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DESIGN AND OPERATION OF THE AGS BOOSTER IONIZATION PROFILE MONITOR*

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Abstract

The AGS Booster Ionization Profile Monitor (IPM) must operate in a vacuum of about 3×10^{-11} Torr. The ultra-high vacuum imposes certain requirements on detector gain and restrictions on construction techniques. Each detector is a two-stage micro-channel plate with an integral substrate containing sixty-four printed anodes. Formed electrodes provide uniform collection fields without the use of resistors, which would be unacceptable in these vacuum conditions. An ultra-violet light calibrates the detector in its permanent mounting. An extra set of electrodes performs a first order correction to the perturbations imposed by the horizontal and vertical collection electrodes. This paper will present details of the design of the profile monitor and recent operational results.

INTRODUCTION

The AGS Booster is a synchrotron whose purpose is three fold. It will increase the AGS proton intensity by allowing the injection of four 1.5 GeV pulses rather than one 200 MeV puls. It will accumulate twenty pulses of polarized protons to boost their intensity as well. Lastly, it will accelerate heavy ions to a momentum suitable for injection into the AGS and RHIC, the Relativistic Heavy Ion Collider. It is an intensifier for AGS beams and a necessary pre-accelerator for RHIC.

The profile monitor in the AGS Booster is a residual gas ionization monitor. The Booster beam ionizes gas molecules in the volume over two sets of collecting wires, one vertical, the other horizontal. The ions would naturally drift radially outward from the space charge of the beam, but electrical fields that are strong enough to redirect their natural radial motion send them to the wires. For strong enough collection fields, the ions travel in rather straight trajectories from their point of generation to the collection wires. The pattern on the wires is thus either a horizontal or vertical projection of the intensity of ion production, which is directly proportional to the beam intensity. Standard, high sensitivity integrating electronics and a real time computer interface acquire the signals, display them, and allow control of the collecting fields and other variables. Figure 1 is a block diagram of the profile monitor and its electronics.

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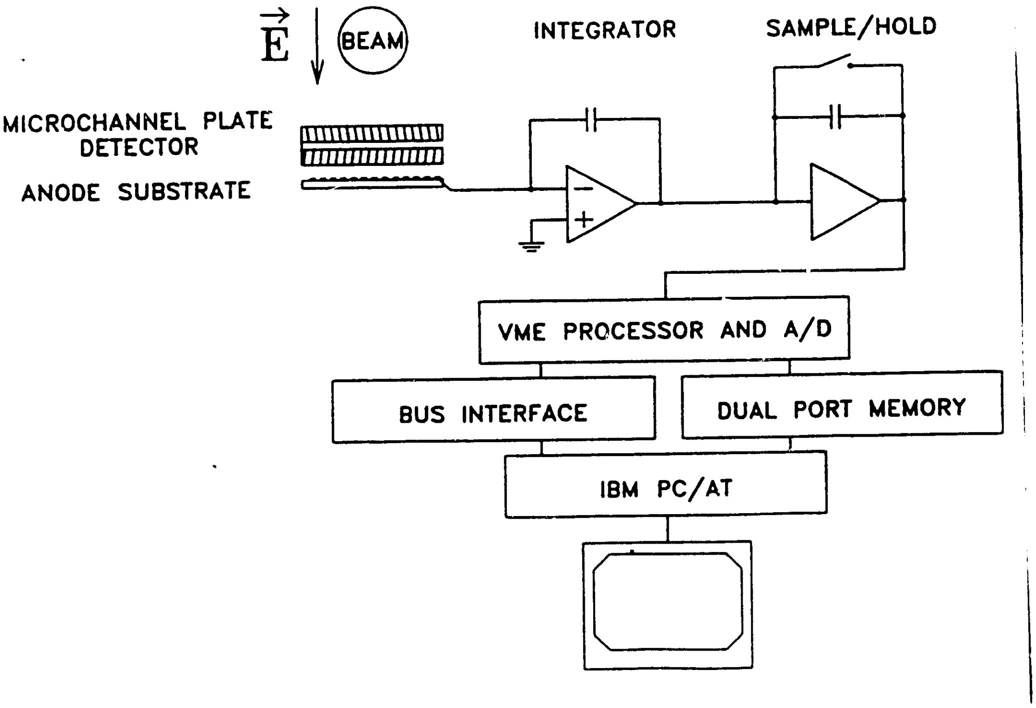

Fig. 1. A block diagram of the Ionization Profile Monitor and its readout electronics. AGS Booster timing signals control the integration and sampling times.

The most severe constraint on the ionization profile monitor design is the ultra-high vacuum of the AGS Booster, nominally 3 x 10^{-11} Torr. This pressure corresponds to a residual gas density of approximately 10^6 gas molecules per cm^3. At these rarefactions, the beam produces ionization signals on the order of picoamps. Furthermore, there is an extremely limited range of construction materials and techniques that one can use in vacuum of this quality. Resistors, for instance, cannot grade potentials in the vacuum since they outgas too much. Aluminum softens at the bake out temperatures in use, so metal parts must be of stainless steel. An appropriate choice of detector, therefore, is a microchannel plate. The microchannel plate has high gain, operates only in a vacuum, and can tolerate bake out temperatures of 300°C.

MCP DETECTOR

A typical microchannel plate has a gain of 10^4 electrons per input electron. Cascaded plates provide higher gain, though not strictly the product of the gains of the individual plates, since saturation effects in the last plate dominate very quickly. In the AGS Booster IPM, the detector is a dual microchannel plate[1] with a specified gain of 10^7 electrons per electron. Ionic inputs to microchannel plates cause slightly different gains from the electron inputs. In fact, the gain of a typical plate can vary with ion species and energy.[2] In order to generate beam inten-sity profiles that are not merely qualitative, the profile monitor design must make these gain variations insignificant. Careful shaping of the electrical collecting fields minimizes these gain effects.

The heart of the profile monitor is the dual microchannel plate detector, which comprises the microchannel plates and their associated anode array. A small distance from the exit end of the plates is a ceramic substrate with sixty-four linear anodes. Each anode is a collecting wire, and runs the length of the plate. The whole detector assembly attaches to four supporting posts on the vacuum side of a flange. Ceramic insulation covers the wires from the detector to two thirty-five pin instrumentation feed-throughs. Ceramic also insulates the wires that provide the bias voltage to the front and back sides of the plates. The unity of the detector/anode assembly allows the anode spacing to be at a rather fine pitch. In fact, the anodes are 1.1 mm wide and are 1.47 mm apart. The length of the anodes is 75 mm, the length of the detector active area.

The gain of the detector is set by the voltage across the input and output faces of the dual plate. There is no electrical separation between the two plates. Generally, the voltage is about 1 kV per plate for the specified gain of 10^7. However, the second plate can easily saturate in the presence of large input signals. This saturation is very deleterious, since microchannel plates have a finite life determined only by the charge extracted from them. Accordingly, the power supply that provides bias volt-age also contains a protection circuit. This circuit reduces the bias voltage to half the full scale voltage, i.e. 500 V per plate. The circuit trips when the current flowing through the detector is .7% of the current that flows with no signal. This is the recom-mended value for the fraction of strip current at which to trip. This power supply circuit uses an optically isolated operational amplifier to compare the signal current to a set current. It also provides a small differential voltage between the exit side of the last microchannel plate and the collecting anodes.

FIELD SHAPING

The collecting fields in this profile monitor merit special consideration. There are constraints on them as well. The primary constraint is that they direct ions to the face of the detector in trajectories that accurately project the beam inten-sity distribution onto the anode wires. This voltage gradient, sufficient to overcome beam space charge effects, seems to be subject to a law of diminishing returns. There always seems to be a further reduction of beam profile width as the collection volt-age increases.[3] However, the ability to generate large fields in confined vacuum chambers falls off rapidly at the higher voltages. The historical value of the voltage gradient at the AGS is somewhere in the range of 1 kV/cm.

A second constraint on the collecting field value, not often noted in devices like these, is that the microchannel plate is an energy analyzer for ions below about 20 keV. Thus, to form accurate profiles, the minimum ionic energy must be above this threshold. The ions of minimum energy form in the tail of the beam closest to the face of the detector, so the collecting field at this distance must accelerate these ions to 20 keV. With careful electrode design, it is possible to maintain a potential of -20 kV at this distance.

The ultra-high vacuum conditions also cause problems in generating graded potentials. Since resistors are forbidden and external resistors would require prohibitively many feedthroughs, shaping of the collection field electrodes is the best way to shape the field itself. Figure 2 shows the final shape of the electrodes and a plot of the equipotential lines. The size of the walls of the box-shaped electrodes should be one quarter the length of the electrode.[4] A close inspection of the equipotentials shows that they are certainly flat enough not to cause any distortion of the beam profile image. A four inch clear aperture being necessary for the beam, the electrodes must form part of the perimeter of an eight inch cube. They are of stainless steel, polished and with no sharp corners.

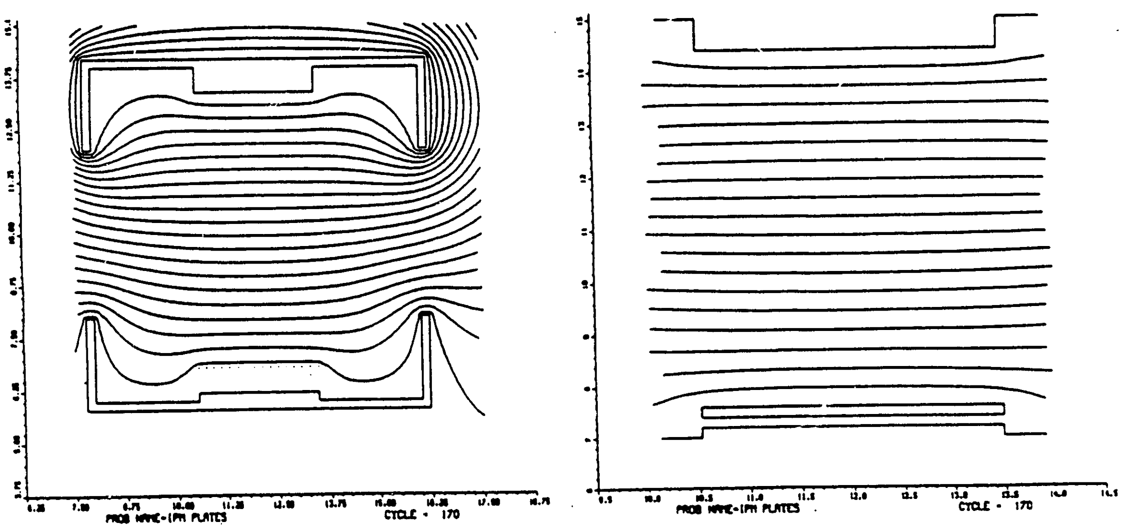

Fig. 2. Poisson calculations of equipotential lines in the ionization profile monitor collection volume. These views are cross-sections of the collection volume and show the characteristic U-shape of the electrodes. Each electrode lip is one quarter the length of the electrode. In both views the -70 kV electrode is at the top and the ground electrode at the bottom;

the voltage between potential lines is 3.5 kV. Scale is in cm. In (a), the input face of the microchannel plate detector is the upper dotted line. This face is held at -2 kV by the bias power supply. The characteristic dual plate capacitor potential lines have given way to flat potential lines due to the lips on the electrodes. In (b), a magnified view of the collecting volume shows that its electric field is essentially constant. Here the microchannel plate detector is the rectangle above the lower electrode.

Each plane has a set of electrodes and the working voltage on each set is nominally 70 kV. To correct the kick on the beam from these fields, a third set of electrodes is between the two collection electrodes. These correction electrodes are at 45° to the horizontal and vertical collection electrodes. The corrector voltage, 99 kV, generates an electric field that cancels, to first order, the effect of the vector sum of the collector fields. Figure 3 indicates the electrodes and their electric fields.

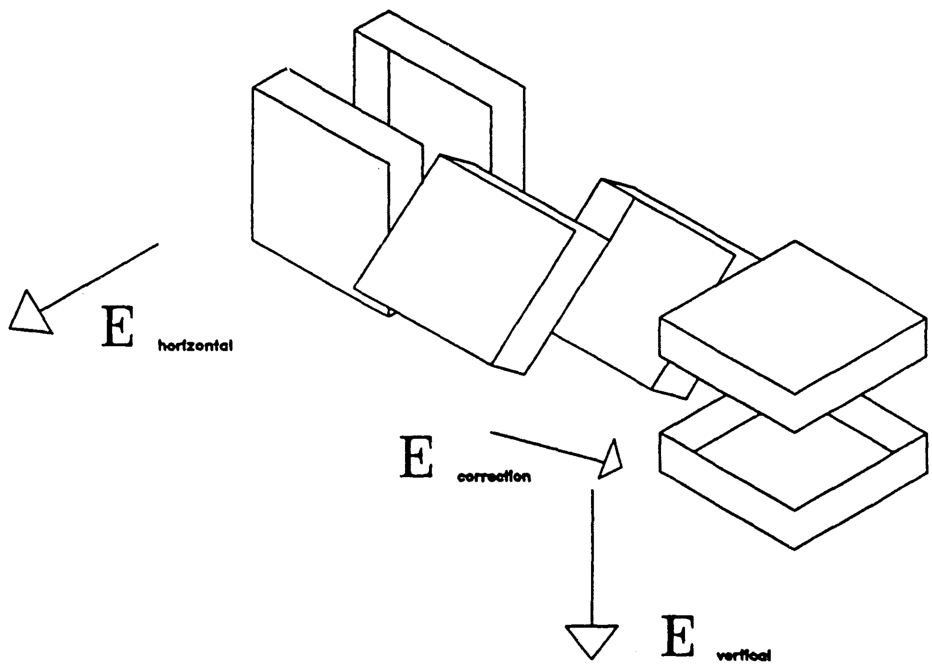

Fig. 3. Schematic diagram of the orientation of the collection electrodes and the corrector electrode. The corrector electrode generates an electric field opposite to the vector sum of the collector fields. The beam direction is from lower right to upper left.

READOUT ELECTRONICS

Each detector plane has sixty-four channels. Each of these channels is input to a low leakage integrator. A commercial VME sample/hold multiplexer and A/D converter with an imbedded microprocessor stores the integrator outputs in a local memory. An IBM PC/AT then reads the memory locations via a commercial bus interface that connects the PC bus to the VME bus. The A/D can scan through all channels and load them into memory in about 1 msec. Timing for the data acquisition is by real time interrupts to the PC, which controls the scanner as if it were the VME host. The timing signals themselves are either standard AGS Booster time line codes or the Booster T0 signal. Both are available for selection by the PC.

A simple calibration system is also available under PC control. An ultra-violet spectroscopy lamp of 180 nm wavelength illuminates the detector briefly in response to a calibration pulse from the computer. The light shines on the detector face through a sapphire window in the vacuum chamber and then through the hole in the top of the collection electrode, since the lamp is physically outside the vacuum. The quantum efficiency of the microchannel plates at this wavelength is about .5%. This calibration system can provide a roughly uniform input to the detector and will monitor the inevitable gain decline of the detectors' gains.

SPECIAL CONSIDERATIONS

High vacuum systems and high gain microchannel plates come with their own special set of precautions. All electrode and mechanical support materials are either stainless steel or ceramic. They must be bankable to 350°C and in the case of metal parts, vacuum fired. Gas evolution is a serious problem in high vacuum systems and devices not essential to acceleration or control should require as little pumping as possible. Microchannel plates in particular may take days to pump down.

The microchannel plates also merit special handling. They store well under a nitrogen atmosphere or in vacuum, but they do not like air for extended periods of a year or so. During assembly into a detector, clean room practices are necessary, including gloves and preferable filtered air. Testing the detector before inserting it into the vacuum chamber consists of verifying a high resistance (20 to 200 megohms) between the faces of each microchannel plate. Any application of bias voltage to the plates will start the electron multiplication. If this bias voltage is present while the plates are in a poor vacuum or in air, the plate will destroy itself due to saturation currents. Essentially, its useful life is spent in the test.

OPERATIONS AND RESULTS

The first use of the IPM came during the AGS Booster commissioning period. Before the Booster had any beam, the calibration system generated a set of profiles. Commands from the remote computer turned on the calibration lamps, which provided the signal for the detectors. With a bias of about 600V per microchannel plate (1200V per detector), small signals appeared in the central positions. These were on the order of the quantization error of the A/D electronics. Increasing the bias voltage to about 800V per plate caused the abrupt appearance of sharp profiles. Thereafter, as the profiles grew with bias, the gain seemed to follow the standard gain versus voltage relationship for photon multipliers. To avoid saturating the output current in the second plate, the bias never went above 1000V. Figure 4 shows typical profiles after using the lamp. The illumination passes through a circular aperture in the high voltage electrode and causes the steep shoulders and non-gaussian shape.

When Booster beam was available, the procedure for obtaining profiles differed slightly. Capturing profiles of real beam requires a collection voltage to be present on the electrodes. Since the power supplies that generate the collection voltages reach their terminal voltage rather slowly, they are turned on first. The AGS Booster control system generates the timing signal for the sample/hold gate and the PC then captures profile data. At this point, the only operator requirements are the setting of voltages for bias and collection, and the setting of gain for the initial stage of integrating electronics. The timing of profile acquisition is preset through the AGS Booster controls system. This timing scheme allows a timing resolution of microseconds throughout the Booster acceleration cycle. Figure 5 is an example of some of the first profiles of the Booster beam. Notice that the horizontal and vertical profiles have different heights and widths. Further analysis showed that the total counts in each profile were the same to within 5%, as they should be.

Presently, the software that controls the IPM also massages the display. This is new since the acquisition of the very first profiles and completes the basic design of the IPM. Figure 6 shows the most recent type of display. The program computes the first three moments of the profile and does a Gaussian fit to the data, superimposing the fit on the profile. These software improvements give a polished look to the data and also allow the rapid evaluation of peak position and total counts.

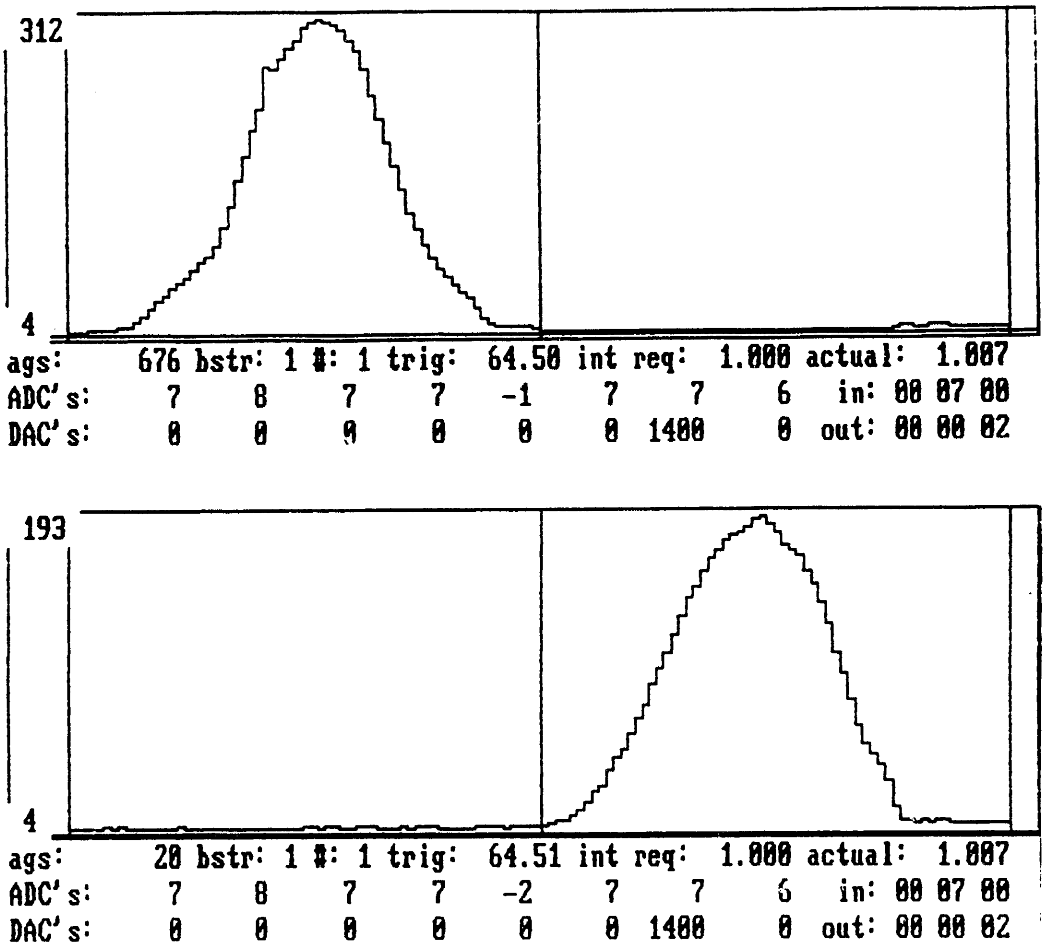

Fig. 4 Calibration system profiles using an ultraviolet lamp. The lamp generates 180 nm photons which the microchannel plate detectors amplify with a quantum efficiency of about .5%. The irregular shapes of the profiles are due to the circular aperture in the electrode through which the light shines, and the casual placement of the lamp. The table at the bottom of the display indicates various readbacks from the electronics and timing signals for the integrator gate. (a) Horizontal detector. (b) Vertical detector.

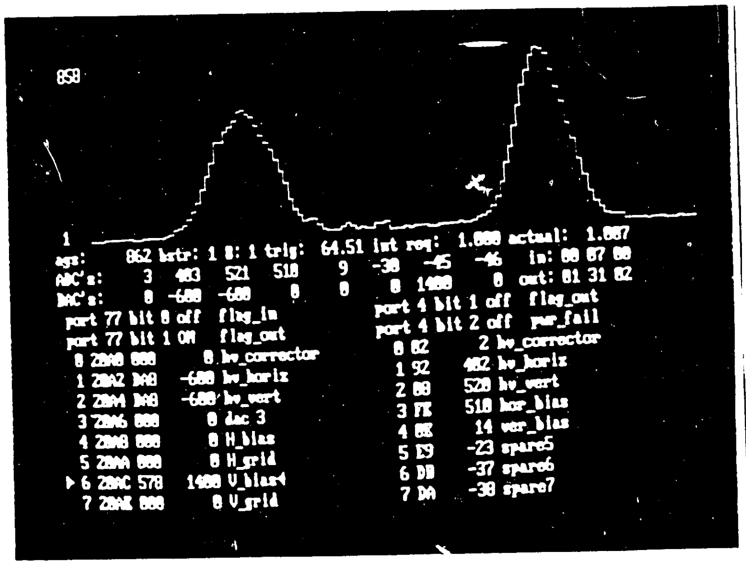

Fig. 5. The first profiles of actual beam in the Booster. The horizontal and vertical planes have different shapes, but the area under each profile is the same. The table below the display is a list of electronic and timing setpoints used in IPM trouble-shooting during the first attempts at operation.

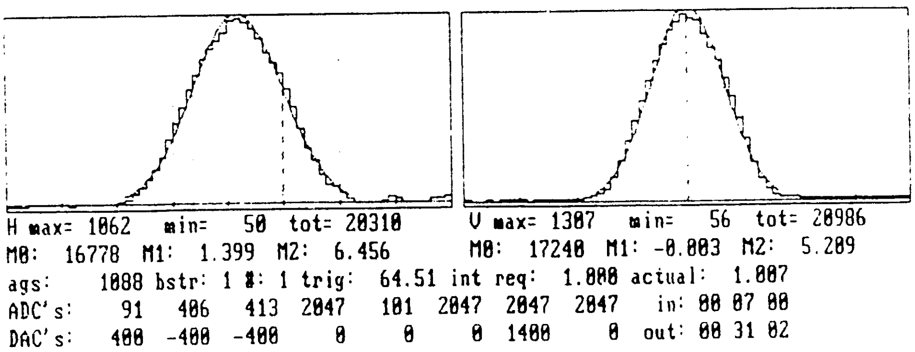

Fig. 6. The present form of display for the profile data. The numerical data give the first three moments of the profiles and readbacks described in Fig. 5. The other data are channel statistics. The software autoscales the display, thus both horizontal and vertical planes have the same height, though the numerical maxima differ. Note the relative constancy of MO, the area under the profiles. Since the same beam generates both profiles, identical detectors would give identical areas.

SUMMARY

The AGS Booster Ionization Profile Monitor has the ability to generate beam profiles even in the tenuous residual gas of a 3 x 10^{-11} Torr vacuum. It uses a microchannel plate detector with an integral anode assembly to generate profiles with a 1.47 mm wire pitch. A computer based scanning ADC system allows for profile acquisition on AGS cycle time scales. Formed electrodes generate fields without the use of resistors and the high voltage design minimizes the distorting effects of beam space charge and differential detector response. A calibration system is integral to the design and first results are very promising. They indicate that the AGS Booster IPM will work in a vacuum range where ionization devices have never seen use.

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