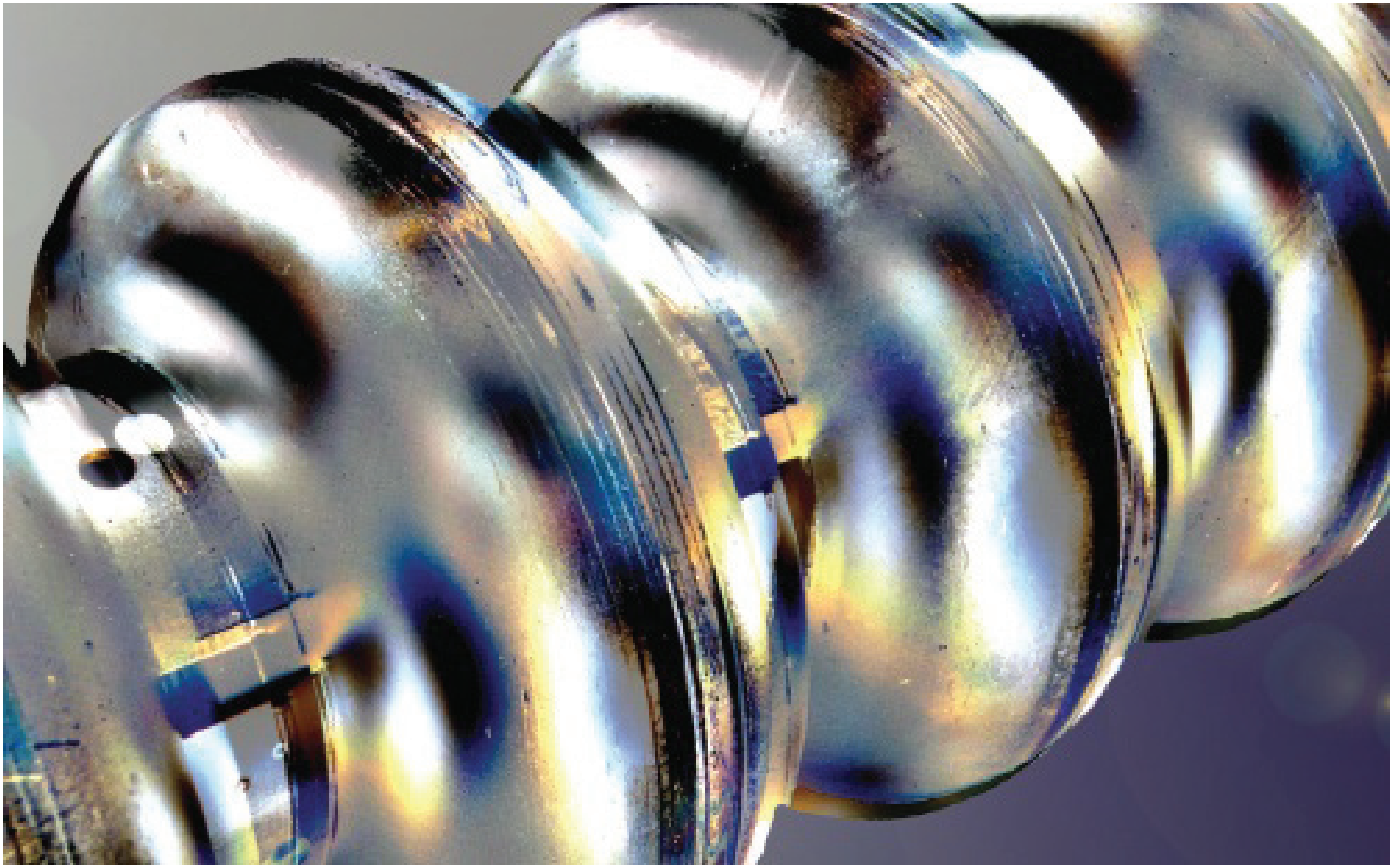
Status of the European XFEL

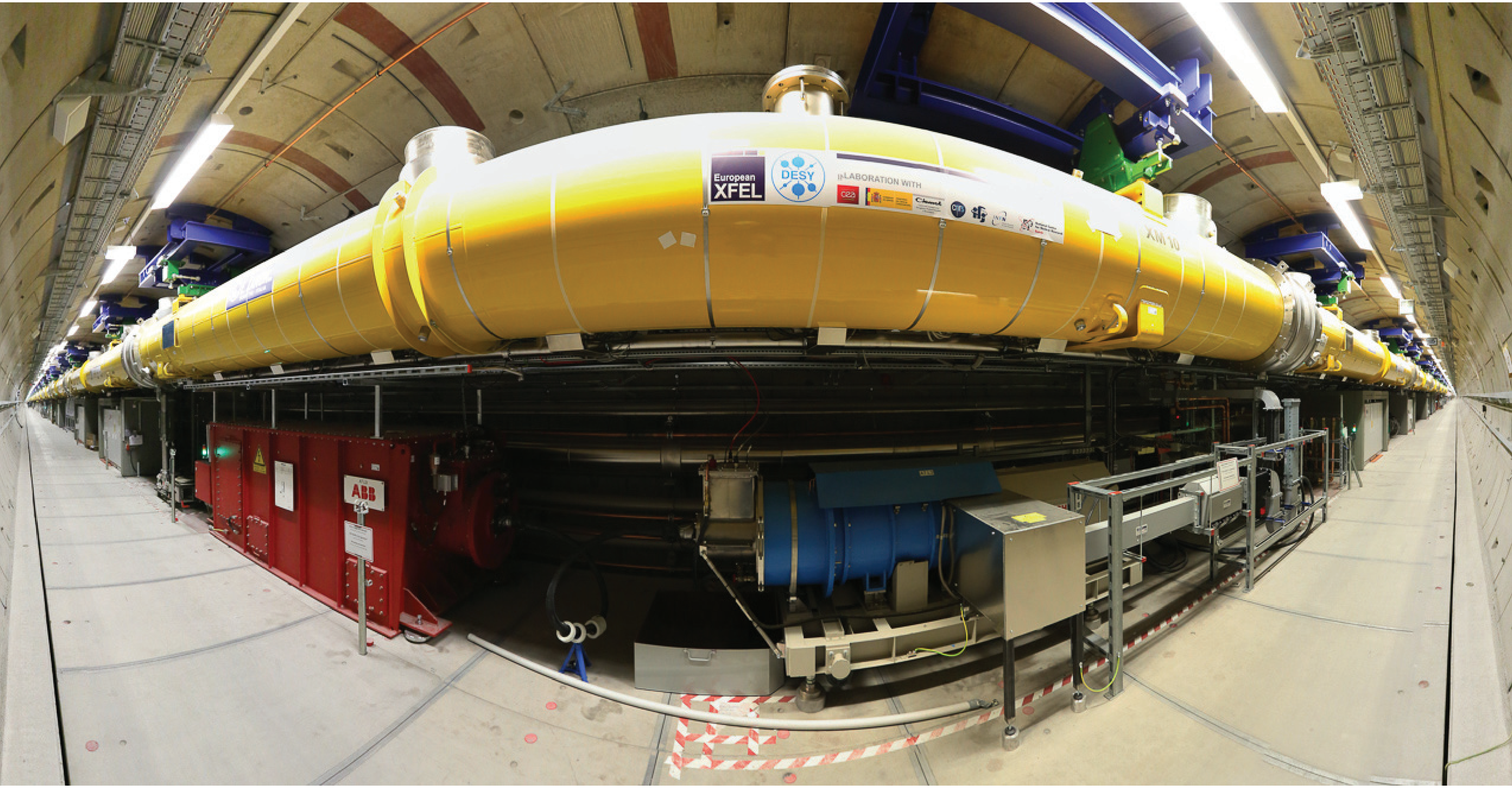
Hans Weise, DESY

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

Superconducting Cavities



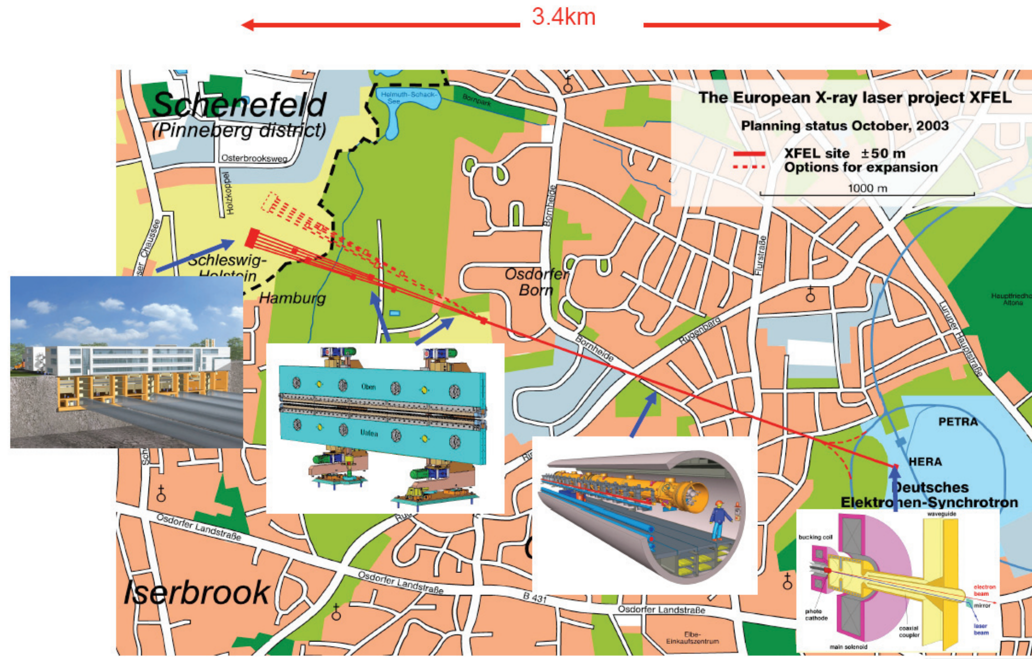
One Kilometer of Cold Linac

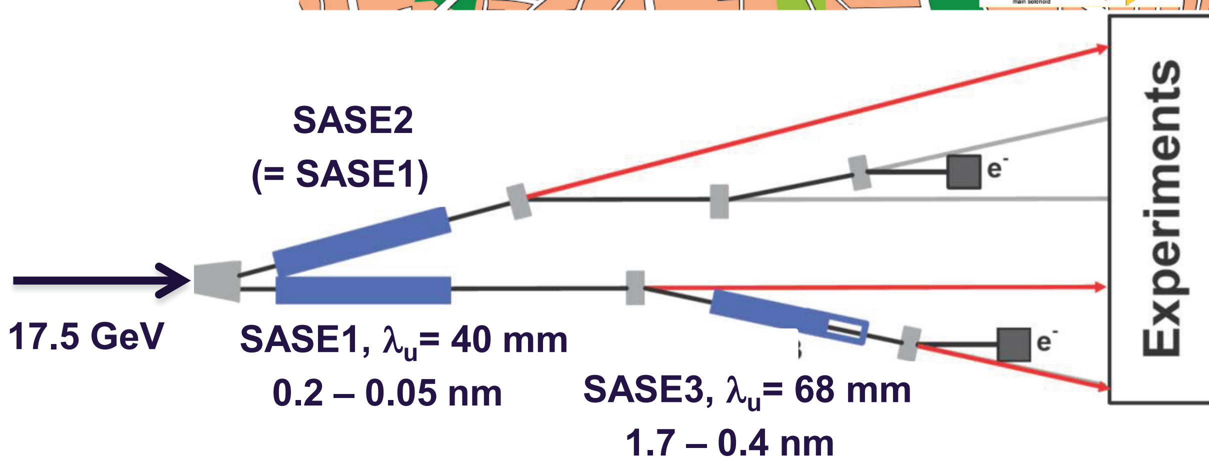


The European XFEL
Built by Research Institutes from 12 European Nations

Some specifications

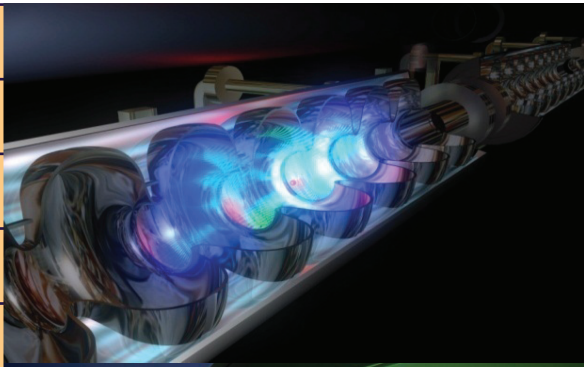
- Photon energy 0.3 - 24 keV
- Pulse duration ~ 10 - 100 fs
- Pulse energy few mJ
- Superconducting linac 17.5 GeV
- 10 Hz (27 000 b/s)
- 5 beam lines / 10 instruments
  - Start version with 3 beam lines and 6 instruments
- Several extensions possible:
  - More undulators
  - More instruments
  - …….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

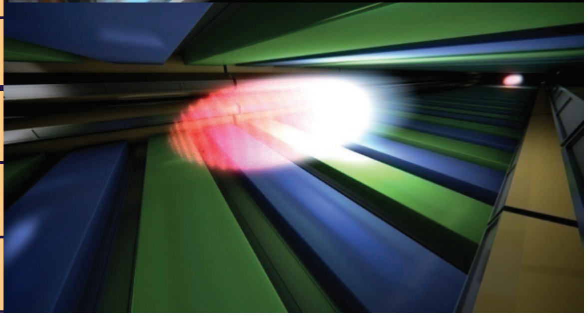


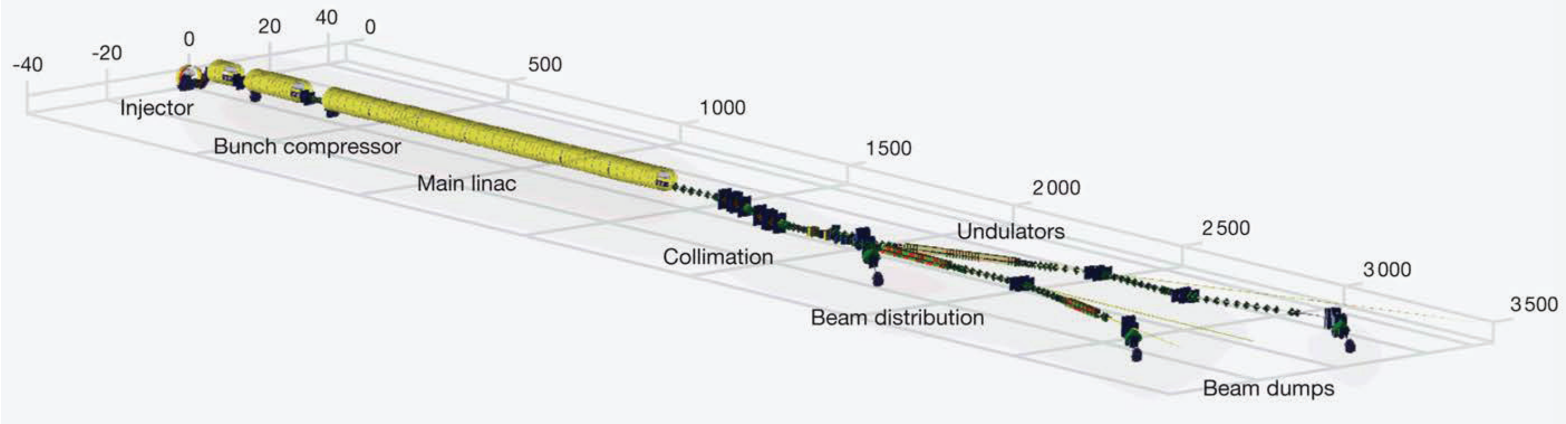


Accelerator Complex with Challenging Parameter Set

Electron beam energy	17.5 GeV
Bunch charge	**0.02 - 1 nC**
Peak current	2 - 5 kA
Slice emittance	**0.4 - 1.0 mm mrad**
Slice energy spread	4 - 2 MeV
Shortest SASE wavelength	**0.05 nm**
Pulse repetition rate	10 Hz
Bunches per pulse	2700
Pulse length	600 µs

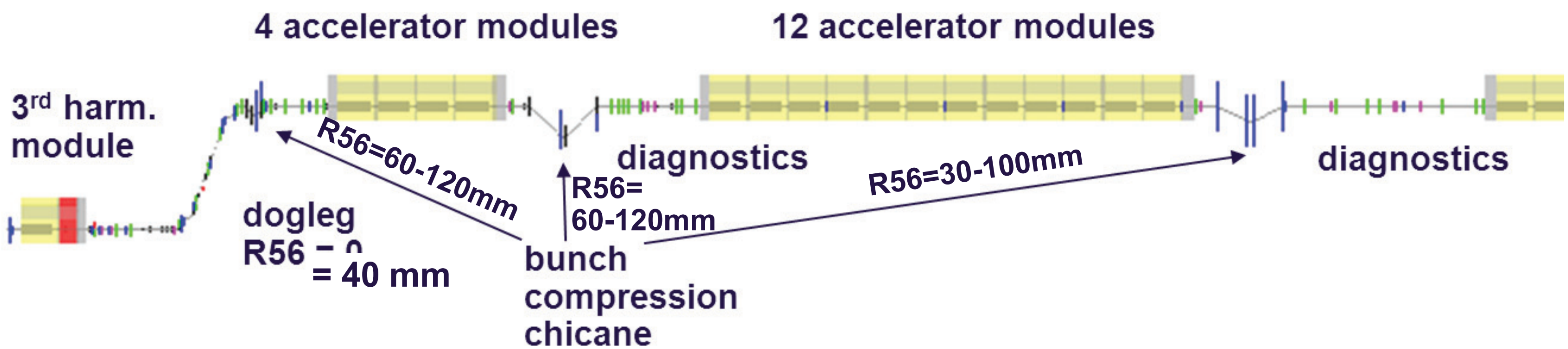






State of the Art 3 Stage Bunch Compression

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

→

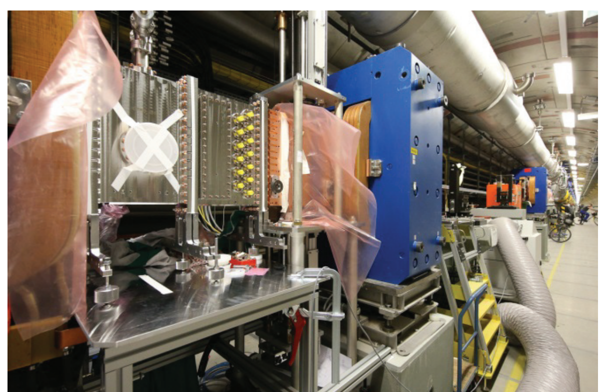
σ_σ = 0.1 mm
I_{peak} = 1 kA
σ_E = 1 %
E = 600 MeV

→

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

→

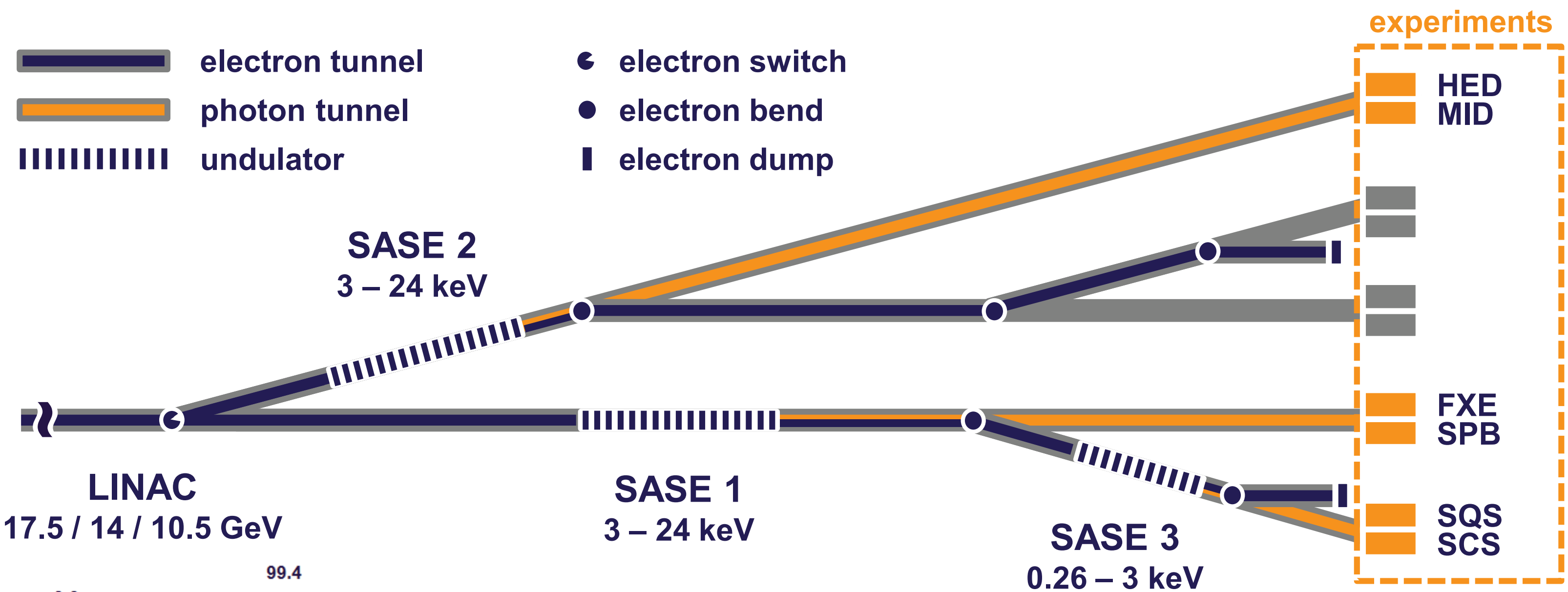
harmonic system

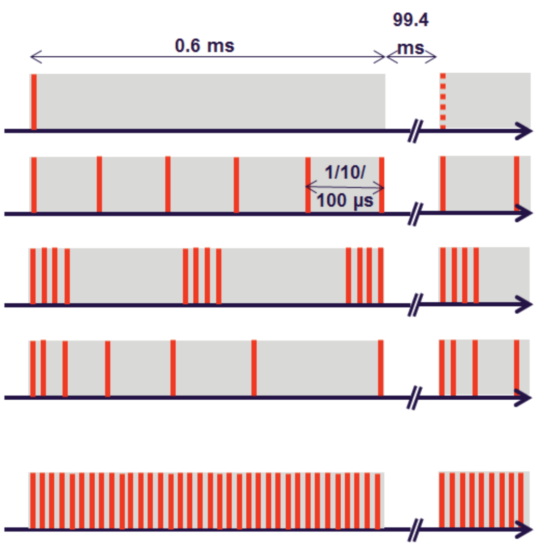


bunch compressor

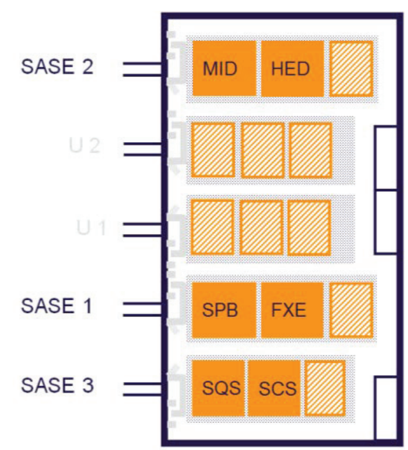
beam diagnostics

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

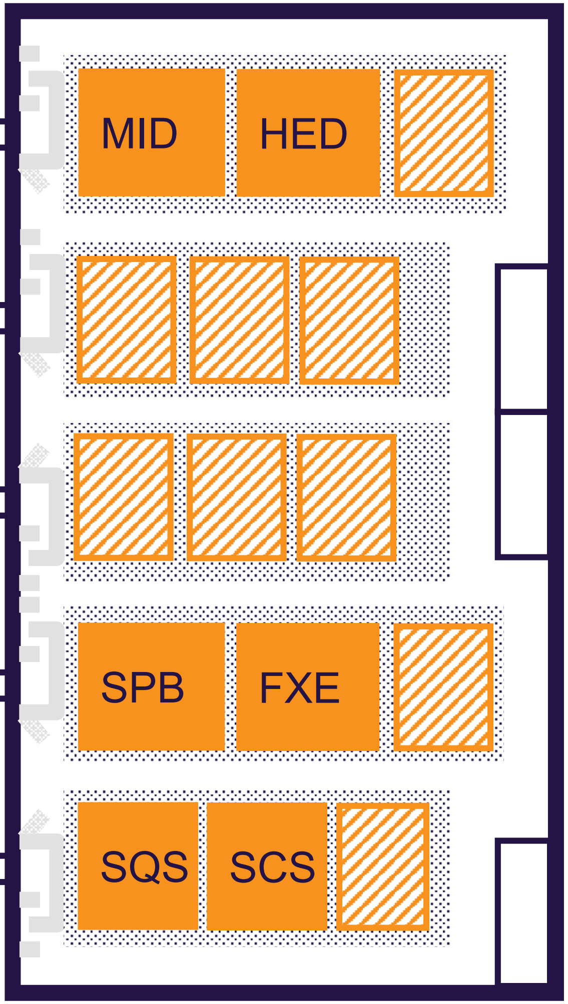
SASE 2

U 2

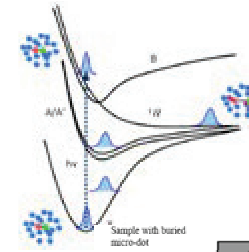
U 1

SASE 1

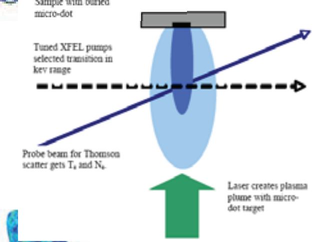
SASE 3



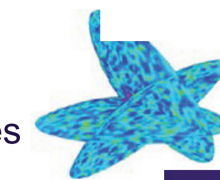
FXE Femtosecond X-ray Experiments



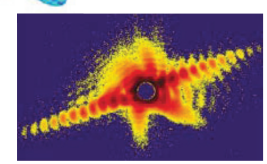
HED High Energy Density Science



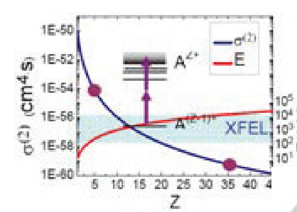
SPB Single Particle & Biomolecules



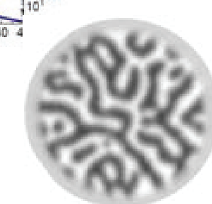
MID Materials Imaging & Dynamics



SQS Small Quantum Systems

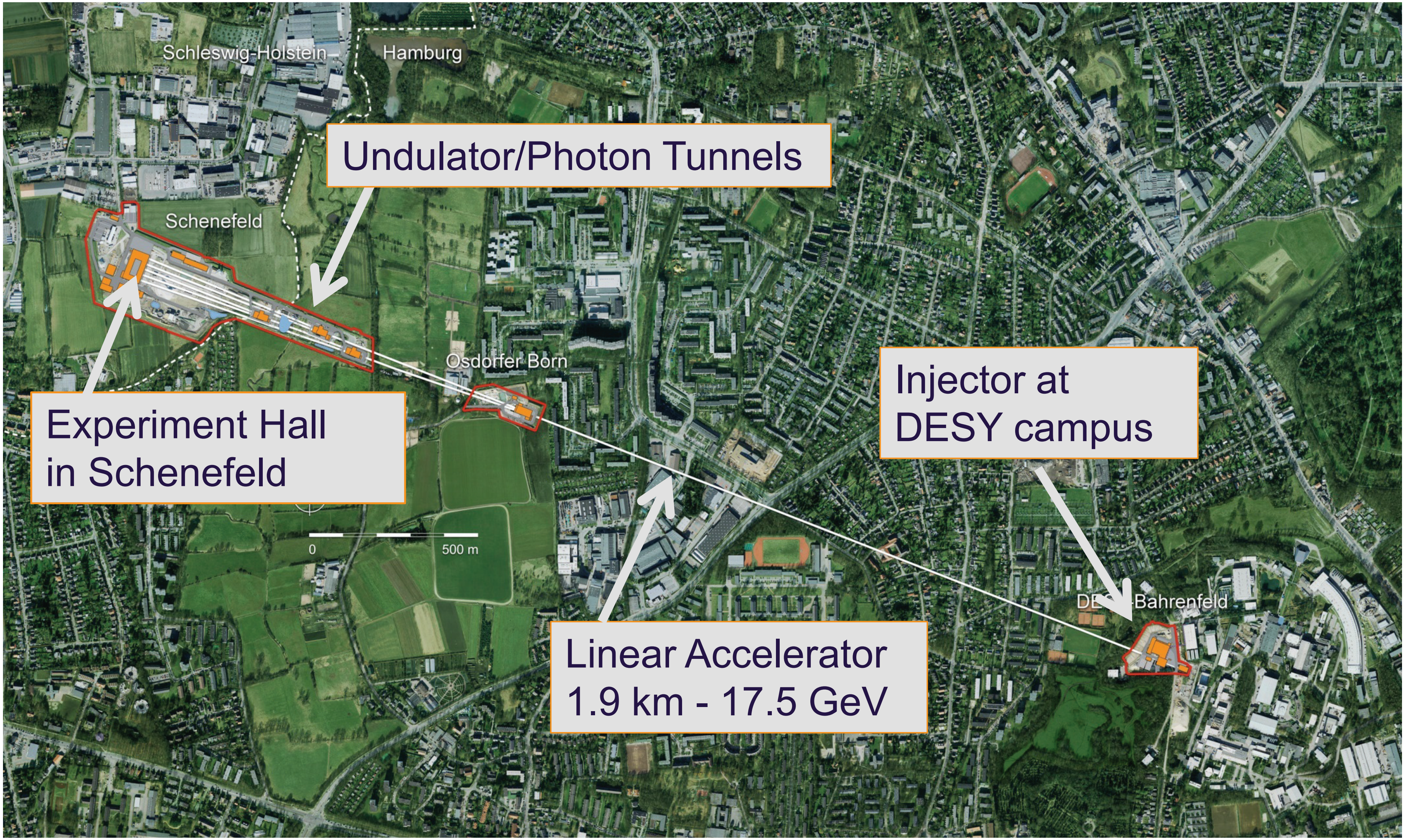


SCS Spectroscopy & Coherent Scattering

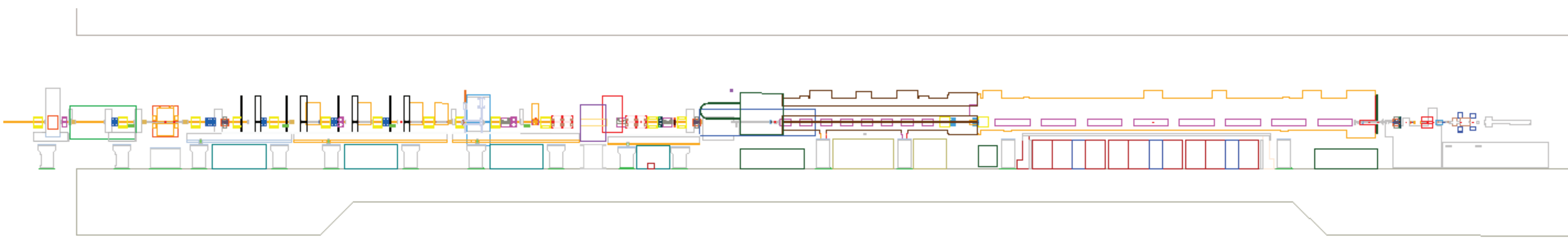


More about experiments: http://www.xfel.eu

European XFEL Layout

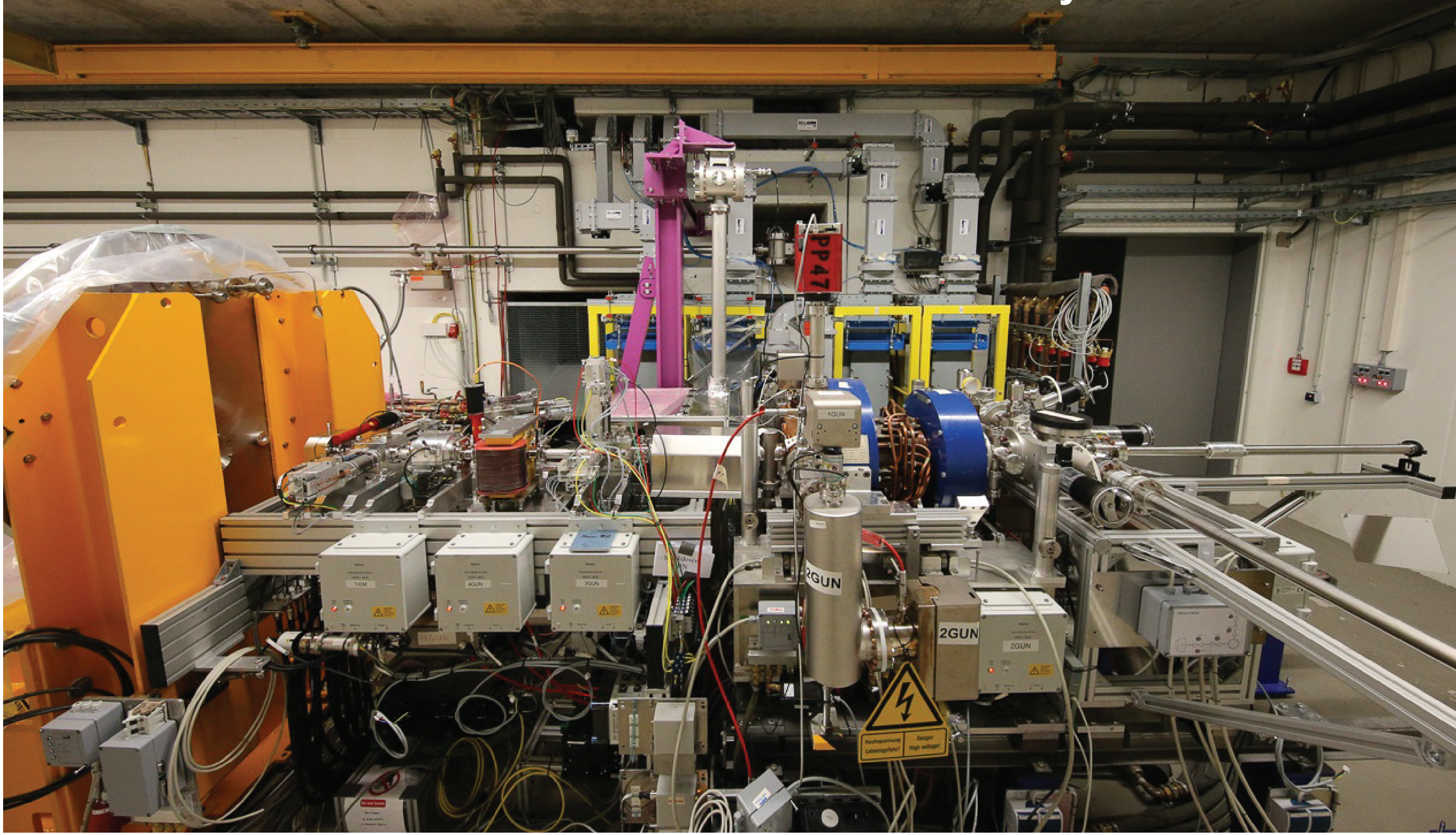


Injector in Operation – First Beam in 12/2015

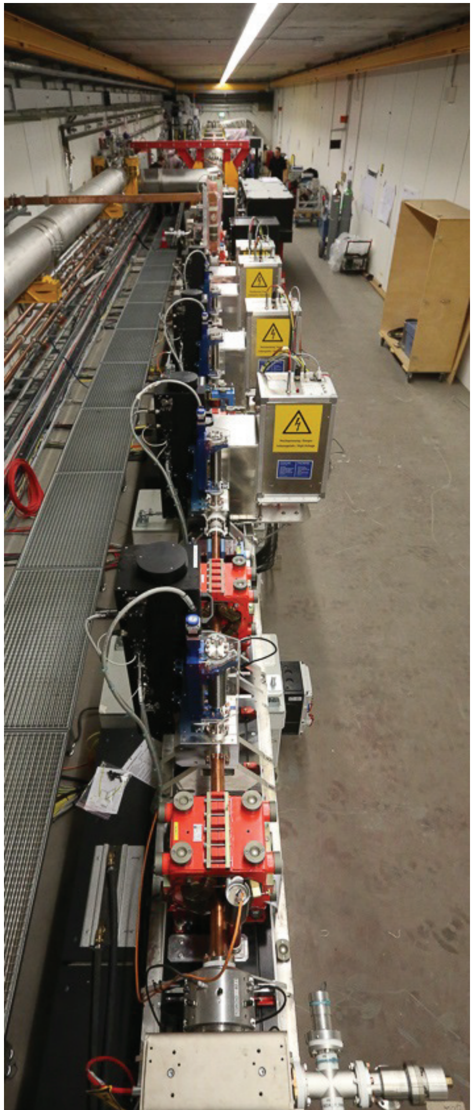


Dump Spectrometer | Transverse Deflecting Structure Diagnostic Section | Laser Heater | 3.9 GHz Module | 1.3 GHz Module | **Gun**

RF Gun Commissioning
a short beam diagnostics section upstream of a standard XFEL 1.3 GHz accelerator module followed by a 3.9 GHz module



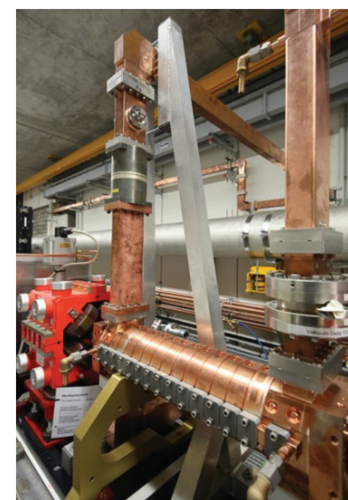
XFEL Injector Status as of 6/2016 (end of commissioning run)



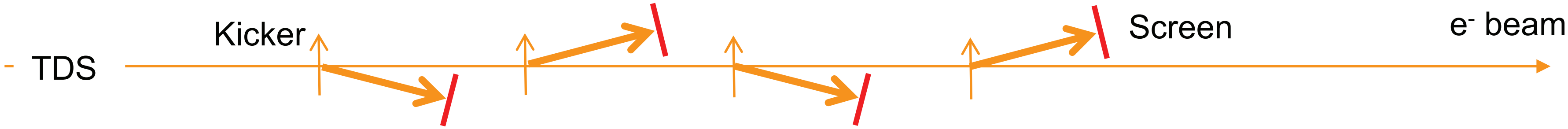
- Injector installation finalized in Q4/2015
- 3.9 GHz module installed in 9/2015
- Injector cool-down started beginning of 12/2015
- First Beam on December 18th , 2015
- Successful commissioning during Q1/2016

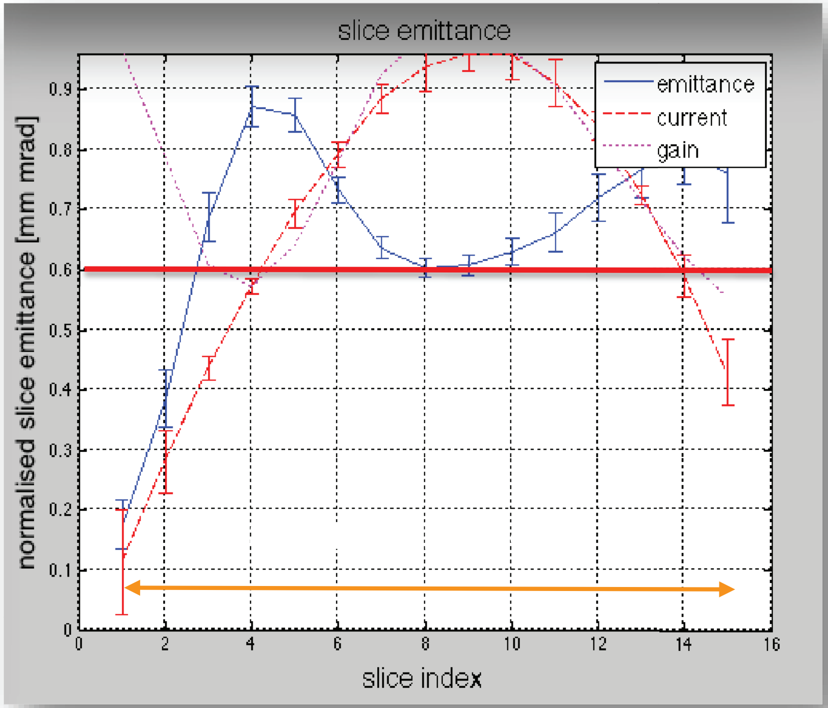
- Emittance measurements done on a routine basis;
- Projected emittance as expected (1...1.5 mm mrad)
- Full bunch train length (2700 bunches) reached and beam stopped in injector beam dump

- Transverse Deflecting System operated
- **Slice emittance measurements give sho 0.5 mm mrad for 500 pC**
- Laser heater commissioning started

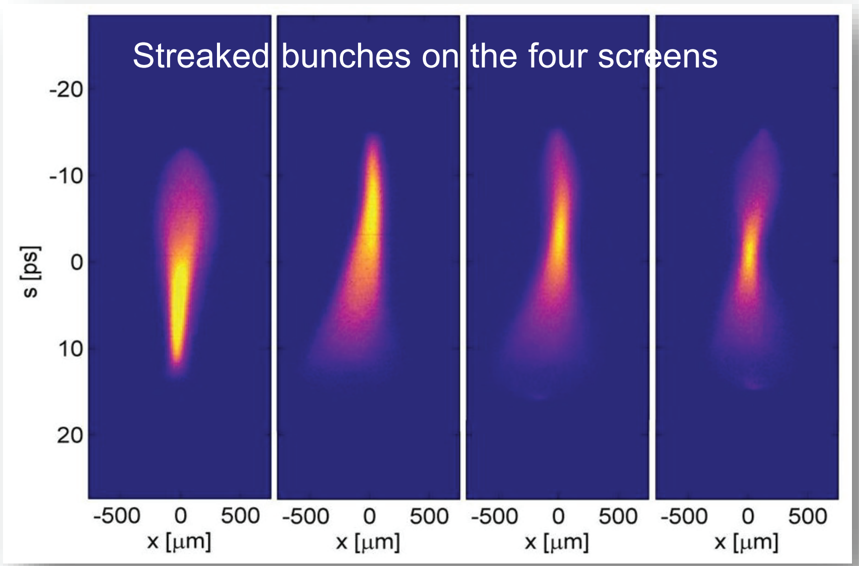


Slice Emittance Measurements
with fast kickers and off-axis screens





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



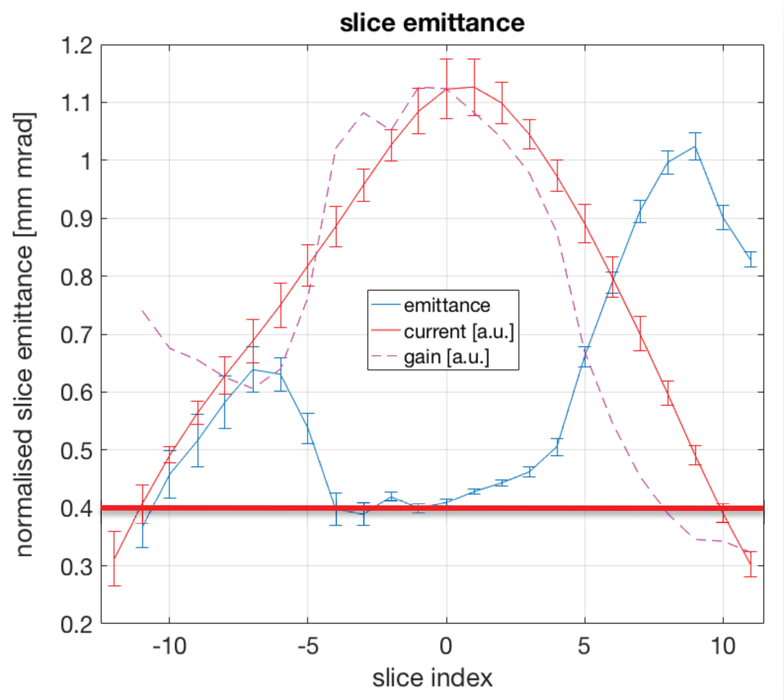
- center slices are reproducibly measured
- 0.6 mm mrad horiz. at 500 pC and 53 MV/m gun gradient
- the smallest slice emittance measured was 0.5 mm mrad at 60 MV/m

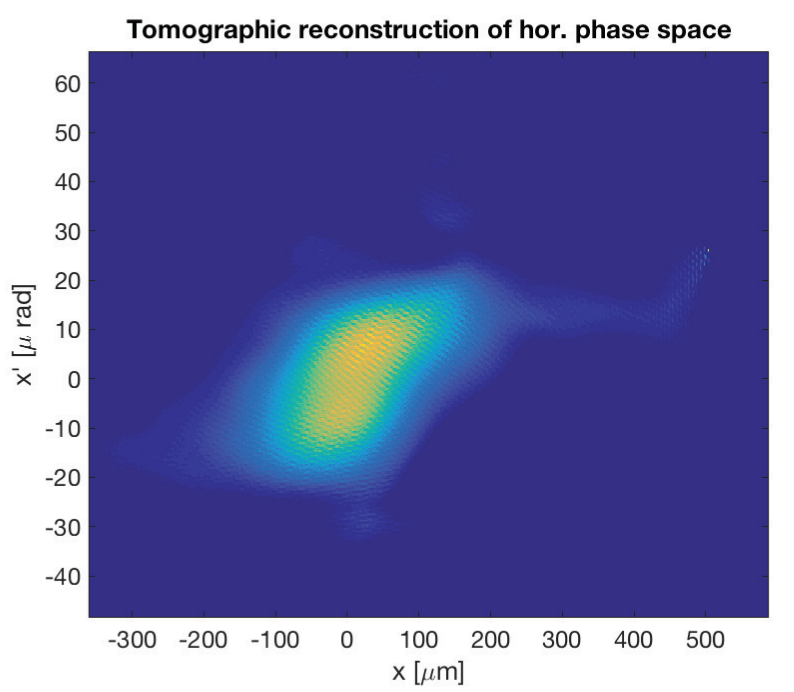
Slice Emittance Measurement Based on Quad Scan

Tomographic reconstruction of the hor. phase space scan

- Results from an **optics scan** with 5 quads and 17 different beam optics. The beam was analyzed on the last screen in the diagnostics section.
- The obtained data was used to **calculate slice emittances** and to reconstruct the hor. phase space of all bunch slices using a tomographic algorithm (MENT*). *MENT: Maximum entropy algorithm

Slice emittances along the bunch. This measurement led to a core slice emittance of 0.4 mm mrad. The gun was operated at 53 MV/m.

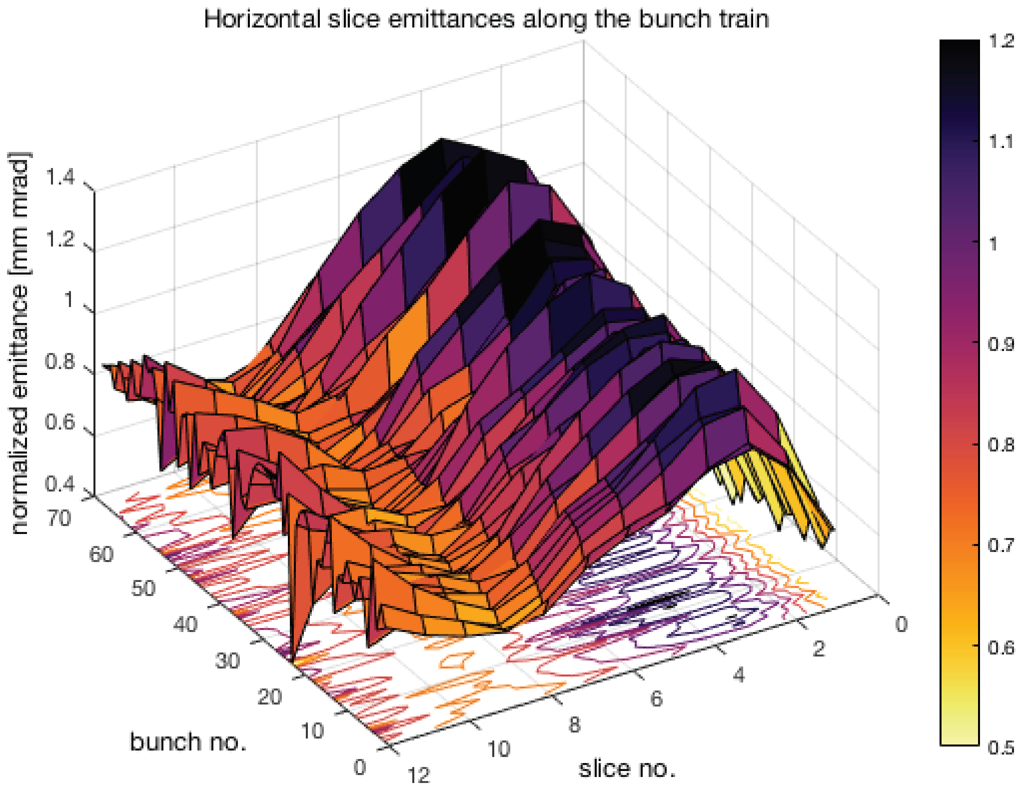




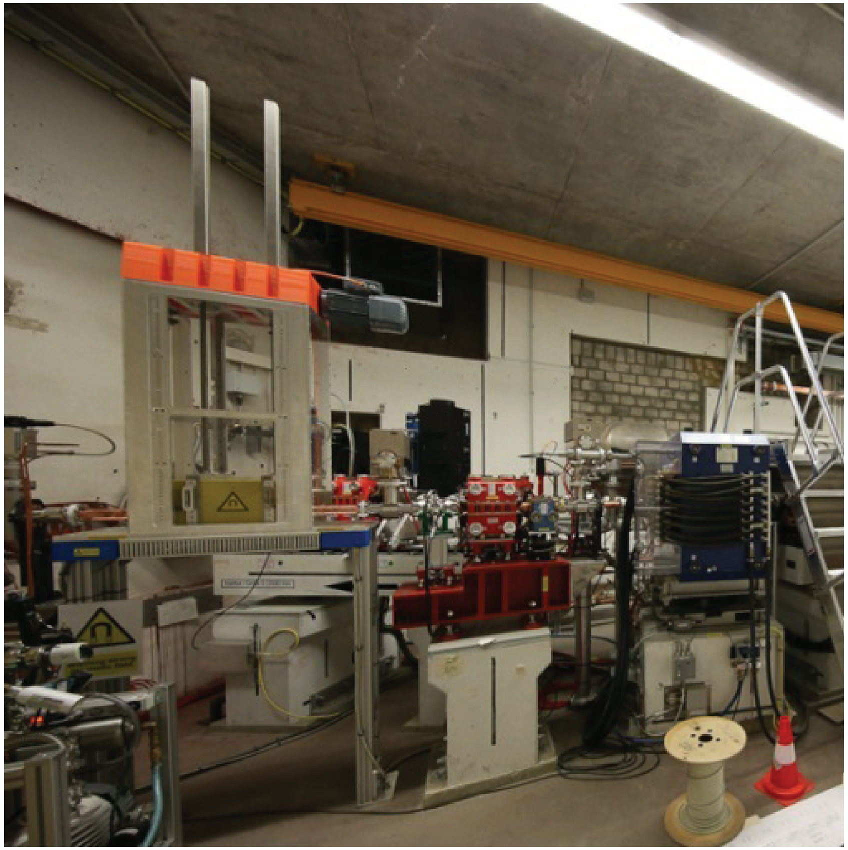
Tomographic reconstruction of the horizontal phase space for the center slice.

Emittance Measurements along Bunch Trains

- The TDS also allows to measure slice emittances along the bunch train.
- The behavior of the slice emittances along the bunch is reproducible over the bunch train. The smallest slice emittance is measured for the core of the bunch.
- The projected emittance and the mismatch parameter are almost constant over the bunch train.

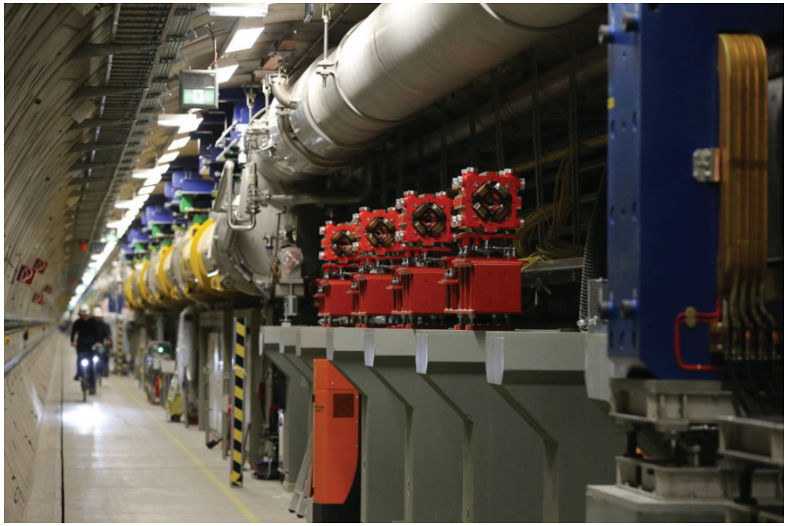


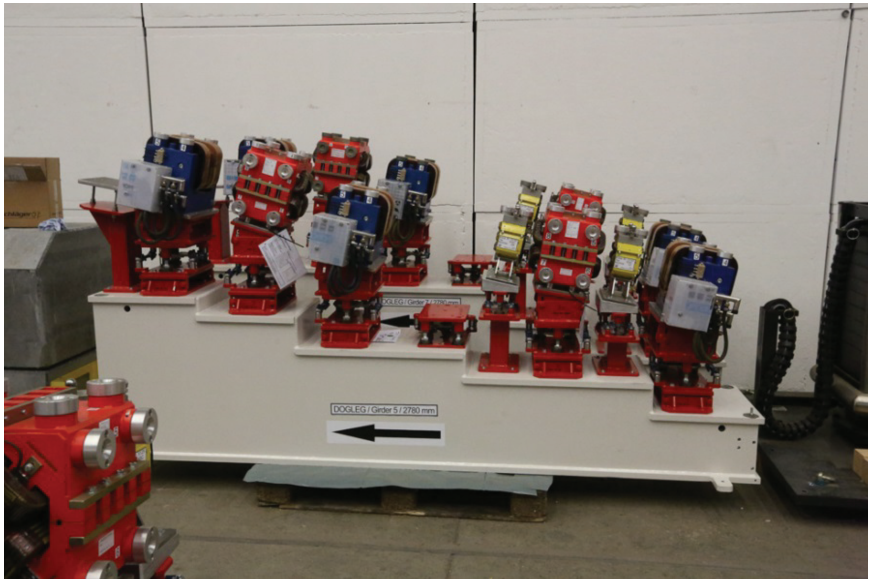
Full Bunch Train Operation

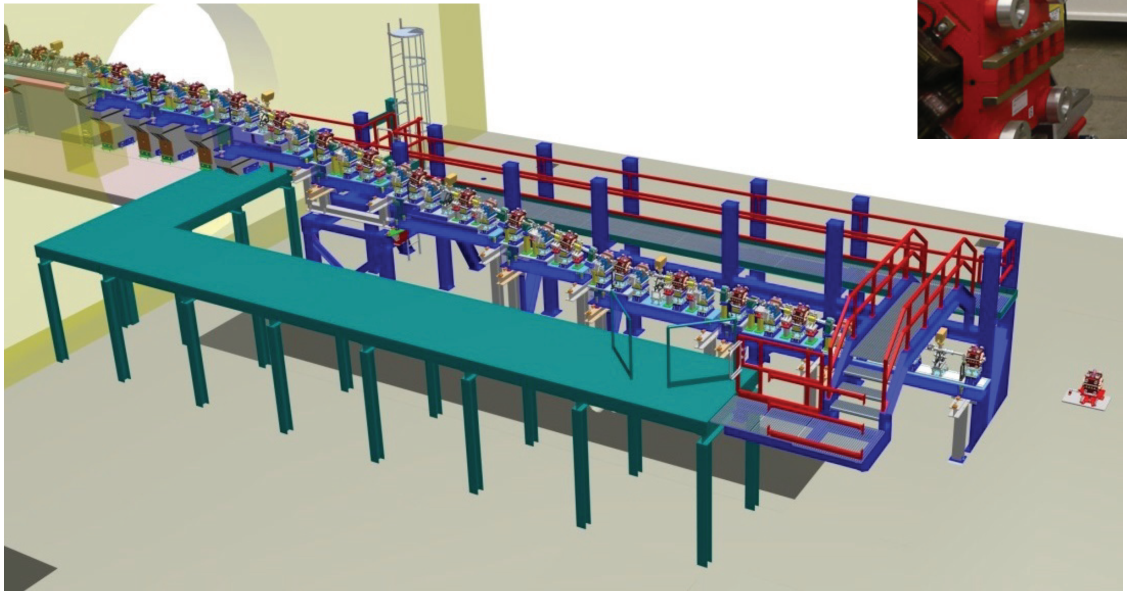


- A dedicated injector beam dump system allows for full bunch train operation
- **24/7 operation** is used to test many operation procedures
- **Operation crew** is getting trained

Warm Beam Line Sections
Dogleg & BC0 in Front of Linac L1

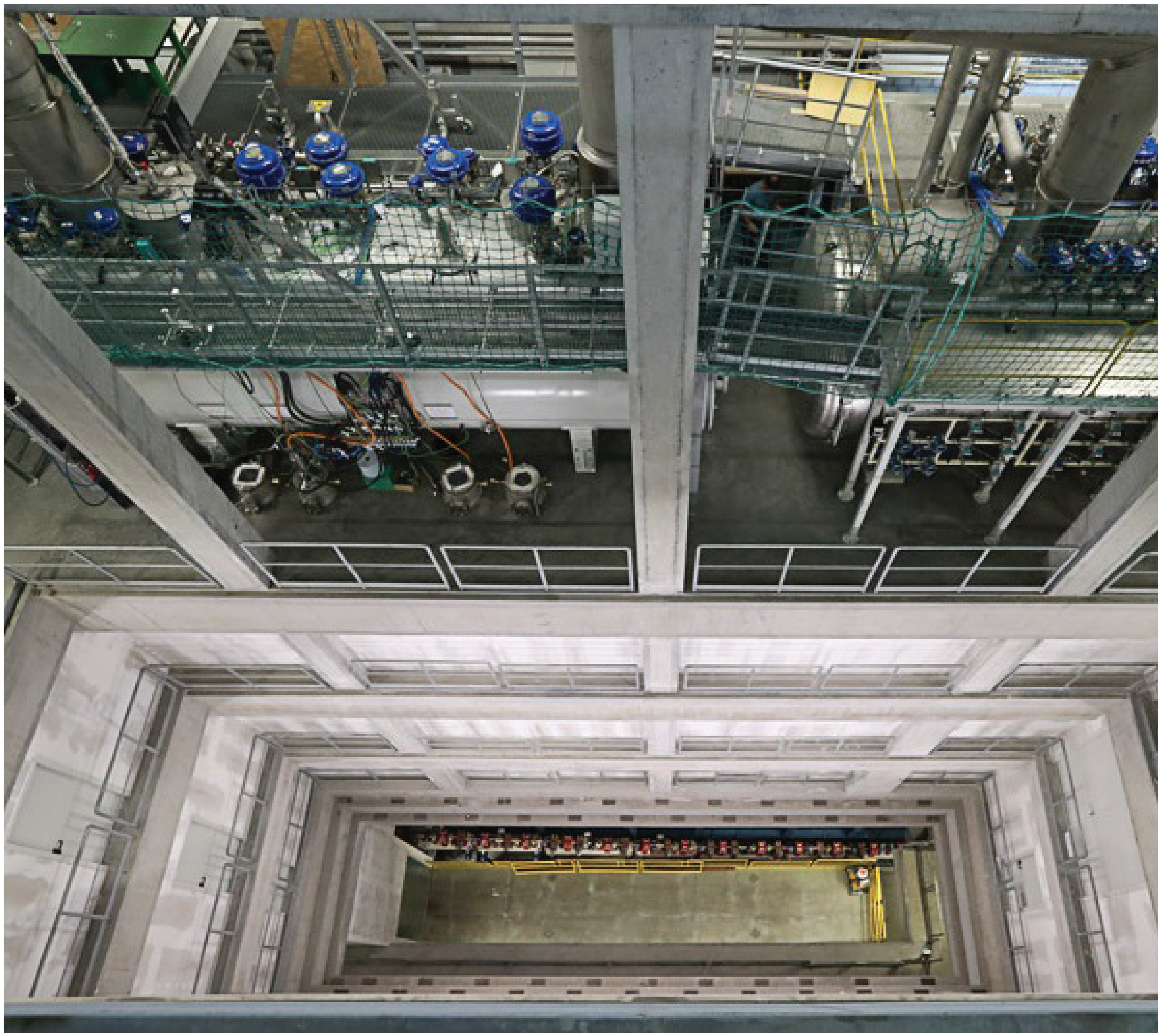




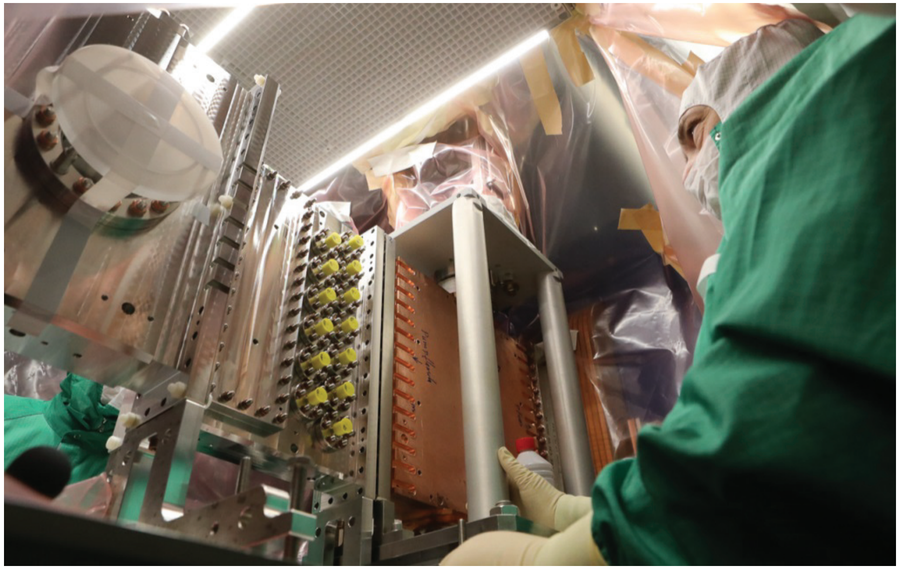
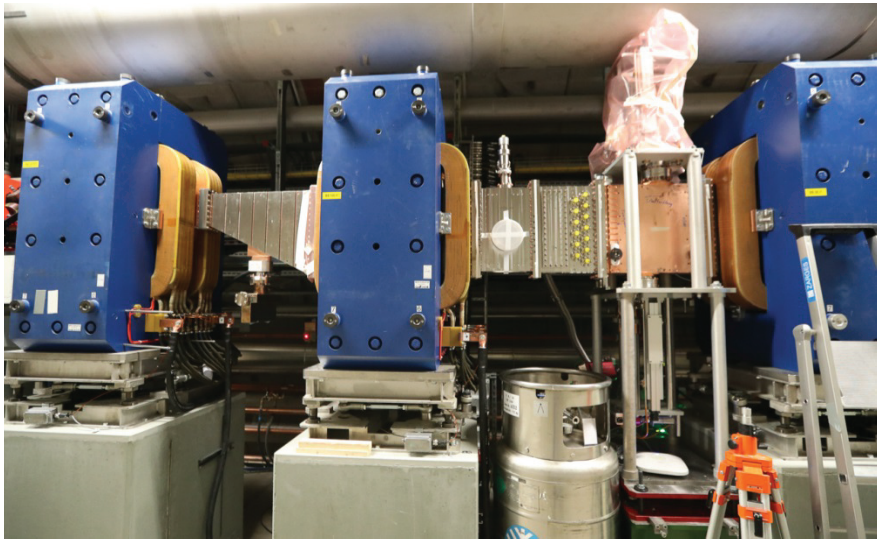


- All girders are pre-assembled in clean rooms
- Tunnel installation requires local clean rooms

A real top-view of the Dogleg Section

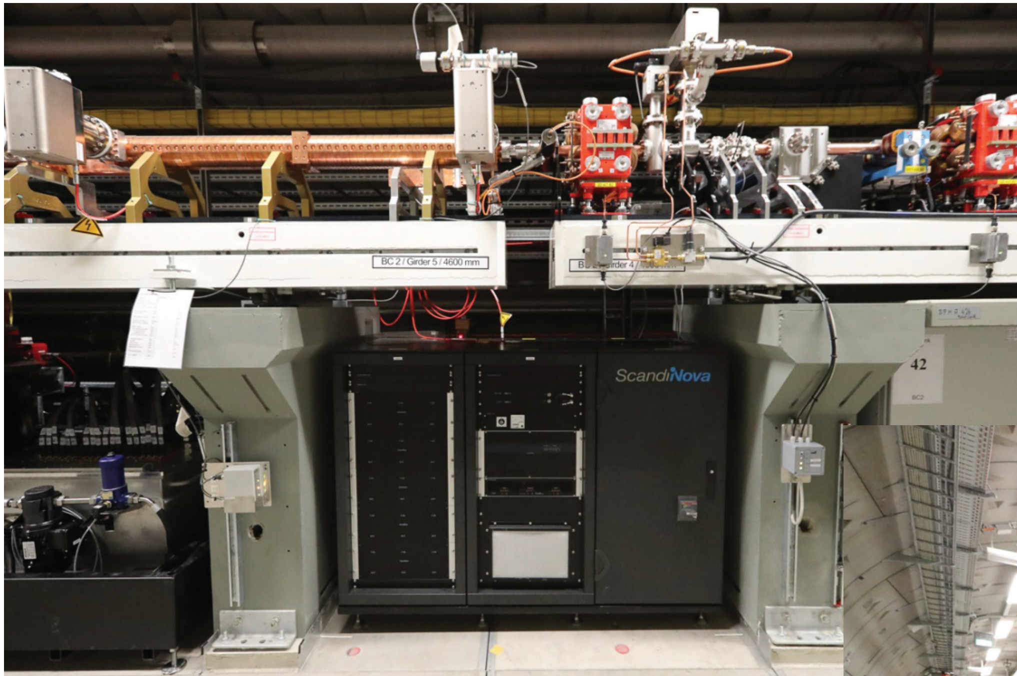


Warm Beam Line Sections
Bunch Compressor Sections – Challenging Installation

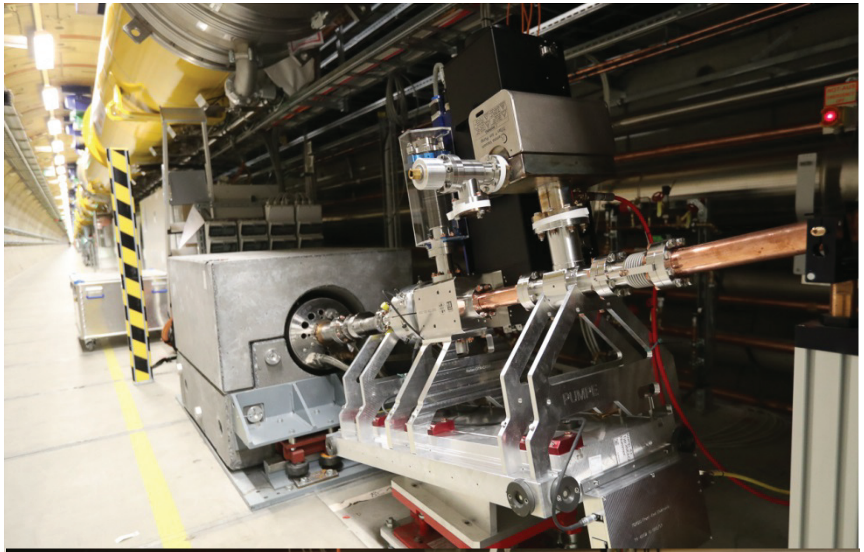

Bunch Compressor BC1

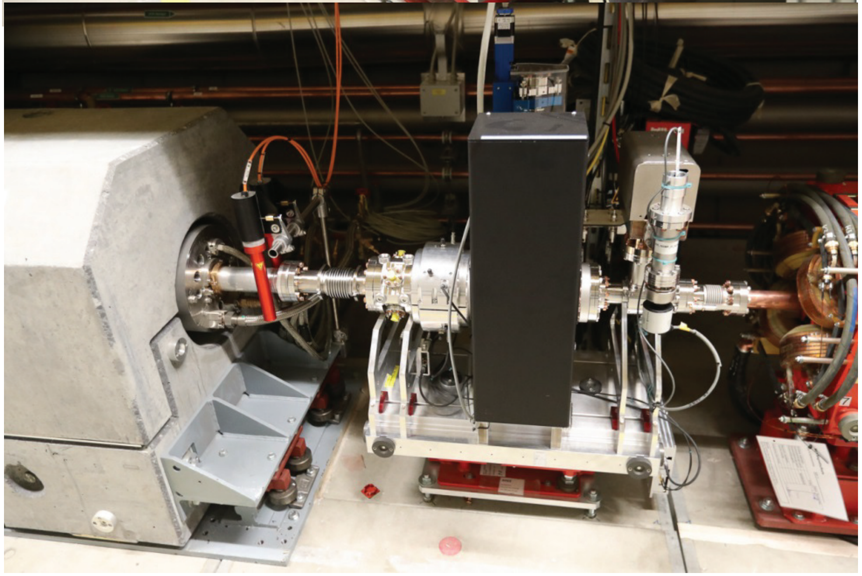
Transverse Deflection System in Bunch Compressor BC2



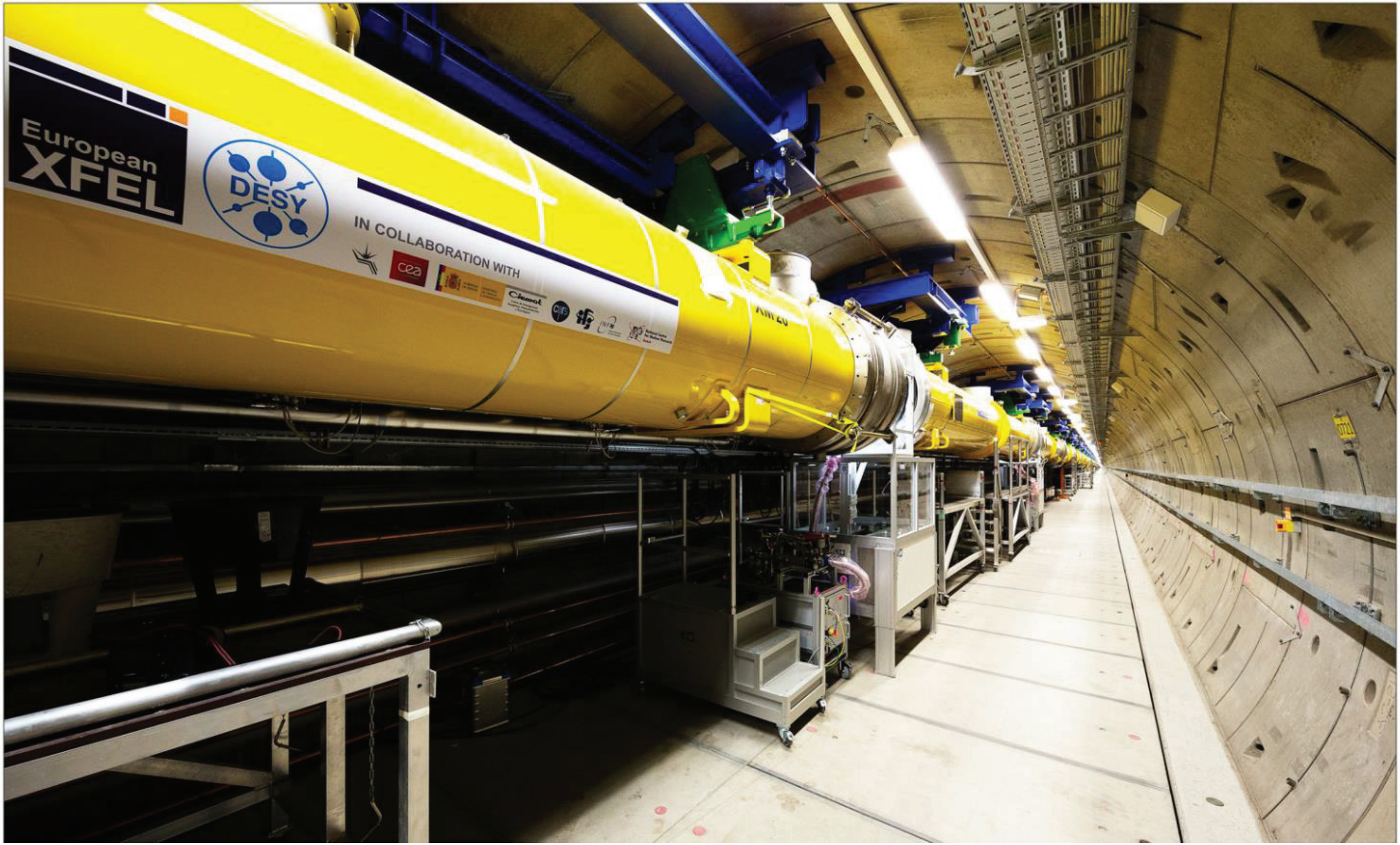
- The BC2 TDS RF station is installed and successfully commissioned.
- TDS structure commissioning is next.
  - Water cooling / temperature stabilization / RF.

Both Bunch Compressors BC1 / BC2 include Commissioning Beam Dumps



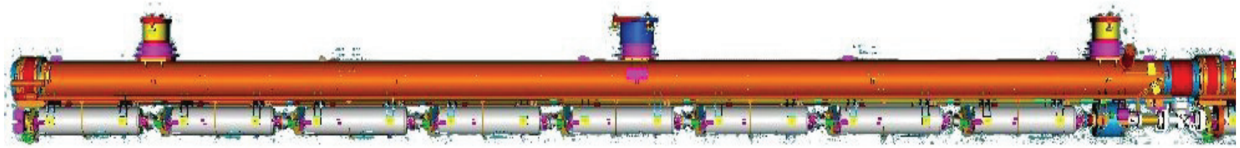


Linear Accelerator

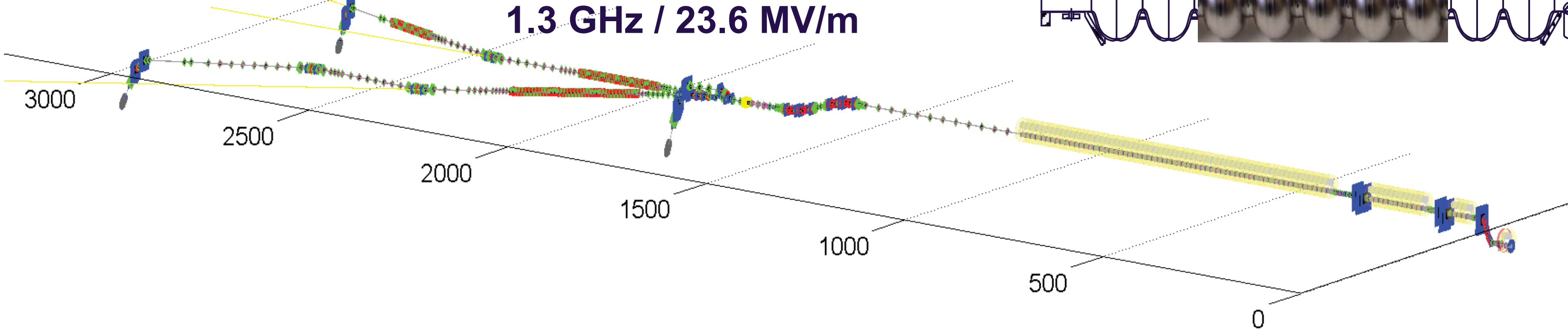


Accelerator Modules

100 accelerator modules



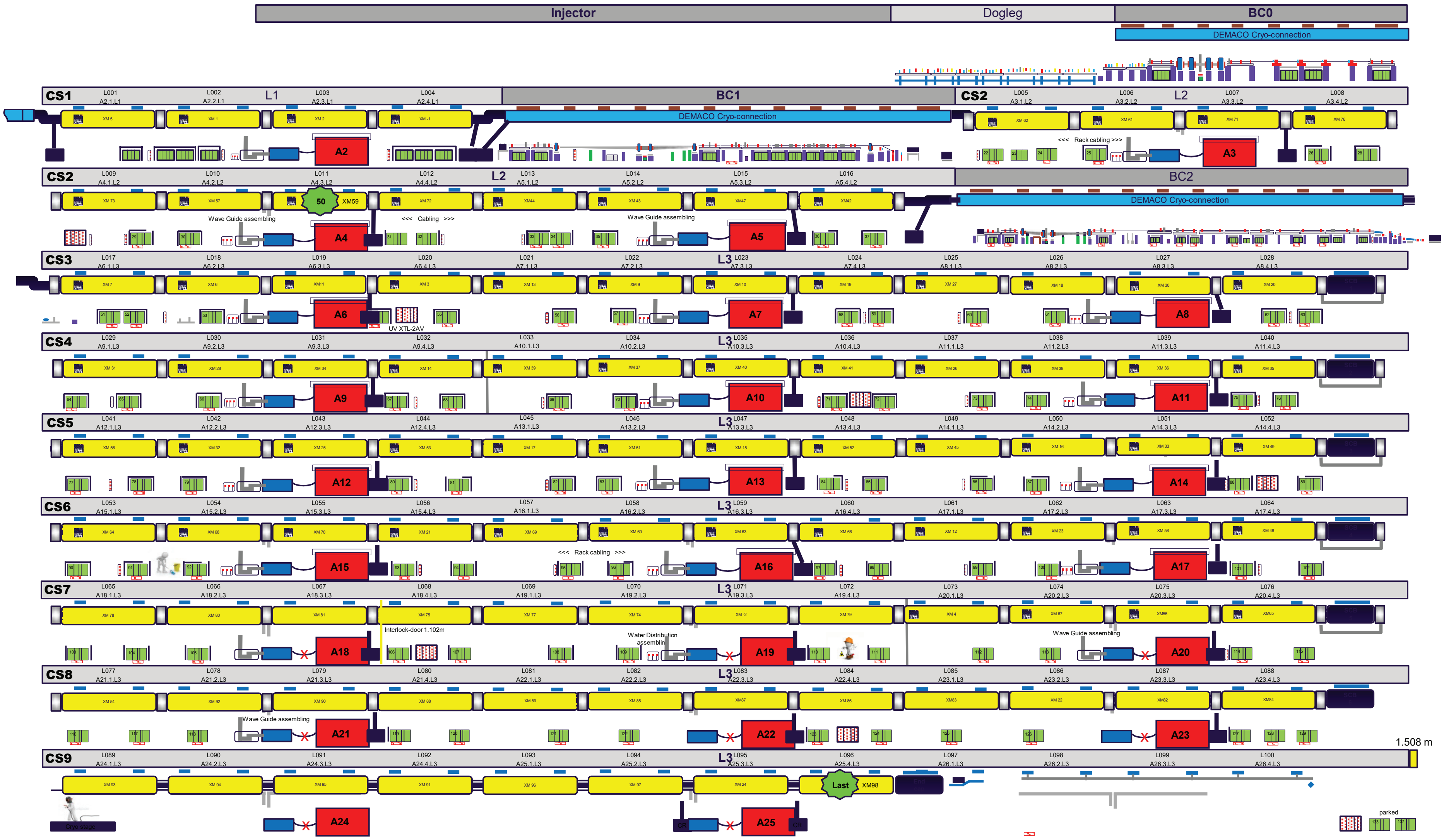
800 accelerating cavities
1.3 GHz / 23.6 MV/m



- The accelerator tunnel (XTL) houses three cold linac sections separated by bunch compressors.
- Down to approx. 50 m behind the last module the complete beam vacuum system is particle free.
- 4 modules / 32 s.c. cavities are connected to one 10 MW klystron.
- 12 modules form a cryogenic string.
- At the XTL end a collimation and separation system is installed.

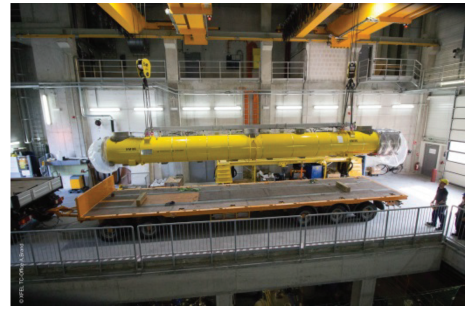
European XFEL

All Accelerator Modules Installed

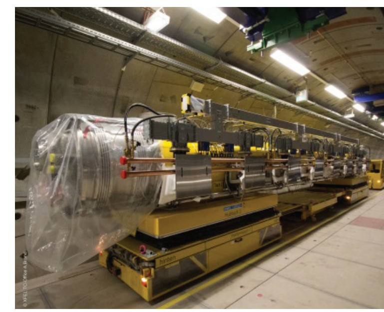


Accelerator Module on its Way to the Tunnel





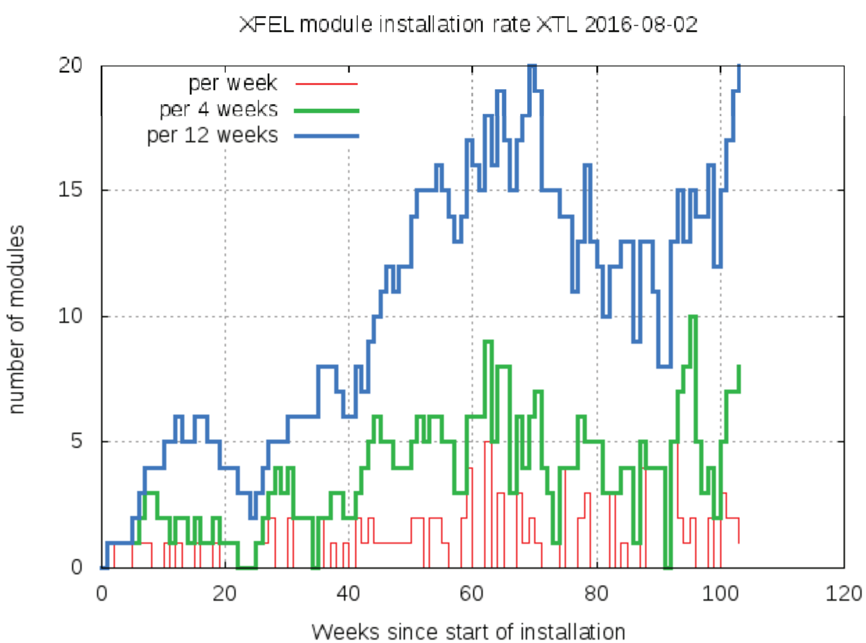


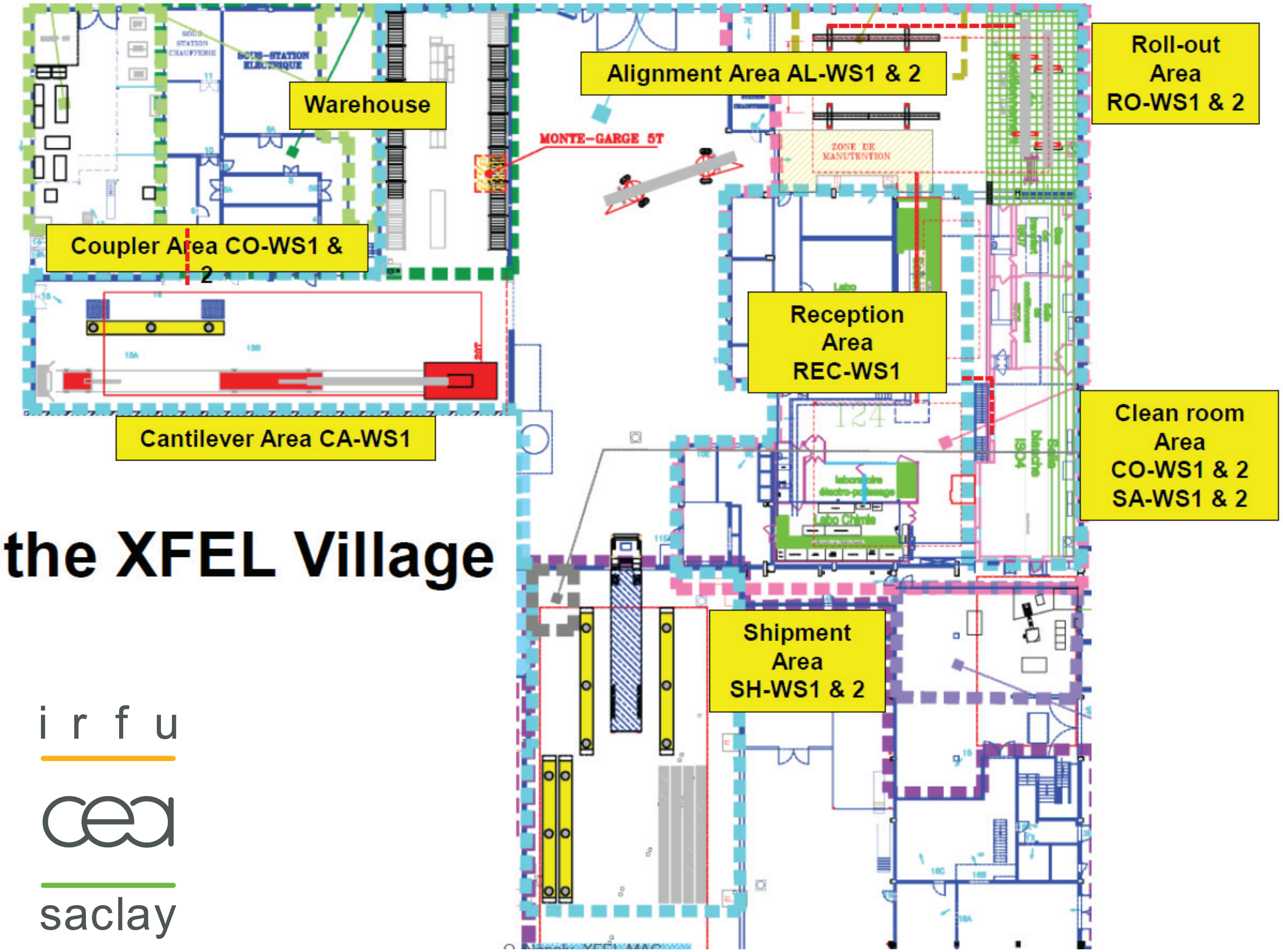

- 1st module July 1st, 2014 – last module August 1st, 2016

The First and the Last Module

- In total 96 modules in 103 working weeks
- The initially projected rate was 1 acc. module per week.
- Variation in coupler availability was compensated by additional efforts at CEA / Irfu wrt. assembly rate.
- Gained experience with module testing was used to shorten test duration of module 40+ .

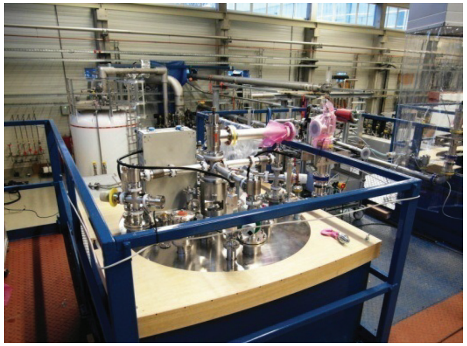


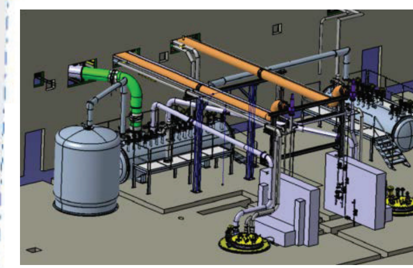
The XFEL Village at IRFU / CEA Saclay



the XFEL Village

AMTF Test Stand Infrastructure at DESY



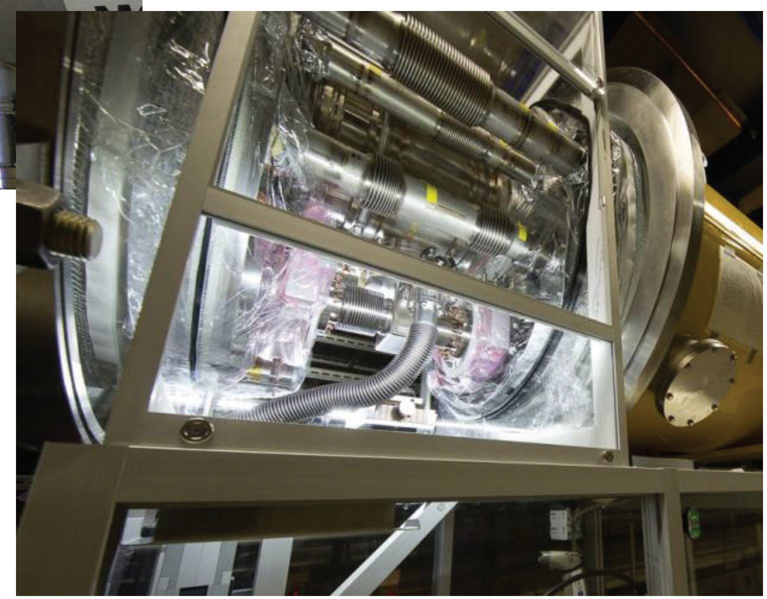


Reference

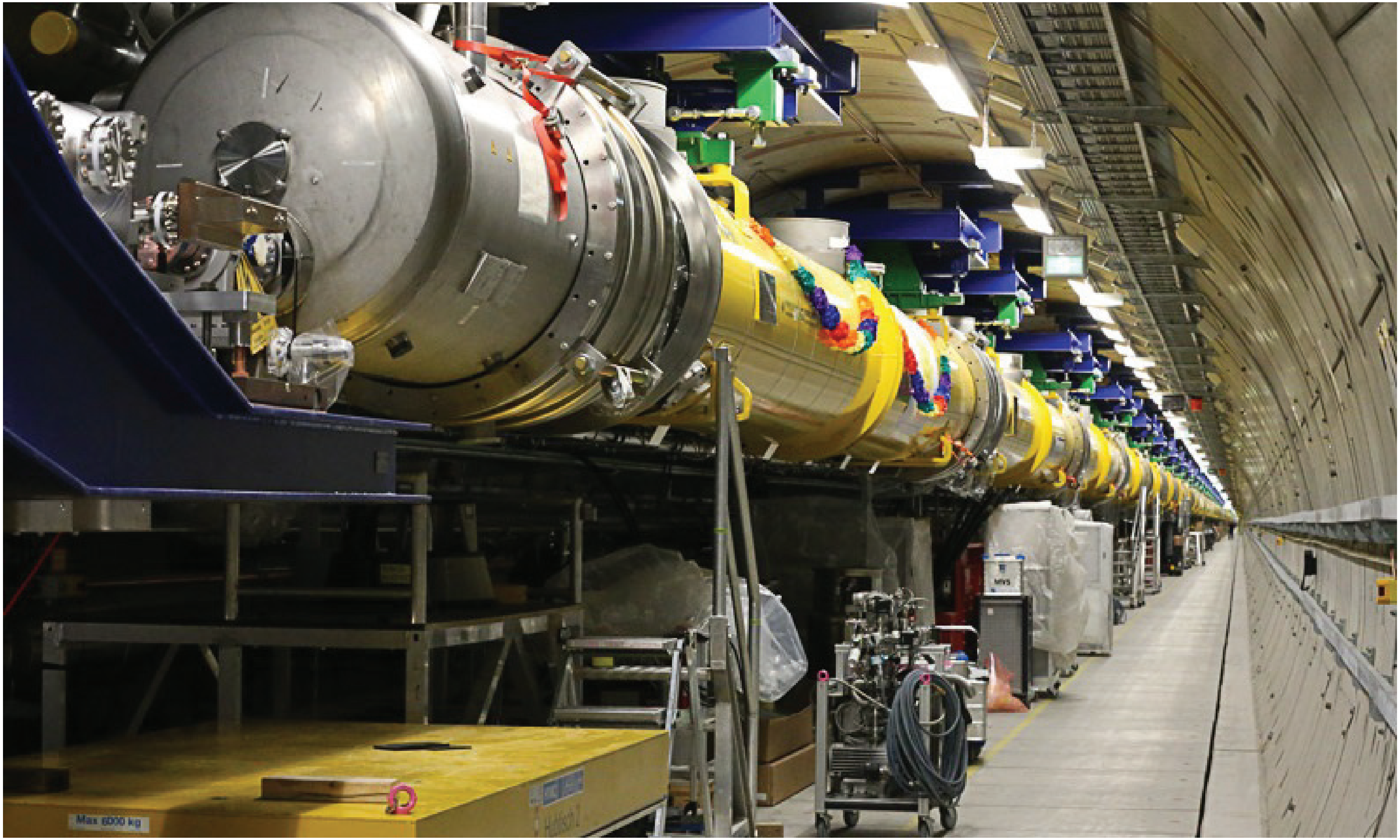
Contributions to the European XFEL Modules

BINP Novosibirsk, Russia	• cold vacuum bellows • coupler vacuum line
CEA Saclay / Irfu, France	• cavity string and module assembly • cold beam position monitors • magnetic shields, superinsulation blankets
CIEMAT, Spain	• Superconducting magnets
CNRS / LAL Orsay, France	• RF main input coupler incl. RF conditioning
DESY, Germany	• cavities & cryostats • contributions to string & module assembly • coupler interlock • frequency tuner • cold vacuum system • integration of superconducting magnets / current leads • cold beam position monitors
INFN Milano, Italy	• cavities & cryostats • contributions to frequency tuners
Soltan Institute, Poland	• Higher Order Mode coupler & absorber

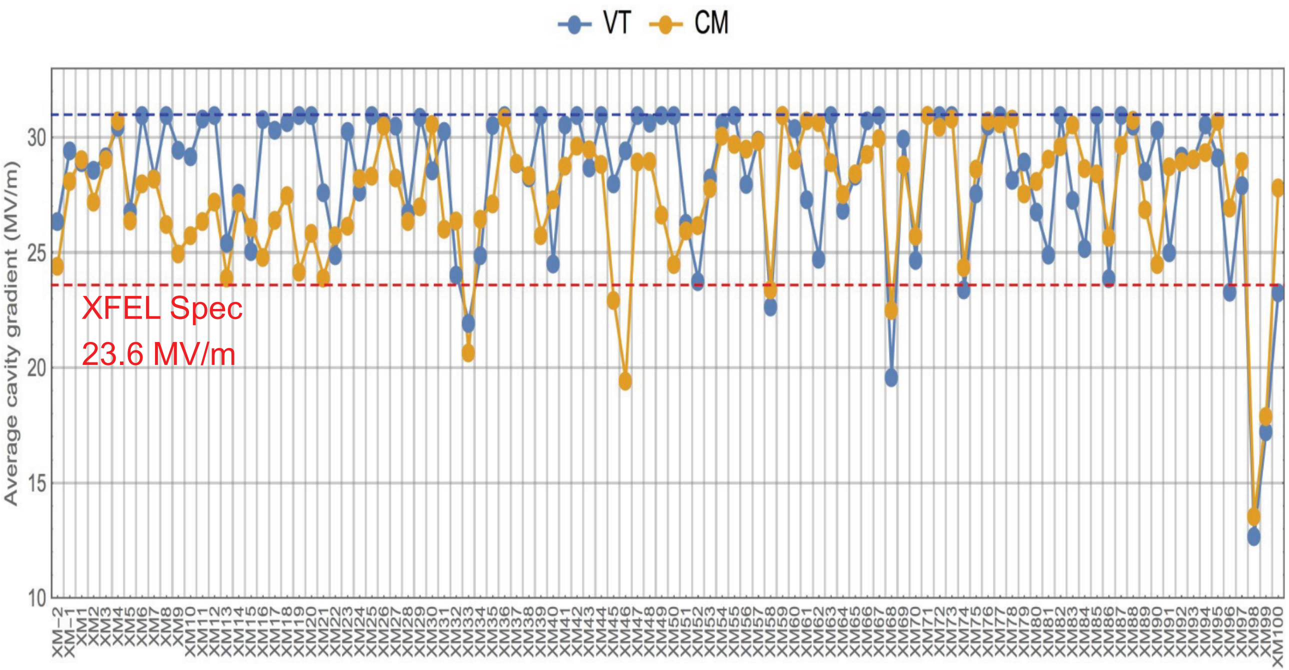
The last Process Line Welding on Sep 9, 2016



The End of Main Linac Section L3



XFEL Module Performance



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

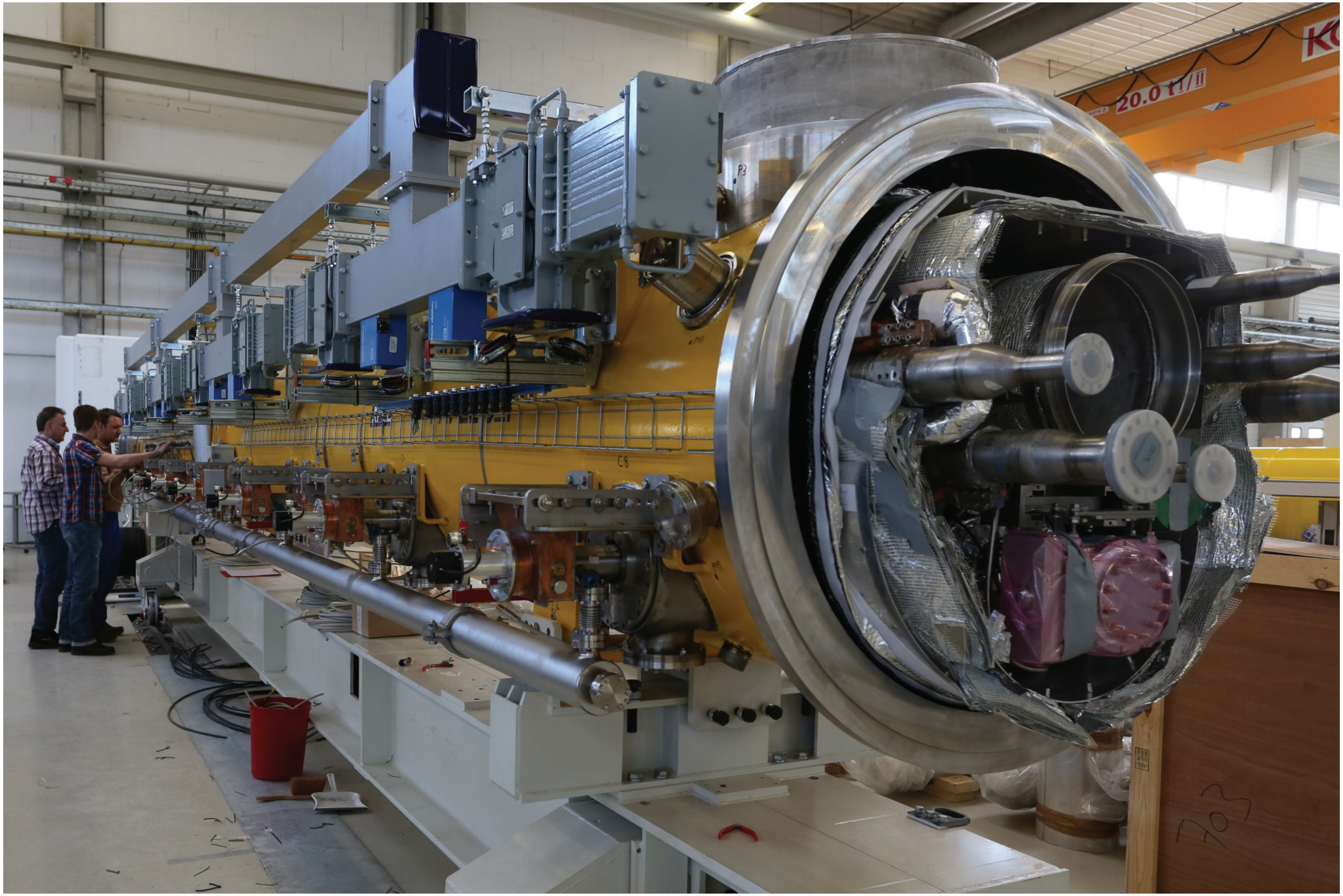
- Module performance well above specs. and visible improvement with time
- Tunnel installation used sorting of modules based on AMTF performance
- XM98 as scavenger module

<u>Remark</u>:

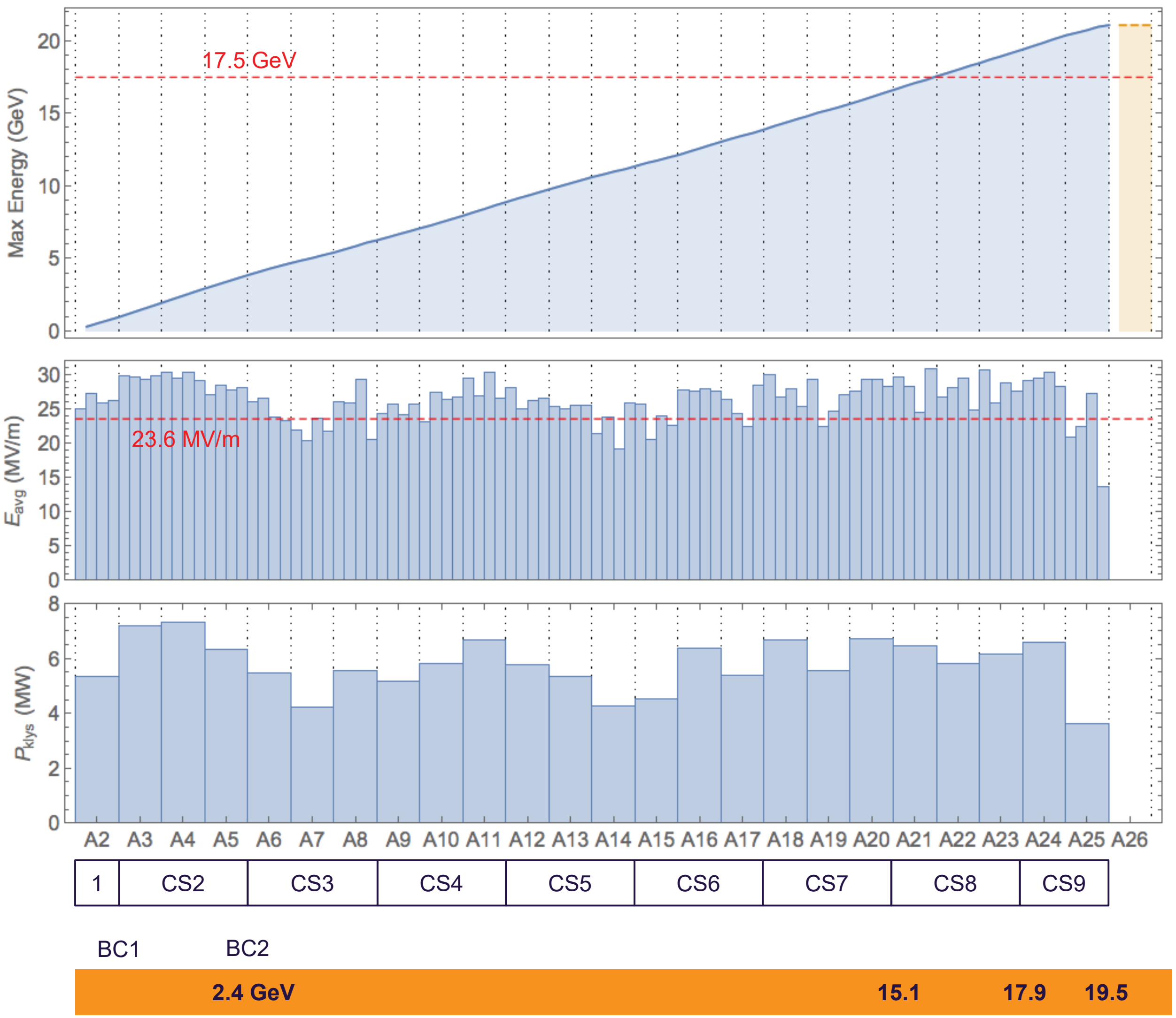
Clipping at 31 MV/m is done due to max. available RF power; limit given by waveguide distribution.

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

Waveguide Tailoring was done for all Modules



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

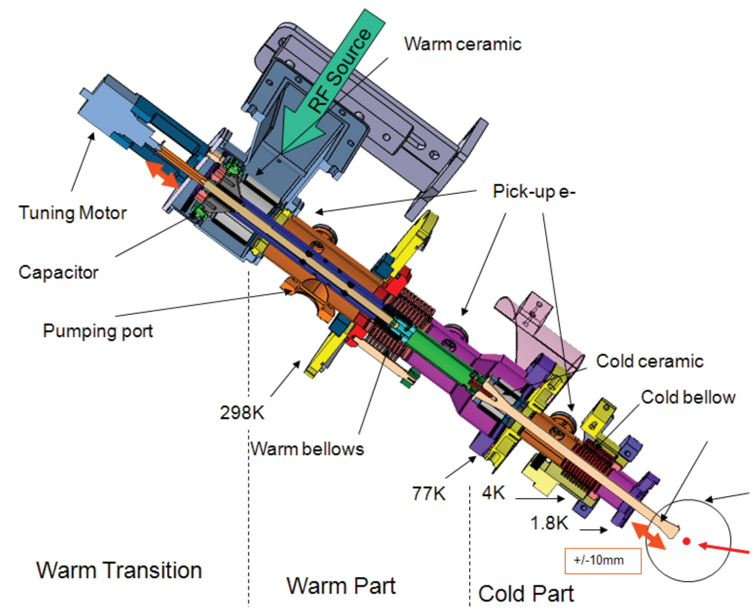
increased max. energy assures higher availability

Accelerator Modules at AMTF & WATF

- During the 2nd production year AMTF module testing was performed without any delay.
- During the end of production the major non-conformity was overheating at the 70k coupler window; all respective warm coupler parts were exchanged.
- Waveguide tailoring was done for all modules.
- Successfully repaired modules were retested at AMTF when needed.
- Not installed are
  - XM8 (leaky cryogenic line)
  - XM46 & XM50 (inacceptable cav.performance)
  - XM99 (leaky beam line)
  - XM100 spare module & replaced by XM-2

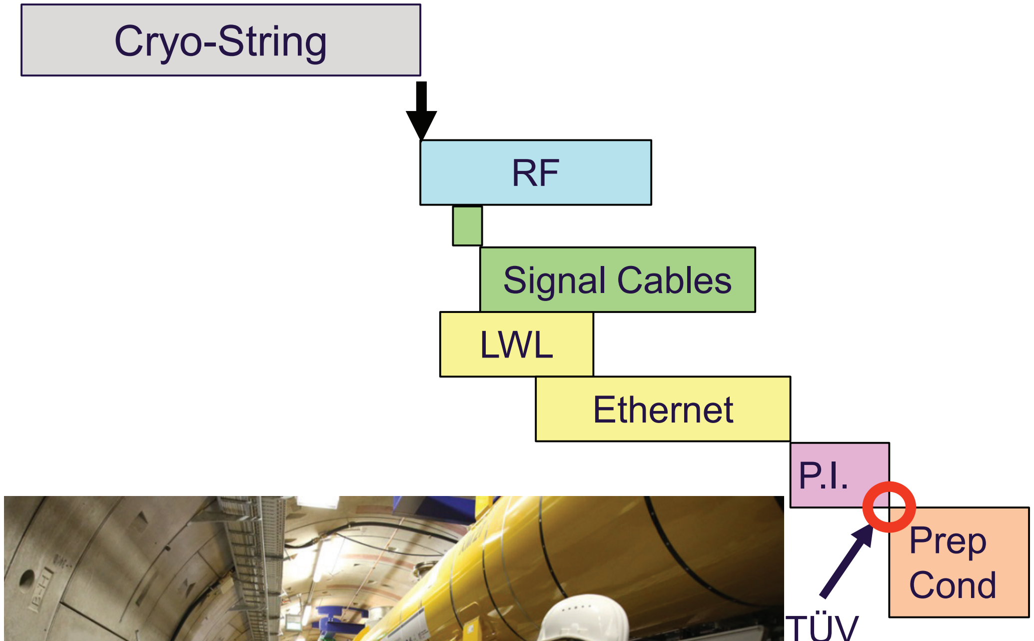
Couplers were the by far the most challenging single items in the supply chain of the modules

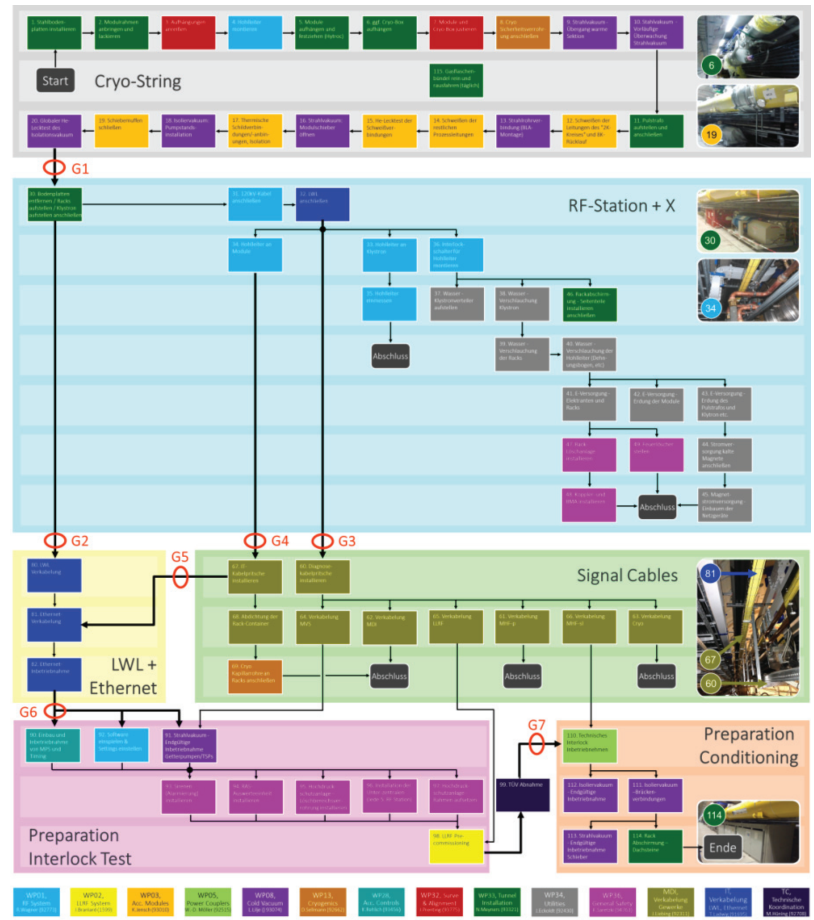
- A total of 800 RF power couplers was produced at **three different vendors**
- The largest fraction was procured by LAL Orsay and produced by Thales / RI
- Approx. 20% were procured from CPI
- RF conditioning of all couplers was done at LAL Orsay at a rate of 10+ couplers/week
- **Coupler delivery rate did not match the module assembly rate**



Tunnel Installation Process

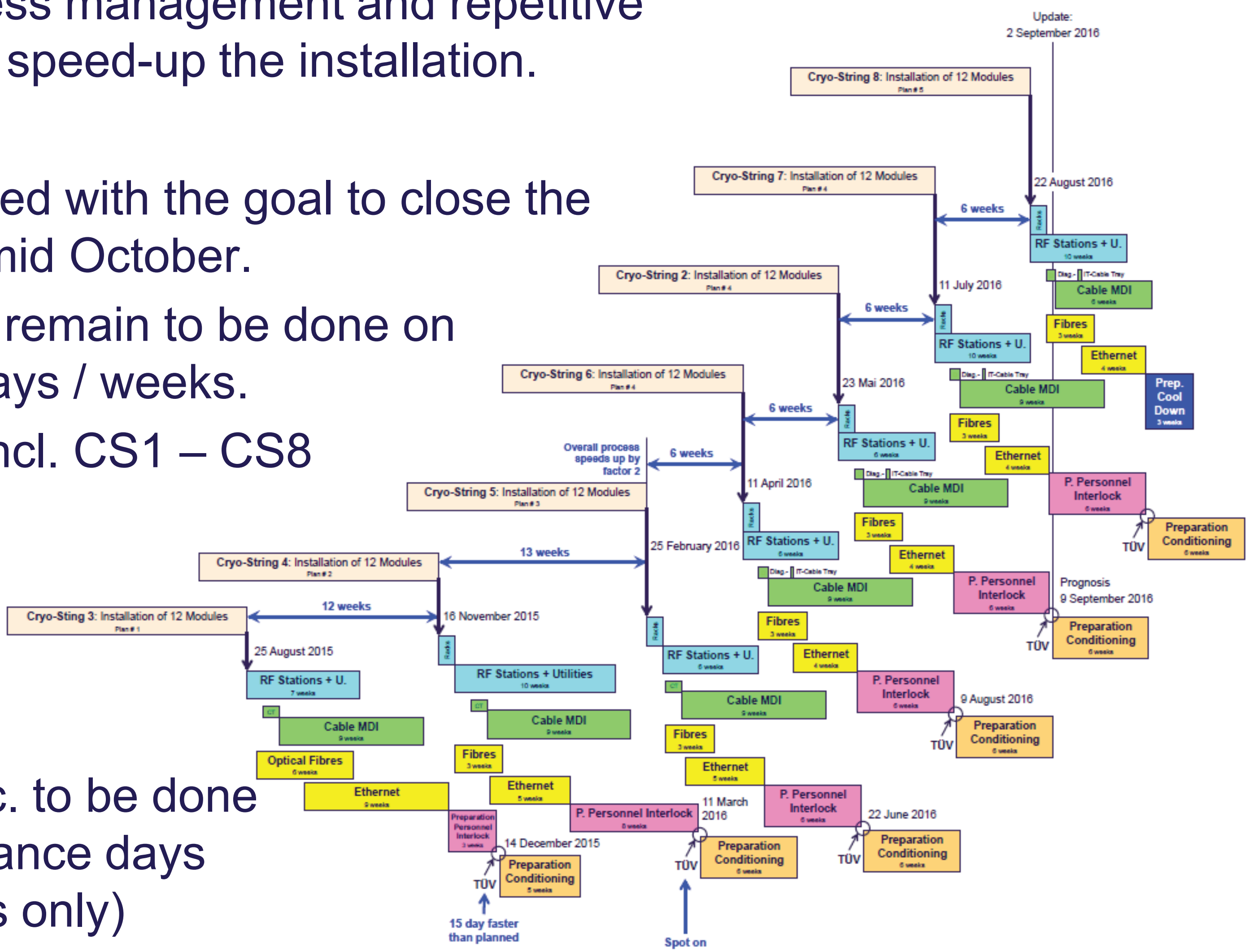
- Optimized global process steps and sequence & daily improvements



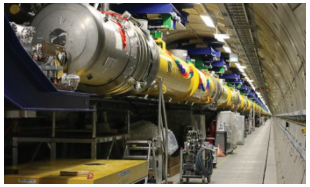


Process Management XTL Installation

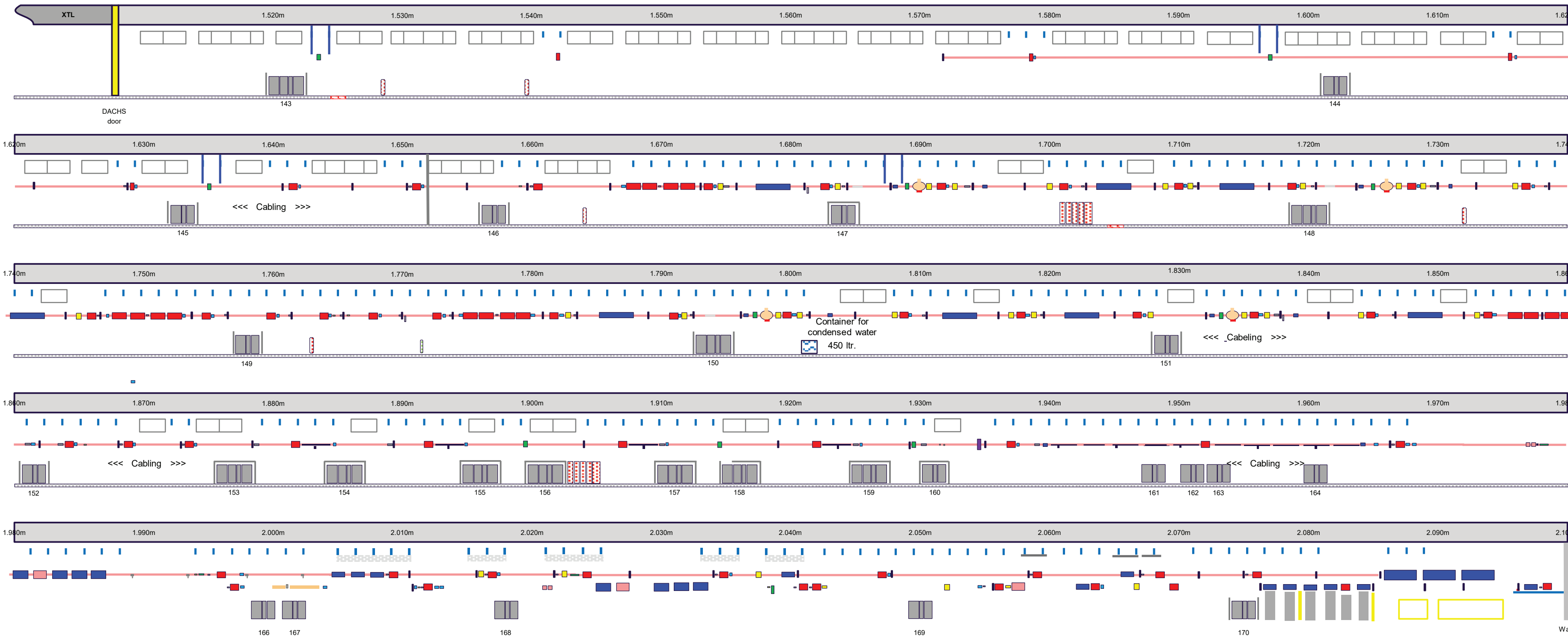
- Improved process management and repetitive tasks helped to speed-up the installation.
- All groups worked with the goal to close the tunnel around mid October.
- Some work will remain to be done on maintenance days / weeks.
- Full operation incl. CS1 – CS8
- CS9 cabling etc. to be done during maintenance days (two RF stations only)

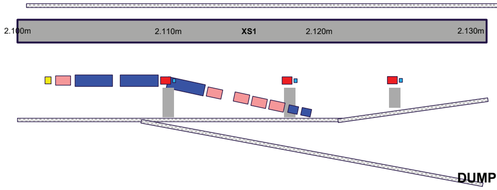


Post Linac Beam Lines upstream of XS1



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



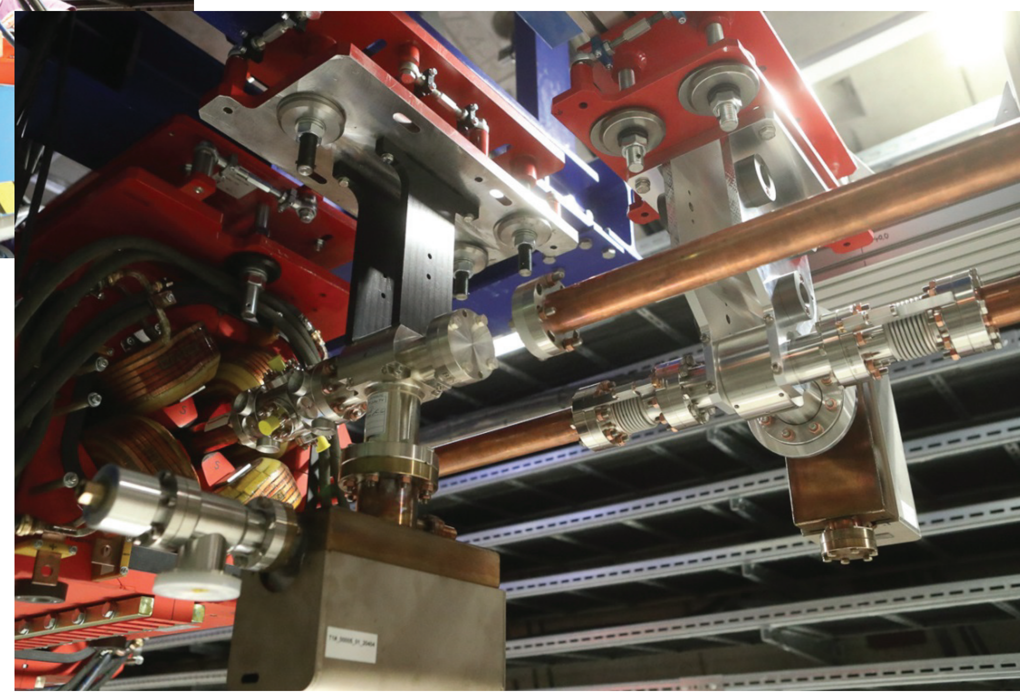


- 200 m beam distribution
- 100 m XS1 dump line

The Temporary Beamline uses Existing Module Suspensions (wherever possible)

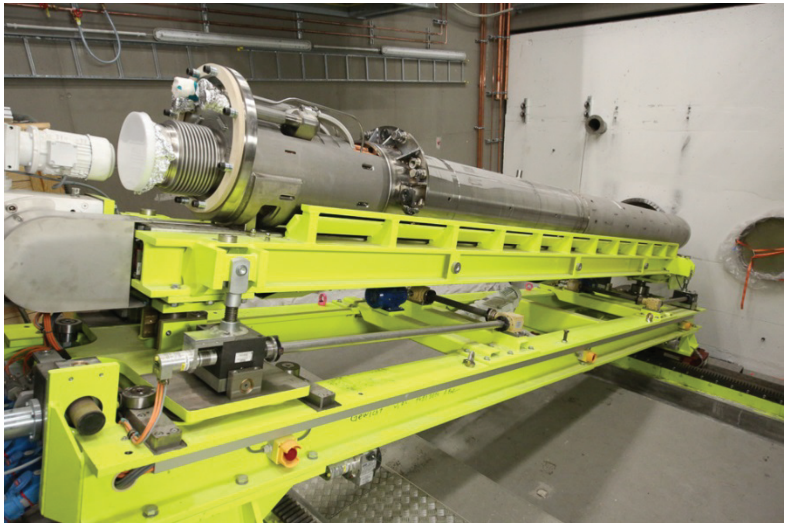
Beamline Installation close to XTL Tunnel End

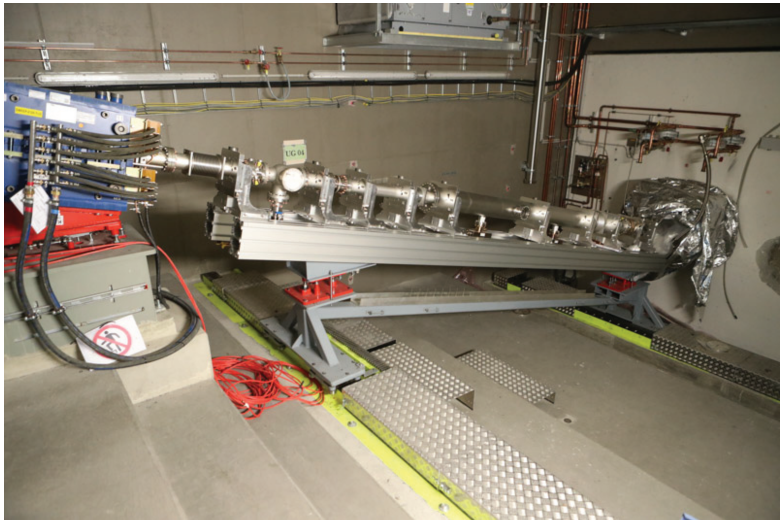
- Installation work mostly finished by end of 9/2016
- The last few T2 beam line meters are done now



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

Warm Beam Line Sections
Transport Line to XS1 Beam Dump



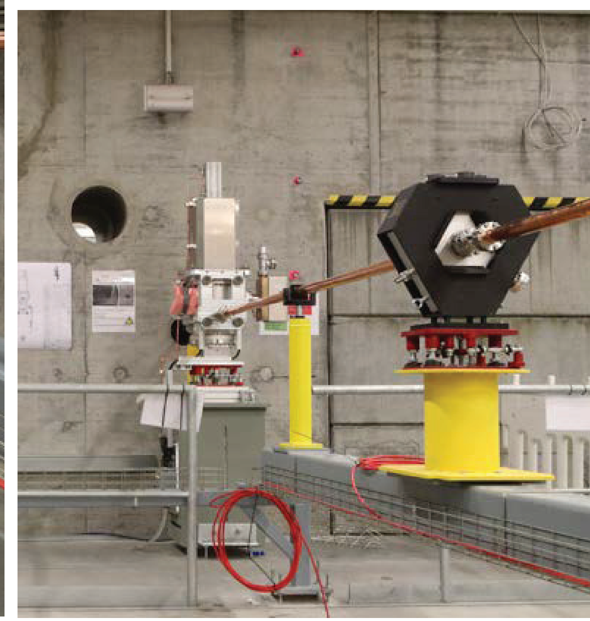


- All beam dumps available and XS1 dump installed
- Special vehicle to exchange activated dumps

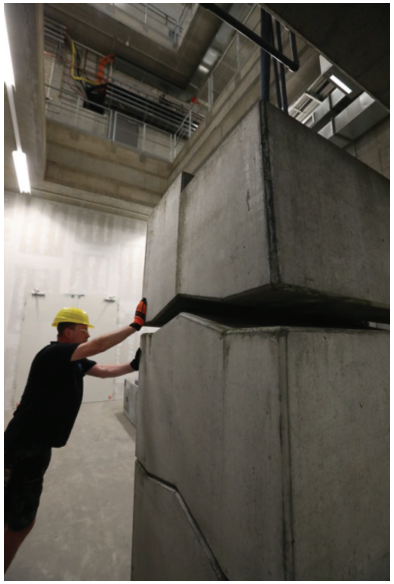
European XFEL

Installation on Top of XS1 Dump Cave

- XS1 installation includes transport towards XTDs
- The safety magnet is installed at the upstream end



Shielding and Personnel Interlock

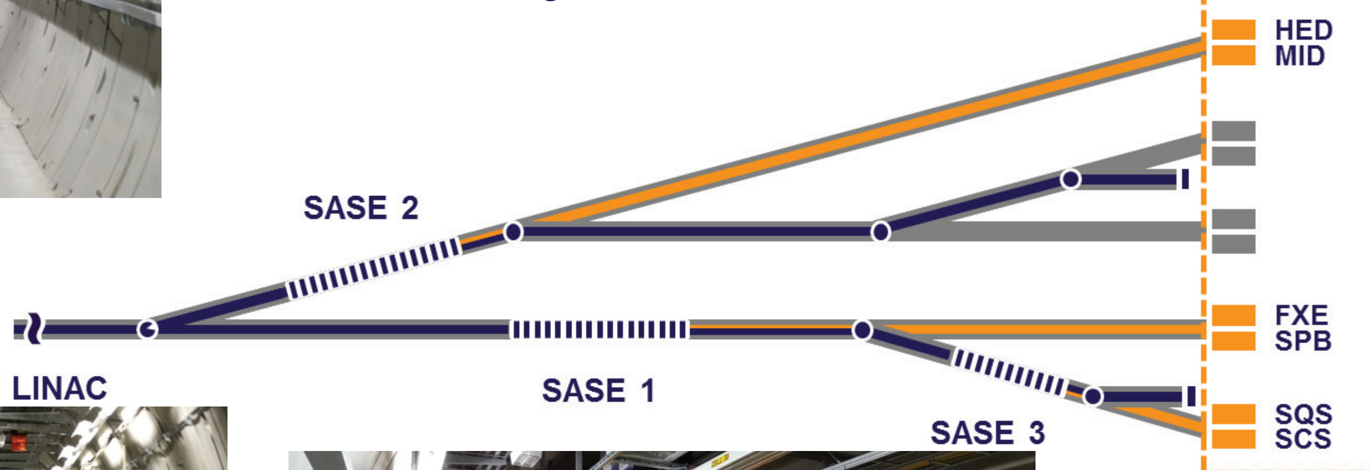


- Shielding and personnel interlock done recently.
- Final internal check of the personnel interlock done Nov. 15/16.

DESY HELMHOLTZ ASSOCIATION

Installation Activities
SASE Undulator Sections

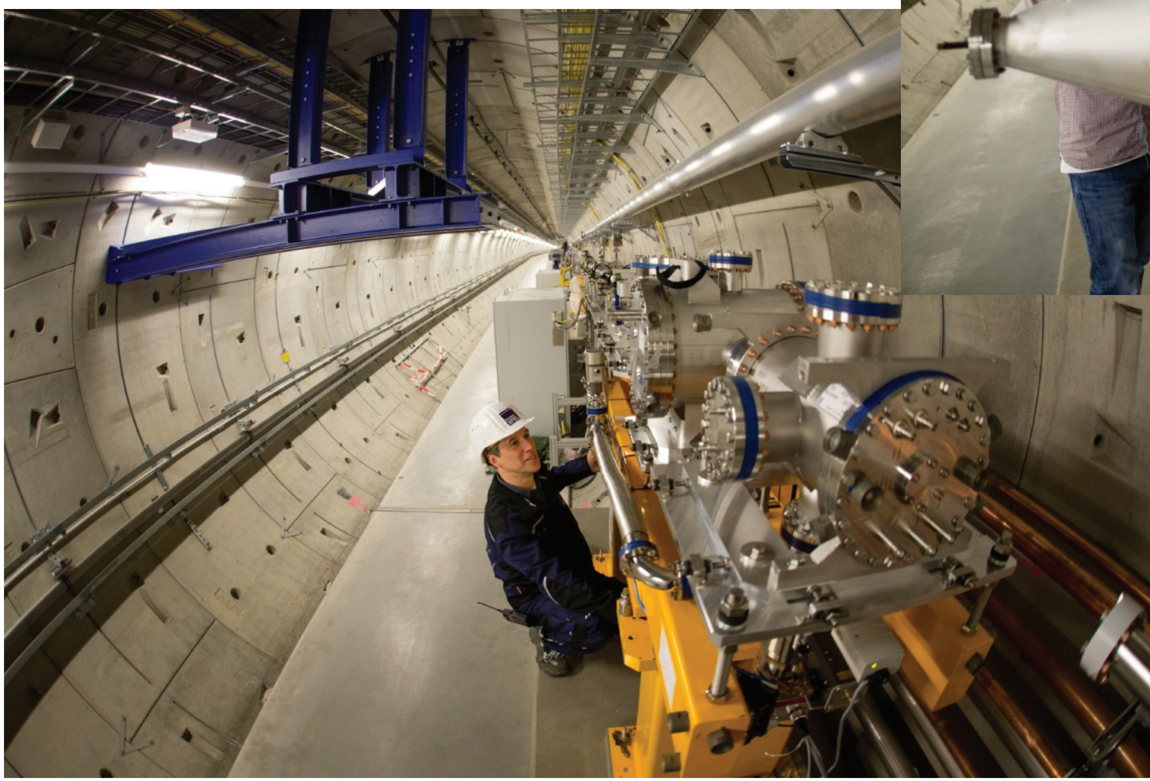
- BINP and DESY teams have finished most of the mechanical vacuum work in the northern branch.
- The southern branch follows immediately.
- With XTL closing all work force available for XTDs.



courtesy of XFEL.EU

SASE Undulator Sections
with special air conditioning hutch

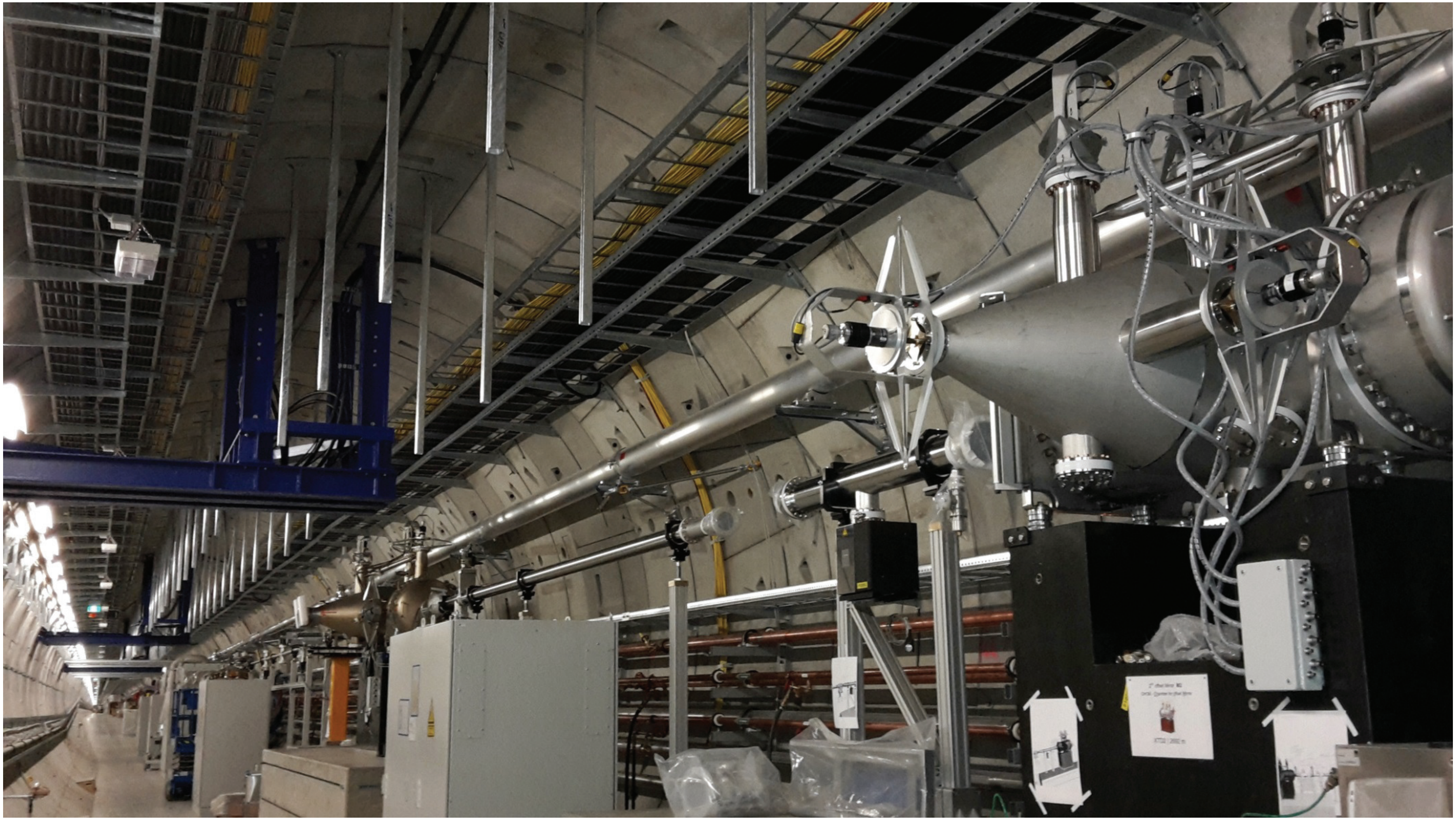
Optical Elements and Photon Diagnostics
SASE1 Beamline



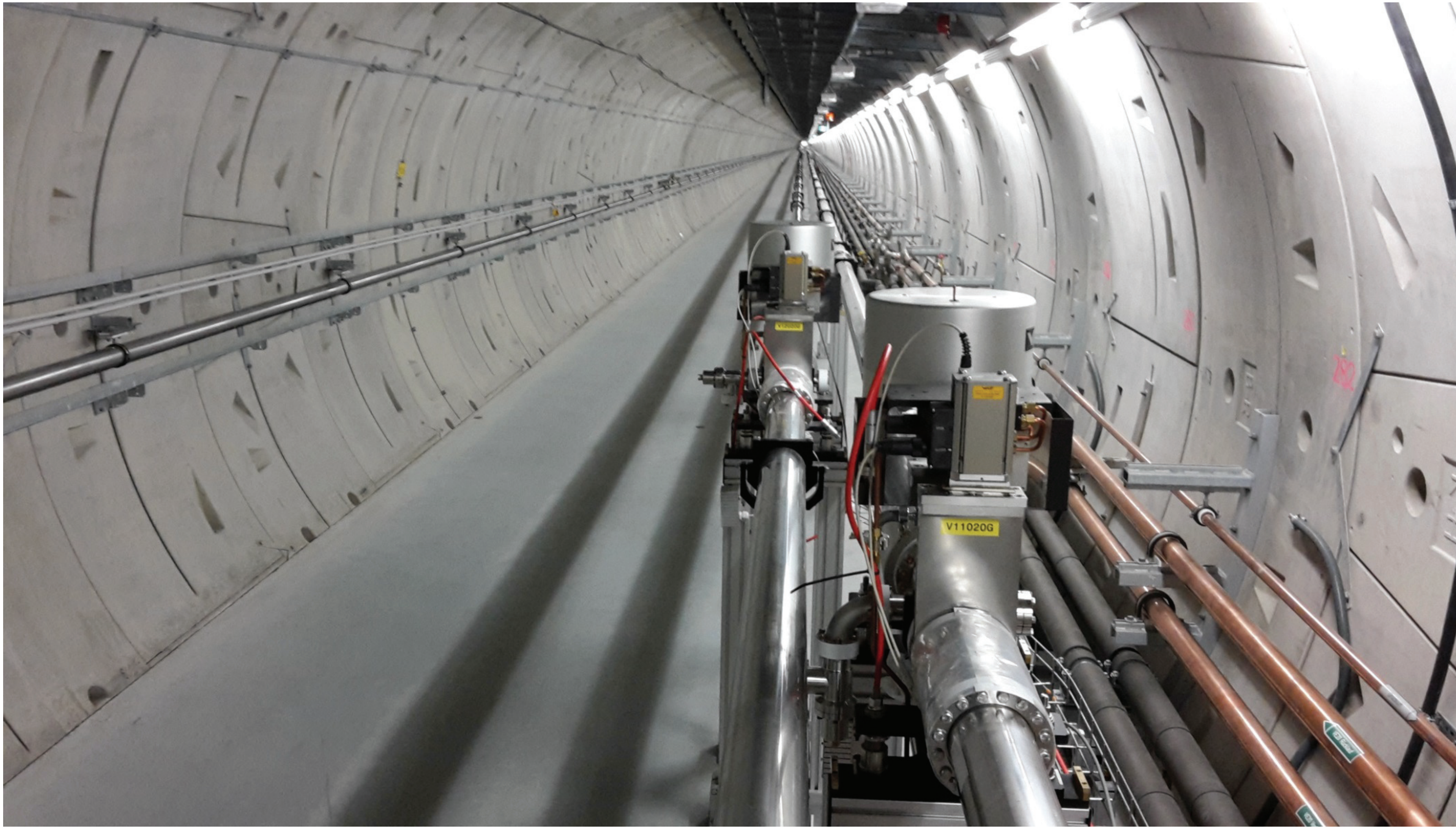
courtesy of XFEL.EU

Installation Activities

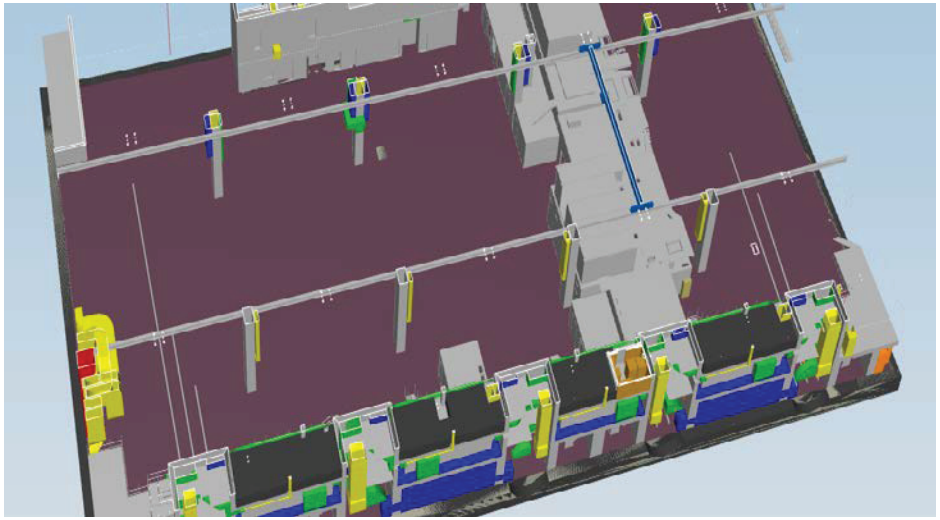
Photon Beam Lines

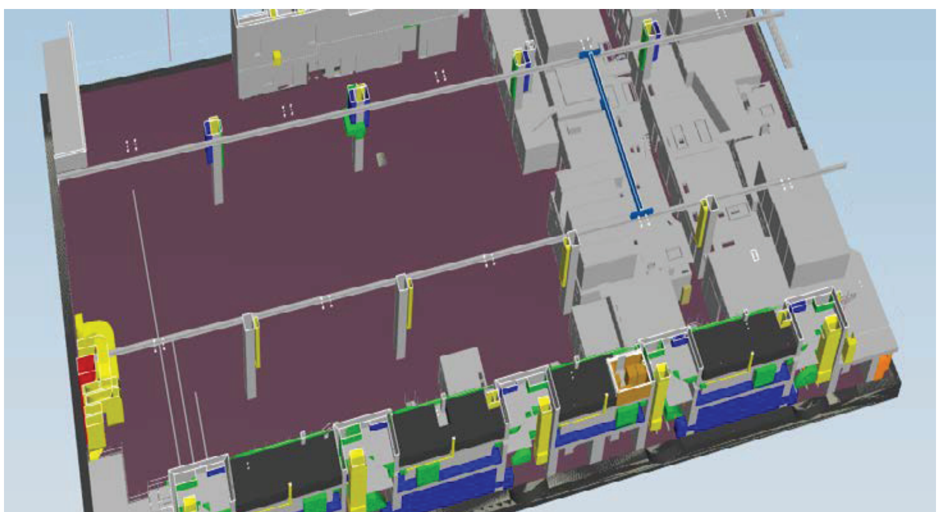


Installation Activities
Photon Beam Lines



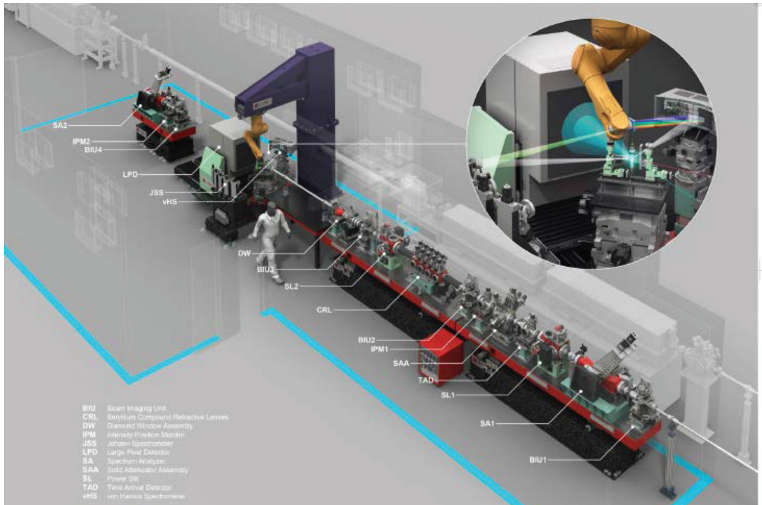
SASE1 and SASE3 Hutches Installation





SASE1 Stations FXE and SPB/SFX

just prior to instrument installation



Courtesy by European XFEL/Rey.Hori

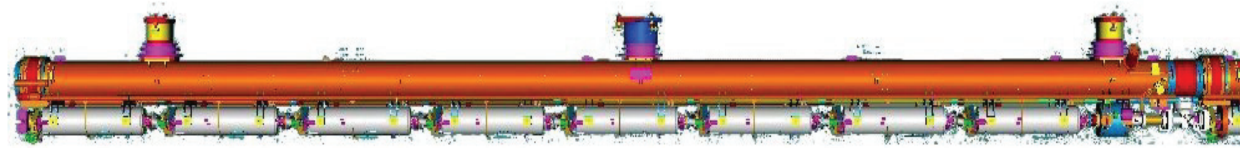
Summary and Outlook

- The fascinating time of accelerator module production / testing / installation comes to an end
- **Tunnel closure is now scheduled for beginning of 12/2016**
- Technical commissioning continues after first cool-down
- Based on injector experience and accelerator module performance we are looking forward to reaching all design parameters
- **The milestone ‚first lasing possible‘ is scheduled 6 months after ‚tunnel closure'**
- User operation will start in 2017
- Full performance is expected approx. 1.5 years after first lasing

more than 1000 participants at the 2016 users' meeting

Contributors to the XFEL Accelerator

100 accelerator modules



800 accelerating cavities
1.3 GHz / 23.6 MV/m