EMITTANCE GROWTH DUE TO BEAM-BEAM EFFECT IN RHIC*

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Abstract

The beam-beam interaction has a significant impact on the beam emittance growth and the luminosity lifetime in RHIC. A simulation study of the emittance growth was performed using the LIFETRAC code. The operational conditions of RHIC 2006 100GeV polarized proton run were used in the study. In this paper, the result of this study is presented and compared to the experimental measurements.

INTRODUCTION

With significant beam intensity improvement in RHIC polarized proton runs in 2005 and 2006, the emittance growth becomes a luminosity limiting factor. The beam-beam interaction causes particle losses and emittance blow up in RHIC. The Beam-beam effect is one of the main causes for the RHIC emittance growth [1]. It is important to understand the beam-beam issues in RHIC both experimentally and with the aid of tracking. To address the beam-beam issue, a set of computer simulation with LIFETRAC was performed with machine parameters based on the beam measurements.

BEAM-BEAM SIMULATION CODE

A package of programs for weak-strong simulation of beam-beam effects in hadron colliders, LIFETRAC, was used in this simulation study. LIFETRAC was developed by D. Shatilov [2] initially for simulation of the equilibrium distributions of particles. It was then extended to the simulation of non-equilibrium distributions, which allows observation of how a distribution evolves with time. The advanced features of LIFETRAC include 2D coupled optics, chromatic modulation of beta-functions, non-Gaussian shape of the strong bunches and non-linear elements for beam-beam compensation. The tracking time is divided into "major steps", usually 10^3 to 10^5 turns per major step. The statistical property of the beam (1D histograms, 2D density in the space of normalized betatron amplitudes, luminosity, beam sizes and emittances) is averaged over all particles and all turns for each major step during tracking. In this way, a sequence of frames representing evolution of the initial distribution is obtained.

The initial 6D distribution of macro-particles can be either Gaussian or read from a separate text file. In addition, the macro-particles may have different "weights". This allows a more reliable representation of the beam tails with a limited number of particles. The number of simulated macro-particles can vary in the range of $10^3$to 10^6.

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SIMULATION OF BEAM-BEAM EFFECT IN RHIC

The operational conditions of RHIC 2006 100GeV polarized proton run were used in the study. Accelerator optics parameters relevant to the simulation are derived from beam measurements during RHIC operations. The important parameters used in this simulation study are listed in Table 1.

Table 1. The RHIC optics and simulation parameters used in this study.

Lattice (RHIC Blue ring)	2006 100GeV proton
Blue tunes (x, y)	28.695, 29.685
Yellow tunes (x, y)	28.697, 29.687
Chromaticity (x, y)	2m, 2m
Beta* IP 6, 8, 10, 12, 2, 4	1, 1, 10, 10, 10, 10 [m]
Blue Initial Emittance x, y	15πμmrad (95% norm)
Yellow Emittance x, y	15πμmrad (95% norm)
Initial Beam Length	1m
dE/E	10^{-3}
Aperture x, y, z	8.5σ, 8.5σ, 10.6σ
Beam-beam parameter	0.004~0.018
Initial particle distribution	Gaussian
number of macro-particles	10^4
Number of simulation steps	10^2
Number of turns per step	10^5
Total turns simulated	10^7
Total RHIC time simulated	2.13 seconds

A set of 7 computer simulations were performed with different beam-beam tune shifts (ν_{bb}=0.004, 0.006, 0.008, 0.010, 0.012, 0.015 and 0.018) keeping other conditions same as table 1. Figure 1 shows the emittance evolution as function of time from these simulations. Here the emittance is defined by $\varepsilon=(\varepsilon_x\varepsilon_y)^{1/2}$ as used in the emittance calculation using the ZDC (zero degree calorimeter) coincident rates of the RHIC experiments. The operation limitation due to beam-beam effect can be indicated by the critical beam-beam tune shift at which the emittance grows rapidly. It can be easily seen, from Figure 1, that this critical beam-beam tune shift is about ν_{bb} = 0.012 which agrees with the observation from the RHIC operations.

The contour plots of beam distributions in (A_x, A_y) plane are shown in Figure 2. The distance between successive contour lines is $e^{1/2}$. Each step corresponds to 10^4 particles tracked over 10^5 turns. The data are averaged over all the particles and over all the turns tracked within the step, that is 10^9 particle-turns for each step.

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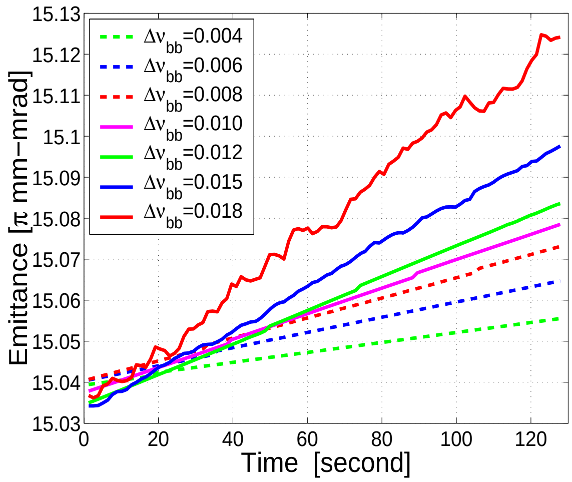

Figure 1. Emittance evolution of beams with different beam-beam parameters as function of time.

EMITTANCE GROWTH RATE DUE TO BEAM-BEAM EFFECT IN RHIC

The 95% normalized emittances averaged over the early 4 hours of beam stores in RHIC are calculated using the ZDC (Zero degree calorimeter) coincident rates of the two major RHIC experiments, PHENIX and STAR. The blue dots and red dots in figure 2 represent the data obtained from RHIC runs 2005 and 2006 [3] verses the beam-beam tune shift respectively. The bunch intensity in 2006 is much higher than in 2005, but the collision points (experiments) were reduced from 3 to 2; therefore, the largest beam-beam parameters are both limited to 0.012.

The emittance growth rate obtained from the simulation is plotted with the solid lines in figure 3 for comparison with the RHIC experimental data. The green line and cyan lines represent horizontal and vertical emittance respectively. The emittance, represented by the purple line, is defined by $\varepsilon=(\varepsilon_x\ \varepsilon_y)^{1/2}$ as used in the emittance calculation using the ZDC coincident rates of the RHIC experiments. It has been observed during the oprations that RHIC beams have nearly round cross sections.

The simulation result is slightly higher than the observation in the RHIC operations. It should be noted that the measured emittance was averaged over 4 hours of beam store, starting 20 minutes after the two beams were brought to collision. The beam-beam parameter was not averaged, but was measured at the beginning of the 4 hour period. Thus, the average value of beam-beam parameter over the 4 hour period could in fact be lower if the effect of beam intensity drop and the beam emittance growth were included. In contrast, the simulation tracks the initial 2.13 minute after the beams are brought to perfect head on collision, when the intensity drop and emittance blow up are both the strongest. This may account for the higher emittance growth rate predicted by the simulation as compared with the calculation based on measurements.

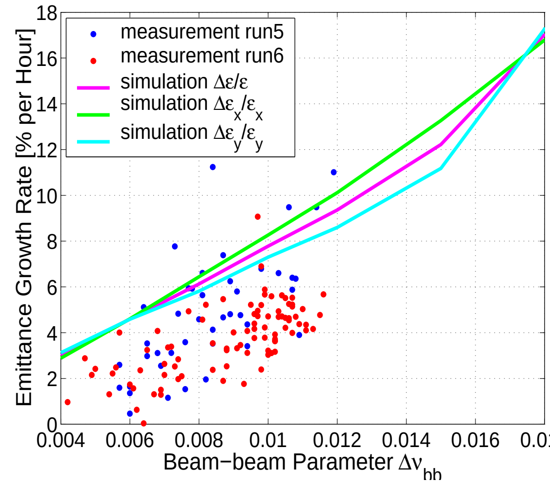

Figure 2. The emittance growth rate from the simulation compared to the measured beam emittance growth of early 4 hours in RHIC stores during Run 2005 and Run 2006 as function of beam-beam parameter.

DISCUSSION AND CONCLUSION

To address the beam-beam issue, a set of computer simulations with LIFETRAC was performed with the machine parameters based on the beam measurements.

The emittance growth due beam-beam effects in RHIC presented in this paper are the initial results of the tracking with LIFETRAC. The Magnet errors and noise are not included. Some advance features of LIFETRAC may also aid to further the understanding of the issues related to emittance growth in RHIC.

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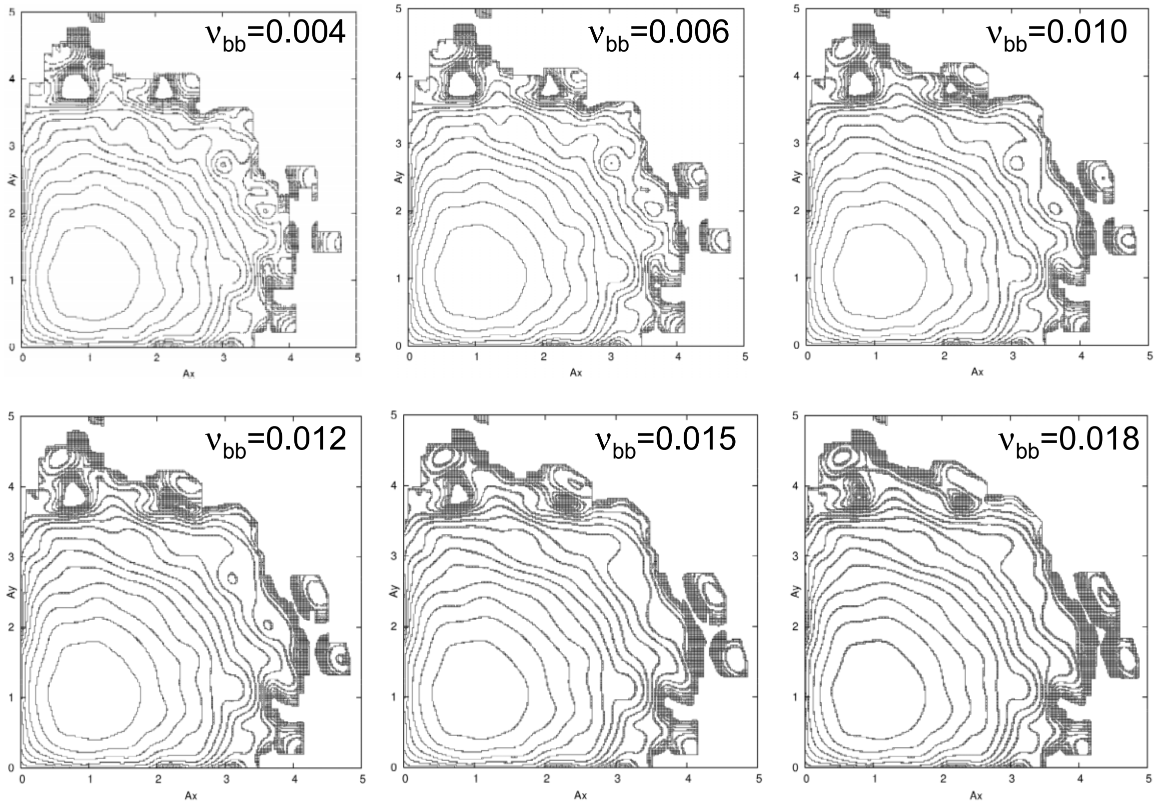

Figure 3: The beam distribution in the plane of normalized betatron amplitudes for different beam-beam tune shifts.

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