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MD2723 - Amplitude Detuning Studies at 6.5 TeV with Various Configurations of the Crossing Scheme

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Summary

Particular interest exists to better understand the amplitude detuning through the LHC cycle in order to shed some light on possible sources of instabilities, and better prepair for the β^* squeeze to $\beta^* = 25$ cm in 2018. This note reports on the amplitude detuning measurements taken on the 3^{rd} of December of 2017 during MD2723. Amplitude detuning measurements are presented at flattop with crossing angles and at end-of-squeeze without and with crossing angles and local orbit bumps. Furthermore tests of the skew octupolar corrections in IP5 done at the end of the MD are presented, with specific focus on forced DA and resonance driving terms measurements.

Contents

1 Introduction

Uncertainties on the possible sources of instabilities affecting the LHC in Run II sparked an interest in a more thourough study of amplitude detuning throughout the cycle at top energy [1]. This MD consists of measuring the amplitude detuning at flattop, at end-of-squeeze without crossing angles, and at end-of-squeeze with full crossing angles including local orbit bumps to measure at operational conditions. These measurements help understand the evolution of the detuning sources through the cycle, they shine some light on the success of the insertion region nonlinear optics corrections, and benefit further studies by the instabilities group. The amplitude detuning measurements are discussed in Sec. 2 (flattop $\beta^* = 1$ m), Sec. 3.1 ($\beta^* = 30$ cm no crossing angles), and Sec. 3.2 ($\beta^* = 30$ cm with crossing angles). All fit values shown in the figures are uncompensated for the increased detuning from the AC dipole excitation [2]. The free amplitude detuning values, compensated for the AC dipole effect, are summarized in table 1.

Further measurements were taken to measure resonance driving terms coming from skew octupolar sources to help validate the calculated a_4 corrections in IP5 [3]. These measurements are reported in Sec. 4.

MD specific details are summarized below:

- Fill number: 6455
- Beam process: RAMP-SQUEEZE-6.5TeV-ATS-1m-2017_V3_V1_MD41210_[END]
- Atlas toridal on, solenoid off
- CMS solenoid off
- Emittance: all planes at $\sim 1\mu$m
- Collimators were set to 9.5 σ (AC dipole aperture measurements were taken to obtain the maximum safe aperture)

2 Flattop

To correct for the tune decay at flattop the amplitude detuning measurements were interleaved with tune corrections with the tune feedback between each beam excitation. The tune variation from the BBQ for the period during the measurements is at the level of $\delta Q < 5 \cdot 10^{-5}$ for both planes of both beams.

Figure 1 shows the amplitude detuning measurements at flattop for Beam 1, while the results for Beam 2 are shown in Fig. 2. The largest detuning is observed in Beam 1 for the direct horizontal detuning term ($\partial Q_x / \partial 2J_X$). However, the measurement quality is poor and cannot be used for conclusive statements. All other detuning terms for both beams are very small and rule out any further significant detuning contributions coming from IP2 and IP8.

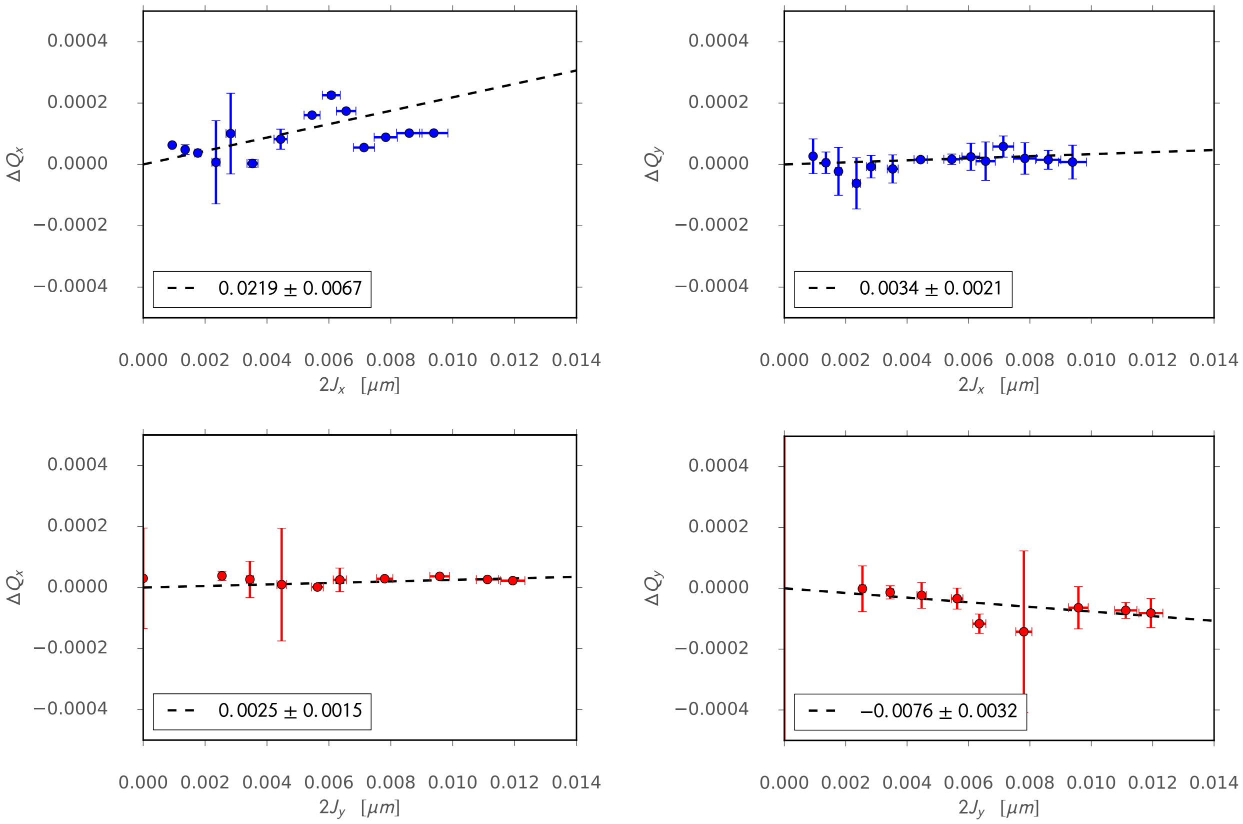

Figure 1: Amplitude detuning at flattop for Beam 1.

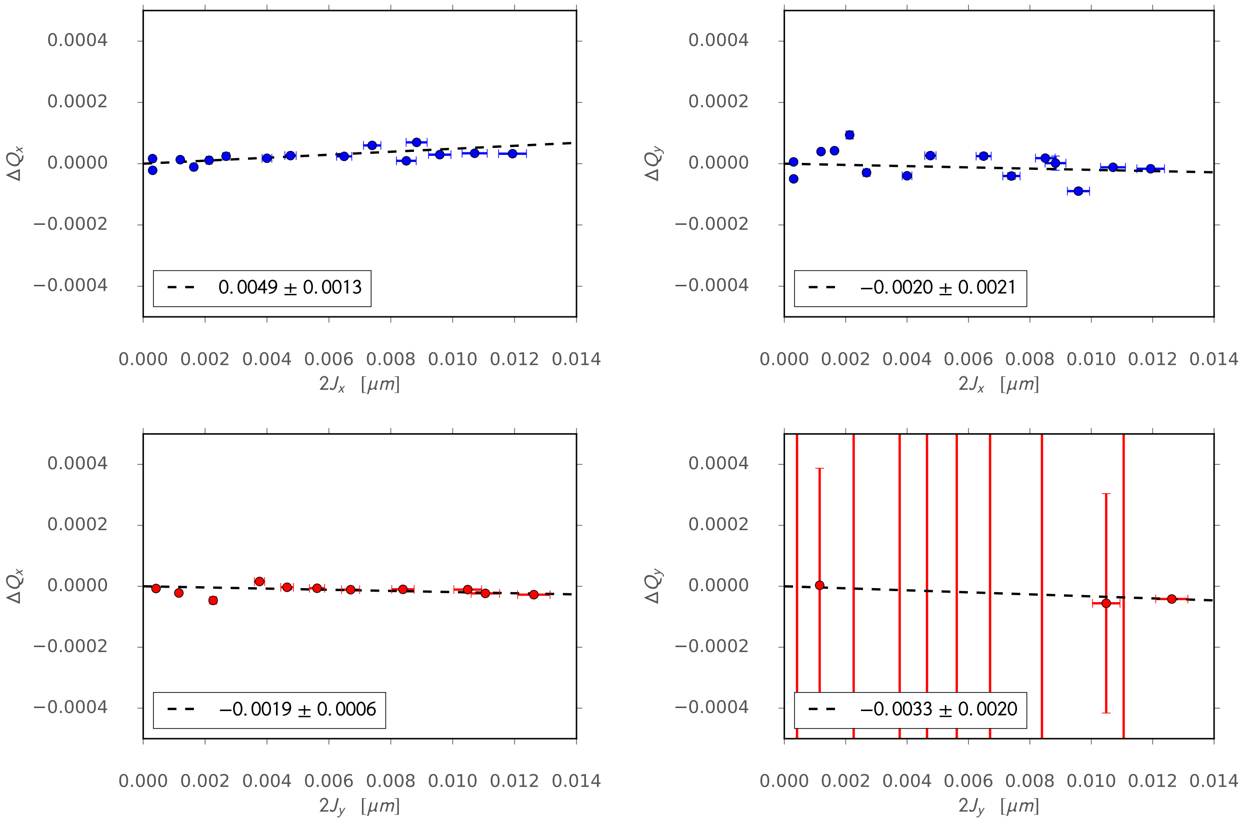

Figure 2: Amplitude detuning at flattop for Beam 2.

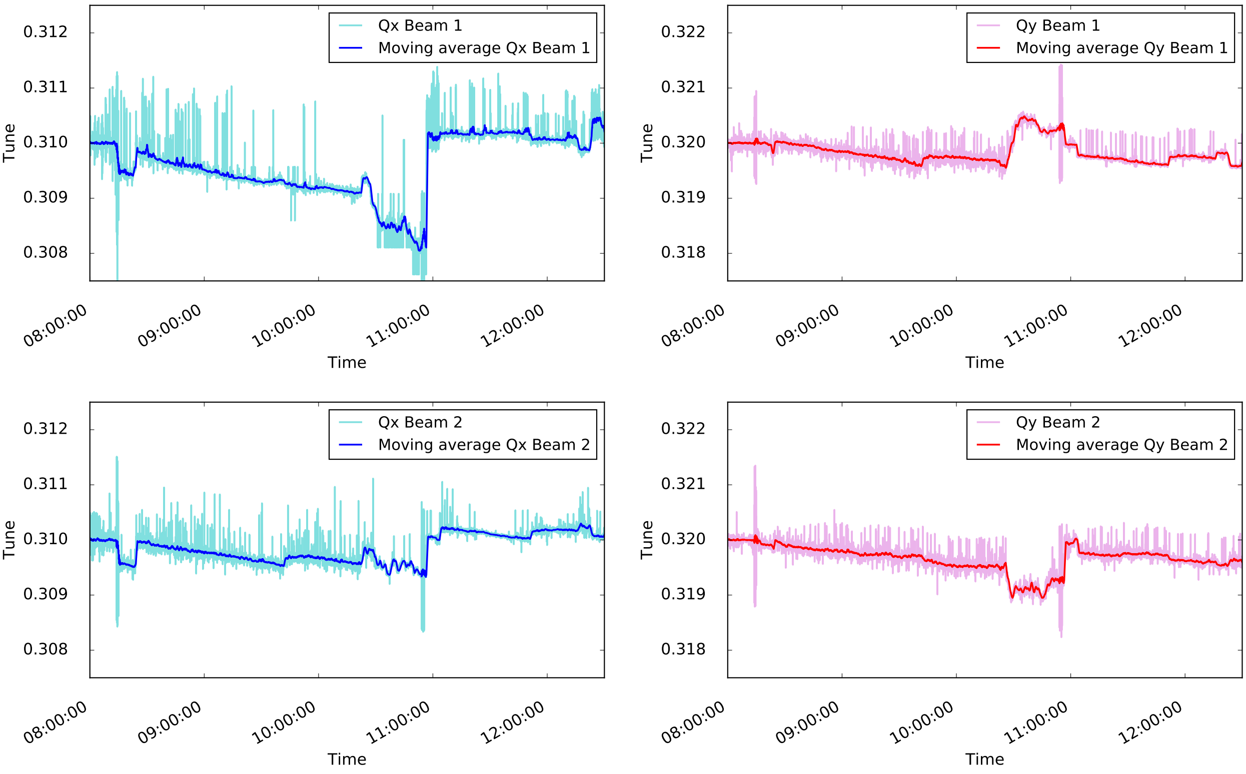

Figure 3: Tune decay measurment from the BBQ for Beam 1 (top) and Beam 2 (bottom) during the measurements at $\beta^* = 30$ cm.

3 End-of-squeeze

For the measurements at $\beta^* = 30$ cm it was decided not to correct the tunes using the tune feedback. This in order to obtain a clearer measurement of the tune decay, and make it easier to calculate the decay compensation from the BBQ data. A moving average over the BBQ data was taken to improve the tune precision before each AC dipole excitation, as presented in Fig. 3. All measurements presented below are corrected for the tune decay by substracting the averaged BBQ tune from the measured natural tune during the AC dipole excitation. Due to blow up in Beam 1, the measurements at $\beta^* = 30$ cm for Beam 1 were more challenging to perform. Unfortunately only large excitations were possible in the vertical plane without crossing angles, and in the horizontal plane with crossing angles. In both cases the amplitudes were more limited than for the Beam 2 measurements.

3.1 30cm without crossing angles

The results for measurments at $\beta^* = 30$ cm and without crossing angles are presented in Fig. 4 for Beam 1 and in Fig. 5 for Beam 2. At end-of-squeeze and without crossing angles the detuning is very small. The results provide a solid confirmation of the success of the b_4 corrections in both IP1 and IP5 as implemented during commissioning.

3.2 30cm with crossing angles

The results for measurments at $\beta^* = 30$ cm and with crossing angles are presented in Fig. 4 for Beam 1 and in Fig. 7 for Beam 2. These measurements are performed with full crossing scheme and includes local orbit bumps present during the 2017 operation. A slight deterioration of amplitude detuning is observed for both beams when introducing the crossing scheme. It should be noted that

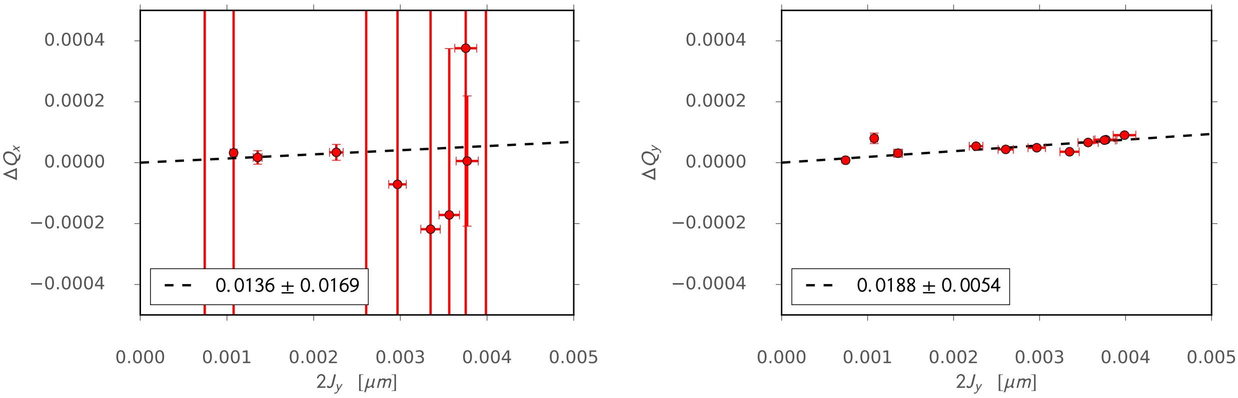

Figure 4: Amplitude detuning at 30cm for Beam 1 without crossing angles.

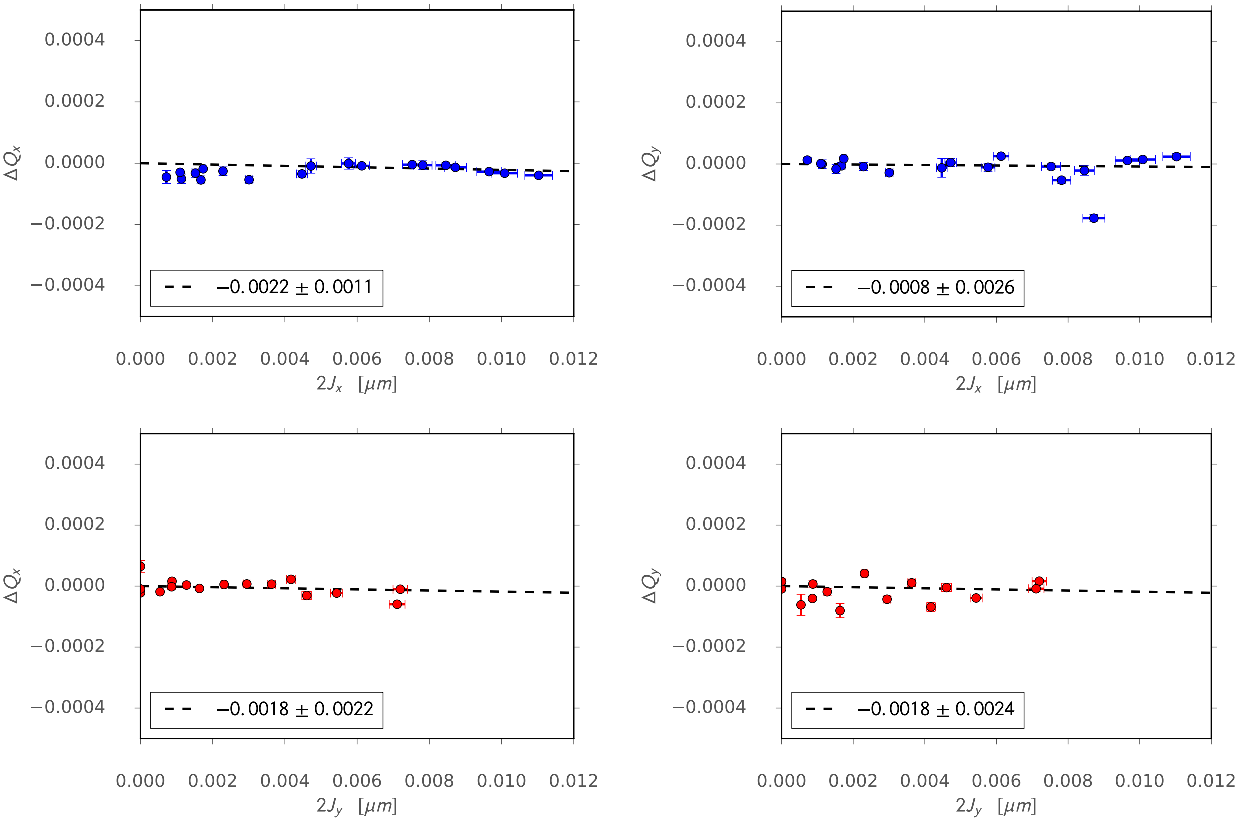

Figure 5: Amplitude detuning at 30cm for Beam 2 without crossing angles.

the detuning obtained for $\partial Q_x/\partial 2J_x$ in Beam 1 is unreasonably large and suggests a closer look should be taken at the post-processing of this specific measurement. The poor quality of this specific measurement puts further doubt on the obtained detuning.

An increase in the detuning terms is also observed in Beam 2 where the cross term $\partial Q_x/\partial 2J_y$ has increased significantly from $-1800\,m^{-1}$ to $-24600\,m^{-1}$ after introducing the crossing angles. Furthermore, a discrepancy is observed between both cross terms. The term $\partial Q_x/\partial 2J_y$ is twice as large as the $\partial Q_y/\partial 2J_x$ term, where a theoretical equivalence is expected. We observe an increase of the detuning terms when intoducing the crossing angles in the interaction points. This strongly suggests that the sources are coming from feed down from higher order multipoles, though a precise order cannot be given at this moment.

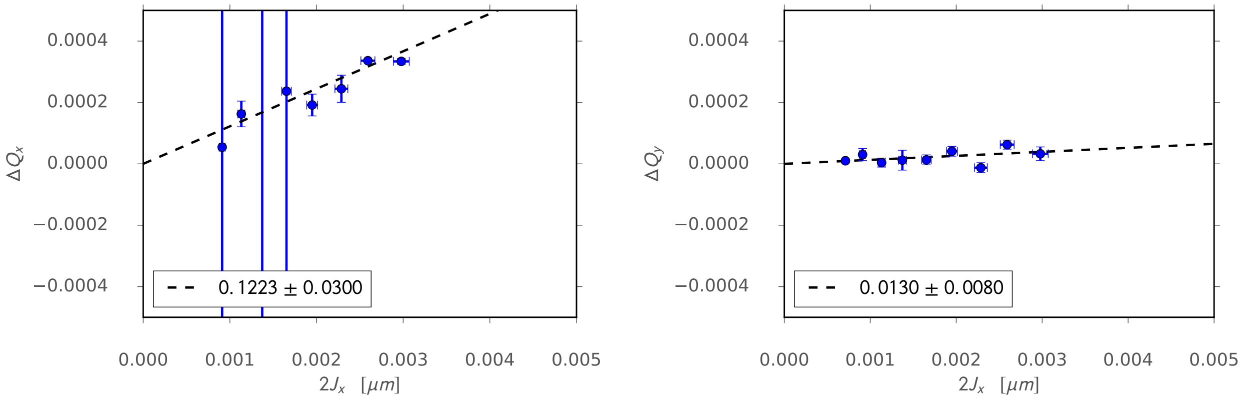

Figure 6: Amplitude detuning at 30cm for Beam 1 with crossing angles.

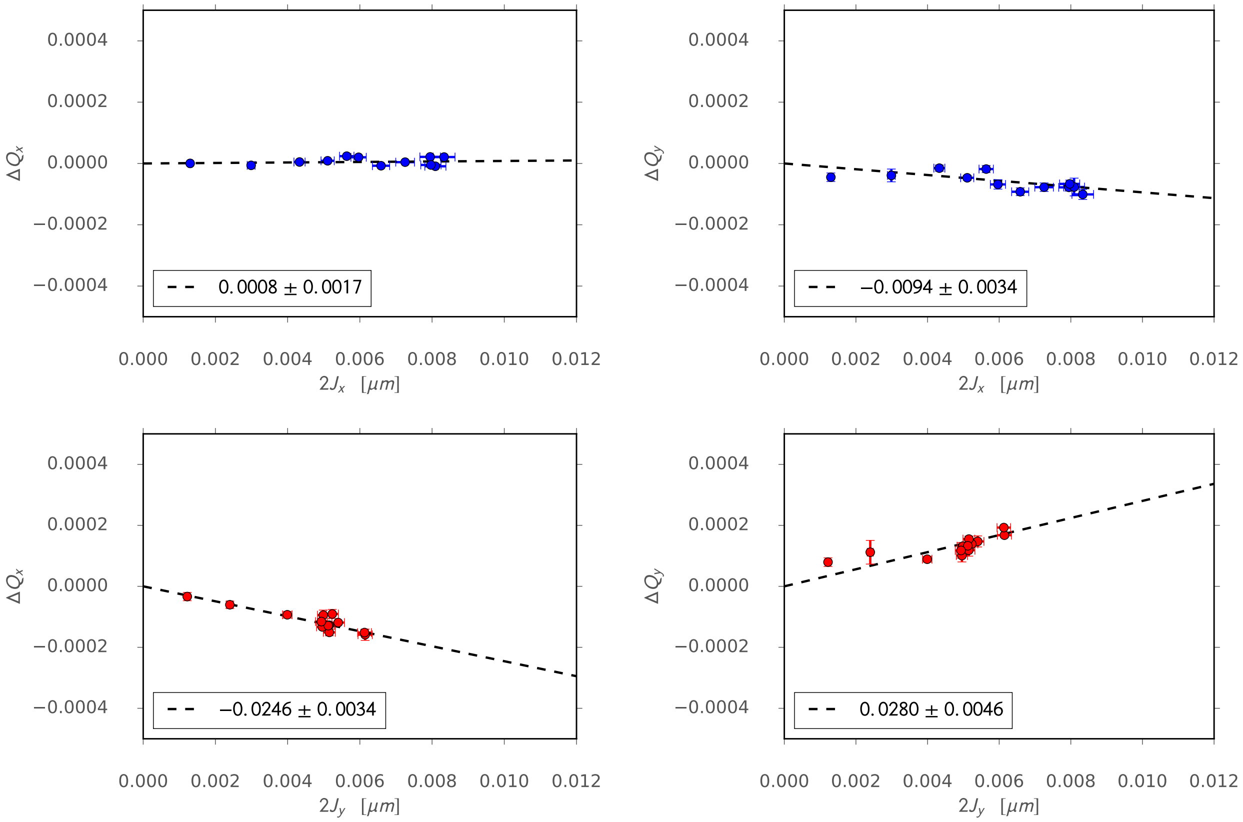

Figure 7: Amplitude detuning at 30cm for Beam 2 with crossing angles.

3.3 Summary of amplitude detuning measurements

Table 1 gives a summary of all free detuning terms (corrected for the AC dipole effect) is given below. Detuning from MOs at 340 A is given in the table for comparison.

Table 1: Summary of amplitude detuning measurements

Detuning terms	$\frac{\partial Q_x}{\partial 2J_x}$ [$10^3\mathrm{m}^{-1}$]	$\frac{\partial Q_y}{\partial 2J_x}$ [$10^3\mathrm{m}^{-1}$]	$\frac{\partial Q_x}{\partial 2J_y}$ [$10^3\mathrm{m}^{-1}$]	$\frac{\partial Q_y}{\partial 2J_y}$ [$10^3\mathrm{m}^{-1}$]
MO 10.8m^{-4} (340A)	98.0	-70.9	-70.9	90.4
B1 flattop	11 ± 3	3 ± 2	2.5 ± 1.5	-3.8 ± 1.6
B1 30 cm NO crossing angles	-	-	-	9 ± 2
B1 30 cm WITH crossing angles	61 ± 15*	13 ± 8	-	-
B2 flattop	2.5 ± 0.7	-2 ± 2	-1.9 ± 0.6	-1.7 ± 1.0
B2 30 cm NO crossing angles	-1.1 ± 0.6	-1 ± 2	-2 ± 2	-0.9 ± 1.2
B2 30 cm WITH crossing angles	0.4 ± 0.9	-9 ± 3	-25 ± 3	14 ± 2

*Quality of measurement is very poor due to lack of points.

4 Correction of a4 in IP5

Nonlinear corrections for skew octupolar (a_4) sources in IP5 were calculated from crossing angle scans during the 2017 commissioning. Tests of the corrections have proven to be unconclusive in previous measurements during $\beta^* = 30$ cm commissioning in 2017. Large diagonal excitations were done with the AC dipole at $\beta^* = 30$ cm and without crossing angles to probe resonance driving terms coming from a_4 sources. A reference measurement was taken without corrections to establish a baseline. As the polarity of the a_4 corrector in IP5 is unknown the correction was trimmed in first with a positive sign of the correction and later with the opposite polarity. A clear increase in losses was observed in both cases, more specifically for the negative polarity. Figure 8 shows the measured forced DA for the three different configurations.

The skew octupolar resonance driving term f_{1210} is measured. Figure 9 shows the aggregation of the measured f_{1210} values along the ring into a single histogram. In blue is the base line measurement without corrections, in green the correction was applied with a positive sign, while the red shows the driving terms with the correction applied with the negative sign. In both cases there is no reduction of the f_{1210} resonance driving term. The observed f_{1210} confirms the previous findings from the forced DA by pointing to the correction with the negative sign as the worst of the two corrections. Further studies are ongoing why the correction is not successfull, and a specific look is taken at the phases of the resonance driving terms for a possible over-correction with the positive polarity correction.

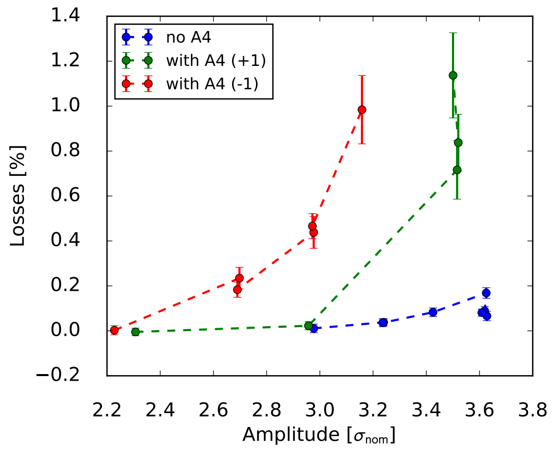

Figure 8: Measured forced DA at end of squeeze with different a4 corrections.

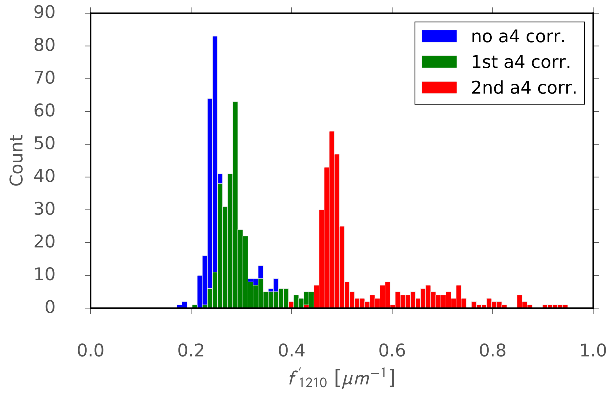

Figure 9: Histogram of measured f_{1210} for different a4 corrections.

5 Conclusions

Amplitude detuning at flattop is observed to be negligible, thus excluding detuning sources in both IP2 and IP8. At end-of-squeeze optics without crossing angles the detuning is measured to be very small. This confirms a good correction of b_4 in both IP1 and IP5. When introducing the crossing angle scheme at $\beta^* = 30$ cm we observe a slight deterioration of the detuning terms. This most likely caused by feed-down from, as yet, unidentified sources, and prompts the interest to study this more closely in view of further squeeze schemes to $\beta^* = 0.25$ cm in 2018. It is recommended to perform thorough amplitude detuning measurements during the 2018 commissioning at smaller (down to $\beta^* = 0.25$ cm) to give further insights in the evolution of the detuning sources along the cycle, and complete the set of measurements for Beam 1.

A general note should be made on the quality of the amplitude detuning measurements. We observe that the measurements with full crossing scheme are more challenging. First of all the incorporated nonlinear corrections greatly reduce the amplitude detuning. Secondly, the crossing angle scheme poses a limit on the available aperture for large excitations, thus resulting in smaller kicks and smaller measured tune shifts. This means that for the first time the measured tune shifts during the amplitude detuning measurements are at the level of the tune decay and observed tune variation. It is thus recommended for future amplitude detuning measurements to measure at smaller amplitude intervals, also at lower amplitudes, in order to improve fitting and reduce the effect of possible tune variations.

No current conclusions can be drawn on the validity of the a_4 corrections in IP5. A clear degradation of both the forced DA and resonance driving terms amplitude is observed for the correction with the negative sign, and points to a rejection of this polarity for the a_4 correction. Further studies on the phase of the driving terms are ongoing and hope to improve the understanding of these a_4 corrections in view of the 2018 commissioning plans.

6 Acknowledgements

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References

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