

# Beam-Based Calibration and Performance Optimization of Cavity BPMs for SwissFEL, E-XFEL and FLASH2

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## Abstract

SwissFEL, the European XFEL (E-XFEL) and FLASH2 all use dual-resonator cavity beam position monitors (CBPMs). The CBPM electronics that is built by PSI has a larger number of calibration parameters that need to be determined in order to maximize the CBPM system performance. Beam measurements with the BPM electronics have been made in BPM test areas at the SwissFEL test injector and FLASH, as well as at FLASH2 where 17 E-XFEL type CBPMs have recently been installed in the undulator intersections. The CBPMs are pre-calibrated in the lab using an automated test and calibration system, and then the final calibration is done with beam. This report discusses beam-based methods to optimize the system performance by improving the pre-beam system calibration as well as the mechanical alignment of the BPM pickup position and angle.

## SwissFEL

- Hard & soft X-ray (0.1-7nm).
- 1-2 bunches, 28ns spacing, 100Hz.
- 10-200pC, max. 5.8GeV.
- Only cavity BPMs (~170).
- 3 CBPM types (8, 16, 38mm apertures).
- Only undulator CBPMs on motorized 2D movers.
- 1st Beam: Injector 12/2015, undul. 12/2016.

## European XFEL

- Hard & soft X-ray (0.05-6nm).
- 1-2700 bunches, 222ns spacing, ~10Hz.
- 20-1000pC, max. 17.5GeV.
- BPMs: ~130 cavity, 30 re-entrant, 300 button.
- 2 CBPM apertures (40.5 & 10mm).
- No CBPMs on motorized movers.
- 1st beam: Injector 3/2015, undul.12/2016.

## FLASH2

- 2nd undulator line for DESY FLASH facility.
- Soft X-ray & VUV (4-80 nm).
- 1-700+ bunches, 200-1000ns spacing, ~10Hz.
- 20-1000pC, max. 1.25GeV.
- 17 cavity BPMs in FLASH2 undulators (E-XFEL type), 10mm aperture.
- 1st beam 3/2014, 1st lasing 8/2014.

## Cavity BPM Test Facilities

### SwissFEL Injector Test Facility SITF

- No undulators: SwissFEL R&D & component tests only.
- 1-2 bunches, 28ns spacing, 10Hz.
- 6 E-XFEL type CBPMs (3 with 10mm, 3 with 40.5mm aperture).
- 4 SwissFEL CBPMs (1x38mm, 1x16mm, 2x8mm aperture).
- 2 of 10 CBPMs on motorized 2D (X/Y) movers.



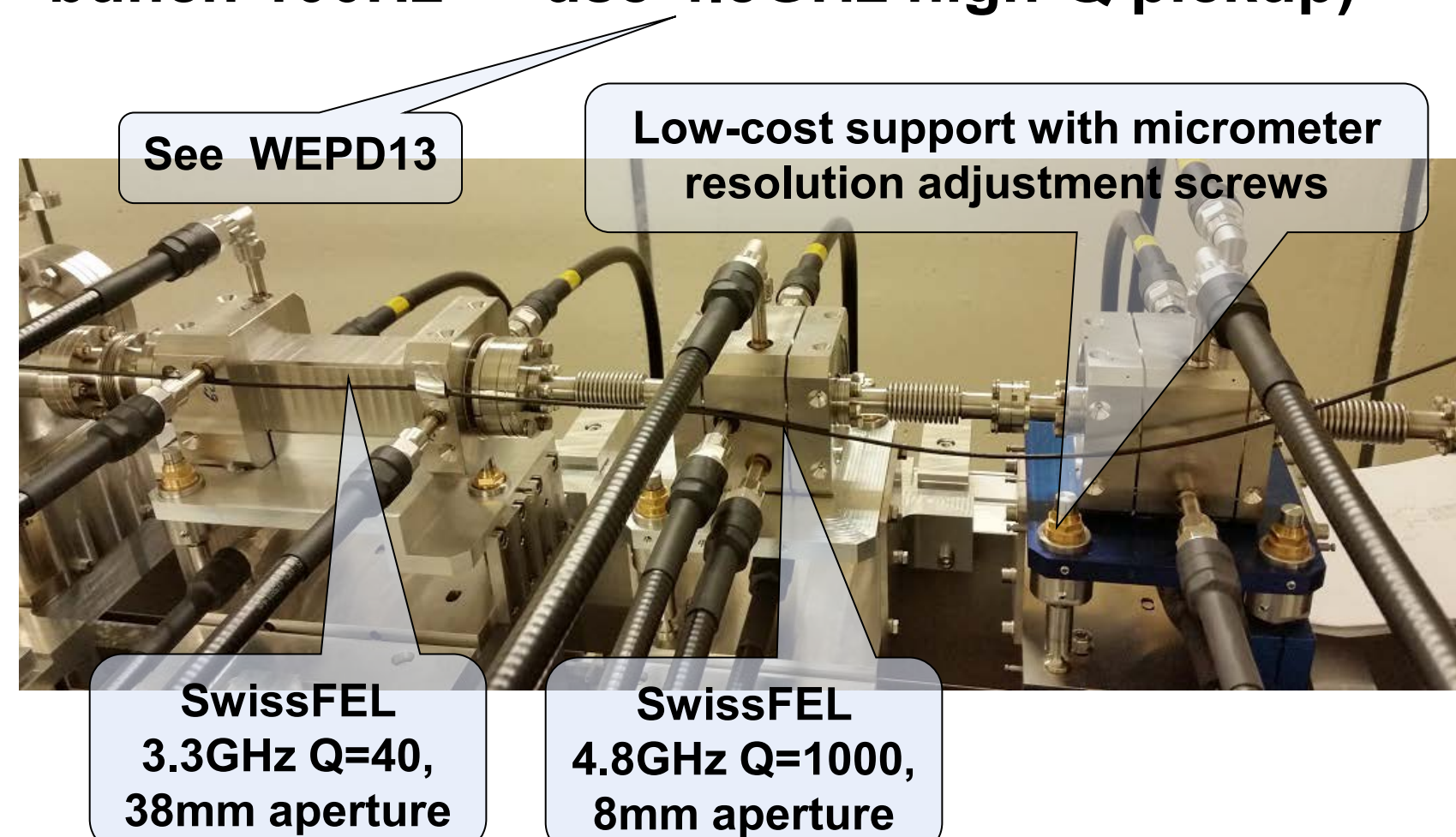
### FLASH1 / FLASH2

- FLASH1: Area with 4 E-XFEL CBPMs (3x10mm, 1x40.5mm aperture).
- FLASH2: 17 CBPMs in undulators are still part-time available for testing, since FLASH2 is still being commissioned.
- Only 4 CBPMs (FLASH1) on motorized movers.

## Cavity BPM System

### Pickups

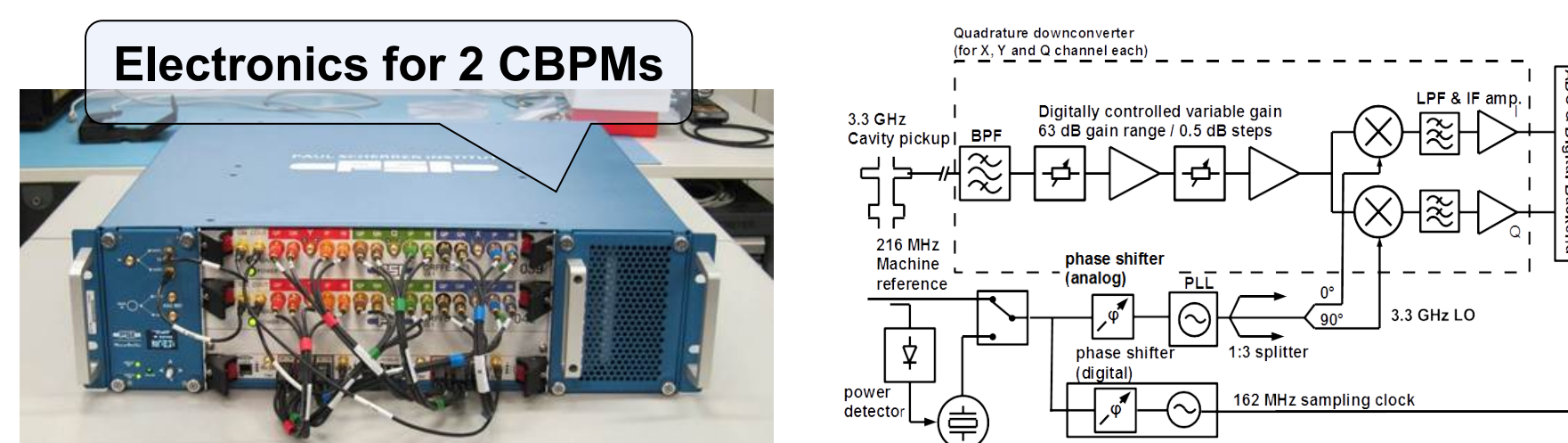
- E-XFEL, FLASH2, SwissFEL: Two resonators, 3.3GHz, low  $Q_L$  (70, 70, 40), mode-suppressing waveguide couplers in dipole cavity.
- Exception: SwissFEL undulator CBPMs (single-bunch 100Hz → use 4.8GHz high-Q pickup)



### Electronics

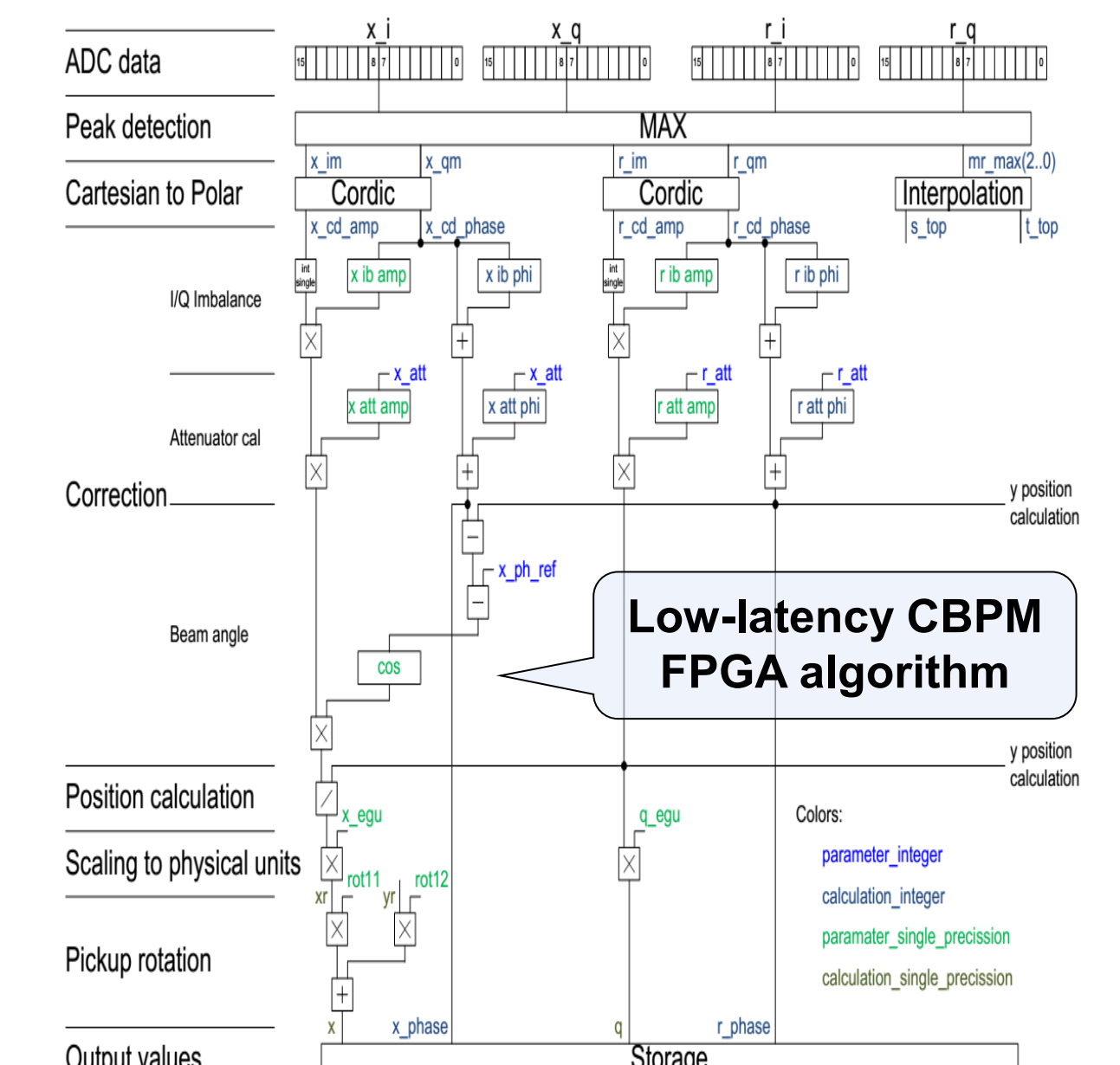
See WEPD12

- Low-Q version: IQ downconversion to baseband, IQ pulse sampling by 160MSPS 16-bit ADC, low-latency position and charge calculation by FPGA board, multi-gigabit fiber optic interfaces (control, timing, feedback systems)

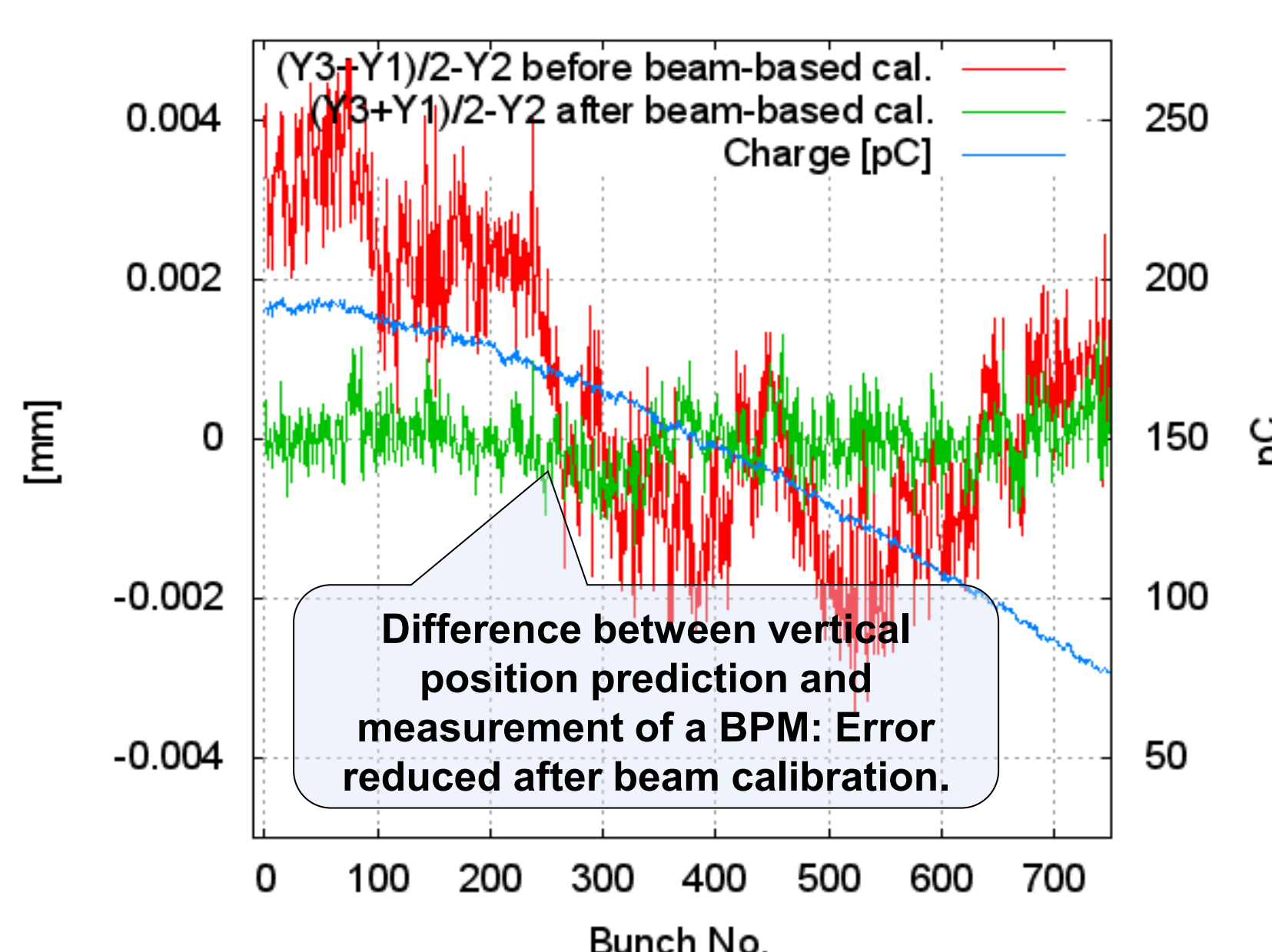
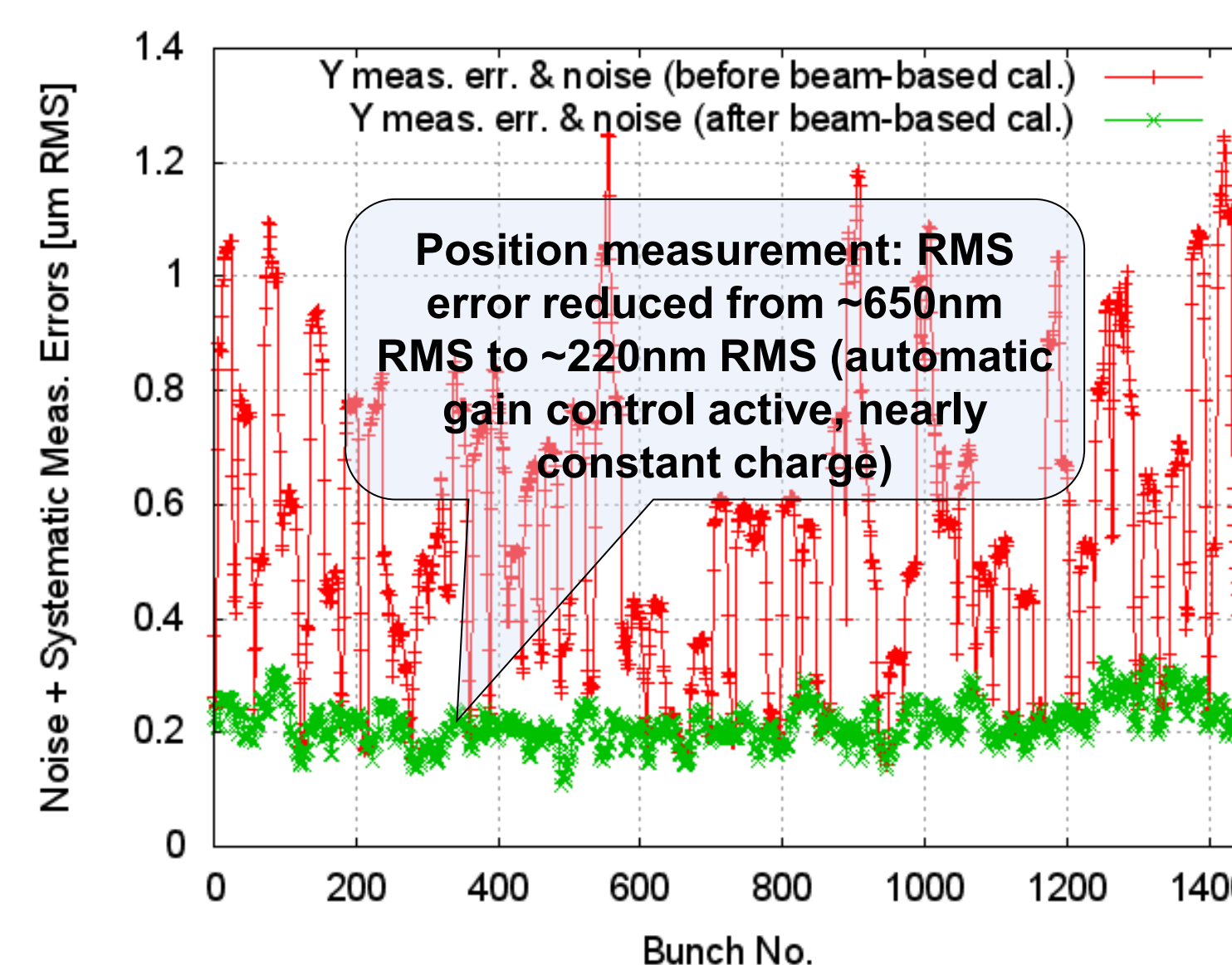


## Calibration Strategy and First Beam Test Results

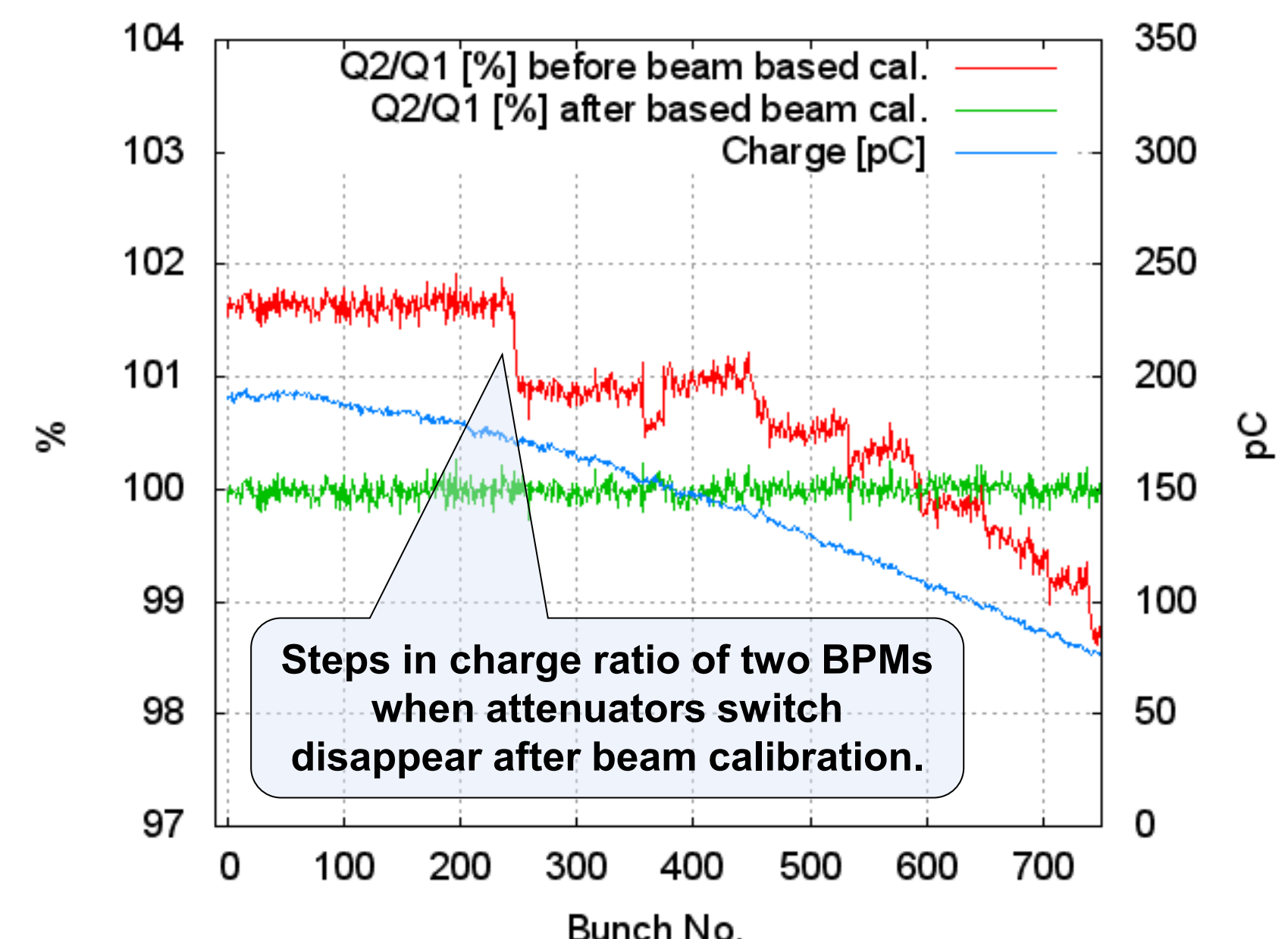
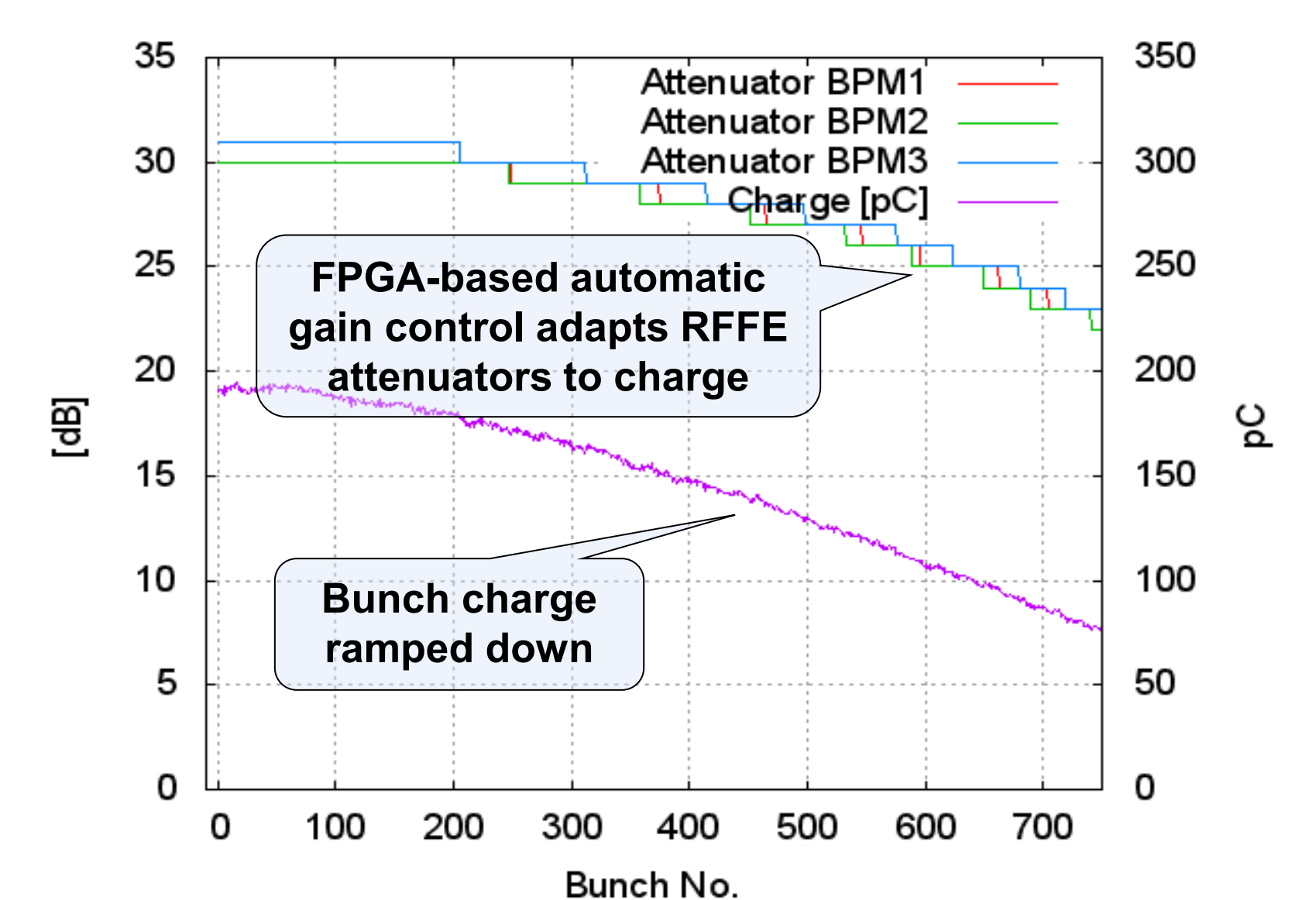
- Want to measure positions and charge (not arrival time).
- Step 1: Pre-beam calibration: Determine scaling factors (charge, position) by measuring pickup & cables, calibrate electronics in the lab with generator (IQ imbalance, gains for 63dB range, 0.5 dB steps, ...), see WEPD12.
- Step 2: Beam based calibration. Use other monitors (X & Y position: Screen, wire scanner, encoder of BPM 2D mover, ...; Charge: Toroid, ...), and other CBPMs, by estimating charge and at one BPM using other BPMs.
- Test at SwissFEL Injector Test Facility & FLASH: Check quality of pre-beam calibration of attenuators, improve it by minimizing deviation of measured and predicted position and charge at one BPM (using other BPMs).



### FLASH



### SwissFEL Injector Test Facility



## Summary And Outlook

The cavity BPM systems for E-XFEL, SwissFEL and FLASH2 are pre-calibrated in the lab. A subsequent calibration of the scaling factors for different attenuator settings with beam reduced the systematic measurement errors that occur when the attenuators are switched. Although the most critical undulator BPMs will normally operate with fixed attenuators, the possibility to change the attenuator settings is useful for beam development shifts or commissioning with 1st beam.