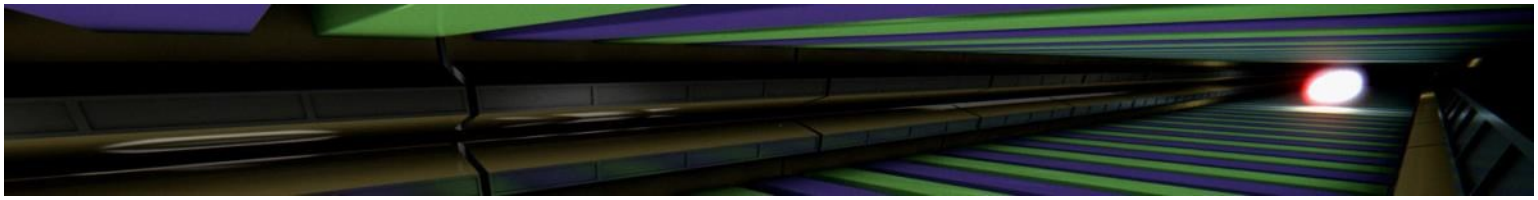


# Status of the European XFEL Accelerator

**Hans Weise & Winni Decking, DESY**

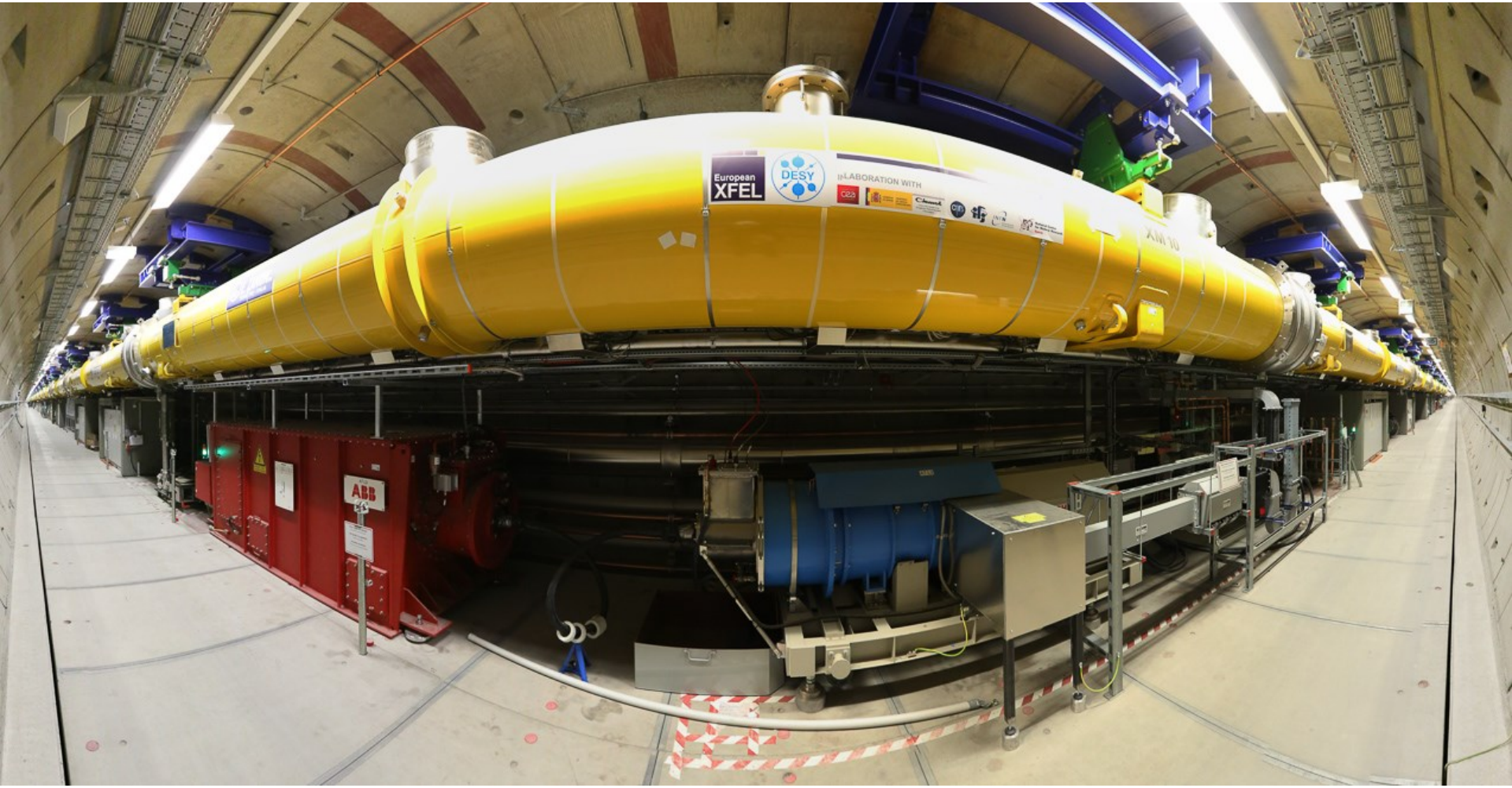
**on behalf of the European XFEL Accelerator Consortium**
**work supported by the respective funding agencies of the contributing institutes; for details please see http:www.xfel.eu**

**European XFEL Users' Meeting**

**25 – 27 January 2017**
DESY, Hamburg and XFEL.EU, Schenefeld, Germany

# One Kilometer of Cold Linac





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# With almost 800 Superconducting Cavities

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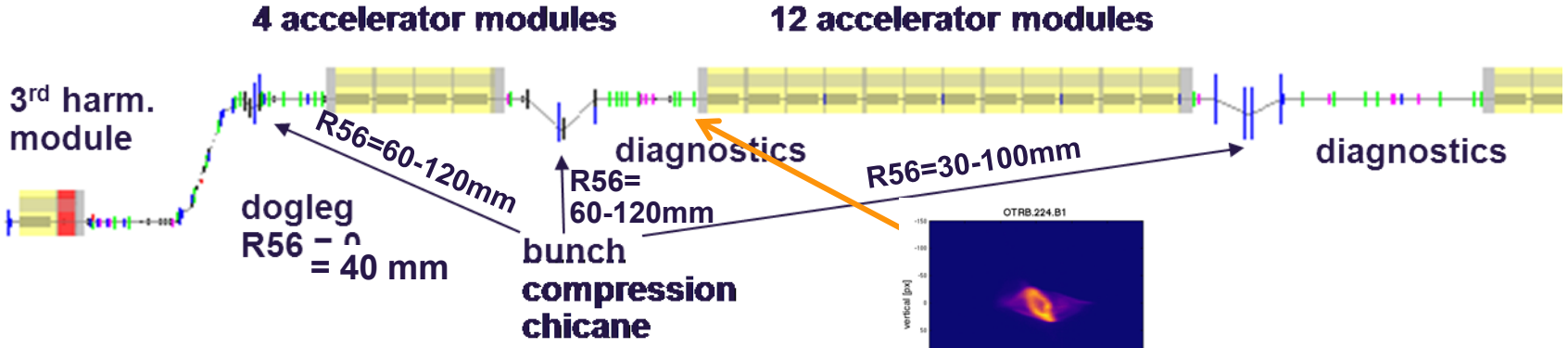
# State of the Art 3 Stage Bunch Compression



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



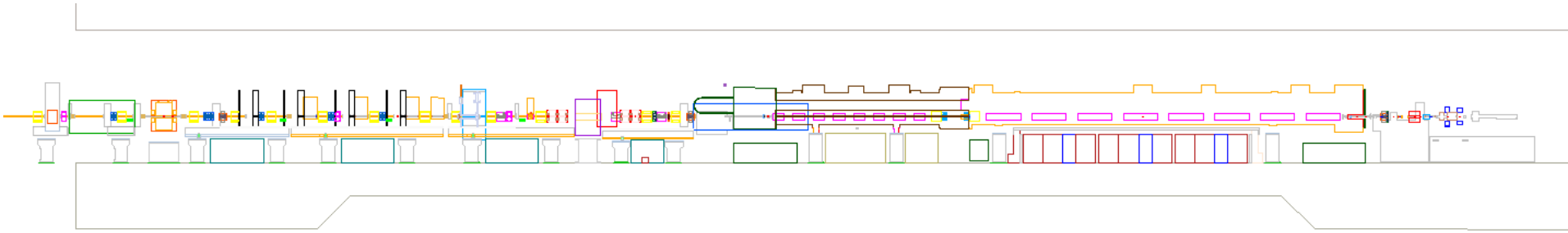

| | | | |
|---|---|---|---|
| $\sigma_\sigma$ = 2 mm | $\sigma_\sigma$ = 1 mm | $\sigma_\sigma$ = 0.1 mm | $\sigma_\sigma$ = 0.02 mm |
| $I_{peak}$ = 50 A | $I_{peak}$ = 100 A | $I_{peak}$ = 1 kA | $I_{peak}$ = 5 kA |
| $\sigma_E$ = 0 % | $\sigma_E$ = 1.5 % | $\sigma_E$ = 1 % | $\sigma_E$ = 0.3 % |
| E = 130 MeV | E = 130 MeV | E = 600 MeV | E = 2400 MeV |

harmonic system

bunch compressor

beam diagnostics

# Injector in Operation – First Beam in 12/2015

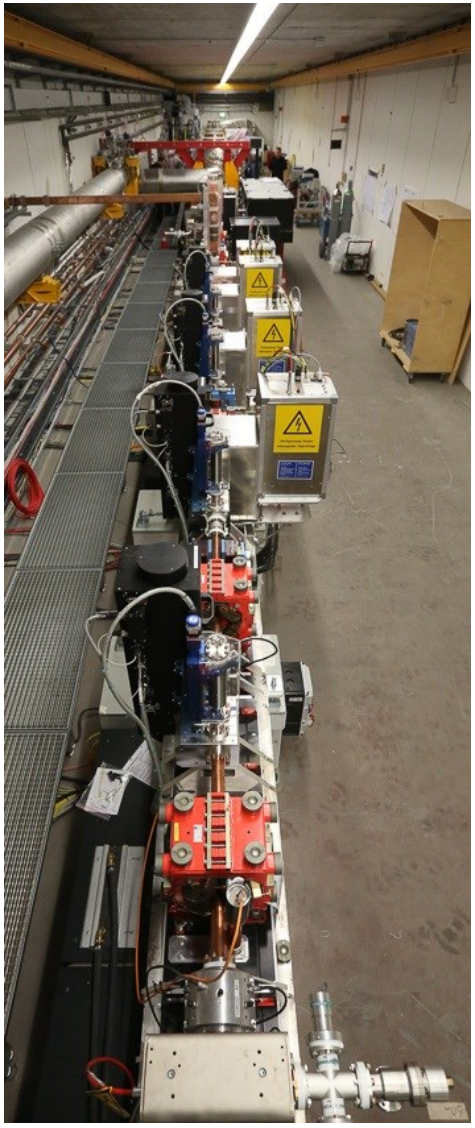


**Dump** Transverse Deflecting Structure

Spectrometer Diagnostic Section Laser Heater 3.9 GHz Module 1.3 GHz Module **Gun**

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

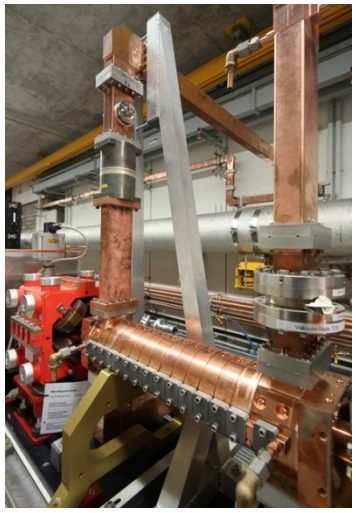




- Injector installation finalized in Q4/2015
- 3.9 GHz module installed in 9/2015
- Injector cool-down started beginning of 12/2015
- First Beam on December 18th , 2015
- Successful commissioning during Q1/2016

- 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 0.5 mm mrad for 500 pC;** also over bunch train
- Laser heater commissioning started



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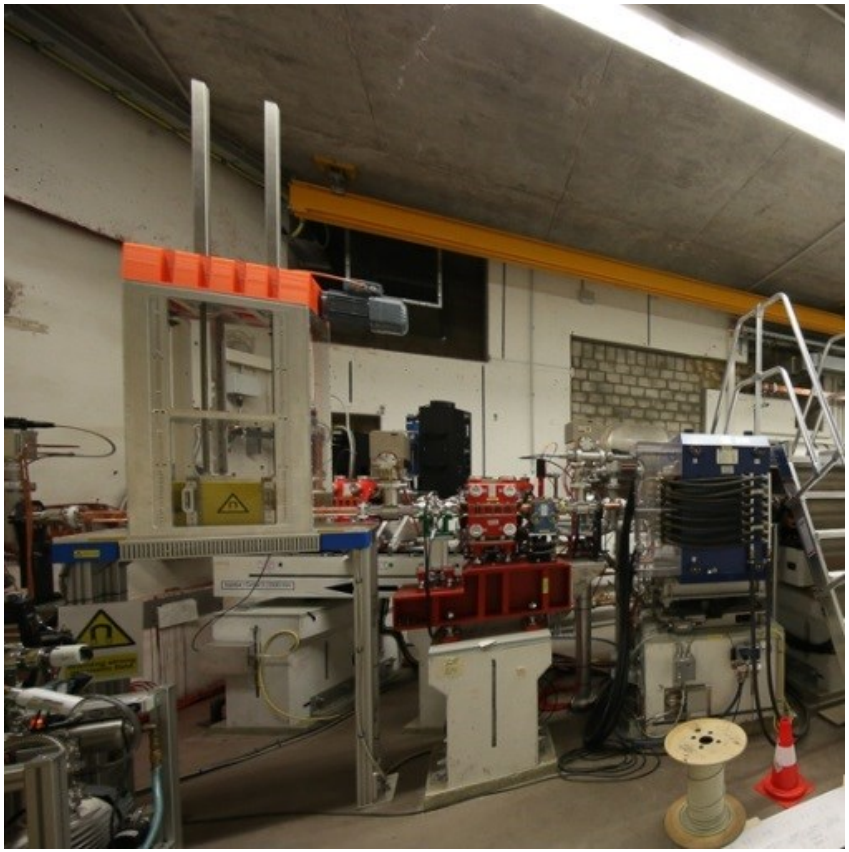
# Full Bunch Train Operation





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

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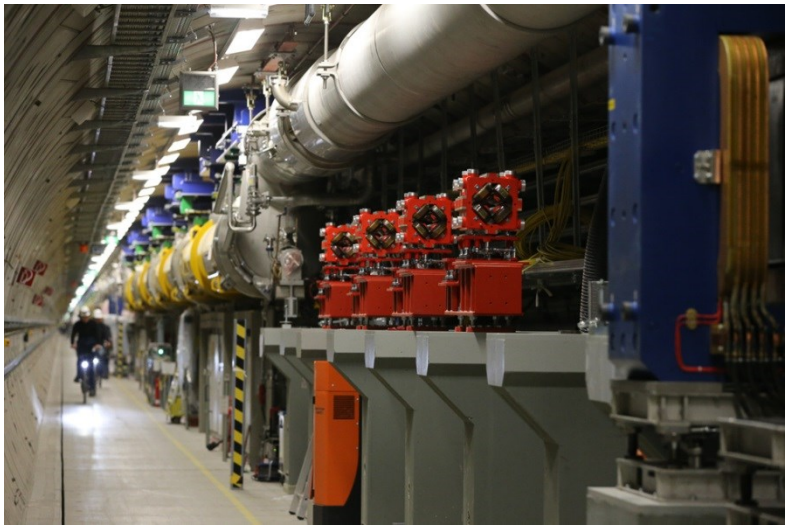
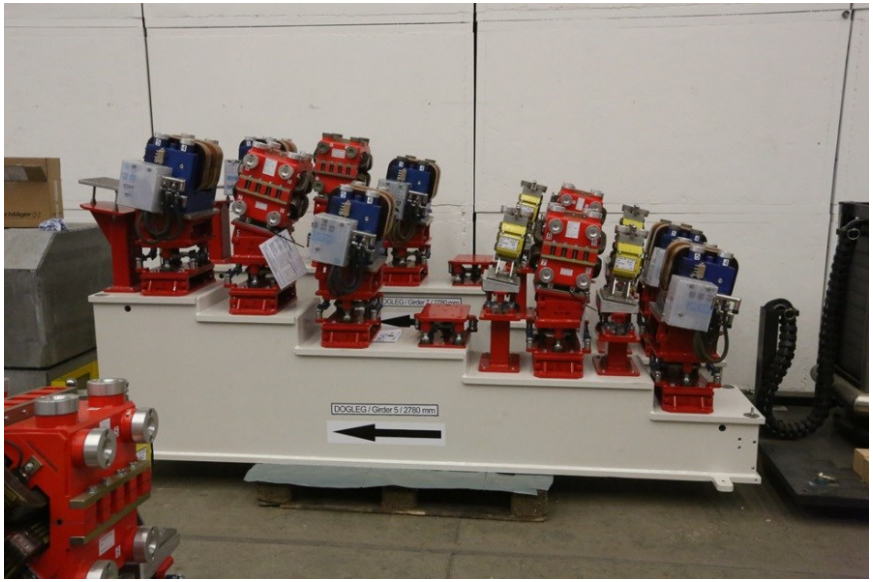
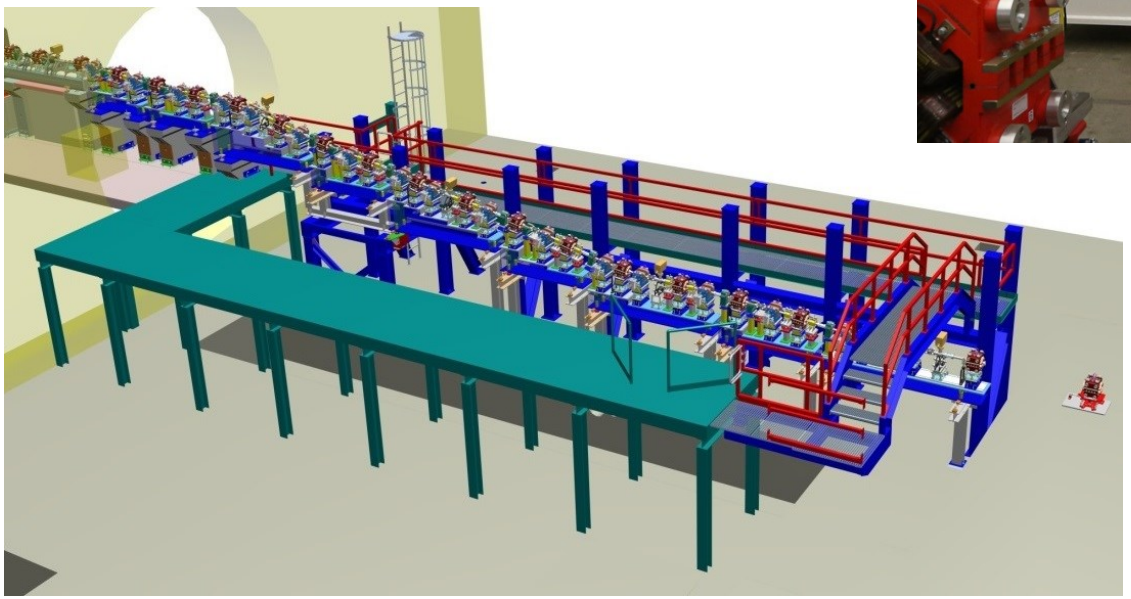
# Warm Beam Line Sections
## Dogleg & BC0 in Front of Linac L1









- All girders were pre-assembled in clean rooms
- Tunnel installation required local clean rooms

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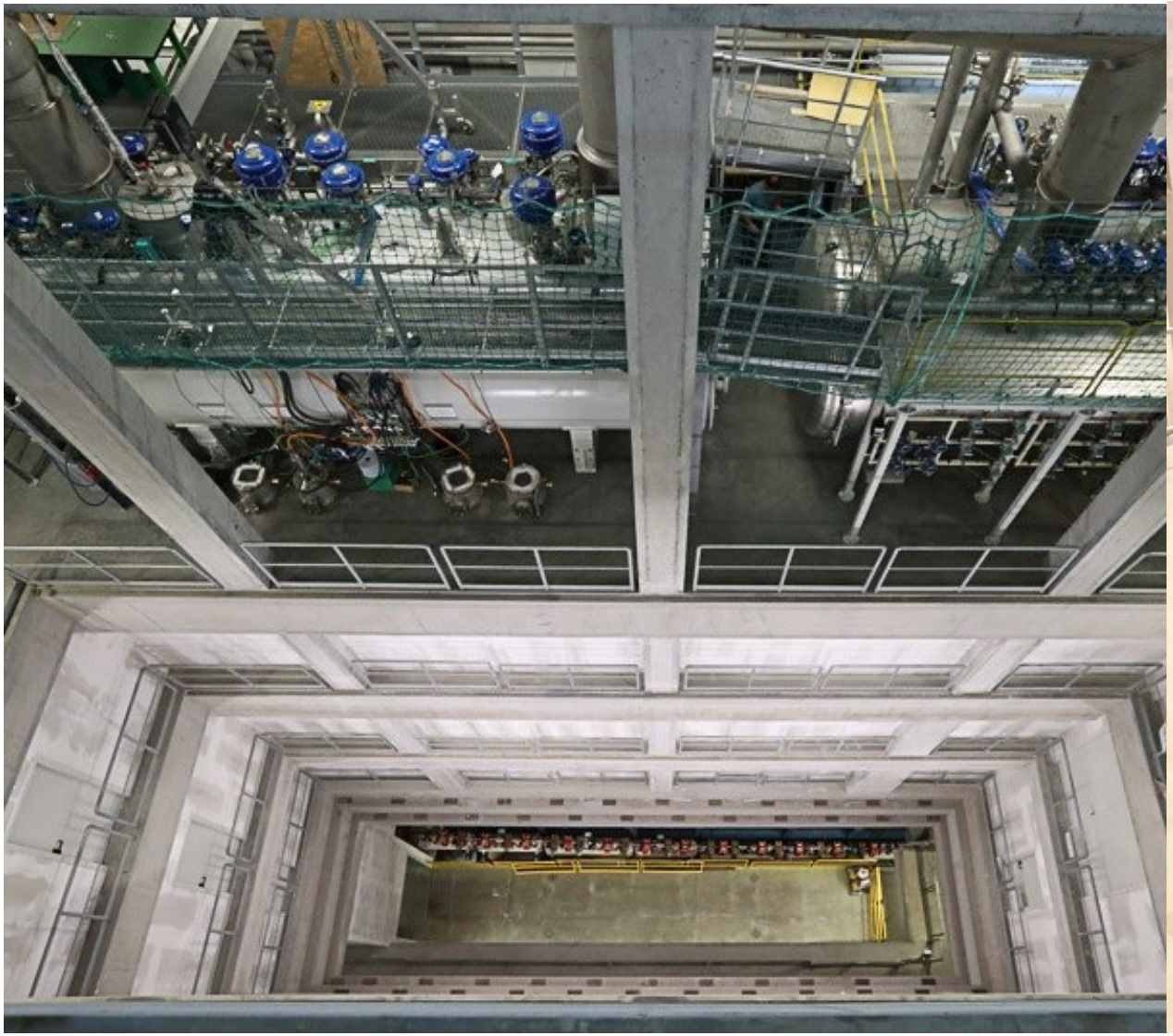
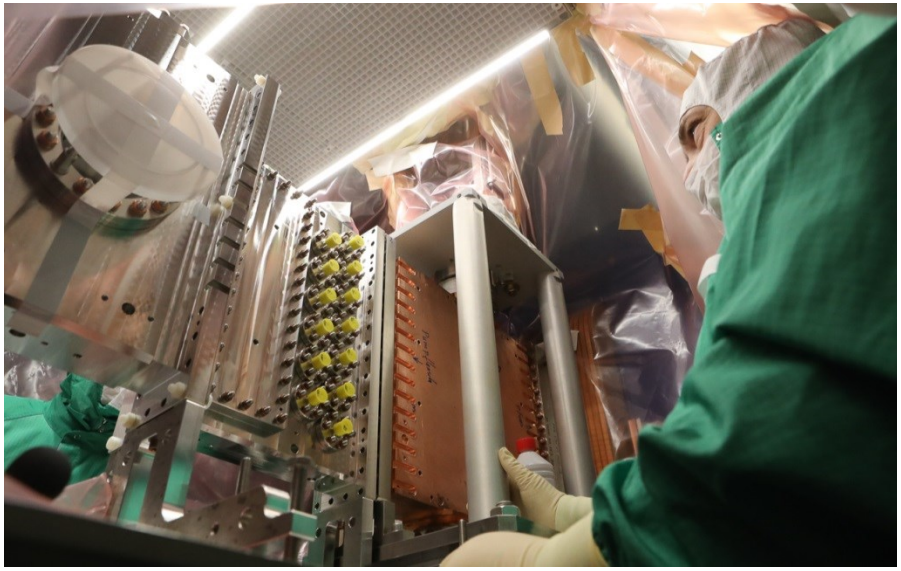
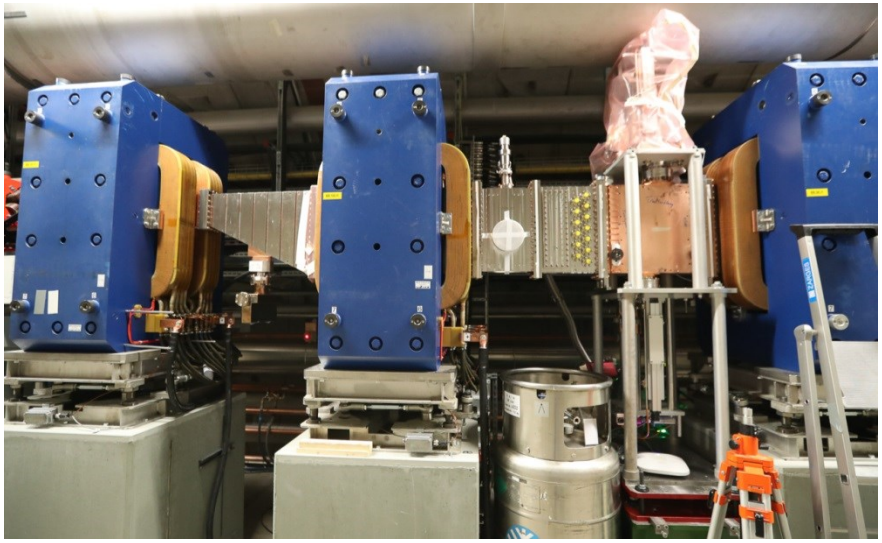
# A real top-view of the Dogleg Section





# Warm Beam Line Sections
## Bunch Compressor Sections – Challenging Installation





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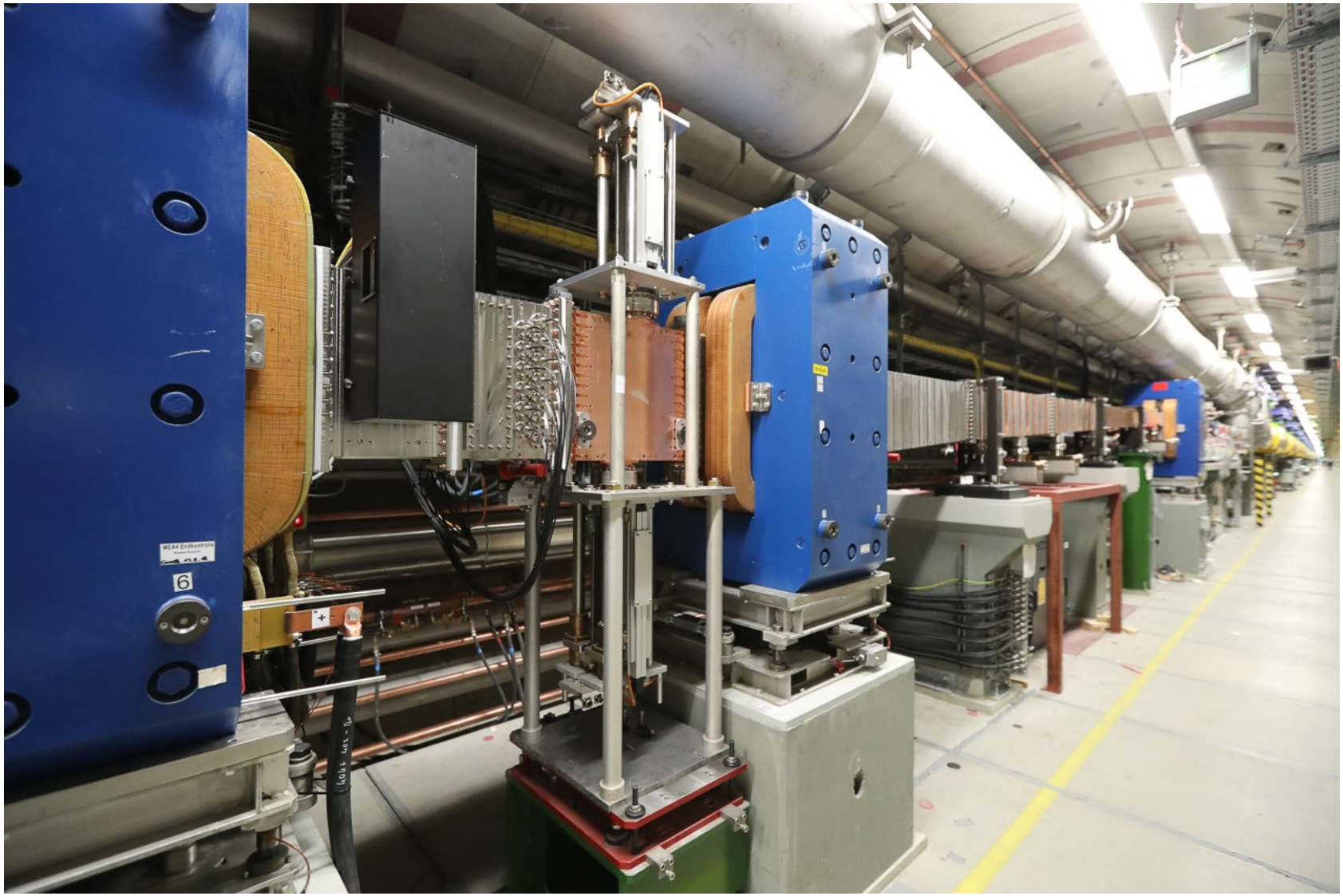
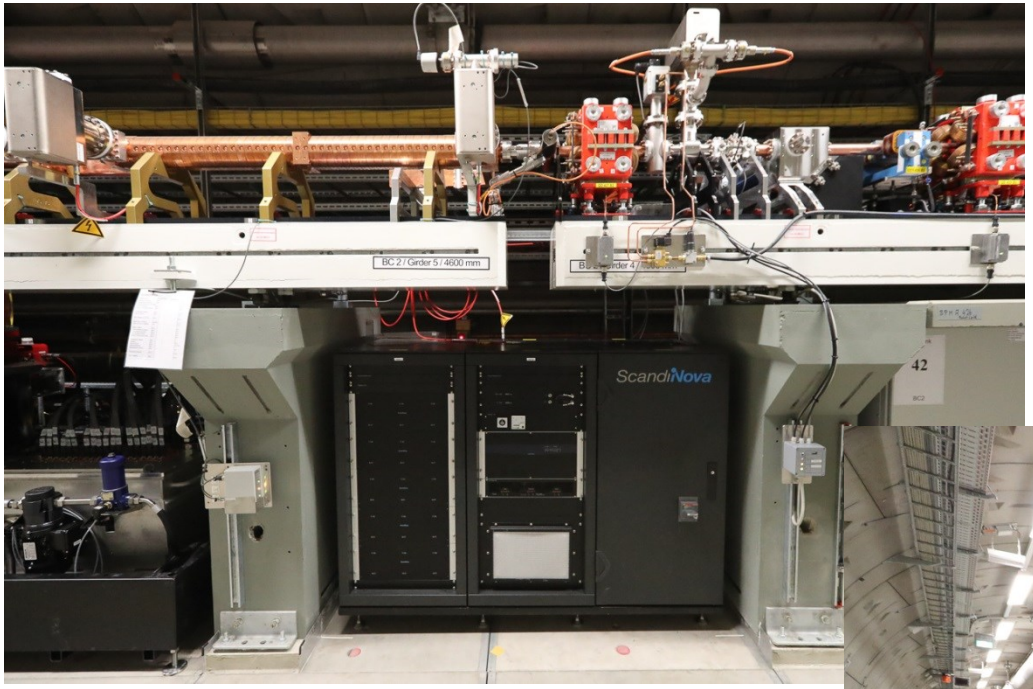
# Bunch Compressor BC1





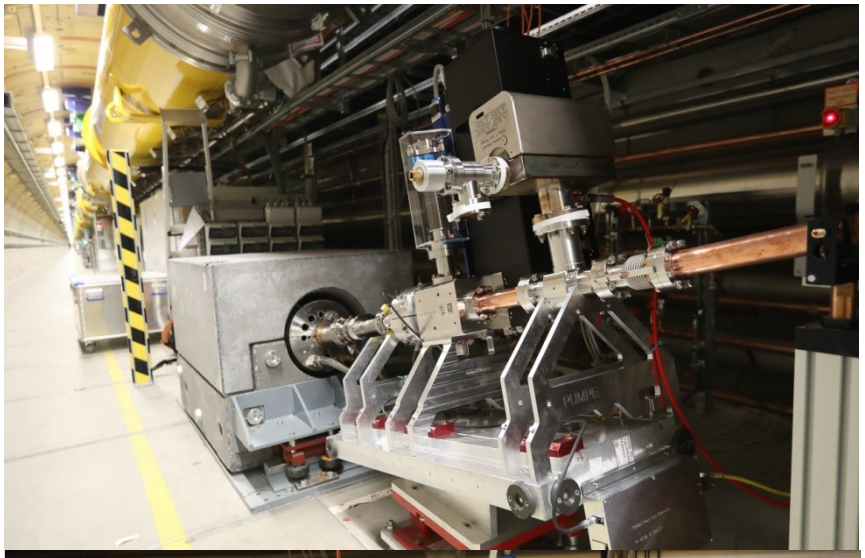
# Transverse Deflection System in Bunch Compressor BC2

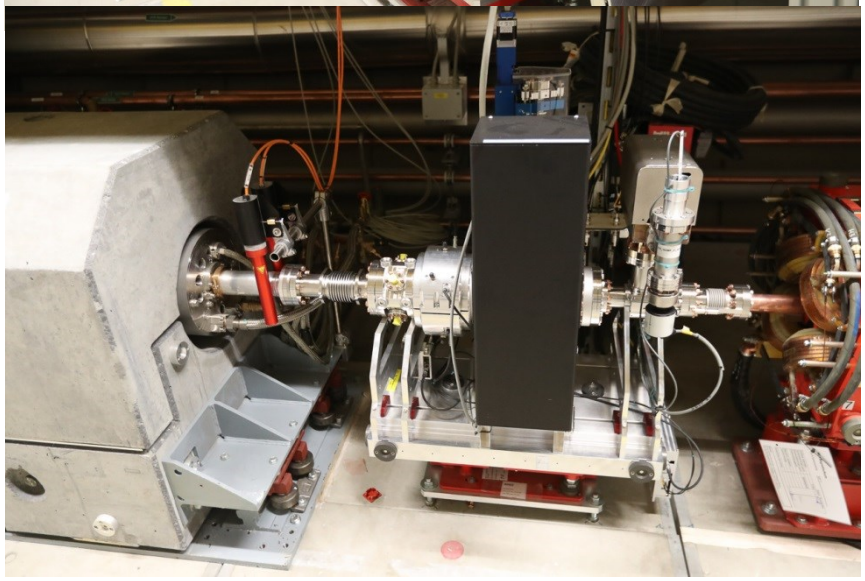




- The BC2 TDS RF station is installed and successfully commissioned.
- TDS structure commissioning is part of the linac commissioning.

# Both Bunch Compressors BC1 / BC2 include Commissioning Beam Dumps





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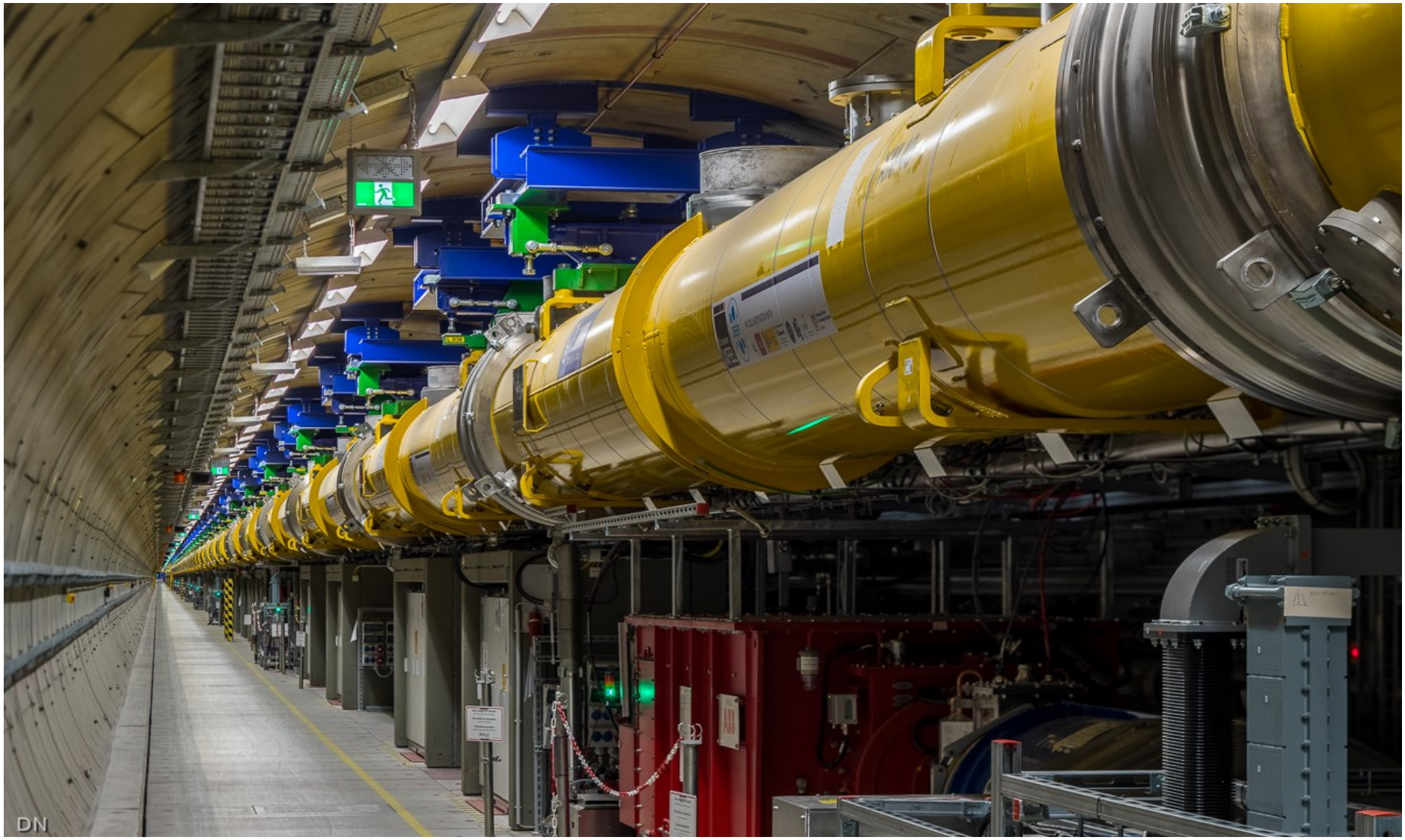
# Linear Accelerator





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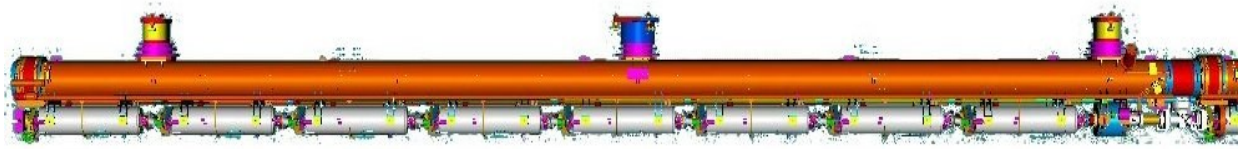
# Accelerator Modules

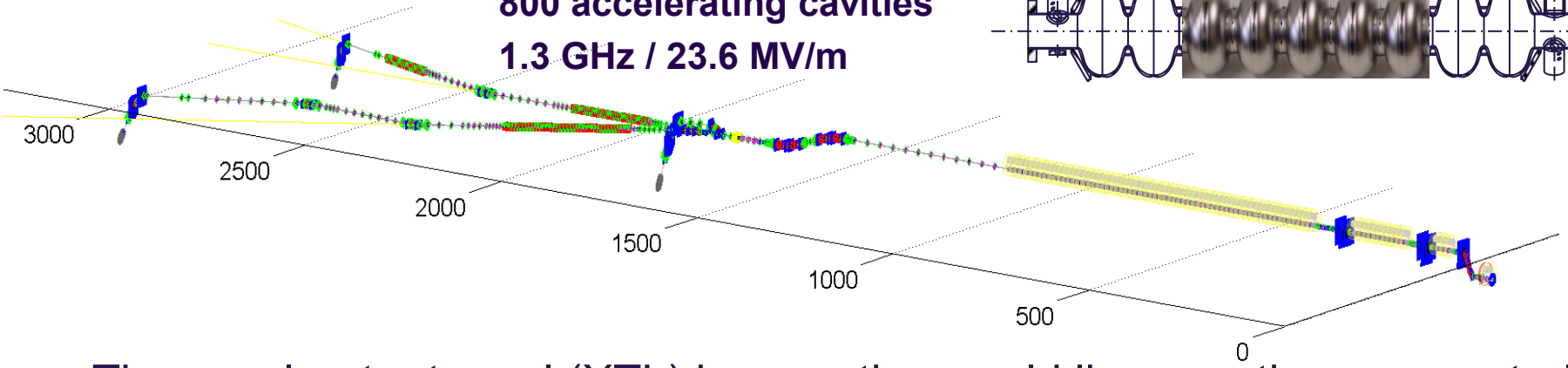


**100 accelerator modules**



**800 accelerating cavities**

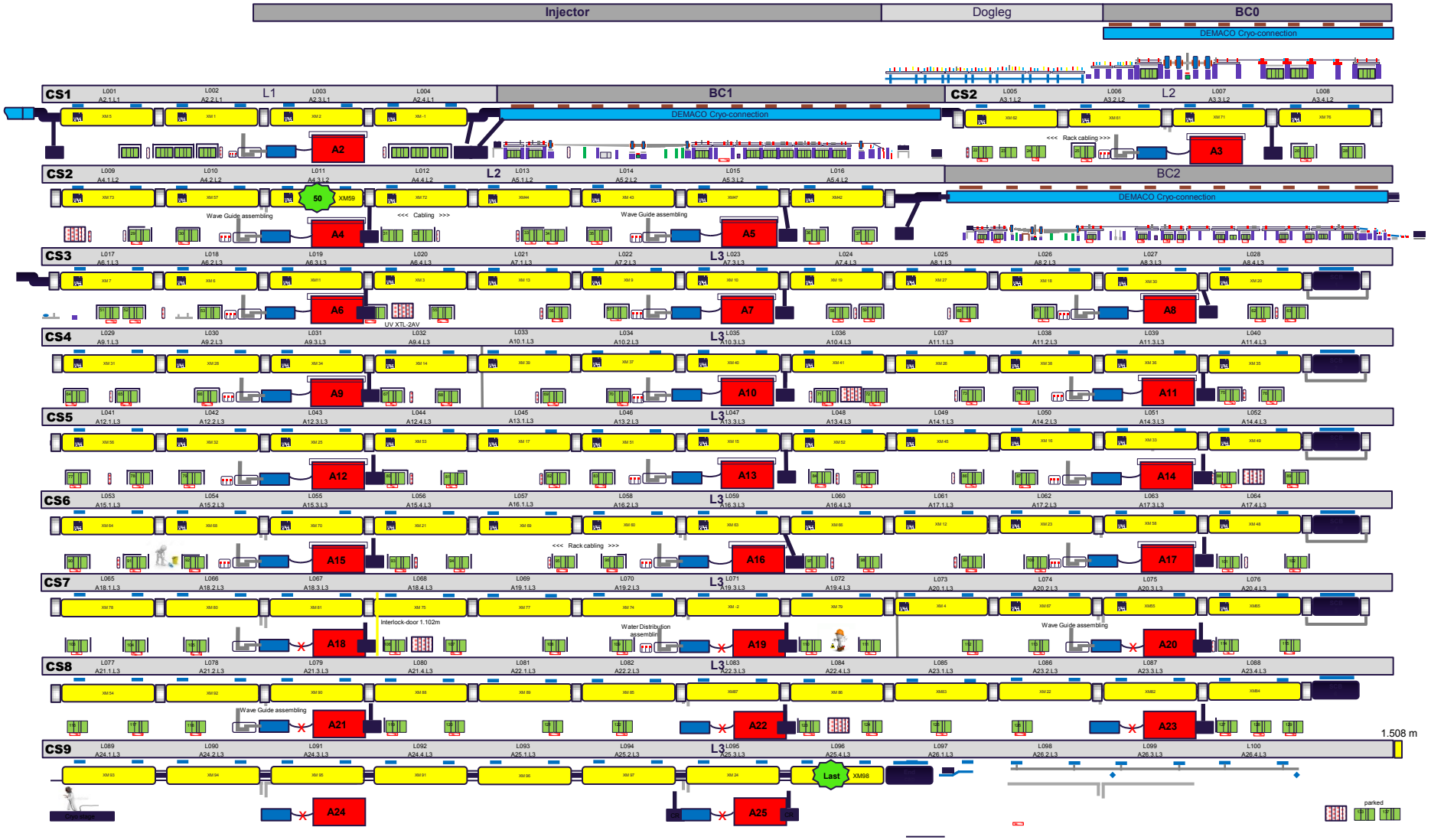
**1.3 GHz / 23.6 MV/m**




- 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.

# All Accelerator Modules Installed

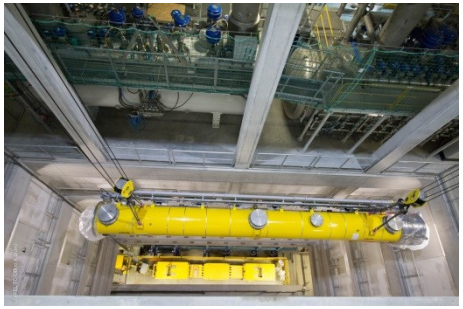
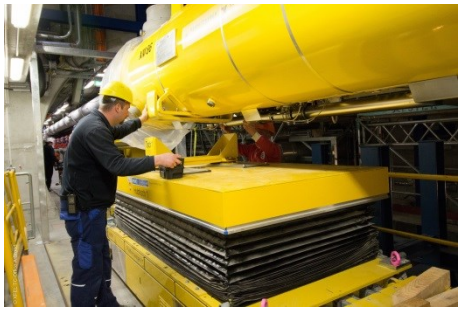




# Accelerator Module on its Way to the Tunnel

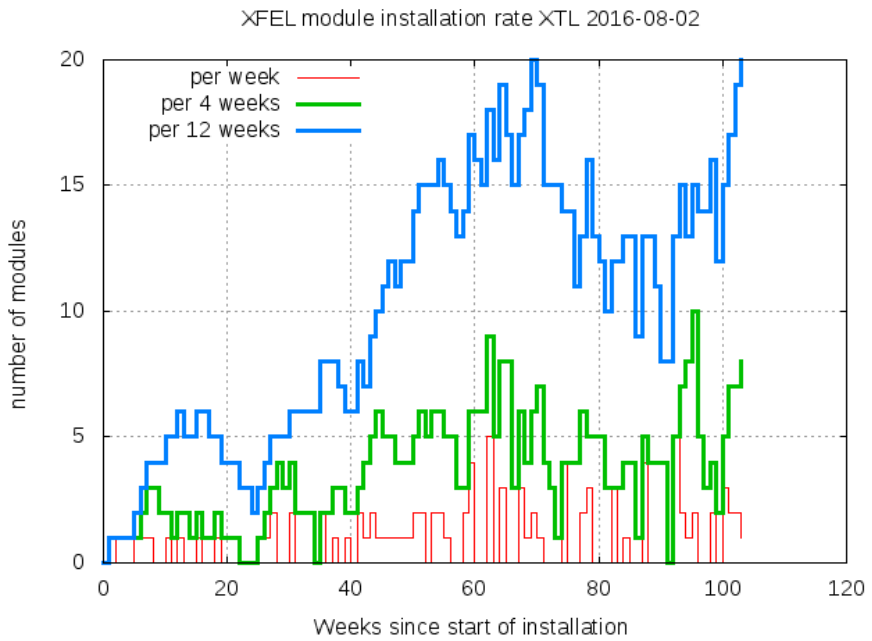


- 1st module July 1st, 2014 – last module August 1st, 2016

# 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 last Process Line Welding on Sep 9, 2016

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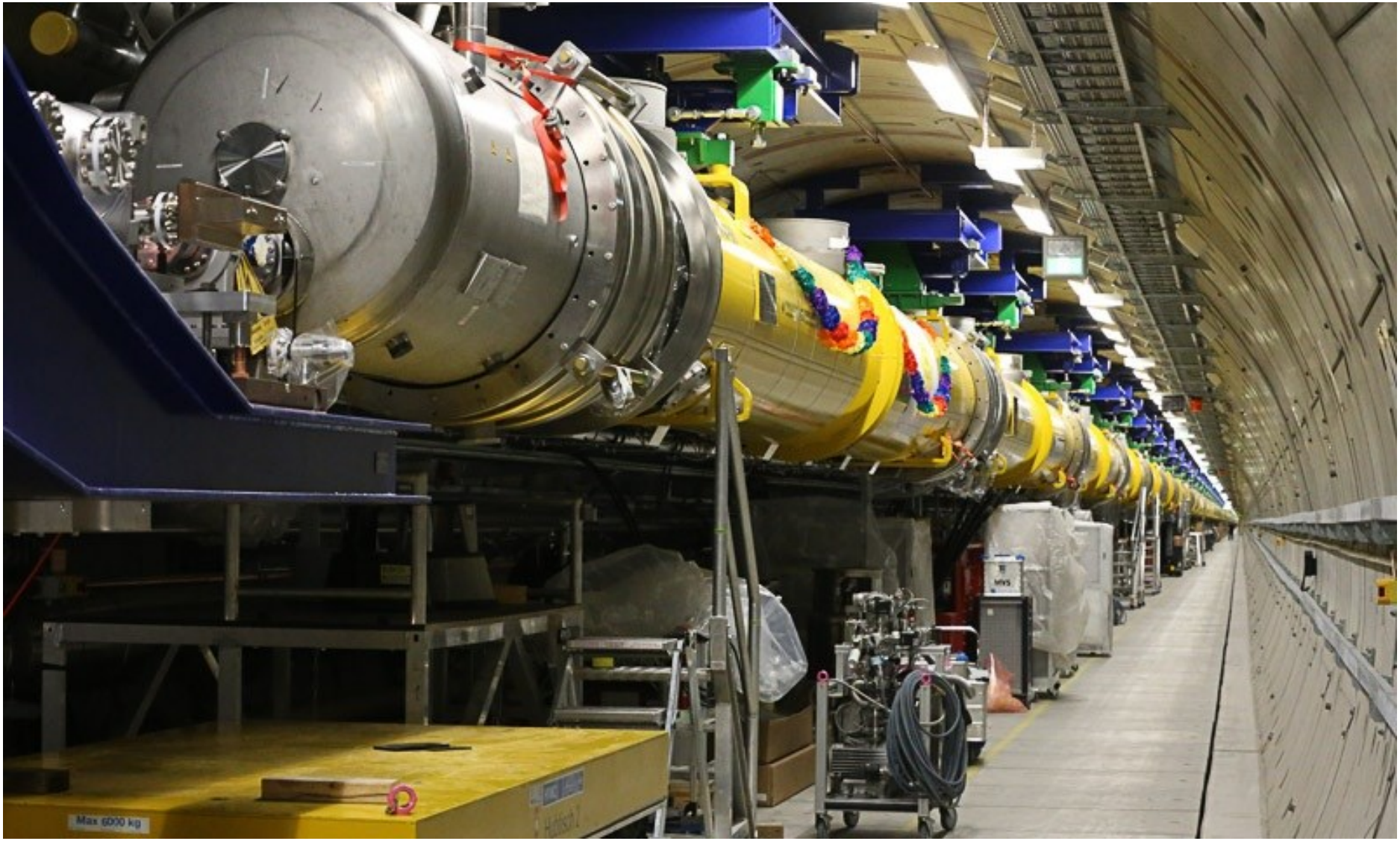
# The End of Main Linac Section L3





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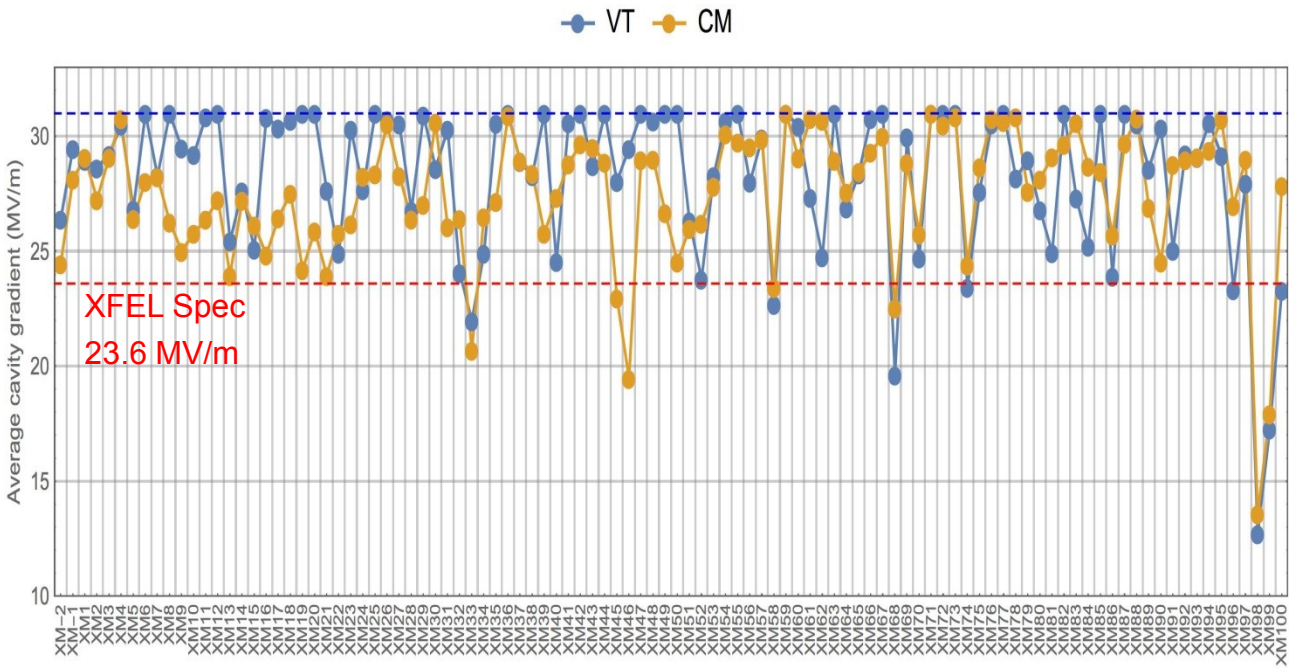
# XFEL Module Performance






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 |

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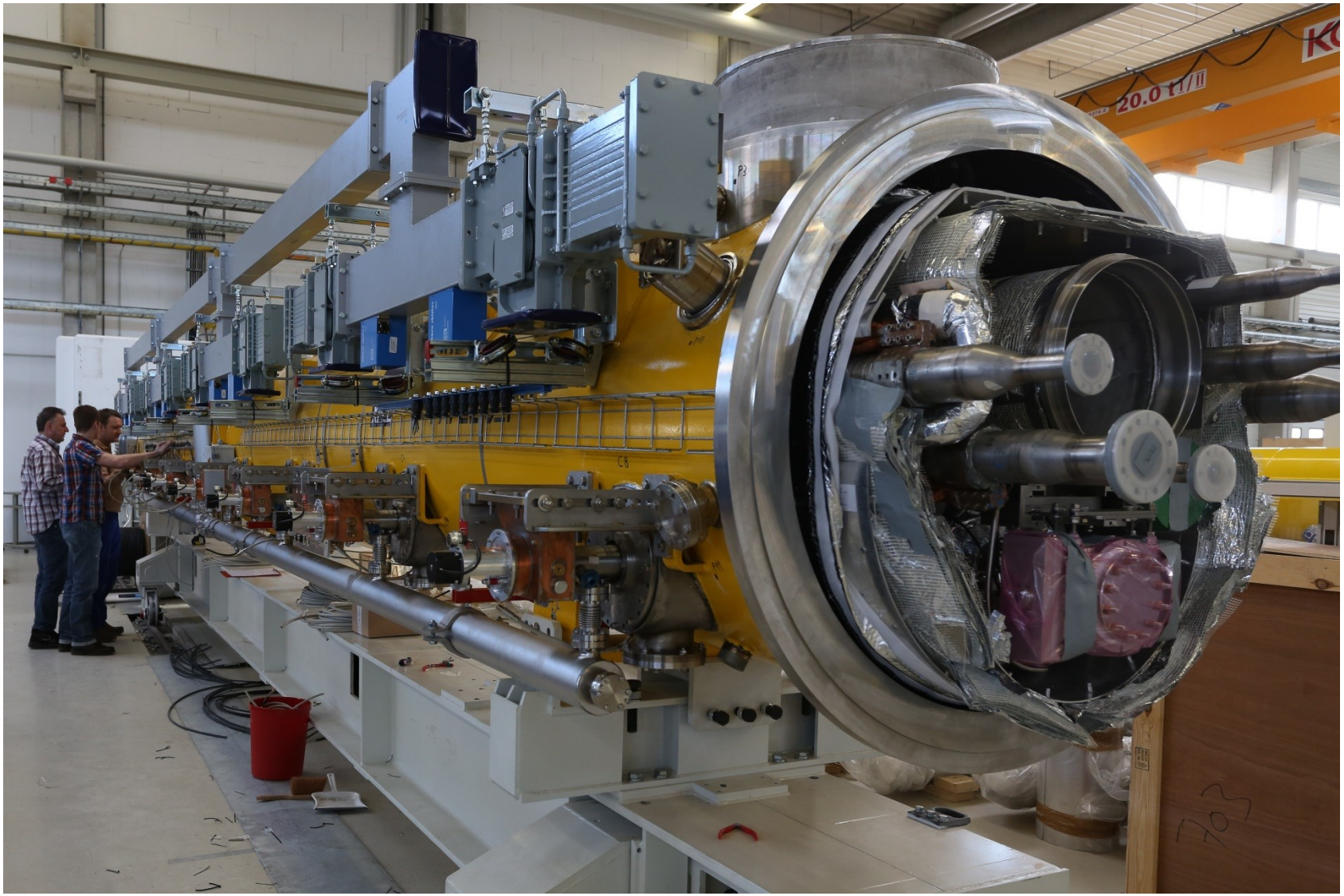
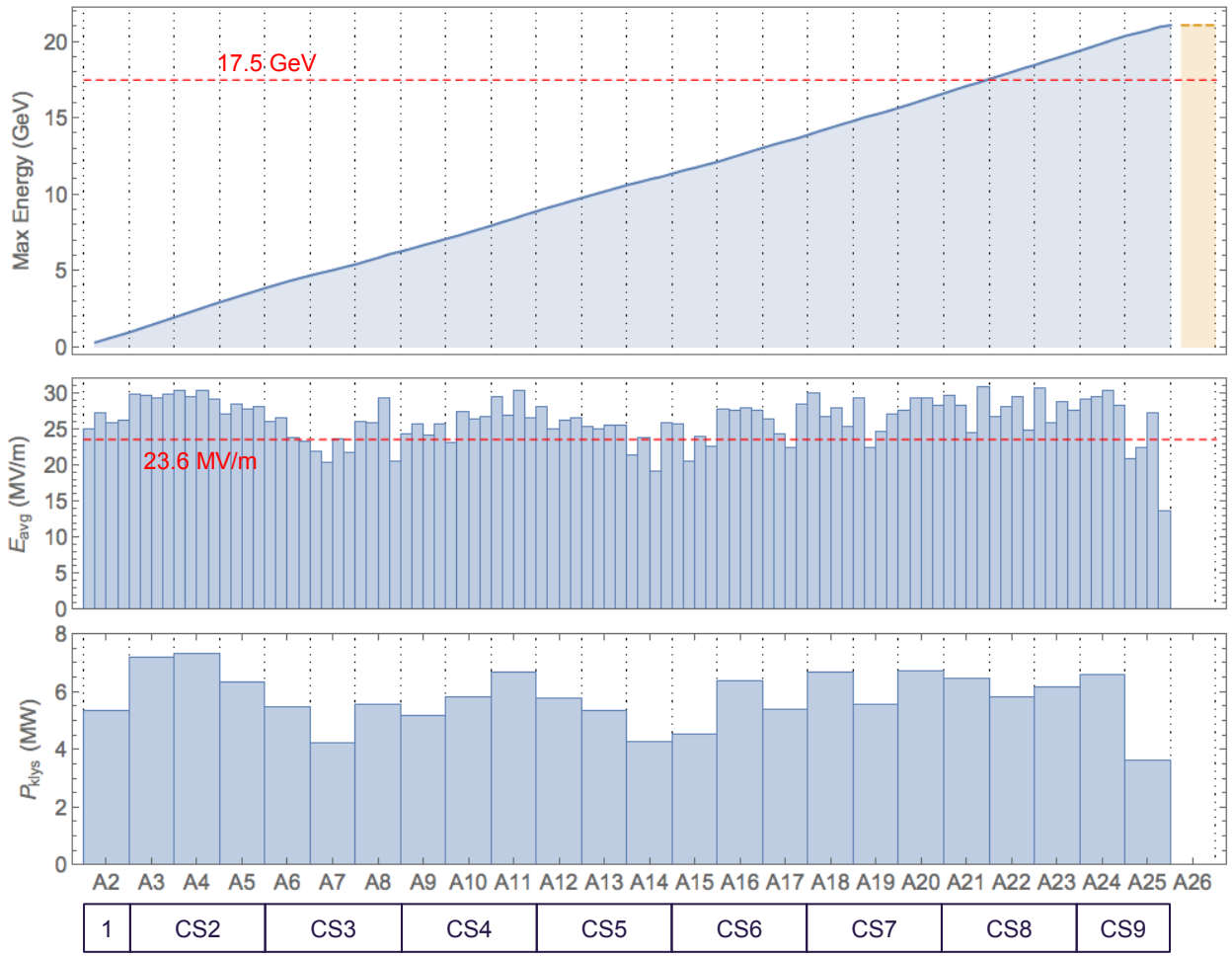
# Waveguide Tailoring was done for all Modules





# 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

# Tunnel Installation Process



- Optimized global process steps and sequence & daily improvements

Cryo-String

RF

Signal Cables

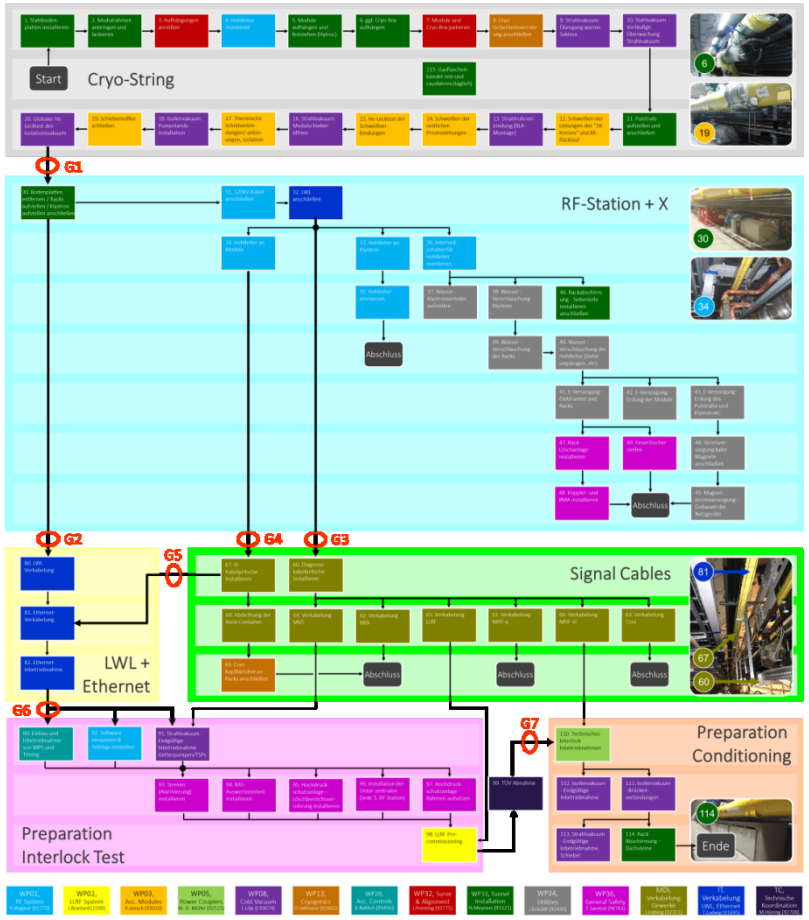
LWL

Ethernet

P.I.

Prep Cond

TÜV



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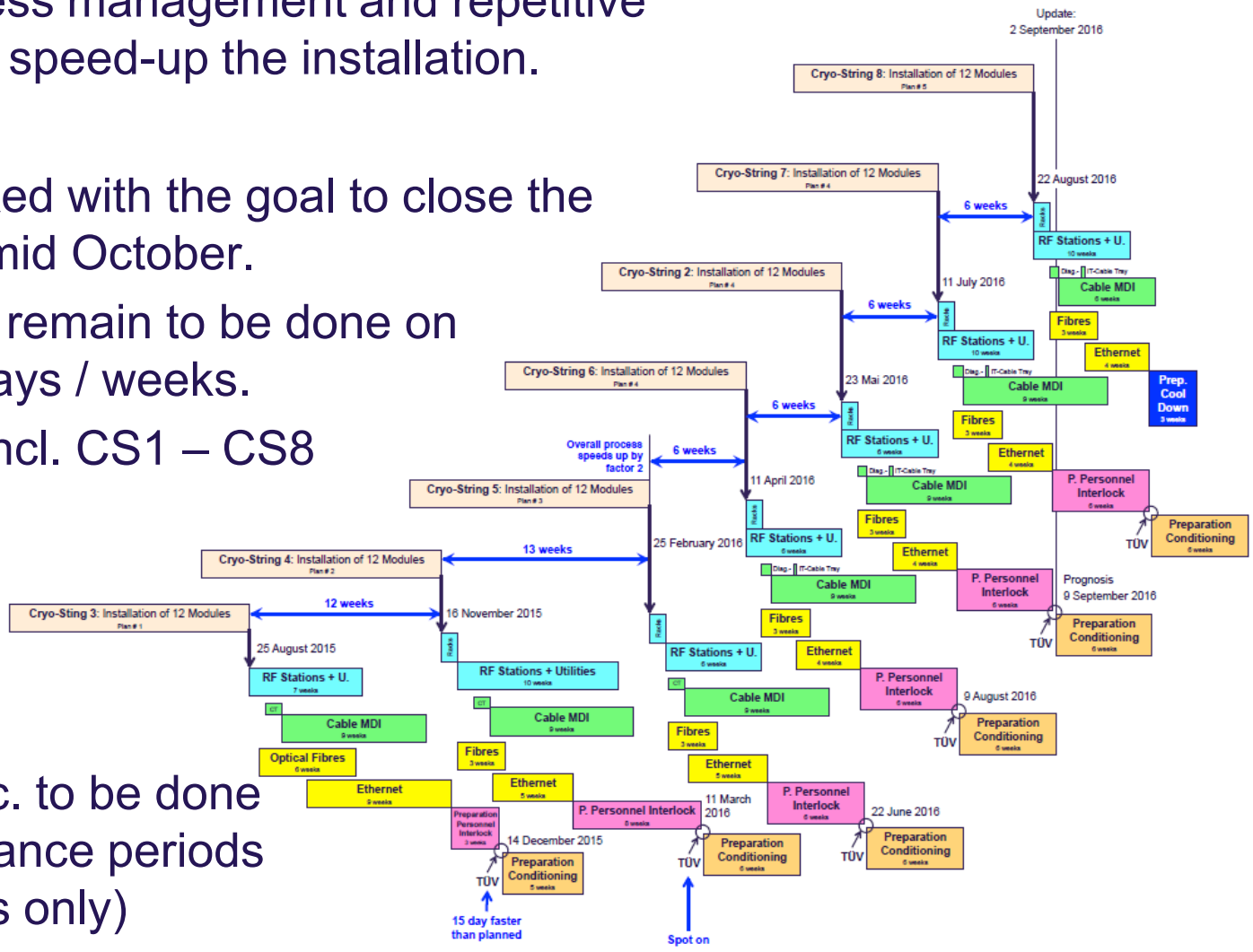
# Process Management XTL Installation



- 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 periods (two RF stations only)



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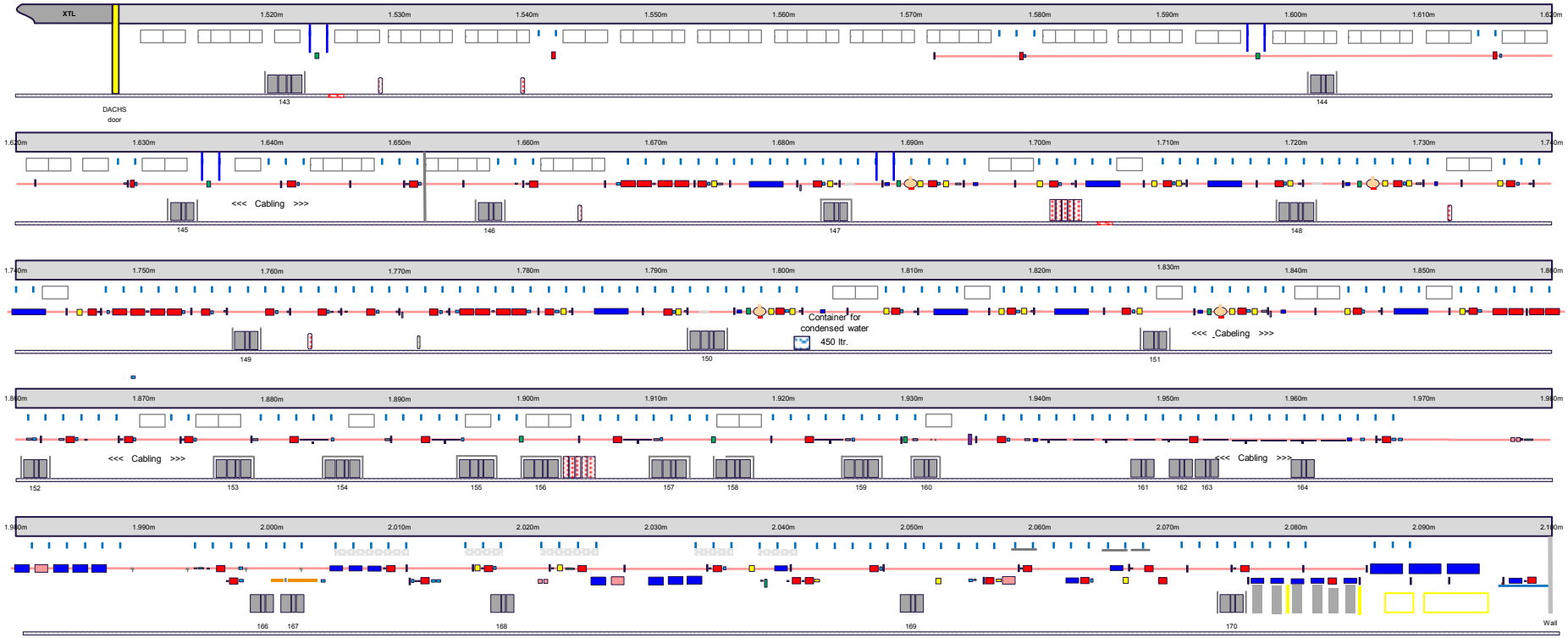
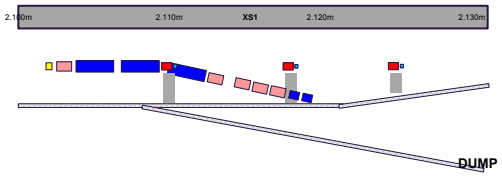
# Post Linac Beam Lines upstream of XS1

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



- 200 m beam distribution
- 100 m XS1 dump line



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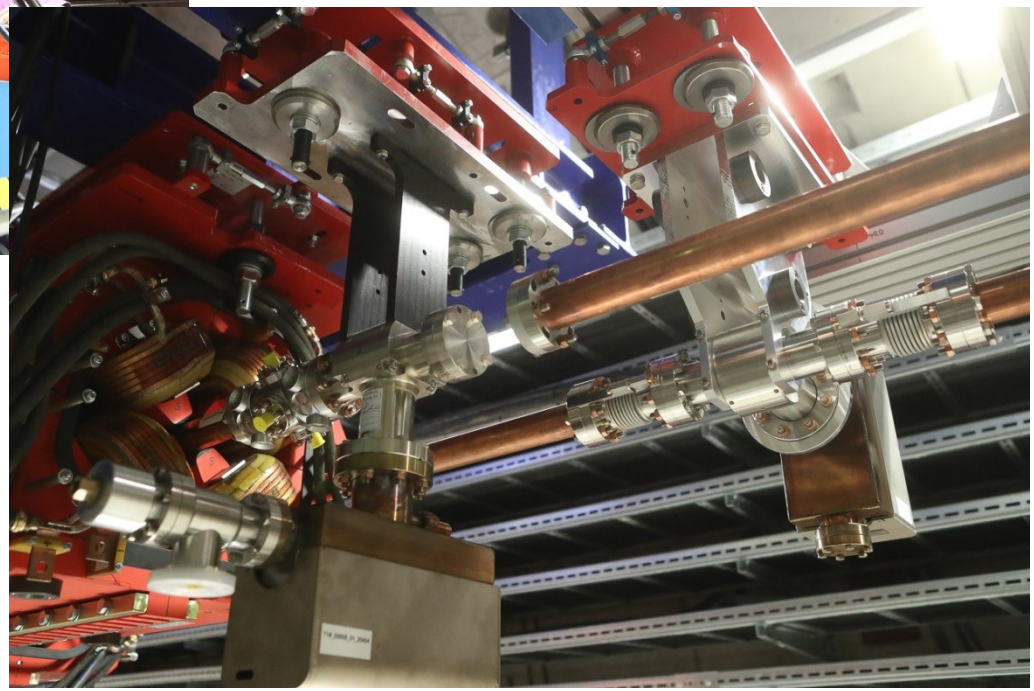
# Beamline Installation close to XTL Tunnel End

- Installation work finished beginning of Q4/2016
- Commissioning finished also.



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



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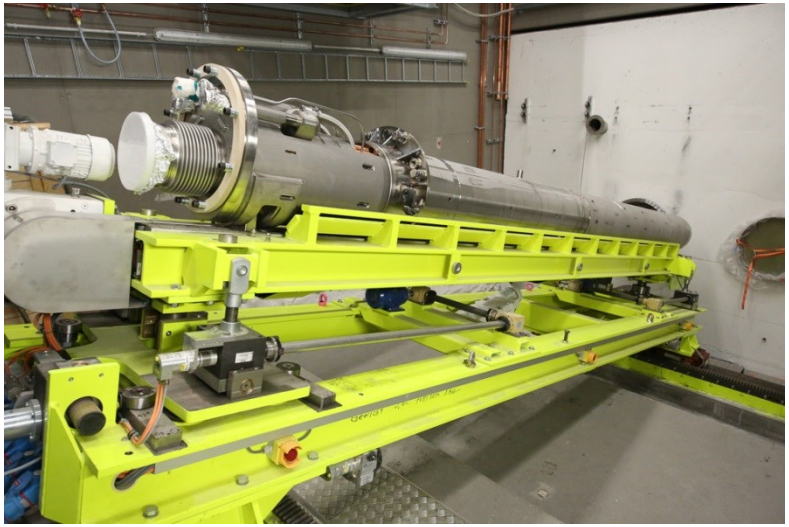
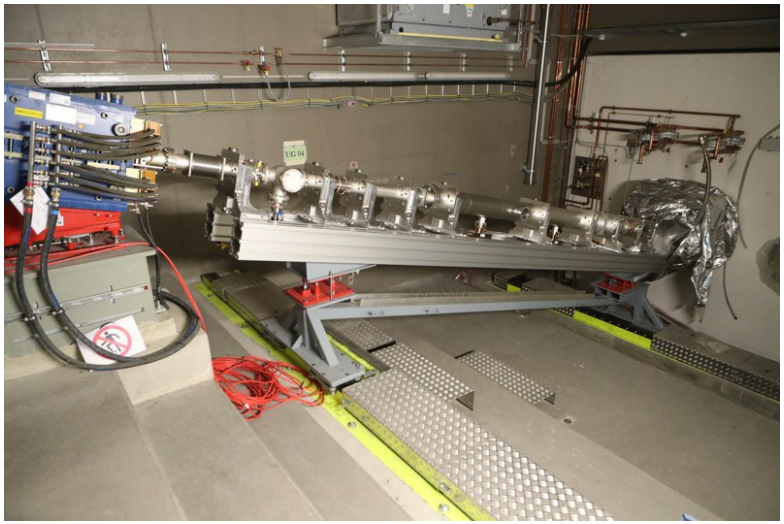
# Warm Beam Line Sections
## Transport Line to XS1 Beam Dump







- All beam dumps available and XS1 as well as main dump installed
- Special vehicles to exchange activated dumps

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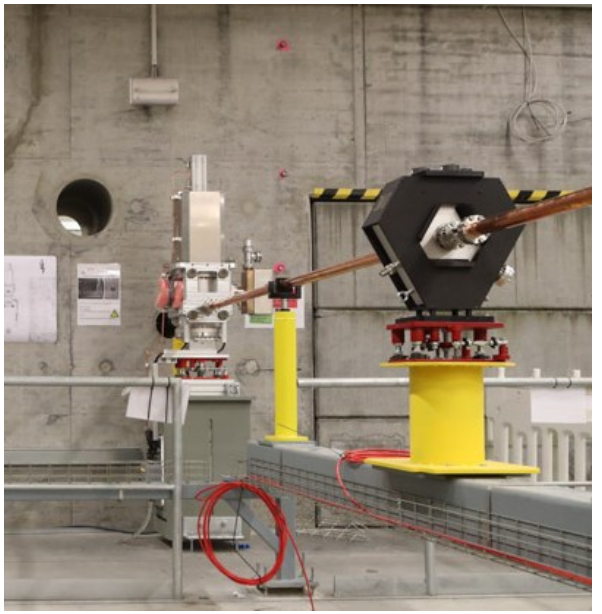
# Installation on Top of XS1 Dump Cave



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





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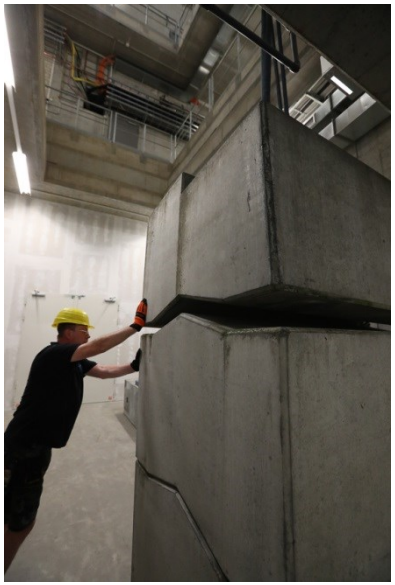
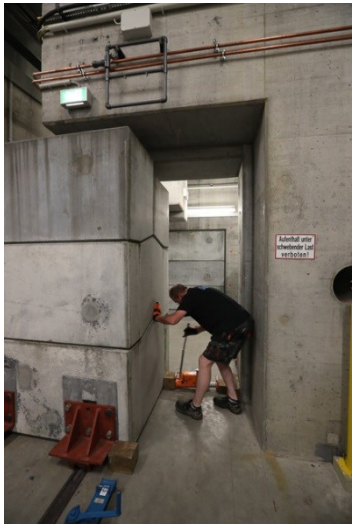
# Shielding and Personnel Interlock





- Shielding and personnel interlock finished in Q4/2016.
- Final internal check of the personnel interlock done Nov. 15/16.



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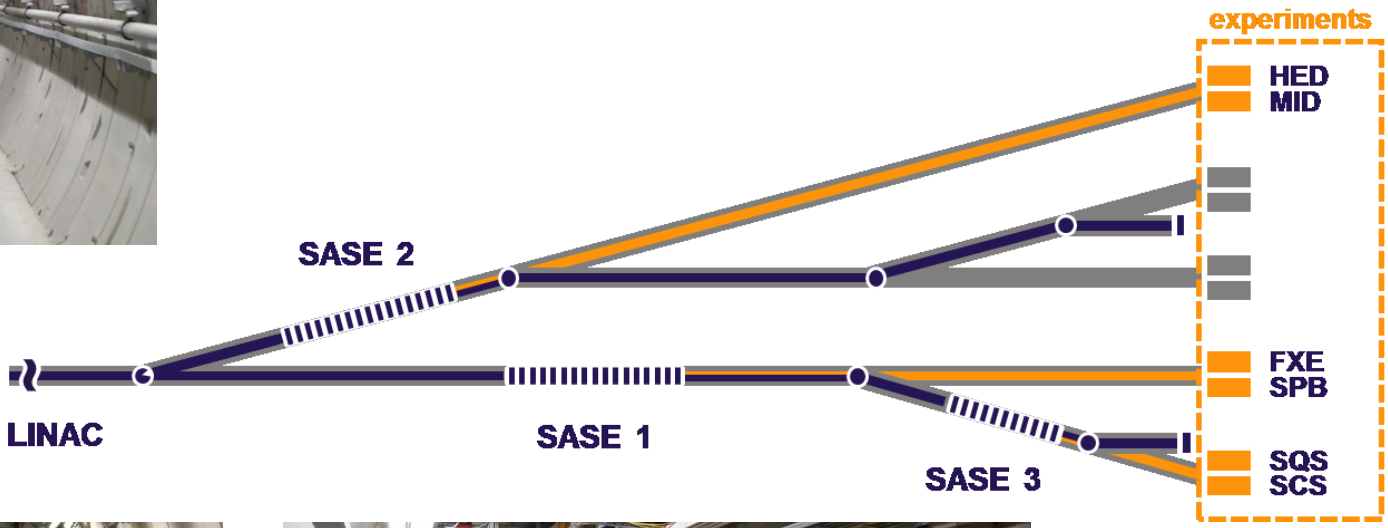
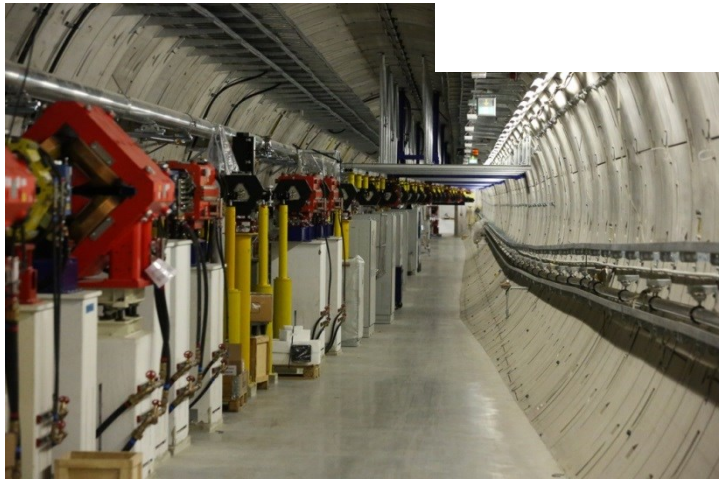
# Installation Activities
## SASE Undulator Sections

- BINP and DESY teams have finished the mechanical vacuum work in the northern branch.
- Work in the southern branch is still ongoing.



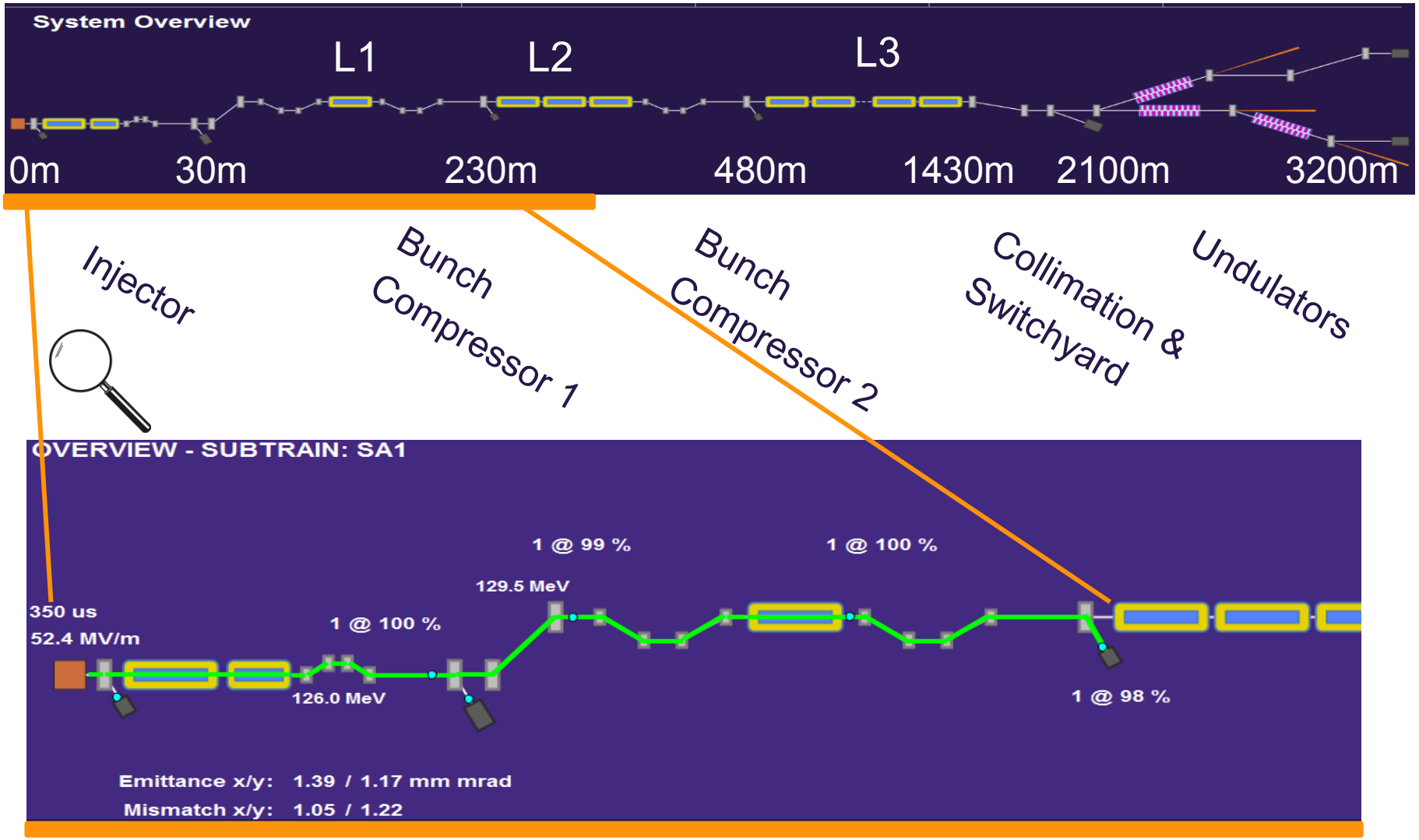



# SASE Undulator Sections
## with special air conditioning hutch

# Linac Commissioning started from Accelerator Control Room (BKR)

# System Overview – BKR Perspective





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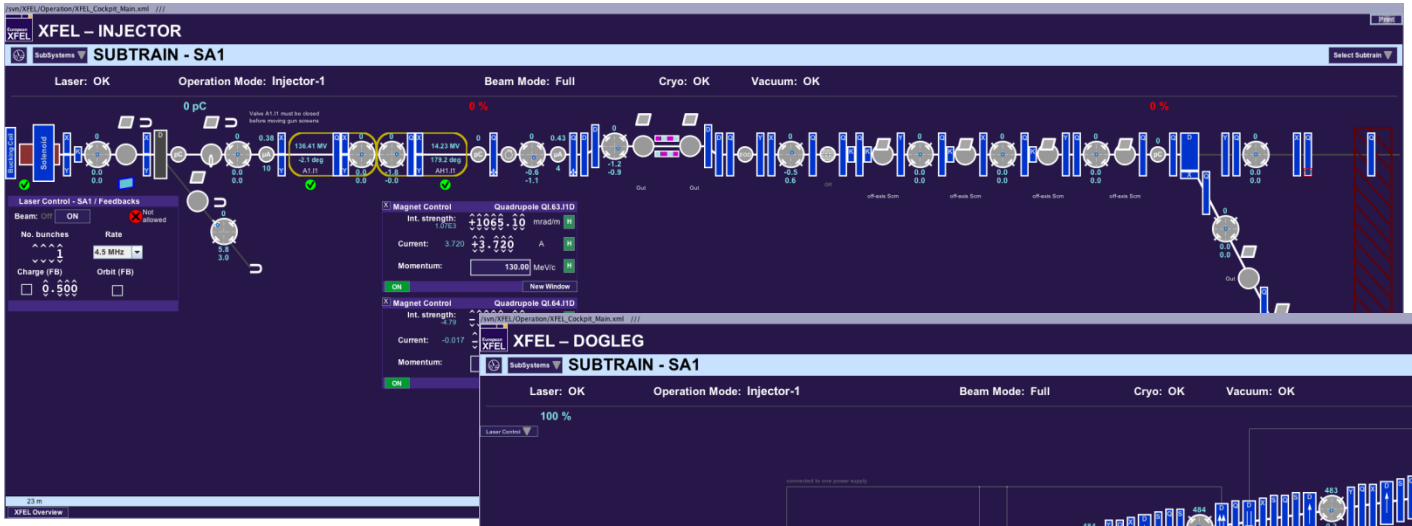
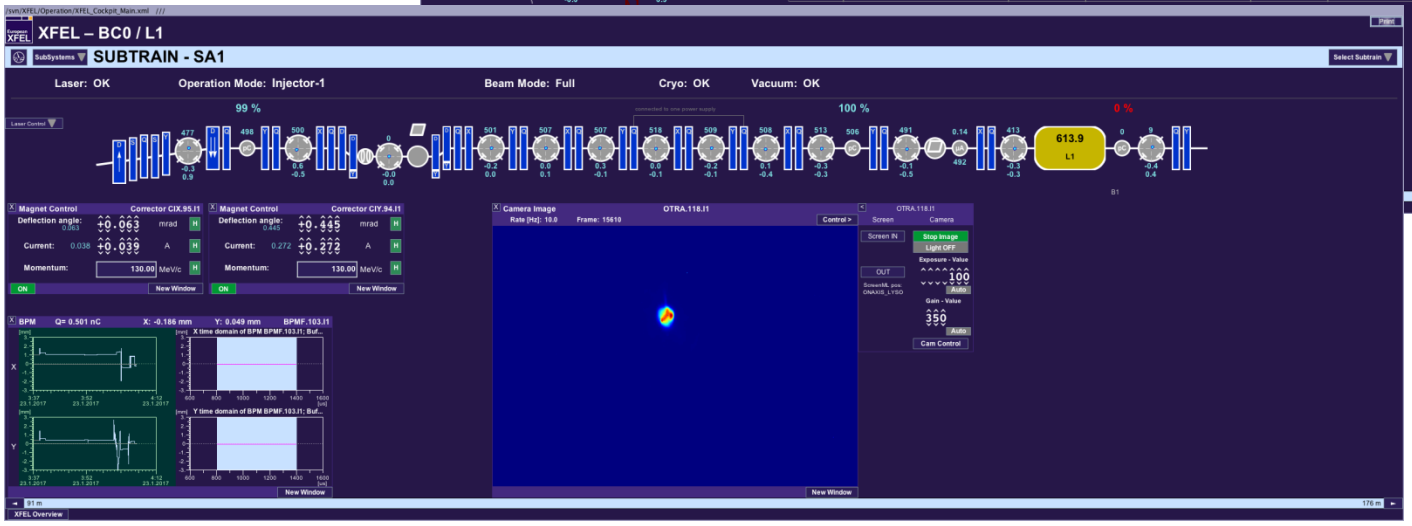
# First Linac Sections on the Control Screen







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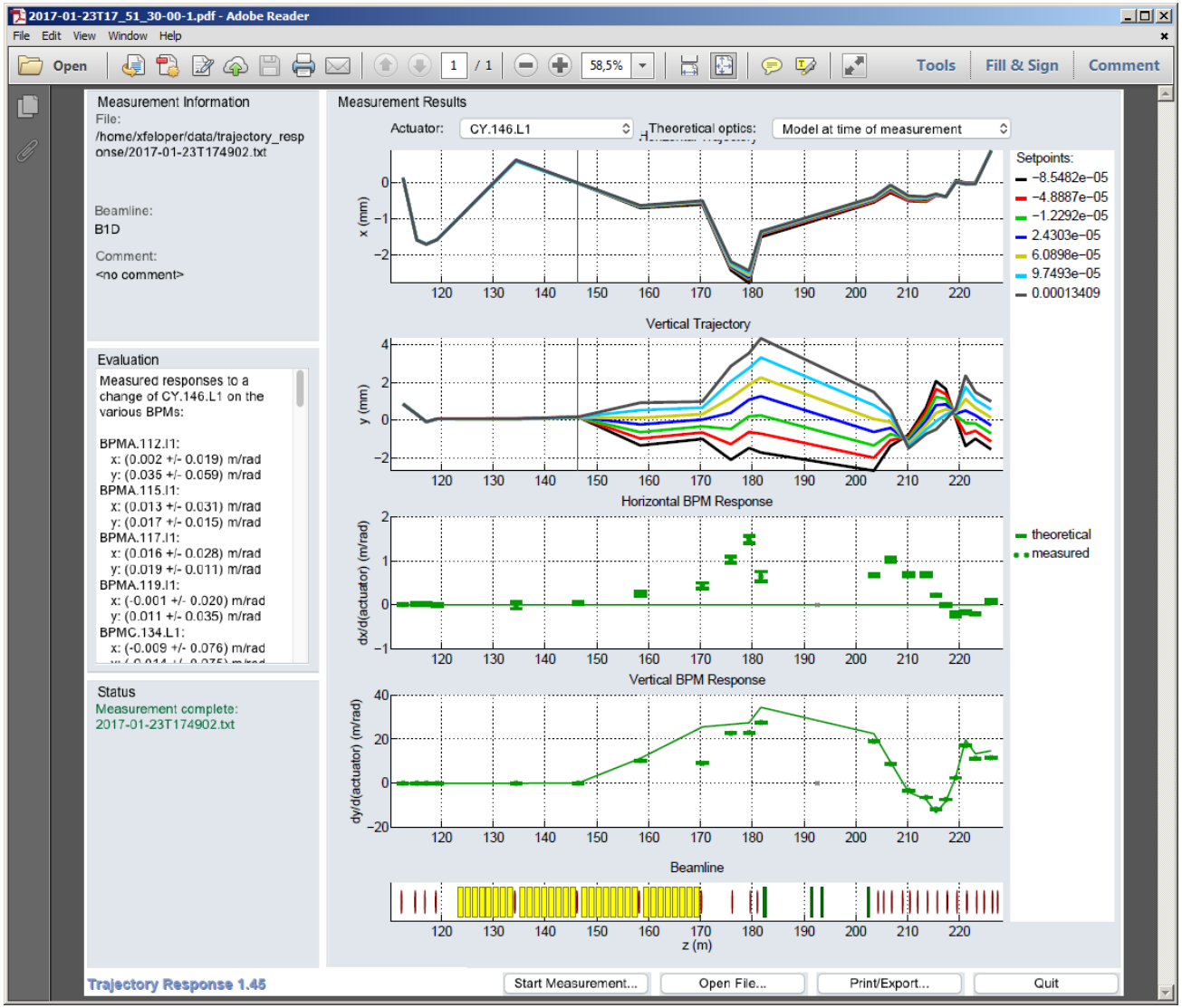
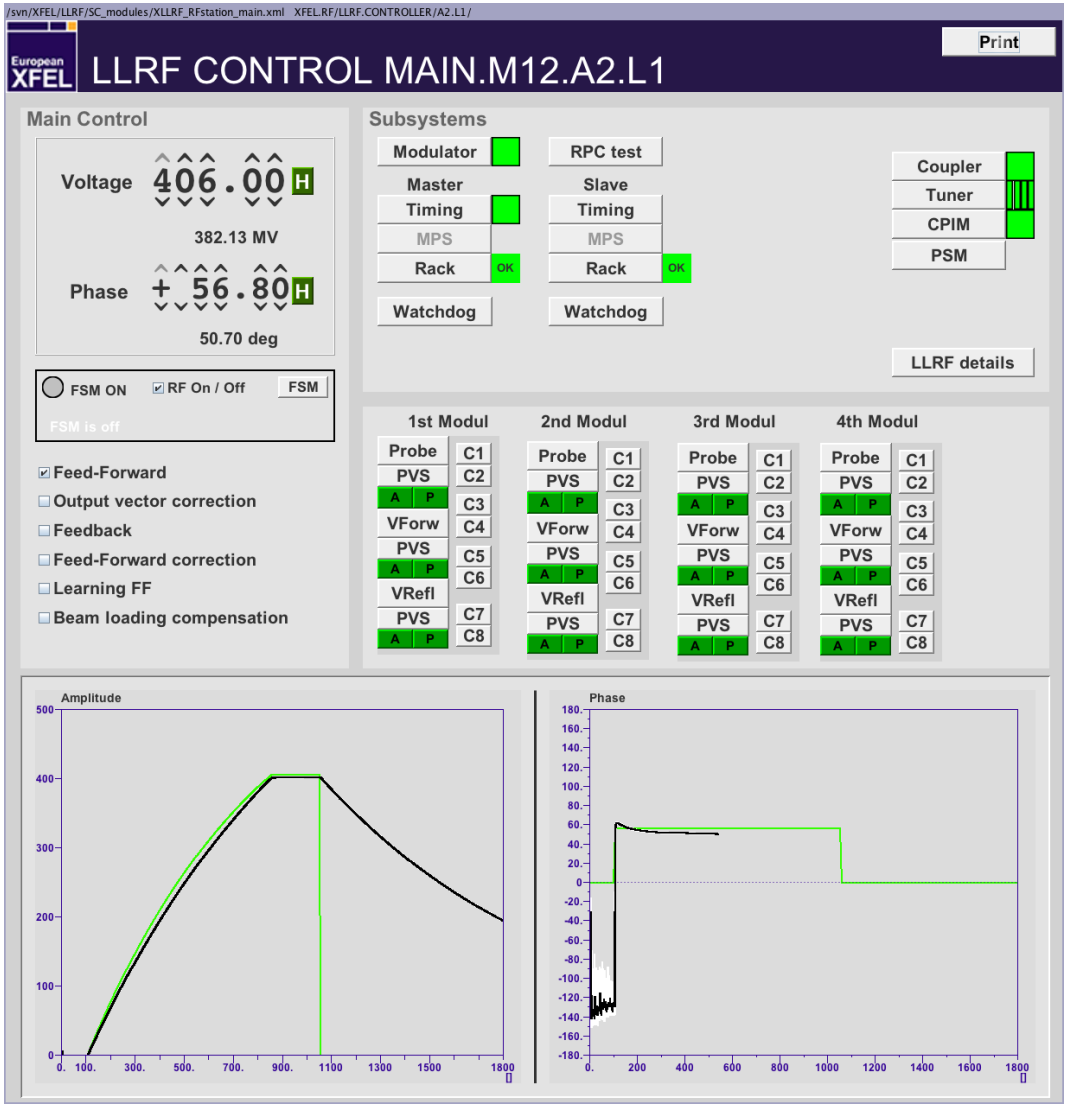
# Work on Trajectory Response (here @ 600 MeV)





# First RF in Linac Section L1



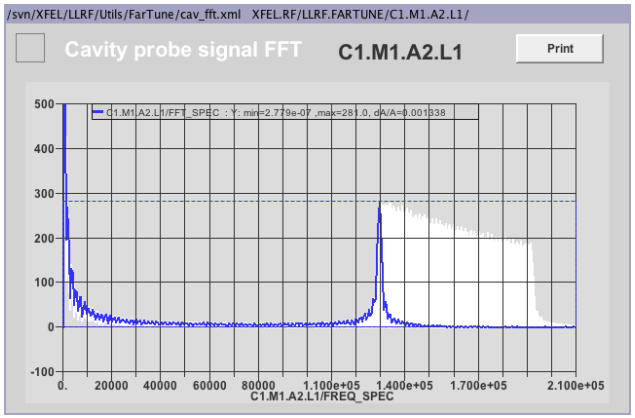


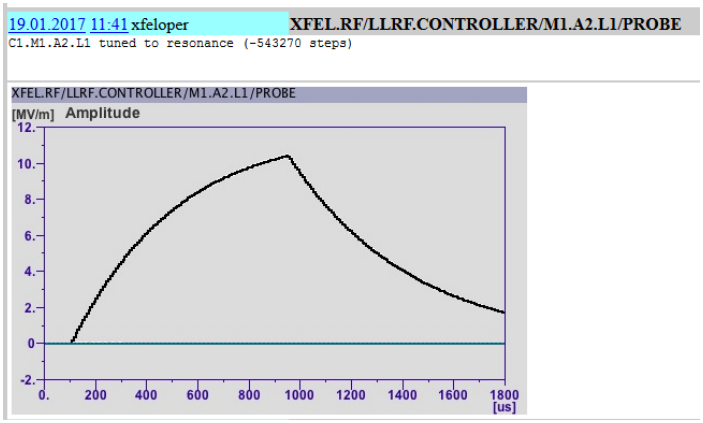

- The pannel shows the vector sum control settings.
- Vector sum amplitude and phase are calculated from probe signals of all cavities.

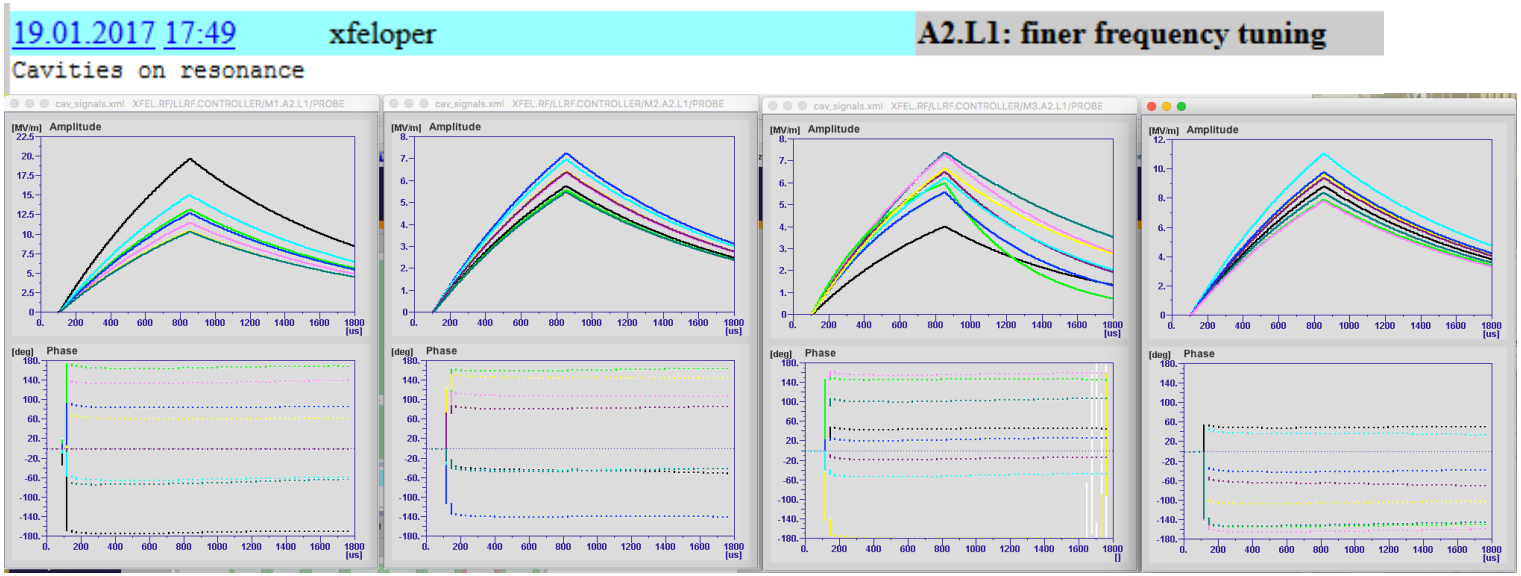
# Full Beam Transmission to BC1 Dump

# 19.01.17 – Linac L1 RF Commissioning





# Still 19.01.17 – 493 MeV in BC1 Dump



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European XFEL

**XFEL Status:** Comissioning up to B1D 24.01.17 14:24

**News:** Design beam energy of 600 MeV reached in BC1

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**XFEL e-Logbook** **Thursday 19. January 2017 Afternoon**

**shift summary**

**Operators**

* Goldbeck, Olaf
* Vogt, Mathias
* Warncke, Ralf
* Scholz, Matthias

**Achievements**

* 99% transmission to B1D
* 98% transmission to B1D with a beam energy of 493 MeV.
* reference file was saved for this beam energy with all magnets cycled.
* Trajectory response measurements (sextupoles were switched on to nominal values, two measurements including the dogleg without sextupoles for comparison)

**Creates optimism but PLEASE give us time!**

new

19.01.2017 23:59 J.Branlard, U.Mavric, D. Kostin, M. Wiencek

**LLRF shift summary:**

- All cavities are tuned except for C7.M1 (no tuner response).
- We can confirm the correct probe channel assignment for all 32 probes
- some tuner driver issues to be follow up during next maintenance day
- Coupler tuning to 4.6e6 for all couplers except Module 3 (no driver response) and M1.C7 (not tuned)
- we can confirm the correct reflected power channel assignment for the Q1-tuned couplers
- we enabled the WORD_MASTER bit (on master TCK7) to include slave partial vector sum

19.01.2017 22:59 Froehlich **Program for night and morning shift**

- Night: Measure responses in dogleg/B1
- Morning: **Switch off injector RF at 8:00 for MKK.** They need to increase the water throughput to the gun and A1 klystrons. Try to transport compressed beam with different nonzero chirp settings; note the attainable transmission and screen images in BC0.

19.01.2017 22:55 mscholz **SlaveTiming.xml**

Event 111 should be around this value. I calculated it from the old delay minus 12.5 ms



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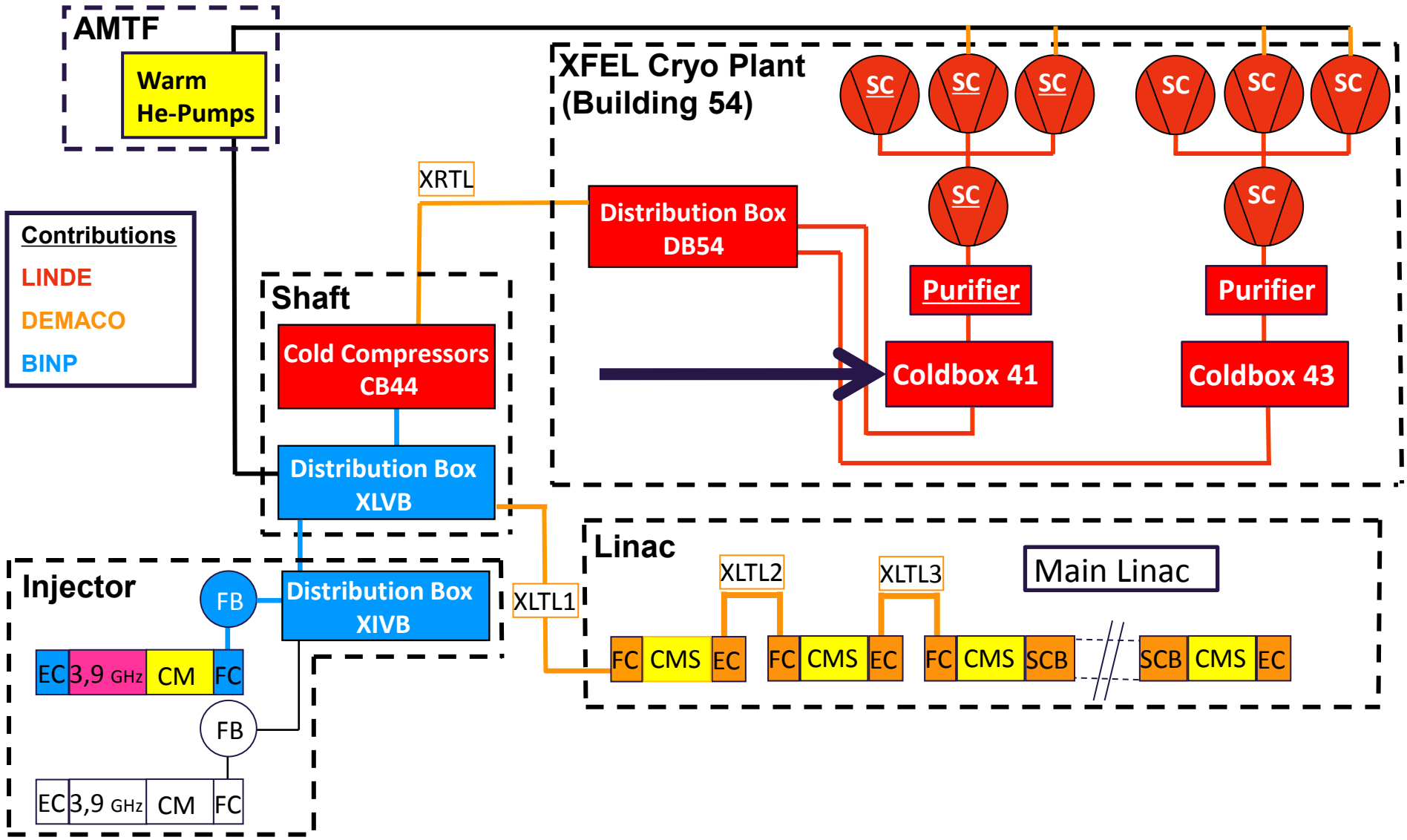
# Overview of XFEL Cryogenic Equipment

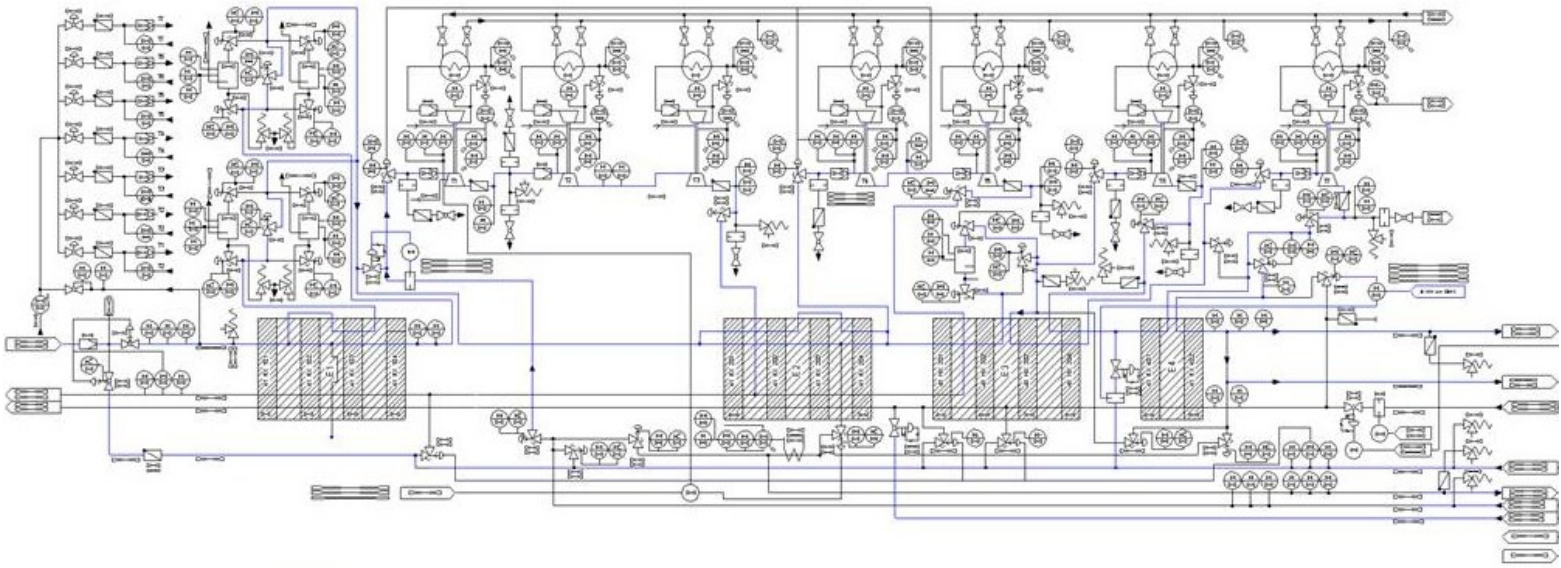




# Overview of XFEL Cryogenic Equipment



**Coldbox 41**



- Expected **Heat Loads**: 2K: 1,9 kW 5/8K: 3,6 kW 40/80K: 24 kW
- 24 / 7 operation; 2 – 3 years operation w/o scheduled breaks
- Refrigerator availability > 99%
- Cold Compressors to reach operating temperature of 2K

# Cryogenics is challenging



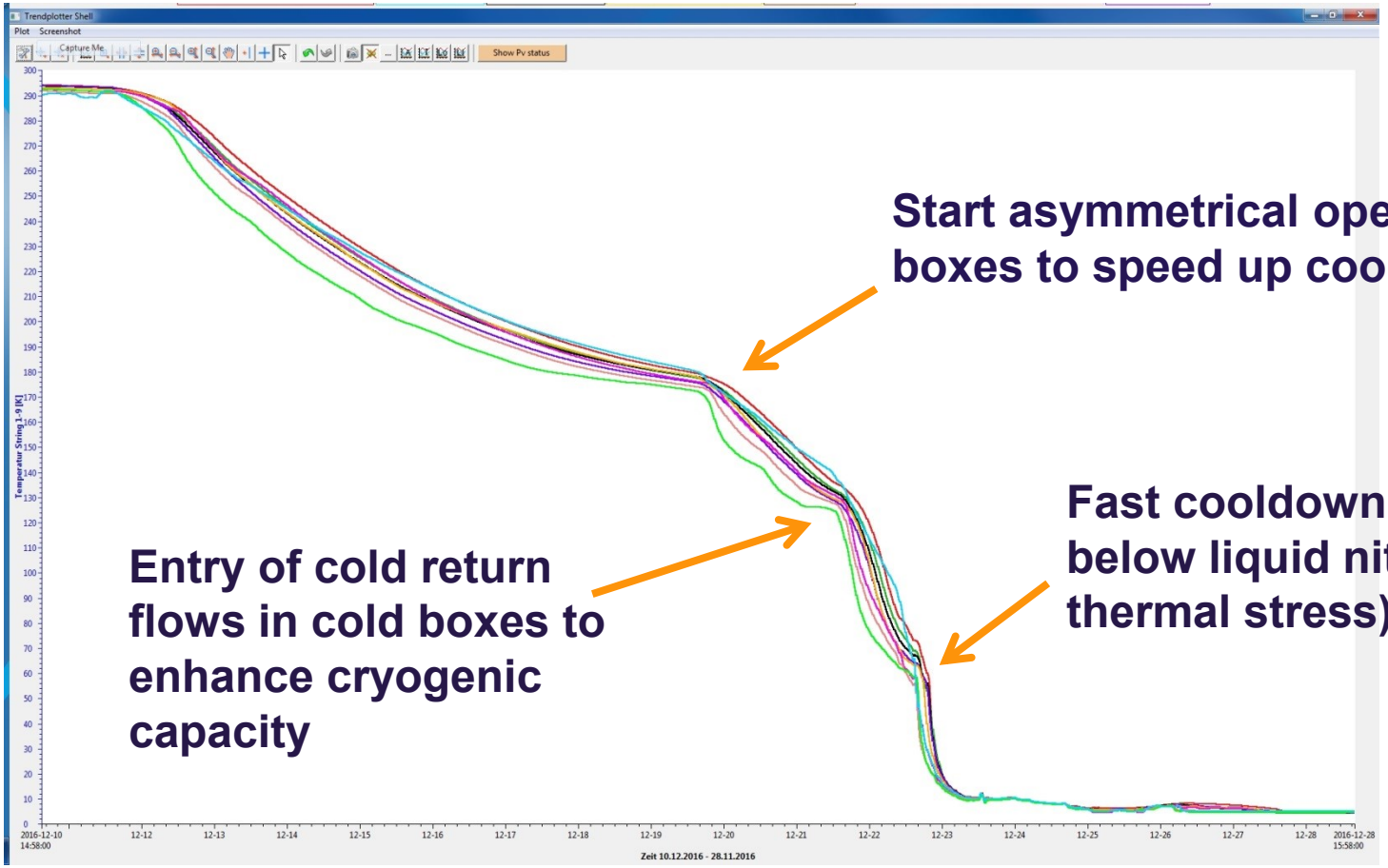
- **Complexity of cryogenic system** requires sufficient time to perform commissioning and establish / optimize operation procedures
- **Gain experience** with new machines, e.g. cold compressors
- **How to deal with…**
  - 671 control valves
  - >3,800 sensors (temperature, pressure, flow, level)
  - 433 regulation loops
  - >22,000 records and >220,000 properties
  - and last but not least … >300 tons of material to be cooled down

Remark to Cold Compressors (CC):

CCs are used instead of warm He-pumps due to efficiency and operational cost reasons. Operation cost saving of ~ 2.5 Mio EUR per year. But each CC system is unique, CCs are very sensitive towards mass flow-, temperature- & pressure changes. Start up of CC can be very time consuming; operational experience required. We are ***entering uncharted waters…***

# First Cooldown of XFEL Linac (300K to 4K)






Start asymmetrical operation of two cold boxes to speed up cooldown

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

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

10.12.2016

24.12.2016

- No Cold Leaks!!!

# 2K Operation reached on January 6th, 2017

## MANY THANKS to the Cryoteam !!!

**BUT….**

- We still need to learn a lot wrt. 2K operation (30.6 mbar)
- Set pressure is not yet reached automatically (many manual interventions are still necessary to avoid failures / CC shut downs)
- Set pressure is not yet reached exactly and pressure stability doesn't reach the envisaged +/- 1% stability
- Different operating parameters for different operating modes still have to be established (mainly for cold compressors)
  - CC are not yet operated at their design values (e.g. driving frequencies, pressure ratios, etc.)
  - 2K return flow has to be stabilized to ensure stable operating conditions of cold compressors
- Pressure and mass flow of 2K return flow has to be stabilized

- **We are still addressing reliability issues of the CC's driving motors**

# Pressure at 2K System

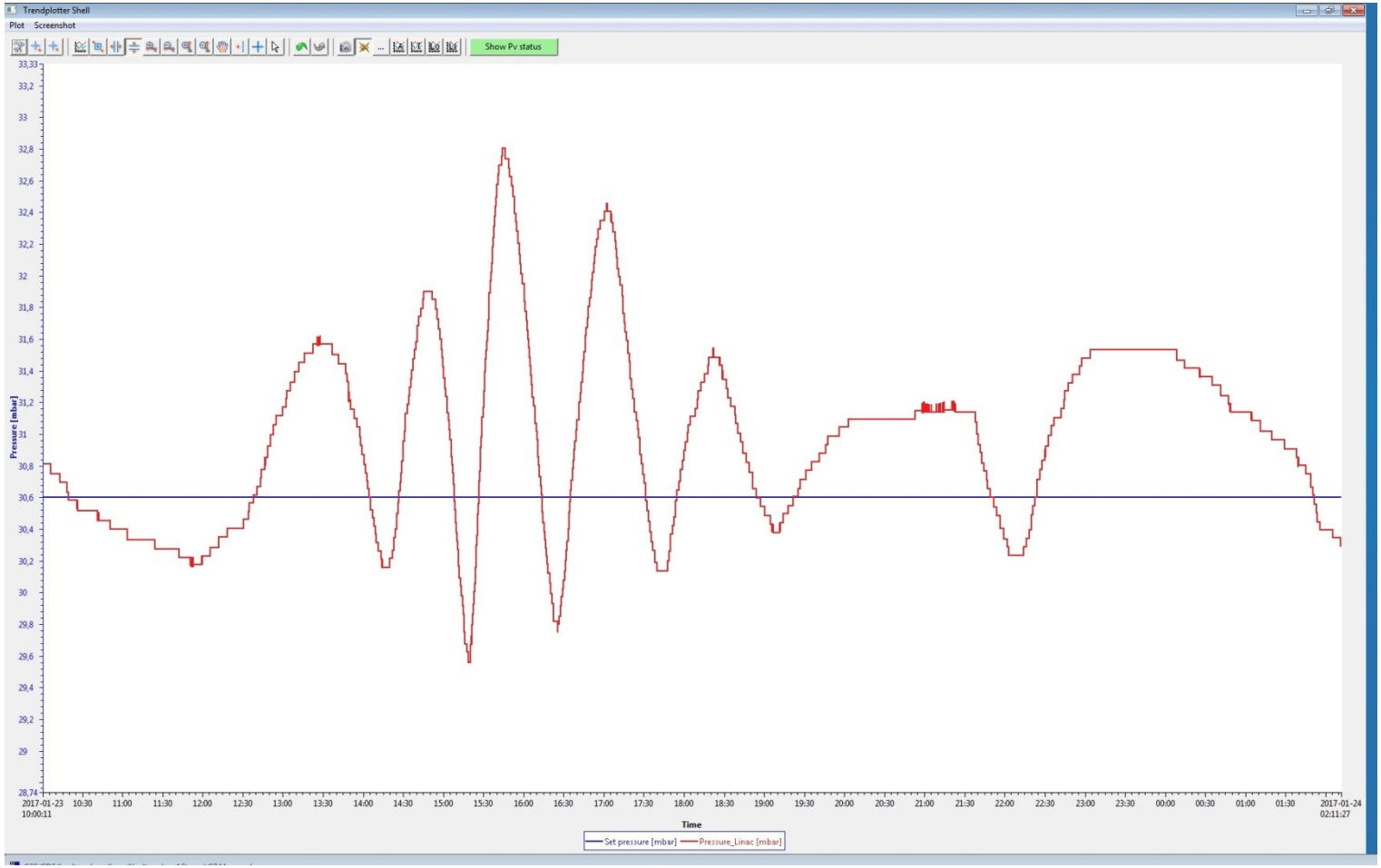


- … is definitely stable enough for all linac commissioning steps.

33

32

30.6 mbar



# Linac commissioning

- Sequential commissioning of accelerator modules and beam lines
  - Injector at 130 MeV
    - ➔ pass on to BC1 beam dump
    - ➔ L1 commissioning (1 RF station until Feb 1st)
  - L1 at $E_{final}$ = 600 MeV
    - ➔ pass on to BC2 beam dump for L2 commissioning
    - ➔ L2 commissioning (3 RF stations until Feb 15th)
  - L2 at $E_{final}$ = 2.4 GeV
    - ➔ pass on to XTL dump for L3 commissioning
  - L3 up to $E_{final}$ = 17.5 GeV (15-18 RF stations, April 15)

- Set-up bunch compression in parallel to linac commissioning

# North Branch Commissioning

- Once Northern Branch is ready…
  - transport beam to main dump after SASE1&3 (April)
- First lasing in SASE1 (May)
- SASE1 photon systems and experiment commissioning follows

- First lasing in SASE3 (June) and following photon systems and experiment commissioning depends on operation priorities and systems readiness

- South branch (SASE2) commissioning depends on installation readiness and operation priorities, first lasing presently scheduled for November

# Summary and Outlook

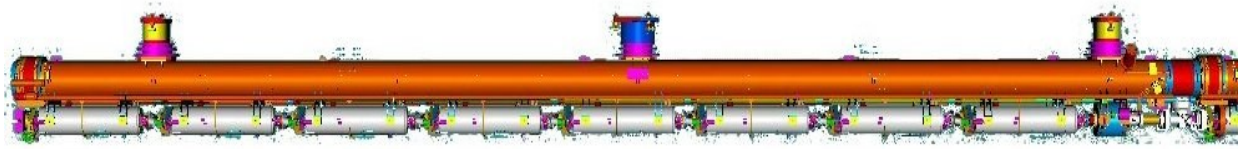
- The fascinating time of accelerator module production / testing / installation comes to an end
- the **Tunnel is closed since beginning of 12/2016.**
- The linac is cooled down to 2K.
- Technical and beam commissioning started.
- Based on injector experience and accelerator module performance we are looking forward to reaching all design parameters
- **The milestone ‚first lasing possible' is still scheduled 6 months after ‚tunnel closure'**
- The first few weeks of commissioning were very successful.
- But give us the time we need. There will be surprises…no doubt.

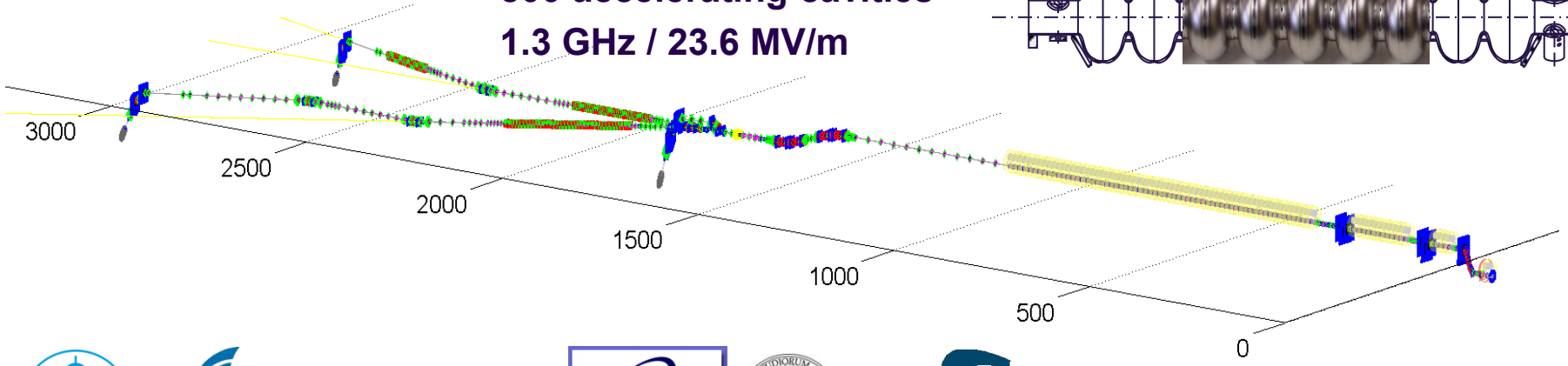
- Full performance is expected approx. 1.5 years after first lasing

# Thanks to all Contributors to the European XFEL Accelerator



**100 accelerator modules**



**800 accelerating cavities**

**1.3 GHz / 23.6 MV/m**