POSITION MEASUREMENTS FOR HEAVY ION BEAMS USING A SODIUM IODIDE SCINTILLATOR

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ABSTRACT

A 50 cm diameter, 1.7 cm thick disc of NaI(Tℓ) scintillator has been mounted to permit edge viewing by four photomultipliers. Energetic heavy ions passing through the scintillator at different positions cause a variation in the division of light among the photomultipliers. We have achieved a performance close to the expected limit for 670 MeV/n neon. Calculations of expected response using an optical model agree well with the measurements.

1. Introduction

In recent years, progress has been made in using scintillators to determine the location at which a charged particle traverses them (Arens 1974; Rogers et al. 1974; Zych et al. 1979; and Arens et al. 1979). These position-measuring scintillators (which Arens et al. call "entopistic") utilize the principle that the scintillation light is gathered unequally by the photomultiplier viewing system, depending upon the position at which the light was generated. A fundamental limit of such systems is set by photoelectron statistical fluctuations within the individual photomultipliers viewing the scintillator. Even though this limit is theoretically only one or two millimeters for many of the systems which have been tested, systematic errors of various kinds have limited the actual performance of these systems to about one centimeter accuracy. In this paper, we describe a position-measuring scintillator for which these systematic errors have been reduced, and which has achieved a performance close to that expected for the system.

2. Apparatus

The basic scintillator is a disc of NaI(Tℓ) 50 cm in diameter and 1.73 cm thick. It was ground to a constant thickness within 50 microns and all of its surfaces were polished to a bright specular finish. Loss of light due to absorption or scattering at a perpendicular encounter with any surface was measured to be less than 5%. Figure 1 shows the mounting of the disc within a plexiglas lightpipe. The lightpipe edges (except at PM faces) were sanded and painted black. The plexiglas and scintillator discs were placed within a hermetic can whose interior was also painted black. The plexiglas had to be dried prior to assembly so that it would not degrade the polished NaI surface. The hermetic container allowed exterior mounting of the photomultipliers. The feedthrough windows were mounted on aluminum membranes which relieved potential thermal stresses due to the differing coefficients of expansion of aluminum and plastic.

3. Calibrations

To calibrate the position-measuring ability of this counter, multiwire proportional chambers were placed on either side of the disc. The counter was exposed to both sea-level muons and to 670 MeV/nucleon neon ions at the Berkeley Bevalac. Figure 2 shows the correlation for the neon particles between the position as measured by the proportional chambers, and the ratio of the responses of an opposite pair of photomultipliers. The beam was near the center of the counter for this portion of the data. The correlation between position and response is evident.

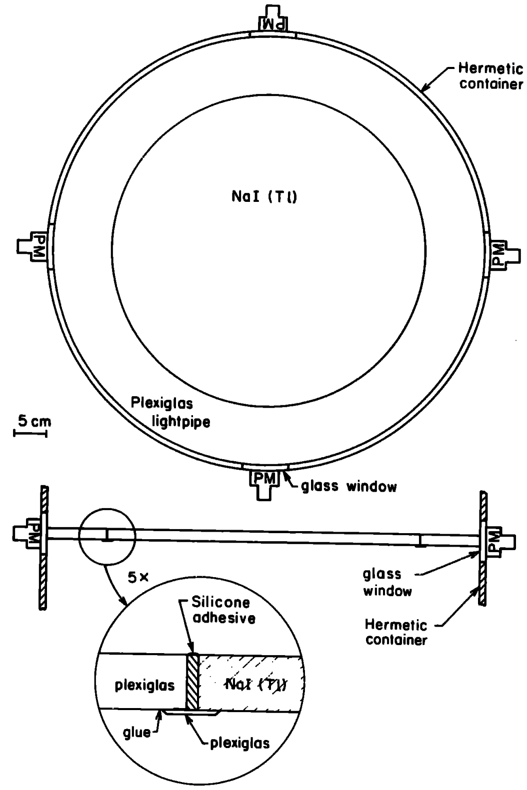
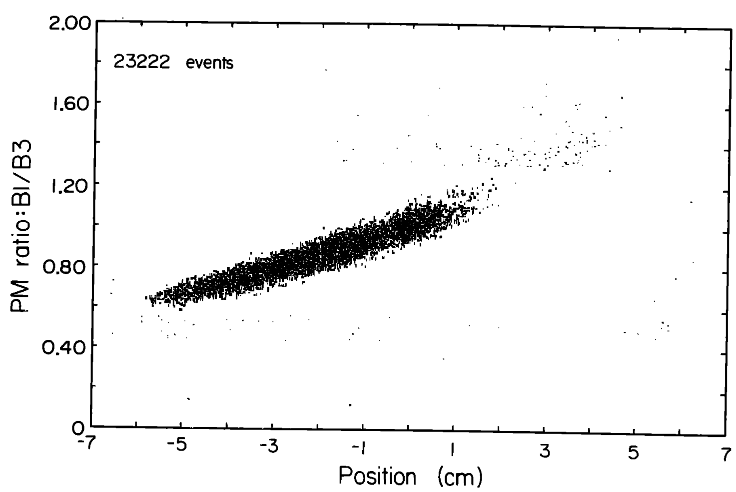


Figure 1. Schematic diagram showing mounting of the scintillator and the viewing system with four photomultipliers.

Figure 2. Ratio of PM response of two opposite PM's versus measured particle position near the center of the disc, for neon ions.



4. Optical Model

The expected response of such a system can be calculated by taking into account the transmission, reflection, and refraction of light within the NaI crystal, at the interface between NaI and the silicone layer, and at the interface between the silicone layer and the plexiglas. Such a calculation should also take account of scattered light due to small defects such as polishing compound residue in the NaI surface, but this degree of refinement has not yet been reached. Instead, the light loss within the scintillator is characterized by a "mean attenuation length" which is found to be about 70 cm. Figure 3 shows the match achieved between the model and the Bevalac data. On average, the match between model and data is good to about two percent, except in regions (about 10% of the area) where a given photomultiplier cannot see, due to the refraction between NaI and the silicone layer.

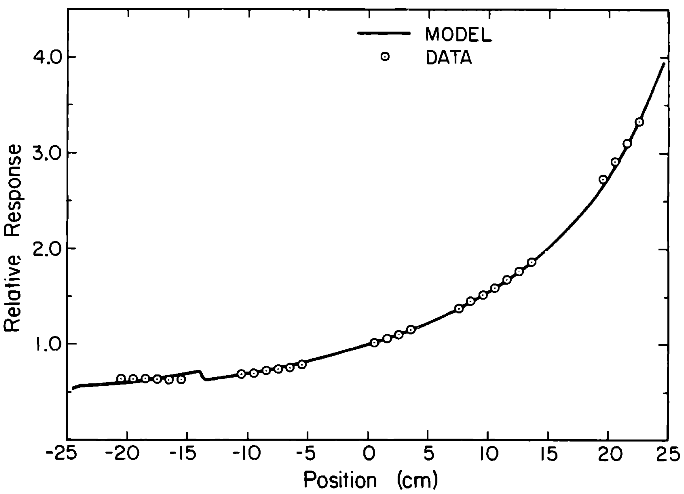


Figure 3. Relative response for a single photomultiplier as a function of position along a diameter of the disc. The phototube is placed at about +40 cm at the outside of the plexiglas lightpipe.

5. Results

Table I presents an analysis of the resulting uncertainty in position measurement due to various causes. The preamp noise and proportional chamber measurement error are not fundamental sources of error and will presumably not be relevant for an experiment with improved preamps. Figure 4 shows the distribution (presented in terms of the difference between the $\log_e$ of the observed PM ratio and the expected $\log_e$ from the optical model) of deviations for a section of data near the center of the counter. The expected performance nearly matches that observed. If the preamp and proportional chamber errors were removed, the resulting position resolution would be 3 mm or less. Scaling from the muons, 1.4 mm would be expected.

Table I -- Uncertainties Expected and Observed for Ratio B1/B3

Source of Error	Expected for 670 MeV/n Neon
Preamp noise	0.042 ± 0.002
Position	0.016 ± 0.002
Photoelectrons*	0.011 ± 0.001
Total Expected	0.046 ± 0.003
Observed	0.051 ± 0.003

* Deduced from the observed sea-level muon resolution, then scaled to neon by 1/ charge Z.

We are currently constructing a new system which employs six PM's instead of the four used for the instrument here. These provide a greater degree of redundancy and better performance in the regions where one or more photomultipliers cannot see due to the refraction. Hopefully we will be able to report on the performance of this new system, which should also have the preamp-noise problem cured, by the time of the conference.

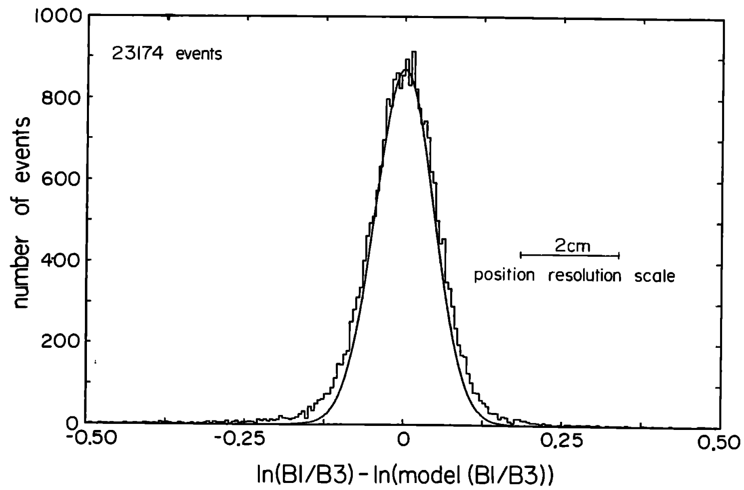


Figure 4. Deviation of response from that expected for particles near the center of the counter.

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