FIRST EXPERIMENTAL OBSERVATIONS FROM THE LHC DYNAMIC APERTURE EXPERIMENT

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Abstract

Following intensive numerical simulations to compute the dynamic aperture for the LHC in the design phase, the successful beam commissioning and the ensuing beam operations opened the possibility of performing beam measurements of the dynamic aperture. In this paper the experimental set-up and the first observations based on the few experimental sessions performed will be presented and discussed in details.

DYNAMIC APERTURE MEASUREMENTS

The basis of the proposed test to probe the dynamic aperture (DA) is the inverse logarithm scaling law for dynamic aperture [1, 2]. This scaling law, derived from tracking data, has been used recently to derive a possible relation between the intensity evolution and dynamic aperture [3]. So far, no particular lifetime issues were observed at injection, thus indicating that the dynamic aperture should be comparable to the mechanical one. This suggests that a more effective strategy for measuring the DA consists of reducing it artificially by acting on some of the non-linear circuits present in the ring. In any case, the injected beam needs to be blown-up in order to have enough particles probing high amplitudes and hence experiencing non-linear effects. This is certainly not the only technique to measure the dynamic aperture and in future also other approaches will be attempted, such as using the aperture kicker to bring the whole bunch to high amplitude.

In light of these considerations, the strategy was as follows (considering that only Beam 1 was used for these measuremets as both rings should feature the same DA):

- The machine is prepared in a configuration that is similar to the operational one apart from the Landau octupoles that are set to zero current after having applied a de-Gaussing cycle. All collimators are put in parking position[1] with only the primary devices set to 12 σ in order to shadow the machine aperture that was measured to be larger than about 13 σ (the triplets being beyond 14 σ) [4].
- A pilot bunch (with $\gamma\,\epsilon_{h,v} = 2\,\mu$m, about 1×10^{10} p) is injected after careful correction of the linear coupling.
- Repeated small kicks are applied with the aperture kicker to blow-up the beam size until losses are observed.
- The losses are recorded and analysed off-line for studying their time-dependence.

This procedure has been repeated by changing the settings of the octupolar spool pieces (MCO) with settings pre-computed and based on numerical simulations with the aim of reducing artificially the dynamic aperture. While the b_4 in the dipoles features alternating sign between the two apertures, the additional strength from the MCOs had a fixed sign all along Ring 1. This, however, generates strong chromatic effects.

The plot shown in Fig. 1 summarises the evolution of the test. Until about 5:30 the beam was prepared and in particular the use of the aperture kicker to blow up the beam was tested. Then, using the nominal settings of the MCOs,

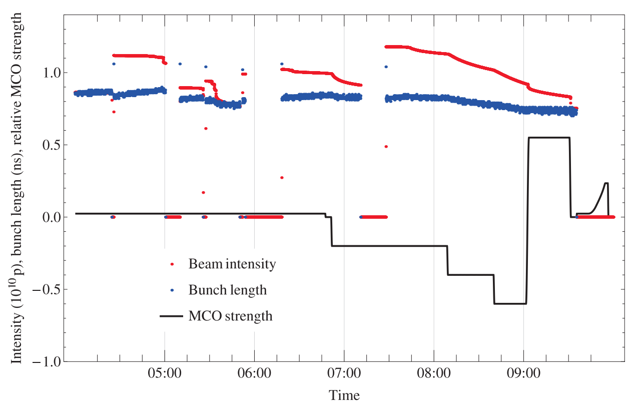

Figure 1: Summary plot of the test performed during the dynamic aperture probing. The intensity is shown together with the bunch length and the strength of the MCOs.

namely those that are supposed to compensate for the b_4 component of the main dipoles, the beam has been excited until the loss limit was reached resulting in decay of the intensity.

Just before 7:00, the MCOs have been changed resulting in another clear intensity decay. For the following steps of the strength of the MCOs the same beam was kept to avoid the need for injecting a fresh bunch (the last injection occurred around 7:30). For each MCO setting a clear intensity decay has been observed. In particular, for the configurations with MCOs at −40 A and −60 A, respectively, we have noticed a reduction in bunch length[2]. This correlates well with the large negative second order chro-

[1] It turned out that the TCDQ in IR6 was left at 8 σ.

[2] The resolution of the bunch length measurement is 125 ps.

maticity. Lastly, the MCOs were moved towards positive currents. During the transient between negative and positive values, a sudden drop in intensity was observed by looking at the details of the intensity evolution.

The evolution of the beam size is monitored via the wire scanner and the synchrotron light monitor. The latter provides a continuous beam size and profile measurement that was regularly cross-calibrated using the wire scanners. The originally round beam is rather well preserved even after the multiple kicks applied with the aperture kicker. The steps in the emittance evolution are indeed the sign of the kicks. In general, wire scanner measurements were performed after the injection and after each kick in order to verify the cross-calibration of the two instruments. The apparent discrepancies between the results from the synchrotron light monitor and the wire scanner are very likely due to the non-Gaussian shape of the beam distribution after the kicks and the standard Gaussian fit applied to the measured data. In particular, the non-Gaussian shape explains the apparent incoherent result concerning losses in between 6:45 and 7:45. Indeed, during this period two intensity decays can be observed in Fig. 1. The first decay seems faster than the second one. Detailed inspection of the measured profiles with the wire scanner (see Fig. 2) reveals that during the first loss period the beam is large. However, the fitted sigma underestimates the actual beam sigma, in particular for the vertical plane.

The situation is even clearer in Fig. 3, where the evolution of the transverse profiles measured by the synchrotron radiation monitor (BSRT) is shown. The profiles have been normalised to their integral. Indeed, while the core is smaller for the data around 6:45 than for the situation around 7:45, the tails are in fact larger for the case around 6:45. In particular this is more evident for the vertical plane. In the off-line analysis it is planned to use the complete information about the beam profile rather than just simple Gaussian fits.

The beam losses correlated to the intensity decay have been monitored by means of the BLMs. The two aperture limits in the machine are the primary collimators (TCP) and the TCDQ and indeed the losses are concentrated at those locations as seen in Fig. 4. It is worth emphasising that the TCDQ is a horizontal device. Hence, nothing can be stated about possible losses in the vertical plane.

The losses at the TCDQ depict a rather smooth decay rather than an instantaneous drop of intensity. This observation seems to indicate that the losses are due to slow non-linear (chaotic) processes instead of an intensity cut-off by a mechanical aperture in the machine. In fact, diffusive-like phenomena would produce continuous losses. In some cases the first spike followed by the long lasting losses might be the sign that some beam was suddenly scraped off and then the diffusion takes over and generate slow losses.

The losses distribution over the whole machine circumference at various times are reported in Fig. 5. The losses are distributed evenly over the ring apart from a sharp spike at the location of the TCDQ. For all six MCO settings the intensity decay appear rather similar except for losses at the collimators in IP2 for the first two loss maps.

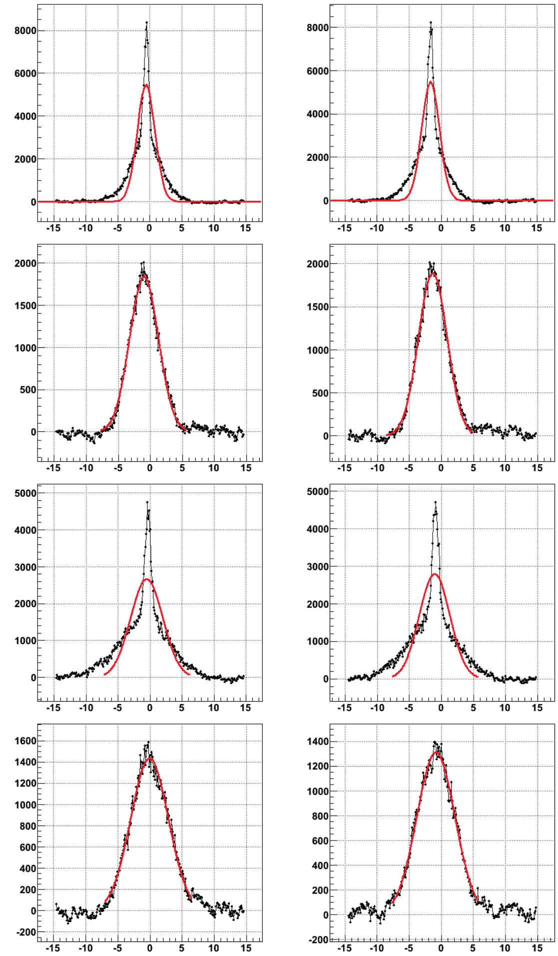

Figure 2: Beam profiles for the horizontal (first two rows) and vertical plane (second two rows), respectively. The first and third rows refer to the profile measured at 6:45, while the second and fourth rows represent the profiles measured at 7:45. The left column refer to the IN scan, while the right column represents the OUT scan. The horizontal scale is in mm.

CONCLUSIONS

The first probing of the LHC dynamic aperture was attempted in dedicated beam experiments in 2011. Data were collected concerning the intensity decay in presence of strong non-linear effects in view of fitting with the proposed scaling law. This analysis is in progress. A correlation between the overall losses and the bunch length has been observed in some cases. This could be explained by the strong impact that the MCOs had on the non-linear chromaticity. In this respect, in future experiments it would be worth testing alternative configurations in which the signs of the MCOs are alternating. This would provide a first-order compensation of the octupolar effects, thus minimising the non-linear chromaticity.

The beam blow up by means of the aperture kicker

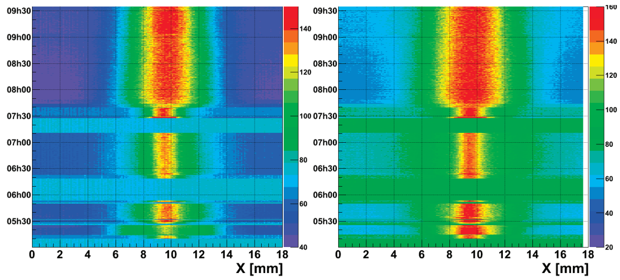

Figure 3: Evolution of the horizontal (left) and vertical (right) beam profiles as measured by the BSRT. The colour scale represents the amplitude of the measured profile. To take into account the difference in total intensity, the profiles have been normalised to their integral.

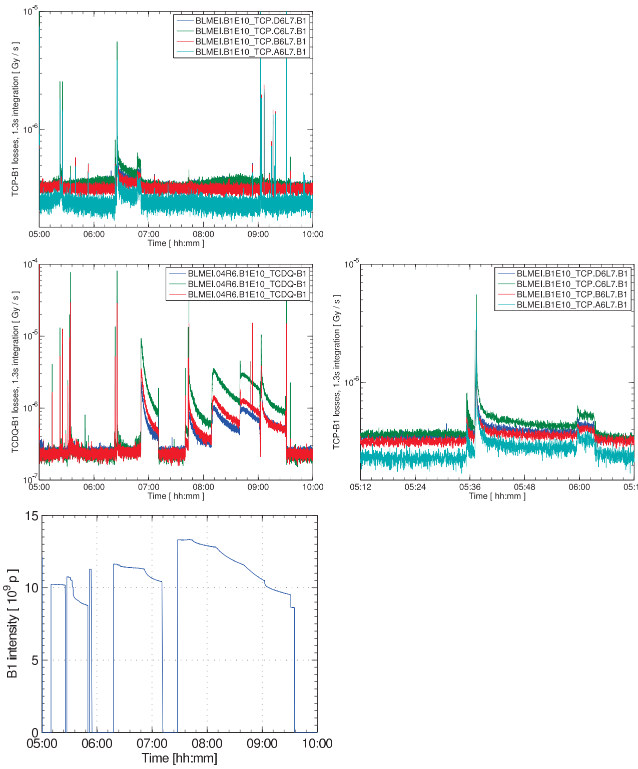

Figure 4: Evolution of beam losses with time on the primary collimators (upper graph) and TCDQ (middle graph) during the dynamic aperture tests. The intensity evolution as measured by the fast BCT is also reported (lower graph). A zoom of a specific loss event for the TCDQ is shown in middle right graph.

proved to be less effective than foreseen as it does not ensure the generation of a Gaussian-like beam distribution. The details of the actual distribution will need to be taken into account in the off-line data analysis. In future studies a different approach should be tried out, based on the use of the transverse damper to excite the beam.

Clearly, it would be interesting to probe also the non-linear dynamics generated by the decapolar spool pieces and this might be included in future experiments.

Finally, it is noteworthy mention that complementary measurements using an improved version of the aperture

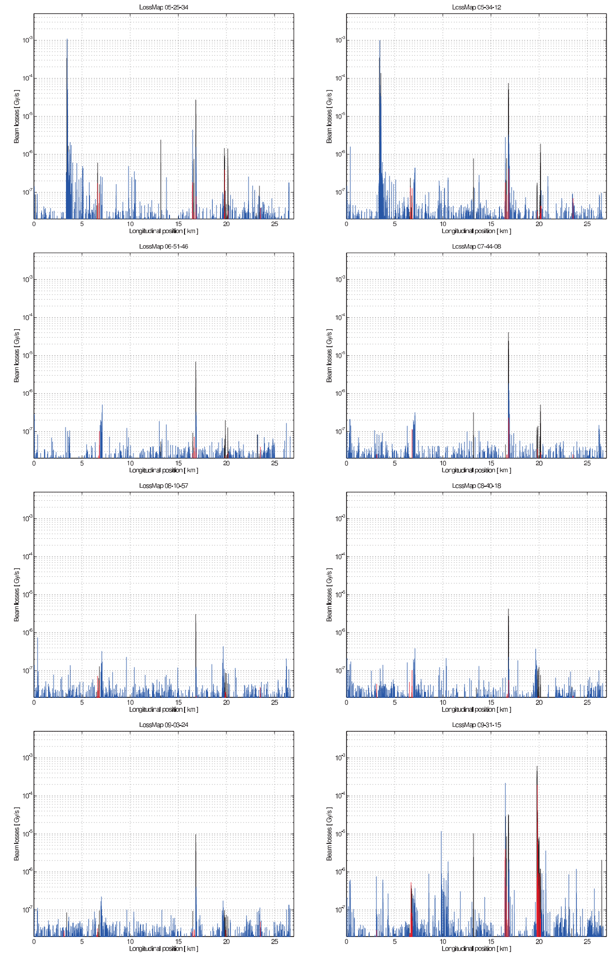

Figure 5: Loss maps during the dynamic aperture tests. The time of each loss map is shown.

kicker, to push the pencil beam to amplitudes comparable with the value of the dynamic aperture for observing the onset of fast losses, will be pursued as complementary measurement during the 2012 experimental sessions at the LHC. These studies are all part of a wider activity aimed at improving the understanding of non-linear single-particle dynamics at the LHC [5, 6].

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