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CAUSES AND SOLUTIONS FOR EMITTANCE BLOW-UP DURING THE LHC CYCLE

M. Kuhn, G. Arduini, B. J. Holzer, J. M. Jowett, V. Kain, F. Roncarolo, M. Schaumann, R. Versteegen, J. Wenninger, CERN, Geneva, Switzerland

Abstract

Emittance measurements during the run 2011 indicated a blow-up of 20 % to 30 % from LHC injection to collisions. At the LHC design stage the total allowed emittance increase through the cycle was set to 7 %. One of the goals of the 2012 LHC run is therefore to understand and counteract the blow-up. Emittance growth measurements through the LHC cycle along with correlations with possible sources are presented in this paper. Solutions are proposed where possible. The emittance determination accuracy relies on the knowledge of the beam optics and on the present performance of the transverse profile monitors. Possible improvements of the diagnostics and of the related data analysis are also discussed.

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INTRODUCTION

One reason for the remarkable performance of the LHC in 2011 was the extraordinary performance of the LHC injectors. Bunch intensities of 1.5 × 10^{11} protons with emittances of 1.9 µm were produced for the 50 ns beams. The analysis of the emittance preservation from SPS extraction to LHC collisions during the summer period of the 2011 LHC run showed an emittance blow-up of ~ 30% between SPS wire scan measurements and the emittances derived from the LHC luminosity, see [1]. During the last part of the LHC proton run, data were collected through the cycle to pin down possible sources of emittance growth. Emittance measurements were obtained through SPS and LHC wire scan measurements, the LHC synchrotron light monitor and the luminosities of ATLAS and CMS – all having intrinsic limitations [2].

The LHC run conditions during the measurement period of 2011 are summarized in Table 1. The conditions in 2012 are similar, the collision energy however is 4 TeV and the β* in the high luminosity experiments 0.6 m.

BLOW-UP THROUGH THE CYCLE

The emittance evolution through the different parts of the LHC cycle was studied in detail in [2]. A summary is given in the following.

The LHC injection plateau

In 2011 no matching screens were available in the LHC. Measurements with the wire scanners in the LHC right after injection compared to the measurements in the last injector, the SPS, do not show measurable emittance blow-up from the injection process, see [2]. The effect of the partly large injection oscillations coming from transfer line trajectory instabilities [3] is kept well under control with the LHC transverse damper [4].

Table 1: LHC run configuration after June 2011

Total number bunches for fill	1380
Max number bunches injected	144
Bunch spacing [ns]	50
Intensity/bunch	1.1 –1.5 ×10^{11}
Intermediate intensity [bunches]	12
Number of injections per fill and beam	12 (+1 pilot)
Filling time	~ 30 min
Number collisions (ATLAS+CMS/ALICE/LHCb)	1318/39/1296, 1331/0/1320
Collision energy per beam	3.5 TeV
Max. luminosity achieved [$cm^{-2}s^{-1}$]	3.6 × 10^{33}

The emittances in the horizontal plane blow up at a rate of about 10 % within 20 minutes during the injection plateau. Simulations suggested that the largest fraction of this growth can be attributed to IBS [2]. Filling takes about 30 minutes and measureable emittance differences are expected for the batches injected one after the other because of this effect. The batch-by-batch emittance differences are clearly visible in the specific bunch-by-bunch luminosity, see Fig. 1.

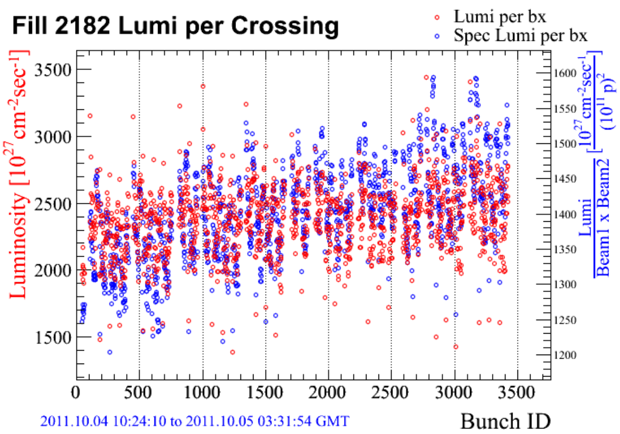

Figure 1: Bunch-by-bunch luminosity and specific bunch-by-bunch luminosity for fill 2182 at beginning of collisions. There is a 10 % difference in specific luminosity for the first batches compared to the last injected batches. *Courtesy A. Ryd, CMS*

The LHC ramp

Only wire scanners could be used during the ramp in 2011 to measure emittances. The standard continuous LHC emittance measurement with synchrotron light monitors (BSRTs) does not produce useful data during the energy ramp [5] and the Beam Gas Ionization Monitor (BGI) was not commissioned. Wire scanner measurements have to be triggered manually and the beam intensity has to be low enough to avoid breaking the wires or causing magnet quenches. Therefore physics beam fills cannot be considered. For several test fills the intensity conditions were fulfilled. A blow-up of more than 20 % was consistently measured for both beams and planes, see Fig. 2 and Fig. 3. The measured beta functions at injection energy and flattop were used and a linear interpolation between these values for any energy in between.

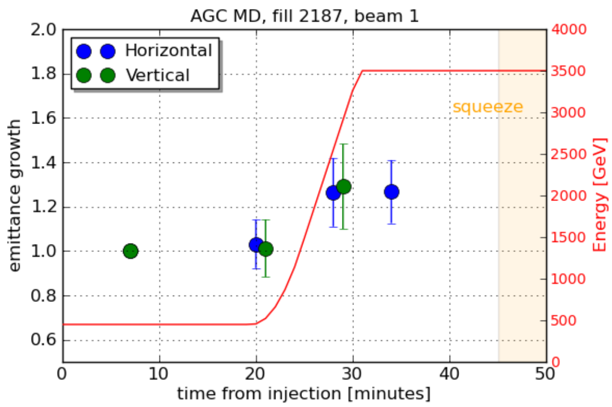

Figure 2: Emittance growth during fill 2187 measured with wire scanners for beam 1. 36 bunches per ring.

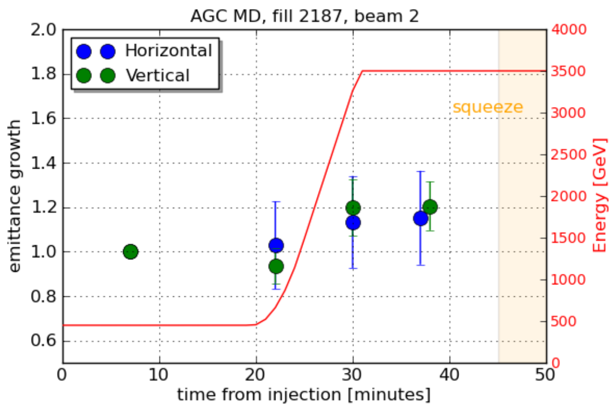

Figure 3: Emittance growth during fill 2187 measured with wire scanners for beam 2. 36 bunches per ring.

The LHC squeeze

In 2011 β* of the high luminosity experiments ATLAS and CMS was reduced from 11 m to 1 m at flattop energy before putting the beams in collision. While the emittances for beam 2 in the vertical and horizontal plane are conserved within measurement accuracy during the beta squeeze, the emittances of beam 1 in the horizontal plane experience significant blow-up of more than 20 %. The blow-up occurs between 5 m and 1.5 m β*. The measured beta functions at β* = 11 m, 3.5 m and 1 m were taken into account for the analysis. The cause is unclear.

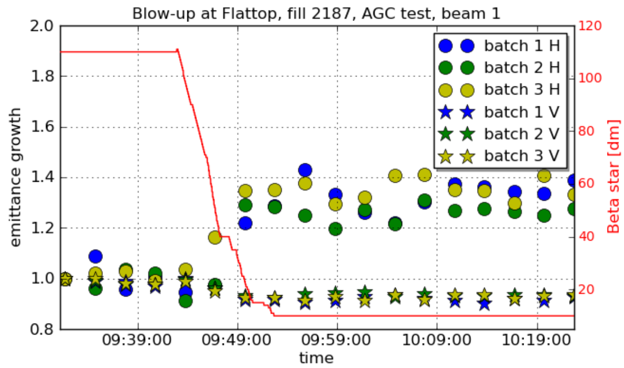

Figure 4: Relative emittance growth for different batches after ramp and during squeeze for Fill 2187, beam 1.

DEPENDENCE ON BUNCH INTENSITY

Towards the end of the LHC proton run in 2011 the bunch intensity was increased further and further to push peak luminosity. The data from the summer period and the last month of proton operation in 2011 were combined to obtain the dependence of emittance growth on bunch intensity, see Fig. 5. The absolute emittance growth seems to be independent of bunch intensity.

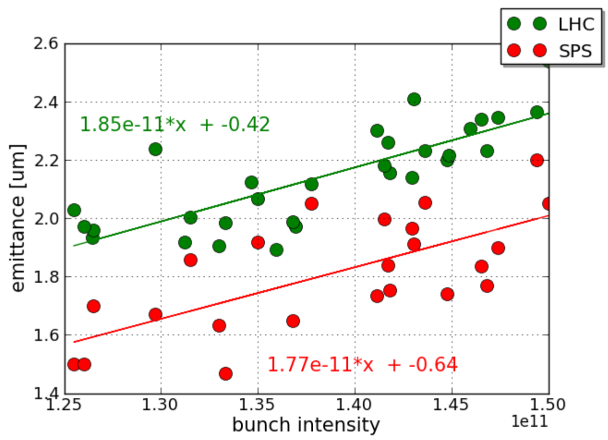

Figure 5: Comparison of emittance from LHC luminosity and emittance of 144 bunch wire scans in the SPS as function of bunch intensity. The absolute growth between SPS extraction and LHC start of collisions seems to be roughly independent of bunch intensity.

POSSIBLE CURES FOR EMITTANCE GROWTH IN 2012

IBS at the LHC injection plateau

The time spent for LHC filling (currently ~ 30 minutes) could be reduced by at least 30 % by introducing dedicated LHC filling cycles in the injectors. This approach has implications on the physics programme in the injectors especially as LHC beams in the injectors need significant time for preparation outside the filling period. Dedicated filling cycles could become an option in case of better reproducibility in the injectors and improvements on the speed of the LHC injection quality checks.

Blowing up the longitudinal emittance right after the injection should reduce the effect of IBS on the transverse emittance. The batch-by-batch longitudinal blow-up was tested successfully during a machine test period near the beginning of the 2012 run, see Fig. 6. More data on transverse emittance are still necessary to understand the effect on horizontal emittance growth.

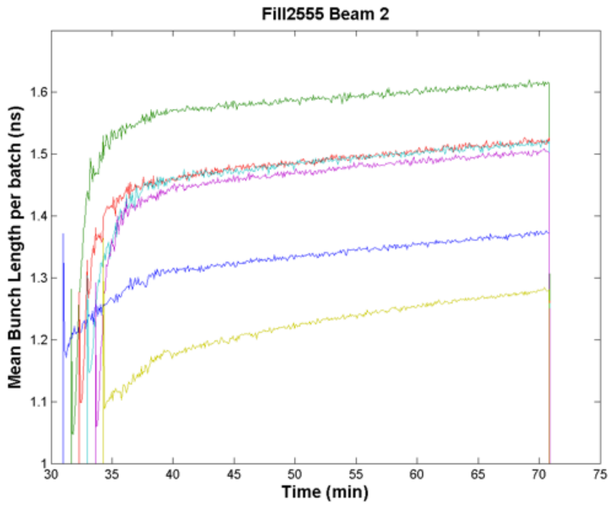

Figure 6: Bunch length evolution during batch-by-batch blow-up test: 6 12 bunch batches were injected. The first and last batch were left to natural blow-up. The other batches were blown up individually right after injection. *Courtesy T. Mastoridis.*

In 2011 the gain of the transverse damper had to be reduced during the ramp to allow the operation of the BBQ based tune feedback [6]. The reduction of the gain takes place before the ramp starts, and leads to an increase of the BBQ amplitudes. The larger oscillations measured by the BBQ could potentially lead to emittance blow-up. To counteract this effect, the possibility to maximise the gain for most bunches around the ring and sacrifice only a few bunches at the beginning of the train with lower gain for tune feedback operation was implemented. The transverse damper gain modulation was successfully demonstrated for several test fills during the beginning of the 2012 run. Wire scan measurements were taken during the ramp. The effect on the emittance growth is not clear yet. More machine test time is required.

IMPROVED INSTRUMENTATION IN 2012

Not all the planned improvements for emittance instrumentation, analysis and applications are available yet at the present early stage of the 2012 run. The first successful tests with the LHC matching monitor have been carried out and the LHC BGI is being commissioned for use during the ramp. The measured beta functions around the ring are being made available for the various instruments in an automatic way. All instruments are still in the process of calibration. More details of the planned improvements can be found in [2].

CONCLUSIONS

In 2011 the LHC transverse emittances grew by about 30 % from SPS extraction to the start of collisions in the LHC. Blow-up occurred during the injection plateau due to IBS (10 % in 20 minutes, horizontal plane), during the ramp for both beams and planes in the order of about 20 % and for beam 1 in the horizontal plane during the beta squeeze (another 20 %). It is still too early to draw conclusions on the growth through LHC cycle for 2012. The different instruments as well as luminosity are still under calibration. Several tests and improvements, such as the transverse damper gain modulation, are planned and have already been partly implemented. The goal for 2012 is to understand the dependence of blow-up on bunch intensity or brightness and possibly correct the blow-up through the LHC cycle.

REFERENCES

[1] V. Kain et al., “Emittance Preservation”, LHC Operations Workshop, Evian, France 2011.

[2] V. Kain et al., “Emittance Preservation in the LHC”, LHC Performance Workshop, Chamonix, France 2012.

[3] L. Drosdal et al, “Sources and Solutions for LHC Transfer Line Stability Issues”, these proceedings.

[4] W. Höfle et al., “LHC Damper Beam Commissioning in 2010”, IPAC 2011, San Sebastian, Spain.

[5] F. Roncarolo et al., “Can we get reliable online measurements of the transverse emittance?”, LHC Operations Workshop - II, Evian, France, 2010.

[6] L. Ponce, “Orbit and tune feedback/diagnostics”, LHC Operations Workshop, Evian, France, 2011.