

Cavity BPM Activities at PSI

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For the PSI Beam Based Feedbacks Group



PSI Provides:

- Undulator & TL cavity BPM electronics for
 - **FLASH-2**: 22 BPMs, 1st beam 1/2014.
 - **E-XFEL**: ~140 BPMs, 1st beam 2015.BPMs also used for transverse Intra Bunch train feedback “IBFB”.
- Cavity BPM system for **SwissFEL**: ~170 BPMs, 1st beam 2016, 3 types/apertures.

BPM Requirements/Specs

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	SwissFEL			E-XFEL	
Parameter	BPM38	BPM16	BPM8	IBFB/TL	Undulator
Quantity	6	114	50	18	117
Length	255 mm	100 mm	100 mm	100 mm	255 mm
Inner Aperture	38 mm	16 mm	8 mm	40.5 mm	10 mm
Pos. Range	±10 mm	±5 mm	±1 mm	±1 (10) mm	
Pos. Noise	<10 μm*	<5 μm*	<1 μm**	<1 (10) μm**	
Drift/Week	<10 μm	<5 μm	<1 μm	<1 (10) μm	
Charge Noise***	<0.1%				
Charge Range	10 - 200 pC			20 - 1000 pC	
#Bunches/Train	1 - 3		1	2700	
Train Rep. Rate	100 Hz			10 Hz	
Bunch Spacing	28 ns		-	222 ns	
Latency	<1 ms			<400 ns	

* Within 30% of max. range.

** Within 50% of max. range.

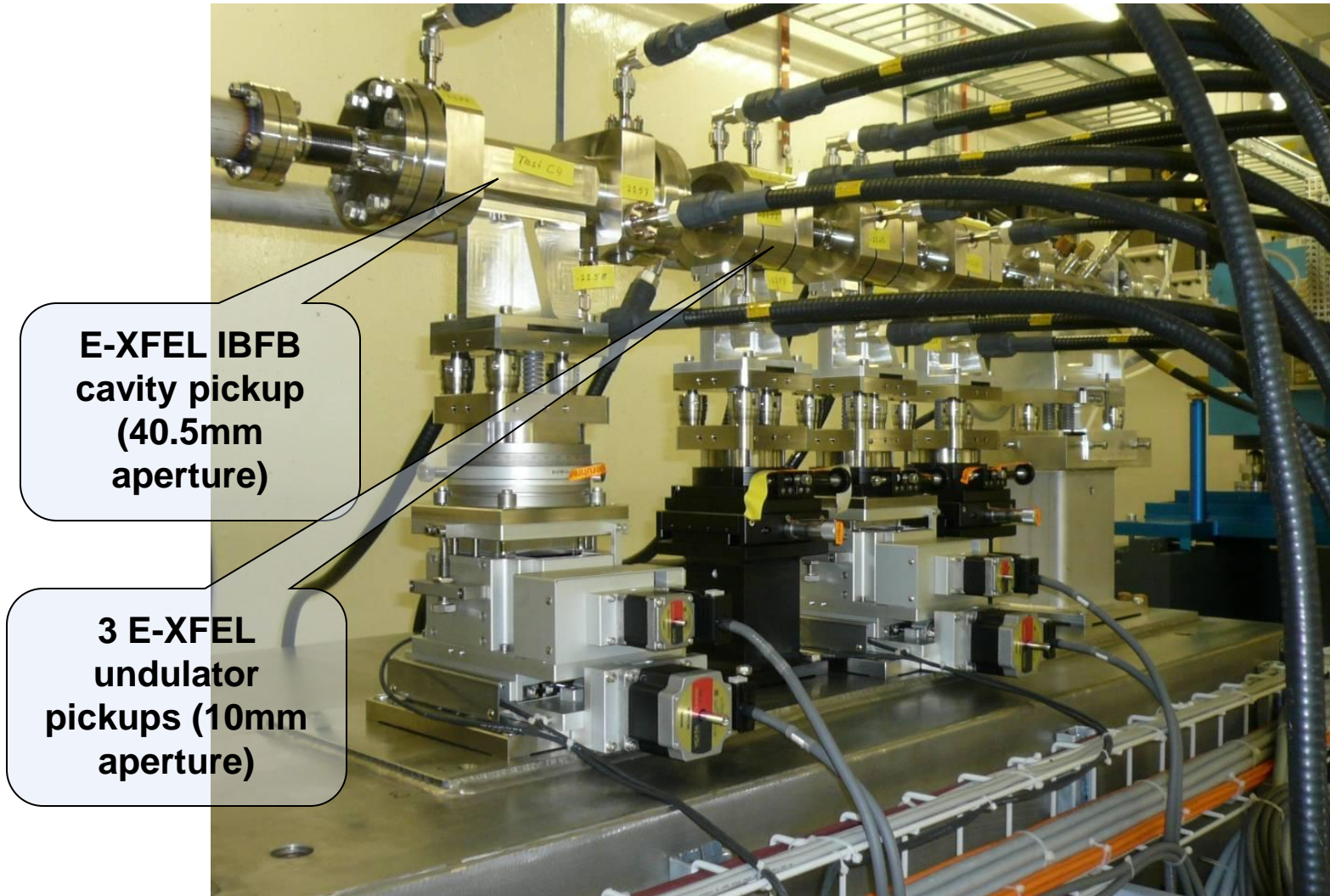
*** Or 30fC, whatever is larger.

Comments:

- E-XFEL & SwissFEL use normal BPMs to measure beam energy (BC, dump, collimator, ...) via dispersion. BPM resolution & drift will determine energy resolution & drift! Need $\pm 1\text{mm}$ range (and low drift & noise over whole range): Energy chirp over bunch train.
- E-XFEL IBFB: Overall feedback loop latency $< 1000\text{ns}$ expected to be sufficient. First few bunches in train are most likely dumped anyway (LLRF ...). Main random perturbation source that requires feedback: Mechanical vibrations \rightarrow IBFB should move bunches to nominal orbit within $\sim 10\mu\text{s}$. E-XFEL will most likely run at $> 1000\text{ns}$ bunch spacing for quite some time ...

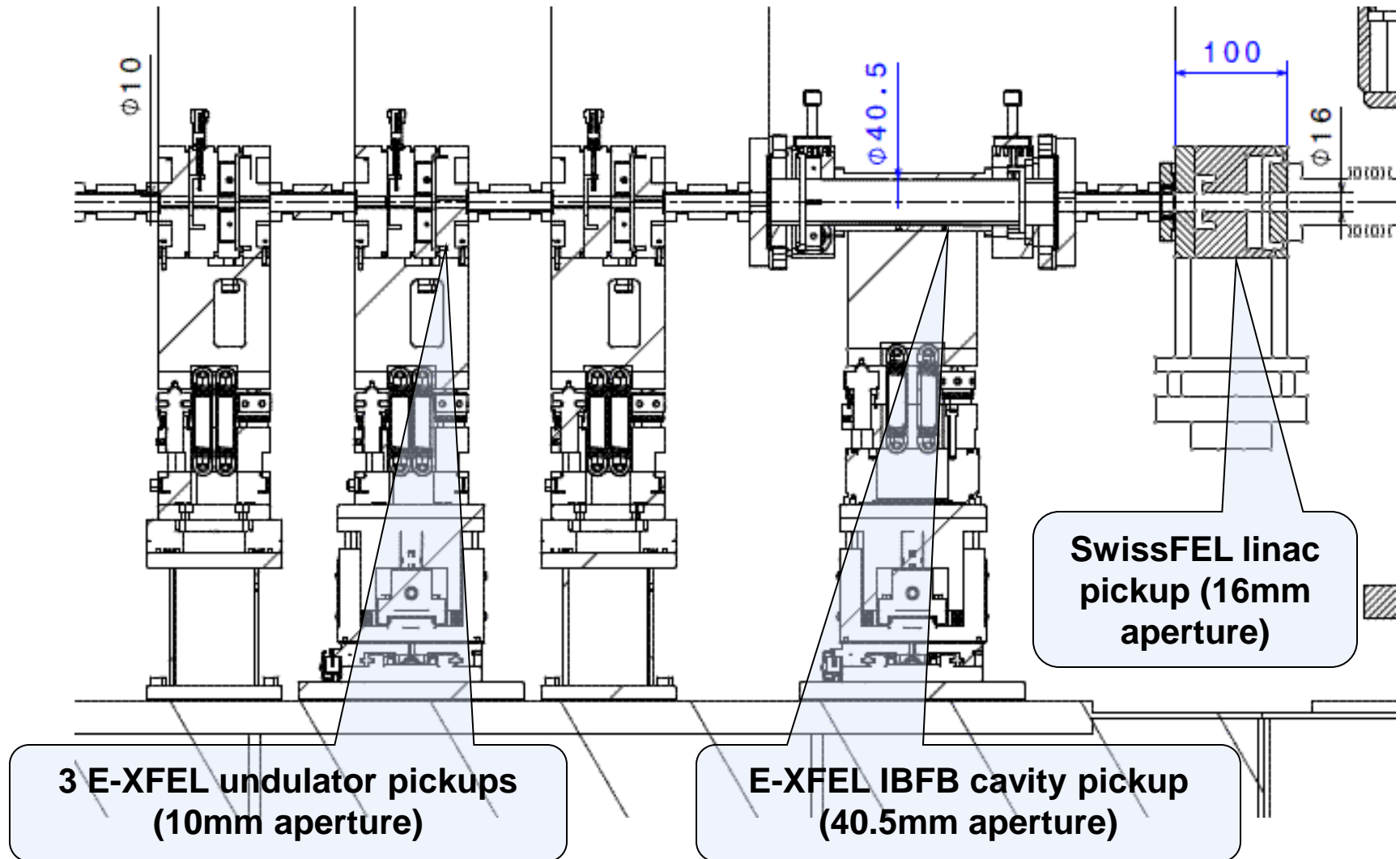
SwissFEL Injector Test Facility

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SwissFEL Injector Test Facility

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SwissFEL Pickup Parameters

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

Parameter (Ref. Resonator)	BPM38	BPM16	BPM8
Gap [mm]	7		
Q_L	40		200
TM ₀₁₀ Frequency [GHz]	3.284		
Charge Signal [V/nC]	66.4	135	47.5
No. of Couplers	2	1	1

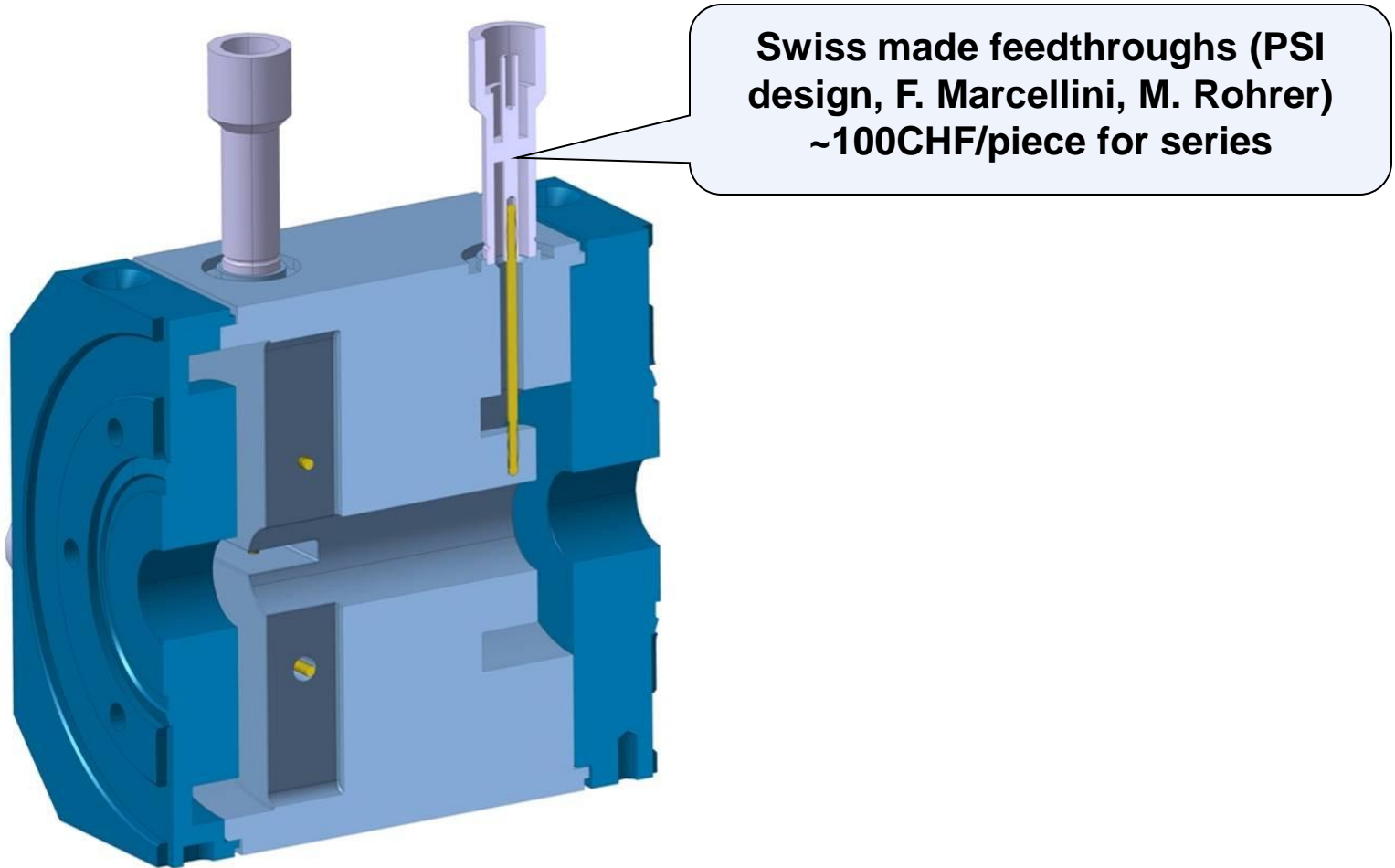
SwissFEL Pickup Parameters

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Parameter (Position Resonator)	BPM38	BPM16	BPM8	E-XFEL Und.
Gap [mm]	14	7	14	3
Q_L	40		200	70
TM ₁₁₀ Frequency [GHz]	3.284			3.3
TM ₀₁₀ Frequency [GHz]	2.389	2.252	2.202	
Position Signal [V/mm/nC]	5.74	7.07	5.23	2.9
Angle Signal [μ m/mrad]	15.5	4.3	9.5	1

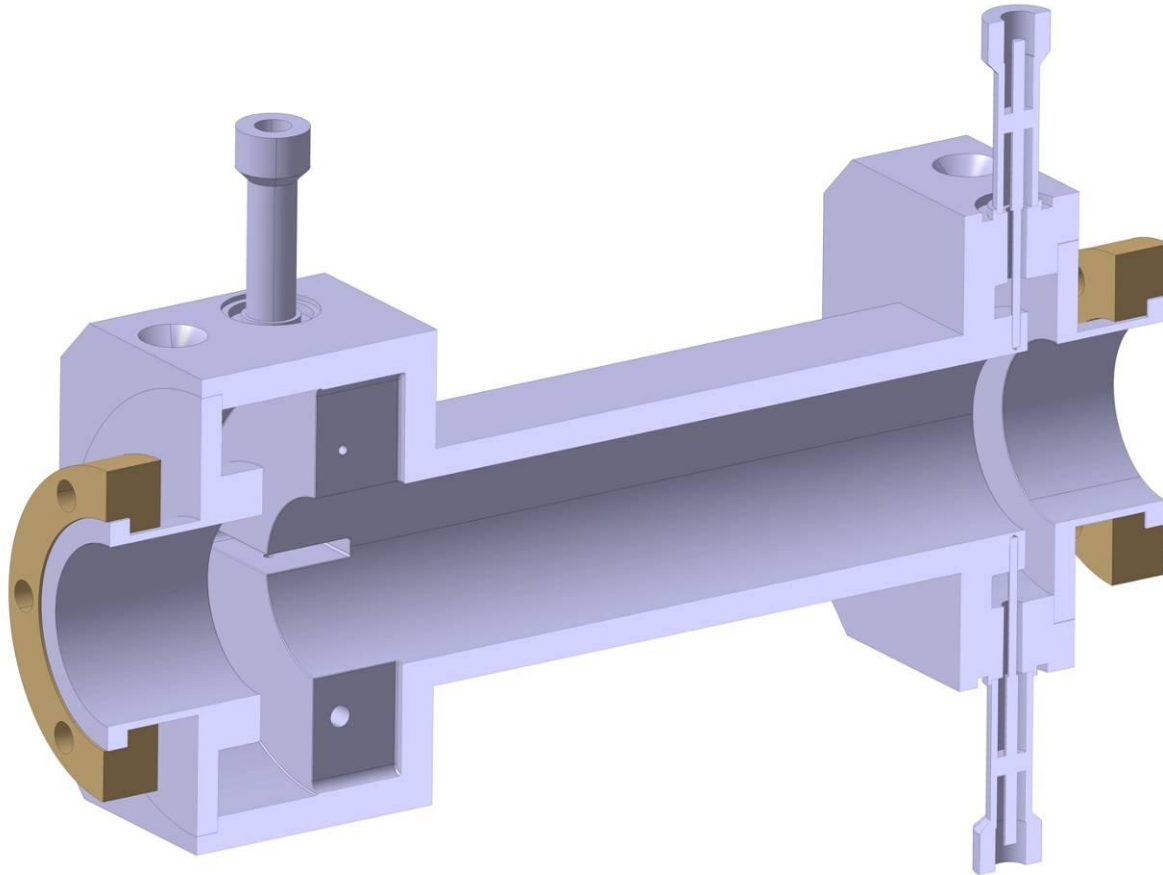
SwissFEL BPM16 Pickup

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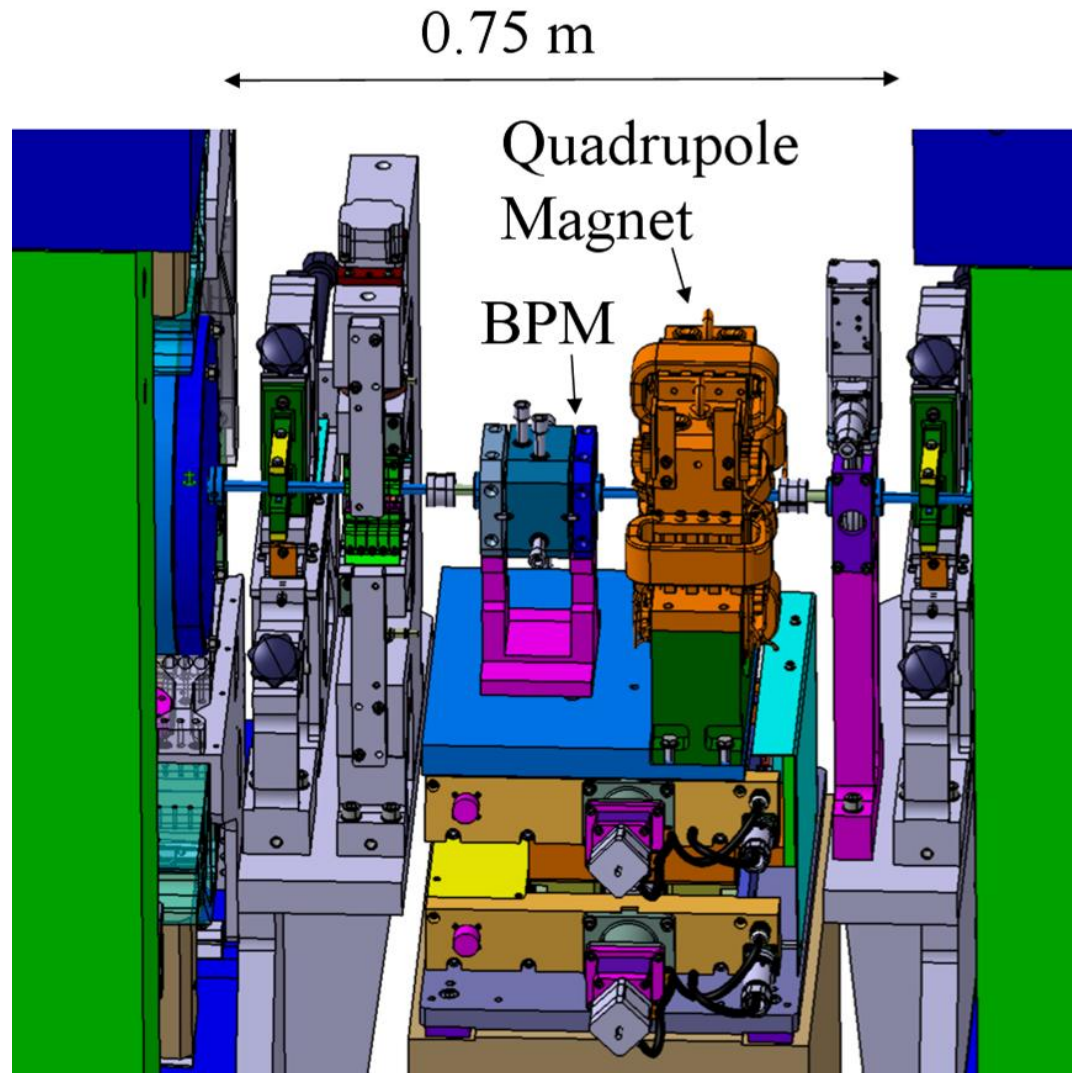
SwissFEL BPM38 Pickup

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SwissFEL BPM8 Pickup

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E-XFEL & FLASH-2 Electronics

- Pre-series in production for FLASH-2.

SwissFEL Pickups

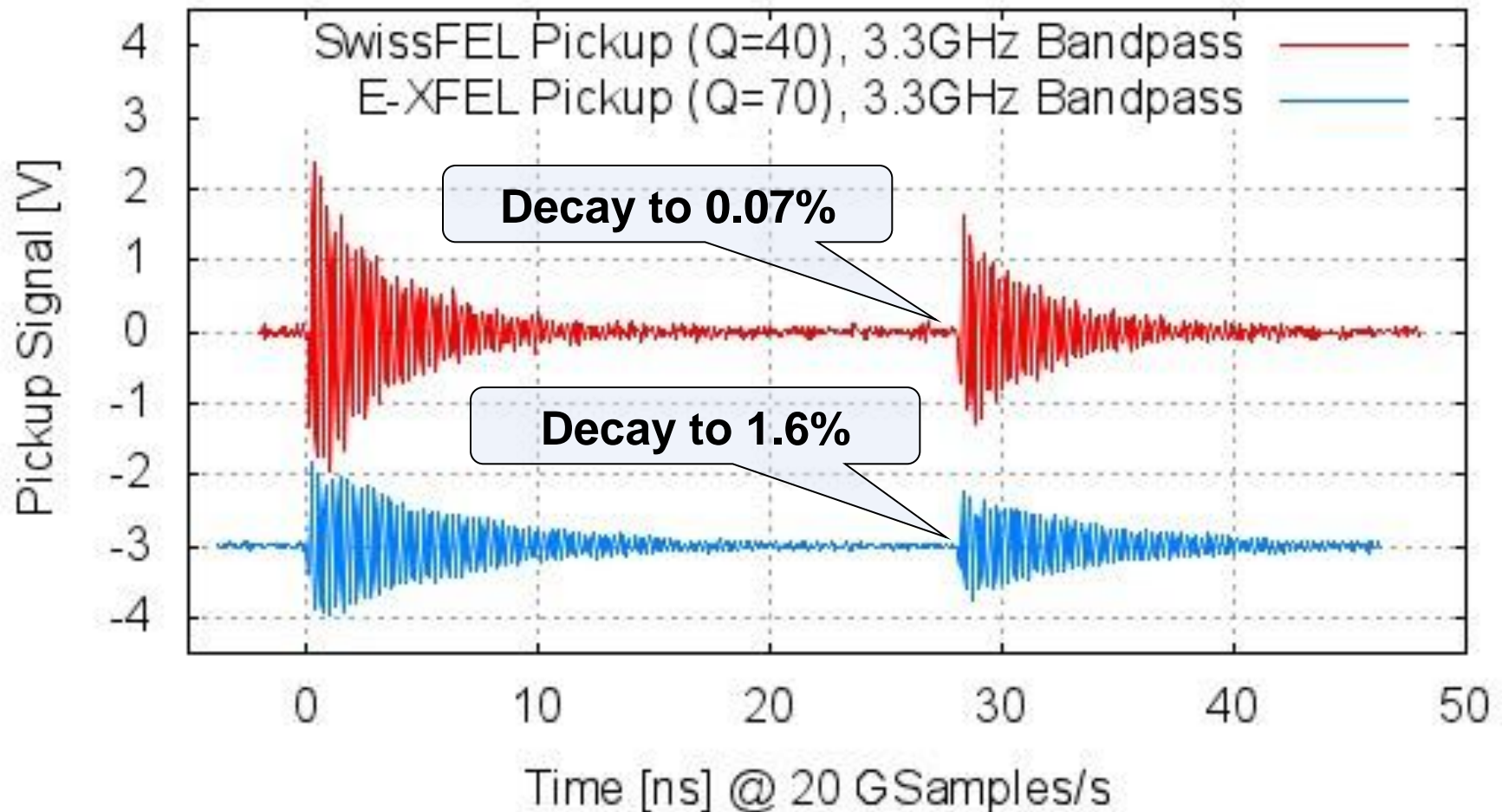
- BPM16 (linac pickup): Design done, starting production (series of 15 first, >100 later).
- BPM38 (“injector” pickup): RF design done, mechanical construction in progress.
- BPM8 (undulator pickup): RF tolerance study in progress.

SwissFEL Electronics

- Use E-XFEL electronics, modify where needed (bunch spacing, ...). 1st linac prototype tested with beam.

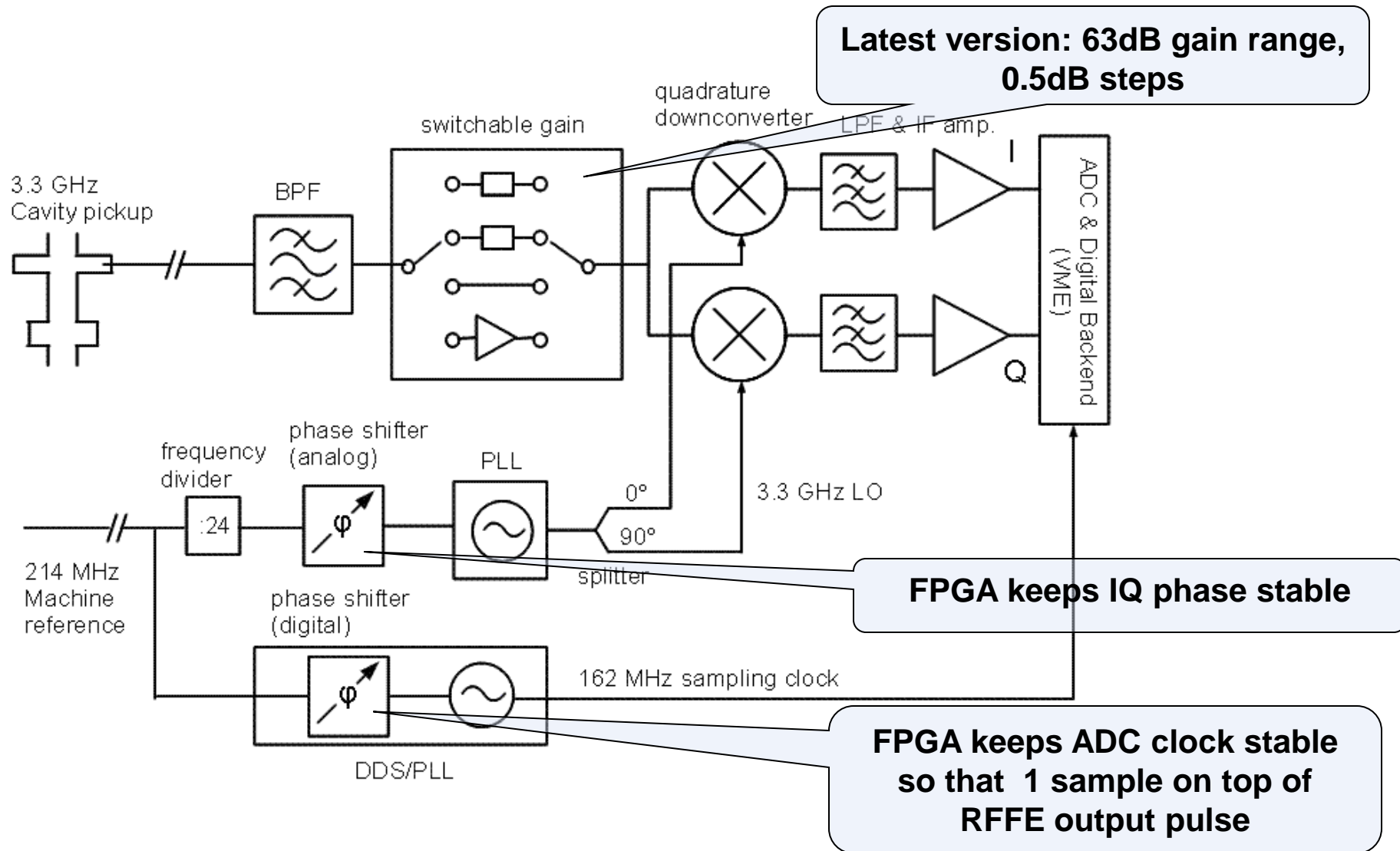
Pickup Signals

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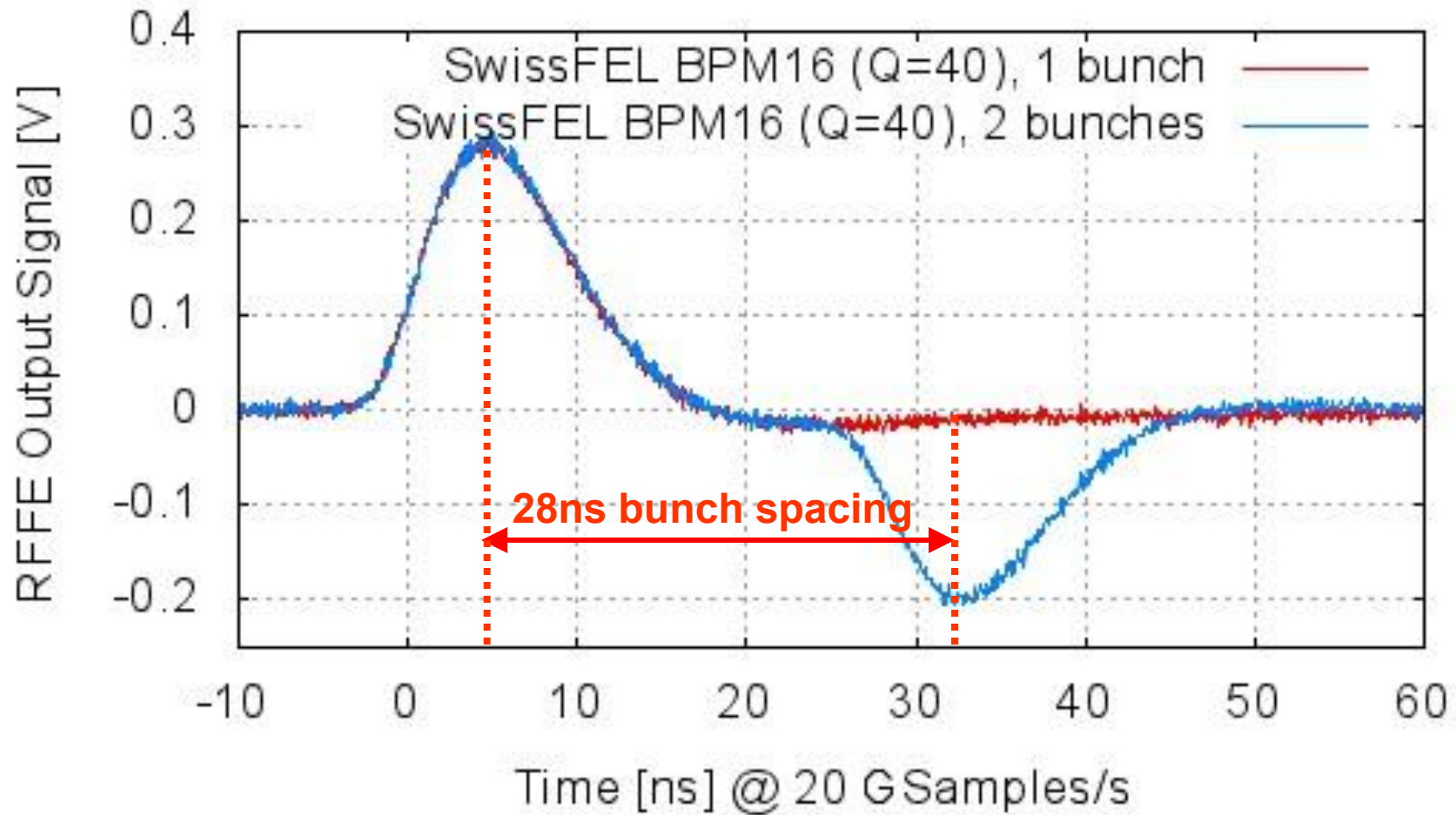
RFFE (Simplified)

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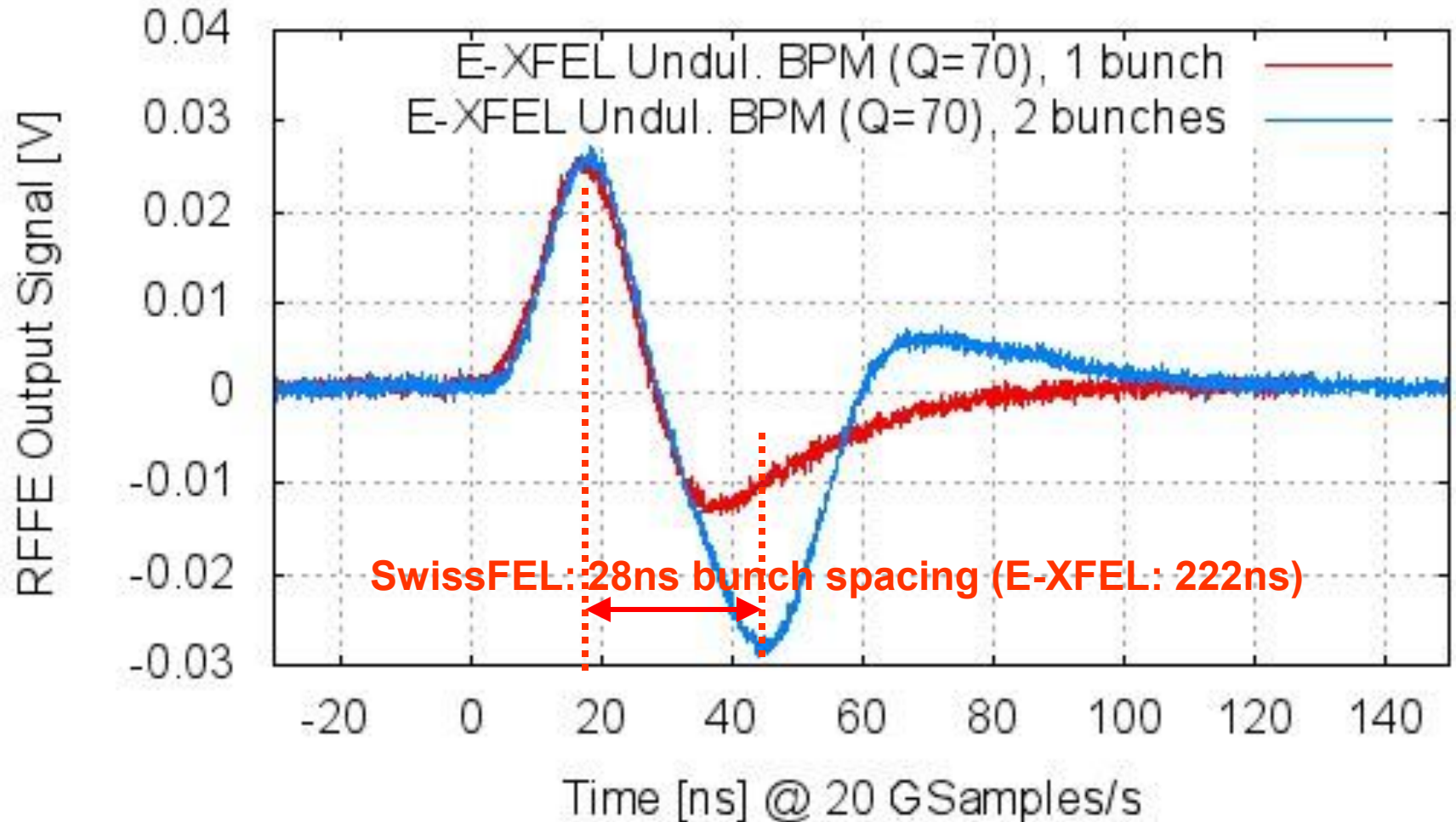
RFFE Output: SwissFEL BPM16

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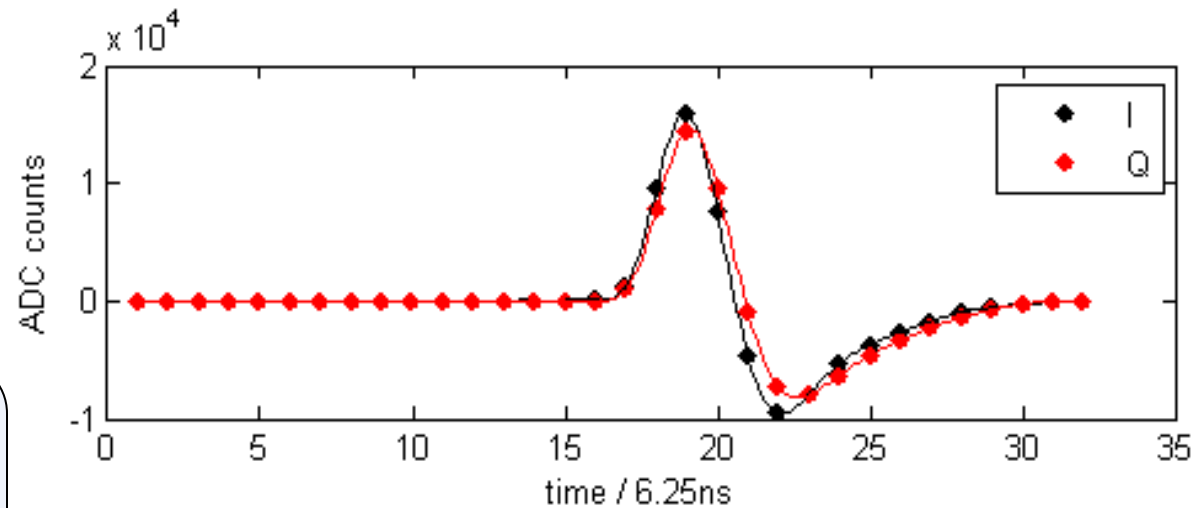
RFFE Output: E-XFEL Undulator

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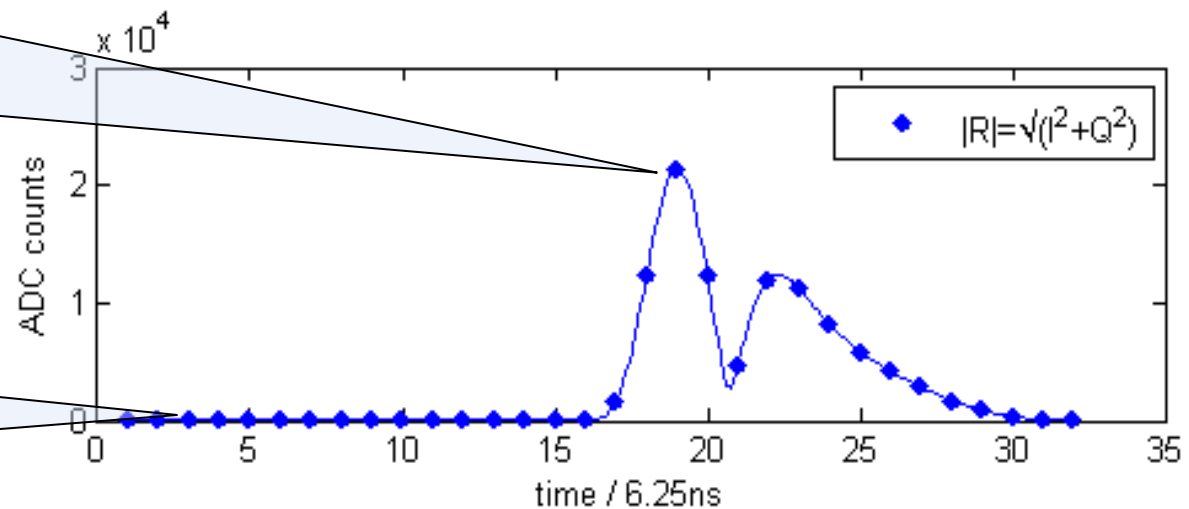


E-XFEL BPM ADC Waveform

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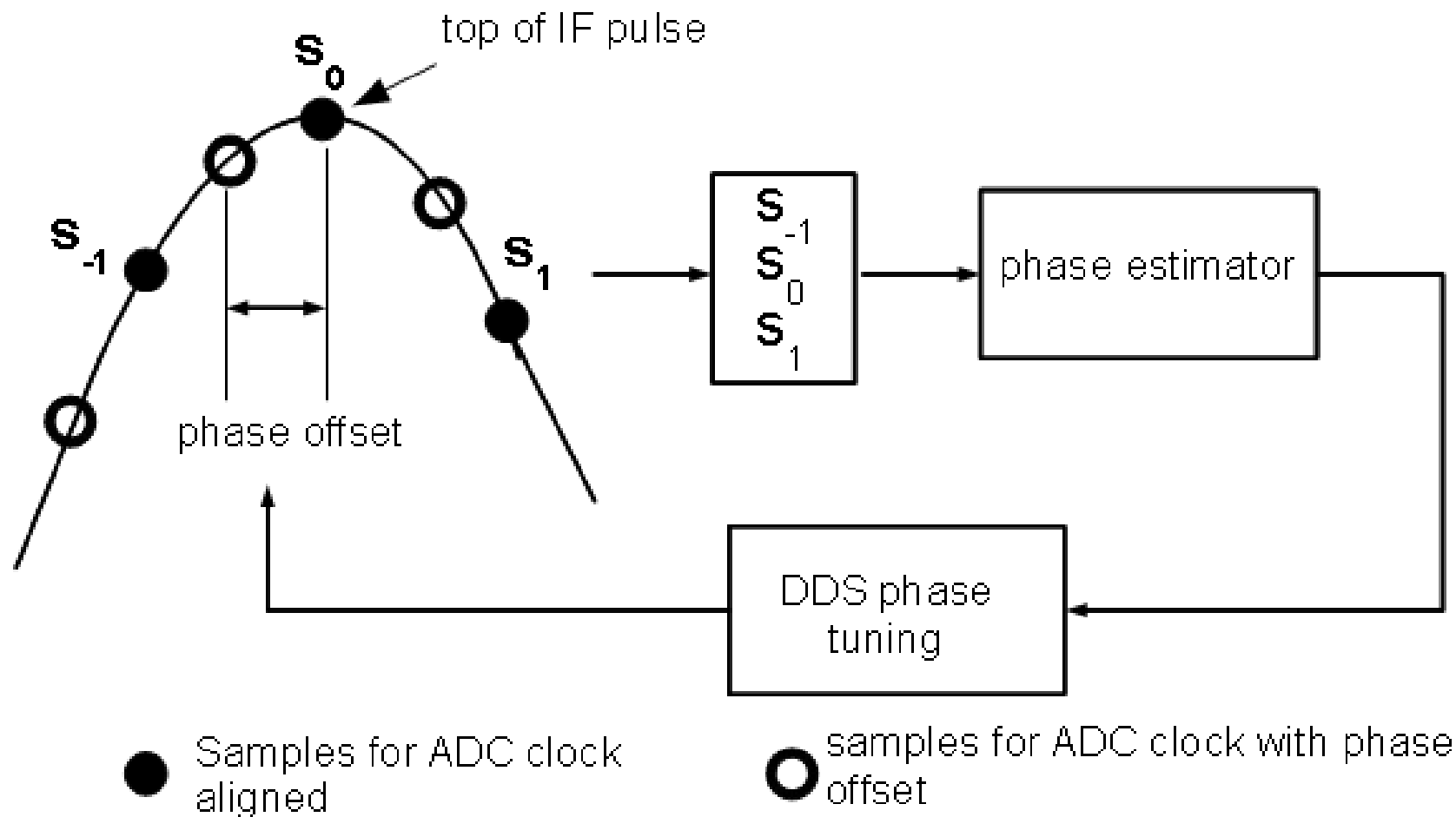
So far: Sample on top of pulse used for position calculation (future: Use more samples ...)

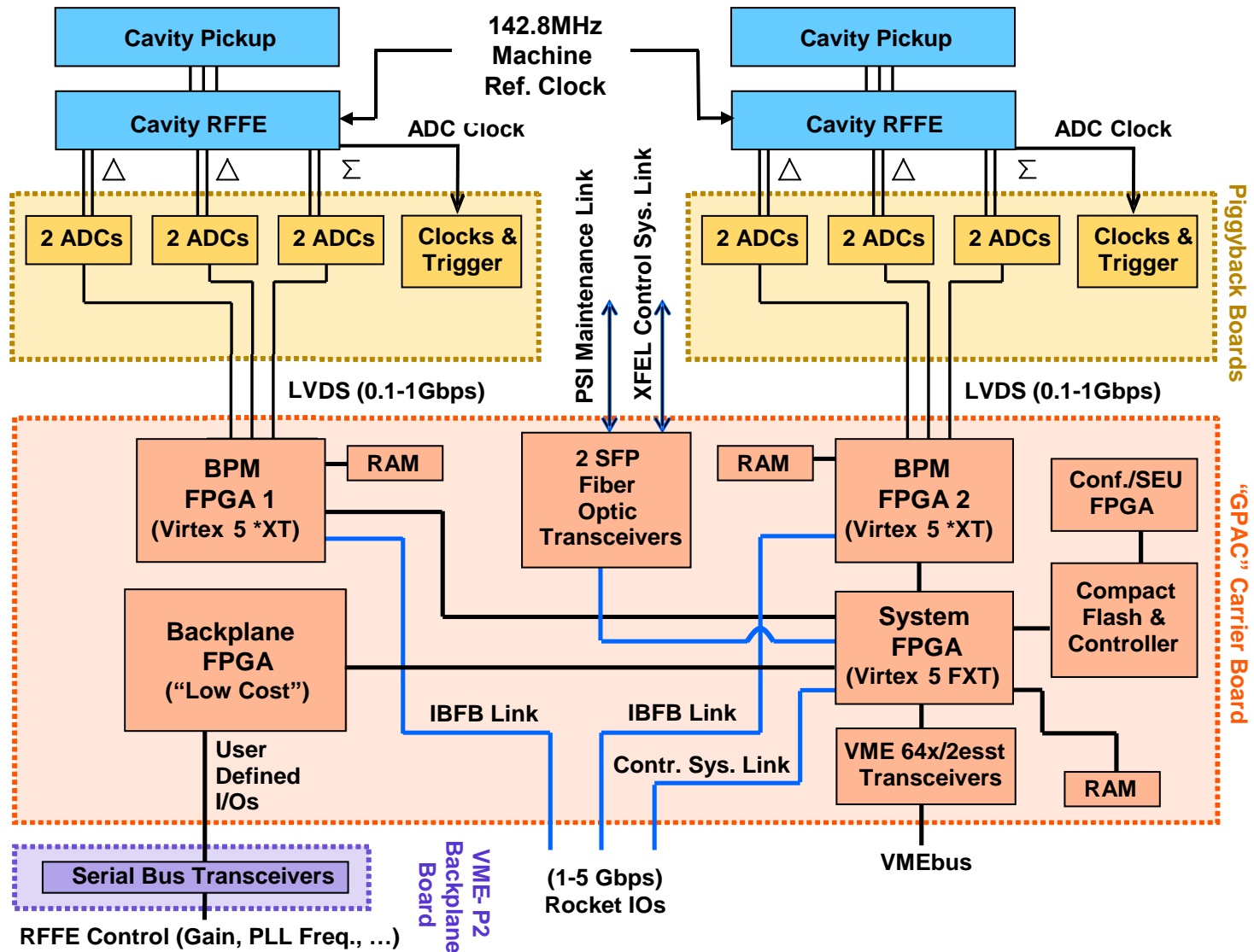


Baseline subtracted from pulse

ADC Clock Phase Feedback

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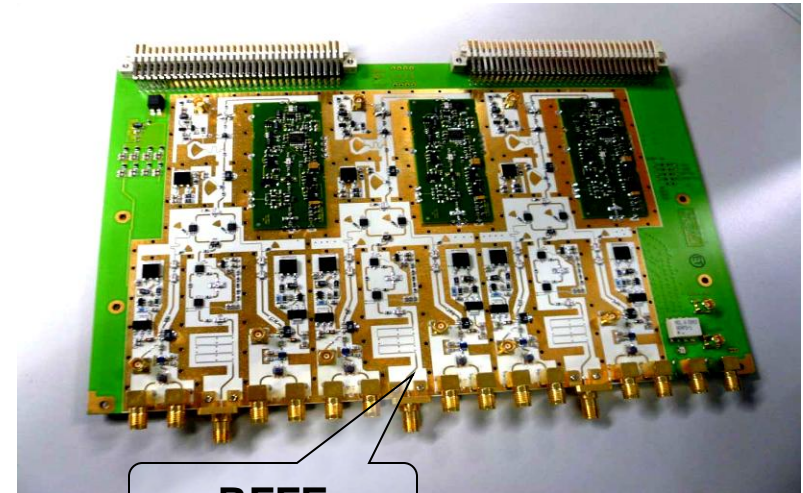


Hardware

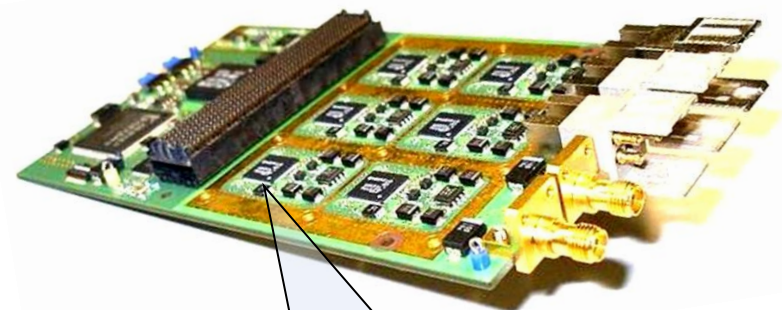
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FPGA Carrier



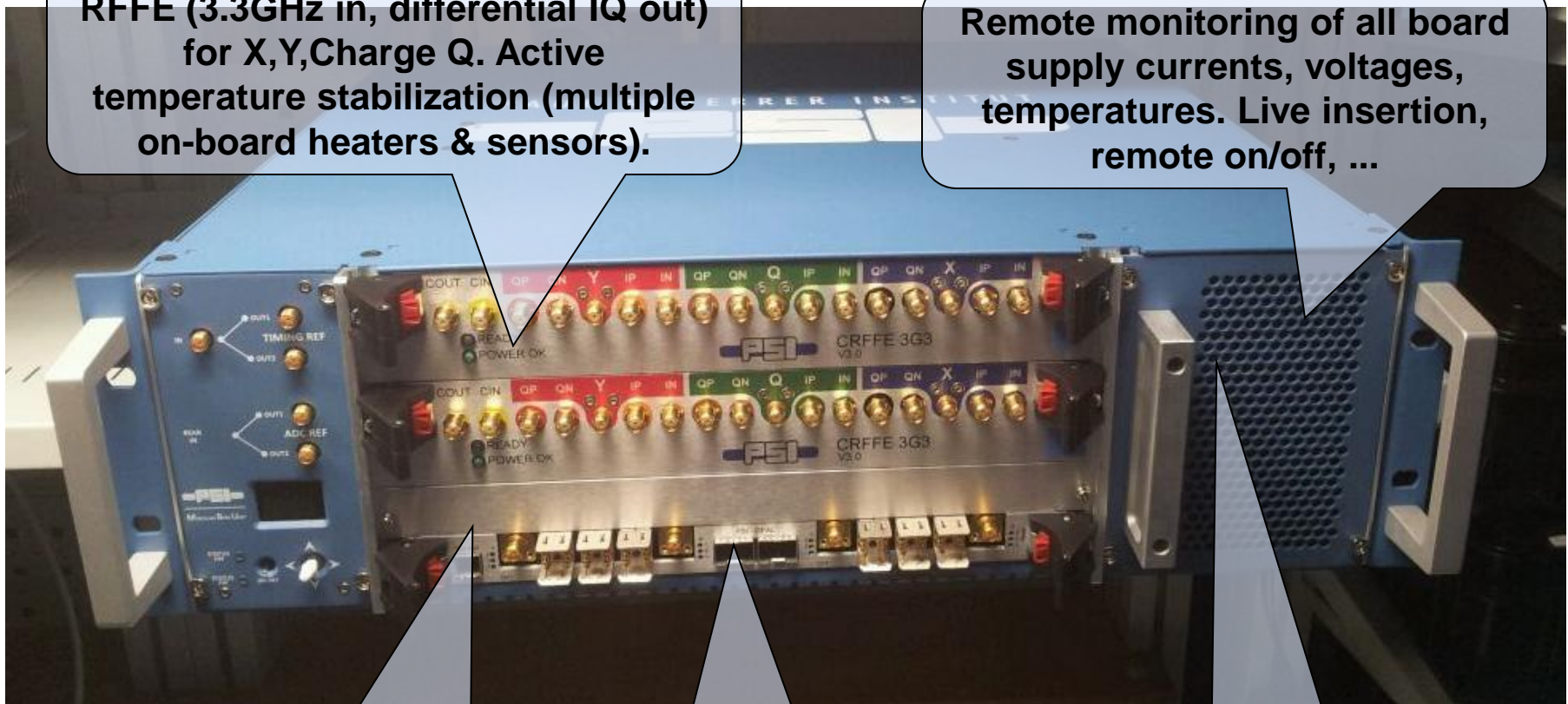
RFFE



ADC Mezzanine

RFFE (3.3GHz in, differential IQ out) for X,Y,Charge Q. Active temperature stabilization (multiple on-board heaters & sensors).

Remote monitoring of all board supply currents, voltages, temperatures. Live insertion, remote on/off, ...



FPGA carrier with two 6x16bit ADC mezzanines, 160MSPS.

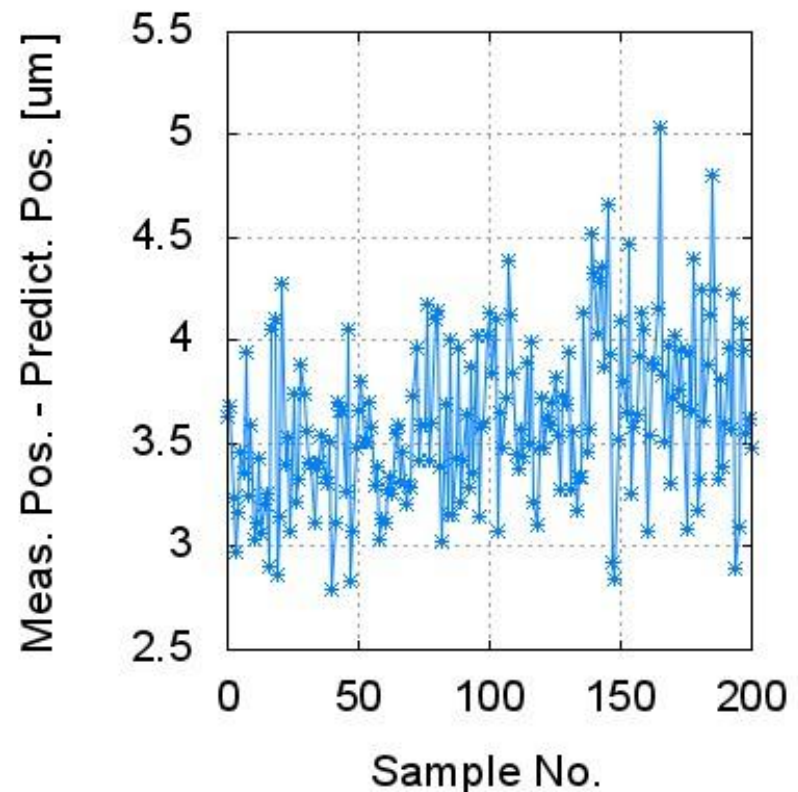
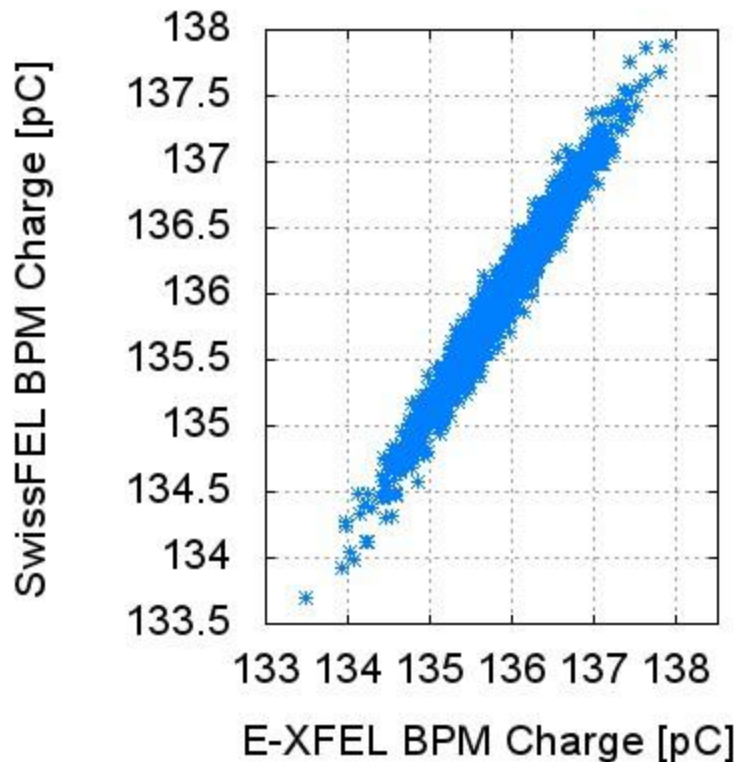
SFP+ (PCIe, Ethernet, custom protocol, ...). 6 more SFP+ at rear side.

8 fans with individual regulation, multiple temp. sensors, ...

SwissFEL BPM16 Test (Linac)

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- Product of pos. noise & charge = $15\text{pC}\cdot\mu\text{m}$ @ low charge
- Pos. noise $<0.8\mu\text{m}$ RMS @ 135pC , $\pm 1\text{mm}$ range.
- Charge noise $<0.1\%$ ($<0.1\text{pC}$ RMS at $Q=135\text{pC}$).



E-XFEL Undulator BPM Beam Test

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Beam Offset (mm)	Beam Charge (pC)	Linear Meas. Range	Measured Resolution ($\mu\text{m-rms}$)	Predicted Resolution ($\mu\text{m-rms}$)
0.1	285	$\pm 2\text{mm}$	0.35	0.33
0.5	285	$\pm 2\text{mm}$	0.40	0.36
1	285	$\pm 2\text{mm}$	0.56	0.4
0.05	183	$\pm 500\mu\text{m}$	0.18	0.165
0.2	2	$\pm 6.4\text{mm}$	11.2	13
≈ 0.06	350	$\pm 250\mu\text{m}$	0.12	(0.06)
unstable				

Position computation in FPGA (incl. IQ imbalance correction, ...). Overall latency <400ns.

- F. Marcellini & M. Rohrer (SwissFEL pickups) → IBIC'12
- M. Stadler (cavity RFFE HW) → IBIC'12
- M. Roggli, D. Treyer (ADC)
- R. Baldinger (FPGA carrier board HW)
- G. Marinkovic, W. Koprek (FPGA FW, SW, HW)
- R. Ditter, R. Kramert (electronics/mechanics)

Thanks also to:

- DESY BPM team (D. Lipka, S. Vilcins et al.)
- PSI vacuum group, mechanical construction & SITF operations team.



Thank you for your
attention!