Status of the European XFEL & SASE 2 instruments

International Workshop Series on the Science and Instrumentation at the European XFEL: Femtosecond X-ray Experiments
Budapest, Dec 9-11, 2009

Thomas Tschentscher
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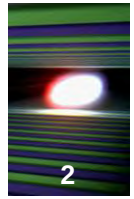
Outline



- **Status of the European XFEL**
  - The project
  - The international facility
  - The status & timeline
- **SASE 2 instruments**
  - SASE 2 source and beam transport
  - Femtosecond experiments
  - Selected instrumentation issues
- **Charge to this workshop**

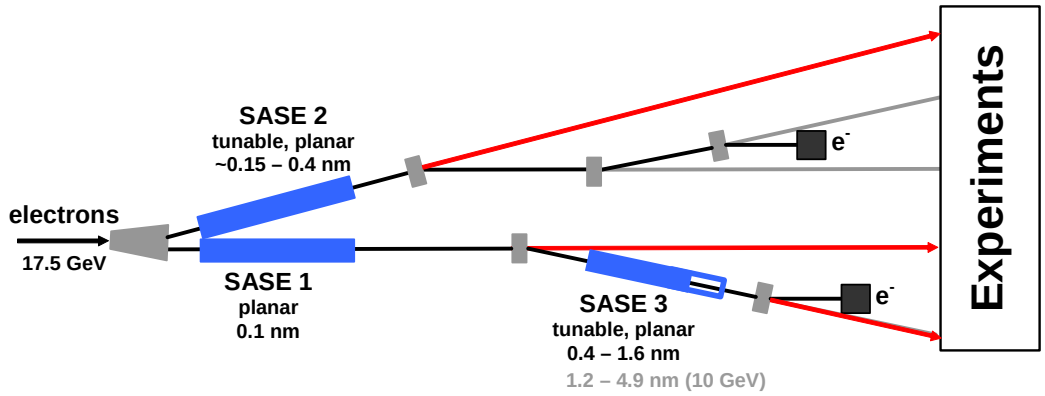
The European XFEL

Some specifications

- Photon energy 0.4–12.4 keV
- Pulse duration <100 fs
- Pulse energy few mJ
- super-conducting accelerator
- 10 Hz/4.5 MHz (27.000 b/s)
- 5 beamlines/10 instruments
  - ➔ **start version with 3 BLs and 6 instruments**
- various extensions possible
  - ➔ **seeding**
  - ➔ **more instruments**

First beam 2014

Start of user operation 2015



European XFEL: A facility with international partners

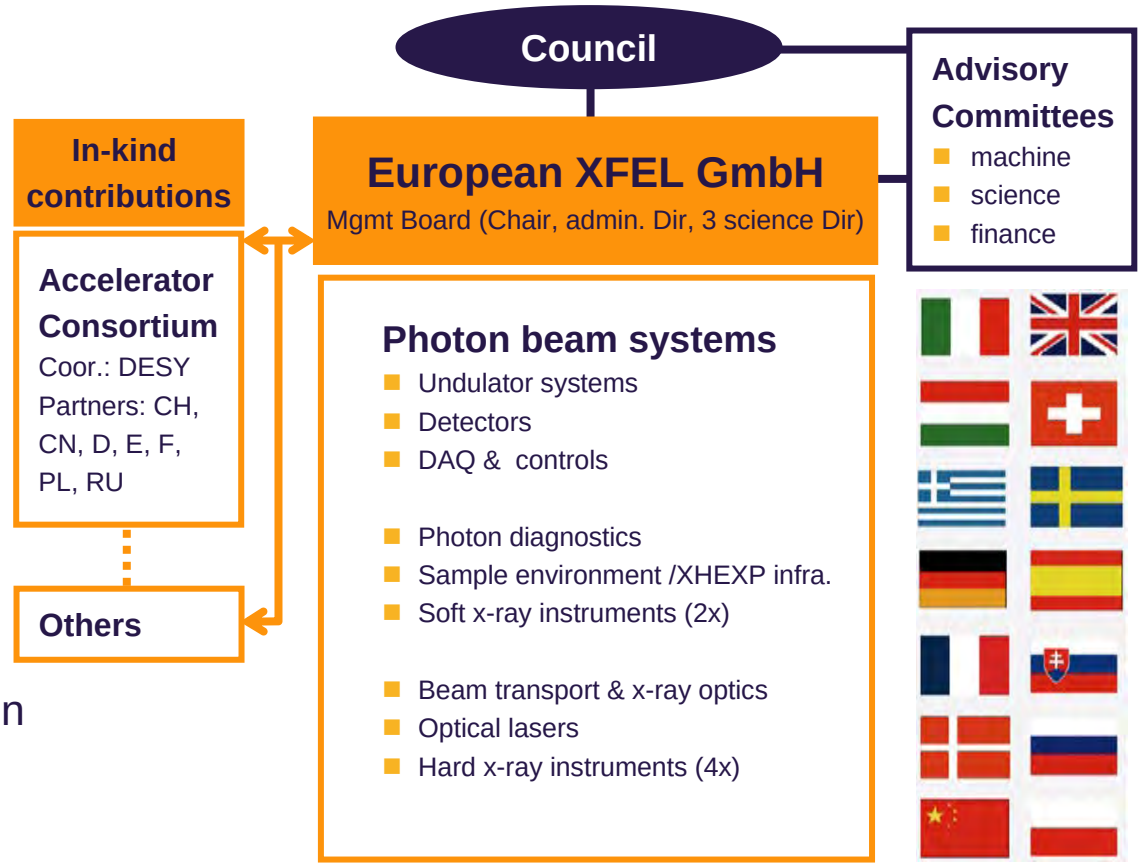
The European XFEL GmbH will be an institute based on German law with initially 10 shareholders representing the international partners. It shall

- construct
- commission
- operate

the European XFEL.

The German shareholder DESY takes special role in the overall process.

- preparation
- host lab
- accelerator construction & operation



The making of …

Hamburg, Jun 05, 2007:
Multilateral agreement & launch

Hamburg, Sep 22, 2008:
Founding documents completed

Berlin, Sep 23, 2009:
Initialling of founding documents

Hamburg, Sep 28, 2009:
Foundation of European XFEL GmbH

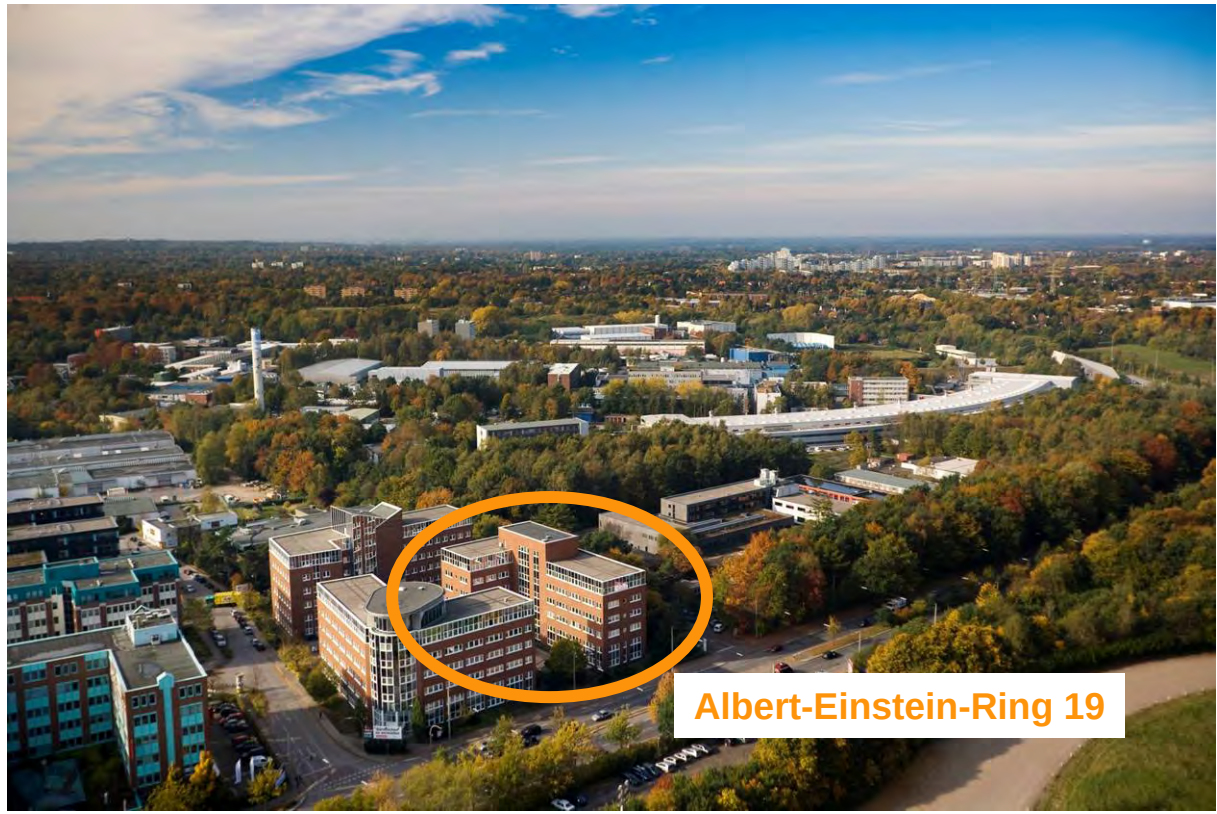
European XFEL

The international treaty

Where are we currently …

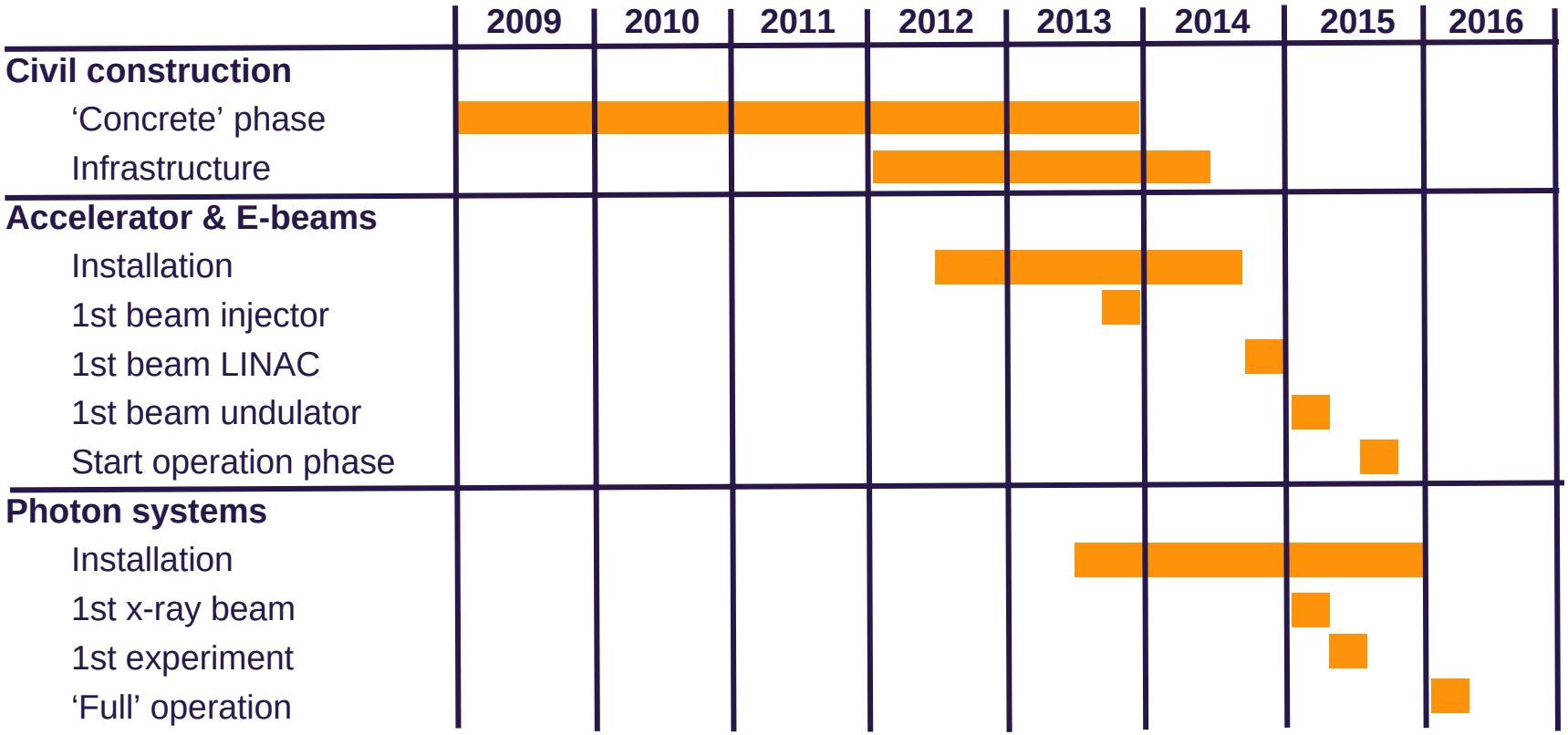
Recruitments & staff working for the project

- 47 staff (Dec 4, 2009)
- Administration
  - → **Human Resources**
  - → **Finance**
  - → **Procurement**
- Engineering
  - → **Undulators**
  - → **X-ray optics**
  - → **DAQ**
- Scientific staff
  - → **all WPs**
  - → **Instruments**
  - → **In-house research**
- Current openings
  - → **Leading scientists (HED, SPB, MID, SCS, opt. lasers)**
  - → **Scientist photon diagnostics**
  - → **Scientist magnetic measurement**



→ **www.xfel.eu**

Overall schedule of the European XFEL



European XFEL – Civil construction

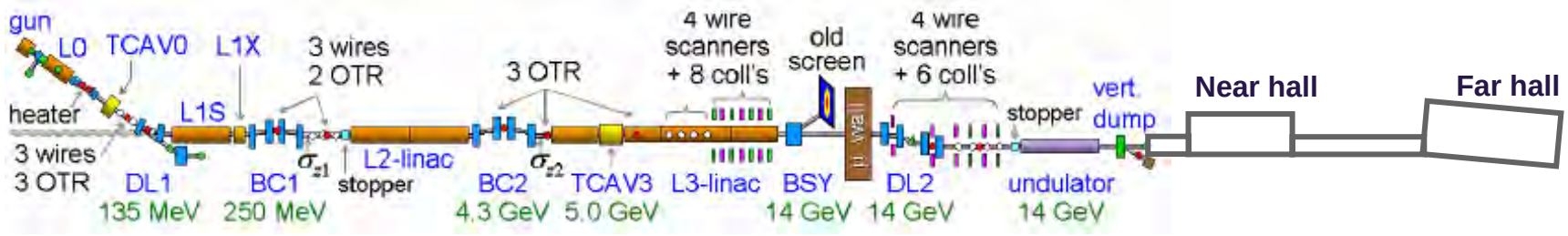
Switchyard, Hamburg-Osdorf

Experiments hall, Schenefeld

Jan 08, 2009 –
Start of civil construction

Injector-site, DESY, Hamburg-Bahrenfeld

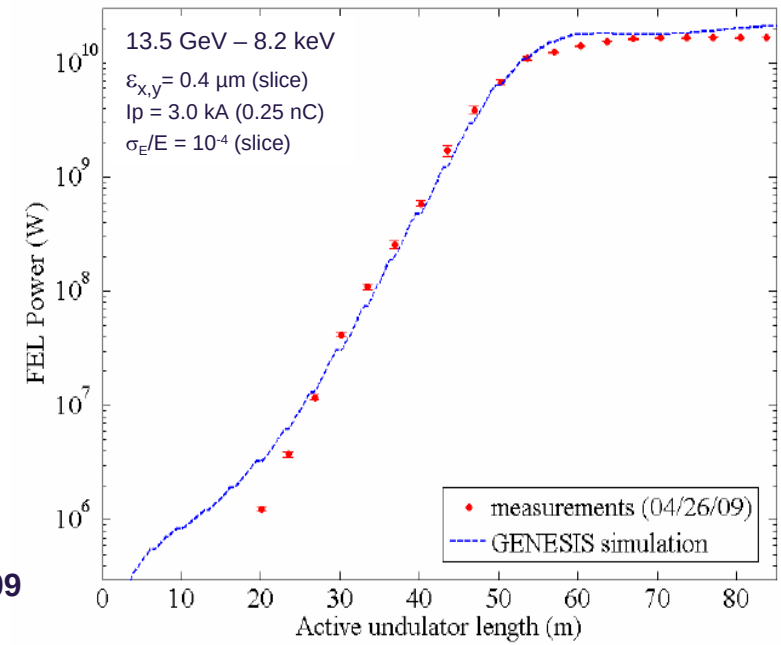
SASE FEL progress at LCLS @ SLAC



Extreme high performance at start

- gun emittance of ~0.4 µm preserved in Linac
- low bunch charges 0.02 – 0.25 nC
- pulse energy close to prediction
- pulse duration tunable: few fs – few 100 fs
- high reliability of x-ray beam delivery
- easy tunable (photon energy, pulse duration)

→ **further improvements to be expected**



P. Emma et al., Proc. PAC 2009

Extrapolation to European XFEL

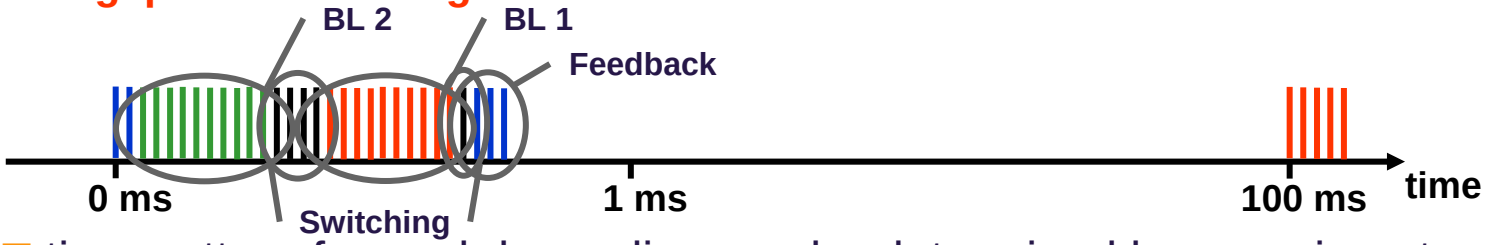
Accelerator performance

- similar emittance (< 0.5 µm) for small charge (0.1 – 0.25 nC)
- still acceptable emittance (~ 1 µm) for 'TDR' charge (0.5 – 1 nC)
- pulse duration in a similar range from few to 100s of femtoseconds
- additional advantage: bunch/pulse train operation
  - ➔ **large number of bunches**
  - ➔ **possibility to serve several beamlines quasi-simultaneous**
  - ➔ **stable operation using feedback schemes**

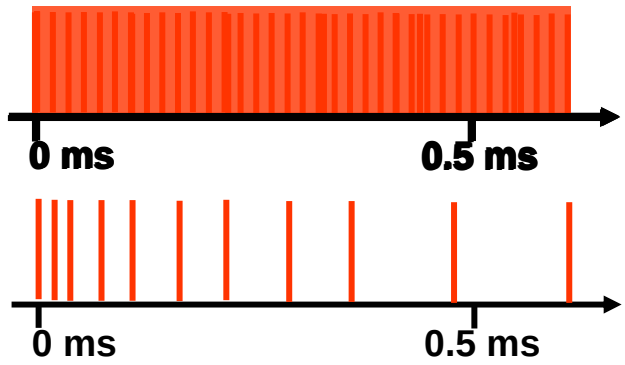
European XFEL time structure

Possible European XFEL delivery patterns

- operate sc-accelerator in almost steady-state mode
- division of bunchtrain into functional portions :
  - → **intra-train feedback → stabilization (x, t, E)**
  - → **two sub-trains going to two e⁻ beam lines**
  - → **gaps for switching between beam lines**



- time pattern for each beam line can be determined by experiment
  - → **single pulses**
  - → **medium repetition rate (10 – 100 kHz)**
  - → **high repetition rates (1 → 4.5 MHz)**
  - → **special fills**
    - logarithmic distribution
    - shorter distances (~700 ps – 220 ns)



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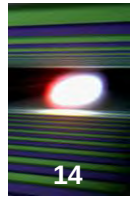
Undulator and FEL performance benefits from smaller emittance

- design undulator length will provide many operational options
  - → **low charge/short-pulses (<80 fs) ⇒ short gain length → opt. undulator length**
  - → **high-charge/long pulses (~80 fs) ⇒ design gain length → more pulse energy**
  - → **access to shorter wavelengths (~0.05 – 0.07 nm) is anticipated**
  - → **options to enhance FEL properties (pulse energy, polarization, two-colour, seeding, …) should be easy realizable**

Outline



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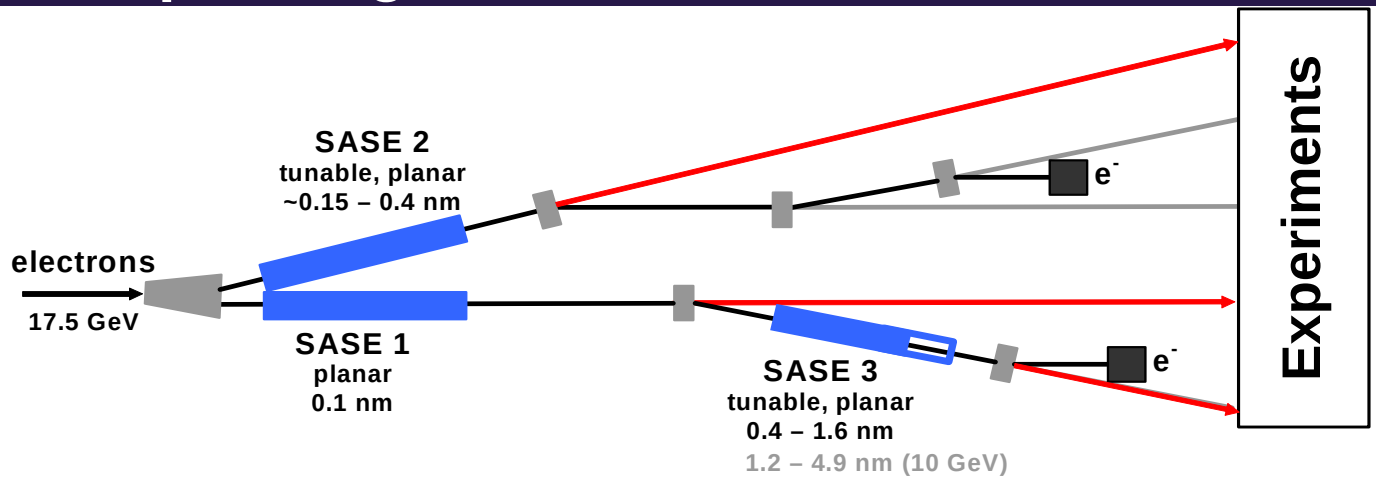
Startup configuration



Source	Instruments	Photon beam line characeristics
SASE 1	**SPB, MID**	FEL radiation ~12 keV; High coherence; Spont. radiation (3rd, 5th harm.)
SASE 2	**FDE, HED**	FEL radiation 3-12 keV; High time-resolution; Spont. radiation (3rd, 5th harm.)
SASE 3	**SQS, SCS**	FEL radiation 0.4 – 3 keV; High flux
		FEL radiation 0.4 – 3 keV; High resolution

SPB	Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules
MID	Materials Imaging & Dynamics
FDE	Femtosecond Diffraction Experiments
HED	High Energy Density Matter

SQS	Small Quantum Systems
SCS	Soft x-ray Coherent Scattering

X-ray beam properties

SASE 2 source properties

- SASE FEL (& spontaneous undulator) radiation
- horizontal polarization
- FEL line gap-tunable from 3.1 to 12.4 keV (closed gap configuration)
  - ➔ **higher photon energies O(20 keV) should be possible**
  - ➔ **3rd and 5th harmonic radiation at 1 and 0.1 % intensity**
  - ➔ **radiation safety issue for harmonics & spont. radiation**

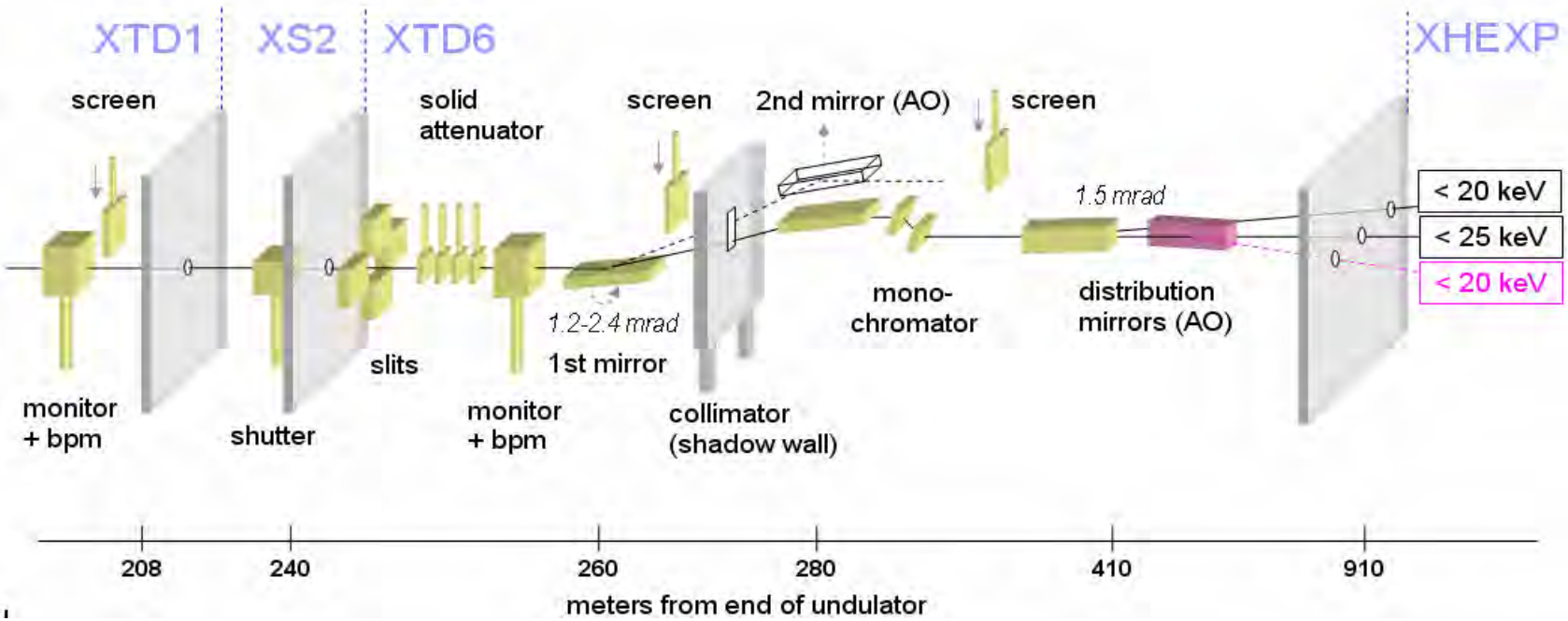
Parameter	Unit	Value	Value
Wavelength	nm	0.1	0.4
Photon energy	keV	12.4	3.1
Photons per pulse	nCb	10^{12}	1.6×10^{13}
Pulse energy	mJ	2	8
Bandwidth	%	0.08	0.18
Coherence time	fs	0.22	0.38
Pulse duration	fs	100	100
Divergence	µrad	0.9	3.4
Source size	µm	85	55

TDR 2006 values

X-ray beam transport

X-ray optics and beam transport has to deliver FEL beam from the source to the instrument while maintaining intensity, duration and wavefront

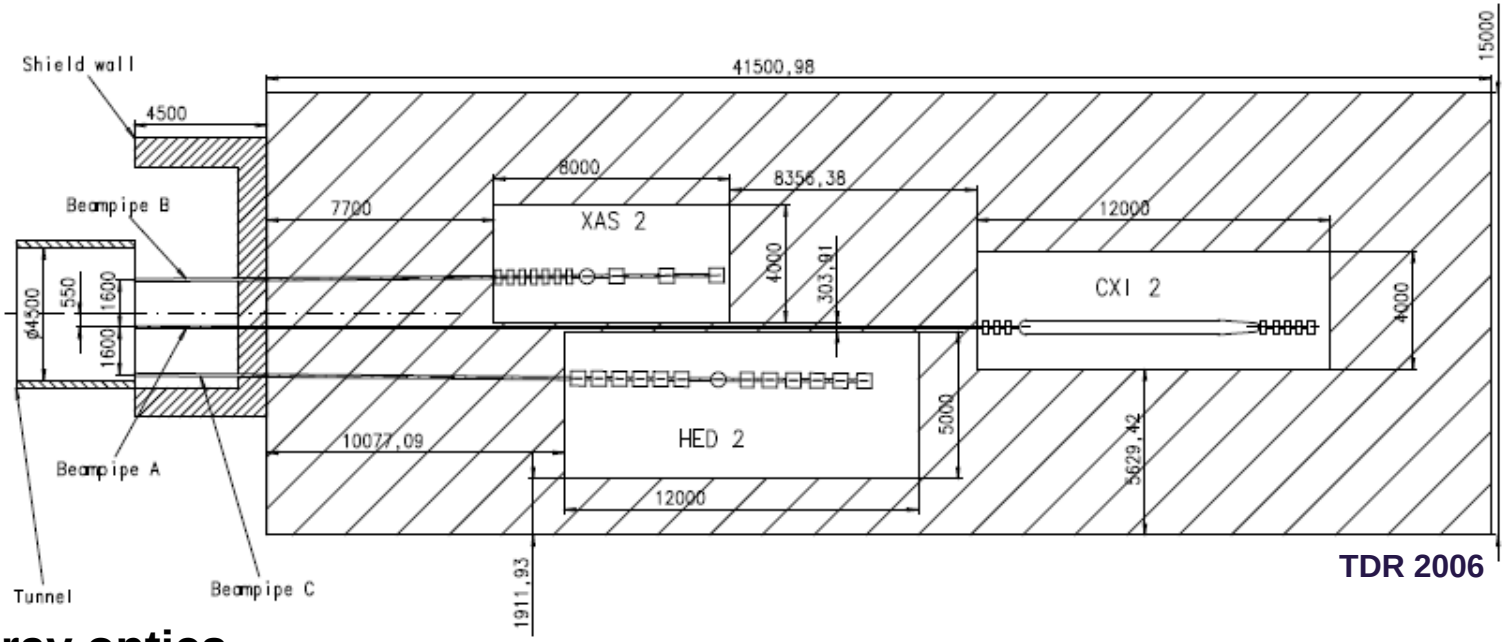
- steering & distribution
- monochromatization
- focusing
- suppression of high energy spontaneous/harmonic radiation



Experiments hall space SASE 2

Geometry

- 3 instruments on 15×42 m² real estate inside experiments hall
- optical laser and control hutches



X-ray optics

- beam transport includes mirrors and monochromator
- special optics: focussing, split&delay, etc. require definition

Femtosecond experiments

Startup scenario led to combination of hard x-ray FDE and XAS instruments, as proposed in TDR-2006, into a single instrument

Science areas

- ultrafast processes in gaseous, liquid, and solid samples
- applications to (bio-)chemistry, physics, materials science

X-ray techniques

- diffraction
- scattering
- spectroscopy
- pump-probe

Special feature : time-resolution O(10 fs)

- preservation of pulse duration
- synchronization of optical laser & x-ray pulses
- time domain diagnostics: arrival/delay, duration, t_o

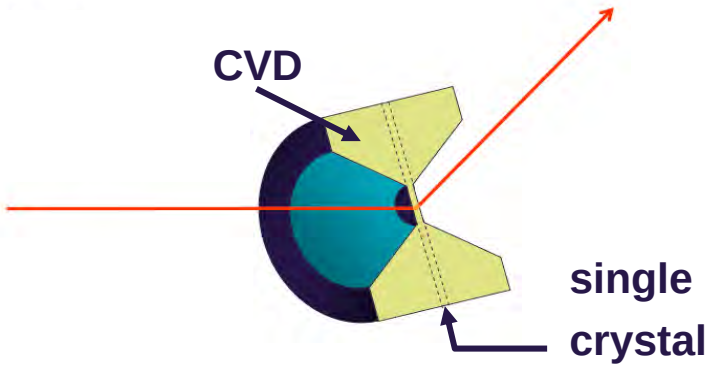
X-ray optics & beam transport

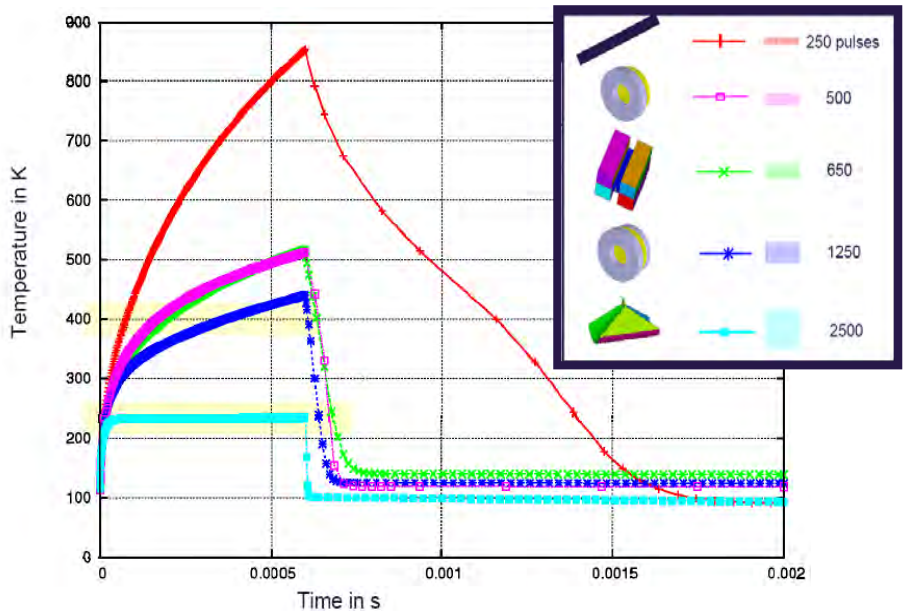
Mirrors

- beam transport and distribution
- grazing angle and coating determine photon energy range
- suppression of higher orders
- collimation & focusing

Monochromators

- bandwidth
- reflectivity
- heat load by pulse train





X-ray photon diagnostics

Due to the fluctuating properties of the SASE FEL sources the photon diagnostic methods in general need to be pulse resolved.

Standard diagnostics

- intensity measurement (absolute, relative, accuracy ?)
- beam position measurement (accuracy ?)

Special diagnostics

- spectral distribution
- temporal properties (distribution, width, arrival)
- polarization
- coherence / wavefronts

Jan Grünert is responsible for the task of x-ray photon diagnostics (standard components & R&D of new elements)

X-ray detector development

Challenges:

- Integrating detectors w. large dynamic range & ‘single photon sensitivity’
- frame readout rates up to 4.5 MHz

Three 2D detector developments have been started

- LPD
- AGIPD
- DSSC

After evaluating the properties of the 3 developments, the LPD detector was dedicated to liquid/amorphous diffraction at this instrument.

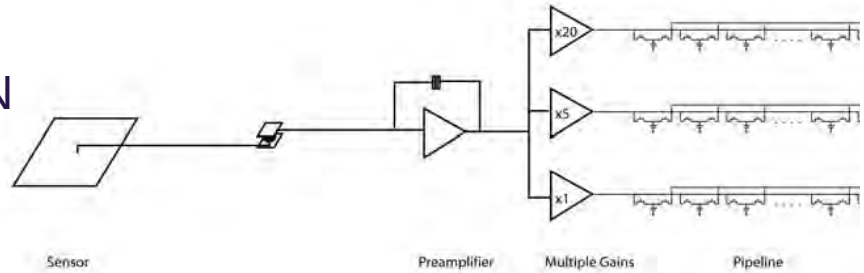
- possibilities and limitations to use this detector in other applications are to be discussed & defined

Large Pixel Detector (LPD)

Multi-Gain Concept

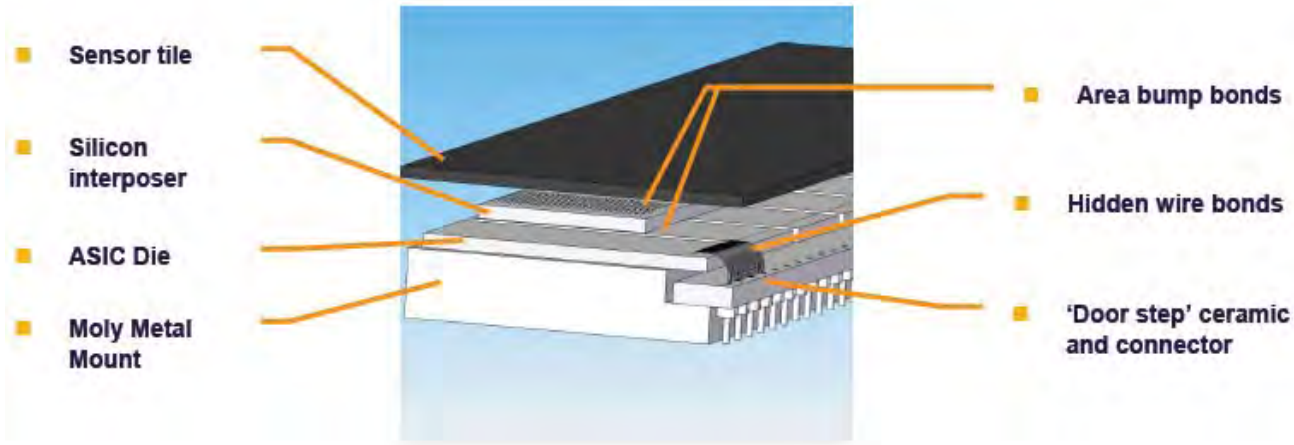
- offers large dynamic range: ~10^5
- Experience with calorimetry at CERN
- Relaxes ADC requirements
- Fits with CMOS complexity

Three-fold analogue pipeline / On-chip ADC



Sensor tile detail

- 128 x 32 pixels
- 500 x 500 µm^2
- edgeless



Performance

- > 6 keV (tbd)
- ~500 events/tr.

collaboration STFC/RAL, U Glasgow

(coordination M. French (STFC/RAL):

Science & Technology Facilities Council
Rutherford Appleton Laboratory

UNIVERSITY of GLASGOW

Anton Plech is the science contact for this project

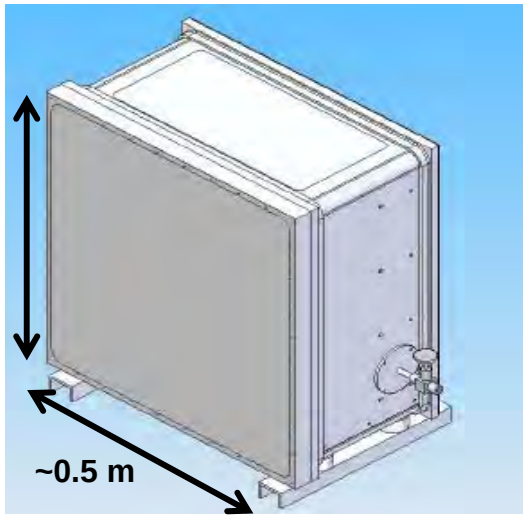
Large Pixel Detector (LPD)

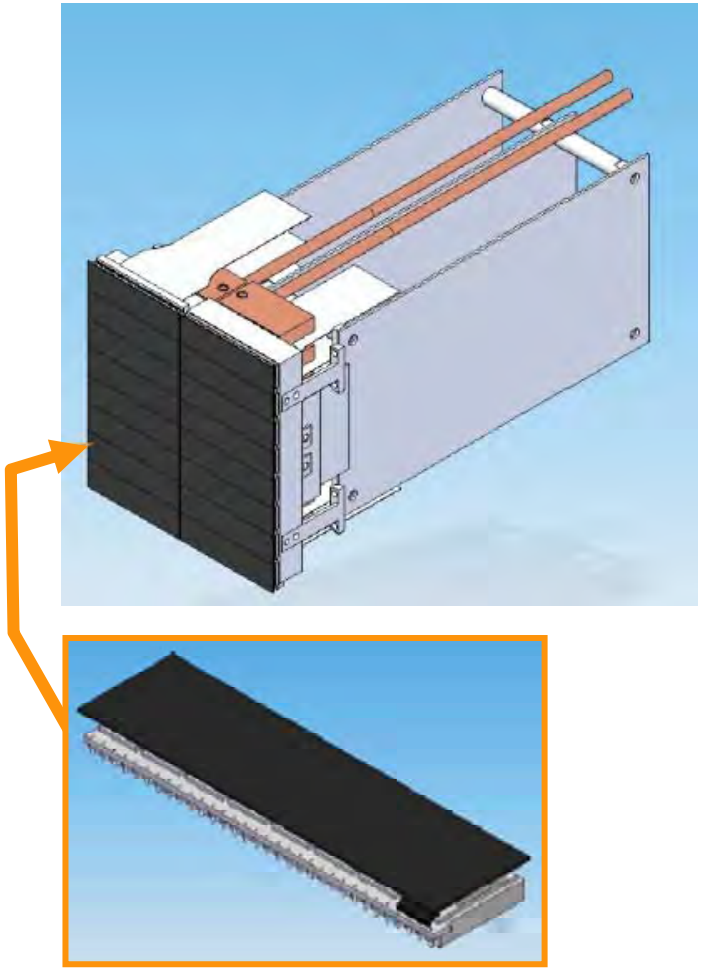
Super-module

- 8 x 2 tiles
- 256 x 256 pixel

The MegaPixel module

- 4 x 4 supermodules
- 1024 x 1024 pixel





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1D detector development

- offer higher spatial resolution and storage capacity, but provide less information

These detectors usually cannot provide spectroscopic information

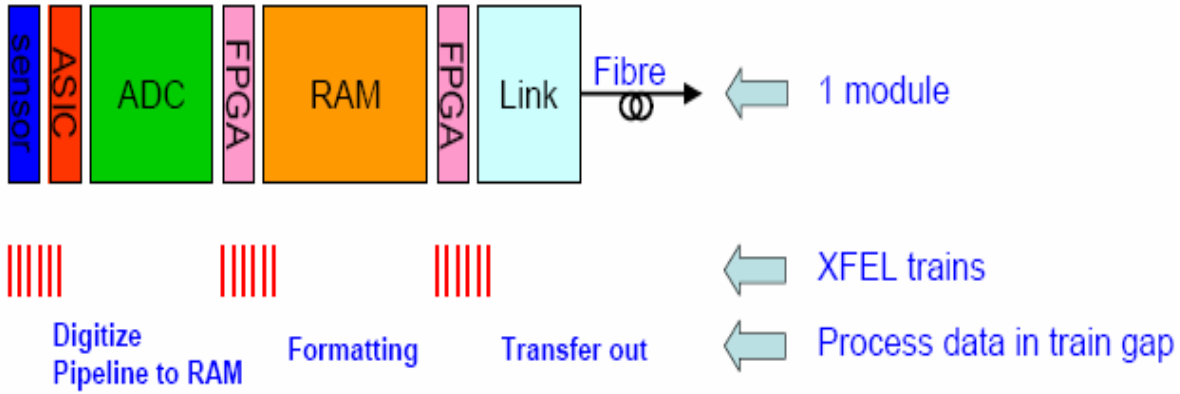
- issue of multiple hits on pixel & resolution

Data acquisition, storage and instrument control

Data acquisition

- 2 Mb per frame
- 1500 × 10 frames/s
- 30 Gb/s

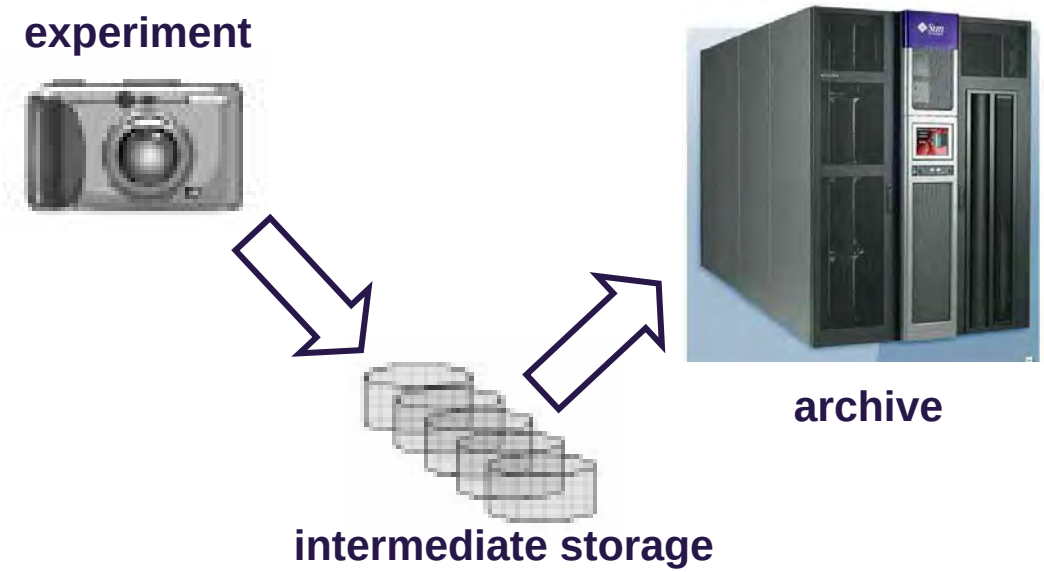
collaboration:
DESY, STFC/RAL



Data storage

- large amounts of data
- ~10 PB archive (scaleable to 100 PB)
- off-line access

collaboration: DESY



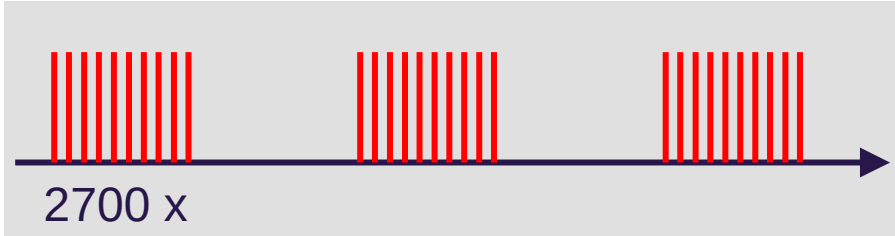
Computing TDR

- available on the XFEL website

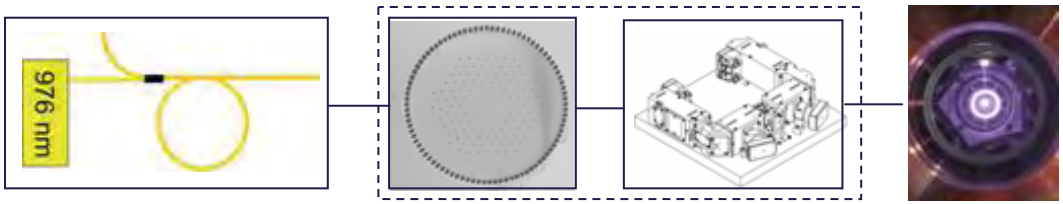
Optical lasers

Challenge

- burst-mode operation
- high average power (>100 W)
- ultrashort pulse duration
- synchronization



layout & test of pump laser



fiber preamplifier G=10^3

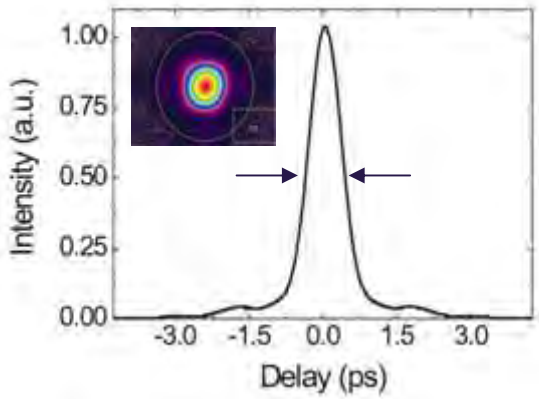
CPA fibre amplifier G>10^4

Yb:YAG slab amplifier (G=100) 400W

Yb:YAG thin disk multipass

Amplifier tests (0.1 & 1 MHz)

- output power >350 W
- M^2~1.3, Δt= 800 fs FWHM



F. Tavella, S. Düsterer (DESY);

collaboration: DESY, HI Jena, ILT Aachen, MBI Berlin

Sample issues

Due to intense beams the interaction of the x-ray beam with the sample cannot be neglected:

- direct beam

  ~10^{16} W/cm^2 (10µm); ~10^{18} W/cm^2 (1µm); ~10^{20} W/cm^2 (0.1µm)

- monochromatic beam (2% eff.)

  ~2×10^{14} W/cm^2 (10µm); ~2×10^{16} W/cm^2 (1µm); ~2×10^{18} W/cm^2 (0.1µm)

- split & delay unit (0.1% eff.)

  ~10^{13} W/cm^2 (10µm); ~10^{15} W/cm^2 (1µm); ~10^{17} W/cm^2 (0.1µm)

- unfocussed beam

  ~2×10^{12} W/cm^2 (full); ~5×10^{10} W/cm^2 (mono.); ~2×10^{9} W/cm^2 (split&delay)

In addition high rep. rates lead to heat load on the sample.

What are the needs and possibilities for sample exchange ?

Preparing conceptual designs for beam transport and scientific instruments

Instrument workshops

- consolidate science case and define requirements for design of beam transport and instruments
- SQS – Nov ‘08, Aarhus
- SPB – Nov ‘08, Uppsala
- HED – Mar ‘09, Oxford
- SCS – Jun ‘09, Villigen
- MID – Oct ‘09, Grenoble
- FDE – Dec ‘09, Budapest

1st meeting European XFEL SAC/MAC

- Jan 25/26, 2010, Hamburg

4th European XFEL Users’ Meeting

- Jan 27-29, 2010, DESY, Hamburg

Charge to the workshop

Refine science scope of FDE instrument

- application areas
- Are there synergies of the various techniques ?

Discuss requirements for FDE instrument

- beam delivery (coherence, focal spots, monochromaticity, split & delay, temporal properties, rep. rates, pulse patterns)
- photon diagnostics
- instrumentation (sample environment, diffractometer, spectrometers)
- detectors and their geometry (2D, 1D (?), streak cameras)
- optical lasers (wavelength, pulse energies)

Sample issues

- sample classes & exchange schemes

FDE instrument layout

- overall concept
- diffraction and scattering
- absorption spectroscopy & Co.

Conclusion

The European XFEL project is up and running.

-

The European XFEL foresees to build an instrument for femtosecond time resolved investigations of a wide class of samples and systems.

-

Early European XFEL experiments are scheduled for 2015. But preparation of the instrument starts now.

Time-resolutions of few femtoseconds seem to be in reach.

-

The European XFEL team is looking forward to working with you over the next years on defining and building this instrument.