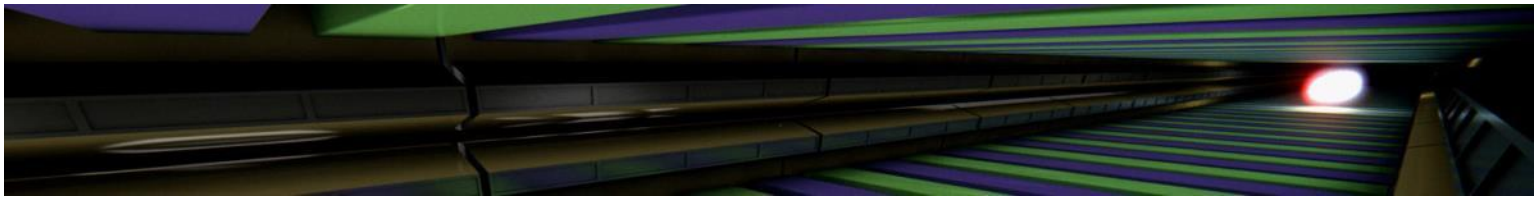

Commissioning and First Lasing of the European XFEL

Hans Weise & Winni Decking, DESY

On behalf of the European XFEL Accelerator Consortium and Commissioning Team
work supported by the respective funding agencies of the contributing institutes; for details please see http://www.xfel.eu

European XFEL

First Lasing.

DESY

ACCELERATORS | PHOTON SCIENCE | PARTICLE PHYSICS

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

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FIRST LASING.

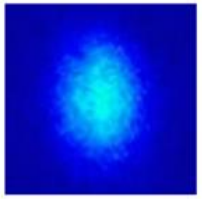
World's largest X-ray laser generates first laser light

1 2 3 4 5

European XFEL

Light of the future »

DESY is the main shareholder of the next generation X-ray laser



17/05/04 · Press-Release

Biggest X-ray laser in the world generates its first laser light

In the metropolitan region of Hamburg, the European XFEL, the biggest X-ray laser in the world, has reached the last major milestone before the official opening in September. The 3.4 km long facility,...

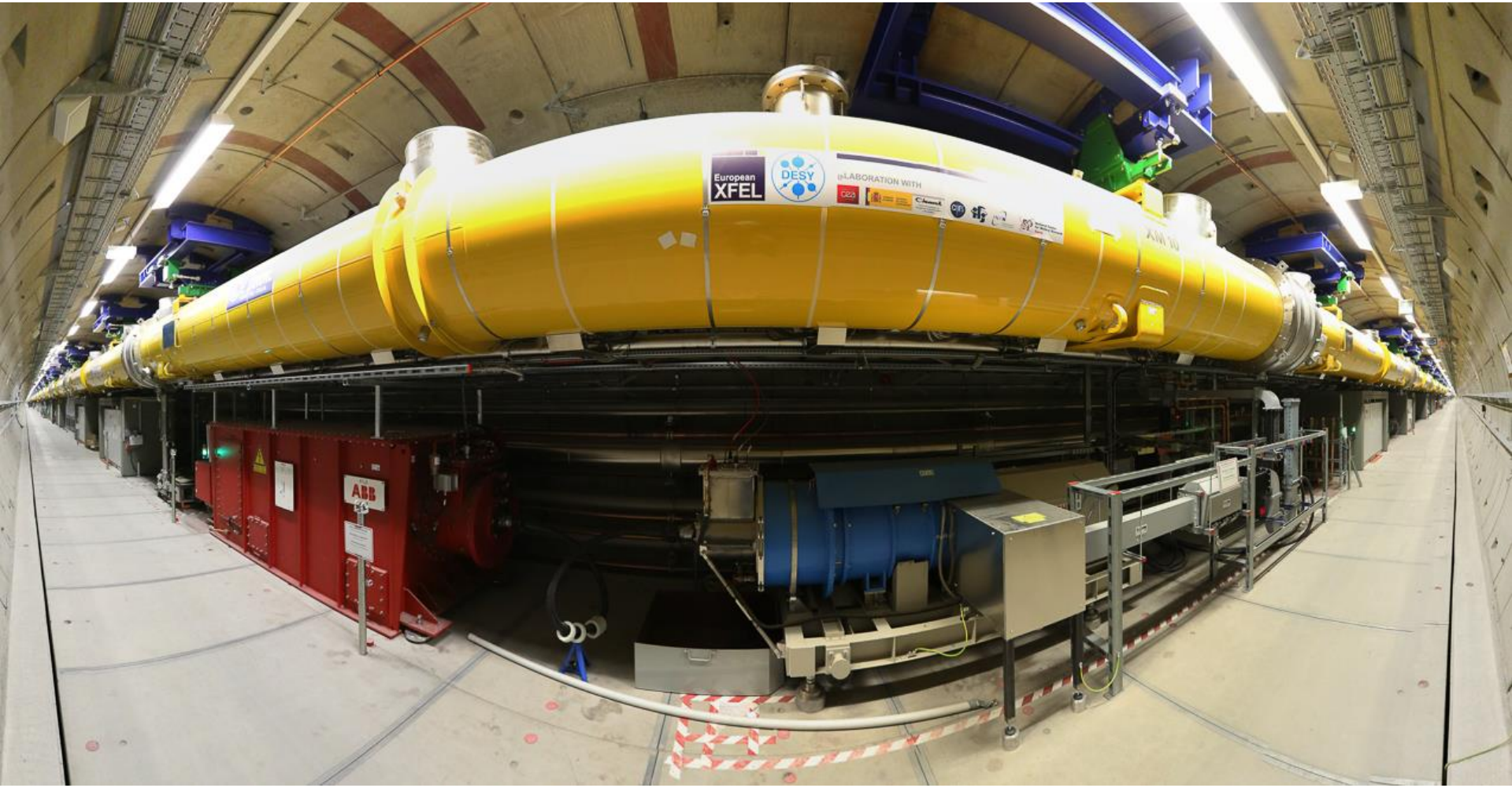
The super X-ray laser »

More about the European XFEL in DESY's research magazine!

HELMHOLTZ ASSOCIATION

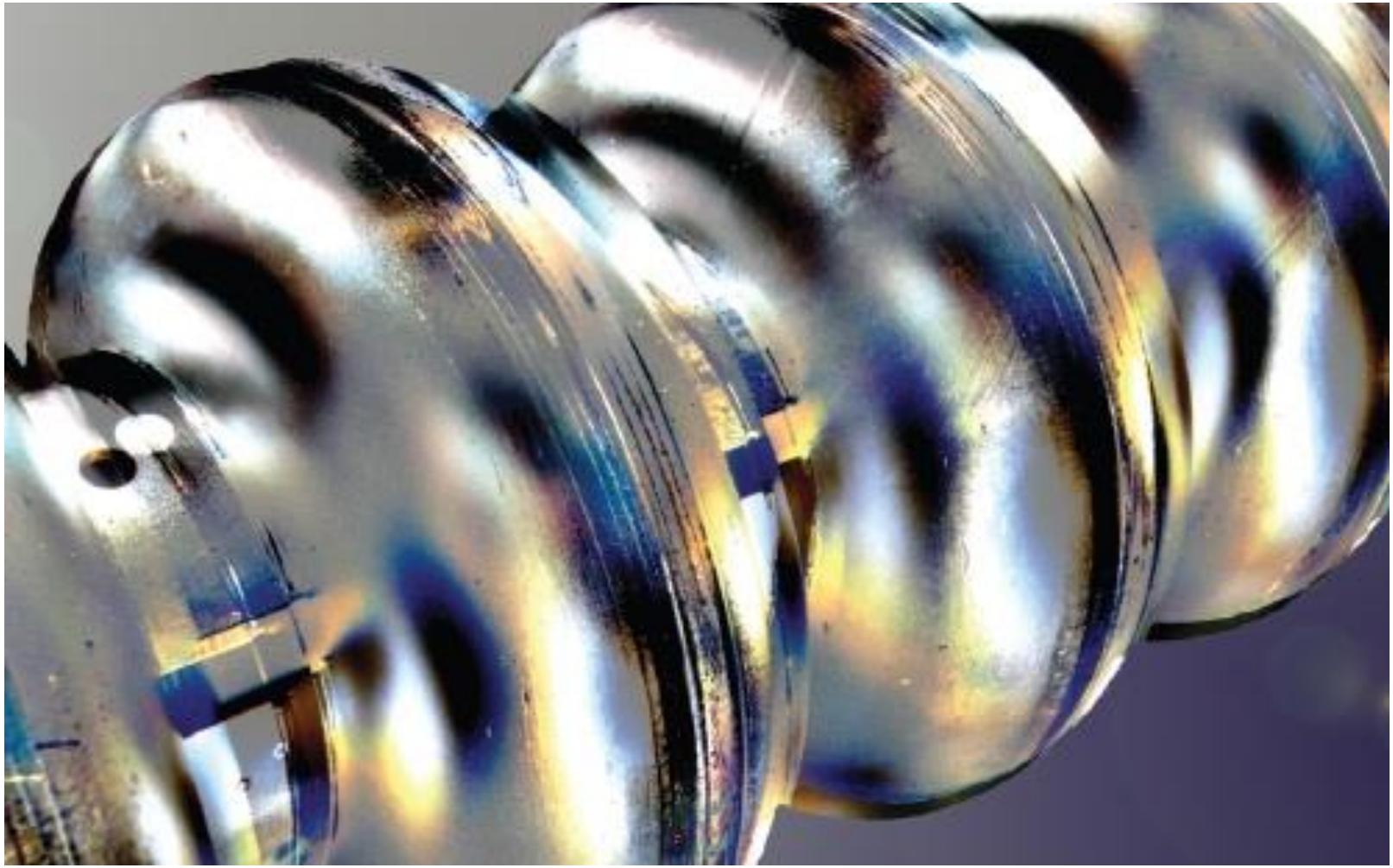
European XFEL

One Kilometer of Cold Linac



European XFEL

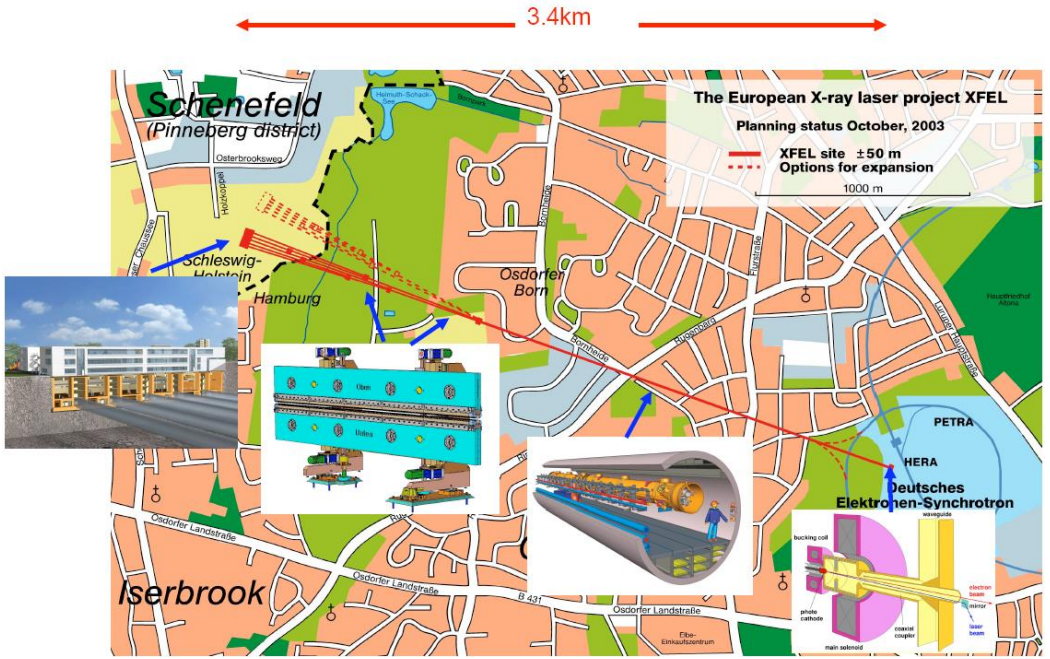
With almost 800 Superconducting Cavities

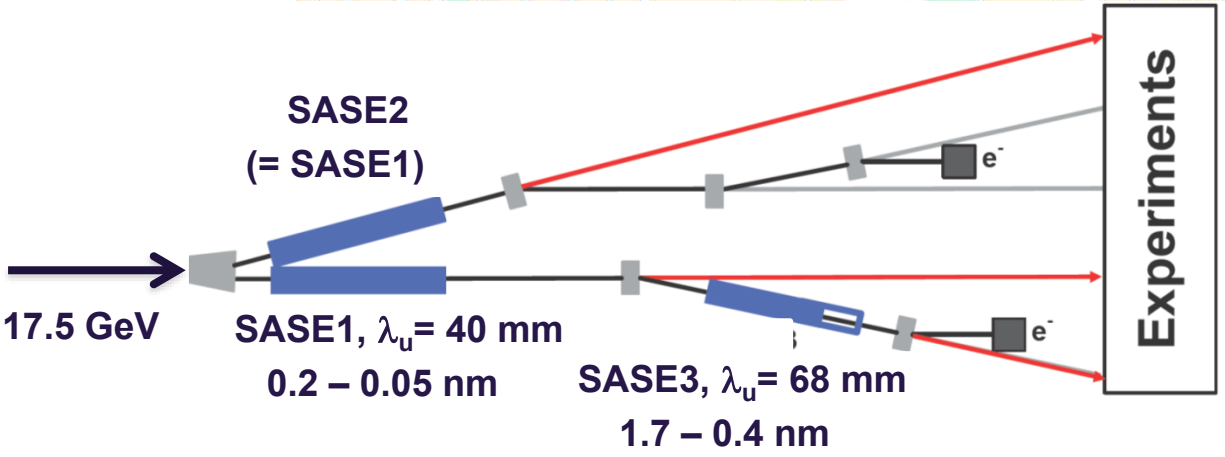


The European XFEL
Built by Research Institutes from 12 European Nations

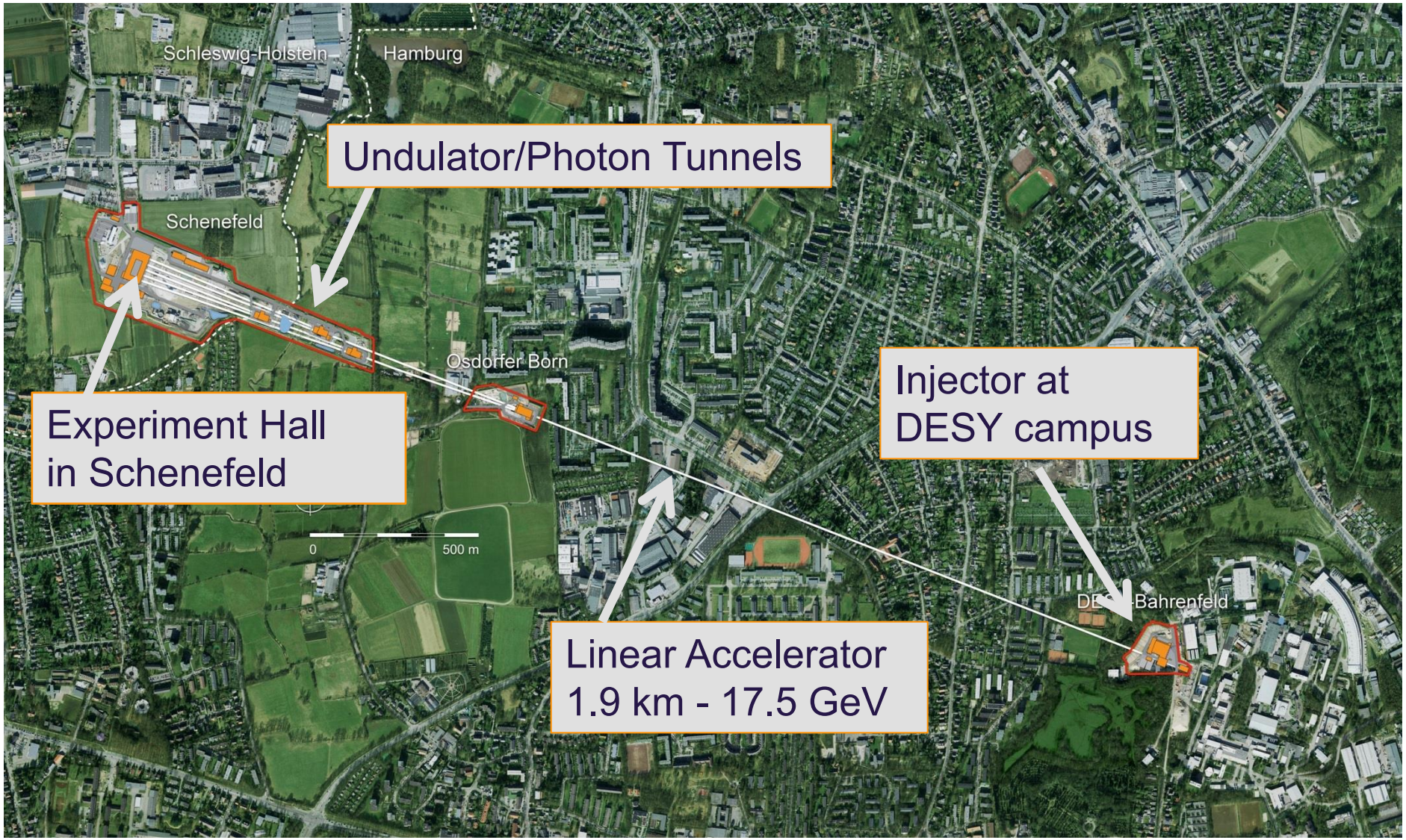
Some specifications

- Photon energy 0.3 - 24 keV
- Pulse duration ~ 10 - 100 fs
- Pulse energy few mJ
- Superconducting linac 17.5 GeV
- 10 Hz (27 000 b/s)
- 5 beam lines / 10 instruments
  - Start version with 3 beam lines and 6 instruments
- Several extensions possible:
  - More undulators
  - More instruments
  - …….
  - Variable polarization
  - Self-Seeding
  - CW operation



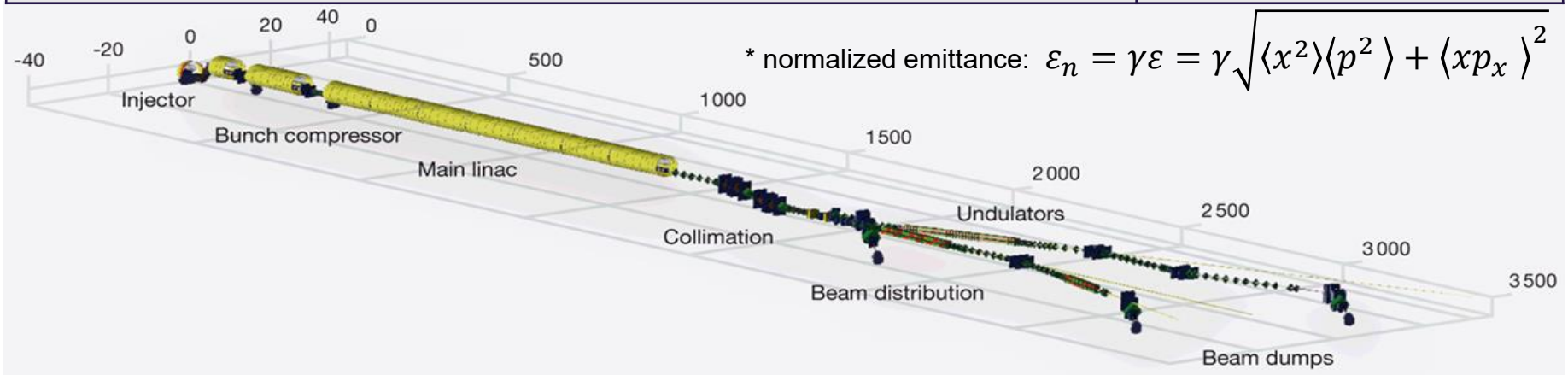


European XFEL Layout



Accelerator Complex with Challenging Parameter Set

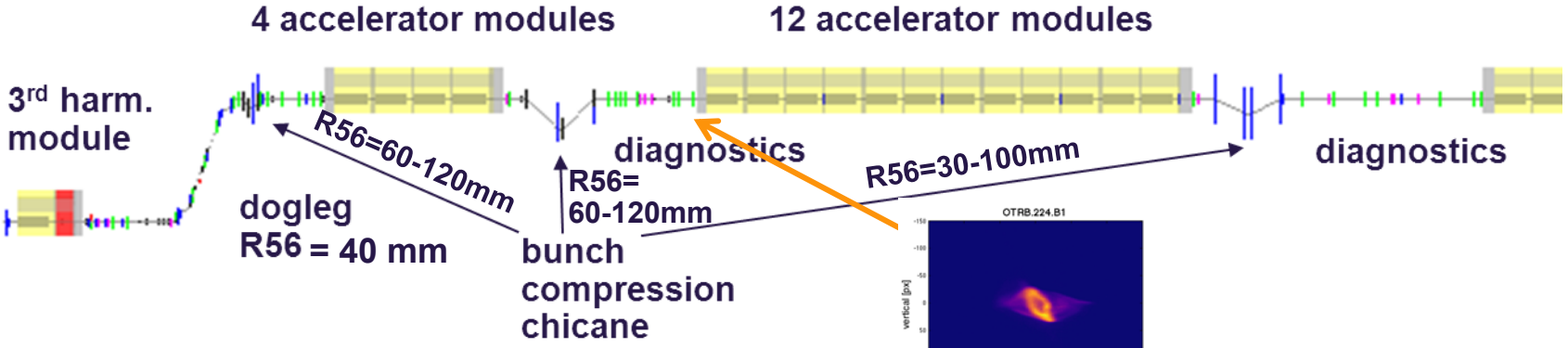
electron beam energy	8/12.5/14/17.5 GeV
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 μs
# of bunches/second	27,000
bunch charge	0.02 – 1 nC
electron bunch length after compression (FWHM)	2 – 180 fs
normalized slice emittance*	0.4 - 1.0 mm mrad
beam power	500 kW
simultaneously operated SASE undulators	3



* normalized emittance: $\varepsilon_n = \gamma\varepsilon = \gamma\sqrt{\langle x^2\rangle\langle p^2\rangle + \langle xp_x\rangle^2}$

State of the Art 3 Stage Bunch Compression

3 stage bunch compression: flexible and less sensitive to noise from RF system



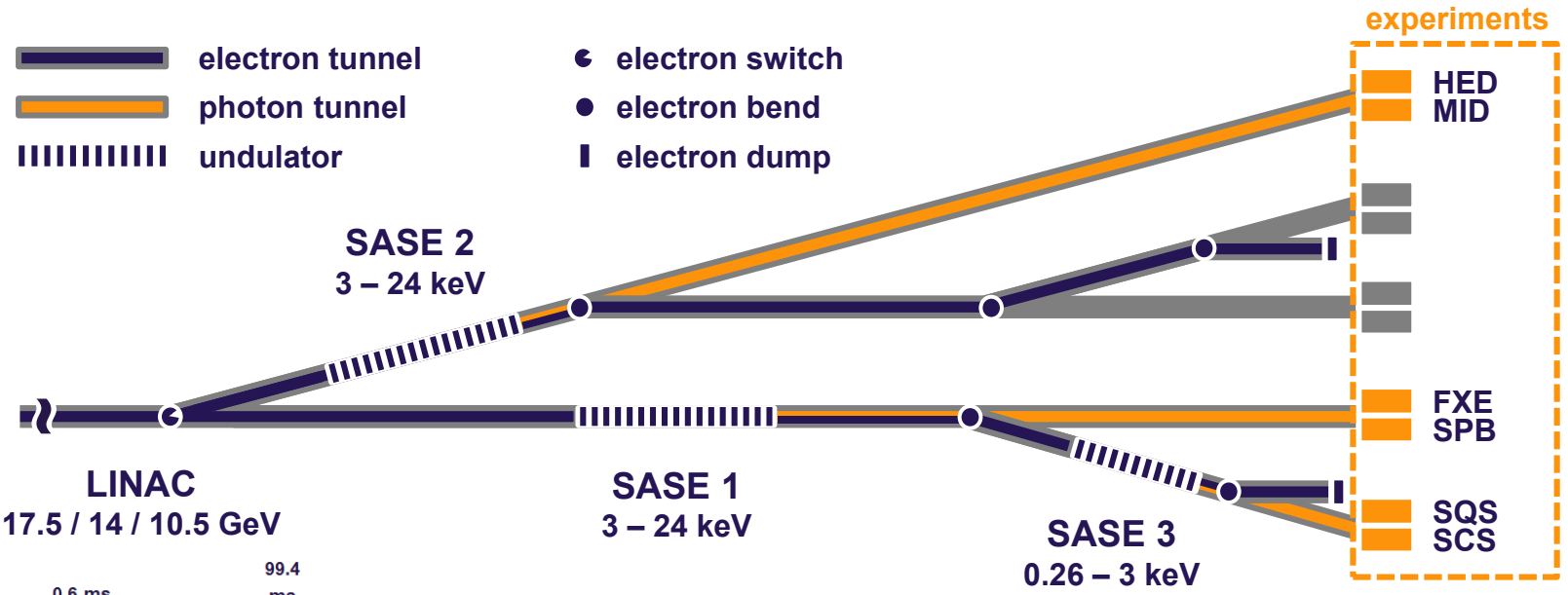
σ_σ = 2 mm	σ_σ = 1 mm	σ_σ = 0.1 mm	σ_σ = 0.02 mm
I_{peak} = 50 A	I_{peak} = 100 A	I_{peak} = 1 kA	I_{peak} = 5 kA
σ_E = 0 %	σ_E = 1.5 %	σ_E = 1 %	σ_E = 0.3 %
E = 130 MeV	E = 130 MeV	E = 600 MeV	E = 2400 MeV

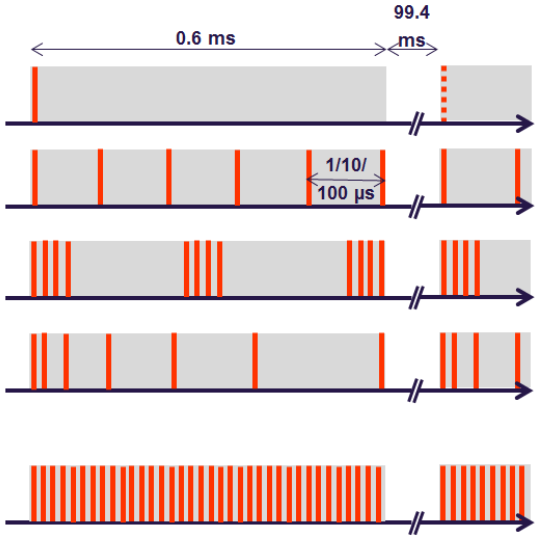
harmonic system

bunch compressor

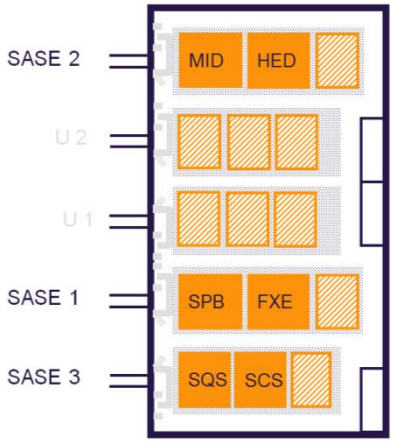
beam diagnostics

X-ray Beamlines for Different Wavelengths with Different Time Structures

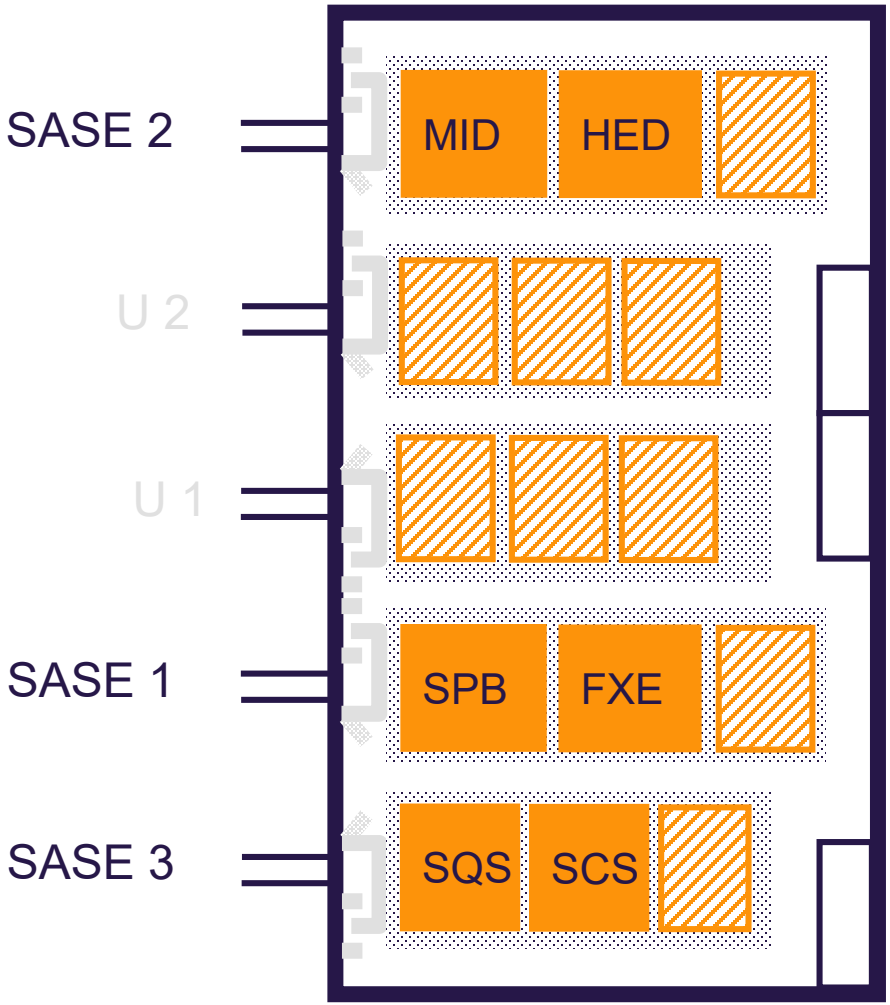




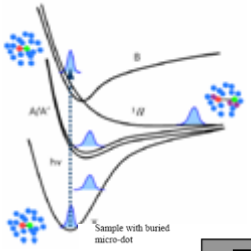
- 2 hard x-ray undulators and beam transport with 4 instruments
- 1 soft x-ray undulator and beam transport with 2 instruments
- all undulators planar and tunable



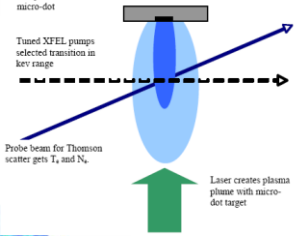
The Suite of Instruments



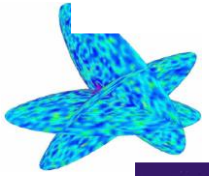
FXE Femtosecond X-ray Experiments



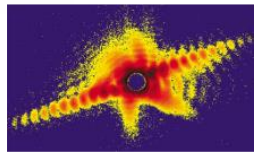
HED High Energy Density Science



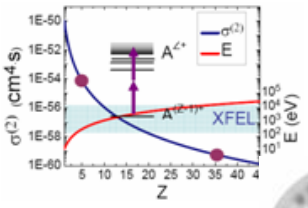
SPB Single Particle & Biomolecules



MID Materials Imaging & Dynamics



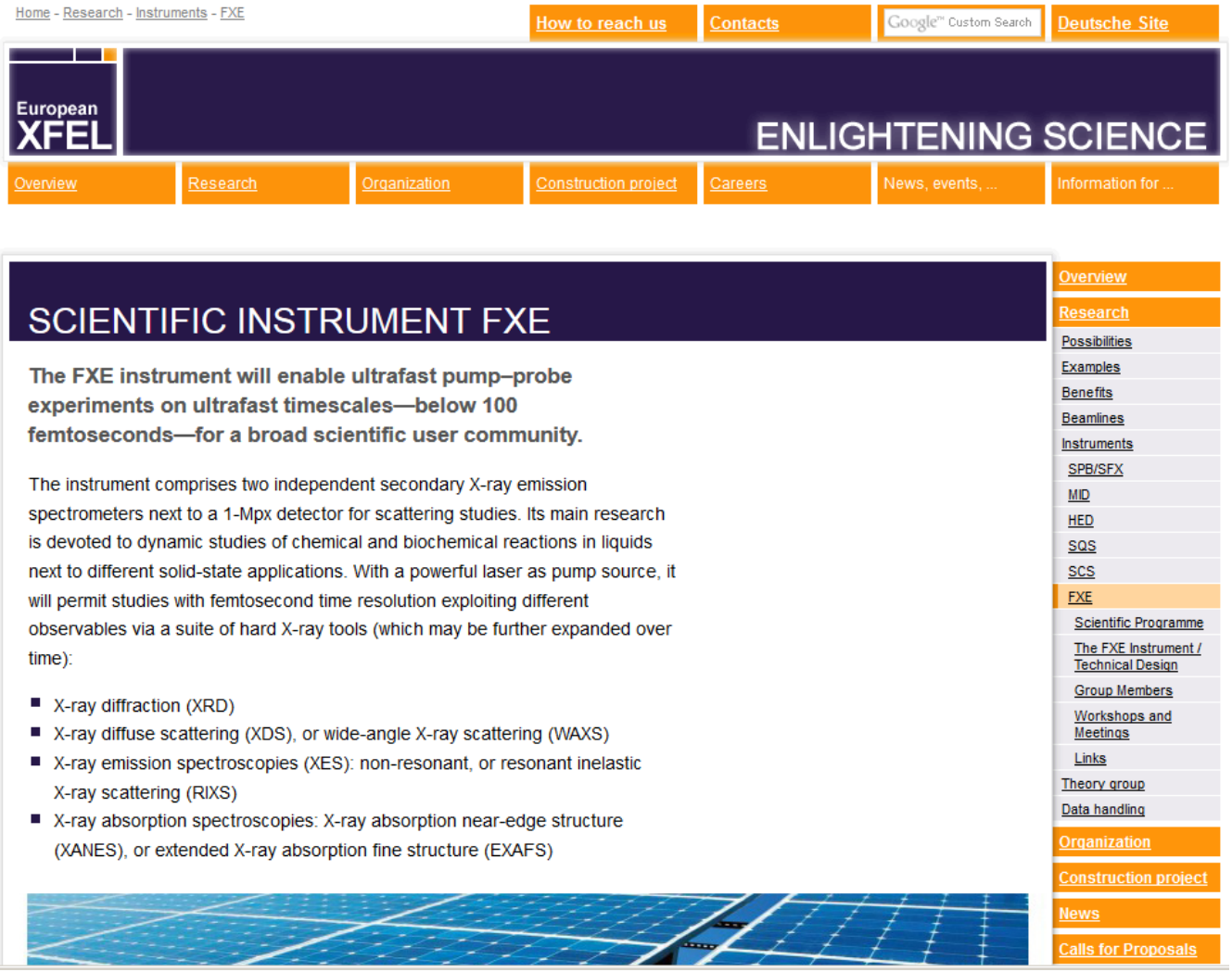
SQS Small Quantum Systems



SCS Spectroscopy & Coherent Scattering

More about experiments: http://www.xfel.eu

First Proposals are using FXE Experiment



Home - Research - Instruments - FXE

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European XFEL — ENLIGHTENING SCIENCE

Overview | Research | Organization | Construction project | Careers | News, events, ... | Information for ...

SCIENTIFIC INSTRUMENT FXE

The FXE instrument will enable ultrafast pump–probe experiments on ultrafast timescales—below 100 femtoseconds—for a broad scientific user community.

The instrument comprises two independent secondary X-ray emission spectrometers next to a 1-Mpx detector for scattering studies. Its main research is devoted to dynamic studies of chemical and biochemical reactions in liquids next to different solid-state applications. With a powerful laser as pump source, it will permit studies with femtosecond time resolution exploiting different observables via a suite of hard X-ray tools (which may be further expanded over time):

- X-ray diffraction (XRD)
- X-ray diffuse scattering (XDS), or wide-angle X-ray scattering (WAXS)
- X-ray emission spectroscopies (XES): non-resonant, or resonant inelastic X-ray scattering (RIXS)
- X-ray absorption spectroscopies: X-ray absorption near-edge structure (XANES), or extended X-ray absorption fine structure (EXAFS)

Overview
Research
Possibilities
Examples
Benefits
Beamlines
Instruments
SPB/SFX
MID
HED
SQS
SCS
FXE
Scientific Programme
The FXE Instrument / Technical Design
Group Members
Workshops and Meetings
Links
Theory group
Data handling
Organization
Construction project
News
Calls for Proposals

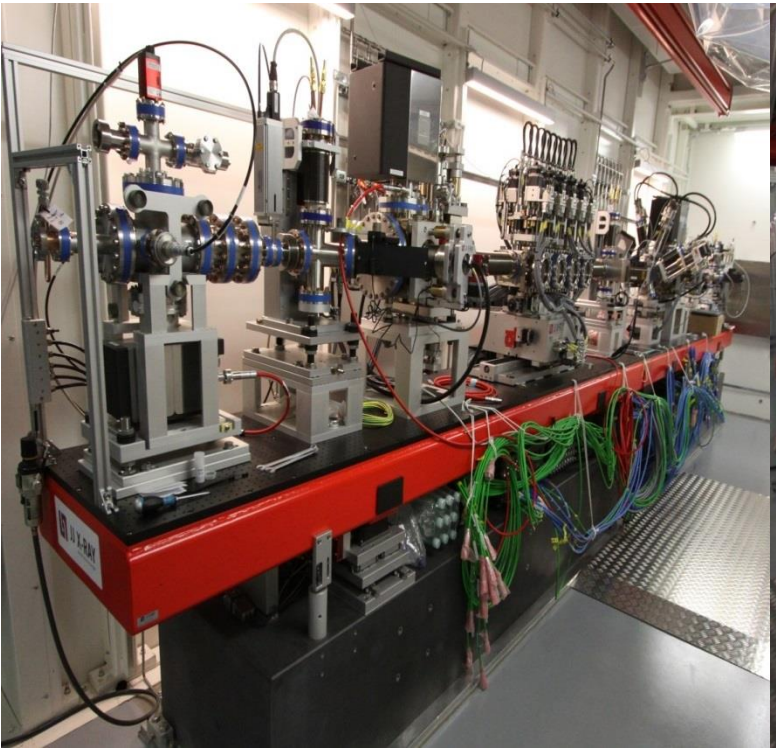
FXE will serve for

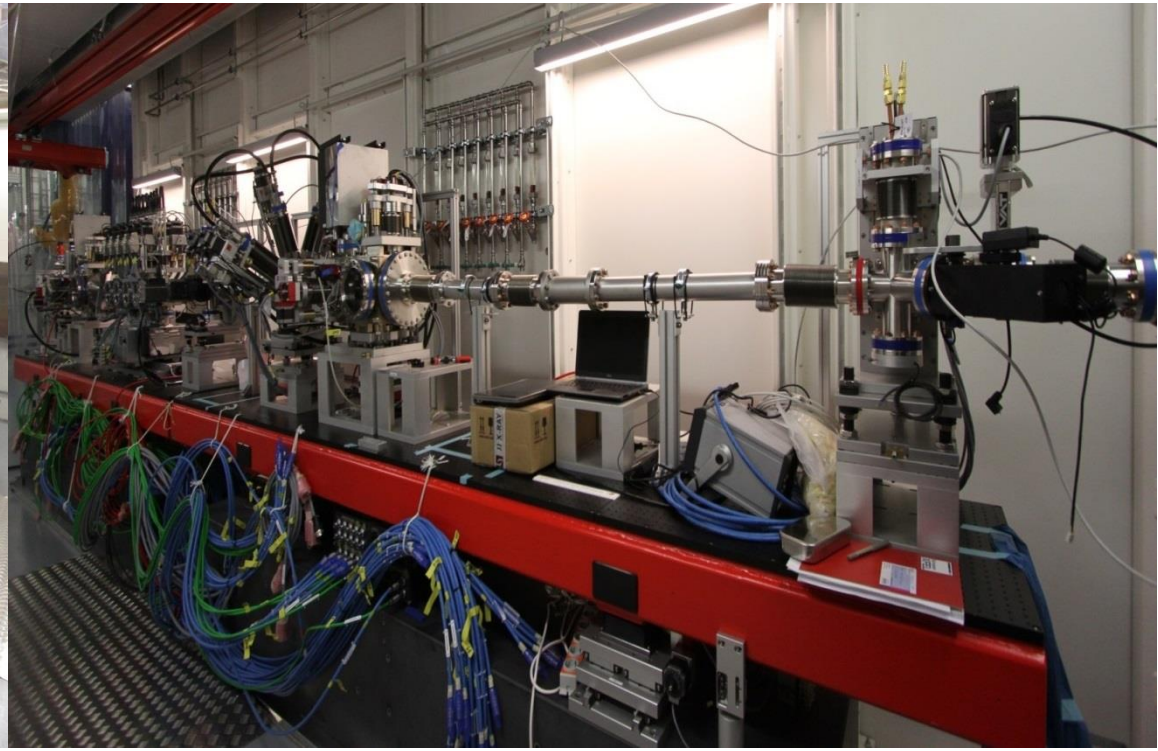
- Chemical dynamics
- Photovoltaic applications
- Photosynthesis
- Catalytic processes
- Material physics

Ultrafast pump-probe on <100fs time scale

Start in 2017

SASE1 - Femtosecond X-ray Experiment (FXE)





Project History

2000: First lasing at 109 nm at the Tesla Test Facility (TTF), now FLASH

2001: TESLA Linear Collider TDR with XFEL appendix

2002: TESLA TDR supplement with stand-alone XFEL

2006: European XFEL TDR

2009: Foundation of the European XFEL GmbH

Start of underground construction

2010: Formation of the Accelerator Consortium

16 accelerator institutes under the coordination of DESY

2012: End of tunnel construction

Start of underground installation

2016: Finish of accelerator installation

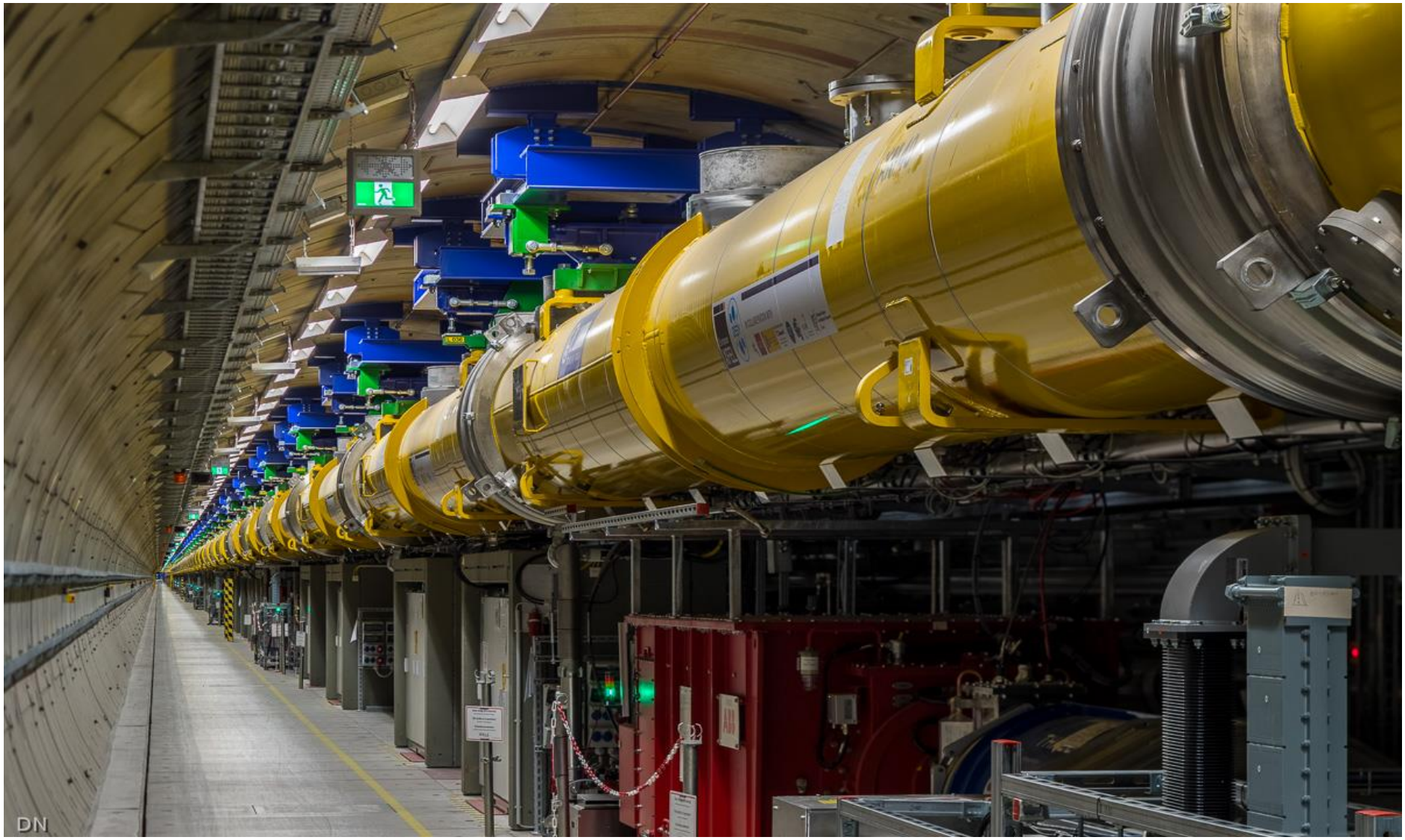
Start of commissioning

Injector in Operation 2015 / 2016

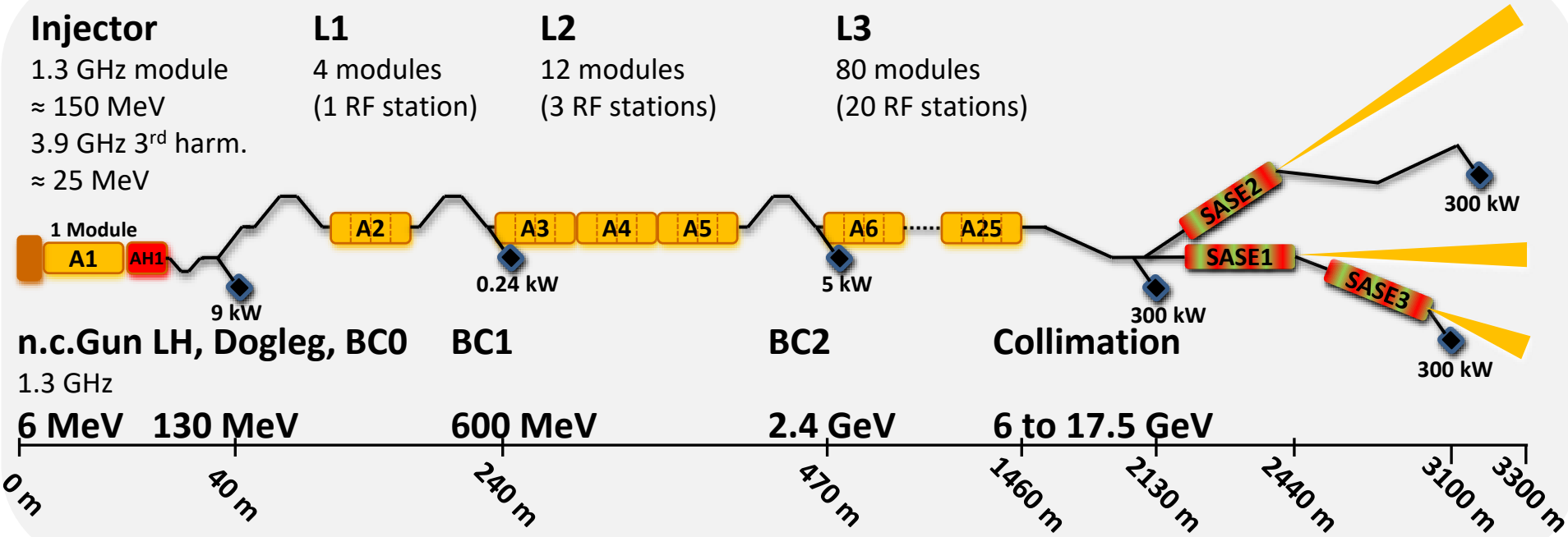
- Photoinjector conditioned and characterized at PITZ, DESY-Zeuthen
- Injector cool-down 12 / 2015
- First Beam on Dec 18th 2015 - commissioning till Q2/2016
- Full bunch train length (27,000 bunches/s) reached for 20pC - 1000pC bunch charges
- Photocathode laser with excellent up-time

  (Yb:YAG laser from Max-Born Institute Berlin; 257 nm ≤ 4 µJ; 3 ps)
- 3.9 GHz system operational from day 2
- Laser heater commissioned

View along L3 accelerator section

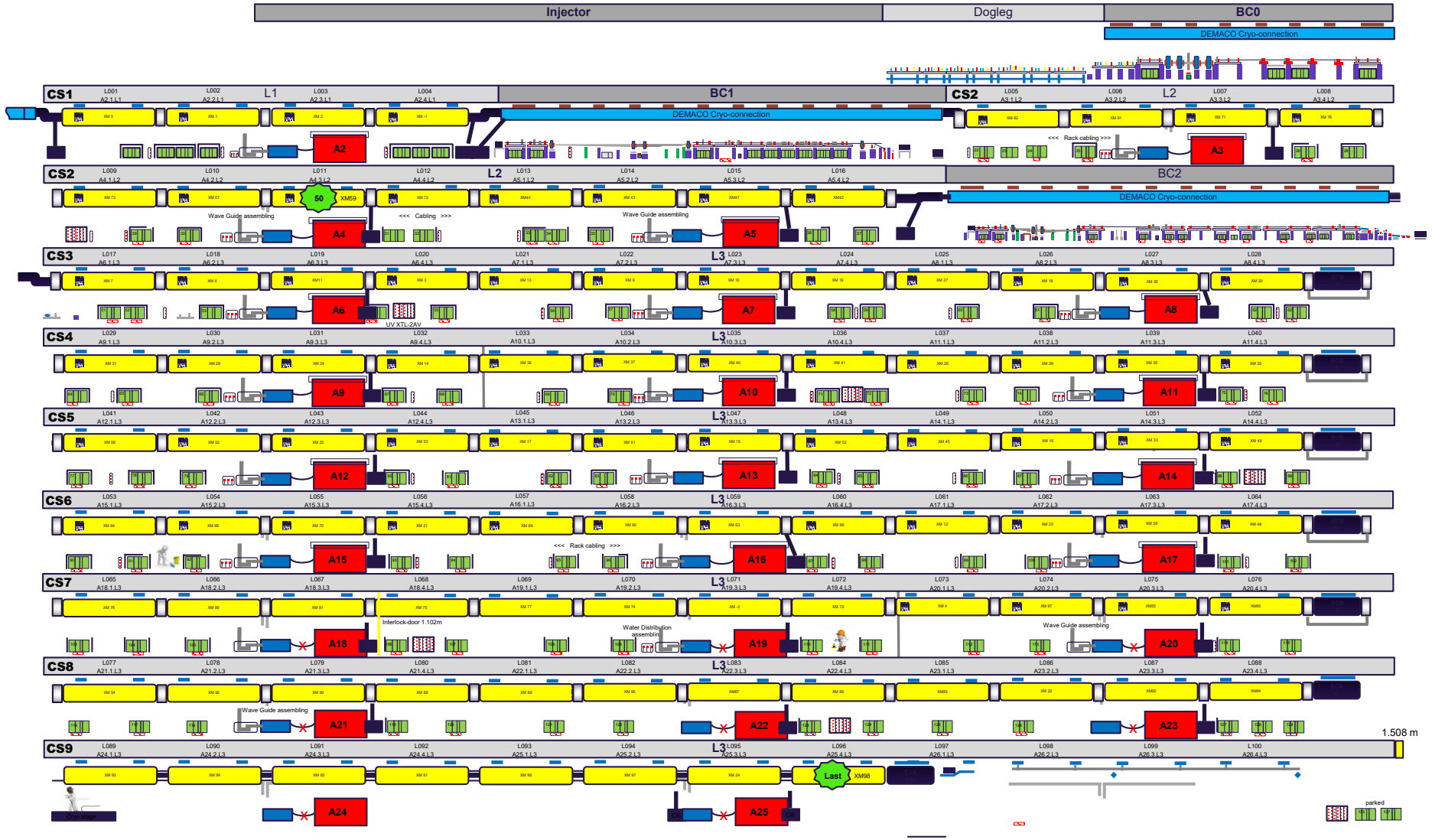


Accelerator Overview

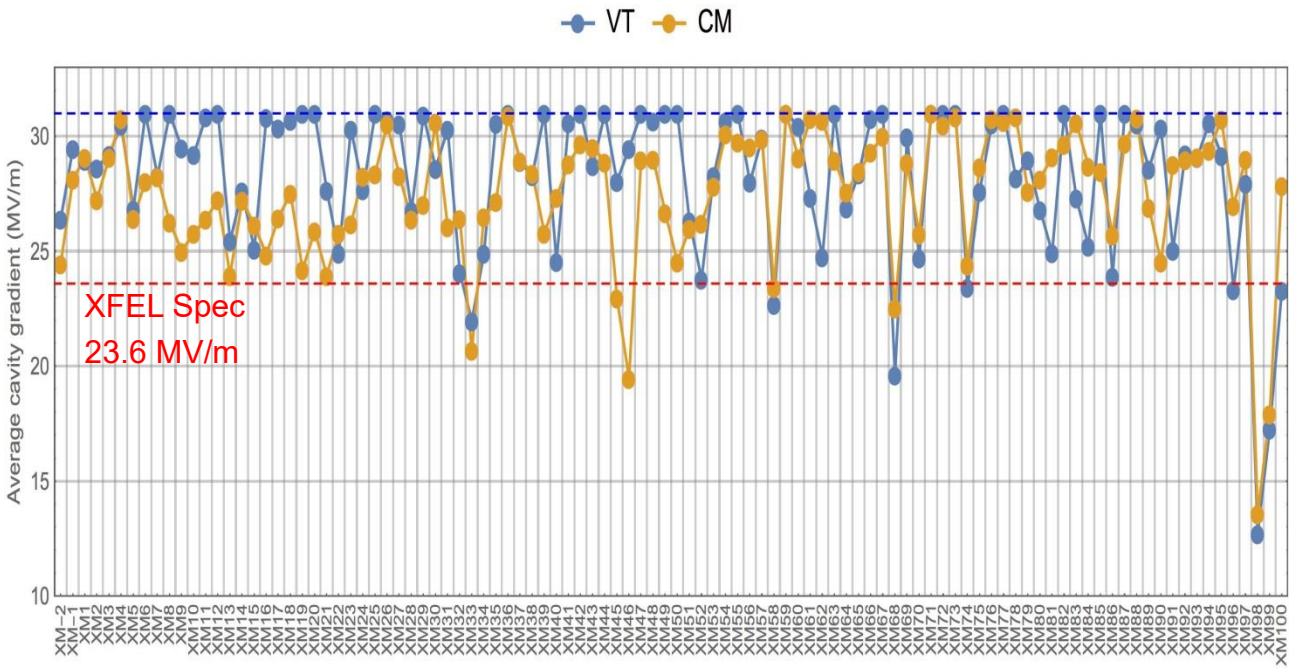


- s.c. linac with 97 1.3 GHz superconducting modules + 1 third harmonic module
- design gradient: 23.6 MV/m; pulsed with 1.4ms pulse length; 600 µs flat top
- 4 modules / 32 s.c. cavities are connected to one 10 MW klystron (“RF station”)
- 12 modules form a cryogenic string
- Down to app. 50m behind the last module the complete beam vacuum is “particle free”

All Accelerator Modules Installed



XFEL Module Performance



vertical test (clipped at 31 MV/m)
module performance

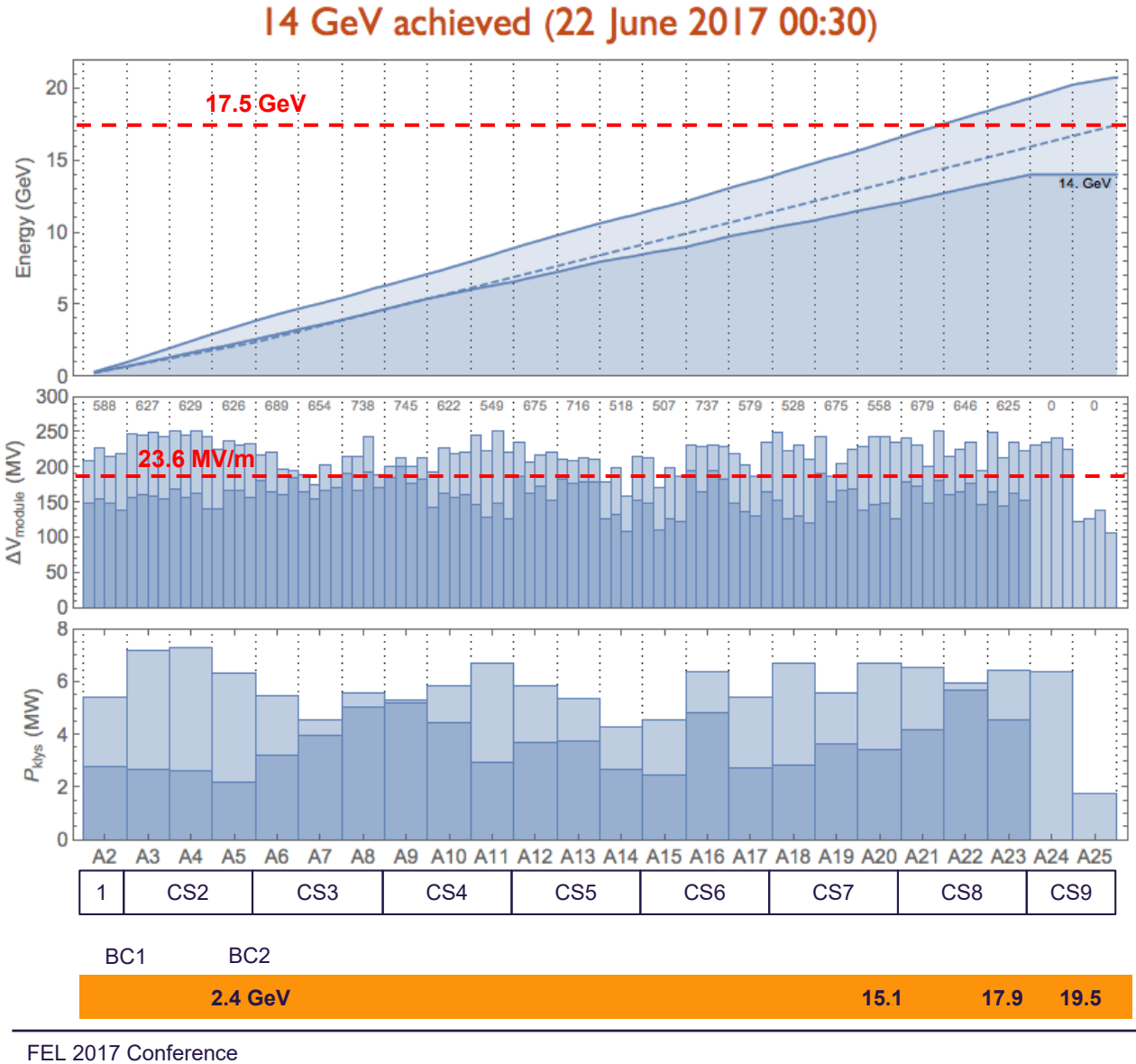
- Module performance well above specs. and visible improvement with time
- Tunnel installation used sorting of modules based on AMTF performance
- XM98 as scavenger module

Remark:

Clipping at 31 MV/m is done due to max. available RF power; limit given by waveguide distribution.

	N_{cavs}	Average	RMS
VT	815	28.3 MV/m	3.5
CM	815	27.5 MV/m	4.8

Energy Reach of European XFEL Modules



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

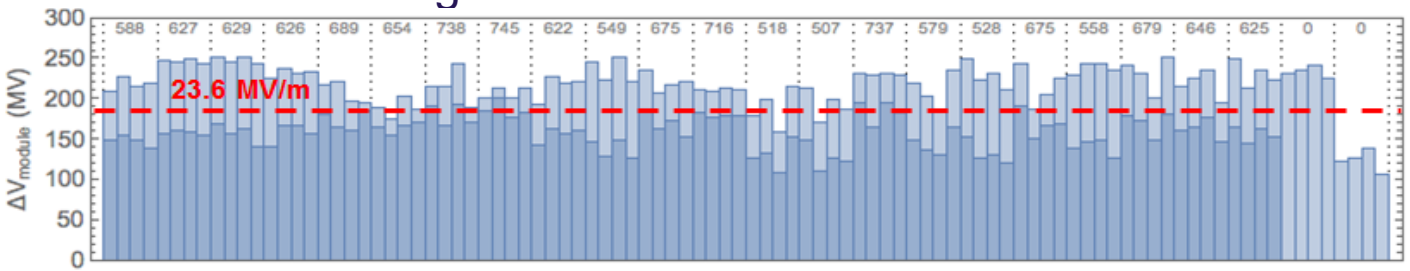
the maximum energy during FEL operation needs to respect the bunch compressor (BC) working points

- 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

Linac performance (as of summer 2017)

- Expected average accelerating gradient is ~26 MV/m
  - after AMTF module test,
  - module waveguide tailoring,
  - ignoring bunch compressor set-points.
- Some gradient reduction observed
  => Tunnel waveguide distribution and calibrations under investigation



- Operation of RF stations “off beam” allows commissioning/investigation of single RF stations parallel to lasing operation.
- More cavities than in AMTF test needed short Multipacting processing.
- So far 4 couplers were disconnected due to temperature rise at warm window; RF conditioning was not easily possible
- Preliminary:
  Average Q-value is >10^{10} estimated from the dynamic cryo losses at 12-14 GeV

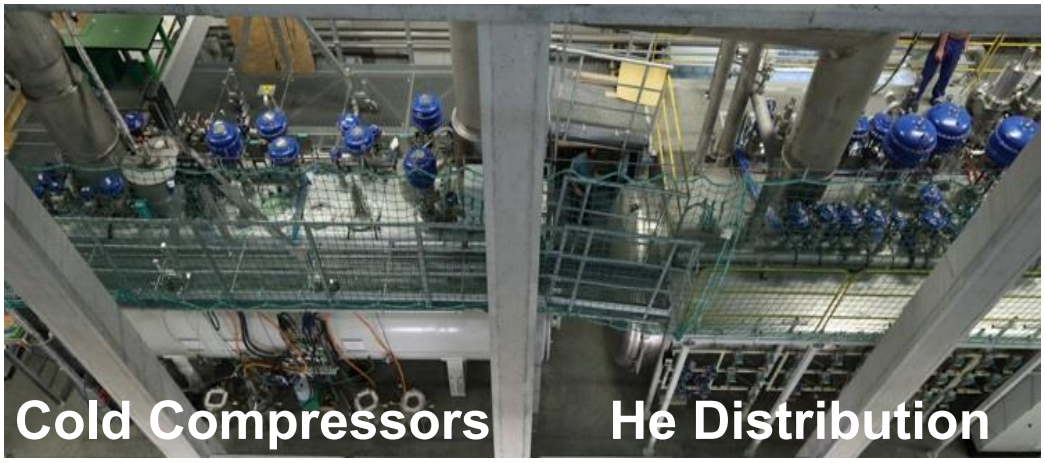
Overview of XFEL Cryogenic Equipment

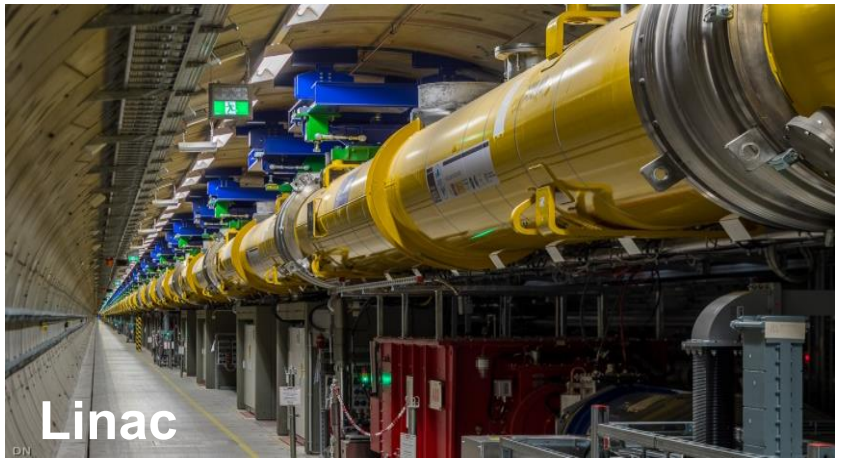
- Cryo plant with cold compressors and extended distribution system
- Cooling capacity:

  2K : >1.9 kW

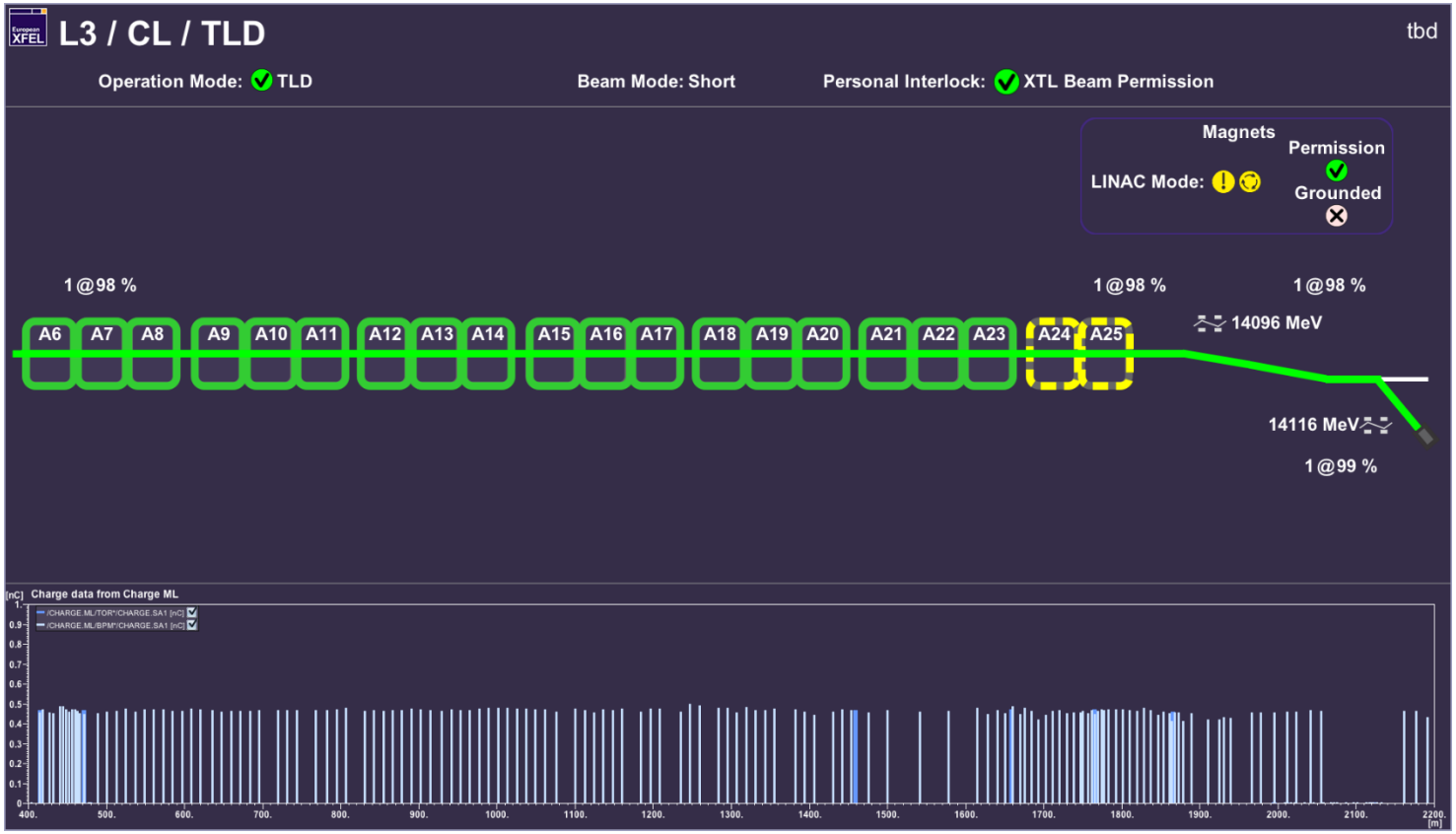
  5/8K : 4 kW

  40/80K : 24 kW
- Linac is **one 1.5 km long cryo-string**
- **Required 2K pressure stability 2% peak**





L3 RF Stations on the Status Pannel



in operation

dito. but shifted off beam

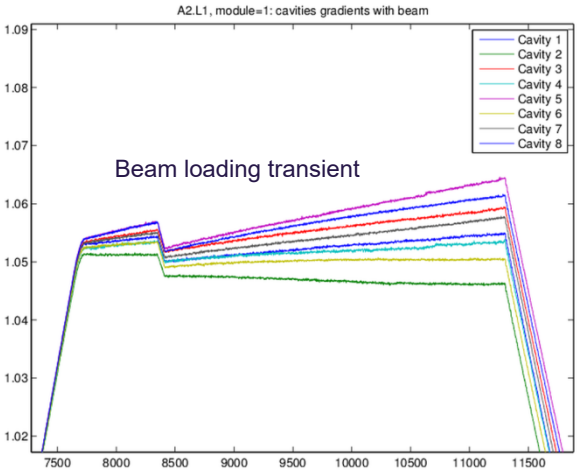
off

- All RF stations including CS8 are commissioned at moderate gradients.
- Operation automized and handed over by experts; energy goal for 2017/2018 reached.
- Detailed measurements will show the path towards higher beam energies.
- The last two stations (CS9) require still longer tunnel access.

LLRF Commissioning included…

Commissioning milestones

- **Initial checks** (LLRF system ready for commissioning)
- **Cold coupler conditioning** (optional)
- **Cavity Forward and Reflected RF signal integrity** (cabling issues? signal saturation?)
- **Frequency tuning** (from parking position)
- **Cavity Probe RF signal integrity** (cabling issues? signal saturation?)
- **Coupler tuning** (target QL)
- **Power-based gradient calibration** (coarse)
- **Cavity phasing** (using waveguide phase shifters)
- **Closed-loop operation** (feedback, learning feedforward)
- **Beam-based gradient calibration** (fine)

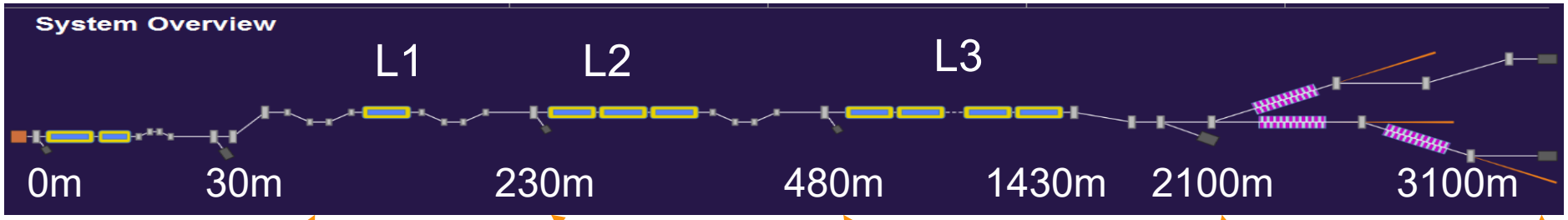


Example: beam induced transient during cavity phasing

Reached goals by now

- **Handed over to operations** and controlled via FSM
- Inner loop RF stability **<0.01 deg, < 0.01%**
- Preliminary measurements of **beam energy jitter ≈ 0.25 x 10^{-4}**

Beamline Commissioning Progress

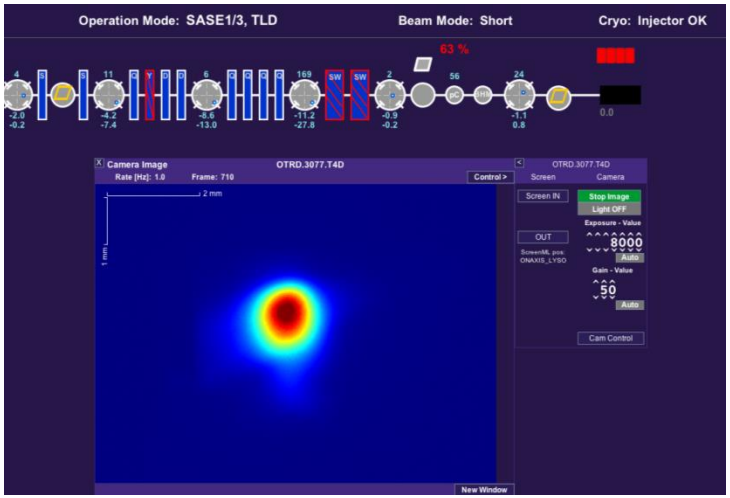


13/01* → 15/01 @ 130 MeV
19/01 @ 600 MeV → 02/02 @ 600 MeV
22/02 @ 2.5 GeV → 25/02 @ 2.5 GeV
19/03 @ 6 GeV
08/04 @ 12 GeV → 27/04*

* Beam permission on 13/01

* Beam permission on 26/04

27/04 Beam spot before dump

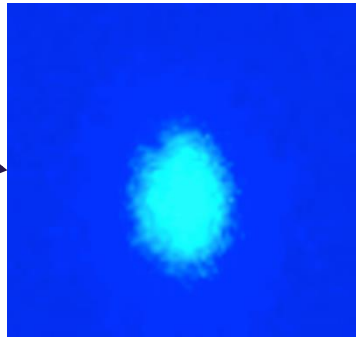


keen on lasing…

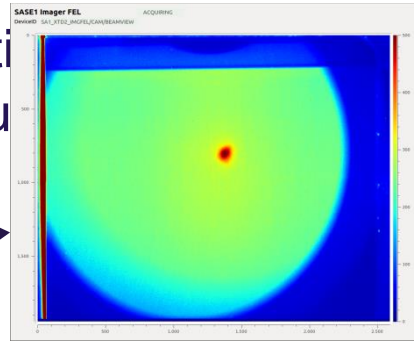
SASE Operation

- First lasing (0.9 nm) reached on May 2nd/3rd.
- Commissioning of the photon beam diagnostics and transport was next.
- Beam based alignment in the SASA1 undulator section followed. And gave good results.
- First laser light at 2 Å on May 24th.
- On May 27th we reached an energy of up to 1 mJ i.e. close to saturation.
- Safety authorities handed out the operati permission for the SASE1 hutches on Ju 21st.
- On June 23rd we lased at 1.5 Å .

SASE spot on YAG screen

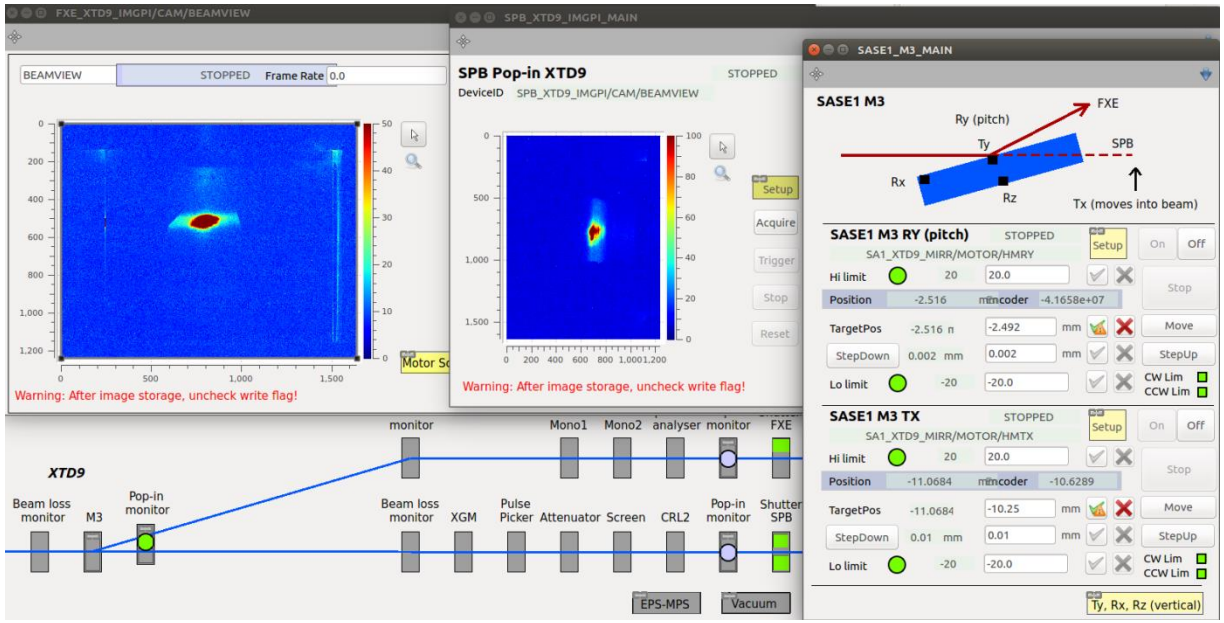


GMD intensity signal (calibrated)



SASE spot on FEL imager

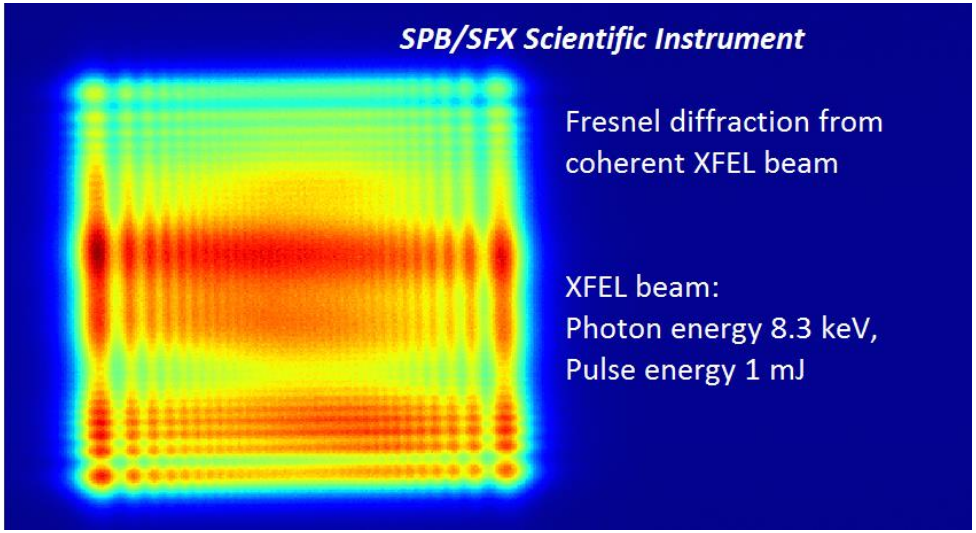
Laser light for FXE and SPB on June 23rd



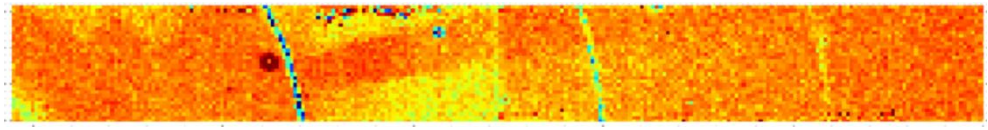
- Both SASE1 hutches (FXE and SPB) got first beam.
- Photon beam diagnostics and transport operated form the DESY accelerator control room.
- Next steps / experiments controlled from experimental hall in Schenefeld.

First Data

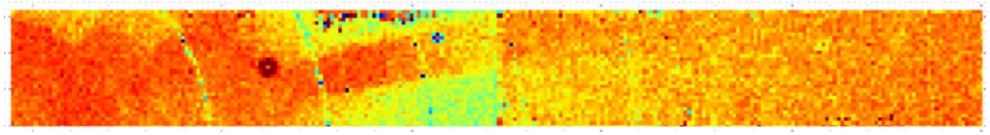
Courtesy XFEL.EU



- Slit scattering SPB, slit 1x1 mm2



- Single shot Si and LaB6 powder diagram FXE



Courtesy XFEL.EU

User Operation European XFEL

1st Call for proposals (SASE1)	1 / 2017
63 proposals received	March 20 / 2017
First lasing in SASE1	May 2 / 2017
First beam in hutches	June 23 / 2017
Commissioning SASE1 and instruments	5 – 9 / 2017
Start of users operation FXE, SPB/SFX	Sept. 14 / 2017 (7 weeks in 2017)
2nd call for proposals (SASE1)	Late Summer 2017
Lasing SASE3	Late Summer 2017
Lasing SASE2	End 2017
Start users operation SASE2 and SASE3	Mid 2018

Guest Scientists during commissioning

General Assembly of the European XFEL Accelerator Consortium

04.05.2017

THANK YOU TO ALL CONTRIBUTORS TO THE EUROPEAN XFEL