

DESIGN OF A PROTON-ELECTRON BEAM OVERLAP MONITOR FOR THE NEW RHIC ELECTRON LENS BASED ON DETECTING ENERGETIC BACKSCATTERED ELECTRONS*

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Abstract

The optimal performance of the two electron lenses that are being implemented for high intensity polarized proton operation of RHIC requires excellent collinearity of the ~ 0.3 mm RMS wide electron beams with the proton bunch trajectories over the ~ 2 m interaction lengths. The main beam overlap diagnostic tool will make use of electrons backscattered in close encounters with the relativistic protons. These electrons will spiral along the electron guiding magnetic field and will be detected in a plastic scintillator located close to the electron gun. A fraction of these electrons will have energies high enough to emerge from the vacuum chamber through a thin window thus simplifying the design and operation of the

detector. The intensity of the detected electrons provides a measure of the overlap between the e- and the opposing proton beams. Joint electron arrival time and energy discrimination may be used additionally to gain some longitudinal position information with a single detector per lens.

INTRODUCTION

Two electron lenses [1] will mitigate the beam-beam effect in the Relativistic Heavy Ion Collider (RHIC) [2] to achieve polarized proton luminosities higher than would be otherwise possible. The almost perfect collinearity of the proton and electron beams is essential for optimal performance of these lenses.

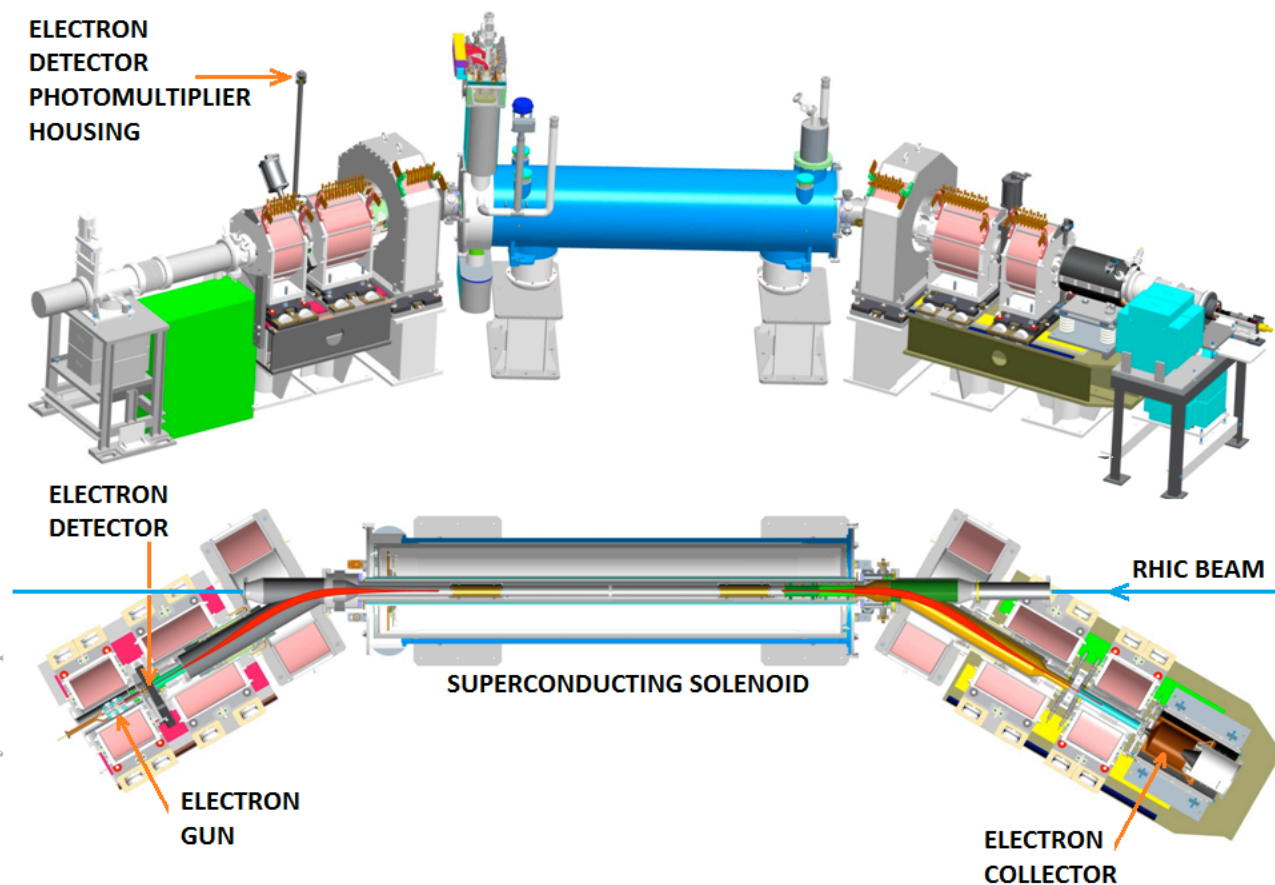


Figure 1: Isometric view and cutaway plan view of one of the two electron lenses to be installed in RHIC.

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The RMS widths of both beams are typically 0.3 mm and their interaction takes place within a 6 T superconducting solenoid with uniform field length of 2m. To monitor and adjust this overlap we will take advantage of the fact that the protons will produce large angle Coulomb scattering of a small fraction of the ~5 keV electrons moving in the opposite direction. Some of these electrons will be back-scattered and will spiral along the magnetic field returning to a location close to the electron gun where they will be detected [3]. The counting rate will be maximized to ensure adequate overlap of the two beams. Figure 1 shows an isometric view and a plan view of one of these lenses. The location of the backscattered electron detector is indicated in both.

DETECTOR DESIGN CONSIDERATIONS

Figure 2 shows schematically an example of spiraling electrons that have been Coulomb back scattered in the beam overlap region at angles of $\pm 50^\circ$ which are calculated [3] to have an energy of 953keV for the case of 250 GeV protons and 5 keV electrons. This spiraling, which initially follows the magnetic field lines within the main solenoid, will drift upward due to the bend in the field lines [3, 4]. This drift is dependent on the energy of the electrons and will be several millimeters for the energies of interest here. We see that the detector needs to be fairly close to the electron beam to detect a significant fraction of the electrons. Placing a semiconductor electron detector in the vacuum seems extremely difficult due to the baking requirements and due to the fact that the depletion layers of silicon detectors have depths that are inadequate to stop the most energetic electrons that are of interest. On the other hand, some energy resolution would be advantageous, as will be discussed below, and therefore channel plate detectors are not desirable. The proposed solution is to let the electrons exit the vacuum through a thin window and to use a scintillation detector.

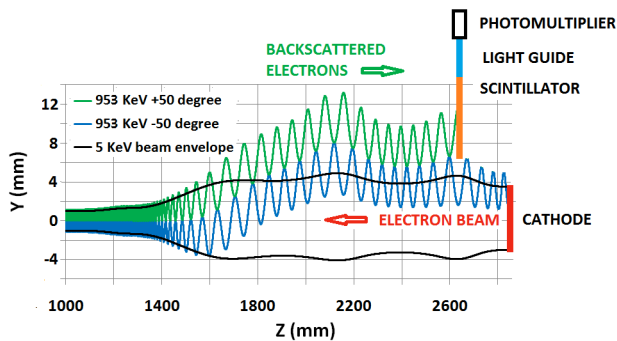


Figure 2: Schematic representation of the backscattered electron detector. Trajectories of two spiraling electrons were generated with an Opera simulation.

Energy resolution is desirable because it allows the electron time of flight information to be used for gaining information about the longitudinal location of the scattering event. An electron of a certain measured energy

has been scattered at a calculable angle [3] and therefore its transit time to the detector is uniquely determined by its point of origin. This fact could in principle be used to provide separate tuning information for each end of the overlap region. In other words rather than maximizing a single rate one would have two numbers to optimize overlap at both ends separately. The limitations of this approach arise from the limited time and energy resolutions, and most importantly from the bunch width and structure. This last factor has been analyzed for a 20 cm RMS wide Gaussian beam assuming perfect time and energy resolutions. Figure 3 shows examples of position probability distributions for the given pairs of detection times and energies. Time zero is defined here as the time when the center of the bunch arrives at the center of the lens.

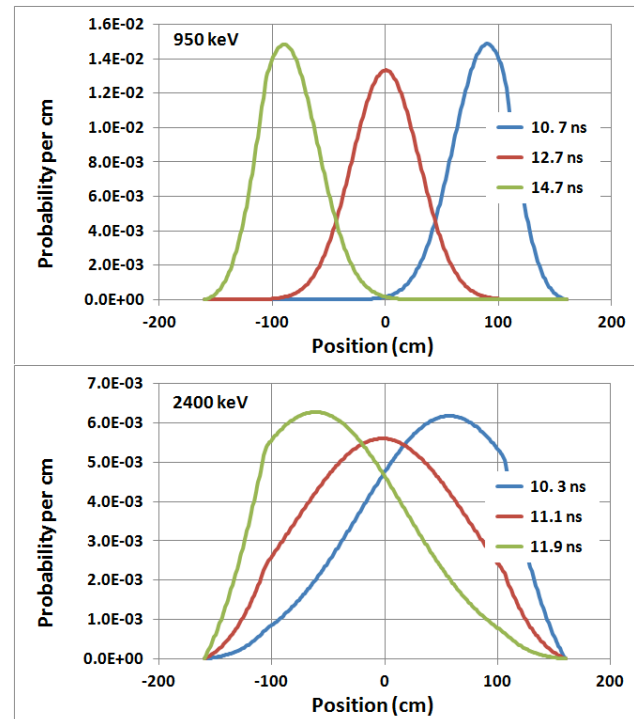


Figure 3: Examples of ideal position resolutions that would be obtained for error-free electron energy and time measurements shown for two energies.

We see that the best performance would be obtained with the lowest energy. The main limitations for the lower electron energies are the difficulty of fabricating a thin enough window, and the energy loss straggling, which effectively deteriorates the energy resolution of the measurement. Folding in energy and time resolutions and more complicated or wider bunch structures will reduce the quality of the information considerably. Yet with good statistics and adequate software we may be able to extract some position information that may be useful for tuning.

Now we will briefly analyze the error introduced in the horizontal overlap measurement by the fact that the electron trajectory bends away from the central axis at both ends of the interaction region (See Fig. 1). A

fraction of backscattered electrons will thus originate from an area where the electron beam isn't centered and this will introduce a small bias in the horizontal overlap measurement. Figure 4 shows the electron beam envelope at one of the electron lens ends and the electron charge density in this beam as a function of the longitudinal coordinate. The electron density scales inversely with the square of the diameter of the beam, which increases as the magnetic field decreases outside of the 6T solenoid. We see that by the time there is significant bending the electron density is so small that the correction will be minimal. This small correction is probably negligible but it could be calculated and applied.

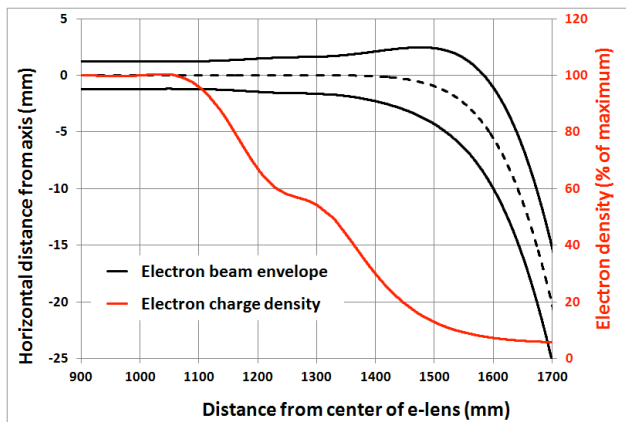


Figure 4: Electron beam envelope (black) and electron charge density (red) at one end of the interaction region.

DESIGN OF THE DETECTOR WELL

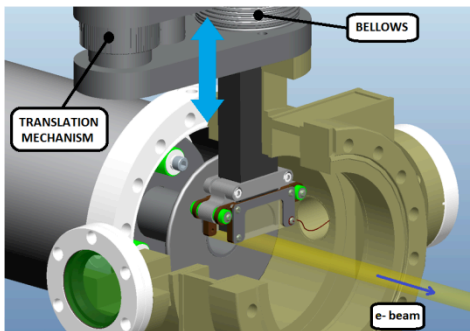


Figure 5: Positioning mechanism and vacuum-side view of the detector well with the attached thin tungsten foil.

To locate the detector in air and close to the electron beam a reentrant cavity with a thin window needs to be installed to achieve the geometry sketched in Fig. 2. The position of this cavity needs to be adjustable to be able to locate its bottom as close as possible to the electron beam without touching it. A thin insulated tungsten foil located in front of the window will measure low energy weak electron currents returning from the electron collector. This foil will also provide protection against overheating the stainless steel window. A tungsten block located on

the gun side of the cavity will be used to sense the fringe of the electron beam when adjusting the vertical position. The current detected on this tungsten block will also be used in the interlock chain that turns off the electron gun. This is necessary because accidental defocusing of this 5 kW beam could cause damage if an appreciable fraction is intercepted.

DISCUSSION AND CONCLUSIONS

The thickness of the window is still under review. The originally planned 0.010" would just stop ~1 MeV electrons [5] which make ~1.5 MeV electrons the lowest energy that could be used. We see from Fig. 3 that this isn't optimal in terms of taking advantage of time-of-flight information. Depending on the outcome of this review a final decision will be made regarding the possible use of a channel plate detector in the vacuum as a fallback option that would provide no energy resolution. Such a channel plate detector would be protected from low energy electrons with an appropriate absorber. This absorber can also be used to establish the threshold electron energy that will be counted. It is possible that some time-of-flight information could still be used but, as we can see from Fig. 3, considerable smearing out of the probability distributions will result from superimposing a wide range of energies. In this case the reentrant well would not be utilized but the same positioning mechanism and electrode configuration would become part of the detector package.

In any event we should have a system that will at least provide an electron-proton "luminosity" signal to help with the adjustment of the beam positions to achieve the best possible overlap, leading to optimal electron lens performance.

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