E1 technologies and applications

ELISS (31.08.2023)

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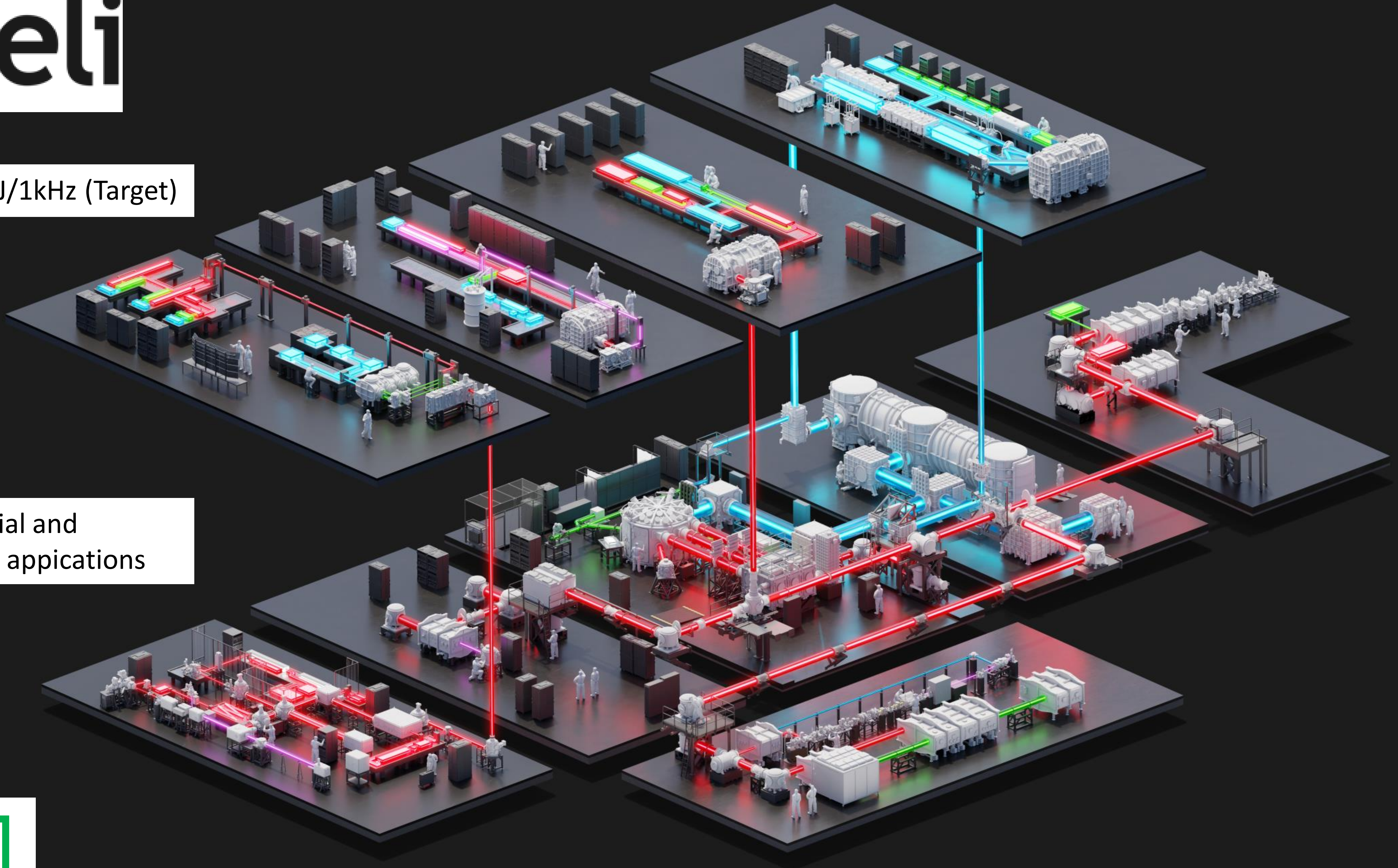
Head of Department for Structural Dynamics
The European Extreme Light Infrastructure ERIC

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

eli

L1: 100 mJ/1kHz (Target)

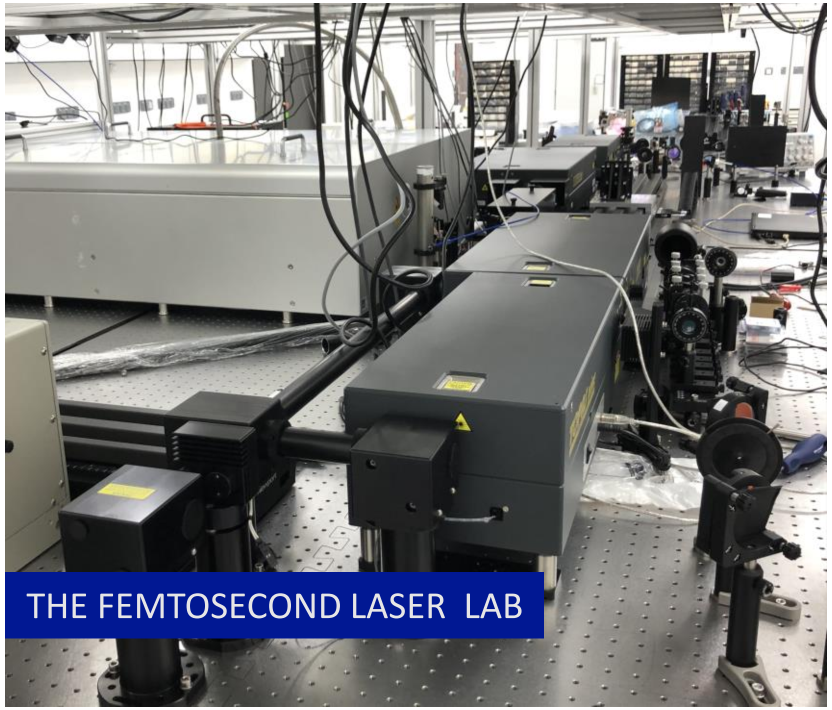
E1: Material and
molecular appications



ELIBIO
Biolab

The **life-science infrastructure** created by **ELIBIO** at ELI Beamlines

GENERAL LABORATORY AREA



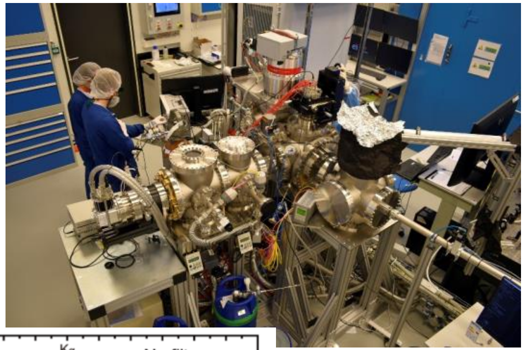
THE FEMTOSECOND LASER LAB

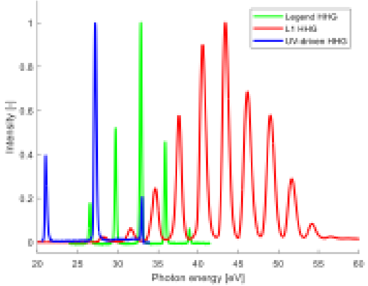
ENVIRONMENTAL SCANNING EM with CRYO COOLING

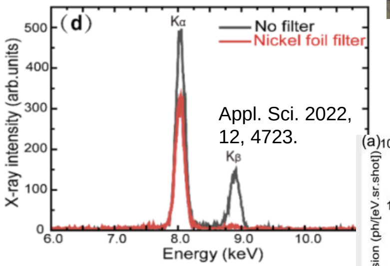
Negligible risk of surface transmission of SARS-CoV-2 in public transportation
Alina Pilipenco, et al.,
Journal of Travel Medicine, taad065, https://doi.org/10.1093/jtm/taad065
Publication date: 2023/5/3

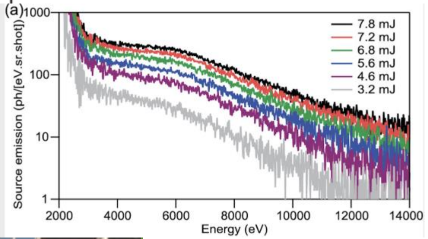
E1, L1 User Science @kHz

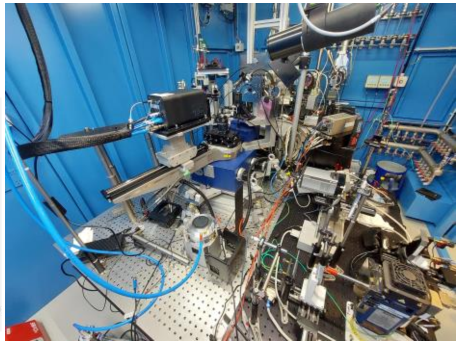
experimental hall and associated labs

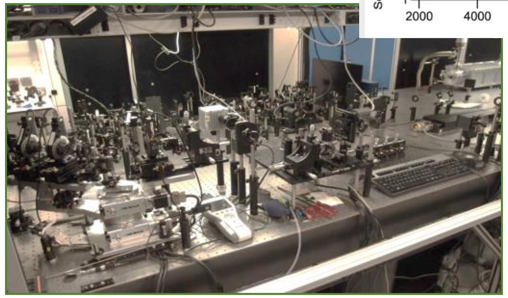


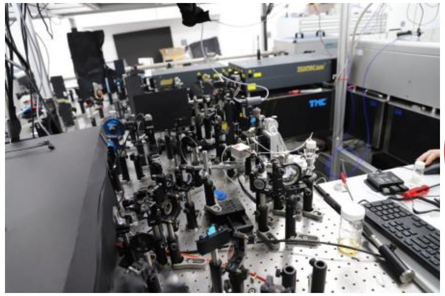






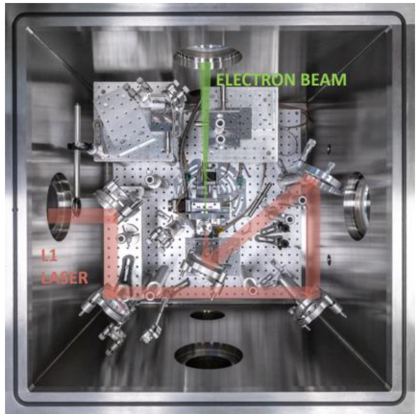






DEPARTMENT OF RADIATION PHYSICS AND ELECTRON ACCELERATION

S. Bulanov, J, Nejdl, G. Gritani, Carlo Lazzarini



Science with Coherent XUV radiation

- AMO science, CDI, XUV material science
- Time of flight spectroscopy, Velocity Map Imaging, XUV spectroscopy
- Pure and doped clusters and droplets, molecular beam, fixed targets
- XUV source development, variety of targets and diagnostics

Hard X-ray science

- X-ray diffraction and scattering, X-ray spectroscopy
- Plasma X-ray source development; Cu tape/liquid targets (water, metal)
- CW X-ray sources for steady state characterization
- Eulerian Cradle diffractometer with fully motorised sample positioning system
- Von Hamos spectrometer geometry; solid, powder, liquid samples

Ultrafast optical spectroscopy (E1 and Biolab)

- Time resolved spectroscopic ellipsometry (E1 optical)
- Transient Current Technique (E1 optical)
- IR spectroscopy
- Femtosecond Stimulated Raman Scattering and Transient Absorption

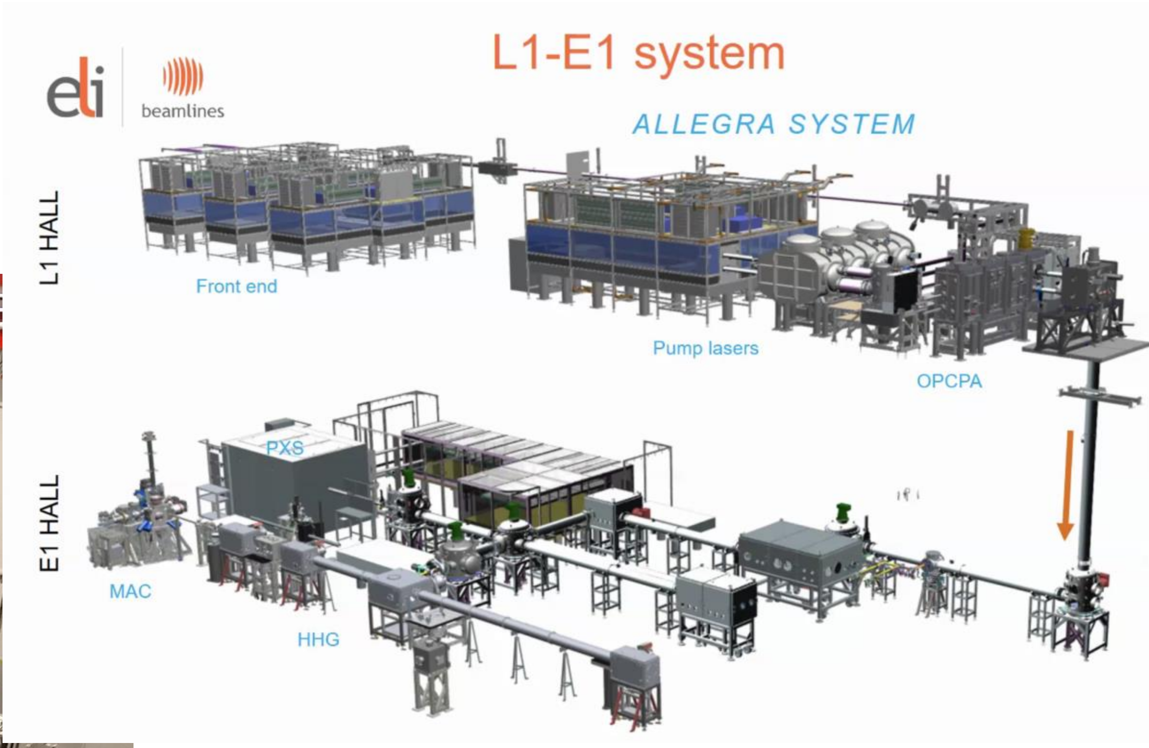
ALFA: kHz electron acceleration

- kHz electron acceleration and X-ray generation

Sample preparations support lab (ELIBIO Biolab)

- Sample preparation, including Bio safety level 2
  - Wet processes, crystallization, cold room
- Supporting spectroscopy methods
- Optical/light microscopy
- Electron microscopy
- Imaging ellipsometry
- …

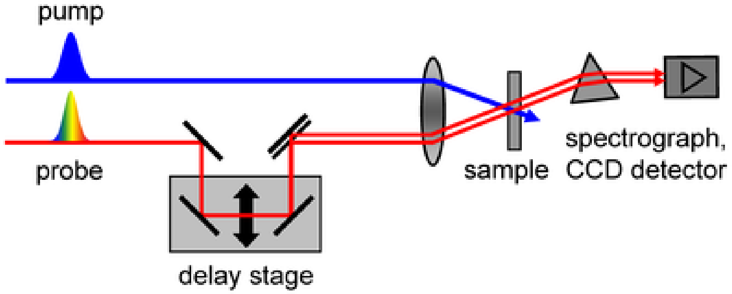
Overview; ELI Beamlins E1 experimental hall and the L1 Allegra kHz laser



***Function* is fundamentally related to dynamics!**

In the E1 experimental hall we have developed beamlines and stations for time-resolved photon science experiments in the mid IR to Hard X-ray range

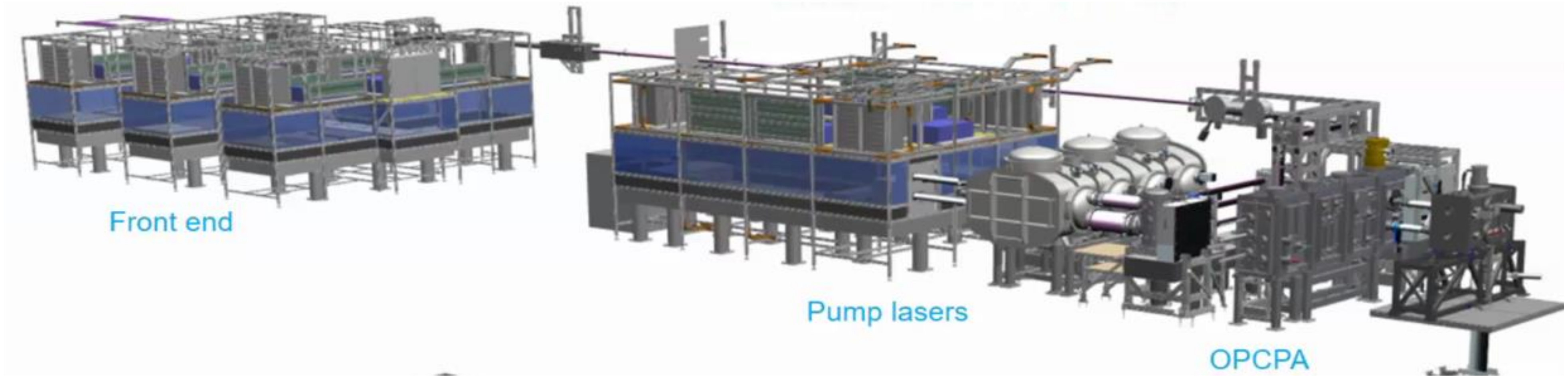
These are used for time resolved experiments using pump-probe techniques to study femtosecond to millisecond dynamics



L1 ALLEGRA System

- The L1 Allegra laser amplifies picosecond pulses in broadband OPCPA and compression to <20 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)**

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



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

To E1

**The higher pulse energies can be provided but at the potential risk of reduced reliability in delivery. Contact ELI staff for discussion.*

Optional drive laser for XUV and X-ray experiments (TiSap)

Coherent Legend Duo Elite		
Energy	Compressed pulse @target	Repetition rate
12 mJ	<35 fs	1 kHz

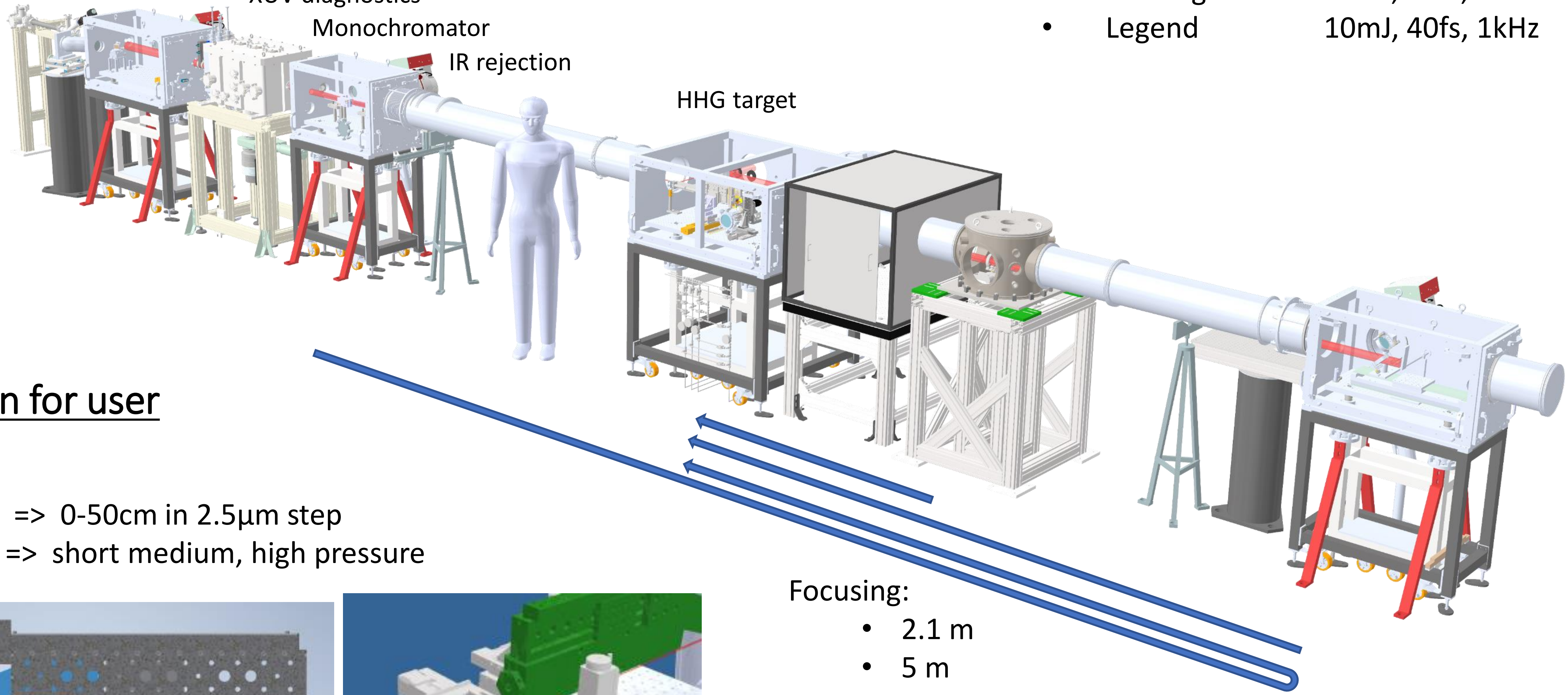
Drive lasers for optical spectroscopy

FSRS, TA and time-resolved ellipsometry, IR spectroscopy, Transient Current

Delays between Femtopower/Solstice doublet lasers controlled 0 fs to 1 ms

Laser	Energy	Compressed pulse @target	Repetition rate
Coherent Astrella	7 mJ	<40 fs	1 kHz
Spectra Physics Doublet /Femtopower	4.5 mj	30 fs	1 kHz
Spectra Physics Doublet/ Solstice	7 mj	40 fs	1 kHz

XUV science; E1 User oriented HHG beamline



Available lasers

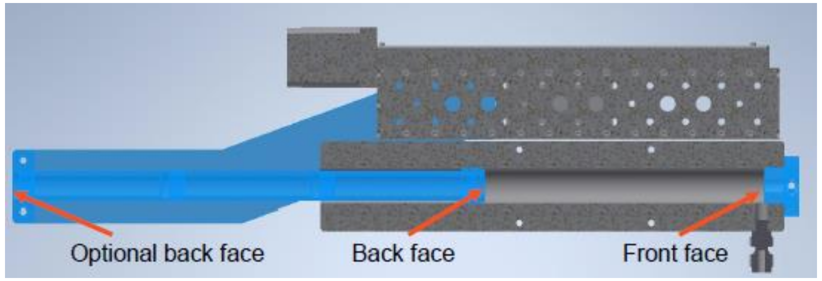
- L1 Allegra 45mJ, 14fs, 1kHz
- Legend 10mJ, 40fs, 1kHz

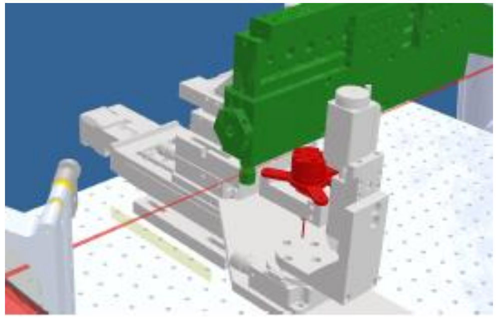
Versatile solution for user needs

- **Motorized gas cell** => 0-50cm in 2.5µm step
- **Even-Lavie valve** => short medium, high pressure

Focusing:

- 2.1 m
- 5 m
- 14.5 m





O Hort, et al. Optics express 27 (6), 8871-8883 (2020)

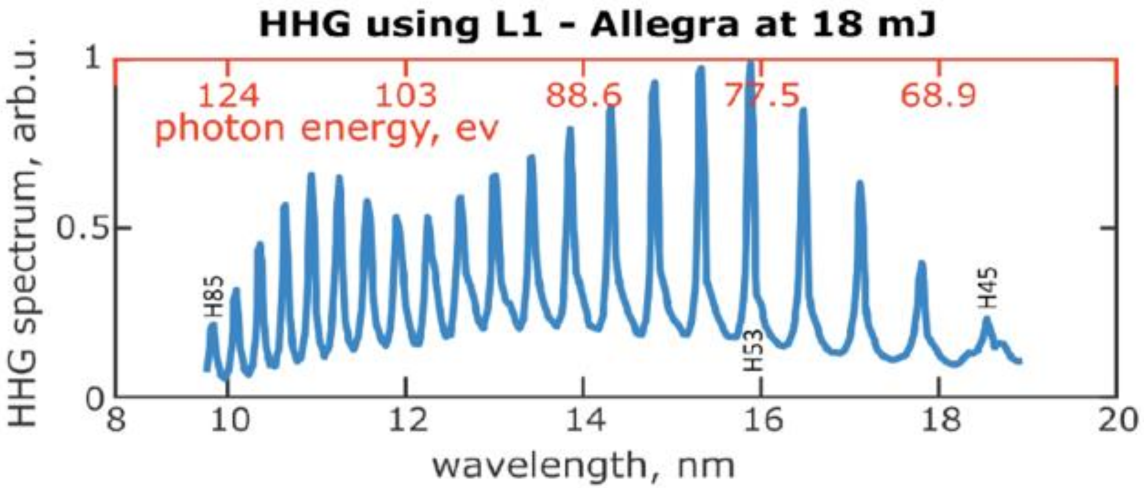
XUV science, High-order Harmonic Generation (HHG) Beamline

Presently the source is set to a 5 m focal length

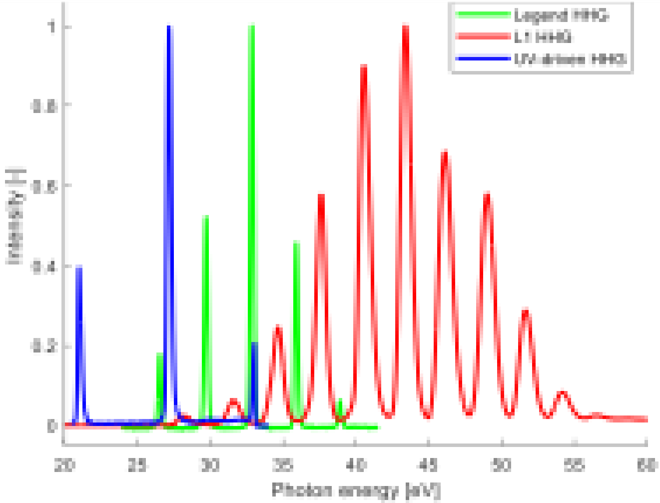
Conversion efficiency up to 5 x 10^{-6} for argon

Diagnostics including a Flat field XUV spectrometer, a calibrated XUV diode, and a wavefront sensor

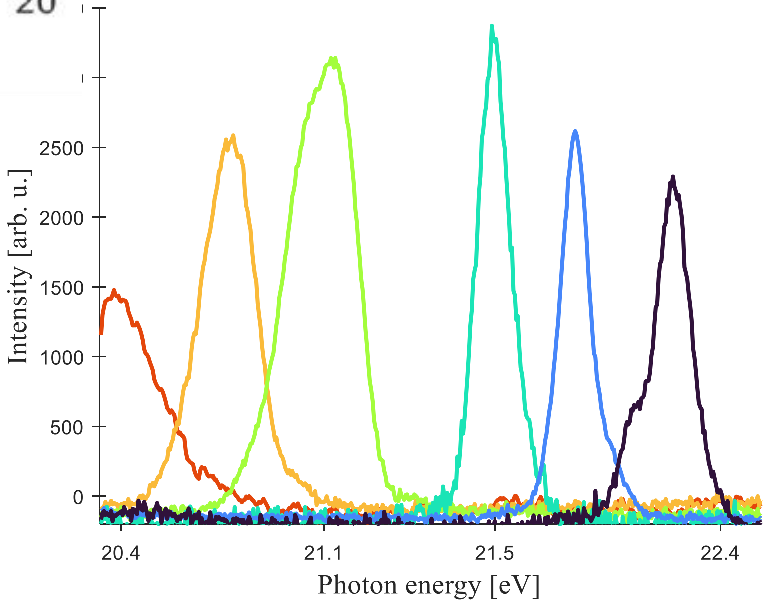
HHG source in short focal length configurations



Examples of HHG under different conditions

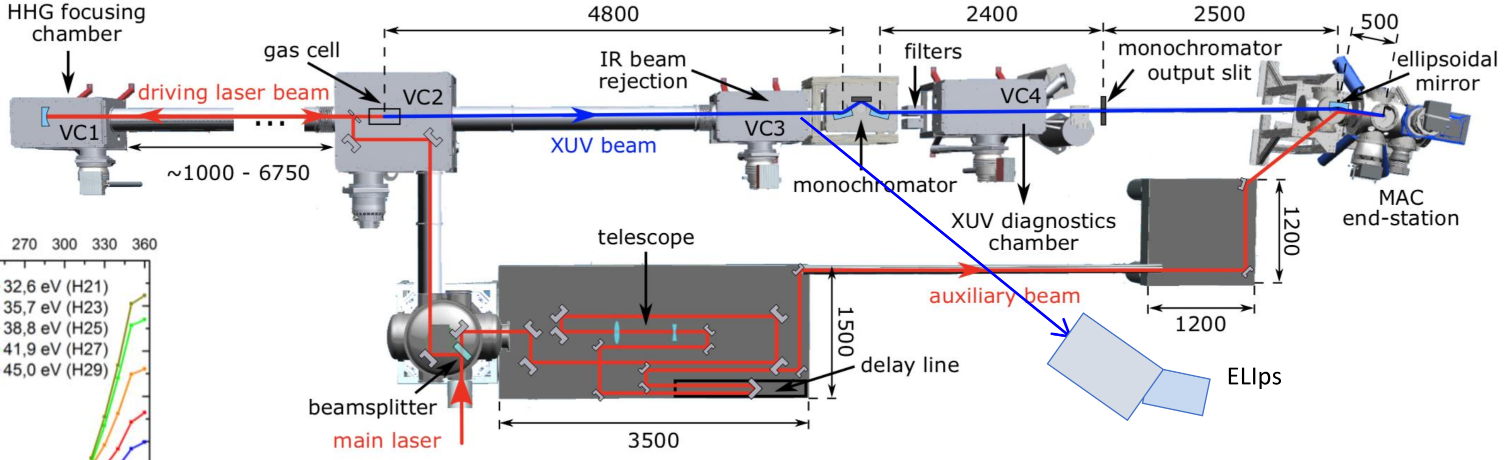


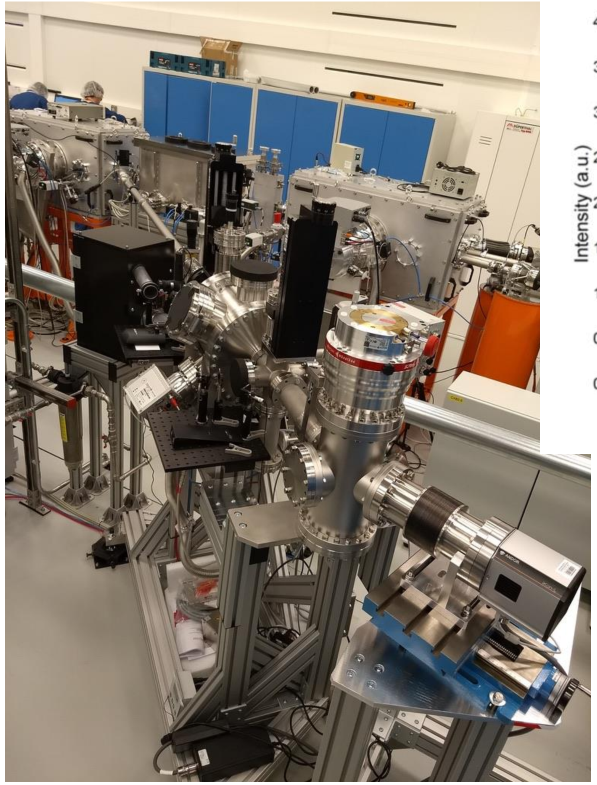
Tubnable XUV pulses

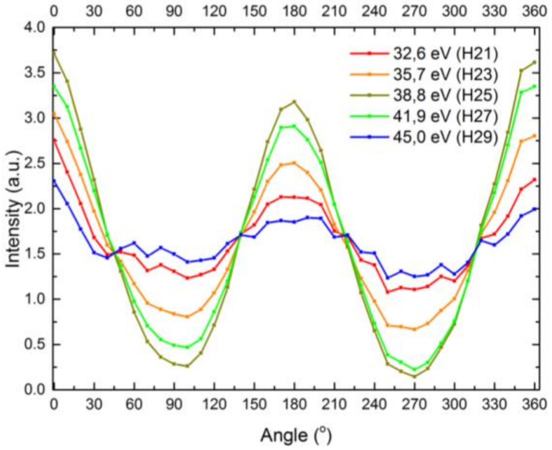


XUV science: HHG source and XUV end stations

ELIps: Vacuum ellipsometry/polarimetry in VUV material science

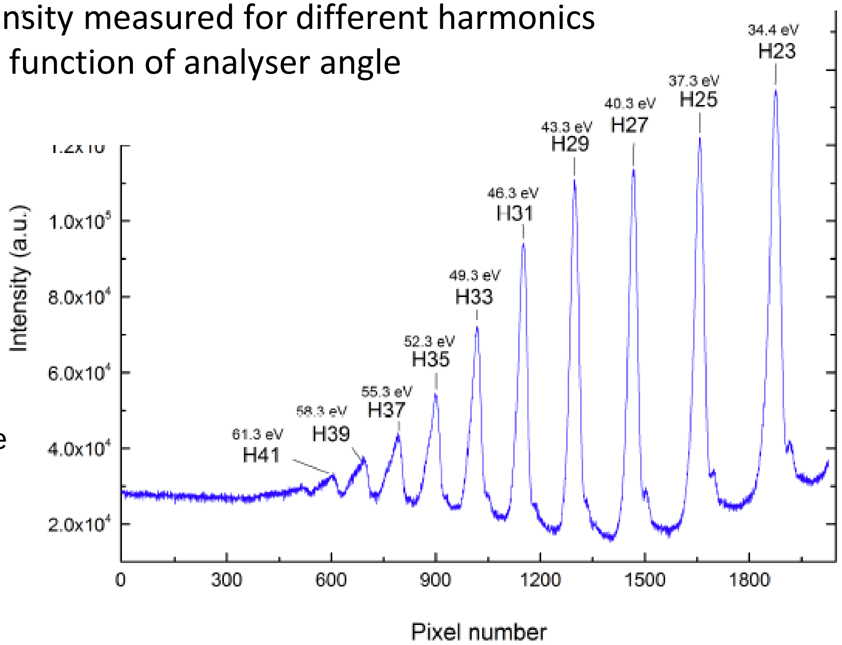


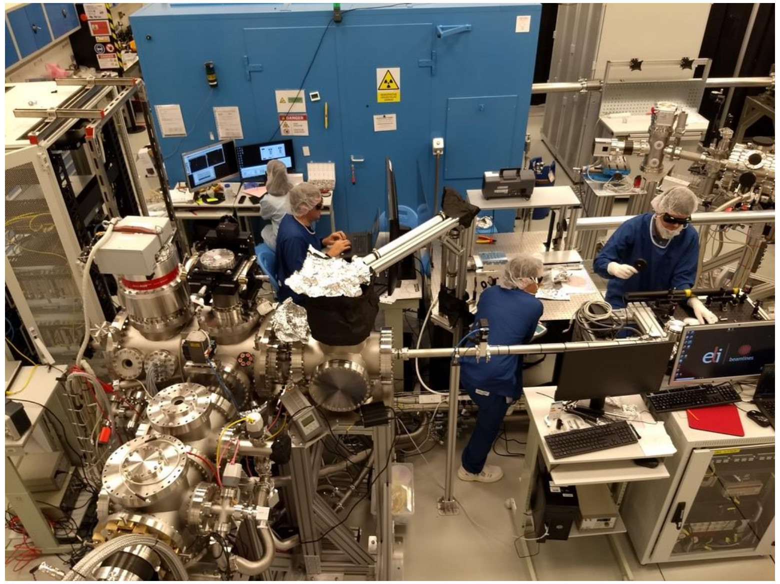




MAC: Multipurpose stations for Atomic, Molecular and Optical (AMO) science and Coherent Diffractive Imaging (CDI)

Intensity measured for different harmonics as a function of analyser angle





Espinoza S., F. Samparisi, F. Frassetto, et al. Characterization of the high harmonics source for the VUV ellipsometer at ELI Beamlines.
J. Vac. Sci. Technol. B **38, 024005 (2020).**

MAC; station for XUV AMO Science

AMO - Atomic, Molecular and Optical

AMO science, mainly gas phase targets

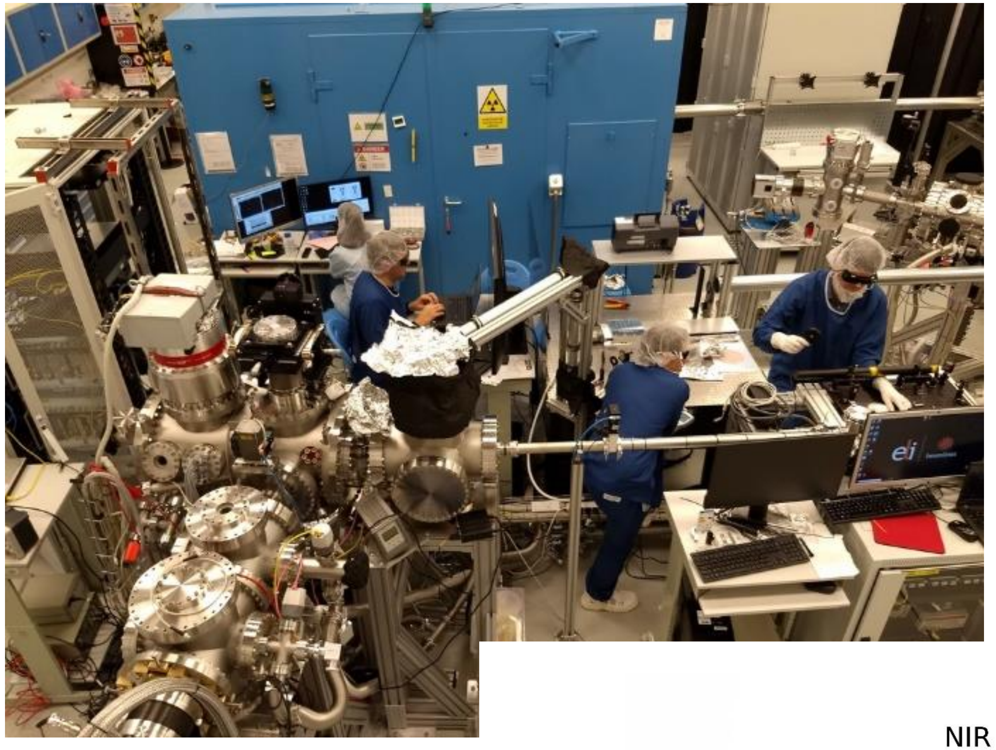
Optical/XUV pump probe experiments using either XUV monochromator or refocusing multilayer optics

Gas phase and fixed targets:

Molecular beam, clusters, aerosols, 5 degrees of motion fixed target stage

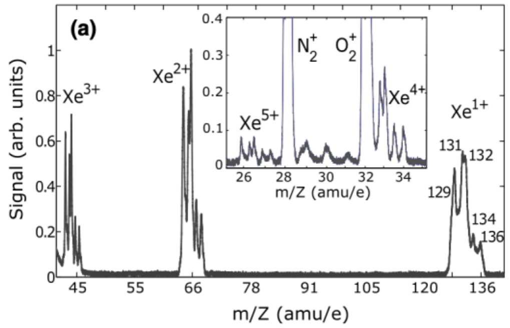
Detectors:

- Ion and electron Time of Flight spectromters
- Velocity Map Imaging (VMI),CMOS and event-driven Tpx3Cam detector (Amsterdam Scientific Instruments) in commissioning
- XUV imaging detector

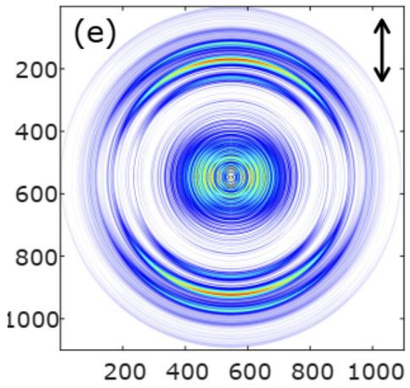


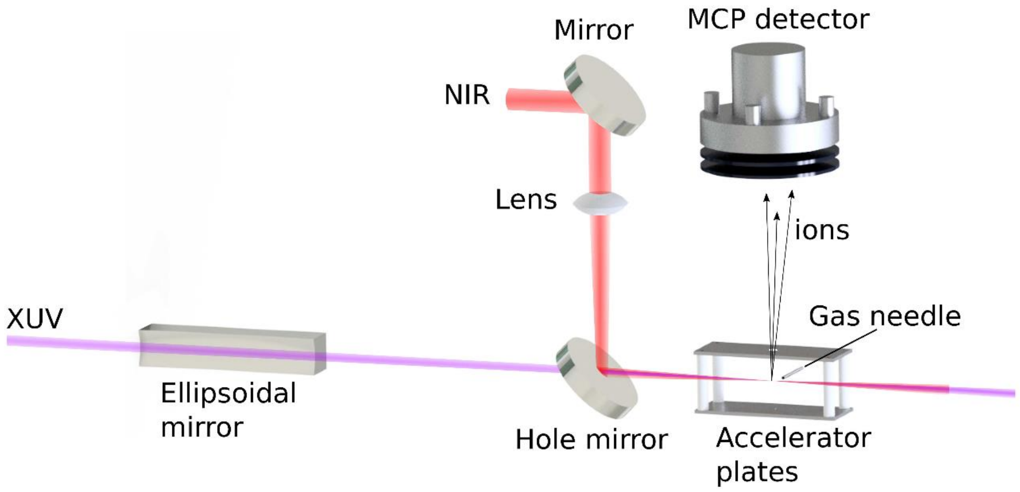
E Klimešová, et al., The European Physical Journal Special Topics, 1-12 (2021)

Time of flight

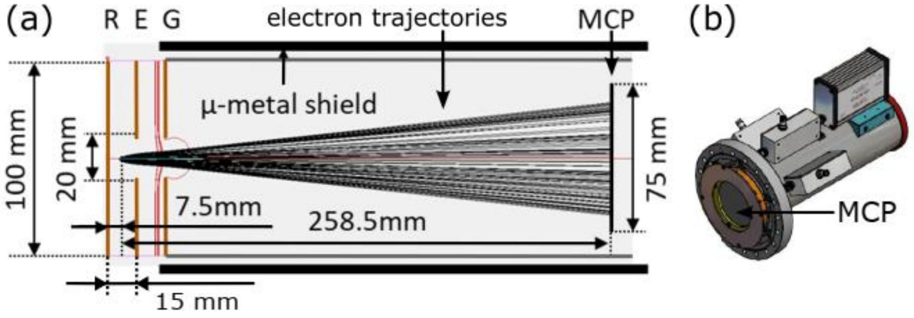


VMI



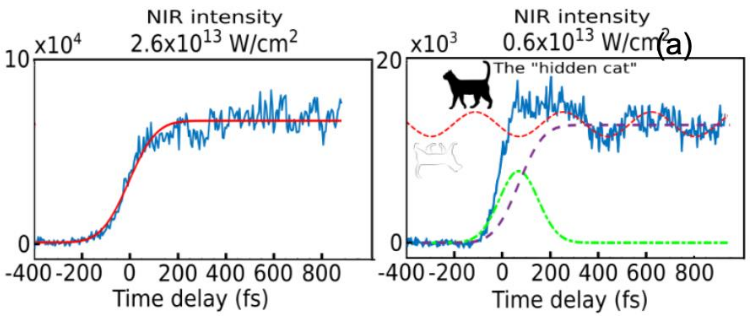


Gas phase time of flight experiment



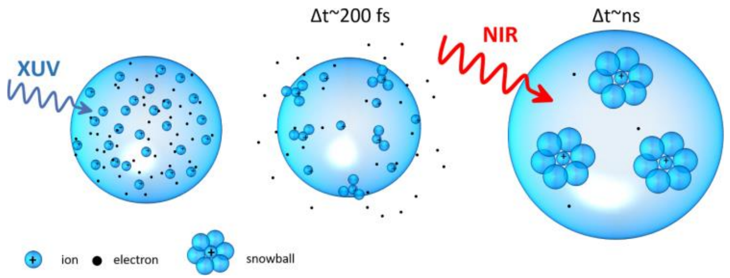
HHG/MAC beamline, recent highlights / publications

Electron correlation dynamics in atomic Kr excited by XUV pulses and controlled by NIR laser pulses of variable intensity
Andreas H. Roos, et al., New J. Phys. 25 013038 (2023)



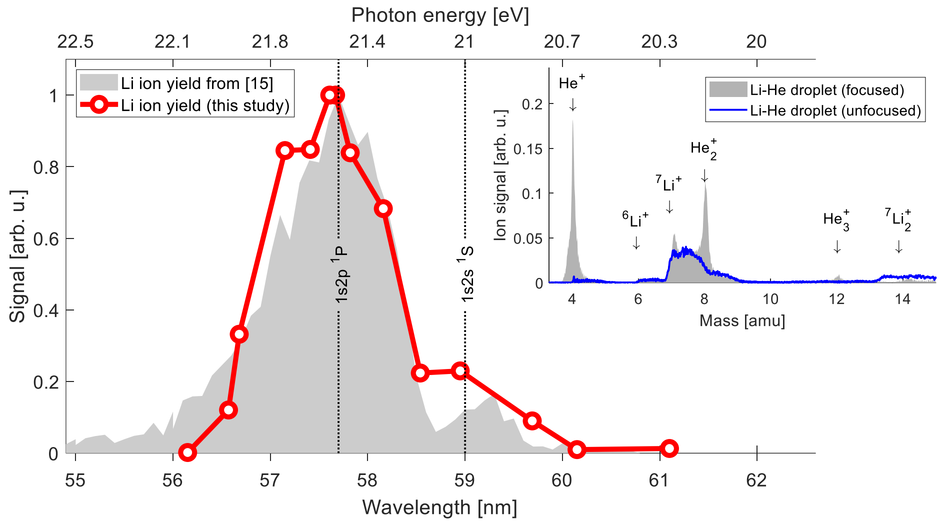
Probing quantum oscillations of an excited electron wavepacket in a superposition of excited states by tuning the NIR intensity.

Long-lasting XUV activation of helium nanodroplets for avalanche ionization
C. Medina, et al., NJP 25 (5), 053030 (2023)

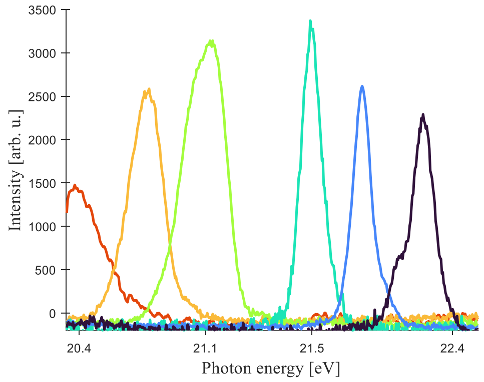


With nanodroplets first irradiated by a weak EUV pulse, nanoplasma ignition by the infrared pulse becomes much more efficient. An effect lasting up to many nanoseconds.

Bright continuously-tunable VUV source for ultrafast spectroscopy
L. Jurkovičova, et al., arXive http://arxiv.org/abs/2301.10508, under review (2023)



Li+ ion yield (red) from Li-doped He nanodroplets excited by a spectrally tuned 7th order harmonic radiation



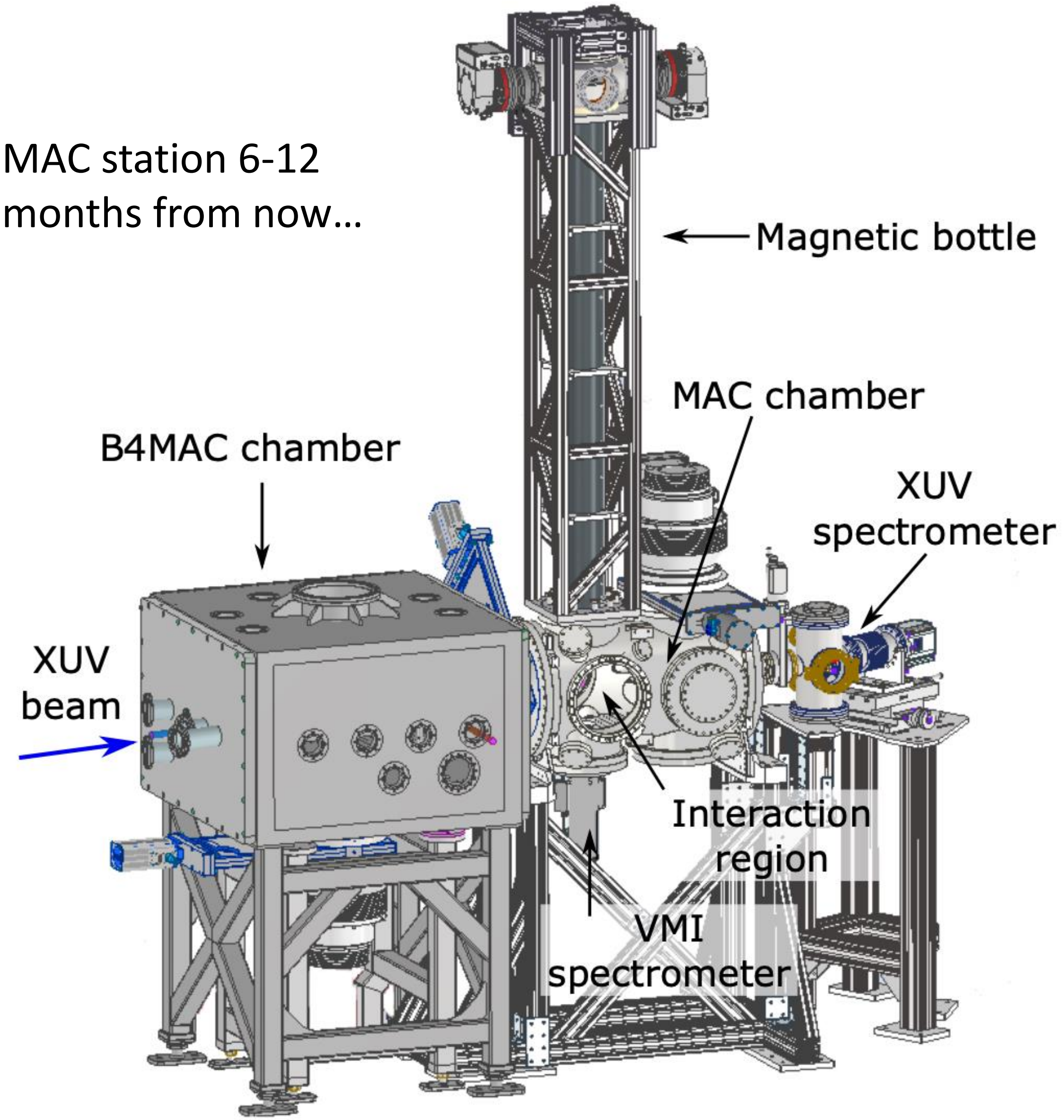
HHG tuning around the peak of the He 1s2p 1P resonance at 21.5 eV

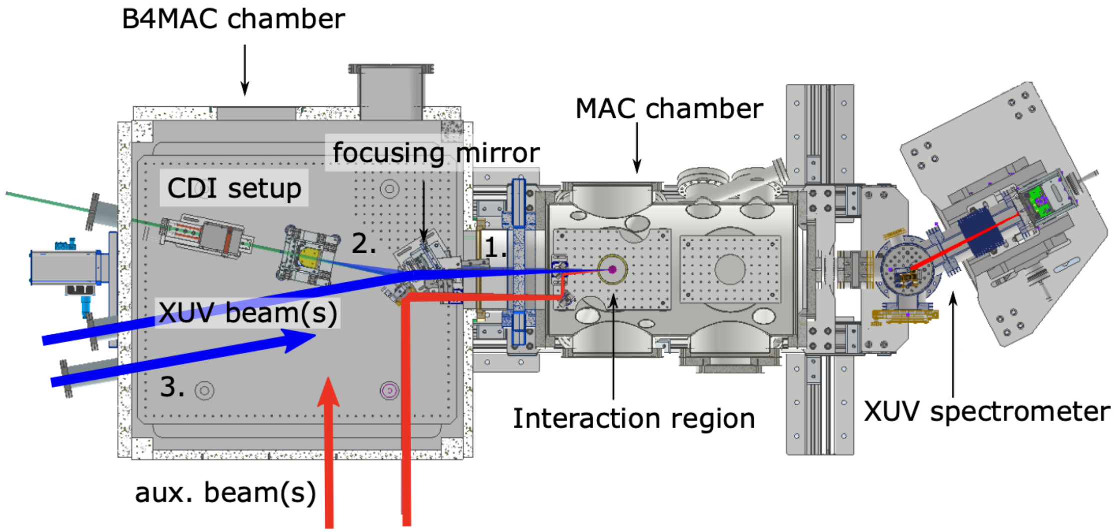
Phase-matched high-order harmonic generation in pre-ionized noble gases
O. Finke *et al.* Sci Rep 12, 7715 (2022). https://doi.org/10.1038/s41598-022-11313-6

MAC; station for XUV AMO Science

AMO - Atomic, Molecular and Optical

MAC station 6-12 months from now…





Immediate instrument upgrades

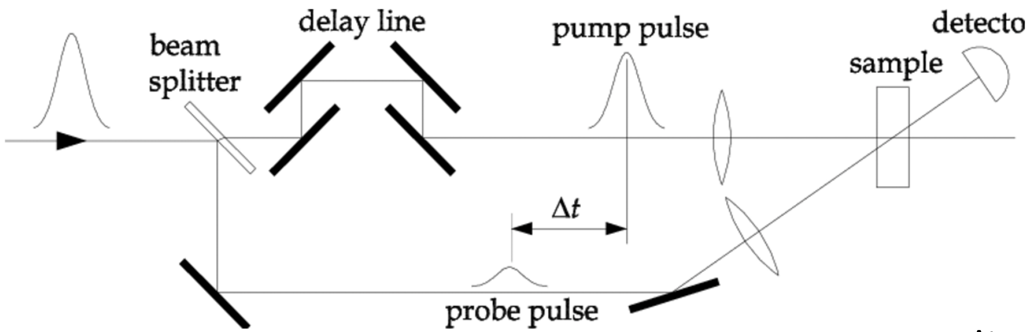
- Magnetic Bottle Electron spoectroemter
- Beam conditioning chamber (B4MAC)
- Coincidence ion/e spectrscopy
- XUV spectrometer

"New" Scientific areas

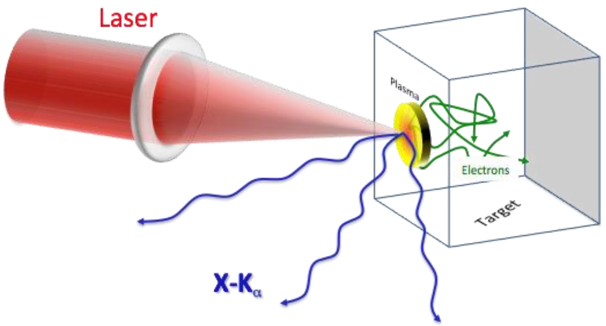
- Extend into/revisit XUV material science
- XUV polarimetry
- XUV-XUV experiments (FSYNC beam)

Hard X-ray science X-ray sources and applications

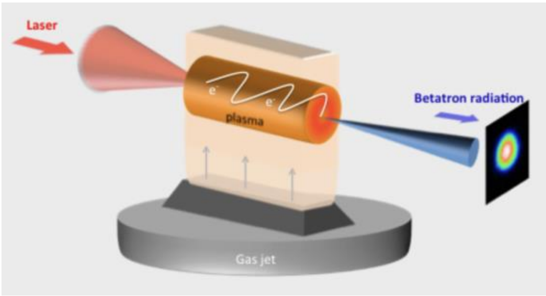
- Diffraction and spectroscopy
- Plasma X-ray source development
- X-ray imaging
- Pulse Radiolysis



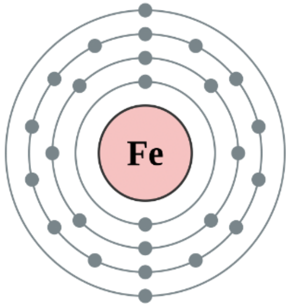
Plasma X-ray Source (PXS)

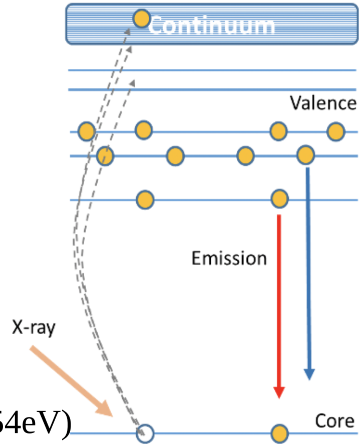


Betatron source



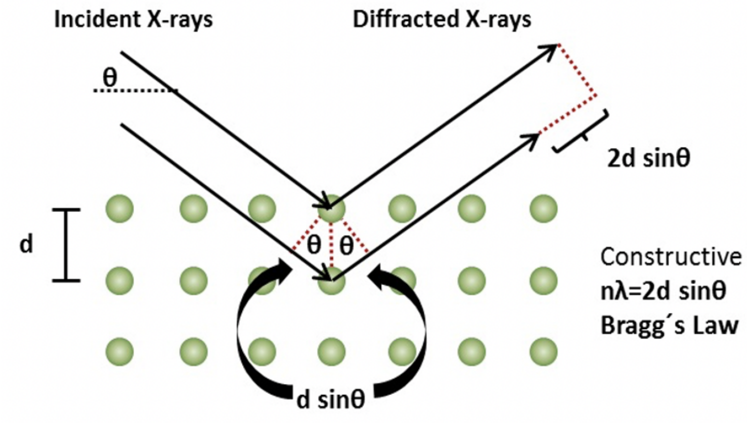
- K-edgeX-ray spectroscopy



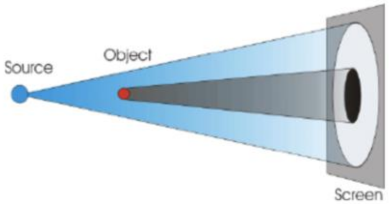


M-absorption edge of Fe (54eV)
L edge ~710 eV
K edge: ~7.1 keV

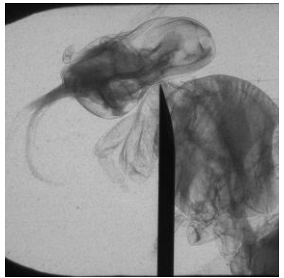
- Atomic resolution diffraction

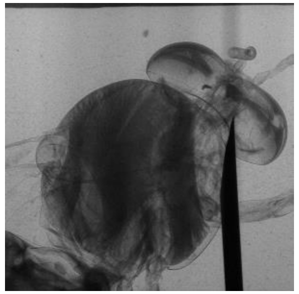


Constructive interference when
$n\lambda = 2d \sin\theta$
Bragg´s Law



X-ray imaging

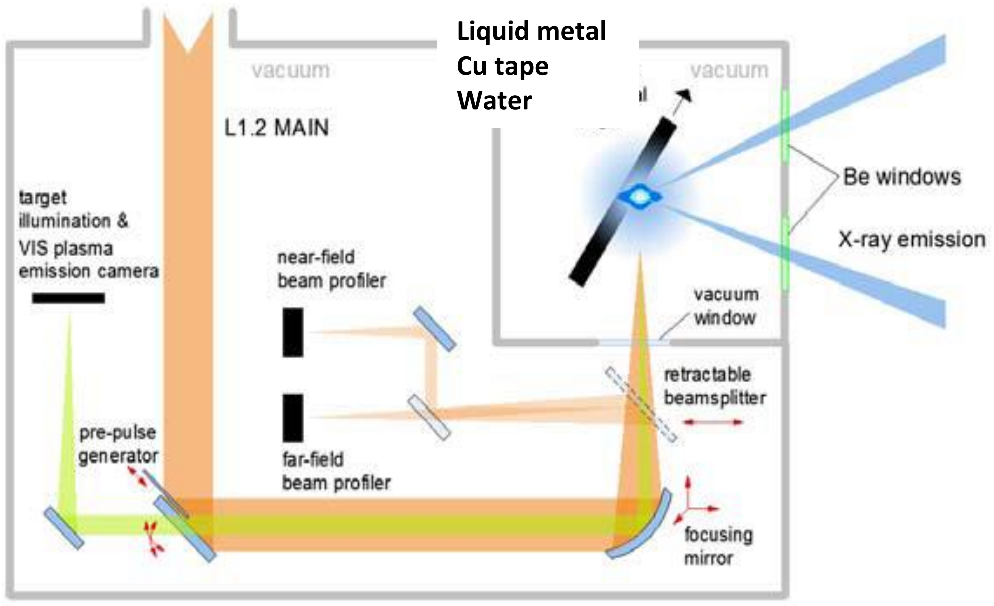


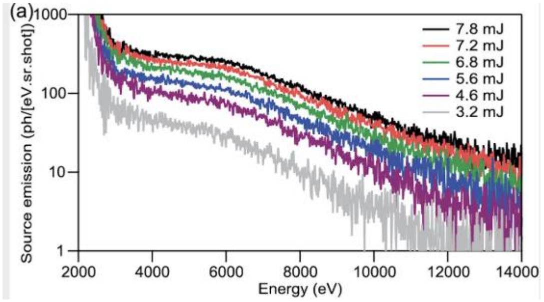


Shadow imaging->Phase contrast imaging, ptychography, …

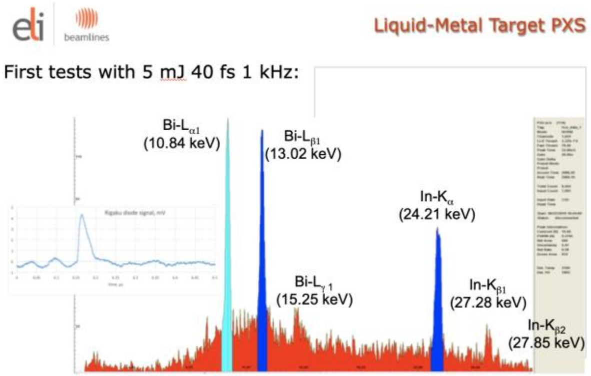
Hard X-ray science, diffraction and spectroscopy

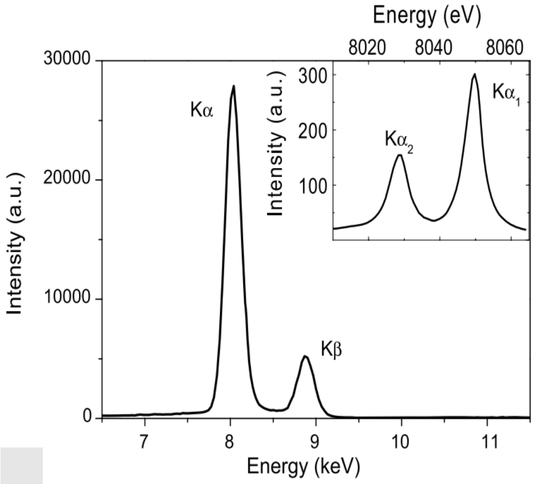
Plasma X-ray sources: Energy range: 2 to 30 keV, 1 kHz





Experiments using the polychromatic emission for absorption and emission spectroscopy





Experiments using the monochromatized emission for diffraction and scattering

Cu Kα

Liquid metal jet source

- OPTICS LETTERS Vol. 27, No. 10, p 866, May 15, 2002

Cu tape source

- F. Zamponi, et al., Applied Physics A volume 96, pages51–58 (2009)
- Elsaesser et al. The Journal of Chemical Physics 140, 020901 (2014)

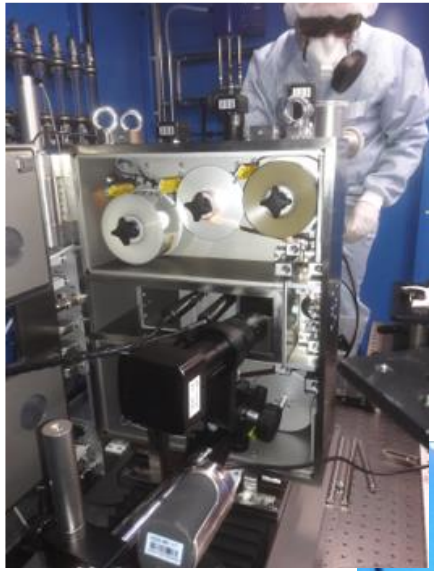
doi: 10.1063/1.4855115

Water jet source

- L. Miaja-Avila et al. Structural Dynamics **2**, 024301 (2015)

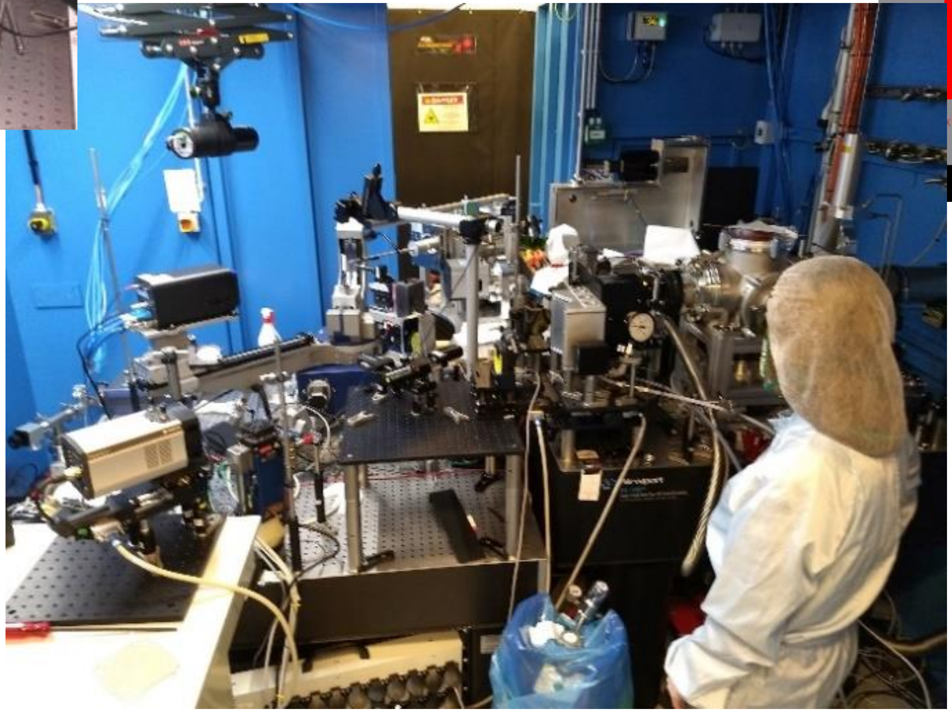
doi: 10.1063/1.4913585

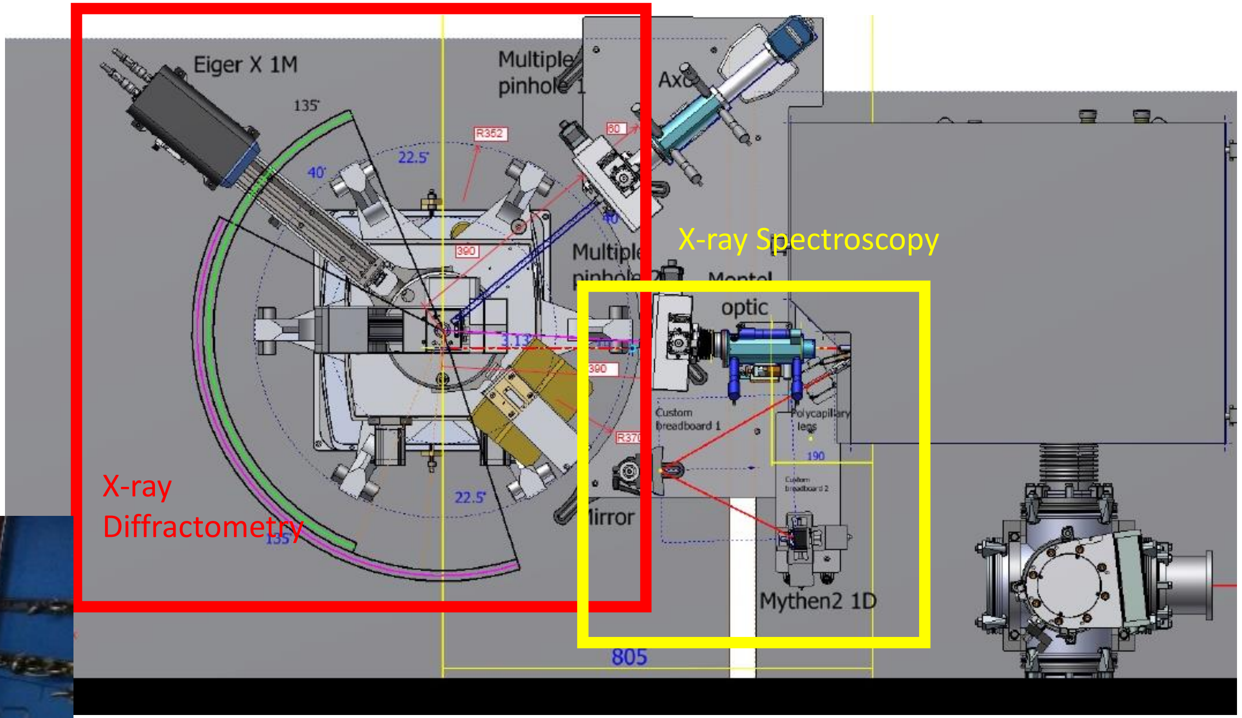
TREX, X ray station at ELI Beamlines



Left: Cu tape source for pulse hard X-ray generation

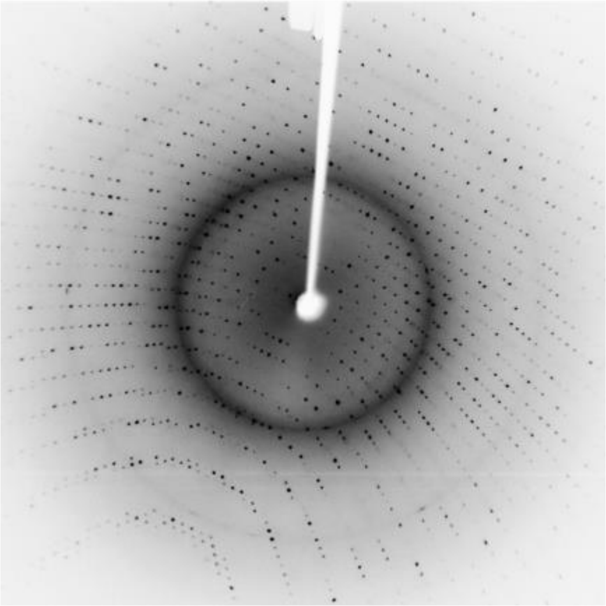
Below: X-ray experiment set up (Diffraction and spectroscopy)





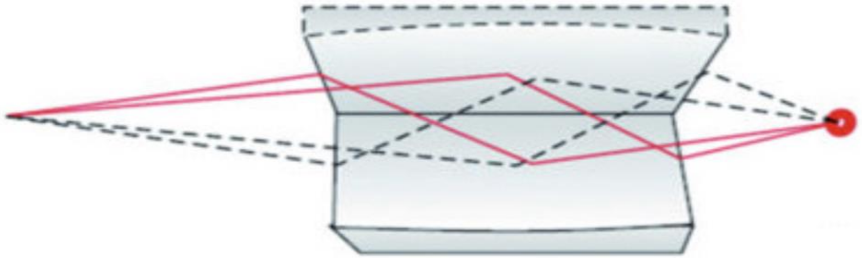
Modular set-ups for diffraction and spectroscopy

Monochromatization and focuisng of X-ray for diffraction applications

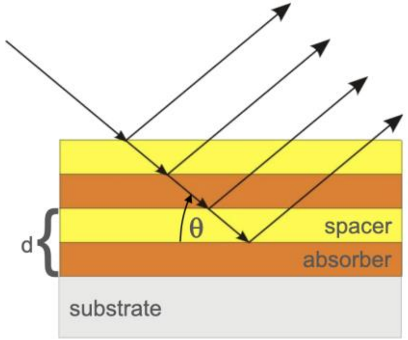


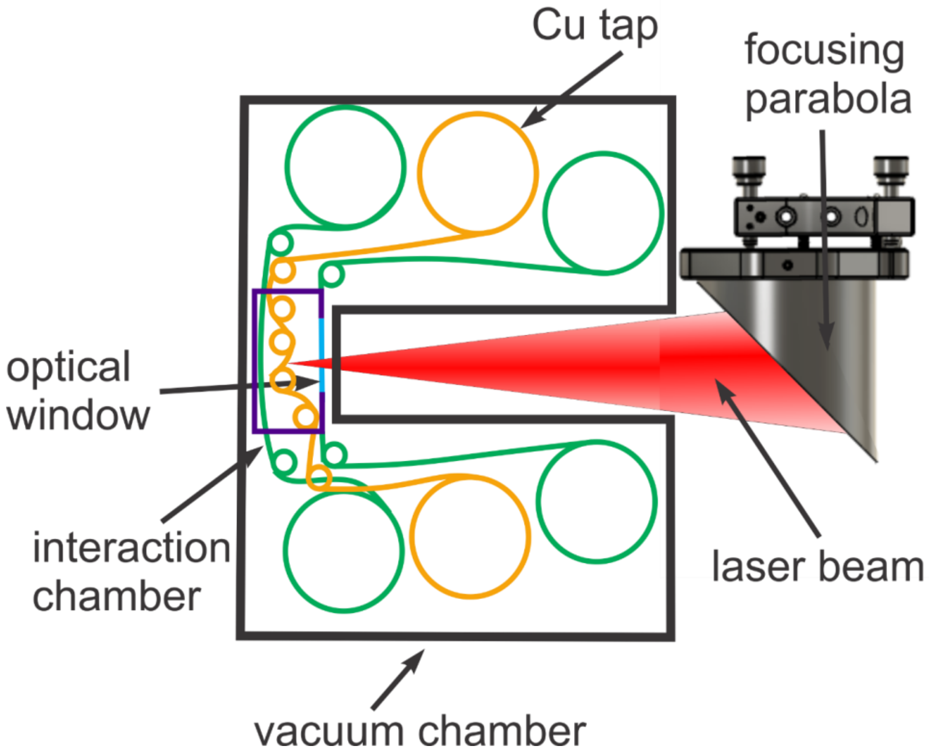
Single crystal X-ray diffraction pattern of lysozyme measured with the PXS source at room temperature (B. Yorke)

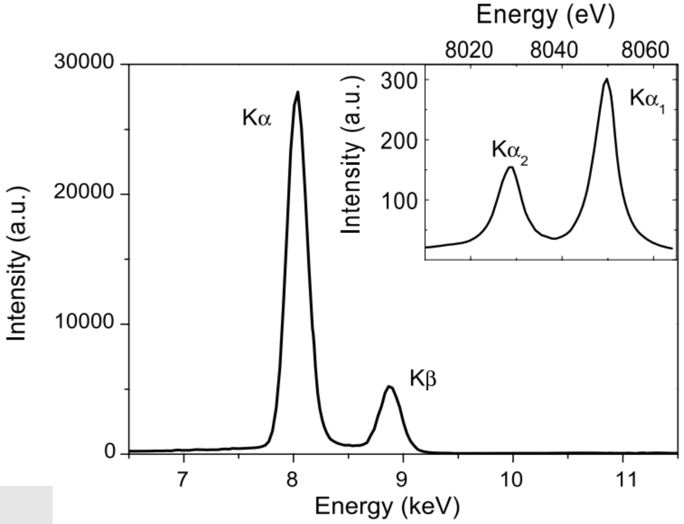
Montel optic



Multilayer coatings on curved substrates



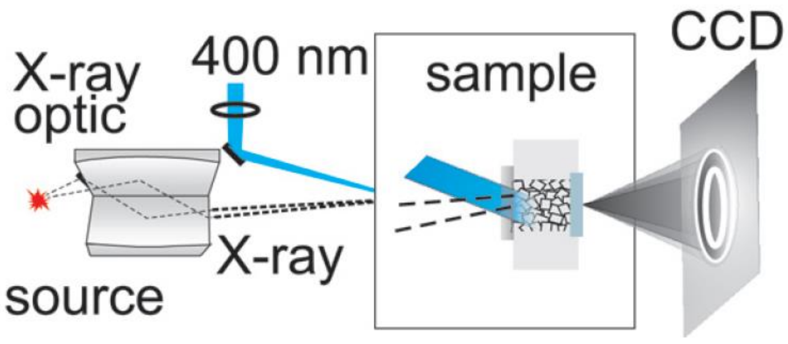


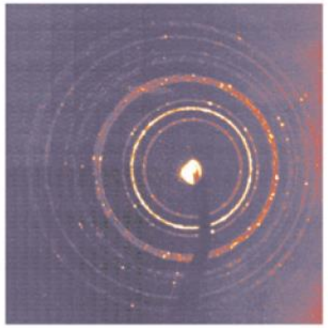


X-ray spectrum of Cu-tape PXS [F. Zamponi et al., Appl. Phys. A, 96, 51-58 (2009)]

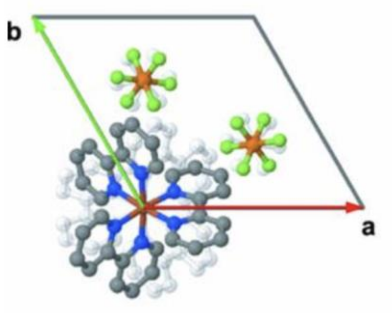
Time-resolved X-ray diffraction, and spectroscopy, using a laser driven plasma X-ray source

Powder diffraction as probe



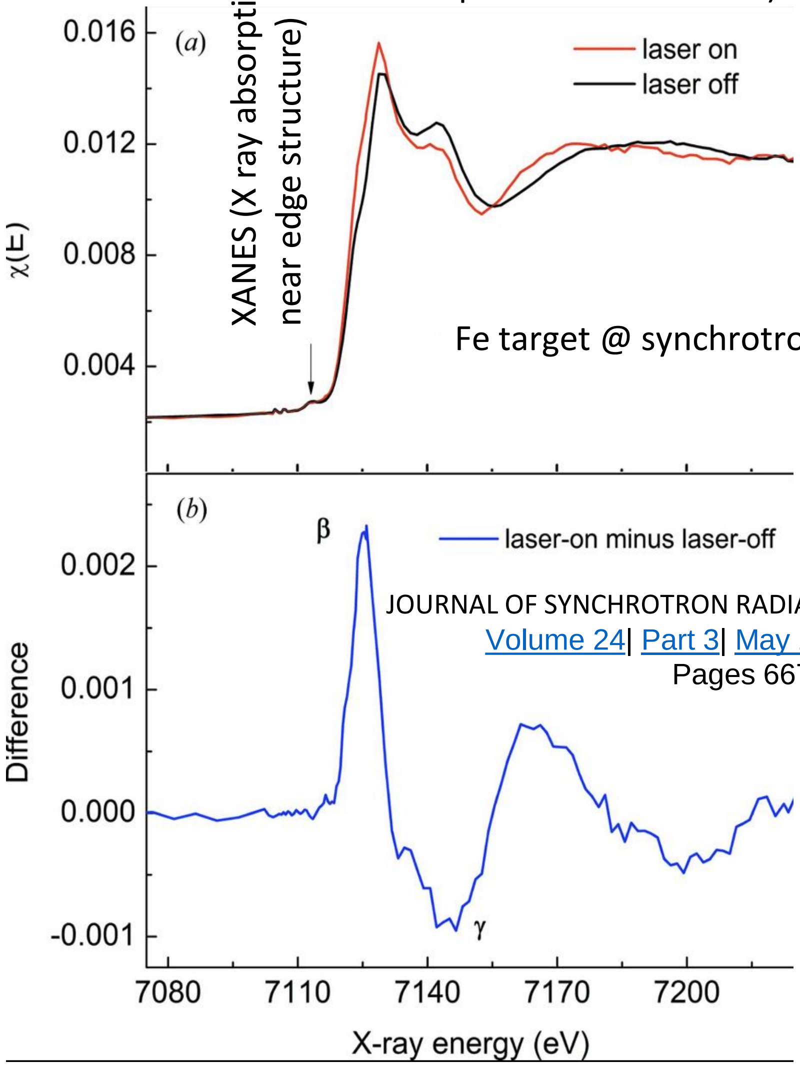


Fe(II)-tris(bipyridine) ($[Fe(bpy)_3]^{2+}$) complexes and their PF_6^- counterions



…or for X-ray absorption spectroscopy

EXAFS (Extended X ray absorption fine structures)



JOURNAL OF SYNCHROTRON RADIATION
Volume 24| Part 3| May 2017|
Pages 667-673

Absorption/activation in the optical range

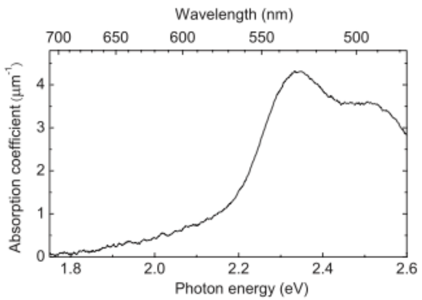
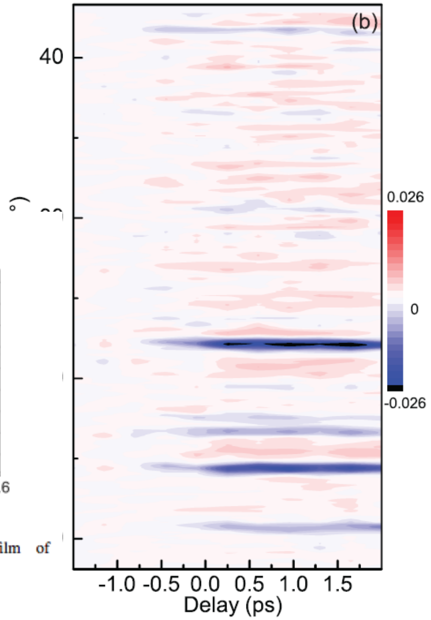
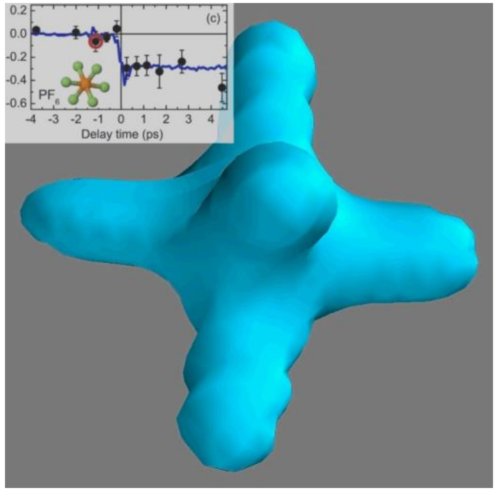


FIG. 2. Absorption spectrum of a poly-crystalline thin film of $Fe(bpy)_3]^{2+}(PF_6^-)_2$.



Charge transfer between the sample sub units



Images from:

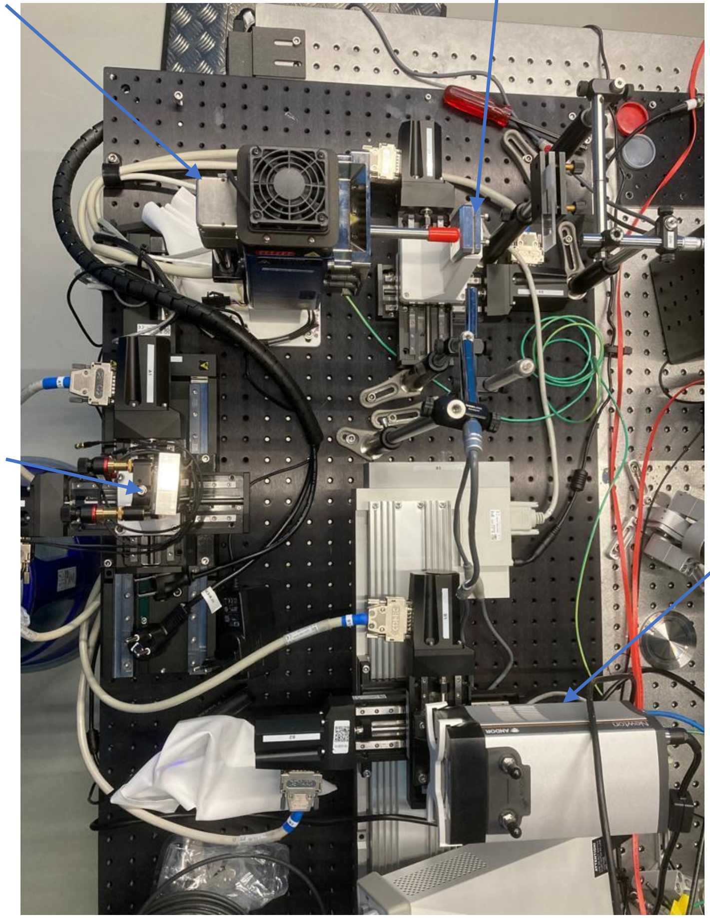
Freyer et al. The Journal of Chemical Physics **138**, 144504 (2013); doi: 10.1063/1.4800223

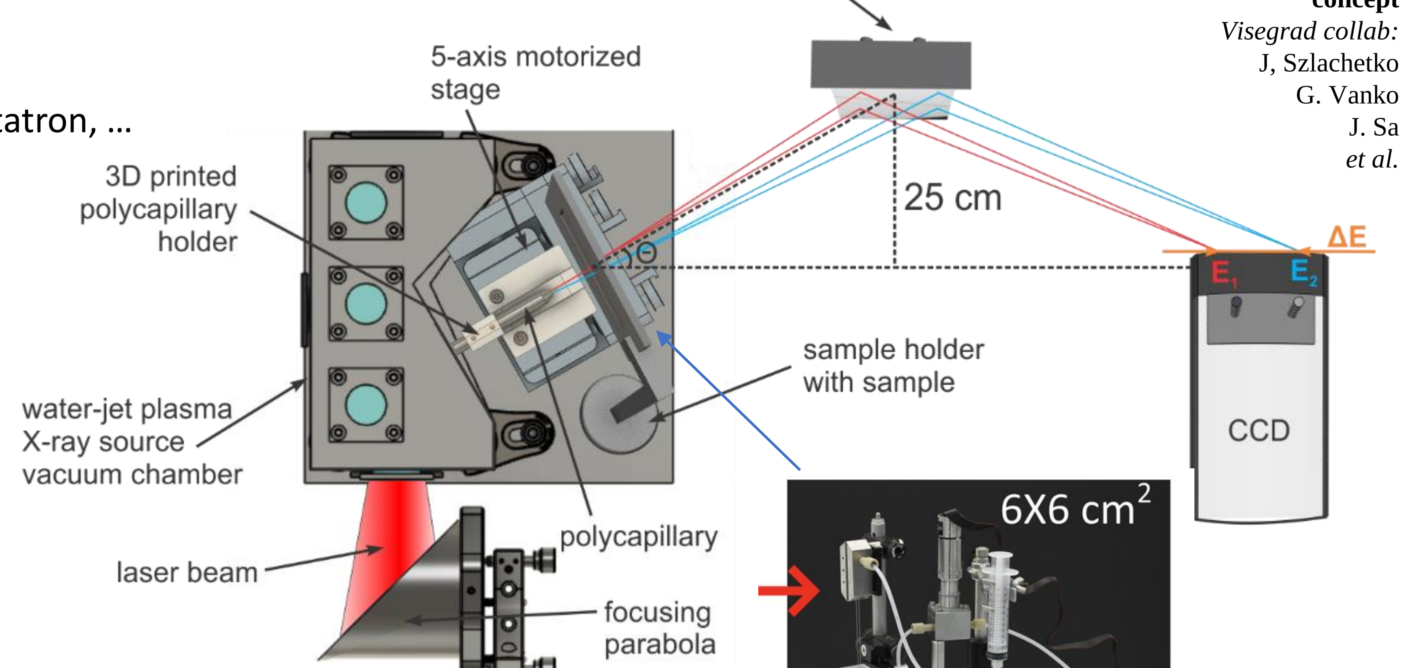
Elsaesser et al. The Journal of Chemical Physics **140**, 020901 (2014); doi: 10.1063/1.4855115

ELI BL X-ray spectroscopy module wiht X-ray tube and water jet source

ELI Beamlines von Hamos XES/XAS spectrometer concept
Visegrad collab:
J, Szlachetko
G. Vanko
J. Sa
et al.

- Von Hamos Geometry
- Motorized and automated
- Modular and adaptable, X-ray tube, Water jet source, Cu tape, Betatron, …
- Configurations for absorption and emission spectroscopy
- Moveable between locations (PXS, E1, E4, Betatron in E2. ….)





Liquid sheet sample delivery system

Recent Publications

X-ray spectroscopy station for offline sample pre-characterization at ELI-Beamlines
A. Zymaková, et al., Under review:

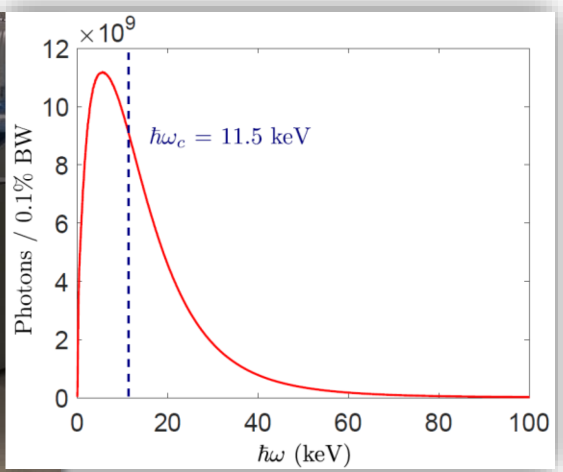
First experiments with a water-jet plasma X-ray source driven by the in-house developed L1 Allegra laser at ELI-Beamlines,
A. Zymaková, *et al.,* Journal of Synchrotron Radiation, Volume 28, Part 6, pages 1778-1785 (2021),

Implementation of a crossed-slit system for fast alignment of sealed polycapillary X-ray optics
Anna Zymaková, *et al.,* Journal of Synchrotron Radiation 27 (6), 1730-1733,

A fast-integrated X ray Emission spectrometer dedicated on the investigation of the Pt presence in gold Celtic coins (3rd - 1st century BCE)
A. Zymaková, et al., X-Ray Spectrometry (2023), DOI: 10.1002/xrs.3354

Outlook: New and upgrades X-ray sources

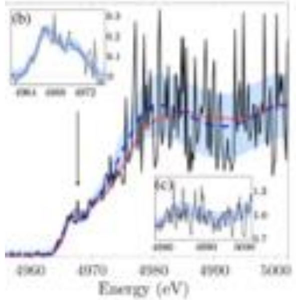
LPA sources for X-ray spectroscopy, Mid IR drive of PXS



Betatron spectrum

- In E2 ideal for Transition Metal k-edge spectroscopy.
- In L1 (L1/ALFA) promising for TM L-edge spectroscopy

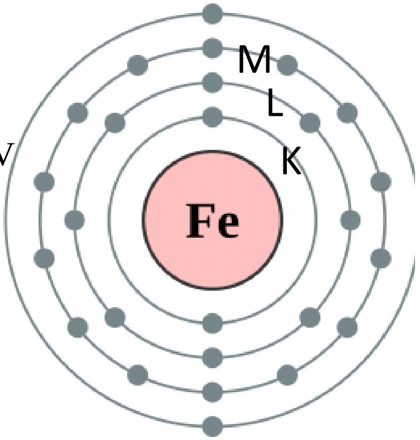
K-edge Ti XANES,
Gemini, CLF (200 TW)

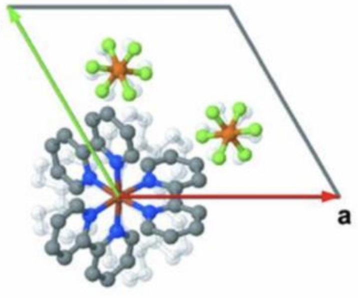


Single shot

Kettle et al.
PRL **123**, 254801 (2019)

M edge (54eV)
L edge ~710 eV
K edge: ~7.1 keV





Date:

Page:

NATURE PHOTONICS DOI: 10.1038/NPHOTON.2014.256

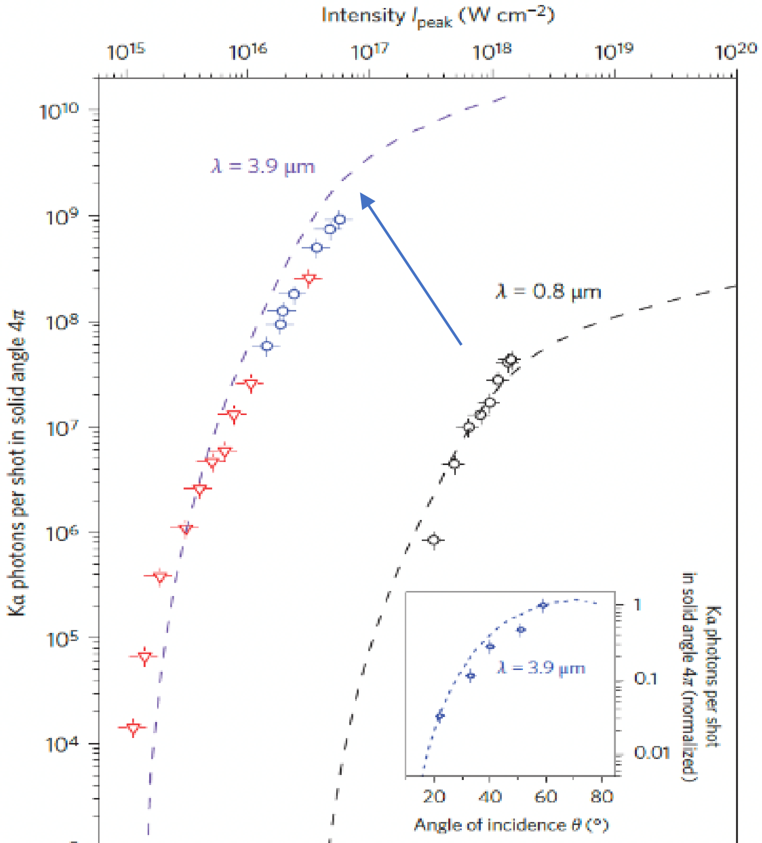


Figure 2 | Generated X-ray Kα flux as a function of the laser-peak intensity. Comparison of experiment (symbols) with theory (dashed lines)

2 orders of magnitude increase by going to 5 um MIR drive and 3 kHz

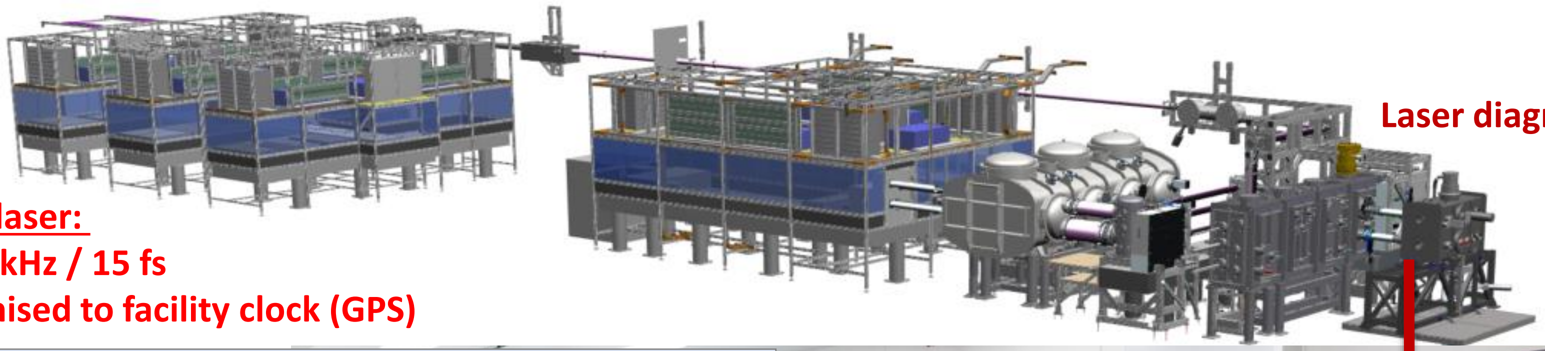
ALFA: Allegra Laser for Acceleration

Compact platform for LWFA electron acceleration and applications

Idea:

I. Develop a compact source of high repetition rate (> 1 kHz) high energy (> 50 MeV) stable electrons

II. Make it open and available for external sser experiments



Laser diagnostics

<u>L1-Allegra laser:</u>
100 mJ / 1 kHz / 15 fs
& synchronised to facility clock (GPS)

- Batysta, F. et al., Optics Express vol. 22, issue 24,30281 (2014).
- Antipenkov, R. et al., doi.org/10.1117/12.2592432 (2021).

<u>courtesy of P. Bakule</u>

ALFA: Allegra Laser for Acceleration

Compact platform for LWFA electron acceleration and applications

Main results:

I. New **ALFA kHz LWFA beamline** driven by **multi-cycle (15 fs) OPCPA power scalable 1 kHz laser**

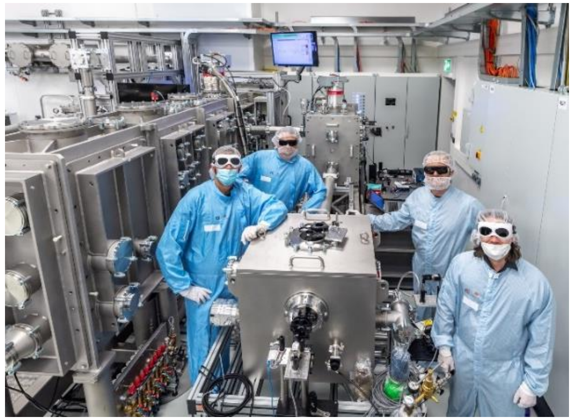
I. Highest electrons energy **(up 50 MeV quasi-monoenergetic)** ever reached at kHz repetition rate

II. Very collimated high energy beams: average divergence **2.1 mrad (FWHM)**

III. Higher power mode at tens of MeV, higher current (0.3 nA for > 20 MeV)

IV. Possibility to accelerate in **continuous 1 kHz mode** over hours

V. First irradiation tests with **in-air dose rate estimated > 1 Gy/s**



New applications made possible:

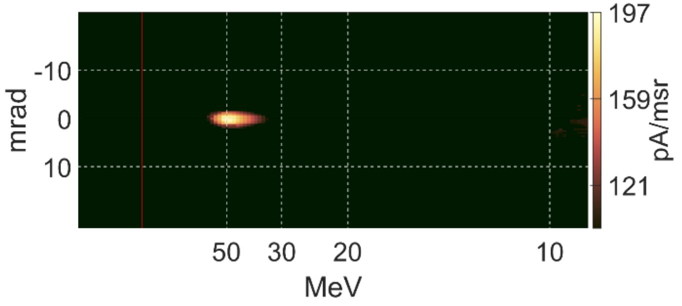
I. Very High Energy Electrons (VHEE) source for radiotherapy

[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



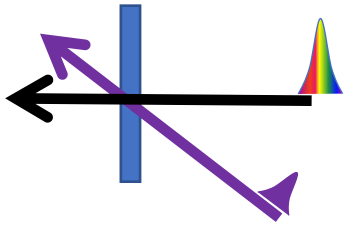
C.M.Lazzarini, et al.,
https://doi.org/10.48550/arXiv.2302.1141

Complementary optical specrtroscopy (E1 and Biolab)

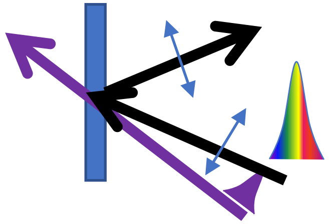
fs-mid-IR

ultrashort
Supercontinuum probe

Actinic pulse
(photo trigger)



fs transient optical absorption



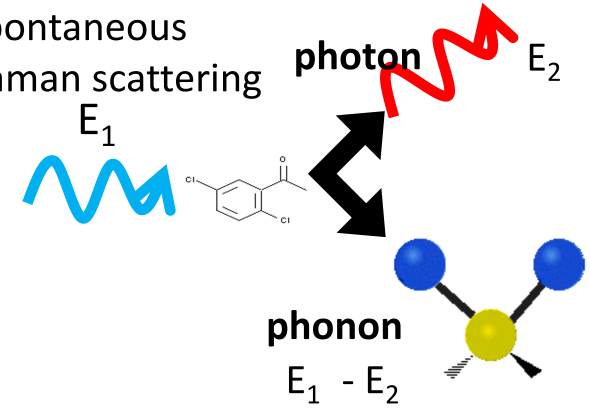
Time resolved ellipsometry

Optical spectroscopy to study dynamics originating from electonic excitations

Tranient optical absorption

Time resolved spectroscopic ellispometry

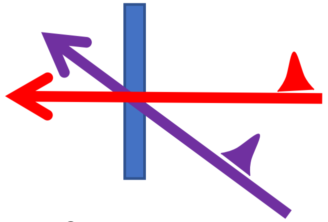
Spontaneous Raman scattering



Optical spectroscopy to study dynamics originating from vibrational excitations

Stimulated Raman scattering

IR spectrsocopy (still in commissioning)

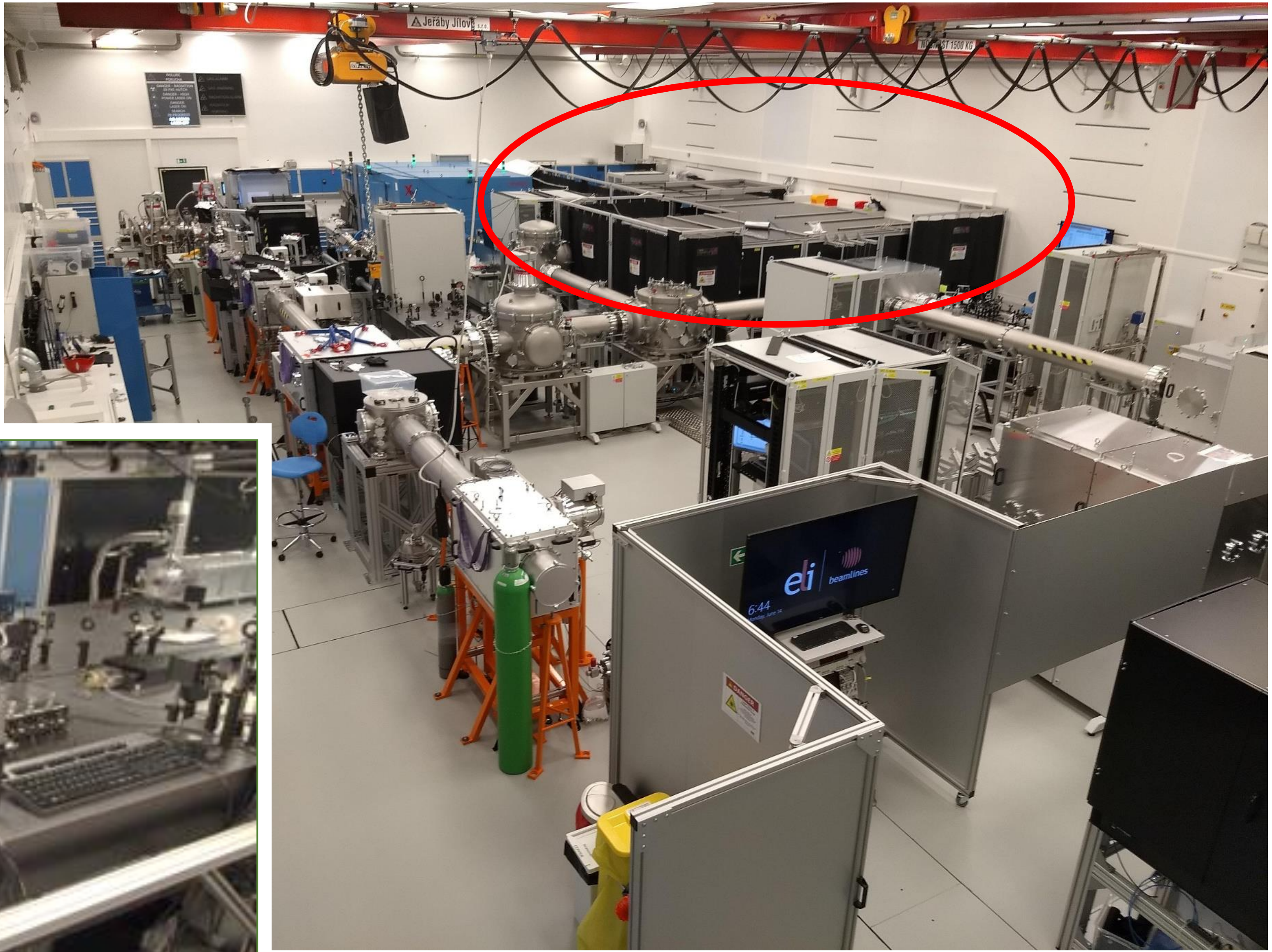


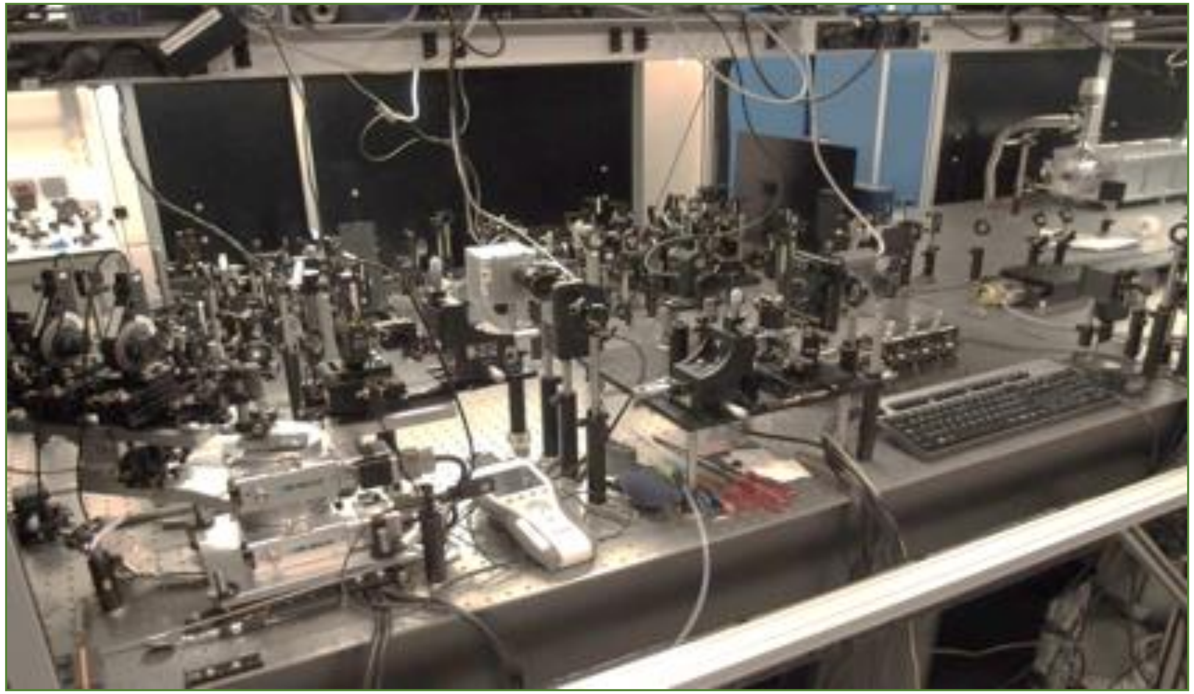
fs transient absorption mid IR

+ Station for Transient Current measurements for detector testing

Optical spectroscopy in E1:

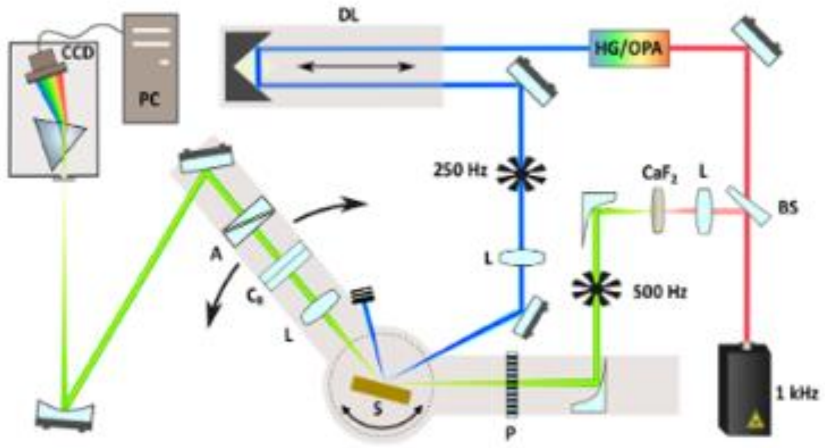
trELIps and TCT in operation
IR in commissioning

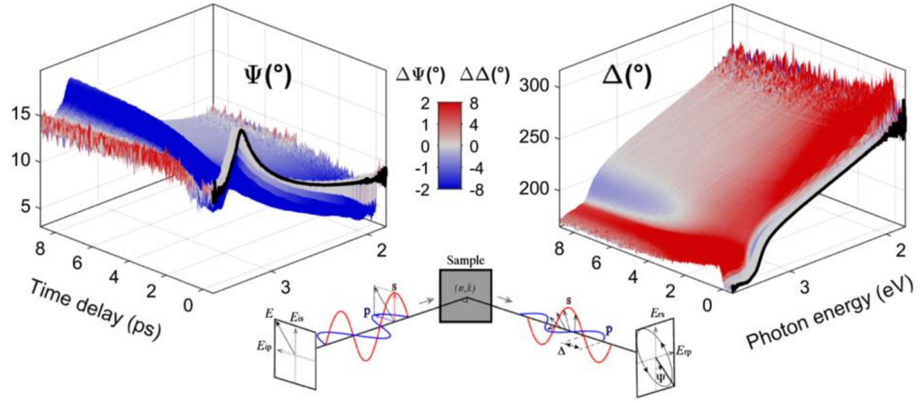




Optical spectroscopy, E1: trELIps and TCT

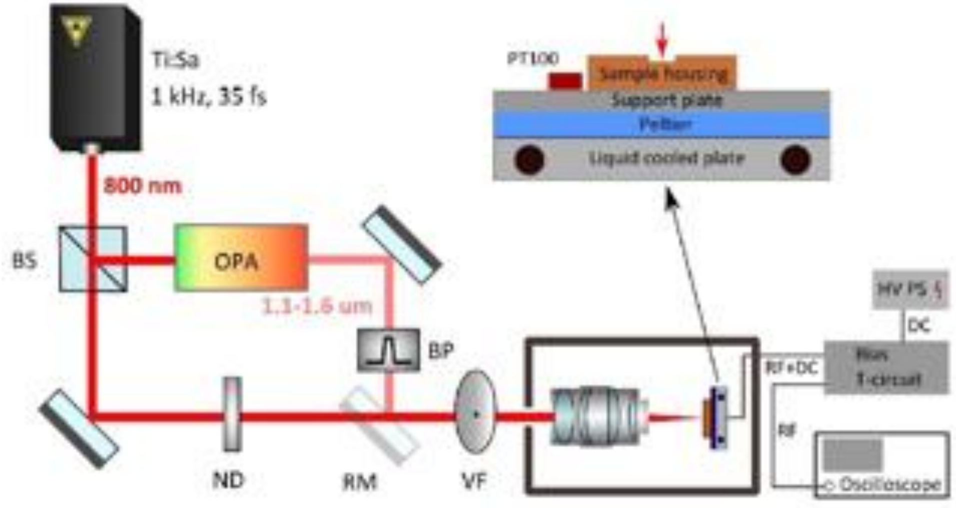
trELIps: Allows you to get transient changes in the dielectric function. Important e.g. for bandgap dynamics in semiconductors, plasmon dynamics and phase transitions

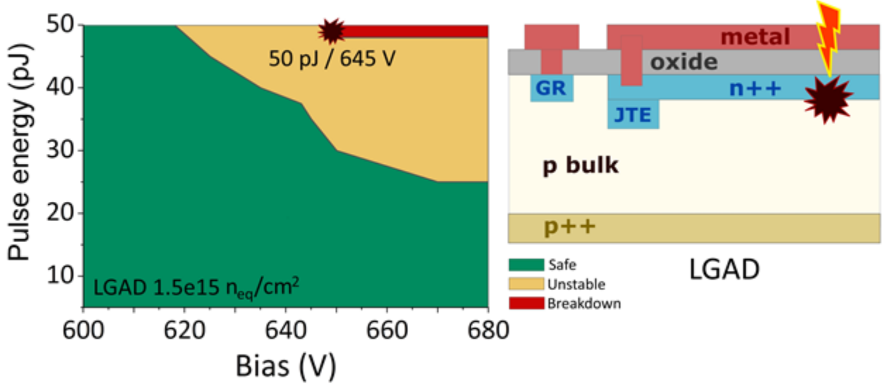




Temporal evolution of the ellipsometric angles Ψ (amplitude ratio) and Δ (phase difference) of the ZnO thin film after non-resonant UV pump measured at 60° angle of incidence

TCT (Transient Current Technique): One an two-photon exposure of new detector types (e.g. Low Gain Avalanch Diodes, LGADs). Safe and risky operting conditions can be identified and studied, e.g as a funcion of radiation exposure





Optical spectroscopy, E1: Selected recent highlights

trELIps:

Femtosecond pump-probe absorption edge spectroscopy of cubic GaN 1 and II
Elias Baron, et al., Journal of Applied Physics 134 (7),
http://arxiv.org/abs/2206.02223

Coherent acoustic phonon oscillations and transient critical point parameters of Ge from femtosecond pump-probe ellipsometry
C. Emminger, et al., Phys. Status Solidi RRL2022,16, 2200058
https://doi.org/10.1002/pssr.202200058

Ultrafast dynamics of hot charge carriers in an oxide semiconductor probed by femtosecond spectroscopic ellipsometry
S Richter, et al., New Journal of Physics 22 (8), 083066 (2020)

Transient dielectric functions of Ge, Si, and InP from femtosecond pump-probe ellipsometry
S Espinoza, et al., Applied Physics Letters 115 (5), 052105 (2019)

Transient birefringence and dichroism in ZnO studied with fs-time-resolved spectroscopic ellipsometry
O Herrfurth, et al., Physical Review Research 3 (1), 013246 (2021)

Photo-induced insulator-to-metal transition and excited states in LaCoO3 using femtosecond pump-probe ellipsometry
M. Zahradnik, et al., Physical Review B, 105 (2022) 235213
https://doi.org/10.1103/PhysRevB.105.235113

TCT:

Exploring the Interpad Gap Region in Ultra-Fast Silicon Detectors: Insights into Isolation Structure and Electric Field Effects on Charge Multiplication
G. Laštovička-Medin, et al., Sensors 2023, 23(15), 6746 (2023)
https://doi.org/10.3390/s23156746

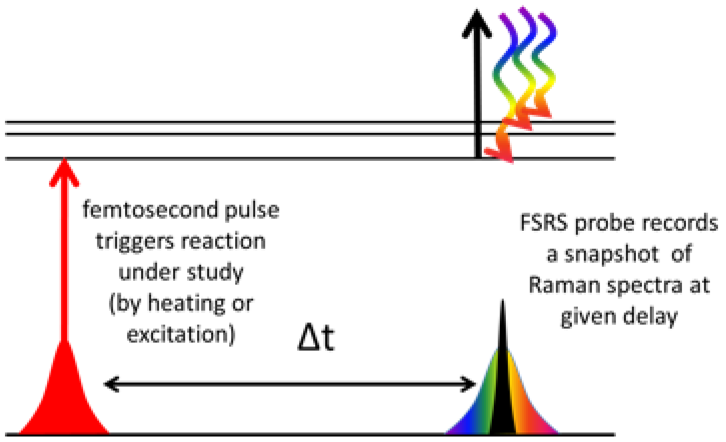
Femtosecond laser-based TCT-TPA and IBIC microscopy: two powerful depth profiling characterization tools for testing the micron-sized sensitive volumes in micro-strips or pixeled detectors for microdosimetry and hadron therapy
G. Laštovička-Medin, et al., Eur. Phys. J. Spec. Top. 232, 1501–1511 (2023)
https://doi.org/10.1140/epjs/s11734-023-00892-8

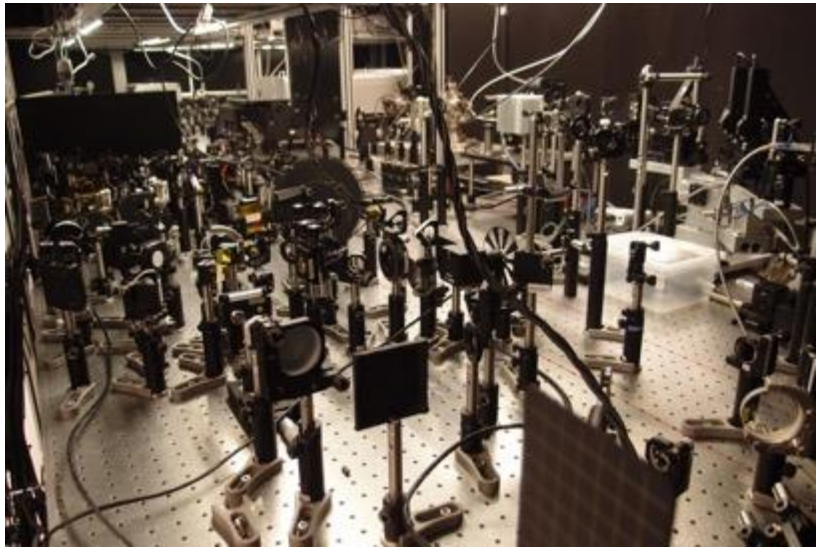
New Insight into Gain Suppression and Single Event Burnout Effects in LGAD
G. Laštovička-Medin, et al., Journal of Instrumentation 18 (02), C02059 (2023)
DOI 10.1088/1748-0221/18/02/C02059

Studies of LGAD performance limitations, Single Event Burnout and Gain Suppression, with Femtosecond-Laser and Ion Beams
G. Laštovička-Medin, et al., Nuclear Inst. and Methods in Physics Research, A (NIMA), DOI: https://doi.org/10.1016/j.nima.2022.167388

Optical spectroscopy, Biolab: FSRS and TA

Femtosecond stimulated Raman spectroscopy allows monitoring Raman vibration spectra of molecules with sub-ps time resolution. When used with reactions that can be triggered, ideally photo-triggered, it is powerful tool to follow reaction dynamics and structural changes with high time resolution and high acquisition speed.





FSRS Stimulated Raman probe:
Time resolution ~100fs
Spectral resolution ~1 cm-1
Observed spectral window 30 - 4000 cm-1
Raman pulse wavelength 760-840 nm
Triggering pulse pump:
Time resolutions ~ 30fs
Spectrum ~ 50 nm

Transient optical absorption (TA)
Probe pulse:
Time resolution: ~20fs
Spectral resolution: ~1 nm
Observed spectral window: 266 – 2500 nm
Triggering pulse pump:
Time resolutions: ~ 30fs
Spectrum: ~ 50 nm

Selected recent highlights

TA and SRS

Sub-Millisecond Photoinduced Dynamics of Free and EL222-Bound FMN by Stimulated Raman and Visible Absorption Spectroscopies
Biomolecules, 13(1) (2023) 161 DOI: https://doi.org/10.3390/biom13010161

Site-specific vibrational spectroscopy with non-canonical amino acids containing frequency-resolved labels
Biophysical Journal 122 (3), 190a-191a
DOI: https://doi.org/10.1016/j.bpj.2022.11.1168

Quantitative Energy Transfer in Organic Nanoparticles Based on Small-Molecule Ionic Isolation Lattices for UV Light Harvesting
ACS Appl. Nano Mater. (2022); https://doi.org/10.1021/acsanm.2c01899

Photochemistry of (Z)-Isovinylneoxanthobilirubic Acid Methyl Ester, a Bilirubin Dipyrrinone Subunit: Femtosecond Transient Absorption and Stimulated Raman Emission Spectroscopy
J. Org. Chem. 2022, 87, 5, 3089–3103

2.4-Å structure of the double-ring Gemmatimonas phototrophica photosystem
Science Advances • 16 Feb 2022 • Vol 8, Issue 7

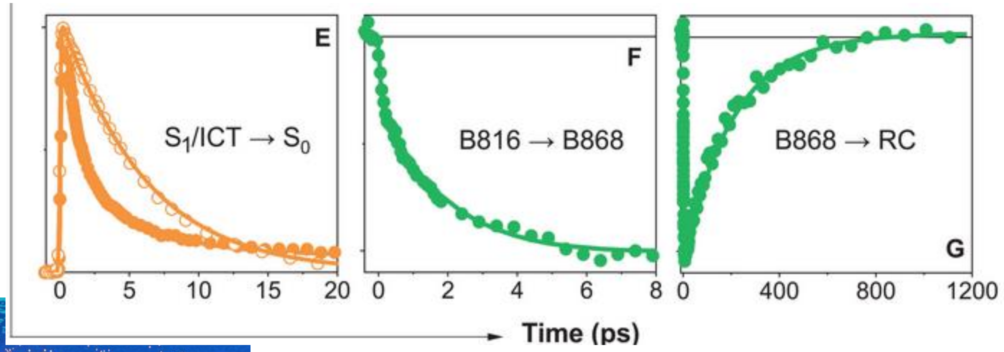
Optical and Infrared Spectroelectrochemical Studies of CN-Substituted Bipyridyl Complexes of Ruthenium(II)
Inorg. Chem. 2021, DOI: 10.1021/acs.inorgchem.0c03579 (2021)

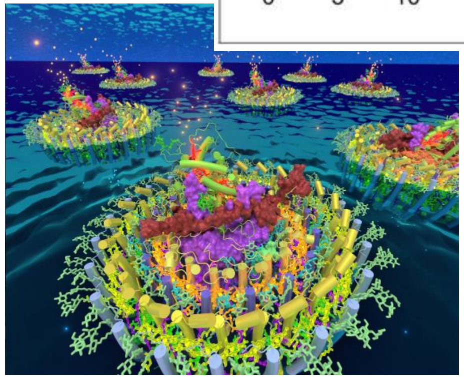
Spectroscopy and excited state dynamics of nearly infinite polyenes
Phys.Chem.Chem.Phys., 2020, 22, 17867

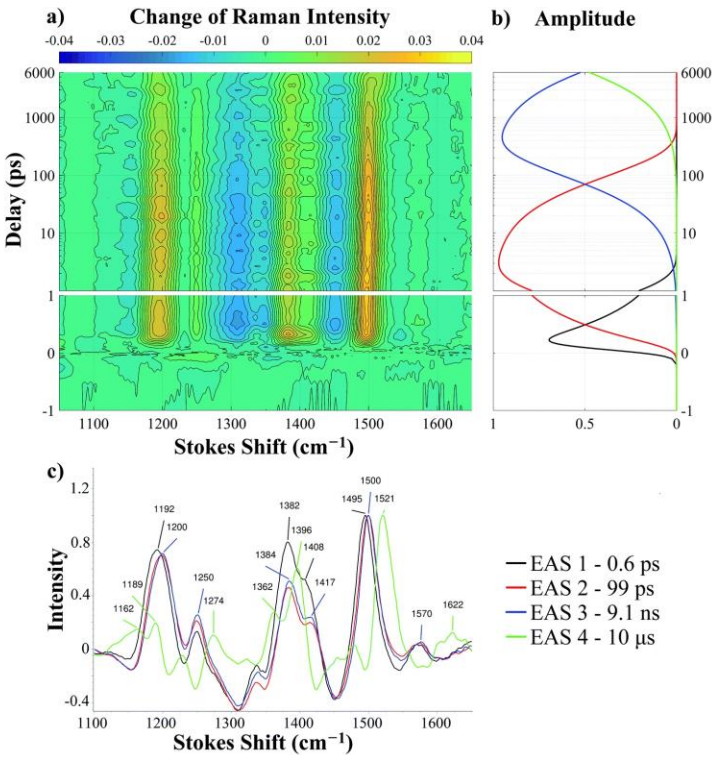
Femtosecond-to-nanosecond dynamics of flavin mononucleotide monitored by stimulated Raman spectroscopy and simulations
Physical Chemistry Chemical Physics 22 (12), 6538-6552 (2020)

Structural dynamics upon photoexcitation-induced charge transfer in a dicopper(I)–disulfide complex
M Naumova, et al., Chemical Physics 20 (9), 6274-6286 (2018)

TA station: Electron transfer kinetics in the RC-dLH1 complex. (part of full figure).



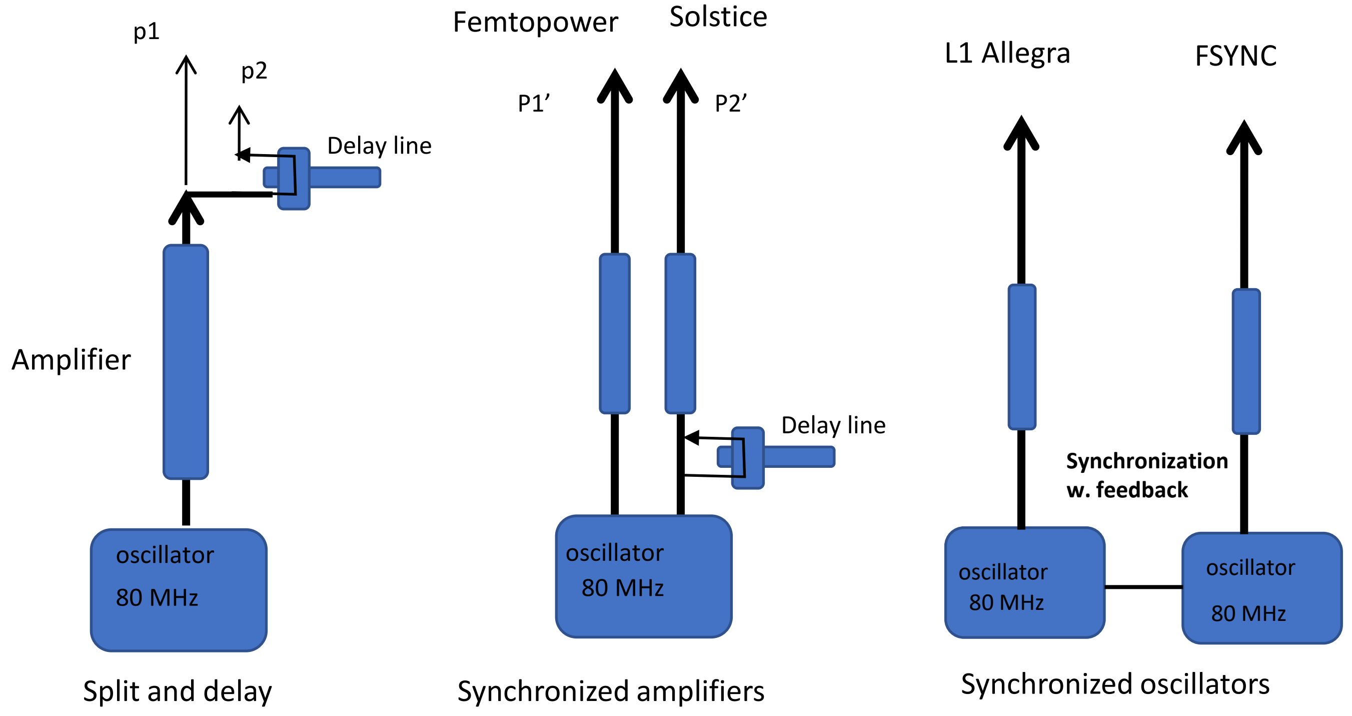


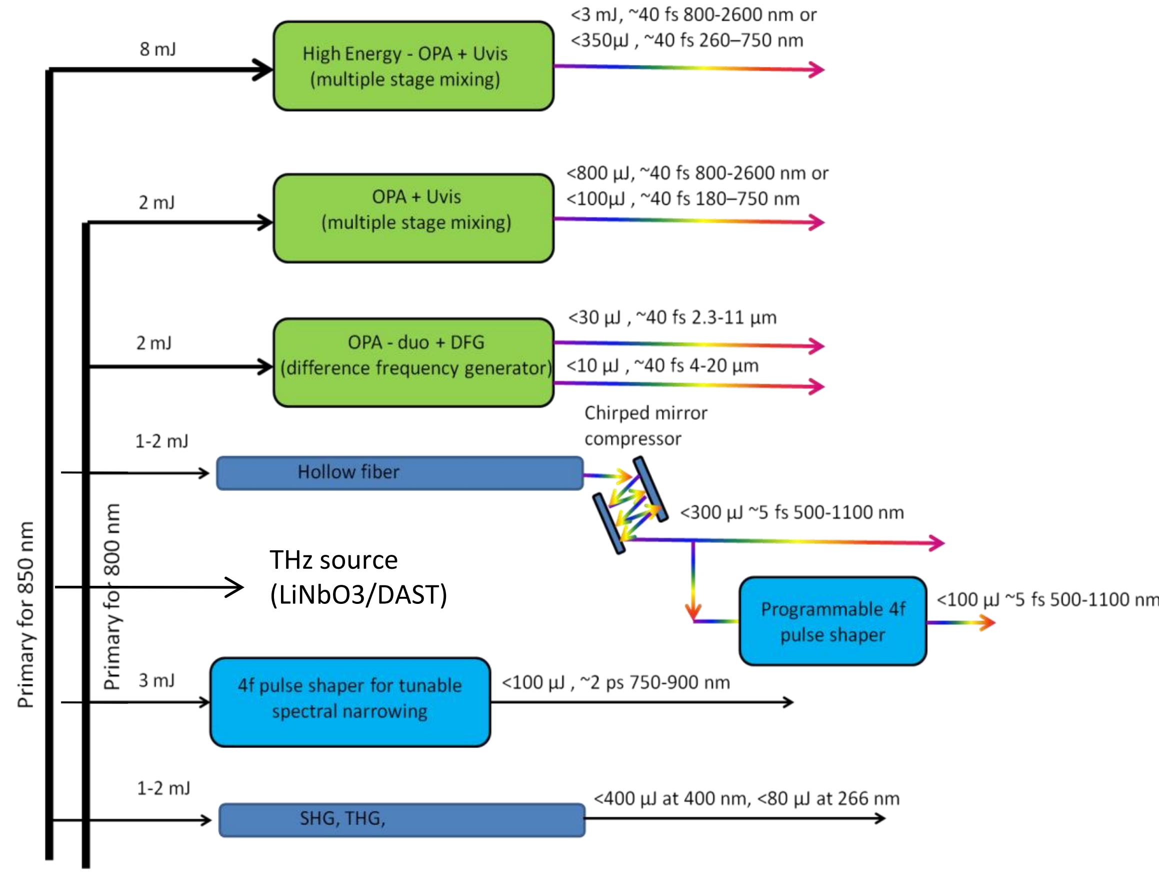


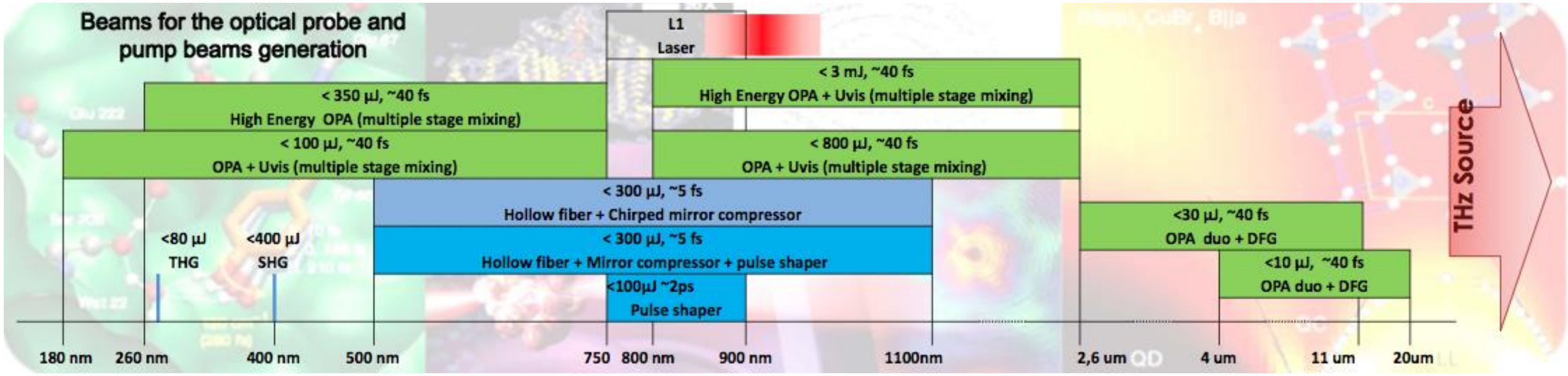
FSRS station: Time-resolved femtosecond-stimulated Raman (FSRS) spectra of FMN in the unbuffered water sample.

RP4 Optical pulse conversion and delays

0 fs to 1 ms delay with fs precision





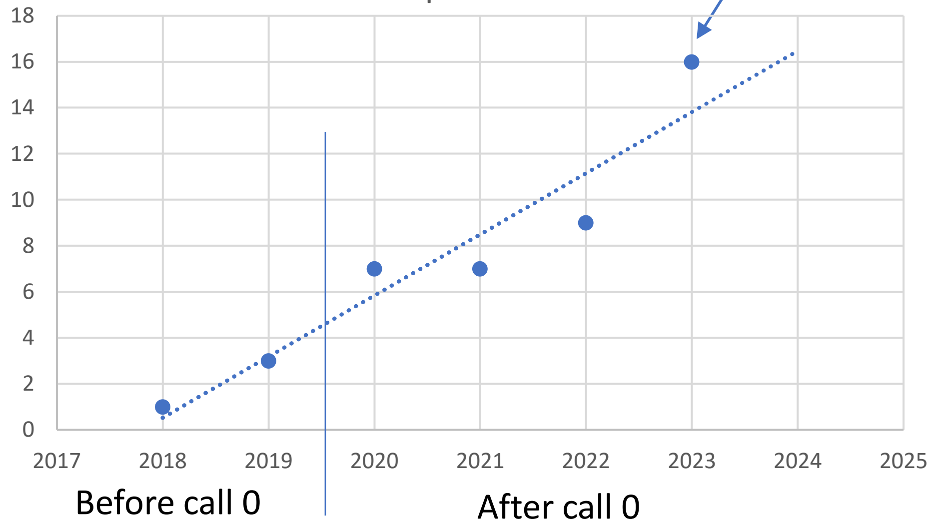


Open call experiments 2020-present and user publications

- **ELI Beamlines E1 and associated labs**

User publications: E1 and associated labs

Published/accepted (12) or presently under review (4)



Before call 0

After call 0

Number of user publications before first call: 4

Number of user publications 3.5 years after first call: 39

Total number of user publications: 43

Call	Nr of applications	Nr of experiments performed or planned
ERIC Call 2 (2023)	40	23 (in scheduling)
ERIC Call 1 (2022)	17	16
BL Call 2 (2021)	29	24
BL Call 1 (2020)	22	22
BL Call 0 (2019)	22	19
sum	130	103

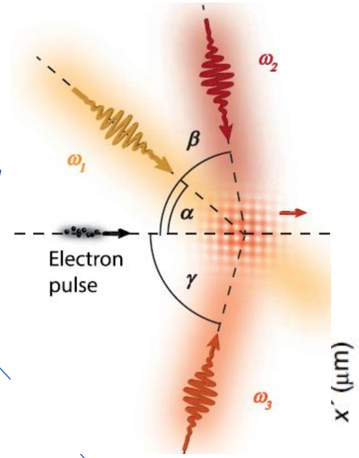
User publications mainly in areas of:

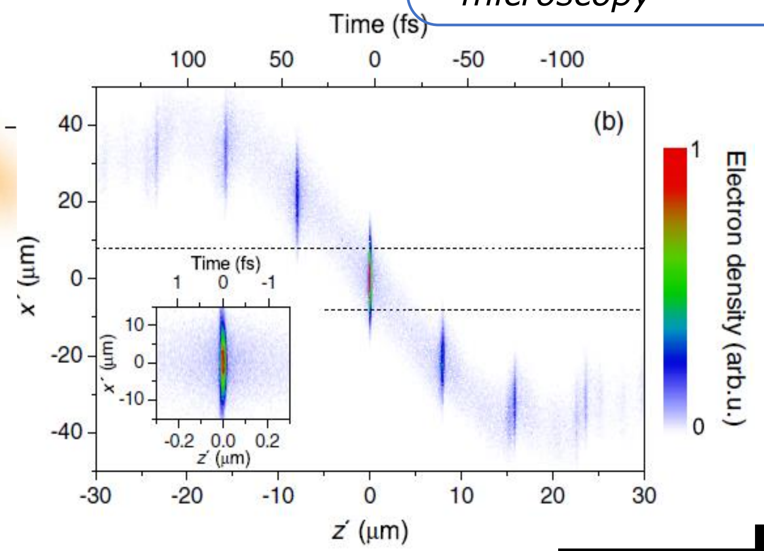
- AMO science
- Material science, wide band-gap semiconductors
- Source development
- Molecular dynamics, photo activated protein dynamcis

Outlook 2: Ultrafast electron diffraction/microscopy

Interfering laser generate isolated electron pulses for time resolved electron diffraction (ED) and microscopy

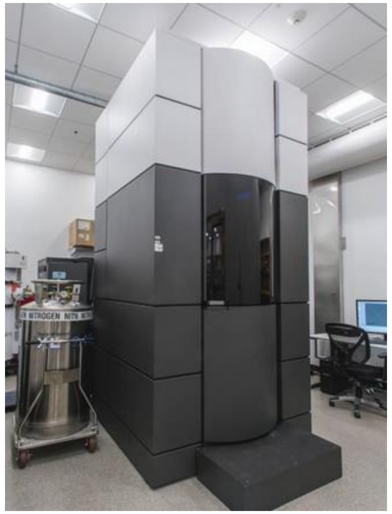
Future



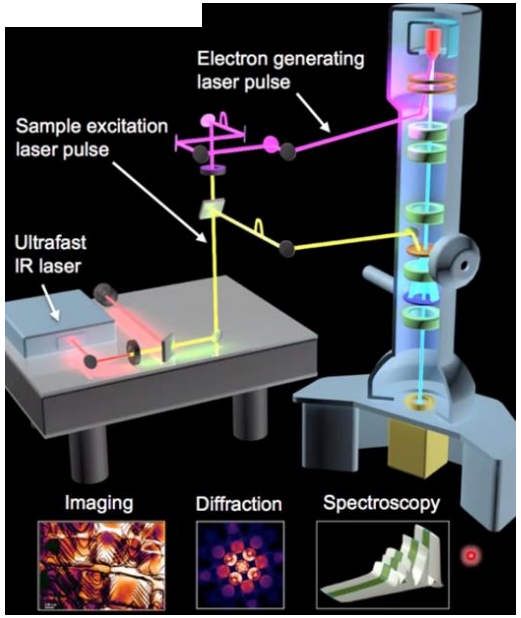


M. Kozak. PHYSICAL REVIEW LETTERS 123, 203202 (2019)

Past and Present



Synchrotrons and EMs for structure. Ultrafast lasers for dynamics



Struct. Dyn. **7**, 054304 (2020); https://doi.org/10.1063/4.0000034

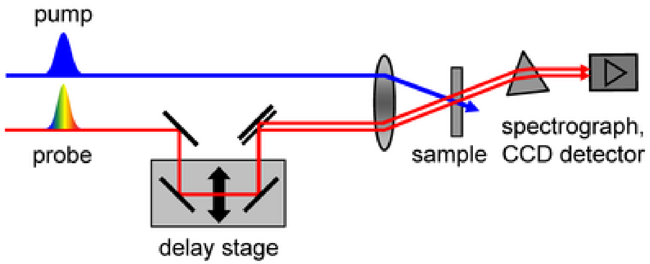
ELI Beamlines E1 technology and applications

Complementarity to facilities and university labs

High complementarity:
Structure and dynamics

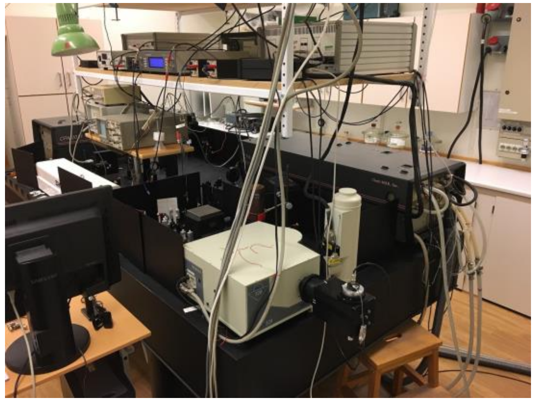
ELI Beamlines

- 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



Synchrotrons:

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



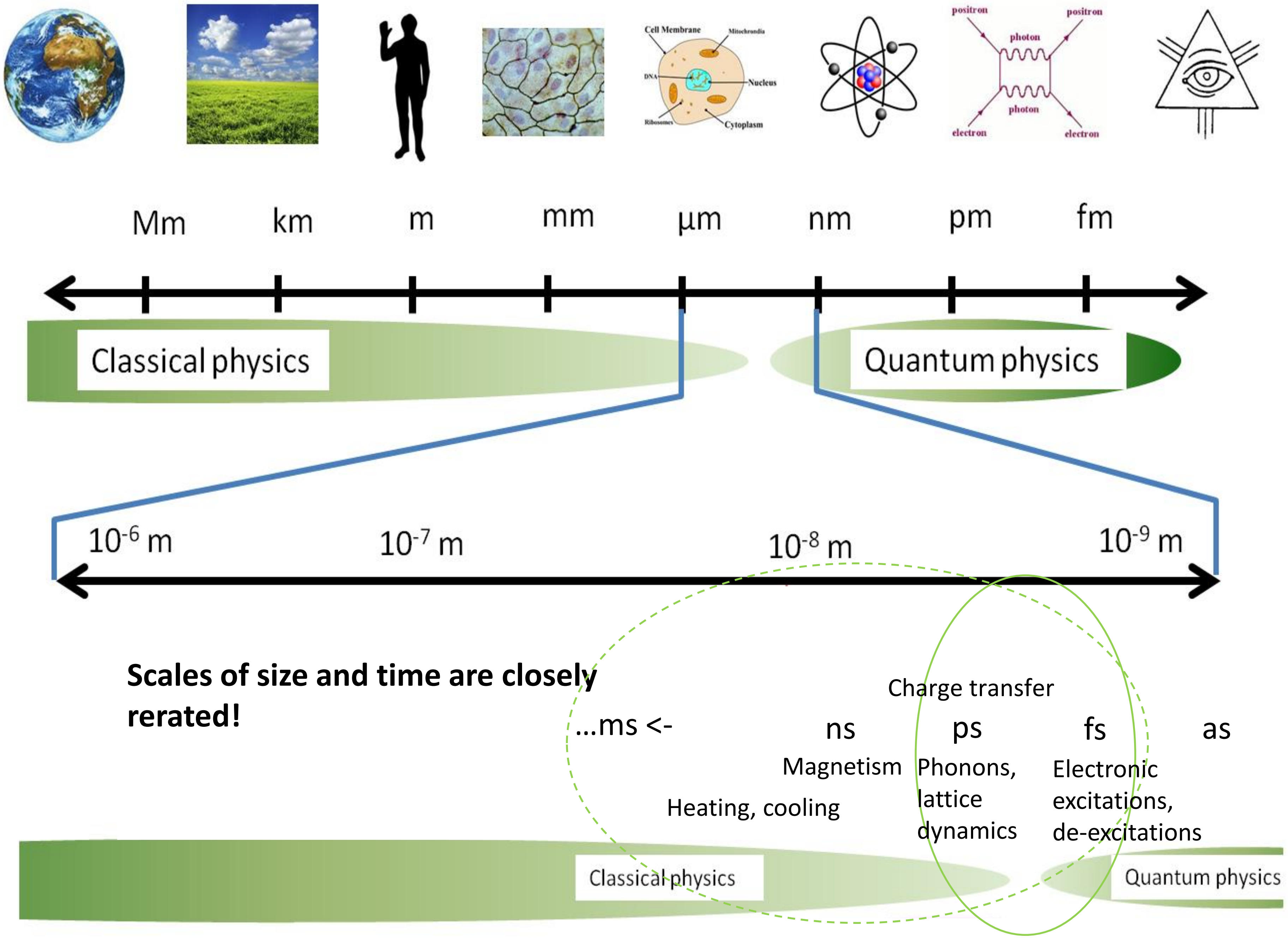
University lab

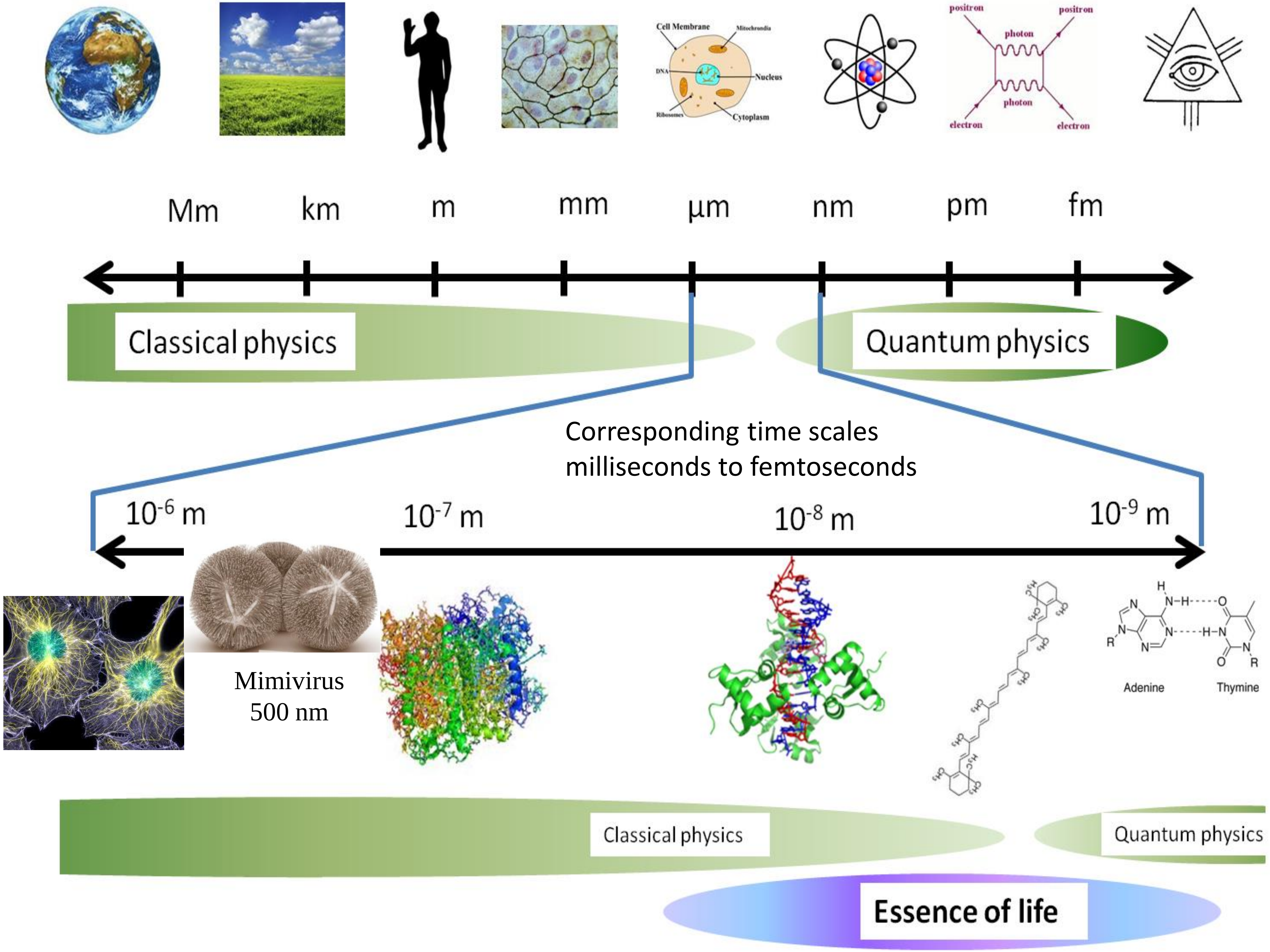
- Availability (once you have it and it is working)
- Big effort to keep updated and maintained for an individual lab
- Risk of under-utilized

X-ray FELs

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

Thank you for your attention

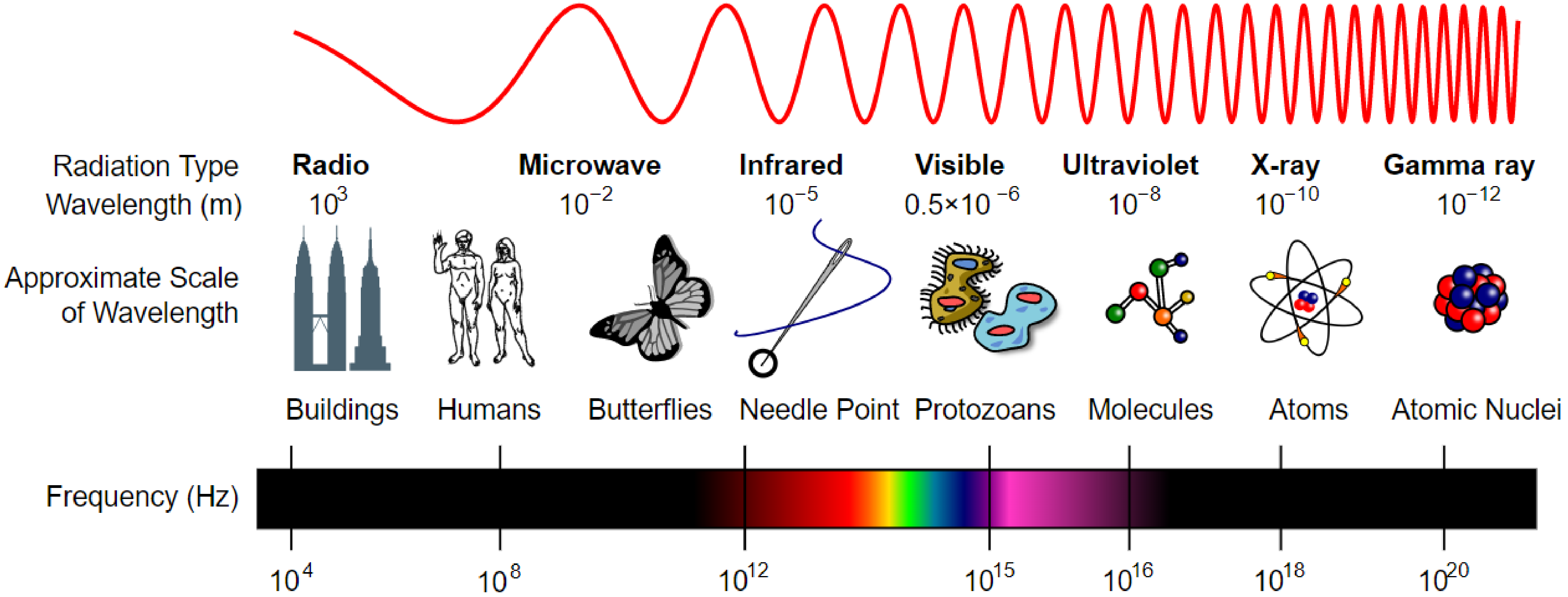

Cell Membrane
Mitochondria
DNA
Nucleus
Ribosomes
Cytoplasm
positron
positron
photon
photon
electron
electron
Mm
km
m
mm
µm
nm
pm
fm
Classical physics
Quantum physics
10-6 m
10-7 m
10-8 m
10-9 m
Scales of size and time are closely rerated!
...ms <-
ns
ps
fs
as
Charge transfer
Magnetism
Phonons, lattice dynamics
Electronic excitations, de-excitations
Heating, cooling
Classical physics
Quantum physics

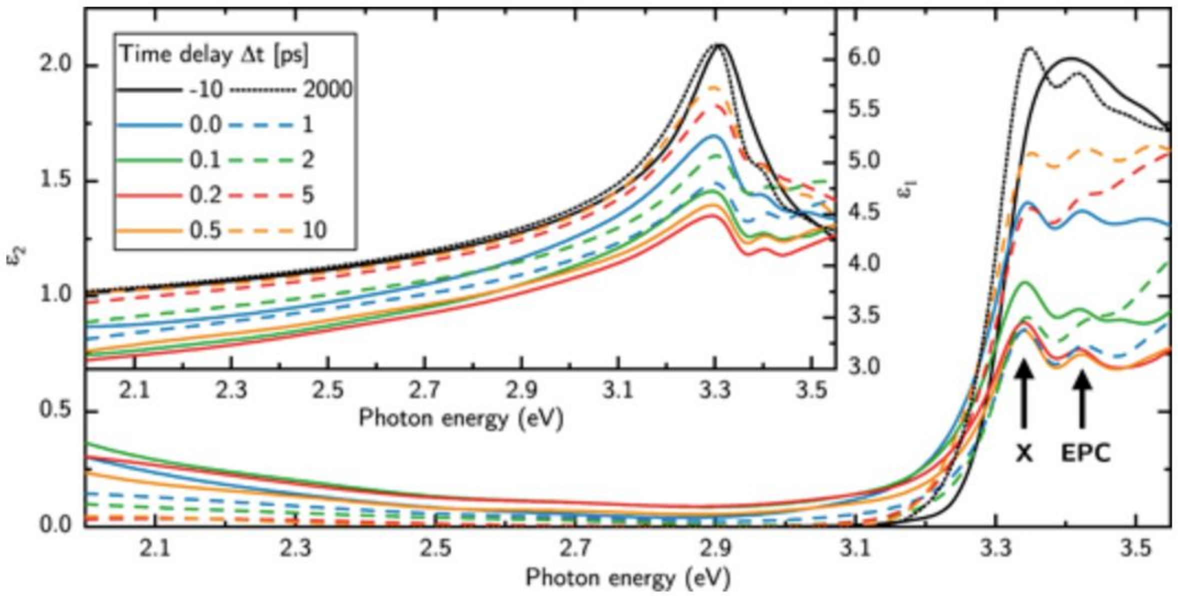

Cell Membrane
Mitochondria
DNA
Nucleus
Ribosomes
Cytoplasm
positron
positron
photon
photon
electron
electron
Mm
km
m
mm
µm
nm
pm
fm
Classical physics
Quantum physics
Corresponding time scales
milliseconds to femtoseconds
10-6 m
10-7 m
10-8 m
10-9 m
Mimivirus
500 nm
Adenine
Thymine
Classical physics
Quantum physics
Essence of life

X-ray radiation

Applications of X-ray sources

CDI, material science, X-ray spectroscopy, ...





Real (ε_1, inset) and imaginary (ε_2, parent figure) part of the DF of the ZnO thin film at selected pump-probe delays.