First Experience with the Standard Diagnostics at the European XFEL Injector

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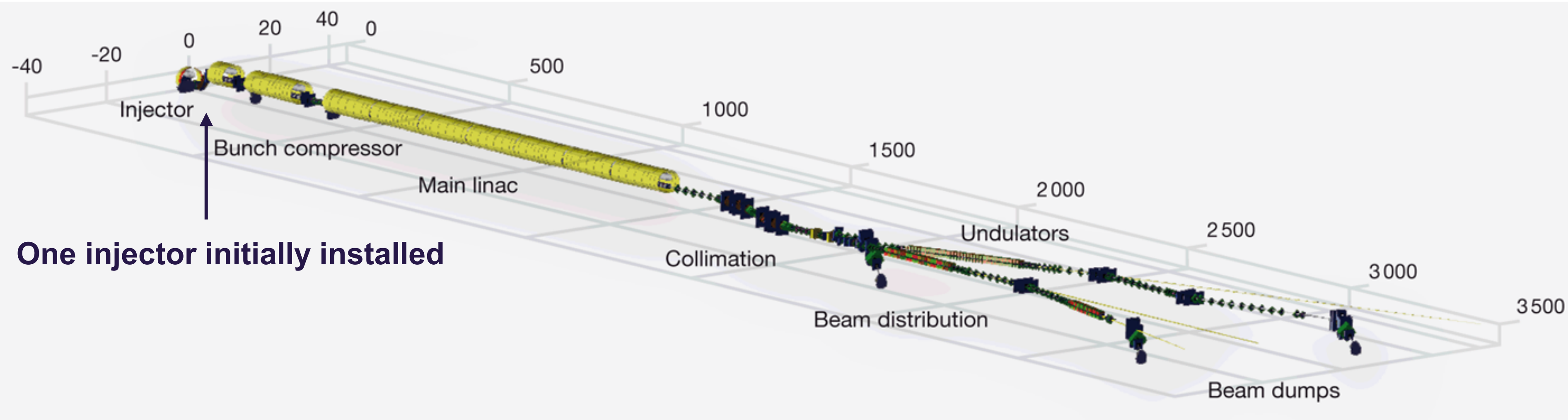
Outline

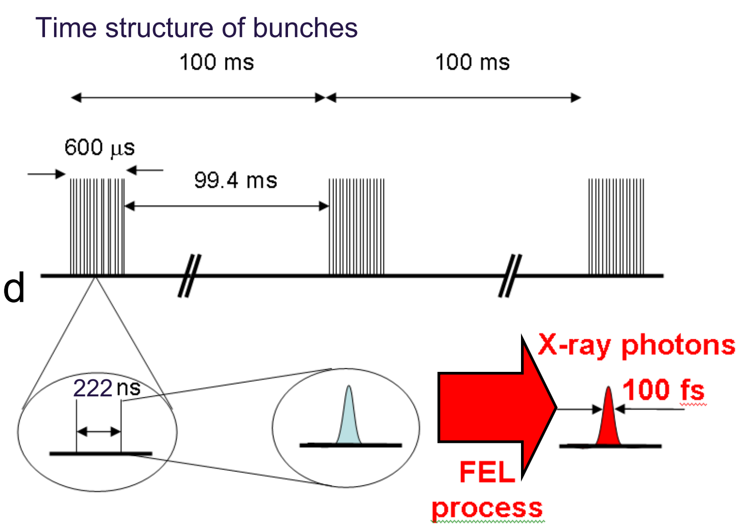
- Overview European XFEL
- Standard diagnostics for the E-XFEL
- Injector
  - Chronological order of beam commissioning
  - Diagnostics setup and experience from injector commissioning and optimization
  - Highlights
    - Emittance along the bunch train
    - TDS operation with off-axis screens
- Summary
- Outlook to E-XFEL commissioning

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 (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



Standard diagnostics for the E-XFEL

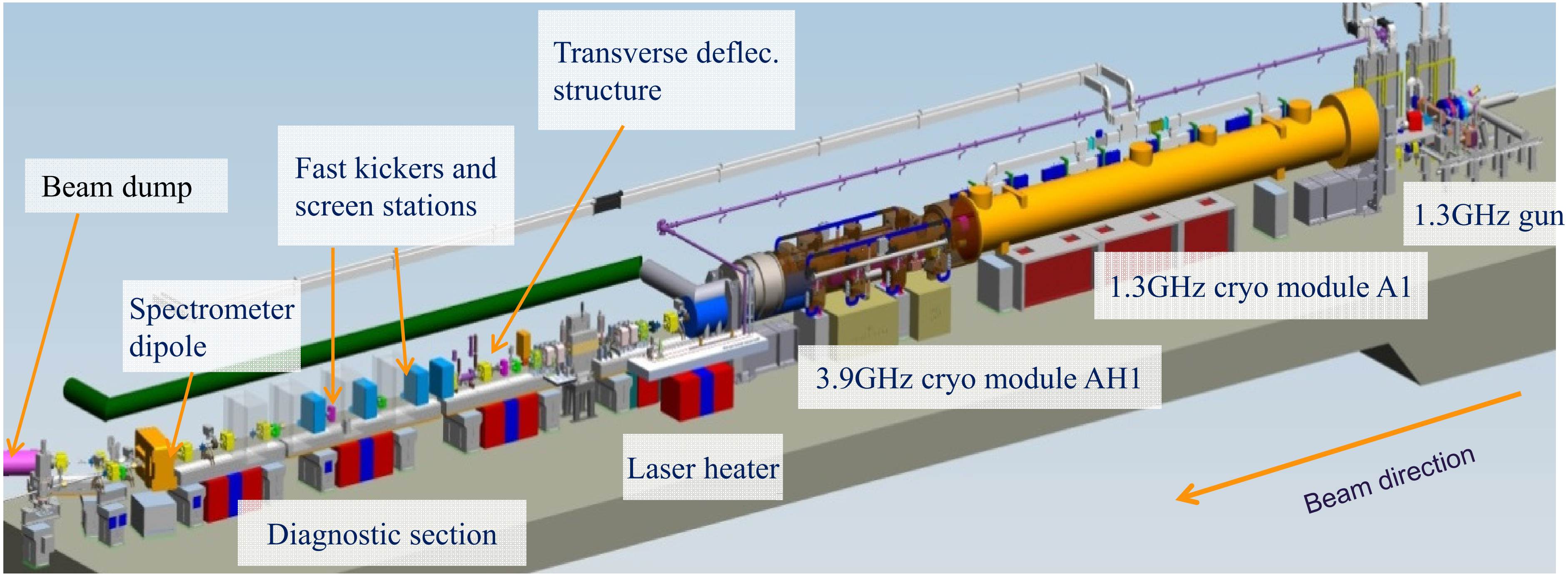
Systems count in total and per section

- 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	29	
	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

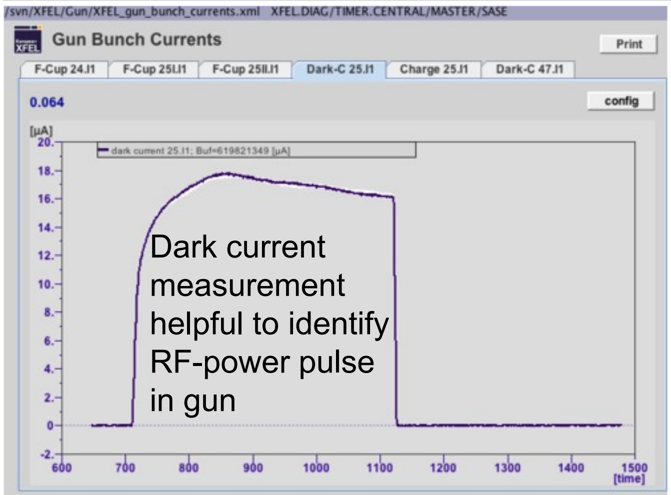
The injector



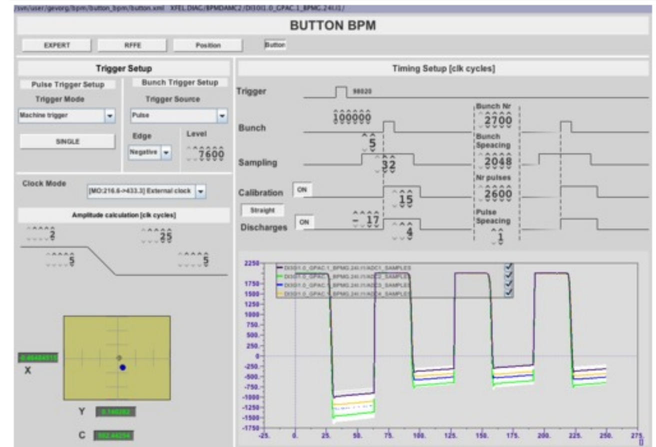
Chronological order of injector beam commissioning

- Gun: high power conditioning started in end of 2013, beam in gun Feb. 2015

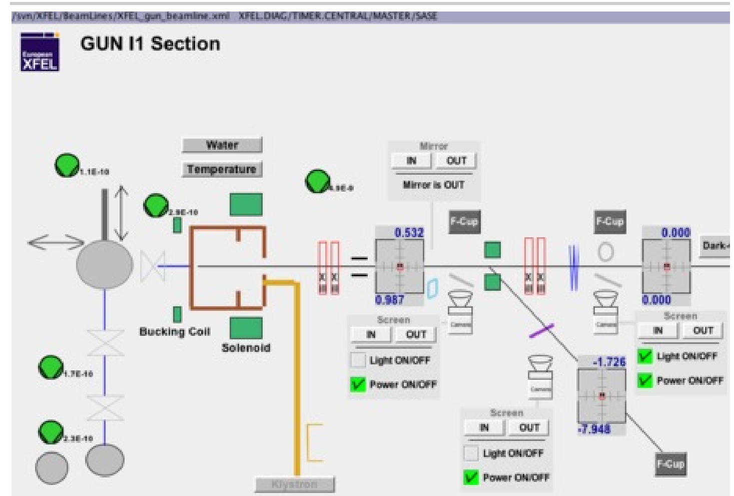
19.12.2014 09:15 xfeloper **Aktuell Dunkelstrom bei 4.5MW, 400us, 230 A Main Solenoid**



06.02.2015 14:22 xfeloper **button.xml**



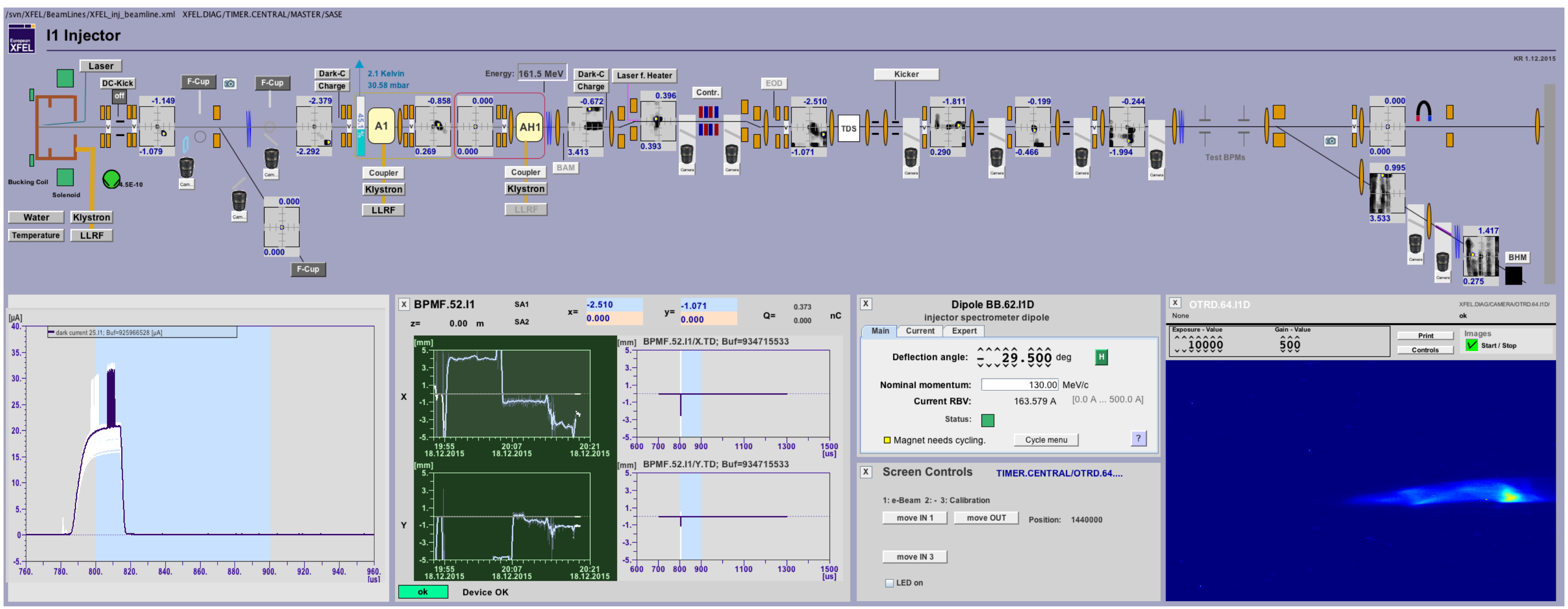
13.02.2015 18:25 xfeloper



- In parallel: installation of accelerator and 3rd harmonic module and warm beam line
- 15. Dec. 2015: cool down of modules finished

Chronological order of injector beam commissioning

- 18. Dec. 2015:
  - all cavities tuned on resonance: accelerator modules ready for beam
  - first electron beam transmitted to the dump within one shift
- 21. Dec. 2015: first emittance measurements
- Up to July 2016: installation of missing components and commissioning, full characterization of the injector at nominal parameters.



Diagnostics setup: BPMs

BPM types

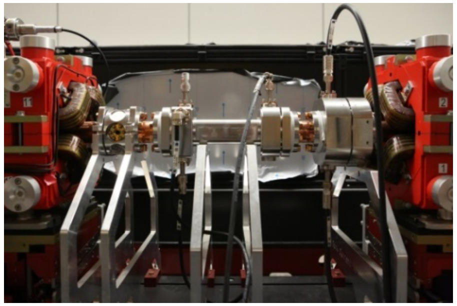
- Button for different beam pipe diameter
- Low Q cavity BPMs with 2 beam pipe diameters
- Reentrant Cavity BPM (30% of cold LINAC)

Collaboration (institutes and tasks)

- CEA Saclay: re-entrant cavity BPM for cold modules including front end electronics TUPG17
- 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

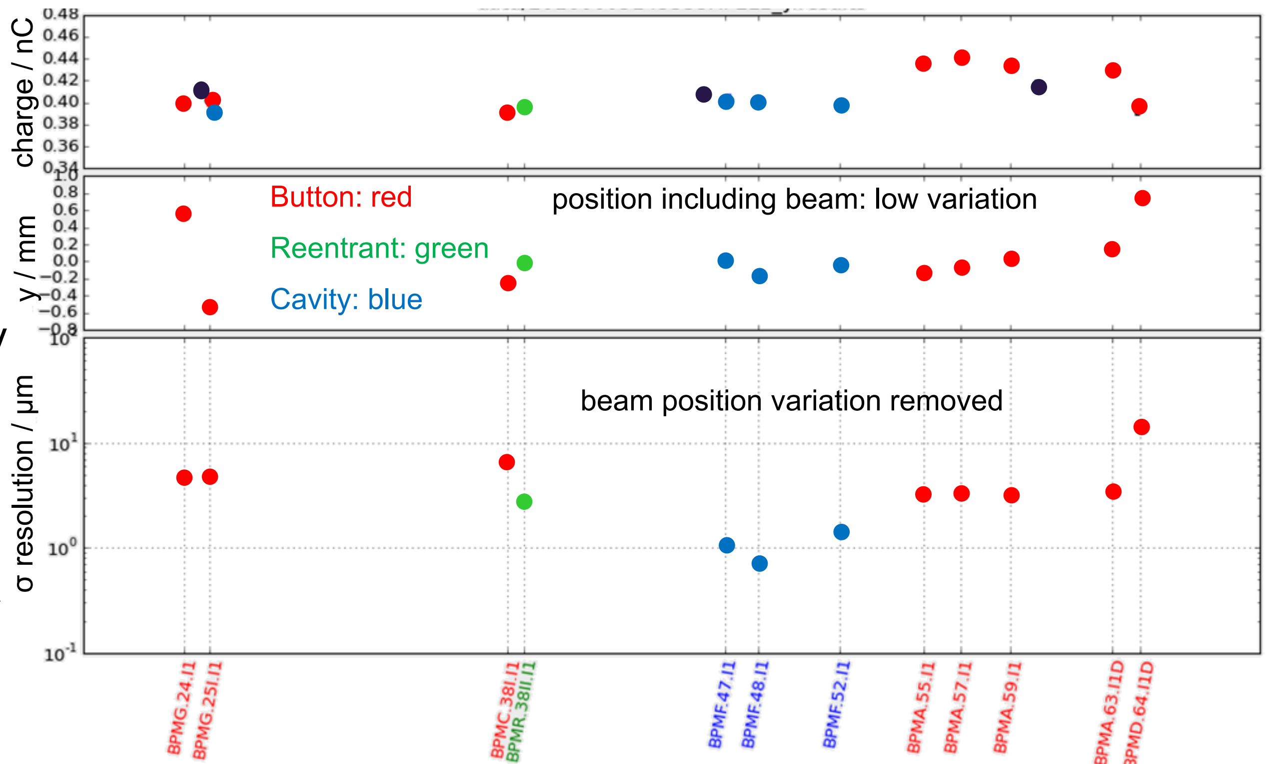


Experience during injector beam commissioning and optimization

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

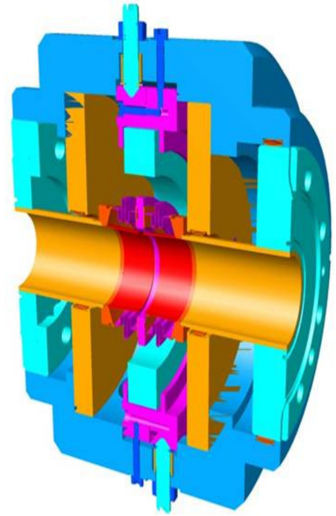
Correlation of each monitor to the others to calculate the resolution, above typically charge and position in vertical plane

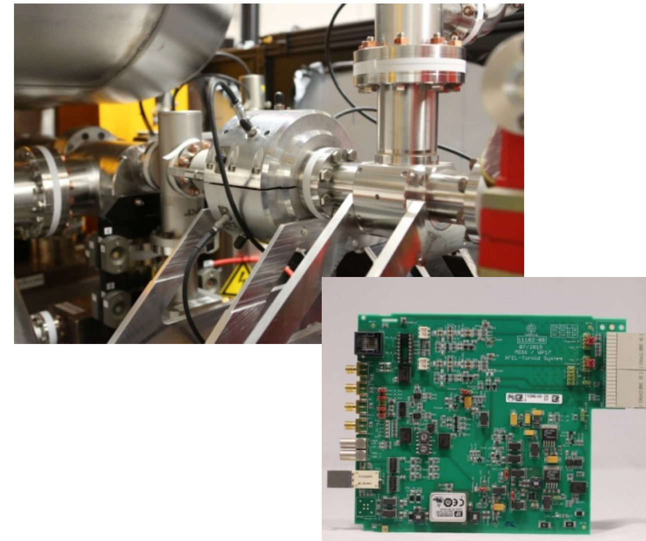


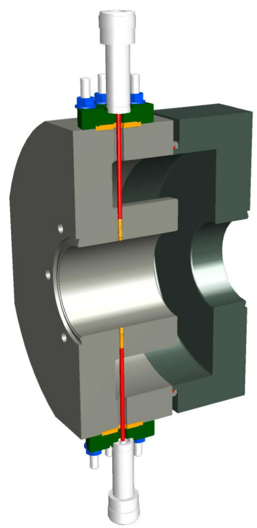
Method see N. Baboi et. al.: http://dx.doi.org/10.1063/1.2401409

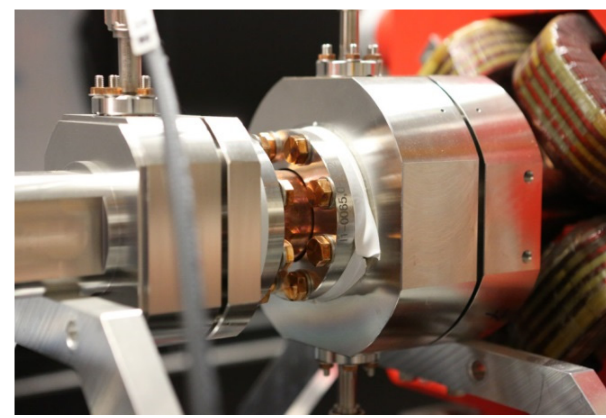
Diagnostics setup: charge monitors

- **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





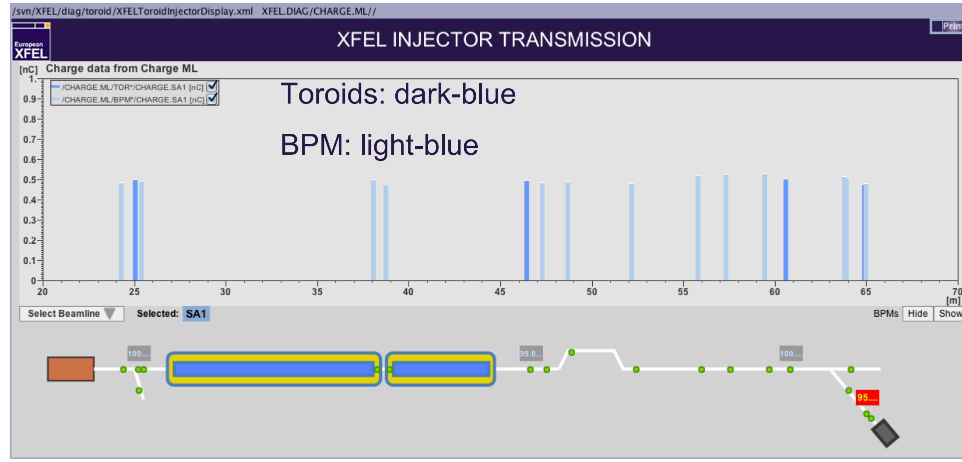


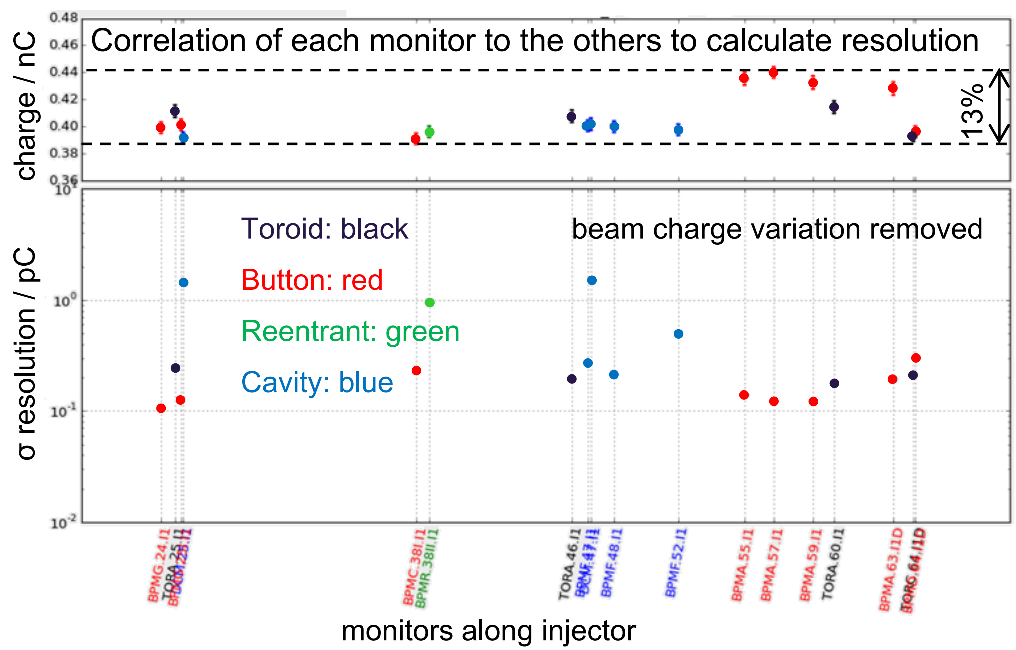


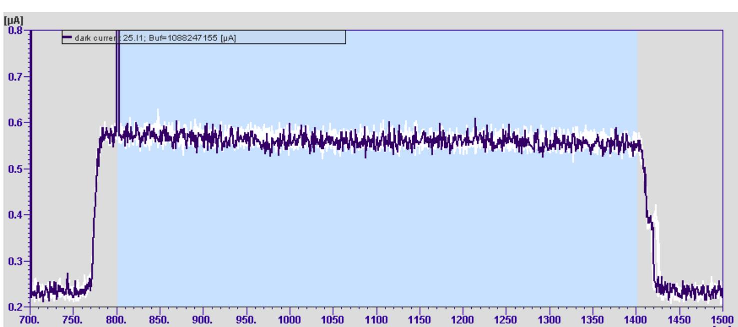
Experience during injector beam commissioning and optimization

Charge monitors

- Operational from day 0
- **Toroids:** self triggered mode for first beam, easy setting of external trigger, even at 1 pC level.
- **BPM** charge: see slide before
- **Faraday cups:** tested with gun
- **DaMon:** dark current measurement shows beam on RF-power pulse nicely, easy adjustment of trigger delay for delay charge reading



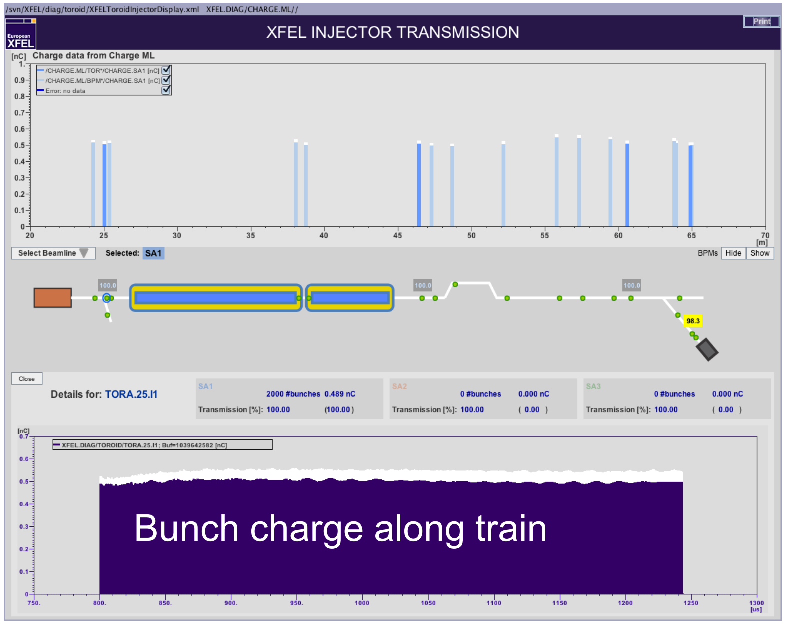


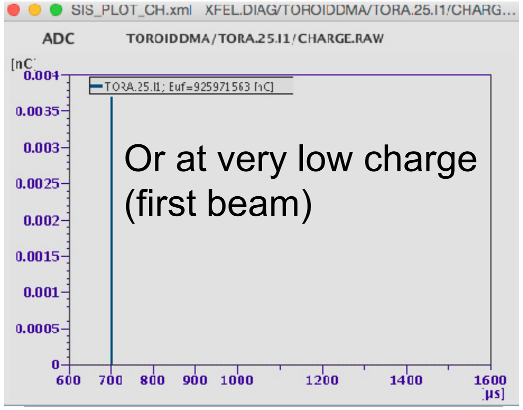


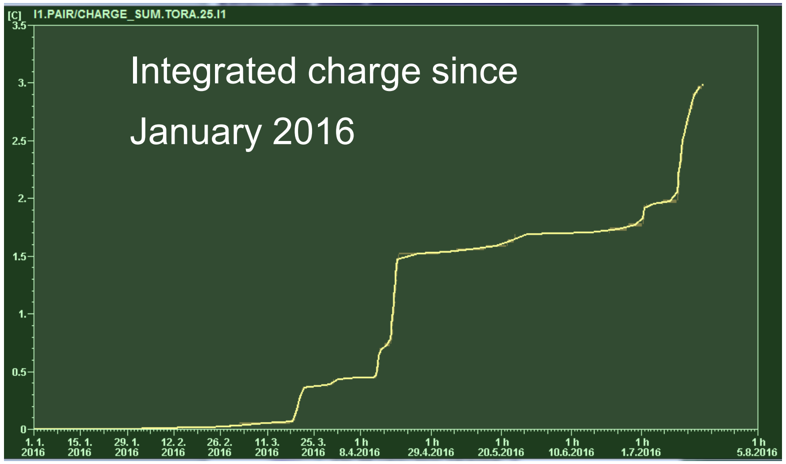
Experience during injector beam commissioning and optimization

Charge monitors

- Injector operation with 27000 bunches / second
- Advantage of multiple bunch per train operation







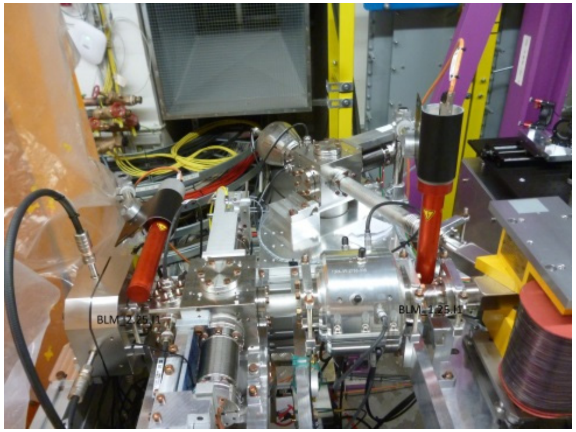
Diagnostics setup: beam loss and halo monitors

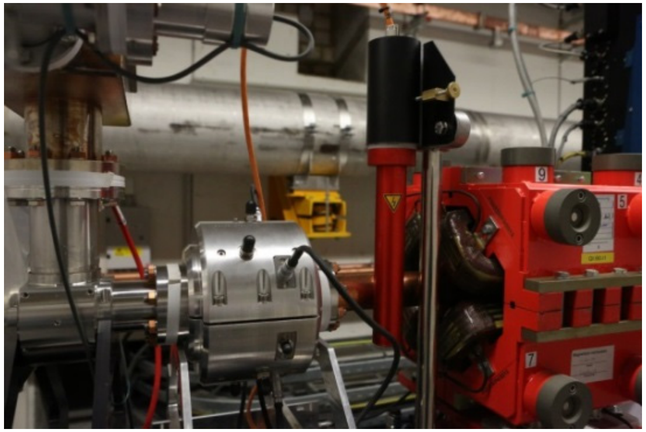
BLMs:

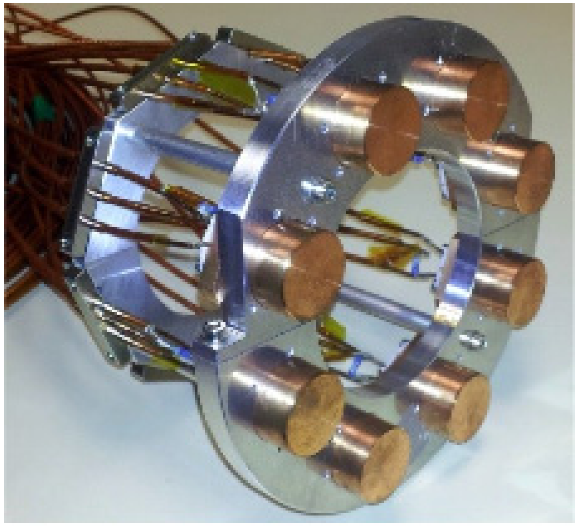
- Scintillators with photomultipliers
- Single bunch resolution
- On board HV generation
- Single, multiple bunch and integration alarms to MPS
- Readout by µTCA board with rear transition module, digital interface to MPS system

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

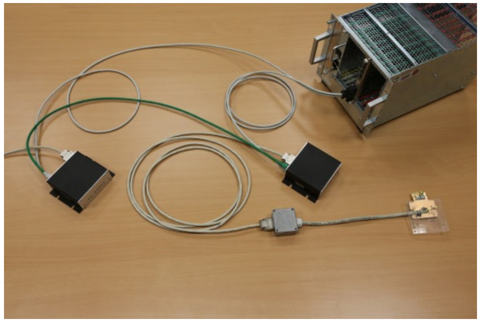


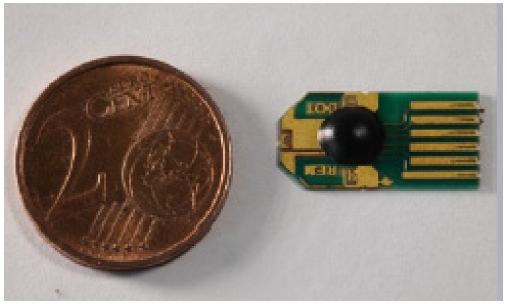


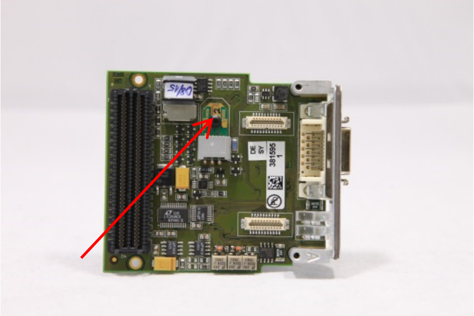


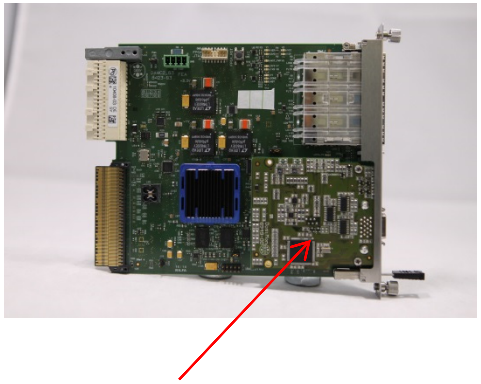
Diagnostics setup: dosimetry

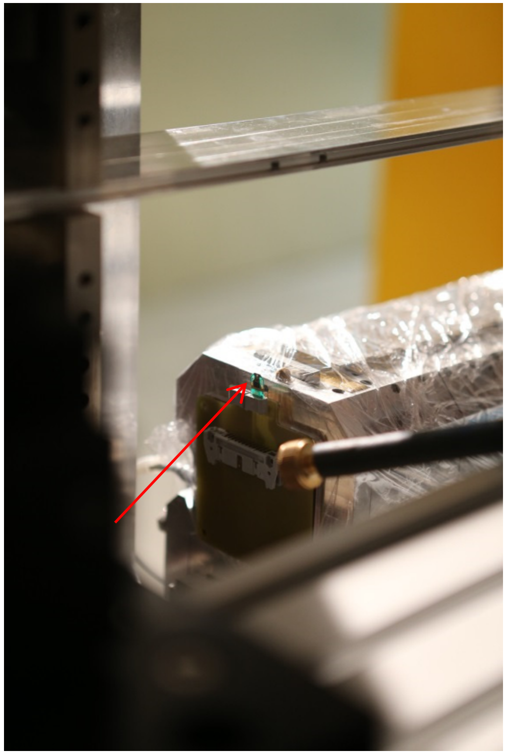
- Gamma sensors RadFets for online measurements of accumulated dose
- Plug-in readout module (according FPGA Mezzanine Card [FMC] standard)
- Hosted on FMC carriers, e.g. DAMC02 or other systems like PSI BPM electronics
- Internal and external sensors:
  - internal sensors on MPS and BPM boards distributed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







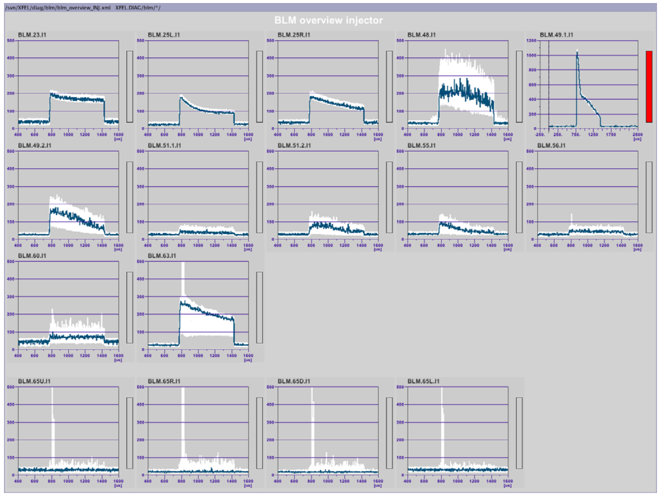


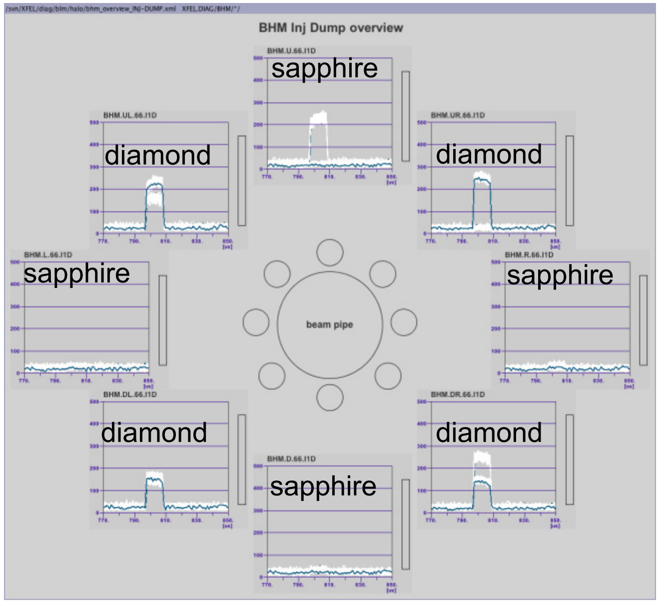


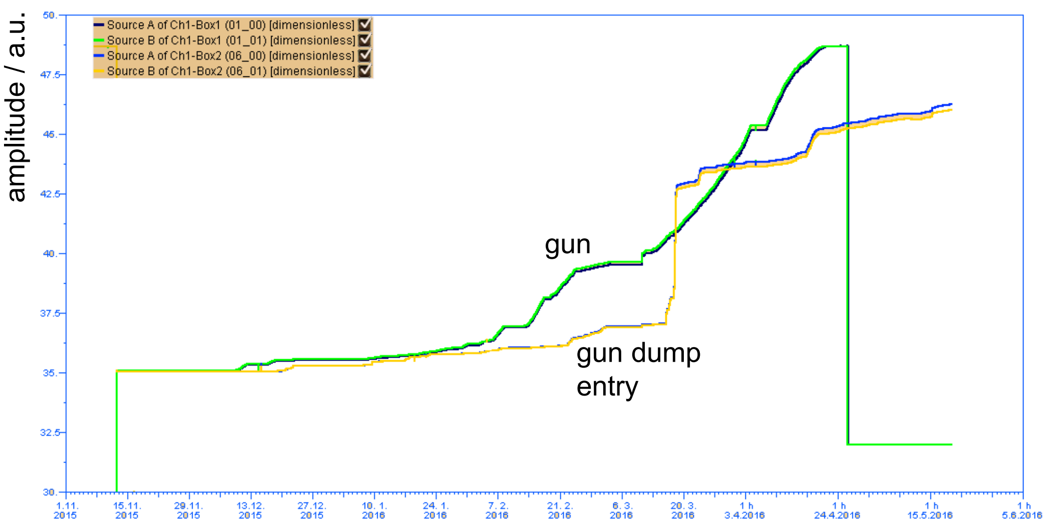
Experience during injector beam commissioning and optimization

BLM, BHM, Dosimetry:

- BLM online monitoring to identify losses; show alarm when threshold is exceeded; match HV (sensitivity) to operation conditions (activation level)
- BHM shows signal even in sapphire channel for misaligned beam
- Online gamma-monitoring of dose at gun and gun dump entry

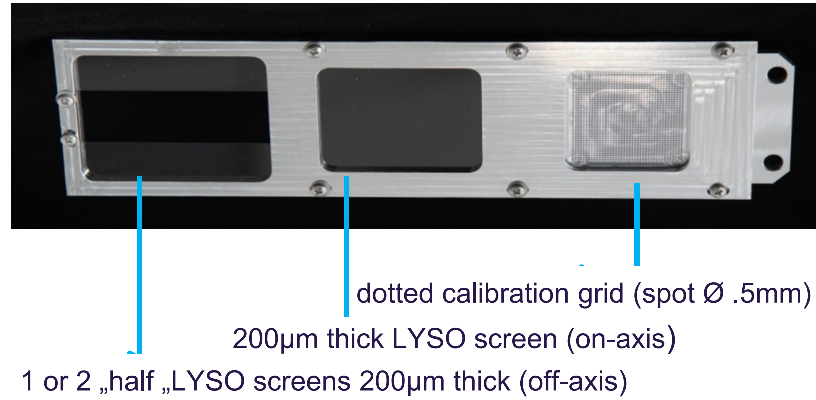


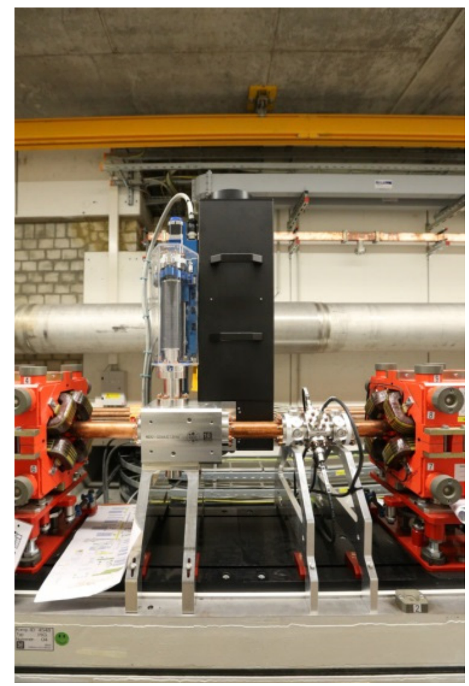


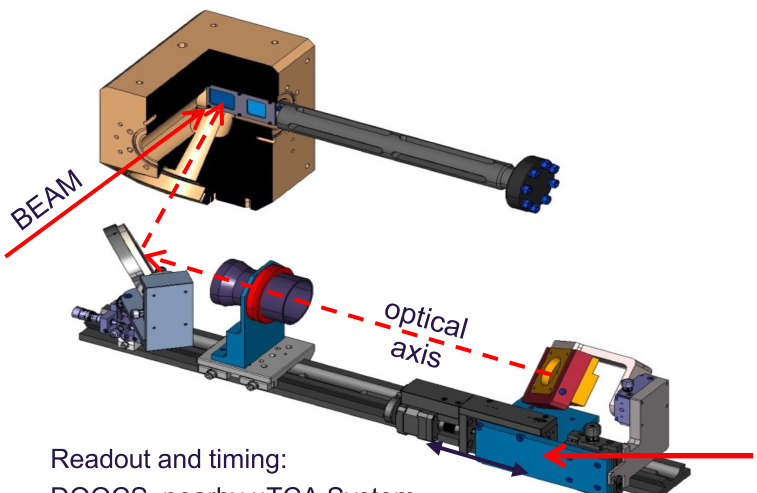


Diagnostics setup: screens

- 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



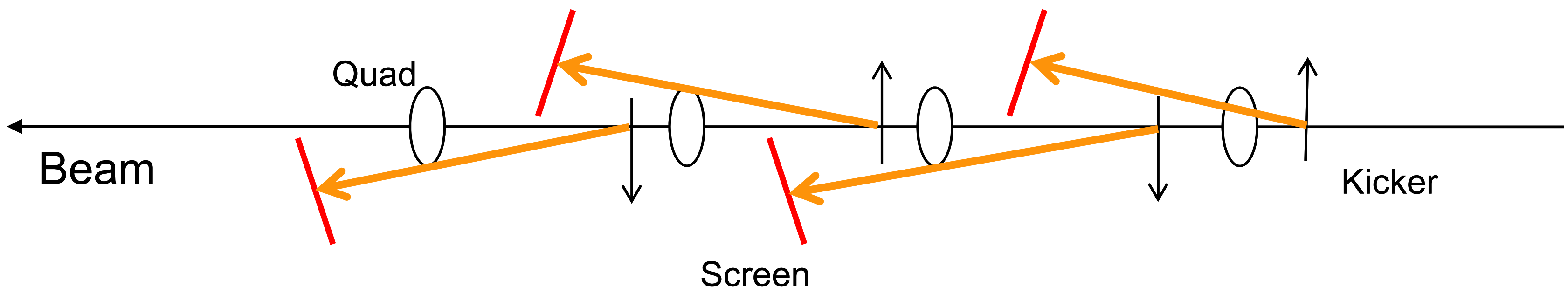


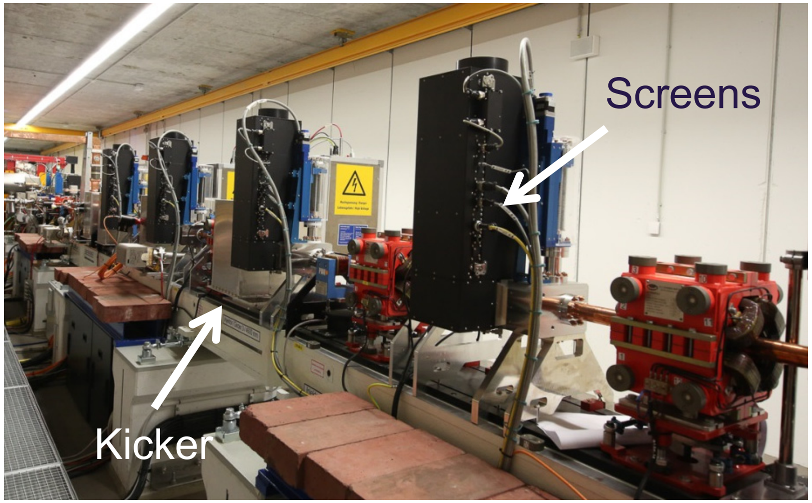


Readout and timing:
DOOCS, nearby µTCA System

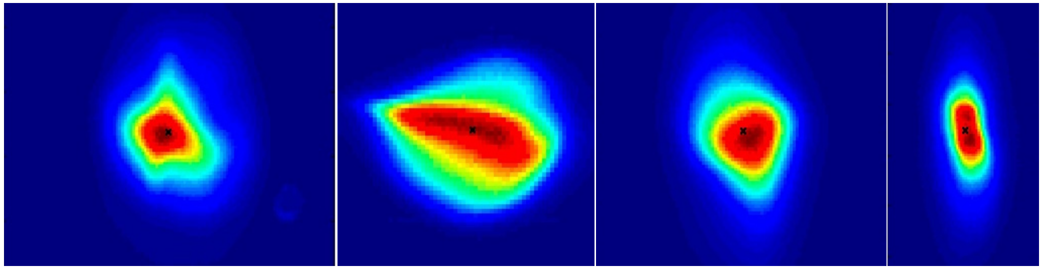
Highlight: emittance along bunch train

Kickers and off-axis screens in the diagnostic section allow to measure emittances of single bunches during operation with long bunch trains.

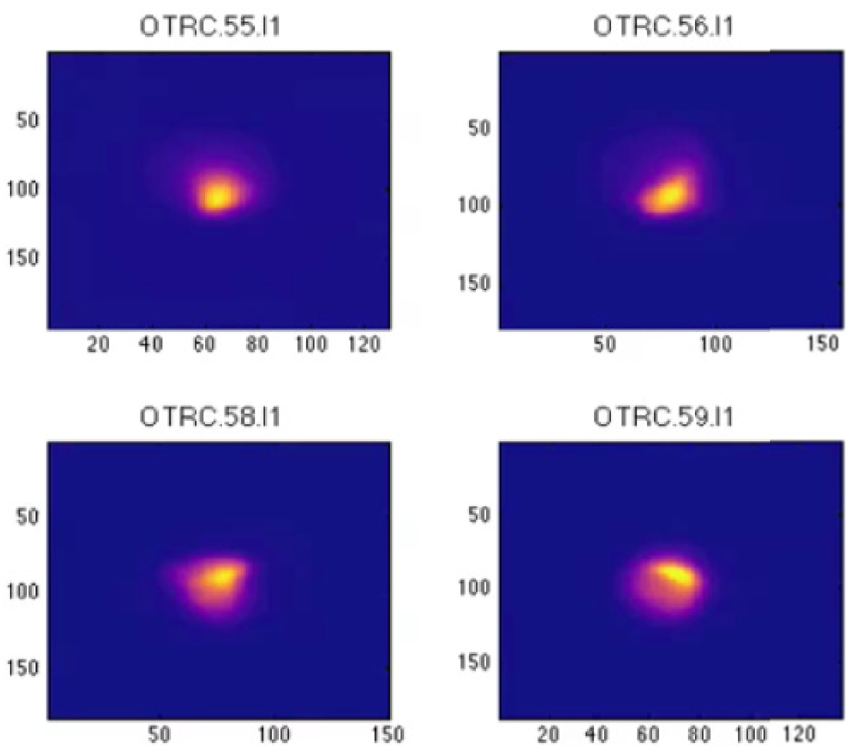


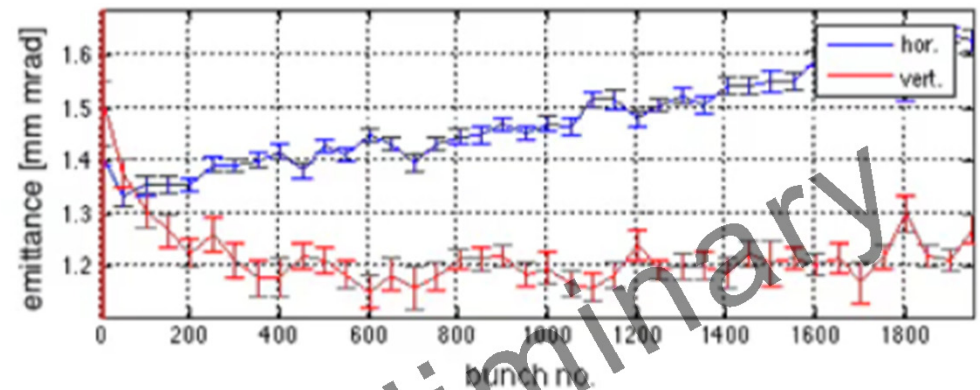


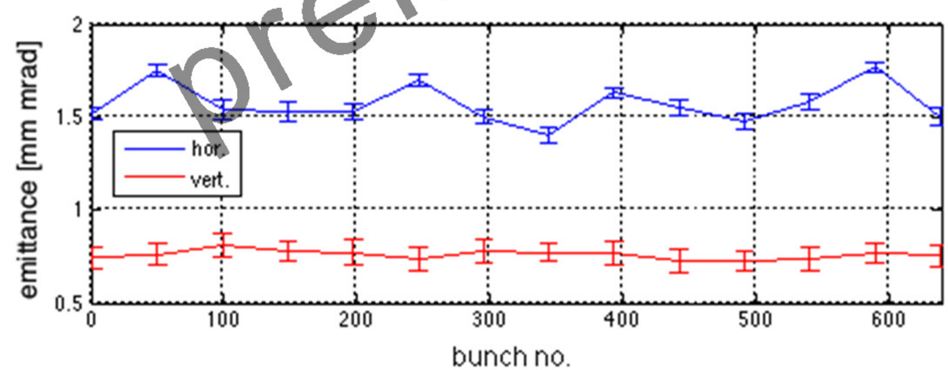
These measurements are fast (2.5 Hz) and allow also to measure the emittance and their evolution over the bunch train.



Highlight: emittance along bunch train





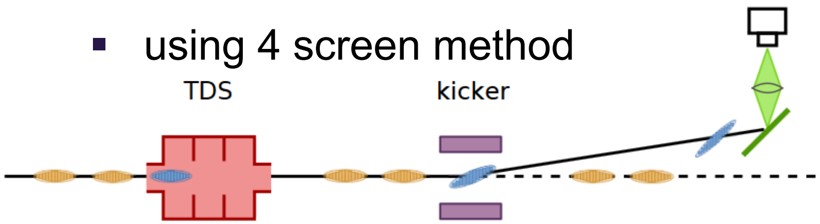


Evolution of the projected emittance for different bunch numbers and two different train conditions, not optimized values, emittance according design

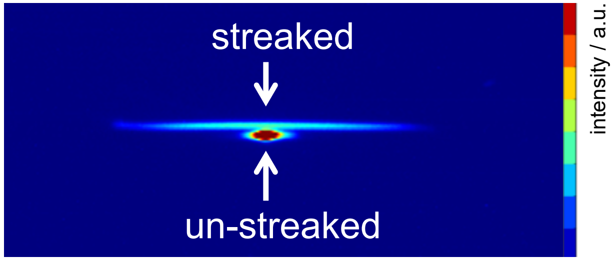
Highlights: TDS operation with off-axis screens

Transverse Deflection Structure:

- First bunch screen image un-streaked, second streaked in dump line
- Slice emittance measurement
  - single bunch streaked by TDS
  - bunch kicked to off-axis screens
  - using 4 screen method



M. Yan et al., http://accelconf.web.cern.ch/AccelConf/IBIC2013/papers/tupc36.pdf

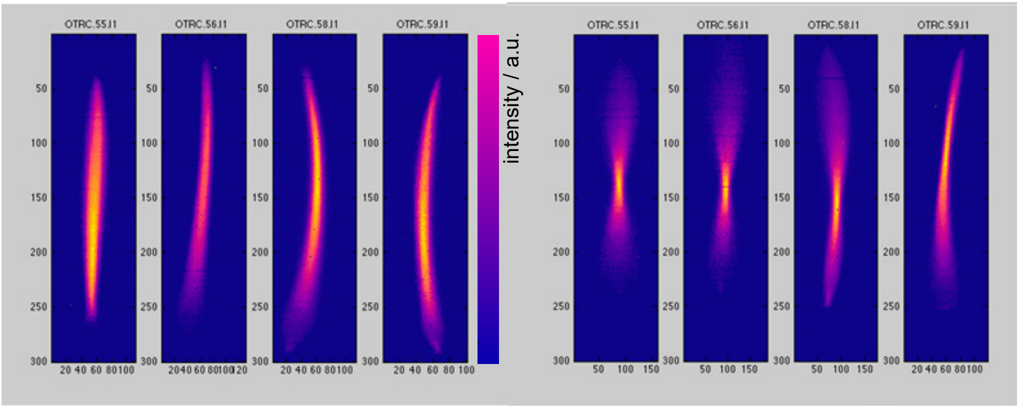


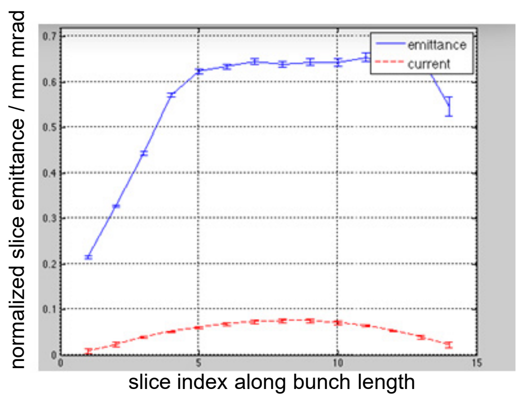
$f = 3$ GHz

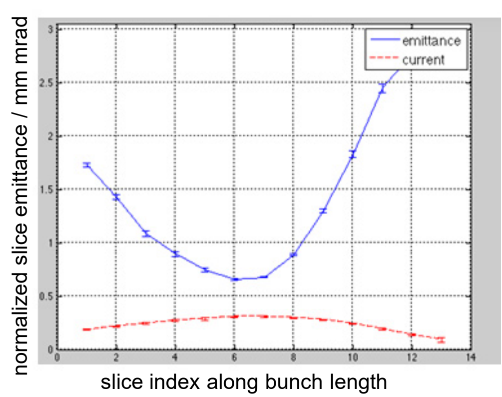
$U_{max} = 15$ MV

$P_{max} = 24$ MW

single bunch







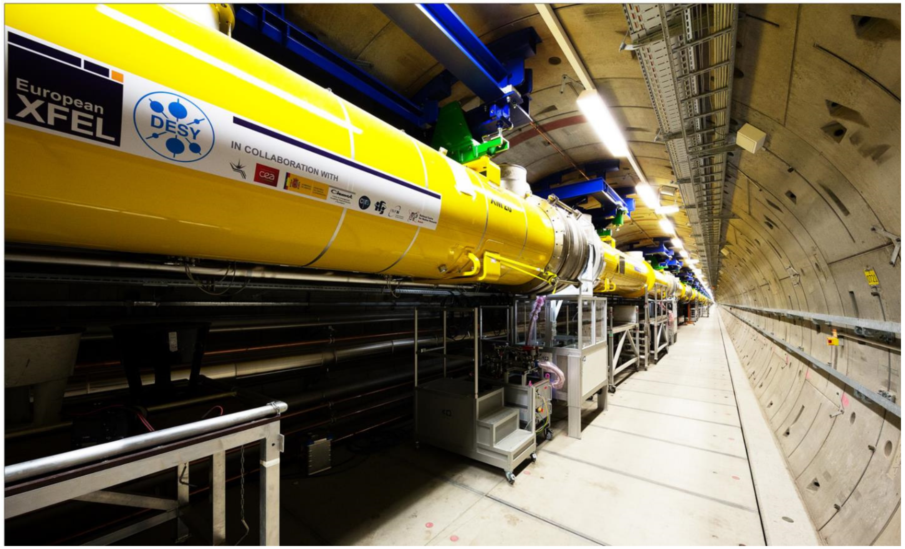
Different machine settings

Summary

- All design values of diagnostics reached
- BPMs and charge monitors ready from day 0 to show beam, self trigger mode for first beam, adjusted trigger delay for control system, resolution fulfill requirements
- Dark current monitor useful to demonstrate high field amplitude in accelerator, to measure dark current and minimize it (dark current kicker and/or collimator)
- Online monitoring of beam losses with BLM and BHM to optimize transmission
- Online monitoring of radiation dose in the accelerator tunnel and inside of racks
- Screen stations used to monitor beam size and calculate emittances with on- and off-axis screens with and without TDS, can be used with long bunch trains parasitically during user operation

Outlook to E-XFEL commissioning

- All vacuum components ready and mostly installed
- Electronics installation and tech. commissioning until Sept. 2016
- BPMs + charge monitors:
  - Laboratory calibration prepared and compared with beam at injector
  - Start with timing self trigger mode, automated setting of timing parameters prepared
- All screen systems ready or even installed and calibrated
- Loss monitors and dosimetry system ready for online monitoring with default thresholds



- Cool down in October followed by tech. commissioning of mainly RF
- … Beam !!!
- An exciting time before Christmas is waiting for us
- Expected first lasing in April 2017

Outlook to E-XFEL commissioning

Thanks to all colleagues who contributed to this work!

Thank you for your attention!