SYNCHROTRON RADIATION IN ERHIC INTERACTION REGION*

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Abstract

The electron-ion collider eRHIC [1] currently under study at BNL consists of a 10GeV high intensity electron beam facility to be added to the existing RHIC complex. The interaction region of this facility has to provide the required low-beta focusing while accommodating the synchrotron radiation generated by beam separation close to the interaction point. In the current design, the synchrotron radiation caused by 10GeV electrons bent by separator dipole magnets will be guided through the interaction region and dumped 5m downstream. However, it is unavoidable to stop a fraction of the photons at the septum where the electron and ion vacuum systems are separated. In order to protect the septum and minimize the backward synchrotron radiation, an absorber and collimation system will be employed. In this paper, we first present the overview of the current design of the eRHIC interaction region with special emphasis on the synchrotron radiation. Then the initial design of the absorber, including its geometrical and physical property, will be described. Finally, our initial investigation of synchrotron radiation in the eRHIC interaction region, especially a simulation of the backward scattering from the absorber, will be presented.

ERHIC INTERACTION REGION

The merging and separation of electron and ion beams in the current design of the eRHIC interaction region is provided by a pair of dipole coils superimposed on the detector solenoid. The detector-integrated dipole (DID) field bends the lower-energy electron beam away from the ion beam. This scheme provides a machine-element free region of ±3m around the IP and a greater detector acceptance at the expense of lower luminosity and a fair amount of synchrotron radiation generation in the interaction region [2]. A certain fraction of the synchrotron radiation fan unavoidably hits the septum plate of the first ion septum quadrupole, at 7.2m from the interaction point (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 IP background.

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FORWARD SYNCHROTRON RADIATION IN THE INTERACTION REGION

The photon spectrum of forward synchrotron radiation can be calculated with [3]:

$$\frac{d^2n}{dtdE} = \frac{P_0\gamma}{E_C{}^2}\frac{S(\omega/\omega_C)}{(\omega/\omega_C)} \quad (1)$$

where P_0 is the synchrotron radiation power, γ is the electron relativistic factor E^e_{total} / E^e_{rest} , E_C is the critical photon energy, and the *S*-function is defined as:

$$S(\frac{\omega}{\omega_C}) = \frac{9\sqrt{3}\,\omega}{8\pi\,\omega_C}\int_{\omega/\omega_C}^{\infty} K_{5/3}(z)\,dz \quad (2)$$

Here, $K_{5/3}(z)$ is the modified Bessel function of the second kind. There are two directions of synchrotron radiation in the eRHIC interaction region: forward (in the direction of the electrons) and backward (in the opposite direction of the electrons). The forward synchrotron radiation background is generated by 10GeV electrons bent through a 0.2 Tesla detector integrated dipole magnet located 1m (from the magnet center to IP) upstream. The backward radiation background is caused by the secondary radiation of the absorber located 7.2m downstream, which is proportional to the primary radiation on the absorber. In the current design, the fraction of the forward radiation fan hitting the absorber is 20% and 27%, generated in the magnets located 1m (from the magnet center to IP) upstream and downstream of the detector, respectively. Figure 1 shows the photon spectrum of forward radiation in the interaction region without masks and on the absorber calculated with the physical parameters of eRHIC interaction region listed in Table 1. The integrated forward radiation on the absorber is 4.8×10^{22} photons/sec.

Table 1: Physical parameters of eRHIC interaction region.

Number of Dipole Magnets at IP	2
Magnetic Field	0.2 Tesla
Magnet Effective Length *L*	1.0 m
Electron Beam Current	0.5 A
Electron Relativistic Factor γ	1.96E+04
Syncrotron Radiation Power P_0	5.08 kW
Critical Photon Energy E_0	13.3 keV

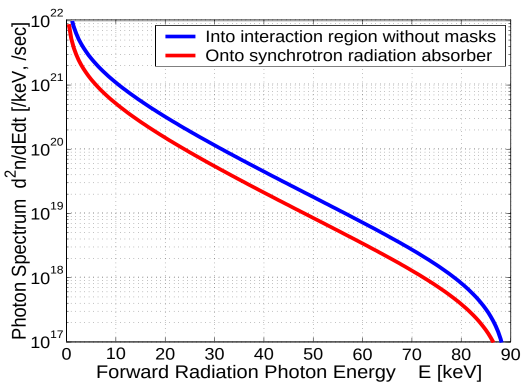

Figure 1: Photon spectrum of forward synchrotron radiation in the interaction region without masks (blue) and on the V-shaped absorber surface (red).

DESIGN OF SYNCHROTRON RADIATION ABSORBER

The design of V-shaped absorber is based on the high power synchrotron radiation absorber of HERA [4]. It not only has to withstand the heat load of the synchrotron radiation, but also has to minimize the backward scattering of the photons. Table 2 lists the geometry, location and material of the vacuum chamber, the detector and the V-shaped absorber. Figure 2 provides a 3D view of the eRHIC synchrotron radiation absorber placed in front of the septum.

Table 2: Geometry, location and material of the absorber, the vacuum chamber, the detector and the IP magnets.

Material of V-shaped Absorber	Copper
Absorber V-opening Width	1 cm
Absorber V-opening Height	3 cm
Absorber V-opening Depth	25 cm
Surface tilt angle of the V-opening	60 mrad
Interaction Point from Absorber	7.2 m
Upstream Magnet from Absorber	8.2 m
Downstream Magnet from Absorber	6.2 m
Material of Vacuum Chamber	Stainless Steel
Diameter of Vacuum Chamber	15 cm
Material of the Detector Surface	Silicon
Diameter of Detector Opening	15 cm

Figure 2: The eRHIC synchrotron radiation absorber.

BACKWARD SYNCHROTRON RADIATION INTO THE IR REGION

Computer Simulations

GEANT [5], a Monte Carlo tool for high-energy physics detector, is used for this simulation study. All the physics processes involving photon-matter interactions are included. They are photoelectric effect, Rayleigh (coherent) scattering, Compton (incoherent) scattering, continuous energy loss, (e^+, e^-) pair production, positron annihilation, hadronic interaction, Bremsstrahlung, ionization and δ-ray production. All the simulation parameters are consistent with the current eRHIC design. The initial forward photons are randomly generated with a energy distribution as seen in Figure 1 (red line) and an uniform transverse (*x*,*y*) distribution on the absorber V-shaped surface. Figure 3 shows a resulting uniform photon distribution across the vacuum chamber in the detector with a total radiation level of 1.2×10^{16}photons/sec due to backward synchrotron radiation from the absorber. The radio of backward radiation in the detector to the forward radiation on the absorber is $1{:}4\times10^6$.

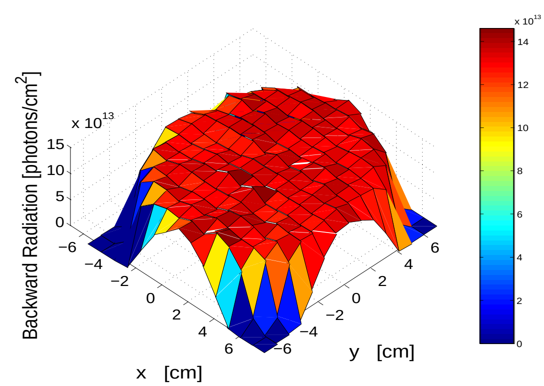

Figure 3: synchrotron radiation photon density distribution in the beam pipe cross section at the detector.

Backward Radiation into Detector Generated from Different Parts of the Absorber Surface

The characteristics of the backward radiation generated from different parts of the absorber surface can be different due to their path and the angle to the detector. To investigate in more detail, we simulated the backward radiation levels associated with different parts of the absorber surface. Figure 4 is a side view of the fraction of forward radiation photons hitting the upper 5% of the V-shaped absorber surface. The resulting backward radiation, figure 5, has higher photon density at the bottom of the detector opening compared to the top. The backward radiation level is 10% more than the backward radiation level averaged over the entire absorber surface.

A similar photon density distribution is obtained from the simulation of 5% forward radiation fan on the upper-middle part of the absorber surface. The backward radiation level is 10% less than the backward radiation level averaged over the entire absorber surface. Figure 6 shows the photon spectrum of backward radiation from upper and middle parts of the absorber surface compared to the spectum averaged over the entire V-shaped absorber surface. It is interesting to note that the summation of the backward radiation photon density from the top-bottom symmetric parts of the V-shaped absorber is very uniform at the detector.

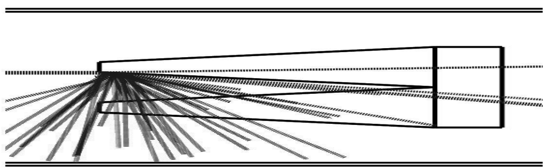

Figure 4: side view of 5% forward radiation fan on the upper part of the V-shaped absorber surface.

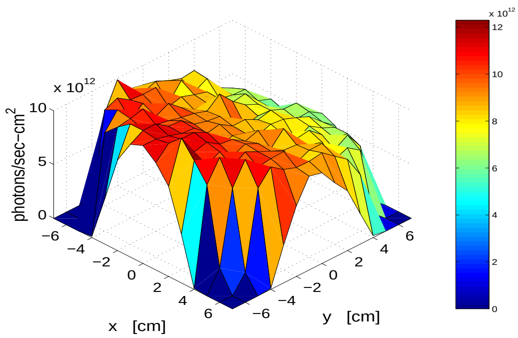

Figure 5: Photon density of backward radiation into detector from the top part (5%) of the absorber surface.

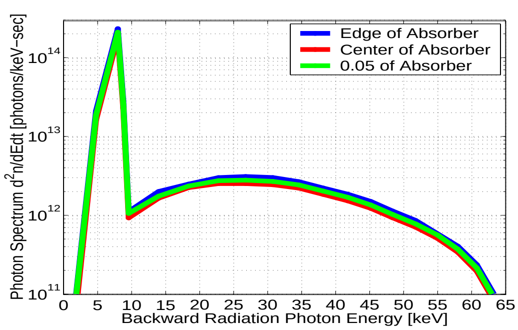

Figure 6: The photon spectrum of backward radiation from upper and middle parts of the absorber surface compared to the level averaged over the entire surface.

Radiation Level vs. Absorber Length

The backward radiation level crucially depends on the material and the tilt angle of the V-shaped absorber surface with respect to the direction of forward radiation. In order to investigate the impact on the surface tilt angle to the backward radiation into the detector, a simulation was also performed with a 10cm absorber depth keeping all other physical and geometrical parameters the same. Figure 7 compares the photon spectrum of backward radiation into the detector from the V-shaped absorbers with depths of 10cm and 25cm. Their corresponding surface tilt angles are 150mrad and 60mrad, respectively. The integrated backward radiation levels into the detector are 7.0×10^{16}photons/sec and 1.2×10^{16}photons/sec for the absorber depths 10cm and 25cm, respectively.

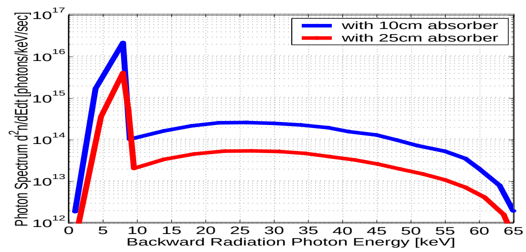

Figure 7: comparison of photon spectrums of backward synchrotron radiation into the detector from the v-shaped absorbers with depths of 10cm and 25cm.

Discussion and Conclusion

With the current interaction design of eRHIC, the integrated forward synchrotron radiation on the absorber is 4.8×10^{22}photons/sec, and the integrated backward radiation in the detector is 1.2×10^{16}photons/sec. Thus the radio of backward radiation in the detector to the forward radiation on the absorber is $1:4\times10^{6}$ for a copper absorber with 25cm depth. A synchrotron radiation mask system needs be designed to limit the opening angle of the backward radiation fan such that the detector components are shadowed from the core of the backward radiation fan.

The simulation study shows that the photon density distribution of backward radiation is very uniform across the detector beam pipe. Most backward radiation photons into the detector have very low energy (<10keV).

The deviation of the backward radiation contributed from different parts of the V-shaped absorber is within 10% of the average radiation level. The summation of the backward radiation from the top-bottom symmetric parts of the V-shaped absorber is also uniform across the detector beam pipe.

The integrated backward radiation levels into the detector are 7.0×10^{16}photons/sec and 1.2×10^{16}photons/sec for the absorber depth of 10cm and 25cm, respectively. The knowledge of backward radiation level vs. the absorber depth provides useful guidelines for more detailed design.

Apart from the backward radiation properties, an investigation on the heat load and temperature distribution on the eRHIC absorber due to synchrotron radiation will also be necessary.

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