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Development of a honeycomb gas proportional counter array for photon multiplicity measurements in high multiplicity environment

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Abstract. A novel gas-based detector using large arrays of honeycomb cells has been developed and tested for use as a pre-shower photon multiplicity detector (PMD) for STAR and ALICE experiments. The appropriate cell design was arrived at using GARFIELD simulations. Prototype chambers with cell dimensions corresponding to STAR and ALICE were fabricated and tested at CERN PS and SPS. The charged particle detection efficiency and the pre-shower characteristics have been studied using pion and electron beams.

1. Introduction

A pre-shower photon multiplicity detector (PMD) has been designed to measure photon multiplicities in the forward region [1] of the STAR and ALICE experiments. Using these measurements on an event-by-event basis, the PMD will be able to study event shapes and fluctuations [2,3]. The PMD consists of a highly segmented detector placed behind a lead converter of suitable thickness. A photon produces an electromagnetic shower on passing through the converter. These shower particles produce signals in several cells of the sensitive volume of the detector. Charged hadrons usually affect only one cell and produce a signal resembling those of minimum ionizing particles (MIPs). Using a suitable photon–hadron discrimination procedure and the information from a charged particle veto placed in front, the photon multiplicity is obtained on an event-by-event basis.

2. Design considerations

The PMD will use gas as sensitive medium. The choice of detector technology for use in pre-shower applications is dictated by the following considerations: (a) signal from charged particles is confined preferably to one cell, (b) low energy δ-electrons should be prevented from traveling to nearby cells and causing cross-talk among adjacent channels, (c) the active volume of the detector should be thin and very close to the converter so that the transverse spread of the shower is minimized, (d) low-energy δ-electrons should be prevented from traveling to nearby cells, in order to minimize cross-talk among adjacent channels, (e) the technology should be amenable to modular design with a minimum of dead space at the boundaries and should not require a staggered layout and (f) the detector material (gas) should be insensitive to neutrons. In a hydrogenous medium, neutrons tend to produce large signals due to recoil protons, which can mimic a photon signal.

Keeping these issues in mind we have used a honeycomb cellular geometry for segmentation and field shaping, with each cell acting like a proportional counter. The honeycomb body made up of copper forms the common cathode and is kept at large negative potential. A gold-plated tungsten anode wire is kept at ground potential, which facilitates easy coupling with front-end electronics. The cells are thus physically isolated from each other by copper walls of suitable thickness to contain the δ-electrons. Optimum values of cell depth and copper wall thickness have been obtained from GEANT simulation [4] of pre-shower development in such a detector. Appropriate cell configuration has been arrived at by cell modeling and prototype tests.

3. Cell simulations

The cell simulations were carried out using MAXWELL [5] and GARFIELD [6] software packages. The detector cell is modeled in MAXWELL according to the parameters given in ref. [7]. The field maps for the entire cell were then generated by GARFIELD. The field configuration within the cell is studied with the help of drift line plots as shown in figure 1a. It shows that the electrons generated almost anywhere inside the volume reach the anode. Only for a small portion (less than about 10% of the entire volume) of the region on either ends, some electrons still escape the drift medium and hit the lids, as shown by dashed lines.

4. Prototype test results

Prototype chambers (96 cells) with cell dimensions corresponding to STAR and ALICE (see table 1) were fabricated and tested at CERN PS and SPS. The response of the detector to charged particles was studied using pion and elctron beams of various energies. For the pre-shower mode of operation, a lead converter of suitable thickness was kept just in front of the honeycomb chamber. The readout of the prototype chamber was carried out using GASSIPLEX electronics [8] and a C-RAMS based data acquisition setup. Three sets of cathode strip chambers was used for tracking the beam particle and efficiency calculations.

Typical pulse height spectra for the prototype detector for operating voltage of -1520 V is shown in figure 1b along with a fit to a Landau distribution. The gas used was a mixture of Ar and CO_2 (in the ratio 70 : 30 by weight). The mean value of the pulse height spectra is taken as the measure of the average energy deposited by the charged particle. The average

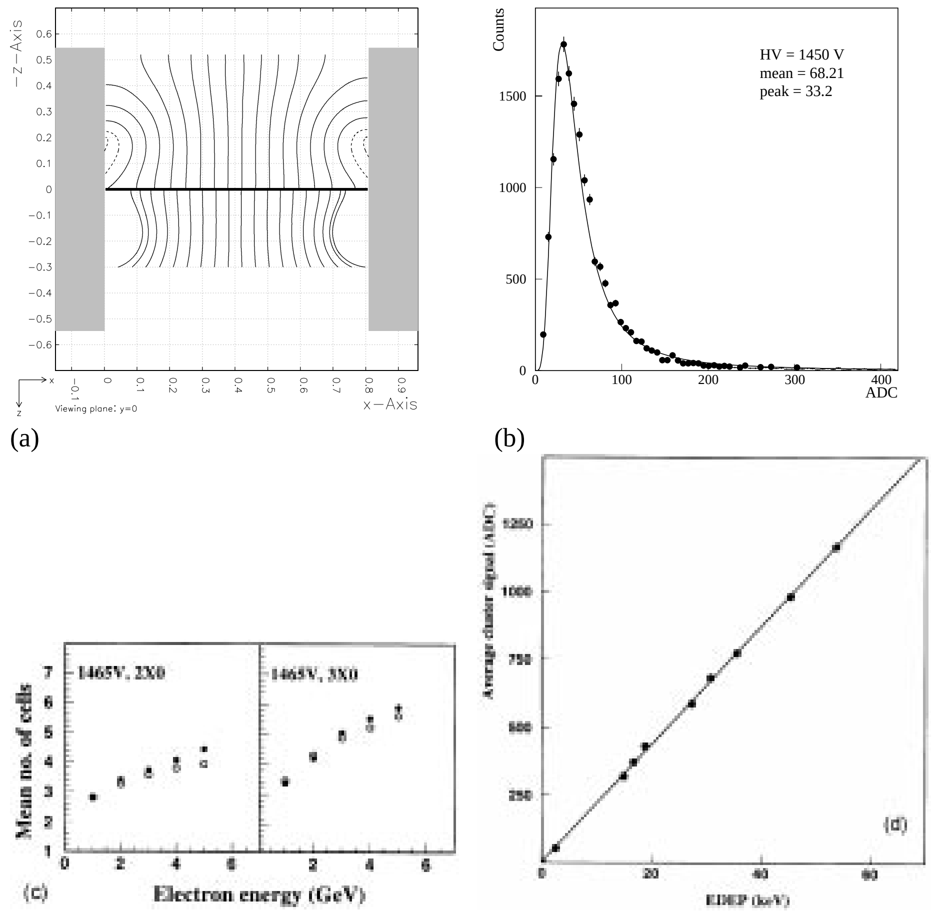

Figure 1. (**a**) Electron drift lines inside the cell volume in *xz*-plane for an extended cathode cell. The thick line in the center represents anode wire. Dashed lines represent drift lines escaping the drift medium and falling on the body of the cell. (**b**) A typical pulse height spectrum from a 7 GeV pion. (**c**) Average transverse shower spread as a function of various electron beam energies. Results are for two operating voltages and two converter thicknesses. (**d**) Average ADC vs. energy deposition for various combinations of electron energy and converter thicknesses in a pre-shower.

cluster size (number of cells fired) is close to unity, suggesting that the energy deposition is essentially confined to one cell. This satisfies one of the basic design criteria of our detector.

The pre-shower characteristics were studied for the prototype detector using electron beams in the energy range of 1–6 GeV at two different operating voltages using $2X_0$ and $3X_0$ converter thicknesses. The electron beam passing through the lead converter produces an electromagnetic shower and thus affects several cells in the detector. The average

Table 1. PMD parameters.

Parameters	STAR	ALICE
Cell size	10.15 mm	4.7 mm
Cell area (active)	0.9 cm^2	0.19 cm^2
Cell depth	8 mm	5 mm
Total no. of cells	82,944	276,480
Total active area of the detector	7.46 m^2	5.25 m^2
η-coverage	2.3–3.9	2.3–3.5
Distance from interaction point	5.5 m	3.5 m

number of cells affected gives us an estimate of the transverse shower size. Figure 1c shows the transverse shower spread as a function of various electron beam energies. Comparing the results with the single particle GEANT simulation (open circles) for electrons, it was found that the average pre-shower cluster size is very close to that obtained in simulation.

Total energy deposition in a pre-shower is represented by the sum of signals (ADC contents) of all the affected cells in a cluster. The mean pulse height in ADC units as obtained from data is plotted against the mean energy deposition values in keV from the simulation spectra for different electron energies and converter thicknesses. Figure 1d shows the calibration relation for an operating voltage of -1465 V. The response of the detector and readout is seen to be fairly linear in the range of energy studied.

5. Summary

The design, simulation and the test data of a gas-based honeycomb proportional counter for photon multiplicity measurements in the STAR and ALICE experiment has been discussed. The design is based on a copper honeycomb matrix as cathode and anode wires placed at the center of each cell. The detector is operated using Ar–CO_2 gas mixture with the cathode at a high negative potential, and the anode wire at ground potential. The design has been optimized by GARFIELD simulations and by prototype studies using high energy pion and electron beams. The test beam results indicate that the charged particle signal is confined mostly to one cell. Under an optimized condition of gas mixture and operating voltage, the average charged particle detection efficiency was found to be $\sim$98%. The pre-shower data show that the transverse shower size is in close agreement with single particle GEANT simulations for a range of converter thicknesses and electron energies. Average pulse height of the pre-shower follows a linear relation with energy deposition for a wide range.

Acknowledgements

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