CALCULATION OF SYNCHROTRON RADIATION FROM HIGH INTENSITY ELECTRON BEAM AT eRHIC*

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Abstract

The Electron-Relativistic Heavy Ion Collider (eRHIC) at Brookhaven National Lab adds an electron beam line to the existing RHIC and improves the luminosity by at least 2 orders of magnitude. It requires a high energy and high intensity electron beam. Thus the synchrotron radiation (SR) coming from the bending magnets and strong quadrupoles could be penetrating the vacuum chamber and producing hazards to electronic devices and undesired background for detectors. In this paper, we calculate the SR spectral intensity and power density distributions on the chamber wall, suggest the wall thickness required to stop the SR, calculate heat load on the chamber, and estimate spectral characteristics of the residual and scattered background radiation outside the chamber.

INTRODUCTION

The Electron-Relativistic Heavy Ion Collider (eRHIC) at Brookhaven National Lab is a proposed upgrade of current operating RHIC. An additional electron ERL would be added and a high intensity electron beam colliding with proton and ion beams could improve the luminosity by 2 orders of magnitude, bringing a new probe in studying quantum chromodynamics (QCD).

However, such a high current (12.6 mA)and high energy (30 GeV) electron beam would produce very strong synchrotron radiation and may produce photons with MeV energy which can easily penetrate the vacuum chamber and destroy the electronic devices. Furthermore, secondary particles produced by interaction of this photon beam and vacuum chamber could induce a strong background which makes the detection impossible. Historically, synchrotron radiation has always been a headache for such type of machines [1].

To protect electronics and detectors from this hazardous synchrotron radiation, we have to fabricate a vaccum chamber with enough wall thickness to stop even MeV photons and design proper cooling channel to dissipate the heat load on the vacuum chamber through the process of photon absorptions. In this paper, we use a dedicated software - Igor Pro with SRW package [2] encoded in paralized python code to do the calculation and further calculation of secondary particle effects using GEANT4 is being planned.

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VACUUM SYSTEM OF ERHIC

ERHIC will be a 6 pass ERL with highest electron energy at 30 GeV. For each pass, it has a 6-fold symmetry [3] and each sextant is composed of an ARC (10 basic cells with overall R_{56} suppressed) and a 200 m long staight section. The 6 beam passes are separated vertically and vacuum chamber in ARCs is shown in Fig. 1. The major parameters of eRHIC electron beam is listed in Table 2. Although the dipole strengths in ARCs are weak ($\rho \approx 234m$), the synchroton radiation is strong due to the high average current and high beam energy, and photons with MeV energy could be generated and shining on the chamber wall. In the interaction regions (6 and 8 o'clock), the vacuum chamber has the same geometry but the synchrotron radiation mainly comes from the strong quadrupoles which are used to focus the beam for collision with proton and ion beams.

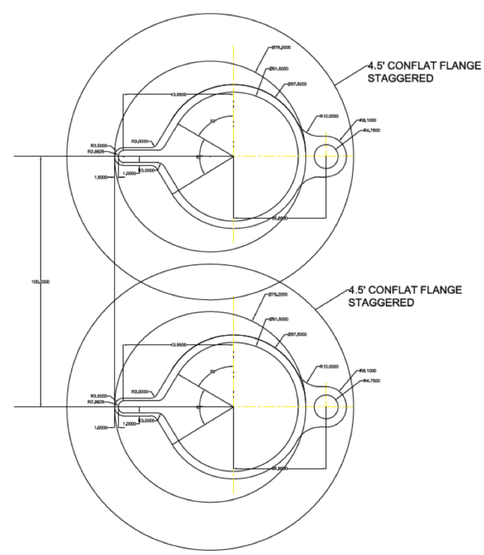

Figure 1: eRHIC is a 6 pass ERL with different passes of chambers seperated vertically. The vertical gap of beam path is 5 mm and big hallow region on the right is used to prevent from back scattered photon interacting with electron beam. Cooling channel is located at where the main part of synchrotron radiation is deposited.

SYNCHROTRON RADIATION IN ARCS

As we mention in previous section, each ARC in eRHIC is composed of 10 basic cells with weak dipoles seperated by short straight sections. In order to calculate the spectral distribution and power density of synchrotron radiation on

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Table 1: Beam Parameters for e- Beam of eRHIC

Name	Value
Maximum energy (GeV)	30
Bunch seperation (ns)	74
Bunch charge (nC)	0.5
Rms bunch length (mm)	2
Average beam current (mA)	12.6
Rms normalized emittance (μm)	4

vacuum chamber, we need to calculate the distance from radiation source (electron beam) to the chamber wall. As Fig. 2 shows, the shortest longitudinal distance is 6.05 m and incident angle of the photon beam is 19.9 mrad.

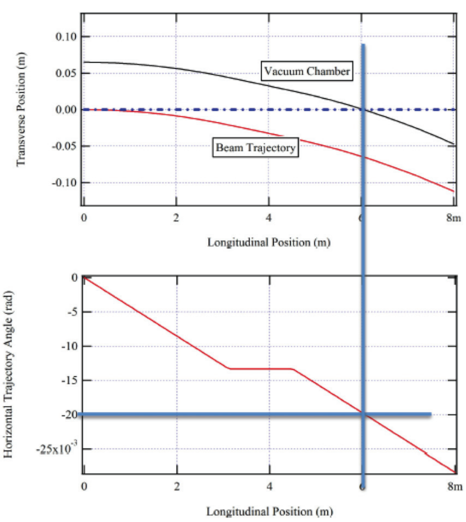

Figure 2: The geometry of beam trajectory and vacuum chamber along the ARC (up) and its derivative (bot).

Based on these geometry calculations and the beam parameters listed in Table. 2, we can calculate the projected power density and photon flux on chamber surface under far field approximation. As is shown in Fig. 3, the unit length surface power density is about 2.02 W/mm for 30 GeV electron beam and photons with 100 keV energy have the highest flux. A 2D histogram is shown in Fig. 4 for a clearer view.

The vacuum chamber of eRHIC is made of aluminium. We need certain thickness to stop the photons from penetrating the chamber. The attenuation length in aluminium is shown in Fig. 5. We also calculated the photon flux after various vacuum chambers with different thicknesses. For example, if we want to reduce the number of photons at around 1 MeV by 8 orders of magnitude, then we need to build the chamber with 20 mm thickness. A local shielding of radiation could also be employed to further reduce the radiation level. A 2D histogram of photon flux is shown in Fig. 6.

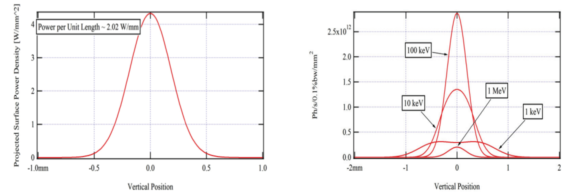

Figure 3: Projected power density dependence on vertical position(left) and photon flux at different photon energy vs vertical position (right) on the surface of vacuum chamber.

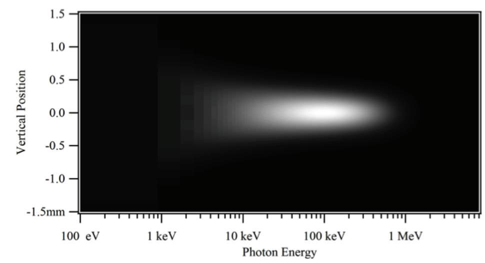

Figure 4: 2D histogram shows the photons emitted are concentrated in high energy (10 keV to 1 MeV) range.

We also calculated the volume power density the radiation deposits in the chamber wall. Unlike the photon flux, the power density decays drastically as the photons travel in the chamber wall. Thus most of the radiation power is deposited near the surface of the vacuum chamber as is shown in Fig. 7. This indicates that most of the low energy photons could be stopped easily while only the high energy photons (which is a small portion of photons) can penetrate deeply into the chamber wall and deposit a tiny portion of total power. However, to avoid the danger these high energy photons may bring to the eletronics outside of chamber, thick chamber wall ($\approx$ 20 mm) should be used.

PRELIMINARY CALCULATION OF SYNCHROTRON RADIATION FROM QUAD TRIPLET IN IR

Calculation of synchrotron radiation from quadrupole triplet in the interaction region is more complicated, because the magnetic field distribution in the quadrupoles is not transversely uniform. This requires tracking trajectories of individual ”macro-electron” through the entire triplet, calculating intensity distributions of synchrotron radiation from each trajectory, and summing-up and aver-

Table 2: Beam Parameters for e- Beam of eRHIC

Name	Value
Horizontal distance from beam to chamber (cm)	6.5
Distance from radiation to chamber (m)	6.05
Incident angle at chamber (mrad)	19.9

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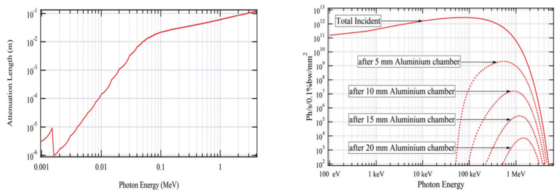

Figure 5: Attenuation length in aluminium vs photon energy(left) and photon flux vs photon energy after different thickness of aluminium chamber (right).

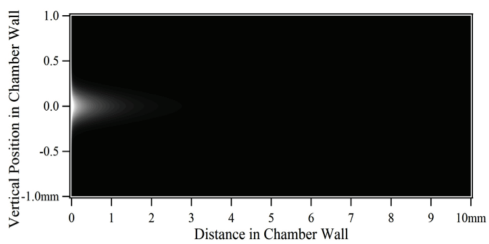

Figure 6: 2D histogram of photon flux propagation in chamber wall.

aging of these distributions over ensemble of the emitting electrons in the beam. In Fig. 8 and Fig. 9, we present some very preliminary results of such calculation, which still require further verifications and cross-checks. In these preliminary intensity distributions, obtained for an observation plane located at 6.3 m from the last quad of the triplet, one can observe typical "features" of radiation from small kick magnets. At lower photon energies (10 keV), the emission cones of the radiation from individual electrons overlap, resulting in a distribution with one maximum located on the axis of the triplet; at very high photon energies (500 keV), more narrow emission cones from individual electrons don't fully overlap (at least at the observation plane being considered), and the resulting distribution has a minimum on the axis of the triplet (where there is no magnetic field inside the quadrupoles). We note that the intensity at 500 keV is 4 orders of magnitude smaller than at 10 keV, which can be explained by relatively weak magnetic field "seen" by most of electrons in the triplet. The work on more detailed analysis of this radiation, as well as the radiation from other sources in the IR, is currently in progress.

CONCLUSION

We calculated the SR spectral intensity and power density distributions and heat load on the chamber wall in eRHIC ARCs and we suggest the wall thickness required to stop the SR. We also estimate spectral characteristics of the residual and scattered background radiation outside the chamber with certain wall thickness. For interaction region, we are working on the complete calculation and understanding of the SR behavior.

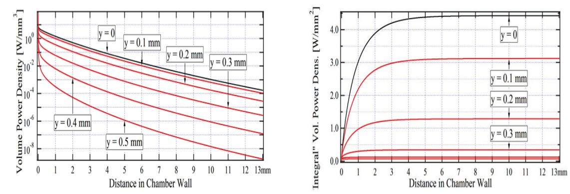

Figure 7: Volume power density vs distance in the chamber at different vertical position(left) and integral volume power density vs distance in chamber at different vertical positions (right).

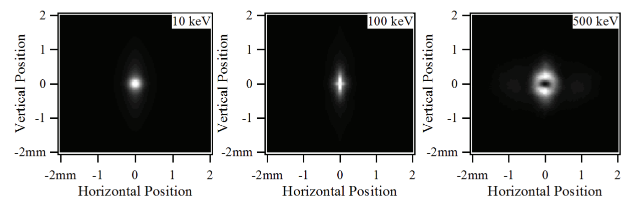

Figure 8: Calculated photon flux after quadrupole triplet vs transverse positions for different photon energies 10 keV (left) 100 keV (middle) and 500 keV (right).

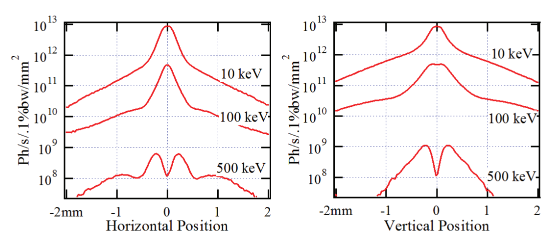

Figure 9: Calculated photon flux after quadrupole triplet with transverse projections for different photon energies 10 keV (left) 100 keV (middle) and 500 keV (right).

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