RHIC-STYLE IPMS IN THE BROOKHAVEN AGS*

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Abstract

Beam profiles in the two storage rings of the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Lab (BNL) are measured with ionization profile monitors (IPMs). An IPM measures the spacial distribution of electrons produced in the beam line by beam ionization of background gas. During the 2012 shutdown we installed a RHIC IPM in the Alternating-Gradient Synchrotron (AGS) to measure horizontal profiles and tested it during the 2013 run. This test was successful and during the 2013 shutdown a vertical IPM was built. This paper describes the new AGS IPMs and shows detector data.

INTRODUCTION

The Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Lab is a pair of concentric synchrotrons in which counter-rotating beams intersect at six points [1]. Beams of ions from protons (E_{max}=250 GeV) to fully-stripped uranium (E_{max}=100 GeV/nucleon) are accelerated and stored for several hours. There are detectors at two of the six intersection points for physics experiments with colliding beams.

Beam is injected into RHIC from a network of five accelerators. There are three primary accelerators: a tandem Van de Graaff, a 200-MeV H^- linac, and the new Electron-beam Ionization Source (EBIS). One of these three accelerators injects beam into the booster synchrotron, which injects into the AGS which injects RHIC.

Ionization profile monitors (IPMs) have been developed at BNL to measure transverse beam profiles in RHIC [2]. An IPM measures the distribution of electrons in the beam line resulting from residual gas ionization during a bunch passage. The electrons are swept transversely from the beam line and collected on 64 strip anodes oriented parallel to the beam axis.

In 2012 we installed a RHIC IPM into the AGS for horizontal profile measurements. The commissioning tests in the 2013 run were successful so for the 2014 run we built and installed a vertical IPM. The vertical AGS IPM is different from the horizontal to accommodate the required large horizontal aperture of the AGS. Also we added electrical coils on the permanent-magnet dipole detector magnets for beta-function measurements.

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DETECTOR

Figure 1 is a schematic of the detector and electronics in the accelerator tunnel, fig. 2 is a photo of the detector, and fig. 3 shows the beam installation. An electric field to accelerate the signal electrons toward the collector is generated in the 100mmx150mm rectangular beam pipe by biasing the top electrode at -6kV. The electrons are forced to travel perpendicularly to the measurement plane by a permanent dipole magnetic with field of 1.4kG. A second, reversed, magnet corrects the AGS beam trajectory.

A signal-gating grid is located between the beam and the collector. This is normally biased at the sweep voltage of -6kV to prevent the signal electrons from passing. To make measurements the grid is pulled to ground by a Behlke transistor switch to allow the signal electrons to pass through to the input of a microchannel plate (MCP) which amplifies the electron flux by 10^4 to 10^7. Because each channel of an MCP has a dead time of 1ms after firing, the MCP can become dynamically depleted if the input electron flux is left on continuusly. Periodically the signal electrons are gated off, with the MCP bias on, so the plate can recharge.

The amplified electron flux falls on an anode circuit board with 64 channels spaced 0.53mm apart. Each channel is connected via vacuum feedthrough to an amplifier mounted on the beam pipe, fig 3. Each amplifier output drives a shielded twisted-pair transmission line to a 50MSPS VME digitizer channel.

A screen-covered rectangular opening in the grounded half of the beam pipe decouples the electron gate from the beam. The collector board with attached MCP is located in a Faraday enclosure with an opening for the electrons covered by a grounded stainless steel honeycomb grid which attenuates rf by 80dB.

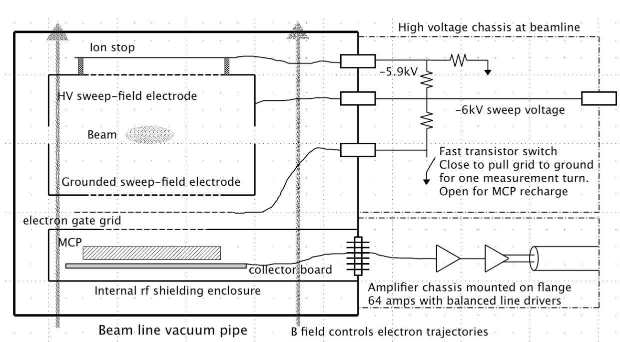

Figure 1: Schematic of detector and electronics located at the beam line.

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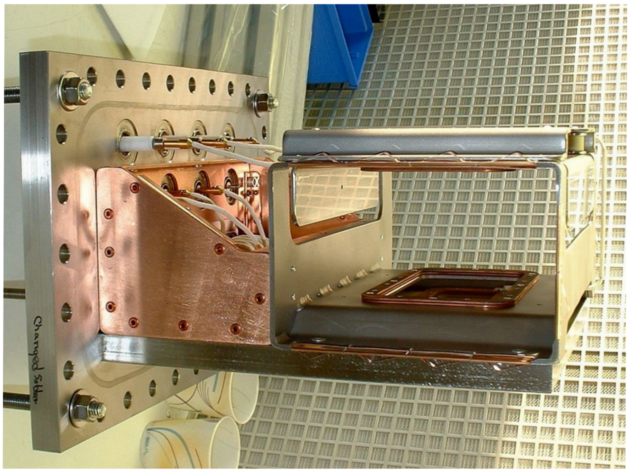

Figure 2: Assembled IPM transducer.

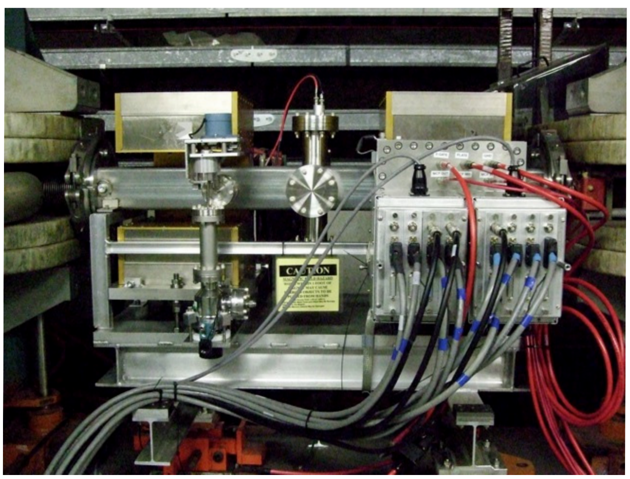

Figure 3: The horizontal detector in the beam line.

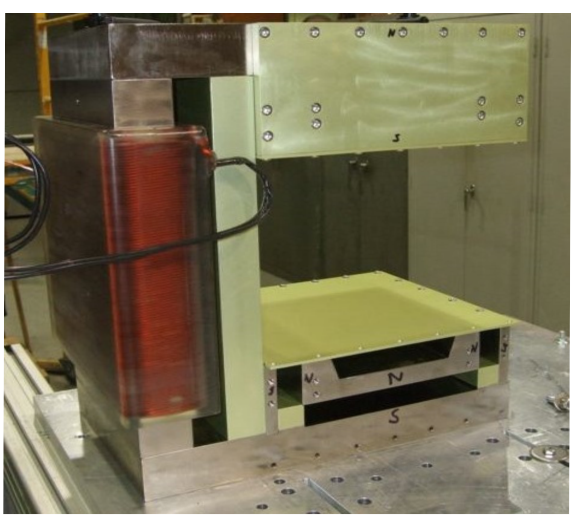

Figure 4: The horizontal detector magnet with the backleg winding.

In 2014 we added electrical coils to the backleg of the dipole magnet, fig 4. These will be used to measure the beam beta function at each IPM. If a steering angle of Δθ is placed at the detector and the beam moves by Δx then the beta function is,

$$\beta = 2\tan(\pi Q)\,(\Delta x/\Delta\theta) \qquad (1)$$

where Q is the tune. To measure the beta function through the acceleration cycle the coil current follows the same program as the main dipoles so the deflection angle, Δθ, remains constant and the beam center is measured through the ramp. This capability is still under development.

DETECTOR COMMISSIONING

One known challenge is the horizontal orbit stability in the AGS. All events in the AGS cycle are timed from the t_0 event. Beam injection is at 143ms, the energy ramp ends at 580ms, and extraction is at 1.4s after t_0. During the cycle the beam moves around horizontally over a range up to 6cm. Since the IPM measurement aperture is 3.4cm, the beam is out of this aperture much of the time.

The profile in fig. 5 was taken at t_0+425ms. The beam was outside of the measurement aperture from injection until halfway up the acceleration ramp. The measurement sequence in fig. 6 shows the beam centers and widths from 375ms, when the beam moved into the aperture, until 1.2s. The red crosses show the beam sigmas and the blue circles show the beam centers.

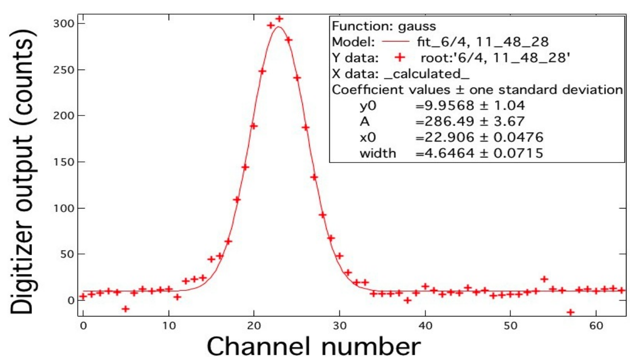

Figure 5: Beam profile during the acceleration ramp.

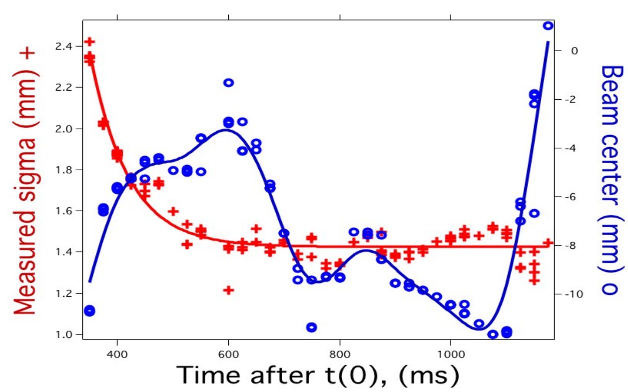

Figure 6: Beam widths (red +) and beam center (blue o) from second half of acceleration ramp to extraction.

A vertical IPM was installed in 2014. This detector is identical to the horizontal except the aperture spacing between the sweep electrode and collector electronics is increased by 5cm to accommodate the need for a larger horizontal aperture. Figure 7 shows horizontal and vertical profile mountain-range plots from one AGS cycle. The horizontal orbit is moving while the vertical orbit is stable.

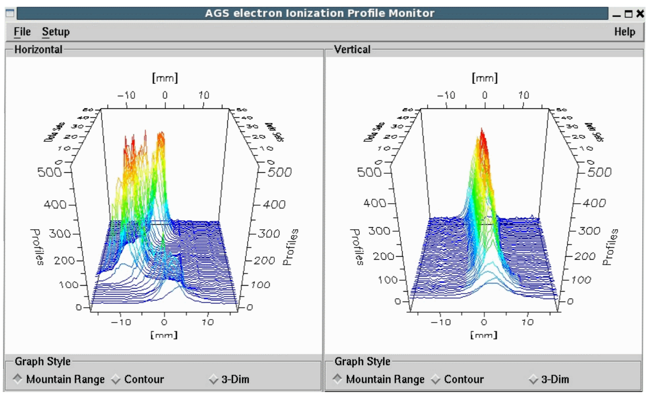

Figure 7: Horizontal and vertical profiles during a single AGS cycle.

The IPM digitizers are triggered at the peak of the beam-bunch signal on each turn. The profiles in fig. 7 are averages over 200 turns. To study injection matching we take several hundred single-turn profiles and fit Gaussians to each turn. With proton beams we need to create a pressure bump to get a statistically adequate number of signal electrons.

Each IPM has a controlled leak that stabilizes the chamber pressure at the desired level. Figure 8 shows data taken during tests. The chamber pressure is raised in steps from $2x10^{-8}$ to $8x10^{-7}$ torr. During actual machine operation the chamber base pressure was $5x10^{-10}$ torr and was raised to 10^{-8} torr for measurements.

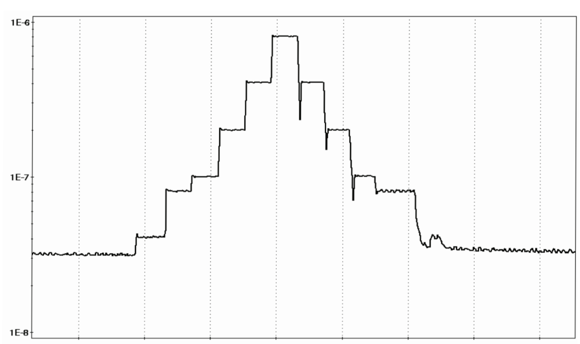

Figure 8: Chamber pressure vs. time for testing of the controlled leak.

Figure 9 is a typical data set showing results of 210 turn-by-turn profile measurements at injection taken with the vertical IPM. The beam was within the aperture of the vertical IPM during the entire cycle, fig. 7. The top plot shows the beam centers vs. turn and the second plot is the FFT of these data. The vertical tune peak is at 0.11. The third plot shows the beam widths vs. turn and the fourth plot is the FFT of these data. There is a weak quadrupole peak at twice the tune frequency and a strong peak at the tune frequency. This pattern is typical of all the measurements taken.

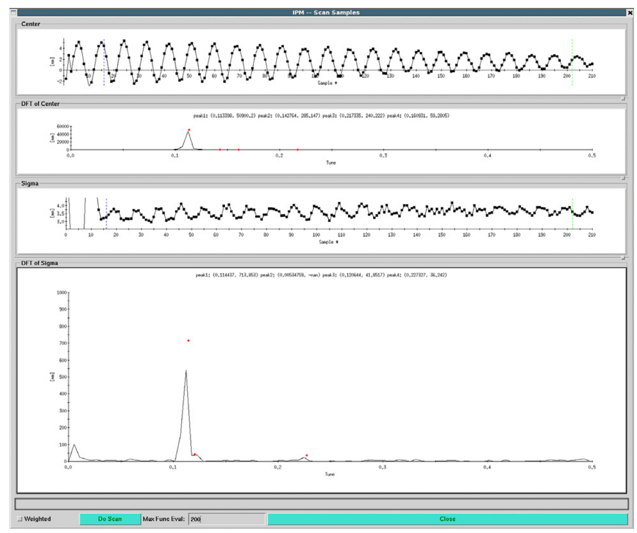

Figure 9: Turn-by-turn of centers (top) and widths (third plot) with FFTs of these data.

SUMMARY

We have installed two RHIC-style IPMs into the AGS. These are operated in turn-by-turn mode for injection studies and multiple averaged profiles measurements for profile evolution up the ramp. The RHIC signal amplifiers are not optimum for AGS operation so we are designing charge-sensitive amplifiers which will integrate over the long AGS bunches. Coils placed on the flux return backleg of the permanent-magnet dipoles will allow measurement of the beta functions.

REFERENCES

[1] http://www.rhic.bnl.gov/

[2] http://accelconf.web.cern.ch/AccelConf/BIW2010/PAPERS/TUPSM010.PDF

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