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Lee.Robert.Carver@cern.ch

MD 755: Instability threshold and tune shift study with reduced retraction between primary and secondary collimators in IR7

L.R. Carver, N. Biancacci, R. Bruce, A. Mereghetti, E. Métral, D. Nisbet, S. Redaelli, B. Salvant, B. Salvachua (CERN, Geneva, Switzerland)

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Summary

The purpose of this MD is to quantify in terms of stabilising octupole current threshold the impedance change when reducing the retraction between the primary and secondary collimators in IR7. This will be performed by first measuring the octupole current threshold required for stability with the tighter secondary collimator settings at 6.5 σ (w.r.t. to the nominal settings at 8 σ), and then measuring the tune shift that occurs when the collimators are moved to the new settings.

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1 Introduction

In order to reach $\beta^* = 40$ cm, the collimation settings with reduced retraction between primaries and secondaries in IR7 need to be qualified from the point of view of cleaning efficiency. This is in order to find signs of hierarchy breakage (see also the collimation working group MD note *"Beta* reach: IR7 collimation hierarchy limit and impedance"* for further details).

For these particular settings, the secondary collimators are closer to the beam and the impedance contribution is increased. According to the analysis made in Ref. [3] based on theory and scaling from measurements made in 2012, this can potentially reduce the intensity threshold for stability by a factor of 2.

The goal of this MD is to better understand the impact of the LHC secondary collimators in IR7 measuring the stabilising octupole current and the induced tune shift. The first is achieved by lowering the current in the Landau octupoles until an instability develops. The second is achieved by performing a tune measurement varying the position of the secondary collimators between the newly qualified setting of 6.5 σ and 20 σ, which will give a measurement that is directly related to the imaginary part of the LHC total transverse impedance.

These measurements will ultimately allow the impedance contribution of the collimator system to be optimised when moving to smaller β^*.

2 MD Procedure

The MD consisted of two consecutive fills, 4290 and 4291, and occurred between 06:10 and 15:00 local time on 29-08-15.

2.1 First ramp: octupole threshold studies

The first ramp contained two nominal bunches (one with 2μm and the other with 3μm emittance) and several probes per beam (required by the collimation team to qualify the hierarchy). The chromaticity was set to Q'≃7/7 in H/V planes when reaching flat top. The instability threshold measurement was performed at the end of the collimation hierarchy MD. The collimation hierarchy was qualified, and the new collimator positions can be found in Fig. 1. During the collimation MD, additional losses were incurred on both nominal bunches in B2. The loss of intensity rendered B2 unsuitable for use in the forthcoming threshold study. An overview of the instability study for fill 4290 can be seen in Fig. 2. A tune shift study was also attempted, but no visible change was observed when moving the collimators between 6.5σ and 20σ. It was therefore decided that a better use of the remaining time would be to dump and re-inject with only a single nominal bunch per beam and attempt to repeat the measurements.

Table 1 gives a summary of the instabilities observed during the first ramp of the MD. Fig. 3 shows output from the Headtail monitor during the instability on B1H. While a clear signal is not present, a weak $|l| = 2$ mode can be seen.

Beam/Plane	Time	$4\sigma_t$[ns]	ϵ_H[μm]	ϵ_V[μm]	$N_b[10^{11}]$	J_{oct}[A]	$Q'H$	$Q'V$	m	$\|l\|$	M	τ[s]
B2V	12:30	1.03	1.6	4.1	0.6	150	7	7	0	-	1	9
B2H	12:30	1.03	1.6	4.1	0.6	150	7	7	0	-	1	12
B1H	12:31	1.0	2.7	1.4	0.8	150	7	7	0	-	1	17

Table 1: Summary of relevant parameters for the instabilities observed during fill 4290.

2.2 Second ramp: octupole threshold studies

The second fill containing one nominal bunch per beam was accelerated to 6.5 TeV. The chromaticity was again set to $\simeq$ 7/7, and an instability analysis was performed by gradually reducing the octupole

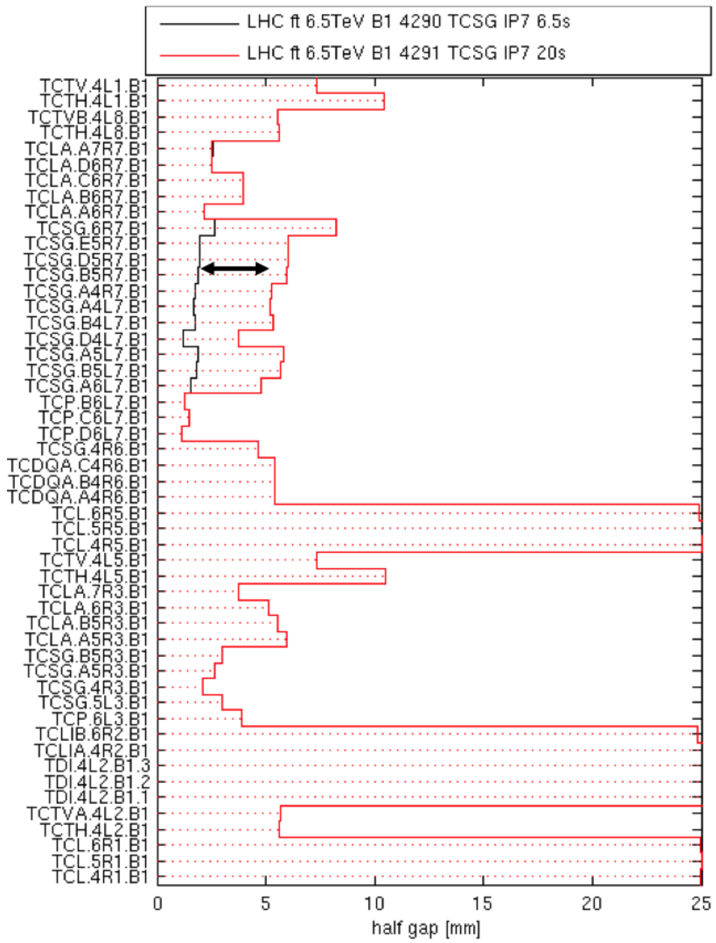

Figure 1: Newly qualified collimator settings for $\beta^* = 40$ cm. The black line shows the position of the secondaries at IR7 for 6.5σ, whereas the red shows the position at 20σ.

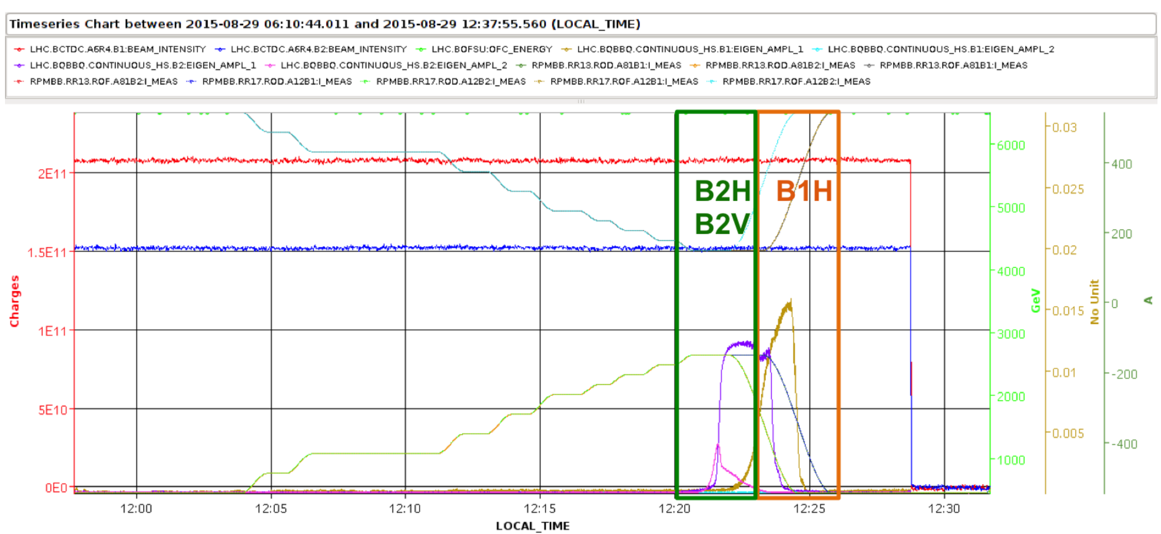

Figure 2: Overview of the instability threshold measurements at the end of fill 4290.

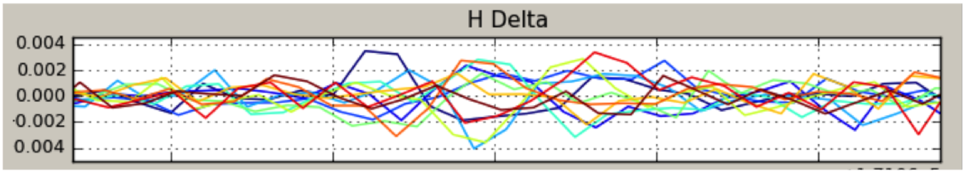

Figure 3: Headtail monitor output for the instability in B1H in fill 4290.

current. An overview of this study can be seen in Fig. 4.

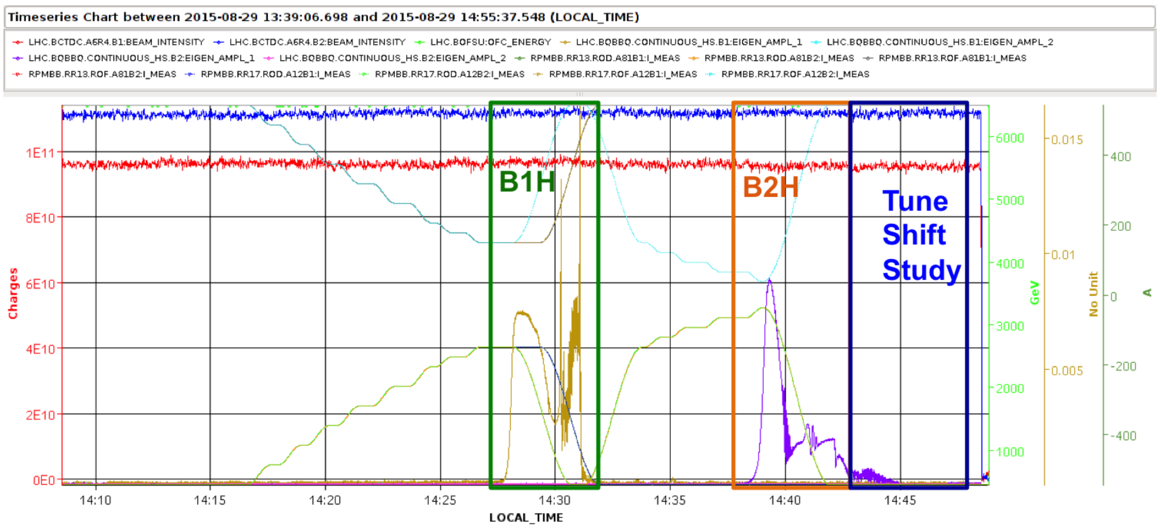

Figure 4: Overview of the instability threshold measurements and the tune shift study measured during fill 4291.

Tab. 2 gives a summary of the instabilities observed during the second ramp of the MD. The Headtail monitor revealed a clear $|l| = 2$ mode in B1H.

Beam/Plane	Time	$4\sigma_t$[ns]	$\epsilon_H[\mu m]$	$\epsilon_V[\mu m]$	$N_b[10^{11}]$	J_{oct}[A]	$Q'H$	$Q'V$	m	$\|l\|$	M	τ[s]
B1H	14:28	1.04	3.3	1.46	0.86	150	7	7	0	2	1	6.4
B2H	14:38	1.11	2.5	1.0	1.0	66	7	7	0	-	1	9.1

Table 2: Summary of relevant parameters for the instabilities observed during fill 4291.

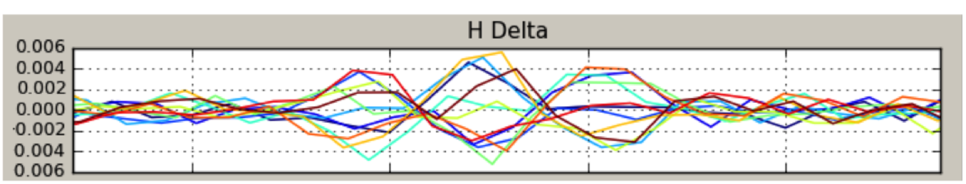

Figure 5: Headtail monitor output for the instability in B1H for fill 4291.

A discussion of these results can be found in the next section.

2.3 Tune shift measurements

After the instability thresholds were measured, the secondary collimators were periodically moved between 20 σ and the newly qualified position of 6.5 σ. The collimators were held at each position for several minutes, and this movement was repeated several times. The turn-by-turn BBQ data was then extracted, and run through the Fourier transform algorithm NAFF [6] in order to accurately extract the tune peak along the gap movements. By taking a moving average throughout the collimator variation, the tune signal can be sufficiently cleaned from the background noise and the tune shift can be calculated.

The tune shift for B1V was measured as $(2.0 \pm 0.4) \cdot 10^{-4}$ and is shown in Fig. 6. The tune shift for B2V was measured as $(1.7 \pm 0.7) \cdot 10^{-4}$ and is shown in Fig. 7. The tune shifts were also measured for the H plane in both beams, but the tune signal was too noisy and no comparison can be made. These are shown by Figs. 10 and 11 found in the appendix.

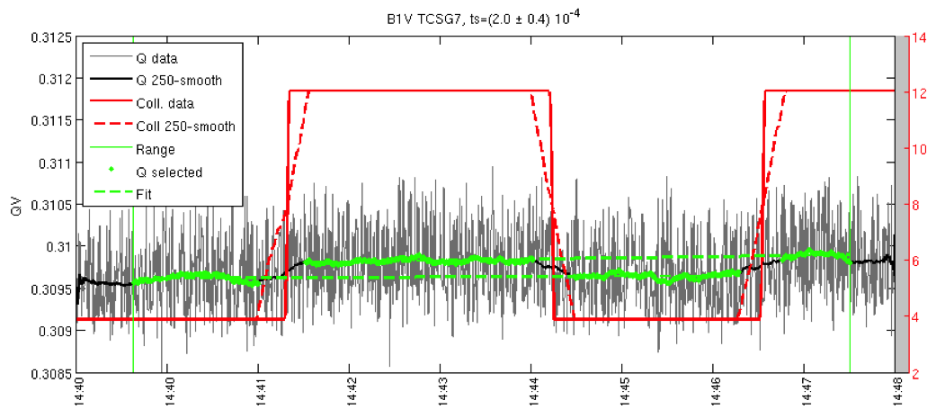

Figure 6: Measured tune shift for B1V when moving collimators between 6.5 σ and 20 σ. The red line shows the collimator position, the thin black line is the tune signal after NAFF processing, the thick black line is the moving average of the tune and the green lines highlight the difference in the average tune.

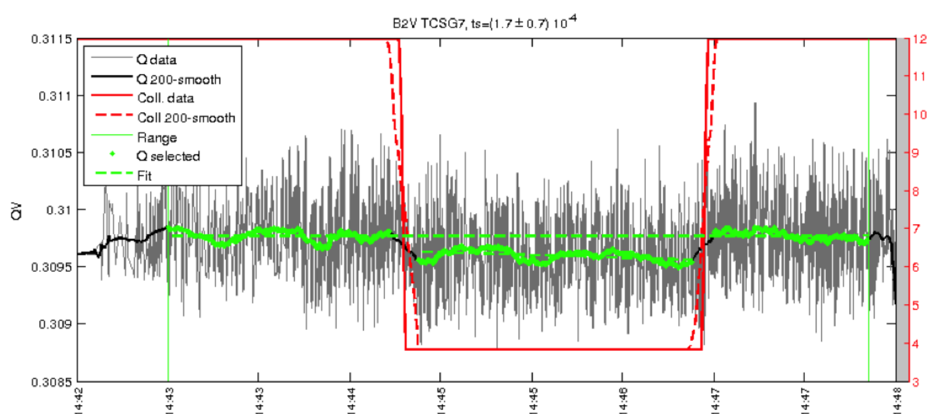

Figure 7: Measured tune shift for B2V when moving collimators between 6.5 σ and 20 σ. The red line shows the collimator position, the thin black line is the tune signal after NAFF processing, the thick black line is the moving average of the tune and the green lines highlight the difference in the average tune.

2.4 Comparison with expectations

The instability measurements from each fill is plotted alongside the prediction from DELPHI in Figs. 8 and 9.

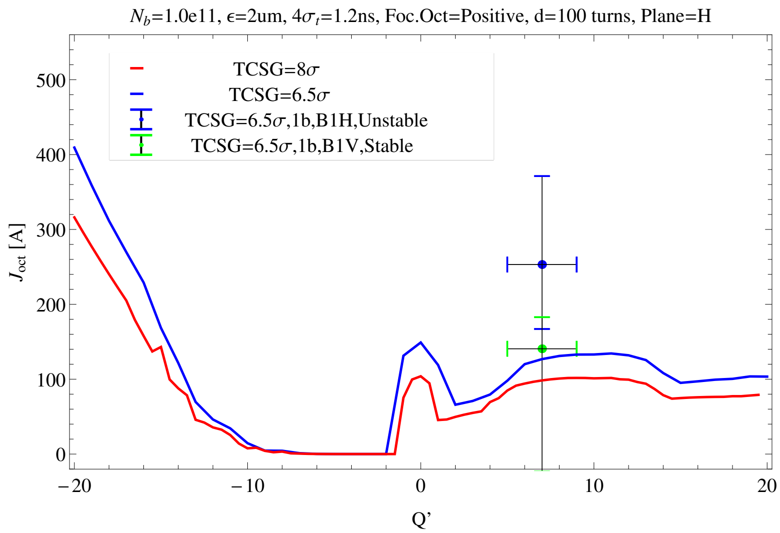

Figure 8: Instability measured for B1 in fill 4290 showed the horizontal plane becoming unstable before the vertical plane, despite the horizontal plane having a much higher emittance.

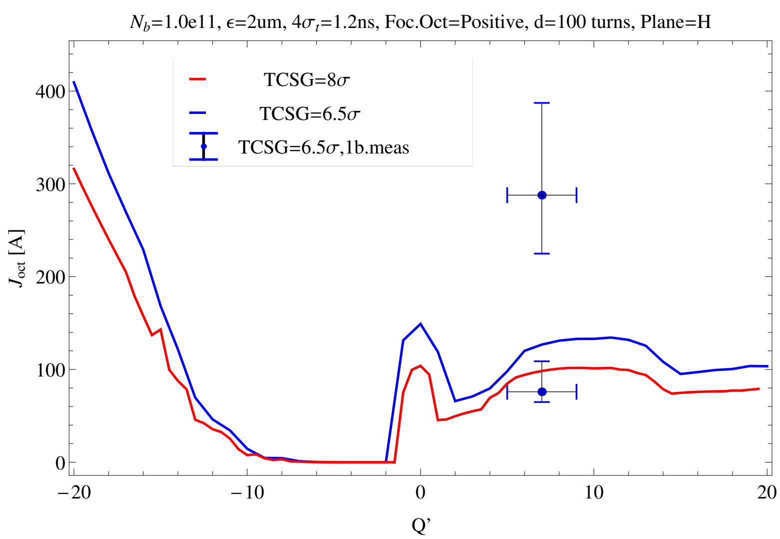

Figure 9: Instability threshold measured for B1H and B2H in fill 4291. A large discrepancy is seen, both between B1 and B2, and with the predicted result from DELPHI.

For fill 4290, the instabilities observed for B2 were disregarded, due to the fact that the transverse distribution may have been altered. For the bunches in B1, the observed instability threshold was not in agreement with what was expected. One bunch became unstable in B1H at a scaled threshold of 250A, despite having a significantly lower emittance in V.

For fill 4291, two instabilities were observed. Both instabilities were for bunches in the horizontal plane despite having much smaller vertical emittances. The agreement was again very poor, both between B1 and B2 as well as when compared with DELPHI predictions. The disagreement between B1 and B2 is likely due to the to the fact that the chromaticity was not well known at 550A, and it can be seen that there is a plateau at $7 < Q' < 14$. However, there are still many uncertainties over the origin of the discrepancy seen between measurements and DELPHI simulations. It possible something was missed during the setup of the MD, as the fact that the plane with the larger emittance became unstable first is counter-intuitive. It is clear that more research is required to attempt to determine whether this is a repeatable effect or if there was a mistake during the MD.

The tune shifts calculated from the impedance model in the vertical plane are compared with the measurements in Tab. 3.

Plane	N_b [10^{11}]	σ_t [ns]	Simulated [10^{-4}]	Measured [10^{-4}]	$Q'H$	$Q'V$	Collimator scheme
B1V	1	1.2	2.3	2.0 ± 0.4	7	7	6.5 σ $\rightarrow$ 20 σ in IP7
B2V	1	1.2	2.3	1.7 ± 0.7	7	7	6.5 σ $\rightarrow$ 20 σ in IP7

Table 3: Summary of measured and simulated tune shift. The tune shifts have been renormalized to $N_b = 10^{11}$ ppb for better comparison with simulations.

Good agreement is achieved for B1 while B2 is less than predicted. As the tune shift is a monotonic function of Q', decreasing towards higher values of Q', the chance that Q' drifted towards higher values is supported by this observation.

3 Conclusions

Octupole current thresholds were measured and compared to the result from MD751 (for Q'=7/7 and secondary collimators at 8 σ, a nominal bunch became unstable at 70 A in the octupoles). Measurements from both beams showed large discrepancies with DELPHI simulations, possibly due to either altered transverse distributions or a mistake in the setting up of the MD. This MD will need to be repeated before any conclusions can be drawn.

The tune shift measurements were performed by varying the secondary collimators in IR7 between 6.5 σ and 20 σ. Measurements were obtained for the vertical plane for B1 and B2, but were unable to be made in the horizontal plane due to the tune signal being too noisy. Comparisons with simulations are in very good agreement for B1V. The tune shift in B2 is, instead, less than predicted as a probable consequence of a Q' drift.

4 Acknowledgments

We would like to acknowledge the LHC and injectors operators for their help during the machine setup and the collimation team for valuable discussions.

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5 Appendix

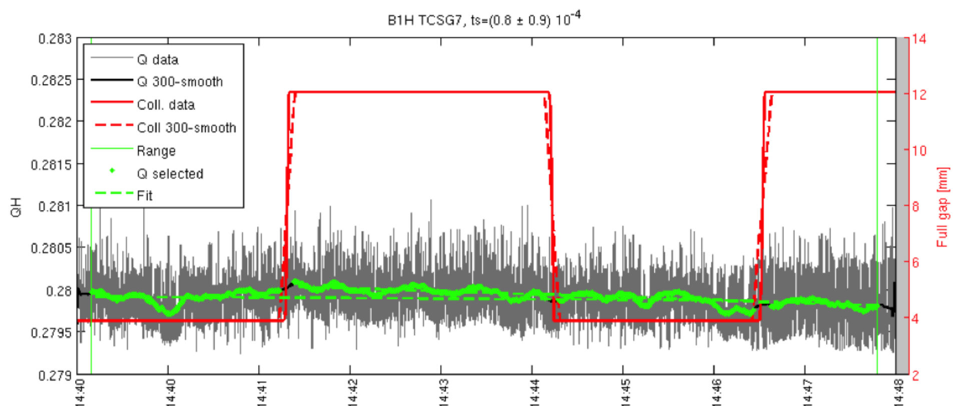

Figure 10: Measured tune shift for B1H when moving collimators between 6.5σ and 20σ. The red line shows the collimator position, the thin black line is the tune signal after NAFF processing, the thick black line is the moving average of the tune and the green lines highlight the difference in the average tune.

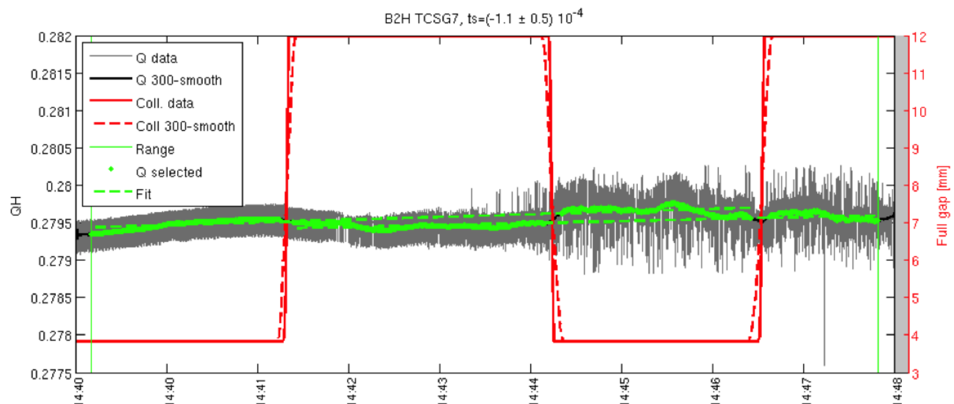

Figure 11: Measured tune shift for B2H when moving collimators between 6.5σ and 20σ. The red line shows the collimator position, the thin black line is the tune signal after NAFF processing, the thick black line is the moving average of the tune and the green lines highlight the difference in the average tune.