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alessio.mereghetti@cern.ch

MD1875 – Impedance Contribution of Single IR7 Secondary Collimators

A. Mereghetti / CERN, BE-ABP, D. Amorim / Université Grenoble Alpes (FR), ex CERN, BE-ABP, N. Biancacci / CERN, BE-ABP, L. R. Carver / University of Liverpool (UK), ex CERN, BE-ABP, E. Métral / CERN, BE-ABP, D. Mirarchi / CERN, BE-ABP, S. Redaelli / CERN, BE-ABP, R. Rossi / CERN, EN-STI, ex BE-ABP, B. Salvant / CERN, BE-ABP, M. Soderen / CERN, BE-RF

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Summary

This report summarises the results of MD1875 about impedance measurements of single LHC secondary collimators in IR7. The activity was carried out during MD block 5 of 2016, on 28th October. The impedance of each collimator was measured from the tune shift induced by cycling its gap. As done in previous measurements of the same kind, the tune was reconstructed from the damped oscillations of the beam when coherently kicked with the MKQA, in order to have a clearer signal. The same methodology was applied to crystals, measured during this MD activity for the first time since the LHC start-up. Due to the high level of losses while kicking and the consequent cut of tails, tune signals are not clean; therefore, measurements do not agree with expectations by a factor 2–3.

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1 Introduction

The LHC collimation system is responsible for a sizable fraction of the LHC impedance budget [1]. In order to accommodate increasingly smaller values of β^*, the operational settings of the collimators must be tightened, hence increasing their contribution to the machine impedance budget. Moreover, beams brighter than those presently available in the LHC, like those foreseen by the HL-LHC project [2], are more sensitive to impedance. Therefore, in view of pushed operational conditions of the LHC, it is important to know the actual contribution from collimators to impedance. Models of the LHC machine impedance and numerical simulations are fundamental predictive tools, and it is essential to benchmark simulation results against precise measurements with beam, either involving entire families of collimators or single devices.

Recent MD activities (i.e. MD314 [3] in 2015 and MD1447 [4] in 2016) were aimed at evaluating the impact on impedance from all the IR7 secondary (TCSG) collimators at 6.5 TeV.

These MD activities have been complemented in 2016 by other activities aimed at measuring the impact on impedance from single collimators; while MD1446 [5] was focussed on the primary (TCP) collimators only, the activity here presented is focussed on the IR7 secondary (TCSG) collimators only. In addition, for the first time since the LHC start-up, the impedance of the crystals installed on beam 1 (B1) was measured with beam.

2 Procedure and Beam Conditions

The impact on impedance was quantified by measuring the tune shift induced on the beam when varying the gap of the IR7 TCSG collimators. The expected tune shift is smaller than the resolution of the BBQ measurements. Hence, the same procedure as that tested in MD1446 [5] was deployed, i.e. the beam was coherently kicked with the tune kicker (MKQA) [6] and the tune was reconstructed from the damped oscillations observed with the ObsBox [7].

The MD activity was carried out on the night between 27th and 28th October [8] 2016, at 6.5 TeV. The optics at flat top was used, at the end of the "combined ramp and squeeze" beam process (i.e. without tune change, or squeezing beams down to β^*=40 cm but remaining at 3 m, or collapsing the bumps for parallel separation at the interaction points, IPs), since the settings of the IR7 collimators do not change throughout these machine configurations. The activity was carried out with the time left by MD1878 [9] on tight collimator settings; hence, measurements had to be performed quickly, with relevant consequences on the quality of data (see Sec 3). In fact, there was no time available either to verify optimum centring of measured collimators or to carefully set the amplitude of the kicks such that minimal losses were induced while still recording sound data.

Figure 1 gives an overview of the main activities carried out during the MD. After a brief period spent at injection energy to set up the MKQA, two fills were carried out. In the first one, impedance measurements were dedicated to the two crystals of B1 at injection energy. Losses while kicking were high, with consequent degradation of the beam quality; hence, it was decided to dump the beams and re-fill the machine, as B1 was no longer usable. The second fill was dedicated to impedance measurements at flat top, first with the crystals, and then with the TCSGs. Losses while kicking were anyway high, and, similarly to before, the quality of the beams degraded rapidly.

Measurements were carried out with two nominal bunches, decreased ADT gain, chromaticity lowered down to 5 on both beams and planes (from the operational value of 15), and the octupole current set to 470 A (knob set at -0.5). The measurements of the crystals were performed cycling their positions between 6.5 σ and 15 σ and between 6.5 σ and 20 σ at injection and at flat top energies, respectively. The measurements of the TCSGs were performed cycling their half–gaps them between 6.5 and 10 σ. There was not enough time to measure each TCSG collimator; therefore, the TCSGs with the expected largest and smallest impact on impedance were selected. Table 1 summarises the tune shifts of the IR7 TCSG collimators of B1 as expected from simulations [10], ordered by increasing value of expected tune shift. The collimators actually measured are highlighted in blue.

The filling scheme used for the activity was the `Single_3b_0_0_0_CollimationImpedance`, already used in MD1446 [5]. Such a filling scheme can host up to three nominal bunches, in buckets 1, 361 and 721 on B1, and 71, 431 and 791 on B2. Moreover, it allows to have non-colliding bunches affected by the same MKQA timing window, with only the first bunch in the witness region.

The synchronisation delays of the MKQA were set at 63.1 and 30.5 μs for B1 and B2, respectively, further optimising what previously used in MD1446 [5] and MD1447 [4]. Figure 2

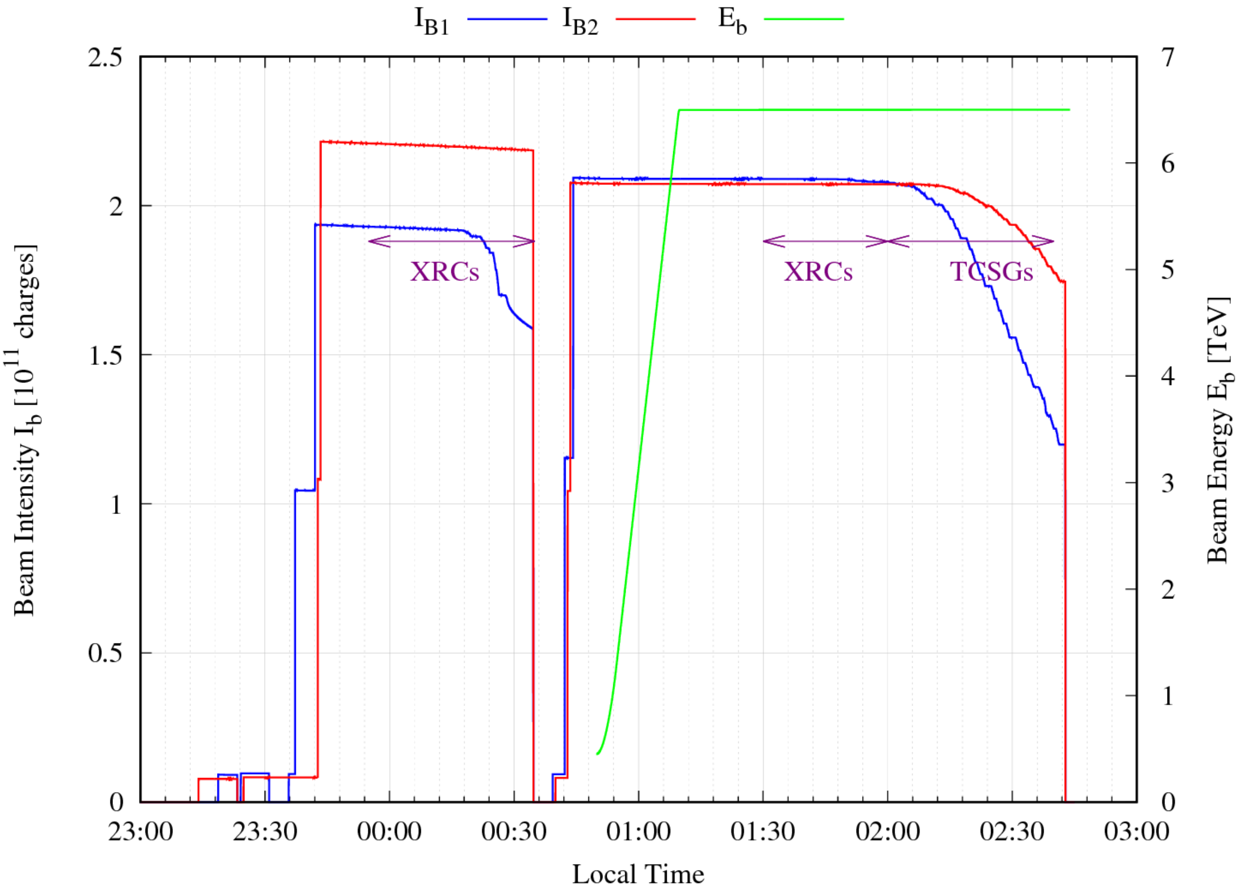


Figure 1: Intensity of B1 (blue curve) and B2 (red curve) as read by the fast beam current transformer (BCTFR) and beam energy (green curve) during the presented MD activity. The time periods of the main activities carried out are highlighted, namely: impedance measurements of crystals (labelled as "XRCs") and impedance measurements of IR7 secondary collimators (labelled as "TCSGs").

shows the achieved synchronisation of the MKQA to the circulating bunches.

3 Results of Impedance Measurements

The measurement procedure and data analysis are similar to those used for the single primary collimators impedance measurement described in [5]. The tune is computed from the bunch-by-bunch and turn-by-turn transverse position data recorded with the ADTObsBox [7] with PySUSSIX [11], the python wrapper for SUSSIX [12]. The first 800 turns of data after the beam excitation were used, this length corresponding to the decoherence time of transverse oscillations.

The top plots of Fig. 3 show the time evolution of the tune during the MD, plotted alongside the secondary collimators physical gaps. The left plot presents data for B1H and the right plot for B2V. The middle and bottom plots show the evolution of the bunch length and bunch intensity, respectively. The data for only one out of the two bunches present in each beam is plotted.

For all bunches, a drift of the tune is clearly visible for the entire duration of the measurements. Nevertheless, a tune variation can be seen when the gaps of some TCSGs are changed. The tune shift caused by an individual collimator is computed by subtracting the tune when the collimator is in the open position to the tune when it is in close position.

Table 1: Tune shifts of the IR7 TCSG collimators of B1 as expected from simulations [10]. The plane where the highest tune shifts are expected is indicated in the last column. Values are listed in increasing order. The collimators actually measured are highlighted in blue.

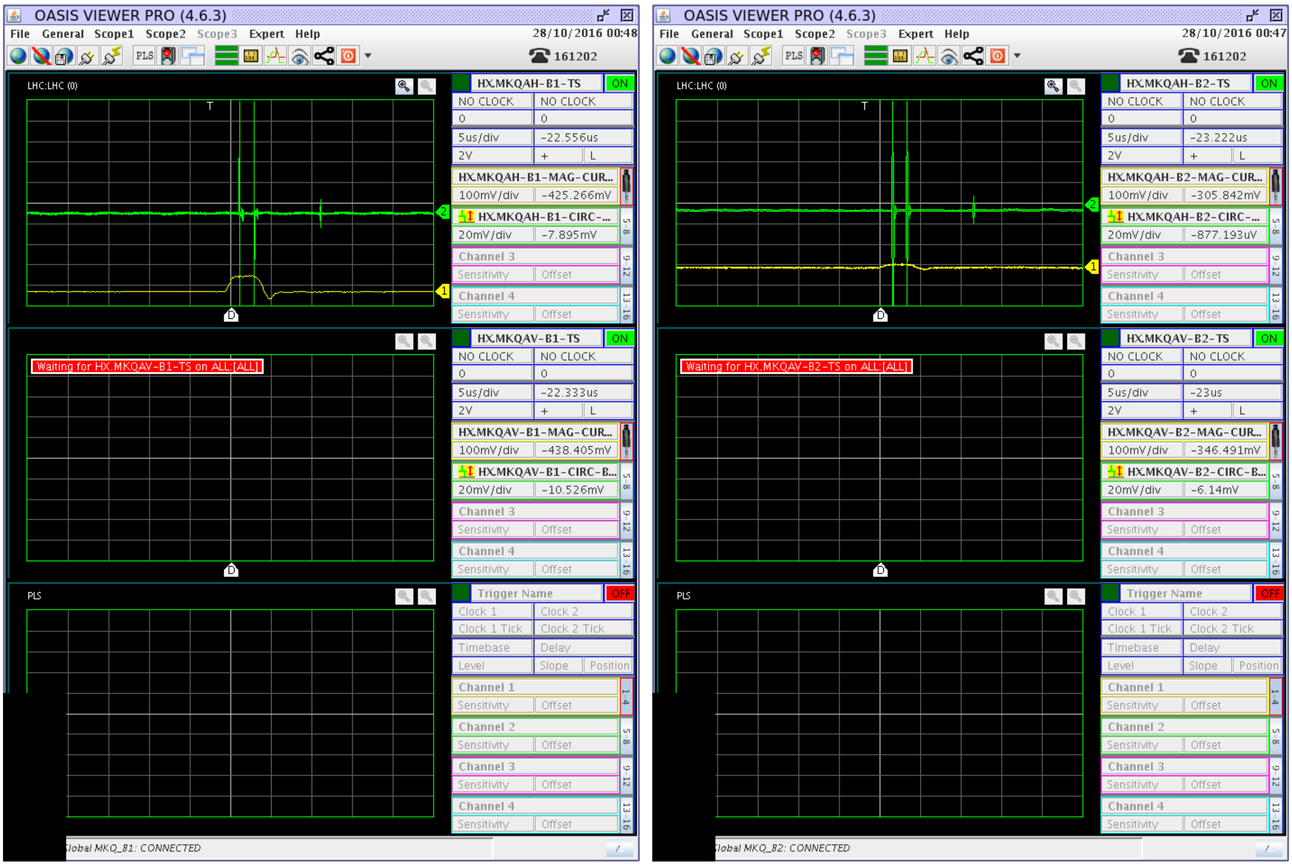
Coll. Name	ΔQ [10^{-5}]	plane
TCSG.D5R7.B1	1.13	V
TCSG.E5R7.B1	1.19	H
TCSG.B5R7.B1	1.23	V
TCSG.A4L7.B1	1.29	V
TCSG.A5L7.B1	1.38	H
TCSG.B5L7.B1	1.41	H
TCSG.A4R7.B1	1.42	V
TCSG.6R7.B1	1.56	H
TCSG.A6L7.B1	2.08	V
TCSG.B4L7.B1	2.39	H
TCSG.D4L7.B1	3.36	V

Because of the limited time of the MD activity, the kick amplitude imparted to the beam for taking measurements was not carefully set up. Therefore, the transverse excursion of the beam at each excitation caused large intensities losses on all bunches. At the end of the measurements, the bunches had lost between 14% and 47% of their initial intensity. The RMS bunch length also appears to shrink (see Fig. 3, lower frames). These heavy losses and bunch shortening significantly affected the tune measurement. As a consequence, the measured tune shifts show large fluctuations from one measurement to another and poor agreement with simulations. The simulated tune shifts are obtained using the LHC impedance model [13] with the real TCSG gaps retrieved from the CERN Accelerator Logging Service with pytimber [14], to better reproduce the real machine conditions.

The ratio of the measured tune shift and the predicted tune shift for the tested collimators are plotted in Fig. 4. The complete results are presented in [15] and show large discrepancies for all beams and planes.

The measurement of TCSG.D4L7.B1 and TCSG.D4R7.B2 carried out during MD 1447 [4] and MD 2193 [16] showed much better agreement between measurements and predictions. Contrary to the activity presented here, during these MDs there was time to carefully set the amplitude of the kicks imparted to the beam for taking data, lowering the intensity of losses and hence obtaining more reliable tune shift measurements.

The tune shifts induced by the two crystal collimators installed on B1 were also measured with the same method as that used for the secondary collimators. Because of the small length of the device, small tune shifts are expected. Moreover, in normal operation these devices are kept in parking position and shielded from the beam. The tune shifts at injection energy are shown in Fig. 5. As for the case of the TCSGs, the devices were moved close to the beam and then away from it several times, while the transverse tune was recorded. Two measurement cycles were performed. A measurement at top energy was also carried out but with only one in–out cycle; the resulting tune shift is shown in Fig. 6. As it can be seen from both figures, the tune shifts induced by the crystal collimators are very small and can be neglected when compared to other sources such as the collimators.



OASIS VIEWER PRO (4.6.3) — 28/10/2016 00:48 — ☎ 161202

LHC:LHC (0)

HX.MKQAH-B1-TS ON
NO CLOCK | NO CLOCK
0 | 0
5us/div | -22.556us
2V | + | L
HX.MKQAH-B1-MAG-CUR...
100mV/div | -425.266mV
HX.MKQAH-B1-CIRC-...
20mV/div | -7.895mV
Channel 3
Sensitivity | Offset
Channel 4
Sensitivity | Offset

Waiting for HX.MKQAV-B1-TS on ALL:[ALL]

HX.MKQAV-B1-TS ON
NO CLOCK | NO CLOCK
0 | 0
5us/div | -22.333us
2V | + | L
HX.MKQAV-B1-MAG-CUR...
100mV/div | -438.405mV
HX.MKQAV-B1-CIRC-B...
20mV/div | -10.526mV
Channel 3
Sensitivity | Offset
Channel 4
Sensitivity | Offset

Trigger Name OFF
Clock 1 | Clock 2
Clock 1 Tick | Clock 2 Tick
Timebase | Delay
Level | Slope | Position
Channel 1
Sensitivity | Offset
Channel 2
Sensitivity | Offset
Channel 3
Sensitivity | Offset
Channel 4
Sensitivity | Offset

[redacted] lobal MKQ_B1: CONNECTED

OASIS VIEWER PRO (4.6.3) — 28/10/2016 00:47 — ☎ 161202

LHC:LHC (0)

HX.MKQAH-B2-TS ON
NO CLOCK | NO CLOCK
0 | 0
5us/div | -23.222us
2V | + | L
HX.MKQAH-B2-MAG-CUR...
100mV/div | -305.842mV
HX.MKQAH-B2-CIRC-...
20mV/div | -877.193uV
Channel 3
Sensitivity | Offset
Channel 4
Sensitivity | Offset

Waiting for HX.MKQAV-B2-TS on ALL:[ALL]

HX.MKQAV-B2-TS ON
NO CLOCK | NO CLOCK
0 | 0
5us/div | -23us
2V | + | L
HX.MKQAV-B2-MAG-CUR...
100mV/div | -346.491mV
HX.MKQAV-B2-CIRC-B...
20mV/div | -6.14mV
Channel 3
Sensitivity | Offset
Channel 4
Sensitivity | Offset

Trigger Name OFF
Clock 1 | Clock 2
Clock 1 Tick | Clock 2 Tick
Timebase | Delay
Level | Slope | Position
Channel 1
Sensitivity | Offset
Channel 2
Sensitivity | Offset
Channel 3
Sensitivity | Offset
Channel 4
Sensitivity | Offset

[redacted] lobal MKQ_B2: CONNECTED

Figure 2: Synchronisation between the MKQA kick and the circulating beam: B1 is shown in the left frame, whereas B2 is shown in the right one.

4 Conclusions

Challenging measurements of tune shift induced by cycling the gap of single TCSG collimators in IR7 at flat top were carried out; the beams were coherently kicked with the MKQA in order to reconstruct the tune from the damped oscillations; each measured collimator was opened and closed in cycles, to appreciate the difference in tune between the two extreme configurations. At the beginning of the MD activity, the same procedure was applied at injection and flat top energy to the two crystals mounted on B1. Due to the limited time available for this MD activity, there was almost no time either to verify optimum centring of measured collimators or to carefully set the amplitude of the kicks such that minimal losses were induced while still recording sound data; hence, measurements had to be performed quickly, with relevant consequences on the quality of data. In fact, even after intense post–processing, the collected data for the secondary collimators do not fit the expectations from simulations by a factor 2–3, the main reason being the degradation of the beams due to tails being cut while kicking. Re–conducting the impedance measurement with a better control of the beam quality would help to check the model of these major contributors to the LHC impedance. The tune shifts measured with the crystal collimators were found very small and can be neglected when compared to other sources such as the collimators.

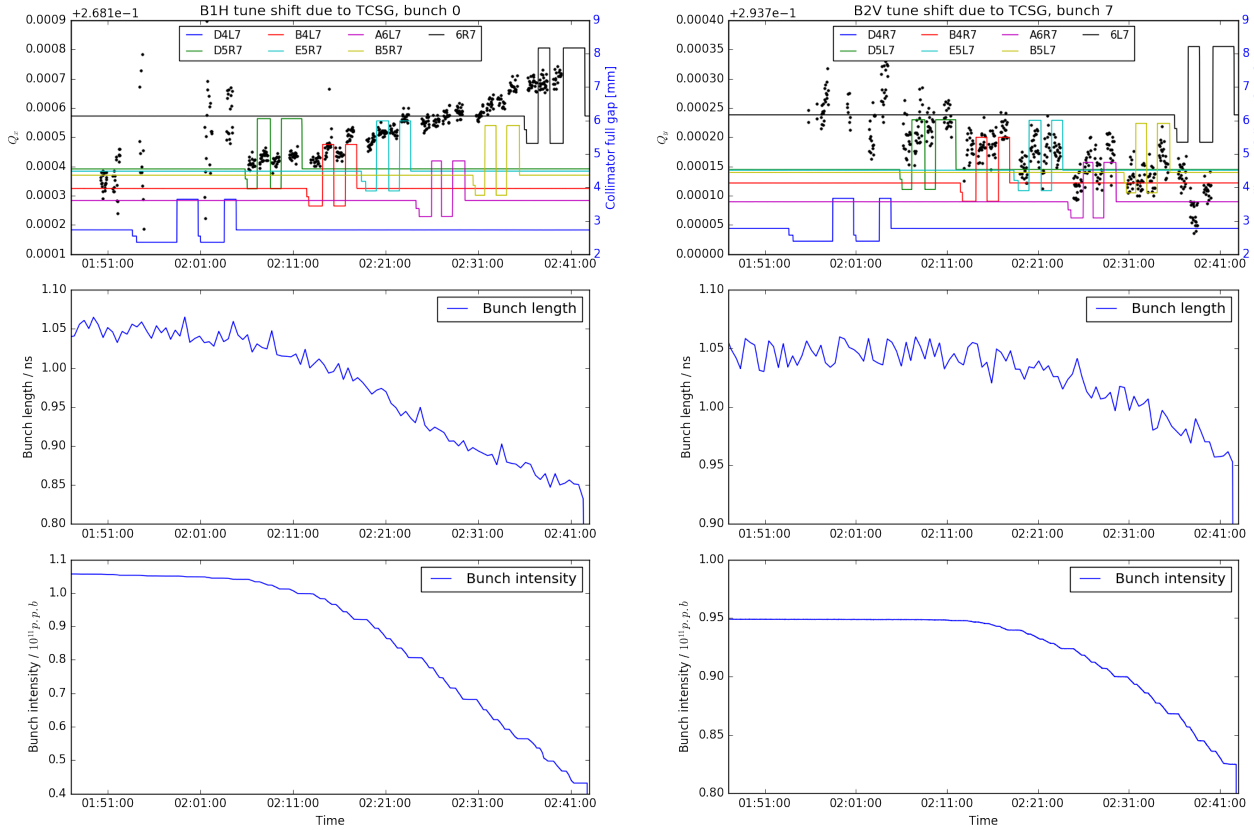


Figure 3: Overview of the evolution of the tune and of beam parameters during the impedance measurements. The top plots show the evolution of the horizontal and vertical tunes (black dots) alongside the collimator positions (curves in solid colors). The middle plots show the evolution of the bunch length, and the bottom plots depict the evolution of the bunch intensity. Only one bunch is presented for each beam, with B1 data on the left and B2 data on the right.

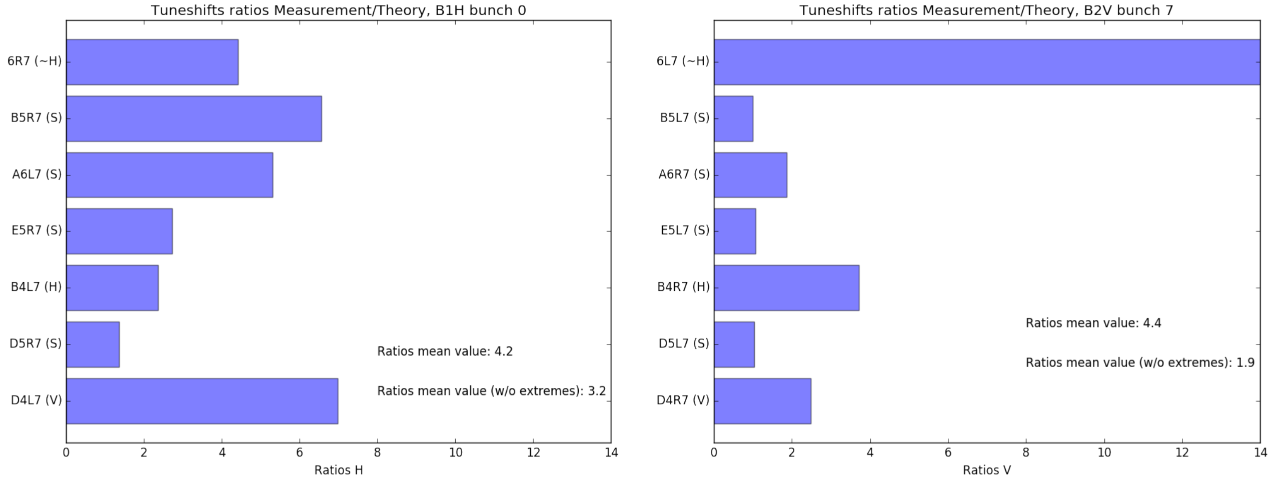


Figure 4: Ratios of the measured tune shifts to that predicted by impedance simulations. The left plot is for B1H and the right plot for B2V. The data from only one bunch is shown.

Acknowledgements

We would like to thank the OP crew, and in particular K. Fuchsberger and G. Crockford, for their assistance during the MD activity.

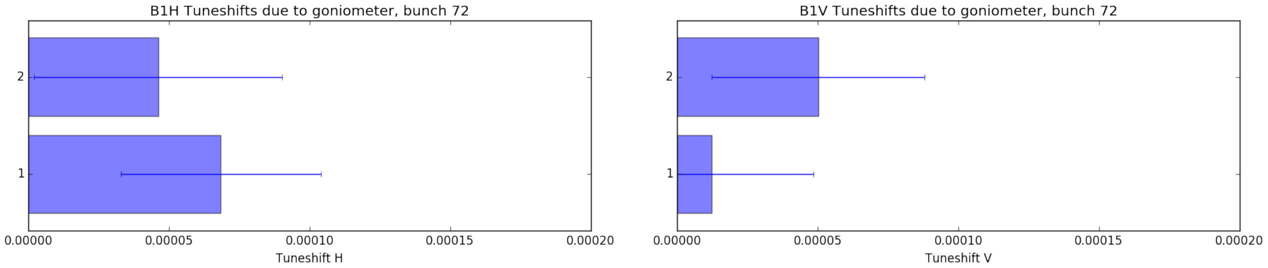


Figure 5: Tune shifts induced by cycling the B1 crystals at injection energy, i.e. 450 GeV.

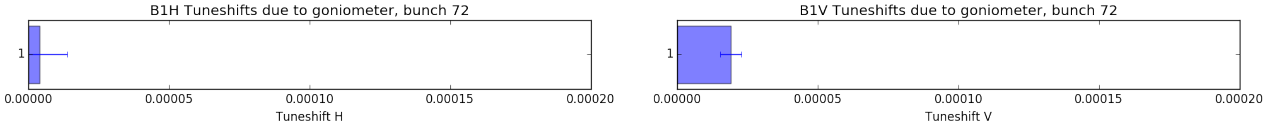


Figure 6: Tune shifts induced by cycling the B1 crystals at flat top energy, i.e. 6.5 TeV.

References

[1] N. Mounet *et al.*, in *Proc. IPAC'13*, pp. 1817–1819.

[2] G. Apollinari *et al.* (eds.), "High Luminosity Large Hadron Collider (HL-LHC) Technical Design Report V.01", CERN, Geneva, Switzerland, Rep. CERN–2017–007–M, Sep. 2017. `https://cds.cern.ch/record/2284929?ln=en`

[3] A. Mereghetti *et al.*, "β^*–Reach – IR7 Collimation Hierarchy Limit and Impedance", Rep. CERN–ACC–NOTE–2016–0007 (2016), CERN, Geneva, Switzerland, `https://cds.cern.ch/record/2120132`

[4] A. Mereghetti *et al.*, "MD1447 – β^*–Reach: 2016 IR7 Collimation Hierarchy Limit and Impedance", Rep. CERN–ACC–NOTE–2020-0021 (2020), CERN, Geneva, Switzerland, `https://cds.cern.ch/record/2715361`

[5] A. Mereghetti *et al.*, "MD1446 – β^*–Reach: Impedance Contribution of Primary Collimators", Rep. CERN–ACC–NOTE–2020–0020 (2020), CERN, Geneva, Switzerland, `https://cds.cern.ch/record/2715360`

[6] R. Barlow *et al.*, "Control of the MKQA tuning and aperture kickers of the LHC", Rep. TE–Note–2010–002 (2010), CERN, Geneva, Switzerland, `https://cds.cern.ch/record/1232062`

[7] M. Soderen, D. Valuch, "ADT ObsBox Data Acquisition", presentation at the LHC Beam Operation Committee, 13th June 2017, CERN, Geneva, Switzerland, `https://indico.cern.ch/event/645898`

[8] LHC OP elogbook, night shift of 27th October 2016, `https://ab-dep-op-elogbook.web.cern.ch/ab-dep-op-elogbook/elogbook/secure/eLogbook.php?shiftId=1081054`

[9] D. Mirarchi *et al.*, "MD1878: Operation with Primary Collimators at Tighter Settings", Rep. CERN–ACC–NOTE–2017–0014 (2017), CERN, Geneva, Switzerland, `https://cds.cern.ch/record/2254674`

[10] N. Biancacci *et al.*, “Collimator impedance: are tighter settings allowed for impedance?”, presentation at the Collimation Working Group, 7th November 2016, CERN, Geneva, Switzerland, `https://indico.cern.ch/event/585875/`

[11] PySUSSIX code repository, `https://github.com/PyCOMPLETE/PySUSSIX`

[12] R. Bartolini, F. Schmidt, “A Computer Code for Frequency Analysis of Non-Linear Betatron Motion”, Rep. SL–Note–98–017–AP (1998), CERN, Geneva, Switzerland, `https://cds.cern.ch/record/702438`

[13] N. Mounet, “The LHC Transverse Coupled-Bunch Instability”, EPFL PhD Thesis 5305 (2012).

[14] Pytimber repository, `https://github.com/rdemaria/pytimber`

[15] D. Amorim, “Summary of collimators tune shift measurement campaigns”, presentation at the 91st Collimation Upgrade Specification Meeting, 11th August 2017, CERN, Geneva, Switzerland, `https://indico.cern.ch/event/657903/`

[16] A. Mereghetti *et al.*, “MD2193 – Impedance Measurements of TCSPM Collimator”, report in preparation.