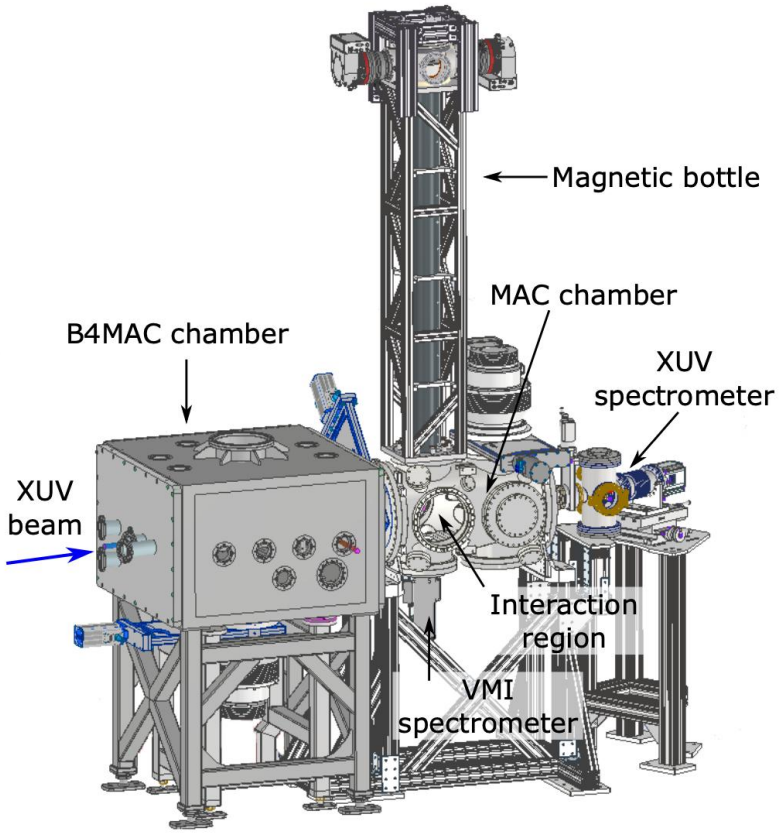
Gas phase and fixed targets:

- Atomic and Molecular beam
- Clusters/droplets (cooled and doped)
- Aerosols
- 5 degrees of motion fixed target stage

E Klimešová, et al., Eur. Phys. J. Spec. Top. 1-12 (2021)
https://doi.org/10.1140/epjs/s11734-021-00192-z







Hard X-ray science, diffraction and spectroscopy

Plasma X-ray sources: Energy range: 2 to 30 keV, 1 kHz

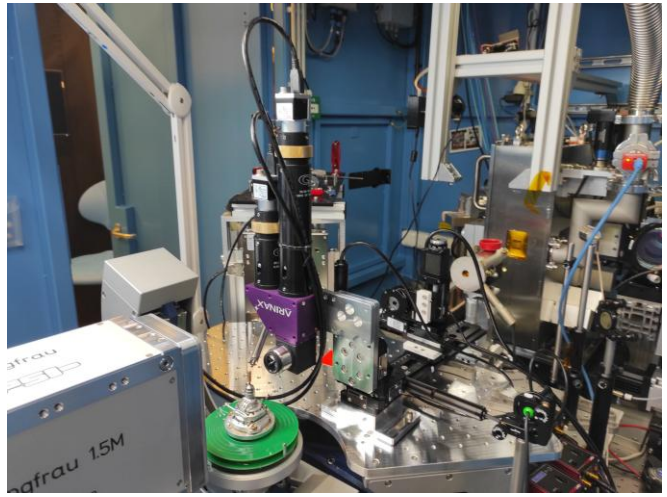
In commissioning

Diffraction module

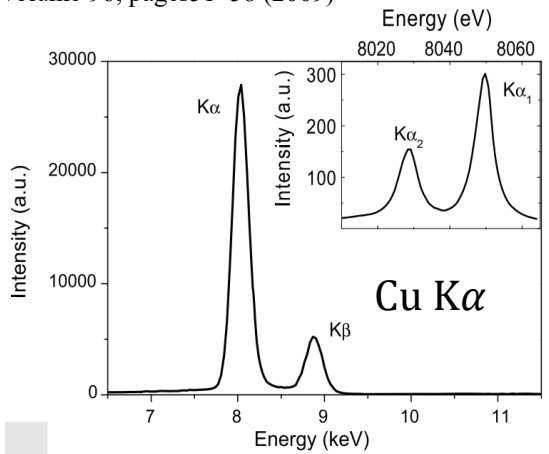
Instrument Responsible

- Borislav Angelov

TREX station



F. Zamponi, et al., Applied Physics A volume 96, pages51–58 (2009)

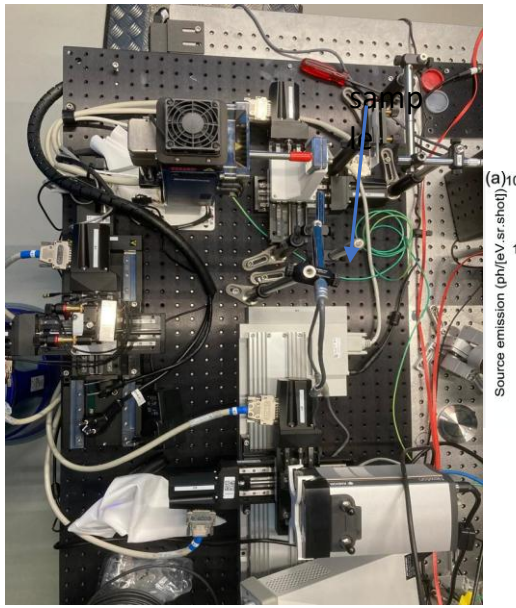


Experiments using the monochromatized emission for diffraction and scattering

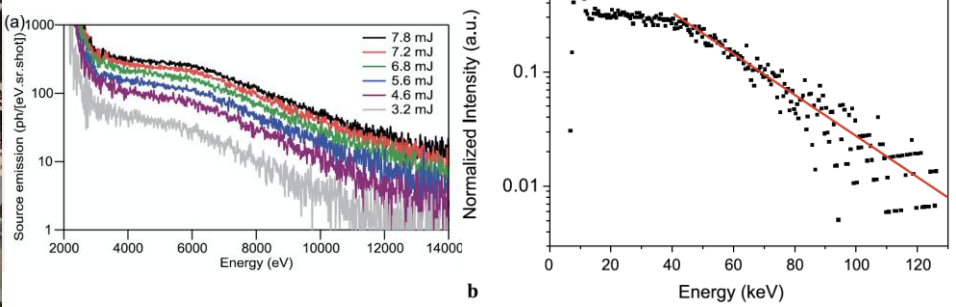
Spectroscopy (von Hamos) module

Instrument Responsible

- Anna Zymakova



L. Miaja-Avila et al. Structural Dynamics **2**, 024301 (2015) doi: 10.1063/1.4913585)



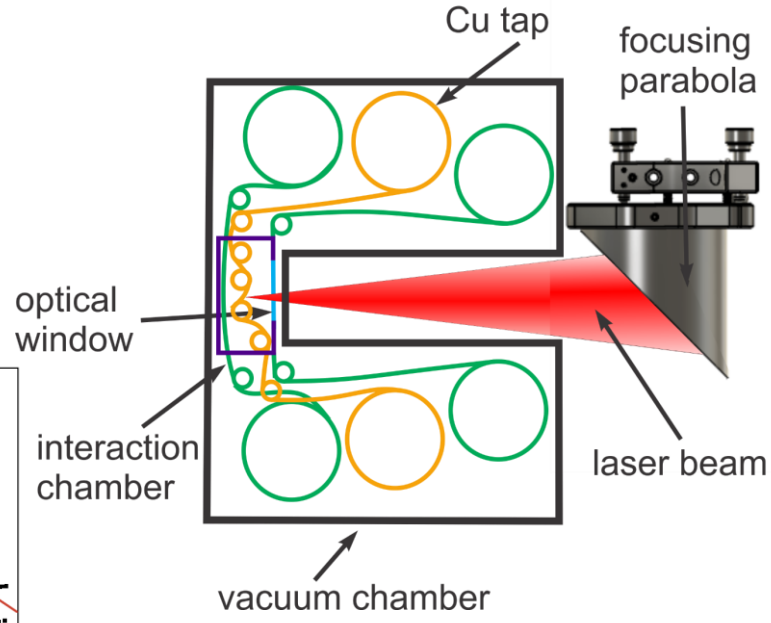
Experiments using the polychromatic emission for absorption and emission spectroscopy

Scientific Reports 13 (1), 17258 (2023) https://doi.org/10.1038/s41598-023-43924-y

Cu tape Plasma X-ray Source (PXS)

Instrument Responsible

- PXS: Jaroslav Nejdl



Sub ps pulse duration
1 kHz repetition rate
Up to 10^6 photons/s on sample

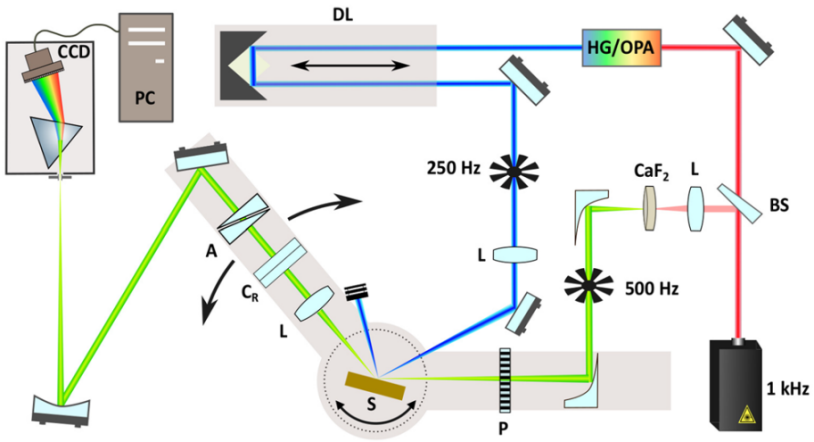
Y. Pulnova, et al., IUCr, Journal of Synchrotron Radiation Volume 32| Part 2| March 2025, https://doi.org/10.1107/S1600577525000645

Ultrafast Optical Spectroscopy 1: Time resolved Spectroscopic Ellipsometrey (trELIps), Transient Current Technique (TCT)

Laser	Energy	Pulse duration	Repetition rate
Coherent Astrella	7 mJ	40 fs	1 kHz

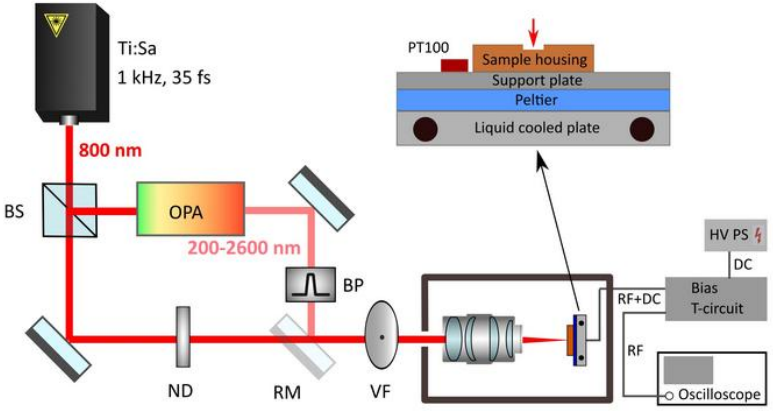
trELIps

Rev.Sci.Instrum. 92 (2021) 033104



fsTCT

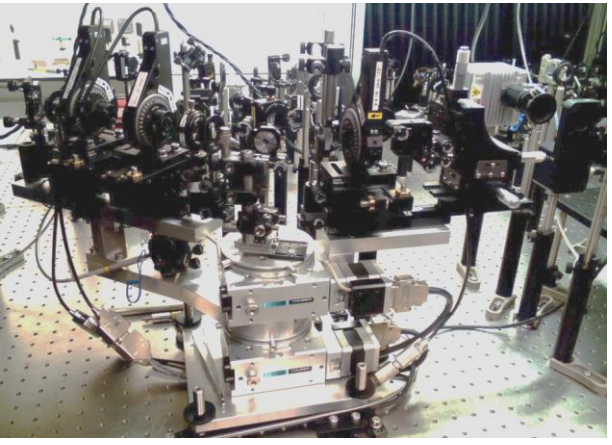
Nucl.Instrum.Meth.A 1041 (2022) 167321



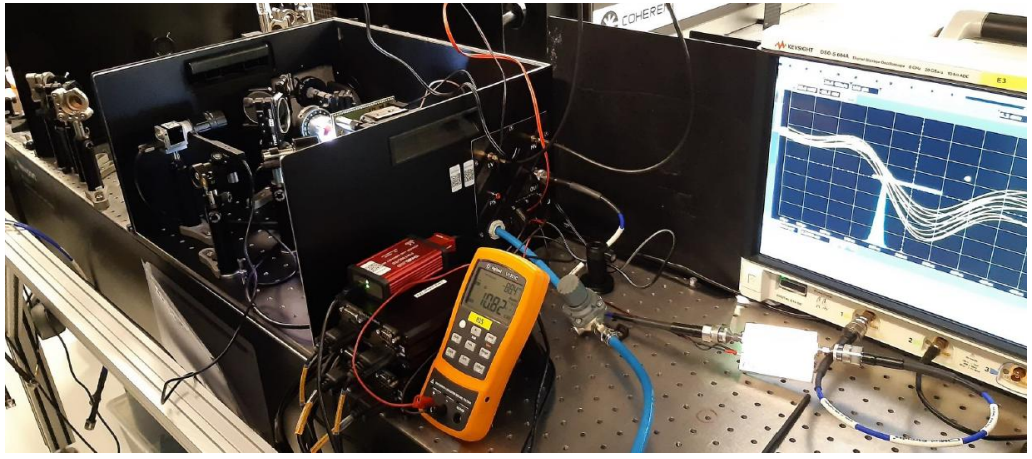
Instrument Responsible

- trELIps: Shirly Espinoza
- TCT: Mateusz Rebarz

Major research areas:
Particle detectors for colliders
Semiconductor detectors
Low Gain Avalanche Diodes
Segmented detectors
Materials processing



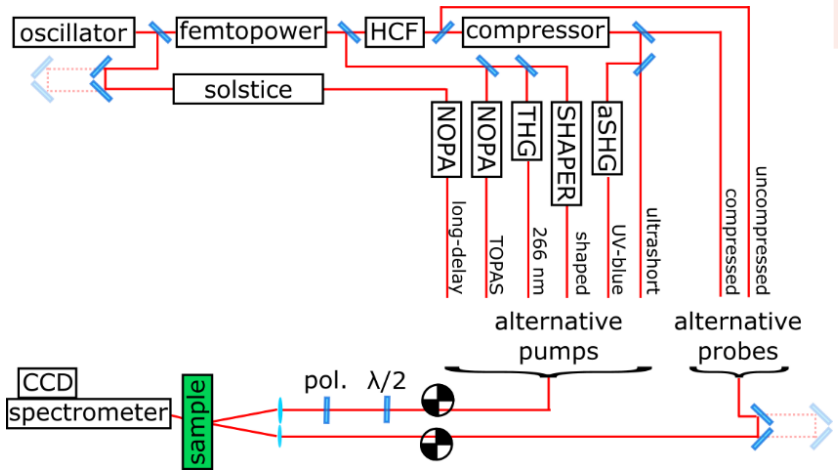
Major research areas:
Semiconductors
Thin films (organic & inorganic)
2D materials
Phase transition materials
Solid/liquid interface
Plasmonics



Ultrafast Optical Spectroscopy 2: Femtosecond Stimulated Rmana Spectroscopy (FSRS) and Transient Absorption (TA)

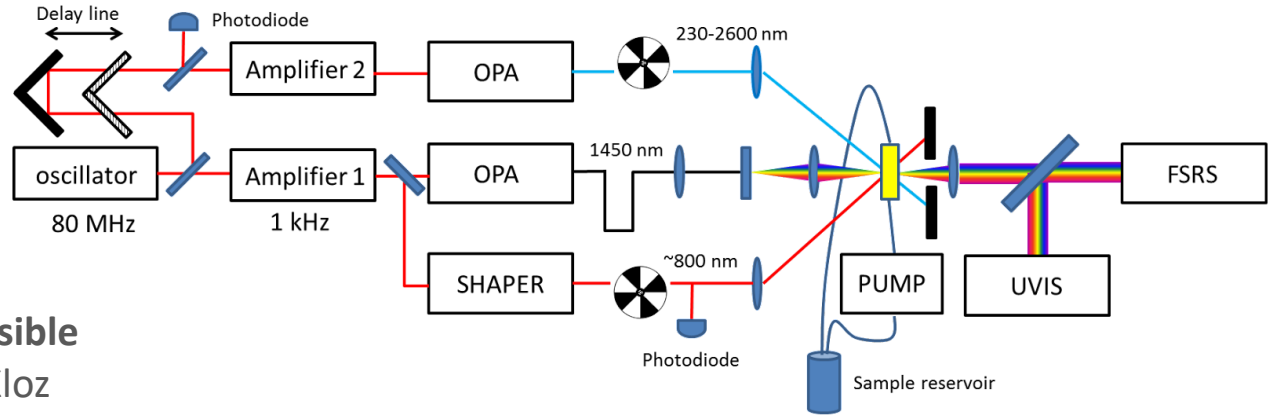
Laser	Energy	Pulse duration	Repetition rate
Spectra Physics Doublet /Femtopower	4.5 mJ	30 fs	1 kHz
Spectra Physics Doublet/ Solstice	7 mJ	40 fs	1 kHz

TA



- Transient absorption
  - Pump – probe
  - Pump power dependency
  - Impulsive time-domain Raman
- Three pulse experiments
  - Prepump – pump – probe
  - Pump – repump (dump) – probe
  - Excited-state impulsive Raman
- Pulse shaper experiments
  - Chirp control of pump
  - Coherent 2D electronic spetroscopy
  - Coherent control
  - Pulse train generation

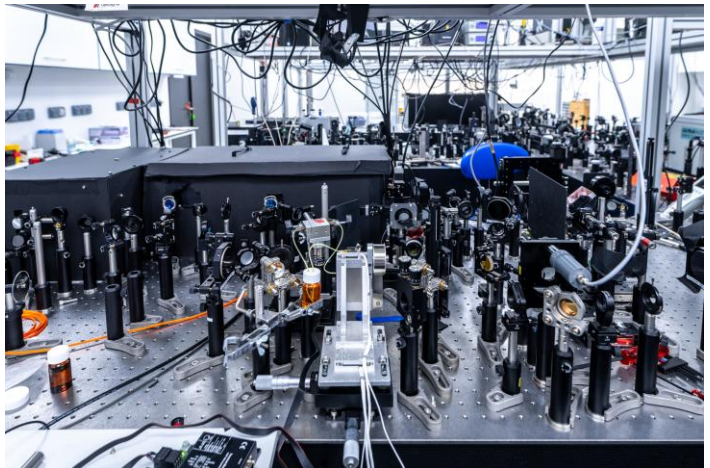
FSRS

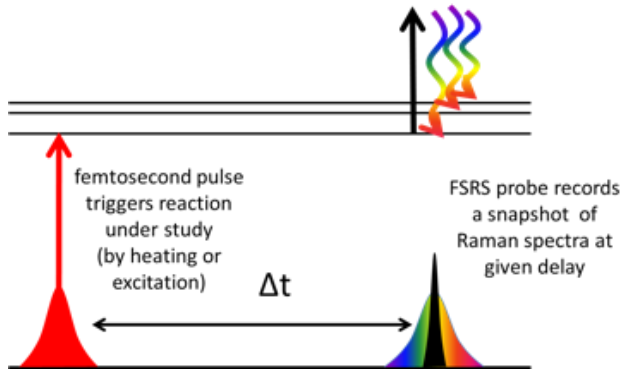


Instrument Responsible

- FSRS: Miroslav Kloz
- TA: Jakub Dostal

Can be measured simultanelously

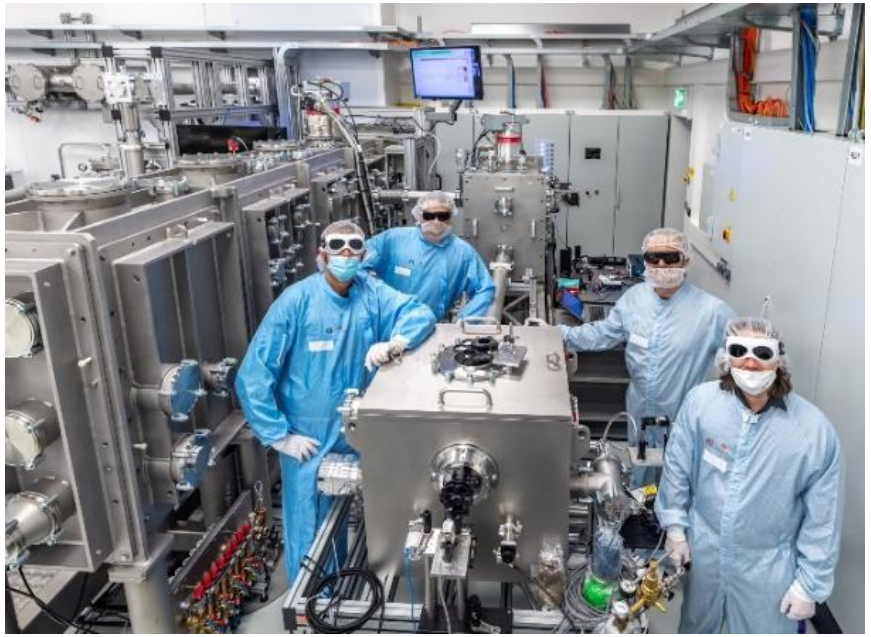


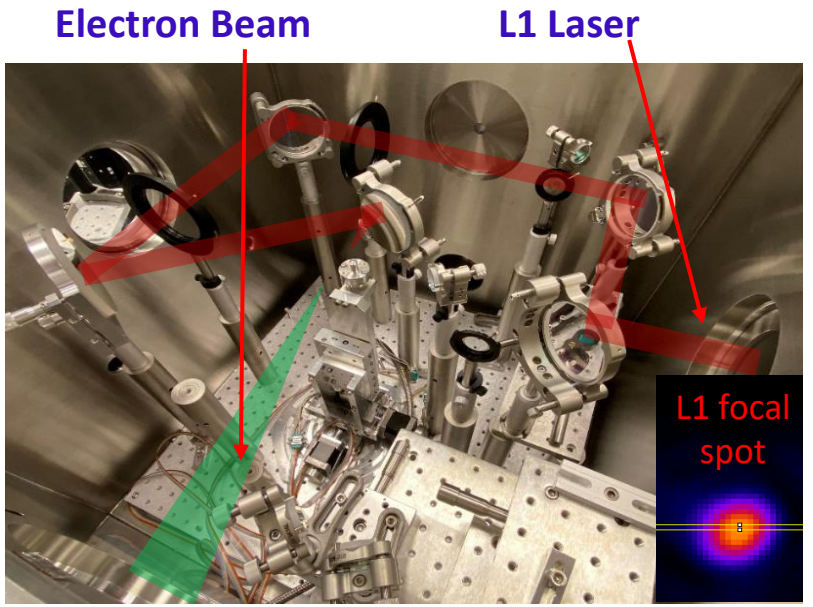


ALFA: Allegra Laser for Acceleration (L1 hall)

Compact platform for LWFA electron acceleration and applications

Instrument Responsible: Carlo Lazzarini





New applications made possible:

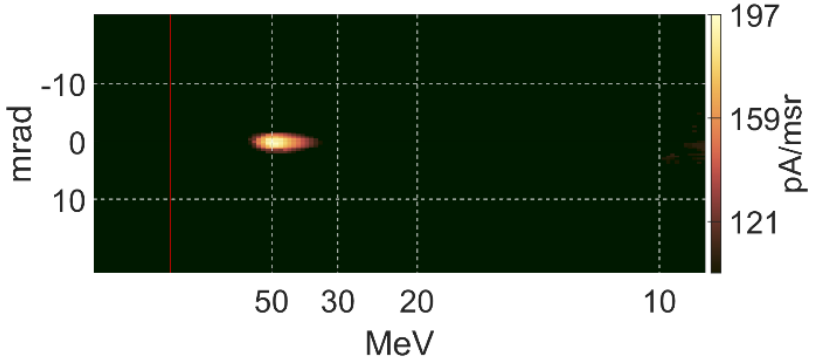
I. Very High Energy Electrons (VHEE) source for radiotherapy

[Citrin, D. E. *N. Eng. J. Med.* **377**, 1065-1075 (2017);Svendsen, K. et al. *Sci. Rep*. **11**, 5844 (2021)]

II. X-ray sources for medical imaging and soft X-ray spectroscopy

[Brummer, T. et al. *Phys. Rev. Accel. Beams* **23**, 031601 (2020)]

III. Electrons as test source for experiments in-air or in-vacuum



Lazzarini et al., Phys. Plasmas 31, 2024

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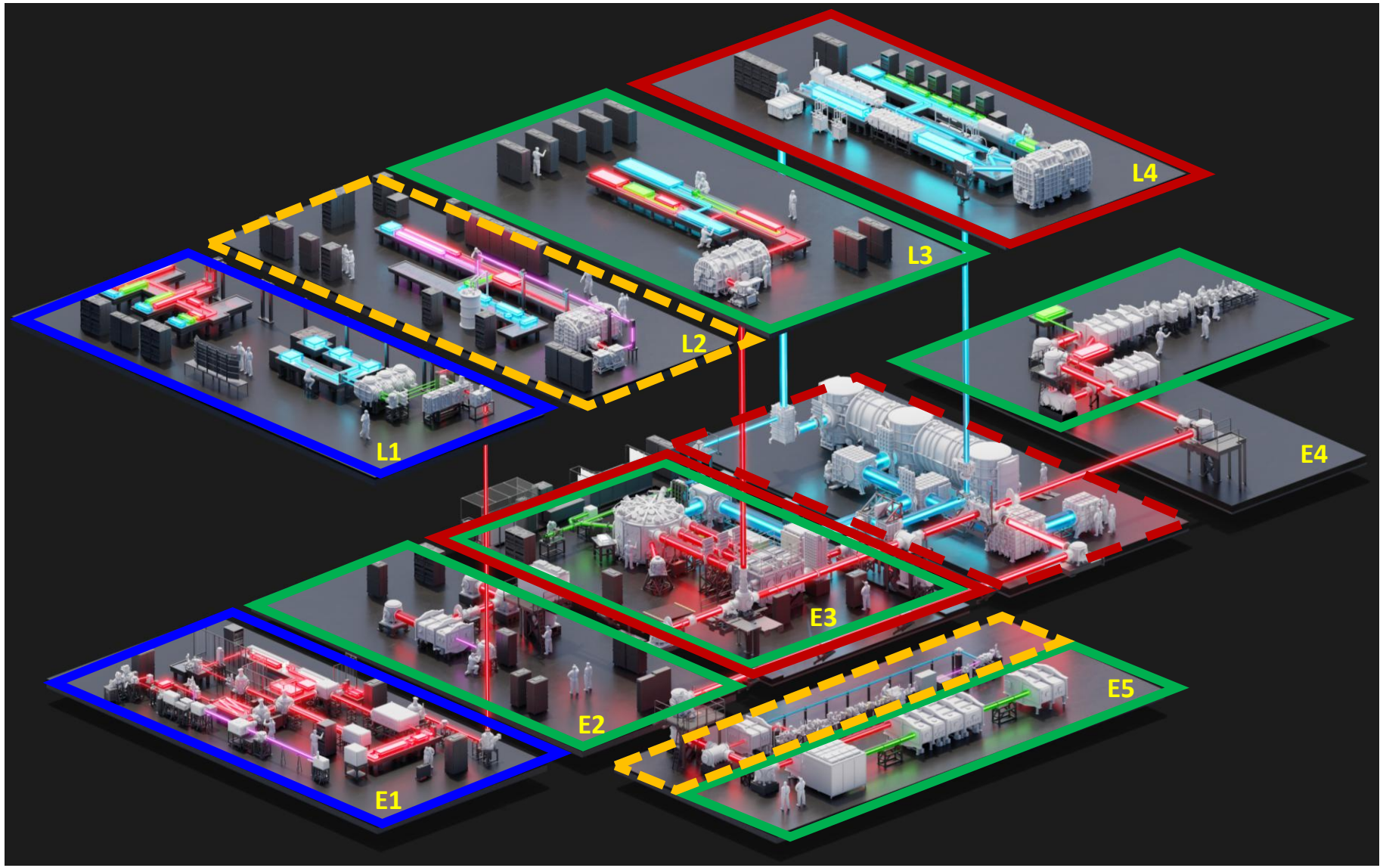
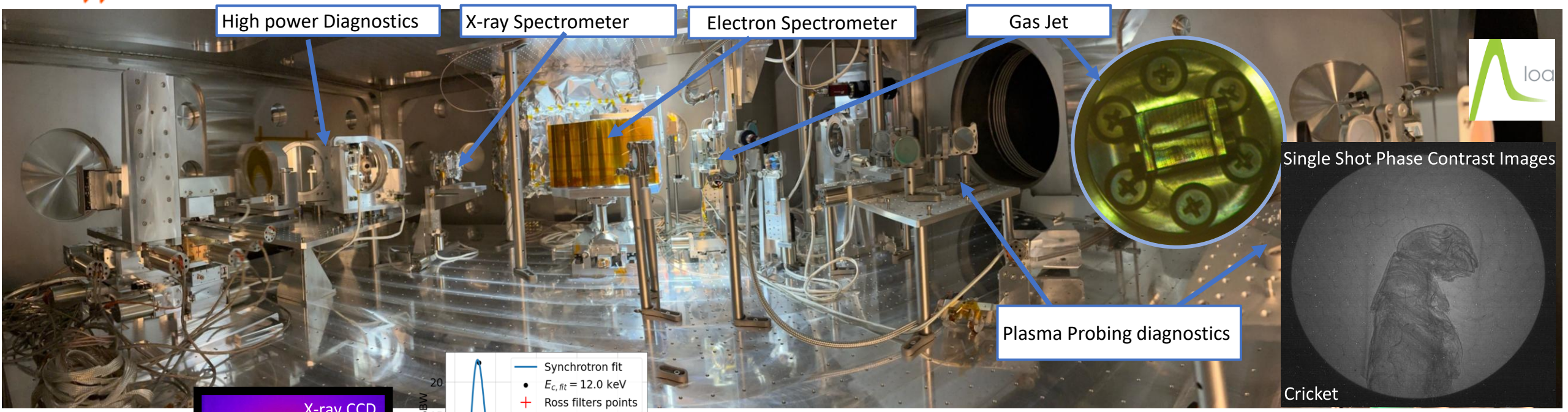
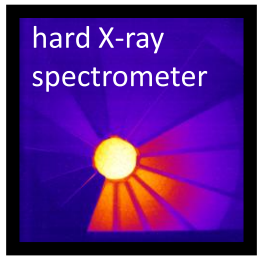


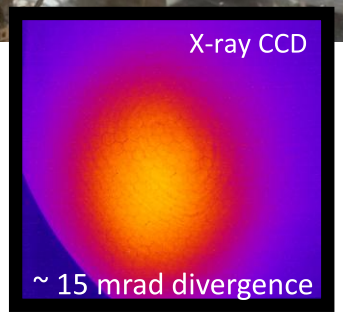
U. Chaulagain, J. Nejdl et al.

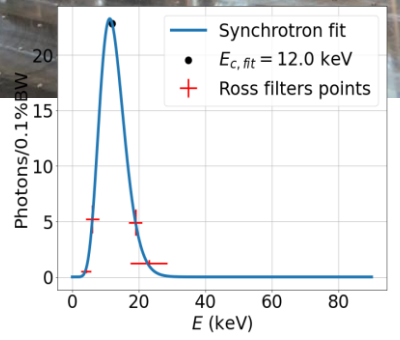
Gammatron Laser-Plasma X-ray source (E2)

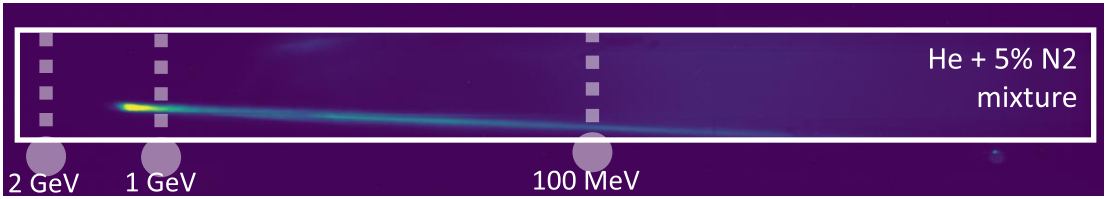
Hard X-ray source (LWFA Betatron) for multidisciplinary applications







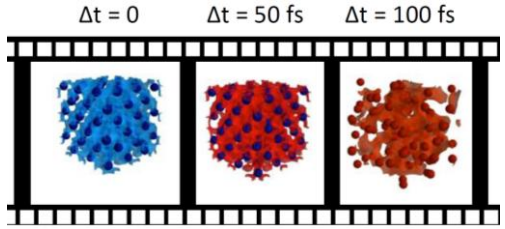




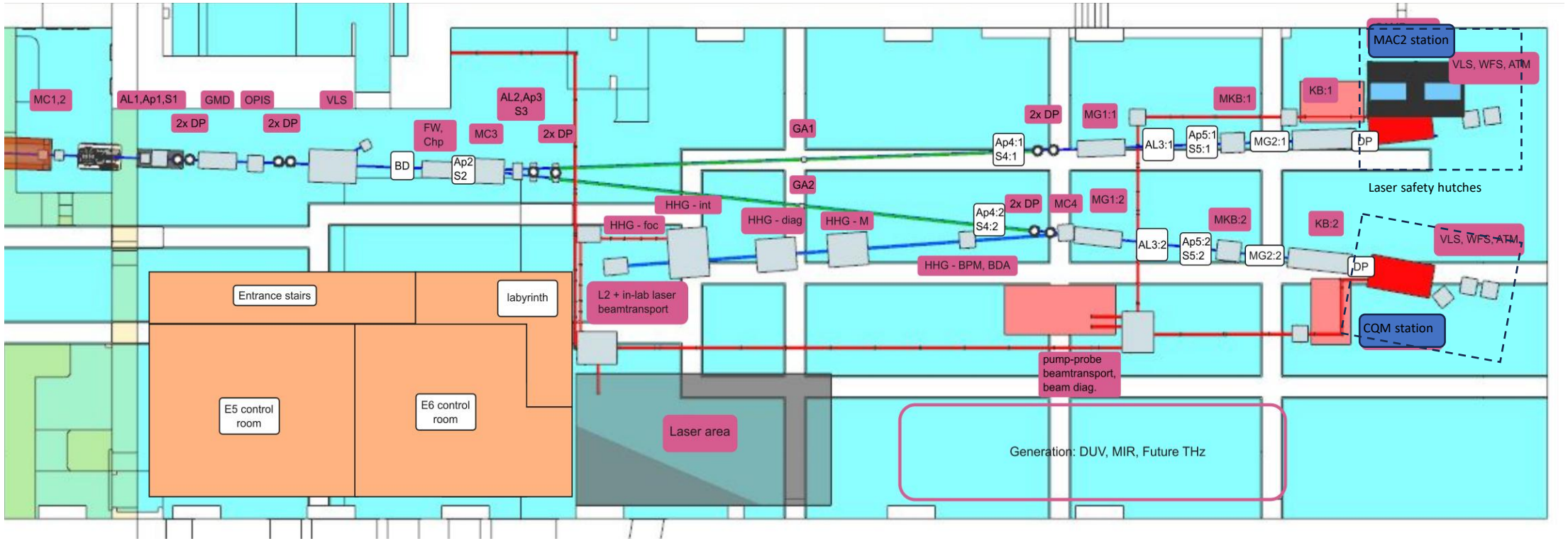
- ✓ Compact synchrotron-like **X-ray source**
  - **~10 fs, < 2μm source size**, collimated (<15mrad)
  - Photon flux ~**10^{10} photons/shot**
  - Critical Energy **>10 keV**
  - Tuneable X-ray energy
- ✓ **Pump beam** (800 nm, 400 nm or 266 nm)

Upcoming experimental campaigns

- Time-resolved X-ray absorption spectroscopy
- Time resolved Laue diffraction



Active participation in TDR for the EUPRAXIA development of a LWFA X-ray FEL at ELI Beamlines



- **Common beamline**
  - GMD, OPIS, VLS detectors
- **MAC end-station beamline**
- **CQM end-station beamline**
  - HHG Beamline (xuv-xuv pump-probe)

MC1,2: Mirror chamber, alignment and deflecting mirrors
AL: Alignment laser
Ap: Aperture
S: Screen
DP: Differential pumping
GDM: Gas Monitor Detector
OPIS: Online photoionization spectrometer
VLS: Variable line spacing spectrometer
BD: Beam dump
FW: Filter wheel

Chp: Chopper
GA: Gas attenuator
MG: Monochromator grating
MKB: Vertical mirror for KB focusing optics
KB: KB focusing optics
WFS: Wavefront sensor
ATM: Arrival time monitor
HHG: High Harmonic Beamline

Valuable contribution from FLASH to the conceptual design of the photon beam transport and user stations

ELI Beamlines kHz technology and applications

Complementarity to facilities and university labs

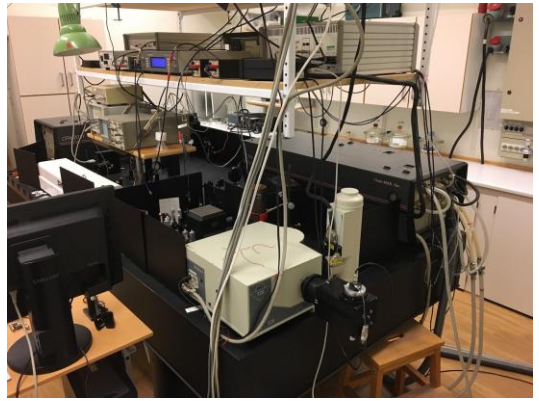
High complementarity to other photon science facilities and research labs for pump-probe studies in ultrafast dynamics

Synchrotrons

- Availability, reliability, tuneability, beam control, flux.
- Limited temporal resolution, synchronization

ELI Beamlines

- Flexible pump-probe experiments, THz to X-rays,
- Synchronization and temporal resolution
- Combination of complementary energy ranges and source parameters.
- Complementary ultrafast techniques (e.g. X-ray and IR/optical)
- Photon probes in combination with electron and ion beams



University lab

- Availability (once you have it and it is working)
- Big effort to keep updated and maintained for an individual lab
- Risk of under-utilization

X-ray FELs

- Photons per pulse, fs pulses, tuneability
- Availability (cost of beamtime), synchronization

Thank You !