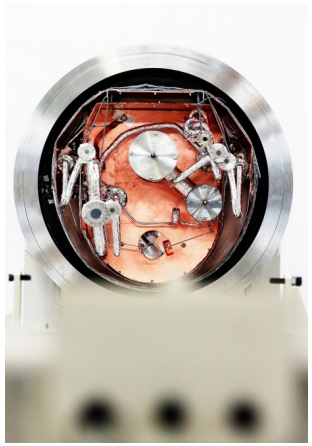
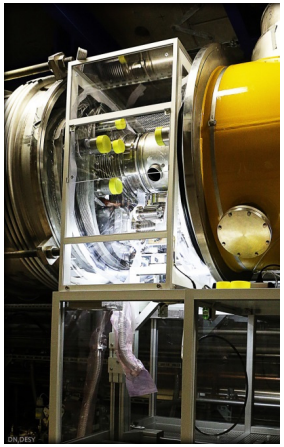
The Diagnostic System at the European XFEL; Commissioning and First User Operation

Dirk Nölle on behalf of the European XFEL Diagnostic/Commissioning Team

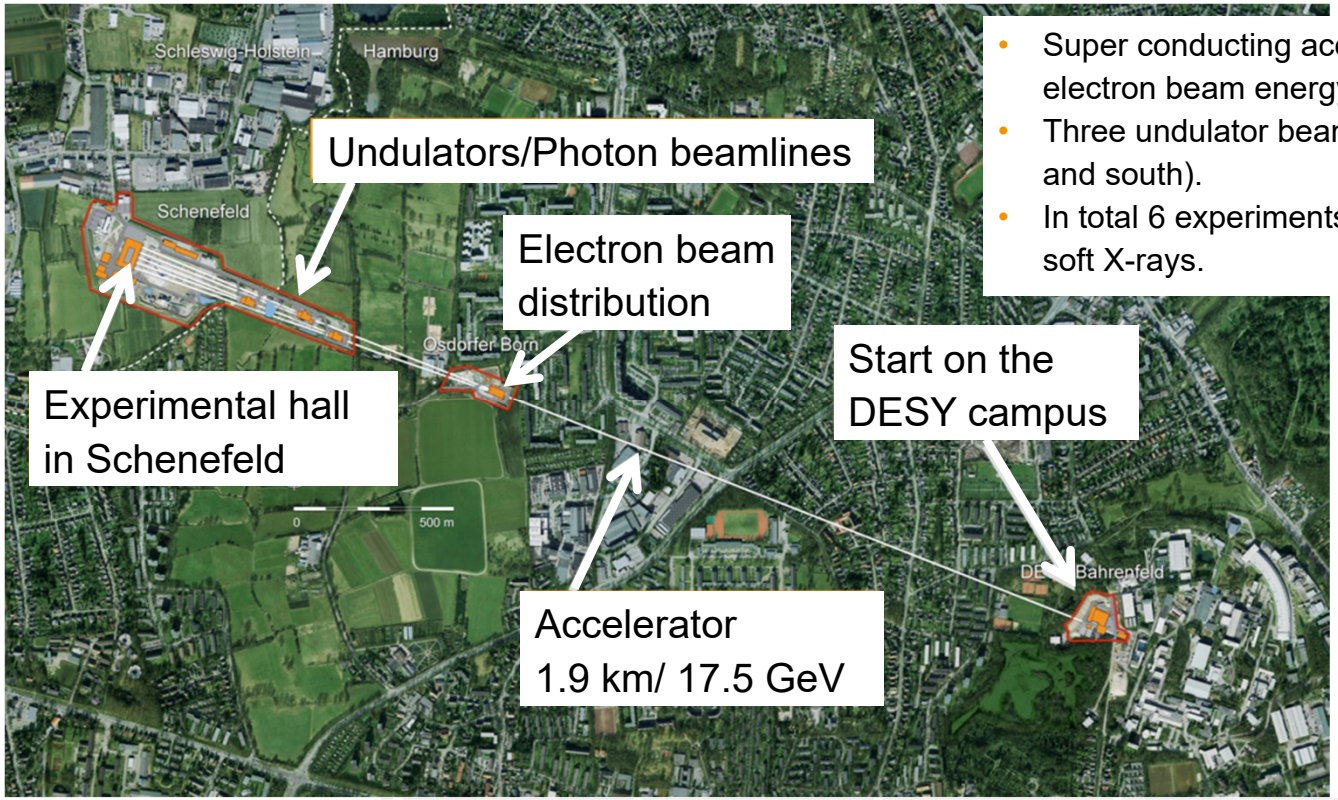
IBIC'18, September 11th, 2018





European XFEL

The European XFEL between Hamburg Bahrenfeld and Schenefeld



- Super conducting accelerator with up to 17.5 GeV electron beam energy.
- Three undulator beamlines in two branches (north and south).
- In total 6 experiments, 4 for hard X-rays and 2 for soft X-rays.

European XFEL

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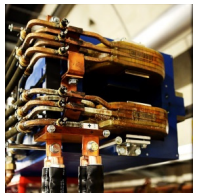
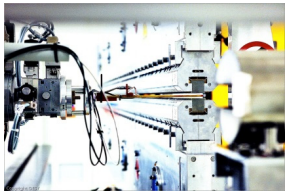
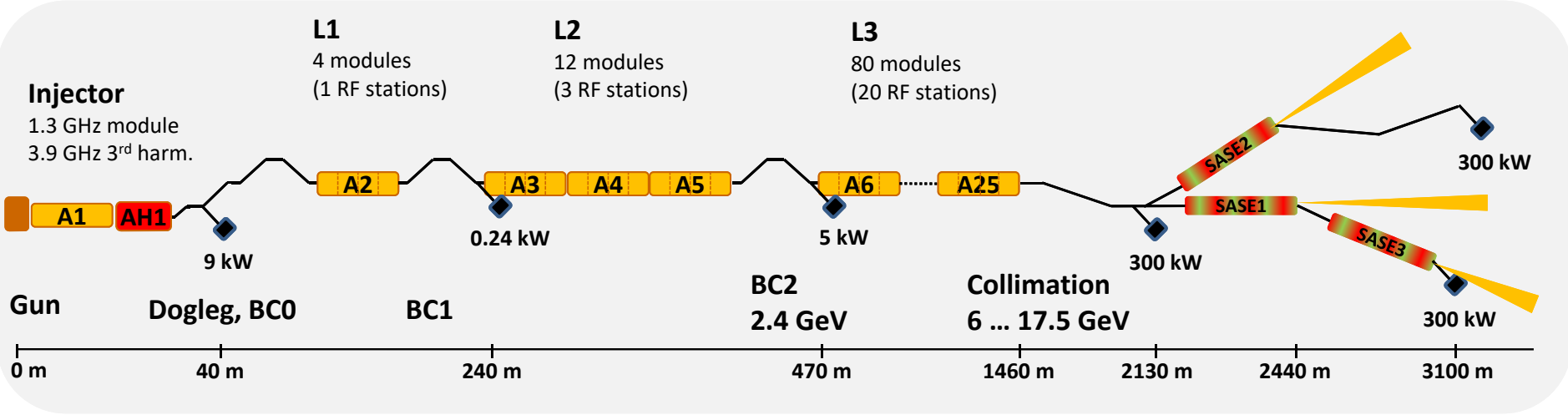
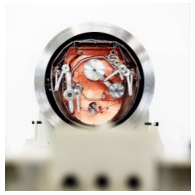
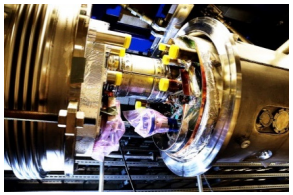
DESY.

Schematic accelerator overview





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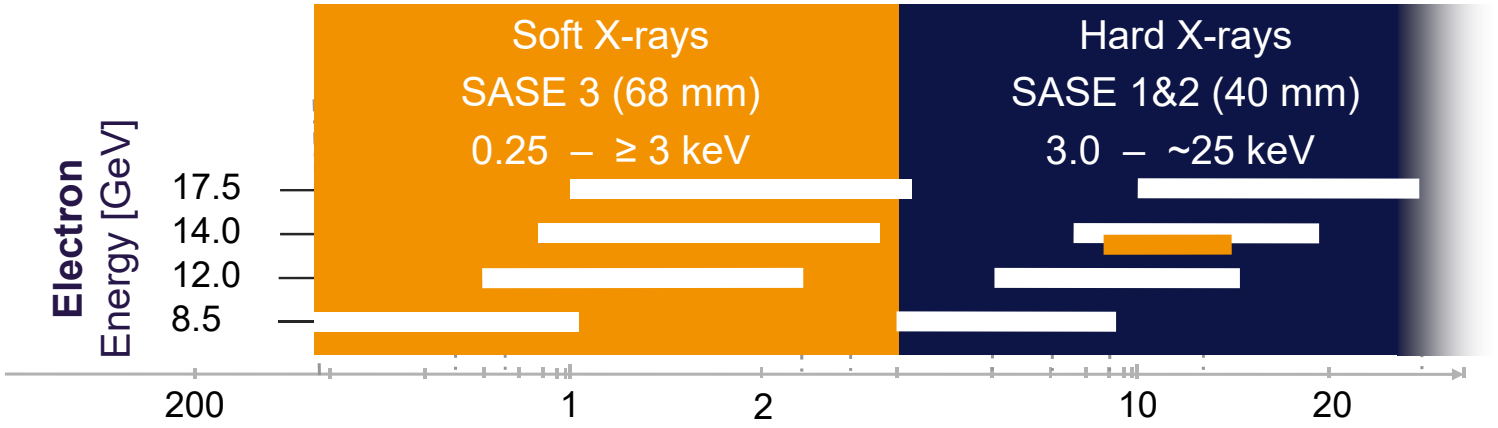
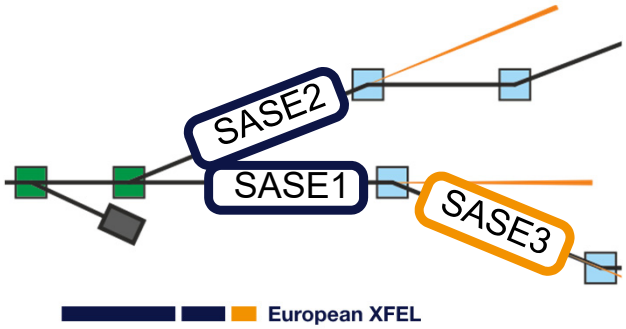
DESY.

The European XFEL covers photon energies from 0.25 keV to 25 keV





Working point during user runs:

- 14 GeV electron beam energy
- 7.5 - 14 keV photon energy (SASE1).

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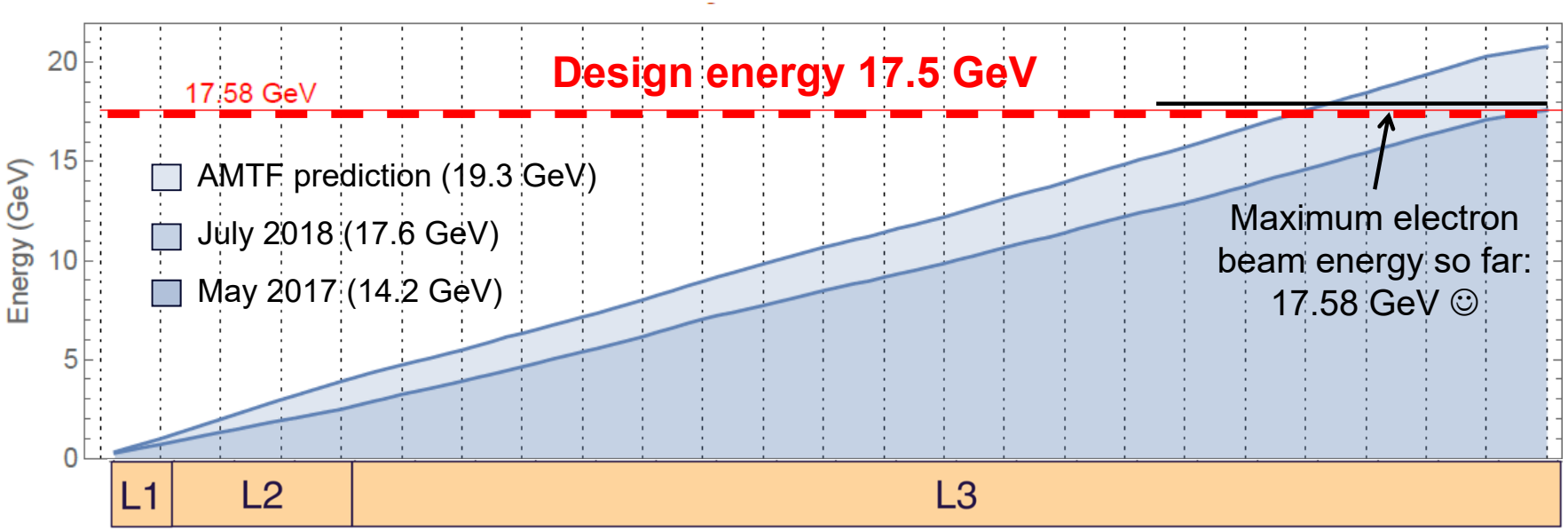
DESY.

The longest superconducting linac in the world is in operation

- 96 superconducting modules in a single cryostat in the main tunnel
- Plus 2 injector modules
- RF components and electronics rack are located below the accelerator.

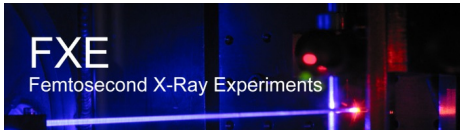
Energy reach of European XFEL modules

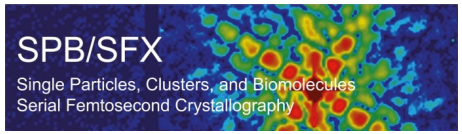


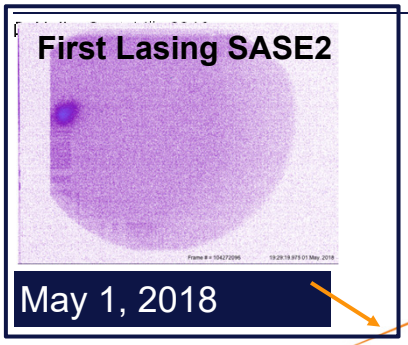
- The accelerator is commissioned accordingly to schedule and towards expected parameters.
- All 25 RF stations are in operation
- The maximum electron beam energy so far is **17.5 GeV**, user operation with **14.0 GeV.**
- There is still potential to increase the RF performance.

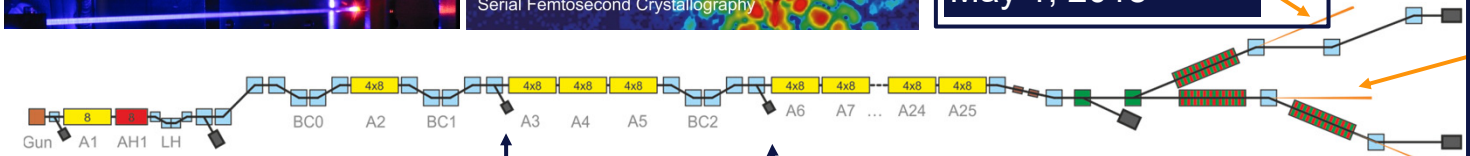
Commissioning timeline

First user runs started in September 2017 (SASE1 beamline)







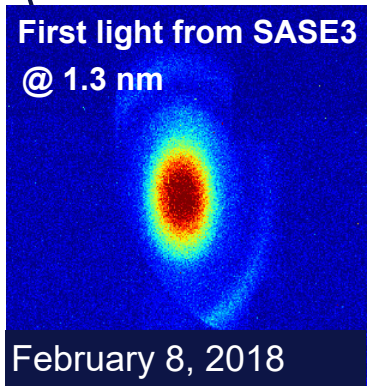


Jan 13, 2017

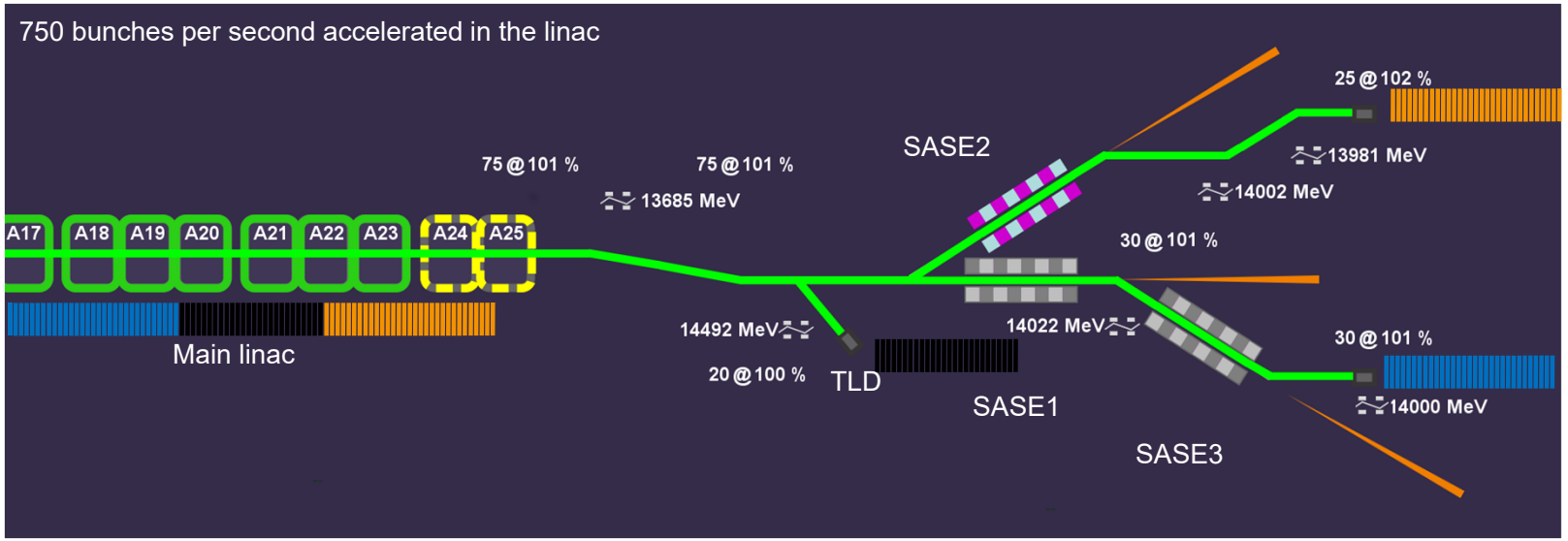
Jan 15, 2017 @ 130 MeV
Jan 19, 2017 @ 600 MeV

Feb 2, 2017 @ 600 MeV
Feb 22, 2017 @ 2.5 GeV

Feb 25, 2017@ 2.5 GeV
March 19, 2017 @ 6 GeV
April 8, 2017 @ 12 GeV

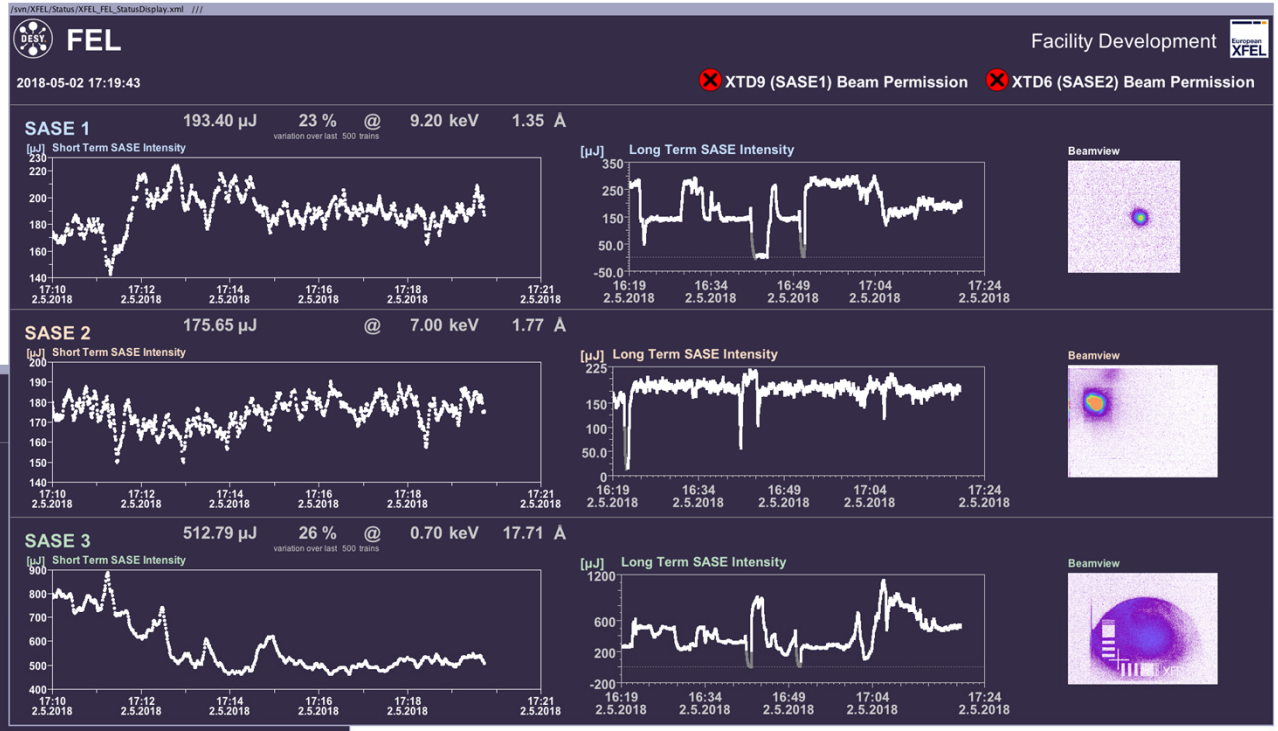


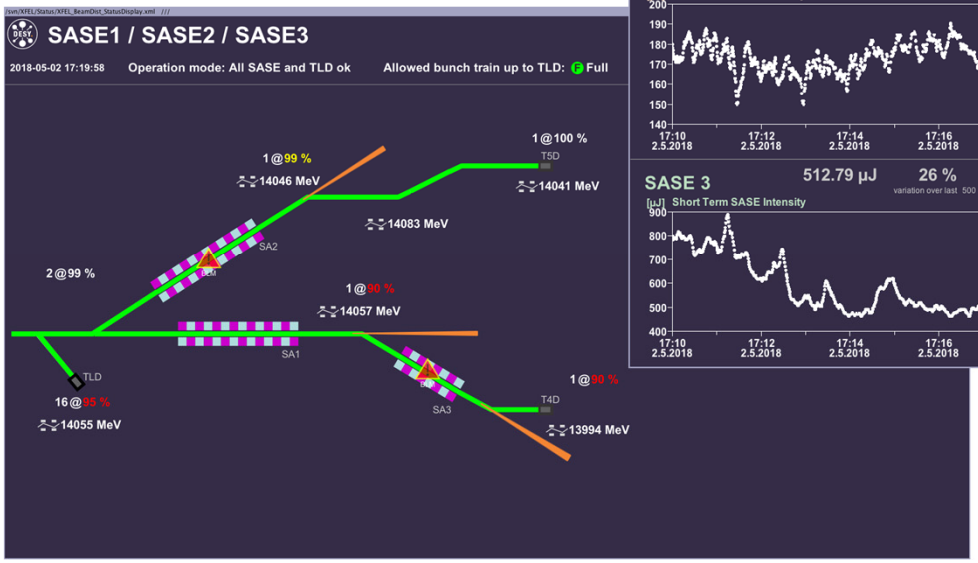
Parallel operation of three beamlines



- Bunches send to TLD during rise time of the distribution kicker.

… and now with 3 FELs on.





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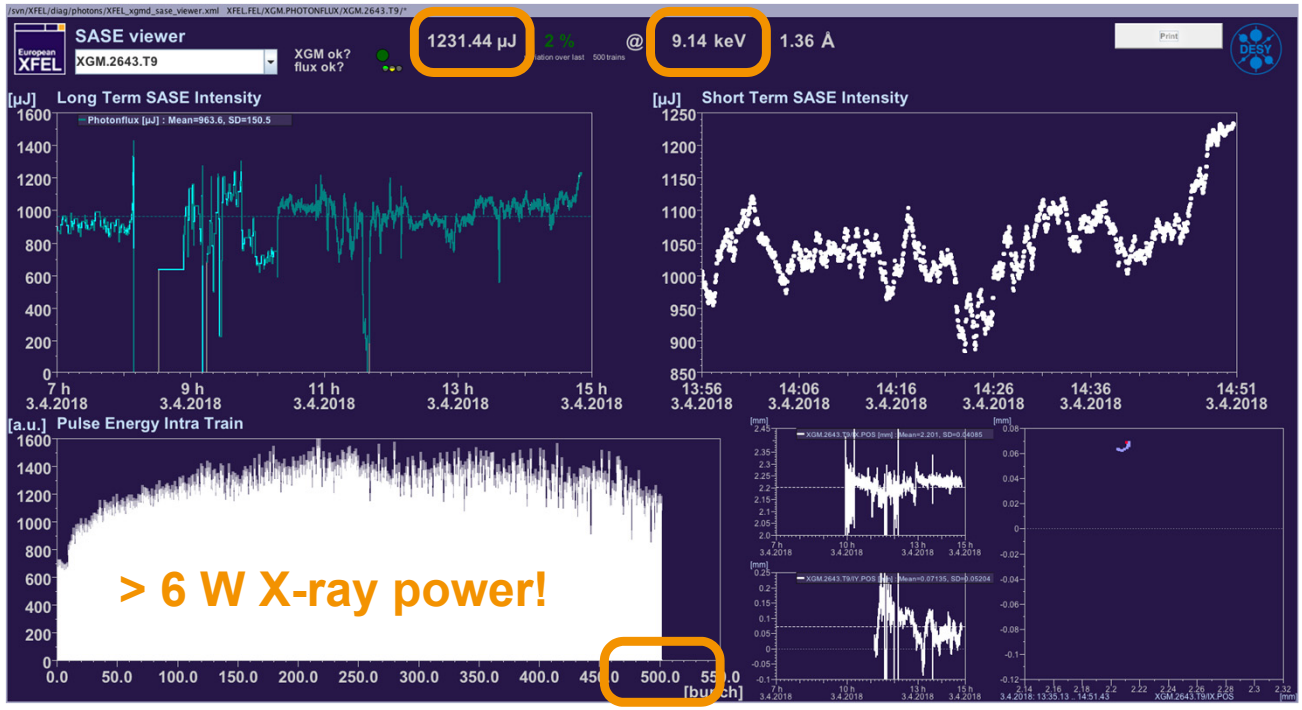
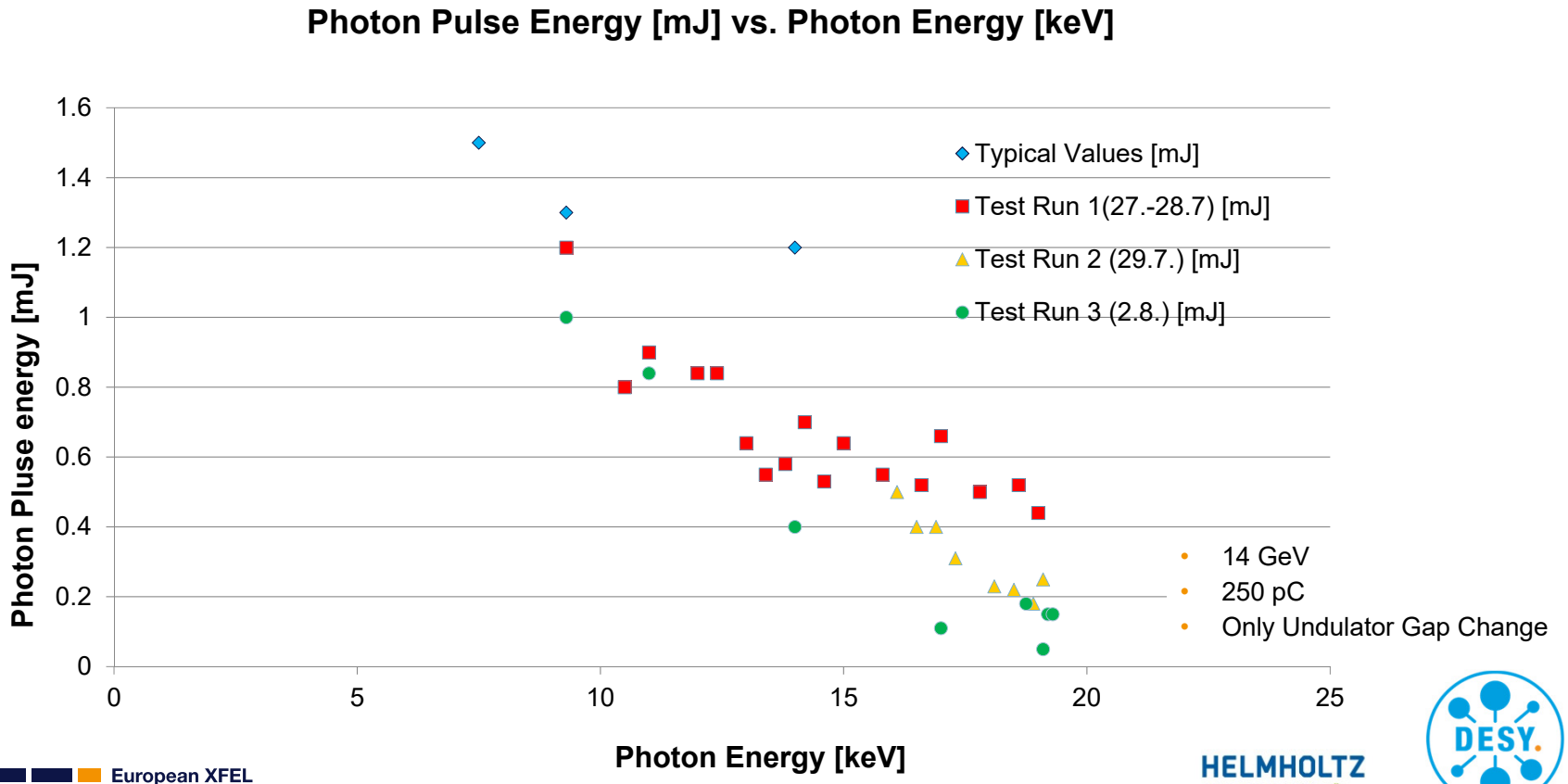
DESY.

SASE delivery with 5000 bunches per second

- The maximum number of SASE pulses generated so far in the SASE1 beamline was 5000/s.
- The pulse train was lasing homogeneously over almost all bunches.
- Limitation by safety to 600/s.
- This number will be increased step by step according to upgrade of safety systems of the photon beamlines.



Highest Photon Energy Operation at SASE1



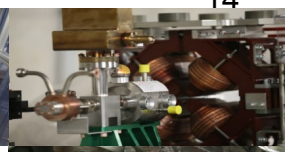
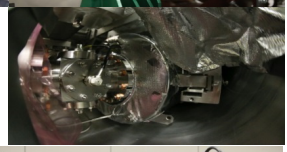
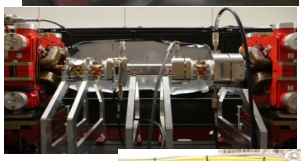
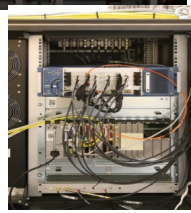
Commissioning of Standard Electron Beam Diagnostics (Slide from DEELS WS 2016)

- Goal:
  - Do Machine Commissioning with Diagnostics
- AND NOT
  - Do Diagnostics Commissioning with the Beam
- Nevertheless
  - It is an iterative process
  - Start with poor performance, but be able to see and to improve the beam
  - See signals and optimize the parameters to improve the performance of the diagnostics.
  - Get both working: Beam and Diagnostics.
- Therefore
  - Technical Commissioning: Prepare devices, check and test interfaces and communication prior to beam operation.
  - Basic Commissioning: Diagnostic guys have to join the first shifts, and support until beam operation is established.
  - Advanced Commissioning: Use dedicated beam time to bring the systems to good performance.

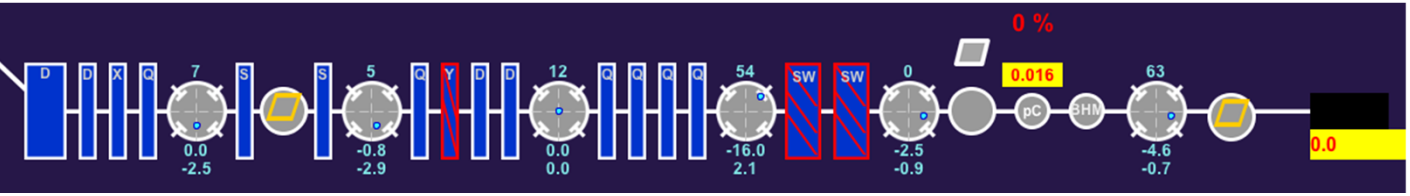
Size of the Diagnostics System of EXFEL

Installed Diagnostics Items	Number
Beam Position Monitors	453
Charge Monitors	51
Screens	67
Wire Scanners	12
Loss Monitors	474
Dosimetry Systems	630
Transverse Deflecting Structures	2
Bunch Compression Monitors	4
Beam Arrival Time Monitors	7
Electro-Optical Systems	3

BPM System: Features

- **In Kind Contribution and Joint Project of PSI, CEA and DESY**
- Triggered mode and Self Trigger -> 1. Beam Steering: almost lost bunches gave position data
- Automatic gain control [AGC] for increased dynamic range for button and cavity BPMs
  - For single pulse operation: AGC off and estimation of attenuators according user settings
- Timing stabilization of cavity and re-entrant signals via synchronized external clock signal
  - But for missing external signal: an internal clock signal can be used
- Additional Features:
  - Pre-calibration of each BPM system before first beam -> already calibrated system from 1. day
  - Integrated FMC: Dosimetry device for online measurement at electronics
  - MPS interface: Orbit walk off alarms
  - Fast data link for feedback applications
  - Maintenance network connection,2nd access channel for control and maintenance,
  - Remote firm- and software updates
  - Electronics with control of temperature and active stabilization
  - …..



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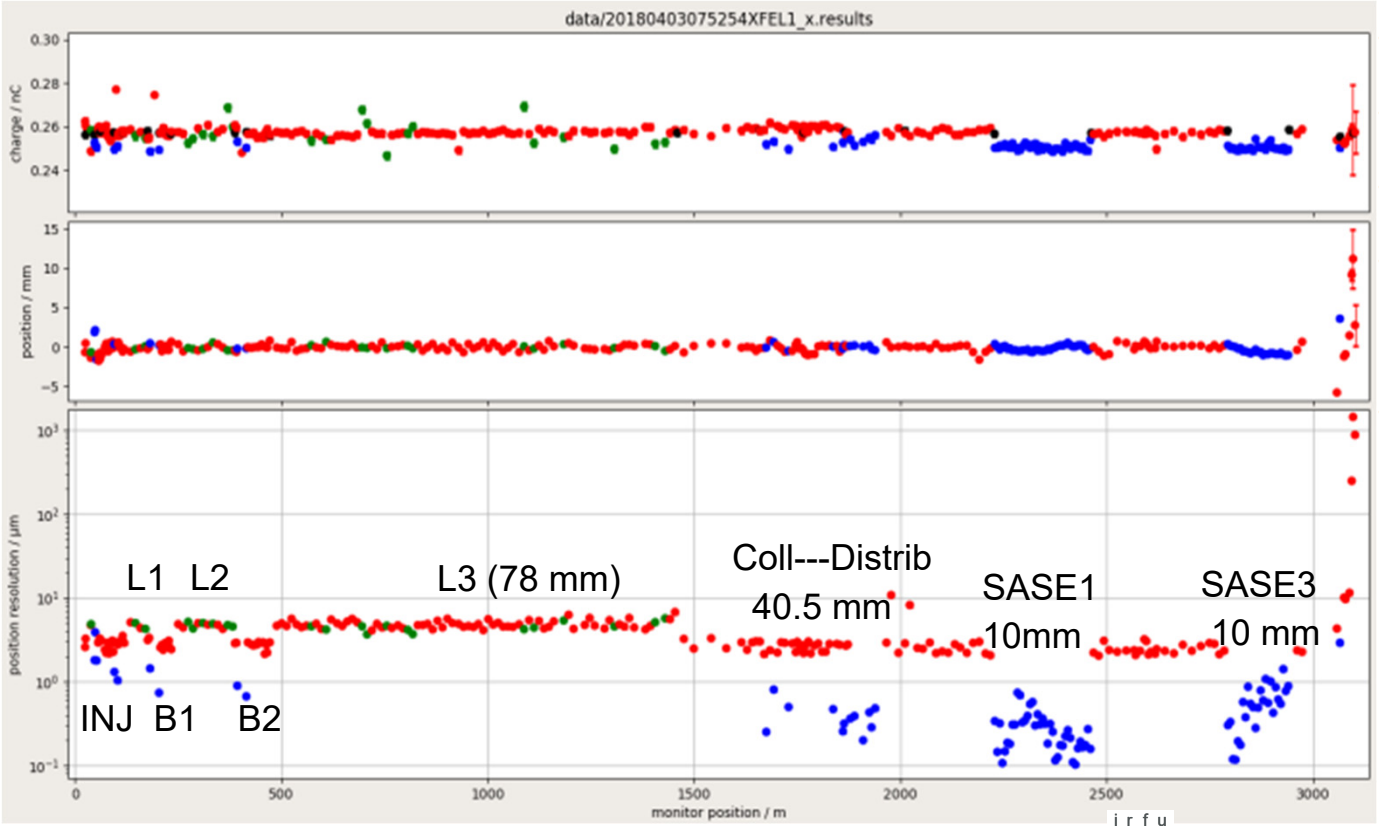
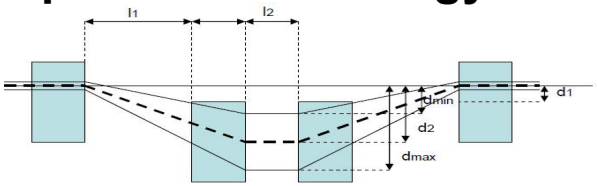
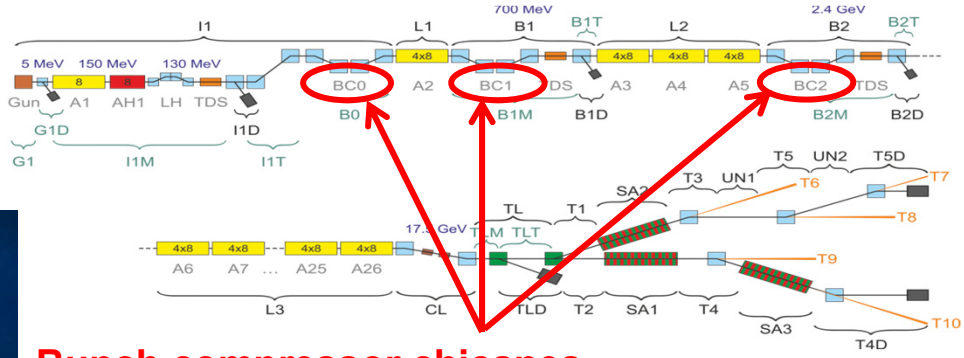
BPM System (Resolution)



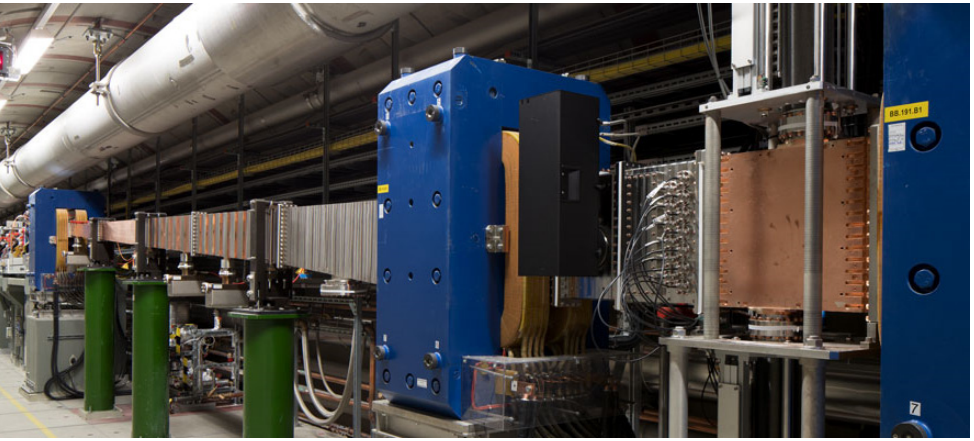
- Red: Buttons
- Green: Re-entrant Cavity BPM
- Blue: Cavity BPM
- The first 6 cavity BPMs : higher resolutions due to 10 dB attenuation.
- The 10 µm resolution for 2 button BPMs at about 2000 m position is due to 100 mm pipe diameter.

Special BPM: Energy BPM / Compressor Chicane

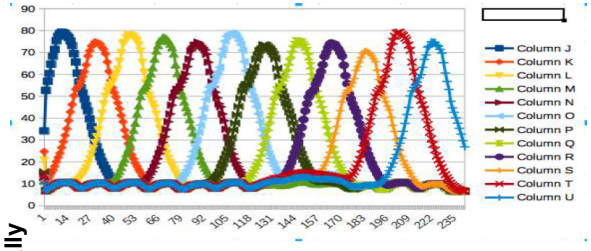




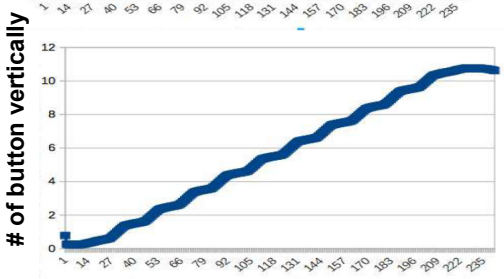
Bunch compressor chicanes



Position sweep in vertical direction delivers “raw” ADC data



including the mechanical offsets from the buttons one obtains a very robust delivery of position data



Applied calibration and position sweep in the button array chamber

- Button array of 26 “standard” button feed-throughs
- Chamber size 40 mm x 400 mm
- Body milled out of 1 piece
- µTCA.4 electronics SIS8300-L2D ADC and custom RTM
  - Also used in FLASH as standard BPM electronics

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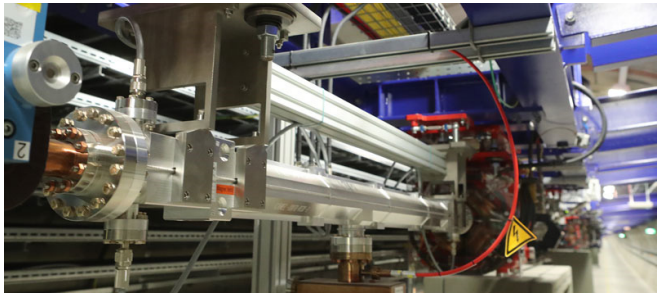
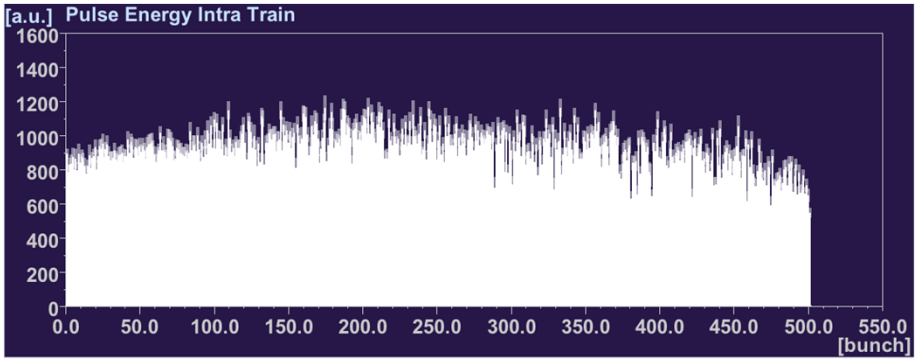
DESY.

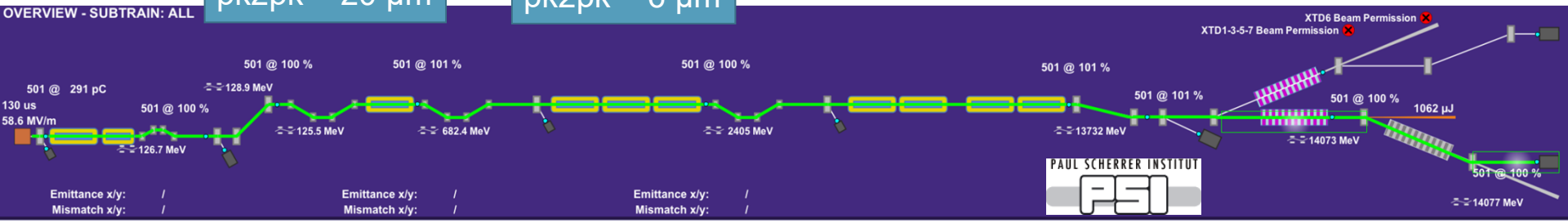
Íntra-Bunchtrain Feedback System (IBFB)



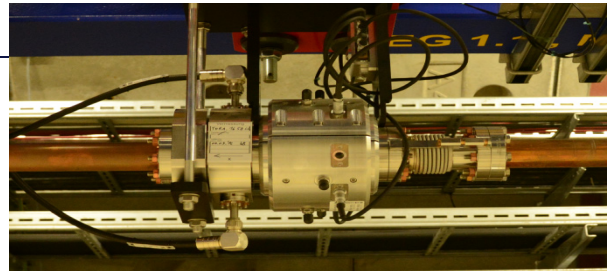


pk2pk ~ 20 µm

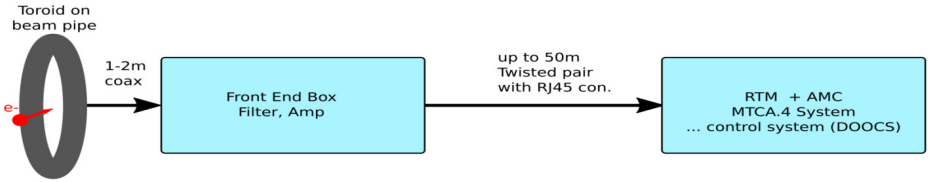
pk2pk ~ 6 µm

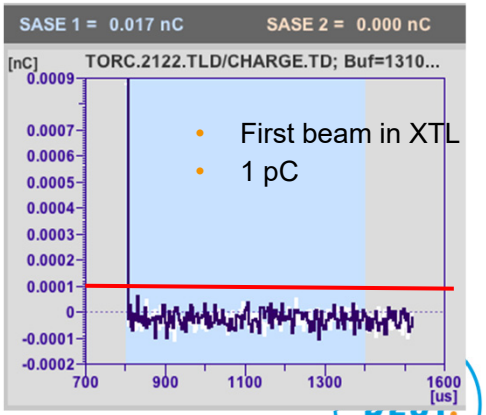


Toroid System - Charge Measurement



- Charge measurement with **~0.2pC resolution RMS**
- 36 Toroids along E-XFEL, based on MTCA.4 with commercial AMC (SIS8300-L2D) and custom RTM
- Timing: Signal and Timing System
- Integrated test pulser functionality
- Machine Protection:
  - **Fast Protection**: transmission of adjacent Toroids connected via fibers and local alarms **cutting within current bunchtrain**
  - **Slow Protection**: consecutive alarms **block further bunchtrains** until user acknowledgement
  - Also gives Interlocks:
    - ► If bunches are detected in beamline section where they are not expected
    - ► If bunch charge is above a given limit
    - ► If integrated charge of a macropulse is above a given limit (e.g. for dump protection)
- Self Trigger: First beam detection on pC level worked reliable!





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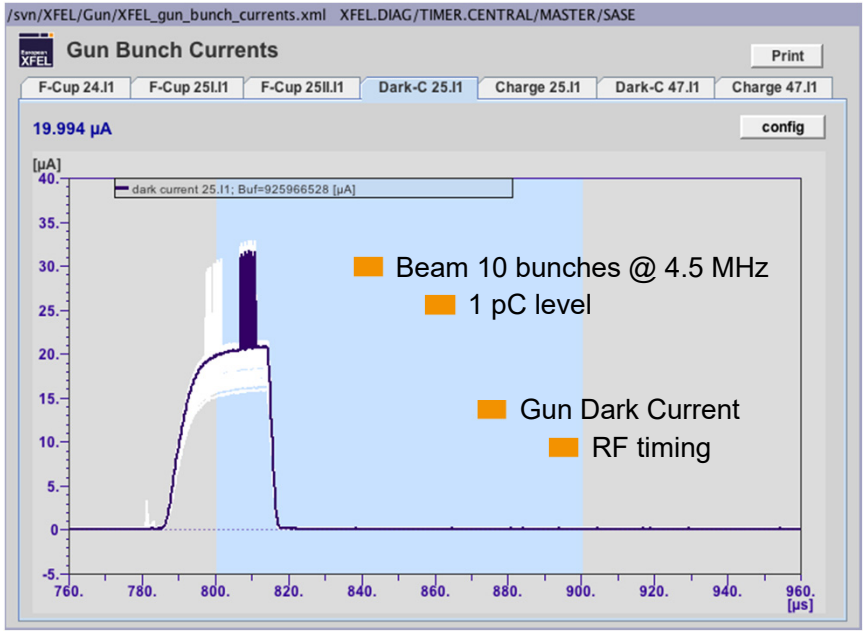
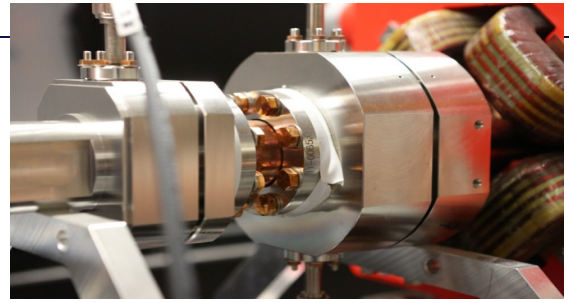
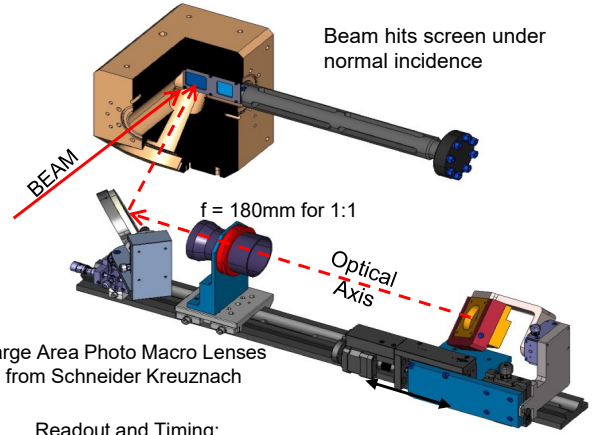
Dark Current Monitor (DCM)

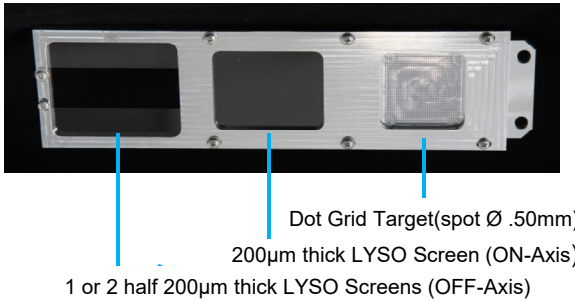


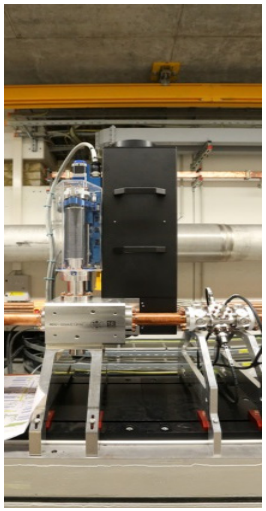


- Simple low Q 1.3 GHz Cavity
- Sensitive to dark current 50 nA level via pile up
- Beam current also gives a signal from fC on
- Almost insensitive to timing,
  - Start trigger sufficient
- Powerful tool to adjust initial Laser and RF timing
- Now mainly used to track field emission from gun and accelerator modules

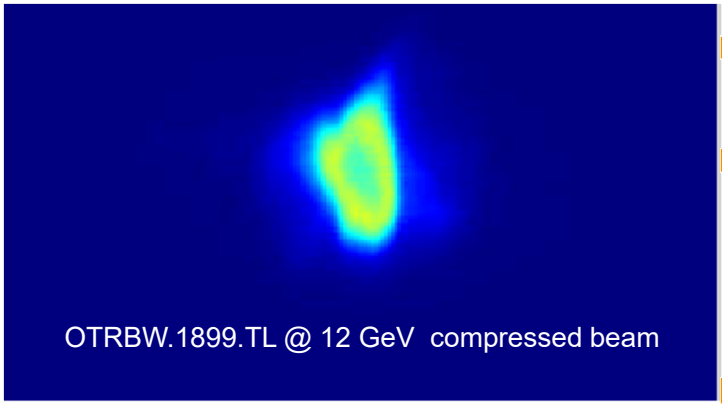
Screen Stations







- All Screens worked during initial beam commissioning
  - If there was beam, it was detected by the screens!
  - No COTR issues
- Lyso Material turned out to be very sensitive
- Spatial suppression of COTR worked fine.
- But beam size measurements overestimate the beam size due to “smoke rings”
- Investigation by G. Kube show, that LYSO Material gets problems at high charge densities.
  - Injector still useful data.
  - At high energy, significant overestimate of Beam Size
  - Check out different Materials, Replacement Program.
- **See Talk by G. Kube (WEOC03)**



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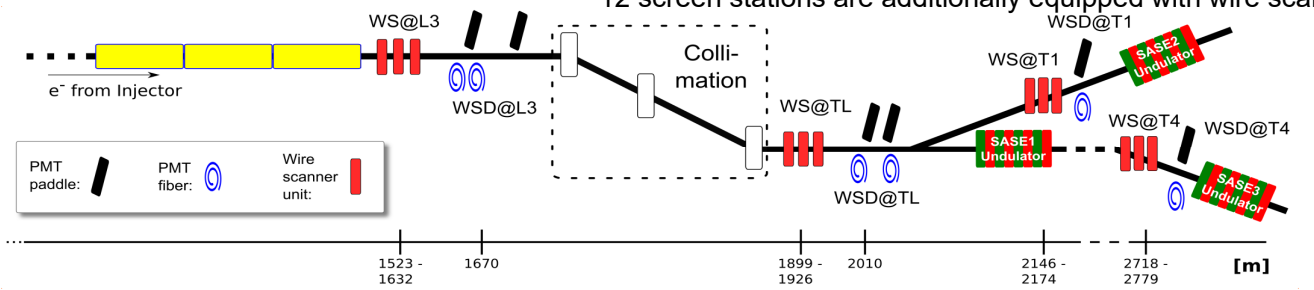
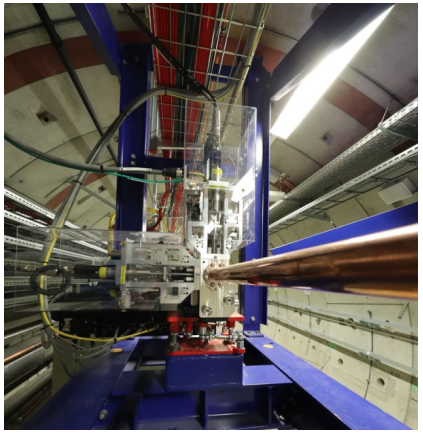
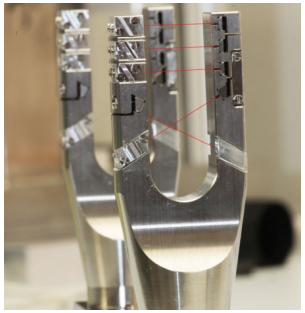
DESY.

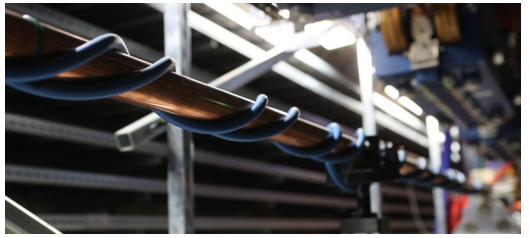
E-XFEL Wire Scanner System

12 screen stations are additionally equipped with wire scanners





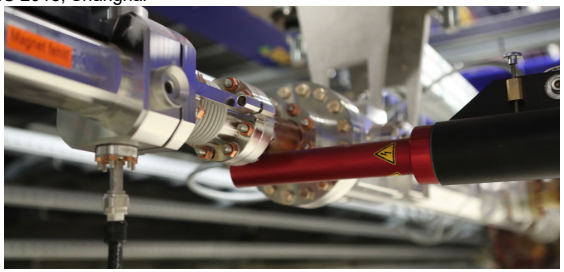


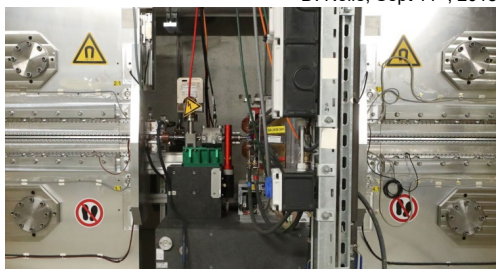


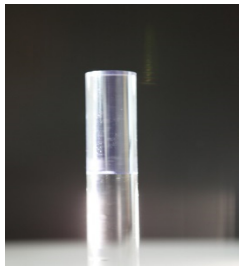
- Wire Scanner consists of horizontal and vertical driven unit
  - 2 wires: 50 – 30 - 20µm tungsten
  - Plus one 60° pair crossed 10µm wires tungsten wire
- Dedicated wire scanner detectors based on XP2243B 6-stage PMT tube with fiber and paddel scintillators
- Regular BLMs can also be used (for Halo measurements)
- In-house development of mechanics and electronics, integrated into MTCA.4 environment
- Slow scan mode: already medium-heavily used for
  - Beam halo measurements
  - Emittance measurements and Matching
- Fast scan mode for long bunchtrains to be commissioned

T. Lensch „The European XFEL Wire Scanner System“, WEPC05

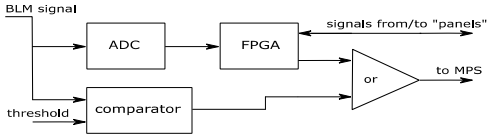
Beam Loss Monitors







- Sensitivity settings: based on machine activation profile
- Plastic scintillators and quartz rods (cherenkov radiation)
- 474 BLMs along the machine, based on MTCA.4 with custom AMC (DAMC02) and RTM
  - **Analog alarm path, independent from digital electronics and timing**



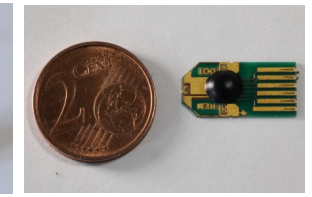
- Machine Protection:
  - **Fast Protection**: single, multibunch and integral alarms **cutting within current bunchtrain**
  - **Slow Protection**: consecutive alarms **block further bunchtrains** until user acknowledgement
  - **Integrated tests:** LED and software alarm
- Plastic Scintillators sensitive to few 100 keV undulator radiation
  - **Undulator BLMs: Change plastic to quartz**

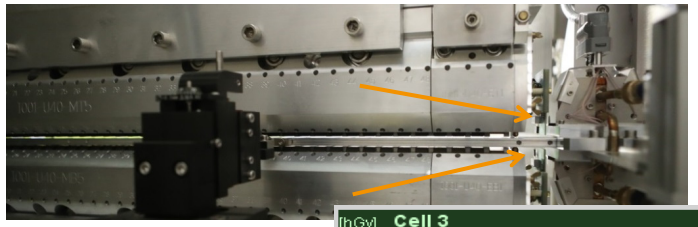
T. Wamsat „The European XFEL Beam Loss Monitor System“, WEOB03

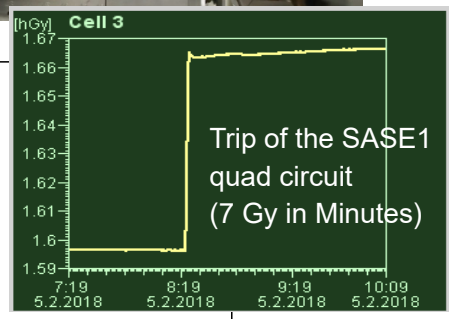
The RadFet Dosimetry System

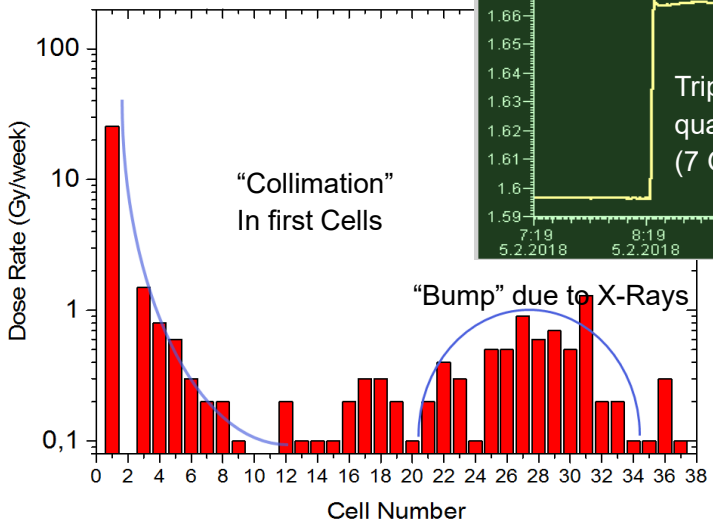
- RadFet System implemented as an FMC module
- It is placed on all MPS boards and in all BPM MBUs
  - ► about 400 sensors in electronics racks
- In addition the FMC can read external sensors.
  - ► 200 external sensora in the undulator system
  - ► 50 external sensors in L3
- Each RadFet has a TLD nearby (cross calibration)
- Potential to release MPS alarms

- Issues:
  - ► Sensors see hard X-rays fro spontaneous radiation
    - Lead hoods to shield are in preparation
  - ► Control Software is not fully available
    - Currently, only undulator data well accessible
    - There is big potential for more essential data.
    - Work ongoing ….





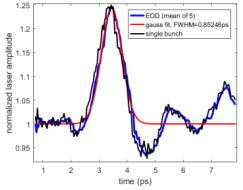


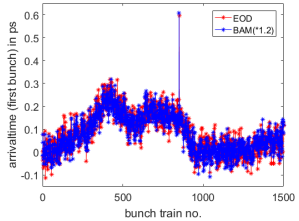


Longitudinal Diagnostics

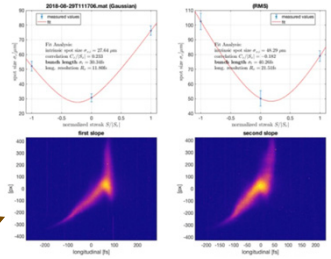
TDS Injector:
Slice Emittance

EOD: long. bunch profile

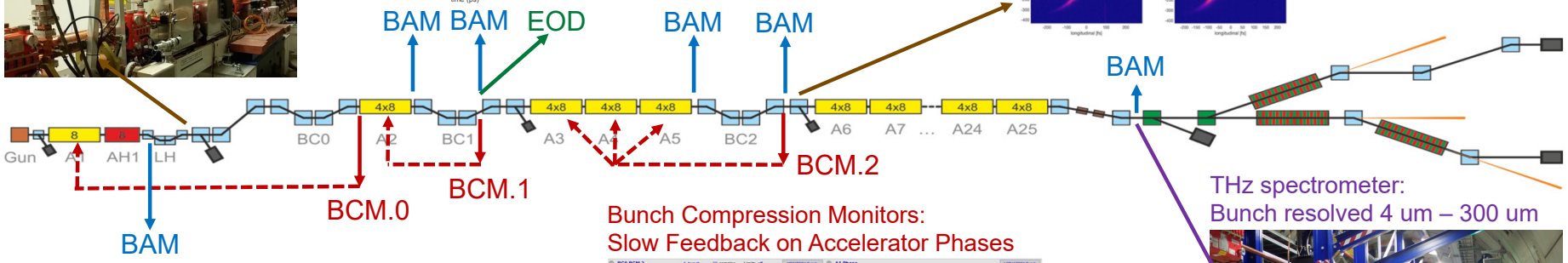




TDS BC2:
Long. Phase Space

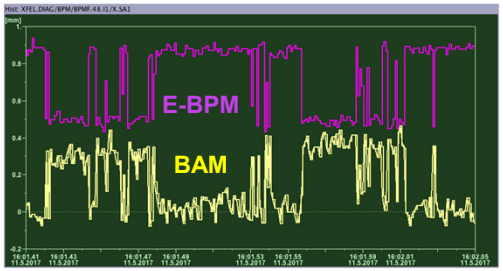


Bunch arrival time at BC1
with BAM and EOD

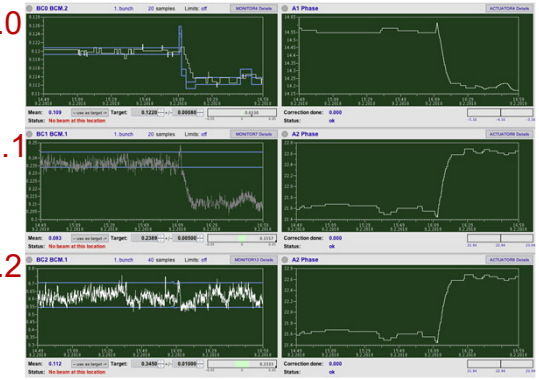


THz spectrometer:
Bunch resolved 4 um – 300 um

Bunch Compression Monitors:
Slow Feedback on Accelerator Phases



BCM.0
BCM.1
BCM.2



European XFEL

More Info: B. Steffen: WEOA03

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DESY.

European XFEL

Summary: There is light at the End of the Tunnel

- EXFEL was successfully commissioned, and has started User Operation
  - Nevertheless, the facility is not operated at full swing.
  - Progress is now driven by Experiments Demands and Possibilities
- All necessary diagnostic systems were operating from T0 on, making the Commissioning Process was very effective.
- Two issues were dominating
  - Smoke Rings for the Screens -> Study on Materials
    - ► Replacement Campaign already started.
  - BLMs and Dosimeters sensitive to (very) hard X-rays
    - ► go to Cherenkov Radiators
    - ► add lead hoods to Dosimeters
- There is still some Advanced Commissioning to be done
  - Treasures to be taken,
    - ► Using more advanced Software, Optimizers
    - ► By implementing Feedbacks

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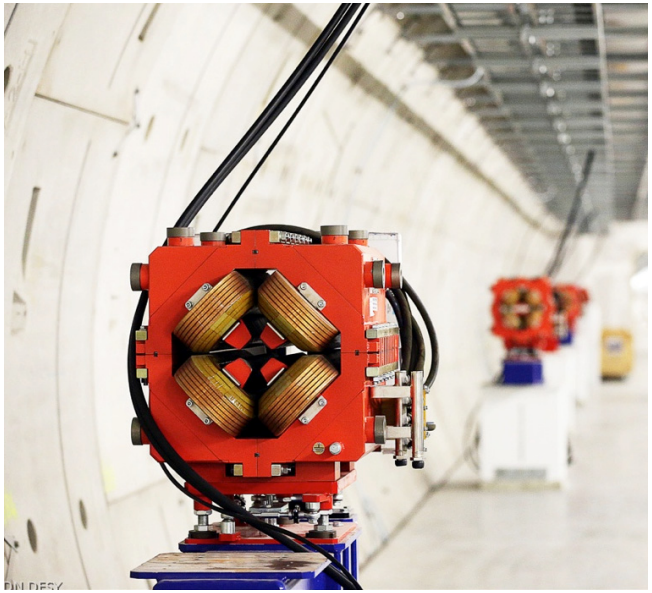
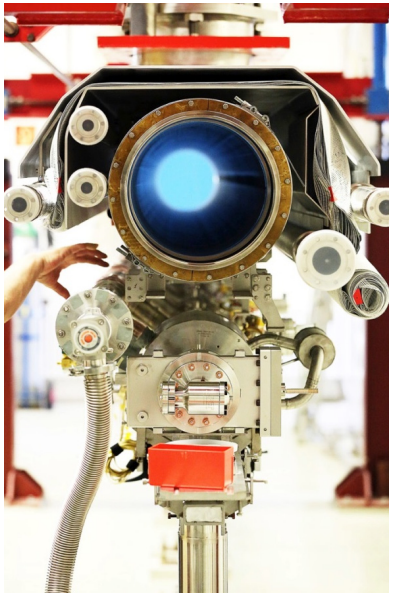
DESY.



Thank you for your attention

European XFEL

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DESY.

(Accelerator) Parameter Space (Status Summer 2018)

Quantity	Unit	Project Goal	Achieved	Routine
electron energy	GeV	8 – 17.5	6 – 17.5	14
bunch repetition within pulse	MHz	Up to 4.5	Up to 4.5	1.1
bunch charge	pC	20 – 1000	100 – 500	250
electron bunch length after compression (FWHM)	fs	2 – 180	20 – 90	50
max. beam power	kW	500 kW	18 kW	1.8 kW
undulators in operation (lasing)		SASE1-3	SASE1-3	SASE1
photon pulses / s / undulator		27000	5000	<1200
photon energy (SASE1)	keV	0.25 - 25	7-19.3	9.3, 14
photon pulse intensity (SASE1) @ 14 GeV, 250 pC, 9.3 keV	mJ		1.5*	1.2
photon pulse intensity (SASE3) @ 14 GeV, 250 pC, 600 – 900 eV	mJ		7	<1*
photon pulse intensity SASE2 (@ 14 GeV, 250 pC, 7.5 keV	mJ		0.9	

* Restricted by safety limitations of SASE1/3 photon beamlines