Laserem buzené zdroje záření a urychlených částic na ELI-Beamlines

Jaroslav Nejdl

By courtesy of Georg Korn, Jakob Andreasson and many others

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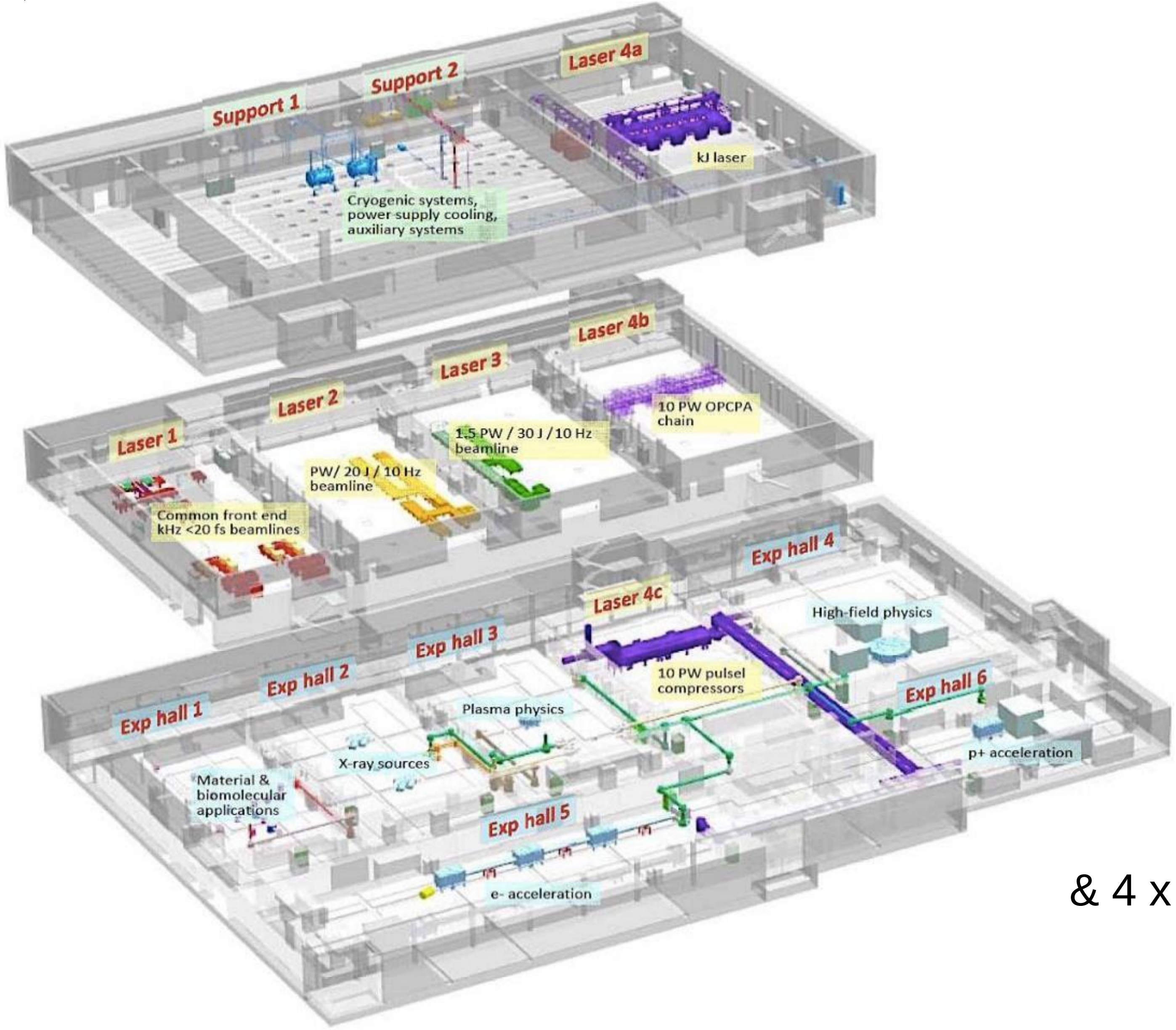
Advanced research using high intensity laser produced photons and particles (ADONIS)
Reg. n. CZ.02.1.01/0.0/0.0/16_019/0000789

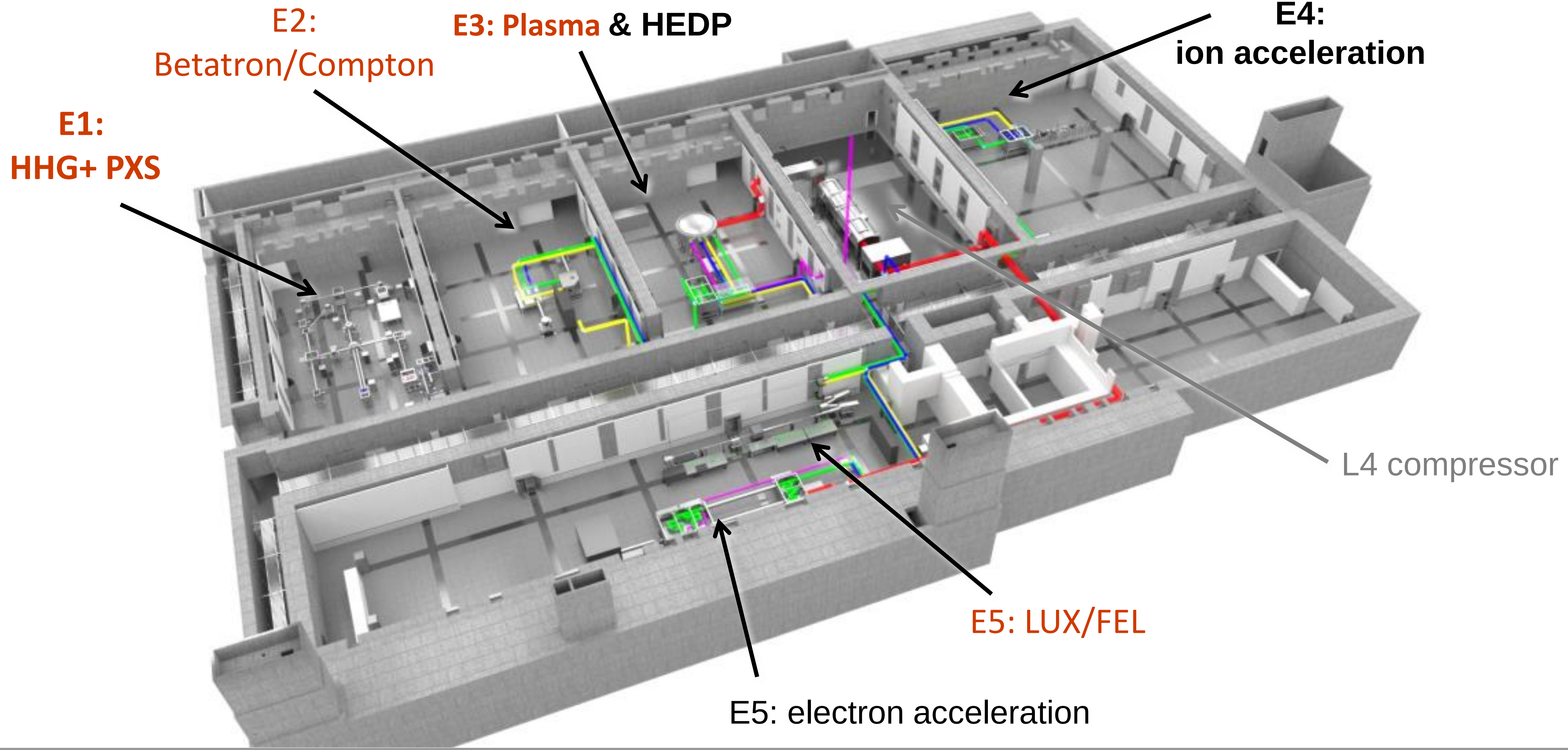
Facility layout and laser drivers for secondary sources



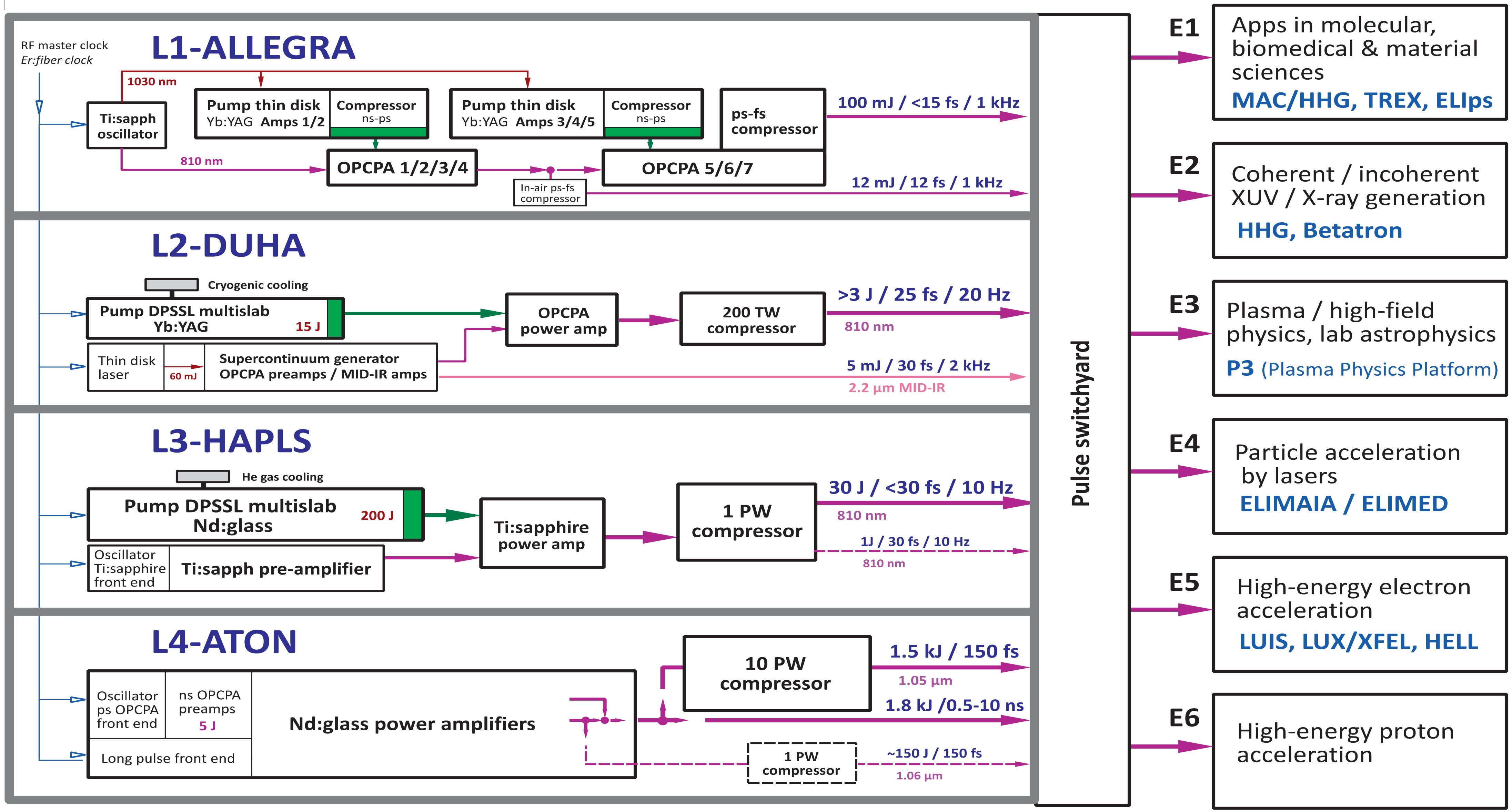
Laser	L1	L2	L3	L4
Energy (J)	0.1	> 2.5	30	1200
Pulse duration (fs)	15	25	30	120
Wavelength (nm)	830	850	820	1060
Rep. rate	1 kHz	50 Hz	10 Hz	1/min

& 4 x 6 mJ + 12 mJ 1 kHz 40 fs commercial lasers

Experimental halls

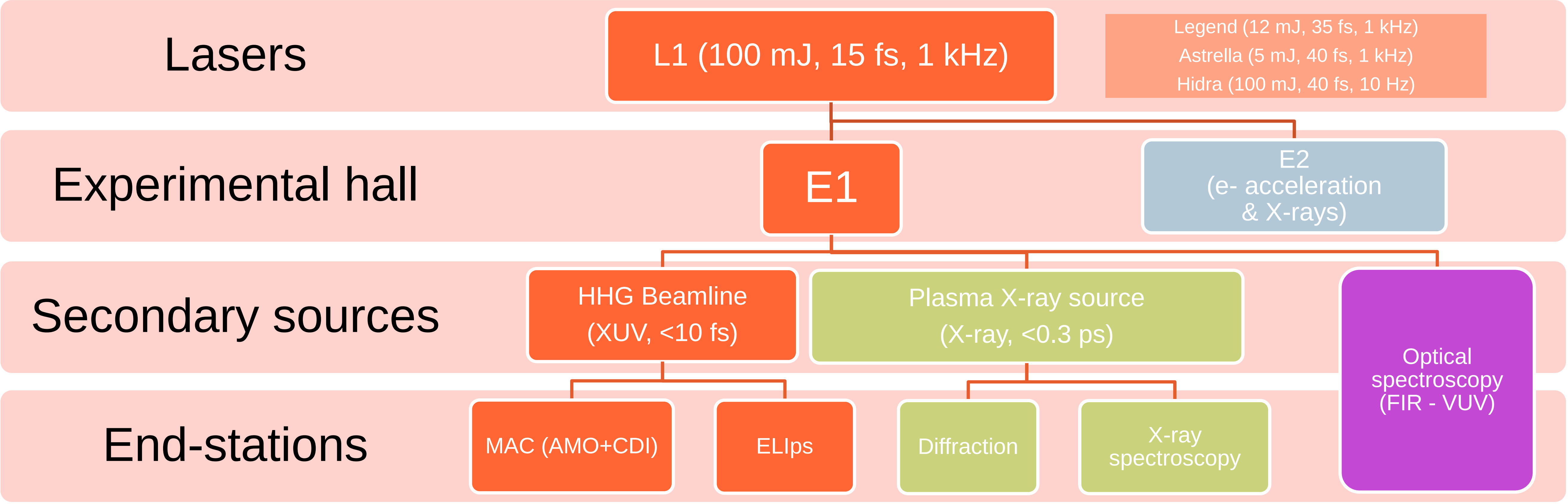


General facility scheme



eli beamlines

Present and near future facility scheme
high-rep rate (1 kHz) chain



L1 currently at 30 mJ, 1 kHz

User assisted commissioning L1 – HHG - MAC/ELIps (summer 2019)

Regular user access (with 40 mJ L1) starting in Q1 2020

Laser-driven X-ray sources in E1

E1

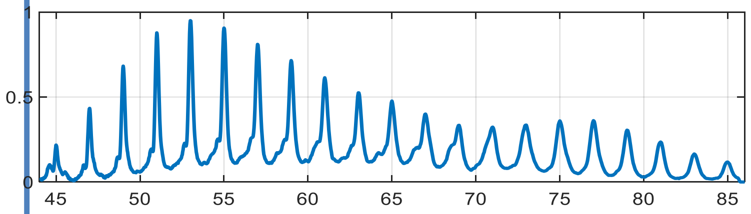
L1 driver

1 kHz, 100 mJ, 20 fs

Astrella, Legend, and Hidra backup

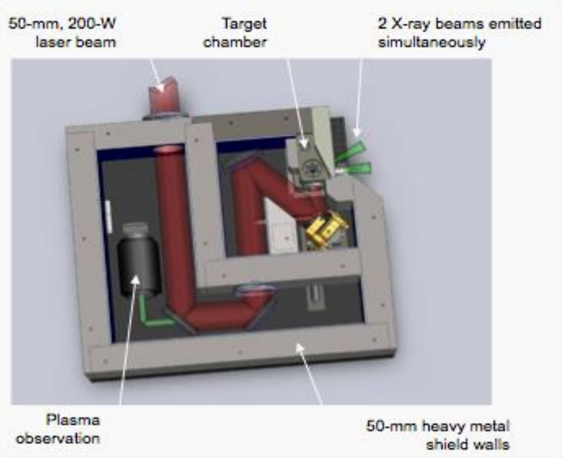
1 kHz, 6 mJ, 12 mJ and 100 mJ (10 Hz), 35 fs

High-order harmonic beamline



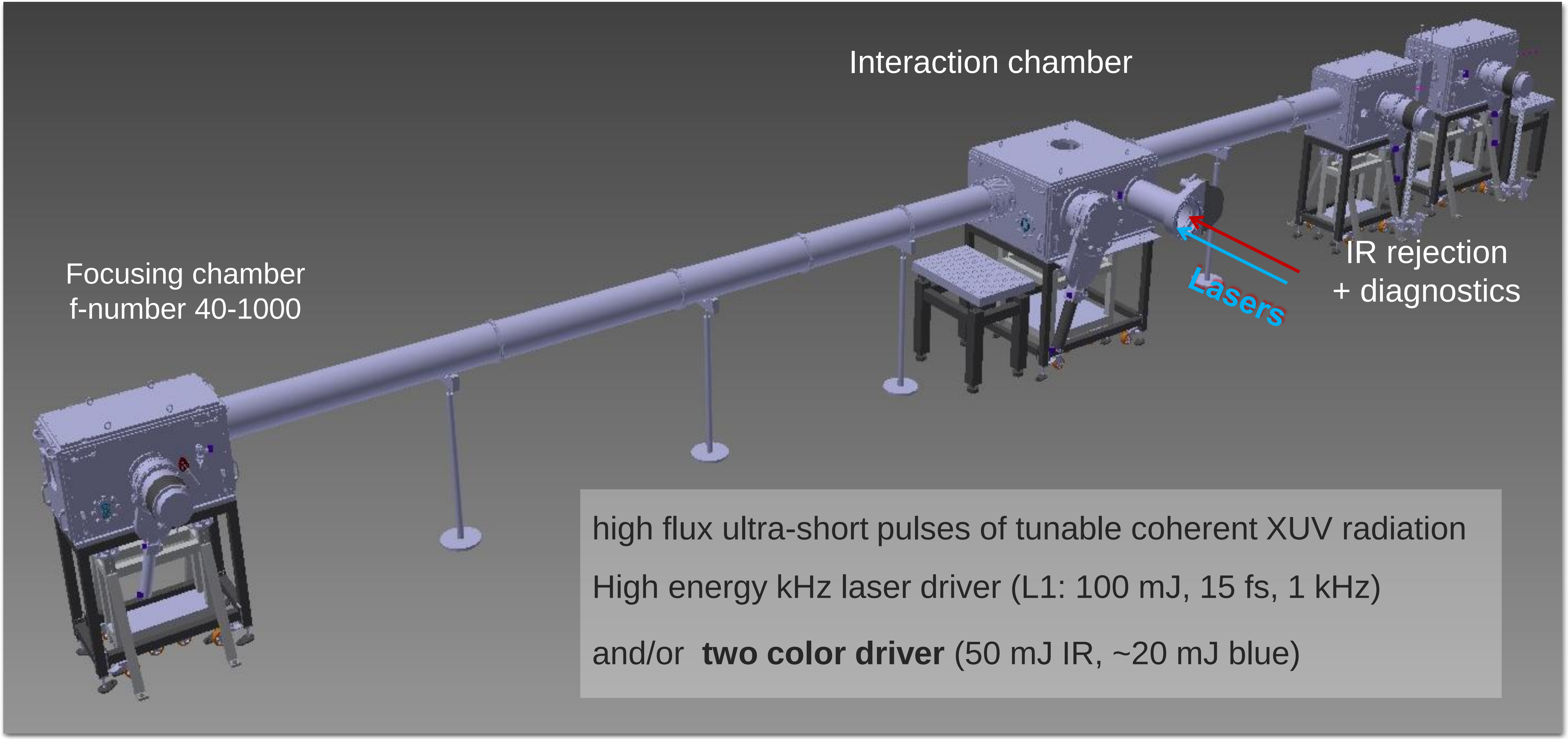
	6 mJ, 35 fs from 2018	L1: 100 mJ, ~15fs from late 2020
Wavelength	10 -120 nm	5 -120 nm
Photons/shot	1E7 to 1E9	few 1E9 -1E12
Duration	< 20 fs	< 10 fs
Polarization	Linear	Lin./Circ./Eliptic

Plasma X-ray source



	6 mJ laser (35 fs)	100 mJ laser (15 fs)
photon energy	3 - 40 keV	3 – 80 keV
photons/(4π sr line or 1keV @10keV)	> 1E7	> 1E9
Source size	< 100 µm	< 100 µm
pulse duration	< 300 fs	<300 fs

HHG Beamline in E1



high flux ultra-short pulses of tunable coherent XUV radiation

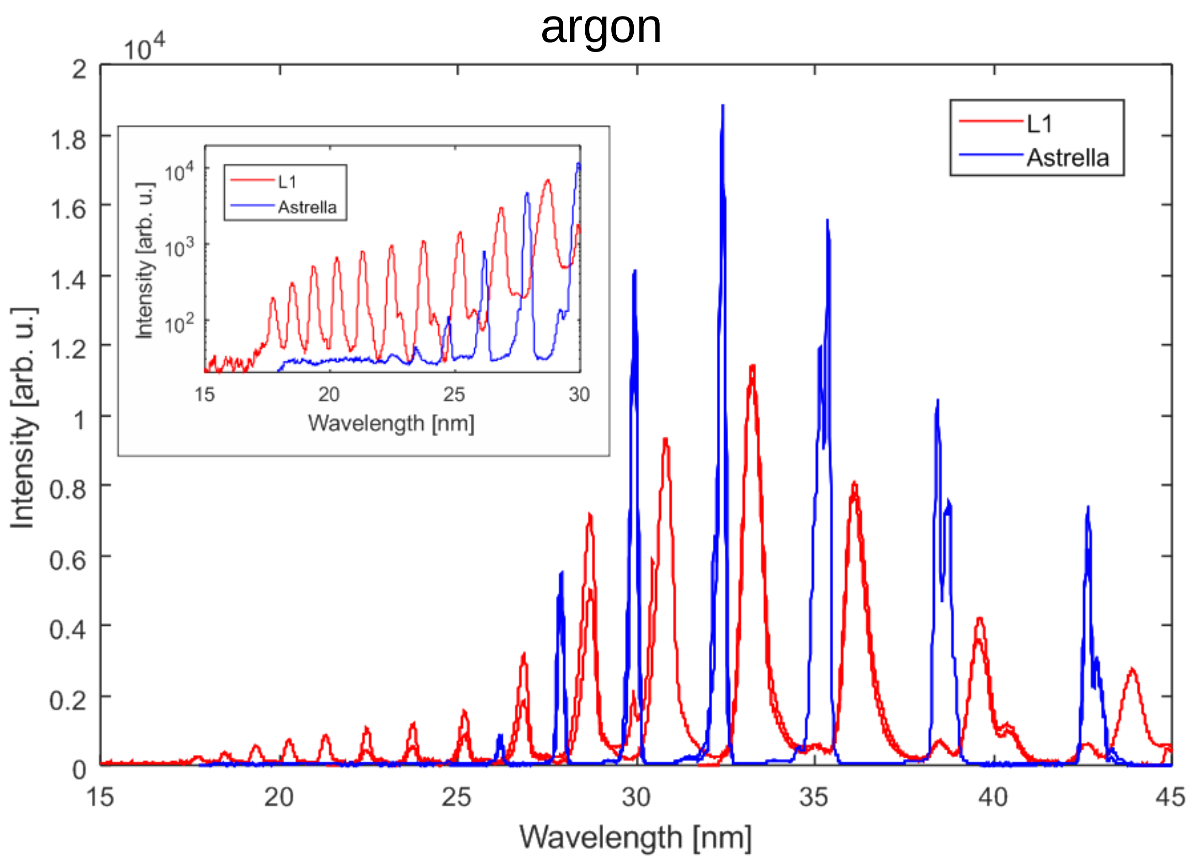
High energy kHz laser driver (L1: 100 mJ, 15 fs, 1 kHz)

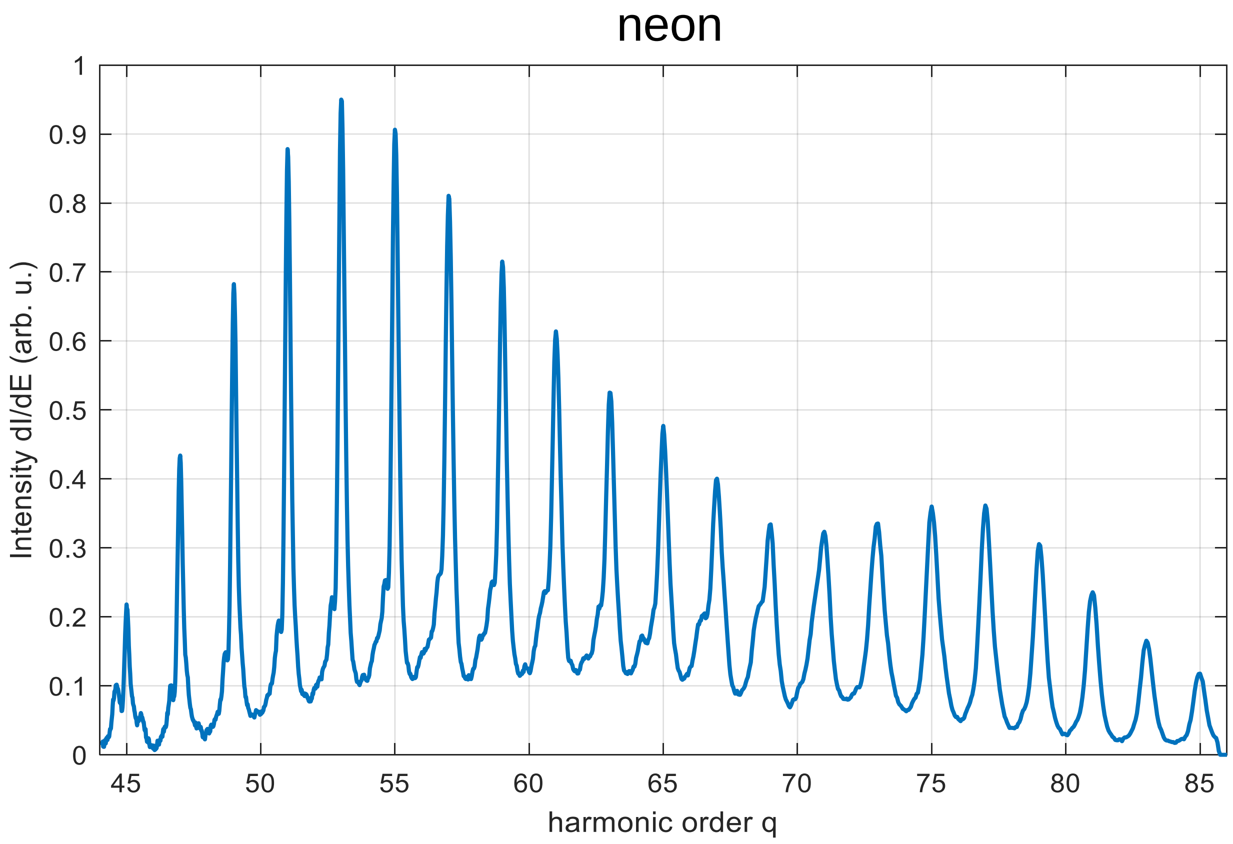
and/or **two color driver** (50 mJ IR, ~20 mJ blue)

Performance with L1 laser

Comparing L1 (OPCPA) to Ti:sapphire: Broader harmonics, redshifted, higher cutoff

$$E_{XUV} \propto E_L \quad \& \quad E_{XUV} \propto 1/T_L$$



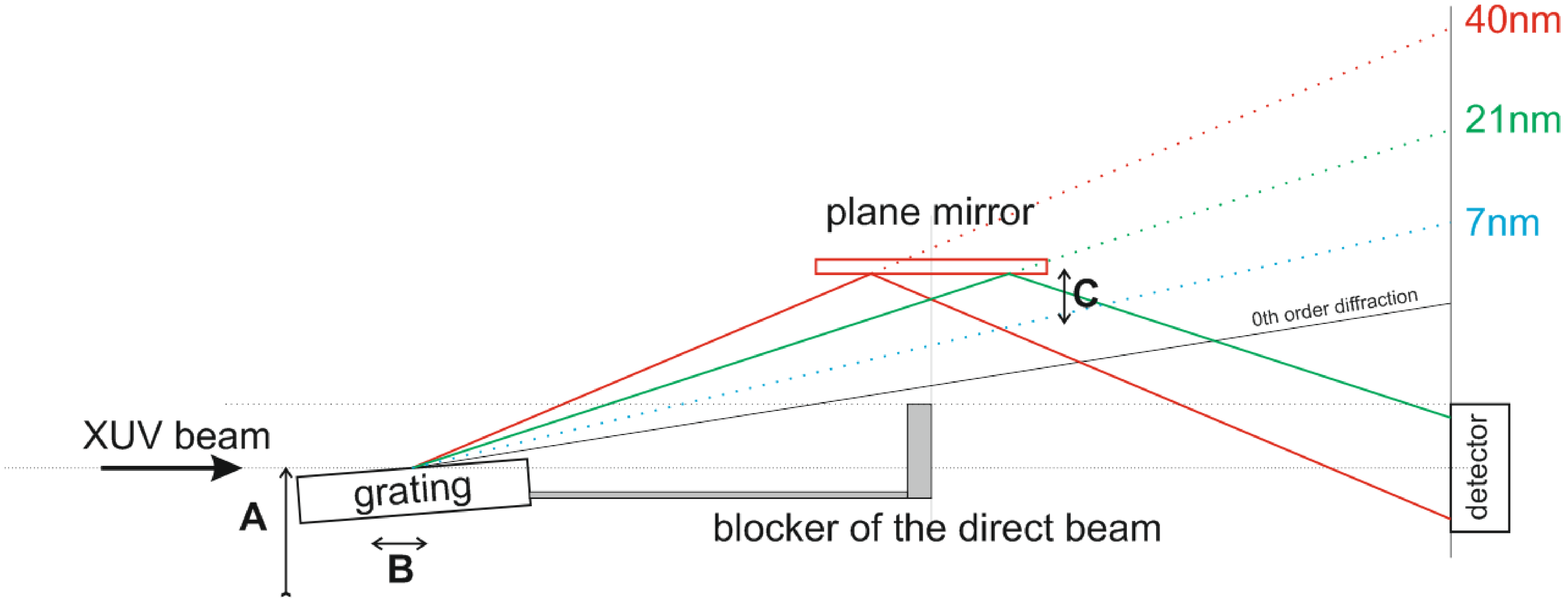


Astrella: λ=810 nm, τ=40 fs, 5 mJ
L1: λ=830 nm, τ=15 fs, 1 mJ

L1: λ=830 nm, τ=15 fs, 10 mJ

Compact XUV spectrometer/ beam profiler

- Fixed *single* detector (on the beam axis)
- Flat-field spectrometer (imaging the source – w/o slit)



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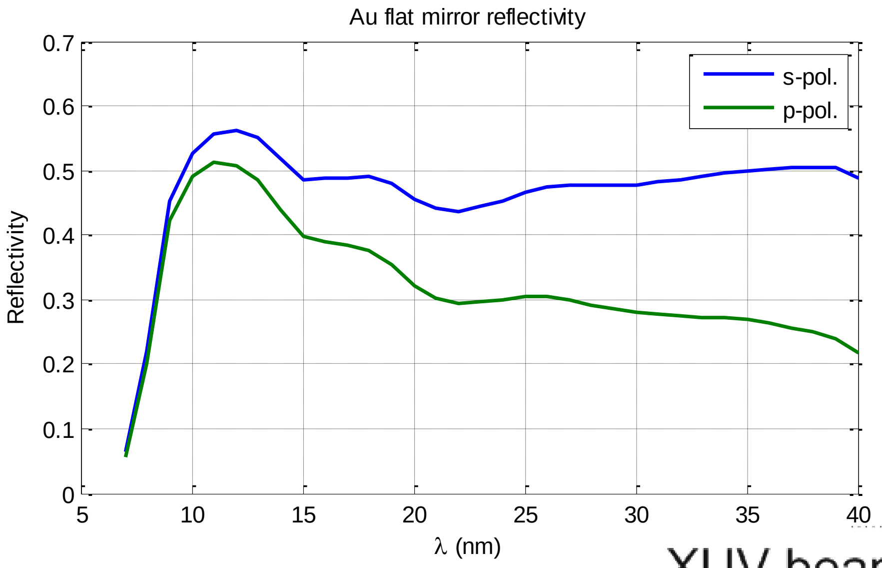

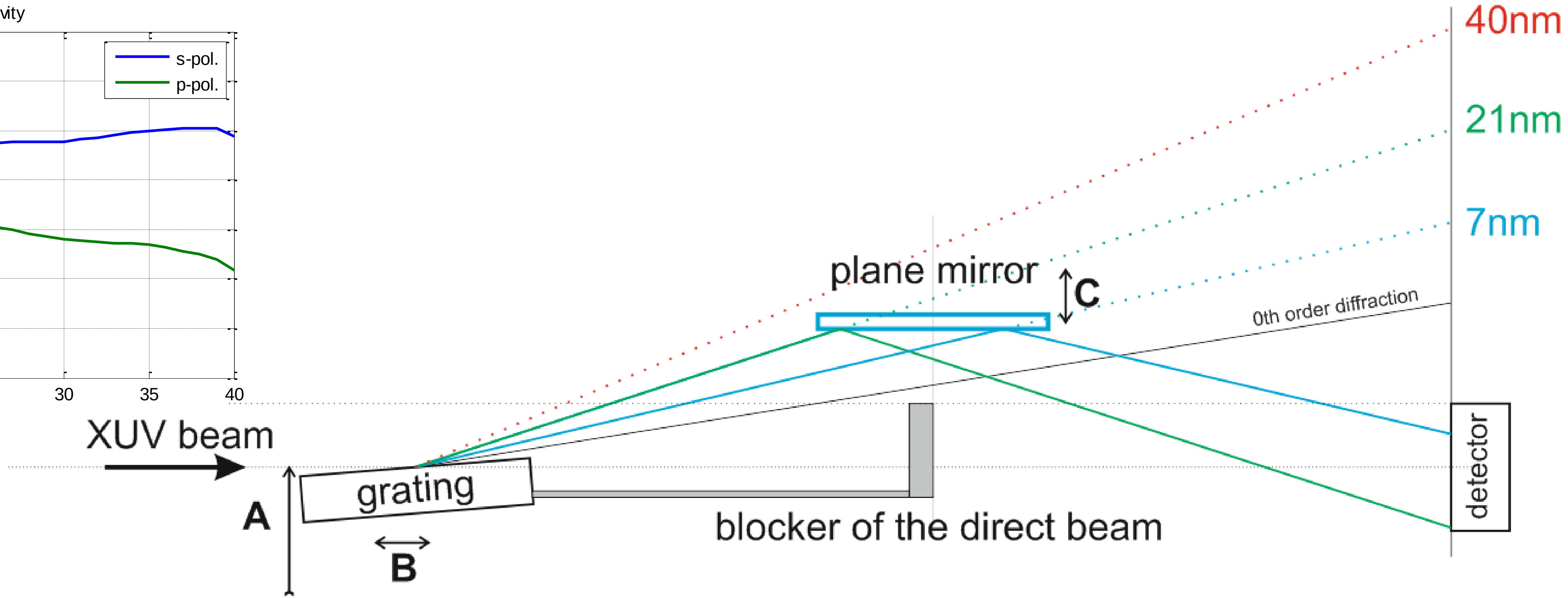

J. Nejdl et al., Proc. SPIE 11111 (2019); doi: 10.1117/12.2532702

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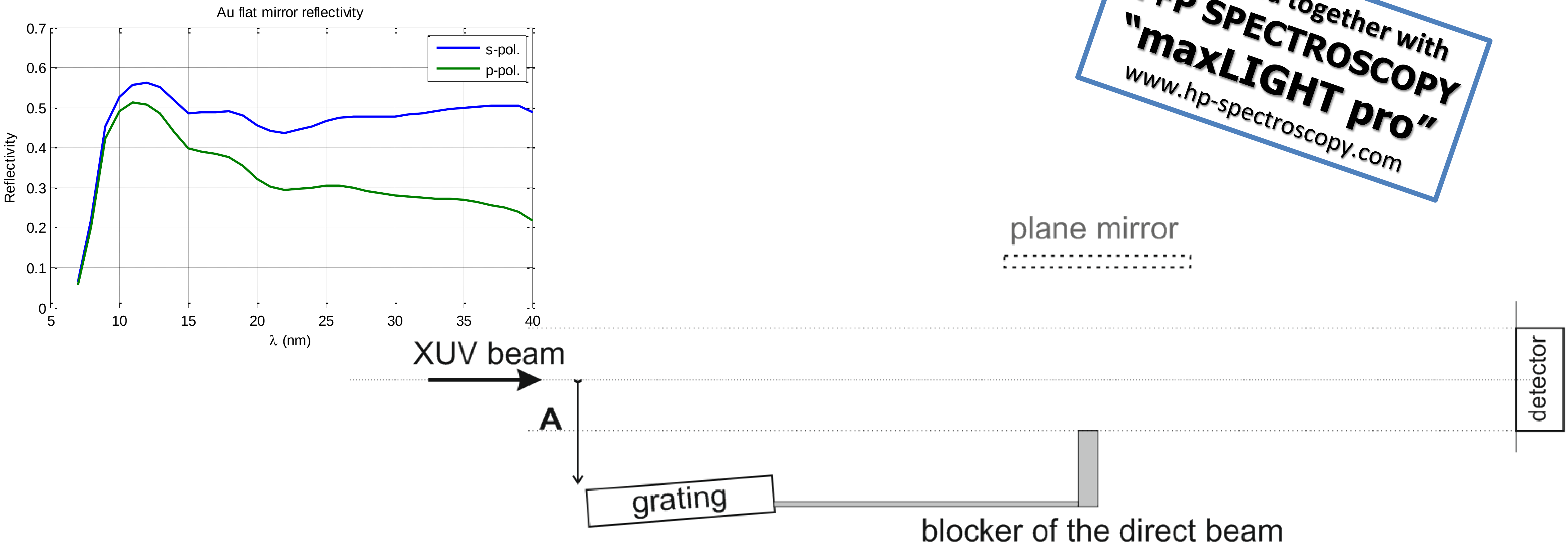

Developed together with
H+P SPECTROSCOPY
"maxLIGHT pro"
www.hp-spectroscopy.com

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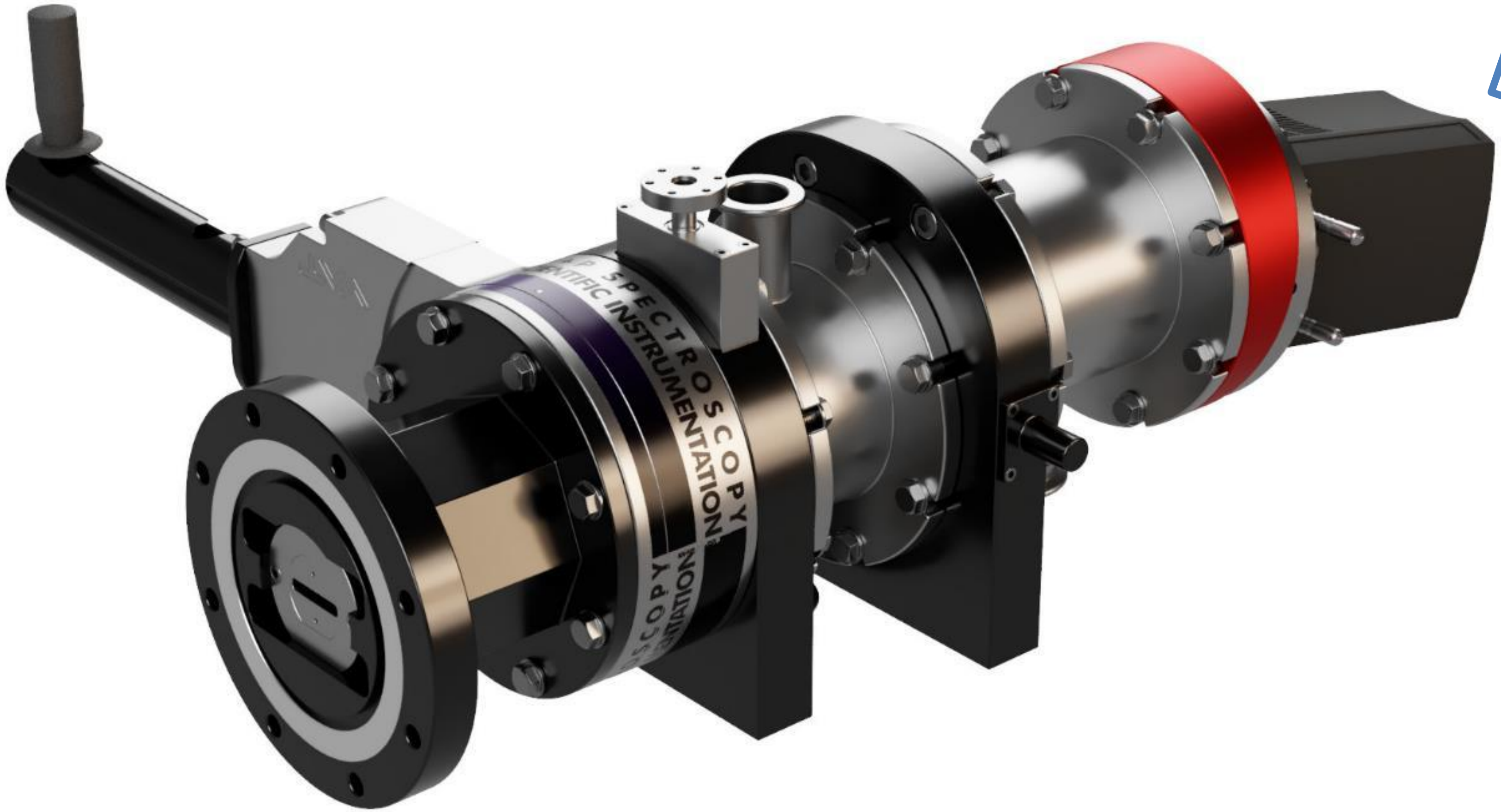

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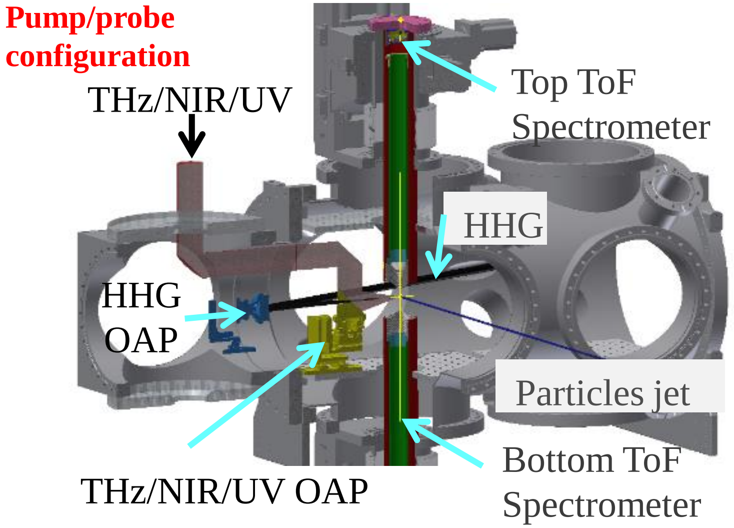
HHG Beamline end-stations

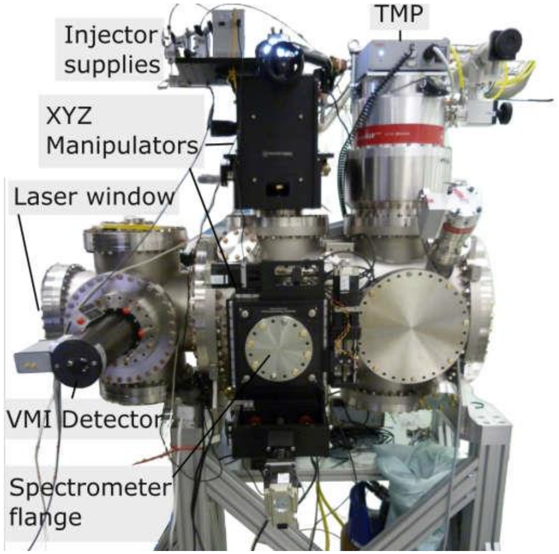
- Multipurpose chamber for Atomic, Molecular and Optical science and Coherent Diffractive Imaging
  - Sample delivery systems:

    gas jets; microfluidic gas-dynamic nozzle
    aerosol nano-particle injector;
    cluster source (cryo-cooled Even-Lavie valve)

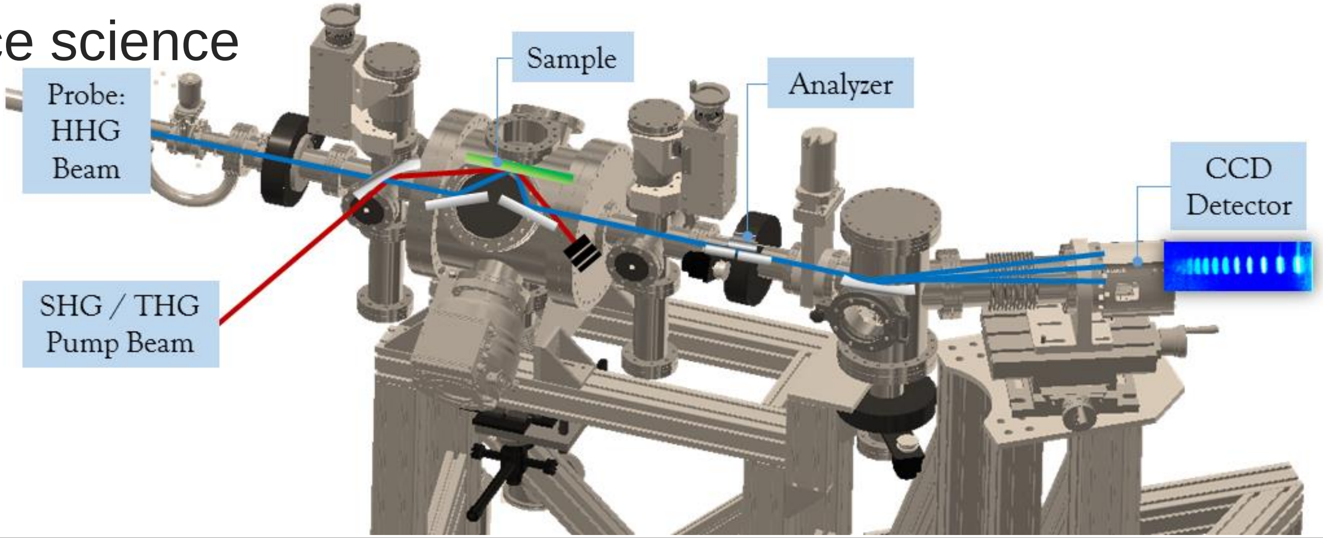
  - Diagnostics:

    Velocity map imaging spectrometer
    Magnetic bottle spectrometer
    Electron and ion time of flight spectrometers
    Various area detectors (X-ray CCDs, MCPs)





- VUV Magneto-optical ellipsometer (ELIps) for surface science
  - Multiple grazing incidence reflection polarizers
  - Spectrally resolved (FF spectrometer)
  - Cryogenic cooling of the sample
  - Switchable magnetic field (±1.5 T)
- Pump beams (Mid IR to XUV) with fs pulses



S. Espinoza et al., Appl. Surf. Sci. **421 B**, 378 (2017)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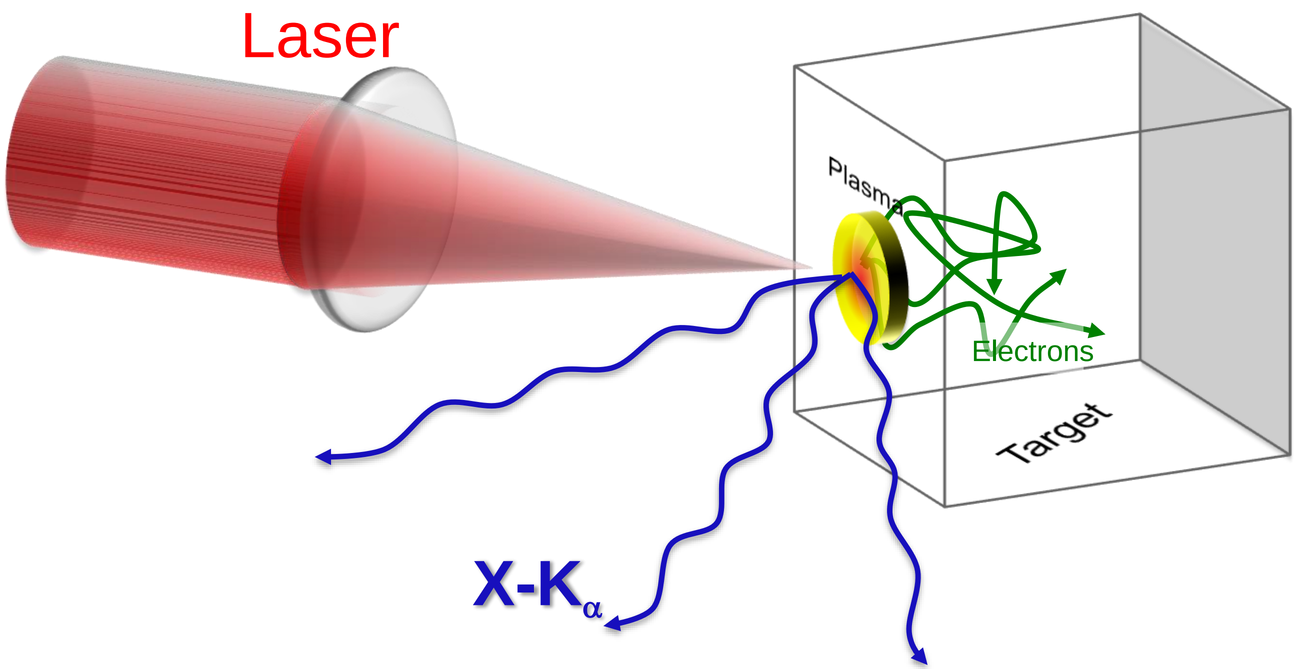
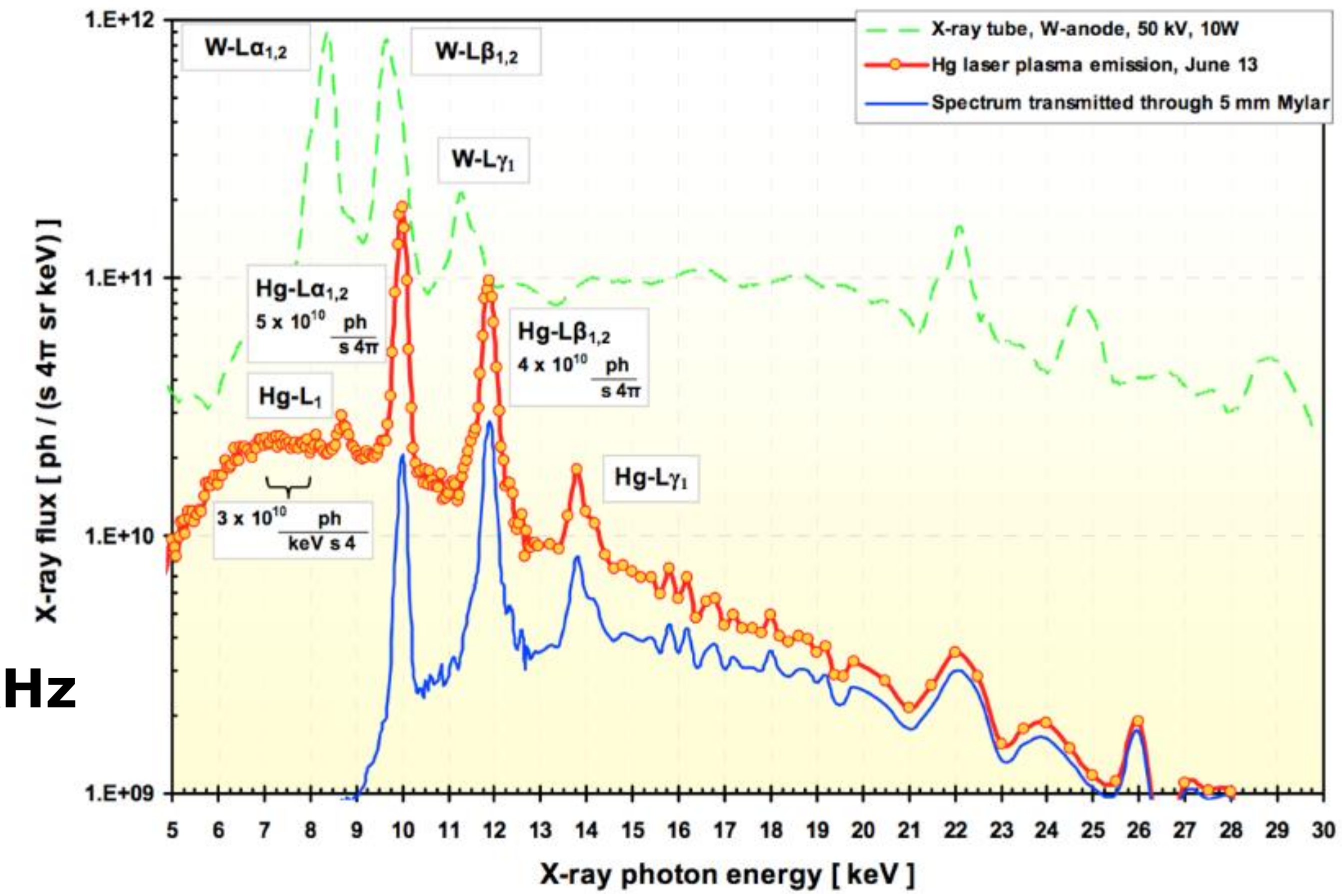
beamlines
DANGER

Plasma X-ray Source (PXS)

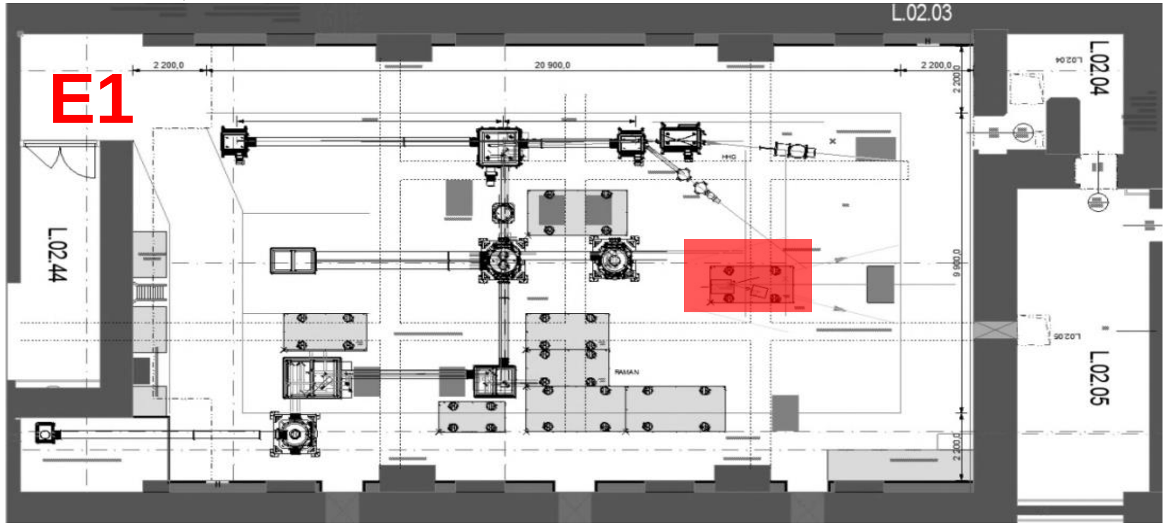


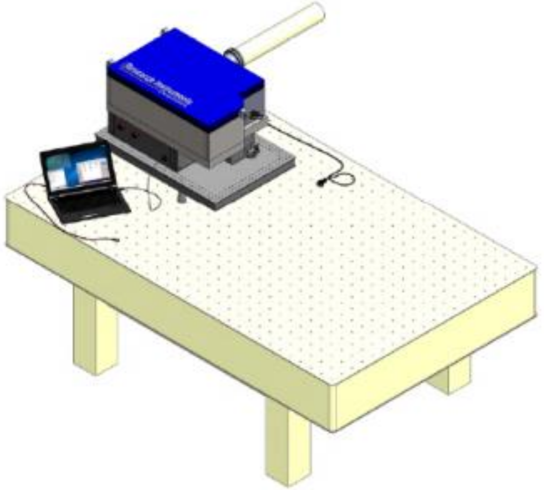


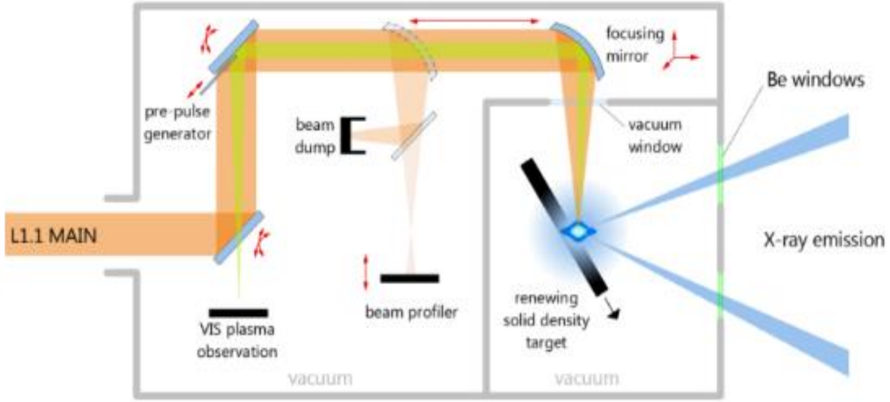
Plasma X-ray sources available at ELI BL: 1 kHz

- Liquid metal jet (commissioning early 2020)
- Water jet source (commissioned Oct 2019)
- Cu tape target K-α source (to be delivered at the end 2020)

Liquid metal jet Plasma X-ray Source (PXS)





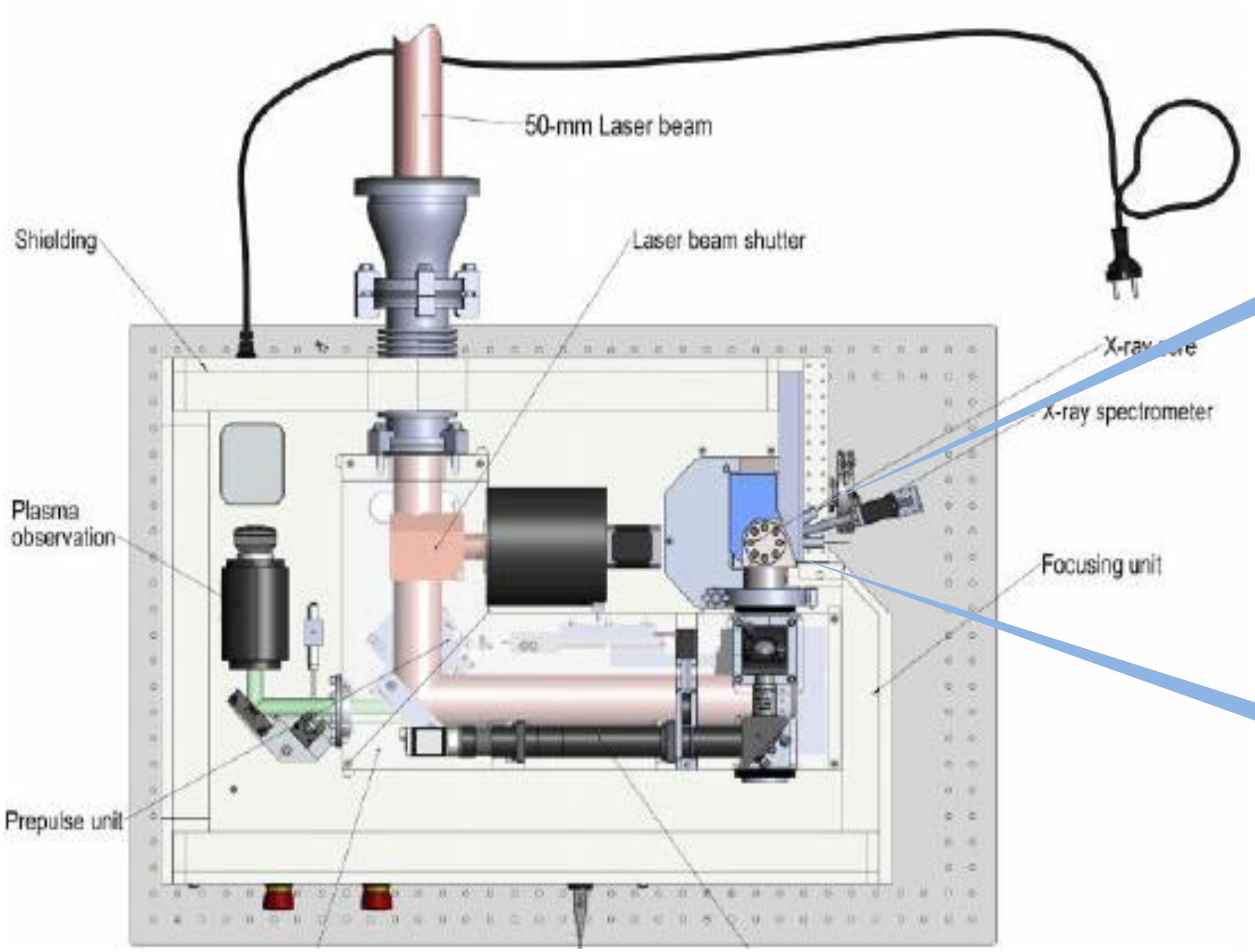


Characteristics:
4π sr emission, 3 – 30 keV
line + continuous spectra
~300 fs pulses
10s μm spot size

Applications:
Time-resolved X-ray diffraction
Small- angle X-ray scattering
X-ray Absorption Spectroscopy
X-ray Imaging
Pulsed radiolysis

Table 1: X-ray source parameters	Phase I 5 mJ laser	Phase II 100 mJ laser	User operation
Minimum hard x-ray photon energy	3 keV	3 keV	3 keV
Photons per shot (photons/(4π sr line) or photons/(4π sr 1keV) @10keV)	$> 10^7$	$> 10^9$	$> 10^9$
Source size	< 100 μm	< 100 μm	< 100 μm
Hard X-ray pulse duration (FWHM)	< 300 fs	< 300 fs	< 300 fs
Collimated	No	No	Focusing optics

Liquid metal jet Plasma X-ray Source (PXS)



polychromatic
high flux
small spot size
OR point source

PXS-BL2

Imaging
Radiolysis
Spectroscopy

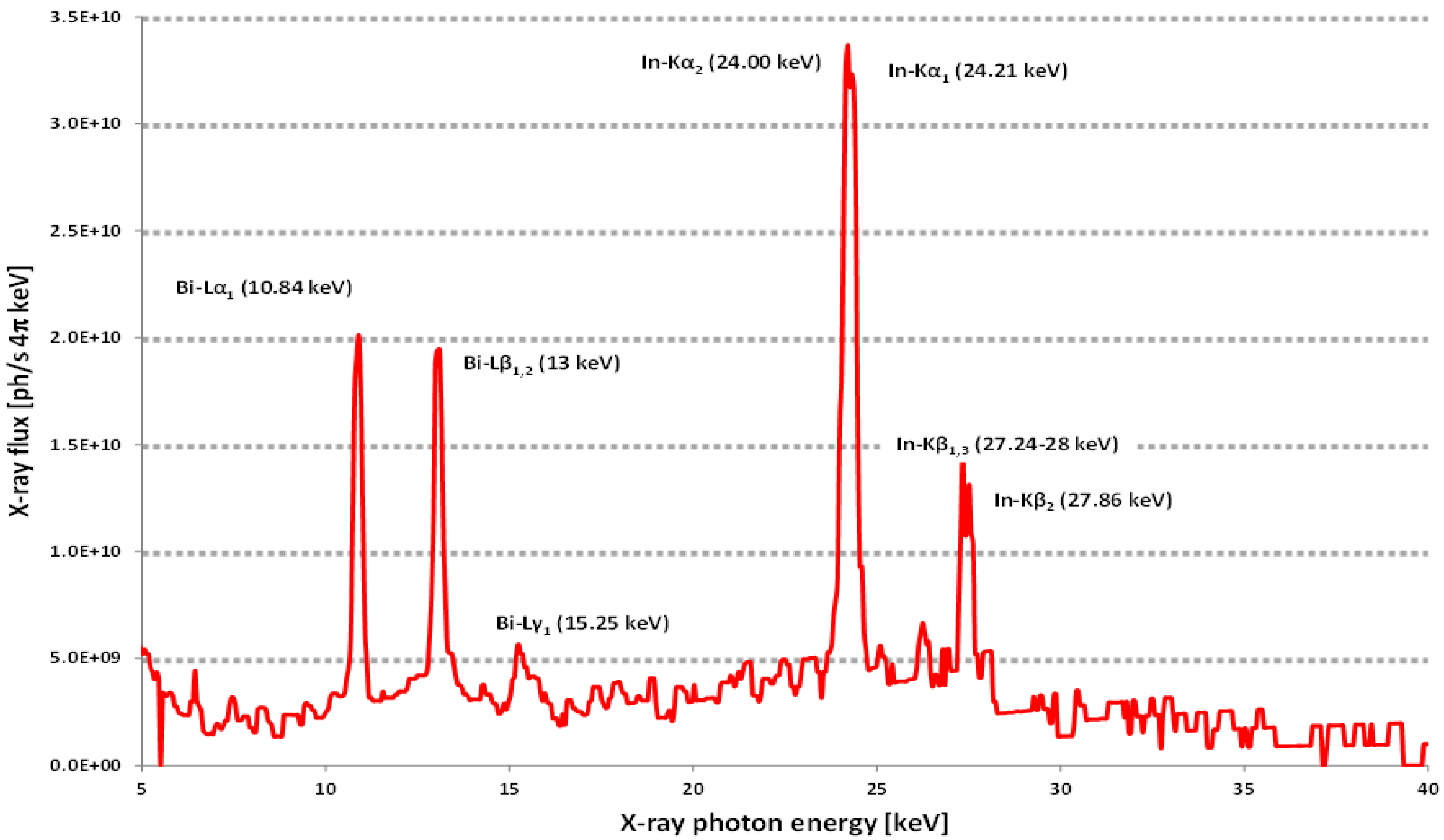
monochromatic
low divergence

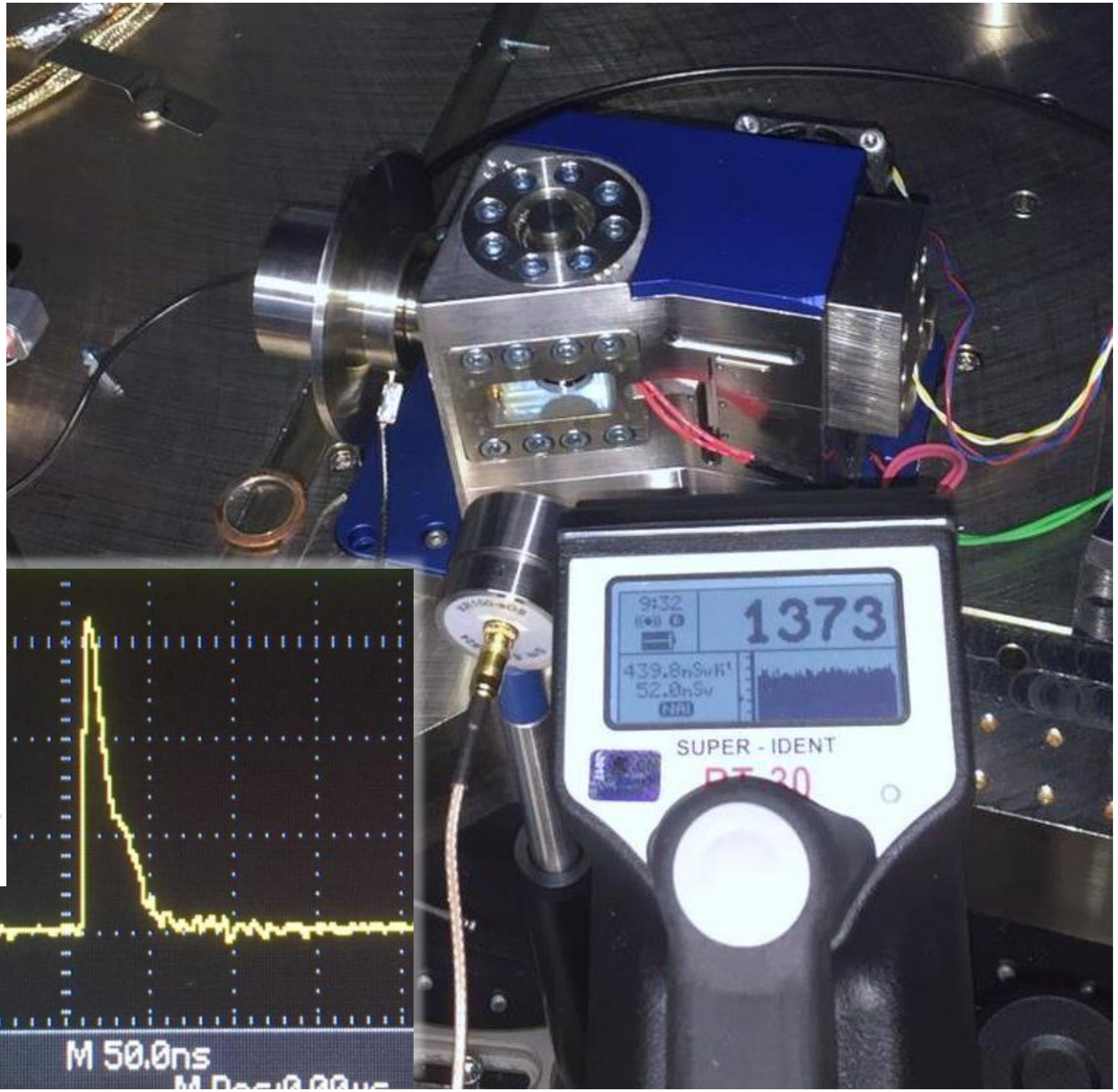
PXS-BL1

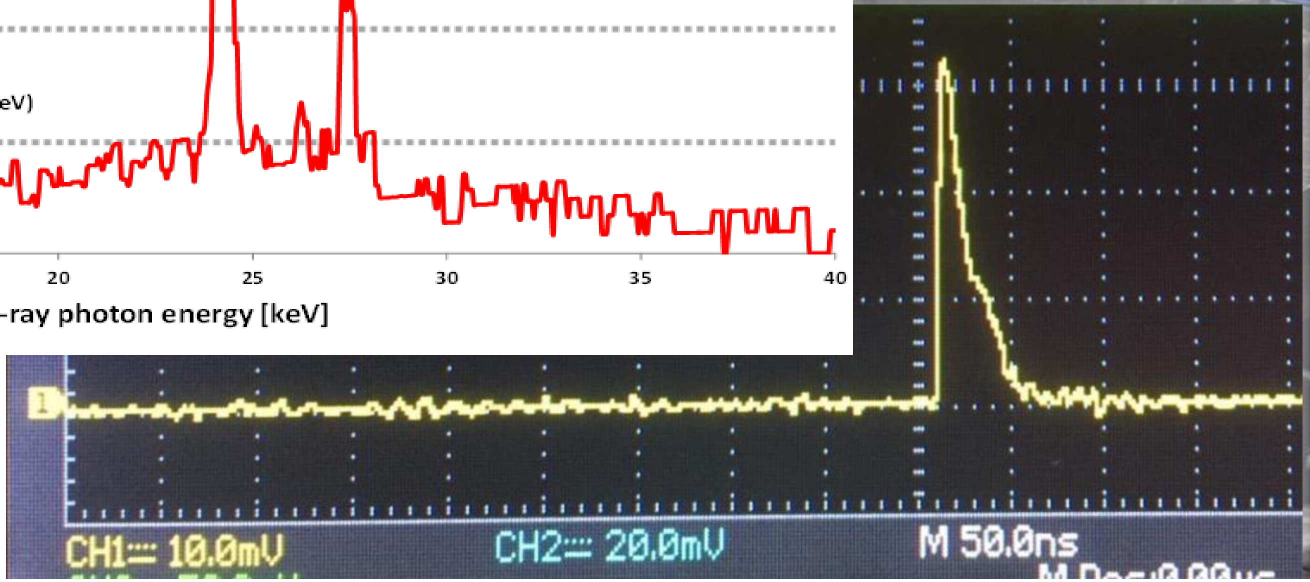
Diffraction

10^6 photons/shot on sample

PXS: first X-rays







5 mJ 40 fs 1 kHz laser:

10^{10} photons/s/sr/1 keV

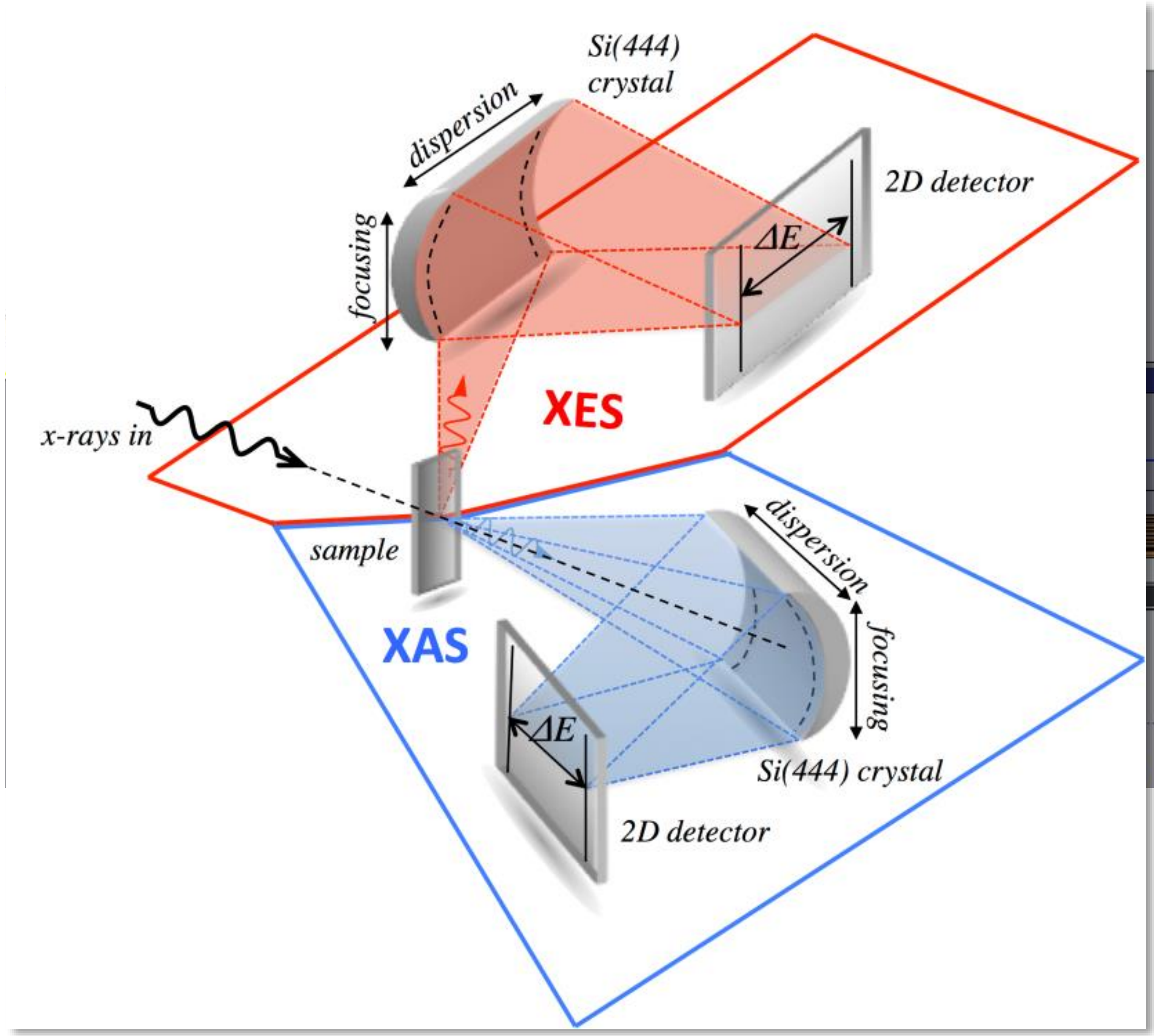
Time REsolved X-ray science (TREX) with PXS

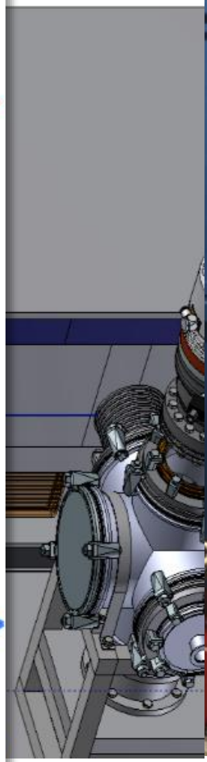
X-ray diffraction and small angle scattering

- Diffractometer
- Cryostream
- Conventional X-ray source and Montel optics
- Main detector: Dectris, Eiger X 1M

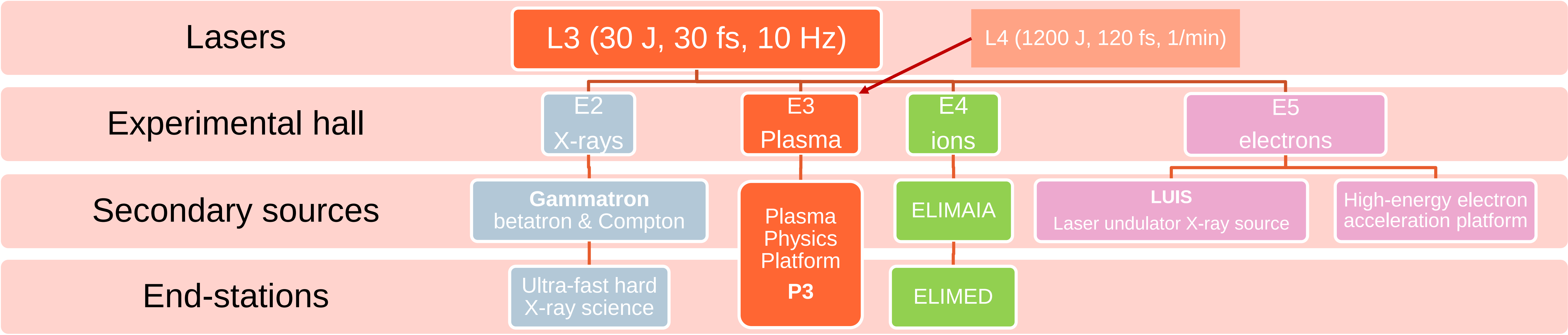
X-ray abs. and em. spectroscopy

- Von Hamos crystal spectrometers
- Conventional Mo X-ray source





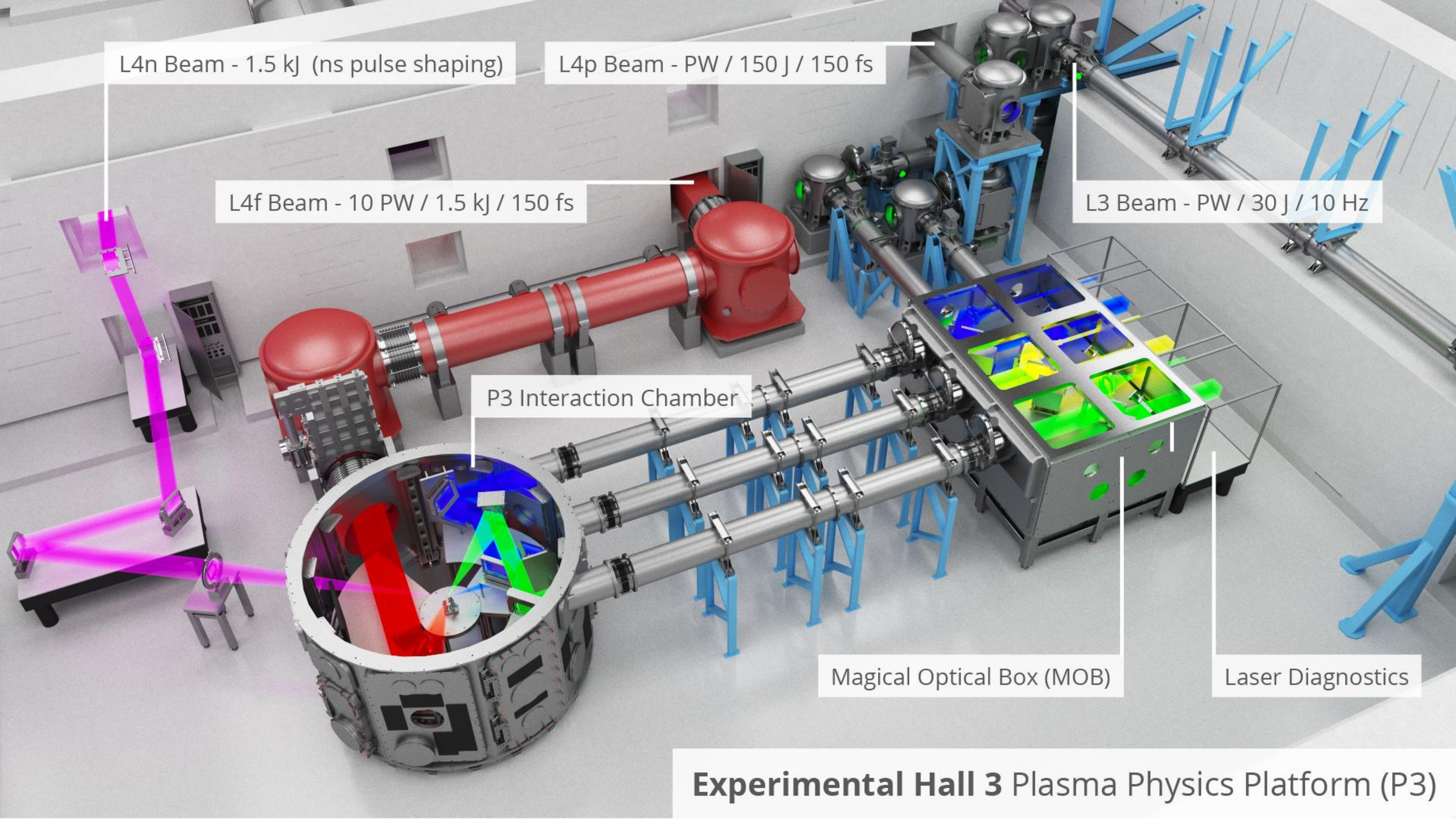
Present and near future facility scheme
high-power (10 Hz/ & 1/min) chain

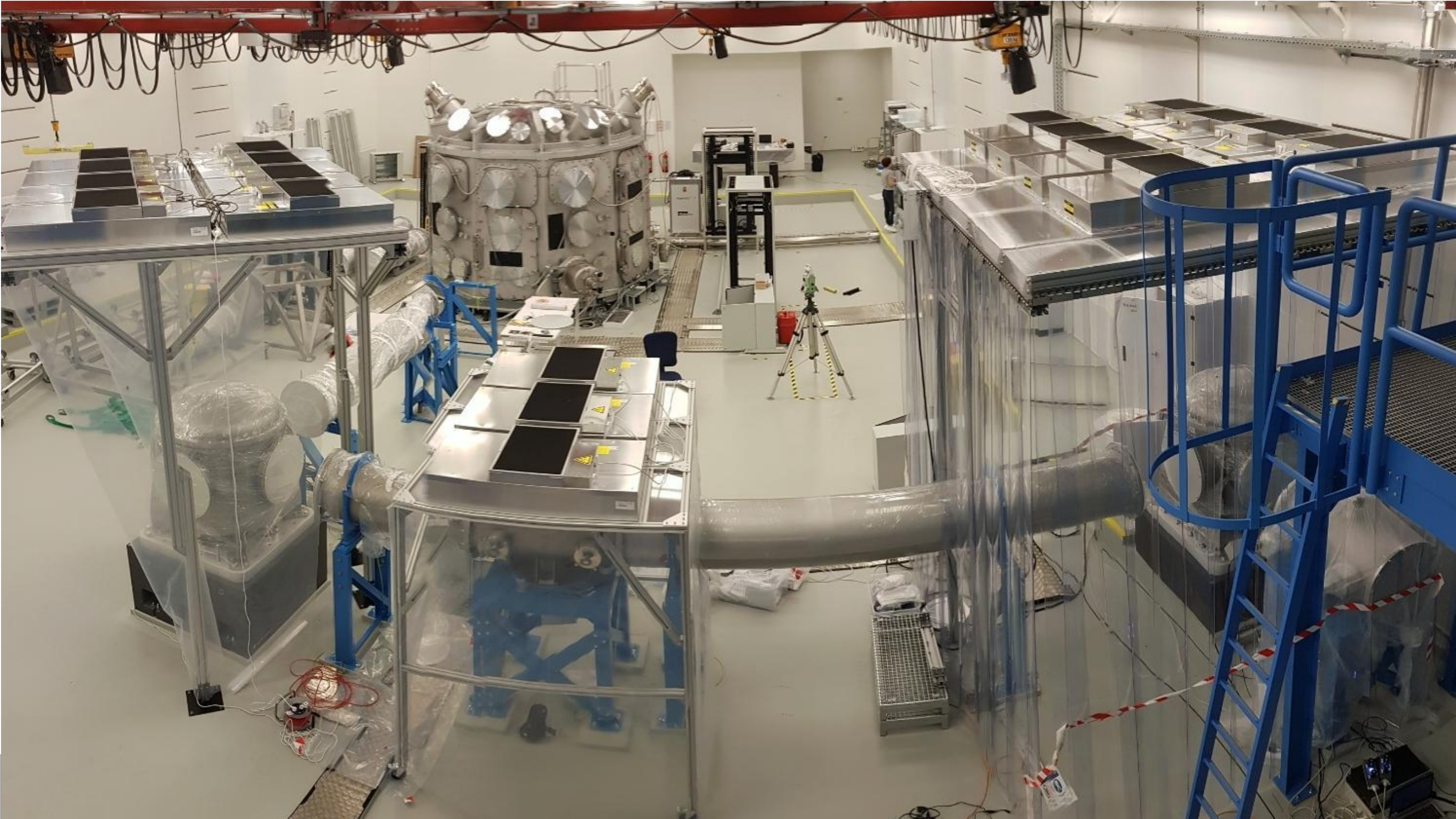


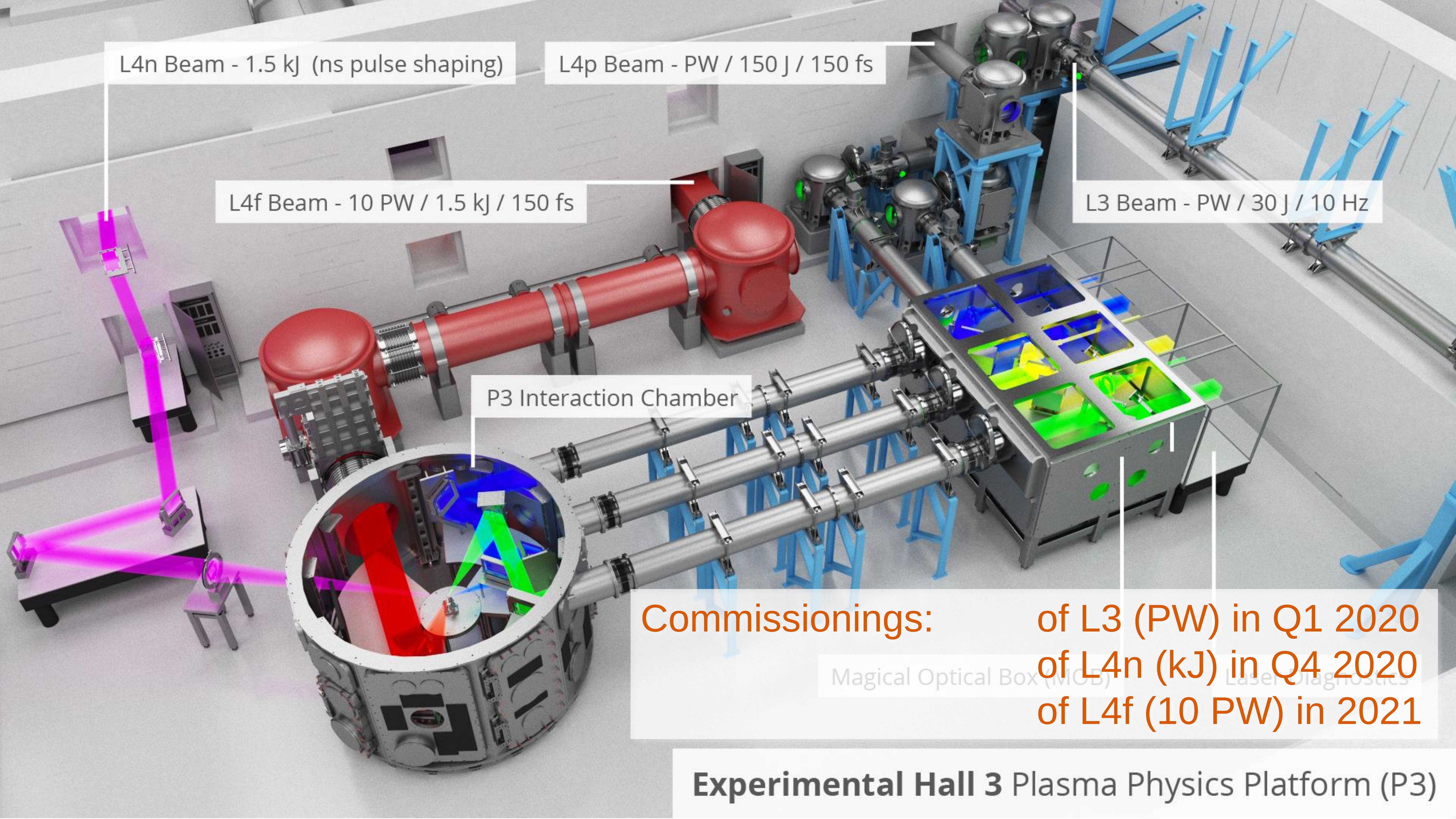
L3: current performance: 10 J, 30 fs, 3.3 Hz, contrast 1:10^{11} @ 20 ps
ramp-up with LLNL assistance 2020-2022

User assisted commissioning: E3/P3 in Q1 2020
E4 in Q2 2020

L4: 10 PW performance 12/2020, experiments (E3) in 2021


L4n Beam - 1.5 kJ (ns pulse shaping)
L4p Beam - PW / 150 J / 150 fs
L4f Beam - 10 PW / 1.5 kJ / 150 fs
L3 Beam - PW / 30 J / 10 Hz
P3 Interaction Chamber
Magical Optical Box (MOB)
Laser Diagnostics
Experimental Hall 3 Plasma Physics Platform (P3)




L4n Beam - 1.5 kJ (ns pulse shaping)
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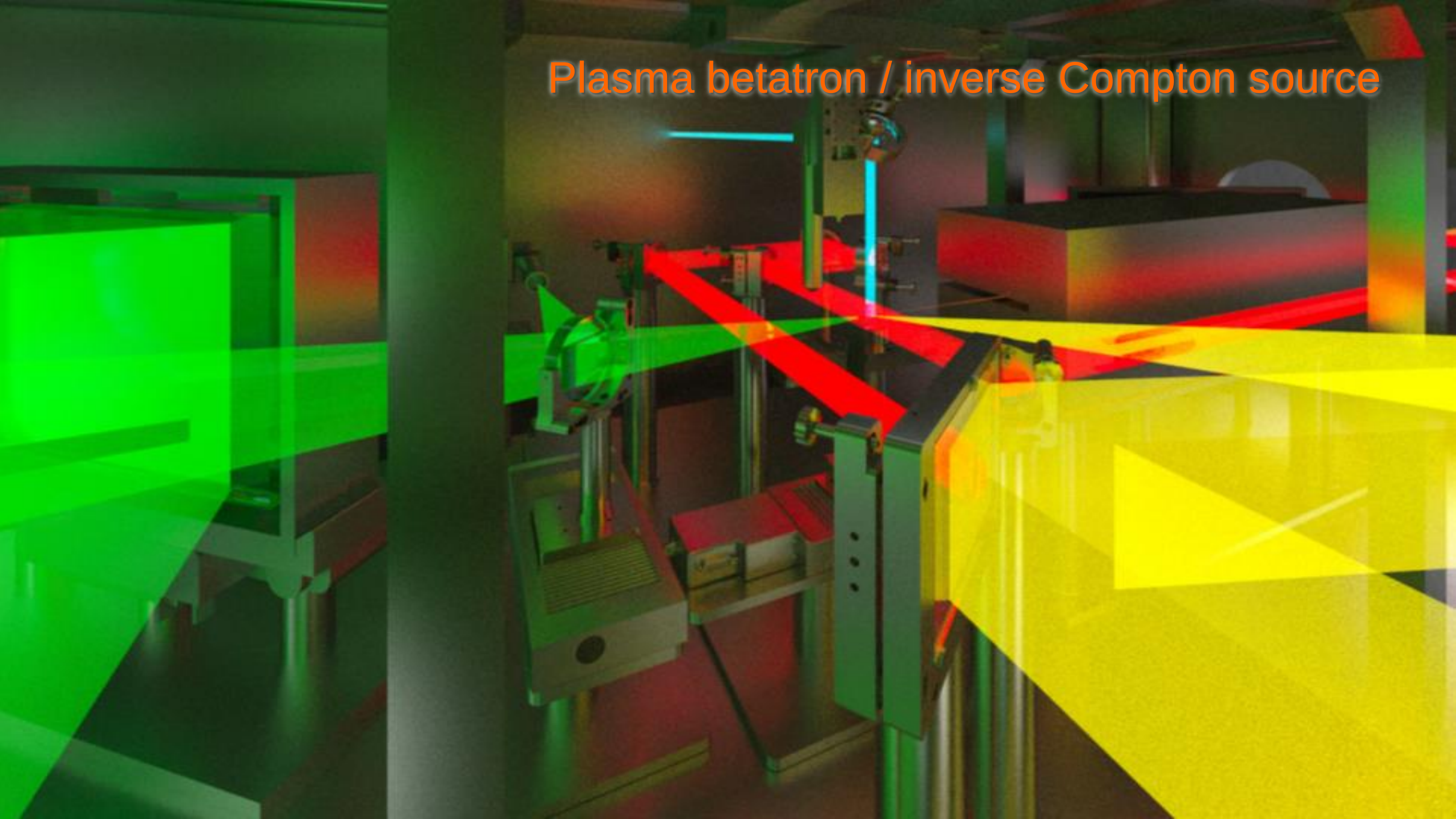
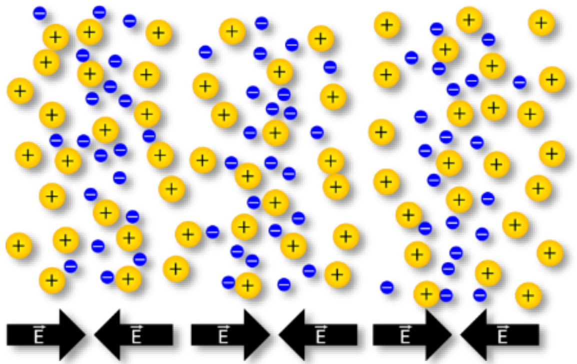
L4f Beam - 10 PW / 1.5 kJ / 150 fs
L3 Beam - PW / 30 J / 10 Hz
P3 Interaction Chamber
Magical Optical Box (MOB)
Commissionings:
of L3 (PW) in Q1 2020
of L4n (kJ) in Q4 2020
of L4f (10 PW) in 2021
Experimental Hall 3 Plasma Physics Platform (P3)


Plasma betatron / inverse Compton source

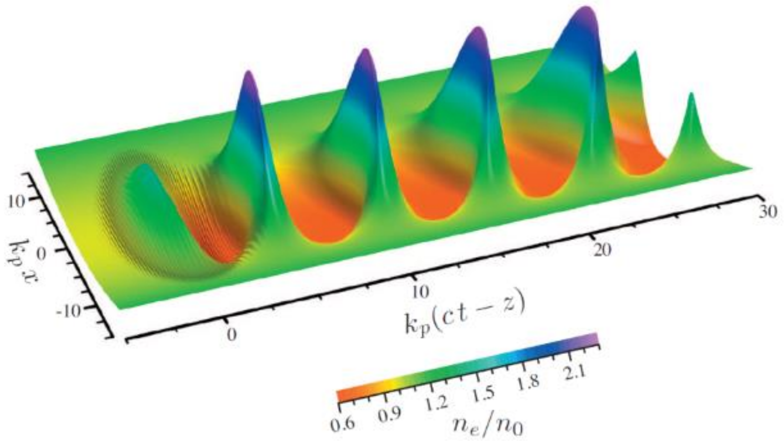
Laser wakefield electron acceleration

- Electron acceleration in laser plasma
    - Plasma wave behind the laser pulse
    - Huge E-filed >100 GV/m possible (conventional RF accelerators <0.1GV/m)

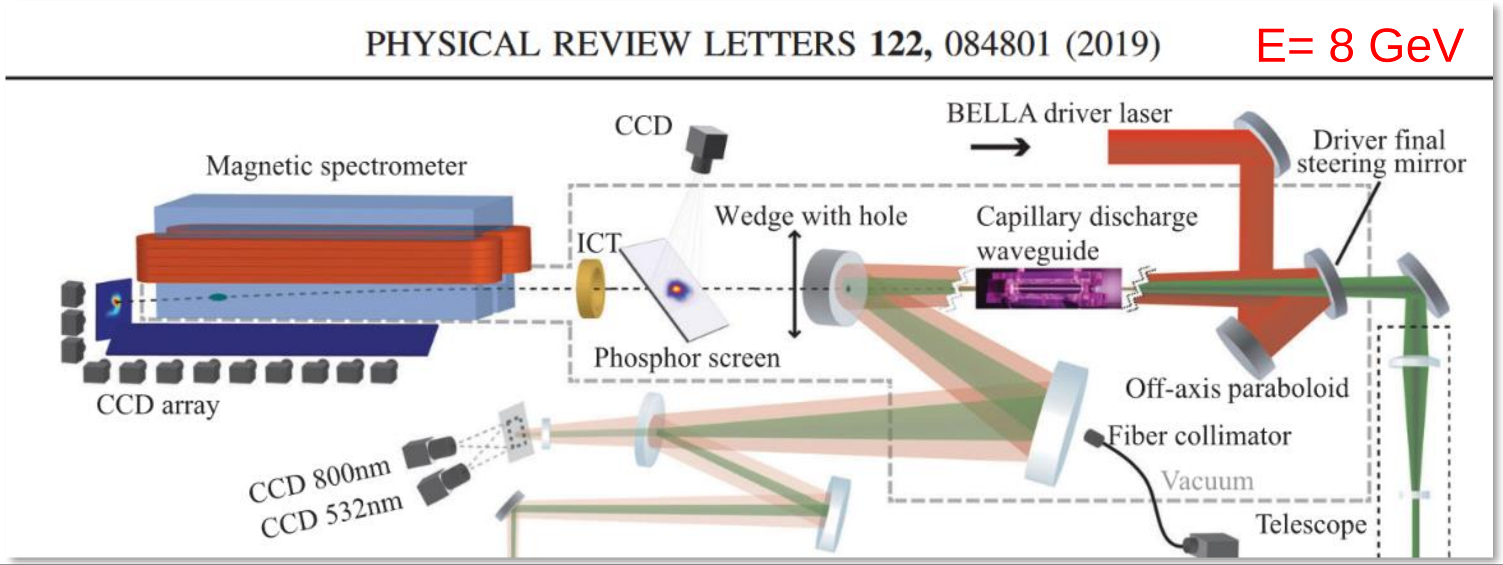


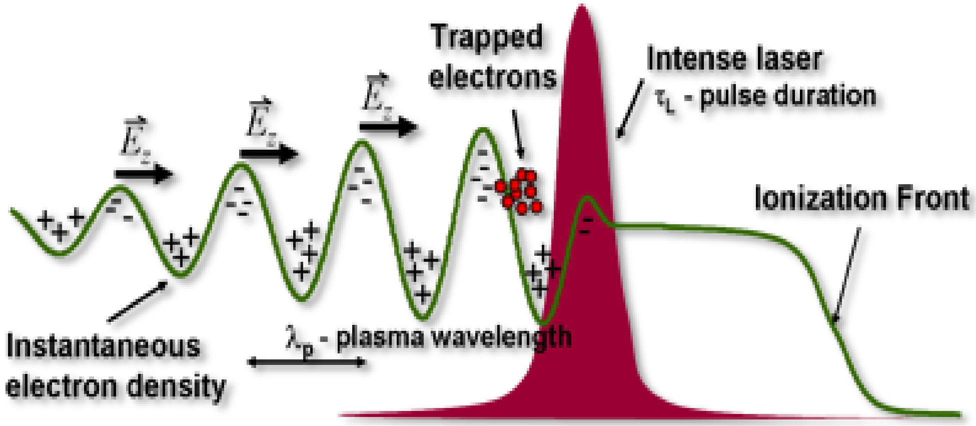
plasma frequency: $$\omega_p^2 = \frac{n_e e^2}{\varepsilon_0 m_e}$$

ponderomotive force: $$F_p = -\frac{e^2}{2\varepsilon_0 c m_e \omega^2} \nabla I$$



E. Esarey *et al.* Rev. Mod. Phys. **81**, p. 1229 (2009)

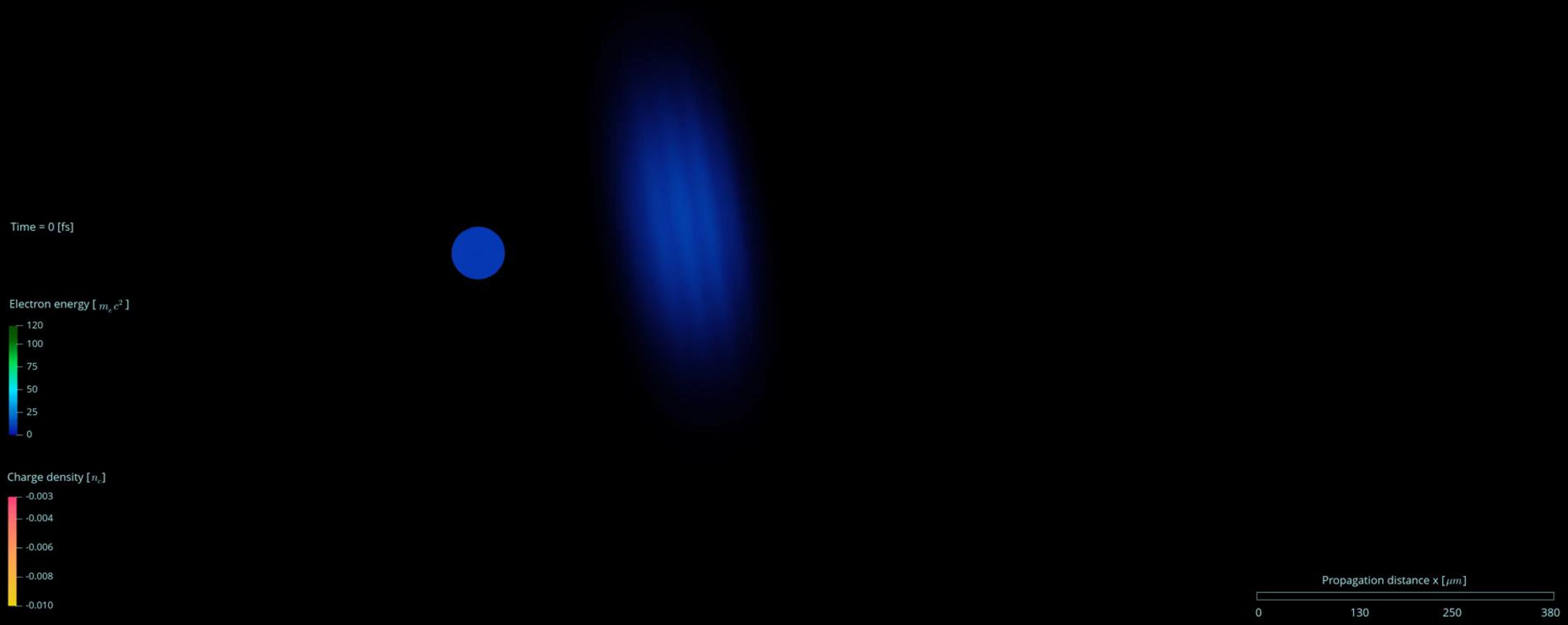




www.engin.umich.edu/research/cuos

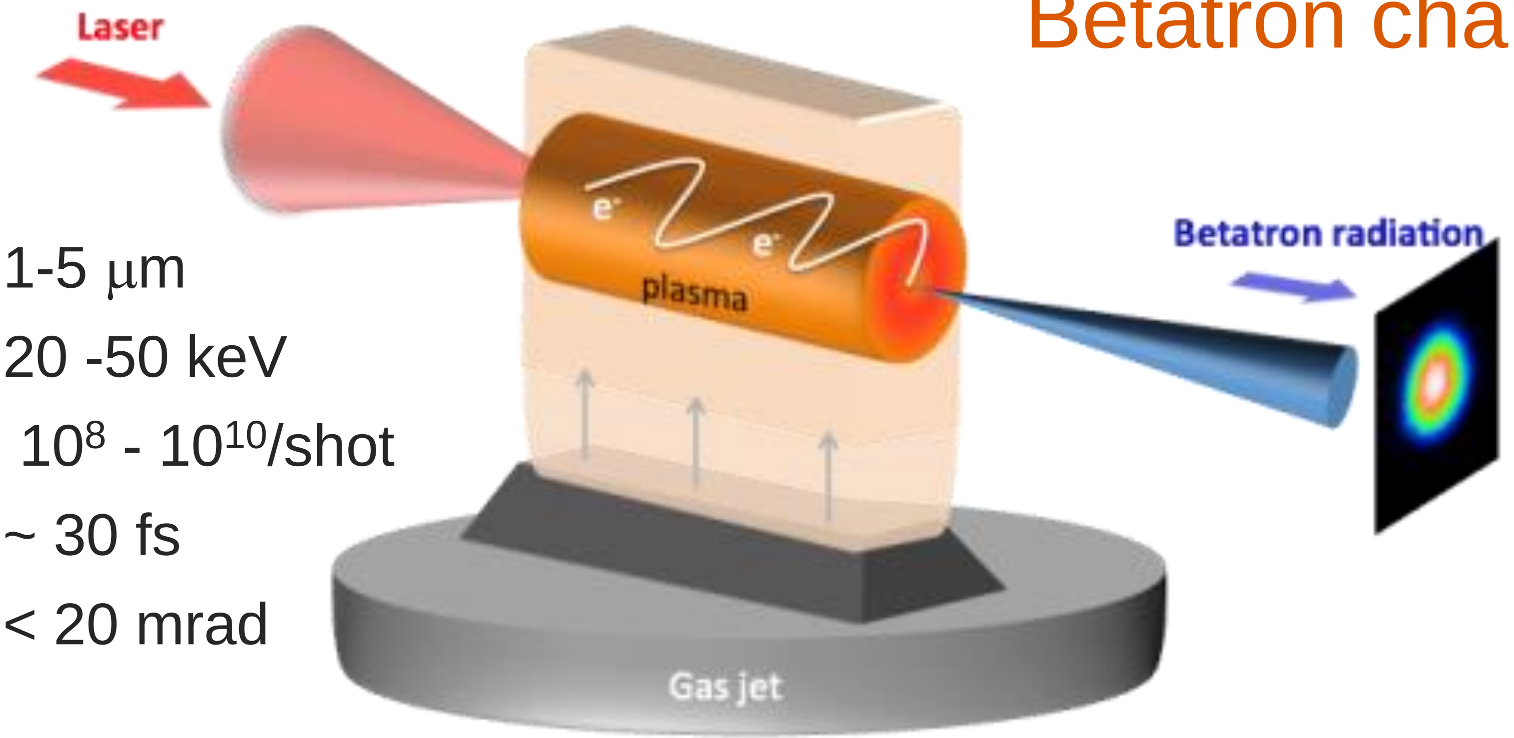
3D PIC simulation

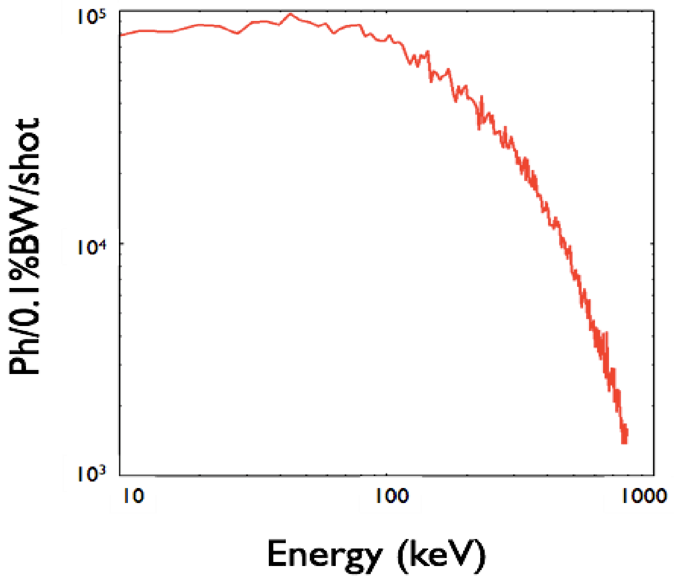
This visualization represents Laser Wakefield acceleration, which is driven by an intense laser that propagates through 400 micrometers of plasma. This is a short laser pulse, which one can imagine as a compact ball of light that excites plasma waves during its travel. Some electrons can be lucky enough to "surf" a plasma wave. Much like the real surfers, it is important for electrons to have some initial velocity to be able to "catch" the wave. Once they start surfing, they can reach very high energies in a short propagation distance.

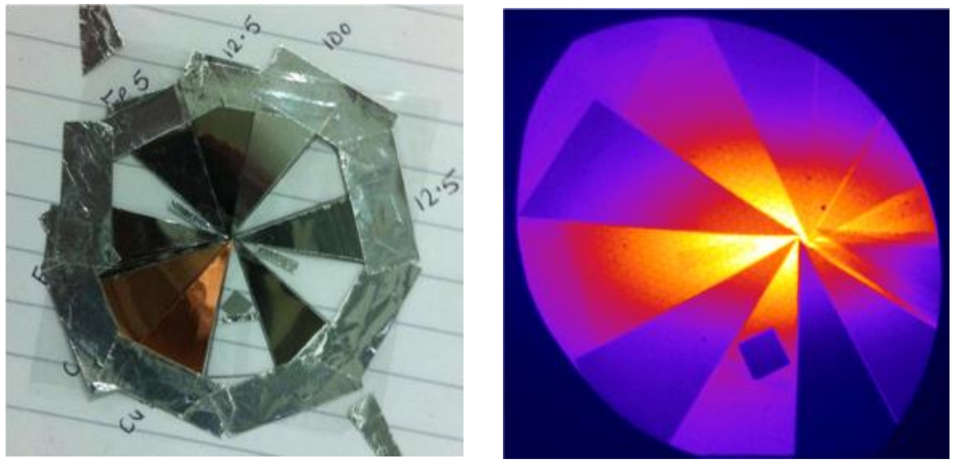


Betatron characteristics

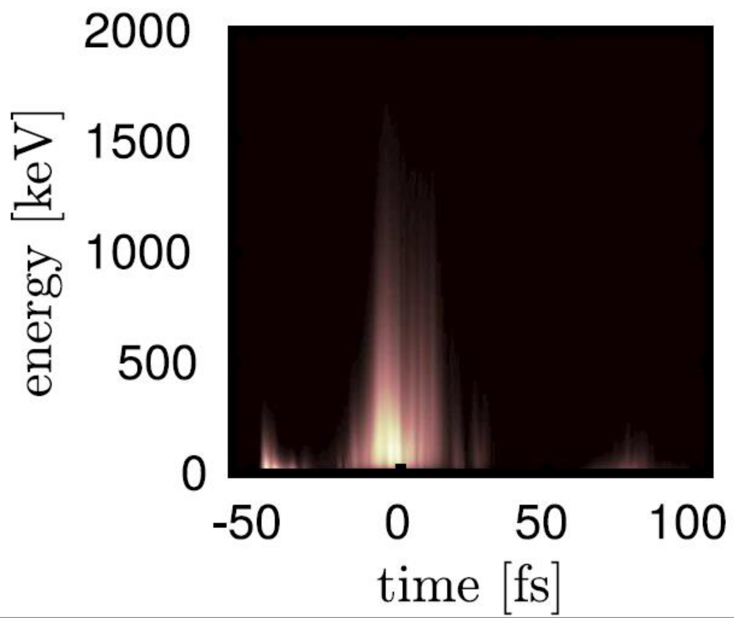
- Source size: 1-5 μm
- Critical Energy: 20 -50 keV
- Number of Photons: 10^8 - 10^{10}/shot
- Pulse duration ~ 30 fs
- Beam divergence < 20 mrad







Spectrometer based on Ross filter pairs



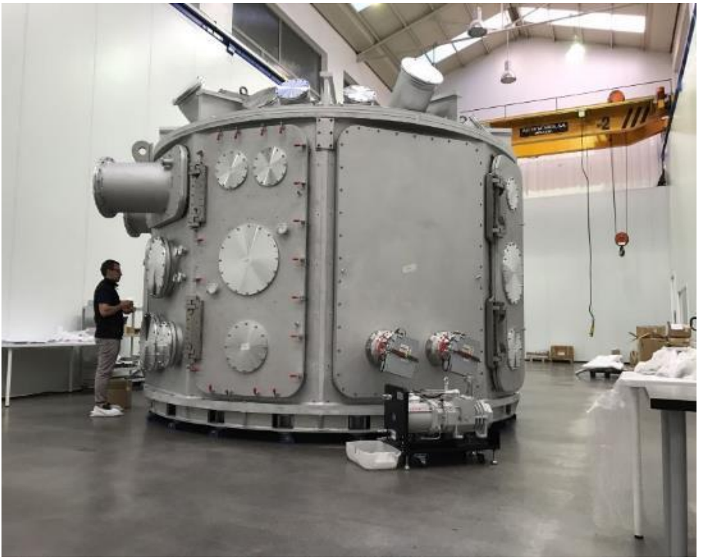
Betatron/ Compton beamline in E2/E3

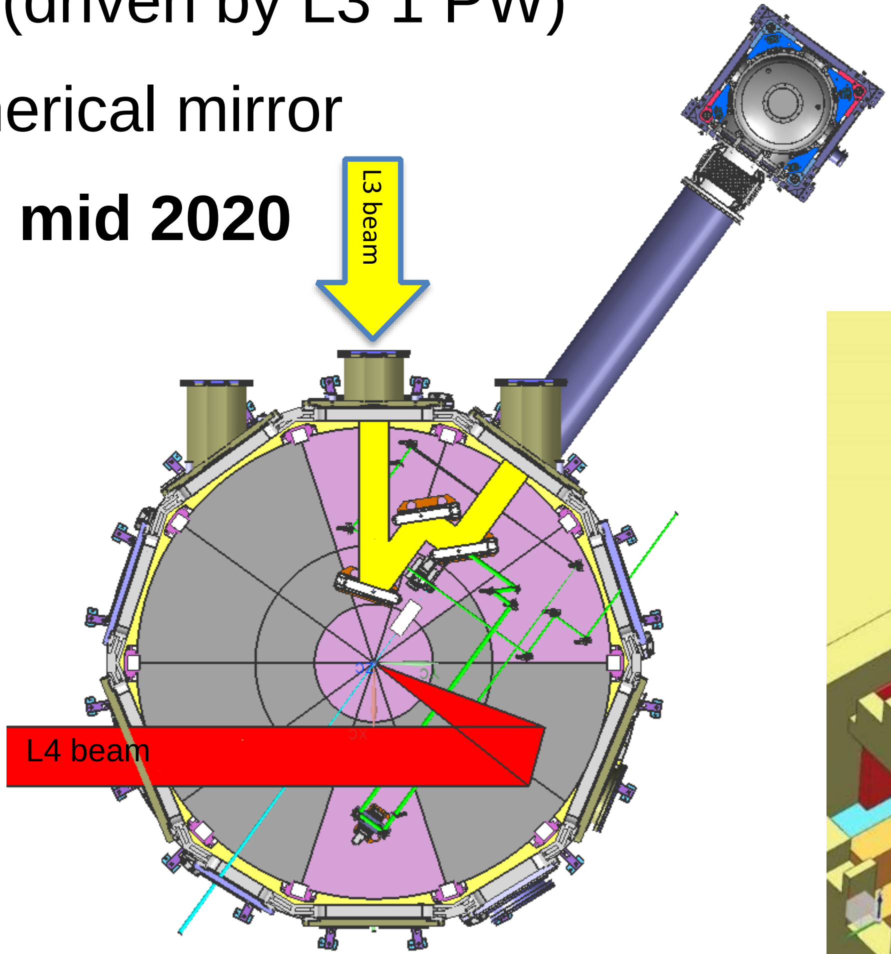
E3: Plasma Physics platform (P3)

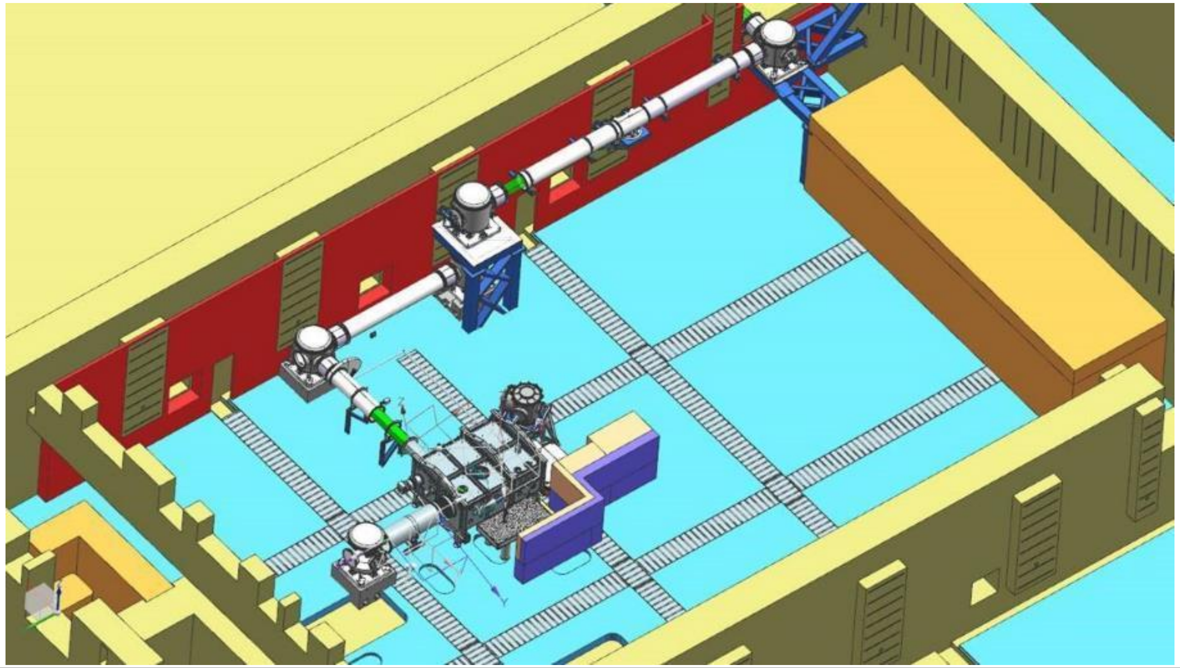
- Betatron/Compton source for plasma and WDM diagnostics (driven by L3 1 PW)
- Focusing by a spherical mirror
- **Operational from mid 2020**

E2: ultrafast X-ray science:

- imaging, Laue diffraction etc.
- Focusing by OAP (f# = 20)
- Designed for high rep. rate (10 Hz)
- Operational from late 2020



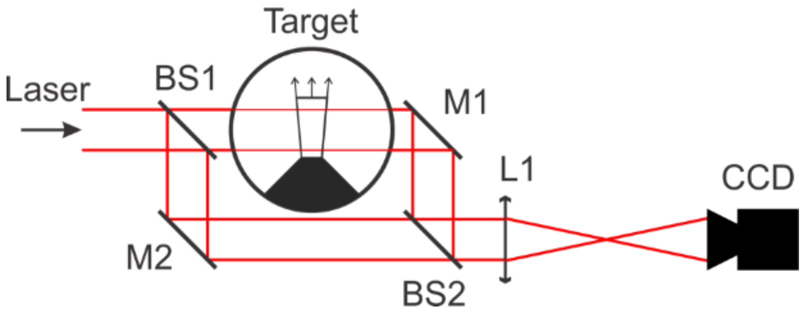


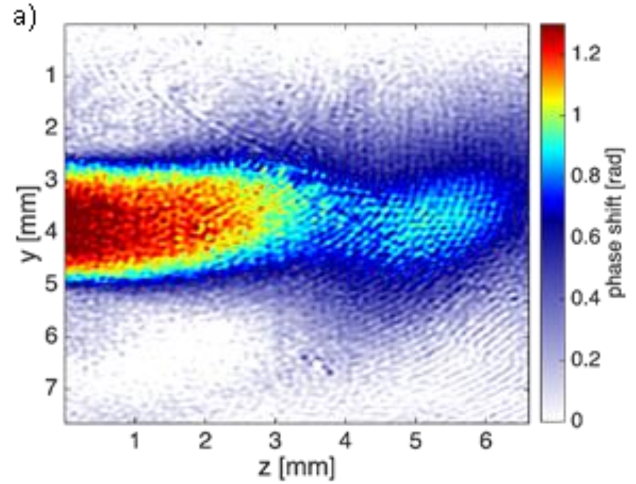


Gas jet characterization (with improved sensitivity)

Traditionally Mach-Zehnder or Nomarski (or WF sensor)

- Single pass
- Imaging on the detector (L1)

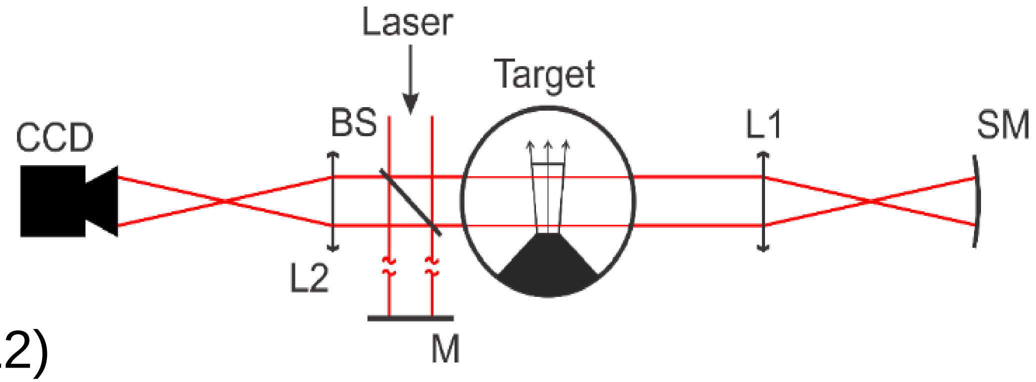


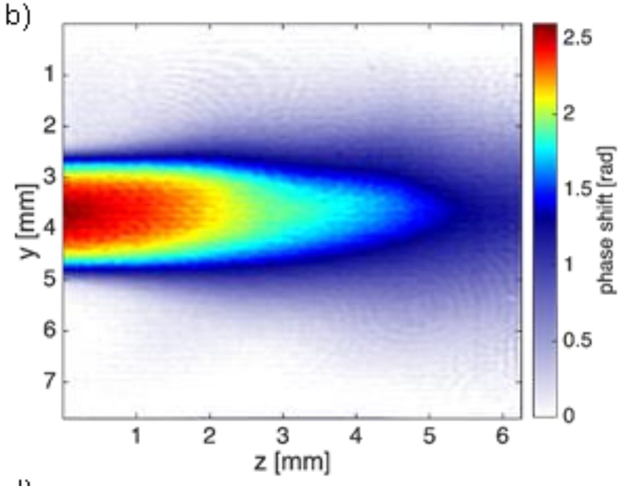


Imaging Michelson interferometer

- Double pass
- **Self-imaging of the jet**

  (L1+SM) and imaging on the detector (L2)

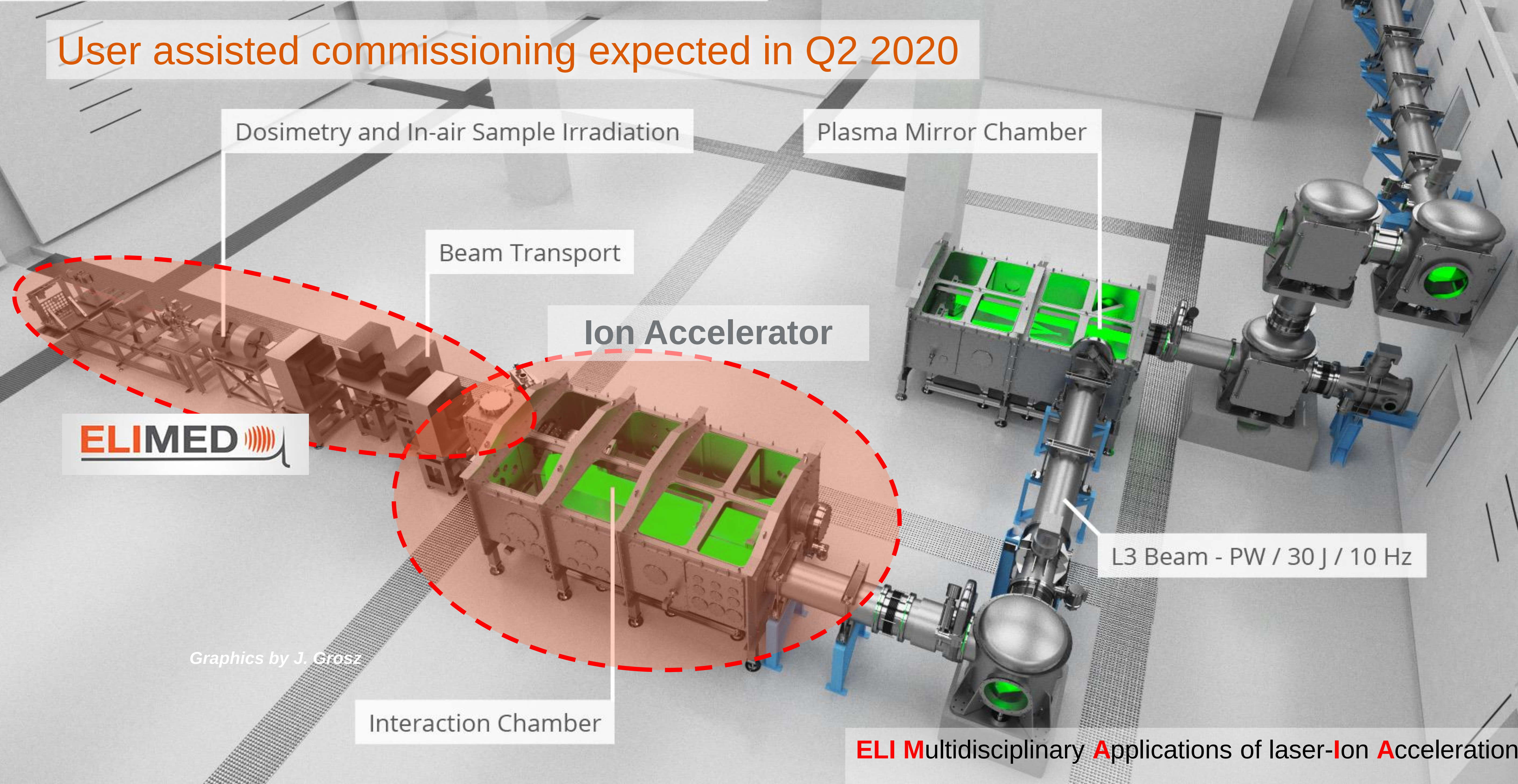




Automated characterization station (with 4 pass configuration) **in development**

Experimental Hall 4 ELIMAIA Ion Acceleration

User assisted commissioning expected in Q2 2020



ELI **M**ultidisciplinary **A**pplications of laser-**I**on **A**cceleration

ELI Beamlines is welcoming users:

www.eli-beams.eu/users

The ELI Beamlines Team

Funding: Project ADONIS No. CZ.02.1.01/0.0/0.0/16_019/0000789 from the ERDF
Project No. LQ1606 the MEYS from the National Programme of Sustainability II
Project No. CZ.1.07/2.3.00/20.0279 co-financed by the ESF and the state budget of Czechia

Thank you for your attention!

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