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medium energy electron-ion collider*

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INTERACTION REGION DESIGN FOR A RHIC-BASED MEDIUM-ENERGY ELECTRON-ION COLLIDER

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Abstract

As a first step in a staged approach towards a RHIC-based electron-ion collider, installation of a 4 GeV energy-recovery linac (ERL) in one of the RHIC interaction regions is currently under investigation. To minimize costs, the interaction region of this collider has to use the present RHIC magnets for focussing of the high-energy ion beam. Meanwhile, electron low-beta focussing needs to be added in the limited space available between the existing separator dipoles. We discuss the challenges and present the current design status of this e-A interaction region.

INTRODUCTION

A staged approach is planned for the construction of the ERL-based electron-ion collider eRHIC at BNL. As a first step, a 4 GeV energy-recovery linac will be installed in one of the existing interaction regions ("2 o'clock"), where it will collide with the "blue" RHIC beam. To minimize the costs for the interaction region, the present ion-ion interaction region will remain largely unchanged.

In the interaction region, the electron and ion beams collide head-on at the interaction point (IP). Since both beams are transported through their individual accelerators and focused by separate low- β insertions, they need to be separated close to the interaction point. Since this separation is accomplished by bending the lower-energy electron beam away from the ion beam in a magnetic dipole field, synchrotron radiation is generated close to the interaction point that needs to be taken into account when designing the interaction region. The detector needs to be appropriately shielded by a special masking scheme to prevent synchrotron radiation photons from causing background problems.

The large energy asymmetry of the two beams results in a forward boost of the collision kinematics. This requires an angular acceptance of the detector as low as 1 degree in the forward (proton) direction. To provide sufficient information for the reconstruction of collision events, the scattered electron has to be detected as well.

DETECTOR FIELD CONFIGURATION

The central detector is equipped with a solenoid of up to 5 T to facilitate particle identification. Because of the extremely asymmetric beam energies, the center of this 5.8 m long solenoid is shifted by 1 m in the direction of the protons; hence it extends 3.9 m in the proton direction and 1.9 m in the direction of the electrons.

Table 1: Parameters of the RHIC-based medium-energy electron-ion collider MEeIC for electron-proton collisions.

electrons:	
beam energy [GeV]	4
geometric emittance [nm]	9.4
β -function at IP [m]	0.5
number of electrons/bunch	$0.31 \cdot 10^{11}$
beam current [mA]	43
rms bunch length [cm]	0.2
disruption parameter	3.1
ions:	
beam energy [GeV]	250
ring circumference [m]	3834
number of bunches	111
geometric emittance [nm]	9.4
β -function at IP [m]	0.5
number of protons/bunch	$2 \cdot 10^{11}$
rms bunch length [cm]	20
beam-beam tune shift	0.0015
luminosity [$\text{cm}^{-2}\text{sec}^{-1}$]	$9.3 \cdot 10^{31}$

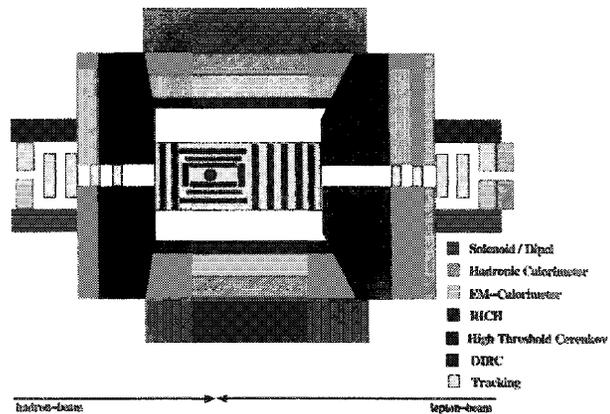


Figure 1: Schematic drawing of the detector configuration.

3 m long dipoles with a magnetic field of 1.0 T (electron-upstream) and 1.25 T (downstream) are added at each end of the solenoid, forming forward spectrometers. At the same time, these dipoles also provide the necessary separation of the two beams. Figure 1 shows a schematic drawing of the detector configuration.

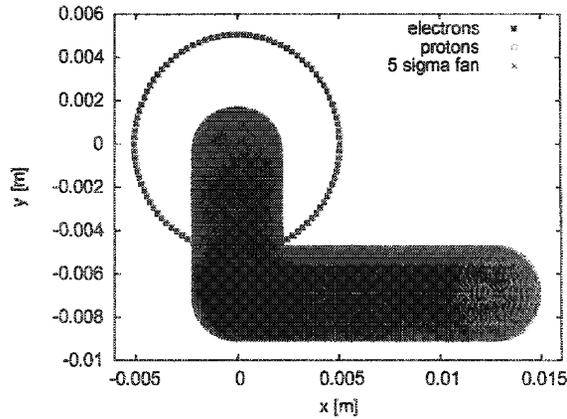


Figure 2: Cross section at the location of the secondary upstream synchrotron radiation collimator (C2). The vertical leg of the synchrotron radiation fan is caused by the weak vertically deflecting dipole and has a total radiation power of kW at a critical energy of keV. The horizontal leg is produced by the strong horizontal spectrometer dipole; it's total power is kW at keV. The vertical dipole bend angle is chosen such that this entire hard synchrotron radiation fan lies outside the 12σ beam ellipse, where it can be completely absorbed by the collimator C2.

SYNCHROTRON RADIATION ISSUES

With a bending radius of 15 m, the two 3 m long spectrometer dipoles generate about 2.4 kW (upstream) and 3.8 kW (downstream) of synchrotron radiation power, with critical photon energies of 9.5 keV (upstream) and 11.8 keV (downstream), respectively, as listed in Table 2. These hard photons would produce unacceptable background conditions in the detector if they were allowed to hit any surfaces within. Since the large opening angle of 200 mrad of the upstream synchrotron radiation fan would require beam pipe apertures of up to a meter if this fan were to be passed through the entire detector, the width of this hard fan needs to be reduced by means of collimators upstream of the detector solenoid.

The width of this hard upstream fan is reduced by a primary synchrotron radiation collimator (C1) at -4.0 m, which absorbs all photons outside the 12σ beam ellipses. To facilitate complete removal of the remaining hard synchrotron radiation fan, a weak, vertically bending dipole is added in between the central solenoid and the strong dipole. The bending angle of this dipole is chosen such that at the location of the secondary collimator (C2), at -3.0 m, the hard synchrotron radiation fan is completely separated from the electron and ion beams, and can therefore be completely removed by this collimator. Figure 2 shows the cross section of the synchrotron radiation fan and the electron and proton beam at the location of this secondary synchrotron radiation absorber at -3.0 m.

On the downstream side, the strong spectrometer dipole

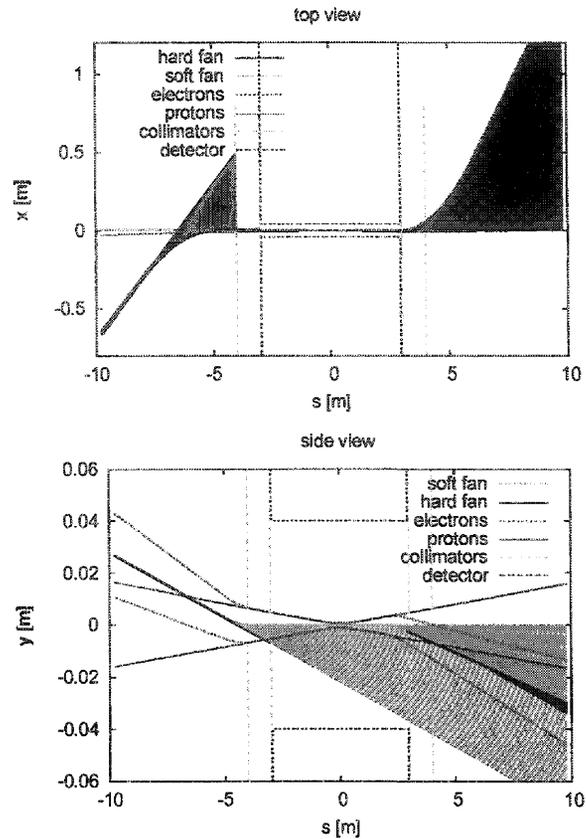


Figure 3: Interaction region geometry, as seen from the top (upper) and side (lower plot). A central detector is shown schematically to indicate the angular acceptance.

produces a very wide, hard synchrotron radiation fan that must be properly absorbed. To prevent back-scattered photons from entering the central detector, any straight line-of-sight from this downstream absorber into the detector has to be avoided. This is again accomplished by adding a weak, vertically bending dipole in-between the solenoid and the strong spectrometer dipole. Two synchrotron radiation masks, located at 3.0 (C3) and 4.0 m (C4) from the IP, minimize the opening angle of the back-scattered photon distribution entering the central detector beam pipe. The soft synchrotron radiation fan from the vertically bending dipole on the upstream side passes through an opening in C3 before it hits C4. The low photon energy, together with the masking effect of C3, ensures that the detector background from photons back-scattered off C4 is tolerable.

LOW- β FOCUSING

Low- β focusing of the electrons will be provided by normalconducting quadrupole triplets adjacent to the detector's spectrometer dipoles, while ions will be focused using the existing superconducting RHIC quadrupole triplets. The electron dispersion is matched to zero at both the IP

Table 2: The physical parameters and synchrotron radiation properties of bending magnets located upstream and downstream of the MeRHIC detector.

Magnet (up/down streams)	Magnet Length [m]	Bending Angle [mrad]	Critical Energy [keV]	Radiation Power [W]
up hard	3.0	200	9.5	2403
up soft	1.0	5	0.7	4.5
down hard	3.0	250	11.8	3755
down hard	1.0	4	0.6	2.9

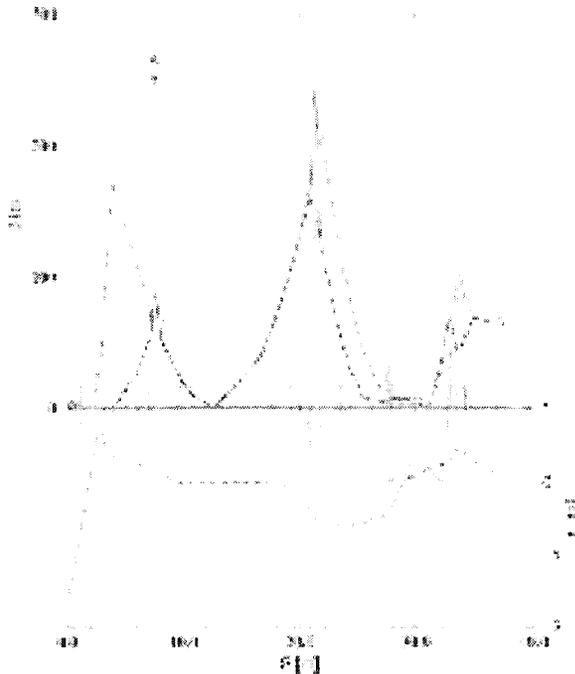


Figure 4: Electron β -functions and dispersion in the interaction region.

and the end of the linac, which turned out to be very challenging due to geometric constraints. Figure 4 shows the electron β -functions of the upstream and downstream end of the detector.

SUMMARY

Using the existing low- β quadrupole triplets of RHIC, we have designed an electron-ion interaction region to study collisions between 250 GeV protons (or 100 GeV/u heavy ions) and 4 GeV electrons. This interaction region design allows angular coverage by the detectors to below one degree, which is required due to the forward kinematics in this extremely asymmetric collider. In the current MeRHIC interaction design a pair of strong horizontal dipoles

will be installed at both end of the detector solenoid, forming forward spectrometers and providing the necessary separation of the two beams. In order to prevent forward and back-scattered photons from entering the central detector a collimation system and mask system will be implemented. In addition, a pair of weak vertically bending dipoles will be added between the detector solenoid and the strong dipoles to provide the complete removal of "direct line-of-sight" into the detector. The investigation of the radiation background in MeRHIC Interaction region consists of an evaluation of forward radiation, direct backward radiation, and the indirect secondary radiation. Currently, at BNL, the studies are been carried out to determine the expected background level in the MeRHIC detector [2].

ACKNOWLEDGMENTS

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- [2] J. Beebe-Wang, "Investigation of the Radiation Background in the Interaction Region of the Medium-energy electron Relativistic Heavy Ion Collider (MeRHIC)", these proceedings