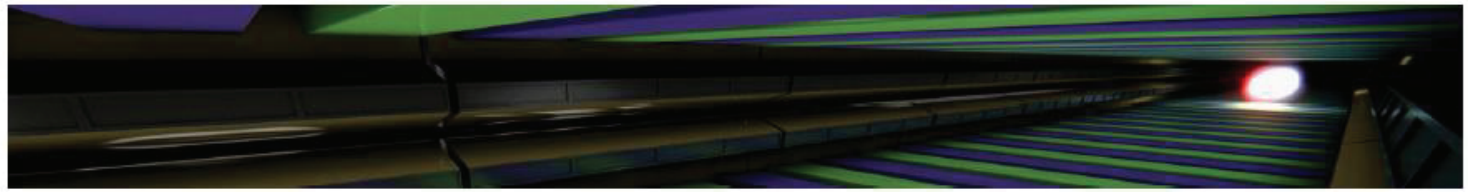

XXV Russian Particle Accelerator Conference (RuPAC 2016)
Peterhof, November 21-25, 2016

THREE TRANSVERSE DEFLECTING SYSTEMS FOR ELECTRON BEAM DIAGNOSTICS IN THE EUROPEAN FREE-ELECTRON LASER XFEL*

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* Work supported by European XFEL GmbH and Ministry of Education and Science of Russia
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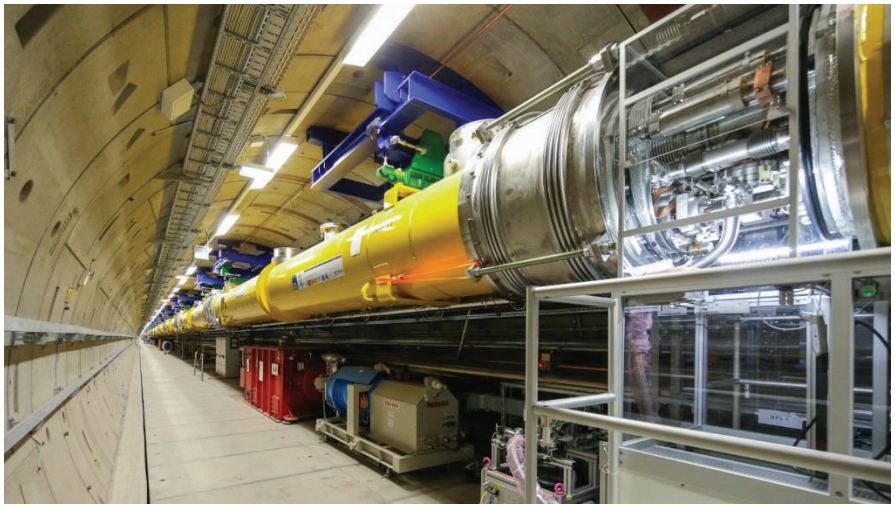
XFEL TDS Systems

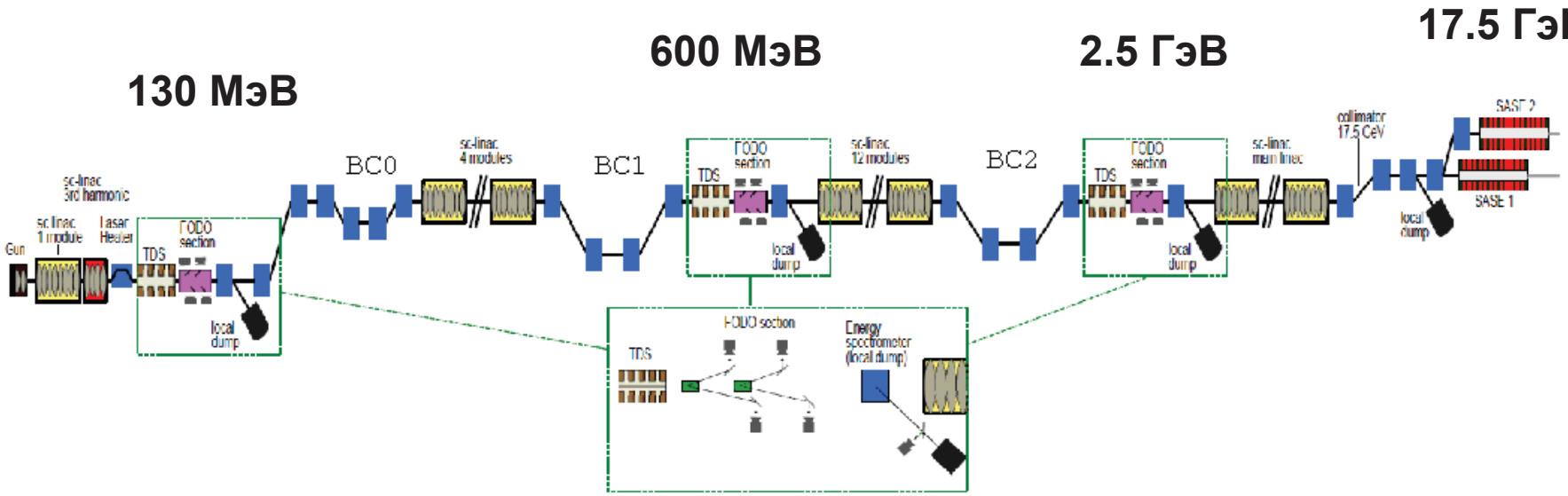
INR RAS and DESY have developed three TDS Systems for XFEL project. They are to be installed:

- in the XFEL injector (z ≈ 53 m)
- In the BC1 section (z ≈ 206 m)
- In the BC2 section (z ≈ 427 m)

for the measurement of

- **Bunch length**
- **Longitudinal phase space**
- **Slice emittance**





XFEL TDS Systems

- LLRF
- TDS INTERLOCK SYSTEM
- TDS TEPTERATURE CONTROL SYSTEM 2
- TDS TEPTERATURE CONTROL SYSTEM 1
- GAS FILLING SYSTEM
- TDS VACUUM SYSTEM
- SURVEY AND ALIGNMENT SYSTEM
- DEFLECTING MAGNET SYSTEM
- REGISTRATING SCREEN SYSTEM

HPRF

- **POWER SUPPLY & CONTROL CABINET**
  - COMPUTER
  - ETHERNET SWITCH
  - RF CONTROLLER
  - SOLENOID POWER SUPPLY
  - UPS
  - Touch Screen Monitor & COMPUTER*
  - POWER DISTRIBUTION
  - CABINET*
- **MODULATOR**
  - MARX MODULE POWER SUPPLY
  - MARX MODULES
  - SEU1/2
  - SYSTEM CONTROLLER
  - CABINET
  - FILAMENT POWER SUPPLY
  - BIAS POWER SUPPLY
- **RF GENERATOR**
  - KLYSTRON
  - SOLENOID
  - LOCAL SHIELDING
  - HIGH VOLTAGE MONITOR
  - CURRENT MONITOR
  - PULSE TRANSFORMER
  - CHOKE
  - OIL TANK
- **WAVEGUIDE SYSTEM**
  - SPARK-DETECTOR
  - WAVEGUIDE GAS PORT*
  - WAVEGUIDE WINDOW 1*
  - DIRECTIONAL COUPLER 1
  - WAVEGUIDE VACUUM PORT
  - DIRECTIONAL COUPLER 2*
  - STRAIGHT WAVEGUIDES
  - E-BENDS
  - H-BENDS
  - BRACKET SET*
- **UHV WAVEGUIDE SYSTEM**
  - E-BENDS
  - TDS VACUUM PORTS
  - WAVEGUIDE WINDOW 2
  - WAVEGUIDE LOAD

TRANSVERSE DEFLECTING STRUCTURE

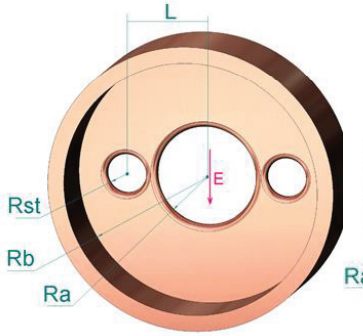
supplied by INR

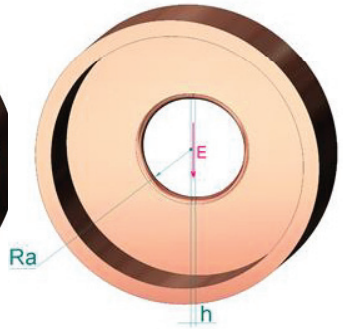
supplied by DESY

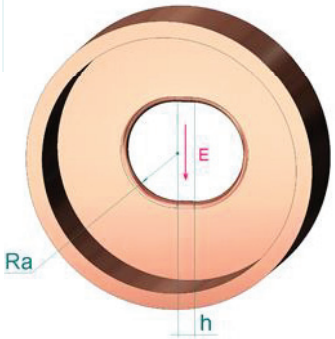
* for TDS INJ

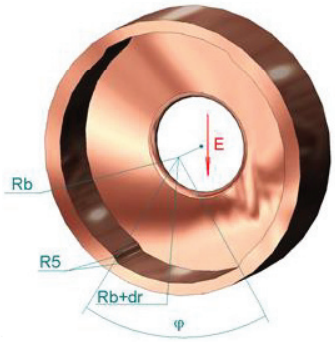
Transverse Deflecting Structure

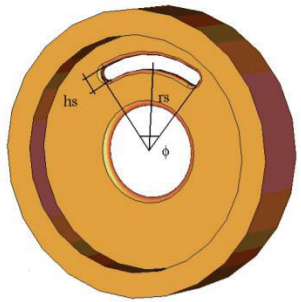
DISK-LOADED STR. WITH TWO PERIPHERAL HOLES (LOLA)	DISK-LOADED STR. WITH OVAL APERTURE HOLE (h=1.7mm)	DISK-LOADED STR. WITH OVAL APERTURE HOLE (h=7.5mm)	DISK-LOADED STR. WITH TWO PERIPHERAL RECESSES	DISK-LOADED STR. WITH RESONANT SLOT

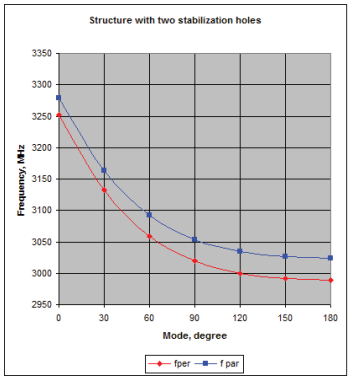


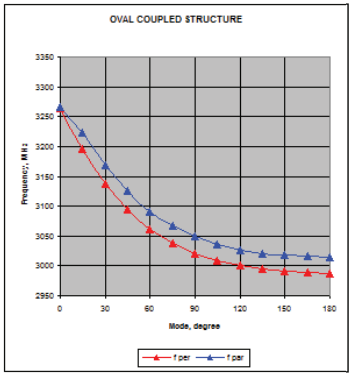


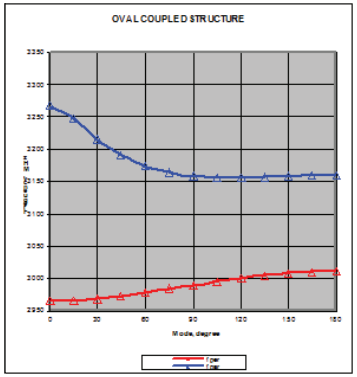


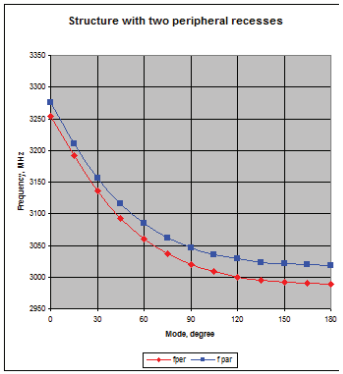


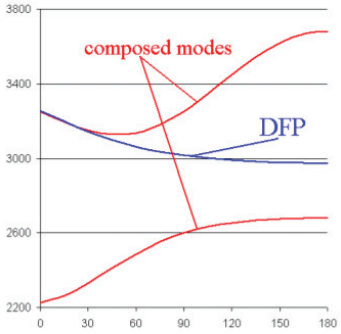






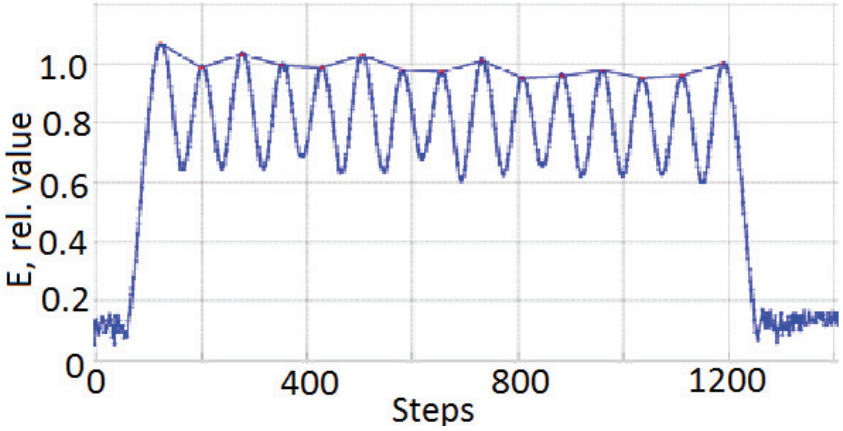


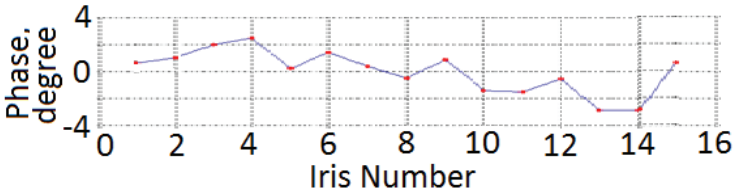


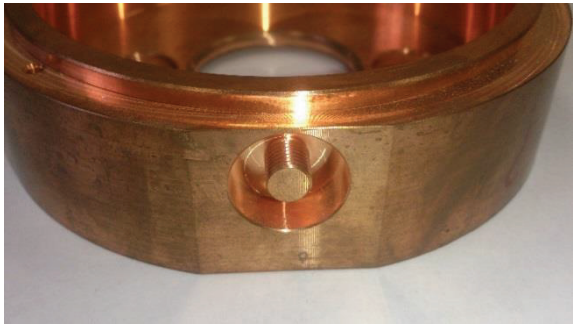


Δf=40MHz	Δf=40MHz	Δf=150MHz	Δf=40MHz	Δf=900MHz

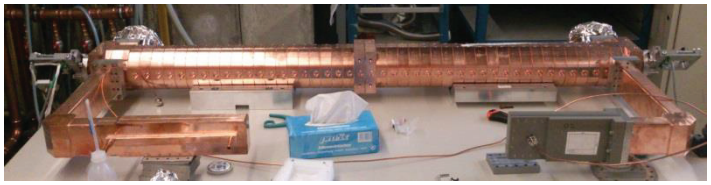
XFEL TDS INJ: Structure tuning

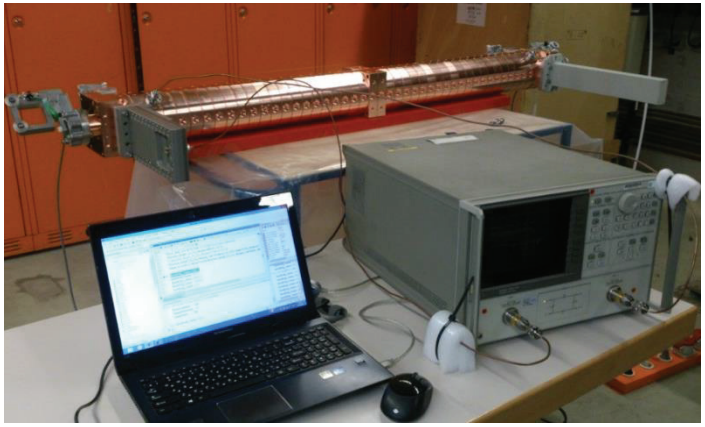


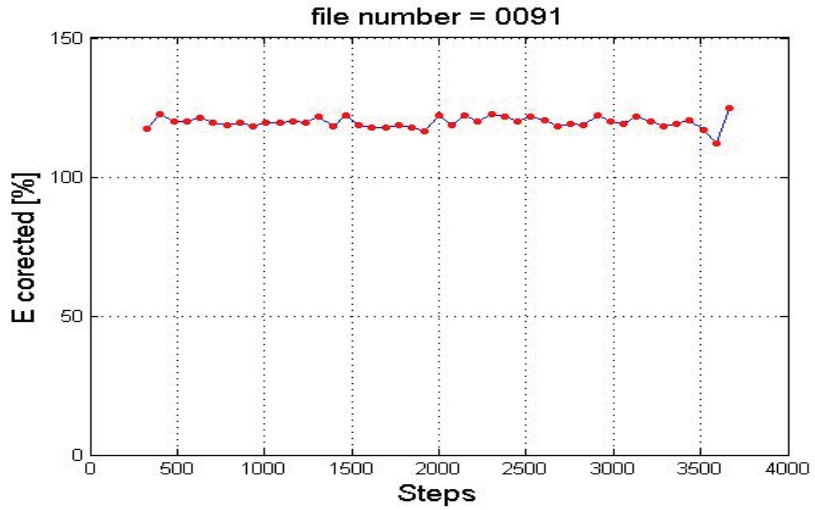


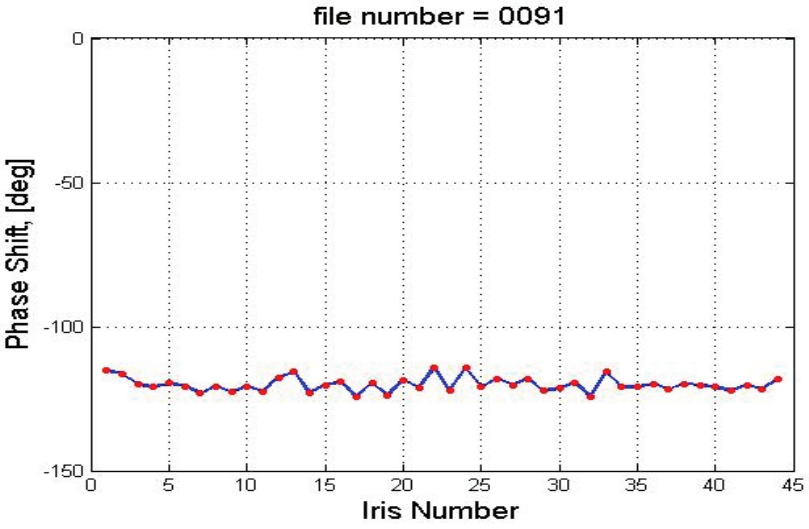


TDS System BC1 and BC2: Structure tuning





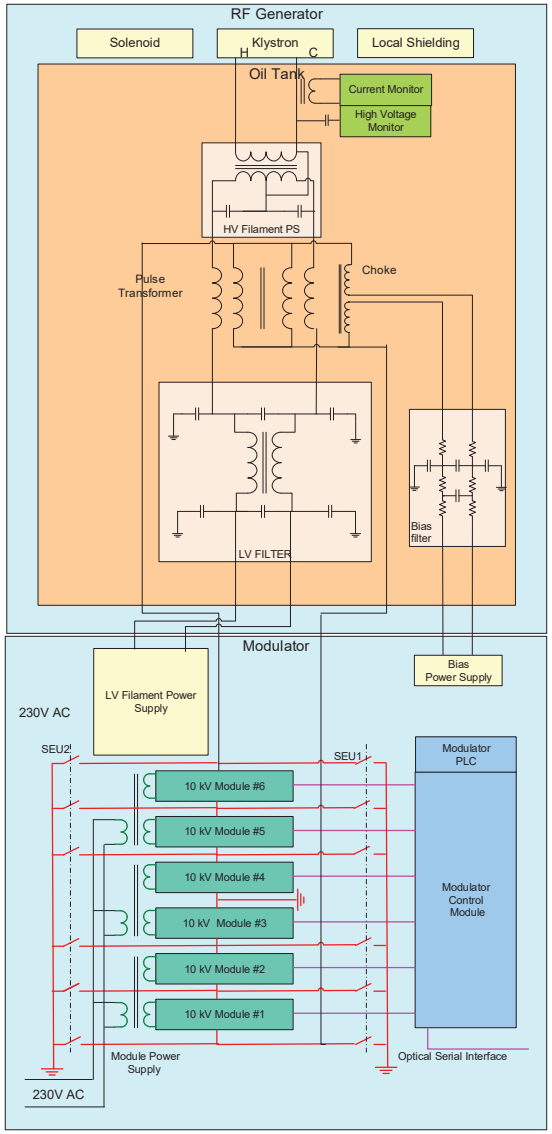


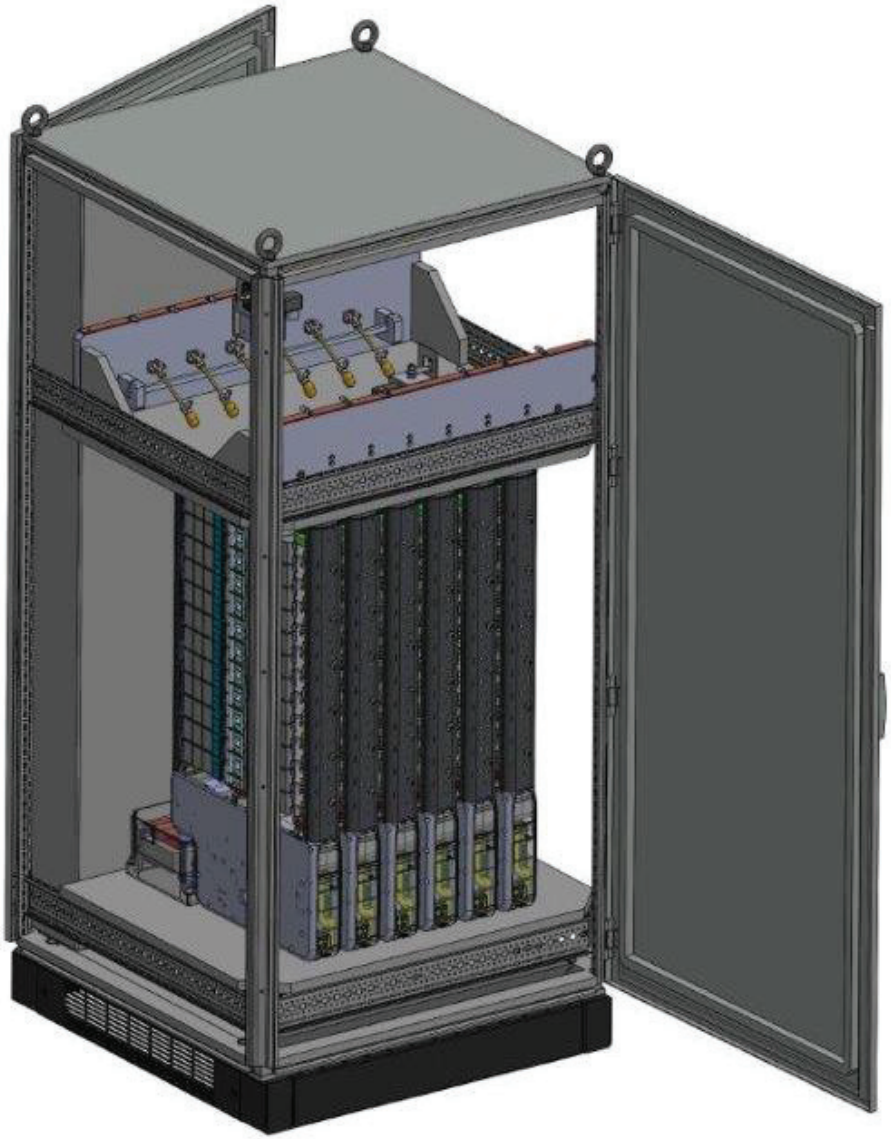


TDS: Solid State Modulators – Arkadiev type

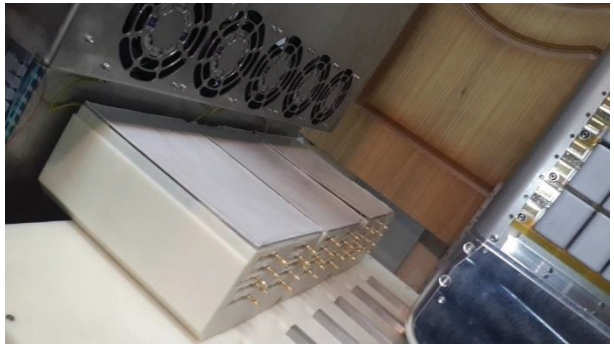
Parameter	Unit	XFEL TDS INJ	XFEL TDS BC1/BC2
Number of modules in the modulator		6	2
Max voltage of the module	kV	8	22
Max voltage of the modulator	kV	48	44
Max voltage in the modulator with respect to the ground	kV	24	22
Max current of the modulator	A	166	1420
Ratio of pulse transformer		2.3	5.7
Max voltage of the klystron	kV	110	250
Max current of the klystron	A	72	250

XFEL TDS INJ: Modulator

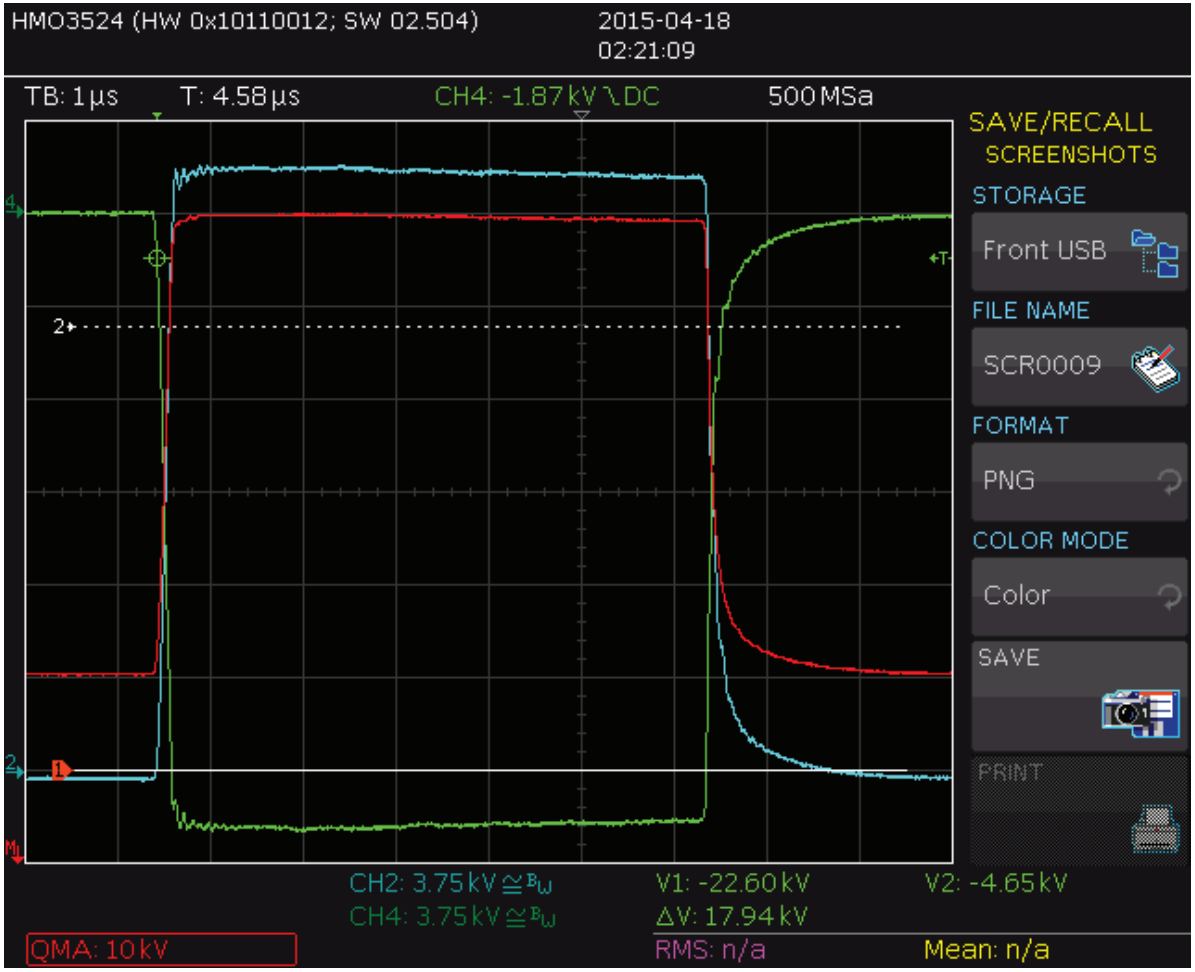




XFEL TDS INJ: Modulator



XFEL TDS INJ: Modulator



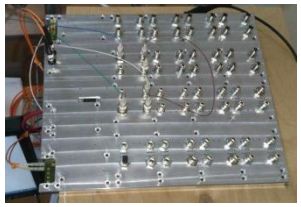
BLUE is positive voltage
GREEN is negative voltage
RED is differential voltage

- Output differential voltage 50kV and nominal current 170A at 6 µsec, 10Hz.
- Pulse flat-top length τ_{ft}=0.1-3.1 µsec (specs). Tested is 6 µsec (flat-top length 5.5 µsec).
- Pulse flat-top voltage uniformity <1%
- Pulse rise time is tr=0.2 µsec.
- Pulse fall time is tf=0.2 µsec.

Power Supply & Control cabinet

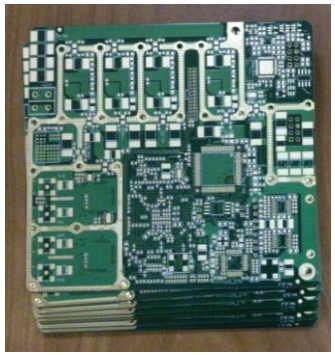
Klystron solenoid power supply

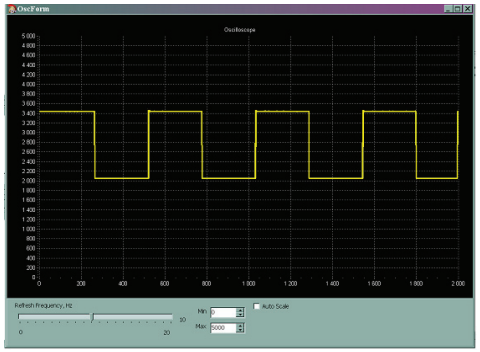
System controller



- UPS Klystron solenoid power supply
- Computer
- Ethernet switch is ready.
- RF controller
- Touch Screen monitor & Computer
- System controller
- Power distribution

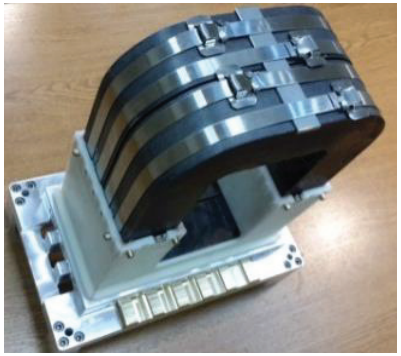
4-channel 200MHz ADC for RF controller

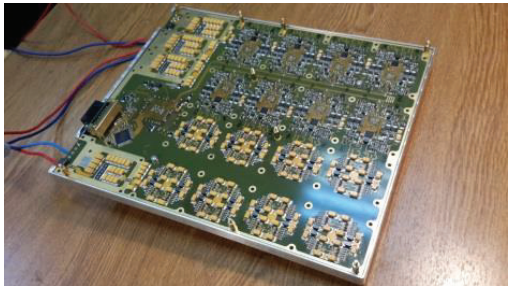




Horizontal axis is the time in the number of samples (200 MHz sample rate). 2000 samples correspond to 10 µsec.

TDS HPRF BC1 is under production



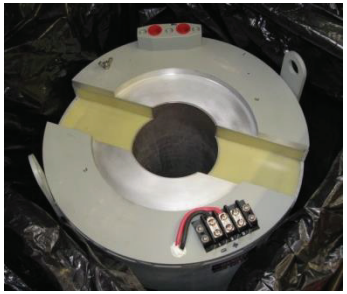


XFEL TDS: Klystrons

CPI klystron VKS-8262HS

is used for the PITZ TDS and for XFEL TDS INJ:

Frequency	2.998 GHz
Peak power	3 MW
Voltage	110 kV
Current	72 A
Pulse length	12 usec
Drive power	80 W



THALES klystron TV2002DoD

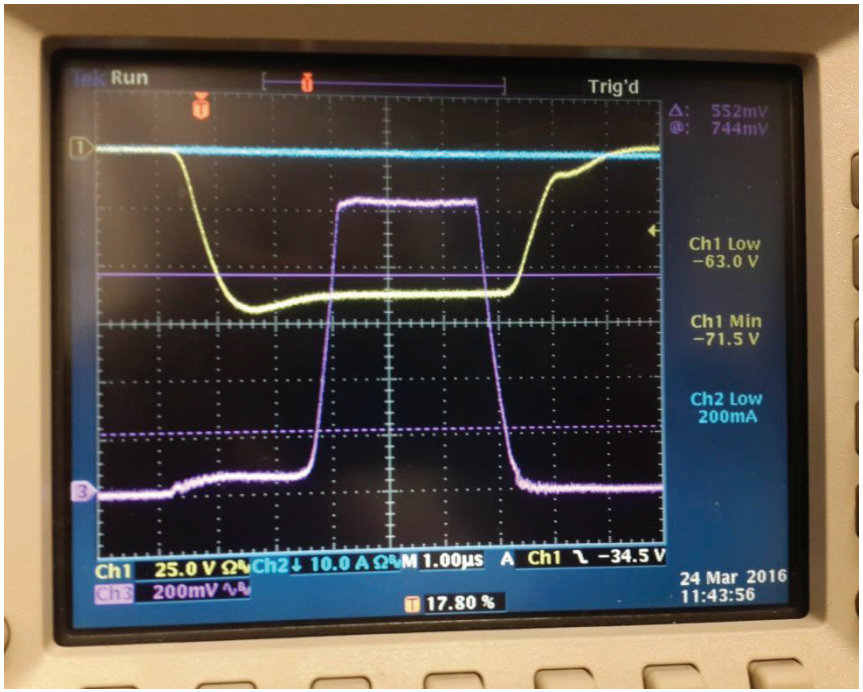
is used for the XFEL TDS BC1 and for XFEL TDS BC2:

Frequency	2.998 GHz
Peak power	24 MW
Voltage	250 kV
Current	250 A
Pulse length	6.5 usec
Drive power	240 W

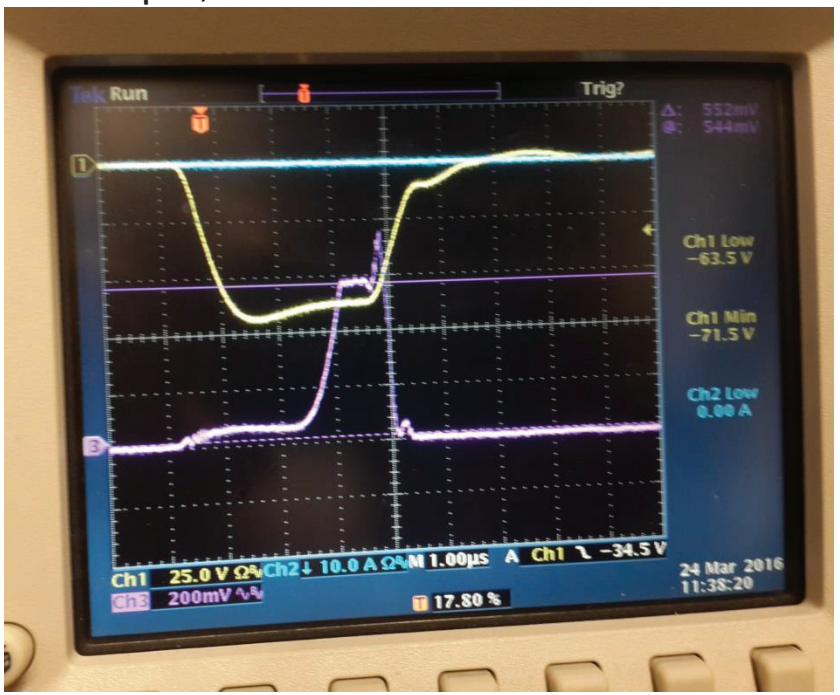
TDS HPRF INJ: RF power test

High power RF test of the TDS HPRF INJ with RF drive of the klystron.
Yellow is the klystron voltage.
Pink is RF power in the klystron waveguide.

Normal operation



Fast interlock within the pulse in the high voltage breakdown event: high voltage interrupts, and current is limited.

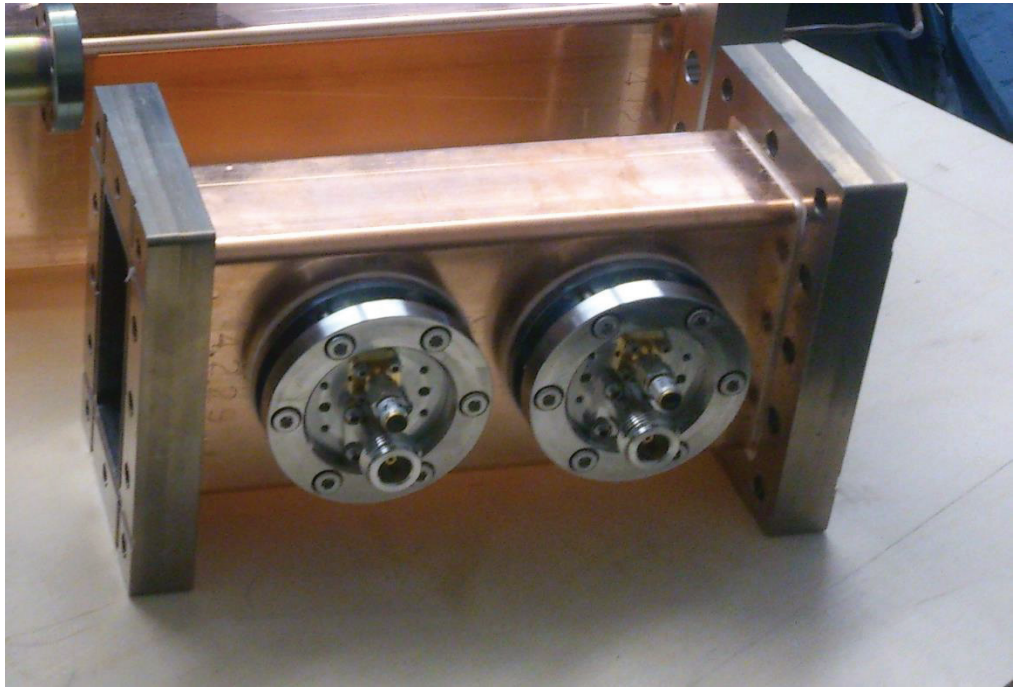


XFEL TDS Waveguide Systems

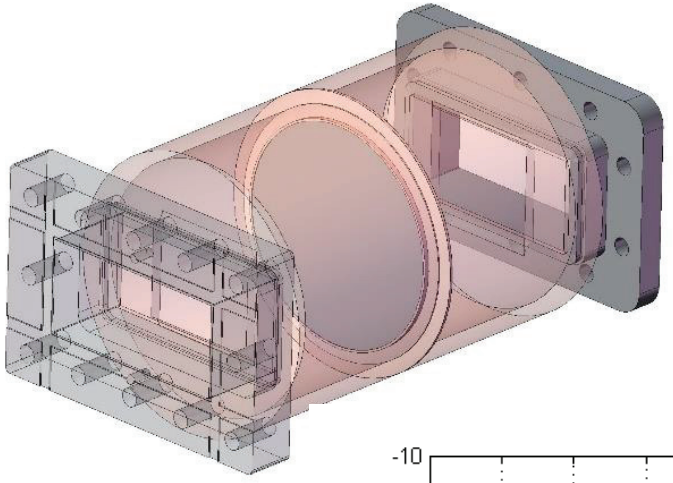
- 55 m long waveguide system for XFEL TDS INJ connects the klystron at -5 floor and the deflecting structure at -7 floor.
- Short waveguide systems connect the klystron and the deflecting structure in the XFEL TDS BC1 and in the XFEL TDS BC2.
- Each waveguide system includes
  - directional coupler,
  - waveguide window,
  - waveguide load,
  - spark detectors,
  - waveguide adapters for ion pumps,
  - E-bends,
  - H-bends,
  - straight waveguides.

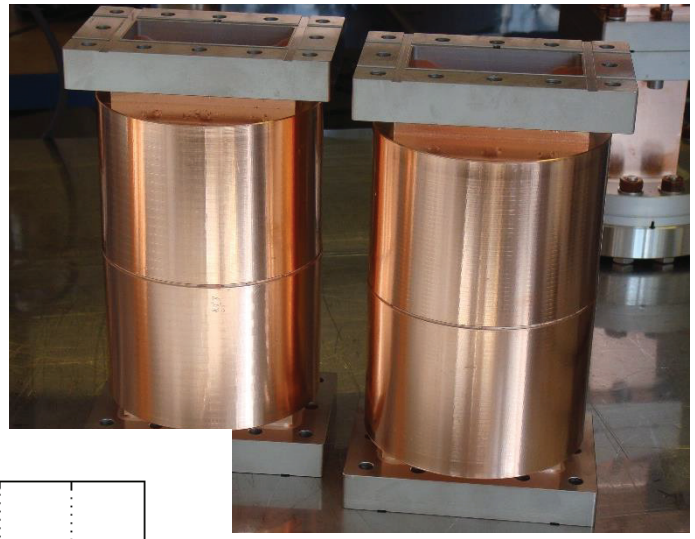
XFEL TDS: Directional coupler

Directional coupler unit No.	Coupling S13, dB	Isolation S14, dB	Directivity D, dB
1	-65.9	-103	37
2	-65.6	-100	34

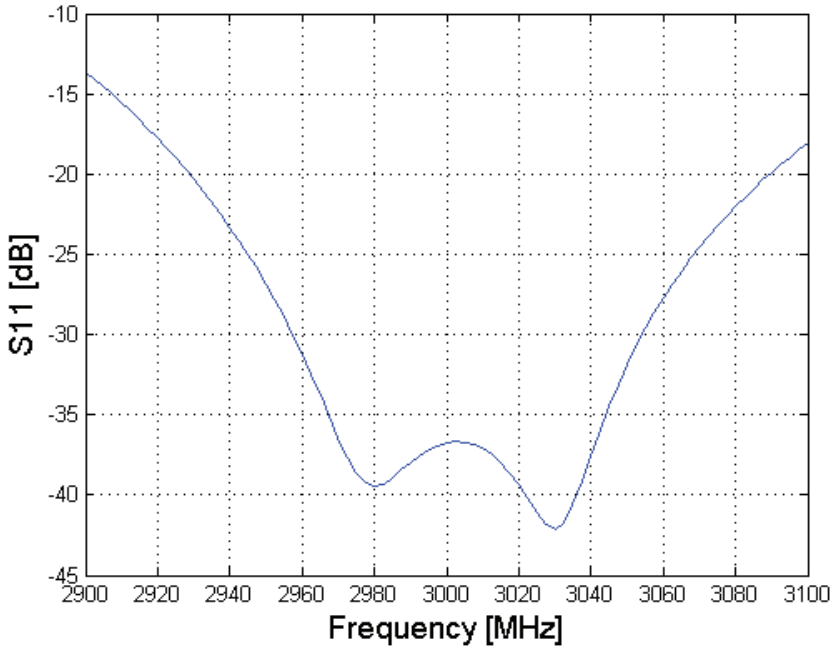


XFEL TDS: Waveguide window



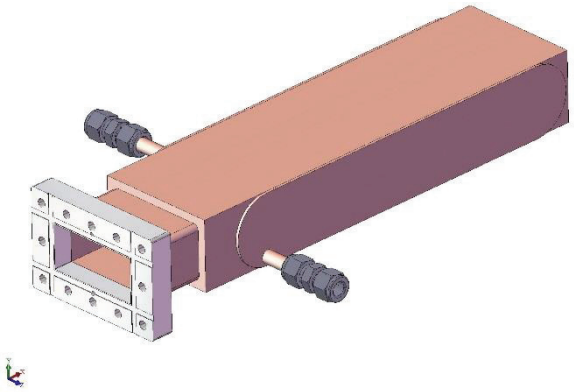


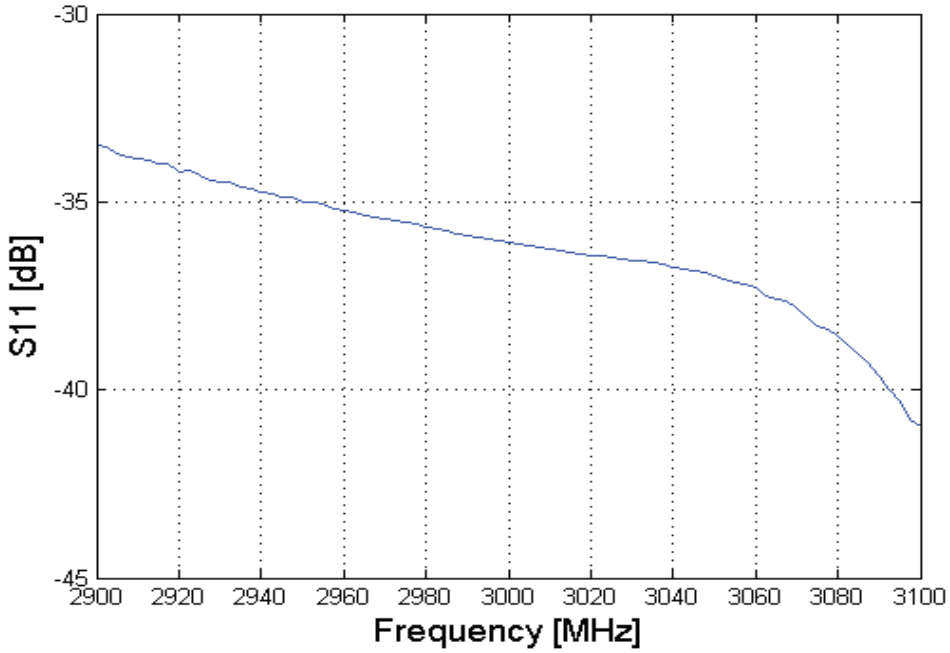
99.7% Alumina

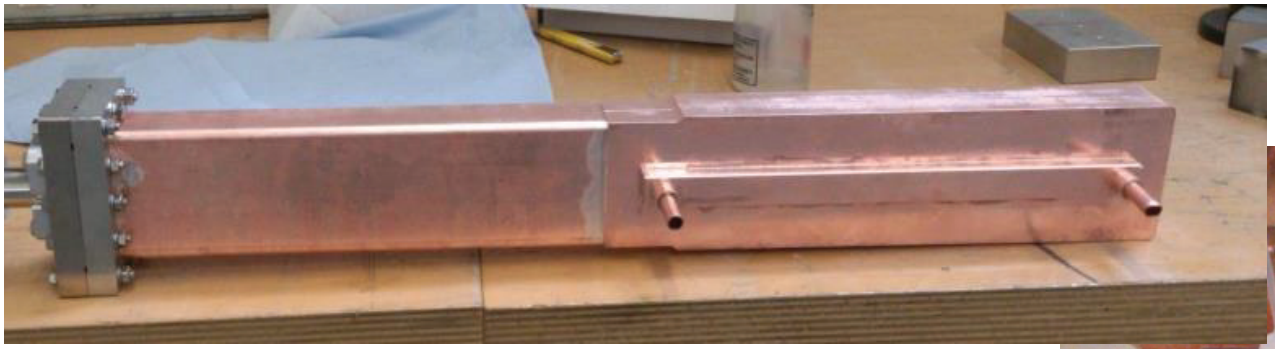


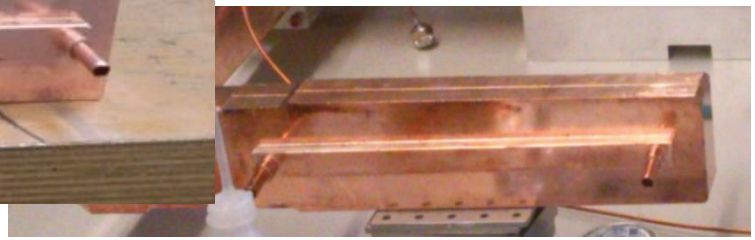
XFEL TDS: Waveguide load

The load is the rectangular waveguide with reducing height an with Sendust coating.



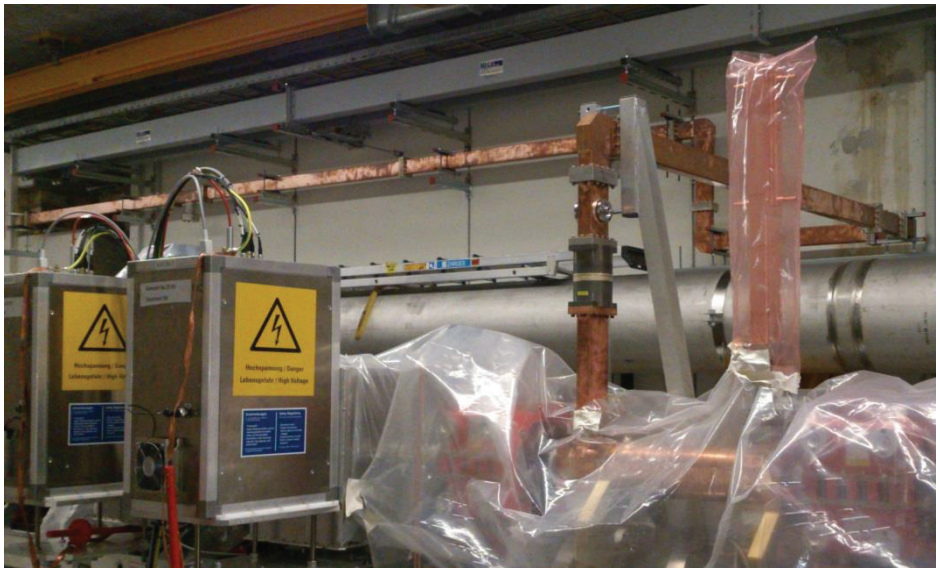






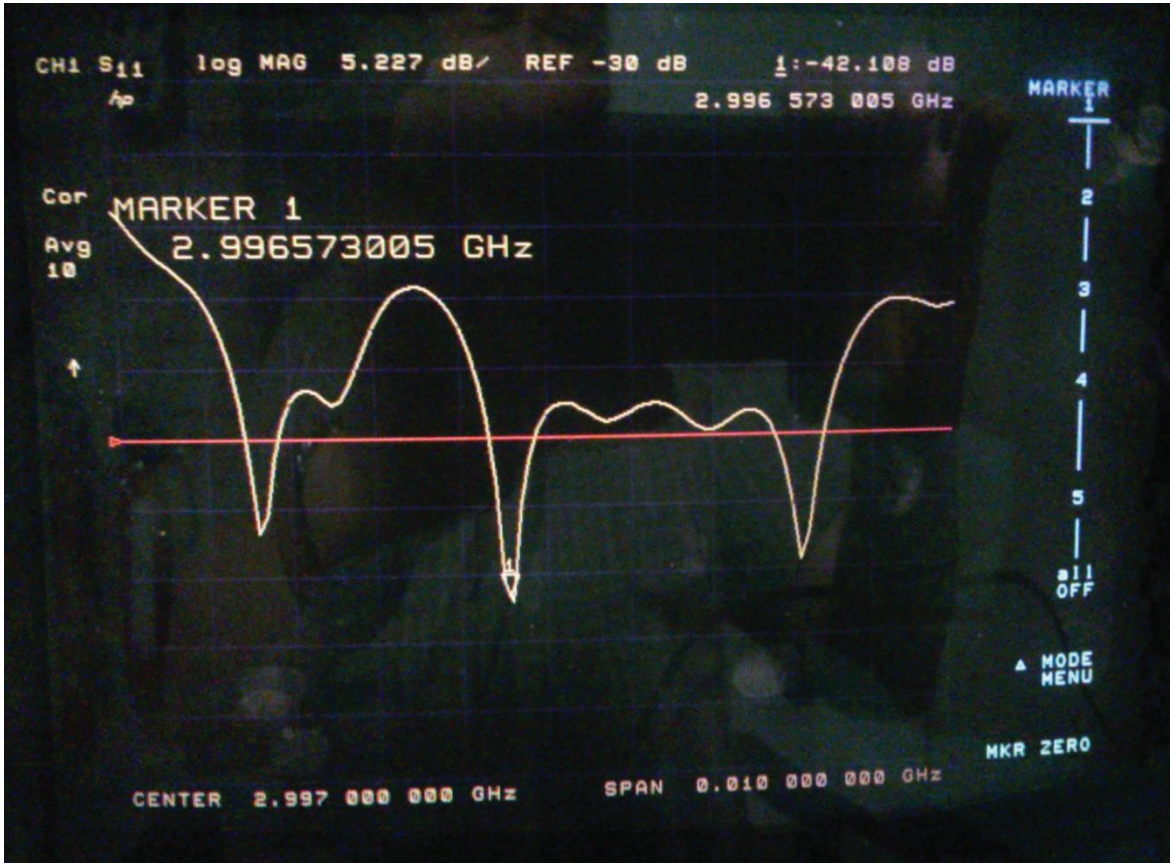
XFEL TDS: Waveguide line

XFEL TDS INJ – assembled 55 m long Waveguide System



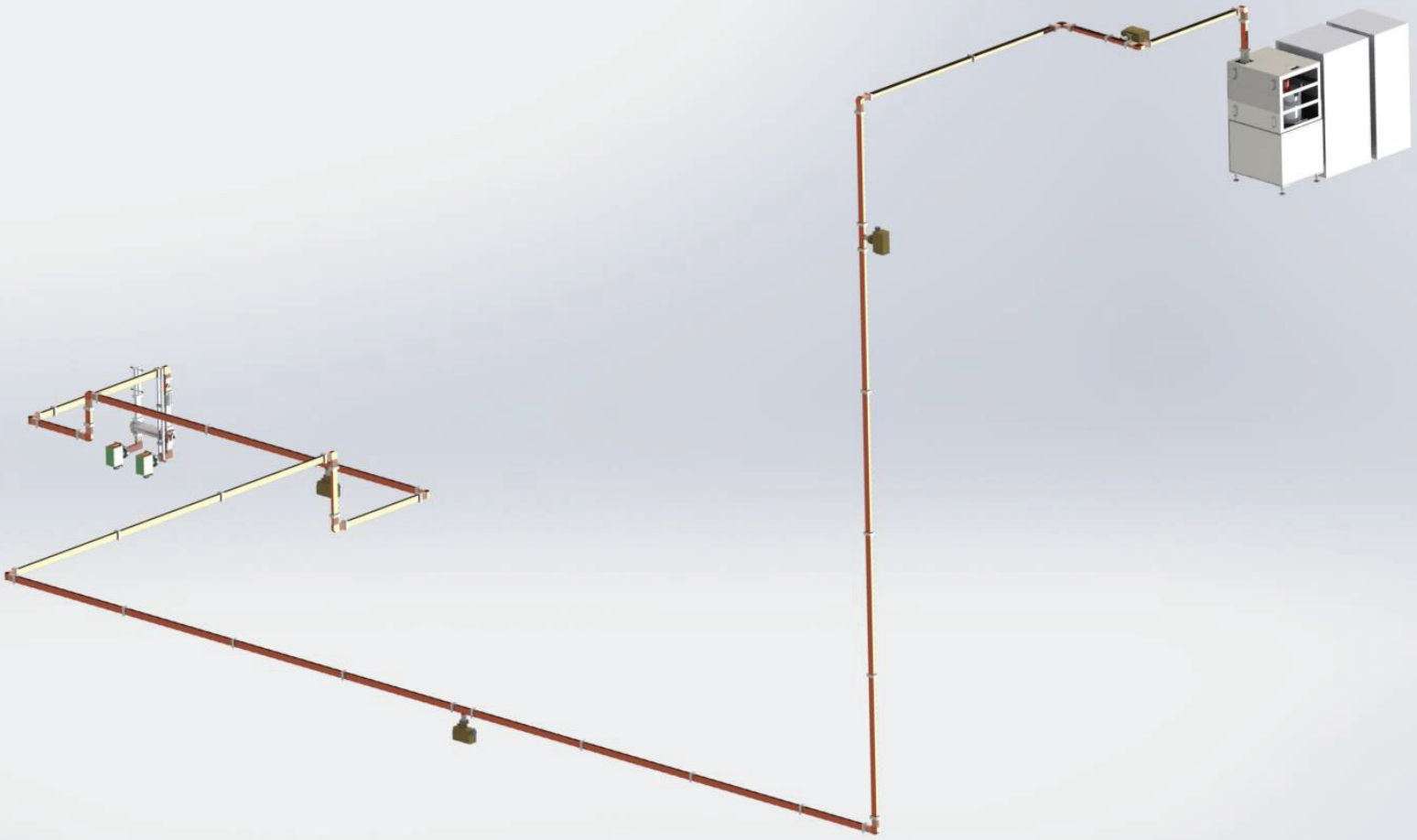
TDS Waveguide System INJ has been assembled at its operating place.

XFEL TDS INJ – 55 m Waveguide System - Matching

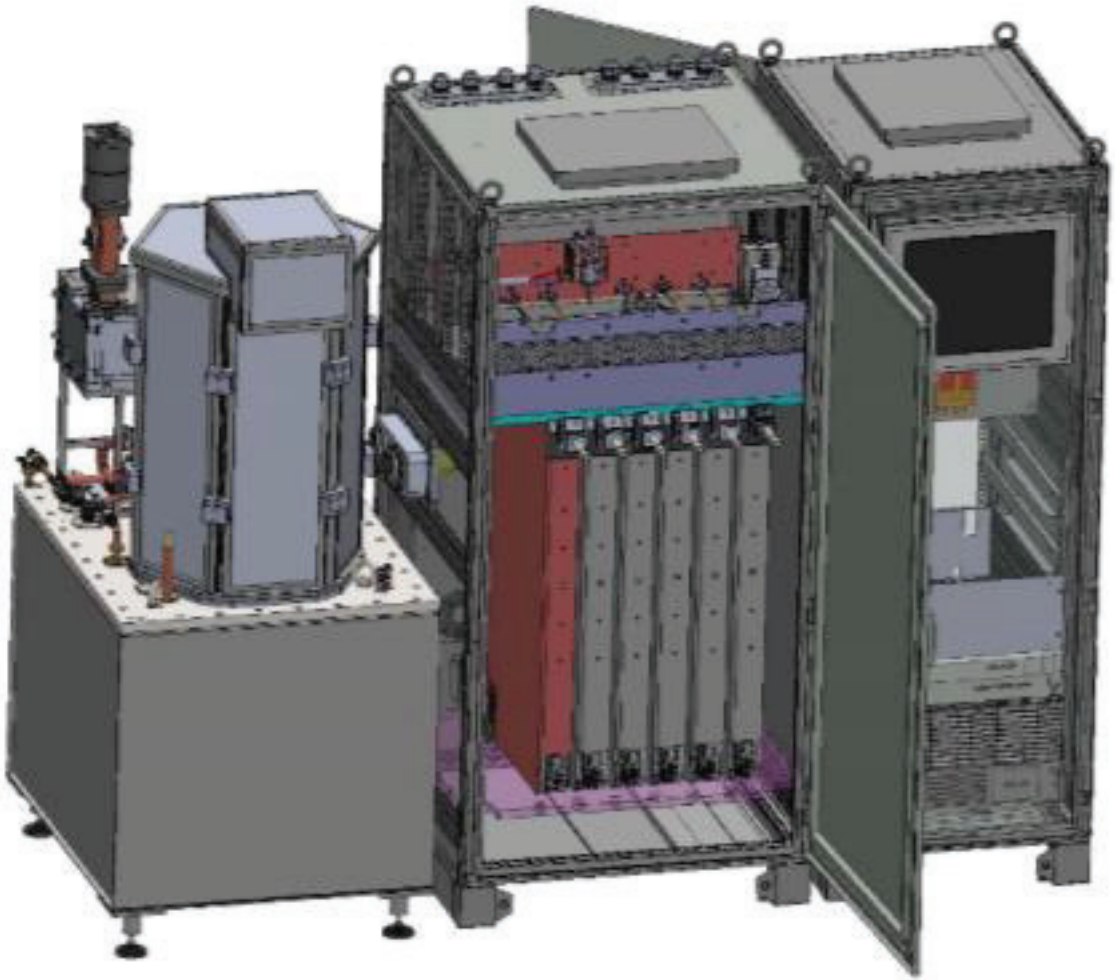


Measured reflection from the Waveguide System and Deflecting Structure in plane of input waveguide flange is S11=-42 dB at operating mode

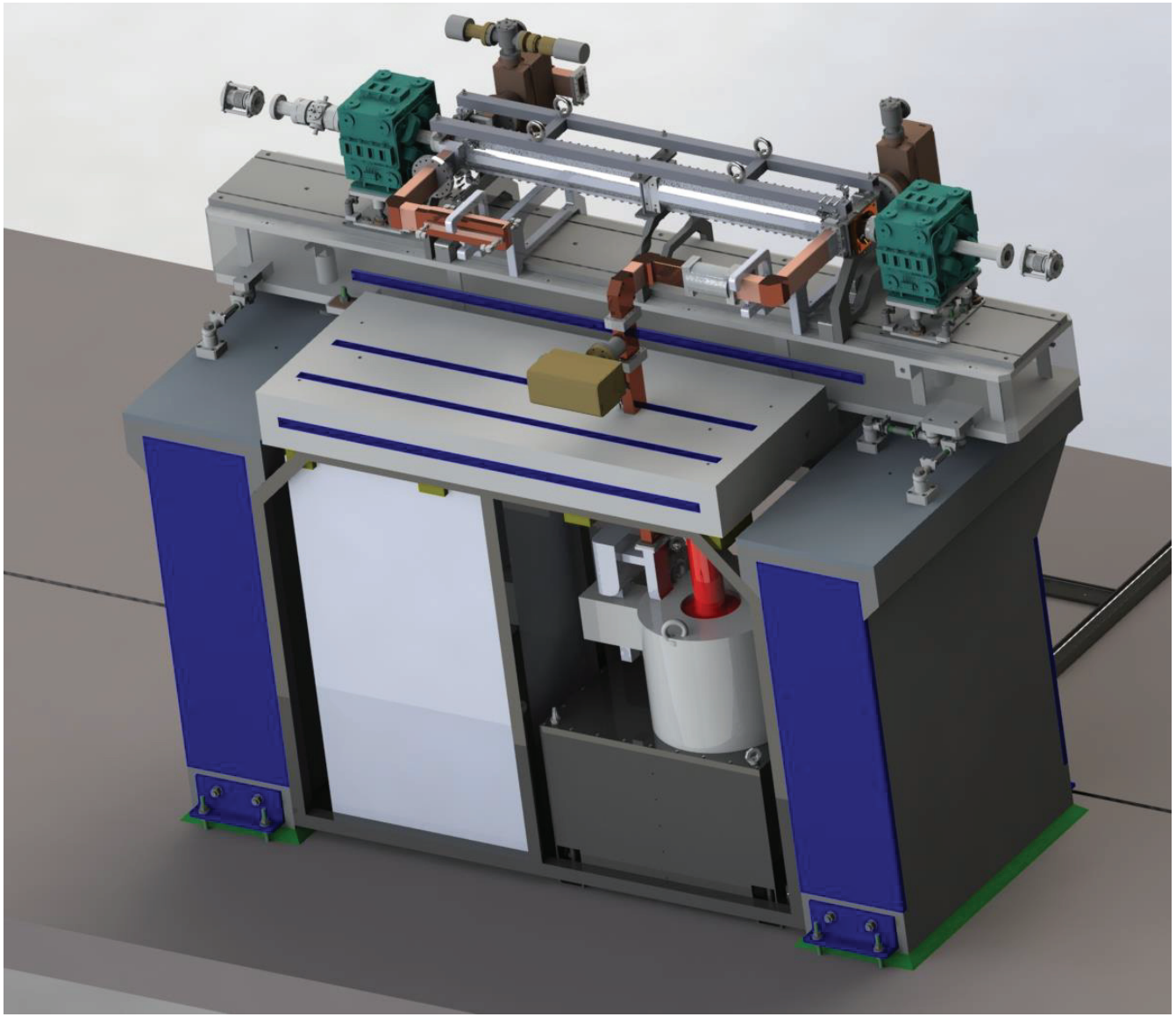
XFEL TDS Systems INJ design



XFEL TDS HPRF INJ design



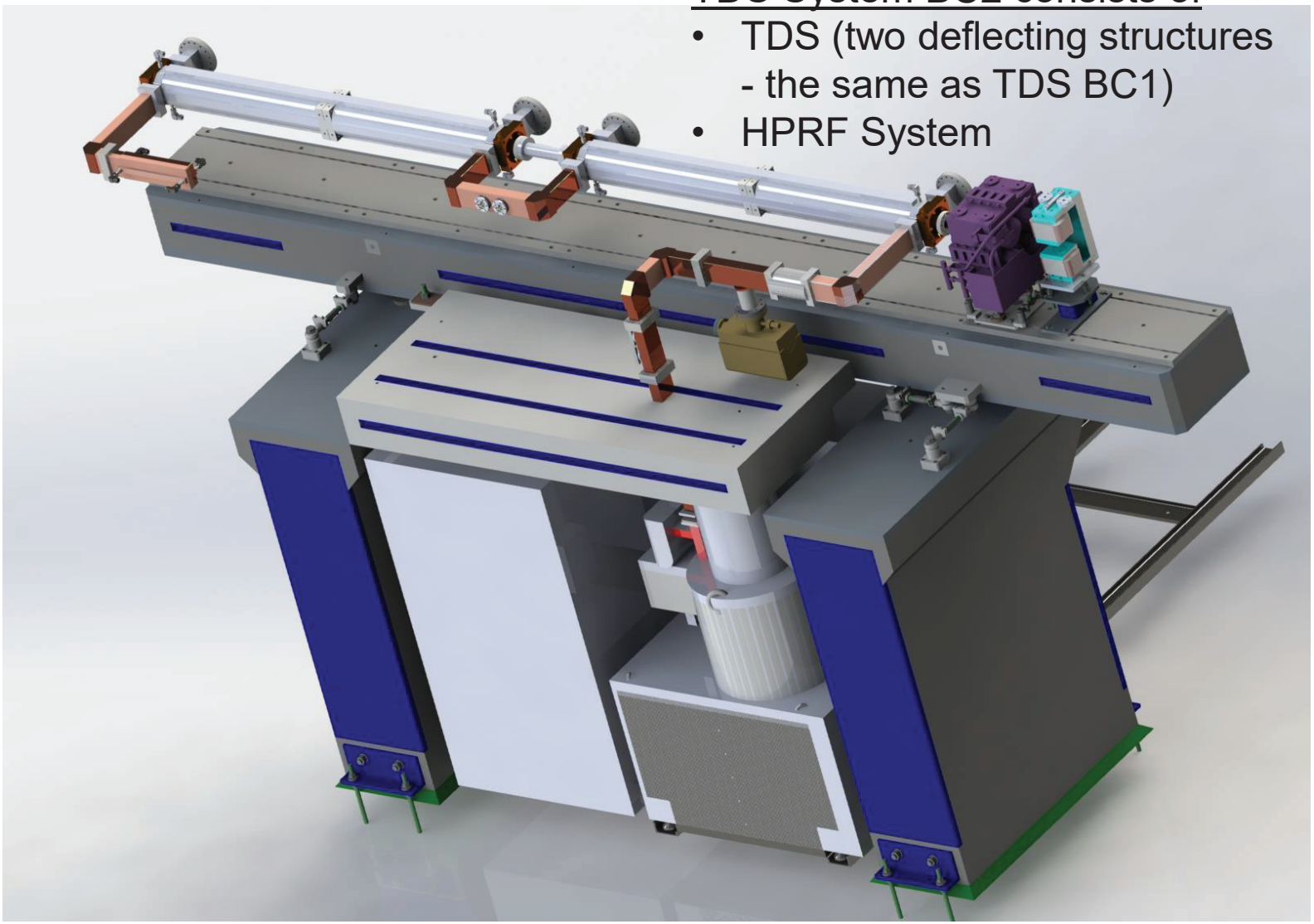
XFEL TDS Systems BC1 design



TDS System BC1 consists of

- TDS (deflecting structure)
- HPRF System

XFEL TDS Systems BC2 design



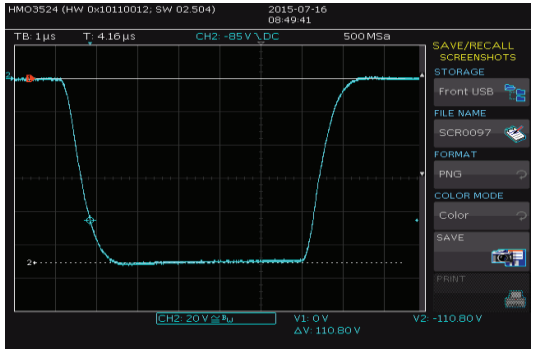
TDS System BC2 consists of

- TDS (two deflecting structures - the same as TDS BC1)
- HPRF System

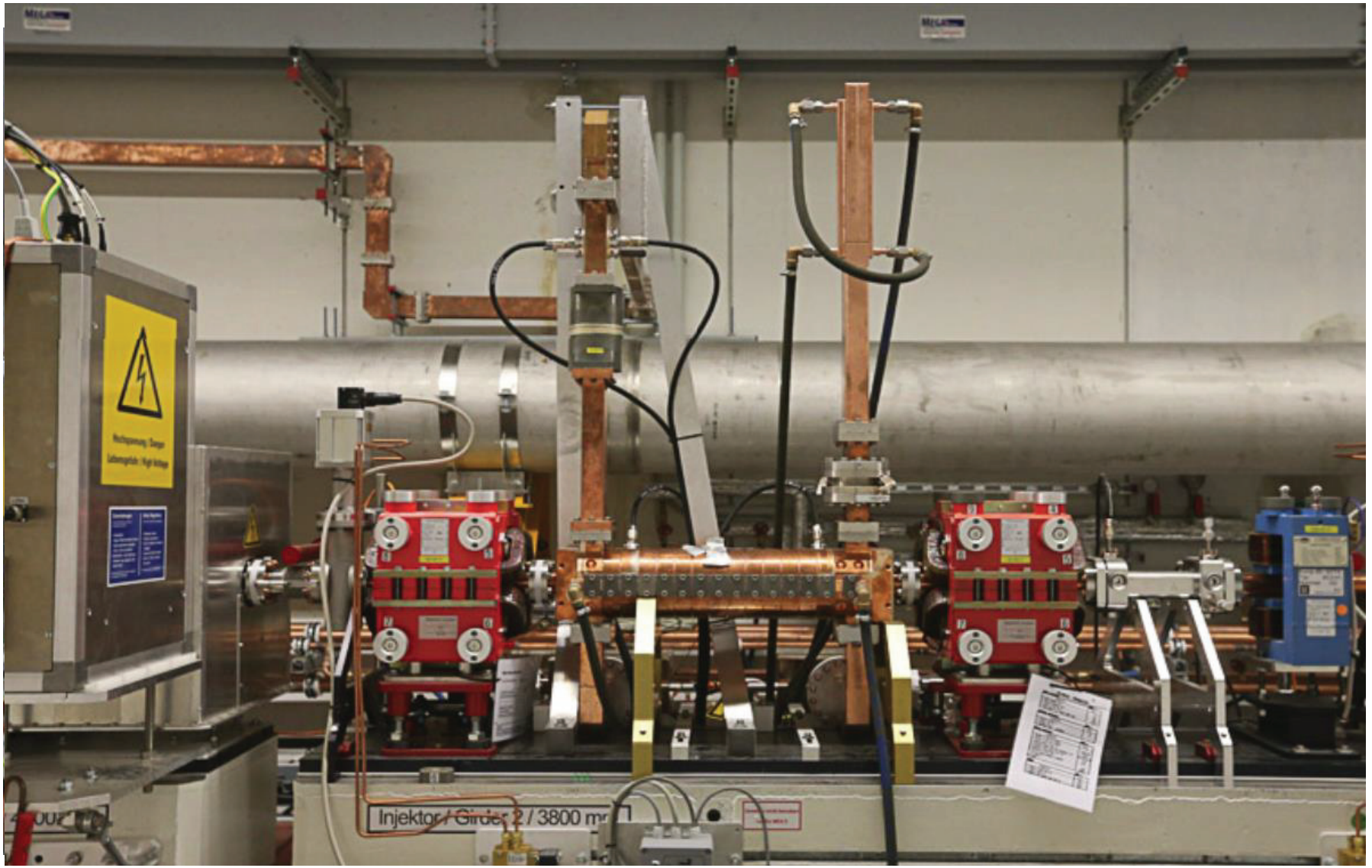
TDS HPRF INJ

HPRF INJ has been installed at XFEL and tested with resistive load:

- *U*=0…110 kV
- *I*=0…82 A
- at τ=6 μsec
- F=10 Hz
- pulse-to-pulse output voltage instability (peak-to-peak) 0.19%
- RMS voltage fluctuation 0.03%
- flat-top voltage non-uniformity <1%



TDS INJ: assembled in the Injector

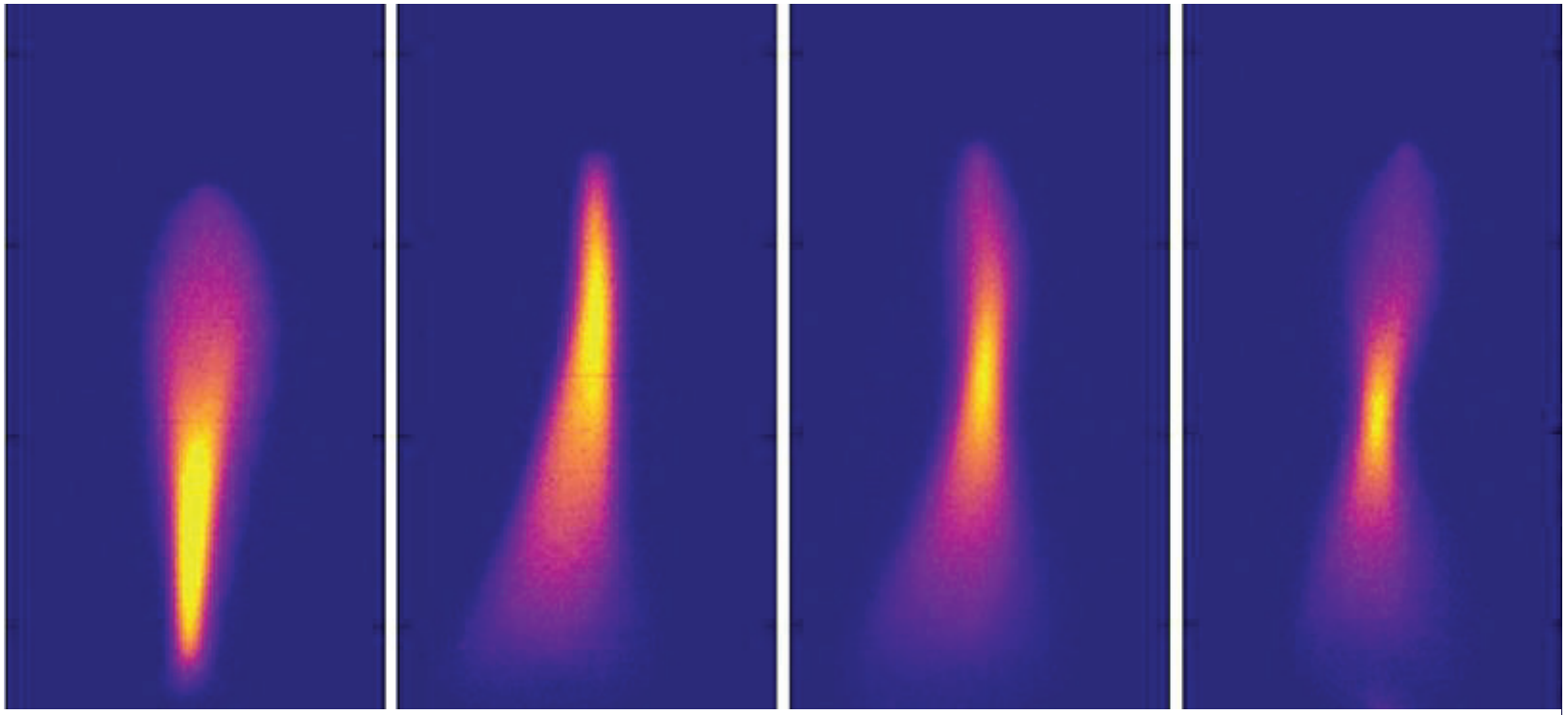


TDS BC2: assembled in the XFEL tunnel

TDS HPRF INJ: electron beam diagnostic test

25 JULY 2016

Electron injector for European XFEL exceeds expectations*



The bright X-ray light of the European XFEL is produced by small bunches of high-energy electrons. Bunch length and slice emittance measurements have been done.

*http://www.xfel.eu/news/2016/electron_injector_for_european_xfel_exceeds_expectations/

TDS Systems: Conclusion

1. TDS System INJ has been tuned and installed at XFEL. It operates for the beam diagnostics.
2. TDS Structures and waveguide systems for XFEL TDS BC1 and XFEL TDS BC2 have been manufactured, tuned and supplied to DESY.
3. TDS Structure BC1 will be assembled on the girder in the XFEL tunnel in accordance with XFEL schedule.
4. The modulator for XFEL TDS BC1 is under production. It will be supplied to DESY, tested at the test stand and installed in the XFEL tunnel then.
5. Two TDS Structures BC2 have been assembled on the girder in the XFEL tunnel.

XFEL TDS Systems

Sincere appreciation to all XFEL TDS cooperation members from

INR RAS, Nano Invest, DESY and MEPHI

for the fruitful and interesting joint work during TDS development, construction and commissioning.

Thank you for attention