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PhD26: Post-processing of ATF resolution measurements 2

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PhD26: Post-processing of ATF resolution measurements 2

LabRF meeting, 11/02/26

Introduction

- I. Corrections
 - A) Estimation of the beam position on the calibration
 - B) Check resampling extremums for oscilloscope interpolation
 - C) Acquisition times distribution

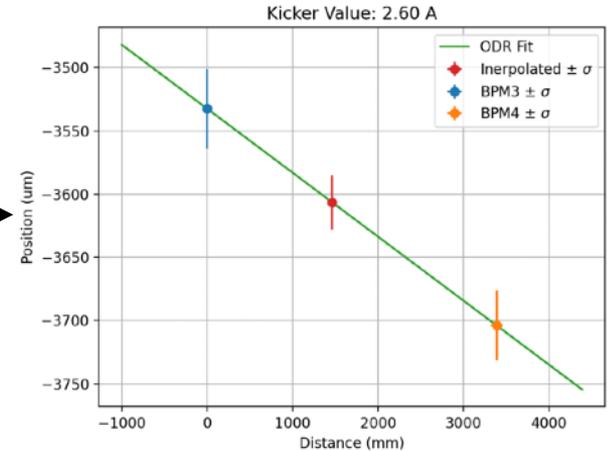
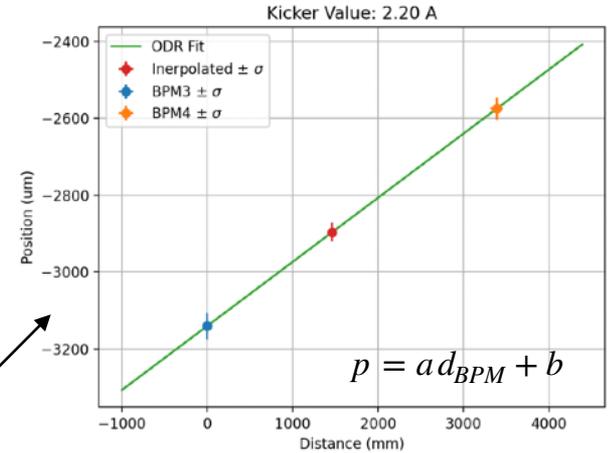
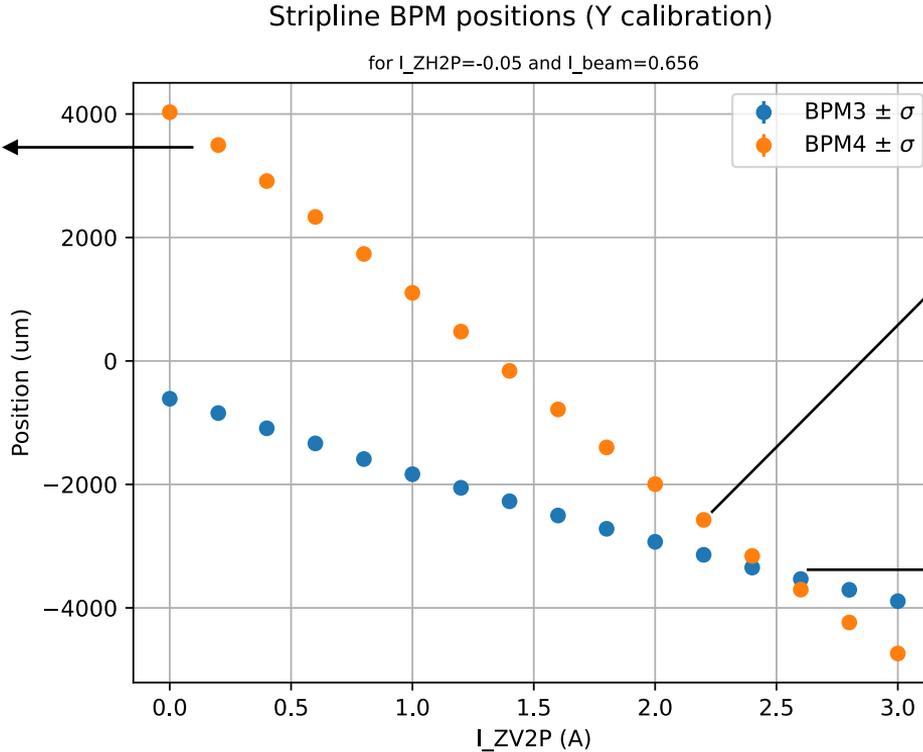
- II. Overall results
 - A) Without resolution algorithm improvements
 - B) Specific cases
 - C) With resolution algorithm improvement

Conclusion

I. Corrections

A) Estimation of beam position on calibration

For each steering magnet magnitude, from the 100 bunches taken, the data is cleaned with criterion $< 5\sigma$ and then the mean value and standard deviation is computed for BPMs 3 and 4 (surrounding the cBPM)



I. Corrections

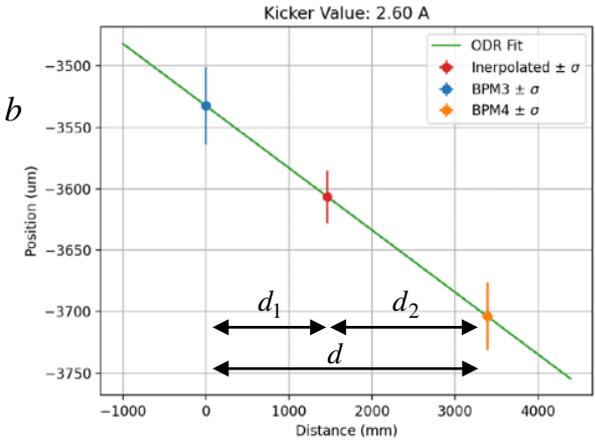
A) Estimation of beam position on calibration

$$p = a d_{BPM} + b$$

Estimation of errors for each kick value:

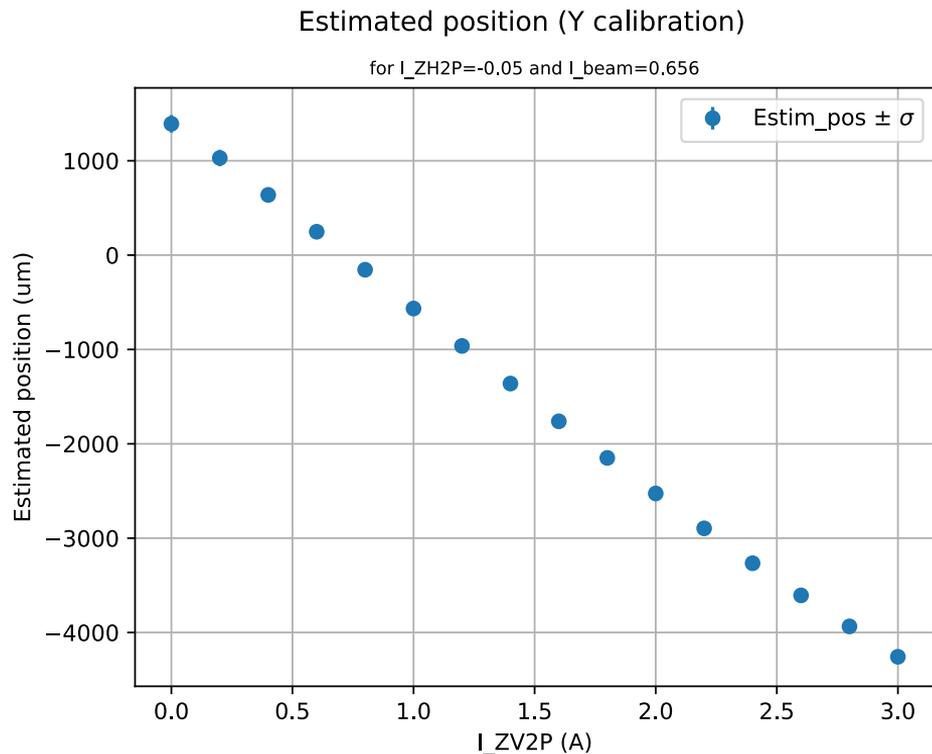
- We consider a error measure distance of 5 cm on d_1 and $d_2 \Rightarrow \sigma_d = \sqrt{\sigma_{d_1}^2 + \sigma_{d_2}^2}$
- Taking into account σ_{BPM_3} , σ_{BPM_4} and σ_d , the **ODR linear fit** gives an estimation of the errors on the slope a and the intercept b : σ_a and σ_b ; and the covariance between a and b : $cov(a, b)$
- The interpolated position is calculated simply as: $p_{int} = a d_1 + b$
- The error on the interpolation is computed with the propagation of errors as:

$$\sigma_{int} = \left(\frac{\partial p}{\partial a} \sigma_a \right)^2 + \left(\frac{\partial p}{\partial d_1} \sigma_{d_1} \right)^2 + \left(\frac{\partial p}{\partial b} \sigma_b \right)^2 + 2 \frac{\partial p}{\partial a} \frac{\partial p}{\partial b} cov(a, b) = (d_1 \sigma_a)^2 + (a \sigma_{d_1})^2 + \sigma_b^2 + 2 d_1 cov(a, b)$$

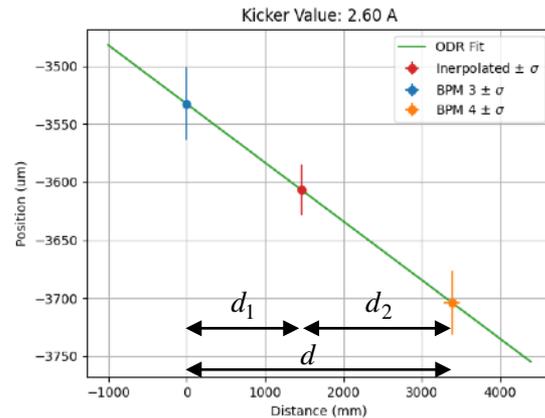


I. Corrections

A) Estimation of beam position on calibration



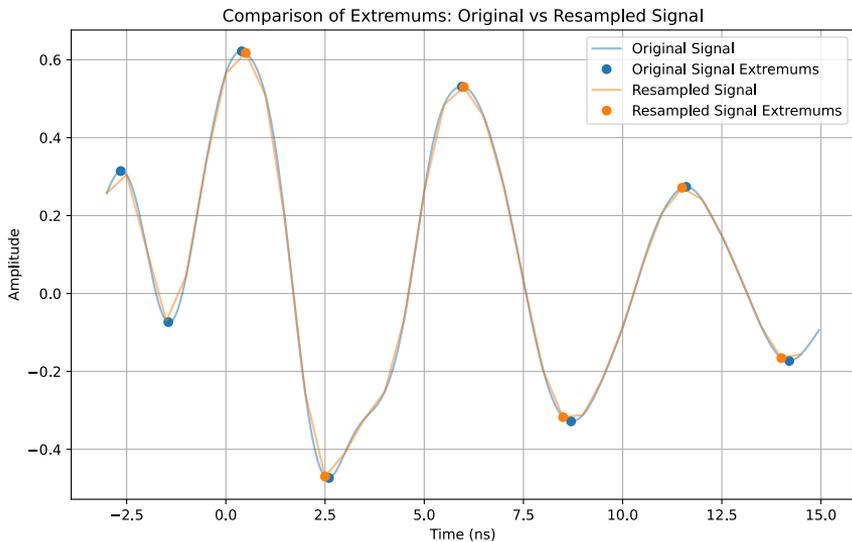
$$p = ad_{BPM} + b$$



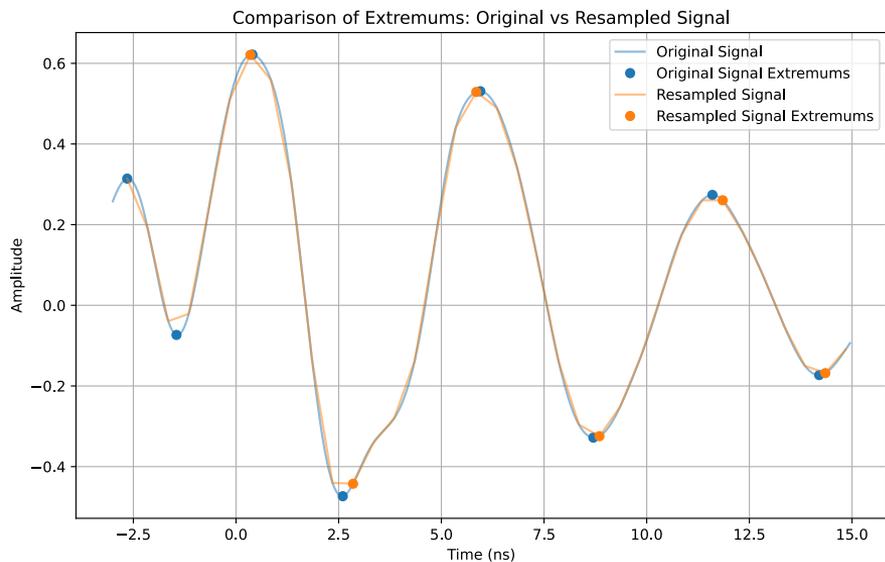
I. Corrections

B) Check resampling extremums for oscilloscope interpolation

offset = 0



offset = 7

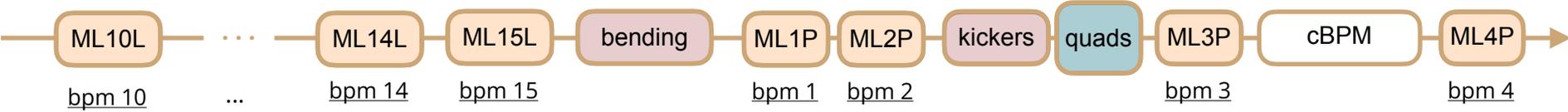


(Result that gave the best resolution)

None of the offsets give a result where all the extremums are the same than the extremums of the “original” interpolated data. The oscilloscope is not performing a linear interpolation.

I. Corrections

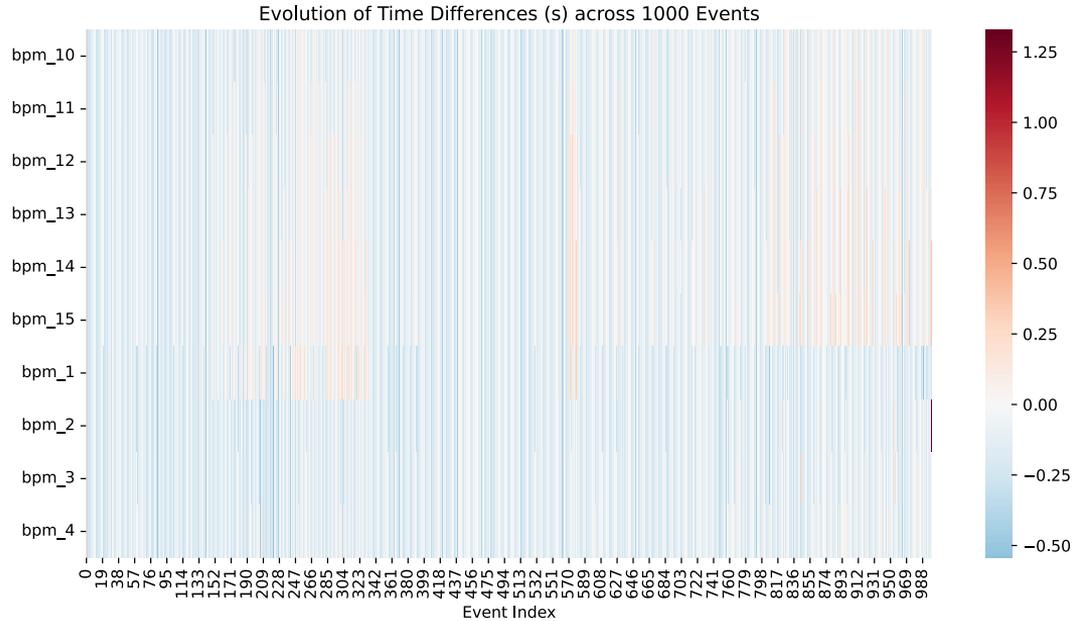
C) Acquisition times distribution



Observing all BPMs time-stamps differences with the oscilloscope acquisition.

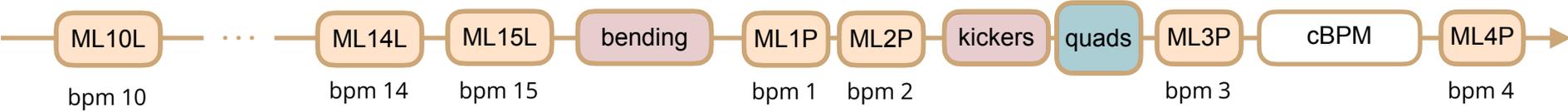
$$t_{diff, BPMx} = t_{s_{cBPM}} - t_{s_{BPMx}}$$

This time difference is observed for all BPMs and all bunches in the Heat-map:

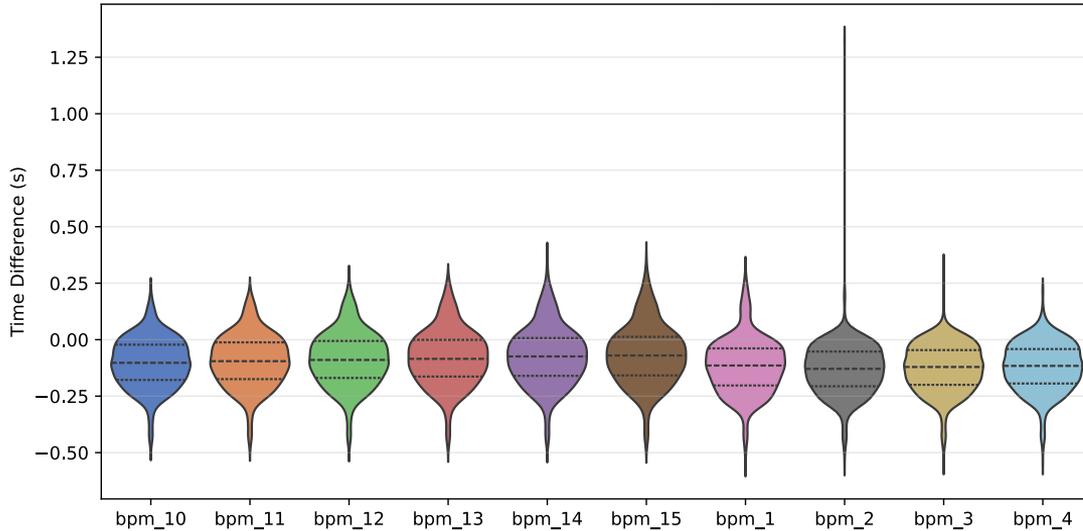


I. Corrections

C) Acquisition times distribution



Distribution of Time Differences per Device



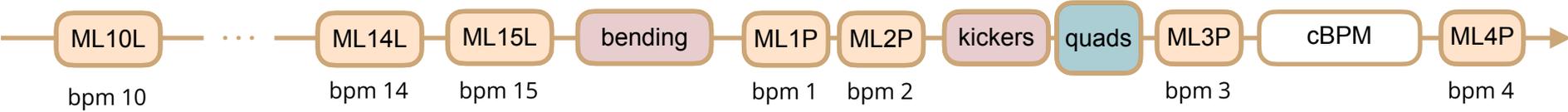
Distribution of time differences for each BPM:

$$t_{diff,BPMx} = t_{ScBPM} - t_{SBPMx}$$

“A violin plot shows the probability density of the data. It will also include all the data that is in a box plot: a marker for the median of the data; a box or marker indicating the interquartile range; and possibly all sample points, if the number of samples is not too high.”

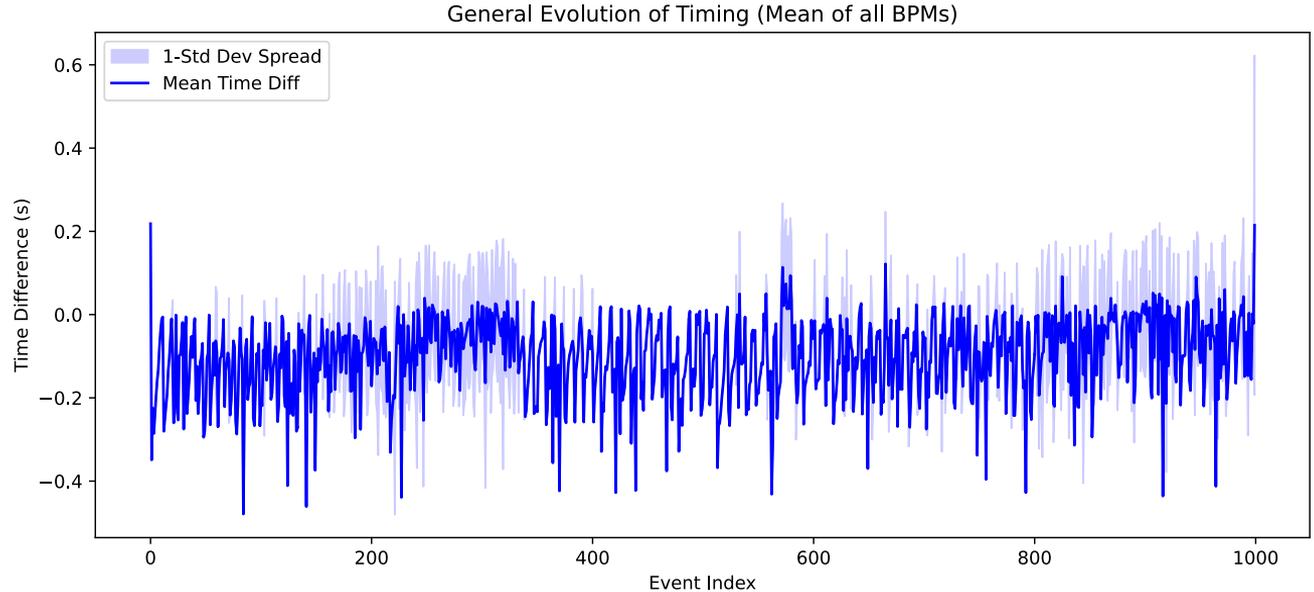
I. Corrections

C) Acquisition times distribution



Averaging for each bunch all the stripline BPMs time-differences and calculating the standard deviation:

$$\overline{tS} = \frac{\sum t_{diff, BPMx}}{\#BPMs}$$



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II. Overall results

- A) Without resolution algorithm improvements
- B) Specific cases
- C) With resolution algorithm improvement

Conclusion

II. Overall results

- 1: IQ plot split in two
- 2: external trigger
- 3: the beam is centred

A) Without resolution algorithm improvement

RESOLUTION RESULTS ON THE X PLANE								
May - June 2025						December 2025		
LO phase-unlocked			LO phase-locked			Lower IF freq (A)		
I_b (nC)	δx (mm)	res (μm)	I_b (nC)	δx (mm)	res (μm)	I_b (nC)	δx (mm)	res (μm)
<u>(23/05)</u>			<u>(17/06)</u>			<u>(08/12)</u>		
0.68	~ 1	228 ²	0.32	0 ³	40.4	0.96	0	12.4
	~ 1.5	178		2	45.4		1	21.9
			0.8	0	111	1.36	0.4	20.8
				2	121	1.49	0.8	22.9
			<u>(23/06)</u>					
			0.44	0	93.2 ¹			
				1.3	57.9			
			0.85	0	83.2 ¹			
				1	37.9			

II. Overall results

- 1: IQ plot split in two
- 2: the beam is centred
- 3: the beam jumped in the middle of the meas.

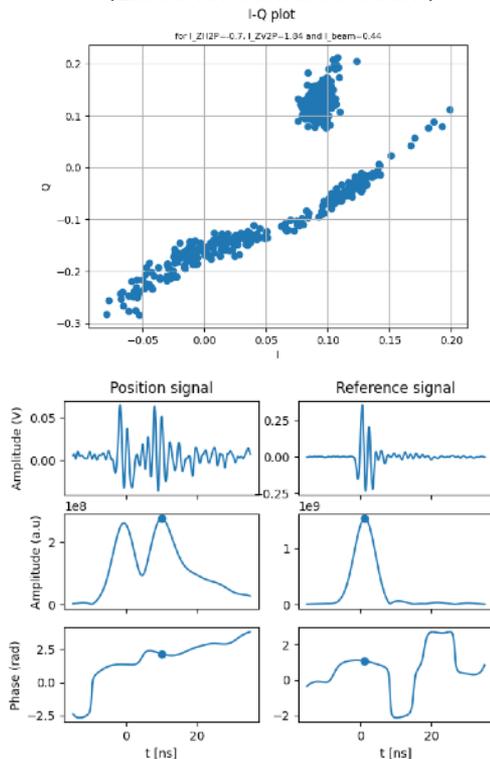
A) Without resolution algorithm improvement

RESOLUTION MEASUREMENTS ON THE Y PLANE											
May - June 2025			December 2025								
LO phase-locked			Lower IF freq (A)			Phase shifter (B)			Double DC (C)		
I_b (nC)	δx (mm)	res (μm)	I_b (nC)	δx (mm)	res (μm)	I_b (nC)	δx (mm)	res (μm)	I_b (nC)	δx (mm)	res (μm)
(17/06)			(05/12)			(08/12)			(08/12)		
0.32	0 ²	19.2	0.35	1	11.1	0.56	0.4	12.3	0.69	0.1	6.88
			(08/12)								
	2.5	33.7	0.46	0.4	41.5	0.88	0	6.82	0.89	0	6.32
0.8	0	23.7	0.72	0.3	8.37	1.33	0.1	7.83	1.04	-0.1	6.71
	2.5	57.1							(15/12)		
			0.89	0	8.5				0.54	0.9	6.03
(23/06)											
0.44	0	13.5							0.66	0.8	13.8 ³
	1	24.8							0.72	0.7	4.89
0.85	0	27.1 ¹							0.80	0.1	4.60
	2	28.4							0.88	0.6	12.4 ¹

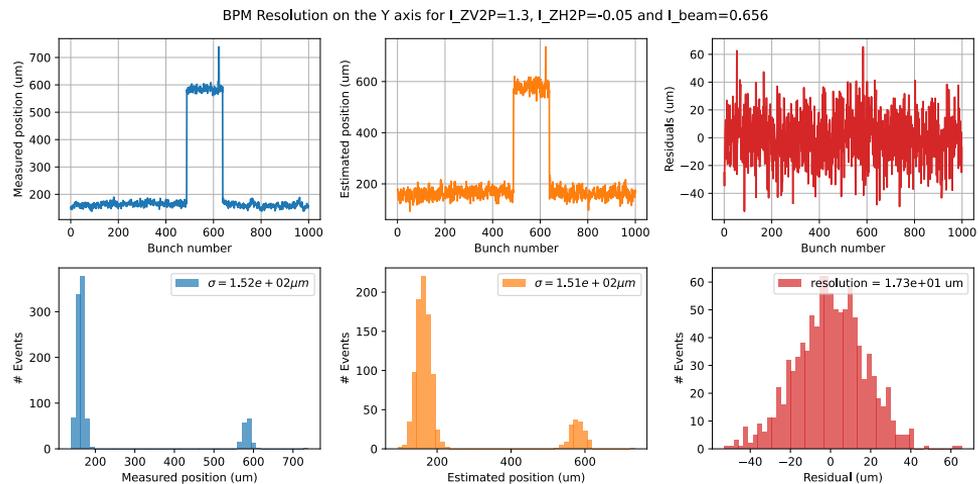
II. Overall results

B) Specific cases:

1: IQ plot split in two
(23/06 for centered beam)



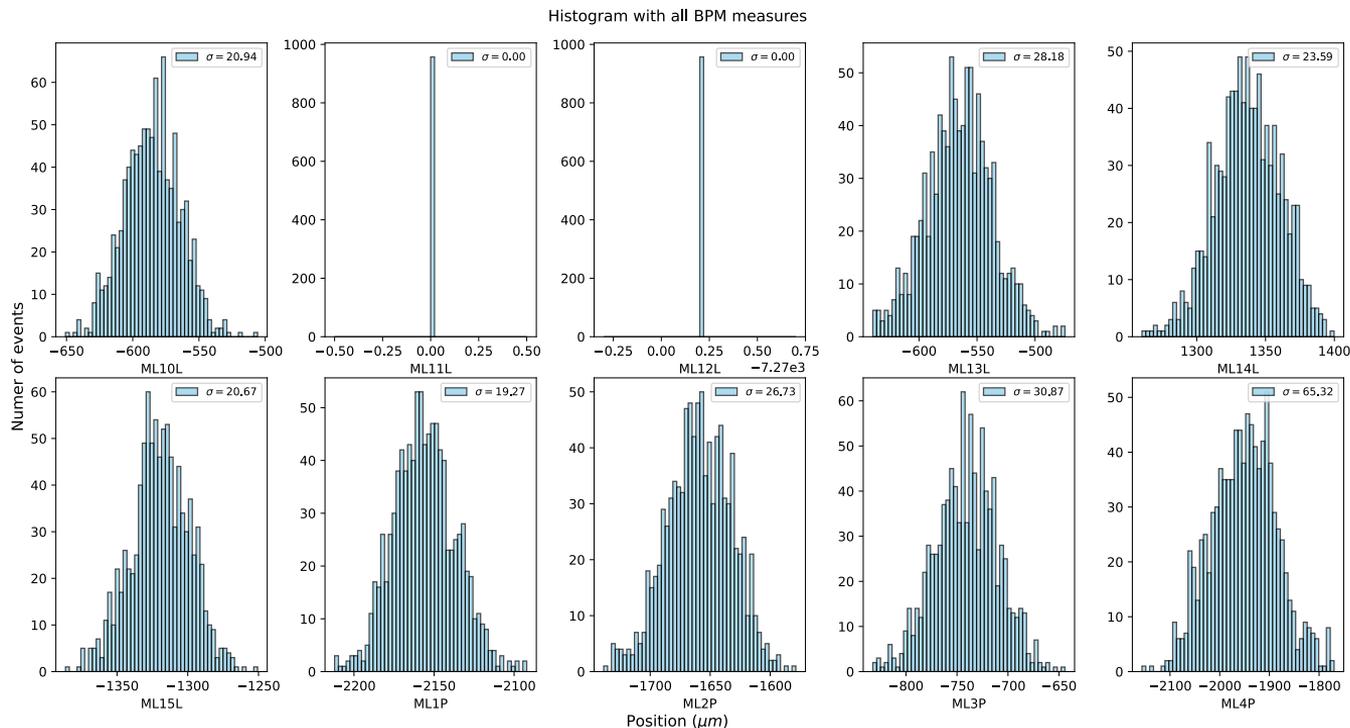
3: the beam jumped in the middle of the meas.



II. Overall results

B) Specific cases:

Lower IF for Y, Ibeam = 0.46

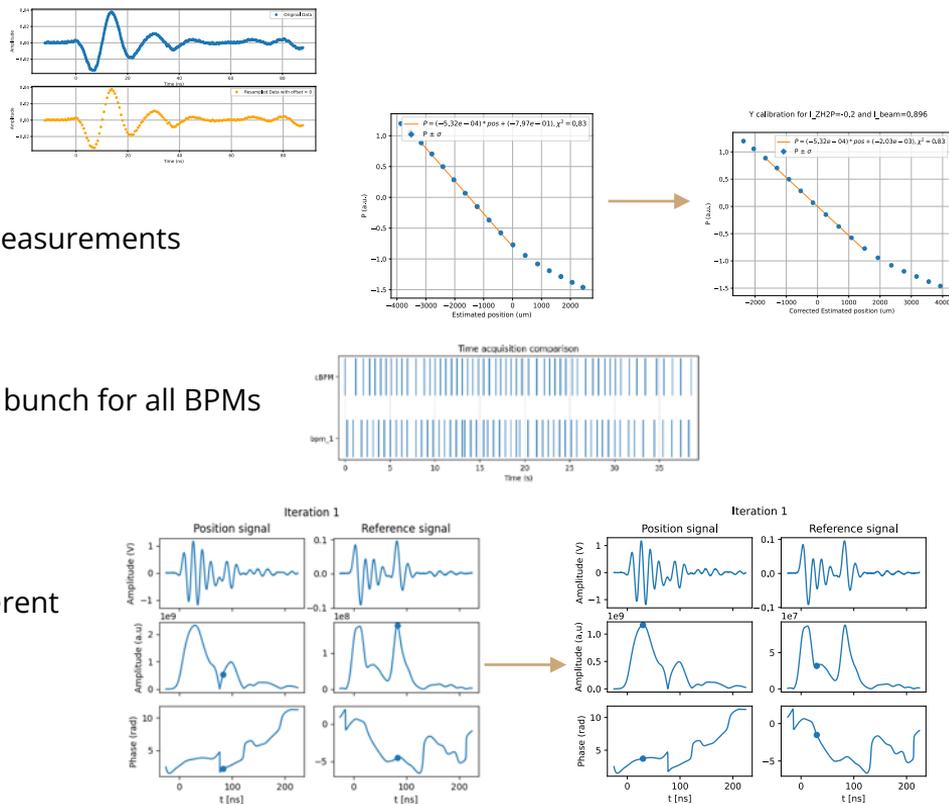


II. Overall results

C) With resolution algorithm improvement

- **Re-sampling:**
removes interpolated points added by the oscilloscope
- **Calibration:**
fixing the statical offset → provides more accurate cBPM measurements
- **Time-stamps comparison:**
selecting only measurements that correspond to the same bunch for all BPMs
- **Fixed sampling point:**
unifies the way the waveform is processed and avoids different position result when there is a reflection of the waveform
- **Removing frozen stripline BPMs**

Changes that were implemented on the DDC, calibration and resolution algorithms:



II. Overall results

1: some BPMs were removed

2: IQ plot split

3: a set of measures was deleted

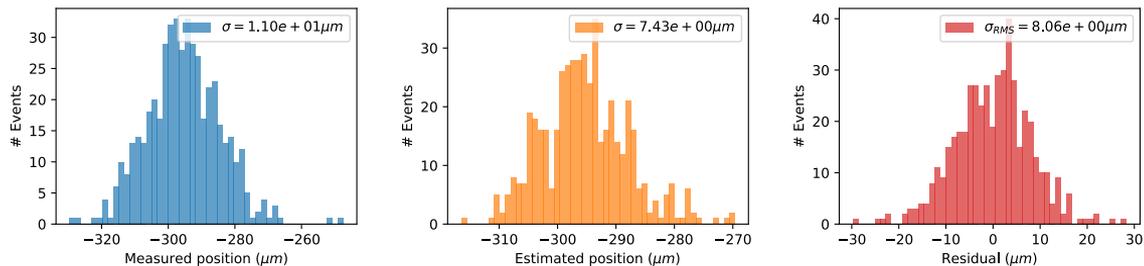
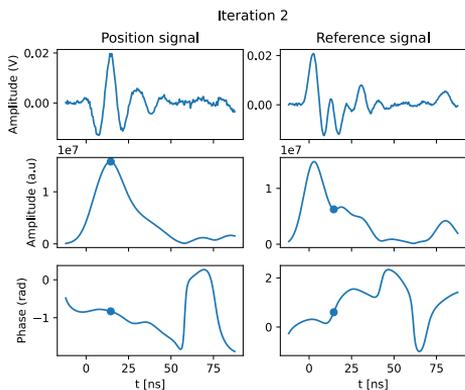
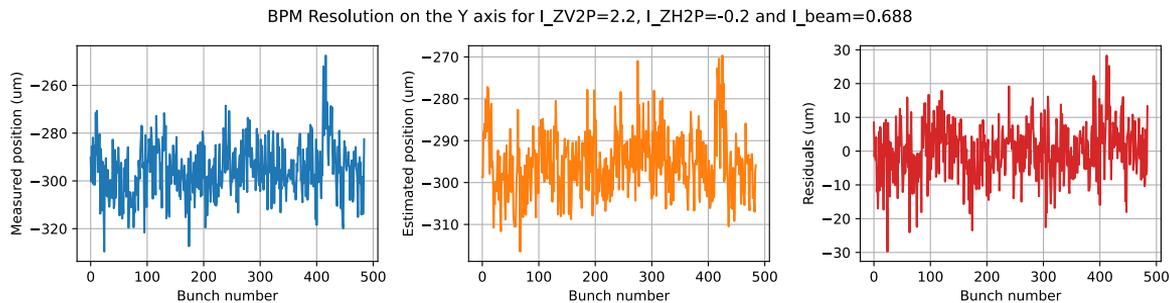
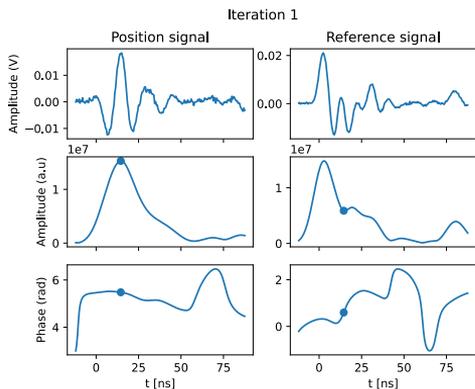
C) With resolution algorithm improvement

RESOLUTION MEASUREMENTS ON THE Y PLANE											
May - June 2025			December 2025								
LO phase-locked			Lower IF freq (A)			Phase shifter (B)			Double DC (C)		
I_b (nC)	δx (mm)	res (um)	I_b (nC)	δx (mm)	res (um)	I_b (nC)	δx (mm)	res (um)	I_b (nC)	δx (mm)	res (um)
(17/06)			(05/12)			(08/12)			(08/12)		
0.32	0	19.2	0.35	1	11.1	0.56	0.12	12.3 7.21 ¹	0.69	0.3	6.88 8.08
	2.5	33.7	(08/12)			0.88	0.18	6.82 4.63	0.89	0.3	6.32 4.63
0.8	0	23.7	0.72	0.08	8.37 4.79	1.33	0.4	7.83 6.47	1.04	0.36	6.74 14.9 ²
	2.5	57.1	(15/12)								
(23/06)			0.89	0.1	8.5 4.45				0.54	0.1	6.03 8.81
0.44	0	13.5							0.66	0.08	13.8 10.6 ³
	1	24.8							0.72	0.06	4.89 3.90
0.85	0	27.1							0.80	0.05	4.60 3.27
	2	28.4							0.88	0.02	12.4 3.16

II. Overall results

C) With resolution algorithm improvement

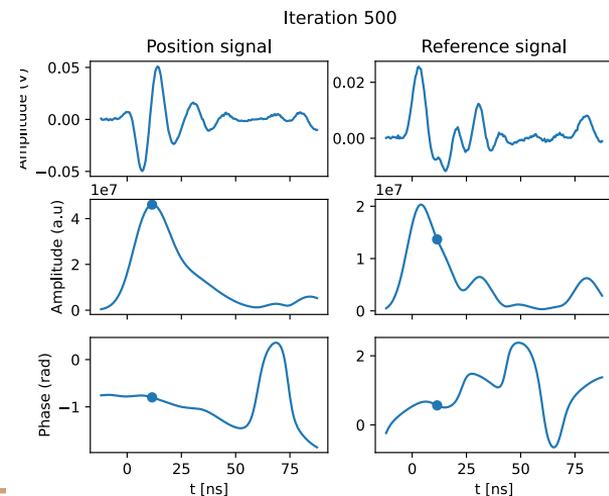
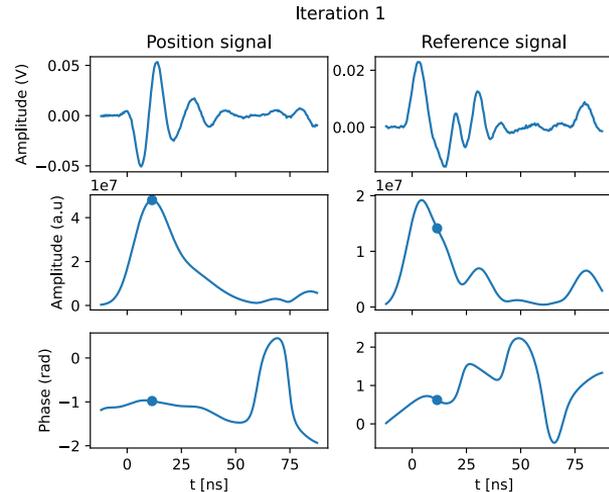
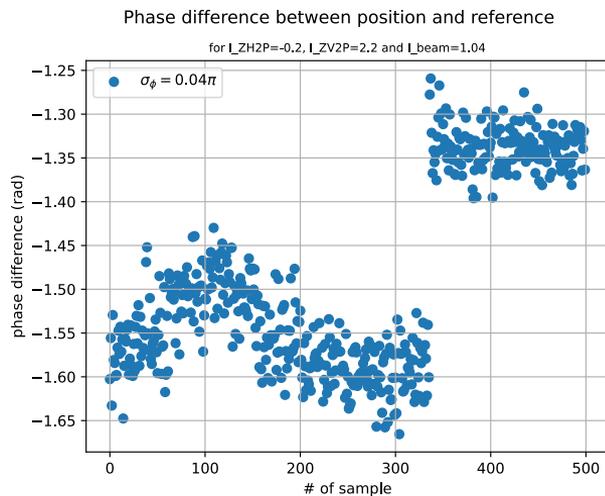
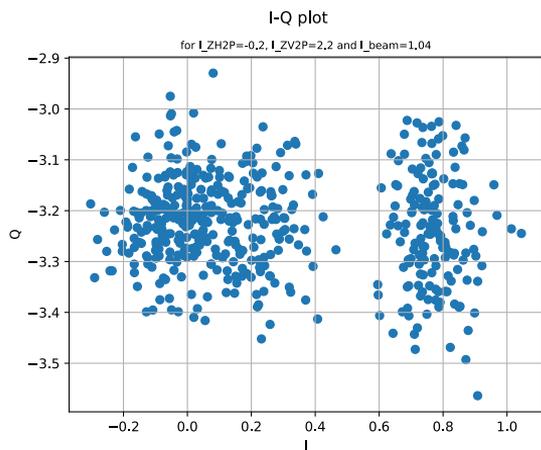
2DC for Y, Ibeam = 0.69



II. Overall results

C) With resolution algorithm improvement

2DC for Y, Ibeam = 1.04



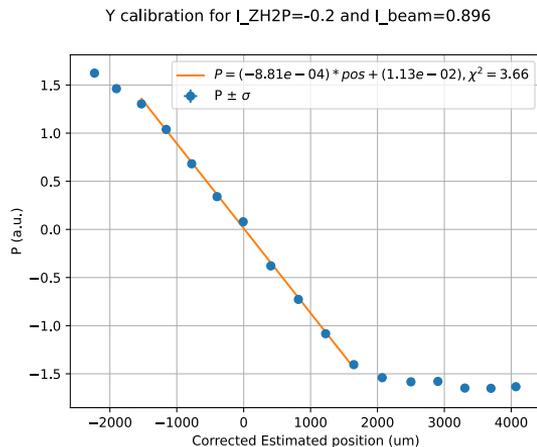
Conclusion

There seems to be an optimal beam intensity, around 0.8 nC/bunch to perform resolution measurements.

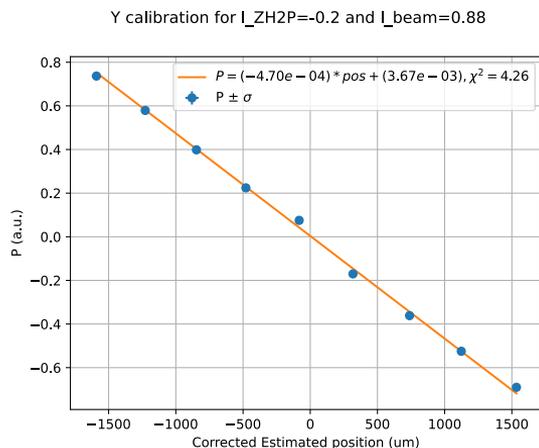
The closer the beam to the center of the cBPM the better the resolution measurement.

Not only the resolution is worth looking at. The linearity and dynamic range play an important role in the cBPM performance.

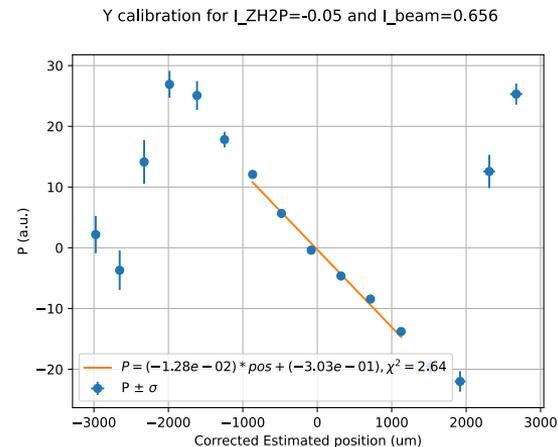
Lower IF (A)



Phase shifter for LO (B)



2DC (C)



Next: - SVD analysis

- DDC alternative: mean value on amplitude and phase over the whole waveform



Thank you for your attention

We gratefully acknowledge the ATF staff for their assistance during the installation and BPM measurements. Special thanks to Toshiyuki Okugi, Alex Aryshev, and Konstantin Popov for their support. We also thank Toshihiro Matsumoto and Hiroshi Kaji for providing the necessary equipment for the measurements.

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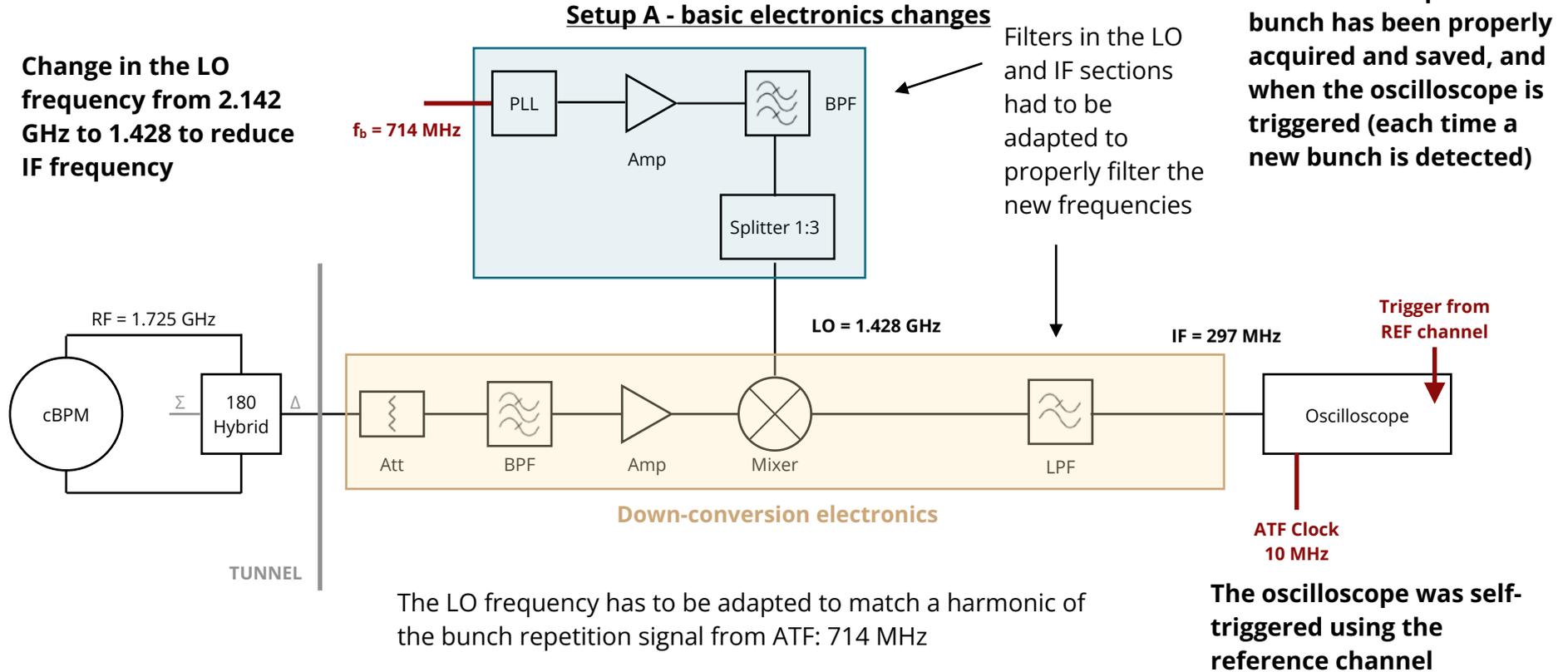
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Back-up slides

I. Resolution measurement and calculation

A) Setups employed for measurements

Change in the LO frequency from 2.142 GHz to 1.428 to reduce IF frequency



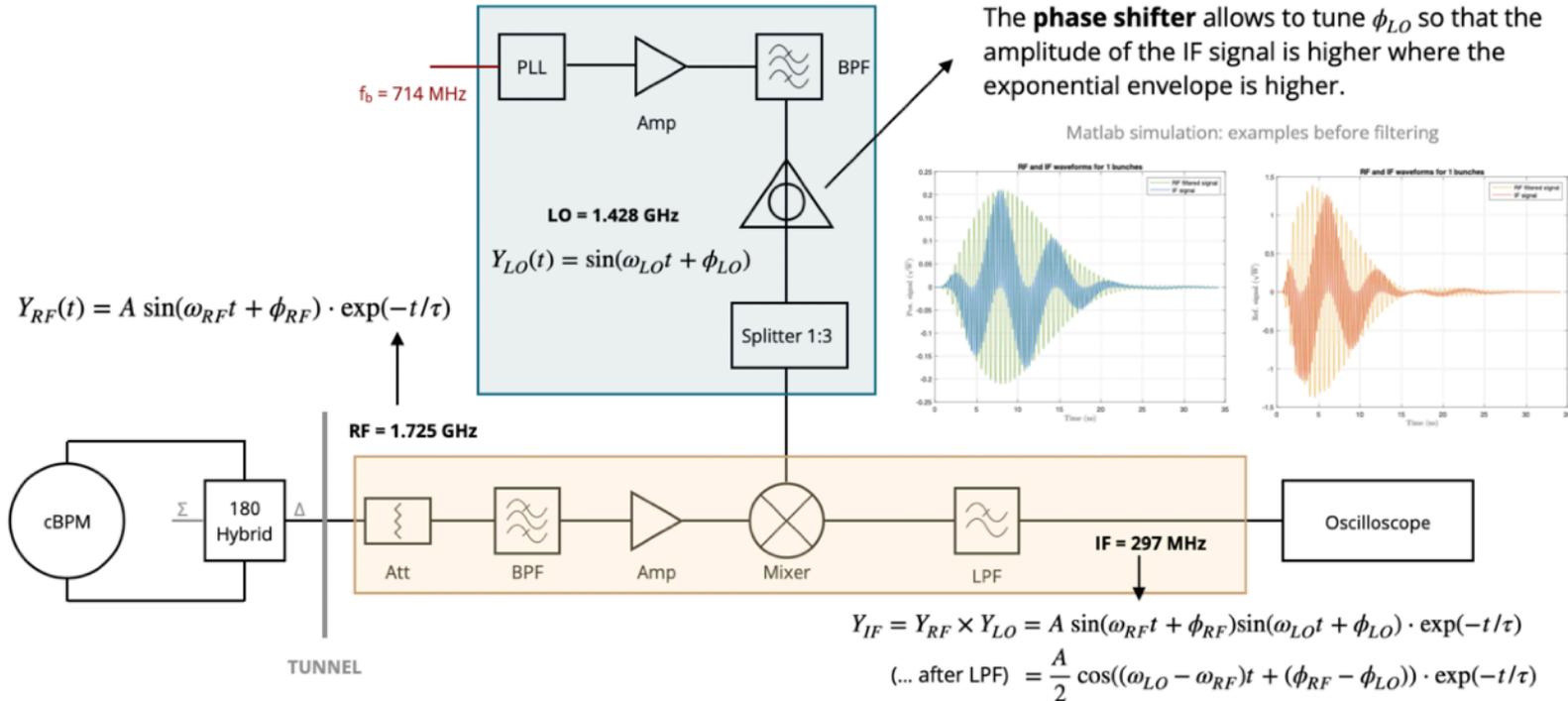
The bunch data (from cBPM and from striplines) is taken every time the data from the previous bunch has been properly acquired and saved, and when the oscilloscope is triggered (each time a new bunch is detected)

I. Resolution measurement and calculation

A) Setups employed for measurements

Setup B - Phase shifter

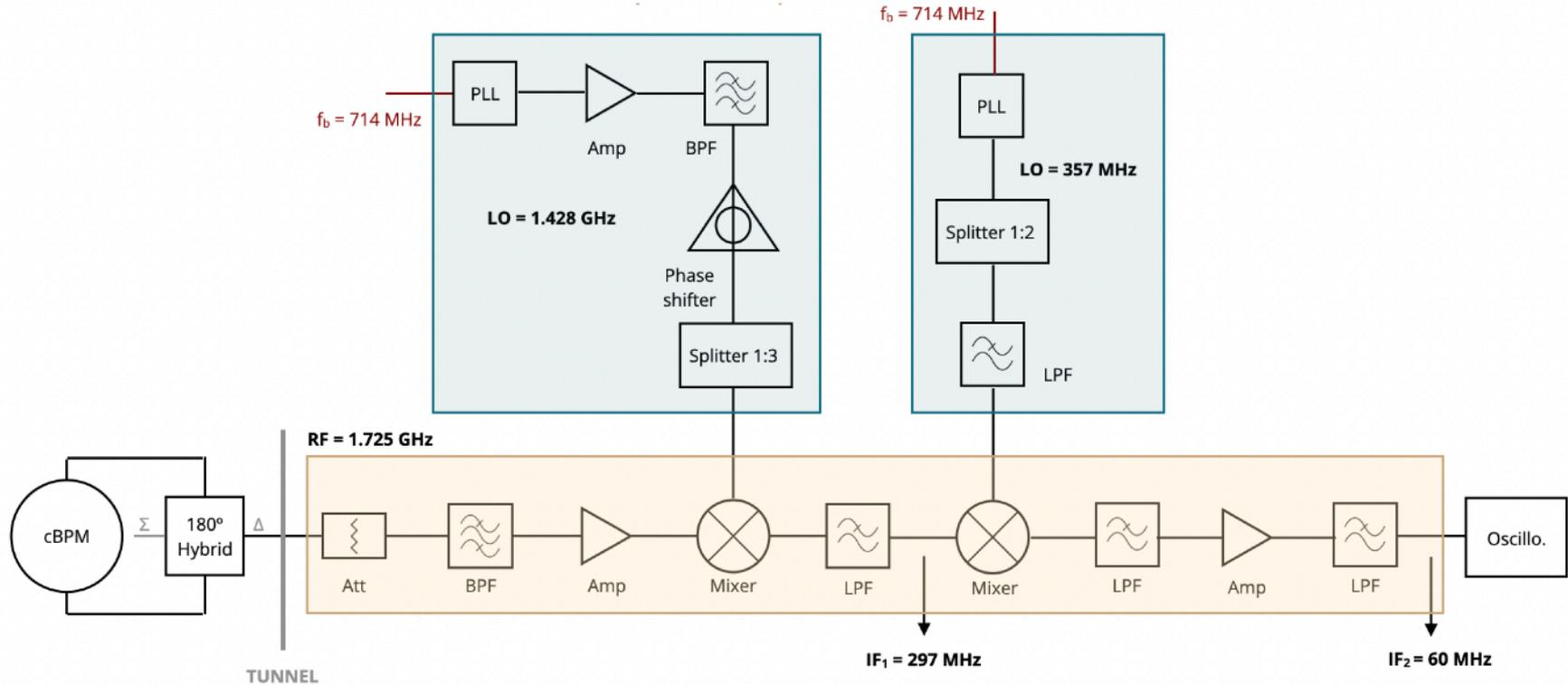
Phase shifter for LO to maximise sensitivity



I. Resolution measurement and calculation

A) Setups employed for measurements

Setup C - double down conversion



I. Resolution measurement and calculation

B) Resolution calculation

Resolution measurements: Model Independent Analysis

cBPM measured values \rightarrow $\begin{pmatrix} d_{k0} \\ d_{k1} \\ d_{k2} \\ \vdots \\ d_{kM} \end{pmatrix} = \begin{pmatrix} d_{00} & d_{10} & d_{20} & \cdots & d_{i \neq k, 0} & \cdots & d_{N0} \\ d_{01} & d_{11} & d_{21} & \cdots & d_{i \neq k, 1} & \cdots & d_{N1} \\ d_{02} & d_{12} & d_{22} & \cdots & d_{i \neq k, 2} & \cdots & d_{N2} \\ \vdots & \vdots & \vdots & & \vdots & & \vdots \\ d_{0M} & d_{1M} & d_{2M} & \cdots & d_{i \neq k, M} & \cdots & d_{NM} \end{pmatrix} \cdot \begin{pmatrix} v_0 \\ v_1 \\ v_2 \\ \vdots \\ v_N \end{pmatrix} \leftarrow$ correlation coefficients

\uparrow
stripline BPM measured values

Taking a long set of data in a unique beam position:

$M = 1000$ is the number of measured waveforms

$N = 10$ is the number of BPMs used

To find the correlation coefficients: $\mathbf{v} = \mathbf{D}_k^{-1} \mathbf{d}_k$. where the inverse of D_k is calculated using the SVD method: $SVD(\mathbf{D}_k) = \mathbf{U} \mathbf{S} \mathbf{V}^T$,

The residuals between measured position and estimated position are calculated as $\mathbf{R}_k = \mathbf{d}_k - \mathbf{D}_k \cdot \mathbf{v}$.

And the resolution is estimated do be the rms of the residuals:

$$\sigma_k = \sqrt{\frac{\sum_i^M R_{ki}^2}{M}}$$

BPMs taken: up-stream: ML10L, ML11L, ML12L, ML13L, ML14L, ML15L, ML1P, ML2P, ML3P ; down-stream: ML4P