Research Highlights from FLASH

Rolf Treusch

DESY-FS

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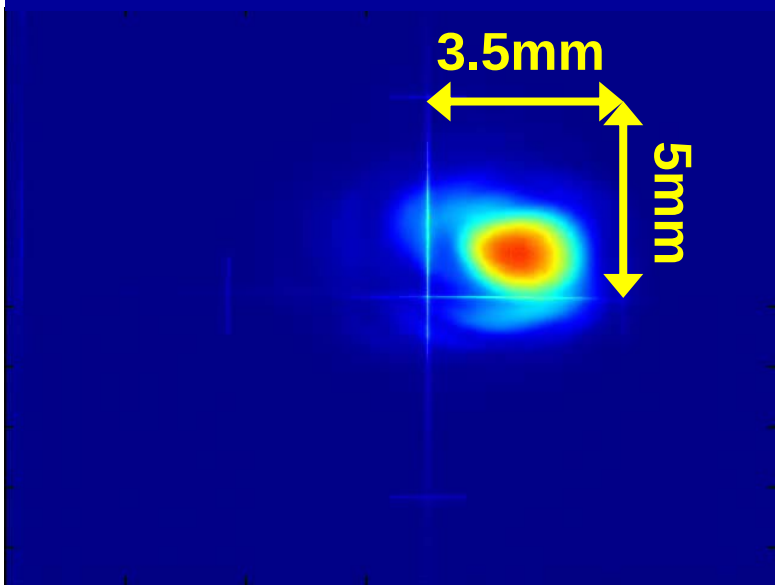
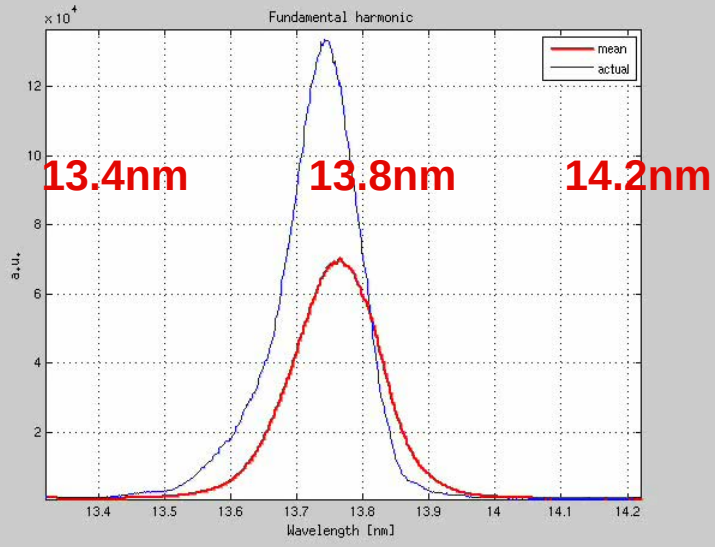
- First Round of User Experiments (overview)
- Science at FLASH: examples
- Summary/Outlook

FLASH performance

Spatial Profile



Spectral distribution



Parameter	Expected (08/2004)	Measured
Wavelength	30 nm	47-13nm
Pulse duration	15-50 fs	10-25 fs
Pulse energy	50-150 µJ	up to 170 µJ (mostly 20-30 µJ)
	at saturation	onset of nonlin. regime/saturation
Bandwidth	0.8%	0.7-1.0%
Divergence	70-80 µrad	< 150 µrad ... 90 µrad

First Round of User Experiments

30 proposals submitted in 2002
29 proposals approved in Sept. 2002
200 scientists involved from
60 institutes and
11 countries

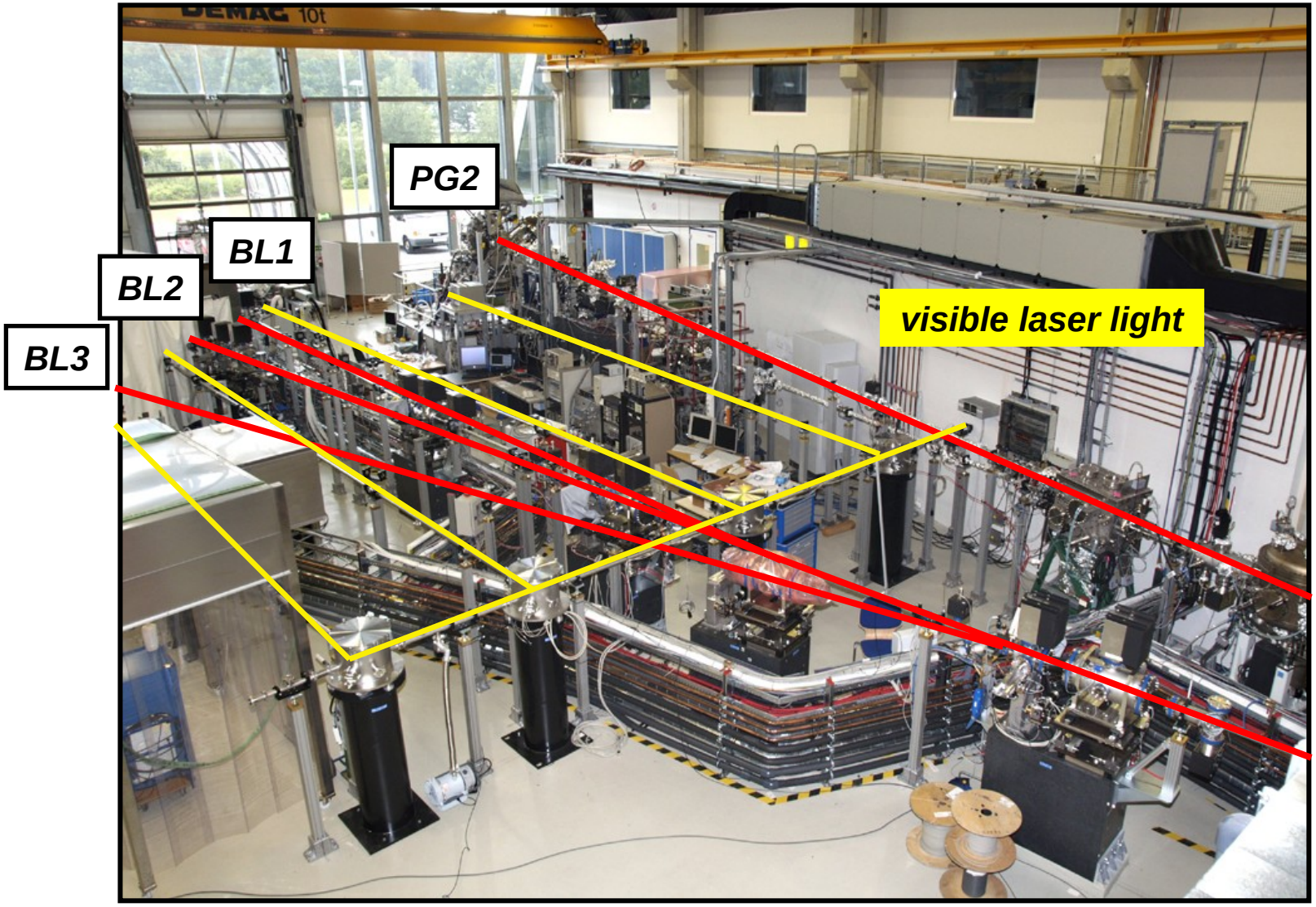
- *11 proposals were combined in a joint project ("peak brightness collaboration")*
- *2 proposals were combined into one project on biological samples (Hajdu, Chapman)*

➔ *18 projects had beamtime in two campaigns:*
Aug. 2005 – Feb. 2006 & May 2006 – March 2007

Research Areas

- **Femtosecond time-resolved experiments**
  - synchronisation FEL - optical laser
  - pump-probe experiments on atoms and molecules
  - sum-frequency generation
- **Interaction of ultra-intense XUV pulses with matter**
  - multiphoton excitation of atoms, molecules, clusters…
  - creation and characterisaton of dense plasmas
  - imaging of 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
  - luminescence under FEL radiation
  - meV-resolution photon and photoelectron spectroscopy of surfaces and solids with nm resolution

FLASH experimental hall



Science at FLASH : examples

- pump probe experiments (M. Meyer et al.)
- cluster experiments (T. Möller et al.)
- multi-photon excitation of atoms (M. Richter et al.)
- single shot diffraction imaging (H. Chapman, J. Hajdu, ...)

We apologize that some of the results which are presently in the publishing process had to be taken out of this copy

Pump-probe experiments in the gas phase
(M. Meyer et al.)

Experimental

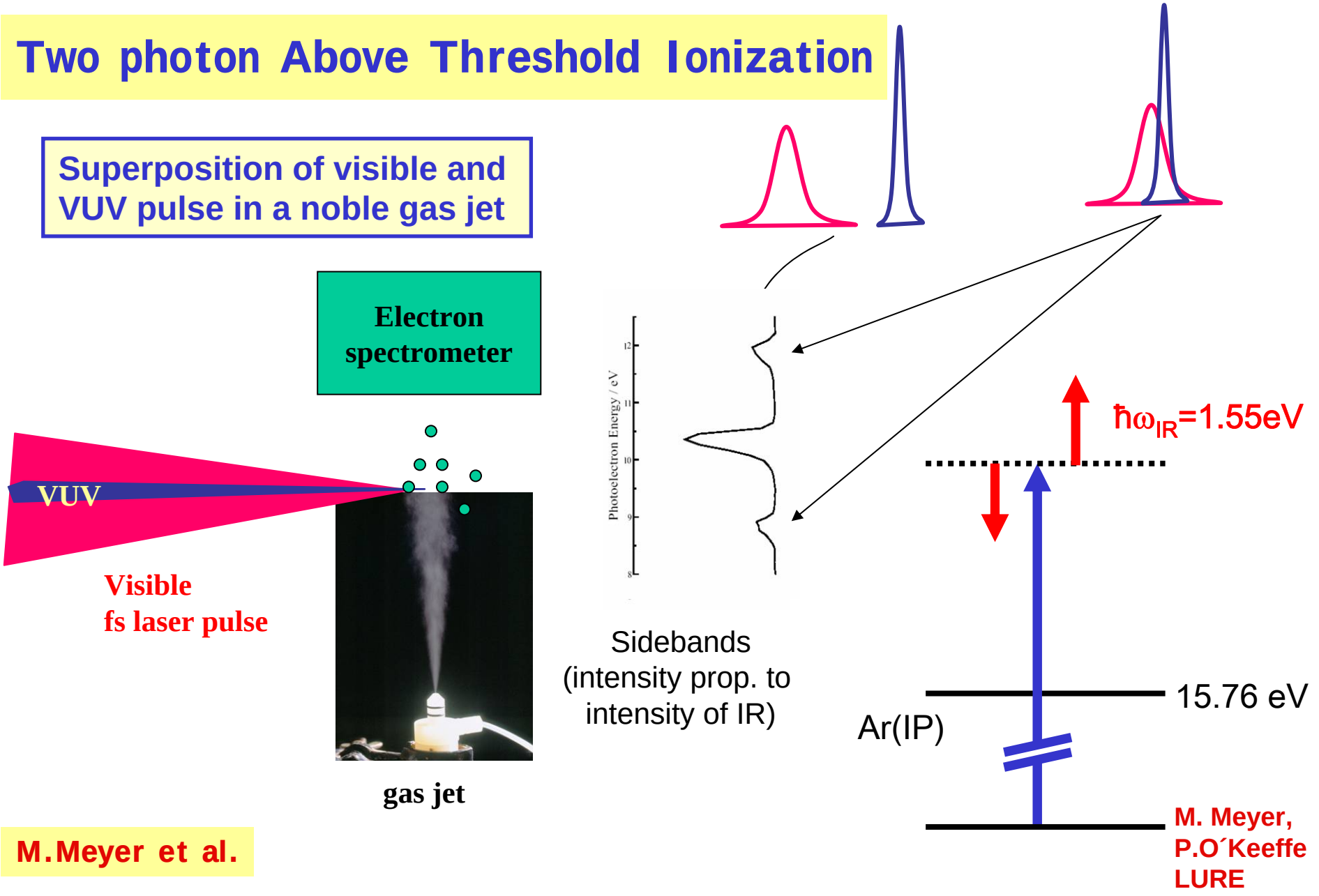
- **LIXAM / LURE (Orsay, France)**
  D. Cubaynes, P. O'Keeffe, M. Meyer
- **DESY (Hamburg, Germany)**
  S. Düsterer, P. Radcliffe, H. Redlin,
  E. Plönjes, J. Feldhaus
- **Dublin City University (Dublin, Ireland)**
  H. Luna, P. Yeates, E. Kennedy, J. Costello
- **Queens University Belfast (U Kingdom)**
  Ph. Orr, D. Riley, J. Pedrosa, C. Lewis
- **Max-Born-Institut (Berlin, Germany)**
  I. Will

Theory

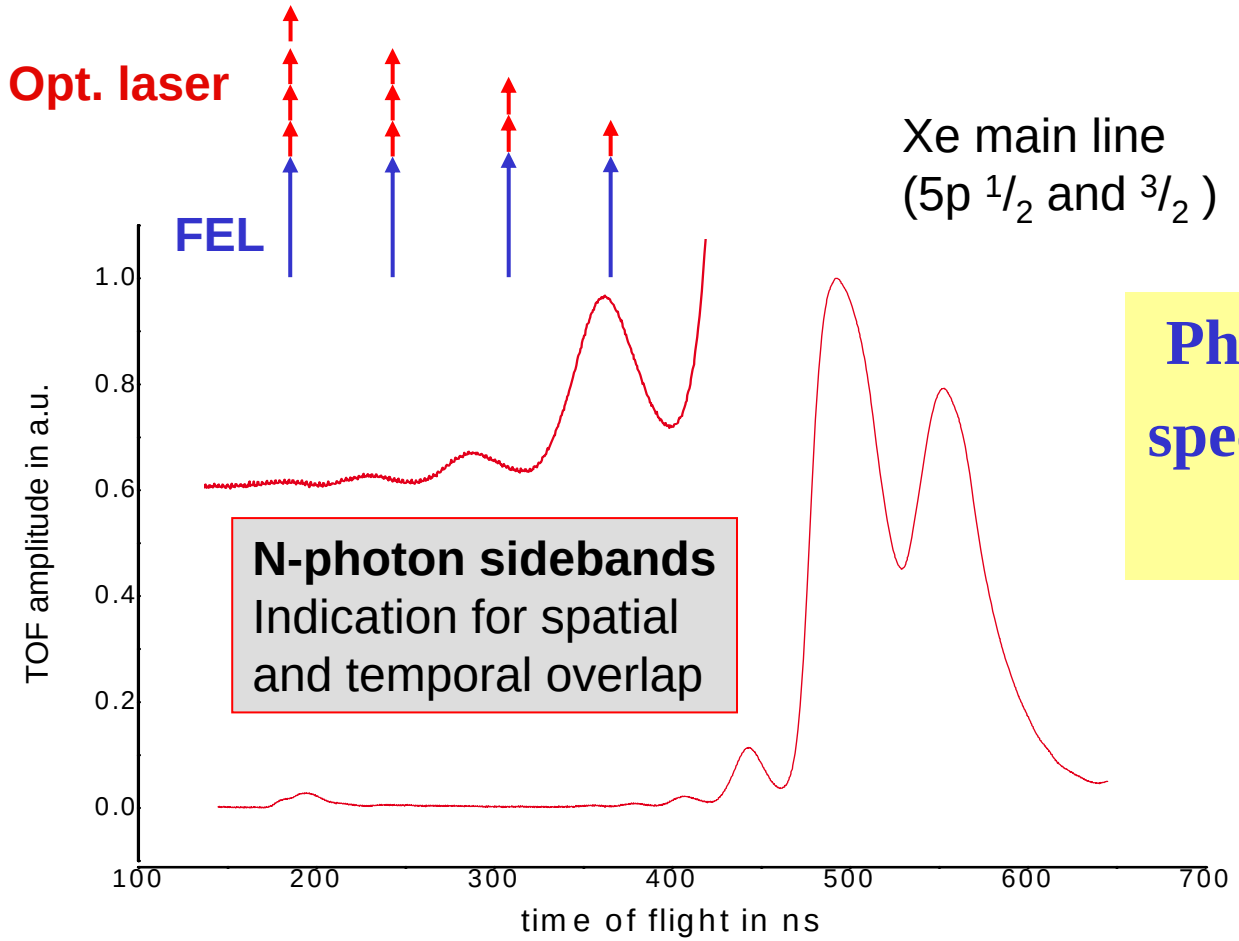
- **LCP-MR (Paris, France)**
  R. Taïeb, A. Maquet
- **FORTH (Heraklion, Greece)**
  P. Lambropoulos
- **University of Moscow**
  A. Grum-Grzhimailo, E.Gryzlova,
  A. Magunov, S. Strakhova

Two photon Above Threshold Ionization

Superposition of visible and VUV pulse in a noble gas jet



M.Meyer et al.



Photoelectron spectrum of Xe

(10-7 mbar)

Average over
50 bunches

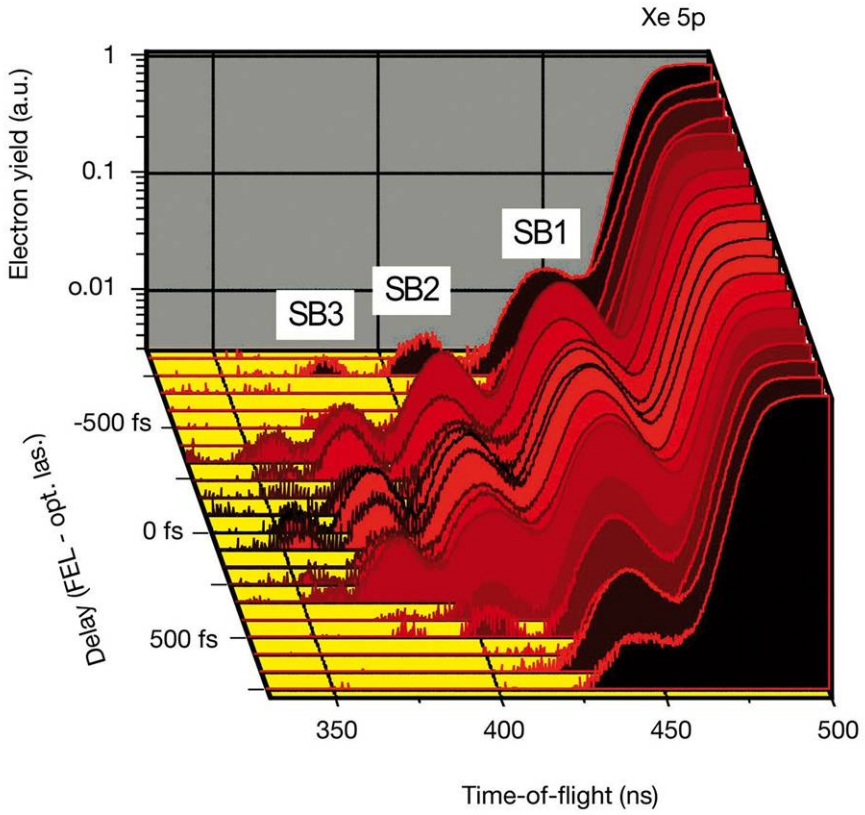
M.Meyer et al.

FEL: ~50 fs, 25.5 nm (~15 µJ, 100 µm focal spot)
Opt. laser: 120 fs, 800 nm (~15 µJ, 30 µm focal spot)

Femtosecond two-color ATI – delay scan

Temporal overlap for 600 fs - Laser + FEL correlation width ~130 fs (FWHM)

→ **jitter + drift only ~250 fs** (rms) while duration of measurement **~ 1 hour**!



FEL: ~20 fs, 13.8 nm
Opt. laser: 120 fs, 800 nm

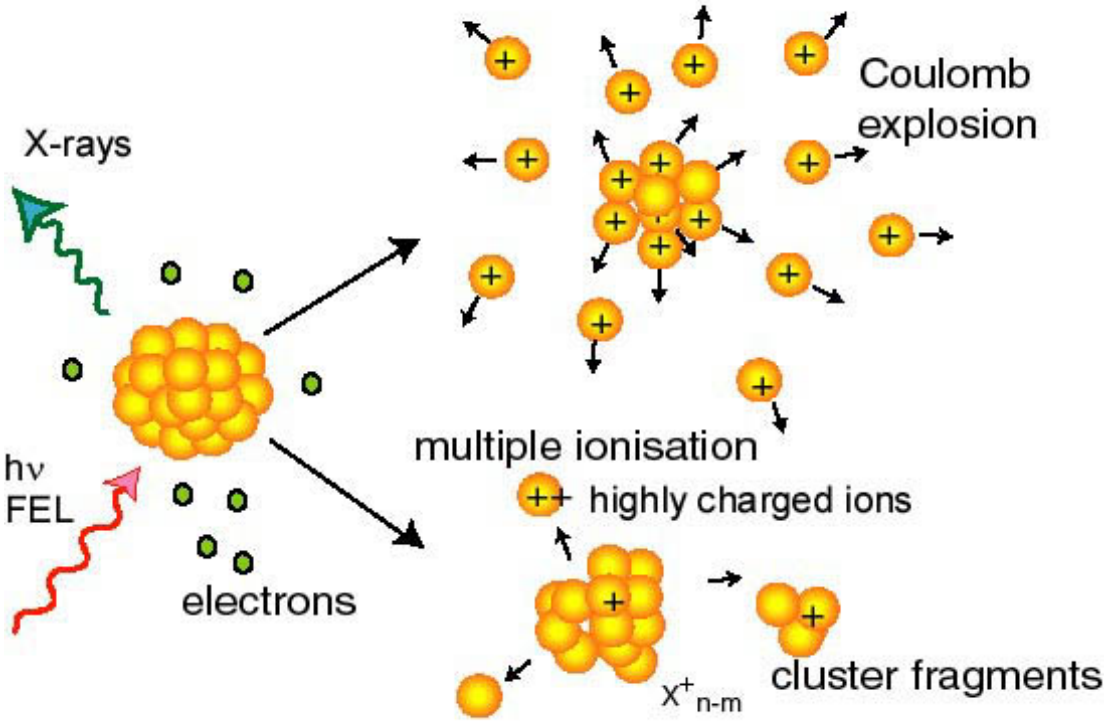
M.Meyer et al.,
Phys. Rev. A 74, 011401 (2006),

P.Radcliffe et al.,
Appl. Phys. Lett. 90, 131108 (2007)

M.Meyer et al.

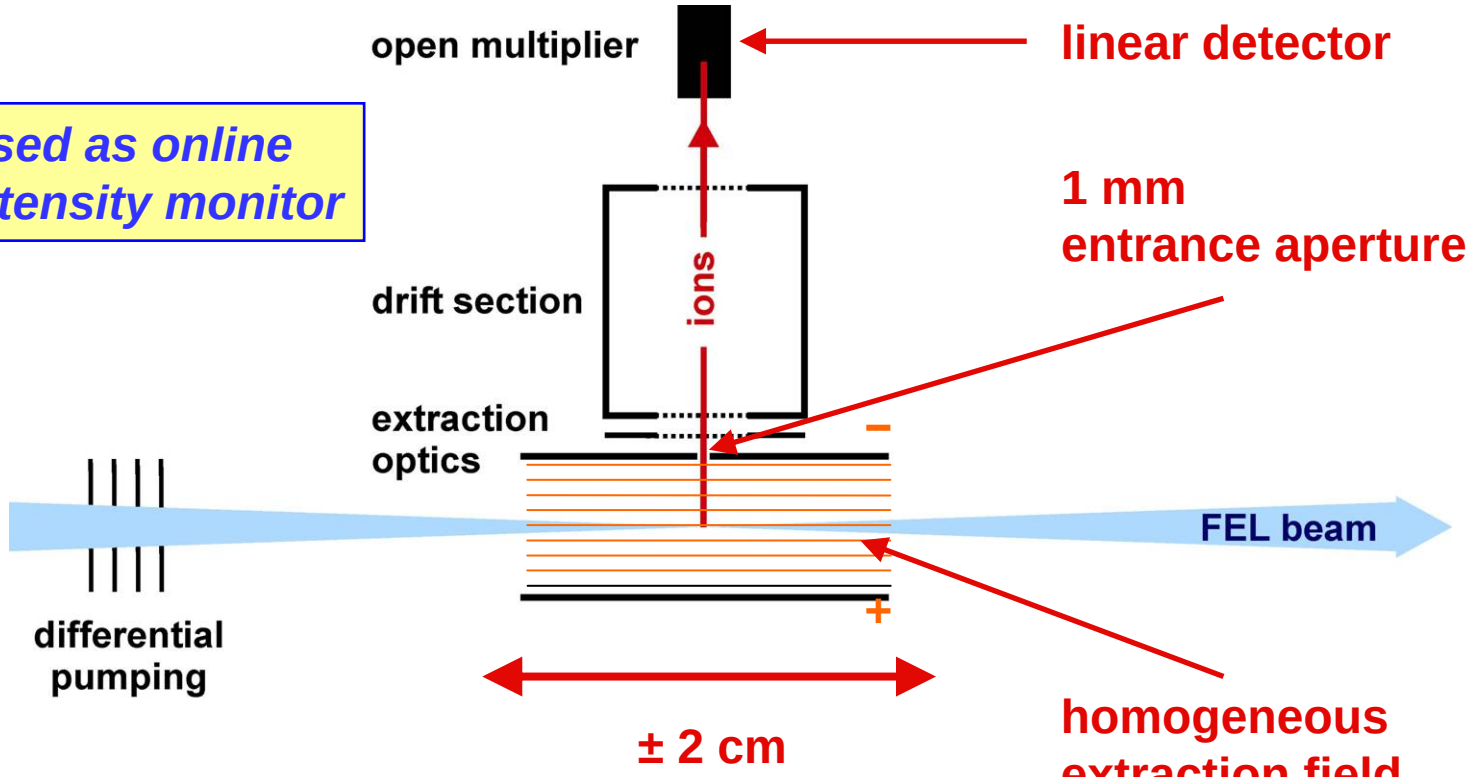
Interaction of intense soft X-rays with Clusters

(T.Möller et al.)



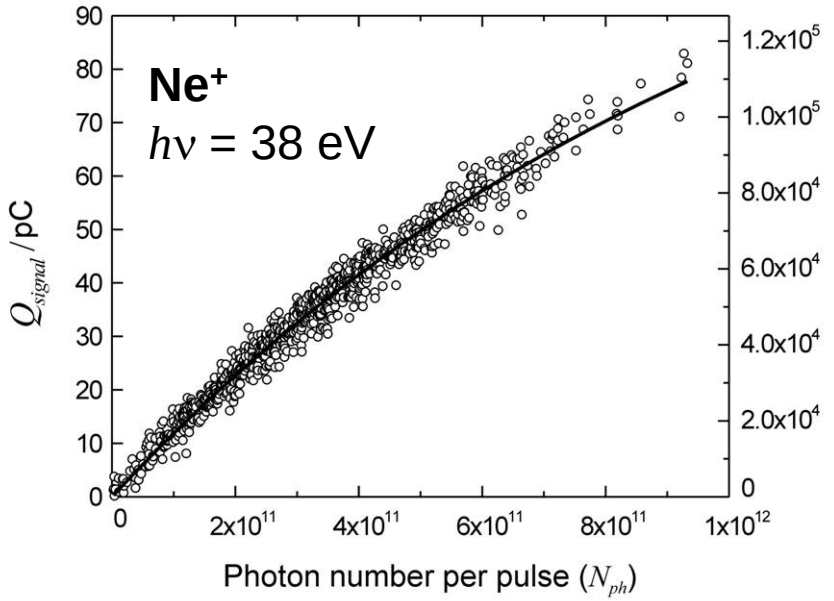
Multi-Photon excitation of atoms in gas phase
(M.Richter et al.)

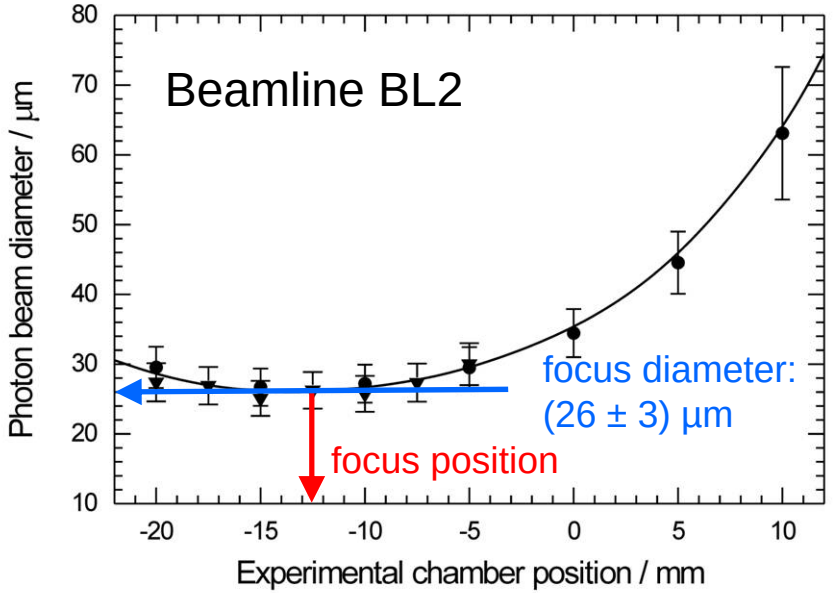
Used as online Intensity monitor



PTB
Photon Radiometry
Ioffe Physico-Technical Institute
DESY

1. Saturation of ion signals due to vanishing targets: Determination of FEL beam size and waist





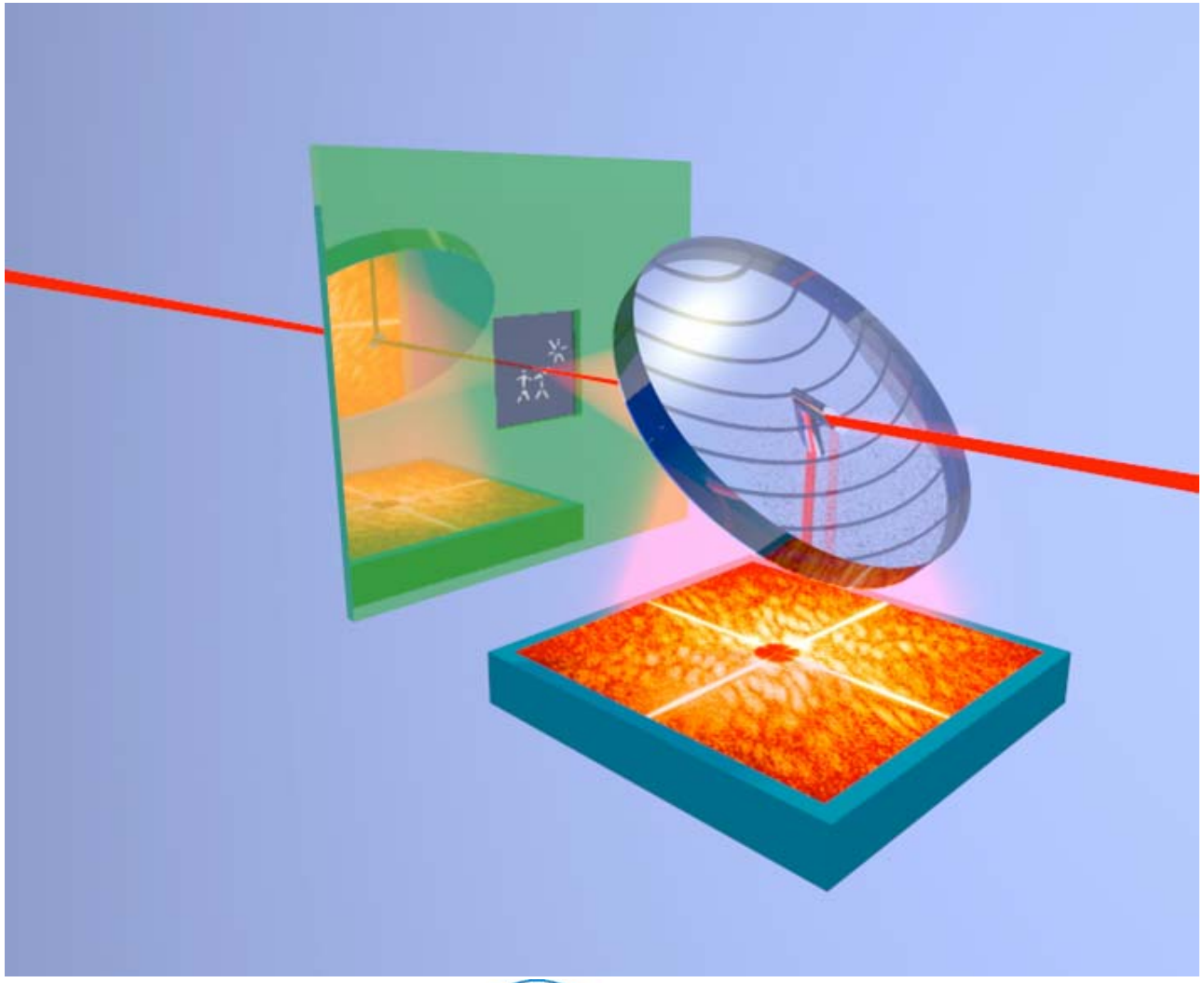
$$N_+(N_{ph}) = N\left(1 - e^{-\sigma \frac{N_{ph}}{A}}\right) \xrightarrow{\text{fit}}$$

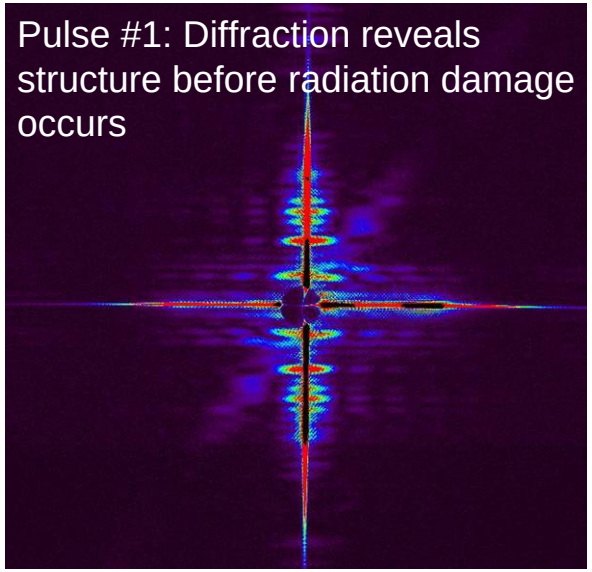
cross section σ is known
photon number N_{ph} is measured
beam cross section A is derived

M.Richter et al.

A.A.Sorokin et al., Appl. Phys. Lett. 89, 221114 (2006)

First demonstration of coherent diffraction imaging with a soft-X-ray FEL (H.Chapman, J.Hajdu)





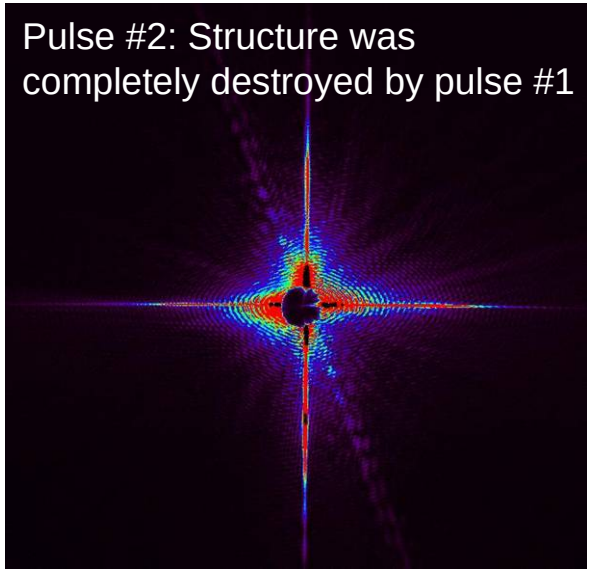
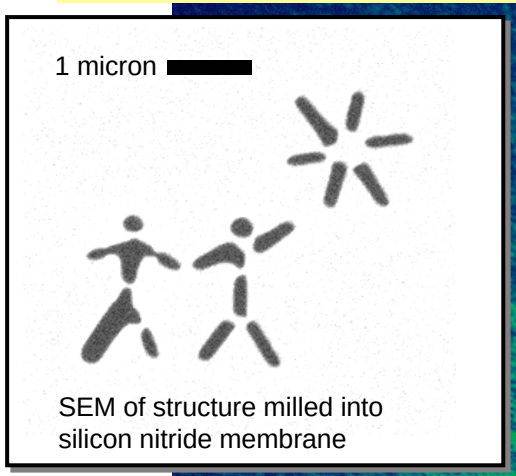
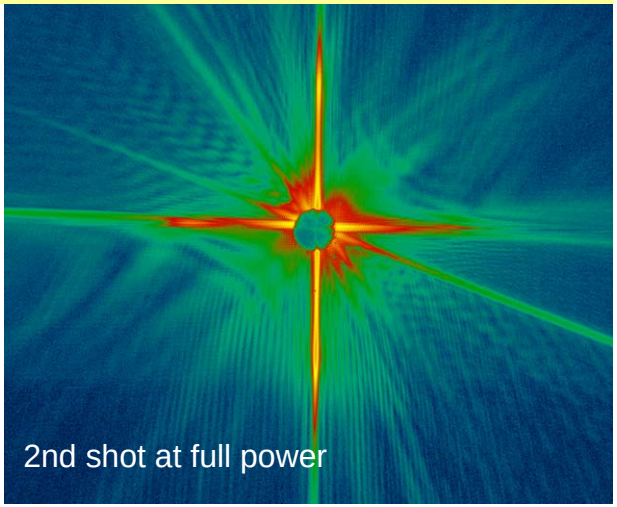
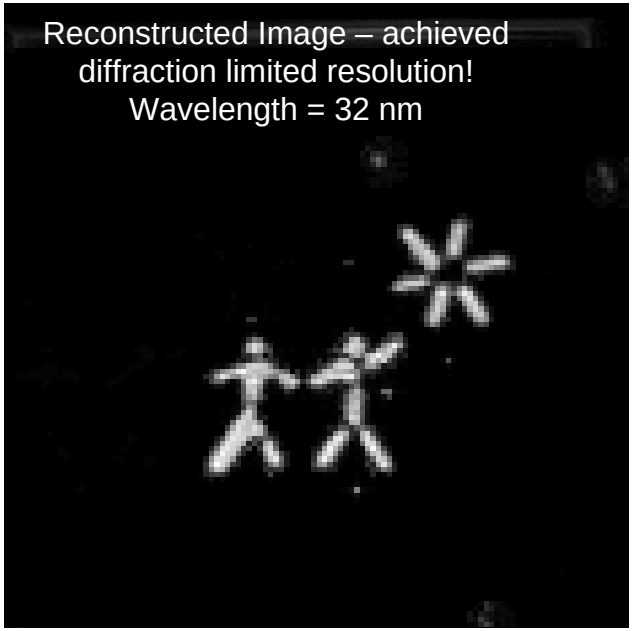


Image reconstructed from ultrafast diffraction pattern



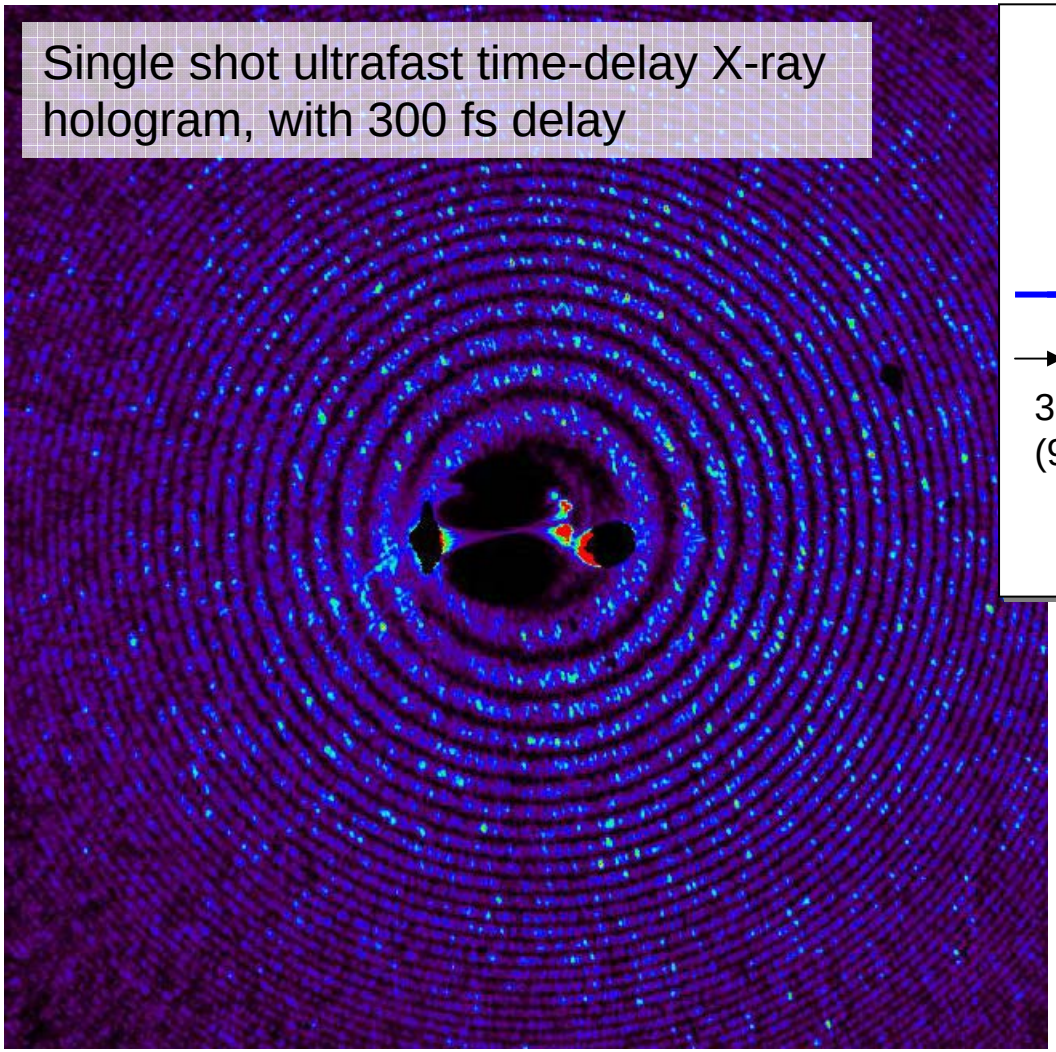
SEM of structure milled into silicon nitride membrane

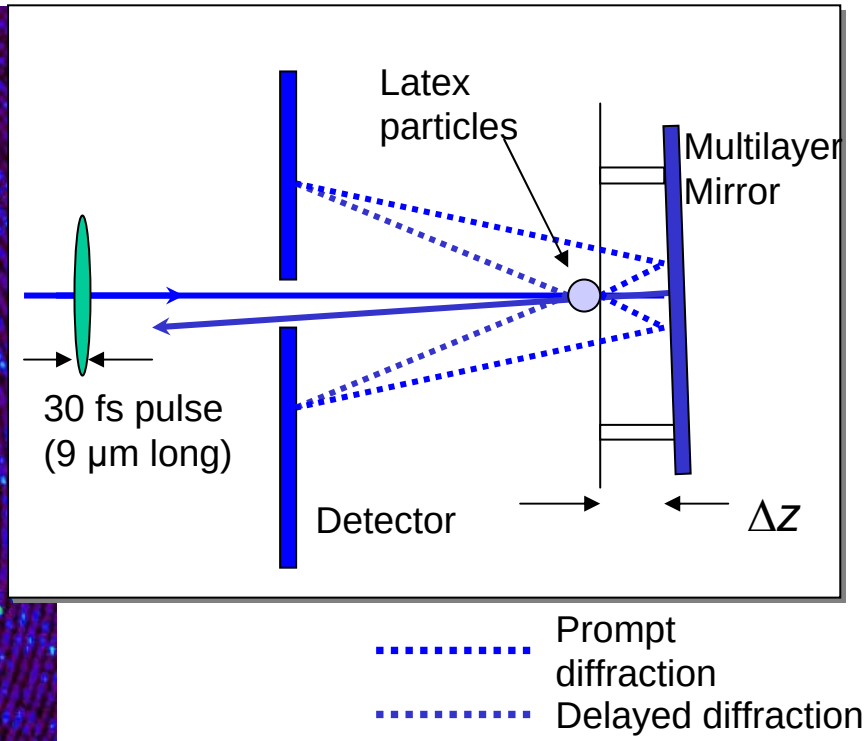




H.N.Chapman et al., Nature Physics 2, 839-843 (2006)

First demonstration of time-delay X-ray holography with 30 fs time resolution measures explosion dynamics





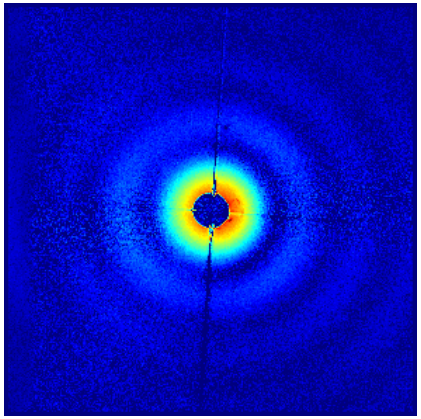
Time delay = $2\Delta z/c$

The pattern is the interference of the waves scattered from the unexploded particle (reference wave) and the same particle during explosion. Many particles generate speckle also. Time delays up to 10 ps show the spheres exploding.

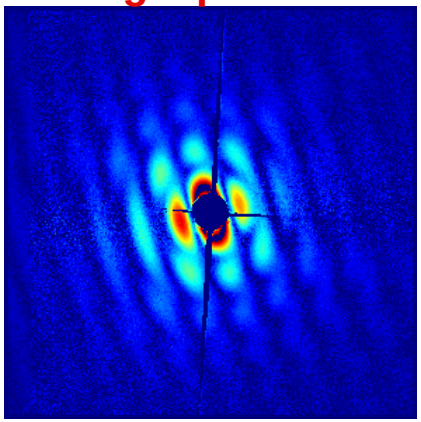
H.N.Chapman et al., Nature 448, 676-680 (2007)

some more diffraction examples:

DNA-sugar complex (about 200 nm diameter), particle jet!

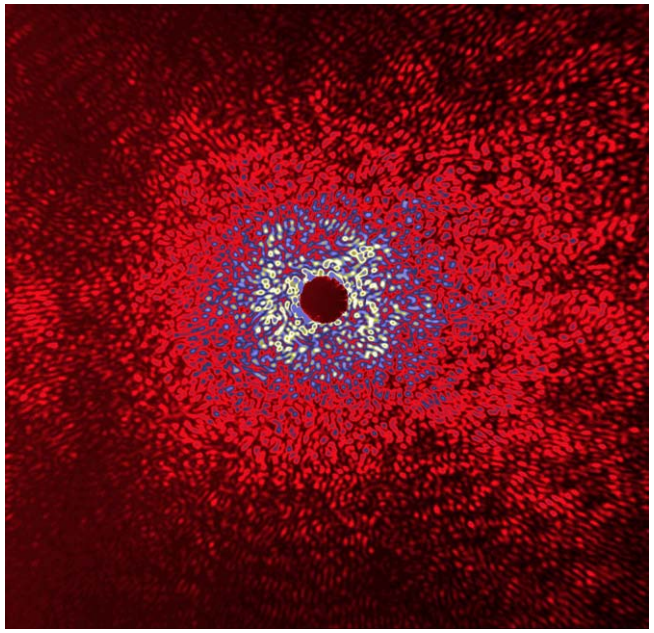


single particle



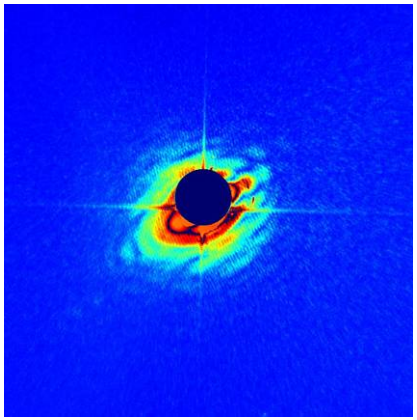
two particles in one shot

coccolith shell (plankton with a $CaCO_3$ skin)

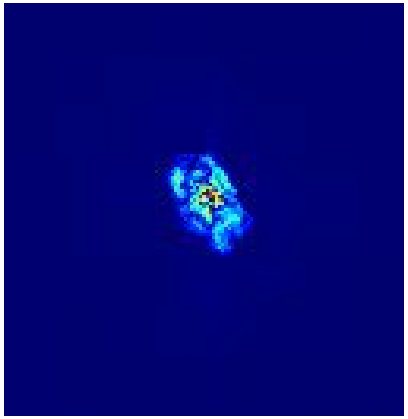


excellent resolution, probably around 20nm (as expected)

picoplankton (on SiN_3 membrane)



diffraction image



crude reconstruction

Summary of user experiments

- 18 projects had beam
- Most experiments are very complex and include many components
  ➔ collaborations, large teams
- Results are very exciting:
  - commissioning of experiments was successful
  - all experiments have taken first useful data demonstrating that their concepts work, all had a lot of “firsts”, some real “breakthroughs” paving the way towards the XFEL
  - most research results in publication list in “manuscript”
- After FLASH extension:
  looking forward to ~6.5nm in fundamental
  with 32 new projects that run until end 2008