



Brookhaven
National Laboratory

BNL-99216-2013-TECH

C-A/AP/63;BNL-99216-2013-IR

Proposal for an Optical RHIC IPM

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September 2001

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Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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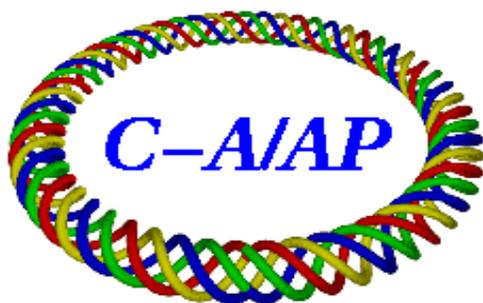
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Overview of IPM problems

Beam-induced noise

The ionization beam profile monitor in RHIC is designed to measure profiles of individual bunches with 120 bunches in the ring (three 28-MHz bucket separation) [1]. The IPM collects electrons generated from beam ionization of background gas. Each time a beam bunch passes through the detector chamber a pulse of electrons with the spatial distribution of the beam is swept from the pipe, amplified by a microchannel plate (MCP) and collected on 64 detector channels. The charge collected on each channel is amplified by a charge-sensitive amplifier and shaper amplifier which puts out a 100-ns pulse.

During the run of 1999 and early in the runs of 2000 and 2001 the detectors worked well. The only problems encountered were a few dead channels. However during the 2000 run, as the beam intensity in RHIC increased, the detectors developed a beam-induced ringing which grew until the noise pickup saturated the amplifiers. The cause of this ringing was found and detector shielding was developed which eliminated ringing in a pulsed-wire measurement intended to simulate the beam. Shielding was installed on one detector at the end of the run and beam-induced noise was not seen.

In 2001 the IPM gave good profile data early in the run but as the beam intensity increased the beam once again started to cause noise which made the profile signal from the electrons useless. The fix in 2001 is to use low-pass-filtered amplifier outputs which were available on the amplifiers. These give noise-free data but the profiles have an integration time constant of $1.6\mu\text{s}$ so the pulses are an average of about 20% of the ring. We have lost the capability to measure individual bunch profiles.

MCP characteristics

A microchannel plate is a 1mm-thick sheet of glass with a honeycomb pattern of $25\mu\text{m}$ -diameter holes. Each of the two MCP's in a RHIC IPM has 7.9×10^6 channels. The total glass surface area per MCP is one m^2 . The length/diameter ratio of a channel is 40. An MCP is compatible with a high-vacuum environment but it requires a long pump-down period.

When the detector was removed in 2000 to install EMI shielding and replaced without an offline bakeout it was not usable for several weeks. Even after the detector chamber vacuum had recovered it was not possible to operate the detector. When bias voltage was applied electron cascades through the channels would liberate adsorbed gases and cause a vacuum runaway.

MCP's have a lifetime of about $0.1\text{C}/\text{cm}^2$. If the bias supplies are turned on for 1s each time a measurement is made, then the plates will show signs of gain depletion after approximately 10^5 measurements. Since the charge delivery is not uniform across the

MCP the gain drop is not uniform. Lower gains in the center of the beam signal will cause artificially large beam-width measurements.

Optical detection of electrons

Concept

In the present detector the signal is electric charge which passes through the vacuum envelope. From operational experience it is clear that the electron signal from the beam provides an accurate and fast measure of beam profiles. However the collector channels also are antennas which couple to the beam fields. Electrical detection of the electrons requires a window which is transparent to electrons and opaque to EMI. This is a problem that has not been solved.

At DESY and at CERN beam profiles have been measured by detecting the ionized electrons optically with phosphor screens [2,3]. The usual method is to place a MCP and phosphor screen in the vacuum and view the screen with a CCD camera through a vacuum window. Recently CERN has tested a system which images the phosphor screen onto a multi-anode photomultiplier tube (PMT).

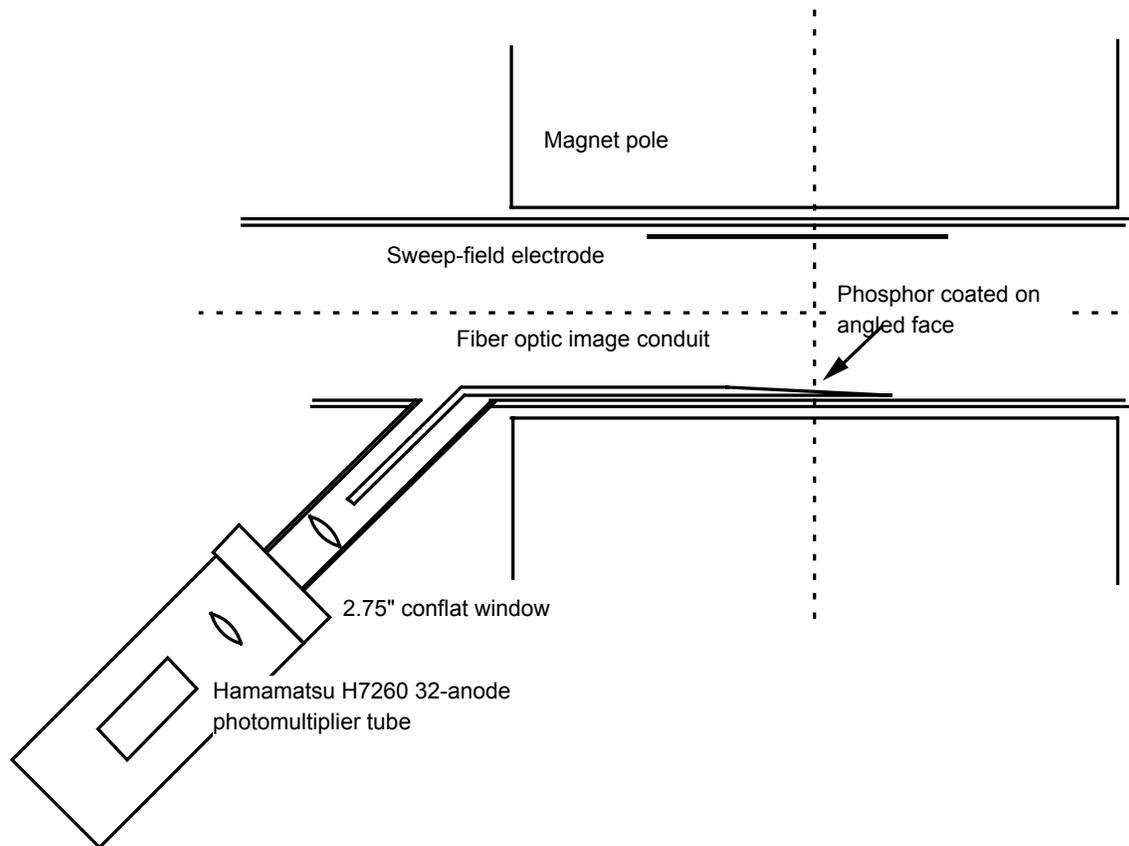
I propose that we investigate using optical detection in the RHIC IPM's. Passing the electron signal through the vacuum envelope optically should eliminate the EMI coupling. A limited R&D project will be required to measure both the time and space resolutions of the proposed system. If these measurements show good results the IPM's would be modified by adding conflat windows to the existing vacuum chambers and installing optical elements mounted on the existing support structures. The IPM magnets would not be changed and the existing amplifiers will be used in the new system.

Detector design

The figure shows the proposed detector design. The electrons from the beam pipe are swept from the pipe and impinge on a phosphor screen which is coated on the angled face of a fiber-optic image conduit. Light from the phosphor is transported along the 4.2x19.2mm rectangular fiber-optic bundle. Where the conduit clears the magnet pole tip a 45° bend sends the image along a 2.75" conflat nipple welded to the IPM vacuum chamber. The bend, shown as an angle, will have a 100-mm radius. The end of the optical conduit is imaged through a vacuum window onto the photocathode of a 32-anode PMT which is located out of the vacuum.

Phosphor screen

The table lists parameters of five phosphor materials which look promising for this application. The light decay time needs to be faster than 110ns to separate bunches spaced by three rf buckets. Also the light has to be peaked around 400nm since this is the maximum sensitivity of the phototube. At this time I am collecting information on light output, vacuum compatibility, radiation resistance, and lifetime for these materials.



Schematic of optical detection added to existing IPM chamber and magnet. Light generated by electrons striking the angled face of the fiber optic conduit is transported to the end of the conduit and focused onto the cathode of the PMT.

Parameters of five possible phosphors.

Phosphor	common name	color light	peak (nm)	decay to 10% (ns)
$\text{Y}_2\text{SiO}_5:\text{Ce}$	P47	blue	400	100
$\text{YAlO}_3:\text{Ce}$	YAP	blue	370	25
$\text{Y}_3\text{Al}_5\text{O}_{12}:\text{Ce}$	YAG	green	550	70
$\text{ZnO}:\text{Ga}$		blue	390	5
C_4H_{10}	anthracene	blue	447	32

Image detection

The electron-generated light will be transported around the magnet pole tips with a rectangular fiber-optic image conduit. One end of the conduit will be polished at a very shallow angle to give a long face along the beam direction and the other end will be perpendicular to the conduit. The angled face will be coated with an appropriate phosphor. A two-achromatic-lens system will project the image of the end of the conduit through a window and onto the image plane of a Hamamatsu H7260 photomultiplier tube.

The H7260 PMT has an anode that is segmented into 32 channels. The channels are separated by 1 mm so to get 0.6mm collector channels the imaging system will have a magnification of 1.67. The PMT channels are 7mm tall so the optical conduit will be $7\text{mm}/1.67=4.2\text{mm}$ thick. A data sheet for this tube is attached at the end of this note.

The photocathode has a quantum efficiency of 20% so one cascade should be started for each 5 photons. With a gain of 10^6 , one cascade will generate 35fC of charge at the anode. The present IPM amplifiers have a noise floor of about 5fC. Also the PMT maximum anode current per channel is 6 μa . For 120 bunches in the ring this would be 640fC/bunch. The IPM amplifiers saturate at about 200fC. We should be able to use the existing IPM amplifiers for the optical IPM without modification.

Estimate of signal size

Several companies make fiber optic image conduits and the available range of numerical aperture seems to be 0.55-0.65. For the purpose of estimate I use N.A.=0.60. N.A. is the sine of the half angle of acceptance of an optical system. If a phosphor screen is covered with a reflective layer as is custom for vacuum installations this means that approximately 4.2% of the generated photons from electron impact will travel down the fiber.

The proposed two-achromat imaging system will have a N.A.=0.125. It is necessary to keep this figure at this level for accurate imaging over a large focal plane. About 8.4% of the photons will be transported through the lens system. A 6keV electron produces about 200 photons in P47 and the photocathode of the PMT has a quantum efficiency of 20%. Stacking up these numbers without any other loss included gives a total electron detection efficiency of the system of 1/7, ie. the system will see one electron in seven that strikes the phosphor. For comparison the present system has a detection efficiency of 1/3.

Proposed development program

The company, Collimated Holes, Inc., has offered to produce two prototypes using existing 5-8mm optic guides for \$2,500. These would be from two different types of conduit so we could test resolutions and light coupling. Fiberguide and Burle Optics also have offered to produce a custom light guide. Applied Scintillation Technologies will coat any screen with any of the phosphors listed in the table. The Hamamatsu PMT costs about \$2,500.

I propose buying a test fiber guide with phosphor coating, building a two-lens optic system and testing the concept using the Kimball Physics electron gun we have for calibration of the electron energy detectors in the booster. If we can achieve an

acceptable level of performance in the test then we will make a decision for a detector for RHIC. We have spare vacuum chambers and mounting hardware. A complete replacement detector can be built in the lab. Tunnel installation will involve removing the existing chambers and replacing with the new chamber.

Conclusion

The RHIC IPM's have performed poorly each year because of beam-induced noise. Experience has shown the electron signal is a good measure of beam profile. Noise problems can be reduced by increasing the charge-integration time constant, but this removes the single-bunch measurement capability. Also the microchannel plates have a finite lifetime and it will be necessary to replace them at one or two year intervals.

It may be possible to replace the existing MCP and anode collector with a multi-channel optic system which will be adequately sensitive to the electron signal and immune to the EMI generated by the beam. Available phosphors are fast enough for single-bunch imaging. Unknown at this time are questions about phosphor lifetimes in the RHIC environment.

The system proposed here will use many of the RHIC IPM components including vacuum chambers, magnets, mounting hardware, amplifiers and VME digitizers.

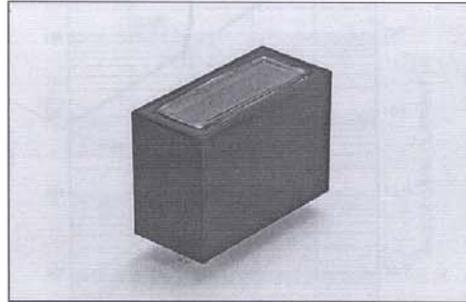
References

- [1] R. Connolly, P. Cameron, R. Michnoff and S. Tepikian, "Performance of the RHIC IPM," Proc. 2001 PAC, Chicago.
- [2] K. Wittenburg, "Experience with the Residual Gas Ionization Beam Profile Monitors at the DESY Proton Accelerators," Proc. 1992 EPAC., 24.3.-28.3, Berlin, Germany and DESY HERA 92-12
- [3] C. Fischer, "Results on Prototype Measurements for LHC Beam Instruments," Proc. 2001 DIPAC, Grenoble, France.

H7260 -HV INPUT PIN TYPE
H7260A -HV INPUT CABLE TYPE

FEATURES

- Multianode 32 Channel Linear Array
- 0.8 × 7 mm Anode, 1 mm Channel Pitch
- High Speed Response
- Low Cross-talk 3 % (Typ.)
- Built-in Voltage Divider Circuit



GENERAL

Parameter		Description/Value	Unit
Spectral Response		185 to 650	nm
Wavelength of Maximum Response		420	nm
Photocathode	Material	Bialkali	—
	Minimum Effective Area per Channel	0.8 × 7	mm
Channel Pitch		1	mm
Window Material		UV glass	—
Dynode	Structure	Metal channel dynode	—
	Number of Stages	10	—
Weight		Approx. 70	g
Insulation Cover Material		P. O. M.	—

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	-900	Vdc
Average Anode Current per Channel		6	μA

CHARACTERISTICS (at 25°C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856K)	50	70	—	μA/lm
	Blue (CS-5-58 filter)	6	8	—	μA/lm-b
Anode Sensitivity	Luminous (2856K)	50	140	—	A/lm
Gain		—	2 × 10 ⁶	—	—
Anode Dark Current per Channel (After 30 min. storage in the darkness)		—	0.2	2	nA
Time Response	Anode Pulse Rise Time	—	0.6	—	ns
	Transit Time Spread (FWHM)	—	0.16 *1	—	ns
Pulse Linearity per Channel (±3 % deviation)		—	0.65	—	mA
Cross-talk		—	3 *2	—	%
Uniformity Between Each Anode		—	1: 0.8	—	—

NOTE: Voltage Divider Current = 0.33 mA at -800 V Input.

*1 Light is irradiated to only one channel at this measurement.

*2 The ratio of signal between a channel and an average of adjacent channels, when the incident light is given to the center channel through 0.8 × 7 mm aperture.

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MULTIANODE PHOTOMULTIPLIER TUBE ASSEMBLY H7260, H7260A

Figure 1: Typical Spectral Response

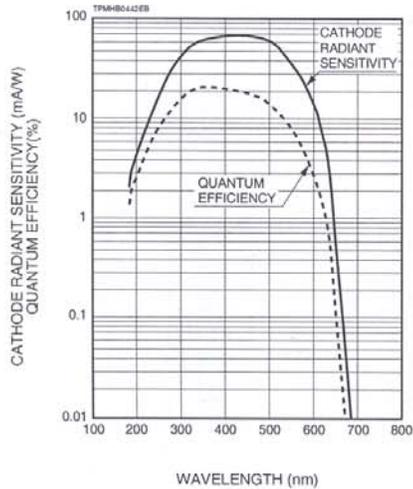


Figure 2: Typical Gain and Anode Dark Current

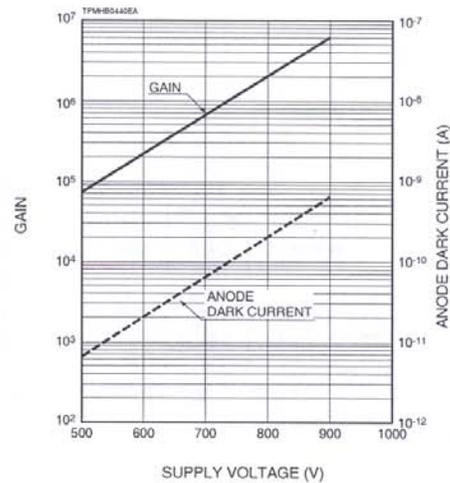


Figure 3: Typical Spatial Resolution

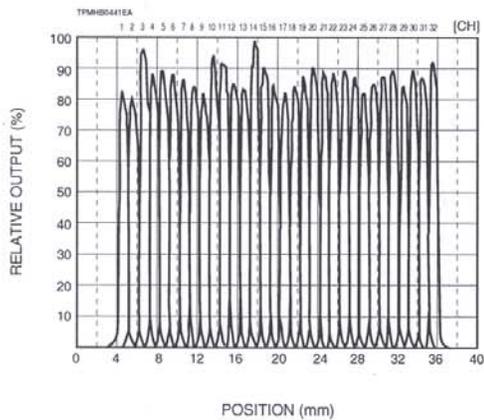


Figure 4: Typical Anode Uniformity

