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**The Calibration and Monitoring System for the
PHENIX Lead-Scintillator Electromagnetic
Calorimeter¹**

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Abstract. A system for calibrating the PHENIX lead-scintillator electromagnetic calorimeter modules with cosmic rays and monitoring the stability during operation is described. The system is based on a UV laser which delivers light to each module through a network of optical fibers and splitters and is monitored at various points with silicon and vacuum photodiodes. Results are given from a prototype system which used a nitrogen laser to set the initial phototube gains and to establish the energy calibration of calorimeter modules and monitor their stability. A description of the final system to be used in PHENIX, based on a high power YAG laser, is also given.

I. INTRODUCTION

The lead-scintillator electromagnetic calorimeter for the PHENIX experiment (1) is a shashlik-type detector consisting of 15552 individual towers which covers an area of approximately 48 m². The calorimeter will be used to measure electron and photon production in relativistic heavy ion collisions at RHIC, and will be an integral part of the particle identification and trigger system for PHENIX. The calorimeter will also be used to measure high p_T photon production and other electromagnetic processes in high energy polarized proton collisions as part of the spin physics program at RHIC.

The calorimeter has an nominal energy resolution of 8%/√E(GeV) and a timing resolution of <100 ps for electromagnetic showers(2). A precision calibration and monitoring system has been developed to achieve an absolute energy calibration of less than 5% for day-one operation at RHIC, and to maintain an overall long-term gain stability of less than 1%. The design of the system will be described, and results will be presented from various tests and module calibrations using cosmic rays.

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FIGURE 1. Laser calibration, monitoring, and light distribution system.

II. SYSTEM DESIGN

The heart of the calibration and monitoring system is a UV laser which supplies light to the calorimeter through a network of optical splitters and fibers. The calorimeter is composed of six sectors, each consisting of a framed, 3 x 6 array of 18 supermodules. Each 67 cm x 67 cm supermodule is a 6 x 6 package of individual modules, each containing four readout towers and four phototubes. Injected laser light excites the plastic scintillator of each module via a "leaky fiber" which "leaks" light with a distribution in depth that simulates an electromagnetic shower. The intensity of light from the laser is monitored at the initial beam splitter with a biplanar photodiode, and at each intermediate splitter and supermodule with PIN diodes. The overall layout of the system is shown in Fig. 1.

A. Laser and Primary Beam Splitter

The UV laser used as the light source for the initial precalibration of the calorimeter modules with cosmic rays was a Laser Science VSL-337ND pulsed nitrogen laser ($\lambda=337$ nm). For the final system, a Continuum Surelite II-10 (2 W, $\lambda=355$ nm) YAG laser will be used. The laser beam intensity is controlled by a set of fixed attenuators and a remotely controlled variable attenuator. Light from the laser is initially split into six equal intensity beams by a set of partially reflecting mirrors. The beam fraction extracted by each mirror passes through a quartz lens and is focused to a point just in front of a quartz fiber. These six 50 m fibers will be 600 mm silica-core/silica-cladding high OH fibers (3M Specialty Fiber FG-600-UAT) which have numerical aperture of

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0.16 and an attenuation length of 60 dB/km at 355 nm. In addition, they are designed for high power applications (up to 5 GW/cm²) in order to handle the extremely high instantaneous power of the focused laser beam. The spot size should be small (< 0.8 times the fiber diameter) to prevent light from entering the cladding and damaging the fiber. Also, the injection angle (θ) must not be too large or too small compared to the numerical aperture of the fiber (typically $0.3 \text{ NA} < \theta < 0.8 \text{ NA}$).

B. Optical Splitters

FIGURE 2. First level optical splitter (1:21)

Two levels of optical splitters are used to distribute the light to each of the individual calorimeter modules. The "first level" splitter, shown in Fig. 2, is designed such that the input fiber projects light onto a bundle of 21 output fibers. The bundle of 5 m x 1 mm dia. plastic fibers is mounted inside a cavity made of UV reflecting Spectralon(3). The reflective cavity collects and diffuses the light leaving the input fiber, improving the efficiency and uniformity of the output fibers. The uniformity is strongly dependent on the cavity depth for short distances, but is limited by other factors, such as end preparation and polish of the fibers, for larger distances. For PHENIX, a cavity spacing of approximately 70 mm will be used, which gives an individual fiber efficiency of 2.8×10^{-3} , a uniformity with a sigma/mean of 5.3%, and a max./min. ratio of 1.25.

Eighteen outputs of the first level splitter are connected to second level splitters inside each of the supermodules (one is connected to a photodiode for monitoring and two are spares). The 1:21, second level 1:38 splitters, and other connecting fibers are the same Hoeschst-Celanese EN-52 jacketed plastic fiber. The design of the second splitter is similar to the first except that the input fiber is included within the bundle of output fibers and projects light onto the back surface of the Spectralon cavity. As shown in Fig. 4, this allows for a more compact design in which the splitter acts as a simple integrating cavity with good output fiber uniformity. Of the bundle of 38 0.6 m long output fibers, 36 go to the calorimeter modules within each supermodule, one goes to a reference PIN diode inside the supermodule, and one goes to an external PIN diode outside the supermodule. The performance of the second level splitter is similar to the first level splitter. The individual output fiber efficiency is $\sim 2.2 \times 10^{-3}$, and the uniformity has a sigma/mean ratio of 7.3% and a max./min. ratio of 1.32.

FIGURE 3. Second level optical splitter (1:38).

C. Calorimeter Modules

The output fibers of the second level splitter are connected to a "leaky fiber" which is inserted into a space along the central axis of each module and is designed to let light "leak" out in such a way as to simulate an electromagnetic shower penetrating into the module. This is accomplished by mechanically scribing a spiral scratch along a 38 cm x 2 mm dia. plastic fiber. Light escapes from the fiber and excites the plastic scintillator tiles in the 4 surrounding calorimeter stacks. The scribe pattern was tuned to give a depth profile which resembled an electromagnetic shower with an energy of 1 GeV. The pattern was determined experimentally by measuring the light output as a function of position along the fiber. Figure 4 shows a cutaway view of a calorimeter module showing the location of the leaky fiber along with the lead-scintillator stacks and readout wavelength shifting fibers.

FIGURE 4. Cut-away interior view of calorimeter module showing stack of scintillator and lead plates, wavelength shifting fiber readout, and leaky fiber inserted in central hole.

The efficiency for converting UV light injected into the module to visible light at the output bundle of wavelength shifting fibers was $\sim 7.6 \times 10^{-4}$. This efficiency includes the leaky fiber efficiency, the conversion efficiency from UV light to blue scintillation light inside the scintillator, and the conversion efficiency of the scintillation light into green light in the wavelength shifting fibers. The overall efficiency to convert the laser light to photoelectrons in a module is of order 4.2×10^{-12} . Given that the calorimeter has an intrinsic light output of ~ 1500 photoelectrons per GeV, ~ 0.2 mJ per pulse from the YAG laser is required to deliver 1 GeV of equivalent energy to each module. Linearity studies and calibration of the calorimeter for high energy polarized proton running at RHIC can require up to 80 GeV per module, or 16 mJ per pulse from the laser.

III. MONITORING PHOTODIODES

Since the energy of the laser varies from pulse to pulse with an rms. variation of $\sim 4\%$, and the average energy can change over periods of hours by more than 10%, it is necessary to measure the pulse-by-pulse light output of the laser with a stable reference device. The biplanar phototube (Hamamatsu R1328U-02) is a highly linear vacuum photodiode with a high current photocathode. As shown in Figure 1, it is positioned at the end of the set of six primary beam splitter mirrors and serves as the primary reference monitor of the beam intensity.

PIN photodiodes (Hamamatsu S-1223-01) are used to monitor the light intensity after each level of splitting. One diode is used to measure the output of each of the 1:21 splitters for each sector. One output of each 1:38 splitter goes to an internal PIN photodiode located underneath the front cover of the supermodule and is used as the reference for that supermodule. A second 1:38 splitter output is connected to an external photodiode located on the interior wall of the sector. This diode is an accessible secondary reference for the supermodule.

The PIN diodes are read out using a high speed voltage amplifier (Elantec 2075). Each diode readout circuit also contains a stable current-mirror source which is switched by an external ECL trigger to deliver a calibration pulse to the voltage amplifier. This calibration pulse is used to monitor the stability of the amplifier and to conveniently test the rest of the readout chain.

IV. ENERGY CALIBRATION AND GAIN MONITORING

The laser calibration and gain monitoring system has been used extensively to study several prototype calorimeter modules in beam tests at the Brookhaven AGS, and is presently being used to establish the initial phototube gain settings for calorimeter modules in preparation for operation at RHIC. Every supermodule is equipped with the same set of 144 phototubes to measure each tower's light output using cosmic ray muons. This is done at a fixed gain setting for each tube, and the same setting is used for each supermodule. At the same time, a spectrum of laser events is collected for each tower and for the internal reference photodiode. The ratio of the signal from the

module towers to the signal from the photodiode is independent of the intensity of the light from the laser and serves as the reference to re-establish the same phototube response (given by the product of gain times quantum efficiency) for the final set of phototubes which are eventually installed in the supermodule. The final tubes are selected from a set of pre-measured tubes and are installed in the supermodule in three groups of 48 tubes with similar gains. This grouping is necessary because only three high voltage settings are available for each supermodule, so all 48 tubes within a given group operate at the same high voltage. Therefore, when the final tubes are installed, there is a large dispersion in the actual response of each tower to the original muon calibration. When the response is renormalized to the original reference response using the laser, as shown in Fig. 5a., the dispersion is reduced to only 2.3%. This residual dispersion is due mainly to the variation in the quantum efficiencies of the phototubes, but is more than a factor of two better than the design goal of 5% in predetermining the initial energy calibration of the calorimeter for RHIC operation.

To determine the ability of the calibration system to monitor and correct for phototube gain variations, the change in muon response over time of a supermodule was measured. The module was calibrated using cosmic ray muons with the standard set of phototubes used for precalibrating all supermodules. The tubes were left on at their nominal operating voltage. Periodic measurements were then made of the muon calibration and compared to the initial values. Figure 5b. shows, for all phototubes in the supermodule, the deviation from initial calibration over a period of one week. The figure includes uncorrected data and the same data renormalized using the laser calibration system. After renormalization, the gain drift variation is reduced to 0.9%.

FIGURE 5. Deviation from initial muon calibration of all channels of one supermodule; a) after installation of final phototubes, b) with no change in phototubes or phototube high voltage after one week. Shaded area is without renormalization using laser calibration and non-shaded histogram is with renormalization.

V. CONCLUSIONS

A precision calibration and monitoring system has been designed for the PHENIX lead-scintillator electromagnetic calorimeter. It is being used with cosmic ray muons to predetermine the initial energy calibration of the calorimeter to better than 5% and to monitor gain drifts to $\sim 1\%$. The system has been used to precalibrate more than half of the 108 modules which will be installed at RHIC. It has performed more than a factor of two better than the design goal and has demonstrated the ability to monitor gain drifts in the phototubes to the required precision. It is therefore expected that the final system will meet the necessary performance requirements for the PHENIX calorimeter. The final system should be available for commissioning and testing at least one year before the initial colliding beams at RHIC.

REFERENCES

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- 3 *Spectralon* is a product of Labsphere, P.O.Box 70, North Sutton, MA 03260.

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