# Experience from the European XFEL.

## Installation of HLRF in a Single Tunnel

## First Baseline Assessment Workshop

BAW · KEK · Tsukuba, Japan

September 7 to 10, 2010

Wilhelm Bialowons · DESY & GDE

# Outline

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# Outline

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- Installation and Commissioning
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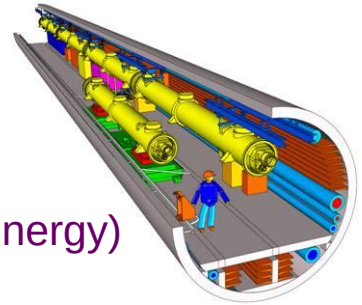
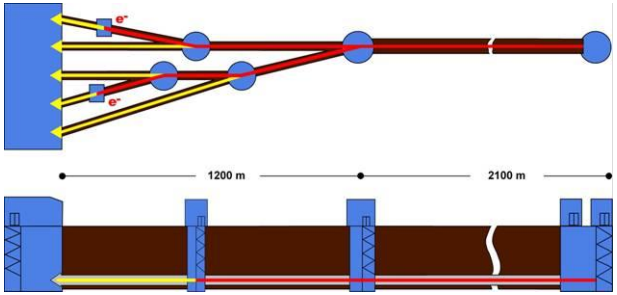
# Introduction: References

- Stefan Choroba, *Design and Status of the XFEL RF System*, 22nd Particle Accelerator Conference, June 25 to 29, 2007, Albuquerque, New Mexico, USA (JACoW: TUXC03).
- Valery Katalev and Stefan Choroba, *Waveguide Distribution System for FLASH*, 6th Workshop on CW and High Average Power RF, May 4 to 7, 2010, ALBA, Barcelona, Spain (InDiCo.cern.ch: 73280).
- Stefan Choroba, *Specification, Procurement, Production, Assembly, Testing, Installation and Commissioning (of the XFEL RF System)*, unpublished.
- Jörg Eckoldt, *Pulse Cables for XFEL*, September 5, 2007, XFEL Project Meeting (DESY EDMS: 933641).

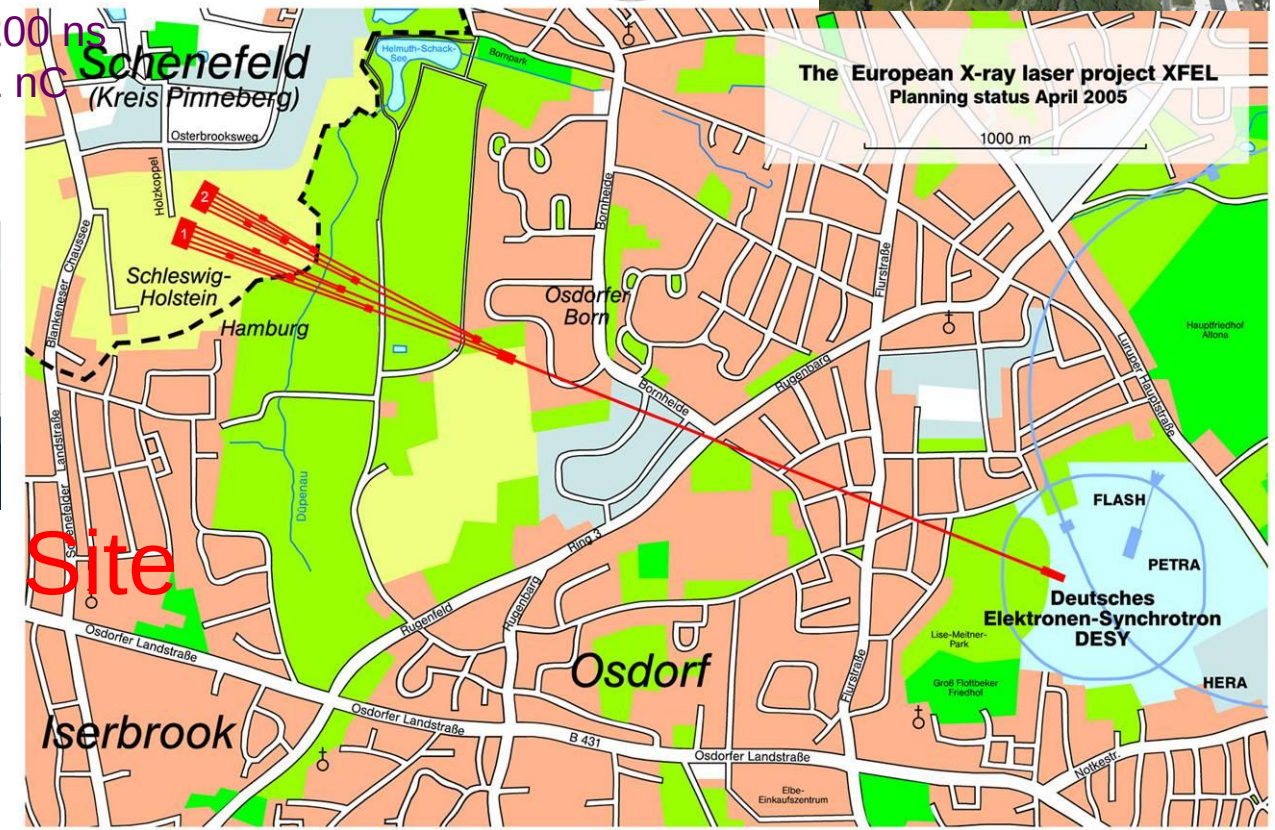
# Introduction: XFEL Overview

| | |
|---|---|
| Beam energy: | 14 GeV (17.5 GeV) |
| No. of active ML klystrons: | 18+2+2 (23+2+2) |
| Wavelength: | down to 0.1 nm |
| Beam pulse length: | 650 μs |
| Repetition rate: | 10 Hz (30 Hz at low energy) |
| No. of bunches per pulse: | 3250 |
| Bunch to bunch spacing: | 200 ns |
| Bunch charge: | 1 nC |

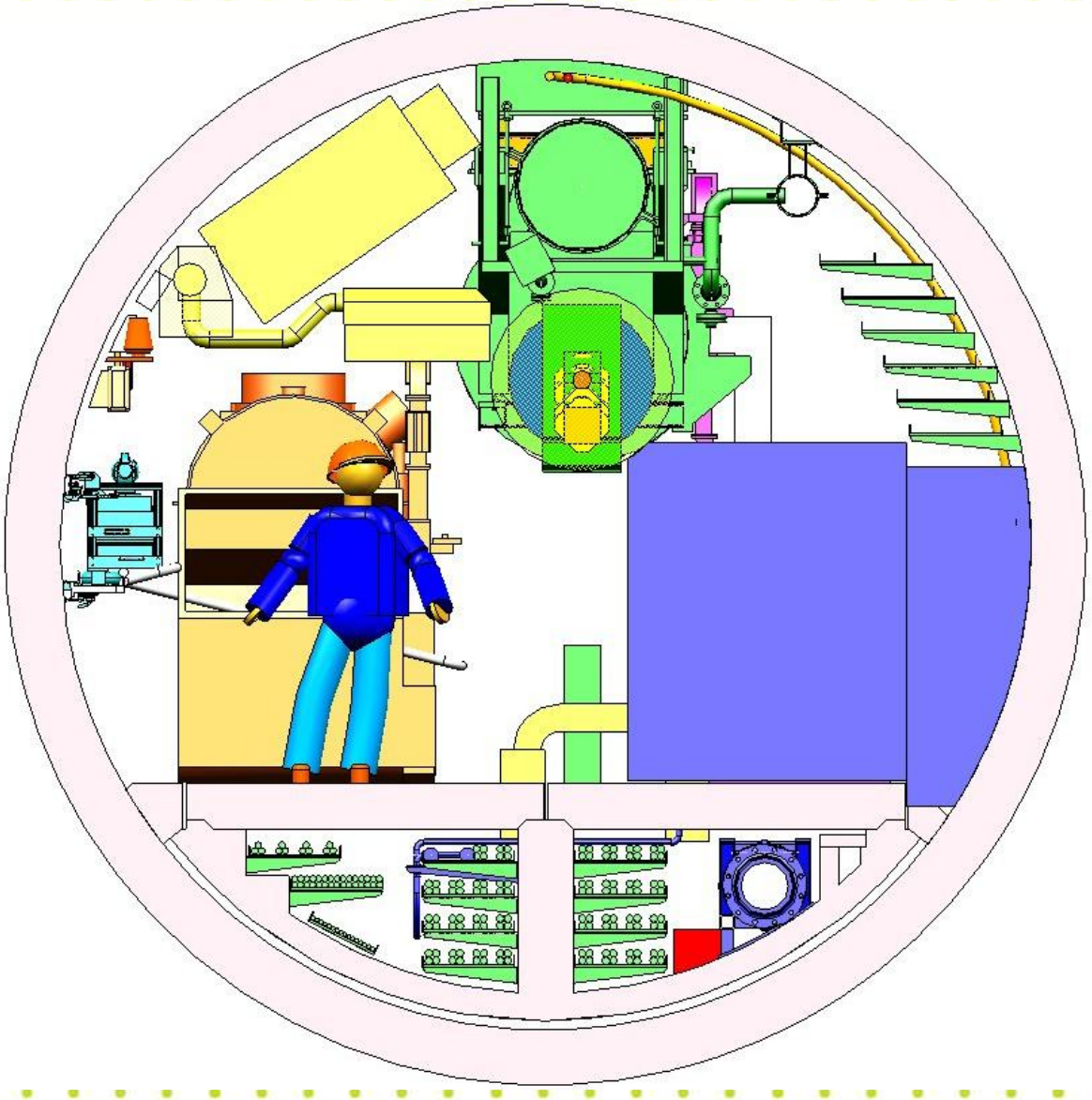






# Introduction: ML Tunnel Cross Section



# XFEL: Tunnel Construction Progress

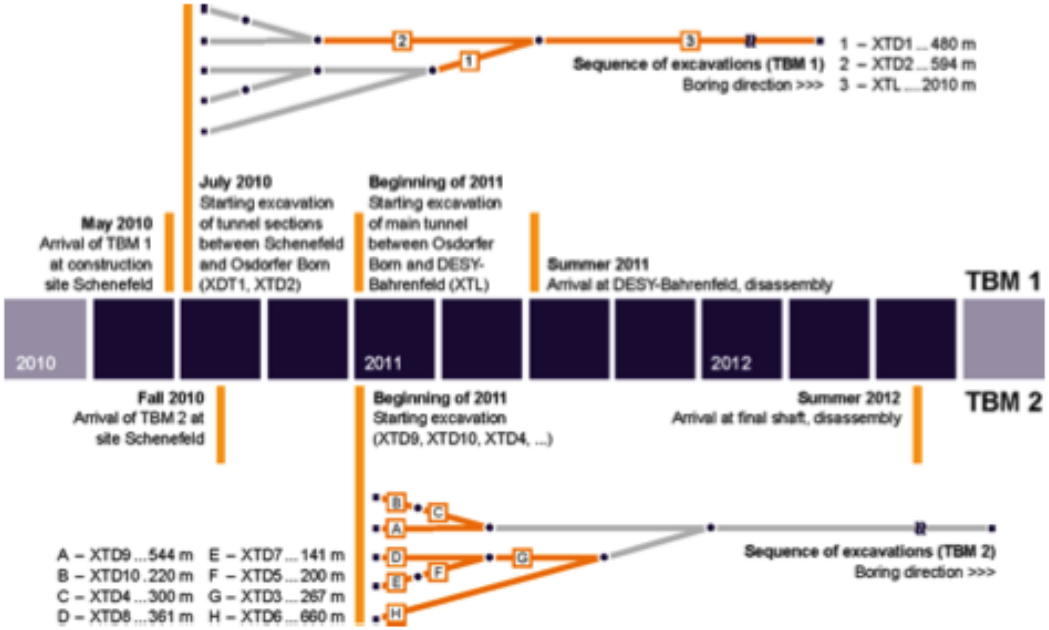
| | | |
|---|---|---|
| Total length of completed tunnels | 477.77 m of 5777 m | 8.3 % |

## TUNNEL BORING MACHINE 1 (TULA = TUnnel for LAser)

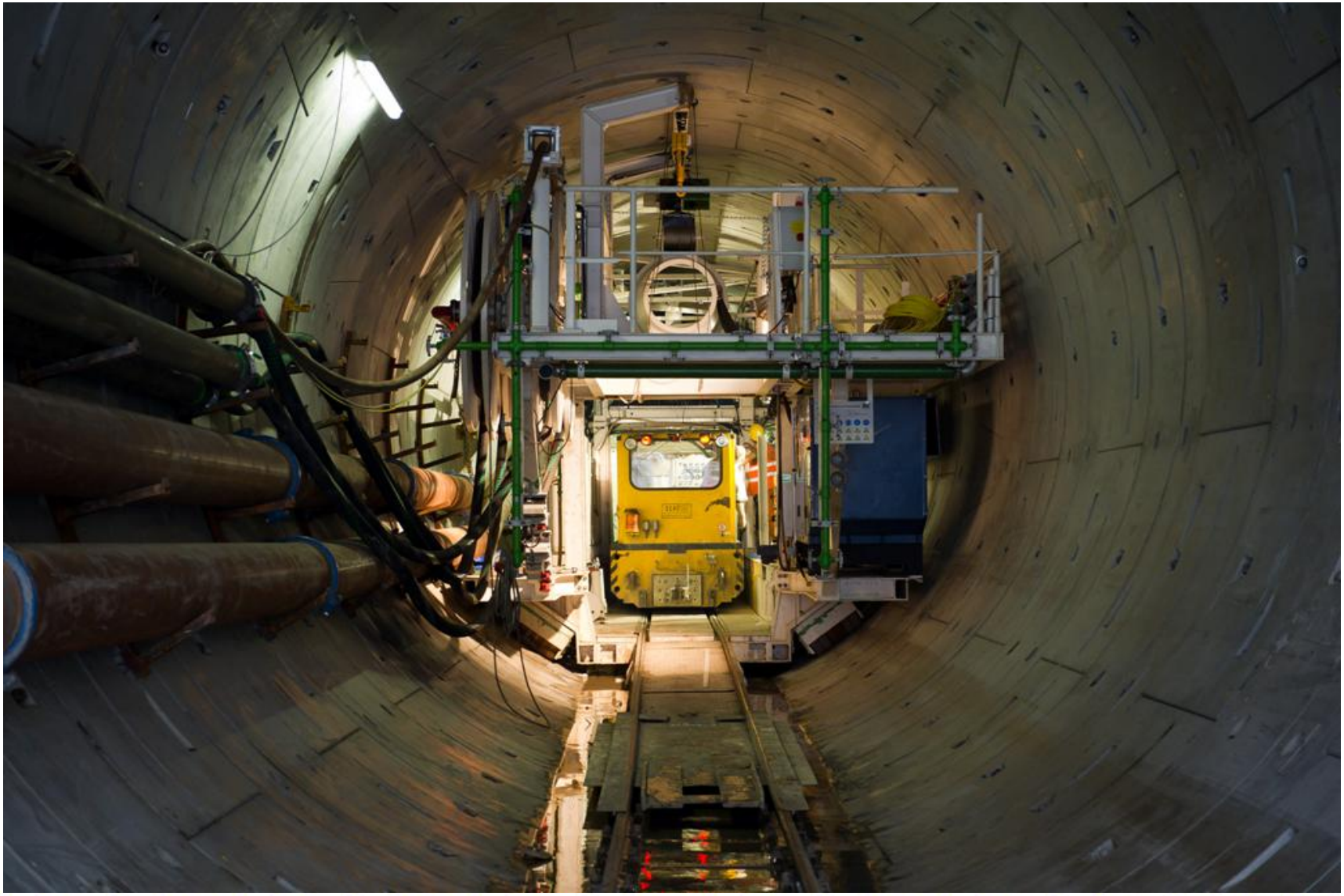
| | | |
|---|---|---|
| Activity | On 31 August 2010, boring of tunnel section XTD1 was completed. In the coming weeks, TULA will be disassembled, transported to the next start shaft and reassembled. The next tunnel boring will begin in mid-October 2010. | |
| Length of completed tunnels | 477.77 m of 3084 m | 15.5 % |
| Number of rings (1.5 m each) | 318 of 2054 | |
| Start date | 07 July 2010 | |

## TUNNEL BORING MACHINE 2

| | | |
|---|---|---|
| Length of completed tunnels | 0 m of 2693 m | 0 % |
| Number of rings (1.5 m each) | 0 of 1801 | |
| Start date | Beginning of 2011 | |

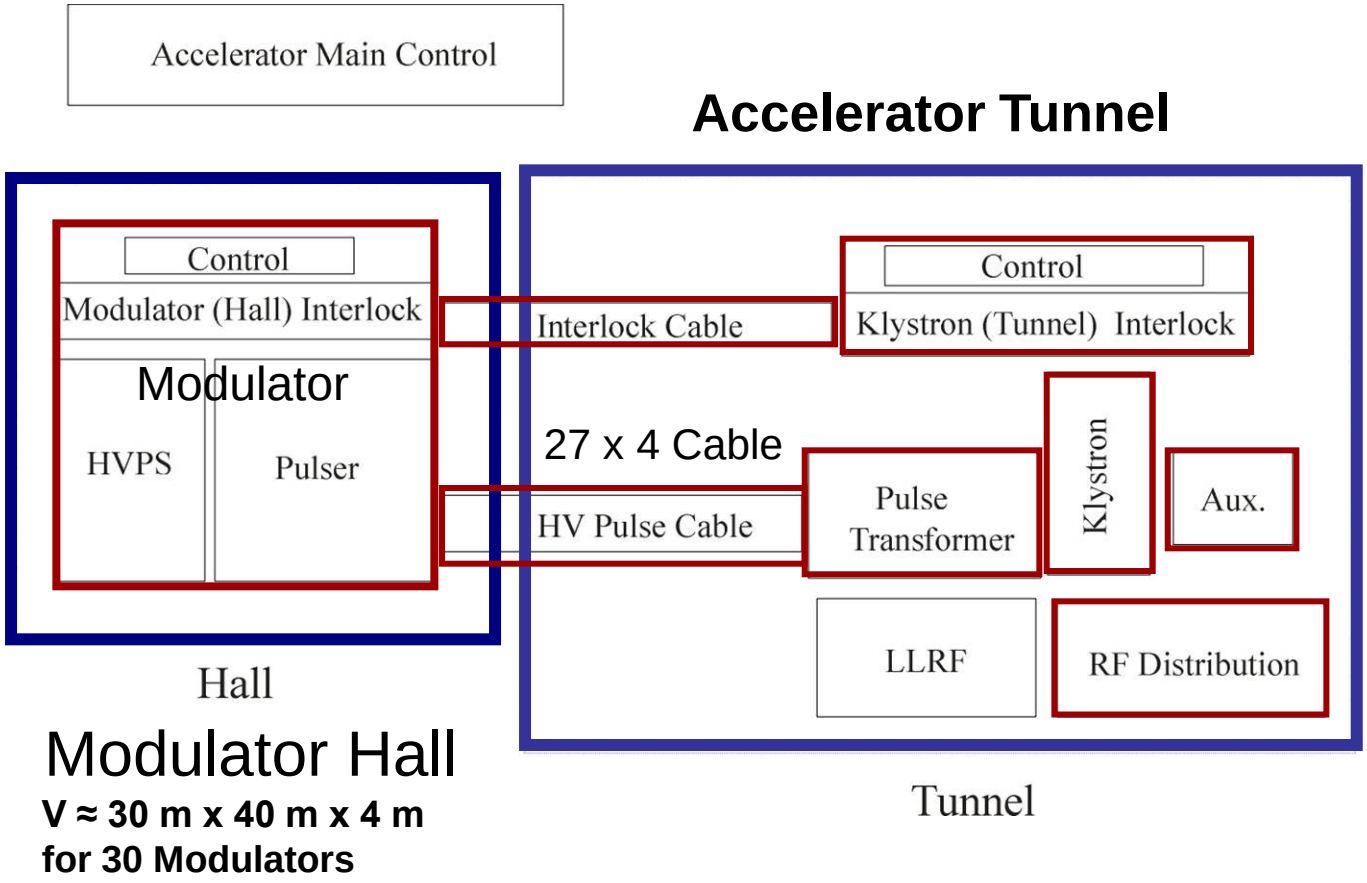


# XFEL: Tunnel Construction Progress

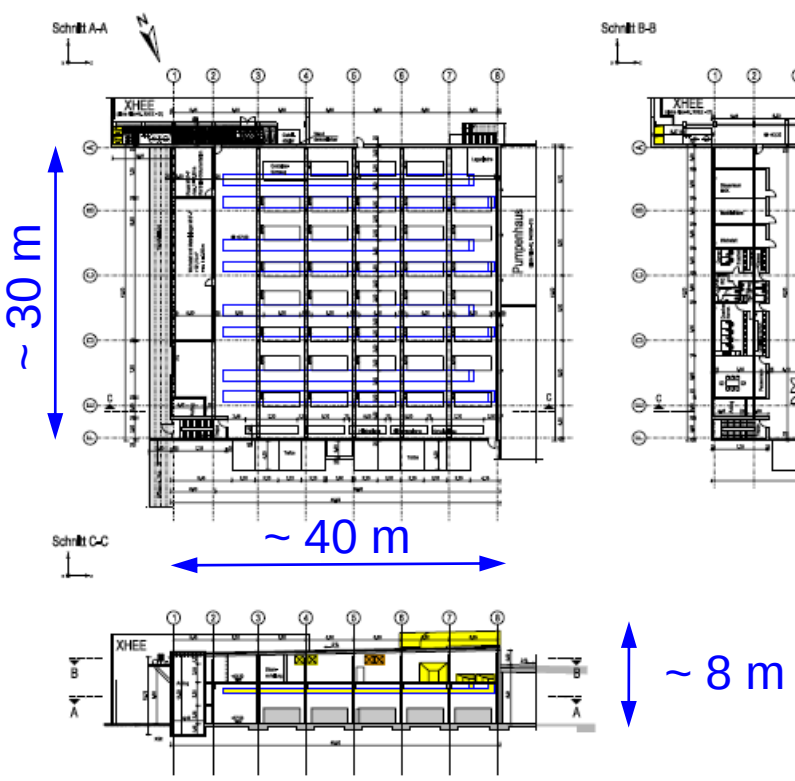


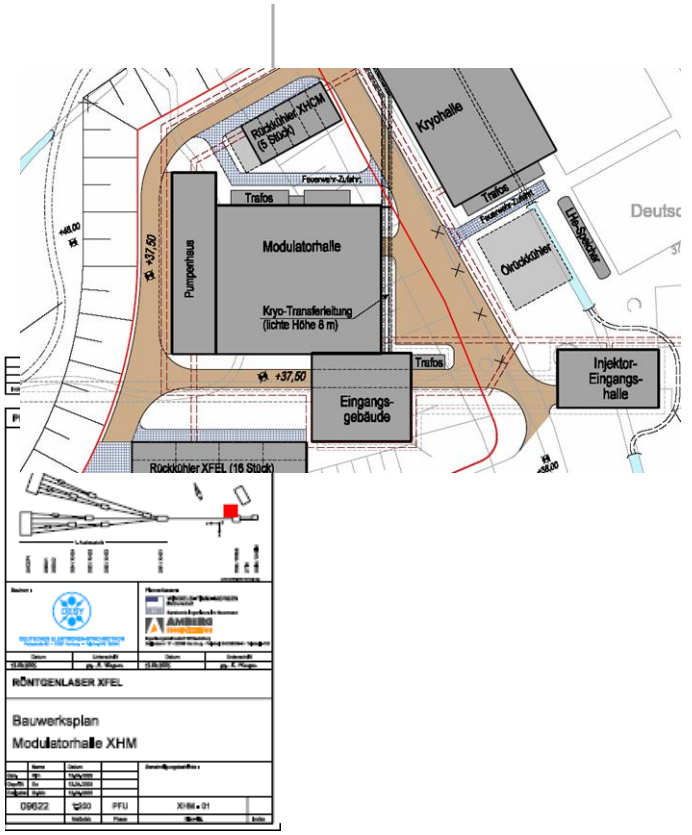
# XFEL RF System Requirements

## Layout of one RF Station



# XFEL RF: Modulator Hall

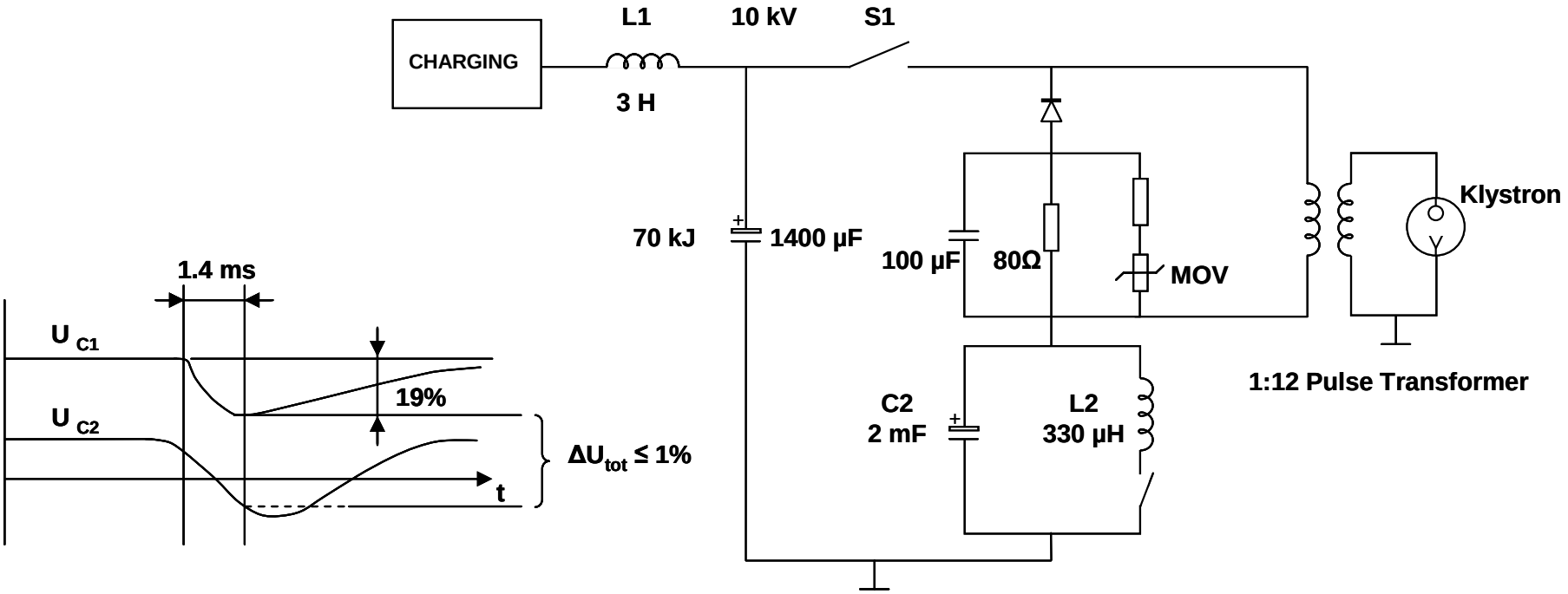



- Maintenance and Repair will be possible during Operation.

# Modulator Requirements

- Modulators must generate HV pulses up to 120 kV and 140 A, 1.57 ms pulse length and 10 Hz (30 Hz) repetition rate
- The top of the pulse must be flat within 1 %
- The bouncer type modulator with its simple circuit diagram was chosen



# XFEL: Bouncer Modulator

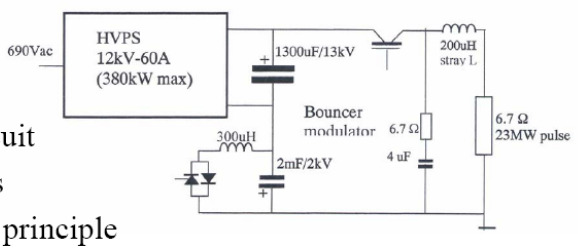
- Industry made subunits (**PPT** (General Vendor), ABB, FUG, Poynting)
- Constant power power supply for suppression of 10 Hz repetition rate disturbances in the mains
- Compact storage capacitor bank with self healing capacitors
- IGCT Stack (ABB); 7 IGCTs in series, 2 are redundant
- Low leakage inductance pulse transformer (ABB) $L < 200\ \mu H$ resulting in shorter HV pulse rise time of $< 200\ \mu s$
- Light Triggered Thyristor crowbar avoiding mercury of ignitrons

# XFEL: Modulator

## Qualification of additional vendors

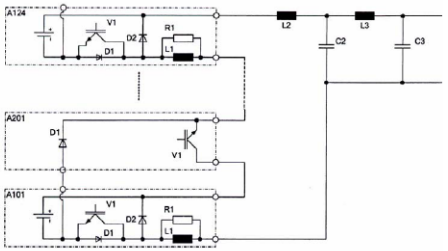
### Bouncer Modulator by Imtech/Vonk?

- Bouncer Type, as specified by DESY
  - 12kV HVPS
  - Bouncer 300uH/4.6kA
- 7st IGCT main switch
- Digital Regulation Circuit
- Analog In- and Outputs
- Well known and tested principle
- delivery time: 12 month



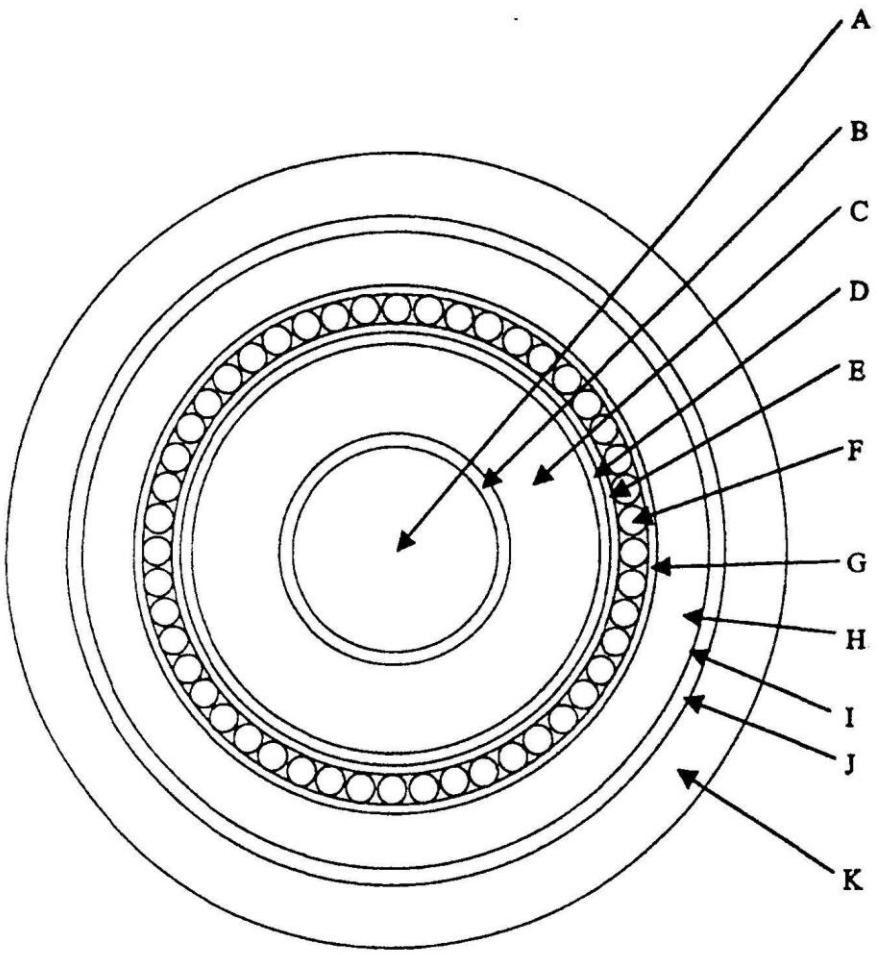

### PSM Modulator by Thomson BM✓

- Different Type:
  - 12kV/2kA w. transformer
  - Pulse Width Modulation
  - 24 switching stages in series
  - FPGA based control
  - 2 stages for redundancy
- Slew rate and pulse shape controllable
- detailed description available, principle already successfully tested (worldwide, i.e. W7/X)
- delivery time: 14 month



Installation at DESY, location Zeuthen

# XFEL: Pulse Cable Design




LEGEND

A. 75mm$^2$ STRANDED BARE COPPER CONDUCTOR (19 WIRES). COMPACT DIAMETER: 10.6mm

B. SEMI–CONDUCTING LAYER: EXTRUDED EPR THICKNESS: 0.7mm – DIAMETER: 12.0mm

C. XLPE INSULATION, MINIMUM AVERAGE THICKNESS: 4.0mm – DIAMETER: 20.2mm

D. SEMI–CONDUCTING LAYER: EXTRUDED EVA THICKNESS: 0.6mm – DIAMETER: 21.4mm

E. SWELLING SEMI–CONDUCTING TAPE, THICKNESS: 0.3mm – DIAMETER: 22.1mm

F. 75mm$^2$ STRANDED BARE COPPER (47 WIRES OF 1.45mm). DIAMETER: 25.0mm

G. SWELLING SEMI–CONDUCTING TAPE, THICKNESS: 0.3mm – DIAMETER: 25.7mm

H. XLPE INSULATION, MINIMUM AVERAGE THICKNESS: 2.6mm – DIAMETER: 31.1mm

I. SWELLING SEMI–CONDUCTING TAPE, THICKNESS: 0.3mm

J. NON CORRUGATED COPPER FOIL 0.2mm THICKNESS, LONGITUDINALLY APPLIED & STUCK TO THE OUTER SHEATH.

K. FLAME RETARDANT & NON CORROSIVE JACKET. MINIMUM AVERAGE THICKNESS: 3.0mm –DIAMETER: 38.9mm

WEIGHT OF CABLE: 2770 kg/km ≃ 8310 kg
MINIMUM BENDING RADIUS: 520mm
MAXIMUM PULLING TENSION: 750daN

# XFEL: Pulse Cable Parameter

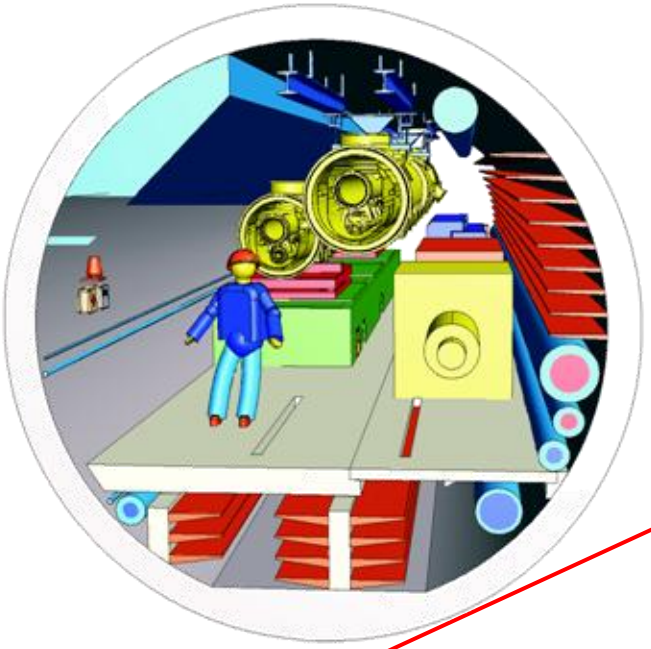
- Maximum Cable Length w/o connections $l$ = 3 000 m
- Cross-Section $A$ = 75 mm$^2$ Cu.
- Four Cables parallel.
- Losses per Cable per Meter without Skin Effect at 10 MW Pulse Power, 65 % Klystron Efficiency, 10 kV Voltage, 1.5 ms Pulse Length and 10 Hz Repetition Rate:
  $P/l$ = 0.5 W/m.
- Cable Cost see SLAC WBS Tool used for the RDR.

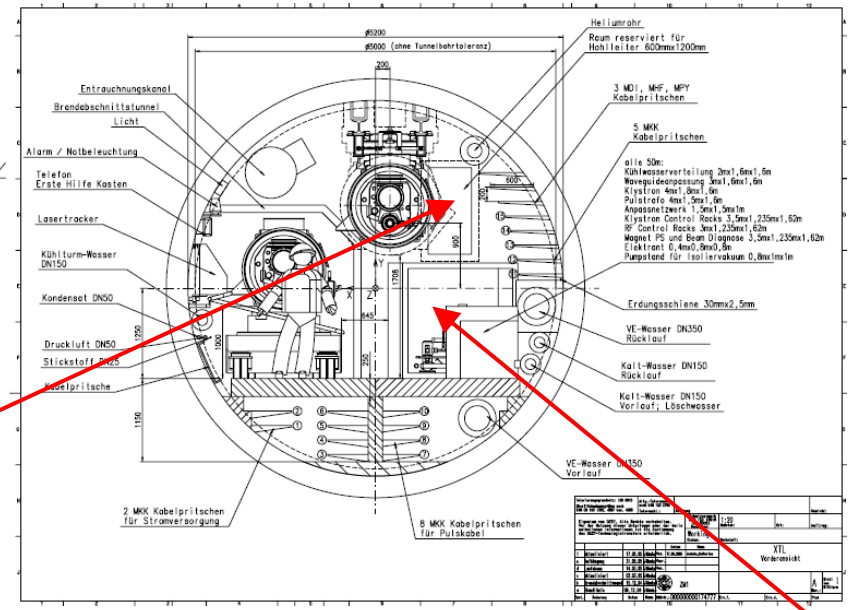
# XFEL: Pulse Cable

## Transport of drums with 3 km HV Pulse Cable

# XFEL RF System Requirements

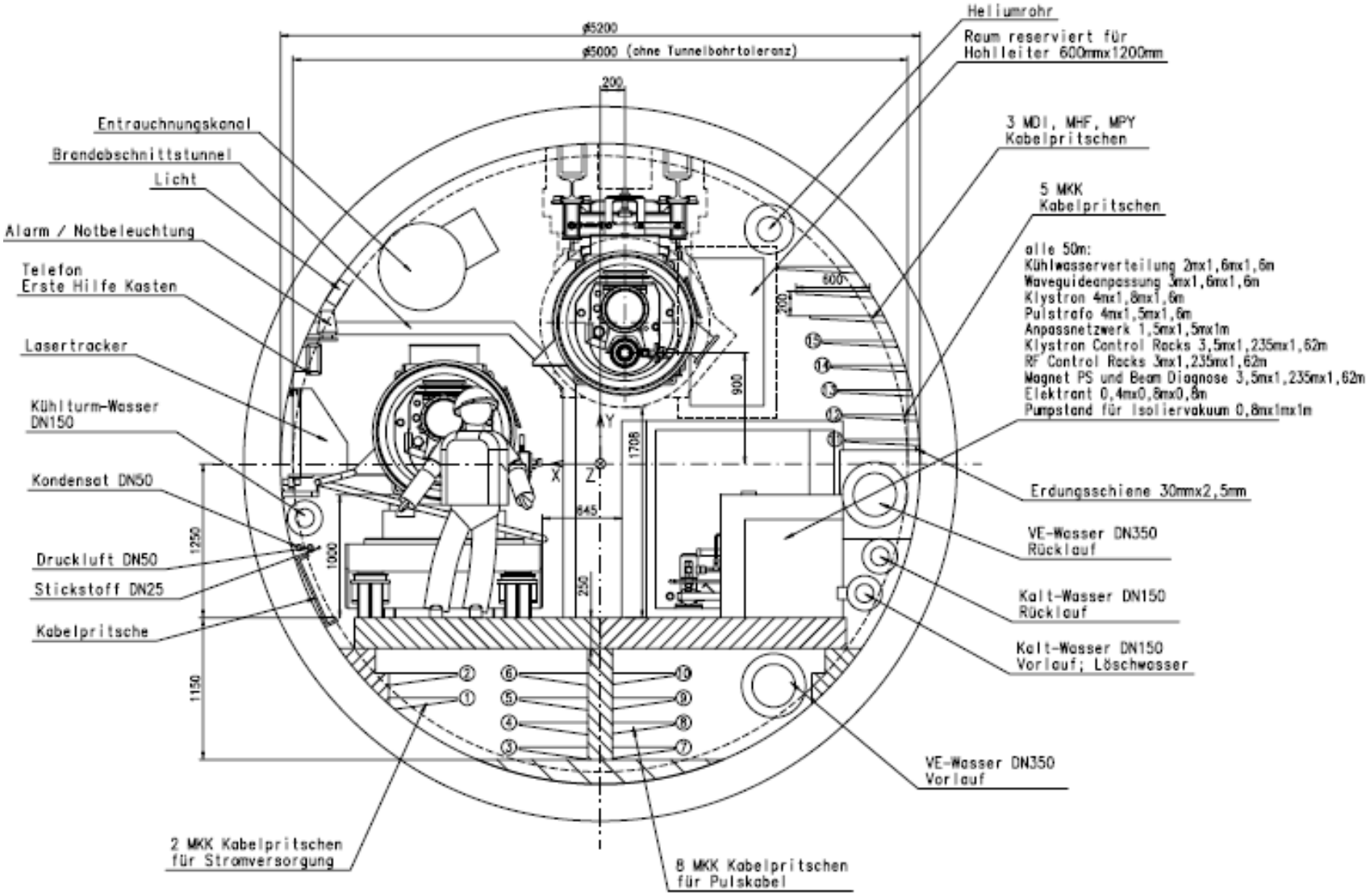
## Layout of the RF Station in the Accelerator Tunnel



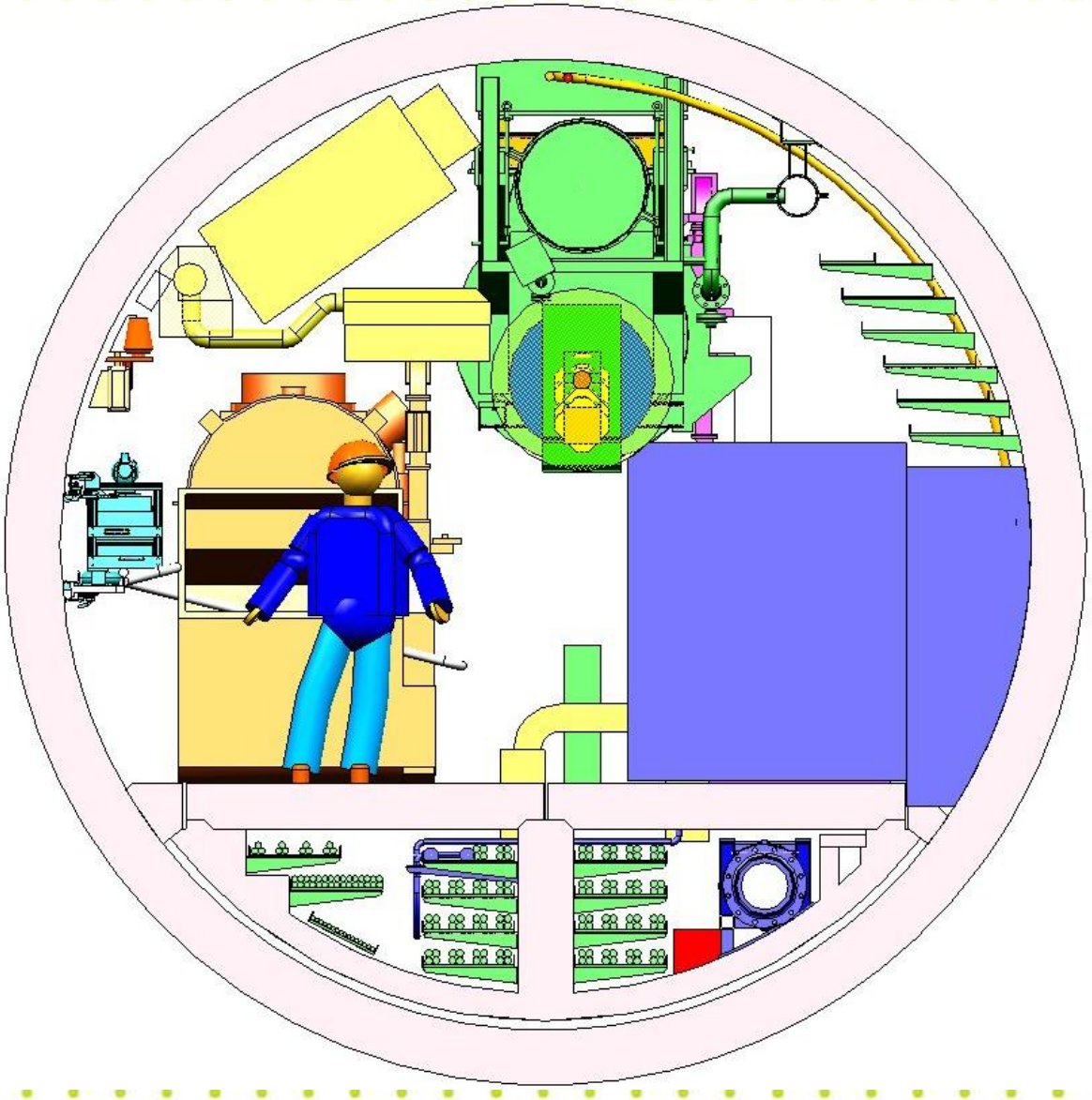



- Tunnel components (klystrons, pulse transformers, auxiliary power supplies etc.) will be installed under the cryogenic module.
- The waveguide distribution will be installed on the side of the cryo module.
- These components are not accessible during accelerator operation.

# XFEL Accelerator Tunnel: Cross Section



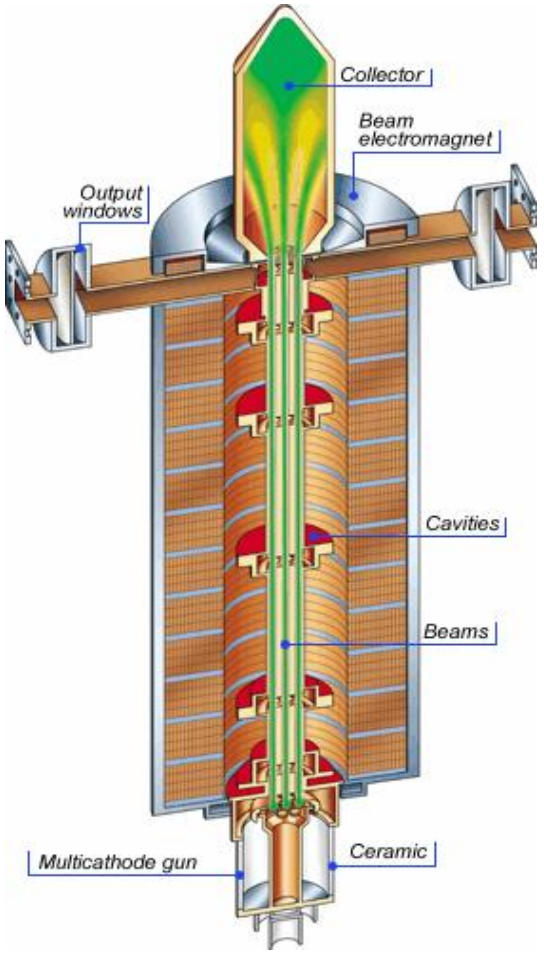
# XFEL Accelerator Tunnel: Cross Section



# RF High Power Source

## Requirements

| | |
|---|---|
| Operation Frequency: | 1.3 GHz |
| Cathode Voltage: | < 120 kV |
| Beam Current: | < 140 A |
| Max. RF Peak Power: | 10 MW |
| RF Pulse Duration: | 1.5 ms |
| Repetition Rate: | 10 Hz |
| RF Average Power: | 150 kW |
| Efficiency: | 65 % |
| Solenoid Power: | < 5.5 kW |
| Length: | 2.5 m |

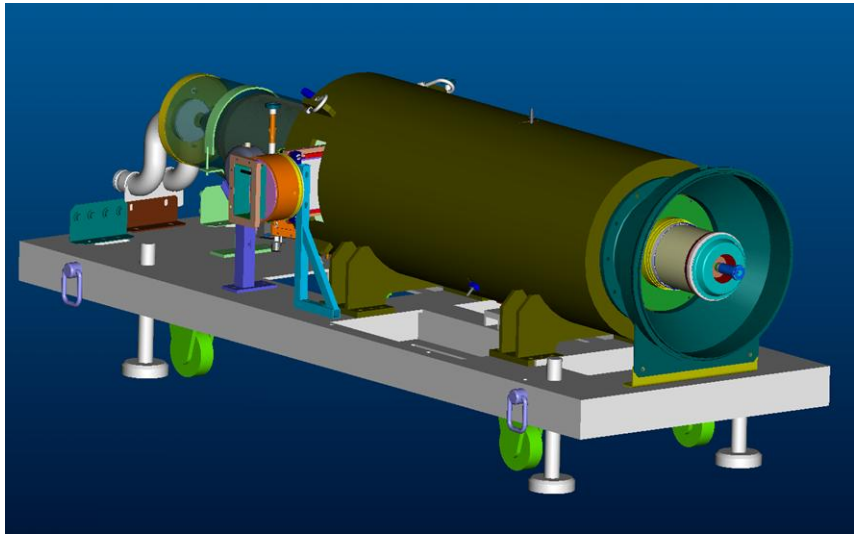



**Multi**Beam **K**lystron (MBK) was chosen

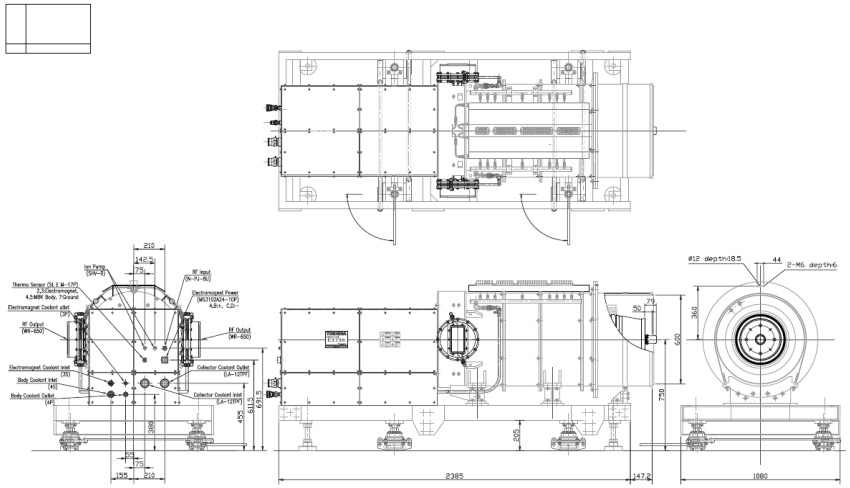
# Horizontal MBK Prototypes

- All 3 Vendors (CPI, THALES and TOSHIBA) have been pre-qualified for delivery of a horizontal MBK.
- All horizontal Prototypes (one per vendor) have been tested at DESY.

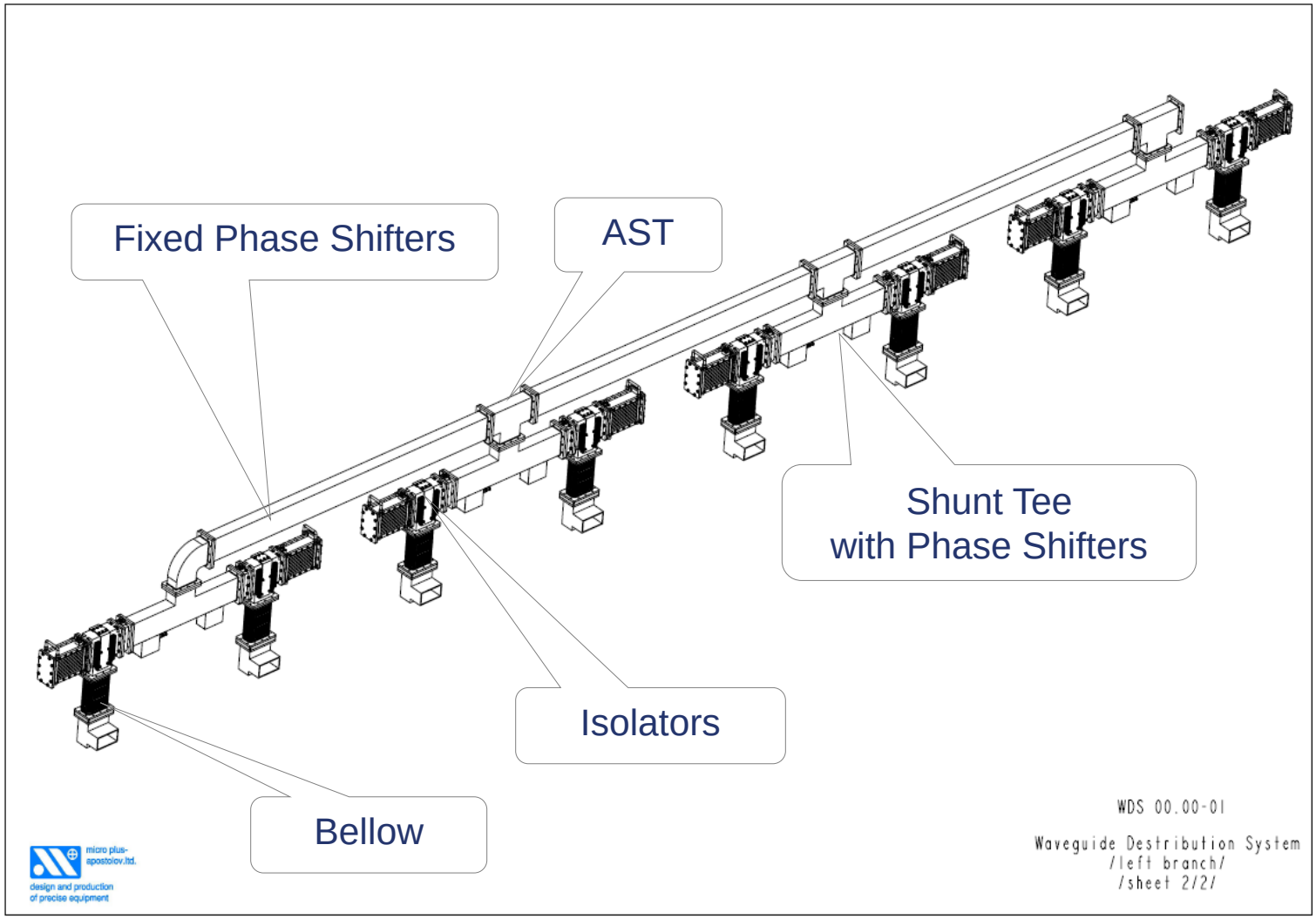
THALES TH1802



TOSHIBA E3736H



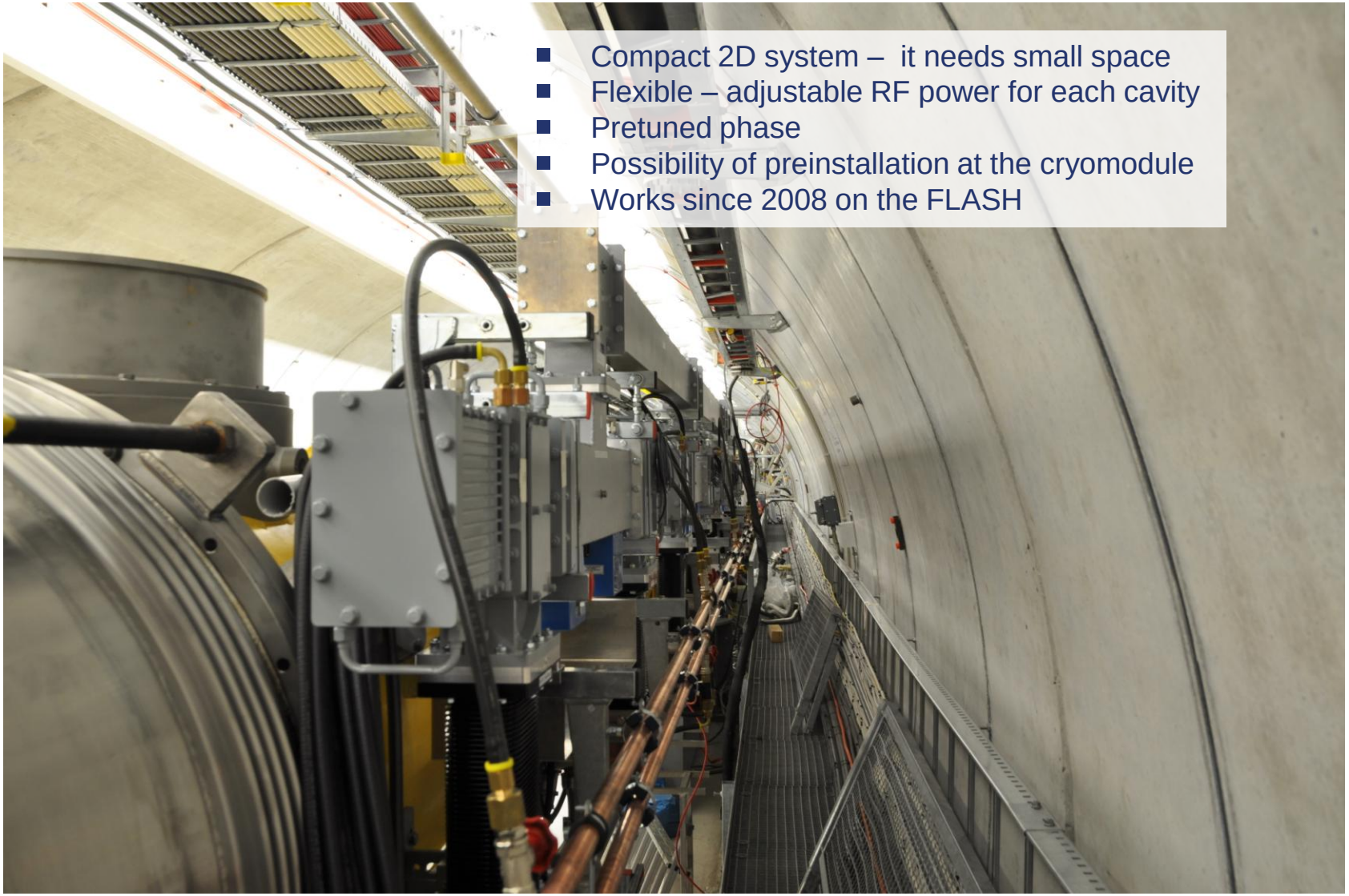
# Wave Guide Distribution



# XFEL Type Wave Guide Distribution for ACC7

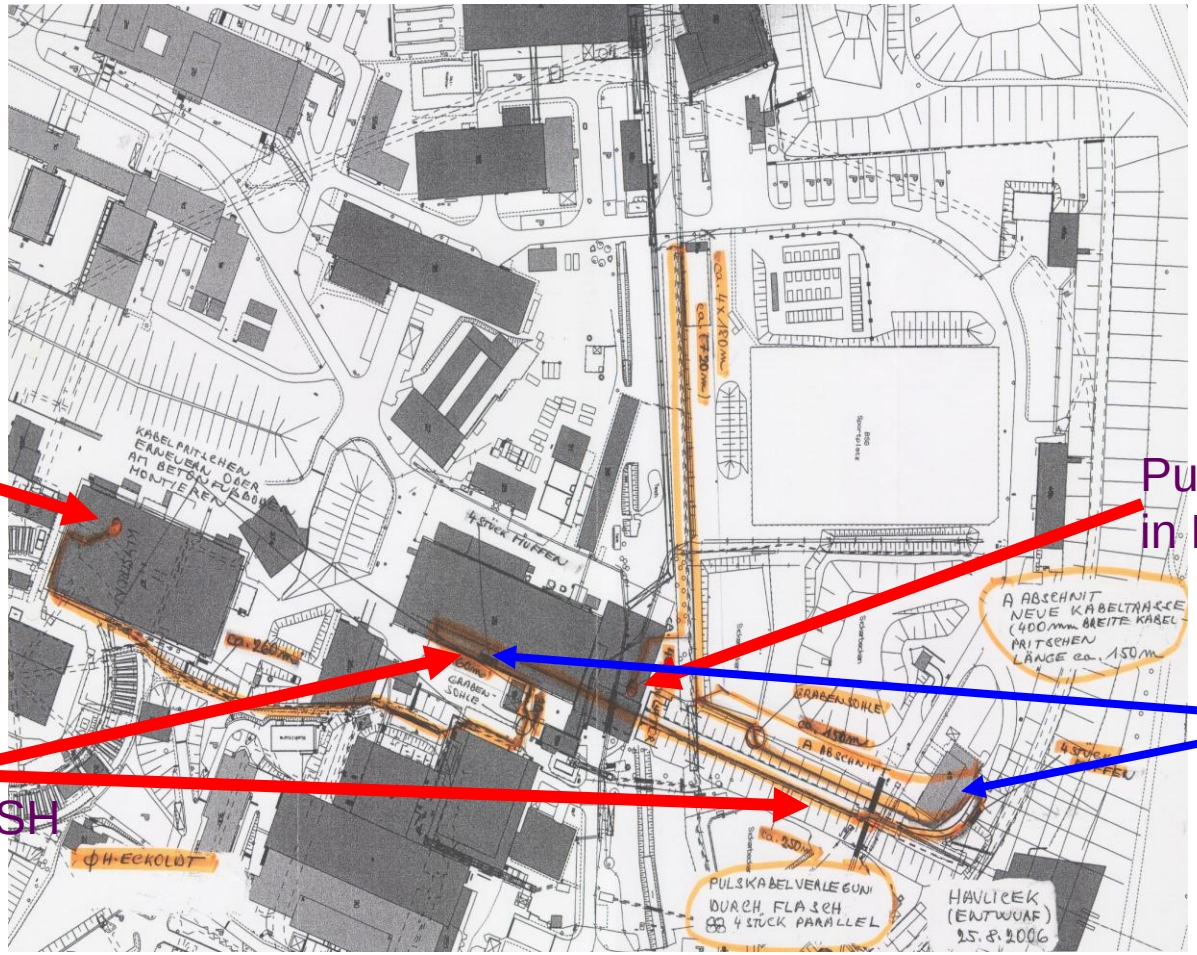
# Transport of ACC7 with Wave Guides

# Wave Guide Distribution in Flash

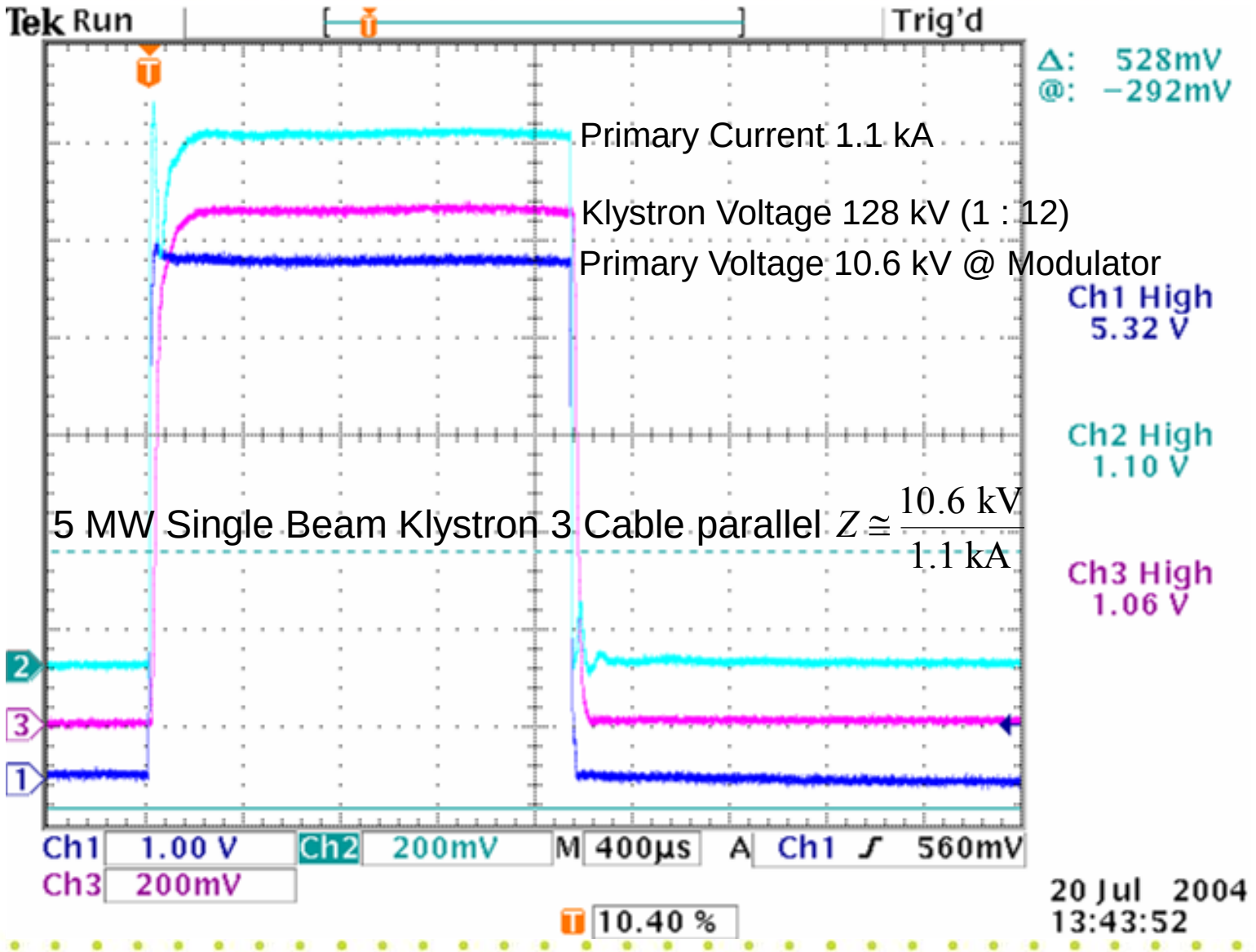


- Compact 2D system – it needs small space
- Flexible – adjustable RF power for each cavity
- Pretuned phase
- Possibility of preinstallation at the cryomodule
- Works since 2008 on the FLASH

# Installation for Pulse Cable Test



# HV Pulse Cable Test



# Specification and Procurement

- Principal layout and design of the RF system components has been finished and prototypes have been constructed and tested.
- Final specifications will be finished soon taking into account prototype test results and results of the details of the interfaces with other work packages and installation requirements of the tunnel and other XFEL buildings.
- Restricted Call for Tender.
- Only qualified Venders are allowed to bid.
- Number of Vendors are not fixed in advance.

# Production

- After placement of contracts with manufacturers or start of production in laboratories the production process must be monitored. All components for the XFEL will be shipped to DESY. After a first inspection and specification check, the components will be assembled into subunits and tested. Until final installation they must be stored.
- The HV pulse modulators will be delivered by the manufacturers and installed in the modulator hall.
- Klystrons, pulse transformers and connection modules from Industry will be tested at the klystron test facility.

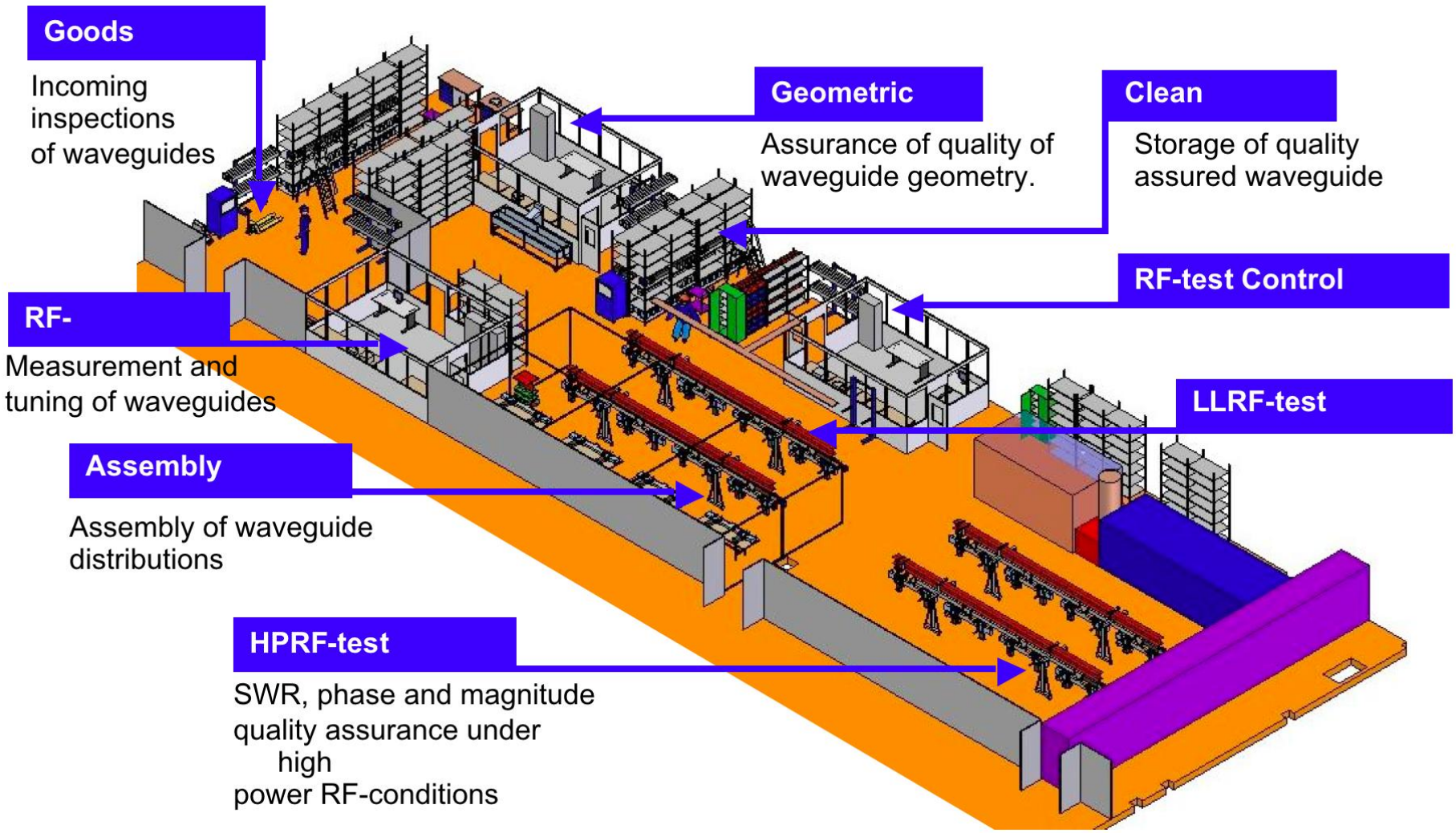
# Production (continued)

- In addition the other components as auxiliary power supplies, preamplifiers and RF interlocks also from industry must be installed in racks and tested.
- The components for the waveguide distribution will be shipped to DESY after successful factory acceptance test. They will be inspected, measured, cleaned and assembled for installation to a specific cryogenic module in the waveguide assembly and test facility, WATF. The average production rate will be one waveguide module distribution per week.

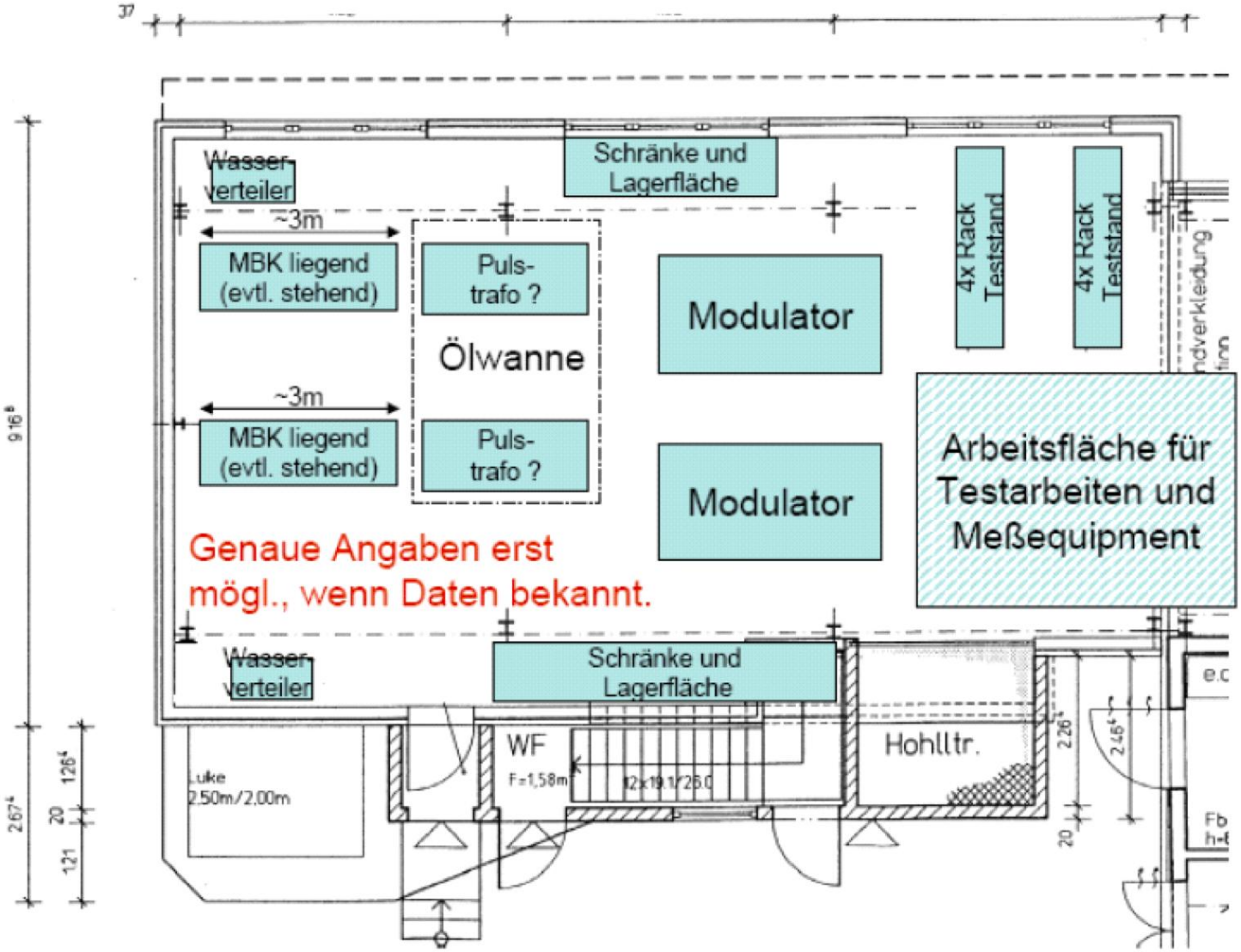
# Wave Guide Assembly and Test Facility

- Special Facility for Assembly and Test of Waveguides
- Components from Industry and Laboratories
- Input Control of Mechanical and Electrical Parameters
- Assembly to Wave Guide Distributions
- The distributions and waveguide components will be tested at low and high power.
- At the end they will be installed at the cryogenic modules or directly at the final installation.

# Wave Guide Assembly and Test Facility



# Modulator Test Facility

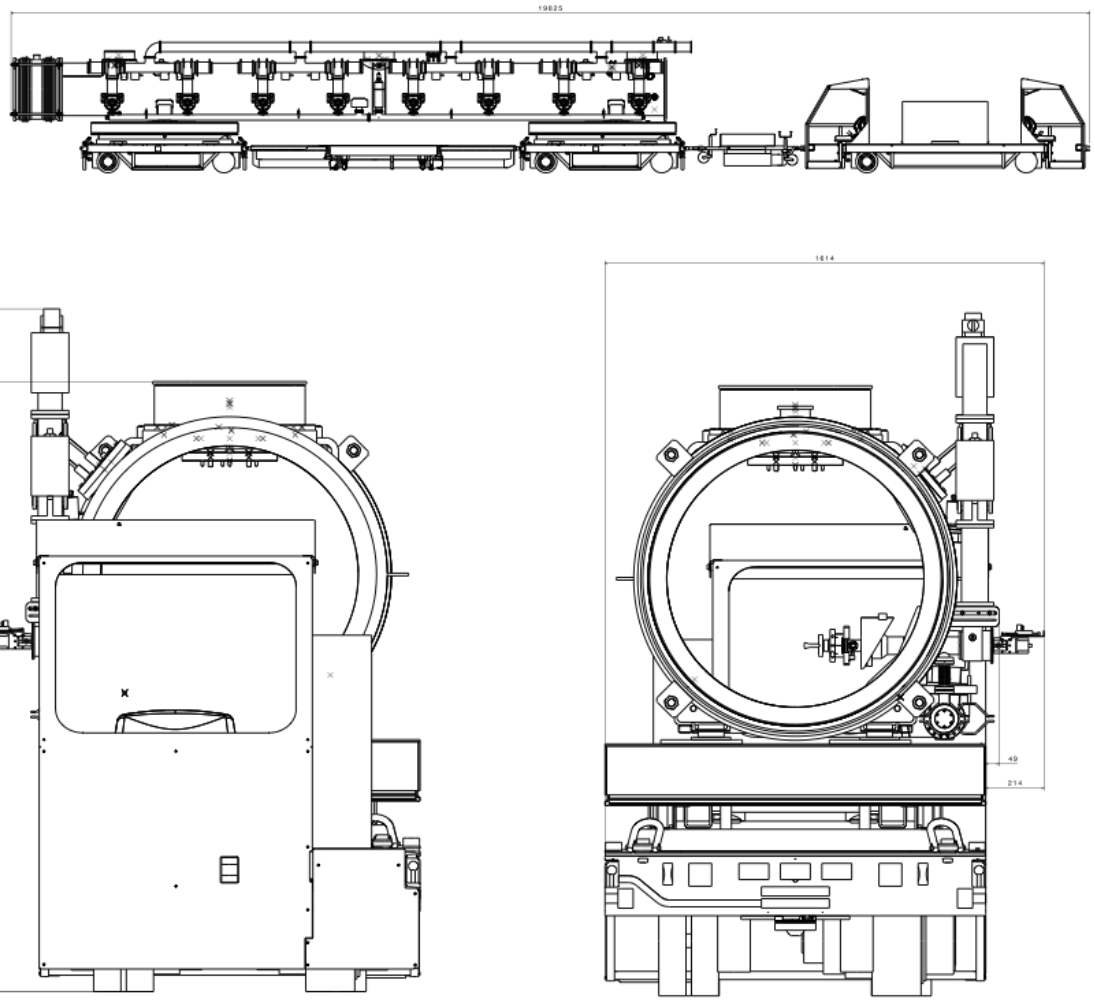


# Klystron Test Facility

- It was already necessary to test vertical and horizontal multibeam klystron prototypes delivered to DESY intensively under different operation conditions and to perform a number of different measurement which will usually not be done during normal operation at an accelerator. A dedicated facility has been set up at DESY, Hamburg, and all prototype klystrons have been tested there.
- Although all series klystron will be delivered fully tested by the klystron manufacturer they will be tested after delivery to DESY. The existing facility must be extended in order to allow for testing of one klystron per month. Possible problems which might not be observed at the klystron vendors productions site could be detected as early as possible before the klystrons will be installed in the accelerator tunnel or the klystron installation floor in the injector building.

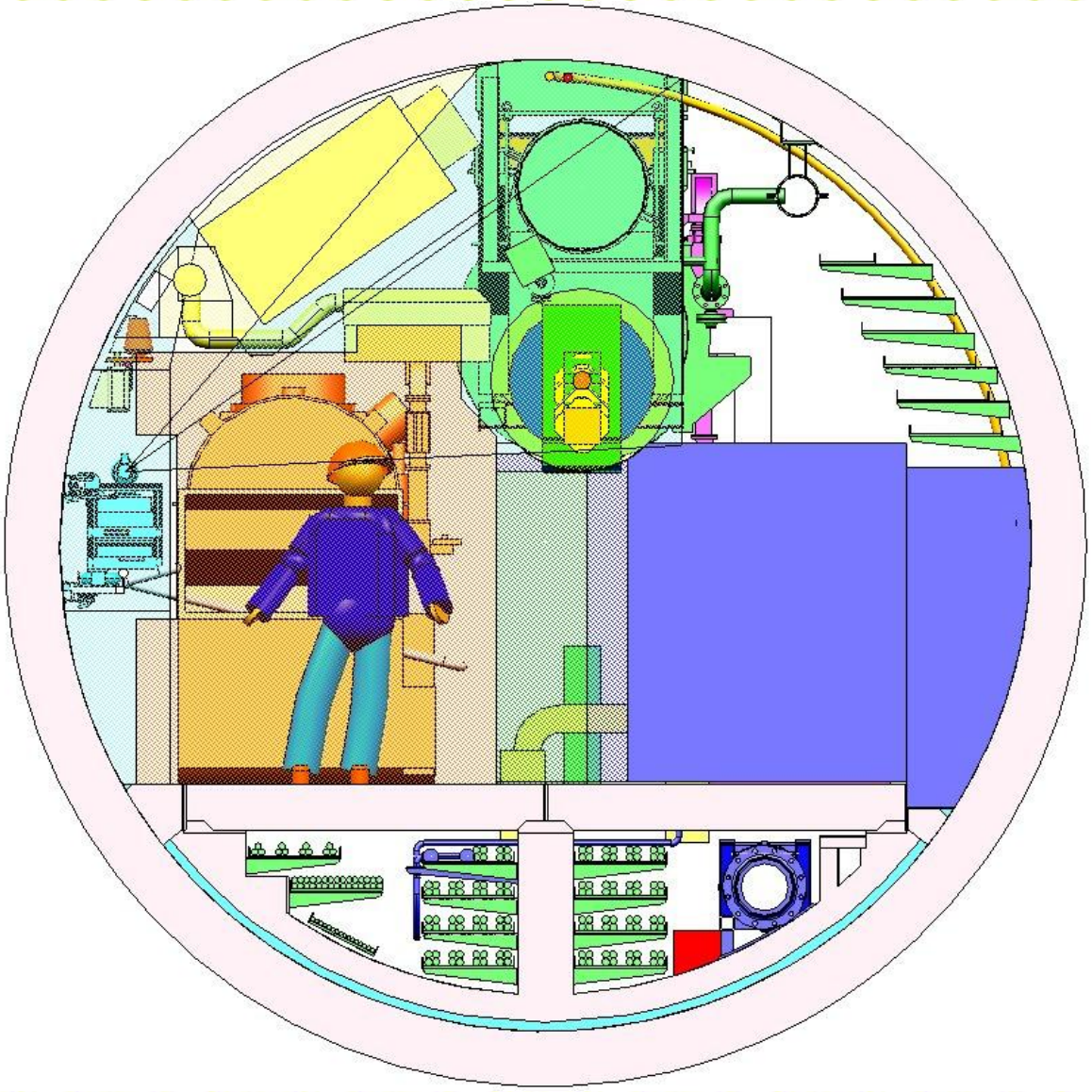
# Klystron Test Facility in DESY Hall II

# Installation and Commissioning



Tunnel Vehicle with Cryo Module and Wave Guide Distribution

# Installation and Commissioning



# Adoption to the Single Tunnel Solution

- The Tunnel Design can be adopted one to one.
- Only the Modulators need either additional Surface or Underground Halls.
- The Maximum Length of one Linac Section is defined by the Pressure Drop in the Gas Return Pipe and should be in the Order of 2.5 km. Therefore the Cryo Plants must be distributed along the Linac.
- The Space for the modulators can be combined with Space for the Cryo Plants.

# Summary

- All components for the XFEL RF system have been designed and constructed during the last years.
- Modifications of some components allowing the installation in the accelerator tunnel and qualification of additional vendors are being continued.
- Determined by the XFEL schedule first RF system components are delivered currently for the various component test facilities.
- The components for the XFEL injector must be received only shortly after. However delivery of the major amount of all components is planned for 2011 to 2012.
- The European XFEL HLRF design can be adopted easily to all ILC single tunnel solutions and be used as fall back solution.