CERN–ACC–NOTE–2020–0020 MD

April 17, 2020

alessio.mereghetti@cern.ch

MD1446 – β^*–Reach: Impedance Contribution of Primary Collimators

A. Mereghetti / CERN, BE-ABP, D. Amorim / Université Grenoble Alpes (FR), ex CERN, BE-ABP, N. Biancacci / CERN, BE-ABP, M. Fiascaris / CERN, HR-LD, ex BE-ABP, E. Métral / CERN, BE-ABP, S. Redaelli / CERN, BE-ABP, B. Salvant / CERN, BE-ABP, M. Soderen / CERN, BE-RF

Keywords: LHC, collimator settings, cleaning inefficiency, loss maps, impedance

---

Summary

This report summarizes the results of MD1446 on impedance measurements of single primary collimators. The measurements were carried out during MD block 3 of 2016, on the night between 10th and 11th September. The impedance of each collimator was measured from the tune shift induced by varying the collimator gap. In order to have a clearer signal, the tune was reconstructed from damped oscillations of the beam, coherently kicked with the tune kicker, as done in previous MD activities. The results are in close agreement with expectations. Another method of kicking the beam was tested at the end of the MD, i.e. via the ADT; this alternative method proved to offer flexibility and precision higher than the former, paving the way to future measurements of the same kind. The merit of this MD activity is related to the possibility of tightening the collimator settings, to accommodate smaller values of β^* in the LHC.

---

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, with the consequent side effect of increasing their contribution to the machine impedance budget. Moreover, the stability of beams brighter than those presently available in the LHC, like those foreseen by the HL–LHC project [2], is more sensitive to impedance. Therefore, in view of pushed operational conditions of the LHC, and in particular in the continuous quest for smaller values of β^*, 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.

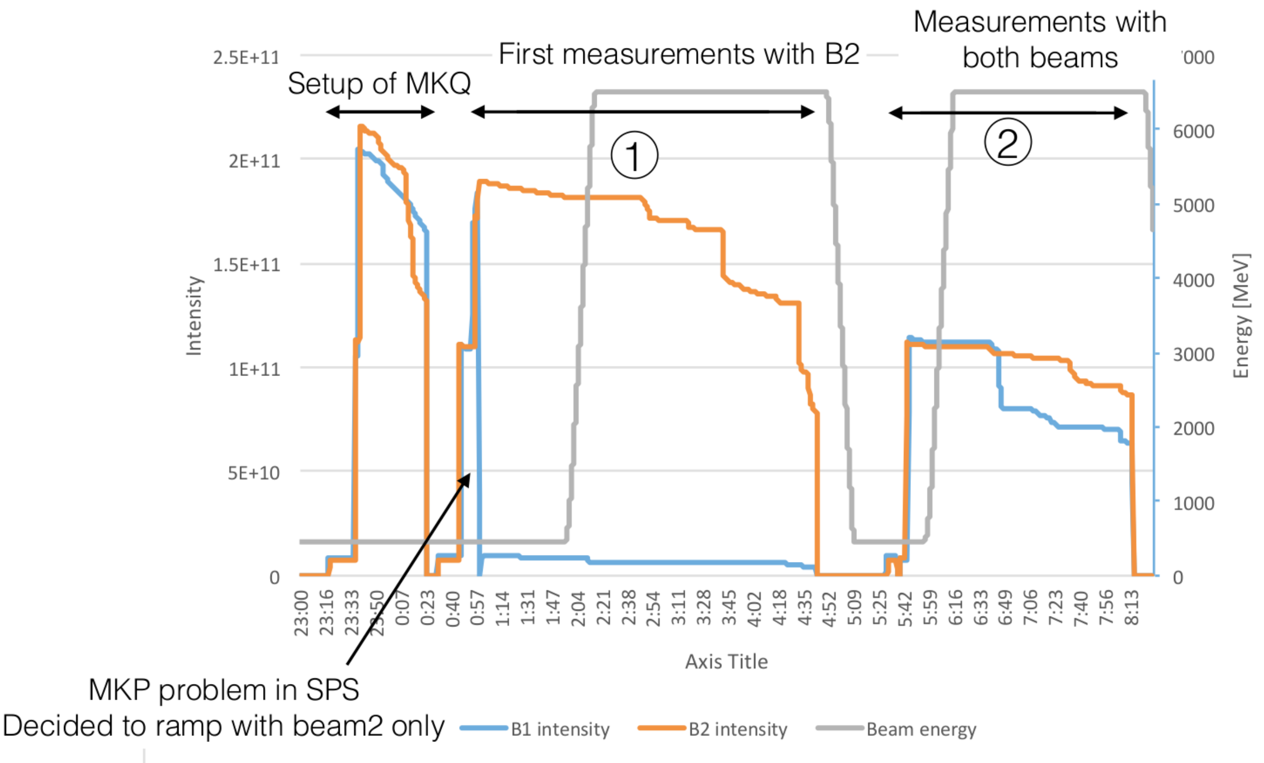


Figure 1: Intensity of B1 (light blue curve) and B2 (orange curve) and beam energy (grey curve) during the presented MD activity. The time periods of key activities carried out are highlighted.

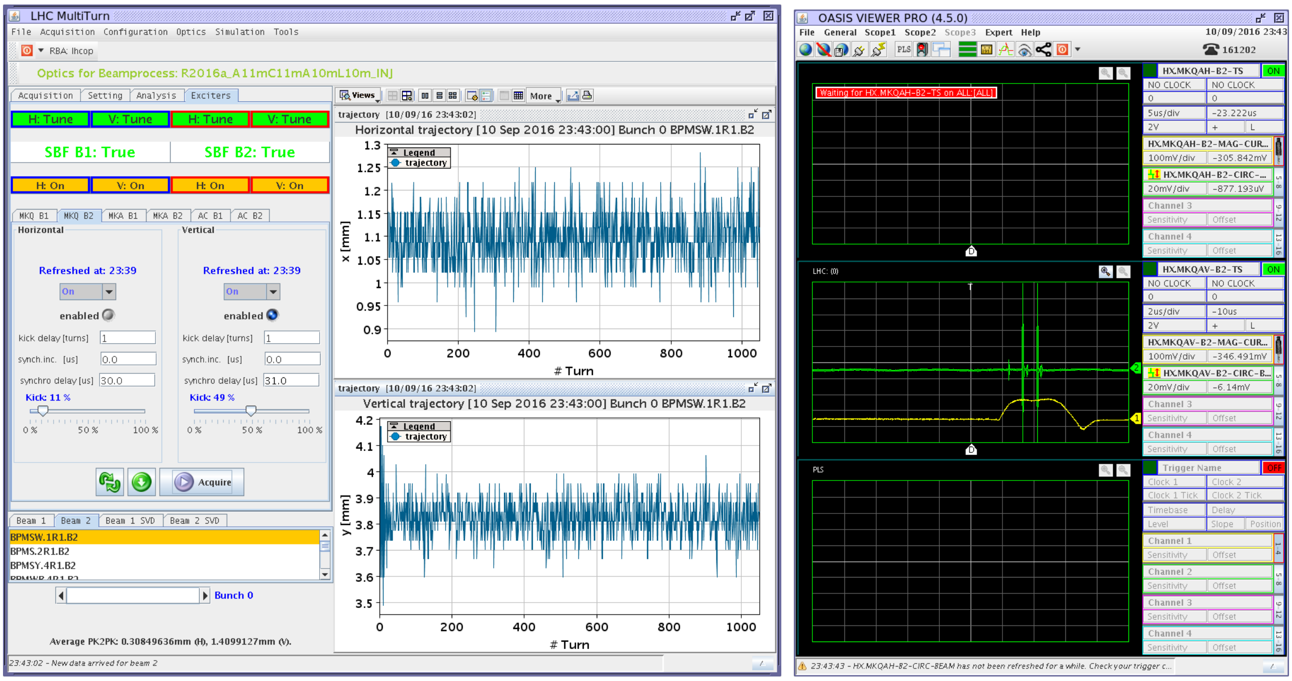
Recent MD activities (i.e. MD314 [3] in 2015 and MD1447 [4] in 2016) were aimed at evaluating the impact on impedance from all the IR7 secondary (TCSG) collimators at 6.5 TeV; contrary to past MD activities, the present one is aimed at measuring the impact on impedance from single collimators; in particular, the focus of this MD activity is on the primary (TCP) collimators. Even though they are shorter and fewer in number, TCP collimators have an impact on the LHC impedance budget similar to that of TCSG collimators, because of their small gaps.

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 TCP collimators. Since the expected tune shift is smaller than the resolution of BBQ measurements, the same procedure as that tested in MD1446 was deployed, i.e. the beam was coherently kicked with the tune kicker (MKQA) [5] and the tune was reconstructed from the damped oscillations observed with the ObsBox [6]. The main set of measurements obtained with the MKQA were complemented with measurements performed kicking the beam with the transverse damper (ADT) in AC–dipole mode [7]. This technique is characterised by a very flexible control of the characteristics of the applied kick, like intensity, time profile, and bucket window.

The MD activity was carried out on the night between 10th and 11th September [8, 9] 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.

Figure 1 shows an overview of the main activities carried out during the MD. After a brief



Optics for Beamprocess: R2016a_A11mC11mA10mL10m_INJ

SBF B1: True

SBF B2: True

Horizontal: Refreshed at: 23:39; On; enabled; kick delay [turns] 1; synch.inc. [us] 0.0; synchro delay [us] 30.0; Kick: 11 %

Vertical: Refreshed at: 23:39; On; enabled; kick delay [turns] 1; synch.inc. [us] 0.0; synchro delay [us] 31.0; Kick: 49 %

BPMSW.1R1.B2
BPMS.2R1.B2
BPMSY.4R1.B2

Bunch 0

Average PK2PK: 0.30849636mm (H), 1.4099127mm (V).

23:43:02 - New data arrived for beam 2

Horizontal trajectory [10 Sep 2016 23:43:00] Bunch 0 BPMSW.1R1.B2

Vertical trajectory [10 Sep 2016 23:43:00] Bunch 0 BPMSW.1R1.B2

10/09/2016 23:43

☎ 161202

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

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

HX.MKQAV-B2-TS ON; NO CLOCK, NO CLOCK; 0, 0; 2us/div, -10us; 2V, +, L
HX.MKQAV-B2-MAG-CUR... 100mV/div, -346.491mV
HX.MKQAV-B2-CIRC-B... 20mV/div, -6.14mV

Trigger Name OFF

23:43:43 - HX.MKQAH-B2-CIRC-BEAM has not been refreshed for a while. Check your trigger c...

Figure 2: B2 MKQA settings used for the tune shift measurements.

period spent at injection energy to set up the MKQA, two ramps were carried out:

First ramp measurements were carried out with two nominal bunches of 0.6 and 1.2 10^{11} protons per bunch. Only B2 could be ramped, since the first injection of B1 was dumped (not satisfactory normalised emittances), and the following issue with the SPS extraction kicker of B1 (MKP) prevented beam from being injected in the LHC. The chromaticity was lowered down to 5 on both beams and planes (from the operational value of 15); the octupole current was reduced to 250 A. Prior to the measurements, the re-alignment to the beam of the TCP collimators was performed, to guarantee optimum centering during the measurements. Tune shifts were measured varying the TCP gaps between 3.5 σ and 6 σ. At the end of the impedance measurements, once the beam was fully degraded, loss maps with the same TCP openings as the innermost ones explored in measurements (i.e. 3.5 σ) were carried out, and then the beams were dumped.

Second ramp measurements were carried out with only a nominal bunch of 1.2 10^{11} protons per bunch. In order to have cleaner tune shifts, beam scraping was performed with the measured collimator prior to the actual measurements. The very first trial was to scrape down to 3.5 σ, for carrying out impedance measurements with 3.7 σ as closest position, but instabilities arose. Hence, it was decided to scrape down to 3.8 σ only, and perform measurements with 4 σ as the smallest gap and 5.5 σ (i.e. the operational gap) as the largest gap. The second ramp was closed by testing beam kicking with the ADT instead of the MKQA; this mechanics was demonstrated to be reliable and reproducible.

The filling scheme used for the activity was the `Single_3b_0_0_0_CollimationImpedance`, prepared on purpose [10]. 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. Such a filling scheme 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 (see Fig. 2, for instance) of the MKQA were set more accurately than what done in MD1447, also enabling kicking on the horizontal plane. The delays were set

Table 1: Collimator settings in IR7 deployed in loss maps (LMs) and during operation.

	family	LMs [σ]	2016 OP [σ]
IR7	TCP / TCSG / TCLA	3.5 / 5.5 / 8	5.5 / 7.5 / 11
IR3	TCP / TCSG / TCLA	15 / 18 / 20	

to 74/30 μs and 64.1/31 μs for B1H/B2H and B1V/B2V, respectively. These correspond to centering the plateau of the MKQA kick at the second nominal bunch.

All the impedance measurements were carried out with the TCSGs at 10 σ (for comparison, their operational settings in 2016 were 7.5 σ) and TCLAs at 11 σ (the same settings as those of 2016 operation). Moreover, measurements involved not only IR7 TCPs but also those in IR3. In the first set of impedance measurements, all IR7 TCPs were kept at the innermost position and only one opened and closed in cycles. In the second set, only one TCP at a time was varied in gap, with the others kept at the largest gap. Prior to the impedance measurements, TCP centres were verified and found to be less than 50 μm off the values set during the 2016 initial commissioning [11], a result that can be regarded as fully satisfactory.

At the end of the first ramp, betatron loss maps were carried out on B2 with 2 σ-retractions between TCPs and TCSGs and the same TCP settings as the innermost ones explored in measurements (i.e. 3.5 σ, see Tab. 1). The regular pattern of B2 loss maps at the end of the ramp is visible [12] (see Fig. 3), but with an improved maximum cleaning inefficiency in the dispersion suppressor (DS) immediately downstream of IR7 by a factor 3–4, thanks to the tighter TCP settings.

3 Results of Impedance Measurements

The tune reconstruction from the bunch-by-bunch and turn-by-turn transverse position data recorded with the ADT ObsBox [7] was performed with PySUSSIX [13], a Python wrapper to SUSSIX [14]. The data of the first 1000 turns after the bean excitation were used. This window length corresponds to the de–coherence time of the transverse oscillation.

In the top plots of Fig. 4 the tune evolution along the MD, in black dots, is plotted alongside the primary collimator gaps, in solid color curves for the vertical planes of Beam 1 and 2. A clear drift of the tune is visible over the 1h30m duration of the measurements. However, a tune variation is noticeable when a TCP gap is changed. Subtracting the tune measured when the collimator is in open position to the one when it is in close position, the tune shift caused by an individual collimator can be computed.

Because of the transverse excursion of the beam during kicking, large intensities losses were observed at the beginning of the procedure on B1 (see Fig. 4, bottom plot). On B2 losses were more moderate when the kicks were applied. These losses did not compromise the tune shift measurements but they should be minimized in the future to avert possible effects on the tune measurement.

The tune shifts measured during the MD were compared to predictions from the LHC impedance model. The impedance simulations were performed using the real TCP gaps retrieved from the CERN Accelerator Logging Service with pytimber [15] in order to better fit the machine conditions. A reasonable agreement is found between simulations and measurements, save for the TCP.C6[L/R]7, for which a factor 1.2 to 2 exists between measurements and simulations. Figure 5 shows the measured and simulated tune shifts for the collimators measured during the MD. Some collimators were measured several times in a row, each blue

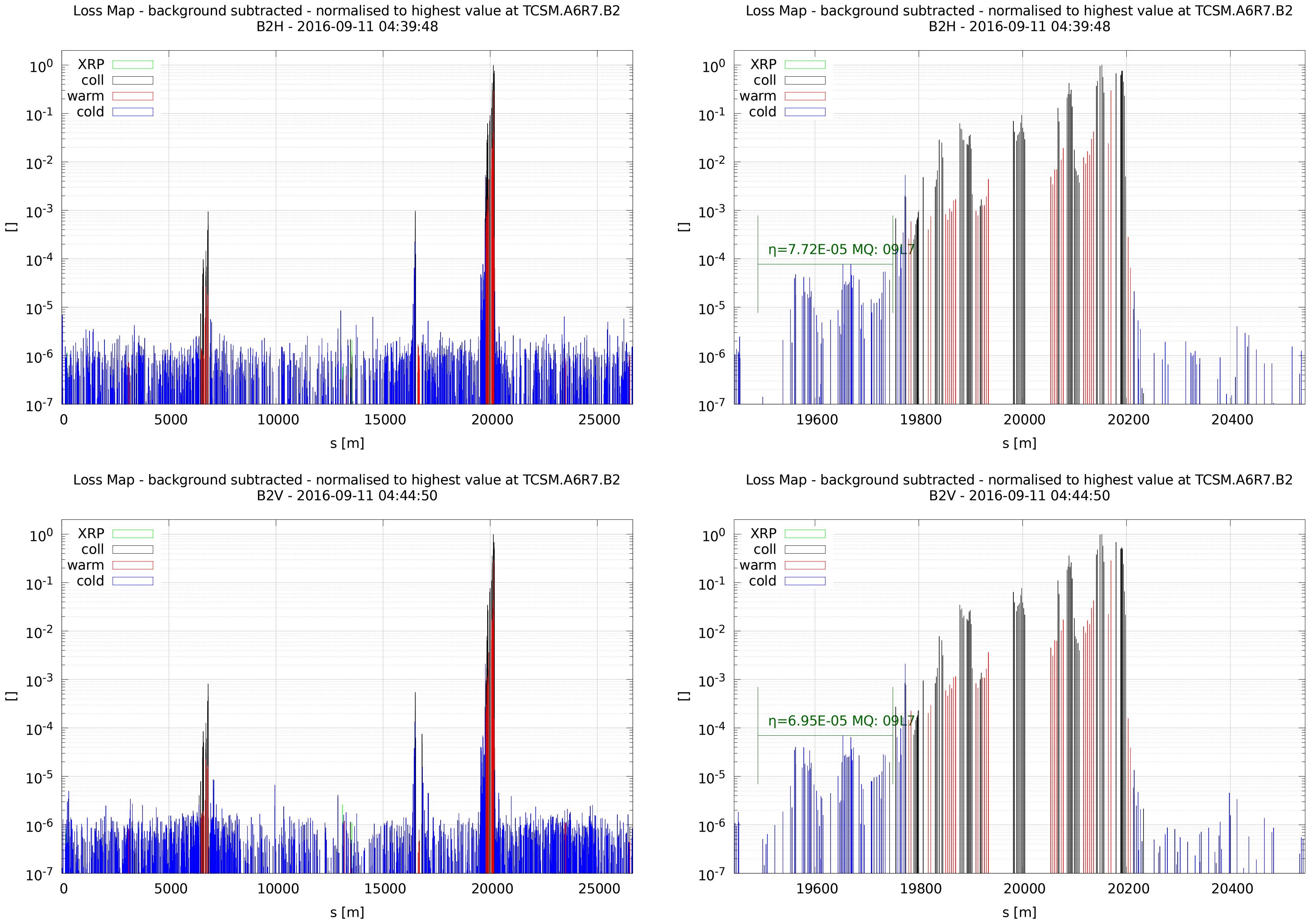


Figure 3: B2H (upper frames) and B2V (lower frames) qualification loss maps with 2 σ-retraction and the same TCP settings as the innermost ones explored in measurements (i.e. 3.5 σ).

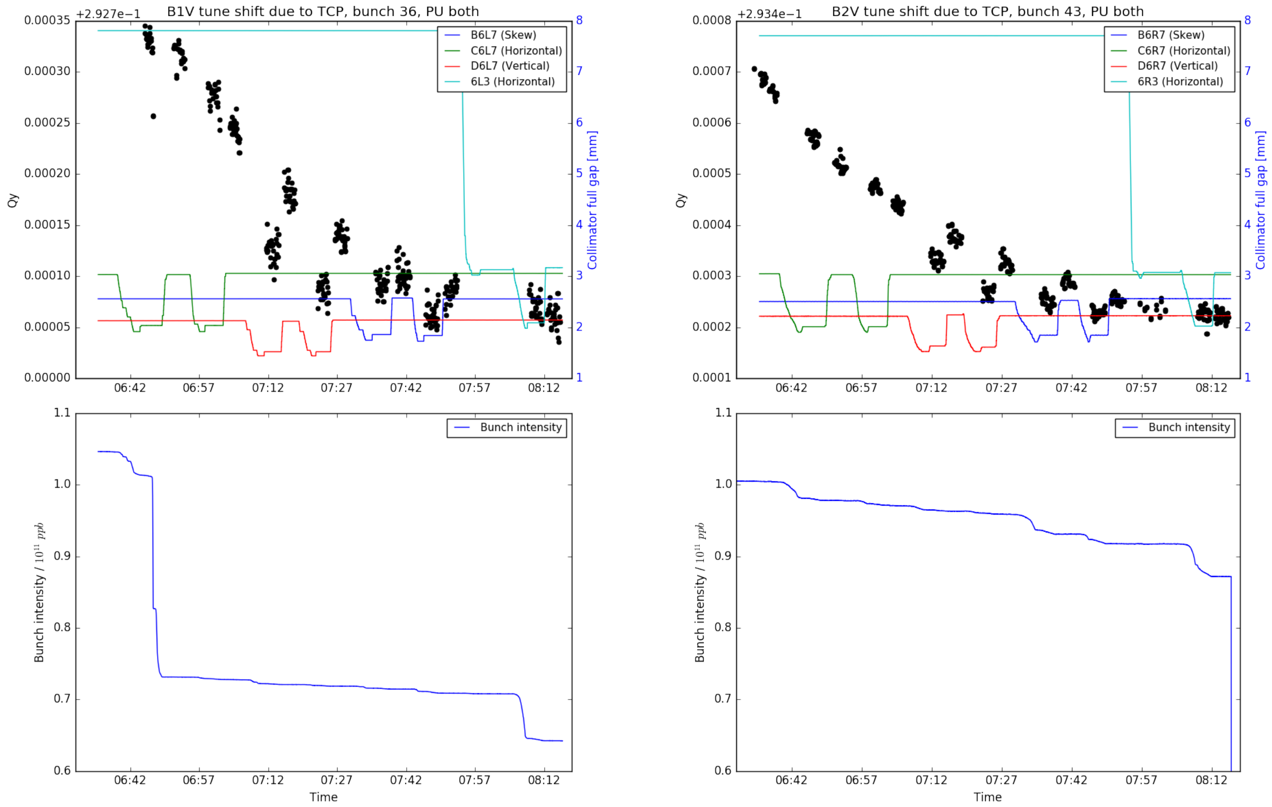


Figure 4: Overview of the tune shift measurements. The top plots represent the vertical tune evolution during the MD alongside the collimators position. The bottom plots show the bunch intensity evolution. Beam 1 data is presented on the left, Beam 2 data on the right.

bar figures the result of one measurement. A good reproducibility of the measured tune shift was achieved between each measurement of the same collimator. The analysis and the results are further detailed in [16].

4 Conclusions

Challenging measurements of tune shift induced by changing the gap of single TCP collimators 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.

The collected data reasonably fit the expectations from simulations, proving the maturity of the impedance model. The only exception is the TCP.C6[L/R]7, for which a factor 1.2 to 2 exists between measurements and simulations.

At the end of the MD activity, measurements were quickly taken with the same procedure but kicking the beam with the ADT instead of the MKQA; the new method proved to be as reliable as the original one, with much larger flexibility.

First loss maps with the tightest TCP settings considered in this activity (i.e. 3.5 σ) and 2-σ TCP–TCSG retraction were taken; the achieved cleaning performance is better than that achieved with operational settings. In order to deploy settings so much tighter than the operational ones, the octupole current necessary to stabilise the beam should be carefully assessed.

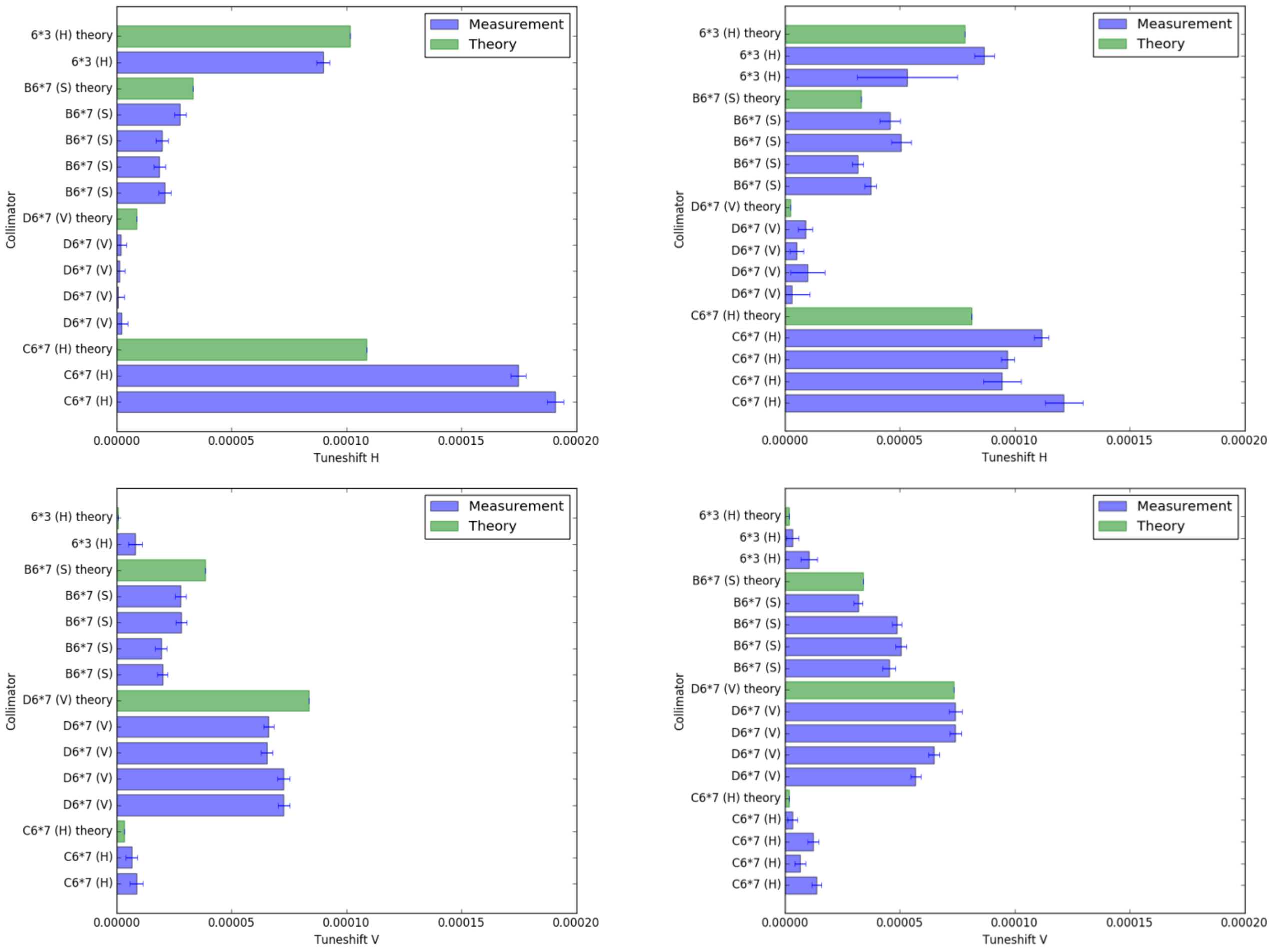


Figure 5: Horizontal (top) and vertical (bottom) tune shifts caused by the TCPs for Beam 1 and Beam 2. Blue bars represent measurements and are compared to impedance model predictions, in green. The collimator orientation (Horizontal, Vertical or Skew) is mentioned alongside the collimator name. Beam 1 data is presented on the left plot, Beam 2 data on the right plot.

Acknowledgements

We would like to thank the OP crew, and in particular L. Ponce and R. Giachino, for their assistance during the MD activity.

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] 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`

[6] 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`

[7] D. Valuch, "Excitation by ADT and Active Bunch by Bunch Tune Measurements", presentation at the 129th SPS and LHC Machine Protection Panel Meeting, 10th June 2016, CERN, Geneva, Switzerland, `https://indico.cern.ch/event/544755/`

[8] LHC OP elogbook, night shift of 10th September 2016, `https://ab-dep-op-elogbook.web.cern.ch/ab-dep-op-elogbook/elogbook/secure/eLogbook.php?shiftId=1079295`

[9] LHC OP elogbook, morning shift of 11th September 2016, `https://ab-dep-op-elogbook.web.cern.ch/ab-dep-op-elogbook/elogbook/secure/eLogbook.php?shiftId=1079305`

[10] B. Salvachua Ferrando, private communication.

[11] G. Valentino, "Collimation System Commissioning in 2016", presentation at the LHC Collimation Working Group Meeting, 25th April 2016, CERN, Geneva, Switzerland, `https://indico.cern.ch/event/522874/`

[12] D. Mirarchi, "Status of Loss Maps Validation", presentation at the LHC Collimation Working Group Meeting, 25th April 2016, CERN, Geneva, Switzerland, `https://indico.cern.ch/event/522874/`

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

[14] 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`

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

[16] 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/`