SIMULATION OF RESONANCE STREAMING AT THE ERHIC ELECTRON STORAGE RING *

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Abstract

To estimate electron beam lifetime and detector background at the future electron-ion collider eRHIC, knowledge of the electron beam halo region is essential. Simulations have been performed to determine the deviation of the transverse beam profile from a Gaussian distribution.

INTRODUCTION

To study collisions between polarized electrons and relativistic heavy ions or polarized protons, adding a $10\,\mathrm{GeV}$ electron storage ring to the existing RHIC accelerator complex is under consideration [1]. In this eRHIC facility, beam-beam tuneshift parameters of $\xi_y = 0.08$ are required for the electron beam in order to achieve a luminosity of several $10^{32}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$. The resulting beam dynamics in the presence of the beam-beam interaction needs to be studied carefully. For that purpose the beam-beam problem can be divided into two different regimes, namely the core and the halo of the electron beam. While the behavior of the beam core determines the luminosity performance of the machine, the evolution of the tails determines the beam lifetime and detector background levels.

electrons:	
ring circumference [m]	1278
number of bunches	120
geometric emittance hor./vert. [nm]	53/9.5
β functions hor./vert. [m]	0.19/0.27
bunch length [mm]	11.7
synchrotron tune	0.04
particles/bunch	$1.0 \cdot 10^{11}$
beam-beam tune shift hor./vert.	0.027/0.08
damping times hor./vert./long. [turns]	1740/1740/870
hadrons:	
ring circumference [m]	3834
number of bun ches	360
geometric emittance hor./vert. [nm]	9.5/9.5
β functions hor./vert. [m]	1.08/0.27
particles/bunch	$1.0 \cdot 10^{11}$ (p),
	$1.0 \cdot 10^{9}$ (Au)
beam-beam tune shift hor./vert.	0.007/0.0035
beam spot size hor.vert. [μm]	100/50
luminosity [$\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	$4.4 \cdot 10^{32}$

Table 1: Interaction region parameters of the electron-ion collider eRHIC.

SIMULATION RESULTS

The simulation technique applied to the study of the transverse beam tails is similar to the one developed by Shatilov [2] and Chen, Irwin, and Siemann [3]. Using normalized coordinates and momenta,

$$x = A_x \sigma_x \cos(\phi_x), \quad (1)$$
$$x' = A_x \sigma_{x'} \sin(\phi_x), \quad (2)$$
$$y = A_y \sigma_y \cos(\phi_y), \quad (3)$$
$$y' = A_y \sigma_{y'} \sin(\phi_y), \quad (4)$$
$$\alpha_x = \alpha_y = 0, \quad (5)$$

the amplitude plane (A_x, A_y) is divided into cells with a size sufficiently small to ensure good resolution [2],

$$\Delta A < 2\sqrt{\alpha}, \quad (6)$$

where the damping decrement α is defined as the inverse of the damping time. In the simulations described here, the cell size is chosen as $\Delta A = 0.005$.
A single particle is tracked for ten thousand damping times; the tracking includes the linear one-turn matrix, the beam-beam interaction, and radiation damping and quantum excitation. After each turn the betatron amplitudes A_x, A_y are calculated and the density of the corresponding cell in the (A_x, A_y) plane is incremented by one. After ten thousand damping times cells with a density above one tenth of the density at the center $(A_x, A_y) = (1, 1)$ are assigned as region I, and cells with a lower density are assigned as region II. During another ten thousand damping times of tracking, phase space coordinates of the particle are saved whenever it moves from region I to region II.
In the next step, region I becomes region O, the hidden region, while region II becomes region I. The particle is launched from a coordinate that is randomly selected from those saved when the particle crossed the border between regon I and II on the previous step. Whenever the particle falls into the hidden region 0, it is re-launched at another randomly selected phase space coordinate of the same set. Again, region I is divided into region I and II according to the density after ten thousand damping times, and coordinates are saved for border crossings from region I to region II during a subsequent ten thousand damping times.
The code has been tested in two steps. First, the beam-

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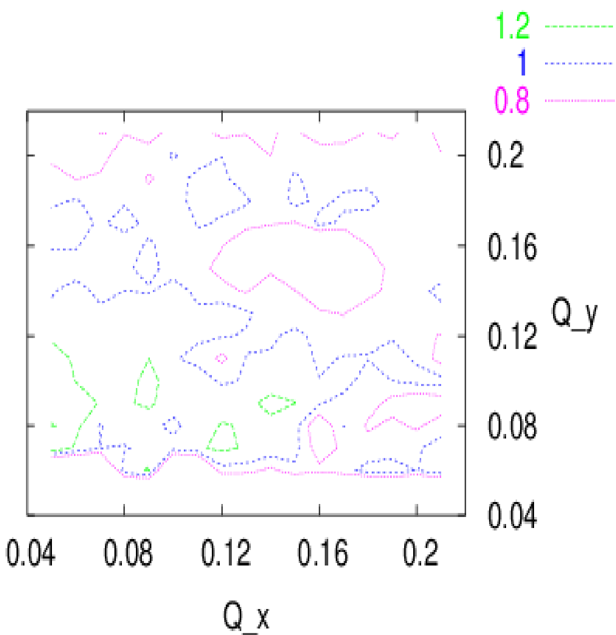

Figure 1: Contour plot of the resulting normalized luminosity $\mathcal{L}/\mathcal{L}_0$ vs. horizontal and vertical electron beam tune. $\mathcal{L}_0$ denotes the geometric design luminosity according to Table 1.

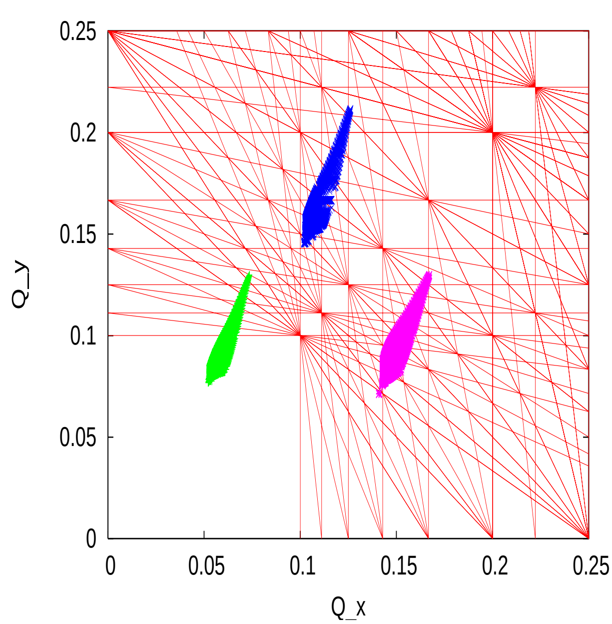

Figure 2: Resonances up to 10th order and necktie diagrams for the three possible eRHIC working points investiated in this study.

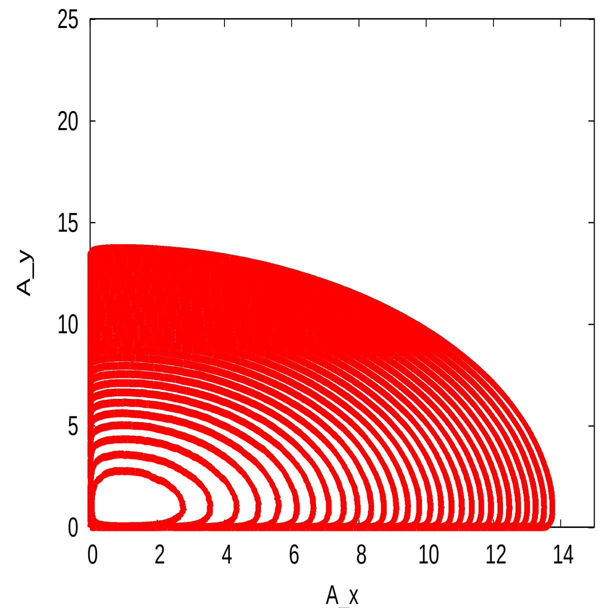

Figure 3: Density contours in the absence of the beam-beam interaction, resulting from the simulation. The density decreases by a factor 10 between level lines.

beam interaction was switched off, so the resulting distribution is expected to be just the one corresponding to a regular Gaussian distribution,

$$\rho(A_x, A_y) = A_x A_y \exp\left(-\frac{A_x^2 + A_y^2}{2}\right). \tag{7}$$

Using the same parameters as given for the examples presented in Ref. [3], the results agree very well. The distribution resulting fro tracking is depicted in Figure 3 and agrees very well with the analytical expression, Equation 7.

Three possible eRHIC working points have been identified based on the resulting luminosity performance [4], namely $(.05, .07)$, $(.10, .14)$, and $(.14, .07)$, see Figure 1. The corresponding necktie diagrams are depicted in Figure 2, together with sum resonances up to 10th order.

None of the three working points leads to excessive population of non-Gaussian beam tails. This can be explained by the small beam size ratio of $\kappa = \sigma_y/\sigma_x = 2.0$, which results in a significant drop in the vertical kick when the vertical position of the test particle exceeds the horizontal beam size [5], thus preventing the build-up of a non-Gaussian tail in the vertical plane. However, the working point $(.14, .07)$ leads to a significant contribution of electrons at vertical amplitudes up to $20\sigma_y$. While this would not reduce the beam lifetime as long as a minimum vertical aperture of $20\sigma_y$ around the entire machine is guaranteed, this may lead to enhanced background problems from synchrotron radiation emitted by these particles in the interaction region.

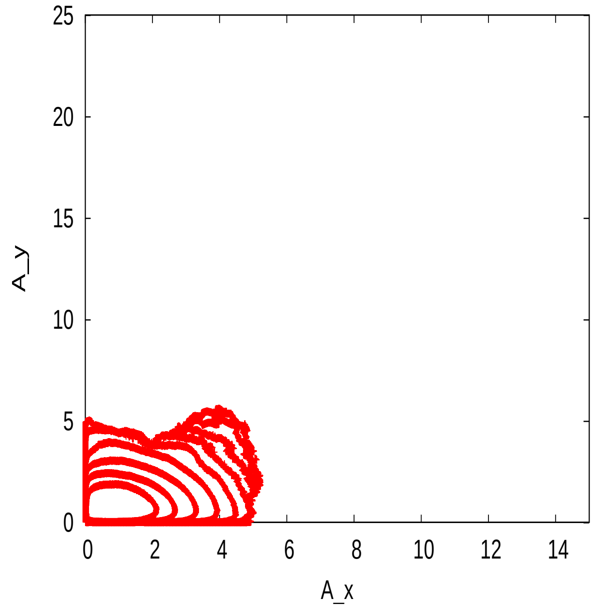

Figure 4: Density contours for the working point $(.05, .07)$.

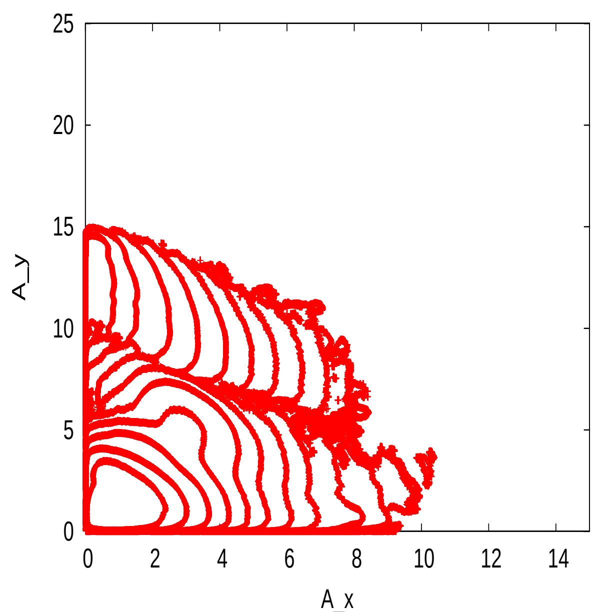

Figure 5: Density contours for the working point $(.10, .14)$.

CONCLUSION

Non-Gaussian transverse beam tails have been studied for three different working points in the proposed eRHIC electron ring, using the method developed by Shatilov [2]. Due to the small ellipticity $\kappa = \sigma_y/\sigma_x = 2.0$ of the eRHIC beams at the interaction point, no excessive population of the vertical electron beam tails occurs. While a minimum aperture of 20σ would be sufficient to ensure long beam lifetime, one of the working points studied here leads to

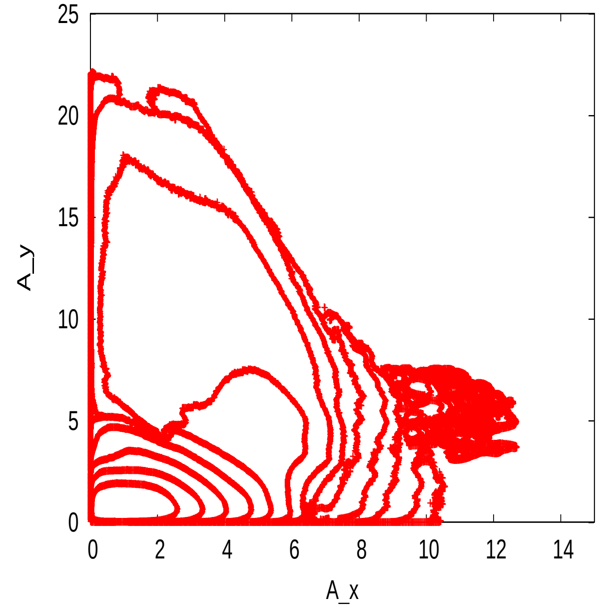

Figure 6: Density contours for the working point $(.14, .07)$.

enhanced photon background in the eRHIC detector from electrons at amplitudes as large as $20\sigma_y$.

ACKNOWLEDGMENTS

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