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h.grote@cern.ch

Comparing Beam-beam Effects in Three LHC Injection Schemes

H. Grote

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Summary

In part of the straight sections of the LHC the two beams share a common beam tube. Therefore the bunches cross each other not only at the interaction point, but as well at many places on either side, with a typical transverse separation of 10 times the transverse beam size. These "parasitic" encounters lead to orbit distortions and tune shifts, in addition to higher order effects.

In this note, the effects of the beam-beam interactions on the orbits, tunes, and luminosity are presented for three different injection schemes: the nominal injection scheme (April 2000), an alternative scheme proposed by P. Collier, and the fully symmetric injection scheme which serves as a reference. [1]

1 Introduction

Since the string of bunches from the injection machine SPS contains gaps, not all possible 3564 "buckets" around the machine are filled, but only about 3000. This in turn causes some bunches to not always encounter bunches in the opposite beam at one or several parasitic collision points (so-called "pacman" bunches), or even at the head-on interaction points ("super-pacman" bunches). A bunch that encounters a bunch from the othe beam at all 124 possible collision points is called "regular". The self-consistent orbits for the nominal injection scheme have been presented in a previous report [2]. Here, we compare this nominal scheme with an alternative scheme proposed by P. Collier [1] which was designed in order to reduce the effect of the electron cloud in the SPS [3],[4] by introducing larger gaps behind each bunch train thus allowing the electron cloud to be absorbed before the next bunch train arrives. Finally, we use the "fully symmetric" injection scheme as a reference; it is derived from the nominal scheme by suppression of bunch trains 10, 20, and 30 (see Appendix).

The three injection schemes are called "A" (nominal scheme), "B" (P. Collier), and "C" (fully symmetric) in the following.

[1]This is an internal CERN publication and does not necessarily reflect the views of the LHC project management.

2 The nominal LHC collision parameters

- four collision points at physics experiments, IP1, IP2, IP5, IP8
- beams crossing vertically with a total angle of 300 μrad at IP1 and IP2, with opposite orientation, horizontally with a total angle of 300 μrad at IP5 and IP8, with opposite orientation
- horizontal separation of about 4 σ at IP2 for halo collisions (reduced luminosity)
- horizontal tune $Q_x = 64.31$, vertical tune $Q_y = 59.32$
- transverse normalized emittance 3.75 μm
- particles per bunch 1.1×10^{11} (new official value)
- 2520 - 2808 bunches per beam (depends on the bunch filling scheme)
- corrected horizontal and vertical chromaticity between +1 and +2

	IP1	IP2	IP5	IP8
$\beta_x^*[m]$	0.5	10	0.5	35
$\beta_y^*[m]$	0.5	10	0.5	35
$\sigma_x[\mu m]$	16	72	16	134
$\sigma_y[\mu m]$	16	72	16	134

Table 1: *Optical parameters of the nominal LHC in collision for protons.*

3 Comparison

3.1 Bunch filling schemes

The three schemes are detailed in the Appendix. Their features are given in Table 2. The super-pacman bunches of scheme C stem exclusively from the longitudinal collision point offset at LHCb by 3/2 bunch spacings (3 extra gaps times 36 bunch trains).

	A ring-1	A ring-2	B ring-1	B ring-2	C ring-1	C ring-2
no. of bunches	2808	2808	2520	2520	2592	2592
no. of regular bunches	1443	1443	1287	1287	1404	1404
min. collisions	48	45	45	45	61	61
max. collisions	124	124	124	124	124	124
no. single super-pacman	252	252	240	240	108	108
no. double super-pacman	3	3	3	3	0	0

Table 2: *Comparison of the three bunch filling schemes.*

3.2 Beam offsets

The number of head-on, and of parasitic encounters varying between 45 and 123 for all non-regular bunches, leads to different self-consistent orbits for these bunches. These differences persist around the machine and are of particular interest at the experiment collision points, but as well at collimators, beam instruments etc. As a demonstration, the horizontal offset at IP1, caused exclusively by beam-beam forces, is shown in Figure 1 for all three schemes. In all plots the spread is not more than $\pm 0.1\sigma$ about the average.

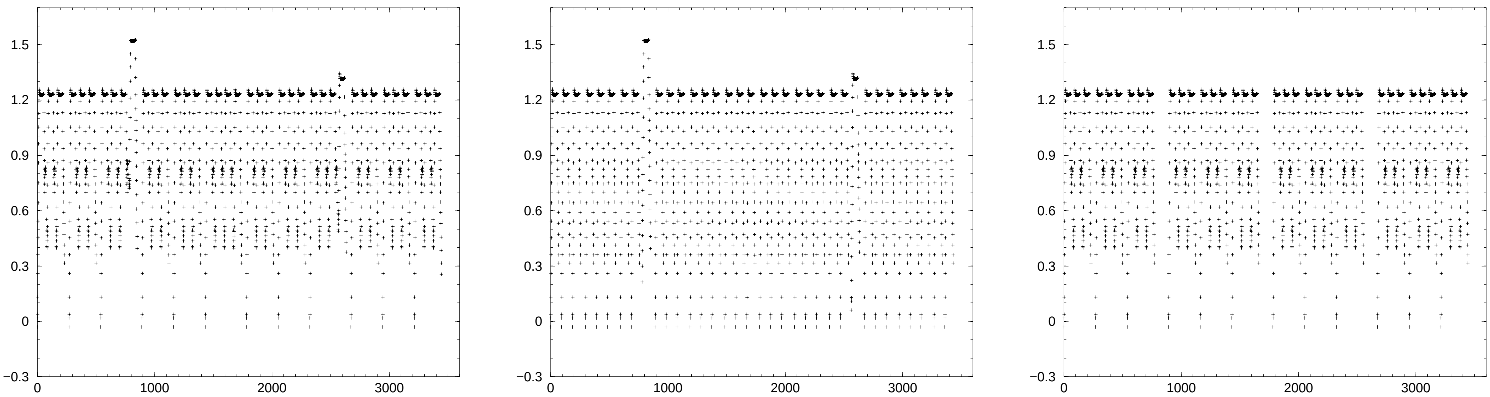

Figure 1: *Horizontal bunch offset in μm at IP1 for filling schemes A (left), B (centre), C (right) as function of the bucket number.*

3.3 Coherent tune, chromaticity, luminosity.

The conclusions from the previous report [2] remain valid cum grano salis.

The coherent x and y tunes of super-pacman bunches at IP8 are shifted by $\xi\ /\ 2\ =\ 0.0017$ with respect to the tunes of all other bunches. This reduction of the coherent tuneshift should not cause any problems.

The chromaticity is somewhat lowered for all bunches, but stays between one and two.

The luminosity is of course primarily proportional to the number of bunches. The mean offsets of the self-consistent orbits at the IPs can easily be corrected globally at each IP which then limits the maximum loss of luminosity for any bunch pair to less than 0.1% at IP1 and IP5.

4 Conclusion

The collision scheme proposed by P. Collier does not present any disadvantages when compared with the nominal collision scheme, as far as beam-beam interactions and their corrections are concerned. However, since the official nominal luminosity is $10^{34}\,cm^{-2}\,s^{-1}$, this collision scheme cannot replace the nominal scheme A without further modifications (e.g. more particles per bunch), or an officially accepted reduction of the luminosity by about 10%.

5 Appendix

5.1 Bunch Filling schemes

The three filling schemes A, B, and C are given below in a (it is hoped) self-explanatory notation (1 means there is a bunch, 0 means none):

```
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1 119 0
```

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72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0  72 1  39 0
72 1 21 0  72 1 21 0 111 0
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```
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1 119 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1 119 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1 119 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1  38 0
72 1  8 0  72 1  8 0  72 1 119 0
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References

[1] P. Collier, *private communication*

[2] H. Grote, *Self-consistent Orbits for Beam-beam Interactions in the LHC*, CERN LHC Project Report 216

[3] F. Zimmermann, The Electron Cloud Instability: Summary of Measurements and Understanding, CERN-SL-2001-035

[4] G. Rumolo, F. Zimmermann, Simulation of Single Bunch Instabilities Driven by Electron Cloud in the SPS, CERN-SL-2001-041