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DESY.

European XFEL

EXZELLENZCLUSTER
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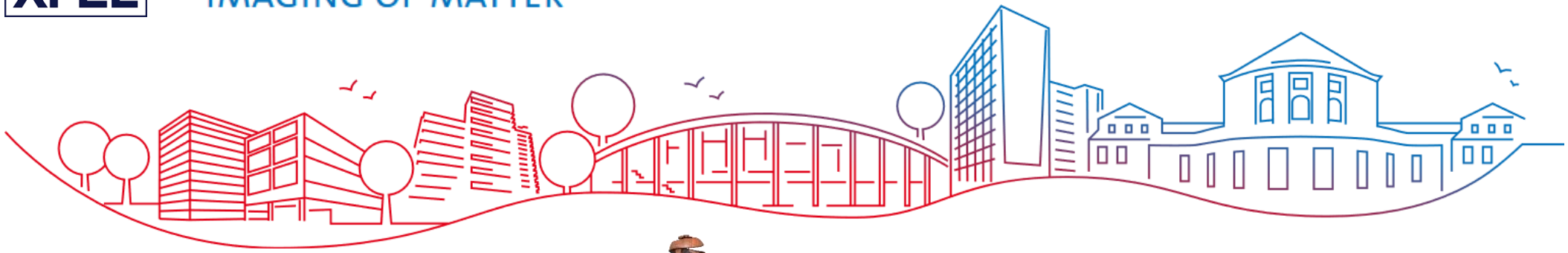
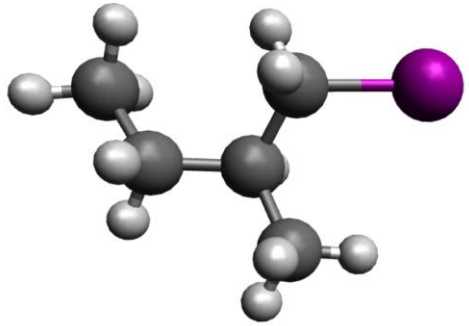
Exploring ultrafast processes in chiral molecules site-specifically



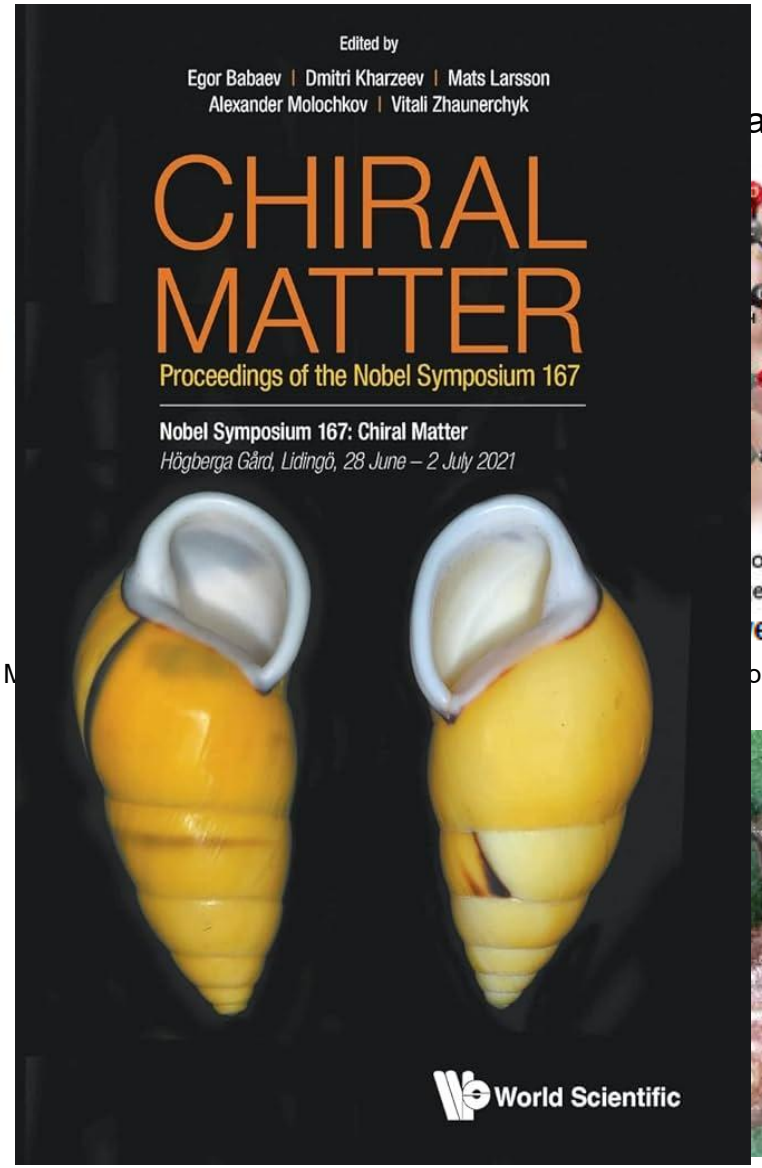
ELI Workshop on Ultrafast Science
12th of February 2026
European XFEL, Germany



Prof. Dr. Markus Ilchen
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Institute for Experimental Physics, University of Hamburg
Deutsches Elektronen-Synchrotron DESY – FS-FLASH
Guestscientist at European XFEL (SQS – Meyer et al.)

Chirality – A mysterious and exciting topic



armaceuticals

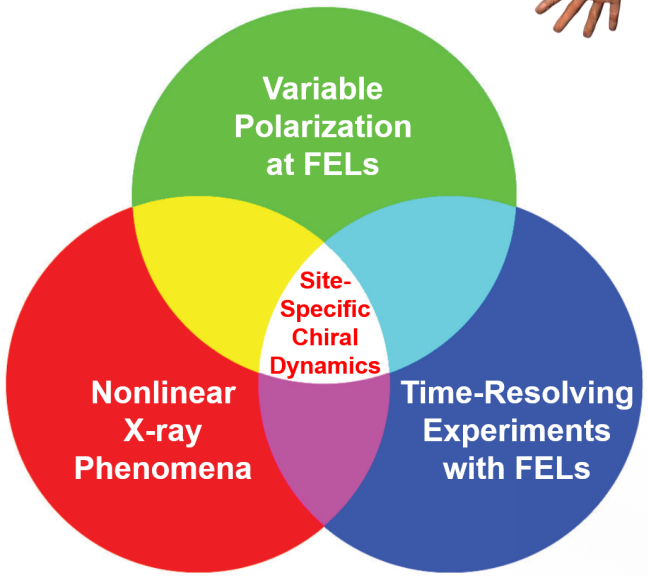
ear; ~50% chiral drugs

oscopy, Netherlands, April 2016

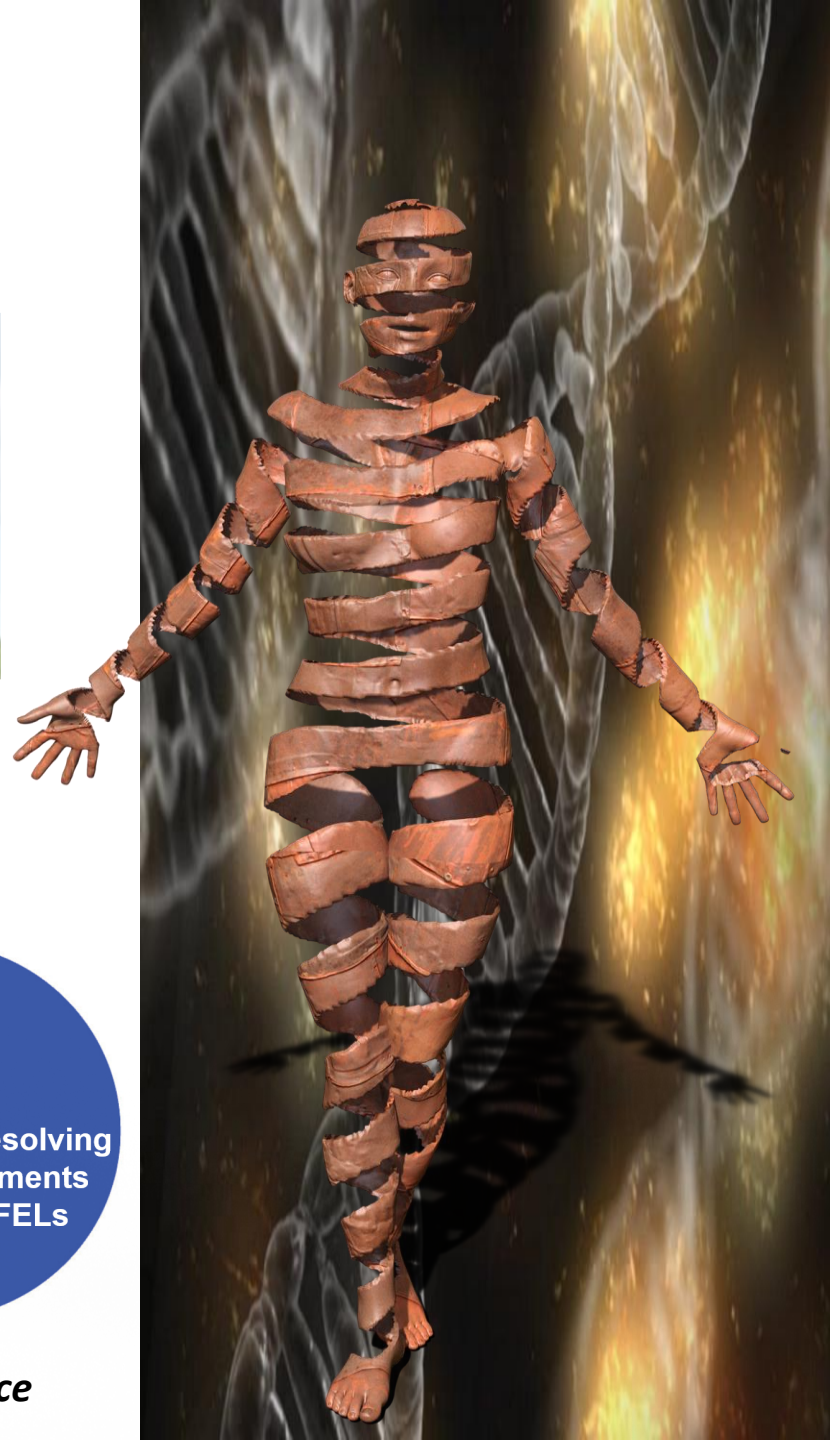
Agrochemicals

Astrobiology Magazine (2009)

•DOI:10.1093/jhered/esp058



A new topic for X-ray science

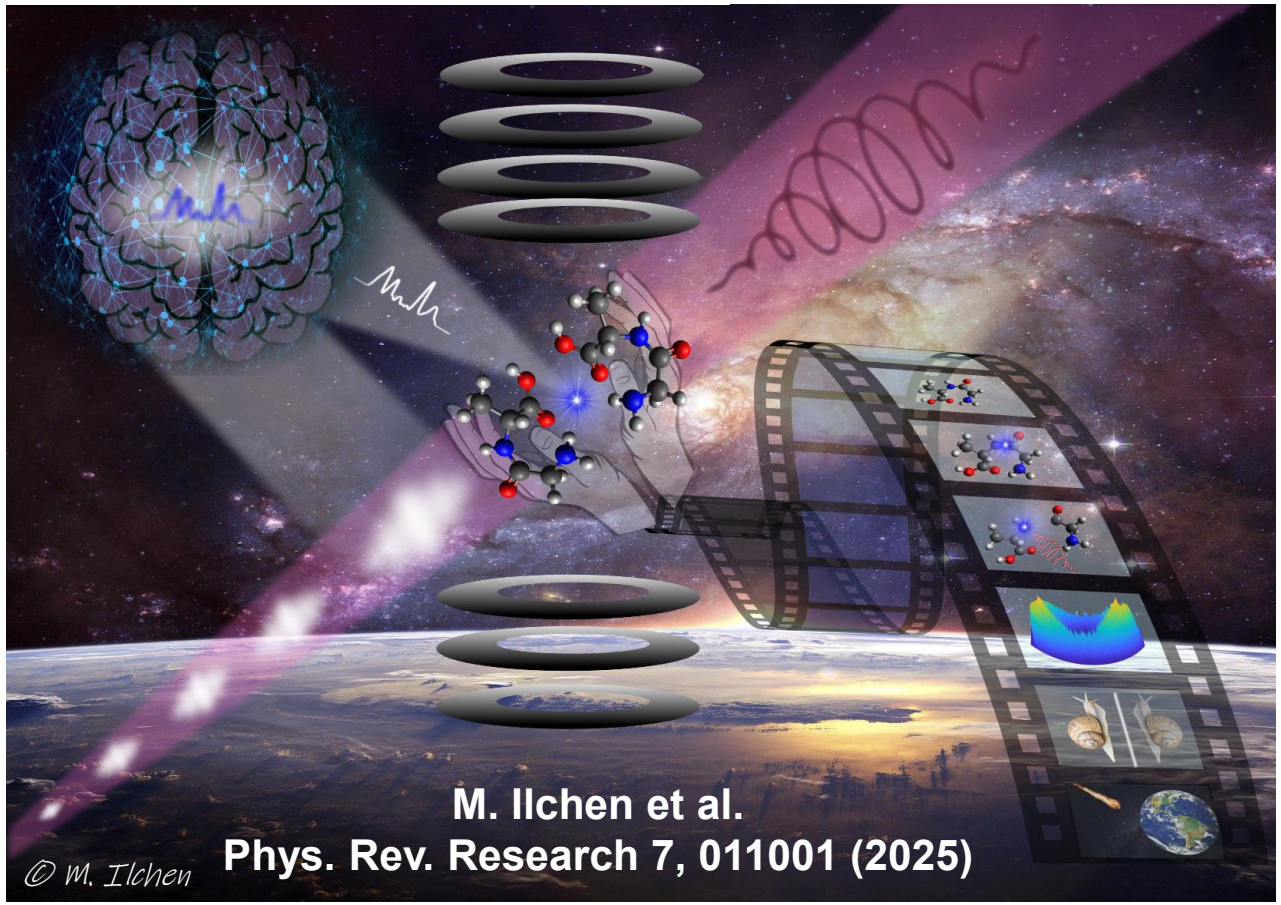


Scientific road of (X)FELs with undulator-based polarization control (for gas-phase studies)

- FERMI
- LCLS
- FLASH
- SwissFEL
- SHINE/SXFEL
- European XFEL

Röntgen Ångström Cluster

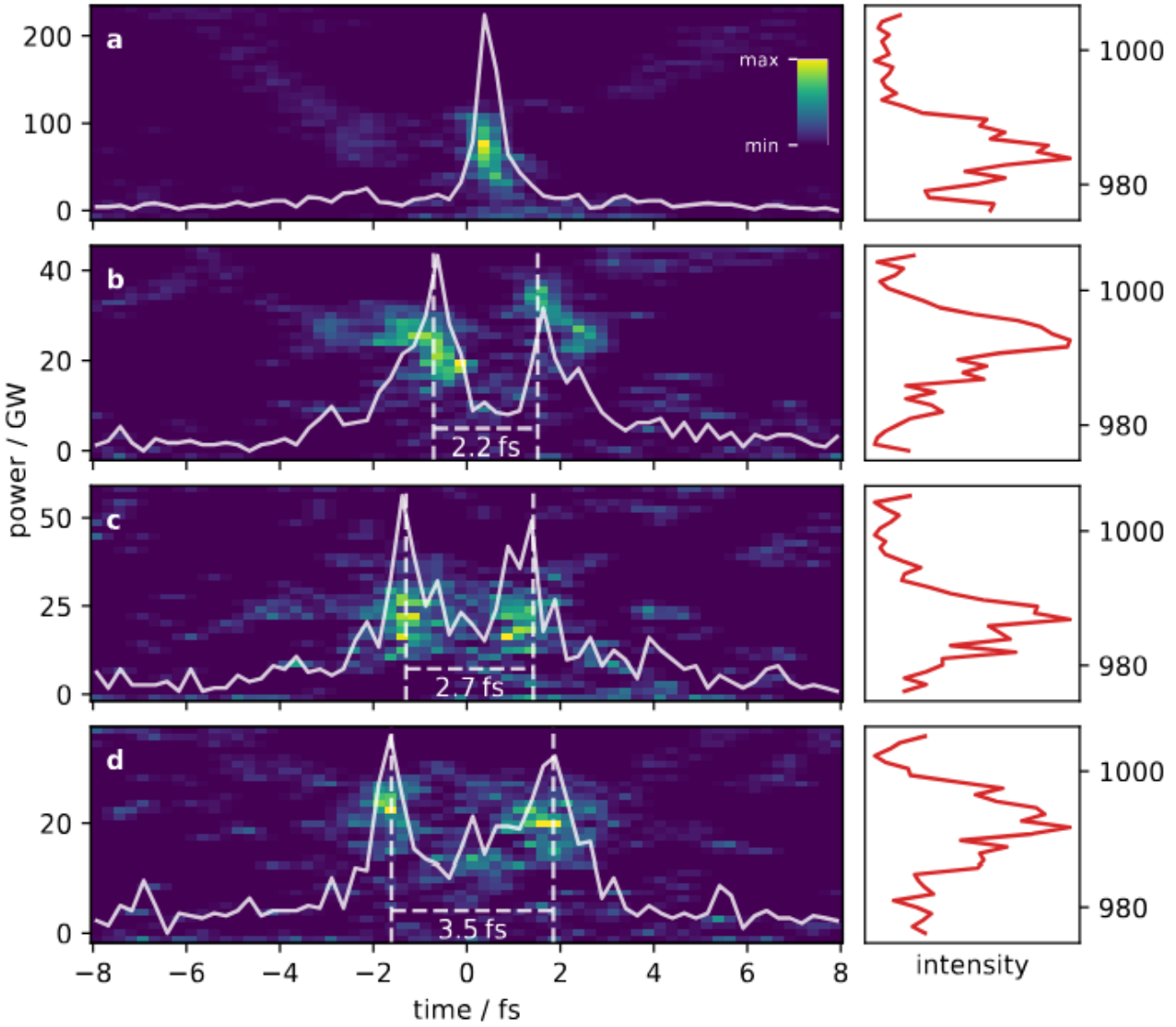
Ilchen/Bari



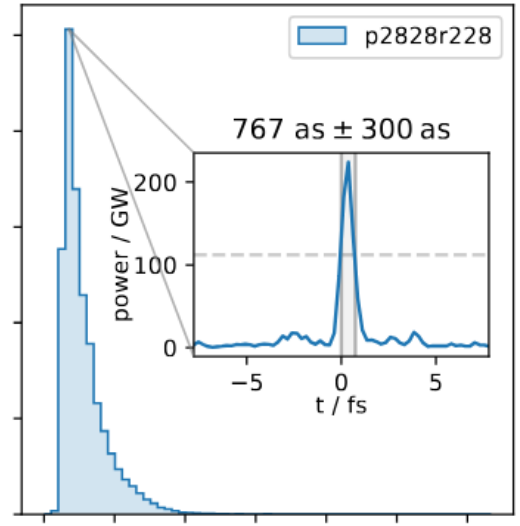
- Diagnostics and instrumentation
- Opportunities for ultrafast und nonlinear stereochemistry
- Nonlinear circular dichroism studies
- Ultrafast dichroic phenomena explored with reaction microscopes
- Exploring orbital angular momenta with twisted photons
- Perspectives for stereochemistry in complex molecules
- Theoretical Perspectives for Polarization-Controlled FELs
  - Atoms - Perturbative Methods, Single-Active-Electron Approximation, i.e., solve the TDSE in some potential, Multi-Electron Approaches like RMT, and Molecules
- Summary and Outlook

Fully characterizing attosecond X-ray pulses – Angular streaking

From first demonstration at EuXFEL to nonlinear spectroscopy of highly transient matter

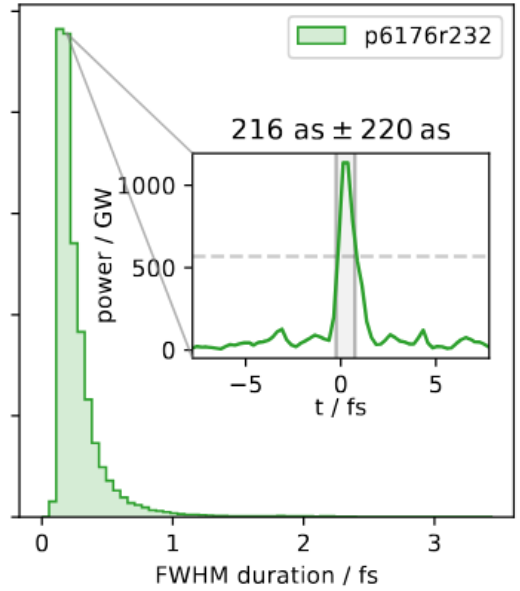


Ilchen and Helml et al. 2022 @ SQS



Meyer et al. 2022 @ SQS

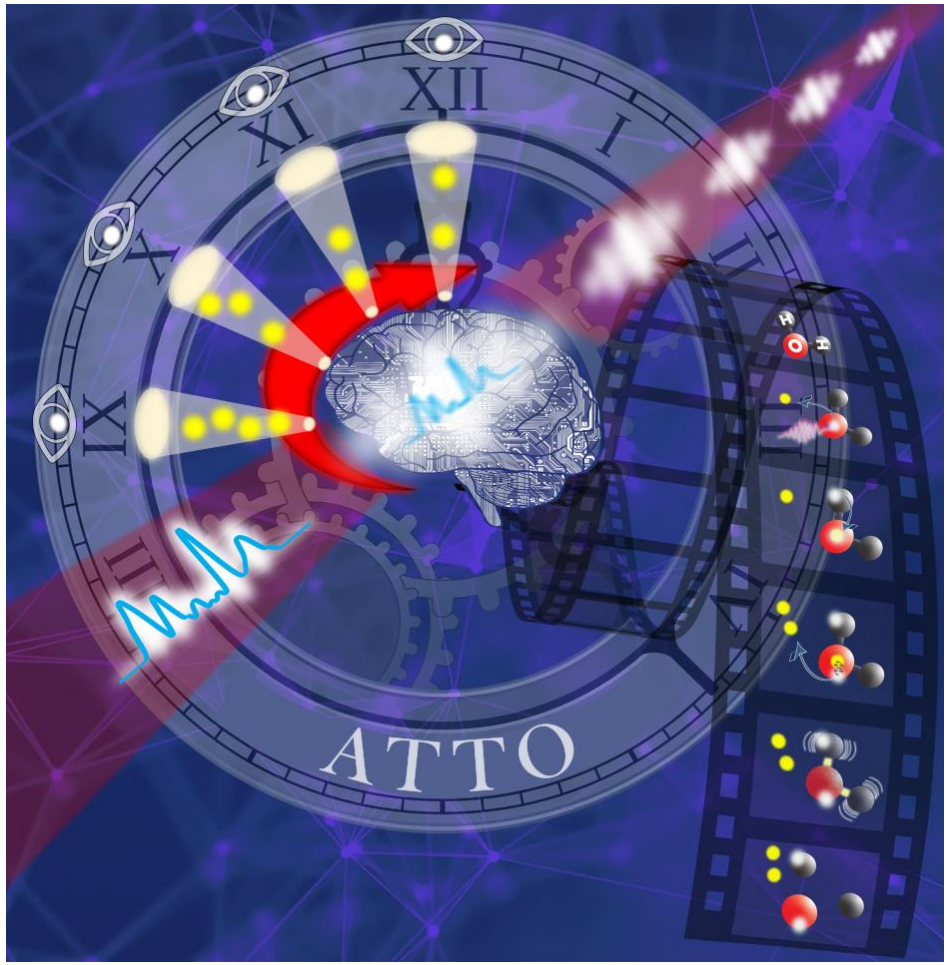
Machine → Serkez et al.

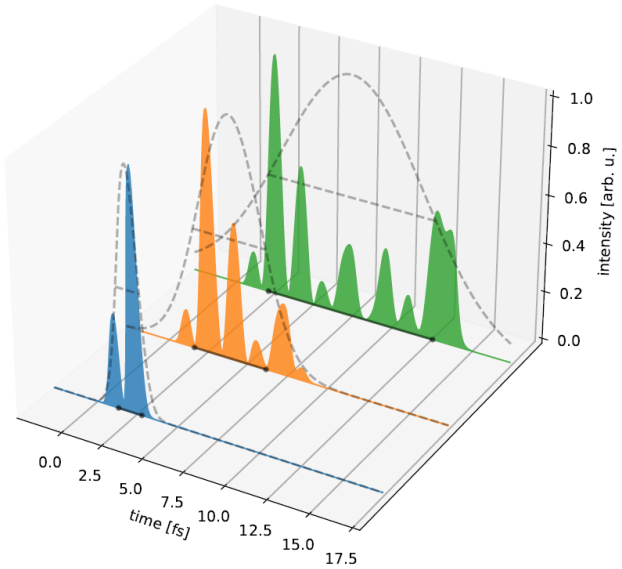


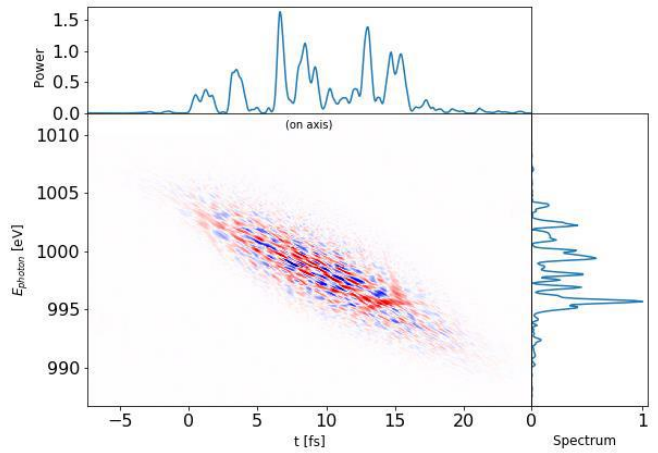
Funke, Ilchen,…, and Helml, arXiv:2408.03858 (2024)

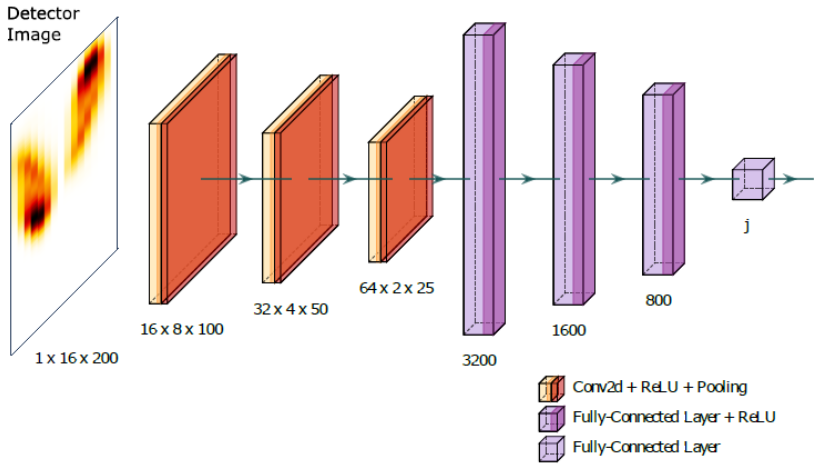
Machine-learning approaches to enhance angular streaking

From first demonstration at EuXFEL to nonlinear spectroscopy of highly transient matter





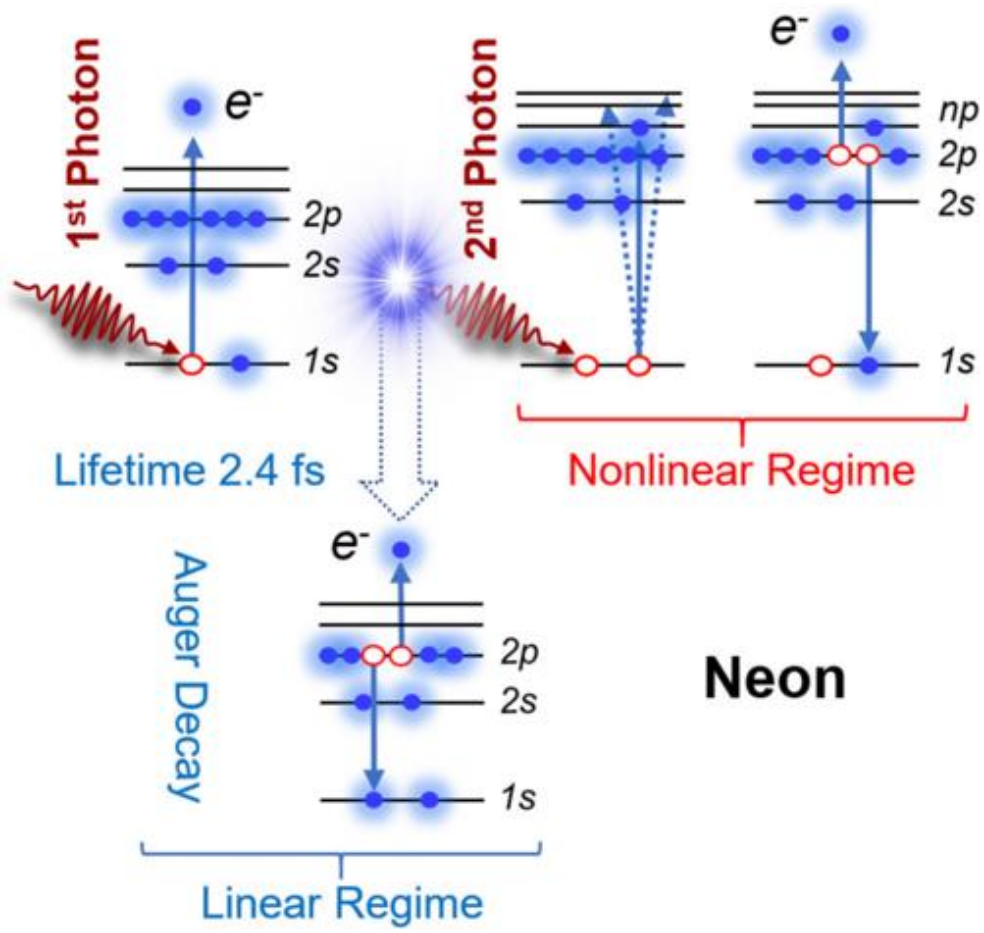




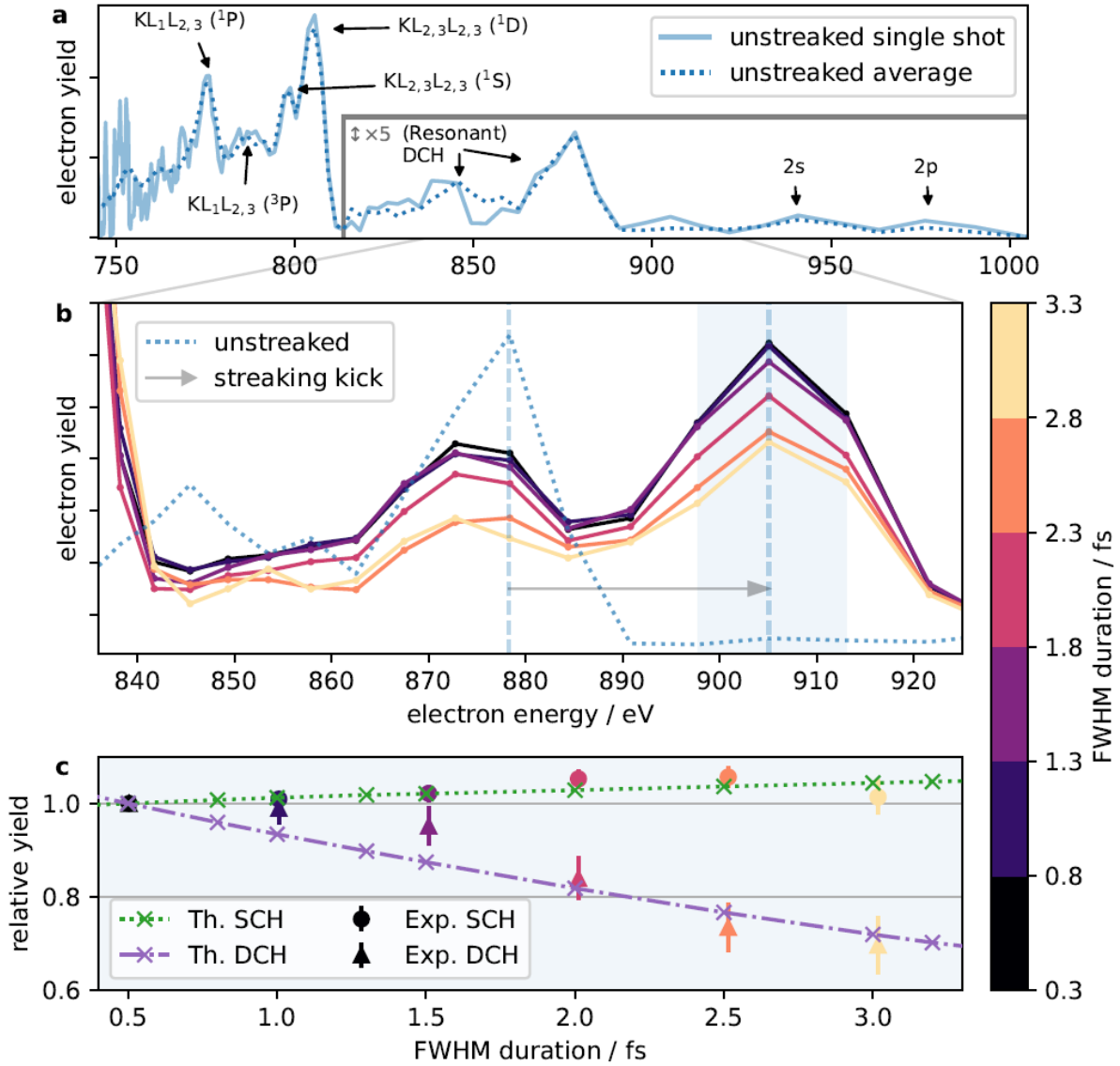
K. Dingel et al. Scientific Reports ***12****, 17809 (2022)*

First publication on fully characterized attosecond X-ray pulses

Opening the door to nonlinear spectroscopy of highly transient matter

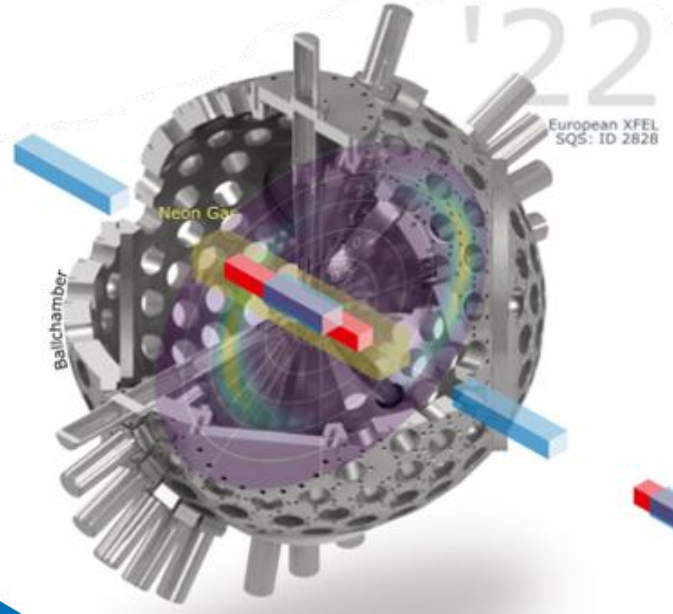


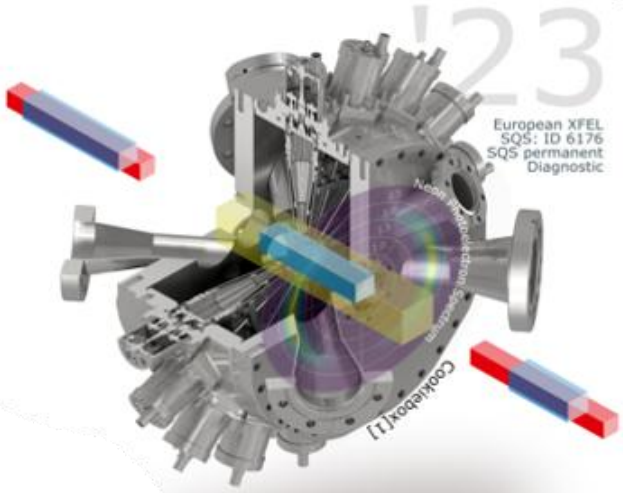
Mazza, Ilchen,…, and Meyer, PRX 10.041056 (2020)

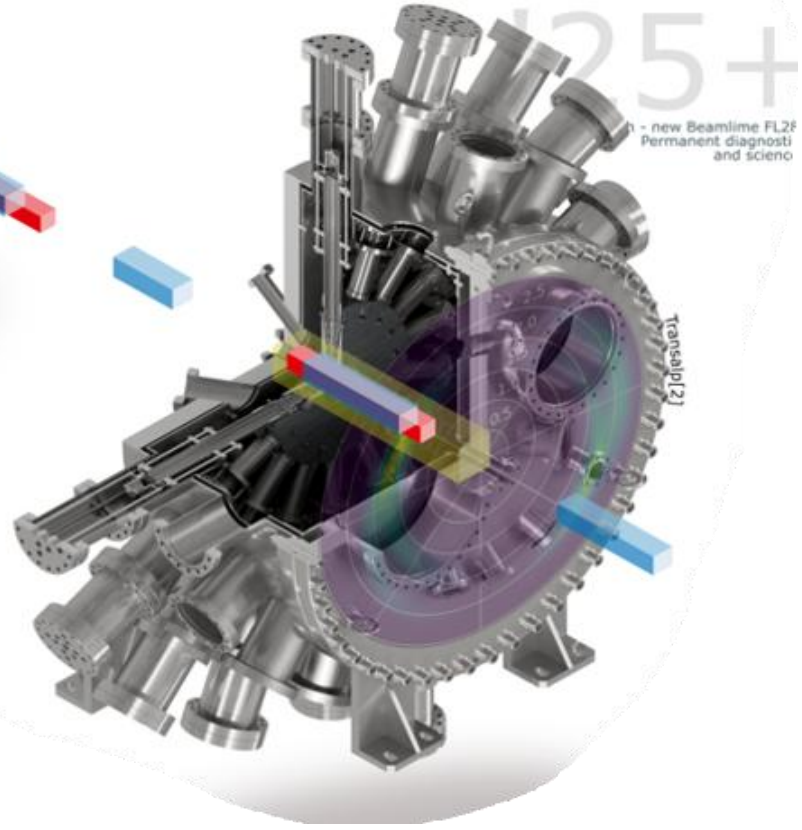


Funke, Ilchen,…, and Helml, arXiv:2408.03858 (2024)

Max von Laue Fest at DESY 2012 – © DESY







FLASH2020+
Making FLASH brighter, faster and more flexible

2022 2023 2024 2025

New strategies for
FEL-based atto-science:

DFG Deutsche Forschungsgemeinschaft

Bundesministerium für Bildung und Forschung

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Partnership of
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DASHH Data Science in Hamburg
HELMHOLTZ Graduate School
for the Structure of Matter

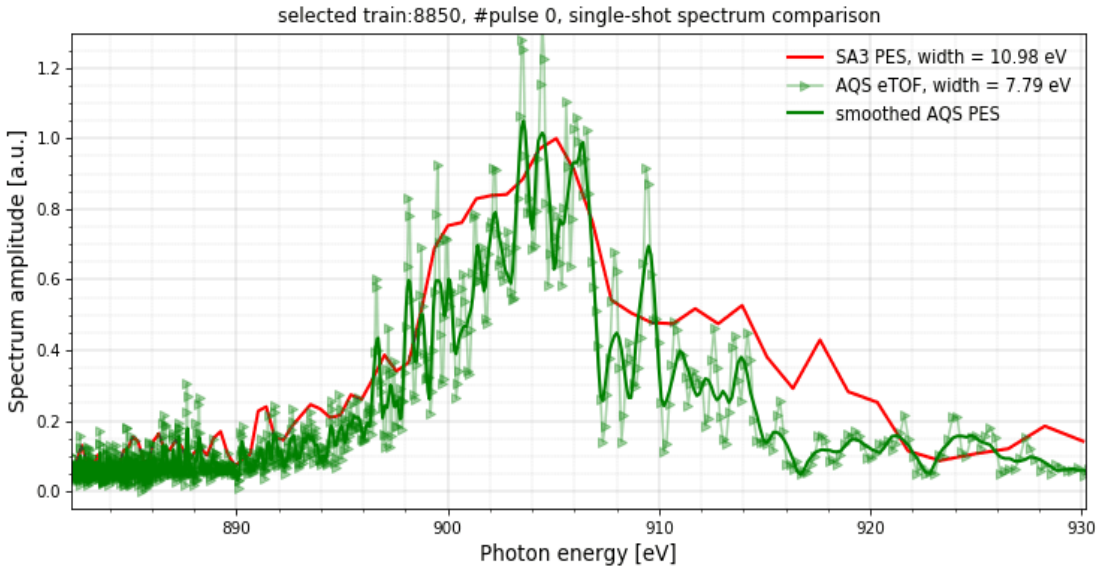
RöntgenÅngströmCluster

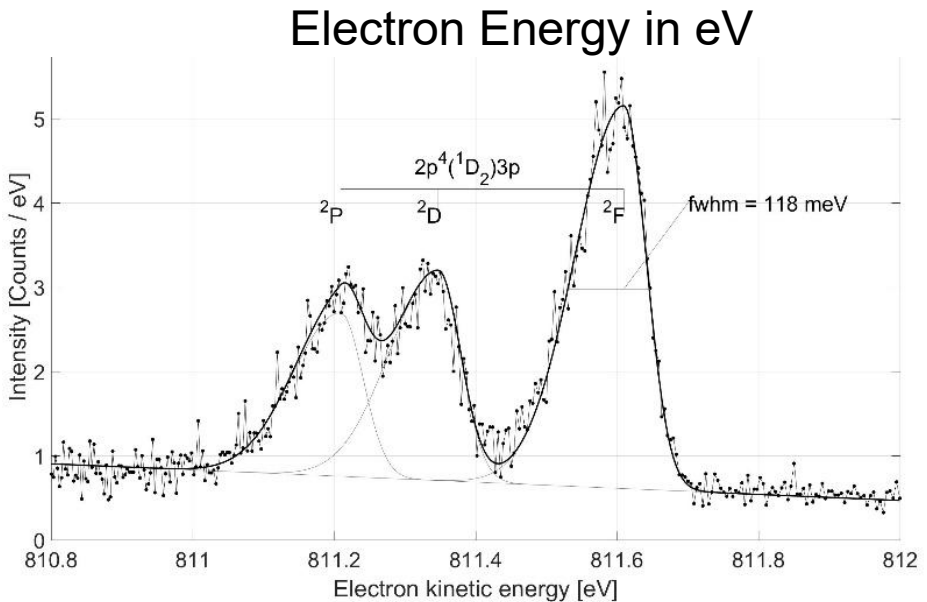
Instrumentation upgrades and advances (selected examples)

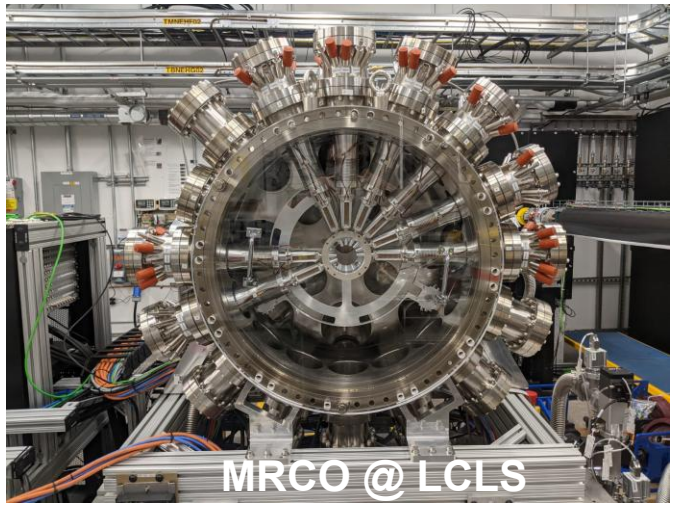
From diagnostic achievements to chirality science at the attosecond frontier in gas and liquid phase

Ball chamber U.Becker
(M. Braune, DESY)

Cookiebox,
J. Viefhaus (HZB)





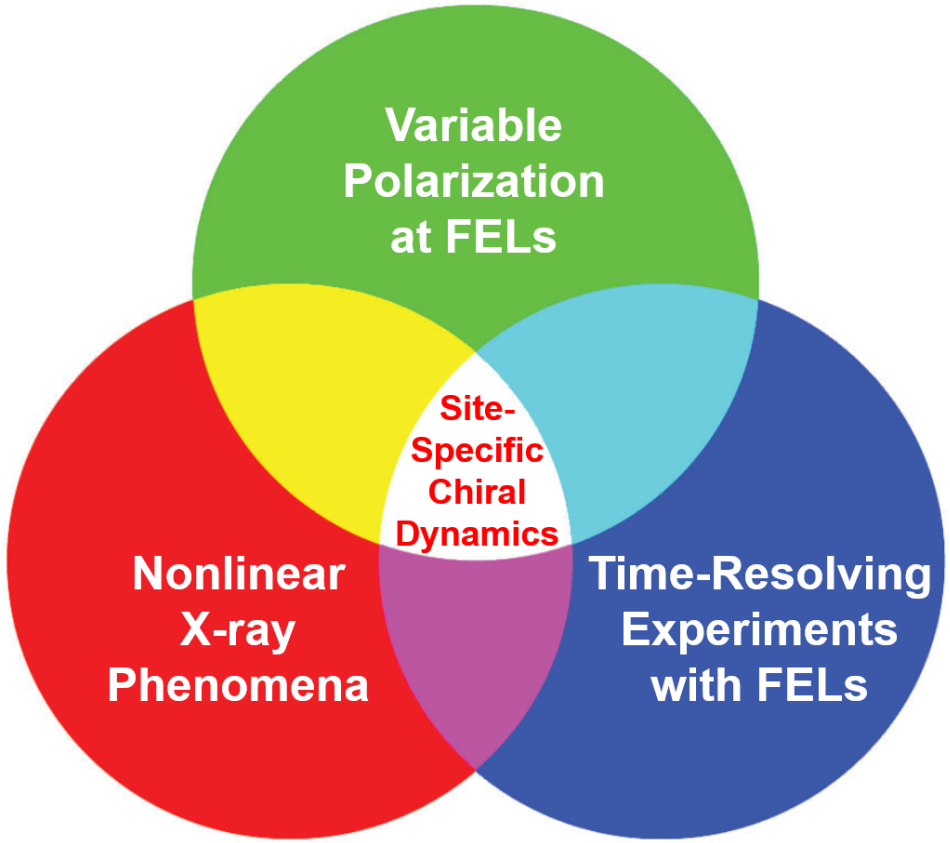


P. Walter *et al*,
J. Synchrotron Rad. **28**, 1364 (2021)

SpeAR Project for atto-streaking
W. Helml et al.

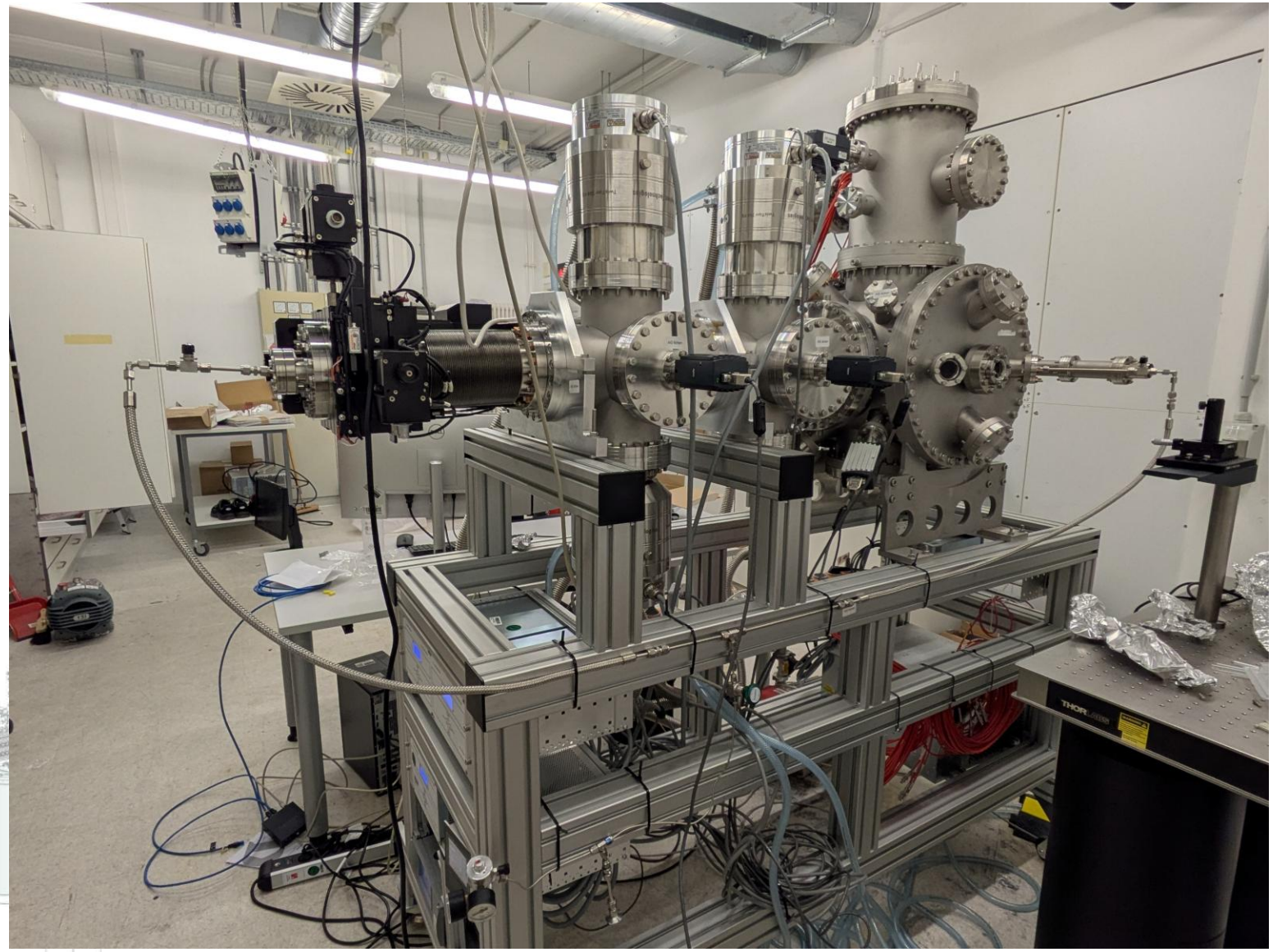
Polarization control for the exploration of dynamics in chiral matter

Attosecond X-ray pulses, conquering the TW-regime, and FEL-polarization control



New perspectives at FLASH 2 and CFEL – DESY/UHH

Exploring chiral dynamics with XUV and soft X-ray pulses



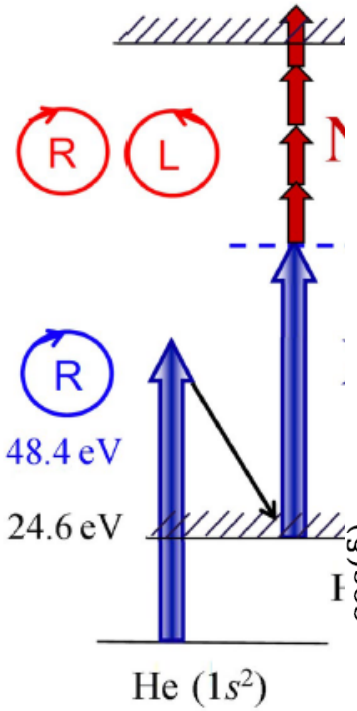
- Double-sided VMI for high resolution of low kinetic energies of electrons available at CFEL (mobile)
- New detection geometries under investigation (Up to 120mm MCPs)
- New gas jet under development for:
  - Pulsed operation
  - Microhydration
  - Temperature control
- OPA for tunable UV granted (not yet purchased)
- Investigation of chiral species and their fragmentation dynamics upon UV excitation starting soon.
- Exploring more complex systems (J. Leroux et al.)

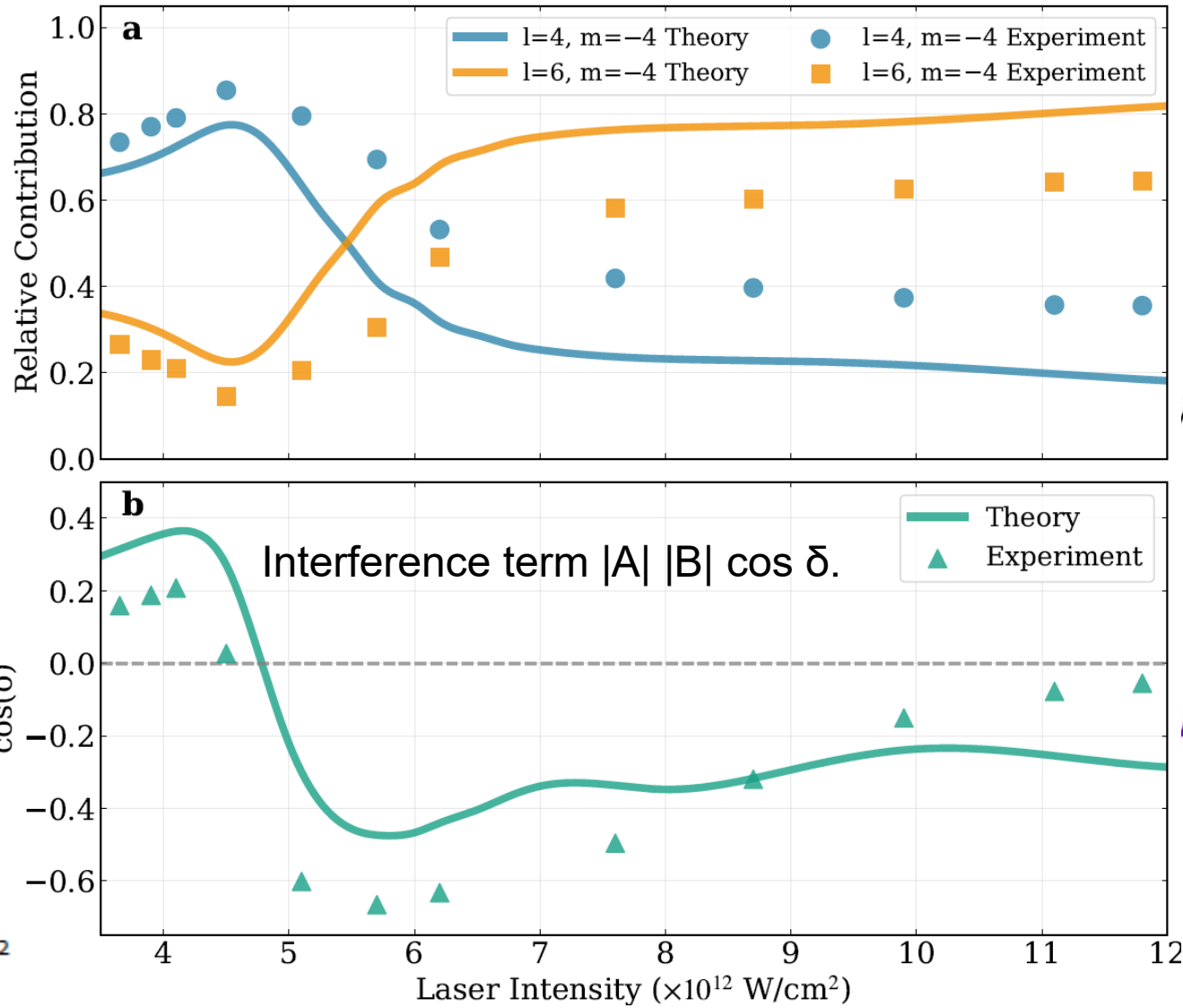
Dichroic light-matter interaction in small systems

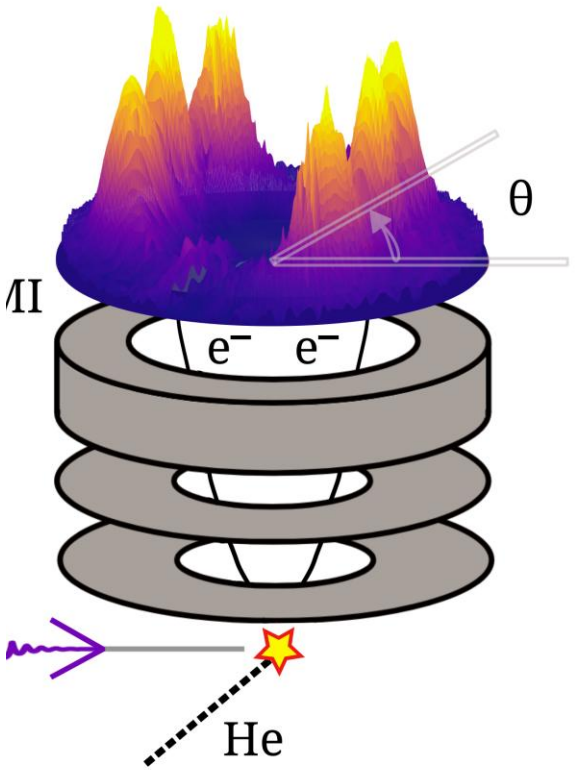
Oriented Helium Ions

Michael Meyer
EuXFEL

Niclas Wieland
UHH







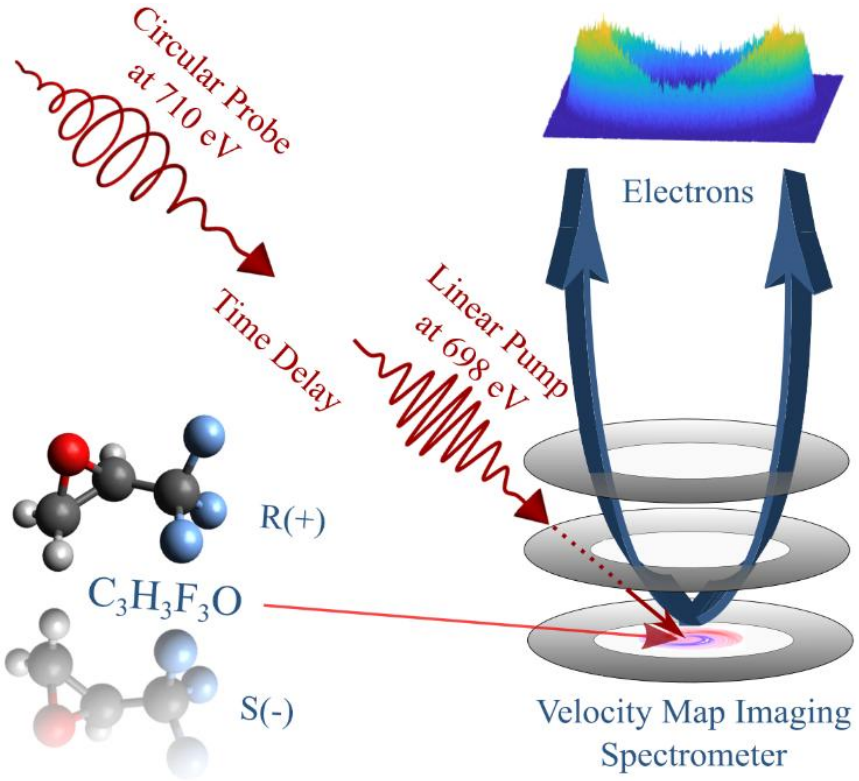
Scientific Reports | (2024) 14:27232

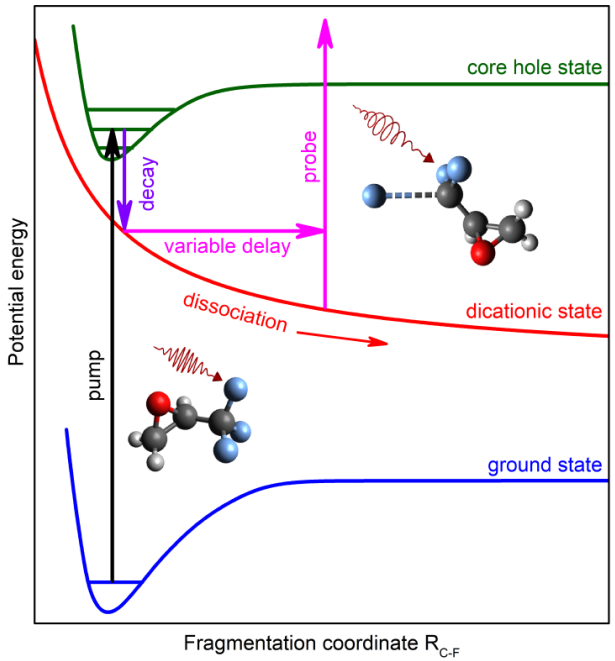
arXiv:2507.17919 [physics.atom-ph]

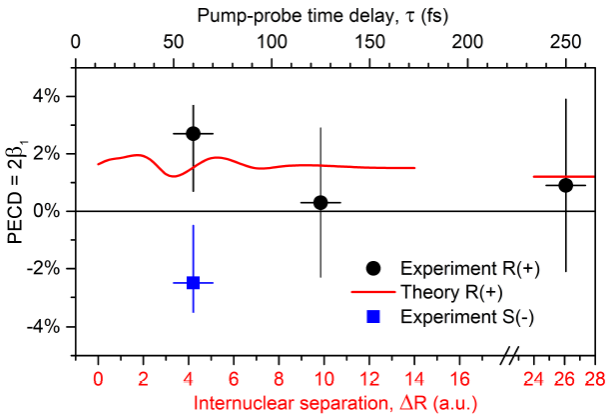
Ultrafast circular dichroism experiments

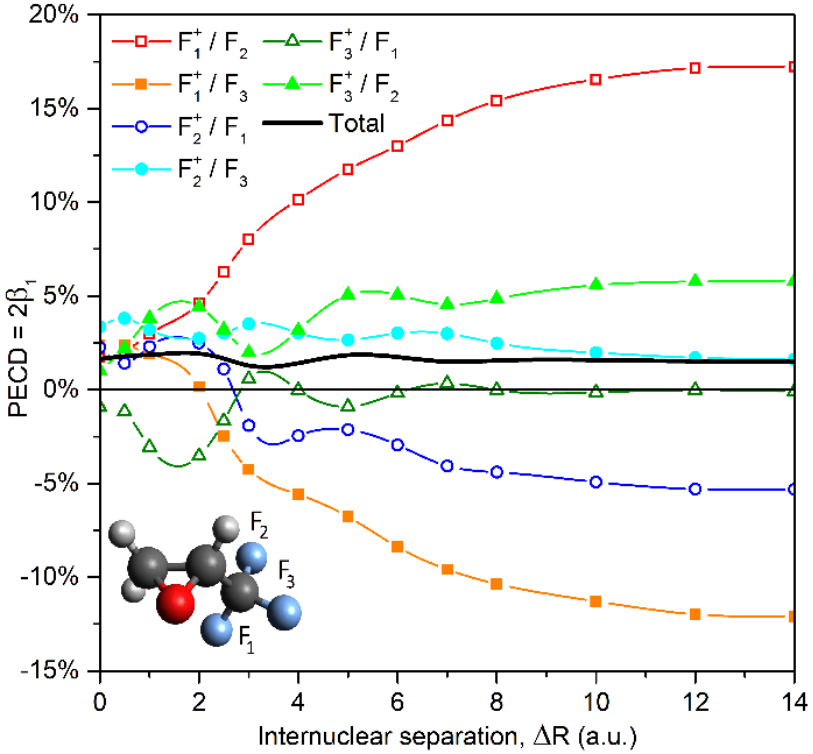
Example of a Kick-Off Chirality Experiment at LCLS

- PECD as tool for chiral recognition!
- Double site-specificity possible!
- Ultrafast chirality at XFELs in reach.







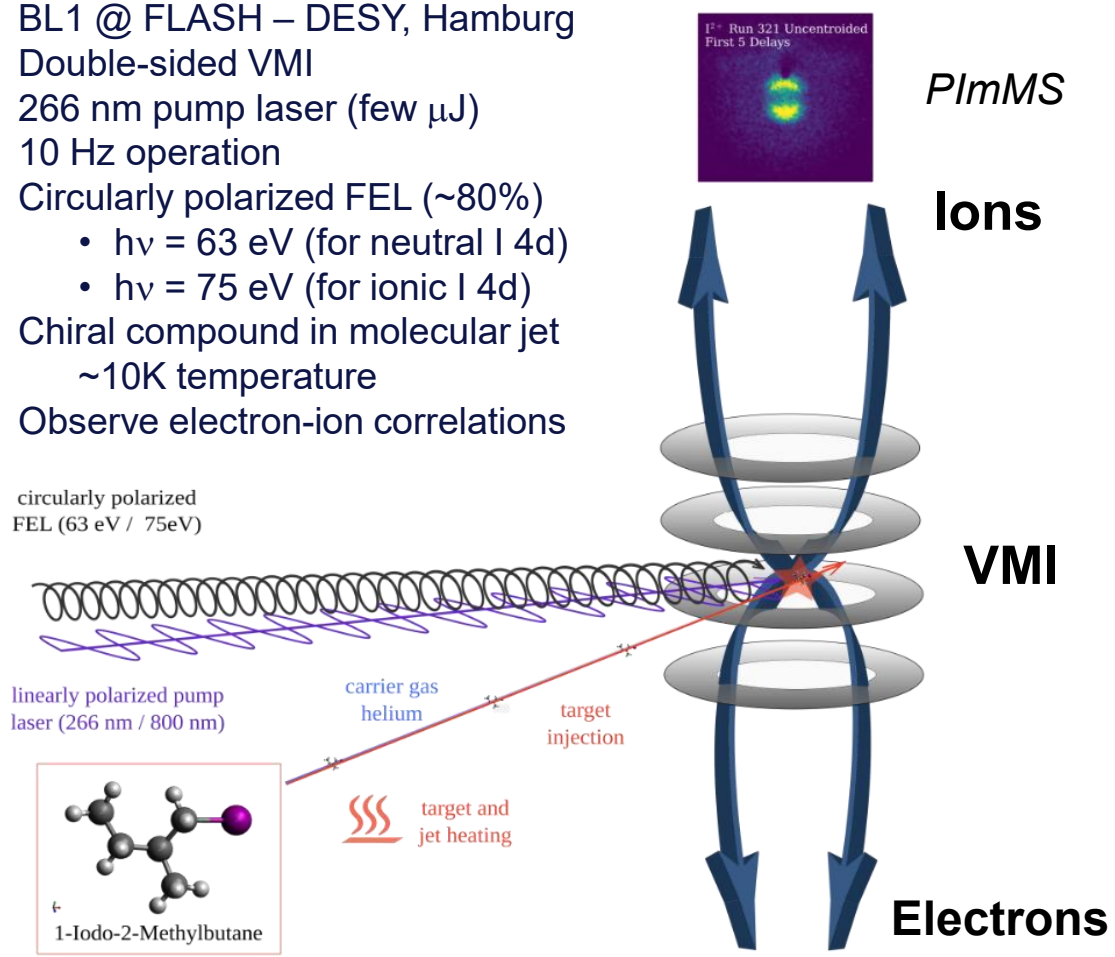


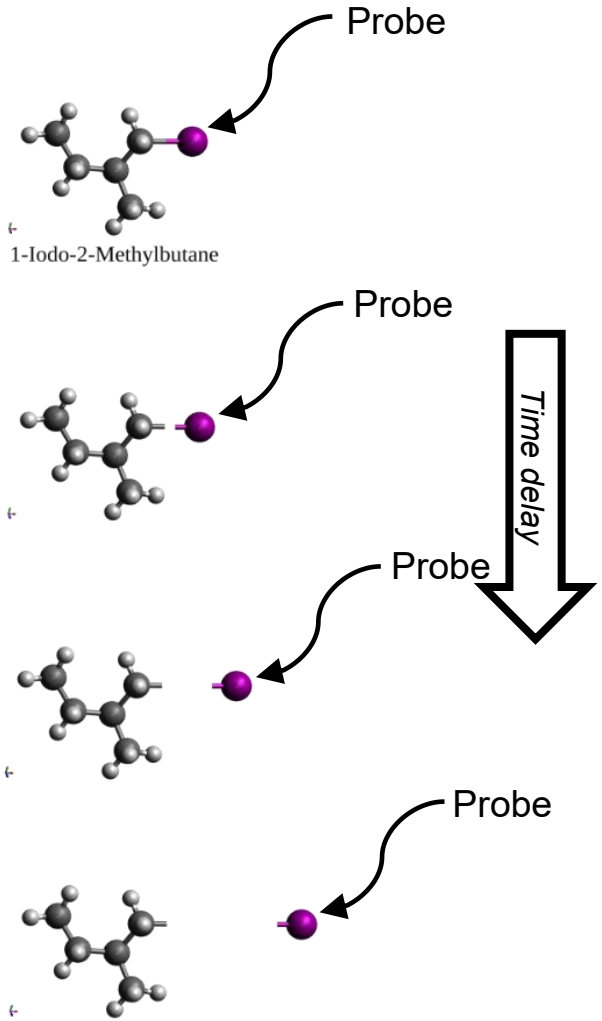
M. Ilchen *et al*,
Communications Chemistry **4**, 119 (2021)

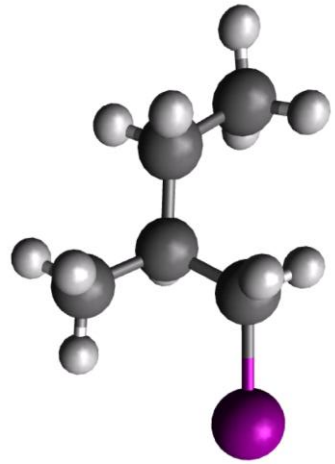
Second chirality experiment – FLASH @ DESY

Establishing electron-ion covariance spectroscopy for PECD studies

- BL1 @ FLASH – DESY, Hamburg
- Double-sided VMI
- 266 nm pump laser (few μJ)
- 10 Hz operation
- Circularly polarized FEL (~80%)
  - hν = 63 eV (for neutral I 4d)
  - hν = 75 eV (for ionic I 4d)
- Chiral compound in molecular jet
  ~10K temperature
- Observe electron-ion correlations







Iodomethylbutane – Simplified animation of photolysis after 266 nm photo-absorption

Collaborations, funding, projects, and outlook

A unique network of science and technology for breaking ground in atto X-ray science

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Acknowledgements

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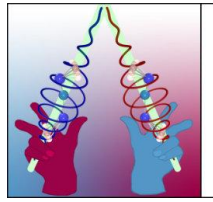

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LCLS

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UNIVERSITET STOCKHOLMS

UNIVERS GOTHEN

Special Thanks to
Kai Tiedtke,
Francesca Calegari
and
Michael Meyer!

Imperial College London

HZB Helmholtz Zentrum Berlin

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