Plan and working progress on cold cBPM for the Main Linac at ILC
Saclay cBPM signal processing

Laura Karina Pedraza, Nuria Fuster, Daniel Esperante, Benito Gimeno

Cold BPM R&D Meeting, 16/05/2024

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I. Project definition

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Development of a **re-entrant cBPM for the ILC Main Linac**

Measurement requirements:

Spatial resolution < 1 μm
Temporal resolution < 369 ns
Dynamic range: 0-35 nm (offset) and 0.1-3.2 nC (bunch charge)

Mechanical requirements:

Mechanical fit of the BPM and the SC quadrupole magnet
Cryogenic and UV conditions have to be met

The designed BPM will initially be tested at ATF (Accelerator Test Facility) and at STF (Superconducting RF Test Facility) at KEK where:

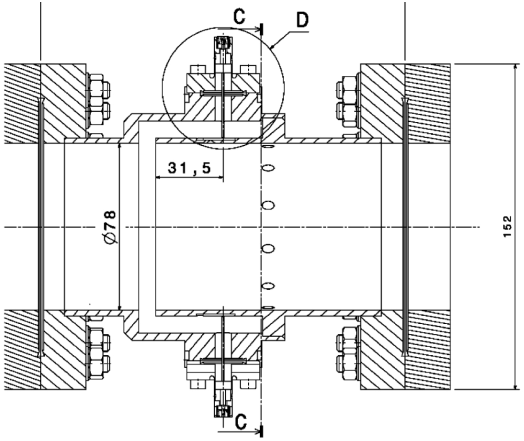
- Temporal resolution has to be matched in order to perform bunch to bunch measurements at STF specially

Beam parameters	**ATF2**	**STF**	**ILC**
Beam energy (GeV)	1.3	0.5	250
Bunch charge (nC)	1.6	0.6	3.2
Bunch spacing (ns)	150 or 307	6.15	369
Bunch length (mm)	7	3	0.3

cBPM type	**Resonance freq (GHz)**	**Quality factor Q_L**	**Decay time τ (ns)**
Saclay	1.724 (dipole)	59 (dipole)	10.90 (dipole)
	1.255 (monopole)	23.8 (monopole)	6.04 ns
Hayano	2.05	217	33.7

H. Hayano, Development of L-Band Cavity BPM for STF, KEK
C. Simon, N. Rouvière, N. Baboi, Performance of a reentrant cavity beam position monitor, DSM, CNRS, DESY

I. Project definition



➡ **Modify the Saclay cBPM design to improve performances**

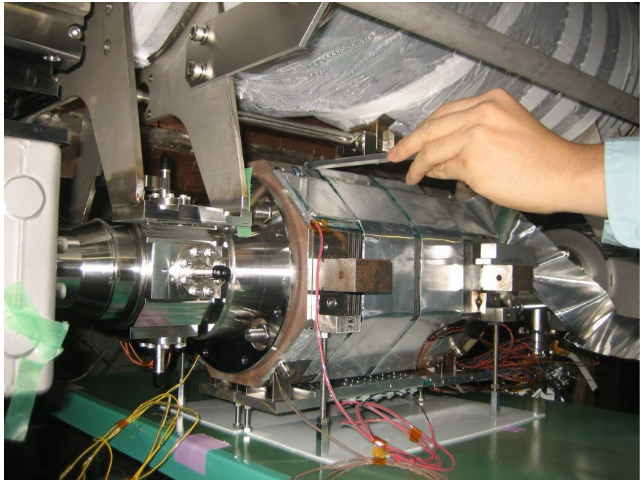
- ❖ Modifications of the Claire Simone design to improve the temporal resolution τ (< 6 ns) → perform bunch to bunch measurements at STF
- ❖ Modifications of the Claire Simone design to increase the spacial resolution and make it suitable for ATF/ILC + cryomodule

➡ **Buy a the cBPM from Claire Simone (Saclay)**

- ❖ Receive cBPM around the fall of 2024
- ❖ Test the cavity and the electronics with beam at ATF at the end of 2024 or beginning of 2025

➡ **Simulate signal processing in MATLAB**

- ❖ Signal processing chain inspired on the one developed by ELI/RHUL
- ❖ Understand read-out chain and estimate behavior with Saclay BPM
- ❖ Evaluate compatibility with a new BPM design and check room for improvement



C. Simon, N. Rouvière, N. Baboi, Performance of a reentrant cavity beam position monitor, DSM, CNRS, DESY

II. Signal processing simulation with ideal components

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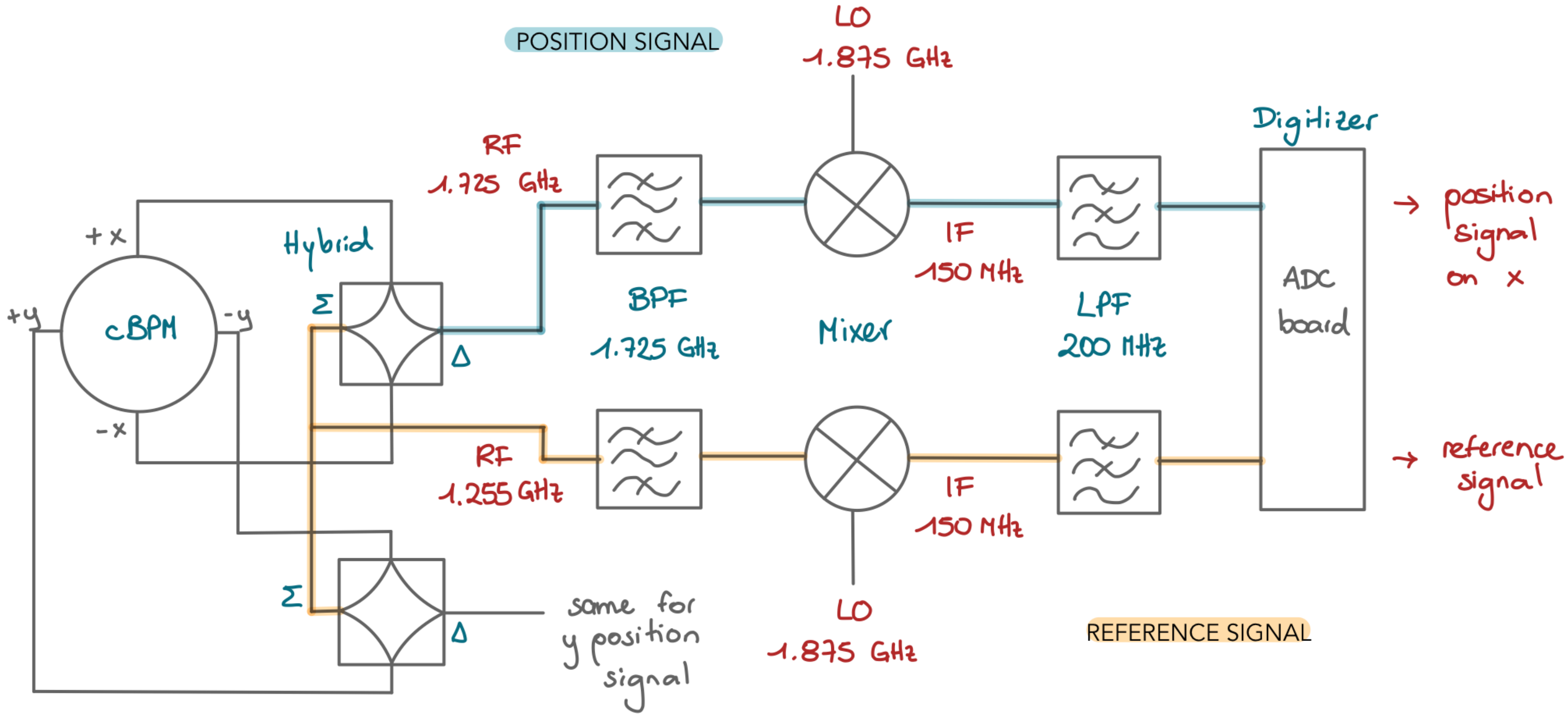
A. Signal extraction



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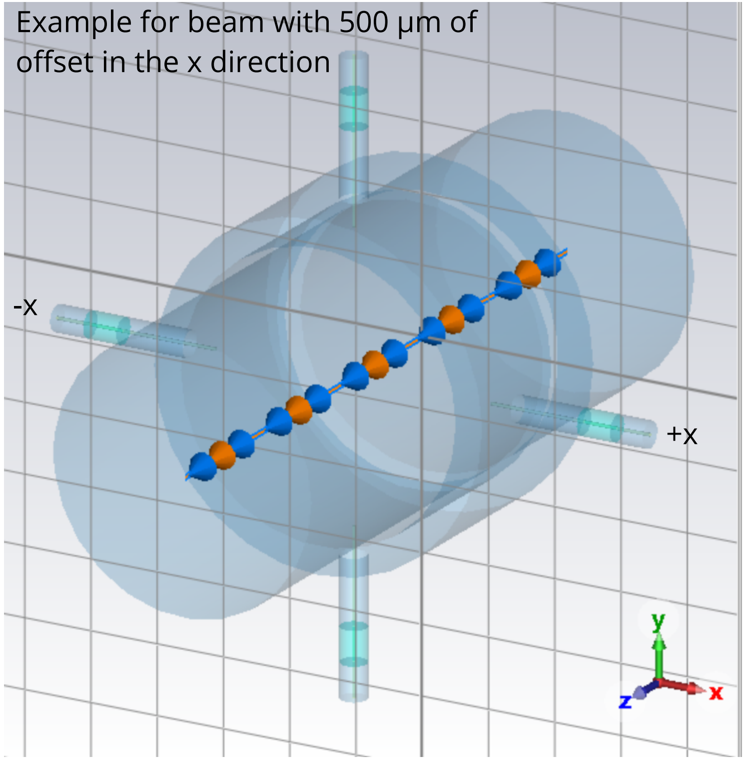
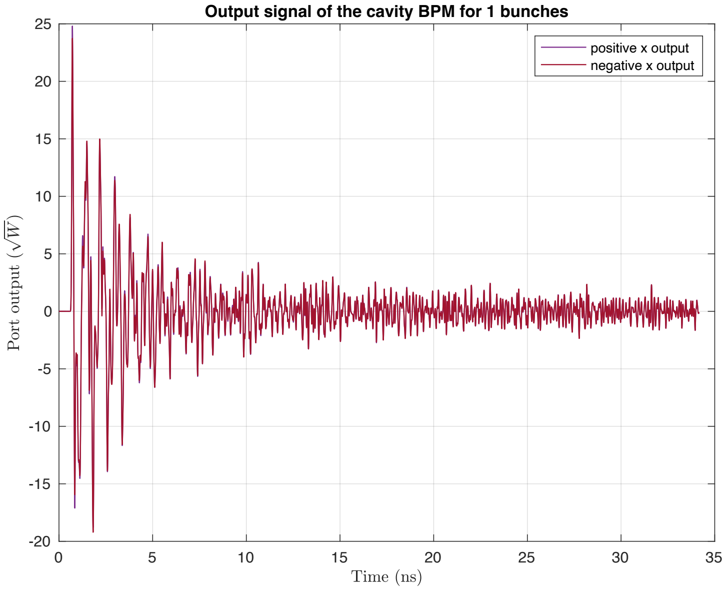
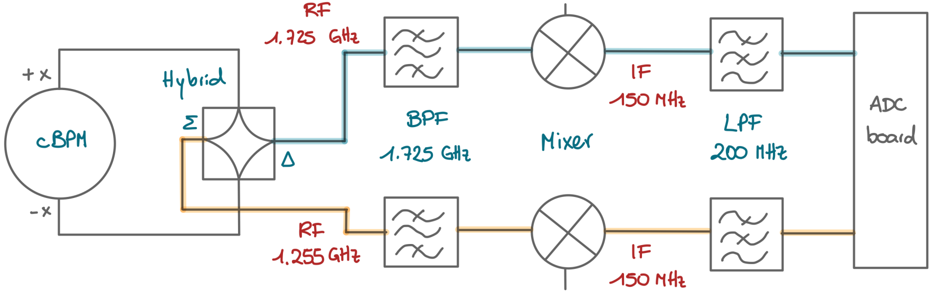


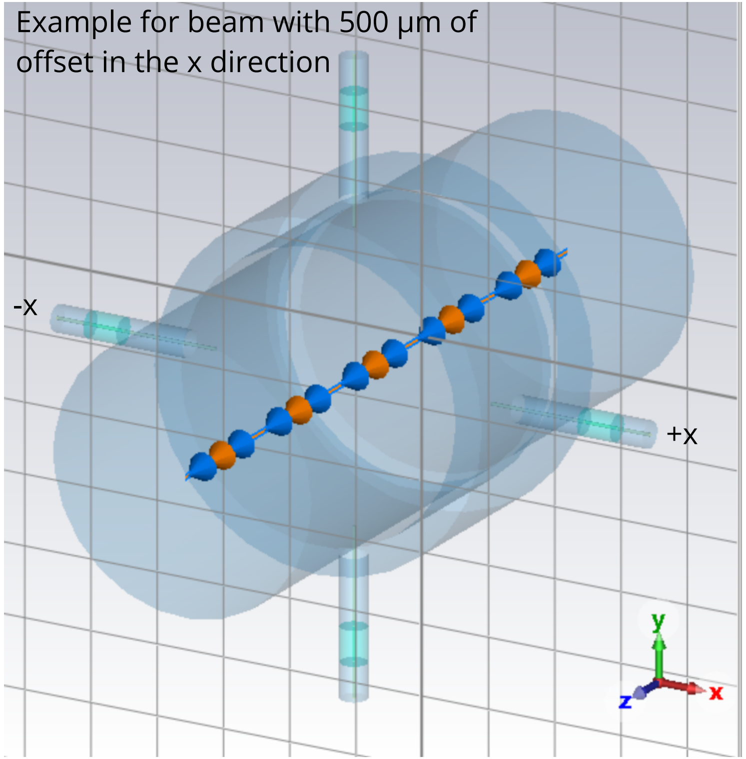


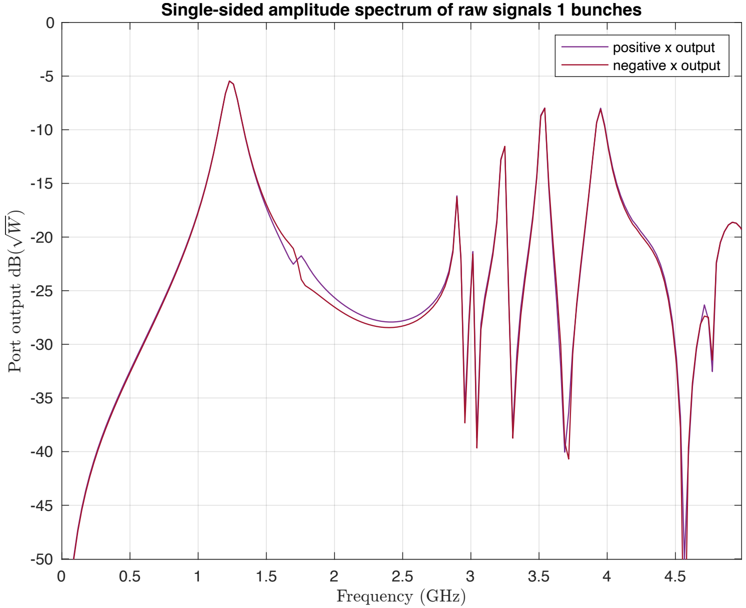


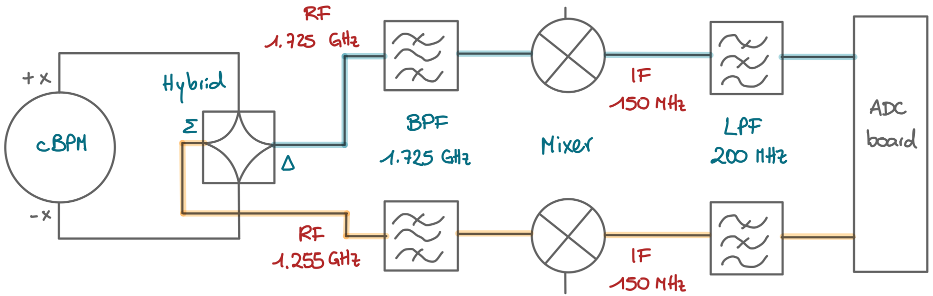
II. Signal processing simulation with ideal components

A. Signal extraction

Example for beam with 500 μm of offset in the x direction

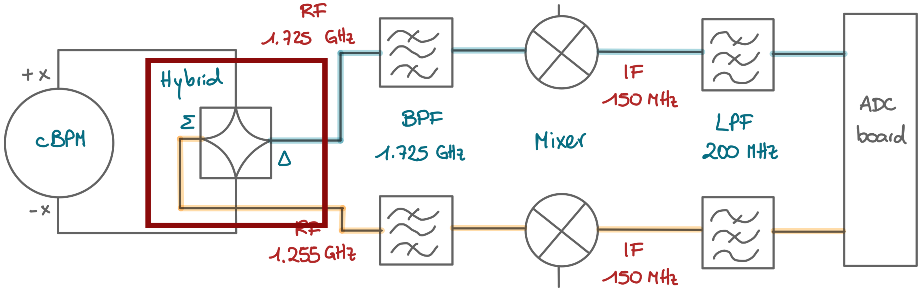


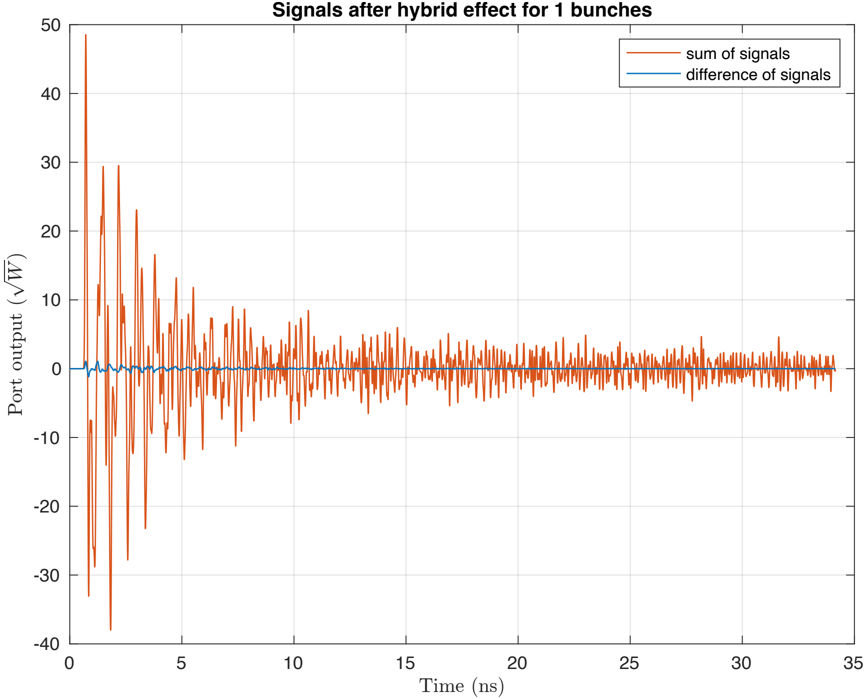


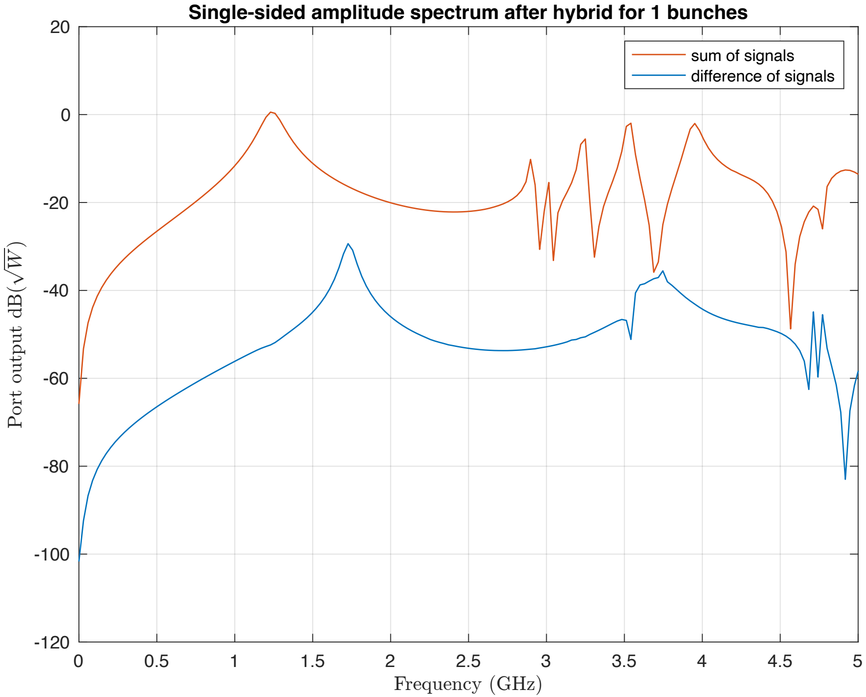


II. Signal processing simulation with ideal components

B. 180º Hybrid

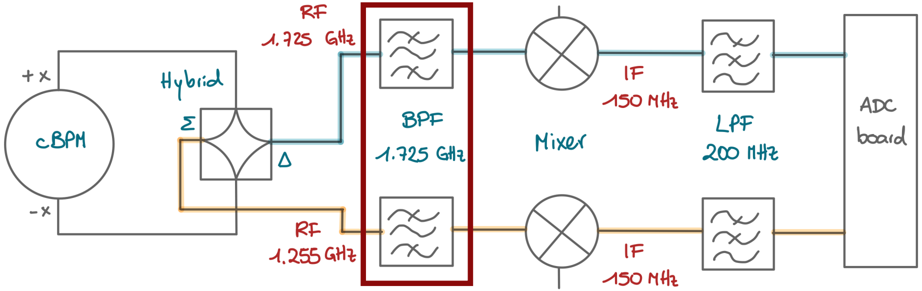




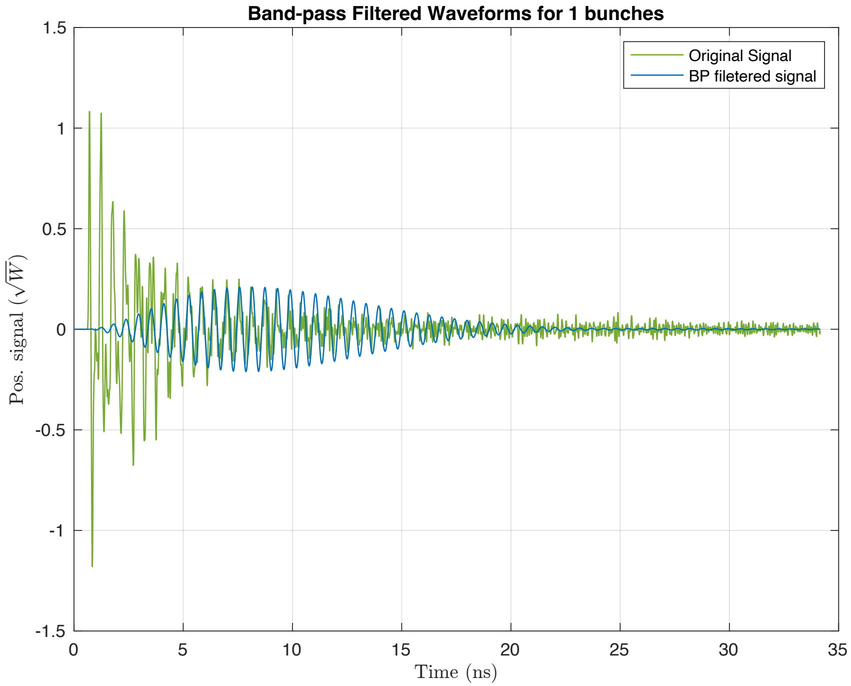


II. Signal processing simulation with ideal components

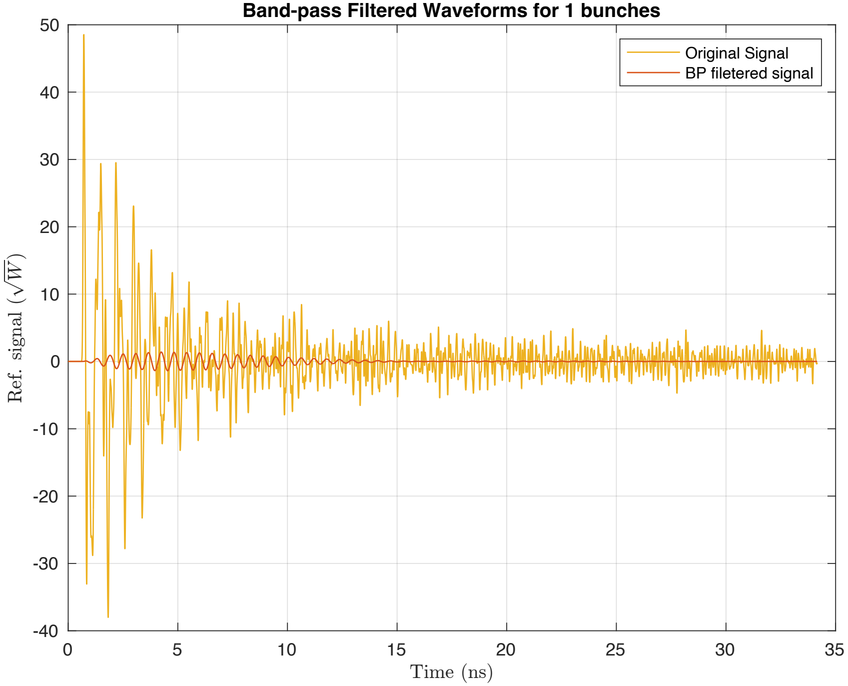
C. RF band-pass filter



For POSITION signal



For REFERENCE signal



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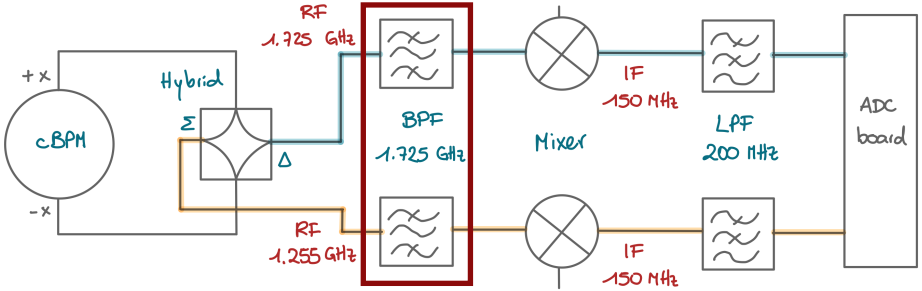

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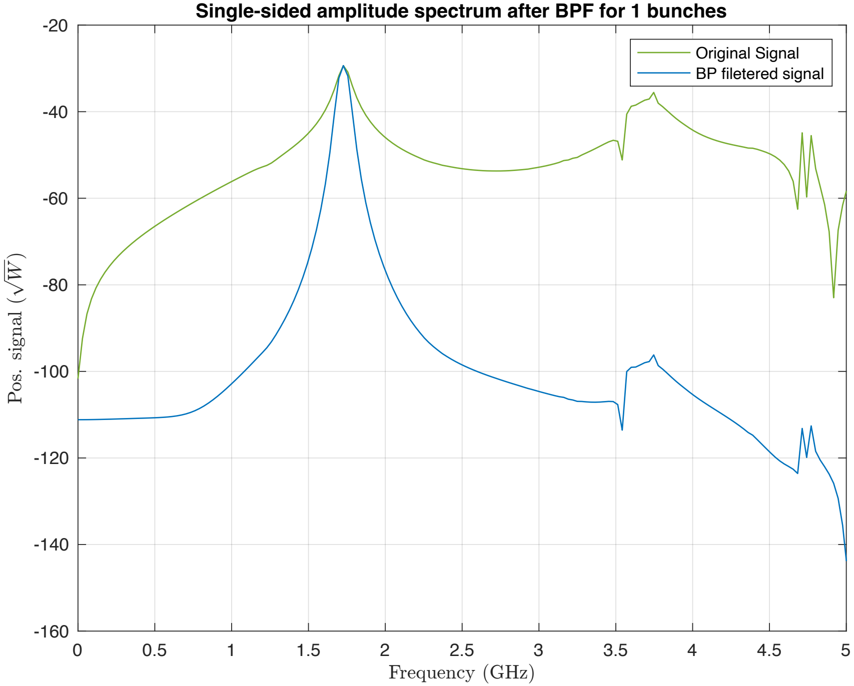
For POSITION signal



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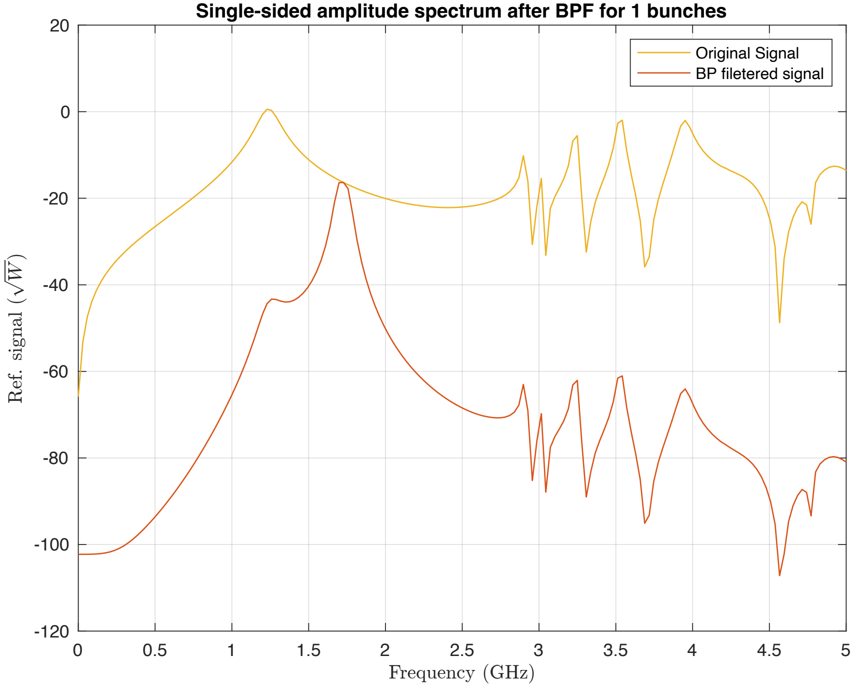
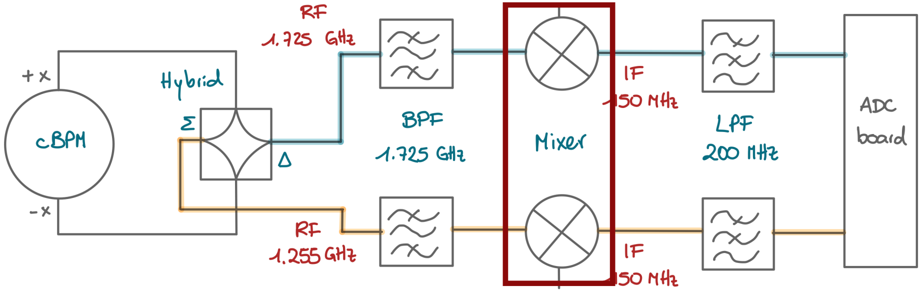
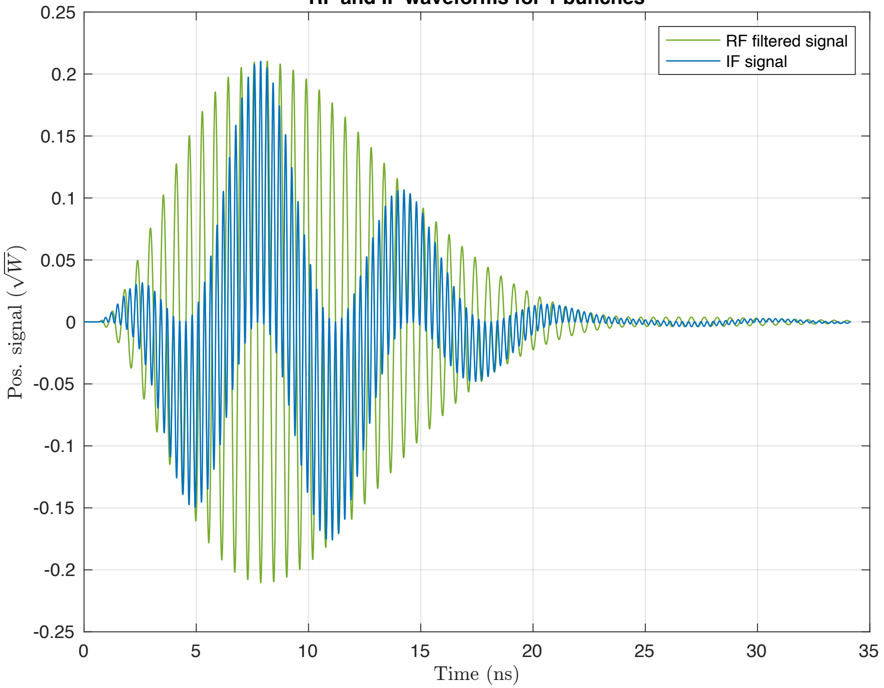


II. Signal processing simulation with ideal components

D. Down-mixing



For POSITION signal



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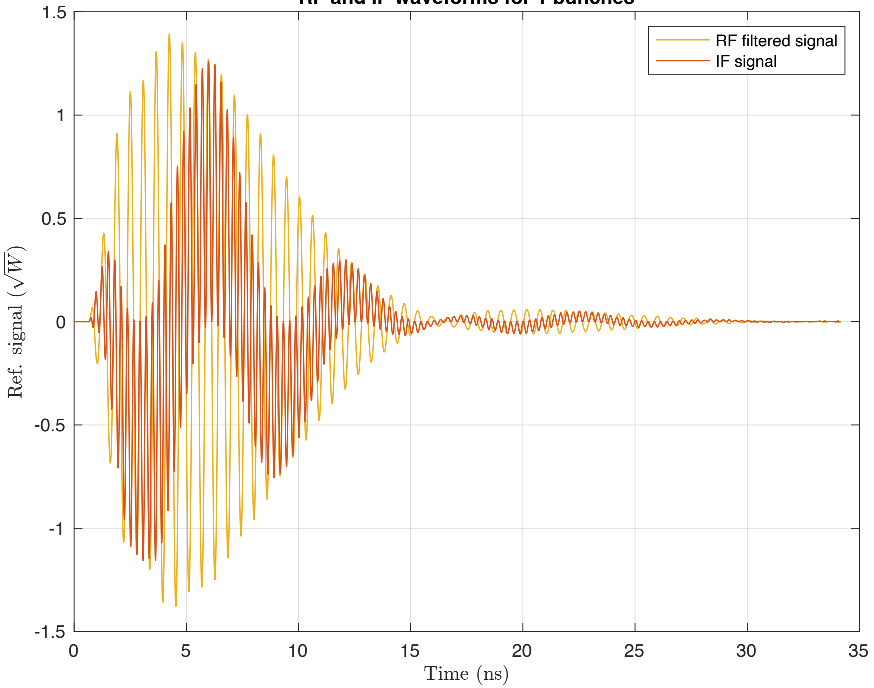

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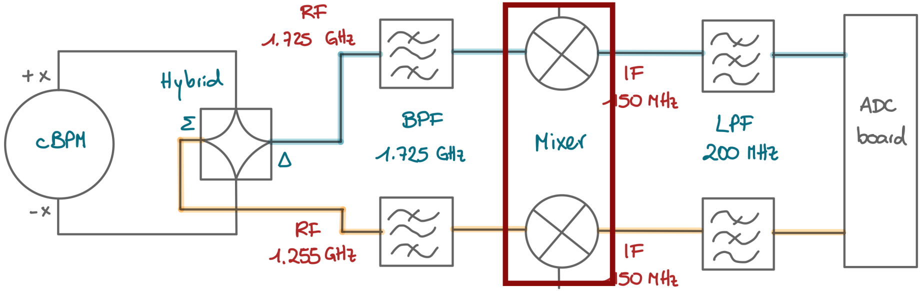
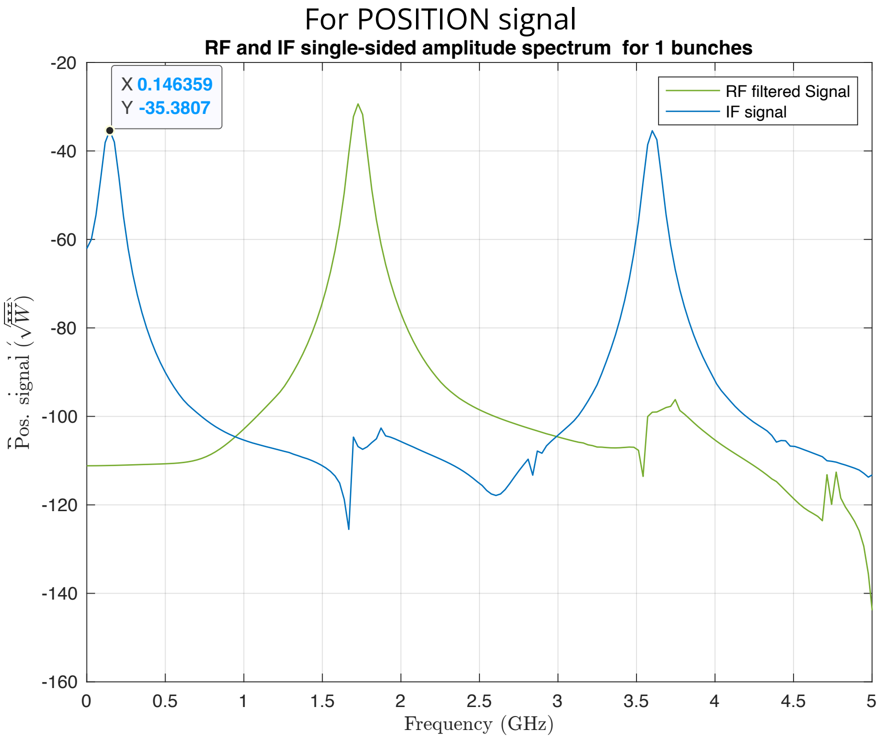
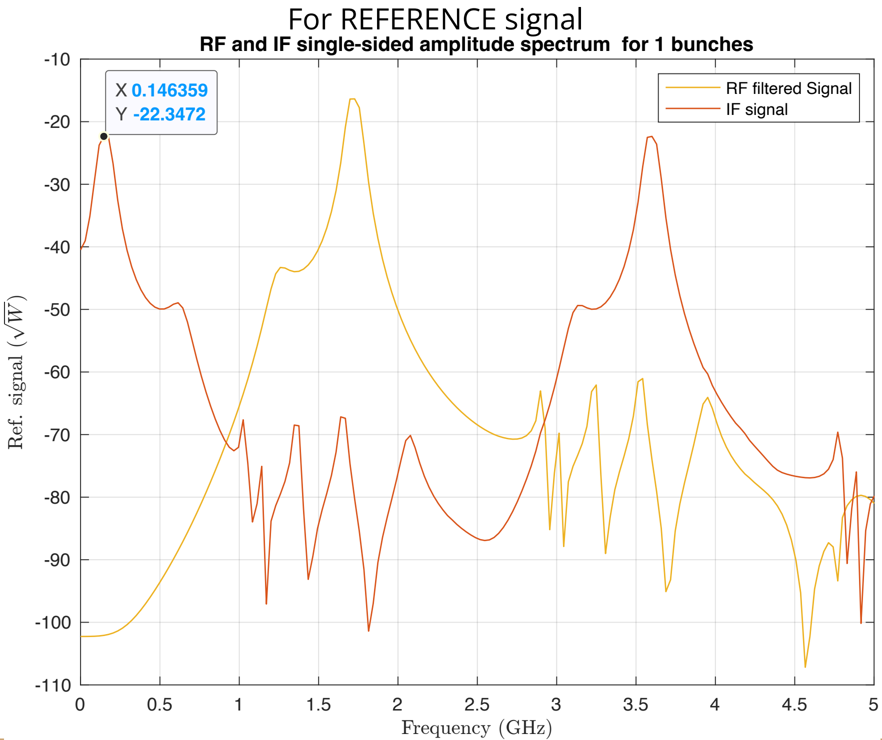
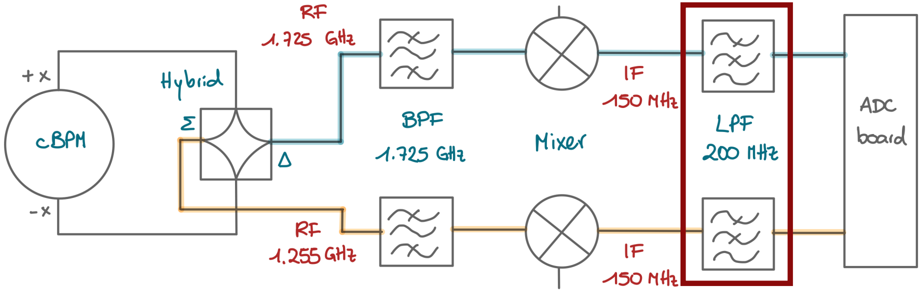




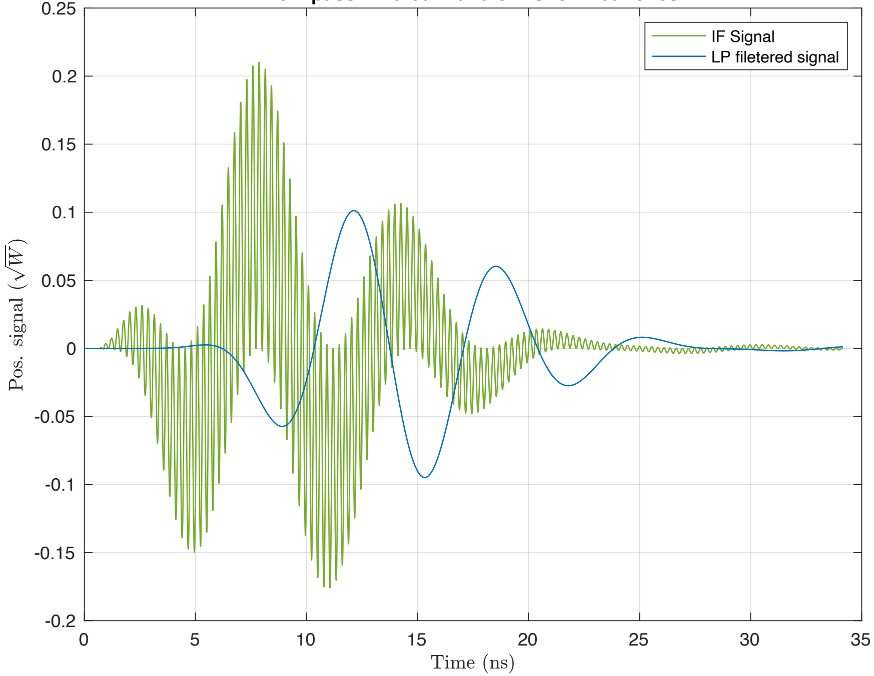


II. Signal processing simulation with ideal components

E. IF low-pass filter



For POSITION signal



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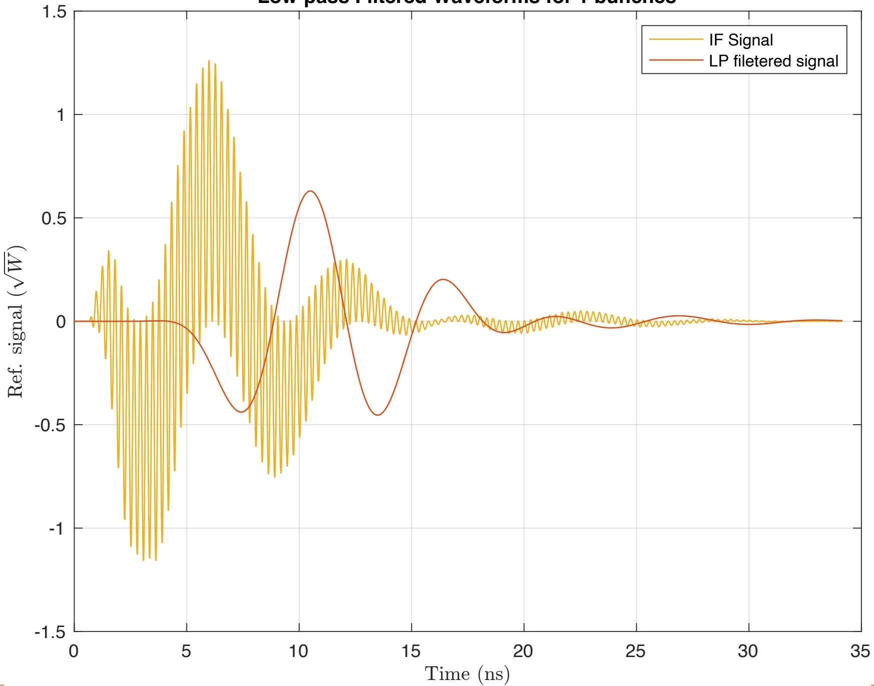

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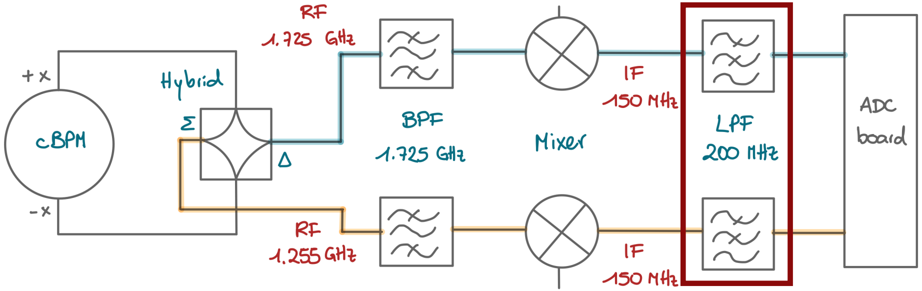

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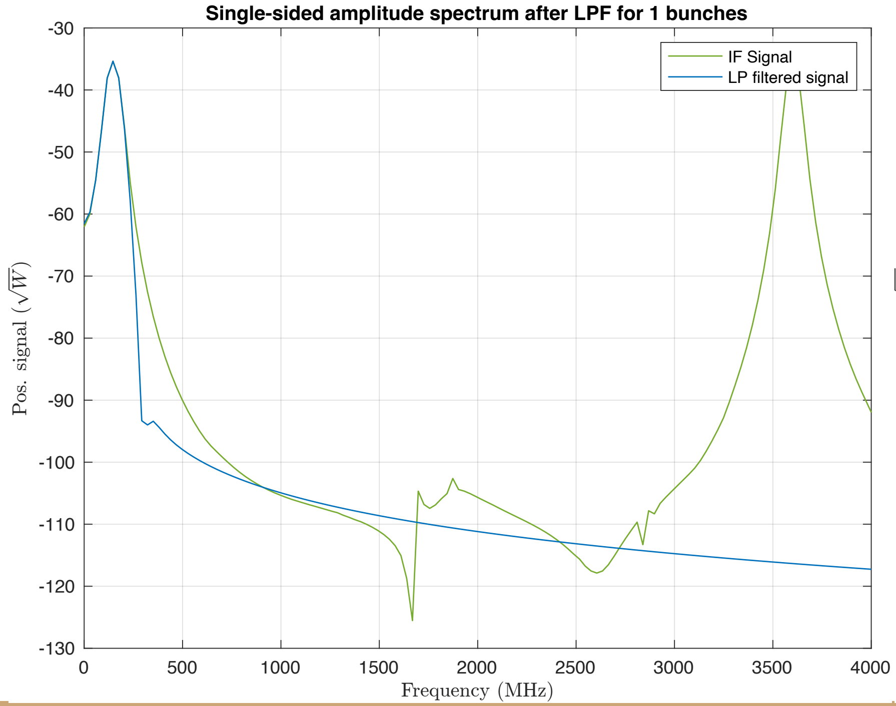

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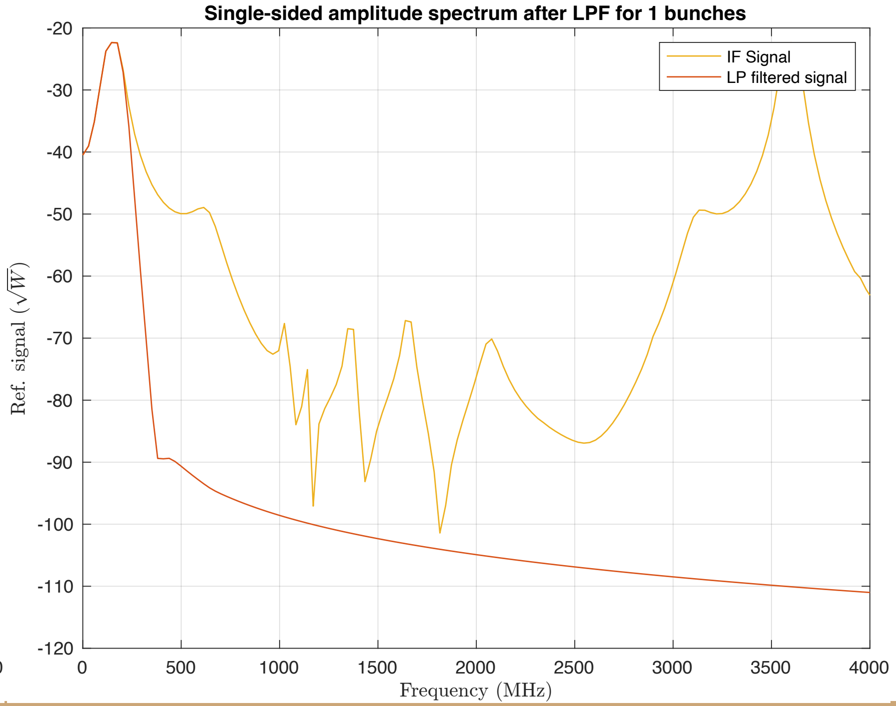
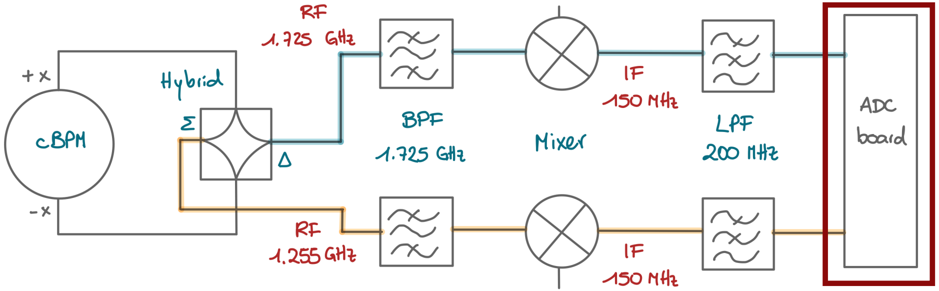


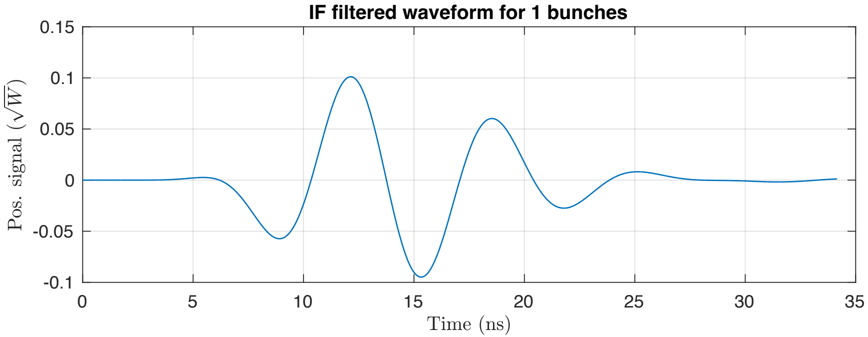
II. Signal processing simulation with ideal components

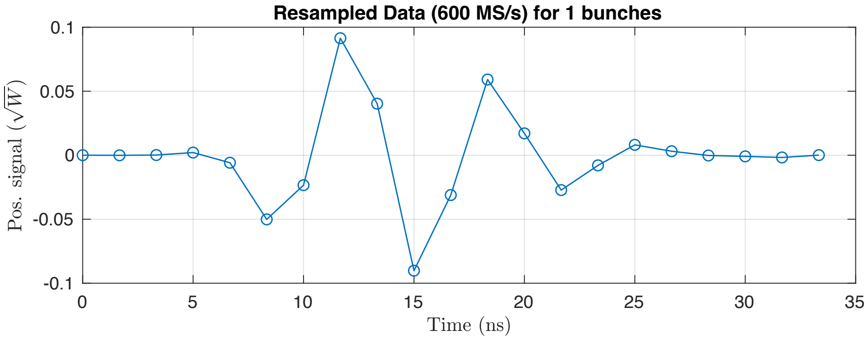
F. Digitizer



Sampling:
600 MS/s

For POSITION signal





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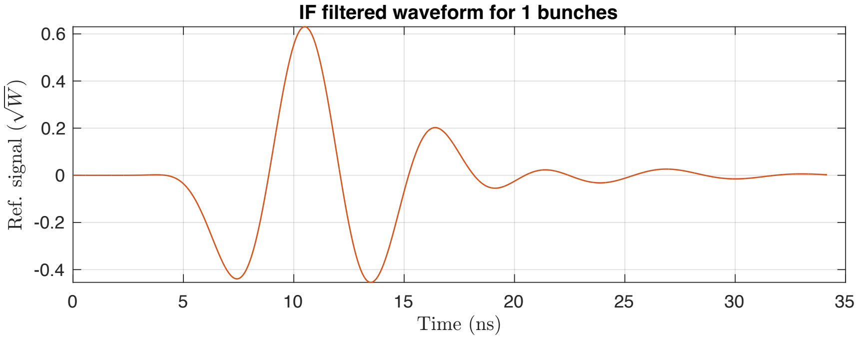

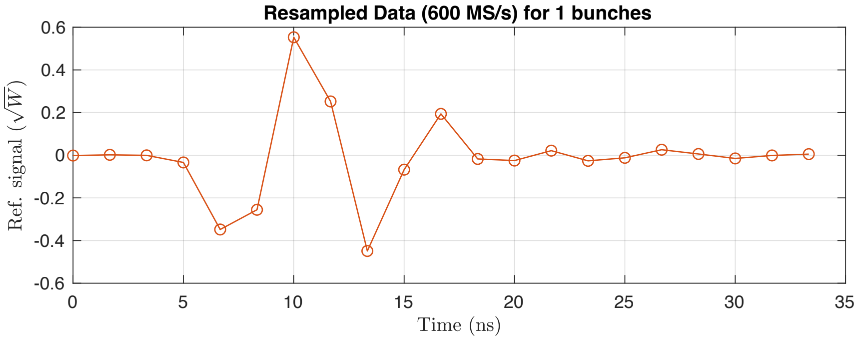

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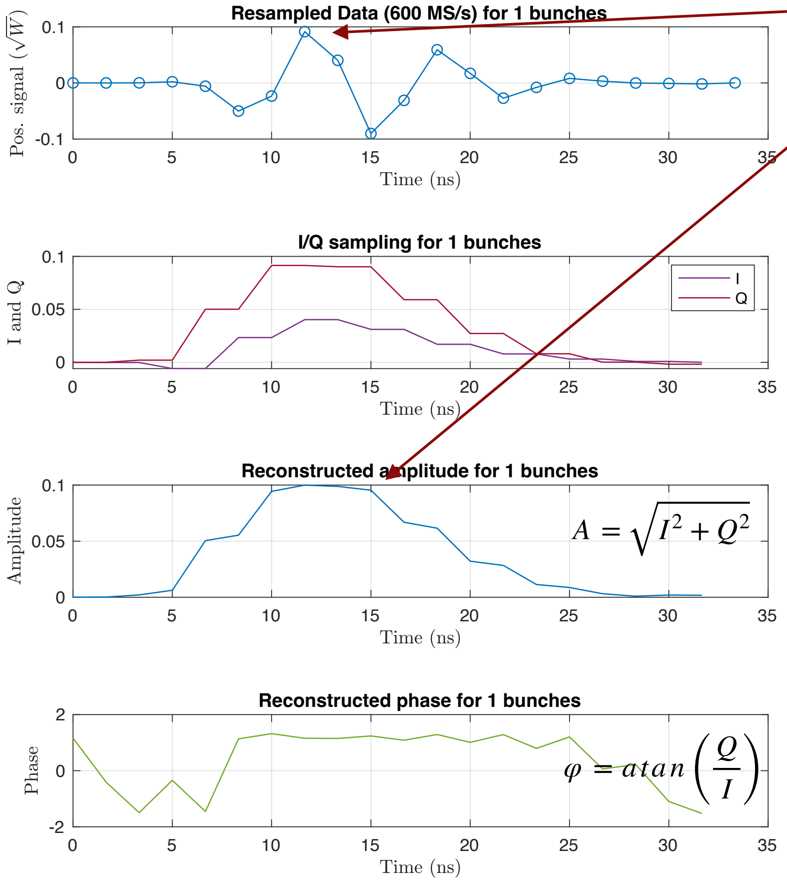
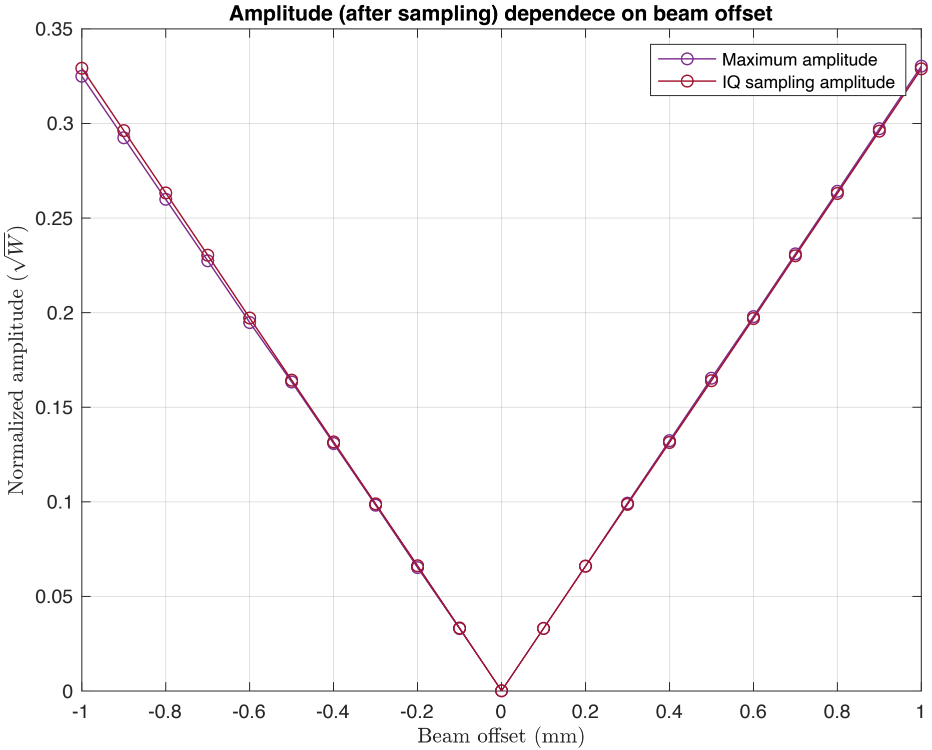
- Take the maximum of the signal or IQ demodulation:

Maximum amplitude

IQ amplitude

(for position and reference signals, and then normalization)





III. Signal processing: Multi-bunch study

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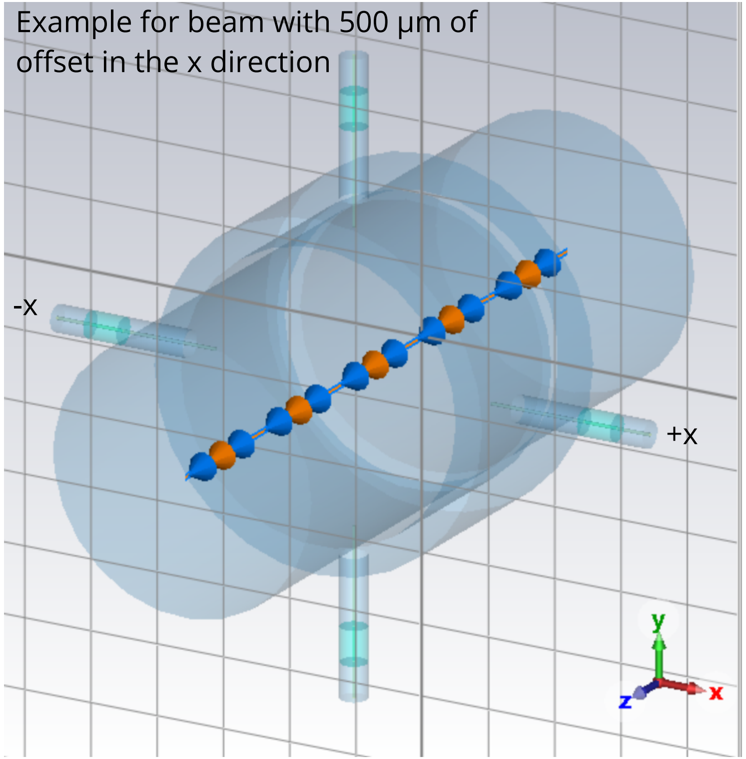
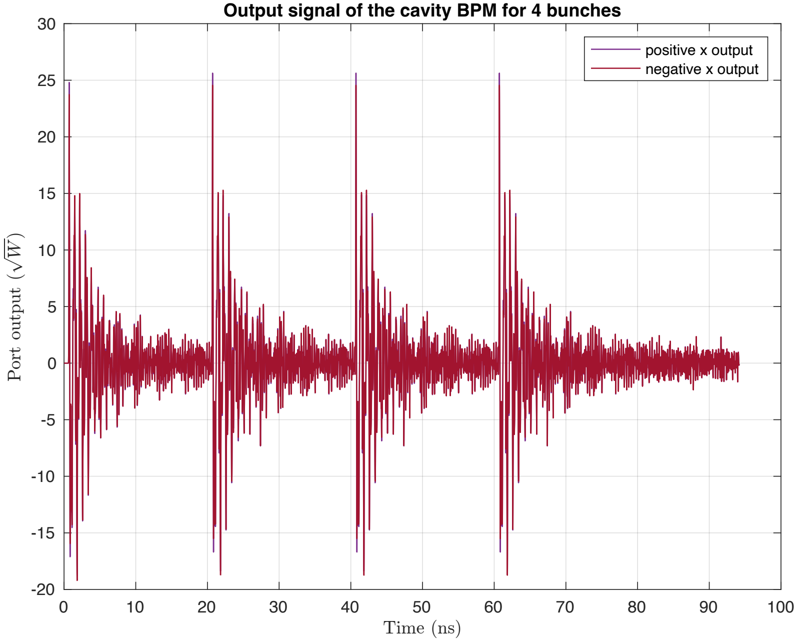
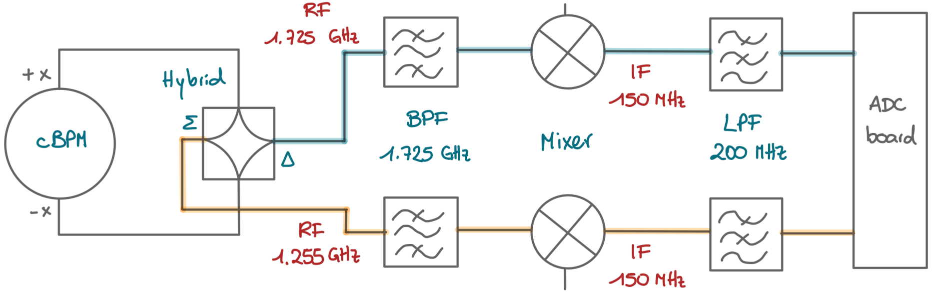
A. Signal extraction for 50 MHz bunch rep.



Bunch repetition: every 20 ns





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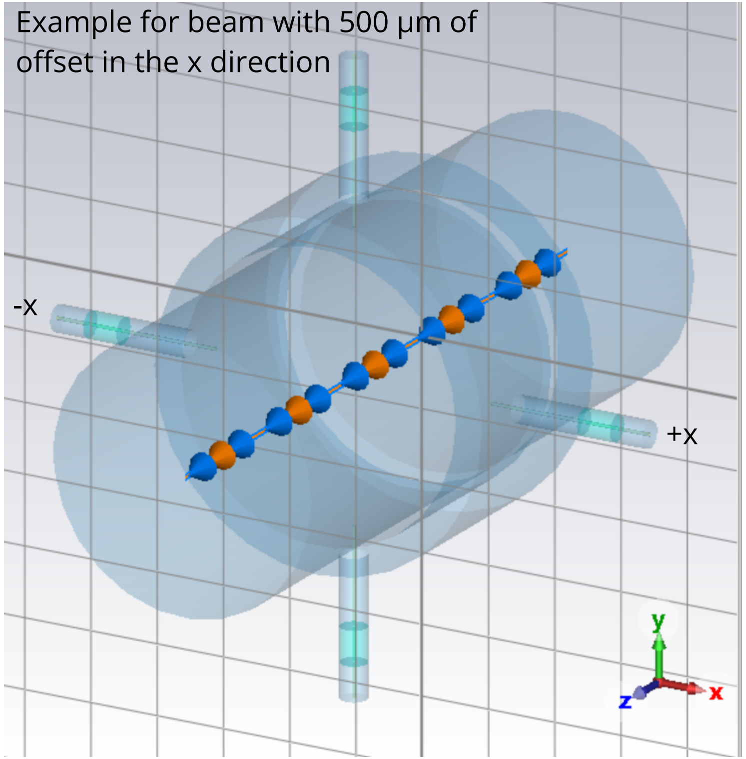
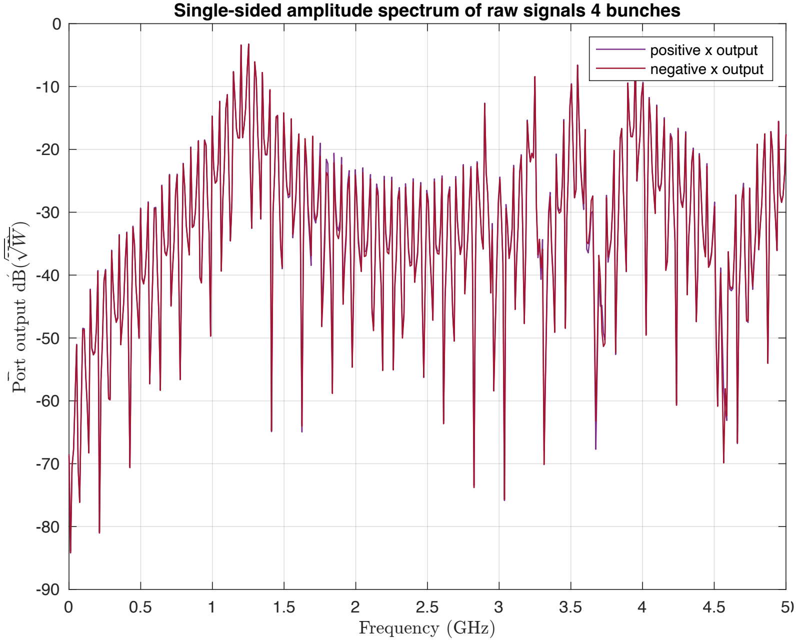
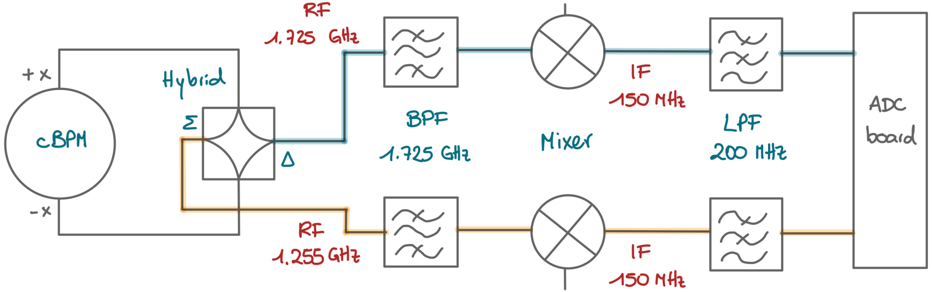


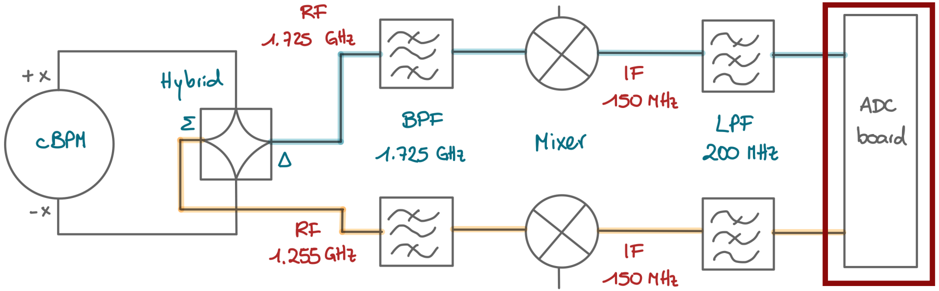
Bunch repetition: every 20 ns





III. Signal processing: Multi-bunch study

B. Sampling for 50 MHz bunch rep.



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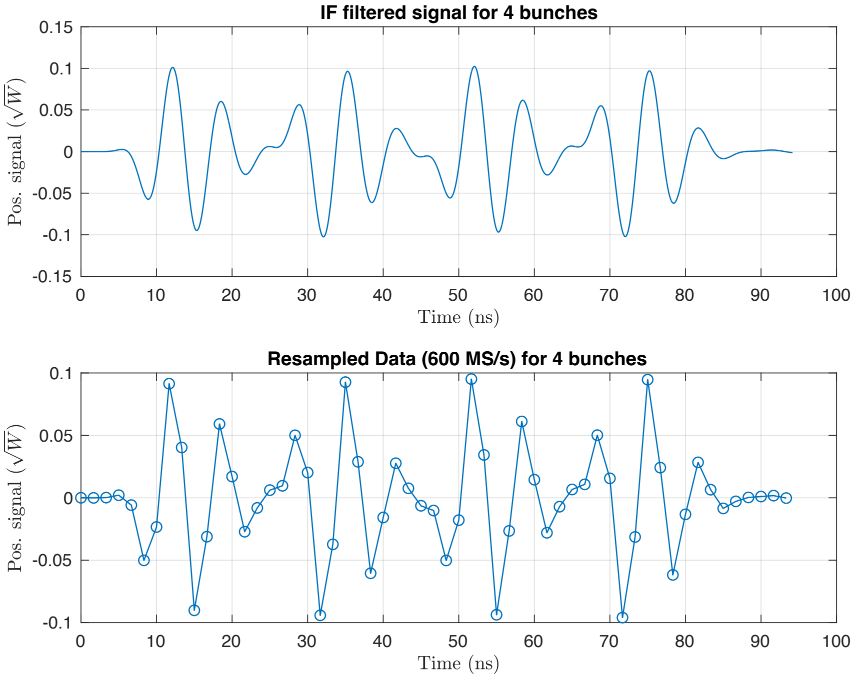
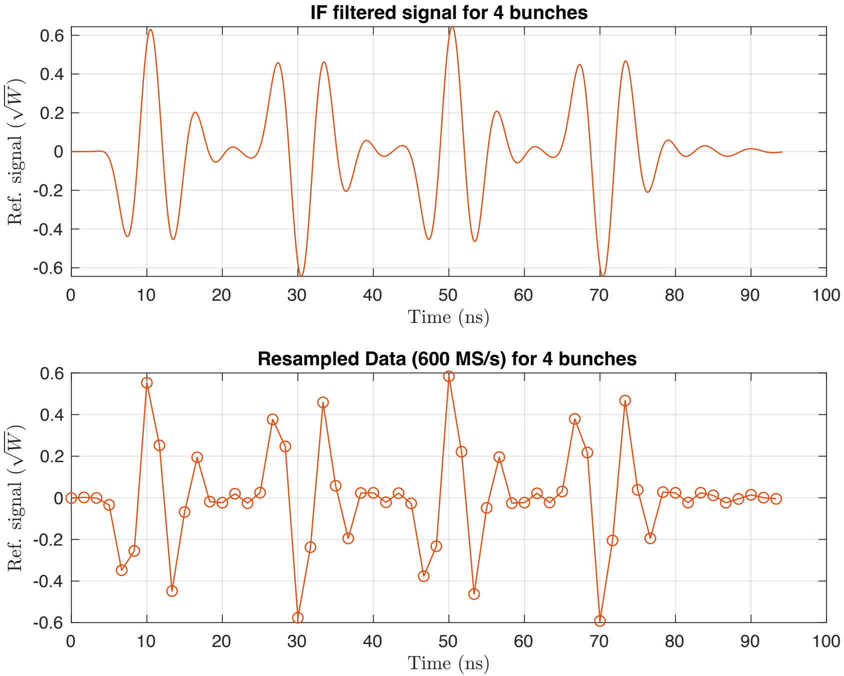
Sampling:
600 MS/s

For POSITION signal



For REFERENCE signal



III. Signal processing: Multi-bunch study C. Amplitude-offset for 50 MHz bunch rep.

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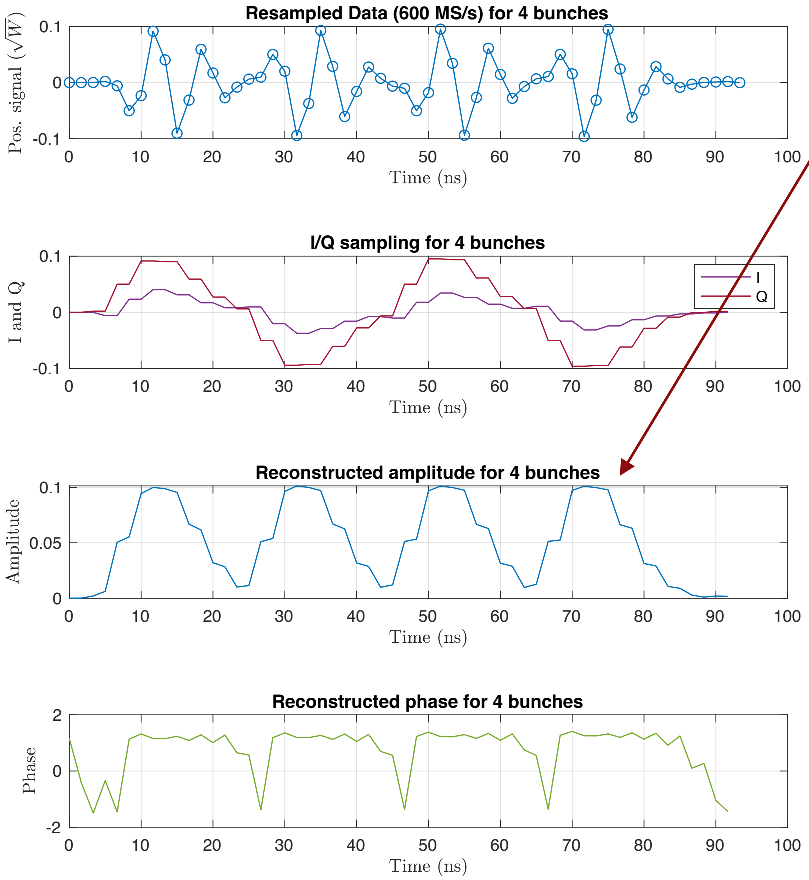
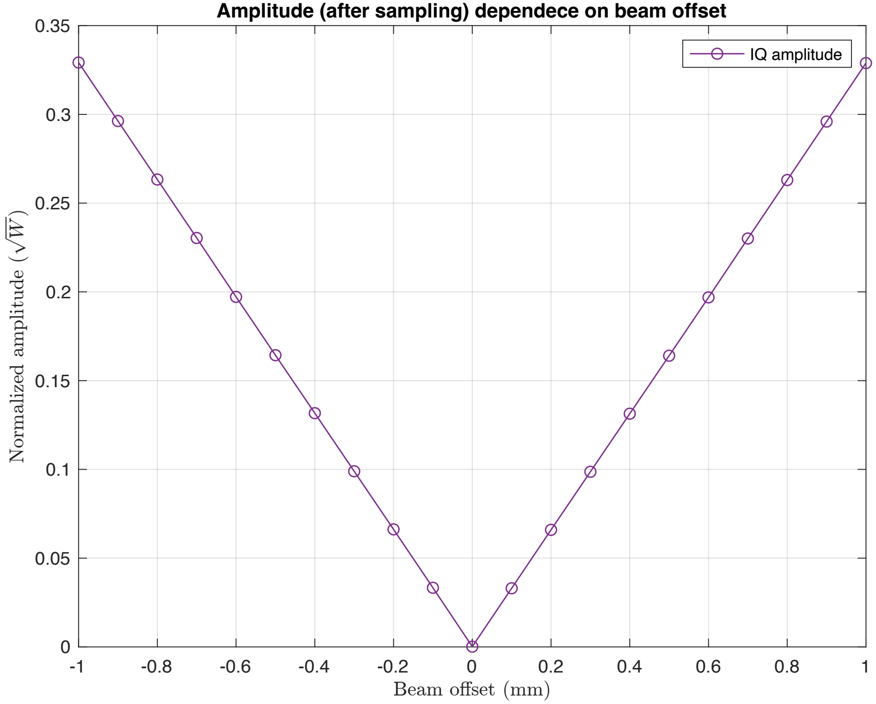
IQ demodulation:



IQ amplitude for each bunch

(normalization with ref. signal)

Bunch 1



C. Amplitude-offset for 50 MHz bunch rep.

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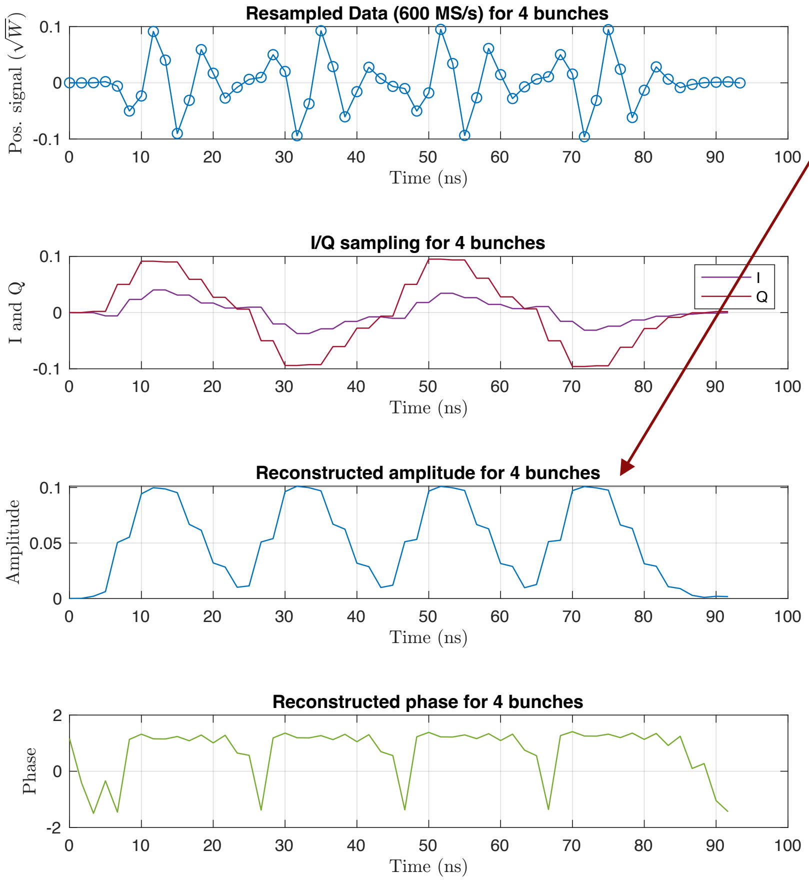
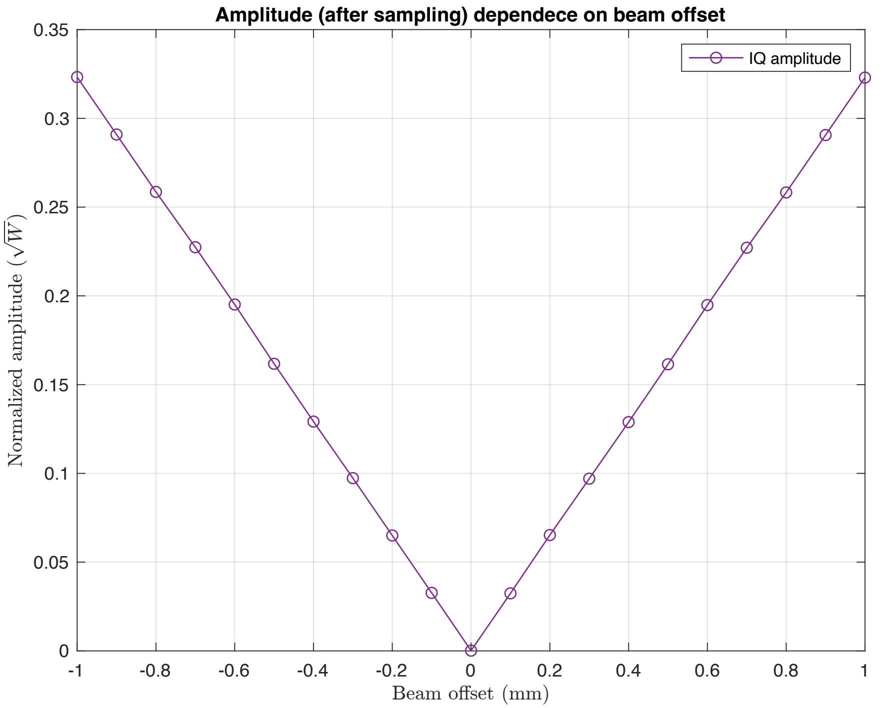
IQ demodulation:



IQ amplitude for each bunch

(normalization with ref. signal)

Bunch 2



C. Amplitude-offset for 50 MHz bunch rep.

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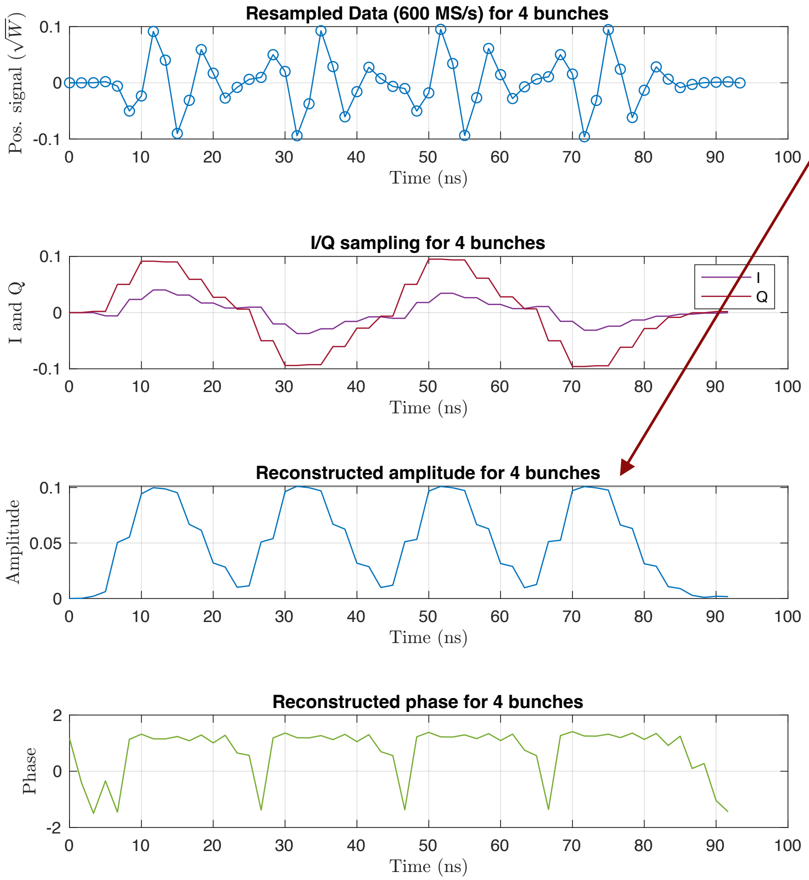
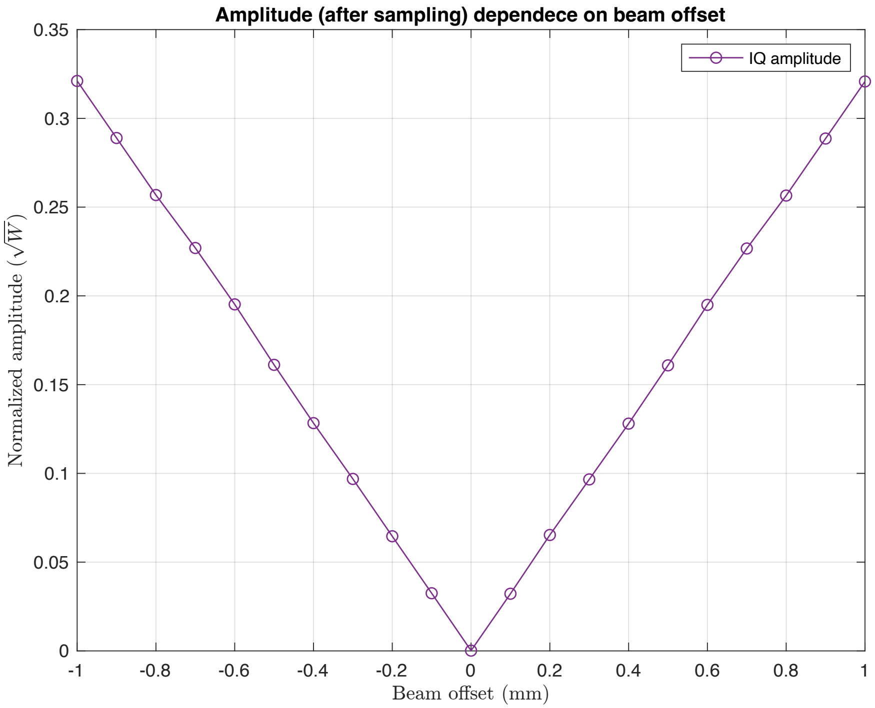
IQ demodulation:



IQ amplitude for each bunch

(normalization with ref. signal)

Bunch 3



III. Signal processing: Multi-bunch study C. Amplitude-offset for 50 MHz bunch rep.

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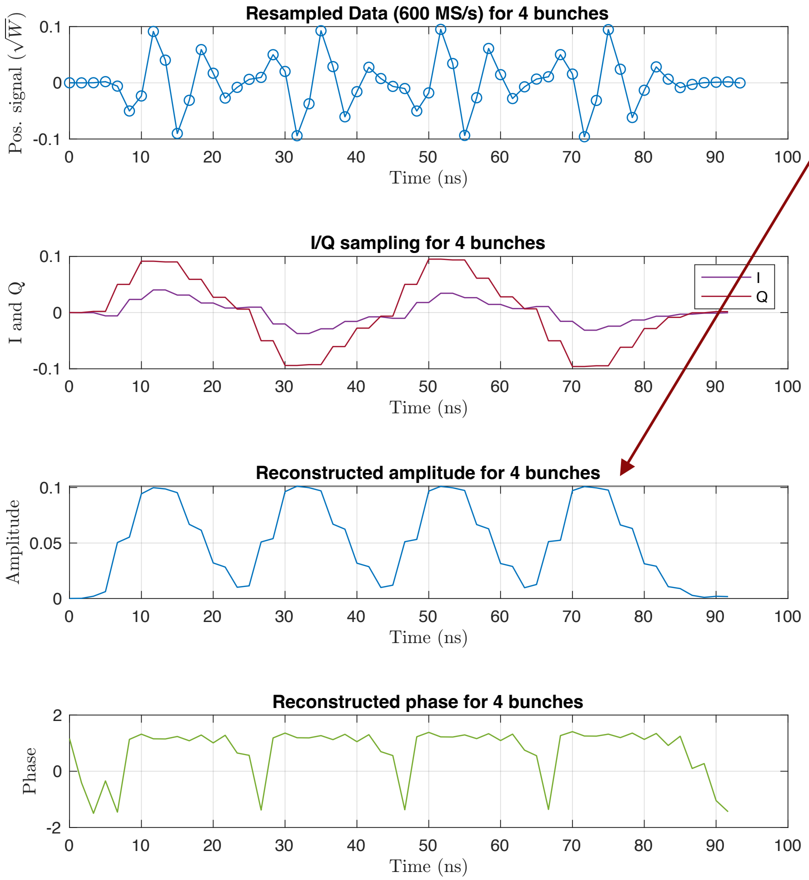
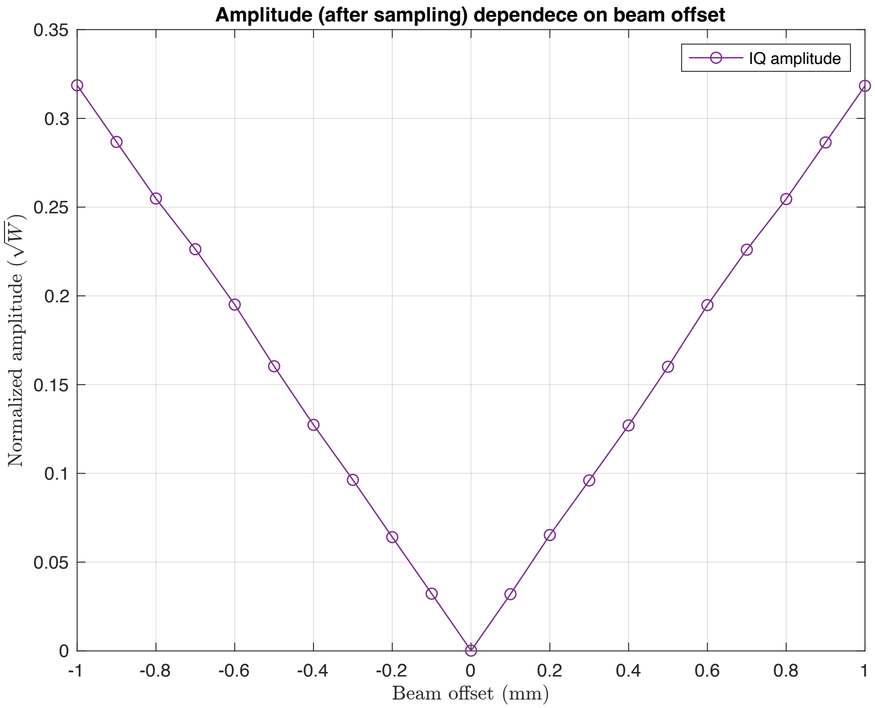
IQ demodulation:



IQ amplitude for each bunch

(normalization with ref. signal)

Bunch 4



III. Signal processing: Multi-bunch study

Preliminary results

Bunch repetition: every 6.15 ns

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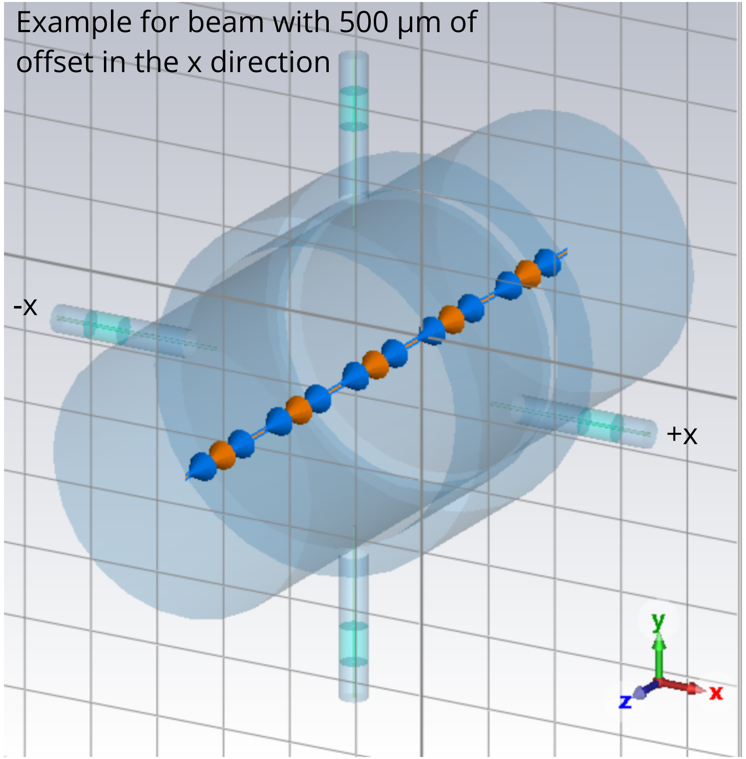
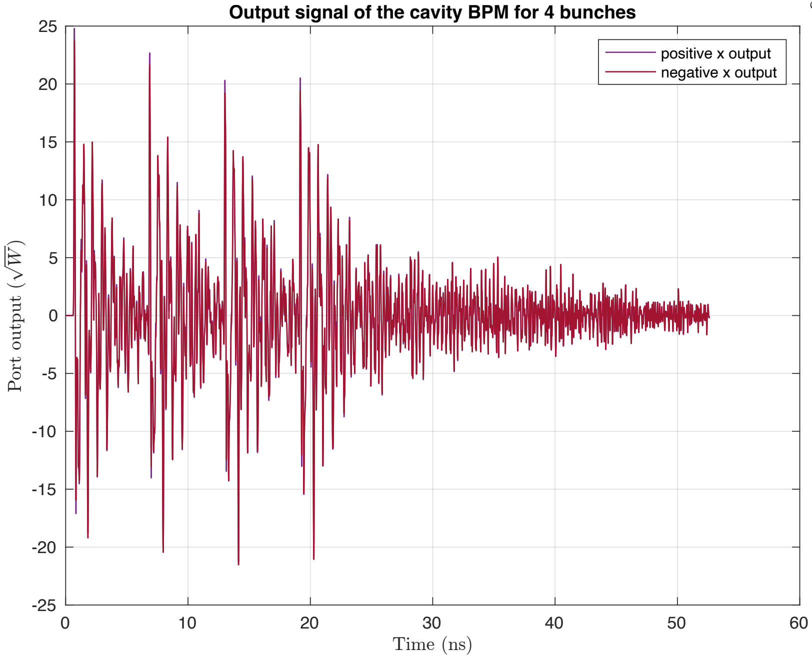
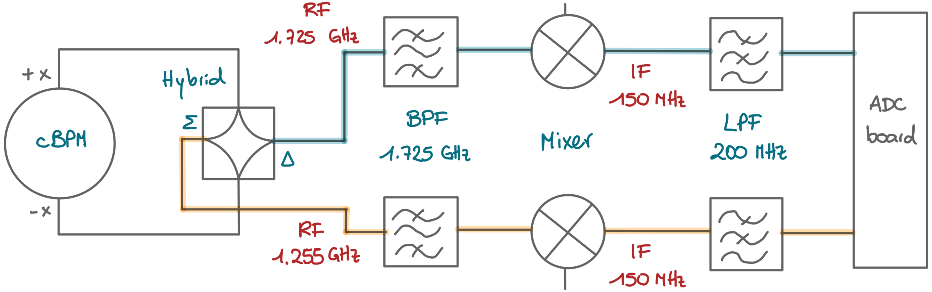
D. Signal extraction for 162.5 MHz bunch rep.







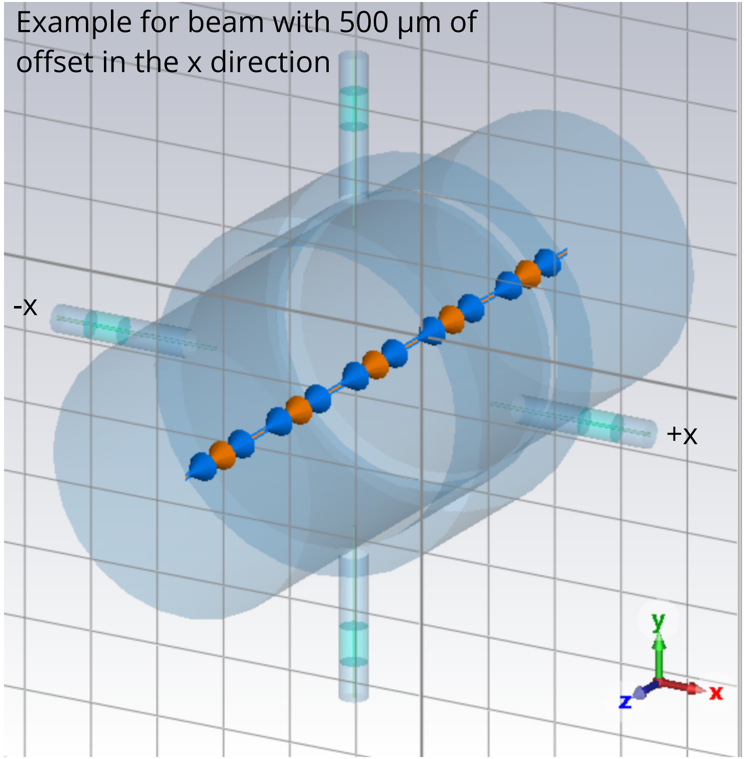
III. Signal processing: Multi-bunch study

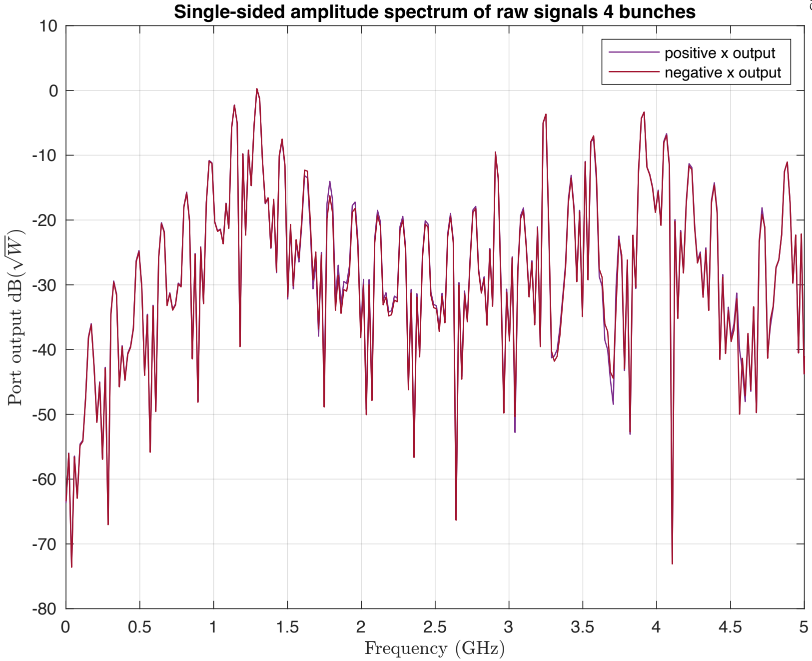
Preliminary results

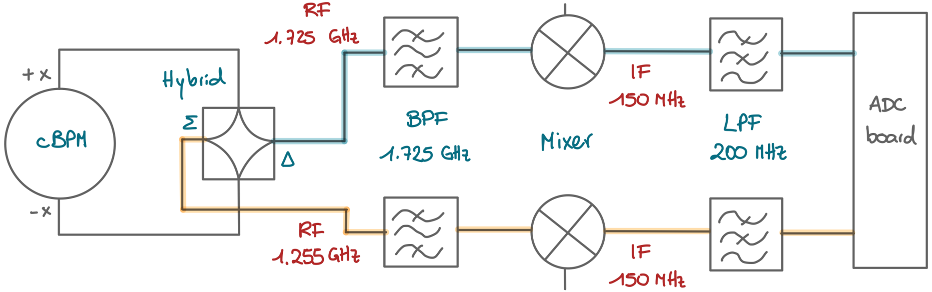
Bunch repetition: every 6.15 ns

D. Signal extraction for 162.5 MHz bunch rep.

Example for beam with 500 μm of offset in the x direction







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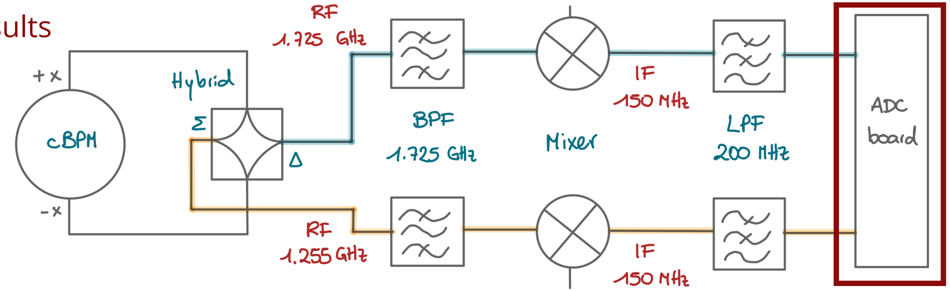
Preliminary results



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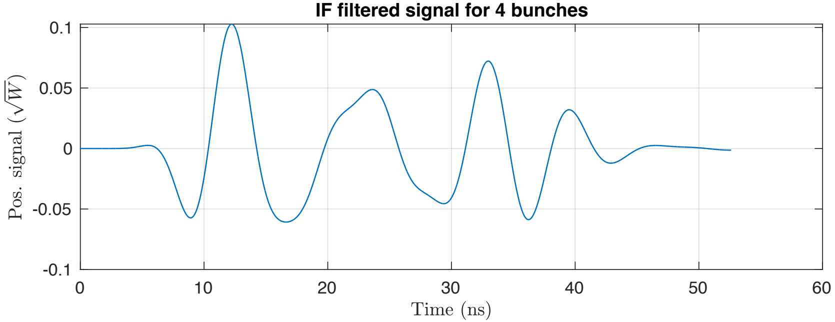
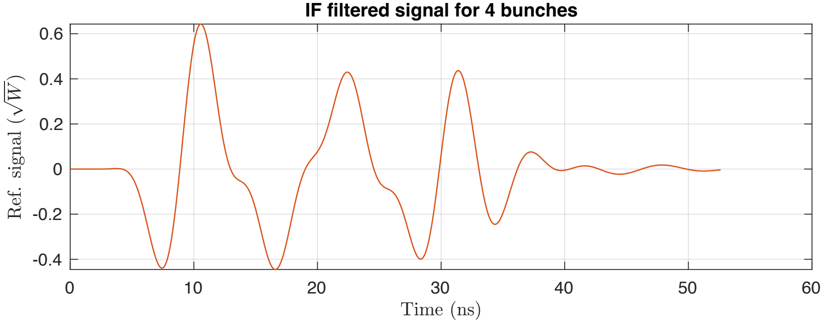
Sampling: 600 MS/s

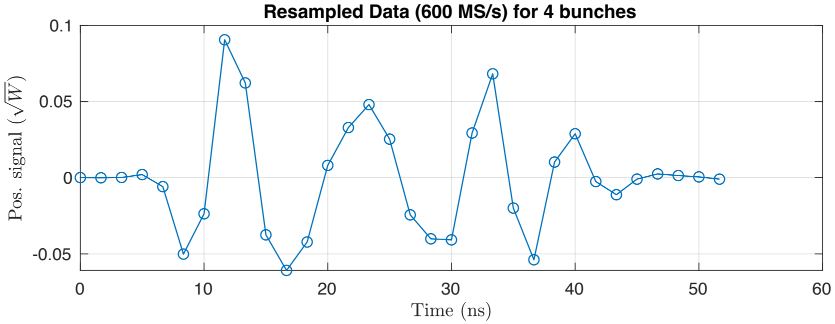
E. Sampling for 162.5 MHz bunch rep.

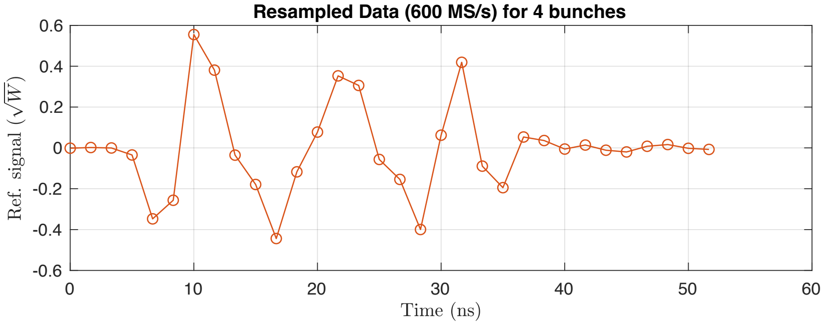
For POSITION signal

For REFERENCE signal









III. Signal processing: Multi-bunch study

F. Amplitude-offset for 162.5 MHz bunch rep.

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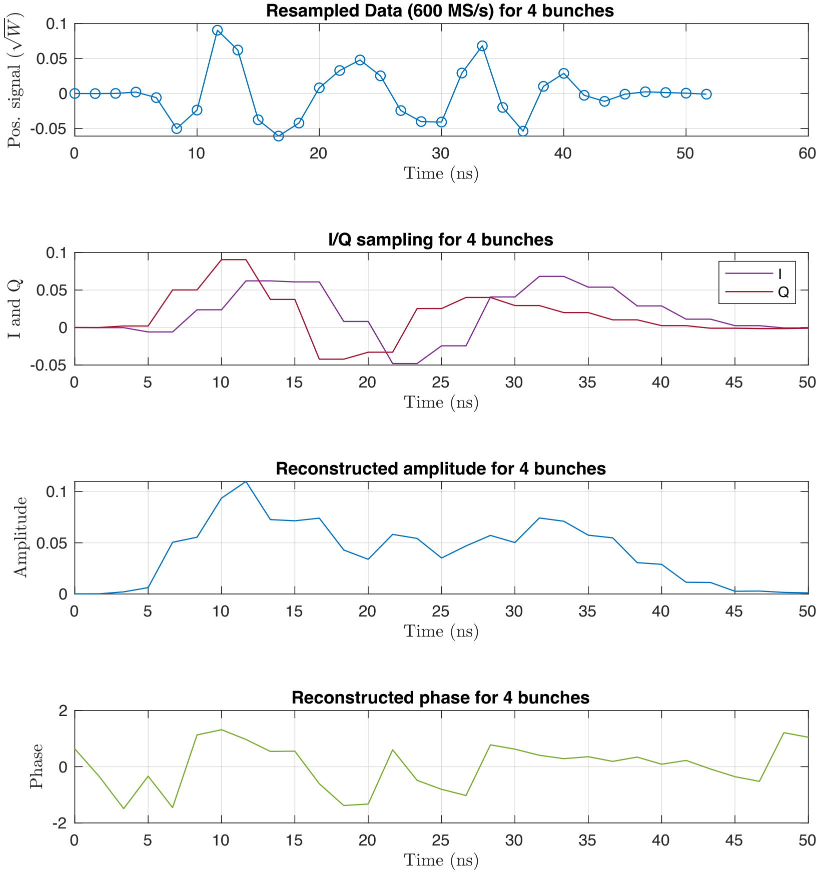
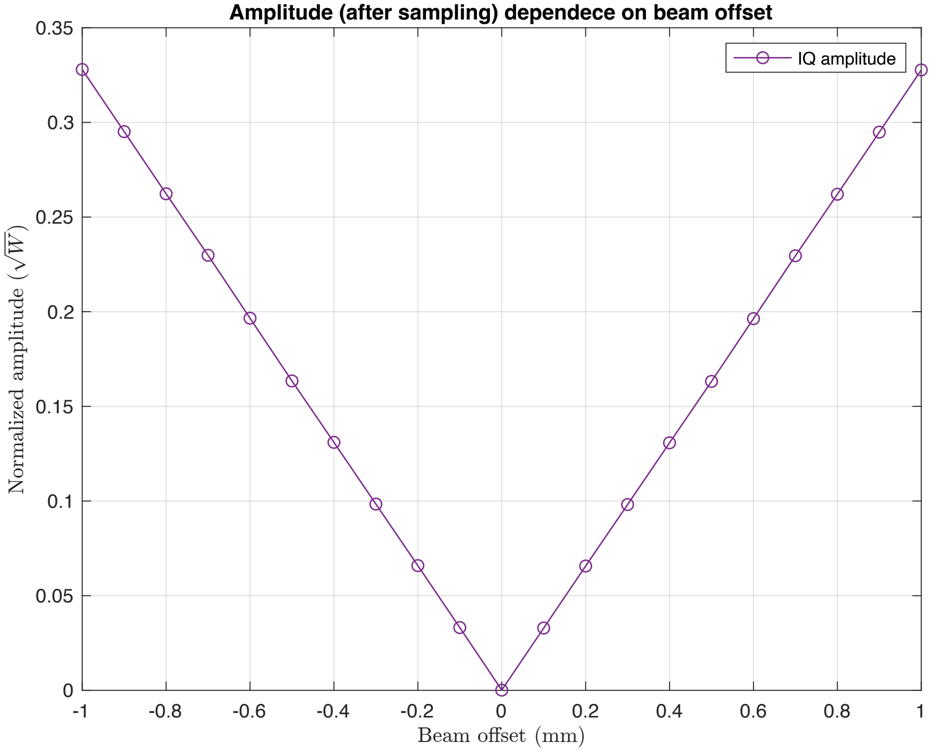
Preliminary results

IQ demodulation:

(normalization with ref. signal)



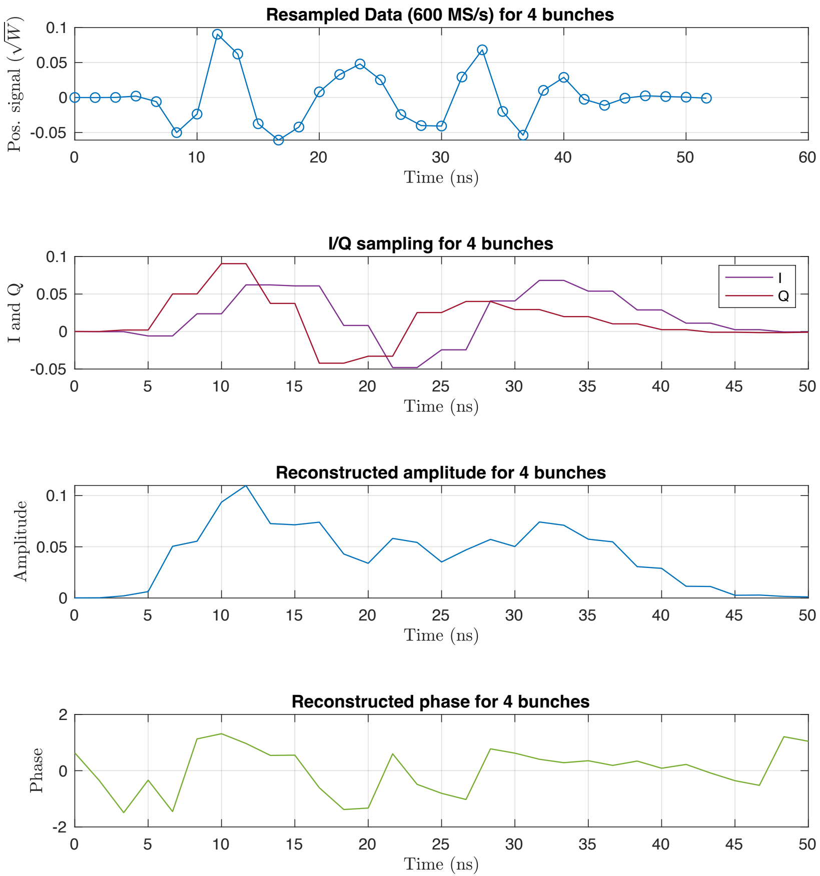
Bunch 1



F. Amplitude-offset for 162.5 MHz bunch rep.

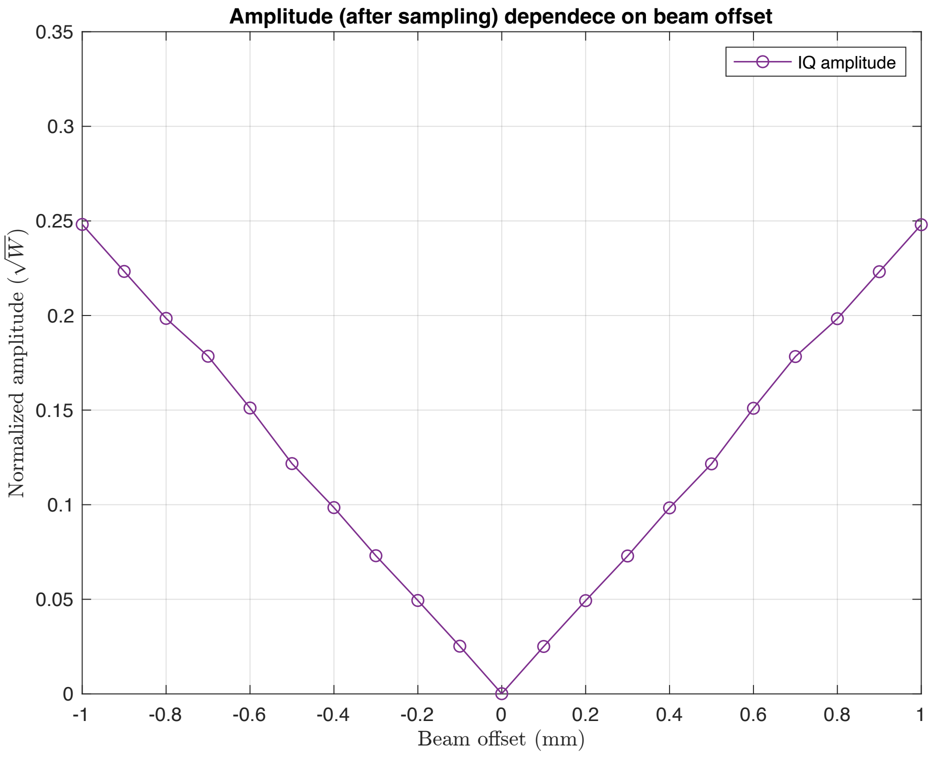
Preliminary results

IQ demodulation:



(normalization with ref. signal)

Bunch 2



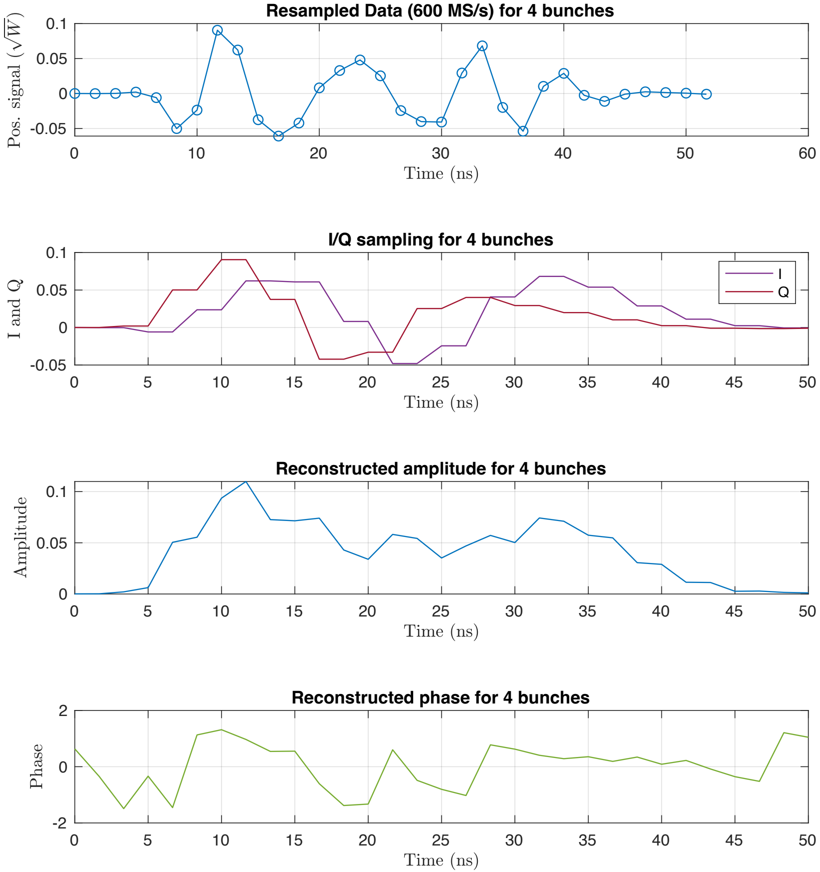
III. Signal processing: Multi-bunch study

F. Amplitude-offset for 162.5 MHz bunch rep.

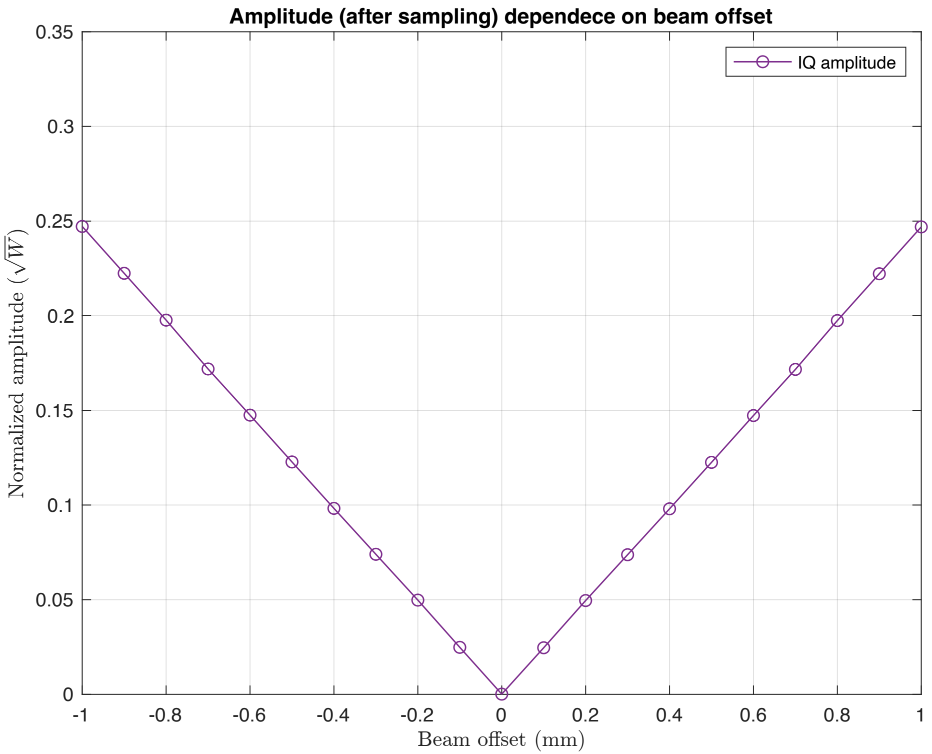
Preliminary results

IQ demodulation:

(normalization with ref. signal)



Bunch 3



III. Signal processing: Multi-bunch study

F. Amplitude-offset for 162.5 MHz bunch rep.

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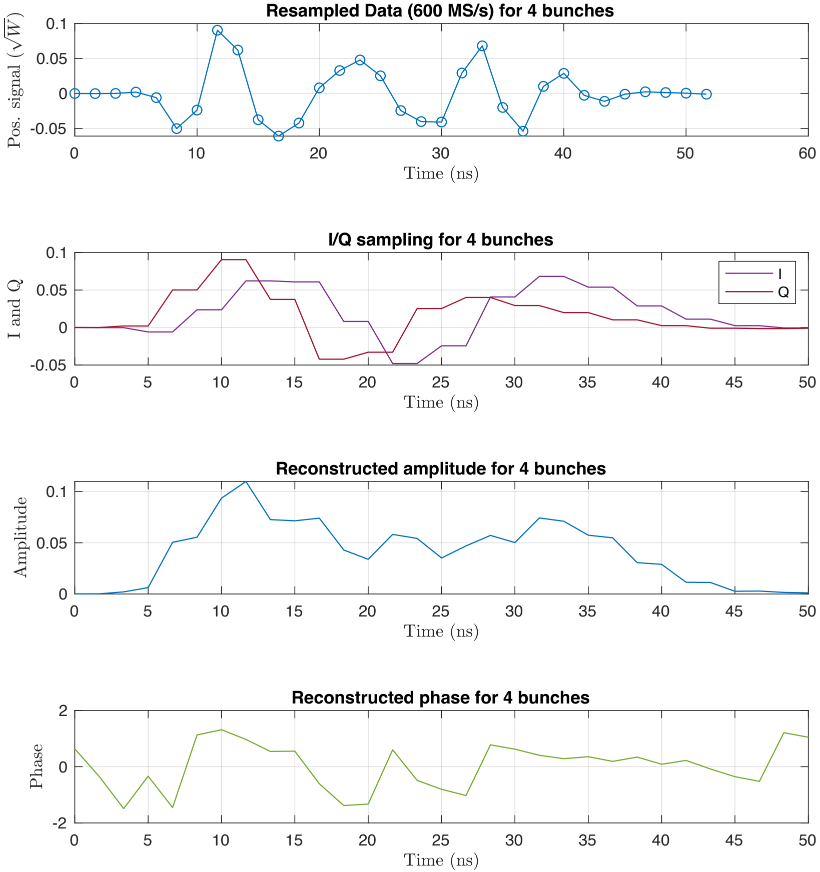
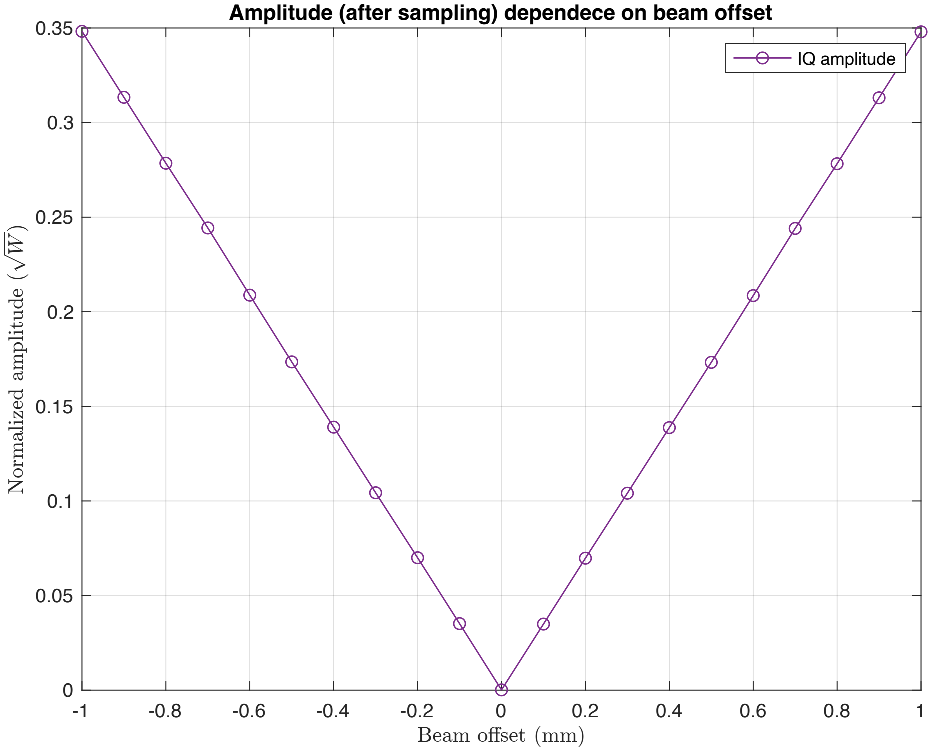
Preliminary results

IQ demodulation:



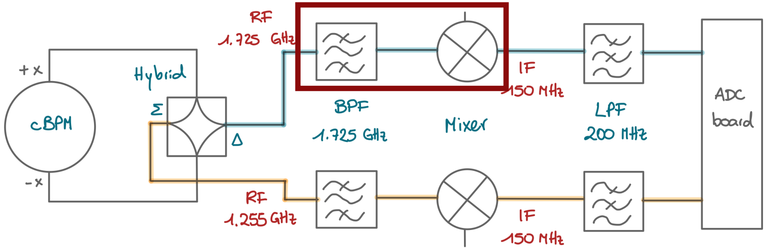
(normalization with ref. signal)

Bunch 4



III. Signal processing: Multi-bunch study

G. BPF and mixing at 162.5 MHz bunch rep.



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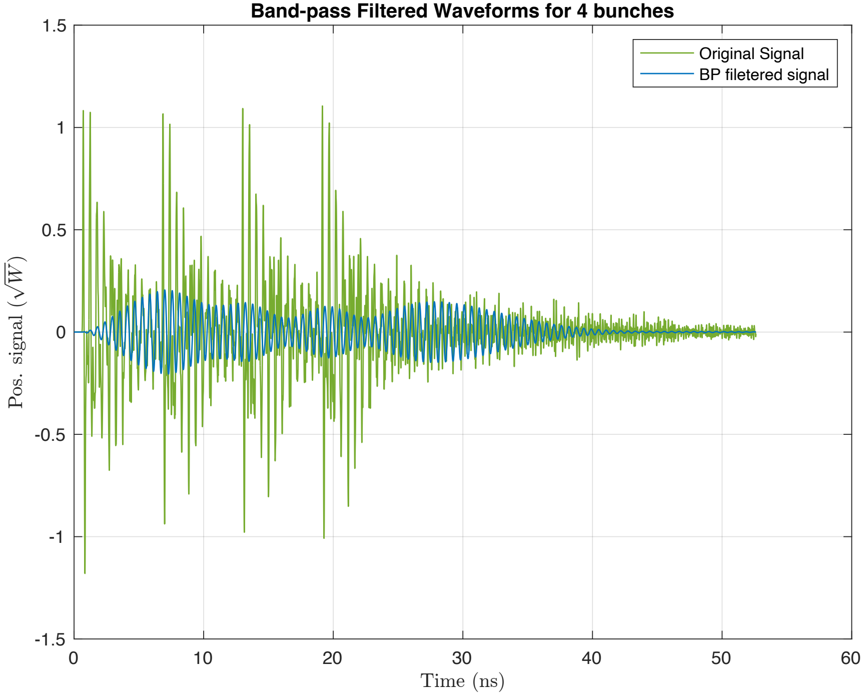
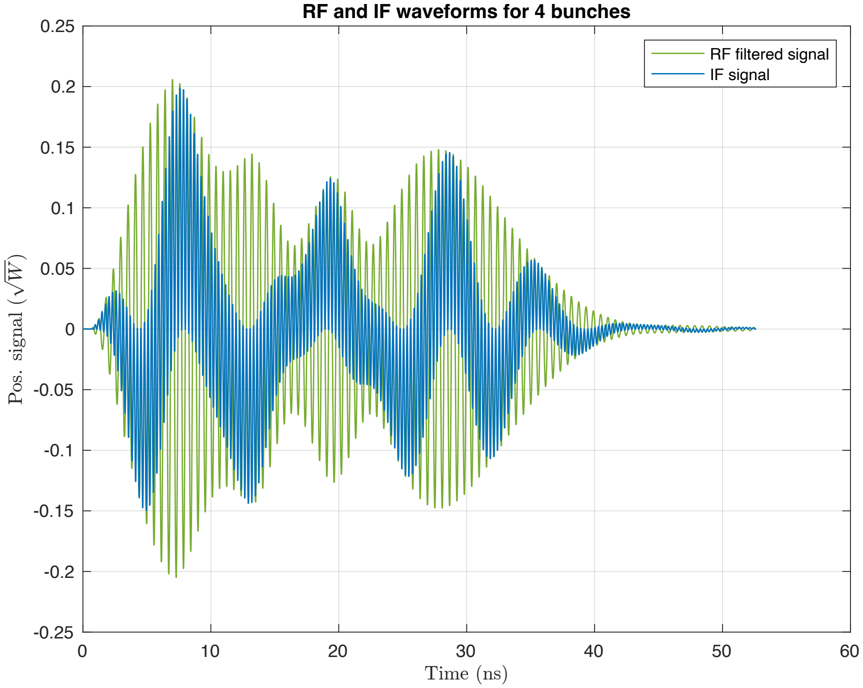
Loss of information of intermediate bunches when filtering?

Preliminary results

RF BPF effect on the time domain:



Mixer effect on the time domain:



IV. Future plans

III. Future plans

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Read-out system simulations

Test similar read-out system with Hayano cBPM output signal

Check other methods for reconstruction of signal (DDC)

Use realistic components
- find main source of noise
- estimate spatial resolution

New cBPM design

Determine what needs to be improved:
- measurement requirements: temporal resolution < 6.15 ns
- measurement requirements: spacial resolution < 1 μm

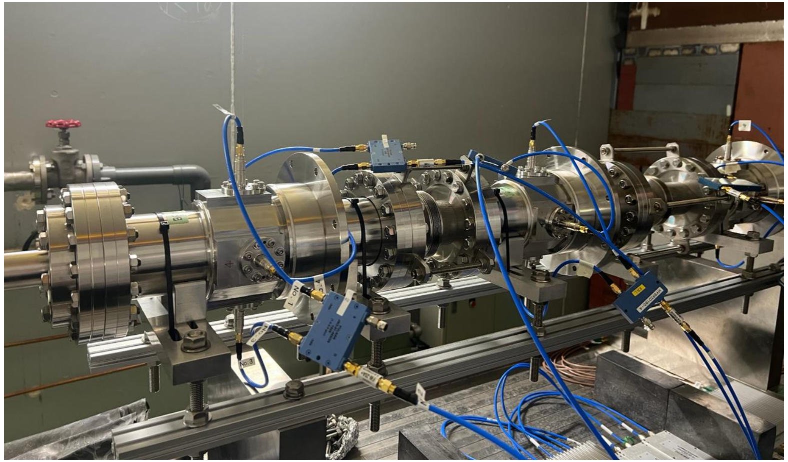
Mechanical attachment to the cryomodule

Post-doc Daniel González currently working on it.

Measurements at ATF and STF

Possibility to perform measurements at the end of 2024 or beginning of 2025, provided that we receive the cBPM from Saclay and have the read-out system ready

Available space to perform measurements at ATF:
- along with the L-band BPMs



Thank you for your attention

laura.pedraza@ific.uv.es

II. Signal processing simulation with ideal components

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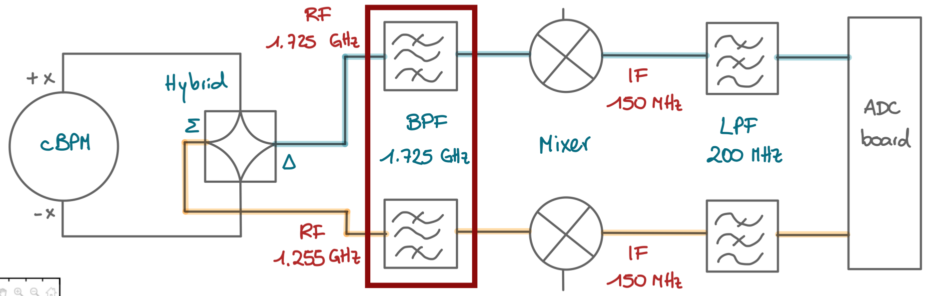
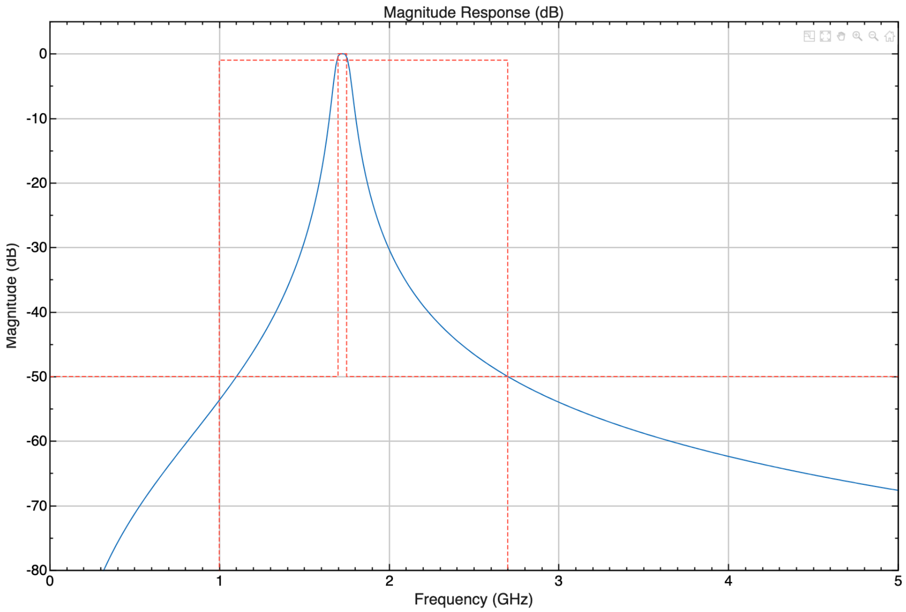
C. RF band-pass filter

BPF: Butterworth
Filter order: 4
band-pass: 1.7-1.75 GHz





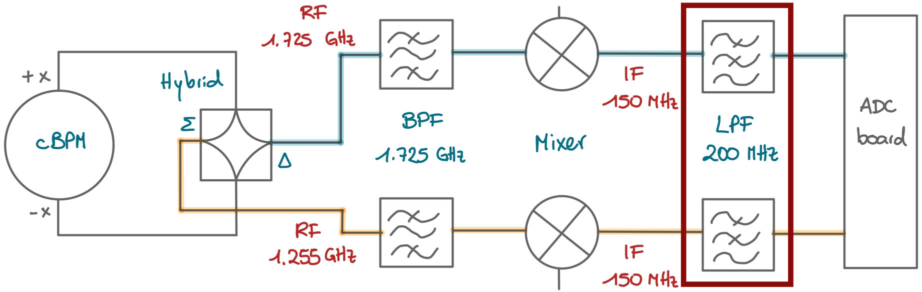
Property	Value
Coefficients	*2x6 double*
DesignMethod	'butter'
FrequencyResp...	'bandpass'
ImpulseRespo...	'iir'
PassbandFrequ...	1.7000e+09
PassbandFrequ...	1.7500e+09
PassbandRipple	1
SampleRate	2.2112e+11
StopbandAtten...	50
StopbandAtten...	50
StopbandFrequ...	1.0000e+09
StopbandFrequ...	2.7000e+09

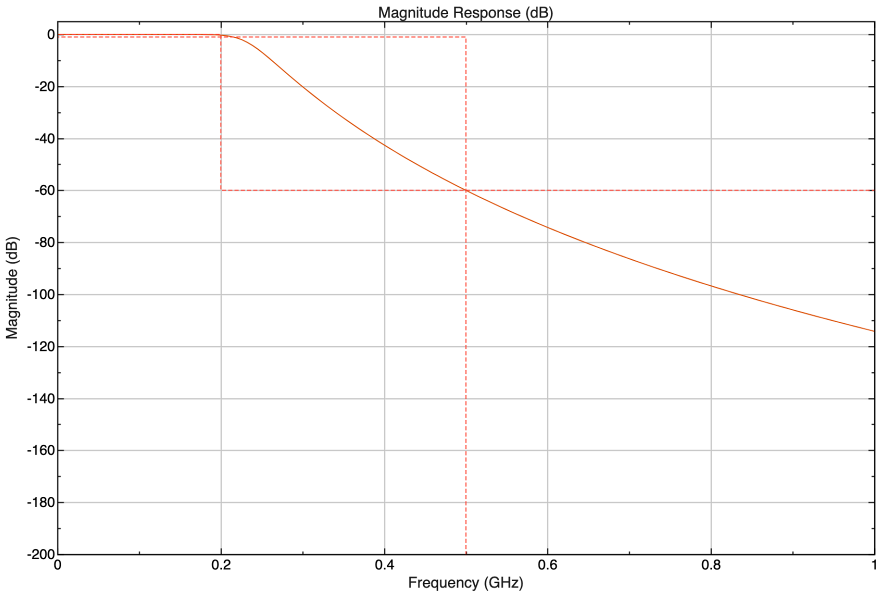
II. Signal processing simulation with ideal components

E. IF low-pass filter

Keeps only IF frequency: 150 MHz

Butterworth BPF:
low pass: up to 200 MHz





1x1 digitalFilter

Property	Value
Coefficients	5x6 double
DesignMethod	'butter'
FrequencyResponse	'lowpass'
ImpulseResponse	'iir'
PassbandFrequency	200000000
PassbandRipple	1
SampleRate	2.2125e+11
StopbandAttenuati...	60
StopbandFrequency	500000000