The European X-ray Free Electron Laser: the first high repetition-rate XFEL

European XFEL

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Hamburg, Germany

ALBA, April 25, 2017

ENLIGHTENING SCIENCE

Overview

- Free Electron Lasers in the x-ray range: scientific goals
- Worldwide status of XFEL facilities
- The European XFEL in Hamburg: layout and main components
- Beamline optics and diagnostics
- Experiment stations, User Consortia
- Lasers, detectors, data acquisition
- Conclusions

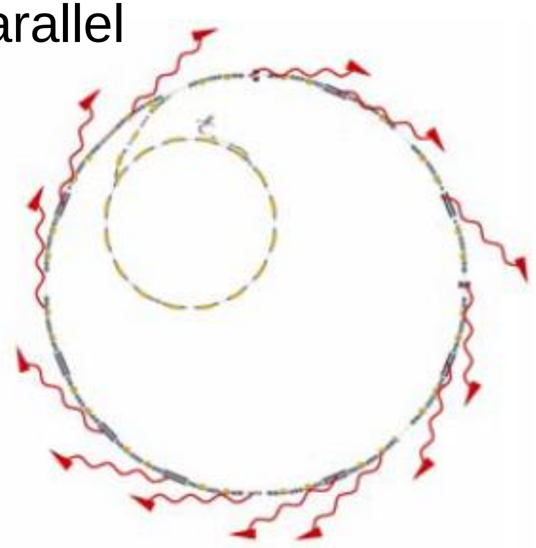
Accelerator-based light sources: Third-generation synchrotrons

- About 50 dedicated storage rings for X-ray production and scientific use worldwide

- A great scientific success story
- Six Nobel prizes in Chemistry awarded for studies on the structure of biological macromolecules performed with Synchrotron Radiation

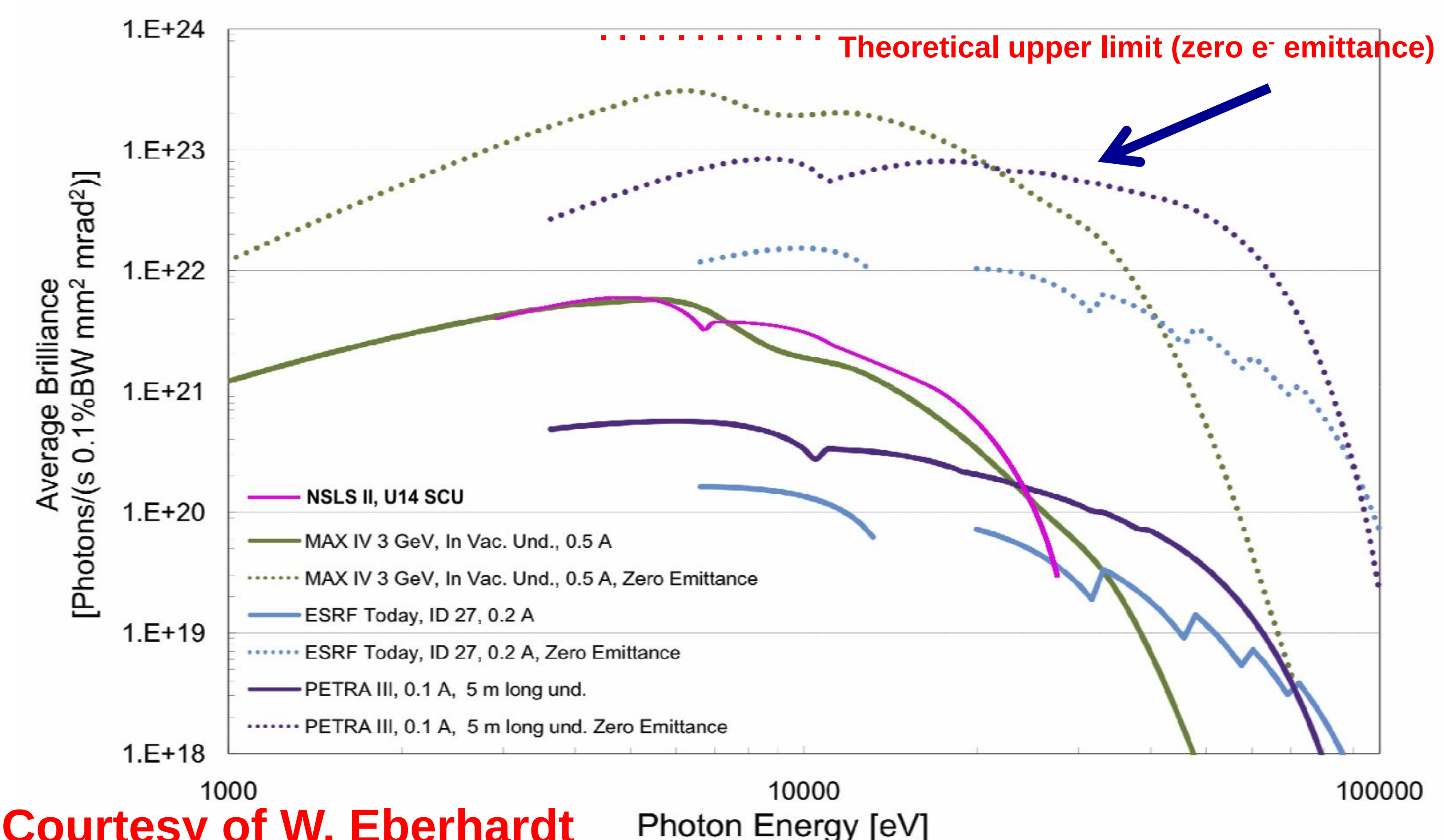
Important properties of storage ring sources

- High pulse-to-pulse reproducibility
- High stability of intensity, position, spectral properties
- High repetition rate
- Geometry allowing a large number of source points/beamlines and instruments operated in parallel

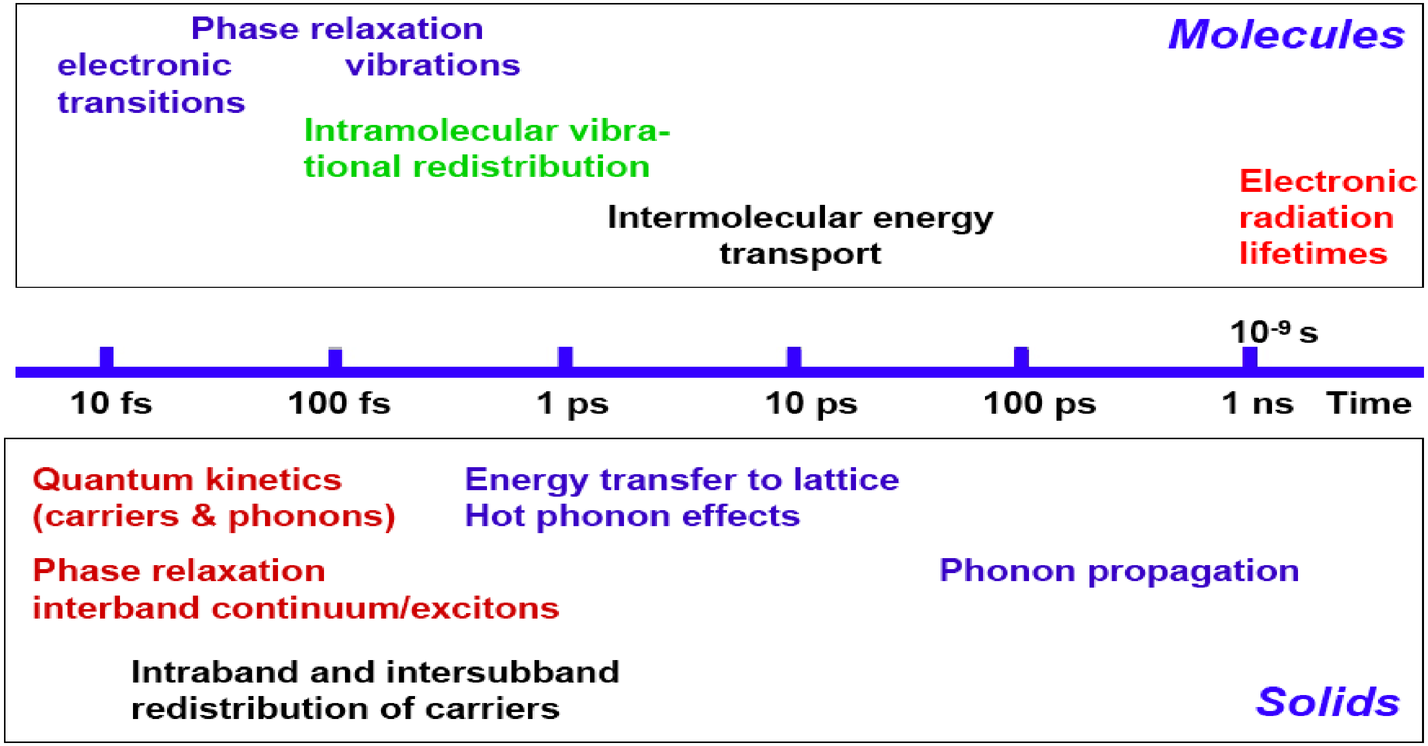


However…

Fundamental limits to brilliance of storage rings



Courtesy of W. Eberhardt



Compression of electron bunches to **<100 fs** preserving (or even increasing) the brilliance and number of photons per bunch is impossible in a storage ring configuration, where the same electrons run through the undulators ~ 10^6 times per second.

This can however be achieved in a single-pass machine such as a linear accelerator, with suitable bunch compressors.

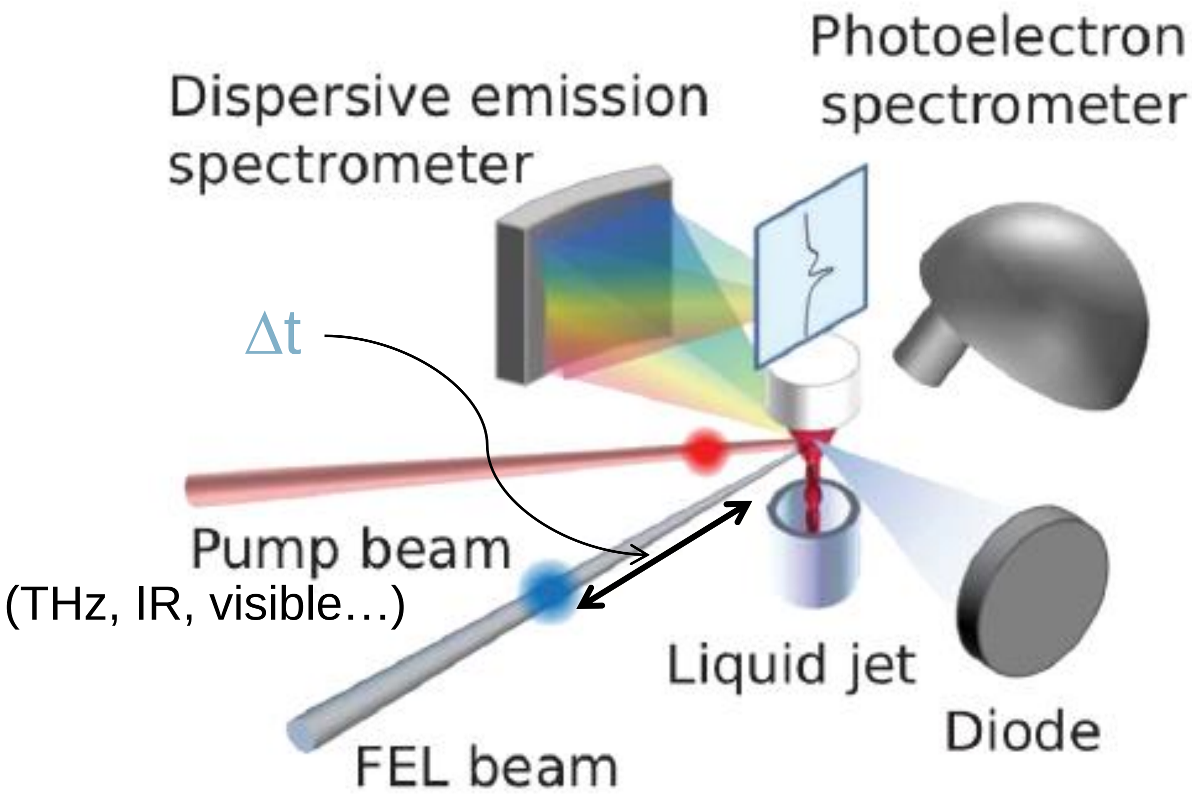
Scientific interest of ultrabright,ultrashort (<100 fs = 10^{-13} s) pulses

- “Molecular movies”
- Beating radiation damage: ”Diffraction before Destruction”

"Pump – probe" experiments

- Interrogate system by the XFEL beam, at time Δt after triggering a process by the pump optical laser beam.

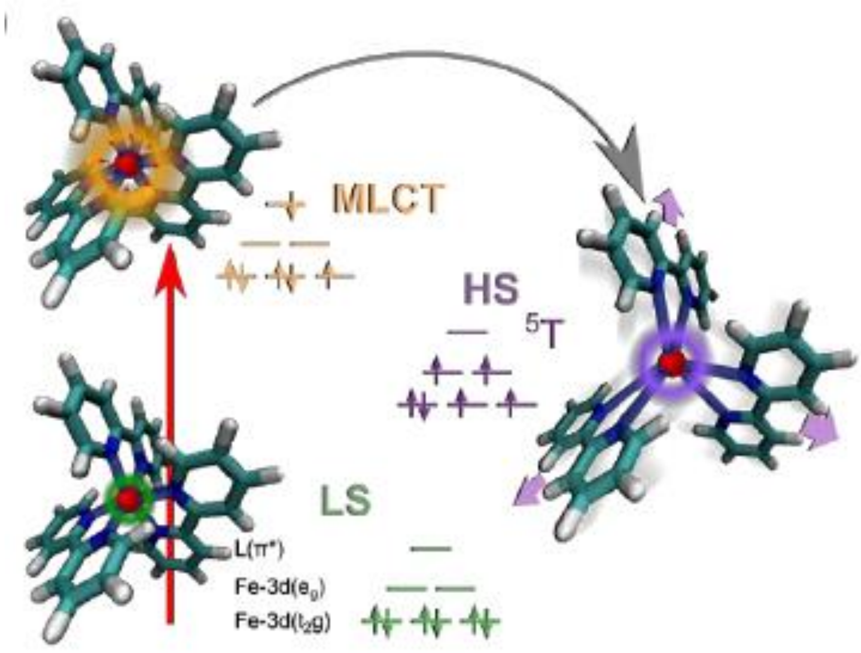
- By varying pump-probe delay Δt, record a "molecular movie



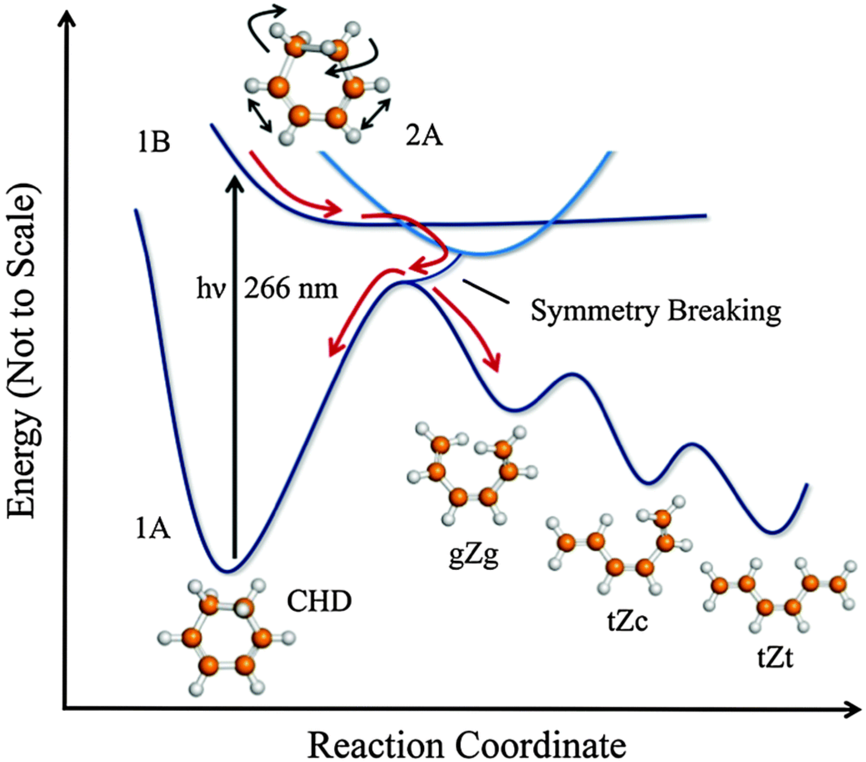
*(After C. Bostedt et al., Rev. Mod. Phys. **88**, 015007 (2016))*

Molecular Movies

Low-spin – High-spin transition in TM bypiridines via electronic excitation



Laser induced isomerization



Time resolution affected by a) pulse duration, b) synchronization & jitter

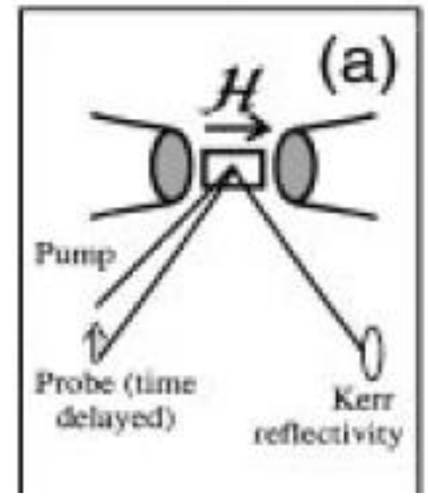
Realistic limit ~ 50 -100 fs

Ultrafast demagnetization by a fs laser pulse: a puzzle since more than 20 years

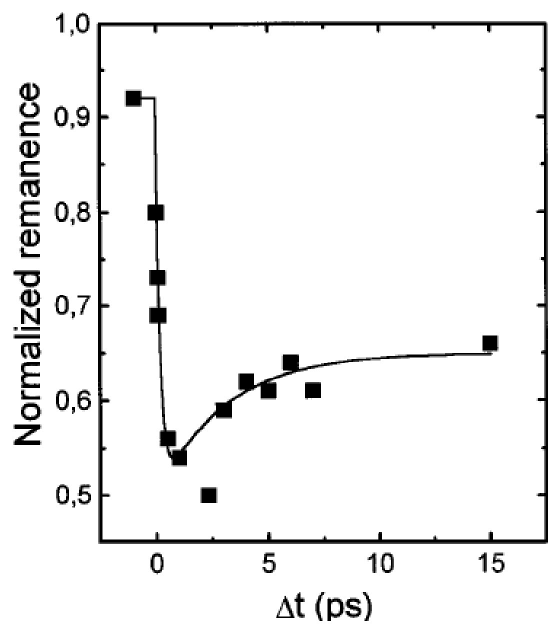
VOLUME 76, NUMBER 22 PHYSICAL REVIEW LETTERS 27 MAY 1996

Ultrafast Spin Dynamics in Ferromagnetic Nickel

E. Beaurepaire, J.-C. Merle, A. Daunois, and J.-Y. Bigot
Institut de Physique et Chimie des Matériaux de Strasbourg, Unité Mixte 380046 CNRS-ULP-EHICS, 23, rue du Loess, 67037 Strasbourg Cedex, France
(Received 17 October 1995)



Pump: 60 fs laser



Two time scales:

One is << *1 ps*

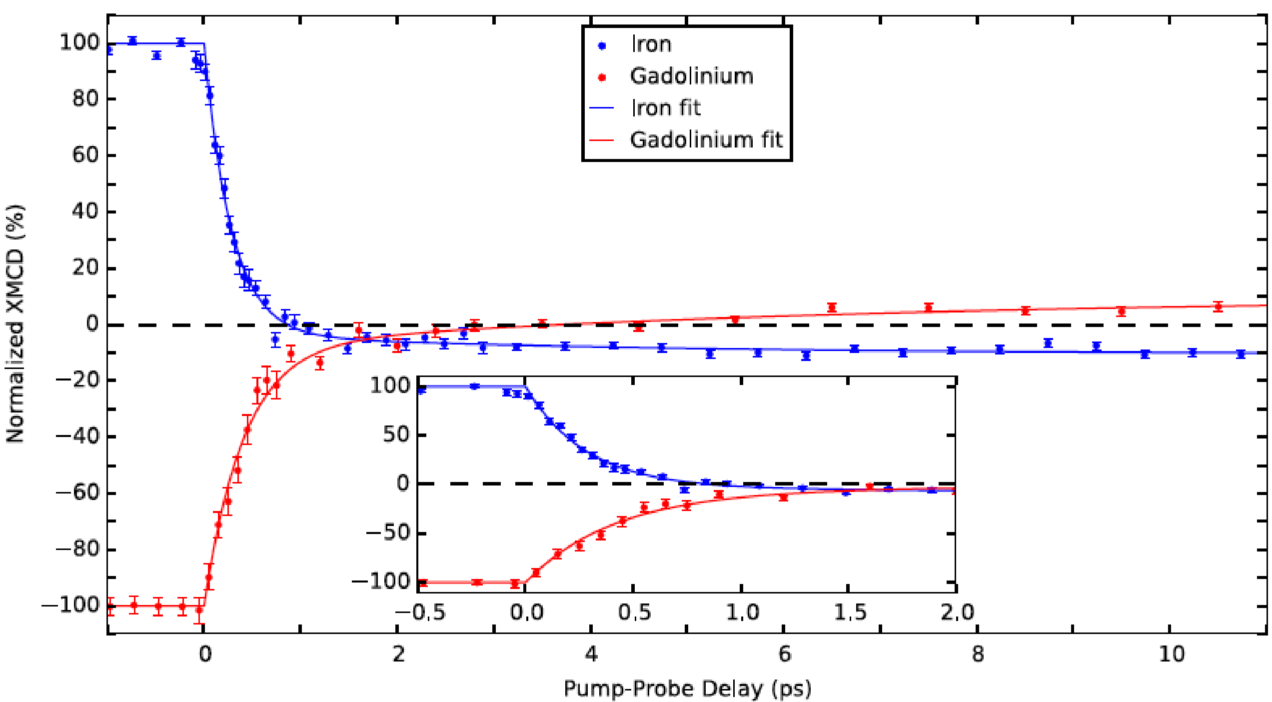
One is ~ *10 ps*

Ferrimagnetic Iron-Gadolinium

REVIEW OF SCIENTIFIC INSTRUMENTS **87**, 033110 (2016)

Femtosecond X-ray magnetic circular dichroism absorption spectroscopy at an X-ray free electron laser

Daniel J. Higley,[1,2,a)] Konstantin Hirsch,[1] Georgi L. Dakovski,[1] Emmanuelle Jal,[1] Edwin Yuan,[1,2] Tianmin Liu,[1,3] Alberto A. Lutman,[1] James P. MacArthur,[1,3] Elke Arenholz,[4] Zhao Chen,[1,3] Giacomo Coslovich,[1] Peter Denes,[4] Patrick W. Granitzka,[1,5] Philip Hart,[1] Matthias C. Hoffmann,[1] John Joseph,[4] Loïc Le Guyader,[1,6,7] Ankush Mitra,[1] Stefan Moeller,[1] Hendrik Ohldag,[1] Matthew Seaberg,[1] Padraic Shafer,[4] Joachim Stöhr,[1] Arata Tsukamoto,[8] Heinz-Dieter Nuhn,[1] Alex H. Reid,[1] Hermann A. Dürr,[1] and William F. Schlotter[1]

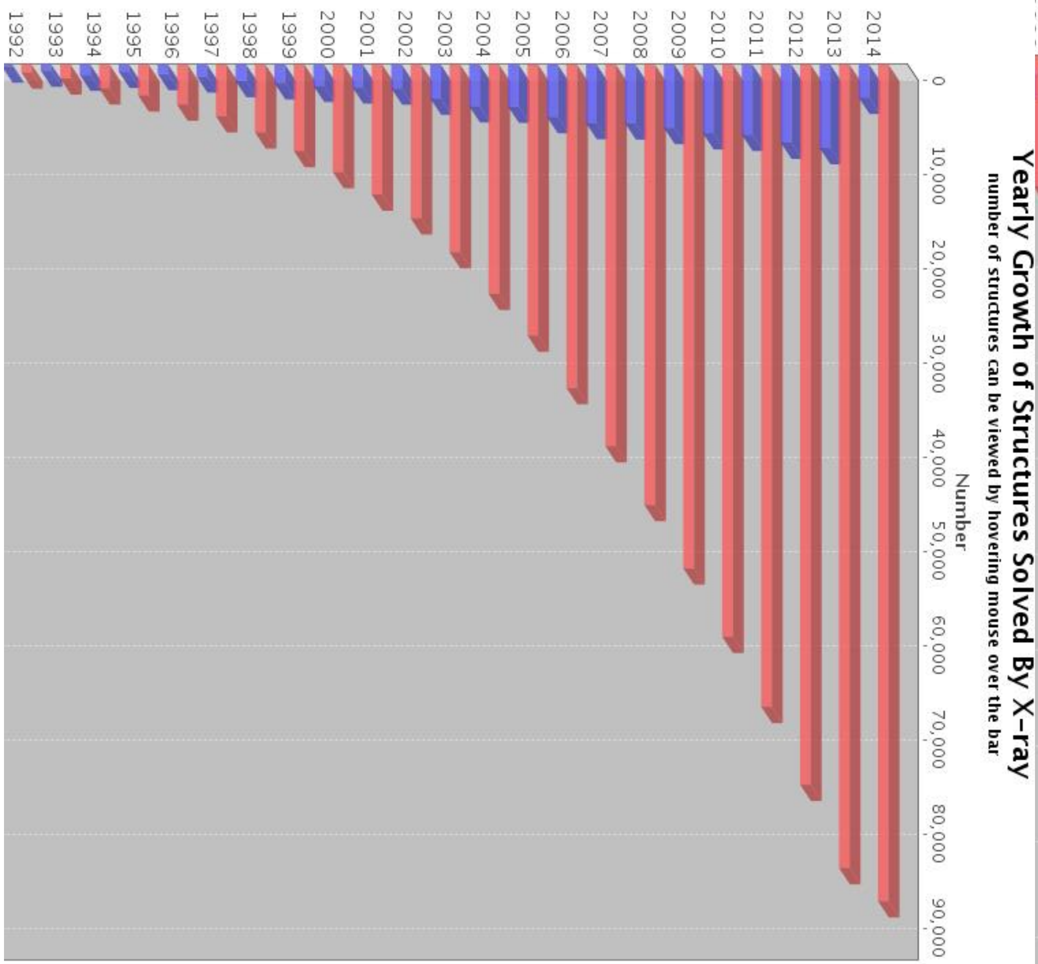


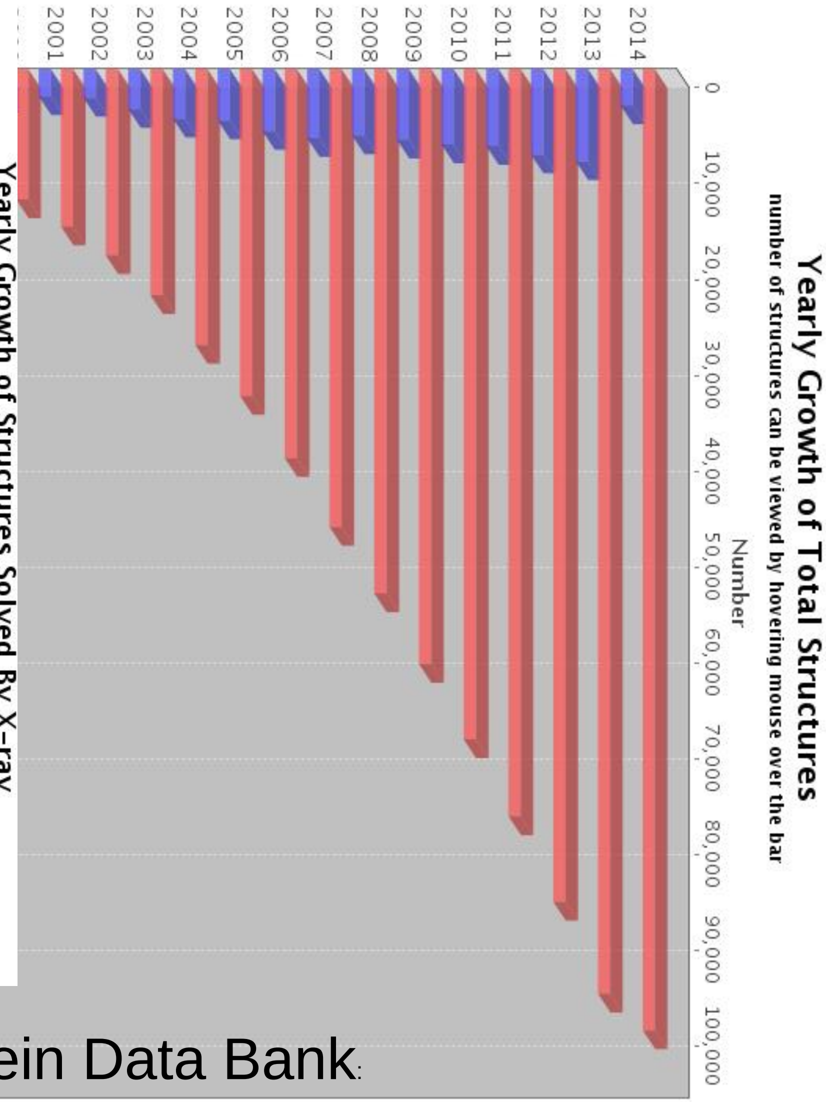
$Gd_{24}Fe_{66.5}Co_{9.5}$

410 fs, 6.5 ps

280 fs, 4.1 ps

Protein Data Bank: 100,000-th structure uploaded in 2014





~ 90% by synchrotron x-rays!

Source: Protein Data Bank

Update to 13.04.2017

- **Total number of structures: 129 184**
- **Of which solved by x-rays: 115 626**

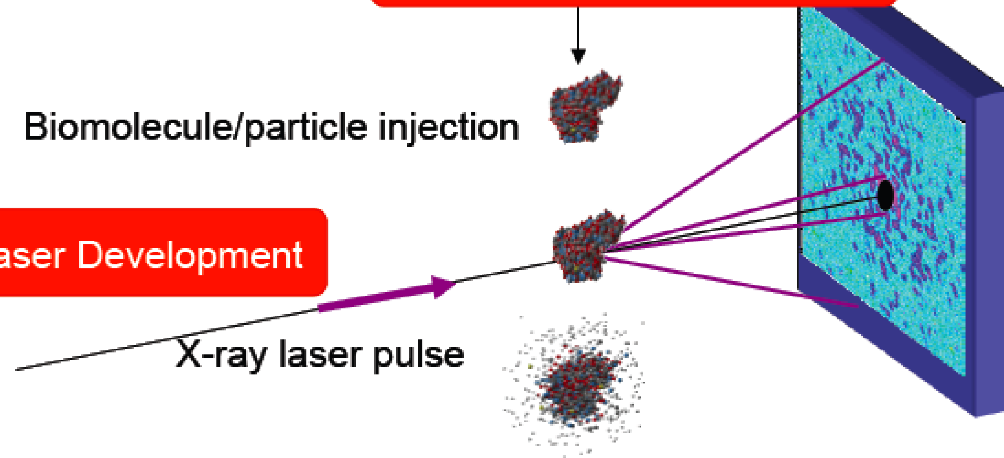
NMR: 11 777

Electron micr.: 1 465

Structural Biology: trying to bypass crystallization

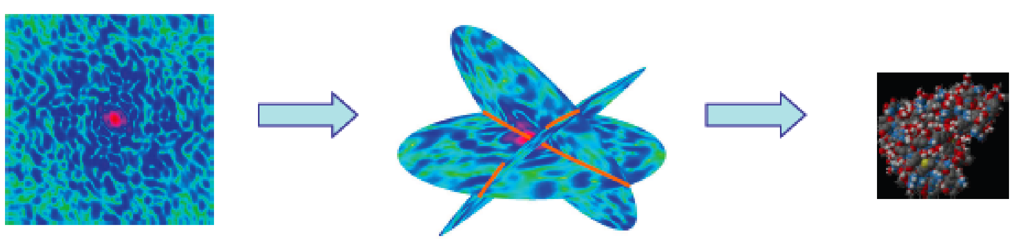
One pulse, one measurement

3. Nanoscale manipulation



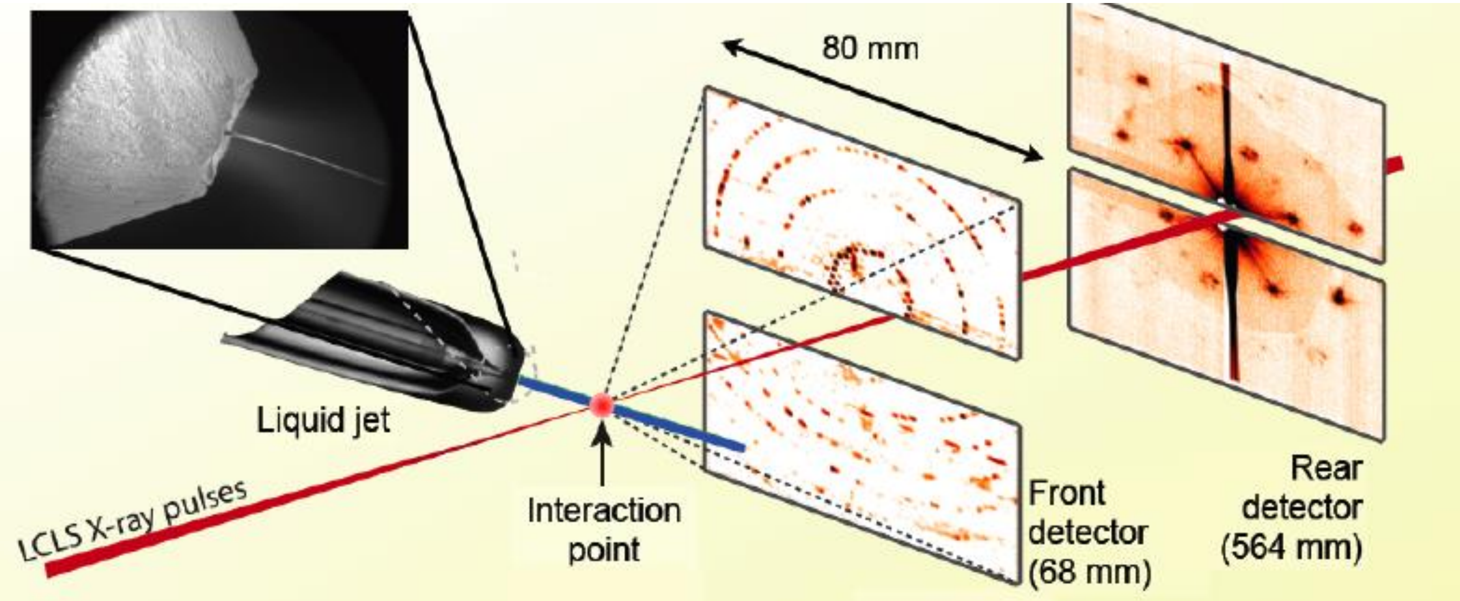
Combine many measurements

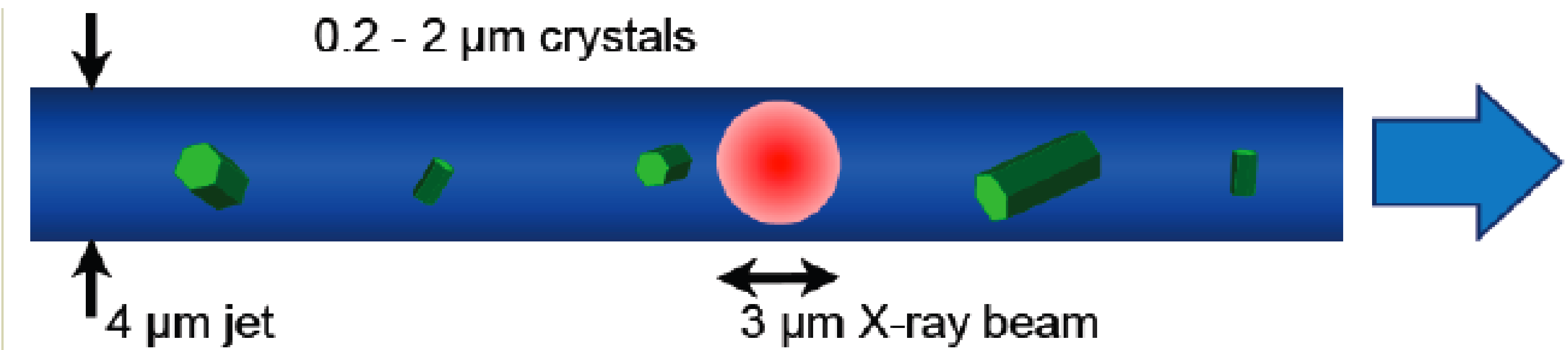
1. Theories of damage and imaging



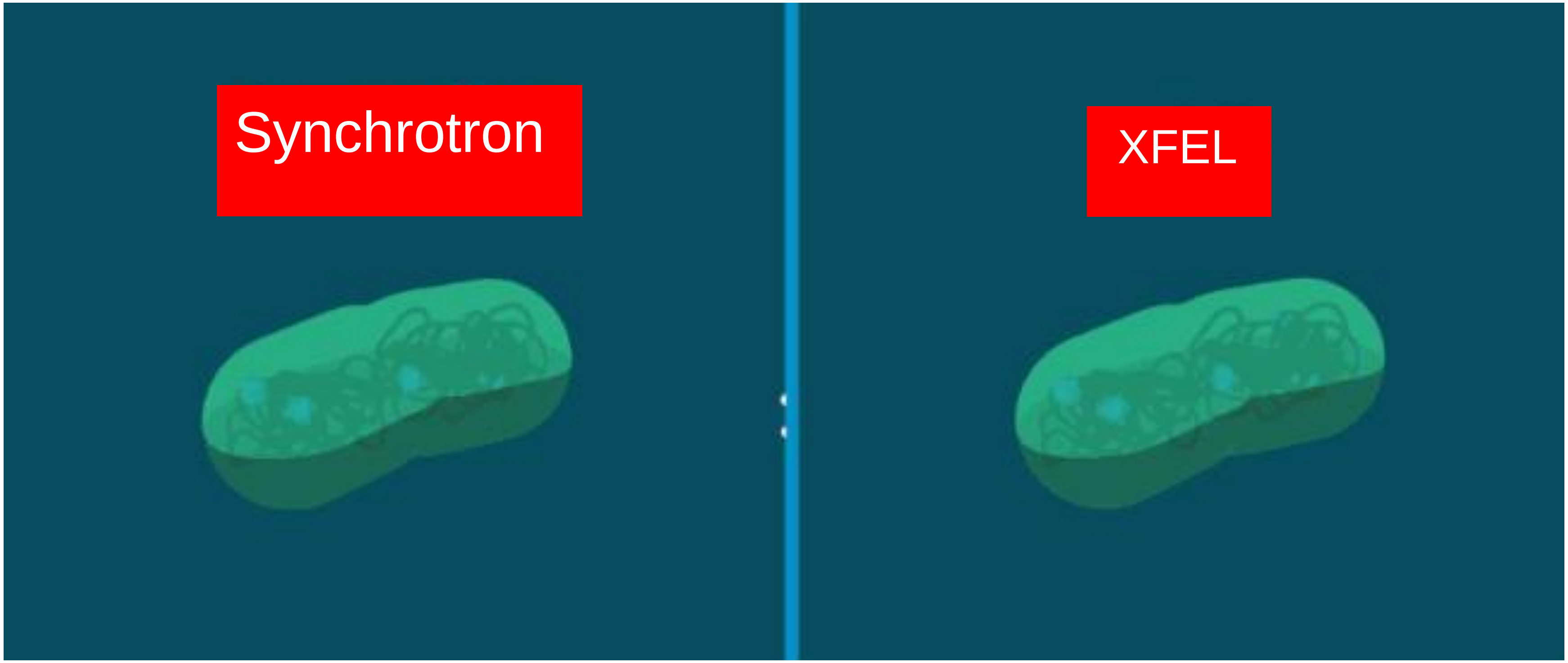
5. Data processing, phasing & reconstruction

Serial Femtosecond crystallography





Beating radiation damage: Diffraction before Destruction



Credits: www.slac.stanford.edu

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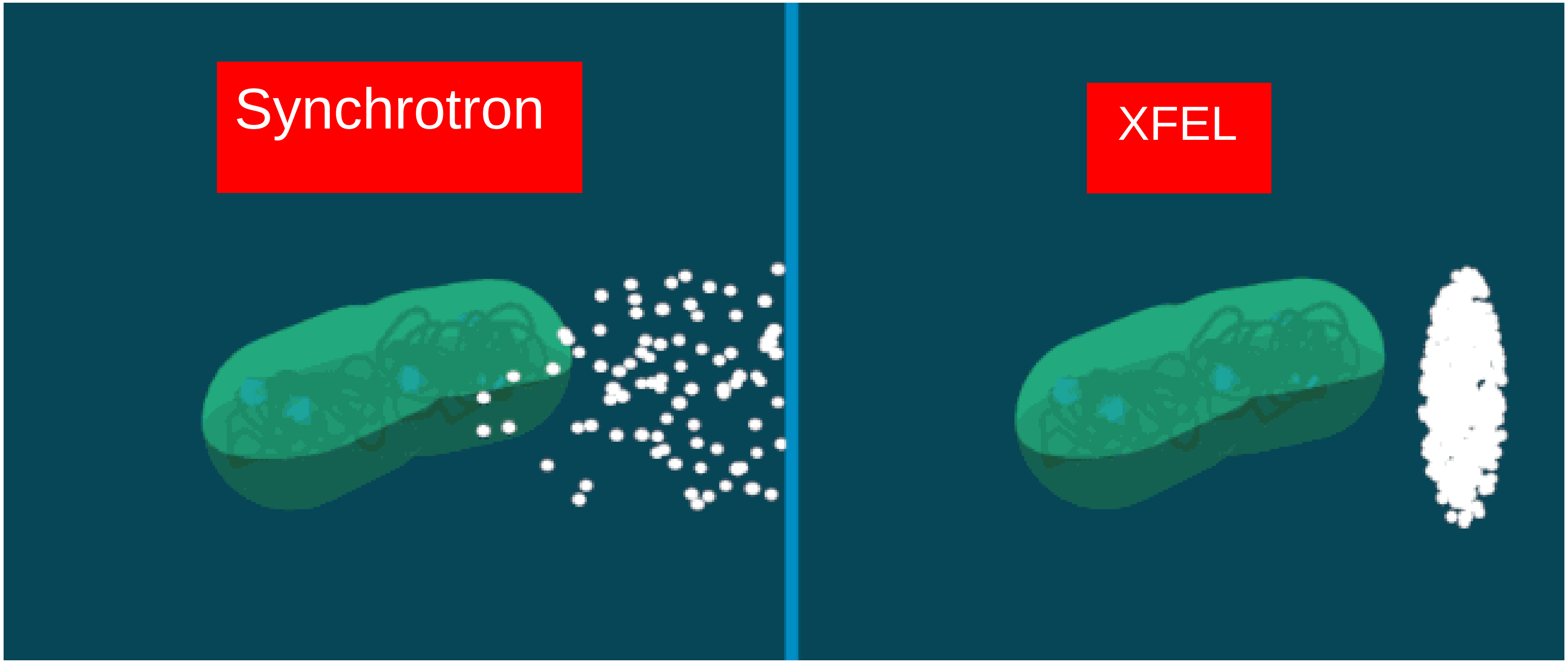

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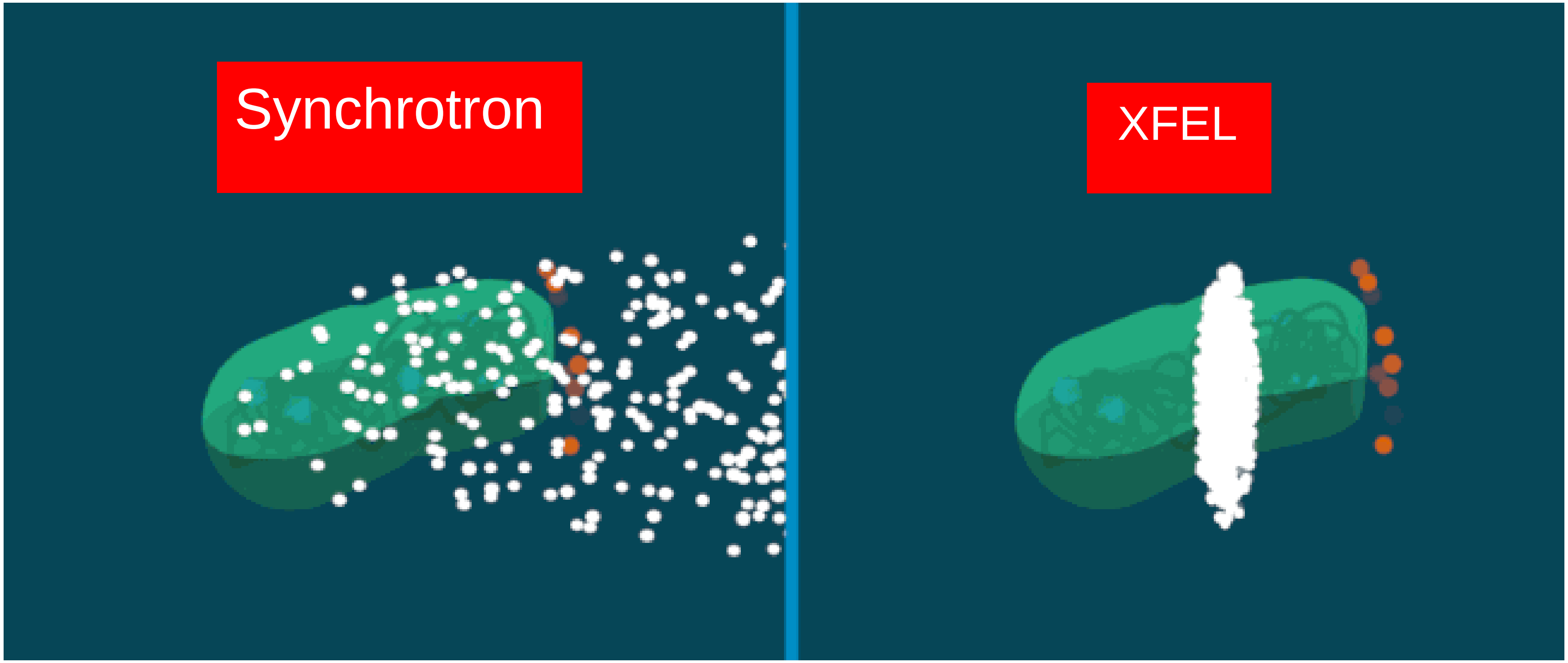

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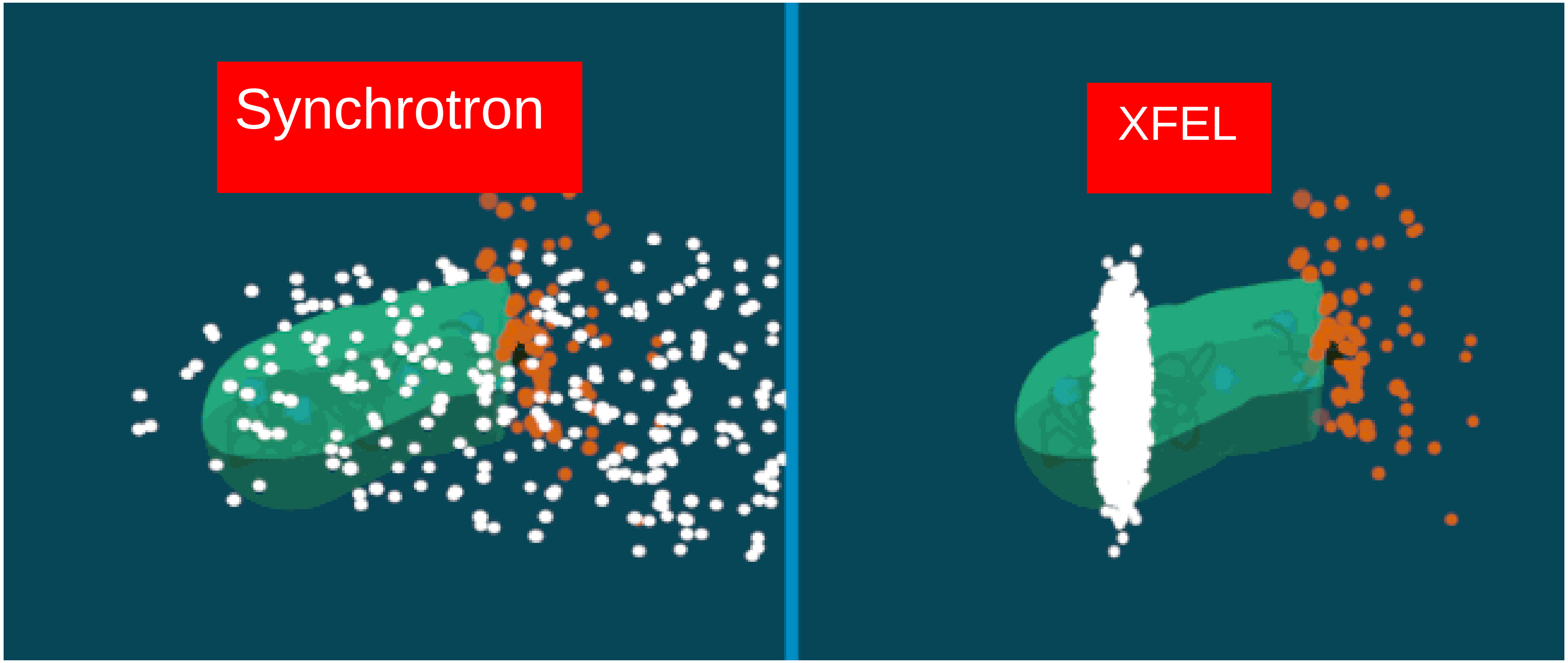

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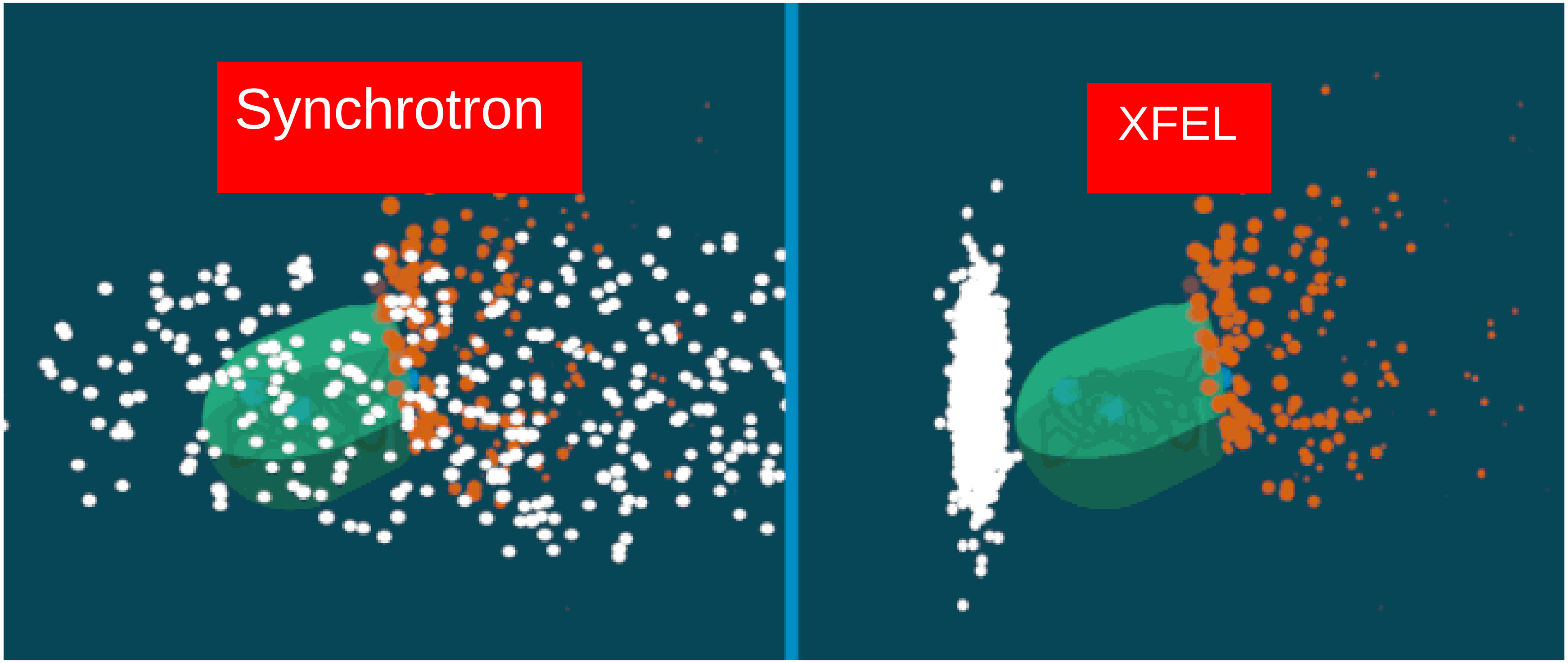


Credits: www.slac.stanford.edu

Photosynthesis, from solar photons to hydrocarbons

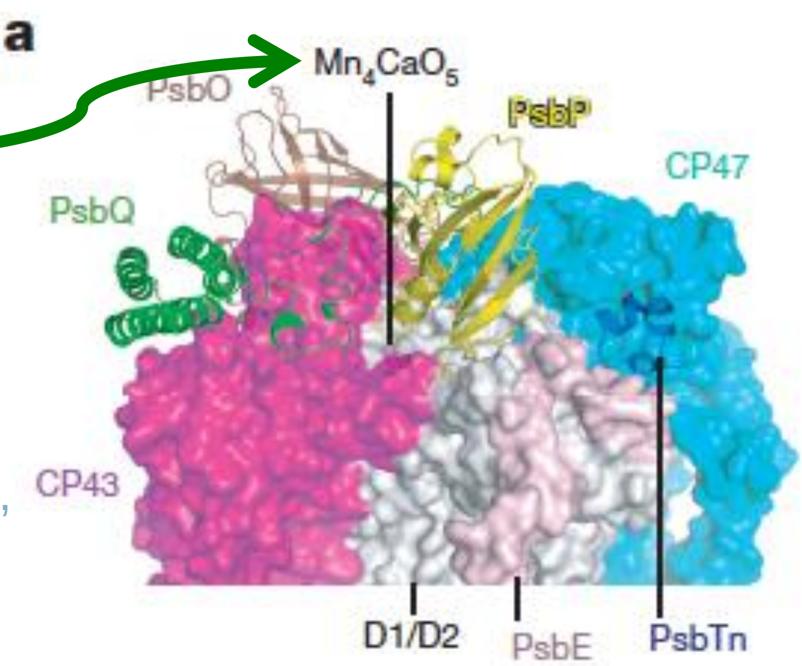
Photosystem II is a 700 kDa protein complex, through which the following reaction takes place in plants, algae, bacteria..:

$$2\,H_2O + 4\,h\nu \Rightarrow O_2 + 4H^+ + 4\,e^-$$

Travel separately to recombine elsewhere and power chemical reactions

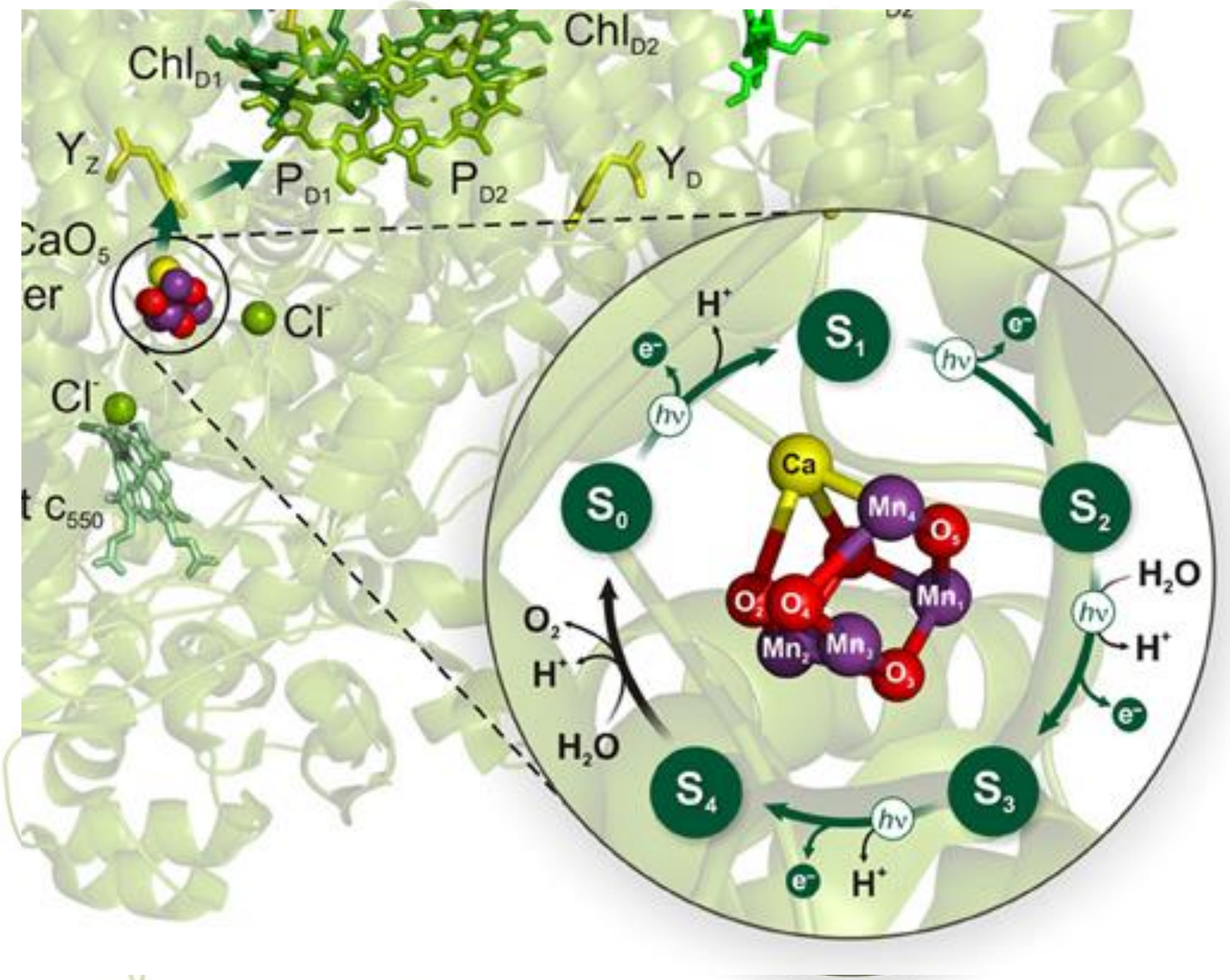
Evolves into the atmosphere

The energy of the four photons is delivered to the OEC “oxygen evolving complex”, Mn_4CaO_5, where most of the action seems to take place



X. Wei et al., Nature 2016, doi:10.1038/nature18020

The Kok Cycle: how does it work?



Big effort to elucidate Kok cycle steps with FEL's

J. Kern et al., Science **340**, 491-495 (2013)

Simultaneous Femtosecond X-ray Spectroscopy and Diffraction of Photosystem II at Room Temperature

Ch. Kupitz et al., Nature **513**, 261–265 (2014)

Serial time-resolved crystallography of photosystem II using a femtosecond X-ray laser

J. Kern et al., Nature Comm. **5**, 4371 (2014)

Taking snapshots of photosynthetic water oxidation using femtosecond X-ray diffraction and spectroscopy

M. Suga et al., Nature **517**, 99-103 (2015)

Native structure of photosystem II at 1.95 Å resolution viewed by femtosecond X-ray pulses

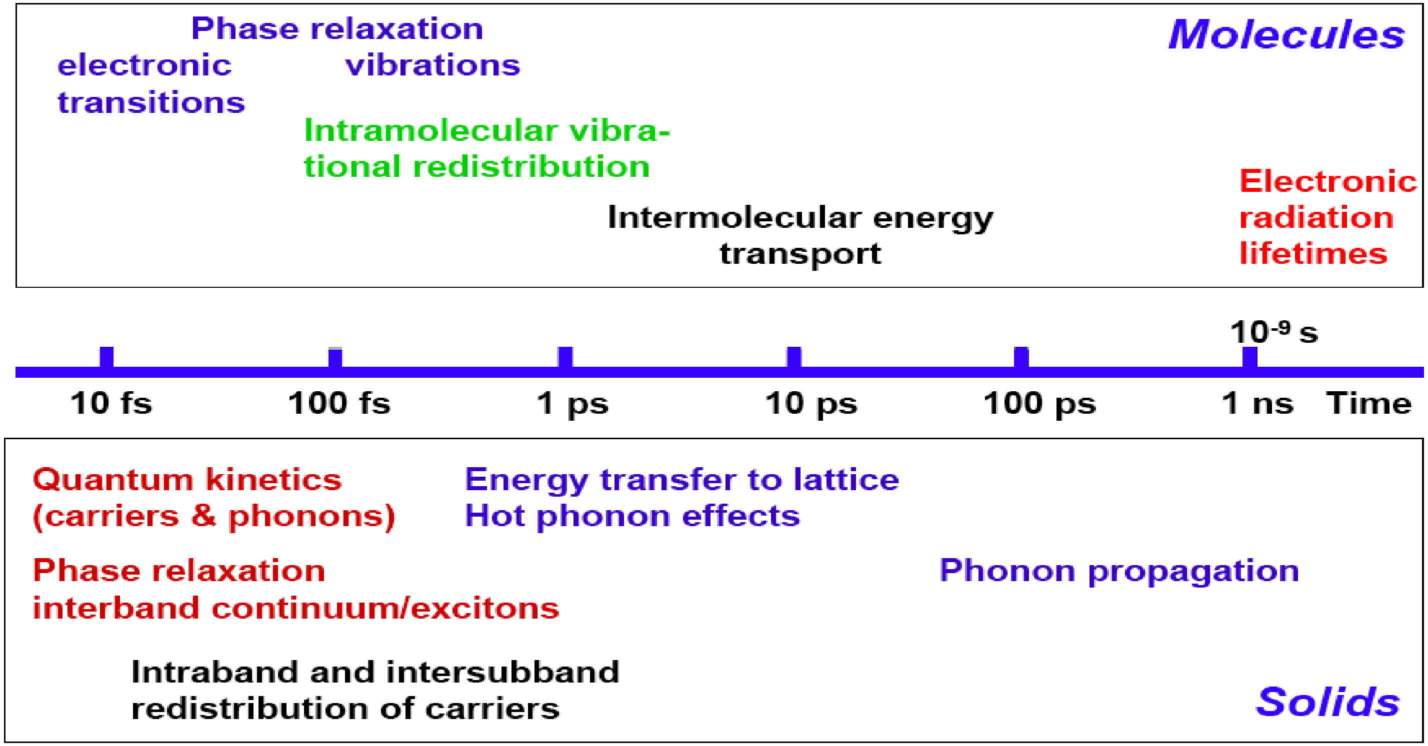
Other areas of great interest

- Non-linear X-ray optics: saturable absorption, stimulated emission/scattering…

- High energy-density, warm dense matter, plasma physics/astrophysics, high field QED

- Physics of liquids: structural information non averaged over relaxation times; higher order correlations…

- …..



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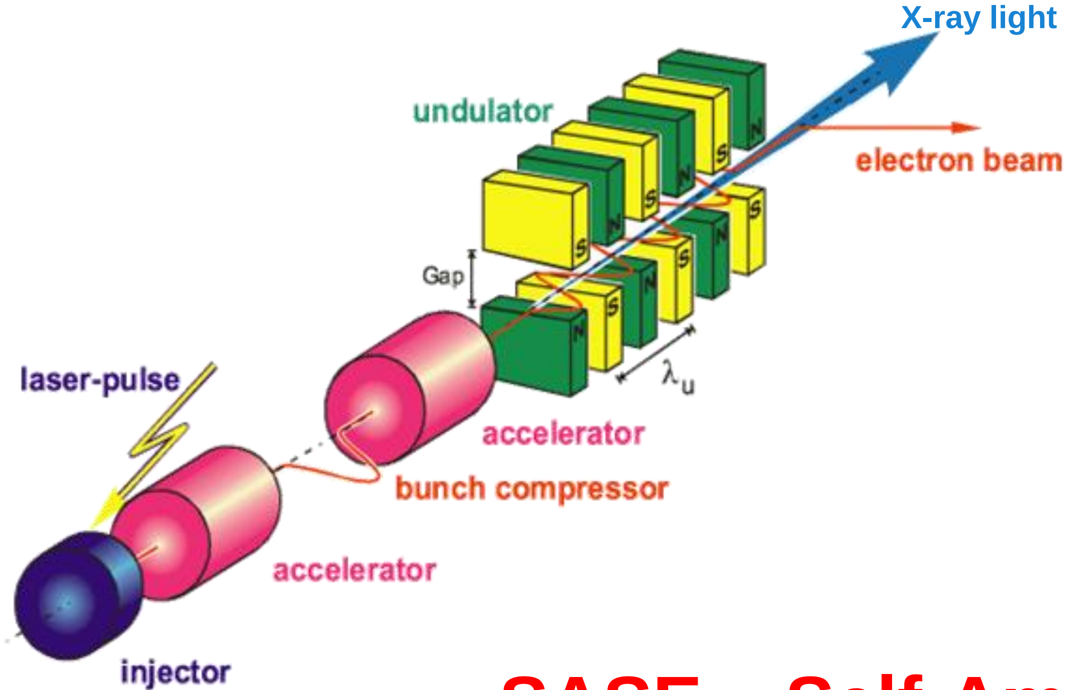
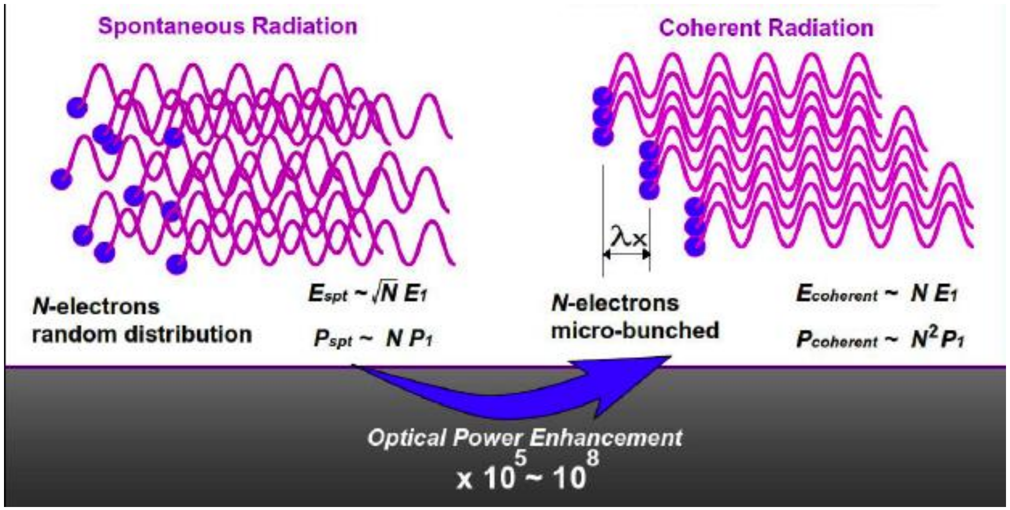
Free Electron Lasers

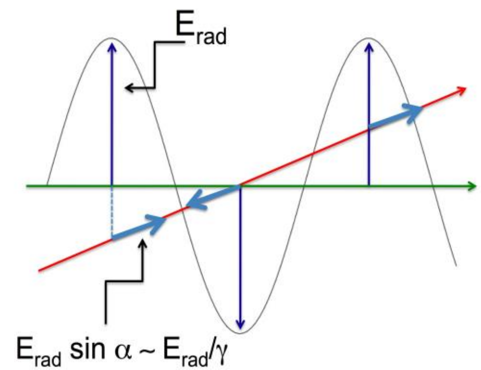


SASE – Self-Amplified Spontaneous Emission

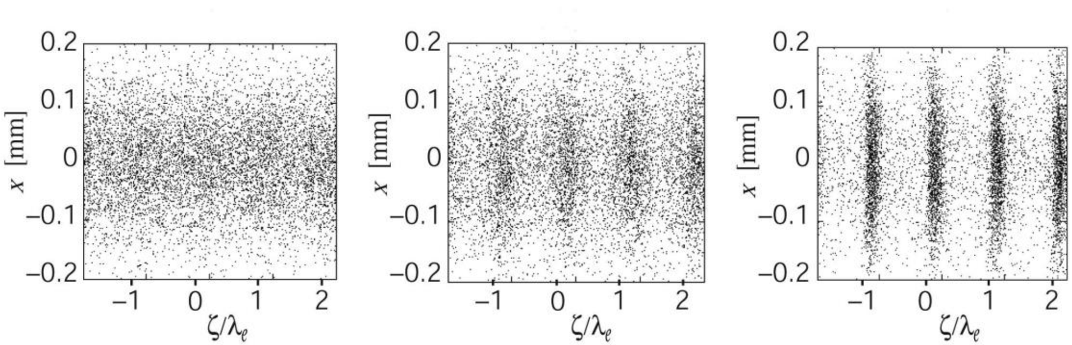
Kondratenko, Saldin (1979)
Bonifacio, Pellegrini, Narducci (1984)

Self-Amplified Spontaneous Emission (SASE)





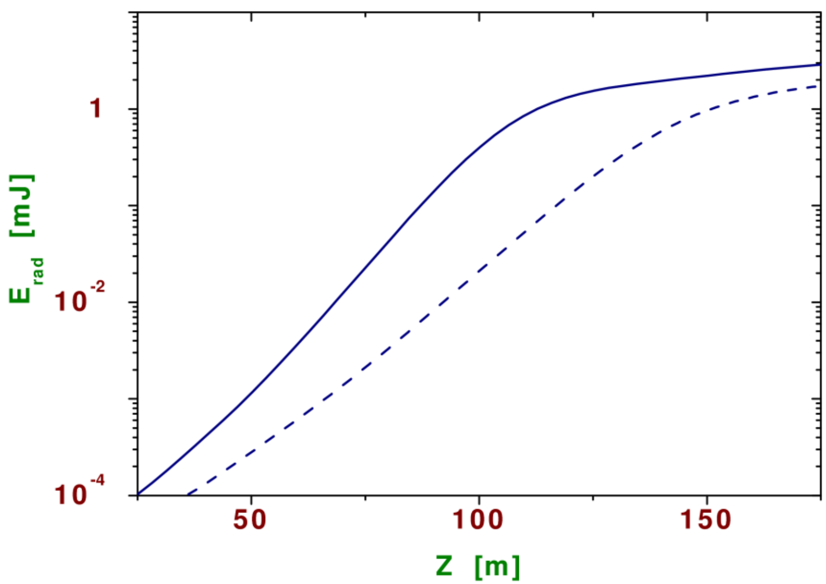
At the undulator resonance, E_{rad} and the electron velocity stay in phase throughout the undulator



The SASE process requires:

A high quality electron beam and very long undulators (see next slide)

FEL theory results in a nutshell



Further restrictions on beam quality:

$\sigma_E/E < \rho$, small energy spread, with

$\rho = (K\,\Omega_p\lambda_u/8\pi c)^{2/3}$ (FEL parameter, helical)

$L_g < Z_R = \pi\, w_0^2/\lambda$ (Rayleigh length)

Power growth along undulator:

$P(z) = P_0 \exp(z / L_g)$ (up to 10 – 100 GW!)

Saturation length ~ $10\, L_g$

Gain length: $L_g \approx \dfrac{(\varepsilon_n\, \lambda_u)^{5/6}}{(I_{peak})^{1/2}\lambda^{2/3}}$

With:

$\varepsilon_n = \gamma\varepsilon$ normalized emittance (~ conserved in a Linac)

I_{peak} = peak electron current

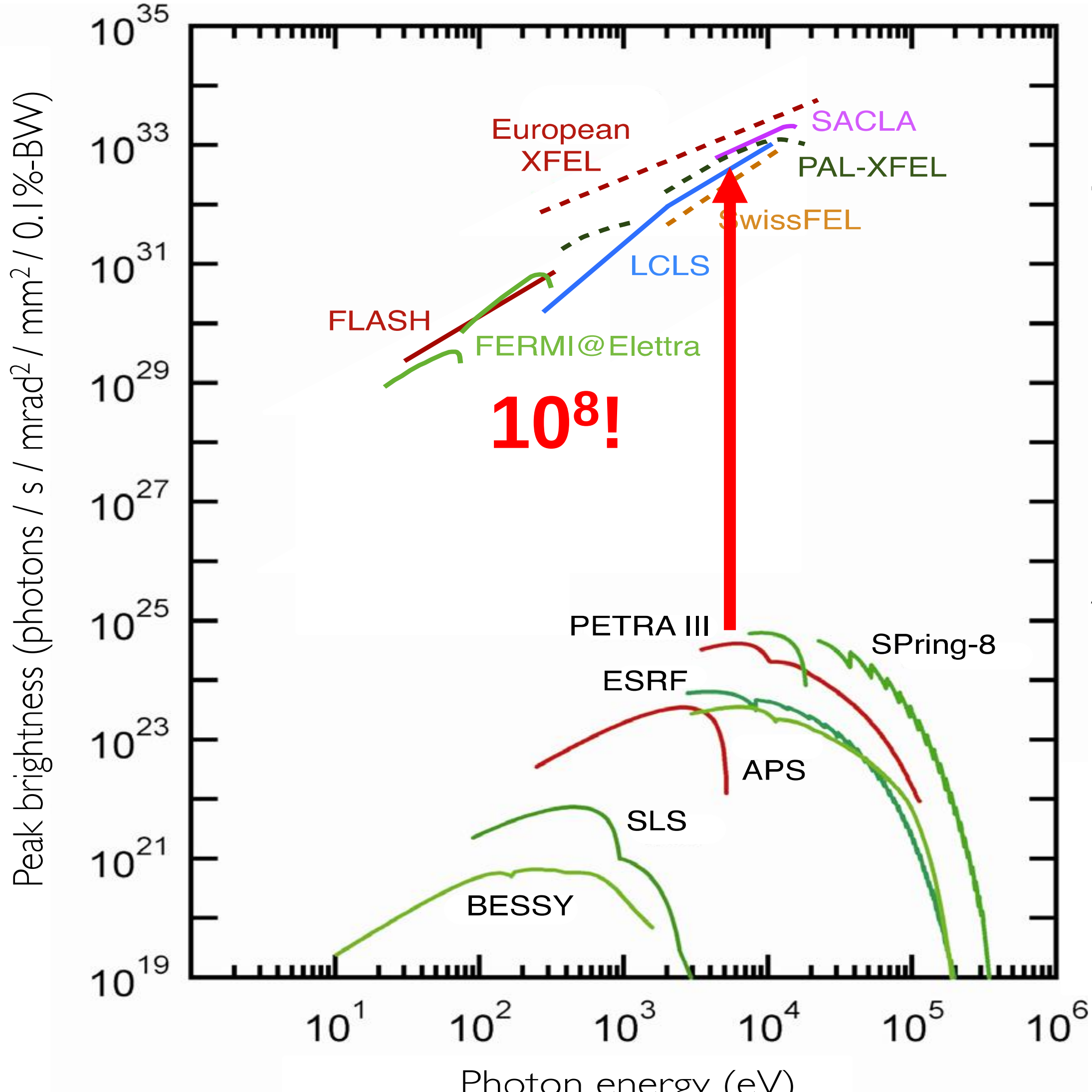
λ_u = undulator period

High transverse coherence when $\varepsilon \lesssim \lambda$

The hard x-ray FEL sources worldwide

Project	LCLS I, US	SACLA, JP	European XFEL	SwissFEL, CH	PAL-XFEL, KR	LCLS II, US
Max. electron energy (GeV)	14.3	8.5	**17.5**	5.8	10	4
Wavelength range (nm)	0.1−4.4	0.06−0.3	**0.05−4.7**	0.1−7	0.06−10	0.20 – 4.7
Photons/pulse	~ 10^{12}	2 x 10^{11}	**~ 10^{12}**	~ 3.6 x 10^{10}	10^{11}−10^{13}	2 10^{11}– 2 10^{10}
Peak brilliance	2 x 10^{33}	1 x 10^{33}	**5 x 10^{33}**	7 x 10^{32}	1.3 x 10^{33}	
Pulses/second	120	60	**27 000**	100	60	10^5 - 10^6
Date of first beam	2009	2011	2017	2016/2017	2016	2019

Potential for high repetition rate XFEL's



Outstanding performance in peak brilliance of XFEL translates into an outstanding **average brilliance for high rep. rate.**

At European XFEL self-seeding and tapering are proposed, with ~ 27 000 pulses/s for ultra high spectral flux

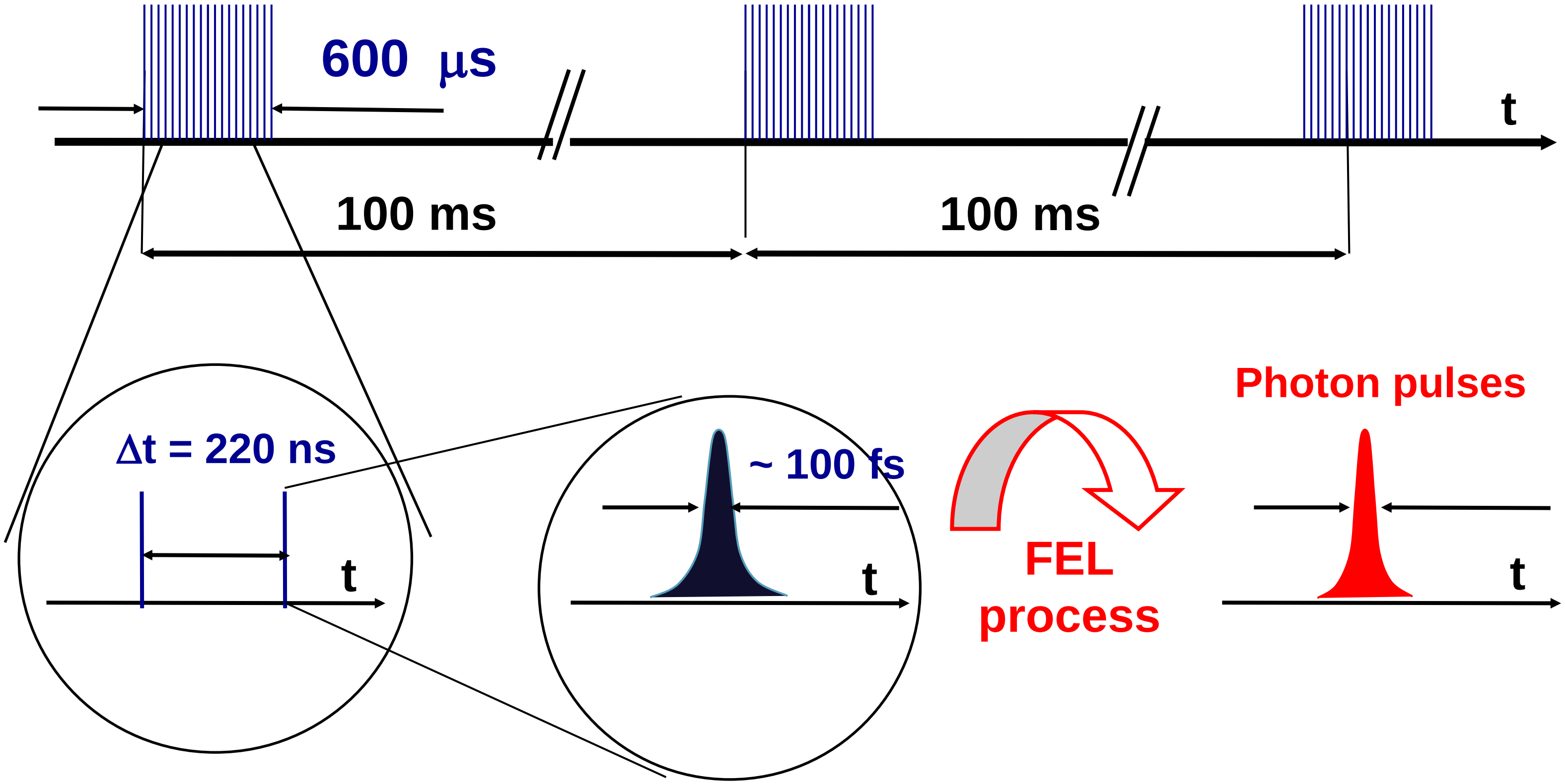
(But don't forget VUV and soft x-ray FEL's!)

FLASH at DESY, in Hamburg, Germany

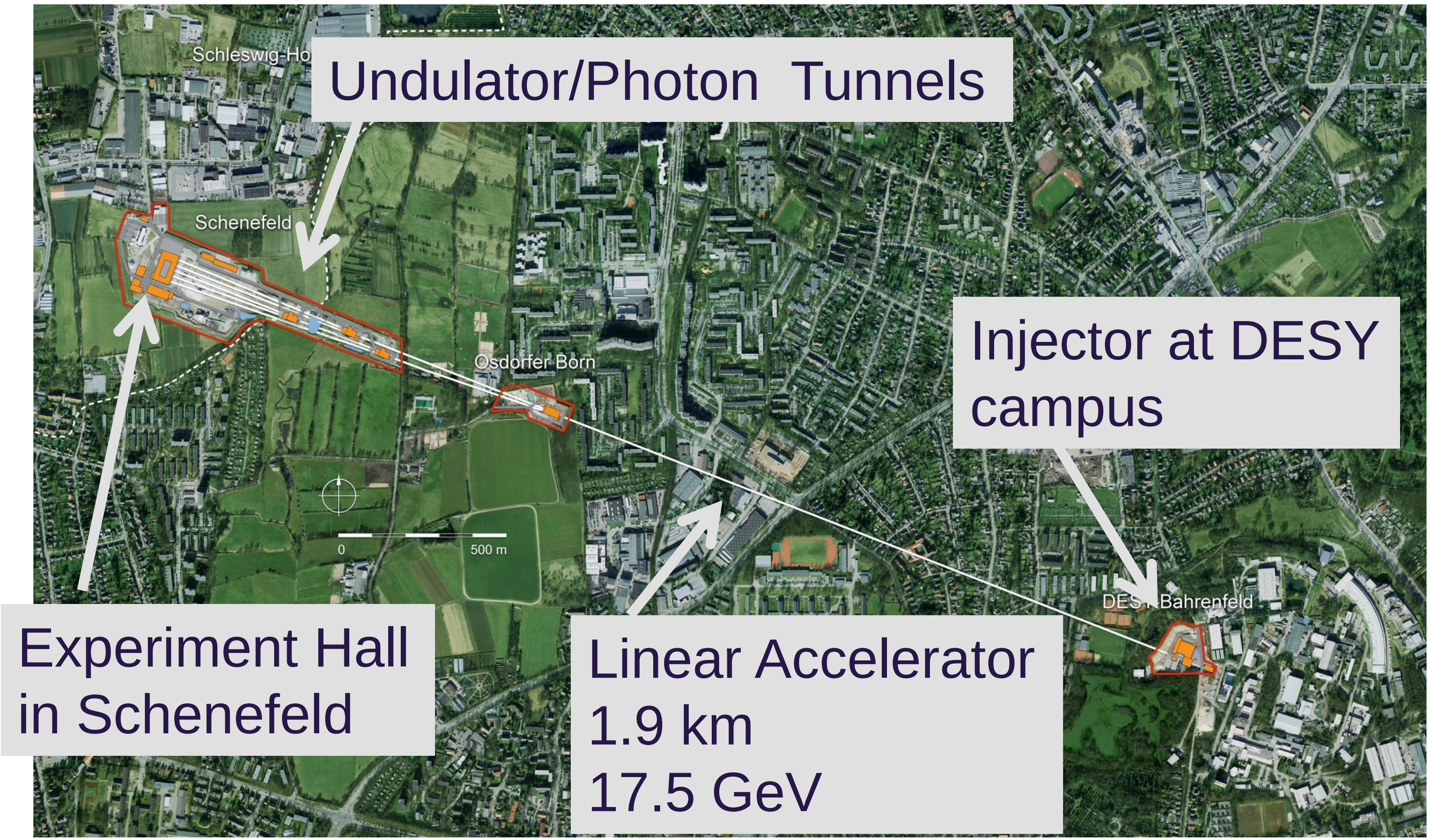
FERMI@ELETTRA in Trieste, Italy

Time structure of the European XFEL

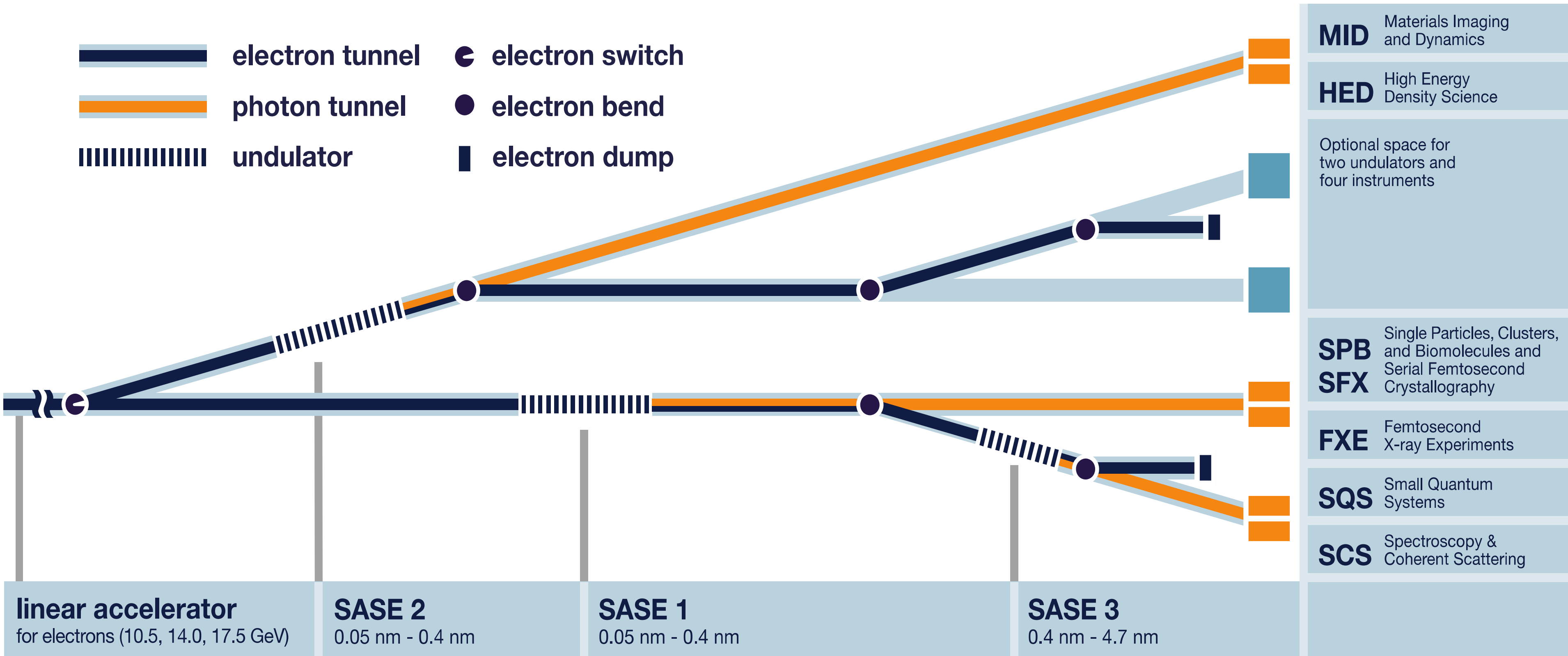
10 electron bunch trains/second
(each with up to 2700 bunches, 0.02 to 1 nC)



Overall layout of the facility



Undulators, x-ray beamline tunnels



SASE2 identical to SASE1, but with self-seeding

European XFEL: the leading hard X-ray FEL

Strength: 27 000 pulses per second is on top of the world!
Faster completion of experiments, throughput (parallel experiments), better statistics, s/n ratio

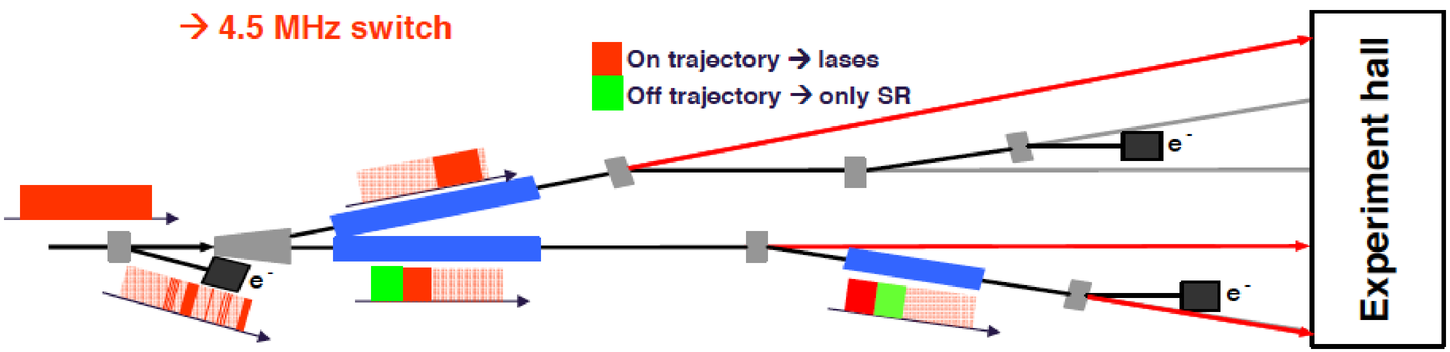
Dedicate & distribute electron bunches to instruments

- Operate accelerator as continous as possible
  → **stability / performance**
- Distribute electron bunch train on two lines
  → **10 Hz switch (few μs duration)**
- Switch on/off lasing for SASE 1/ SASE 3 line (optional)
  → **4.5 MHz switches**
- Determine exact bunch pattern
  → **4.5 MHz switch**

Goal: 3 experiments sharing beam for 12 hrs;

Alternate 3 for the other 12 hrs shift

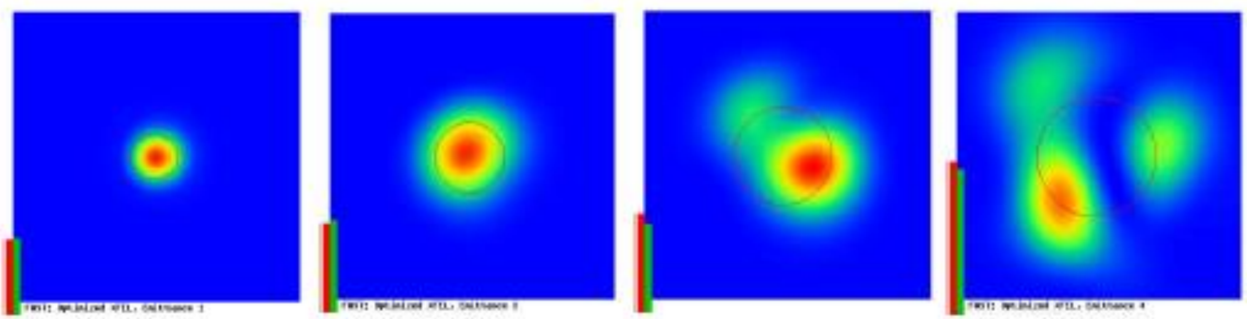
6 exp. groups every day!



Electron bunch distribution : 27.000 bunches/sec to 3 (5) beamlines; in average 10-20 Hz and ~800 (500) pulses/train; using kicking methods to make bunches lase only in dedicated undulator

Advantages of high electron energy

E.A. Schneidmiller, M.V. Yurkov, (DESY), IPAC2016, paper MOPOW012



$$\hat{\epsilon} = 2\pi\epsilon/\lambda$$

$$\epsilon \sim 1/\gamma$$

Figure 4: Typical slice distribution of the radiation intensity for optimized SASE FEL with $\hat{\epsilon}$ = 1, 2, 3, 4 (from left to right). Circle denotes rms spot size. SASE FEL operates in the saturation. Simulations have been performed with code FAST [23].

ELs

	LCLS	SACLA	EXFEL	SWISS FEL	PAL XFEL
Energy [GeV]	13.6	8.0	17.5	5.8	10
Wavelength [A]	1.5	0.6	0.5	0.7	0.6
ϵ_n [mm-mrad]		0.4	0.4	0.4	0.4
$\hat{\epsilon}$	1	2.7	1.5	3.4	2.1

Countries participating in the European XFEL

- Germany
- Russia
- France
- Italy
- Poland
- Sweden
- Switzerland
- Hungary
- Slovakia
- Denmark
- Spain
- United Kingdom

Organization of the European XFEL non-profit company

In-kind Contributions

Accelerator Consortium

Coordinator:
DESY
Institutes from D, F, I, CH, PL, ES, RU, SE…

Other In-kind Contributors

European XFEL GmbH

Council
Chair M. M. Nielsen

Management Board

Managing Directors

R. Feidenhans'l, Chair
C. Burger, Admin. Director

Scientific Directors

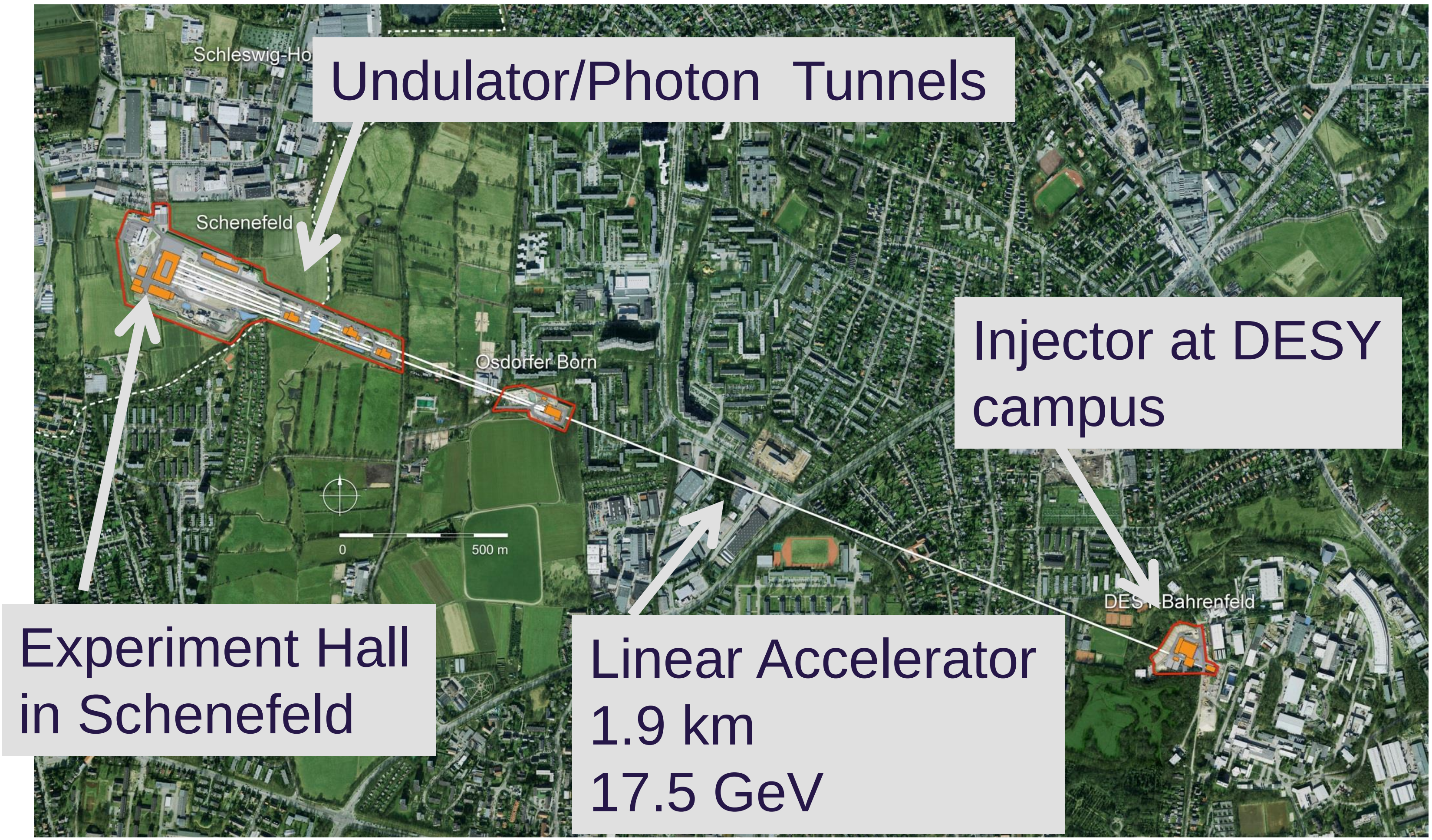
S. Molodtsov
A. Schwarz
T. Tschentscher

+ ~270 people from 41 countries!

Advisory Committees

SAC
MAC
AFC
IKRC +
Det. AC
Lasers AC

Overall layout of the facility



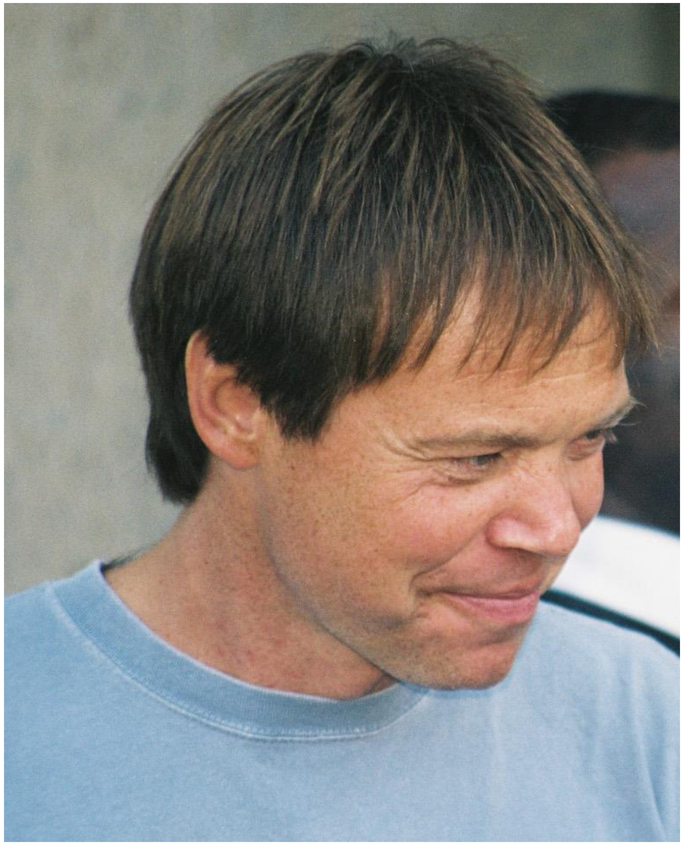
Accelerator Consortium

Cold magnets

Power supplies for cold magnets

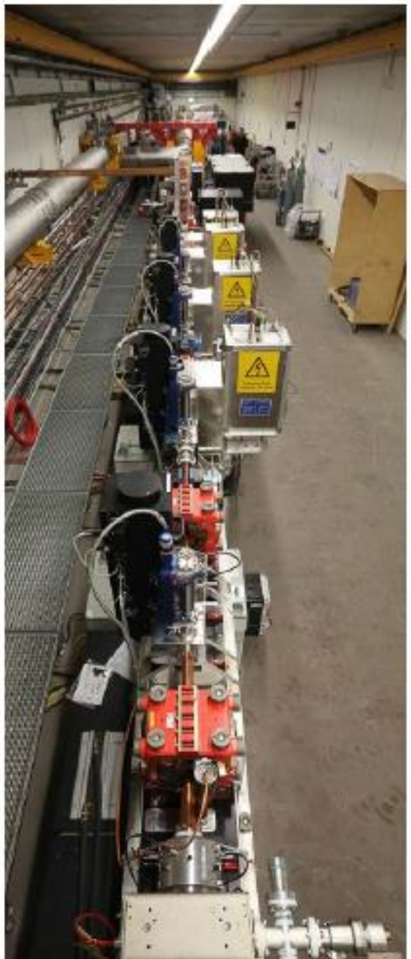
The leaders of accelerator construction and commissioning

Hans Weise



Winni Decking

Injector Commissioning Dec. 2105 – July 2016

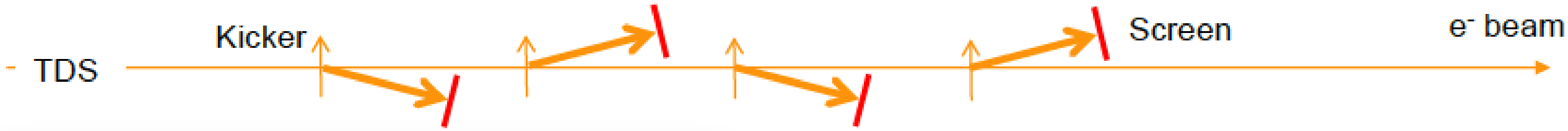


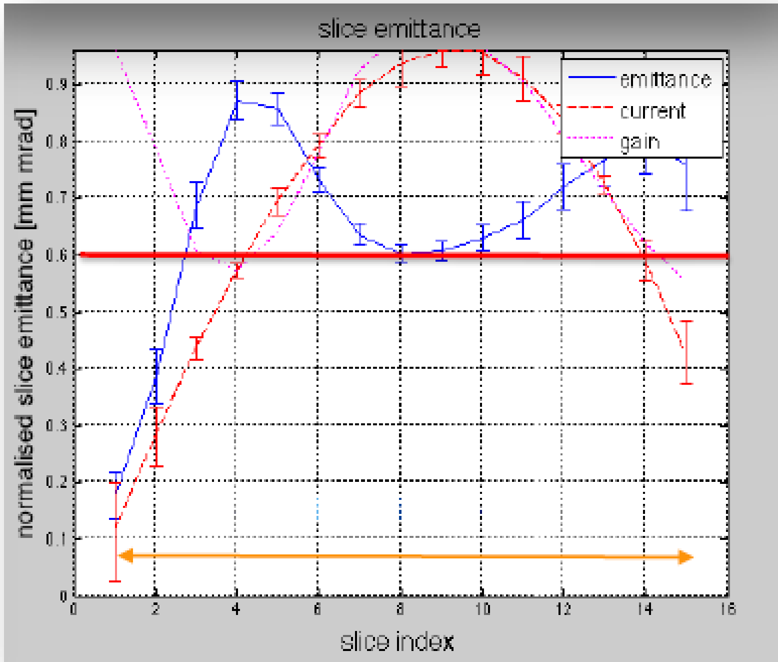
- Injector installation finalized in Q4/2015
- 3.9 GHz module installed in 9/2015
- Injector cool-down started beginning of 12/2015
- First Beam on December 18th , 2015
- Successful commissioning during Q1/2016

- Emittance measurements done on a routine basis;
- Projected emittance as expected (1...1.5 mm mrad)
- Full bunch train length (2700 bunches) reached and beam stopped in injector beam dump

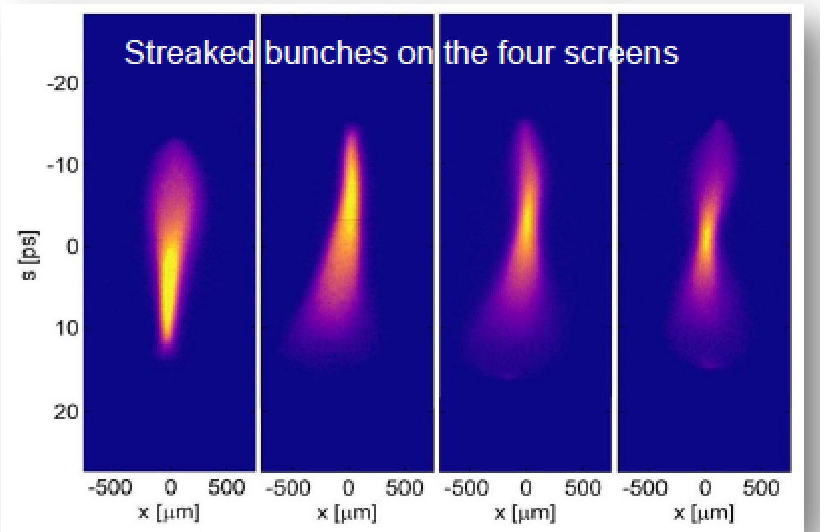
- Transverse Deflecting System operated
- **Slice emittance measurements give 0.5 mm mrad for 500 pC;** also over bunch train
- Laser heater commissioning started

Slice emittance measurements with fast kickers



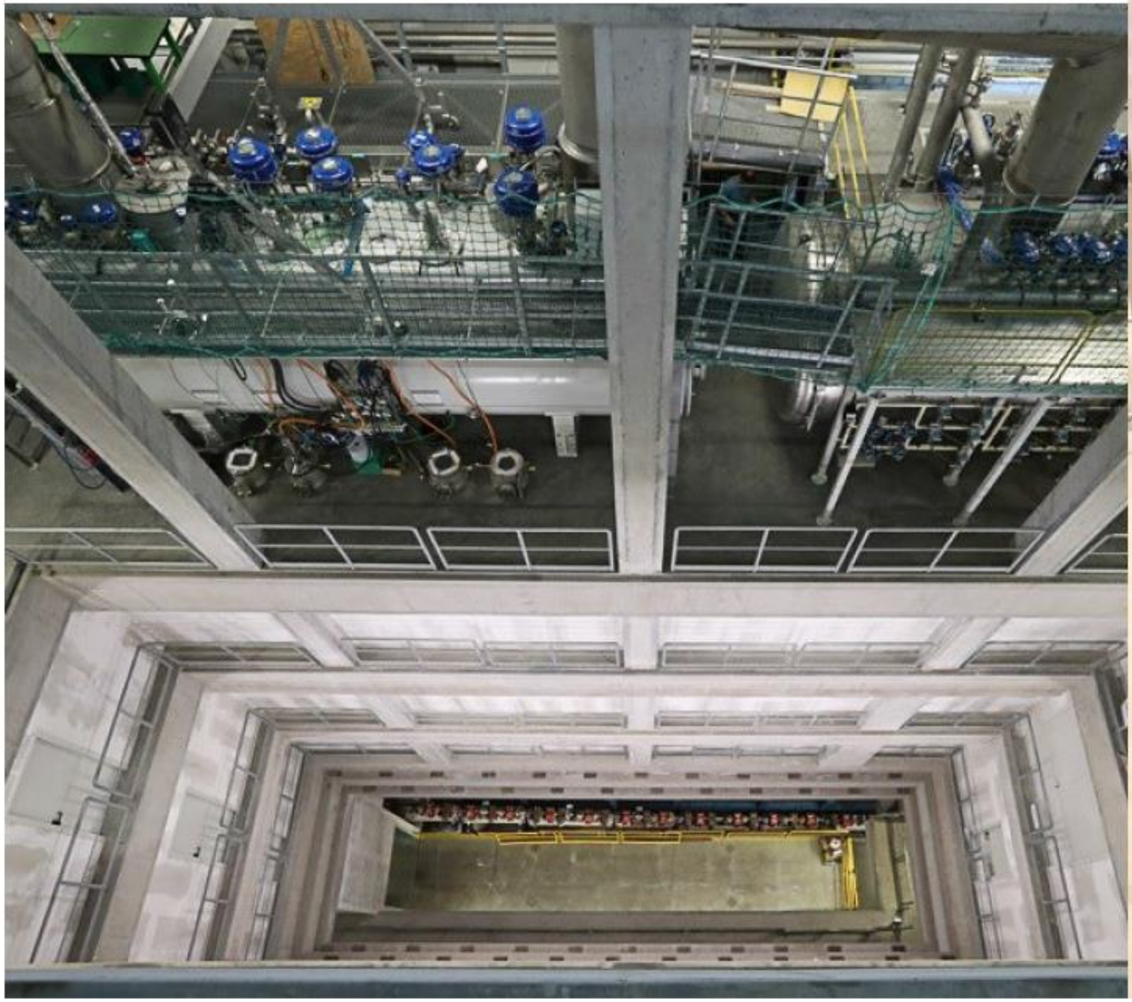


slice emittances can be measured and evaluated within 20 seconds using fast kickers and off-axis

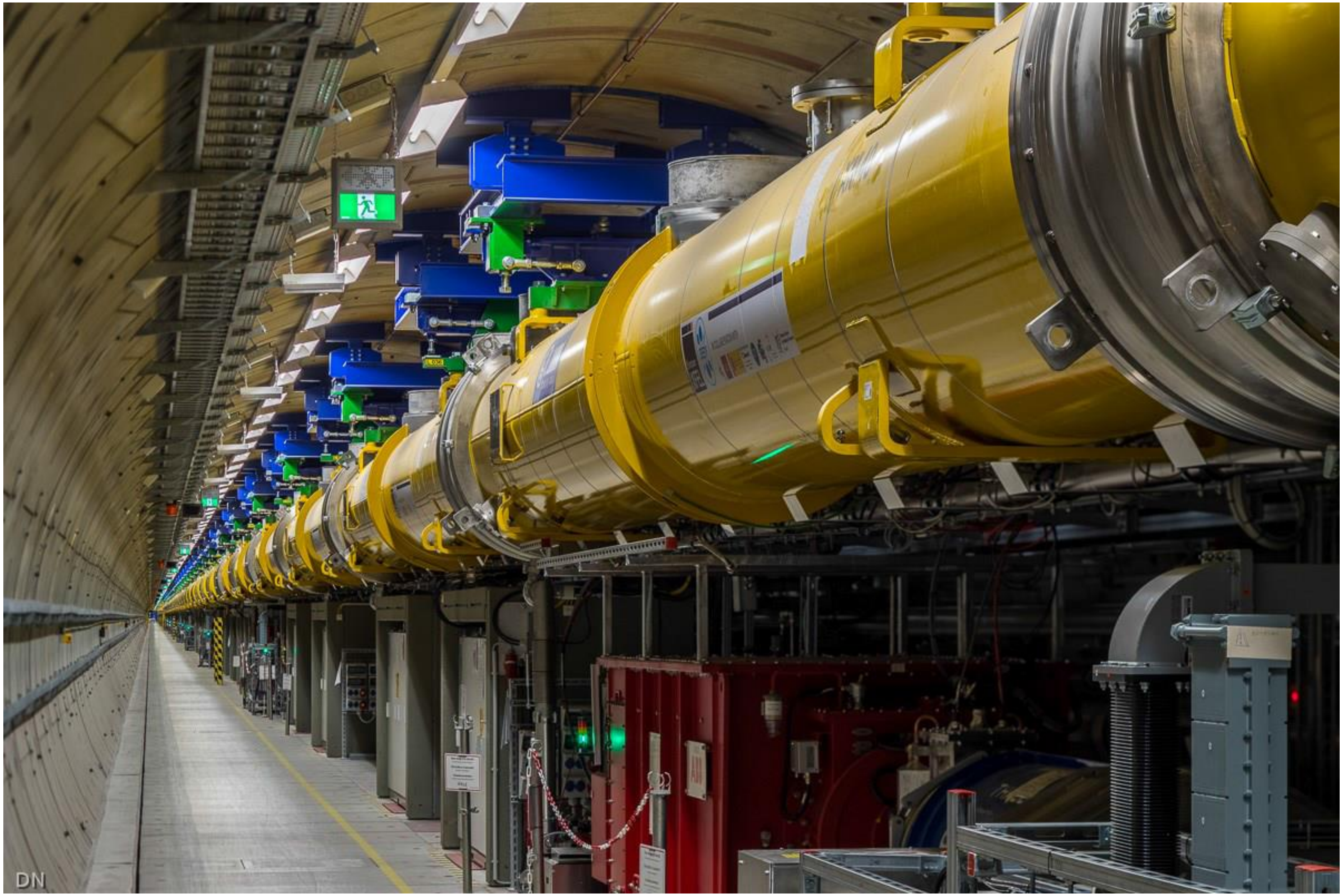


- center slices are reproducibly measured
- 0.6 mm mrad horiz. at 500 pC and 53 MV/m gun gradient
- the smallest slice emittance measured was 0.5 mm mrad at 60 MV/m

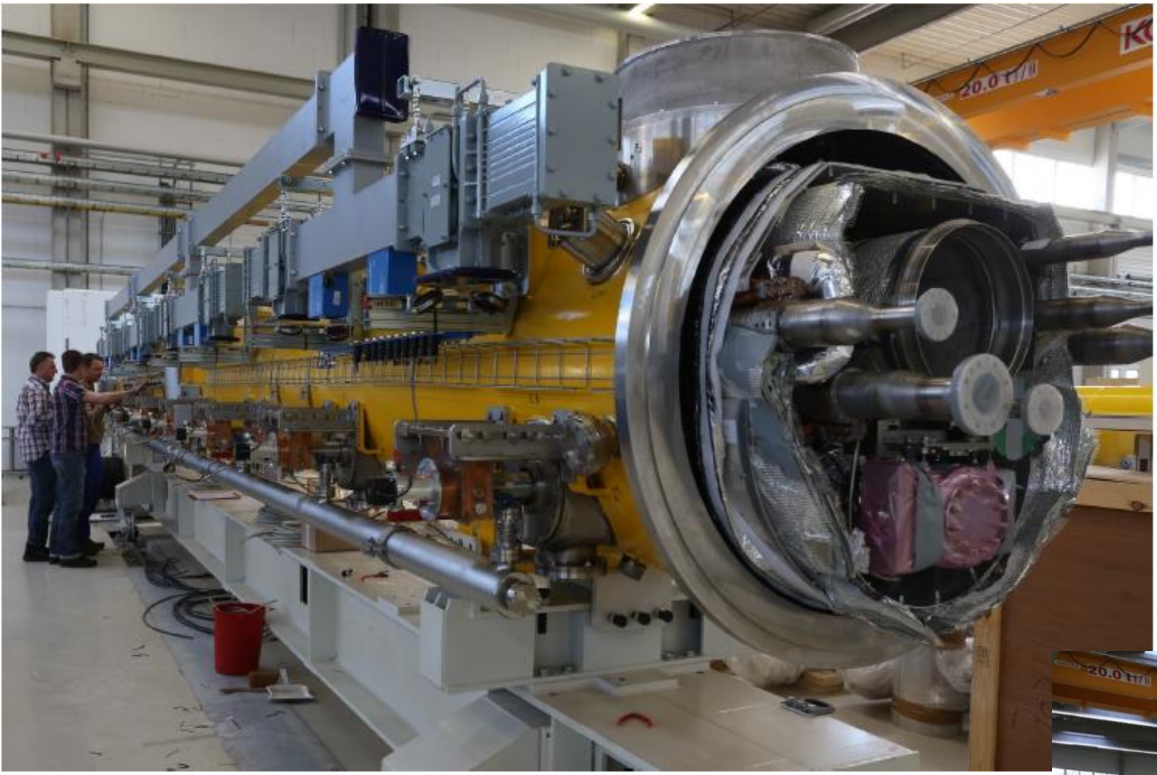
“Dogleg” from injector to main linac



Cold Linac: 96 accelerating cryomodules, each 12.5 m long

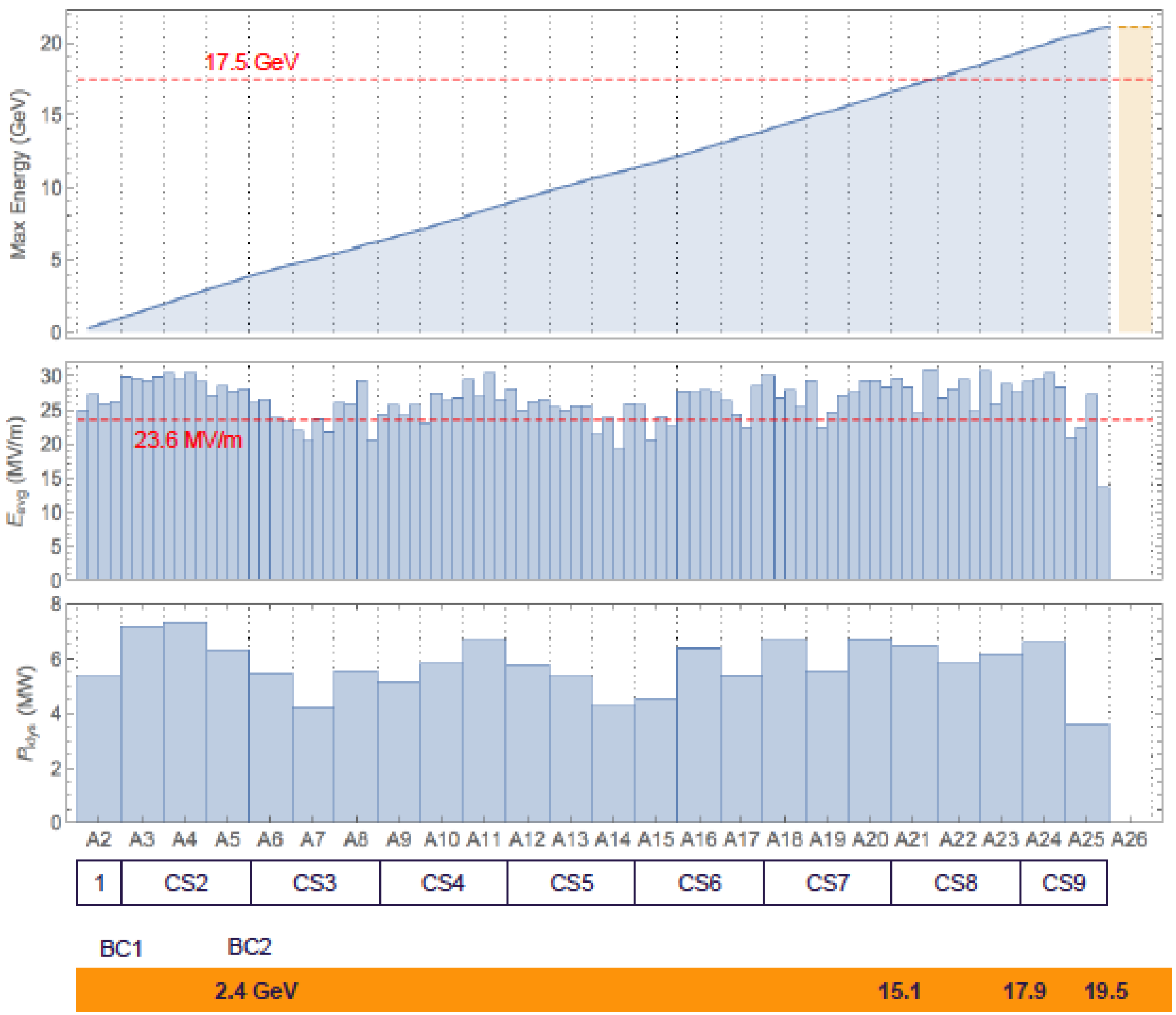


Accelerator Modules in the test hall (AMTF) at DESY



Second (of three) bunch compression stage

Accelerating gradient exceeds specs



maximum energy reach

- after tunnel installation *and*
- according to accelerator module test

	Installed (GeV)	Module (GeV)
CS1	1.	1.05
CS2	3.89	4.06
CS3	6.29	6.72
CS4	8.91	9.49
CS5	11.38	12.09
CS6	13.92	14.76
CS7	16.63	17.62
CS8	19.42	20.44
CS9	21.09	22.23

the maximum energy during FEL operation needs to respect the bunch compressor (BC) working points

- 2.4 GeV nominal BC2 energy
  leads to approx. 19.5 GeV
- higher BC2 energy (e.g. 3.3 GeV)
  allows for > 20 GeV

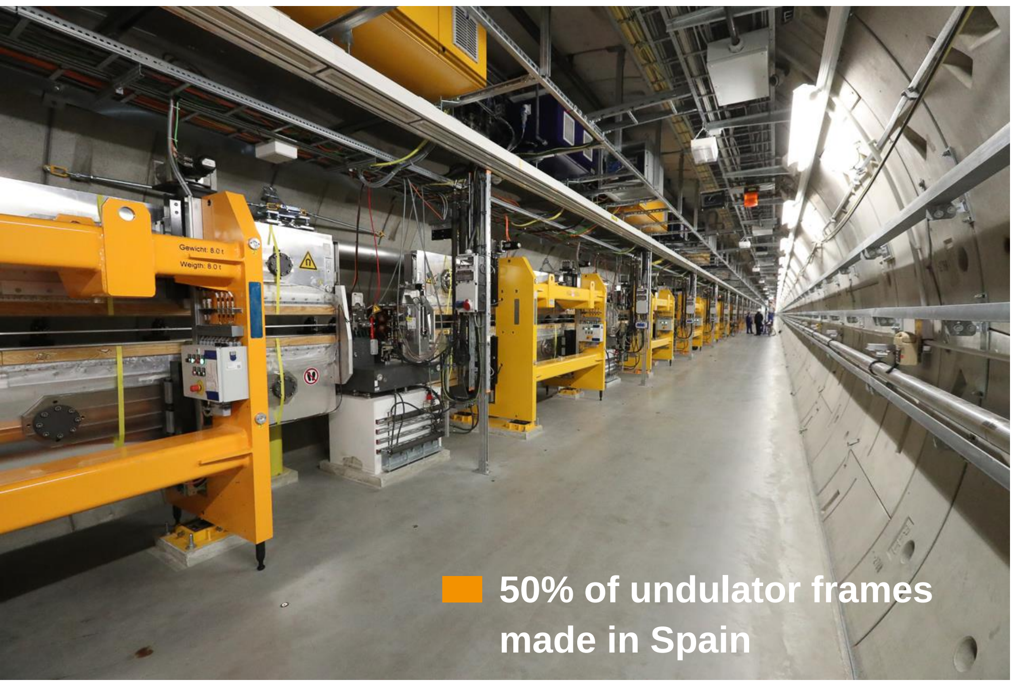
increased max. energy assures higher availability

Status of Linac commissioning (20.04.2017)

- Linac cool-down started end of Nov. 2016
- 4K achieved Dec. 28, 2016
- Cool-down to 2K achieved 06 Jan. 2017
- First injection in the Linac, mid-January
- Status 20.04.2017: beam accelerated through the entire Linac to 12 GeV, with low slice emittance (~ 0.5 mm mrad) and 30 compressed bunches per train.
- READY FOR LASING IN MAY!!

Status of Undulators

SASE1 and SASE3: Hardware installed & Aligned
Control System operational
Air Conditioning commissioned
All 35 gaps closed to 10.000mm

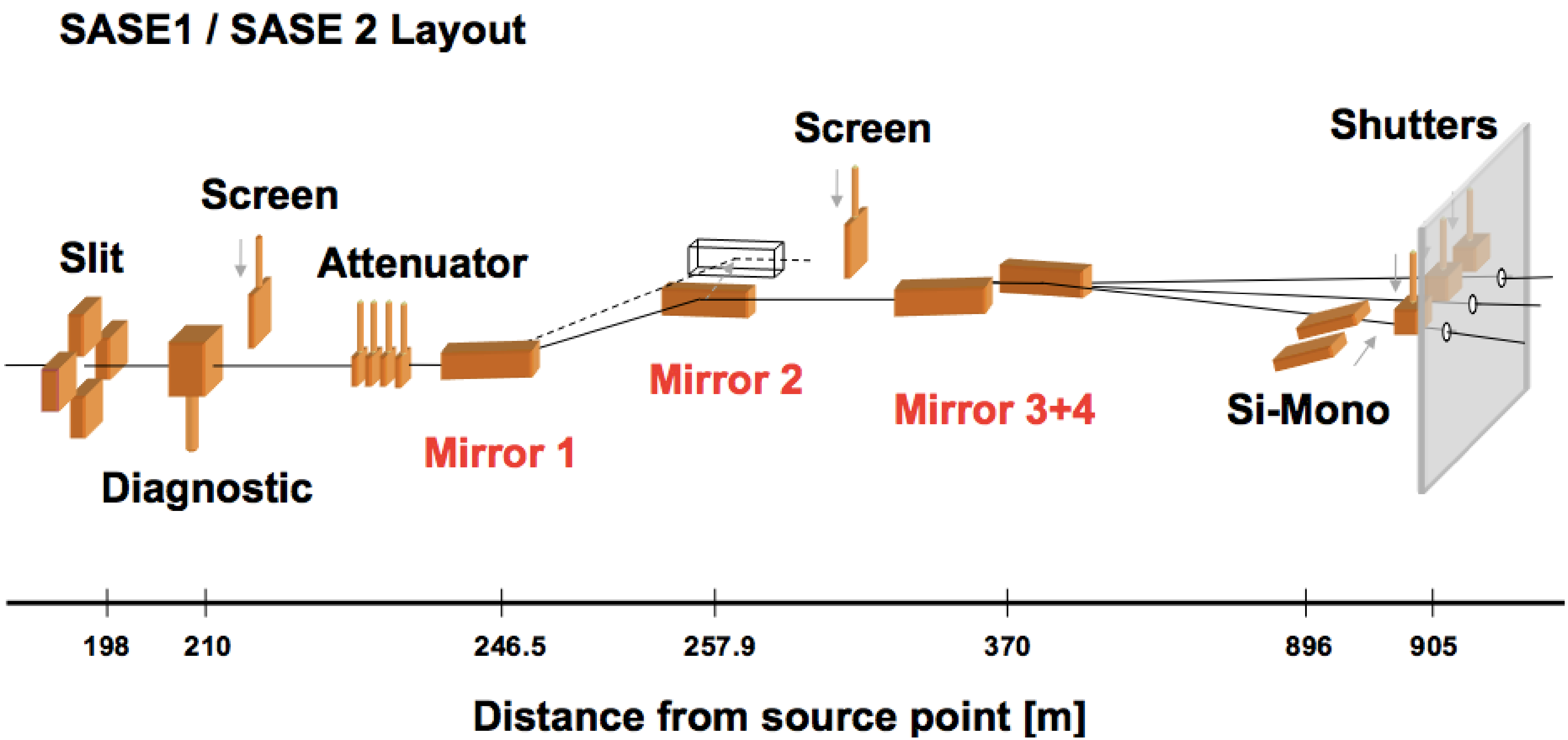


50% of undulator frames made in Spain

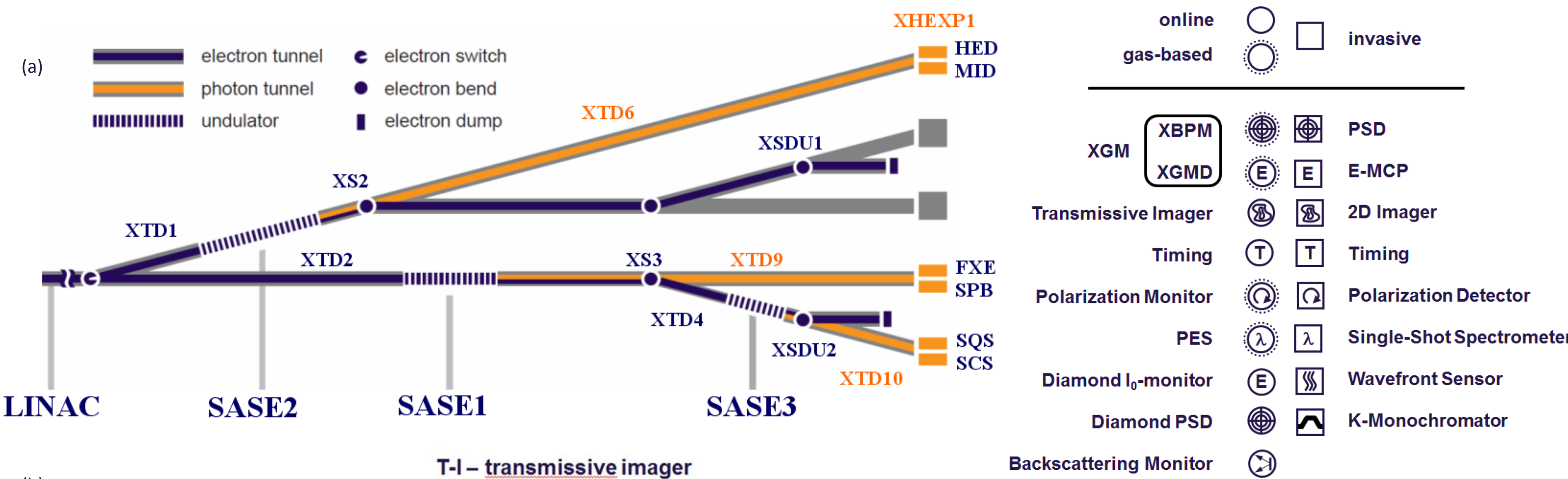
SASE1 segments behind thermal shields

- SASE1 and SASE3 ready for beam: end of March 2017
  SASE2: end of summer 2017

Optical transport beamlines (Harald Sinn)

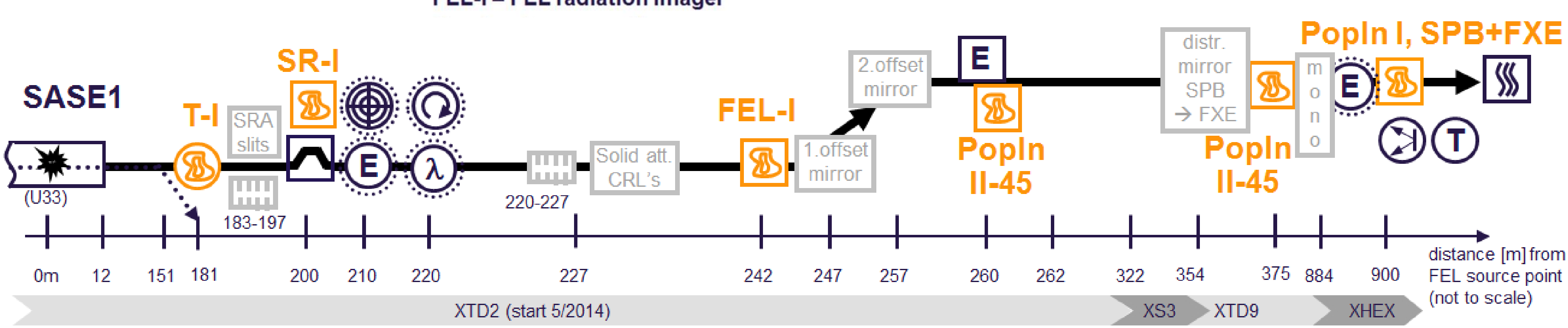


(a)



(b)

T-I – transmissive imager
SR-I – spontaneous radiation imager
FEL-I – FEL radiation imager



Courtesy H. Sinn, J. Grünert, A. Koch

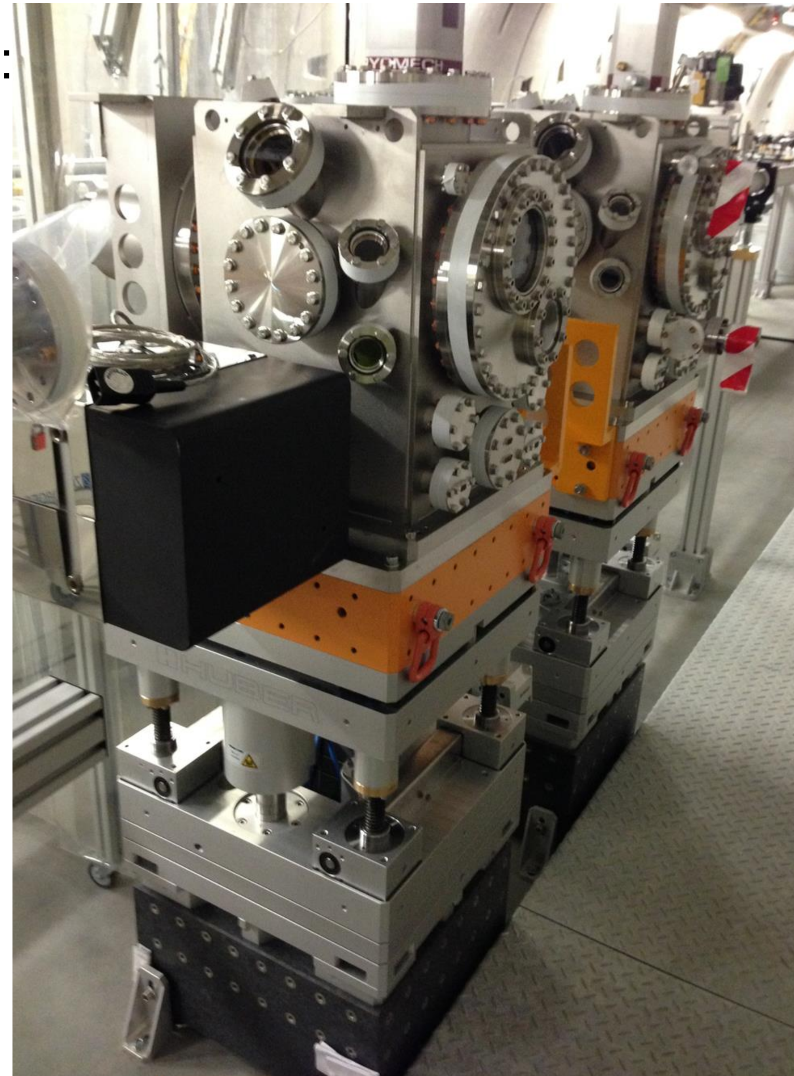
Installation X-ray mono finished in October 2016

Courtesy H. Sinn

Transport into tunnel:
30 September 2016

Final assembly:
27 September 2016

Vivien Sleziona Xiaohao Dong



Cryo-version of ACCM, Deming Shu, APS

Some more (last) items (SASE3 soft X-ray mono)

Arrival in Schenefeld
17 October 2016

Daniele La Civita

Courtesy H. Sinn

Installation 19 October 2016

Some more tunnel pictures (SASE1)

Courtesy H. Sinn

Differential pump + XGM in XTD9

Status of X-ray mirrors (Harald Sinn)

Metrology on first long JTEC mirror by Maurizio Vannoni

Status of X-ray mirrors

Area	Type	Quantity	Received	Comment
SASE1	Beam transport	3	3	Coated, ready for installation
SASE3	Beam transport	3	3	Ready for coating
SASE2	Beam transport	3	3	Coating end of January
SASE3	Soft Mono pre-mirrors	2	1	2nd mirror ships end of January
SASE3	Soft Mono Gratings	3	2	Initial configuration (short grating) received
MID	Steering	2	2	Ready for coating
SPB	KBs	6	6	Delivered February, being installed
SCS	KBs	3	0	September 2017
SQS	KBs	2	0	December 2017
Total		**27**	**20**	

17.3.2016: First superpolished mirror ready

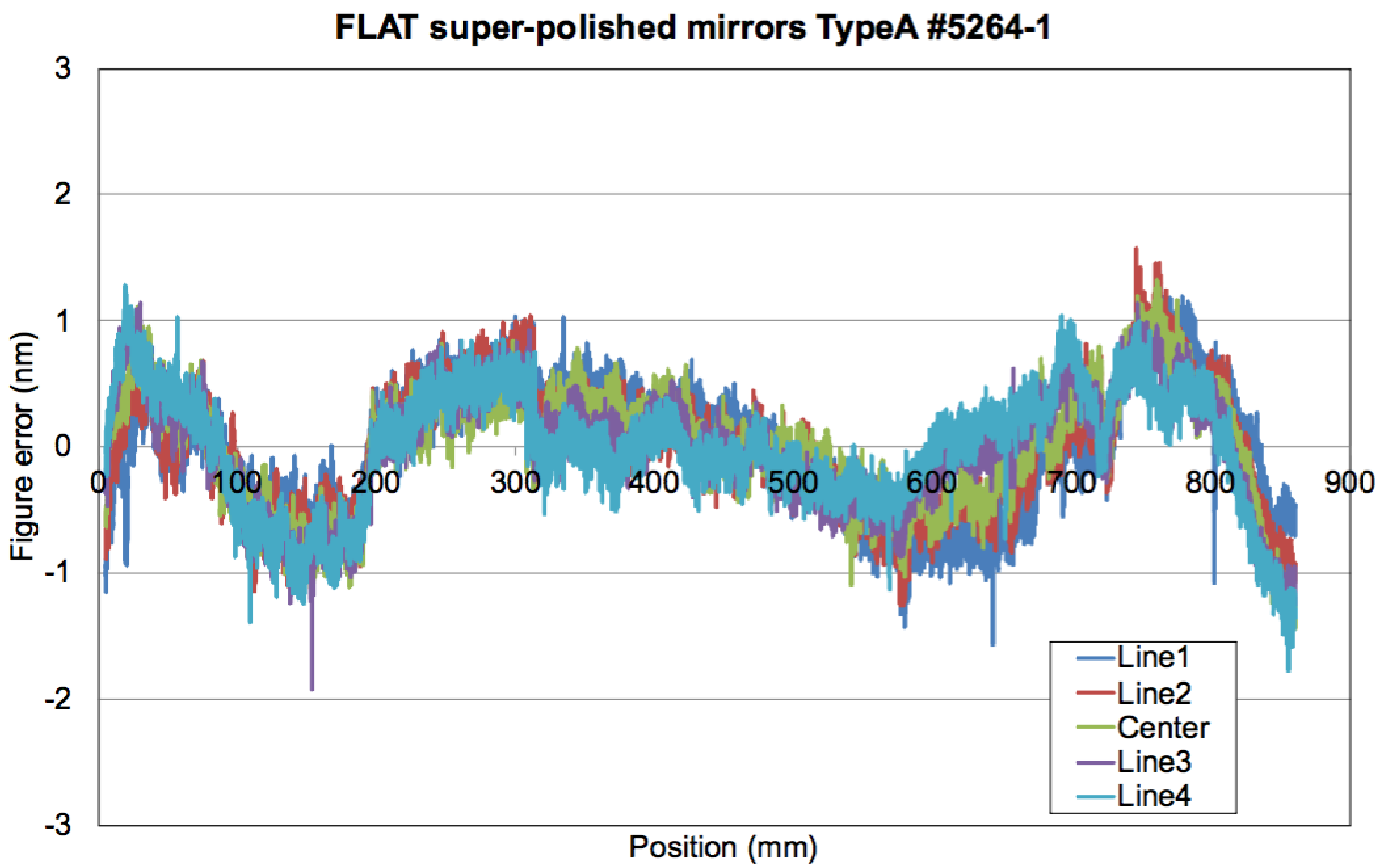


Figure 1-2: Tangential shape error profiles of Mirror #5264-1.

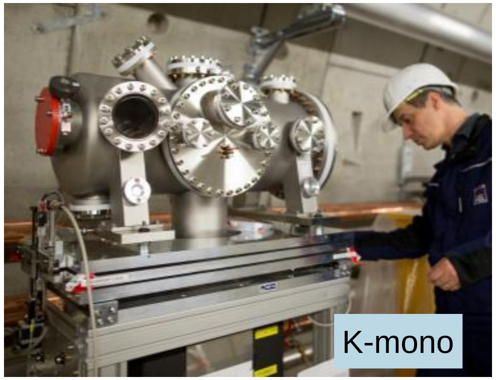
from JTEC, Japan

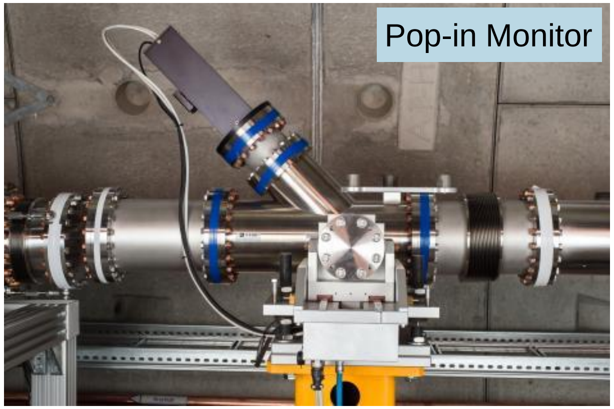
X-ray Diagnostics

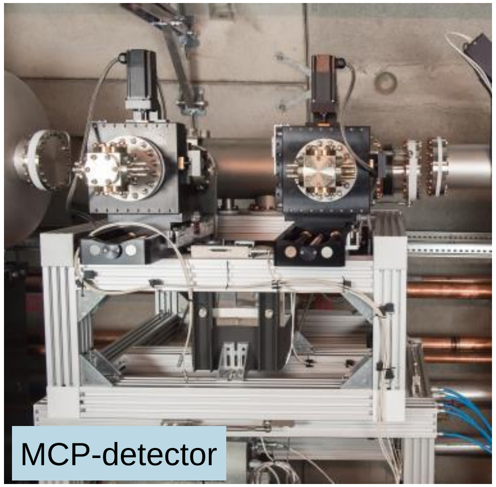
from: Jan Grünert, WP74, European XFEL

SASE1 installation status

► Vacuum systems XTD2: all planned WP74 vacuum systems are installed in the SASE1 tunnel







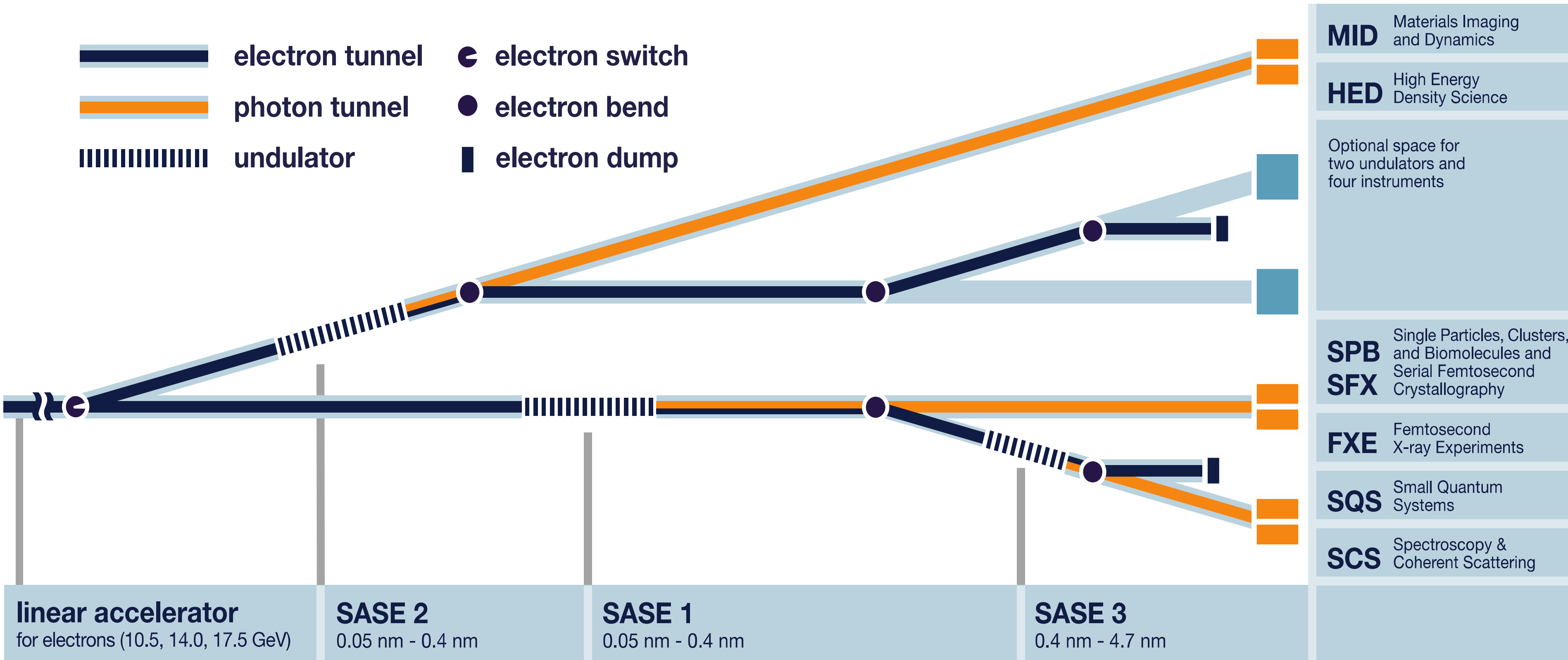
X-ray Diagnostics

- WP74 status SASE1 installation :
  - all planned WP74 vacuum systems are installed in SASE1 (XTD2 and XTD9 tunnels)
  - all devices are cabled and under technical commissioning

Jan Grünert, WP74, European XFEL

slide from Jan Grünert

Undulators, x-ray beamline tunnels



SASE2 identical to SASE1, but with self-seeding

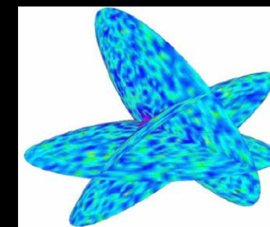
Schenefeld campus, headquarters building

Headquarters building in Schenefeld

Scientific instruments

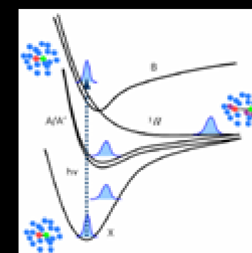
Hard X-rays

SPB/SFX: Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules
- Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.



MID: Materials Imaging & Dynamics
- Structure determination of nano-devices and dynamics at the nanoscale.

FXE: Femtosecond X-ray Experiments
- Time-resolved investigations of the dynamics of solids, liquids, gases



HED: High Energy Density Matter
- Investigation of matter under extreme conditions using hard X-ray FEL radiation, e.g. probing dense plasmas

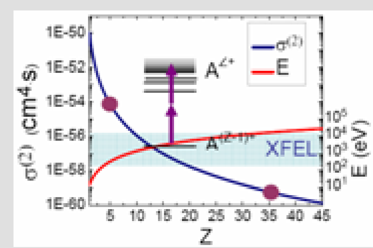
Soft x-rays

SQS: Small Quantum Systems

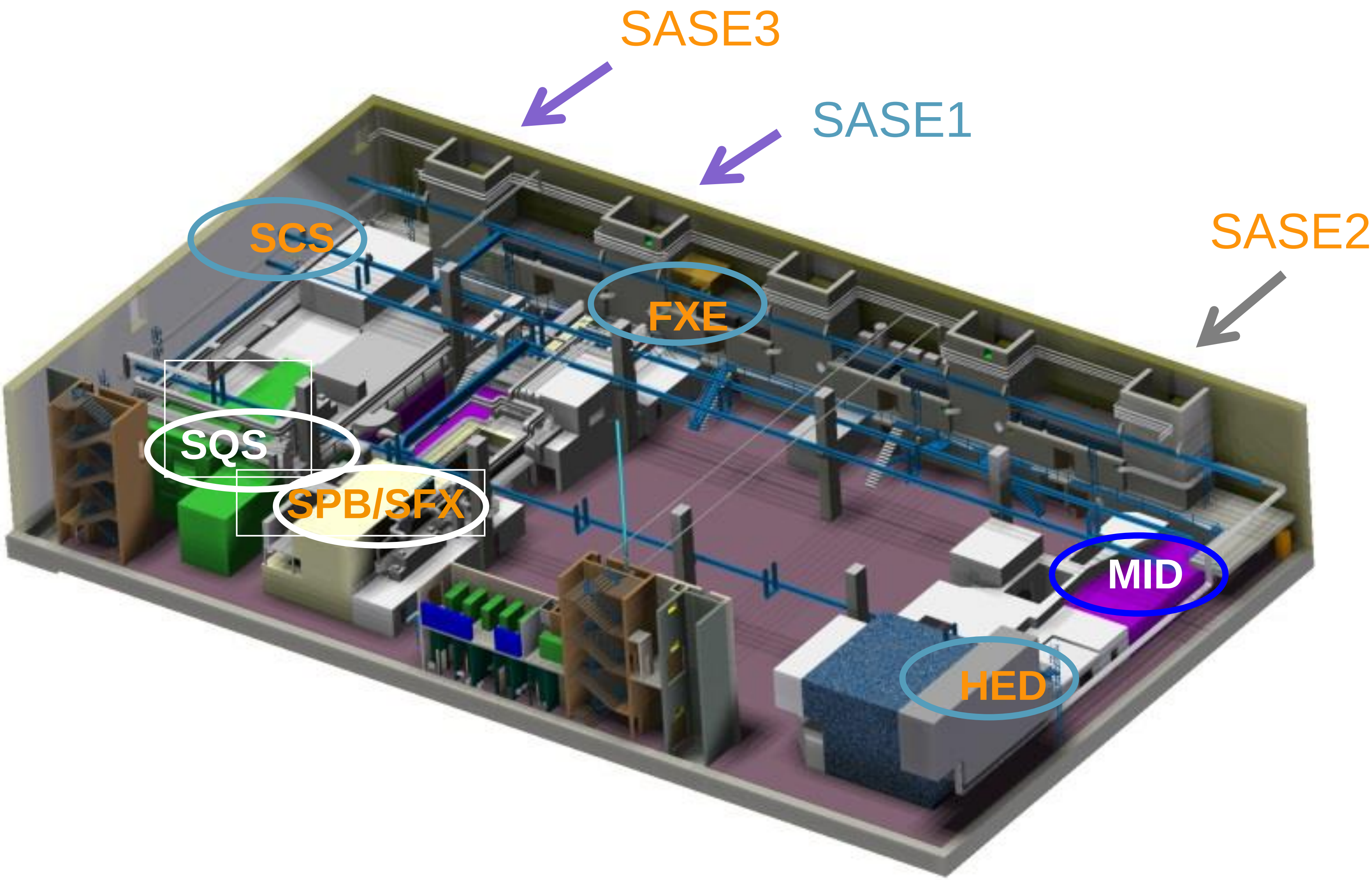
Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

SCS: Soft x-ray Coherent Scattering/Spectroscopy

Electronic and real structure, dynamics of nano-systems and of non-reproducible biological objects



Experiment Hall overview



Hutches in Experiment hall

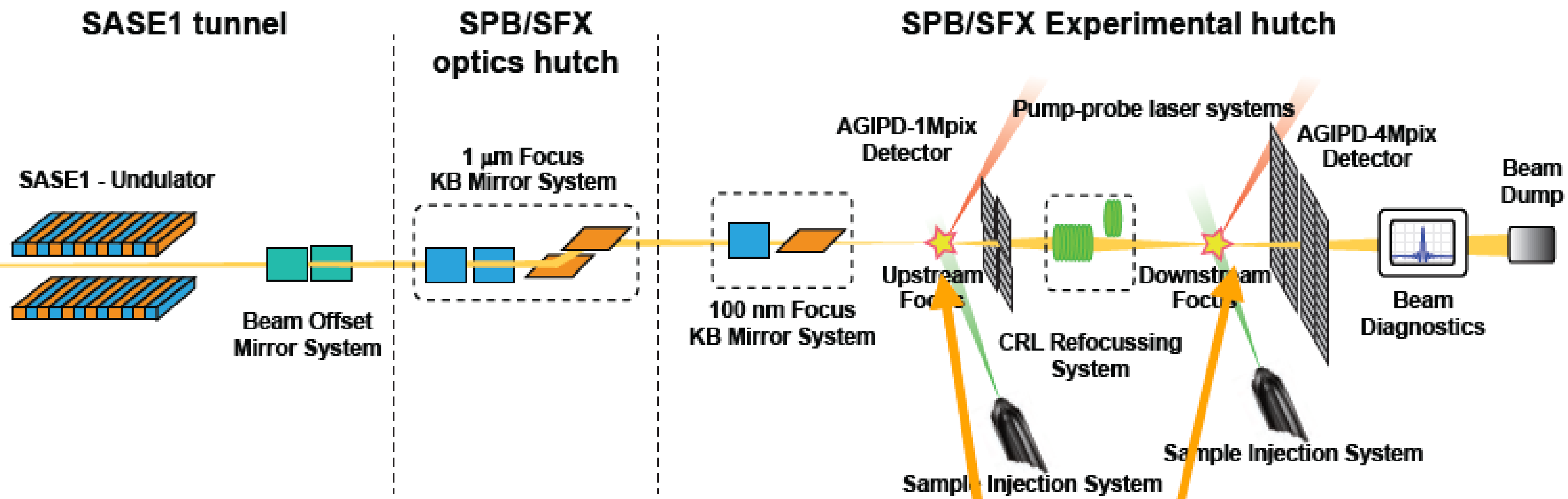
User Consortia: additional instrumentation

- 1.Bio-labs in XHQ, ancillary facilities XBI
- 2. Expansion of computational capabilities DataXpress
- 3. A station for nanocrystallography on a hard X-ray branch SFX
- 4. High-energy lasers and pulsed high field magnet for the High Energy Density Instrument HIBEF beamline
- 5. An additional versatile experimental chamber for oriented molecular species COMO
- 6. A RIXS station for the soft X-ray branch hRIXS
- …in addition a Time-res. Photoemission Station on SASE3 is under discussion; and a variable polarization afterburner for SASE3 is co-developed with PSI Villigen

User Consortium XBI: 500 m2 lab space for bio-sciences

- Funds from Sweden, EMBL, USA, Slovakia, Germany, Finland…

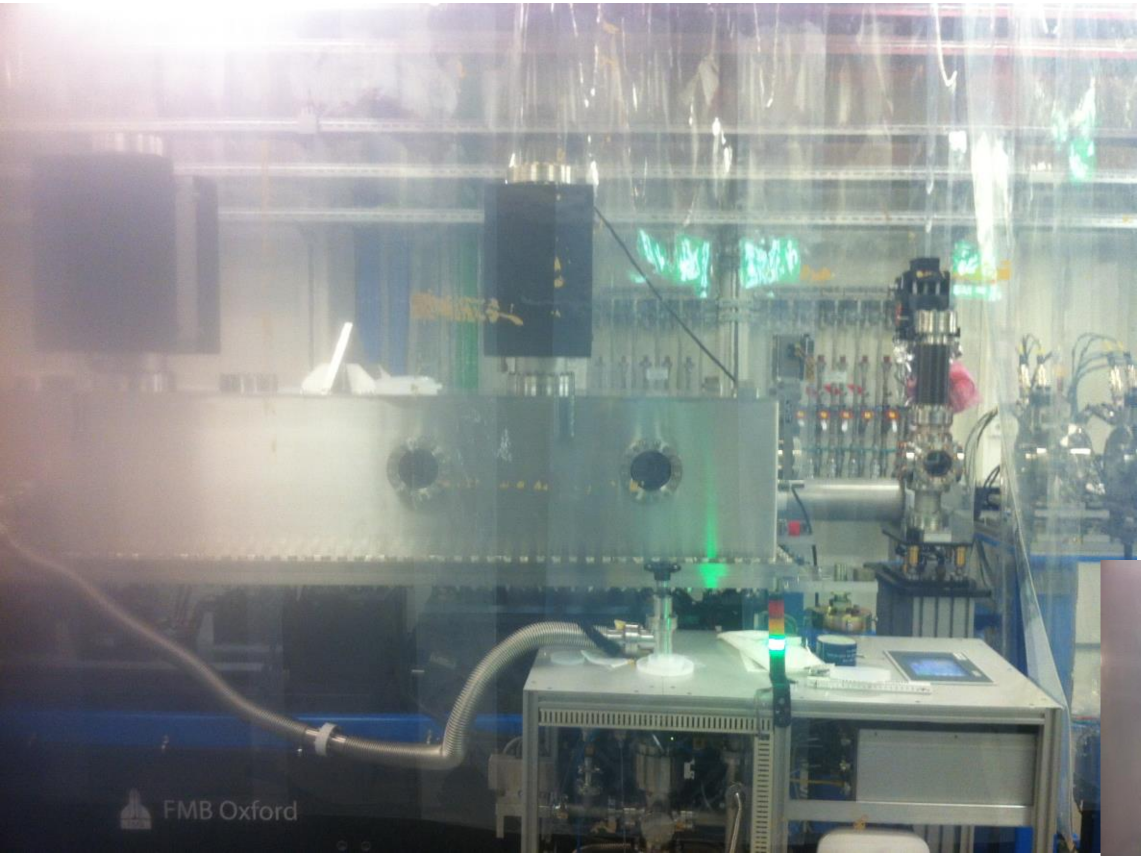
User Consortium SFX: second station on SPB



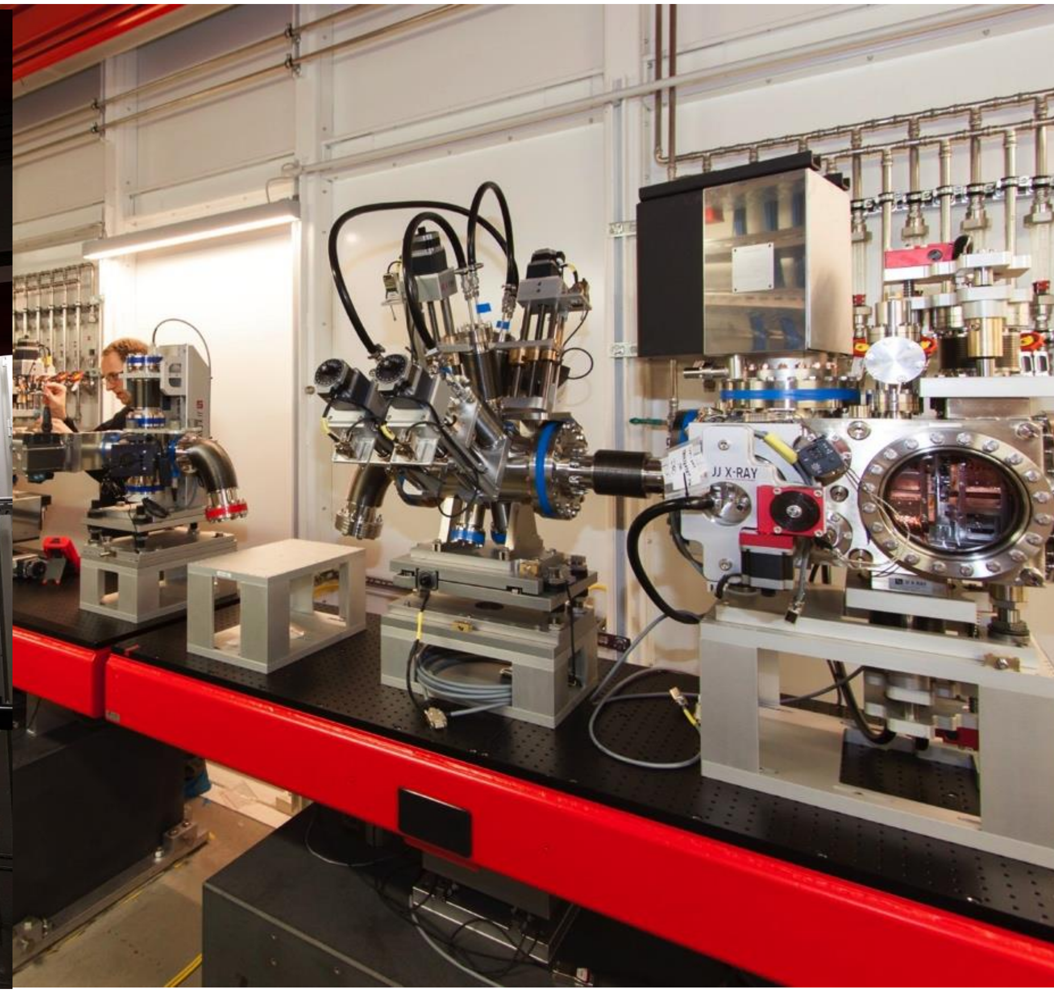
Funds from Germany, Sweden, UK, Slovakia, US, Switzerland, Australia

Two interaction regions

Single Particles and Biomolecules/Serial fs Xtallography



Femtosecond X-ray Experiment, FXE (Christian Bressler)

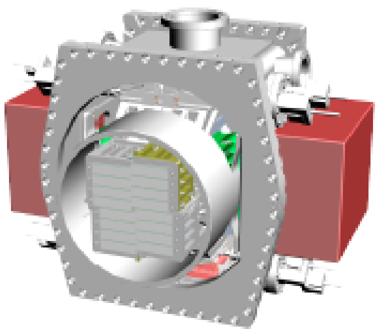


Overall schedule of the European XFEL

1st Call for proposals (SASE1)	Deadline 20 March 2017, 63 proposals
First lasing in SASE1	May 2017
Commissioning SASE1 and instruments	May-September 2017
Start of users operation FXE, SPB/SFX	September/October 2017 (2 months)
2nd call for proposals	Summer 2017
Lasing SASE3	Summer 2017
Lasing SASE2	Very early 2018
Start users operation SASE2 and SASE3	Mid 2018

2-dim fast position sensitive detectors (M. Kuster)

Adaptive Gain Integrating Pixel Detector (AGIPD)



Energy Range 3 – 13 (25) keV

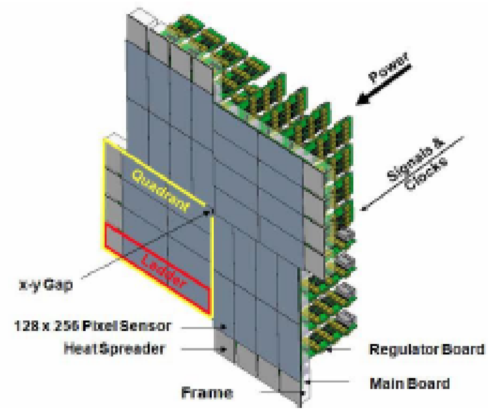
Dynamic Range 10^4 ph/px/pulse@12 keV

Single Photon Sens. Yes

Memory ≈380 images

Pixel Size 200×200 μm^2

MiniSDD Sensor with Signal Compression (DSSC)



Energy Range 0.5 – 6 (25) keV

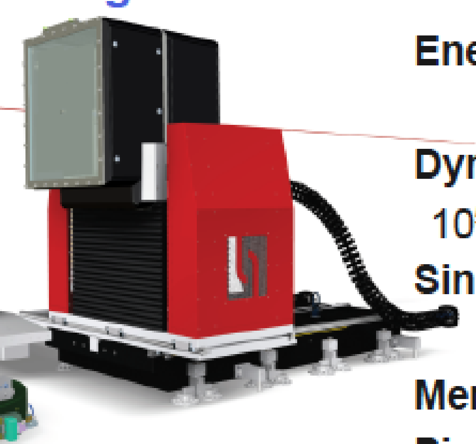
Dynamic Range ≈100 ph/px/pulse@1 keV

Single Photon Sens. No

Memory ≈800 images

Pixel Size 236×236 μm^2

Large Pixel Detector (LPD)



Energy Range 3 – 13 (25) keV

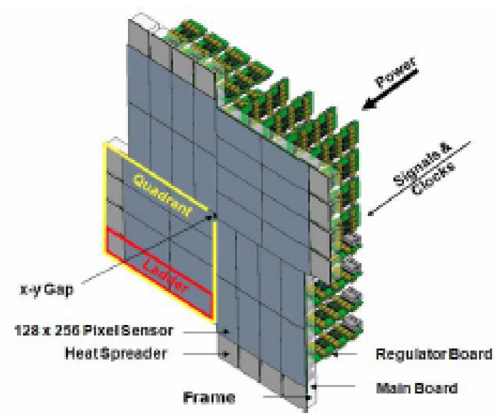
Dynamic Range 10^5 ph/px/pulse@12 keV

Single Photon Sens. Yes

Memory ≈512 images

Pixel Size 500×500 μm^2

DePFET Sensor with Signal Compression (DSSC)



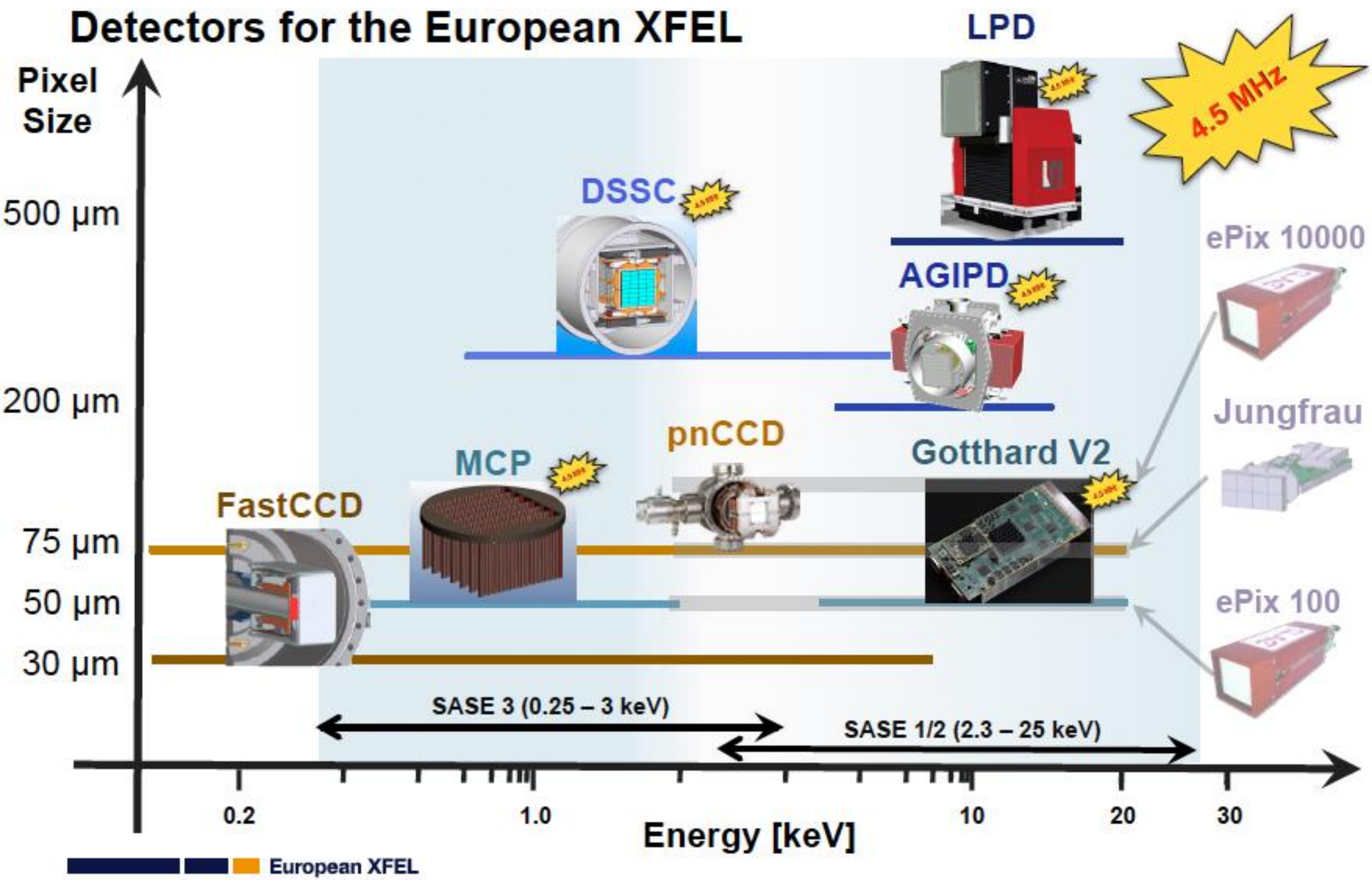
Energy Range 0.5 – 6 (25) keV

Dynamic Range 6000 ph/px/pulse@1 keV

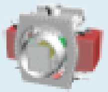
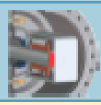
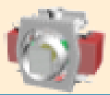
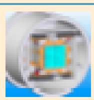
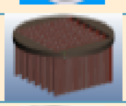
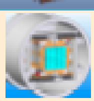
Single Photon Sens. Yes

Memory ≈800 images

Pixel Size 236×236 μm^2


Detectors for the European XFEL
Pixel Size
500 µm
200 µm
75 µm
50 µm
30 µm
LPD
4.5 MHz
DSSC
AGIPD
ePix 10000
Jungfrau
pnCCD
MCP
Gotthard V2
FastCCD
ePix 100
SASE 3 (0.25 – 3 keV)
SASE 1/2 (2.3 – 25 keV)
0.2
1.0
10
20
30
Energy [keV]
European XFEL

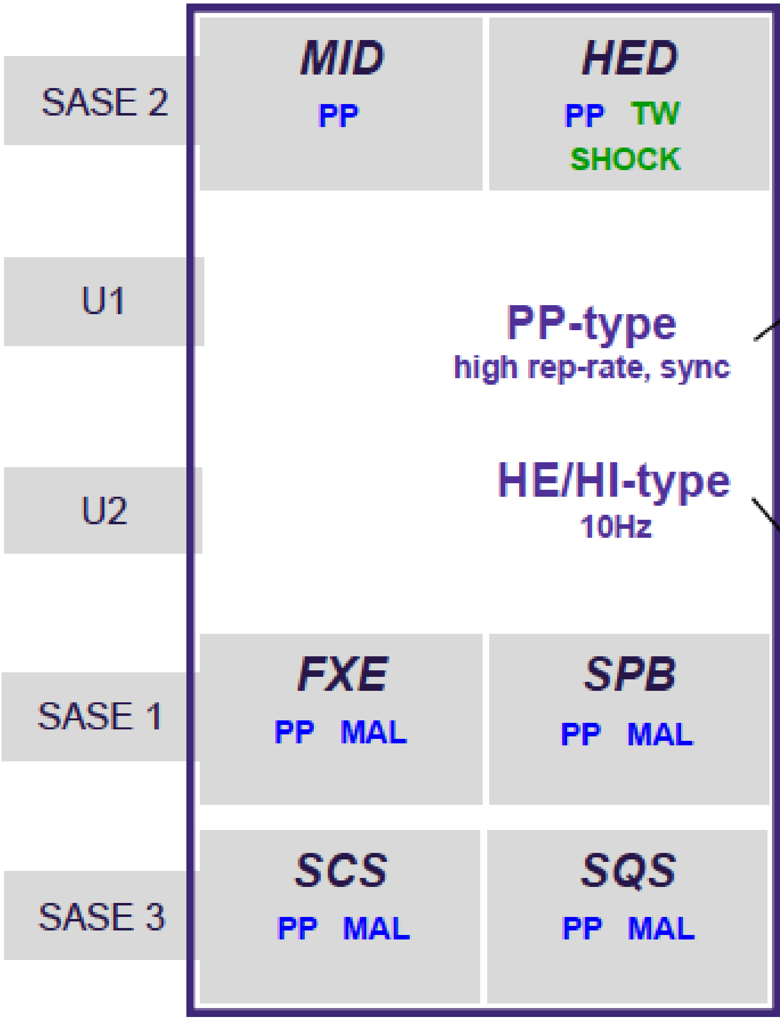
Detectors – Timeline and Status (M. Kuster)

Detector System		Beam Line	Scientific Instrument	Project Status	Arrival at XFEL	Ready for Installation at Experiment
AGIPD		SASE I	SPB	DAQ/Control Integration	December 2016	May 2017
LPD		SASE I	FXE	Integration/ Testing	February 2017	June 2017
FastCCD		SASE III	SCS	DAQ/Control Integration	May 2016	July 2017
AGIPD		SASE II	MID	Integration	February 2017	September 2017
Gotthard V2		SASE I-III	FXE/HED/ MID/SPB/ Diagnostics	Development	February 2018	April 2018
DSSC MiniSDD		SASE III	SCS	Development	February 2018	May 2018
MCP DLD		SASE III	SQS	Development	February 2017	
DSSC DEPFET		SASE III	SCS/SQS	Development	Sensors available 2017	

External: Development → Integration → Testing → Commissioning Calibration DAQ/Control Integration

at XFEL: End-2-End Test → Beam Line Integration Commissioning → User Operation

Optical lasers for experiments (Max Lederer)



Types of experimental lasers:

PP **pump-probe:**

- sub-15…300fs, mJ-class, 0…4.5MHz, 800nm
- UV…mid-IR, THz

MAL **molecular alignment:**

- sub-20fs, 1…10mJ, 800nm („kick")

or

- 1J-class, 10Hz ns („adiabatic")

In-house R&D

100TW **high intensity (HI):**

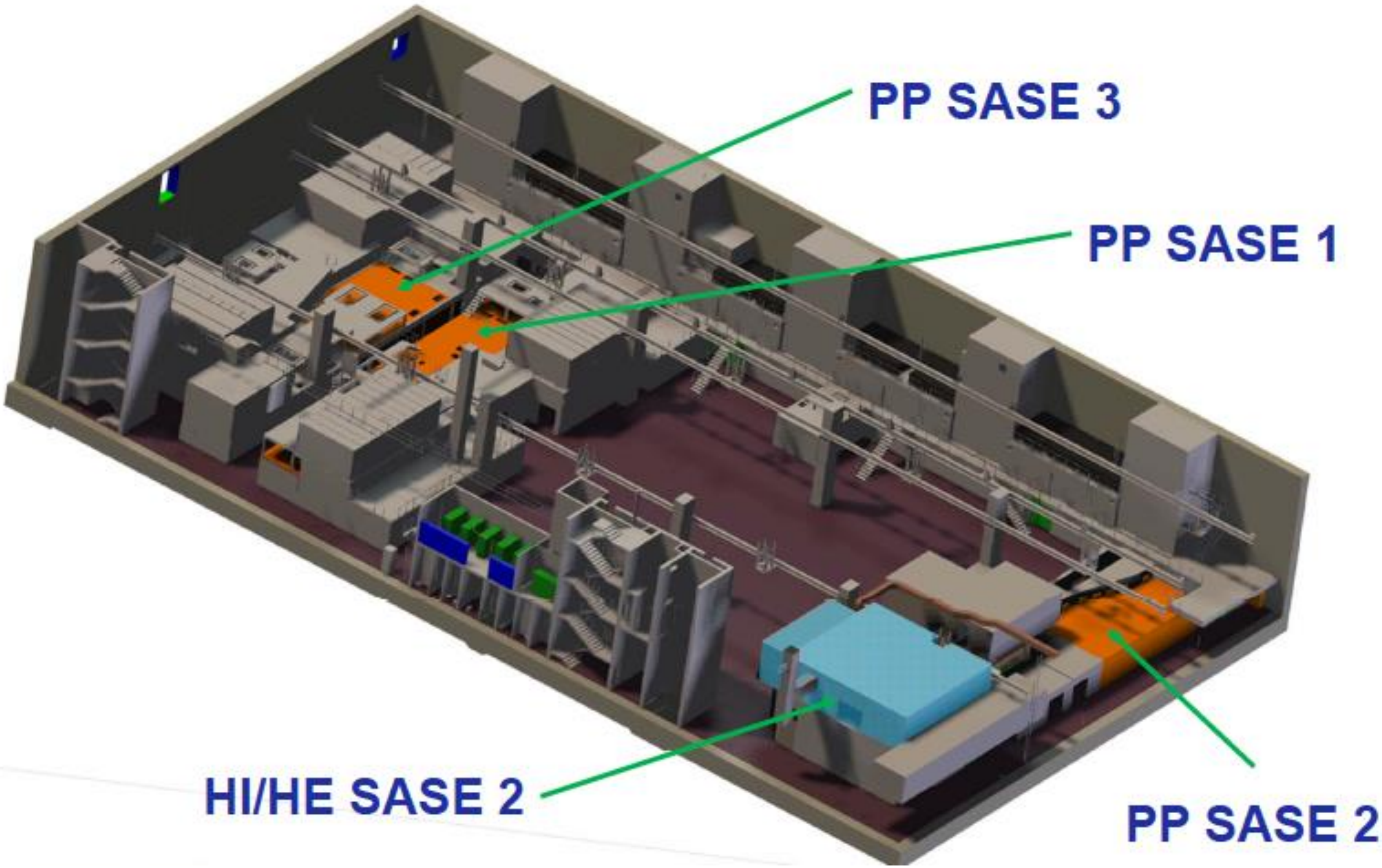
- <30fs, 10Hz, 100 TW–class laser, Tisa

100J **high energy (HE):**

- 100J … kJ-class ns-laser, 10Hz, green, exp. ramp

UC „HiBEF"

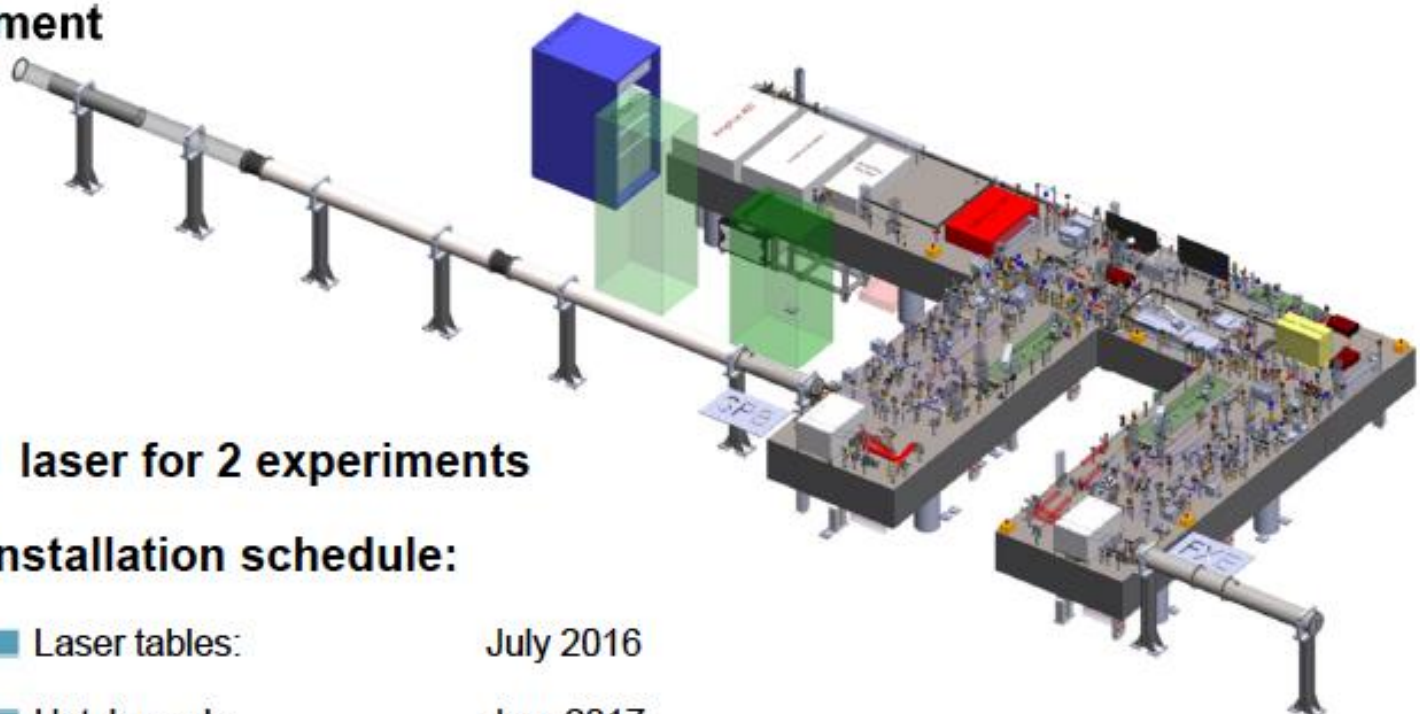
Laser installations at the European XFEL (M. Lederer)



Pump-probe optical laser production for SASE1

(Max Lederer)

to SPB-Experiment



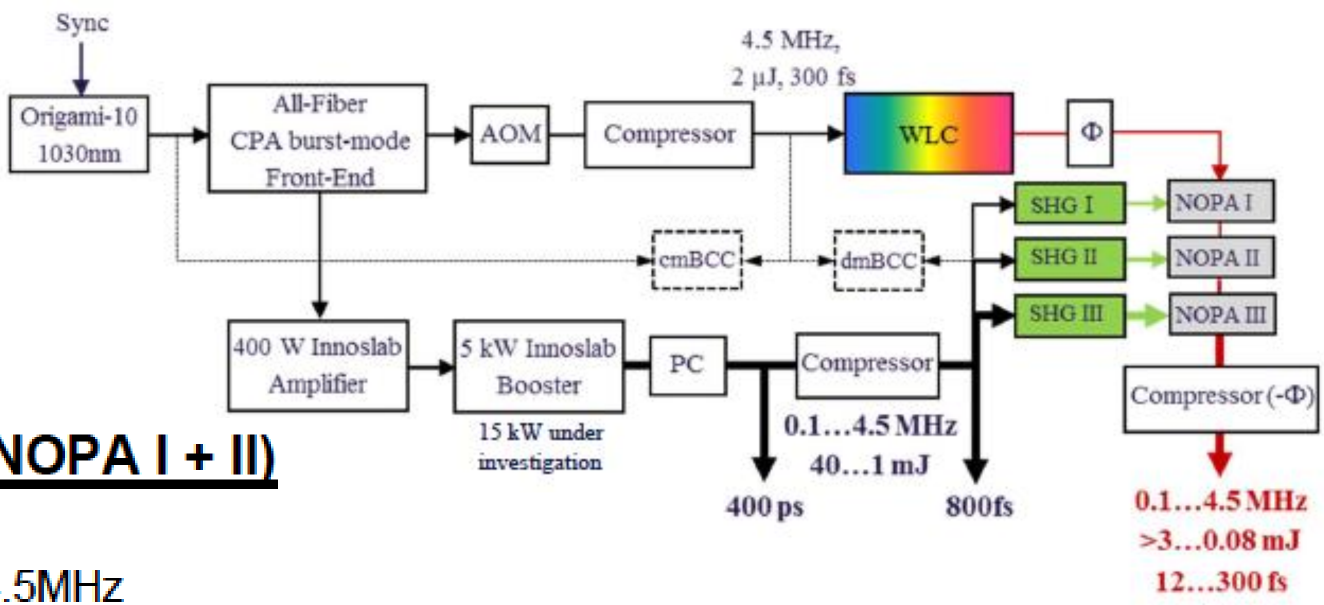
to FXE-Experiment

- **1 laser for 2 experiments**
- **Installation schedule:**

Laser tables:	July 2016
Hutch ready:	Jan. 2017
Beam to experiment:	Q3 2017

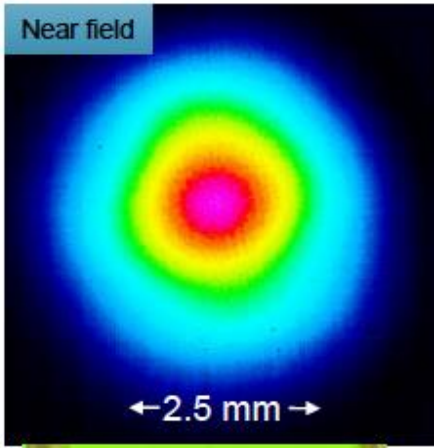
Set up and delivered parameters (Max Lederer)

Pump-Probe laser concept: *fs-pumped NOPA*



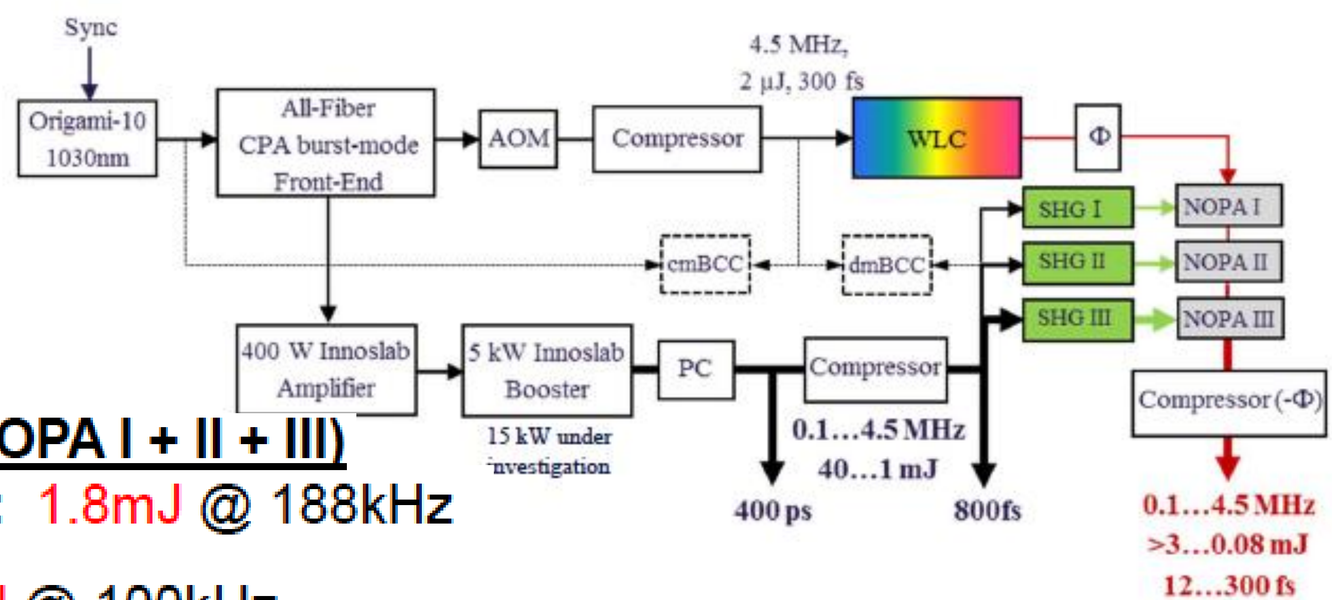
Setpoints 1 and 2 (NOPA I + II)

- **Pulse energies:**
  - ➩ 80 µJ @ 4.5MHz
  - ➩ 330 µJ @ 1.1MHz
- **Burst power:** 360W (600 µs)
- **Pulsewidth:** 15fs
- **Spectrum:** 13.8 fs Fourier-limited pulse
- **Burst-noise:** 2.5 % rms
- **Burst shape:** clean, arbitrary sequences possible



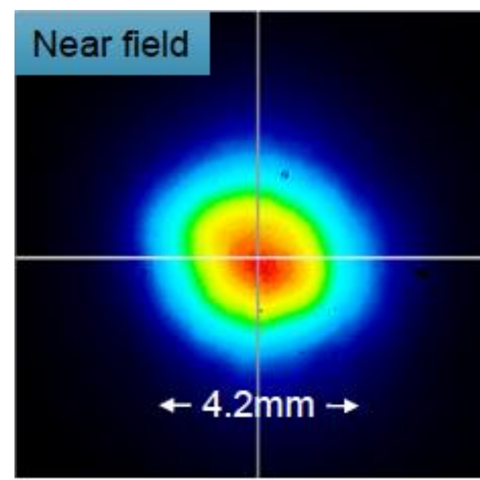
Set up and delivered parameters (Max Lederer)

Pump-Probe laser concept: ***fs-pumped NOPA***



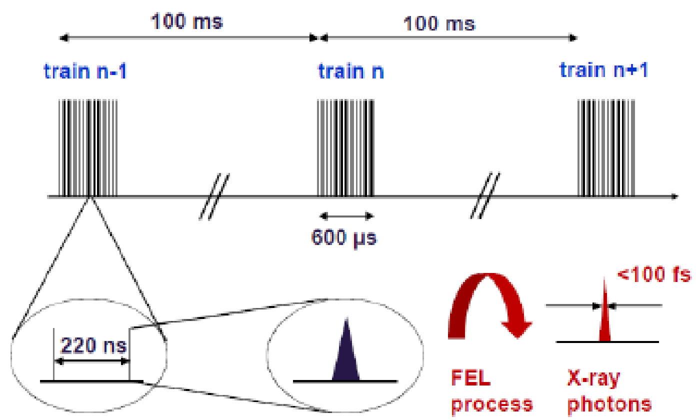
Setpoints 3 and 4 (NOPA I + II + III)

- **Pulse energy:** 1.8mJ @ 188kHz
  3.25mJ @ 100kHz
- **Burst power:** >300W (600 µs)
- **Pulsewidth:** <15fs
- **Beam quality:** $M^2 < 1.2$



Data Acquisition (K. Wrona)

- Readout rate driven by bunch structure
  - 10 Hz train of pulses
  - 4.5 MHz pulses in train
- Data volume driven by detector type



Detector type	Sampling	Data/pulse	Data/train	Data/sec
1 channel digitizer	5 GS/s	~2 kB	~6 MB	~60 MB
1 Mpxl 2D camera	4.5 MHz	~2 MB	~1 GB	~10 GB
4 Mpxl 2D camera	4.5 MHz	~8 MB	~3 GB	~30 GB*

Detector data rates are huge

* Limited by AGIPD detector internal pipeline depth (352 img/sec), hence factor 3 compare to LPD 1MPx

Estimate of total data bandwidth and volume per year

Experiment type	Max instantaneous Bandwidth (GB/s) off the detector	Expected data volume per year (compressed)	Expected data volume per year (not compressed)
FDE	1.95GB/s	3.4 PB	3.4 PB
MID hard	1.95GB/s	0.6 PB	1.7 PB
MID soft	-	2 TB	2 TB
SPB gas	10GB/s	1 PB	54 PB
SPB gas aligned	10GB/s	7.6 TB	54 PB
SPB droplet	10GB/s	6. 6PB	6.6 PB
HED	20MB/s	0.4 PB	0.4 PB

Some assumptions

- 3 x 2D 1Mpix detectors
- <512> frames per train
- 220 days per year
- Hardware efficiency 70%
- DAQ efficiency 90%

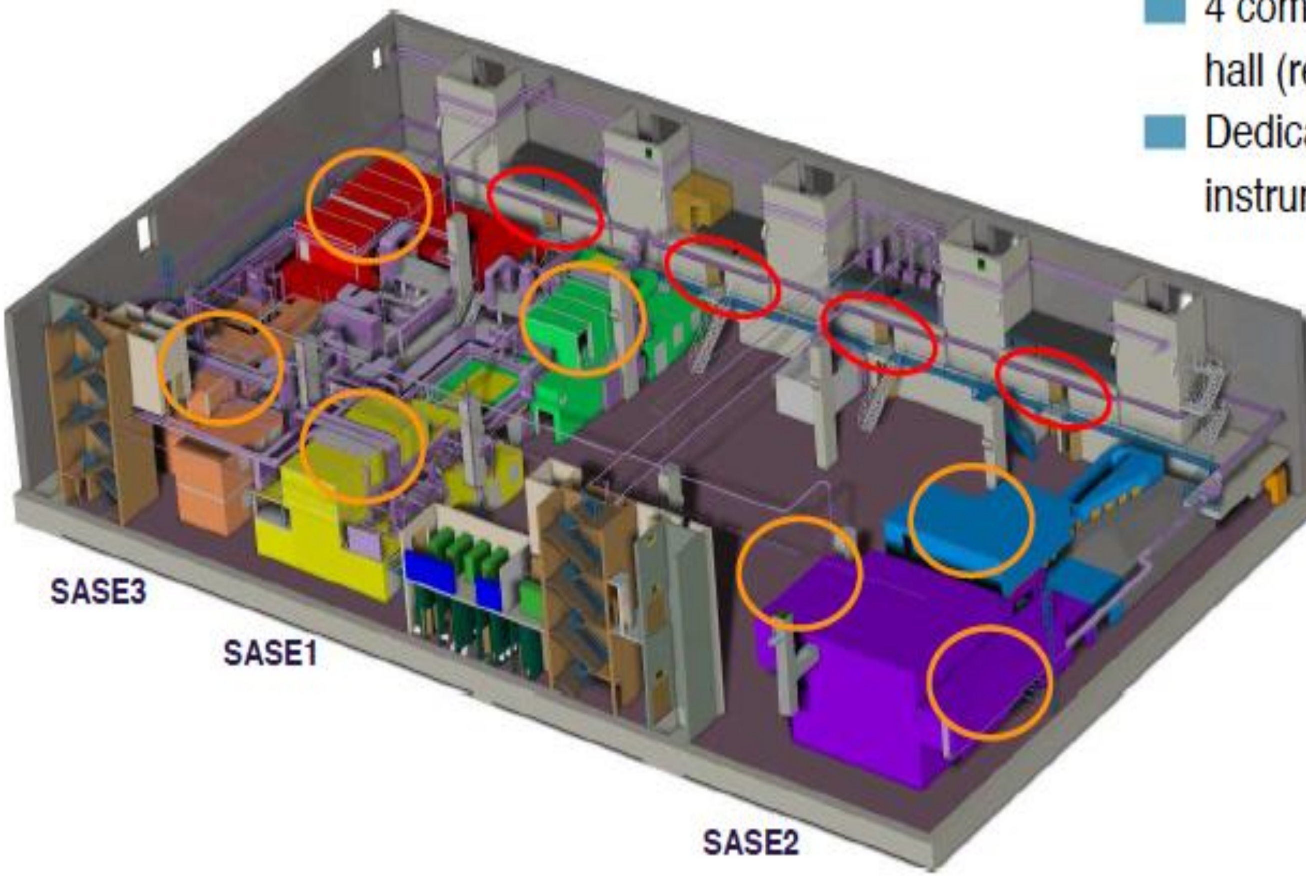
Turn-on estimation for integrated data volume:

Full year 1: ~ 20 PB
Full year 2: ~ 33 PB
Full year 3: ~ 82 PB

Note: at full performance we expect

- Parallel operation of 3 (later 5) instruments
- In a 12 hour shift
- All with 2D detectors of increasing size…

DAQ Hardware location in Experiment Hall

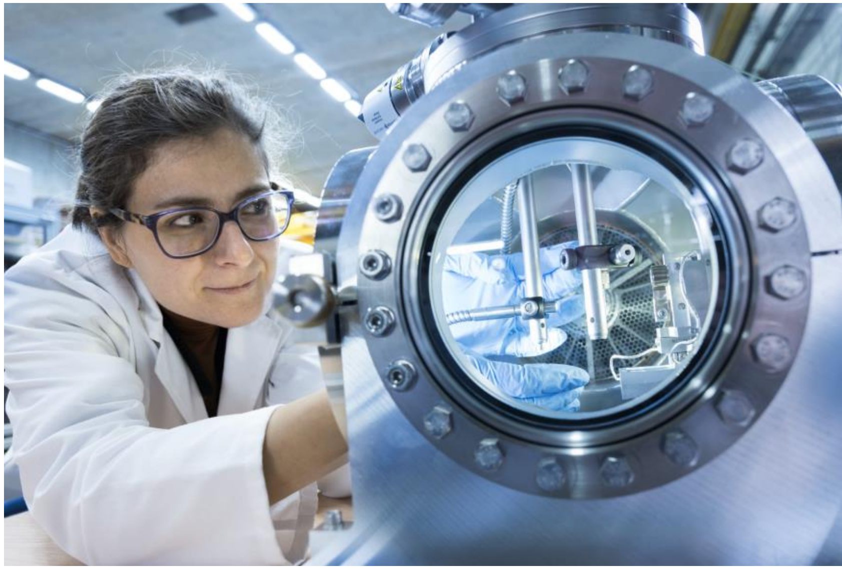


- 4 computer rooms in the experiment hall (red, a.k.a. balcony rooms)
- Dedicated rack rooms for the instruments (orange)

Courtesy K. Wrona

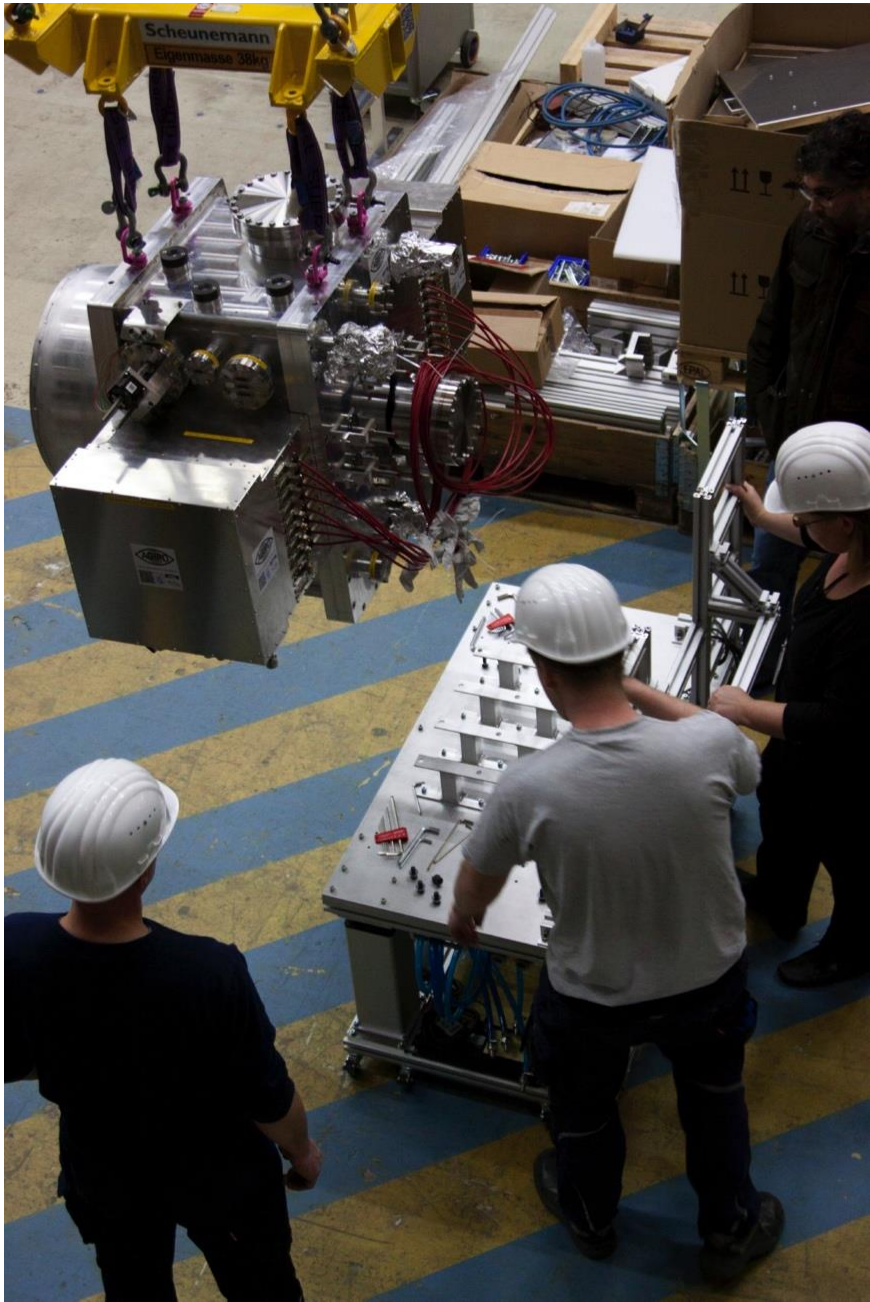
Conclusions

- First lasing (SASE1) in May 2017 is a VERY realistic goal by now!
- Call for proposals for SASE1 instruments (FXE, SPB-SFX) is completed, 63 proposals received
- First user experiments by September 2017 on SASE1, full deployment of 6 instruments by 2018.
- "Multiplexing", beam switching should increase worldwide supply of FEL radiation by large factor
- A large effort has been devoted to ancillary equipment and facilities



Conclusions

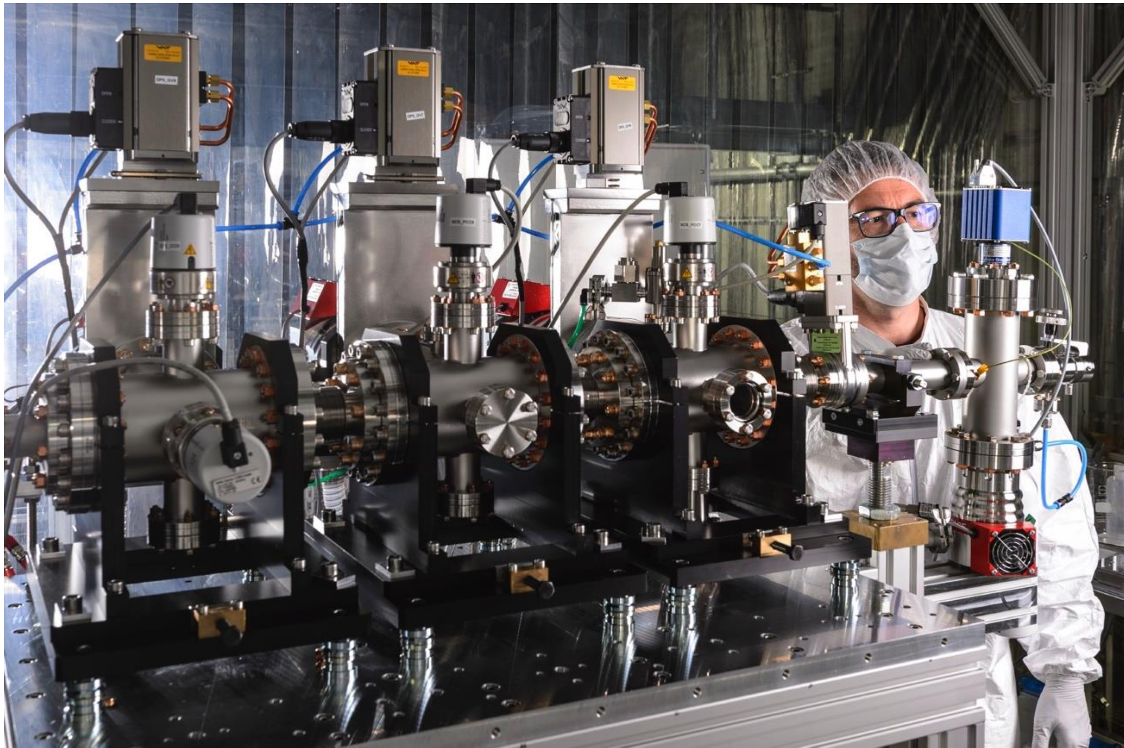
- Overall **excellent results** of recruitment!
- DESY expertise on, and infrastructure for, SC accelerators and FLASH experience **absolutely crucial** to lead, verify, test and improve production of components at other labs (in-kind contributions)
- Hopefully, another **success story of European collaboration** in science, impregnated with ESRF-style user support culture



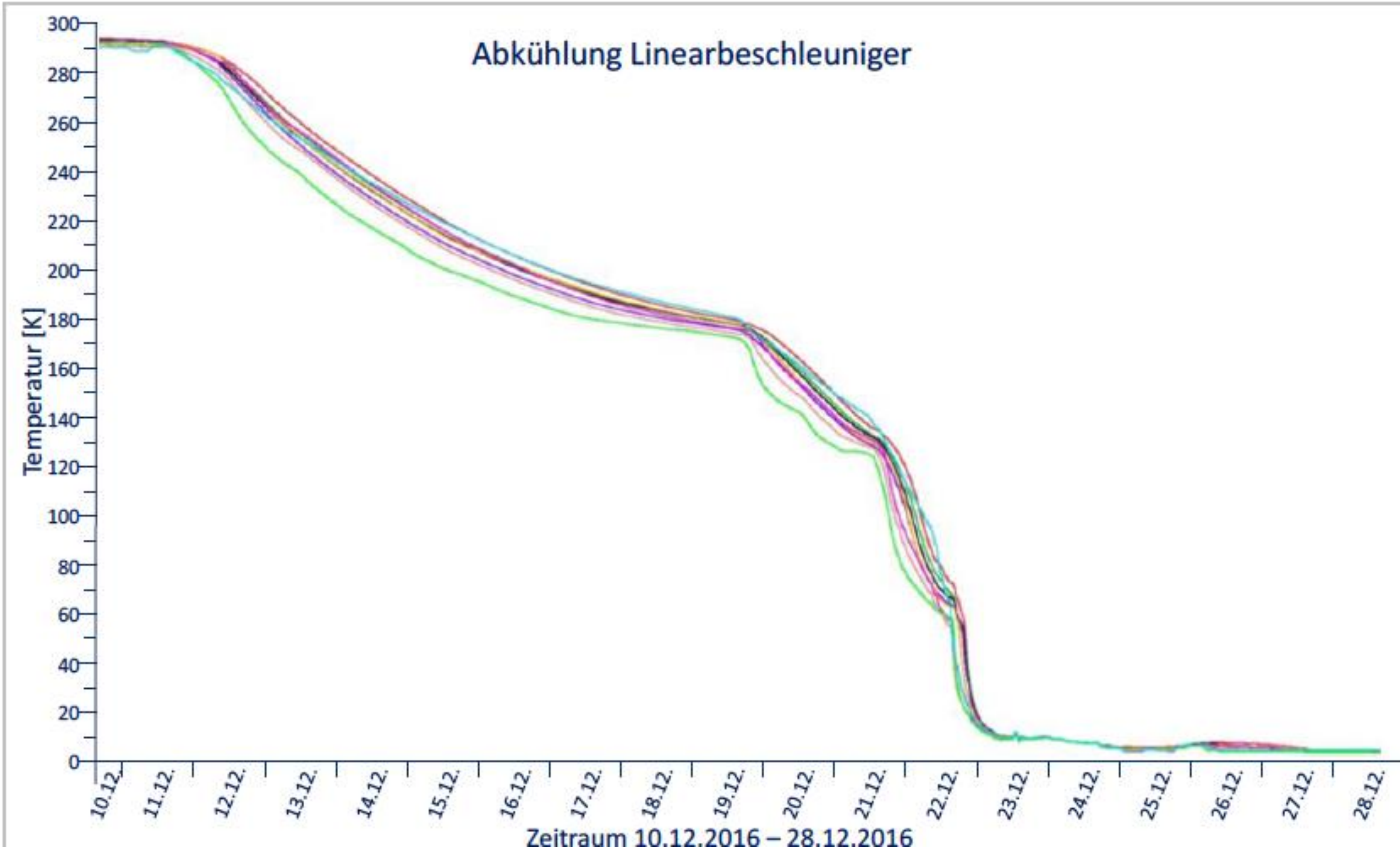
Thanks….

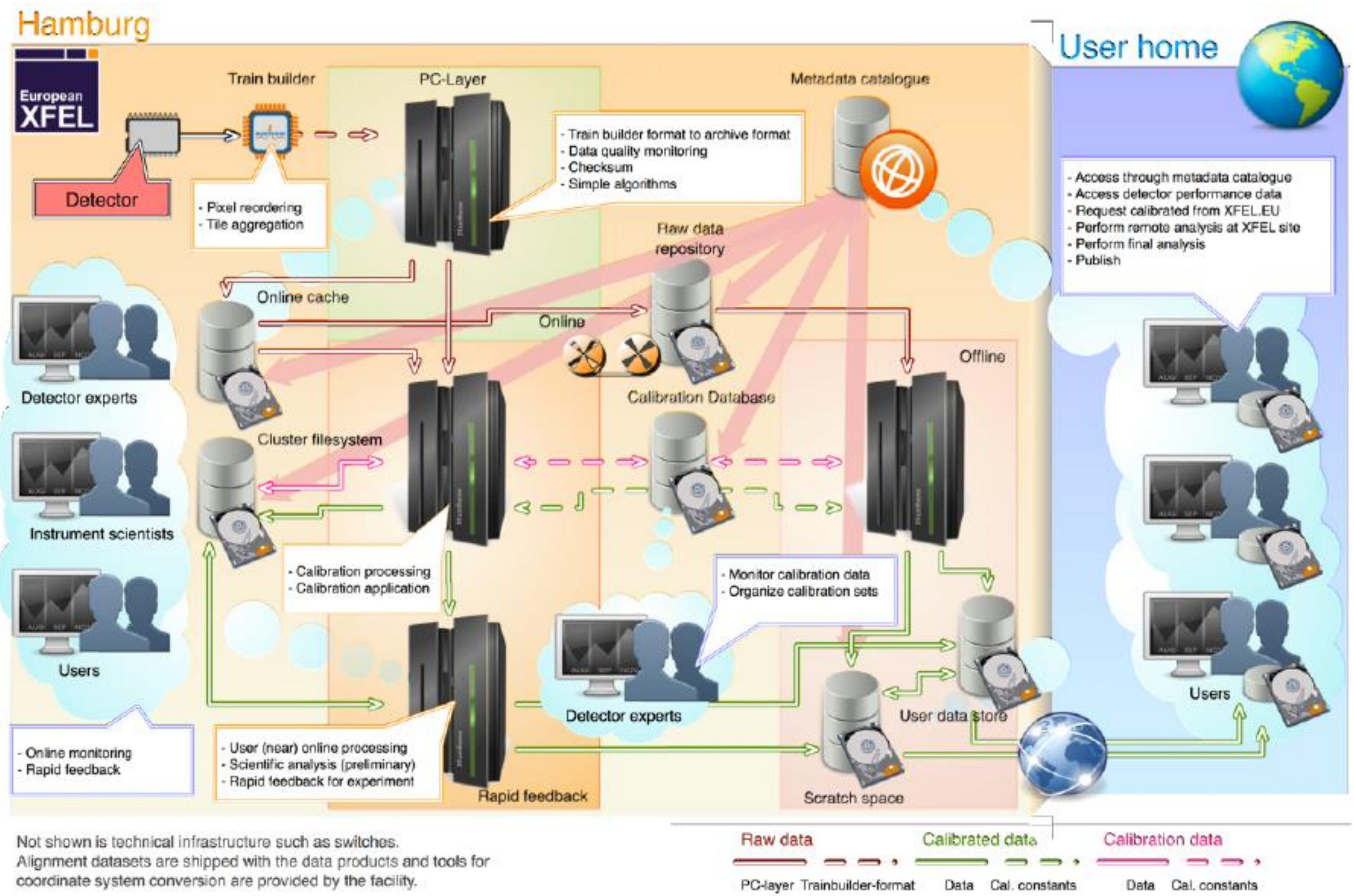
- To all European XFEL and DESY staff for the work presented here

- …and to you for your hospitality and attention!



Supplementary slides


Abkühlung Linearbeschleuniger
Temperatur [K]
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
10.12.
11.12.
12.12.
13.12.
14.12.
15.12.
16.12.
17.12.
18.12.
19.12.
20.12.
21.12.
22.12.
23.12.
24.12.
25.12.
26.12.
27.12.
28.12.
Zeitraum 10.12.2016 – 28.12.2016



Not shown is technical infrastructure such as switches.
Alignment datasets are shipped with the data products and tools for coordinate system conversion are provided by the facility.

Data Policy

Data policy

- European XFEL strives to follow the recommendations of the “PanData” project
- Includes additions introduced by recently approved ESRF data policy

The Photon and Neutron data infrastructure initiative

- founded in 2008
- concluded in 2011
- 13 European institutions


PaN-data Europe

Deliverable D2.1

Common policy framework on scientific data

Data policy in a nutshell

- First 3 years after end of experiment: only P.I. can access data

- Data ownership
  - *Who is the owner of the data? Who can make decisions?*
  - "Community at large". During embargo period PI has rights and responsibilities w.r.t data.
- Data curation
  - *Who is the data custodian? What are the responsibilities of data custodian?*
  - European XFEL. European XFEL will make sure that data is properly curated and accessible
- Data archiving
  - *How long raw data is archived?*
  - Minimum 5 years, standard 10 years
- Open access to data
  - *How is access to data regulated?*
  - After embargo period data becomes openly accessible