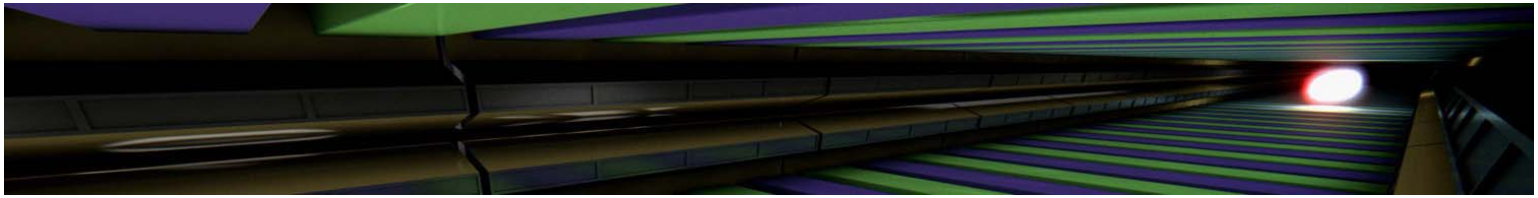


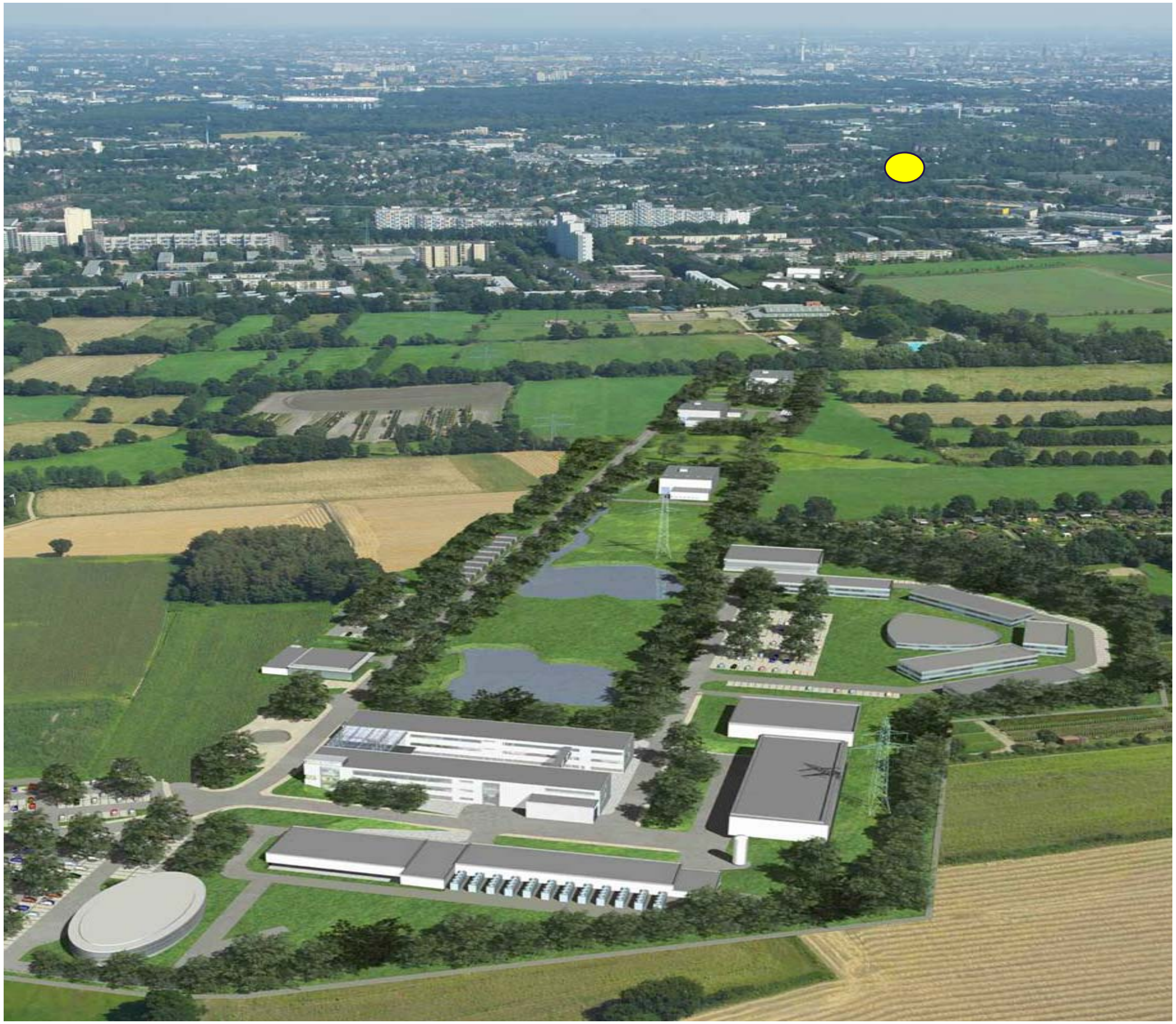
Status of the European XFEL and plans for a HED instrument

International Workshop on the High Energy Density Science
Endstation and Associated Instrumentation at the European XFEL

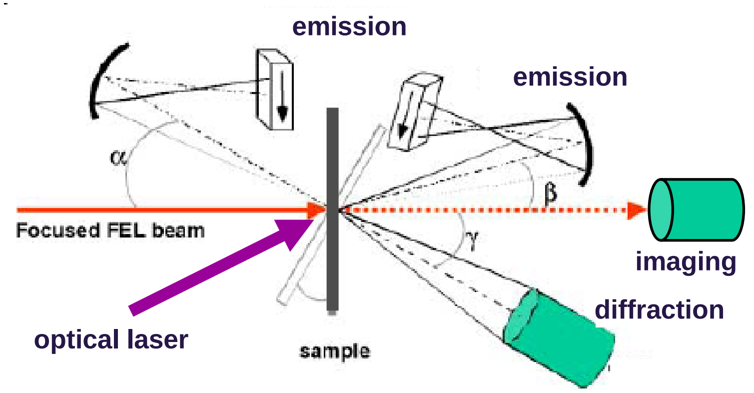
Oxford, Mar 30 - Apr 1, 2009

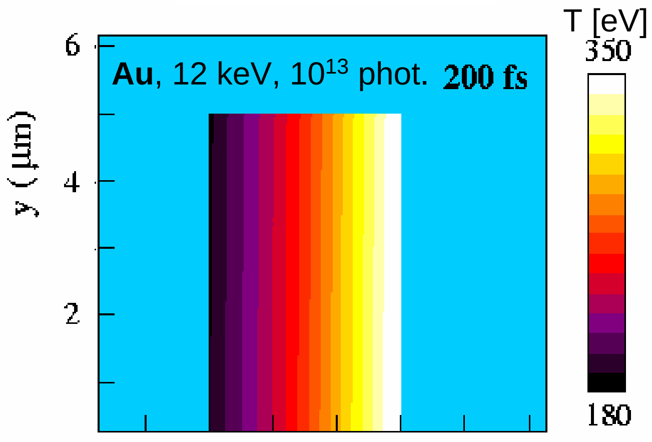
Thomas Tschentscher

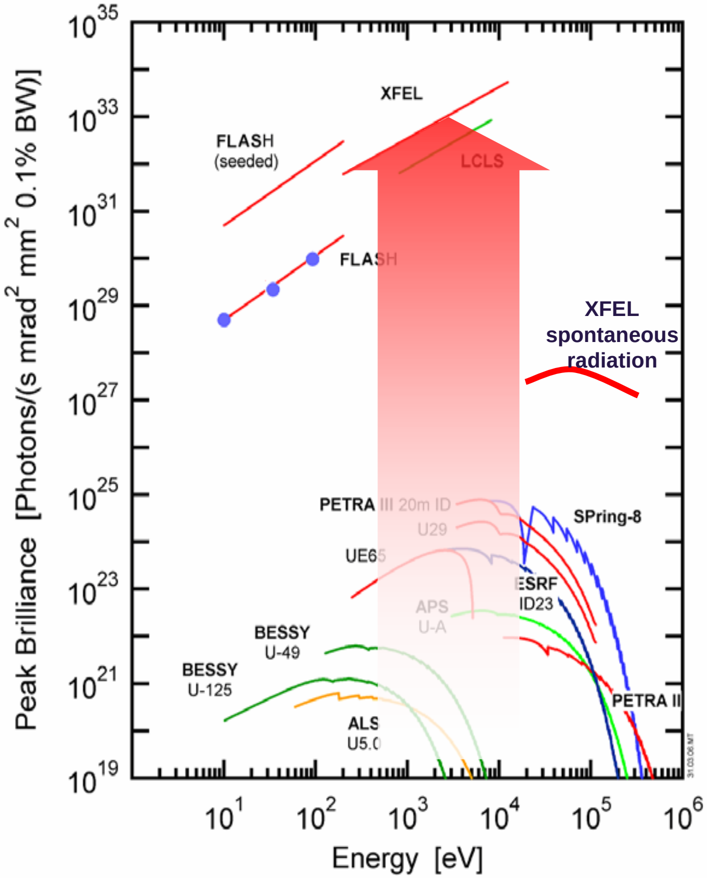
thomas.tschentscher@xfel.eu



Peak brilliance matches HED characteristics





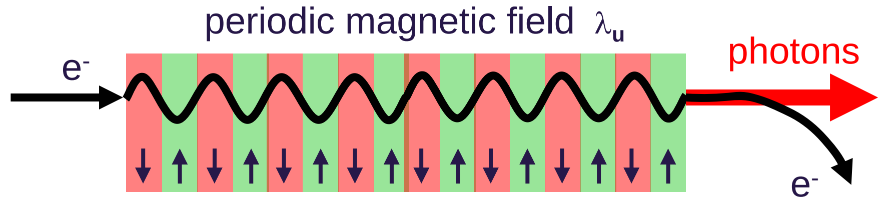


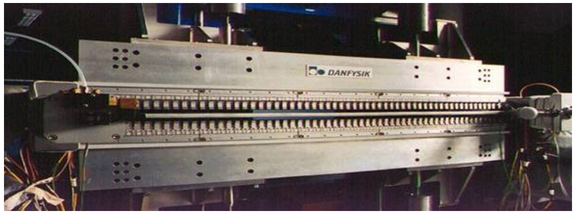
- pulse duration **100 fs**
- pulse intensities **10^{12}-10^{14}**

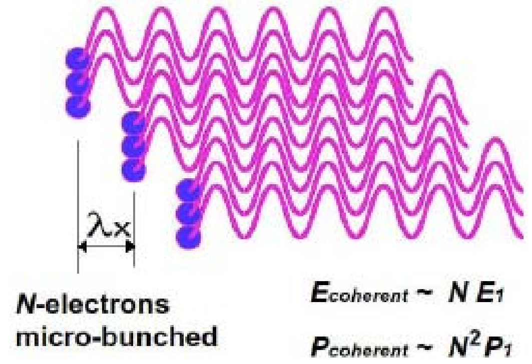
X-ray free-electron lasers

Concept

- stimulate emission of ‘free’ electrons
  - ➔ **free selection of photon energy**
  - ➔ **synchrotron radiation as sp. source**
  - ➔ **interaction of radiation field with electron bunch introduces coherence**
- x-ray energies
  - ➔ **single pass schemes are needed**
- various schemes
  - ➔ SASE
    - start from shot noise
    - most reliable for hard x-rays
  - ➔ seeded FELs







$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right) \qquad K = \frac{e\lambda_u B}{2\pi\, m_o c}$$

Critical electron beam parameters

- Emittance ε ($\Delta x \times \Delta x'$)
- Bandwidth & pulse duration

New scientific applications

Ultrashort pulse duration (few – 100 fs)

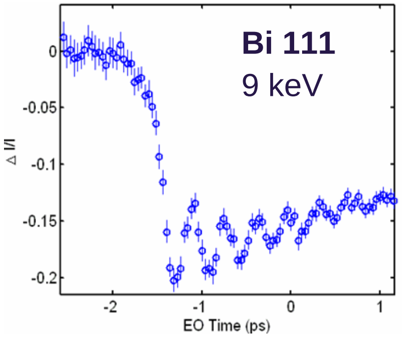
- time resolution allowing to resolve phonon dynamics & chemical reactions
- disentangle excitation & relaxation processes

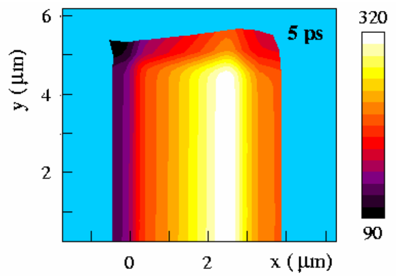
Extreme intensities

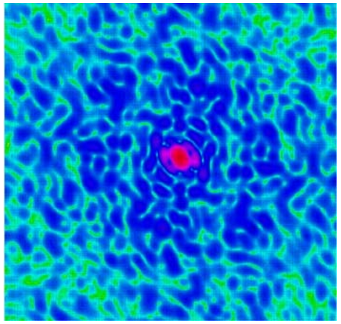
- 10^{12} – 10^{14} photons for x-ray measurement
- pump efficiently using x-rays (minimally interacting)
- non-linear processes

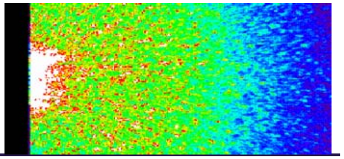
Coherent radiation

- new imaging methods with atomic resolution
- coherent spectroscopy for studying equilibrium dynamics





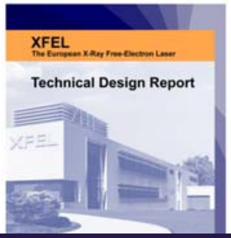




European XFEL

Broad scientific case

- **atomic, molecular, cluster physics**: gases, jets, traps, …
- **high energy density sciences**: plasmas at near-solid density
- **condensed-matter physics**: surfaces, phase trans., magnetism, …
- **materials science**: imaging, time-resolved processes, …
- **geo-sciences**: high-pressure states, …
- **chemistry**: solids, liquids, gases, …
- **life-sciences**: molecules, assemblies, cells, …
- **quantum optics**: non-linear, high-field, multi-photon, …



LCLS, First Experiments (2000), www-ssrl.slac.stanford.edu/lcls
TESLA XFEL, Technical Design Report (2001), ---
BESSY FEL, Visions of Science (2001), www.bessy.de
ELETTRA, 2002, www.elettra.trieste.it/projects/fermi_public
European XFEL, 2006, www.xfel.eu
…

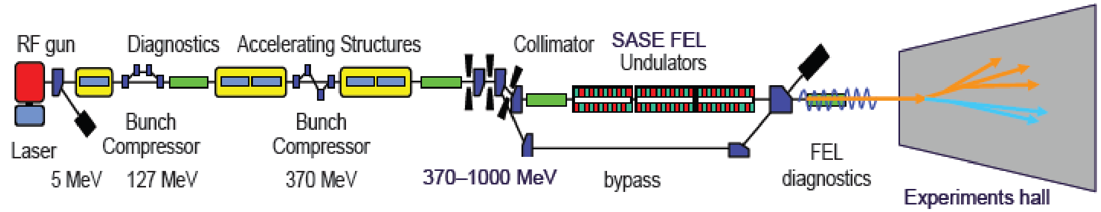
HED scientific instrument scope (TDR)

- Investigation of matter at high temperature, pressure, ionisation (→ plasmas)
- X-ray generation of high energy density states of matter (WDM, HDM)
  - **Isochoric heating of matter to well-defined WDM states**
    - Improve description of matter in transition from solids to plasmas
    - Usage of various laser and x-ray diagnostics
  - **HDM experiments and plasma spectroscopy**
    - Generation of well-defined samples
    - Redistribution dynamics in plasma matter
  - **Interaction of intense x-ray pulse and matter on atomic time and length scales**
    - study dynamics for the case of Bragg diffraction: occurrence of single photon damage
  - **Hollow ion emission**
    - probe atoms in intense Coulomb fields: a new probe for local plasma conditions
- X-ray probing high energy density states of matter
  - **Magnetic field generation and probing**
    - Magnetic field development following intense IR irradiation
  - **Radiation hydrodynamics: *Forest-fire* experiments**
    - Ionisation dynamics in dense cluster jets following intense IR irradiation
  - **High pressure states of matter**
    - structural dynamics following shock generation in solid matter

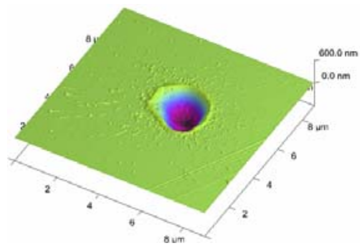
→ Proposal of 2 instruments for HED research: 1 for soft / 1 for hard x-rays

First HED experiments using XUV FELs

FLASH at DESY, Hamburg



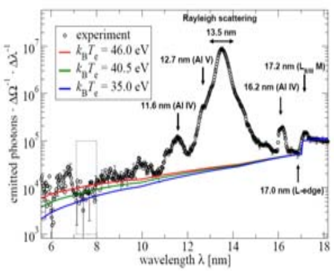
- WDM generation
  - B. Nagler et al.



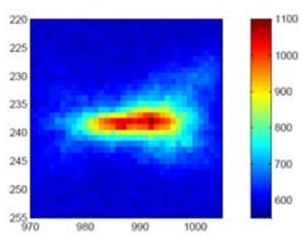
Saturable absorption curve
(to be published)

- Plasma emission spectroscopy
  - U. Zastrau,T. Whitcher et al.

Int. dependent XES
(to be published)



- Inelastic ‘Thomson’ scattering
  - R.R. Fäustlin et al.



H plasmon peaks
(to be published)

Dedicated European XFEL HED instrument

Scientific drivers

- Strongly-coupled plasmas
  - ➔ **EOS, WDM, excitation & probing**

- Plasma dynamics and spectroscopy
  - ➔ **atomic states, opacity, time-dependent processes**

- Excited solids
  - ➔ **solid-to-plasma transition, high pressure states**

Instrumentation sessions

- Novel instrumentation and diagnostics
  - ➔ **lasers, laser techniques, spectroscopy, detectors**

Additional ideas and related areas of application of FEL radiation should be discussed in the working groups.

Project overview *European XFEL*

X-ray free-electron laser user facility with a 17.5 GeV superconducting linear accelerator.

- Low emittance electron beams for SASE FEL process
- Several FEL undulators covering wide range of x-ray parameters
- Dedicated instruments for wide range of scientific applications

- Construction cost 986 M€
- **First beam: 2014**
- **Full operation: 2015**

- 14 international partners

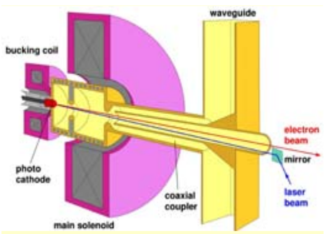
Layout overview

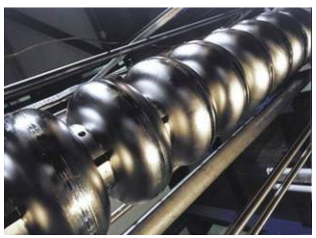
DESY-site Hamburg

Schenefeld-site Schleswig-Holstein

Accelerator ~ 2 km

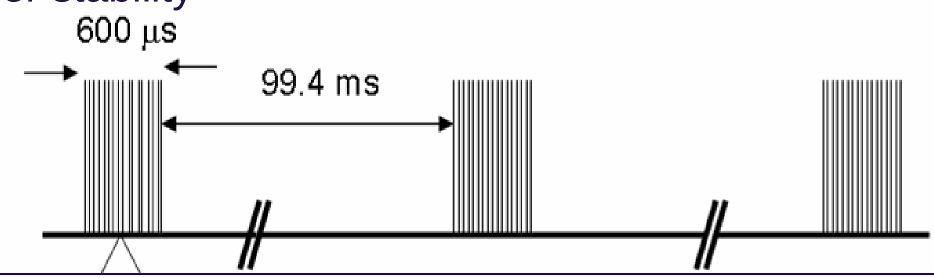
Beam distribution/FELs ~ 1.4 km





sc technology enables delivery of up to 30000 pulses/s

- allow combination of peak & average brightness
- apply feedback mechanisms for higher stability
- operate many experiments parallel



Repetition rate of HED experiments

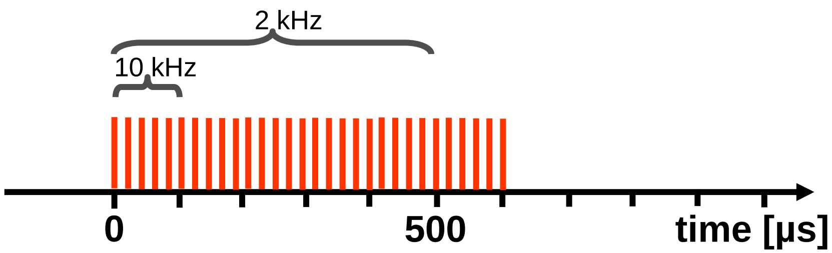
HED experiments (so far) require high peak brilliance.

What about additionally using high repetition rates ?

- investigation of dilute systems and/or small effects
- utilize high rep. rate for investigation of temporal development (ns-scale)

European XFEL time pattern

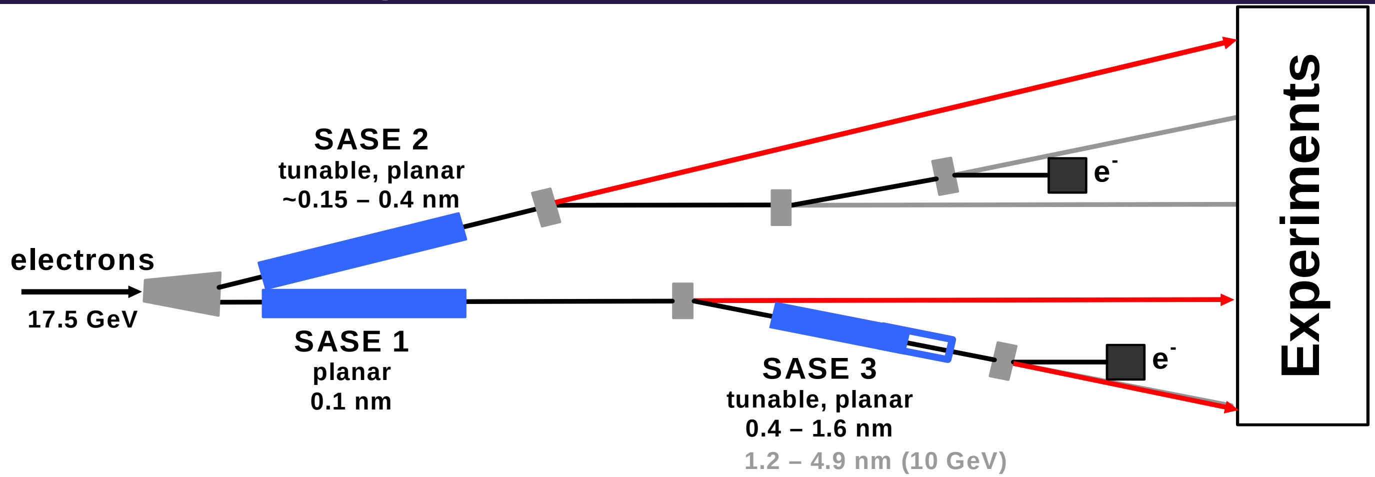
- basic rep. rate 10 Hz
- intra-train rep. rate
  100 kHz – 1 MHz – (>?)5 MHz



Instruments limitations

- optical lasers
- sample delivery
- detection (systems)
- x-ray delivery

Startup configuration



Source	Instruments	Photon beam line characteristics
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 0.25 – 3 keV; High flux
		FEL radiation 0.25 – 3 keV; High resolution

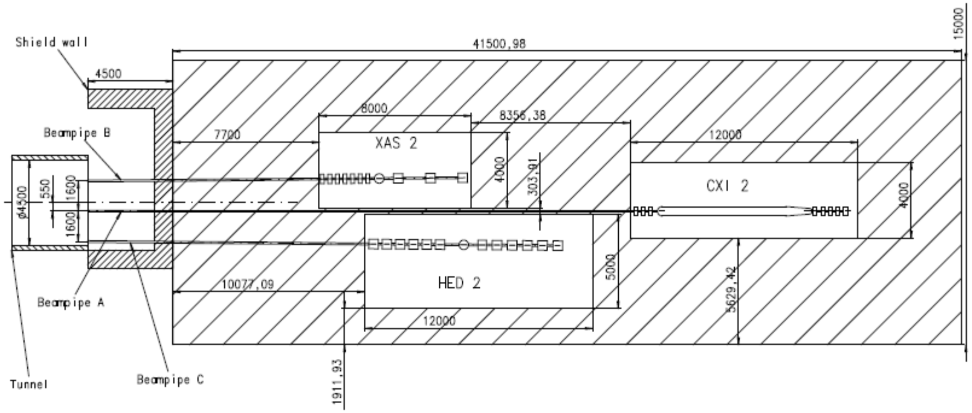
SPB	Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules
MID	Materials Imaging & Dynamics
FDE	Femtosecond Diffraction Experiments
HED	High Energy Density Matter

SQS	Small Quantum Systems
SCS	Soft x-ray Coherent Scattering

Beam parameters SASE 2/HED

Geometry

- 3 instruments on 15×42 m^2 real estate inside experiments hall
- source distance ~920 m



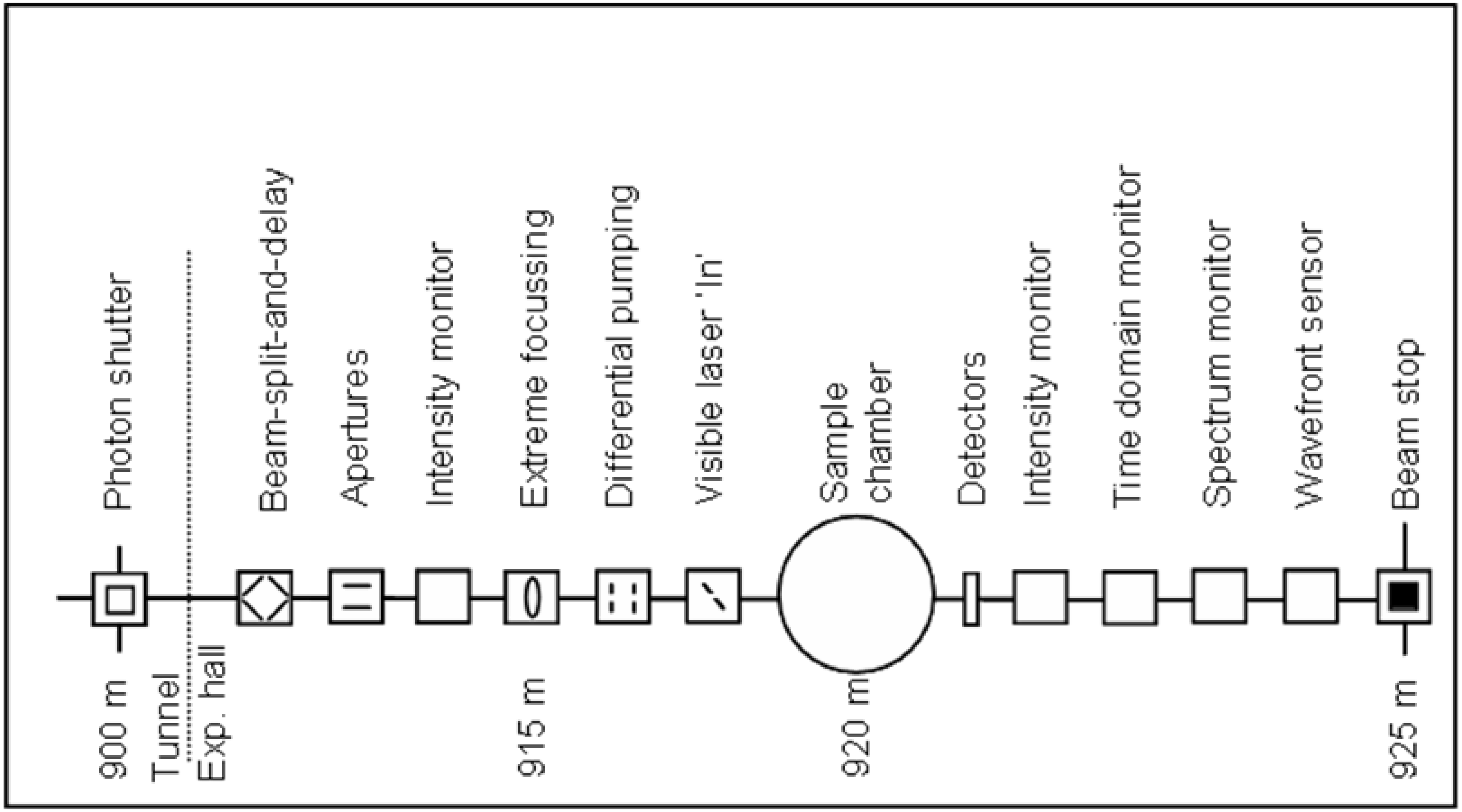
SASE 2 x-ray source

- 3.1 keV, bw 0.18 %, 3.4 µrad → ~3 mm, 1.6×10^{13} phot./pulse
- 12.4 keV, bw 0.08 %, 0.84 µrad → ~0.8 mm, 1.0×10^{12} phot./pulse
- linear polarization
- odd (3^{rd}, 5^{th}, 7^{th}, …) harm. & spont. radiation available at smaller intensity
- 'full' spatial & partial temporal coherence

X-ray optical elements

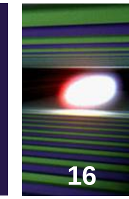
- plane mirrors → transport & distribution
- monochromator → reduce bw to ≤0.01 %
- special optics: focussing, split&delay, etc. require definition

HED instrument



TDR-2006

HED instrumentation



X-ray beam conditioning
- Tunability, provision of higher harm. or spont. radiation
- Beam size 1 – 100 µm
- X-ray split-and-delay (2-color)
- Photon diagnostics: photon number, spatial, spectral & temporal distribution, sync.

Sample manipulation & environment
- Gasous, liquid & solid samples
- UHV conditions
- Fast exchange and sample alignment (~1 µm)

Optical lasers
- Generation of HED samples
- Probing techniques, e.g. Fourier-Domain-Interferometry

Spectrometers
- Visible & (soft) x-ray emission spectroscopy
- Space-, energy-, time-resolved methods

Detectors
- 0D and 2D techniques
- X-ray streak camera

Optical lasers

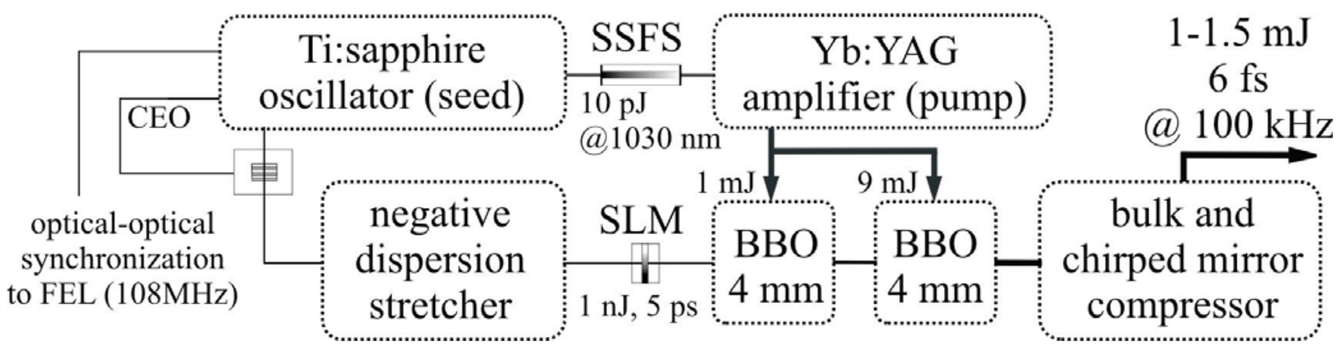
A. Ultrashort probe laser (mJ/ fs pulses)

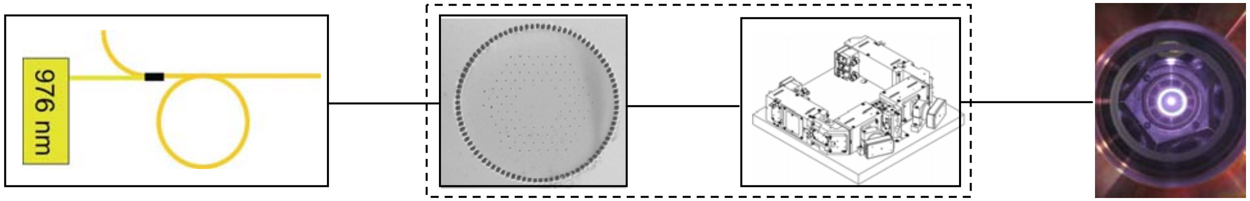
- various probing techniques
- HHG generation and gaseous plasmas
- capable of high repetition rates 100 kHz -5 MHz

FLASH PP laser (dev. MBI Berlin)

New development (F. Tavella et al.)

- OPCPA scheme using Ti:Sa oscillator → sub-10 fs; 1 mJ; 100 kHz
- high power amplifier required (kW class)
  - → **fiber amplifier: coll. with Tünnermann (U Jena)**
  - → **Yb:YAG amplifier: coll. with Hoffmann (ILT Aachen)**



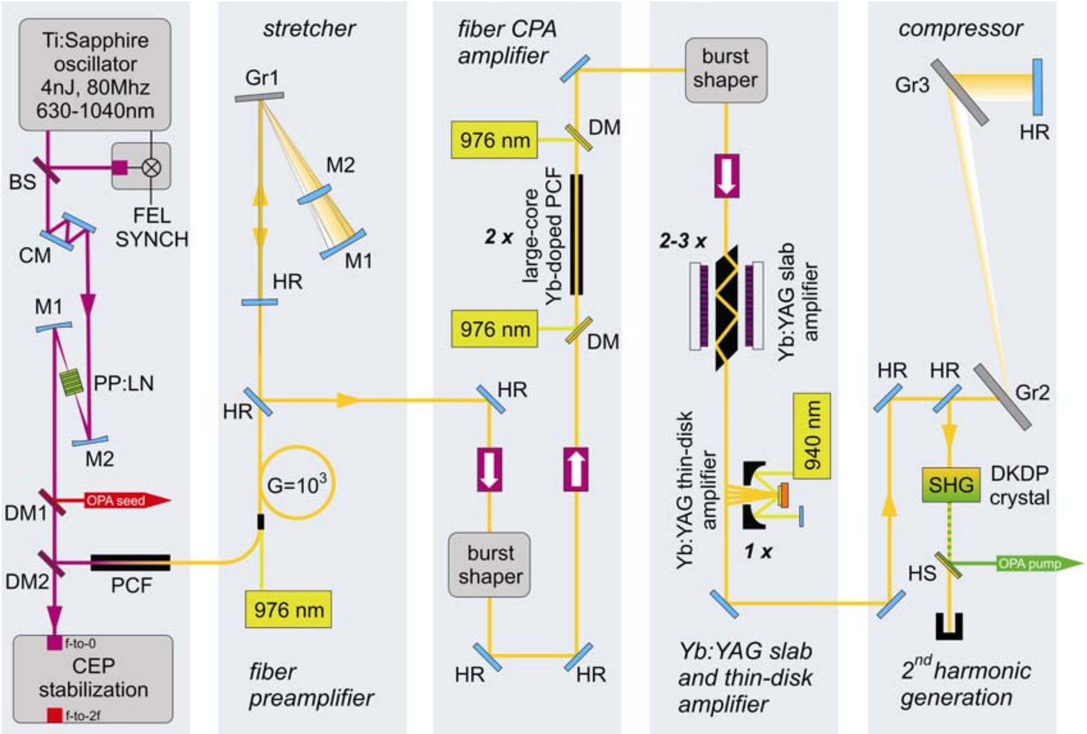


fiber preamplifier
$G=10^3$

CPA fiber
amplifier
$G>10^4$

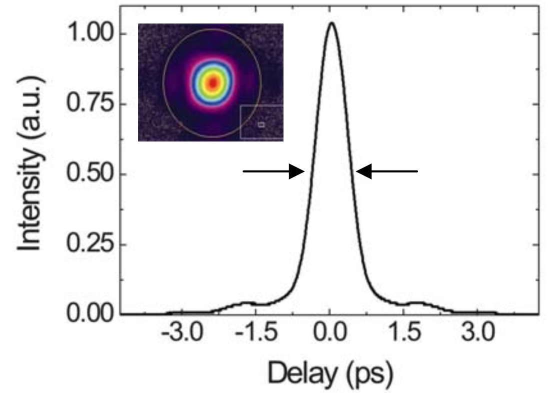
Yb:YAG slab
amplifier
(G=100) 400W

Yb:YAG thin
disk multipass
amplifier



Amplifier tests (0.1 & 1 MHz)

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



OPCPA pump
(SH-Yb:YAG) 515 nm

slide/material courtesy F. Tavella (DESY)

Optical lasers

A. Ultrashort probe laser (mJ/fs pulses)

B. Ultrashort pump laser (1 J/10 fs pulses)

- use ‘standard/commercial’ technology for (1-100) TW class systems
- 30 – 50 fs pulse duration
- 0.1 – 10 J pulse energy
- 10 Hz repetition rate
- contrast ratio ~10^8-10^{10}

C. Longpulse pump laser (100 J/100 ns)

- particular need for shock generation
- parameters / repetition rate / impact(s) / availibility ?? → R&D

Project scope

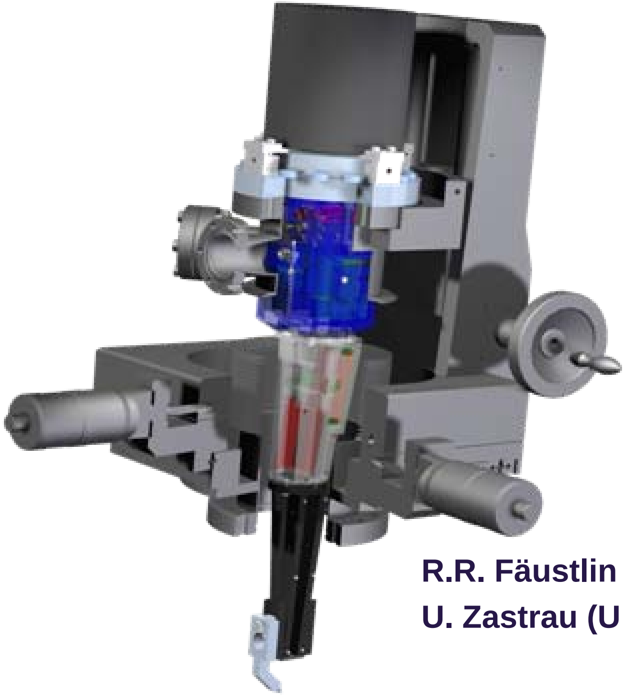
- TDR: 2× system A. and 2× system B. (with slight modifications)
- startup: 1× system A. and 1× system B.

→ **talk by J.-C. Chanteloup**

Spectrometers

Implementation of existing and development of new schemes

- in general high efficiency is required (solid-angle, throughput)
- spectral resolution depends on application
- spatial and temporal resolution might be needed
- various spectral ranges (vis./UV-XUV/X)



R.R. Fäustlin (DESY),
U. Zastrau (U Jena), et al.

→ talk by D. Neely

X-ray detection schemes

TDR – conventional detectors

- At the time it was not considered critical to use detectors more sophisticated than x-ray diodes or CCDs (with 10 Hz rep. rate). Furthermore no detailed requirements for spatial resolution and dyn. range were given.
- One exception was the demand for a x-ray streak camera with sub-fs resolution, high efficiency and reliability for (time-resolved spectroscopy)

  This request led to call for proposals (2007) to develop/build such a system:
  - → **working system: robust, efficient & reliable with 500 to 1000 fs resolution**
  - → **0.1 – 4 keV; 10% overall efficiency; 10 Hz; < 100 kg**
  - → **1D for spectral and 1D for temporal resolution**

  This call was not successfully answered.

Beyond (outside present scope)

- 1D detectors → powder diffraction, …
- 2D detectors → diffraction, scattering and coherent imaging technique

→ talk by C. Youngman

Charge to this workhop

This Workshop is the initial activity for the next step towards setting up the HED instrument at the European XFEL. Its results will be the basis for a conceptual design of instrument and beam transport.

Science

- Identification of scientific drivers for instrumentation

Technical issues

- x-ray parameters & instrumentation
- optical laser parameters & instrumentation
- other instrumentation

User community issues

- establish a HED user group (list, email, future meetings, …)
- define R&D projects, preparatory experiments, contributions

Brief report

Conceptual design :	**early 2010**	**Installation :**	**2014**
Technical design :	**2011/12**	**Start of operation :**	**2015**

Some technical issues :

X-ray instrumentation

- define various types of applications using x-rays to generate or to probe HED samples → classification possible ?
- requirements
  - **x-ray parameters**
  - **required instrumentation**
  - **detectors**
- where is R&D required

Optical laser instrumentation

- define various types of applications using optical lasers to probe or to generate HED samples → classification possible ?
- requirements
  - **optical laser parameters**
  - **used techniques**
- where is R&D needed

Bring together in discussing experiments combining both techniques

Conclusion

Ultrashort & intense x-rays from European XFEL offer new opportunities for the investigation of High Energy Density systems and matter under extreme conditions.

♦

European XFEL project enters the next phase with the definition of beam transport and scientific instruments. Interaction with user community important to develop conceptual designs.

♦

Early European XFEL experiments scheduled for 2015. But experimental HED program using x-ray FELs starts now.

♦

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