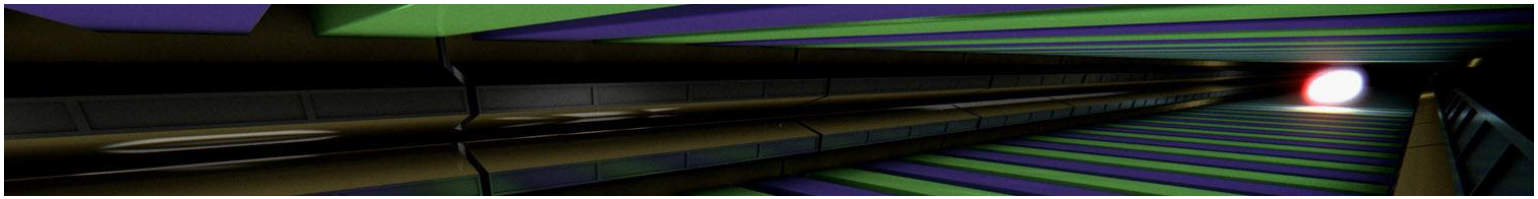


Accelerator Challenges and Status of the European XFEL

Holger Schlarb (DESY)

for the Accelerator Consortium

European XFEL

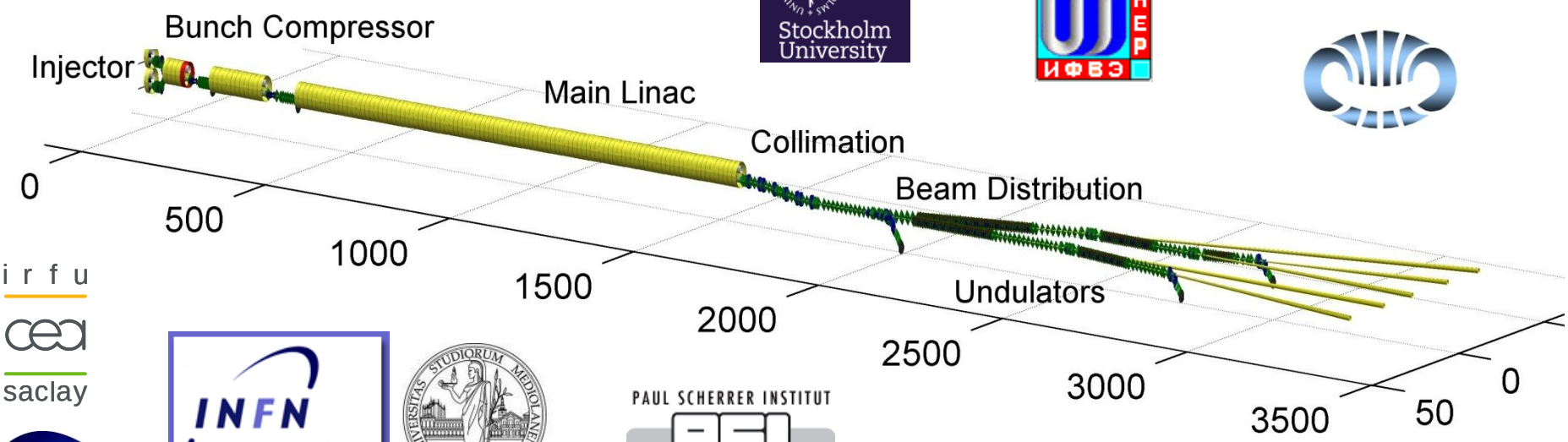
Accelerator Consortium

DESY

HELMHOLTZ ASSOCIATION

UPPSALA UNIVERSITET

Stockholm University



irfu

cea

saclay

INFN Istituto Nazionale di Fisica Nucleare

PAUL SCHERRER INSTITUT PSI

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Wrocław University of Technology

Institute of High Energy Physics Chinese Academy of Sciences

NARODOWE CENTRUM BADAŃ JĄDROWYCH Świerk

European XFEL

Accelerator Consortium

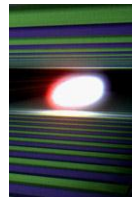
- 16 Institutes that construct the European XFEL accelerator by contributing in kind
- Accelerator Consortium Coordinator: DESY, Hans Weise
- Advisory Body: Accelerator Consortium Board

2nd meeting of the Accelerator Consortium Board, October 2011

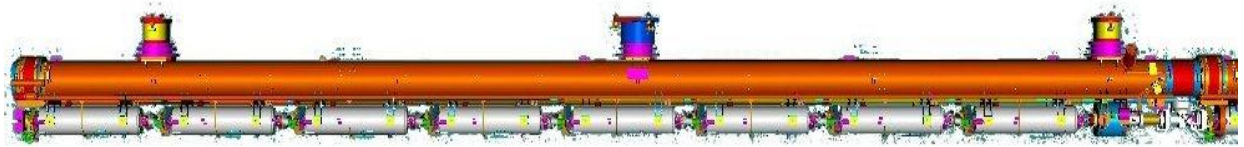
⇨ 1st XFEL accelerator consortium meeting: 16-19 April 2012

Gathering the international collaboration that constructs the European XFEL (accelerator and photon systems)

Accelerator Complex: From the14.0 GeV Start -up Version



80 accelerator modules

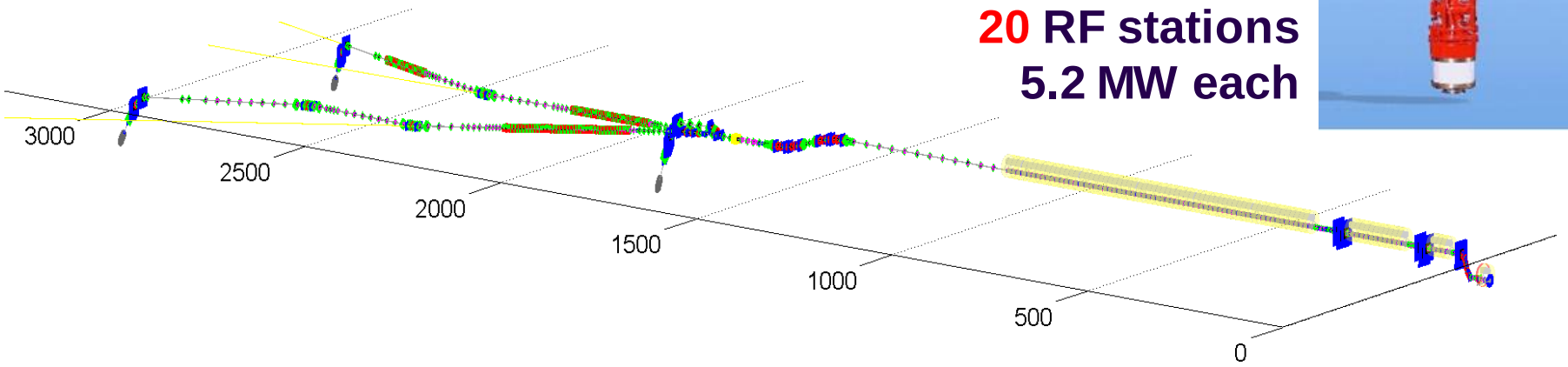


640 accelerating cavities

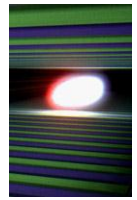
1.3 GHz / 24.3 MV/m

20 RF stations

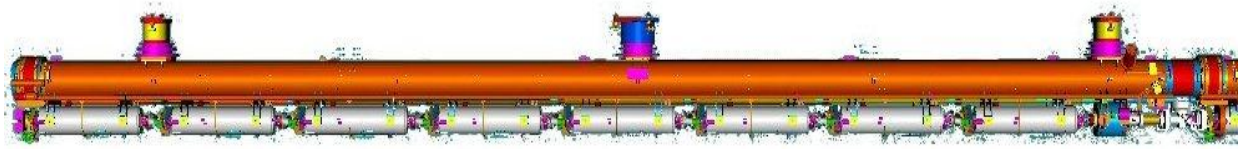
5.2 MW each



Accelerator Complex: Back to the17.5 GeV Start -up Version



100 accelerator modules

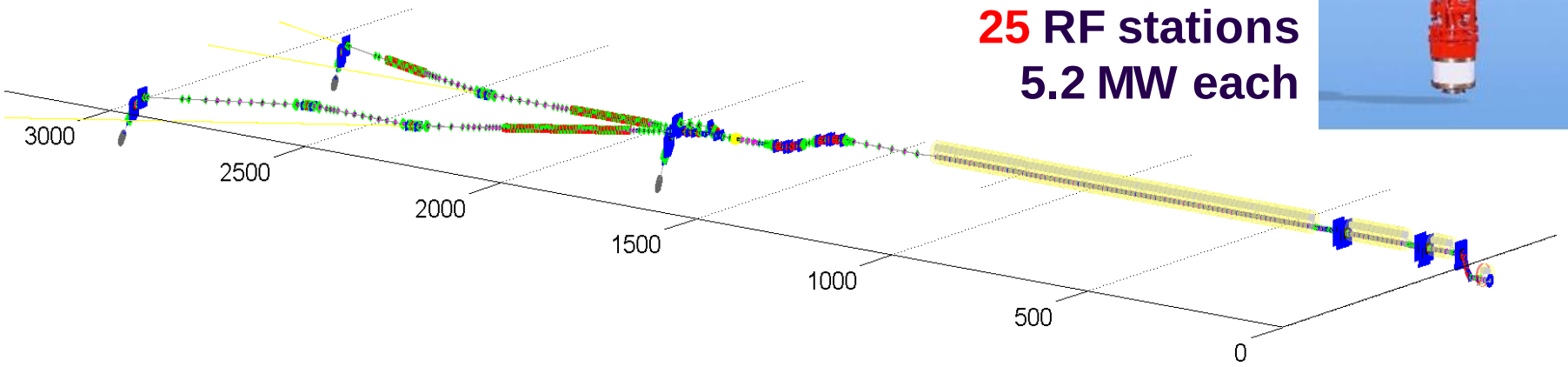


800 accelerating cavities

1.3 GHz / 23.6 MV/m

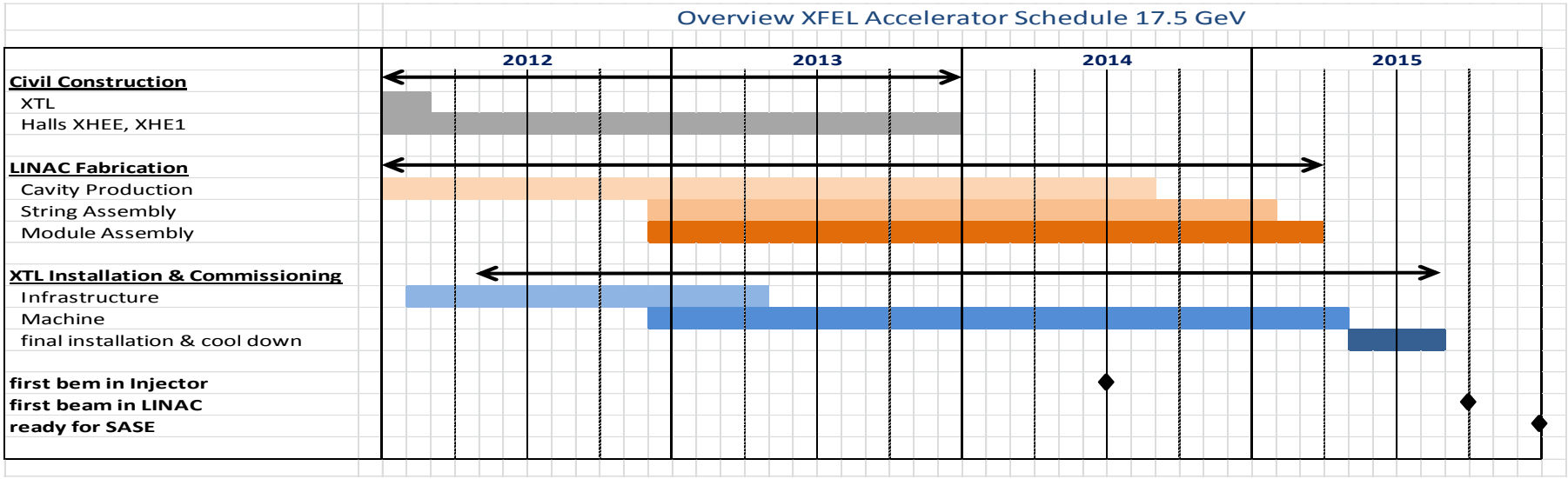
25 RF stations

5.2 MW each



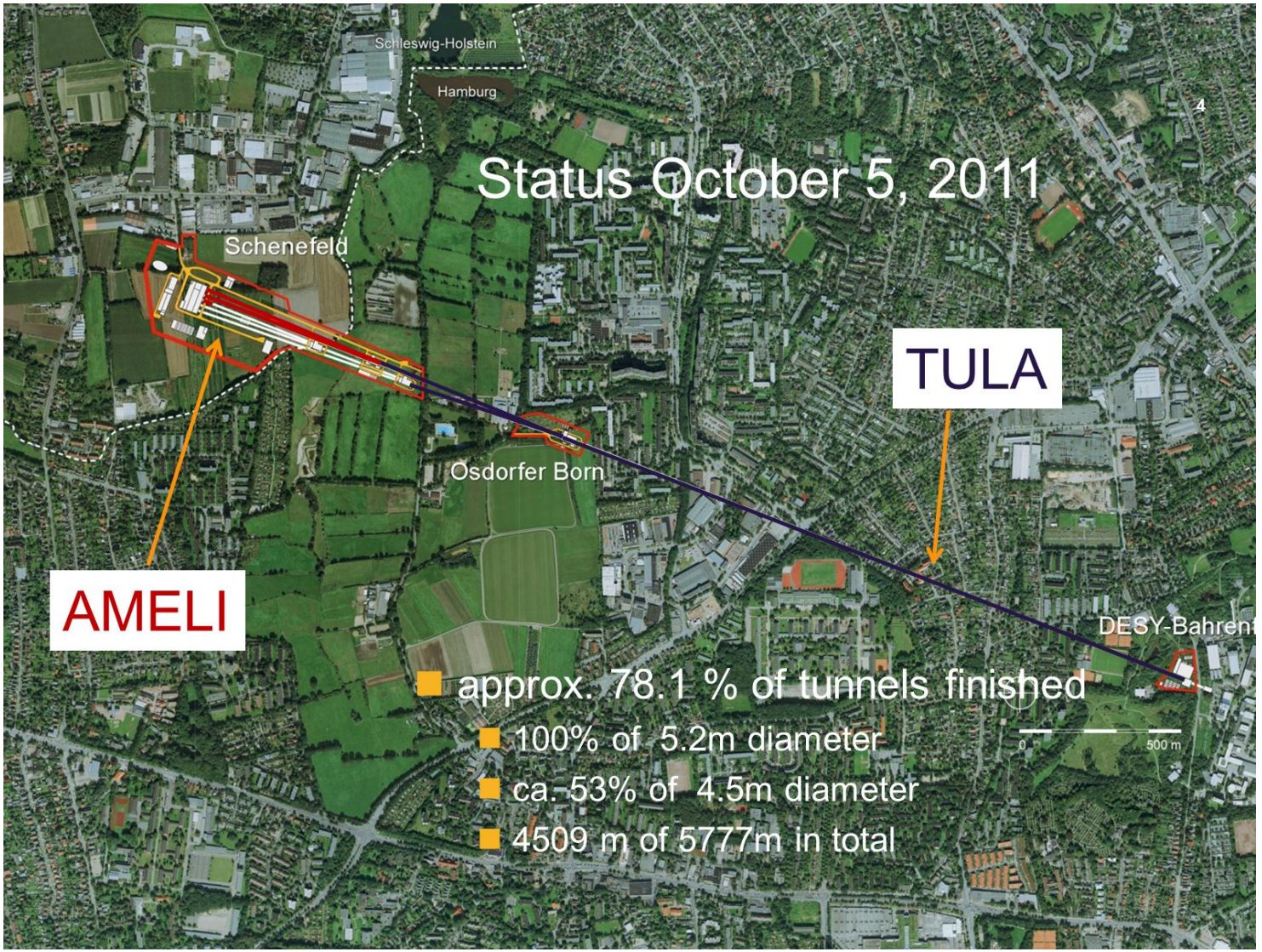
Scheduling

- Tremendous progress of construction, infrastructure planning and ramp up of accelerator component fabrication
- Working hard to finish installation in time for
  - start of injector commissioning mid 2014
  - start of linac commissioning mid 2015
  - observe first SASE by end of 2015



European XFEL

The European XFEL

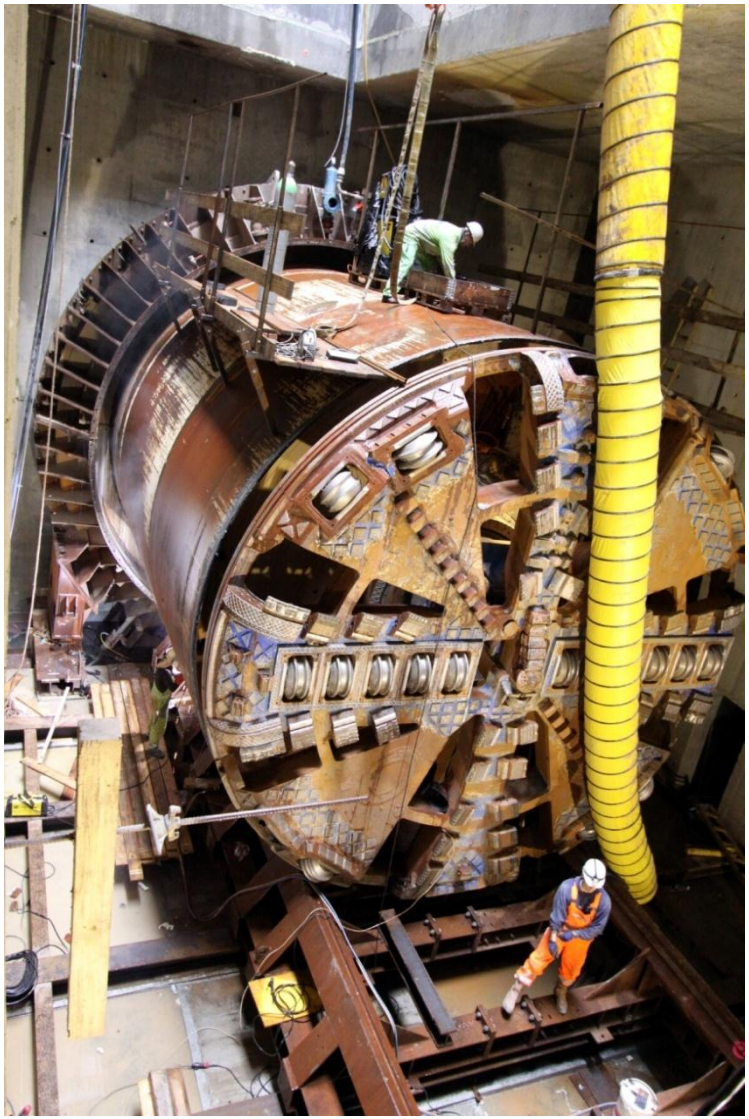


European XFEL

The Injector Building

European XFEL

Injector Building



European XFEL

Linac Tunnel: preparing the floor

European XFEL

… to Build a Large and Long Tunnel

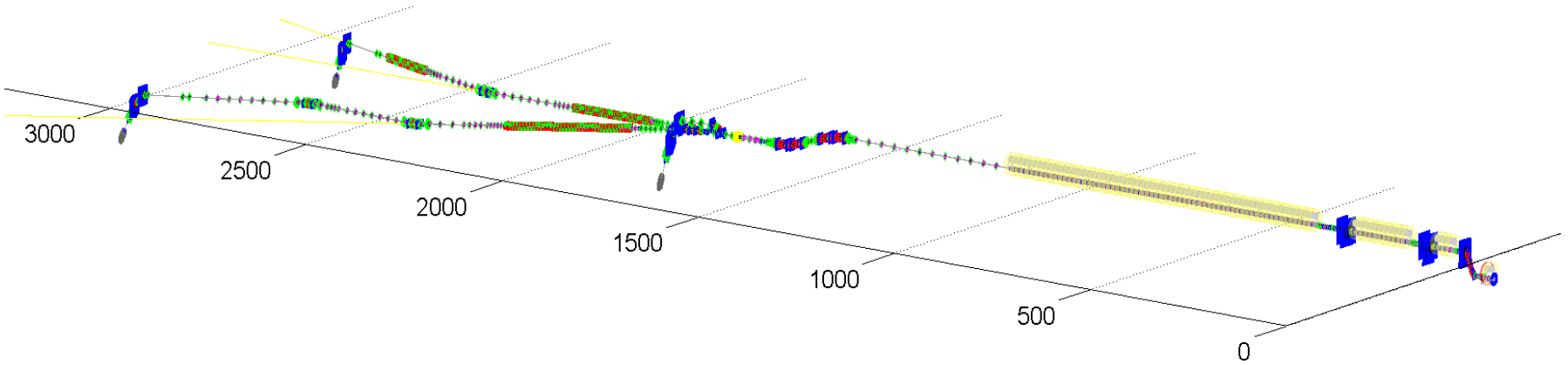

tunnel radio (temporarily)
welding line for heavy loads
fire-fighting water (temporarily)
halfen rails for cable trays etc.
electricity (temporarily)
electrical grounding
floor plates

European XFEL

Beam Distribution Shaft – XS1

European XFEL

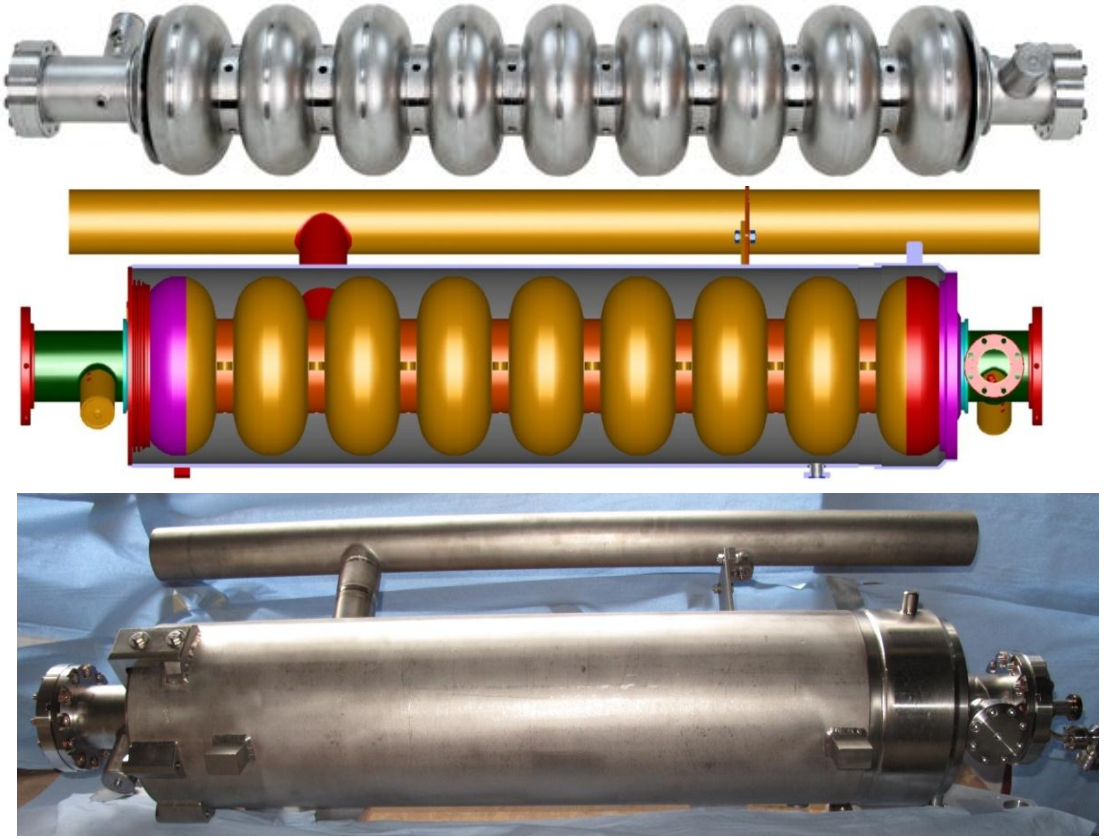
XFEL – New Parameter Set



	Baseline	New Parameter Set
Electron Energy	17.5 GeV	10.5/14/17.5 GeV
Bunch charge	1 nC	0.02 - 1 nC
Peak current	5 kA	5 kA
Slice emittance	< 1.4 mm mrad	0.4 - 1.0 mm mrad
Slice energy spread	1.5 MeV	4 - 2 MeV
Shortest SASE wavelength	0.1 nm	0.05 nm
Pulse repetition rate	10 Hz	10 Hz
Bunches per pulse	3000	2700

European XFEL

Cavities - Large Series Production

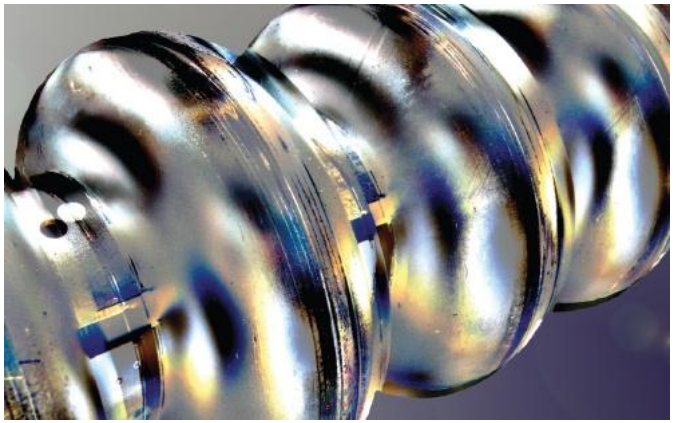


- Worldwide approx. 300 9-cell cavities were produced over the last 15 years.
- **The European XFEL requires 800 cavities at a production rate of up to 8 cavities per week and 1 module per week.**
- Acceptance testing is a challenge by itself and requires a large infrastructure.

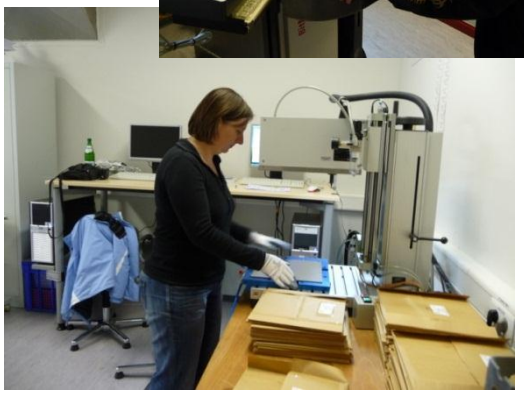
European XFEL

Niobium / Cavities

Eddy current scanning of XFEL niobium sheets at DESY



Equipment for tactile 3D dimension measurement

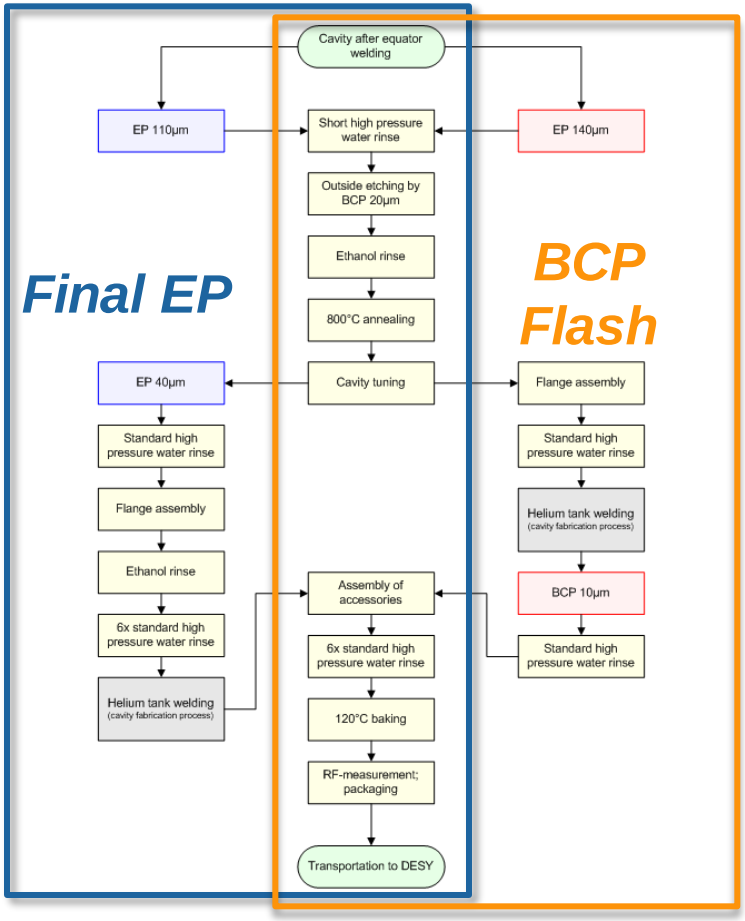


Equipment for sheets marking

- More than 6,000 niobium sheets arrived, the next 2,000 to come soon.
- In average 40% of all niobium incl. tubes etc. delivered to cavities vendors (status 3/2012).
- Material for remaining 160 cavities contracted.
- Reference cavities from both companies arrived and currently tested.
- Commissioning of infrastructure at cavity vendors is next.
- First cavities expected for summer 2012.

Cavities – Preparation & Reference Cavities

- **Two schemes** for the final surface treatment:
  - **Final EP at Research Instr.**
  - **BCP Flash at Zanon Inc.**



- **At each company**
- 4 dedicated Cav's for set-up of infrastructure
- 4 dedicated Cav's for qualification of infrastructure
- **Close supervision of**
- **infrastructure set-up, processes, procedures and handling**
- by DESY + INFN Milano
- **Specification w/o performance guarantee, thus:**
  - the risk of unexpected low gradient or field emission is with DESY
  - responsibility for re-treatment at DESY

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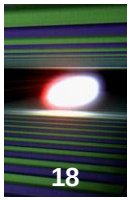
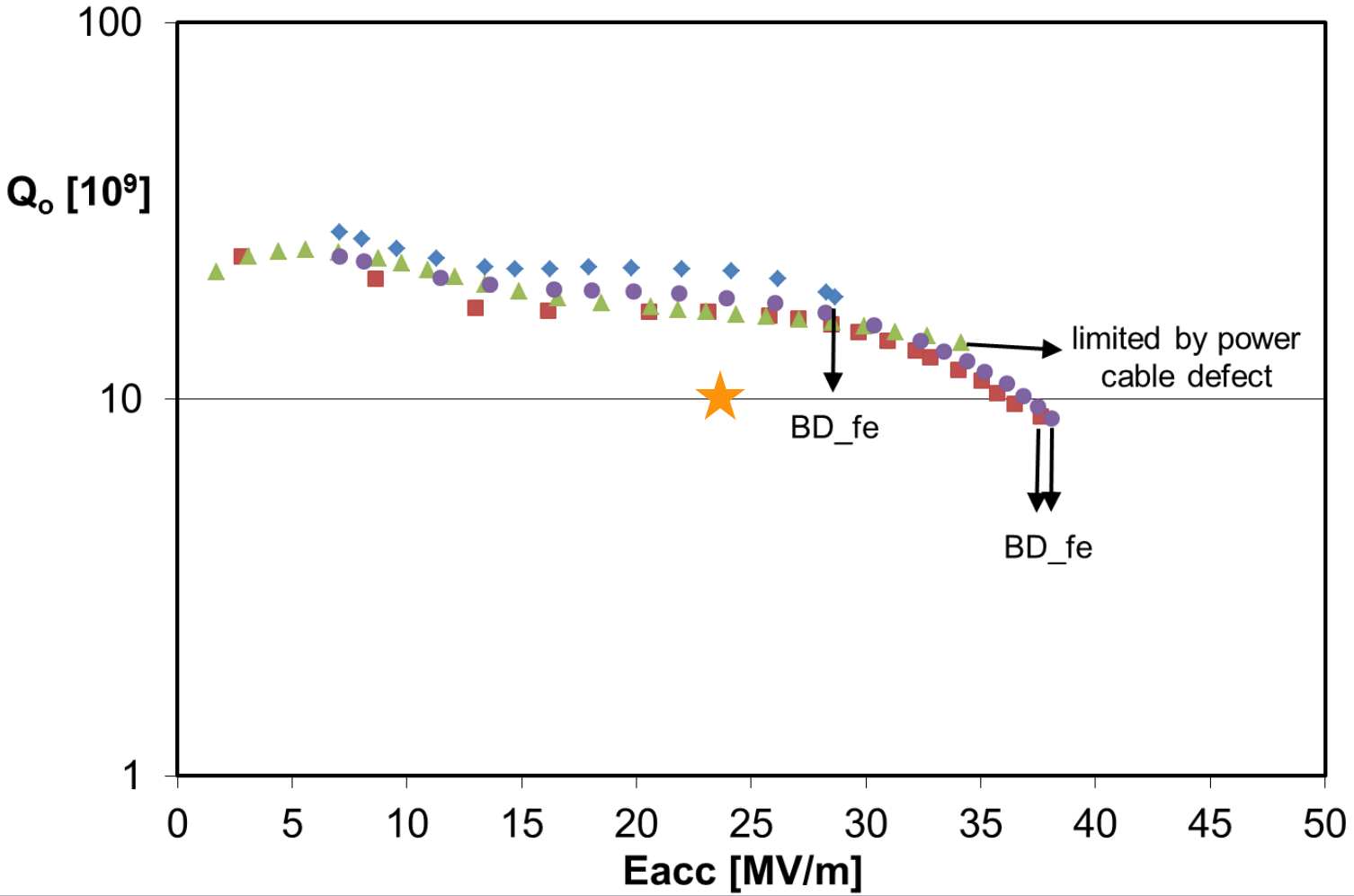
Status of Reference Cavities: Research Instr.

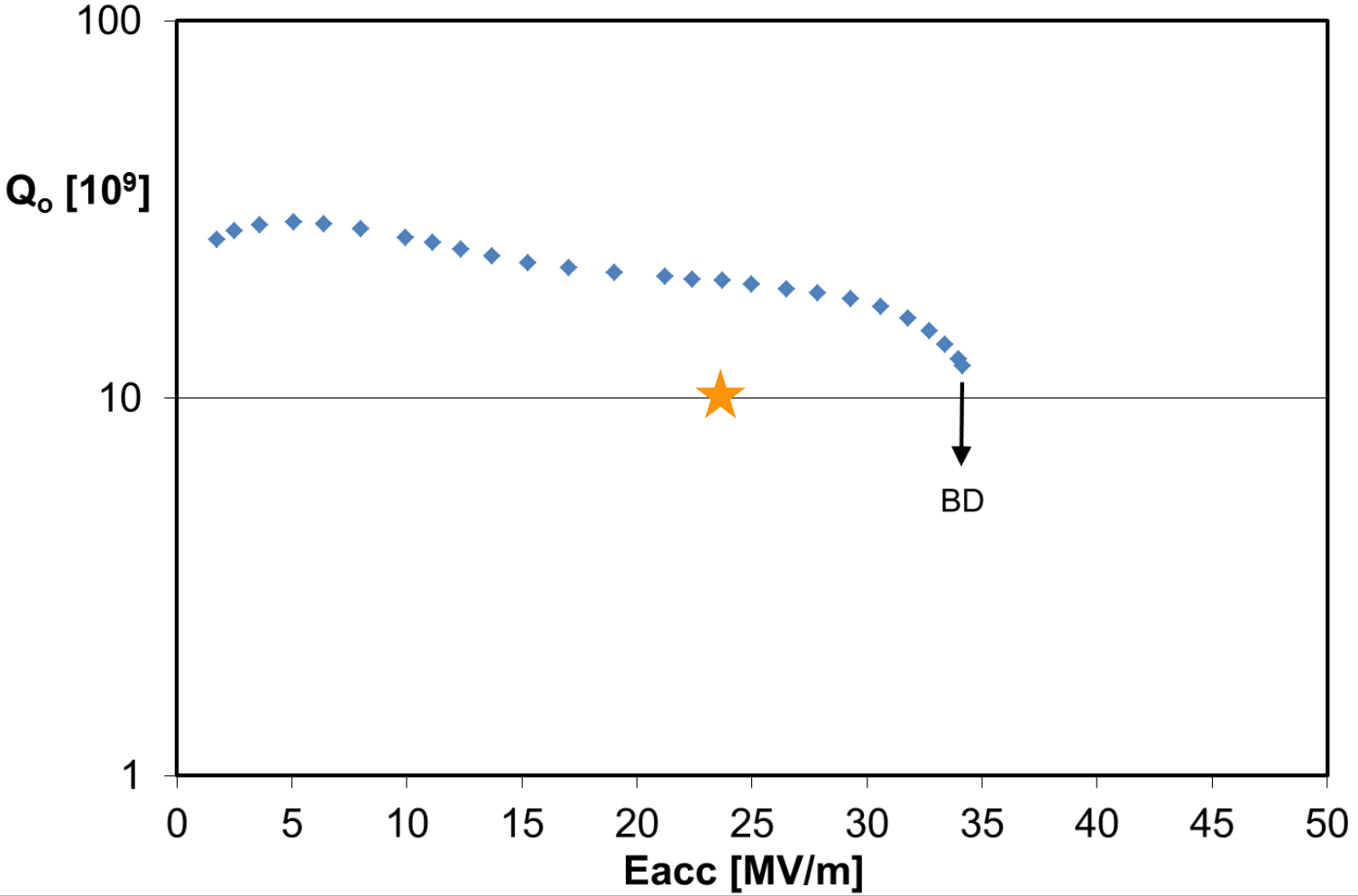


- **Acceptance test done with all four RI reference cavities E_{acc} > 28 MV/m!**



Status of Reference Cavities: EZ

- First cavity vertical acceptance test successful
- Three cavities ready for vertical acceptance test



European XFEL

Zanon Infrastructure

European XFEL

RI Infrastructure

European XFEL

Cold Mass and Vacuum Vessel

- 58 plus 25 cryostats and vacuum vessels ordered; fabrication on-going; sub-components ready for assembly.
- Production schedule uncritical. First units will arrive very soon (5/2012); storage at DESY and CEA foreseen.
- Remaining 20 cryostats: Call for tender (by DESY) prepared.

E. ZANON SINCE 1919

Institute of High Energy Physics
Chinese Academy of Sciences

INFN DESY HELMHOLTZ ASSOCIATION

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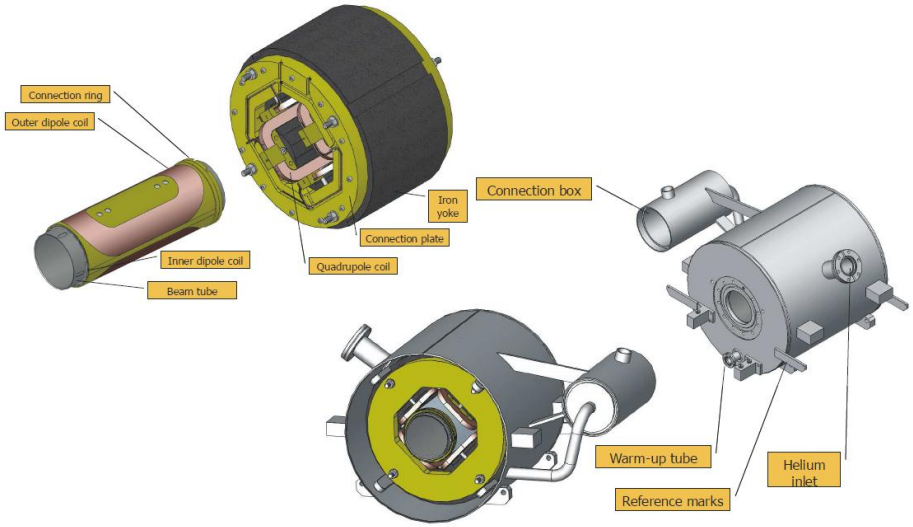
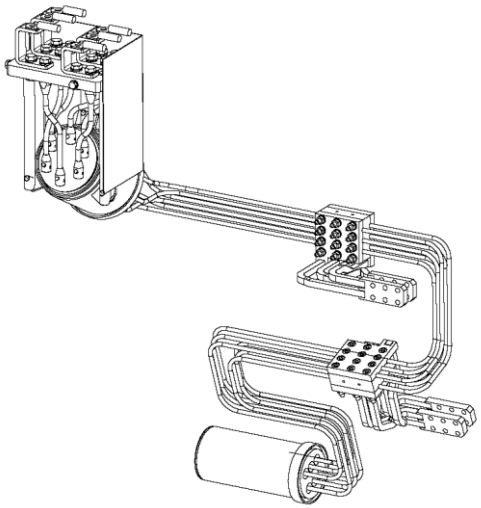
Cold Magnets and Current Leads

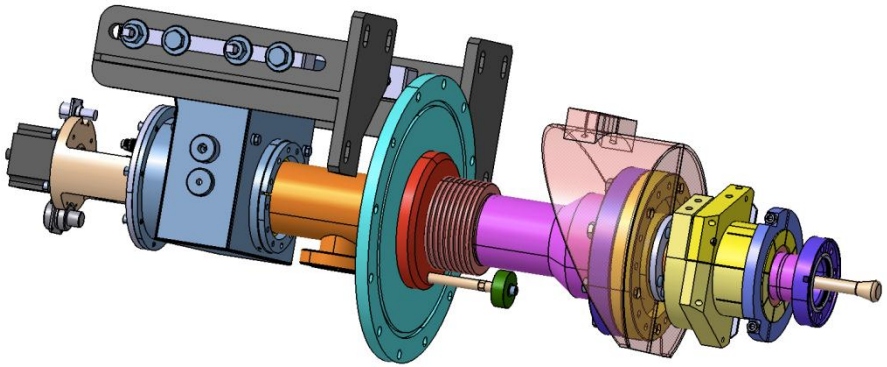




- **magnets itself** are a CIEMAT In-kind contribution; recent challenge: TUEV qualification of the vendor (ISO 3834-2)
- DESY supports activities and takes care of **beam tube copper plating** and **current leads**; both contracts were placed, series production to be started soon
- **quad testing** at DESY under preparation, i.e. expert team from IFJ established
- software for both DAQ and database to be finalized
- overall **schedule for first magnets** looks quite challenging!

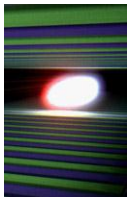
European XFEL

RF Power Coupler

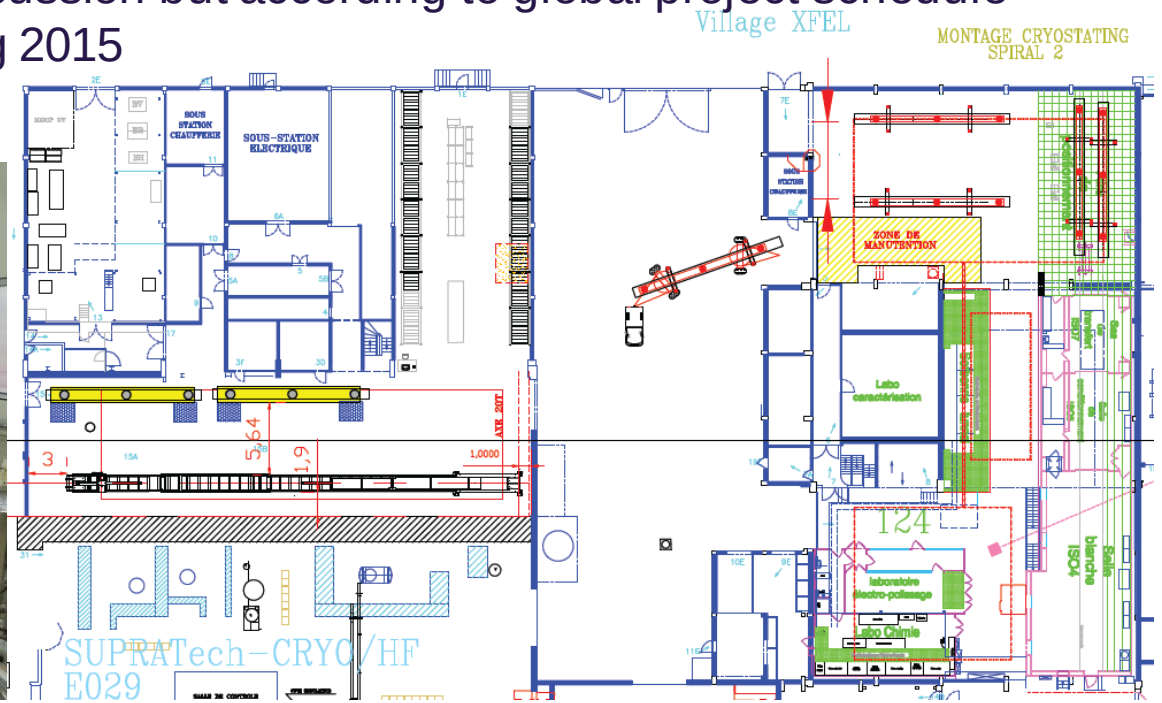


- The coupler production schedule became a real challenge and assumes that any further mistakes are to be avoided. Brazing and copper plating processes are challenging!
- **The start of the series production is still to be very critically addressed!!!**
- The pre-series modules get some extra attention by LAL & DESY.
- DESY has ordered 32 additional couplers in order to support the ramp-up and to make couplers available for the first modules.
- Coupler conditioning requires thorough preparation.
- DESY is responsible for the coupler interlock. Electronic board development is almost finished. Production is next.

Saclay Infrastructure for String and Module Assembly

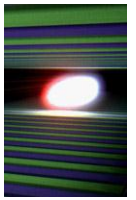


- Publicity and call for candidatures last summer
- Restricted CFT based on cryomodule assembly specifications
- Selection of industrial contractor finished; contracts to be placed now
- Pre-series assembly of three modules in 2012
- First series assembly scheduled for end of 2012
- Exact start date still under discussion but according to global project schedule module #100 expected for spring 2015

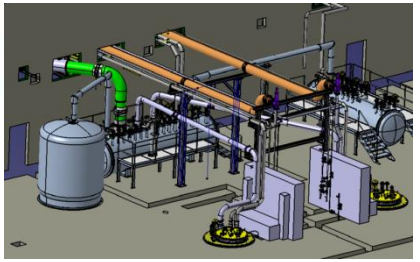


European XFEL

AMTF Test Stand Infrastructure



- Impressive AMTF infrastructure exists but some essentials still missing (e.g. vert. cryostats)
- schedule remains challenging until last minute
- schedule becomes only
- viable due to slightly
- delayed cavity delivery
- start module tests ok



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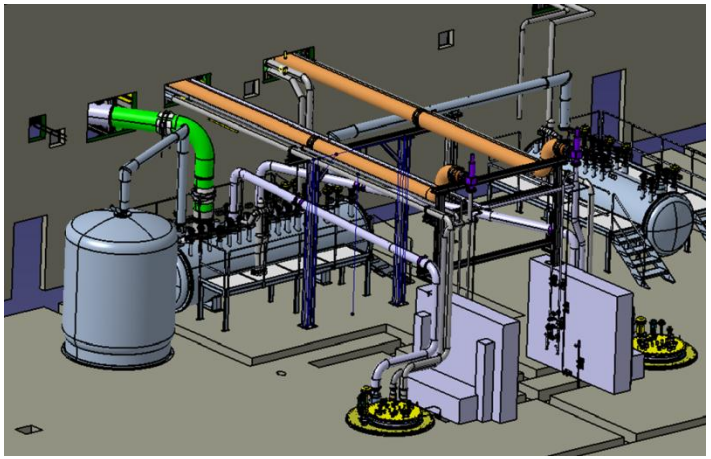
Cold Linac Infrastructure

- Refurbishment of HERA cryo plant started
- Challenging schedule because of early operation start in 2014 to operate the XFEL injector

- Planning, production and installation of cryogenic equipment for accelerator an AMTF continued



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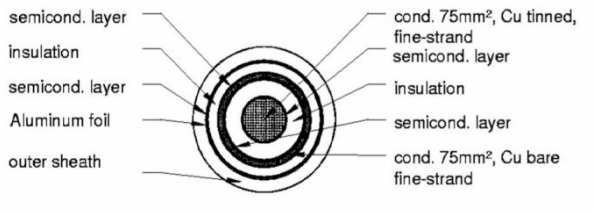
High power RF System

- Contracts for klystrons, modulators, pulse cables awarded
- Pulse transformers to be awarded Q1/2012

- Pulsed cables



- Modulator hall erected

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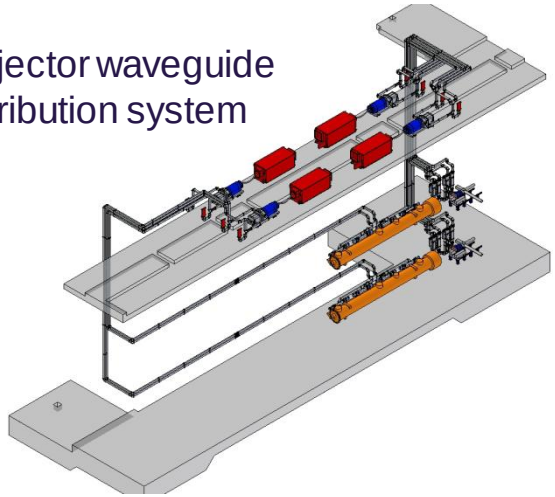
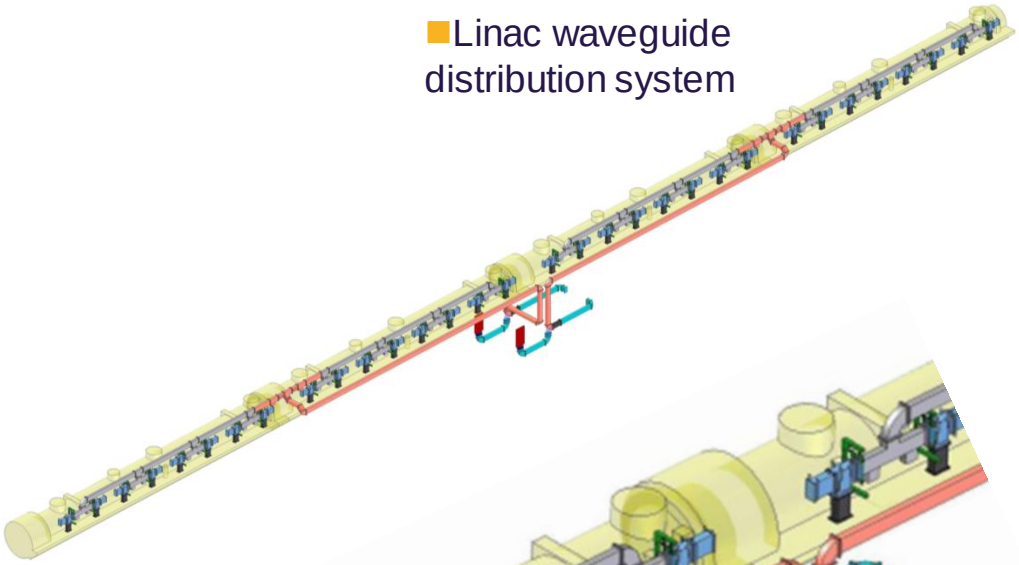
Waveguide distribution

- Injector waveguide distribution system



- Linac waveguide distribution system

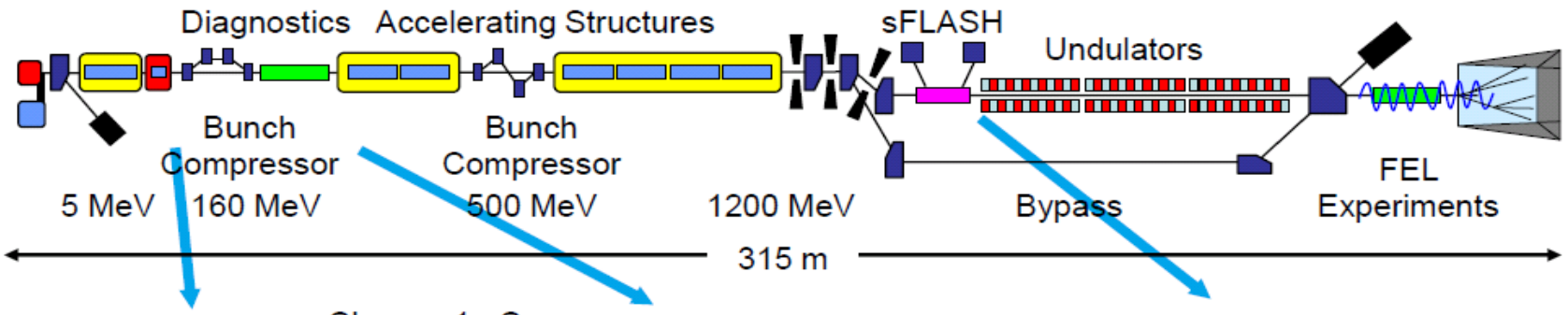


- specifications for waveguide components ready
- tendering will start soon
- large number of different types of waveguides
- interfaces and potential interferences to be further discussed

European XFEL

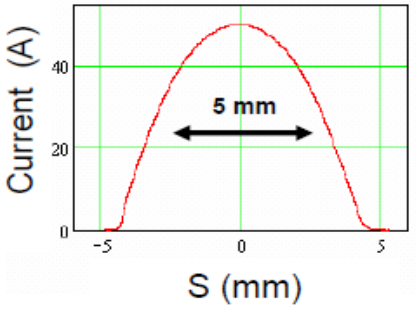
Longitudinal beam dynamics critical

Bunch compression 50A-2.5kA: stringent demands on LLRF

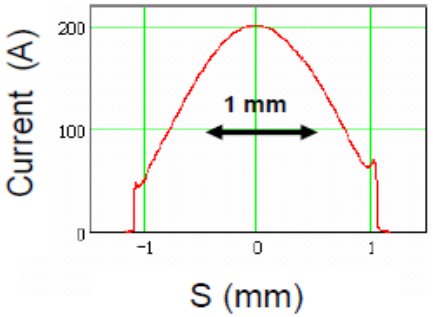


Charge: 1 nC

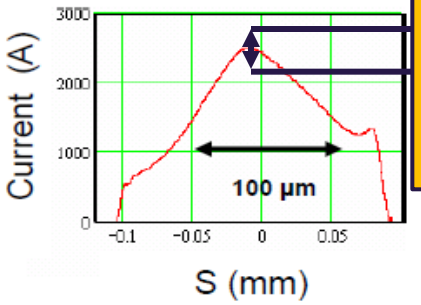
50 A



200 A



2.4 kA



Peak current & shape Mainly ϕ

Timing jitter BC2

Voltage | Phase | Incoming

$$\Sigma_{t,f}^2 = \left(\frac{R_{56}}{c_0}\right)^2 \cdot \frac{\sigma_{V_1}^2}{V_1^2} + \left(\frac{C-1}{C}\right)^2 \cdot \frac{\sigma_{\phi_1}^2}{\omega_{rf}^2} + \left(\frac{1}{C}\right)^2 \cdot \Sigma_{t,i}^2$$

FLASH: 7.0ps/%
XFEL: 3.3 ps/%

2 ps/deg
L-band

0.05 ps/ps
C=20

Requirements:

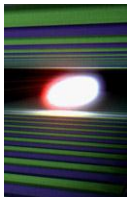
dV/V<10^{-4}…10^{-5}

dϕ < 0.01°

Scale ~ 1/C

European XFEL

Parameter overview LLRF system



	nominal	Min/max
# of RF channels	~ 3000	NA
# of LLRF stations 1.3 GHz SRF	25	NA
# of LLRF stations 3.9 GHz SRF	1	NA
# of LLRF stations 1.3 GHz NRF (RF Gun)	1	NA
Field amplitude stability dA/A	1e-4	3e-5/2e-4
Field phase stability	0.01deg	0.003deg/ 0.05deg
# of piezo driver/sensors	800/800	NA
# MTCA crates	52	NA
# RF channels per station (32 cavities)	118	NA

Precision fully automated system with high flexibility:

- varying beam load: beam current, bunch spacing, bunch pattern
- varying macro-pulse to macro-pulse structure
- changes in gradient, phase, gradient slopes, phase slopes
- incorporate beam based signals (arrival time, compression, energy)
- very robust and reliable system with high availability (downtime < 1%)
- ultra-high precision for 20% of RF stations (<<0.01%, <<0.01deg)

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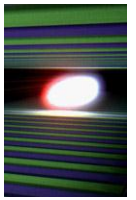
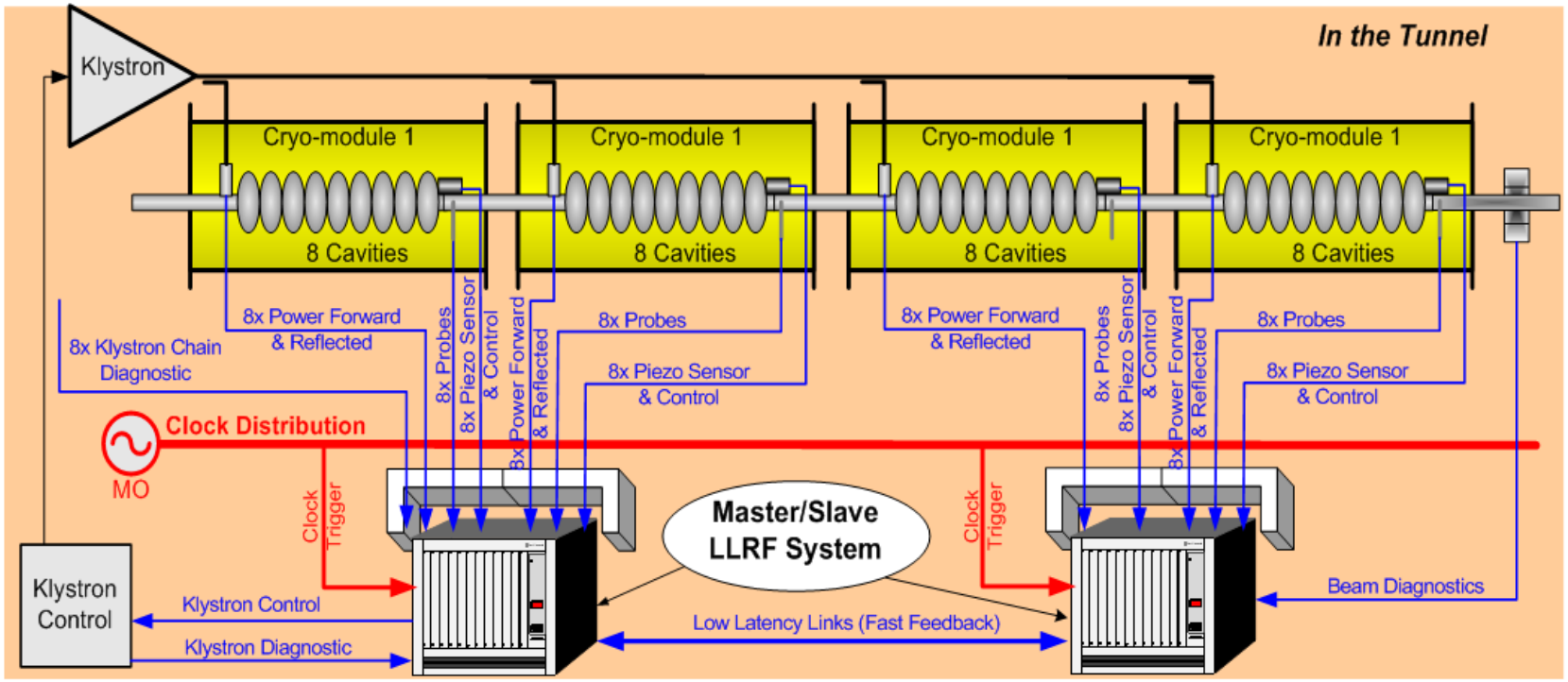
Consequences from FLASH operation



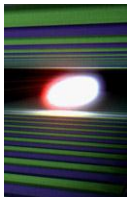
- 2 semi-distributed uTCA stations (25 RF stations)



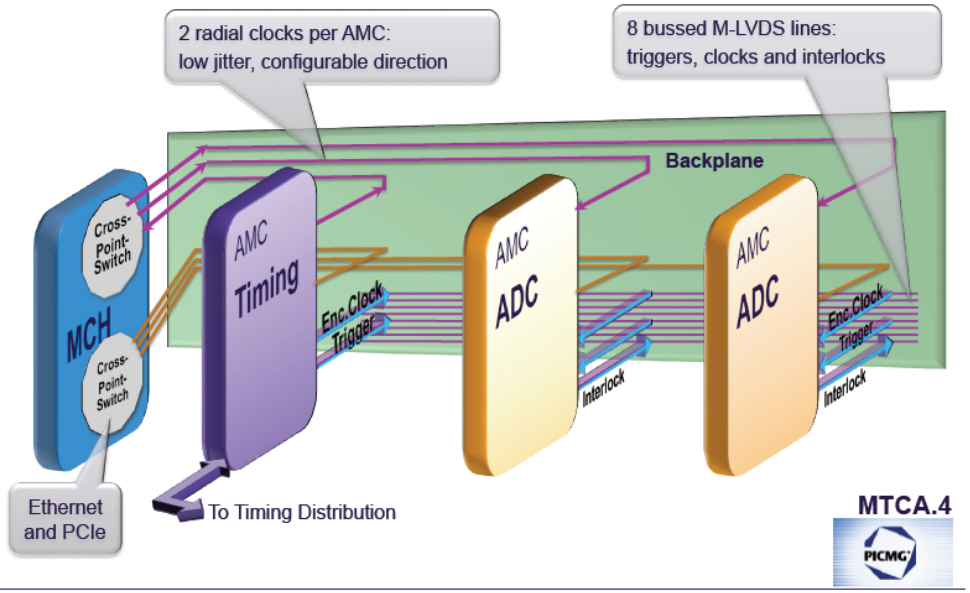
Driving Argument → Short pickup cables for low drifts (10fs/m/K) and prevent crosstalk from high power cables

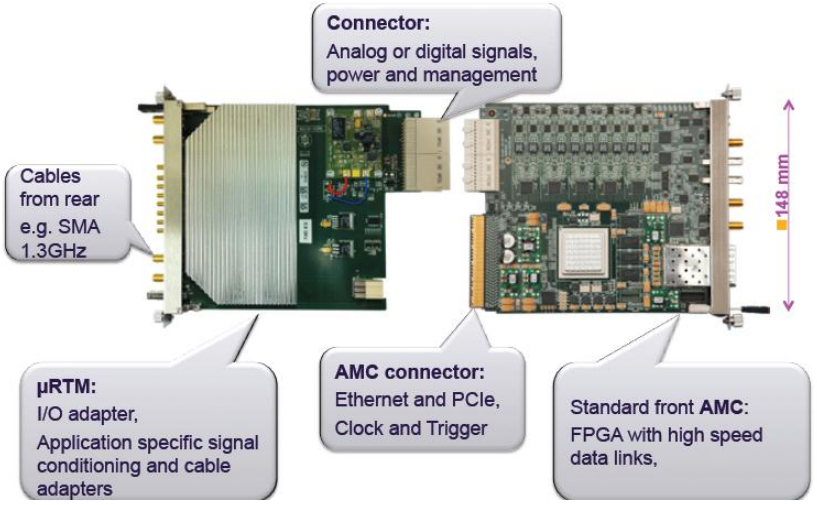
European XFEL

Electronic development based on MTCA.4



- Modular system with re-usage of developed board (reduce total numbers)
- Support timing, clock and interlock signals (within standard)
- Sophisticated Crate management system
- Recently released by PICMG = PCI Industrial Computer Manufacturers Group
- Serial link allows both high precision analog & high power digital processing
- Well received by industry …





See talks WP10.6 RFTech
-> K. Czuba & M. Grecki

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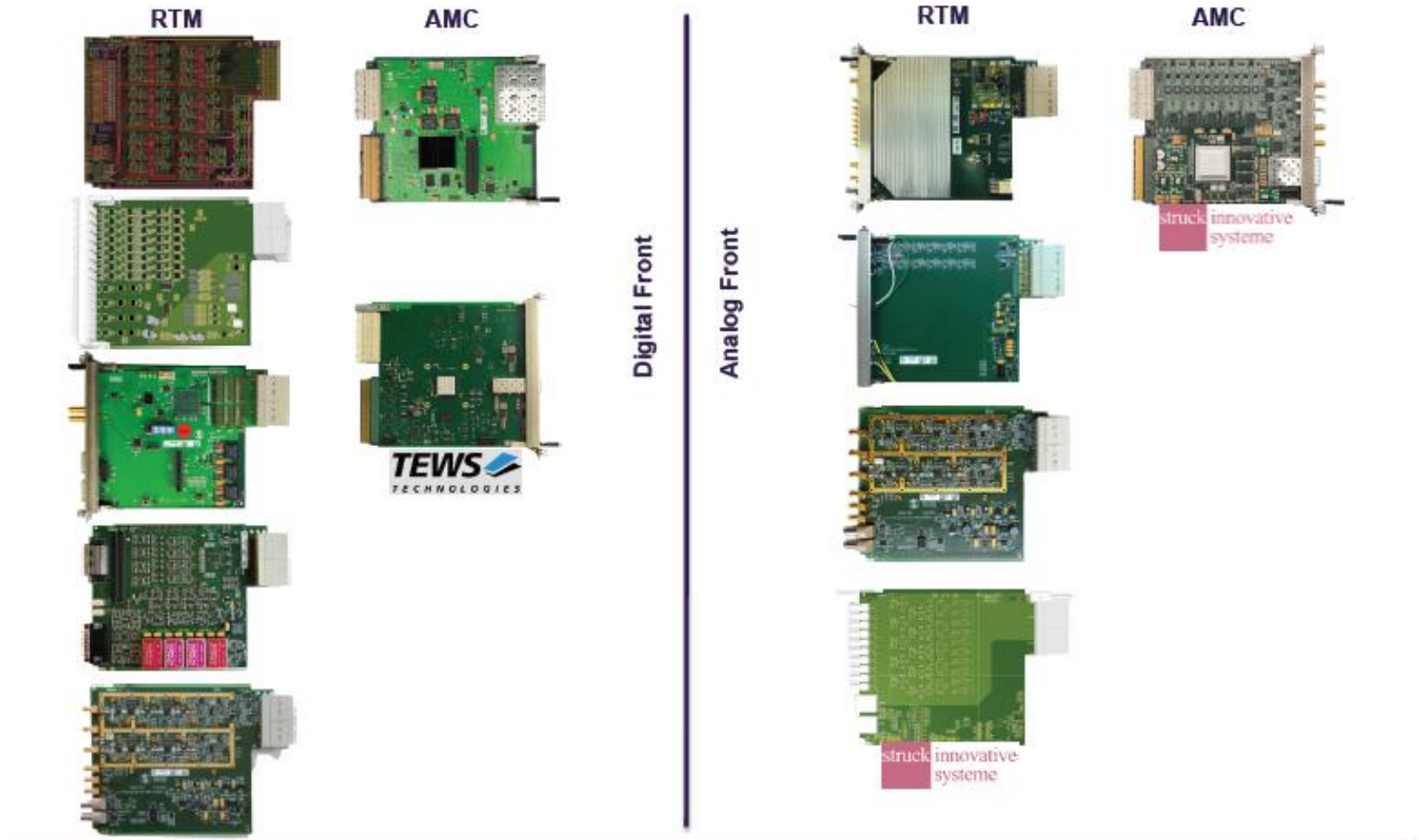
Electronic development based on MTCA.4



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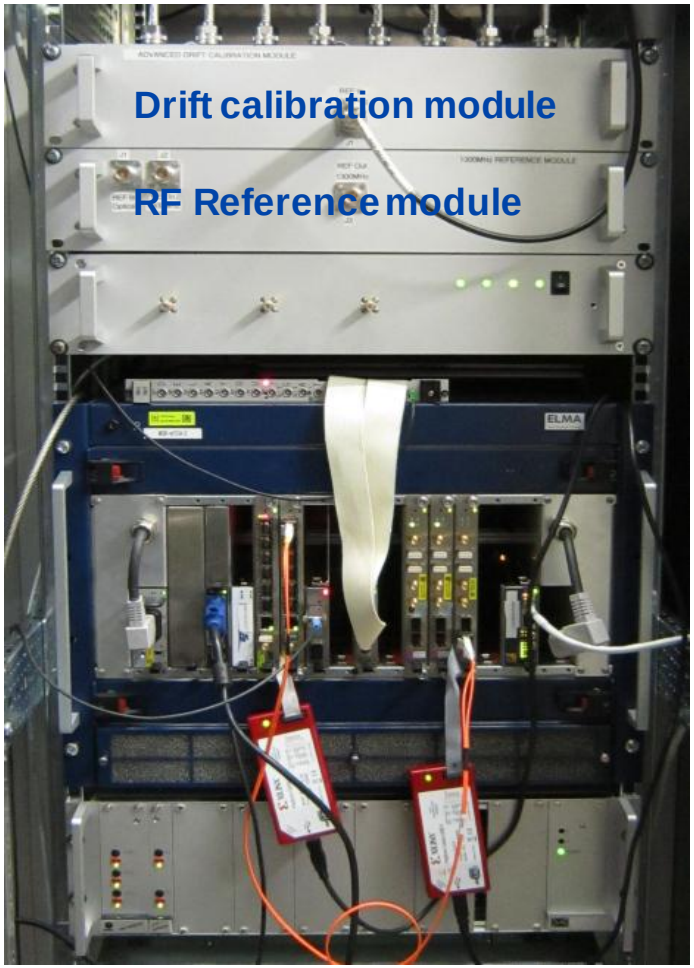
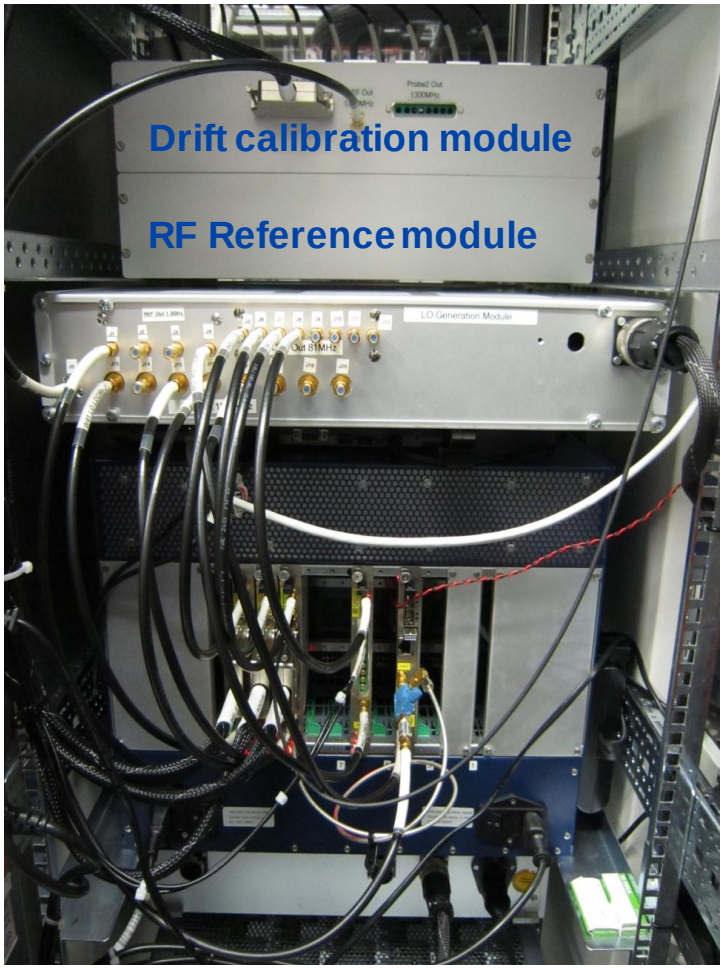
LLRF prototype test at FLASH

- uTCA Prototype Front view

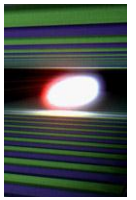


- uTCA Prototype Rear view

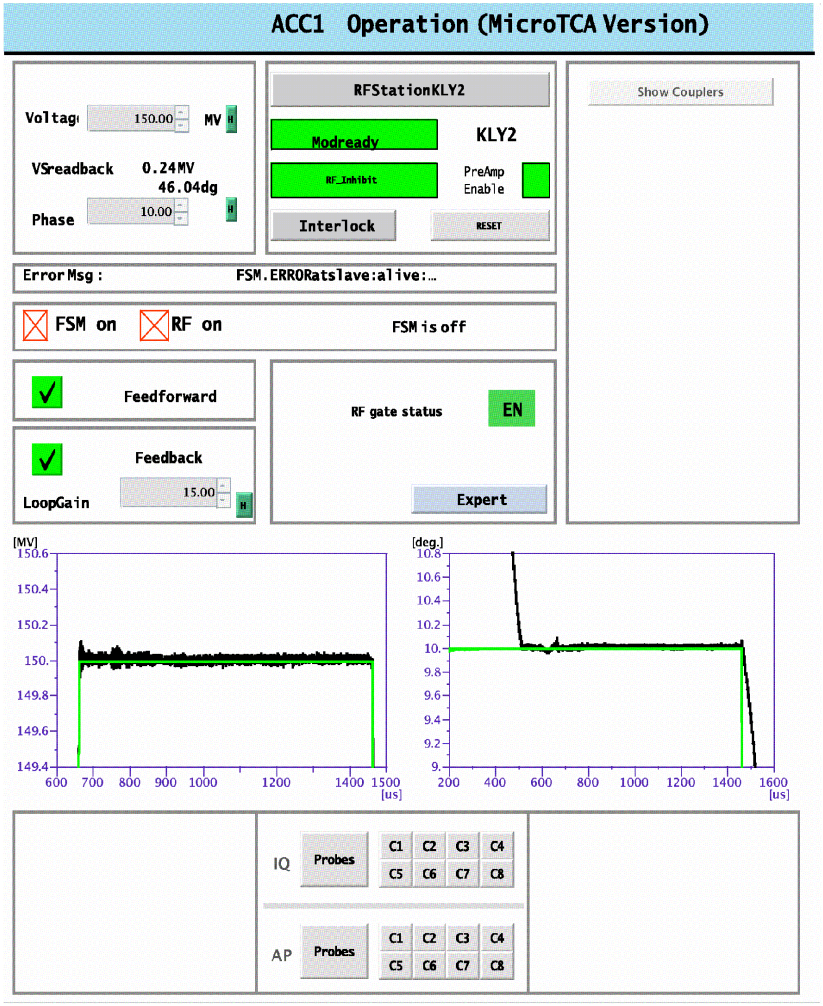


European XFEL

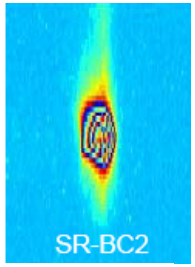
Beam operation using the uTCA-platform

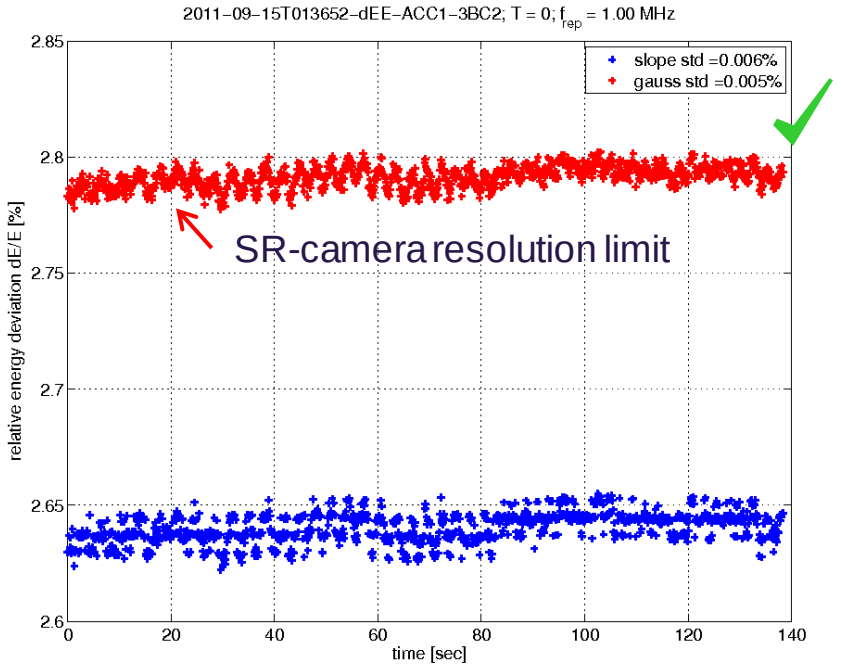


- FLASH operation :



- On-crest energy stability :



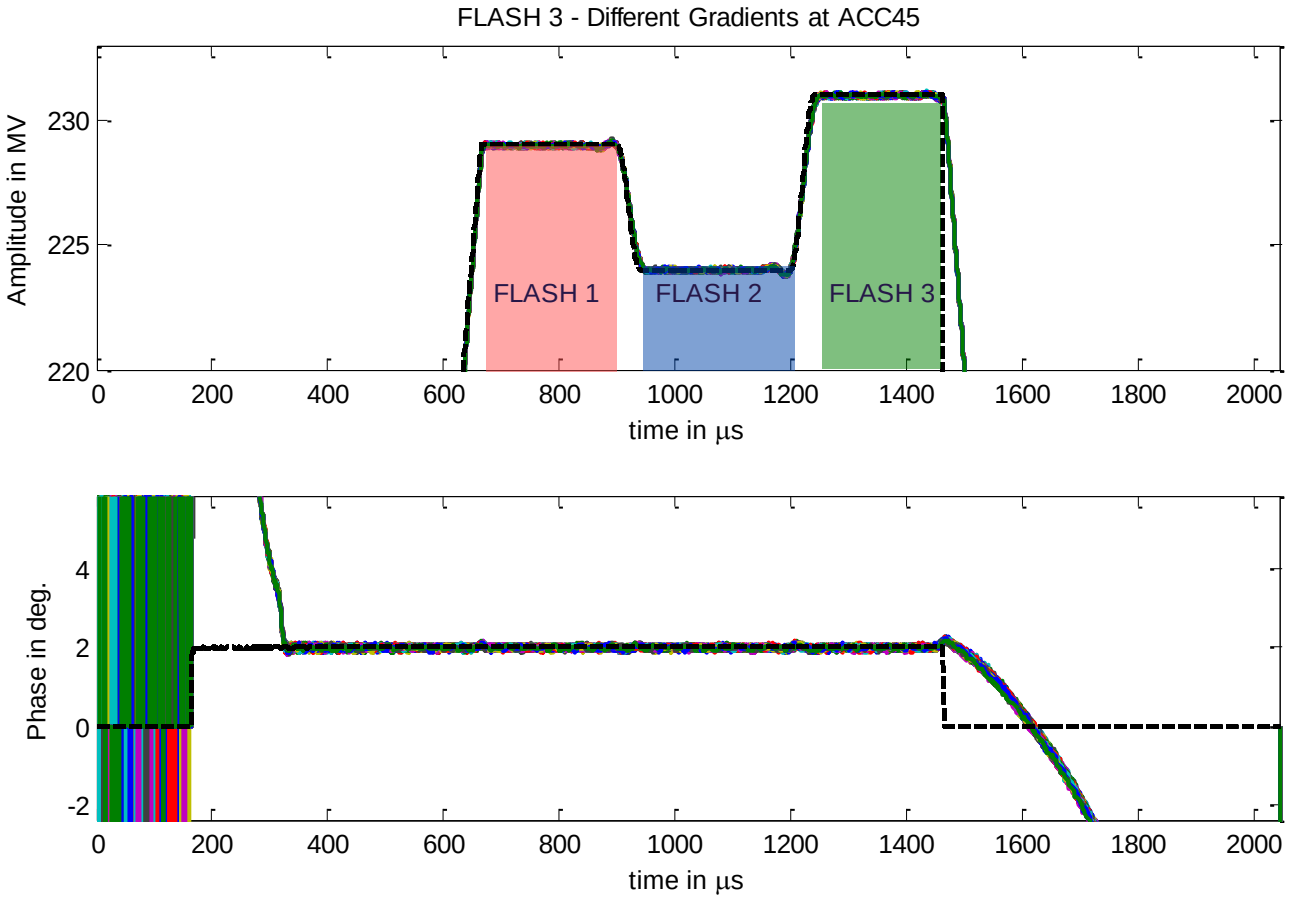


→ Energy stability dE/E=5E-5.

European XFEL

Multiple – gradient/phase operation

- Preparation of software for FLASH 1 & 2 & 3 operation!



- Used gradient steps -2% and + 3% with 40us transient time
- Setting up time < 10 sec

European XFEL

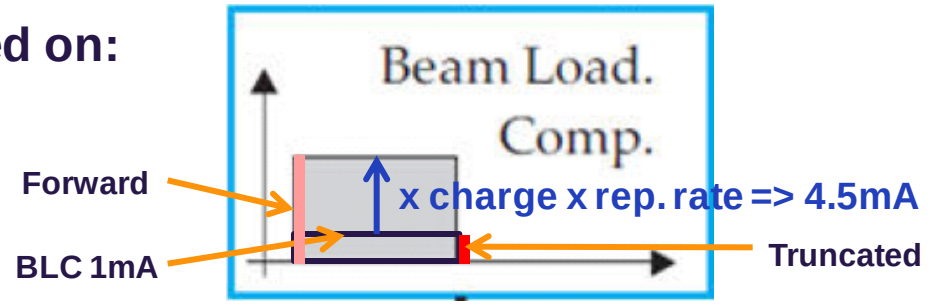
Large beam loading: LLRF test during 9mA run

ILC studies: 3 MHz, 1.5 nC = 4.5mA XFEL Parameters

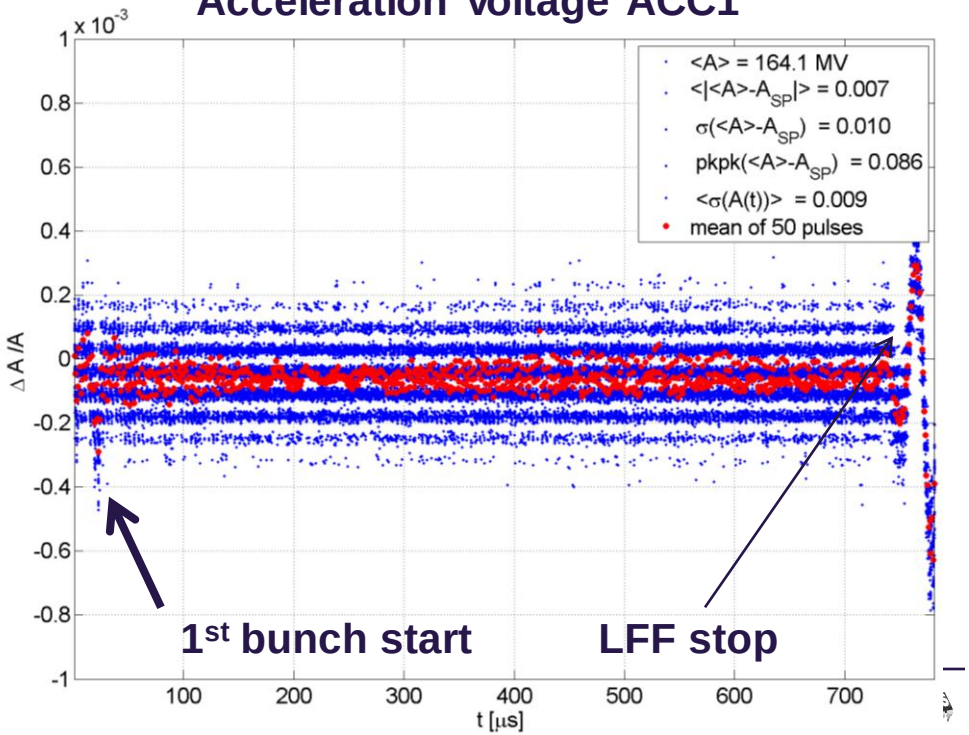
All field control applications are turned on:

LFF, MIMO FB, BLC

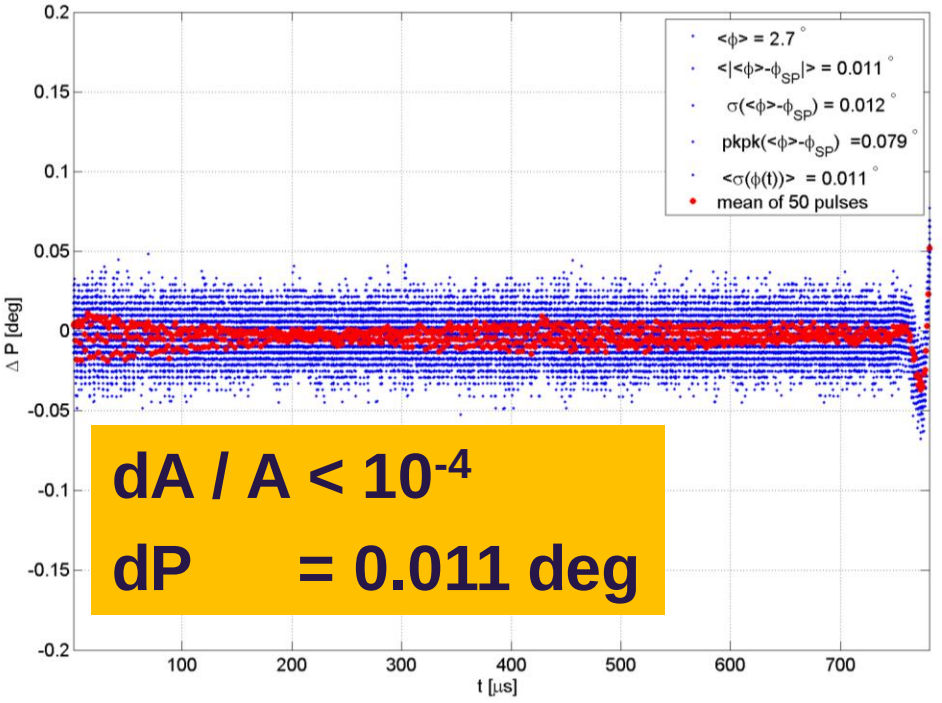
Remark: single bunch transient > 1e-4



Acceleration Voltage ACC1



Acceleration Phase ACC1

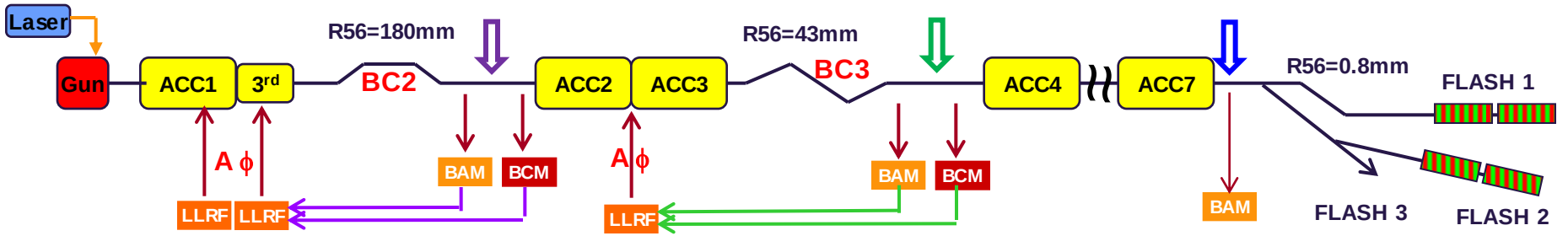


dA / A < 10^{-4}

dP = 0.011 deg

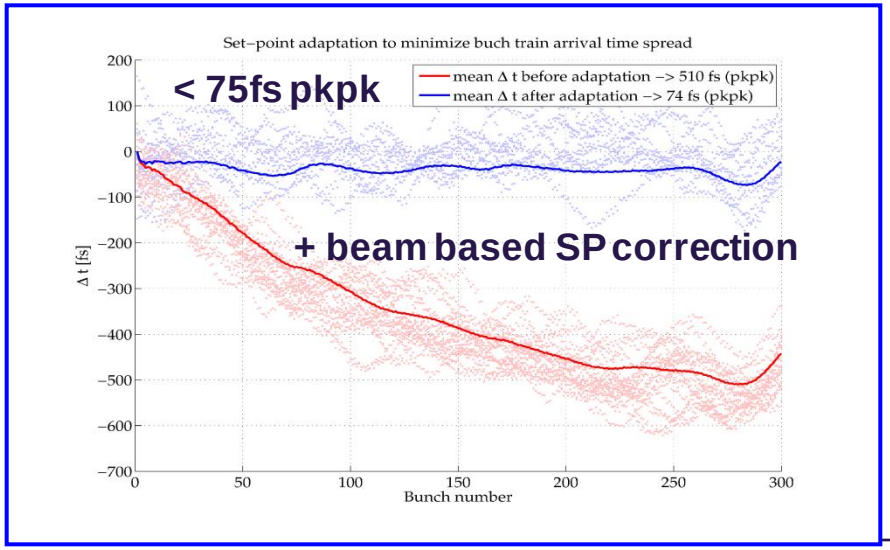
European XFEL

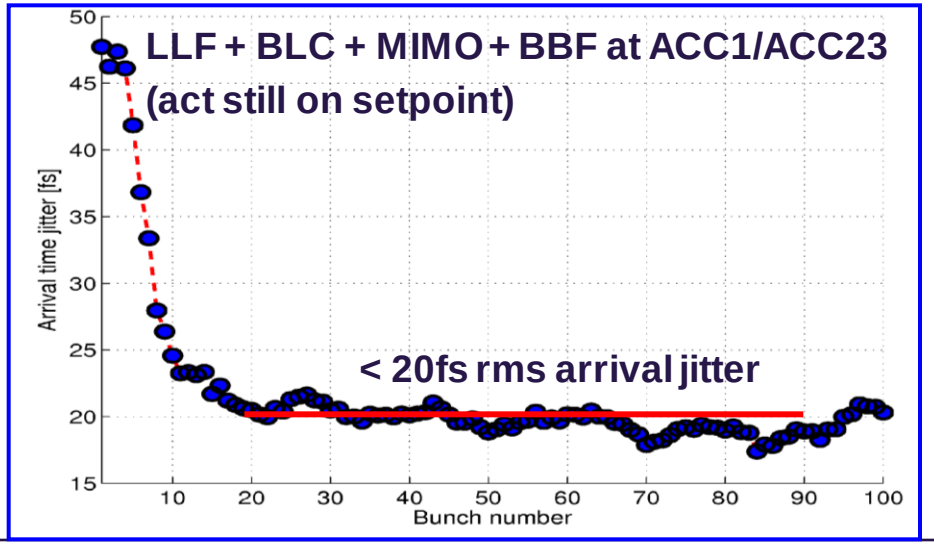
Beam based feedback



Beam Based Feedbacks:

- BAM and BCM after BC2 ⇒ amplitude and phase in ACC1 and ACC39
- BAM and BCM after BC3 ⇒ amplitude and phase in ACC23





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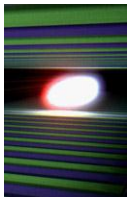
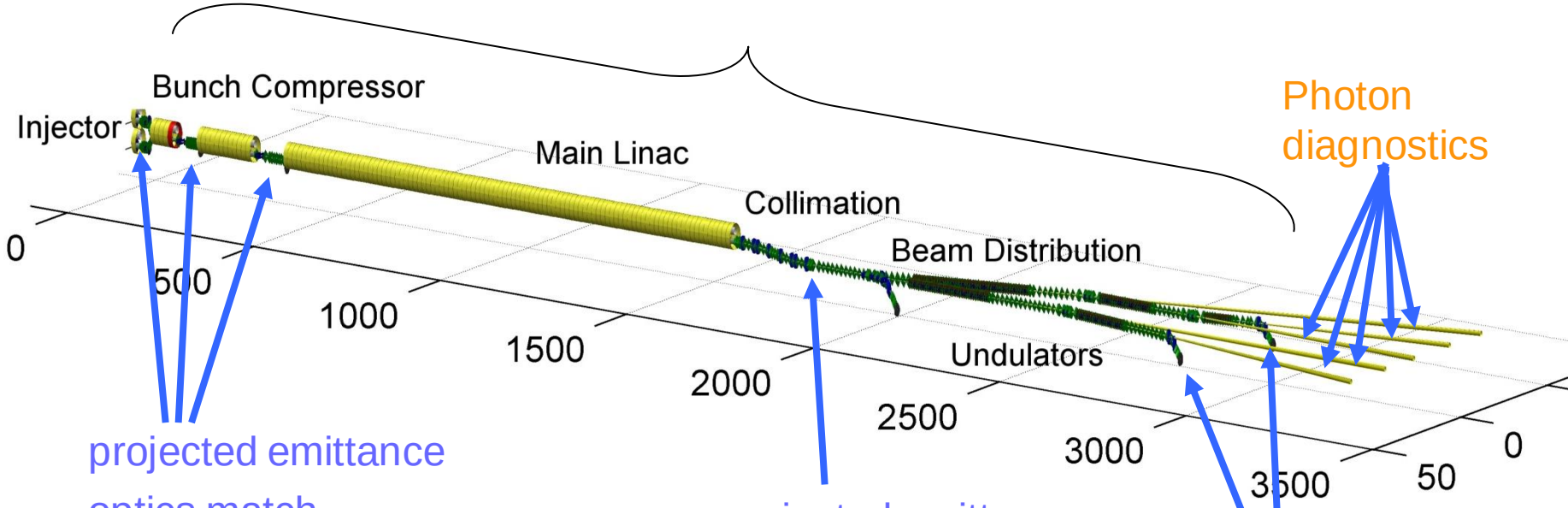
European XFEL

Beam Diagnostics



beam position, beam intensity, beam losses, dark current



projected emittance
optics match
energy
energy spread
rel. peak current
arrival time
slice emittance
long. bunch shape

projected emittance
optics match
energy
energy spread
rel. peak current
arrival time

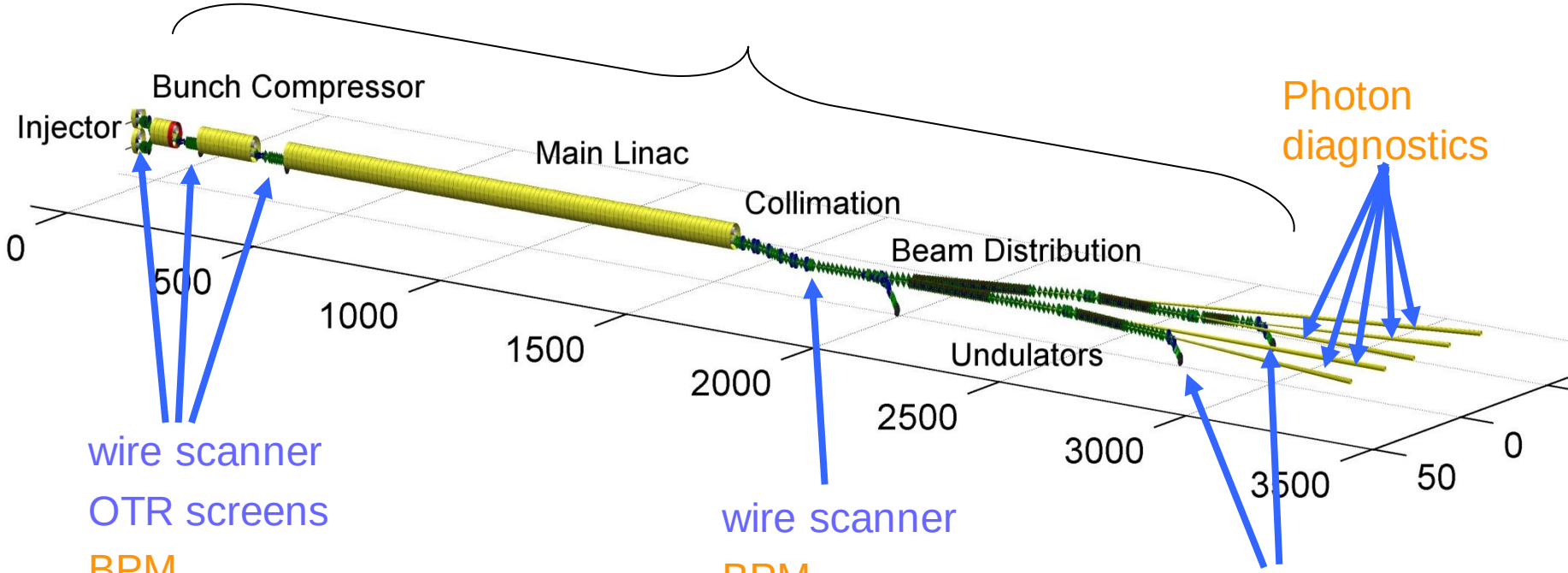
projected emittance

within bunch
within bunch train
from train to train

European XFEL

Beam Diagnostics

BPM, Toroids, Fibers, loss monitors, screens, dark current monitors



wire scanner
OTR screens
BPM
SR monitors
coherent diffraction radiation
transverse deflecting structure
electro-optical methods

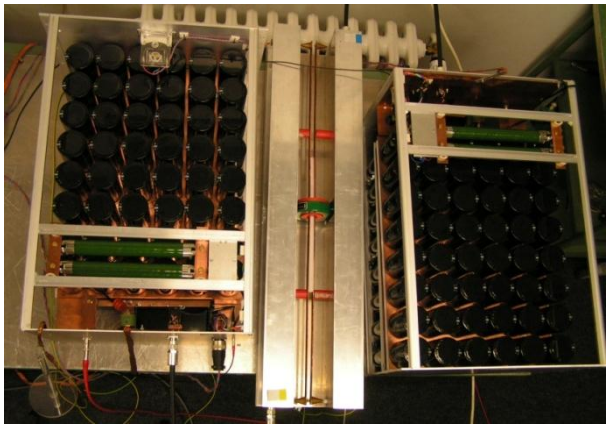
wire scanner
BPM
SR monitors
coherent diffraction radiation
electro-optical methods

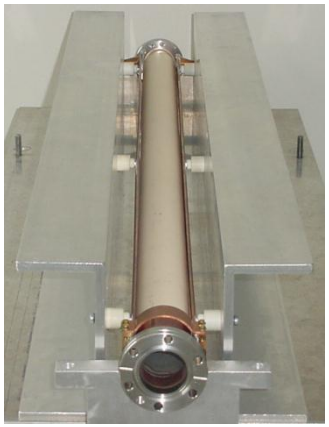
OTR screens

within bunch
within bunch train
from train to train

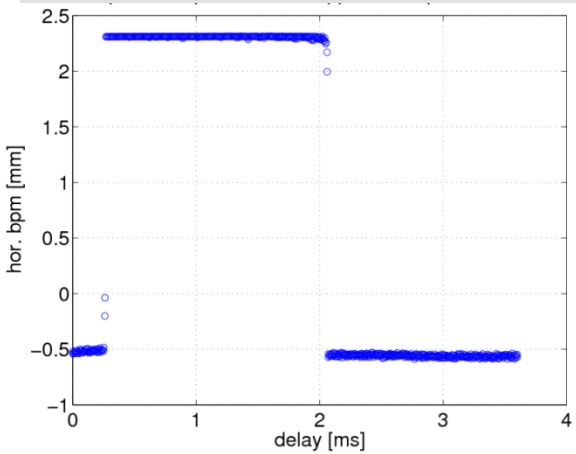
Beam Distribution

- Development of ultra-stable flat-top pulser
- Pre-Series production 2012

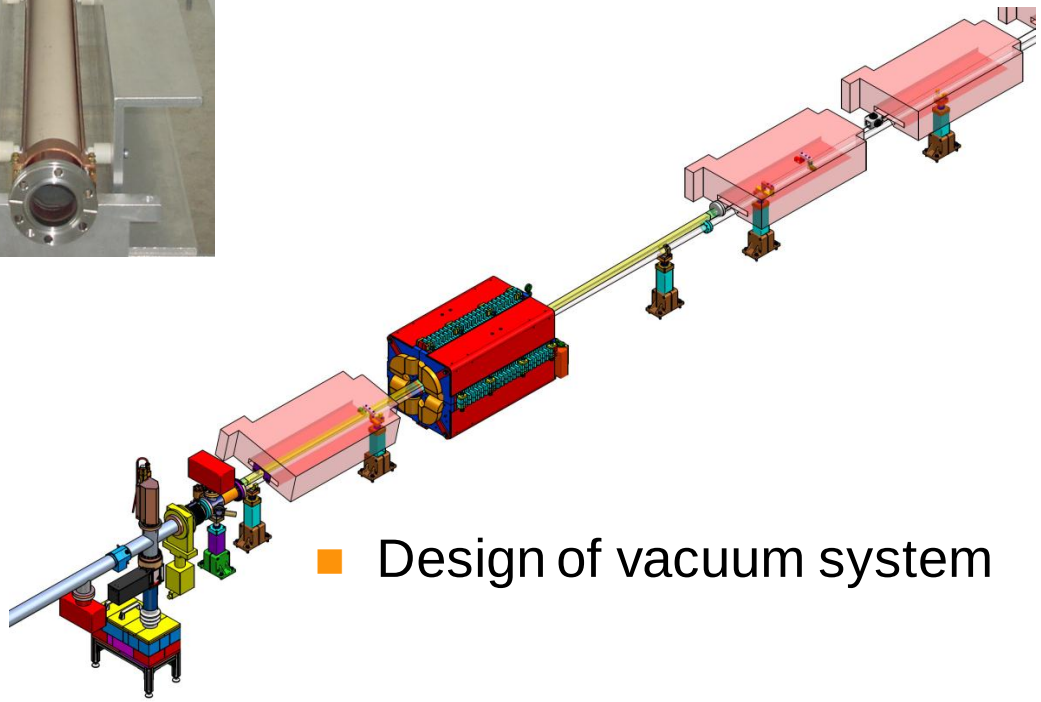




Stabiltity measurements at FLASH

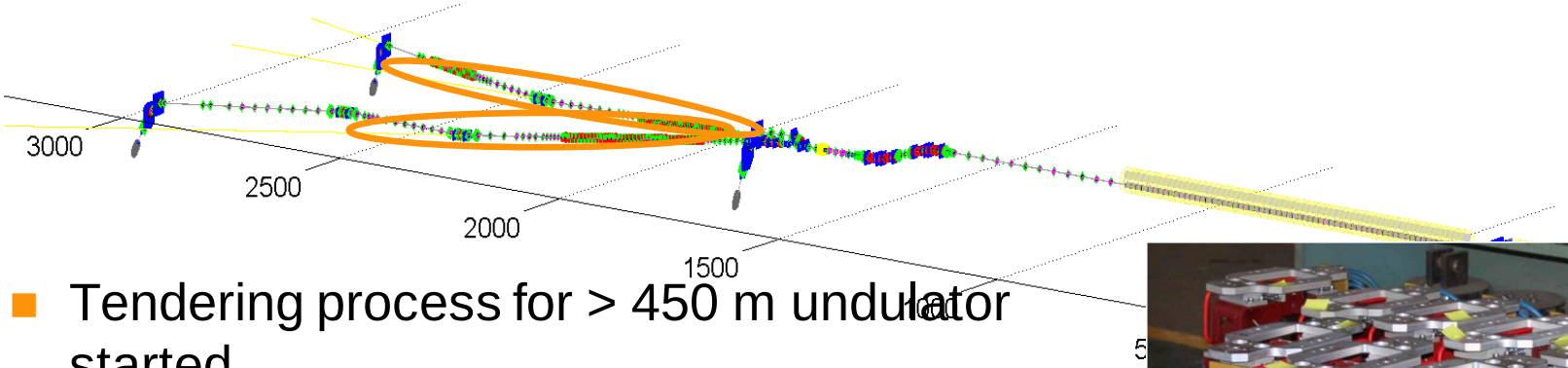


- Design of septum magnet

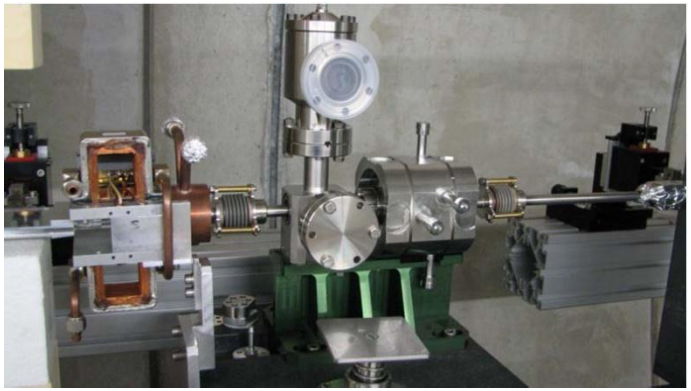


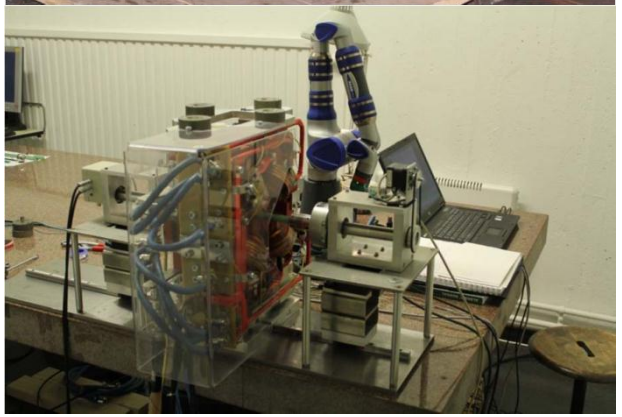
- Design of vacuum system

European XFEL – Undulators



- Tendering process for > 450 m undulator started
- Focusing quadrupoles manufactured and shipped for precision fiducialization
- Prototype of undulator intersection set-up in mock-up tunnel



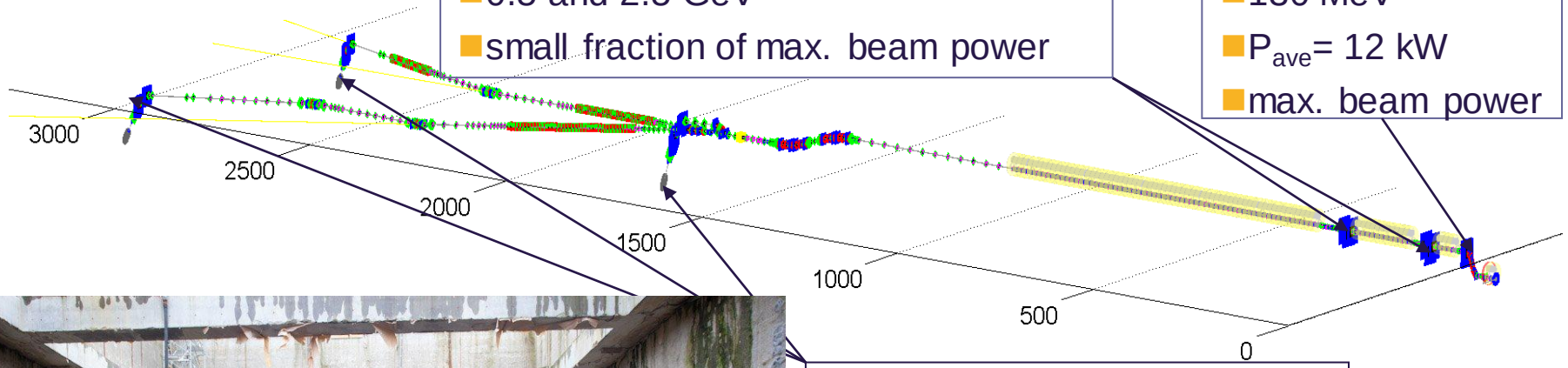


European XFEL

Beam Dumps

- bunch compressor diagnostic dumps
- 0.5 and 2.5 GeV
- small fraction of max. beam power

- injector dumps
- 130 MeV
- P_{ave}= 12 kW
- max. beam power

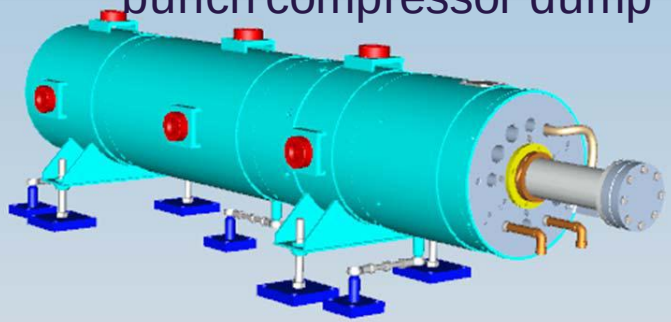


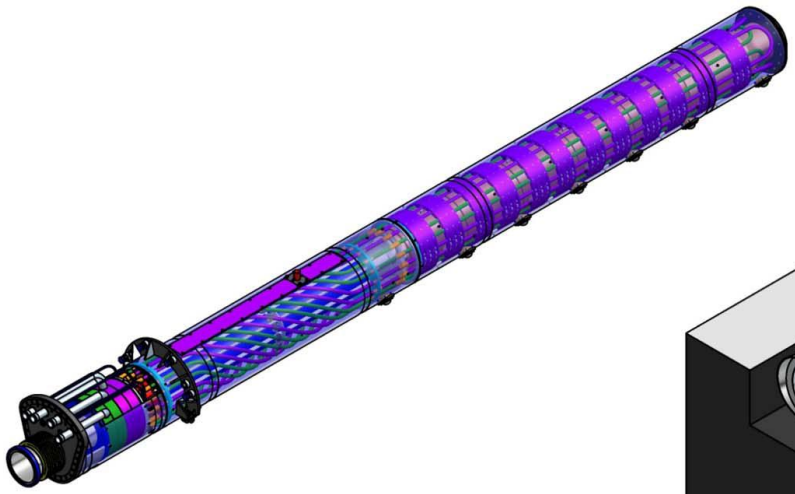
- main beam dumps
- up to 25 GeV
- P_{ave}= 300 kW
- 1/2 max beam power
- beam magnified
- slow sweep to distribute heat

Beam Dumps

- Production readiness reviews for all beam dumps finished
- Selection of main suppliers, setting-up of production process underway
- Dump equipment test for main dumps planned for Q4/2013

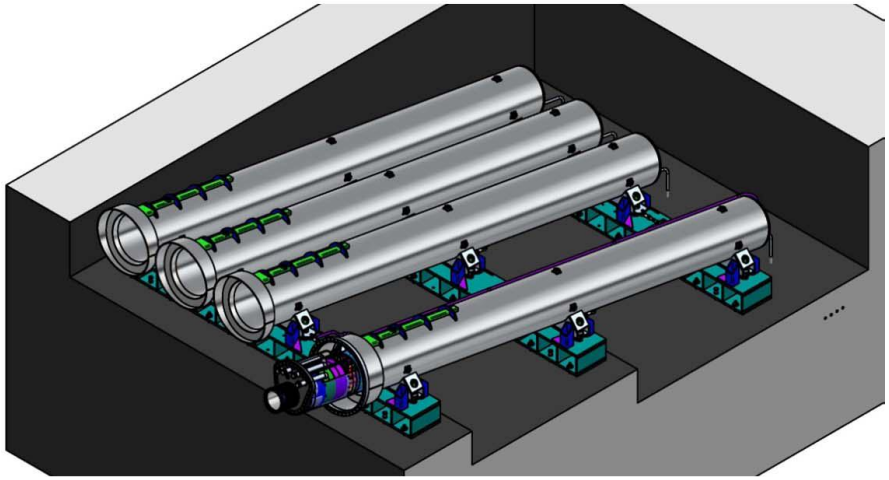
bunch compressor dump





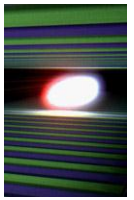
Design of the main dump (Qty 5)

main dump



European XFEL

Scientific Instruments for the European XFEL



Hard x-rays

SPB : Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules

- Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.

MID : Materials Imaging & Dynamics

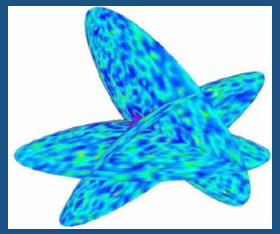
- Structure determination of nano-devices and dynamics at the nano-scale.

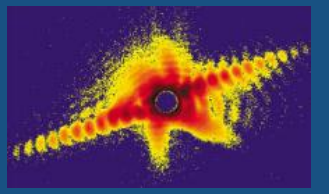
FXE : Femtosecond X-ray Experiments

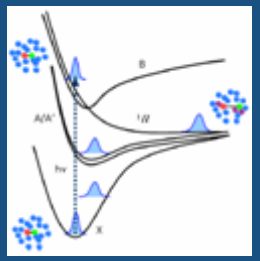
- Time-resolved investigations of the dynamics of solids, liquids, gases

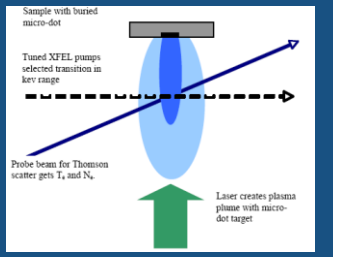
HED : High Energy Density Matter

- Investigation of matter under extreme conditions using hard x-ray FEL radiation, e.g. probing dense plasmas









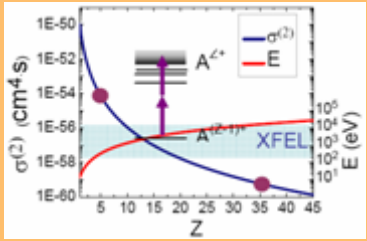
Soft x-rays

SQS : Small Quantum Systems

- Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

SCS : Soft x-ray Coherent Scattering/Spectroscopy

- Electronic and real structure, dynamics of nano-systems and of non-reproducible biological objects



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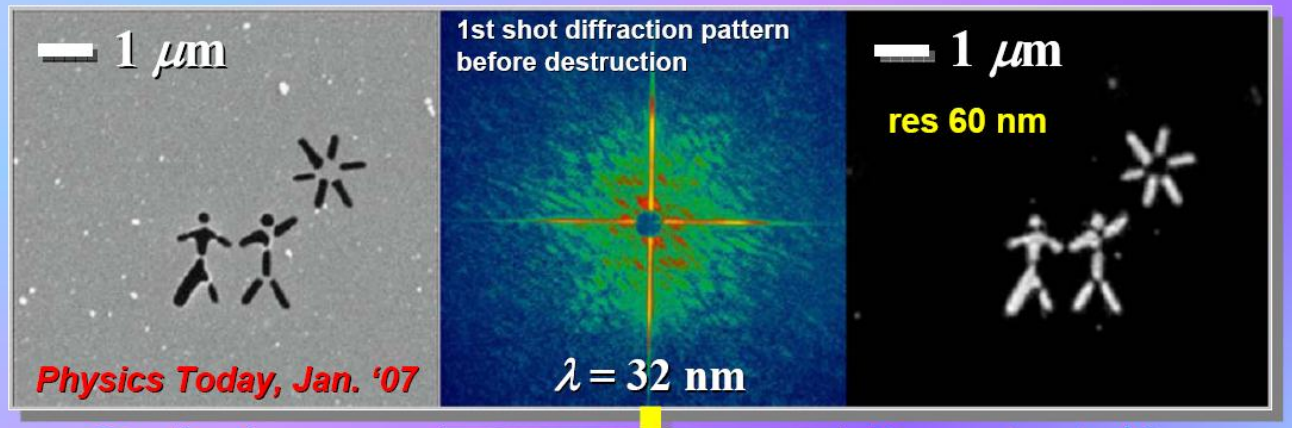
European XFEL

Looking to a bright future …

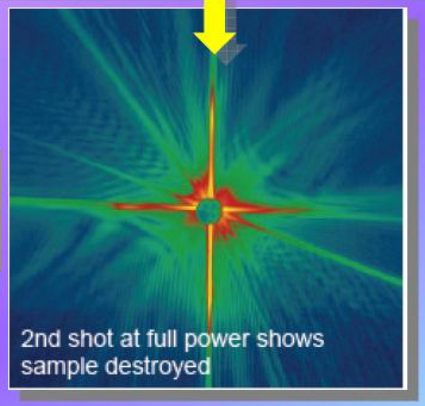
Image Reconstructed from an Ultra-Fast (25 fs) FEL Diffraction Pattern at *FLASH*



Starting Image (etched into silicon nitride film)

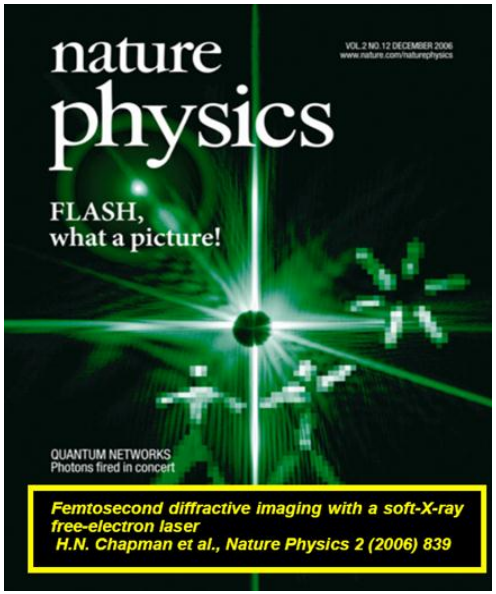
H. Chapman, J. Hajdu

Reconstruction by A. Barty, Feb. '06

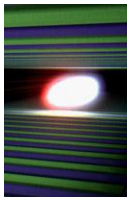


Reconstructed Image

The 20-μm-wide square film was destroyed by the laser pulse, but a computer algorithm reconstructed the original image from the diffraction pattern.



nature physics, December 2006



Thanks for attention