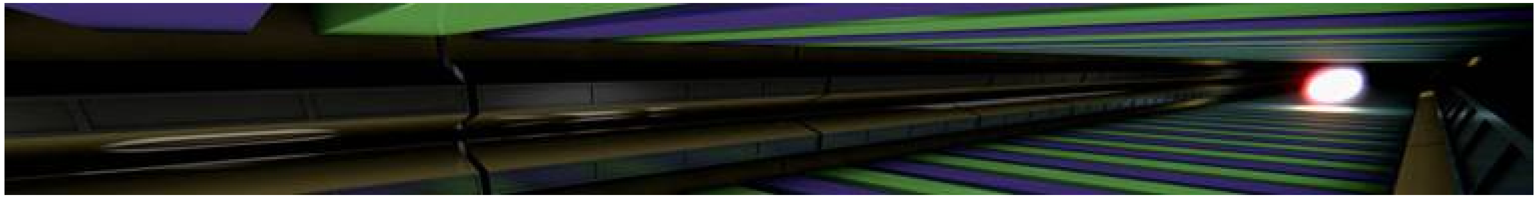
European XFEL



X-ray systems layout & development strategy

4th European XFEL Users meeting

Hamburg, Jan 26/27, 2010

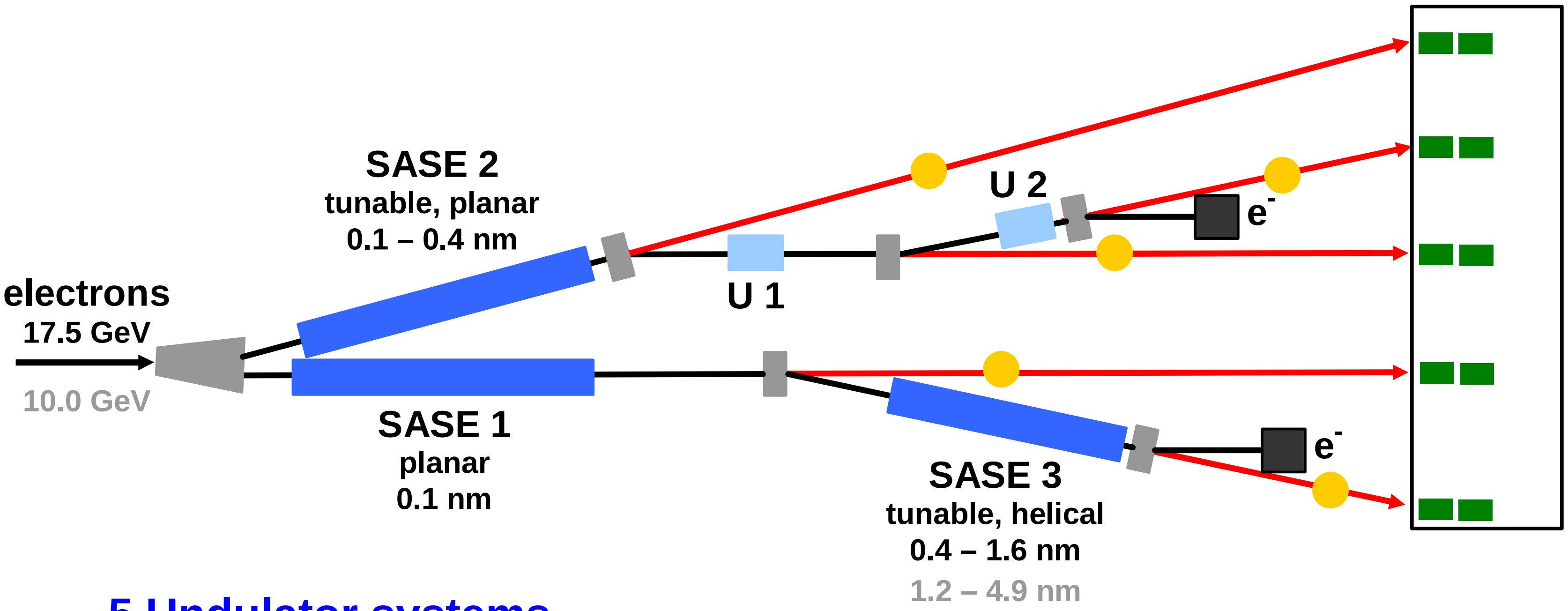
Thomas Tschentscher

thomas.tschentscher@xfel.eu

Outline

- **TDR & startup layouts**
- **Recent developments**
  - Instrument workshops (Oct ’08 – Dec ’09)
  - Start of LCLS operation
- **Development strategy**
  - Start of operation (2015)
  - Longterm
- **Conclusions**

TDR layout photon beam systems (2006)



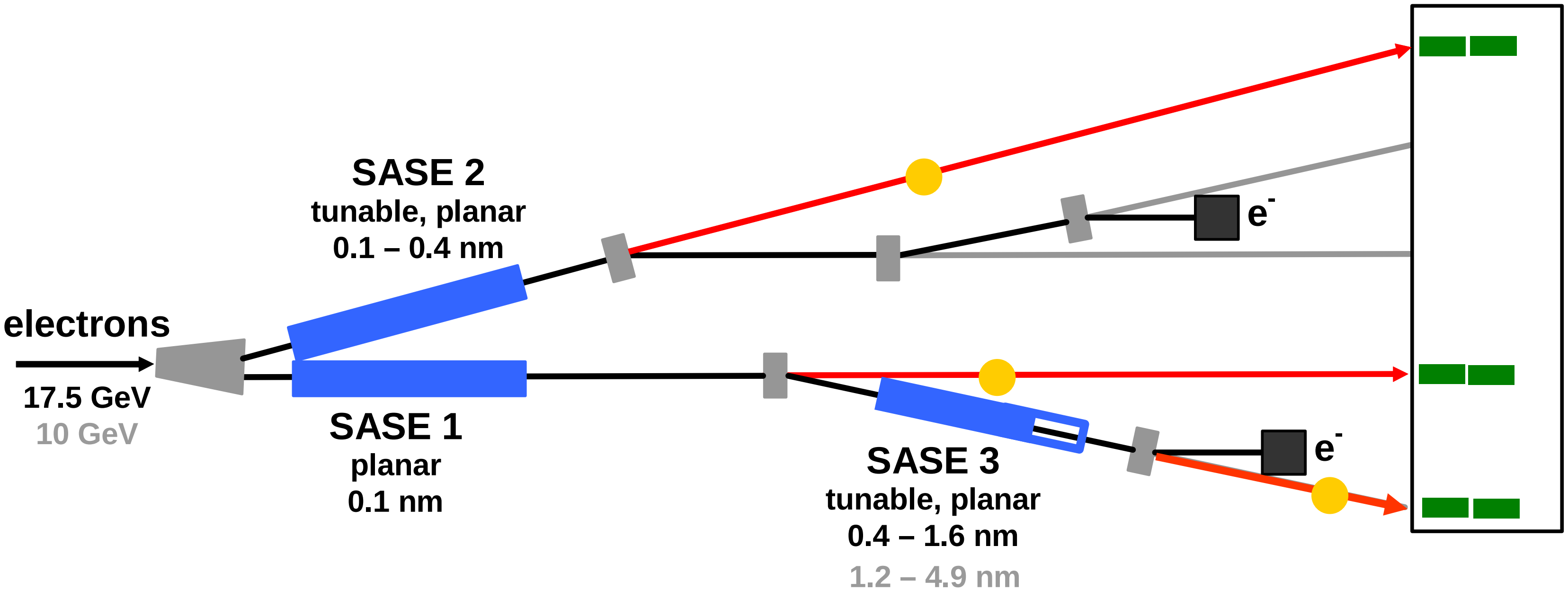
5 Undulator systems
5 Photon diagnostics
5 Photon beamline
10 Instruments

Infrastructure for scientific instruments

- 3 2D area detectors
- optical laser systems
- sample environment R&D
- special instruments
- preparation & characterization labs.

European XFEL

Startup layout photon beam systems (2008)



3 FEL undulator systems
3 Photon diagnostics
3 Photon beamline
6 Prioritized instruments

Infrastructure for scientific instruments
- **reductions in numbers and R&D**

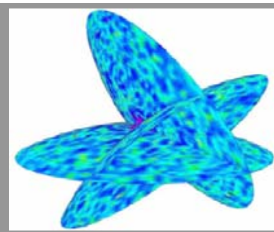
Scientific instruments

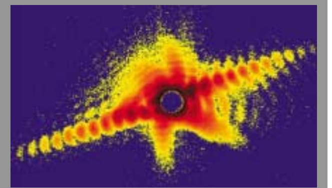
SASE 1

SASE 2

Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules (SPB)

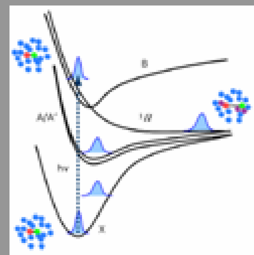
- Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.





Materials Imaging & Dynamics (MID)

- Structure determination of nano- devices and dynamics at the nanoscale.

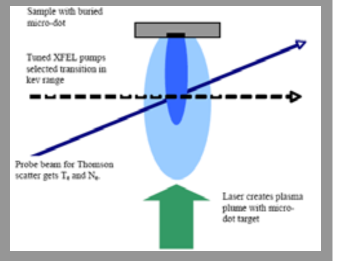


Femtosecond X-ray Experiments (FXE)

- Time-resolved investigations of the dynamics of solids, liquids, gases

High Energy Density Matter (HED)

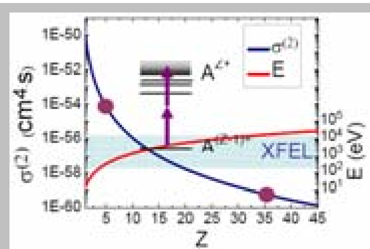
- Investigation of matter under extreme conditions using hard x-ray FEL radiation, e.g. probing dense plasmas



SASE 3

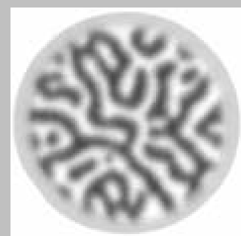
Small Quantum Systems (SQS)

- Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena



Spectroscopy and Coherent Scattering (SCS)

- Structure and dynamics of nano-systems and of non-reproducible biological objects



Instrument workshops

6 workshops for 6 instruments

- Small Quantum Systems (SQS), U Aarhus, 29-31 Oct 2008
- Single Particle and Biomolecules (SPB), U Uppsala, 20-22 Nov 2008
- High Energy Density science (HED), U Oxford, 30 Mar – 1 Apr 2009
- Spectroscopy & Coherent Scattering (SCS), SLS, Villigen, 2-4 Jun 2009
- Materials Imaging and Dynamics (MID), ESRF, Grenoble, 28/29 Oct 2009
- Femtosecond X-ray Experiments (FXE), KFKI, Budapest, 9 – 11 Dec 2009

Input from wide community

- Attendence of more than 450 scientists from ~20 countries
- Discussion of science driven requirements to x-ray delivery and instrumentation of the end-stations
- Workshop reports and summary of all meetings are in progress





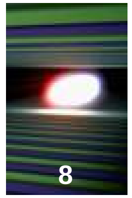

User requests for X-ray delivery

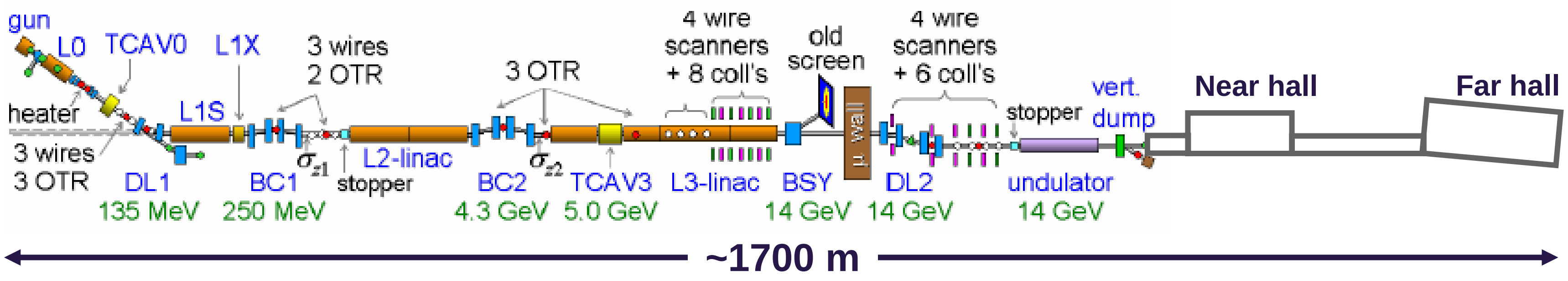
		Photon energy [keV]	Tuna-bility	Polariza-tion	Beam size [μm]	BW	Rep.rate	OL-PP/ X-PP
SASE 1	SPB	~6 (?) – 12	-	-	0.1, 2, 5, unfocus.	nat.	~MHz	Yes (2x)/ No
SASE 1	MID	~6 – 12(5), ~25	-	Vertical linear	1, 10, 25, unfocus.	nat., 10^{-4}, 10^{-5}	4.5 MHz	Yes/Yes
SASE 2	FXE	~4 - 18	±3%	Linear	10, 100, line, unf.	nat.,10^{-4}	4.5 MHz	Yes/ No
SASE 2	HED	4 - 20	±3%	Linear	1,3,10,100 unfocus.	nat. - 10^{-6}	10 Hz (+)	Yes/Yes
SASE 3	SQS	~0.28 – 3	±3%	Variable	1, 100 unfocus.	nat.	4.5 MHz	Yes/Yes
SASE 3	SCS	~0.28 – 2	±3%	Variable	1,10,100 unfocus.	3×10^{-5}	0.03-1 MHz	Yes/Yes

- Photon energy → Extend range towards soft & hard
- Polarization → Variable polarization is needed (soft x-rays)
- Beam size → Several foci in 1 location
- BW → Very high resolution
- OL-PP/X-PP → Various x-ray split&delay

European XFEL

SASE FEL progress at LCLS @ SLAC



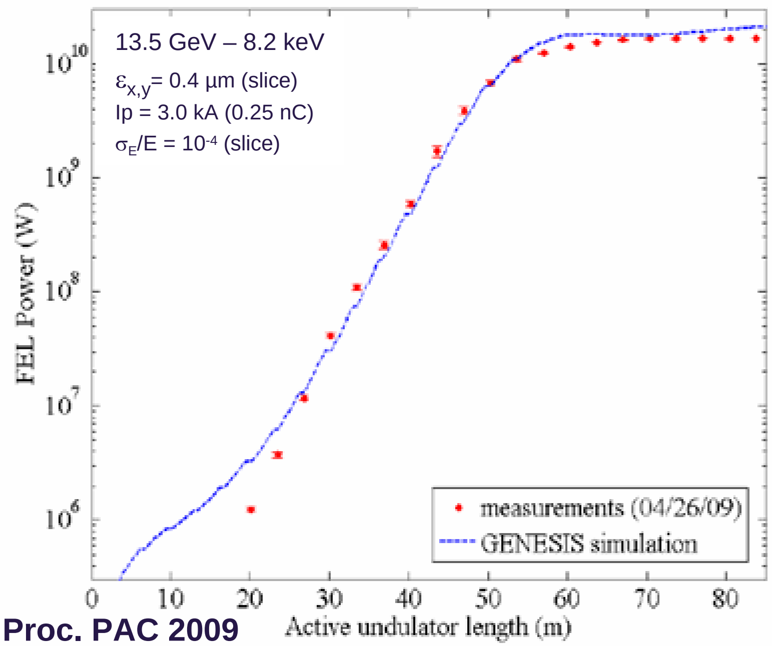


Extreme high performance at start

- 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)

Great progress for hard x-ray FELs !

- Hard x-ray FEL process work as predicted
- (Slice) emittance is key number
- Few femtosecond x-ray pulses are possible



P. Emma et al., Proc. PAC 2009

Expectations following LCLS start

At instrumentation workshops fairly general assumptions were made

Photon numbers	10^{12} (hard x-rays) to 10^{14} (soft x-rays)
Pulse duration	few femtoseconds to 100s of femtoseconds
Synchronisation	better 10 fs
Overall time resolution	<10 fs
Stability	positional <10 %
	spectral <<0.1 %
	temporal <100 fs
	coherence properties <10%
Tuning times	few minutes (max.)

Extrapolate this performance to high repetition rates

- Benefits
- Challenges

Scientific applications and high repetition rates

Requirement of high peak brilliance

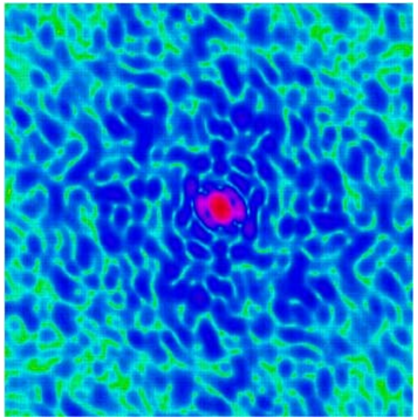
- scattering strength, e.g. to observe single-pulse diffraction pattern
- non-linear or multi-photon excitation

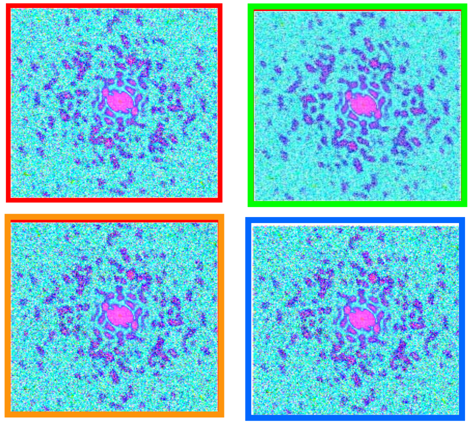
Requirement of high average brilliance

- collection of significant number of events
- ultra-dilute samples : extremely small number of scatterers per IA volume

Example: 3D structures by single particle coherent diffraction imaging

single shot diffraction pattern
⇒ high peak brilliance





10^5 – 10^7 patterns req. for 3D reconstruction
⇒ high average brilliance

Challenges using high repetition rates

Particle flight time (ions, electrons)

- Using time-of-flight detectors requires to uniquely define the time scale. While electrons are fast and likely enable MHz pulse rates, for ions the typical flight times are (many) microseconds.
  - → **A limitation in repetition rate to ~20/50 – 100 kHz for ion TOF measurements**

Sample excitation due to x-ray or optical laser

- Stroboscopic pump-probe experiments are generally limited in usable repetition rate by decay of the sample system (excited by opt. laser, FEL or other means).
- Decay can easily take up to few 100 ns (⇒1 MHz) or even up to µs (⇒100 kHz).

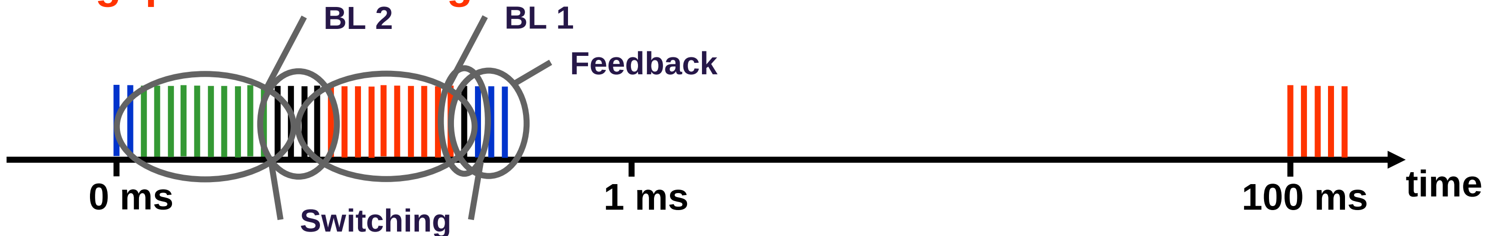
Sample damage due to intense x-ray

- Usually not a problem for x-ray science, but full intensity FEL pulses can interact strongly, in particular when focussed.
- Sample damage will make exchange before arrival of the next pulse necessary. Currently laser facilities move from sub-Hz to the 1 – 10 Hz regime ! This could turn into general limitation for FEL experiments on solids (and certainly for >kHz).

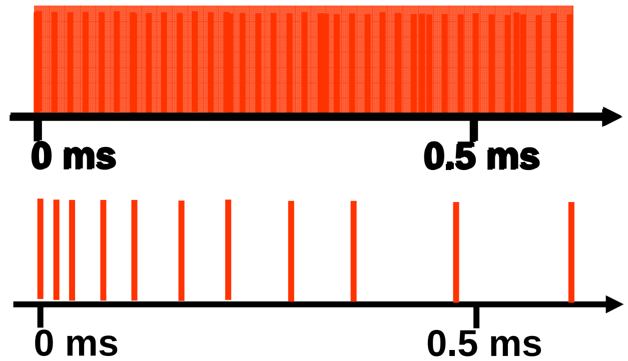
European XFEL time structure

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**



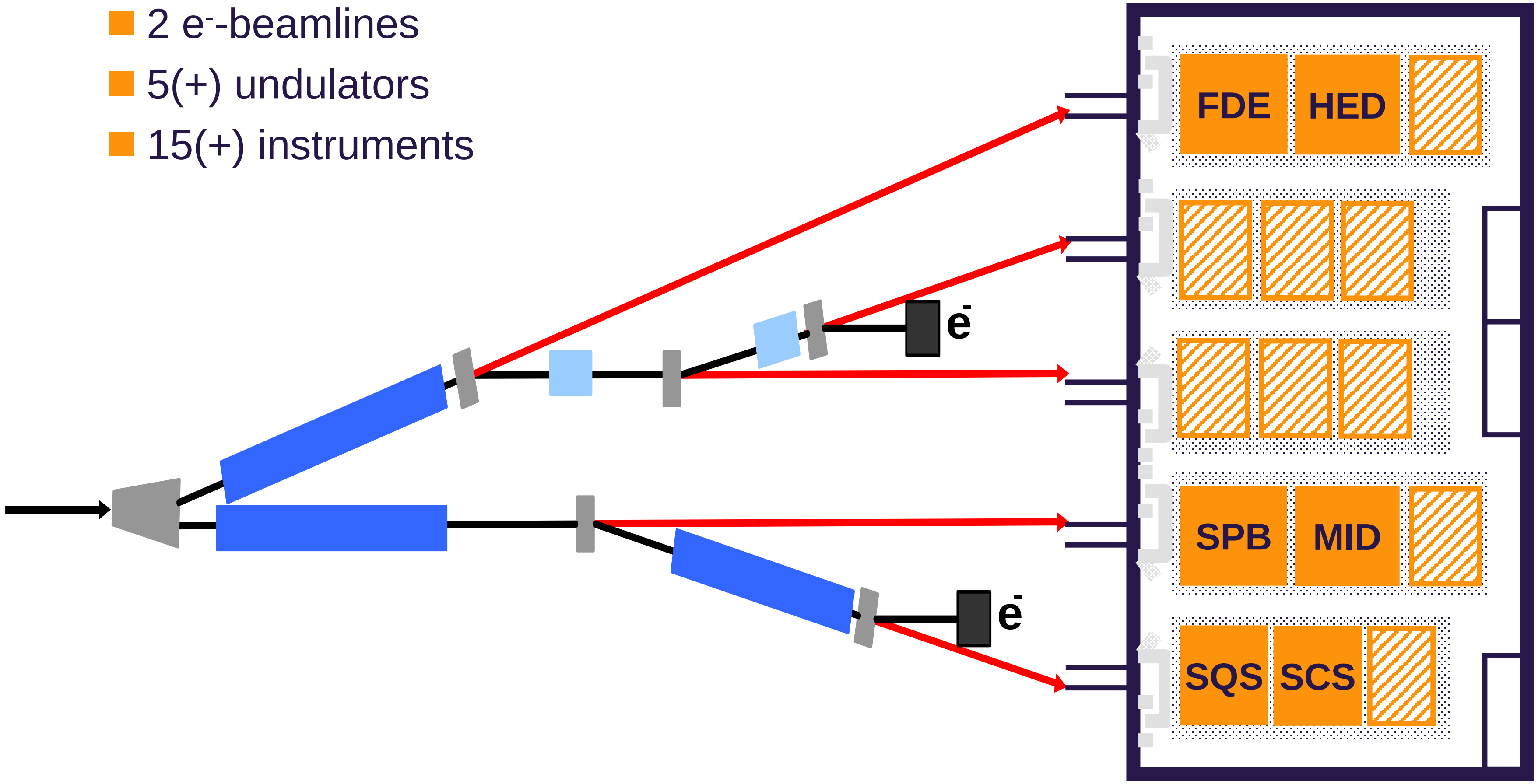
- time pattern for each beam line can be determined by experiment
  - ➔ **single pulses**
  - ➔ **medium repetition rate (10 – 100 kHz)**
  - ➔ **high repetition rates (0.1 → 1 → 4.5 MHz)**
  - ➔ **special fills**
    - logarithmic distribution
    - shorter distances (~700 ps – 200 ns)



Simultaneous operation of many instruments

Within the bunchtrain

- 2 e⁻-beamlines
- 5(+) undulators
- 15(+) instruments



Boxes only placeholders !

Development strategy I (Start of operation 2015)

Goals

- optimize to generate state-of-the-art (in 2015!) multi-user facility
  - ➔ **recognize and react to user requests**
  - ➔ **investigate and react to LCLS results**
- retain flexibility as to further external and internal inputs and ideas

A. Confirm "Burst Mode" operation for the European XFEL

- Make the most out of this operation mode !

B. Take advantage of lower emittance results

- Optimize parameters; refine working point

C. Incorporate emerging user requests

- Adapt to user request; improve user facility aspect

Confirm “Burst Mode” operation for the European XFEL

- **Provide maximum number of pulses per second**
- **Distribute pulses efficiently to many users quasi in parallel**
- **Cater for variable time patterns for the different undulator beam lines**
- **Develop schemes to maximize user throughput**

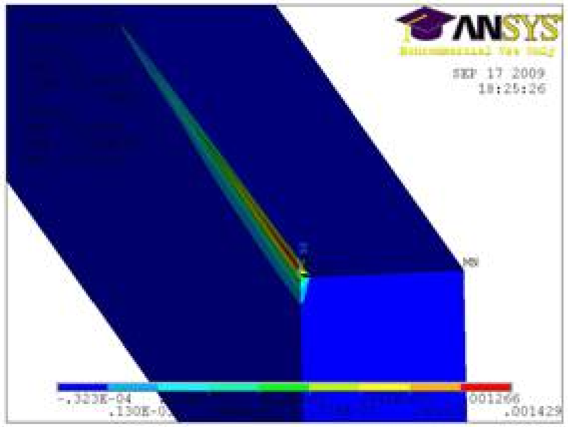
⇒ **Push**

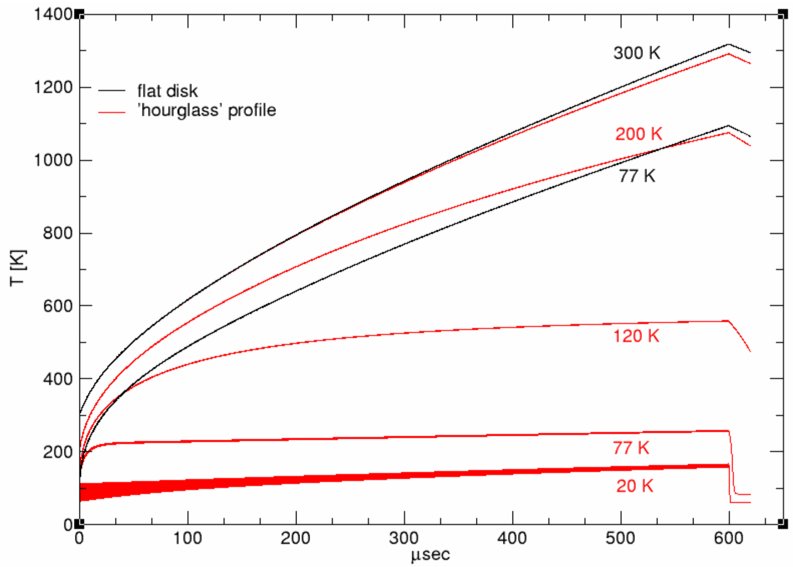
- Fast bunch distribution schemes
- X-ray optics R&D
- Sample environment technologies
- 2D detector developments and DAQ/Data Management
- Triggering capabilities (“event selection”)
- Analysis procedures of vast amount of data
- Laser development

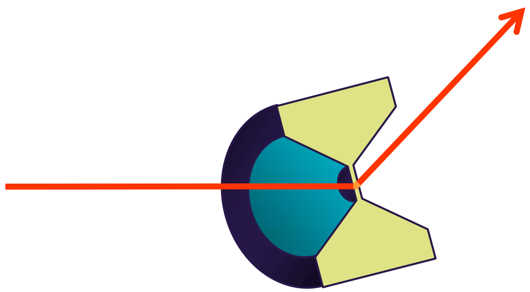
Push burst mode: X-ray optics

High repetition rate corresponds to high average power

- Extreme flatness mirrors
  - ➔ **Si bulk, diamond coating, 300 K, 3000 pulses/600 µs, 12 keV**
    - Heat bump of ~1.4 nm
  - ➔ **Si bulk , diamond coating, 150 K, 3000 pulses/600 µs, 0.2 keV**
    - Heat bump of ~2 nm
- Monochromators
  - ➔ **Thin diamond in Laue geometry**
  - ➔ **Expand x-ray beam**
    - Si possible (ΔT~15 K)







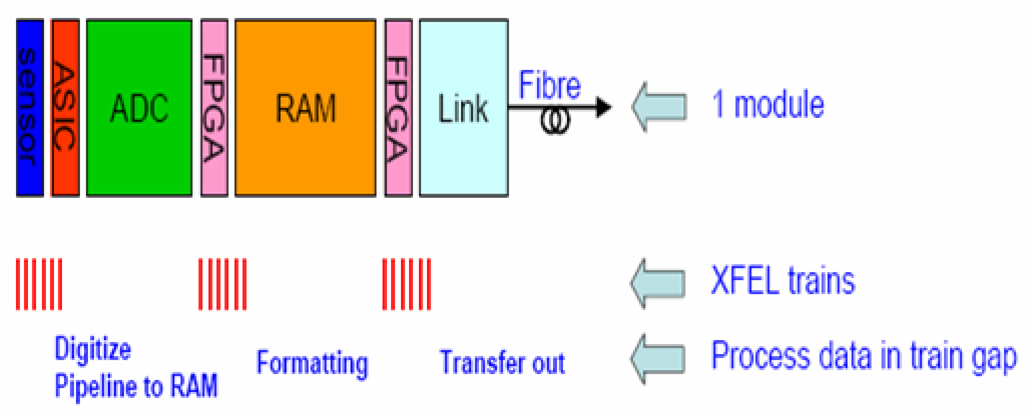
Push burst mode: 2D detectors & DAQ/DM

2D detector developments for "burst mode" capability

- three developments with world experts ongoing since 2007
- no principal show stoppers found (→Detector Advisory Committee)
- pixel size and frame storage are interconnected
  - ➔ **minimum pixel size ~200 µm**
  - ➔ **number of frames per train that can be stored limited (~200→500→1000)**
  - ➔ **invoke "triggering" strategies (reject "empty" or "bad" events)**

DAQ & Data mangement strategies

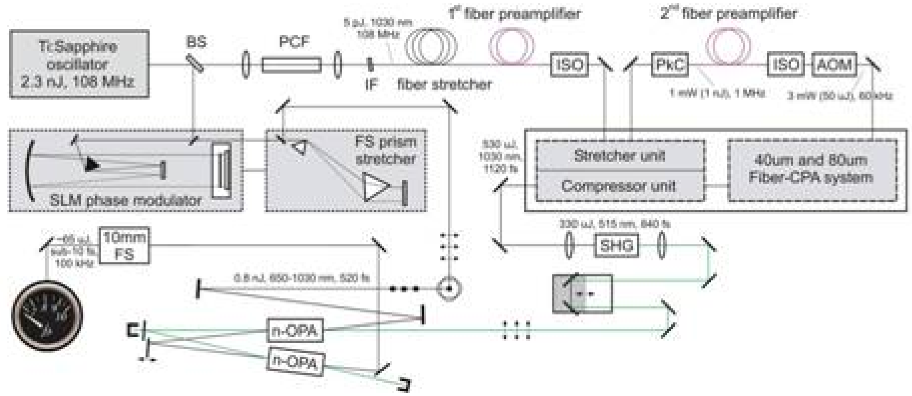
- High frame rates
- Large storage volume
- Data utilisation strategies



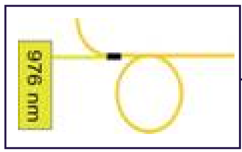
Push burst mode: Optical laser development

Experiments high repetition rate laser systems with 0.1 – 4.5 Mhz

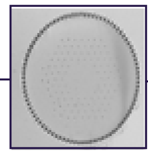
- >1 mJ pulse energy requested for several applications (some trade-off possible between rep.rate and pulse energy)
- Few fs pulse duration & overall time-resolution <10 fs
- Proof of concept
  - ➔ **100 kHz, ~65 µJ, <8 fs**
    (Optics Lett. accepted)



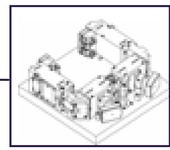
- Increase pump power



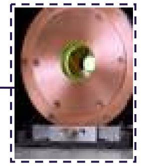
fiber preamplifier



CPA fiber amplifier



Yb:YAG slab amplifier



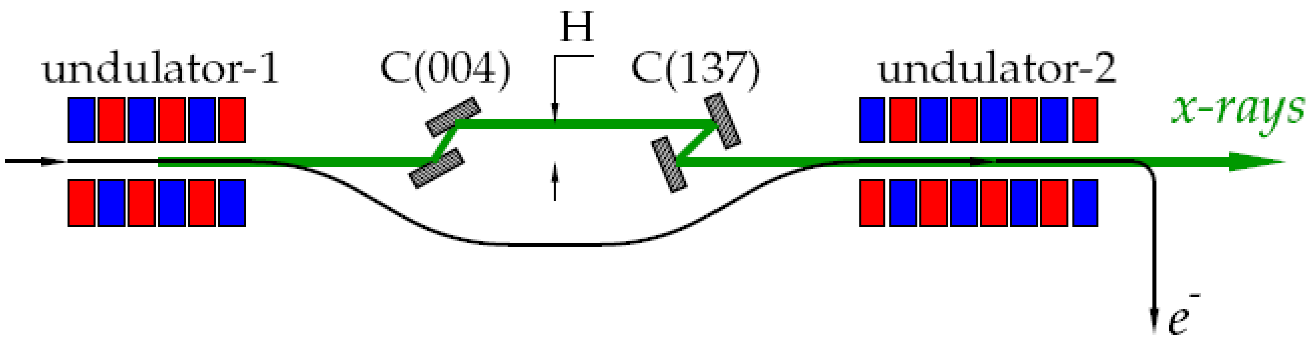
Yb:YAG thin disk amplifier (Trumpf GmbH)

Collaboration:
DESY
Uni Jena
ILT Aachen
European XFEL

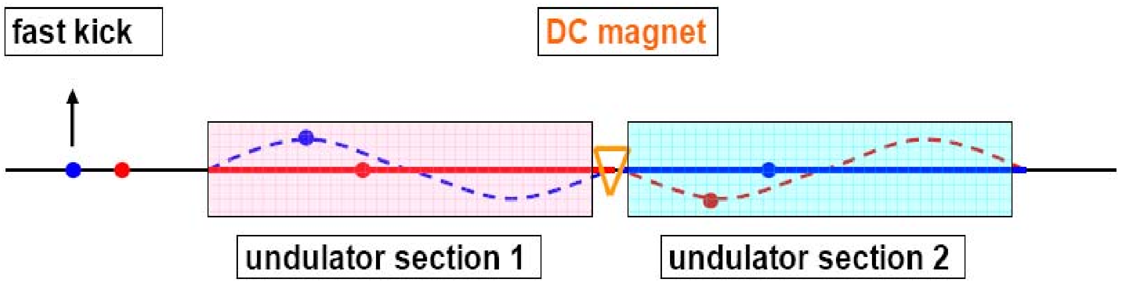
Take advantage of lower emittance results

New, improved FEL scenarios become possible

- Undulators allow for saturation at 20-25 keV photon energy (talk RB)
- Self-seeding could replace high res. monochromators



- Fast e-bunch deflection for improved photon delivery (talk RB)
  - ➔ **Two-colors**
  - ➔ **Angular separation**



Incorporate emerging user requests

- **Adjust photon wavelength ranges of SASE1 to SASE3 (lower E_{ph})**
- **(Re)introduce variable polarization for SASE3 (using freed funds)***
- **Refine layout of instruments**
  - Main applications
  - Instrumentation needs
    - ➔ **Special x-ray optics**
    - ➔ **Detectors (number, smaller pixel, 1D, X-ray streak camera)**
    - ➔ **Lasers**
    - ➔ **Sample delivery & environment**
  - Identify facility vs. user contributions to instruments

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Development strategy II (Longterm)

Fill the remaining tunnels and instrument areas (→ €€€…)

- U1, U2, SASE3*, SASE4?
- 6 → 10 → 15 instruments

Investigate CW mode of operation (see talk R. Brinkmann)

- European XFEL is the only machine existing where such a switch is possible within “reasonable” costs
- Continue participation in R&D on a limited scale (DESY)
- Would need considerable additional resources
- Decision not before 2015

Conclusions

- **European XFEL is in the process of refining the**
  - x-ray beam delivery
  - Scientific instruments
- **First series of instrumentation workshops 2008/09**
- **LCLS results confirm x-ray FELs and promise improved performance**
- **Strategy for start of operation (2015) and longterm established**
- **Proceed with layout and first conceptual designs**

Thank you
for your attention &
for very valuable input