Design of The SwissFEL BPM System

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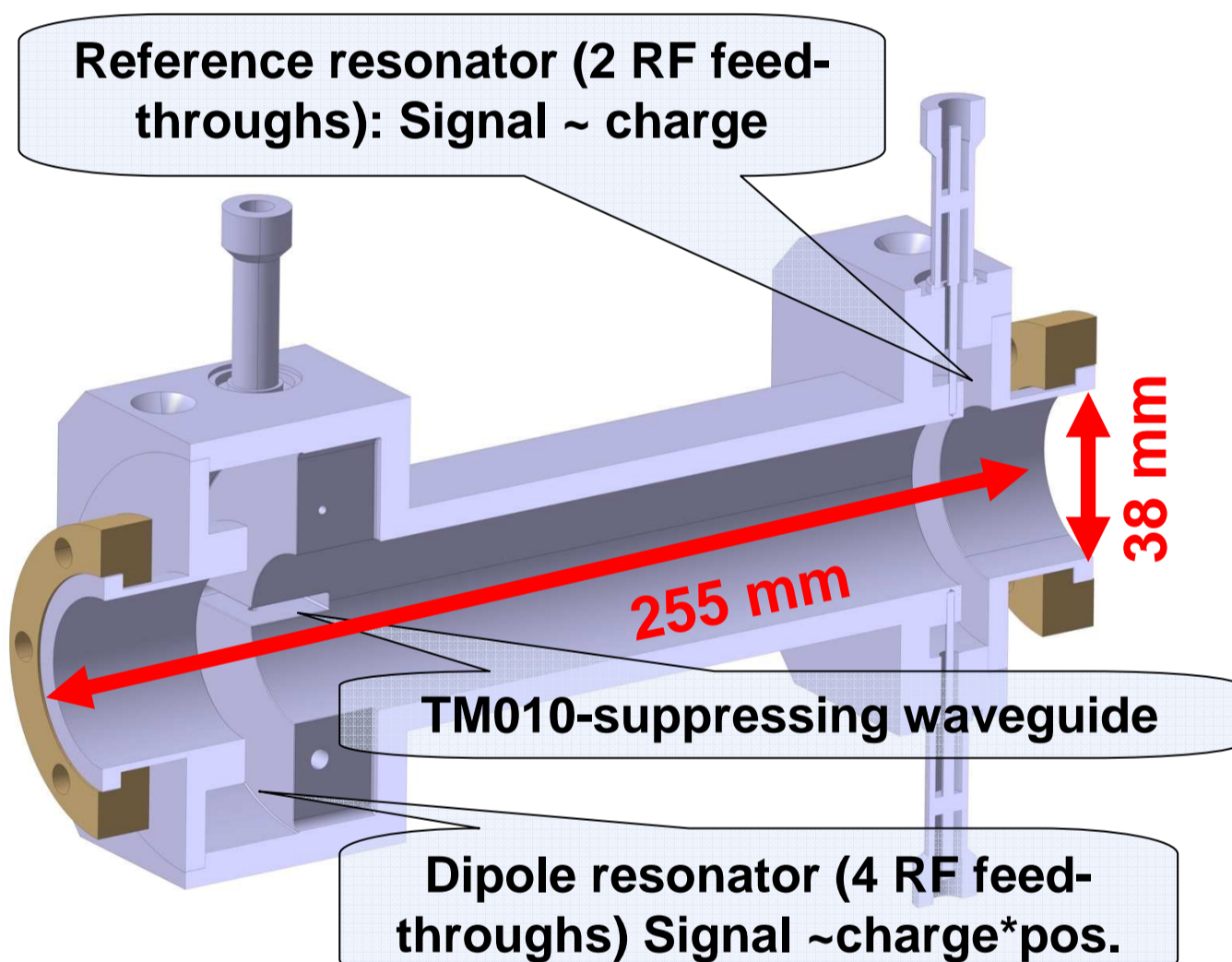
Abstract

SwissFEL is a Free Electron Laser (FEL) facility being constructed at PSI, based on a 5.8GeV normally conducting main linac. A photocathode gun will generate two bunches with 28ns spacing at 100Hz repetition rate, with a nominal charge range of 10-200pC. A fast beam distribution kicker will allow to distribute one bunch to a soft X-ray undulator line and the other bunch to a 0.1nm hard X-ray undulator line. The SwissFEL electron beam position monitor (BPM) system will employ three different types of dual-resonator cavity BPMs, since the accelerator has three different beam pipe apertures. In the injector and main linac (38mm and 16mm aperture), 3.3GHz cavity BPMs will be used, where a low Q of ~40 was chosen to minimize crosstalk of the two bunches. In the undulators that just have single bunches and 8mm BPM aperture, a higher Q will be chosen. This paper reports on the development status of the SwissFEL BPM system. Synergies as well as differences to the E-XFEL BPM system will also be highlighted.
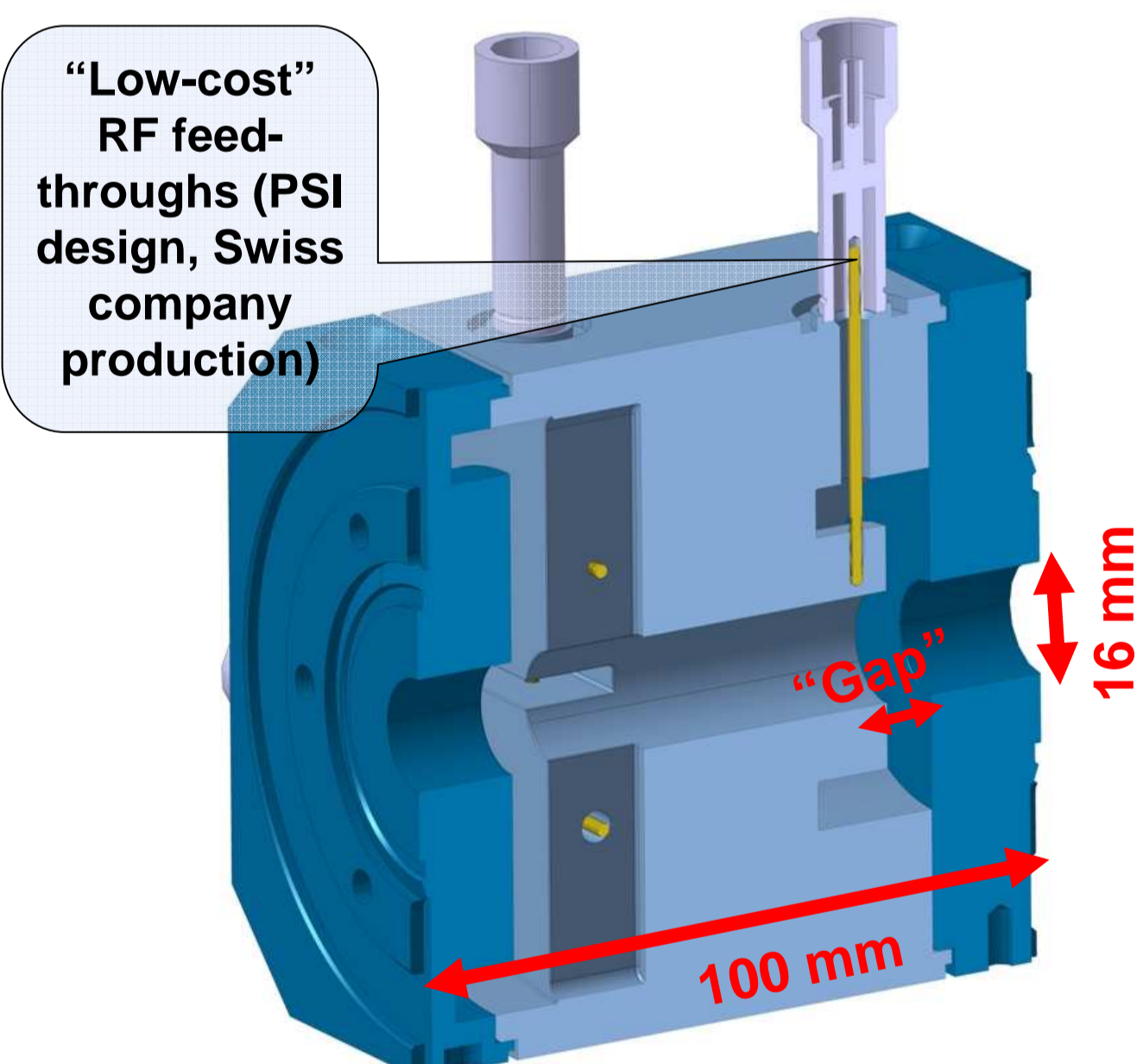
BPM Pickups

- Based on SACLA/E-XFEL Design
- Optimized for low charge & costs
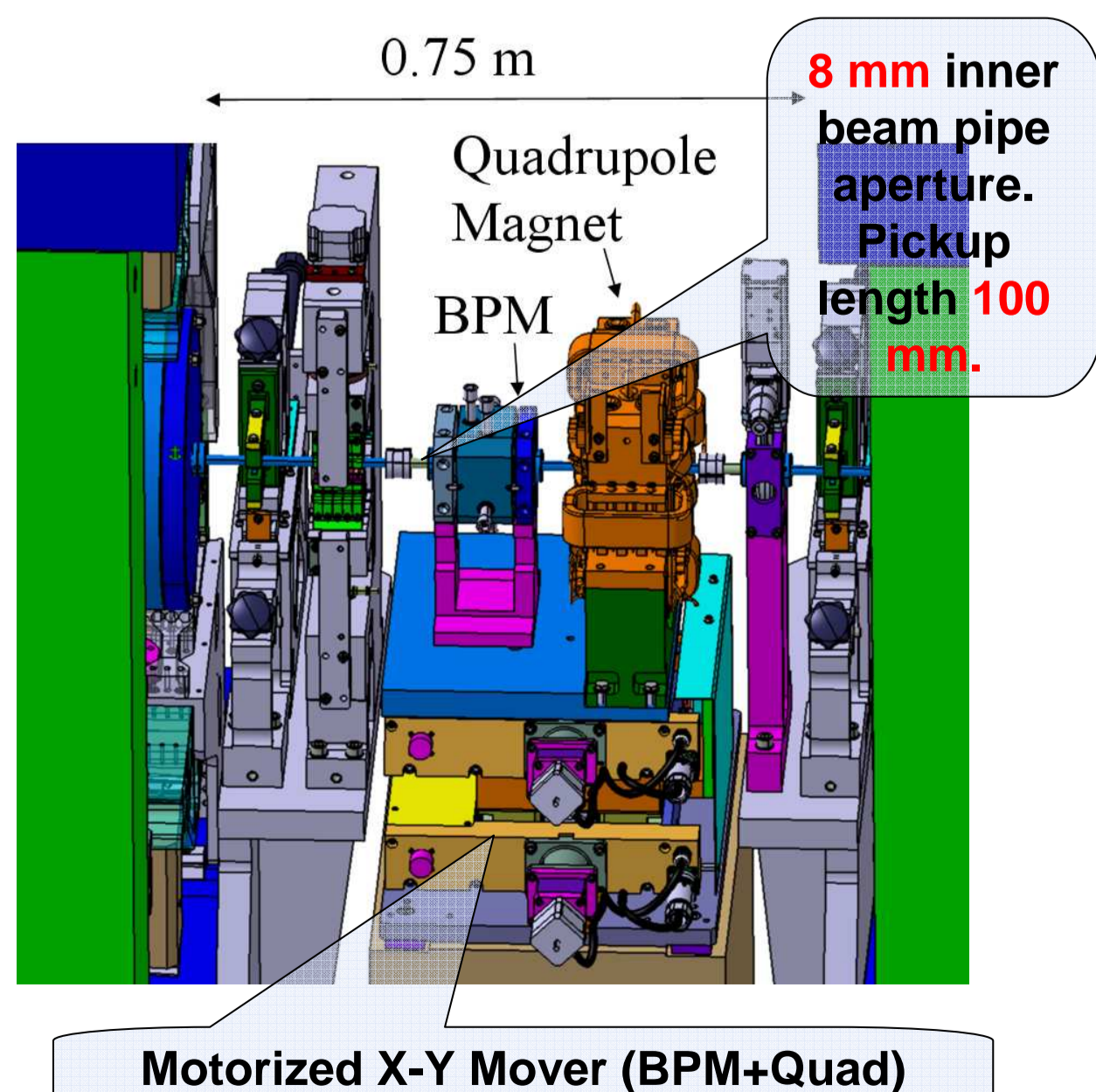- 3 apertures -> 3 types. Only cavities.
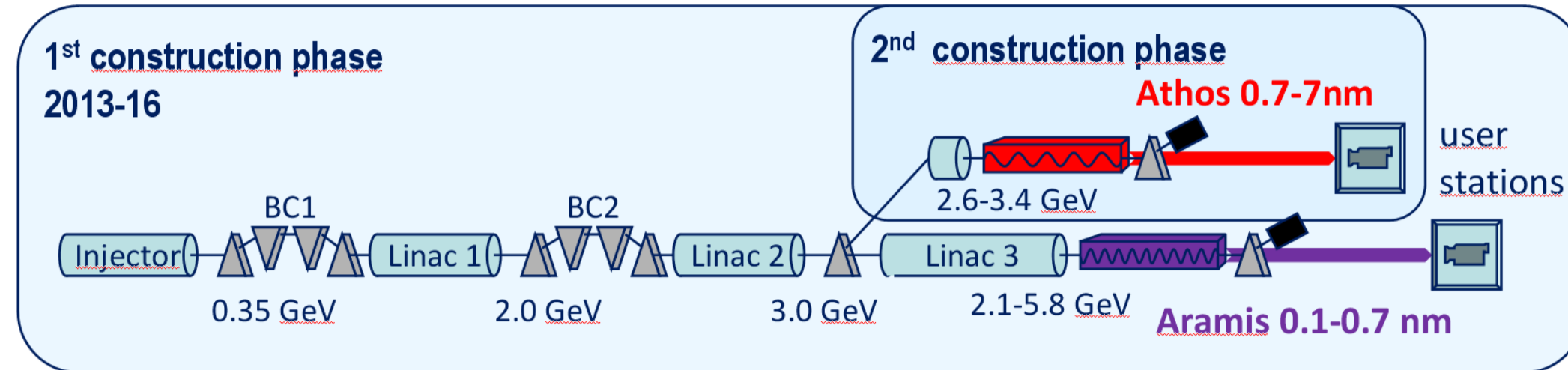
BPM38 (Dump, BC2, Kicker-Area)

Reference resonator (2 RF feed-throughs): Signal ~ charge

38 mm
255 mm

TM010-suppressing waveguide

Dipole resonator (4 RF feed-throughs) Signal ~charge*pos.

BPM16 (Linac, Transfer Lines)

"Low-cost" RF feed-throughs (PSI design, Swiss company production)

"Gap"
16 mm
100 mm

BPM8 (Undulators)

0.75 m

8 mm inner beam pipe aperture. Pickup length 100 mm.

Quadrupole Magnet
BPM

Motorized X-Y Mover (BPM+Quad)

SwissFEL

1st construction phase 2013-16

2nd construction phase

Athos 0.7-7nm

user stations

2.6-3.4 GeV

Aramis 0.1-0.7 nm

Injector | BC1 | BC2
0.35 GeV | Linac 1 | 2.0 GeV | Linac 2 | 3.0 GeV | Linac 3 | 2.1-5.8 GeV

Construction site. June 27, 2013

Machine Parameters

- 5.8GeV normal conducting C-band linac
- Photocathode gun, S-band injector
- X-band for RF linearization
- Phase 1: Hard X-ray undulator line
- Phase 2: Soft X-ray undulator line
- 10-200pC bunch charge
- 2 bunches with 28ns spacing
- Fast kicker: 1 Bunch per undulator line
- 100Hz rep. rate

BPM Requirements

Parameter	BPM38	BPM16	BPM8
Quantity	6	114	50
Length	250 mm	100 mm	100 mm
Inner Aperture	38 mm	16 mm	8 mm
Pos. Range	±10 mm	±5 mm	±1 mm
Pos. Noise	<10 μm*	<5 μm*	<1 μm**
Drift/Week	<10 μm	<5 μm	<1 μm
Charge Noise***		<0.1%	
Charge Range		10-200 pC	
#Bunches/Train		1-3	1
Train Rep. Rate		100 Hz	
Bunch Spacing		28 ns	-

* Within 30% of max. range.
** Within 50% of max. range.
*** Or 30fC, whatever is larger.

BPM8 = Undulator BPM

BPM Electronics

BPM Test Area at SwissFEL Injector Test Facility (SITF)
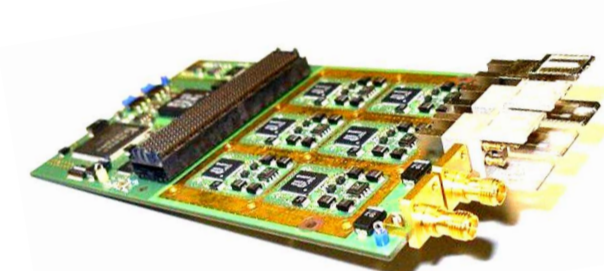
RF Front-End
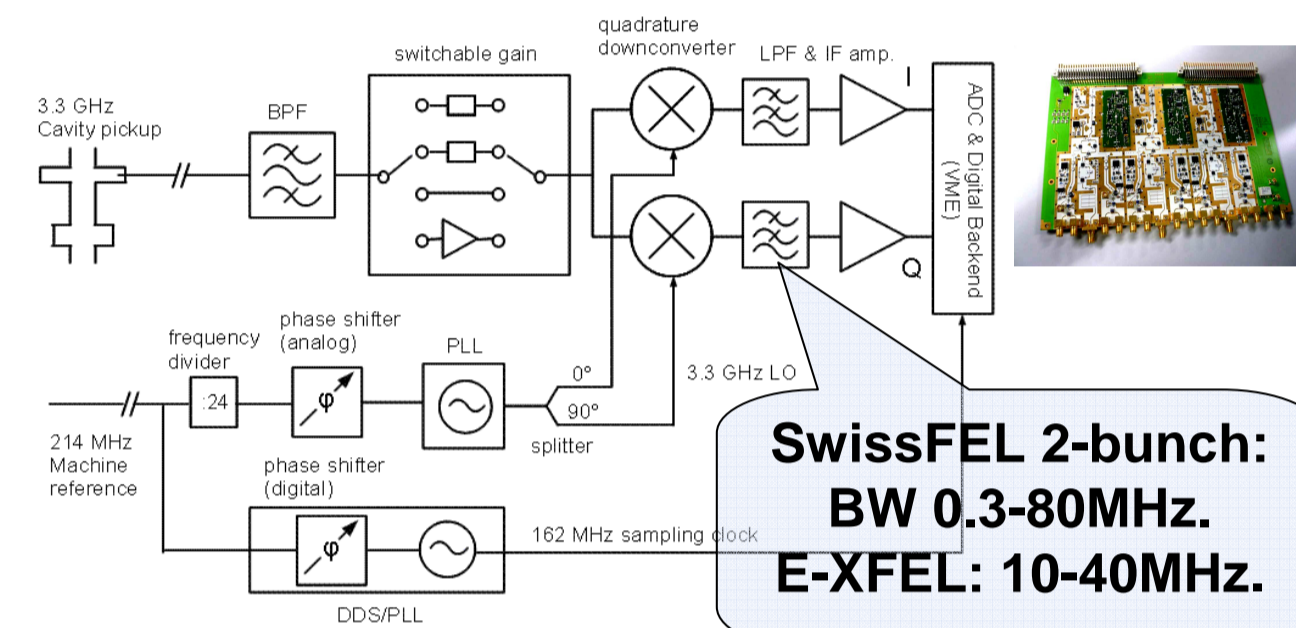
SwissFEL 2-bunch: BW 0.3-80MHz.
E-XFEL: 10-40MHz.

IQ downconversion (baseband/IF) programmable LO & ADC clock frequency & phases. Version 2: 24dB range, 8dB steps. New version 3: 63dB gain range, 0.5dB steps.

ADC Mezzanine

- 6-Channel 16-Bit
- Max. 160MSPS
- 700MHz BW
- Programmable clock phase & divider
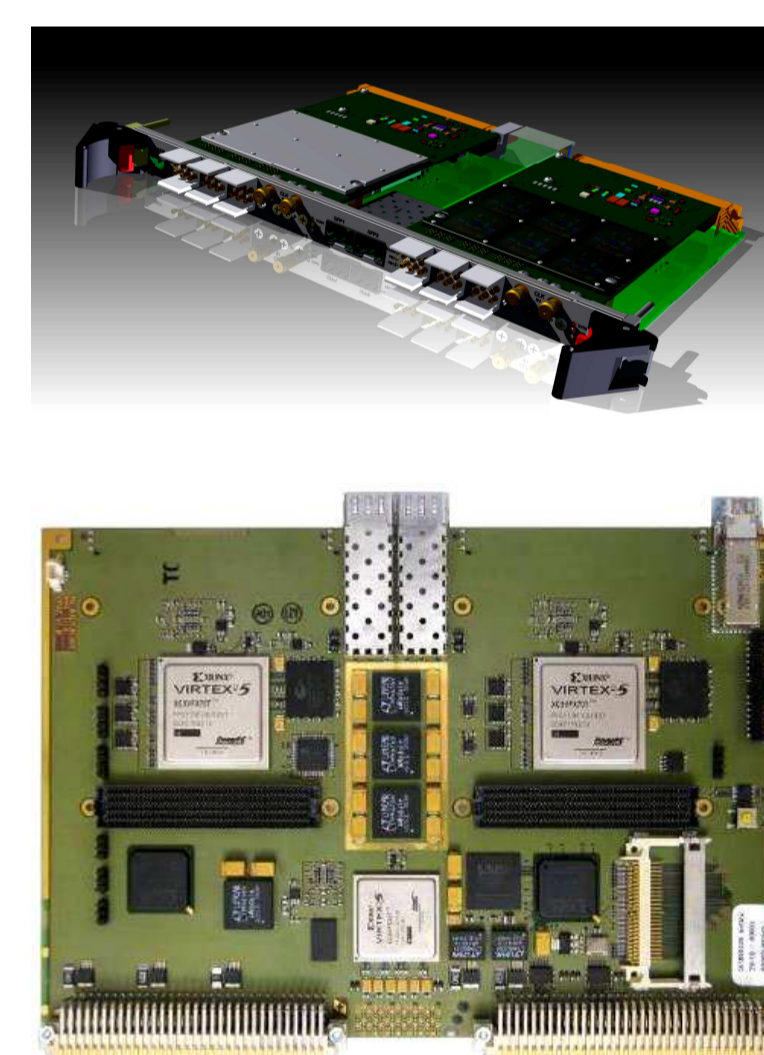- Ext. clock
- Differential inputs

Modular BPM Unit "MBU"

- SwissFEL: 2 Cavity RFFEs (E-XFEL: Also 4 Button RFFEs, ...)
- 1 "GPAC" FPGA Carrier + 2 6-/8-Channel ADCs Mezzanines
- Temperature & power regulation, remote monitoring
- Control/Timing/Feedback Interface: Multi-Gigabit Fiber Links
- All boards designed at PSI

FPGA Carrier Board

- Two connectors for ADC/DAC mezzanines
- 8x12Bit or 6x16 bit ADC/DACs (LVDS parall.) per mezzanine, connected to FPGA each, with application-specific firmware ("BPM" FPGAs)
- One FPGA for generic firmware (interfaces to control, timing, ...): "System" FPGA
- Interfaces: Multi-Gigabit (max. 5Gbps) links to front (2xSFP), rear (8x), mezzanines (2x8). Protocols: Ethernet, PCIe, Custom.
- Present prototype: 3x Virtex-5 (3x PowerPC440, on-board Linux)
- Under development: New version, Artix-7 & Kintex-7 FPGA, TMS320C66xx DSP with 1-8 cores (20-160 GFLOPS)
- Used for SwissFEL, E-XFEL, FLASH2.

Pickup Parameters

Parameter	BPM38	BPM16	BPM8
Gap [mm]	14	7	14
QL		40	200
TM110 Frequency [GHz]		3.284	
TM010 Frequency [GHz]	2.389	2.252	2.202
Position Signal [V/mm/nC]	5.74	7.07	5.23
Angle Signal [μm/mrad]	15.5	4.3	9.5

E-XFEL: 2.9 V/mm/nC (QL=70)

Parameter	BPM38	BPM16	BPM8
Material		Stainless Steel 316LN	
Distance From Position To Ref. Resonator [mm]	180	60	50

Reference Cavity

Parameter	BPM38	BPM16	BPM8
Gap [mm]		7	
QL		40	200
TM010 Frequency [GHz]		3.284	
Charge Signal [V/nC]	66.4	135	47.5
No. of Couplers	2	1	1

First Beam Test Results @ SITF

SwissFEL BPM Prototype: RFFE Output Signals (IQ outputs, just Q shown)

Low Bunch-Bunch Crosstalk

28ns bunch spacing
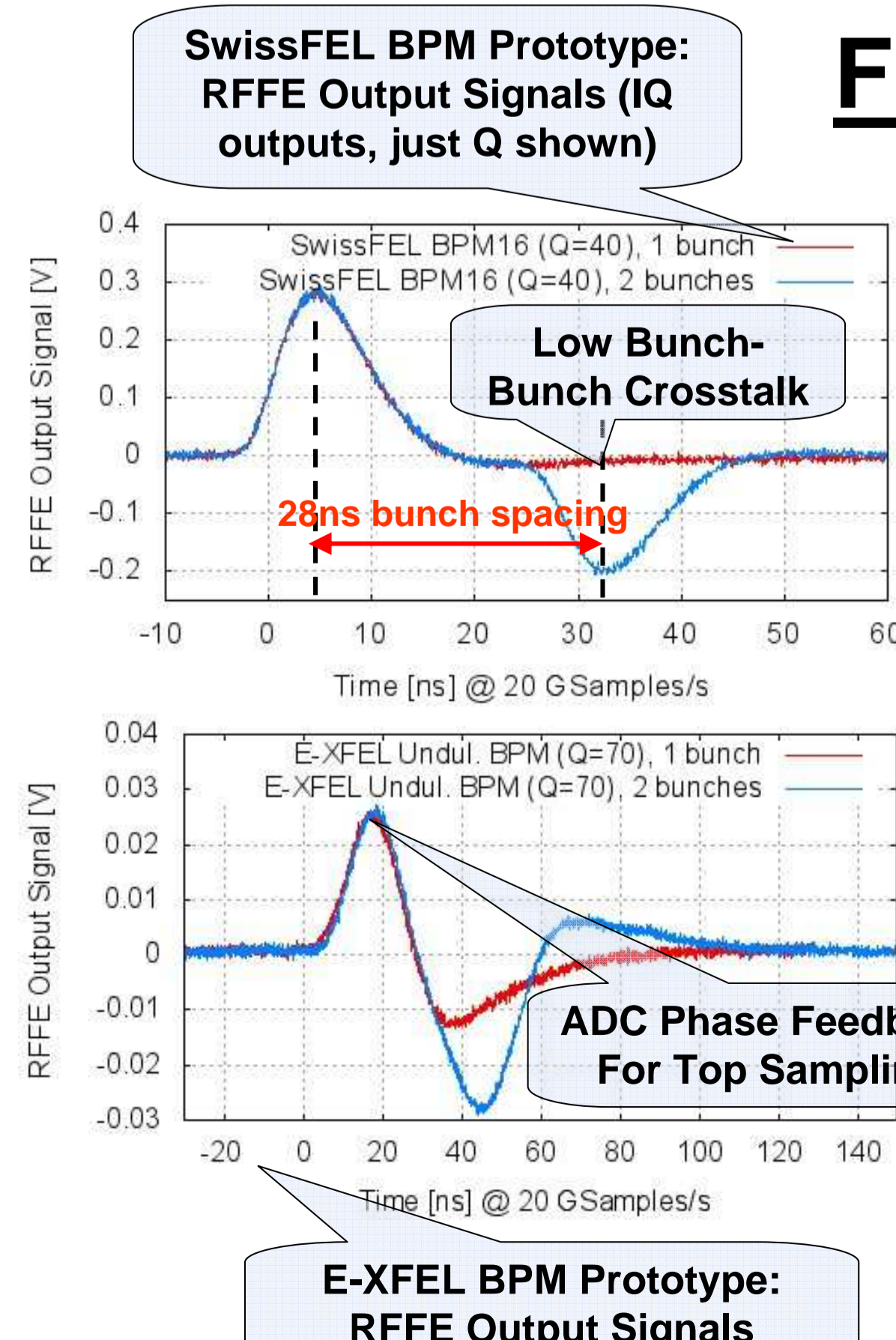
- Beam test at PSI SwissFEL Injector Test Facility:Test area with 5 cavity BPMs (4 E-XFEL, 1 SwissFEL BPM16)
- BPM16: Product of charge & position noise <15μm·pC at low charge (3x below spec).

SwissFEL BPM16 position resolution measurement: Difference of SwissFEL & E-XFEL (extrapolated) BPM position reading. <0.8μm RMS noise at 135pC & 0.35 mm offset (range > ±1mm)

ADC Phase Feedback For Top Sampling

E-XFEL BPM Prototype: RFFE Output Signals

Decay to 0.07%
Decay to 1.6%

Raw Signals of SwissFEL BPM16 (QL=40) & E-XFEL Undulator Cavity Pickup (QL=70)
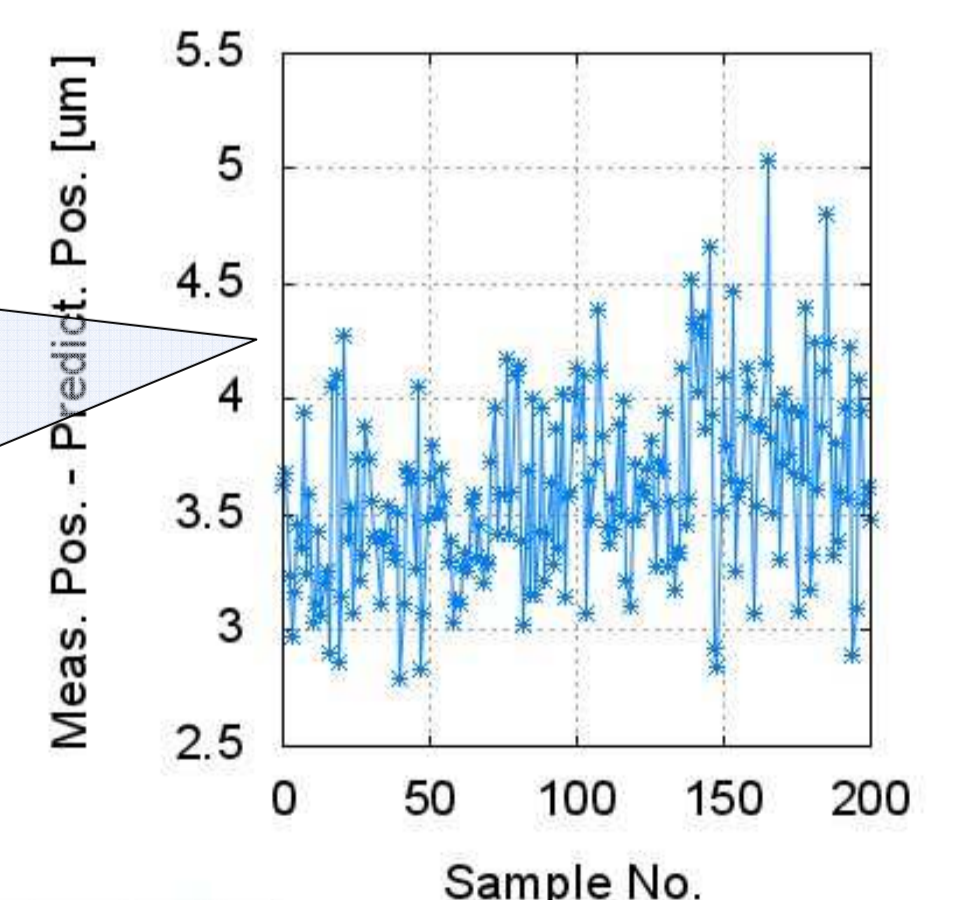
SwissFEL BPM16 Charge resolution measurement: Correlation with E-XFEL undulator BPM. <0.1pC RMS charge noise at 135pC bunch charge.