Photon Science at FLASH:
Overview of multi-bunch experiments

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Workshop on Linac Operation
with Long Bunch Trains
DESY, June 6, 2011

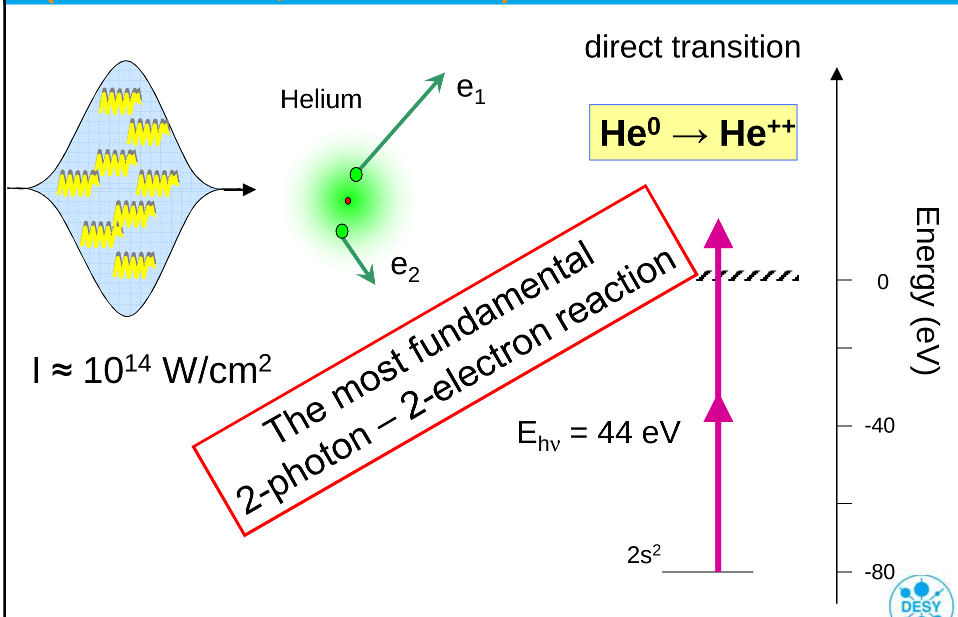
HELMHOLTZ
GEMEINSCHAFT

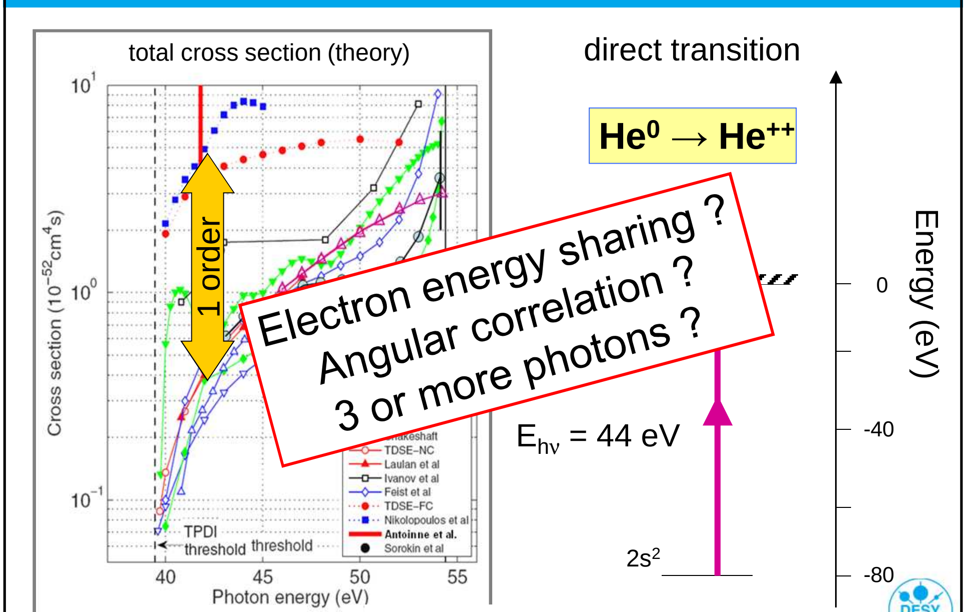
DESY

"Classes" of multi-bunch experiments

- **AMOP** (atomic, molecular and optical physics) **& Cluster** experiments:
  ultra-dilute samples, low cross-sections, often multi-photon processes
  ➔ multi-bunch for statistics
- Single-shot **X-ray diffraction imaging** with injected particles
  ➔ multi-bunch for hit-rate
- **Condensed matter** physics, in particular **femto-magnetism** (partially in light of 3rd harmonic)
  ➔ mainly need short pulses for time-resolved (pump probe) measurements, typically attenuate (fundamental) to ~1µJ, multi-bunch for statistics
- **Raman-Spectroscopy:** "*photon in – photon out*" with meV resolution, i.e. "throwing away" most of the photons
  ➔ needs high rep. rate, maximum intensity, minimum bandwidth (seeding)
- **Additional feature:** Long bunch trains & **BAM** feedback / kicking bunches, for pulse arrival time stability

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 8)

Lamb and Nikolopoulos ,NJP 10, 025012 (2008)

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

Kheifets, JP 40 (2007)

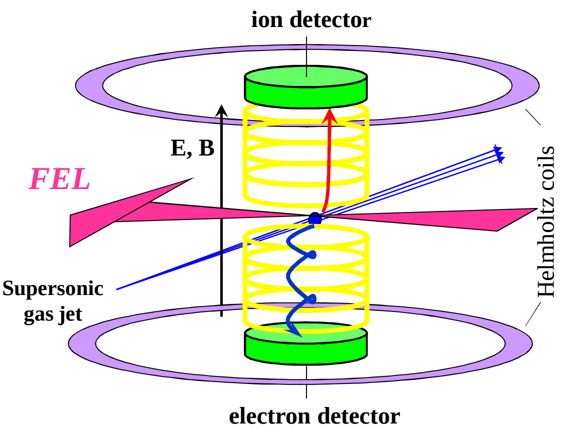
Ivanov and Kheifets, PRA 75, 024702 (2007)

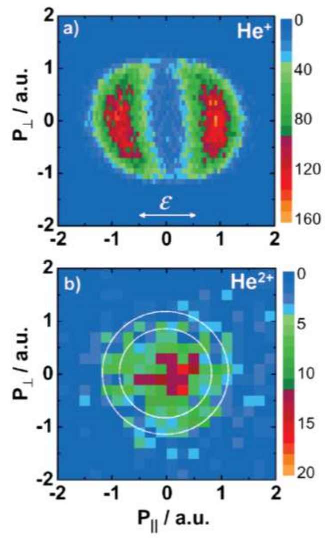
Nikolopoulos and Lambropoulos, JPB 40, 1347 (2007)

Kheifets et al. PRA 75, 024702 (2007)

Theory needs to be tested !!

Approach: FLASH + Reaction Microscope

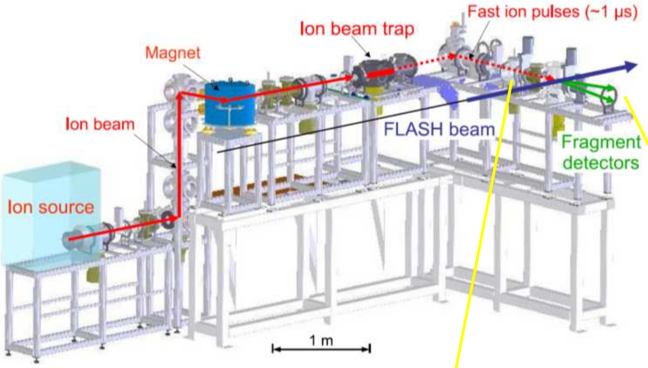




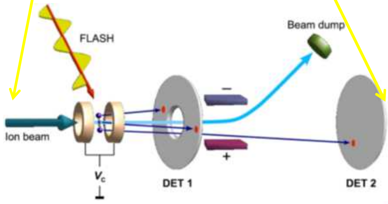
A.Rudenko et al.,
PRL 101, 073003 (2008)

AMOP: TIFF (trapped ion fragmentation at a FEL)

A.Wolf, H.B.Pedersen et al.



- ultra-dilute target (ions stored in trap)
- low cross-sections (would happily take 1mJ/pulse, length doesn‘t really matter)
- stable pointing crucial (S/N ratio)
- TOF → 100 / 200 kHz

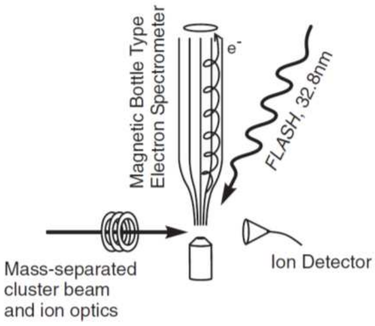


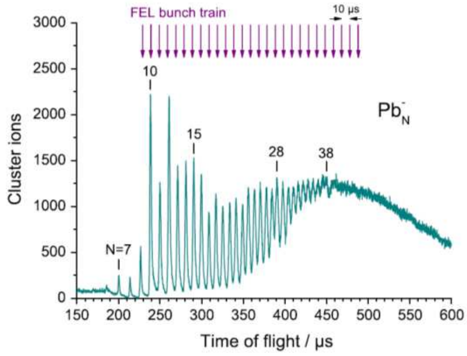
Summary R.Moshammer et al., A.Dorn et al., A.Wolf et al.

- measurements of fragmentation kinematics of ultra-dilute samples (rare-gas molecules, N_2, D_2, organic molecules, Li, two-atomic ions, …)
- low cross-sections, multi-photon processes
- typically longer wavelengths (20- 44nm)
- 500 / 200 / 100 kHz due to flight time in TOF detectors
- need many, many pulses for good statistics (in particular for reaction microscope where only single-hit detection is feasible, i.e. one fragmentation process per pulse)
- for dynamics: short pulses (low bunch charge) and stable pulse length across train required!

Metal clusters (Pb, Au): metallic or not?

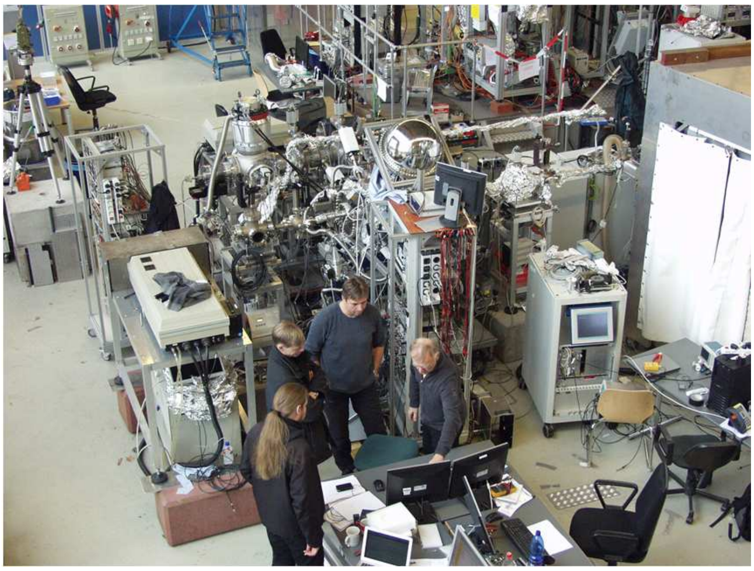
K.H. Meiwes-Broer et al.





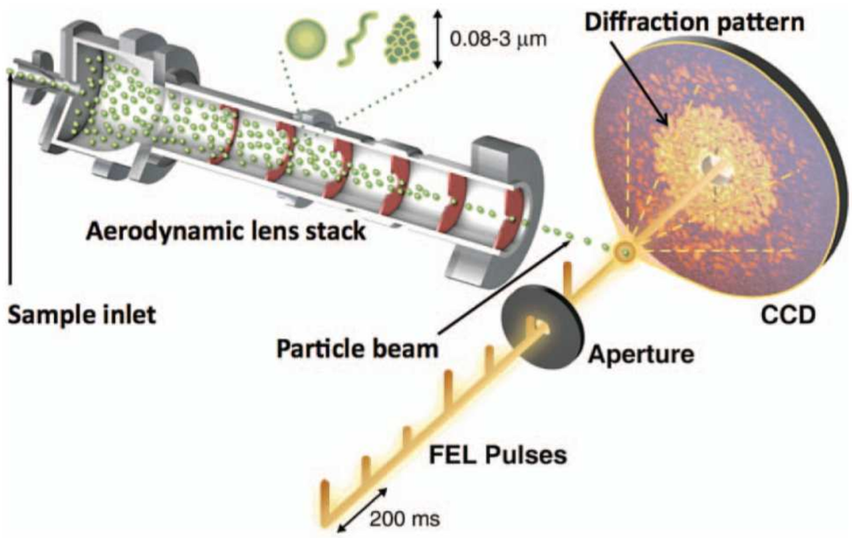
- ultra-dilute target (isolated, mass-selected clusters, few atoms per cluster)
- recent parameters (for Au clusters): 4.7nm, up to 350 bunches, 1MHz
- detect sub-eV shifts in photoelectron energies,
  now with hemispherical electron energy analyzer instead of magnetic bottle
  ➔ avoid the TOF limitation
- stable wavelength across train most crucial

Cluster experiment by Meiwes-Broer et al.



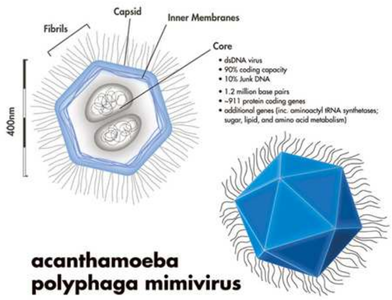
Single-shot X-ray diffraction with injected particles

H.Chapman, J.Hajdu et al.

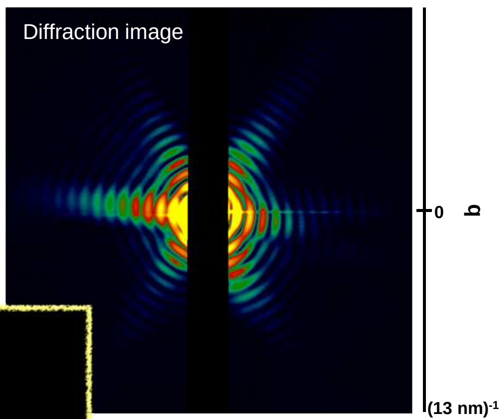


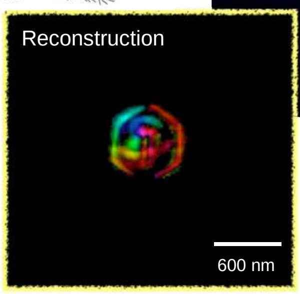
M.J. Bogan et al., Aerosol Science and Technology, 44:i–vi (2010)

Measured Mimivirus diffraction image & 2D-reconstruction



Graphic: wikipedia.org

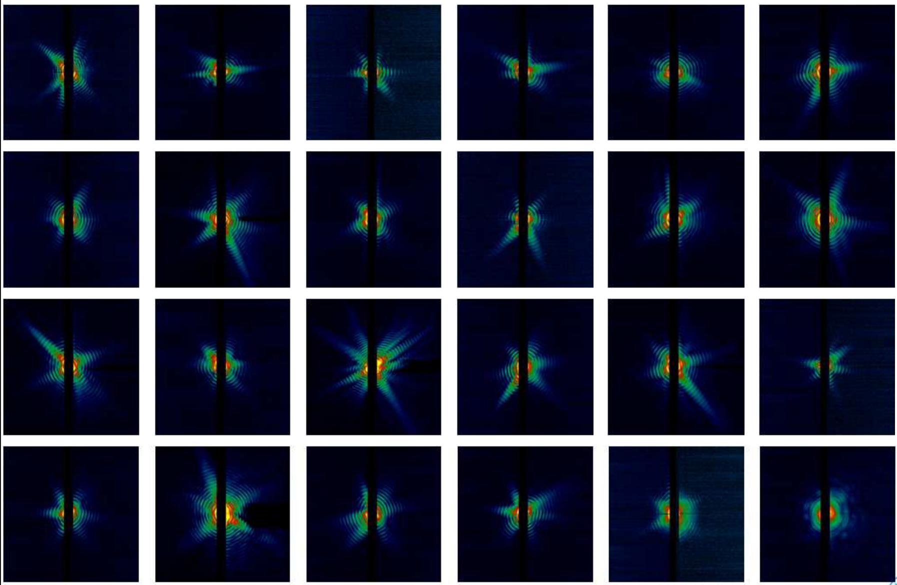




Wavelength = 7 nm
1 CCD pixel = 30 µm
Data nx = 1024
q_max is at 15.4 mm
CCD z = 30 mm
NA ~ 0.51

H. Chapman et al., manuscript in preparation

Goal: assembly of randomly oriented 2D-images into a 3D-structure needs many, many images!



Summary H.Chapman, J.Hajdu et al.

> single-shot diffraction imaging for structure reconstruction of biological samples (e.g. picoplankton, viruses) and other nano-samples

> fixed samples (on Si_3N_4 membranes) with single pulse

> injected samples (aerosol, hypersonic expansion or in coaxially gas jet), arbitrary, non-synchronized particle distribution
➔ multi-bunch for “hit rate”

> high resolution requires shortest wavelengths (7nm and below, goal is water window)

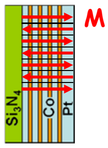
> typically high bunch charge (intensity matters, pulse length less crucial)

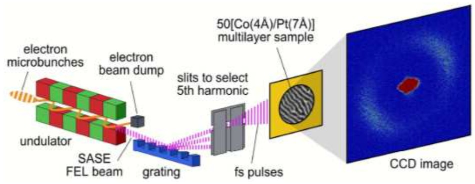
> multi-bunch, ≥ 100kHz, limited by 2D-detector (CCD) readout rate

Cond. matter: magnetism studies with FEL harmonic

C.Gutt, S.Eisebitt et al.

Co/Pt multilayers form a periodic magnetic domain pattern with magnetic moments m_j parallel and antiparallel to the surface normal.

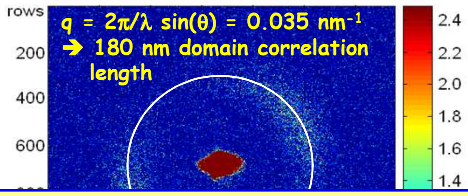


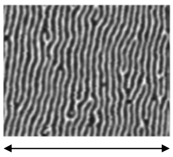


Measurement at Co L_3-Edge (778 eV)

$$M(q) = \sum_j m_j \exp(iqr_j) \quad \text{(magnetisation density)}$$

$$I(q) = |M(q)|^2$$





5 µm

Magnetic force microscopy

C.Gutt et al., PRB 79, 212406 (2009)

Required 1000*100 pulses with 7000 phot./pulse on sample

≥ 4 orders of magnitude can be gained at FLASH by
- appropriate optics (special grating…)
- improved detector
- 3rd harmonic instead of 5th
- higher pulse energies now (with longer pulses)

➔ single shot experiments probably feasible

Summary Condensed Matter experiments

> need short FEL pulses for time resolved studies

> mostly work with attenuated fundamental or harmonics (limited by space charge or sample destruction), typically around 1µJ
➔ at short wavelengths substantially superior to HHG lasers

> require high repetition rates for good statistics, but for X-ray imaging again limited to single bunch due to CCD readout time

Conclusions

- about 50% of the experiments at FLASH require multi-bunch operation (i.e. > 1 bunch/train)
- typical repetition rates 100 / 200kHz
- very different requirements:
  - stable SASE across train (need all)
  - highest intensity
  - stable 3rd harmonic
  - stable (short!) pulse length (determination still a challenge)
  - precise arrival time / minimum time jitter
  - smallest wavelength/energy spread across train

"They want to have the cake and eat it!!!"

The end.

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