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Dynamic aperture evaluation with the beam-beam head-on compensation at IP12

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In this note, the dynamic apertures (DA) are numerically calculated for the 250 GeV polarized proton (pp) run optics. An electron lens at IP12 for the head-on beam-beam compensation is included.

1 Introduction

At the current working point for the RHIC polarization proton (pp) run, the fractional tunes are constraint between 2/3 and 0.7. The vertical faction tune 0.7 will impact both the luminosity lifetime and the polarization. And when the horizontal tune is close to 2/3, the beam lifetime is affected by the third order betatron resonance. To further increase the luminosity, we can increase the bunch intensity N_b and reduce the β^*. At 250 GeV, assuming bunch intensity $N_p = 2.0 \times 10^{11}$ and $\beta^* = 0.9$ m at two collision points IP6 and IP8, the total beam-beam tune shift is 0.02, which pushes the particles in the core of the bunches to the horizontal or vertical third order resonances.

Electron lens (e-lens), actually an low-energy electron beam, has been proposed for the RHIC beam-beam head-on componensation. Based on [1], if the electron beam current matches the proton bunch intensity and has the same Gaussian transver particle distribution, the beam-beam tune spread can be greatly reduced and then the particles are kept away from the main betatron and spin resonances. E-lens for the beam-beam head-on compensation may probably reduce the proton bunch's emittance growth rate and increase the colliding beam lifetime. Moreover, the single proton bunch intensity can be further increased since the beam-beam tune spread is reduced.

To check the benefits and the challenges of using the e-lenses for the RHIC head-on beam-beam compensation, numerical simulations have to be carried out. These studies include the stability of single particles and the emittance growth of a proton bunch. In this note, we will numerically calculate the dynmaic apertures with the 250 GeV polarization proton (pp) run optics with an e-lens at IP12. The effects on the DA from β^* at IP12, full/partial beam-beam compensation, and fluctuations in the electron beam intensity are checked.

2 Simulation paramters

Tab. 1 lists the optics and beam paramters for the following simulation. Fig. 1 is the layout of RHIC rings and ineteraction points.

The 250GeV RHIC pp optics is used for this study. At this moment, we assume that the proton beams collide only at IP6 and IP8. And we put the e-lens at IP12. The β^*s at the IP6 and IP8 are $\beta^*_{x,y} = 0.5$m, and the βs at IP12 are $\beta_{\mathrm{IP12},x,y} = 20$m. The $\beta_{x,y}$s at other sextant symmetric points are $\beta_{x,y} = 10$m. Two uncollisional tunes are $(28.695, 29.685)$. Before particle tracking, the linear chromaticities $Q'_{x,y}$ are set to 1. The magnet field errors in the triplet quadrupoles and separation dipoles and some limited local corrections are included.

The weak-storng beam-beam interaction model is used. The opposite beam and the electron beam are assumed rigid at the interaction points. The interaction between the proton partciles and the electron beams is modeled as another beam-beam interaction. At IP12, the electron beam has the same transverse Gaussian distribution as the proton beam. For the full head-on beam-beam compensation, the electron particle particles in the interaction region is twice of the proton bunch intensity, $N_e = 2N_p = 4.0 \times 10^{11}$.

Table 1: RHIC parameters used in the simulations.

quantity	unit	value
lattice		
beam-beam collision points	-	IP6, IP8
envelop function at beam-beam collision points $\beta^*_{x,y}$	m	0.5
e-lens location	-	IP12
envelop function at e-lens location $\beta^e_{x,y}$	m	20
envelop function at all other IPs $\beta^*_{x,y}$	m	10
proton beam		
ring circumference	m	3833.8451
energy	GeV	250
relativistic γ	-	270
harmonic number	-	360
rf cavity voltage	KV	300
particles per bunch N_p	-	2×10^{11}
normalized transverse rms emittance $\epsilon_{x,y}$	mm mrad	2.5
transverse rms beam size at collision points $\sigma^*_{x,y}$	mm	0.068
transverse rms beam size at e-lens $\sigma^e_{x,y}$	mm	0.430
transverse tunes (Q_x, Q_y)	-	$(28.695, 29.685)$ and $(28.685, 29.695)$
chromaticities (ξ_x, ξ_y)	-	$(1, 1)$
beam-beam parameter per IP $\xi_{\mathrm{p}\rightarrow\mathrm{p}}$	-	-0.01
electron beam		
number of electrons per bunch passage N_e	-	4×10^{11}
transverse rms beam size at interction point	mm	0.430
beam-beam parameter per e-lens $\xi_{\mathrm{e}\rightarrow\mathrm{p}}$	-	$+0.02$

The six-dimentional simpletic tracking code SixTrack is used for most of the following studies. The partciles are tracked element-by-element in 6-D between the beam-beam interation points. At the beam-beam interaction points, 4-D beam-beam transverse kicks are applied. To calculate the tune footprint and tune diffusion, Sussix is used.

3 Tune footprint calculation

In this section, we will calculate and compare the tune footprints with and without the head-on beam-beam compensation. The on-momentum particles are launched in the $(x/\sigma_x, y/\sigma_y)$ plane up to 6σs with $p_x = p_y = 0$. The turn-by-turn (x, y) data from 1000 turn tracking with SixTrack are used to calculate the betatron tunes over 1000 turns.

In Fig. 3, the left and right plots show the tune footprints without and with the head-on beam-beam compensation. And the top and bottom plots show the tune footprints without and with the IR multipole errors. The uncollisional tunes without beam-beam interactions are $(Q_x, Q_y) = (28.695, 29.685)$.

From the left two plots in Fig. 3, the linear beam-beam incoherent tune shift is about 0.02. Without the beam-beam compensation, the tune spreads are mainly decided by the beam-beam interactions at IP6 and IP8.

The rigth two plots show the tune footprints with the full beam-beam compensation. For comparison, the tune footprints without beam-beam interactions in blue dots are also shown. Clearly the tune footprints with the beam-beam interactions and their compensations are greatly reduced. With the full beam-beam compensation, slight foldings ans twists are observed in the tune footprints.

4 Tune diffusion calculation

In the section, we will calculate the tune diffussion in 1000 turn tracking. The betatron tunes in the first and second 500 turns are accurately calcualted with Sussix. The tune diffusion is defined as $|\Delta Q| = \sqrt{\Delta Q_x^2 + \Delta Q_y^2}$, where ΔQ_x and ΔQ_y are the tune differences between the first and second 500 turns. The

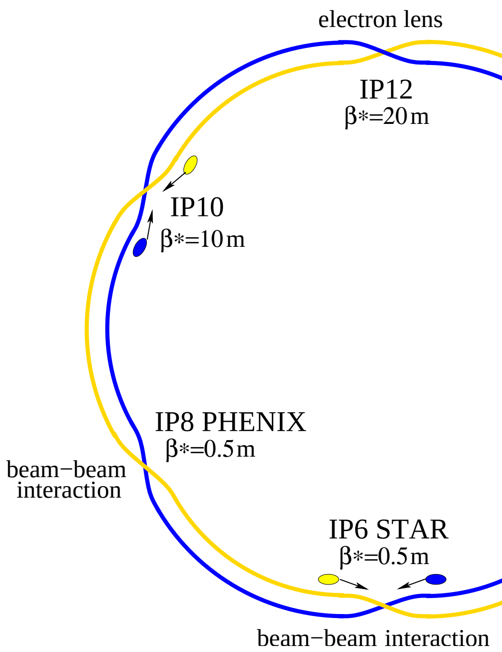

Figure 1: Layout for the simulation.

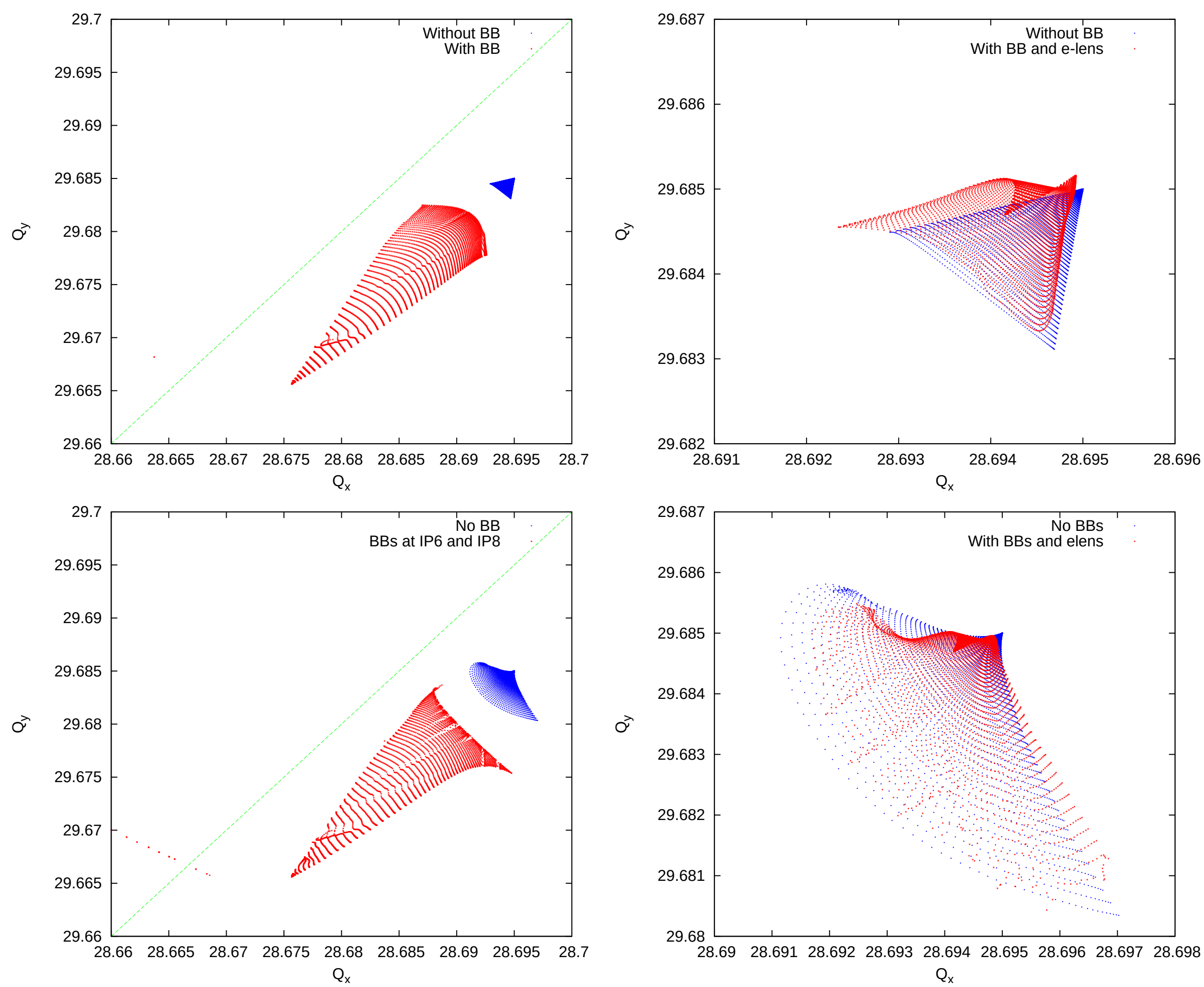

Figure 2: Tune footprints without and with the head-on beam-beam compensation.

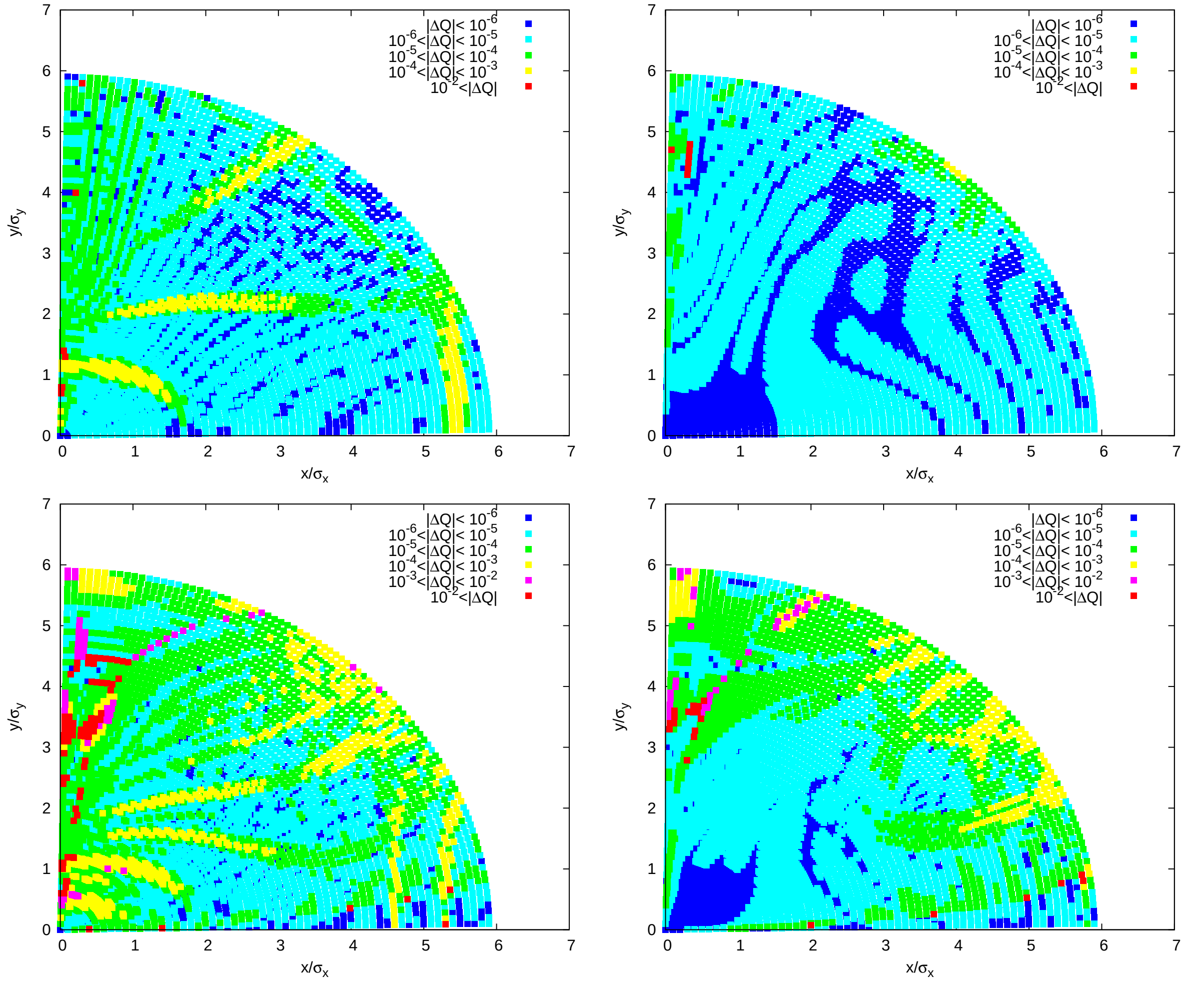

Figure 3: Frequency maps without and with the head-on beam-beam compensation.

on-mentumn particles are launched in the $(x/\sigma_x, y/\sigma_y)$ plane up to 6σs with $p_x = p_y = 0$ for this study. In the tune diffusion plots, dots with different colors mean different orders of tune diffusions.

In Fig. 3, the top and bottom plots are the frequency maps without and with IR multipole errors, respectively. The left and right plots show the freqency maps without and with head-on beam-beam compensation.

From the left two plots in Fig. 3, no matter with or without IR multipole errors, there are some yellow curves below 4σs. The yellow dots means that the particles have tune diffussions between 10^{-4} to 10^{-3}. The particles with tune diffusions larger than 10^{-4} are likely to lose in the long-term tracking.

From the right two plots in Fig. 3, with the beam-beam compensation, the yellow structures only can be seen above 4σs. This means that the head-on beam-beam compensation does help stabilize the particles in the core of bunch below 4σs.

5 Dynamic aperture calculation

From now on, we will numerically calculate the dynamic apertures. In these studies, single particles in 5 phase angles in $(x/\sigma_{x,0}, y/\sigma_{y,0})$ space are tracked to 10^6 turns. Both on-momentum and off-momentum particles with $\delta = \Delta p/p_0 = 0.0007$ are launched. The step in the dynamic aperture seraching is 0.2σ.

Tab. 2 shows the DAs with the nominal beam and e-lens parameters given in Tab. 1. The minimum DA among these 5 phase angles for each case is listed in the last column.

Without IR multipole errors, for the on-momentum particles, the minimum DAs without and with the head-on beam-beam compensation are 8.4σs and 8.8σs. For the off-momentum particles with $\delta = 0.0007$, the minimum DAs without and with the head-on beam-beam compensation are 4.3σs and 3.9σs. Then, at the uncollisional working point $(Q_x, Q_y) = (28.695, 29.685)$, with the head-on beam-beam compensation, for the on-momentum particles, there are 0.4σs increase in the minimum DA. While for the off-momentum particles with $\delta = 0.0007$, there are 0.6σ drop in the minimum DA.

Then we include the IR multipole errors and their limited local corrections in IR6 and IR8. For the on-momentum particles, the minimum DAs without and with the head-on beam-beam compensation are 4.8σs and 5.5σs. For the oof-momentum particles with $\delta = 0.0007$, the minimum DAs without and with the head-on beam-beam compensation are 4.2σs and 3.6σs. Therefore, with the head-on beam-beam compensation, for the on-momentum particles, there are 0.7σs increase in the minimum DA. For the off-momentum particles with $\delta = 0.0007$, there are 0.6σ drop in the minimum DA.

According to the study, for the uncollisional working point $(Q_x, Q_y) = (28.695, 29.685)$, the head-on beam-beam compensation increases the minimum DAs for the on-momentum particles by about 0.5σs. But for the off-momentum particles with $\delta = 0.0007$, it decreases the minimum DAs by about 0.5σs. Table. 3 lists the linear and nonlinear chromaticities for this optics. Nonlinear chromaticities can be corrected with multi- sextupole families.

Table 2: Dynamic apertures with and without full head-on beam-beam compensation

IRerrcorr	δ	N_p [$\times 10^{11}$]	N_e [$\times 10^{11}$]	Dynamic Apertures [σ] 15°	30°	45°	60°	75°	Min.
No	0	2.0	0	12.0	8.4	9.6	10.7	10.7	8.4
No	0	2.0	4.0	12.3	9.9	8.8	9.2	12.0	8.8
No	0.0007	2.0	0	4.3	4.7	6.2	6.4	6.9	4.3
No	0.0007	2.0	4.0	5.2	3.9	4.3	5.1	5.9	3.9
Yes	0	2.0	0	6.2	5.9	4.8	5.6	5.9	4.8
Yes	0	2.0	4.0	6.4	5.5	5.4	5.8	6.6	5.5
Yes	0.0007	2.0	0	3.6	4.2	4.6	4.8	4.9	4.2
Yes	0.0007	2.0	4.0	4.2	3.6	3.6	4.5	4.5	3.6

Table 3: Linear and nonlinear chromaticities for the simulation optics

Condition	Q'_x	Q'_y	$\frac{1}{2}Q''_x$	$\frac{1}{2}Q''_y$	$\frac{1}{6}Q'''_x$	$\frac{1}{6}Q'''_y$
Without IRerr	1.0	1.0	2466	3022	672623	-526985
With IRerrcorr	1.0	1.0	2481	2993	674943	-517868

6 DAs with different β^* at IP12

From this section, we will check the changes in the dynamics apertures with various optics and beam parameters.

First we check the DAs with different β^* at IP12 where the e-lens is located. In this study, β^*_{IP12} is set to be 5m, 10m and 20m, respectively. The electon beam's transverse sizes are always assumed to be the same as the proton beam's. Tab. 4 shows the DAs with different β^* at IP12 for full and half head-on beam-beam compensation. For half beam-beam compensation, the particles in the electron beam in the interaction region is $N_e = N_p = 2.0 \times 10^{11}$.

According to Table. 4, under the full head-on beam-beam compensation, for the off-momentum particles with $\delta_p = 0.0007$, the minimum DA drops while β^*_{IP12} increases from 5m to 10m and to 20m. Under the half head-on beam-beam compensation, the minimum DAs with $\beta^*_{IP12} = $ 5m and 10m are also larger than that with $\beta^*_{IP12} = $ 20m.

7 DAs with partial beam-beam compensation

Here we calculate the DAs with partial head-on beam-beam compensation. The number of the electron particles in the interaction regions ranges from 1.0×10^{11} to 4.0×10^{11}. $N_e = 4.0 \times 10^{11}$ is for the full head-on beam-beam compensation. In this study, the proton bunch intensity is kept, $N_p = 2.0 \times 10^{11}$. The electron beam's transverse beam sizes are same to that of the proton beam at IP12. The β^* at IP12 is 20m.

Table 4: DAs with different β^* at IP12

IRerrcorr	δ	β^*_{IP12} [m]	N_p [$\times 10^{11}$]	N_e [$\times 10^{11}$]	Dynamic Apertures [σ] 15°	30°	45°	60°	75°	Min.
Full BB compensation:										
No	0	5	2.0	4.0	17.2	13.6	11.0	12.8	17.4	11.0
No	0	10	2.0	4.0	13.6	12.4	13.3	11.7	15.4	11.7
No	0	20	2.0	4.0	12.3	9.9	8.8	9.2	12.0	8.8
No	0.0007	5	2.0	4.0	5.8	5.1	5.2	5.6	5.5	5.1
No	0.0007	10	2.0	4.0	5.3	4.5	4.8	5.1	5.7	4.8
No	0.0007	20	2.0	4.0	5.2	3.9	4.3	5.1	5.9	3.9
Yes	0	5	2.0	4.0	6.6	5.8	6.3	6.3	7.2	5.8
Yes	0	10	2.0	4.0	6.4	5.9	6.0	6.1	6.9	6.0
Yes	0	20	2.0	4.0	6.4	5.5	5.4	5.8	6.6	5.4
Yes	0.0007	5	2.0	4.0	5.3	4.5	4.8	5.1	5.7	4.5
Yes	0.0007	10	2.0	4.0	4.9	4.1	4.3	4.5	4.7	4.1
Yes	0.0007	20	2.0	4.0	4.2	3.6	3.6	4.5	4.5	3.6
Half compensation:										
No	0	5	2.0	2.0	16.8	13.5	13.6	13.7	17.0	13.5
No	0	10	2.0	2.0	14.1	11.8	13.0	14.0	15.3	11.8
No	0	20	2.0	2.0	12.7	9.5	10.1	10.7	11.4	9.5
No	0.0007	5	2.0	2.0	4.5	4.1	5.5	6.5	7.2	4.1
No	0.0007	10	2.0	2.0	4.3	4.2	5.2	5.7	9.3	4.2
No	0.0007	20	2.0	2.0	4.3	3.9	4.8	5.7	7.1	3.9
Yes	0	5	2.0	2.0	7.2	5.7	6.4	6.4	7.2	5.7
Yes	0	10	2.0	2.0	7.2	5.7	6.0	6.4	6.9	5.7
Yes	0	20	2.0	2.0	6.4	4.9	5.4	5.9	6.1	4.9
Yes	0.0007	5	2.0	2.0	4.1	4.1	4.2	4.9	5.8	4.1
Yes	0.0007	10	2.0	2.0	3.6	3.6	4.2	4.9	5.4	3.6
Yes	0.0007	20	2.0	2.0	3.3	3.5	4.2	4.8	4.9	3.3

Table 5: Dynamic apertures with partial beam-beam compensation

IRerrcorr	δ	N_p [$\times 10^{11}$]	N_e [$\times 10^{11}$]	Dynamic Apertures [σ] 15°	30°	45°	60°	75°	Min.
No	0	2.0	1.0	12.4	9.1	9.8	10.8	11.3	9.1
No	0	2.0	2.0	12.7	9.5	10.1	10.7	11.4	9.5
No	0	2.0	3.0	12.8	9.7	8.6	10.5	11.8	8.6
No	0	2.0	4.0	12.3	9.9	8.8	9.2	12.0	8.8
No	0.0007	2.0	1.0	3.9	4.2	4.8	6.5	7.1	3.9
No	0.0007	2.0	2.0	4.3	3.9	4.8	5.7	7.1	3.9
No	0.0007	2.0	3.0	3.9	3.5	4.1	5.7	6.2	3.5
No	0.0007	2.0	4.0	5.2	3.9	4.3	5.1	5.9	3.9
Yes	0	2.0	1.0	6.7	6.4	5.3	6.0	6.2	5.3
Yes	0	2.0	2.0	6.4	4.9	5.4	5.9	6.1	4.9
Yes	0	2.0	3.0	6.7	5.3	5.4	5.7	6.5	5.3
Yes	0	2.0	4.0	6.4	5.5	5.4	5.8	6.6	5.4
Yes	0.0007	2.0	1.0	3.4	3.8	4.3	4.8	4.9	3.4
Yes	0.0007	2.0	2.0	3.3	3.5	4.2	4.8	4.9	3.3
Yes	0.0007	2.0	3.0	3.5	3.5	3.9	4.5	4.8	3.5
Yes	0.0007	2.0	4.0	4.2	3.6	3.6	4.5	4.5	3.6

Tab. 5 shows DAs with partial and full head-on beam-beam compensation. Without the IR multipole errors, for the off-momentum particles with $\delta_p = 0.0007$, the minimum DAs are 3.9σs for $N_e = (1.0, 2.0, 4.0) \times 10^{11}$. For $N_e = 3.0 \times 10^{11}$, the minimum DA is 3.5σs. With the IR multipole errors and their limited local corrections in IR6 and IR8, for the off-momentum particles with $\delta_p = 0.0007$, the minimum DAs

Table 6: DAs with the electron beam intensity fluctuations

IRerrcorr	δ	N_p [$\times 10^{11}$]	N_e [$\times 10^{11}$]	$\Delta N_e/N_e$	Dynamic Apertures [σ] 15°	30°	45°	60°	75°	Min.
Full BB compensation:										
No	0	2.0	4.0	0	11.5	12.1	11.3	12.2	12.2	11.3
No	0	2.0	4.0	0.1%	11.5	11.5	11.3	11.3	11.5	11.3
No	0	2.0	4.0	0.5%	11.5	11.9	12.3	11.3	12.1	11.5
No	0	2.0	4.0	1%	10.9	11.9	12.0	11.6	12.1	10.9
No	0	2.0	4.0	2%	11.0	11.3	11.6	12.2	11.6	11.0
No	0.0007	2.0	4.0	0	7.9	7.5	8.6	9.5	9.5	7.5
No	0.0007	2.0	4.0	0.1%	7.9	7.5	9.8	9.8	10.4	7.5
No	0.0007	2.0	4.0	0.5%	7.9	7.9	9.4	10.3	11.0	7.9
No	0.0007	2.0	4.0	1%	7.9	6.8	9.4	8.6	8.9	6.8
No	0.0007	2.0	4.0	2%	7.8	8.2	9.8	8.6	11.0	7.8
Yes	0	2.0	4.0	0	8.4	5.9	6.3	6.2	6.2	5.9
Yes	0	2.0	4.0	0.1%	8.4	6.3	6.3	6.1	6.2	6.1
Yes	0	2.0	4.0	0.5%	7.2	5.8	6.2	6.8	6.7	5.8
Yes	0	2.0	4.0	1%	5.9	6.0	5.9	5.9	6.7	5.9
Yes	0	2.0	4.0	2%	5.6	5.5	6.1	6.2	6.9	5.5
Yes	0.0007	2.0	4.0	0	5.6	5.3	6.0	5.6	6.7	5.3
Yes	0.0007	2.0	4.0	0.1%	5.2	5.0	6.1	5.6	6.2	5.0
Yes	0.0007	2.0	4.0	0.5%	5.7	5.7	5.5	6.1	5.9	5.5
Yes	0.0007	2.0	4.0	1%	5.6	5.3	5.5	6.1	5.6	5.3
Yes	0.0007	2.0	4.0	2%	5.2	4.9	6.1	5.6	6.1	4.9
Half BB compensation:										
No	0	2.0	4.0	0	11.5	12.1	11.3	12.2	12.1	11.3
No	0	2.0	4.0	0.1%	11.5	11.3	12.4	12.6	12.1	11.3
No	0	2.0	4.0	0.5%	12.0	11.3	12.3	11.6	12.4	11.3
No	0	2.0	4.0	1%	11.5	11.9	12.4	11.3	12.1	11.3
No	0	2.0	4.0	2%	10.9	11.9	12.0	11.6	12.1	10.9
No	0.0007	2.0	4.0	0	7.9	7.5	8.6	9.5	9.5	7.5
No	0.0007	2.0	4.0	0.1%	6.8	7.5	9.5	10.7	9.5	6.8
No	0.0007	2.0	4.0	0.5%	7.8	6.5	9.4	10.7	9.9	6.5
No	0.0007	2.0	4.0	1%	7.9	7.9	9.4	10.3	11.0	7.9
No	0.0007	2.0	4.0	2%	7.9	6.8	9.4	8.6	8.9	6.8
Yes	0	2.0	4.0	0	8.4	5.9	6.3	6.2	6.2	5.9
Yes	0	2.0	4.0	0.1%	8.4	5.9	5.5	5.9	6.2	5.5
Yes	0	2.0	4.0	0.5%	8.4	5.9	6.0	6.2	6.1	5.9
Yes	0	2.0	4.0	1%	7.2	5.9	6.2	6.8	6.7	5.9
Yes	0	2.0	4.0	2%	5.9	6.1	5.9	5.9	6.7	5.9
Yes	0.0007	2.0	4.0	0	5.6	5.3	6.0	5.6	6.7	5.3
Yes	0.0007	2.0	4.0	0.1%	4.9	5.1	5.5	6.1	5.9	4.9
Yes	0.0007	2.0	4.0	0.5%	4.2	5.2	5.9	6.1	6.1	4.2
Yes	0.0007	2.0	4.0	1%	5.7	5.7	5.5	6.1	5.9	5.5
Yes	0.0007	2.0	4.0	2%	5.6	5.3	5.5	6.1	5.6	5.3

are 3.3σs - 3.6σs for $N_e = (1.0, 2.0, 3.0, 4.0) \times 10^{11}$. According to this study, at the uncollisional working point $(Q_x, Q_y) = (28.695, 29.685)$, the minimum DA is not sentitive to the electron beam intensity from $N_e = 1.0 \times 10^{11}$ to 4.0×10^{11}.

8 DAs with fluctuations in electron beam intensity

Here we check the effect of the fluctuation in the electron beam intensity onto the DAs. In this study, turn-by-turn random fluctation in the electron beam intensity is included. The maximum change in the electron beam intensity is ΔN_e. In this study, $\Delta N_e/N_e$ is chosen to be 0, 0.1%, 0.5%, 1%, 2%. The DA calculations

Table 7: DAs with different proton bunch intensities

IRerrcorr	δ	N_p	N_e	Dynamic Apertures [σ]					
		[$\times 10^{11}$]	[$\times 10^{11}$]	15°	30°	45°	60°	75°	Min.
Full BB compensation:									
No	0	1.5	3.0	13.1	10.1	9.0	9.9	11.8	9.0
No	0	2.0	4.0	12.3	9.9	8.8	9.2	12.0	8.8
No	0	2.5	5.0	11,0	9.3	8.4	9.2	12.2	8.4
No	0.0007	1.5	3.0	5.3	4.3	4.5	5.1	6.9	4.3
No	0.0007	2.0	4.0	5.2	3.9	4.3	5.1	5.9	3.9
No	0.0007	2.5	5.0	5.1	3.9	4.6	4.9	5.7	3.9
Yes	0	1.5	3.0	6.7	5.7	5.6	5.8	6.5	5.7
Yes	0	2.0	4.0	6.4	5.5	5.4	5.8	6.6	5.4
Yes	0	2.5	5.0	5.9	4.8	5.1	5.6	6.4	4.8
Yes	0.0007	1.5	3.0	4.9	3.6	3.9	4.8	4.5	3.6
Yes	0.0007	2.0	4.0	4.2	3.6	3.6	4.5	4.5	3.6
Yes	0.0007	2.5	5.0	4.1	3.5	3.6	4.2	4.4	3.5
Half BB compensation:									
No	0	1.5	1.5	13.0	9.9	10.3	11.0	11.4	9.9
No	0	2.0	2.0	12.7	9.5	10.1	10.7	11.4	9.5
No	0	2.5	2.5	12.4	9.3	9.2	10.1	11.4	9.2
No	0.0007	1.5	1.5	4.4	4.4	5.4	5.9	7.5	4.4
No	0.0007	2.0	2.0	4.3	3.9	4.8	5.7	7.1	3.9
No	0.0007	2.5	2.5	3.5	3.6	4.8	4.9	6.4	3.5
Yes	0	1.5	1.5	7.1	5.5	5.7	6.0	6.3	5.5
Yes	0	2.0	2.0	6.4	4.9	5.4	5.9	6.1	4.9
Yes	0	2.5	2.5	5.5	5.2	4.8	5.5	6.3	4.8
Yes	0.0007	1.5	1.5	3.6	3.6	4.4	4.8	4.9	3.6
Yes	0.0007	2.0	2.0	3.3	3.5	4.2	4.8	4.9	3.3
Yes	0.0007	2.5	2.5	3.3	3.5	4.1	4.6	4.9	3.3

are done with Tracy-II. The maximum tracking turn is 10^5. Table. 6 shows the DAs with fluctuations in electron beam intensity under full and half head-on beam-beam compensations, respectively.

According to Table. 6, at current working point and in 10^5 turn tracking, there is no clear tend in the minmum DAs during $\Delta N_e/N_e$ changes from 0 to 2%. Long-term tracking may be needed for further check.

9 DAs with different proton bunch intensities

Here we calculate the DAs with different proton bunch intensities. N_p are chosen to be 1.5×10^{11}, 2.0×10^{11}, and 2.5×10^{11}. The DAs with full and half head-on beam-beam compensation are calculated, respectively. Tab. 9 shows the DAs with different proton bunch intensities under the full head-on beam-beam compensation. Tab. 10 shows the DAs with different proton bunch intensities under the half head-on beam-beam compensation.

For the off-momentum particles with $\delta = 0.0007$, the minimum DA change is below 0.4σs when the proton bunch intensity changes from 1.5×10^{11} to 2.0×10^{11} and 2.5×10^{11}. The luminosity will increase by 50% when the proton bunch intensity increases from 2.0×10^{11} to 2.5×10^{11}.

10 Summary

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