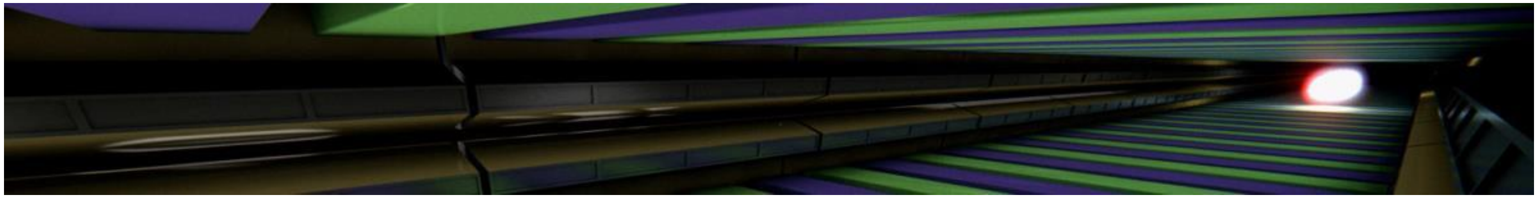
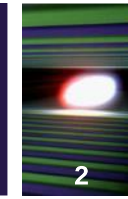


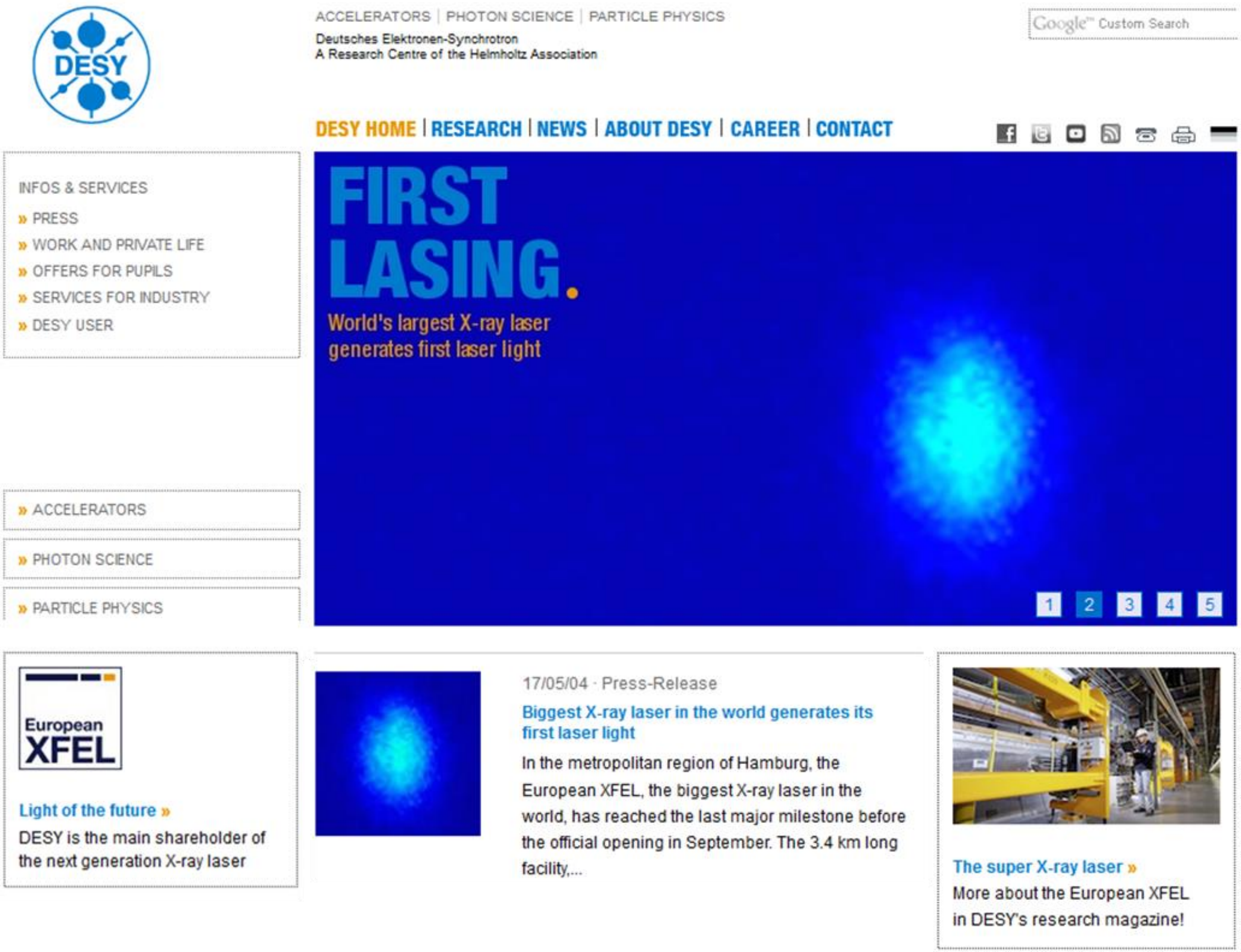
European XFEL Status

Hans Weise & Winni Decking, DESY

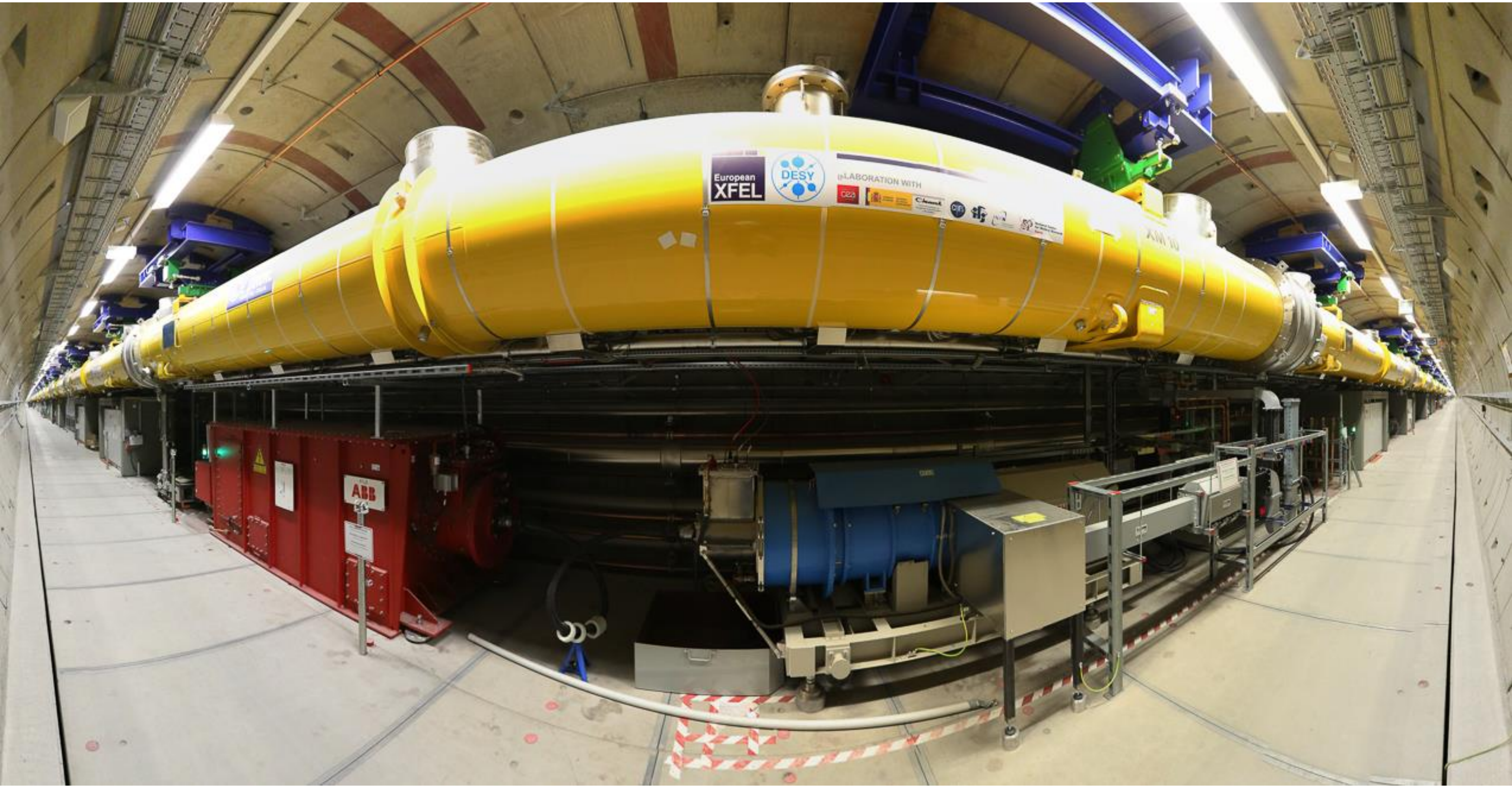
On behalf of the European XFEL Accelerator Consortium
work supported by the respective funding agencies of the contributing institutes; for details please see http://www.xfel.eu

First Lasing.

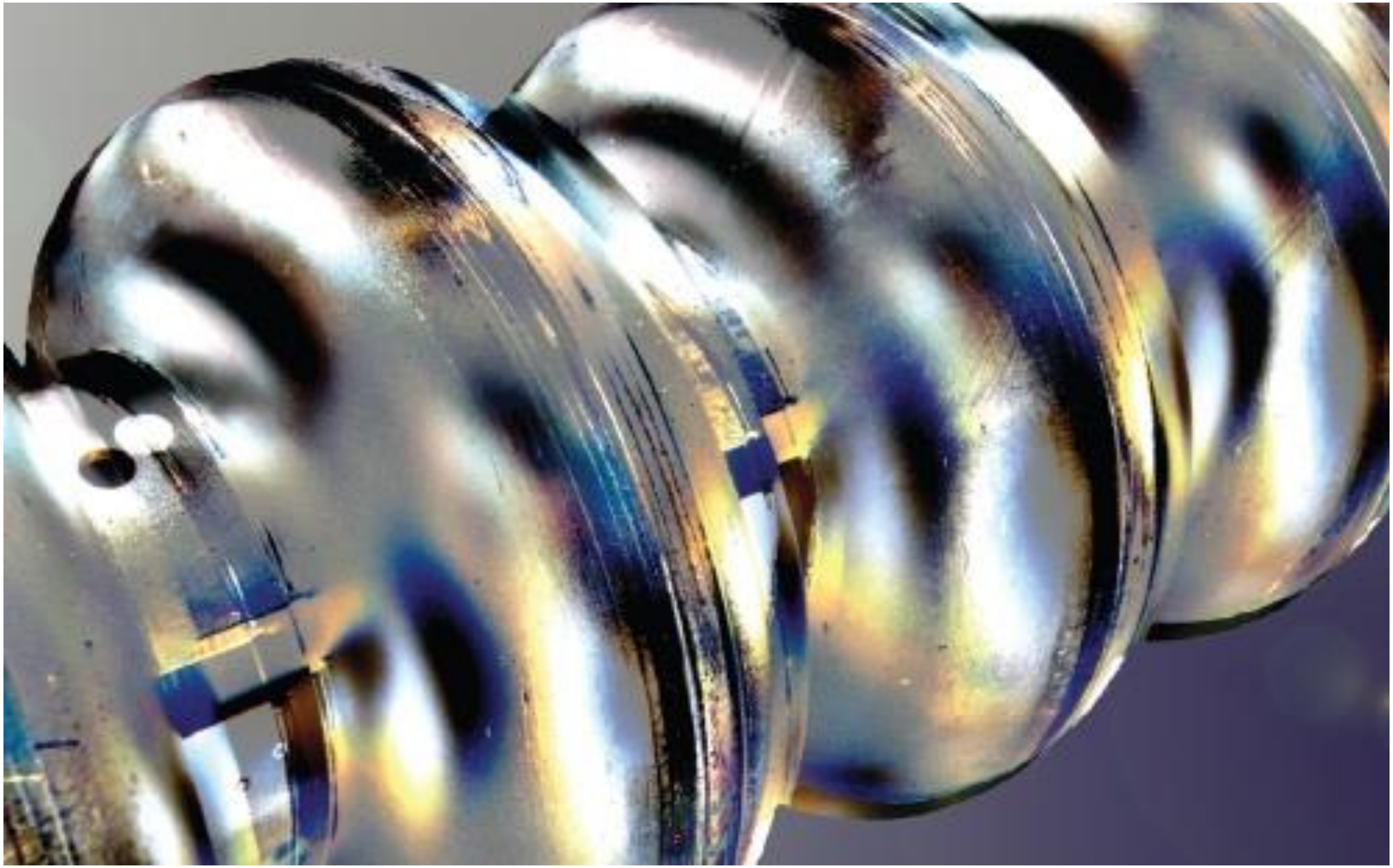




One Kilometer of Cold Linac



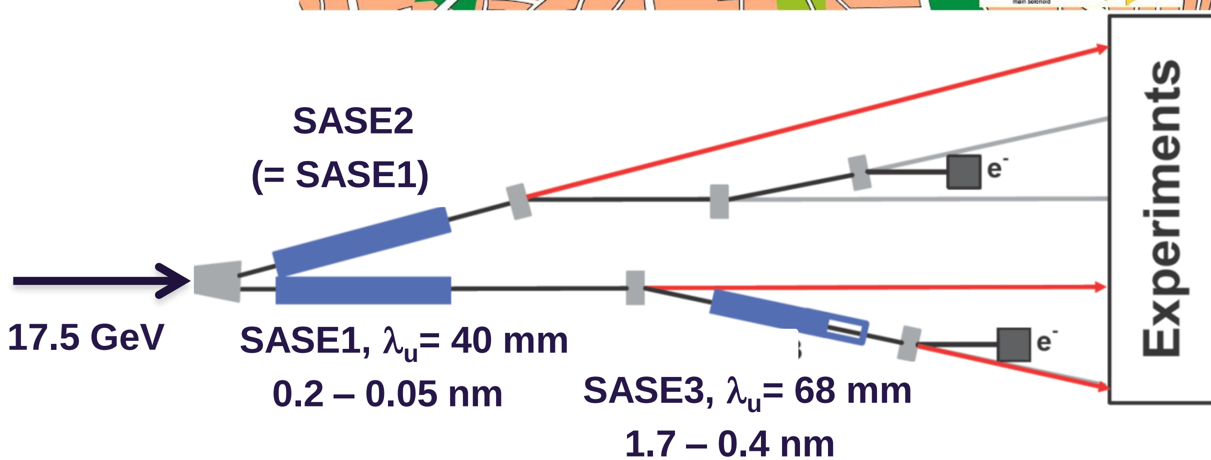
With almost 800 Superconducting Cavities



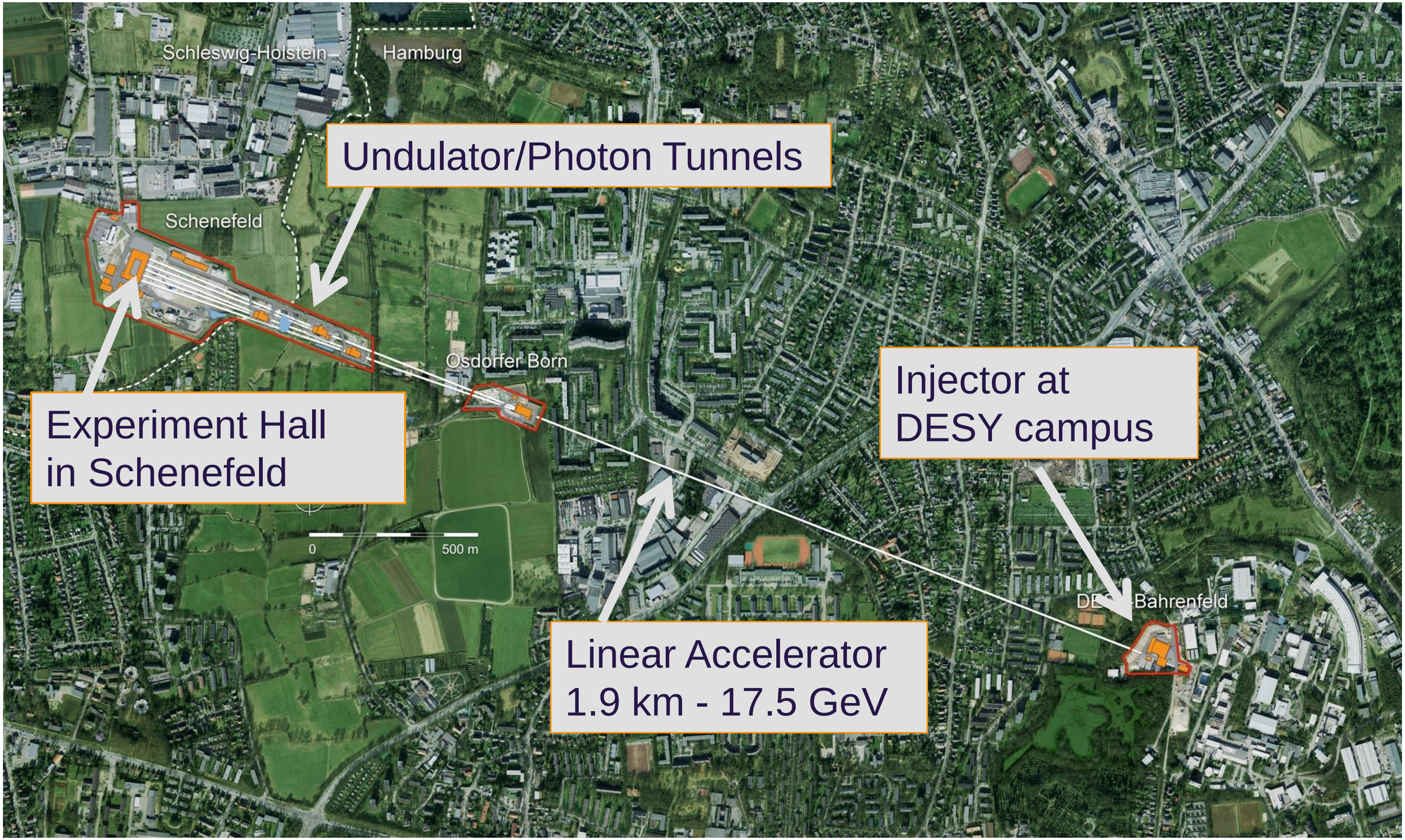
The European XFEL
Built by Research Institutes from 12 European Nations

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



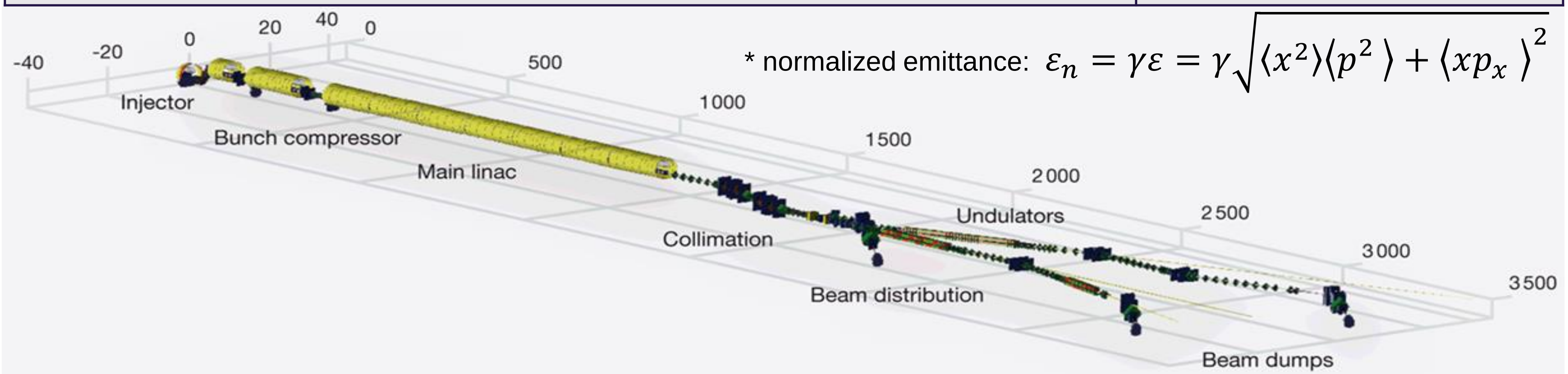
European XFEL Layout



Accelerator Complex with Challenging Parameter Set

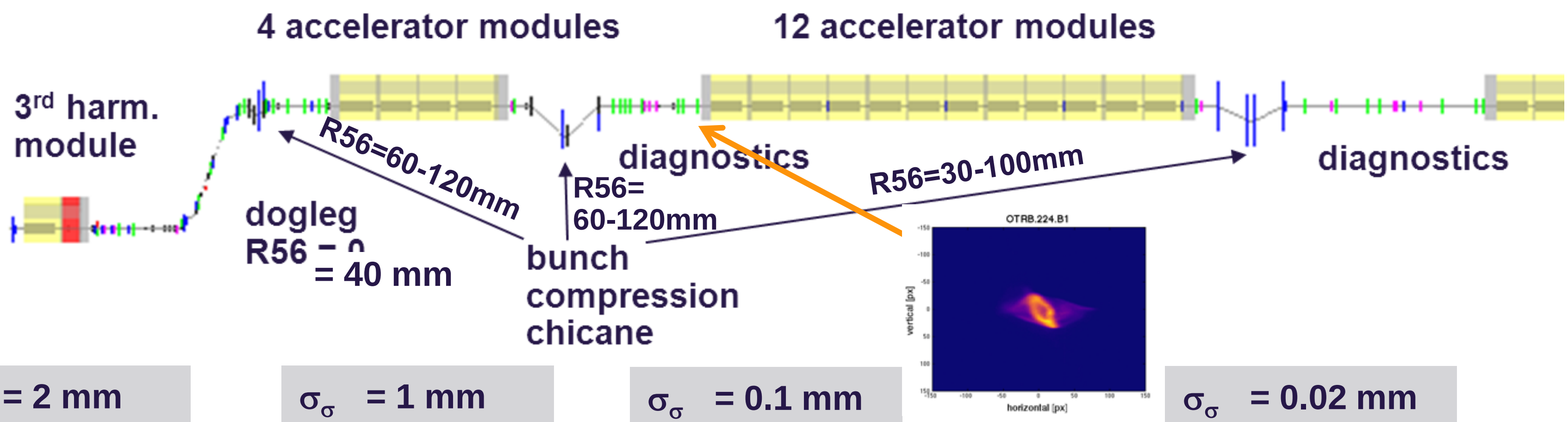
electron beam energy	8/12.5/14/17.5 GeV
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 μs
# of bunches/second	27,000
bunch charge	0.02 – 1 nC
electron bunch length after compression (FWHM)	2 – 180 fs
normalized slice emittance*	0.4 - 1.0 mm mrad
beam power	500 kW
simultaneously operated 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
I_{peak} = 50 A
σ_E = 0 %
E = 130 MeV

→

σ_σ = 1 mm
I_{peak} = 100 A
σ_E = 1.5 %
E = 130 MeV

→

σ_σ = 0.1 mm
I_{peak} = 1 kA
σ_E = 1 %
E = 600 MeV

→

σ_σ = 0.02 mm
I_{peak} = 5 kA
σ_E = 0.3 %
E = 2400 MeV

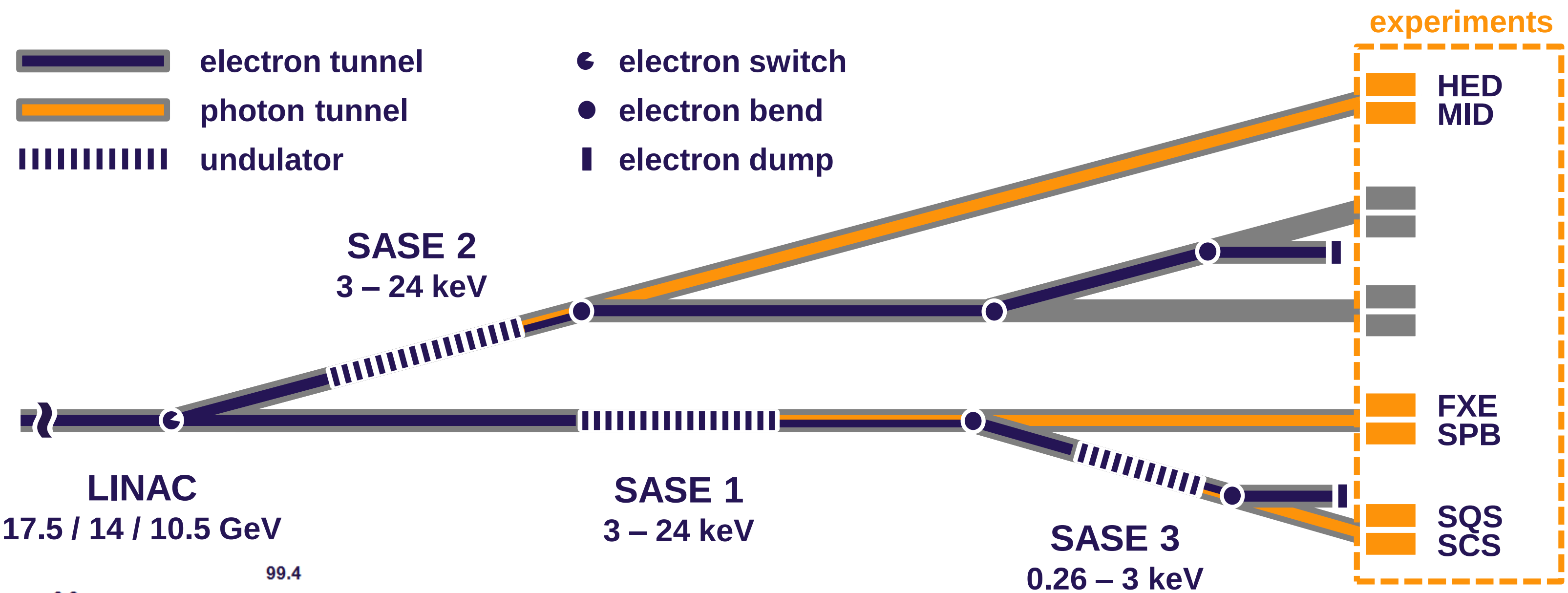
→

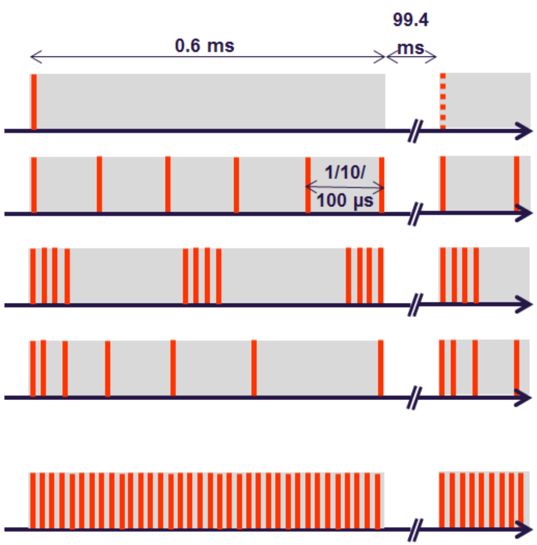
harmonic system

bunch compressor

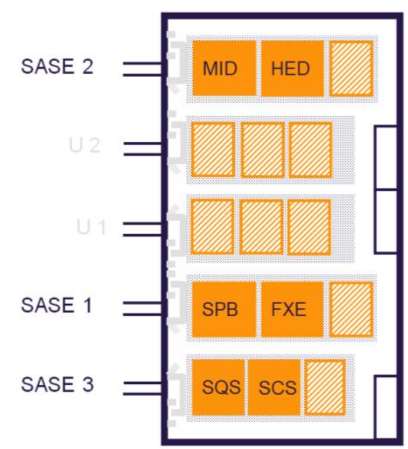
beam diagnostics

X-ray Beamlines for Different Wavelengths with Different Time Structures

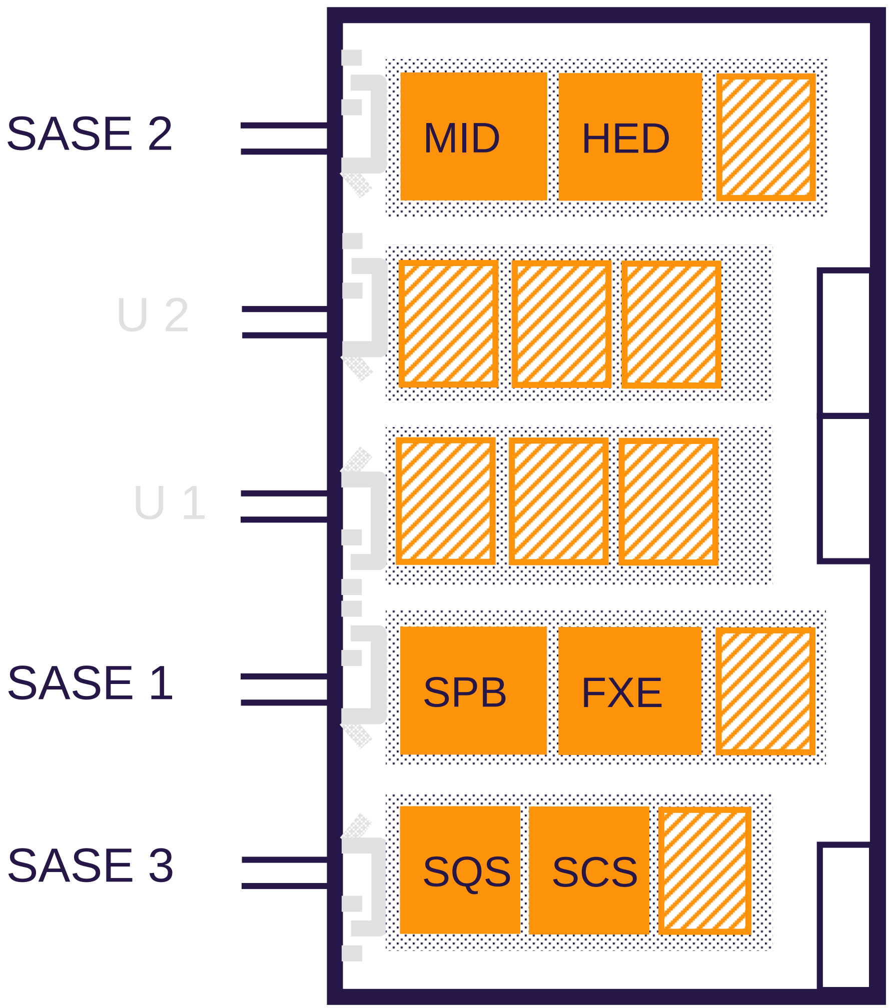




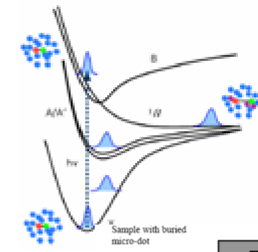
- 2 hard x-ray undulators and beam transport with 4 instruments
- 1 soft x-ray undulator and beam transport with 2 instruments
- all undulators planar and tunable



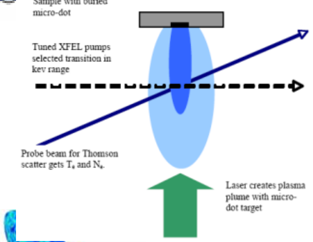
The Suite of Instruments



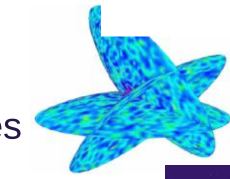
FXE Femtosecond X-ray Experiments



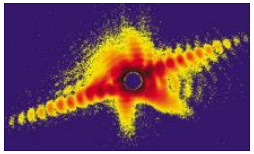
HED High Energy Density Science



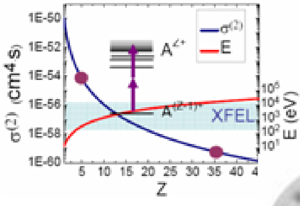
SPB Single Particle & Biomolecules



MID Materials Imaging & Dynamics



SQS Small Quantum Systems



SCS Spectroscopy & Coherent Scattering

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

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

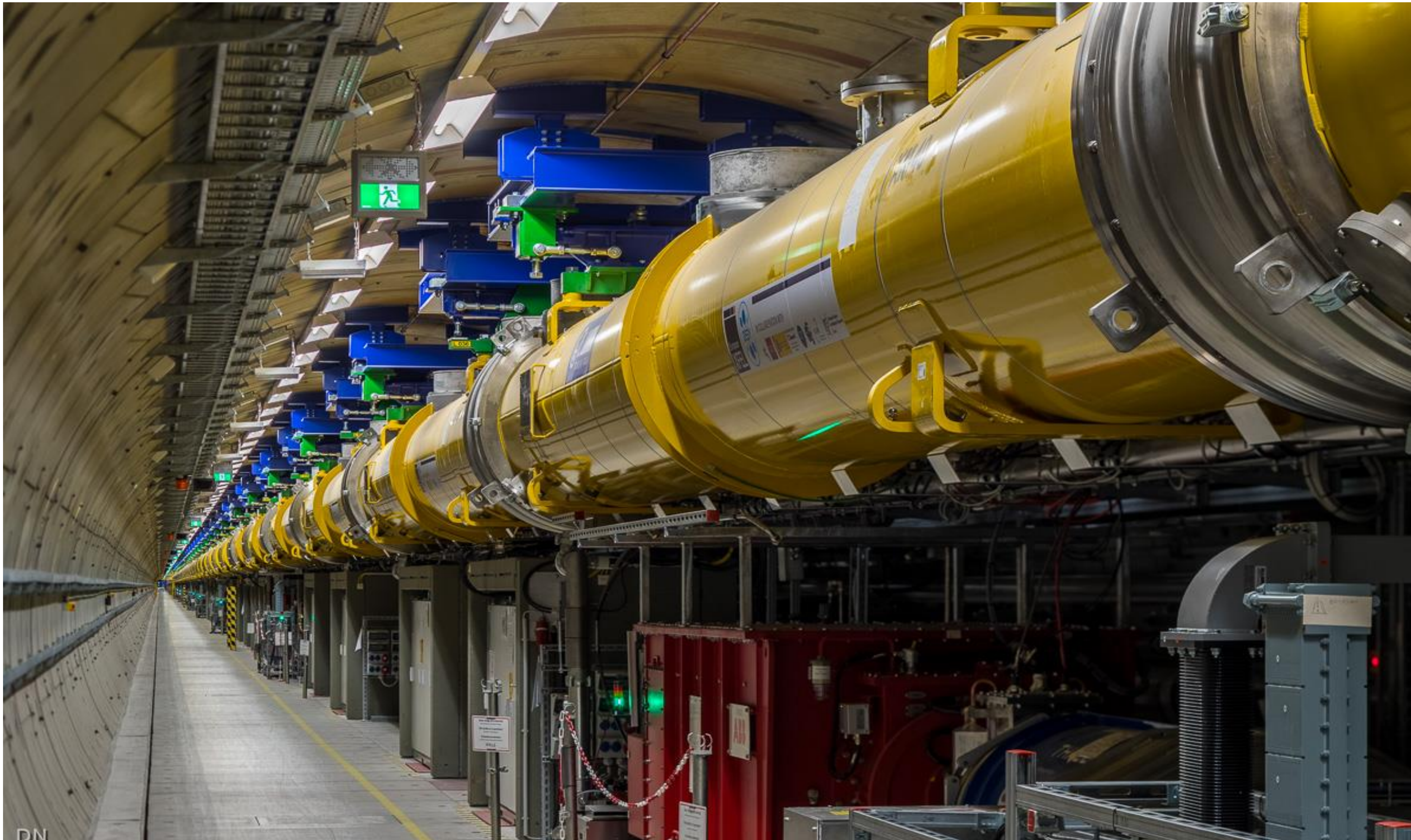
Commissioning Plan (include as many systems as early as possible)

12/16	Linac Cooldown
01/17	Injector at 130 MeV (3 RF stations)
01/17	L1 commissioning (+1 RF station)
02/17	L2 commissioning (+3 RF stations)
02 - 04/17	L3 commissioning (+15 RF stations)
05/17	Beam through SASE1 & SASE3 undulator sections
end 05/17	Milestone "First Lasing Possible"
06 - 08/17	Commission SASE1 photon beamline and experiment Consolidate FEL operation at 8-10 keV photon energy
09/17	First user experiments (total 800 hours)
2018	Continue facility commissioning + 2000 user hours
2019	Routine operation with 6 experiments + 4000 user hours

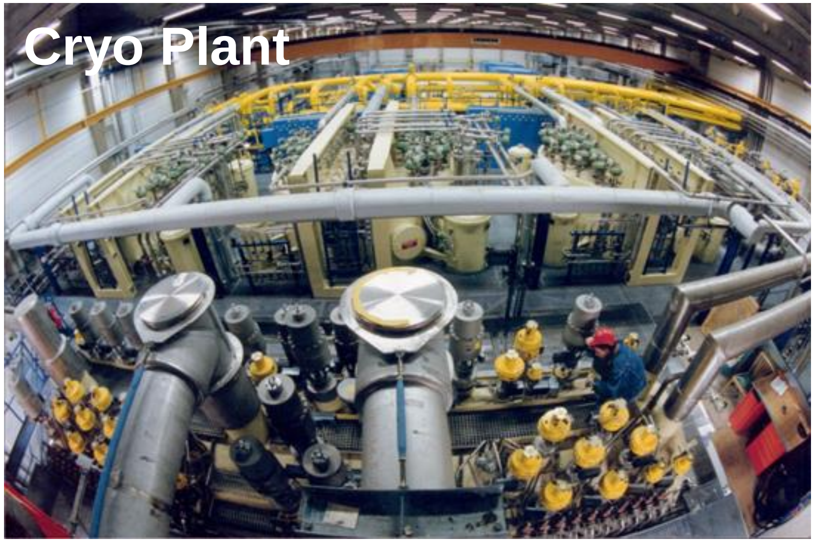
Injector in Operation 2015 / 2016

- 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

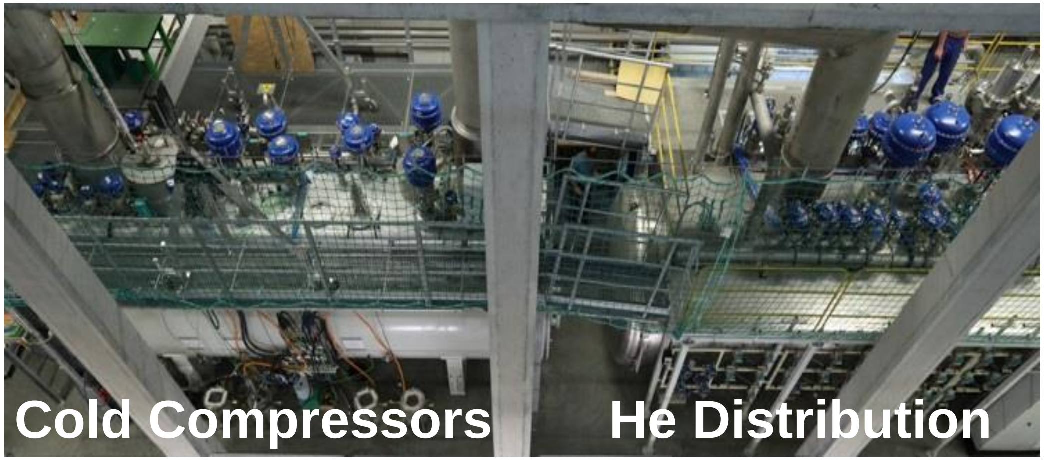
View along L3 accelerator section

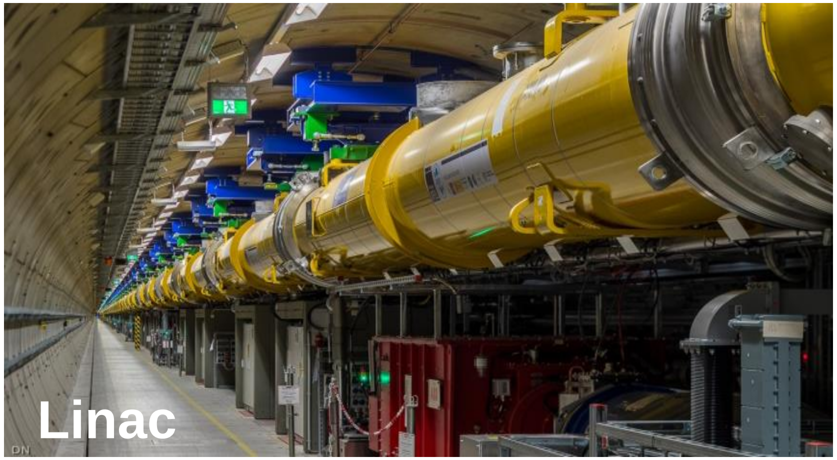


Overview of XFEL Cryogenic Equipment

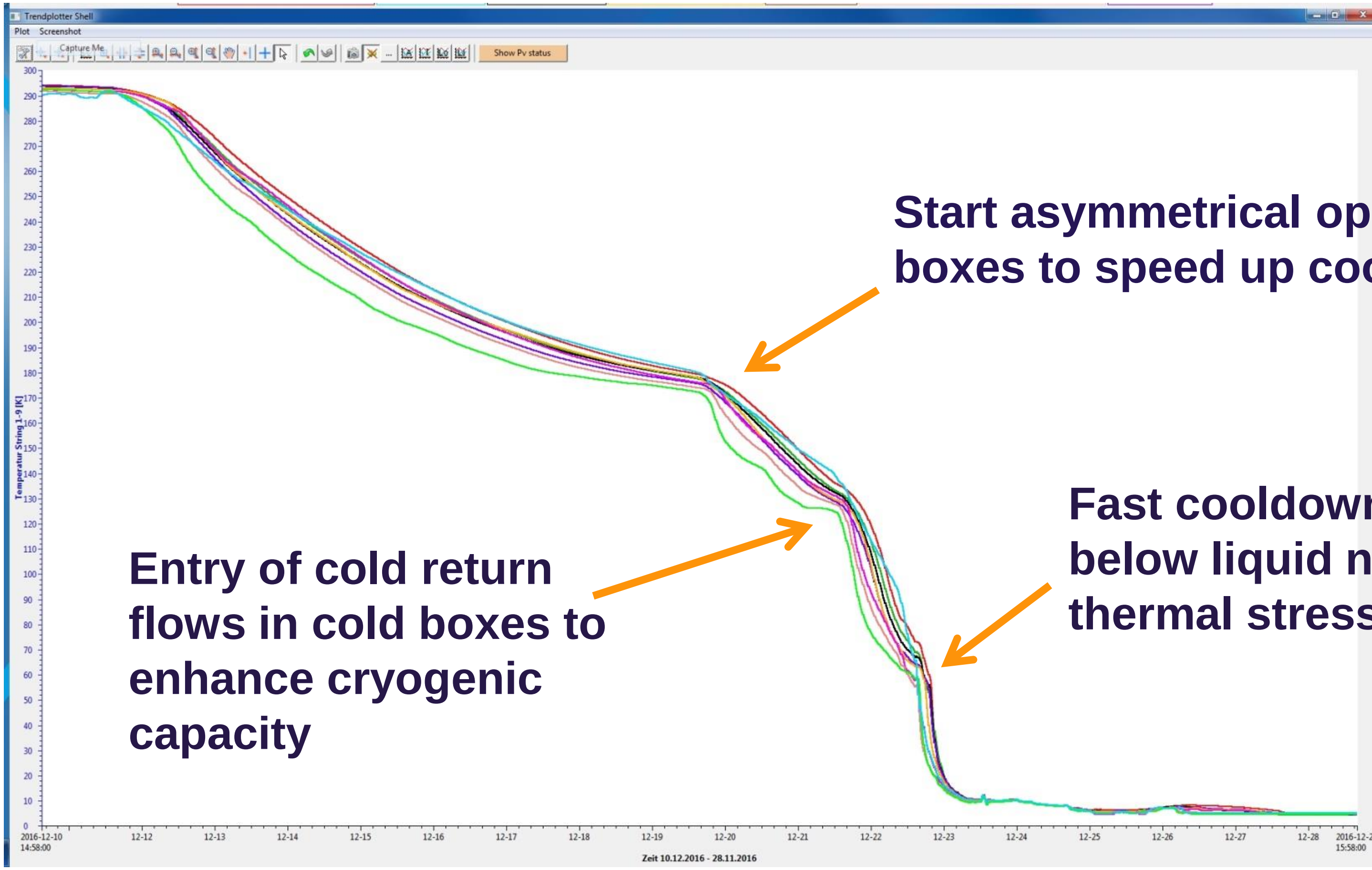


- Cryo plant with cold compressors and extended distribution system
- Cooling capacity:
  - 2K : >1.9 kW
  - 5/8K : 4 kW
  - 40/80K : 24 kW
- Linac is **one 1.5 km long cryo-string**





First Cooldown of XFEL Linac during Dec 2016



Start asymmetrical operation of two cold boxes to speed up cooldown

Entry of cold return flows in cold boxes to enhance cryogenic capacity

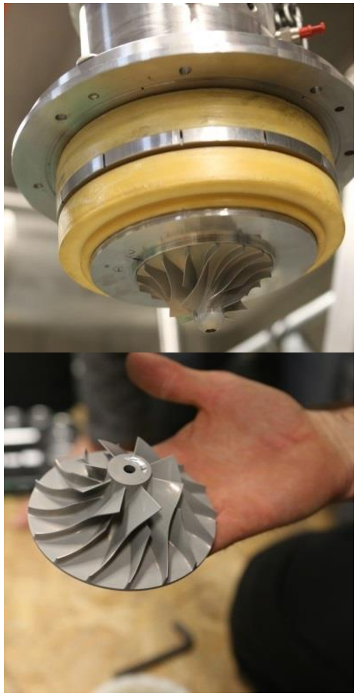
Fast cooldown at temperatures below liquid nitrogen (no more thermal stress)

10.12.2016

24.12.2016

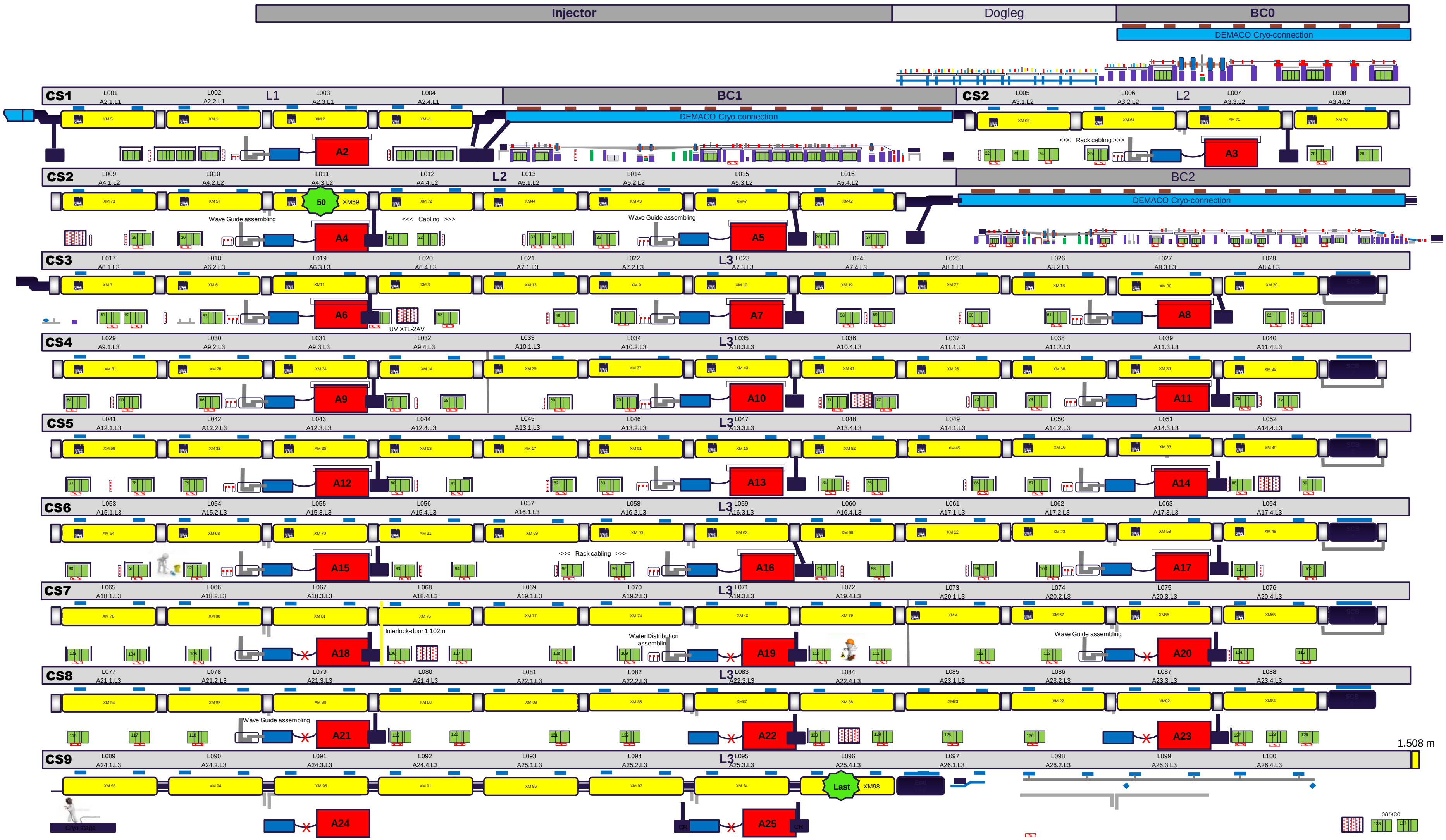
- **No Cold Leaks!!!**

Cryogenics is very challenging

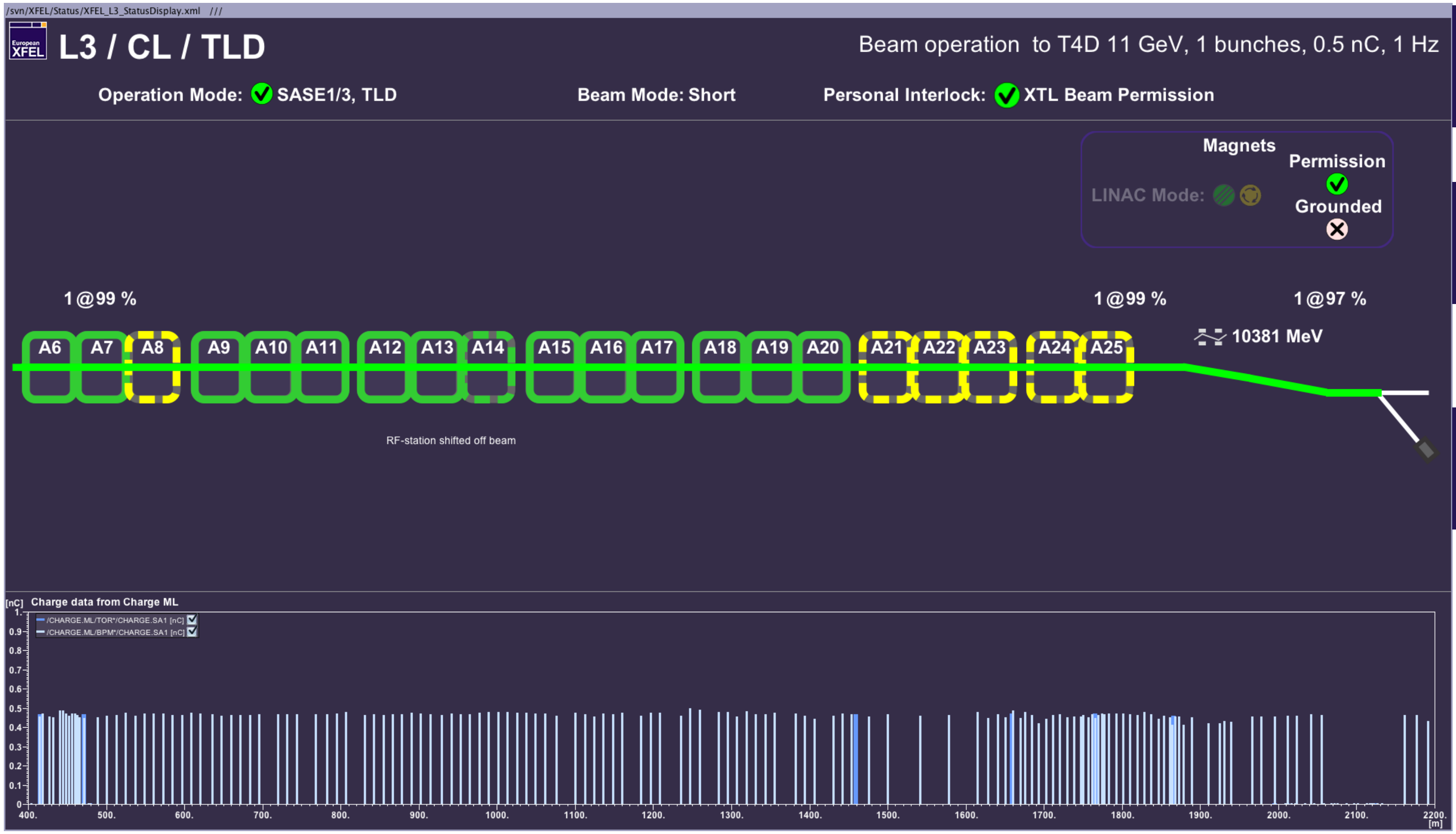


- **Complexity of cryogenic system** asked for sufficient commissioning time; experts had to establish / optimize operation and to **gain experience** with new machines, especially the used cold compressors.
- **How to deal with…**
  - 671 control valves
  - >3,800 sensors (temperature, pressure, flow, level)
  - 433 regulation loops
  - >22,000 records and >220,000 properties
  - and last but not least … **>300 tons of material to be cooled down**
- **Required 2K pressure stability** of 2% peak from LLRF requirements (cavity detuning)
- Tedious adjustment of regulation loops
- Inner-system heaters to counteract dynamic processes

We cooled down all 96 accelerator modules



L3 RF Stations on the Status Pannel

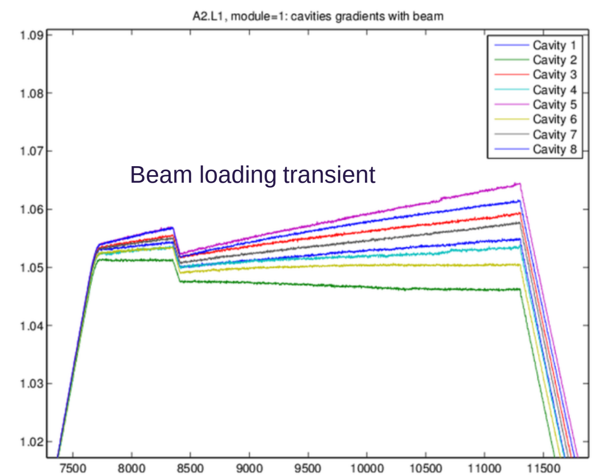


- All RF stations including CS7 are commissioned at moderate gradients.
- Detailed measurements will show the path towards higher beam energies.
- CS8 is meanwhile ready for LLRF commissioning; thanks to maintenance days.
- The last two stations (CS9) require still longer tunnel access.

LLRF Commissioning includes…

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)

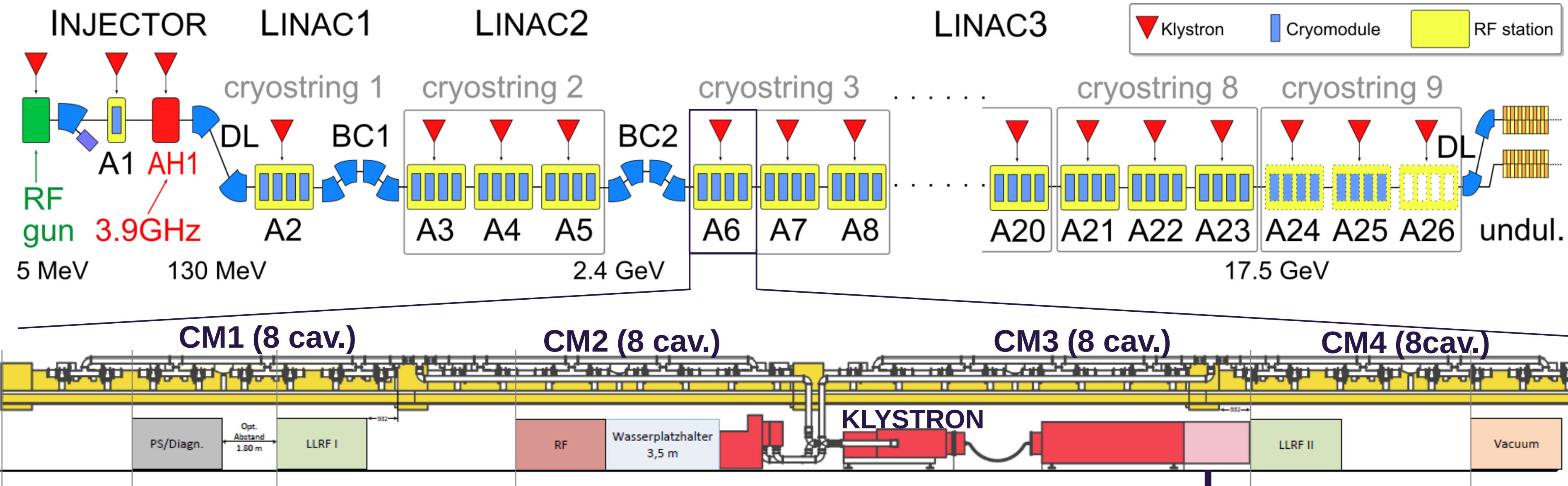


Example: beam induced transient during cavity phasing

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 ≈ 10^{-4}**

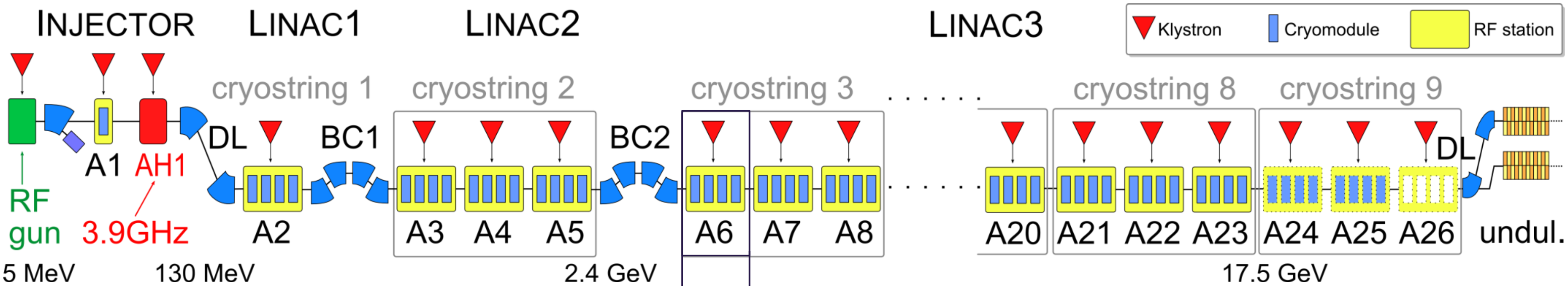
XFEL RF System

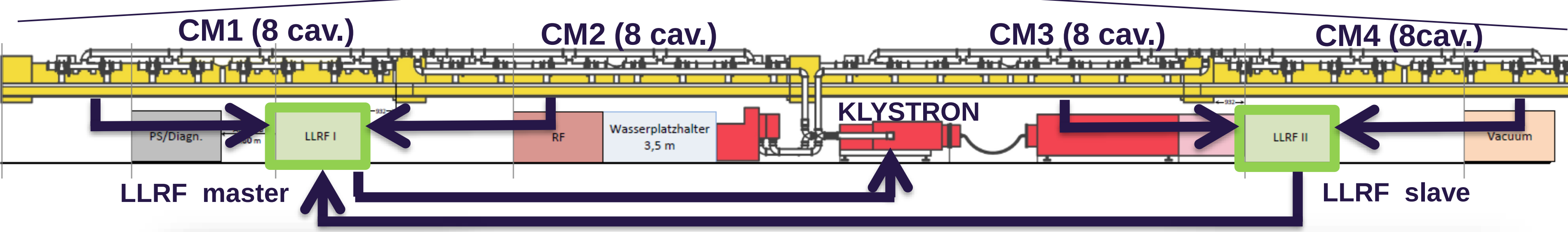


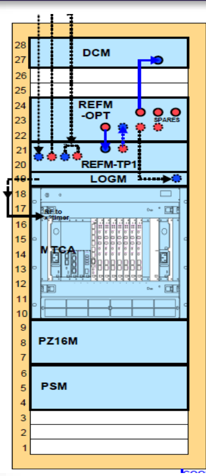
Klystron and modulator below module

- HV Modulators in surface hall
- Connected to pulse transformer via up to 2km long pulse cables

XFEL LLRF System







Drift compensation

Reference synchr. + distr.

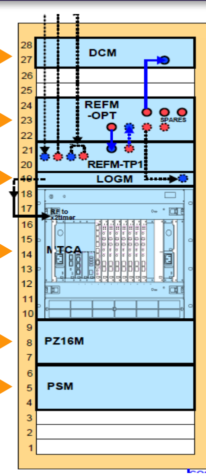
Clocks + local oscillator

Main controller crate (MicroTCA)

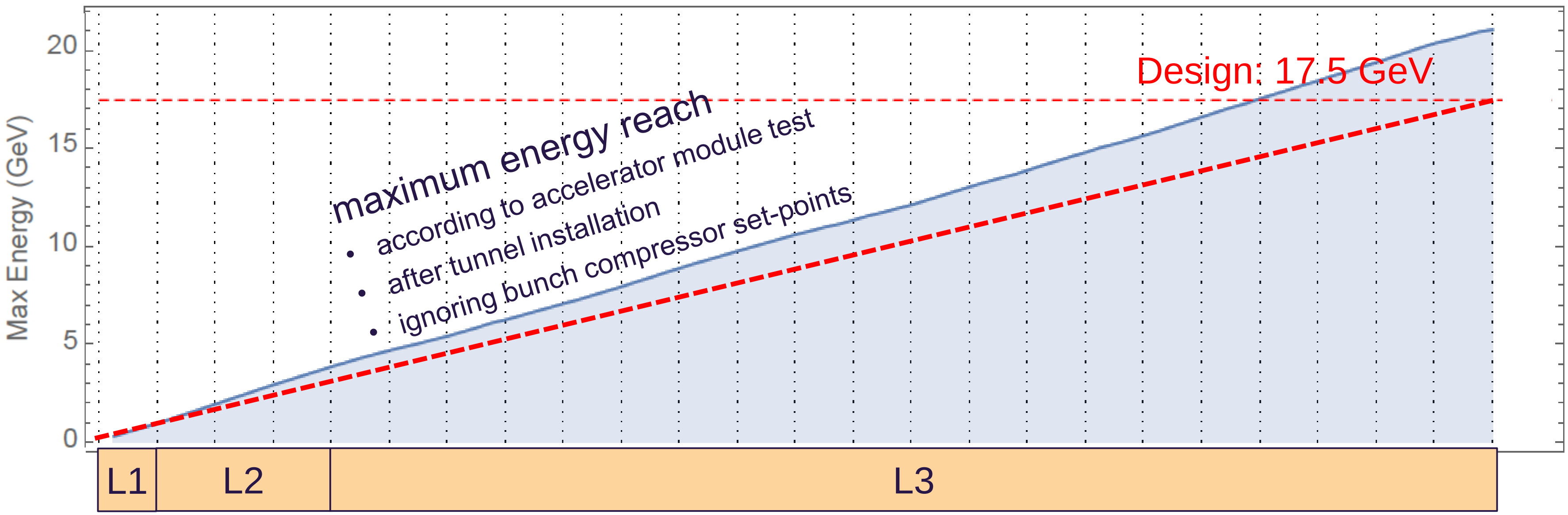
Piezo*

Power supplies

* not installed yet

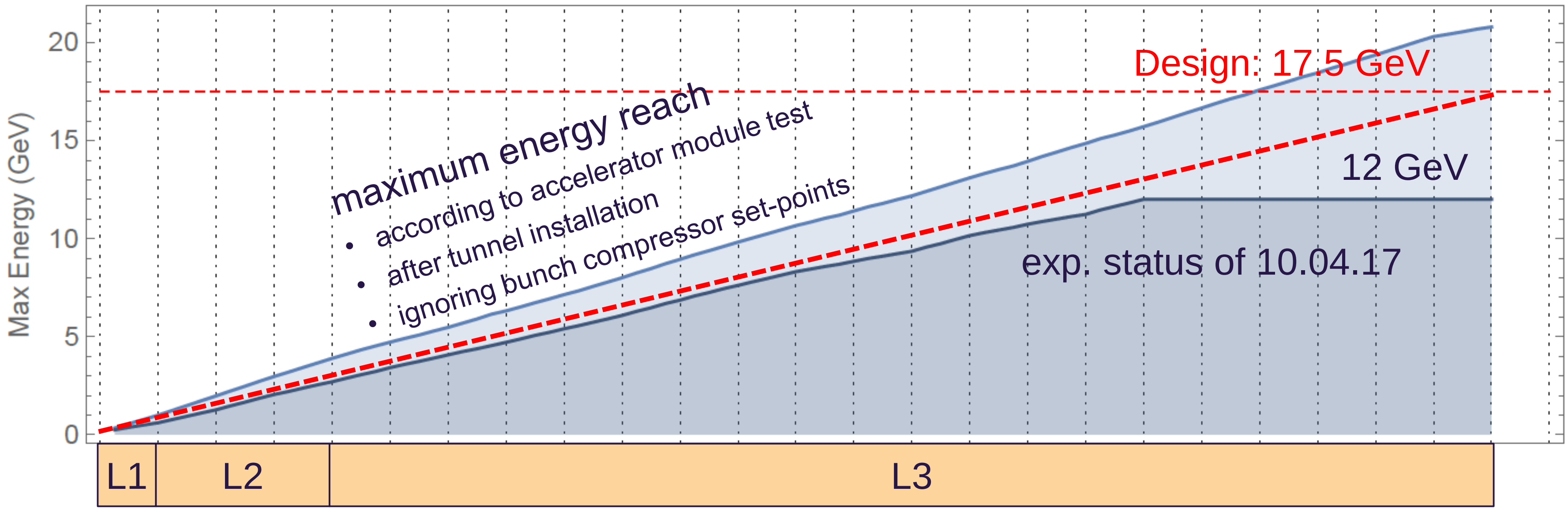


Energy Reach of European XFEL Modules



- Average accelerating gradient after pre-installation module test and waveguide tailoring
  - 26 MV/m, (design 23.5 MV/m)
- Some additional gradient reduction due to tunnel waveguide distribution
- Excess energy reach will enhance operation reliability

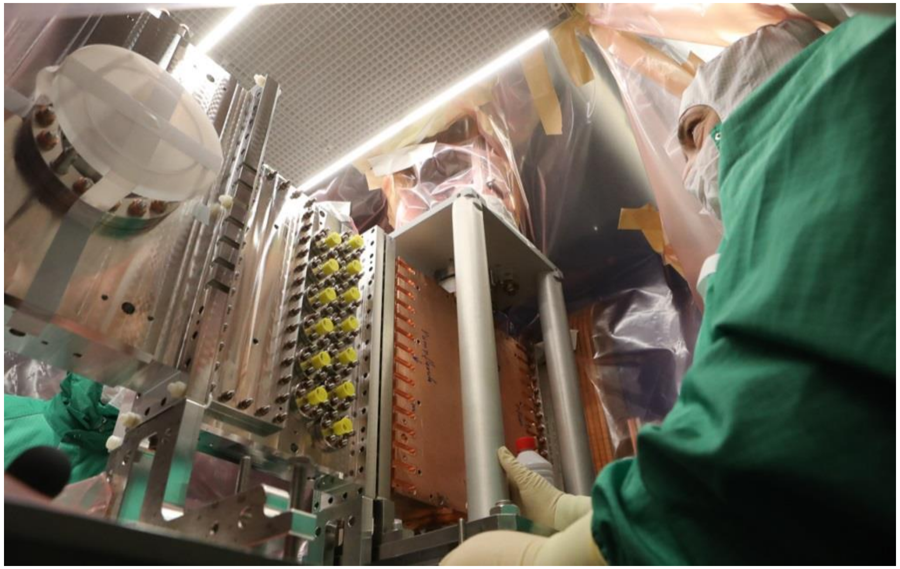
Operating Gradients used so far

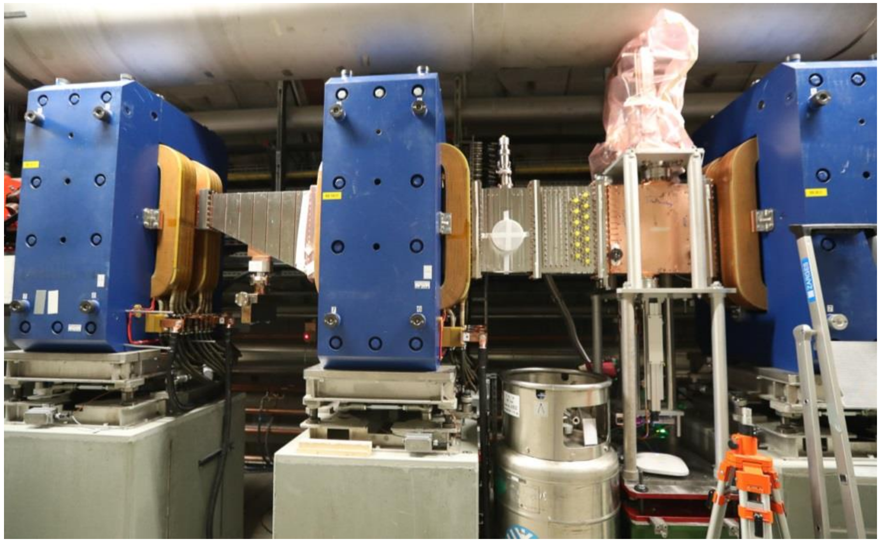


- After initial commissioning design gradient almost reached
- Operation of RF stations "off beam" allows final commissioning of single stations parallel to XFEL lasing operation
- Quite some RF cavities needed short multipactor processing around 16 to 20 MV/m.
- So far 4 couplers were disconnected due to temperature rise at warm window; RF conditioning was not easily possible.

Warm Beam Line Sections

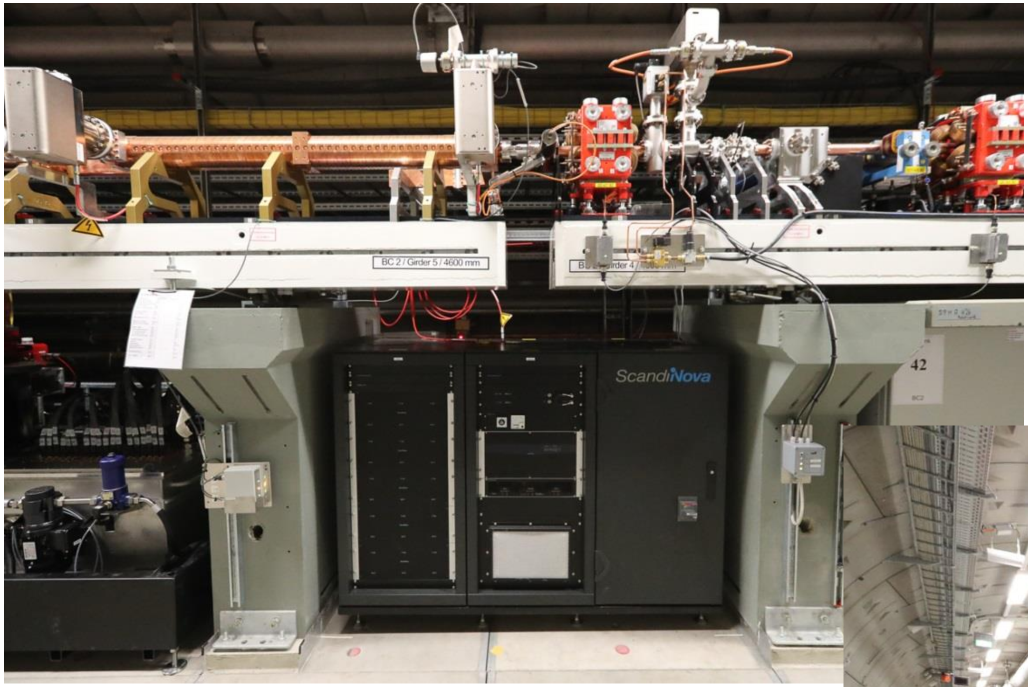
Bunch Compressor Sections – Challenging Installation





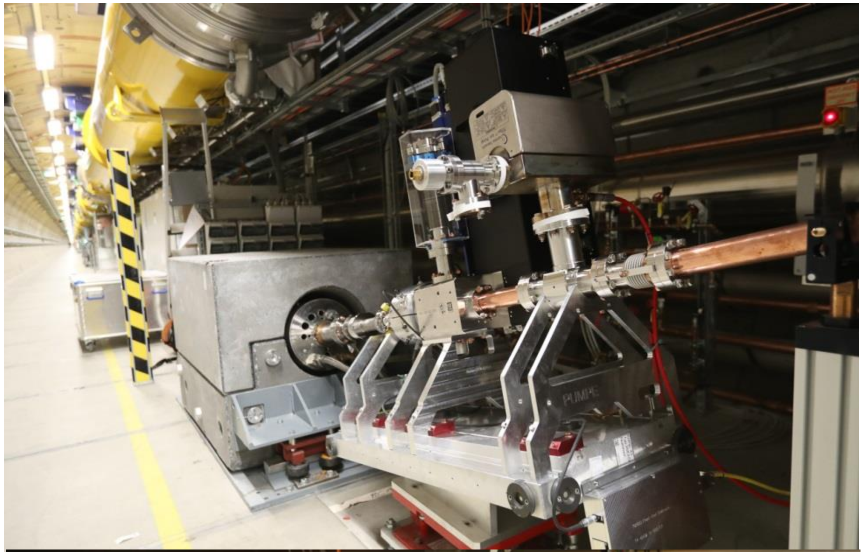
Bunch Compressor BC1

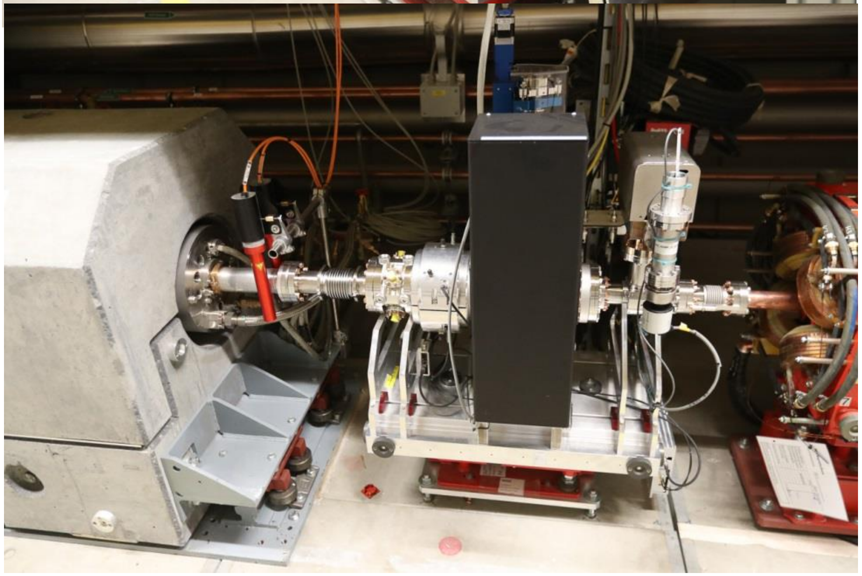
Transverse Deflection System in Bunch Compressor BC2



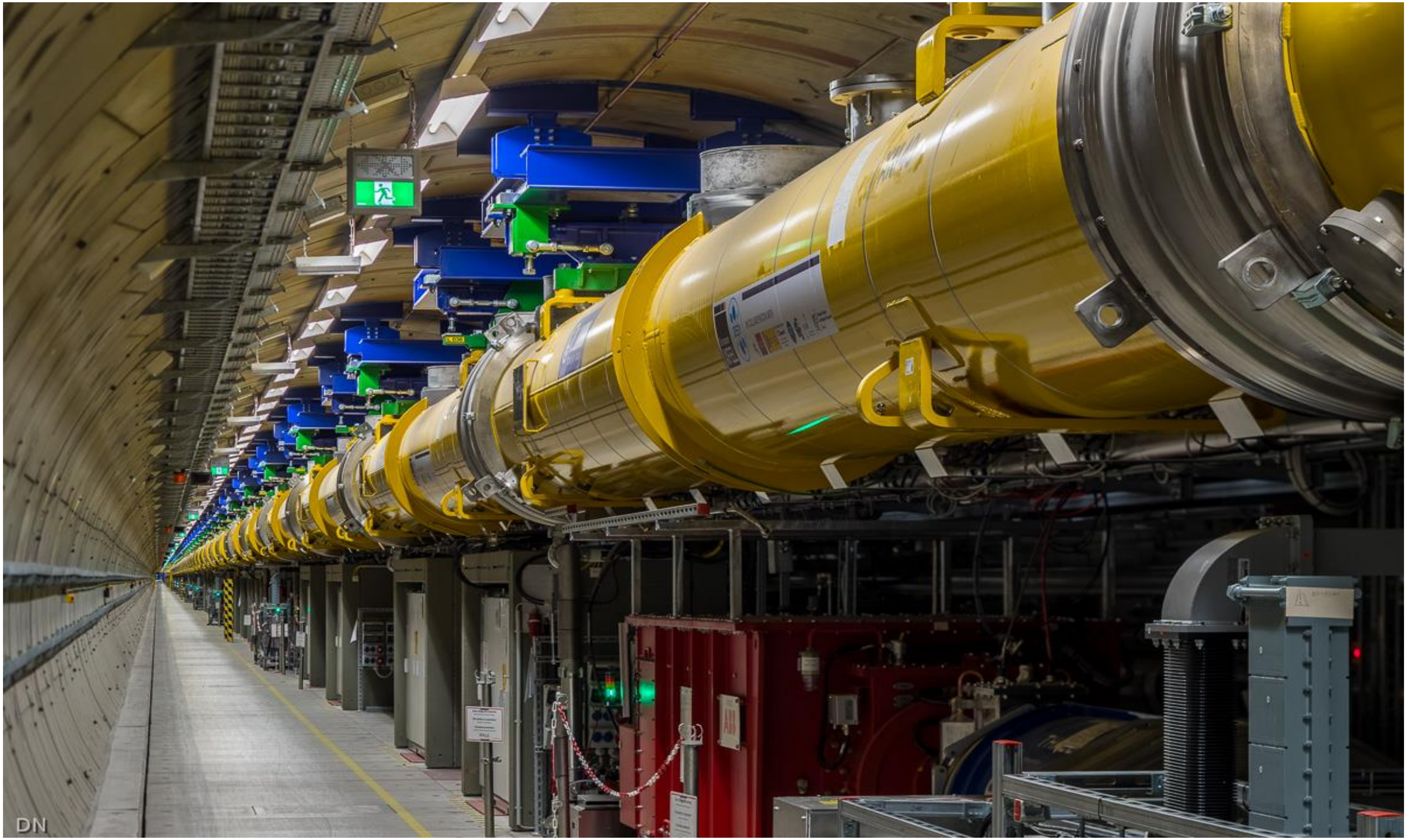
- The BC2 TDS system is one important system to be used to verify short bunch lengths during linac setup.

Both Bunch Compressors BC1 / BC2 include Commissioning Beam Dumps



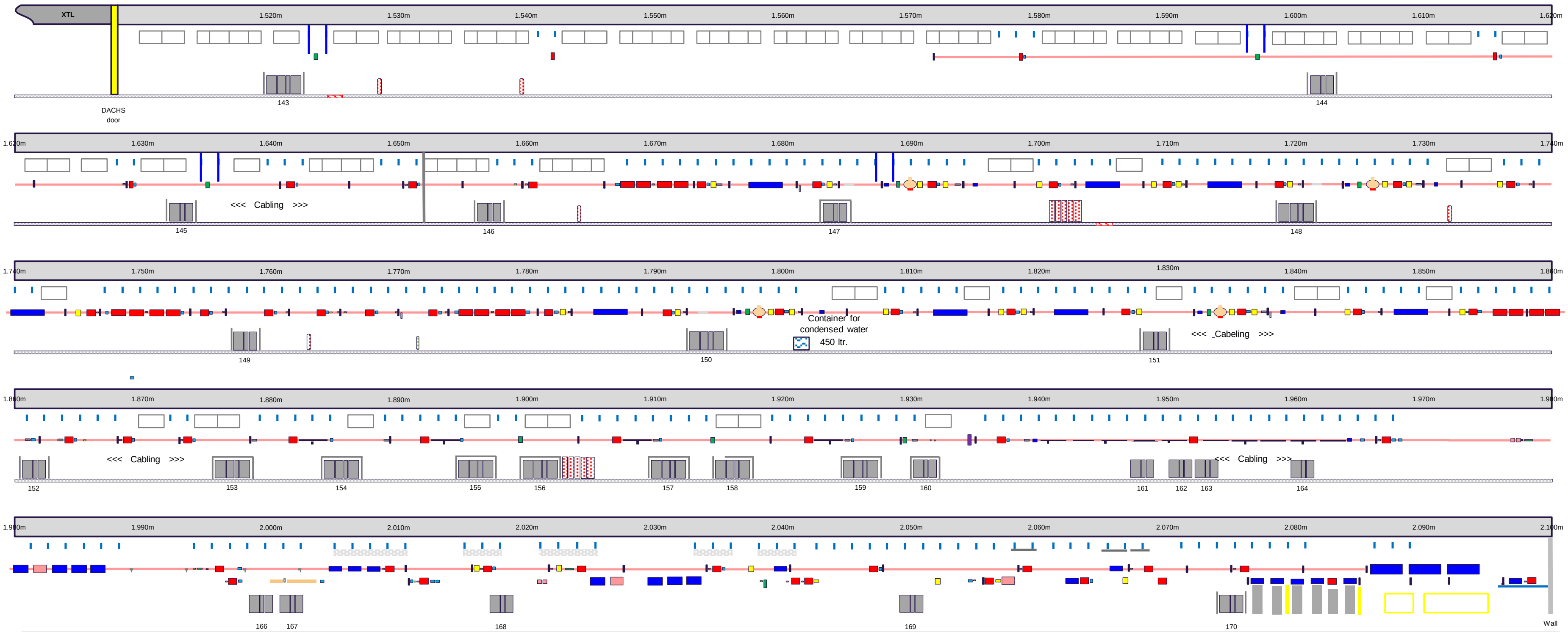


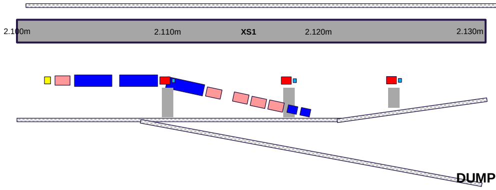
Linear Accelerator



Post Linac Beam Lines upstream of XS1

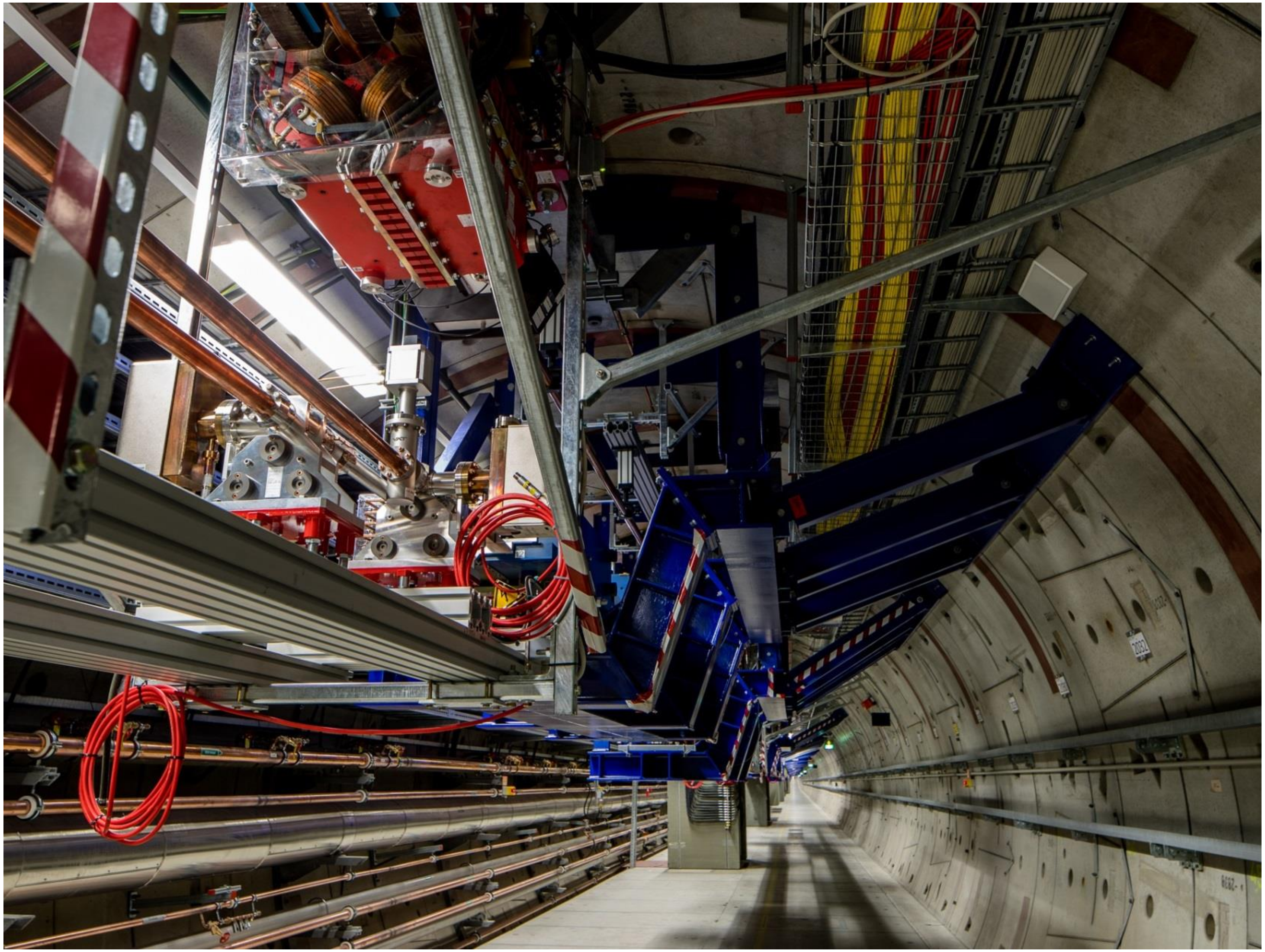
- 200 m transport line (eq. to 4 + 12 modules)
- 200 m collimation





- 200 m beam distribution
- 100 m XS1 dump line

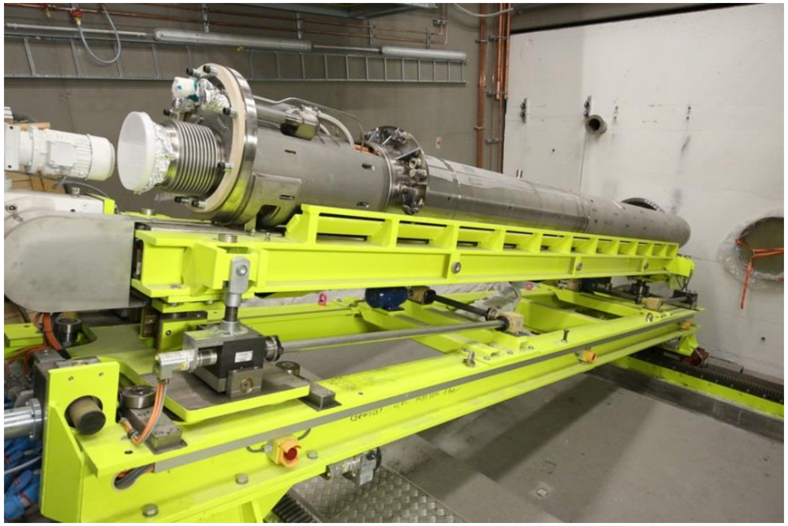
Transfer Lines at the End of the Main Linac Tunnel (XTL)



- All beam lines are suspended from the ceiling
- Engineering of ‘hanging’ system needed some effort but result is very satisfying

Warm Beam Line Sections

Transport Line to XS1 Beam Dump



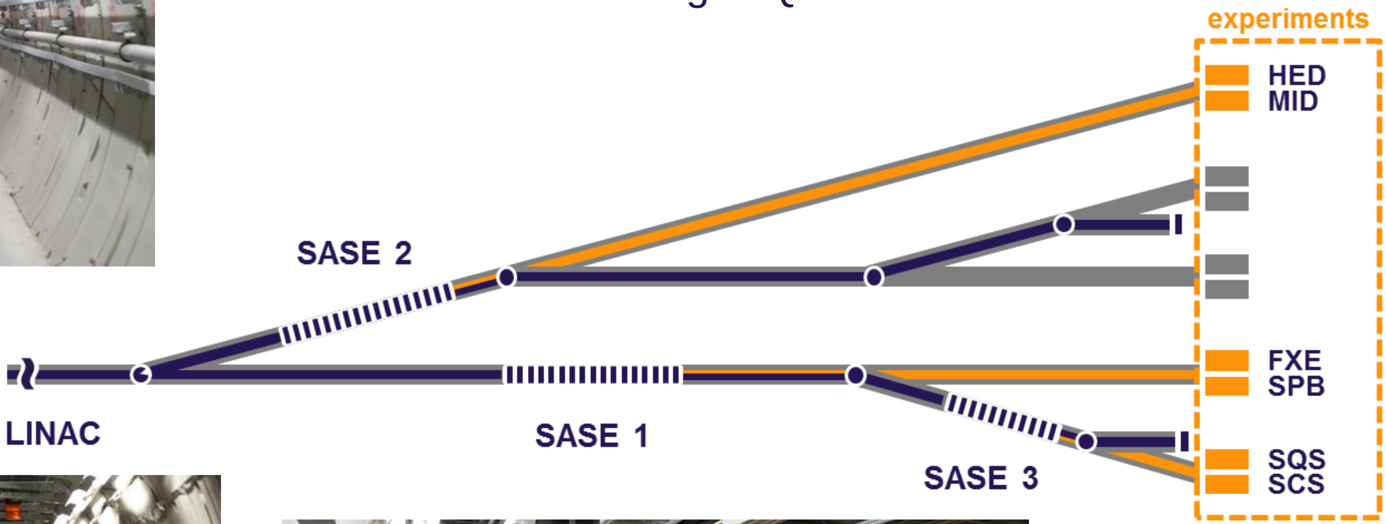
- Three 300 kW main beam dumps
- Special vehicles to exchange activated dumps

Installation on Top of XS1 Dump Cave

- XS1 installation includes transport towards XTDs

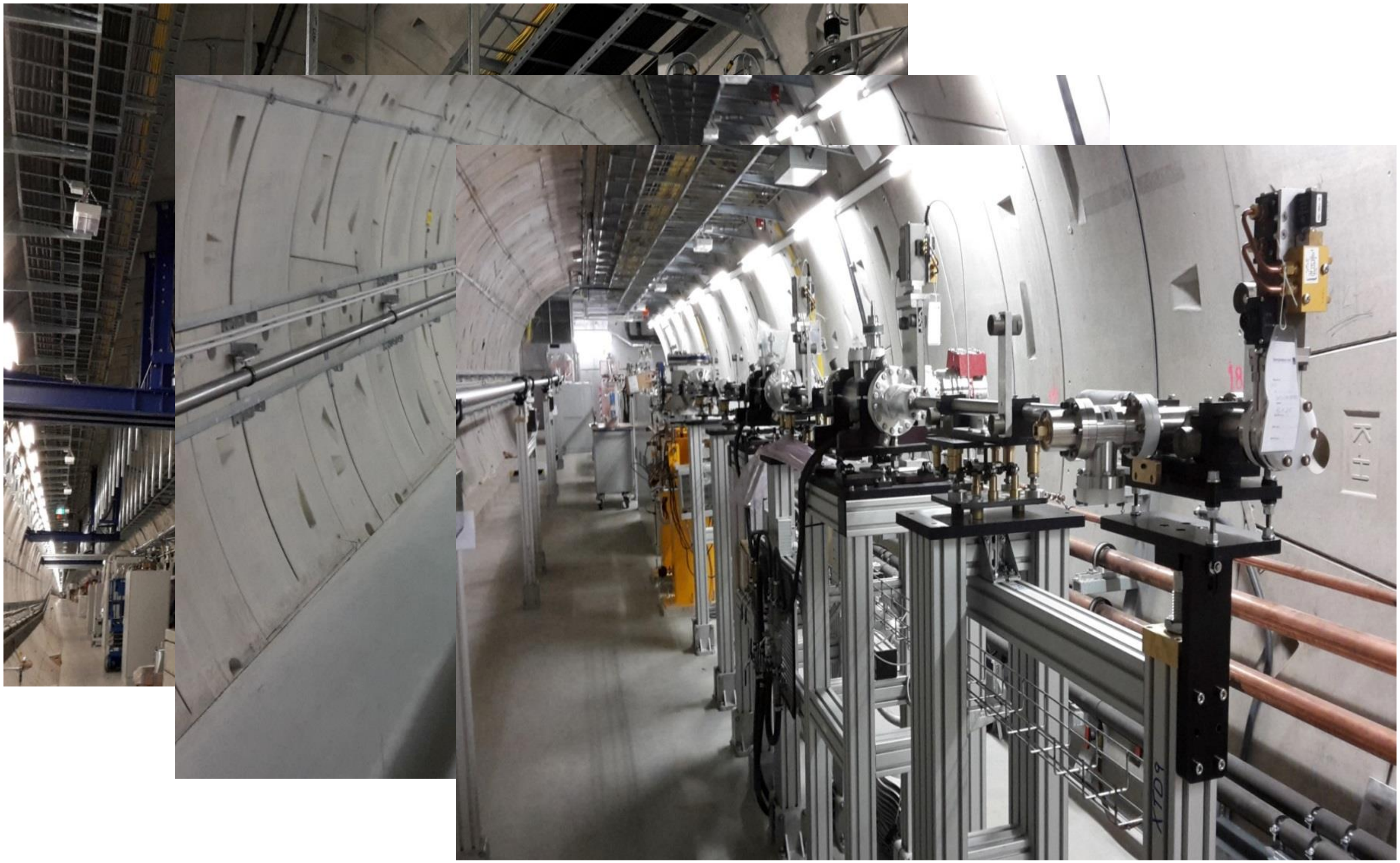
Final Installation Activities
SASE2 Undulator Section

- Mechanical vacuum work in the southern branch almost finished.
- Technical commissioning in Q3/2017.



SASE Undulator Sections
with special air conditioning hutch

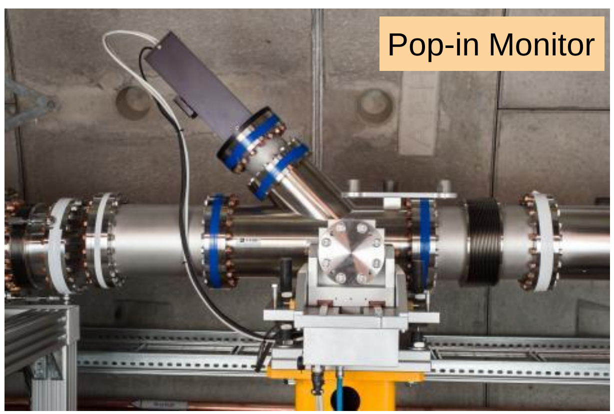
Installation of Photon Beamlines

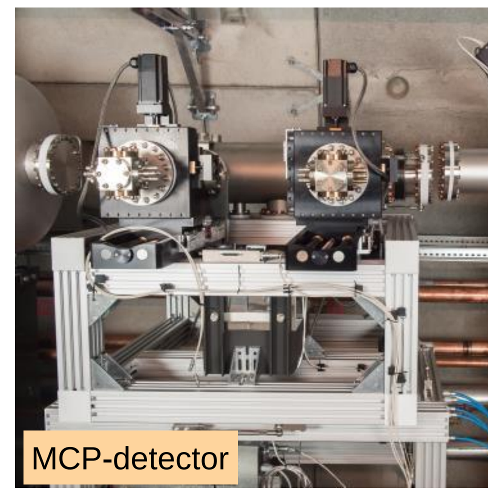


Differential pump + XGM in XTD9

courtesy of XFEL.EU

Photon Beam Diagnostics Status SASE1 – XTD2

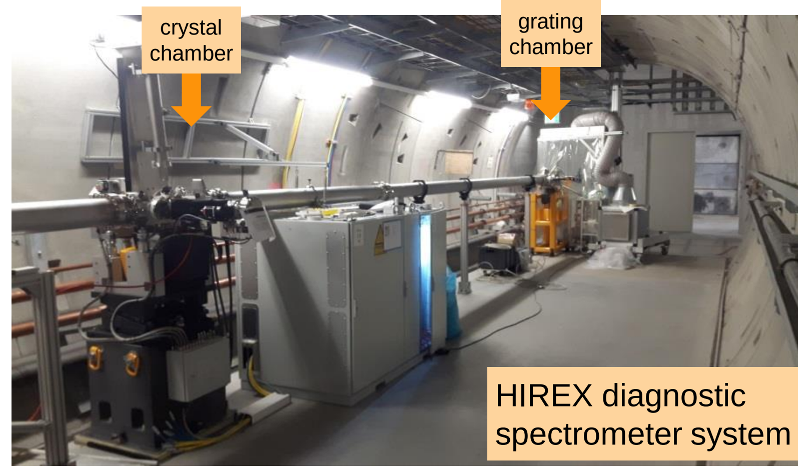




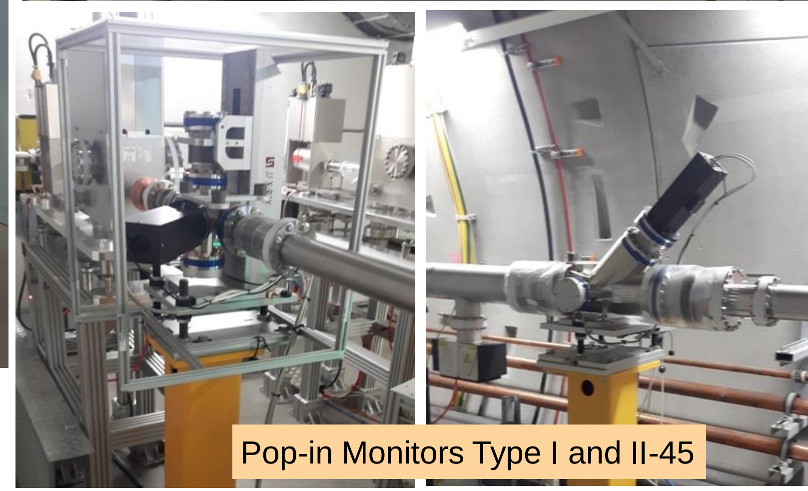
Photon Beam Diagnostics Status SASE1 – XTD9


XGM@XTD9


HIREX crystal chamber

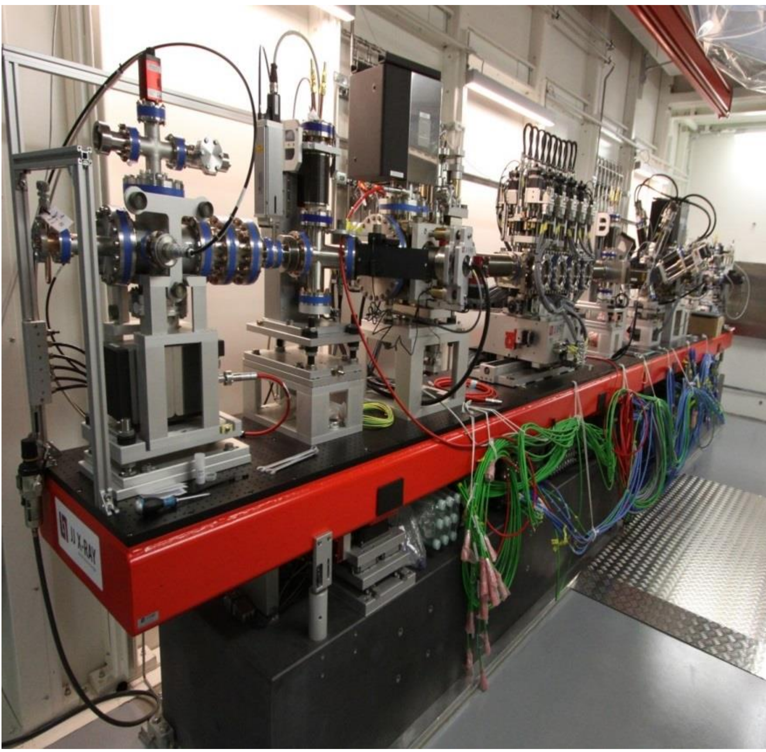


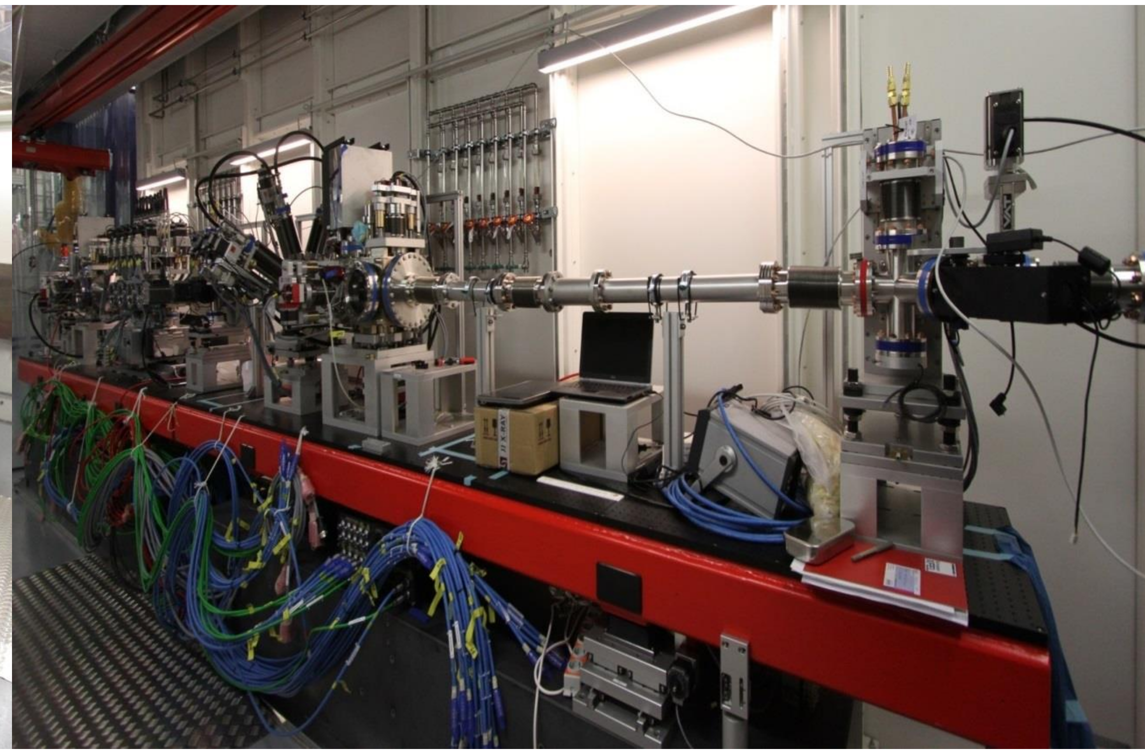
HIREX diagnostic spectrometer system


Pop-in Monitors Type I and II-45

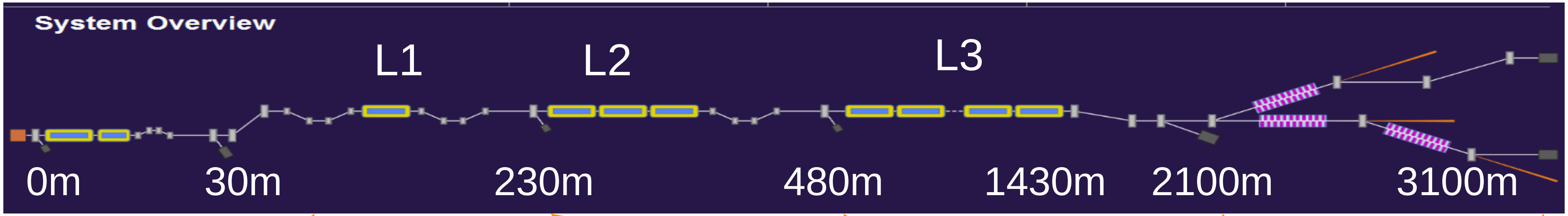
XHEXP – SASE1 science instruments

SASE1 - Femtosecond X-ray Experiment (FXE)





Beamline Commissioning Progress



13/01*

15/01 @ 130 MeV
19/01 @ 600 MeV

* Beam permission on 13/01

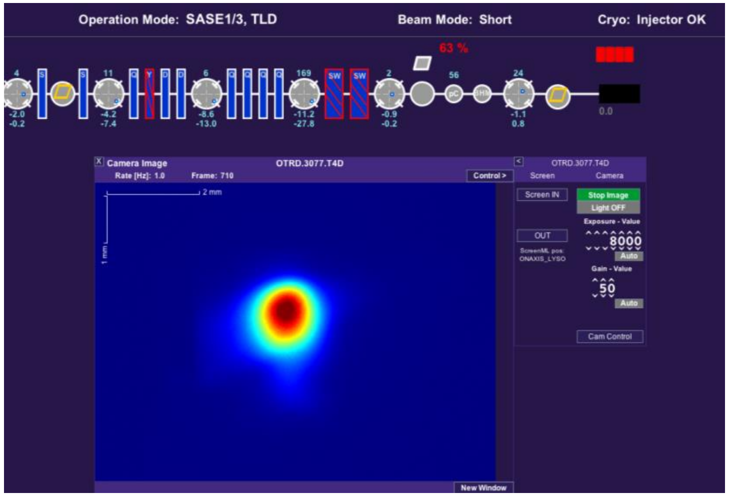
02/02 @ 600 MeV
22/02 @ 2.5 GeV

25/02 @ 2.5 GeV
19/03 @ 6 GeV
08/04 @ 12 GeV

27/04*

* Beam permission on 26/04

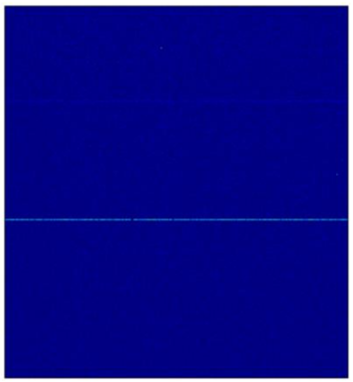
27/04 Beam spot before dump



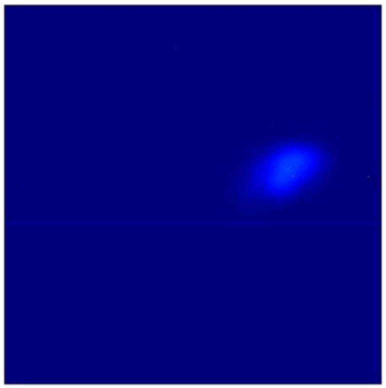
keen on lasing…

First signal from FEL radiation 02.05.17 - 03.05.17

- low energy 6.4 GeV working point for beam based alignment
- no undulator beam based alignment yet, no laser heater



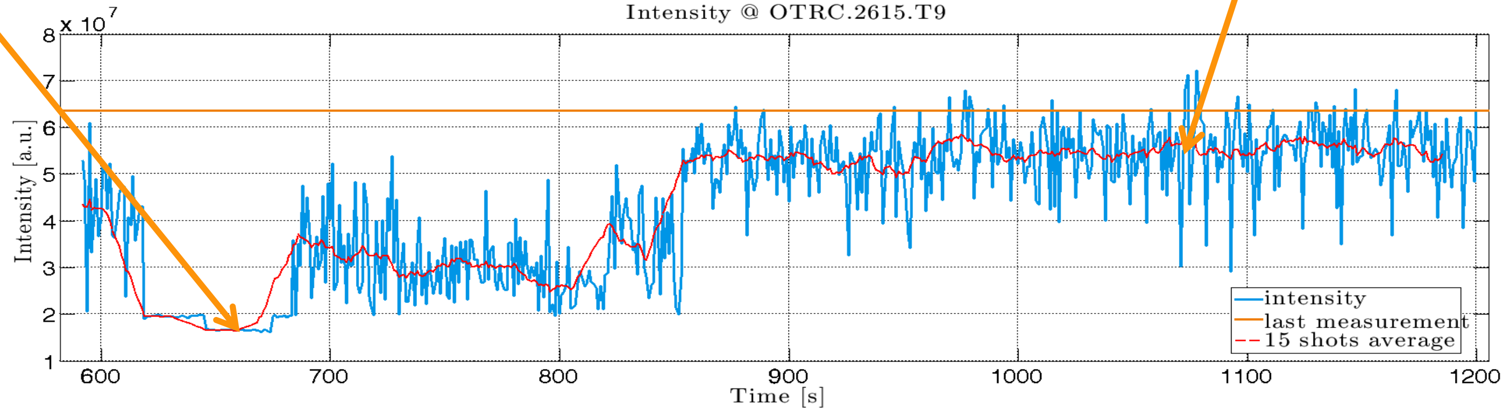
some tweaking of compression and trajectory



E = 6.4 GeV

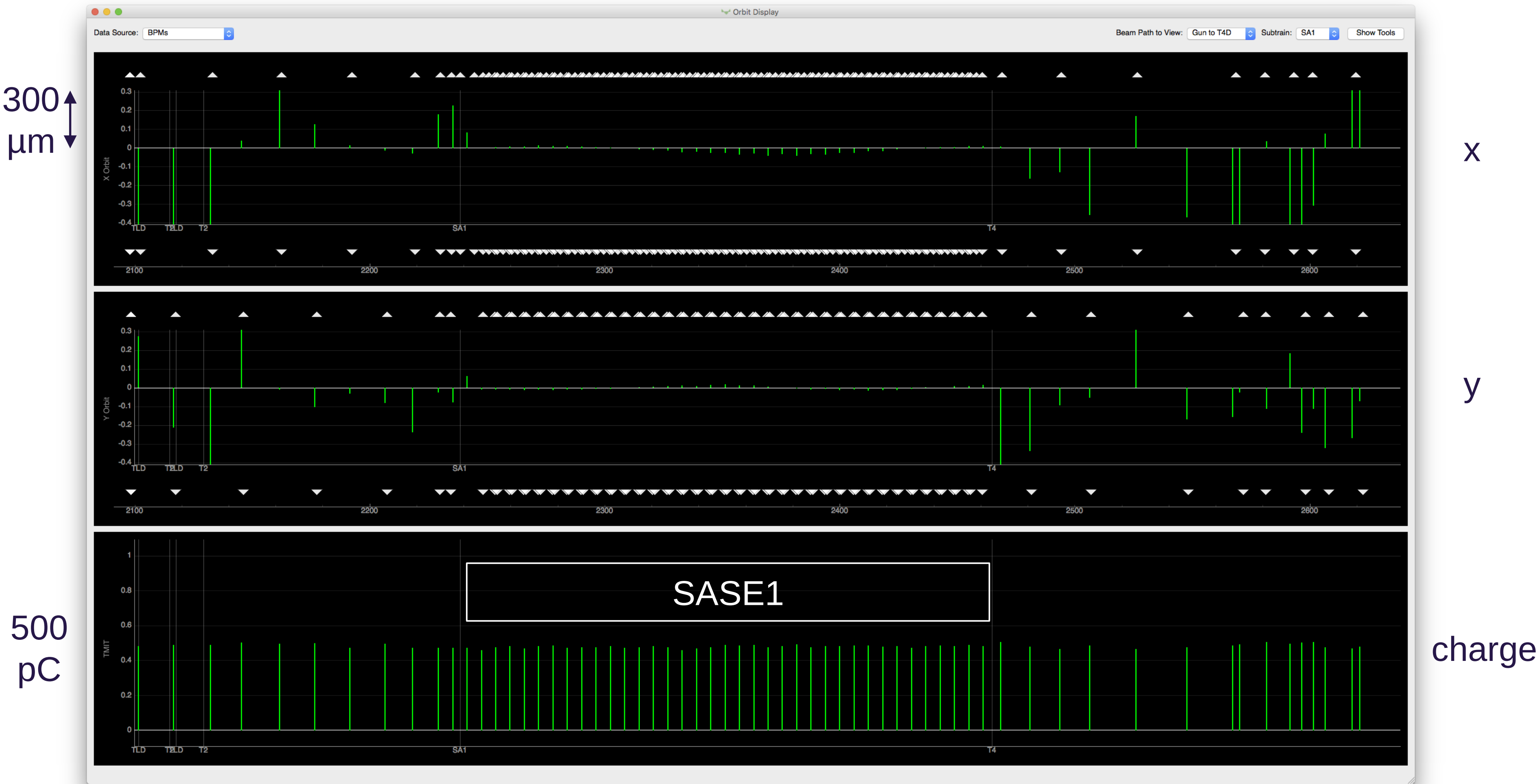
K = 3.5

9 Å

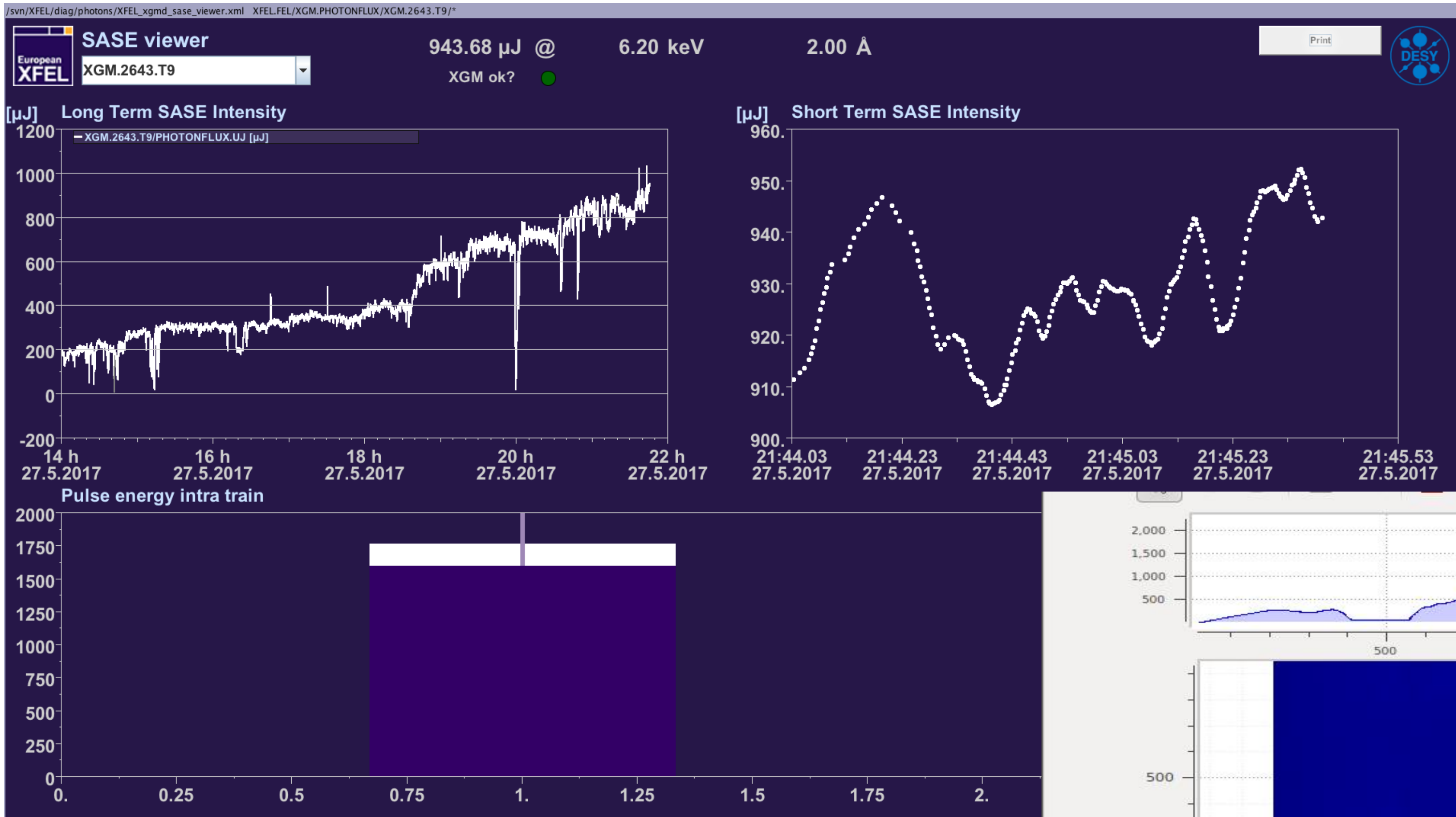


Systematic approach towards short wavelengths

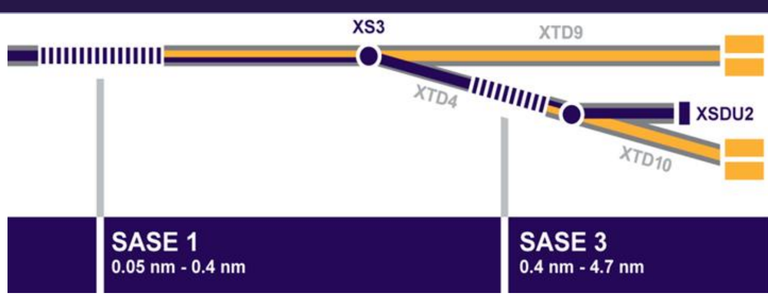
- After first lasing a systematic approach (BBA and commissioning of undulator ctrl) was chosen.
- Photon beam diagnostics was commissioned. Well prepared for lasing at short wavelength…

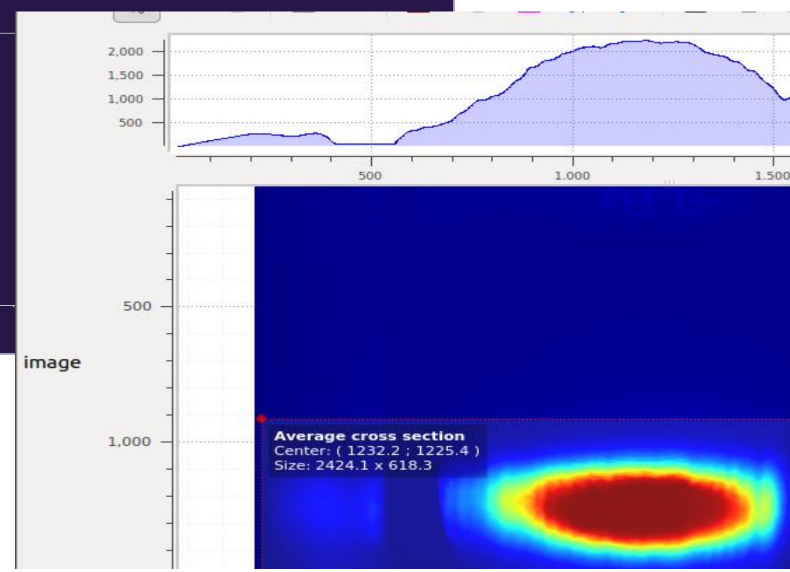


Lasing at 2 Angstroem



- orbit & compression feedback in operation
- transport to SASE1 exp area is next





photon beam at the end of XTD9

Guest Scientists during commissioning

General Assembly of the European XFEL Accelerator Consortium
04.05.2017

Elettra Sincrotrone Trieste
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THANK YOU TO ALL CONTRIBUTORS TO THE EUROPEAN XFEL

cea SACLAY
Ciemat
cnrs IN2P3 Les deux infinis
INFN LASA
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