Report on research activities for the PhD in "Accelerator Physics" (32nd cycle)

Studies and Measurements on Cavity Beam Position Monitors for Novel Electron Linacs

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Agenda

- ELI-NP
- Cavity Beam Position Monitor
- Measurements at DESY
- Measurements at SPARC
- Conclusions

ELI-NP Gamma Beam System

ELI-NP GBS is an **Advanced Gamma Source** for studies in new nuclear spectroscopy and new photonuclear physics.

It is a **Compton back-scattering** machine with a **tunable energy** of the gamma photons between 0.2 and 19.5 MeV, a **narrow bandwidth** (0.5%) and a **high spectral density** (>10^4 photons/sec/eV).

The EuroGammaS consortium, led by INFN, is responsible for its development and delivery. The machine installation is scheduled for 2019.

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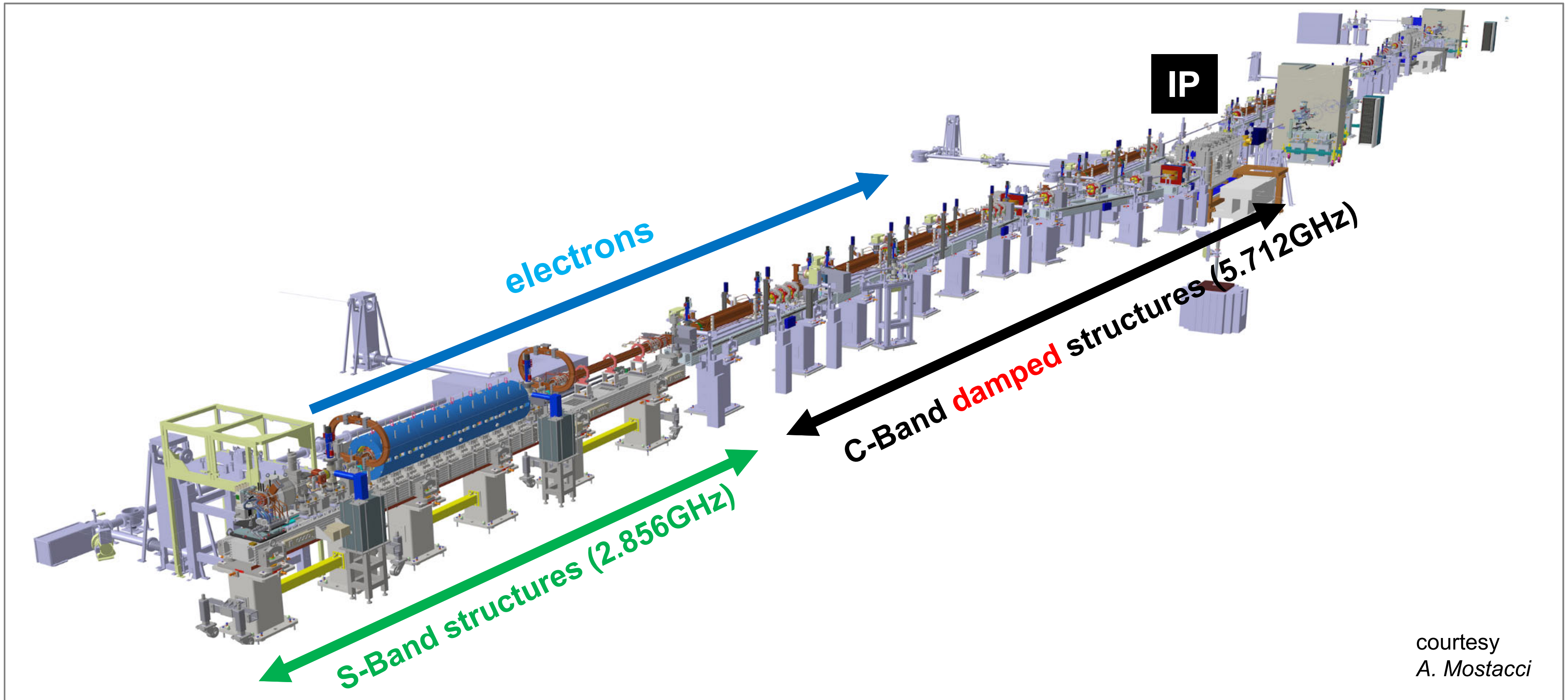
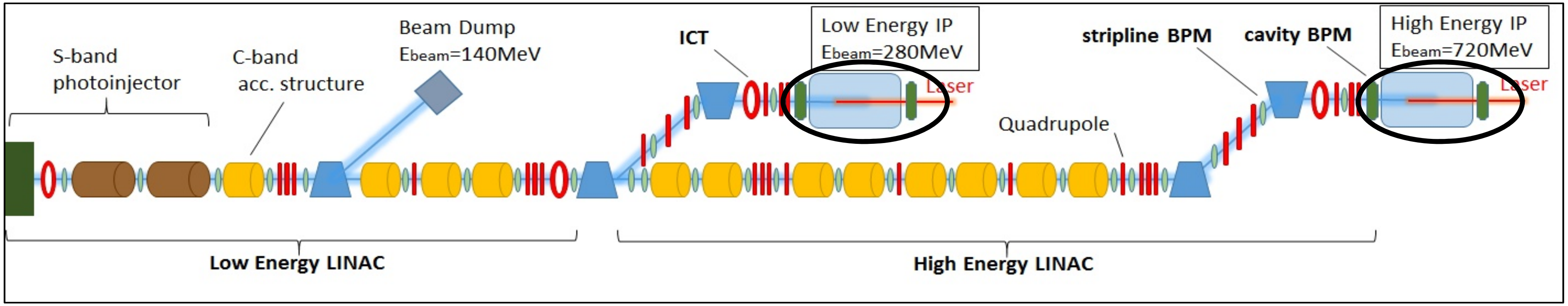
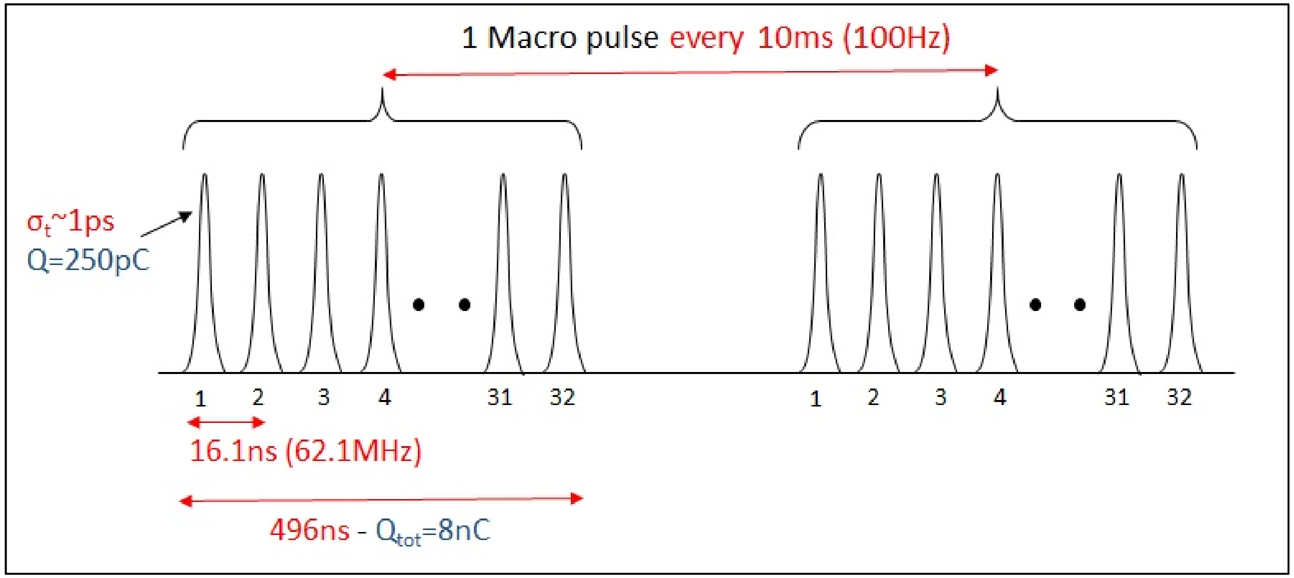
ELI-NP Layout





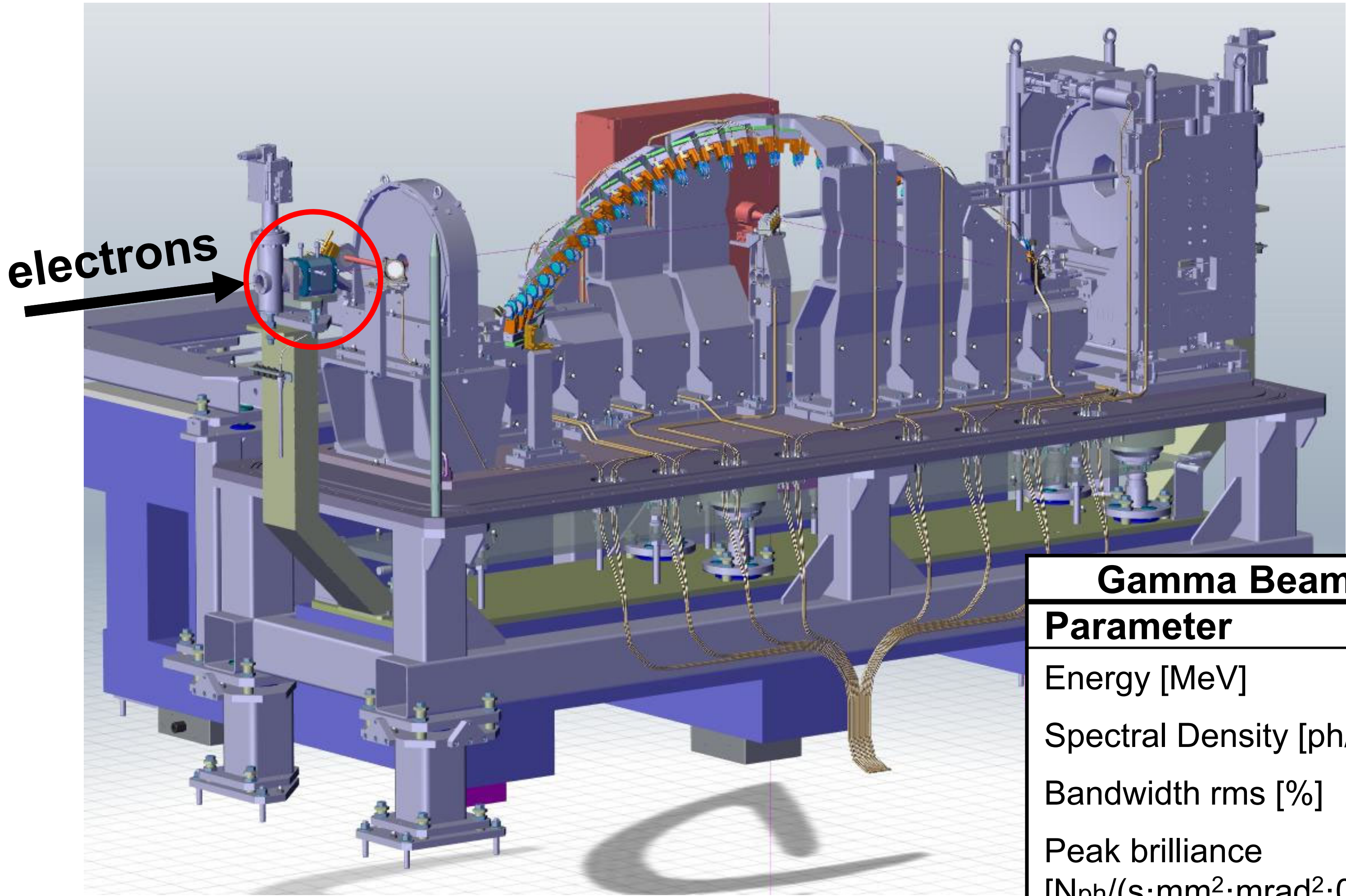
Beam Parameters and structure



Electron Beam Specifications

Parameter	Value
Max. Energy at IP [MeV]	280 – 720
Macro Pulse rep. Rate [Hz]	100
Number of bunches	up to 32
Bunch spacing [ns]	16.1
Bunch length [ps]	0.91
Bunch charge [pC]	25-250
Bunch Energy Spread	< 0.1%

Interaction Point



Courtesy of N. Beaugerard, ALSYOM

Gamma Beam Specifications	
Parameter	**Value**
Energy [MeV]	0.2 – 19.5
Spectral Density [ph/(s·eV)]	0.8 – $4 \cdot 10^4$
Bandwidth rms [%]	≤ 0.5
Peak brilliance [N_{ph}/(s·mm^2·mrad^2·0.1%)]	10^{20} – 10^{23}

By using an **optical re-circulator**, a single **laser pulse** will collide with a multi-bunch (32) **electron beam** at the interaction point, generating **the gamma beam by Compton back-scattering.**

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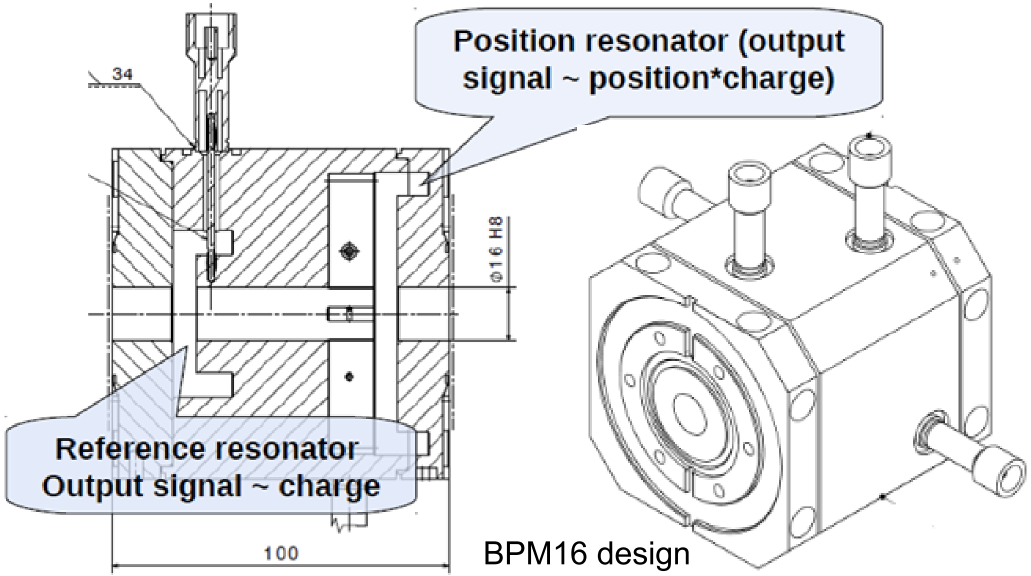
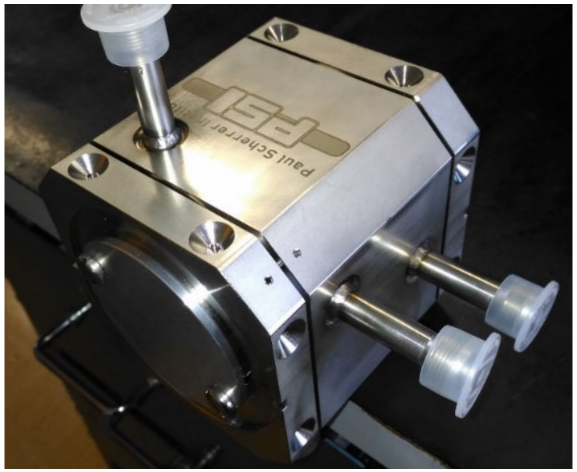
Cavity BPM (PSI BPM16 Design)





General Pickup Parameters

Parameter	Value
Material	Stainless Steel 316LN
Length [mm]	100
Inner Aperture [mm]	16
Distance from Pos. To Ref. Resonator [mm]	60

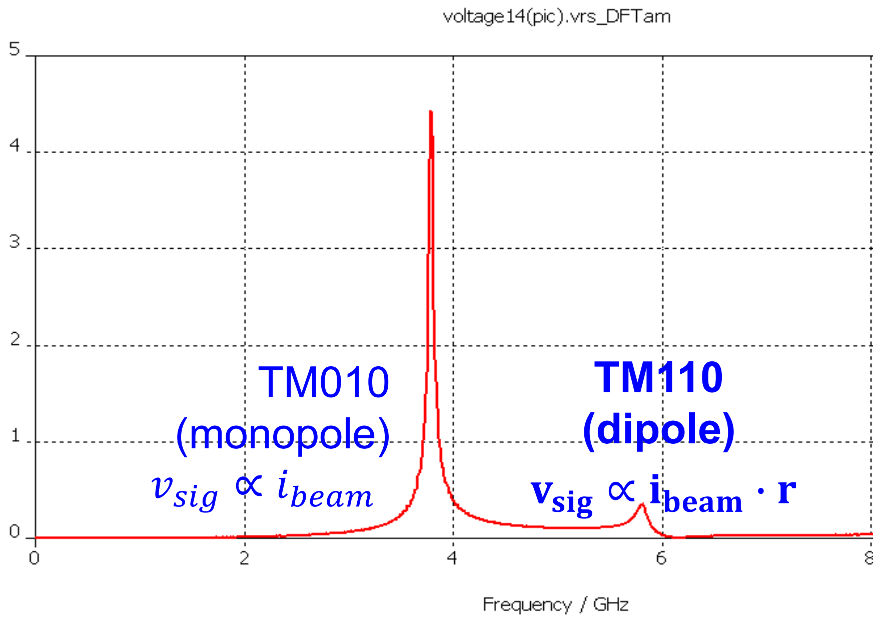
Position Cavity Resonator

Parameter	Value
Gap between res. walls [mm]	7
Q_L	40
TM_{110} Frequency [GHz]	3.284
TM_{010} Frequency [GHz]	2.252
Position Signal [V/mm/nC]	7.07
Angle Signal [μm/mrad]	4.3

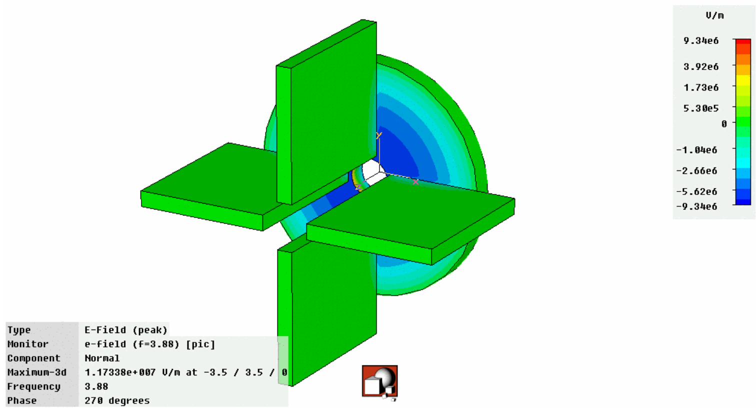
Reference Cavity Resonator

Parameter	Value
Gap between res. walls [mm]	7
Q_L	40
TM_{010} Frequency [GHz]	3.284
Charge Signal [V/nC]	135
Angle Signal [μm/mrad]	4.3

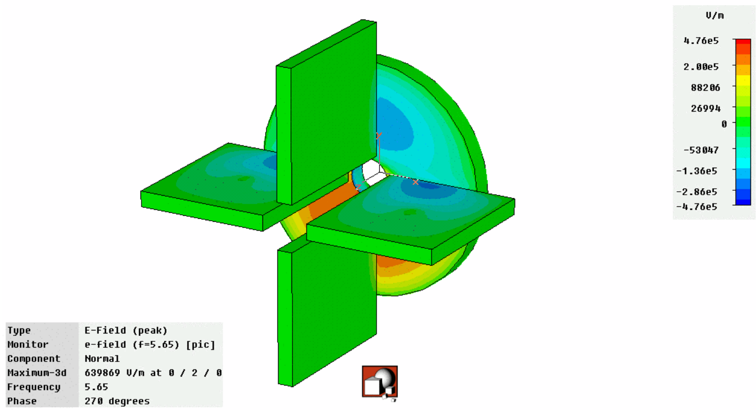
Cavity BPM



monopole mode



dipole mode



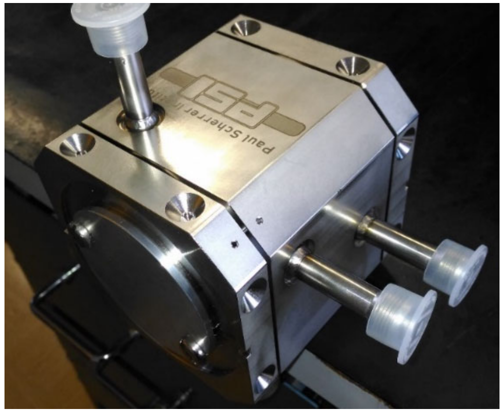
courtesy
D. Lipka

Common Issues:

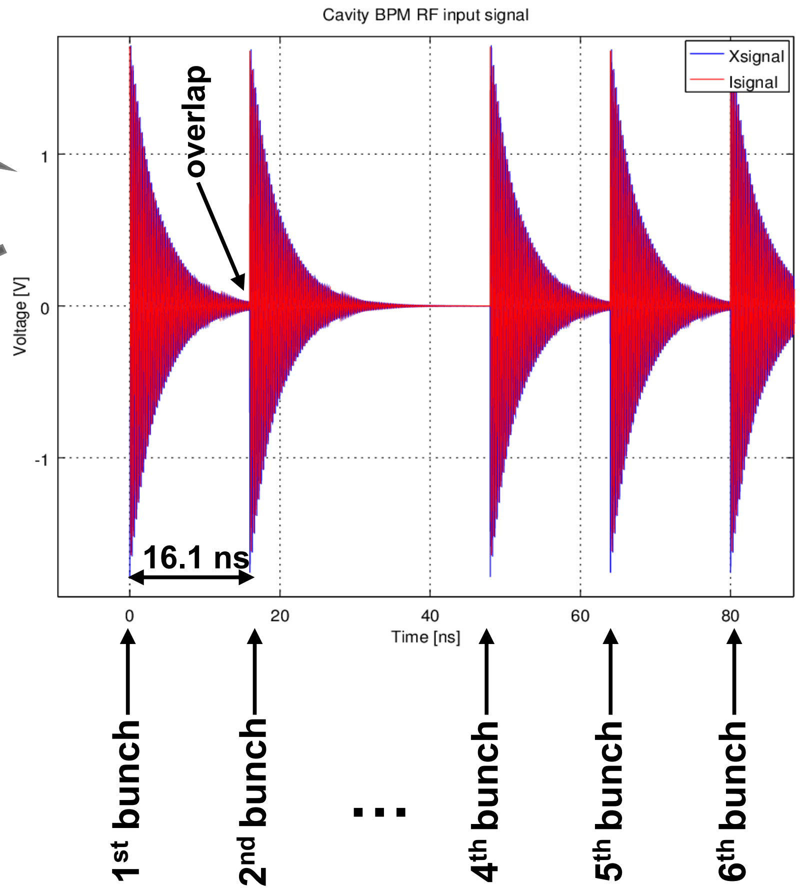
- Finite Q of TM010 leaks into TM110
- Coupling of X-Y (tight mechanical tolerances to minimize it)
- A reference cavity is needed to avoid charge dependency of the signal.

Cavity BPM

Cavity BPM



Output Signal



Libera for Cavity

ADC	4 channels, 500MS/s, 14bit
SoC	ZYNQ 7035 / ARM Cortex A9
ADC buffer	4kS/channel (~8us)
Variable attenuation	31dB, channel-independent
Input signal freq.	C-band, S-band
Ref. signal freq.	Up to 250MHz

Instrumentation Technologies

Goal: 1 μm resolution

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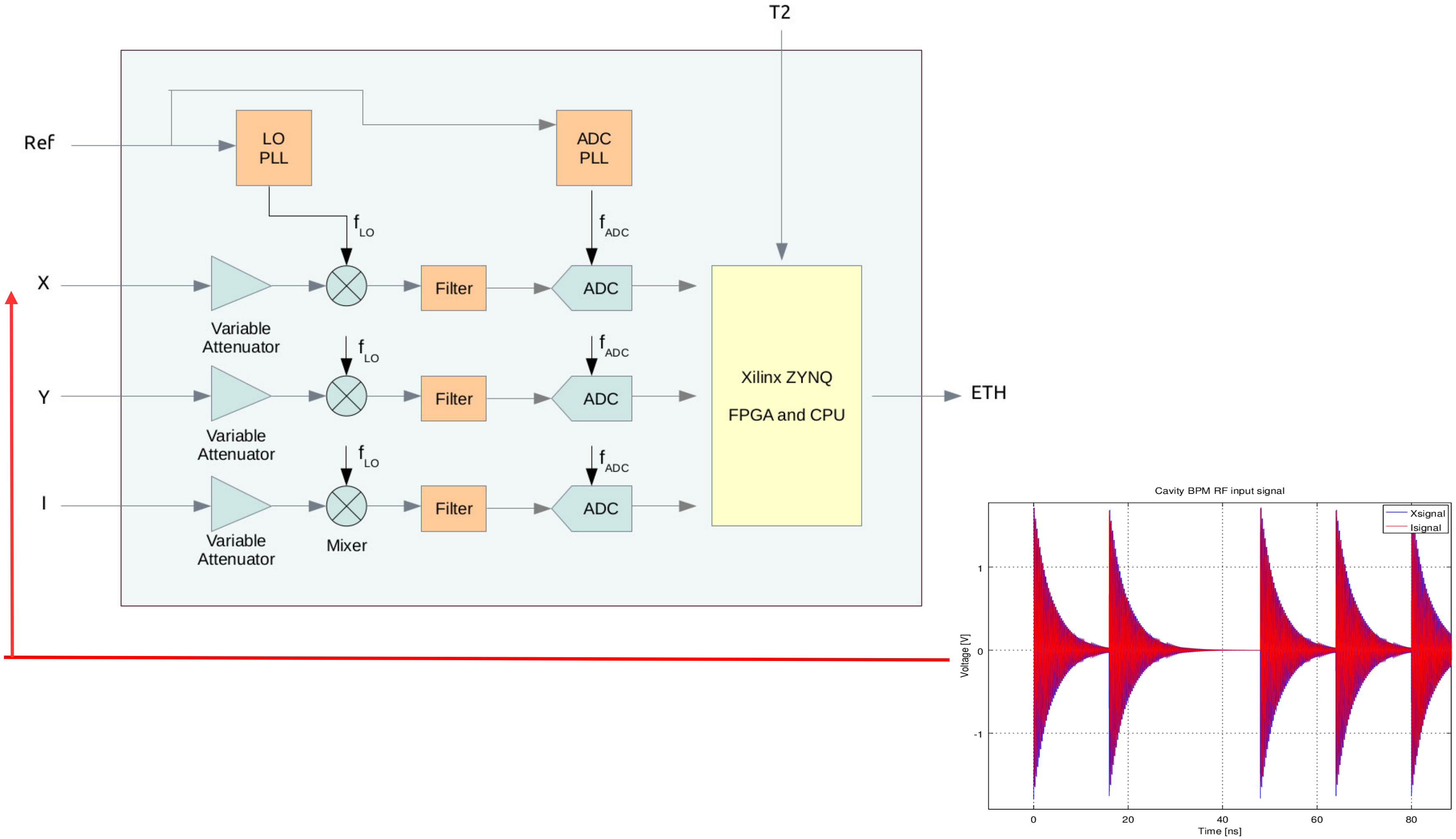
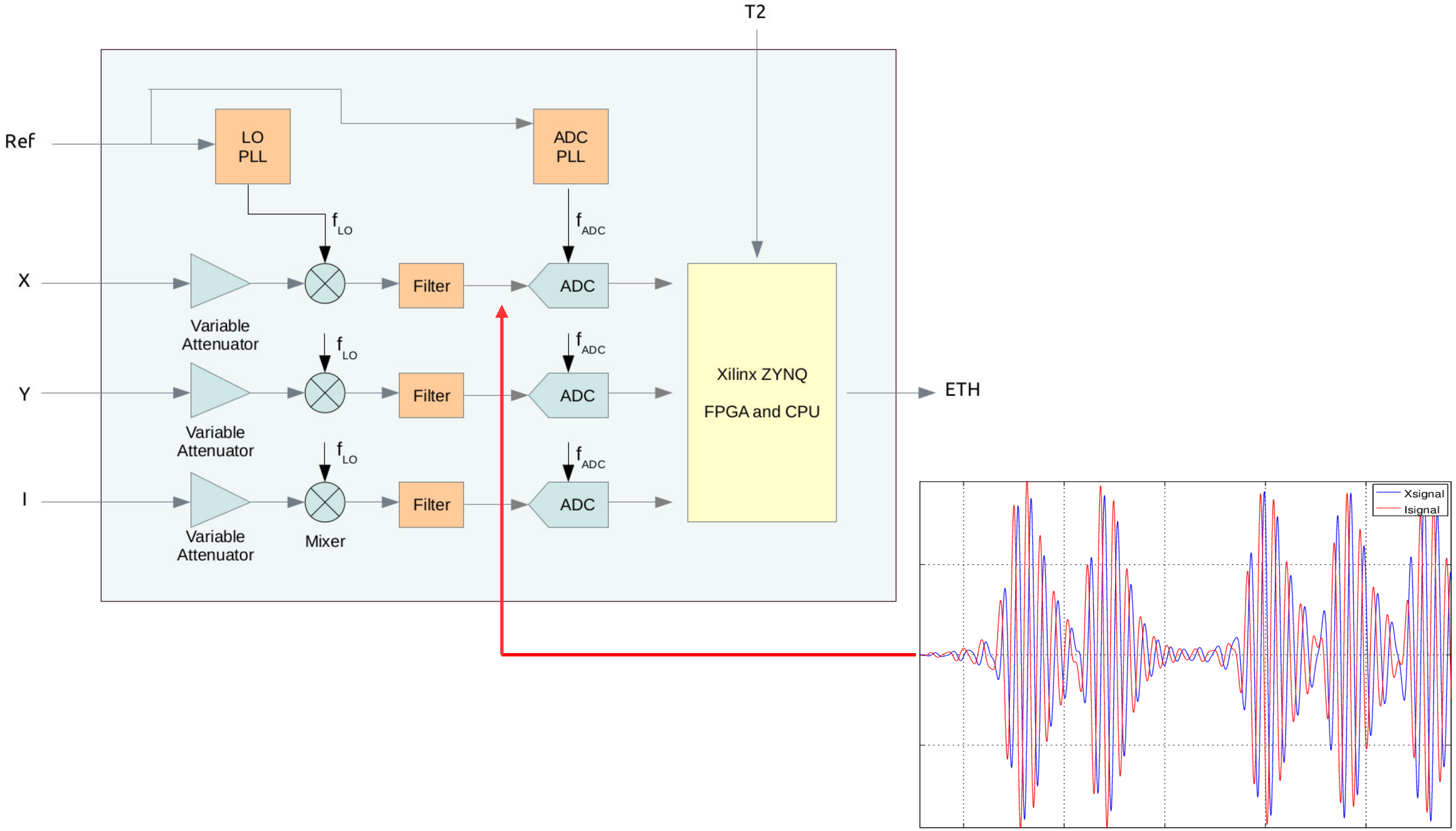
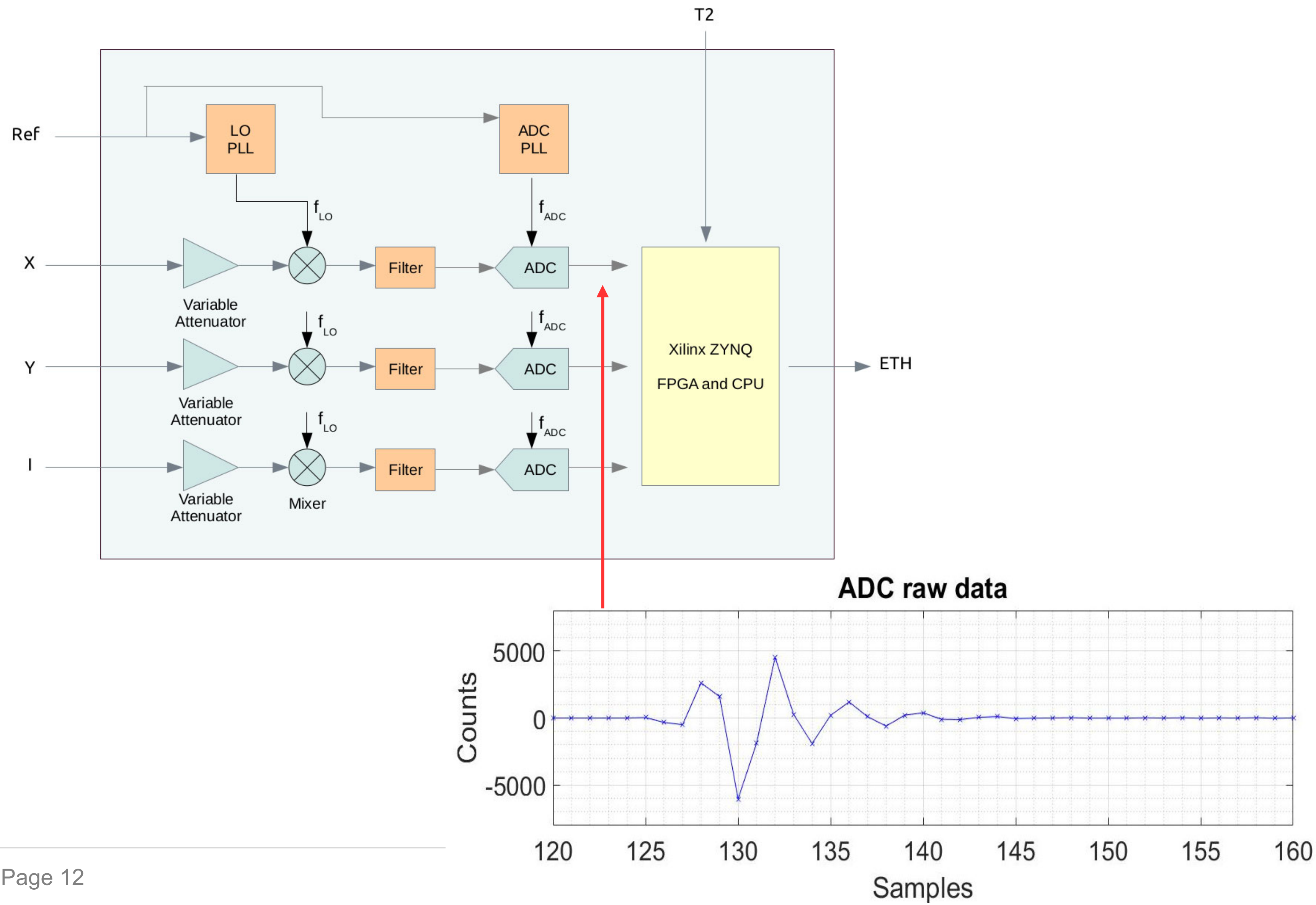
Signal processing (1/3)



Signal processing (2/3)



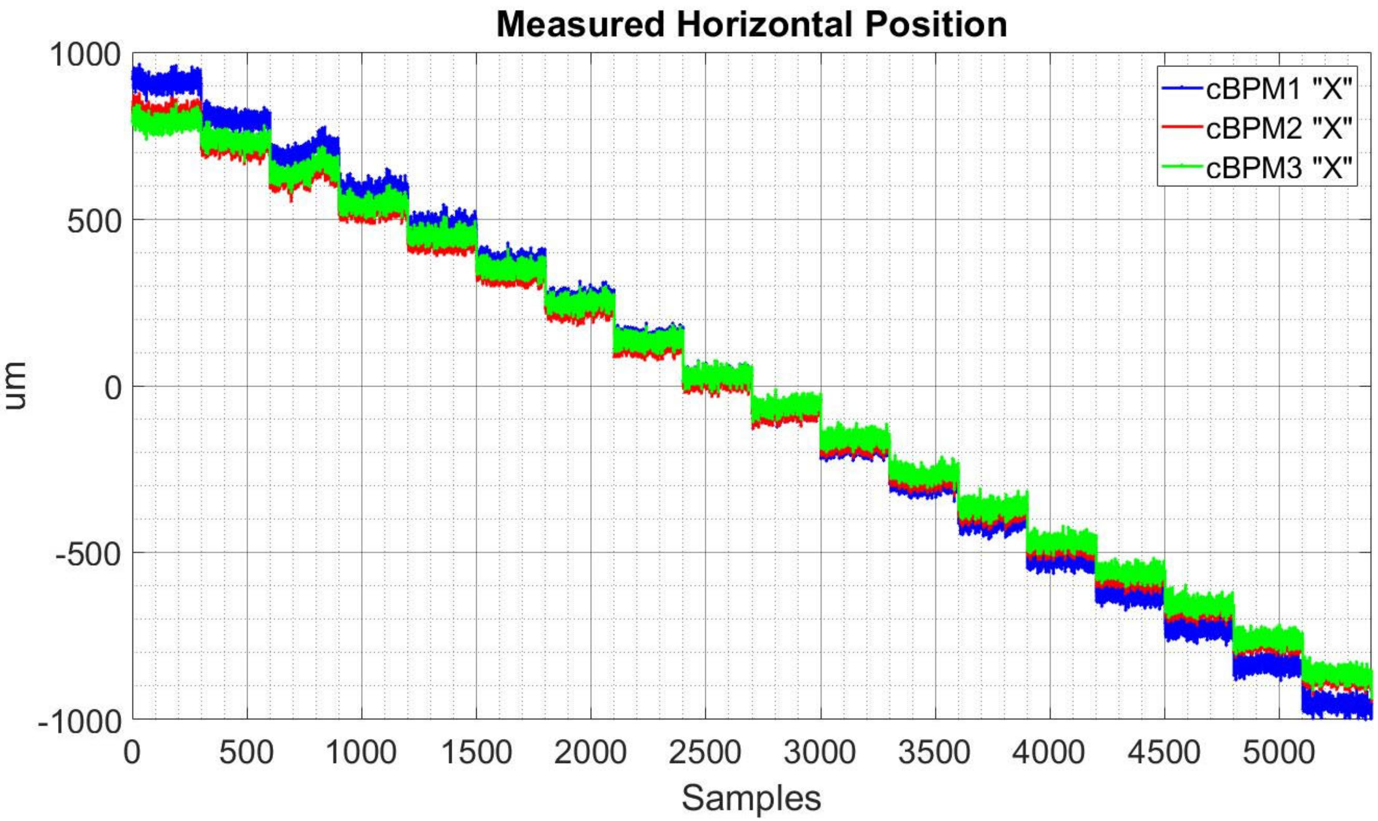
Signal processing (3/3)



Measurements on read-out electronics at FLASH (DESY)

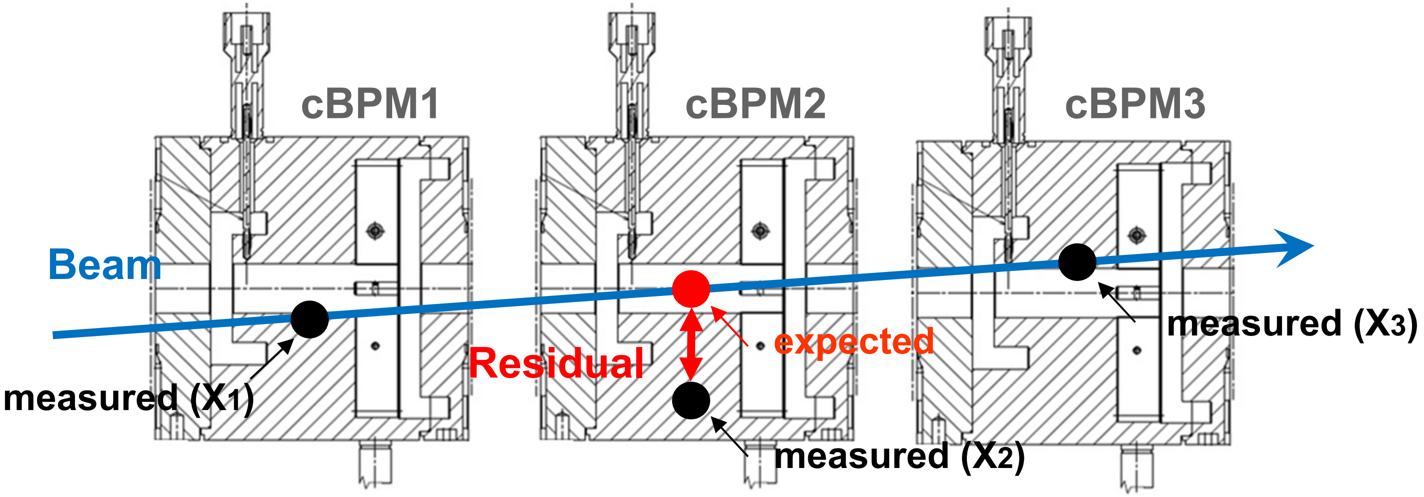
Cavity BPM	FLASH	ELI-NP
Parameter	**Value**	**Value**
Q_L	70	40
Dipole Res. frequency [GHz]	3.3	3.284
Reference Res. Frequency [GHz]	3.3	3.284
Dipole Sensitivity [V/mm/nC]	3	7.07
Reference Sensitivity [V/nC]	60	135

Horizontal position measurements



Horizontal position of the beam measured by the three cBPMs, using the horizontal movers. A difference in gain was detected and compensated for cBPM1

Resolution Measurements



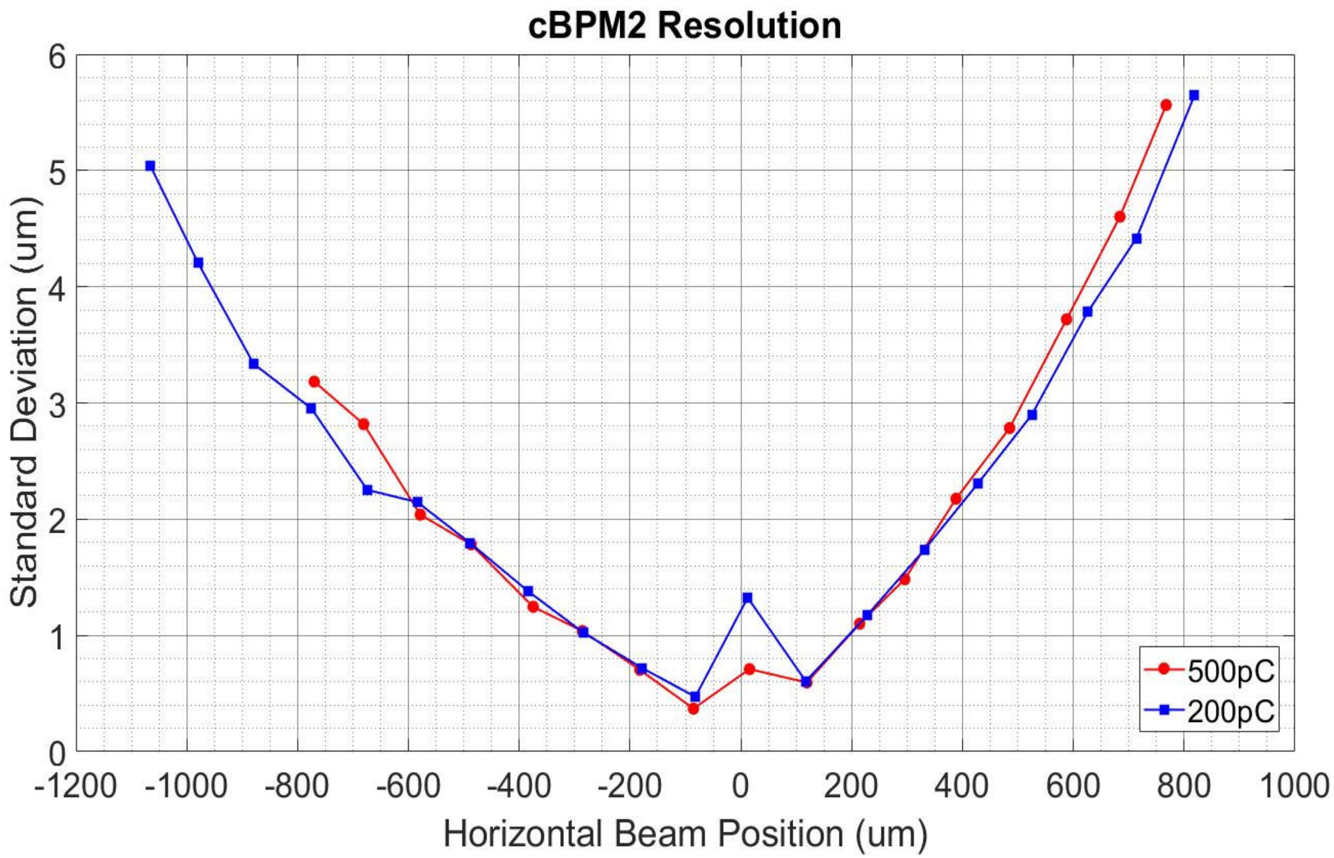
$$ResX_2 = X_2 - \frac{X_1 + X_3}{2}$$

$$\sigma_{ResX_2} = \sqrt{\sigma_{X2}{}^2 + \frac{\sigma_{X1}{}^2 + \sigma_{X3}{}^2}{4}} = \sqrt{\frac{3}{2}} * \sigma_X$$

Position resolution measurements was performed with three cBPMs

The resolution of the device under test (cBPM2) is calculated by measuring the residual for cBPM2 (the difference between the position measured by the cBPM2 and the expected position calculated with the measurements of cBPM1 and cBPM3).

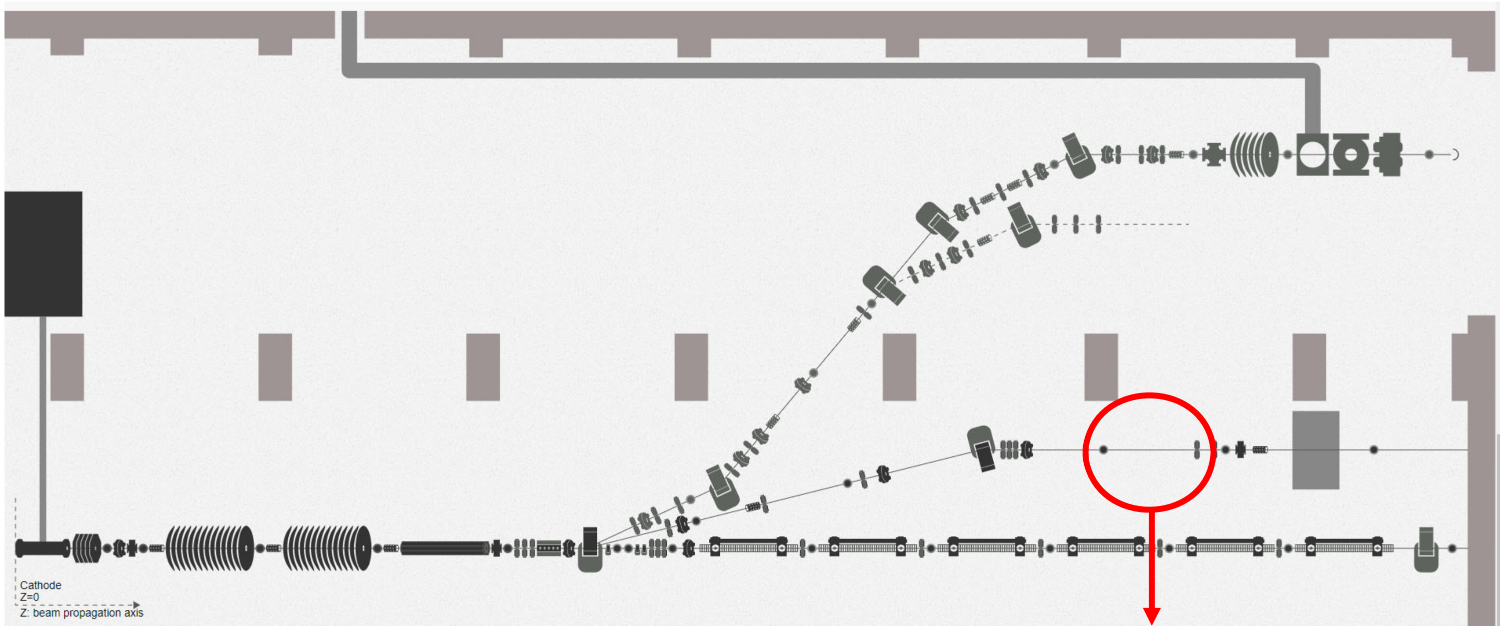
Resolution Measurements

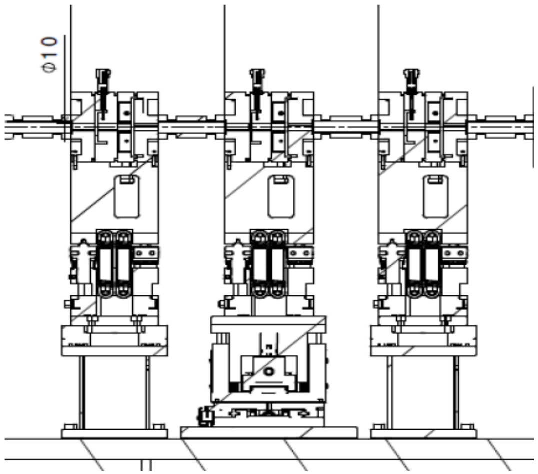


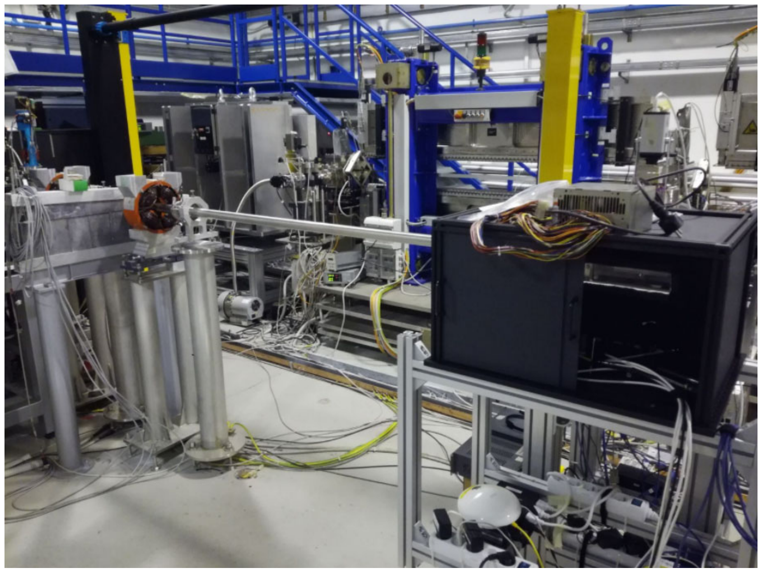
Resolution measurements at FLASH show two main issues:

- **The resolution depends on the position of the beam.** We believe that this depends on a high jitter (3ps) of the external reference signal at FLASH (i.e. FLASH setup problem).
- **The resolution at the center get worse.** We believe that this is related to the digital signal analysis performed by the instruments (i.e. read-out electronics problem).

Test Bench Position at SPARC







Conclusions

- **Cavity BPM of ELI-NP and their related electronics look promising in achieving the required resolution (1 µm over a maximum beam offset range of ±1 mm) for bunch by bunch measurements for ELI-NP.**

- **Further tests on them are planned at SPARC to complete cBPM characterizations to measure:**
  - Resolution for different beam positions within ±1 mm from the center
  - Resolution for different bunch charges
  - Linearity (within ±1 mm)
  - Effects of an incident angle (angle signal: 4,3 µm/mrad)
  - Resolution on charge measurements
  - Stability
  - Comparison between cBPM and sBPM

- **All the measurements will support the design of a new type of cBPM, that will match the requirements of EuPRAXIA Linac, currently under study.**