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A Prototype Ionization Profile Monitor for RHIC

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RHIC PROJECT

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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 single-plane prototype ionization profile monitor (IPM) was installed near the end of the AGS-to-RHIC transfer line (ATR) and tested during the sextant commissioning run. It measured vertical profiles of single bunches of Au nuclei with intensities of 0.6-1.0 x 10^8 particles. These profiles are compared to profiles on a fluorescent screen (WF3) [5] located 2m downstream from the IPM. This paper describes the detector and gives results from the beam test.

Electron kinematics

The electron liberated in an ionizing collision has an initial velocity from the collision and has a force on it from the space-charge electric field of the bunch. Both defocusing effects are reduced by placing the detector in a magnetic field oriented parallel to the desired drift direction.

Consider first the defocusing effect of the space-charge electric field of the beam bunch. This field has components which are parallel and perpendicular to the desired drift direction, but only the perpendicular component, $E_\perp$, has a defocusing effect. The electron trajectory is the vector sum of uniform acceleration parallel to the sweep field and a cycloidal drift parallel to the beam axis. The $E_\perp$ x B drift speed is,

$$s = E_\perp/B \tag{1}$$

and the gyration radius is,

$$R = E_\perp m/qB^2. \tag{2}$$

The maximum space-charge field in RHIC will be 1.3 x 10^5 V/m. With a magnetic field of 0.2 T, the gyration radius will be ~20 μm, about 4% of the collector anode spacing, and the electron will drift parallel to the anode by <0.2mm.

The second defocusing effect is the momentum impulse from the ionizing collision. The energy spectrum of recoil electrons has an extremely high energy tail but over 95% of recoil electrons have energies less than 500 eV. In an external magnetic field an electron spirals around the field line where it was created at the Larmor radius. 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.

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 [6] is attached to the circuit board and insulated from the ground plane by 0.125 mm Kapton. The amplifier 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 [7] ($C=2pF, \tau=4\mu s$). The integrator outputs are connected to AD783 track-and-hold amplifiers with a common gating signal. The AD783's are connected to AD846 amplifiers [8] 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 [9]. The VXI cards are read by a Labview [10] program.

Test Results

The prototype IPM was placed near the end of the ATR just a few meters in front of the switching magnet. During the sextant commissioning run the IPM could be operated only when the beam was going into the beam stop on the 0° switching magnet line. The vertical deflection of the IPM magnet was not corrected so the beam could not be matched into RHIC with the magnet on.

Before the sextant was ready for beam, a set of data was taken in which the IPM profiles and WF3 profiles were recorded. 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 for one of the narrow-beam bunches. The IPM data shows quite different signals on alternating channels. The odd and even channels go through separate feedthroughs, front-end circuit boards, cables, and digitizers so this is not an unlikely feature. The reason for this structure has not yet been investigated.

Gaussian profiles were fit to the beam histograms using IGOR [11]. A comparison between the beam widths measured with the IPM and flag is made 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. This is expected since the beam is diverging and the screen is downstream.

A number of data sets were taken with an extremely broad beam which excited about half of the channels fairly uniformly making it impossible to fit profiles. Several ion pumps near the IPM were turned off and data were taken as the pressure rose. Figure 5 shows the sum of the voltages on the 48 channels plotted vs. the product of the bunch intensity and the pressure. The point at zero was a "no bunch" event and shows the low background.

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 6 shows the profile 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. Finally, the detector channel at the center of the distribution is plotted vs. the magnetic field in fig. 7. This plot together with fig. 6 shows the measured profiles are nearly constant with magnetic fields from 0.1 to 0.5 T.

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. The prototype gave an alternating-channel gain effect which is being investigated, and several channels showed no signal, a result of somewhat hurried assembly to meet the run deadline. It was susceptible to debilitating backgrounds 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.

Acknowledgments

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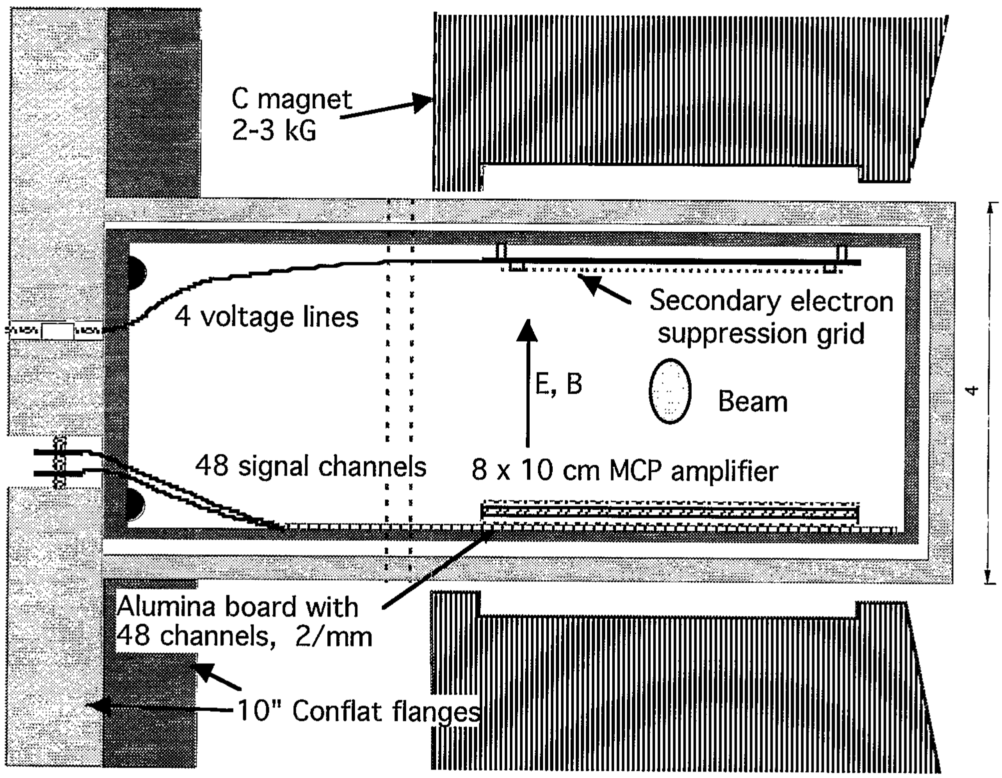

Figure 1. Cross section of IPM. View is looking down the beamline. In this experiment the orientation was rotated 90° CW so the detector mounting flange was horizontal.

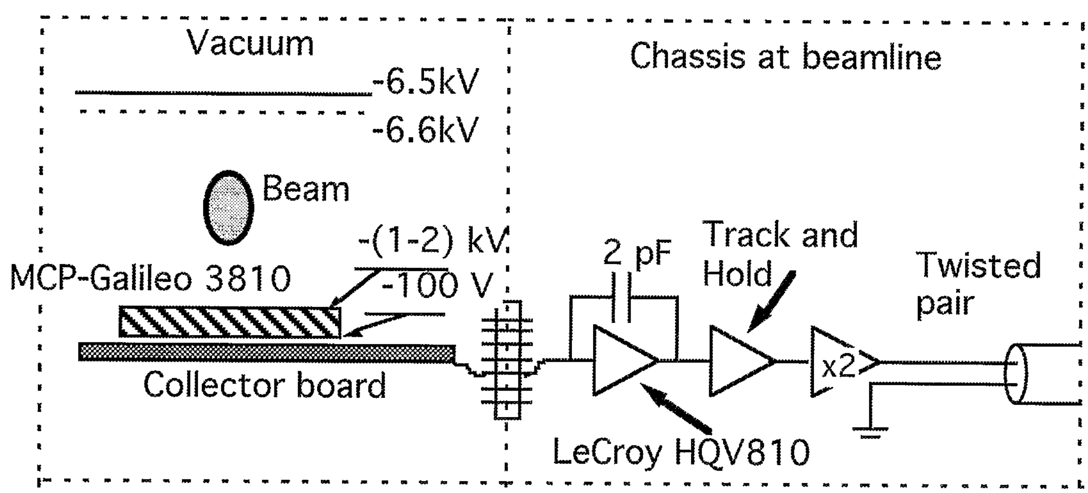

Figure 2. Schematic of the electronics in the tunnel. The trigger signal for the track-and-hold is generated by a digital delay generator in the instrument racks.

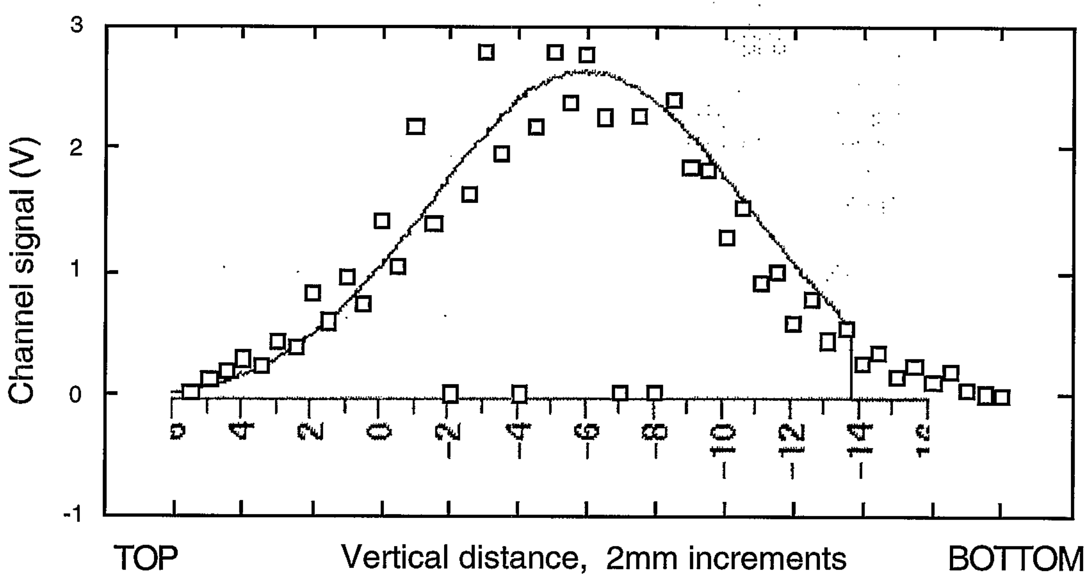

Figure 3. A Gaussian fit to the fluorescent screen profile, solid curve, overlaid the data collected from the IPM. The screen was located about 2m downstream and the beam was diverging.

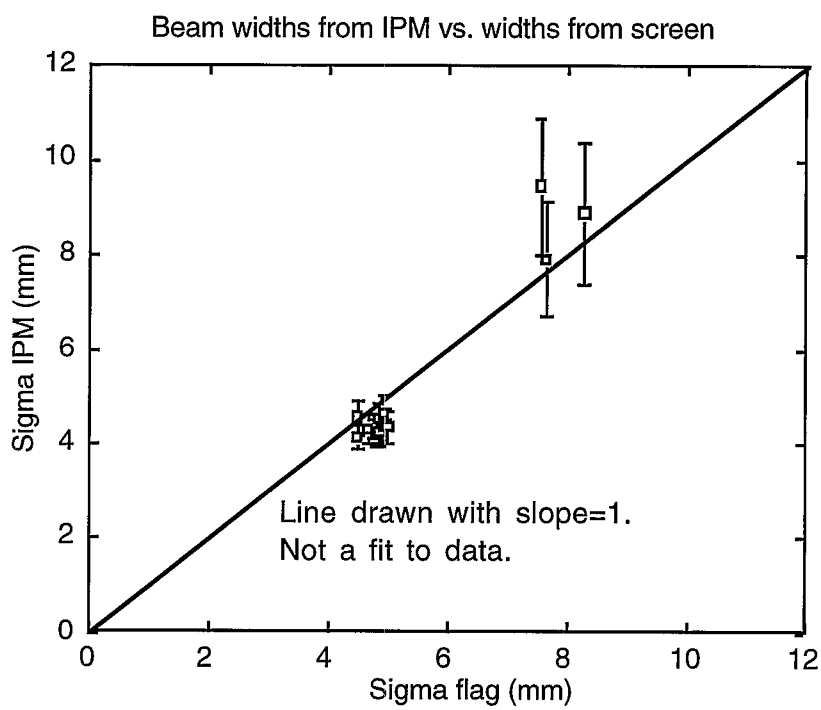

Figure 4. Gaussian profiles were fit to both the IPM data and the fluorescent screen data. Here sigma(IPM) is plotted vs. sigma (screen).

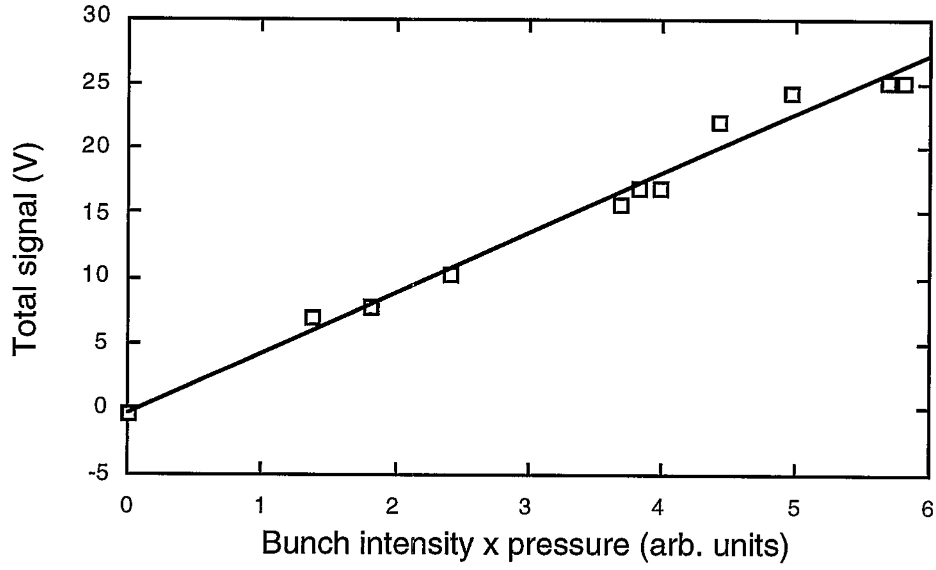

Figure 5. Sum of the voltages on all collection channels plotted vs. the product of the bunch intensity and pressure.

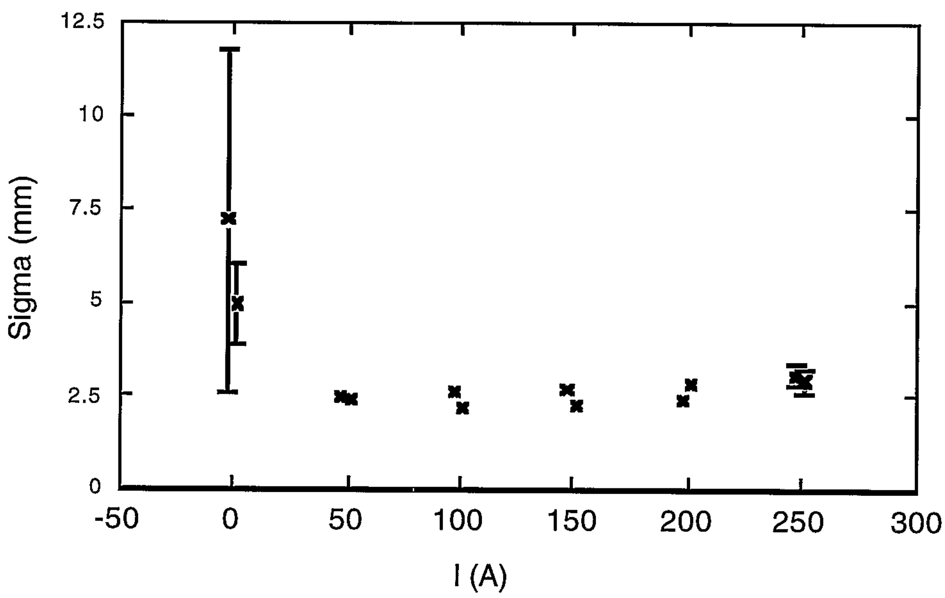

Figure 6. Beam width (sigma) from Gaussian fit to IPM data plotted vs. magnet current. Field is about 0.1T/50A.

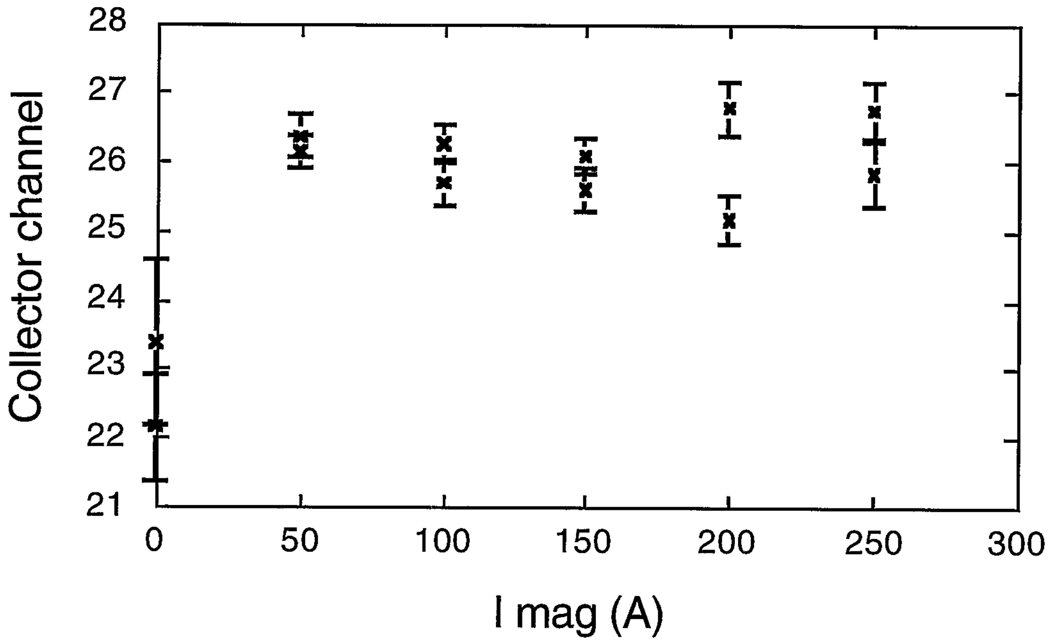

Figure 7. Beam profile center (channel) vs. magnet current.