ELI ALPS Research Institute
New horizons in ultrafast science

Status and user access at the ELI-ALPS Research Institute

Attosecond science at ELI-scale

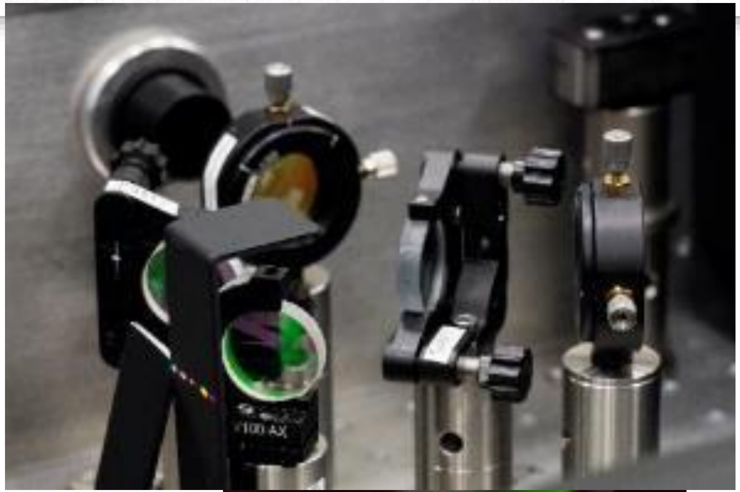
Katalin Varjú
ELI ALPS, Science Director

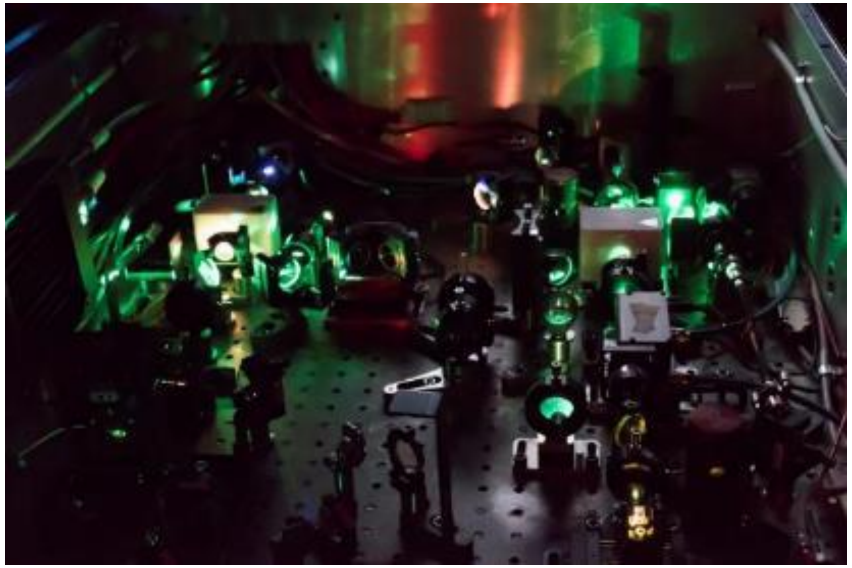
ELISummerSchool 2023

SZÉCHENYI 2020
Hungarian Government
European Union European Regional Development Fund
INVESTING IN YOUR FUTURE

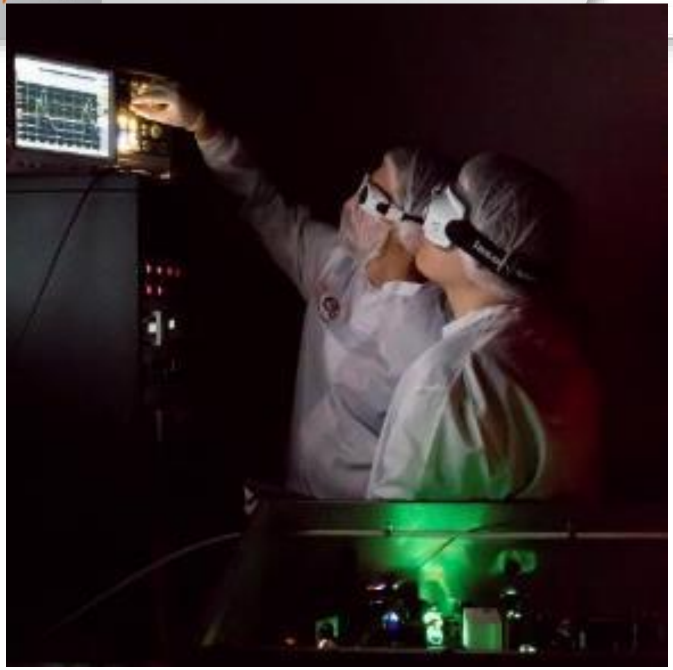
Virtual tour of ELI ALPS I.
modern, custom designed building

Virtual tour of ELI ALPS II.
cutting edge research technology in the laboratories





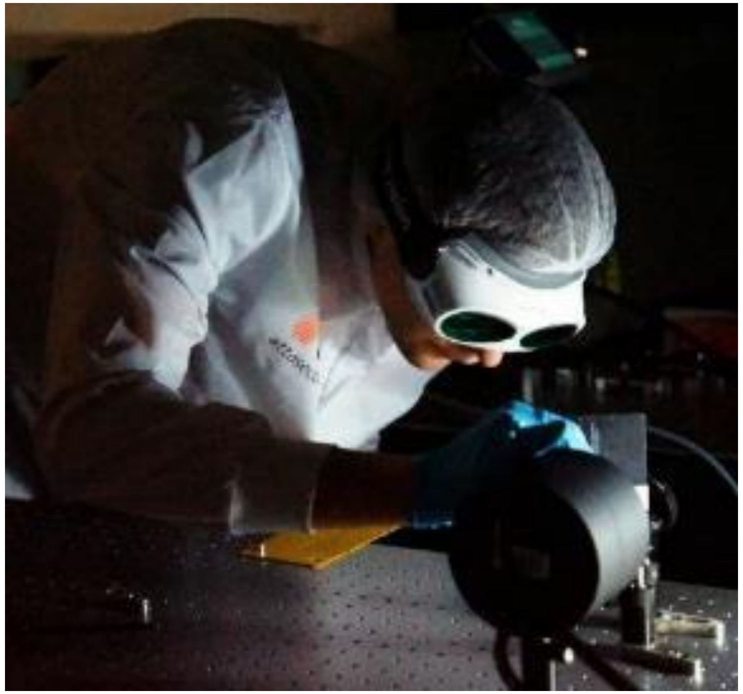
Virtual tour of ELI ALPS III.
motivated, dedicated personnel



Open positions in

Laser science, AMO, condensed matter and plasma physics

@ junior, postdoc and technician level



So what is extreme light?

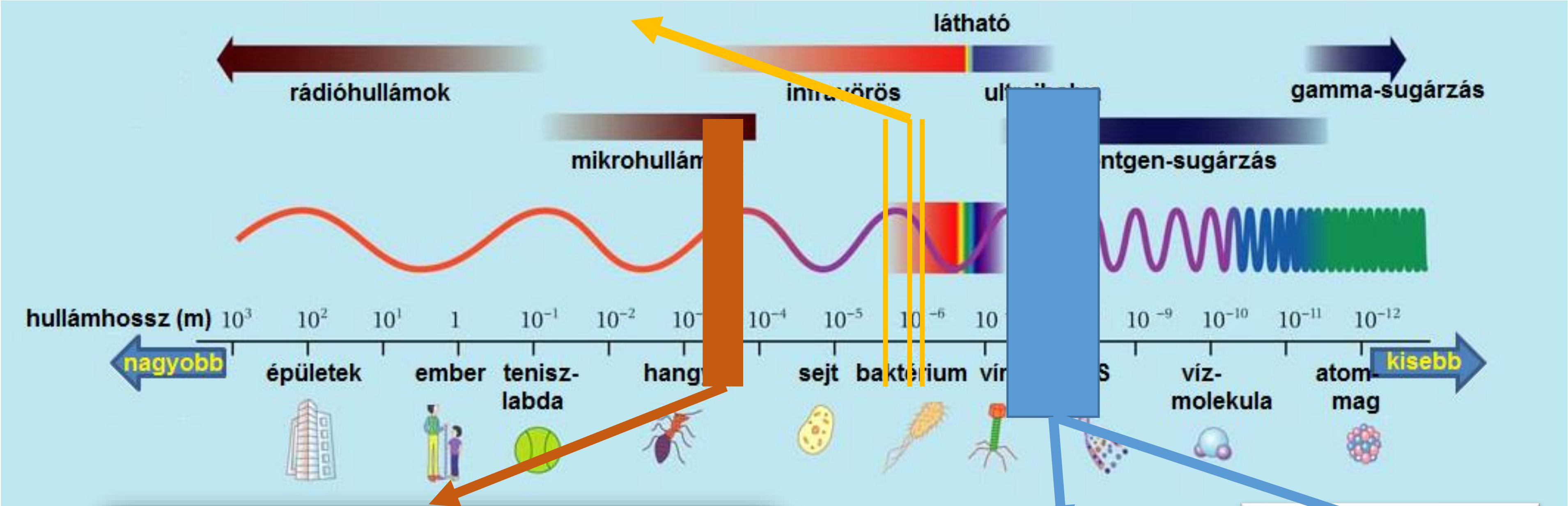
MIR (3.1 µm)
100 kHz, 3 GW

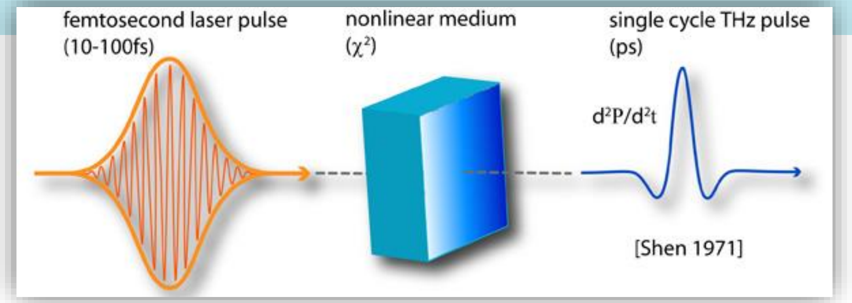
HR (1030 nm)
100 kHz, 1 TW

SYLOS (860 nm)
1 kHz, 20 TW

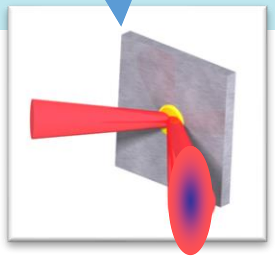
HF PW (800 nm)
10 Hz, 2 PW

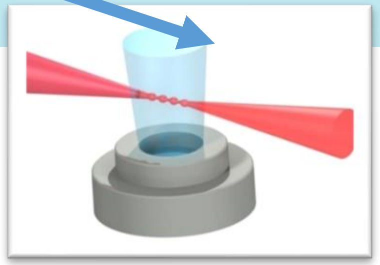
lasers





intense THz pulses

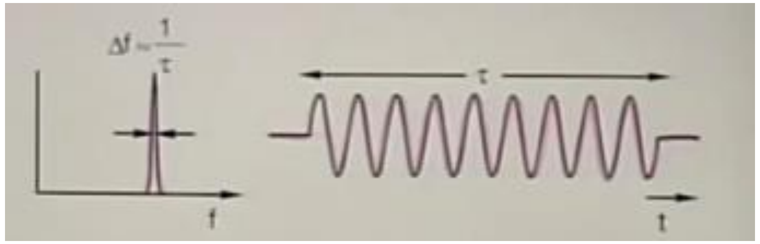




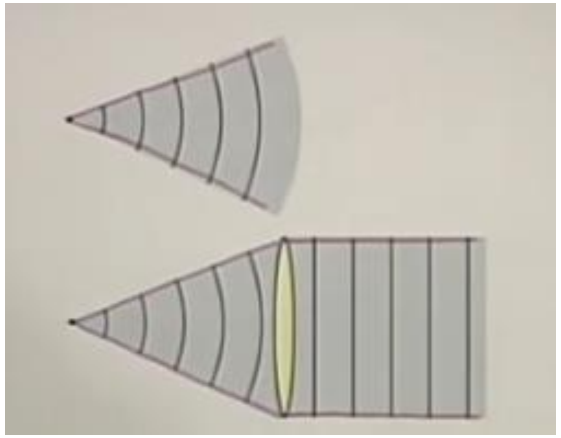
attosecond pulses

LASER = light source with special properties

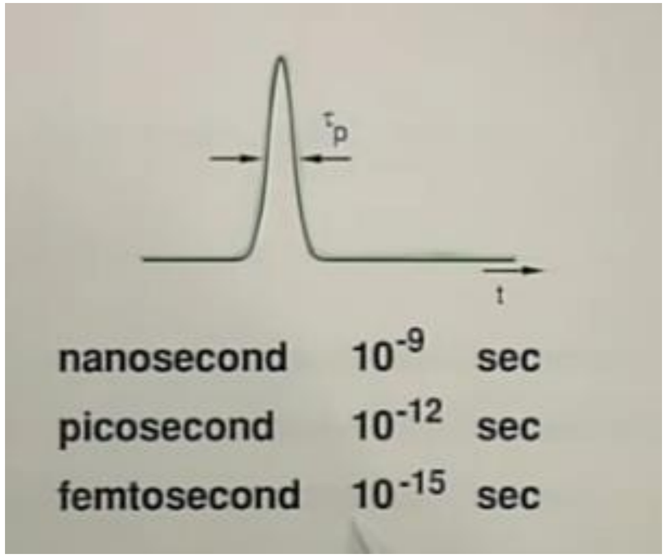
Monochromatic / very good temporal properties

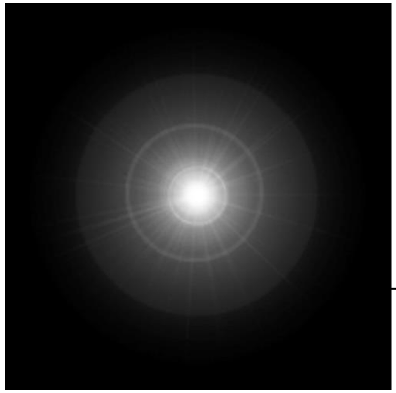


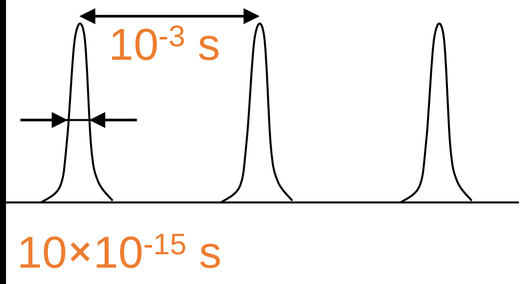
Collimated / very good spatial properties



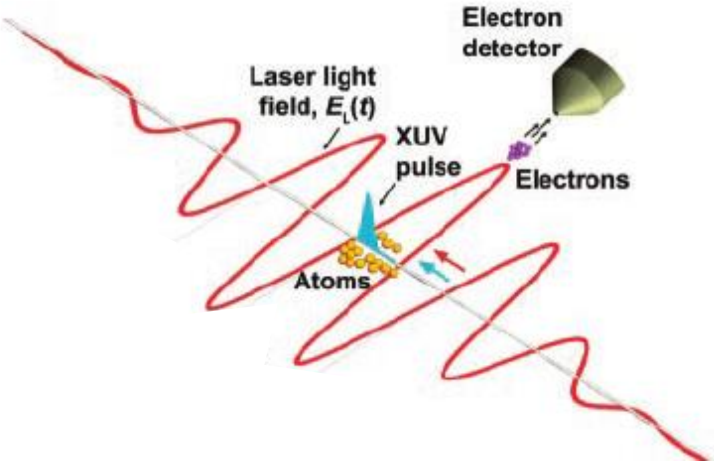
Short bursts



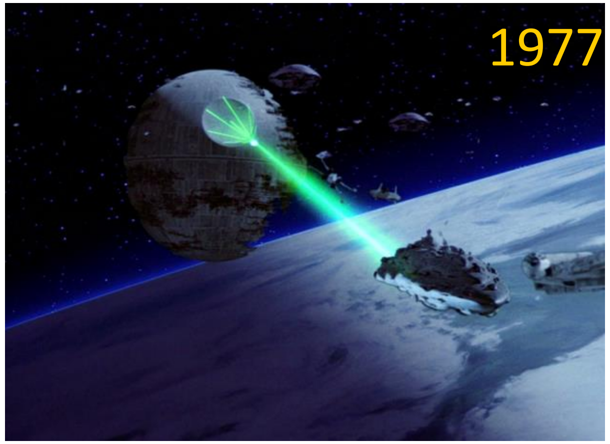




- concentrated energy
- high field strengths
- studying ultrafast processes
- field-induced processes



Laser based technologies



https://en.wikipedia.org/wiki/List_of_laser_applications

Scientific, Military, Medical, Industrial, Commercial etc.

e.g. mobile phone manufacturing

LASER TYPES

- fiber laser
- UV solid-state laser
- solid-state laser
- CO_2 laser
- ultrashort pulse laser
- UV excimer laser
- IR diode laser

MACHINE PROCESS

- edge
- pattern
- area
- holes

Touchscreen

- cutting of extremely thin, hard cover glass
- cutting of touchscreen foil
- structuring of conducting layers

Screen

- generation of polycrystalline layers
- encapsulation of laminated glasses

Battery

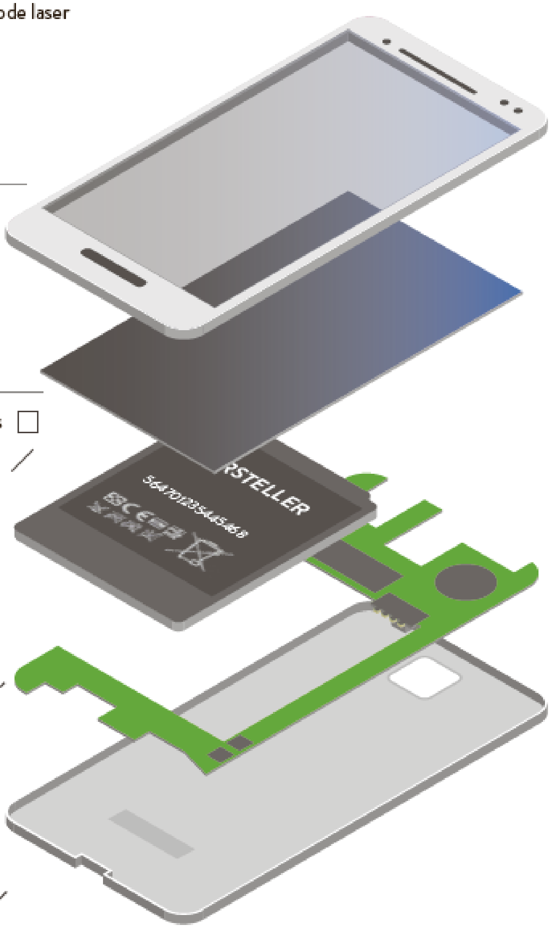
- welding of battery case
- marking logo, data-matrix-code, and serial number

Circuit board

- structuring of conductor tracks
- cutting of foil circuit boards
- drilling of contact holes

Housing

- cutting of housing
- marking logo and serial number



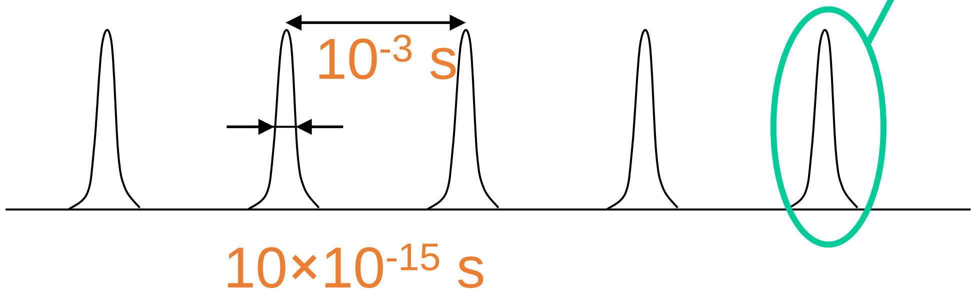
ELI lasers have extreme high peak powers

$$P = \frac{E}{t}$$ power

$E = 50$ mJ

$\tau = 10$ fs

1000 Hz



$$P = \frac{E}{\tau} = 5\cdot10^{12}\ \text{W} = 5\,\text{TW}$$

peak power

x2600

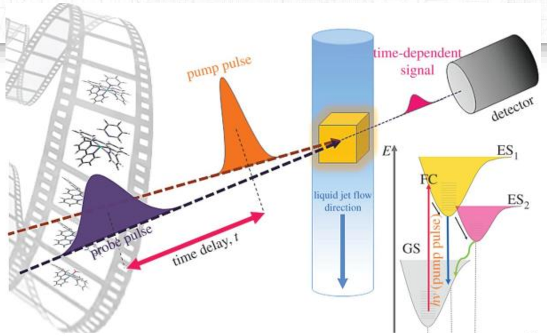
defines strength of interaction

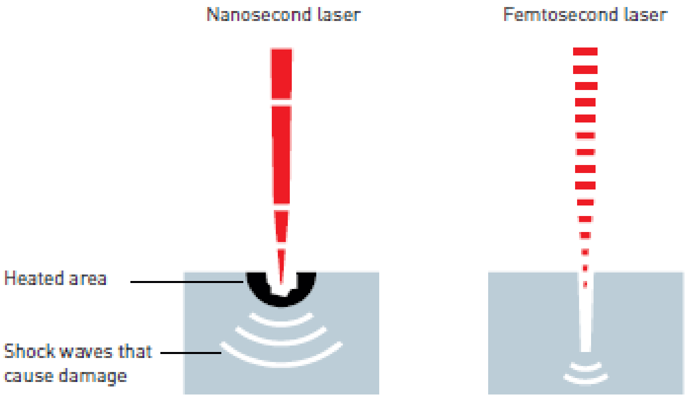
electric field strength can be billion times stronger than Coulomb field attaching electron to nucleus

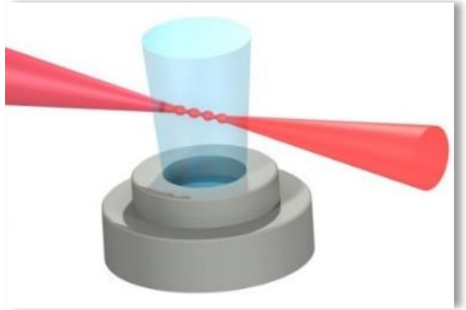
What is inside the laser boxes?

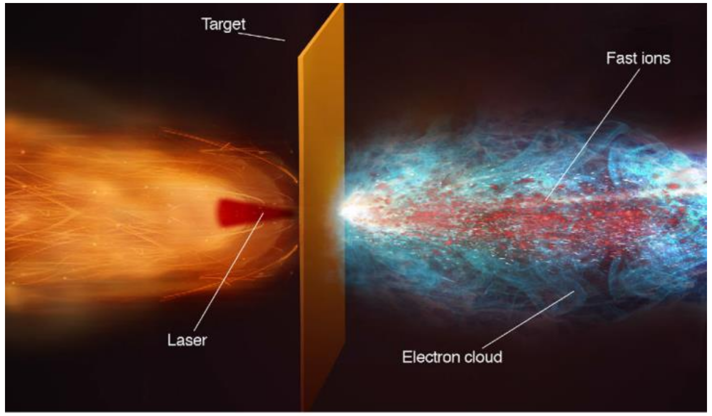
Applications of short /intense laser pulses

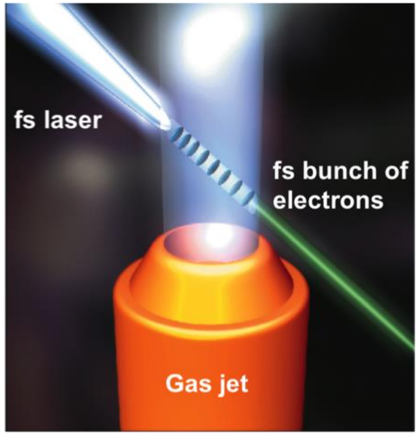
- **studying fast chemical dynamics (femtosecond pump-probe)**
- material processing
- attosecond pulse production
- studying electron dynamics (attosecond pump-probe)
- particle acceleration (electron, proton)
- radiobiological effect of pulsed radiation
- plasma dynamics
- laboratory astrophysics
- initiating fusion
- …



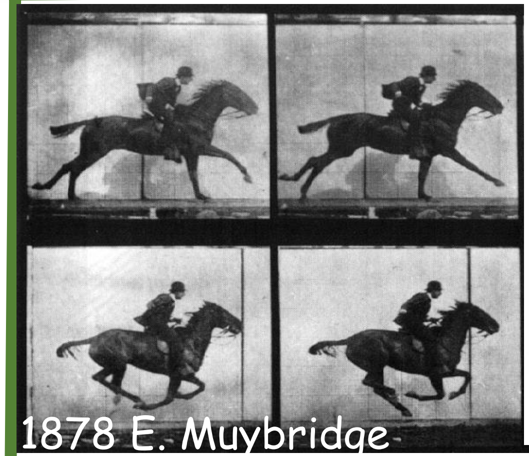


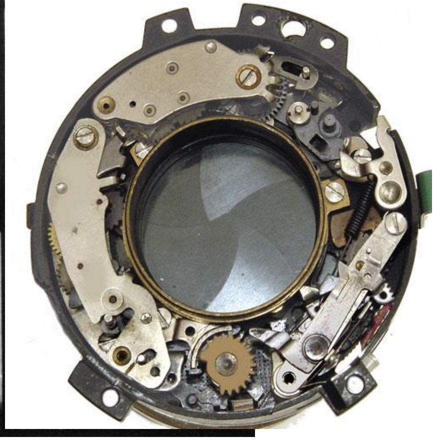






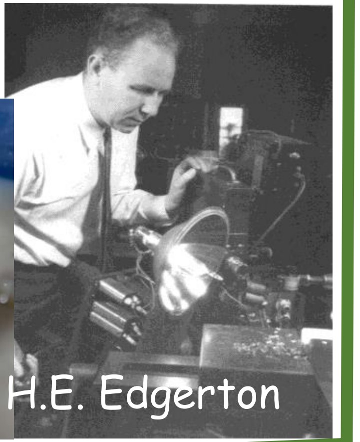
Study/ Representation of dynamics

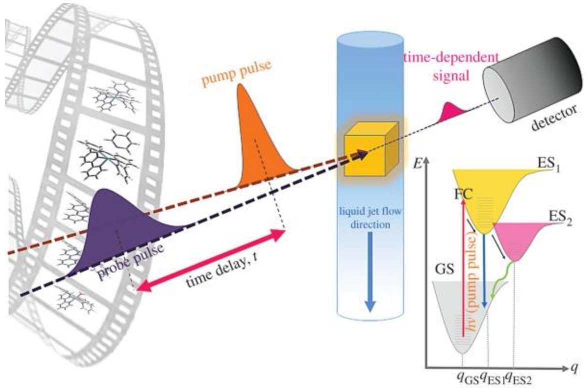

1878 E. Muybridge



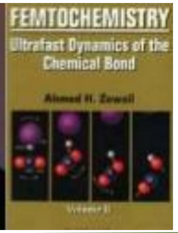
mechanical
shutter: ms

electronically
synched flash: µs-ns

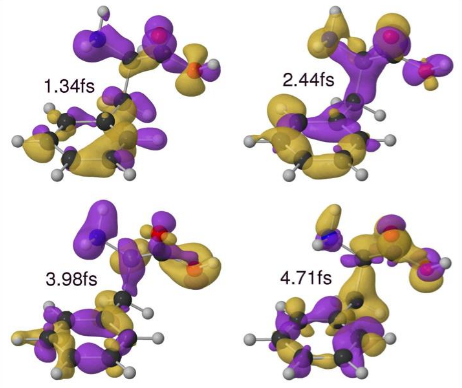

1937 H.E. Edgerton




1999

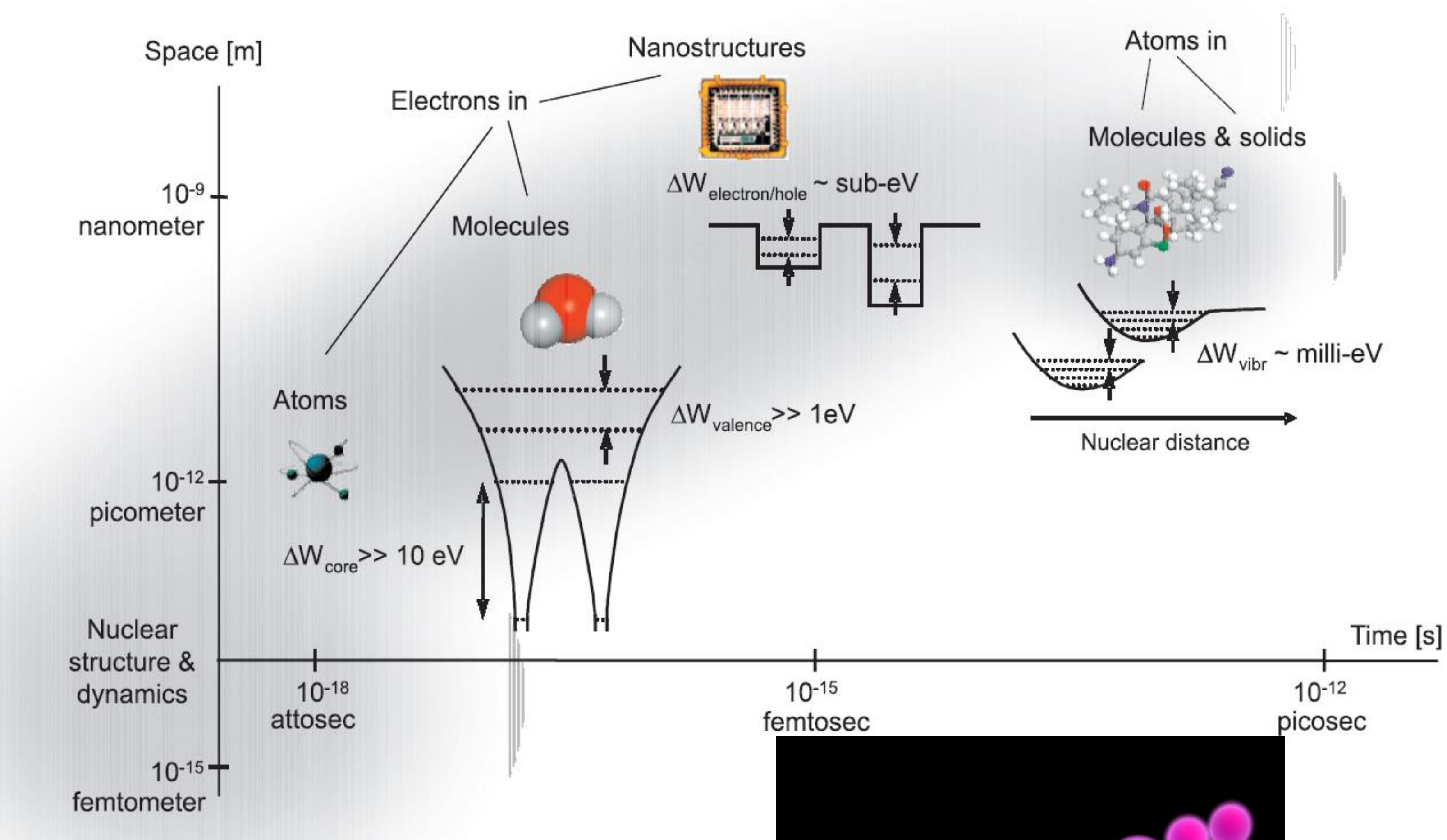


laser
pump-probe
ps – fs – as

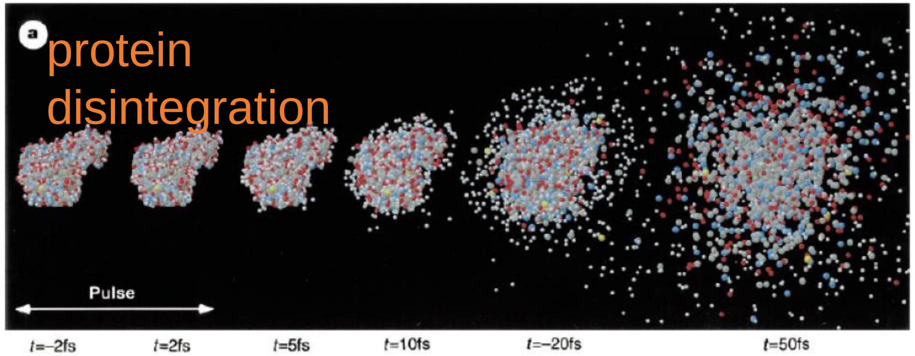


charge redistribution in phenylalanine

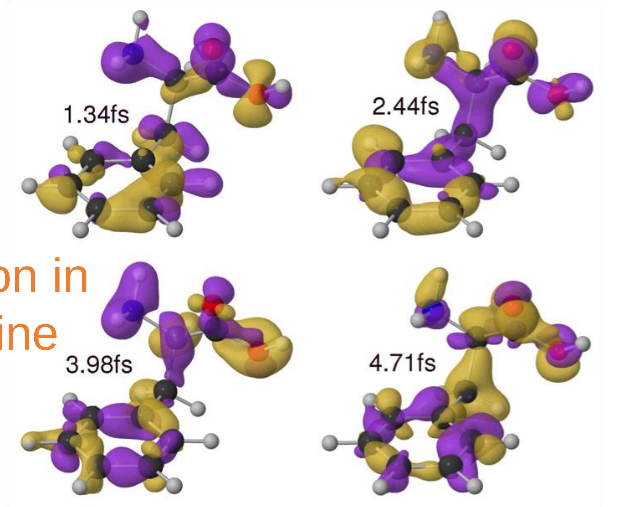
Characteristic time - characteristic size

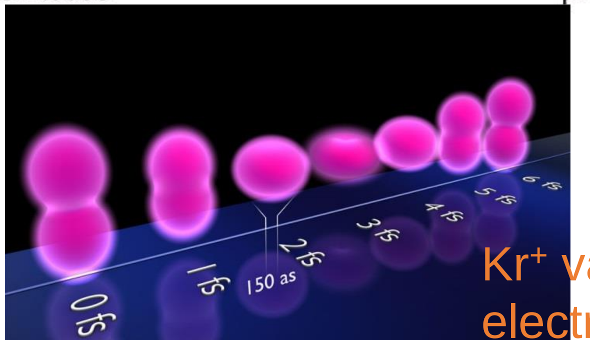


F. Krausz, M Ivanov, Rev Mod Phys **81**, 163 (2009)



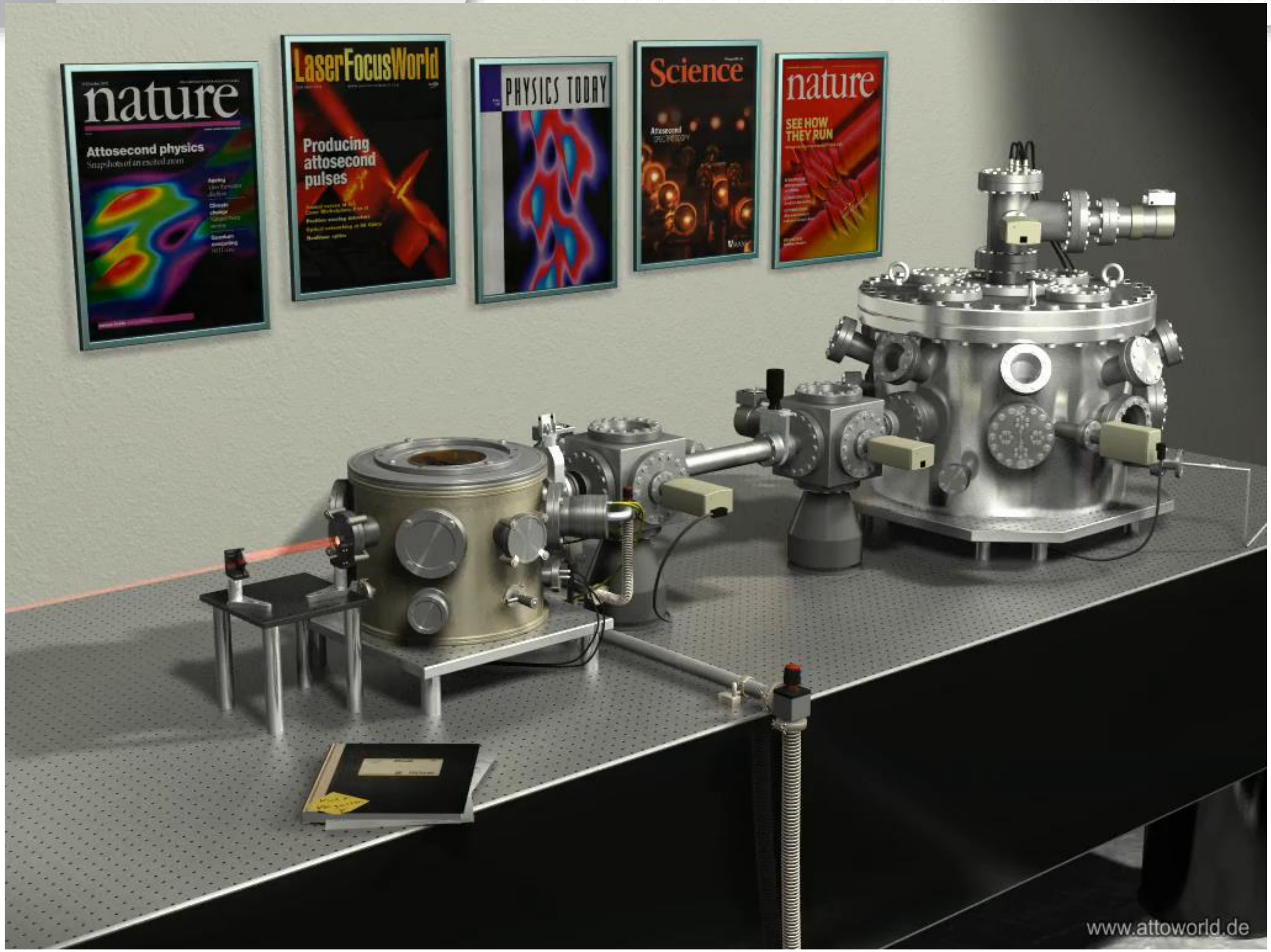
charge redistribution in phenylalanine





Kr^+ valence electron orbits

An attosecond experiment – the scheme



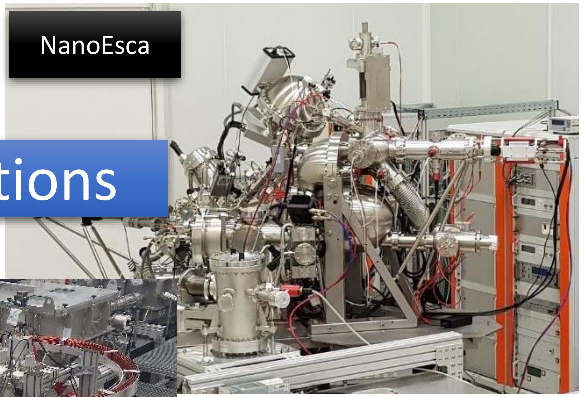
www.attoworld.de

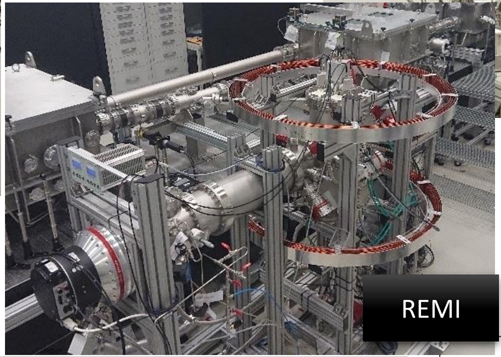
Portfolio of research opportunities
Capacity, Capability and Uniqueness

Lasers

Endstations

NanoEsca





REMI

SeSos

Simulation tools

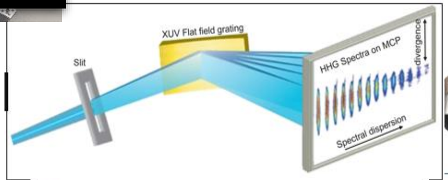
Simulation tools in intense laser matter interaction

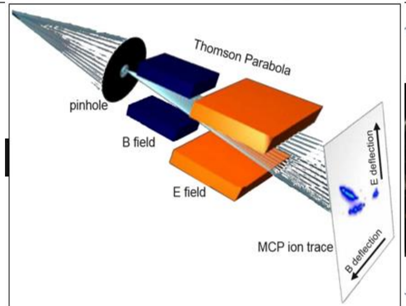
10^{12-16} | 10^{16-17} | 10^{17-23}

Hydrodynamic codes	Particle In Cell (PIC)	Simplified PIC
ESTHER MULTI-fs CHIC CRASH	WARPX OSIRIS EPOCH LPIC PIConGPU	WAKE CALDER-CIRC
Ionisation, Pre-Plasma formation, Plasma fluid expansion	Charge dynamics (particle acceleration), Plasma field dynamics (absorption, HHG)	

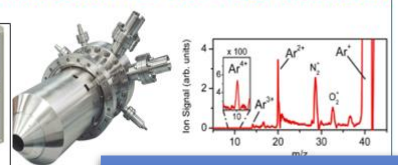
Featured in p19-20 https://hpc.kifu.hu/sites/default/files/2021-06/HPC_Echo_2021.pdf

Metrology

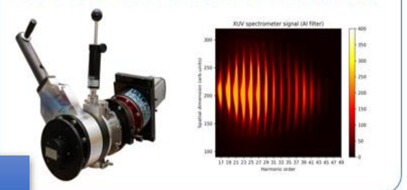




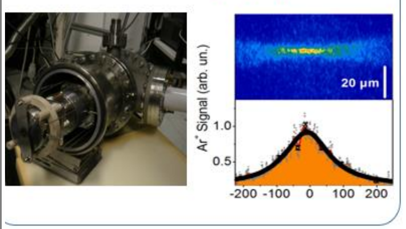
Electron/Ion TOF (5x + high resolution)



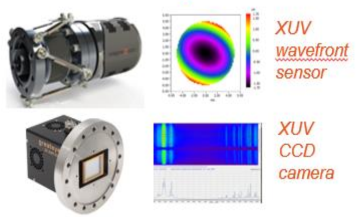
XUV/VUV Photon spectrometer (5x)



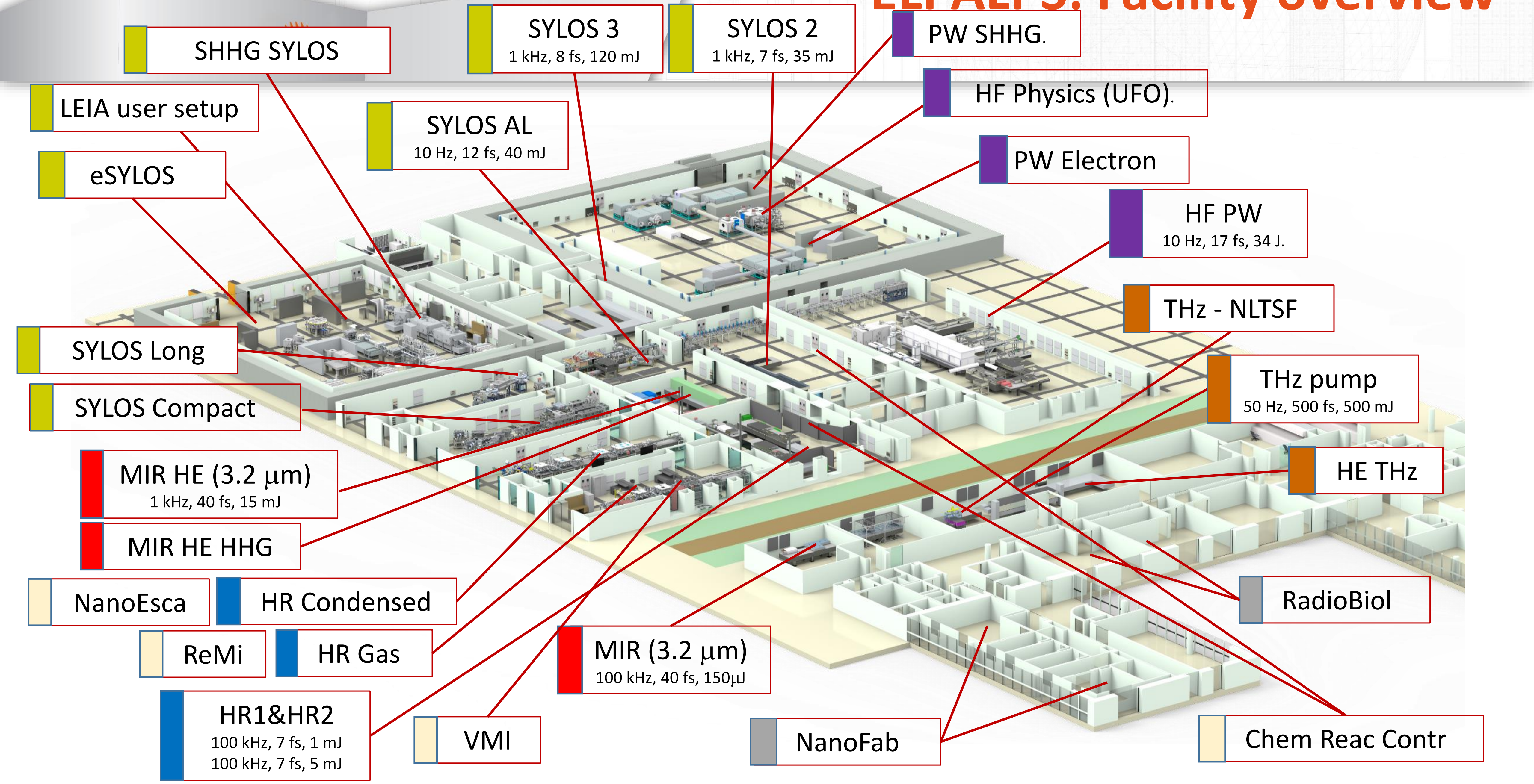
Ion Microscope (2x)



Beam diagnostics



ELI ALPS: Facility overview



List of Lasers

	(Target) Specifications
HR1	100 kHz, 30 fs, 1.8 mJ 100 kHz, <7 fs, 1 mJ
HR2	*100 kHz, <6 fs, 5 mJ, CEP*
HR Alignment	*1 kHz, 7 fs, 1 mJ*
MIR	100 kHz, <42 fs, 130 μJ, CEP 100 kHz, <20 fs, 70 μJ, CEP
MIR-HE	*3.2um, 1 kHz, CEP, <50 fs, 20 mJ or <25fs, 10 mJ* *1.6um, 1 kHz, CEP, <100 fs, 12 mJ*
SYLOS 2	1 kHz, <7.5 fs, >30 mJ (flat top), >24 mJ (Gaussian), CEP
SYLOS 3	*1 kHz, <8 fs, >120 mJ, CEP*
SYLOS Alignment	10 Hz, <12 fs, >40 mJ
SYLOS Alignment 2	*10 Hz, 15 fs, 40 mJ*
HF PW	*10 Hz, <17 fs, 34 J* 2.5 Hz, 25 fs, 10 J
THz Pump	1 kHz, 100 fs, 4 mJ 50 Hz, <0.5 ps, 0.5 J, synch

100 kHz, 1 kHz, 10 Hz, single shot

850 nm, 1030 nm, 3.2 μm

150 μJ, 1 mJ, 30 mJ, 30 J

most few cycles

many CEP-stable

List of Secondary Sources

Secondary Source	Specifications
GHHG HR1 & 2 GAS (LTA4)	>270 pJ @ generation, >50 pJ on target; 166 as; @100 kHz; 30-70 eV
GHHG HR1 & 2 CONDENSED (LTA3)	current status 270 pJ @ generation XUV monochromator installed incl. time-compensation stage
GHHG SYLOS COMPACT (LTA2)	400 nJ @ generation in Ar, ~1 μJ in Xe
GHHG SYLOS LONG (LTA1)	400 nJ @ generation in Ar, ~1 μJ in Xe
SHHG SYLOS (MTA)	In commissioning
SHHG PW (HTA)	In commissioning
MIR HE GEN ATTO	In commissioning
NLTSF / THz SPECTROSCOPY (THz)	energy: 10 μJ at source, 5 μJ at sample; useful spectral content: 0.15-2 THz; peak THz field at sample: ≥450 kV/cm
THz HIGH ENERGY (THz)	energy ~ 1 mJ, @50 Hz useful spectral content 0,15 – 1,5 THz
ELECTRON SYLOS (MTA)	In commissioning
ELECTRON PW (HTA)	In commissioning

XUV – X-ray attosecond pulses

THz pulses

electron accel.

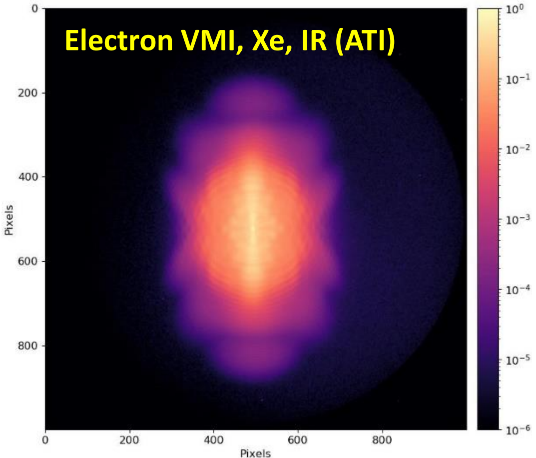
List of experimental stations

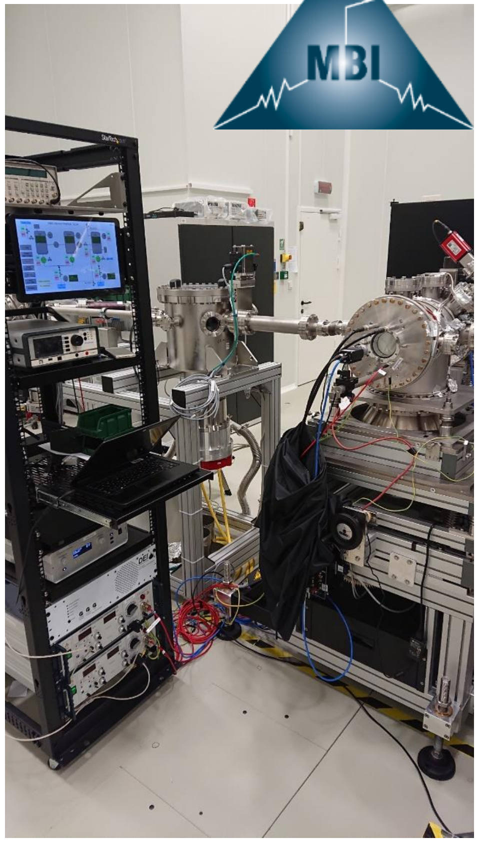
Experimental Stations	(*Target*) Capabilities
REACTION MICROSCOPE / COLTRIMS	Coincidence measurements @ 100 kHz
VMI SPECTROMETER ENDSTATION	Velocity map imaging, reconstruction capabilities, installed on HR GHHG and MIR
CONDENSED MATTER STATION (NANOESCA)	PEEM with spin filter, operated with internal VUV source, CEP stable oscillator, IR-XUV
MAGNETIC BOTTLE e SPECTROMETER – collab FORTH	Specifically developed for the SYLOS GHHG Compact beamline within Impulse
NANOFABRICATION	electron beam lito + focused ion beam
NANOSCIENCE: time resolved ELLIPSOMETRY	Light induced processes on solid surfaces, involving changes in the electron distribution of the sample
NANOSCIENCE: Scanning Nearfield Microscope	Mapping optical near-field of illuminated samples in different excitation geometries (reflection and transmission)
LIDT and LASER MACHINING test station	Mobile station to study laser machining / damage process dynamics
CHEMICAL REACTION CONTROL STATIONS (GPRC; TAS)	transient absorption setup for condensed samples on HR + gas phase reaction control on SYLOS
LIQUID JET ENDSTATION – collab LMU	Liquid target for laser for XUV illumination, equipped with photon spectrometer.
MULTIDIMENSIONAL SPECTR. (femtobiology) – collab BRC	Variable excitation and detection for transient absorption measurements on biological samples
RADIOBIOLOGY / BIOMEDICAL LAB	Standard biology toolset, zebrafish embryo test model, radiobiology toolset (irradiator, dosimetry)
eSYLOS IRRADIATION FACILITY (biol, chem, phys samples)	Mobile instrument for interdisciplinary studies with pulsed irradiation, including dosimetry
eSYLOS X-RAY GENERATOR	Ultrafast soft X-ray spectroscopy station
HIGH FIELD PHYSICS STATION (PW)	Multipurpose high-field physics station, using gas, liquid and nano-foil and nano-photonic structured targets
CHEMICAL PREP LAB	Standard chemistry toolset

Experimental stations for gas phase studies

VMI-ES

to obtain energy- and angle resolved information on ions and electrons resulting from the photoionization or photofragmentation of atoms, molecules or nanoparticles

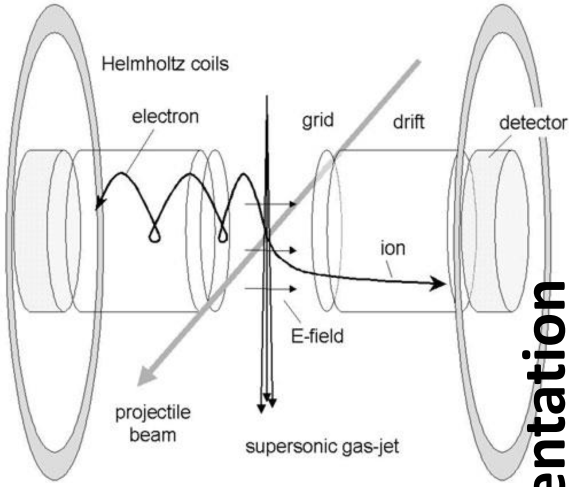


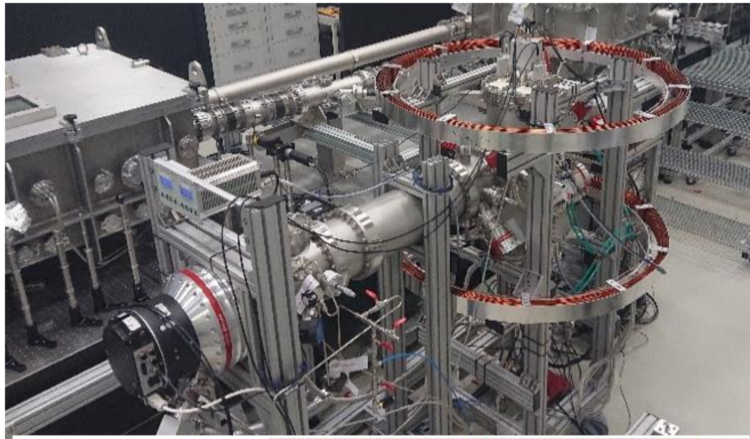


ReMi / Coltrims

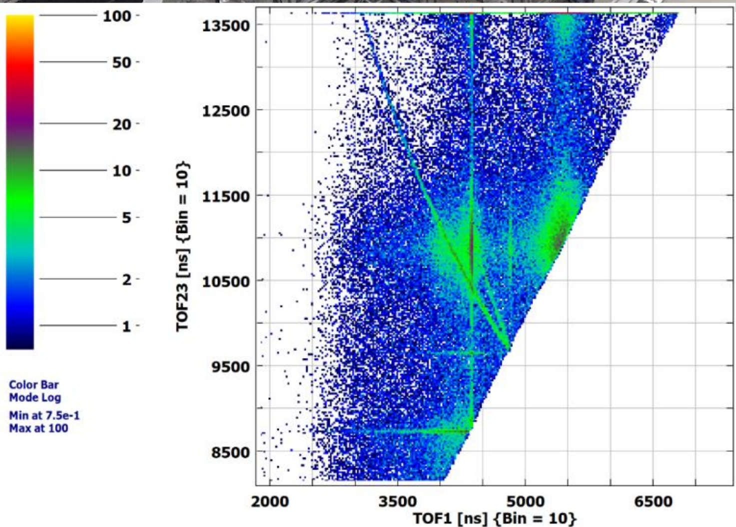
Kinematically complete experimental study of ion and electron fragments detected in coincidence

RoentDek Handels GmbH
UHV-Detectors
Supersonic Gas Jets
Multifragment Imaging Systems

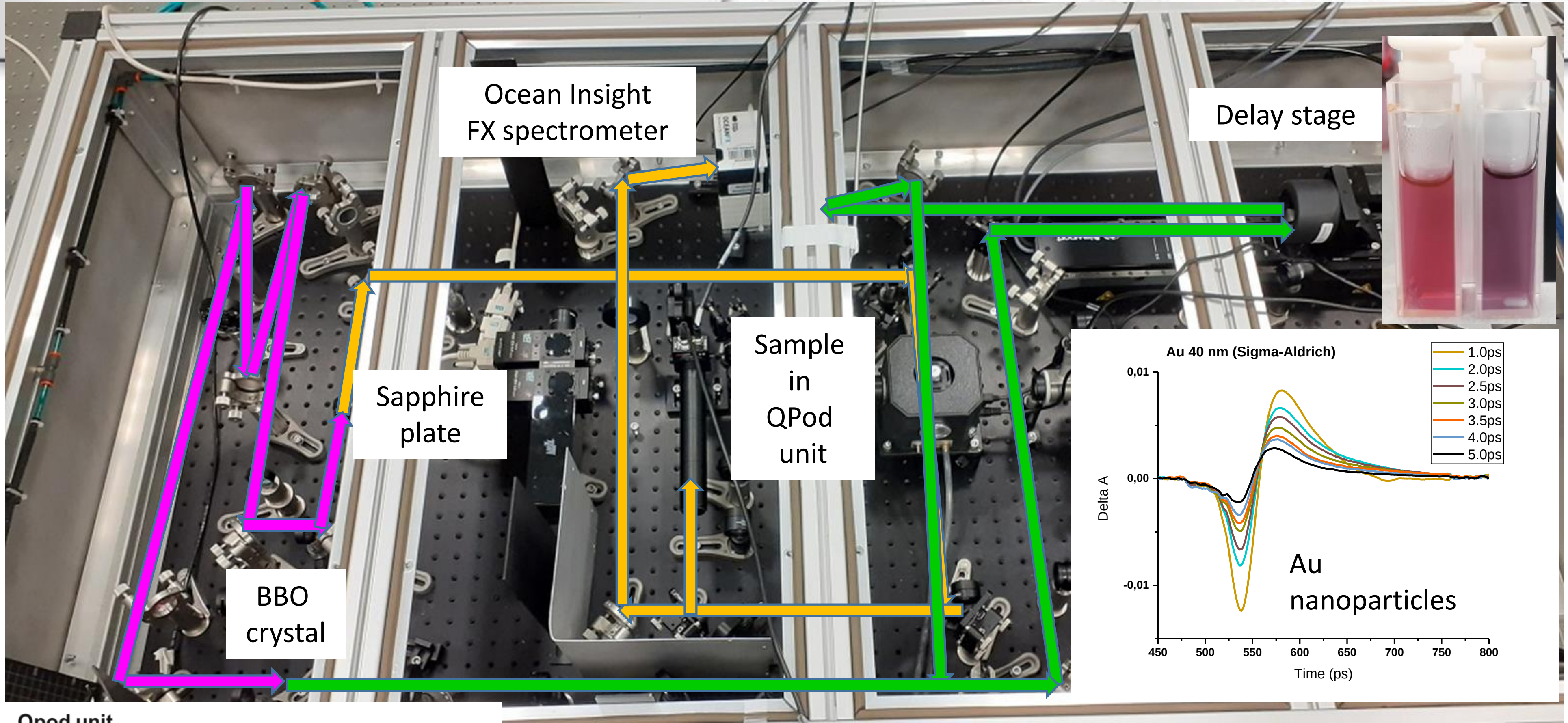


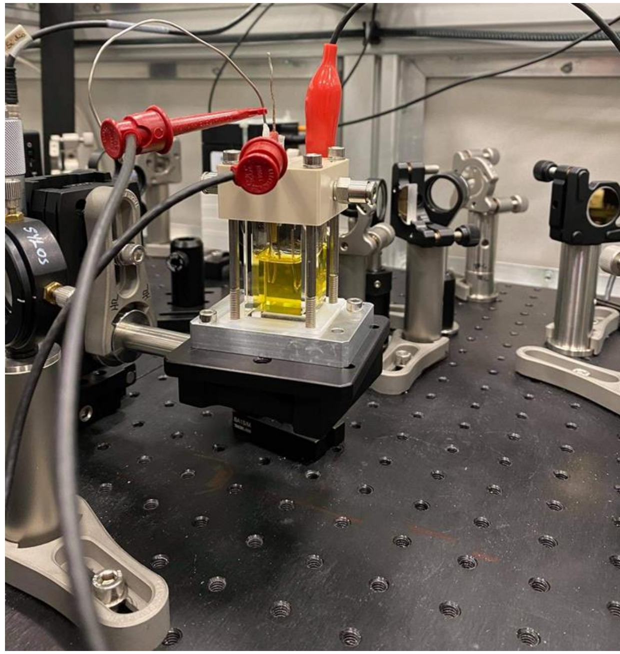


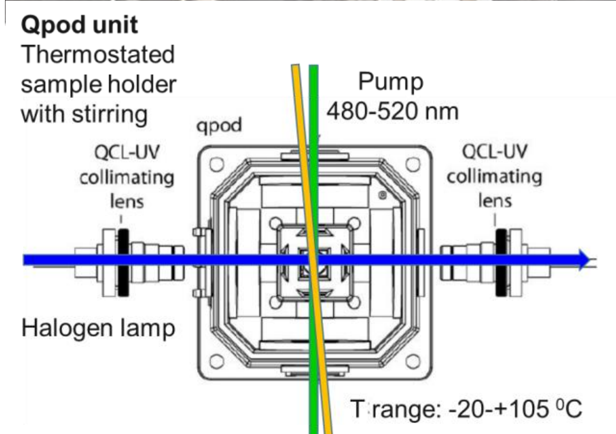
CO_2 fragmentation

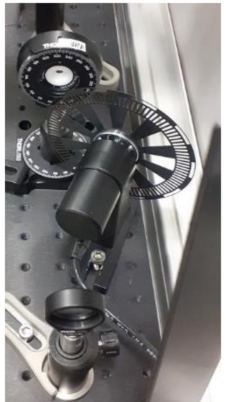


Transient Absorption Spectrometer (TAS) setup

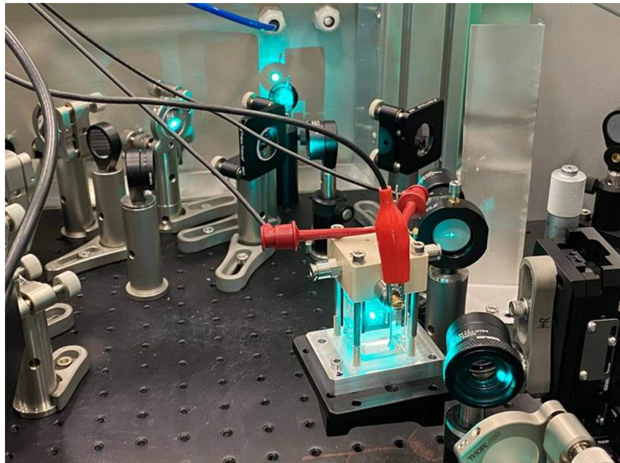




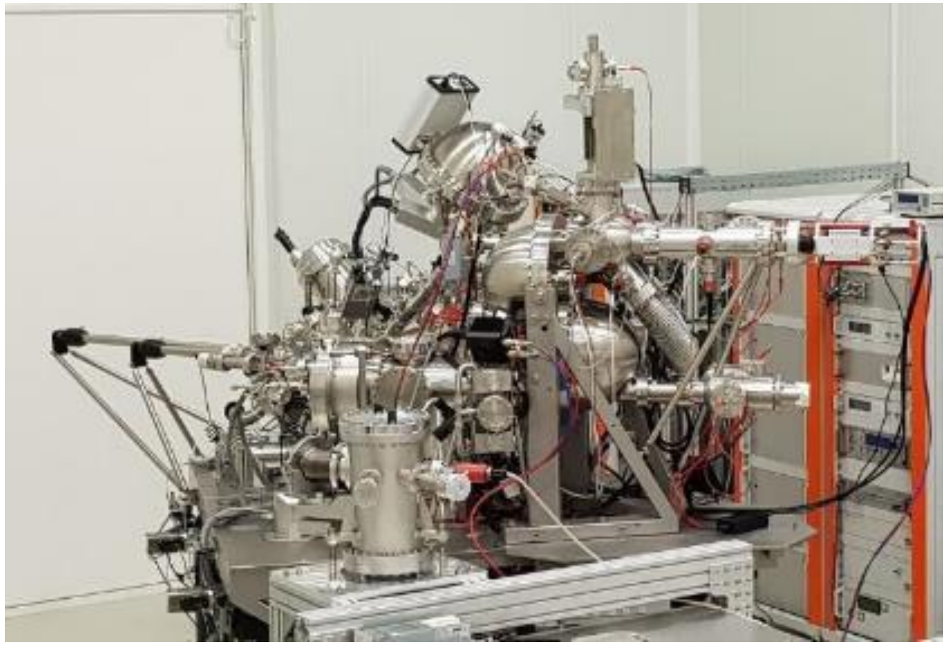




White light (probe beam) generation with sapphire plate
Green or UVC light (pump beam, SH) generation with BBO crystals (~25-40 fs, 100 kHz)
Optical chopper used at 6 kHz for Lock-in measurements and 2 kHz for measuring the spectra

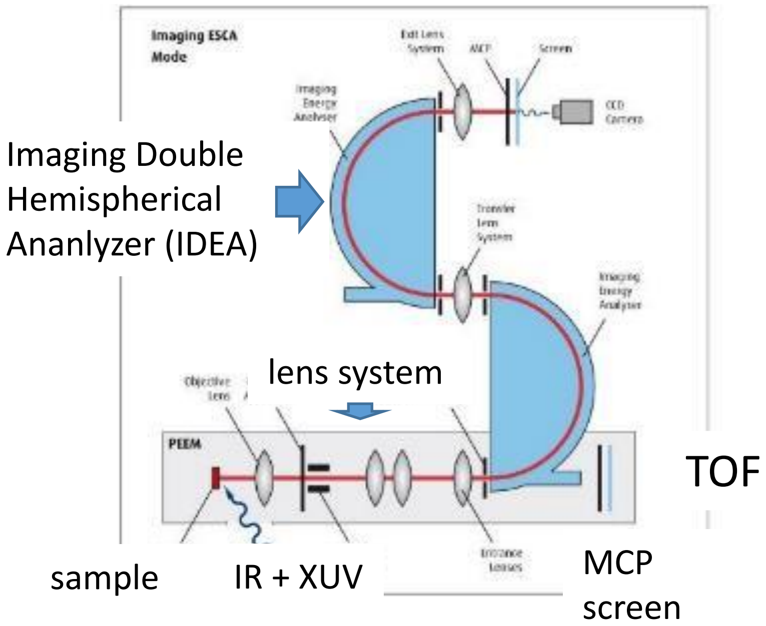


Condensed matter / surface science: NanoESCA endstation



scientaomicron

Spin domains on an iron plate
(recorded at ELI w Hg lamp)



M. Escher et al., J. Phys.: Condens. Matter 17 (2005) S1329

Core capabilities:

- Photoemission Electron Microscopy (PEEM) mode: laterally resolved microscopy of the sample surface
- Imaging Photoelectron Spectroscopy mode: lateral and energy resolution
- Momentum microscopy: imaging of the momentum space with energy resolution
- Spin dependent imaging in both real and momentum space with a state-of-the-art Au/Ir(100) imaging spin filter

D. Vasilyev et al., J. Electron Spectr. Relat. Phenom. 199 (2015) 10

Time-resolved NanoESCA constant energy slices on Rh(111) in momentum space

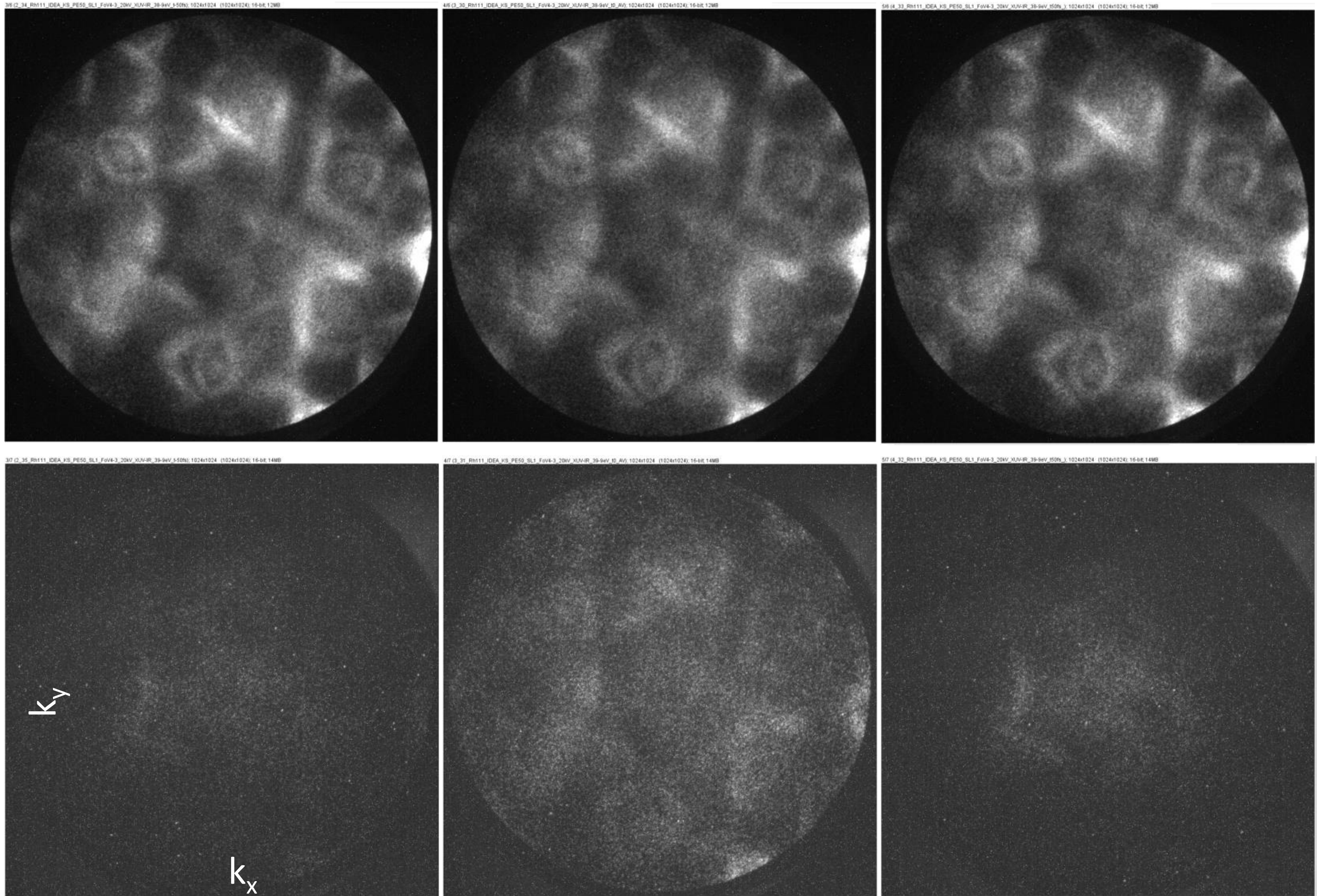
delay (IR-XUV): -50 fs | 0 fs | 50 fs

$E-E_F$= 38.9 eV

occupied state below Fermi-edge

$E-E_F$= 39.9 eV

excited state above E_F



photon energy: ~39.6 eV (monochromatized 33rd harmonics)

- First time resolved studies in momentum space by the NanoESCA end station.
- At t_0 excited states are populated by the NIR pump, and probed by XUV.
- The excited state relaxation was monitored as a function of delay.

THANK YOU FOR YOUR ATTENTION!

ELI ERIC User Call(s)

https://www.eli-laser.eu
https://up.eli-laser.eu/

2nd call under implementation
3rd call to open in September, 2023

Contact us at
https://www.eli-alps.hu
user.office@eli-alps.hu

SZÉCHENYI 2020

HUNGARIAN GOVERNMENT

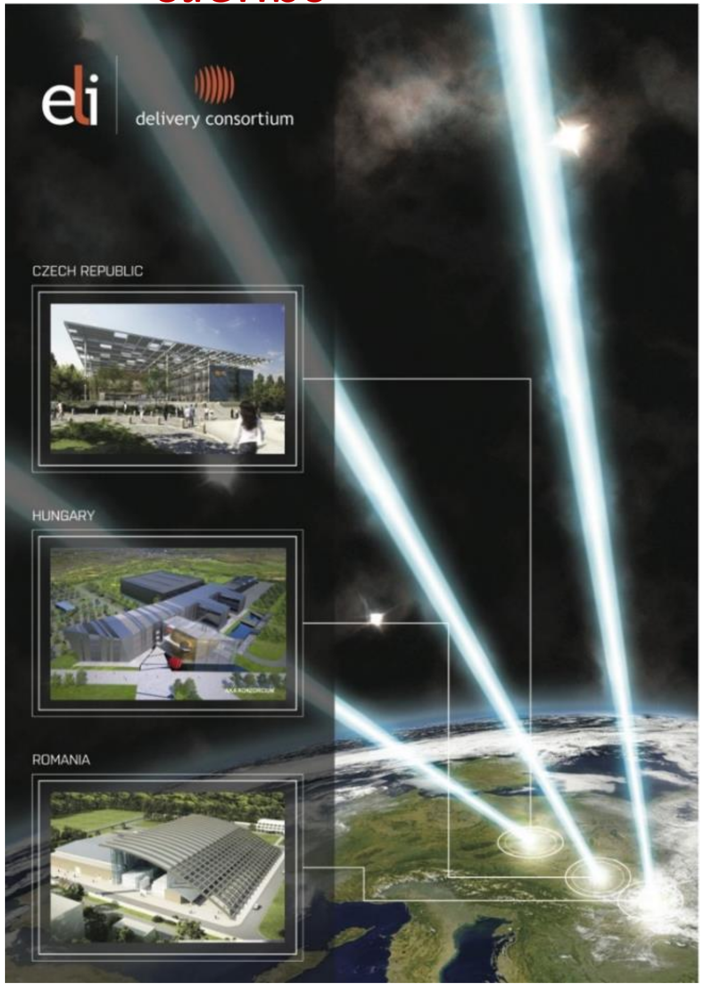
European Union
European Regional Development Fund

INVESTING IN YOUR FUTURE

The ELI project: a distributed research infrastructure

links to Research

ELI ALPS in the knowledge square



ELI MISSION:

- To strengthen Europe’s leading role in laser physics.
- Create worldwide collaboration network in science.
- **Pushing the frontiers of science**.
- **User facility for researchers of various disciplines** (physics, chemistry, material science, radiobiology, etc).
- Provide access to state-of-the-art technology.
- (in commissioning phase)

ELI ALPS in the knowledge square

The ELI project & Uni Szeged
links to Education

Mutual benefits:

- **Locally trained personnel** for ELI ALPS
- **Exposing students** (MSc, PhD) to a world-class **research environment**.
- Attracting international research collaborations to Szeged.
- Interdisciplinary research activities between ELI and Uni Szeged (Transmutation, Medicine, etc.)

ELI ALPS in the knowledge square

The ELI project & Science Park
links to Innovation&Technology

from abandoned military base to

high tech Science Park

ELI ALPS acts as

- a condensation nucleus to **attract companies to the region with I&T profile (3-5 thousand jobs in 15 years)**
- share core facilities, research technology
- need of state-of-the-art laser technologies, **financing laser/photonics industry development**
- **contribute to industrial development via results of in-house + user research**

The ELI project & dissemination activities

links to civil society

ELI ALPS in the knowledge square

To **increase public awareness for research achievements**.
To **increase the attractiveness of science and research careers** for the younger generation.