FERMILAB-CONF-10-139-AD

SIMULATIONS OF HEAD-ON BEAM-BEAM COMPENSATION AT RHIC AND LHC *

A. Valishev†, FNAL, Batavia, IL 60510, USA

Abstract

Electron lenses are proposed as a way to mitigate head-on beam-beam effects for RHIC and LHC upgrades. An extensive effort was put together within the US LARP in order to develop numerical simulations of beam-beam effects in the presence of electron lenses. In this report the results of numerical beam-beam simulations for RHIC and LHC are presented. The effect of electron lenses is demonstrated and sensitivity of beam-beam compensation to machine parameters is discussed.

INTRODUCTION AND PREVIOUS RESULTS

Compensation of beam-beam effects in hadron colliders using low-energy electron beam lens (EL) is a promising technology. Two ELs have been installed in the Tevatron collider, and vast experience was gained from their operation [1]. In the current machine configuration the beam-beam effects in the antiproton beam are dominated by long-range interactions, which makes impossible the application of ELs for head-on beam-beam compensation (BBC). Yet, Tevatron EL experiments provide abundant data for the development of simulation codes [2].

Increase of the single bunch luminosity by either raising the bunch intensity or by decreasing the transverse emittance is an effective path for a collider luminosity upgrade. Other options, such as increasing the number of bunches, require costly hardware upgrades. For instance, the Tevatron luminosity exceeded the design goal mostly owing to the use of very bright bunches, with beam-beam parameter for both beams reaching 0.028.

The RHIC luminosity upgrade program [3] proposes the increase of beam-beam parameter up to 0.03, which will be problematic without one or another form of beam-beam effect mitigation, and ELs have been adopted to provide partial head-on BBC [4]

For the nominal LHC beam parameters with 1.15×10^{11} protons per bunch and the transverse emittance of 3.75 μm, the total beam-beam tune shift will not exceed 0.015. A naive approach with decreasing the transverse emittance by a factor of 2 would increase the beam-beam tune shift to 0.03 and provide a significant gain in luminosity. In this case, however, the beam-beam effects would become a strong limiting factor.

Numerical simulations are an important tool for evaluation and design of beam-beam compensation schemes. The Beam-Beam Simulations group within the US LARP [5] develops a number of simulations aimed at the demonstration of potential benefit of head-on BBC for the performance of RHIC and LHC, and at the design of actual EL BBC schemes. Results obtained by different codes for identical simulation conditions are verified in order to uncover program deficiencies and improve the quality of simulation predictions (see Fig. 1).

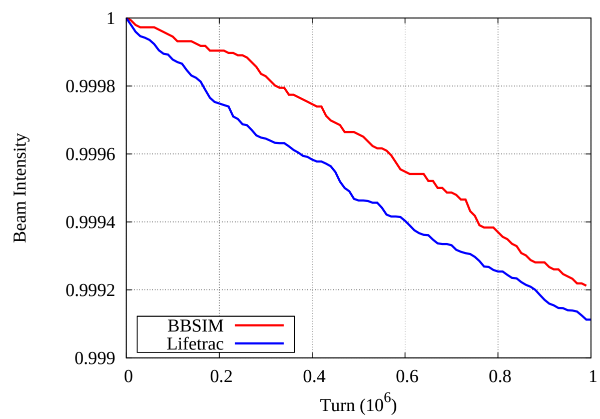

Figure 1: Evolution of bunch intensity in RHIC at 1/2 BBC ($\xi = 0.02$). Comparison of two codes: BBSIM [6] and Lifetrac [7] running the same simulation case.

Previous simulations indicated that head-on BBC with an electron lens may provide an improvement of the beam intensity life time for RHIC and LHC at higher than nominal bunch intensities [8, 6, 7]. It was found that a partial (50%) compensation is advantageous, while the full compensation almost invariably leads to life time degradation. However, these simulations were limited to one or few machine configurations, and a more extensive study was deemed necessary in order to explore the effect of the EL over a large range of machine parameters. The studied parameters include the betatron tunes, betatron phase advance between the main interactiomn point (IP) and the EL, shape of the electron beam, machine nonlinearities, and misalignment of the EL beam.

This paper describes the results of simulation studies of beam-beam effects in RHIC and LHC performed with the Lifetrac code [10]. Simulations with other codes are presented in [11, 12, 13].

* Work supported by the Fermi Research Alliance, LLC under Contract DE-AC02-07CH11359 with the United States Department of Energy, and by the DOE through the US LHC Accelerator Research Program (LARP).
† valishev@fnal.gov

EFFECT OF EL BEAM MISALIGNMENT

The topic of interest in RHIC BBC studies was the effect of the EL beam offset. Simulations were performed for the RHIC lattice, which included high-order multipoles. The fractional betatron tunes were $Q_x = 0.685$, $Q_y = 0.695$, the beam-beam parameter was 0.02. A Gaussian EL with the size matched to the proton beam was placed at IP10, and was set to provide 50% compensation (i.e. tune shift of 0.01). The results of the vertical EL position scan are presented in Fig. 2. Remarkably, this simulation predicts the particle losses to be insensitive to the misalignment of electron and proton beams. A similar effect was observed in beam studies at the Tevatron [2].

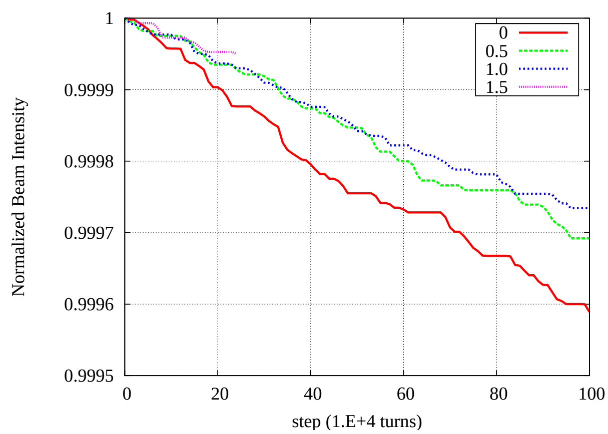

Figure 2: Evolution of bunch intensity in RHIC at 1/2 BBC ($\xi = 0.02$) for various transverse offsets of the EL beam. Labels denote the amount of vertical EL offset in units of beam sigma.

RESULTS FOR THE LHC

The LHC model used in simulations represented the ring by a series of linear 6D transformations between the IPs. The first and second order chromaticity was included by the use of chromatic drifts [10]. A bunch of 10^4 macroparticles was tracked for 10^7 turns in a typical simulation run. The entire simulation was 6D symplectic. In order to evaluate the beam life time an aperture restriction was placed at the distance of 6 σ of the beam and particles reaching this aperture were counted and their coordinates collected.

This simulation is lacking machine nonlinearities, especially the high-order multipoles of the final focus, which were shown to be an important factor in the particle dynamics [14]. Yet the simplified simulation can serve as an upper estimate of the attainable machine performance.

At the nominal beam-beam parameter of 0.015 the simulation shows no particle losses, thus the tune scans were performed at higher values of ξ in order to determine the range of betatron tunes where BBC improves beam life time. In Figures 3 and 4 the particle losses (in percent per hour) are plotted as a function of betatron tunes (w.r.t. the nominal working point of $Q_x = 0.31$, $Q_y = 0.32$) for $\xi = 0.03$ and 0.04, correspondingly. The two cases are presented, with no beam-beam compensation, and 50% compensation using a matched Gaussian EL. As one can see, at

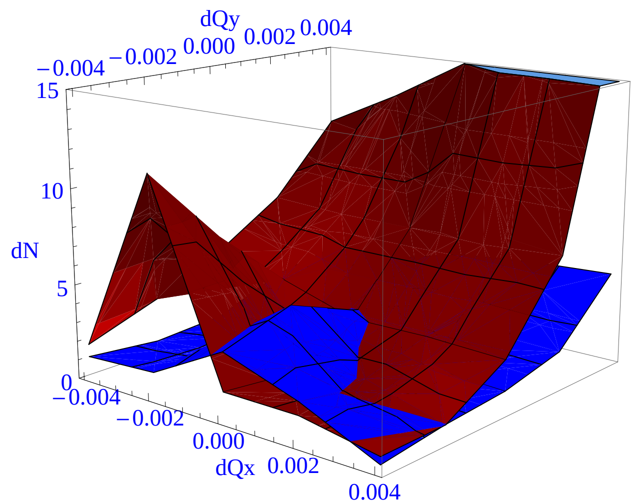

Figure 3: Particle losses with (red) and without (blue) beam-beam compensation. $\xi = 0.03$.

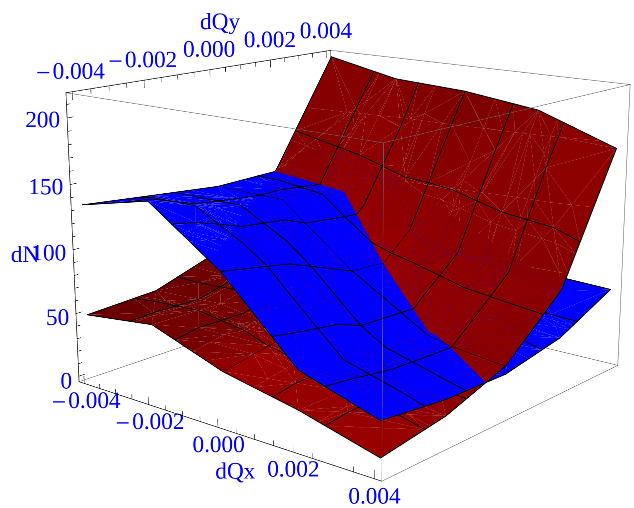

Figure 4: Particle losses with (red) and without (blue) beam-beam compensation. $\xi = 0.04$.

$\xi = 0.03$ the head-on BBC improves beam life time only in a small area of the scanned tune space (± 0.004). Perhaps a wider tune scan could prove otherwise. At higher beam intensity the effect of EL is more pronounced, as it provides a factor of 2 to 3 improvement in particle losses over a large range of tunes.

SUMMARY

Simulations of head-on beam-beam compensation at RHIC predict low sensitivity to the electron beam misalignment at moderate values of beam-beam parameter (0.02).

According to simulation studies with a simplified LHC model, electron lens may be effective for mitigation of particle losses only at very high bunch intensity (above 3×10^{11}). Implementation of a more realistic machine model including the final focus nonlinearities and benchmarking of the simulations with other codes is in progress.

ACKNOWLEDGMENTS

We thank W. Fischer, A. Kabel, H.J. Kim, Y. Luo, G. Robert-Demolaize, and T. Sen for collaboration and useful discussions. The author is grateful to F. Schmidt for hospitality at CERN and fruitful collaboration.

REFERENCES

[1] Shiltsev et al., New Journal of Physics **10** 043042 (2008). V. Shiltsev et al., Phys. Rev. ST Accel. Beams **11**, 103501 (2008).

[2] A. Valishev et al., "Progress with Tevatron Electron Lens Head-on Beam-Beam Compensation", these Proceedings, TUPD070

[3] W. Fischer, "RHIC Luminosity Upgrade Program", these Proceedings, TUXMH01

[4] W. Fischer et al., "Status of the RHIC Head-on Beam-beam Compensation Project", these Proceedings, MOPEC026

[5] `http://uslarp.org`

[6] H.J. Kim, T. Sen, "Beam-Beam Compensation Using Electron Lens in RHIC", PAC'09, Vancouver, 2009, WE6PFP032

[7] A. Valishev, V.Shiltsev, "Electron Lens for Beam-Beam Compensation at LHC", PAC'09, Vancouver, 2009, WE6PFP034

[8] Y. Luo et al., "Weak-Strong Simulation of Head-On Beam-Beam Compensation in the RHIC", PAC'09, Vancouver, 2009, MO4RAC05

[9] W. Fischer et al., "LHC Beam-Beam Compensation Studies at RHIC", PAC'09, Vancouver, 2009, WE3PBI03

[10] D. Shatilov et al., "Lifetrac Code for the Weak-Strong Simulation of the Beam-Beam Effects in Tevatron", PAC'05, Knoxville, 2005

[11] H.J. Kim, T. Sen, "Electron Lens in RHIC", these Proceedings, TUPD066

[12] Y. Luo, W. Fischer, "6-D Weak-strong Simulation of Head-on Beam-beam Compensation in the RHIC", these Proceedings, THPE102

[13] W. Fischer, Y. Luo, C. Montag, "Bunch Length Effects in the Beam-beam Compensation with an Electron Lens", these Proceedings, THPE100

[14] Y. Papaphilippou and F. Zimmermann, Phys. Rev. ST Accel. Beams **2** 104001 (1999).