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PRELIMINARY SIMULATIONS OF EMITTANCE GROWTH DUE TO AN EXTERNAL NOISE IN COLLIDING BEAMS IN THE LHC

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Abstract

Preliminary results from simulations are presented using the COherent Multi-Bunch Interaction code (*COMBI*). Two bunches colliding head on, under the influence of an arbitrary sourced white noise are considered. The effect of noise on both flat and round beams is simulated and the emittance growth as a result is observed and studied. Preliminary results suggest that there is no significant difference in emittance growth due to the use of flat beams under the influence of uncoupled external white noise operating at HL-LHC parameters.

INTRODUCTION

Noise is an unavoidable issue in large particle accelerators such as the Large Hadron Collider (LHC). An external noise can induce a beam offset which can lead to a diffusion of particle motion, emittance growth and a reduction in luminosity [1]. An upgrade to enable higher luminosities to be achieved in the LHC has been proposed [2]. This will result in more particle collisions at the designated Interaction Points (IPs), this however could lead to pile up in the machine detectors. To prevent pileup in the machine, luminosity levelling has been proposed and a number of luminosity levelling scenarios have been suggested [3,4]. In the case of β^* levelling, it has been suggested that using flat beams in the IPs could be advantageous [5–7]. The parameters suggested for the HL-LHC will result in a larger beam-beam interaction than in the current LHC set up. This in combination with an external noise could lead to a decrease in luminosity over time.

In this paper, emittance growth from an external, arbitrarily sourced white noise is analysed in the context of colliding beams, using the strong-strong simulation code *COMBI*. Simulations using both flat and round beams were undertaken using HL-LHC and nominal LHC parameters for comparison. The final aim of this emittance study is to compare these results with the study undertaken by Ohmi [8] providing an analytical comparison.

DIFFERENT LUMINOSITY LEVELLING SCENARIOS

There are a number of different luminosity levelling scenarios that have been suggested [4], these include;

- β^* levelling; This method of levelling involves starting initially with a beam cross section that is larger than the nominal value and is gradually reduced as the luminosity decays exponentially. This method of luminosity levelling is easily implemented, however during the squeeze the β function will grow rapidly in the region near the IP.

- Beam offset will reduce the luminous overlap region between bunches. This is relatively easy to implement and can be applied independently in all IPs, however such a beam offset can lead to a number of effects in terms of the beam-beam effect. A large offset of the order of RMS beam size can lead to a reduction in tune spread. This reduces beam stability which in turn, could lead to the excitation of coherent modes.

- Crab cavity luminosity levelling. Crab cavities have been implemented successfully in electron colliders to increase the luminosity back to a nominal value after the beam luminosity decays. Crab cavities can however be implemented in such a way as to anti-crab the beam. This enables the bunch overlap to be increased over time, through variation of the crossing angle. Crab cavity luminosity levelling can be applied in a similar way to β^* levelling, in that the beam can initially have a luminosity smaller than the target luminosity and be sequentially increased, correcting for the luminosity decay. The crossing angle at each IP can be controlled independently and easily by altering the voltage of the cavities.

- Using flat beams involves levelling along only the crossing angle plane. This results in the tune shift being held constant in the other planes and the movement of the collimators to be minimised. This may allow a more flexible and less complicated levelling method from an operation standpoint. Although never implemented in the LHC, previous experience in the $Sp\bar{p}S$ collider showed no significant implications for this beam operation [9].

THE SIMULATION

COMBI is a strong-strong simulation that provides a self consistent field calculation on every turn. The bunches used in this simulation consist of 2.5×10^6 macro particles. Utilising this number of macro-particles minimised both the computational time and the numerical noise. The beam-beam force is calculated for every particle in both bunches

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using the HFMM method [10]. One bunch per beam collided at one IP and experienced a deflection due to the head on beam-beam interaction. A deflection due to white noise was applied to all the particles in the bunch at a second IP, every turn. An undamped noise acting on the particles in the bunch will induce an emittance growth that will continue to grow if left undamped. The rate at which this emittance grows is analysed under varying levels of noise. Noise was applied to the angle variable of the particles in the bunches and increased from 0.1×10^{-2} to 0.3×10^{-2} in increments of 0.05×10^{-2} in units of the RMS x'. The strength of the beam-beam interaction can then calculated from the beam-beam parameter. The beam-beam parameter is well known and is given by,

$$\xi = \frac{N_p r_p \beta^*}{4\pi\gamma\sigma^2}, \tag{1}$$

where N_p is the bunch population, r_p is the classical proton radius, β^* is the beta function at the interaction point and γ and σ are the relativistic factor and the bunch size respectively. Thus it can be seen, changing the bunch size (due to external noise), the bunch population and the β^* function at the IP will effect the strength of the beam-beam interaction.

The emittance growth for flat and round beam profiles were studied in the context of colliding beams, at one IP under the influence of an external noise for both nominal and HL-LHC parameters. In the HL-LHC it should be mentioned that two IPs are present. Preliminary results suggest that there will be no significant difference in emittance growth. The starting parameters of the simulation are given by Table 1.

Table 1: Nominal and HL-LHC Parameters

Params LHC	Nom. Values	HL-LHC Values
Bunch Intensity N_p	1.15×10^{11}	2.20×10^{11}
Bunch Profile	Round	Flat
$\beta^*_{x/y}$ [m]	0.6/0.6	0.3/0.075
$\xi_{x,y}[10^{-3}]$	3.4/3.4	5.9/0.15
$E_{collision}$ [TeV]	14	14
$\epsilon_{initial}$ [μm]	3.75	2.5
Bunch Spacing [ns]	25	25

Altering the β^* values along the x and y plane such that they are no longer equal, changes the beam aspect ratio. Changing this ratio allows the beam profile to be altered and hence be made flat in the y plane. The relationships between the β^* values and the beam aspect ratio are given by,

$$\beta^*_x = r\beta^*, \tag{2}$$

$$\beta^*_y = \frac{\beta^*}{r}, \tag{3}$$

$$\beta^* = \sqrt{\beta^*_x \times \beta^*_y}, \tag{4}$$

where the total $\beta^* = 0.15m$ in the HL-LHC which gives a beam aspect ratio r, equal to 2. Thus the beam will be flat in the y plane for these simulations.

In these simulations, the effects from longitudinal motion and crossing angles have been ignored. Colliding beams were modelled for 100,000 turns. This amounts to approximately 9 seconds of machine time. The emittance growth due to collisions between round and flat beams was analysed. Simulating both round and flat beams provides a comparison between emittance growth under LHC and HL-LHC parameters. Removing the first 1000 turns removes any decoherence between the beams. This is an artefact of the simulation and not of any underlying physics.

RESULTS

Round Beams

An external noise applied to a beam will lead to an emittance blow up. As the noise acting on the bunches increase, the emittance growth induced by the external noise will also increase. If the noise acting on the beams is left undamped this emittance growth will lead to beam quality and luminosity degradation. The round beams with an external noise,

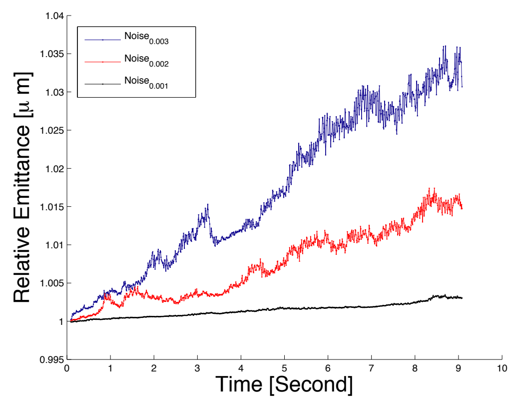

Figure 1: The effect of an external white noise on round beams.

experience an emittance growth of 0.30%, 1.4% and 3.2%, respectively, for increasing values of noise, as can be seen in Fig 1. This emittance growth will increase the RMS beam size which will hence lead to a decay in the luminosity. The luminosity was calculated considering only the bunch centroids. This enabled the use of an analytical formula with all geometric reduction factors ignored [4]. The reduction of luminosity with the round beam profile can be seen in Fig 2.

Flat Beams

Flat beams were also simulated with an external noise. In the flat beam profile, β-functions in the x and y plane are different. This results in a beam beam parameter that is not equal in both planes. Fig 3 and 4 show the emittance growth and decrease in luminosity for flat beams under an external noise. The flat beams undergo an emittance growth of 0.8%, 1.8% and 3.6% respectively, for increasing values of noise. These preliminary findings suggest that the emittance growth using flat and round beams is not significantly different.

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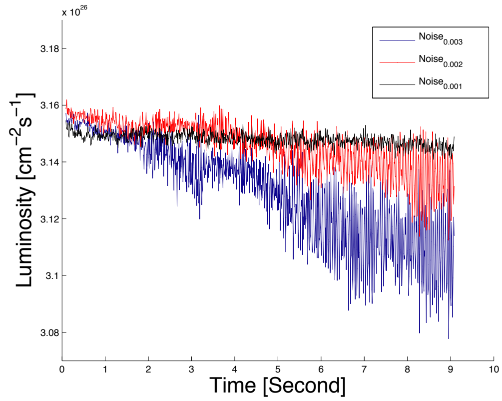

Figure 2: Luminosity decay with the round beam profile at nominal LHC parameters.

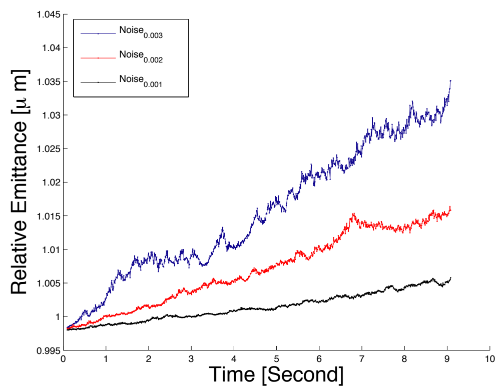

Figure 3: Emittance growth along the x plane for the flat beam profile.

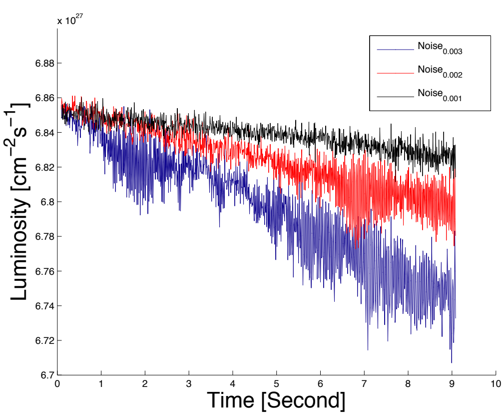

Figure 4: The luminosity decrement in the x plane with the flat beam implemented.

CONCLUSION

The emittance growth experienced in the case of flat and round beams appears to be approximately equal if the initial decoherence at the beginning of the simulation is removed. The slight difference between the two bunch profiles is likely a result of the simulation and not of any underlying physics. It may be the case that the flat bunches utilised here may take longer to reach a colliding bunch equilibrium. However it is important to stress that these are preliminary simulations and are not yet conclusive. The noise model utilised here in simulations of single head on collisions, with no long range interactions and a zero crossing angle, is uncoupled between transverse planes. Introducing a model for a coupled noise could induce an emittance growth along both transverse planes. This may result in a large emittance growth along the flat plane, since a beam with a smaller emittance will be more sensitive to an external noise. Extending *COMBI* to include other HL-LHC scenarios is currently on going, including the possibility to also consider the effect of long range interactions on flat beams as well as other possible luminosity levelling scenarios.

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REFERENCES

[1] V.A. Lebedev, “Emittance Growth due to Noise and its Suppression with the Feedback System in Large Hadron Colliders”, *No. SSCL-Preprint–188. Superconducting Super Collider Lab., Dallas, TX (United States), 1993*.

[2] L.Rossi O. Brüning, “High Luminosity Large Hadron Collider A description for the European Strategy Preparatory Group”, No. CERN-ATS-2012-236. 2012.

[3] J.P. Koutchouk, “Luminosity optimisation and levelling”, *In. Proc. Charmonix 2010 workshop on LHC performance*, CERN-ATS-2010-026,2010.

[4] B.D. Muratori, T. Pieloni, “Luminosity Levelling techniques for the LHC”, *ICFA Mini-Workshop on Beam-Beam effects in Hadron Colliders*, CERN BB2012.

[5] X. Buffat et al, “Colliding during the squeeze and β^* levelling in the LHC”, *In. Proc. Shanghai 2013, IPAC 13*, CERN-ACC-2013-0140.

[6] F. Zimmermann, “Luminosity Limitations at Hadron Colliders”, No. CERN-SL-2001-009-AP. 2001.

[7] S. Fartoukh, “Prospective for Flat Beam Optics”, LHC MAC no. 19, 2006.

[8] K. Ohmi et al, “Beam-beam effects with an external noise in the LHC”, *In. Proc. Albuquerque, PAC 07*.

[9] P.E. Faugeras, *et al.*, “Proposal to upgrade the luminosity of the $Sp\bar{p}S$ collider by a factor of 2”, CERN SPS/89-18 (DI).

[10] W.Herr et al, “Hybrid fast multipole method applied to beam-beam collisions in the strong-strong regime”, *Physical Review Special Topics-Accelerators and Beams, APS*.