LHC Injectors Upgrade

1 October 2018

Optics Measurements at 160 MeV

Summary of measurements performed in

Ana García-Tabarés Valdivieso, Piotr Skowronski

1. Introduction
2. RING 1
3. RING 2
   - Change in the quadrupolar settings
   - Comparison of two set of measurements.
   - β from amplitude 2018.08.06 vs 2018.09.14
   - β^{A}-beating calibrated vs β^{ϕ}-beating
4. RING 3
5. RING 4

β function reconstruction techniques

β from phase

Based on the combination of at least three phase advance values between two given BPMs i and j.
Relative value
✗Uncertainty of the β function is strongly dominated by the phase advance value and its errorbar.
✗Assuming an quadrupolar error of K1 10^{-4}. Even with ideal simulated data we obtain 10% β-beating systematic error.

β from amplitude

Based on the amplitude recorded at a given BPM
✗Absolute value biased by the calibration factor of each individual BPM.

Introduction

- Summary of the measurements performed the following days:
  1. 06 August: Ring 2
  2. 14 September: All rings
  3. 25 September: Ring 4
- The same measurement principle for the three measurements:
  1. Perform measurements in the alternative working point Q3Q5: Measure β using both β^{ϕ} and β^{A} approaches. Compute the BPM calibration factors as the ratio between the two β,

$$C_{\mathrm{i}} = \frac{\beta_i^{\phi}}{\beta_i^{\mathrm{A}}} \tag{1}$$

  2. Perform measurements in the normal working point with the same conditions: same beam intensity and same BPM gain. Apply the calibration factors obtained in the Q3Q5 optics.

Why measuring in the Q3Q5 working point?

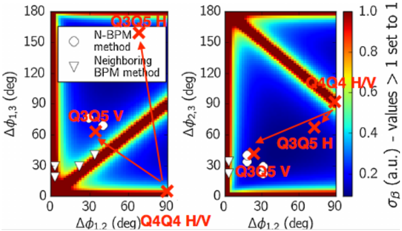


Figure 1: β^{ϕ} uncertainty for phase different combinations of phase advance values.

Phase advance between consecutive BPMs is constant for all the BPMs.

1. Q4Q4
   - Horizontal 96.1°
   - Vertical 96.3°
2. Q3Q5
   - Horizontal 76.1° ($\Delta\phi \approx$ 14° w.r.t. 90°)
   - Vertical 122.1° ($\Delta\phi \approx$ 32° w.r.t. 90°)

RING 1: Measurements at Q3Q5 and Q4Q4

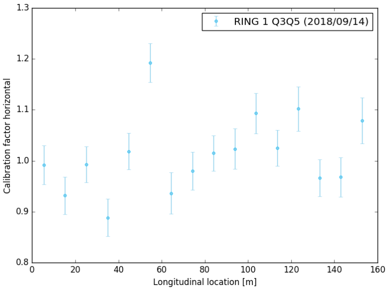
Beam parameters: Natural & Driven tune

	Horizontal		Vertical	
	Natural	Driven	Natural	Driven
Q3Q5	3.38	0.375	5.425	0.428
Q4Q4	4.27	0.268	4.28	4.285

Beam intensity and BPM gain

- Gain: $2 \cdot 10^{11}$
- Intensity $\approx 120 \cdot 10^{10} \pm 10 \cdot 10^{10}$ ppb.

Calibration factors measured @ Q3Q5

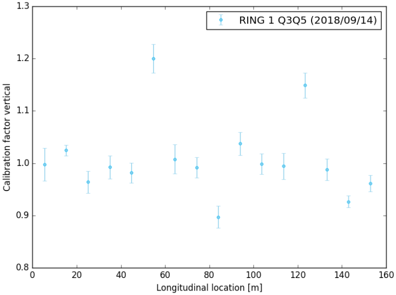


Horizontal calibration factors Ring 1

The uncertainty of the β function, and therefore of the calibration factor, in this working point is dominated by the statistical error.
Large calibration factor in BPM6 due to smaller β^{A} than in the rest of the BPMs and larger β^{ϕ} than the average.

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Horizontal	3.9%	$6.53 \cdot 10^{-4}$ [2 π]

Calibration factors measured @ Q3Q5

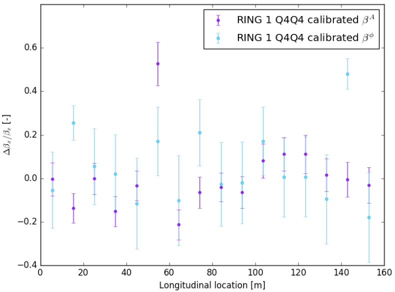


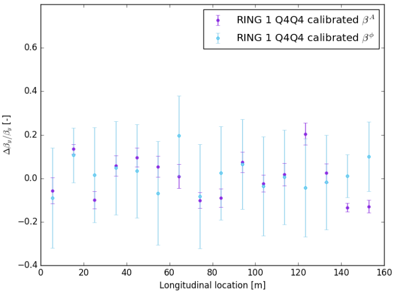
Vertical calibration factor Ring 1

Large calibration factor in BPM6 due to smaller β^{A} value than in the rest of the BPMs and larger β^{ϕ} value than the average β value.
Not clear if the calibration factor is larger because of large β-beating or if it is really an calibration factor effect. $\rightarrow$ it is being analyzed.

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Vertical	1.9%	$1.05 \cdot 10^{-3}$ [2 π]

Ring 1: Results Q4Q4 β^{ϕ} vs β^{A} calibrated





Summary	Horizontal	Vertical
$\sigma(\langle\sigma\beta^{\phi}\text{-beating }\rangle)$	17%	20%
$\sigma(\langle\sigma\beta^{A}\text{-beating }\rangle)$	8%	4%

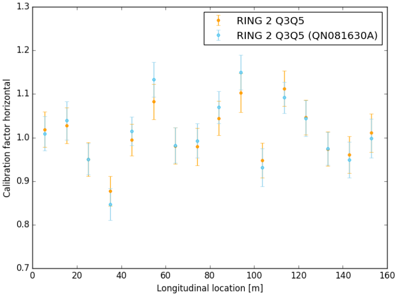
RING 2: Measurements at Q3Q5 and Q4Q4

Beam parameters: Natural & Driven tune

	2018.08.06				2018.09.14			
	Horizontal		Vertical		Horizontal		Vertical	
	Natural	Driven	Natural	Driven	Natural	Driven	Natural	Driven
Q3Q5	3.386	0.3835	5.431	0.437	3.387	0.382	5.43	0.435
Q4Q4	4.266	0.262	4.283	4.291	4.275	0.270	4.285	4.289

- Intensity $\approx 120 \cdot 10^{10} \pm 10 \cdot 10^{11}$ ppb.
- Optimal gain for measurements performed using an optimized gain of $2 \cdot 10^{11}$. Same gain used for both working points.

Calibration factors measured @ Q3Q5 with different quadrupolar settings.



Horizontal calibration factors Ring 2

The current of the quadrupole (QN081630A) was modified in order to induce β-beating and check if the β^{ϕ} and β^{A} were changing in the same way.

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Hor.	4.03%	$2.9{\cdot}10^{-3}$ [2π]
Hor. (QN0816)	3.9%	$1.9{\cdot}10^{-3}$ [2π]

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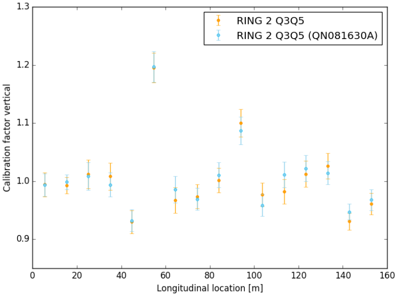
Calibration factors measured @ Q3Q5 with different quadrupolar settings.

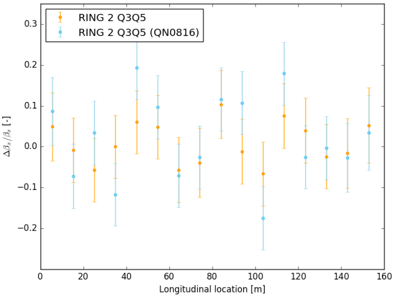


Vertical calibration factor Ring 2

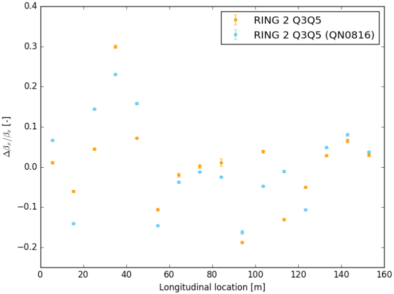
Calibration factors measured using the two quadrupolar configurations are compatible $\rightarrow$ good reproducibility.
The spike in BPM6 can be observed in both measurement's.

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Ver.	2.1%	$2.7 \cdot 10^{-3}$ [2π]
Ver. (QN0816)	2%	$2.1 \cdot 10^{-3}$ [2π]

β^{ϕ}-beating and β^{A}-beating @ Q3Q5 with different quadrupolar settings



Horizontal β^{ϕ}-beating.



Horizontal β^{A}-beating.

In overall, horizontal β^{ϕ} and β^{A} change in the same way when changing the quadrupole current with the exception of BPM 6.

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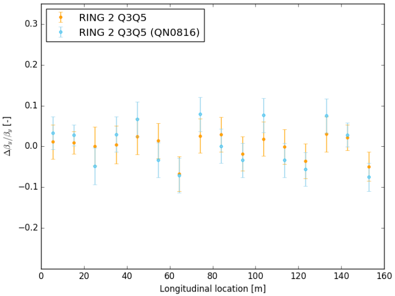
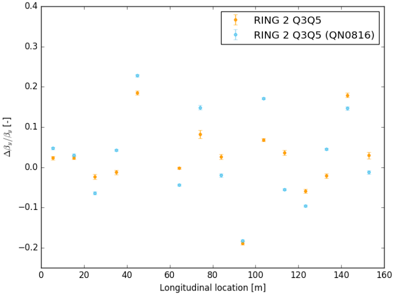
β^{ϕ}-beating and β^{A}-beating @ Q3Q5 with different quadrupolar settings



Vertical β^{ϕ}-beating.

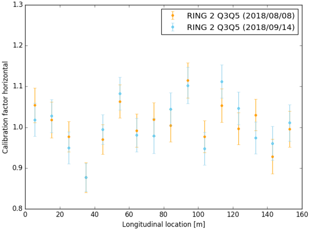


Vertical β^{A}-beating.

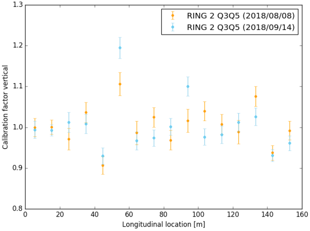
In overall, vertical β^{ϕ} and β^{A} change in the same way when changing the quadrupole current.

Calibration factors measured in different days

First set of measurements (08.06) were performed using H1H2 while the second set of measurements were performed using H1.



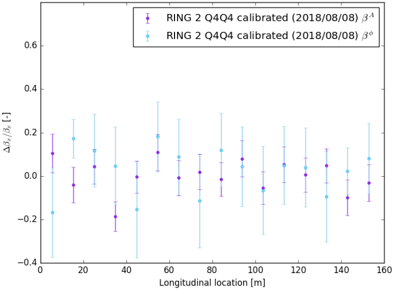
Hor. calibration factors

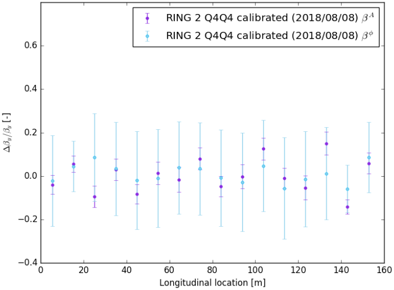


Ver. calibration factors

	Horizontal		Vertical	
	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
2018.08.06	4%	$2.9 \cdot 10^{-3}$ [2 π]	2.4%	$5.3 \cdot 10^{-3}$ [2 π]

β^{ϕ}-beating and β^{A}-beating @ Q4Q4 two different data sets.





Summary	Horizontal	Vertical
$\sigma(\langle\sigma\beta^{\phi}$-beating $\rangle)$	18%	20%
$\sigma(\langle\sigma\beta^{A}$-beating $\rangle)$	8%	5%

✗Synchronization issue for some BPMs in Q4Q4 observed during the measurements performed in 09.14.

RING 3: Measurements at Q3Q5 and Q4Q4

Beam parameters: Natural & Driven tune

	Horizontal	&	Vertical	
	Natural	Driven	Natural	Driven
Q3Q5	3.383	0.379	5.423	0.431
Q4Q4	4.274	0.269	4.290	4.294

Beam intensity and BPM gain

- Gain: $5 \cdot 10^{11}$
- Intensity $\approx 120 \cdot 10^{10} \pm 10 \cdot 10^{10}$ ppb.

Calibration factors measured @ Q3Q5

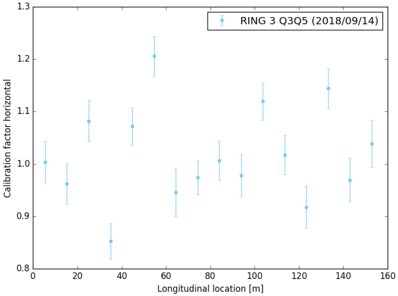


Figure 2: Horizontal calibration factors Ring 3

Larger calibration factor obtained for BPM 6. Some re-analysis are being done in order to understand this large value that appears in all the rings but not in both planes.

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Horizontal	3.9%	$1.4 \cdot 10^{-3}$ [2 π]

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Calibration factors measured @ Q3Q5

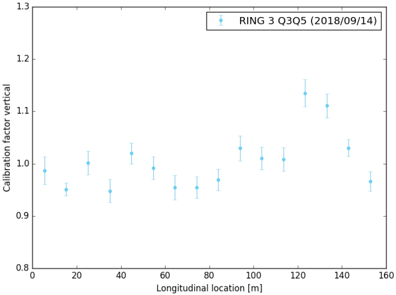
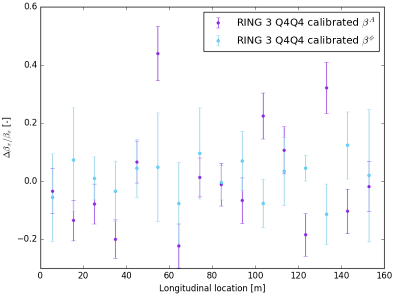
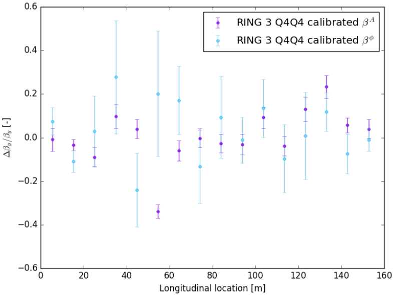


Figure 3: Vertical calibration factor Ring 3

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Horizontal	2%	$1.9 \cdot 10^{-3}$ [2 π]

β^{ϕ}-beating and β^{A}-beating @ Q4Q4





Summary	Horizontal	Vertical
$\langle \sigma\beta^{\phi}$-beating $\rangle$	12%	14%
$\langle \sigma\beta^{A}$-beating $\rangle$	7%	4%

RING 4: Measurements at Q3Q5 and Q4Q4

Beam parameters: Natural & Driven tune

	Horizontal		Vertical	
	Natural	Driven	Natural	Driven
Q3Q5	3.377	0.373	5.42	0.424
Q4Q4	4.28	0.276	4.3	4.307

Beam intensity and BPM gain

- Gain: $5 \cdot 10^{11}$
- Intensity $\approx 120 \cdot 10^{10} \pm 10 \cdot 10^{10}$ ppb.

Calibration factors measured @ Q3Q5

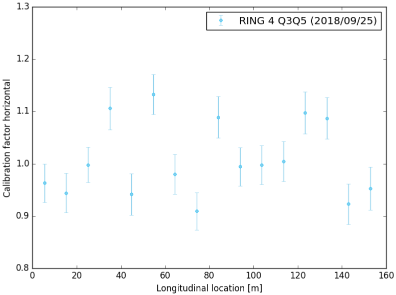


Figure 4: Horizontal calibration factors Ring 4

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Horizontal	3.8%	$1.7 \cdot 10^{-3}$ [2 π]

Calibration factors measured @ Q3Q5

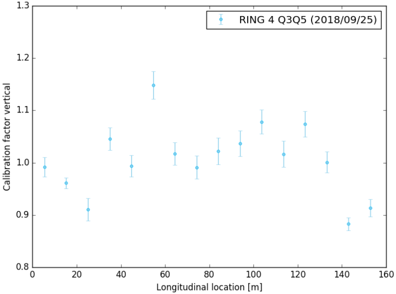
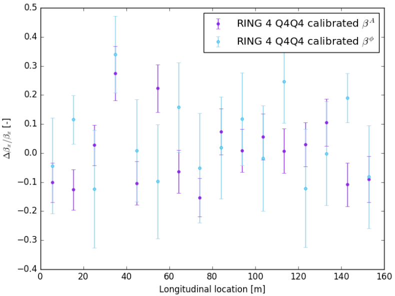


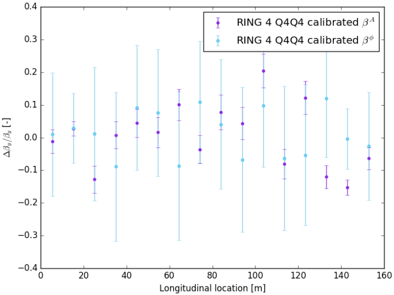
Figure 5: Vertical calibration factor Ring 4

Larger calibration factor obtained for BPM 6. Some re-analysis are being done in order to understand this large value that appears in all the rings but not in both planes.

Summary	$\langle \sigma C_i \rangle$	$\langle \sigma \phi_{i,j} \rangle$
Vertical	2%	$1.4 \cdot 10^{-3}$ [2 π]

β^{ϕ}-beating and β^{A}-beating @ Q4Q4





Summary	Horizontal	Vertical
$\langle \sigma\beta^{\phi}$-beating $\rangle$	16%	19%
$\langle \sigma\beta^{\mathrm{A}}$-beating $\rangle$	7%	5%

Conclusions

- The configuration of a new working point (Q3Q5) has allowed us to measured the calibration factors in all the rings.
- Even if the phase stability is bettwer in the horizontal plane, the calibration factor systematic errors are larger in this plane. This is due to the vertical phase advance is further from 90 than in the horizontal plane.
- Ring 2 measurements, performed in different days, show a poor reproducibility of the measurements in vertical plane. Therefore the calibration factors have to be recomputed periodically.
- Large improvement in the β-error reconstruction of the BPMs. Nontheless, a more accurate calibration would help to decrease the β^{A}-calibrated uncertainty. Additionally β^{A} calculation is being rewritten in order to include more source of errors in the β uncertainty and it will potentialy increase β^{A} uncertainty.