ALICE spectrometer polarity reversal


Keywords: crossing angle, spectrometer polarity, beam separation, parasitic encounters

Summary

The external crossing-angle bump in IR2 of LHC partly compensates the crossing angle created by the ALICE spectrometer. In view of the spectrometer polarity reversal requested by ALICE during the 2011 Pb-Pb run, a fast procedure consisting in reversing IP2 external crossing angle after ramp and squeeze of beams was envisaged. This requires a passage through zero external crossing angle, exposing beams to beam-beam interactions at parasitic encounters where normalized separation is less than one sigma. A test of the reversal at the end of physics fill no. 2319 showed that beam sizes are large enough at these locations not to have significant effects on intensity or emittance. Consequently, the fast polarity reversal procedure was validated and the full operational cycle was tested with a few bunches before adoption in the future physics fills.
1. Introduction

The total vertical crossing angle at IP2 of LHC results from the superimposition of the ALICE spectrometer bump angle, whose magnetic fields are independent of energy, and external IP2 bump angle:

\[ \theta_{yc} = \frac{\pm 490 \ \mu\text{rad}}{E / (Z \text{ TeV})} + \theta_{yext} \]  

where E is the total energy per unit charge and the signs are given in terms of the slope of the orbit of Beam 1. In the first part of the 2011 Pb-Pb run, the spectrometer angle was +140 \( \mu \text{rad} \), partly cancelled by the external bump of \( \theta_{yext} = -80 \ \mu\text{rad} \) giving the total crossing angle equal to +60 \( \mu\text{rad} \). The ramp and squeeze settings do not depend on the inner spectrometer bump, and were set up for \( \theta_{yext} = -80 \ \mu\text{rad} \). But the spectrometer polarity has to be reversed for physics, implying reversal of the external crossing angle too. In order to avoid re-optimising all injection, ramp, squeeze and collimation settings, it was suggested to use existing ramp and squeeze settings with the reversed spectrometer polarity, and then to reverse the external bump only at the end of the squeeze. This would mean having \( \theta_{yc} = -220 \ \mu\text{rad} \) during injection, ramp and squeeze, then reversing the external angle from \( \theta_{yext} = -80 \ \mu\text{rad} \) to \( \theta_{yext} = +80 \ \mu\text{rad} \), to get \( \theta_{yc} = -60 \ \mu\text{rad} \) for the final total vertical crossing angle at the end of the squeeze. Beams would still be separated in the horizontal plane. Nevertheless, it means getting through a situation of small normalized separation at parasitic encounters for zero external angle. An end-of-fill MD was scheduled to validate this plan of ALICE spectrometer polarity reversal. We wanted to change the external angle at IP2 from \( \theta_{yext} = -80 \ \mu\text{rad} \) to \( \theta_{yext} = +80 \ \mu\text{rad} \) in small steps at the end of a physics fill, to check the effect of beam-beam interaction. This note first presents calculations of the polarity reversal showing the potentially critical situation at zero external crossing. Then results of the end-of-fill test for fast polarity reversal are given.

2. Motivation

Fig. 1 represents vertical beam envelopes for \( \theta_{yext} = -80 \ \mu\text{rad} \) and \( \theta_{yext} = +80 \ \mu\text{rad} \), for reversed ALICE spectrometer bump (−140 \( \mu\text{rad} \)). These would correspond to initial and final situation of the bump reversal. For 200 ns spacing bunches, parasitic encounters are about 30 m far from IP2 (dashed lines on the plots of Fig. 1 and 2). This means that their effects on the beams are not influenced by the spectrometer angle, but only by the external bump.

Figure 1 : Vertical beam envelopes (5\( \sigma \)) before (right) and after (left) the external bump angle reversal from \( \theta_{yext} = -80 \ \mu\text{rad} \) to \( \theta_{yext} = +80 \ \mu\text{rad} \), for −140 \( \mu\text{rad} \) ALICE spectrometer angle.
Figure 2: Horizontal (right) and vertical (left) beam envelopes (5σ) at zero external crossing angle, and for −140 μrad ALICE spectrometer angle.

At zero external crossing in the vertical plane, beams are only separated by the parallel horizontal separation, as shown by Fig. 2. The normalized separation

\[ r_{12} = \frac{\sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}}{\max(\sigma_{x_2}, \sigma_{y_2})} \]  

(0.0)

is then minimum at the encounters. The quantity \( r_{12} \) is plotted versus total crossing angle in Fig. 3 for the outer left encounter. As one can see, the separation becomes less than one sigma at the intermediate position, when the external bump is cancelled.

Figure 3: Normalized separation at the outer encounter left of IP2 versus total vertical crossing angle, for −140 μrad ALICE spectrometer angle.

In order to validate the fast polarity reversal, we had to go through the zero external crossing position described by Fig. 2 and Fig. 3, and check intensity evolution, losses and beam sizes. To do that we used circulating beams at the end of a physics fill before they were dumped for re-injection.

3. Test of fast polarity reversal

The external crossing angle was reversed by steps of 10 μrad during Fill 2319 between 15:14 and 15:50 on 24th November 2011. Fig. 4 shows the evolution in time of the beam sizes. The intermediate position was crossed around 15:27. Effects on beam sizes were negligible. These are large enough at the parasitic encounters, so that the interaction has very small effects.
Figure 4: Beam sizes of B1 and B2 between 15:00 and 16:00. External bump reversal happened between 15:14 and 15:50.

The beam intensities were about $2.5 \times 10^{12}$ charges equivalent to $8.1 \times 10^7$ ions per bunch at the beginning of the test. Their evolutions during the spectrometer polarity reversal are plotted on Fig. 5. Again the progressive modification of the external crossing angle is of negligible effect since the slopes of intensities versus time are not perturbed. The sudden variation at 15:52 was attributed to a trim of the skew quadrupoles to try to correct the coupling.

Figure 5: Intensity of B1 and B2 between 15:00 and 16:00. External bump reversal happened between 15:14 and 15:50.

4. Conclusion

The test in view of a fast polarity reversal of the external bump in IR2 showed that beams do not suffer from beam-beam effect at the intermediate position when they are separated by less than one sigma. It means that beam sizes are sufficiently large at the parasitic encounters locations. It allowed the run to be continued with the ramp and squeeze procedures using existing settings and reversed spectrometer bump polarity, and then to reverse the external crossing angle once at flat top energy. This was done successfully with 6 on 6 bunches first on 28 November, to test automatic operation. This scheme was then used successfully in operation for the last 10 days of the ion run 2011. The resulting measured orbits without taking the spectrometer bump into account are shown in Fig. 6.
Figure 6: Orbits and envelopes as measured after the reversal (left: B1, right: B2).