Double-sided detector for electron beam alignment and measurement of back-streaming electrons in ExtendedEBIS at BNL

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Abstract. We developed an electron beam detector installed between the superconducting solenoids in ExtentedEBIS. The detector is two-sided. Each side has 4 quadrant plates with an aperture slightly larger than the electron beam radius. The gun-side is for alignment of primary electron beam. The collector side detector is to measure the electrons back-streaming from the collector or the downstream electrodes to the cathode. It is important to understand how the back-streaming electrons behave and how to control it. The detector was designed with considerations of heat load. The influence on the electric potential distribution was investigated. A detector test showed that the back-streaming electrons were affected by the external electromagnetic fields and the space charge of the primary electron beam. It was proved that the behaviour of the electrons can be observed by this detector.

1. Introduction

An electron beam ion source (RhicEBIS) at Brookhaven National Laboratory has been operated to provide several types of ions to RHIC and NSRL [1]. A high current electron beam (up to 10 A) is compressed in 5T-superconducting solenoid to have 500 A/cm2. In the test laboratory, an updated EBIS (ExtendedEBIS) is being developed [2]. Figure 1 is a schematic drawing. There are two identical 5T-superconducting solenoids in series. They are separated by 200 mm. The development is to increase the ion trap capacity and to have a pulsed gas injection system in the superconducting solenoid. The gas system is for polarized helium-3 [3] and other gases especially for hydrogen and helium-4.

As a part of ExtendedEBIS development, a double-sided detector for electrons was developed to install between the superconducting magnets. One of the purposes is helping to align the electron beam from the cathode with the gun-side detector. In ExtendedBEIS, transverse correction coils are needed to adjust the magnetic field from the cathode to the collector [4]. If there is a detector for electron beam position, it will be helpful for this correction.

The other purpose is to observe the back-streaming electrons with the collector-side detector. The primary electrons from the gun enter the collector and are deflected by a reflector toward the collector wall. Some electrons are backscattered in the wall without large energy loss and go back to the gun [5, 6]. In addition, some electrons moving near the central axis are elastically reflected directly to the gun [6]. These back-streaming electrons are reflected by the gun and then enter the collector again. Some of them may repeat the reflection several times. The back-streaming electrons may cause the beam to stop by affecting the primary beam or hitting an electrode as an overloading current to trip the power

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supply. To avoid this, the transverse magnetic fields and drift tube potentials are adjusted. It is expected that the back-side detector can be used for the field adjustment and for more basic research to understand the behavior of the back-streaming electrons.

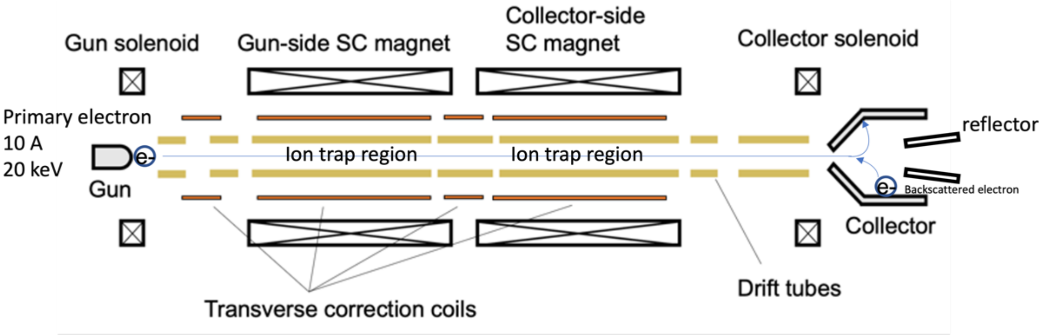

Figure 1. Schematic drawing of ExtendedEBIS.

2. Detector design

Figure 2 (a) shows a drawing of the detector in the chamber between the superconducting solenoids. The primary electron beam emitted by the gun travels from left gun-side to right collector-side. The detector is seen like Fig.2 (b) and (c) from the gun-side and the collector-side, respectively. The detector is composed of Molybdenum quadrants with apertures. The aperture diameter is 6 mm. This is larger than the beam diameter (4 mm). Each quadrant was connected to an oscilloscope with a 50-ohm resistor termination. The detector was actuated by a pneumatic linear feedthrough. It was inserted between drift tubes. The gap between the drift tube and the detector was 7 mm. The vertical position was able to be adjusted by changing the position of a stopper of the linear actuator. The detector could be pushed horizontally by screws. To do this, there was a bellow between the chamber and the flange of the linear feedthrough. The entire system is isolated from the vacuum chamber by a ceramic break.

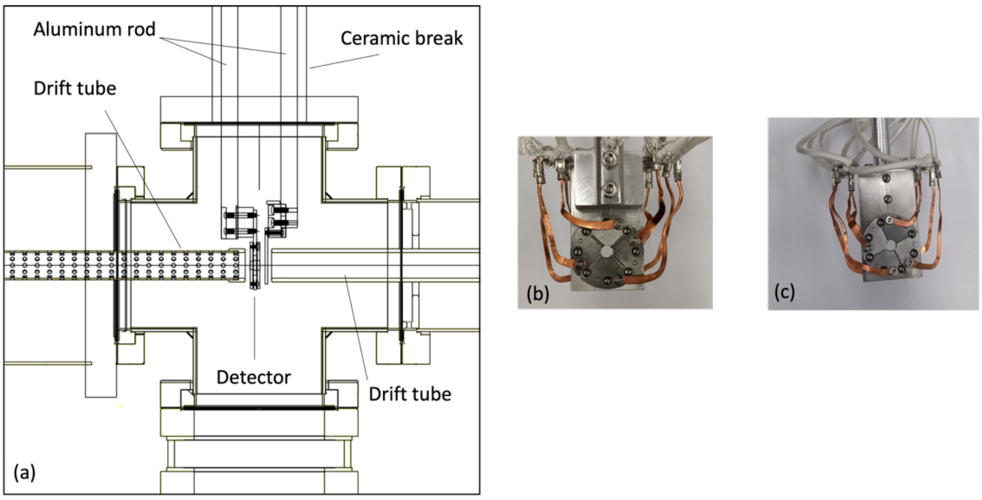

Figure 2. (a) Drawing of detector in mid-chamber between superconducting solenoids. The electron beam comes from the gun-side (left) to the collector-side (right). The detector is connected through an aluminum rod to a linear feedthrough to retract when it is not needed. A ceramic insulator is placed between the detector and the aluminum rod. (b) Gun-side detector viewed from the gun-side (c) Collector side detector from the collector-side.

Since the primary electron beam from the gun has a high power, the temperature rise was considered. The part of the primary beam and the back-streaming electrons hit detector. The current is expected to be up to 100 mA. The beam pulse is around 100 ms for ionization. Repetition rate is about 1/4 Hz. The electron energy is about 30 keV. The beam power averaged as continuous heat is 75 W. If the steady heat is conducted from the detector to the feedthrough at the room temperature, the temperature rise at the detector was estimated to be 150 degrees Celsius. The melting point of Molybdenum is 2617 degrees. Therefore, this temperature rise is acceptable. Meanwhile, the temperature should be higher right after a single beam pulse irradiation. The deposited energy by a single pulse is 300 J. The heat capacity of the detector is 2.4 J/degree Celsius. Therefore, the instant temperature rise is estimated to be 130 degrees Celsius. This is also acceptable.

The influence of the detector insertion on the potential distribution was investigated. A 2D beam simulation was carried out with TRAK [7]. The model is shown in Fig.3 (a). The electron beam simulation started from the inside of the solenoid where the field is 5 T on the left in the figure. The beam propagated in a drift tube with the radius of 10 mm. Then the beam passed through the detector aperture with the 3-mm radius. There is a gap between the drift tube and the detector. The simulation was done with the gaps of 7 mm and 20 mm. The tube and the detector were surrounded by the mid-chamber wall. The potentials are 30 kV on the drift tube and the detector, and 12 kV on the camber wall. The electrons were assumed to be emitted from the cathode at 0 V and 0.18 T. The total energy of the electrons was 30 keV. The beam radius in the solenoid was determined from the cathode radius and the ratio of the magnetic fields. The beam current was 10 A. The black curve in Fig.3 (b) represents the trajectory of the outermost electron, or the beam radius. The horizontal axis, z, is zero at the detector. The beam radius becomes larger as moving toward the detector. This is because the magnetic field is smaller in the mid-chamber region than in the solenoid. Figure 3 (b) represents the potential distribution on the axis with 7 mm (red) and 20 mm (blue) gaps. The potential is lower for z < -400 mm than that for z > -200 mm. This corresponds to the beam radius change because of the reduction of the magnetic field. The 2 kV potential rise around z = 0 mm is due to the small radius of the detector aperture. So, when ions are extracted, the detector potential should be lowered with a consideration of the 2 kV potential rise, otherwise it blocks the ions. On the other hand, with 20 mm gap, there is a potential drop around -5 mm while almost no drop with 7 mm. This means that 7 mm gap, which is used in the detector design, is small enough to avoid large deceleration of the electron beam.

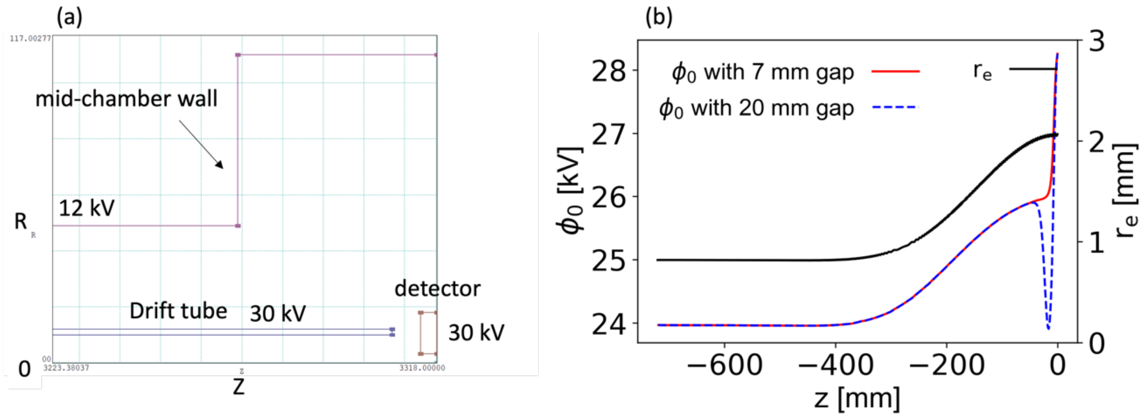

Figure 3. (a) Axisymmetric model in mid-chamber to calculate electric potential. The left border is in 5 T field in the gun-side superconducting solenoid. The right border is at the place where the detector is inserted in the mid-chamber. The gap between the drift tube and the detector was 7 mm or 20 mm in the simulation. Electron beam propagates from the left to right. (b) Electric potential on the central axis as a function of the distance from the detector. The potential with 7 mm gap (red) shows almost no drop while the potential with 20 mm (blue) has a drop to one in the 5 T field.

3. Detector test results

The detector was tested with a 2.7-A primary beam from the cathode. The pulse shape was trapezoidal (200 us rise - 500 us flat - 200 us fall). The cathode bias was -9.7 kV. The detector and most of the drift tubes were at 0 V. Firstly, we adjusted the transverse correction field to see no signal on the detector. This means that the primary beam and the back-streaming electrons did not hit the detector. The signals on the quadrants of the collector-side detector are shown as black lines. Then we added more transverse fields after the detector, namely in the collector-side superconducting magnet and in the chamber in front of the collector solenoid. With this configuration, beam current was observed on the collector-side detector (blue line). Since the transverse field after the detector does not affect the position of the primary beam at the detector, the primary beam still did not hit the detector. Therefore, the observed beam current was of the back-streaming electron. This result proves that the back-streaming electrons can be observed with the detector. In addition to the transverse field, 2 kV voltage was applied to the drift tube in the collector-side superconducting magnet. The shapes of the signals were changed (green line). This indicates that the electric field also affect the amount of the back-streaming electrons.

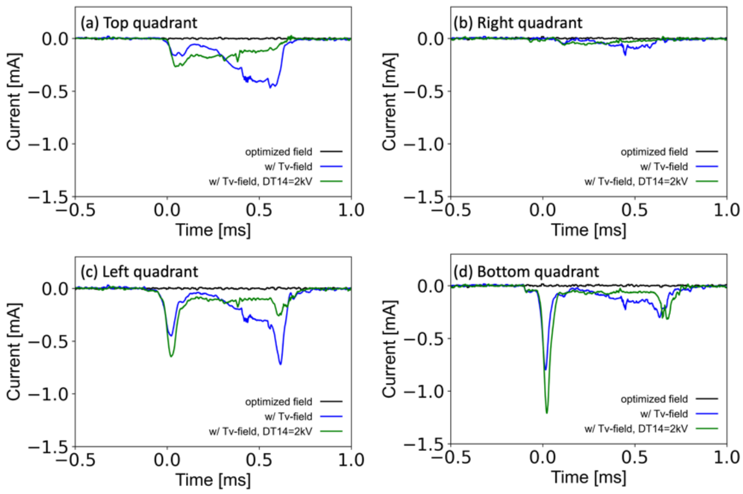

Figure 4. Signals on (a) top quadrant, (b) right quadrant, (c) left quadrant, and (d) bottom quadrant of the collector-side detector. Black curves are signals with an optimized transverse correction magnetic field. Blue curves are signals with more transverse field. Green curves are with more transverse field and 2-kV voltage on a drift tube behind the detector.

For different primary beam currents, the back-streaming electrons were measured. Figure 5 (a) shows the beam current waveforms on the top quadrant of the collector-side. The red curve shows the current waveform when the primary beam was 1.3 A. The trapezoidal beam shape was similar to the primary beam. As the primary beam became larger to 2.1 A (blue) and 2.8 A (green), the beam shape of the back-streaming electrons was distorted. This indicates that the space charge of the primary beam affects the trajectories of the back-streaming electrons, and the effect changes during the beam pulse. We integrated the current waveform to obtain beam charges. The integrated charge for each quadrant was plotted in Fig.5 (b). The sum of the integrated charges was plotted as black points. The sum was increased as the primary beam was increased from 1.3 A to 1.7 A. The charges at top (red), left (green), right (blue) were also increased while the bottom (magenta) was decreased. The interpretation is that the larger number of the primary electrons hit the wall of the collector, and thus more electrons were backscattered. At the same time, the beam shape of the back-streaming electrons was distorted to have smaller integrated charge at the bottom quadrant. On the other hand, when the primary current was increased from 1.7 A, the sum of the charge was decreased, the top and the right were increased, and the bottom and the left were decreased. This means that the back-streaming electrons were pushed toward upper-right by the space charge of the primary beam. The decrease of the sum may mean that the back-streaming electrons were skimmed somewhere like the entrance of the collector. The result shows that the space charge effect is not just repelling outside but distortion of the shape of the beam of the back-streaming electrons. It was shown from the test that the detector can be used to investigate this kind of complicated space charge effect on the back-streaming electrons.

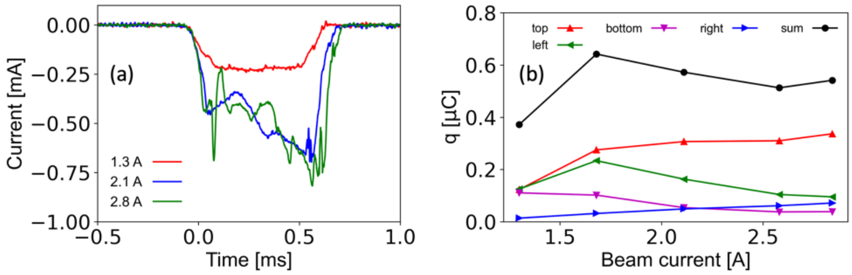

Figure 5. (a) Beam current of back-streaming electrons detected by top quadrant on the collector-side. The primary beam current were 1.3 A (red), 2.1 A (blue), and 2.8 A (green). (b) Integrated charge of the back-streaming electrons on each quadrant for different primary beam current. Red, green, magenta, and blue represents top, left, bottom, and right quadrant, respectively. Black points show the sum of the integrated charges of the quadrants.

4. Conclusion

A double-sided detector was developed for alignment of the primary electron beam and investigation of the back-streaming electrons in ExtendedEBIS. Calculation shows that the detector withstands the heat load on the primary beam, and it does not significantly affect the electrical potential. Experiments were conducted to test the detector. It was shown that the back-streaming electrons can be observed and the reaction to the space charge of the primary can be investigated with the detector.

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