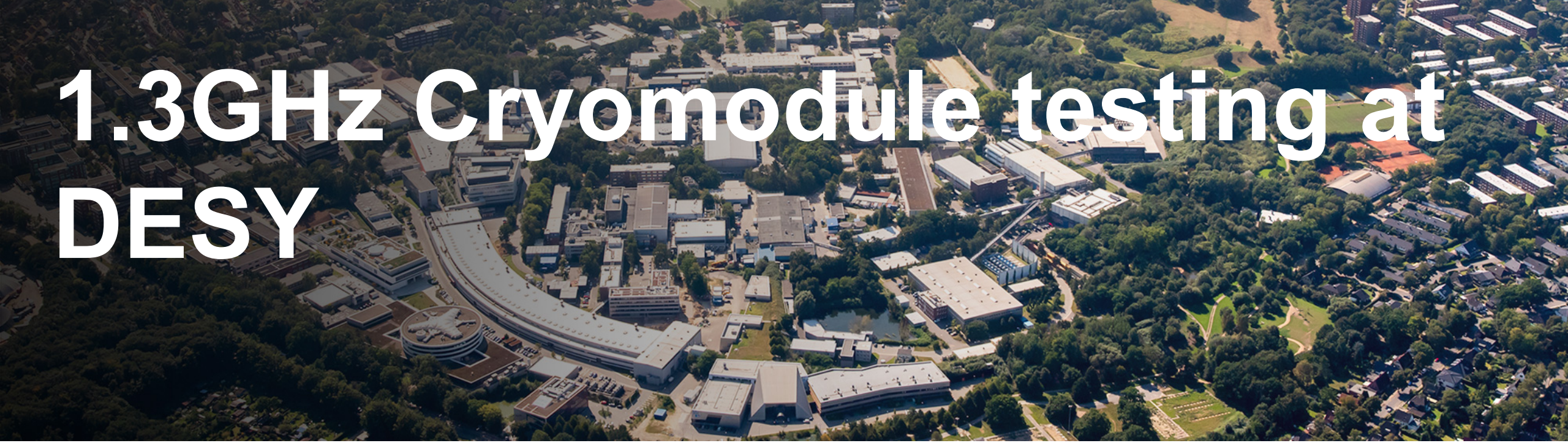


1.3GHz Cryomodule testing at DESY

Mateusz Wiencek
CHILFEL Seminar, 03.03.2022

HELMHOLTZ

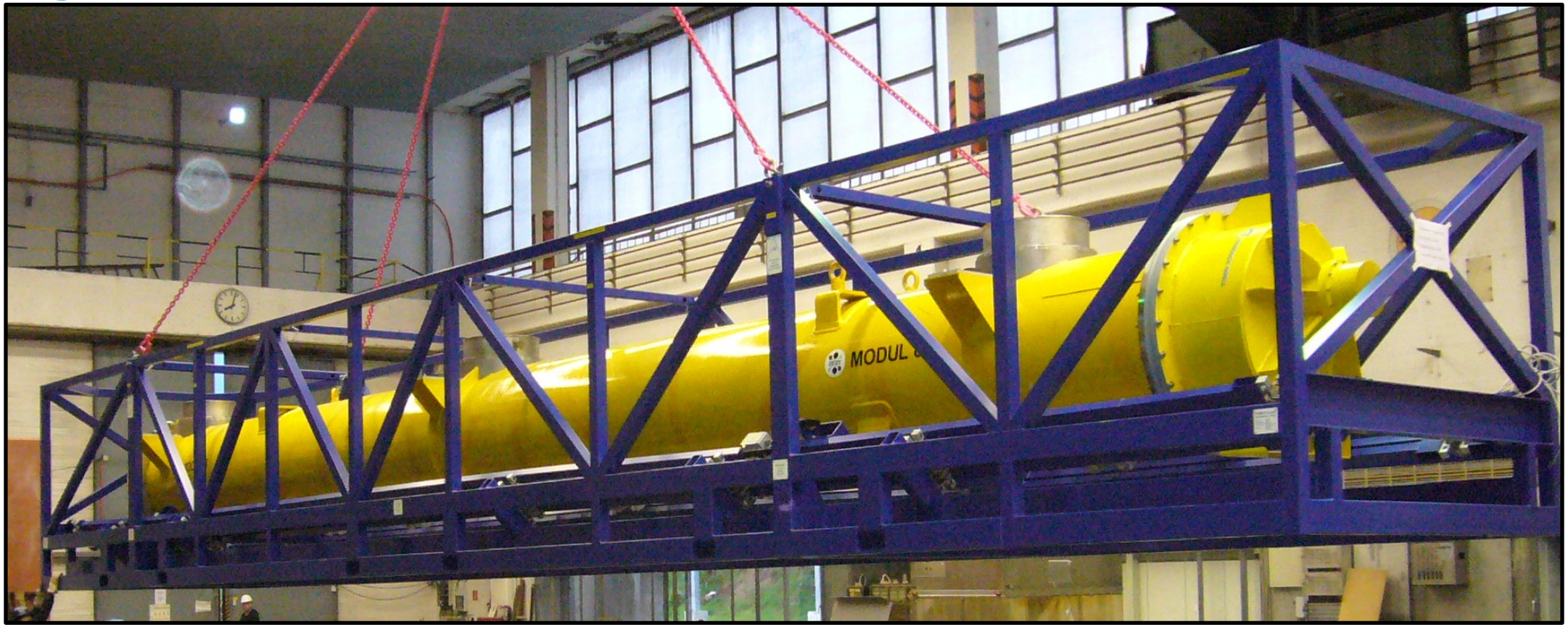
European XFEL

DESY.

OUTLINE

- DESY Experience with Cryomodules
- AMTF Hall Overview
- Cryomodule testing sequence
- Serial tests for XFEL
- Practical examples
  - PXM3.1
  - PXM2.1

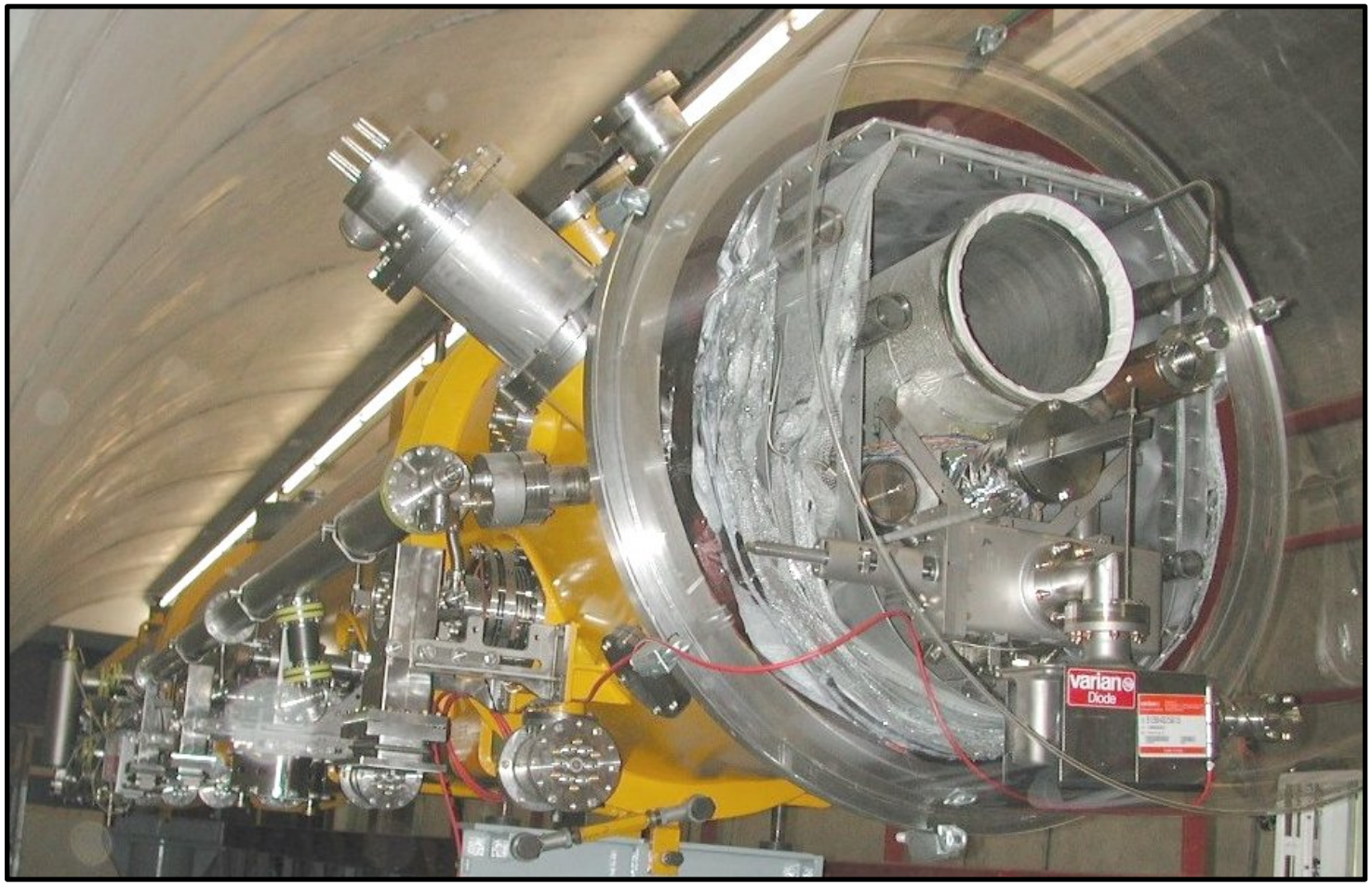
DESY experience with Cryomodules



DESY Experience with cryomodules

Historical background

- First 1.3 GHz cryomodule was build at DESY in 1995 by members of the international TESLA collaboration
- The TESLA Test Facility (TTF) was built in order to study the TESLA technology
- Later, after the Linear Collider Technology decision, the TESLA Collaboration was converted into the TESLA Technology Collaboration (TTC) which promotes the use of superconducting accelerator R&D

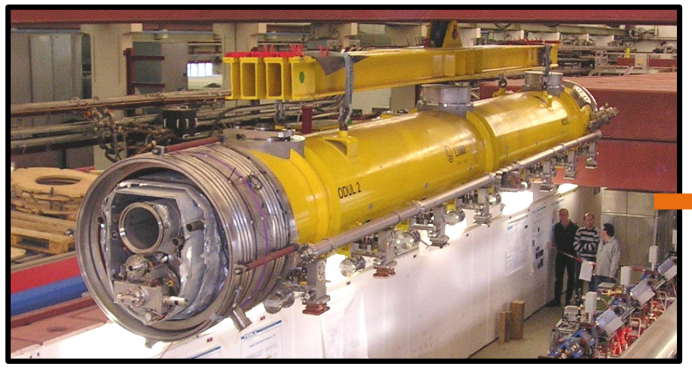


DESY Experience with cryomodules

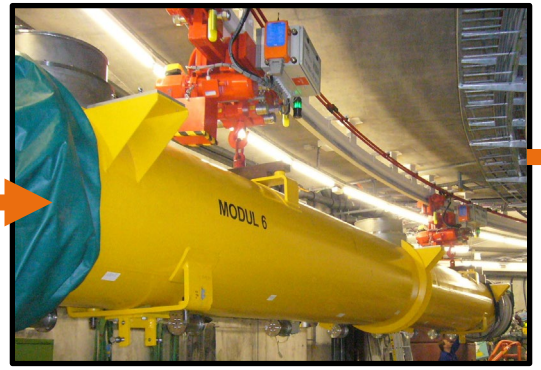
Historical background

- Since this time plenty of upgrades in design introduced

1998

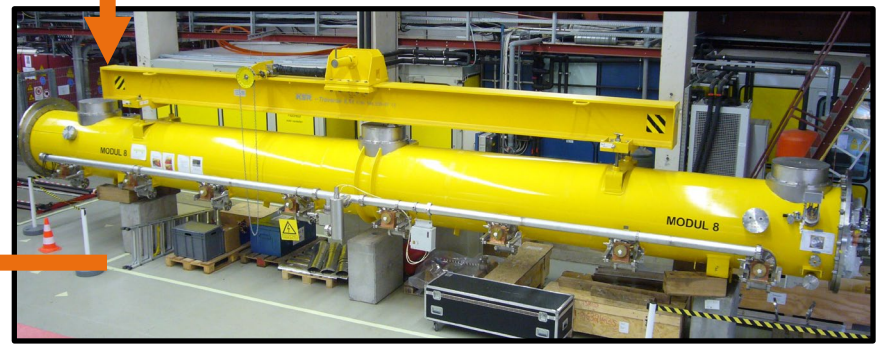


2002



2007 DESY module installed at Femilab

2008



2010 – First XFEL prototype

2012 – Third XFEL prototype

Courtesy K. Jensch

DESY Experience with cryomodules

XFEL

- Final cryomodule design used to build the XFEL accelerator
  - 100 series cryomodules were produced between 2013 and 2016
  - 97 cryomodules were installed in the tunnel and are in operation since 2017
- Some of the „intermediate” designs still operating in FLASH

AMTF Hall Overview

AMTF Hall Overview

Layout

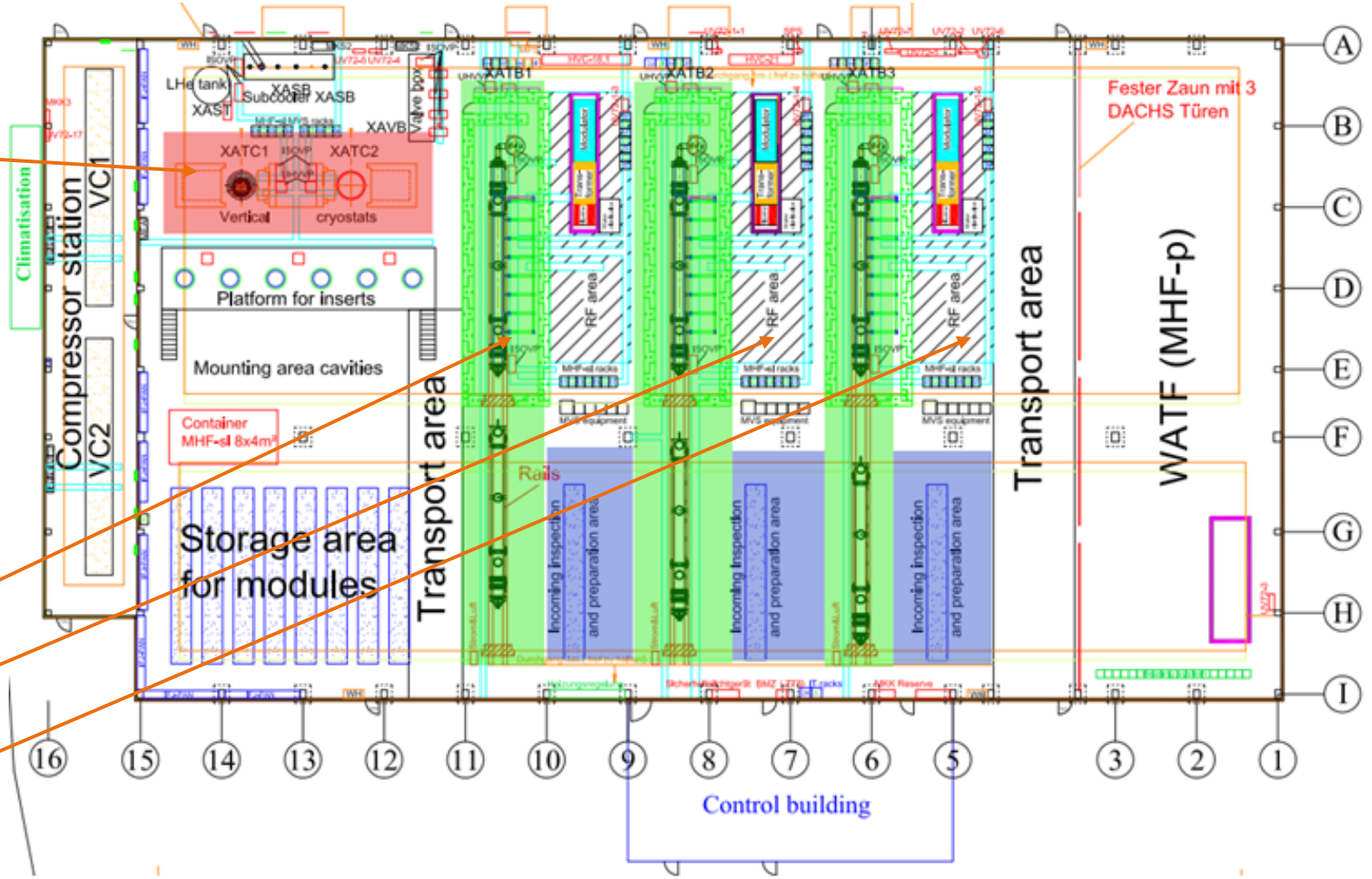
2 Vertical cryostats

- Approx. 2.000 L He volume
- Operating T: 4.2 → 1.4 K
- 6 cavities inserts (R&D, different frequencies accelerator cavities)

3.9GHz Cryomodule test stand

1.3GHz Cryomodule test stand

R&D test stand



AMTF Hall Overview

1.3GHz Test stand overview

5MW klystron

Adjustable waveguides system

LLRF system

Power meters

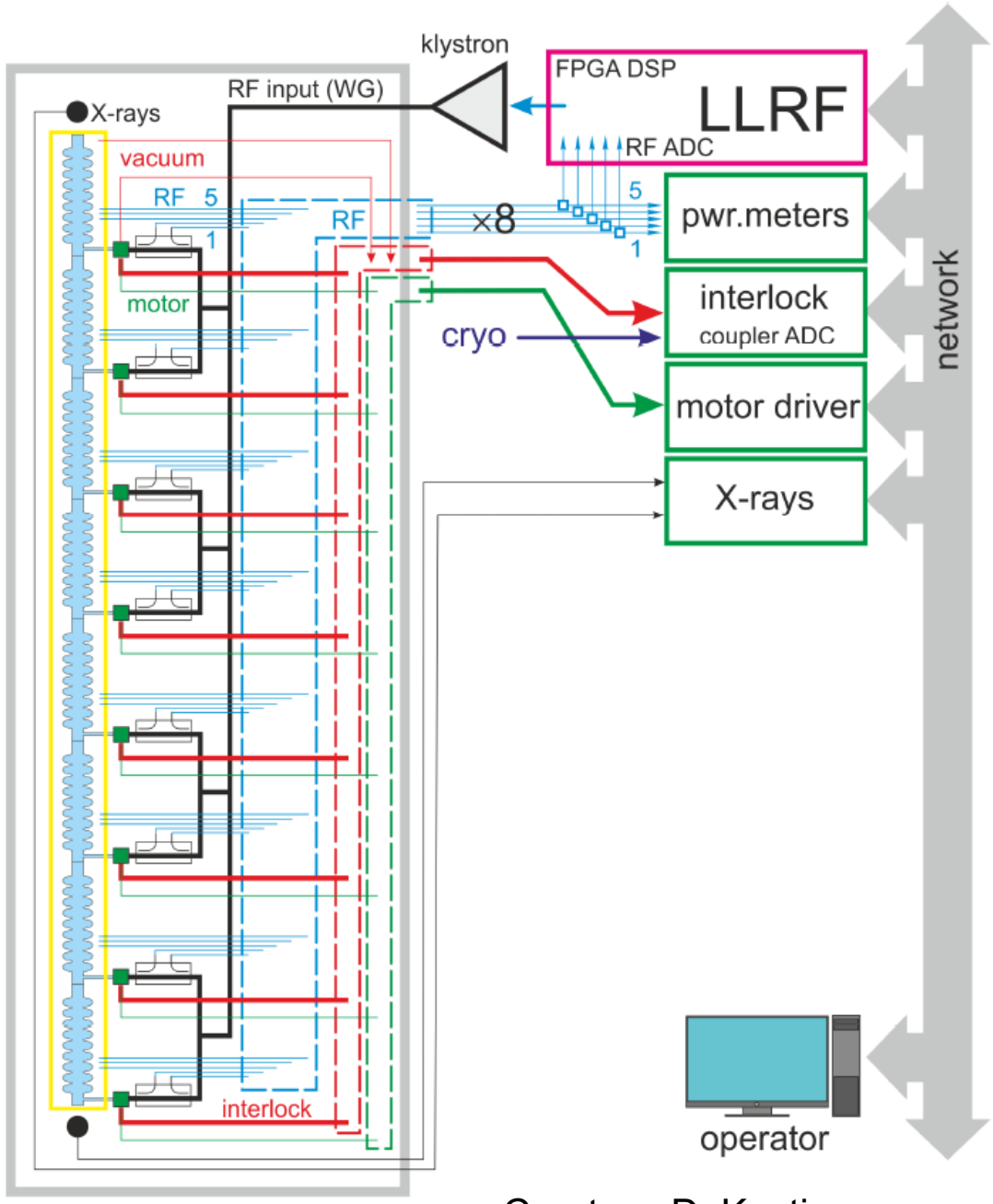
Personal interlock system

Technical interlock system

Cavity tuner driver

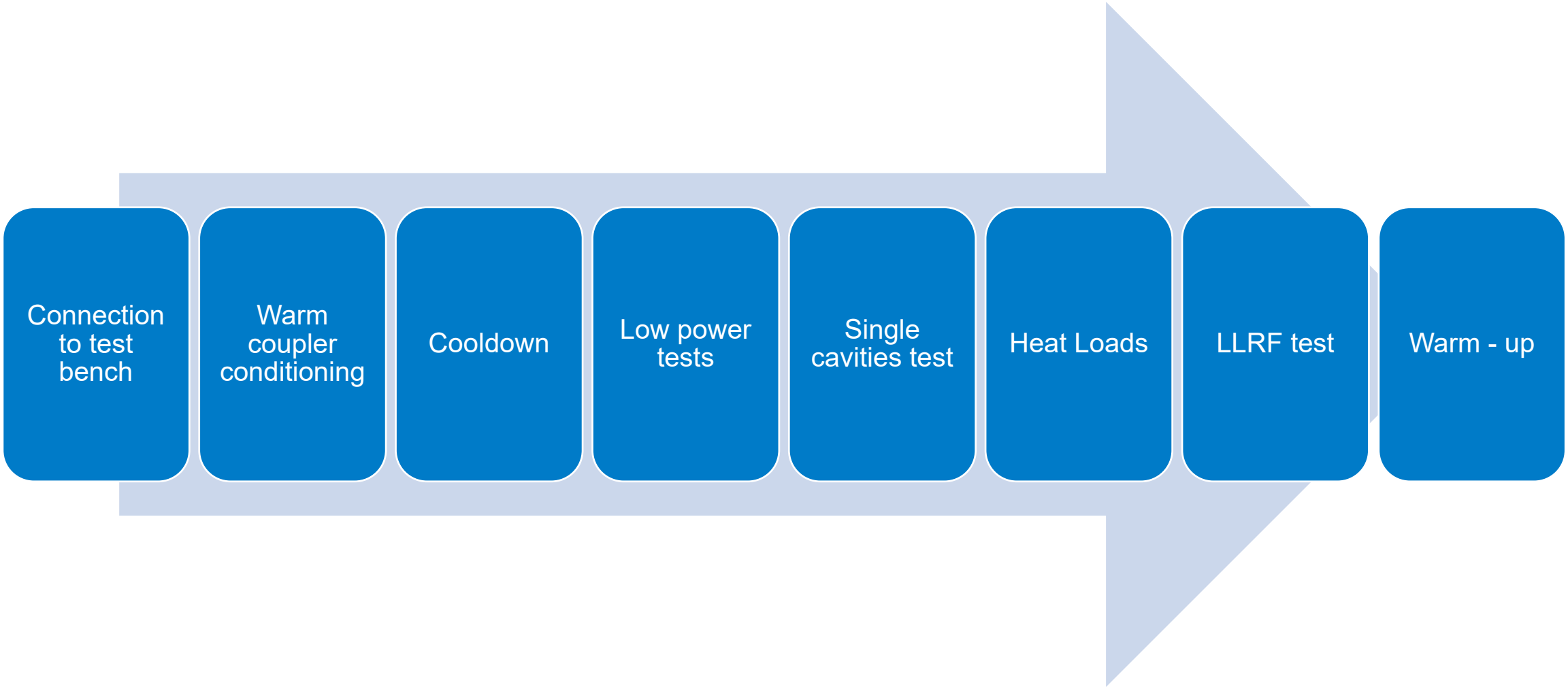
Coupler tuner driver

Radiation monitoring



Courtesy D. Kostin

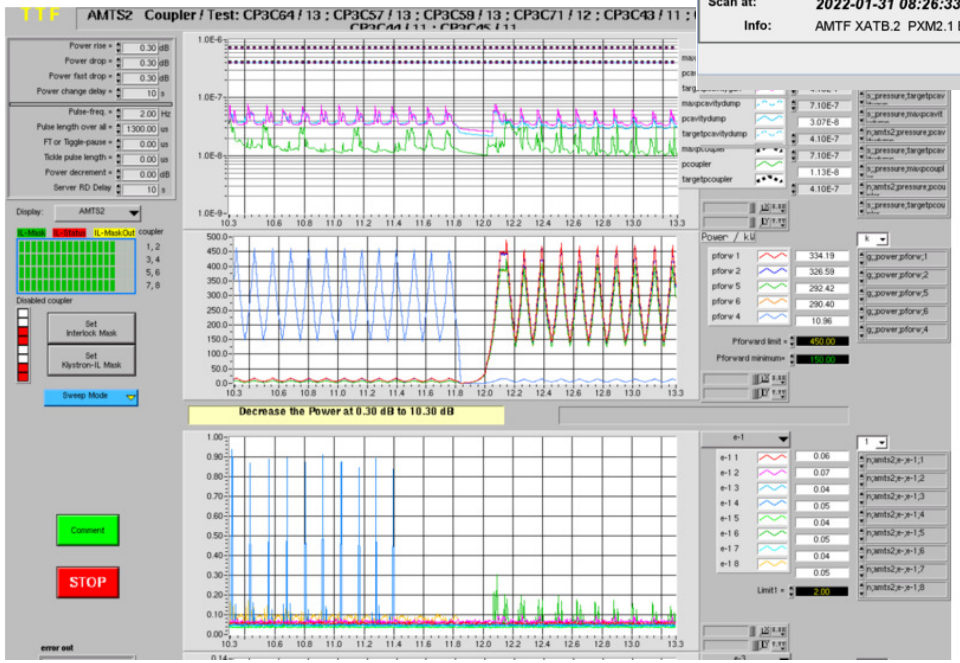
Cryomodule testing sequence



Cryomodule testing sequence – at room temperature

Cryomodule connection to test bench, LCs, warm coupler conditioning

- Beam line connection
  - LC, RGA
- All module cryogenic pipes are connected to cryogenic circuits
- Integral leak check
- Insulation vacuum leak check
- Warm coupler conditioning
  - Starting at 20us RF pulse and few kW
  - Up to 1300us and 450kW per coupler

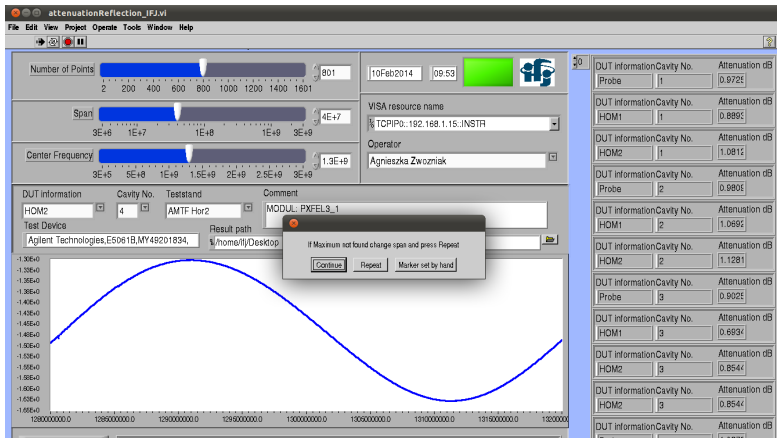


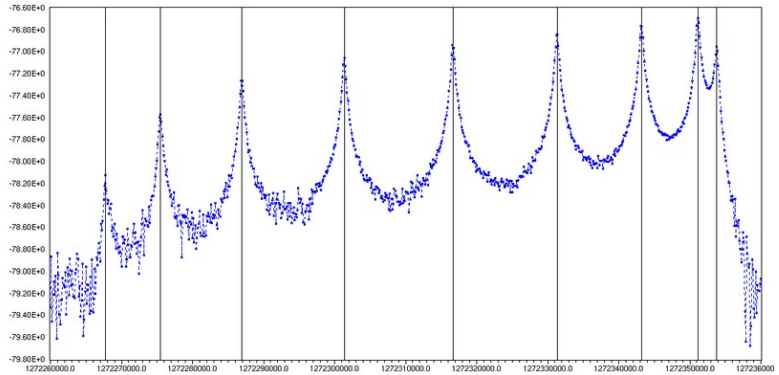
Cryomodule testing sequence – 2K

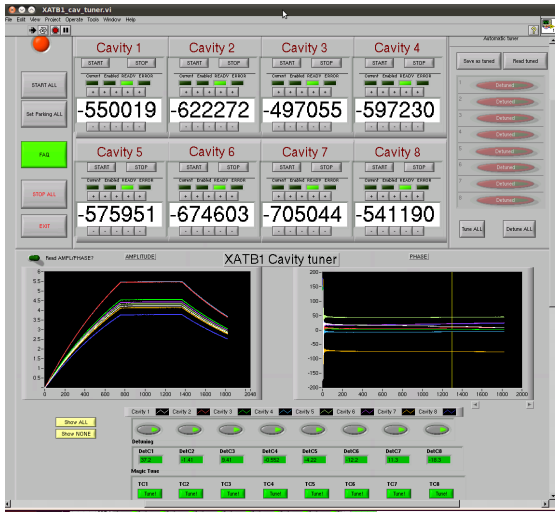
Low RF power measurements

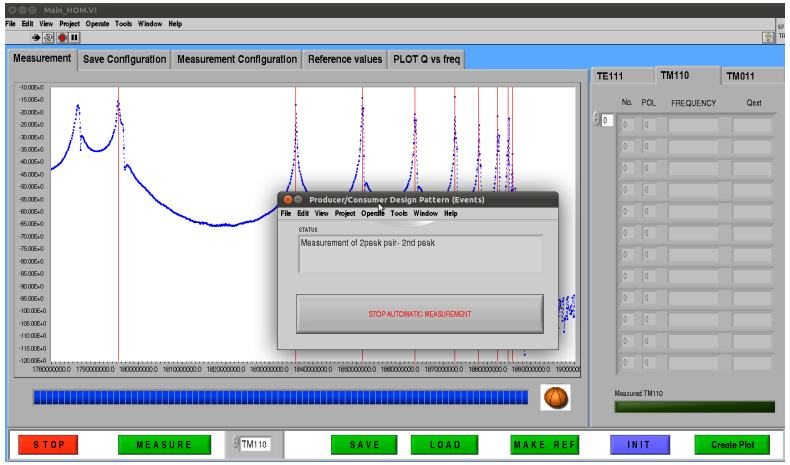
Mostly performed with using of Vector Network Analyzer

- Cold RF cables calibration
- FM Spectra measurements for each cavity
- Cavities tuning to 1.3GHz
- HOM Spectra measurements





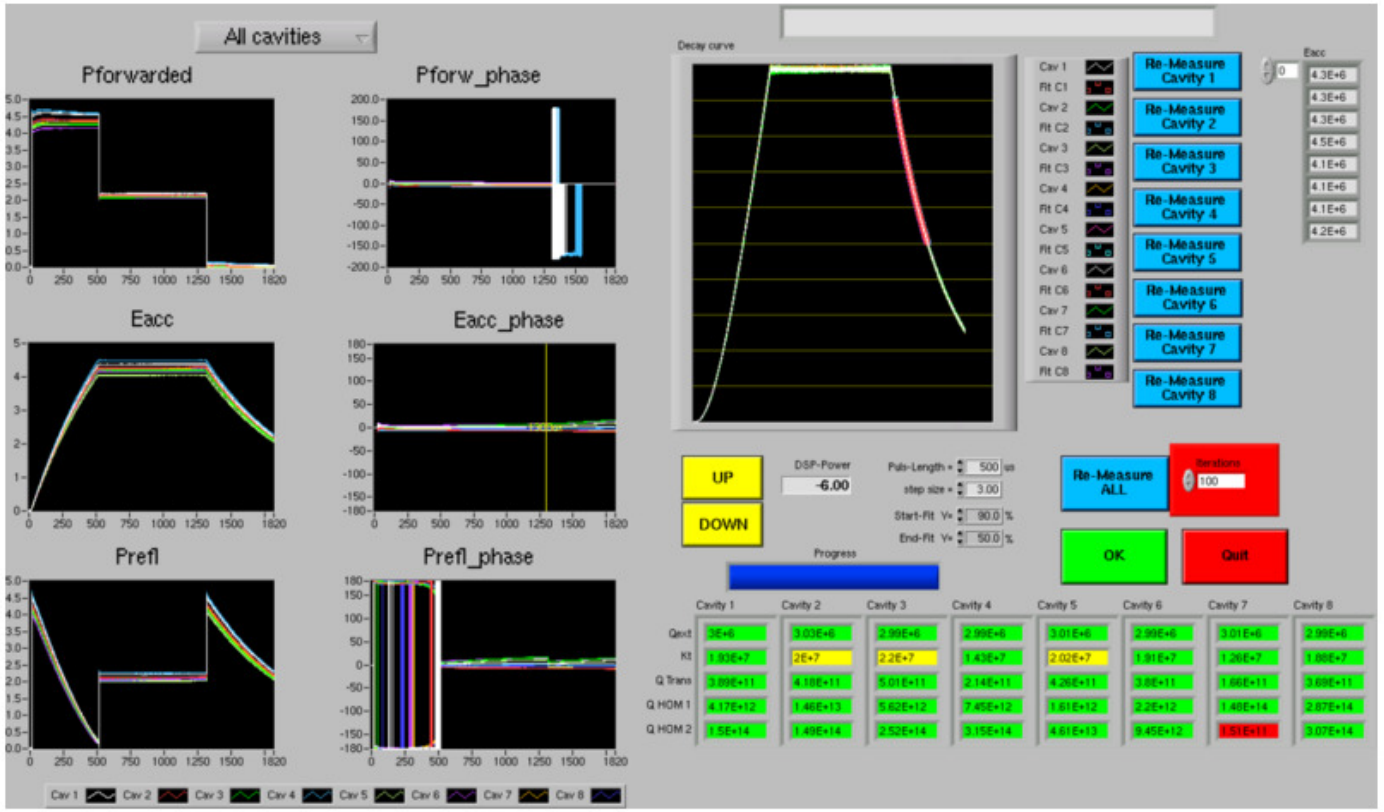




Cryomodule testing sequence – 2K

Cryomodule calibration

- Because of non – linear effects at higher accelerating fields (Lorentz Force detuning, microphonics) probe calibration is performed
- All cavities are tuned very precisely
- Q_{ext} of all couplers are set to desired value
- Cavities accelerating field is calculated from Incident power
- K_t coefficient is calculated
- Based on K_t accelerating field is calculated from Probe power

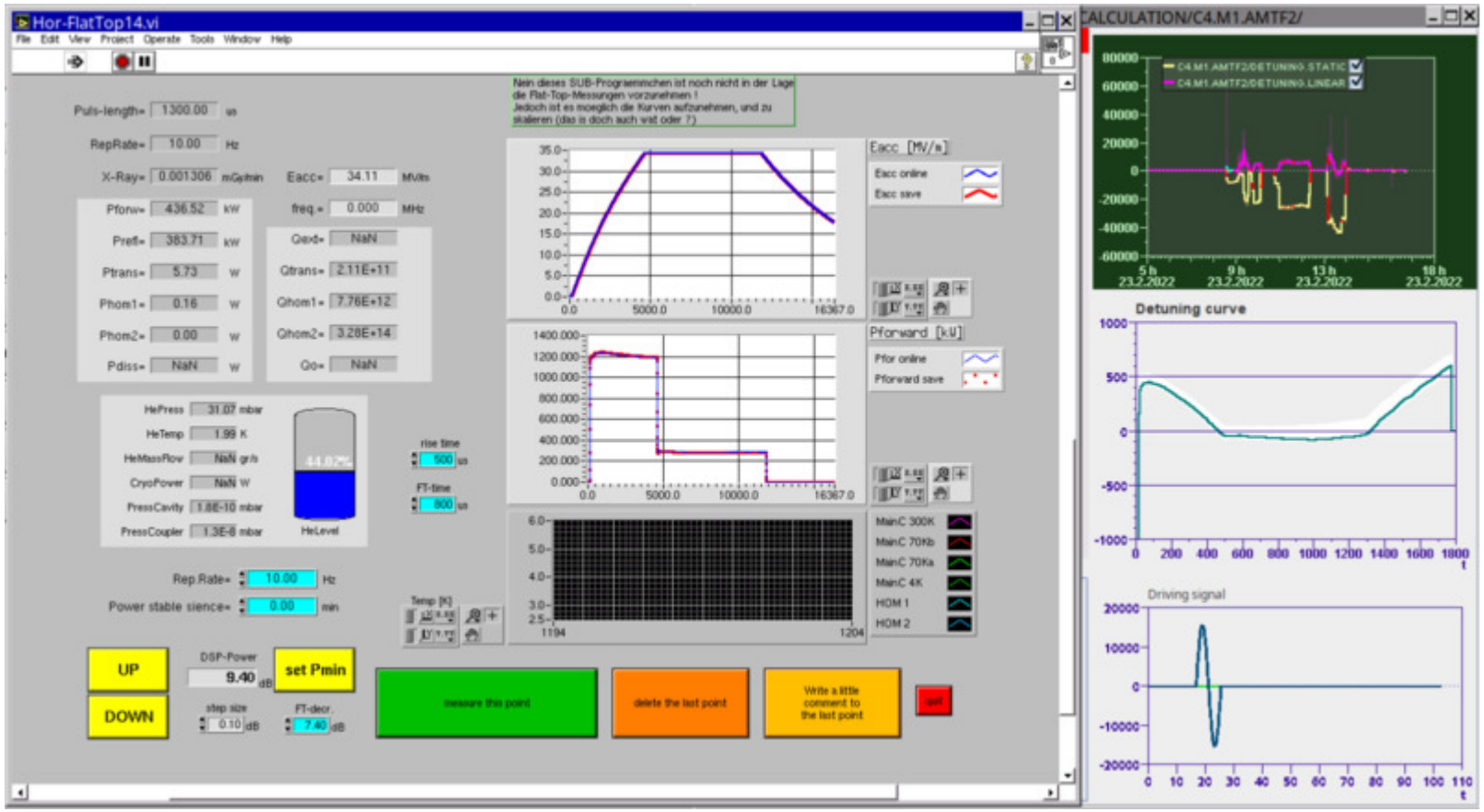


Cryomodule testing sequence – 2K

Single cavities measurements

- So called „Flat – top” measurement performed to obtain operating gradient for each cavity in the module

- Values are used to produce tailored waveguide system in order to optimize energy gain for the beam in accelerator



Cryomodule testing sequence – 2K

Heat Loads measurement

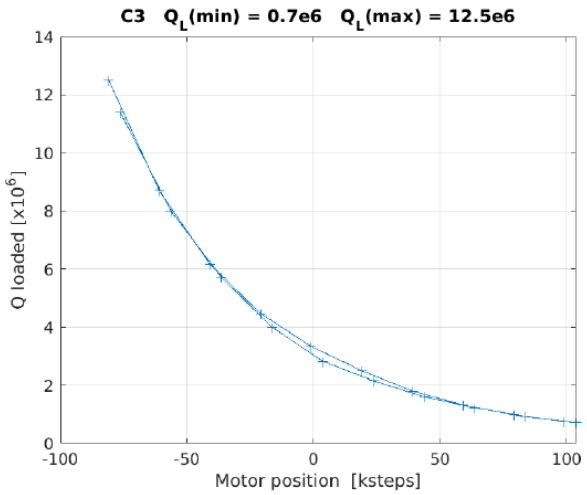
- Due to resolution of the cryo system there is no possibility to measure Q0 of single cavity in the module
- Heat Loads at 2K circuit measured to evaluate cryogenic power needed to operate in tunnel
- Averaged Q0 of the module is calculated from difference Dynamic – Static losses

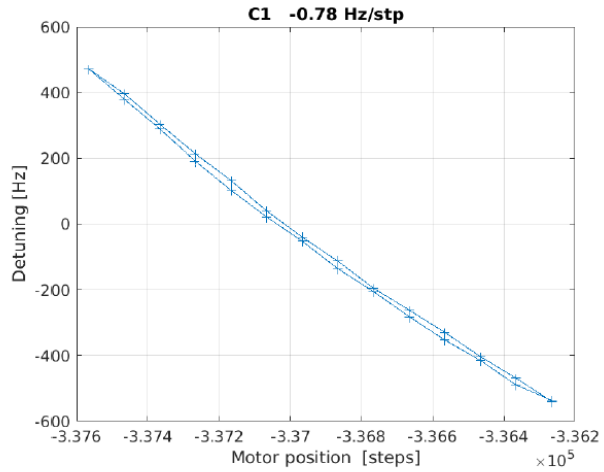
Cryomodule testing sequence – 2K

LLRF checks

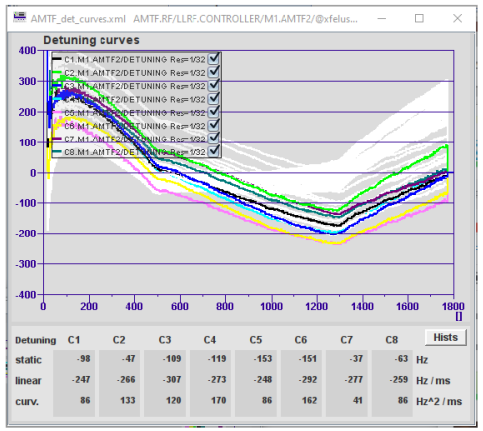
LLRF checks are important from accelerator control point of view

- QI scan
- Cavity frequency tuner scan
- Piezo scan
- Lorentz force detuning coefficients
- Lorentz force detuning compensation
- Sub-pi mode identification

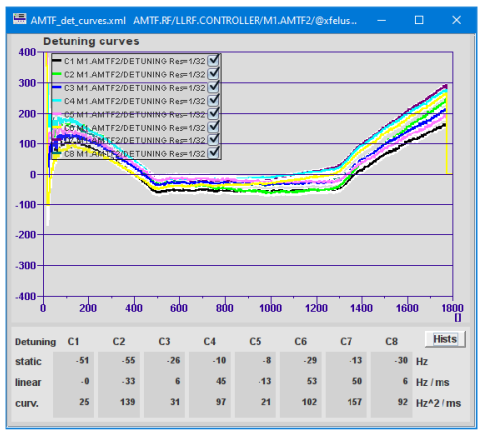




Piezo OFF



Piezo ON



Serial tests for XFEL

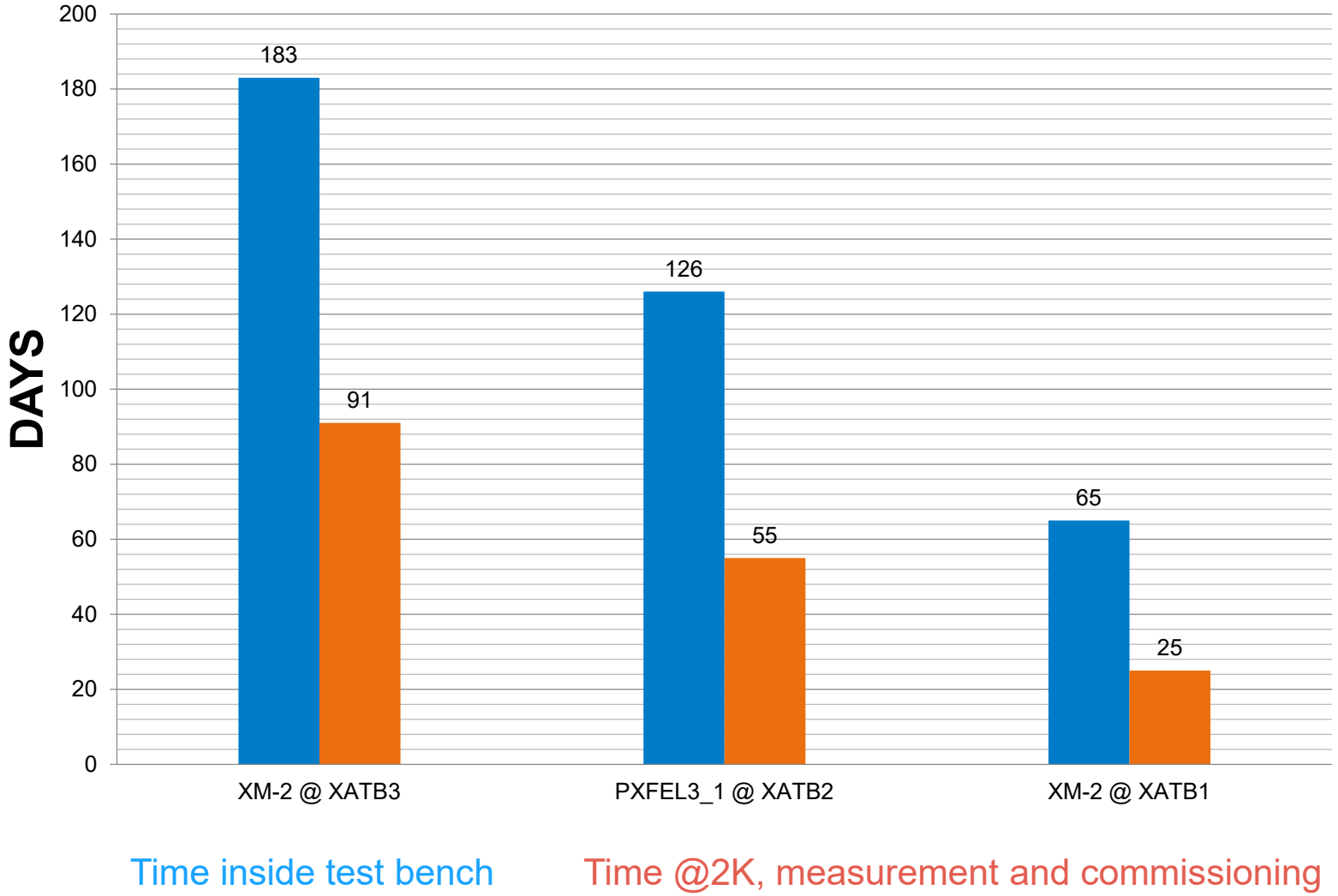
Serial tests for XFEL

For XFEL 106 modules were produced

- 3 prototypes
- 3 pre-series
- 100 series cryomodules
  - Cavities tested in vertical cryostat in DESY
  - Almost complete assembly kits shipped to CEA - SACLAY
  - Cryomodules assembled in CEA/Saclay (France)
  - Cryomodules tested in DESY before tunnel installation

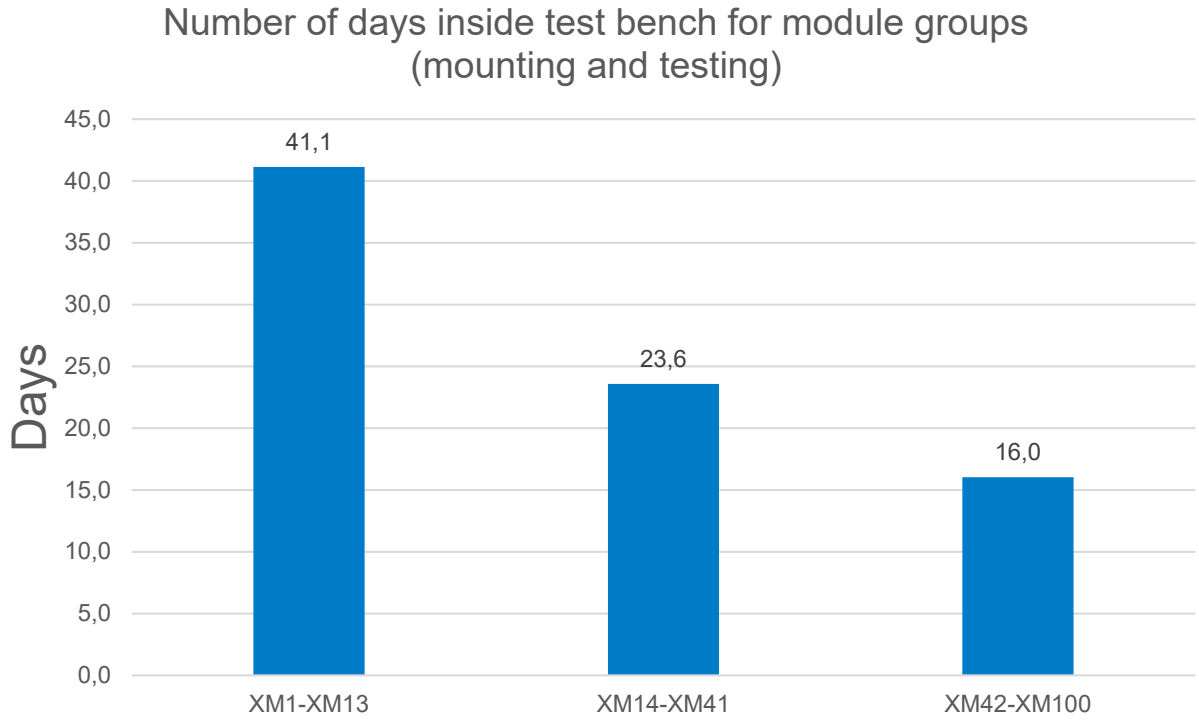
Serial tests for XFEL

- First cryomodule tests at new AMTF Hall were dedicated to:
  - Test – bench commissioning
  - Training testing crew
- First test bench commissioned: XATB3



Serial tests for XFEL

- 107 serial tests were performed for 100 serial cryomodules
- This task took 2 years with testing crew of around 30 people working on two shifts
- Two reviews and optimization of the testing procedures and mounting approaches performed

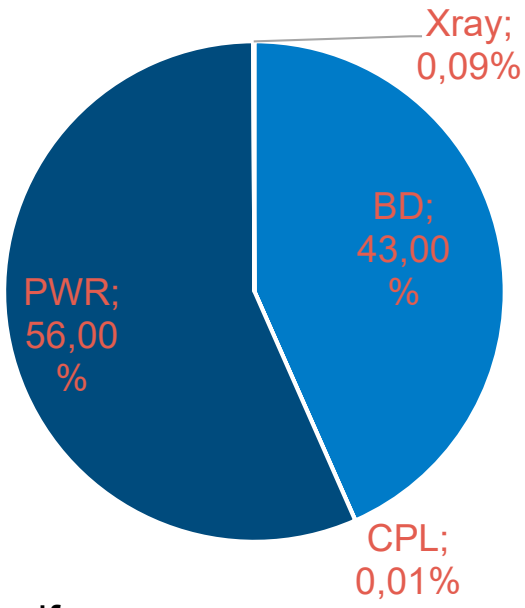


Serial tests for XFEL

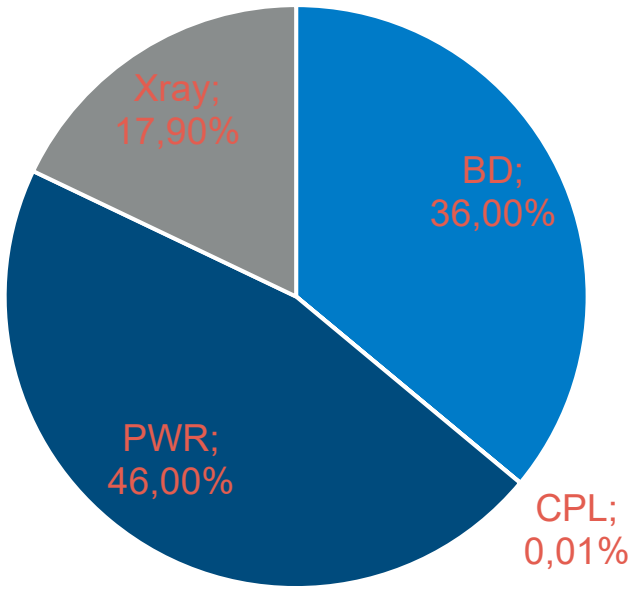
Overall performance statistics

Gradient	Maximum (clipped at 31 MV/m)	Operating (specified 23.6 MV/m)
Cryomodule	28.5 MV/m	27.5 MV/m
Vertical	30.1 MV/m	28.6 MV/m

Cavities maximum gradient limitations



Cavities operating gradient limitations



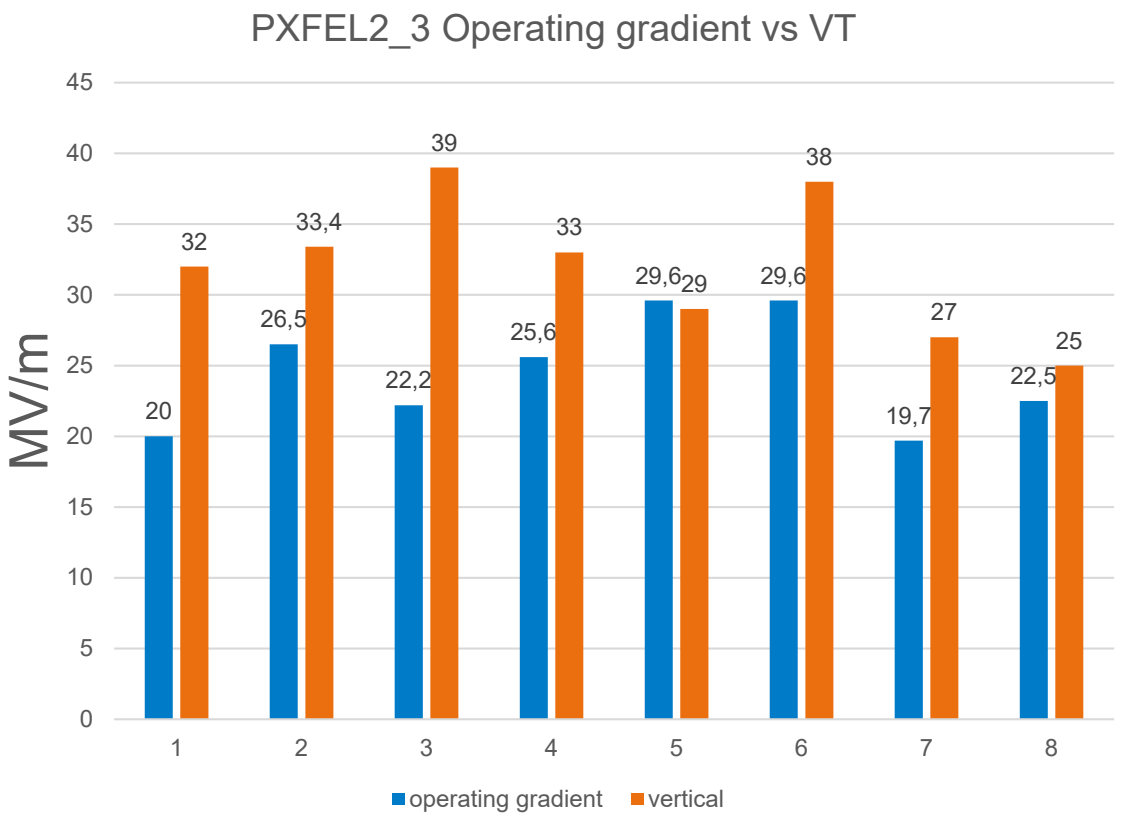
More details can be found here:
https://accelconf.web.cern.ch/srf2017/papers/mopb106.pdf

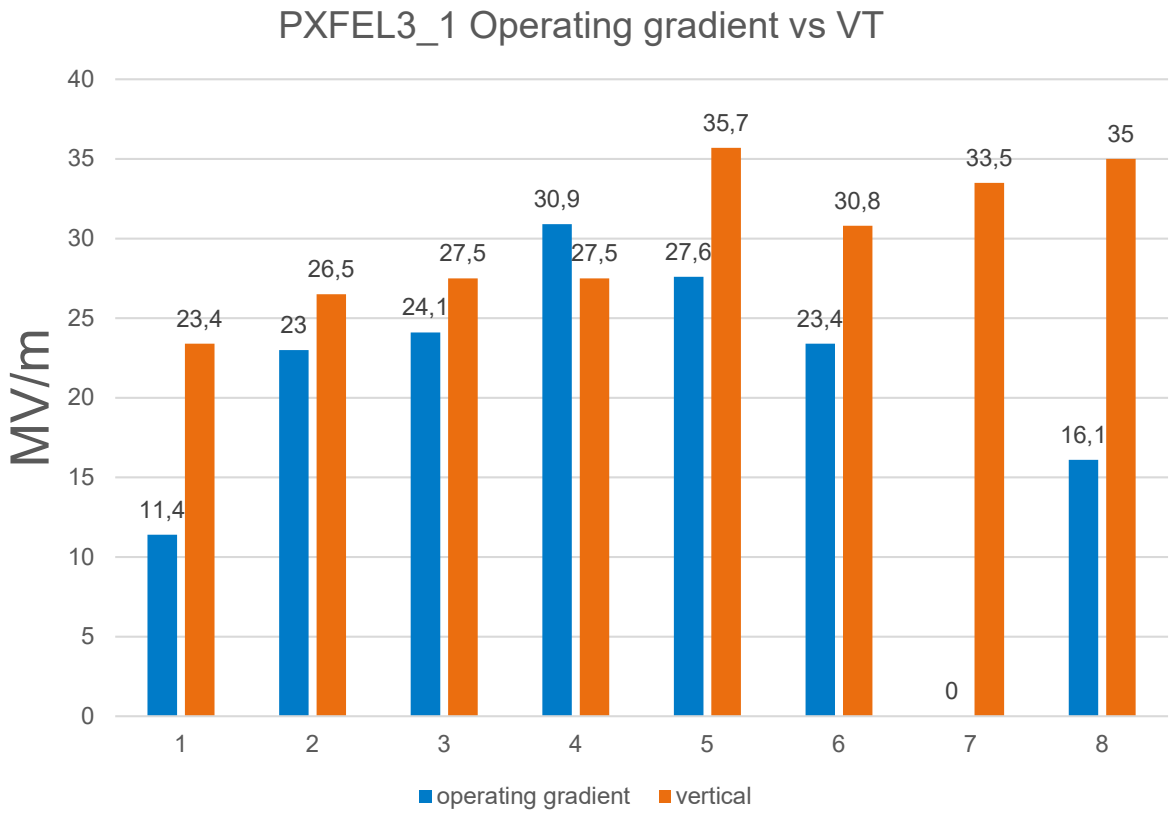
Some practical examples – PXM3.1 & PXM2.1

PXM3.1 and PXM2.1 history

- Modules PXFEL2 and PXFEL3 were build as prototypes for XFEL
- Main purpose was to train assembly crew in France (CEA Saclay)
- Therefore these assemblies were not focused on RF performance
- First module used to train test stand connections, and tests were also used as a training for serial module tests for XFEL
- After testing those modules in DESY, they were put to storage for XFEL building phase

PXFEL2, PXFEL3 performance



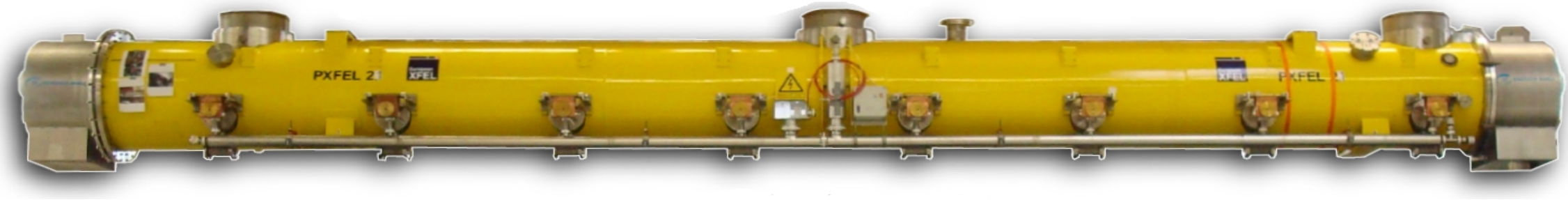


CAV7 not tested due to HOM rejection filter problem

PXFEL2, PXFEL3

Refurbishing

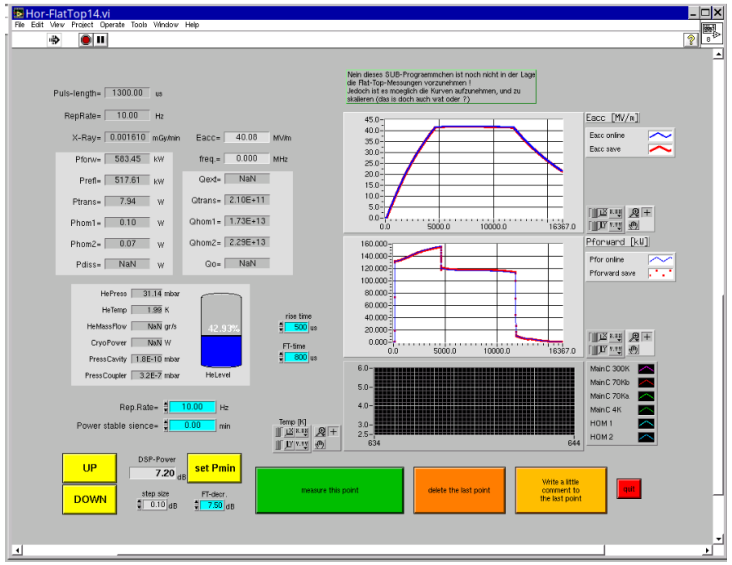
- It was decided to dismount cryomodules completely
- Cavities were dismounted from strings and re-treated (HPR)
- Cryomodules were renamed PXFEL2 → PXM2, PXFEL3 → PXM3
- All cavities were tested vertically in order to accept them for new modules
- Some cavities exchanged in string

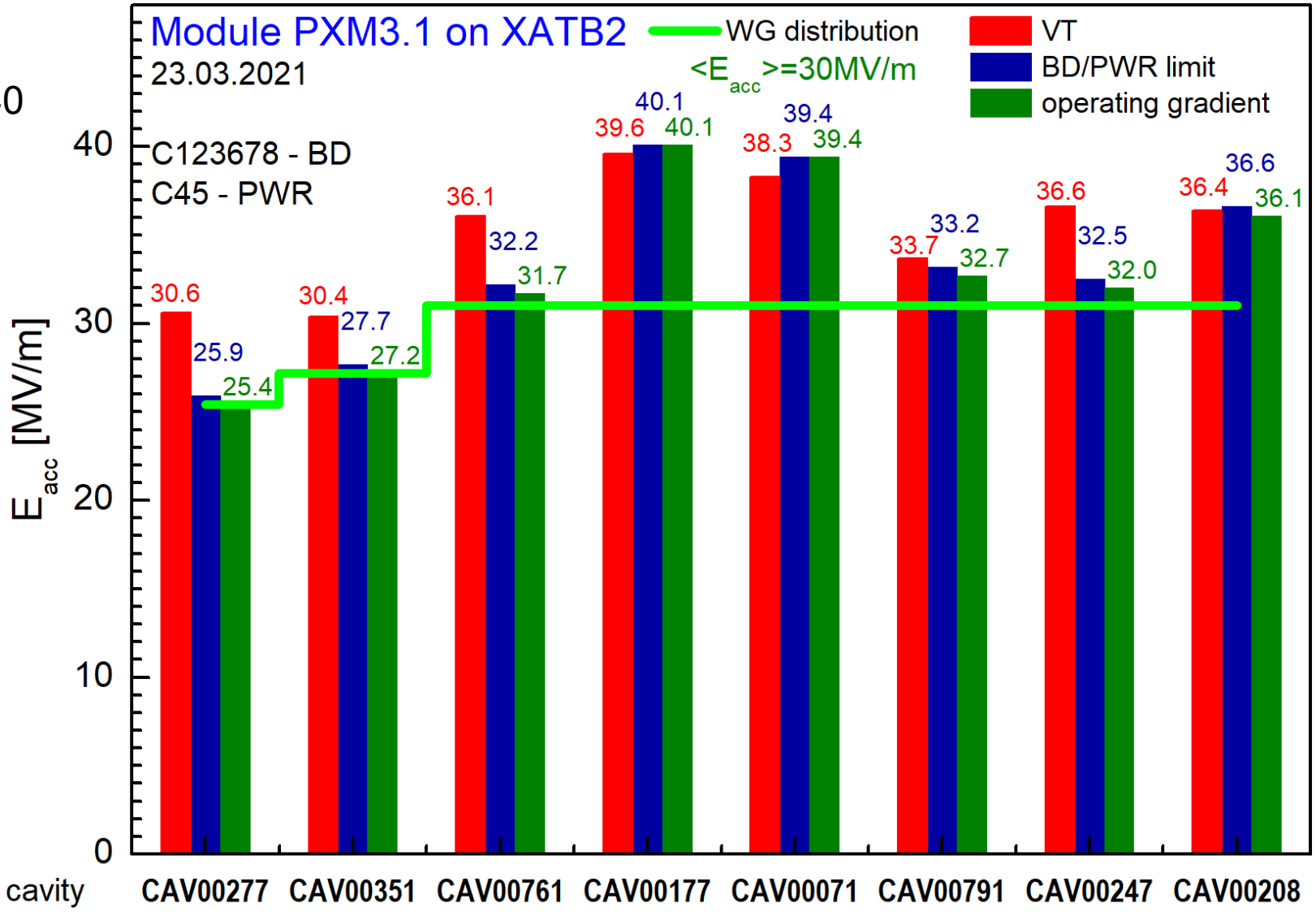


PXM3.1 refurbished module performance

RF performance

- 2 cavities operated stable at 40 MV/m!

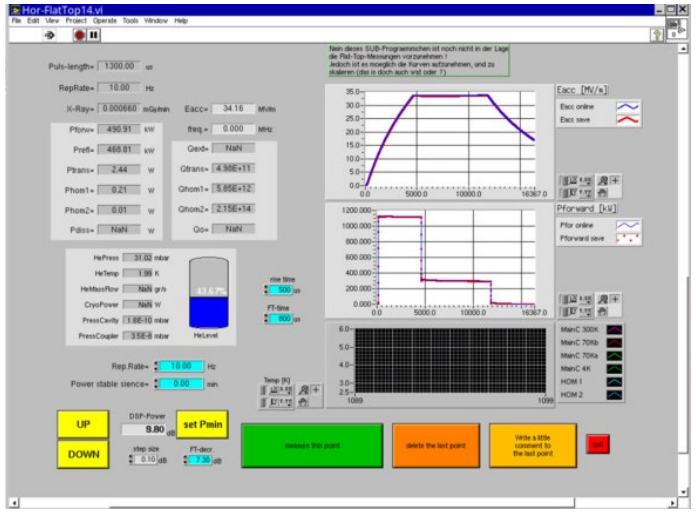


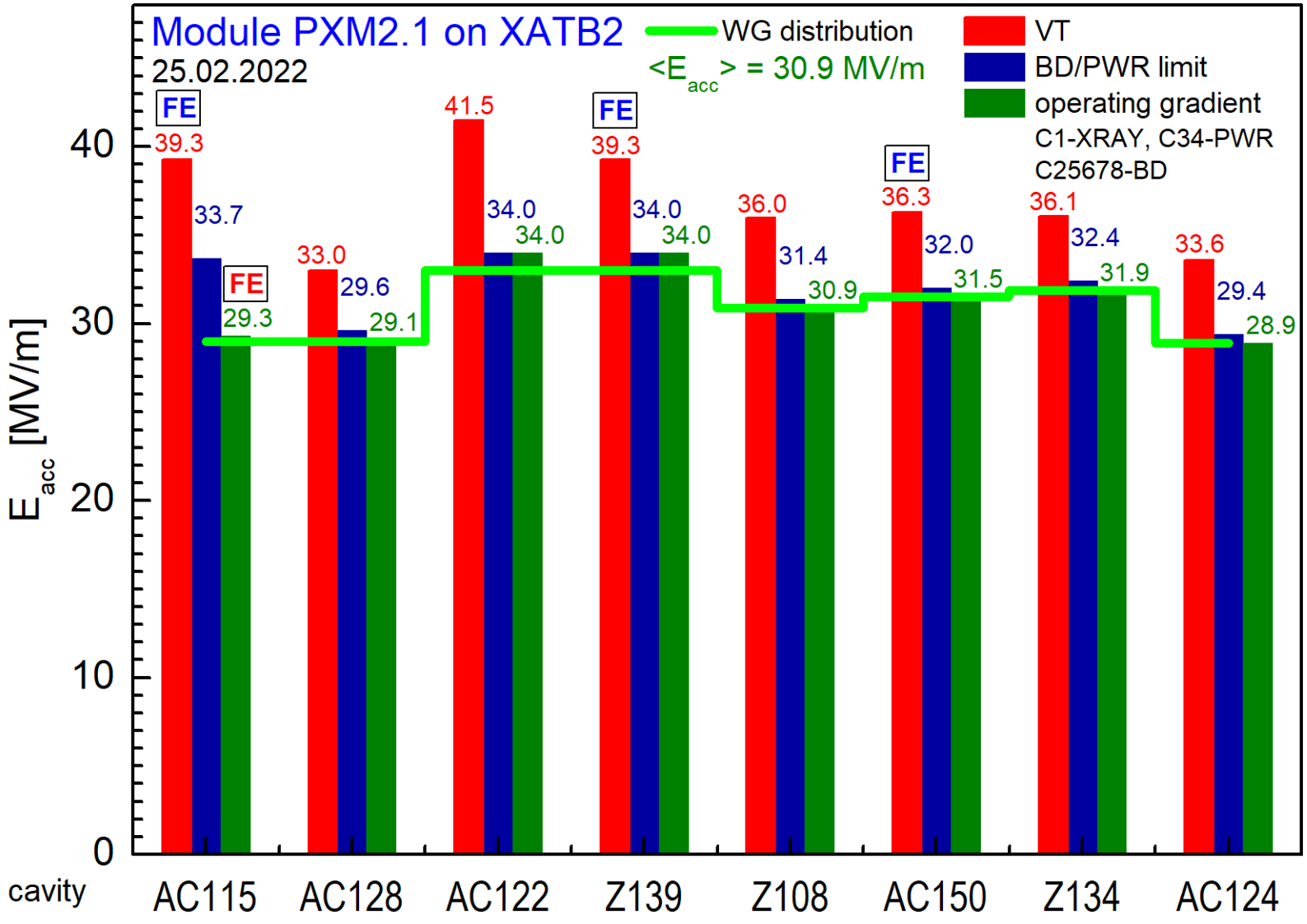


PXM2.1 refurbished module performance

RF performance

- 2 cavities Limited by Input Power at 34 MV/m





Summary

- DESY has over 25 years of experience in building and testing of SRF cryomodules
- During this long time two FELs were built on site
- Currently, FLASH is during upgrade phase
- Two prototype XFEL modules were refurbished for FLASH upgrade
  - Both of them shows very good RF performance
  - We are looking for beam operation later this year!
- **Refurbished modules shows one of the best performance worldwide**

Thank you

I will be happy to answer Your questions…

Contact

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