

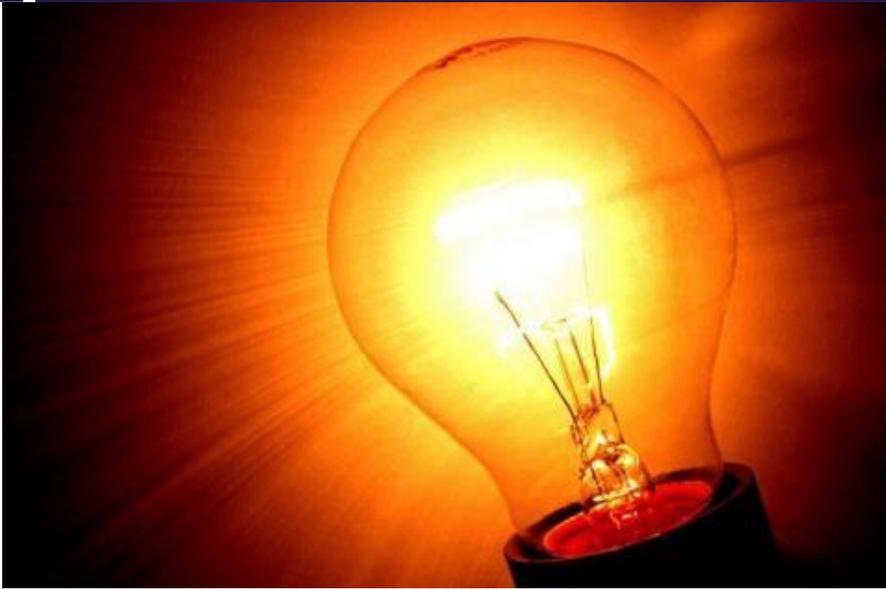


European XFEL

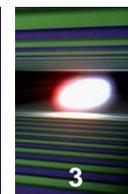
A unique (x-ray) photon source

EuroForum School on Instrumentation 2013, CERN, May 27-31

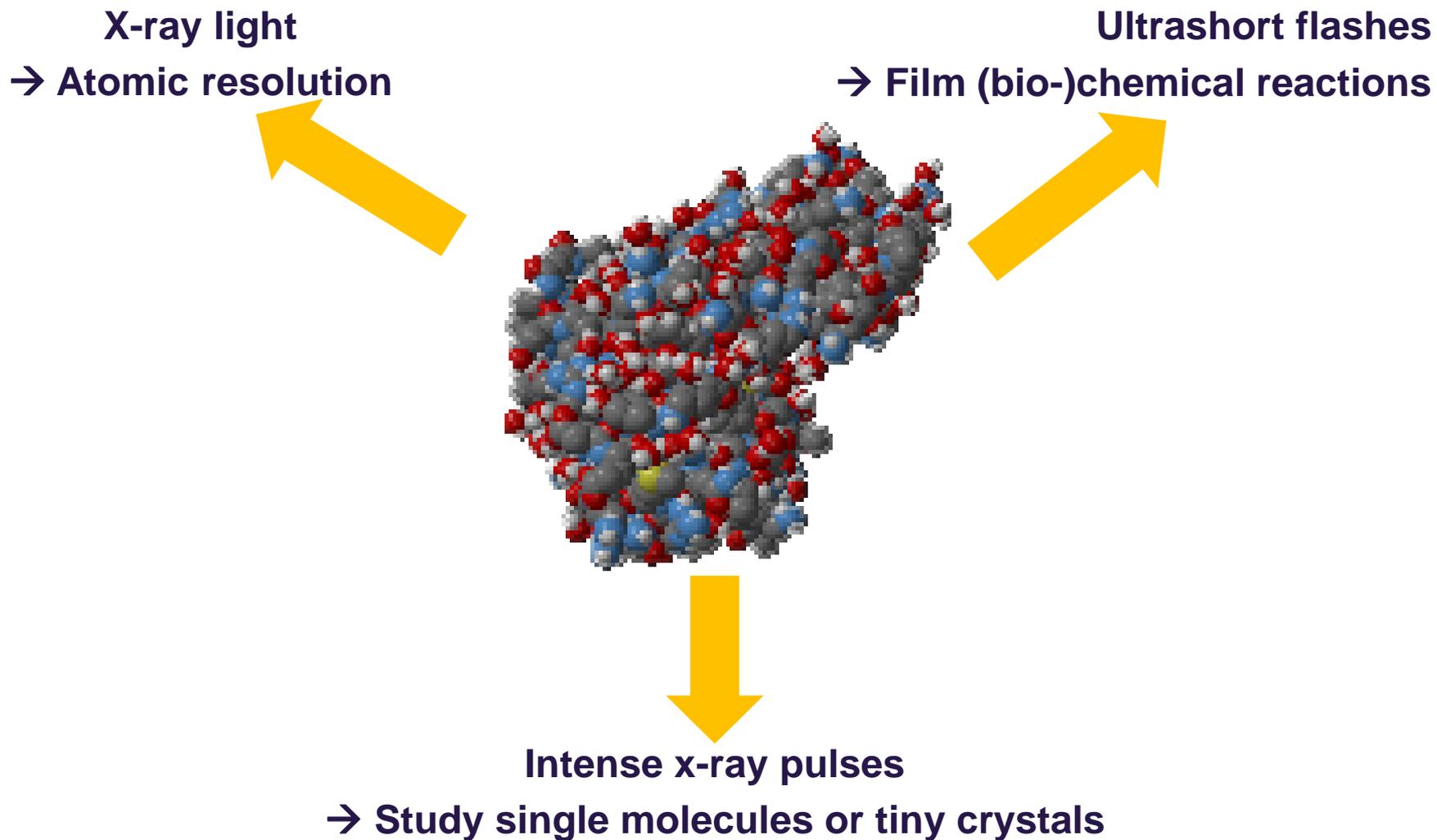
[thomas.tschentscher@xfel.eu](mailto:thomas.tschentscher@xfel.eu)



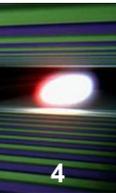
# Why x-ray free-electron lasers ?



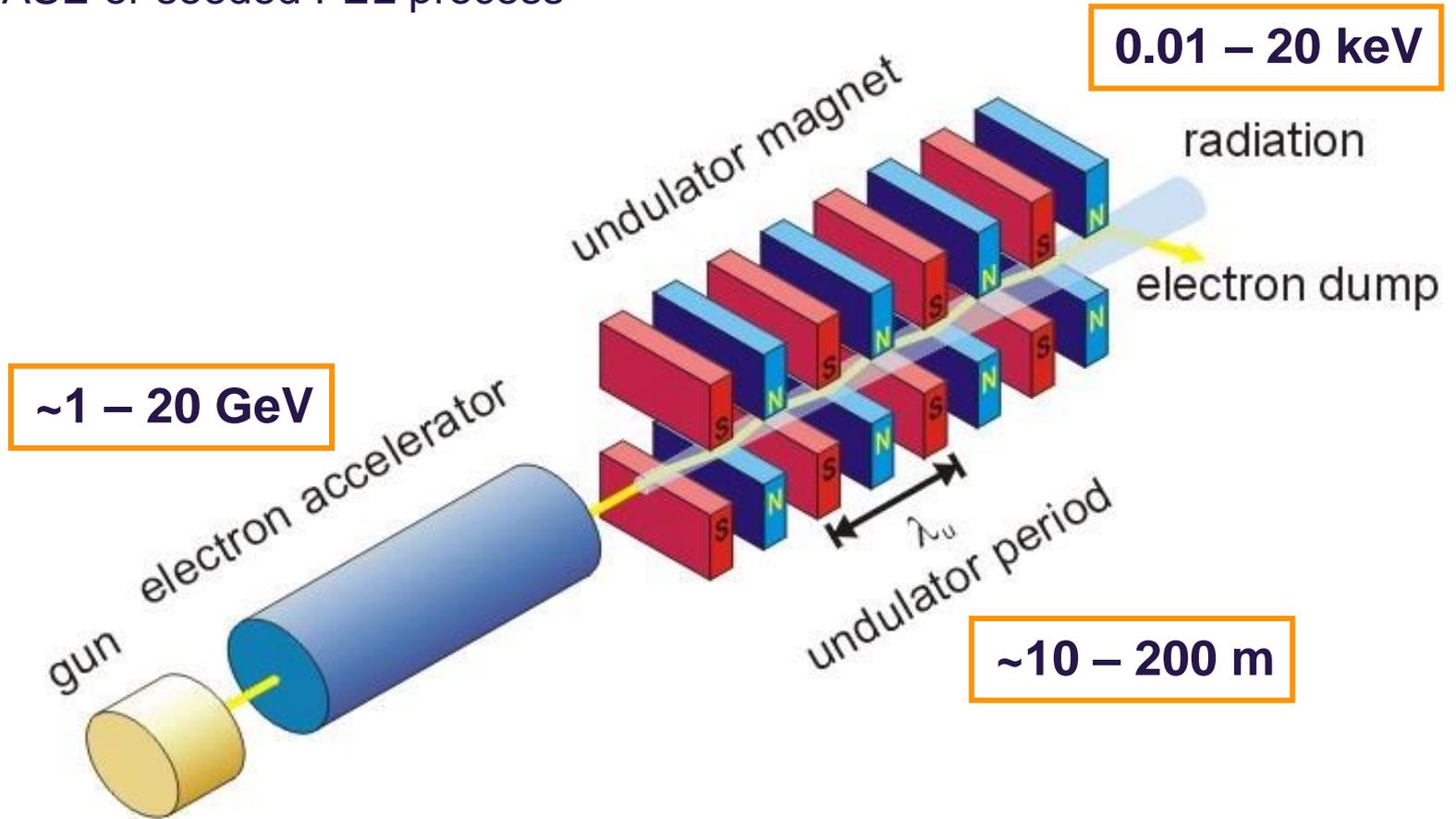
3



# An x-ray free-electron laser



- low emittance high energy electron accelerator
- SASE or seeded FEL process

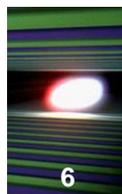


# The electron accelerator

- Low electron beam emittances  $< 10^{-6}$  m
- High peak currents  $\sim 5$  kA



# The FEL device

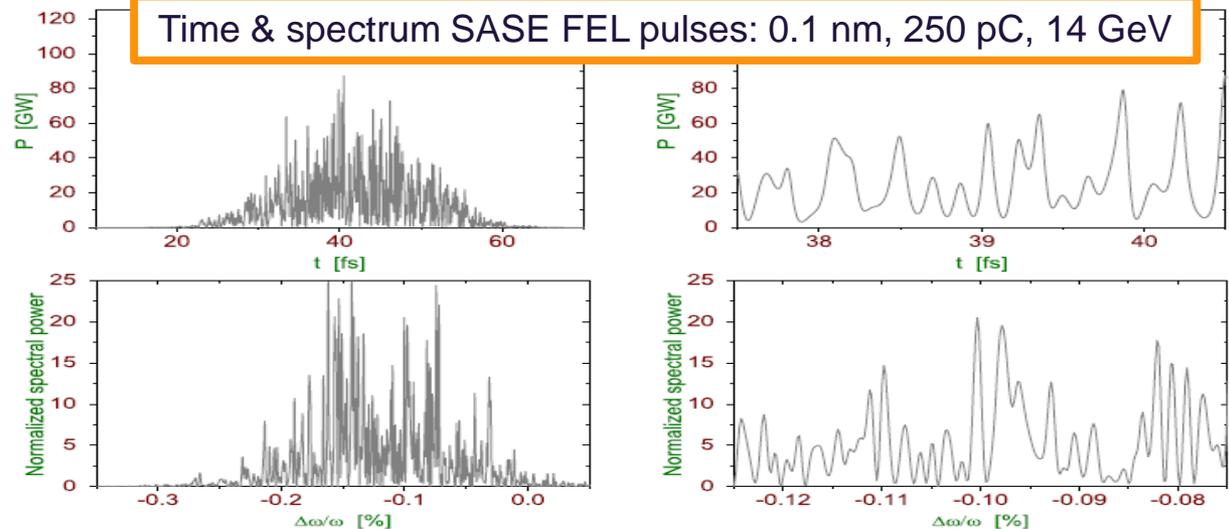
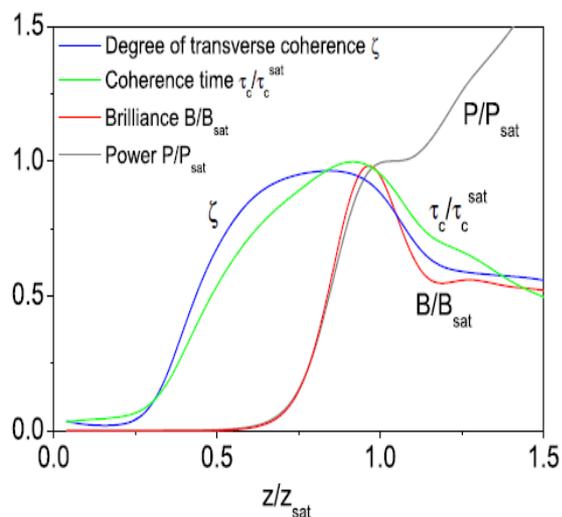


- Self-amplified spontaneous emission in single pass
- 1000s of periods (few cm) to reach saturation
- $\mu\text{m}$  precision over 5 m length;  $>200$  m total length

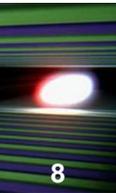


## European XFEL beam parameters

Parameter	Unit	
Photon energy	keV	0.27 - 24
Pulse energies (@saturation)	$\mu\text{J}$	0.2 - ~4000
Pulse duration	fs	2 - 107
Power density	$\text{W}/\text{cm}^2$	$\sim 10^{13} - 10^{18}$
Spectral bandwidth		$\sim 10^{-3}$
Source size	$\mu\text{m}$	30 - 60 (100)
Coherence degree		0.4 - 0.96

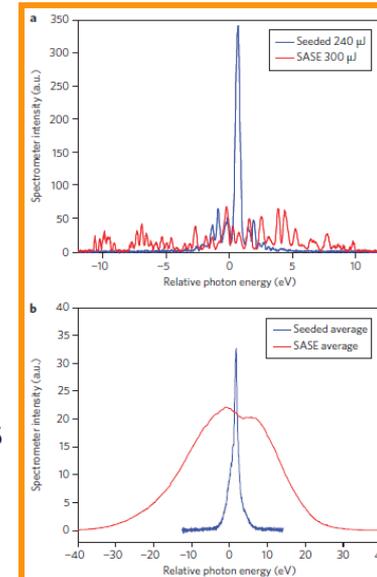
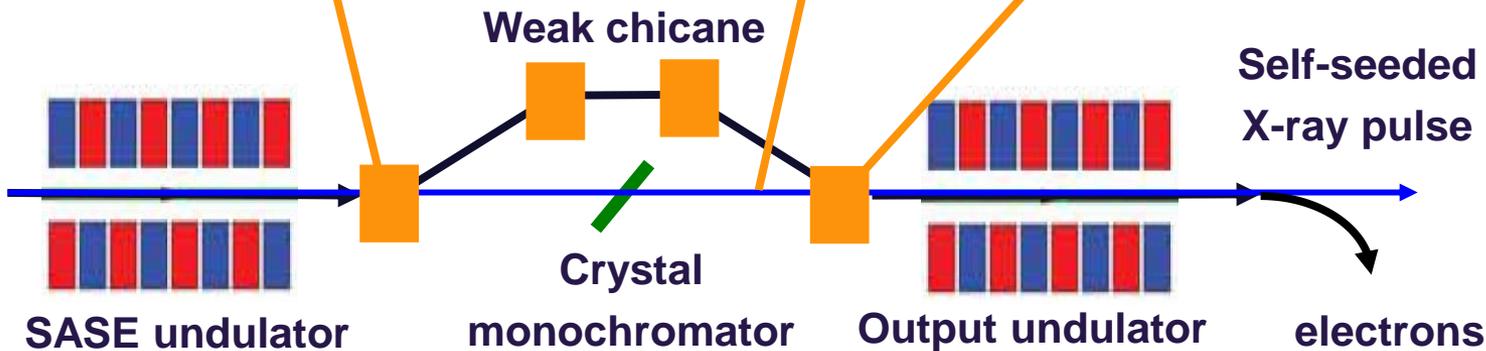
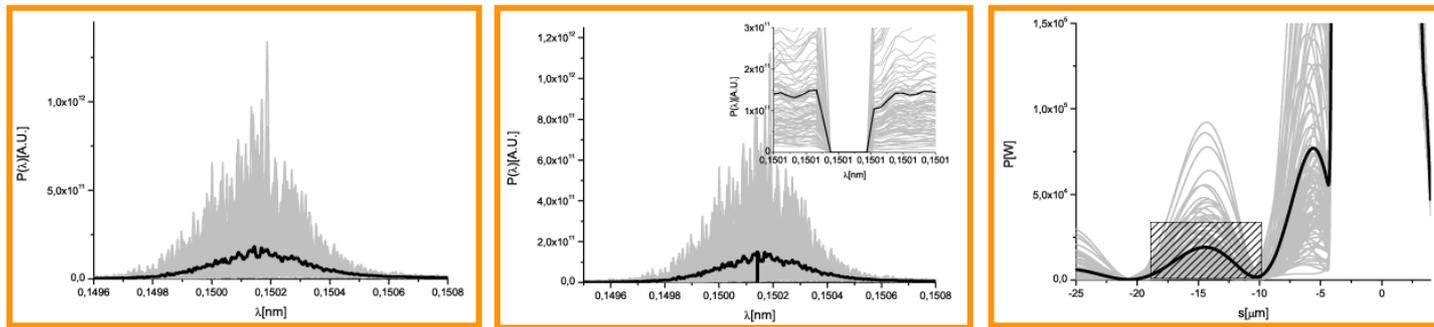


# Towards fully coherent radiation: Self seeding



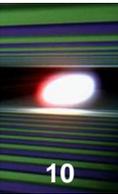
In absence of external coherent sources for seeding the FEL process

- Use forward scattered part from Bragg diffraction (Geloni et al., JMO 58, 1391 (2011))
- Experimental proof at LCLS successful (Amann et al., Nature Phot. 6, 693 (2012))



# Soft/Hard X-ray FELs worldwide





## Investigation of dynamic processes

- ultrafast, pico- & femtosecond phenomena govern many physical, chemical and biological processes

## Investigation of nano-scale, disordered, non-crystalline matter

- geometrical structures of particles and bio-systems
- properties of matter at un-common length scales

## Investigation of highly excited matter

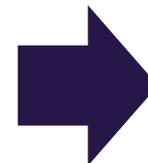
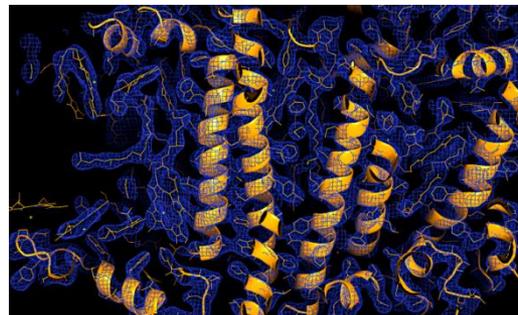
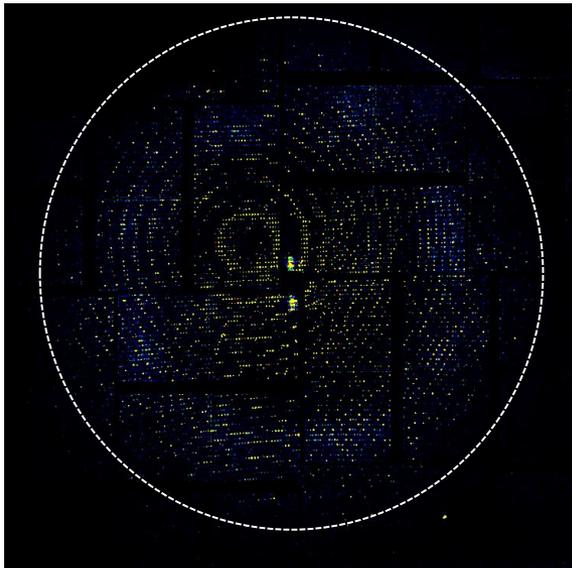
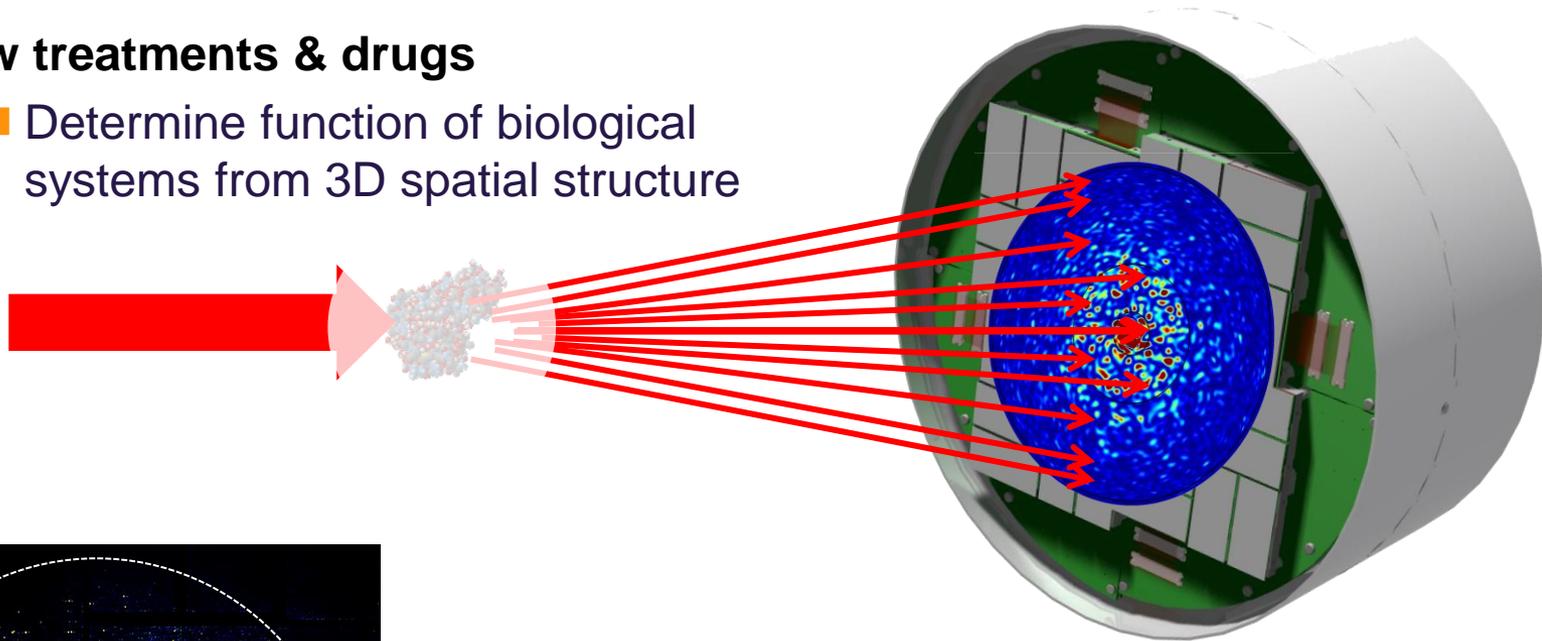
- x-ray excitation and non-linear phenomena
- measurement of extremely short-living states

**Often combination of these techniques are required**

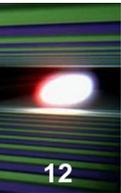
**⇒ X-Ray Free-Electron Laser sources open new scientific possibilities**

## New treatments & drugs

- Determine function of biological systems from 3D spatial structure



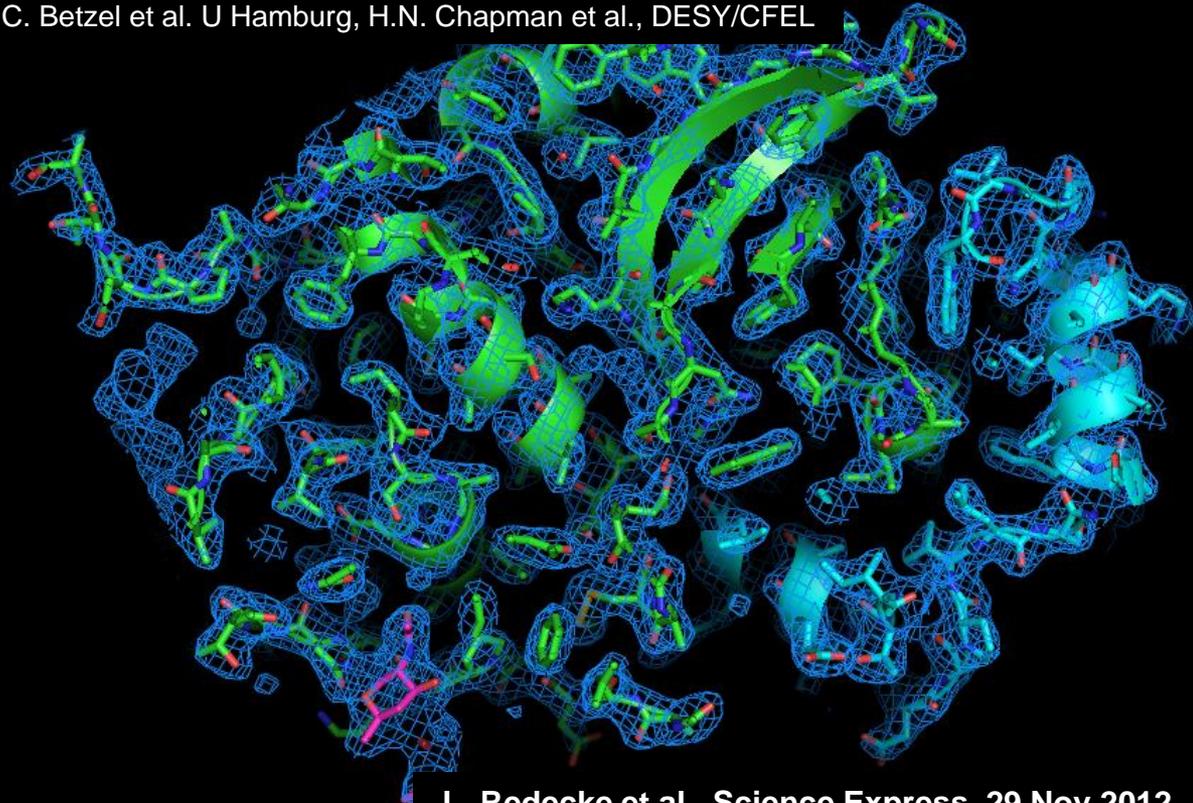
# Solve unknown bio-structures (nano-crystall.)



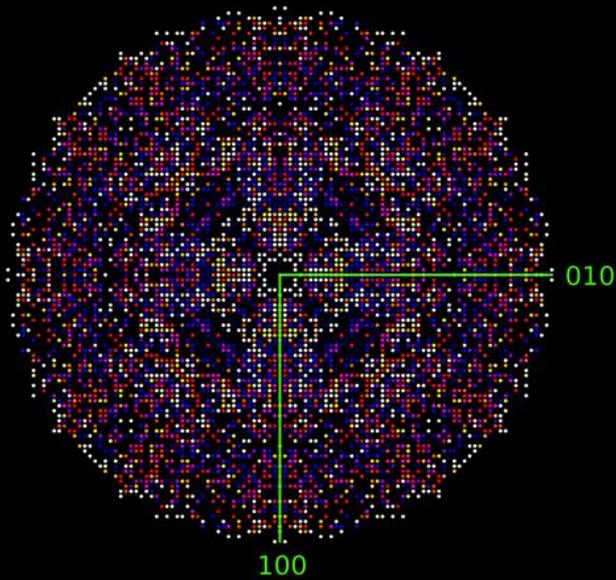
- Yet unknown Cathepsin B structure solved to 2.1 Å
- 3,953,201 frames/8 hrs/357,555 “crystal hits”/156,565 ind.

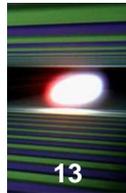
Data courtesy:

R. Koopman et al., U Tübingen, L. Redecke et al. U Lübeck,  
C. Betzel et al. U Hamburg, H.N. Chapman et al., DESY/CFEL



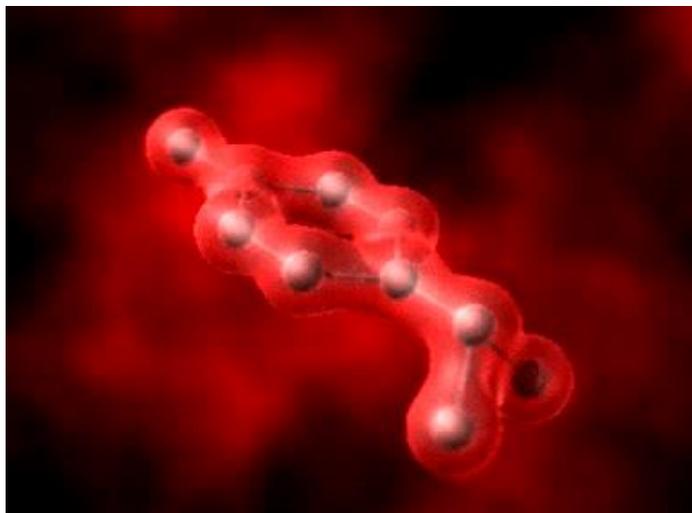
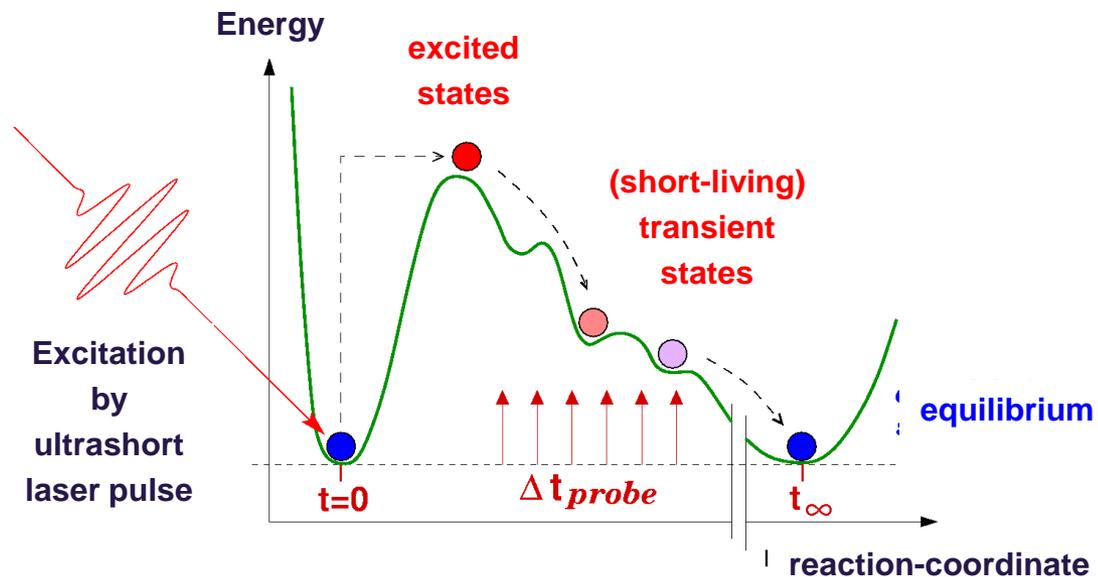
L. Redecke et al., Science Express, 29 Nov 2012



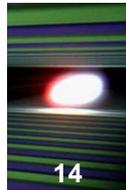


## Better chemistry

- ,Look‘ and understand how chemistry works on the atomic level

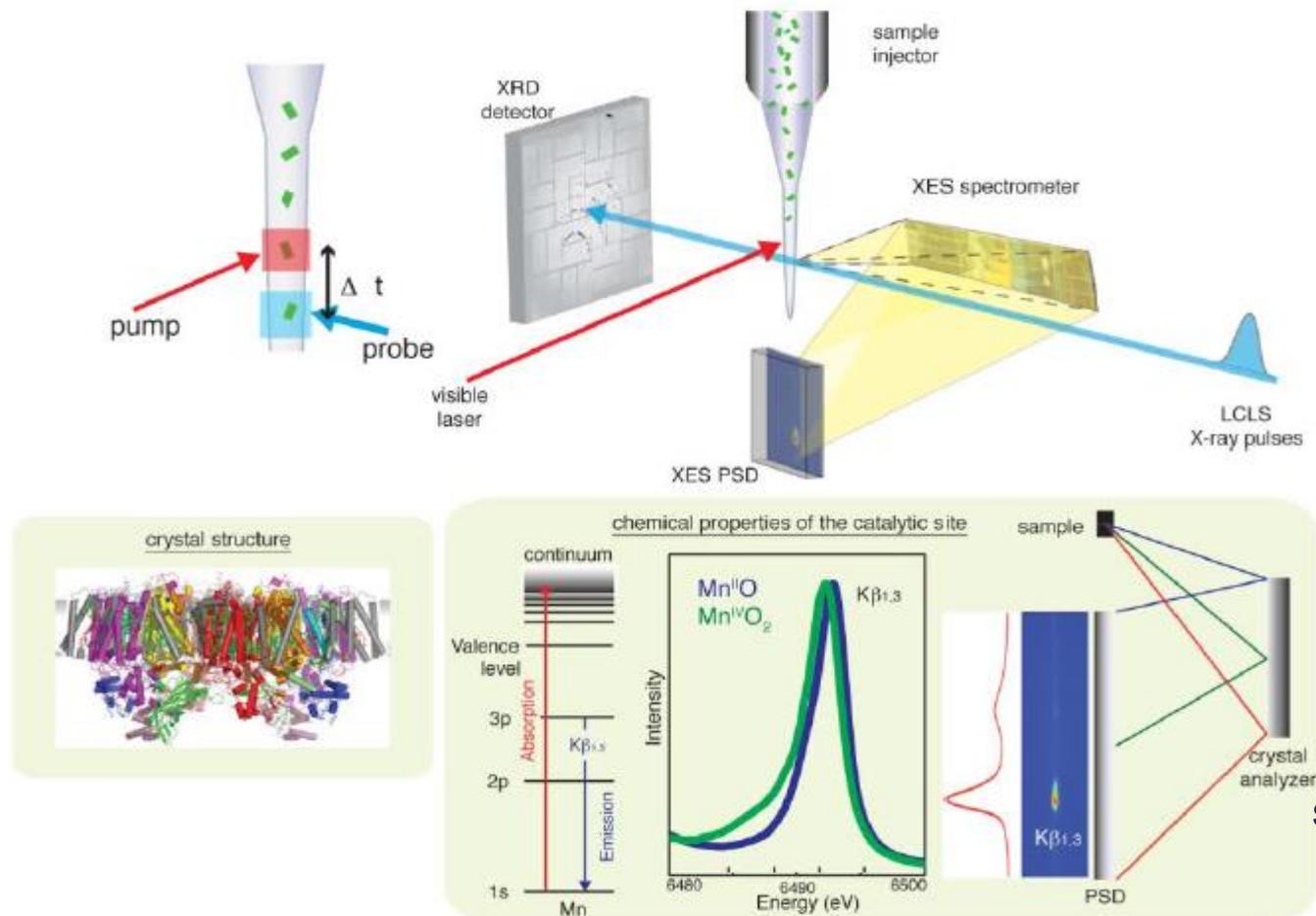


# Solve photo-system II secrets



## Time-resolved scattering & spectroscopy

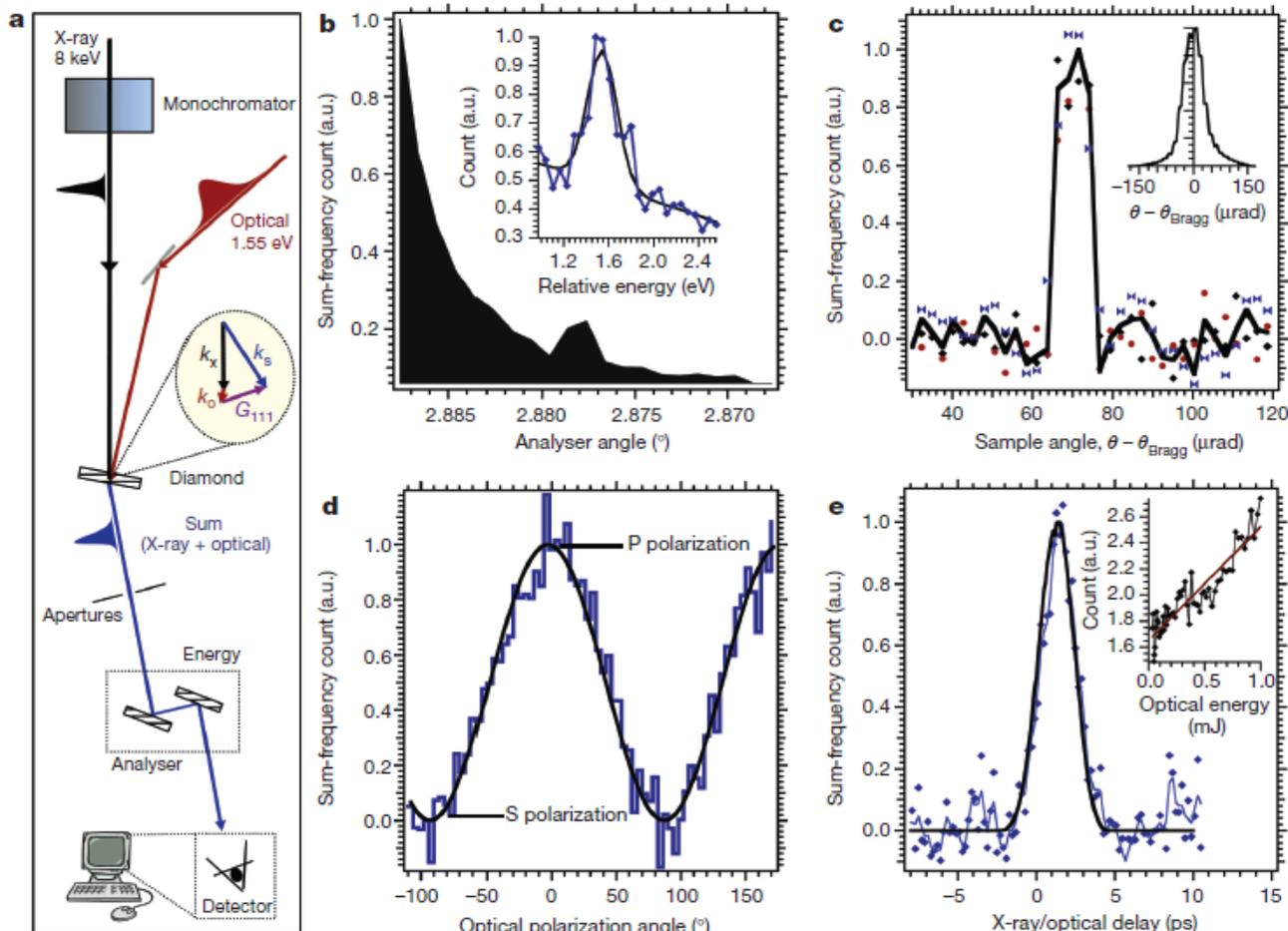
- Determine excited state structure & confirm undamaged  $Mn_4CaO_5$  state



J. Kern et al.,  
Science Express,  
14 Feb 2013

## X-ray and optical wave mixing

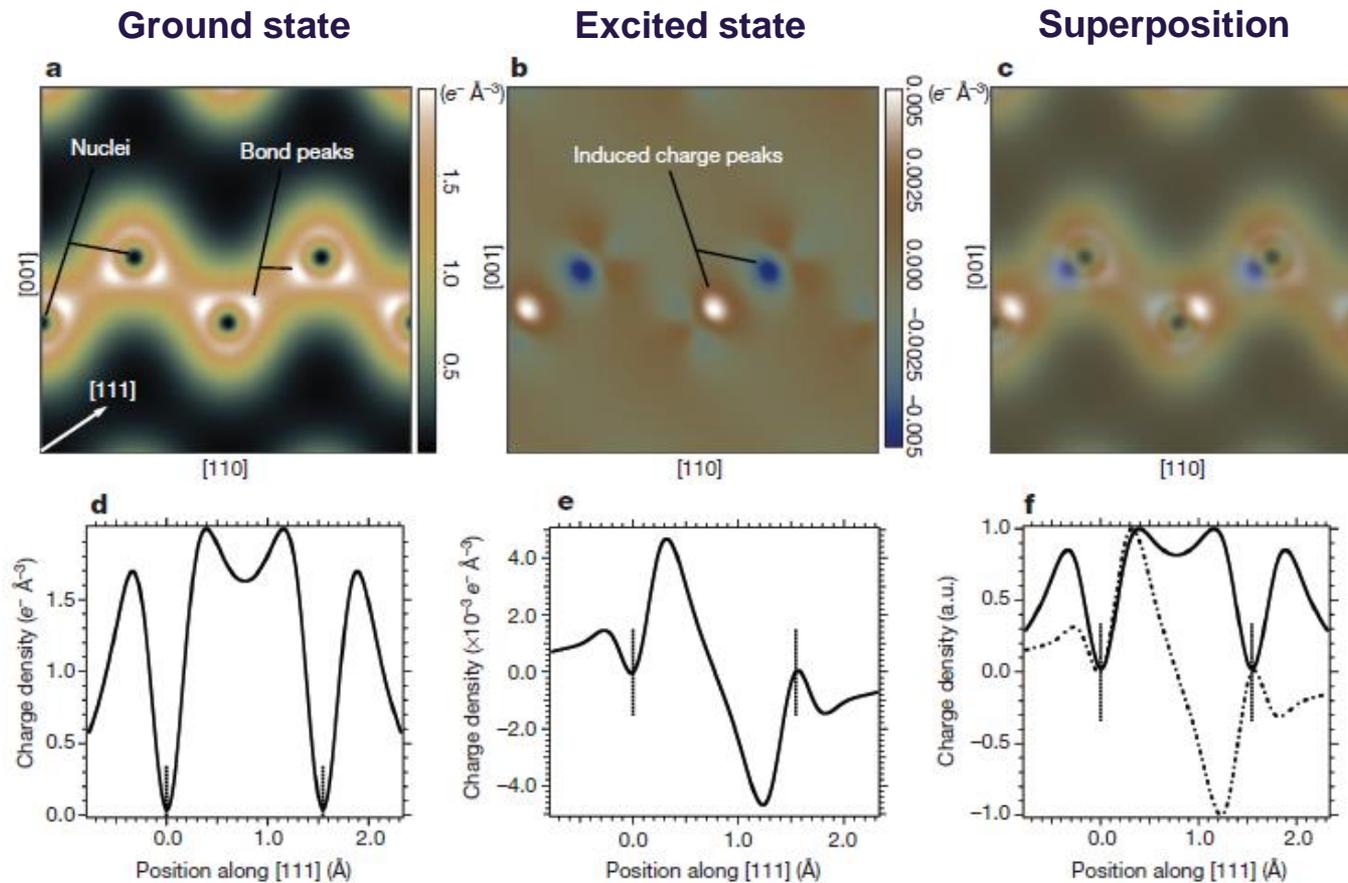
- Observe non-linear x-ray processes



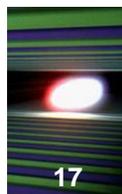
T.E. Glover et al.,  
Nature **488**, 603  
(2012)

## Valence electron system

- Measure optically induced charges and associated microscopic fields

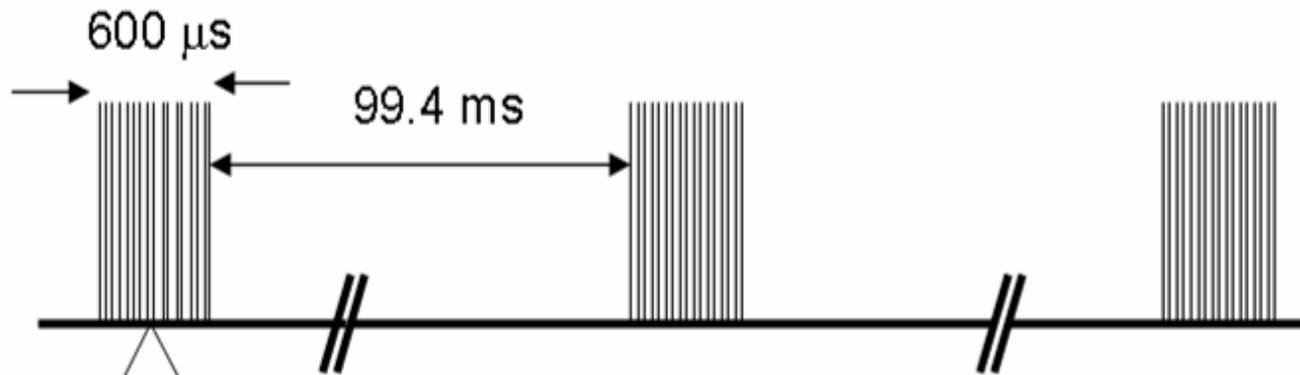


T.E. Glover et al.,  
Nature **488**, 603  
(2012)



## Time delivery pattern

- Pulsed radio-frequency
- Trains of e<sup>-</sup>/x-ray pulses
- Up to 27.000 e<sup>-</sup> bunches/sec



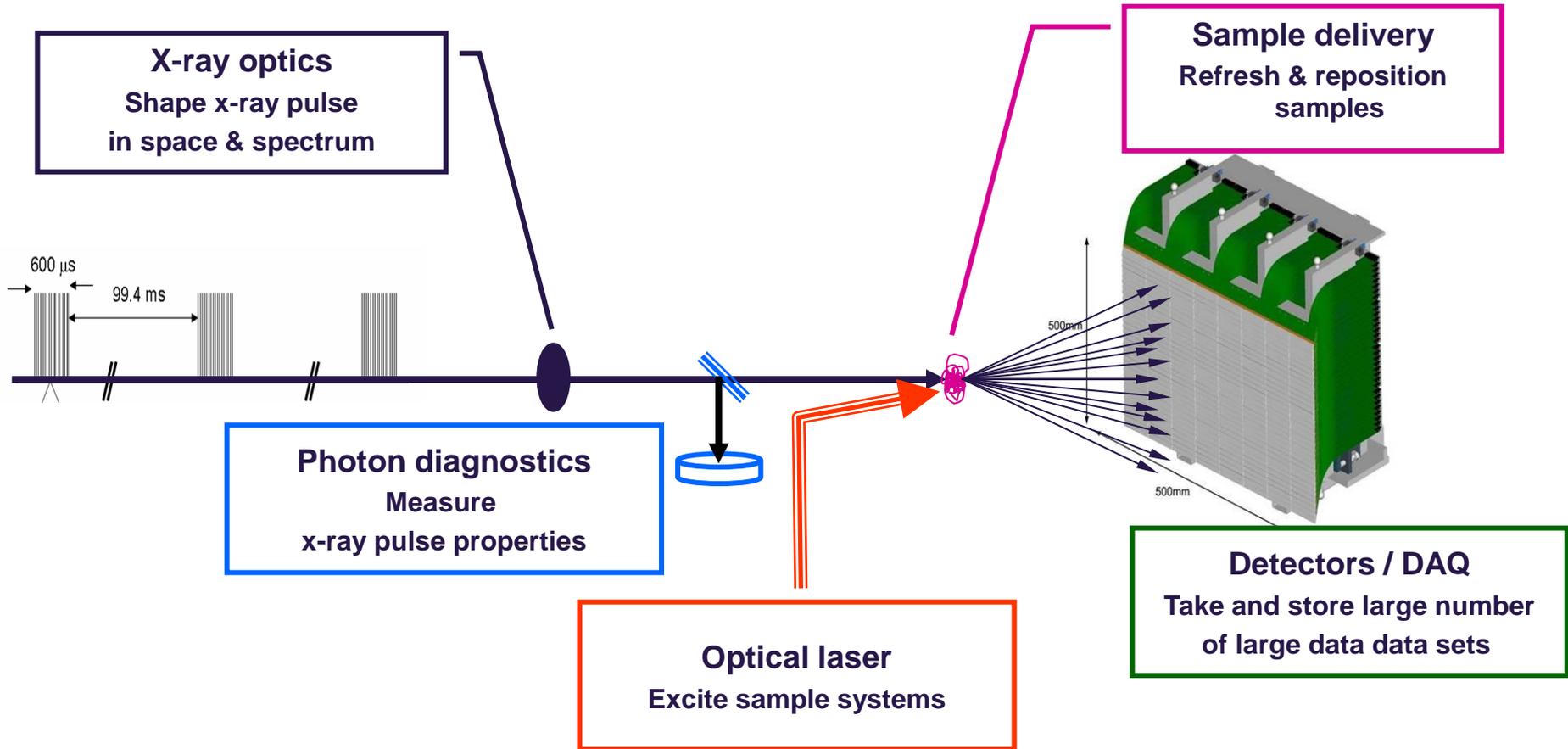
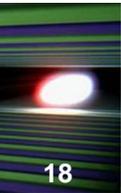
### Advantages

- High average brilliance (flux)
- Feedback for time & space stabilization
- Dedicated pulse delivery defined by needs of science program

### Disadvantages

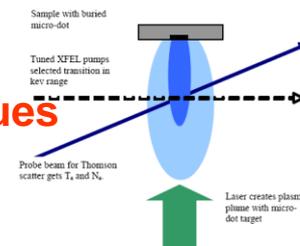
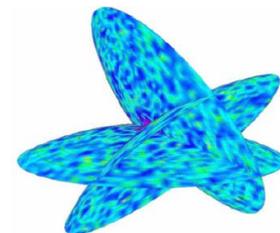
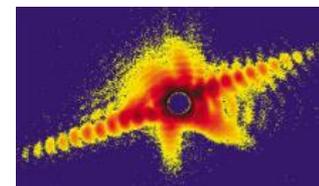
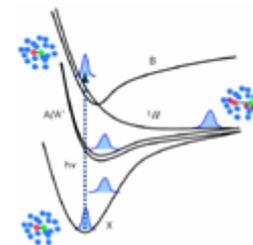
- Very high repetition rate within train
- Technology challenge for energy transport, sample replacement, data transfer
- Cycling of components

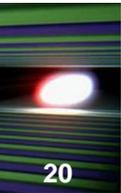
# X-ray delivery and instrumentation @ 4.5 Mz



## 4 science instruments for hard x-ray FEL radiation

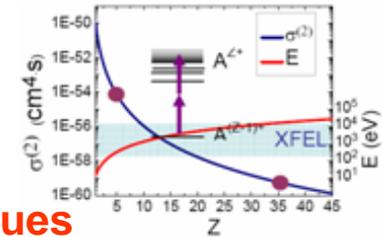
- Femtosecond X-ray Experiments (FXE)
  - Ultrafast dynamics of liquids and solid matter
  - Combination of spectroscopic & scattering techniques
- Materials Imaging & Dynamics (MID)
  - Coherent diffraction imaging from nano-structured samples
  - X-ray photon correlation spectroscopy of nanoscale dynamics
- Single Particle & Bio-imaging (SPB)
  - Coherent diffraction imaging from single particles
- High Energy Density Physics (HED)
  - Ultrafast dynamics of highly excited matter (Solids, WDM, HDM)
  - Combinations of scattering, diffraction & spectroscopy techniques





## 2 science instruments for soft x-ray FEL radiation

- Small Quantum Systems (SQS)
  - ➔ Ultrafast dynamics of atoms, ions & clusters
  - ➔ Combination of spectroscopic & coherent scattering techniques
  
- Spectroscopy & Coherent Scattering (SCS)
  - ➔ Ultrafast dynamics of complex solids
  - ➔ Combination of high resolution inelastic spectroscopy & coherent scattering techniques



## Detector development

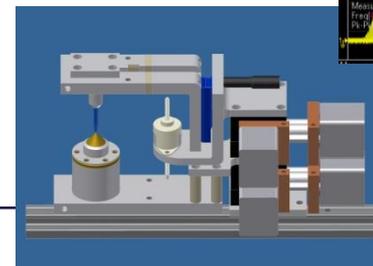
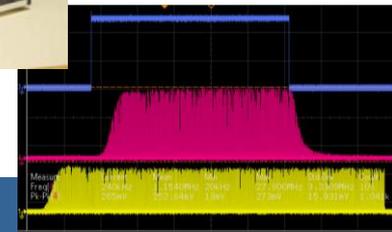
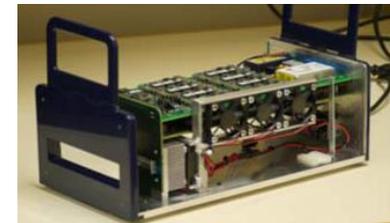
- High rep rate, efficient, high dyn. range

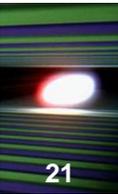
## Optical laser and synchronisation

- High rep rate, synchronized, pulse-on-demand

## Sample delivery methods

- High rep rate, precise





**X-ray FELs provide laser like, ultra-short, intense and coherent radiation from the XUV all way up to very hard x-rays.**



**This radiation opens new & unique opportunities for x-ray research in a broad range of applications. First breakthrough scientific applications show this capability.**



**The European XFEL as an international research infrastructure has started construction. Several challenging and beyond current state-of-the-art instrumentation developments are part of this effort.**



**Early experiments are scheduled for 2016.**