Design and first prototype of cavity BPM electronics for the ELI-NP project

Manuel Cargnelutti, Libera Workshop 2016, 09.06.2016

Presentation outline

- The ELI-NP project
- Cavity BPM requirements
- Electronics layout and simulations
- First prototype: purpose and results
- Conclusions

The ELI-NP project

Magurele - Romania

Very high intensity laser

- 2x 10 PW lasers

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Intense and brilliant γ beam

- obtained by incoherent Compton back scattering

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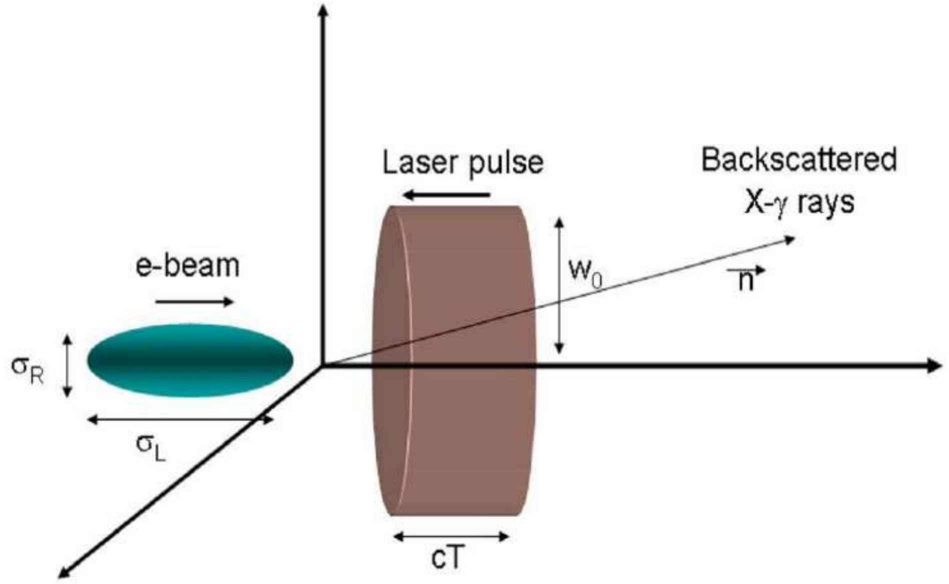
Single and Combined studies

Compton back scattering

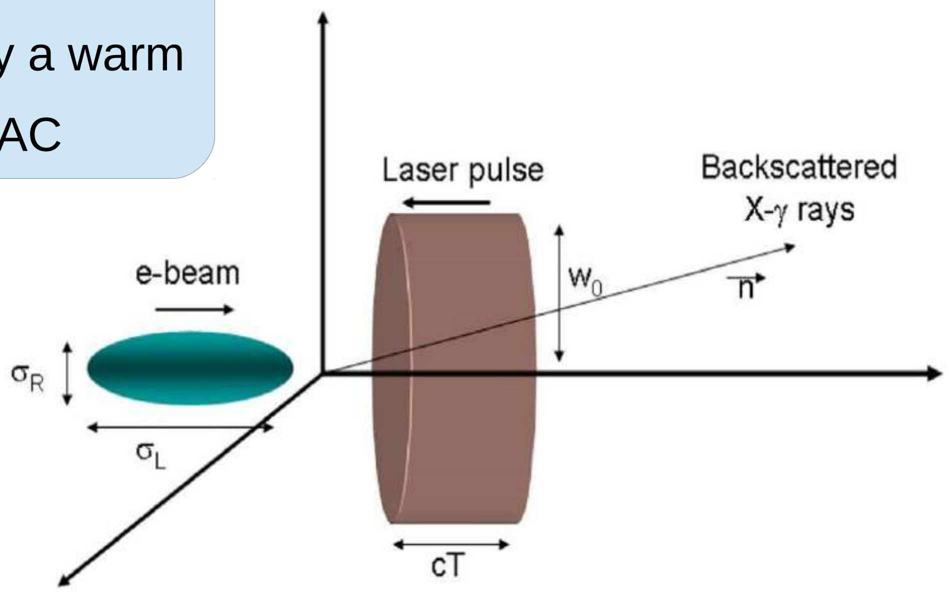
Interaction between relativistic electrons and laser pulses



Compton back scattering

Interaction between relativistic electrons and laser pulses

720 MeV electrons produced by a warm C-band LINAC



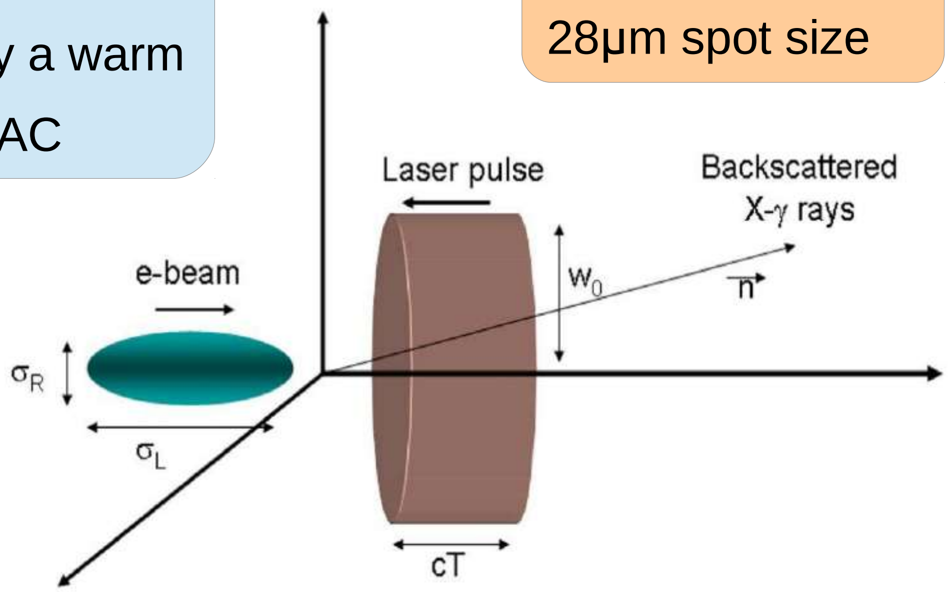
Compton back scattering

Interaction between relativistic electrons and laser pulses

720 MeV electrons produced by a warm C-band LINAC

0.2 J laser pulses

28μm spot size



Compton back scattering

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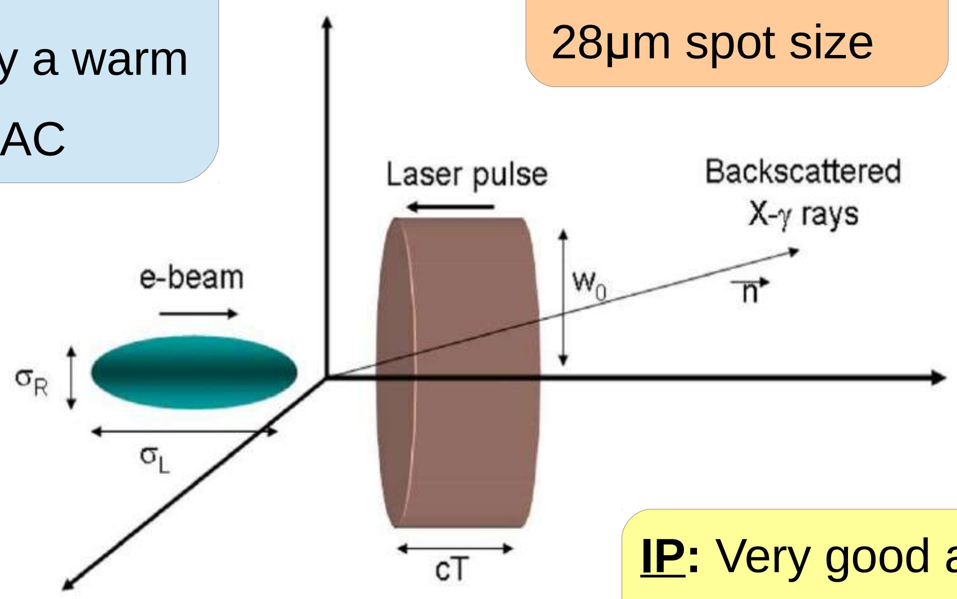

<u>IP</u>: Very good alignment is required → **BPM resolution**!

Electron Beam Parameters:

Parameter	Value
Energy (MeV)	80-720
Bunch charge (pC)	25-400
# bunches in the train	≤ 32
Bunch separation (ns)	**16.1**

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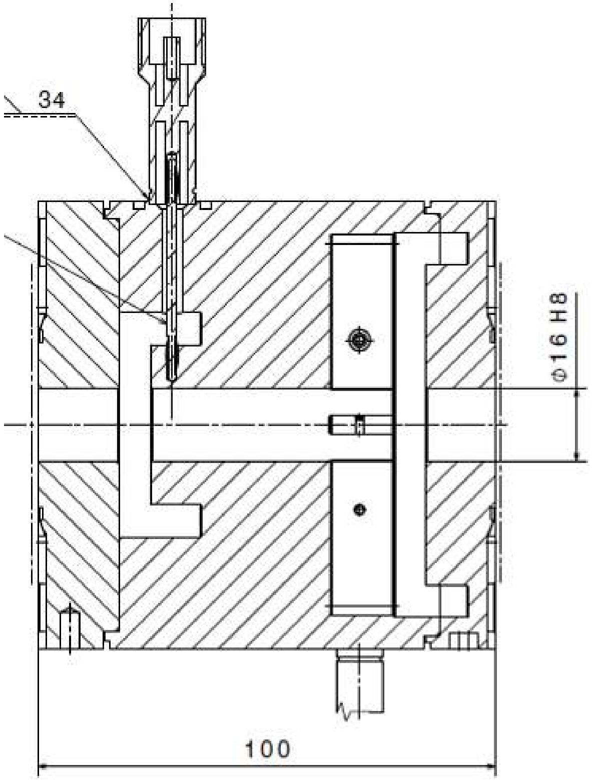
BPM requirements:

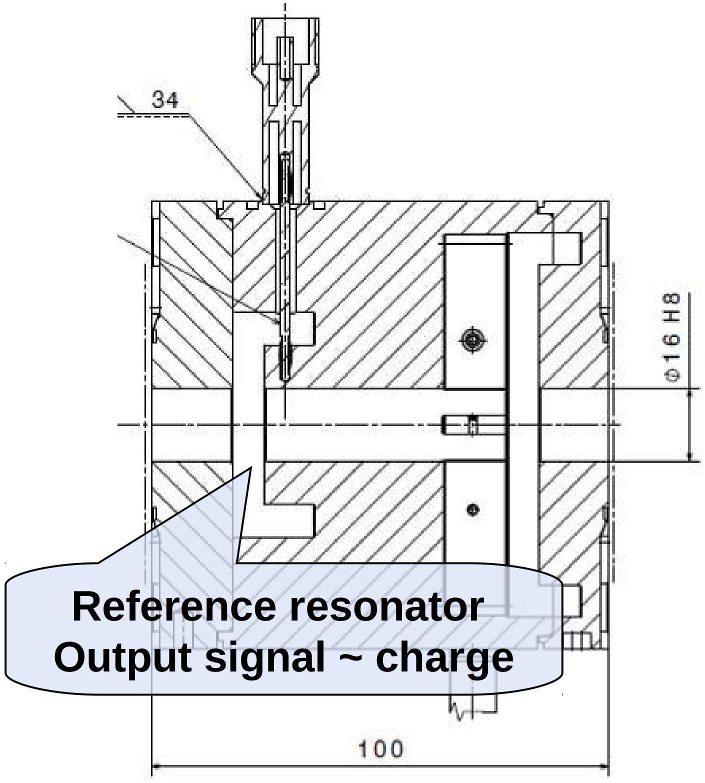
- Sub-μm position resolution in the range of +/- 1mm
- Bunch-by-bunch position measurement

Cavity BPM pickup



PSI – BPM16 pickup

Cavity BPM pickup



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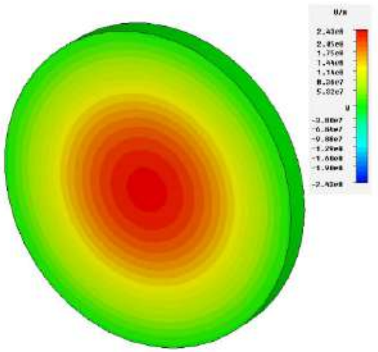
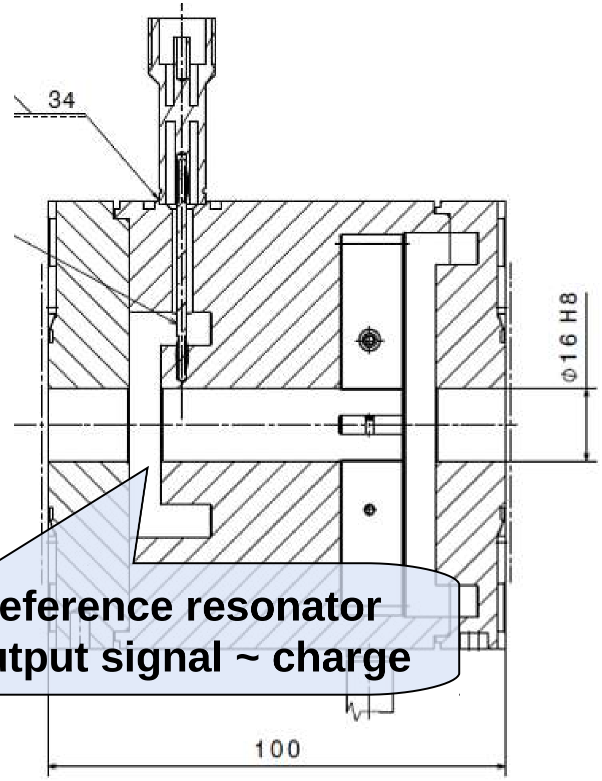


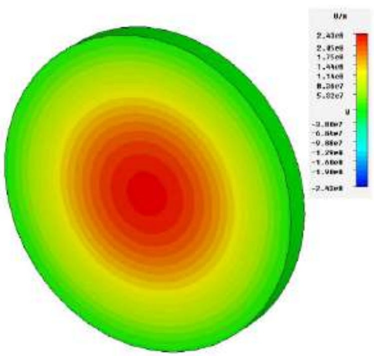
Mode TM_{110}



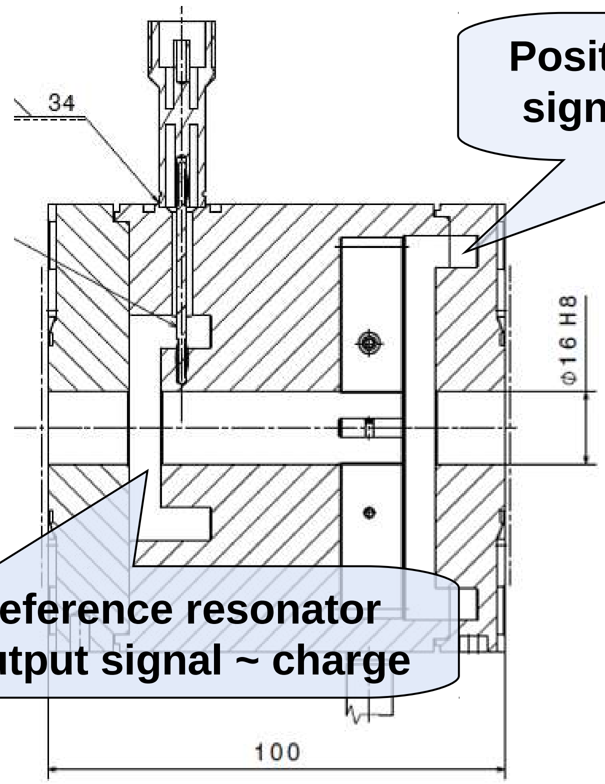
Reference resonator
Output signal ~ charge

PSI – BPM16 pickup

Cavity BPM pickup



Mode TM_{110}



PSI – BPM16 pickup

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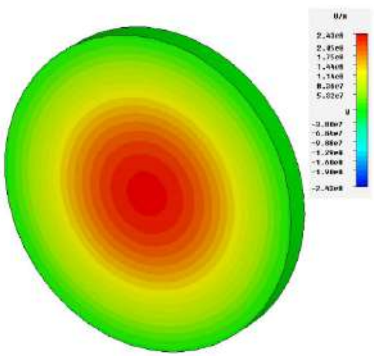
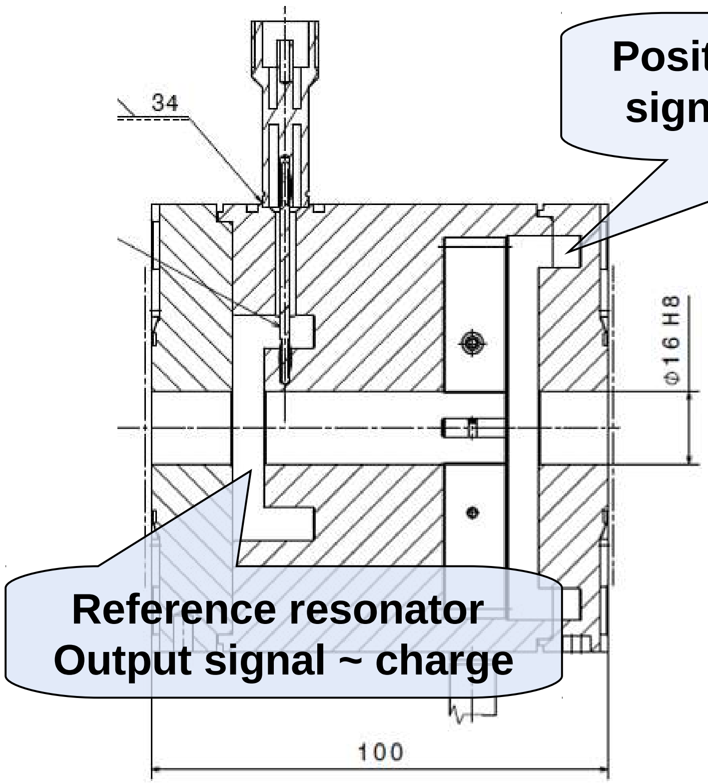
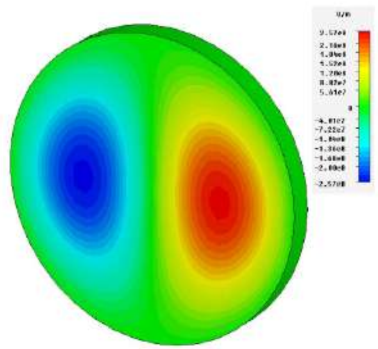


Mode TM_{110}

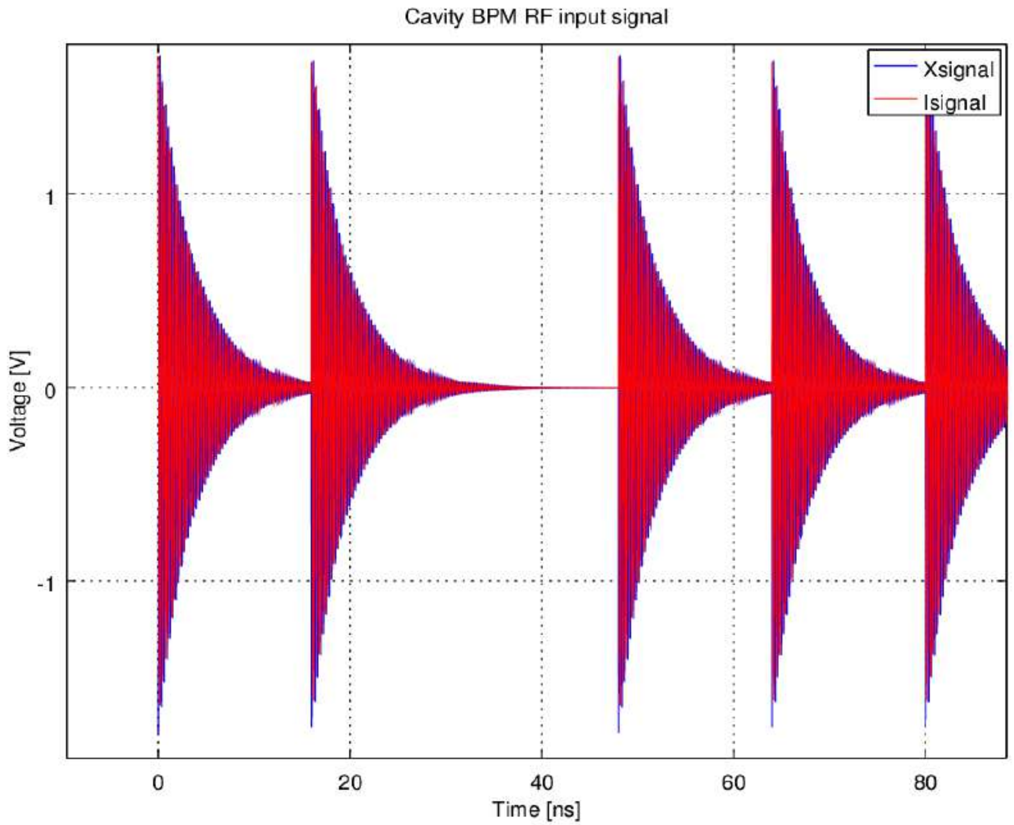




Mode TM_{010}

PSI – BPM16 pickup

Cavity BPM output signal

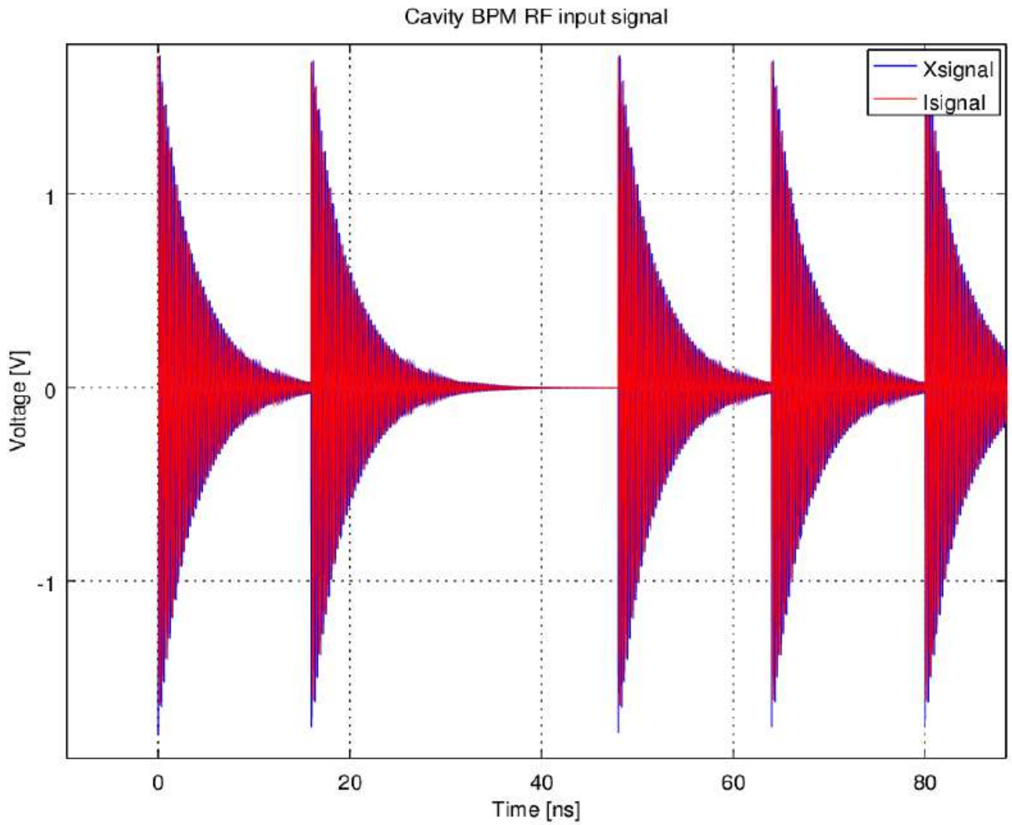


$$f_{res} = 3.284GHz$$

$$Q = 40$$

$$T_{decay} \cong Q/f_{res} = 12.1ns$$

Cavity BPM output signal



$$f_{res} = 3.284GHz$$

$$Q = 40$$

$$T_{decay} \cong Q/f_{res} = 12.1ns$$

$$V_{ref} :\ -3 \div 18\, dBm$$

$$V_{x,y} :\ 23 \div 45\, dBm$$

Libera

Cavity BPM electronics

Libera Spark

Instrumentation Technologies

Cavity BPM electronics

Libera Spark

+

- Down-conversion
- ADCs @ 500MHz
- Xilinx ZYNQ 7035
- Specific algorithms

Cavity BPM electronics

Libera Spark

+

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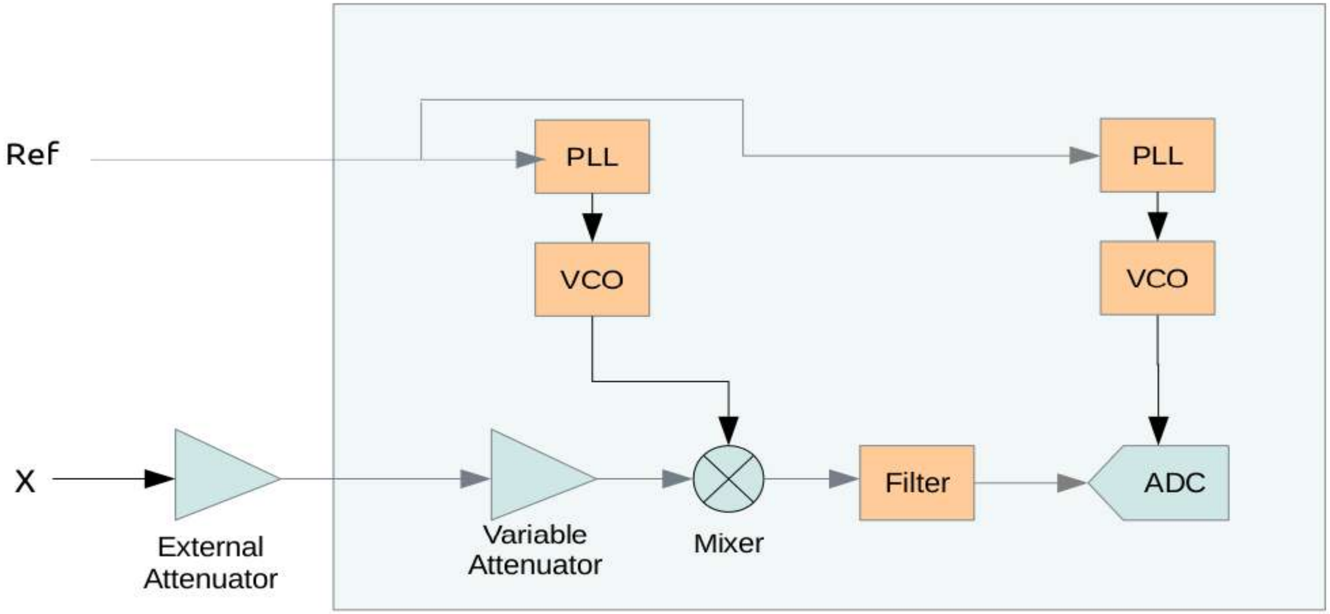
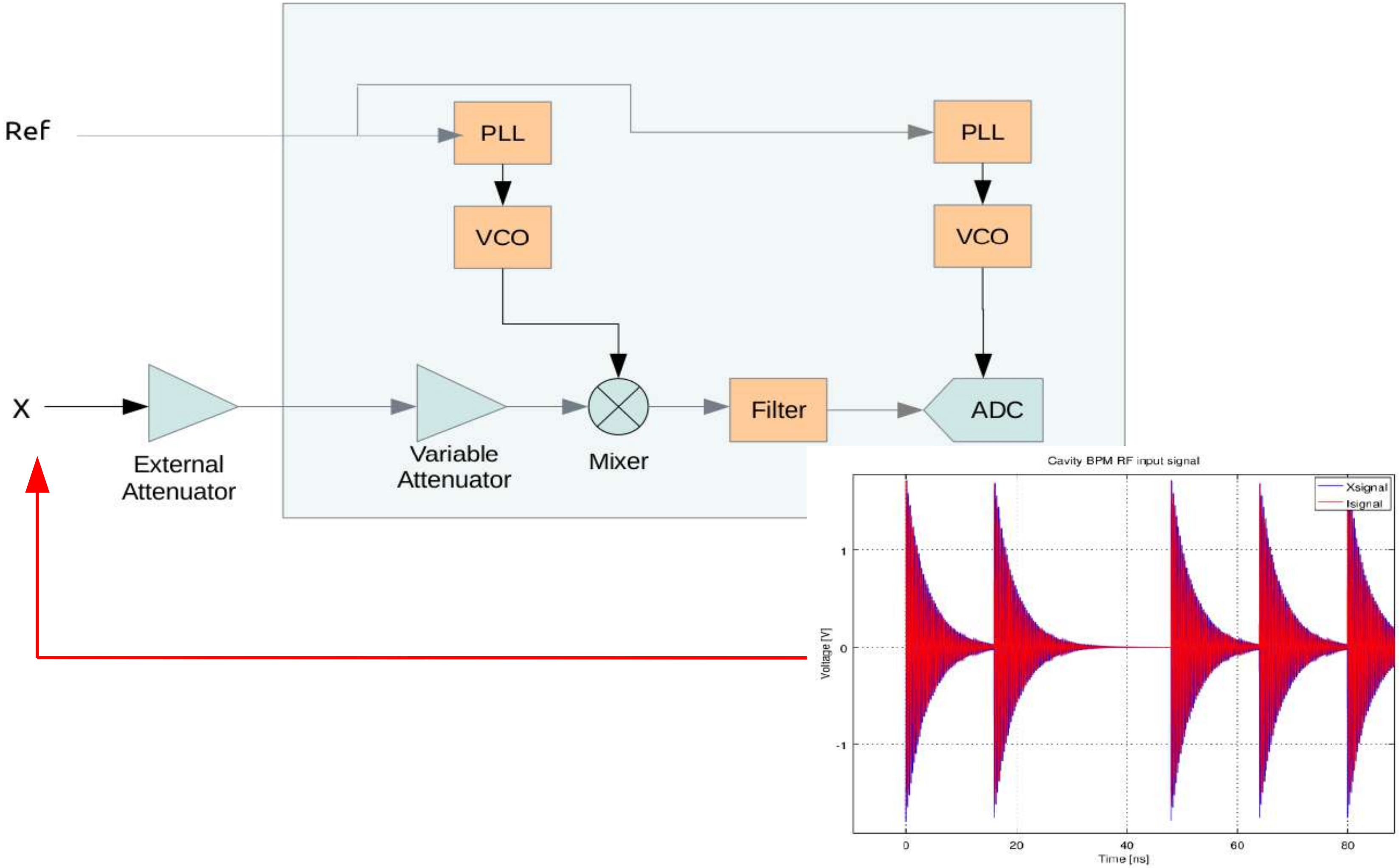
- S-band, C-band and X-band
- High-Q and Low-Q
- Single bunch and bunch trains

Instrumentation Technologies

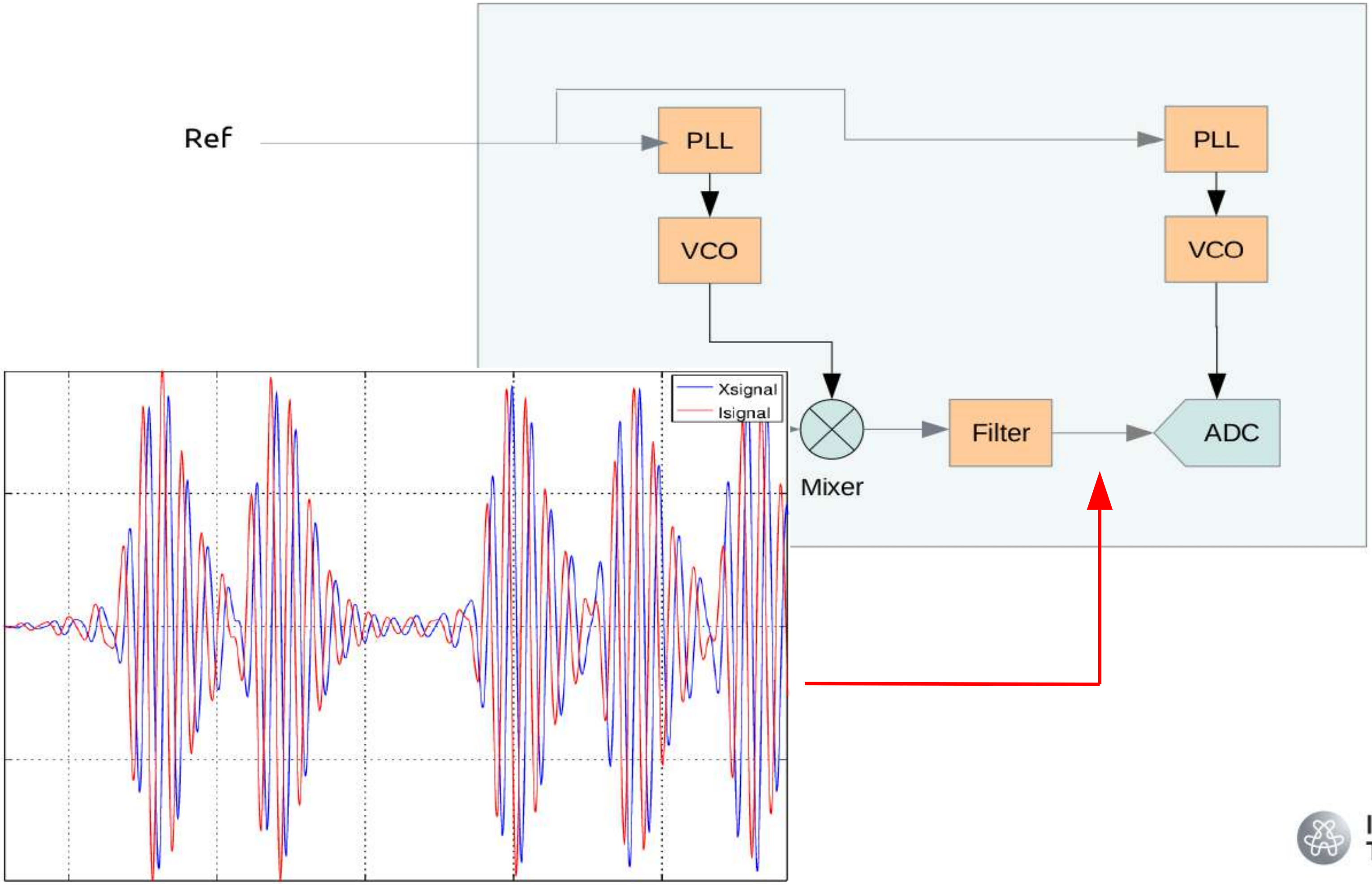
Cavity BPM electronics



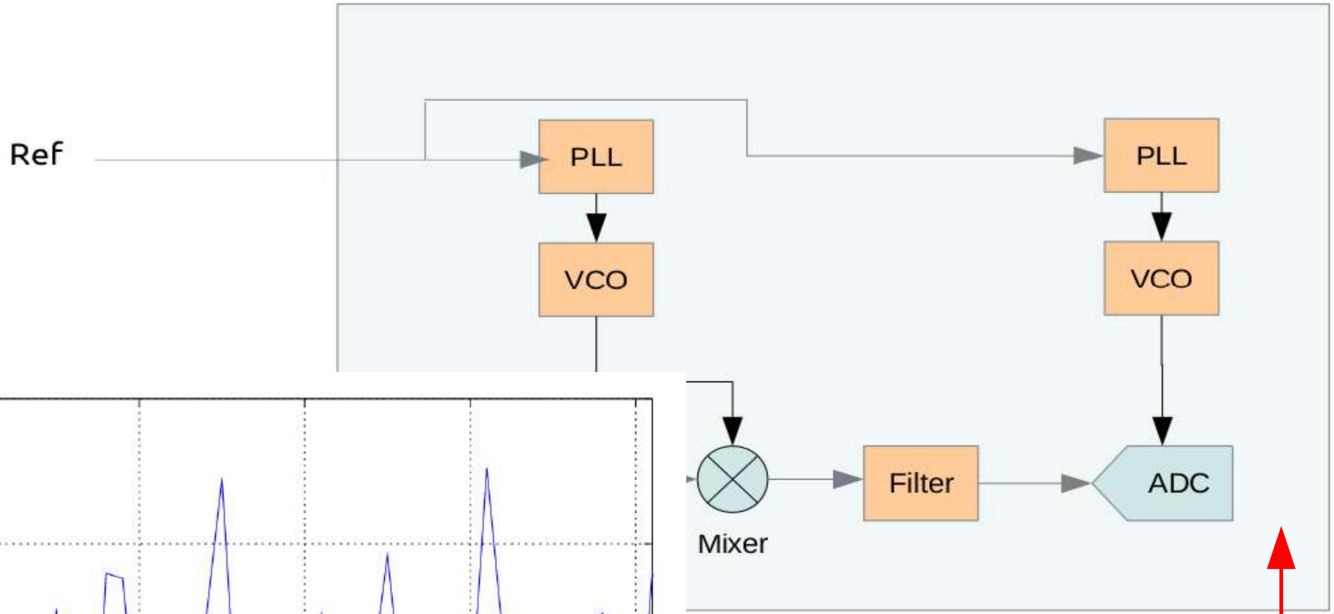
Cavity BPM electronics

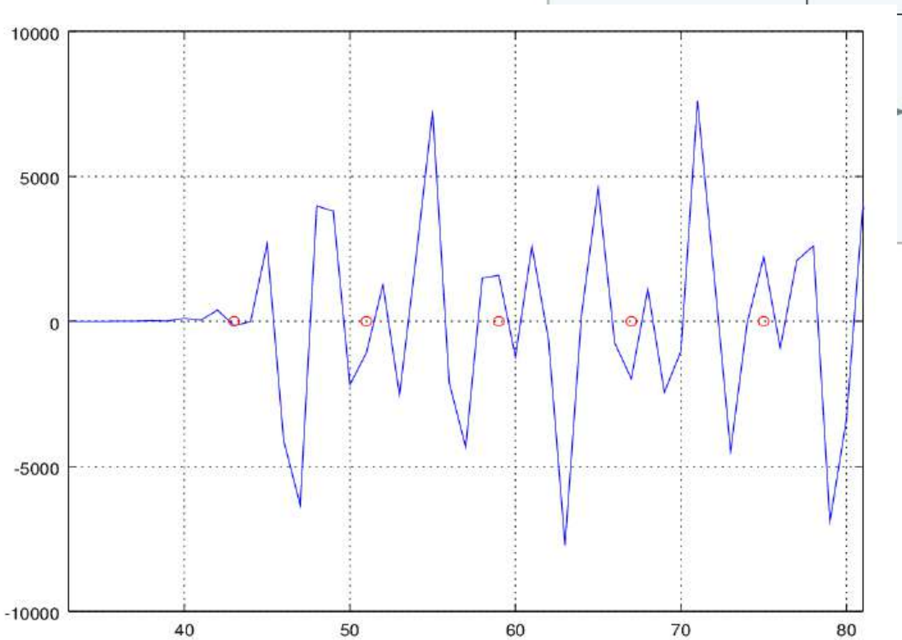


Cavity BPM electronics



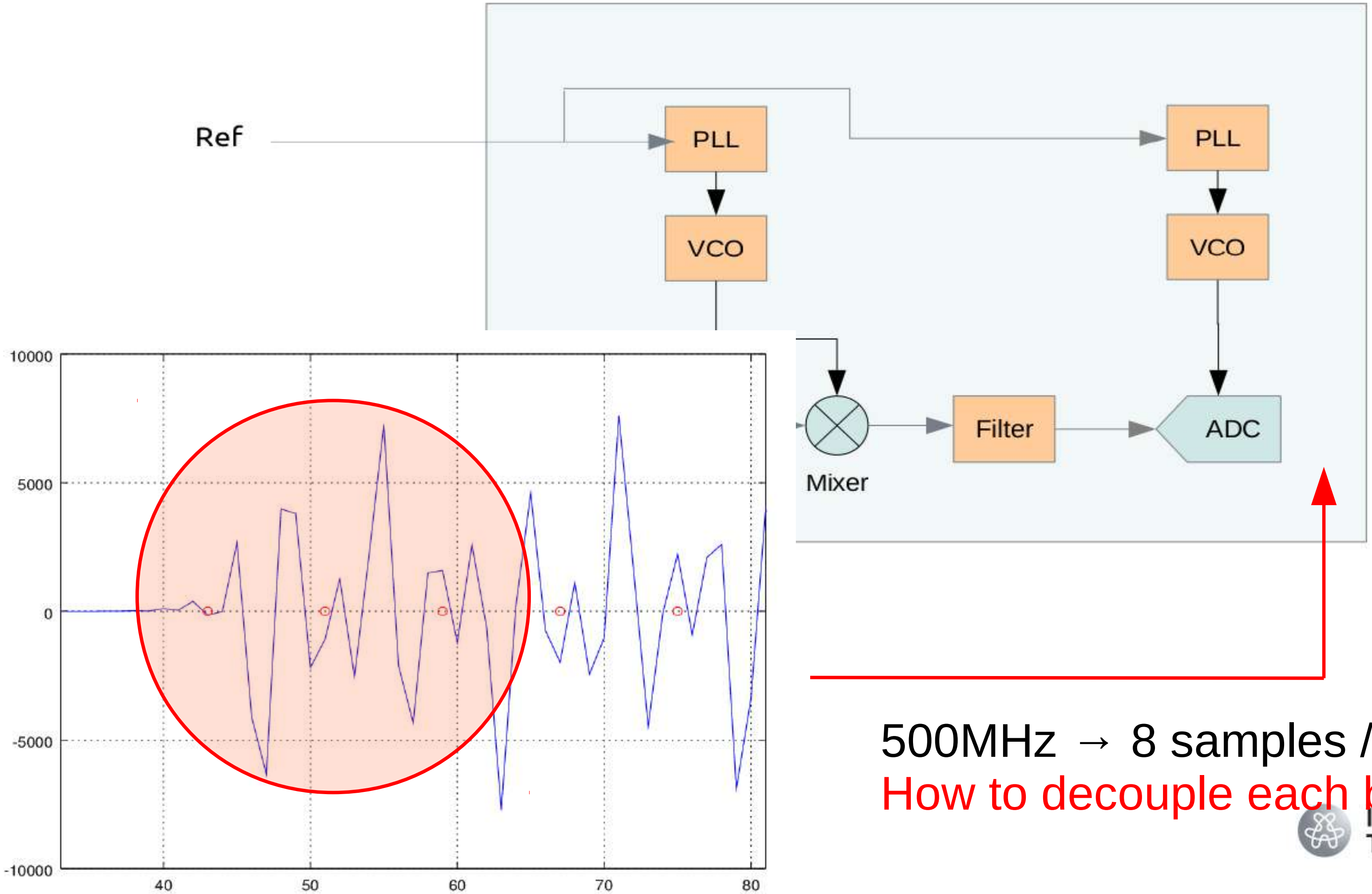
Cavity BPM electronics





500MHz → 8 samples / bunch

Cavity BPM electronics

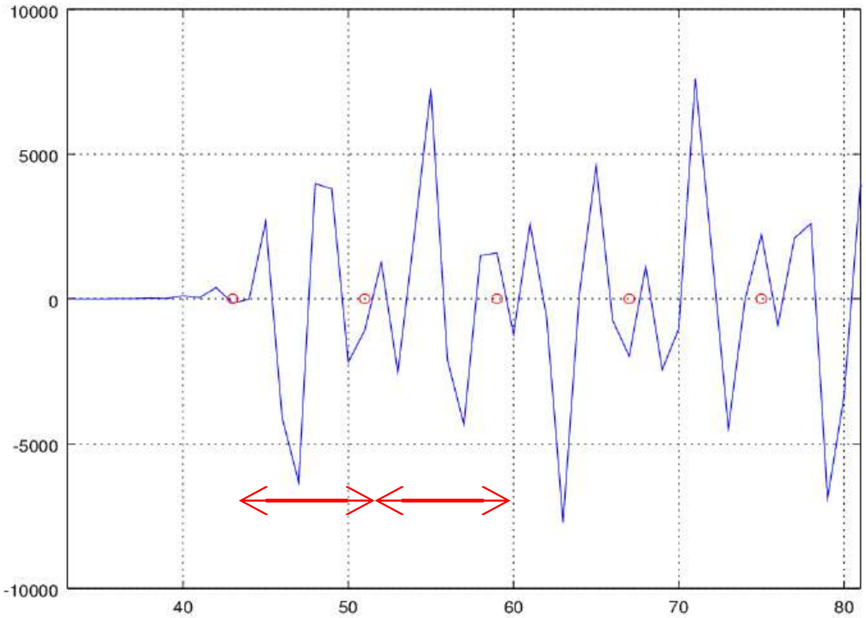


500MHz → 8 samples / bunch

How to decouple each bunch?

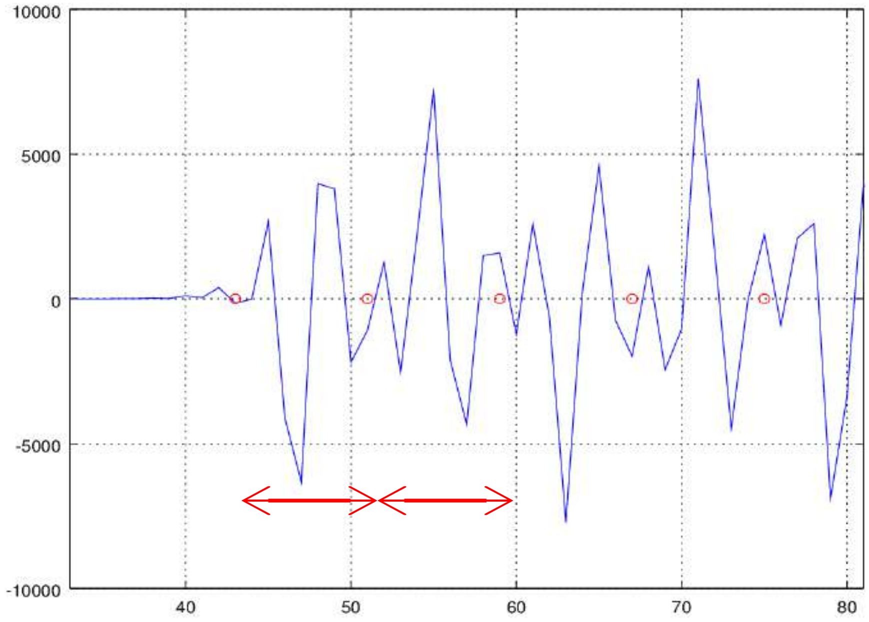
FPGA: deconvolution filter

- Define bunch processing windows



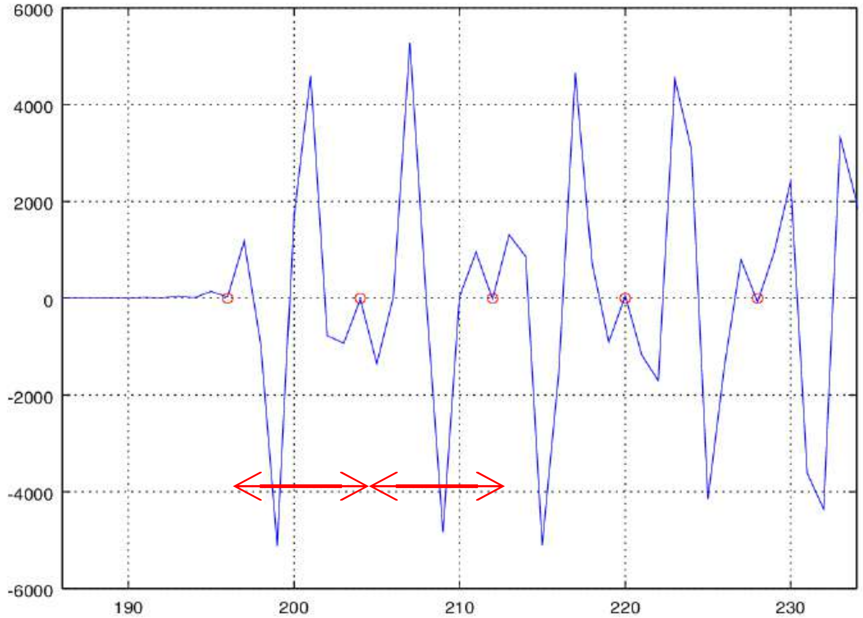
FPGA: deconvolution filter

- Define bunch processing windows
- Center of mass of bunch → center of window



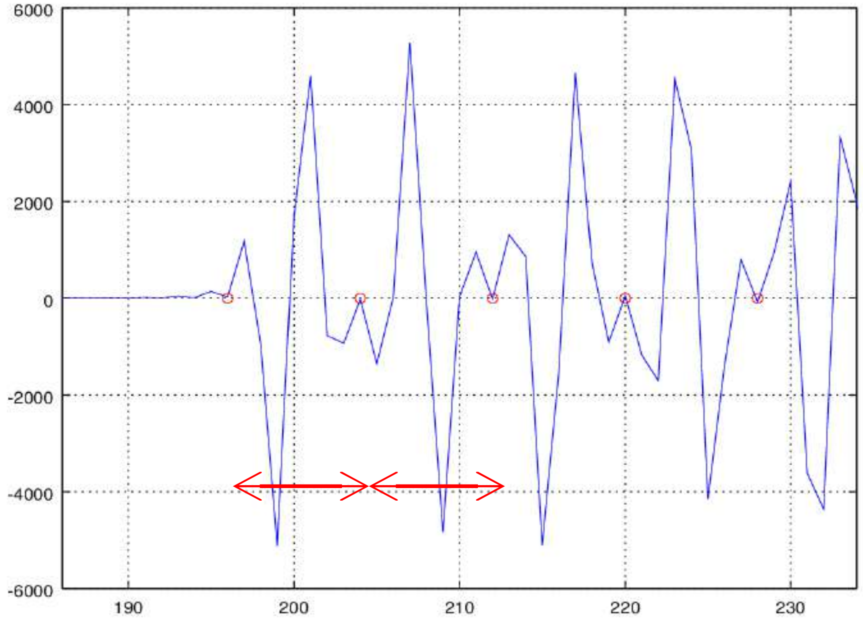
FPGA: deconvolution filter

- Define bunch processing windows
- Center of mass of bunch → center of window
- Deconvolution filter: compress each bunch response



FPGA: deconvolution filter

- Define bunch processing windows
- Center of mass of bunch → center of window
- Compress and impose border conditions



$$V_r, V_x, V_y$$

Libera

FPGA: deconvolution filter

- Define bunch processing windows
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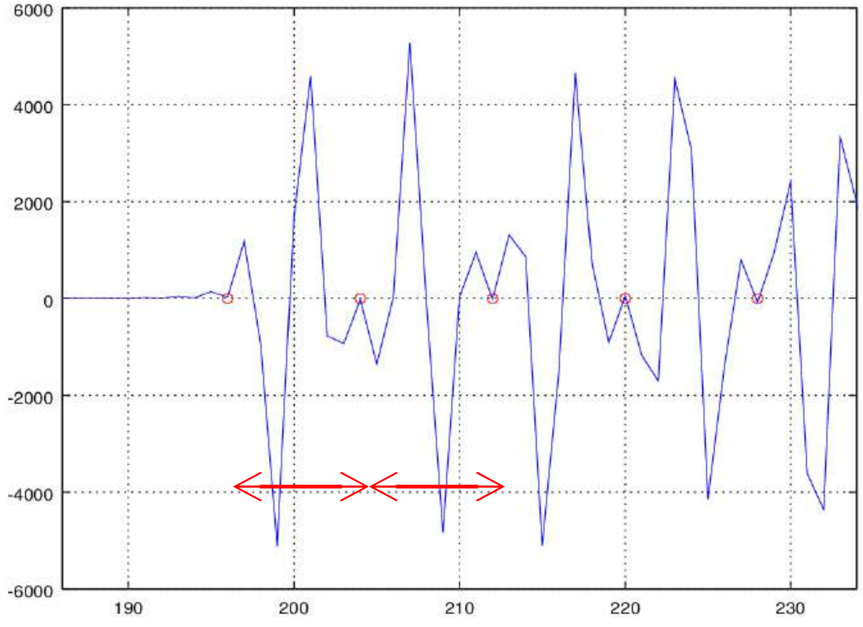


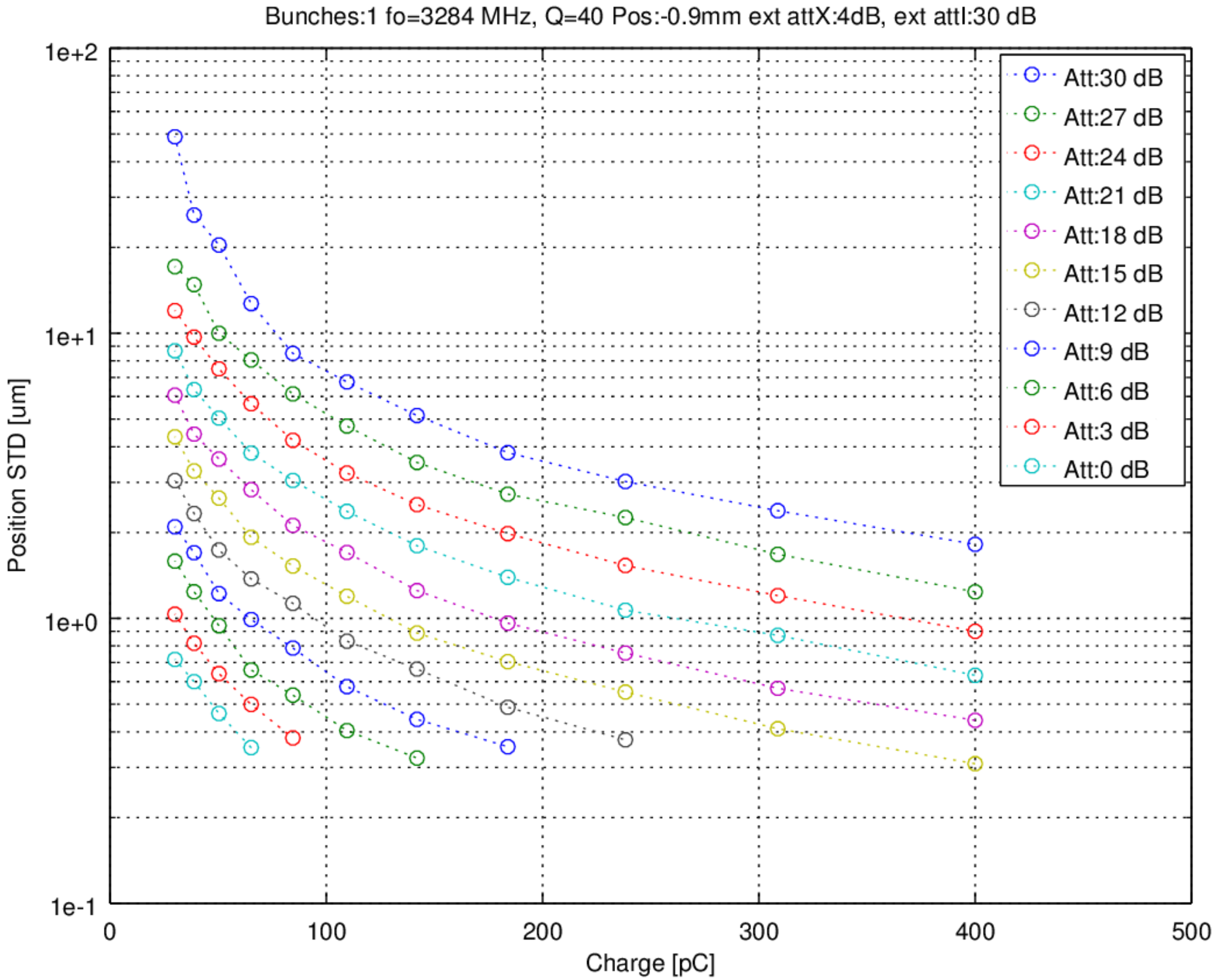
$$V_r, V_x, V_y$$

$$X = K_x \frac{V_x}{V_r}$$

$$Y = K_y \frac{V_y}{V_r}$$

Instrumentation Technologies

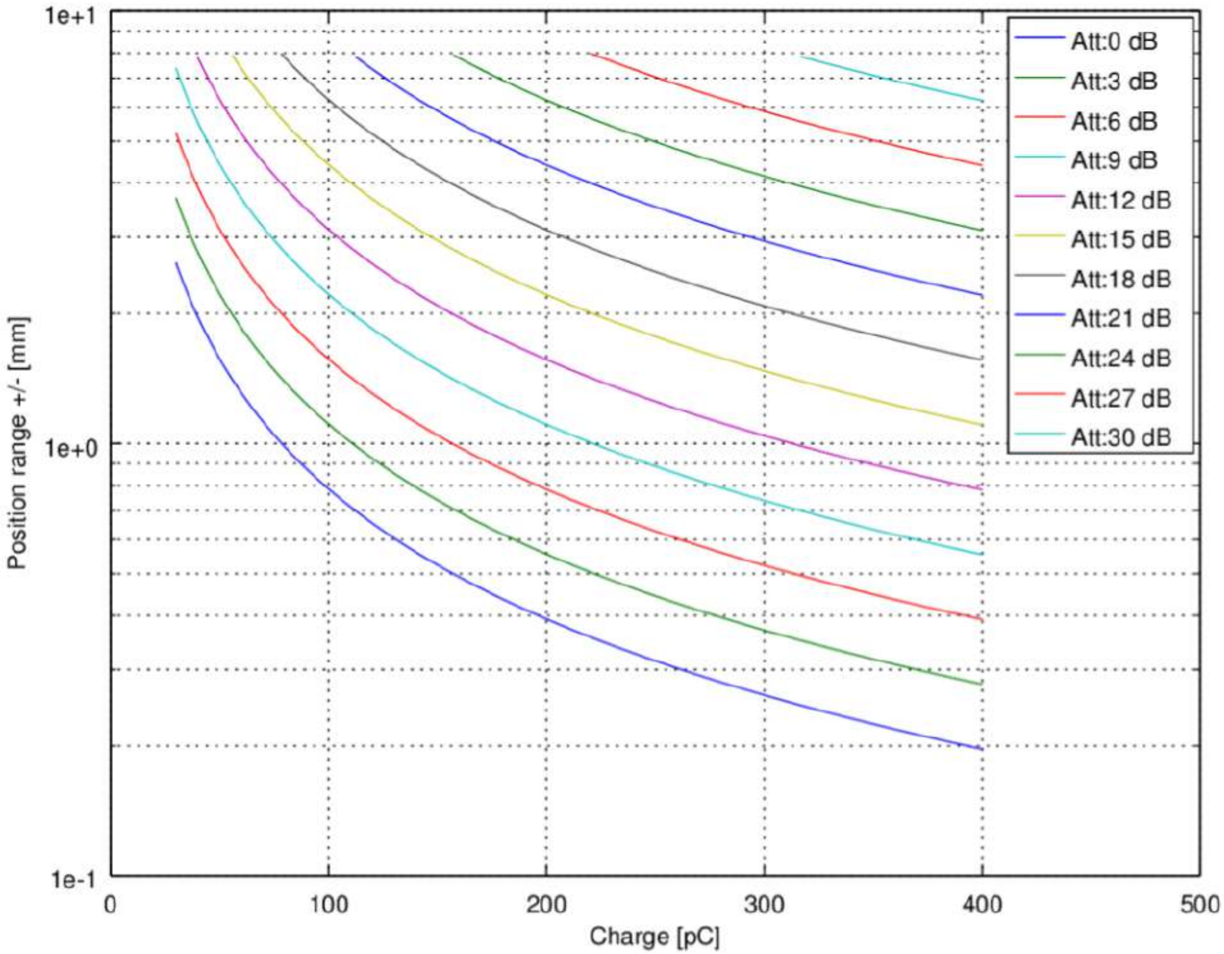
Position Resolution – single bunch



< 1µm

Libera

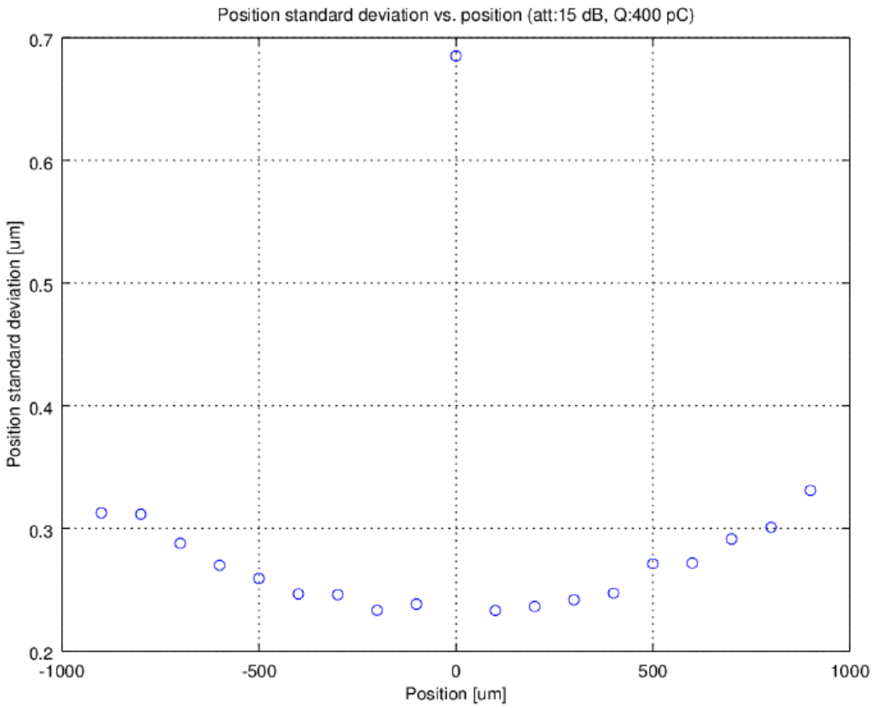
Position range – single bunch



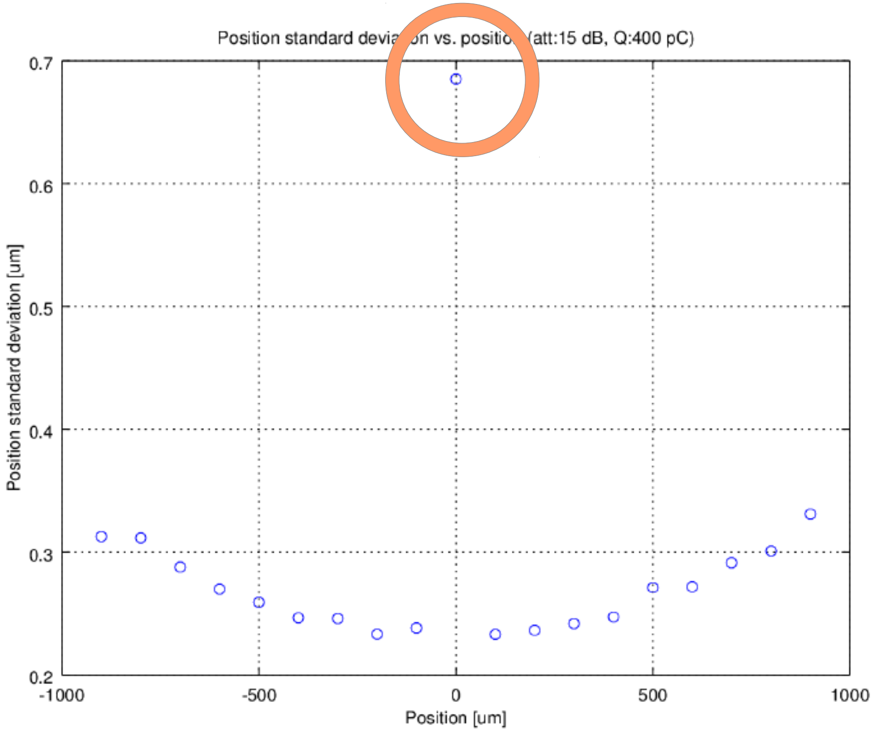
± 1mm

Instrumentation Technologies

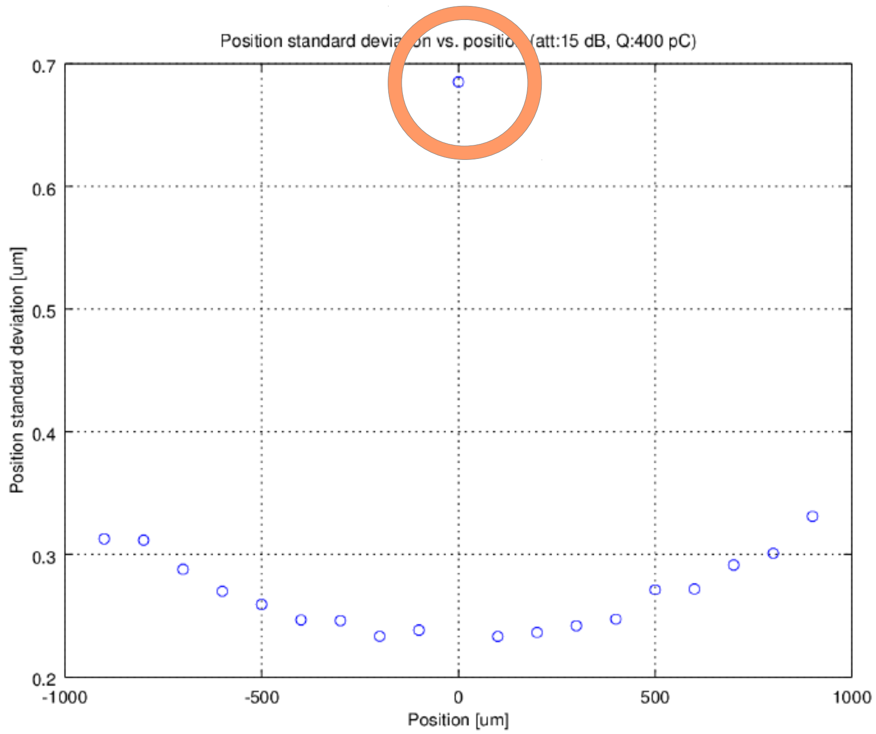
Position Resolution – single bunch

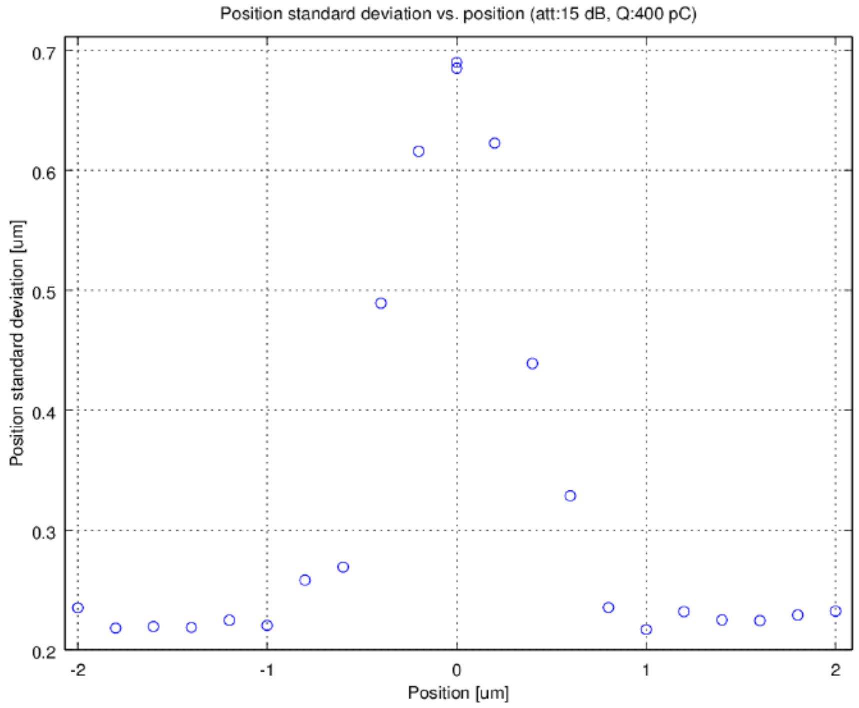


Position Resolution – single bunch

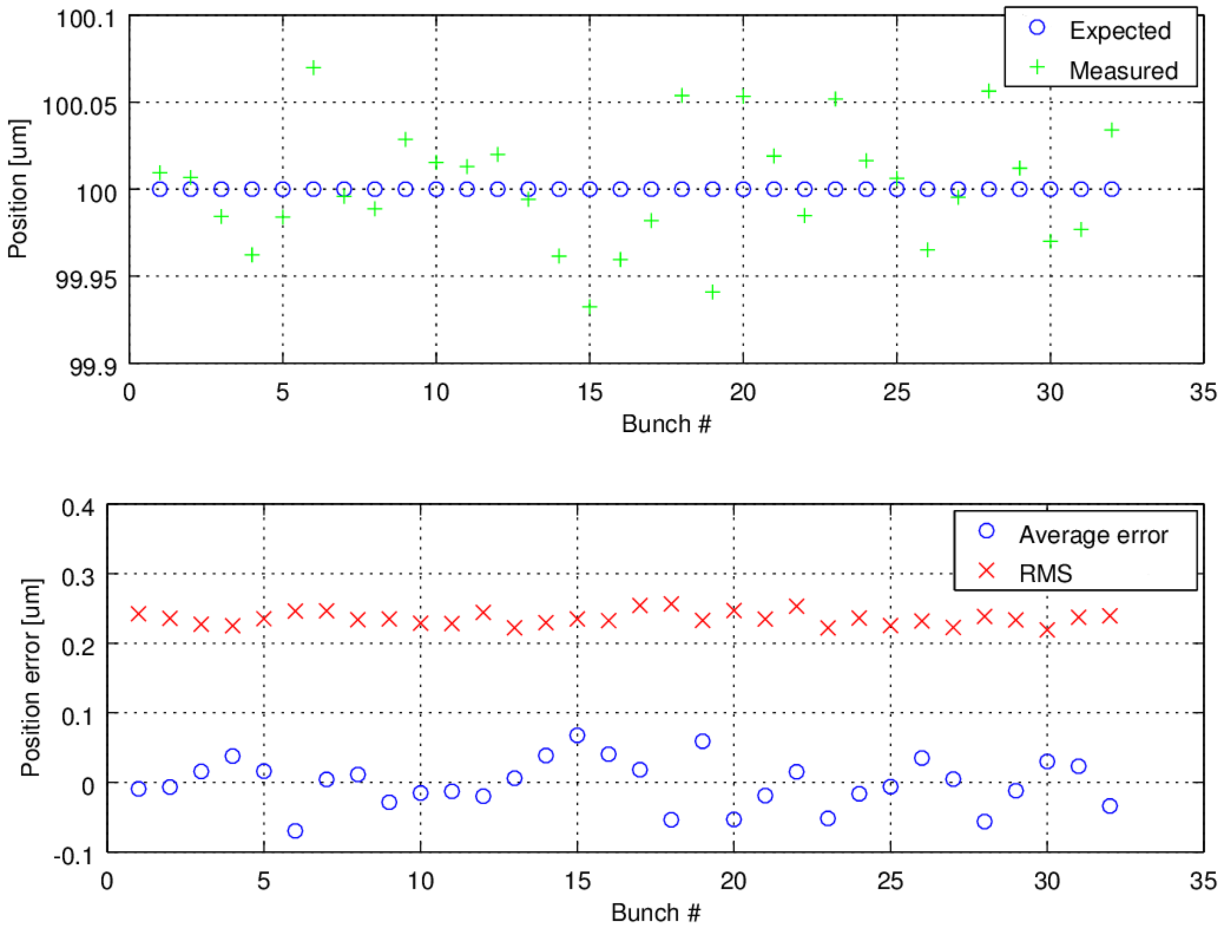


Position Resolution – single bunch





Position Resolution – bunch train



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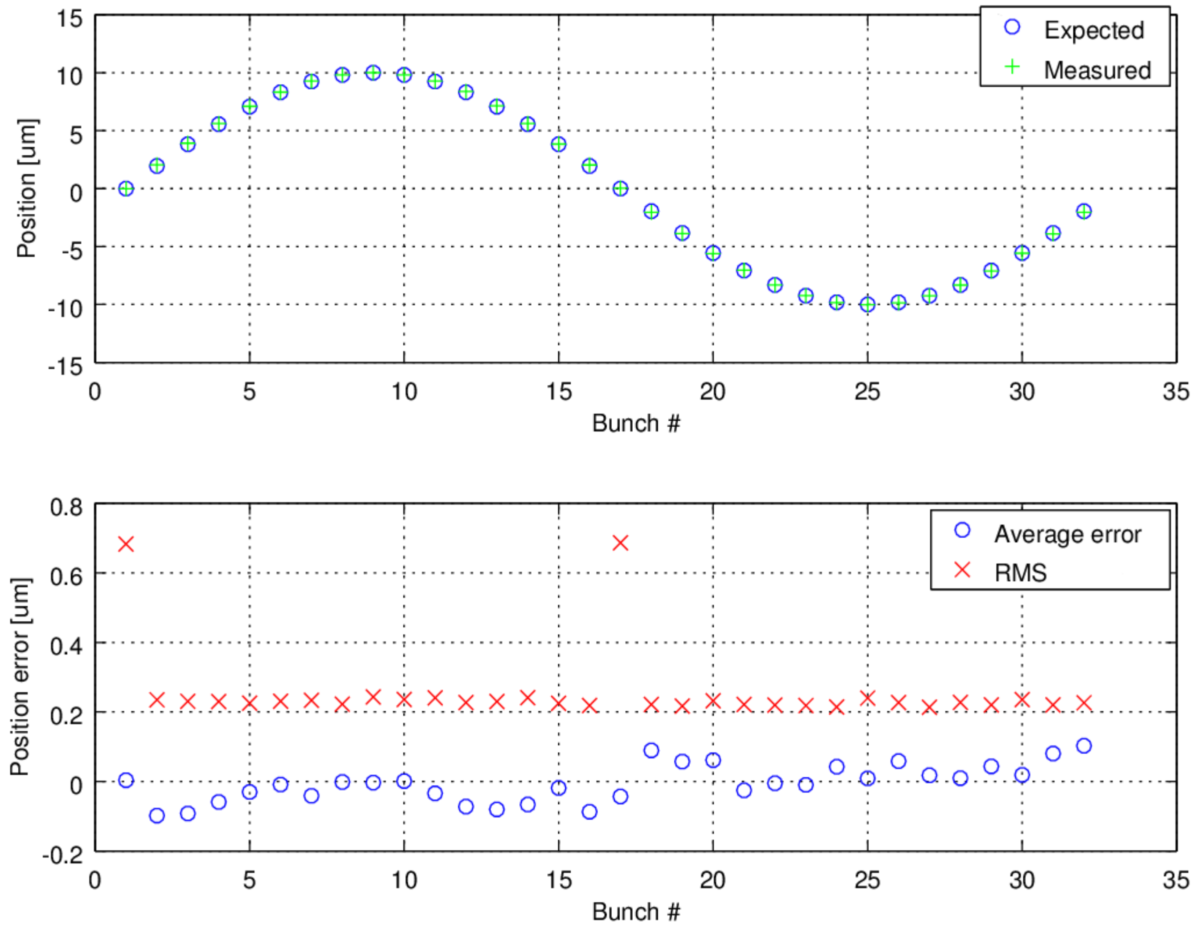

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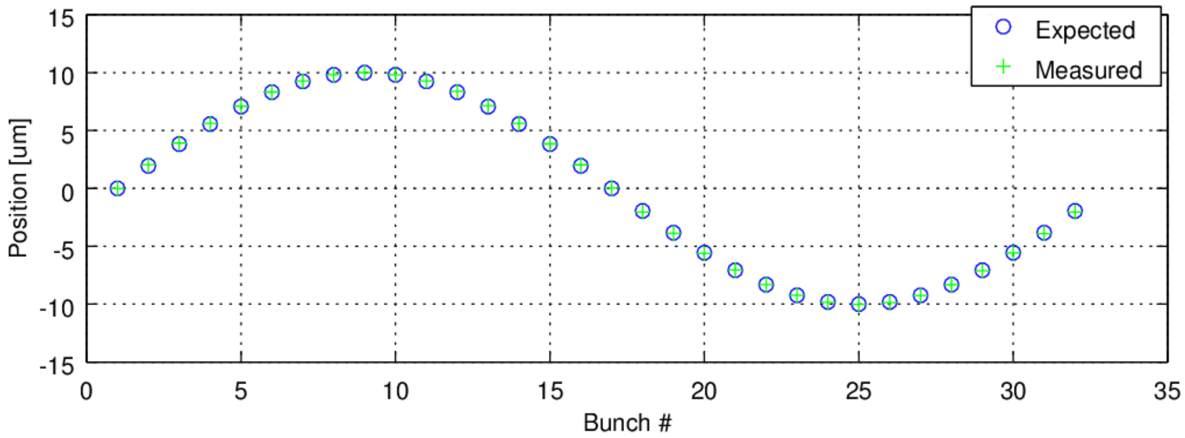
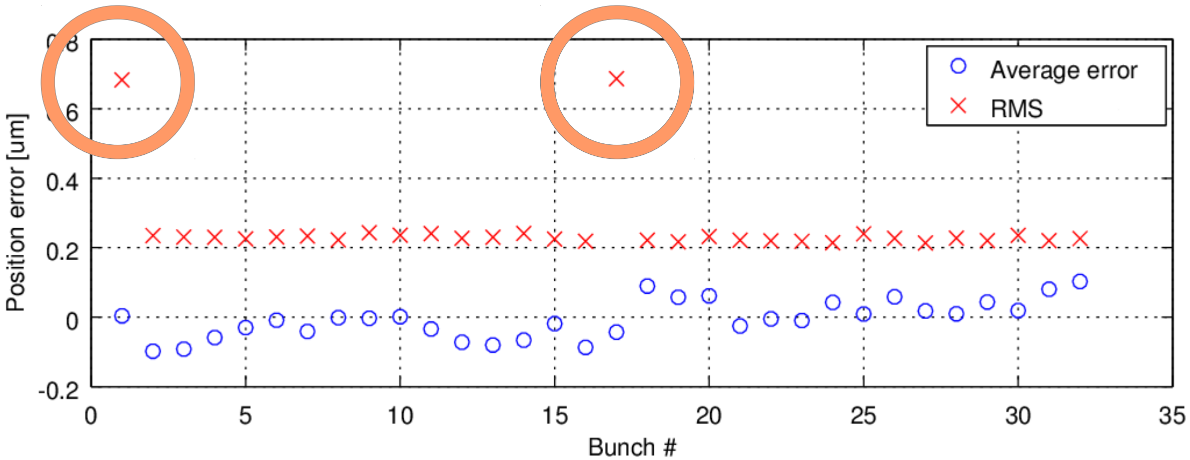


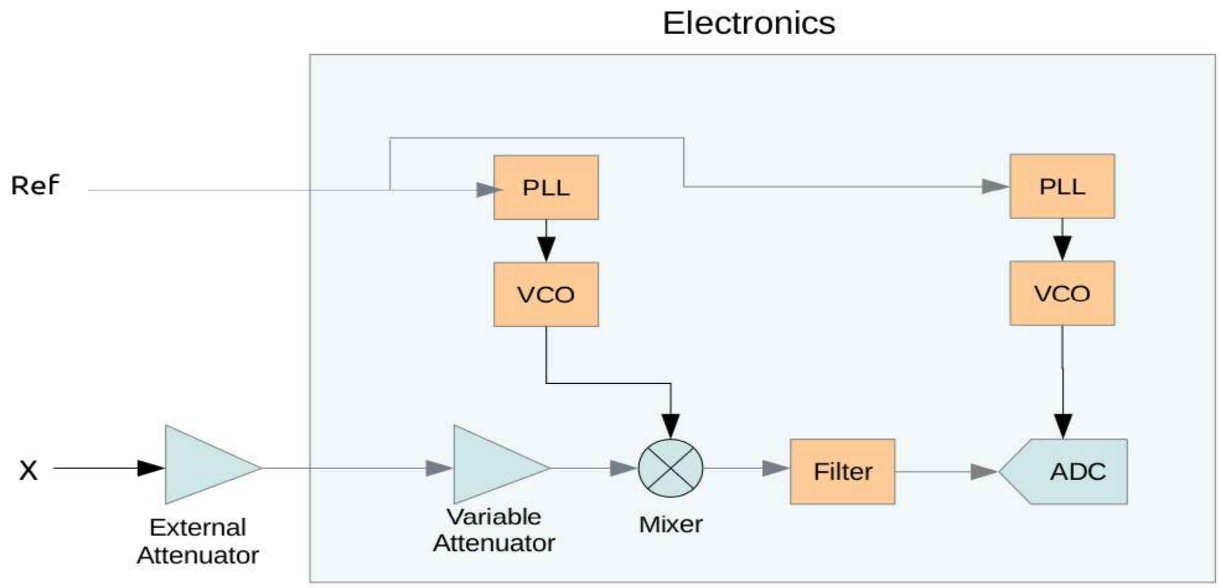


First prototype

Purpose:
validate some of the concepts which are essential for the system implementation.

The Phase 1 prototype is an interconnection of components and commercial evaluation boards.

First prototype



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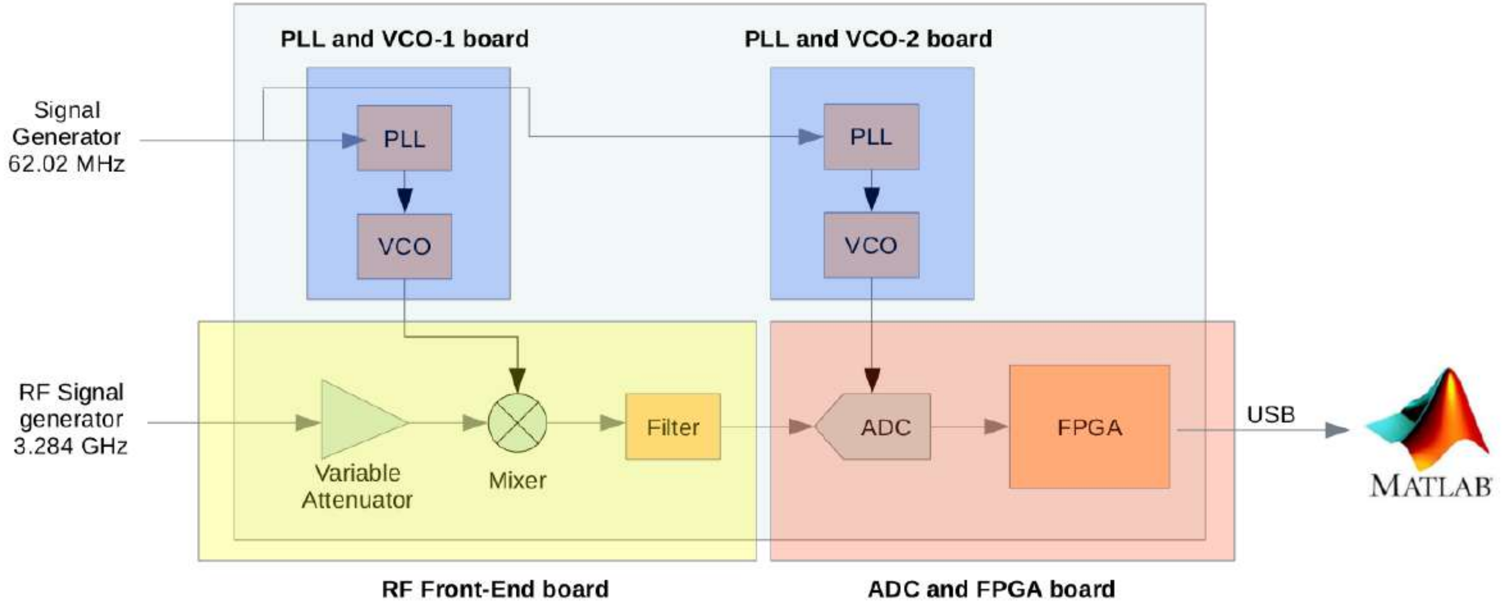

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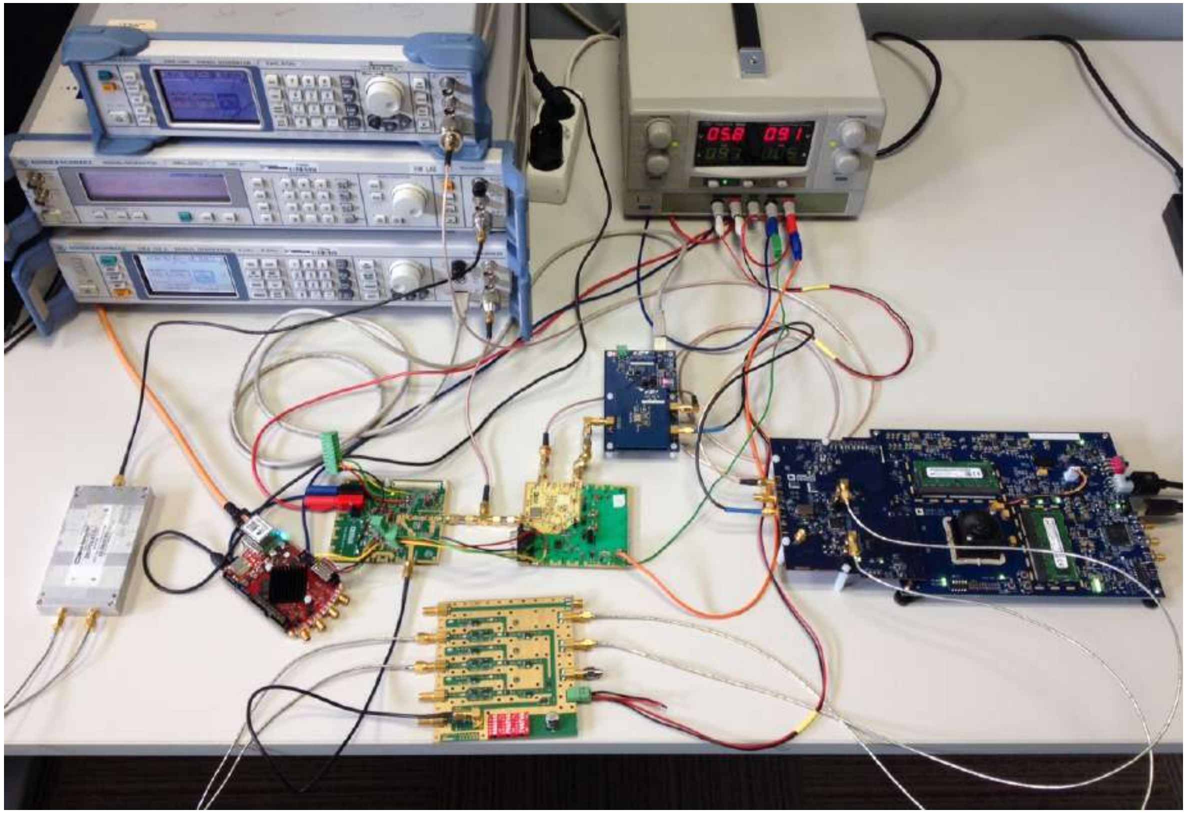


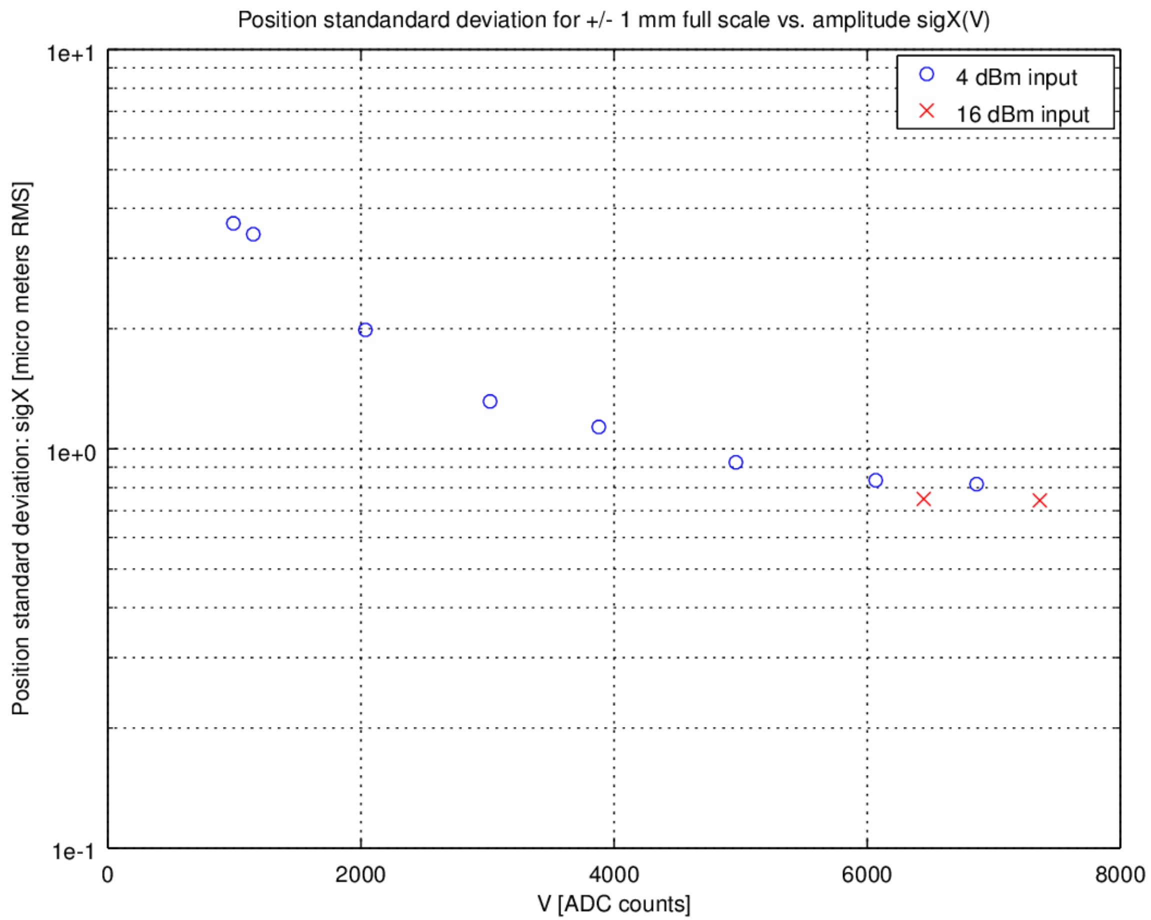
First prototype

Validation:

- individual board measurements

- combined measurements with sine-wave input signals: estimation of the achievable position resolution based on the noise introduced by the RF front-end

First prototype



Conclusions

- Cavity BPM electronics are in development
- Can operate at different frequencies, cavities, beam modes
- Simulations and first prototype confirm sub-µm resolution
- New potential instrument platform based on 500MS/s ADCs

Thanks for your attention!

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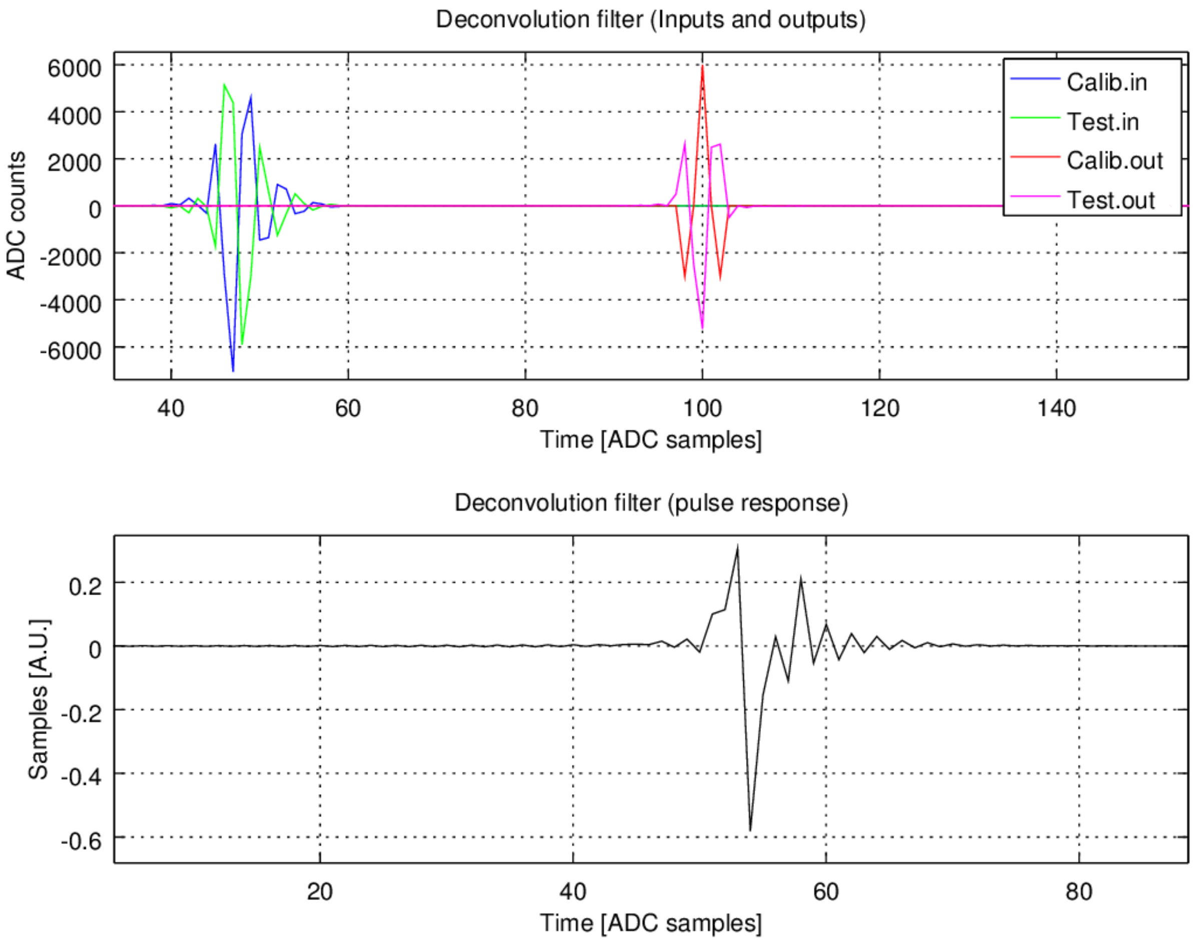
Appendix: deconvolution filter



Appendix: performance evaluation formula

The input signals X and I are IQ down-converted to the base-band to get V_X and V_I Position is later calculated as:

$$X = X_{FS}\frac{V_x + \Delta V_x}{V_I + \Delta V_I}$$

Assuming ΔV_X and ΔV_I Gaussian variables with same variance $\sigma_V{}^2$ the position measurement standard deviation can be calculated as:

$$\sigma_x = X_{FS}\frac{\sigma_V}{V_I}\sqrt{1+\frac{1}{V_I}} \simeq X_{FS}\frac{\sigma_V}{V_I}$$