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BEAM-BEAM ISSUES WITH TWO INTERACTION POINTS IN ERHIC*

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Abstract

In this article, we study the beam-beam interaction related issues with two interaction points in the current eRHIC ring-ring design. We carried out strong-strong beam-beam simulation in a 2-d bunch intensity scan. We observed coherent beam-beam instability and emittance blowup with 2 collisions per turn at lower bunch intensities than the case with only 1 collision per turn. To deliver collisions to the two experiments simultaneously, we proposed a new bunch filling pattern to avoid 2 collisions per turn for any electron or proton bunch. We proved that the parasitic beam-beam effect with the new bunch filling pattern is negligible.

INTRODUCTION

For the eRHIC ring-ring design [1], it is preferable to have two interaction regions as RHIC. RHIC consists of two rings which intersect at six interaction points (IPs). Each ring has six symmetric arcs and six straight interaction regions (IRs). Currently, there are two physics program detectors in RHIC, STAR at IP6 and PHEIX at IP8. During the routine operation of RHIC, there are 111 bunches in each ring, and about 100 of them collide twice each turn at IP6 and IP8.

The beam-beam interaction at IP increases the beam's tune spread and may cause incoherent and coherent beam instabilities. Beam-beam parameter is used to measure the strength of the beam-beam interaction. For the current eRHIC design, according to the operational experiences of KEKB and RHIC, the beam-beam parameters with 1 collision per turn are 0.1 for the electron beam and 0.015 for the proton beam. However, with two detectors or two collisions per turn per bunch, the beam-beam parameters will be doubled.

In the following, we first carry out a strong-strong simulation to study the beam-beam effects with two interaction regions. Then we propose a new bunch filling pattern to deliver collisions simultaneously to the two detectors and at the same time to avoid two collisions per turn for any electron or proton bunch. In the end we evaluate the effects of the parasitic beam-beam interaction with the new bunch filling pattern.

STRONG-STRONG SIMULATION

In the strong-strong beam-beam simulation, each electron or proton bunches are represented by macro-particles. At collision, each bunch is sliced longitudinal. The transverse electric and magnetic fields from each slice are calculated by solving the Poisson equation with the particle in cell method.

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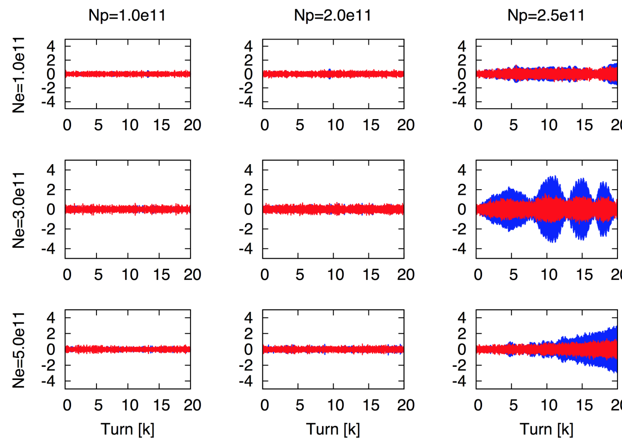

Figure 1: The horizontal centriod motion with 1 collision per turn in the 2-d bunch intensity scan.

Between two adjacent IPs, the particles are simply transferred with linear matrices. For this study, the machine and beam parameters defined in the eRHIC design parameters v2.1 are used. We only focus on the collision between the 10 GeV electron and 275 GeV proton beams.

For the case with 1 collision per turn and the case with 2 collisions per turn at IP6 and IP12, only one electron bunch and one proton bunch are involved. For the case with 2 collisions per turn at IP6 and IP8, three electron bunches and three proton bunches are involved. For the eRHIC beam-beam studies, we have been using two strong-strong beam-beam simulation codes, BeamBeam3D [2] by Dr. Qiang and BBSS [3] by Dr. Ohmi. However, to be able to study the case with collisions among multiple bunches, we used SimTrack [4]. The results with 1 collision per turn from SimTrack were benchmarked with that from BeamBeam3D and agreed well.

For the strong-strong beam-beam simulation, we focus on the coherent beam-beam motion and the evolution of beam sizes and luminosity. We track particles up to 20,000 turns which is about 5 radiation damping periods of the electron ring. We will show the results from a 2-d bunch intensity scan. The electron bunch intensity was scanned from 1.0×10^{11} up to 5.0×10^{11} with a step size of 1.0×10^{11}, and the proton bunch intensity from 0.5×10^{11} up to 2.5×10^{11} with a step size of 0.5×10^{11}. The design bunch intensities for the electron and proton beams are 3.05×10^{11} and 1.11×10^{11} respectively.

Figures 1-3 show the evolution of horizontal centroid motion of both beams in the 2-d bunch intensity scan. The bunch centroid motion reveals the unstable coherent dipole mode motion of bunches which is caused by the beam-beam interaction in our study. From the plots, with 1 collision per

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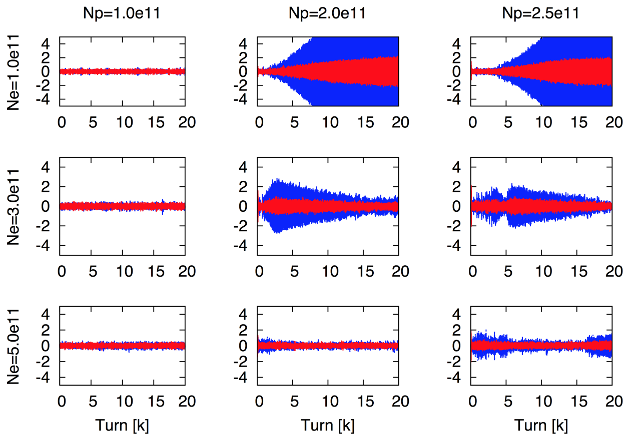

Figure 2: The horizontal centriod motion with 2 collisions at IP6 and IP12 per turn in the 2-d bunch intensity scan.

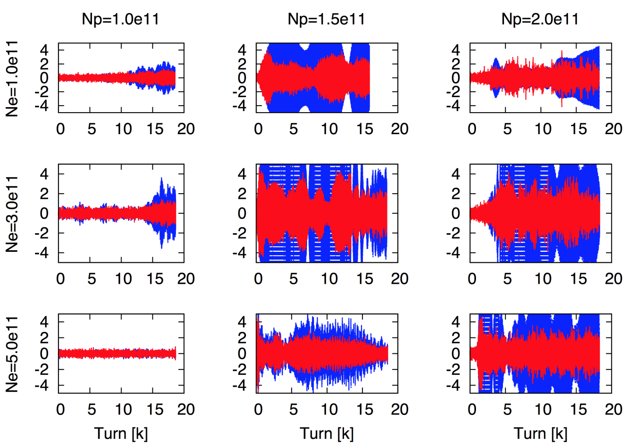

Figure 3: The horizontal centriod motion with 2 collisions at IP6 and IP8 per turn in the 2-d bunch intensity scan.

turn per bunch , the dipole coherent motion shows up when the proton bunch intensity is larger than 2.5×10^{11}. With two collisions per turn at IP6 and IP12, the dipole coherent motion shows up when the proton bunch intensity reaches 2.0×10^{11}. For the case with two collisions at IP6 and IP8, the the dipole coherent motion shows up when the proton bunch intensity reaches 1.0×10^{11}.

In the following, we define

$$\kappa = \frac{L(N_p, N_e)}{L(N_{p0}, N_{e0})} \frac{N_{p0}}{N_p} \frac{N_{e0}}{N_e}, \qquad (1)$$

where $N_{p,e}$ are the bunch intensity, $L(N_p, N_e)$ the averaged luminosity in the last 1000 turn, $N_{p0} = 0.5 \times 10^{11}$ and $N_{e0} = 1.0 \times 10^{11}$. κ should be constant or very close to 1 if there is no beam size increase when we increase the proton and electron bunch intensities.

Figures 4-6 show κ in the above 2-d bunch scan. For the case with 1 collision per turn, κ keeps above 0.9 until the proton bunch intensity reaches to 2.0×10^{11}. For the case with 2 collisions per turn at IP6 and IP12, κ keeps above 0.9 when the proton bunch intensity is less than 1.5×10^{11} and the electron bunch intensity is less than 3.0×10^{11}. For

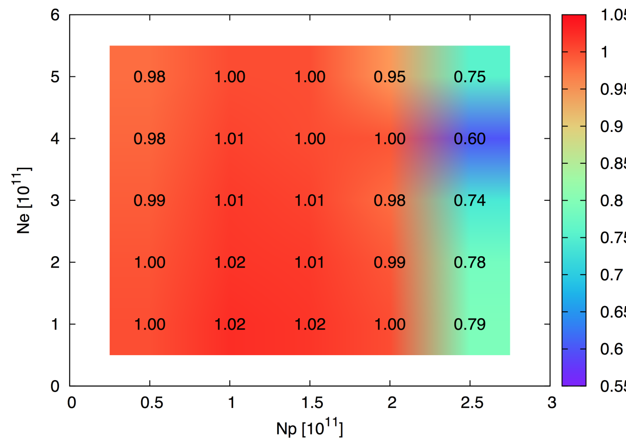

Figure 4: Normalzied luminosity with 1 collision per turn in the 2-d bunch intensity scan.

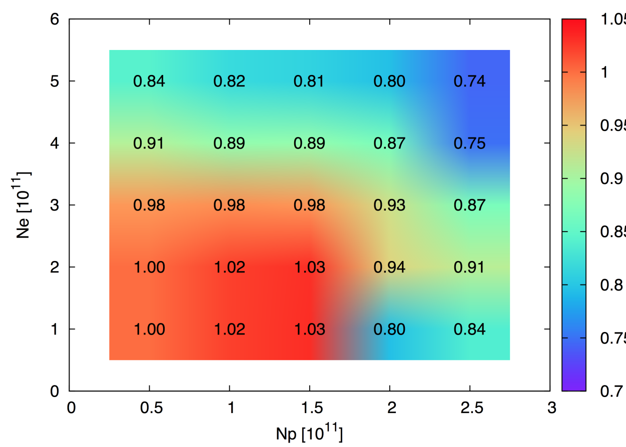

Figure 5: Normalzied luminosity with 2 collisions at IP6 and IP12 in the 2-d bunch intensity scan.

the case with 2 collisions per turn at IP6 and IP8, κ keeps above 0.9 only when the proton bunch intensity smaller than 0.5×10^{11}.

In summary, from the above 2-d bunch intensity scan, two collisions per turn per bunch will cause coherent beam-beam instability and beam emittance blowup at lower bunch intensities than the design bunch intensities. Therefore, we should avoid 2 collisions per turn per for any proton and electron bunches.

BUNCH SHIFT SCHEME

To provide collisions simultaneously to the two detectors at IP6 and IP8 and to avoid two collisions per turn for any electron or proton bunch at the same time, we came up a new bunch filling pattern. The new bunch filling pattern requires: 1) 112 MHz RF system for the proton ring, 560 MHz RF system for the electron ring, 2) Fill protons in every proton ring buckets, 3) Fill the electron ring with 3 identical bunch trains. Each train includes 2 batches, the first batch with 240 electron bunches, the second batch with 239 electron bunches. The bunch space within each batch is 5 electron

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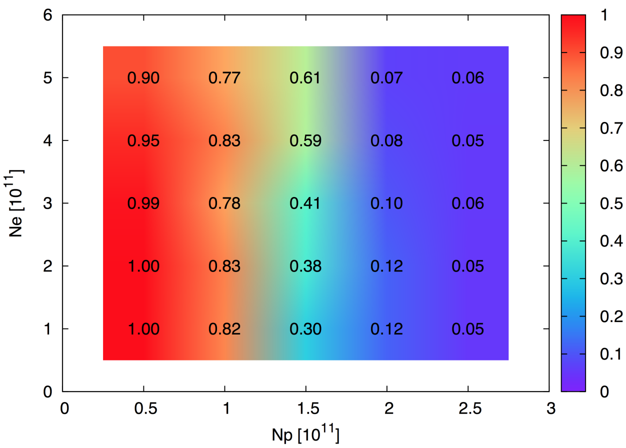

Figure 6: Normalzied luminosity with 2 collisions at IP6 and IP8 in the 2-d bunch intensity scan.

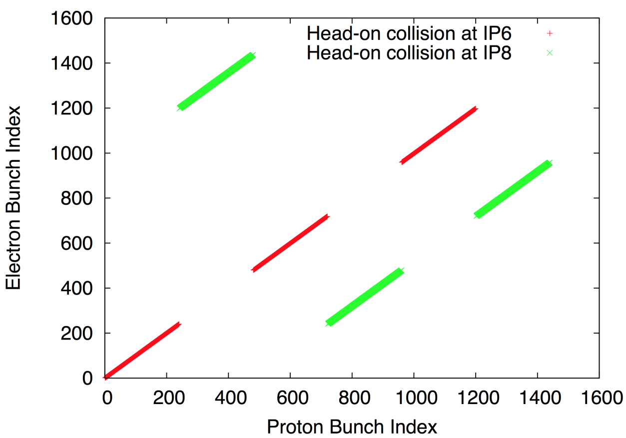

Figure 7: Collision map of the proton and electron bunches with the bunch shift filling pattern.

buckets. The gap between the first and the second batches is 2 electron ring buckets, while the gap between the second batch to the next train is 3 electron ring buckets. 4) The detector at IP8 is moved clockwise, or towards IP10, by 1 electron bucket or 0.53 m.

Here we temporarily ignore the abort gap. With the above bunch shift scheme, there are 1440 proton bunches and 1437 electron bunches. Figure 7 shows the head-on collision pattern with the new bunch filling scheme. Each proton or electron bunch only collides once per turn at either IP6 or IP8. There are totally 720 collisions at IP6 and 717 collisions at IP8 each turn. The collision rates at each detector is about half of that with 1 detector. With the bunch shift scheme, we do not need to change the current eRHIC design beam parameters or re-do previous beam-beam simulation studies with 1 collision per bunch per turn.

PARASITIC BEAM-BEAM INTERACTION

In the present eRHIC interaction region design, the common beam pipe is 9 m long with the interaction point at the center. With two experiments and the above bunch shift scheme, each bunch will undergo 12 long-range beam-beam interactions, with 6 long-range beam-beam interactions at each experiment. Figure 8 shows the locations of these long-range beam-beam interactions for protons at IP8. The nearest long-range beam-beam interaction is 0.53 m away from the IP.

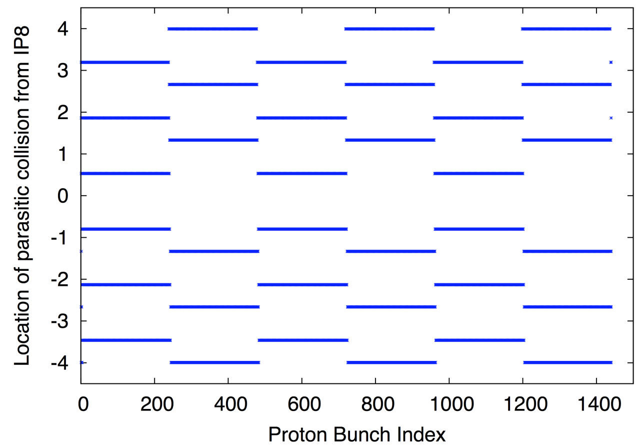

Figure 8: Parasitic beam-beam interactions for proton bunches at IP8 with the bunch shift filling pattern.

The design horizontal crossing angle between the electron and proton rings at the interaction point is 22 mrad. With the above bunch shift scheme, the horizontal separation at the nearest long-range beam-beam interaction point corresponds to $82\sigma_p$ or $71\sigma_e$. Therefore, the long-range beam-beam effect is negligible for the eRHIC design.

SUMMARY

In this article, we carried out strong-strong beam-beam simulation to study the beam-beam effects with 1 and 2 collisions per bunch per turn. The simulation results show that with the current eRHIC design parameters, coherent beam-beam instability and emittance blowup are observed at lower bunch intensities. To simultaneously deliver collisions to the two detectors at IP6 and IP8, we proposed a bunch shift scheme to avoid 2 collisions per turn for any electron and proton bunch. We proved that with the new filling pattern, the effect of parasitic collision can be ignored.

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