Plastic Scintillator Centrality Detector for BRAHMS

Y. K. Lee

The Johns Hopkins University, Baltimore, Maryland 21218, USA

R. Debbe and J. H. Lee

Brookhaven National Laboratory, Upton, New York 11973, USA

Hironori Ito, and S.J. Sanders

University of Kansas, Lawrence, Kansas 66045, USA

Abstract

An array of forty tiles of thin plastic scintillators is used to construct the outer layer of the charged particle multiplicity detector for the BRAHMS experiment at the Relativistic Heavy Ion Collider (RHIC). Each tile is a square with 12 cm long sides and 5mm thickness. The light from each of the scintillators is collected by wavelength shifting fibers embedded on the periphery. The light collection is uniform within 5% over the tile with the edge effect limited to 4mm along the edge. The response is found to be linear in the high multiplicity environment at RHIC with Au+Au beams at $\sqrt{s_{NN}}$ of 200 GeV.

Key words:
PACS: 29.40.Mc

1 Introduction

Thin plastic scintillators with wavelength shifting fibers embedded on the periphery for light collection are well known for having uniform collection efficiency over the whole area and are successfully employed in large stacks for electromagnetic sampling calorimetry [1–3]. A single layer, moderately segmented, free-standing array of such thin scintillator tiles has not been studied before, but offers an attractive choice as a charged particle multiplicity detector where particle production is very large, as is the case at RHIC.

The Broad RAnge Hadron Magnetic Spectrometers experiment (BRAHMS) is designed to measure charged hadrons produced in relativistic heavy ion collisions at the

RHIC[4,5], over a wide range of rapidity and transverse momentum.

The study of these extended systems needs a good characterization of the degree of overlap of the ions when they interact, i.e. the centrality of the collision. The multiplicity of charged particles is expected to have a monotonic correlation to the centrality of the collision[6,7] and is the variable of choice to define the geometry of the interaction. The BRAHMS centrality detector measures the multiplicity of charged particles, and consists of an inner array of silicon strip detectors, and an outer array of plastic scintillator tiles in a geometry of two barrels concentric with the beam line. The present paper discusses the design and characteristics of the outer array of plastic scintillator tiles and how it performed in the RHIC environment. The silicon multiplicity arrays will be discussed in a separate publication.

The centrality detector is designed to be used in collisions of systems that range from p+p to Au+Au reactions, and to provide a hardware trigger for the experiment. The current design allows an off-line analysis at 5 % steps at least up to semi-central events for Au+Au, and at larger steps for lighter nuclei such as Si+Si. The azimuthal angle coverage is made as symmetric and as complete as possible without obstructing the particle paths to the spectrometers.

2 Centrality Detector Arrays

The BRAHMS spectrometers consists of the Mid-Rapidity Spectrometer that covers angles from 30^0 to 90^0 and measures momentum up to 10 GeV/c at full current, and the Forward Spectrometer that covers angles from 2.3^0 to 30^0 and measures momenta of fully identified particles up to 30 GeV/c. The centrality detector arrays are concentric barrels of silicon strip detectors and plastic scintillator tiles located at the pivot position of the two spectrometers. This position coincides with the collision point of the beams at RHIC. The inner barrel is made of 25 silicon wafers each subdivided into seven active regions for 175 discrete channels. These detectors are located 5.3 cm from the beam axis. The outer barrel is made of 38 scintillator tiles at 13.7cm from the beam. Both barrels cover the pseudo-rapidity range of $-2.2 < \eta < 2.2$. Fig. 1 shows a schematic of the eight-tile, ladder-like panels, indicating where tiles are removed to accommodate the spectrometer acceptances. Fig. 2 shows a picture of the supporting arrangement for holding the scintillator ladders around the beryllium beam pipe. The enclosure for the silicon strip detectors are also shown mounted next to the beam pipe. Only two tiles instead of eight are mounted vertically on the right to avoid adding mass in front of the Mid-Rapidity Spectrometer. Similarly only four tiles are mounted vertically on the left in order to accomodate the Forward Spectrometer.

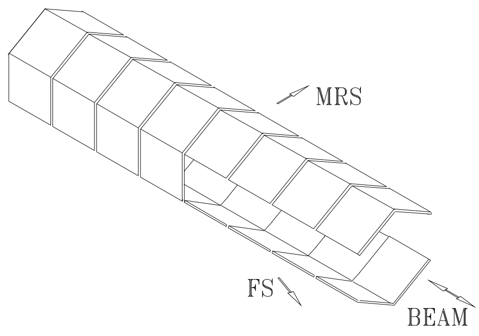

Fig. 1. Schematic drawing of the multiplicity counter array with scintillator tiles. MRS for the Mid-Rapidity Spectrometer; FS for the Forward Spectrometer.

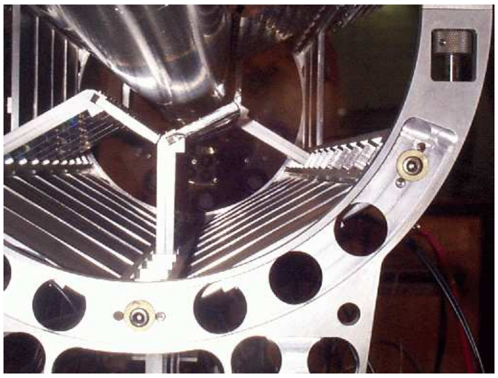

Fig. 2. Photograph of tiles and silicon strips mounted around the beryllium beam pipe.

The moderately segmented scintillator array is particularly suitable for event selection and its fast timing capability allows its inclusion in the first level trigger. The higher segmentation of the silicon array allows for a more accurate off-line determination of multiplicity and pseudorapidity density distribution $dn/d\eta$, but these detectors are too slow for use in the first level trigger. The adopted degree of segmentation for the tiles was based on the expected multiplicity of charged particles in each segment and the rate of events with high-energy deposition arising from secondary particles. The multiplicity in each tile should be within the linearity range of the photomultiplier and the ADC and still take full advantage of the photo-electron statistics of the photomultiplier.

3 Plastic Scintillator Tiles Assembly

The thickness of the tile is chosen so that the mass in the vicinity of the collision region is minimized but a sufficient number of photoelectrons per minimum ionizing particle is collected for acceptable energy resolution. Based on the experiences at CDF[1] and STAR[3] it was decided to embed two turns of wavelength shifting fibers on the periphery and use both ends of the fiber for light collection. Since the space requirement allows the placement of the photomultipliers within a meter from the scintillator tiles there was no need to splice on additional transparent optical fibers to guide light to the photomultiplier.

The scintillator tiles are 5 mm thick and are squares of 12cm x 12cm dimension. To accomodate two turns of the wavelength shifting fibers, a 2mm deep and 1.2mm wide groove was machined along the edge of the tile. In Fig. 3 the dimensions of the tile and groove are given. The lower right corner of the tile shows a spur-like arrangement for extracting the fiber from the groove.

It is well known[1–3] that the embedded optical fibers in this arrangement

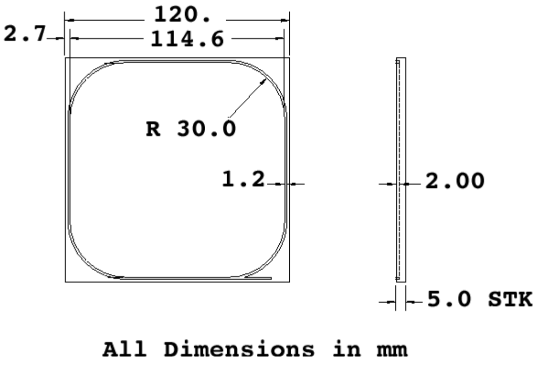

Fig. 3. Detailed drawing of one tile.

collect light after many reflections, to the extent that the light is almost diffuse, thus avoiding the need to polish the edge of the tiles for specular reflection. After machining, a minimum cleaning of the grooves was carried out with emery paper and its inner surfaces of the grooves were left unpolished.

The wavelength shifting optical fiber Kuraray S-type K11[8] is multi-clad to increase the light trapping efficiency by 50% over the conventional single clad fibers, achieving an acceptance light cone opening angle of 26^0[8] and a numerical aperture $NA = 0.72$. Beside the consideration of the matching of wavelength to the photomultiplier response and the transparency, the minimum allowed bending radius and the durability of the fiber under the bent conditions are important factors. The brittleness of the fiber comes from the core which has molecular orientation along the drawing direction. The Kuraray S-type fibers have a high tolerance for bending at some sacrifice of transparency. The diameter of the fiber chosen, 0.83 mm, is the maximum value allowed for the required bending radius of 3 cm. The long term durability of the fiber under bending conditions is well studied[9]. The depth and shape of the groove was based on the prototype of the tile first provided by the STAR electromagnetic calorimeter group[3]. The minimum bending radius of the fiber was kept at 3 cm throughout the fabrication process. Both ends of the optical fiber extend for a length of 75 cm out of the scintillators and are covered with a black light tight jacket.

The scintillating material of the tiles is BICRON BC404A[10]. The tiles are then wrapped with white bond paper and black Tedlar PVF film[11]. The choice of the white bond paper with high fiber content was made on the basis of study by the CDF group[1].

The photomultipliers used for this detector are Hamamatsu H3178-61 assemblies. The assembly is based on the 1.5 in. diameter tube R580-17 which has green enhanced photocathode[12]. The coupling of the fibers to the photomultipliers(PMT) is done with black Delrin disks with the same diameter as the photomultiplier assembly. On each disk two holes are drilled. The fibers are inserted in the holes and the light shielding jackets for the fibers are glued onto the Delrin disks with black RTV. The exposed ends of the fibers are then ground, polished and glued to the window of the photomultiplier. Additional epoxy was applied over the black RTV to secure the fibers in place.

4 Performance of the Scintillator Tile Assembly

Individual tiles were first tested for a uniform response over their surface and near their edge using cosmic rays. The three multi-wire tracking chambers and two scintillator paddles used as triggers were mounted in a stack with suitable spacing so that several tiles could be inserted between the chambers. The axis of the stack was oriented vertically to accept the cosmic rays. The wire chambers had spacial resolution of better than 0.3 mm. The profile in Fig. 4 shows that the uniformity is within 5%. The edge effect is confined within 4 mm along the edge. This effect is partly due to the finite angular resolution in selecting the vertical incidence of cosmic rays for the scan.

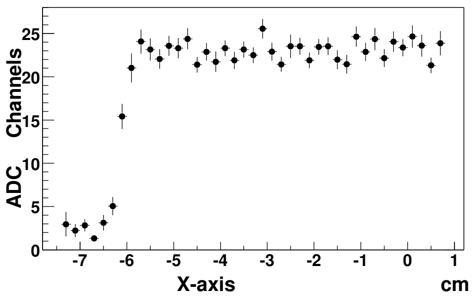

Fig. 4. The profile of the response of the tile to cosmic rays with scan direction parallel to one edge.

As a measure of the light collection, the number of photoelectrons emitted at the photomultiplier cathode was measured for single minimum ionizing particle (MIP) passing through the tile at a normal incidence angle. First the gain of the PMT was calibrated with its own dark current. Fig. 5a shows the single photo-electron peak collected from pulses amplified 100 times. Fig. 5b shows the spectrum of single minimum ionizing particles collected from pulses amplified 10 times. The separation of the single photo-electron peak from the pedestal in Fig. 5a corresponds to 10 channels in Fig. 5b. Then the single-MIP spectrum shown in Fig. 5b was fitted by convolution of the single photo-electron response using Poisson statistics. The number of photoelectrons for a single-MIP event ranged from 20 to 25.

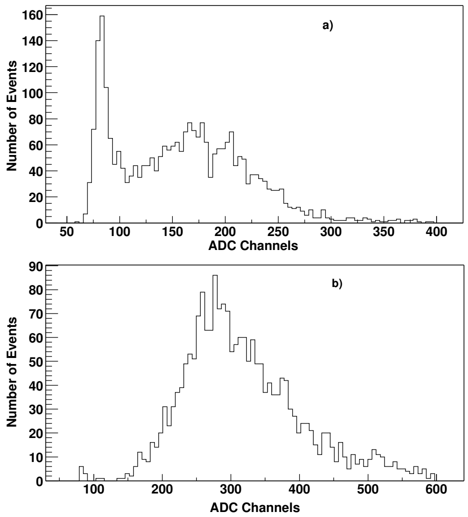

Fig. 5. a) Shows single photo-electron in photomultiplier H3178-61 (amplified 100X). b) Shows the single MIP (amplified 10X) collected from cosmic rays.

The linearity of the photomultiplier assembly H3178-61 was tested with a point like source of light whose intensity falls as $1/r^2$ where r is the distance between the source and the photo-cathode. To obtain a point like source of light an LED was placed inside a volume with diffuse reflecting walls. This volume (a cube in this particular case) had a small orifice to let the light out. (The PMT did not have a direct view of the

LED.) The cube was mounted on a track such that its distance to the PMT can be changed with a stepping motor. Displacement and different biases of the LED were used to study a range of pulse heights that extends up to values corresponding to the maximum measured multiplicity in each tile in Au-Au collisions at RHIC (200 MIPs per tile at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}} = 200 GeV$). Fig. 6 shows the results of the measurement: average pulse height versus number of steps of the stepping motor. Three sets of data are displayed: full circles represent the mean of pulse height distributions obtained with the LED driven with a bias voltage such that the mean value at step 0 lies on channel 1000. The full triangle symbols are used to show the mean of pulse heights attenuated by 20 db. To obtain this data set, the bias of the LED was raised such that the step 0 point produces again a mean at ADC channel 1000. Finally, filled squares are used to plot the third set of points where the signal of the PMT was attenuated by 26 db. Once again, in order to obtain these points the LED bias is raised. The pulse height at step 0 for this set is 10 volts (with 50 Ohm termination), comparable to the biggest pulses produced by Au-Au interactions. The curve in Fig. 6 is a fit to $1/r^2$ law for the data set with attenuation of 26 db. The fit assumes a uniform background and an off-set in motor steps corresponding to the value of r of the stepping motor at the origin. As the source of light moves away from the photocathode the mean pulse height has the same position dependence for the three sets of data. No deviation from the quoted pulse height linearity (2%) is observed. This is in agreement with the estimate that the peak anode current of the H3178 photomultiplier is 20 mA for the maximum multiplicity; a value well below the 150 mA listed in the specification sheet of the R580-17 Hamamatsu[12] tube used to read the tiles.

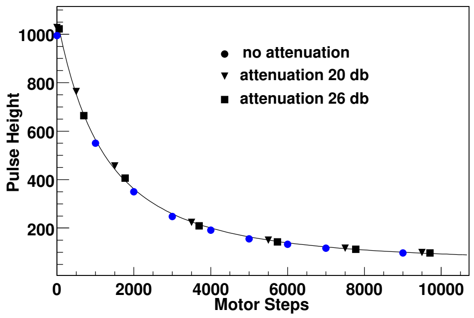

Fig. 6. Linearity of photomultiplier measured with an integrating cube mounted on a track covering three ranges of light level from LED. The curve is a fit to $1/r^2$.

The calibration of the scintillator tiles after mounting in the centrality detector frame at the Collider was carried out both with cosmic rays and with the colliding beams. The signals from the anode is split internally in a Lecroy 4413 discriminator with 5% of it going into a discriminator and 95% to a 15bit LeCroy 1885F ADC. To calibrate the tiles with cosmic rays, the data were taken with a trigger derived from the coincidence between any two tiles. In an off-line analysis the spectra were filled with those events with coincidences between directly opposing tiles. The main concern for calibration comes from the wide dynamic range of the spectrum when multiplicity per tile can be as high as 200. The LeCroy

1885F ADC has a quoted integral linearity of ± 0.5% for the 15 bit operation mode which is adequate for the extrapolation of the single MIP calibration by 200.

5 Performance with the colliding beams at the RHIC

During the initial run at RHIC a total of 38 tiles were mounted on a hexagonal aluminum frame with six ladders. Each ladder had 8 tiles. For clearance of particle paths to spectrometers from interactions points, 6 tiles toward the Mid-Rapidity Spectrometer side and 4 tiles toward the Forward Spectrometer side were not installed.

In-situ calibration of the tiles with colliding beams was carried out by selecting single MIP events on each tile with measured vertex position. The scintillator-optical fiber combination is susceptible to the temperature variation and aging over a few months. Although the wave-length shifting fibers are robust, any history of excessive bending can affect the transparency and light collection. Over one year of application in the RHIC environment there was no noticeable aging or deterioration of the tiles and fibers.

The mass of the tile array includes the 5 mm thick scintillators as well as the aluminum supporting frames, and another inner layer of silicon strip detectors with attendant electronics. Non-MIP events such as multi-particle break up of nuclear events are important sources of background. The study with the colliding beams Au+Au at $\sqrt{s_{NN}} = 130 GeV$ indicates that such events occurred in the tiles in roughly 4% of the events with central collisions.

In analyzing the data the minimum-bias event was defined as having a signal in one of the global trigger at BRAHMS[5] and at least one "hit" in the tile array to reduce very peripheral collisions induced by electromagnetic dissociation and random beam-gas interactions. For other than the minimum-bias events the collision centrality can be selected by multiplicity in the tiles. As an example the 33% selection of the multiplicity spectrum is shown in the hatched region of Fig. 7.

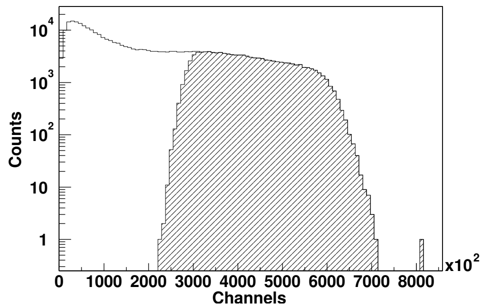

Fig. 7. Sum spectrum of 38 tiles showing multiplicity distribution. The distribution of 33% central events is shown with the hatched region.

In the 2001-2 run at RHIC a centrality trigger was implemented to select the 25% most central collisions with high efficiency. The definition of this trigger requires a collision condition from basic beam-beam counter trigger, and further requires a large deposited energy in the tile multiplicity array. The outputs from individual tiles are split with 5% of the signals feeding into discriminators. The discriminator outputs are applied through majority-logic units to the BRAHMS trigger system [5] to produce the centrality trigger on the first level that gates the ADC's, TDC'c, and starts the TPCs gating grids. The arrangement performed well at the RHIC to select the $\sim 25\%$ most central collisions.

6 Conclusion

A charged particle multiplicity detector was built for the BRAHMS experiment at RHIC using an array of thin plastic scintillators. To insure uniformity of light collection over the scintillator, a wave-length shifting optical fiber was embedded in the periphery of the square scintillators. An adequate degree of segmentation was accomplished in order to limit the dynamic range of each tile in the high multiplicity reactions from the colliding beams at the RHIC. A moderate degree of segmentation was also necessary for off-line correction needed when a background process leads to an anomalously large energy deposition in one of the tiles. Because of the wide dynamic range needed to measure the multiplicity in the colliding beam reaction, the calibration of the tiles requires extrapolation of the single MIP calibration by a large factor. The uniformity of the light collection and the linearity of the response over the wide dynamic range was tested. The robustness and fast response time of the scintillators compliments well the highly segmented silicon strip detectors which were also installed as an inner multiplicity array layer. The centrality detector was successfully deployed in the RHIC experiment and the scintillator outputs are incorporated in the first level hardware trigger of the experiment.

We are grateful to the members of the BRAHMS collaboration whose participation made this work possible, and special thanks go to C. Chasman and F. Videbaek. This work was supported by the Division of Nuclear Physics of the U.S. Department of Energy under grant numbers DE-AC02-98CH10886 and DE-FG03-96ER40981.

References

[1] S. Aota, *et al.*, Nucl. Instr. and Meth. *A* 352 (1955) 557.

[2] O. Grachov, *et al.*, STAR Note 274 (Brookhaven National Laboratory), 1994.

[3] S. Bennett, Wayne State University, private communication.

[4] K. Ashktorab, *et al.*, BRAHMS, Conceptual Design Report, BNL-62018 (Brookhaven National Laboratory), 1994.

[5] M. Adamczyk, *et al.*, BRAHMS Collaboration, Nucl. Instr. and Meth. in press.

[6] X. Wang and M. Gyulassy, Phys. Rev. D 44 (1991) 3501.

[7] S. A. Bass, *et al.*, Prog. Part. Nucl. Phys. 41 (1998) 225-370.

[8] Kuraray America, Inc., 200 Park Avenue, New York City, New York 10166, USA.

[9] K. Hara, *et al.*, Nucl. Instr. and Meth. A 411 (1998) 31.

[10] BICRON, 12345 Kinsman Road, Newbury, Ohio 44065, USA.

[11] E. I. du Pont de Nemours and Company, Willmington, Delaware, USA.

[12] Hamamatsu Corporation of America, Bridgewater, NJ 08807 USA.