CAMP at FLASH (II): *Flexible User End Station for Multidimensional Imaging Experiments*

Artem Rudenko

for the CAMP collaboration

Max Planck Advanced Study Group,

Centre for Free Electron Laser Science, Hamburg

New Science Opportunities at FLASH
DESY, Hamburg, October 12-14, 2011

CAMP: CFEL-ASG Multi Purpose

Outline

- *Introduction: science drivers*
- *CAMP: next generation end station for multidimensional imaging with XUV/X-ray FELs*
- *Few examples of photon / ion / electron imaging and correlation experiments:*

  from AMO to solid state physics, material science and biology
- *CAMP at FLASH: current status and updates*

  focusing optics, polarization control, …

Science at FELs

Huge flux & peak intensity

Dilute samples,

non-linear processes

Short pulses

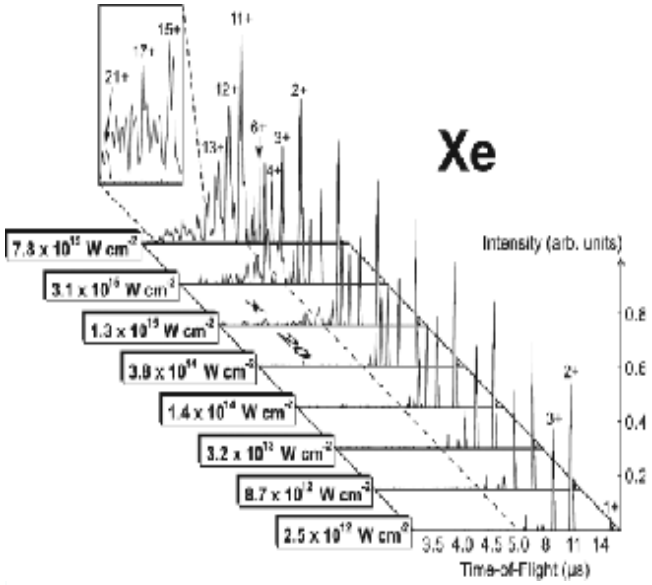
Femtosecond dynamics,

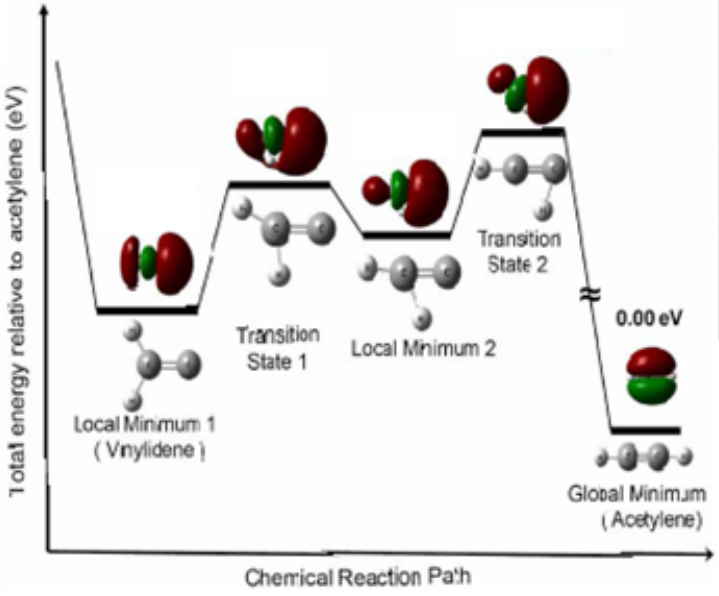
pump-probe experiments

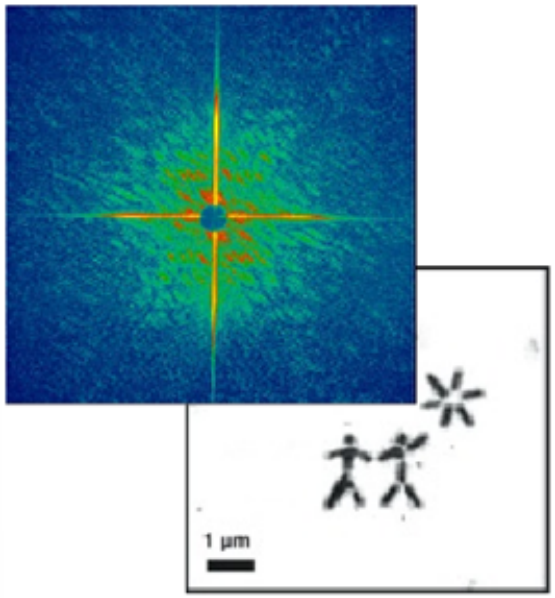
Coherent radiation

Coherent diffractive imaging

of nano-scale objects







A.A. Sorokin et al., Phys. Rev. Lett. ***99****, 213002 (2007).*
H. Pedersen et al., Phys. Rev. Lett. ***98****, 223202 (2007).*
A. Rudenko et al., Phys. Rev. Lett. ***101****, 073003 (2008).*
L. Young et al., Nature ***466****, 56 (2010).*
D. Doumy et al., Phys. Rev. Lett. ***106****, 083002 (2011).*
B. Nagler et al., Nature Phys. ***5****, 693–696 (2009).*

I. Rajkovic et al., Phys. Rev. Lett. ***104****, 125503 (2010).*
J.H. Yiang et al., Phys. Rev. Lett. ***105****, 263002 (2010).*
M. Krikunova et al., J. Chem. Phys. ***134****, 024313 (2011).*

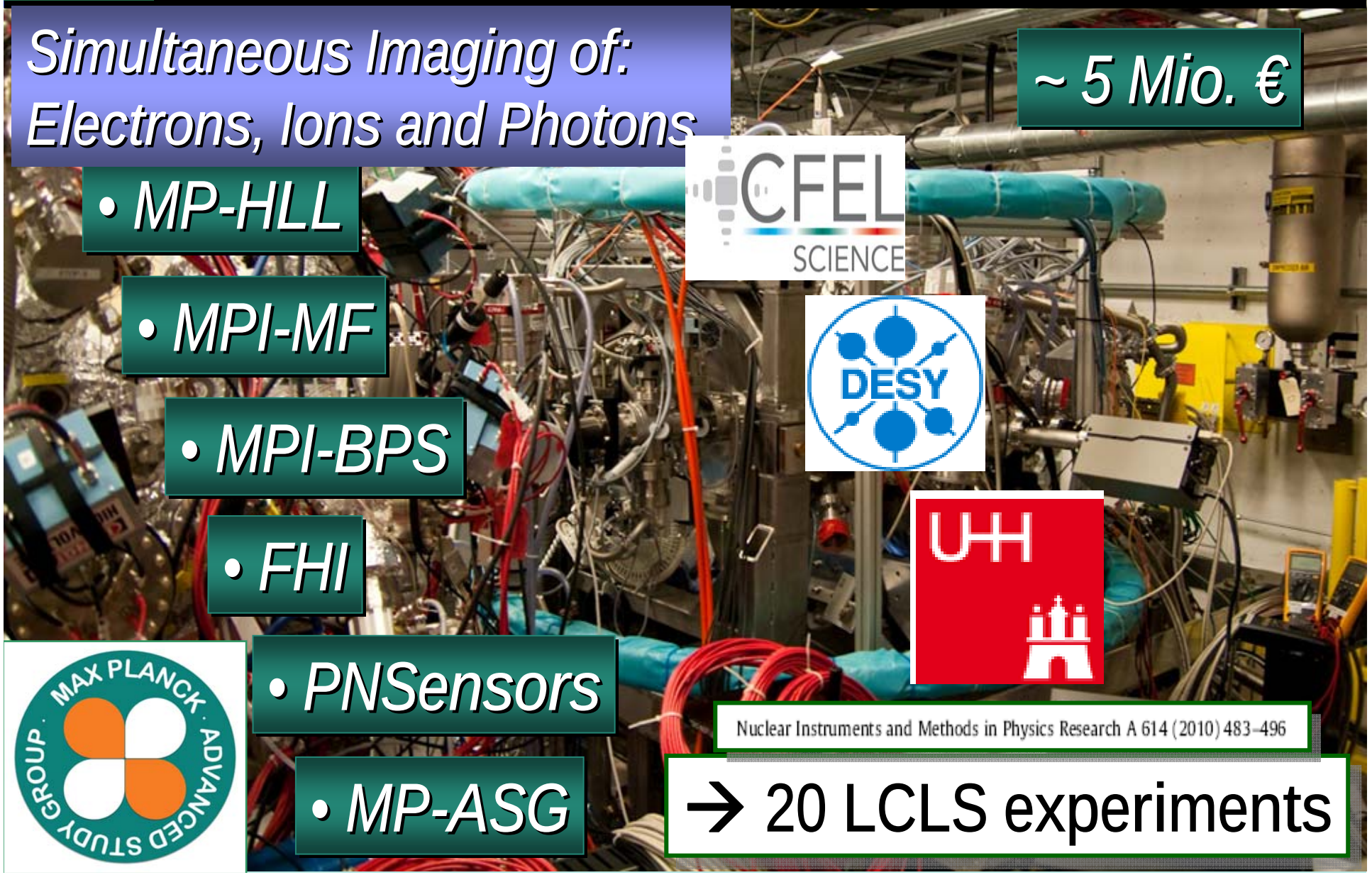
H.N. Chapman et al., Nature Phys. ***2****, 839 (2006); Nature* ***470****, 73 (2011).*
A. Mankuso et al., Phys. Rev. Lett. ***102****, 035502 (2009).*
M.M. Seibert et al., Nature ***470****, 78 (2011).*

Prerequisites for Multi-Purpose User End Station

- ***Modular design***
- ***Flexible target environment***
- ***Charged particle detection & imaging***
- ***XUV / X-ray photon detection & imaging***
- ***Coupling of the external lasers***
- ***Very limited amount of beamtime***

Quest for 'universal' instrumentation

The CFEL-ASG Multipurpose (CAMP) Instrument



Simultaneous Imaging of: Electrons, Ions and Photons

~ 5 Mio. €

- MP-HLL
- MPI-MF
- MPI-BPS
- FHI
- PNSensors
- MP-ASG

CFEL SCIENCE

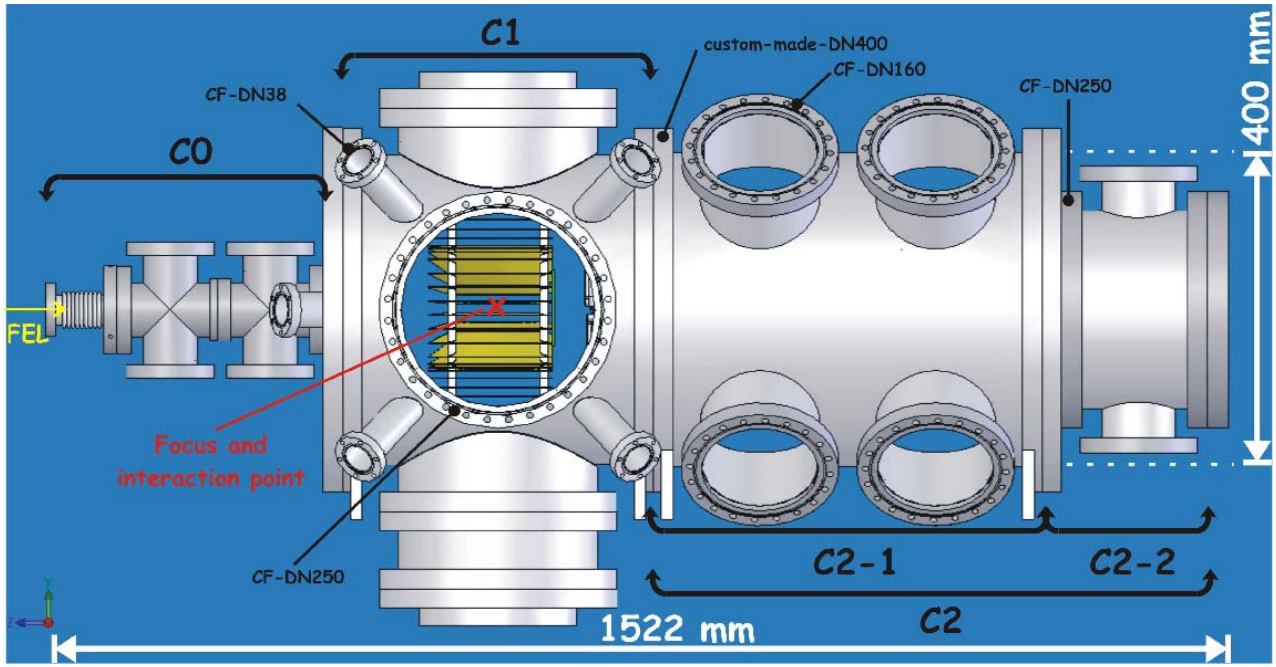
DESY

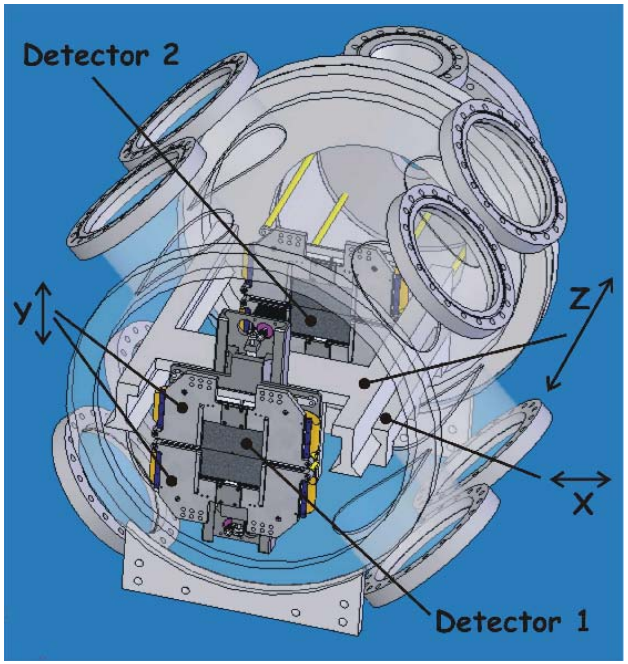
UHH

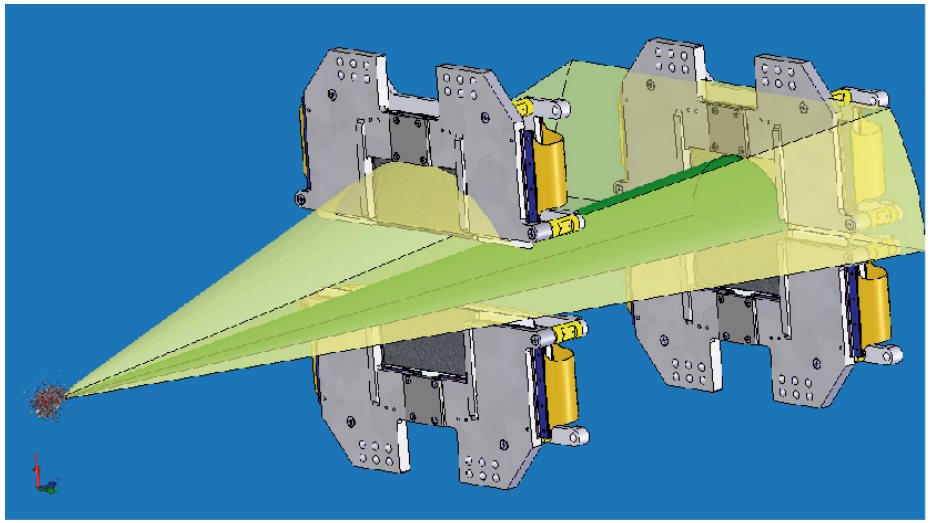
Nuclear Instruments and Methods in Physics Research A 614 (2010) 483–496

→ 20 LCLS experiments

The CFEL-ASG Multipurpose (CAMP) Instrument



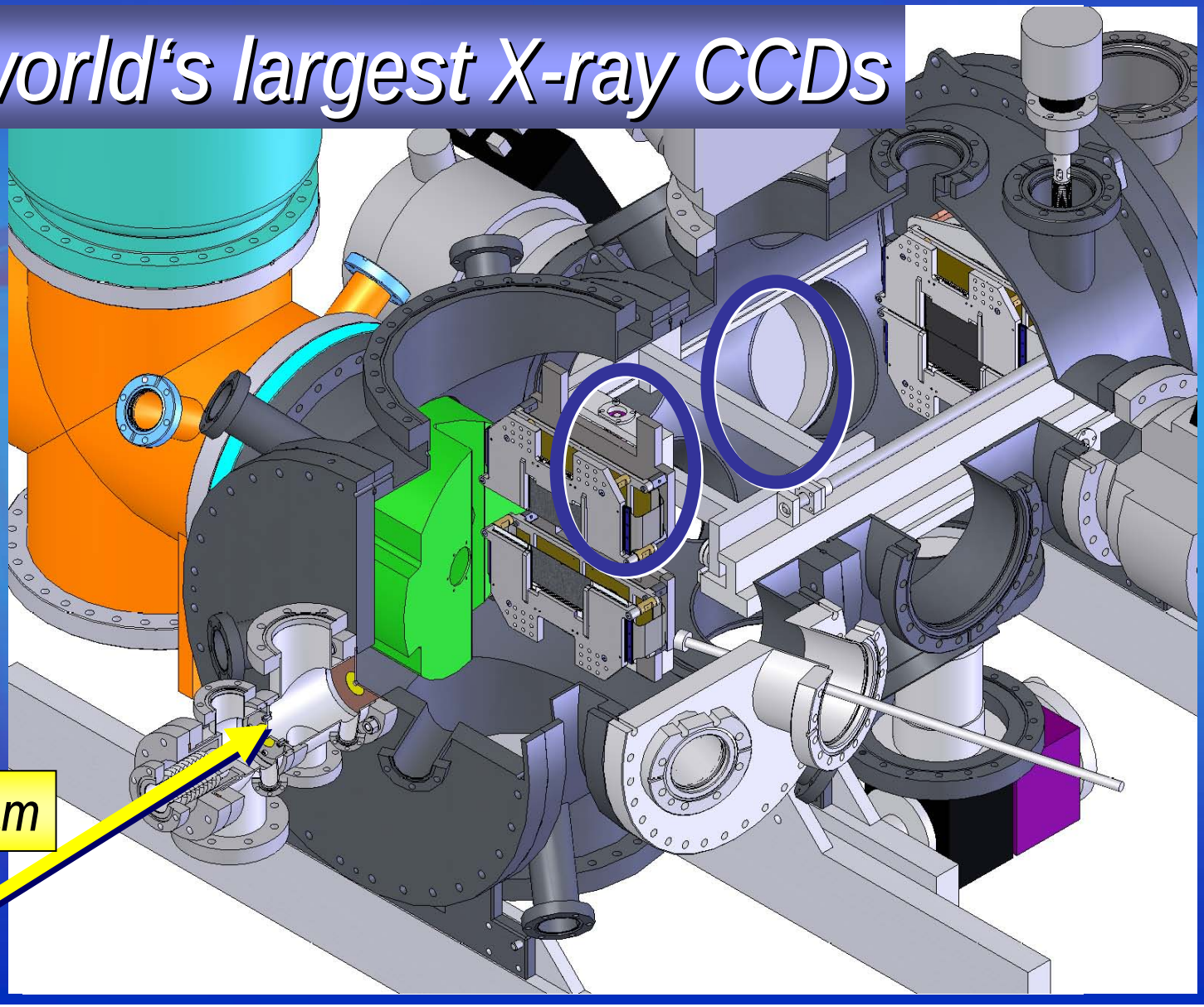




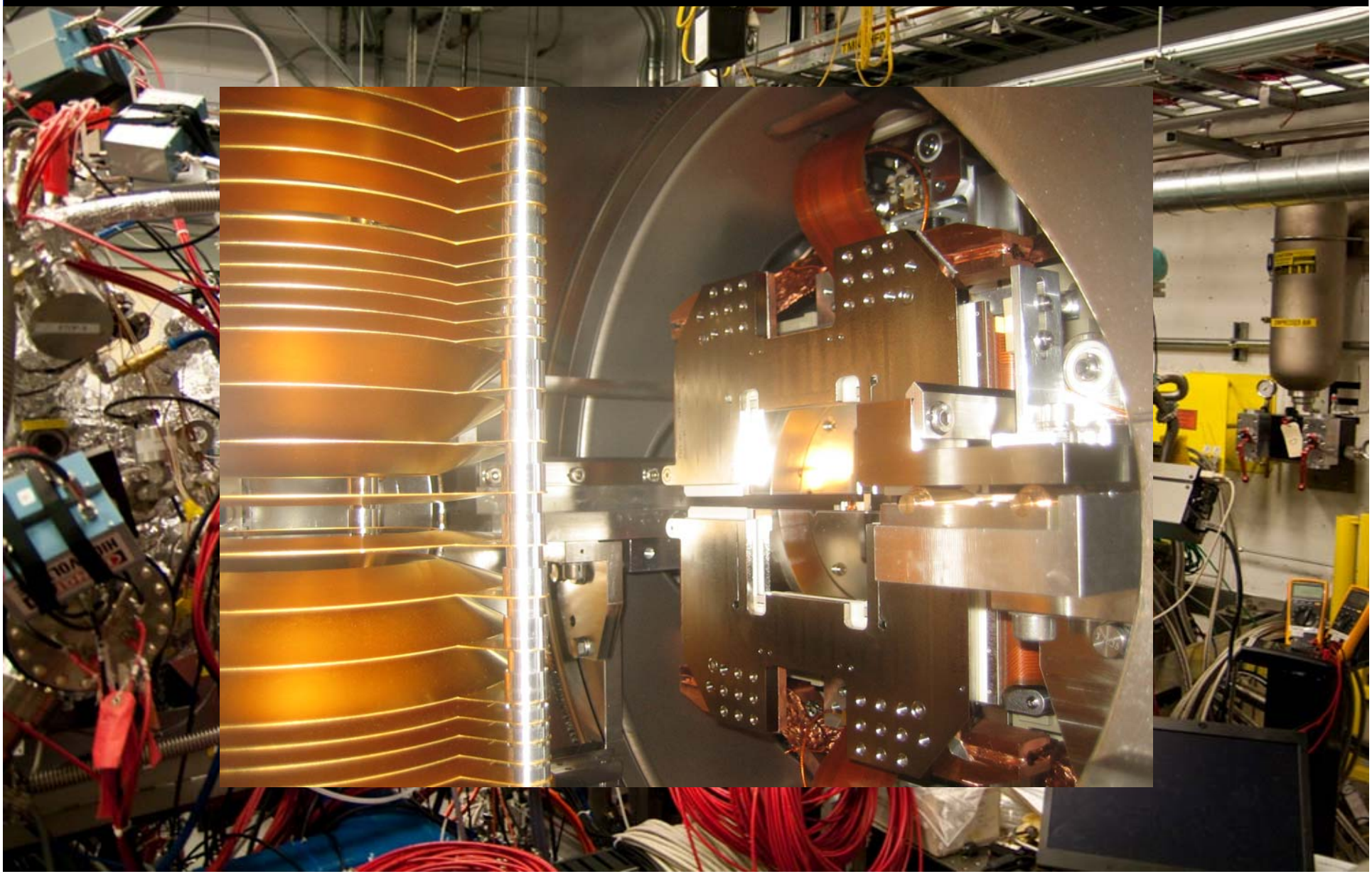
L. Strüder *et al.*,
Nucl. Instr. Meth. Phys. Res. A. **614**, 483 (2010).

The CFEL-ASG Multipurpose (CAMP) Instrument

The world‘s largest X-ray CCDs



The CFEL-ASG Multipurpose (CAMP) Instrument

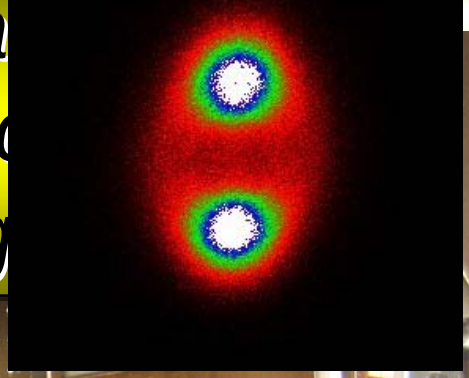


The CFEL-ASG Multipurpose (CAMP) Instrument

ion imaging

Isotropic ensemble

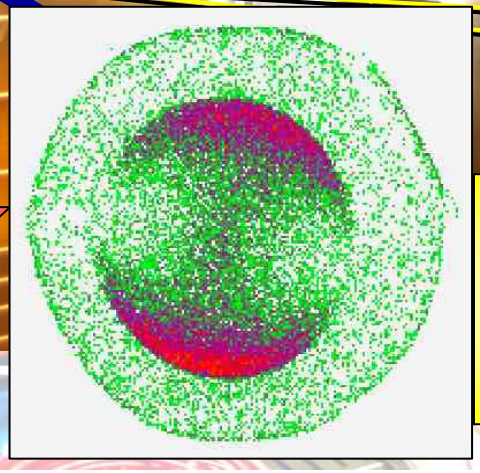
Aligned molecules



FEL

Double-sided velocity map imaging spectrometer or “reaction microscope”

electron imaging



Jet target:

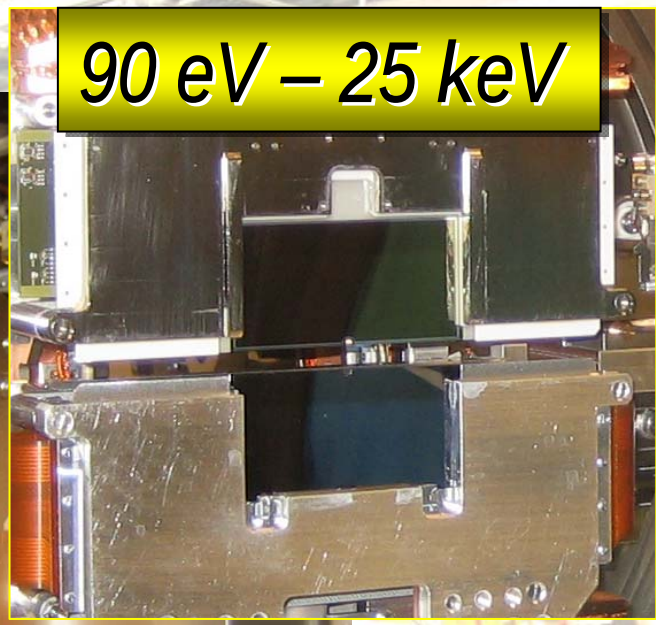
atoms, (cold) molecules, clusters, viruses, nanocrystals,…

The CFEL-ASG Multipurpose (CAMP) Instrument

Ion imaging

scattered and fluorescence photon imaging

90 eV – 25 keV



FEL

MPI Semiconductor Lab (Munich):

1024x1024 pixels

pixel size: 75 x 75 μm^2

active area: 59 cm^2

frame rate: up to 200 Hz

single-photon resolution at E > 40 EV

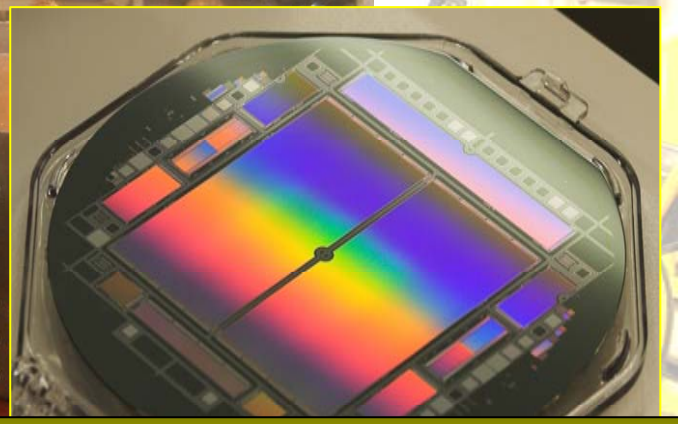
up to 10^3 photons (1keV) per pixel

ΔE=40/80eV @ 100/2000eV

Q.E. ≥ 90 % from 0.8 to 10 keV

operating range 1 eV < E < 25 keV

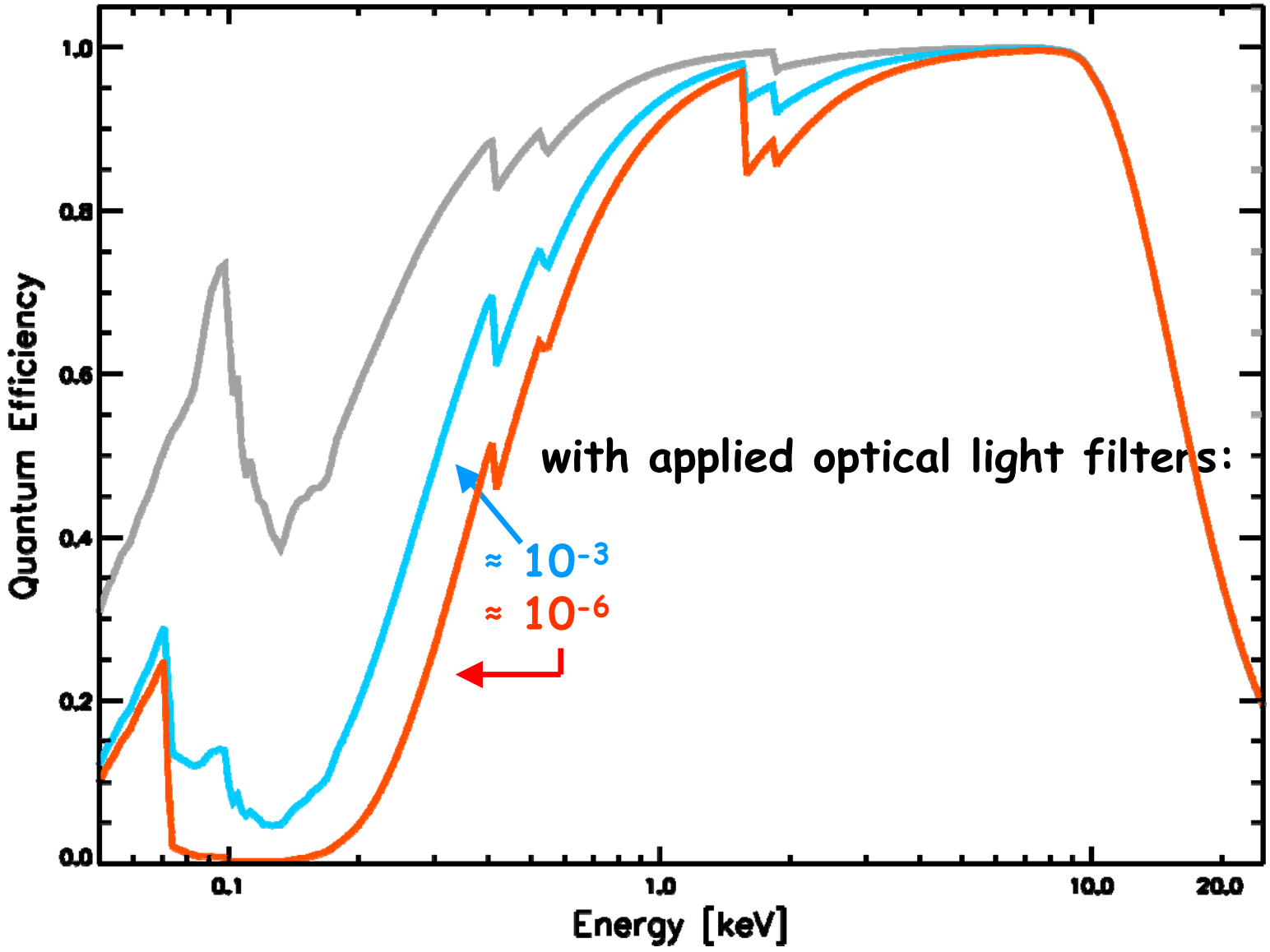
optimized for 90 eV < E < 15 keV



electron imaging

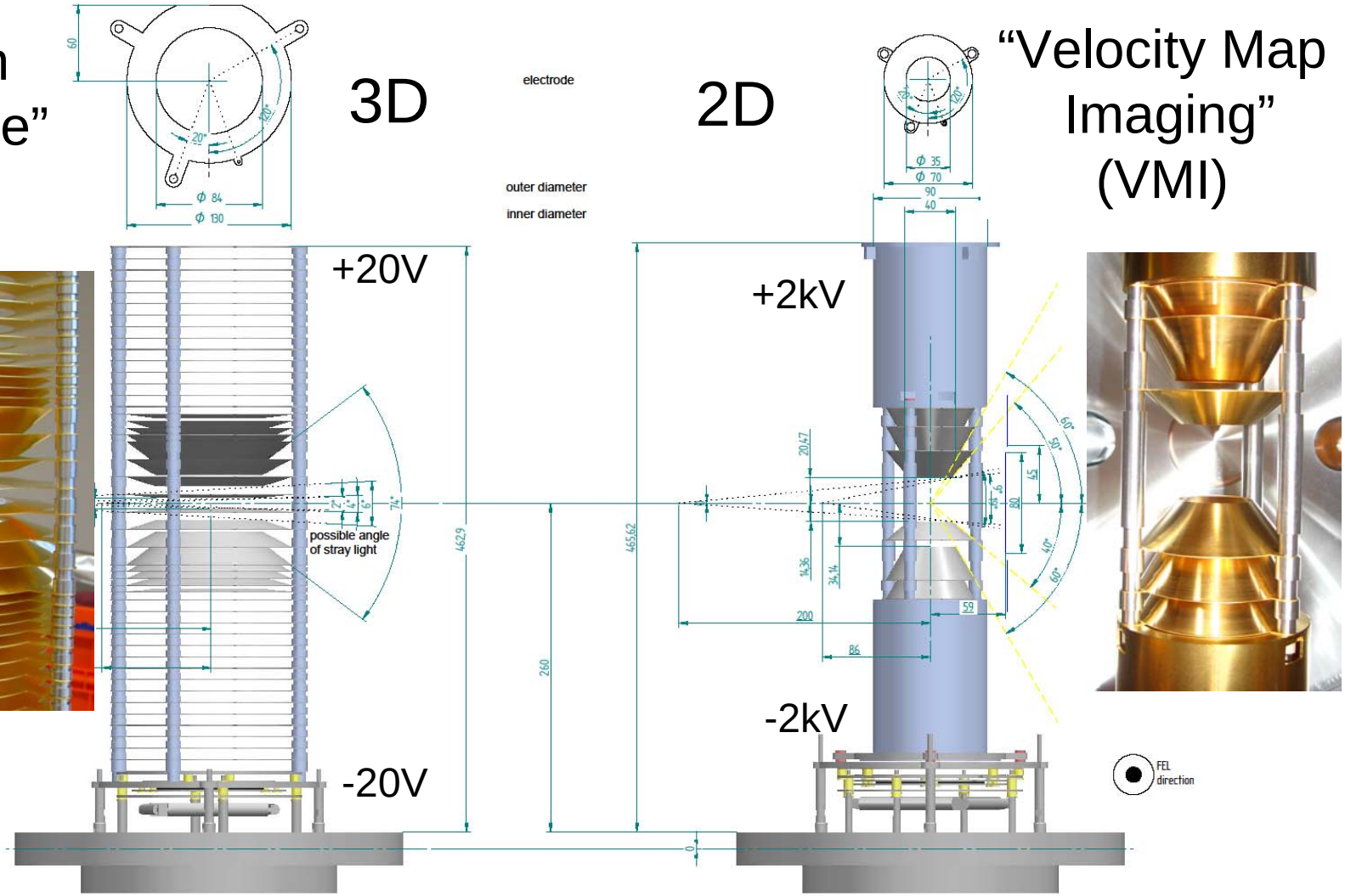
1 Mega Pixels, 200 Hz

Quantum Efficiency of the pnCCD detector



CAMP Electron and Ion Spectrometers: ReMi and (double-sided) VMI

"Reaction Microscope" (ReMi)



"Velocity Map Imaging" (VMI)

AMOLF high-energy VMI; Uppsala Ion TOF, FHI electron TOF(s), …

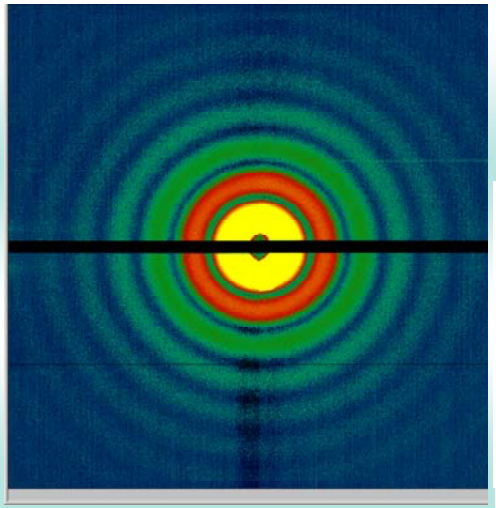
CASS: CFEL-ASG Software Suite

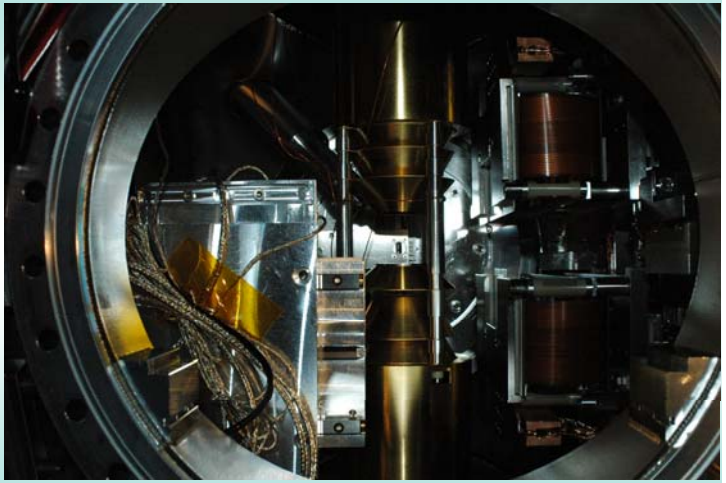
- *Combines the data from 2 pnCCDs, two commercial CCDs, up to 16 fast digitizer channels, and the beamline data*
- *Provides online viewing of the data, hit finder, correlation maps etc.*
- *Attached to the DAQ system at LCLS, being prepared for stand-alone operations (at FLASH, SACLA, …)*

L. Foucar, J. Küpper, S. Kasemeyer, N. Coppola, A. Barty, T. White, M. Scholz et al.

CAMP experiments at LCLS

- Fluorescence and ion spectroscopy on atoms
- Coulomb explosion imaging of molecules
- (Time-resolved) photoelectron diffraction & holography from aligned molecules
- Coherent diffractive imaging of aligned molecules
- Clusters: fragmentation and scattering, IR pump / X-ray probe
- Coherent diffractive imaging of fixed targets, nanocrystals, aerosols and viruses
- Ultrafast dynamics in laser / X-ray excited semiconductors, insulators and magnetic materials





Multiple ionisation of atoms:

correlation between charge state and fluorescence

$Xe,\ \hbar\omega = 1500\ eV,\ I \sim 10^{16}\ W/cm^2$

Charged states up to Xe^{36+} observed – much higher than expected!

Xe^{26+}: 1503 eV

Xe^{30+}: 1781 eV

Xe^{36+}: 2548 eV

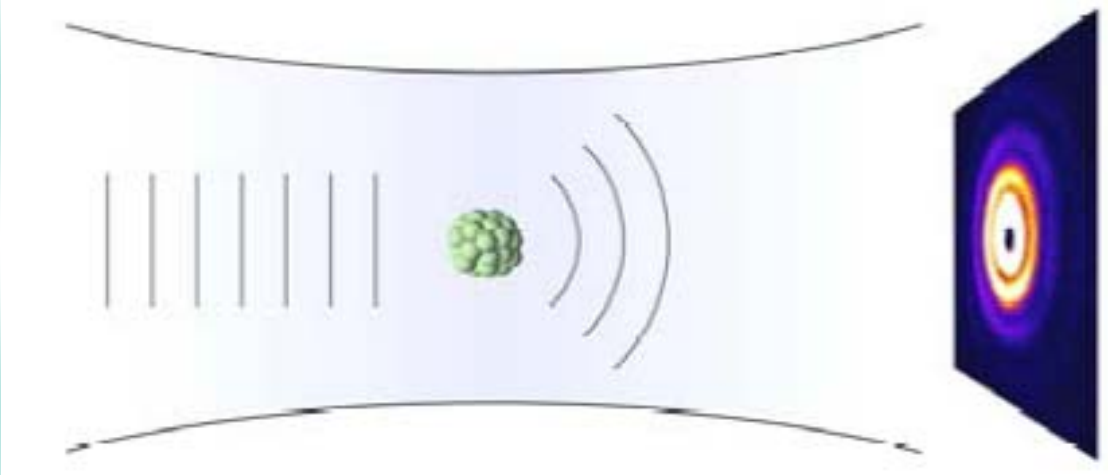
Xe^{40+}: 3001 eV

Combined analyses of ion and fluorescence spectra shows that resonant excitations are responsible for ultra-efficient ionization

Rudek et al, to be submitted to Nature Phys.

Rare gas clusters:
a nano-lab for FEL science

- *easy sample delivery, variable nano-scale size*
- *large scattering cross sections*



- *accessible for theory*
- *fragmentation/scattering data in optical and XUV domain*

Rare gas clusters:
a nano-lab for FEL science

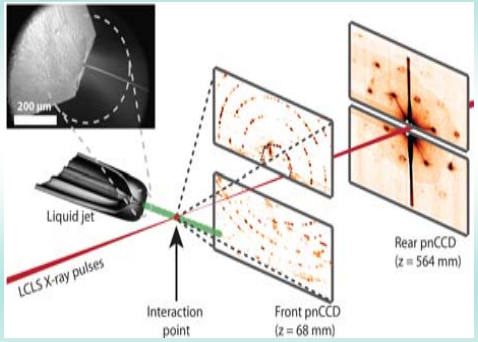
Christoph Bostedt, Sebastian Schorb, (*LCLS*)
Daniela Rupp, Marcus Adolph, Tais Gorkhover,
Thomas Möller (*Technische Universität Berlin*)

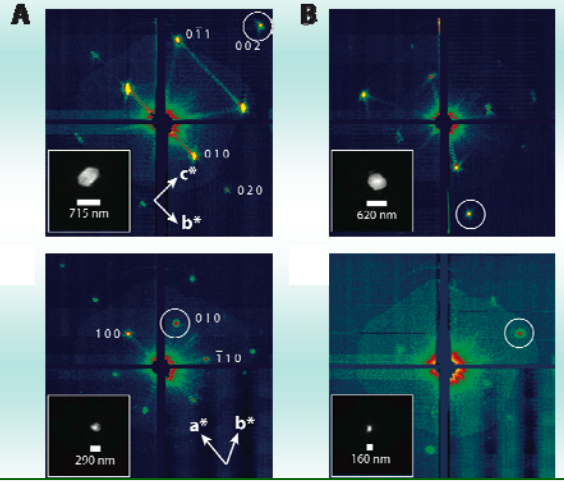
Pulse length: 70-300 fs $\hbar\omega$ ***= 800-1500 eV Xe clusters, ~30 nm radius***

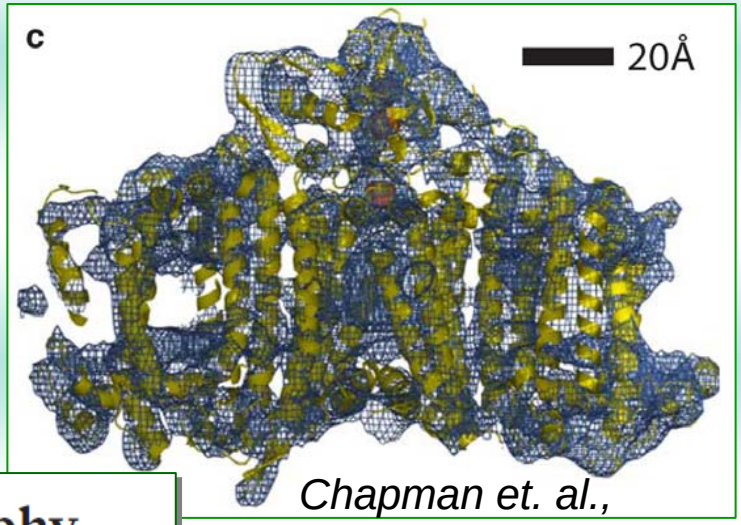
Simultaneous single-shot measurement of ion charge state distributions and diffraction patterns allows for size-selective *(from the ring spacing),* ***single intensity*** *(from the scattered photon number)* ***spectroscopy of rare gas clusters***

+ electron & fluorescence spectra!

Coherent diffractive imaging

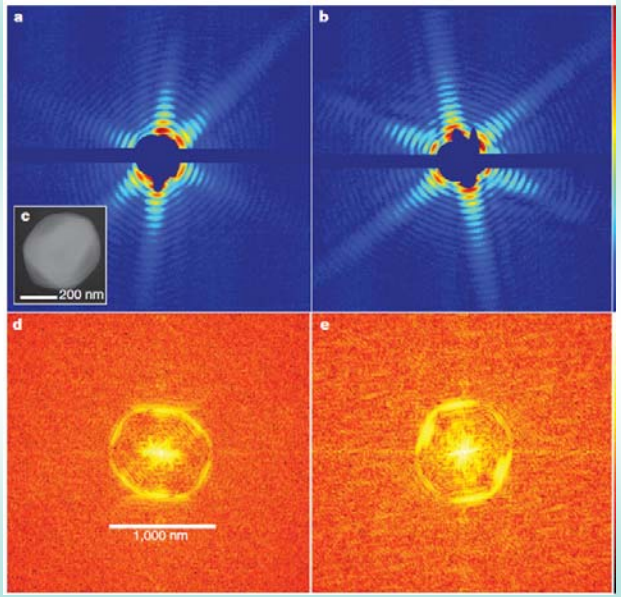






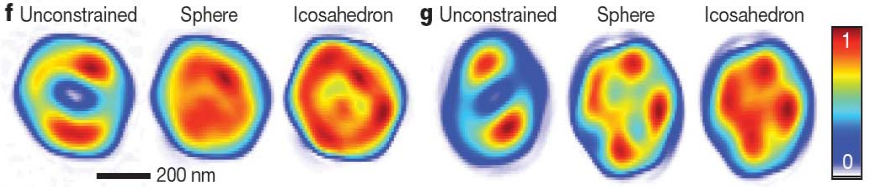
Femtosecond X-ray protein nanocrystallography

*Chapman et. al., Nature **470** 73 (2011)*



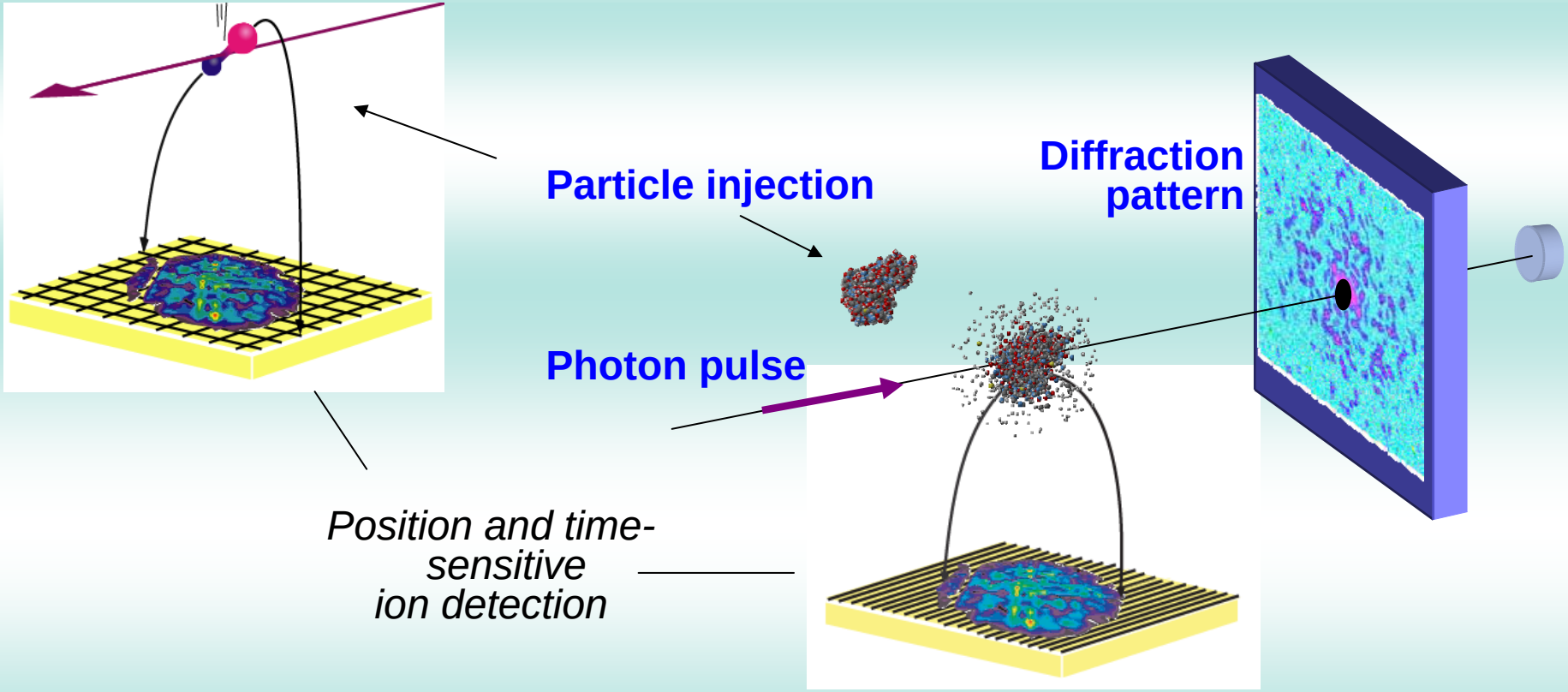
Variety of results on nanocrystals, single viruses, aerosols etc.

Single mimivirus particles intercepted and imaged with an X-ray laser *Seibert et. al., Nature **470** 78 (2011)*



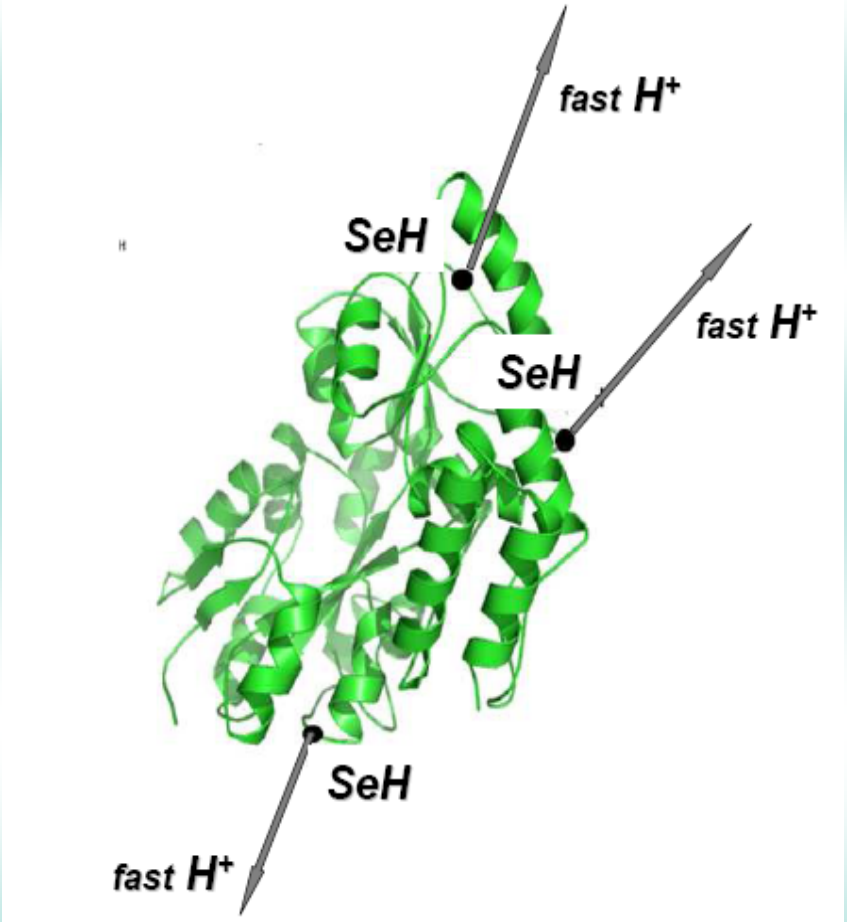
Retrieving sample orientation from emission pattern of ionic fragments

works nicely for small molecules, questionable for large ones!



Retrieving sample orientation from emission pattern of ionic fragments

Maltose binding protein

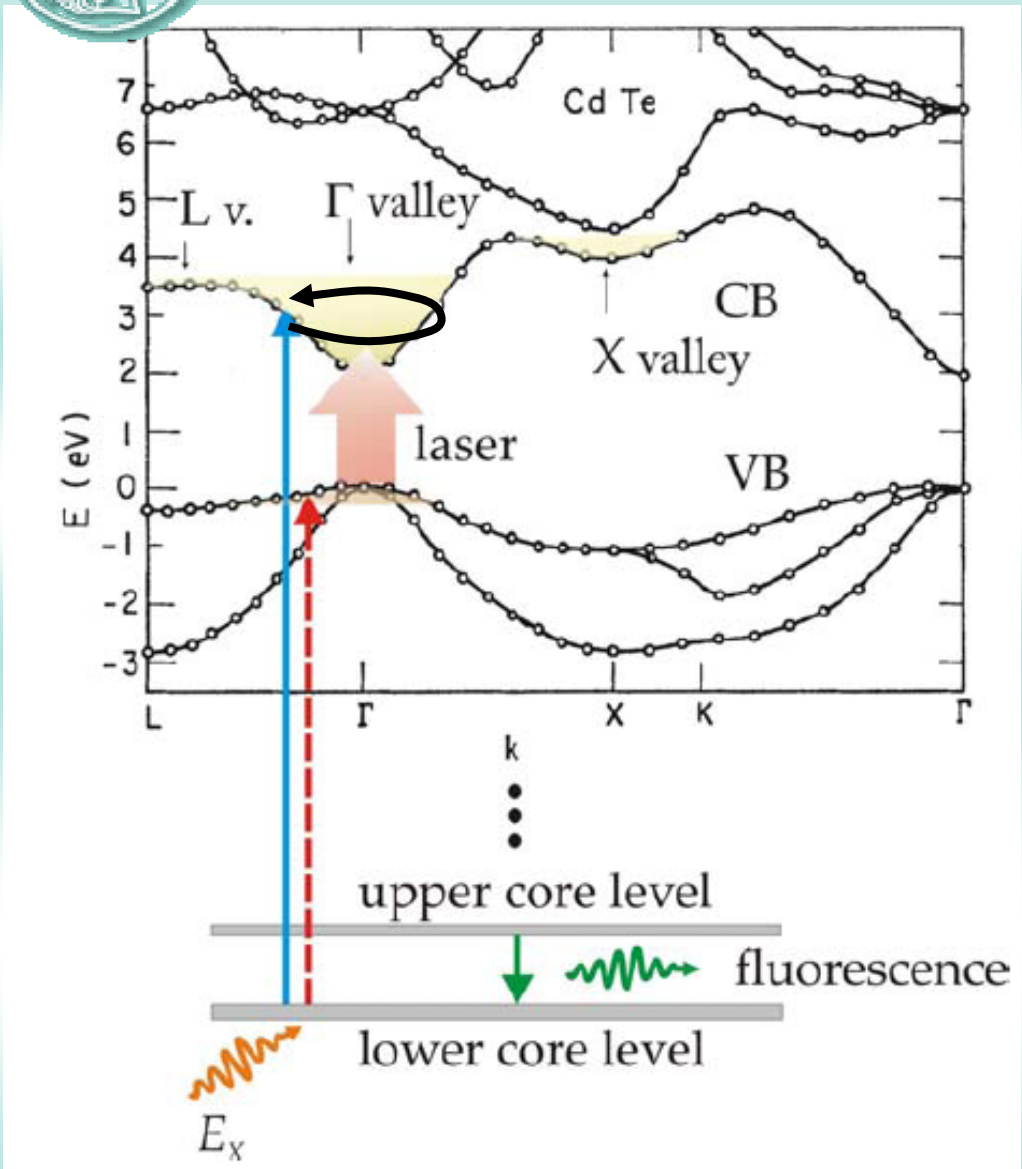


➢ *Retrieve spatial orientation of a large molecule by detecting few "reporter" fragments*

- *First experiments hindered by the sample delivery issues*

- *Better targets, higher repetition rates needed!*

Ulrafast dynamics in solids



Simultaneous measurements of diffraction, fluorescence and Auger/photo-electron spectra as a function of the delay

Faton Krasniqi et al,
XPP July 2011

Current status and perspectives

- ***CAMP:*** *stays at LCLS for 2012, then goes back to Hamburg*
- ***LAMP: LCLS-ASG Michigan Project*** *dedicated* ***CAMP replacement*** *at LCLS*

BMBF funding for CAMP modification, focusing optics, etc.

Coordination: TU Berlin (Th. Möller and S. Eisebitt)

Technische Universität Berlin

In collaboration with Max Planck ASG, CFEL Coherent Imaging Division, University of Konstanz

Planned new features

- ***Focusing optics: KB mirrors***

  Goal: ~ 1 μm focus (group of Th. Möller, TU Berlin)

- ***Wave front diagnostic*** CFEL coherent imaging group

- ***New targets (e.g., dedicated cluster and nano-droplet jets)*** (group of Th. Möller, TU Berlin)

- ***Magnetic sample environment*** (group of S. Eisebitt, TU Berlin)

  (including pump-probe arrangement) Univ. of Konstanz

- ***Soft X-ray polarizer*** (group of S. Eisebitt, TU Berlin)

Possible experiments

- *AMO:*
  - *Correlated (time-resolved) ion/electron/photon spectroscopy of atomic and molecular fragmentation*
  - *Photoelectron diffraction from aligned molecules*
- *Clusters: time-resolved imaging, ion and electron spectroscopy*
- *Femtochemistry: pump-probe experiments in a liquid phase*
- *Coherent diffractive imaging of fixed targets, nanocrystals, single bioparticles, aerosols etc; radiation damage studies*
- *Solid state physics: imaging of ultrafast magnetic phenomena, dynamics in laser-excited semiconductors, …*

Bring your suggestions!

CFEL-ASG Multi Purpose: CAMP collaboration

Led by Max Planck Advanced Study Group at CFEL
Sascha Epp, Benjamin Erk, Lutz Foucar, Andre Hömke, Faton Krasniqi, Daniel Rolles, Benedikt Rudek, Artem Rudenko, Carlo Schmidt (*MPG-ASG Hamburg*)
Christian Kaiser, Kai-Uwe Kühnel, Robert Moshammer, Claus-Dieter Schröter, Joachim Ullrich *(MPI für Kernphysik, Heidelberg)*
Andreas Hartmann, Robert Hartmann, Günter Hauser, Peter Holl, Nils Kimmel, Daniel Pietschner, Christian Reich, Lothar Strüder, Georg Weidenspointer *(MPI Halbleiterlabor / MPI für extraterrestrische Physic / PN Sensor GmbH, München)*
Lukas Lomb, Robert Shoeman, Ilme Schlichting (*MPl für medizinische Forschung, Heidelberg)*
Frank Filsinger *(Fritz-Haber-Institut, Berlin),* Hubert Gorke *(Forschungszentrum Julich)*
Ivan Rajcovic, Simone Techert, (*MPI für biophysikalische Chemie, Göttingen)*
Andrew Aquila, Nicola Coppola, Tjark Delmas, Heinz Graafsma, Lars Gumprecht, Helmut Hirsemann, Lotte Holmegard, Jochen Küpper, Daniel DePonte, Stephan Stern, Joachim Schulz, Sebastian Trippel, Cornelia Wunderer, Henry Chapman group, (*CFEL / DESY, Hamburg*)
Marcus Adolph, Tais Gorkhover, Thomas Möller, Daniela Rupp (*TU Berlin*)
Christoph Bostedt, John Bozek, Ryan Coffee, Jacek Krzywinski, Marc Messerschmidt, Sebastian Schorb, Mike Bogan, Christina Hampton, Ray Sierra, Dmitry Starodub, ShinIchi Wada (*SLAC*)
Axel Hundertmark, Arnaud Rouzee, Marc Vrakking *(AMOLF, Amsterdam / MBI Berlin)*
Jan Thogersen, Jochen Maurer, Henrik Stapelfeldt *(Arhus University)*
Per Johnson *(Lund University),* Matthias Frank *(LLNL),* Janos Hajdu group *(Uppsala University)*
Kiyoshi Ueda *(Tohoku University), Kyonobu Nagaya (Kyoto University),* Nora Berrah *(Western Michigan University),* Marc Simon, Loic Journel, Tatiana Machenko *(UPMC Paris)*