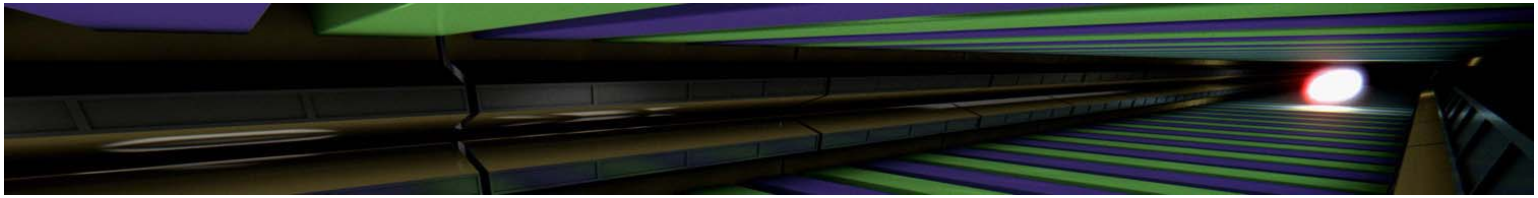

The MID instrument

International Workshop on the
Materials Imaging and Dynamics Instrument at the European XFEL
Grenoble, Oct 28/29, 2009

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Outline

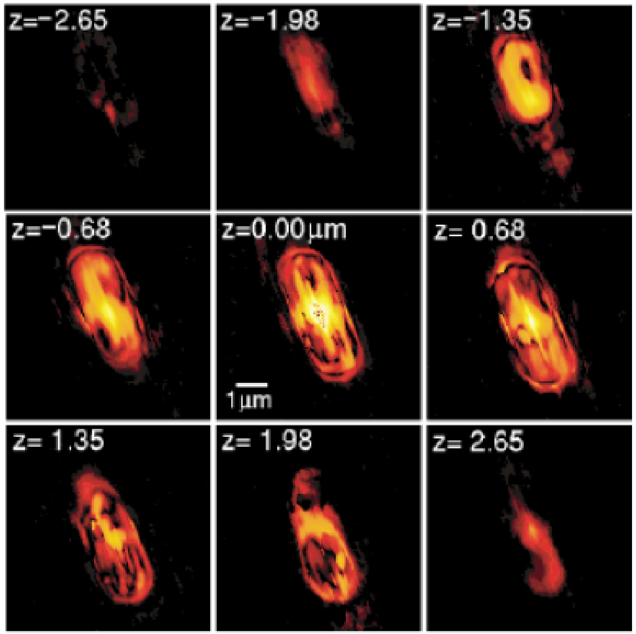
- **History of the MID instrument**
  - PCS & CXI proposals
  - startup scenario
  - SCS and SPB instruments
- **X-ray beam parameters**
  - SASE 1
  - beam properties
- **Some instrumentation issues**
  - repetition rate
  - sample damage
  - detectors
  - synergy of techniques
- **Charge to this workshop**

Scientific motivation

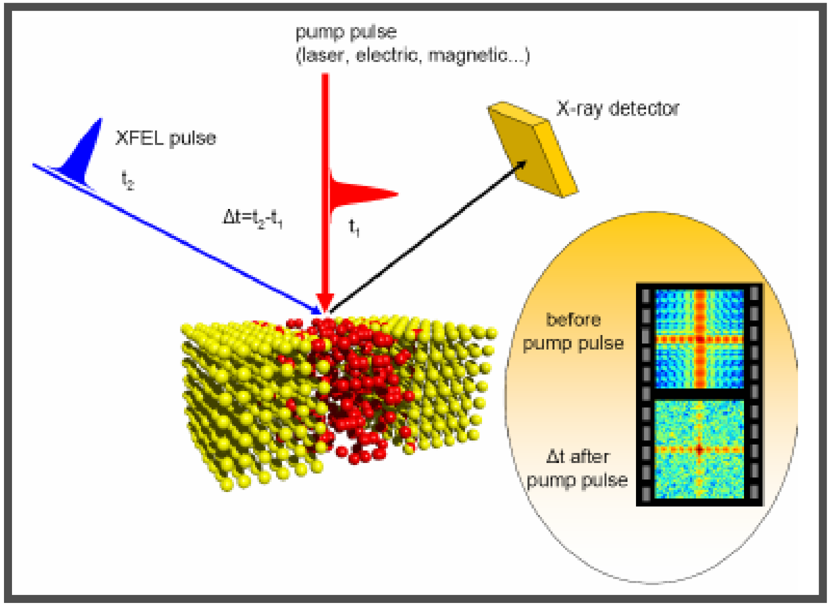
FELs provide for hard x-ray regime a very high flux of coherent photons

- Apply methods for coherent radiation to new systems yet inaccessible
- Develop new techniques yet unfeasible

Density distributions and structural properties of nanoscale systems (here CXI of Au nanoparticles)



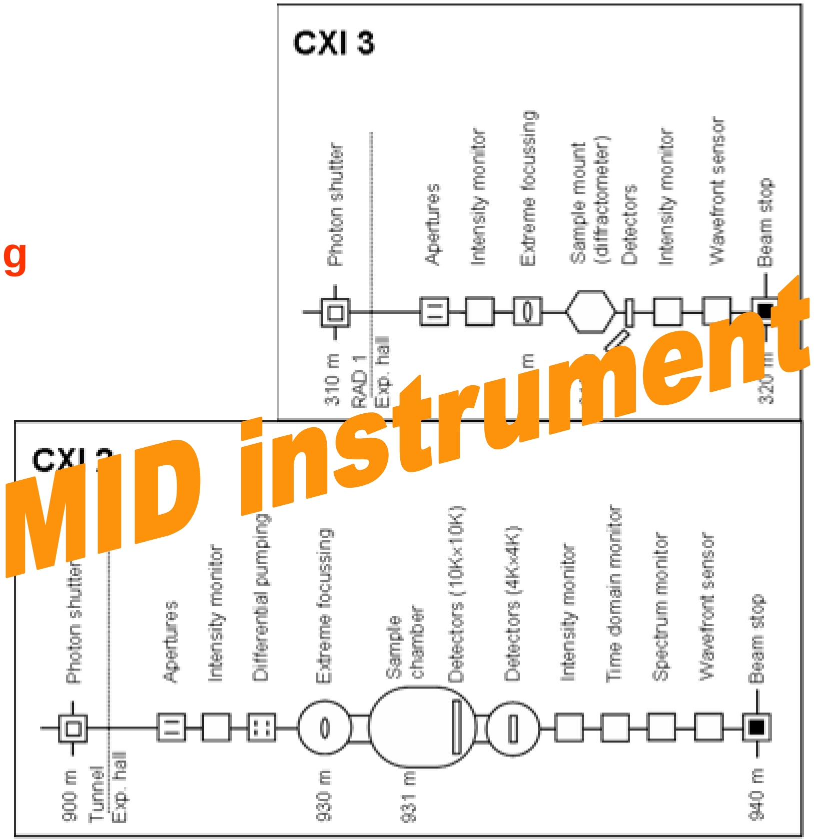
Non-equilibrium fluctuations following excitation by an optical laser pulse



Requested for CXI experiments in 2006 (TDR)

Coherent x-ray scattering and lensless imaging in materials science

- 3D nanoscale structural analysis
  - → **Nanomaterials**
  - → **Mesoscale systems**
  - → **Dynamic processes/fluctuations**
  - → **Materials properties during processing**



3 instruments

- tunable soft x-rays → **SCS**
- tunable hard x-rays
- very hard spontaneous radiation

Requirements (for hard x-rays)

- focal spot sizes 0.1 – 1 µm
- tunability (3)8 – 12 keV
- monochromaticity 10^{-4} (1 µm) and 10^{-3} (0.1 µm)
- forward scattering and large angle diffraction

Requested for XPCS experiments in 2006 (TDR)

X-ray Photon Correlation Spectroscopy

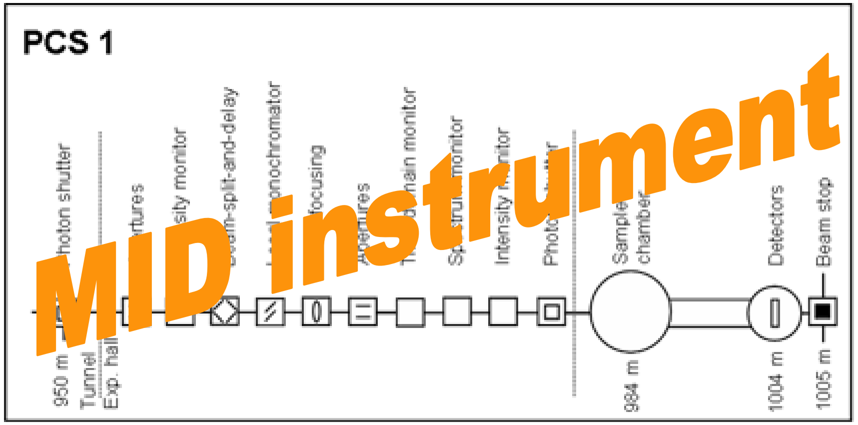
- Nanoscale dynamics of disordered systems
  - → **Glas dynamics**
  - → **Phonon spectroscopy**
  - → **Surface properties**
  - → **Time-resolved magnetic scattering**
  - → **Non-equilibrium dynamics**

2 instruments

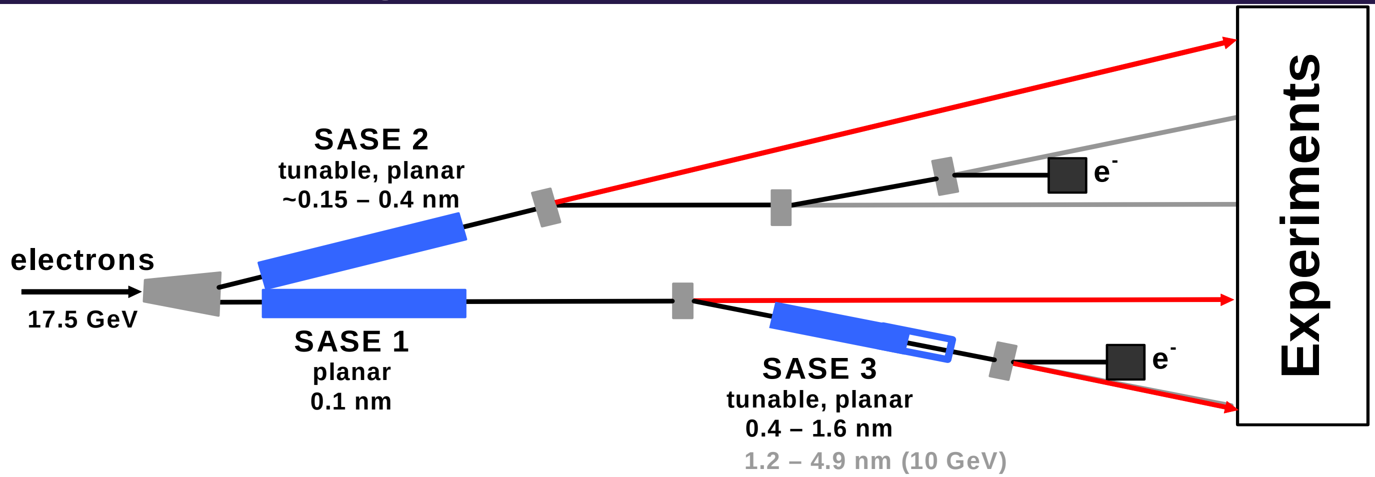
- tunable soft x-rays → **SCS**
- hard x-rays

Requirements (for hard x-rays)

- focal spot sizes 0.1 – 1 µm
- fixed energy 12 keV (36 keV)
- monochromaticity 10^{-4}
- forward scattering



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 0.4 – 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

Instruments for coherent scattering

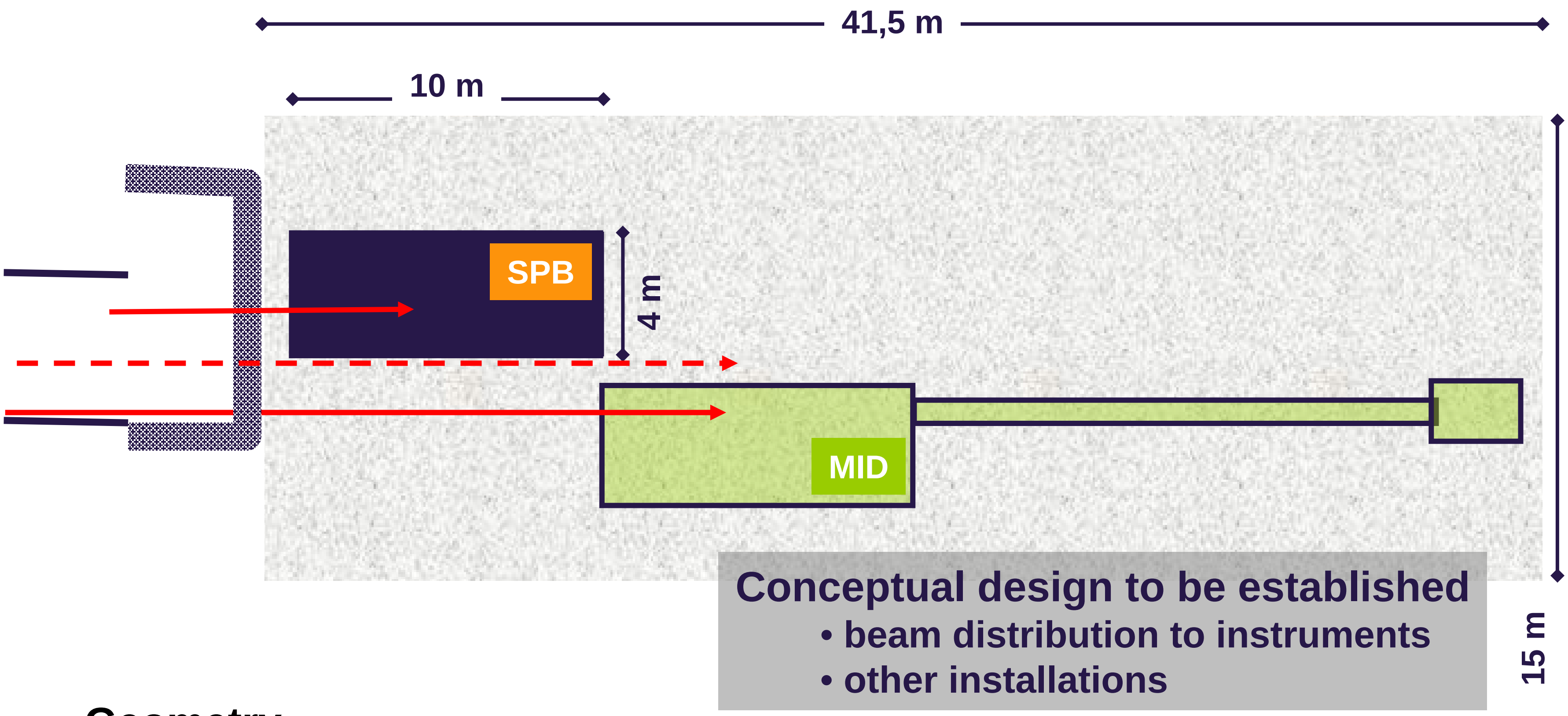
Hard X-rays → 12.4 keV

- MID instrument combines the features of the proposed instruments for XPCS and coherent imaging of nano-structures
  - **high precision diffractometer for sample manipulation and various sample environments**
  - **detectors at near (~m) and far (~20m) distances**
  - **beam delivery: mono (on-request); focusing (100 µm; 1 µm; <100 nm)**
- SPB instrument for single particles (gas or injected)

Soft X-rays → ~0.4 – 3.1 keV

- SCS instrument has been conceived to serve the requirements by the user community to carry out coherent scattering in the soft X-ray regime (few 100 eV – 2/3 keV)
  - **flexibility for various sample environments required**
  - **detector arrangements to be determined**
  - **beam delivery: mono (perm.); focussing (??)**
  - **variable polarization has high priority in beyond baseline program**
- SQS instrument for investigation of non-linear, high-field and time dependent processes in atoms, molecules & clusters

SASE 1 instruments : SPB & MID



Geometry

- 3 instruments on 15×42 m² real estate inside experiments hall
- 2 will be realized in first step
- source distance ~1000 m

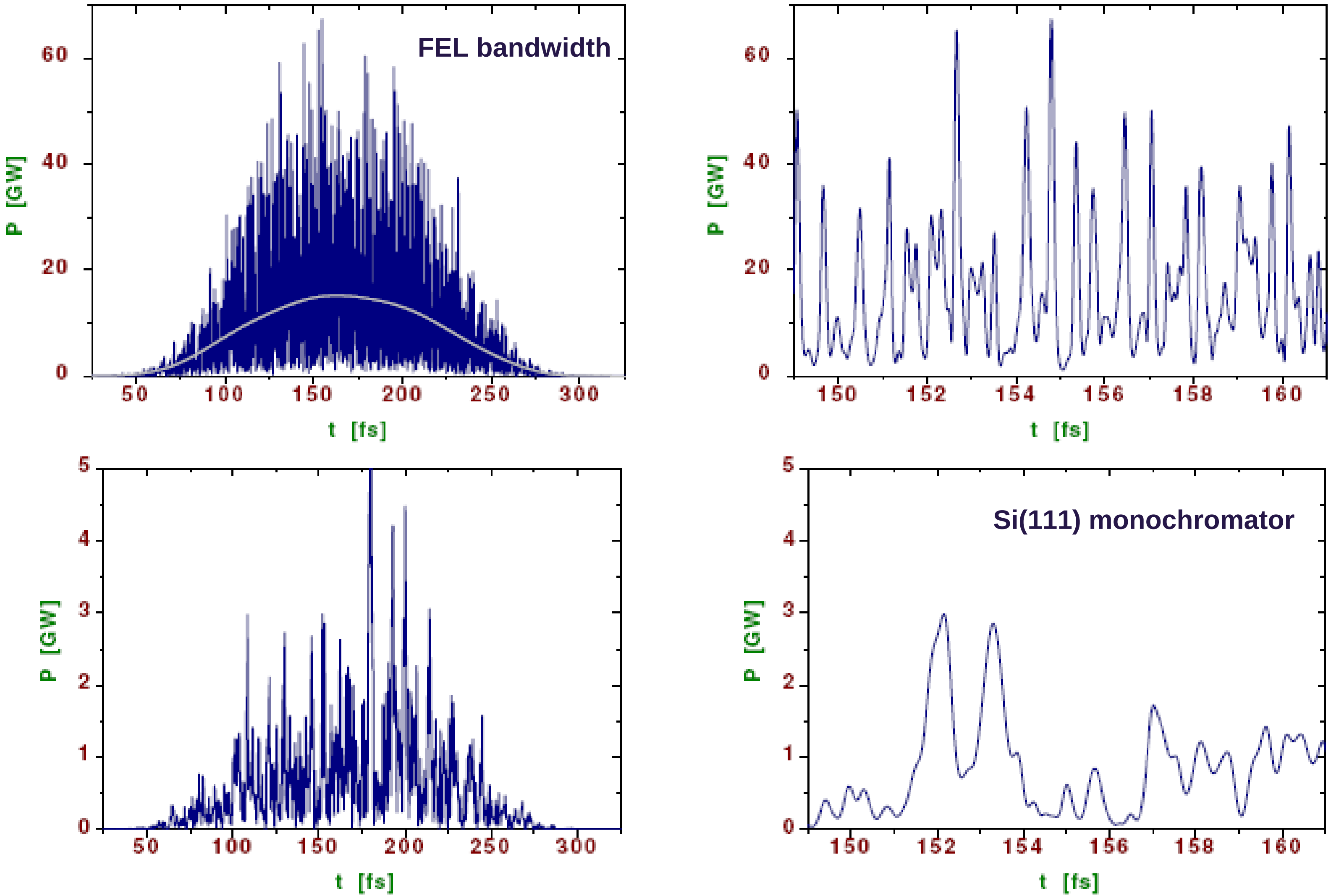
X-ray beam properties

SASE 1 source properties

- SASE FEL (& spontaneous undulator) radiation
- horizontal polarization
- fundament FEL line at 12.4 keV (closed gap configuration)
  - → **no smaller photon energies**
  - → **higher photon energies might be accessible**
  - → **3rd and 5th harmonic radiation at 1 and 0.1 % intensity**
- ~10^{12} photons or 2 mJ
- intrinsic (FEL) bandwidth ~0.08%
- coherence time ~0.2 fs
- source size 70 µm
- source divergence 1 µrad
- pulse duration O(100) fs

Accelerator parameter	Unit	Value
Fundamental wavelength	nm	0.1
Electron energy for 0.1 nm	GeV	17.5
Bunch charge	nCb	1
RF pulse repetition rate	Hz	10
Electron bunch repetition rate during RF pulse	MHz	5
Max. number of electron bunches per RF pulse		3250
Duration of electron bunchtrain	µs	650

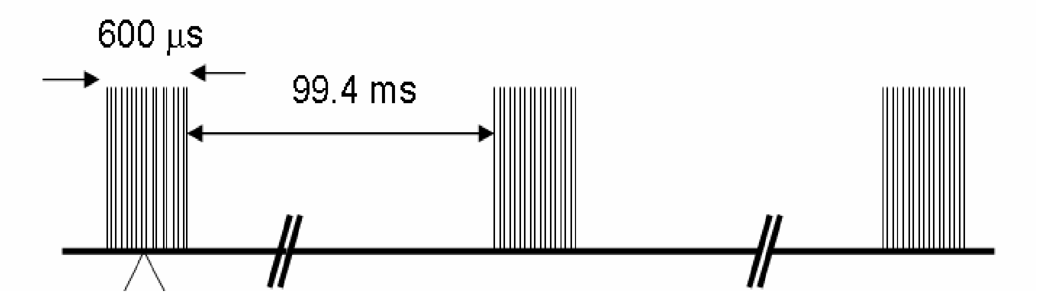
Temporal x-ray beam properties (SASE 1)



Simulations performed by E. Saldin, E. Schneidmiller and M. Yurkov

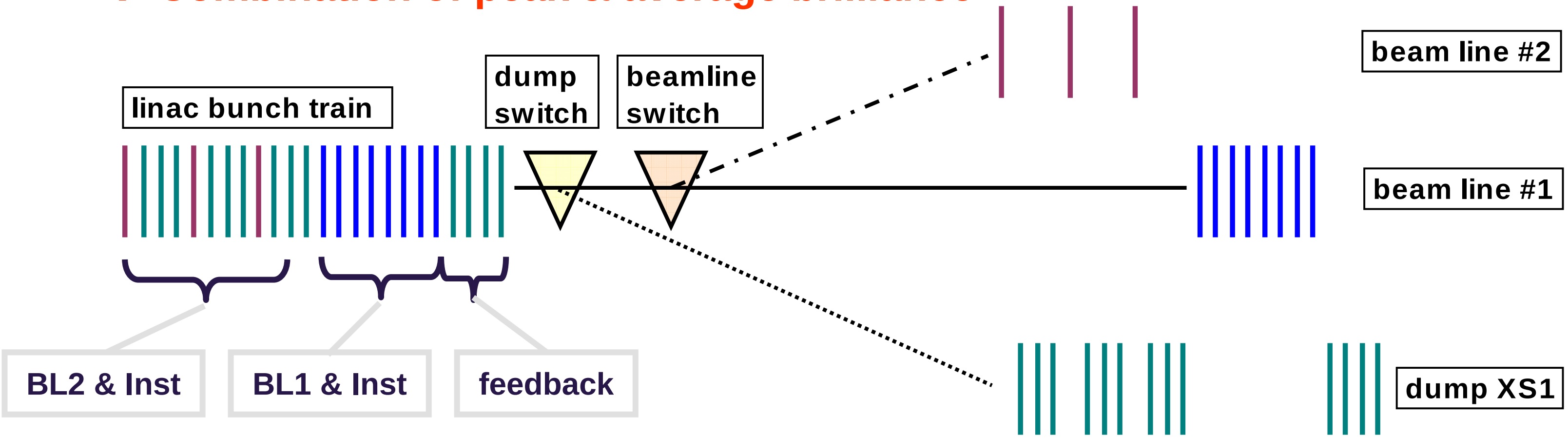
Time pattern of accelerator & photon delivery

Electron bunch delivery



Advantages for user operation

- enables stabilization by intra-bunch feedback
- higher flexibility of operation for simultaneous user experiments
- large number of delivered FEL pulses
  - → **Combination of peak & average brilliance**



European XFEL

Repetition rate issues

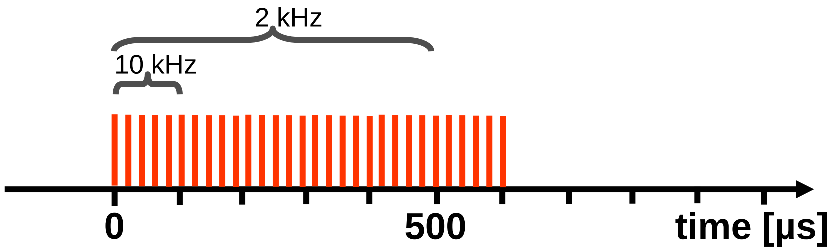
MID experiments require high peak brilliance (coherence, duration). But what are the needs, requirements and possibly limitations about using higher repetition rates ?

- basic rep. rate 10 Hz
- intra-train rep. rate

  100 kHz – 1 MHz – 5 MHz

  or

  1 µs – 1 µs – 0.2 µs
- shorter distances possible
- pulse pattern rather flexible



Instrumentation issues

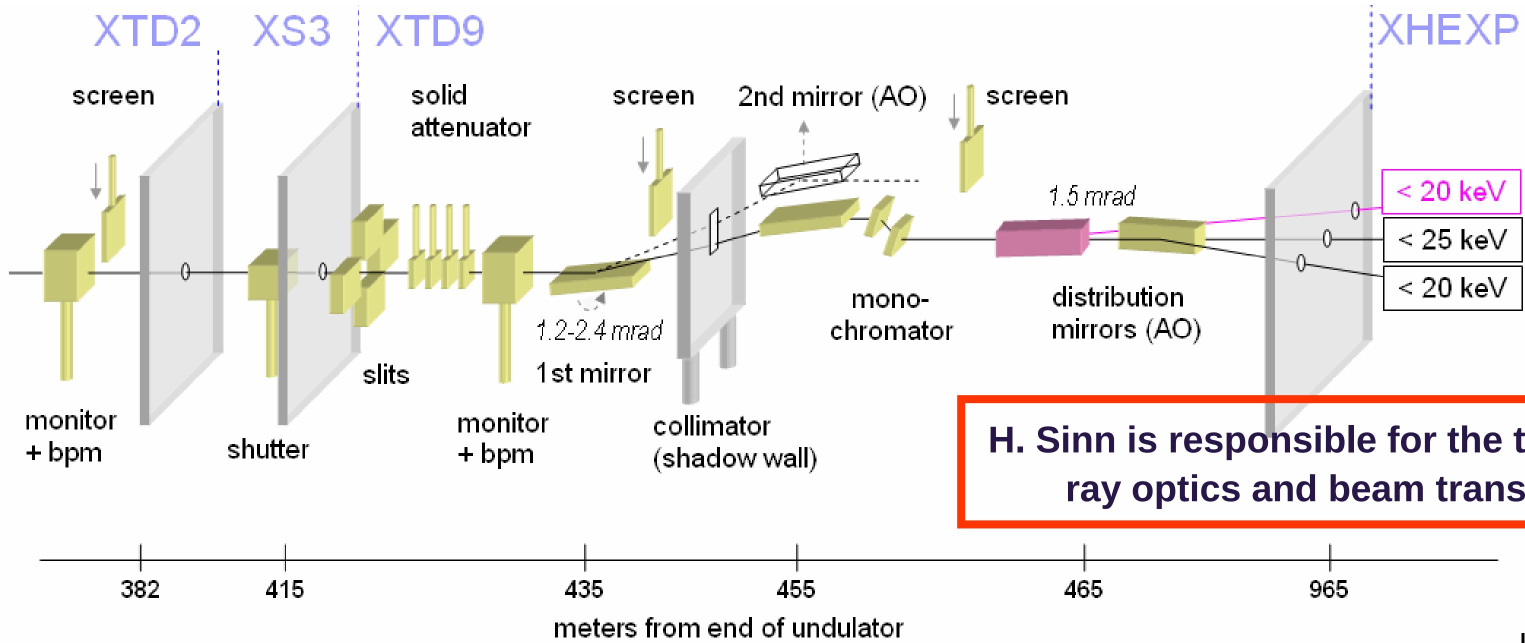
- x-ray delivery
- sample delivery
- detection (systems)
- optical lasers

DESY HELMHOLTZ ASSOCIATION

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
- suppress high energy spontaneous/harmonic radiation

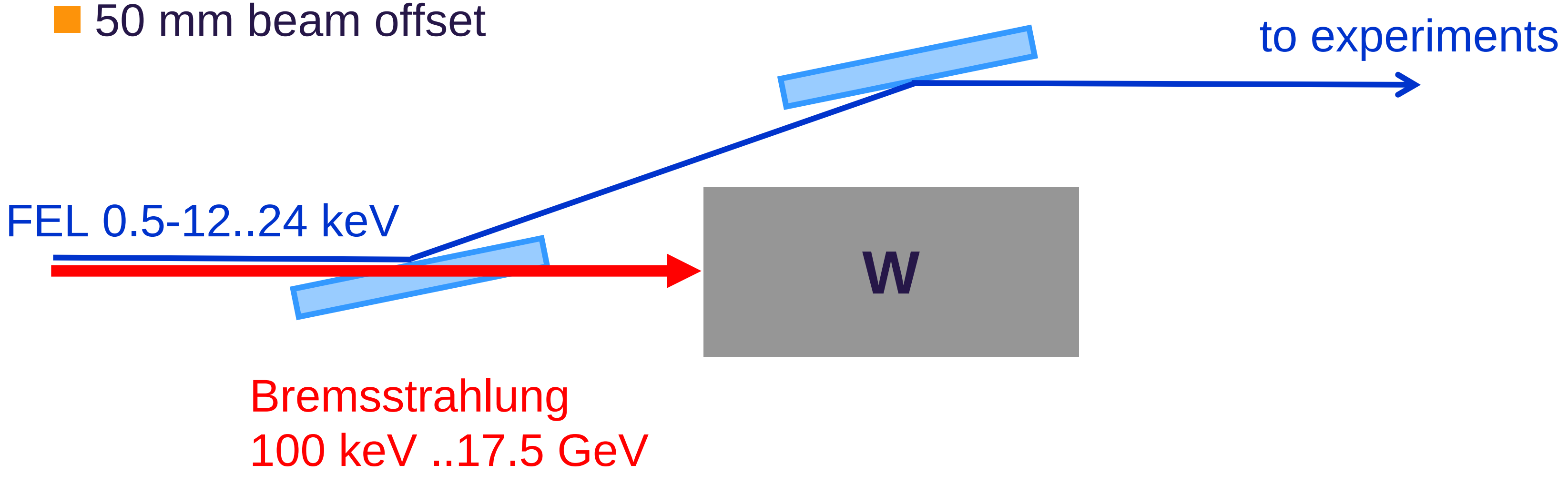


H. Sinn is responsible for the task of x-ray optics and beam transport

Radiation protection

Bremsstrahlung incident (beam loss in undulator)

- 50 mm beam offset



Radiation shielding exp. hall

- limitations for transport of higher harmonics & spont. radiation
- two-mirror concept provide much better cut-off
- high energies only via mono. ?

SASE 1	**one mirror, Pt coating**	**> 22 mm Pb**
	one mirror, C-coating	**12-20 mm Pb**
	two mirrors, Pt-coating	**3-7 mm Pb + 10 mm Fe**
	two mirrors, C-coating	**10-20 mm Fe**

X-ray photon diagnostics

Due to the fluctuating properties of the SASE FEL sources the photon diagnostic methods in general needs 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

X-ray detector development

Challenges:

- Integration with large dynamic range & 'single photon sensitivity'
- frame readout rates up to 5 MHz

Three 2D detector developments have been started → LPD, AGIPD, DSSC. After evaluating the properties of the 3 developments, the AGIPD detector was dedicated to diffraction imaging with the understanding that this detector might also serve photon correlation experiments.

- there might be limitations to this, due to varying requirements

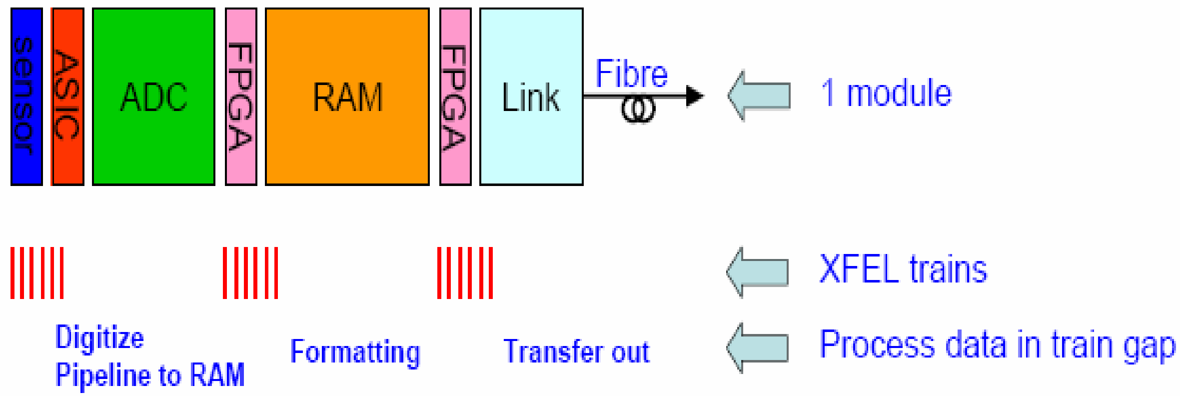
Initial R&D showed the linking beween the size of the pixels and the number of storage places.

1D detector development

- simpler in many aspects, but provides less information
- started to collect requirements for definition of specific cases
  - → **provide information, best define requirements**

Heinz Graafsma is responsible for the task of x-ray detector development

Data acquisition, storage and instrument control



Data acquisition

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

collaboration: DESY, STFC/RAL

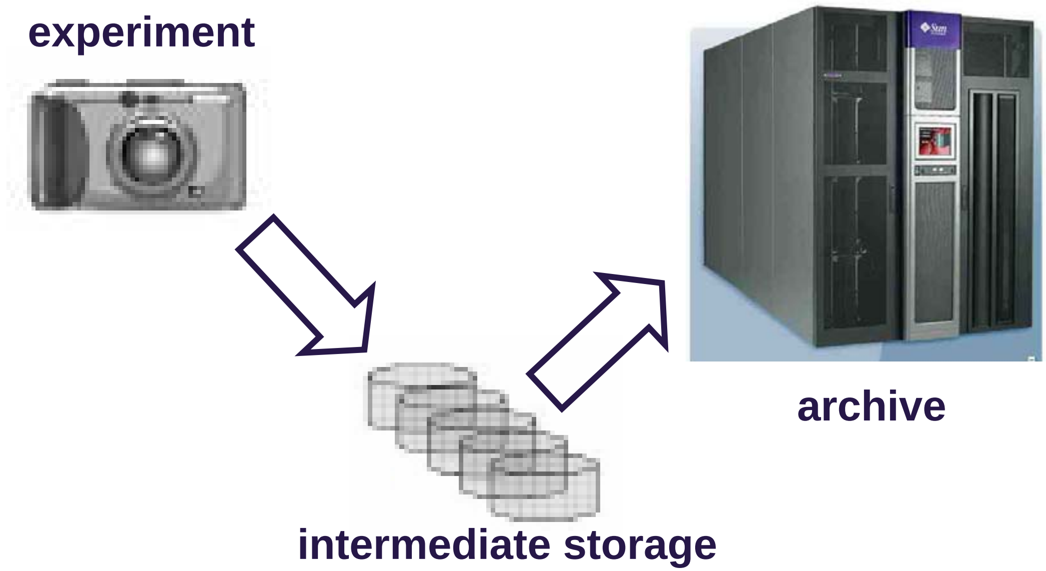
Data storage

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

collaboration: DESY

Computing TDR

- soon available on the XFEL website



Chris Youngman is responsible for the task of DAQ & control

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 ?

Charge to the workshop

Refine science scope and discuss required instrumentation for MID instruments

- requirements to beam delivery (coherence, wavefronts, focal spots, monochromaticity, split & delay, temporal properties)
- beam delivery (rep. rates, pulse patterns)
- requirements to photon diagnostics
- requirements to instrumentation (sample environment, diffractometer)
- detectors (geometry, 2D, 1D (?), …)
- optical lasers

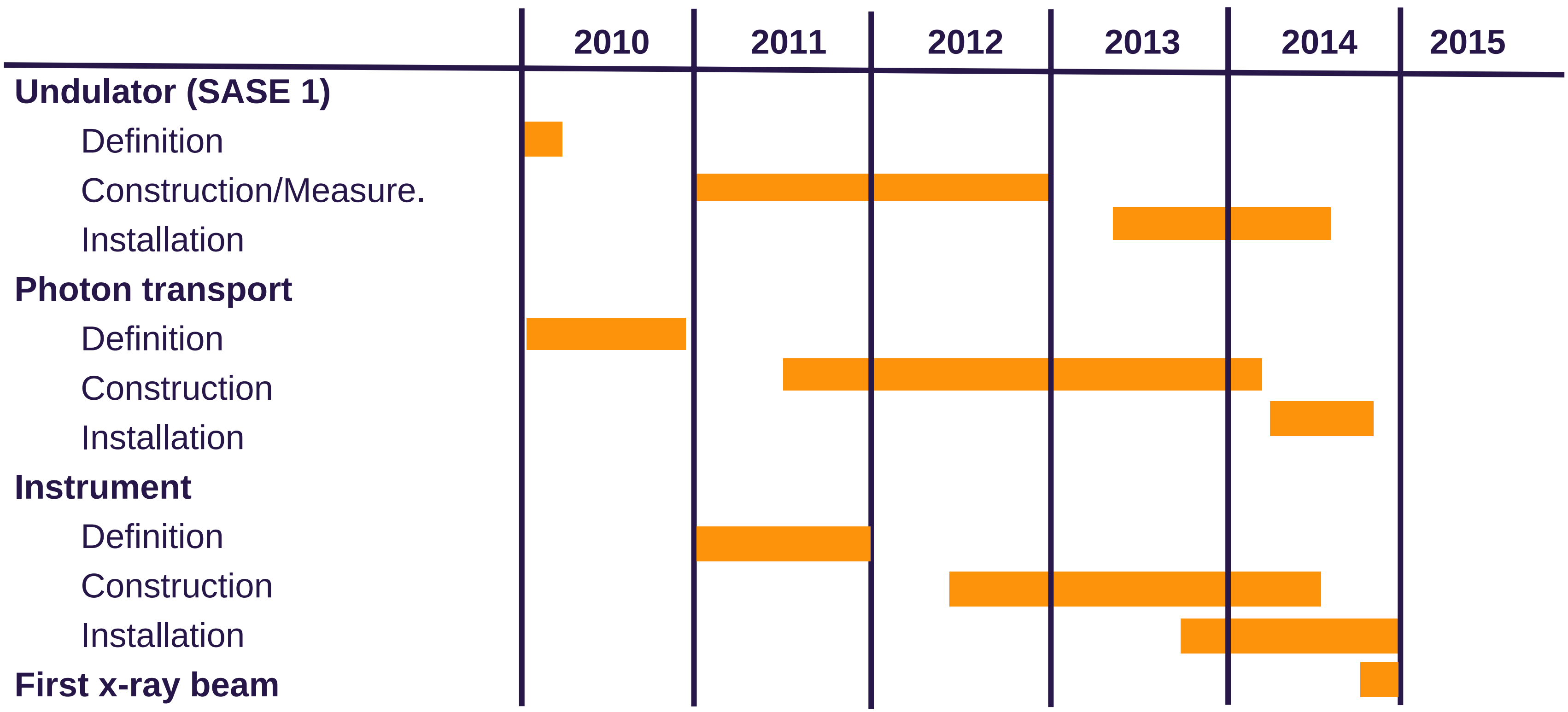
Sample issues

- sample classes & exchange schemes

MID instrument layout

- overall concept
- short / long detector distances
- forward / large Q scattering

A coarse schedule for the MID instrument



Conclusion

Both, diffraction imaging and photon correlation techniques offer new opportunities to investigate nanoscale systems. Hard x-ray FEL radiation offers many of the properties required for such experiments.

♦

The European XFEL project foresees to build the MID instrument for these applications. Requirements for this instrument need to be narrowed down.

♦

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

♦

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