INTERACTION REGION DESIGN FOR THE ELECTRON-ION COLLIDER ERHIC [*]

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Abstract

To facilitate the study of collisions between 10 GeV polarized electrons and 100 GeV/u heavy ions or 250 GeV polarized protons at luminosities in the $10^{33} cm^{-2} sec^{-1}$ range (e-p case), adding a 10 GeV electron storage ring to the existing RHIC complex has been proposed. The interaction region of this electron-ion collider eRHIC has to provide the required low-beta focussing, while simultaneously accomodating the synchrotron radiation fan generated by beam separation close to the interaction point, which is particularly challenging. The latest design status of the eRHIC interaction region will be presented.

INTRODUCTION

The interaction region of an electron-ion collider is particularly challenging. Not only does it have to focus both beams to small, equal spot sizes at the interaction point (IP) to maximize luminosity, but it also has to merge and subsequently separate the two beams which travel in two separate storage rings. This merge and separation is realized by bending the lower-energy electron beam away from the ion beam, which results in a fair amount of synchrotron radiation generated in the interaction region. This radiation ahs to be passed safely through the detector, and an arrangement of masks has to protect the detector from backscattered photons.

In contrast to an earlier design [1], the scheme presented here provides a machine-element free region of $\pm 3\,\mathrm{m}$ around the IP, at the expense of lower luminosity. This new scheme provides a greater detector acceptance and may therefore be preferred [2].

BEAM SEPARATION

Generation of synchrotron radiation in the interaction region can be avoided altogether by introduction of a crossing angle, thus providing the required separation of the two beam without the need of magnetic dipole fields. Assuming a minimum required separation of the two beams of $d = 25\,\mathrm{mm}$ at the entrance of the first ion septum quadrupole, and a distance of that magnet from the IP of $l^* = 5$, the necessary crossing angle can be estimated at $\Theta = 5\,\mathrm{mrad}$. Introduction of a $5\,\mathrm{mrad}$ crossing angle, however, reduces the luminosity by a factor of five due to the relatively long ion bunch length of $\sigma_z \approx 20\,\mathrm{cm}$. This can in principle be overcome by introducing a crab-crossing scheme [3, 4], which would roate the long ion bunches into the direction if the oncoming electron bunches, thus resulting in head-on collisions in the co-moving frame. The required transverse deflecting voltage of the RF crab cavities is calculated as [4]

$$V_\perp = \frac{cE\tan\Theta}{e\omega_{\mathrm{RF}}\sqrt{\beta^*\beta_{\mathrm{crab}}}} \qquad (1)$$

where c is the velocity of light, E the beam energy, e the beam particle charge, and ω_{RF} the RF voltage. β^* and β_{crab} denote the β-functions at the IP and the location of the crab cavity, respectively.

For a $250\,\mathrm{GeV}$ proton beam, an RF frequency of $\omega_{\mathrm{RF}} = 2\pi\cdot 200\,\mathrm{MHz}$, and β-functions of $\beta^* = 1.08\,\mathrm{m}$ and $\beta_{\mathrm{crab}} = 400\,\mathrm{m}$, the required RF voltage is calculated as

$$V_\perp = 14.4\,\mathrm{MV}. \qquad (2)$$

This voltage is about ten times higher than that for the KEKB crab cavities [5], a system which has been developed but has not yet been installed and tested with beam. Therefore it was decided to design the eRHIC interaction region with zero crossing angle.

To provide head-on collisions the two beams have to be separated by magnetic dipole fields. At the entrance of the first on septum quadrupole, $7.2\,\mathrm{m}$ from the IP, this separation d has to be sufficiently large to provide $20\sigma_{x,e}$ aperture for the electron beam, $12\sigma_{x,p}$ for the hadron beam, plus space for the $10\,\mathrm{mm}$ thick septum itself, including vacuum chambers. To minimize the required separation at the septum, horizontal beam sizes $\sigma_{x,e}$ and $\sigma_{x,p}$ at that location therefore have to be kept small. In the case of the ion beam, where the emittance is given by the existing RHIC beam, the horizontal beam size is expressed as

$$\sigma_{x,p}(7.2\,\mathrm{m}) \propto \sqrt{\beta^*_{x,p} + \frac{(7.2\,\mathrm{m})^2}{\beta^*_{x,p}}} \approx \frac{7.2\,\mathrm{m}}{\sqrt{\beta^*_{x,p}}}, \qquad (3)$$

because the septum quadrupole is the focusing element closest to the IP. This relation imposes a lower limit on the horizontal β function β^*_x at the IP, and therefore limits the attainable luminosity.

The electron beam size $\sigma_{x,e}$ at the septum can in principle be minimized by reducing the emittance accordingly. However, since beam sizes at the IP have to be matched, this requires larger electron β functions at the IP. Increased β-functions at the IP result in a larger beam-beam tuneshift and therefore limit luminosity. Table 1 lists the main interaction region parameters chosen in this design.

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electrons:	
ring circumference [m]	1278
number of bunches	120
geometric emittance hor./vert. [nm]	53/9.5
β functions hor./vert. [m]	0.38/0.54
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
ions:	
ring circumference [m]	3834
number of bun ches	360
geometric emittance hor./vert. [nm]	9.5/9.5
β functions hor./vert. [m]	2.16/0.54
particles/bunch	$1.0 \cdot 10^{11}$ (p), $1.0 \cdot 10^{9}$ (Au)
beam-beam tune shift hor./vert.	0.007/0.0035
luminosity [$\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	$2.2 \cdot 10^{32}$

Table 1: Parameter table.

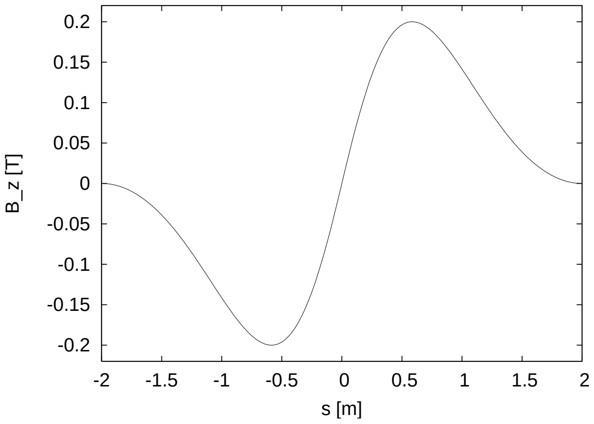

Figure 1: Vertical magnetic field component B_z of the detector integrated dipole (DID) used for beam separation. The interaction point (IP) is located at $s = 0$.

The required beam separation is provided by dipole coils superimposed on the detector solenoid [6], thus leaving the entire detector volume between the innermost common superconducting quadrupoles machine-element free. Figure 1 schematically shows the dipole field component of such a detector-integrated dipole (DID) on the solenoid axis.

SYNCHROTRON RADIATION ACCOMODATION

Photon background in the detector is caused by two types of photons, namely those directly emitted by the beam, and those backscattered from various surfaces in the interaction region. The geometry of the interaction region and the detector has to be chosen such that only synchrotron radiation photons emitted by electrons in the transverse tails of the distribution can hit surfaces near the detector or the detector itself, while all photons from the core of the beam pass safely through the detector and only hit surfaces at a large distance from the detector. A well-designed masking system has to ensure that only a small, tolerable fraction of photons backscattered from those surfaces reaches the detector.

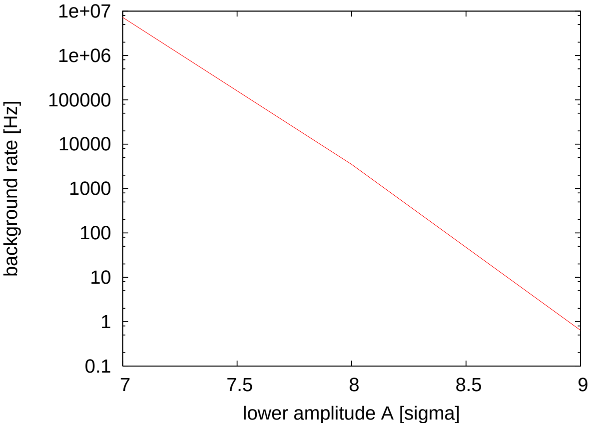

Figure 2: Background rate due to synchrotron radiation photons generated by electrons at amplitudes greater than A, as function of A.

The background rate due to direct hits can be estimated by calculating the probability of finding an electron in the transverse beam tails beyond a minimum amplitude A with the bunch crossing rate. With a bunch crossing rate of $28\,\mathrm{MHz}$, a background rate of about $1\,\mathrm{kHz}$ is considered sufficiently low. This translates into a minimum aperture requirement for the synchrotron radiation fan such that all photons generated by electrons at transverse amplitudes of up to 8σ pass through the interaction region, see Figure 2.

A certain fraction of the synchrotron radiation fan unavoidably hits the septum plate of the first ion septum quadrupole, at $7.2\,\mathrm{m}$ from the IP. This septum is therefore equipped with a dedicated synchrotron radiation absorber to minimize the amount of backscattered photons that may eventually hit the detector, thus contributing to backgound there. Synchrotron radiation masks limit the opening angle of the backscattered radiation fan such that the detector components are shadowed from backscattered photons from the core of the incident fan. Detailed simulation studies are being performed to evaluate and optimize the masking scheme [7]. A top view of the central part of the interaction region is shown in Figure 3.

LOW-β FOCUSING

Focusing of both beams is provided by magnets outside the detector volume, at distances larger then $3\,\mathrm{m}$ from the IP. The electron low-β triplet is shared by both beams; its effect on the ion beam, however, is practically negligible due to the much higher beam energy. The minimum aper-

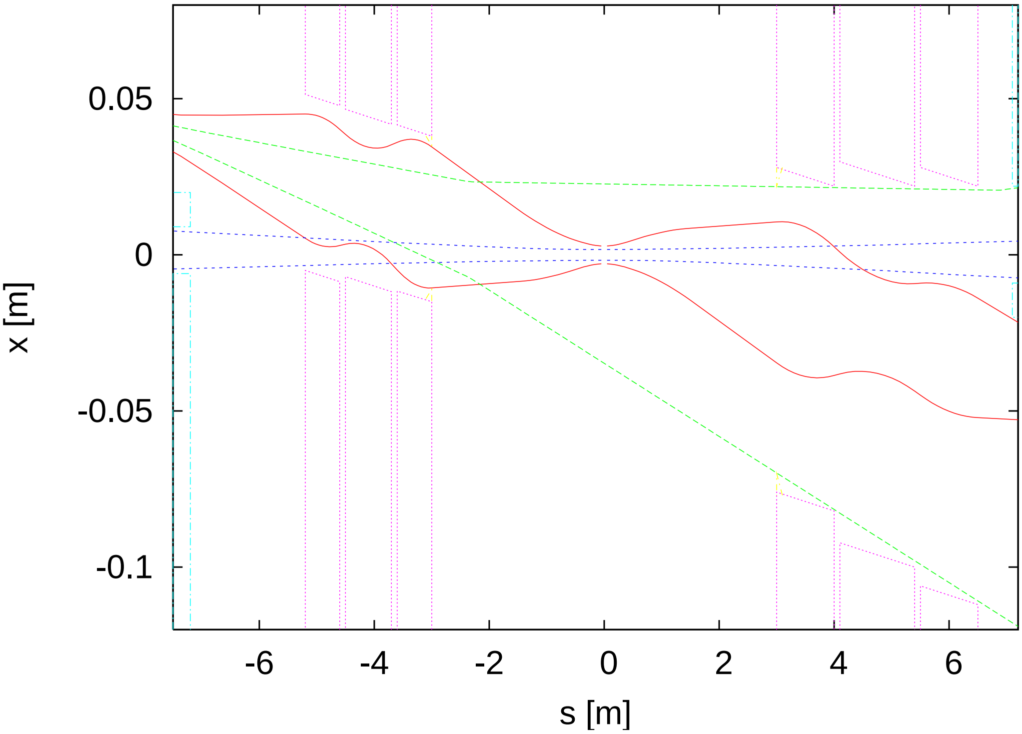

Figure 3: Top view of the eRHIC interaction region with the 20σ electron beam (red), the 12σ ion beam (blue), and the synchrotron radiation fan generated by the 5σ electron beam (green). The apertures of the superconducting electron low-β quadrupoles (magenta) are tailored according to the sizes of the beams and the fan. The normal-conducting ion septum quads are indicated in light blue.

ture of these magnets is determined by the size of the synchrotron radiation fan from 8σ electrons, the $20\sigma_e$ electron beam, and the $12\sigma_p$ ion beam - whichever is largest. On the electron-upstream side this minimum is given by the requirement of sufficient aperture for both beams, as shwon in Figure 3. On the electron-downstream side of the detector, the magnet aperture is dominated by the requirement to safely pass the 8σ synchrotron radiation fan. In order to keep peak magnetic fields in the electron downstream quadrupole at the $2\,\mathrm{Tesla}$ level, the length of these large-aperture magnets has been chosen larger than on the electron-upstream side.

On the electron-upstream side, the same magnets could be used; however, it may be more cost efficient to use either normal-conducting magnets of the same length as downstream, or build a superconducting triplet of reduced length. The latter would provide a reduced horizontal electron beam size at the upstream septum. This provides an apportunity to reduce the separation angle on the upstream side, which in turn somewhat reduces the synchrotron radiation fan width on the downstream side and therefore the aperture requirements there.

Low-β focusing of the ion beam is provided by a normal-conducting septum-quadrupole triplet similar to the one described in Ref. [1], starting at $7.2\,\mathrm{m}$ distance from the IP.

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