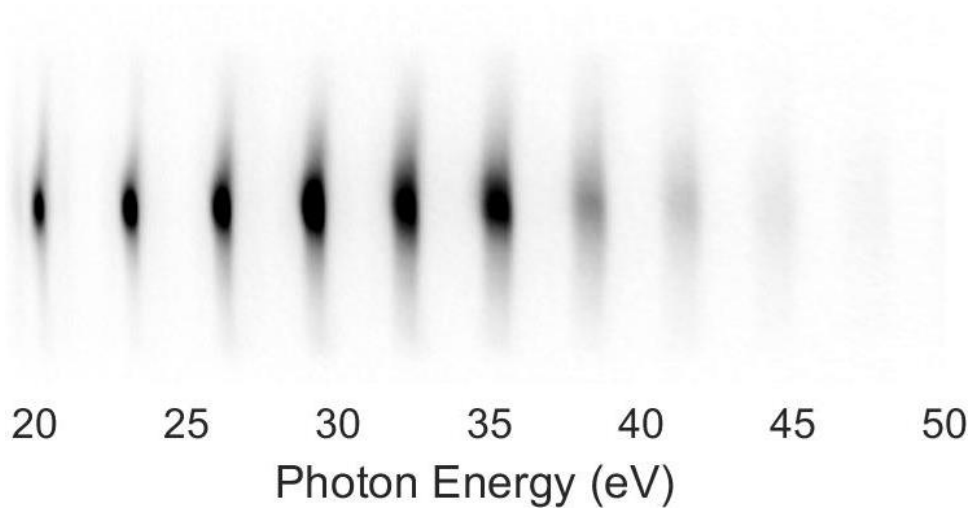
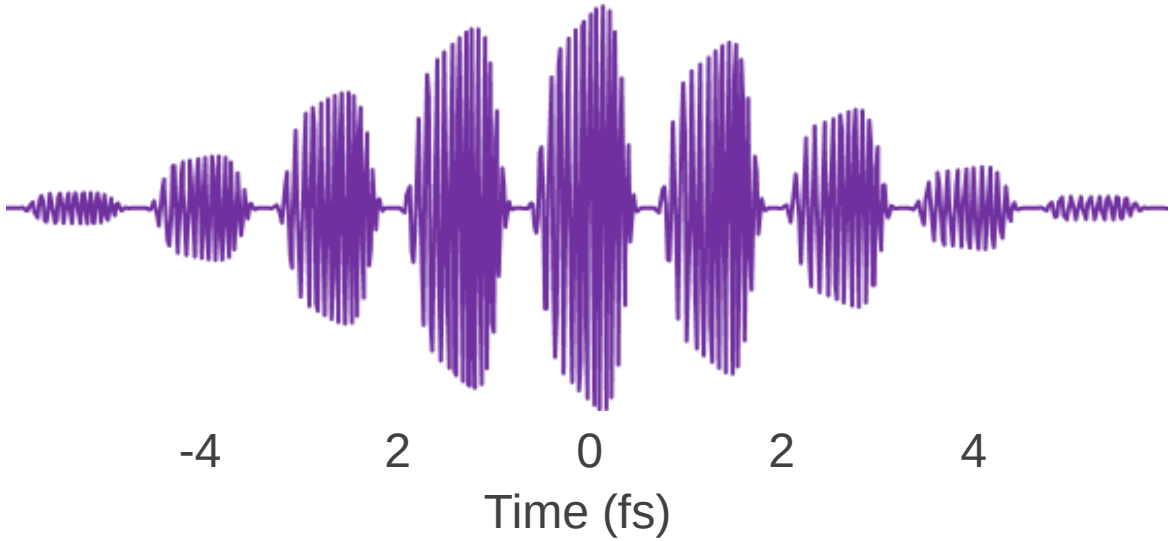
High-harmonic generation and EUV Science

Peter M. Kraus

Advanced Research Center for Nanolithography (ARCNL), Amsterdam, The Netherlands.

EUV source workshop, 04.11.2019, Amsterdam, The Netherlands.





ARCNL NWO AMOLF Universiteit van Amsterdam VU Vrije Universiteit Amsterdam Gemeente Amsterdam Provincie Noord-Holland ASML

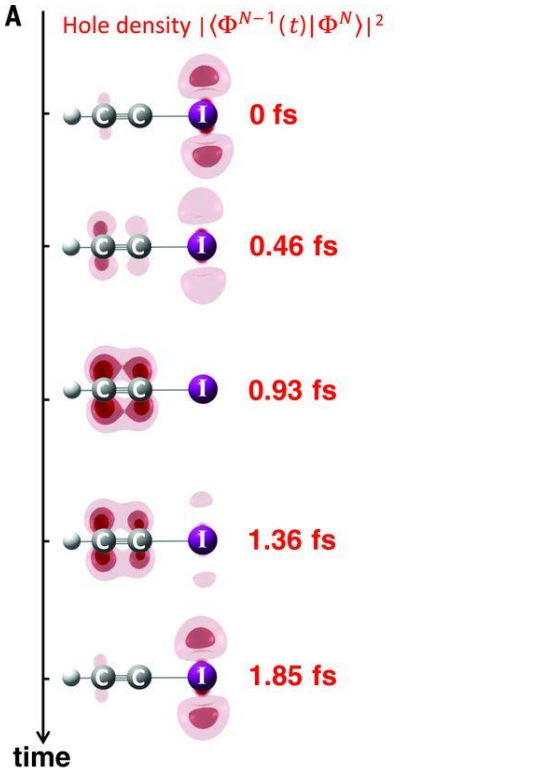
Ultrafast and ultrasmall

Electron dynamics

- Ultrashort pulses

Small structures

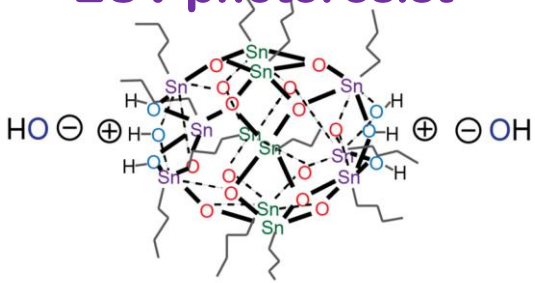
- Short wavelengths



P. M. Kraus et al. Science 350 790 (2015)

G. S. M. Jansen et al., *Opt. Express* **26**, 12479 (2018)).

EUV photoresist



exposure

τ = ?

?

High-harmonic generation enables (sub-) fs time resolution and nm spatial resolution!
(but is not suitable as a source for lithography)

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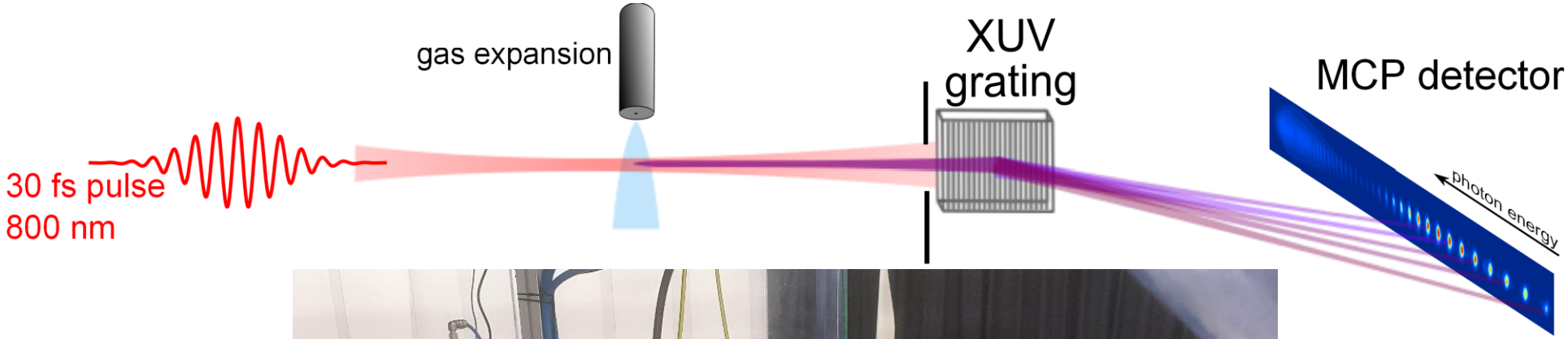
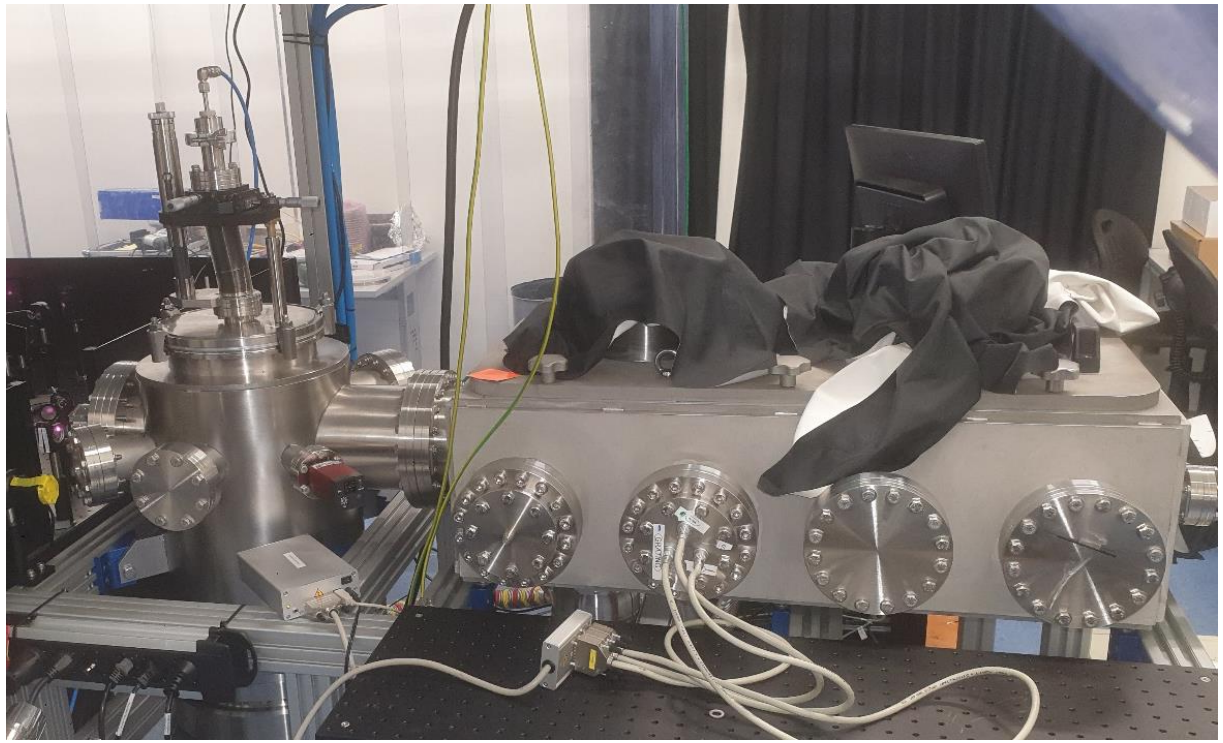
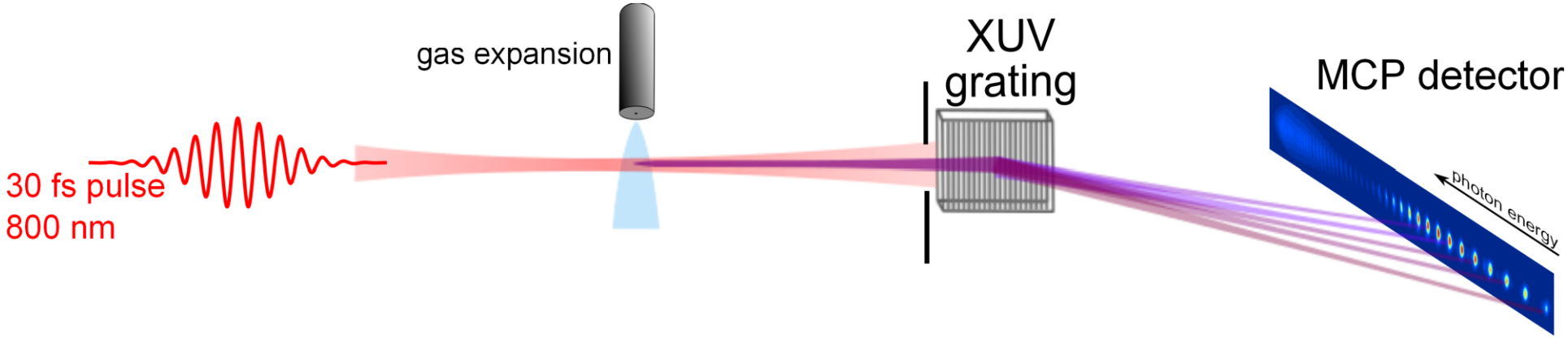
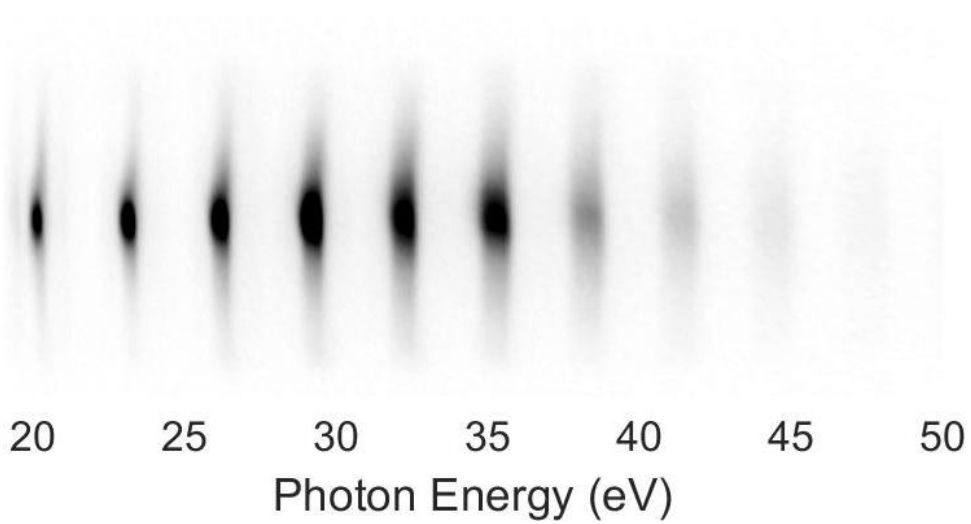
An outside look at HHG

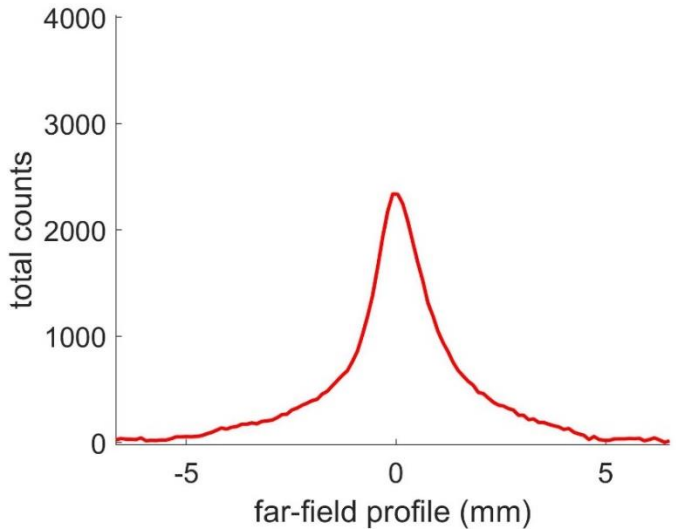




An outside look at HHG







Double Gaussian beam profile; pulse energy is lost in wings.
Broad wings prohibit imaging of embedded structures.

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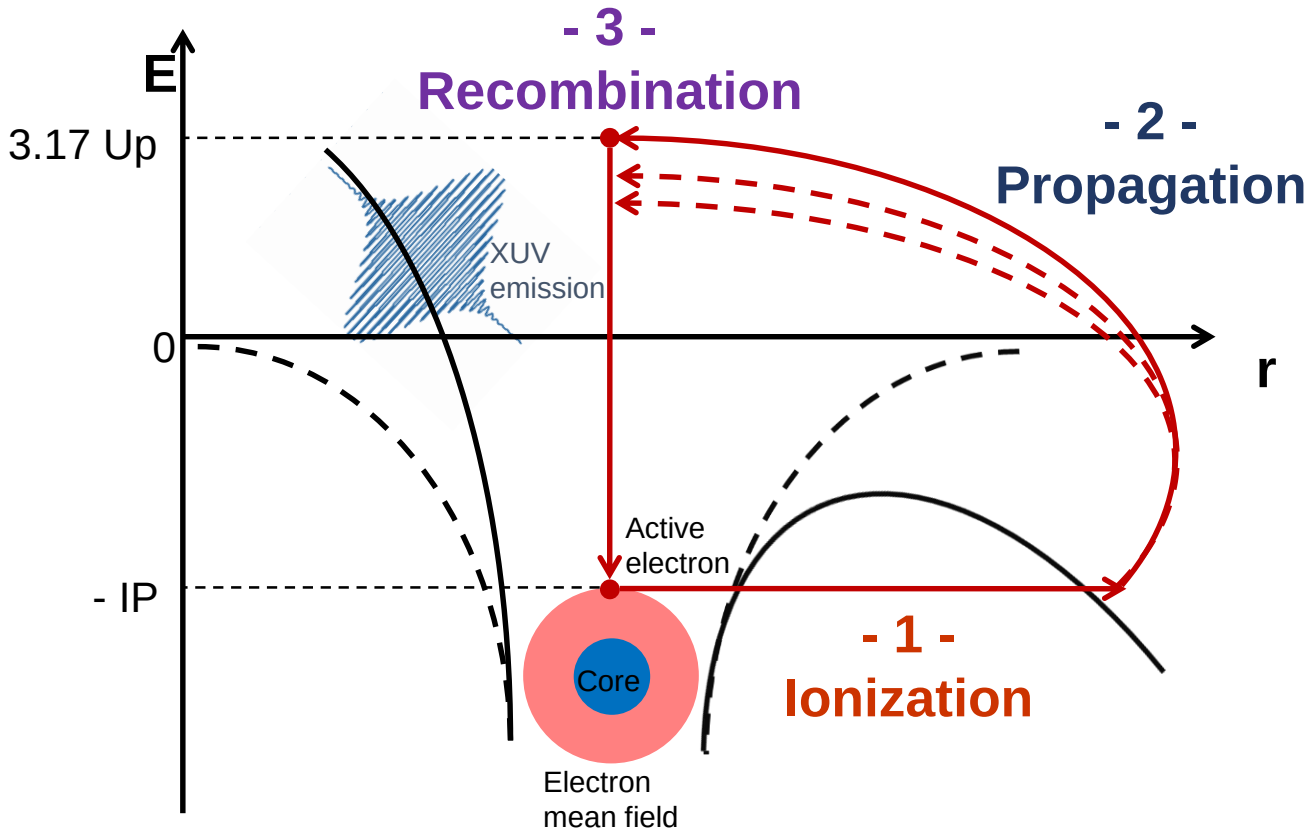
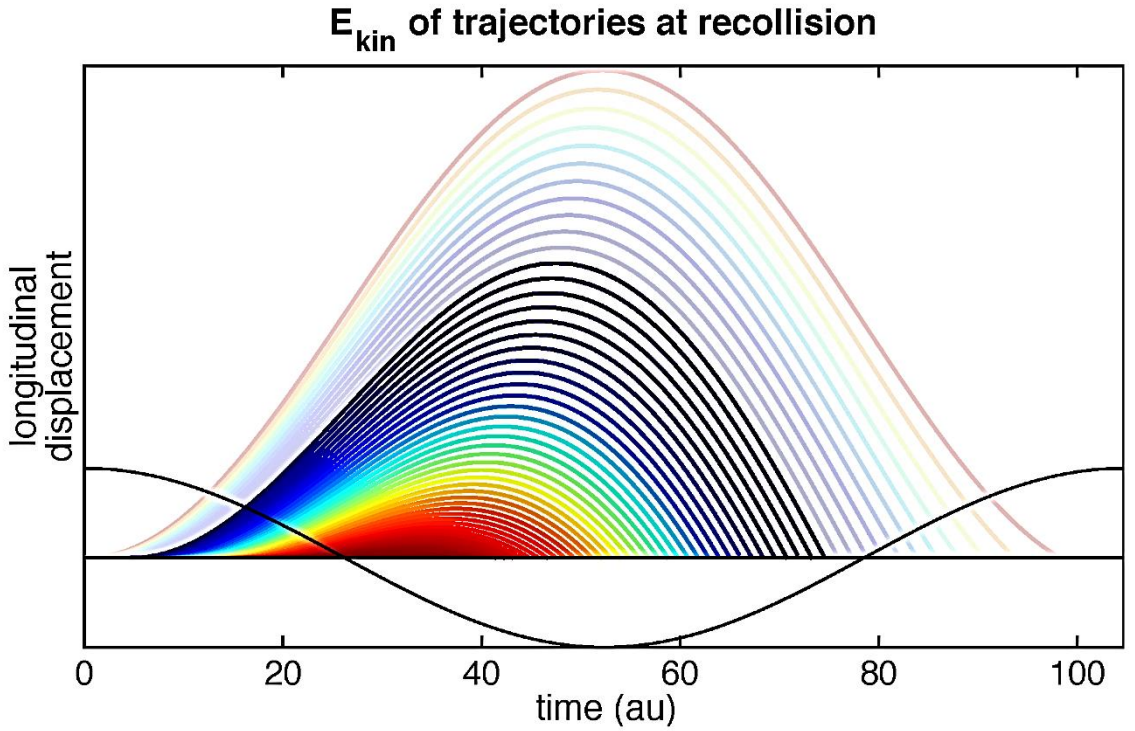
An inside look into HHG





C. Hofmann et al., *Applied Sciences*, *8*, 341 (2018)

For each generated energy there are two electron trajectories contributing:

Long and short trajectories

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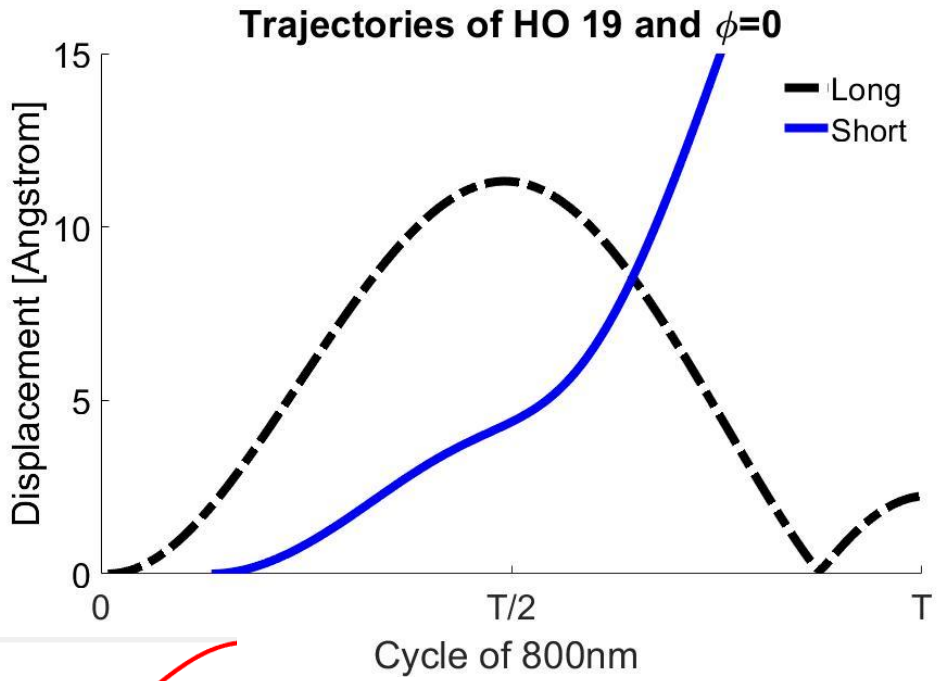
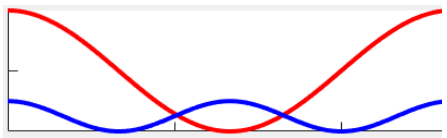
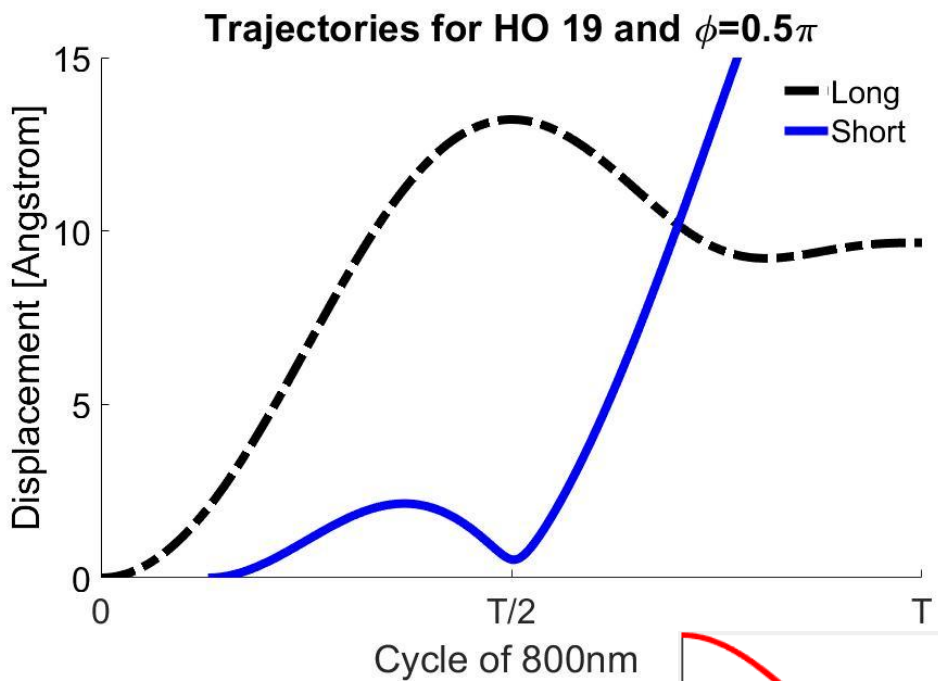
Trajectory selection in two-color HHG

Adding an orthogonally polarized 400nm pulse changes the trajectories of the electrons.

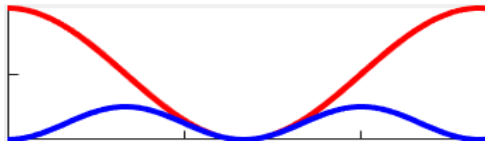


ϕ=0





ϕ =0.5π



S. Roscam Abbing et al., arXiv:1910.06470 [physics.optics] (2019).

ϕ: relative phase between 800 nm and 400 nm fields

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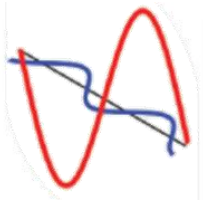
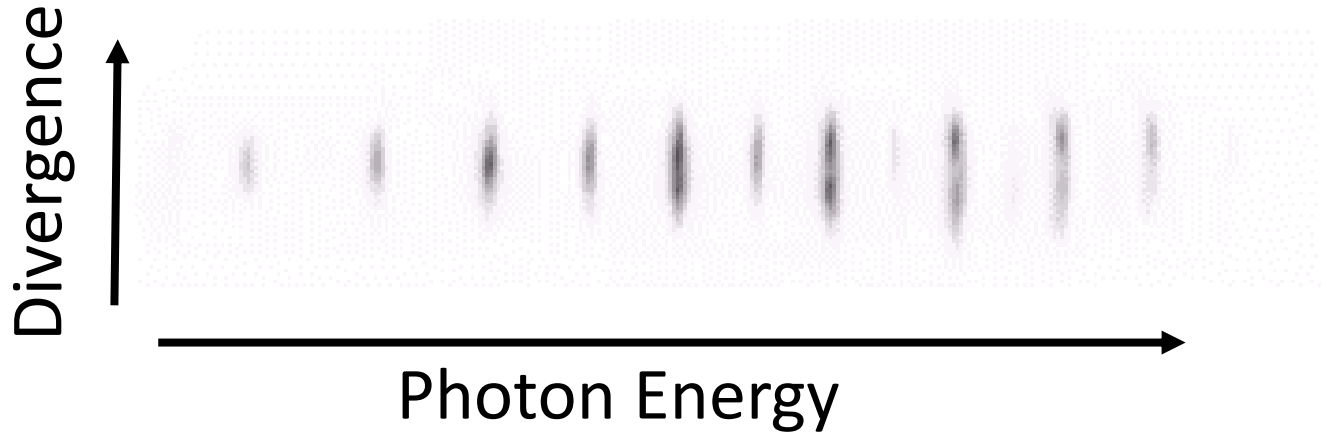
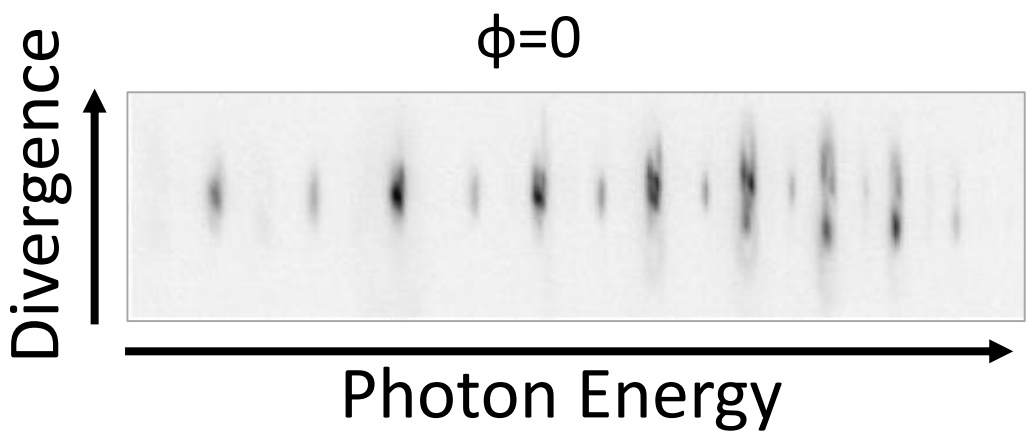
Two-color HHG controls divergence

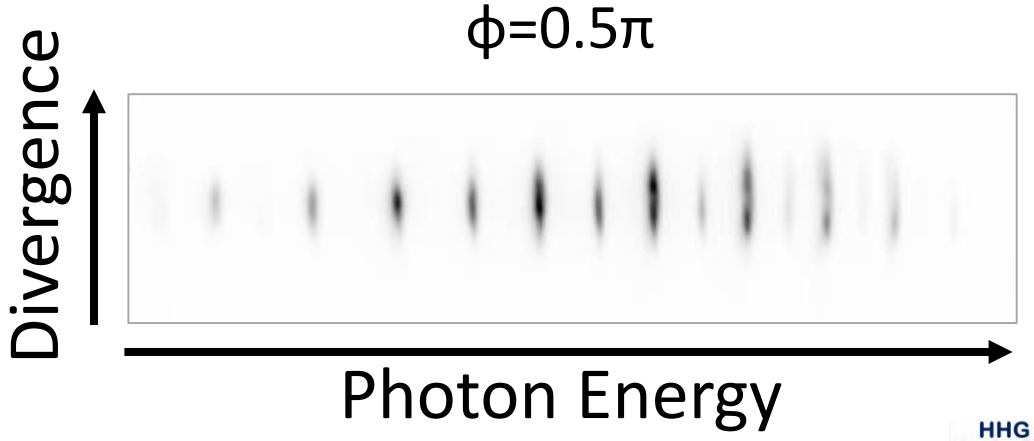
Video: HHG signal as function of phase of two-color field.



800 nm
400 nm (orthog. pol.)
15% rel. int.







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S. Roscam Abbing et al., arXiv:1910.06470 [physics.optics] (2019).

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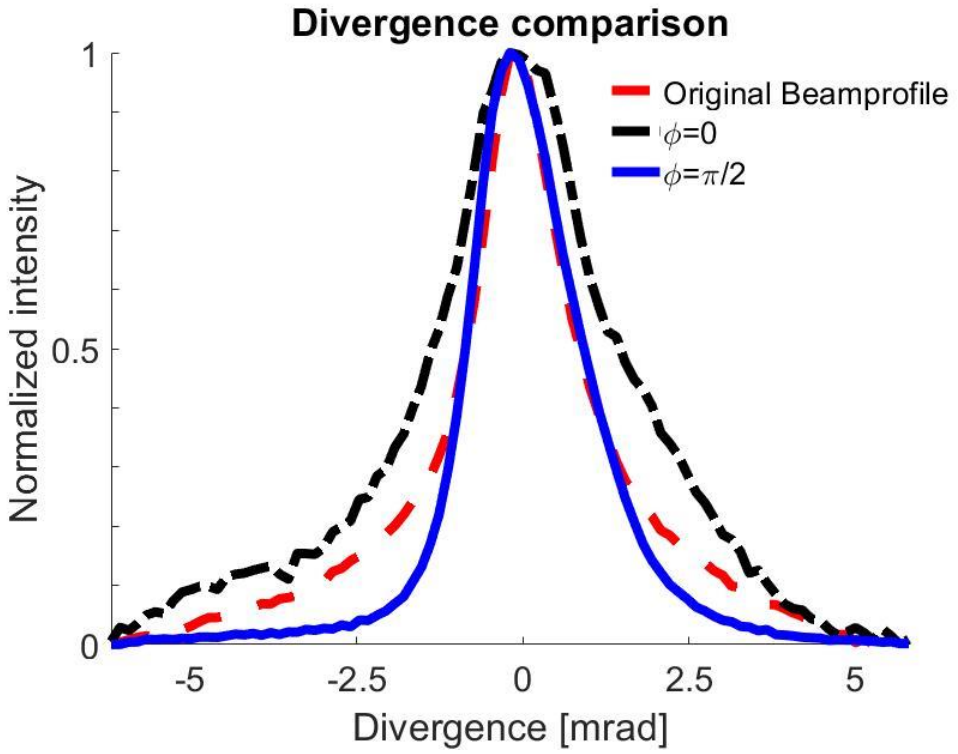
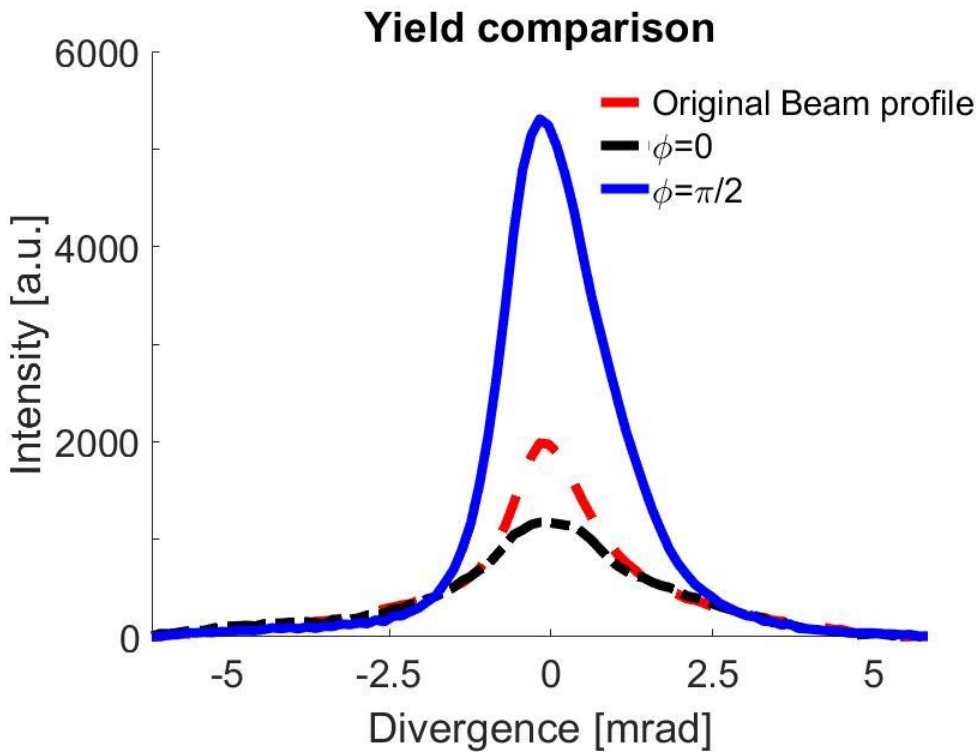
Divergence in HHG





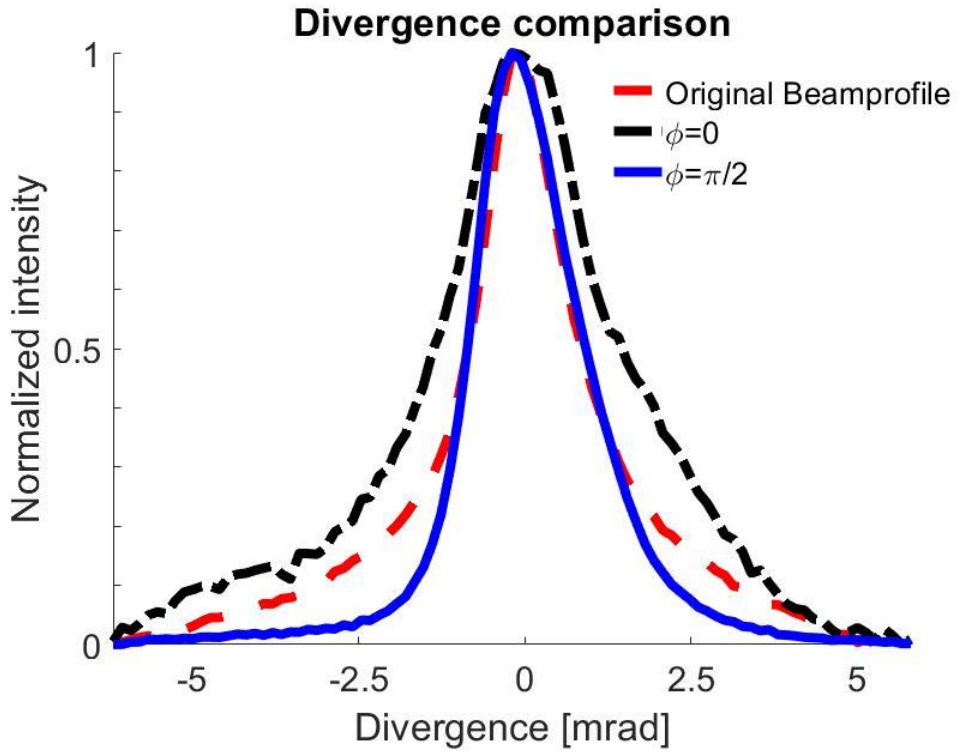
Adding a perpendicular 400 nm pulse to the generation process enables divergence control.

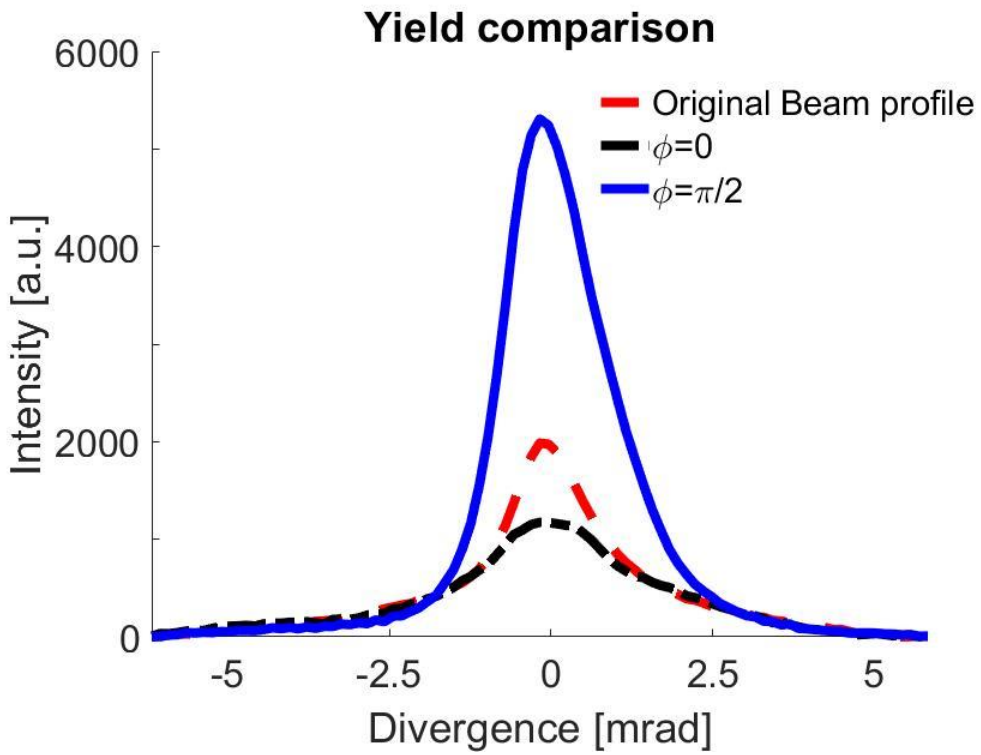
When selecting short trajectories, the total photon flux increases as well!

The optics are easy to implement.

The scheme enables micro-focussing of HHG

Divergence in HHG





Poster: "Divergence Control of High-harmonic Generation Enables High-brightness extreme-ultraviolet sources"
by Sylvianne Roscam Abbing

Preprint: S. Roscam Abbing et al., arXiv:1910.06470 [physics.optics] (2019).

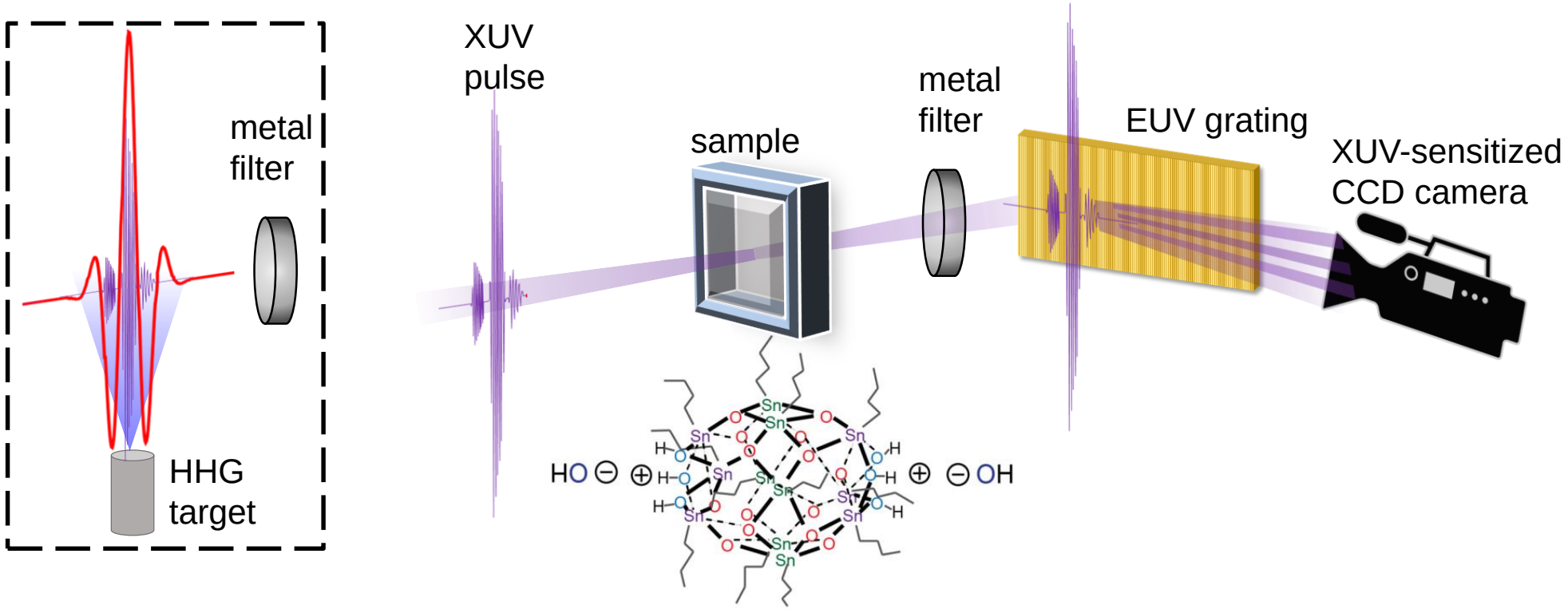
Exposure kinetics of photoresists

1. Time-resolved extreme-ultraviolet transient absorption

2. Time-resolved extreme/deep-ultraviolet luminescence

XUV Absorption and exposure in a single setup

Measure the complex dynamics in materials relevant for EUV lithography and understand how to improve them.



Unique feature of HHG-XANES: Simultaneous exposure and spectrally resolved absorption spectroscopy in the XUV with chemical sensitivity.

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Objective: Measure exposure kinetics as function of dose in photoresists.

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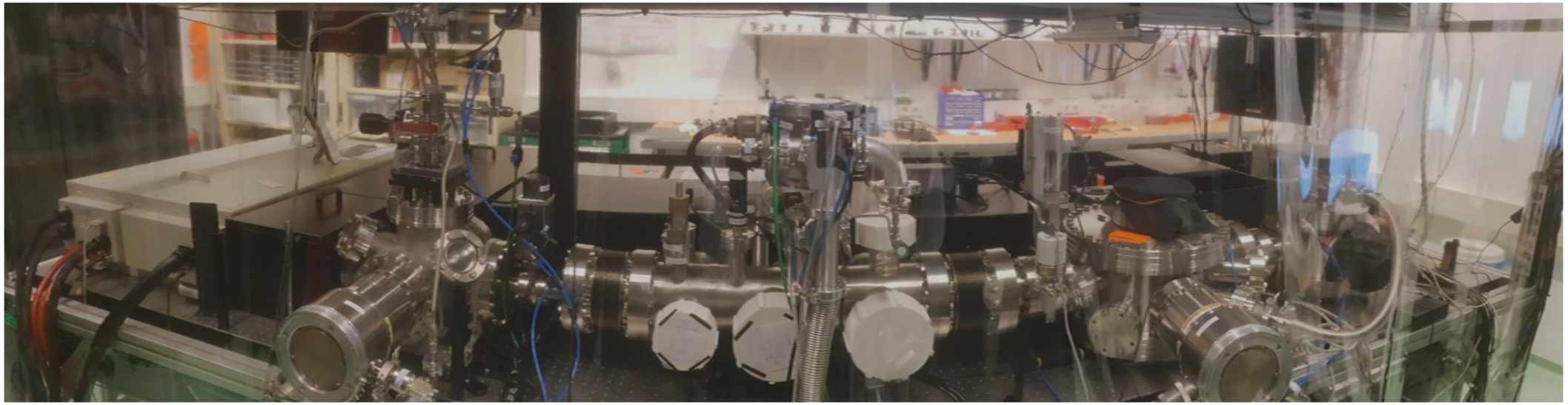
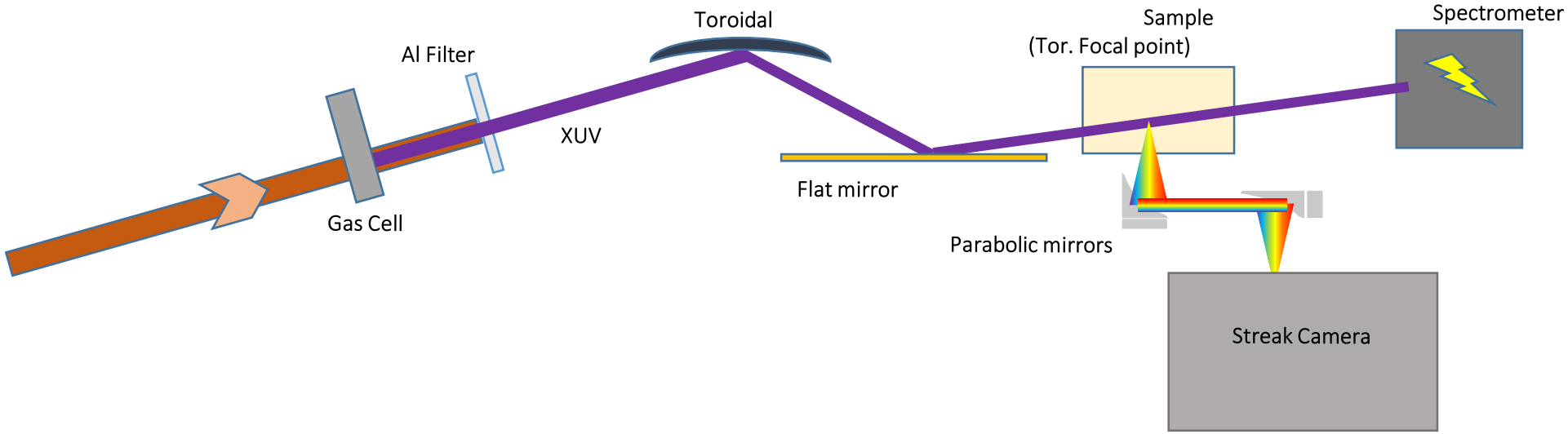
Spectroscopy of EUV materials with HHG





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Collaboration with Sonia Castellanos and Fred Brouwer.

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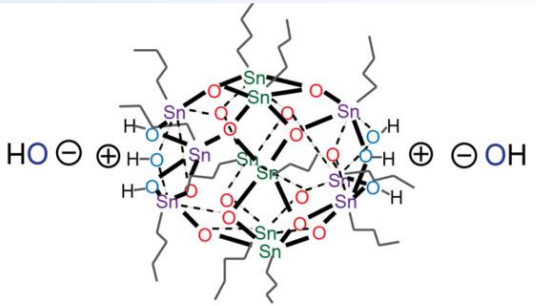
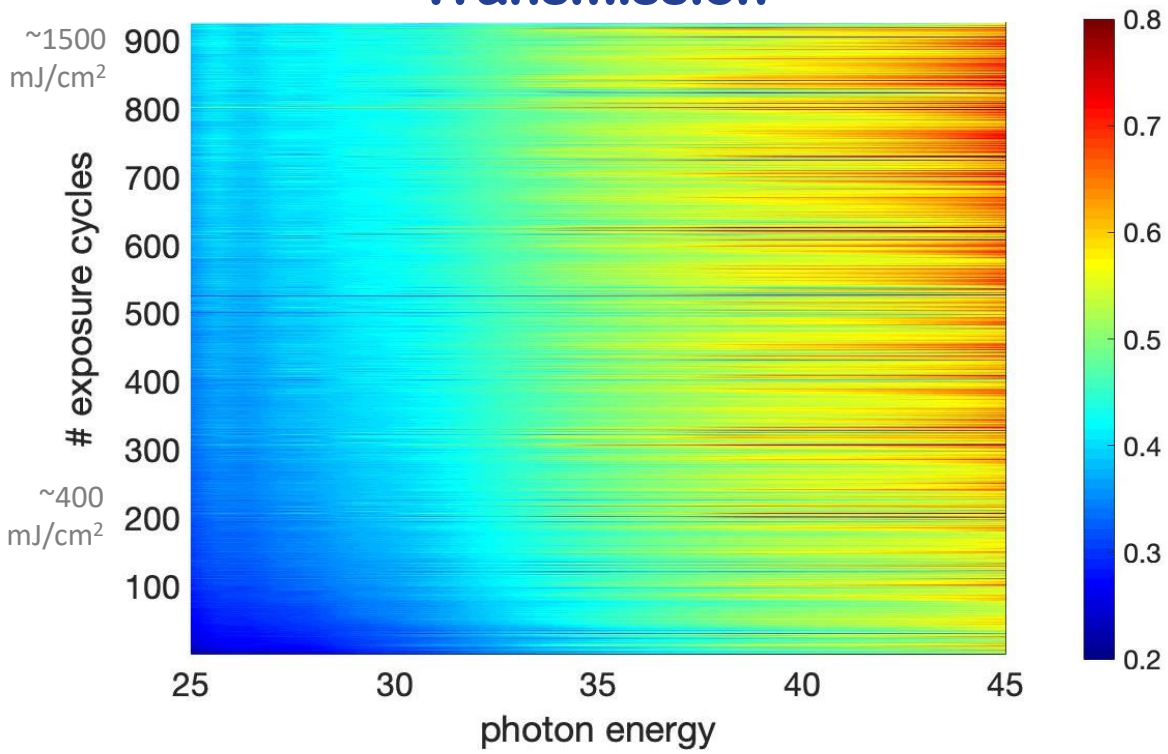
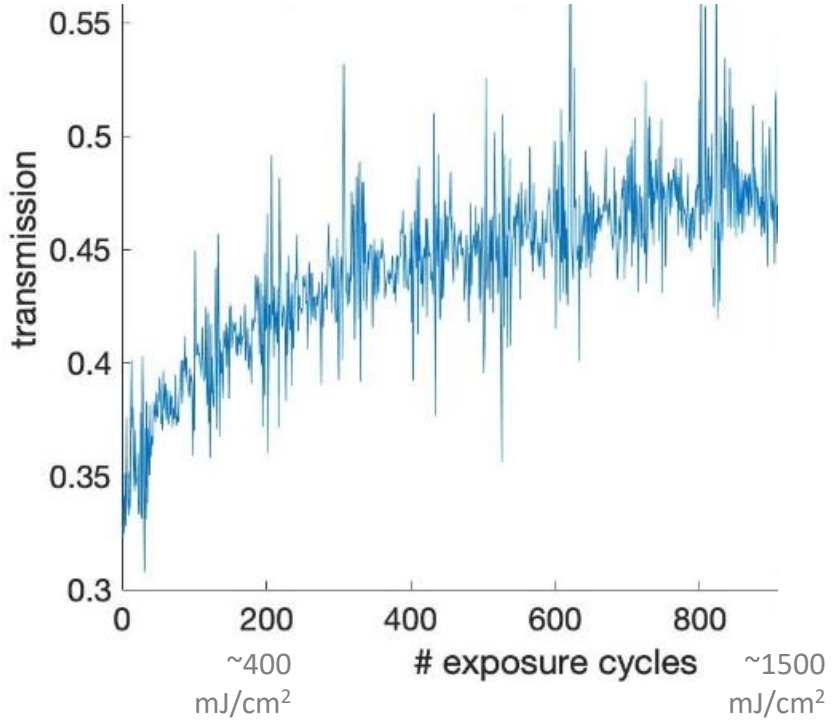
XUV absorption tracks photochemistry

Exposure and absorption spectroscopy of tin-oxo cages from 25-45 eV: Follow 4d-LUMO transitions in Sn (25-30 eV).



Transmission





Overall transmission increase: Butyl side chain dissociation.
Ongoing: Extraction of photoresist quantum yield

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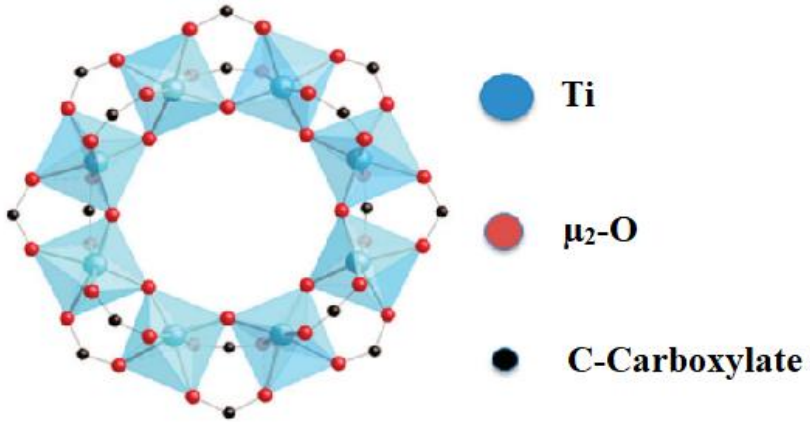
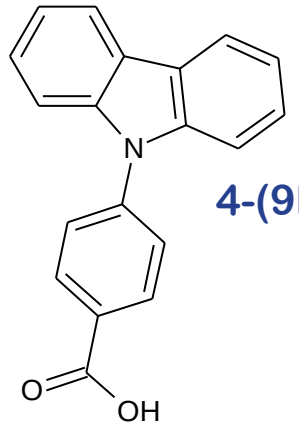
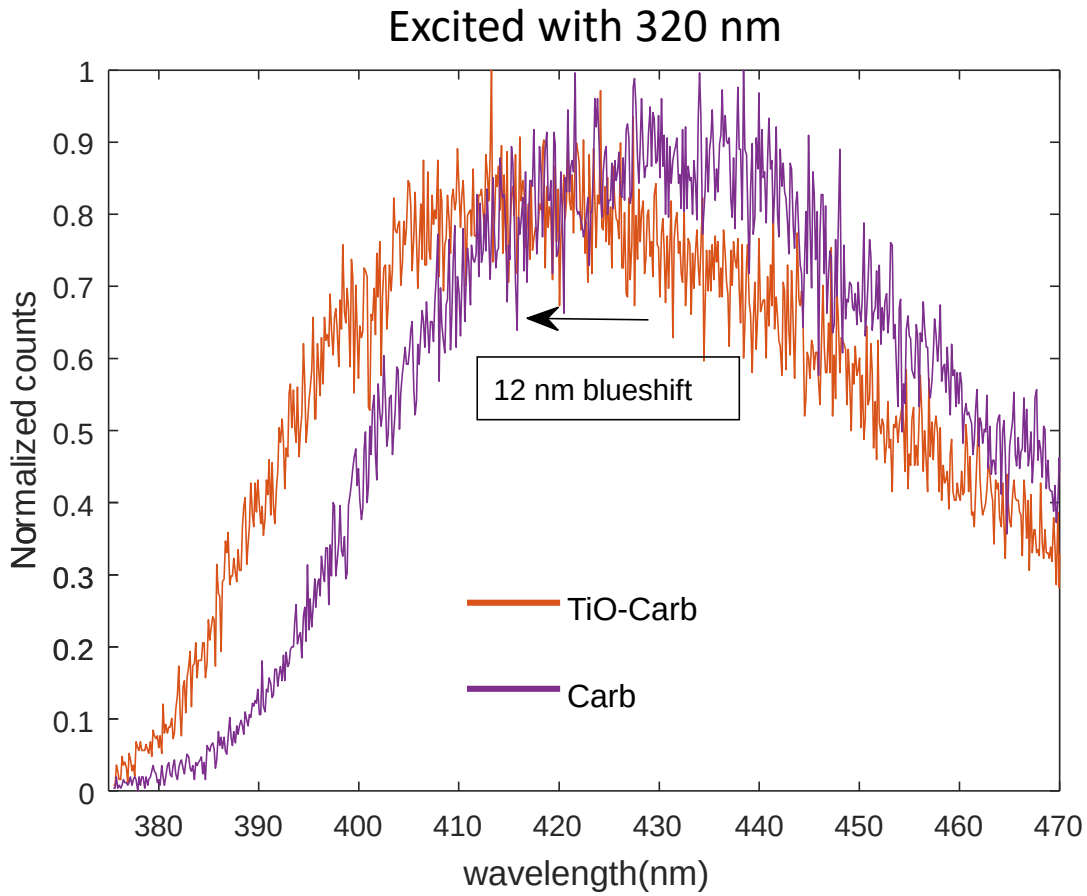
Luminescence of metal-oxo photoresists

Energy converted into luminescence will not drive a chemical reaction.





4-(9H-Carbazol-9-yl)benzoic acid



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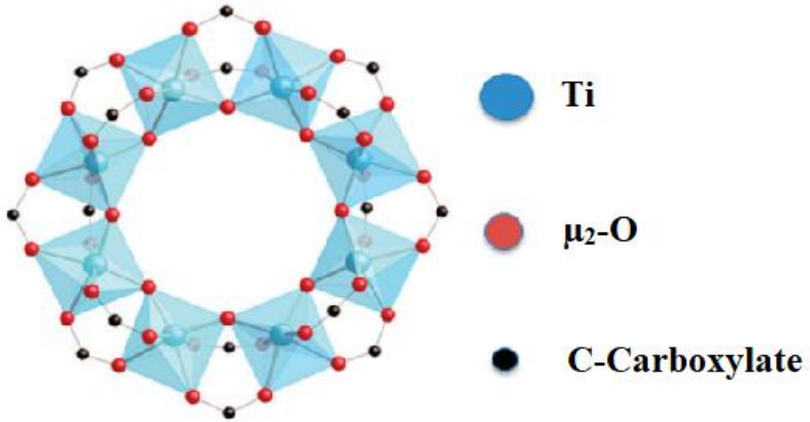
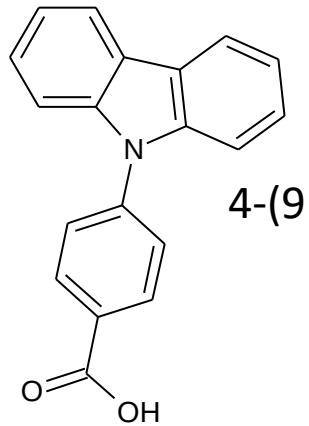
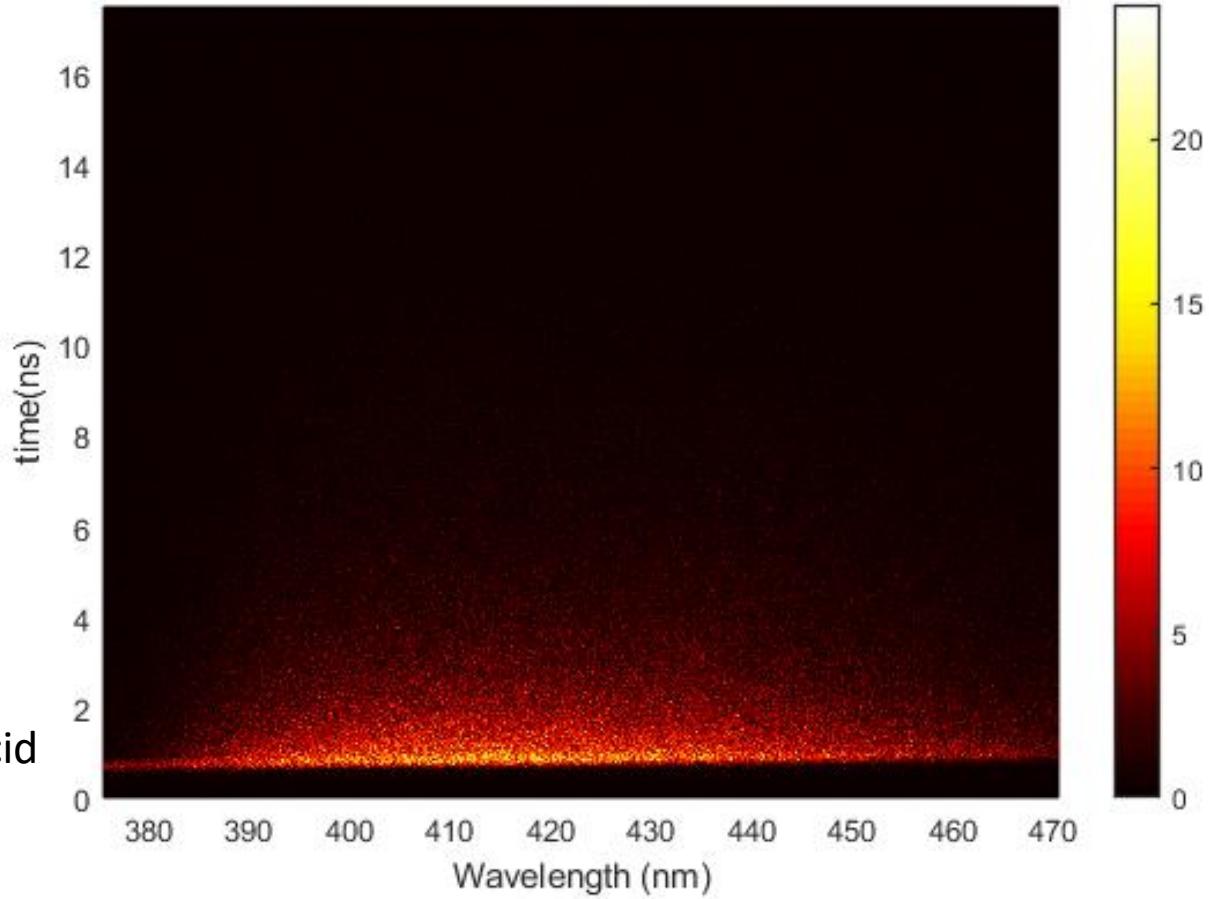
Time-resolving the luminescence





4-(9H-Carbazol-9-yl)benzoic acid



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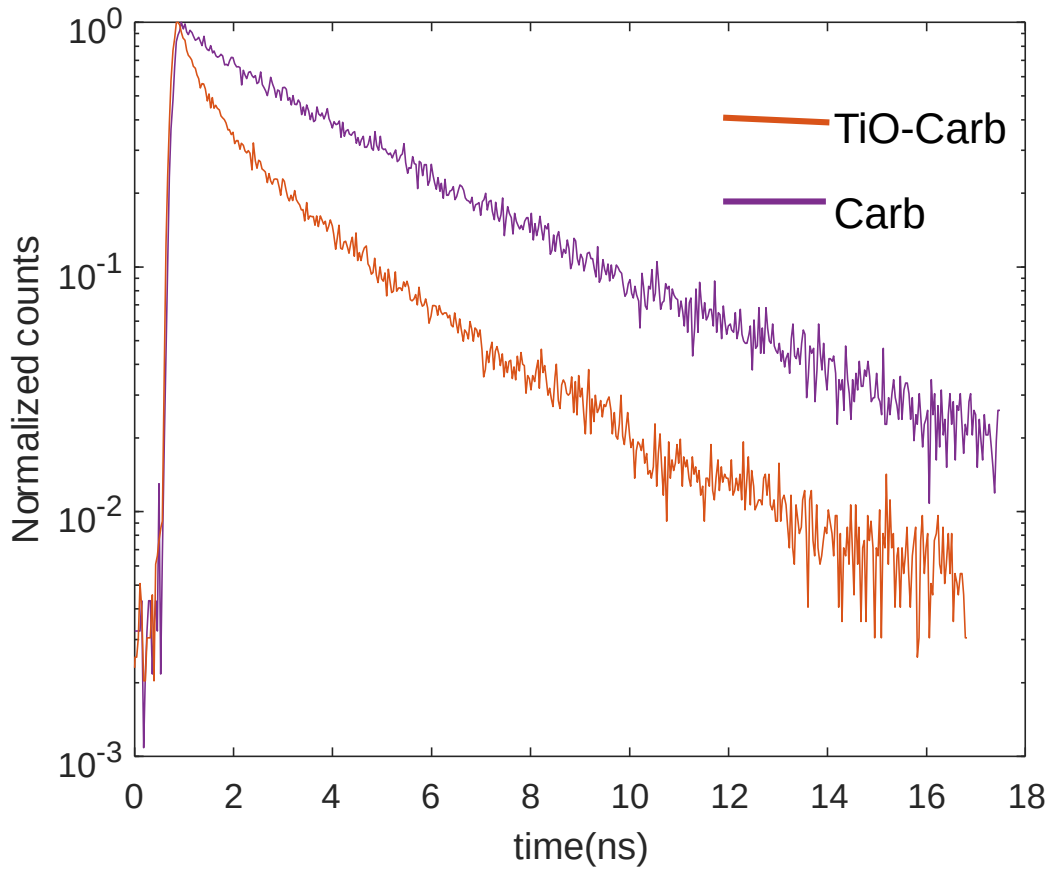
Observation of sub-nanosecond radiative relaxation



Mono-exponential for Carbazol: 3.2 ns (Carb)
Bi-exponential for cluster: 0.54 & 2.8 ns (TiO-Carb)
Possible hint at additional decay channel and charge transfer.
Ongoing: Extension of technique to extreme ultraviolet excitation.

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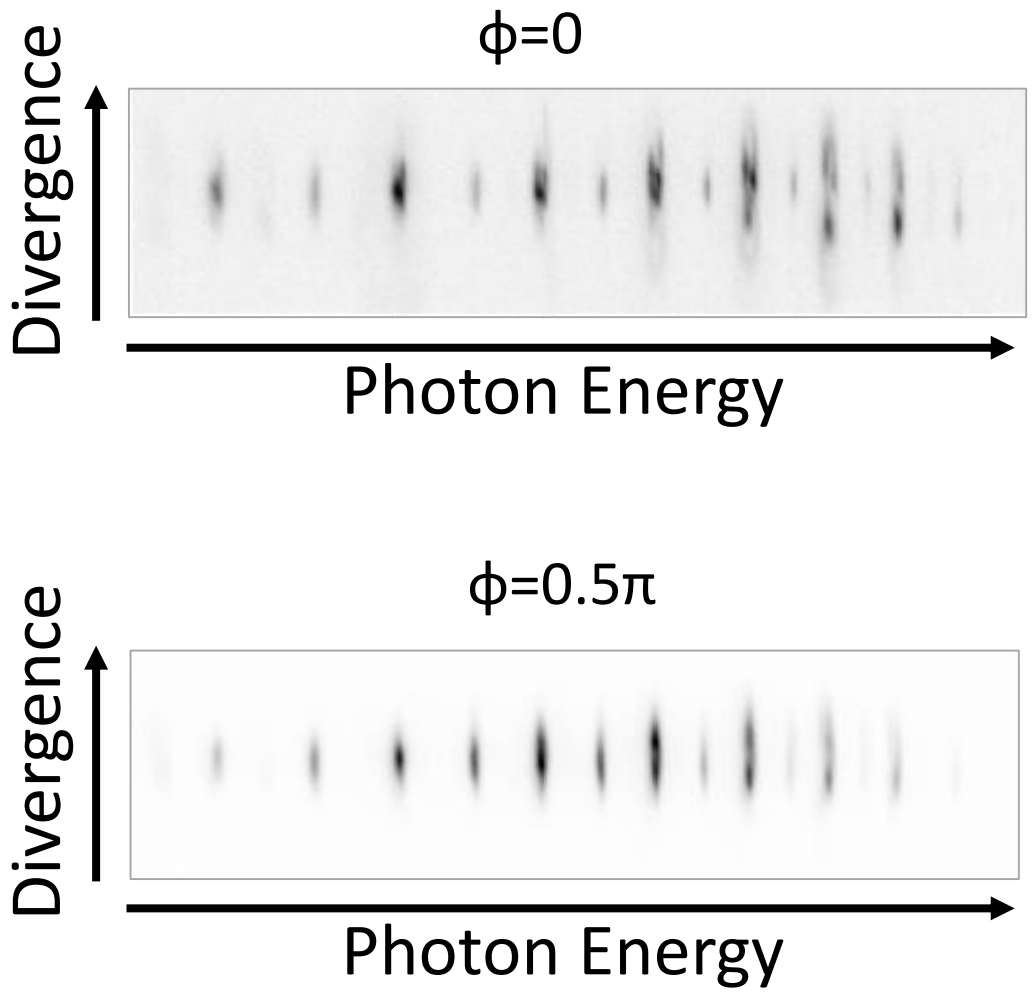
Conclusions

1. Developed experimental method for divergence control of high-harmonic generation.

2. Used table-top extreme ultraviolet absorption to follow the exposure kinetics of a photoresist.

3. Used time-resolved luminescence to identify alternative decay channels besides chemical reactions.



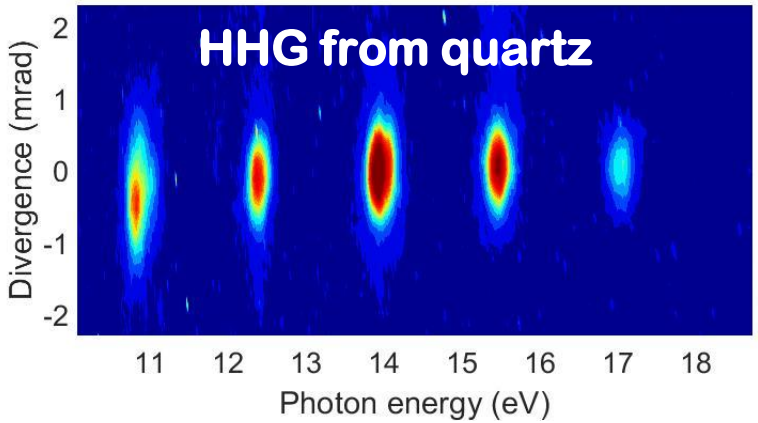
Outlook

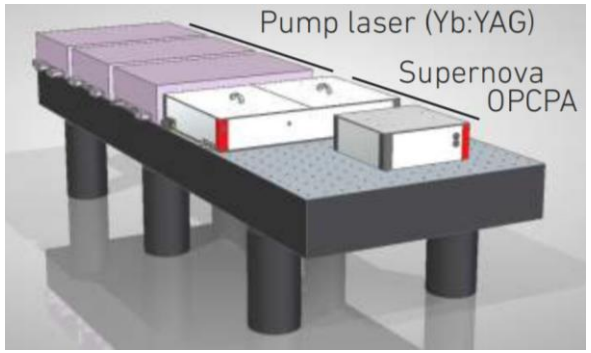
New schemes for HHG:

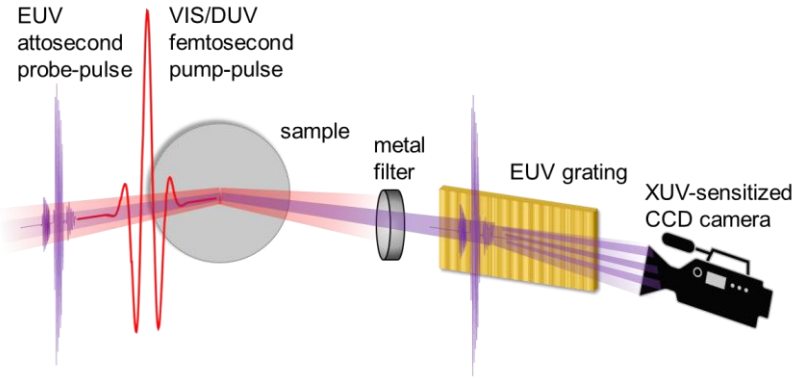
- Solid-state HHG
- High-flux water-window soft x-ray HHG

Time-resolved experiments on EUVL materials:

- Time-resolved XUV-excited optical luminescence
- Ultrafast pump-probe spectroscopy







Thank You!

HHG and EUV science group at ARCNL:
Sylvianne Roscam Abbing
Maarten van der Geest
Filippo Campi
Reinout Jaarsma
Najmeh Sadegh (not in picture, Brouwer group)
Faegheh Sajjadian (until Jan 2019)
ZhuangYan Zhang (not in picture)
Evelien Wooning (not in picture, until Aug 2019)
Alexandra Zeltsi (not in picture)

Ongoing collaborations at ARCNL:
Sonia Castellanos
Fred Brouwer

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