Design and Beam Test Results of Button BPMs for the European XFEL

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Abstract

The European X-ray Free Electron Laser (E-XFEL) will use a total of ~300 button BPMs along the whole accelerator, and additionally 160 cavity BPMs. The pickups for the button BPMs have been designed by DESY, whereas the electronics has been developed by PSI. This paper gives an overview of the button BPM system, with focus on the RF front end electronics, signal processing, and overall system performance. Measurement results achieved with prototypes installed at the DESY FLASH linac and at the SwissFEL Injector Test Facility (SITF) are presented. The single bunch position noise obtained with button pickups in a 40.5 mm aperture beam pipe is as low as ~11 µm at 20 pC bunch charge.

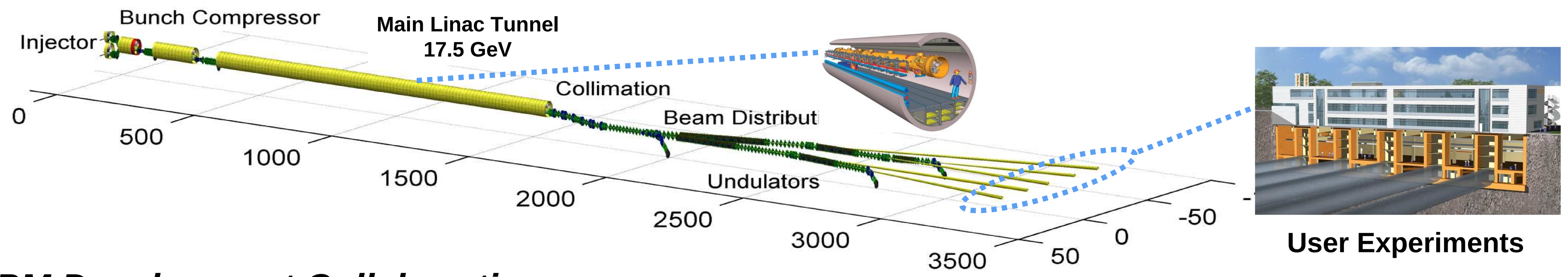
Introduction

E-XFEL Machine Parameters

- 17.5 GeV superconducting linac
- Trains of 2700 bunches
- ≥ 222ns bunch spacing
- 10 Hz train repetition rate
- 100 (20) pC to 1 nC bunch charge
- Arbitrary bunch patterns
- SASE undulators, 0.1 nm wavelength

BPM Types and Requirements

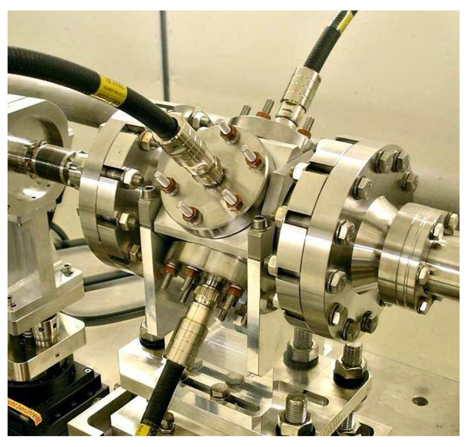
BPM Type	#	Inner Pipe Diam.	Train Averaged / Single-Bunch Resolution	Range For Max. Resolution	Drift per hour/ per week
„Cold“ Standard BPM (Button, Re-Entrant Cavity)	71, 30	78 mm	10 µm / 50 µm	±3mm	10 µm / 50 µm
„Warm“ Standard BPM (Button)	228	40.5 mm	10 µm / 50 µm	±3mm	10 µm / 50 µm
Precision BPM (Cavity)	12	40.5 mm	1 µm / 10 µm	±1 mm	1 µm / 10 µm
Undulator BPM (Cavity)	117	10 mm	0.1 µm / 1 µm	±0.5 mm	0.1 µm / 1 µm



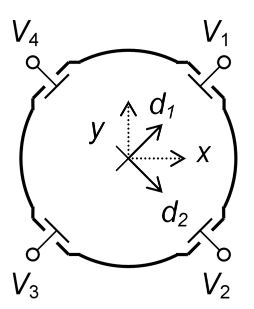
BPM Development Collaboration

- Pickups: DESY (buttons, cavities), CEA/Saclay/Irfu (re-entrant cavities)
- Electronics / firmware / software: PSI, except RF front end for “cold” re-entrant cavities (CEA/Saclay/Irfu)

Beam Pickup



- "cold" button pickups (linac cryo modules): 78 mm aperture, 20 mm buttons, k = 17 mm
- "warm" button pickups (beam transfer lines): 40.5 mm aperture, 16 mm buttons, k = 11 mm
- First order model of beam position from electrode voltage magnitudes (near origin);



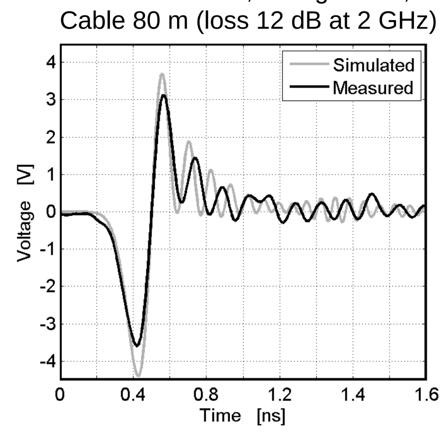
$$d_1 = k\frac{V_1 - V_3}{V_1 + V_3}$$

$$d_2 = k\frac{V_2 - V_4}{V_2 + V_4}$$

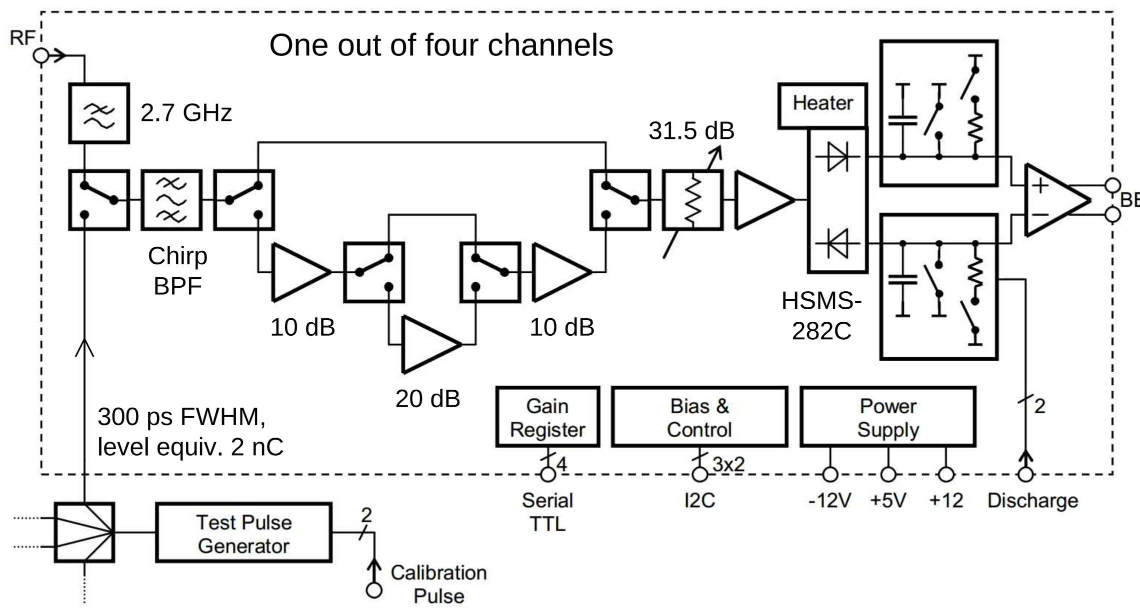
RF Front End

Pickup Signal

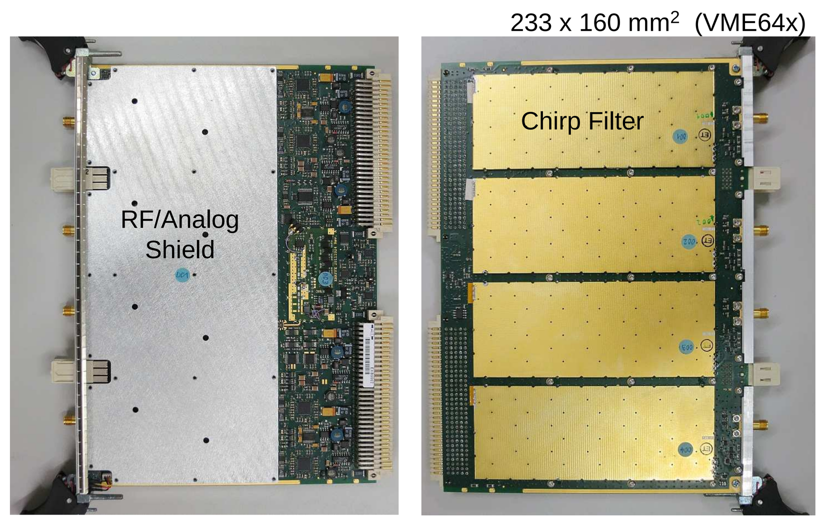
"warm" Button, Charge 1 nC, Cable 80 m (loss 12 dB at 2 GHz)



3-dB spectral width is 0.5 to 3.3 GHz.

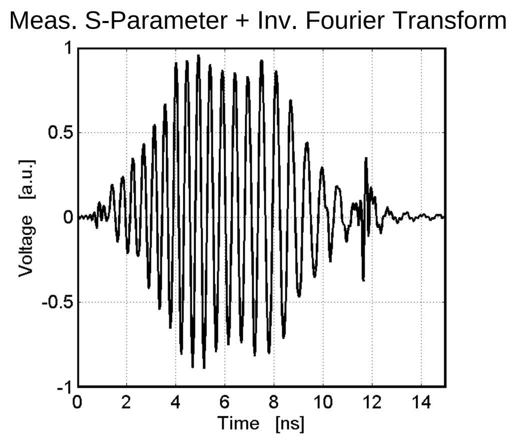


233 x 160 mm² (VME64x)



Chirp Filter Impulse Response

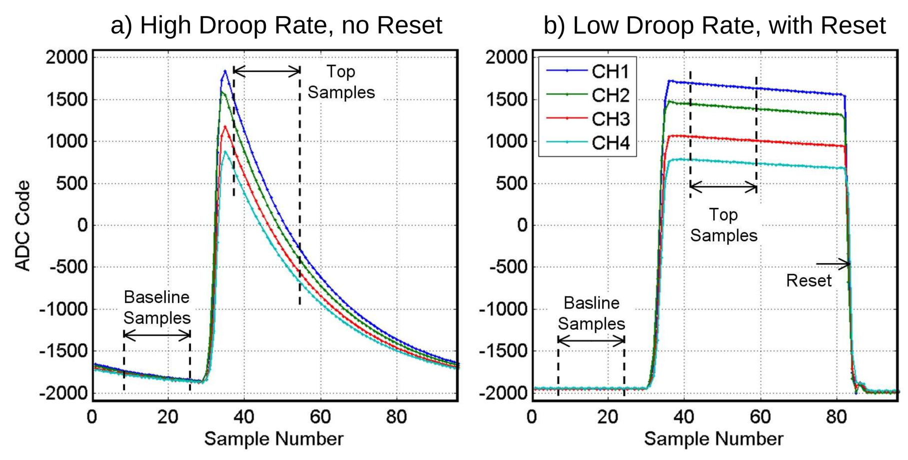
Meas. S-Parameter + Inv. Fourier Transform



Principle and Functions

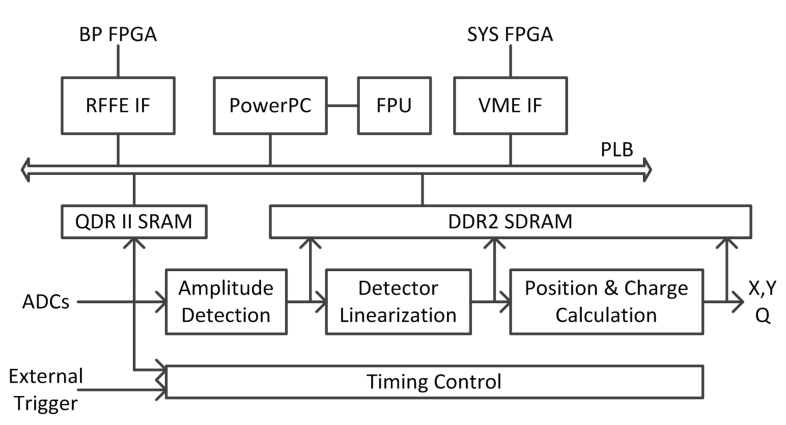
- Pulse stretching, amplification, and amplitude detection
- Band limit from 1.5 to 2.3 GHz (machine RF is 1.3 GHz)
- Chirp filters stretches sub-ns pickup pulses to 6 ns FWHM
- Gain adjustment range >60 dB
- Temperature-stabilized balanced diode detectors
- Hold circuit with reset and droop rate control
- Two modes: a) self-triggered, b) high performance
- Balanced ADC buffer amplifier with offset adjustments
- Test pulser for in-situ self-test and detector calibration

Meas. ADC Waveforms of one Bunch at 433 MSa/s



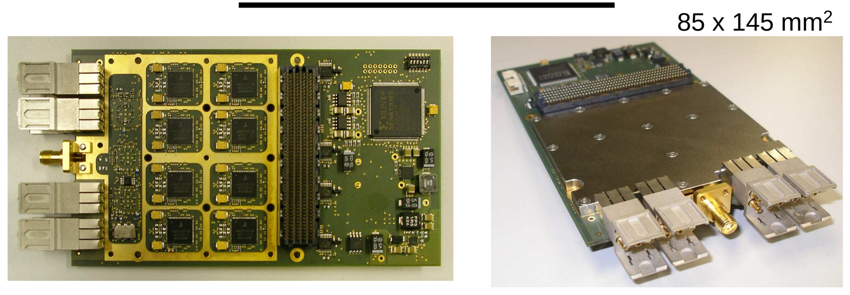
96 samples = 222 ns

Firmware



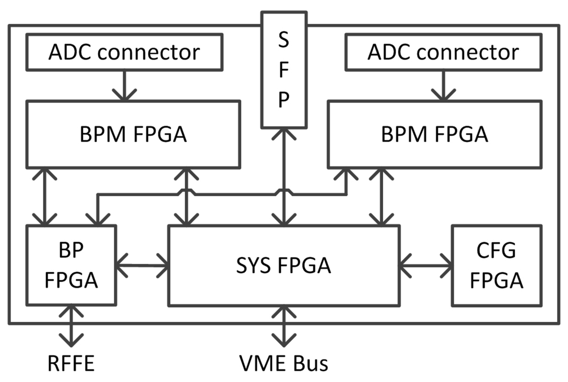
ADC Mezzanine

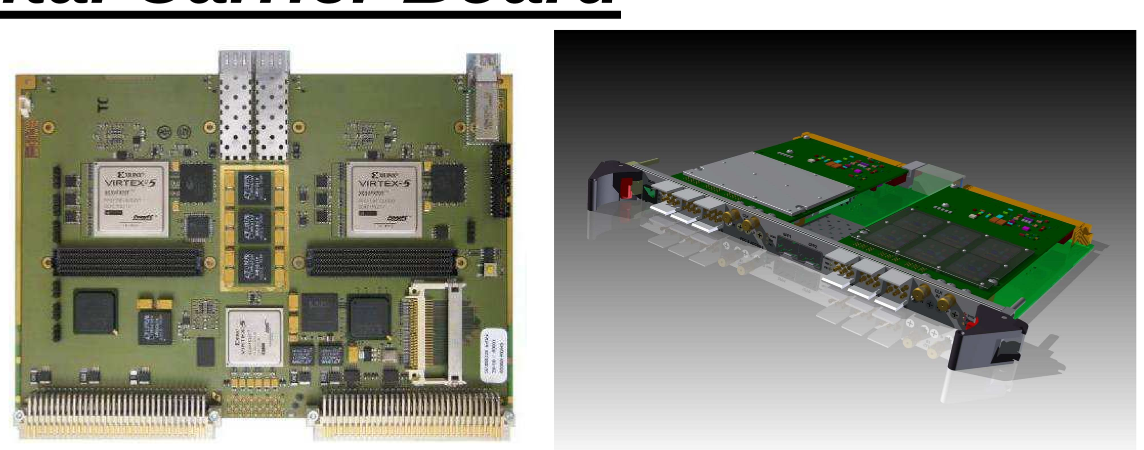
85 x 145 mm²



- 8-channels, 1.3 GHz BW, balanced inputs
- 12-Bit, max. 500 MSa/s, Intersil KAD5512P
- Internal or external clock
- Adjustable clock PLL, divider, delays

Digital Carrier Board





- One “GPAC” digital carrier board with two 8-channel ADCs mezzanines serves 4 button BPMs
- Two BPM-FPGAs Xilinx Virtex-V for ADC waveform acquisition and position/charge calculation
- One Backplane FPGA for communication with RFFEs
- One “System” FPGA for generic firmware (interfaces to control, timing, ...)
- Interfaces: Multi-Gigabit (max. 5 Gbps) links to front (2 x SFP), rear (8 x) with custom or standard protocol (Ethernet, PCIe, ...)

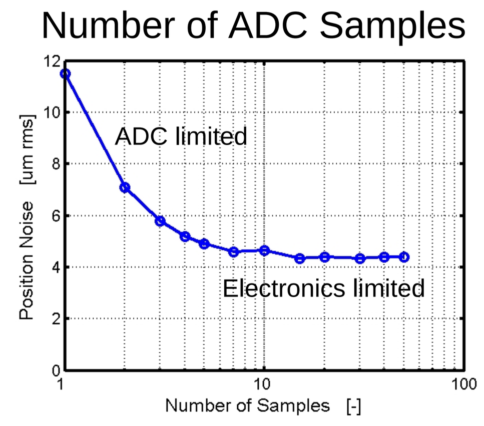
Beam Tests

at PSI SwissFEL Test Injector

- "cold" button pickup
- 25 m pickup cables (3.8 dB)
- Split signals to two RFFEs
- Single bunch operation
- 90 pC equiv. bunch charge

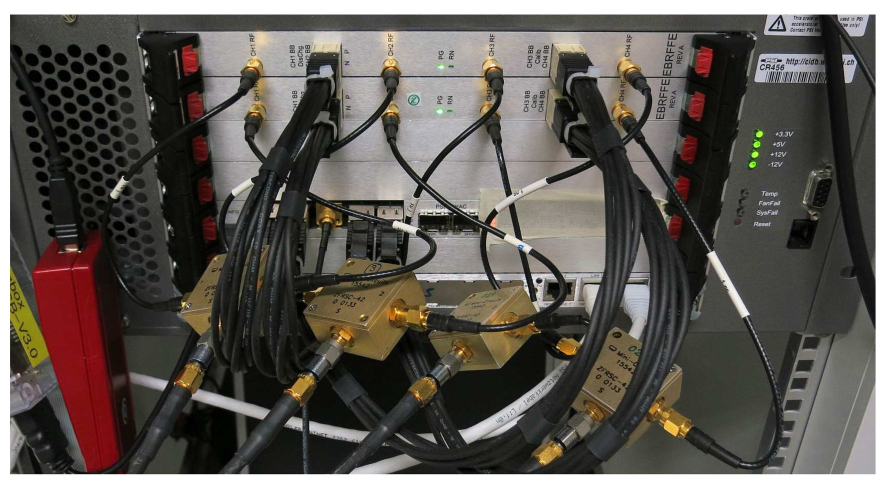
Single bunch position noise is <5 µm at 90 pC.

Position Noise vs. Number of ADC Samples



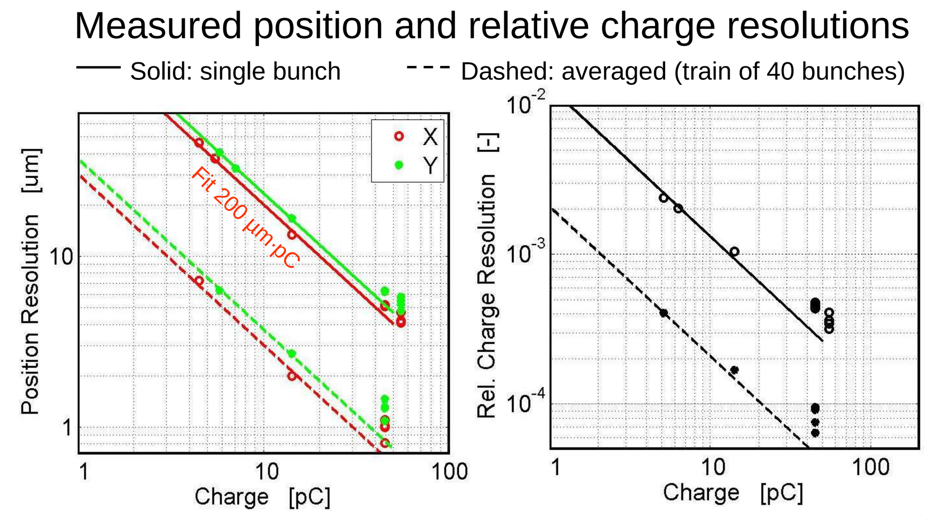
at DESY FLASH

- "warm" button pickup
- 40 m pickup cable (loss 6.1 dB @ 2 GHz)
- Split signals from one pickup to two RFFEs
- Bunch trains
- 4.5 – 50 pC equiv. bunch charge



Charge limited position noise is 200 pC·µm below 40 pC.

Measured position and relative charge resolutions



Ongoing Tests

- Resolution at higher charges
- Linearity w.r.t. Position
- Linearity w.r.t. Charge
- Temperature dependency
- Drift