

Attosecond photoionisation dynamics of large water clusters

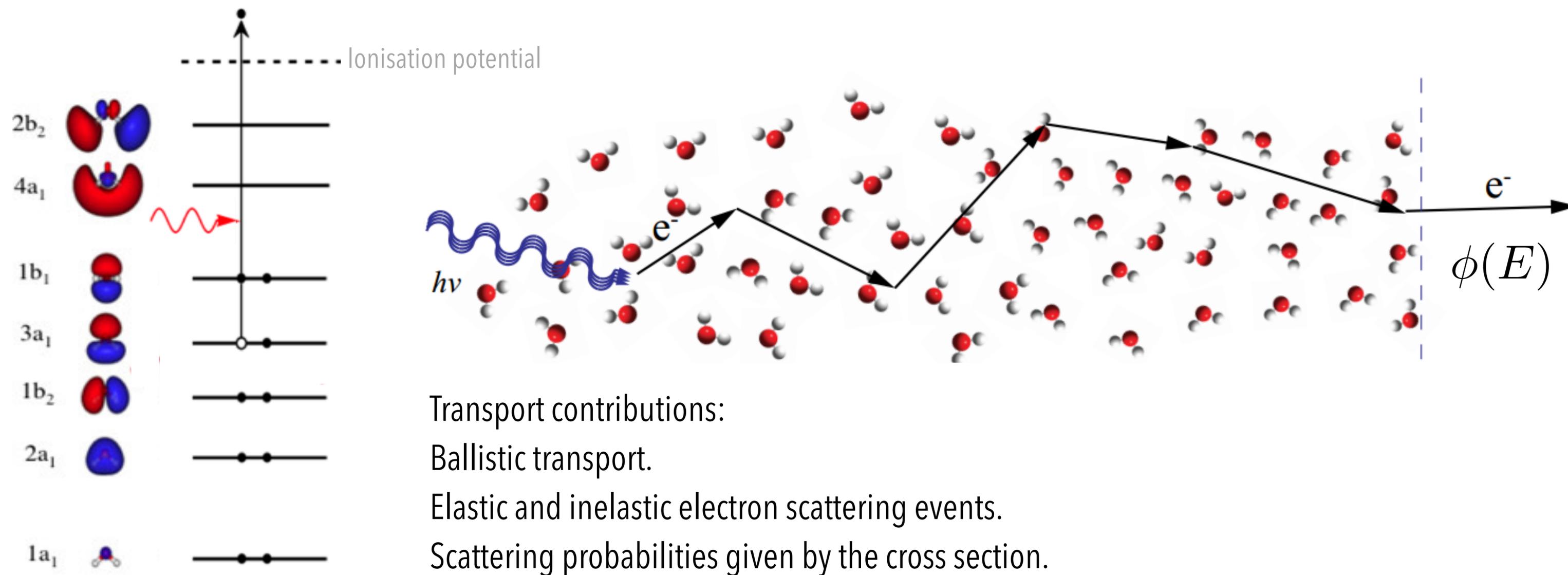
Andrea Trabattoni

Institute of Quantum Optics, Leibniz University Hannover
Center for Free-Electron Laser Science, DESY



Ionisation and photoelectron scattering in water

Fundamental mechanism in radiation damage, atmospheric (aerosol) chemistry, etc.



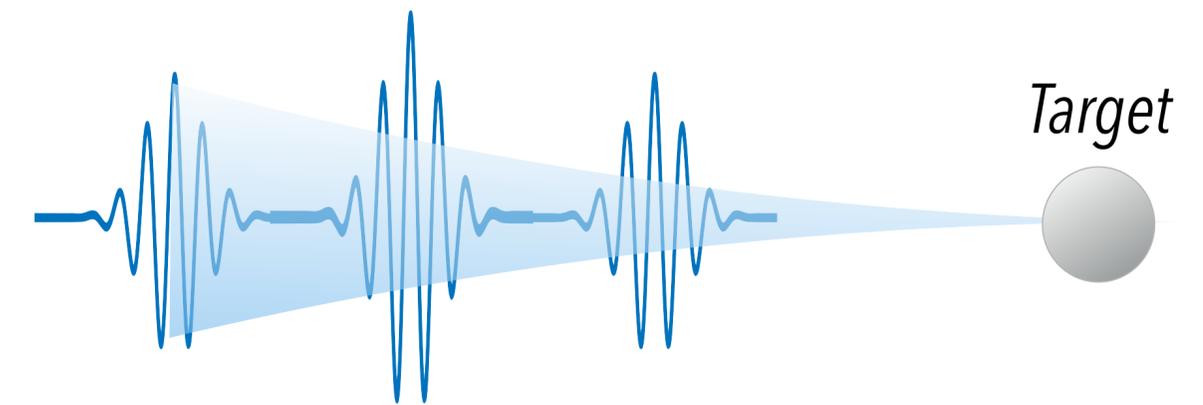
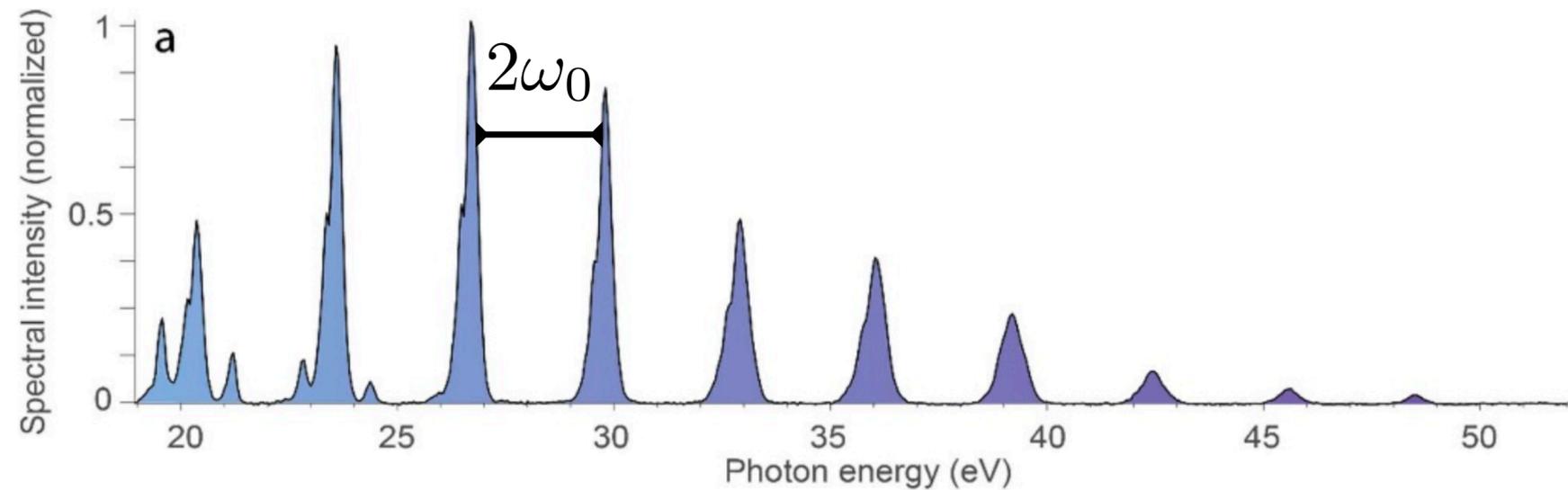
T. Fransson et al. (2016), Chem. Rev., 116(13), 7551-7569

S. Hartweg, ETH Diss No.: 26008

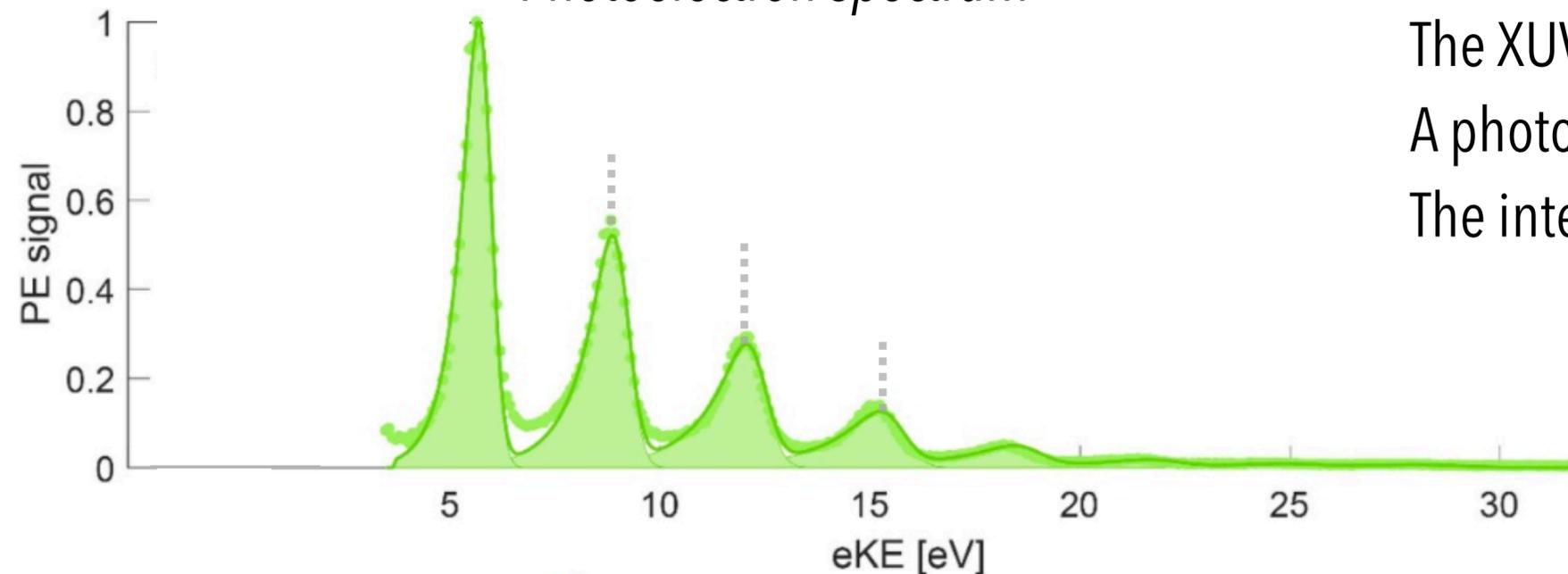
RABBIT: Reconstruction of Attosecond Beating By Interference of Two-photon Transitions

A power tool to study the phase of photoelectron wave packets

High-harmonic generation XUV spectrum



Photoelectron spectrum



The XUV comb induces photoionisation in the target.

A photoelectron spectrum is produced.

The interaction with the fundamental field (ω_0) creates sidebands.

P. M. Paul, et al., *Science* 292, 1689 (2001)

Trabattoni A., et al, *J. Phys. Photonics* 2 035007 (2020)

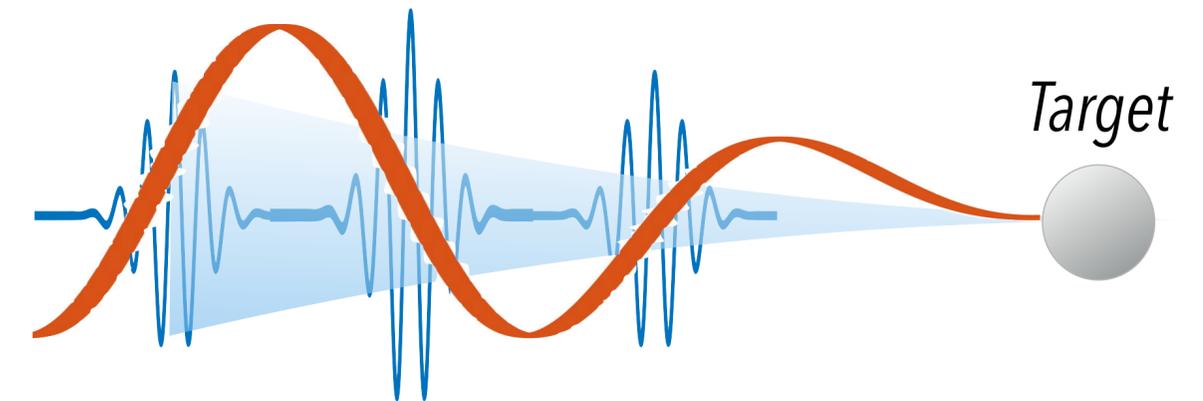
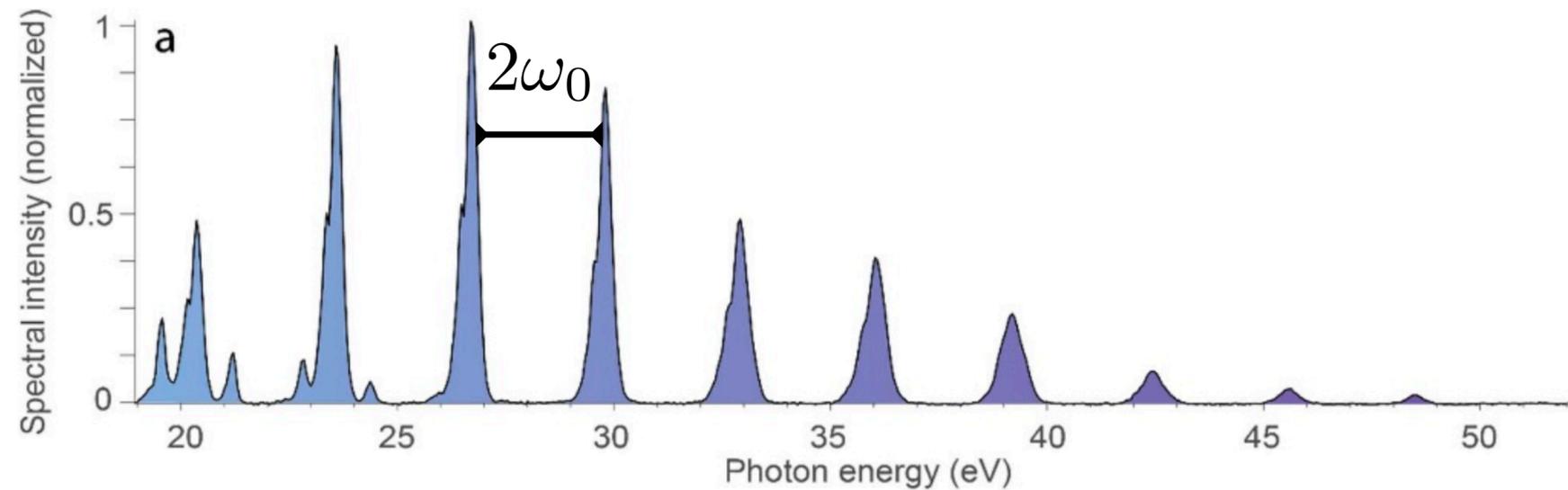
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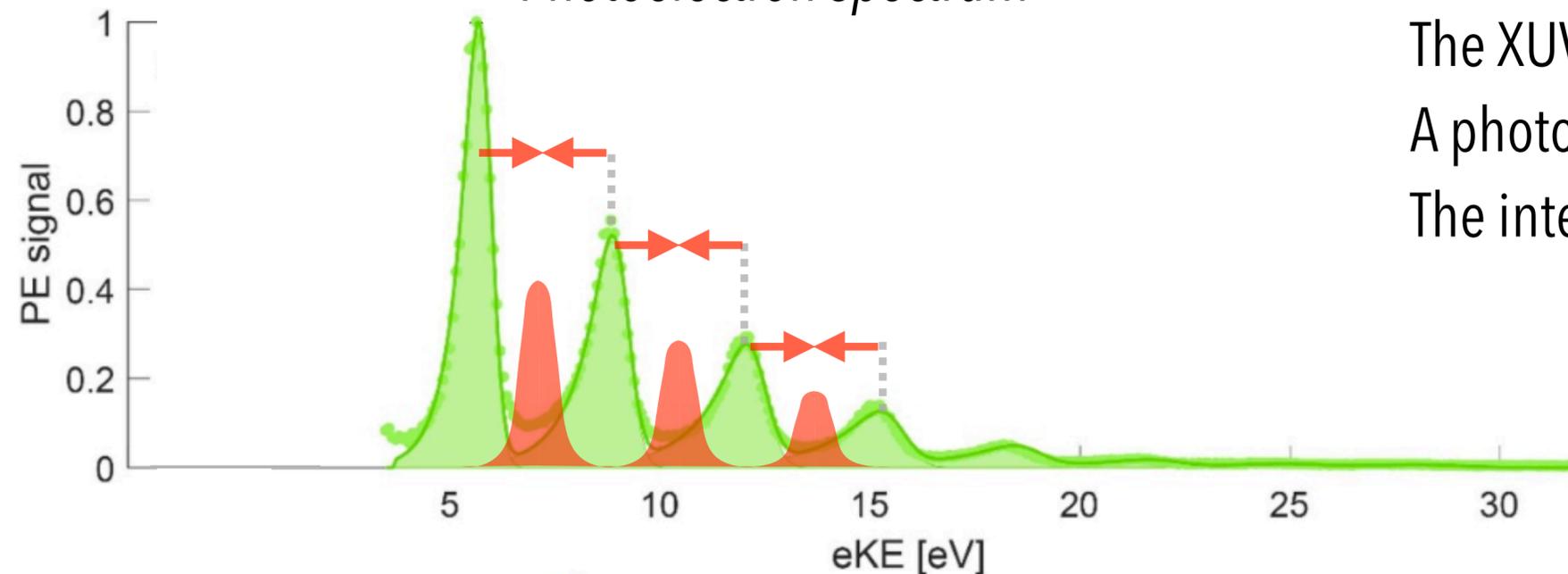
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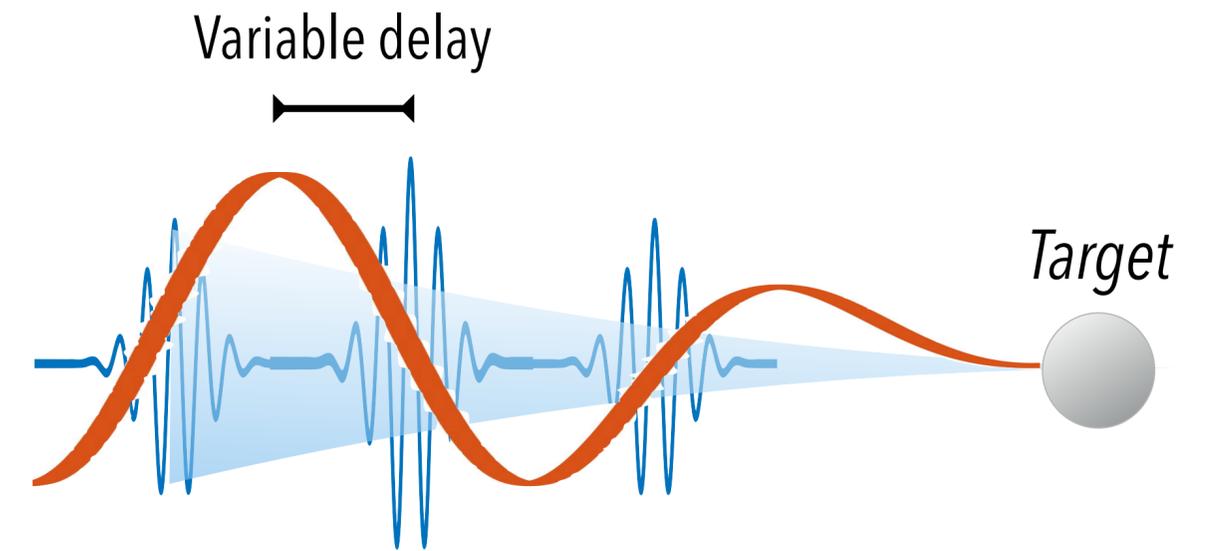
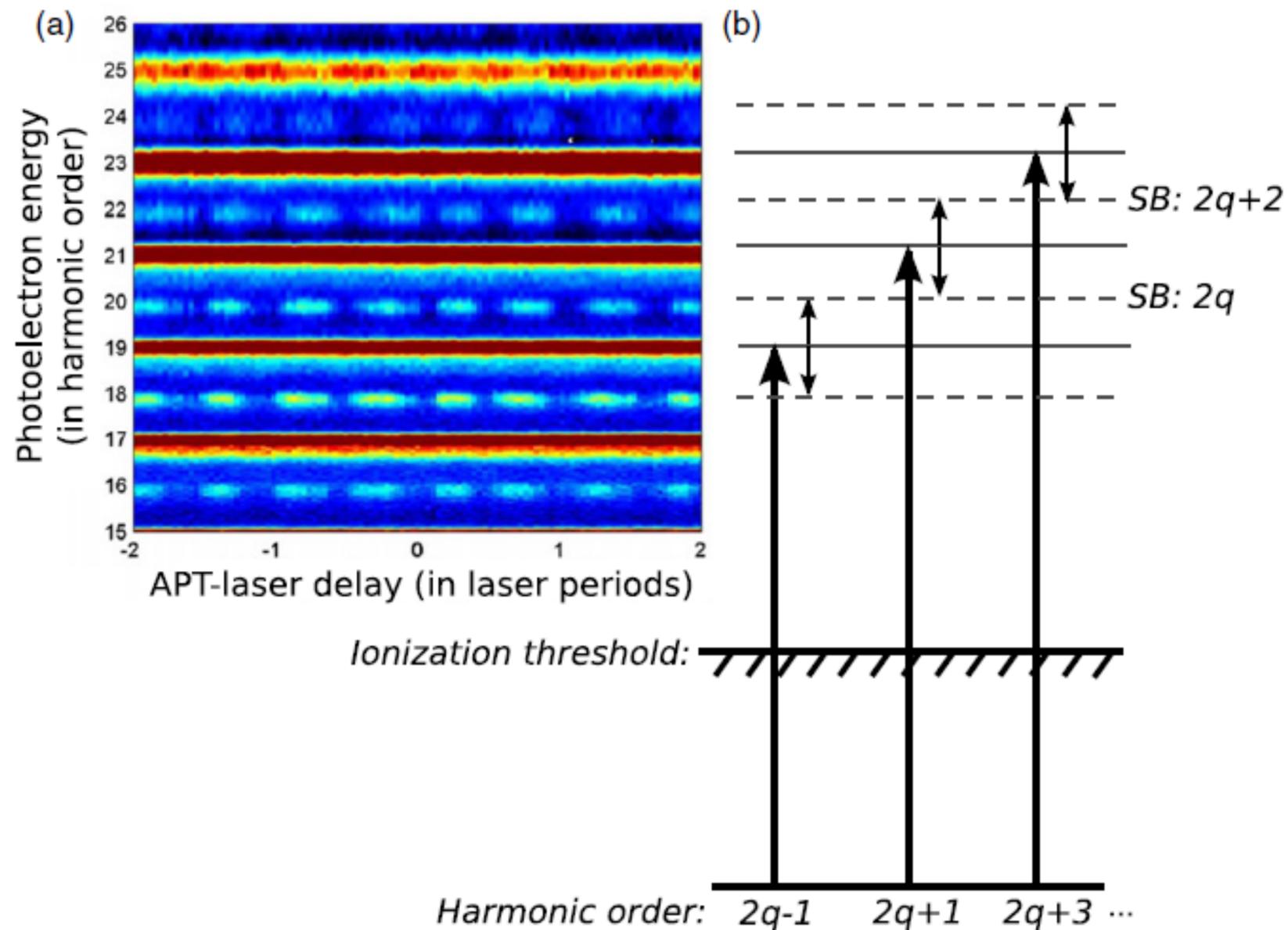
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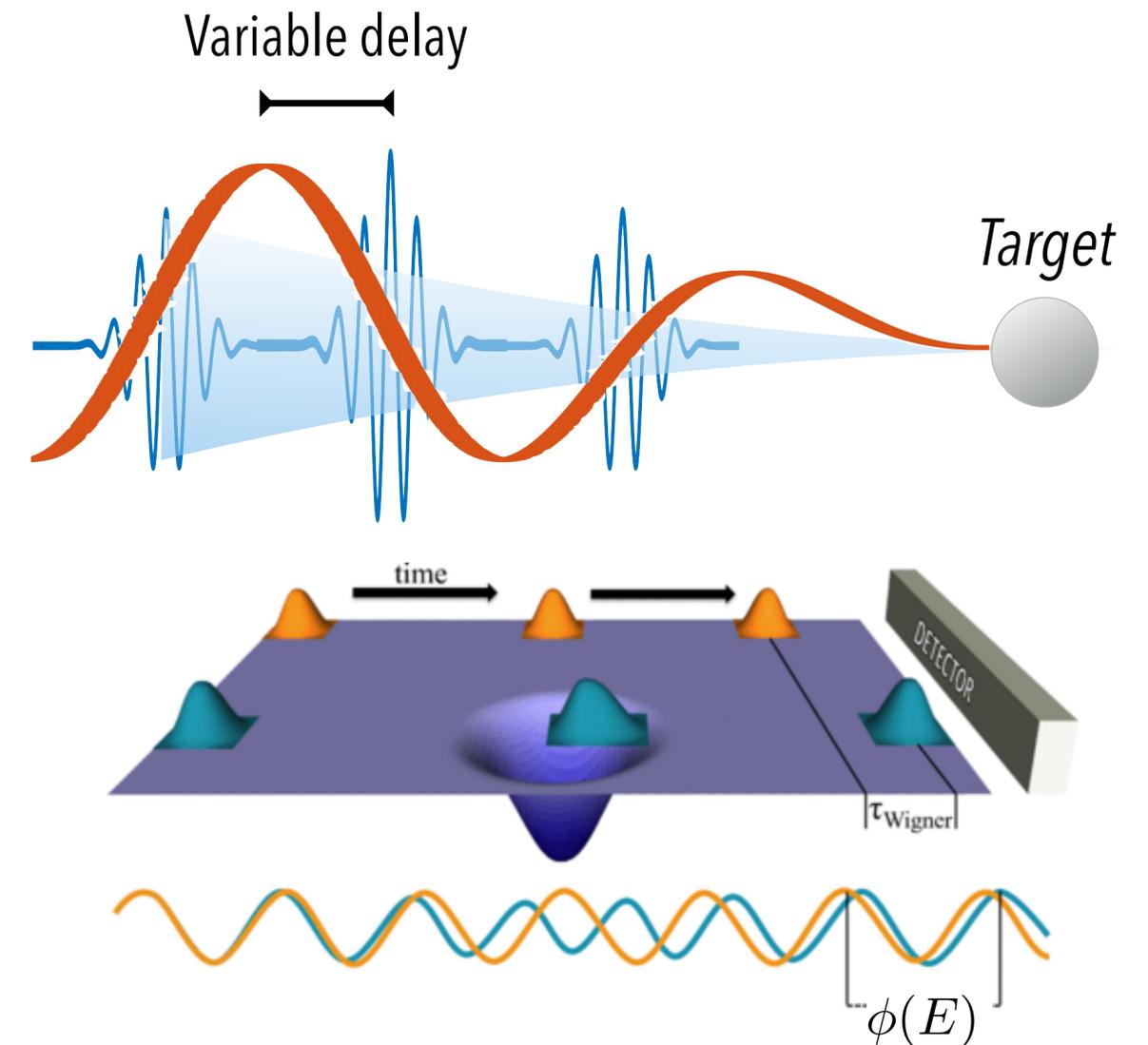
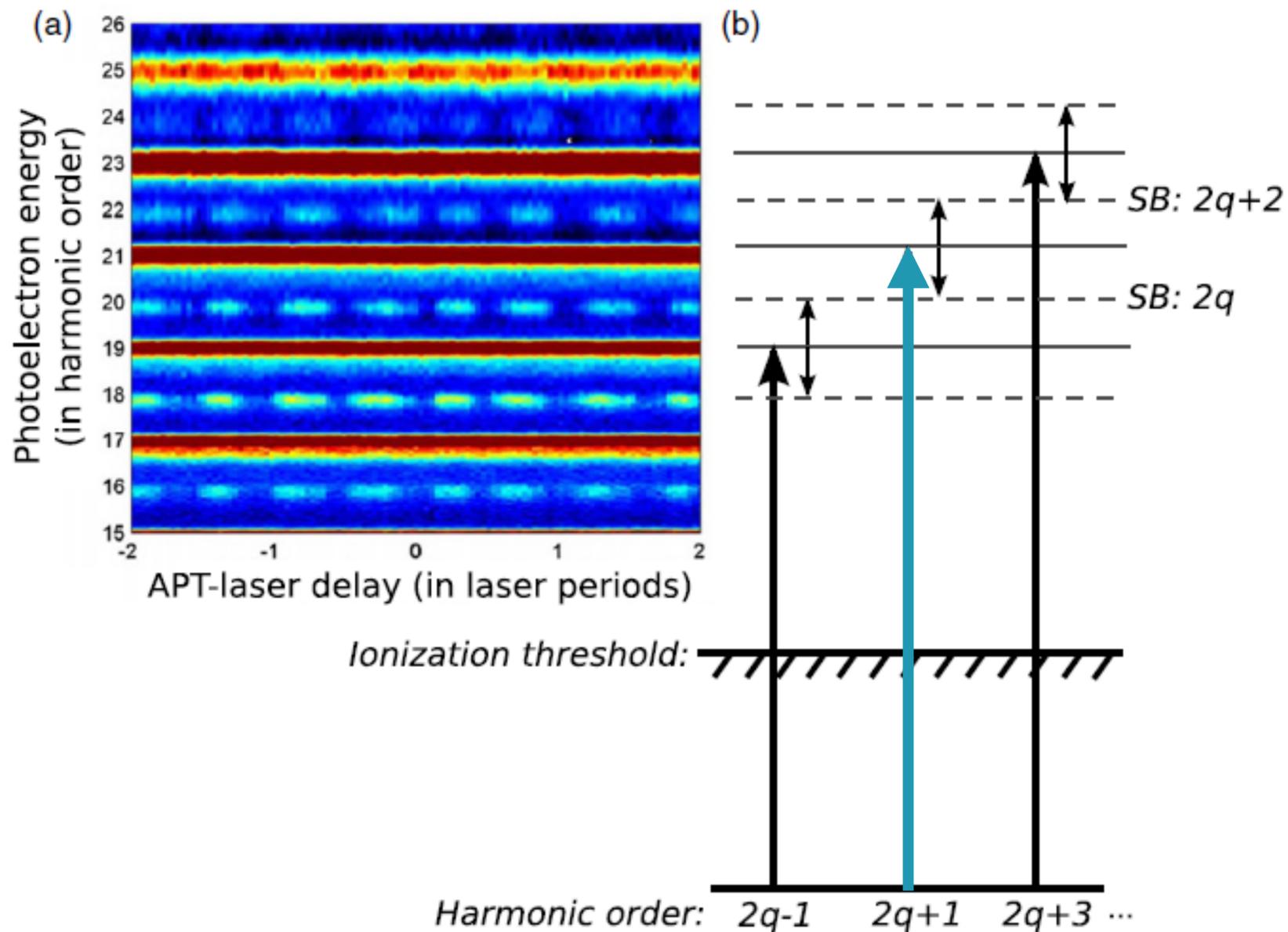
A power tool to study the phase of photoelectron wave packets



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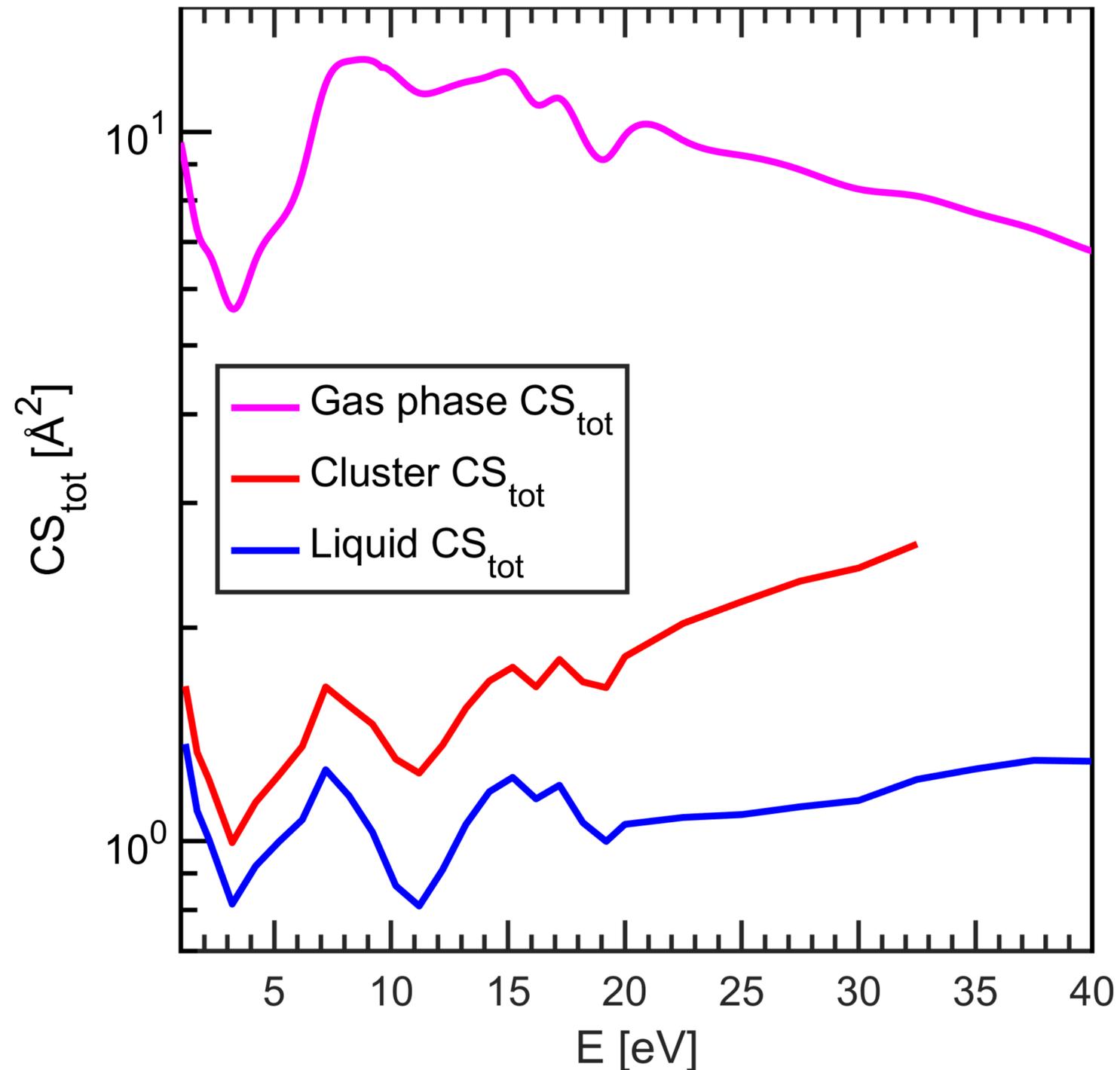


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Scattering delays of large water clusters



Nanoconfined water as in clusters shows different properties than in bulk or gas phase.

The difference between monomer and liquid emission times has been measured to be ~ 50 as between 20-30 eV.

In small water clusters: up to 200 as between 18-20 eV.

Large water clusters?

K. Horn et al., Phys. Rev. Research 7, 013212 (2025)

Jordan et al., Science 369, 974-979 (2020)

X. Gong et al., Nature 609, 507-511 (2022)

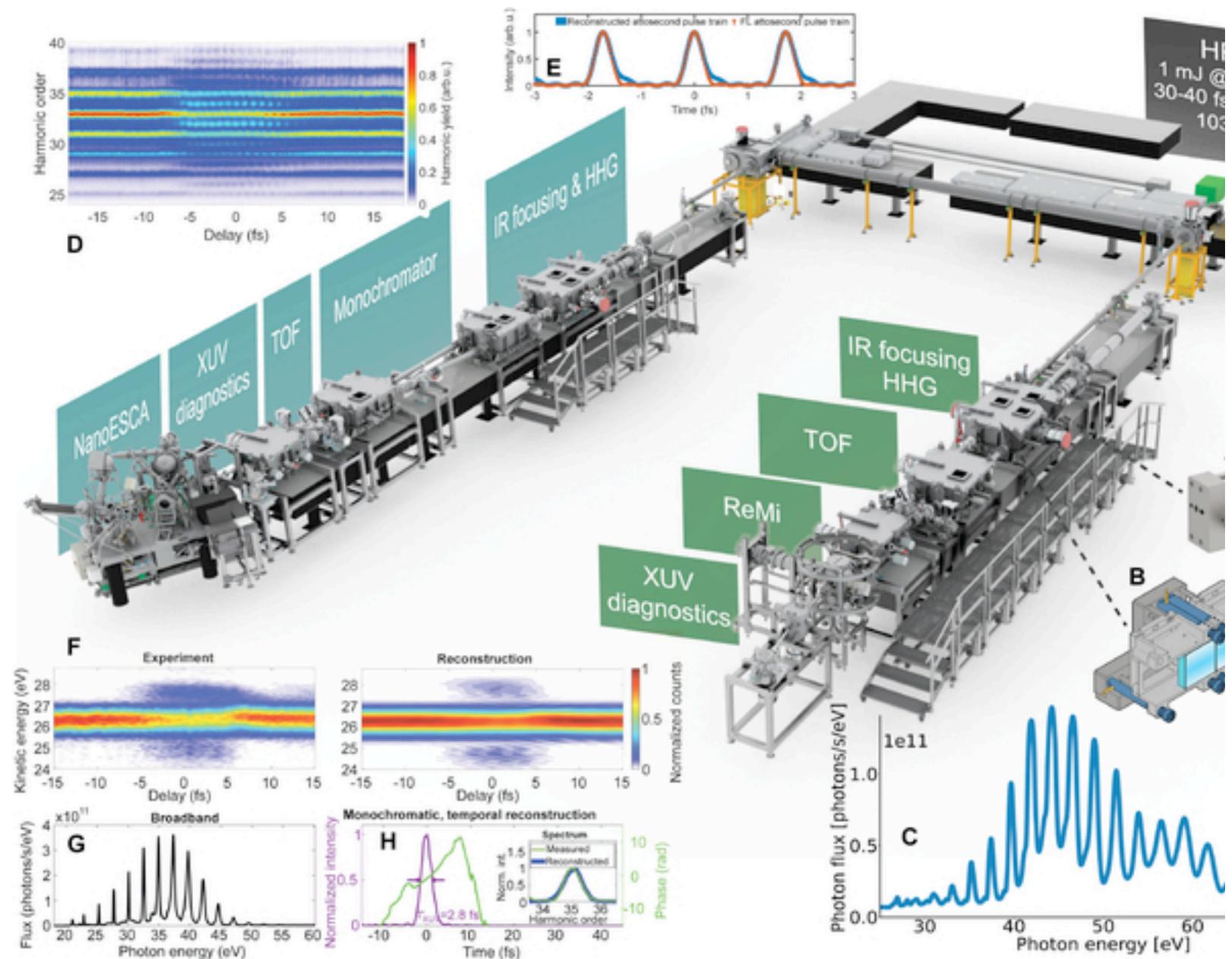
Experiment @ eli

HR XUV beamline at ELI-ALPS

Rabitt measurements at 100 KHz rep. rate.

Detection: electron time-of-flight (eTOF) spectrometer.

A monochromator enabled selection of individual harmonic orders for spectral reference.



Experiment @ eli

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Water cluster source

Continuous source of water clusters.

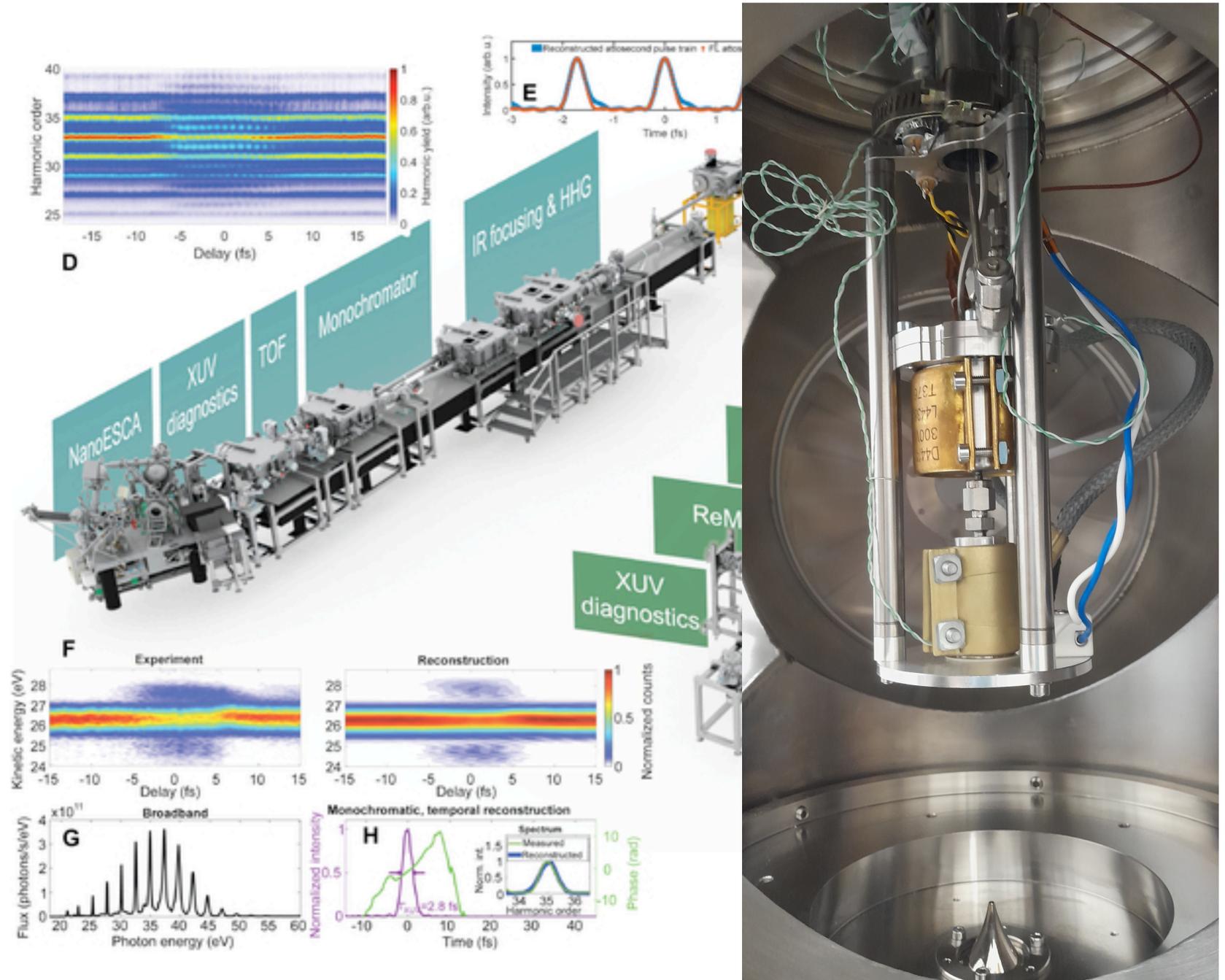
Supersonic expansion in a He-seeded molecular beam.

~500 water molecules/cluster.



Katinka Horn (DESY, ETH)

In collaboration with the group of Ruth Signorell (ETH, Zurich)



M. Shirozhan, et al. Ultrafast Sci. 4, 0067 (2024)

Rabbitt in Helium

Benchmark measurement in He.

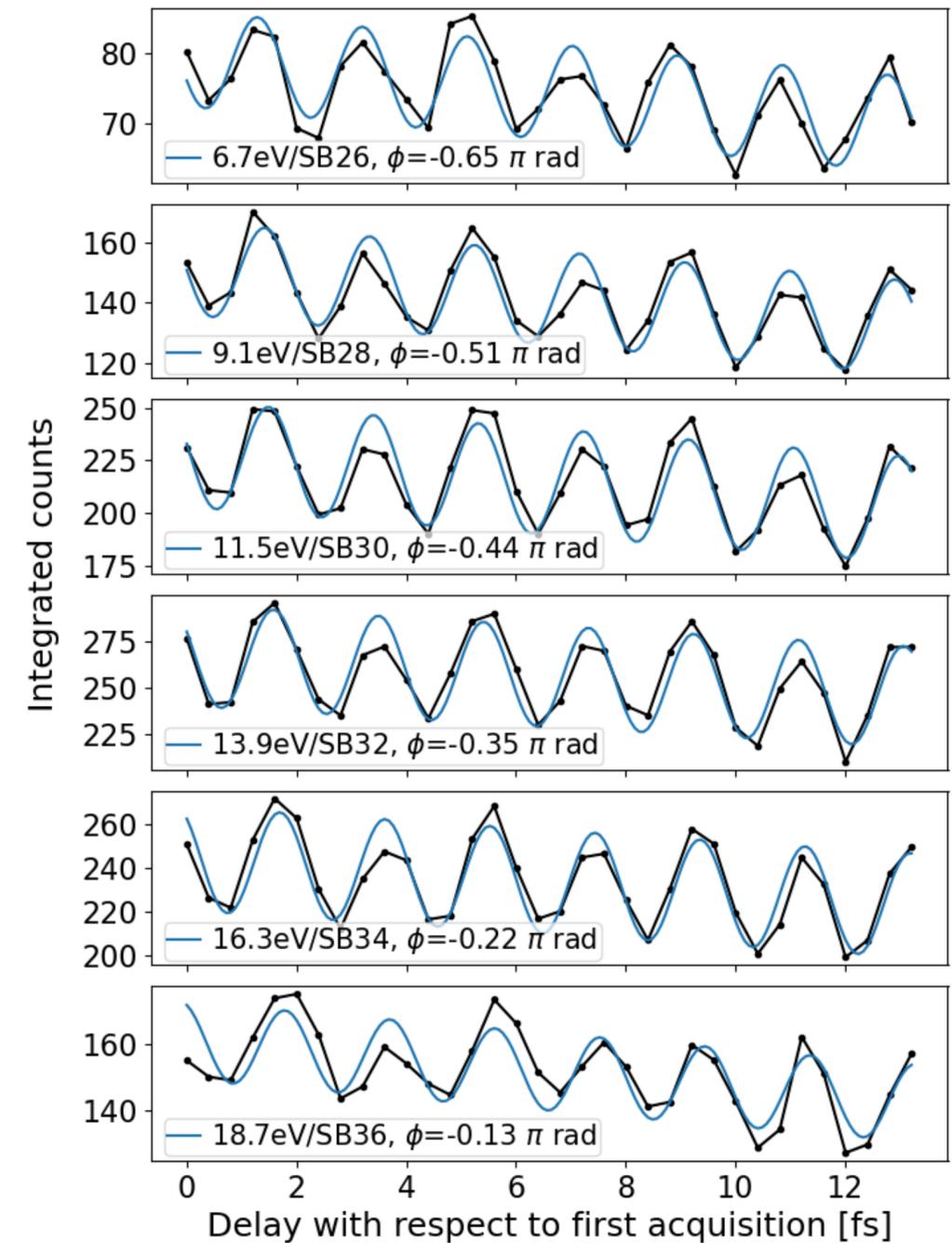
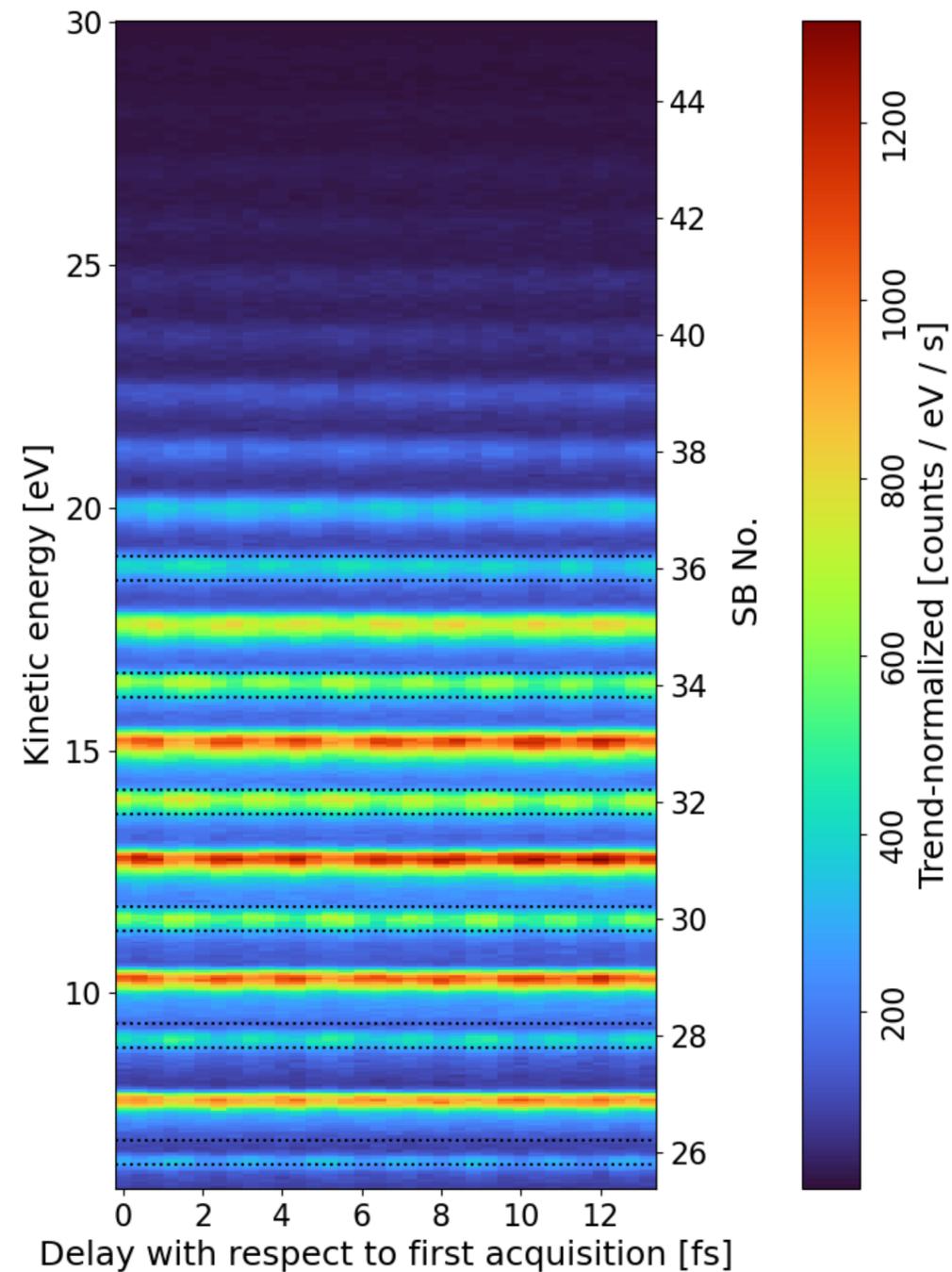
Also He shows a nonzero phase:

Attochirp + He Wigner delay \sim Attochirp

$$\phi(E) = 0.16 \pm 0.016 \text{ rad/H}$$

H = harmonic order

$$\phi(E) = 43 \pm 5 \text{ as/H}$$



Y. Mairesse et al., Science 302, 1540-1543 (2003)

J. Mauritsson et al., Phys. Rev. A 72, 013401 (2005)

S. Heuser et al., Phys. Rev. A 94, 063409 (2016)

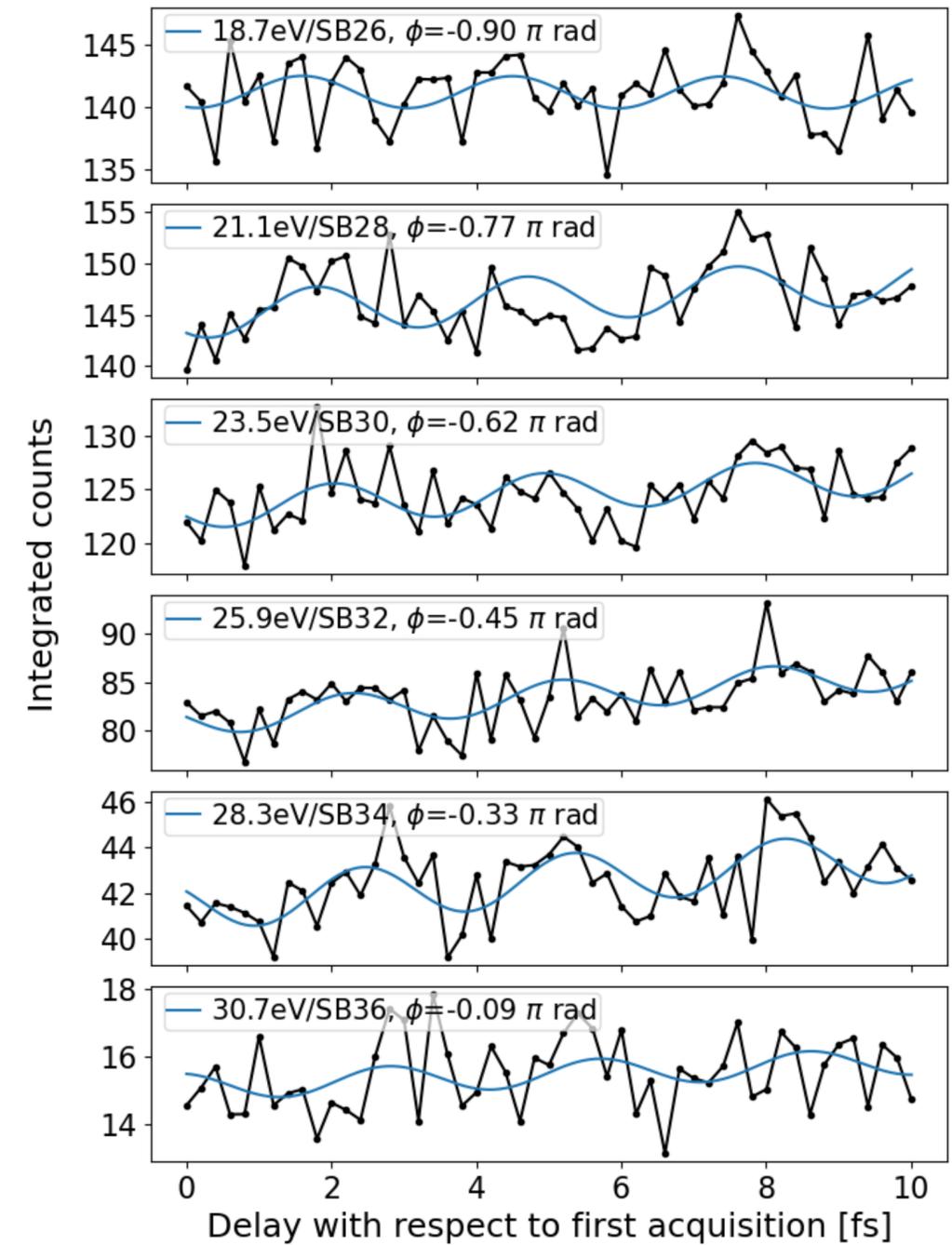
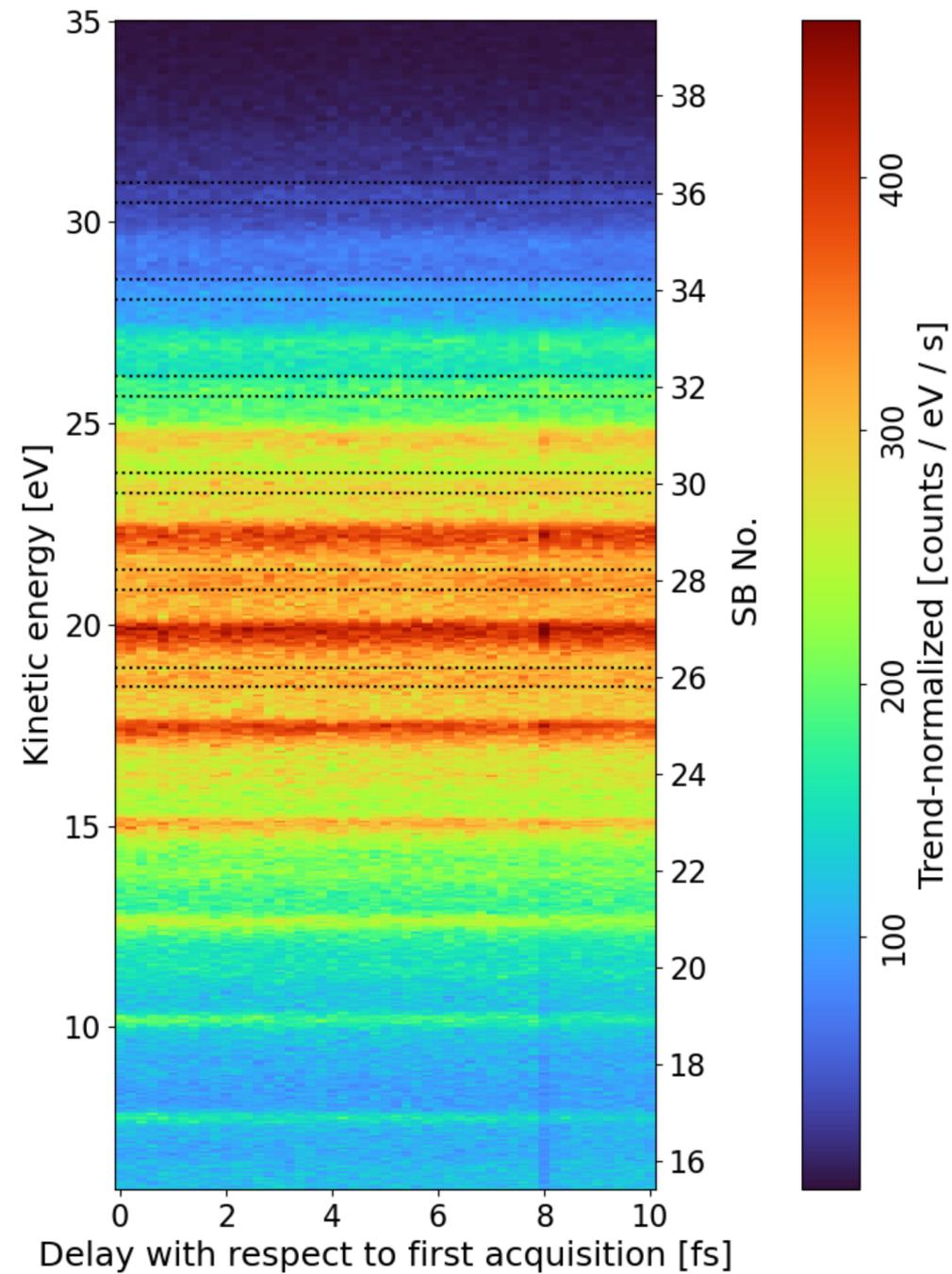
Rabbitt in water clusters

Challenging S/N.

High repetition rate is crucial here.

Limited target density.

$$d_{wc}/d_{He} < 10^{-3}$$



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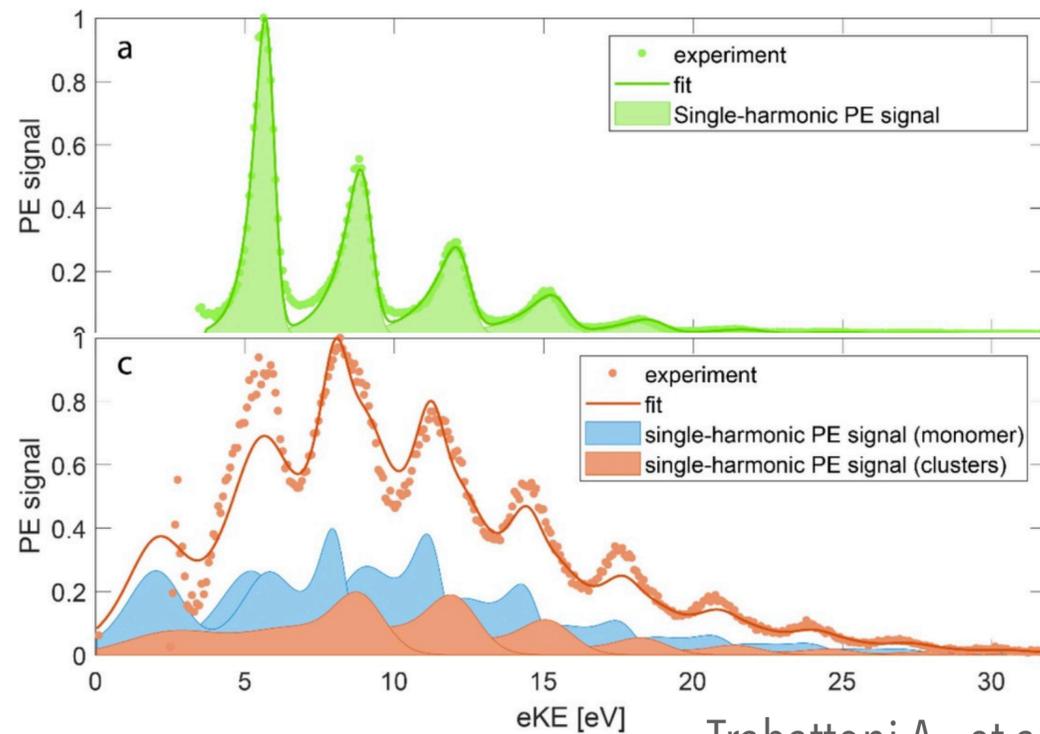
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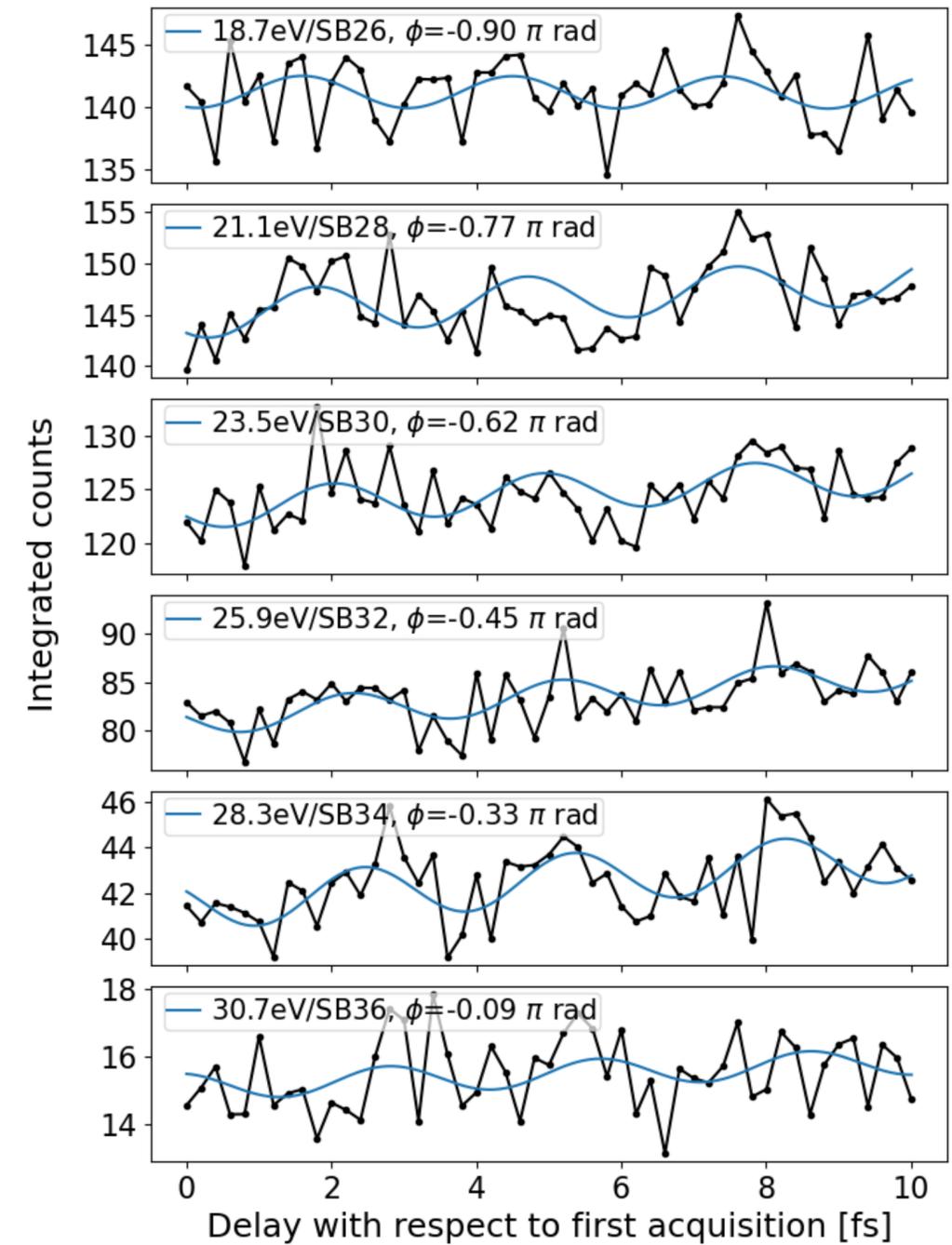
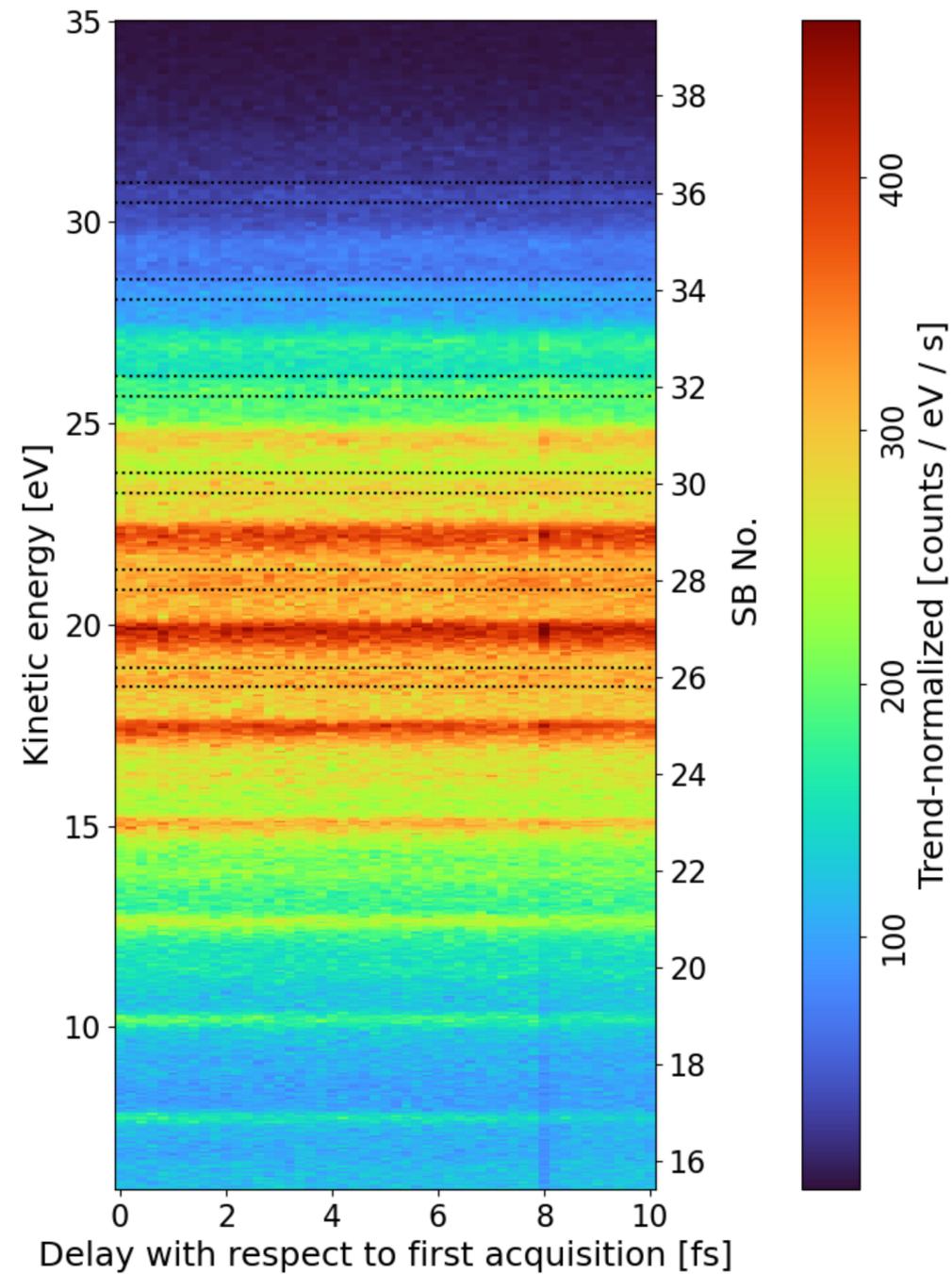
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Complex ionisation spectrum.



Trabattoni A., et al, J. Phys. Photonics 2 035007 (2020)

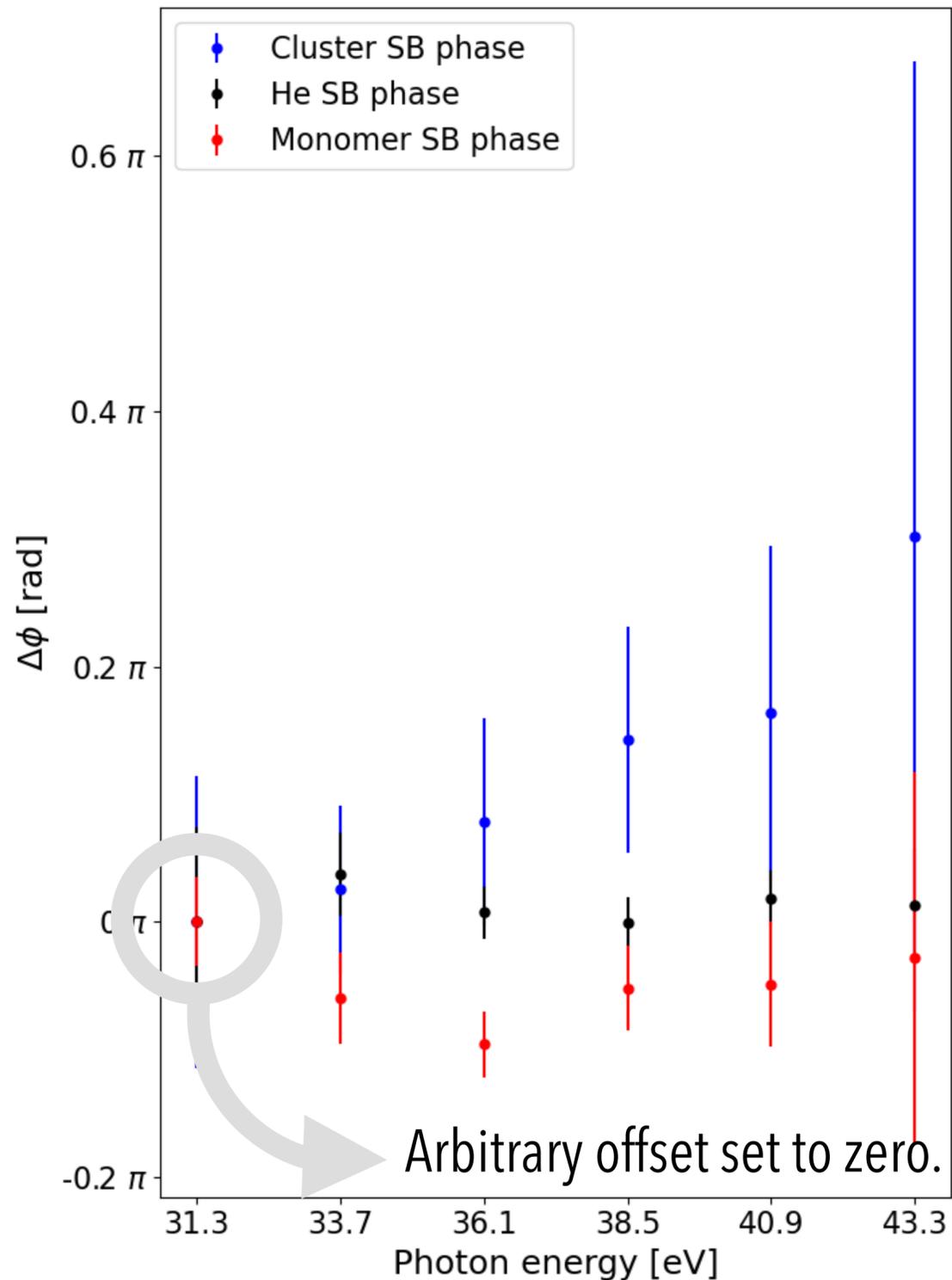


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Scattering phase in water clusters



The energy-dependent phase was measured in He, water monomers and clusters.

We measured relative phases. No absolute values.

Clusters show a positive (linear?) trend deviating from He and water monomers.

$$\phi^{\text{wc}}(E) \sim 70 \pm 30 \text{ as/eV}$$

The origin of the trend is under investigation.

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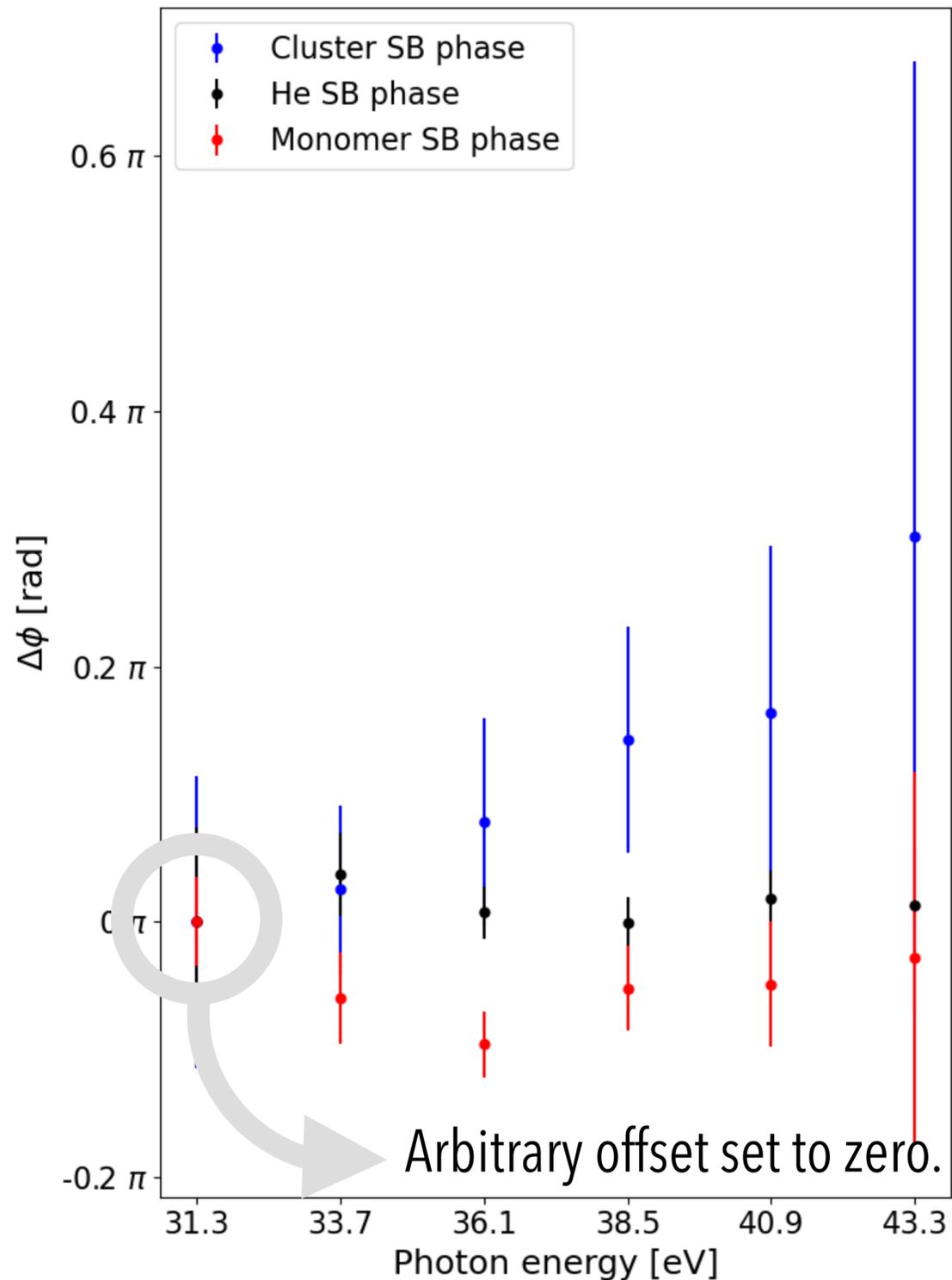
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Conclusions

New understanding on the effect of transport scattering in water clusters on the photoelectron emission times.

comparison with smaller clusters and liquid water.

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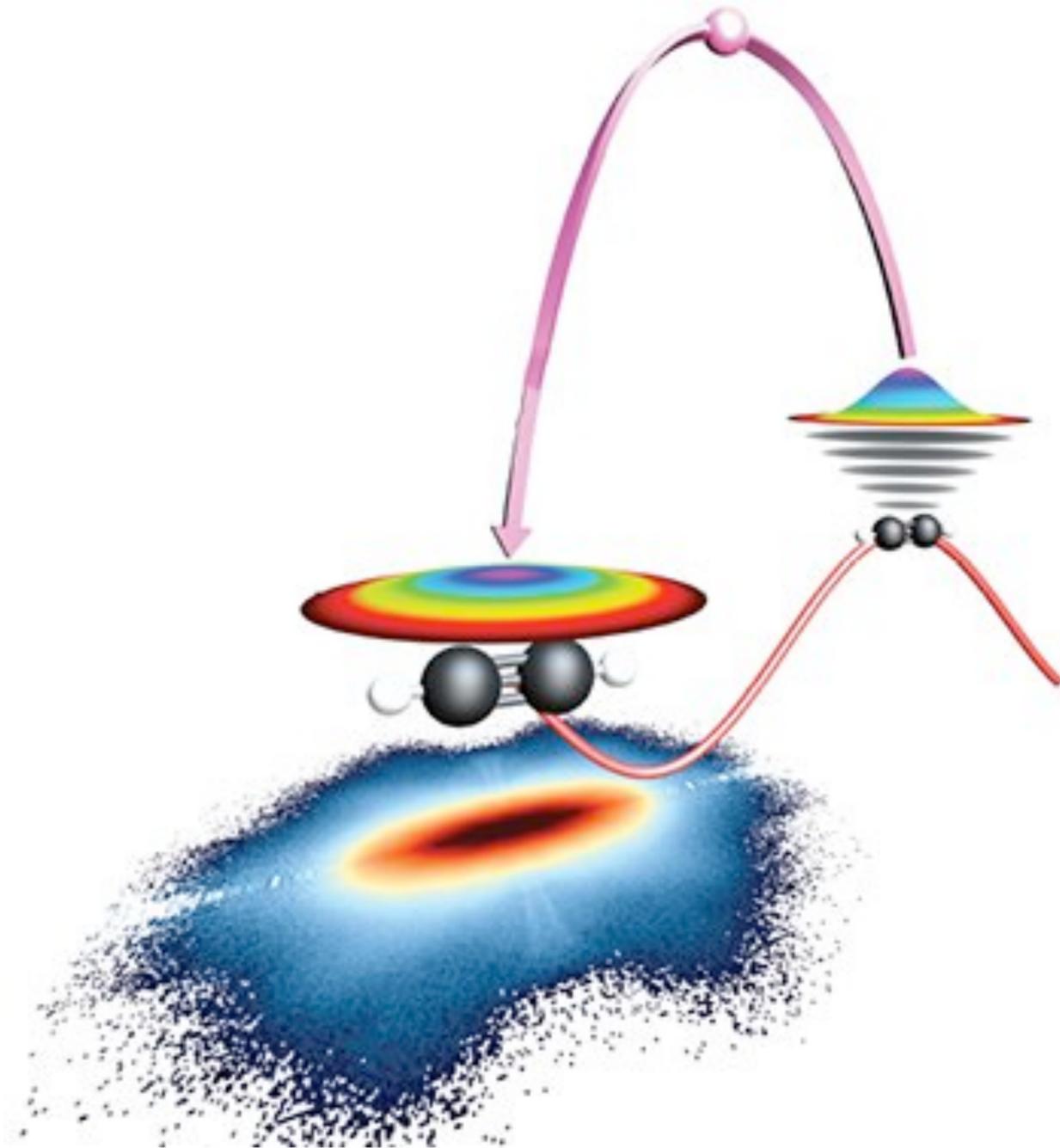
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Upcoming collaboration: two-color laser-induced electron diffraction



Ultrafast imaging of molecular structures.

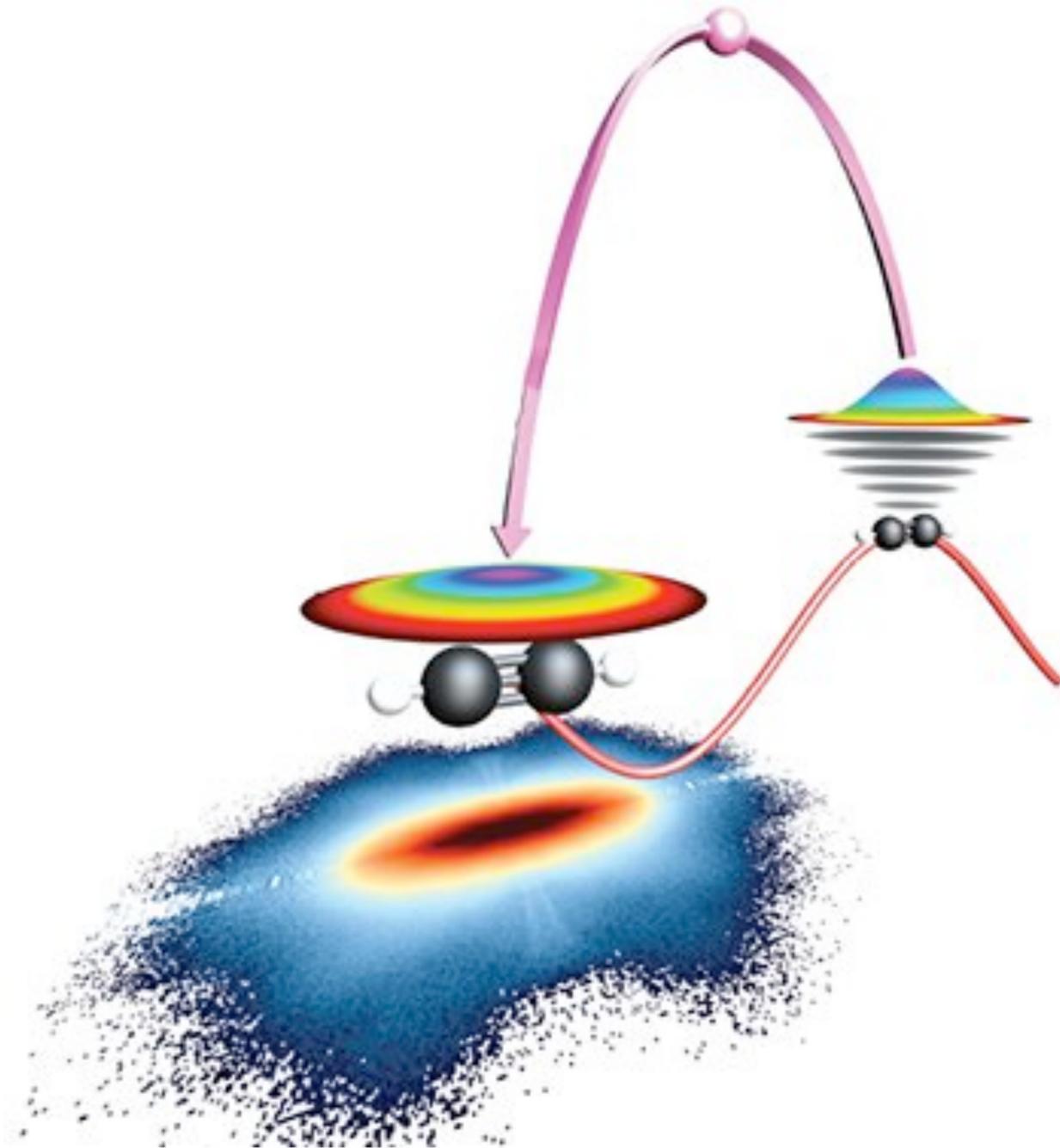
<http://atto.icfo.es/>

Blaga et al., Nature (London) 483, 194 (2012)

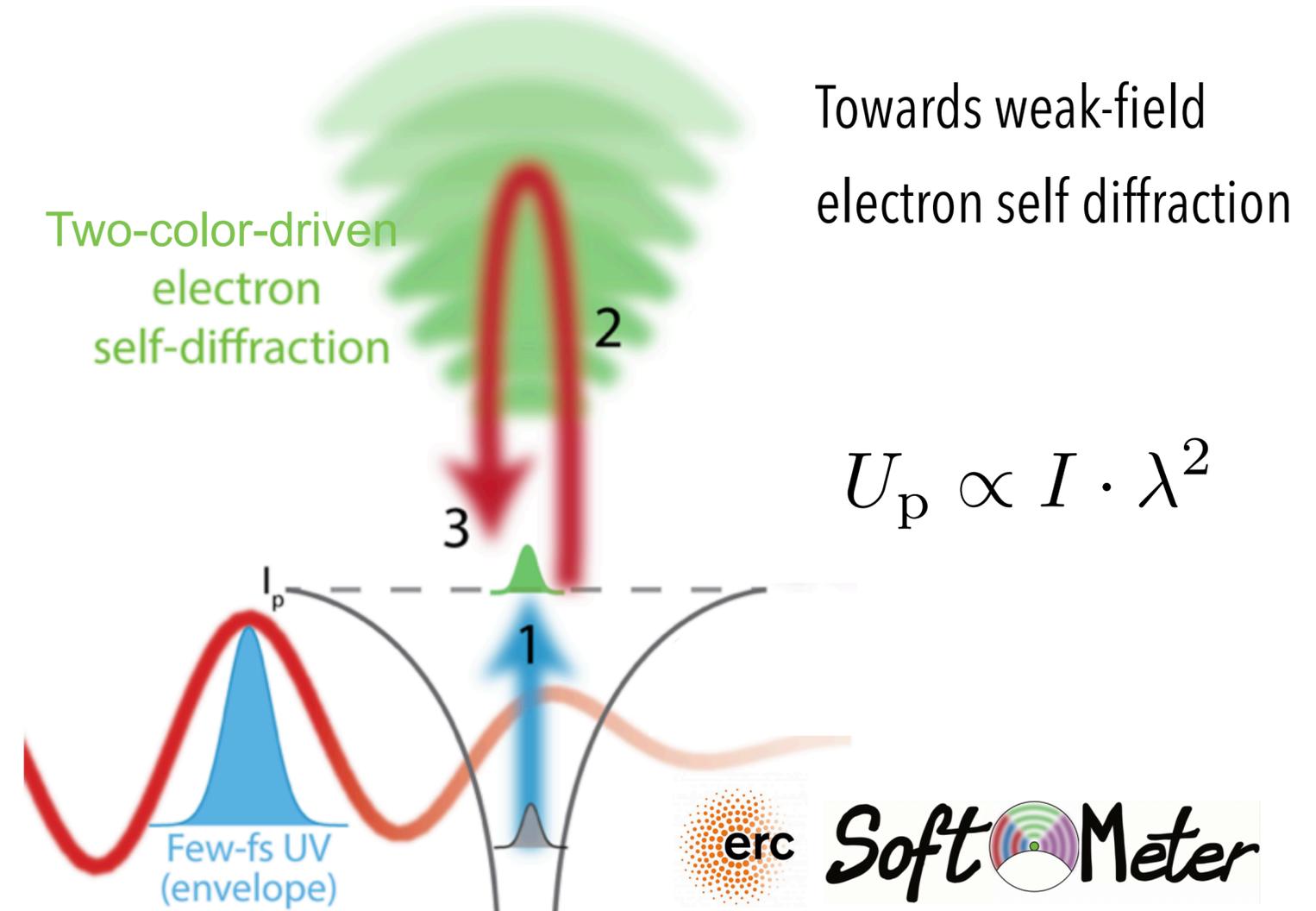
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U. De Giovannini et al 2023 J. Phys. B: At. Mol. Opt. Phys. 56 054002

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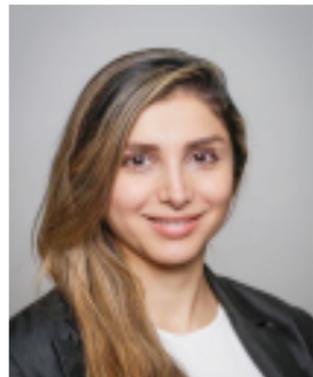
Experiment at  eli

Two-color photoelectron re-scattering.

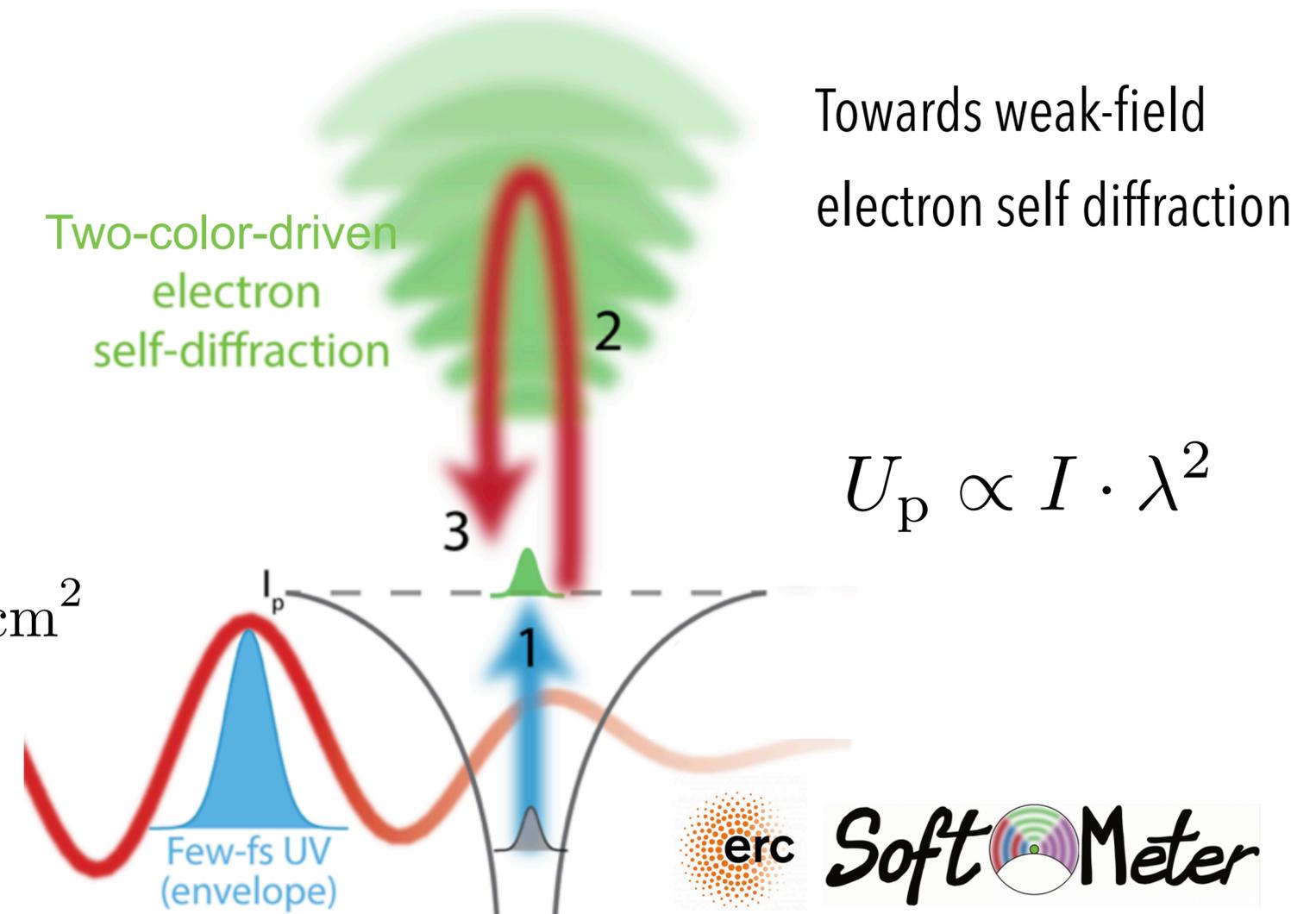
The experiment will be performed at Nanoplasmonics and Low-Temperature Solid-State Physics Facility (NLTSF).

Ultra-intense THz pulses, field strength ~ 0.5 MV/cm.

U_p values larger than 10 eV are achievable, while $I \sim 10^{10}$ W/cm²



Fatemehsadat Ghaffari (DESY)



<http://atto.icfo.es/>

Blaga et al., Nature (London) 483, 194 (2012)

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Acknowledgements



Meet the group!

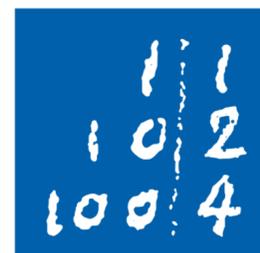
CFEL-ATTO group @DESY

ETH zürich

Bruce Yoder
Ruth Signorell



HR XUV beamline team
NLTSF team



zukunft.
niedersachsen

