Experience with the standard diagnostics at the European XFEL

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HELMHOLTZ ASSOCIATION

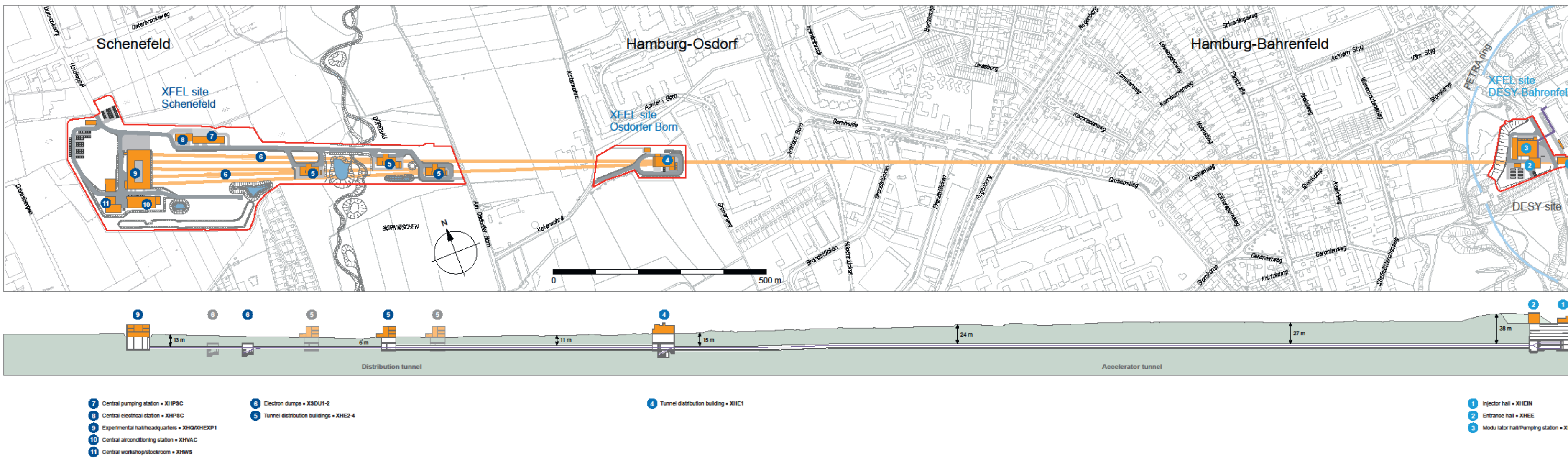
DEELS workshop SOLEIL, 13.06.2017

DESY

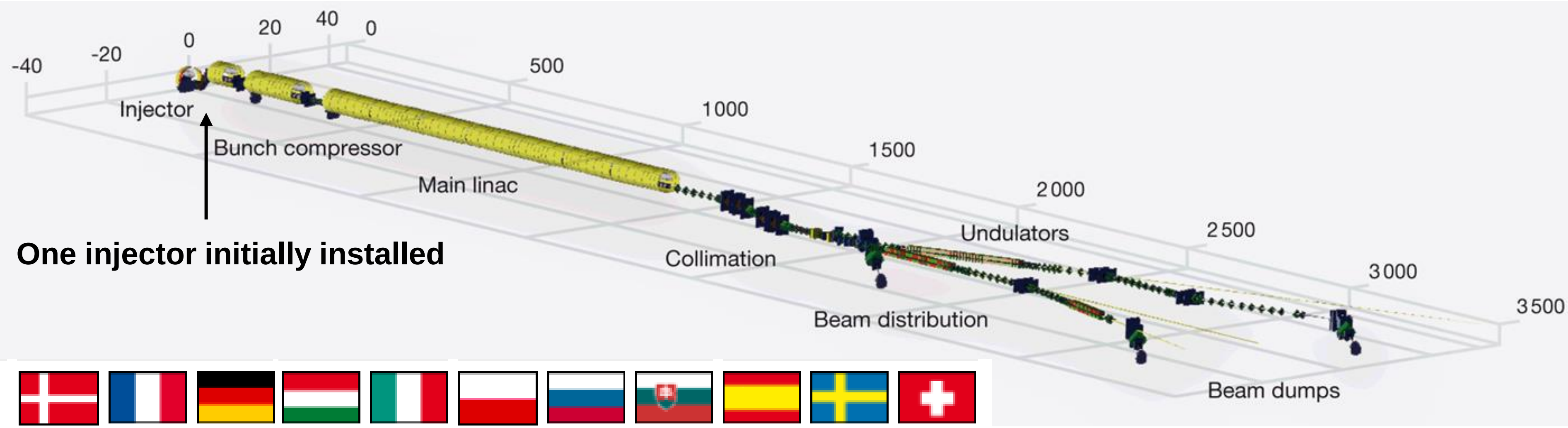
Outline

- Overview European XFEL
- Standard diagnostics: beam position, charge, beam loss monitors, dosimetry and screen stations
- Summary
- Outlook

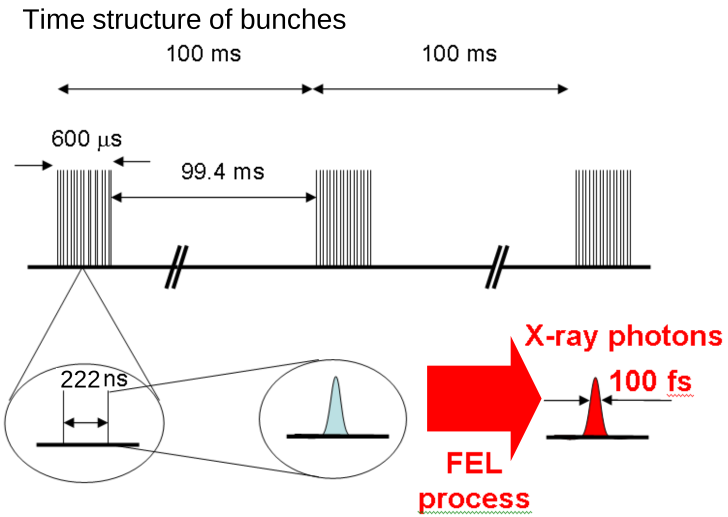
Overview European Xray Free-Electron Laser



Overview European Xray Free-Electron Laser



- 17.5 GeV superconducting electron linac
- RF photo-injector, two bunch compression stages
- 3 SASE FEL with variable gap (plus 2 spontaneous source, extension possible)
- Up to 2700/RF Pulse @ 10 Hz or 27000 bunches/second with superconducting technology
- 5 experimental stations to be extended to 10
- Potential extension with a second experimental hall



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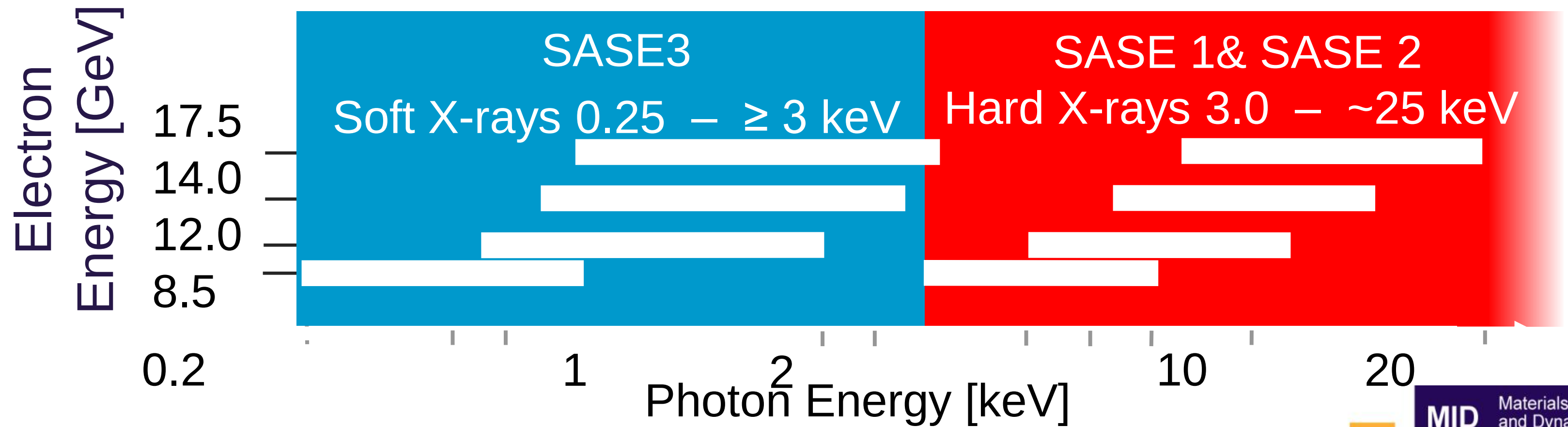
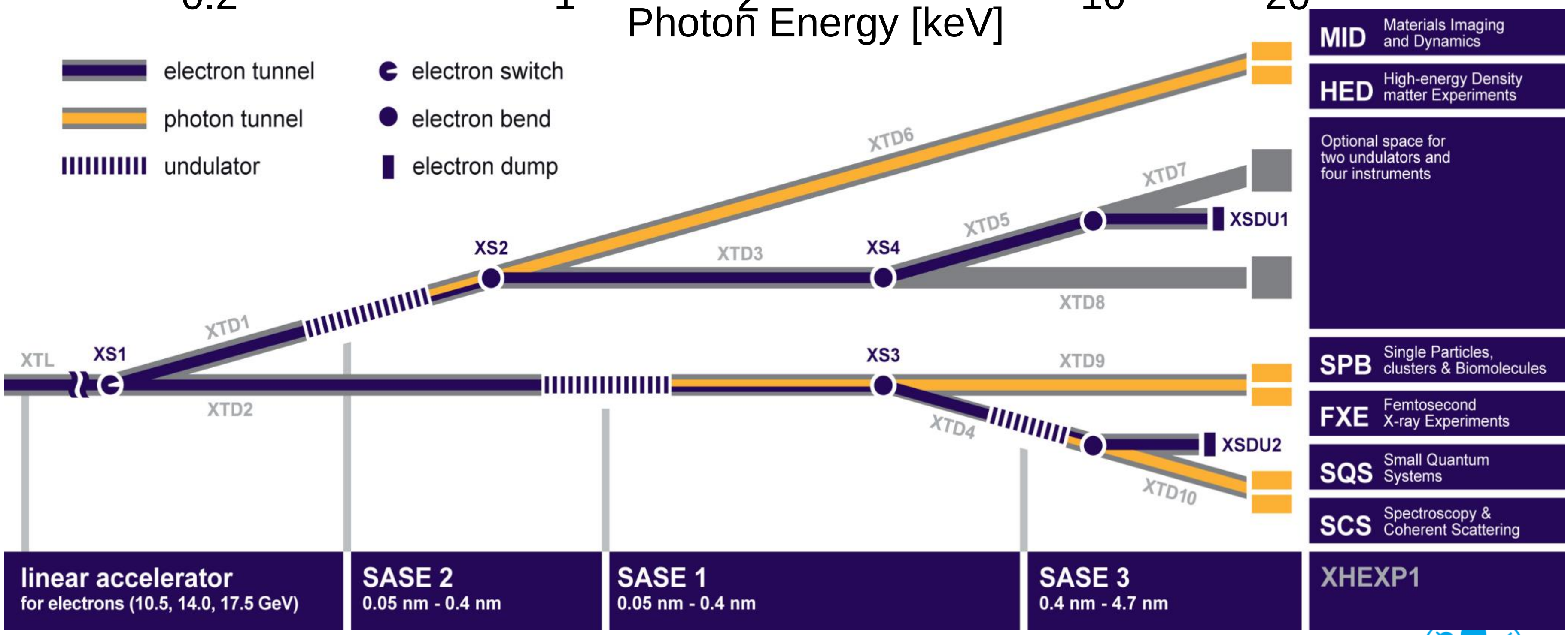




courtesy W. Decking

Overview European Xray Free-Electron Laser

2000: First lasing at 109 nm at the Tesla Test Facility (TTF), now FLASH

2001: TESLA Linear Collider TDR with XFEL appendix

2002: TESLA TDR supplement with stand-alone XFEL

2006: European XFEL TDR

2009: Foundation of the European XFEL GmbH

Start of underground construction

2010: Formation of the Accelerator Consortium:

16 accelerator institutes under the coordination of DESY

2012: End of tunnel construction

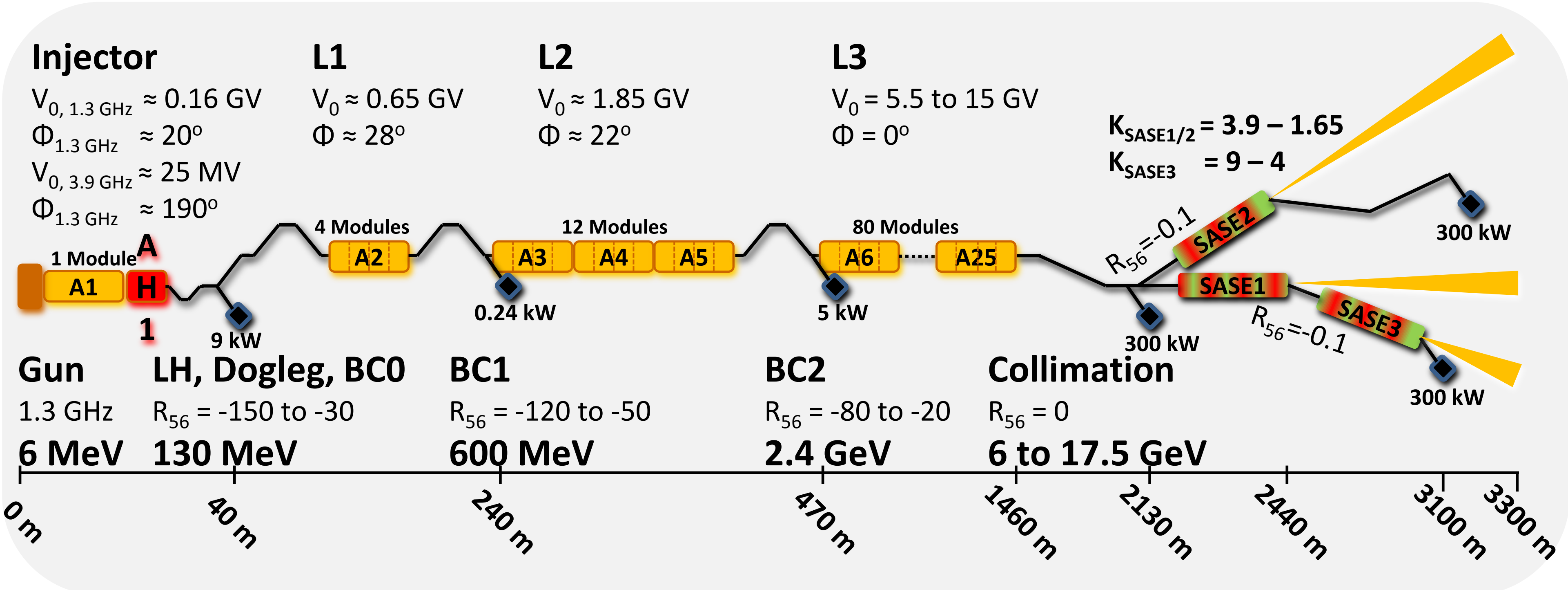
Start of underground installation

2016: Finish of accelerator installation

Start of commissioning

courtesy W. Decking

Overview European Xray Free-Electron Laser



- Superconducting linac with 97 1.3 GHz superconducting modules
- 10 Hz pulsed mode with 600 µs flat-top, 2700 bunches/pulse
- Variation of bunch charges between 20-1000 pC foreseen to vary final pulse length
- Fast distribution of bunches into beam distribution lines

courtesy W. Decking

Overview European Xray Free-Electron Laser

- Photoinjector conditioned and characterized at PITZ, DESY-Zeuthen
- Injector cool-down 12/2015
- First Beam on 18/12/2015- commissioning till Q2/2016
- Full bunch train length (27000 bunches/s) reached for 20pC-1000pC bunch charges
- Photocathode laser (Yb:YAG laser from Max-Born Institute Berlin 257 nm ≤ 4 µJ; 3 ps) with excellent up-time
- 3.9 GHz system operational from day 2
- Laser heater commissioned (but not in routine operation)

For diagnostics see report DEELS workshop 2016

courtesy W. Decking

Overview European Xray Free-Electron Laser

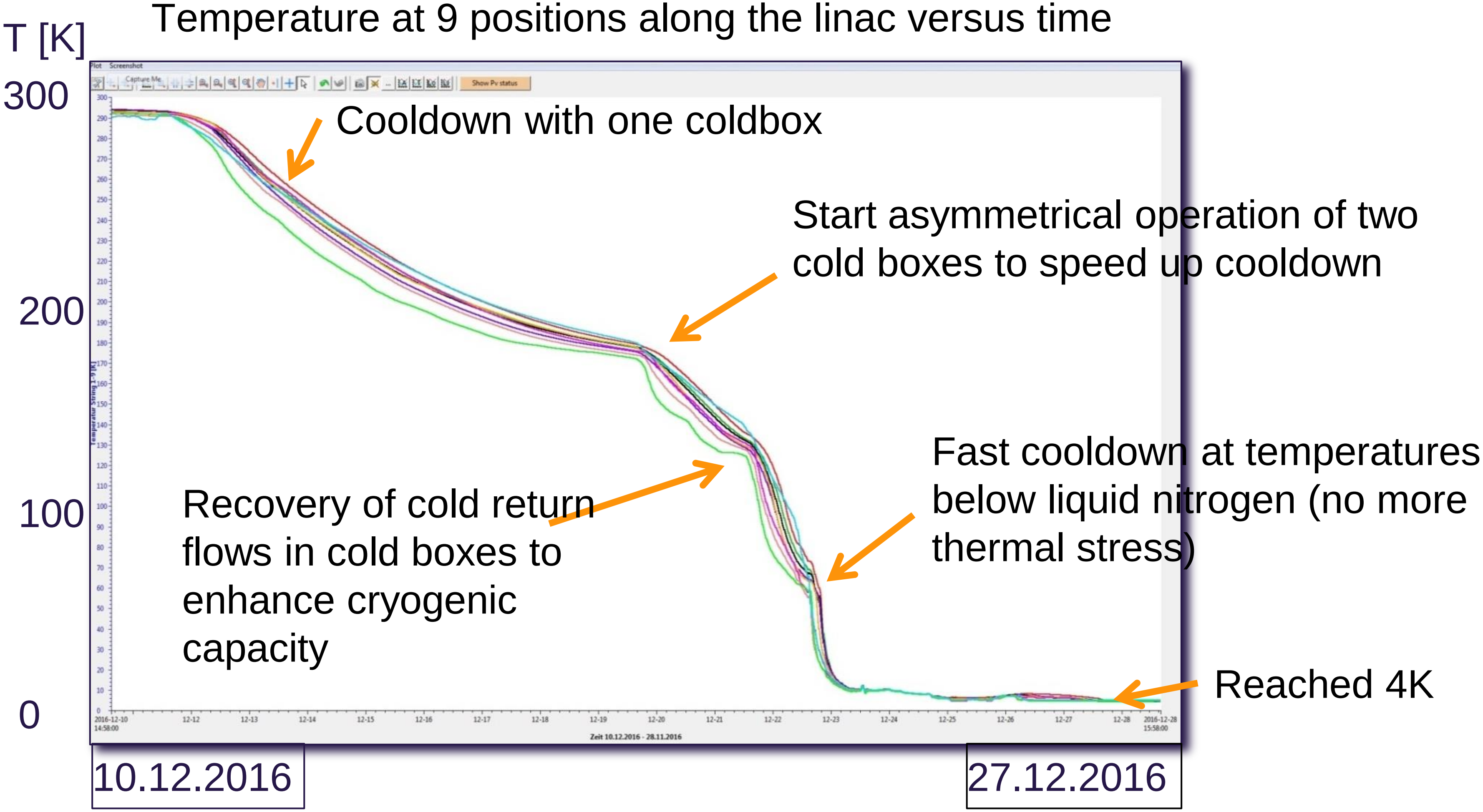
Strategy: get as many systems in the game as soon as possible

12/16	Start: Cooldown
01/17	Injector at 130 MeV (3 RF stations)
01/17	L1 commissioning (+1 RF station)
02/17	L2 commissioning (+3 RF stations)
02-04/17	L3 commissioning (+15 RF stations)
05/17	Beam through SASE1 & SASE3 undulator sections
End 05/17	Milestone "First Lasing Possible"
06-08/17	Commission SASE1 photon beamline and experiment Consolidate FEL operation at 8-10 keV photon energy
09/17	First user experiments (total 800 hours)
2018	Continue facility commissioning + 2000 user hours
2019	Routine operation with 6 experiments + 4000 user hours

courtesy W. Decking

First Cooldown of XFEL Linac (>300 t)

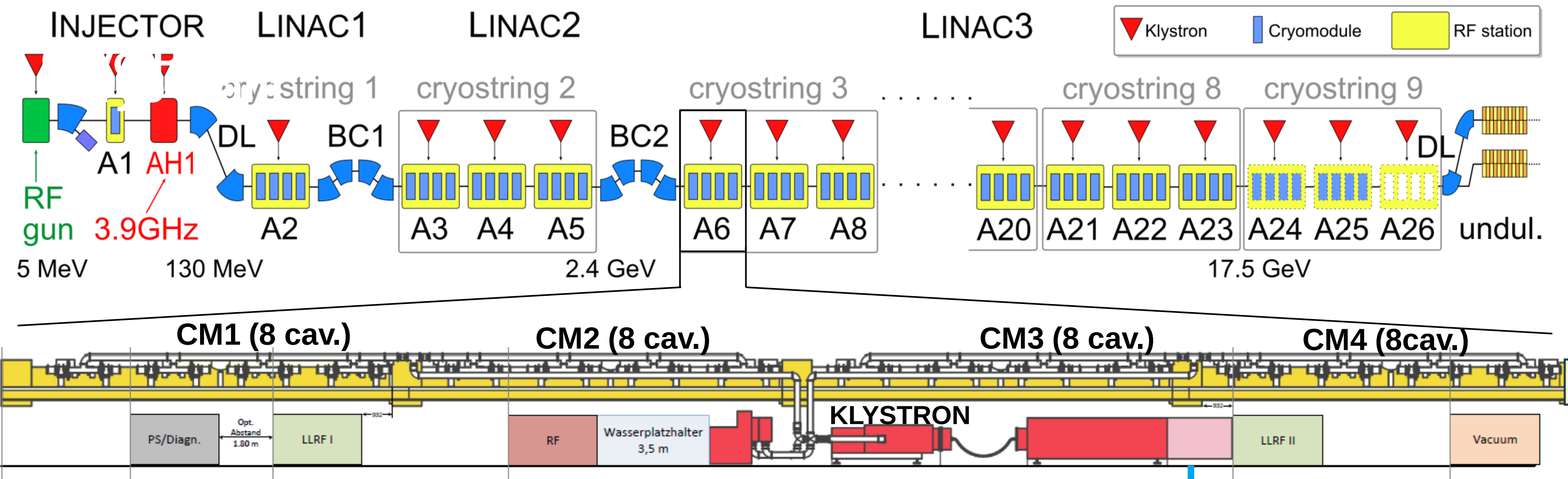
Temperature at 9 positions along the linac versus time



No cold leaks !

courtesy W. Decking

Overview European Xray Free-Electron Laser

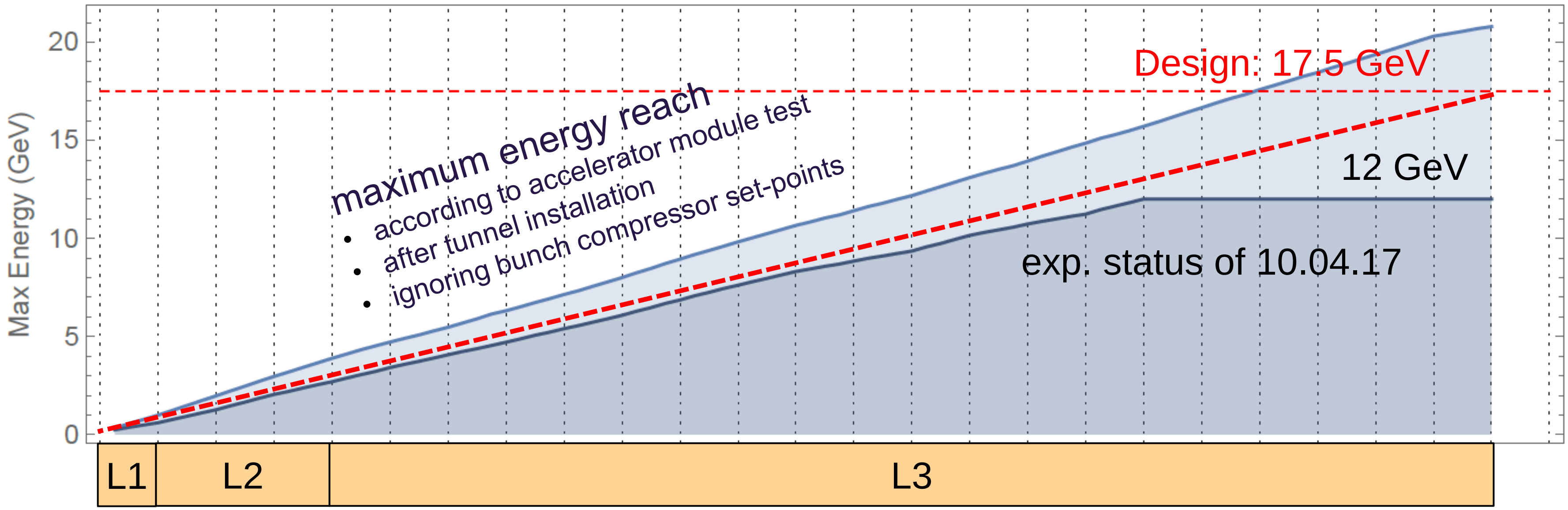



Klystron and modulator below module

HV Modulators in surface hall
Connected to pulse transformer
via up to 2km long pulse
cables

courtesy W. Decking

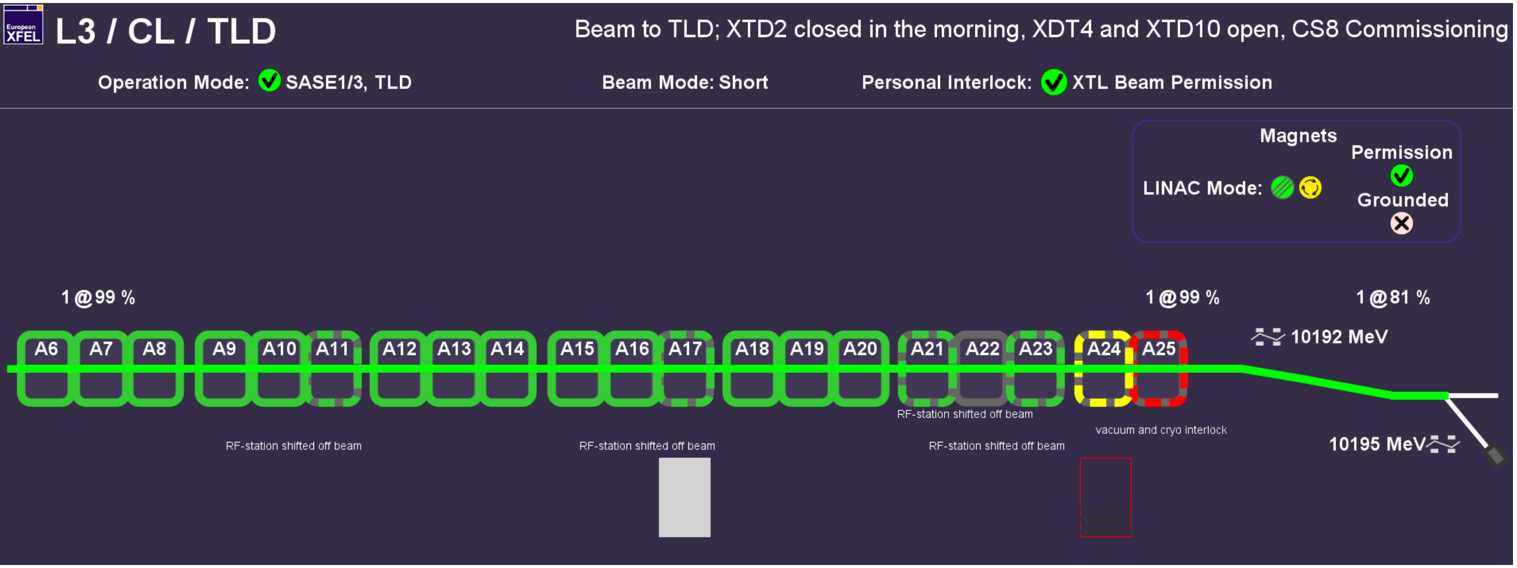
Overview European Xray Free-Electron Laser



- Average accelerating gradient after module test and waveguide tailoring
- 26 MV/m, (design 23.5 MV/m)
- Some additional gradient “loss” due to tunnel waveguide distribution
- After initial commissioning design gradient almost reached
- Operation of RF stations “off beam” allows final commissioning of single stations parallel to XFEL operation

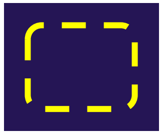
courtesy W. Decking

Overview European Xray Free-Electron Laser



in operation

dito. but shifted off beam



off

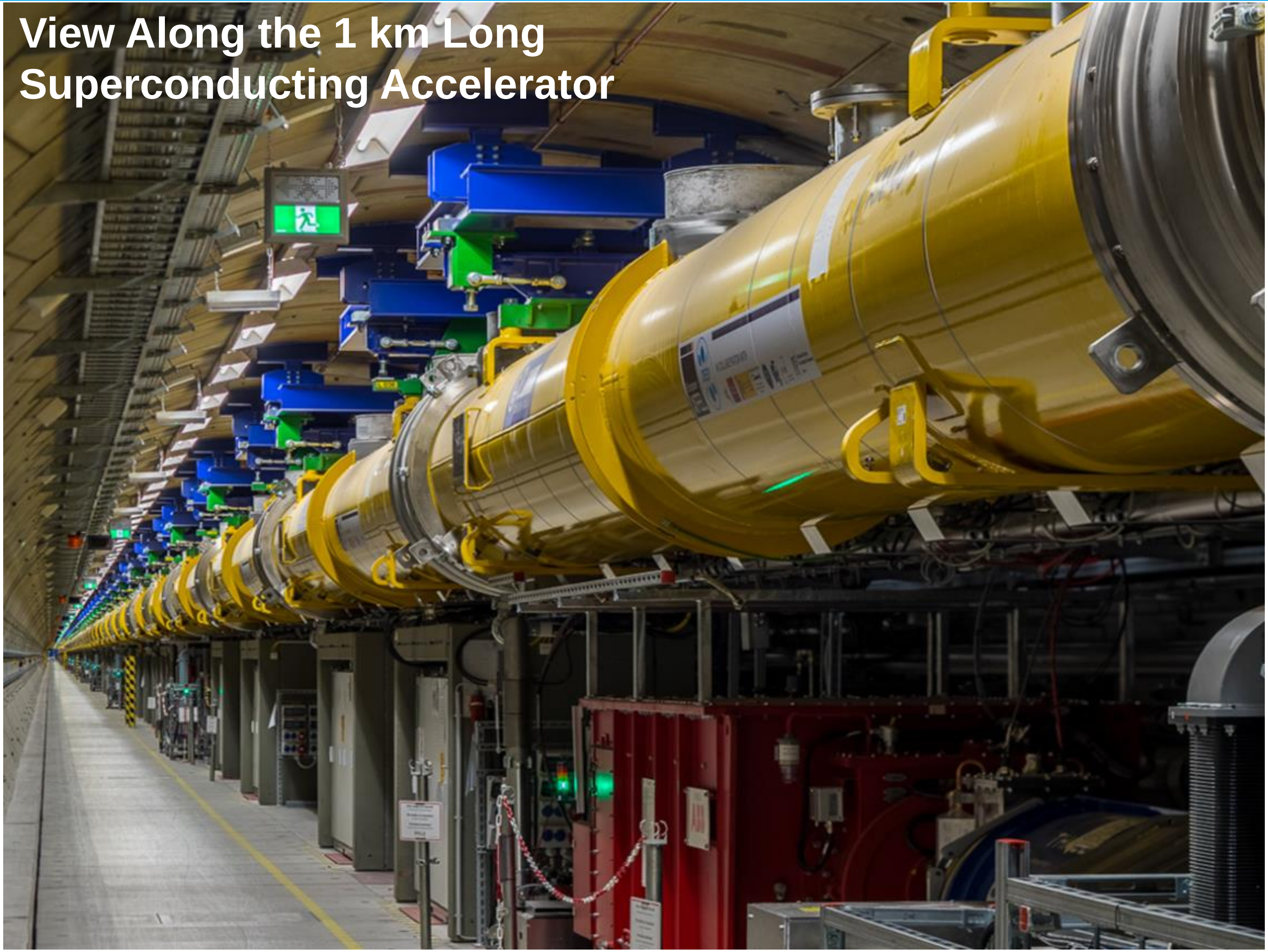
- 20 out of 25 RF stations are commissioned
- Handed over to operations and controlled via FSM
- Inner loop RF stability <0.01 deg, < 0.01%
- Preliminary measurements of beam energy jitter ≈ 10^{-4}

courtesy W. Decking

Overview European Xray Free-Electron Laser

courtesy W. Decking

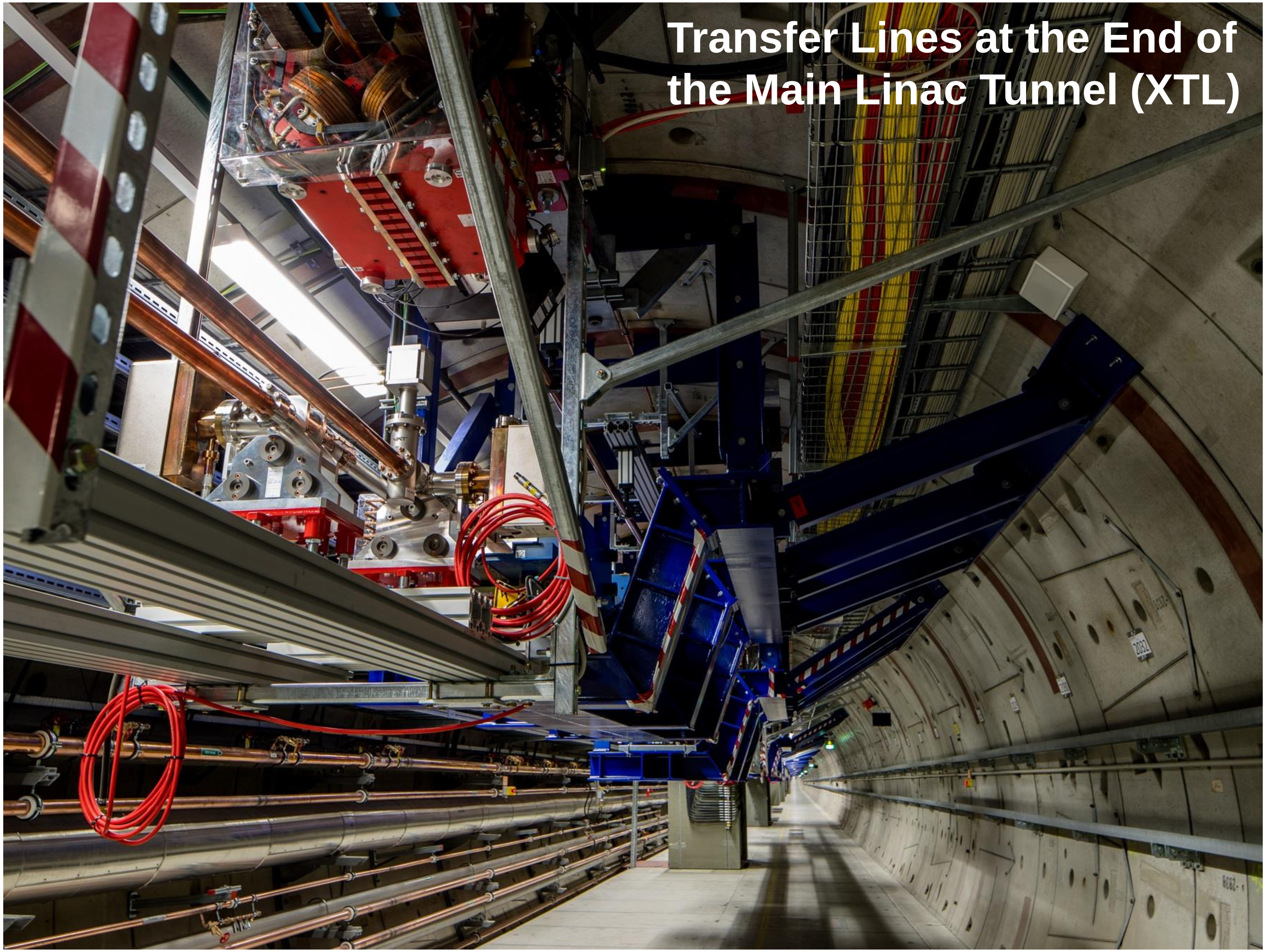
Overview European Xray Free-Electron Laser



View Along the 1 km Long Superconducting Accelerator

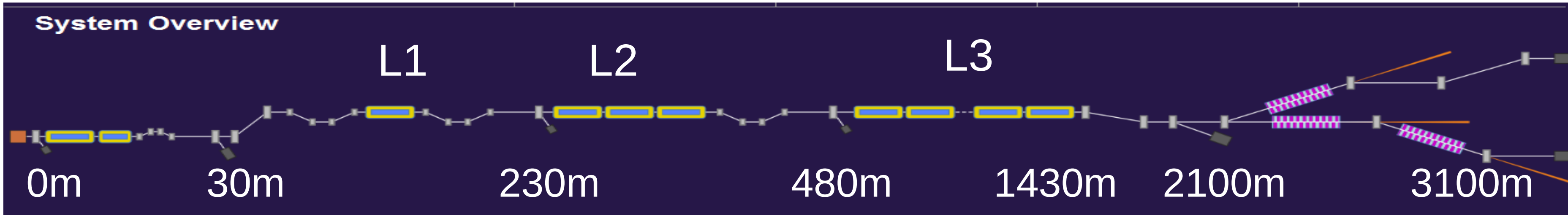
courtesy W. Decking

Overview European Xray Free-Electron Laser



courtesy W. Decking

Overview European Xray Free-Electron Laser



13/01*

15/01 @ 130 MeV
19/01 @ 600 MeV

* Beam permission on 13/01

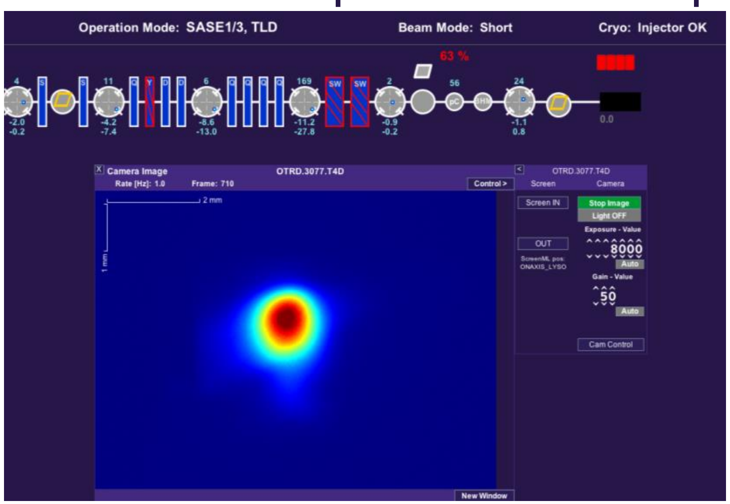
02/02 @ 600 MeV
22/02 @ 2.5 GeV

25/02 @ 2.5 GeV
19/03 @ 6 GeV
08/04 @ 12 GeV

27/04*

* Beam permission on 26/04

27/04 Beam spot before dump



courtesy W. Decking

DESY

Overview European Xray Free-Electron Laser

Quantity	Target	Achieved
electron energy	14 GeV	12 GeV%
macro pulse repetition rate	10 Hz	**10 Hz**
RF pulse length (flat top)	600 µs	**600 µs**
# bunches / second	600	**300$**
bunch charge	0.5 nC	**0.1, 0.5 nC**
electron bunch length after compression (FWHM)	90 fs	**90 fs**
Normalized slice emittance	1 mm mrad	**0.6 mm mrad**
beam power	4.2 kW	1.8 kW

$: in the injector

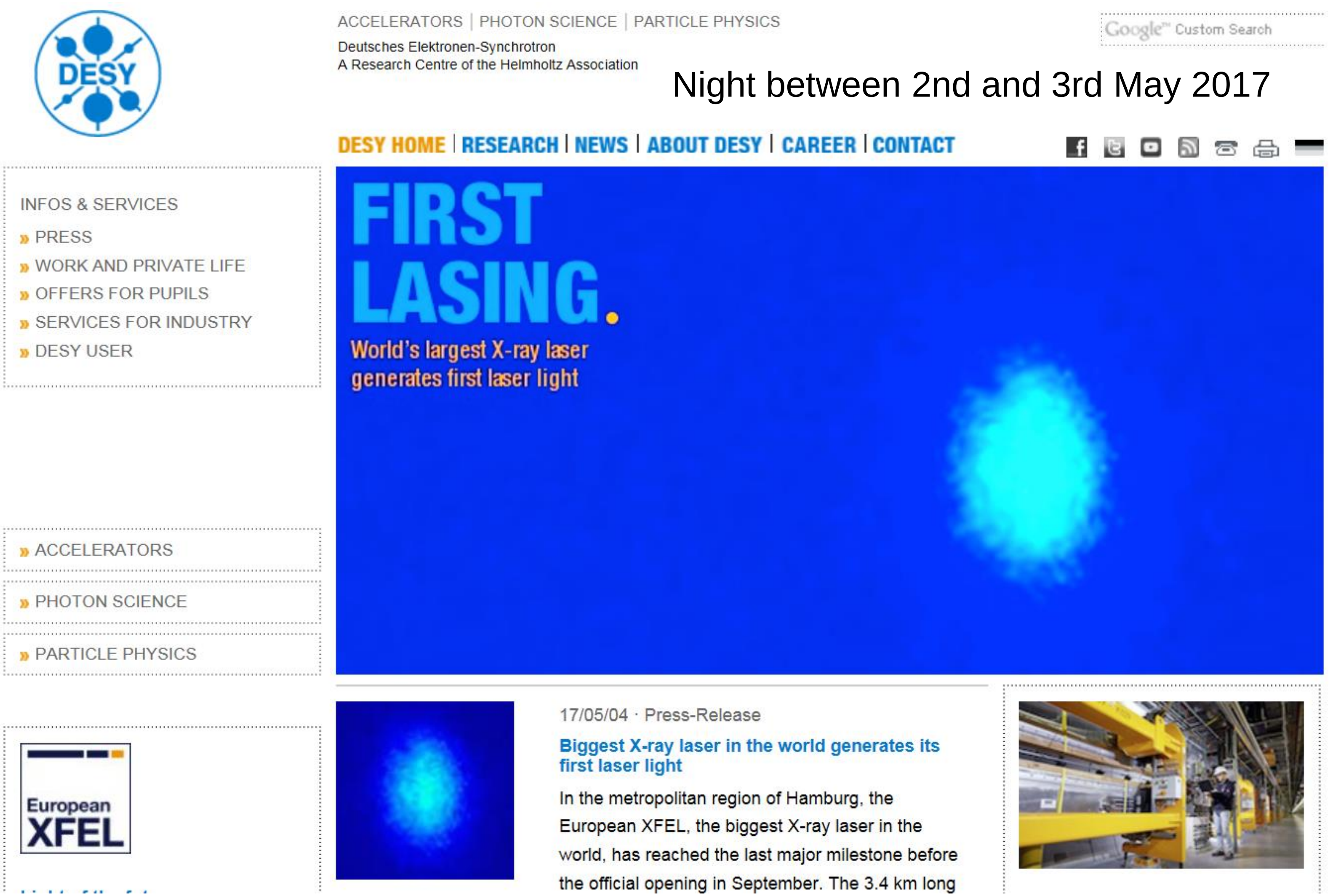
% Initial commissioning at reduced gradients & 3 more stations ready

$ Machine protection system ‘soft’ limit

courtesy W. Decking

Overview European Xray Free-Electron Laser

Night between 2nd and 3rd May 2017



courtesy W. Decking

Overview European Xray Free-Electron Laser

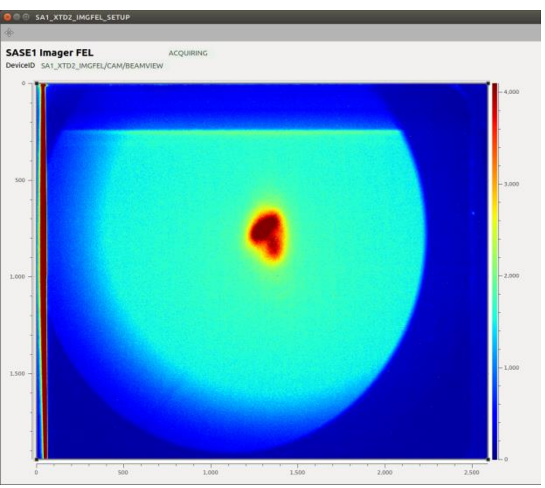
Improvement of beam position in SASE beamline increases energy

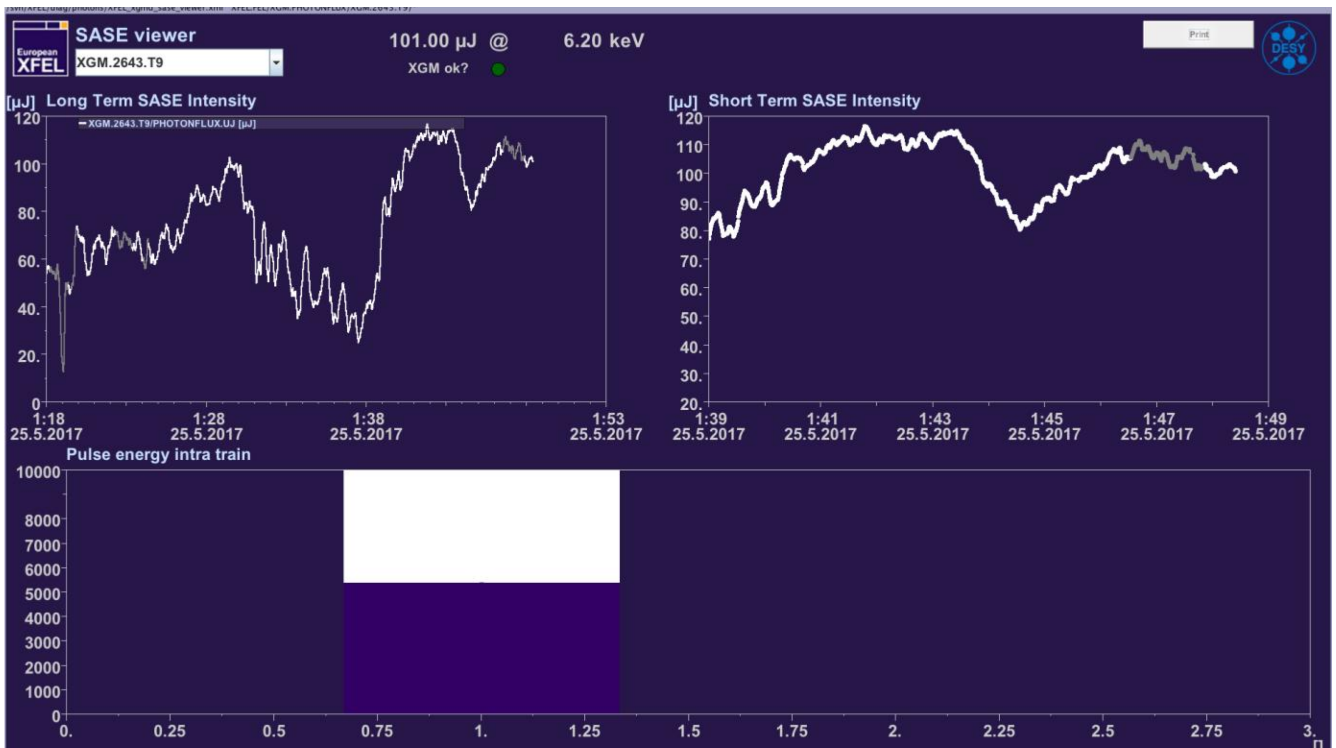
25.05.2017 0:00: dnoelle **Lasing at 2 Angström with pulse energies up to 100 µJ**

using a beam with 500 pC ad 10.3 GeV with moderate compression settings.

Using the results from the last BBA (nichtshift from 23rd to 24th of May) the SASE1 undulator was closed segment by segment, always correcting the orbit to the BBA straight line. After about 10 segments being closed, first indications of SASE could be seen on the first imager in the photon beamline. After closing more undulators the signal could be tuned, and intensity measurement by the XGM show up to 100 µJ SASE pulses at a wavelength of 2 Angström or 6.2 keV. The SASE operation could be keept over night and during the next day with variing but still some 10 µJ level.

25.05.2017 01:48 **XFEL** fbrinker, dnoelle, jgruenert, zpisarov **6.2 KeV, 500 pC, 10.3 GeV signal on XGM**





Standard diagnostics for the E-XFEL

Systems count in total and per section

- Gun
- Injector
- XTL: the long accelerator with collimator section
- XTD: undulator sections up to dumps

All components, except wire scanners, used in entire facility are tested in injector

System	Subsystem	Gun	Injector [XTIN]	XTL	XTDs
BPM system	Button	3	7	162	126
~ 460	Cavity Ø 10 mm				103
	Cavity Ø 40.5 mm		3	19	5
	Reentrant		1	23	
	Button Compressor			3	
	HOM		2		
Charge	FCUP	4			
~ 50	DaMon	1	1	7	
	Toroid	1	3	16	15
Screens	Simple	3			
~ 70	Complete		7	26	16
	Dump		1	4	5
	Compressor			3	
Wire scanners				6	6
12					
Loss monitors	BLM	1	18	230	240
~ 490	BHM		1	1	2

Diagnostics setup: BPMs

BPM types

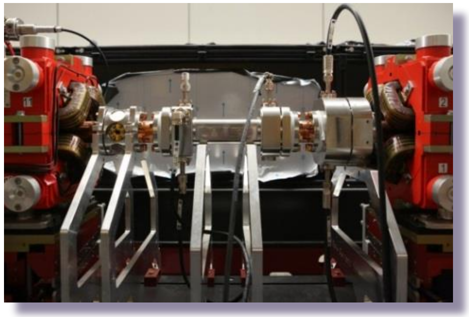
- Button for different beam pipe diameter
- Low Q cavity BPMs with 2 beam pipe diameters
- Reentrant Cavity BPM (30% of cold LINAC)

Collaboration (institutes and tasks)

- CEA Saclay: re-entrant cavity BPM for cold modules including front end electronics
- DESY: button and cavity BPM mechanics
- PSI: front end electronics (button and cavity BPM) and digital back end (all)

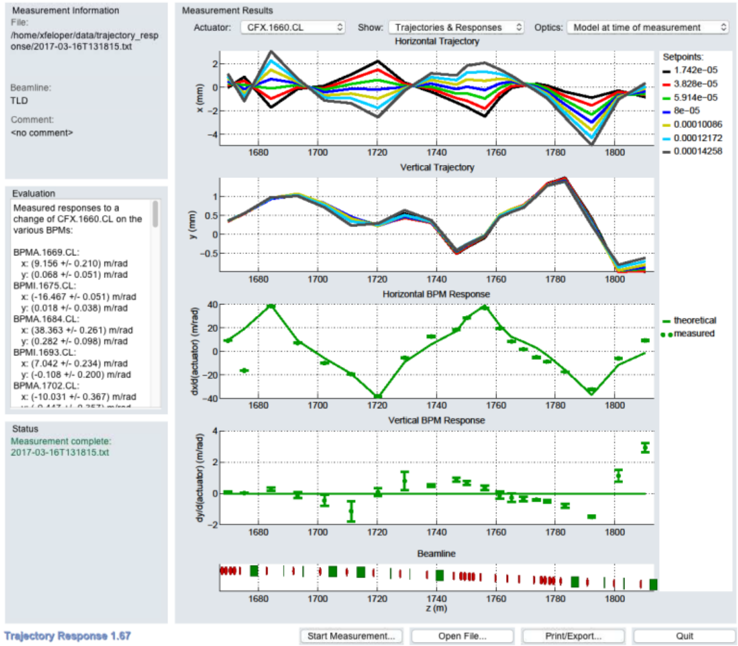
Readout

- MBU (Modular BPM Unit)
- Single bunch measurement
- Connection to DOOCS via a FPGA-FPGA bridge with optical fibers.
- Decoding of E-XFEL timing protocol in MBU

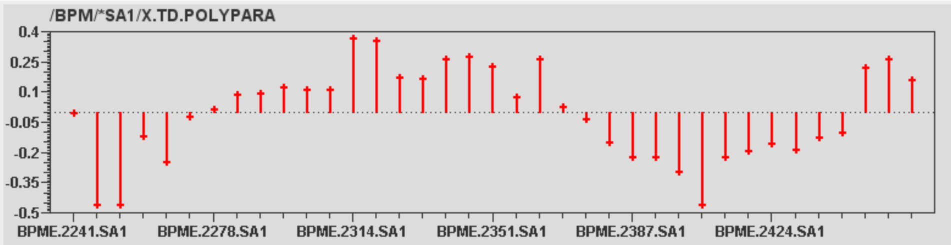


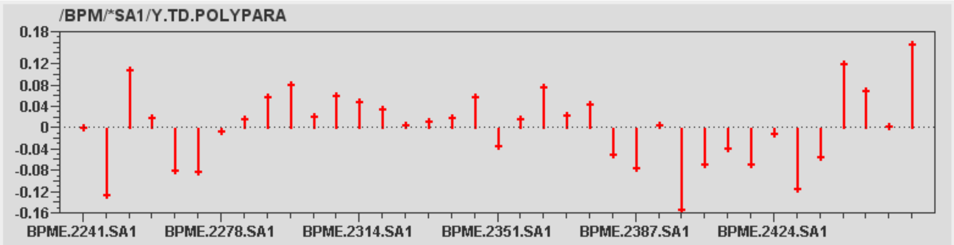
Diagnostics: BPMs

- Operational from day 0
- Start with self trigger mode: voltage above ADC threshold, find beam bucket precisely, beam detected immediately
- Trigger delay measured, set in control system, followed by fine adjustment for cavity BPMs
- Laboratory calibration used and checked for buttons and cavity BPMs, reentrant cavity BPM calibrated beam based
- Stable, robust operation, except some communication problems between PSI backend and DESY µTCA system still recently in the SASE1 section



- Undulator BPM offsets in SASE1 section after BBA:

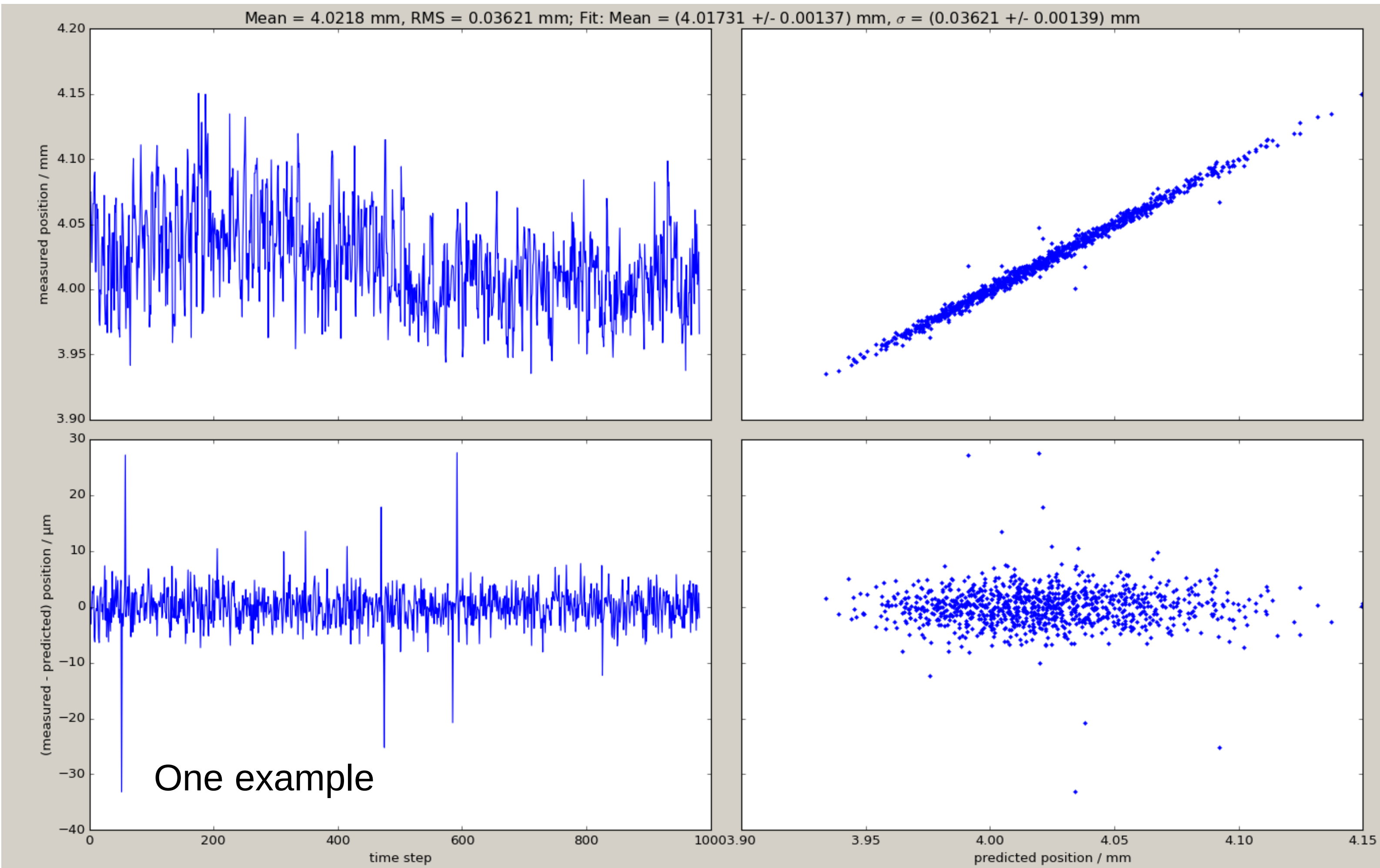




BPM: resolution measurement

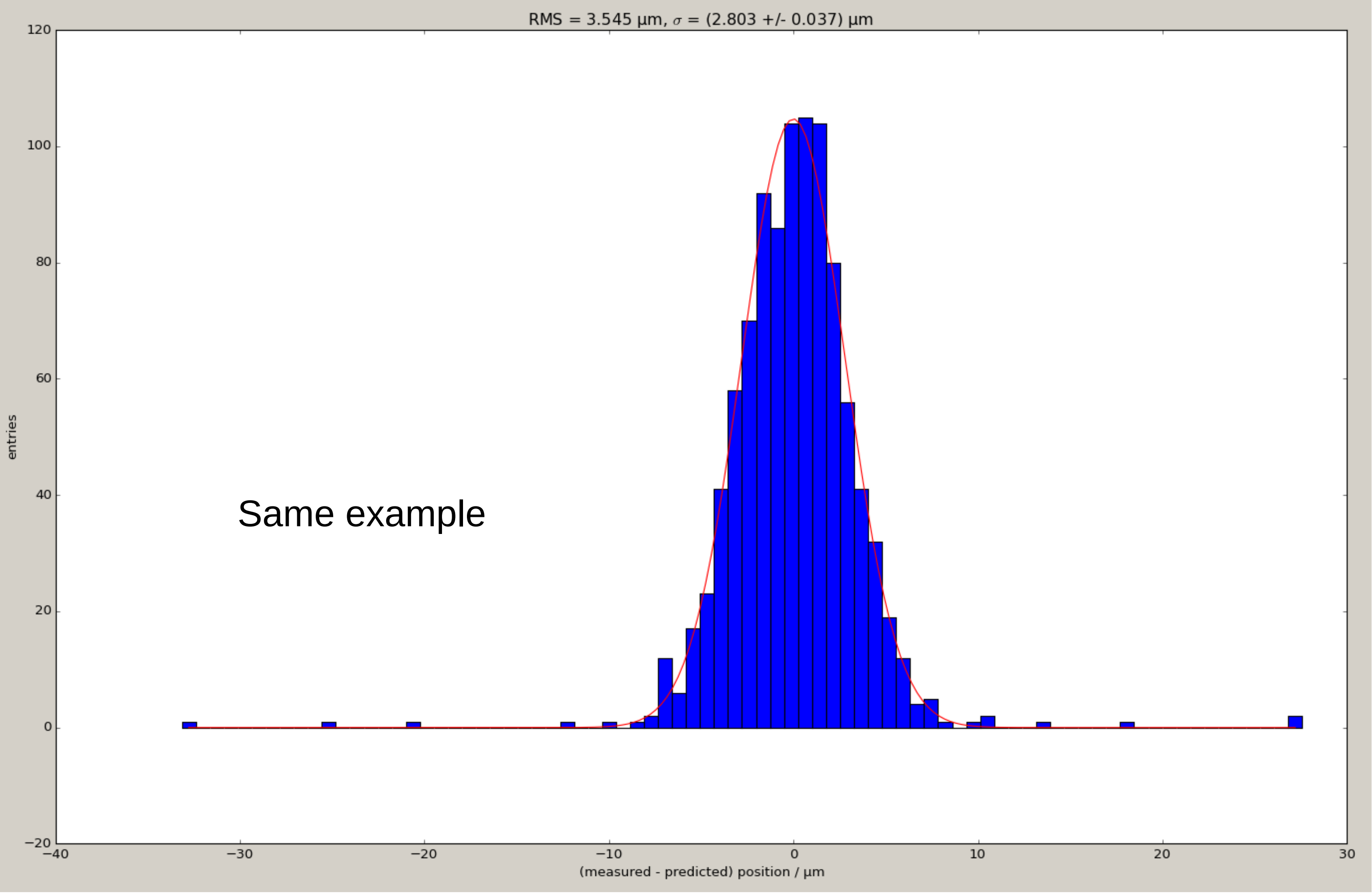
- One BPM compared to all others with model independent analysis

Method see N. Baboi et. al.: http://dx.doi.org/10.1063/1.2401409



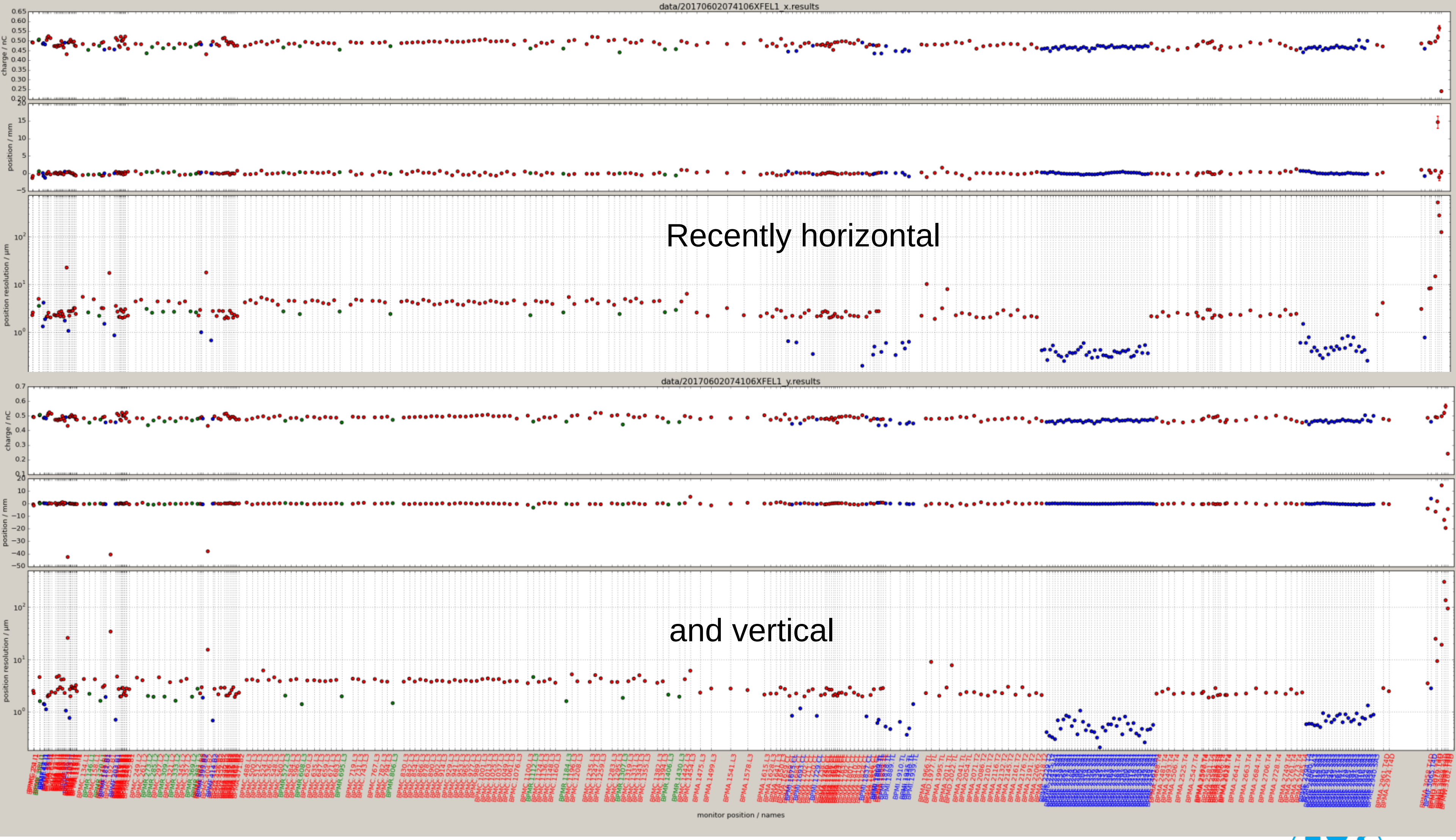
BPM: resolution measurement

- Analysis of residual results in standard deviation from gaussian fit



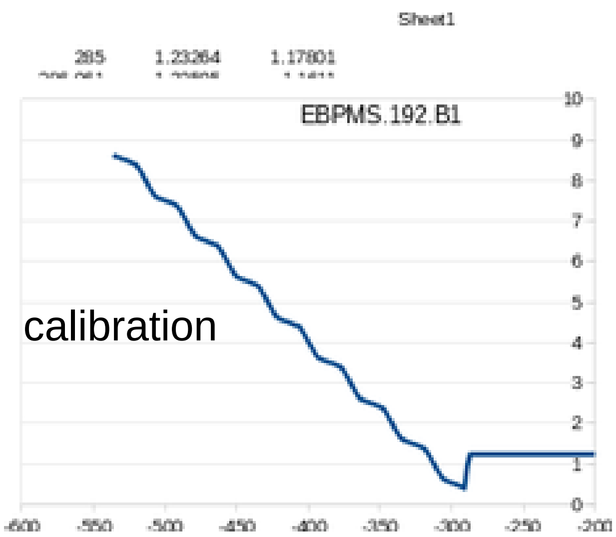
BPM: resolution measurement

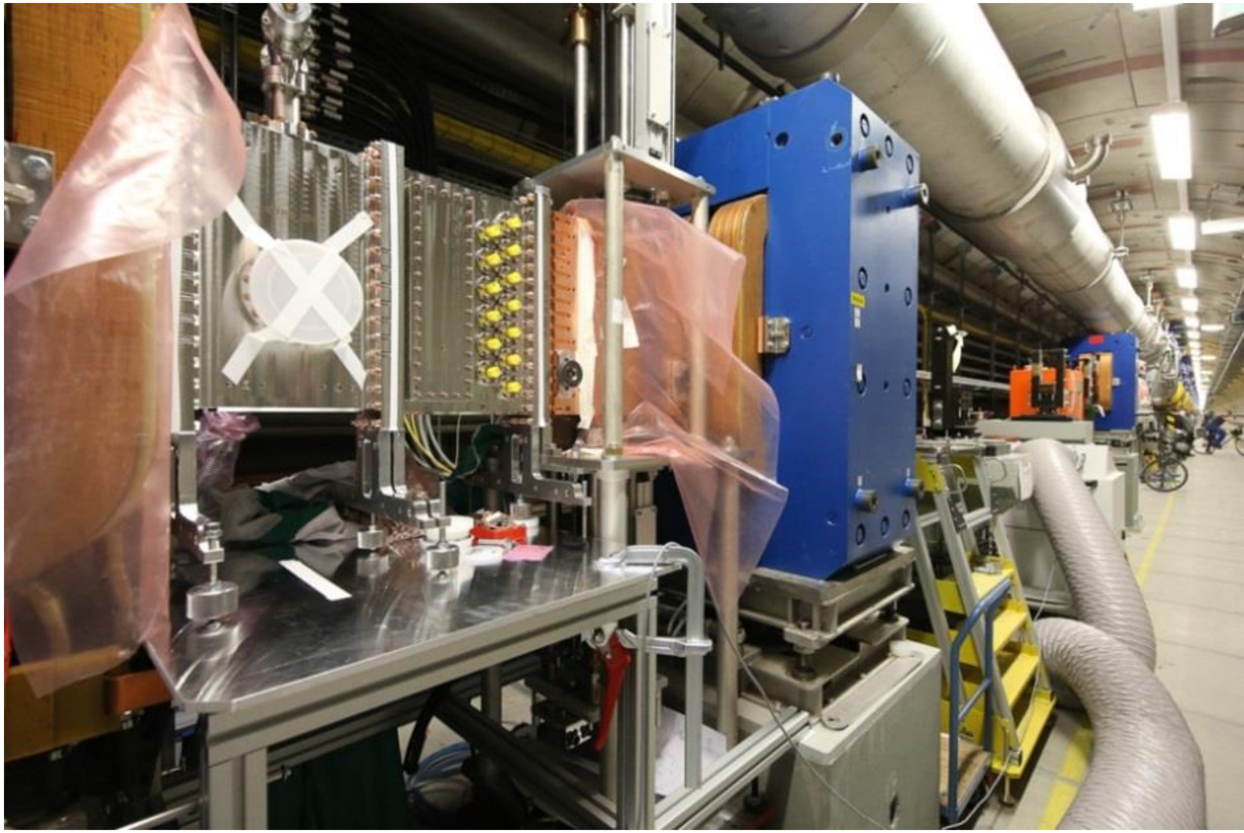
- Do this for all BPMs



BPM: bunch compressor

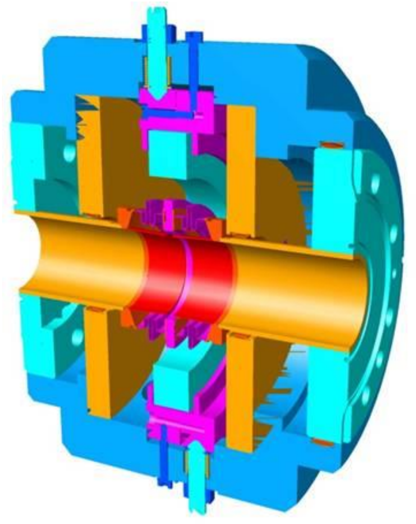
- Special construction at bunch compressor with 400 mm x 40 mm inner chamber aperture
- FLASH button electronics

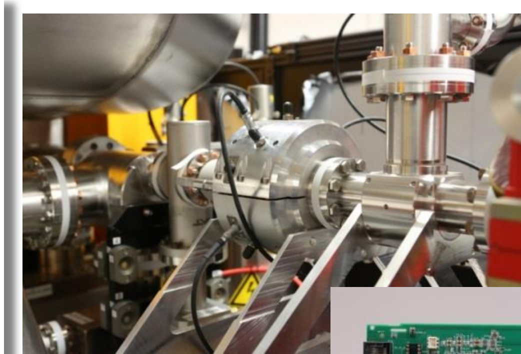


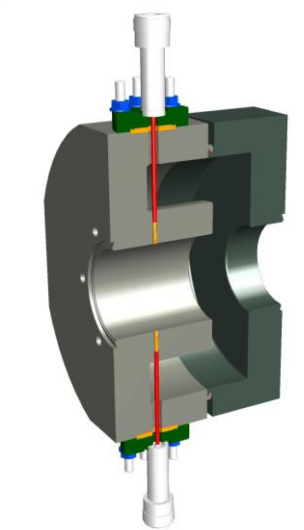


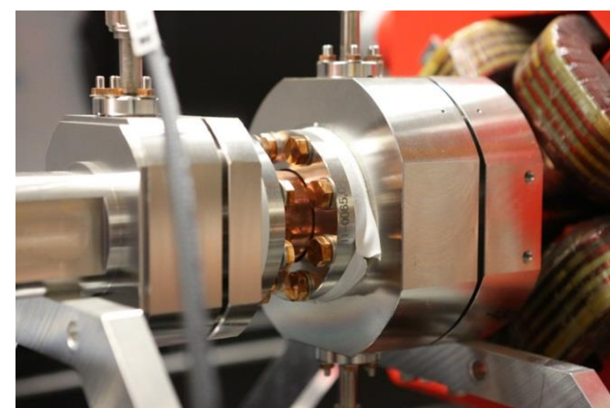
Diagnostics setup: charge monitors

- **Toroids or Current transformers** provide differential signal from RFFE processed in µTCA; test-winding for calibration and self-test; connection to MPS for transmission
- **Dark current Monitors** (DaMon) low Q resonators at 1.3 GHz to provide field amplitude from beam and dark current bunches, signal processing via down conversion and log-amplifiers
- Additional data from BPMs and Faraday cups



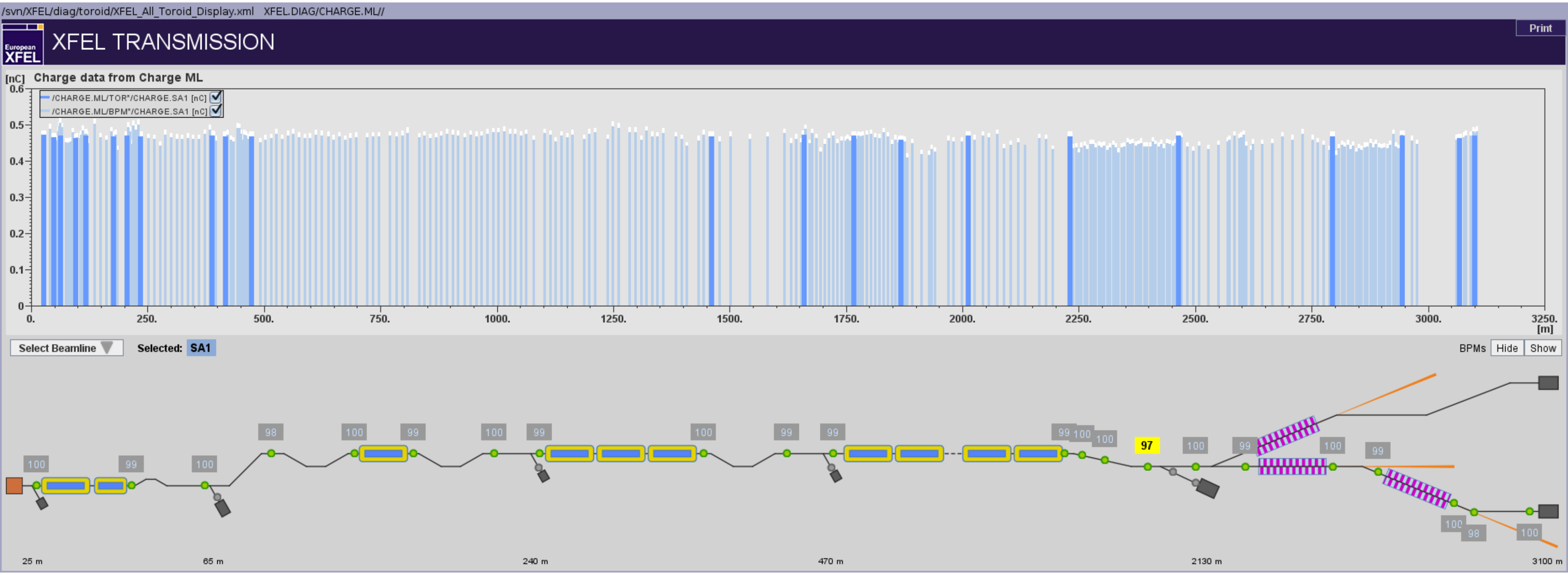






Diagnostics: charge monitors

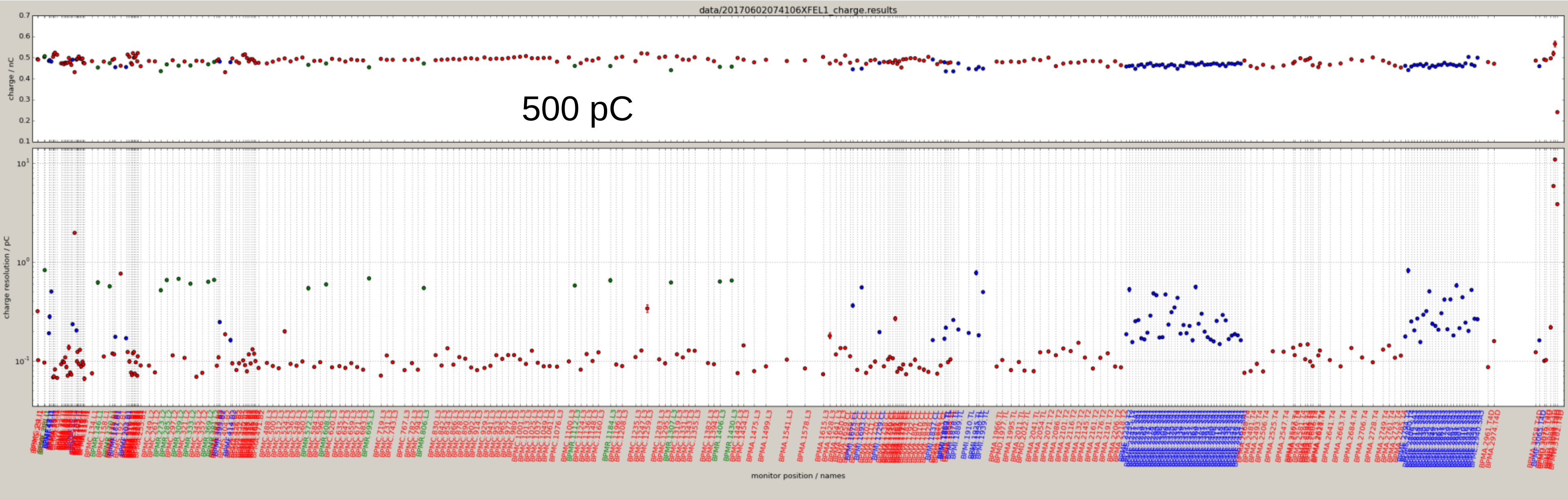
- Charge transmission GUI with Toroid (dark blue) and BPMs (bright blue)



- Start with self trigger, operational from 1st day
- Based on laboratory calibration, beam based adjusted at BPMC and Toroid in dump (4%)

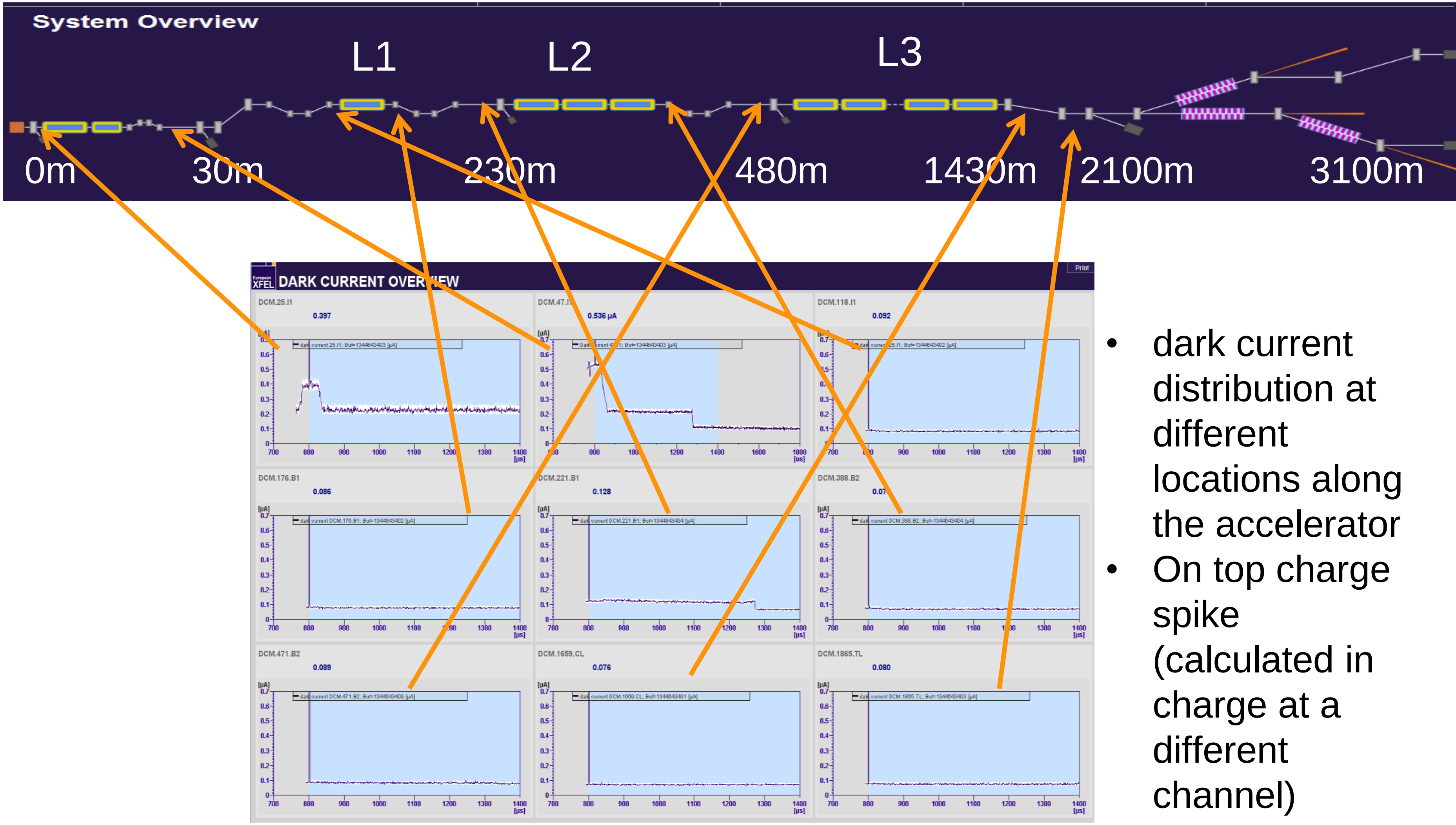
Diagnostics: BPM charge resolution

> Charge resolution of BPMs; Toroids will be included later



Buttons (red) better charge resolution compared to cavities (green and blue), all below 1pC

Diagnostics: dark current monitor



- dark current distribution at different locations along the accelerator
- On top charge spike (calculated in charge at a different channel)

Charge can be detected with few fC at DC channel (helpful after maintenance)

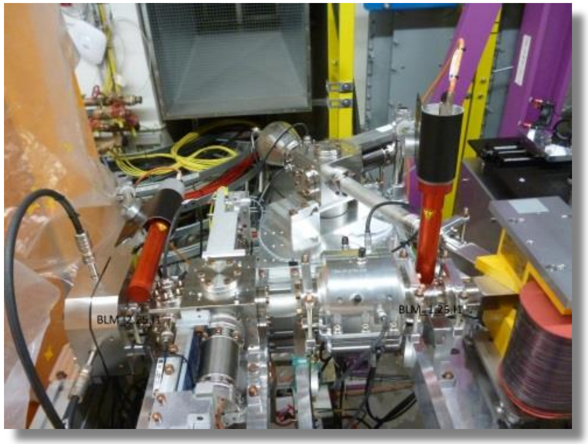
Diagnostics setup: beam loss and halo monitors

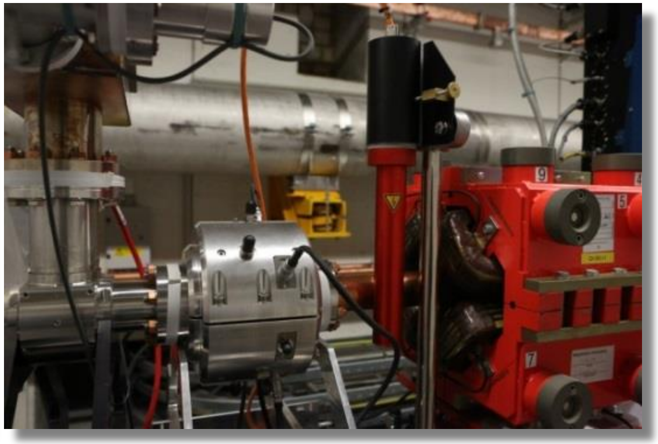
BLMs:

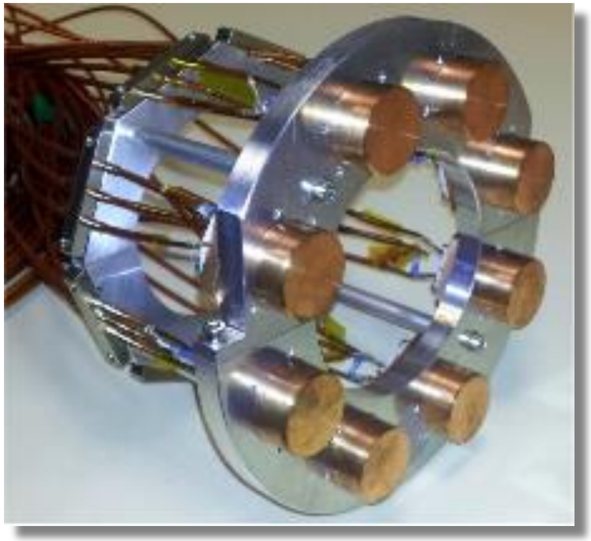
- Scintillators with photomultipliers
- Single bunch resolution
- On board HV generation
- Single, multiple bunch and integration alarms to MPS
- Readout by µTCA board with rear transition module, digital interface to MPS system

Halo monitors (BHM):

- Radiation hard sensors: diamond and sapphire with different sensitivities to enhance dynamic range
- Installed in dump line around pipe
- Readout similar to BLMs





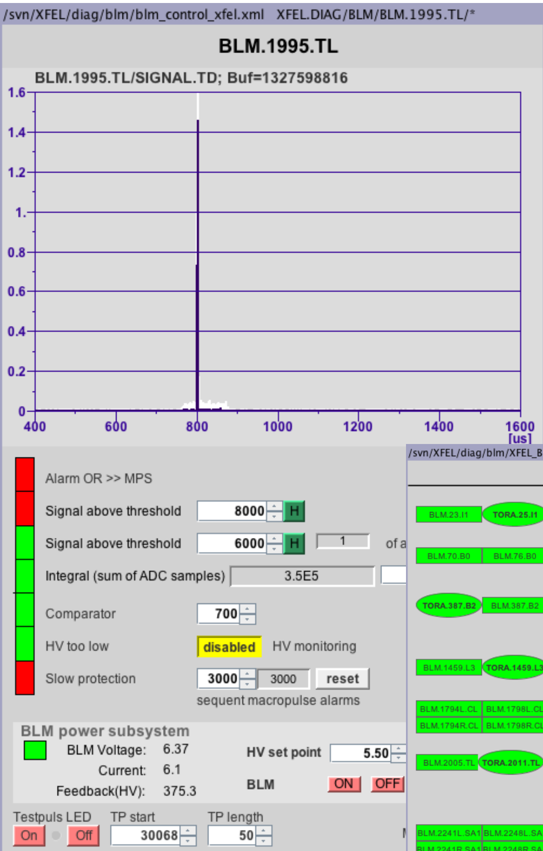


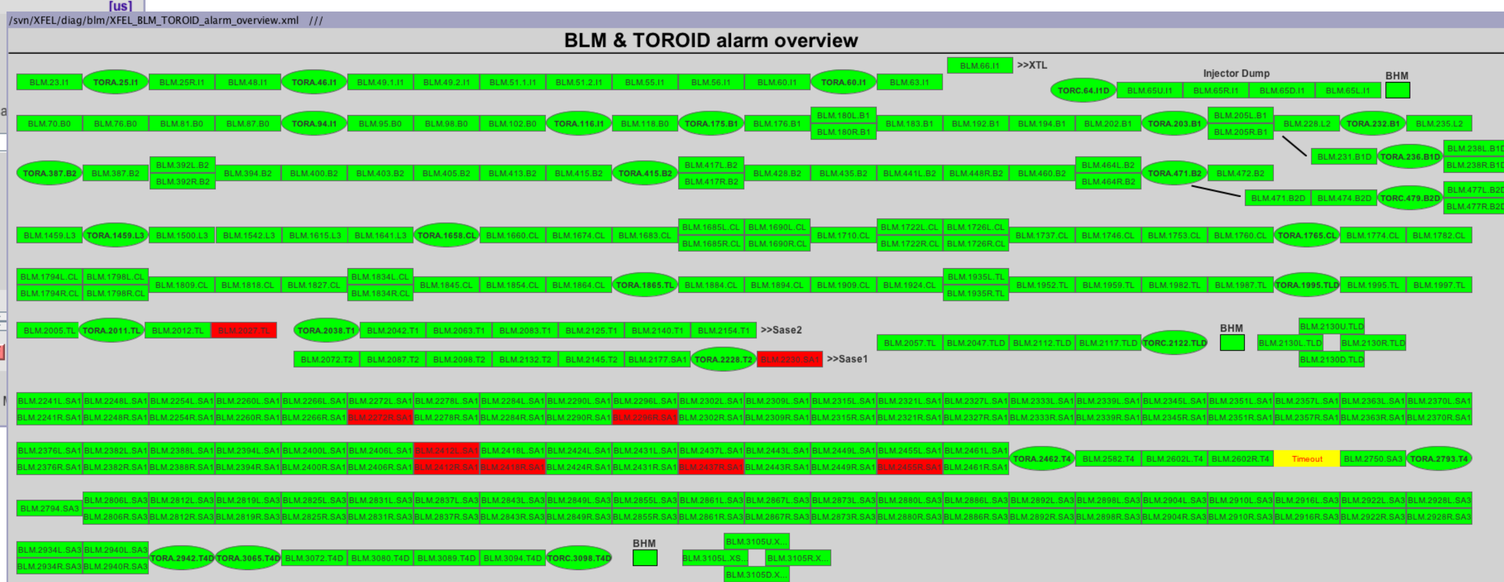
Diagnostics: beam loss monitors

> During operation BLM show losses and alarms

> If number of macro-pulse above threshold is exceeded the signal is transmitted to MPS and inhibits beam

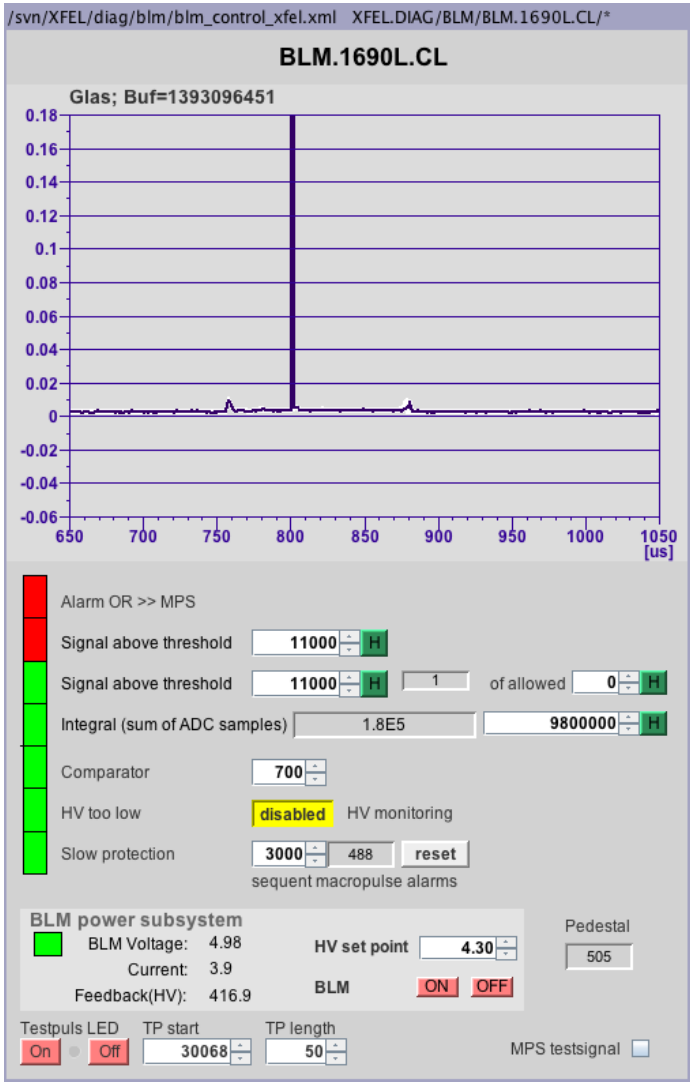
> Reset necessary; orbit correction





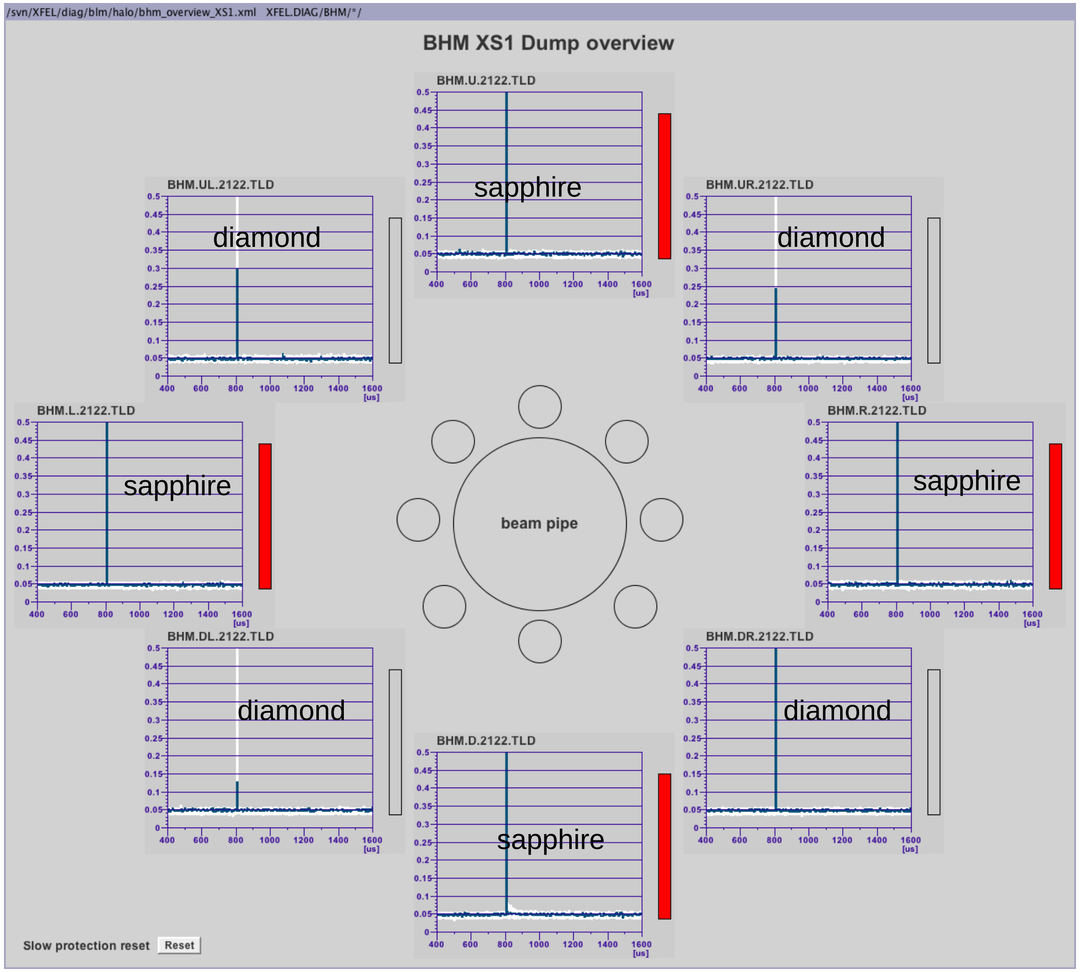
Diagnostics: beam loss monitors

- Detected beam before and after main bunch
- Sensitivity of dark current monitor is lower compared to BLM but charge estimated about few fC (with DaMon)
- Problem with photo cathode pockels cell, is solved last week



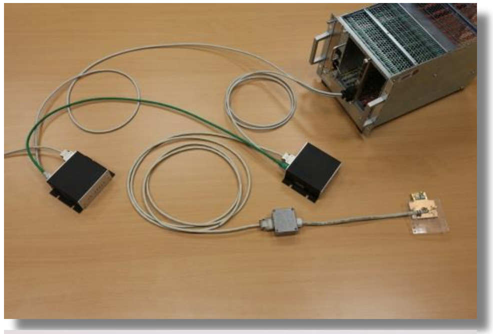
Diagnostics: beam halo monitors

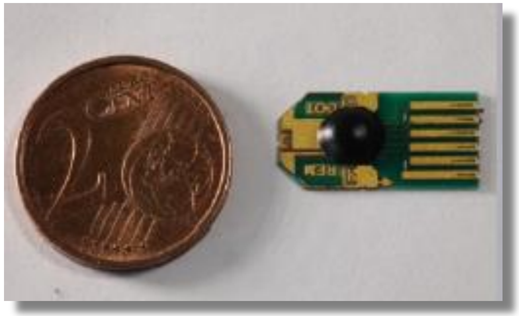
- Example with large beam size at first main dump
- Causes alarm to MPS

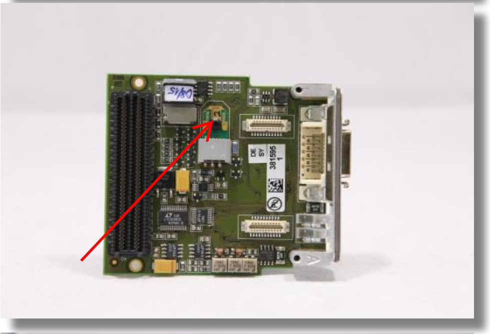


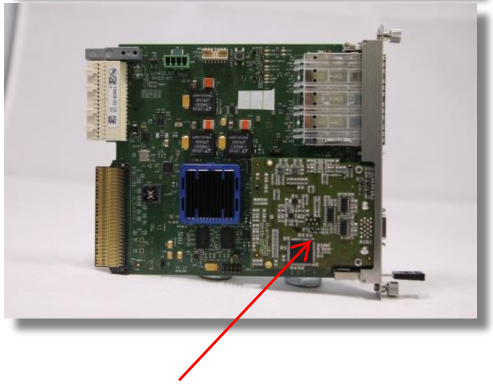
Diagnostics setup: dosimetry

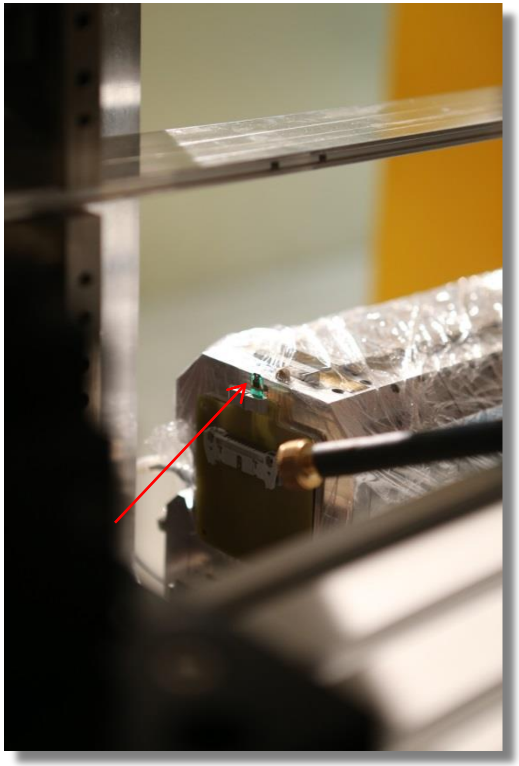
- Gamma sensors RadFets for online measurements of accumulated dose
- Plug-in readout module (according FPGA Mezzanine Card [FMC] standard)
- Hosted on FMC carriers, e.g. DAMC02 or other systems like PSI BPM electronics
- Internal and external sensors:
  - internal sensors on MPS and BPM boards distributed inside the machine racks
  - outside of racks, connected via field bus system
- Option to extend for Neutron dosimetry





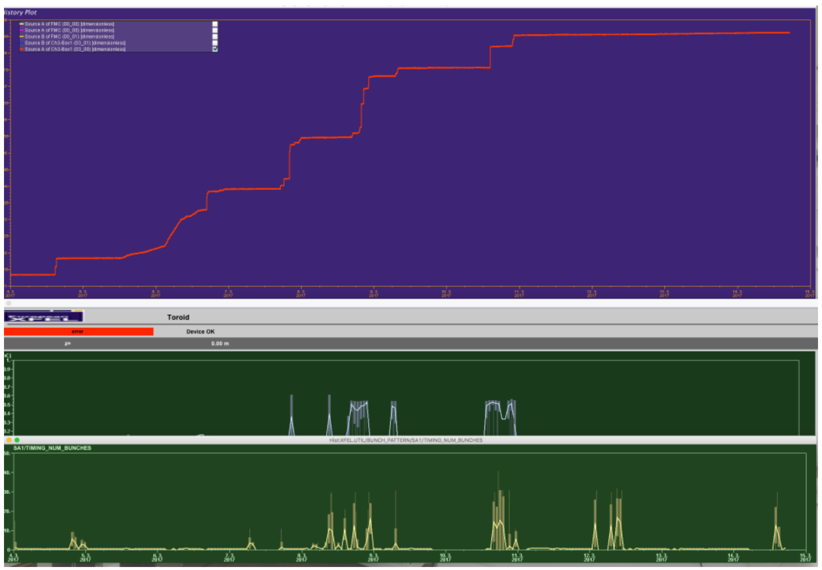


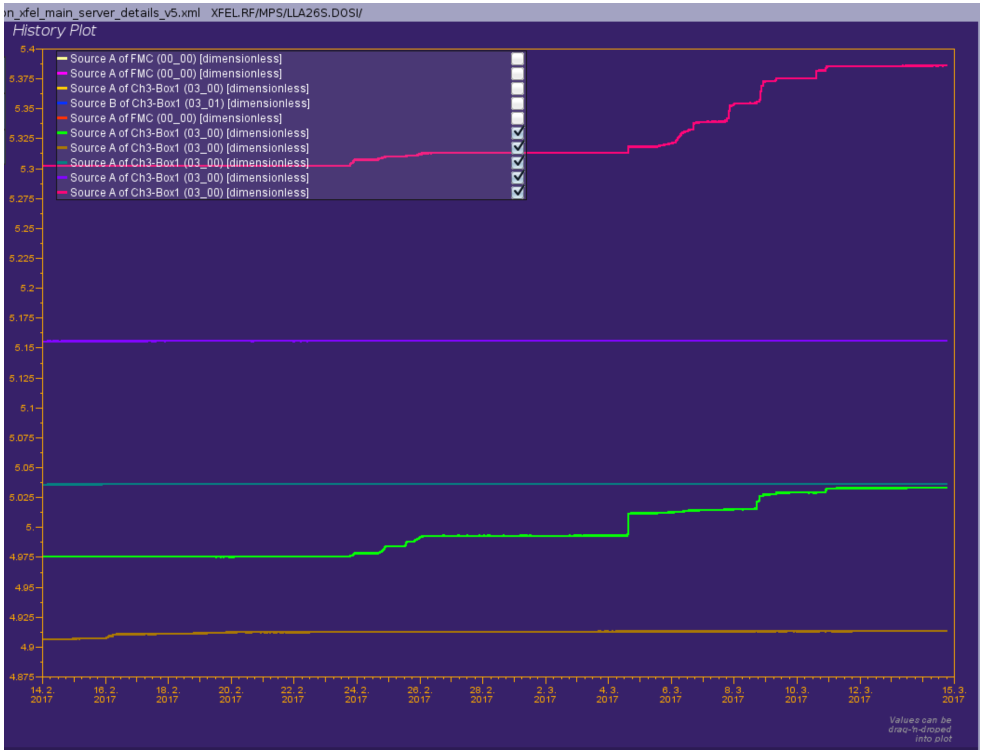




Diagnostics: dosimetry

Logbook entry: “The plot shows the readings from RadFet sensors outside of the shielding. The scaling is roughly 5.6 Sv/V. The brown line is a sensor in A6, green and pink are external sensors in A26.
The others are A25 and one station in the middle of the L3. One can see some dose at the L3 entrance, I think due to B2D operation and at the end of L3 at the last module.
The dose at the end is roughly 0.5 Sv.”



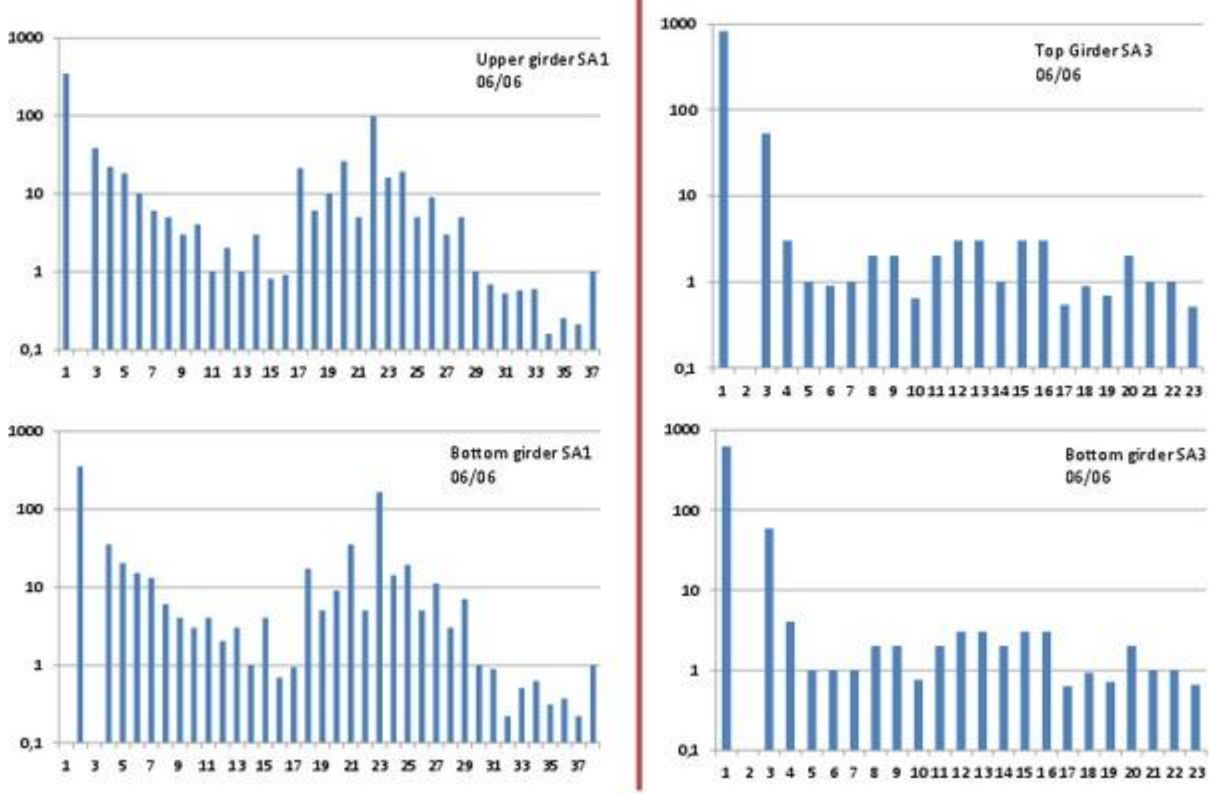


raw data of the radfet at the end of L3 together with toroid charge in TLD and bunch number

Diagnostics: dosimetry

Logbook entry: Overview on the radiation doses at SASE1 and SASE3

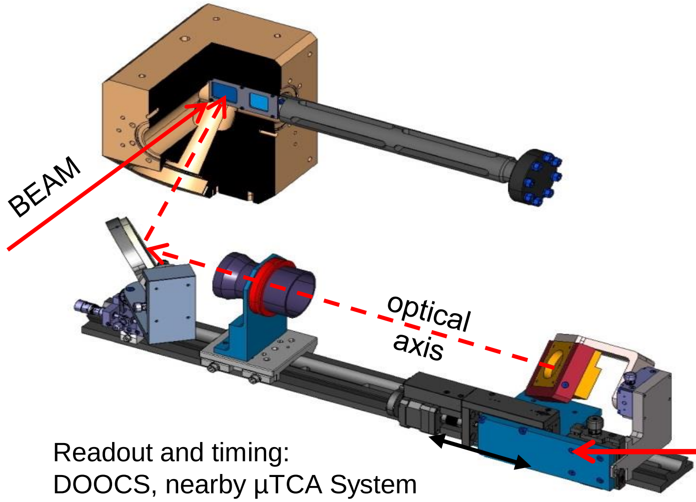
Increase on the absorbed doses is seen over the last week/Weekend in SASE1 and SASE3. The picture summarizes the current level in Gy per undulator cell of SASE1 and SASE3, both at top and bottom girders of the undulators.

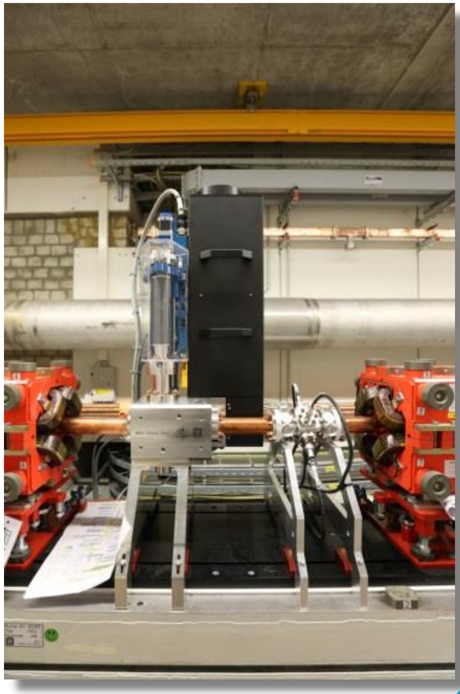


Doses in Gy at SASE1 and SASE3 cells as for 06/06/2017 at 8:00AM

Diagnostics setup: screens

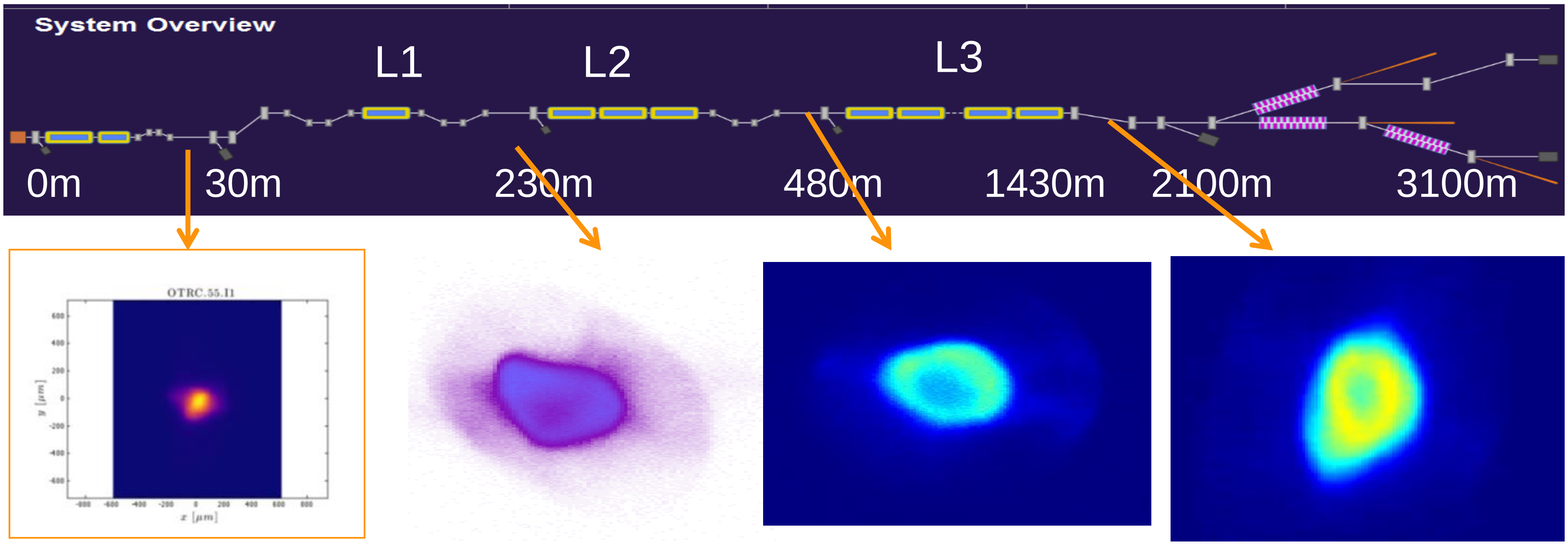
- Scintillator screens perpendicular to the beam, camera under 45° for spatial suppression of COTR
- Scheimpflug principle to extend depth of field over entire screen
- Screen actuator on mover to insert different targets: on- and off-axis screens and grid
- Camera Basler Aviator avA2300-25gm with possible two different lenses (1:1 and 1:2) on mover to focus the spot, optical resolution ≤ 10µm for 1:1
- Wire scanner will be used as well





Diagnostics: screen

„Smoke rings“

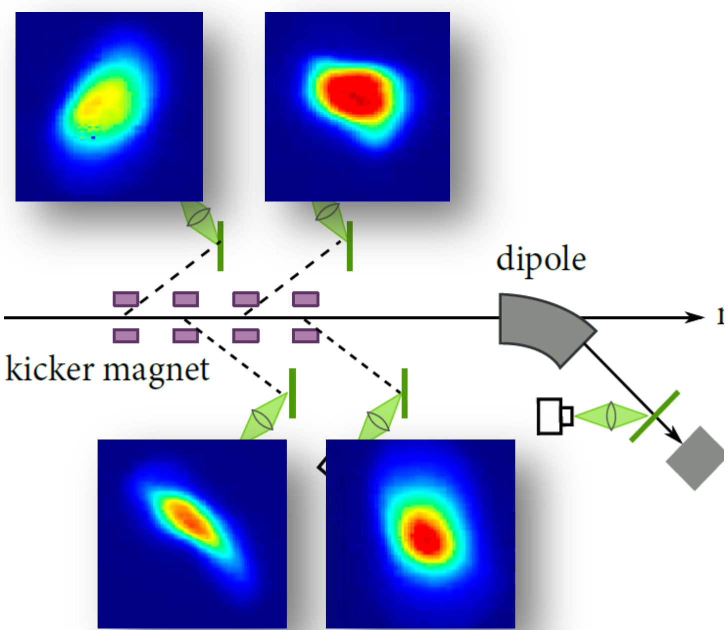


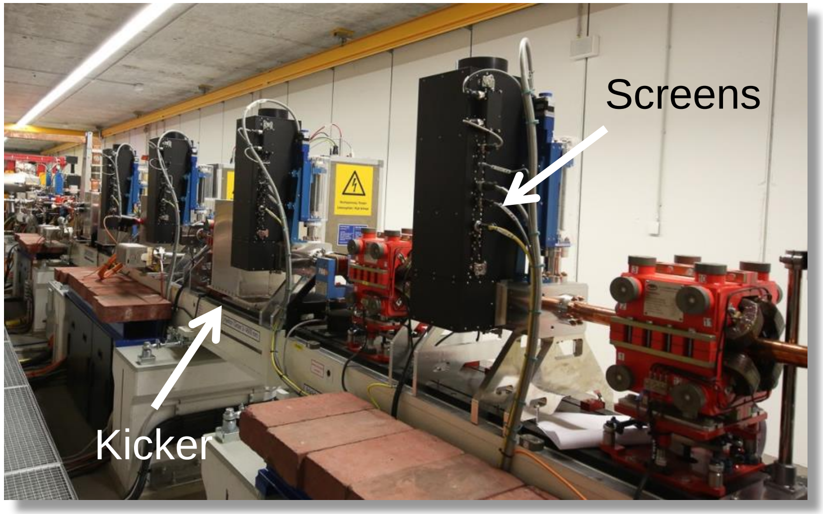
- Images of scintillating screens along the beam line
- Structure is present even after acceleration and compression
- Can be observed in simulations (non-linear space charge effect), but should be more sensitive to phase-advance …
- Maybe decrease of light intensity for higher charge density ?

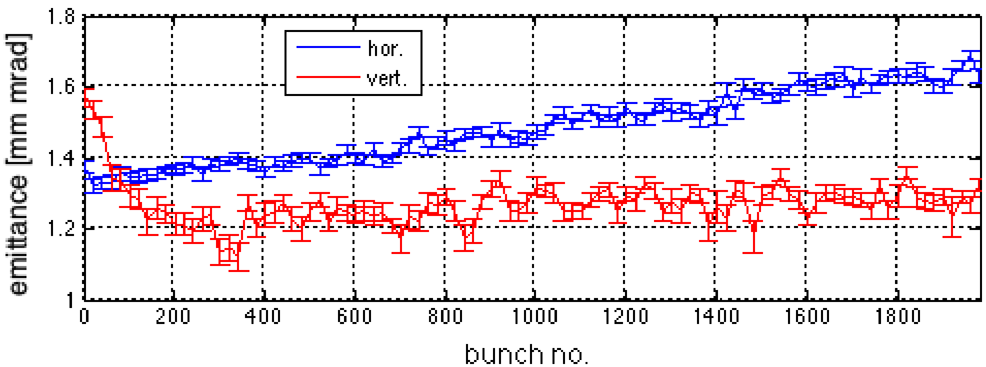
courtesy W. Decking

Diagnostics with screen stations: emittance along bunch train

Scheme of the XFEL injector diagnostics section







- Fast kickers kick single bunches out of the trains to off-axis screens
- "Semi-parasitic" diagnostics during beam delivery
- Together with transverse deflecting system also used for slice diagnostics

- Variations along the train can be monitored
- Corrections to provide uniform conditions along train

courtesy B. Beutner, M. Scholz

Diagnostics: Wire scanner

Tungsten wire thickness 10, 20 and 30um

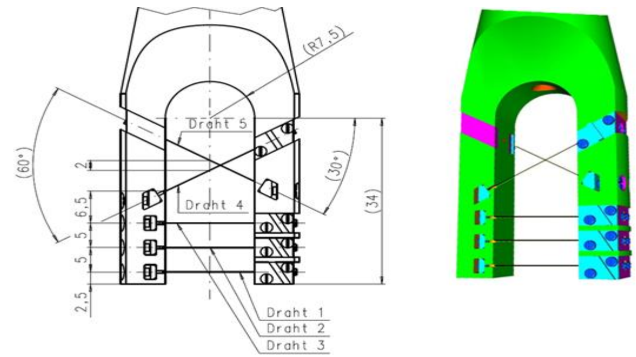
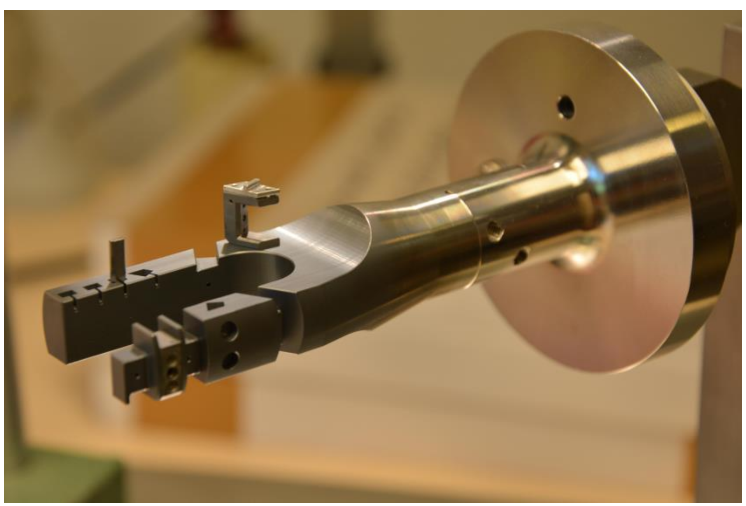
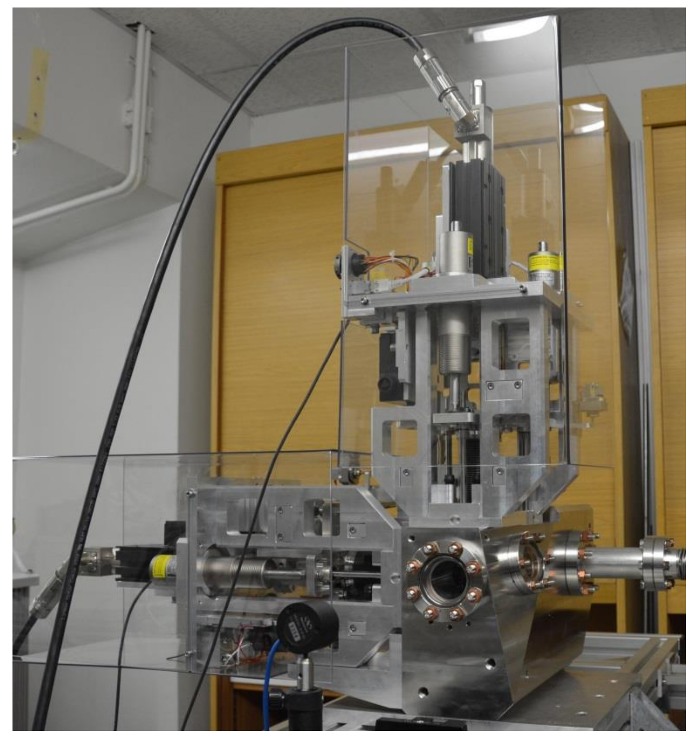


Figure 4 WS fork with wires: dimensions (left) and a 3D view (right).

Table 3 Wire scanner specifications

Units to install	24 (3x4 stations vertical/horizontal)
Number of wires per fork	3 + 2 (3x90deg, +/-60 deg)
Wire material	Tungsten
Fork gap	15mm
Wire-wire distance (0deg)	5mm
Stroke	53mm
Scanning modes	Fast (1m/s, <100ms/scan), Slow
Measurement duration	5 sec (per Emittance measurement station, i.e. 4 scanners)
Position accuracy in a cycle	2 µm (rms)
Width accuracy per cycle	2 % (rms)
Wire positioning error	1 µm





Diagnostics: Wire scanner

31.05.2017 11:16 Froehlich, Lensch, Liu **First test of wire scanners with beam**

We moved the first vertical wire (i.e. the 10 um W wire of the horizontal wire scanner) of OTRBW.1523.L3 into the beam. Beam losses are visible on the BLMs downstream and on the dedicated wirescanner detectors.

The first horizontal wire (for vertical wirescans) worked as well.

Summary

- EU-XFEL started with lasing this year
- BPMs, Toroids, BLMs and BHMs worked before beam appeared, self-trigger mode helpful for beam commissioning
- BPMs and Toroids within specification
- DaMon detects very low beam charges
- BLMs and BHMs work well with machine protection
- BLMs very sensitive to detect side bunches
- Dosimetry can be correlated with expected radiation
- Screens used to measure transverse distribution, „smoke rings“ under investigation
- Wire scanners started to be commissioned

Outlook

- Wire scanners will be commissioned further
- SASE2 installation ongoing
- SASE2 commissioning expected second half of October this year
- 2 seed sections with 2 cavity BPMs without reference to be commission

Outlook

Thanks to all colleagues who contributed to this work!

Thank you for your attention!