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A PROTOTYPE IONIZATION PROFILE MONITOR FOR RHIC

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Abstract

Transverse beam profiles in the Relativistic Heavy-Ion Collider (RHIC) will be measured with ionization profile monitors (IPM's). Each IPM collects and measures the distribution of electrons in the beamline resulting from residual gas ionization during bunch passage. The electrons are swept transversely from the beamline and collected on strip anodes oriented parallel to the beam axis. At each bunch passage the charge pulses are amplified, integrated, and digitized for display as a profile histogram. A prototype detector was tested in the injection line during the RHIC Sextant Test. This paper describes the detector and gives results from the beam tests.

1 INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab will accelerate and store beams of ions ranging from protons to gold nuclei [1]. Transverse beam profiles will be obtained by measuring the distribution of free electrons formed by beam ionization of the residual gas [2,3]. The electrons are swept from the beamline by a transverse electric field, amplified by a microchannel plate (MCP), and collected on a circuit board with strip anodes oriented parallel to the beam axis. A uniform magnetic field, parallel to the sweep electric field, counters the defocusing effects of space charge and recoil momentum [4].

A prototype IPM was installed near the end of the AGS-to-RHIC transfer line (ATR) and tested during the sextant commissioning run [5]. It measured vertical profiles of single bunches of Au nuclei containing 0.6-1.0 x 10^8 particles. These profiles are compared to profiles on a fluorescent screen (WF3) located 2m downstream from the IPM [6]. Here we describe the detector and give results from the beam test.

2 ELECTRON KINEMATICS

The transverse density of ionization events in the residual gas is a map of the transverse beam distribution. To obtain a vertical beam profile it is necessary to extract each electron from the beamline at the Y coordinate where it was formed. However, the ionizing events impart momenta to the electrons, and the electrons are formed in the space-charge electric field of the beam. The impulse from the collision and the transverse component of the space-charge electric field can move the electrons perpendicular to the sweep direction resulting in a measured profile which is wider than the beam. To counter these effects the detector is placed in a magnetic field parallel to the electric field which sweeps the electrons from the beamline.

Consider the defocusing effect of the space-charge electric field of the beam bunch. This is a radial field whose strength increases with radius to a maximum near the beam's edge. At each point in the beamline the space-charge field has a component which is parallel to the desired drift direction and one that is perpendicular to it. Only the perpendicular component, $E_\perp$, has a defocusing effect.

An electron subjected to perpendicular electric and magnetic fields will drift with a cycloidal motion in the direction defined by the vector product **E x B** with a velocity of,

$$v = (E \times B)/B^2 \qquad (1)$$

and a gyration radius of,

$$R = Em/qB^2. \qquad (2)$$

During bunch passage there is a transverse electric field which would broaden the profile without the magnet. With the magnet the electron responds to this field by moving with a cycloidal pattern parallel to the collector anodes.

The maximum space-charge field in RHIC will be about 10^5 V/m. With a magnetic field of 0.2 T, the gyration radius will be <20 μm everywhere in the beamline and electrons will drift parallel to the anode by <0.2mm. Therefore profile broadening by the space-charge field is eliminated. Also, by the same mechanism, potential profile distortions from errors in the sweep electric field are eliminated.

The second defocusing effect is the momentum impulse from the ionizing collision. The energy spectrum of recoil electrons extends to 64 GeV in RHIC but over 95% of them have energies <500 eV. In a magnetic field the electron trajectory is a helix whose radius depends inversely on the transverse component of momentum. A 0.2T field confines a 500 eV electron to a Larmor radius of <0.4 mm which is less than the spacing between collector anodes. By placing the detector in a field of ~0.2T most of the electrons are collected on the anodes over which they are formed.

MASTER

3 DETECTOR DESIGN

The detector is shown in fig. 1. The vacuum chamber is made from a 38-cm long piece of 10 x 15 cm rectangular Al tubing with a 4.5-cm long piece of tubing welded into the side, forming a 'T'. This is placed between the poles of a 'C' magnet which produces fields of up to 0.5 T. Shims on the magnet poles make the field lines parallel within the active area of the detector. All of the detector parts and electrical feedthroughs are mounted on a 10" conflat flange which mounts on the side flange of the 'T'.

Two rectangular brackets hold the collector board and chevron MCP amplifier on one side of the beam and a sweep-field electrode and secondary electron suppression grid on the other side. The collector board is 0.625 mm-thick alumina, plated with gold, and etched with 48 collection anodes. The anodes are 10-cm long and spaced 0.5 mm center-to-center. At one end of each anode a plated through hole conducts the charge to a trace on the back which takes the signal to the edge of the board. A wire connects each trace to a pin on a D-connector vacuum feedthrough.

Figure 2 shows the circuit. The collector anodes are at ground potential to eliminate leakage currents. A Galileo 3810 chevron MCP amplifier [7] is attached to the circuit board and insulated from the ground plane by 0.125 mm Kapton. The MCP has an 8x10 cm collection area and a maximum gain of 10^7 when biased at 2.0 kV. In this experiment a bias of 1.2 kV gave almost full-scale reading from the digitizers. A sweep field is generated by biasing the opposing electrode at -6.5 kV. This gives electrons about 2.5 keV which is the peak of the detection efficiency for MCP's.

A 30-cm long cable connects the signal feedthrough to the front-end electronics. The charge collected on each channel is integrated by one channel of a LeCroy HQV810 8-channel charge-sensitive preamplifier (C=2pF,τ=4μs) [8]. The integrator outputs are connected to AD783 track-and-hold amplifiers with a common gating signal. The AD783's are connected to AD846 amplifiers [9] set to a gain of 2, giving a charge sensitivity of 1V/pC. Each signal is carried out of the tunnel on a 100 Ω shielded twisted-pair cable. The signals are digitized by 24-channel A/D boards in VXI which were built for the BPM system [10]. The VXI cards are read by a Labview [11] program.

4 TEST RESULTS

Beam profiles were taken with a very broad beam ($\sigma \approx 8$ mm) and a narrower beam ($\sigma \approx 4.5$ mm). In these measurements the magnetic field was 0.2 T. Figure 3 shows the IPM beam-profile data overlaid with a Gaussian fit to the screen profile (WF3) for one of the narrow-beam bunches.

Gaussian profiles were fit to the beam histograms. A comparison between the beam widths measured with the IPM and WF3 is shown in fig. 4. A line with unity slope is drawn to aid in comparison. The profiles of the narrow beam fit entirely on the detector so the gaussian fits were much better. These ten profiles averaged widths of 0.91 of the screen profiles. Because the beam is diverging and the screen is downstream the WF3 profile should be wider than the IPM.

Later, twelve beam profiles were measured with the IPM while the magnetic field was changed in 0.1-T steps from 0 to 0.5 T. Corresponding flag profiles were not measured for these data. Figure 5 shows the profile
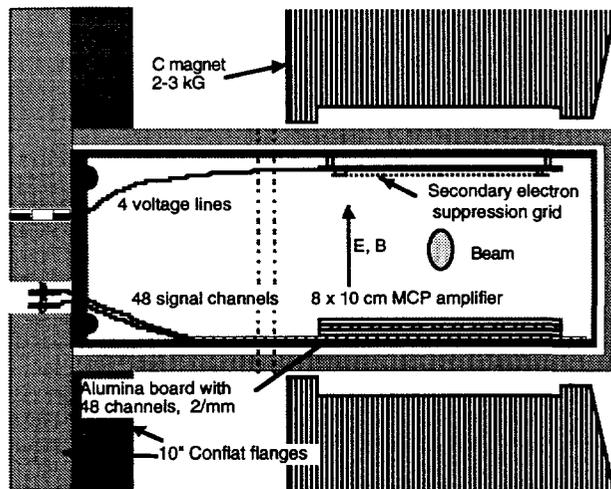

Figure 1. Cross section of IPM. View is looking down the beamline. In this experiment the orientation was rotated 90° CW so the detector mounting flange was horizontal.
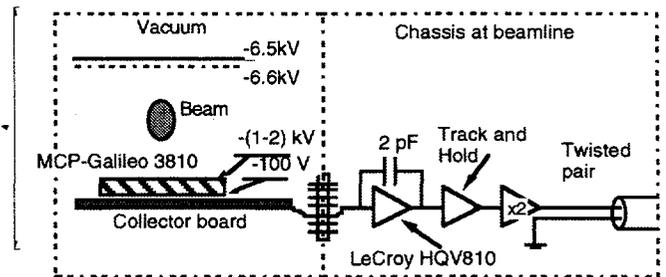

Figure 2. Schematic of the electronics in the tunnel. The trigger signal for the track-and-hold is generated by a digital delay generator in the instrument racks.

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widths vs. magnetic field. Without the magnetic field the measured profiles are several millimeters too wide. In this case a field of 0.1 T seems to give adequate electron focusing.
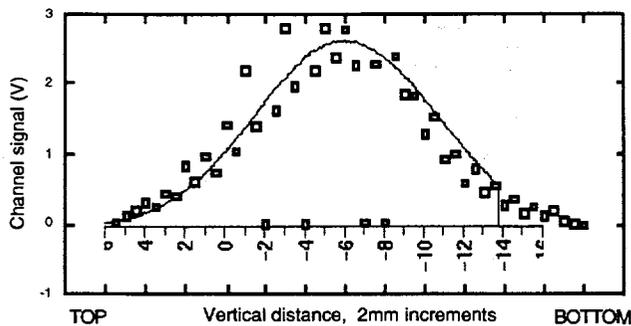

Figure 3. A Gaussian fit to the fluorescent screen profile, solid curve, overlaid the data collected from the IPM. The screen was located 2m downstream and the beam was diverging.
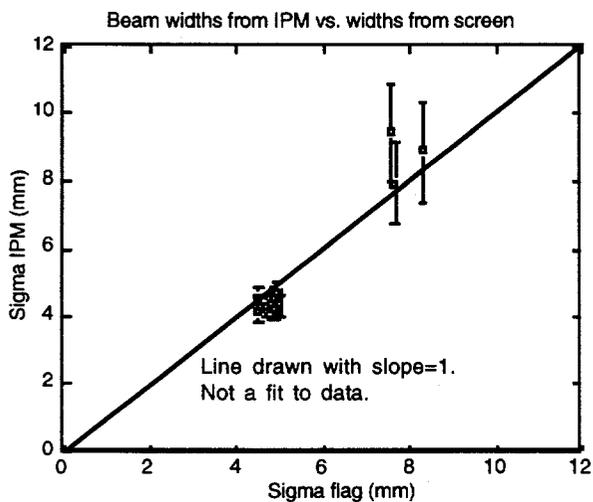

Figure 4. Gaussian profiles were fit to both the IPM data and the fluorescent screen data. Here sigma(IPM) is plotted vs. sigma (screen).

5   CONCLUSION

The prototype IPM produced accurate profiles of single bunches with intensities of 5-10% of the RHIC design intensity. From the signals and the measured bunch intensities the ionization cross section is estimated to be 1.2×10^{-15} cm^2, which is approximately the cross section that was expected [12]. Large backgrounds swamped the beam signal when the beam did not pass cleanly through the section of beamline containing the

IPM. RHIC will have collimators so this should not be a problem.

The electrons fall out of the beamline in ~2 ns and the MCP is capable of time resolution of <100 ps so the speed of this detector is limited only by the signal size and the digitizing electronics. It should be possible to measure a single bunch on a turn-by-turn basis.
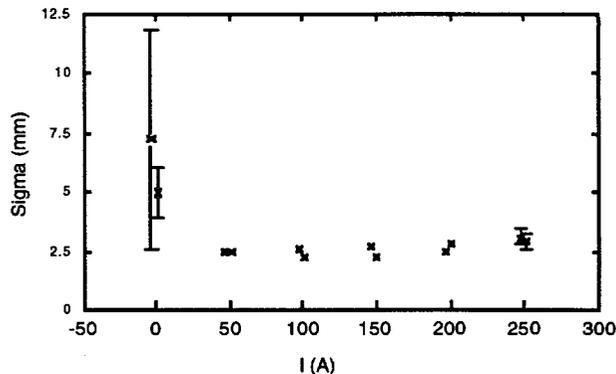

Figure 5. Beam width (sigma) from Gaussian fit to IPM data plotted vs. magnet current. Field is about 0.1T/50A.

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