Photon Science at FLASH

from pictures to movies

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HELMHOLTZ GEMEINSCHAFT

DESY

Current parameters of FLASH

Wavelength range (fundamental):
4.1 - 47 nm

Spectral width (FWHM):
0.7 - 2 %

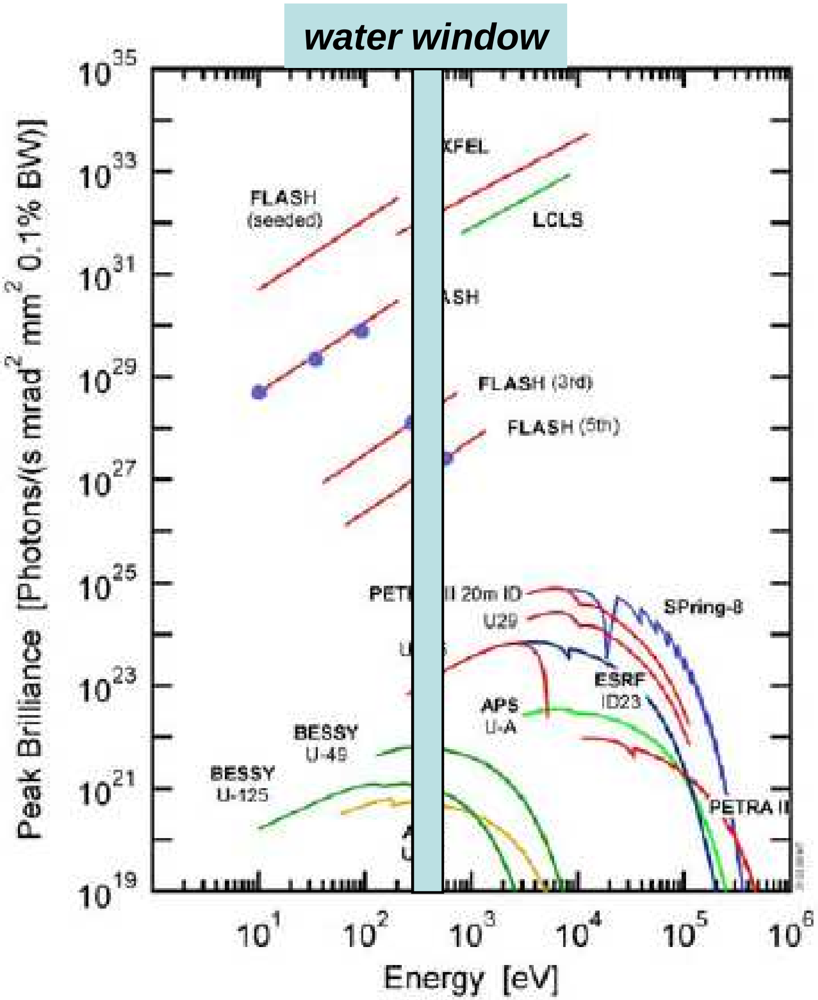
Pulse energy:
up to 400 µJ (average),
500 µJ (peak)

Pulse duration (FWHM):
20 - 200 fs

Peak power (fundamental):
1 - 5 GW

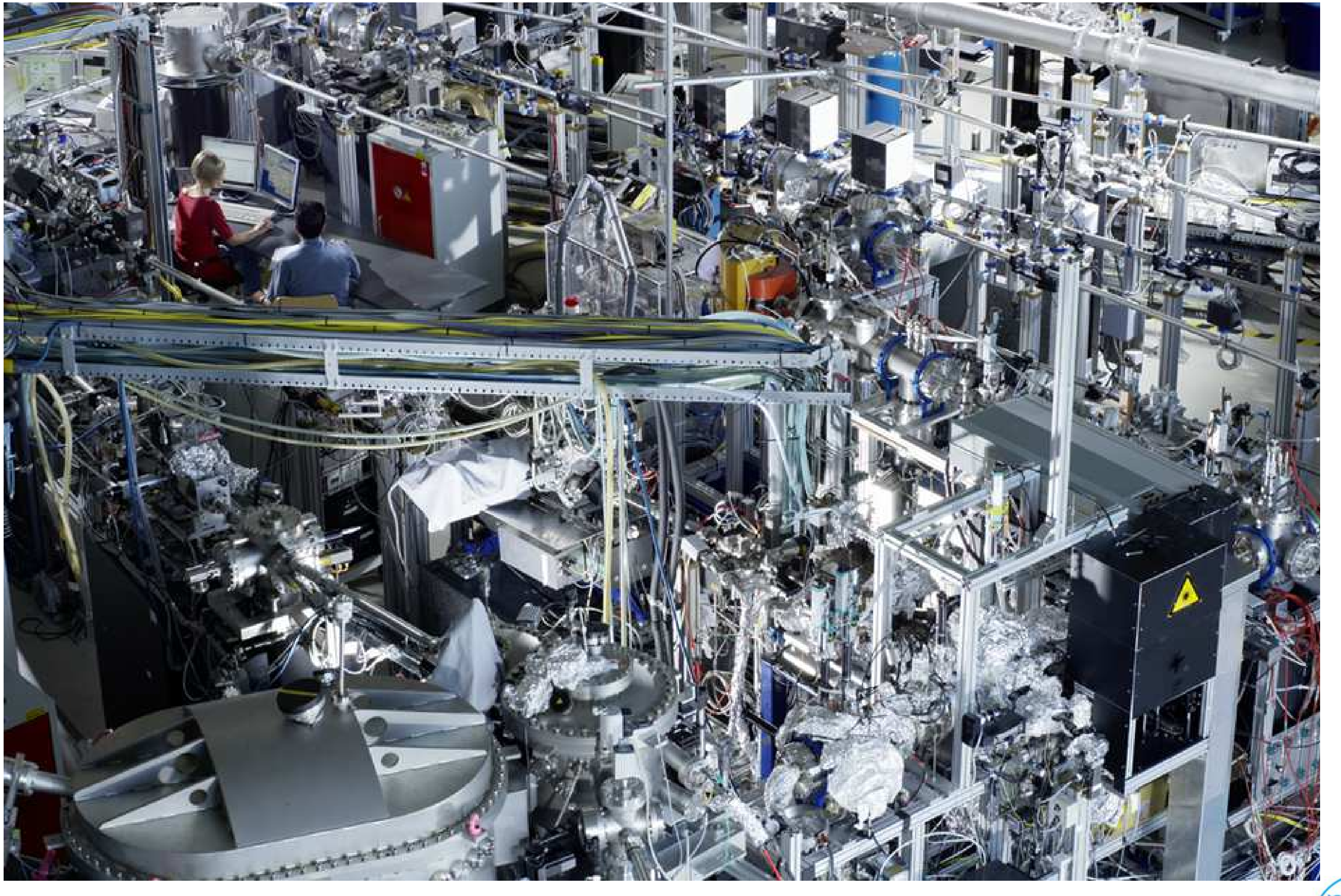
Average power (fundamental):
up to 0.3 W (up to 3000 pulses / sec)

Peak brilliance:
10^{29}-10^{31} …



peak brilliance

Research Highlights from FLASH



Research Areas

Femtosecond time-resolved experiments

- synchronization FEL - optical laser
- pump-probe experiments on atoms and molecules (femto-chemistry)
- sum-frequency generation

Interaction of ultra-intense XUV pulses with matter

- multiphoton excitation of atoms, molecules, clusters…
- creation and characterizaton of dense plasmas
- imaging of nano-objects and biological samples

Investigation of extremely dilute samples

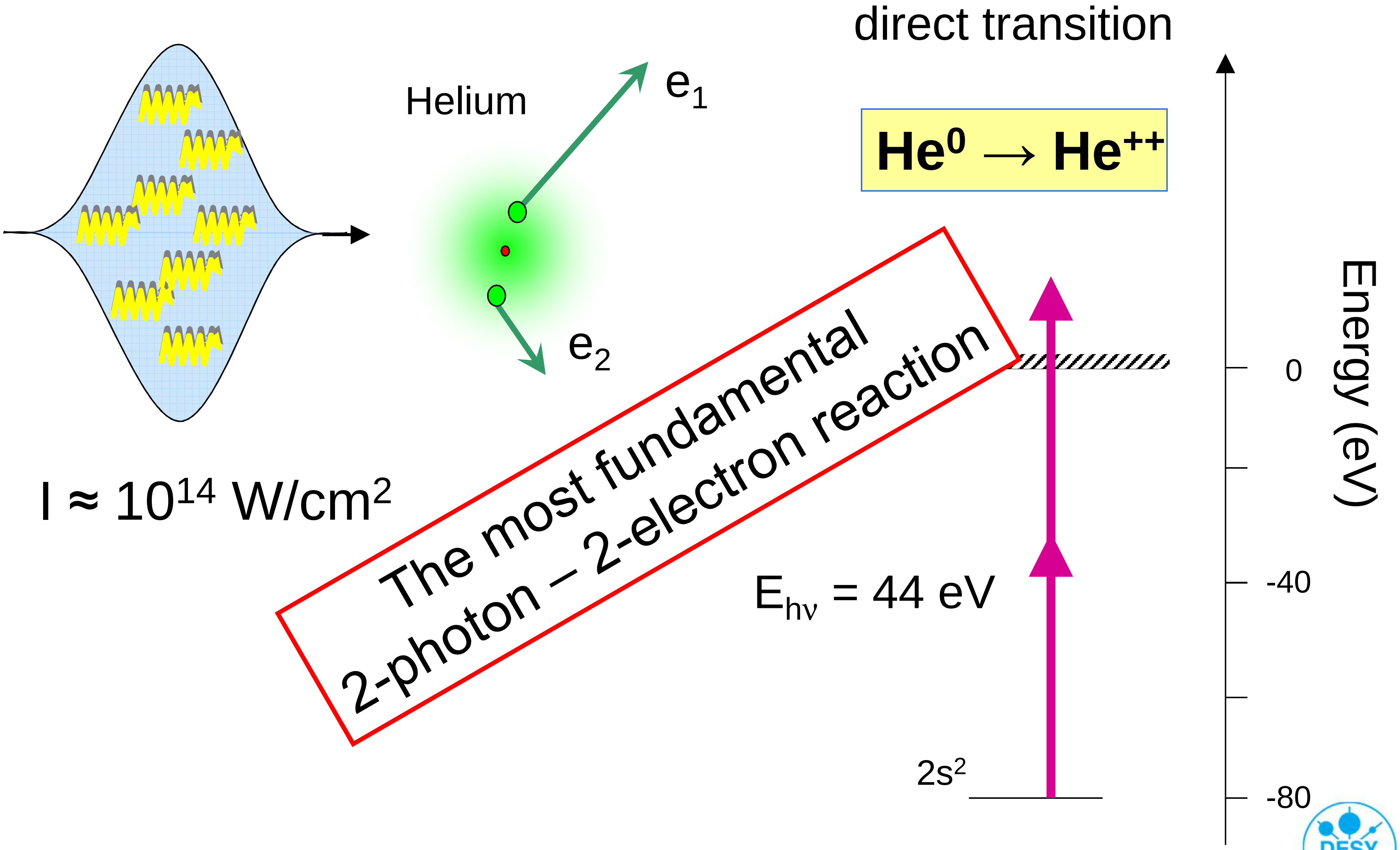
- photodissociation of molecular ions
- highly charged ions
- mass selected clusters

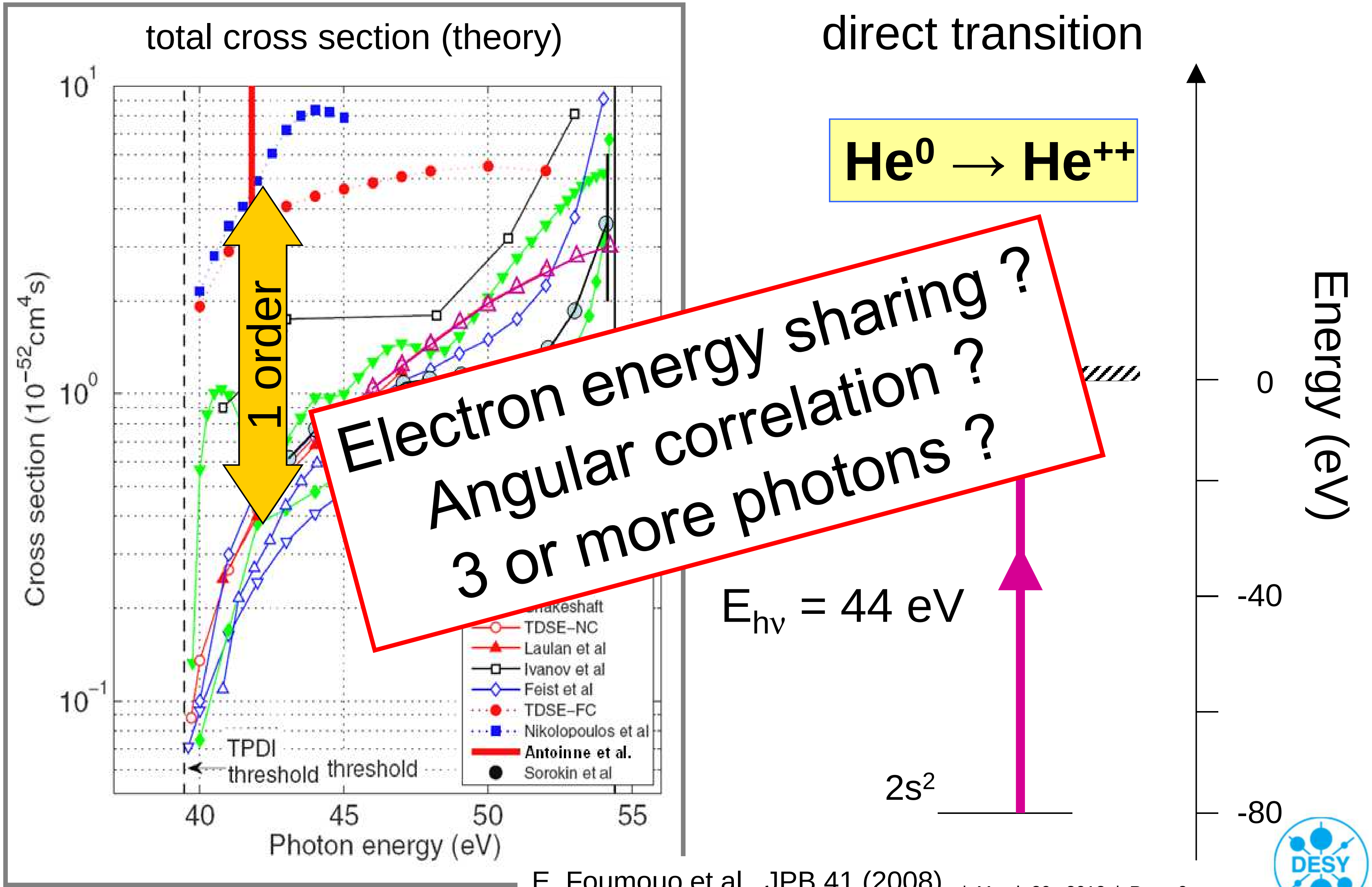
Investigation of surfaces and solids

- XUV laser desorption
- surface dynamics
- femto-magnetism
- study of highly correlated materials
- luminescence under FEL radiation
- meV-resolution photon and photoelectron spectroscopy of surfaces and solids with nm resolution

AMOP: Two-Photon Double Ionization of He

R.Moshammer, J.Ullrich et al.





E. Foumouo et al., JPB 41 (2008)

Two-Photon Double Ionization of He: theory

Theoretical papers (not complete)

Palacios et al., PRA 77 (2008)

Faist et al., PRA 77, 043420 (2008)

Guan et al., PRA 77, 043421 (200

Horner et al., PRA 77

Foum ...)

Lamb ... nd Nikolopoulos ,NJP 10, 025012 (2008)

Foumouo et al., JPB 41, 051001 (2008)

Kheifets, JP 40 (2007)

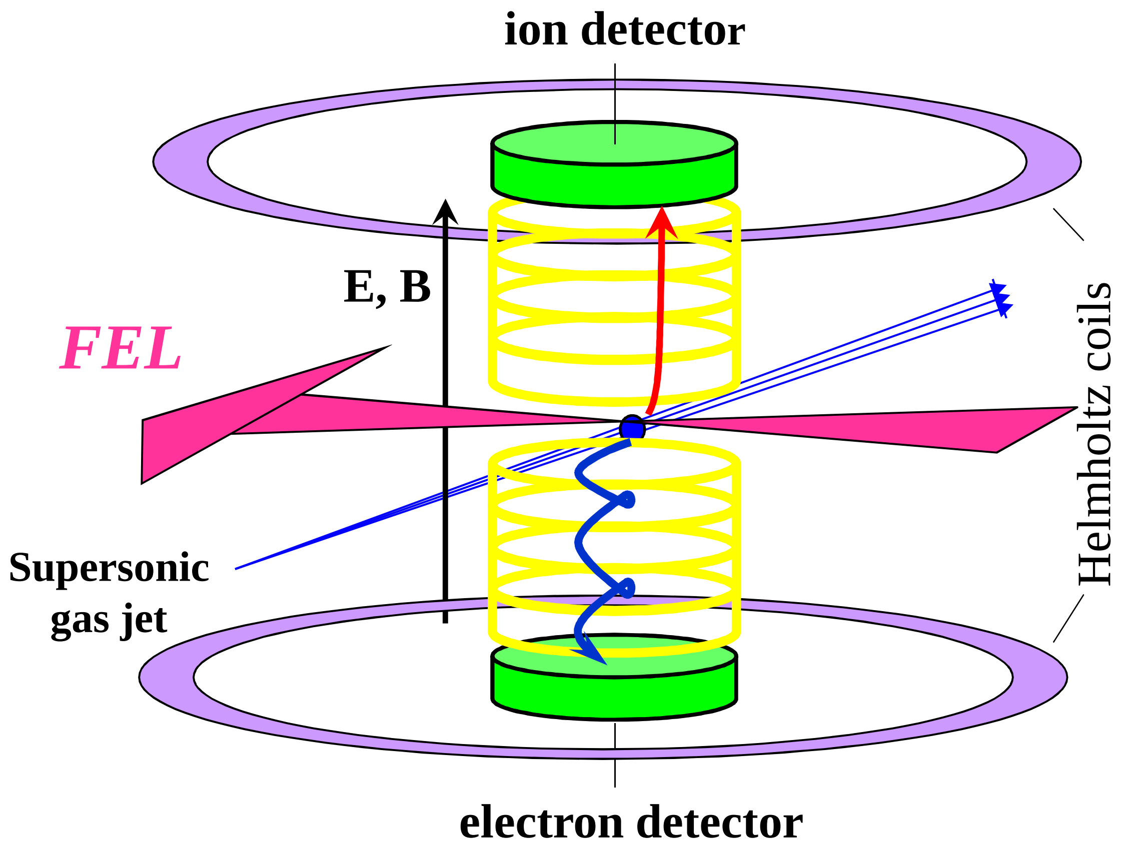
Ivanov and Kheifets, PRA 75, 024702 (2007)

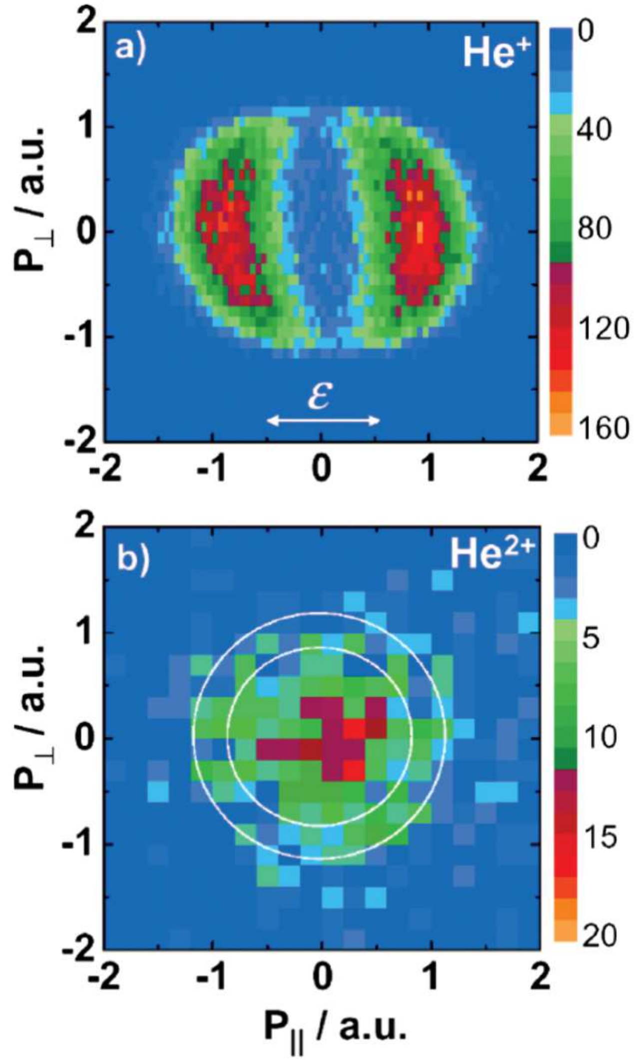
Nikolopoulos and Lambropoulos, JPB 40, 1347 (2007)

Kheifets et al, PRA 75, 024702 (2007)

Theory needs to be tested !!

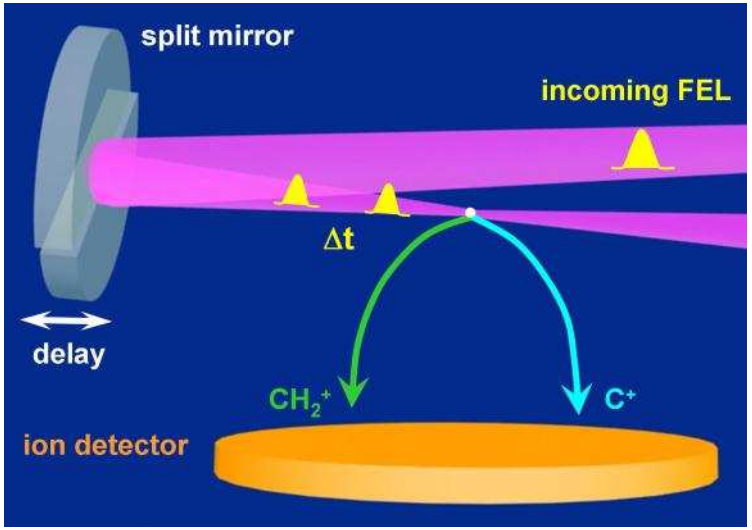
Approach: FLASH + Reaction Microscope



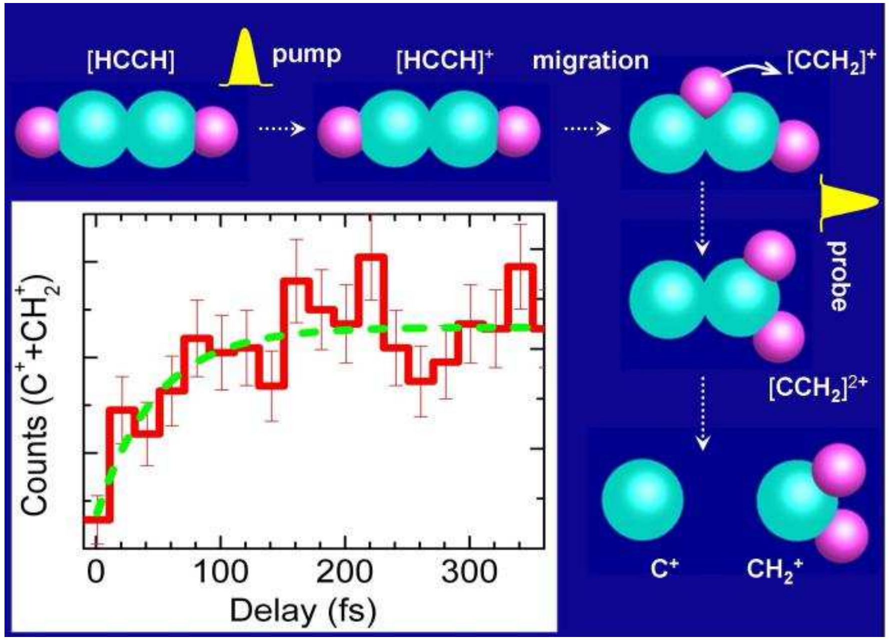


A. Rudenko et al.,
Phys. Rev. Lett. 101, 073003 (2008)

Ultrafast isomerization of acetylene
R.Moshammer et al.



- XUV-XUV pump-probe experiment
- 32.6nm, ~40 fs (FWHM) pulse length
- split spherical multi-layer mirror
  (1" Mo/Si mirror, 50 cm focal length,
  20 µm focus diameter)



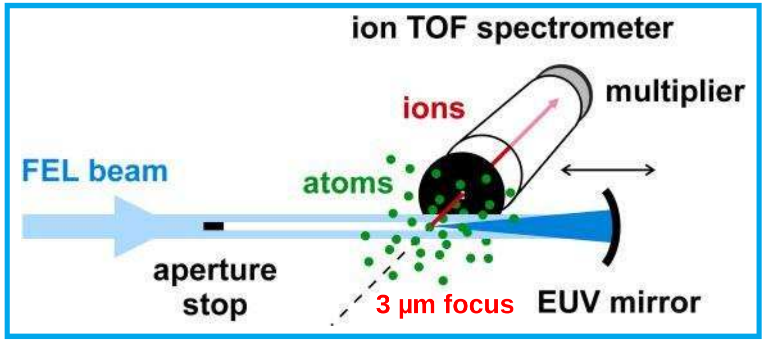
Recording the yield of characteristic C^+ + CH^{2+} fragment-pairs that emerge from the dissociation of the product molecule (CCH2) as a function of pump-probe time delay

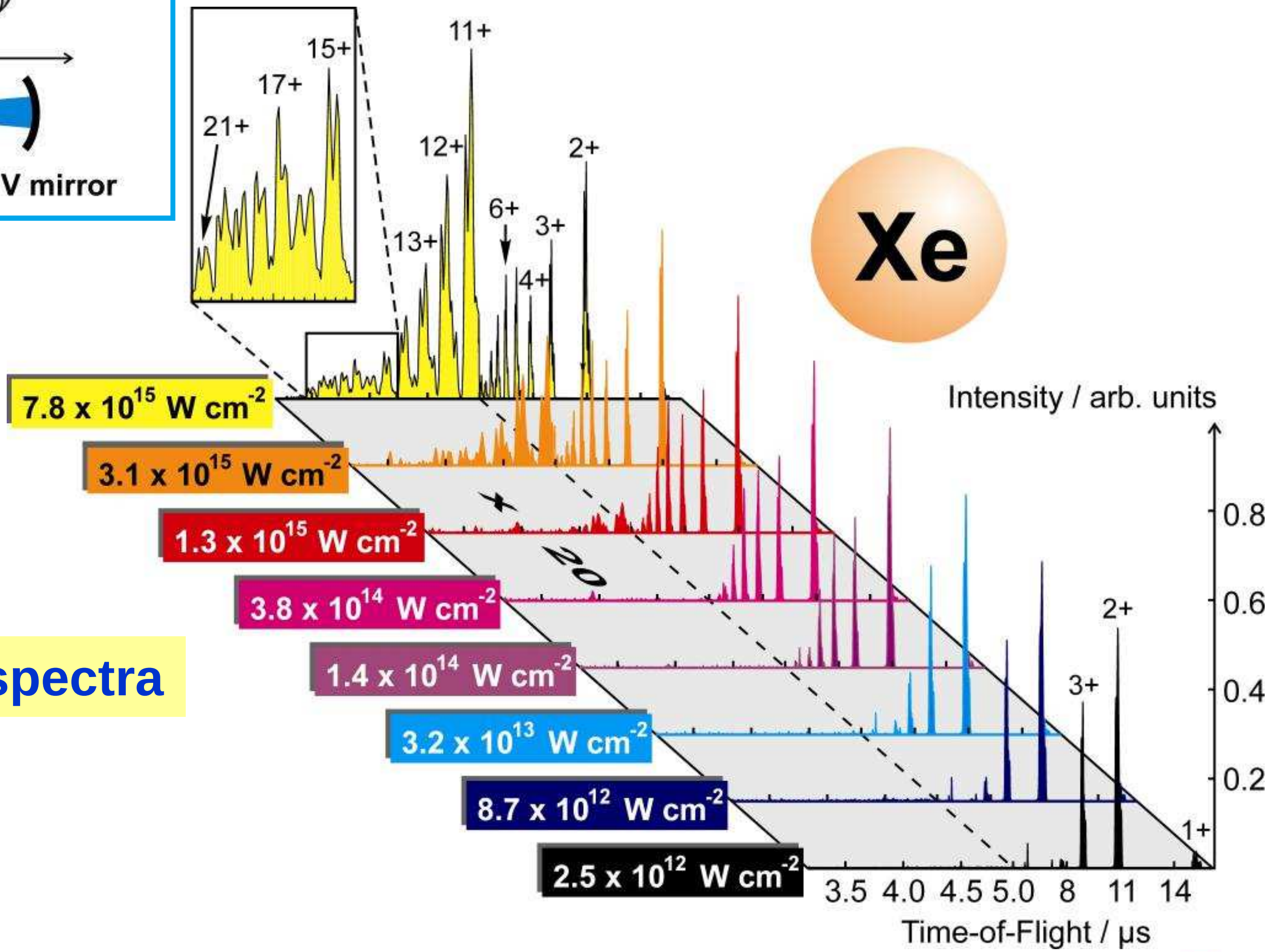
➔ isomerization time of (52 ± 15) fs

Y.H. Jiang et al.,
Phys. Rev. Lett. 105, 263002 (2010)

Multiple ionization of Xenon at 13.4 nm / 92.7 eV

M.Richter, K.Tiedtke et al.



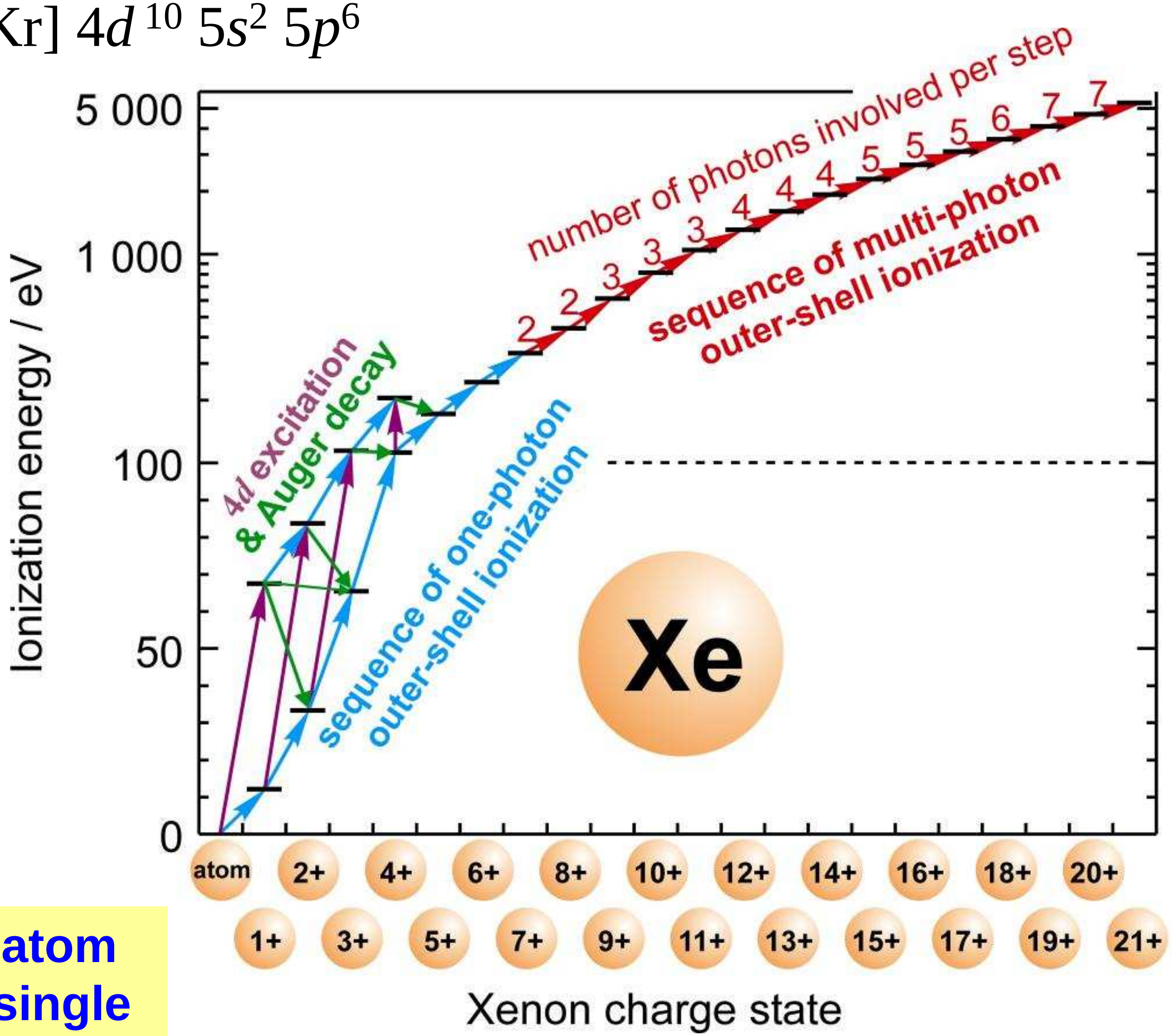


ion TOF spectra

A.A. Sorokin et al.,
Phys. Rev. Lett. 99, 213002 (2007)

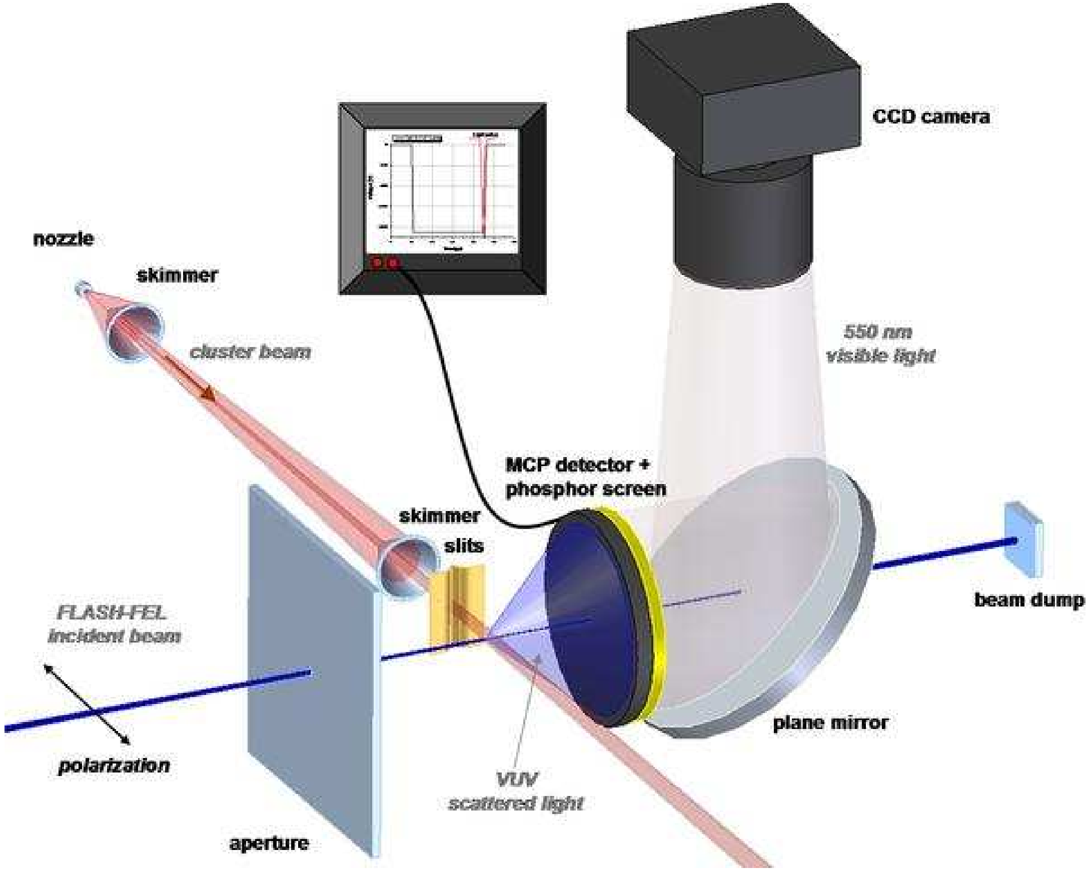
How does it work?

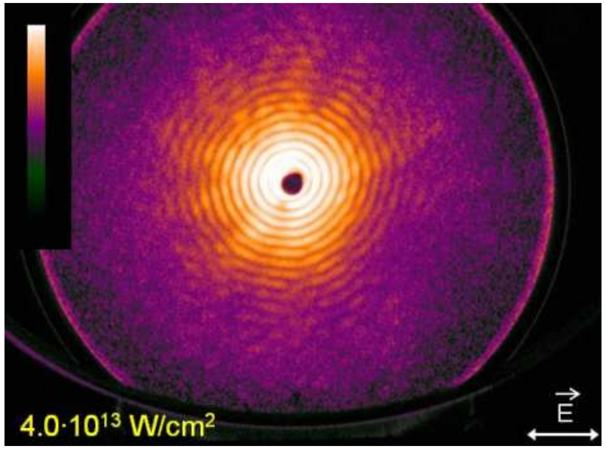
Xe: [Kr] $4d^{10}\,5s^2\,5p^6$



>57 photons/atom absorbed in single Pulse → Xe^{21+}

Single-shot scattering on Xenon nanoclusters
C.Bostedt, T.Möller et al.

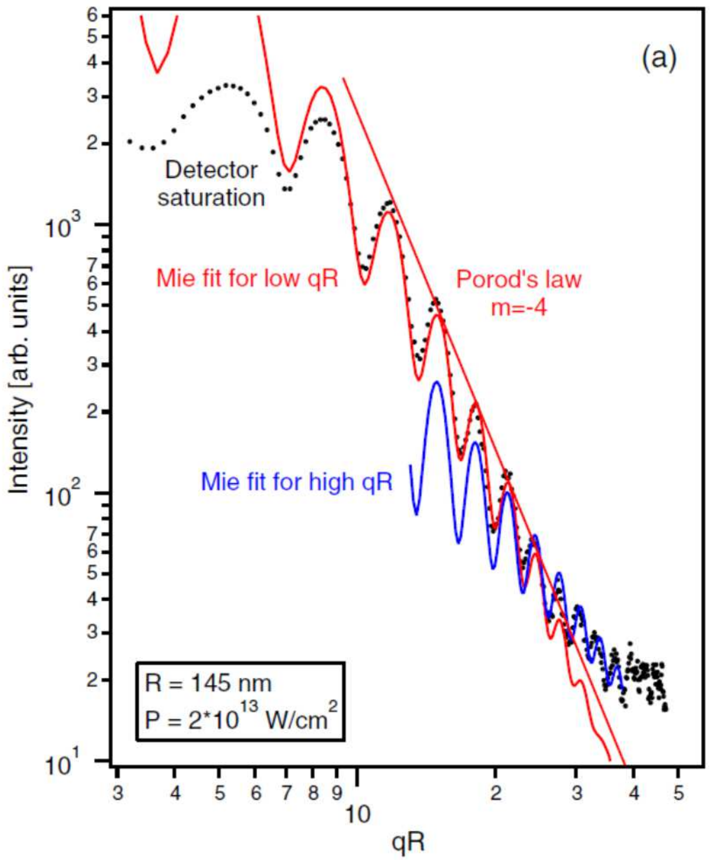




Used the scattering signal to track ultrafast changes in the electronic structure of the clusters

Scattering snapshots show that transiently highly charged species are created before the cluster disintegrates in a Coulomb explosion

C. Bostedt et al.,
Phys. Rev. Lett. 108, 093401 (2012)



considerably large clusters:
<N> = 1 - 5 x 10^8 atoms
size range 110-190nm

optical constants of developing nanoplasma can be derived from scattering pattern

yields insight into ultrafast processes in highly excited systems where conventional spectroscopy techniques are inherently blind

Coherent single-shot X-ray diffraction imaging
H. Chapman, J. Hajdu et al.

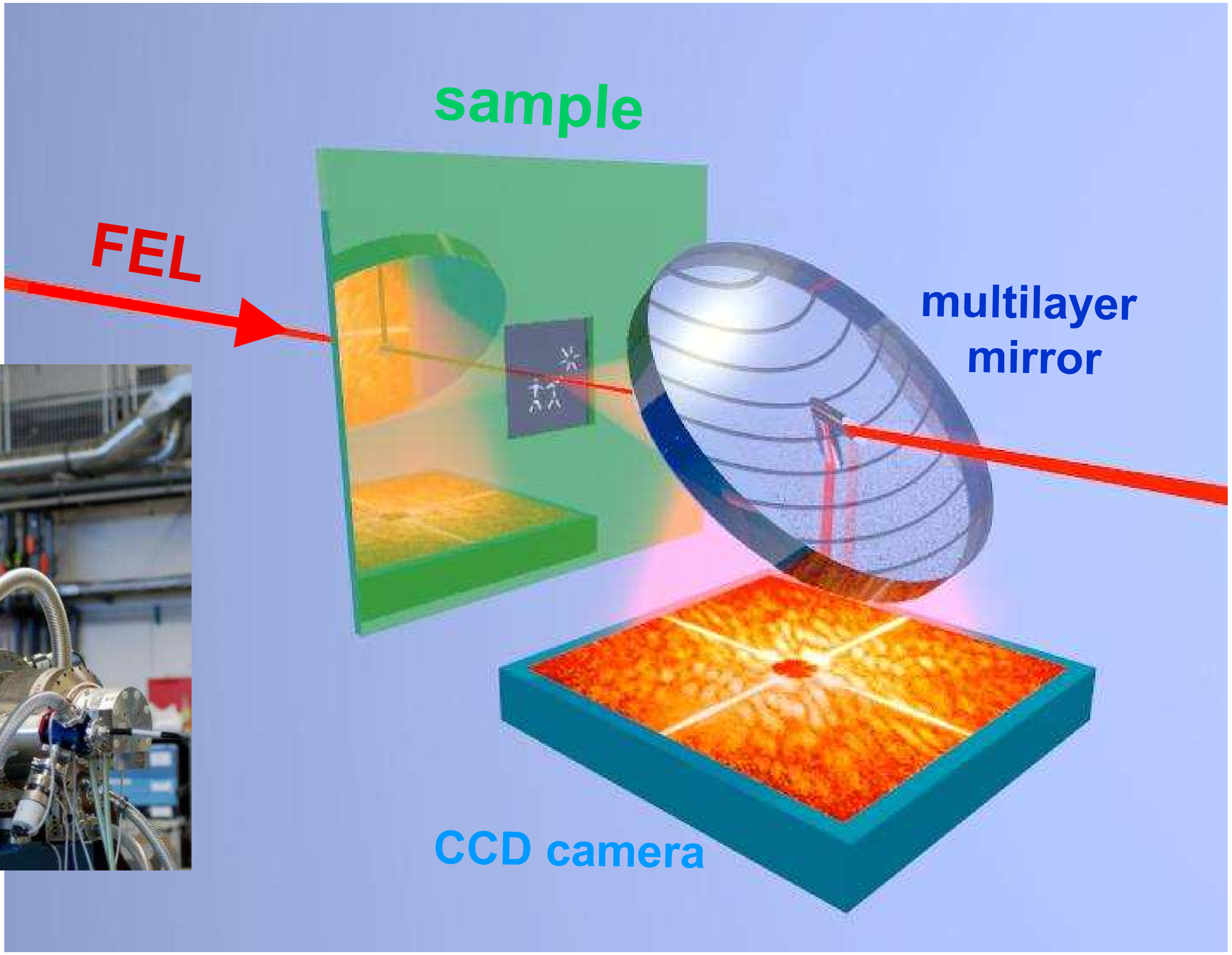
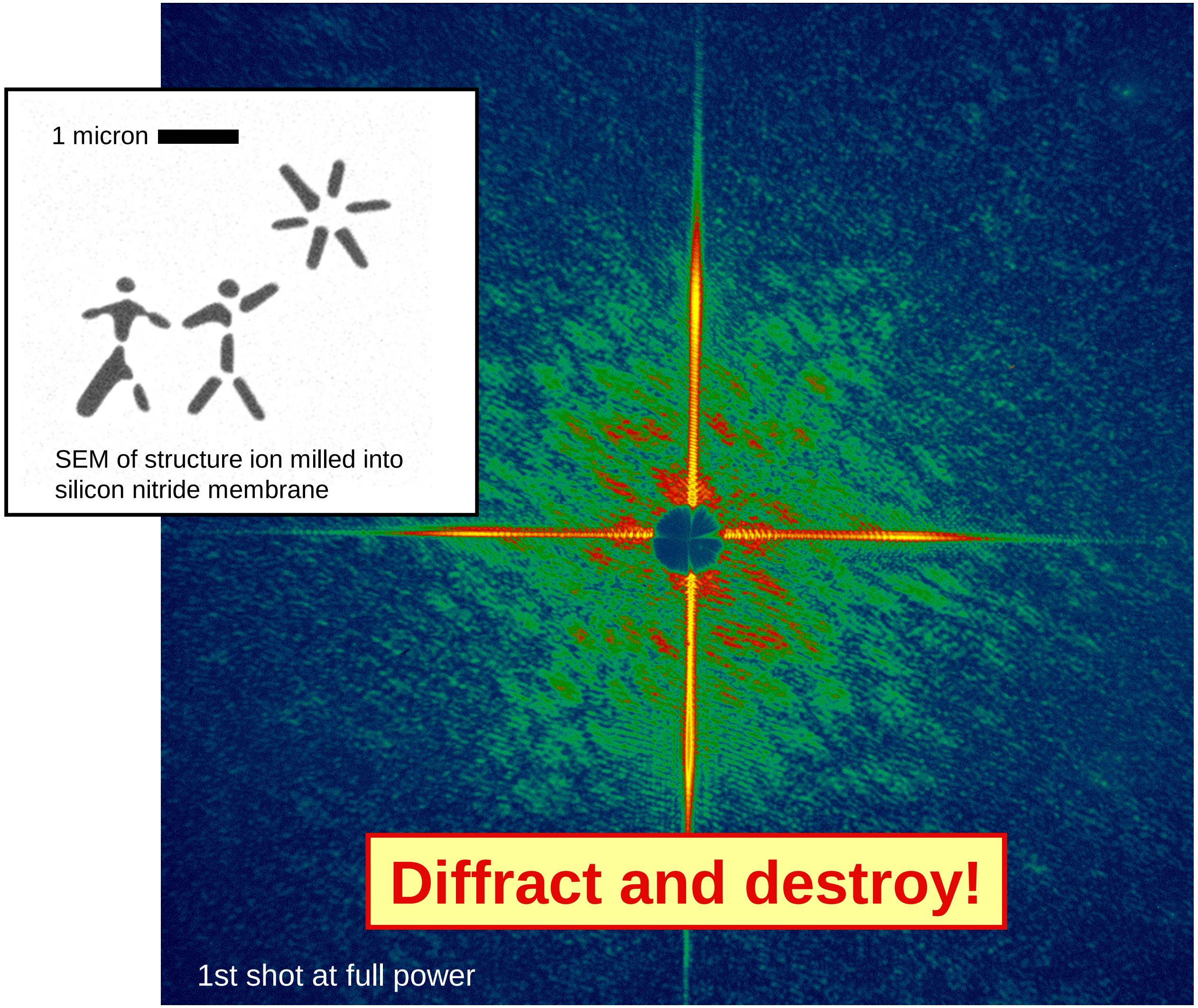
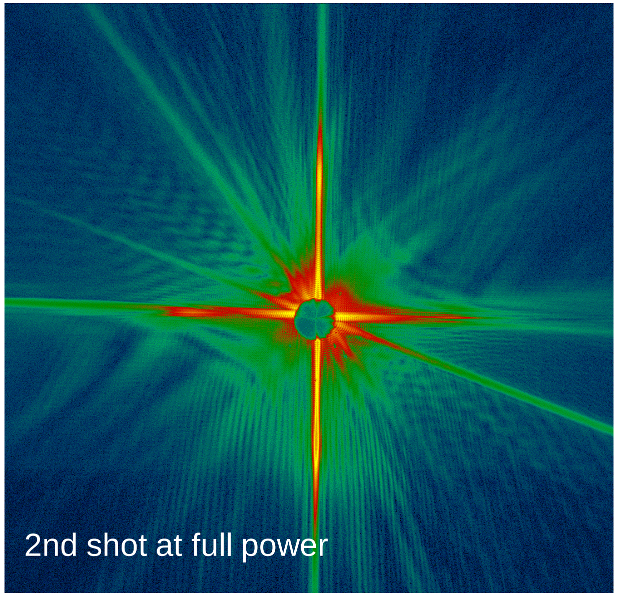
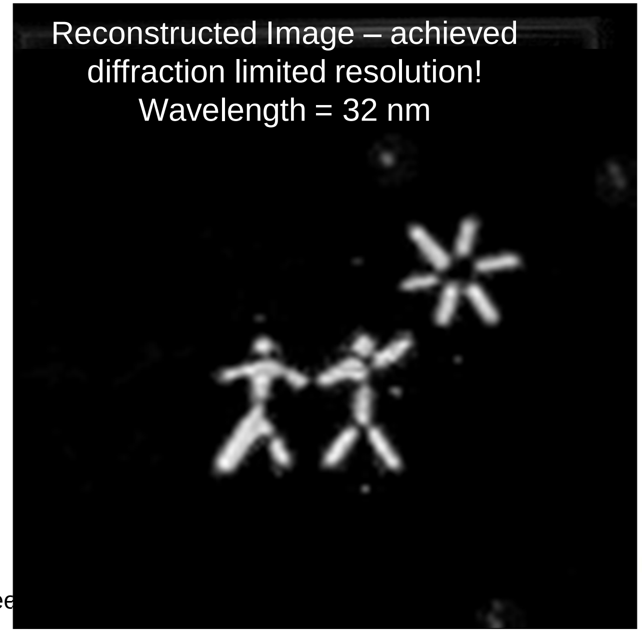


Image reconstruction from ultrafast diffraction pattern







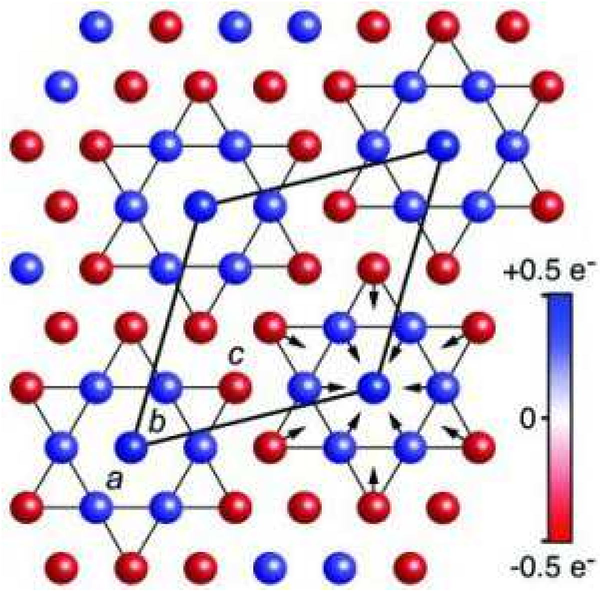
H.N. Chapman et al.,
Nature Physics 2, 839-843 (2006)

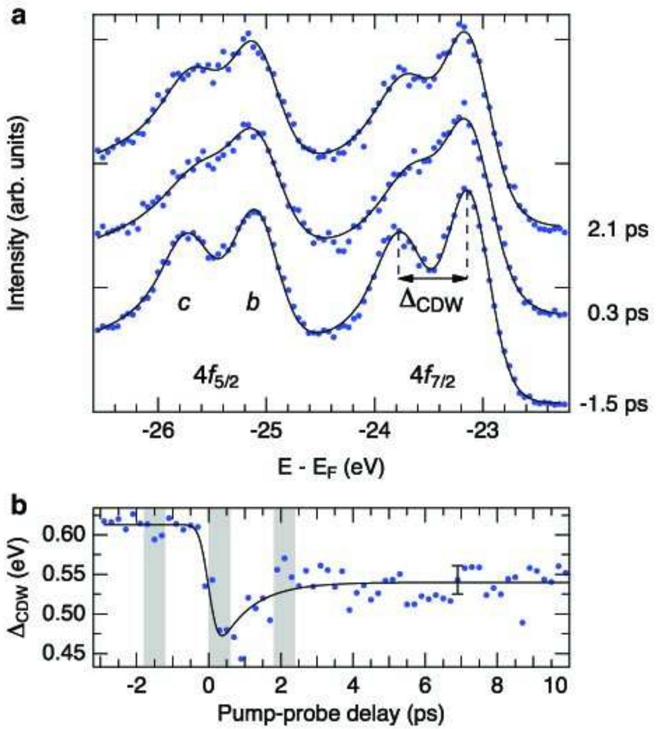
Ultrafast Melting of a Charge Density Wave in TaS_2

S.Hellmann, W.Wurth, L.Kipp et al.

CDW in the layered, strongly correlated electron material 1T-TaS_2 ➔ splitting of $4f_{5/2}$ and $4f_{7/2}$ levels

driven out of equilibrium by an intense optical laser pulse, subsequent nonequilibrium dynamics probed by FLASH pulses





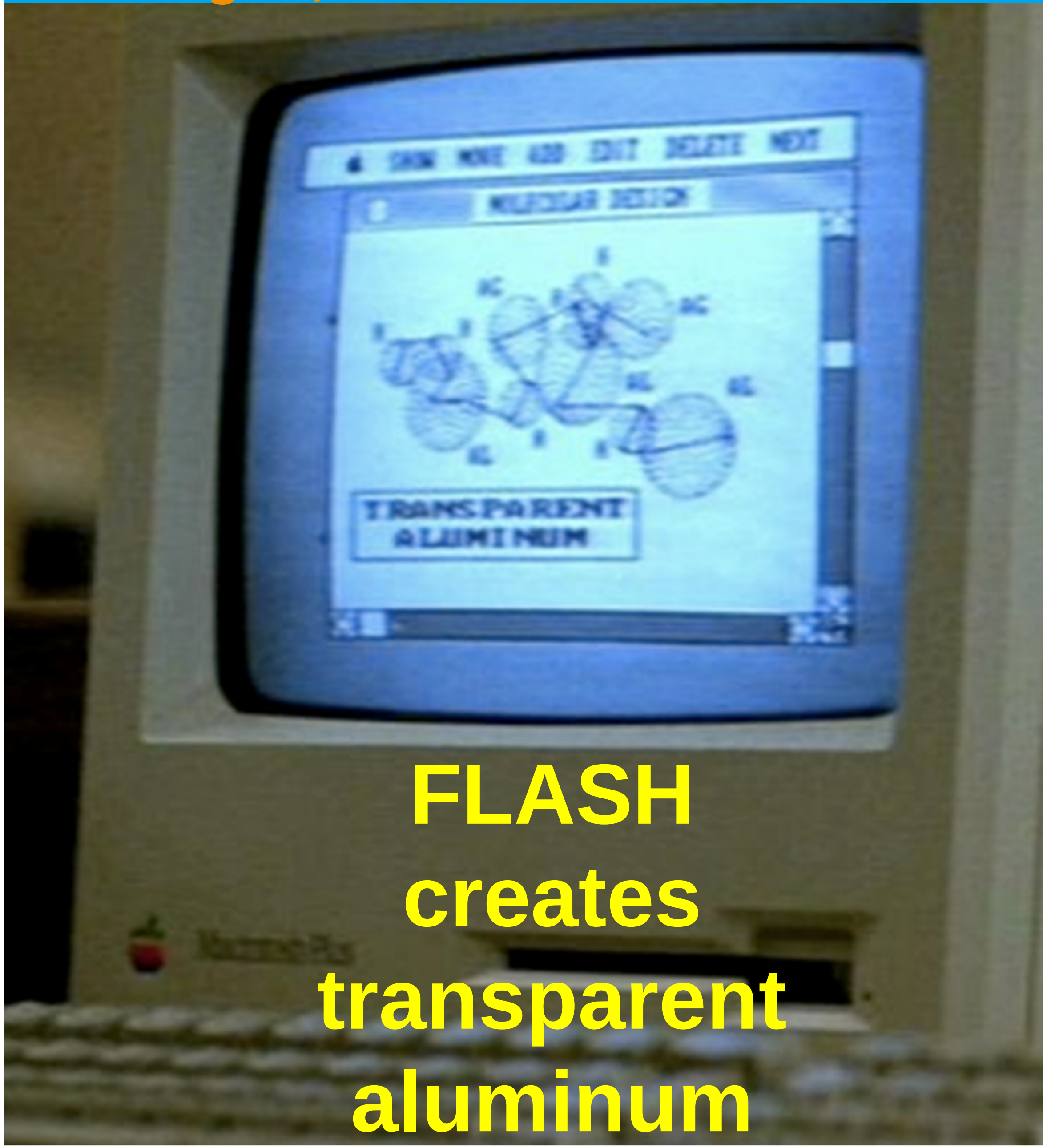
optical laser pump – FEL probe experiment

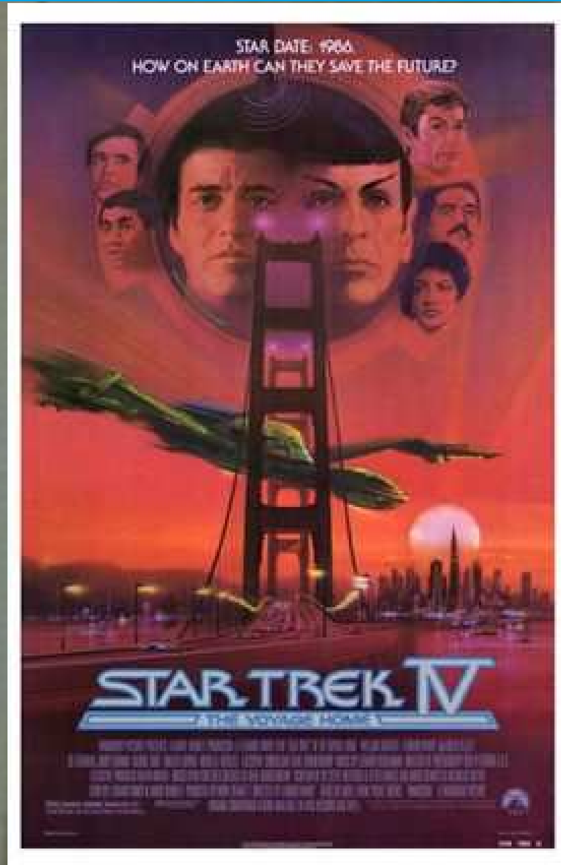
time resolved core-level photoemission spectroscopy with high temporal and energy resolution

S. Hellmann et al.,
Phys. Rev. Lett. 105, 187401 (2010)

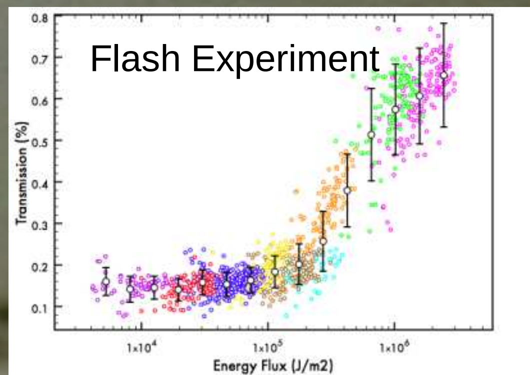
Plasma Physics: Transparent Aluminium

B.Nagler, S.Toleikis et al.

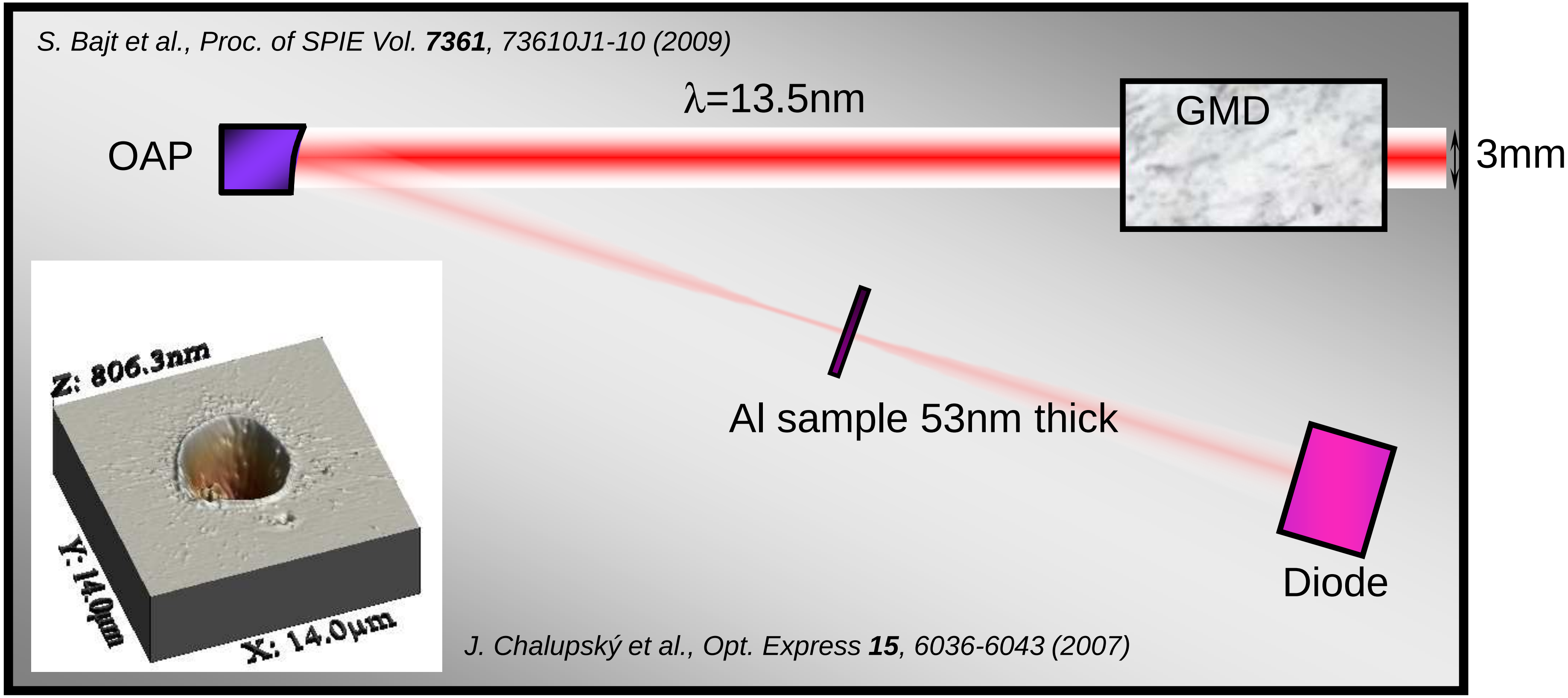




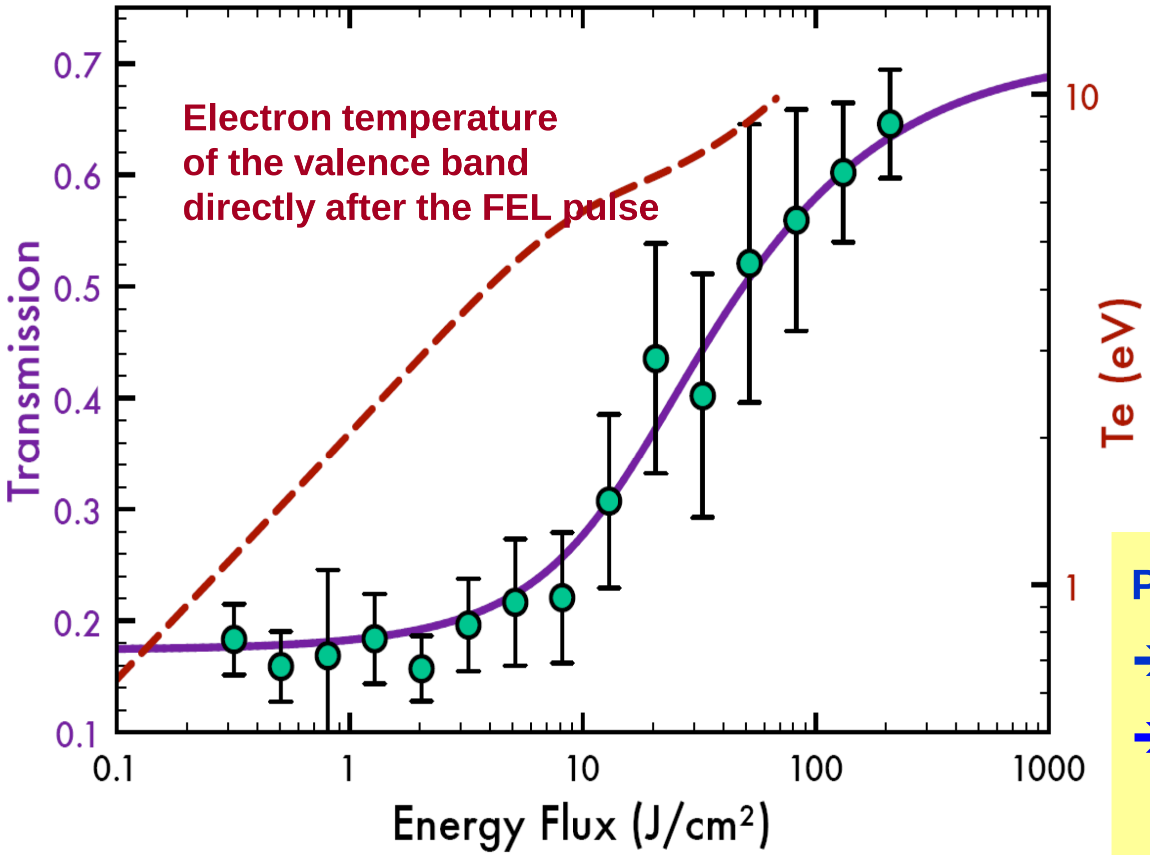
FLASH creates transparent aluminum



Microfocusing setup



Transmission dependent on power density

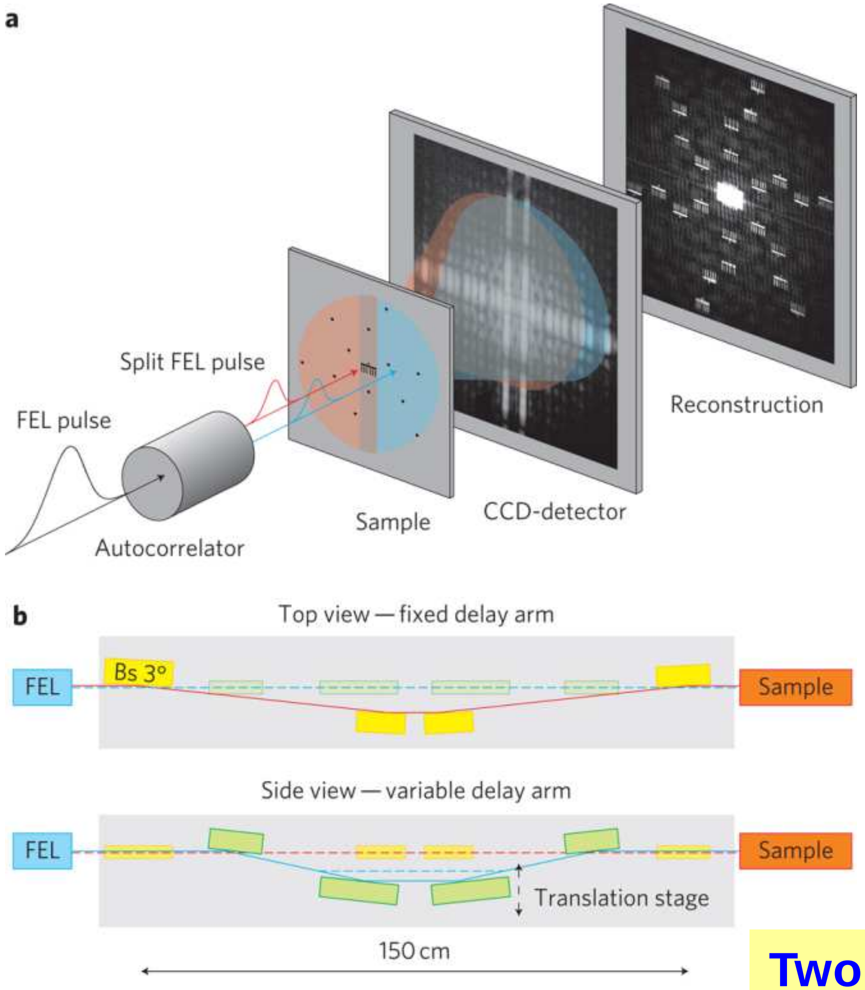


Photoionization of L-shell electrons

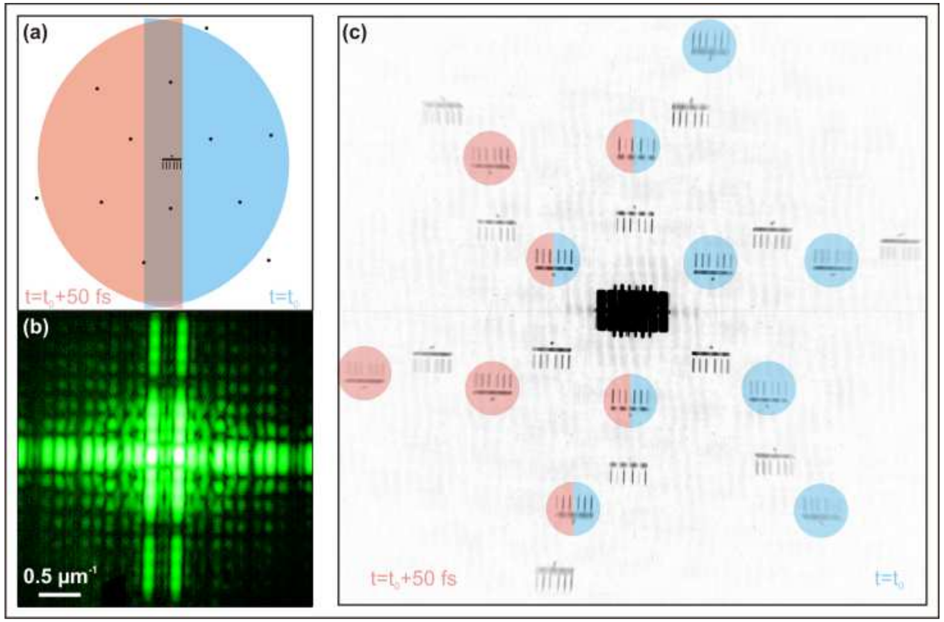
- ➔ **L-shell core hole state**
- ➔ **L-shell shift, Recombination time: ~50 fs**
- ➔ **Quenching of bound-free absorption**

B. Nagler et al., Nature Physics 5, 693 (2009)

"Fastest X-ray movie"
C.M. Günter, S.Eisebitt et al.



Holographic encoding used to overcome the fundamental readout limitations of pixelated detectors required for image formation



Two consecutive snapshots of an object, separated by 50 femtoseconds only, recorded in a single hologram exposure and disentangled afterwards

C.M. Günter et al.,
Nature Photonics 5, 99-102 (2011)

Publications

1. S. Hellmann, C. Sohrt, M. Beye, T. Rohwer, F. Sorgenfrei, M. Marczynski-Bühlow, M. Kalläne, H. Redlin, F. Hennies, M. Bauer, A. Föhlisch, L. Kipp, W. Wurth and K. Rossnagel,
Time-resolved x-ray photoelectron spectroscopy at FLASH,
New J. Phys. 14, 013062 (2012); http://dx.doi.org/10.1088/1367-2630/14/1/013062

2. B. Iwan, J. Andreasson, A. Andrejczuk, E. Abreu, M. Bergh, C. Caleman, A.J. Nelson, S. Bajt, J. Chalupsky, H.N. Chapman, R.R. Fäustlin V. Hajkova, P.A. Heimann, B. Hjörvarsson, L. Juha, D. Klinger, J. Krzywinski, B. Nagler, G.K.Pálsson, W. Singer, M.M. Seibert, R. Sobierajski, S. Toleikis, T. Tschentscher, S.M. Vinko, R.W. Lee, J. Hajdu, N. Tîmneanu,
TOF-OFF: A method for determining focal positions in tightly focused free-electron laser experiments by measurement of ejected ions,
High Energy Density Phys. 7, 336-342 (2011); http://dx.doi.org/10.1016/j.hedp.2011.06.008

3. S. Roling, B. Siemer, M. Wöstmann, H. Zacharias, R. Mitzner, A. Singer, K. Tiedtke, and I.A. Vartanyants,
Temporal and spatial coherence properties of free-electron-laser pulses in the extreme ultraviolet regime,
Phys. Rev. ST Accel. Beams 14, 080701 (2011); http://dx.doi.org/10.1103/PhysRevSTAB.14.080701

4. Björn Siemer, Tim Hoger, Marco Rutkowski, Stefan Düsterer, and Helmut Zacharias,
XUV Free-Electron Laser Desorption of NO from Graphite (0001),
J. Phys. Chem. A 115, 7356-7361 (2011); http://dx.doi.org/10.1021/jp2011793

5. W. Wierzchowski, K. Wieteska, T. Balcer, D. Klinger, R. Sobierajski, D. Żymierska, J. Chalupský, V. Hájková, T. Burian, A.J. Gleeson, L. Juha, K. Tiedtke, S. Toleikis, L. Vyśın, H. Wabnitz and J. Gaudin,
X-ray topographic investigation of the deformation field around spots irradiated by FLASH single pulses,
Radiation Physics and Chemistry 80, 1036-1040 (2011); http://dx.doi.org/10.1016/j.radphyschem.2011.02.034

6. T. Gorniak, R. Heine, A.P. Mancuso, F. Staier, C. Christophis, M.E. Pettitt, A. Sakdinawat, R. Treusch, N. Guerassimova, J. Feldhaus, C. Gutt, G. Grübel, S. Eisebitt, A. Beyer, A. Gölzhäuser, E. Weckert, M. Grunze, I.A. Vartanyants, and A. Rosenhahn,
X-ray holographic microscopy with zone plates applied to biological samples in the water window using 3rd harmonic radiation from the free-electron laser FLASH,
Opt. Express 19, 11059-11070 (2011); http://dx.doi.org/10.1364/OE.19.011059

… (more than 150 publications so far)

http://hasylab.desy.de/facilities/flash/publications/selected_publications/

The end.

On the road towards further exciting scientific results and challenges at FLASH