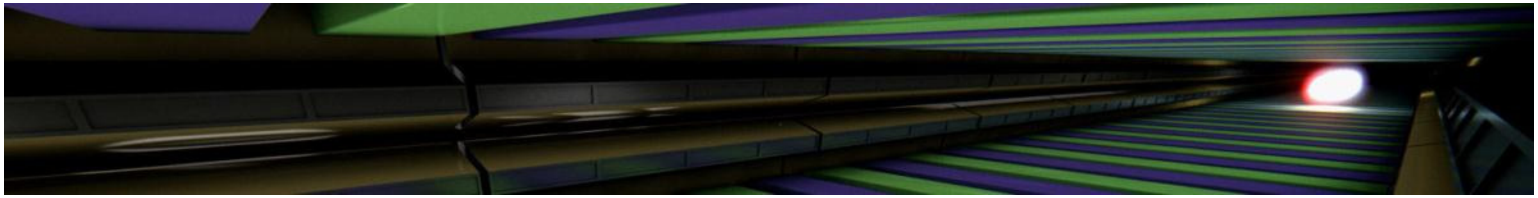


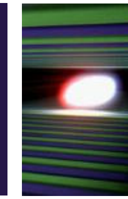
STATUS OF THE EUROPEAN XFEL

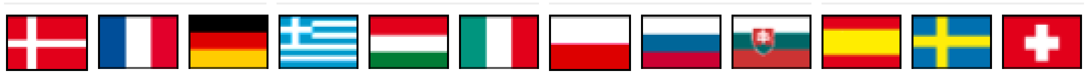
CONSTRUCTING THE 17.5 GeV SUPERCONDUCTING LINEAR ACCELERATOR

Markus Hüning, DESY

for the European XFEL Accelerator Consortium

- Up to 17.5 GeV SC Linac, 27000 pulses per second
- Three moveable gap undulators for hard and soft X-rays
- Initially 6 equipped experiments





- Built by 12 European Nations at DESY, Hamburg
- Budget 1.150 MEuro incl. preparation and commissioning

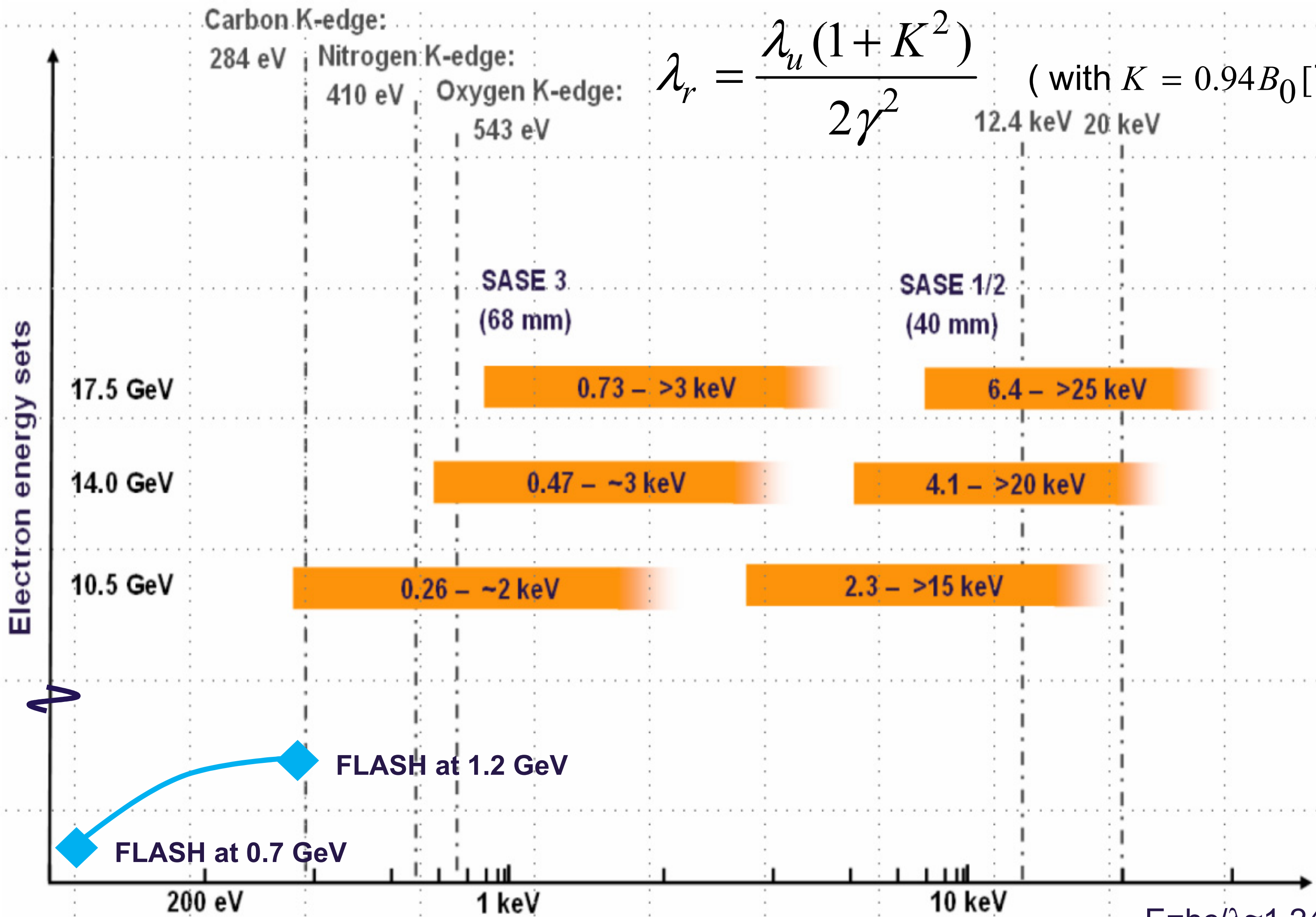
Parameters

Quantity	Value
electron energy	10.5/14/17.5 GeV
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 μs
bunch repetition frequency within pulse	4.5 MHz
bunch charge	0.02 – 1 nC
electron bunch length after compression (FWHM)	2 – 180 fs
Slice emittance	0.4 - 1.0 mm mrad
beam power	500 kW
# of modules (containing eight 9-cell superconducting 1.3 GHz cavities)	101
accelerating gradient for 17.5 GeV	23.6 MV/m
# of 10 MW multi-beam klystrons	27
average klystron power (for 0.03 mA beam current at 17.5 GeV)	5.2 MW
photon wavelength	0.05 – 4 nm

Photon Energy Reach

$$\lambda_r = \frac{\lambda_u(1+K^2)}{2\gamma^2}$$

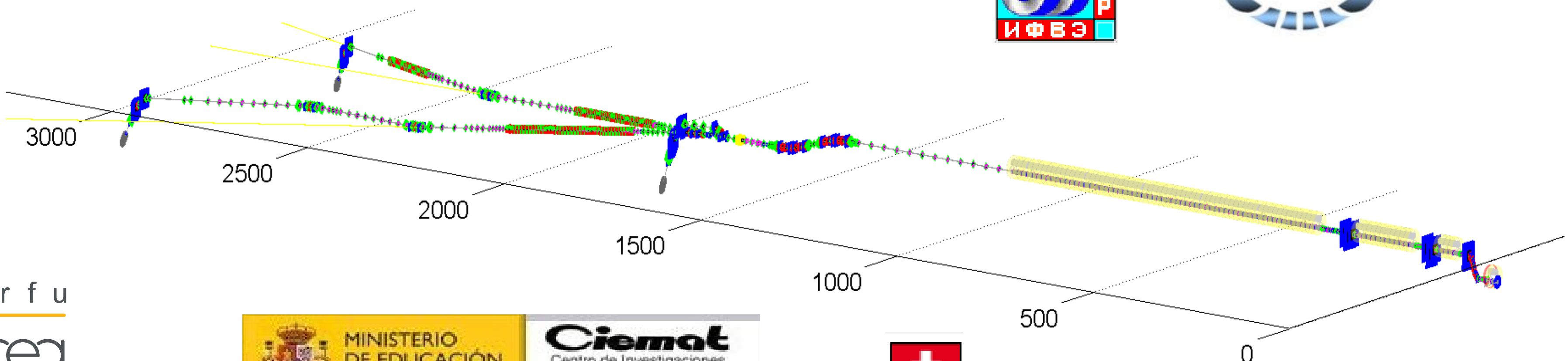
(with $K = 0.94 B_0[\mathrm{T}]\lambda_u[\mathrm{cm}]$)



E=hc/λ≈1.24e-6/λ

Accelerator Consortium: 16 Institutes that construct the Accelerator 'In-Kind'

DESY
HELMHOLTZ ASSOCIATION
Stockholm University
UPPSALA UNIVERSITET
IHEP ИФВЭ

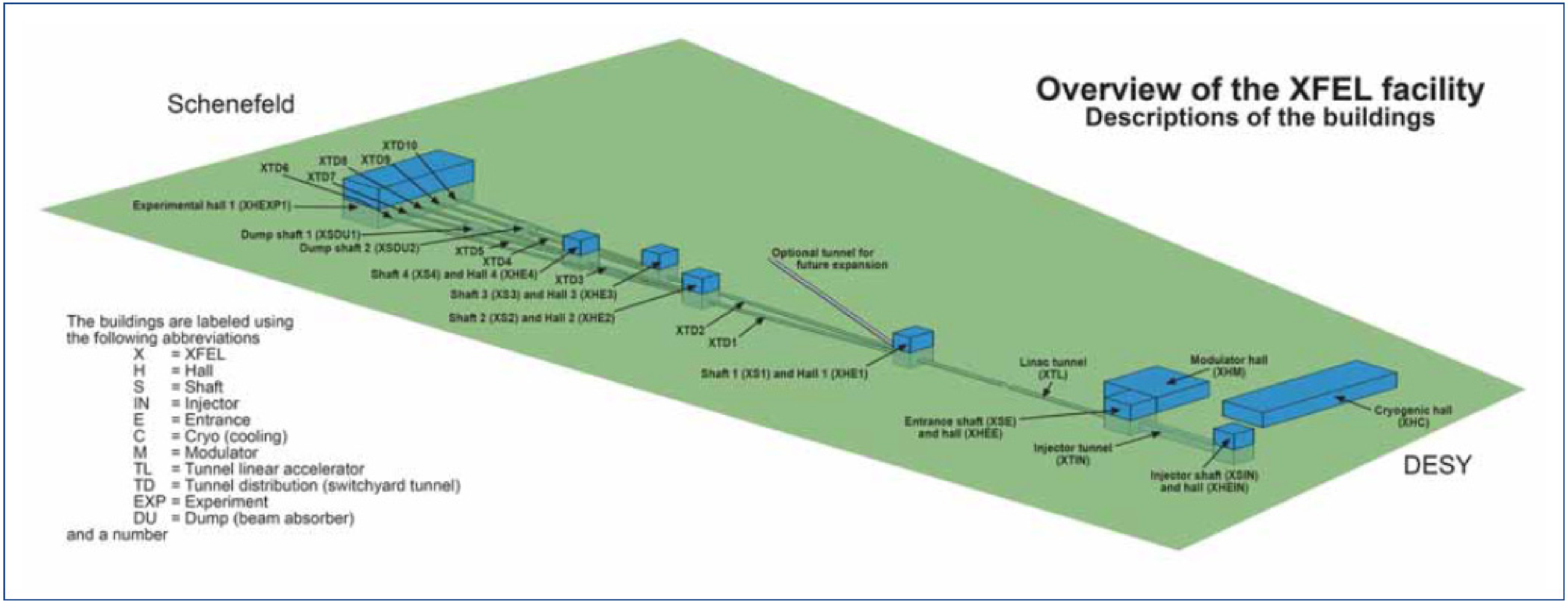


irfu
cea
saclay
cnrs
In2p3
MINISTERIO DE EDUCACIÓN Y CIENCIA
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
UNIVERSIDAD POLITECNICA MADRID
PAUL SCHERRER INSTITUT
PSI
INFN
Istituto Nazionale di Fisica Nucleare
UNIVERSITAS STUDIORUM MEDIOLANENSIS
ifj
Wrocław University of Technology
NARODOWE CENTRUM BADAŃ JĄDROWYCH
Świerk

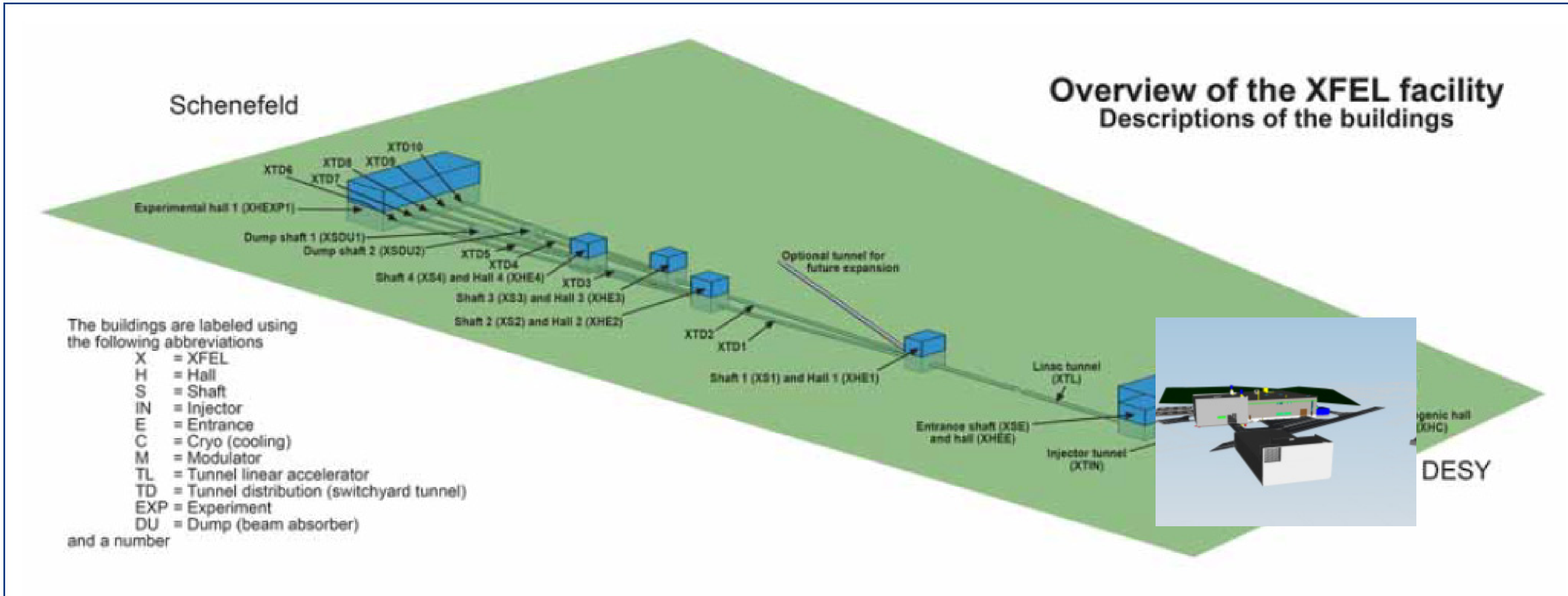
Civil Construction Status

- Three construction sites
- 5.8 km tunnels
- 12000 m^2 surface are buildings
- 150000 m^3 of underground building volume

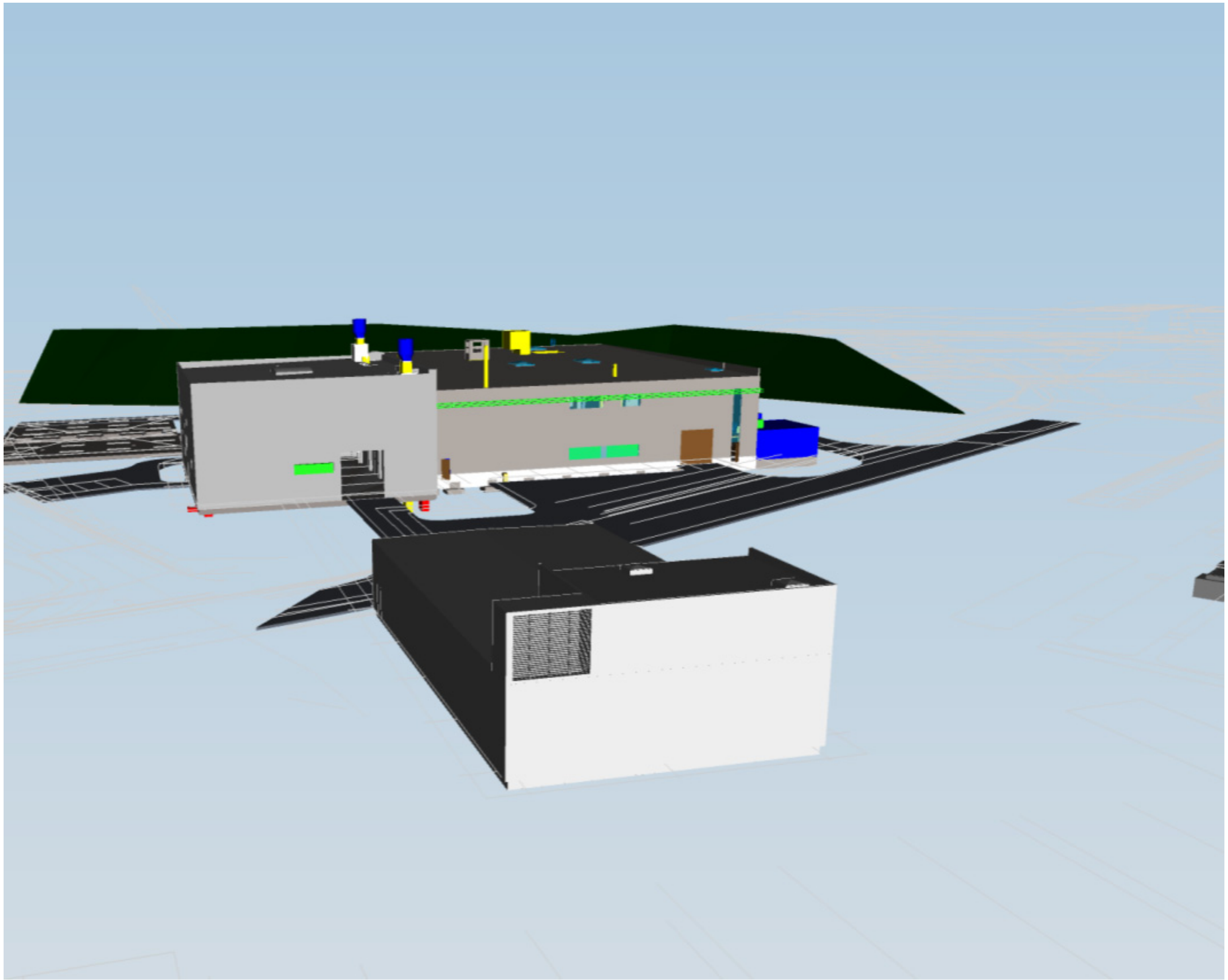
The Bahrenfeld Construction Site



The Bahrenfeld Construction Site

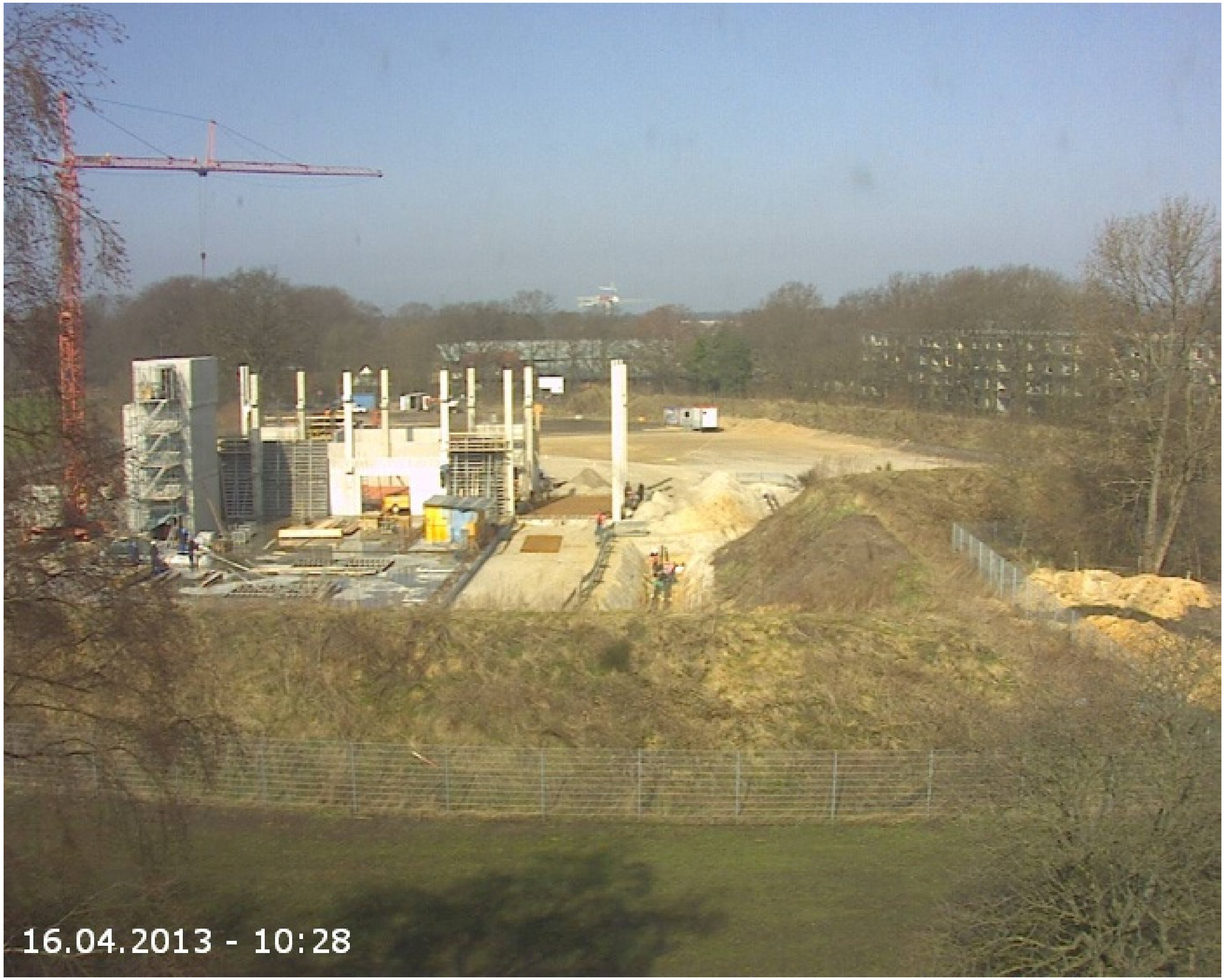


The Bahrenfeld Construction Site



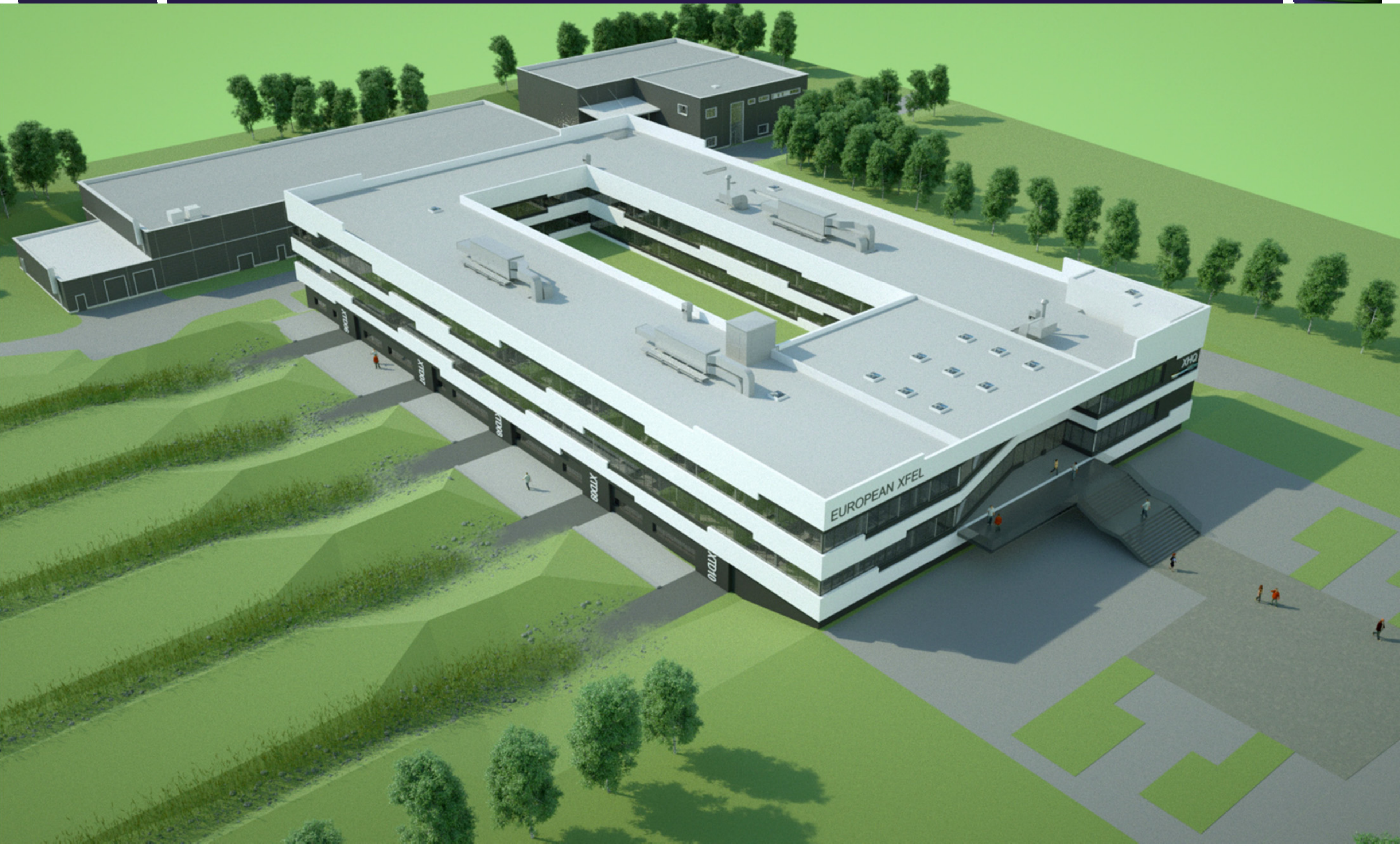
The Bahrenfeld Construction Site

XHE1 (Osdorfer Born)



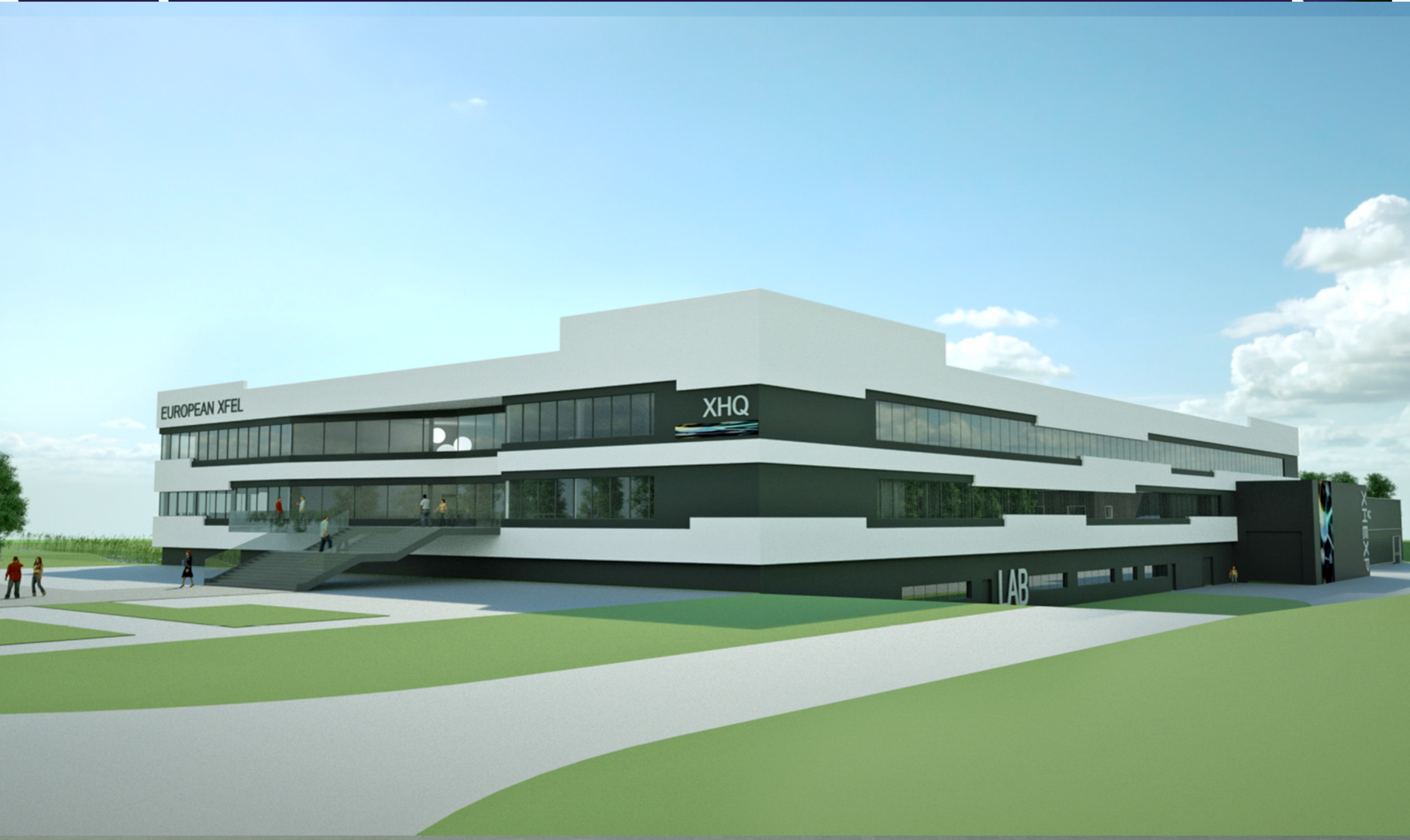
Schenefeld Site

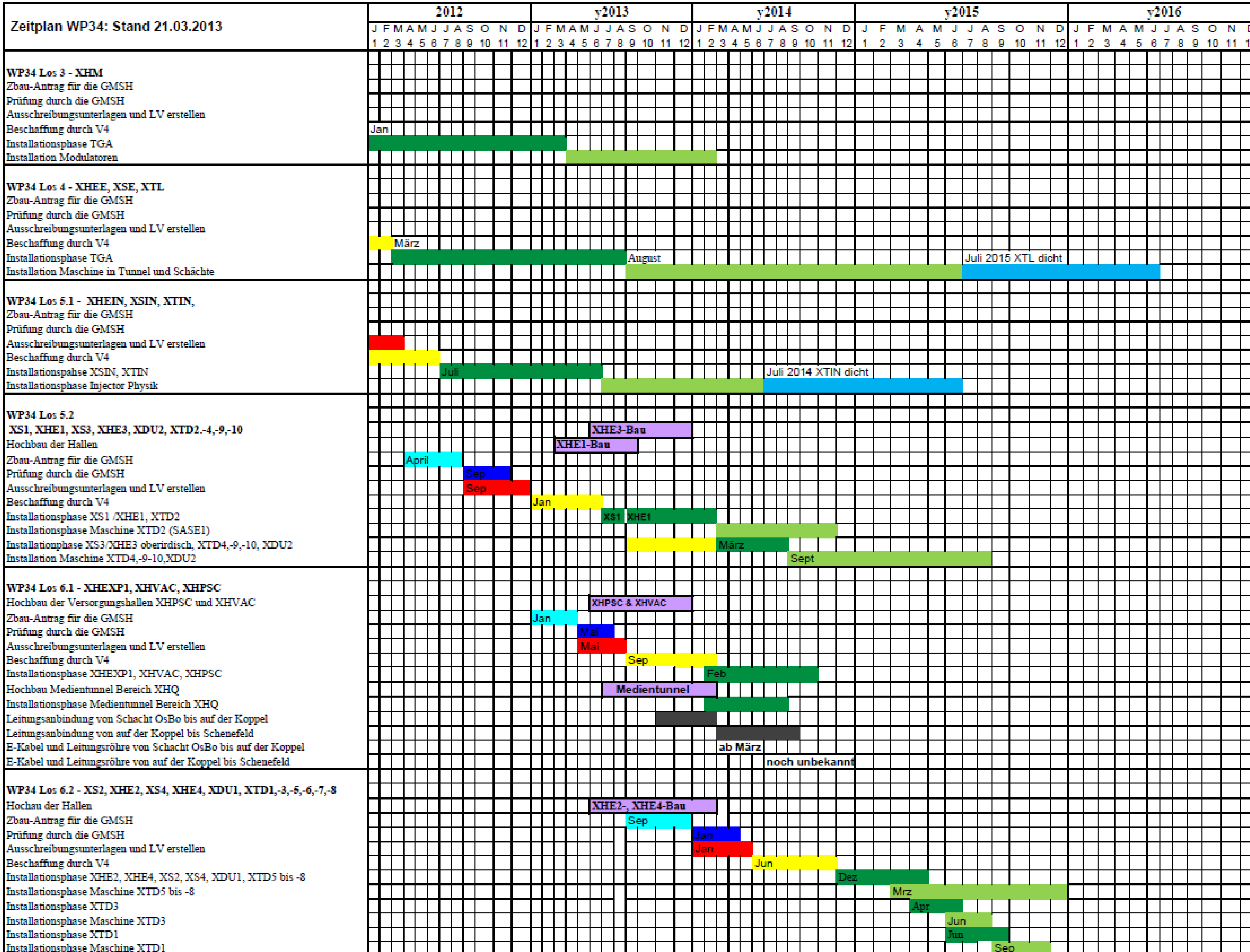
Architect’s concepts for the XHQ building

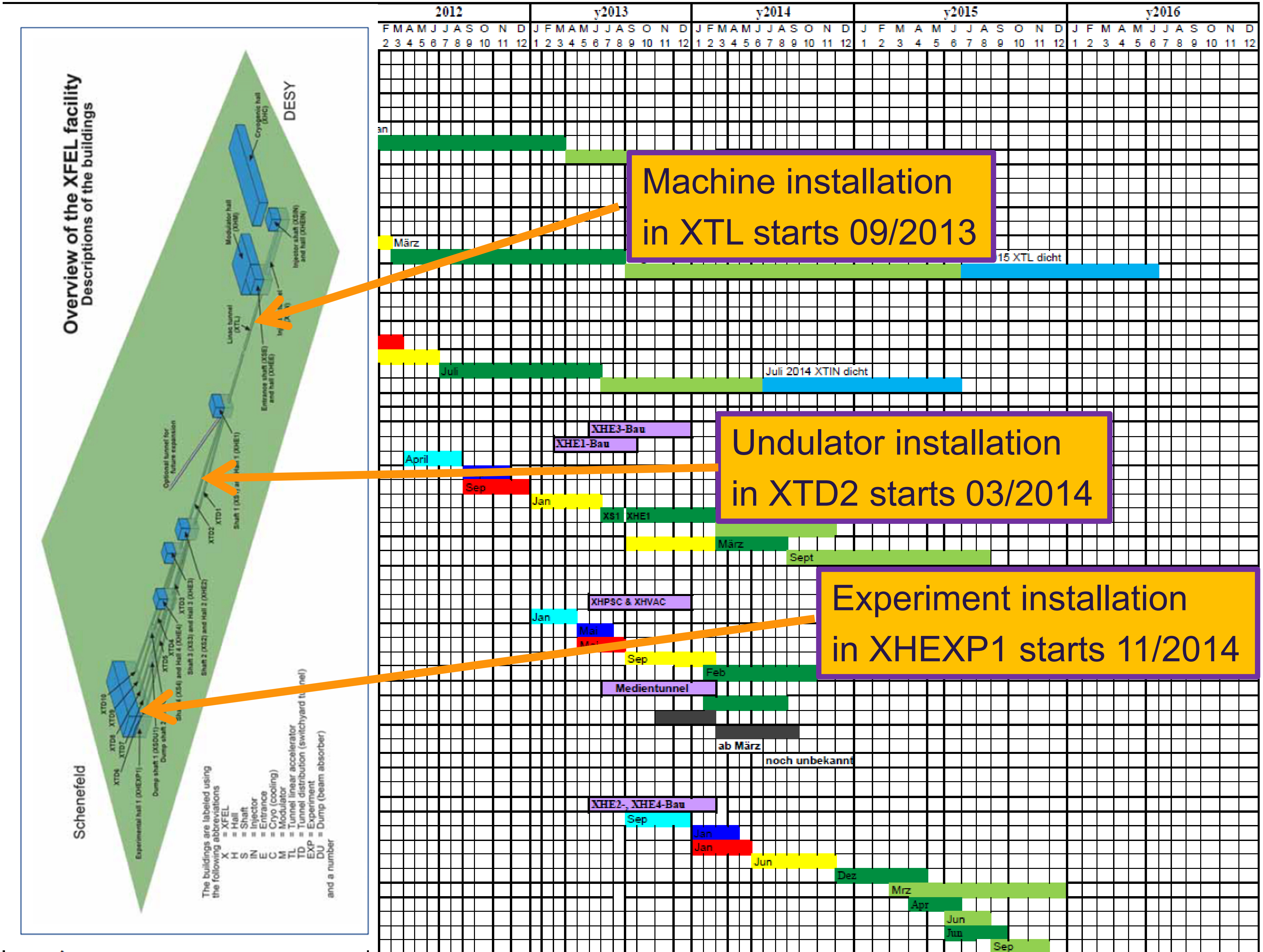


Architect's concepts for the XHQ building

Architect's concepts for the XHQ building

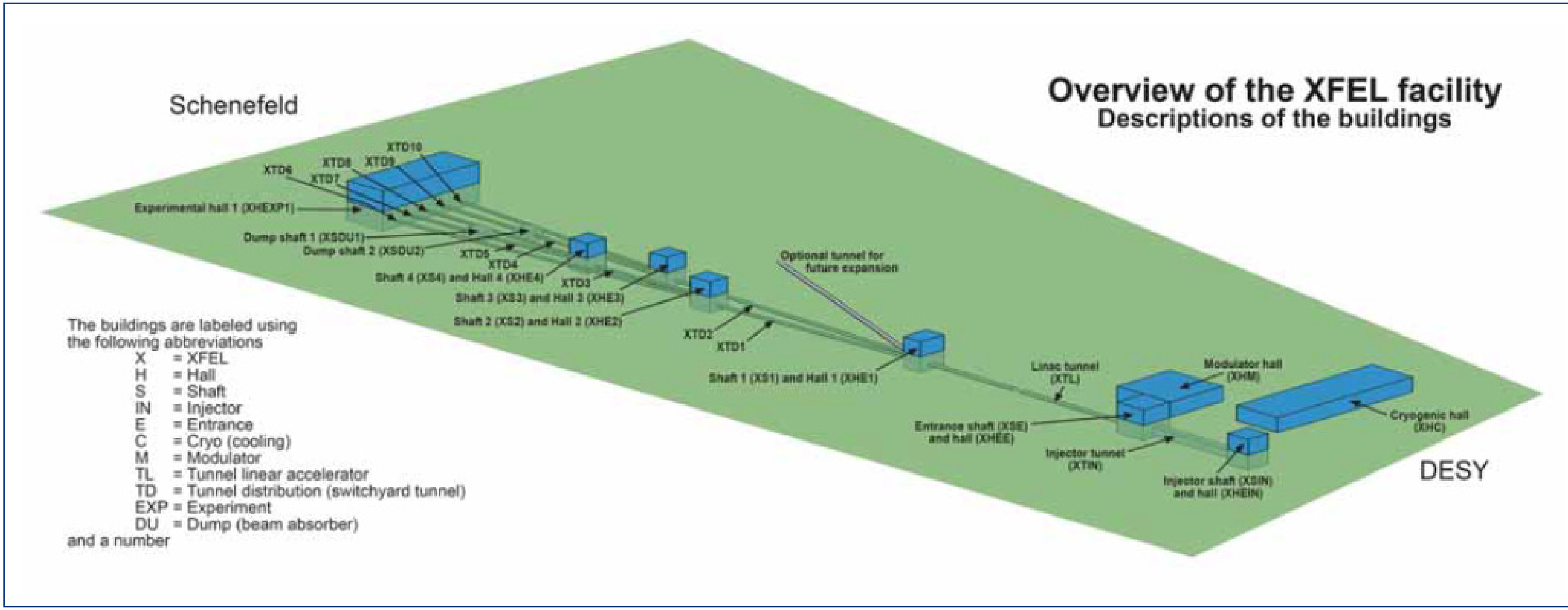



Zeitplan WP34: Stand 21.03.2013
2012
y2013
y2014
y2015
y2016
J F M A M J J A S O N D
1 2 3 4 5 6 7 8 9 10 11 12
WP34 Los 3 - XHM
Zbau-Antrag für die GMSH
Prüfung durch die GMSH
Ausschreibungsunterlagen und LV erstellen
Beschaffung durch V4
Installationsphase TGA
Installation Modulatoren
Jan
WP34 Los 4 - XHEE, XSE, XTL
Zbau-Antrag für die GMSH
Prüfung durch die GMSH
Ausschreibungsunterlagen und LV erstellen
Beschaffung durch V4
Installationsphase TGA
Installation Maschine in Tunnel und Schächte
März
August
Juli 2015 XTL dicht
WP34 Los 5.1 - XHEIN, XSIN, XTIN,
Zbau-Antrag für die GMSH
Prüfung durch die GMSH
Ausschreibungsunterlagen und LV erstellen
Beschaffung durch V4
Installationspahse XSIN, XTIN
Installationsphase Injector Physik
Juli
Juli 2014 XTIN dicht
WP34 Los 5.2
XS1, XHE1, XS3, XHE3, XDU2, XTD2.-4,-9,-10
Hochbau der Hallen
Zbau-Antrag für die GMSH
Prüfung durch die GMSH
Ausschreibungsunterlagen und LV erstellen
Beschaffung durch V4
Installationsphase XS1 /XHE1, XTD2
Installationsphase Maschine XTD2 (SASE1)
Installationphase XS3/XHE3 oberirdisch, XTD4,-9,-10, XDU2
Installation Maschine XTD4,-9-10,XDU2
XHE3-Bau
XHE1-Bau
April
Sep
Sep
Jan
XS1
XHE1
März
Sept
WP34 Los 6.1 - XHEXP1, XHVAC, XHPSC
Hochbau der Versorgungshallen XHPSC und XHVAC
Zbau-Antrag für die GMSH
Prüfung durch die GMSH
Ausschreibungsunterlagen und LV erstellen
Beschaffung durch V4
Installationsphase XHEXP1, XHVAC, XHPSC
Hochbau Medientunnel Bereich XHQ
Installationsphase Medientunnel Bereich XHQ
Leitungsanbindung von Schacht OsBo bis auf der Koppel
Leitungsanbindung von auf der Koppel bis Schenefeld
E-Kabel und Leitungsröhre von Schacht OsBo bis auf der Koppel
E-Kabel und Leitungsröhre von auf der Koppel bis Schenefeld
XHPSC & XHVAC
Jan
Mai
Mai
Sep
Feb
Medientunnel
ab März
noch unbekannt
WP34 Los 6.2 - XS2, XHE2, XS4, XHE4, XDU1, XTD1,-3,-5,-6,-7,-8
Hochau der Hallen
Zbau-Antrag für die GMSH
Prüfung durch die GMSH
Ausschreibungsunterlagen und LV erstellen
Beschaffung durch V4
Installationsphase XHE2, XHE4, XS2, XS4, XDU1, XTD5 bis -8
Installationsphase Maschine XTD5 bis -8
Installationsphase XTD3
Installationsphase Maschine XTD3
Installationsphase XTD1
Installationsphase Maschine XTD1
XHE2-, XHE4-Bau
Sep
Jan
Jan
Jun
Dez
Mrz
Apr
Jun
Jun
Sep

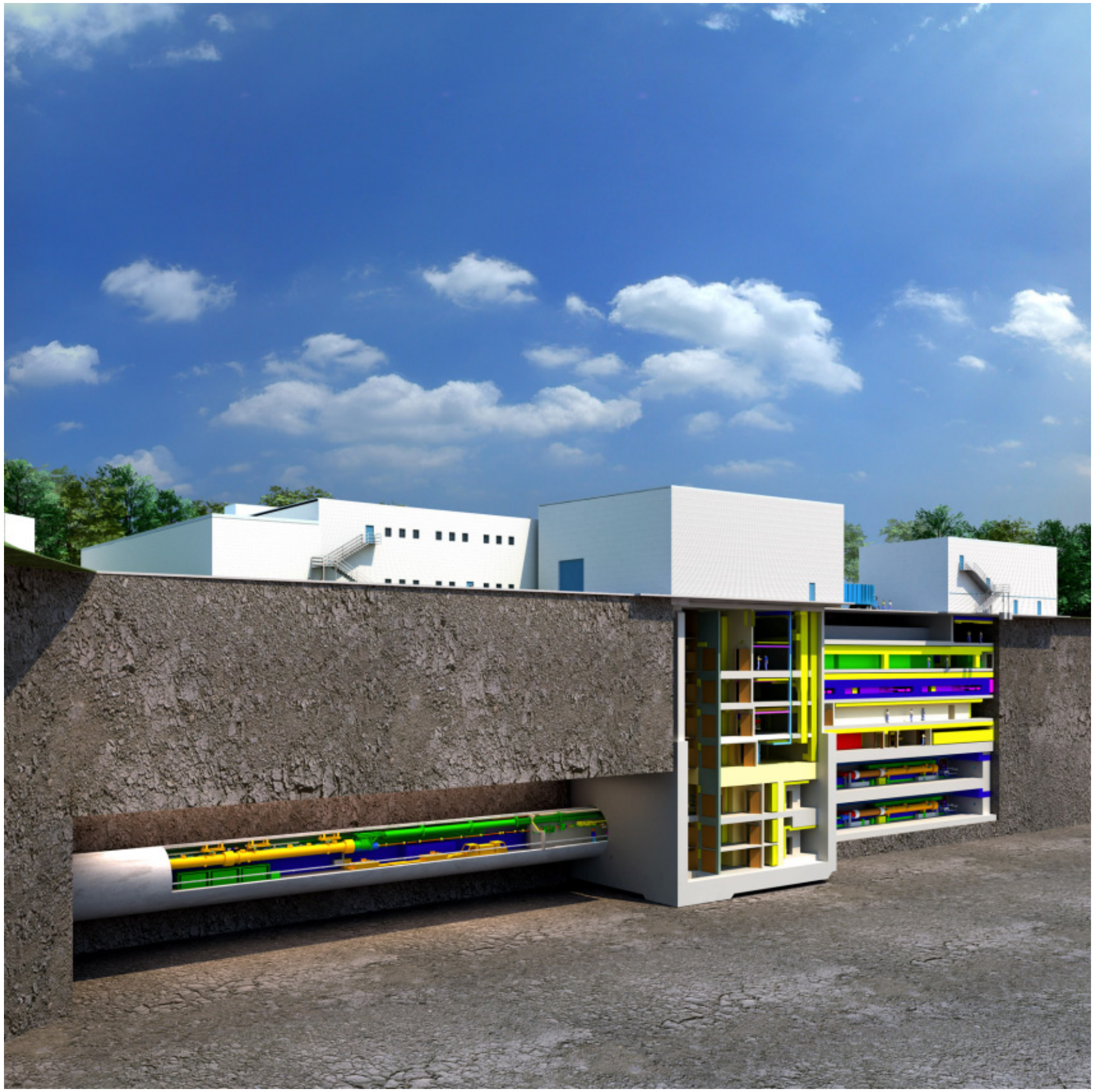


Overview of the XFEL facility
Descriptions of the buildings
DESY
Schenefeld
2012
y2013
y2014
y2015
y2016
Machine installation in XTL starts 09/2013
Undulator installation in XTD2 starts 03/2014
Experiment installation in XHEXP1 starts 11/2014
März
15 XTL dicht
Juli
Juli 2014 XTIN dicht
XHE3-Bau
XHE1-Bau
April
Sep
Jan
XS1
XHE1
März
Sept
XHPSC & XHVAC
Jan
Mai
Sep
Feb
Medientunnel
ab März
noch unbekannt
XHE2-, XHE4-Bau
Sep
Jan
Jan
Jun
Dez
Mrz
Apr
Jun
Jun
Sep

Injector Complex

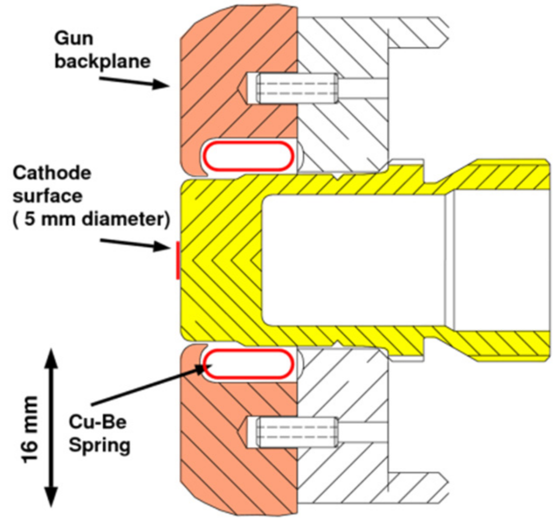


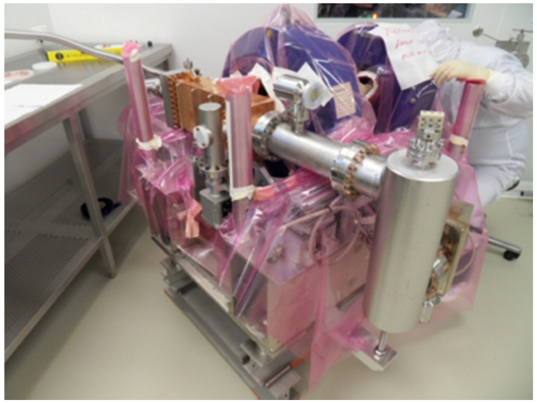
Injector Complex

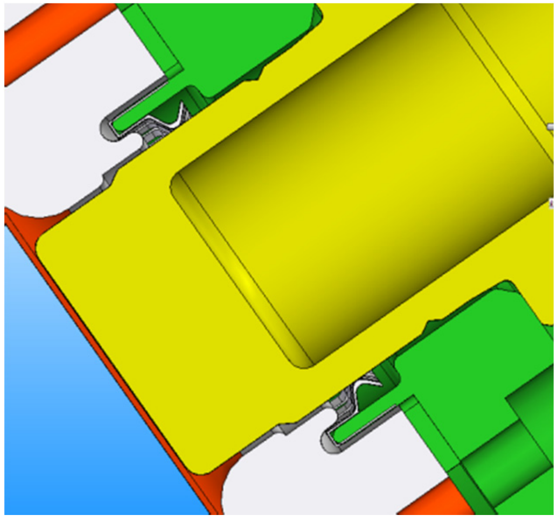


RF Gun

- Identified cathode spring as weak point → redesigned
- Gun conditioning well underway at PITZ (photo injector test stand)
- Single RF window with dry compressed air (in PITZ: SF_6) → final test in injector (09/2013)







Injector Installation

September 1st

November 1st

Injector Installation

October 31st

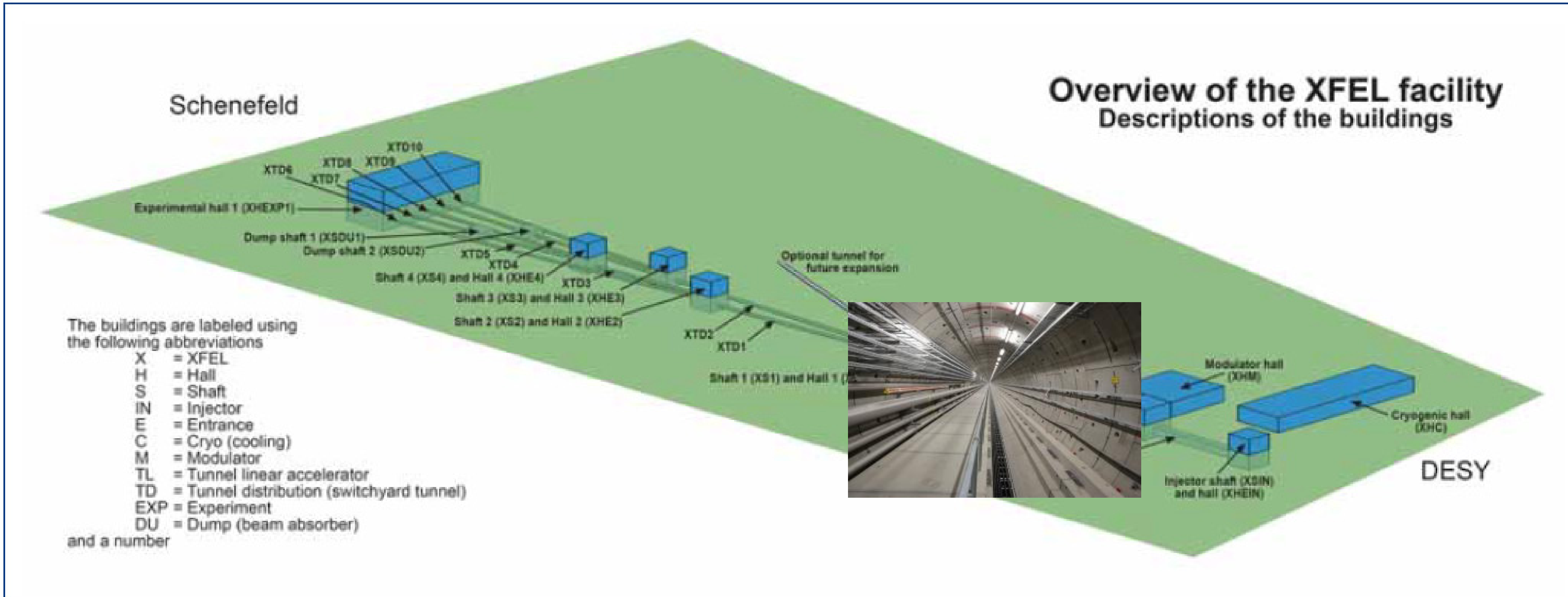
March 1st

Injector Installation

February 28th

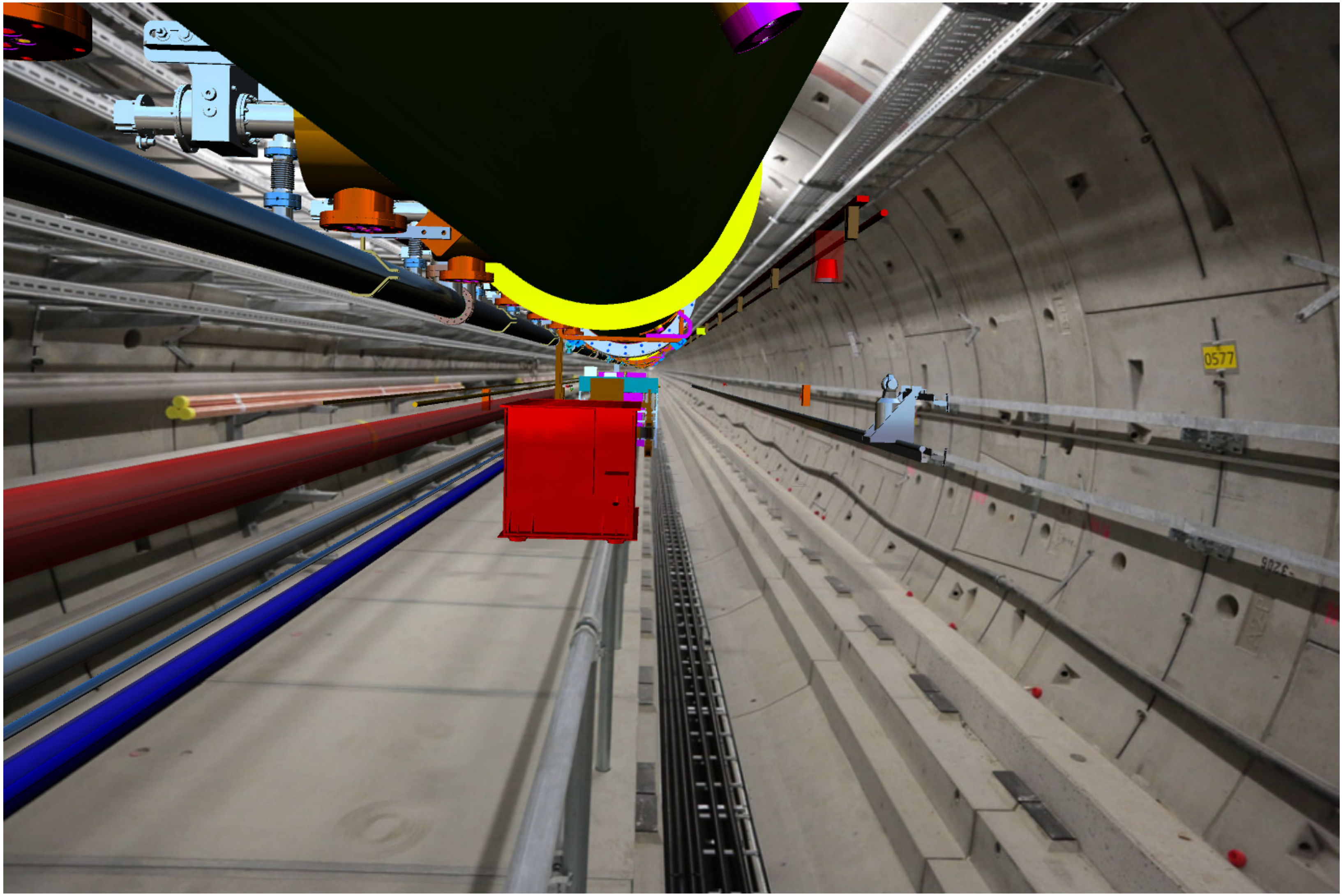
July 1st

Main Linac


Overview of the XFEL facility
Descriptions of the buildings
Schenefeld
XTD10
XTD8
XTD9
XTD6
XTD7
Experimental hall 1 (XHEXP1)
Dump shaft 1 (XSDU1)
Dump shaft 2 (XSDU2)
XTD5
XTD4
Shaft 4 (XS4) and Hall 4 (XHE4)
XTD3
Shaft 3 (XS3) and Hall 3 (XHE3)
Shaft 2 (XS2) and Hall 2 (XHE2)
XTD2
XTD1
Optional tunnel for future expansion
Modulator hall (XHM)
Cryogenic hall (XHC)
Injector shaft (XSIN) and hall (XHEIN)
DESY
The buildings are labeled using the following abbreviations
X = XFEL
H = Hall
S = Shaft
IN = Injector
E = Entrance
C = Cryo (cooling)
M = Modulator
TL = Tunnel linear accelerator
TD = Tunnel distribution (switchyard tunnel)
EXP = Experiment
DU = Dump (beam absorber)
and a number

Main Linac

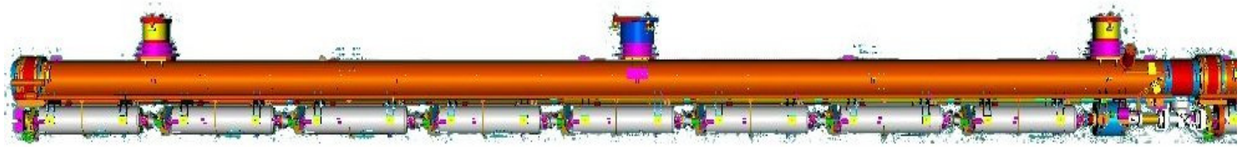
Main Linac



Scenes from the main Tunnel

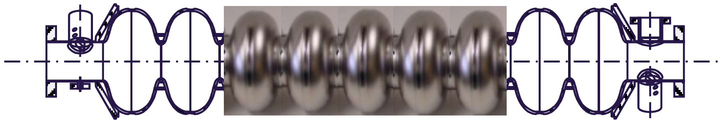
Accelerator Complex

100 accelerator modules

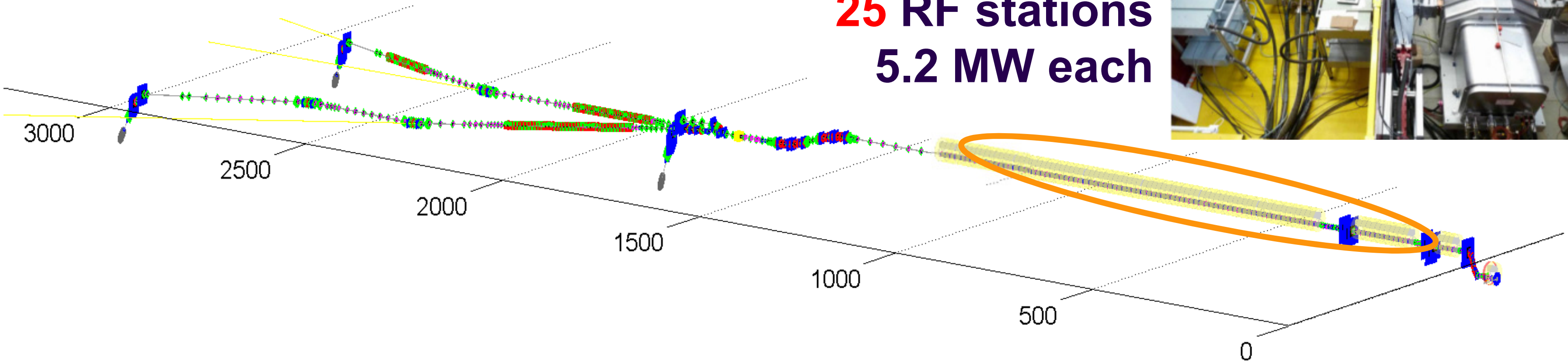


800 accelerating cavities

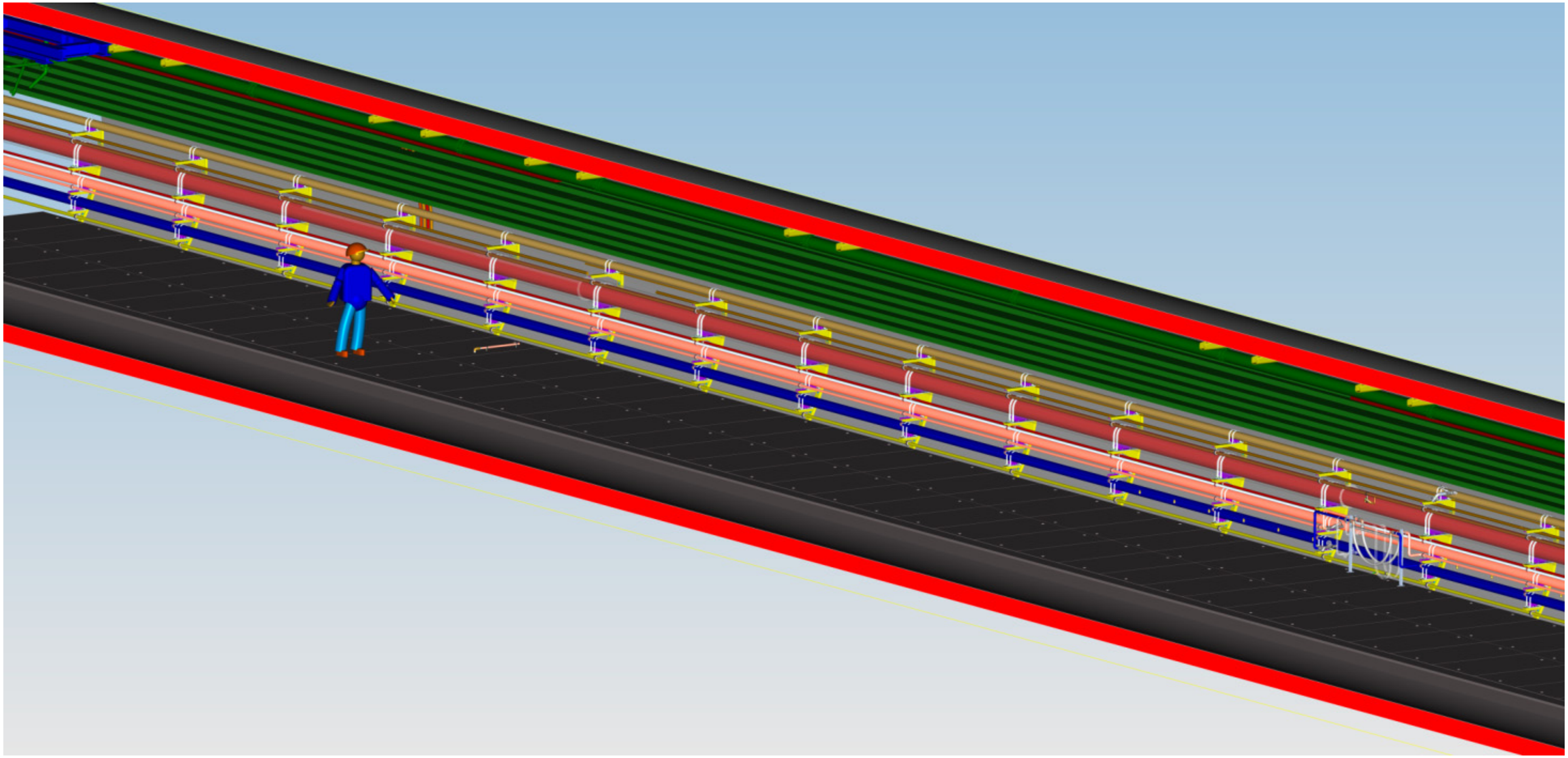
1.3 GHz / 23.6 MV/m



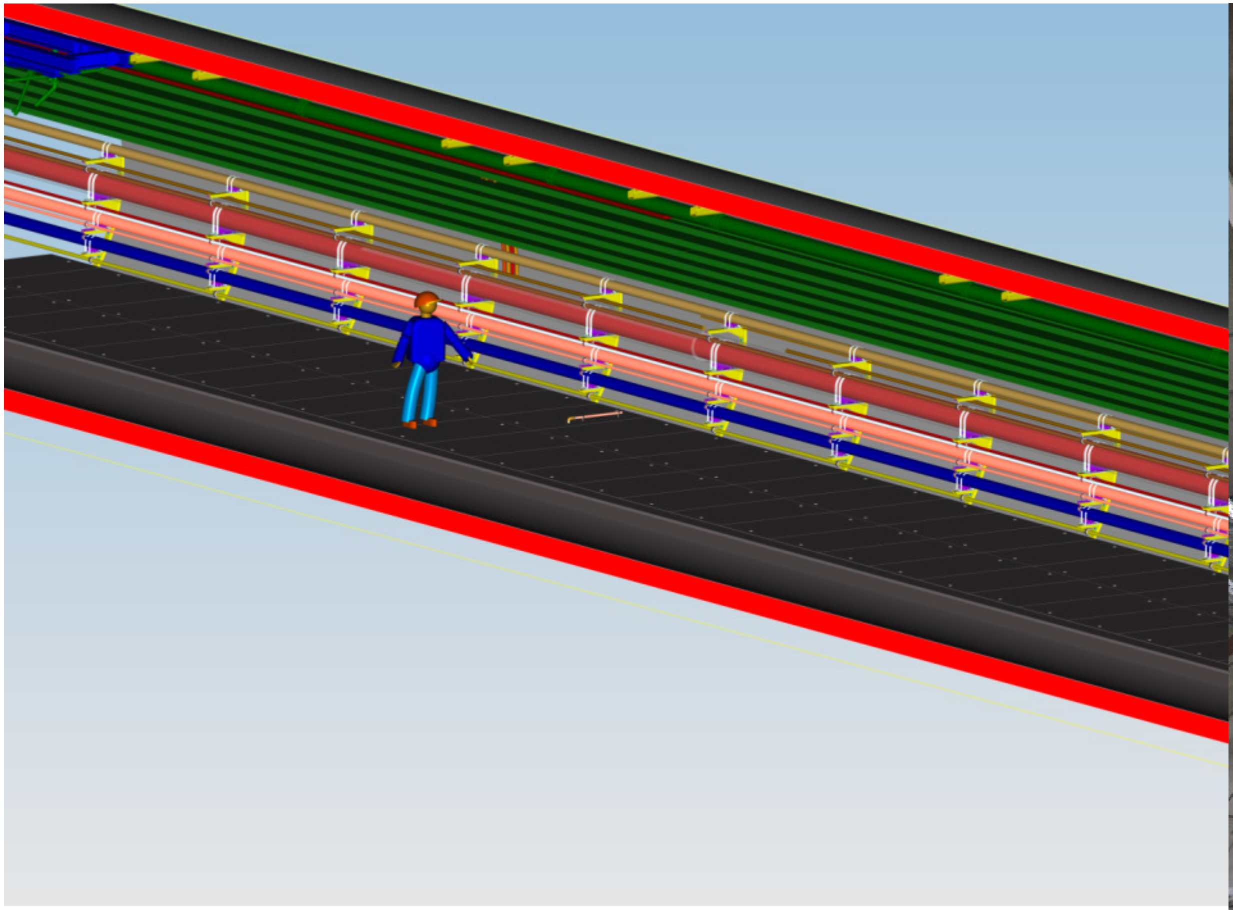
25 RF stations
5.2 MW each

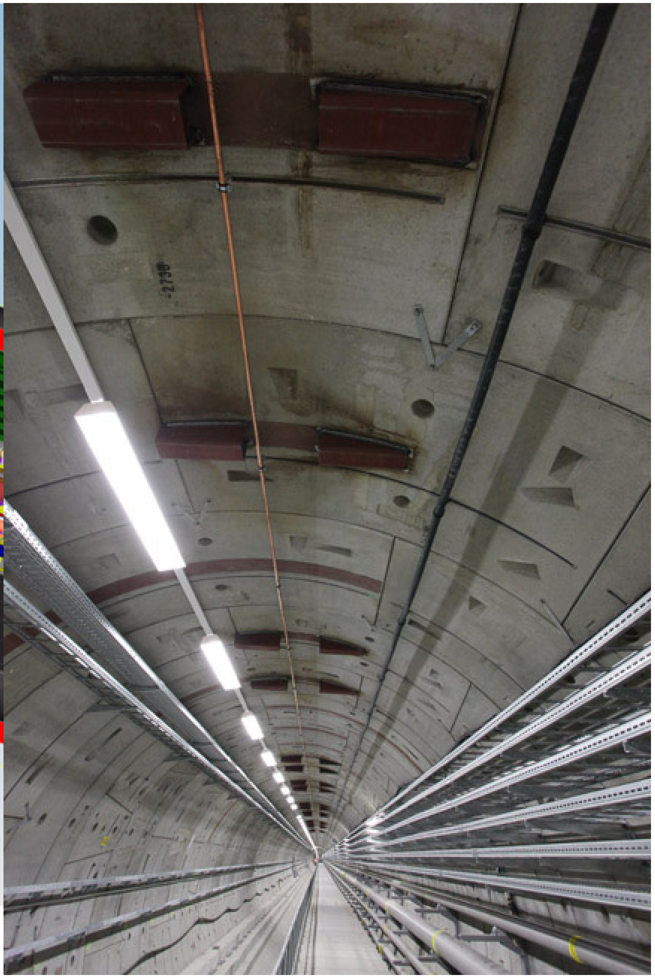


Installation of the Cryo String

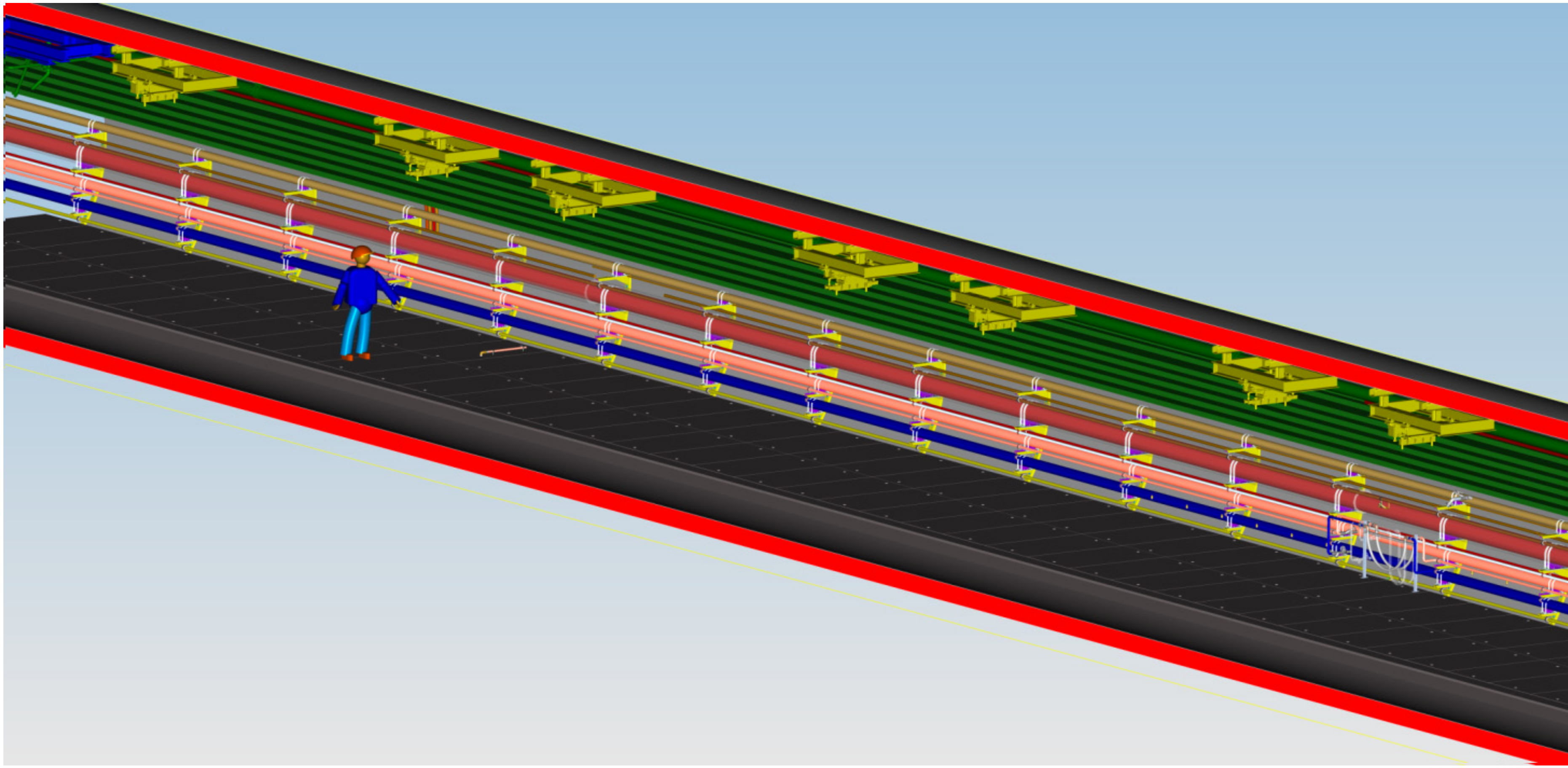


Installation of the Cryo String

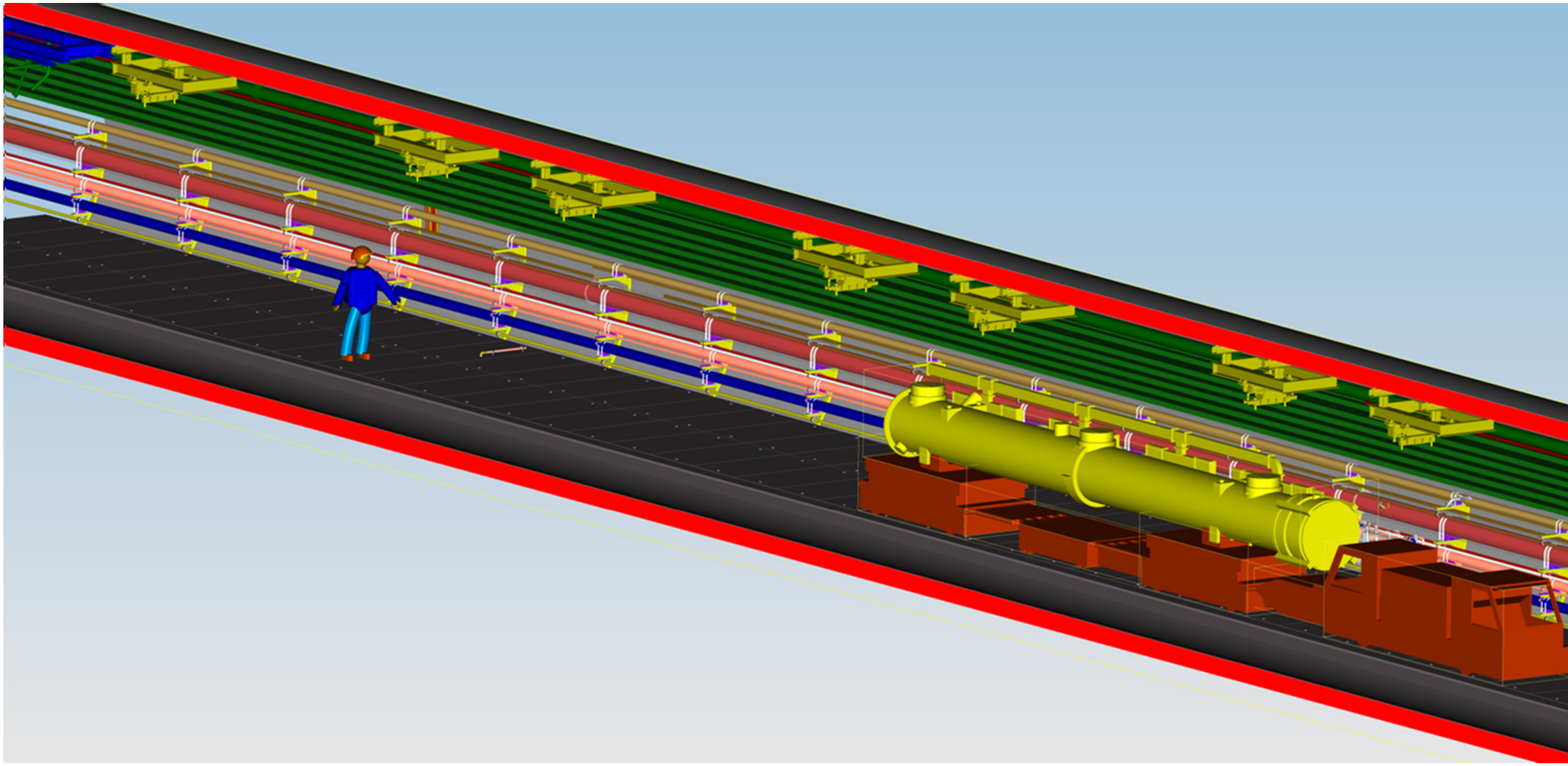




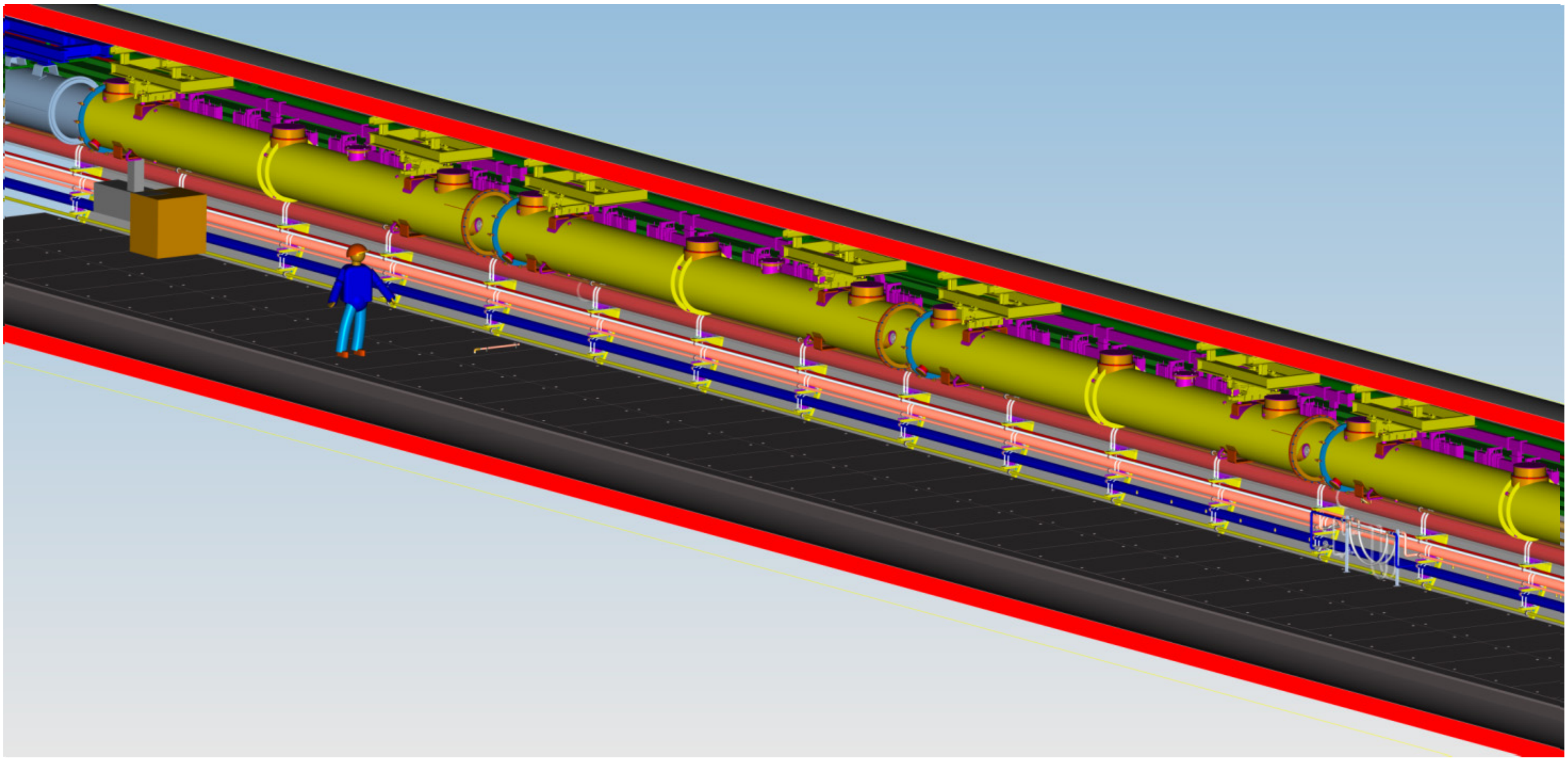
Installation of the Cryo String



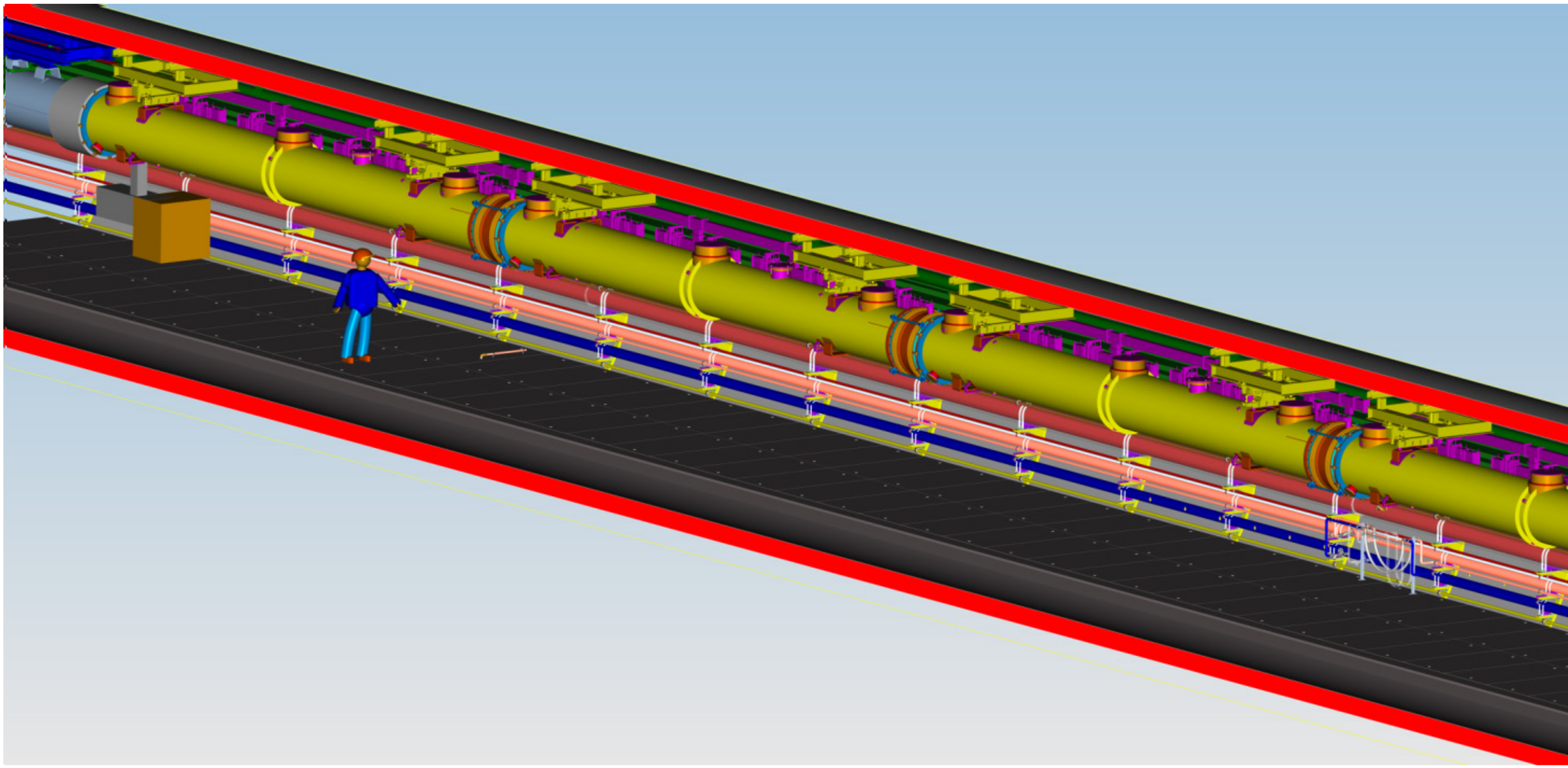
Installation of the Cryo String



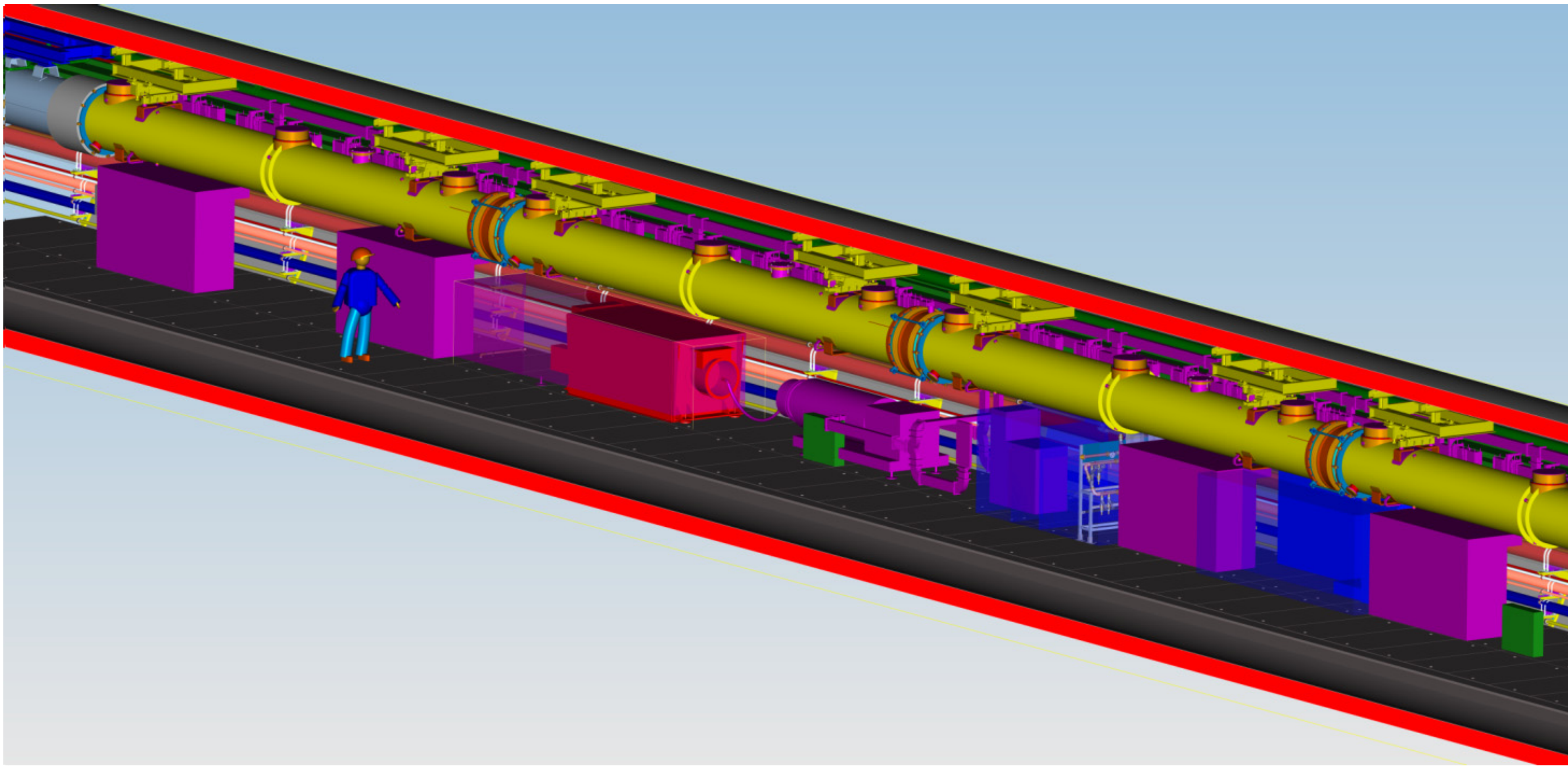
Installation of the Cryo String



Installation of the Cryo String

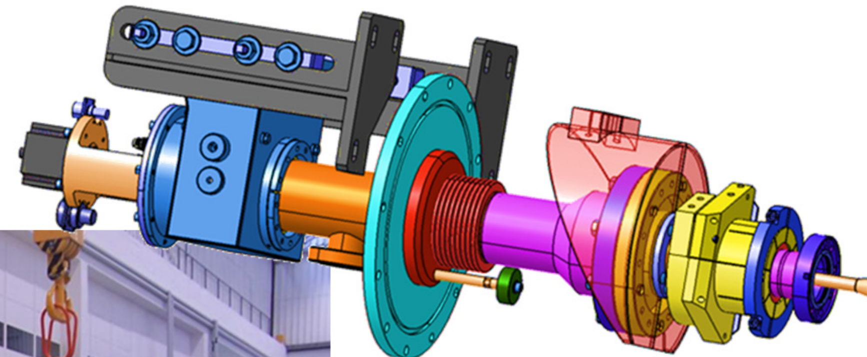


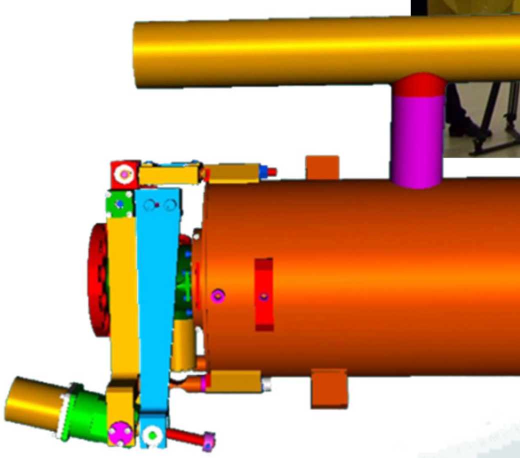
Installation of the Cryo String

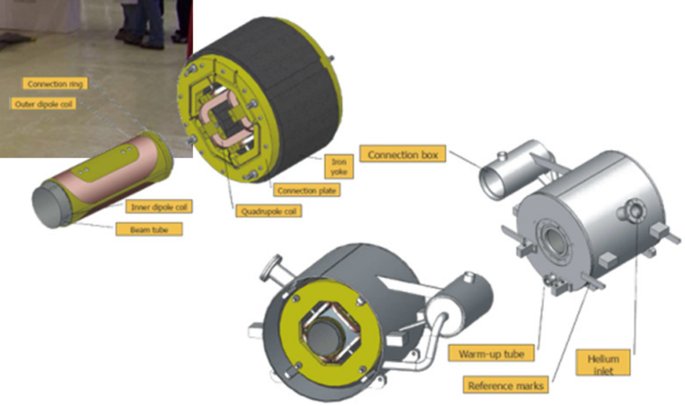


European XFEL

Accelerator Module







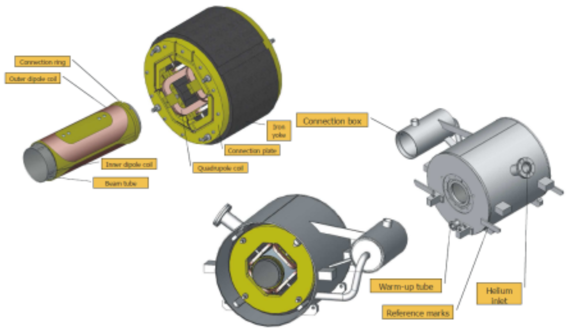
DESY HELMHOLTZ ASSOCIATION

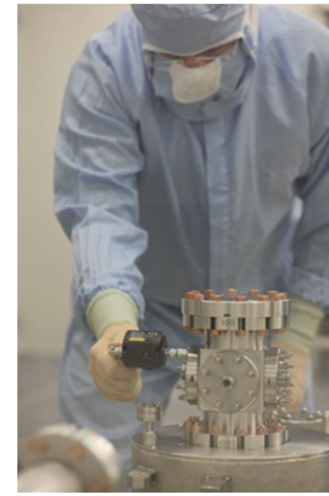
Superconducting Cavities

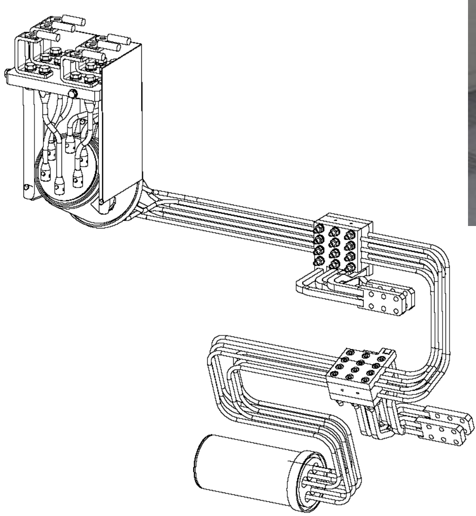
Cavity Production

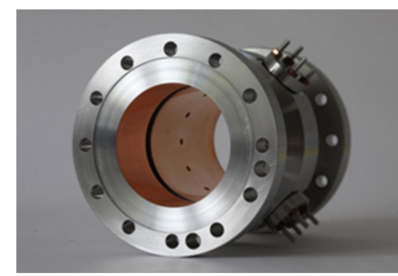
- Two vendors for mechanical production and preparation of 800 cavities
  - Both vendors produced cavities in the past
  - Meanwhile cavity preparation of both vendors qualified
- More than 100 cavities produced so far
- 22 cavities tested in the AMTF
  - 19 met performance goal (23.6 MV/m at $Q_0=10^{10}$) immediately and considerably
  - 3 met performance goal after re-treatment (HPR)

Cold Magnets, Current Leads and BPM





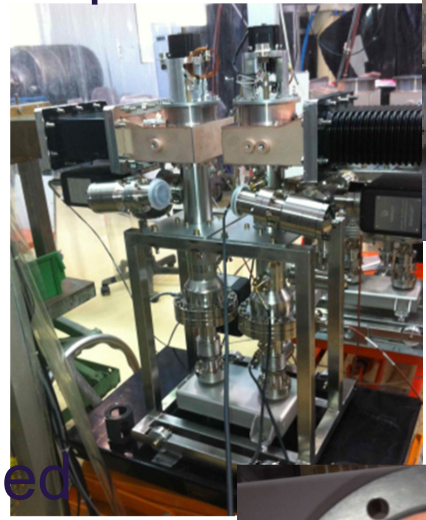


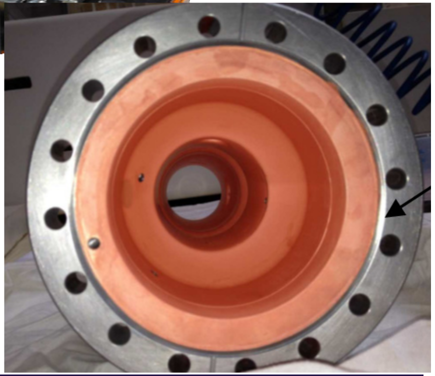


- **25 magnets** measured at DESY
- **current leads** for first modules available
- 60% of BPM series hardware on stock
- Assembly halted because of buffer overflow

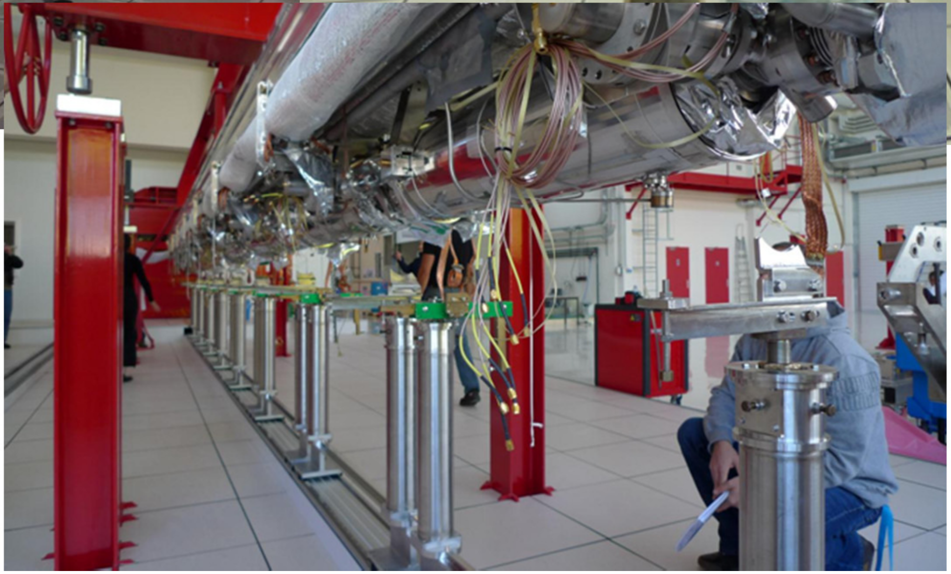
RF Power Couplers

- first XFEL couplers produced successfully conditioned
- despite problems with copper plating, the production started
  - at present a reliable rate of 2 per week can be assumed
  - an increase to 4 per week is expected soon; new infrastructure
- Unclear when 8 per week will be reached
- The problem is the copper plating of the warm external conductor WEC
- RF conditioning infrastructure ready and to be commissioned now



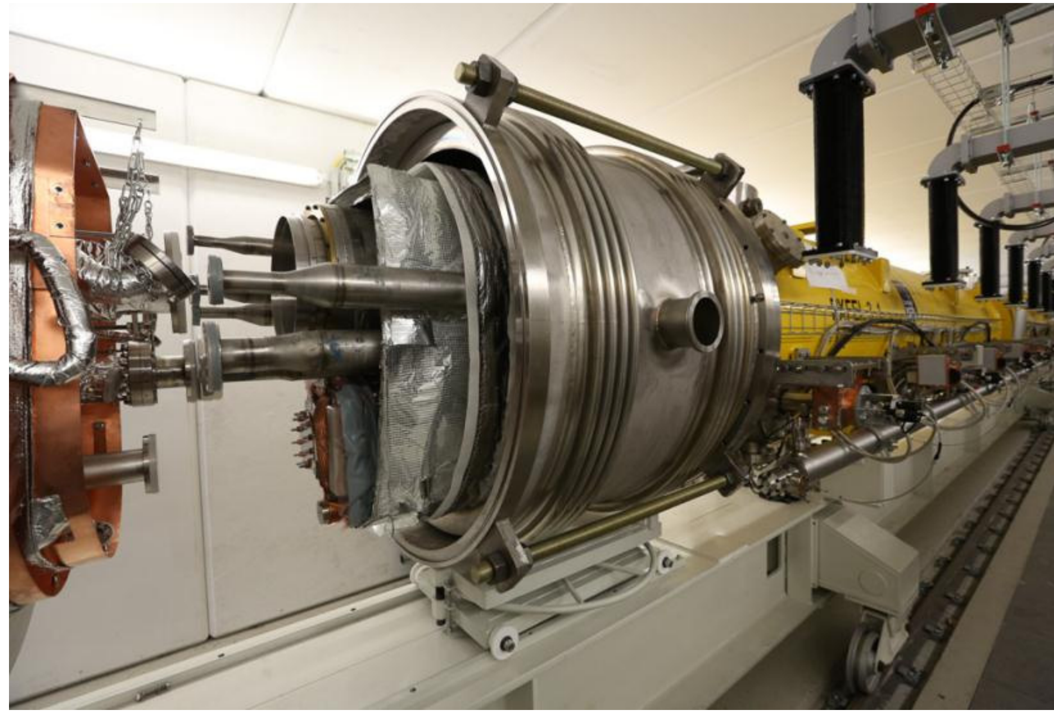


Couplers-String-Module



Module Testing

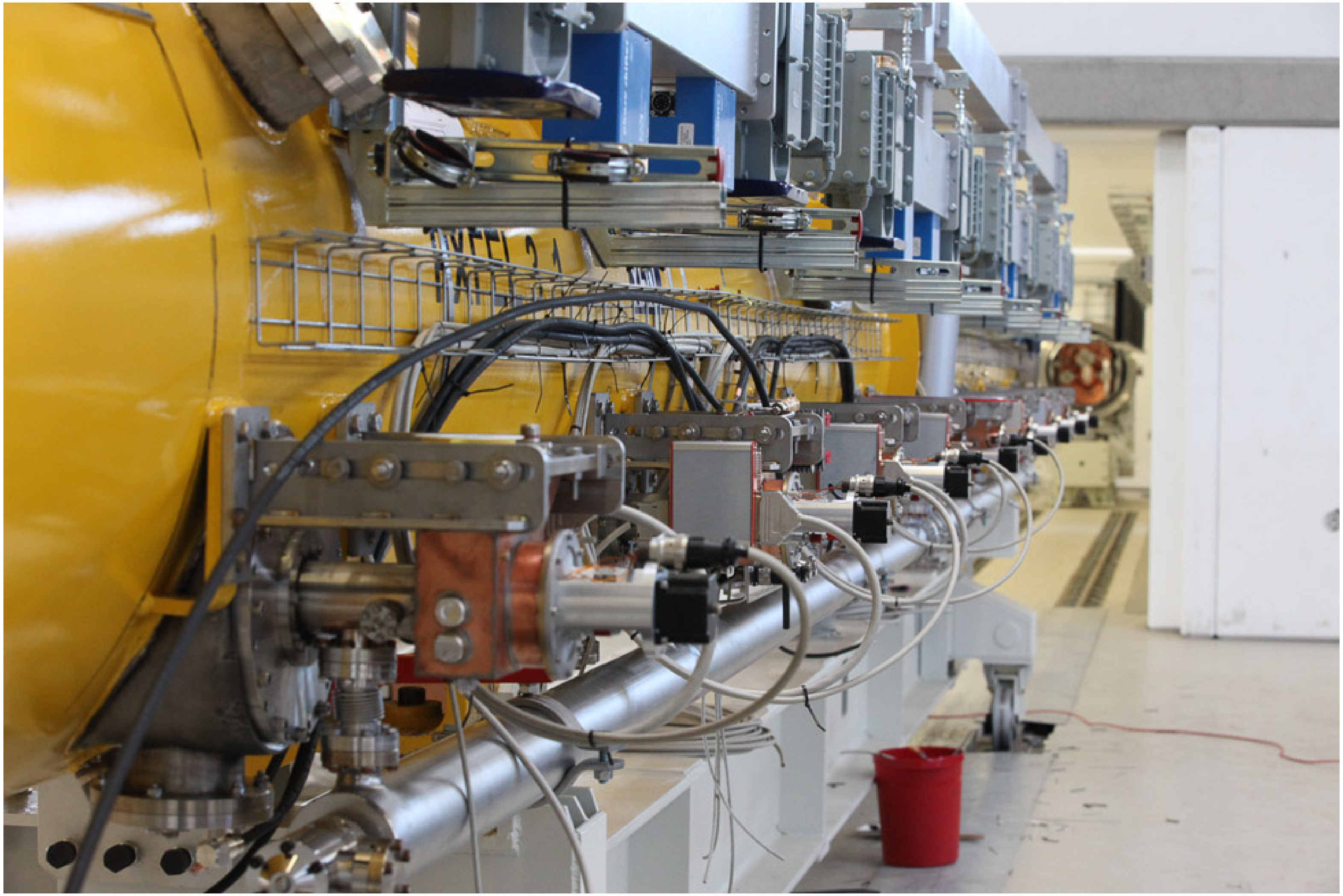
- Module testing takes 2 weeks per module
- Three parallel test stands allow for through-put of 1.5 module peer week (assume 1 for now)



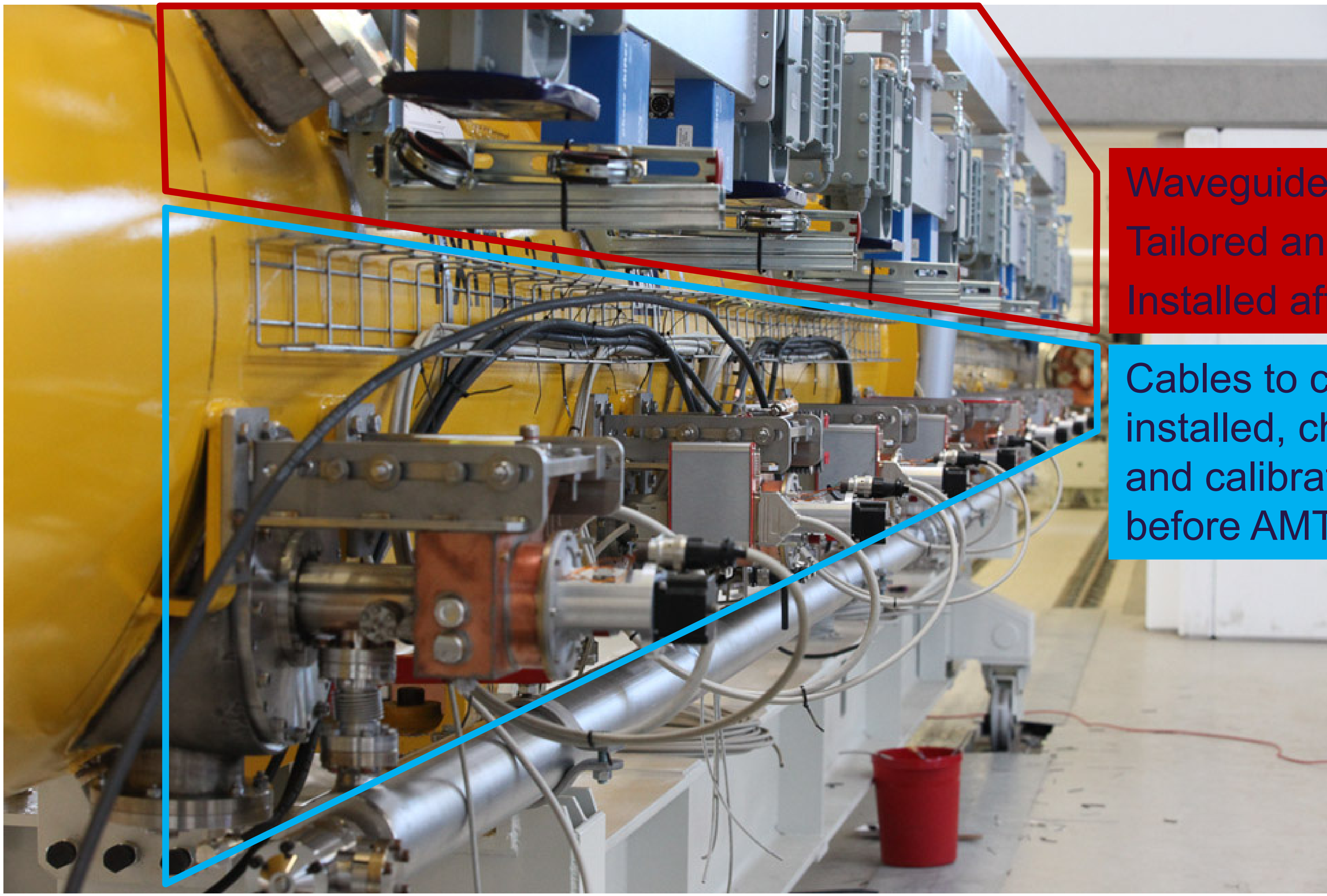
		Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday
PLAN I - MODULE	XATB 1	A	B	B	B/C	C	C	D	D	D	D	D/E	E	E	F	
	XATB 2								A	B	B	B			C	C
	XATB 3															A

Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesda	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday
						A	B		B	B		C	C	C/D	D	D	D	D	E	E	E/F
C/D	D	D	D	D	E	E	E/F	F					A	B	B	B/C	C	C	D	D	D
B	B	B/C	C	C	D	D	D	D	D/E	E	E	F								A	B

External Equipment at Module



External Equipment at Module



Waveguides and cables
Tailored and calibrated
Installed after AMTF test

Cables to coupler installed, checked and calibrated before AMTF test

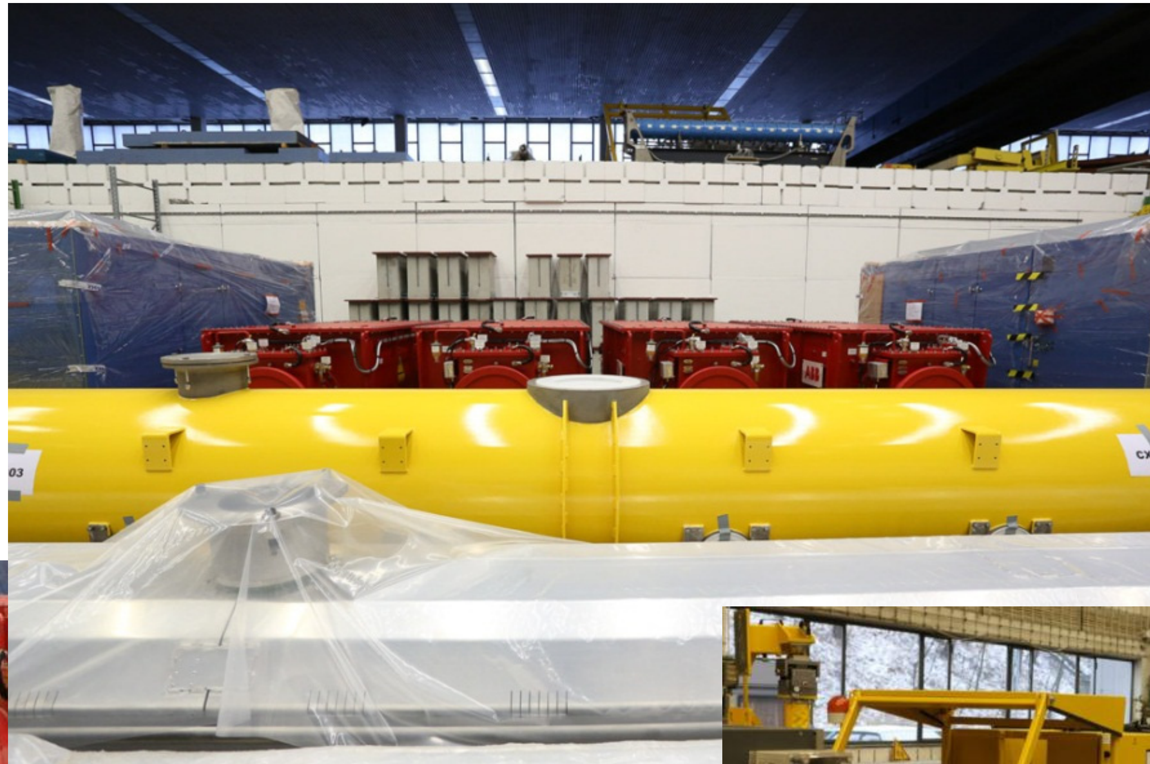
Module Manufacturing Schedule

- Series production of modules starts in summer 2013
- In the present scenario a total of 112 weeks is required for module production → already end of 2015
- In addition 3 months are needed for testing, installation and subsequent work

⇒ Carefully assess and readjust production speed once a steady rate is established

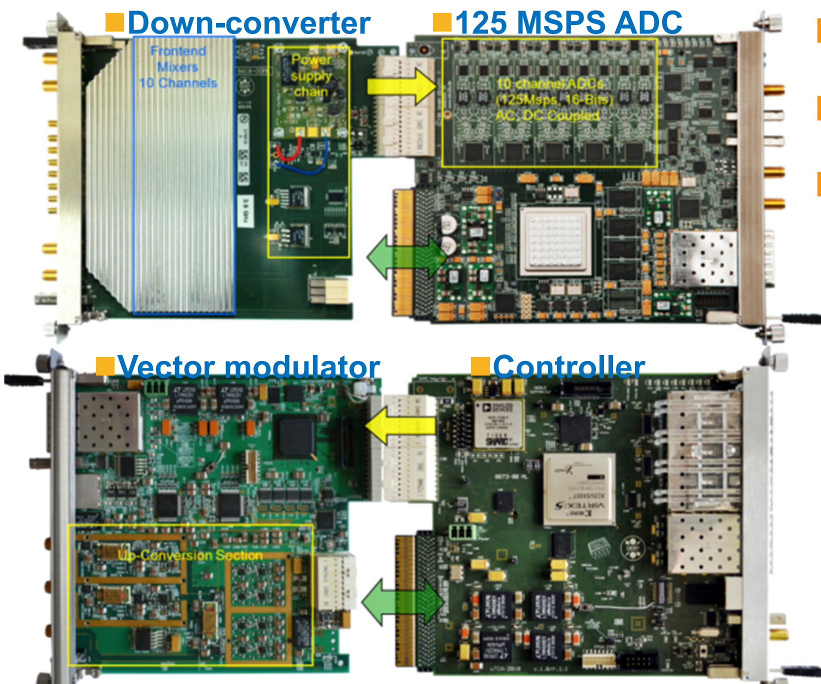
Infrastructure allows for an increase by a factor 1.5

Stock pile

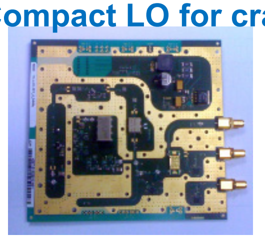


Low Level RF System

MicroTCA based LLRF system

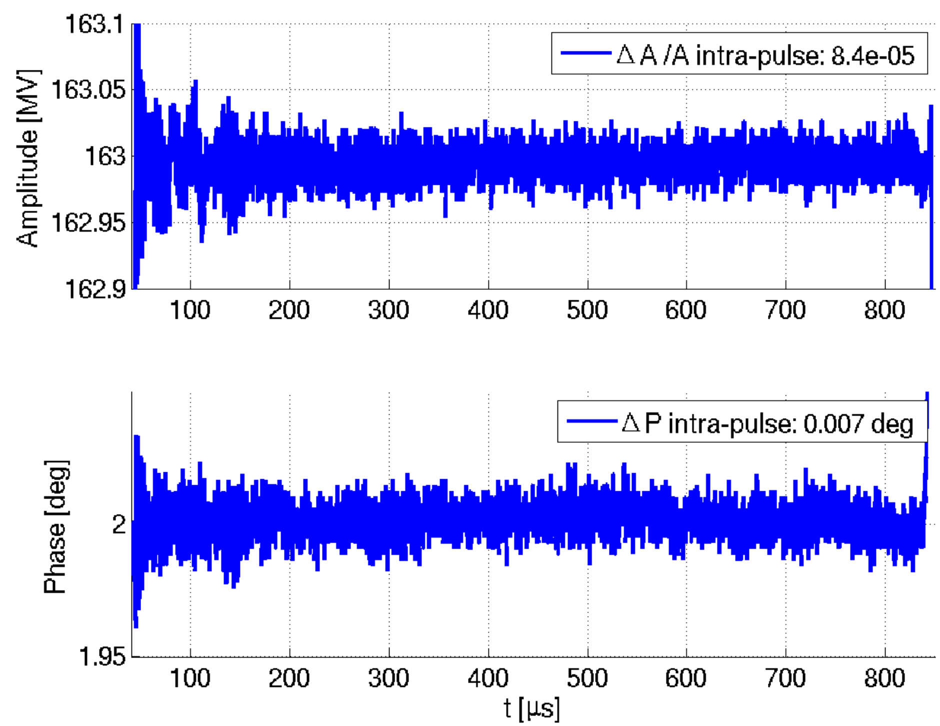


Compact LO for crate

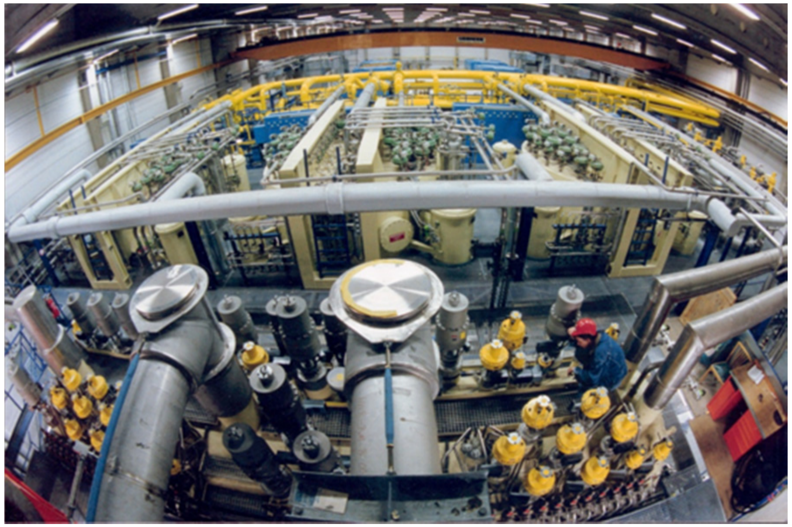


MTCA.4 Crate

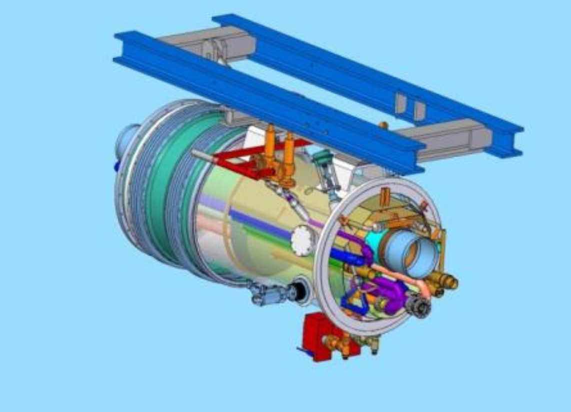
- RMS amplitude regulation 9 x 10−5
- Phase regulation of 0.007°
- expected beam energy stability < 0.005%

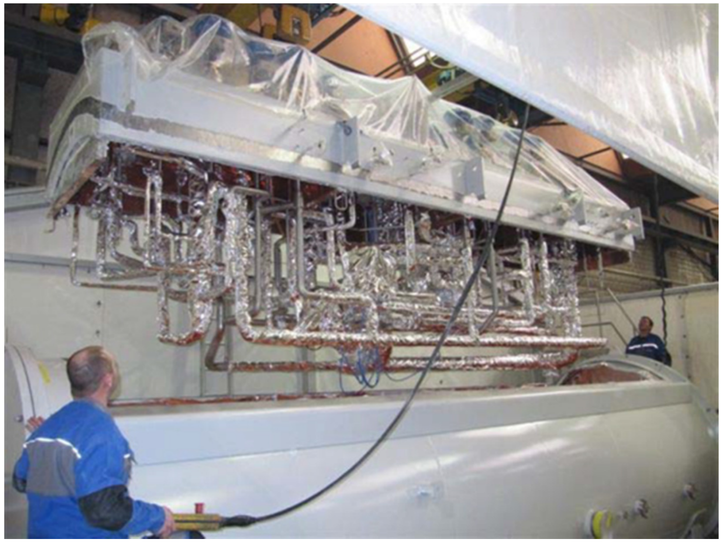


Cold Linac Infrastructure

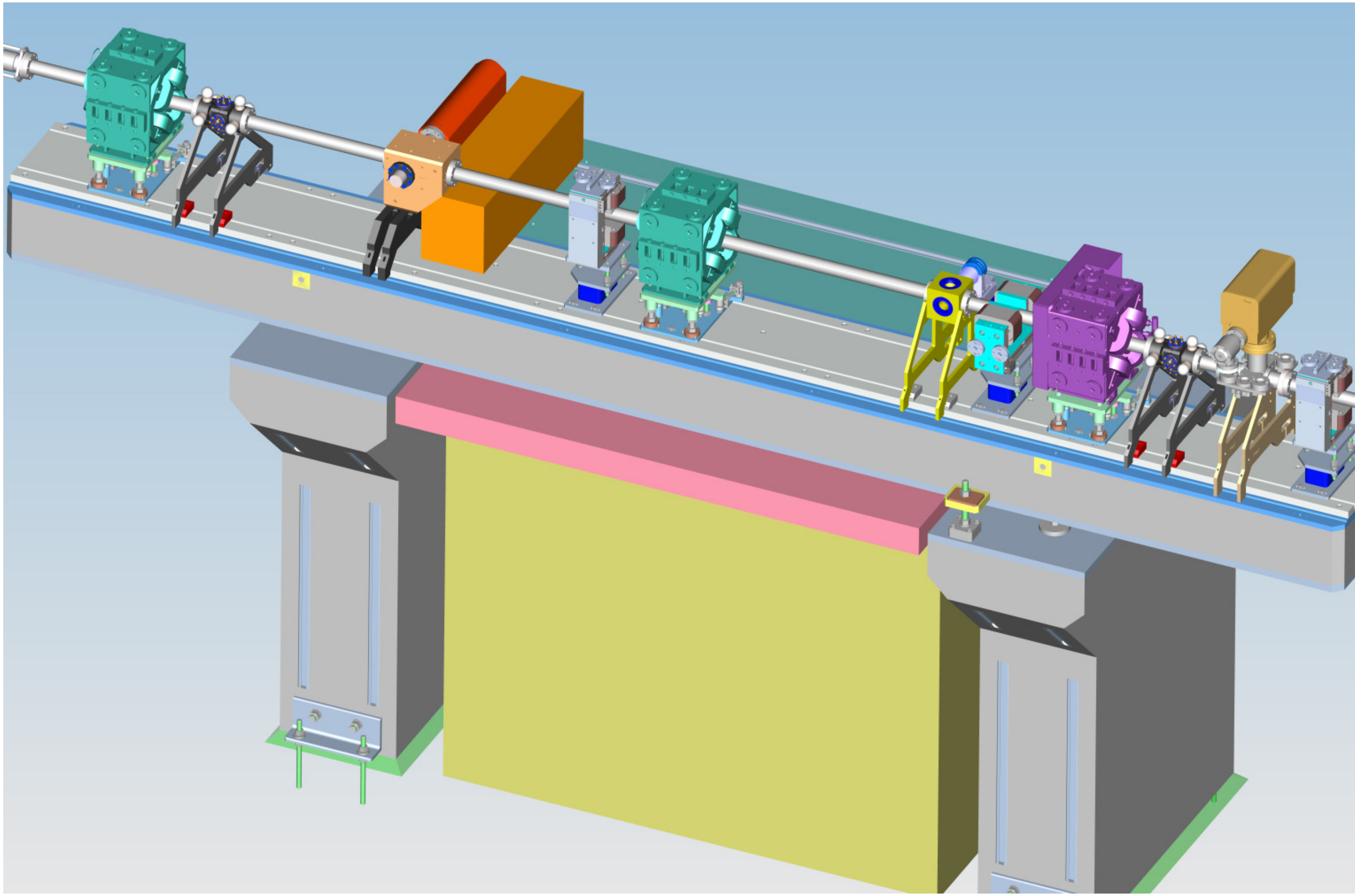


- Refurbishment of HERA cryo plant close to completion (3 months ahead of schedule)
- Factory acceptance test of CB44 (2K box) has started ahead of schedule
- However, serious delay of main transfer line (affects injector start-up)
- Feed and end caps, bypass lines and string connection boxes late but OK



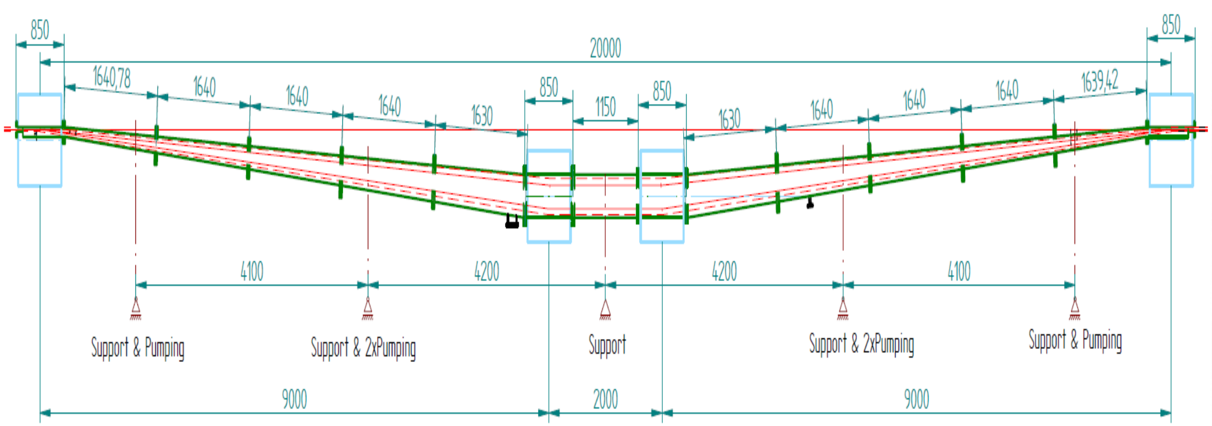


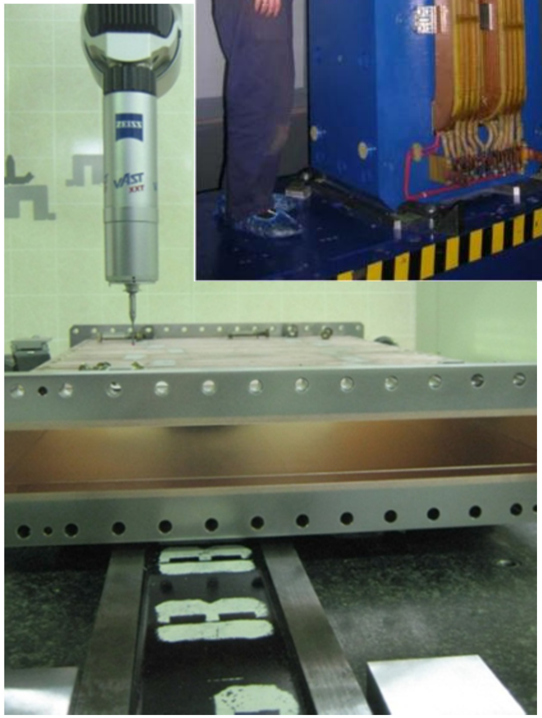
Accelerator Installation – Warm Beamlines



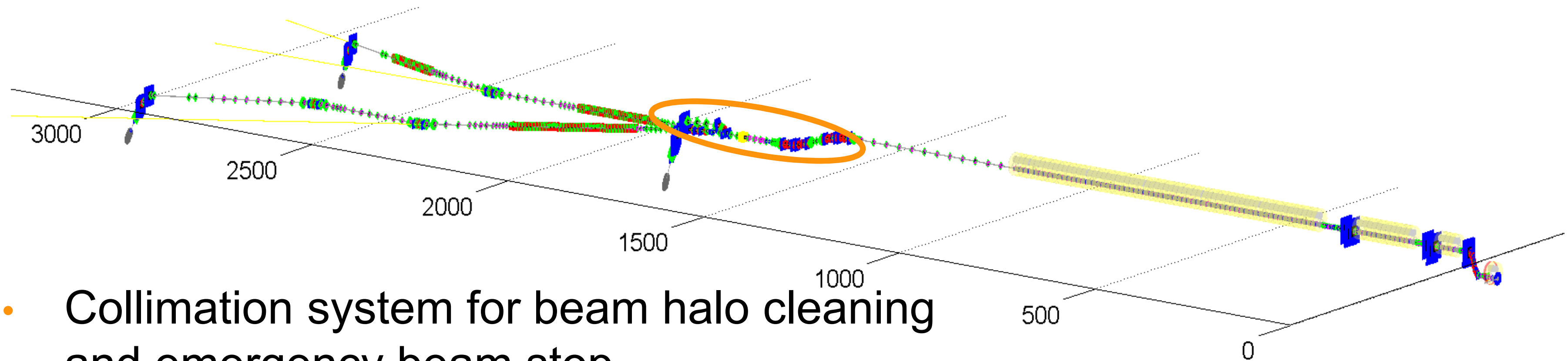
Bunch Compression Chicanes

- Fixed wide vacuum chamber for variable R56
  - No moving vacuum parts in the vicinity of superconducting structure
  - No wake from bellows
  - Fast changes of R56 via beam energy
- First dipole magnets for the chicane produced
  - Challenging field quality requirements will be achieved by individual pole shimming



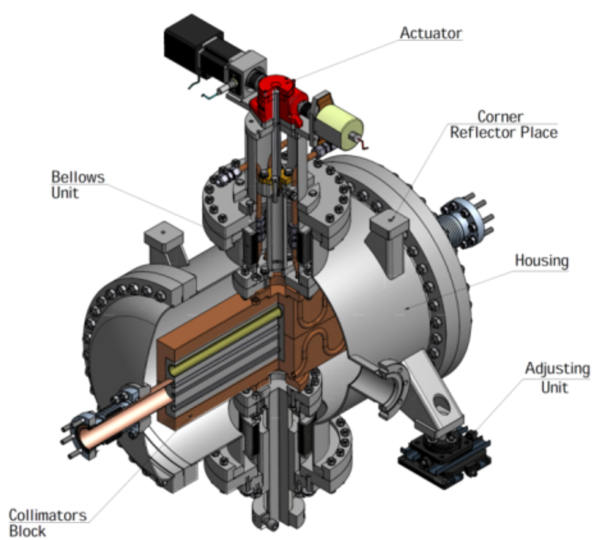


Collimation & Beam Distribution

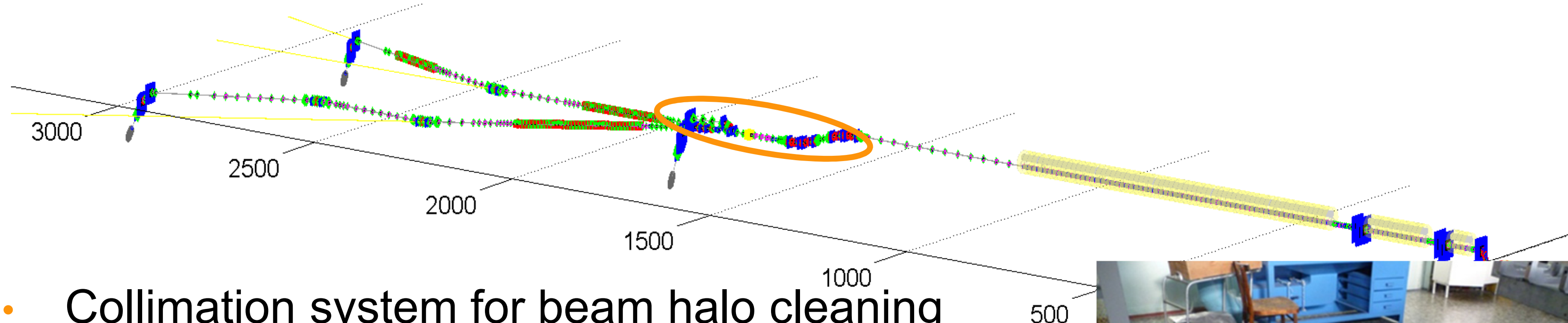


- Collimation system for beam halo cleaning and emergency beam stop
- Transvers Intra-Bunch Feedback
- Flexible beam distribution system for quasi-simultaneous operation of two primary electron beam lines

XFEL Collimator



Collimation & Beam Distribution



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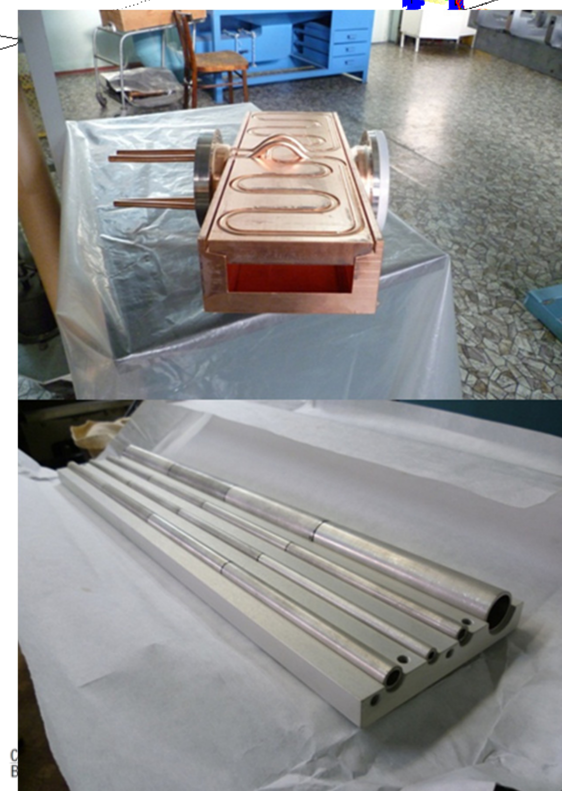
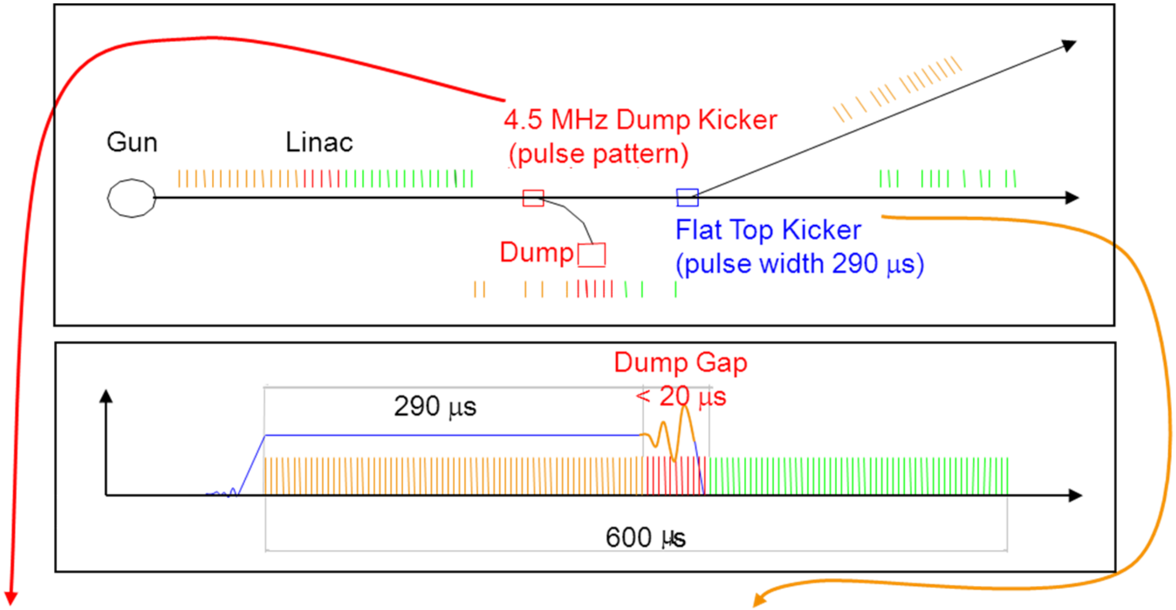
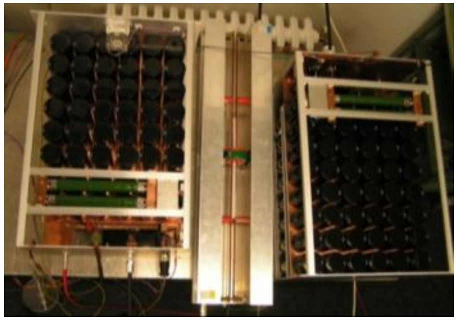
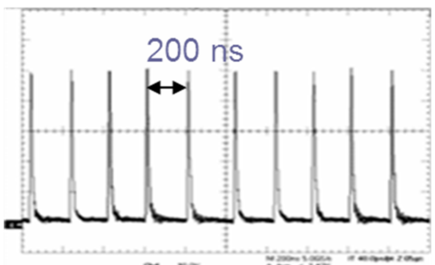


Pulse Distribution



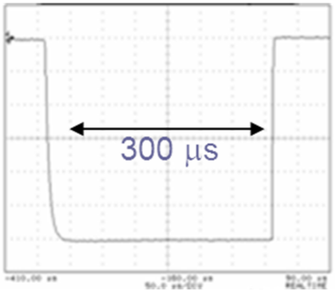


- low accuracy (>1 %)
- 4.5 MHz burst operation

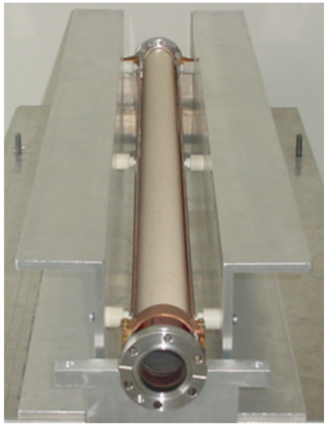


example:
pulser prototype measurement

- high accuracy (< 0.01 %)
- 10 Hz operation

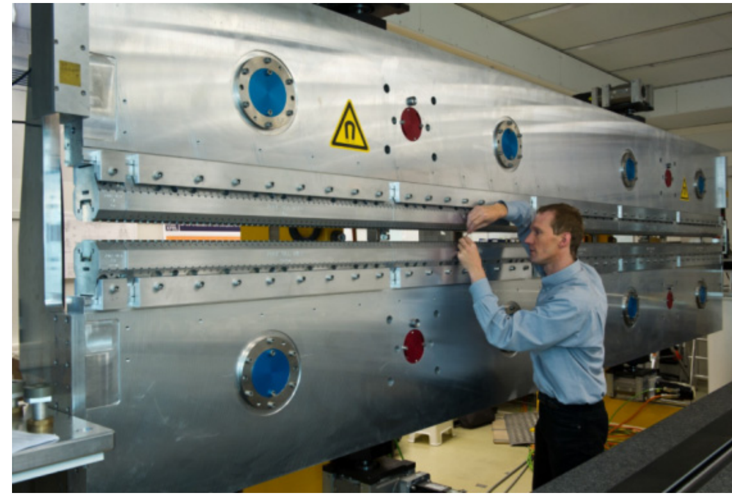


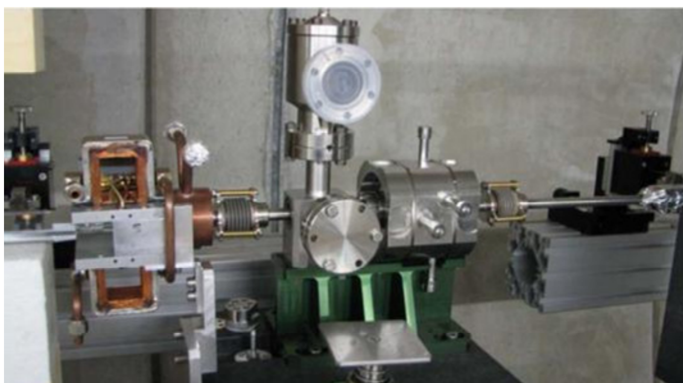
example:
pulser prototype measurement



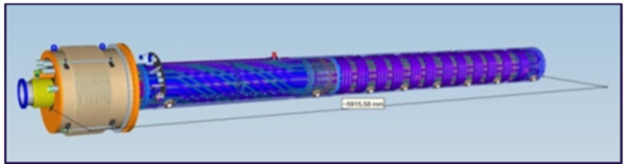
European XFEL – Undulators

- Series production of 90 undulators started
  - Today 22 tuned, 18 ready for installation
- Focusing quadrupoles manufactured and precision fiducialization
- Series production of intersection components started



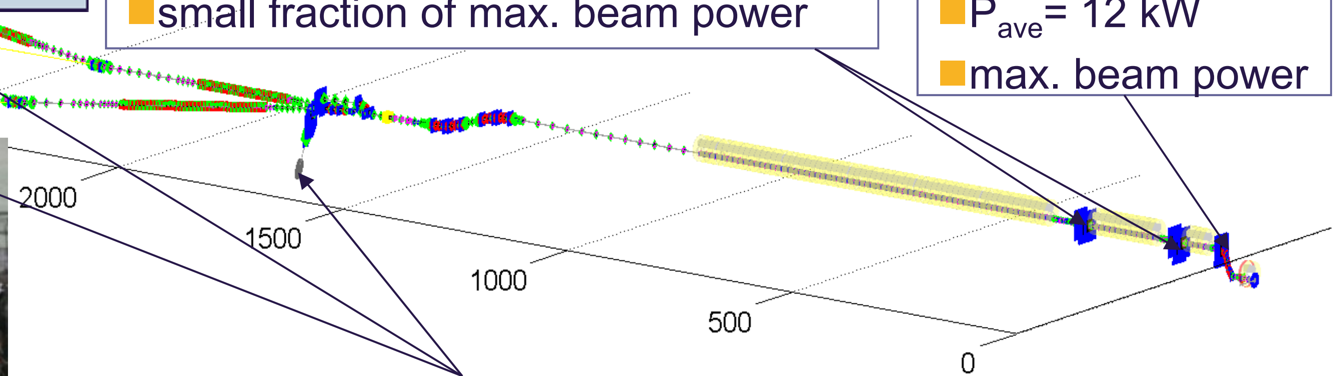


Beam Dumps



- bunch compressor diagnostic dumps
- 0.5 and 2.5 GeV
- small fraction of max. beam power

- injector dumps
- 130 MeV
- P_{ave}= 12 kW
- max. beam power



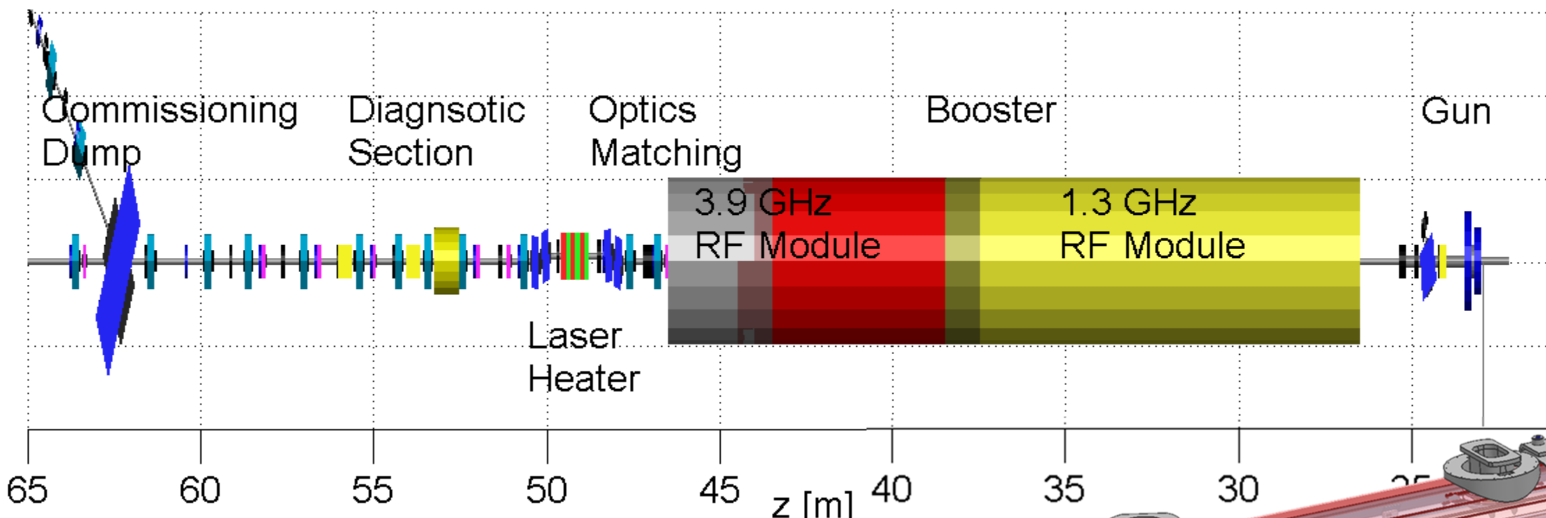
- main beam dumps
- P_{ave}= 300 kW
- 1/2 max beam power

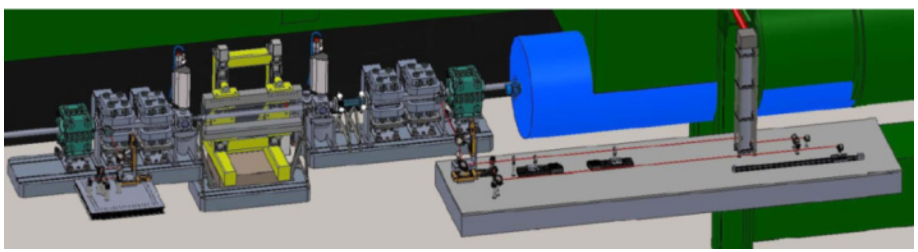
- Dumps needed for injector, bunch compressors, and several main dumps
- DESY took over responsibility for dumps procurement
- Production schedule tight, no contingency

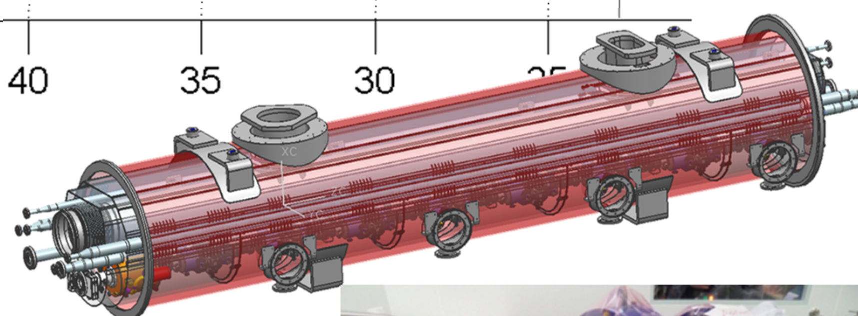
Machine Commissioning

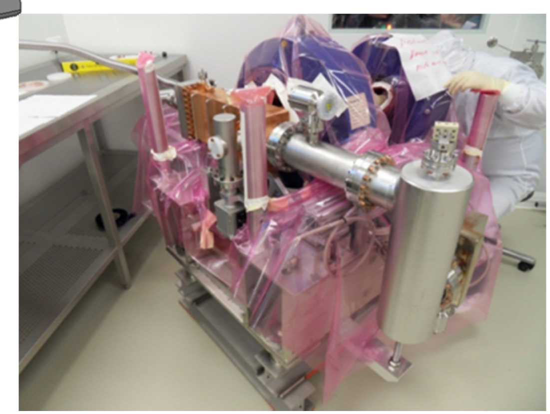
- Injector installation will be finished and injector tunnel closed in 2014
- Main linac installation will be finished and accelerator tunnel closed in 2015
- Let‘s call the time when main linac is cold $\mathbf{T_0}$

Injector

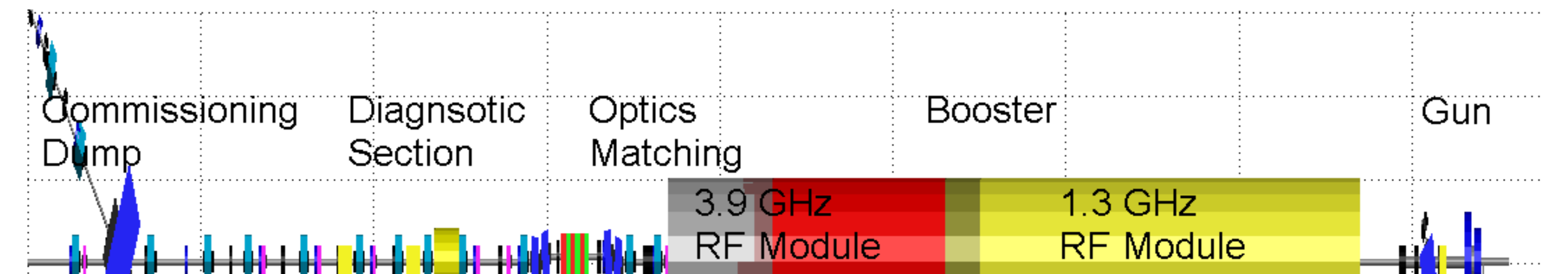

Commissioning Dump
Diagnsotic Section
Optics Matching
Booster
Gun
3.9 GHz RF Module
1.3 GHz RF Module
Laser Heater
65
60
55
50
45
z [m]
40
35
30





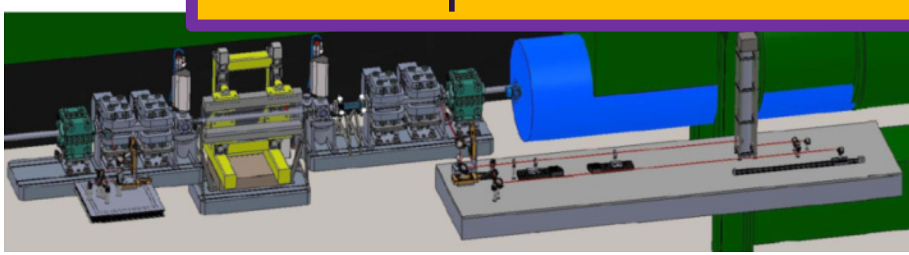


Injector



Injector contains practically all systems found in the main linac as well

⇒time spent here reduces time spent on main linac



Injector Commissioning

- Achieve full XFEL parameters

Quantity	Value
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 μs
bunch repetition frequency within pulse	4.5 MHz
bunch charge	0.02 – 1 nC
Slice emittance	0.4 - 1.0 mm mrad

- Commission sub-components like
  - laser heater, 3.9 GHz System, diagnostics, controls, feedbacks, automation, …
- One year prior to start-up of main linac (minimum demand from commissioning plan, happens to be in line with availability of cryogenics)

Injector Commissioning

- Establish routine operation
- ‘Teambuilding’

- 1 year time span appears sufficient for
  - some tests, „trial and error“, …

“Ever tried. Ever failed. No matter.
Try again. Fail again. Fail better.”

Samuell Beckett, 1983

XFEL Overall Commissioning

‚Preparatory Work‘:

- Technical Commissioning of all subsystems as far as possible under installatio/open tunnel conditions (i.e. warm coupler conditioning, …)
- Tunnel close
- Cool-down
- Pre-beam check-out
- LLRF:
  - Cavity tuning and high-power tests without beam
  - Beam to BC1 dump, commission one RF station
  - **T_0+3 month**: beam transport through linac possible

Initial E-beam parameters

Quantity	Value
electron energy	~~10.5/14~~/17.5 GeV
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 µs
bunch repetition frequency within pulse	~~4.5 MHz~~ 100 kHz
bunch charge	~~0.02 – 1 nC~~ 0.5 nC
electron bunch length after compression (FWHM)	~~2 – 180 fs~~ 90 fs
Slice emittance	~~0.4 –~~ 1.0 mm mrad
beam power	~~500 kW~~ 5 kW

XFEL Overall Commissioning – Milestones

1. **First Beam through Linac**
   - 17.5 GeV, 10 Hz, 0.5 nC, 100 kHz beam is transported through the linac to the TLD dump
   - Control: Charge, peak current, energy and trajectory are controlled by slow feedbacks.
2. **First Beam through northern Beamline (T_0 + 5 month)**
   - Electron beam based trajectory alignment in undulator
3. **First Lasing observable in SASE1 (T_0 + 7 month)**
   - First lasing is observed at 0.16 nm
   - Commissioning of photon diagnostics & beam line
4. **First Lasing observable in SASE3 (T_0 + 8 month)**
5. **First Lasing observable in SASE2 (T_0 + 12 month)**

XFEL Overall Commissioning – Milestones

1. **First Beam through Linac**

Identified fast track to first lasing

Sacrificing stability and running all feedbacks and subsystems

First beam to SASE1: **T_0+2 month**

First lasing in SASE1: **T_0+4 month**

Subsequently parallel commissioning of left out systems and photon systems

3. **First Lasing observable in SASE1 (T_0 + 7 month)**
   - First lasing is observed at 0.16 nm
   - Commissioning of photon diagnostics & beam line
4. **First Lasing observable in SASE3 (T_0 + 8 month)**
5. **First Lasing observable in SASE2 (T_0 + 12 month)**

First User Operation

- One charge, one energy
- Single bunch to 100 kHz (maybe more ??)
- first SASE-photons as soon as possible to allow commissioning of photon beam lines and experiments
- Approx. 1000 user hours in first year, serving one undulator a time

"Conditions for 'First User Experiments'

→ experiments can use x-ray beam at TDR performance, but with limited flexibility in terms of pulse pattern, pulse length and photon wavelength"

In both commissioning scenarios
10 month after cool-down

Further Development

- Multi-bunch operation
- Quasi-simultaneous operation of SASE1 and SASE2 beam line
- Flexibility in wavelength and bunch length
- Seeding
- ….

Last Words

- Progress on construction, infrastructure planning and ramp up of accelerator component fabrication
- Challenge to get the series production of accelerator modules up to speed
- Working hard to finish installation in time for
  - start of injector commissioning end 2014
  - start of linac commissioning 2015
  - observe first SASE by early 2016

Thanks to all people contributing to this exciting project