COLLIDING DURING THE SQUEEZE AND β^* LEVELLING IN THE LHC

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Abstract

While significantly more complicated in term of operation, bringing the beams into collisions prior to the β squeeze rather than after presents some advantages. Indeed, the large tune spread arising from the non-linearity of head-on beam-beam interactions is profitable, as it can damp impedance driven instabilities much more efficiently than external non-linearity such as octupoles. Moreover, this operation allows to level the luminosity in the case when the peak luminosity is too high for the experiments. Operational issues are discussed and experimental results from the LHC are presented.

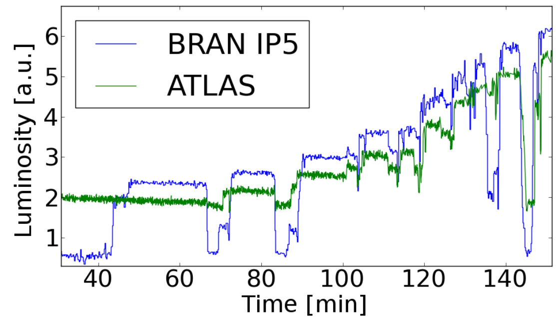

Figure 1: Luminosity during first attempt of β^*LL.

INTRODUCTION

Operating the betatron Squeeze with Colliding Beams (SCB) could be beneficial for the Large Hadron Collider (LHC) operation in two main aspects. First, as described in [1], the tune spread from Head-On (HO) beam-beam interaction is significantly more efficient than other sources of detuning available to damp impedance driven instabilities. As coherent instabilities have been observed at the end of the squeeze during the 2012 run of the LHC despite of the stabilizing techniques put in place [2], it seems natural to cure this instability using the strongest damping mechanism available, HO collisions. Second, this procedure can be used as a Luminosity Levelling (LL) technique, known as β^*LL.

ORBIT STABILITY AT THE IP

The feasibility of SCB in the LHC was investigated experimentally. In particular, the beams stability can be critical when colliding beams with a transverse offset of the order of σ, the rms beam size, as already observed in the LHC [1, 3]. While such separations would not necessarily lead to an instability, orbit stability remains the key component to fully profit from the stabilizing effect of HO collision during the squeeze.

Experimental Results

In order to test the long term reproducibility of the orbit at the Interaction Point (IP) during the squeeze, three similar experiments were conducted [4, 5]. The beams were pre-squeezed to $\beta^* = 3$ m in IP1&5 using the usual operational sequence for luminosity production. The beams were then brought into collision in IP1&5 and the squeeze was continued in steps down to $\beta^* = 0.6$ m. Figure 1 shows the luminosity in both IPs during the first experiment. The corresponding separation computed from the reduction factor is also shown on Fig. 2a. The variation of the orbit at the IP during the execution of the squeeze steps is in the order of 1 σ, which is corrected afterwards by optimizing the luminosity. The corrections are then fed forward for following tests. The maximum variation of the orbit at the IP was reduced to ~ 0.5 σ during the second experiment, by repeating the same procedure with corrections implemented during the first attempt (Fig. 2b). It appears that the correction remained valid three weeks after the first run of the SCB. A third experiment of this type was performed with a train of 36 bunches, showing no complications with respect to previous attempts with single bunches. The measured luminosity follows the expected increase with β^*, as shown by Fig. 3, within the error bar defined by 10% β beating at the lowest β and 20% at intermediate steps.

A fourth experiment was conducted with SCB from $\beta^* = 9$ m down to 0.6 m. The beams separation was measured using beam position monitors adjacent to the IP (Fig. 4), which are in qualitative agreement with measurements from luminosity reduction factor.

Reproducibility in Standard Operation

The orbit corrections at IP1 applied during fills for luminosity production of the 2012 run of the LHC are shown on Fig. 5a. Despite of the significant drift over the year, the fill to fill correction remained mostly below 10 μm, i.e. $\sim 0.6\sigma$, as shown by their distribution on Fig. 5. This implies that in most of the fills, SCB could have been performed reliably by feeding forward the corrections applied in each fill. There exists some outliers for which the correction is larger than 1 σ. Such cases could be dealt with by frequent optimization of the luminosity with a transverse offset and possibly using a feedback on the beam positions at the IP interpolated from adjacent monitors. In case this should not be sufficient, resulting in a configuration with beams colliding with a transverse offset, the stability will

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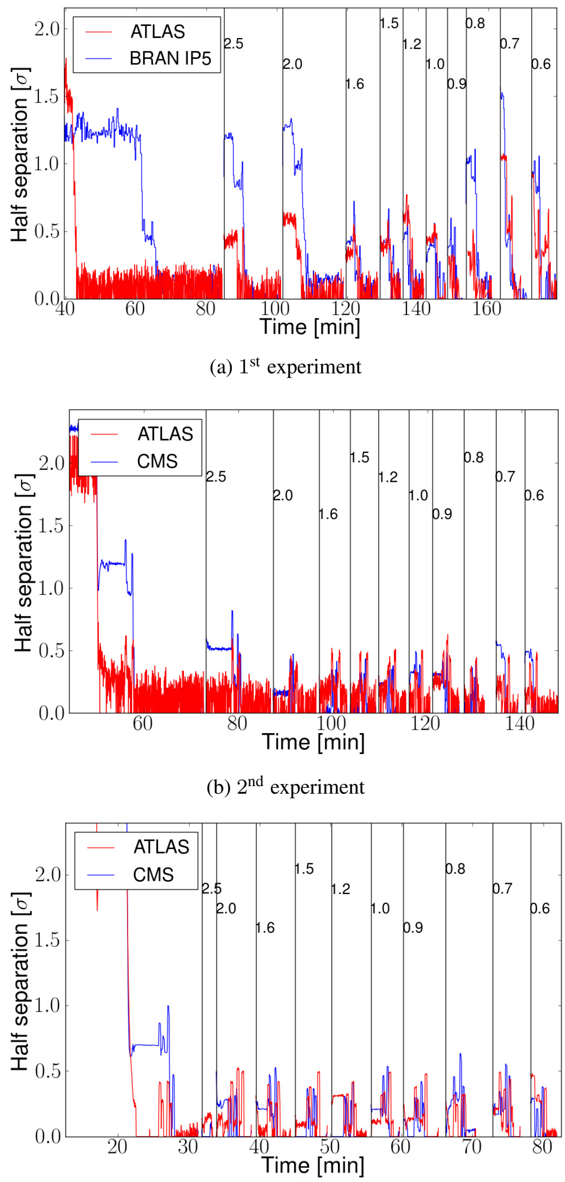


(a) 1[st] experiment

(b) 2[nd] experiment

(c) 3[rd] experiment

Figure 2: Transverse separation at the IP computed using measured luminosity reduction factor, while squeezing with colliding beams. The vertical lines mark the intermediate steps, with the corresponding β^* in IP1&5. A luminosity optimization is performed at each of these steps.

be reduced, which may not necessarily lead to a coherent instability.

The implications on the control system greatly depend on the flexibility required by the experiments for β^*LL. Indeed, the current control system is based on the definition of a fixed sequence of optics, the strength of the magnets being varied form their value in one optics to the next by interpolation [6]. While this system is already satisfactory to execute SCB, it does not allow β^*LL with full flexibility, i.e. the luminosity cannot be varied independently in each IP. It is nevertheless possible to perform β^*LL providing

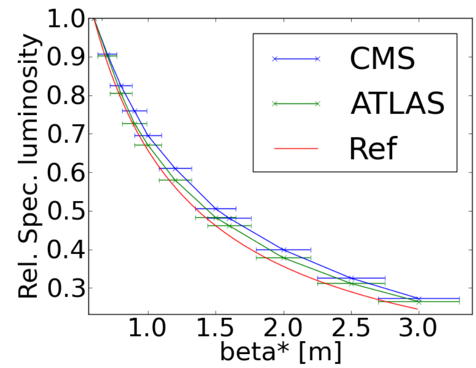


Figure 3: Measured and expected specific luminosity reduction due to β^*.

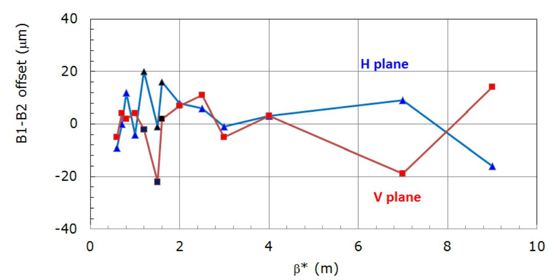
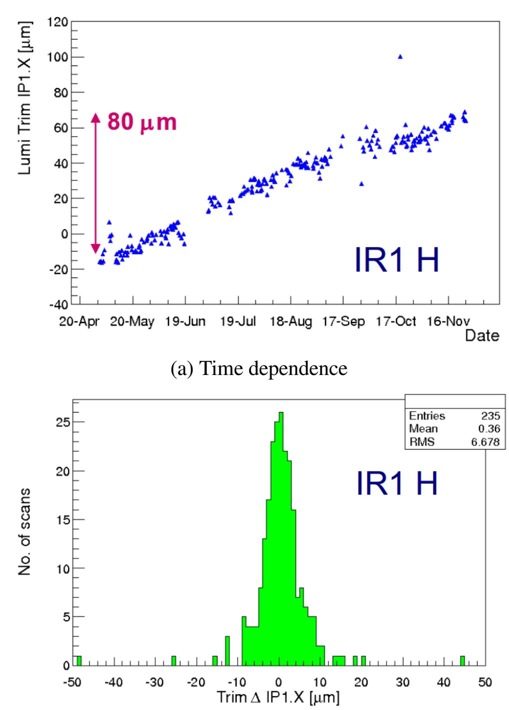


Figure 4: Beam separation at the interaction point interpolated from adjacent beam position monitors.



(a) Time dependence

(b) Distribution of fill to fill differences

Figure 5: Distribution of the fill to fill correction of the orbit at the IP from luminosity optimisation with a transverse offset during the 2012 run.

that the optics sequence is known in advance, e.g. if only one IP is being levelled with β^*, or a subset of IPs are being levelled synchronously.

COLLIMATOR IMPEDANCE AND BEAM STABILITY

The impedance of the LHC is dominated by the collimators [7]. Efficient collimation, implying small collimator gaps, is required to achieve small β^*[8]. As such collimator settings are strictly required only for small β^*, it could be greatly beneficial for the beam stability to relax the settings while the beams are not colliding HO and bring the collimators closer to the beams only when it is required. This has two main implications, first the low β^* part of the squeeze, which requires tight collimator settings, should be operated with colliding beams. Second, the loss spikes due to scraping associated with the inward movement of the collimators should remain under control. Extrapolation from present experience suggests that this is feasible, further studies are nevertheless required to fully understand the operational implications.

While introducing some complications in the operation of the squeeze, this technique would allow not only to cure the instabilities at the end of the squeeze but also to gain a significant margin on the beams stability, for higher beam brightness and machine impedance.

COLLIMATOR MOVEMENT AND LEVELLING

During the squeeze, the tertiary collimators are moved in order to follow the modification of the crossing angle orbit bump and of the beam size. While such movement was never required during luminosity production in 2012, it will be required to perform β^*LL. Proper studies are therefore required to ensure machine protection during each levelling step without having to interrupt luminosity production which would cost an unacceptable overhead for the experiments, that would have to turn their acquisition on and off at each levelling step [9].

FLAT BEAMS

Flat beams, with $\beta^*_x \neq \beta^*_y$, could be advantageous when considering β^*LL. In particular, levelling with β^*only in the plane perpendicular to the crossing angle reduces the modification of the orbit bump and, consequently, might allow to relax the movement of the collimators.

The separation bump is collapsed during the SCB, which leaves aperture in the separation plane previously required for the orbit bump. Depending on the scenario, the luminosity gain from using the extra aperture to lower β^*in the separation plane can be greater than 10% [10].

Whereas flat beam collisions could not be tested in the LHC due to lack of time, experience in previous collider, such as the S$p\bar{p}$S collider, did not bring up major issues from routine operation with flat beams [11].

CONCLUSION

Dedicated experiments have demonstrated the feasibility of SCB in the LHC. In particular, the orbit reproducibility has been found to be sufficient to use a feed forward approach in order to keep the orbit stable at the IP. This observation is supported by the reproducibility of the corrections applied during fills for luminosity production during the 2012 run of the LHC. It was found that the beam position measured by monitors adjacent to the IP could be used to improve the operational robustness. No unexpected obstacle were encountered during the four tests of SCB, further studies are nevertheless required to render the procedure fully operational.

There is a strong interest for the LHC in using SCB to avoid impedance driven instabilities at the end of the squeeze and gain a significant margin in beam brightness and machine impedance by profiting of the stabilizing effect of HO beam-beam interactions earlier in the operational cycle.

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