# A SPLIT-ELECTRODE FOR CLEARING SCATTERED ELECTRONS IN THE RHIC E-LENS*

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*Abstract*

We are designing two electron lenses that will be installed at RHIC IR10 to compensate for the head-on beam-beam effect. To clear accumulated scattered electrons from 100 GeV proton-electron head-on collisions in the e-lens, a clearing split electrode may be constructed. The feasibility of this proposed electrode was demonstrated via the CST Particle Studio and Opera program simulations. By splitting one of the drift tubes in the e-lens and applying ~ 380 V across the two parts, the scattered electrons can be cleared out within several hundred micro-seconds. At the same time we can restrict the unwanted shift of the primary electron-beam that already passed the 2-m interaction region in e-lens, to less than 15um.

## INTRODUCTION

Two electron lenses (e-lens) for head-on beam-beam compensation in the Relativistic Heavy Ion Collider (RHIC) are being fabricated, and will be installed in the RHIC IR10 [1-4]. The layout of these two electron lenses is detailed elsewhere [2,-4]. Figure 1 illustrates the horizontal layout of one electron lens.

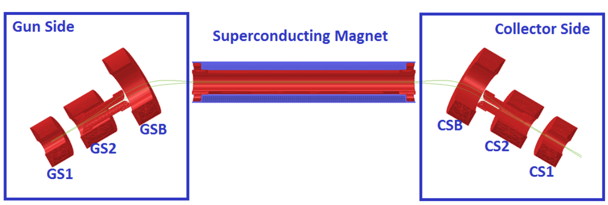


Figure 1: Layout of the electron lens.

In these two e-lenses, the proton beam will collide head-on with an electron beam, generating scattered electrons. This is an effect in addition to the desired electro-magnetic field generated by the electron beam. The differential scattering cross-section of the scattered electron is evaluated as [5, 6]:

$$\frac{d\sigma}{d\Omega} = \frac{Z^2}{4}\cdot\left(\frac{e^2}{E}\right)^2\cdot\frac{1}{sin^4(\theta/2)}\cdot\left[1-\left(\frac{pc}{E}\right)^2 sin^2\left(\frac{\theta}{2}\right)\right]\cdot \left[1+\frac{2E}{M_p c^2}\right]^{-1}\cdot\left[1+\frac{q^2 tan^2(\theta/2)}{2M_p^2}\right], \quad (1)$$

where $p, E,$ and $\theta$ are the momentum, energy, and scattering angle of the electron. From (1), we obtain the function between the angles and the energies of the scattered electrons, which is given elsewhere [5]. In contrast to the definition of the scattering angle given in that publication, we use a different one in this paper; namely, the scattering angle is the acute angle between the scattered electron vector and the proton beam axis, no matter whether the scattered electrons or protons go forward or backward.

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## TRAPPED SCATTERED ELECTRONS IN THE E-LENS

Initially, the two RHIC e-lenses were designed for 250GeV proton head-on beam-beam compensation, and the magnetic field along the proton beam line is almost flat. We are not concerned with scattered electrons generated by the 250 GeV proton and electron beams collision since very few will get captured.

To use the e-lens for the 100 GeV proton beam, we must increase the size of the electron beam in the superconducting solenoid to match the size of the proton beam To reduce the power consumption of the gun solenoid (GS1), this can be achieved by lowering the magnetic field in the main superconducting solenoid, while maintaining the magnetic field constant on the electron gun cathode inside the GS1.

At the same time, to assure the stability of the primary electron beam, the fringe field at the two sides of the main superconducting solenoid must not change. Thus, the longitudinal magnetic field will exhibit two bumps (A and B) as depicted in Figure 2.

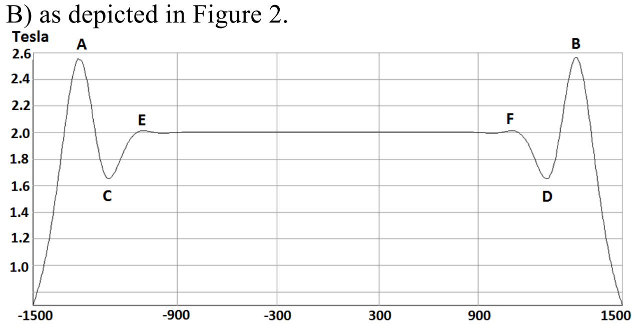


Figure 2: The longitudinal distribution of the magnetic field for operation with 100 GeV protons

Because of these two magnetic mirrors, some scattered electrons will be trapped in the e-lens. The loss cone angle of a magnetic mirror can be calculated by [7]:

$$\theta = arcsin\sqrt{\frac{B_0}{B_1}}, \quad (2)$$

where $B_0$is the main magnetic field, and $B_1$is the bump field at the A or B position in Figure 2. For operation with

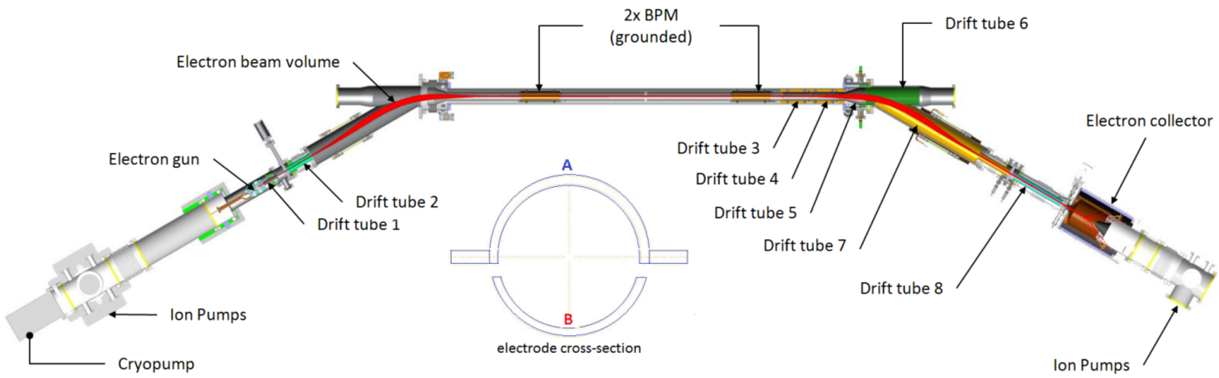


Figure 3: The layout of drift tube system in the e-lens and the split electrode's cross-section.

100 GeV protons we have, $B_0 = 2\,T$ and $B_1 = 2.55\,T$, signifying that the scattered electrons with an angle between 62.3 degrees and 90 degrees will be trapped between these magnetic mirrors. These scattered electrons will accumulate in the e-lens, in addition to ions produced through ionization of the residual gas. The accumulated electrons and ions can induce instabilities in the circulating proton beam and will alter the focusing properties of the e-lens. More information about ionization, the theory of ion- or electron-motion in electrostatic and magnetic fields, and the effects of ions and scattered electrons on the proton beam can be found in ref. [8].

To avoid instabilities in the proton beam, these scattered electrons and ions must be cleared from the e-lens. The first approach is to eliminate one of the two magnetic bumps (A or B in Figure 2). However, this will break the symmetry of the electron transport system; it also would reduce the magnetic field between the superconducting magnet and CSB (or GSB) to 0.1 Tesla which may also induce instabilities in the primary electron beam.

Another approach is to use a pair of electrodes in the e-lens to produce a transverse field. With the electrostatic field of this split electrode, the trapped electrons and ions can be cleared out by combining cyclotron motion and velocity change.

## CLEARING THE SCATTERED ELECTRONS WITH A SPLIT ELECTRODE

The proposed electrodes are obtained by modifying one of the existing drift tubes in e-lens drift tube system. Figure 3 shows the layout of drift tube system in the e-lens. In Figure 2, the magnetic mirror lies between A and B, i.e., about 1300 mm from the center. In Figure 3, the drift tube 4 covers the section from 1200 mm to 1400mm, a suitable location for clearing the scattered electrons.

To verify the feasibility of using the split electrode, we sampled and tracked several scattered electrons with the CST Particle Studio [9] and the OPERA [10] programs. In these simulations, the scattered electrons are produced by the 100 GeV proton and the 5 keV primary electron beams.

Table 1: A Sample of Five Scattered Electrons in 100 GeV Proton Operation

| | Energy (keV) | Angle (degrees) | Program Used | Scattering direction |
|---|---|---|---|---|
| 1 | 93.661 | 85.9 | CST & Opera | Backward scattering |
| 2 | 208.642 | 74.90 | CST & Opera | |
| 3 | 409.338 | 64.24 | CST & Opera | |
| 4 | 20.147 | 67.05 | Opera | Forward scattering |
| 5 | 55.911 | 85.15 | Opera | |

The feasibility of the proposed split electrode was verified via CST Particle Studio. The magnetic field in Figure 2 was used in tracking. The electrostatic field is created by the different potentials on the electrode section A and section B in Figure 3. Scattered electrons with 208 keV and 74.9 degree angle were used.

Figure 4 shows the trajectory of the scattered electron. The electron comes from outside of the electrode and is reflected by the magnetic bump A/B in Figure 2. From figure B and C in Figure 4, we find that the scattered electron beam is shifted to one side. The different colors in figure 4 denote different energies. The scattered electrons will be collected by section A in Figure 3, which could constitute another detectable signal for the overlap of the proton and electron beams.

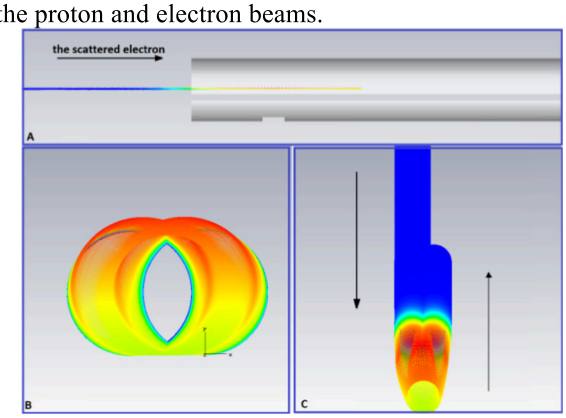


Figure 4: The drift tube electrode and the scattered electron trajectory as tracked by CST.


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## ELECTRODE VOLTAGE AND CLEARING TIME

The reason that the scattered electrons can be moved out is not the electrostatic force itself. It is because of the cross-field drift [7, 8], that is, the combined effects of the E and B fields.

The non-relativistic velocity of cross-field drift can be expressed as [7]:

$$v_E = \frac{E}{B} \quad (3)$$

This drift velocity is independent of the particle charge, mass, and velocity. Because the direction of movement of this cyclotron motion is determined only by the direction of the E and B fields, it is independent of the particle's initial velocity (longitudinal or transverse). All electrons and ions move to only one side.

At the same time, from Equation (3), we find that the primary electrons have the same drift velocity as the scattered electrons. Assuming that the 5 keV primary electron beam drift is 0.015 mm (one pass), which is 20 times smaller than its beam size of 0.3mm, then for a 60 mm separation and 200 mm long parallel-plate electrode, the needed voltage for this 15 um shift is only 380 V.

Figure 5 plots the time as function of longitudinal position for one pass of the 2nd, 3nd, and 4th scattered electrons in Table 1. The electrons are tracked with the OPERA program, starting from 0 mm to +Z, and then returning to 0 mm.

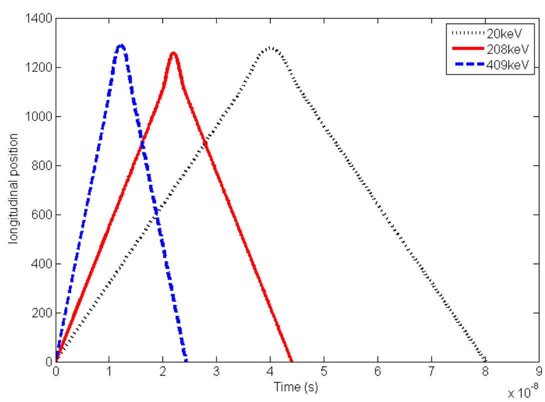


Figure 5: Position as function of time for the second, third and the fourth scattered electrons. See Table 1.

Table 2: Scattered Electrons' Drift Velocity and Time

| Parameters | #2 | #3 | #4 | Units |
|---|---|---|---|---|
| Energy | 208 | 409 | 20 | keV |
| Drift time | 0.42E-8 | 0.41E-8 | 1.12 E-8 | s |
| Drift velocity | 1840.5 | 1840.5 | 1840.5 | m/s |
| Drift distance | 7.73 E-6 | 7.55 E-6 | 20.6 E-6 | m |
| Total Drift | 30 E-3 | 30 E-3 | 30 E-3 | m |
| Turns need | 3881 | 3974 | 1457 | |
| One Turn Time | 2*4.4E-8 | 2*2.43E-8 | 2*8.1E-8 | s |
| **Total Time** | **341.5 E-6** | **193.1 E-6** | **236.0 E-6** | s |

The effective drift time is defined from the start of their entry into the electrode, turning back, and getting out of the electrode. Thus, we can calculate the drift distance for different scattered electrons, and assess how many turns they need for a 30 mm drift, which is the distance to the edge of the electrode.

From Table 2, we can find that it will take several hundred micro seconds for the scattered electron to be cleared out with a 380 V electrode potential difference.

## DISCUSSION

In this paper, we propose fabricating a split electrode to clear the scattered electrons that could be trapped in the e-lens during operation with 100 GeV protons. We demonstrate that the proposed split electrode can remove the scattered electrons, using drift tube 4 in the e-lens as our split electrode. Because all scattered particles move to one side, this electrode confers another advantage, viz., we can use the collected particles as an alternative signal for aligning the proton-electron beams' head-on collision.

## ACKNOWLEDGMENTS

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