MD6843: Methods for non-linear optics correction at small action

E.H.Maclean M. Le Garrec R. Tomás, K. Paraschou

Many thanks to OMC team and EIC!

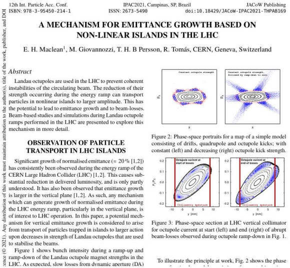
MD objectives

- **Initial plan: measure NL optics with small action kicks via small AC-dipole + BBQ and via ADT. Parasitically obtain data to measure 3Qy resonance.**
- **In practice: Focused on measurent and correction of 3Qy, with some parasitic measurements at lower AC-dipole kicks (also discussed at LSWG on 26/04)**

  → primary aim was to obtain good measurement of $3Q_y$ and make test of correction

$3Q_y$ resonance at injection potentially detrminental to several aspects of LHC operation

MD in Run2 suggested resonance islands from $3Q_y$ could contribute to ϵ_y growth during ramp



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A MECHANISM FOR EMITTANCE GROWTH BASED ON NON-LINEAR ISLANDS IN THE LHC

E. H. Maclean[1], M. Giovannozzi, T. H. B Persson, R. Tomás, CERN, Geneva, Switzerland

Abstract

Landau octupoles are used in the LHC to prevent coherent instabilities of the circulating beam. The reduction of their strength occurring during the energy ramp can transport particles in nonlinear islands to larger amplitude. This has the potential to lead to emittance growth and to beam-losses. Beam-based studies and simulations during Landau octupole ramps performed in the LHC are presented to explore this mechanism in more detail.

OBSERVATION OF PARTICLE TRANSPORT IN LHC ISLANDS

Significant growth of normalised emittance (≈ 20 % [1,2]) has consistently been observed during the energy ramp of the CERN Large Hadron Collider (LHC) [1,2]. This causes substantial reduction in delivered luminosity, and is only partly understood. It has also been observed that emittance growth is larger in the vertical plane [1,2]. As such, any mechanism which can generate growth of normalised emittance during the LHC energy ramp, particularly in the vertical plane, is of interest to LHC operation. In this paper, a potential mechanism for vertical emittance growth is considered to arise from transport of particles trapped in islands to larger action upon decreases in strength of Landau octupoles that are used to stabilise the beams.

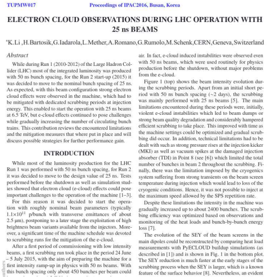
Figure 1 shows bunch intensity during a ramp-up and ramp-down of the Landau octupole magnet strengths in the LHC. As expected, slow losses from dynamic aperture (DA)

Figure 2: Phase-space portraits for a map of a simple model consisting of drifts, quadrupole and octupole kicks; with constant (left) and decreasing (right) octupole kick strength.

Figure 3: Phase-space section at LHC vertical collimator for octupole current at start (left) and end (right) of abrupt beam-losses observed during octupole ramp-down in Fig. 1.

To illustrate the principle at work, Fig. 2 shows the phase

$3Q_y$ is candidate for driving lifetime reduction in conjunction with e-cloud



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ELECTRON CLOUD OBSERVATIONS DURING LHC OPERATION WITH 25 ns BEAMS

*K.Li ,H.Bartosik,G.Iadarola,L.Mether,A.Romano,G.Rumolo,M.Schenk,CERN,Geneva,Switzerland

Abstract

While during Run 1 (2010-2012) of the Large Hadron Collider (LHC) most of the integrated luminosity was produced with 50 ns bunch spacing, for the Run 2 start-up (2015) it was decided to move to the nominal bunch spacing of 25 ns. As expected, with this beam configuration strong electron cloud effects were observed in the machine, which had to be mitigated with dedicated scrubbing periods at injection energy. This enabled to start the operation with 25 ns beams at 6.5 TeV, but e-cloud effects continued to pose challenges while gradually increasing the number of circulating bunch trains. This contribution reviews the encountered limitations and the mitigation measures that where put in place and will discuss possible strategies for further performance gain.

INTRODUCTION

While most of the luminosity production for the LHC Run 1 was performed with 50 ns bunch spacing, for Run 2 it was decided to move to the design value of 25 ns. Tests performed before the shutdown as well as simulation studies showed that electron cloud (e-cloud) effects could pose important challenges to the operation of the machine [1–3].

For this reason it was decided to start the operation with roughly nominal beam parameters (typically 1.1×10^{11} p/bunch with transverse emittances of about 2.5 μm), postponing to a later stage the exploitation of high brightness beam variants available from the injectors. Moreover, a significant time of the machine schedule was devoted to scrubbing runs for the mitigation of the e-cloud.

After a first period of commissioning with low intensity beams, a first scrubbing run took place in the period 24 June – 5 July 2015, with the aim of preparing the machine for a first intensity ramp-up in physics with 50 ns beams. With this bunch spacing only about 450 bunches per beam could

air. In fact, e-cloud induced instabilities were observed even with 50 ns beams, which were used routinely for physics production before the shutdown, without major problems from the e-cloud.

Figure 1 (top) shows the beam intensity evolution during the scrubbing periods. Apart from an initial short period with 50 ns bunch spacing (~2 days), the scrubbing was mainly performed with 25 ns beams [5]. The main limitations encountered during these periods were, initially, violent e-cloud instabilities which led to beam dumps or strong beam quality degradation and considerably hampered efficient scrubbing to take place. This improved with time as the machine settings could be optimized and gradual scrubbing did occur. In addition, technical limitations had to be dealt with such as strong pressure rises at the injection kicker (MKI) as well as vacuum spikes at the damaged injection absorber (TDI) in Point 8 (see [6]) which limited the total number of bunches in beam 2 throughout the scrubbing. Finally, there was the limitation imposed by the cryogenics system suffering from strong transients on the beam screen temperature during injection which would lead to loss of the cryogenic conditions. Hence, it was not possible to inject at the maximum speed allowed by the SPS repetition rate.

Despite these limitations the intensity in the machine was gradually increased up to about 2400 bunches. The scrubbing efficiency was optimized based on observations and monitoring of the heat loads and bunch-by-bunch energy loss [7].

The evolution of the SEY of the beam screens in the main dipoles could be reconstructed by comparing heat load measurements with PyECLOUD buildup simulations (as described in [1]) and is shown in Fig. 1 in the bottom plot. The SEY reduction is much faster at the early stages of the scrubbing process when the SEY is larger, which is a known feature of the surface behavior [8]. Nevertheless, an evident

Clear motivation for correction
→ but LHC designed without any correctors intended for $3Q_y$ compensation at injection

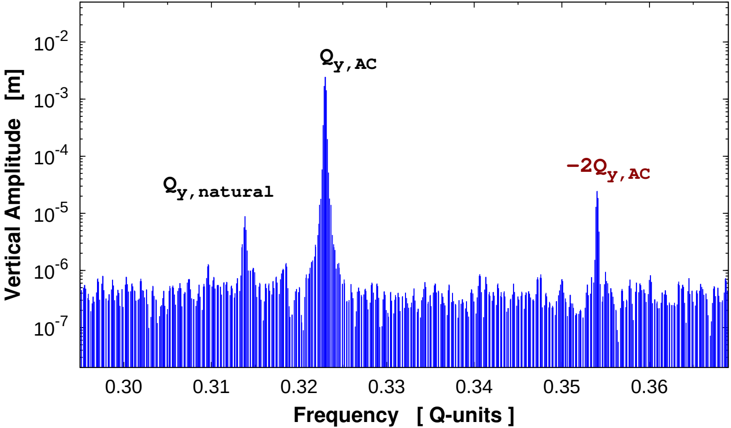
- **MSS** → chromatic coupling skew-sextupoles in arcs
  → designed to suppress influence on $3Q_y$
- **MCSSX** → skew-sextupole corrs in ATLAS/CMS/ALICE/LHCb insertions
  → never planned for use at injection, common to LHCB1/2, inside Xing-scheme
  → Summer student project (E.Waagaard, 2021) showed MCSSX had strength to correct $3Q_y$ in LHC models

First attempt to measure and correct $3Q_y$ RDT (f_{0030}) at injection using IR-skew-sextupoles performed in FMD1

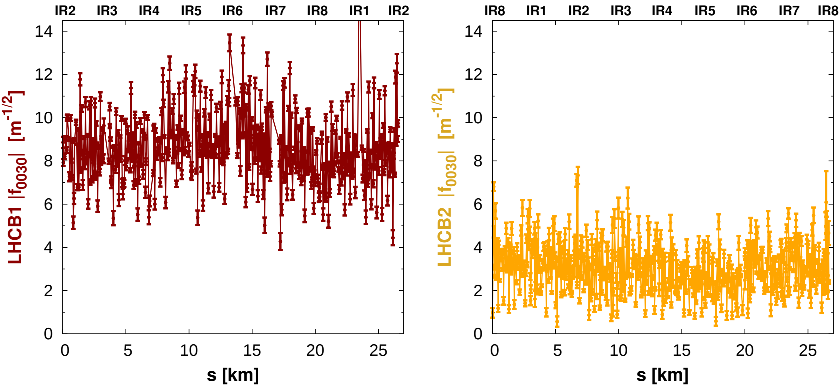
→ **measure/correct $|f_{0030}|$ resonance driving term ($-2Qy$ line in vertical spectra)**

→ **could obtain very clear measurements of $-2Qy$ line even at moderate kick amplitudes**

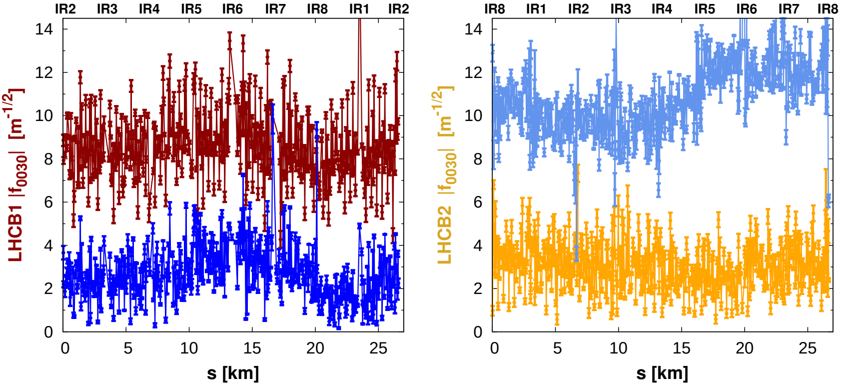
→ **will test offline improvement of RDT measurent upon inclusion of raw BBQ TbT**



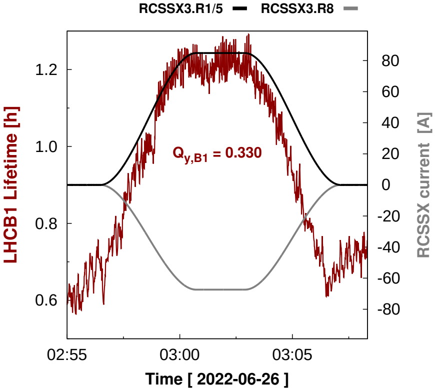
$3Q_y$ RDT of LHCB1 is factor 2-3 worse than for LHCB2

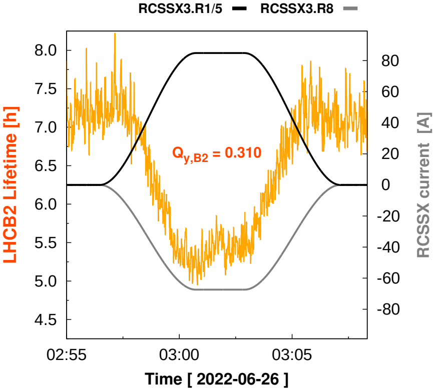


Key challenge with MCSSX is finding simultaneous correction of LHCB1/2
→ **Found good correction of LHCB1 which gave degraded LHCB2**



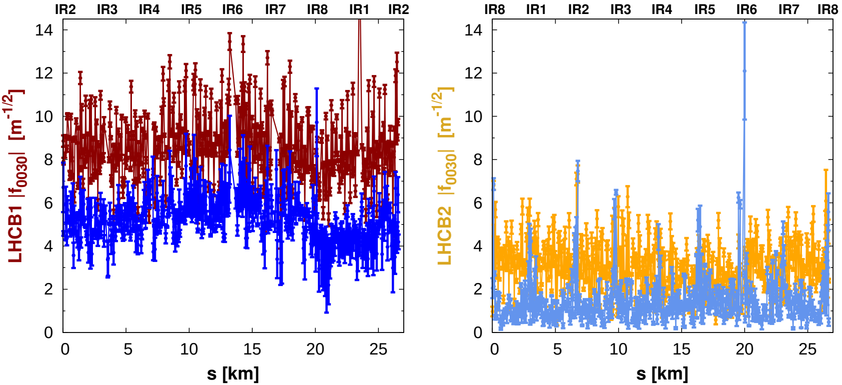
Beam1 optimized correction improved lifetime of LHCB1 close to $3Q_y$ while deteriorating LHCB2 lifetime



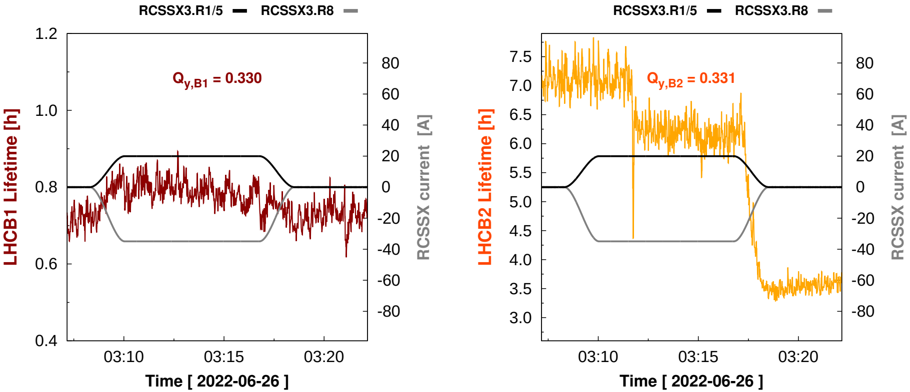


Key challenge with MCSSX is finding simultaneous correction of LHCB1/2

→ **Found good correction of LHCB2 which gave slight improvement to LHCB1 (below)**



Beam2 optimized correction improved lifetime of LHCB2 close to $3Q_y$ while not deteriorating LHCB1 lifetime



After validating impact of corrections at flat-orbit checked RDT and feed-down with crossing-angles applied

- **Saw some further deterioration of the RDTs when crossing-scheme were applied**
- **LHCB2 correction still worked well with crossing-scheme, generated minimal feed-down**
  → but only improved the worse LHCB1 RDT by 20 |%
- **Stronger LHCB1 correction worked less well, generated ∼ 4 % beta-beat and very substantial coupling, and spoiled LHCB2**

Corrections were passed on to Kostas for tests with nominal bunches in MD6924

Very successful MD!

- **Demonstrated for first time we could correct $3Q_y$ with IR-a3 correctors (never intended for this purpose)**
  → showed that directly optimizing the RDT was beneficial for pilot lifetime
- **Raised many interesting questions for study in future**
  → can we achieve an operational correction of both beams simultaneously
  → how stable is the $3Q_y$ at injection (decay, Xing-dependence etc...)
  → how to correct 3Qy in the ramp?
- **Didn't manage to achieve all low-action studies originally envisaged**
  → in course of measuring / correcting 3Qy obtained some parasitic data to test NL-optics measurement with small ACD kicks
  → **but didn't manage tests of detuning and RDT measurement via ADT**
  → still of significant interest
  → remaining tests relatively straightforward and could be short parallel MD at injection