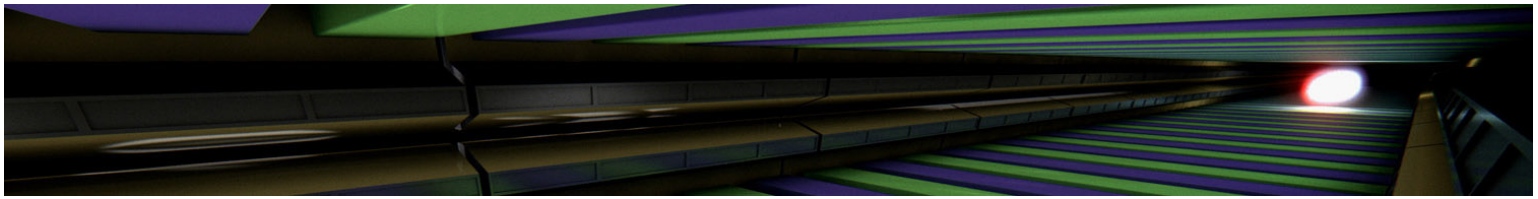
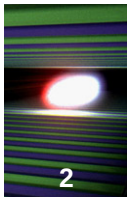


Construction of the RF System for the European XFEL

S. Choroba, V. Katalev for the WP1
XFEL RF System

The European XFEL
Built by Research Institutes from 12 European Nations

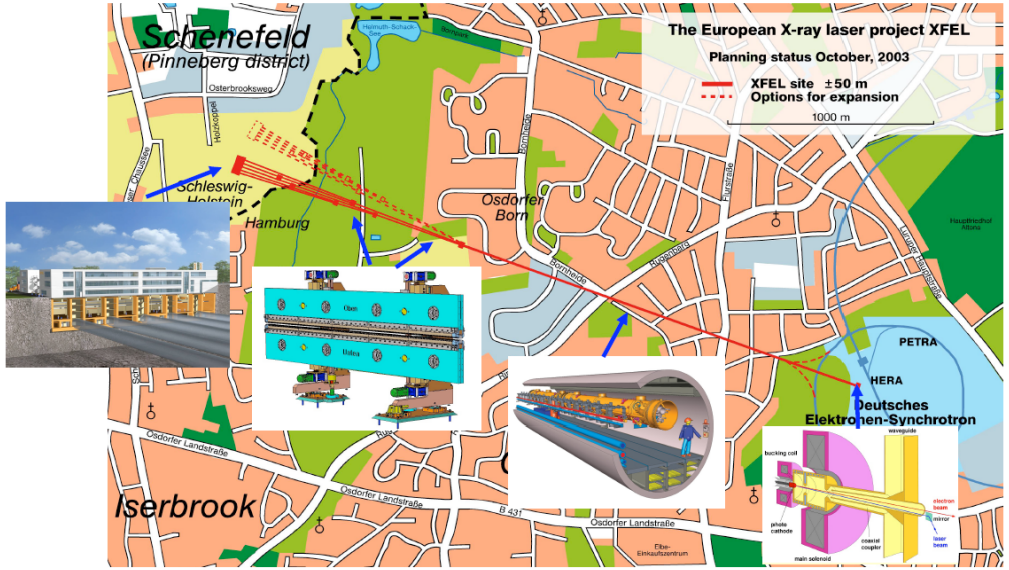


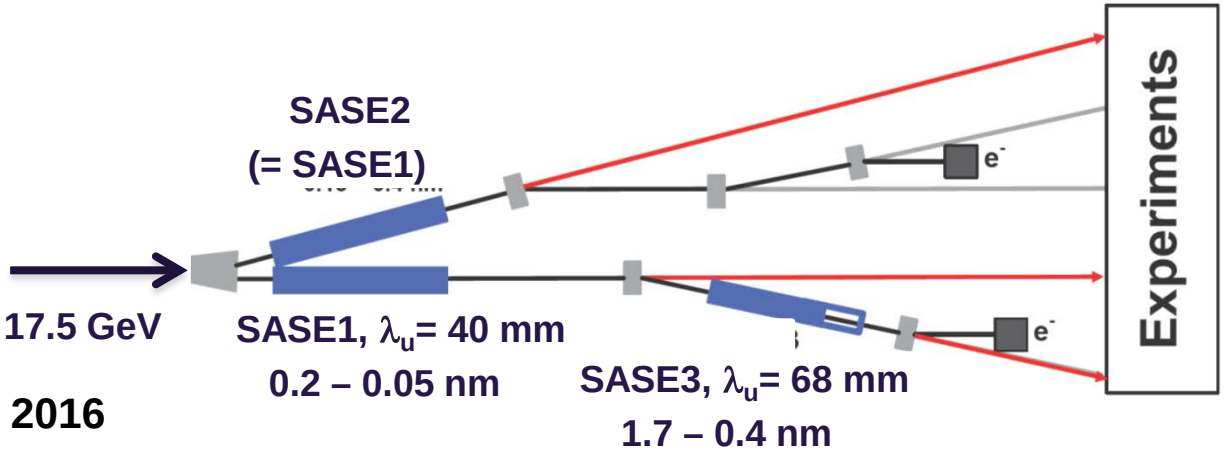
Budget 1.150 MEuro incl. preparation and commissioning

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 beamlines and 6 instruments
- Several extensions possible:
  - More undulators
  - More instruments
  - …….
  - Variable polarization
  - Self-Seeding
  - CW operation

First electron beam 2nd half of 2016



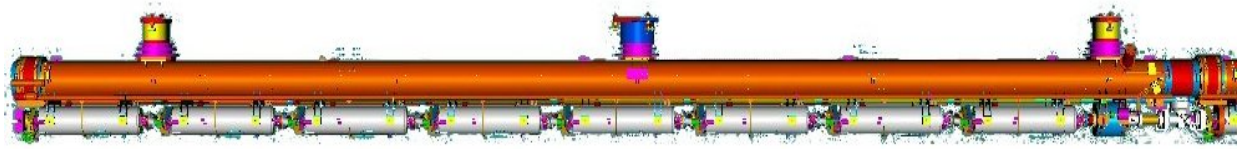


Courtesy of H. Weise, DESY

European XFEL

A Superconducting Accelerator for 17.5 GeV

100 accelerator modules



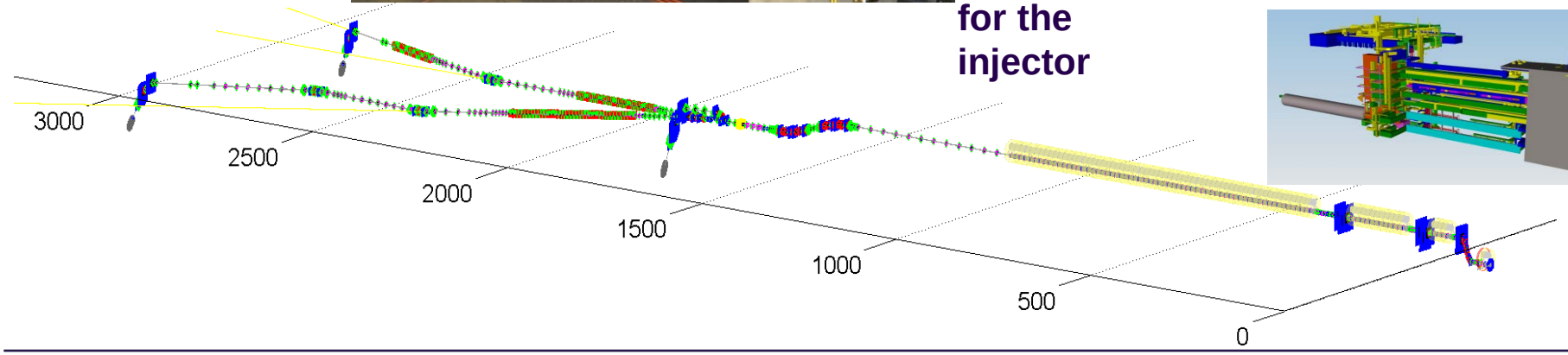
800 accelerating cavities

1.3 GHz / 23.6 MV/m

25 RF stations 5.2 MW each for the main linac

plus

2 RF stations for the injector

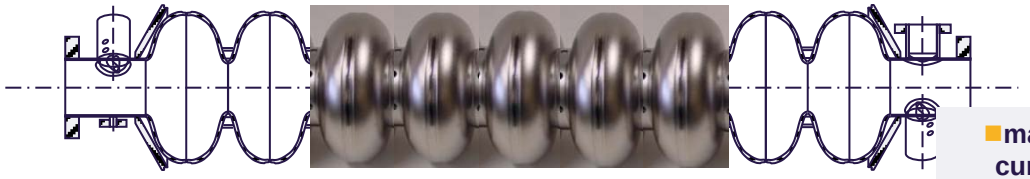


European XFEL

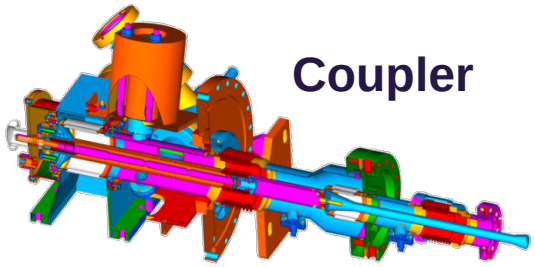
1.3GHz Nine-Cell SC Cavitiy

1.3GHz Accelerator Modules

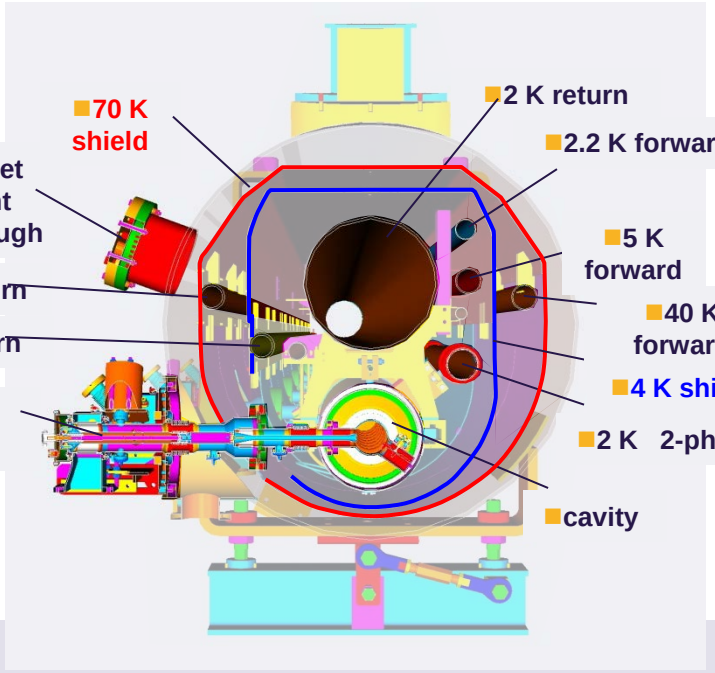
Cavity made of niobium, operated at 2K, gradient >23MV/m Q=10^{10} at 1.3GHz



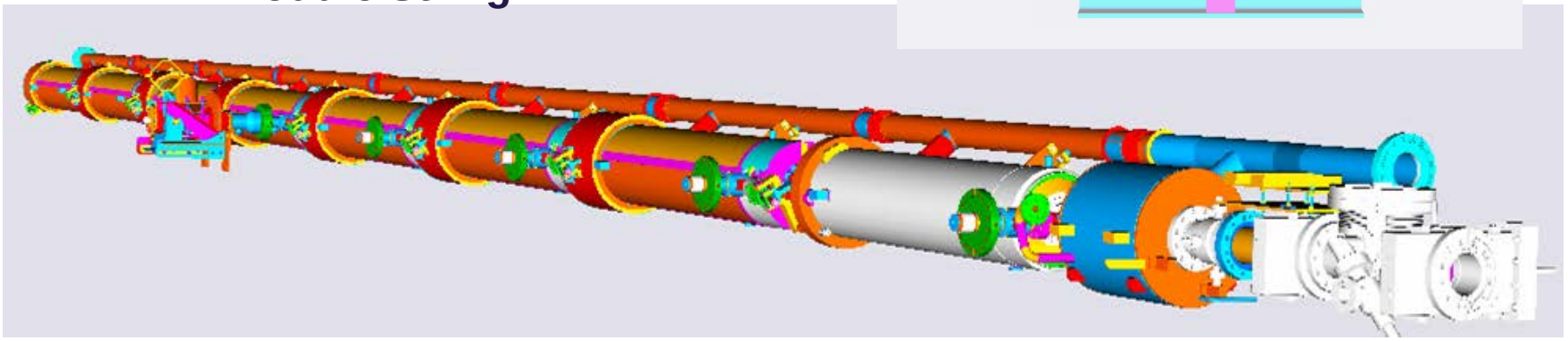
Coupler



Cryomodule



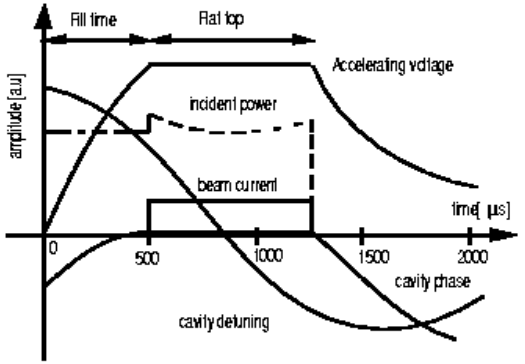
Module String



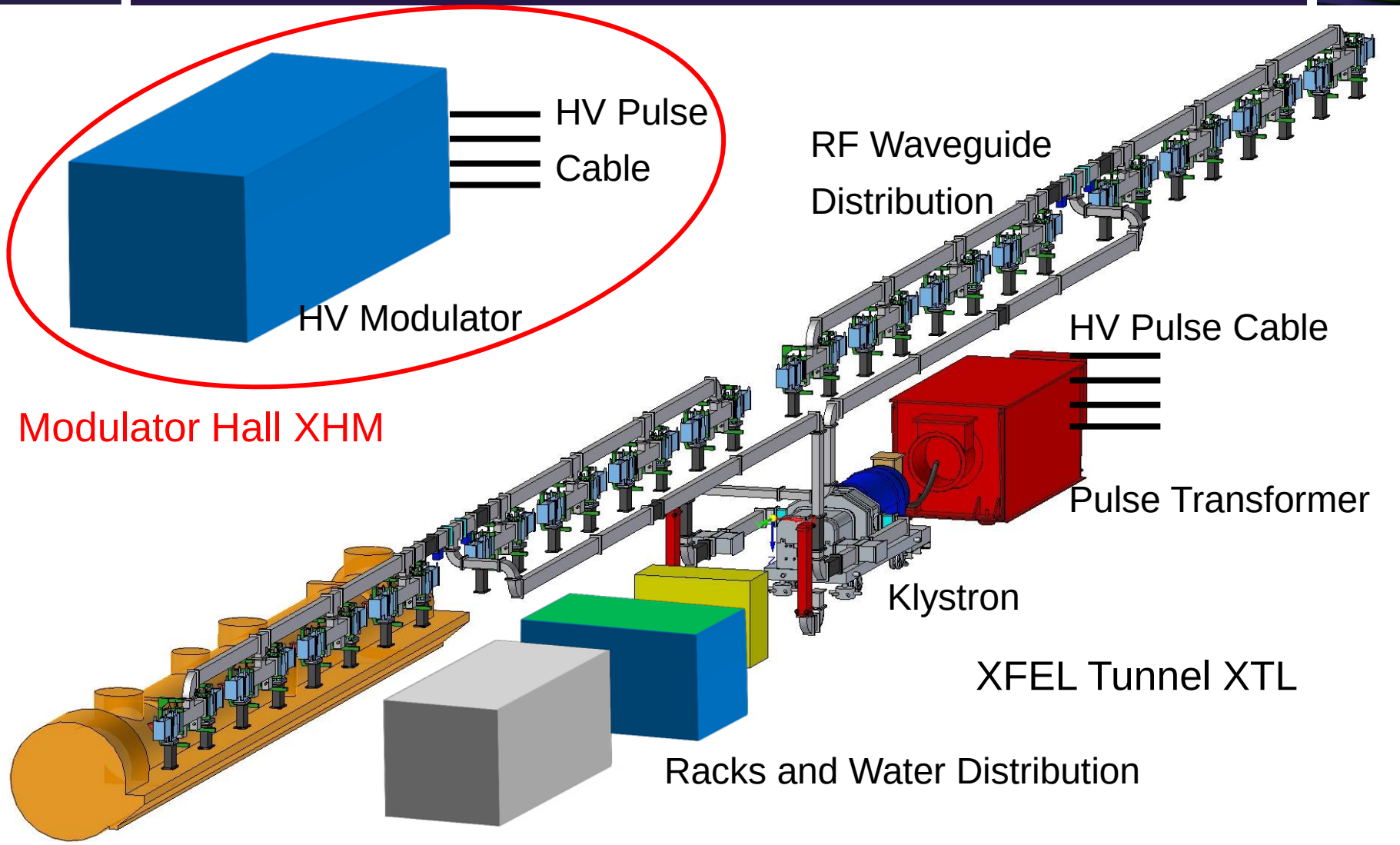
XFEL High Power RF Requirements

- Number of sc cavities: 800 total for **17.5GeV**
- Power per cavity: **122 kW**
- Gradient at 17.5GeV: **23.6 MV/m**
- Power per 32 cavities (4 cryo modules): 3.9MW
- Power per RF station: **5.2MW** (including 10% losses in waveguides and circulators and a regulation reserve of 15%)

- Number of RF stations: **27**, active **25**
- Number of RF stations Main Linac: **25**, active **23**
- Macro beam pulse duration: 650μs
- RF pulse duration: **1.38ms**
- Repetition rate: **10Hz (30Hz)**
- Average RF power per station: **72kW (150kW)**



RF Station Overview

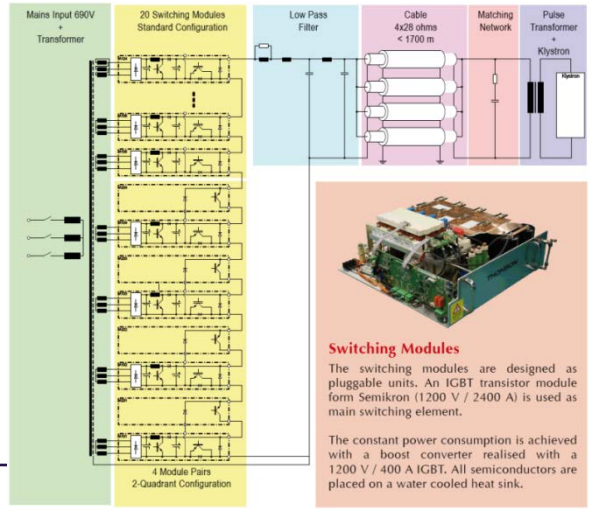


European XFEL

HV Pulse Modulator

	typical	max.
Modulator Pulse Voltage	9.6kV	12kV
Modulator Pulse Current Voltage	1.62kA	1.8kA
Klystron Gun Voltage	**115kV**	**132kV**
Klystron Gun Current	**135A**	**150A**
High Voltage Pulse Duration (70% to 70%)	**1.57ms**	**1.7ms**
High Voltage Rise and Fall Time (0 to 99%)	0.15ms	0.2ms
High Voltage Flat Top (99% to 99%)	1.37ms	1.5ms
Pulse Flatness during Flat Top	±0.2%	±0.3%
Pulse-to-Pulse Voltage fluctuation	±0.1%	±0.1%
Energy Deposit in Klystron in Case of Gun Spark	<20J	20J
Pulse Repetition Rate	**10Hz**	**10Hz (30Hz)**
Pulse Transformer Ratio	1 :12	1 :12

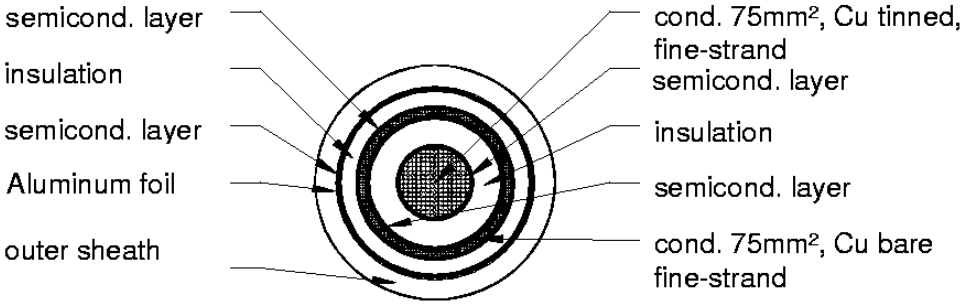
Ampegon Pulse Step Modulator



DESY HELMHOLTZ ASSOCIATION

Pulse Cable and Pulse Transformer

Pulse Cable connecting modulators and pulse transformers: triaxial, 4 parallel, each 25 Ohm, diameter 30mm
dielectric material: XLPE



European XFEL

Multi Beam Klystron

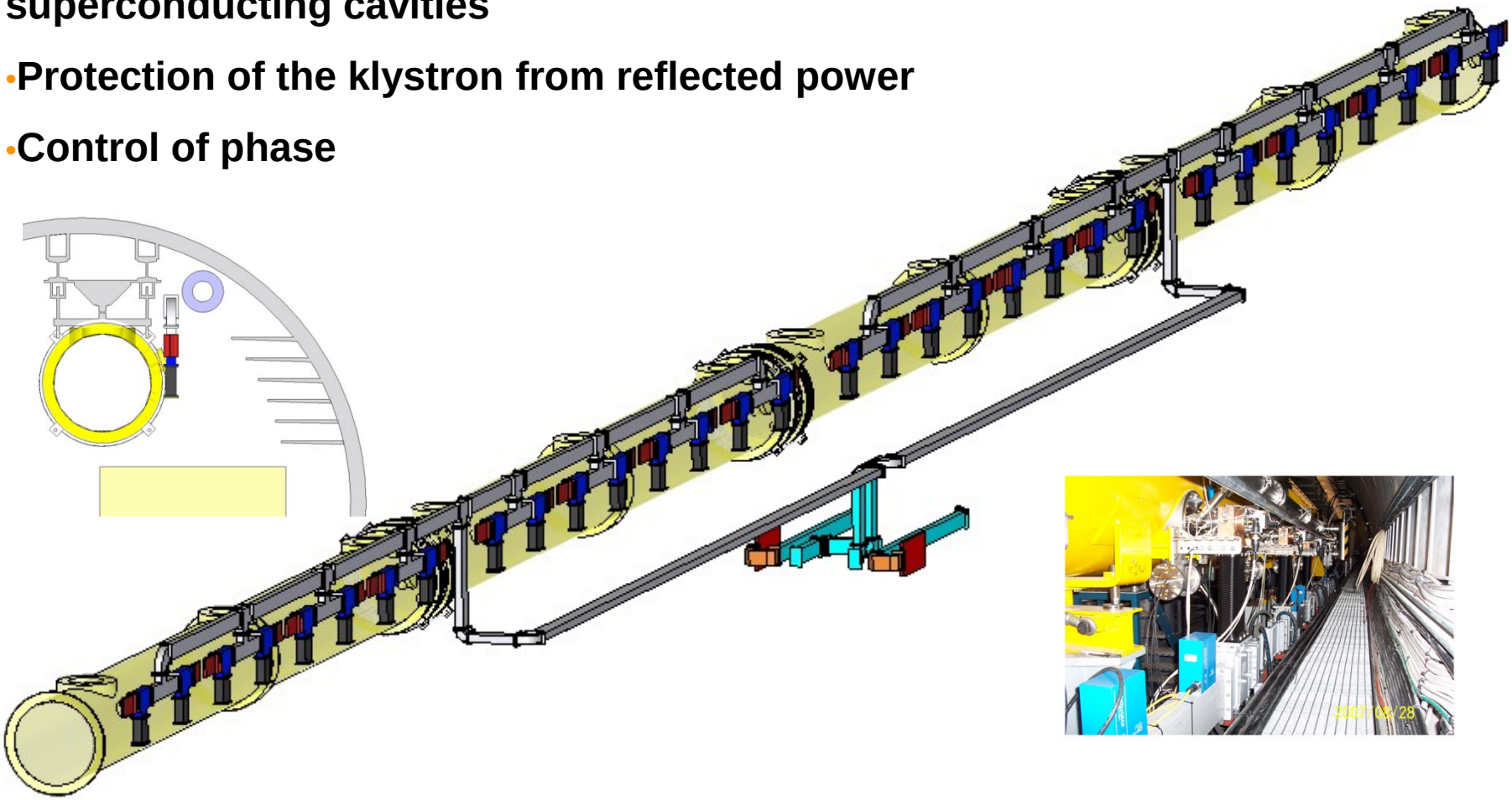
- RF Frequency: 1.3GHz
- Cathode Voltage: < 120 kV
- Beam Current: < 140 A
- Max. RF Peak Power: 10MW
- RF Pulse Duration: 1.5ms
- Repetition Rate: 10Hz
- RF Average Power: 150kW
- Efficiency: 63%
- Solenoid Power: < 5.5kW

Toshiba E3736H

Thales TH1802

RF Power Distribution

- **Distribution of klystron output power to the superconducting cavities**
- **Protection of the klystron from reflected power**
- **Control of phase**

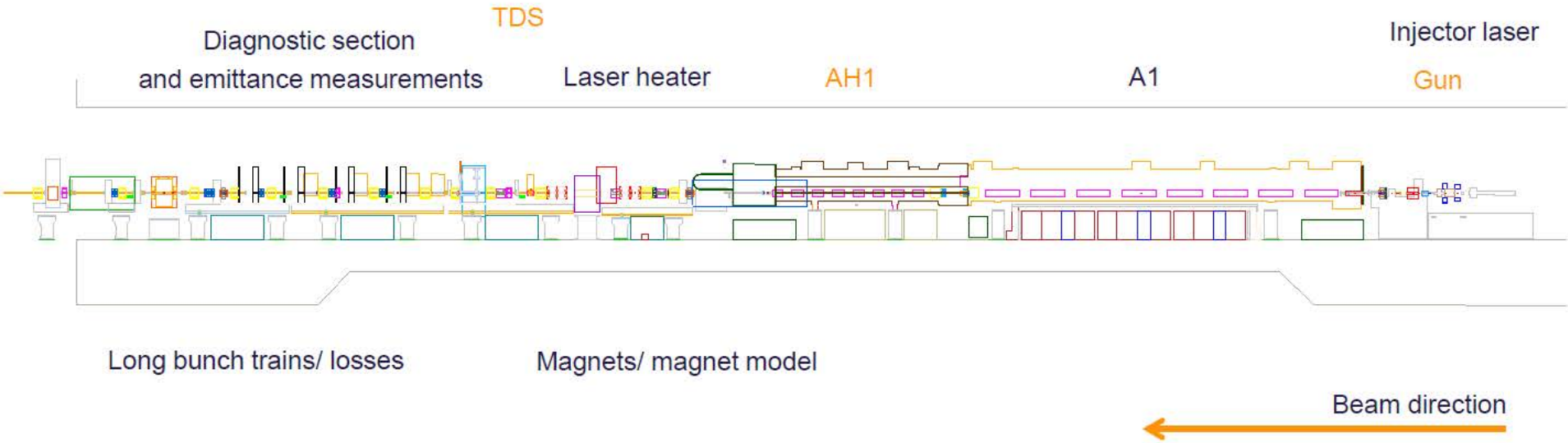


RF System Components Status

- 26 multi beam klystrons delivered, 19 of 22 Thales TH1802, all Toshiba E3736H
- All HV modulators delivered and installed
- All pulse transformers and connection modules delivered
- All waveguides delivered
- All auxiliary components delivered

European XFEL

XFEL Injector

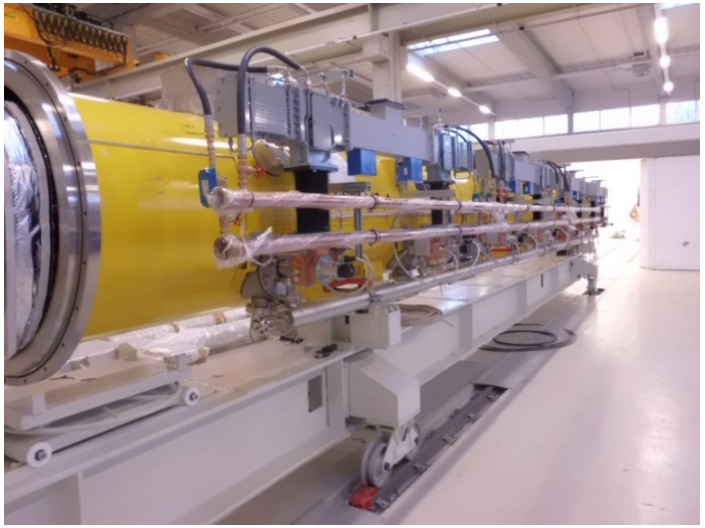


- Courtesy of H. Weise, DESY

European XFEL

XFEL Injector High Power RF Requirements

- Number of RF stations: **2** (1 for RF Gun and 1 for cryomodule)



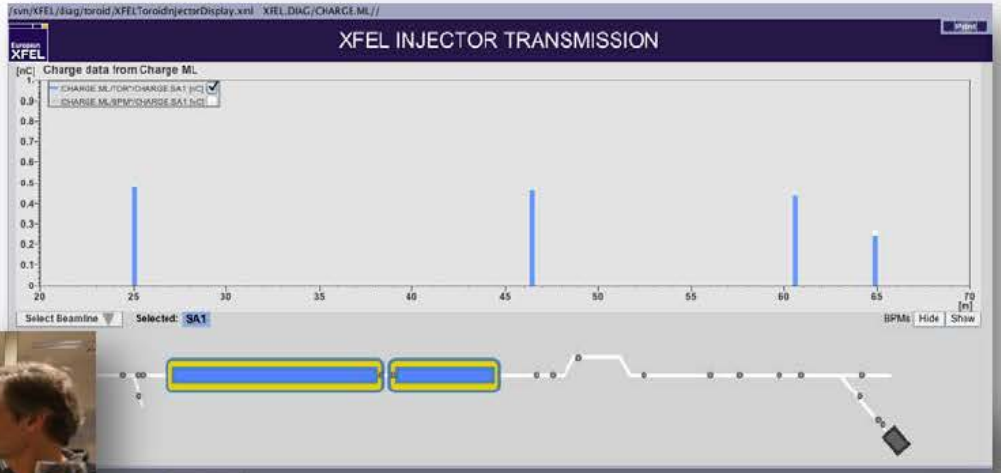
- RF Gun RF station: up to **6.5MW at RF Gun (~8MW generated by the Klystron max. 10MW), 680μs, 10Hz**

  (taking into account losses in waveguide distribution system)

- Cryomodule RF station: **1.3MW, 1.38ms, 10Hz** (as for main linac, but one quarter of RF power)

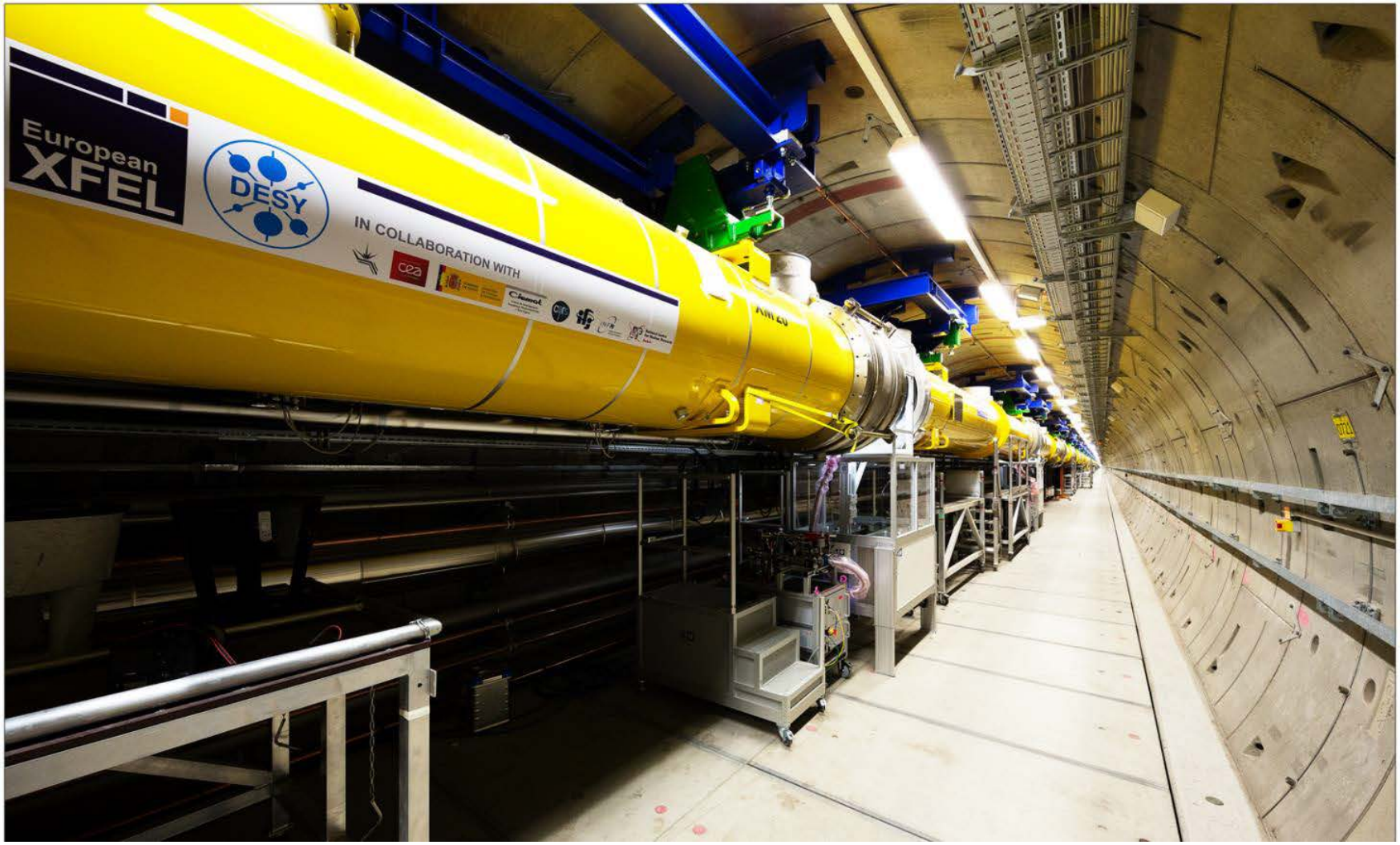
XFEL Injector first beam

- December 18, A1 was operational, electron beam with 130 MeV transported to the dump.



- Courtesy of H. Weise, DESY

Main Linac Installation

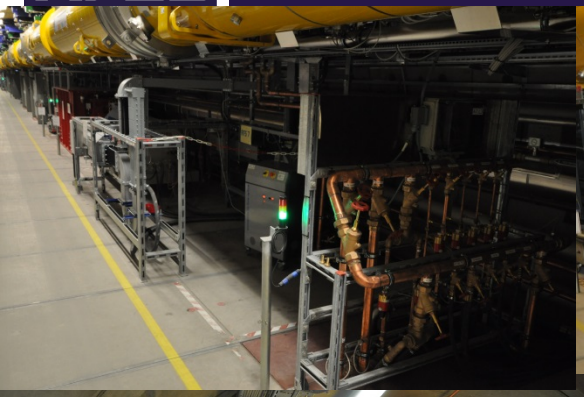


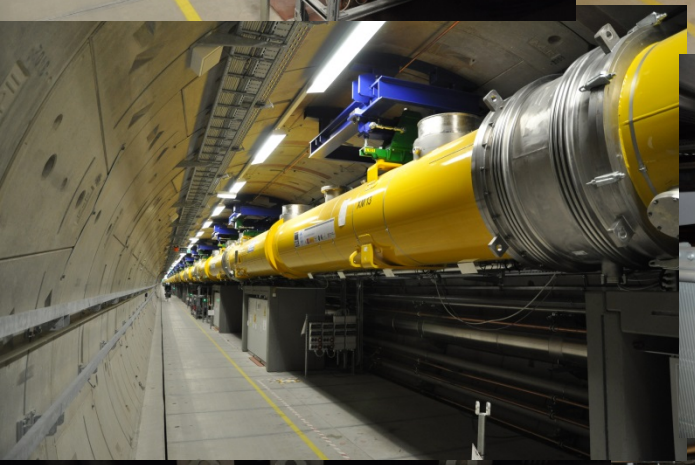
European XFEL

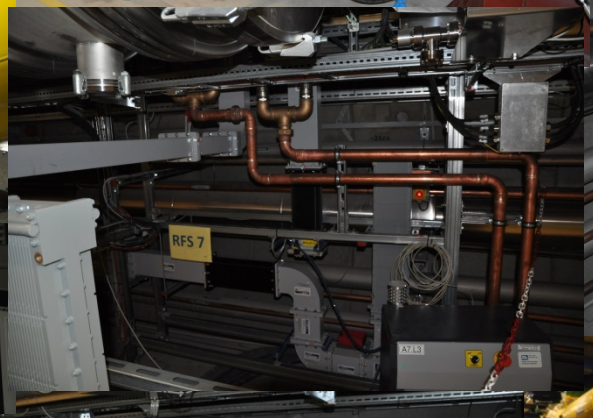
RF Station in Main Linac

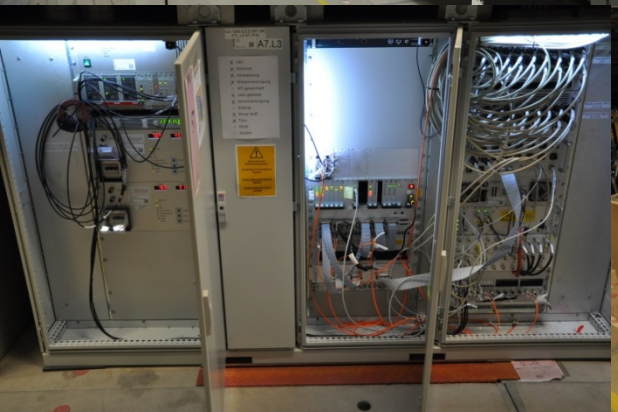
European XFEL

RF Station Components in XFEL

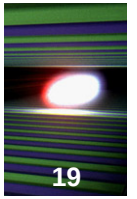


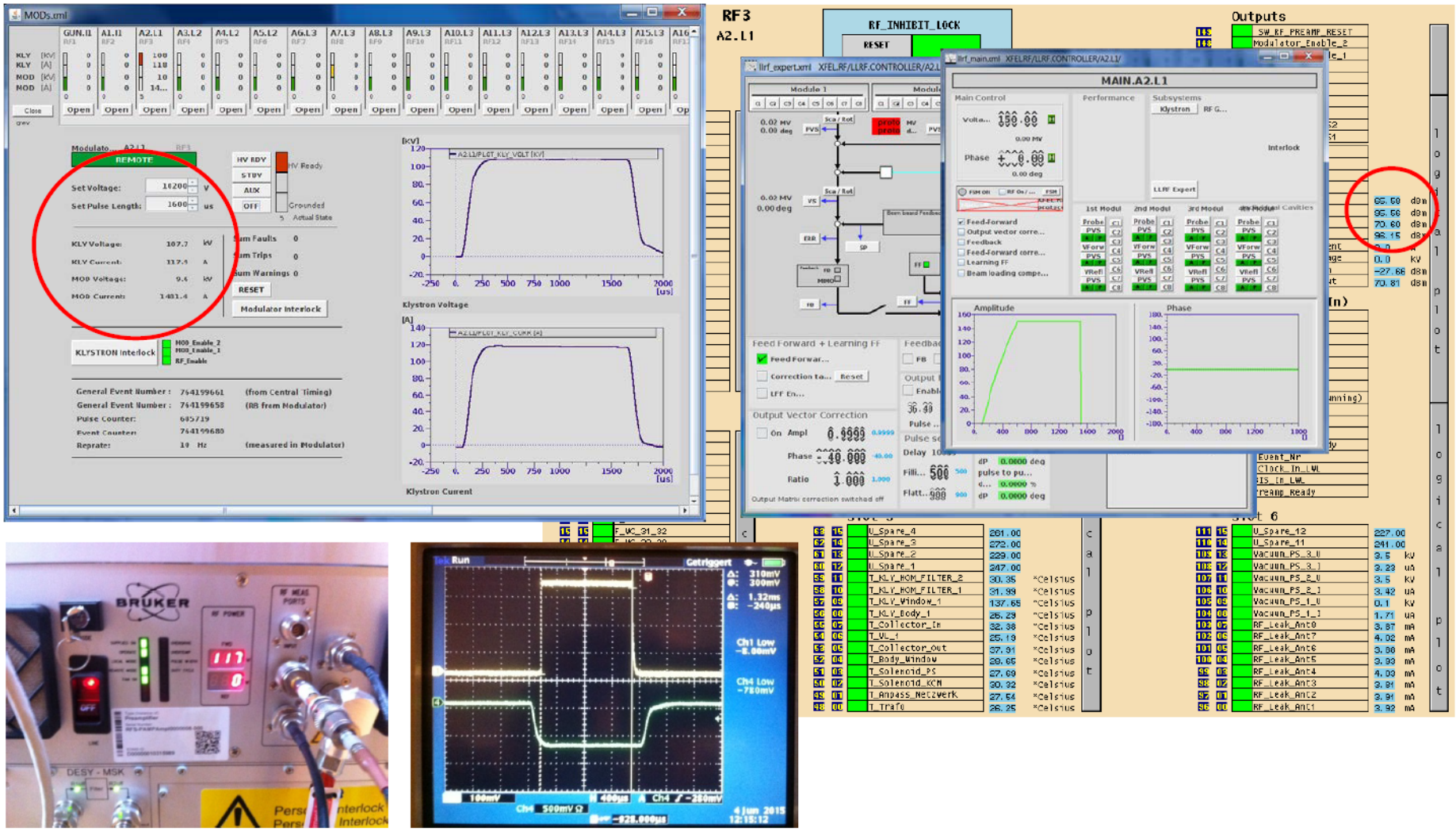






RF Station Commissioning

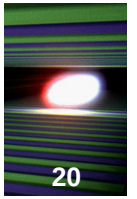


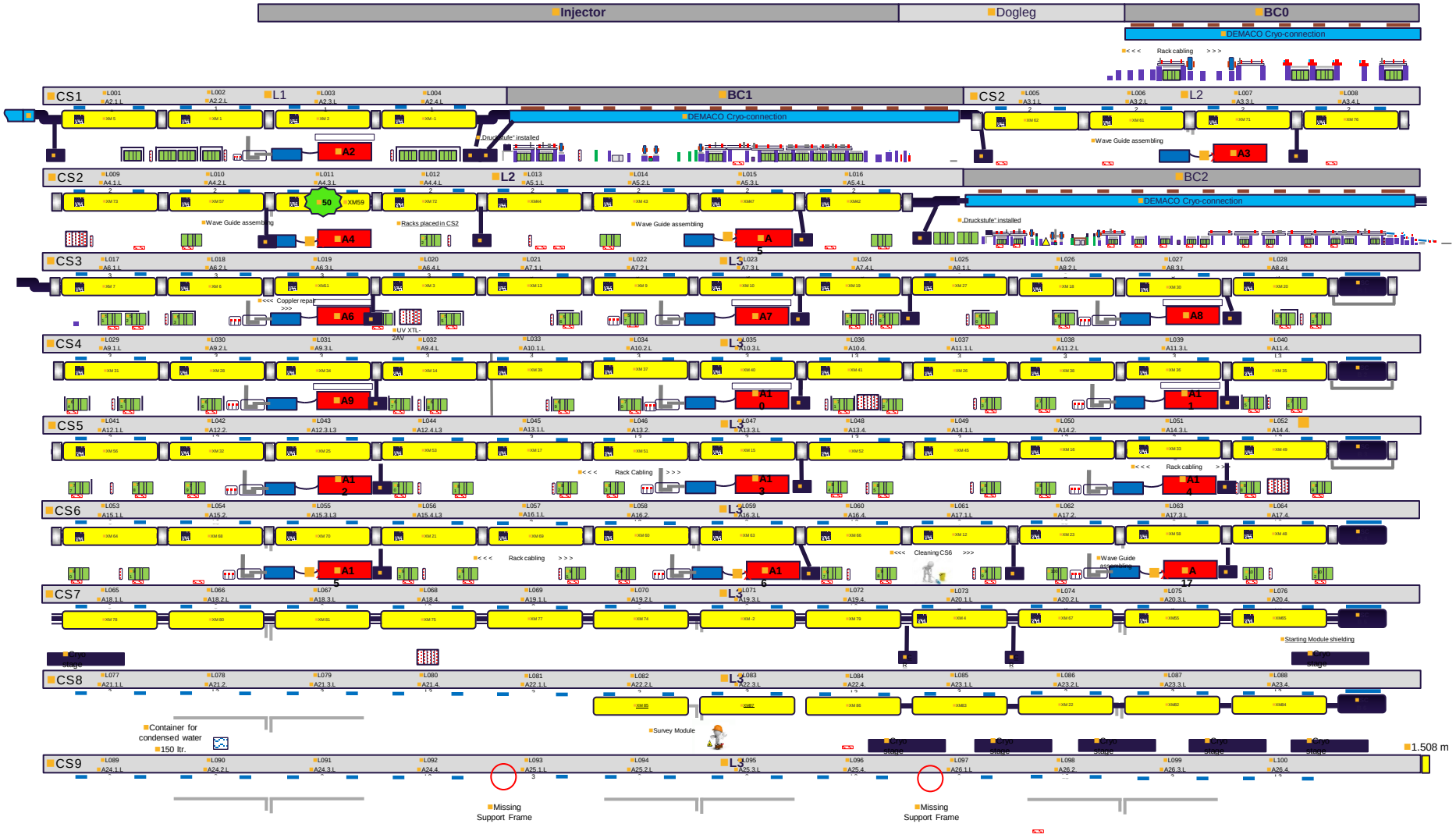


Construction of the RF System for the European XFEL

83 Modules installed in main linac
7 RF-Station ready and commissioned
15 RF-Station in preparation

Status: 27.05.2016





Module Measurement Results

Specification for Waveguide Distribution (WD) production

WD number	063
WD type[1]	*Left*
Cryomodule name	*XM70*

Cavity number[2]	1	2	3	4	5	6	7	8
Cavity gradient[3], MV/m	15.7	22.2	30.7	23.0	23.8	26.8	31.0	27.3
Cavity power[4], kW	59	118	225	127	136	172	230	178

P_{WD} [5] ≈ 1.2 MW

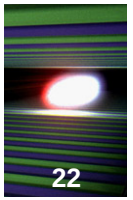
1 *WD position in the RF station* L (1) R (2) L (3) R (4)
2 *Cavity number in the beam direction*
3 *The smaller number for a pair of cavities will used*
4 *Cavity power is calculated by MHF-p based on accelerator parameters from XFEL TDR*
5 *Preliminary estimation of waveguide distribution power*

Signed for and behalf of WP01

B.Yildirim

Data 08.12.2015

Updated Requirements

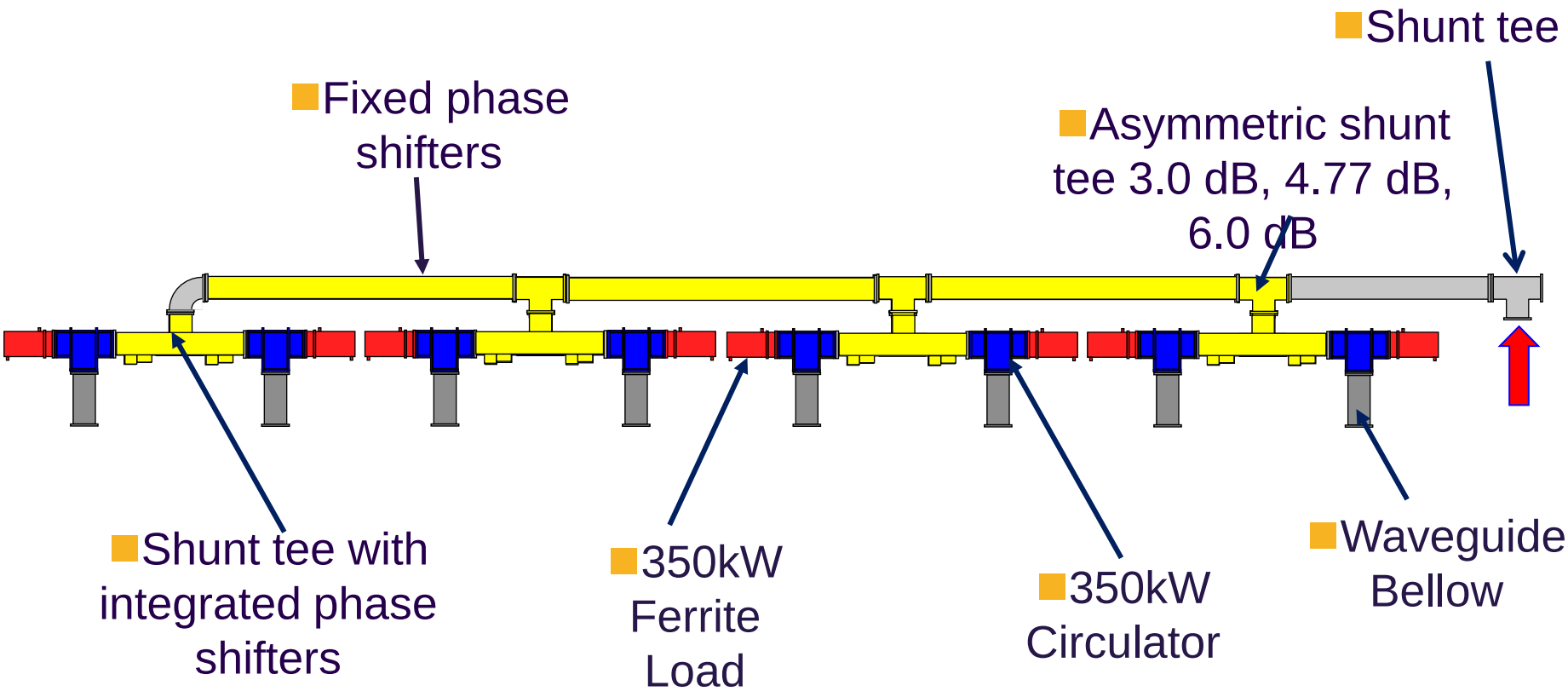


- 5.2MW, 1.37ms, 10Hz per RF station

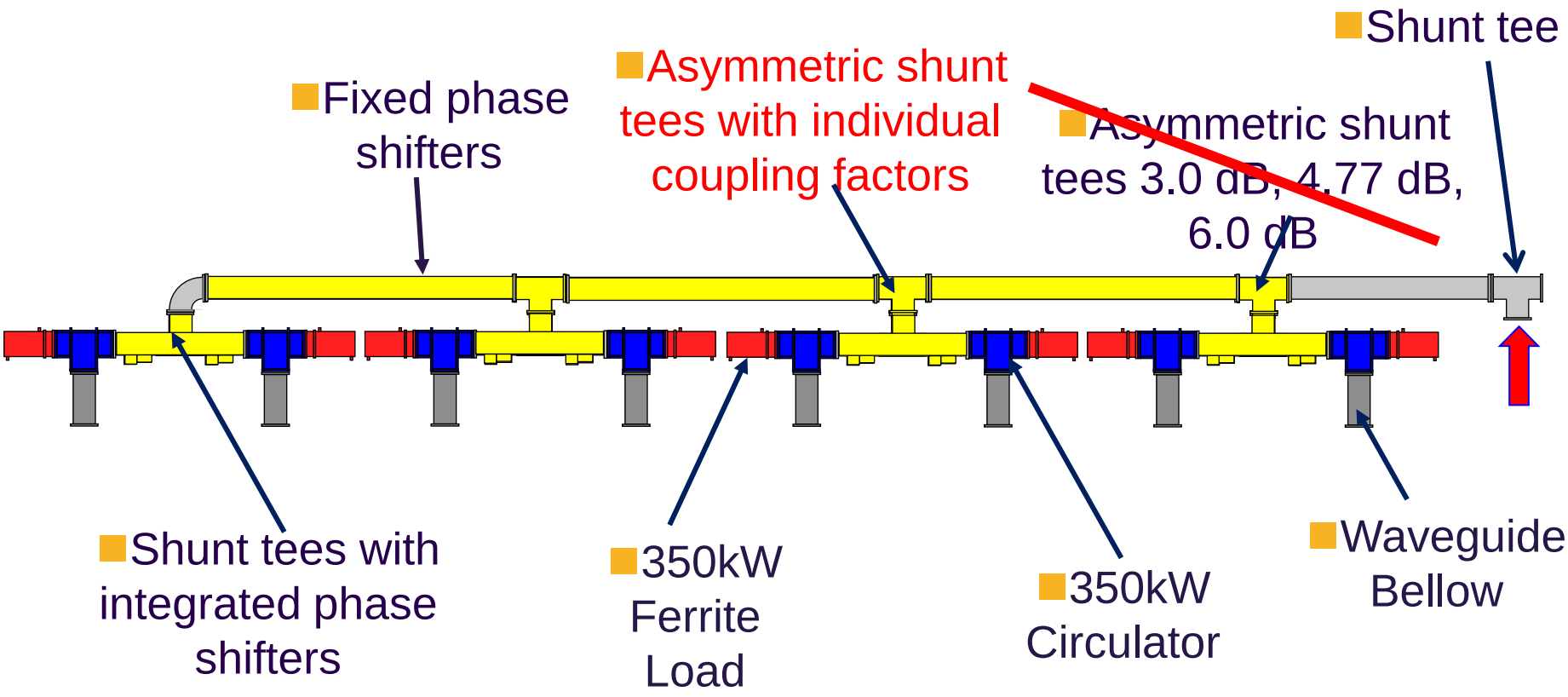
Equal power to 32 cavities (TDR 2007)

- Allow for adjustment of power for a pair of cavities (~2011, proposal to power a pair of cavities assuming sorting of SC cavities before assembly in modules)
- Allow for adjustment of power for each individual cavities and modules (2014, due to performance difference of SC cavities within a pair after module assembly)
- Allow for adjustment of power for each individual cavities and modules and for large spread of cavities (2014, due to performance difference of SC cavities within a pair after module assembly, large spread)

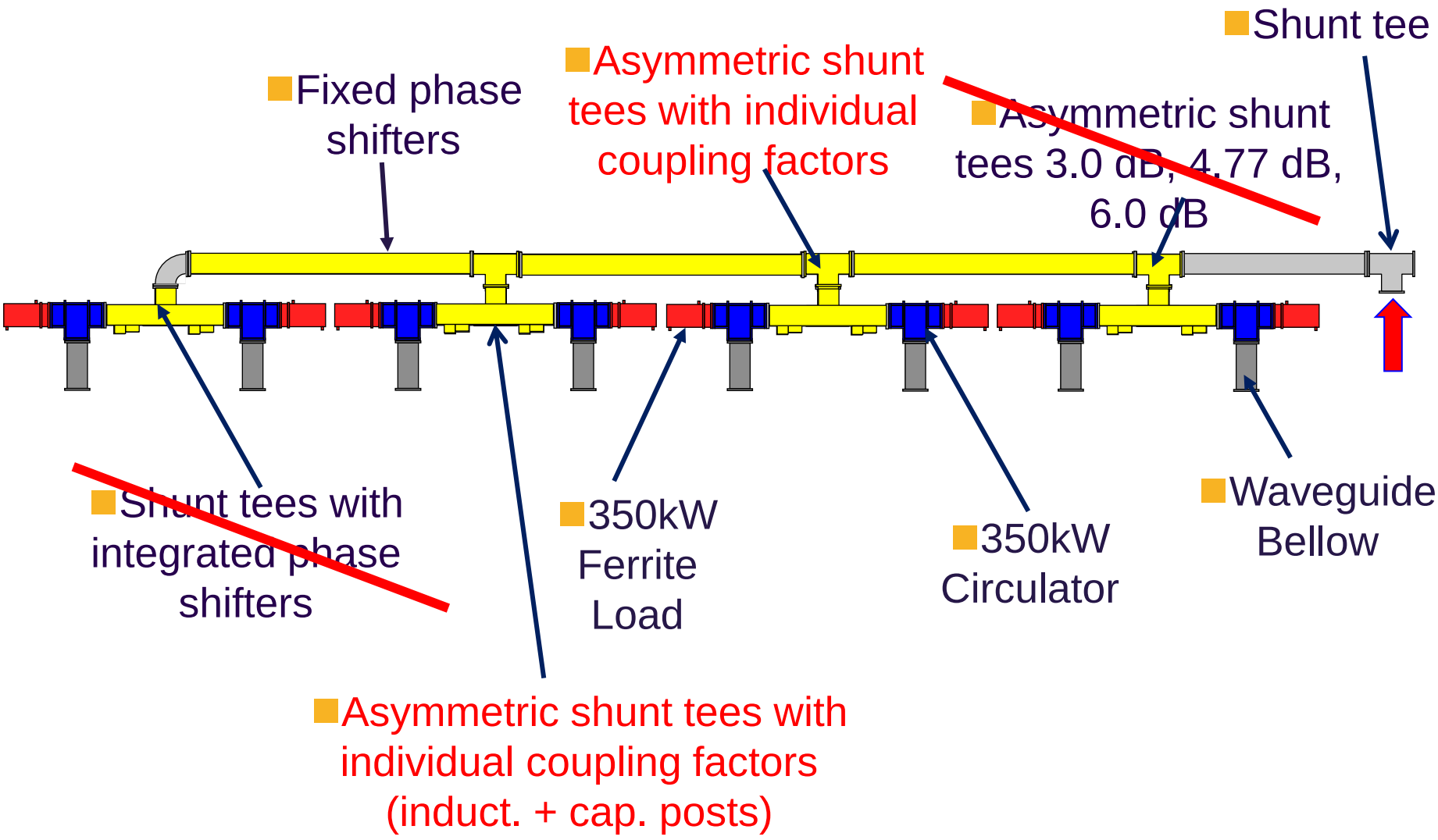
Module Waveguide Distribution



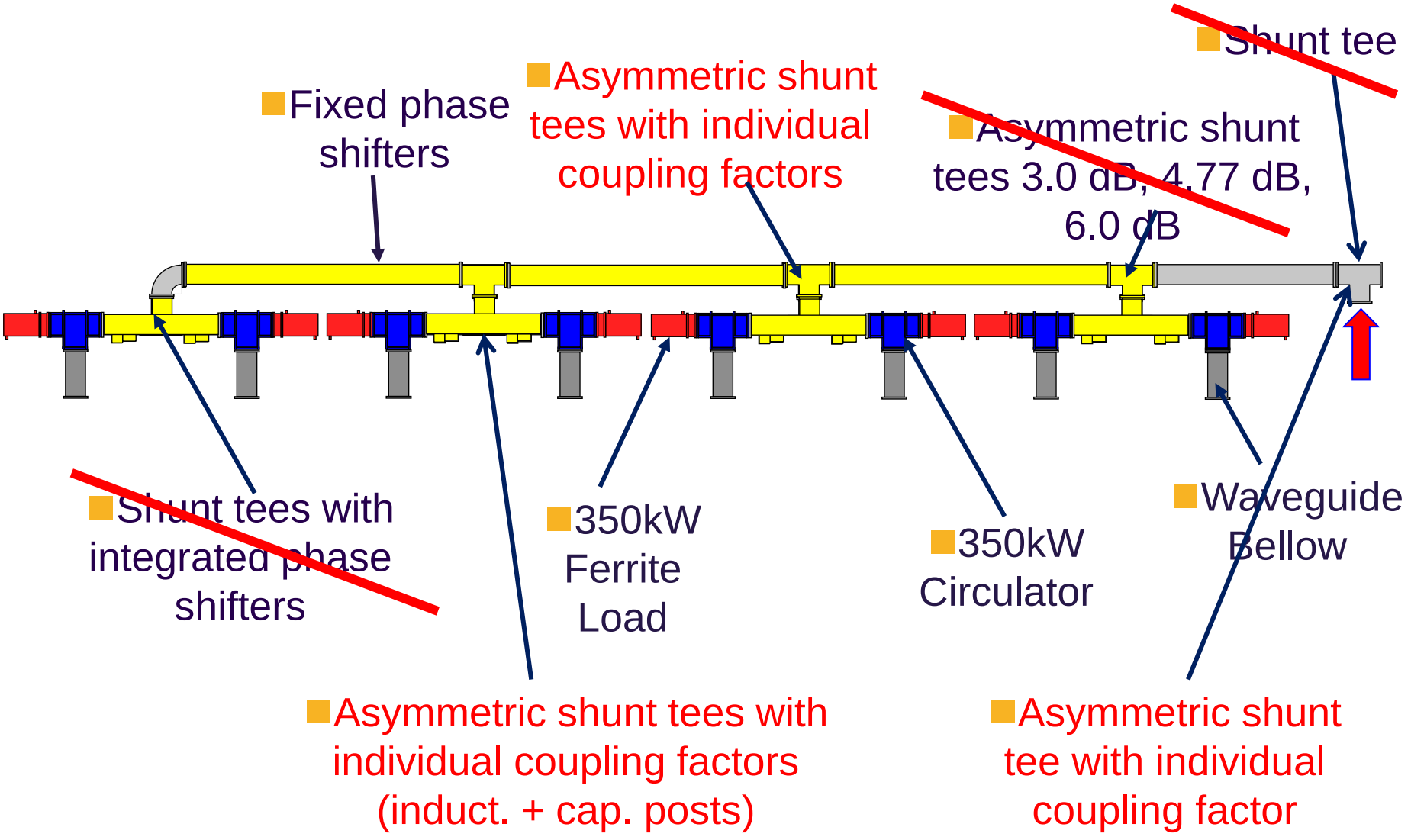
Module Waveguide Distribution (pair of cavities)



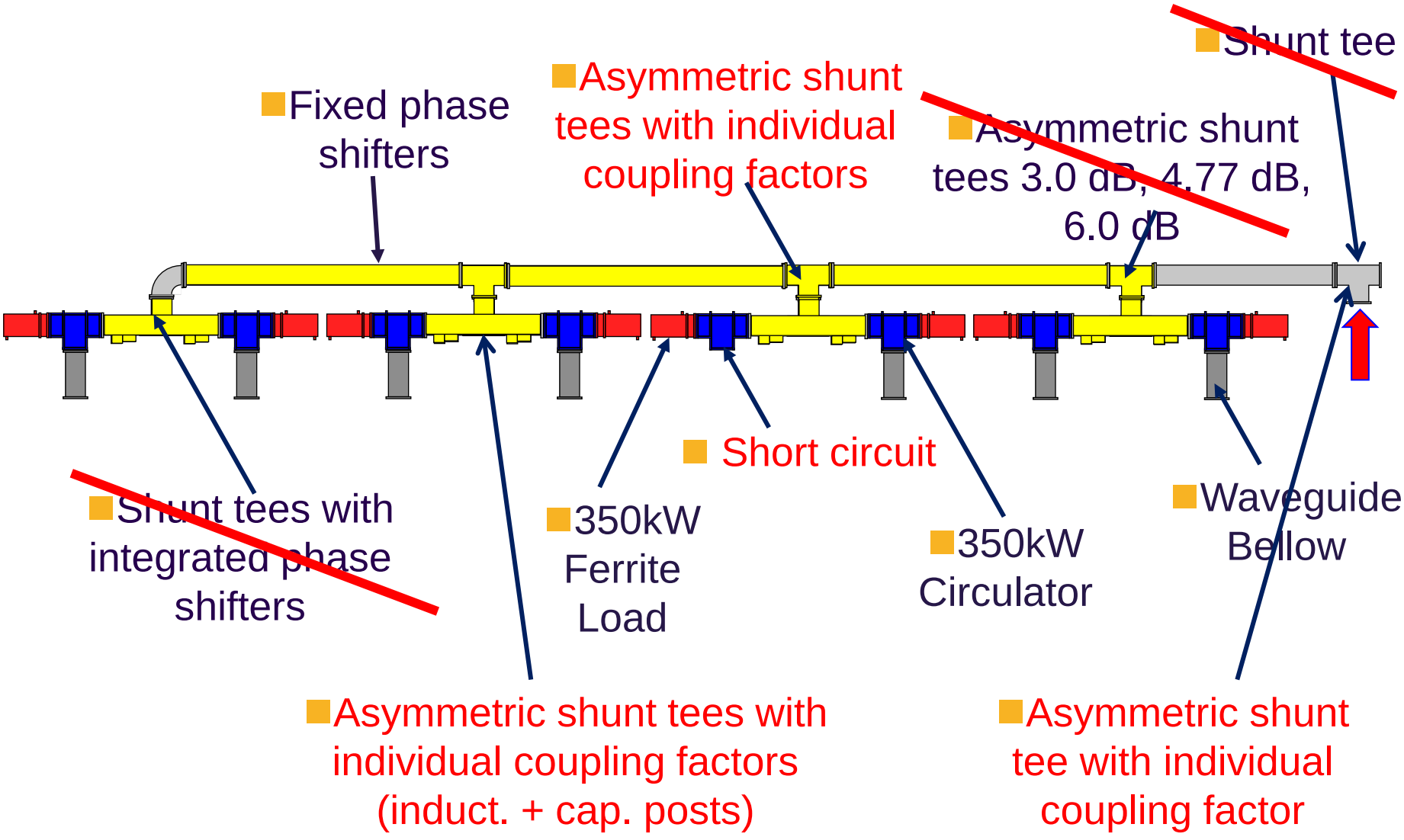
Module Waveguide Distribution (individual cavities)



Module Waveguide Distribution (individual cavities and modules)

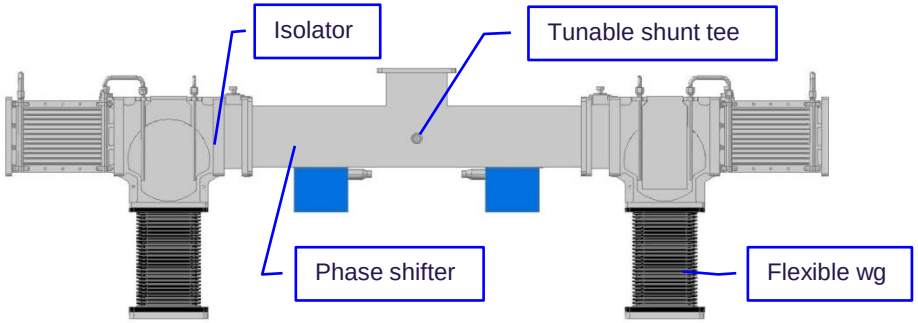


Module Waveguide Distribution (individual cavities and modules and large gradient spread)



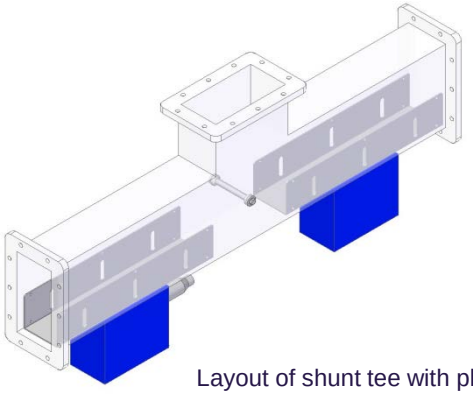
Binary cell with integrated phase shifters

- 8 types of binary cells – AR, AL, BR, BL, CR, CL, DR, DR – have a power coupling range 1.6 – 5 dB
- Phase dynamic range not less 70 degree



350 kW Isolator – circulator with integrated load

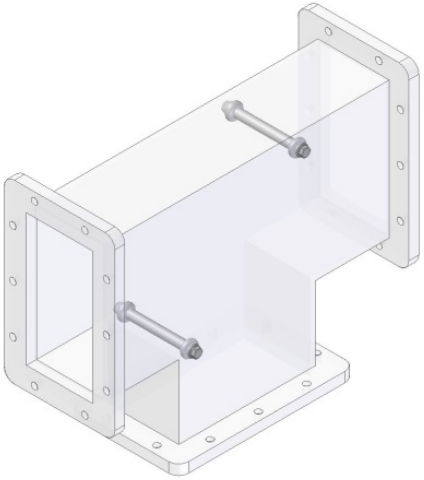
Binary cell under test



Layout of shunt tee with phase shifters

Asymmetric shunt tee and fixed phase shifter

Tunable Asymmetric Shunt Tee
with coupling range 2 – 8 dB



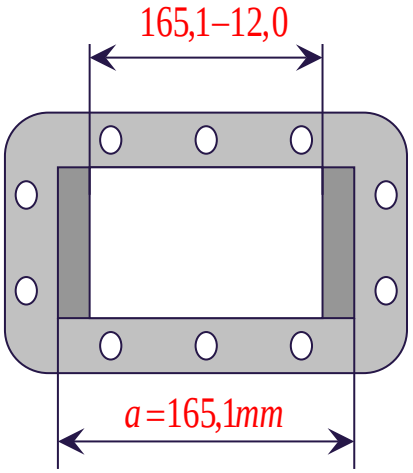
Fixed phase shifter

2387 mm length

type A (153 mm x 78mm)

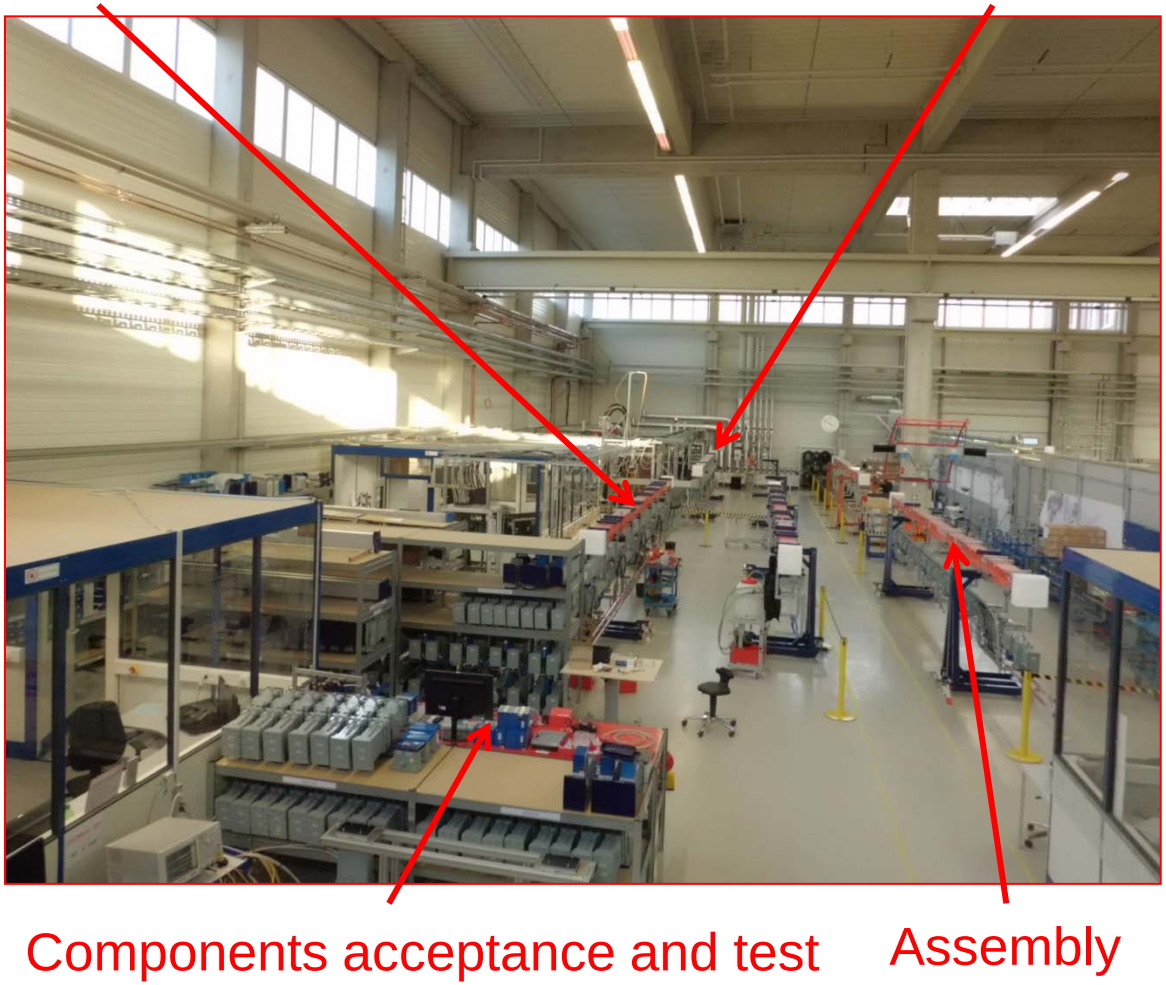
type B (156 mm x 78 mm)

to compensate of the phase shift 210 and 160 degree



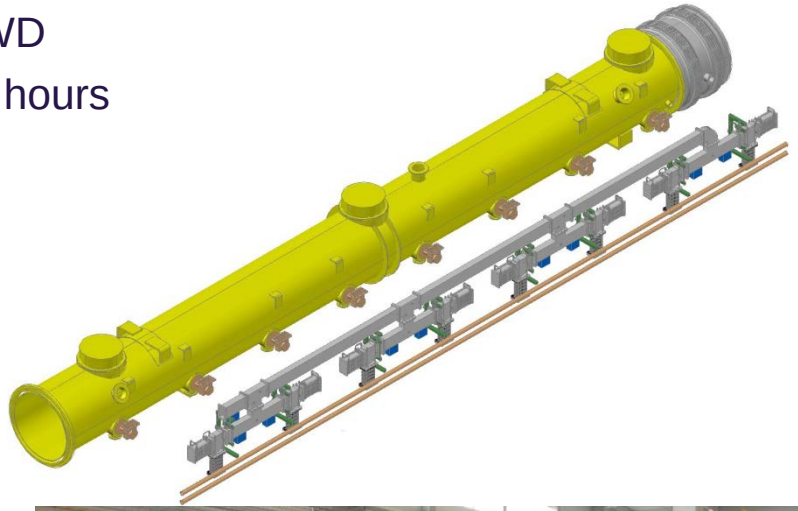
WATF

- Acceptance, test and preparation of subsystems (waveguide components, cables, cooling system, supports), specification, assembly, test of waveguide distributions and connection
- 4 working places – Binary cell assembly and tuning, WD assembly and mechanical adjustment, LLRF and HPRF stand
- 12 specific test stands for tuning and adjustment of WD component (input geometrical control, air tightness test, step motor test, WG cleaning and drying, shunt tee tuning etc.)
- Measurement process is automated
- Storage place for 6 WD components
- Production rate – 2 tailored WD per week now reached
- Connection to modules in AMTF



WD and cryomodule at AMTF

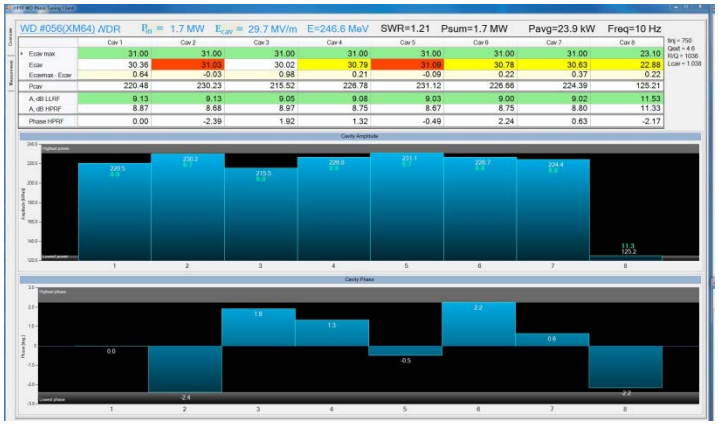
- WD is connected to cryomodule with special 6 DoF (degree of freedom) setup at AMTF
- The cryomodule itself is the support for the WD
- WD Installation at cryomodule takes about 7 hours



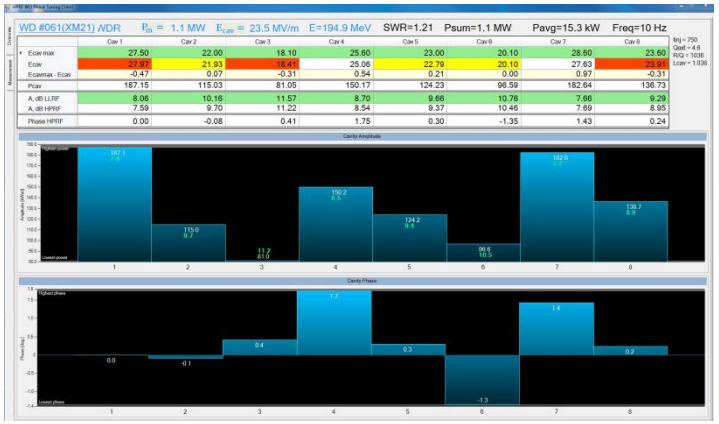
Power pattern for different WDs

High Power RF Test Results Δ = +250 MEV ⇨ 4 new ACC = 5 standard ACC

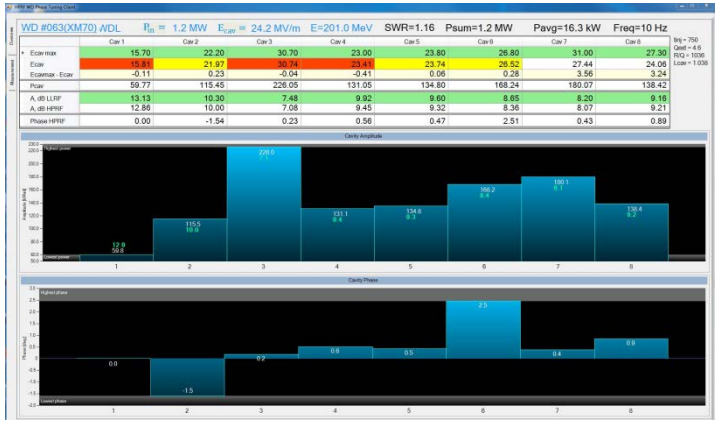
WD#56 EXFEL WD = 247 MeV Standard = 192 MeV



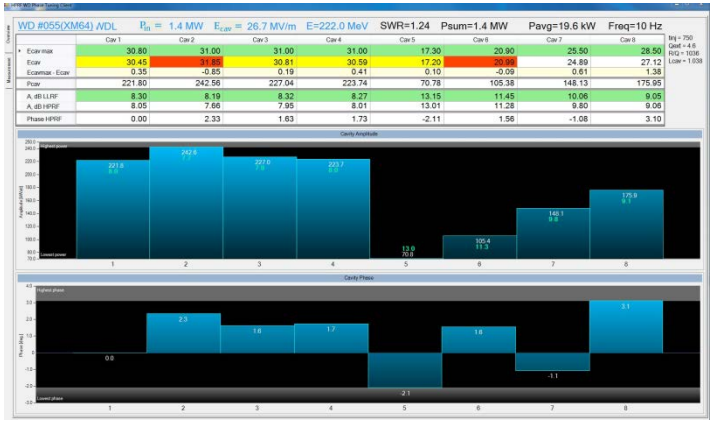
WD#61 EXFEL WD = 195 MeV Standard = 150 MeV



WD#63 EXFEL WD = 201 MeV Standard = 130 MeV



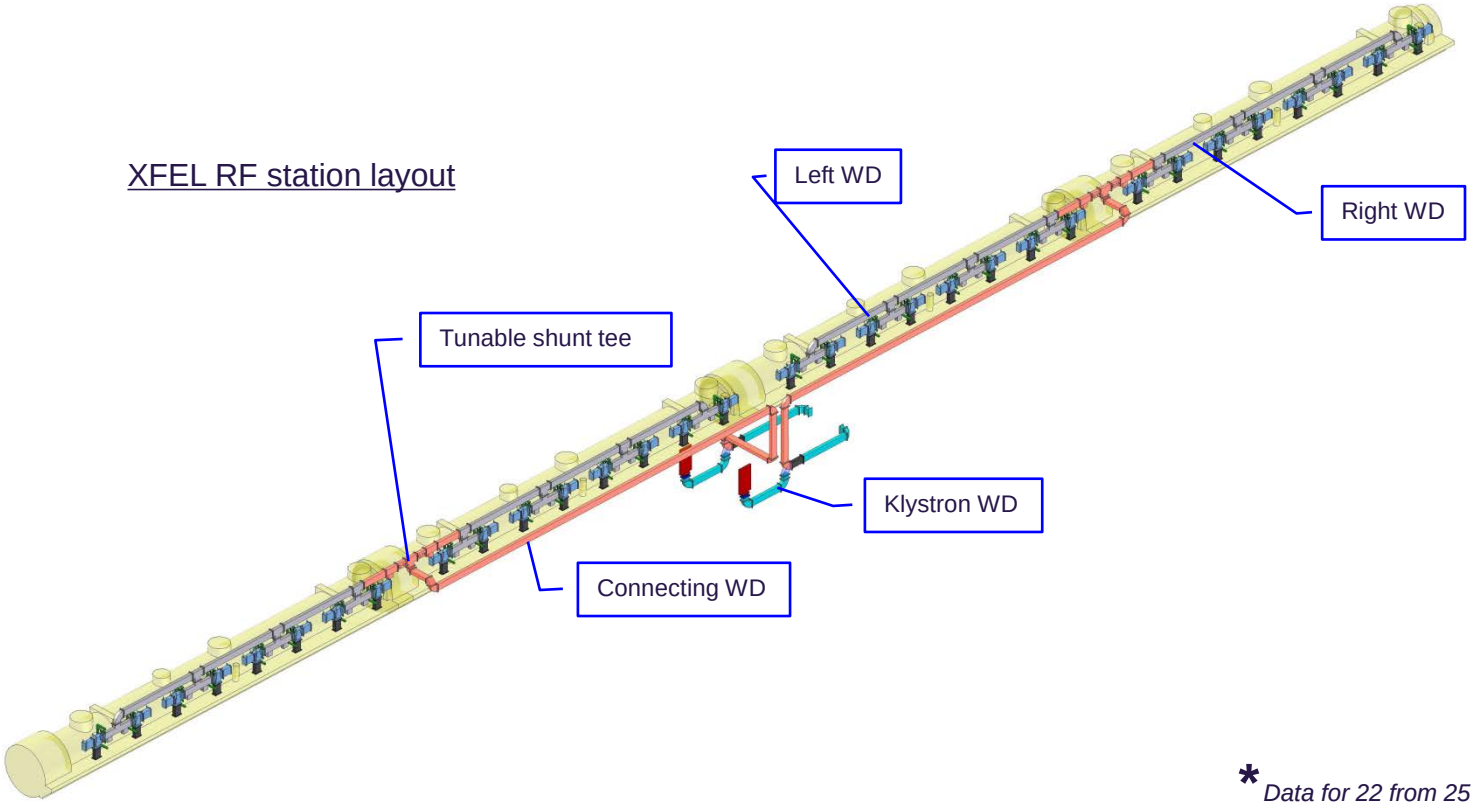
WD#55 EXFEL WD = 222 MeV Standard = 143 MeV



XFEL Waveguide Distribution*

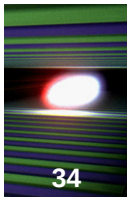
- Max achievable linac energy is **20.1** GeV (theoretically)
- Linac energy with specific waveguide distribution is **19.5** GeV (practically)
- Linac energy with standard waveguide distribution is **15.7** GeV (theoretically)

XFEL RF station layout



* *Data for 22 from 25 RF stations*

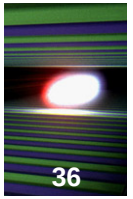
Summary



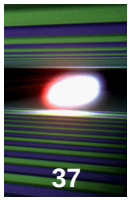
- The European XFEL requires 27 10MW, 1.4ms, 10Hz high power RF stations
- 2 RF Stations of the Injector in operation
- 7 RF Stations of the Main Linac commissioned
- 15 RF Stations in preparation
- Tailoring of waveguide distributions allows to make use of the maximum cavity accelerating gradient
- The total achievable linac energy will be increased by 3-4GeV

- Thank you very much for your attention

Spare Transparencies



XFEL RF System

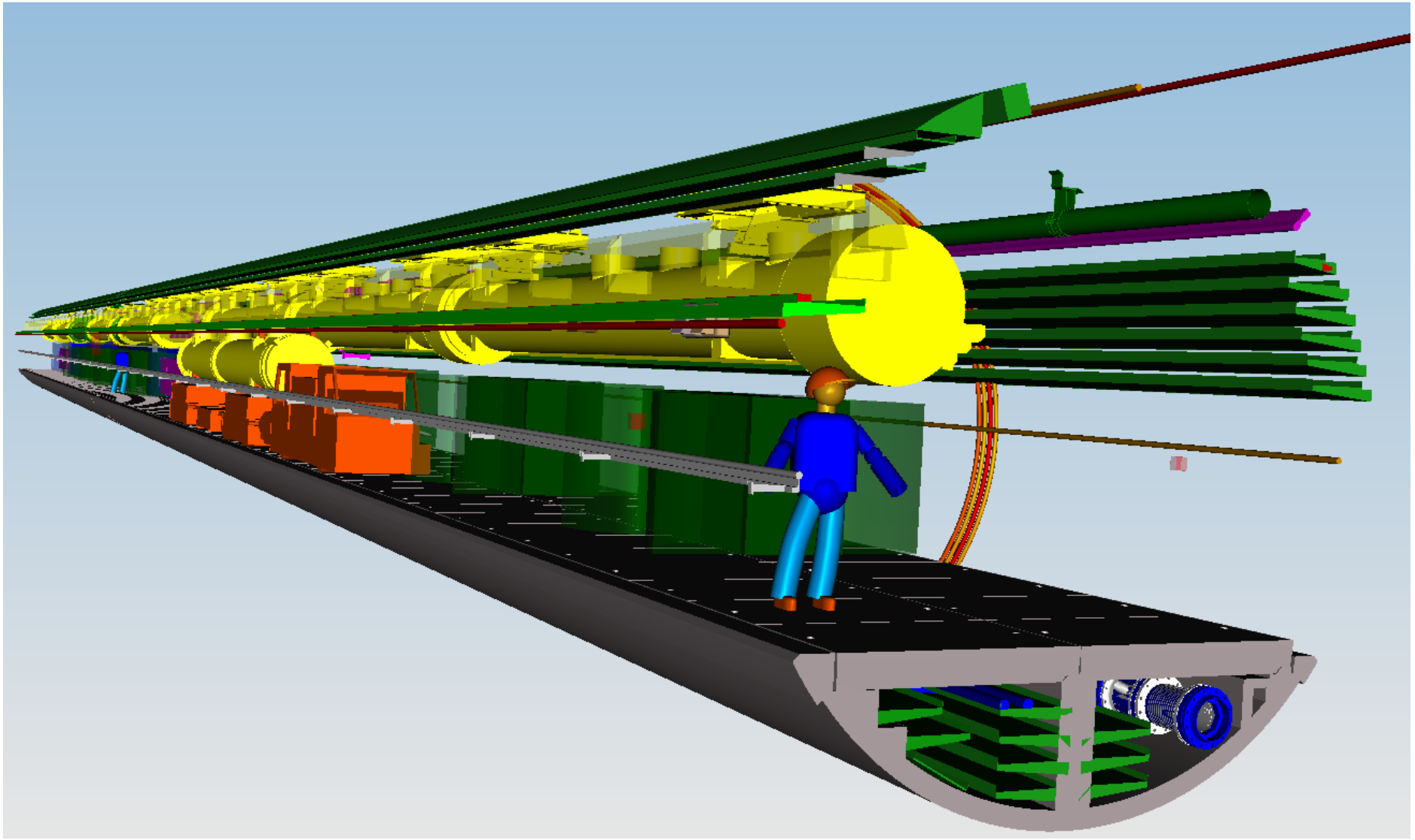


27 RF stations generating high power RF and distributing it to the cavities of the linac

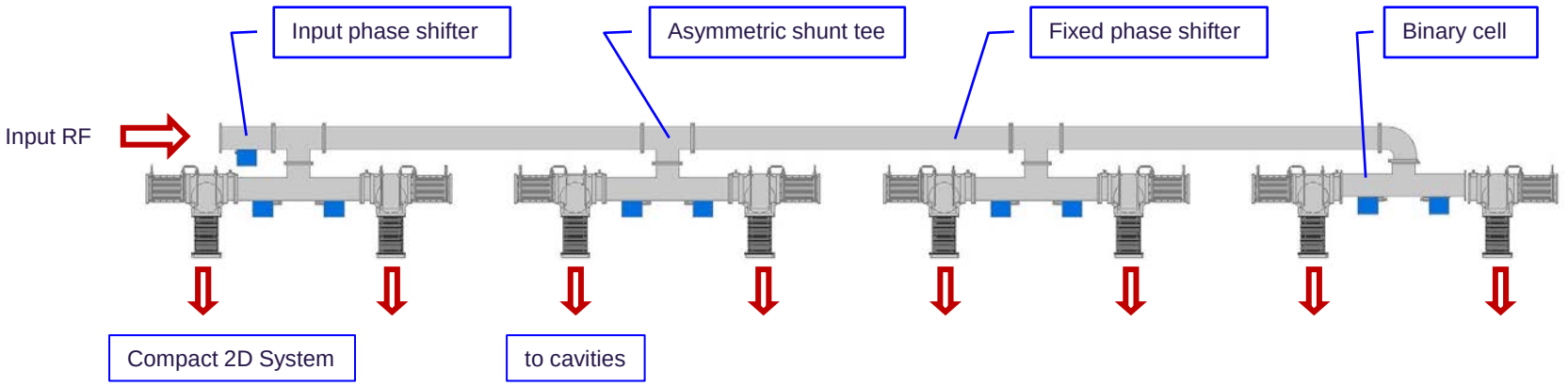
- 27 klystrons
- Auxiliary power supplies and racks for 27 RF stations
- 27 preamplifiers
- 27 RF interlocks
- Interlock, control, power and signal cables for 27 RF stations
- Interlock glass fibres for 27 RF stations
- 27 modulators
- 27 pulse transformers with connection modules
- Complete RF waveguide distribution

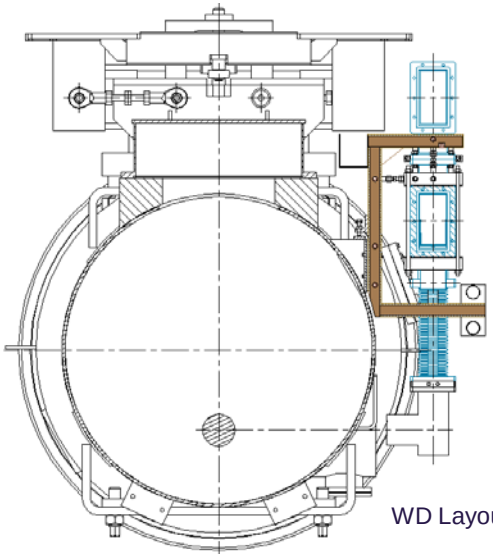
European XFEL

CAD Model of LINAC installation



Cryomodule Waveguide Distribution layout





WD Layout in XFEL Tunnel

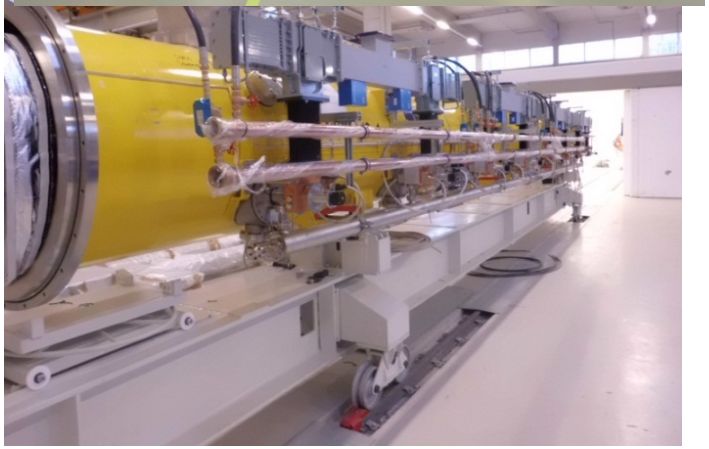
LLRF waveguide distribution test and tuning at WATF

Assembly of Waveguide Distribution

- Waveguides at AMTF

- Waveguides at girder during installation test

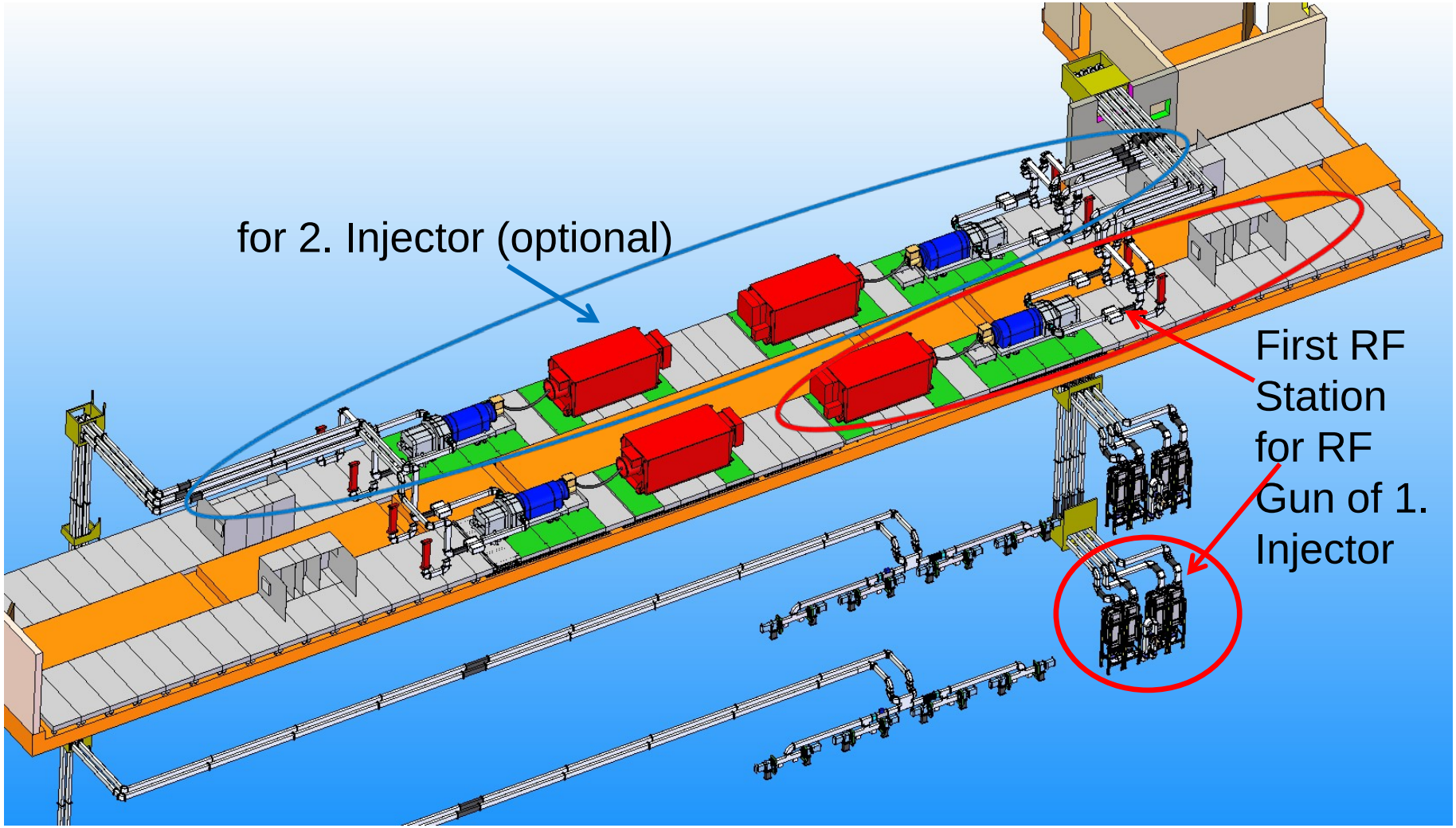
- WATF with girders for waveguide assembly



- Waveguides with cooling tubes at module during installation test

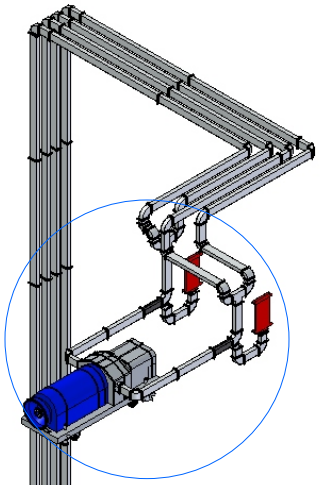
European XFEL

XFEL Injector RF Stations



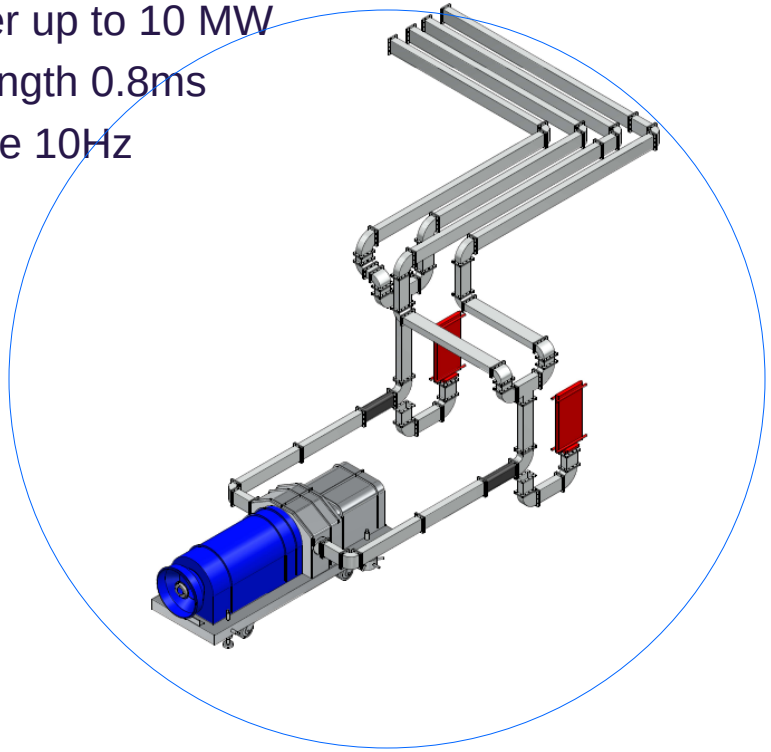
RF Station 1 in Injector on Underground Floor 3

Gun Waveguide Distribution (1)



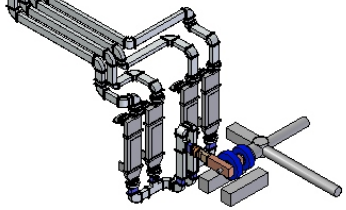
Klystron Waveguide Distribution **IKWD7**

- RF Power up to 10 MW
- Pulse Length 0.8ms
- Rep. Rate 10Hz



Connecting Waveguide Distribution **IGCW7**

Girders and supports designed to compensate mechanical misalignment and thermal expansion



Gun Waveguide Distribution **IGWD7**

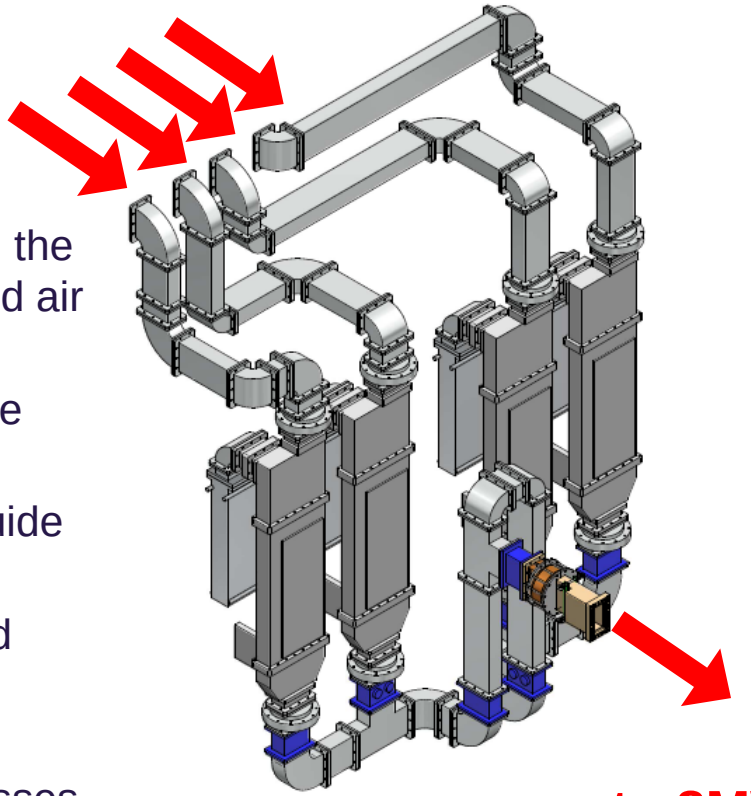
Gun Waveguide Distribution (2)

Goal

- To supply the Gun with RF power 6.5 MW (up to 8MW) with high reliability

Features

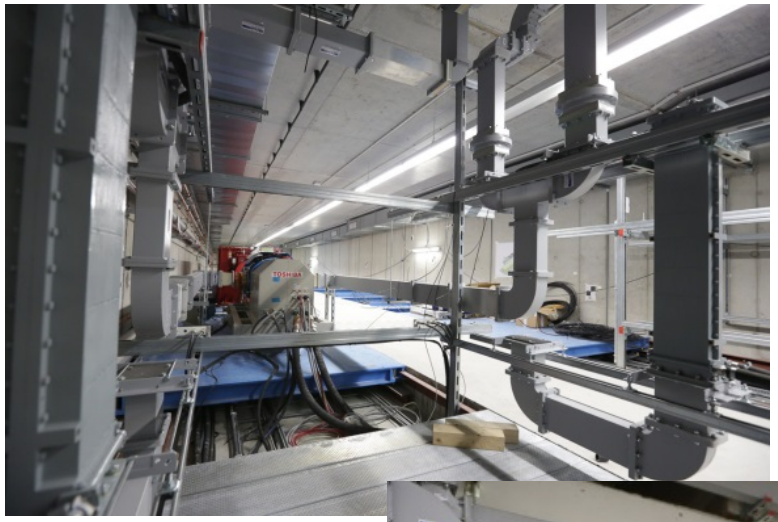
- No SF6 in tunnel and waveguide distribution
- To increase the power capability of the circulators and the high power shunt tee before gun the 1.5bar pressurized air is used
- To increase the waveguide reliability four circulators are used
- No movable parts inside the waveguides – the waveguide phasing is controlled by dry air flow
- Waveguide Distribution for Gun has been coarse tuned with fixed phase shifters only.
- The loss of the waveguide system is about 0.8-0.9 dB (due to – 0.3 dB waveguide losses, 0.4 dB isolators losses, 0.2 dB phasing losses)
- Before the all of power isolators have been tested up to 2 MW for short circuit with two phases (0 and 90 degree)

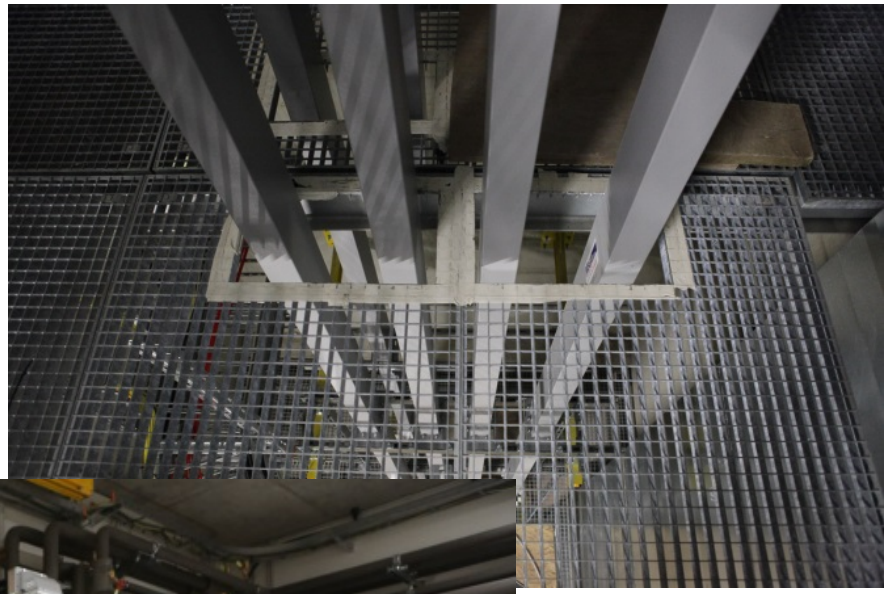


Pulse length 0.65ms

Rate 10Hz

Gun Waveguide Distribution (3)





Pulse Transformer Installation

Klystron Installation