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A STUDY OF ELECTROMAGNETIC SHOWERS IN THE HIGH DENSITY PROJECTION CHAMBER

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Abstract

A prototype module of a High density Projection Chamber (HPC) has been tested in an electron beam. The HPC, with the shower conversion separated from the charge collection, offers a simple, homogeneous large volume detector with an energy resolution of $12.5\%/\sqrt{E}$ and an exceptionally fine granularity both along and transverse to the shower axis. The results from the test are presented together with a description of the calorimeter system.

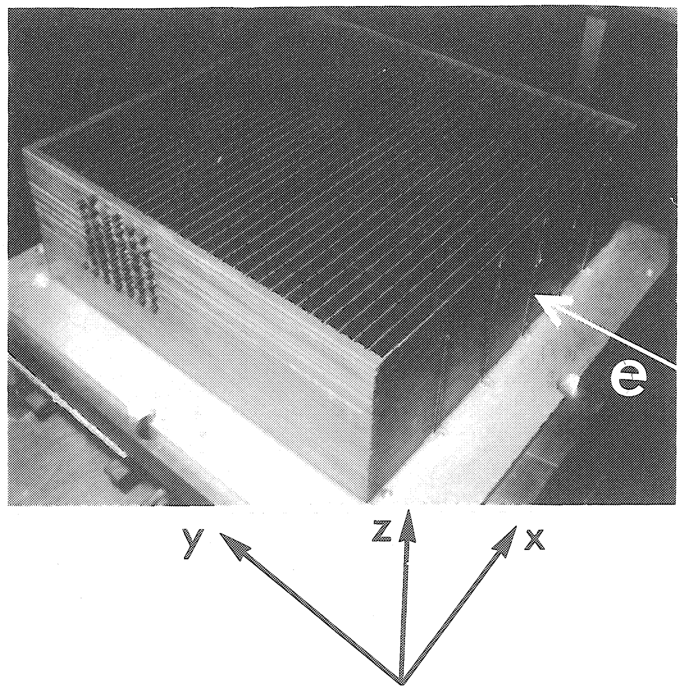
1. Introduction

The High Density Projection Chamber is shown in fig. 1. Construction methods and early tests of the HPC have been published [1-2]. The calorimeter forms mechanically a self stable structure, and has in addition the following main advantages as compared to other calorimeters.

- It separates the converter region from the detection region by drifting the ionization through the sampling channels to a multiwire proportional chamber with cathode pad read-out.
- It leads to a fine granularity reconstruction of the shower limited in resolution by the drift channel width in the longitudinal (y) direction, by the cathode pad size in the x direction and the sampling frequency for the measurement of the drift time in the z direction.
- For equal granularity the number of electronic read-out channels is reduced by an order of magnitude with respect to other calorimeters.

These features make the HPC very well suited for example as electromagnetic calorimeter for future large experiments which will require fine granularity for separating showers from other particles in the narrow jets expected, and for the separation of pions from electrons, i.e. electromagnetic from hadronic showers. As such calorimeters will be required to cover a large solid angle a very high number of read-out channels will be needed.

In the following we shall describe an HPC module with lead converter and results obtained with it in an electron test beam at DESY, Hamburg, and in a muon beam at CERN, Geneva. We shall first describe the module itself (the lead stack) and the electronics of the read-out system. Then, after a short outline of the test conditons, we shall discuss the data reduction and the results.



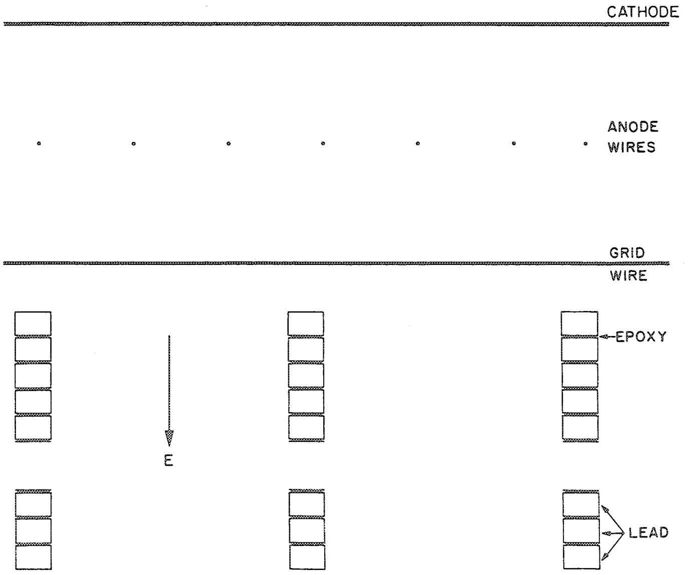


Fig. 1 (a) The High density Projection Chamber test module before addition of the multiwire proportional chamber. The external dimensions are 14cm*36cm*38cm, lead walls 1.5 mm thick and gas slots 10 mm wide and (b) cut through three of the laminated lead walls, showing also the grid wires and the proportional chamber.

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2. The HPC lead stack

The present High Density Projection Chamber is characterized by the following features (fig. 1).

The 1.5 mm wide lead converter walls are made from 1 mm thick lead strips which are parts of a grid structure, insulated from each other by an epoxy which also acts as a bonding agent. The lamination gives added strength to the converter. The mechanical stability of this system is now being studied, using a module which can simulate a large cylindrical calorimeter. The initial measurements are reassuring.

The 10 mm wide gas sampling channels (slots) between the lead walls act as drift channels where the shower ionization is drifted by an electric field created by connecting the consecutive lead plates to a voltage divider.

The drift field created by such a structure has been calculated and is shown in fig. 2. With the insulating layers retracted o.1 mm from the lead edge we eliminate the disturbing charging up effects seen in other devices. The distortion of the field due to the laminations lead to some losses of electrons drifting near the walls. With the ratio between lead plate thickness and slot width less than 1/8 the loss is negligible.

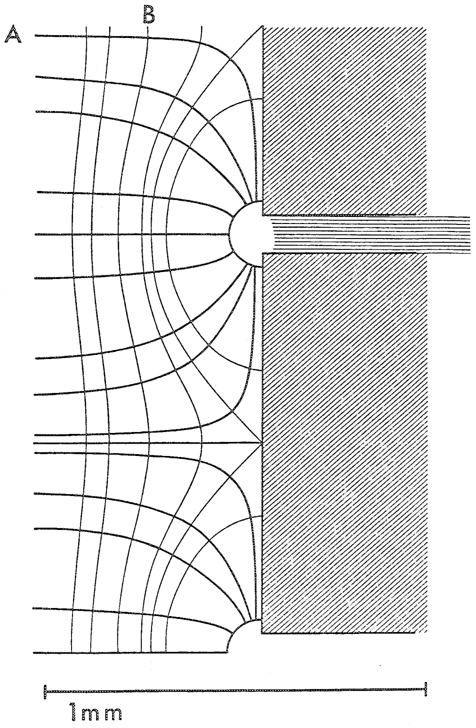

Fig. 2 Detail of the electrical equipotential lines (A) and field lines (B) near the walls of the drift slots.

The detection of the drifted charge takes place at the end of the drift channels with a multiwire proportional chamber with 20 μm anode wires spaced by 4 mm. The anode wires are separated from the drift channel by a grounded grid of 100 μm wires 1 mm apart, giving full transmission of the charge [2].

Cathode pad read-out will be tested with a new lead stack in the near future. The present stack has 31 gas slots, representing 8.3 radiation lengths of lead. Its total dimensions are shown in fig. 1.

For the tests we used a gas mixture of 80% Ar and 20% CO_2. The properties of the transverse diffusion of the drifting electrons in such a system had been studied earlier [1-2], including the effect of a magnetic field on the amount of charge collected [3].

3. Electronics

The high voltage of the proportional chamber was chosen to give a gas multiplication of the order of 1000. With ∿ 120 electrons produced by a minimum ionizing particle traversing the slot perpendicularly this results in a minimum charge pulse per slot in the range of 20 fC.

After preamplification the pulse shape is characterized by a few nanoseconds rise time followed by an exponential fall off with a time constant of 0.56 μs. The preamplifiers are linear with a noise level standard deviation equivalent to 4 fC when integrating over 1 μs.

The signal proceeds to the integrating unit (fig. 3) which consists of a fast switch alternatingly directing the signal to either of two integrating units. When one unit is integrating the other is being strobed into an analog to digital converter and reset to zero. The integration intervals could be chosen as 0.3 or 1.0 μs.

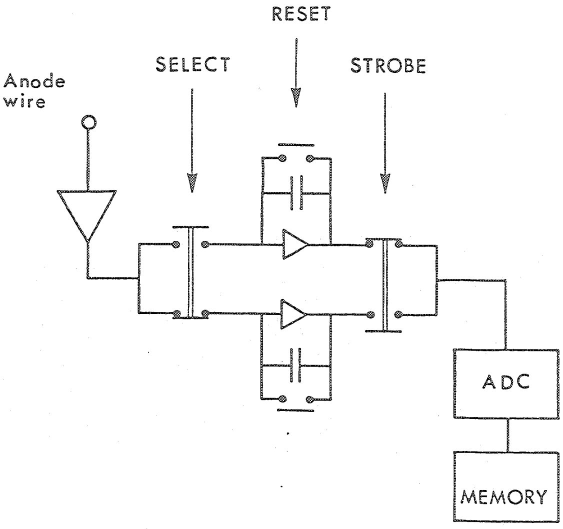

Fig. 3 Schematic diagram of the read-out electronics for the HPC multiwire proportional chamber.

The system had 12 preamplifiers and 12 integration time intervals resulting in 144 words per event. We refer to such a word as the signal or charge in a given cell. Each preamplifier thus accepts on the average the charge from a gas depth of about 26 mm, i.e. not covering a whole number of slots.

As has been mentioned above a new test module is being made and will be tested in the near future. The new stack will have the same lead wall/gas slot structure as the present, but it will be 16 radiation lengths long and will be furnished with a cathode pad read-out system. In addition there will be a new electronics chain with 200 ns integration time intervals and flash ADC's. This will enable a three dimensional shower reconstruction possibility, and higher accuracy in position determination in the drift direction.

4. The electron beam

From the DESY electron synchrotron we received an electron beam produced by converting a fraction of the electrons in the main beam to photons and reconverting photons produced in a narrow forward cone. The resulting electrons where guided through spectrometer magnets and collimators to the HPC. Beam energies between 0.5 and 4 GeV were easily obtainable.

The energy distribution of the beam showed a tail on the low side, but the main part of the intensity was within 4% for 4 GeV, widening to 7.5% for 0.5 GeV. With the collimators the beam intensity was kept at ∿ 10 per second arriving in bunches separated by 1 μs, with a duty cycle of 0.25. Over the 12 μs drift/readout period there was therefore a negligeable probability for double electron events.

5. Data reduction

The signal recorded in the wire chamber was used both for measurements of the amount of charge produced (energy measurement) and the drift time for reconstruction of the spatial distribution of the shower. We made a study of the drift velocity in the HPC configuration by measuring the drift time in the first slot when the electron beam was entering at different heights in the stack. The results are shown in fig. 4 together with measurements made by Piuz with the same gas mixture [4]. The two sets of velocities are seen to be in good agreement with each other. The shower tests were made with a drift voltage of 35 V/mm, corresponding to a drift velocity of 12.5 mm/μs.

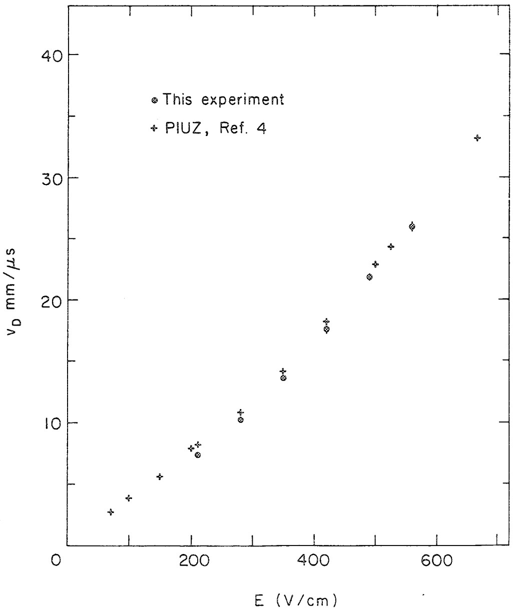

Fig. 4 Drift velocity in 80% Ar, 20% CO_2 mixture as function of drift voltage, measured in the HPC. Also plotted are the data of Piuz for the same gas mixture.

The final value of collected charge was obtained, after correcting for the pedestal, by dividing by the amplification factor. As an average one ADC count corresponded to 1 fC.

The different preamplifiers were accepting charge from different number of slots, ranging from 1.3 to 3.0 slots. The geometrically expected ratios between the number of slots connected to each preamplifier was compared to the respective charges recorded for muons traversing the stack. These values agreed within 7%, showing that the gas amplification was constant to within this uncertainty from slot to slot.

As a calibration of the position measurement accuracy with the HPC we recorded muons from a beam at CERN, penetrating the stack at right angles to the lead walls. The muons were also recorded by a wire chamber with 4 mm wire spacing placed in front of the stack. The muons traversed 1.6 m of heavy concrete before reaching the chamber.

After unfolding the pulse shape for each preamplifier signal a least squares fit to the recorded HPC track coordinates reproduced the wire chamber as shown in fig. 5 and gave an angular spread of the tracks in agreement with that of the trigger system.

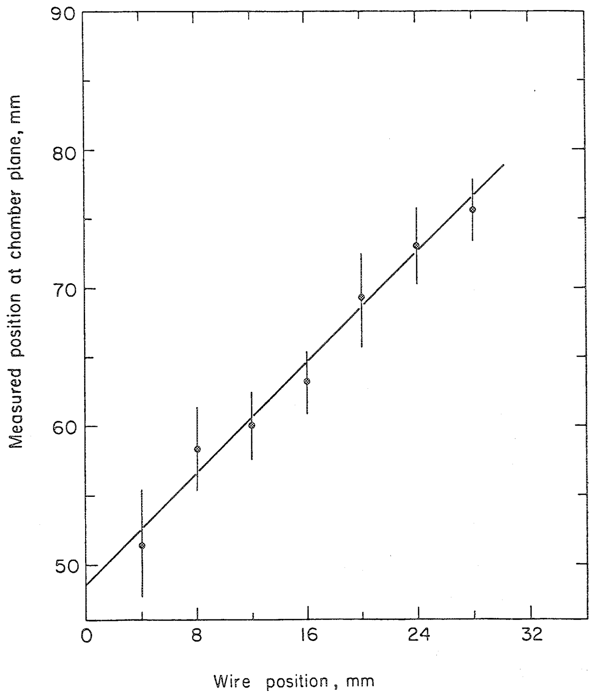

Fig. 5 Position measurement for muons entering the HPC through a multiwire proportional chamber. The positions were obtained by reconstructing the muon track in the HPC and projecting it back to the wire chamber plane.

This clearly demonstrates the capability for the HPC for reconstructing tracks, which will be of great importance when wanting to separate hadronic from electronic showers.

6. Energy resolution

In Fig. 6 we show a scatter plot indicating the mean charge distribution for 1000 1.0 GeV electron showers. Due to the limited length of the calorimeter, only 8.3 radiation lengths, the shower is not completely contained.

A comparison between the longitudinal development of the showers with that given by simulations using the EGS Monte-Carlo programme [5], shows that the HPC recorded shower extends further than the

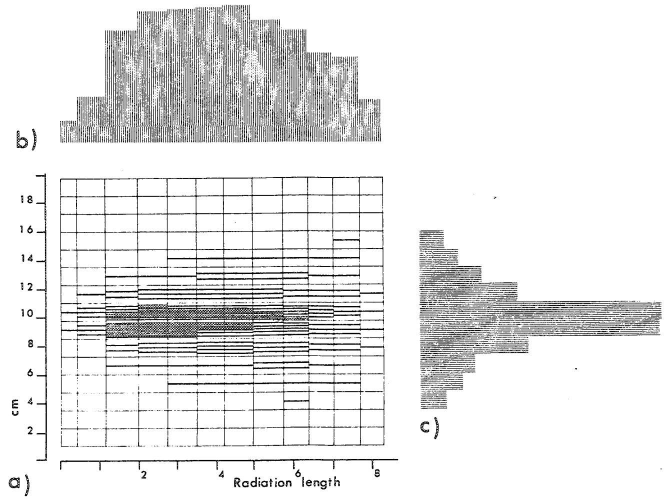

Fig. 6 (a) Scatter plot where the density of the lines indicates the charge deposit measured in the 144 cells of the HPC for 1 GeV electrons; (b) and (c) the projections of respectively the longitudinal and the transverse distribution of charge deposit (arbitrary scales).

simulated ones. An explanation for this may be the soft photons in this region, seen by the HPC, but omitted from the simulation. We have used a lower cut of 1.0 MeV for electrons and 0.1 MeV for photons in the EGS simulation.

When summing the charge for an event, cuts have been applied to reduce the fluctuations due to delta electrons, i.e. replacing a cell charge above a certain high limit by the mean charge for that cell. These cuts have been chosen after a study of their effect on the energy resolution and the linearity of the energy response. Fig. 7 shows the measured charge deposit as a function of electron energy. For comparison are included curves to indicate the expected respons for full containment and for a calorimeter of 8.3 radiation lengths. The latter is computed using the formula for shower development given by Aguilar-Benitez et al. [6].

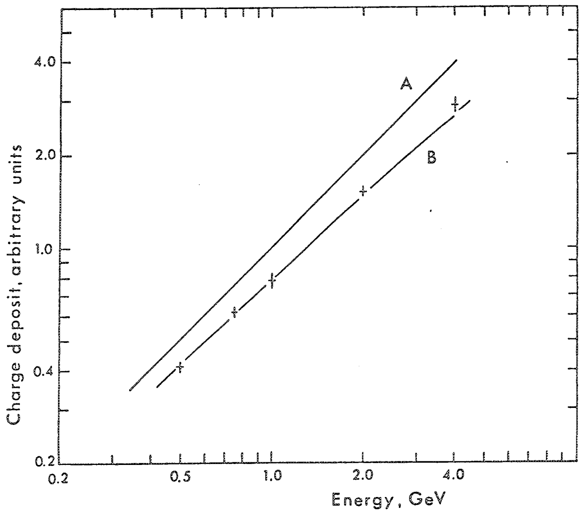

Fig. 7 Total charge deposit as function of electron energy. Line A refers to the expectation for full containment of the structure. Curve B is the calculated response curve for a calorimeter of length 8.3 X_0. The points are the experimental values normalized at 1 GeV.

The relative energy resolution, $\Delta E/E$ after corrections for noncontainment, is shown as a function of energy in fig. 8. The result can be given as $\Delta E/E = 12.5\%/\sqrt{E}$ and is applicable to calorimeters of this kind with a size sufficient to contain the full shower. Data with the HPC in a magnetic field will be taken in the near future.

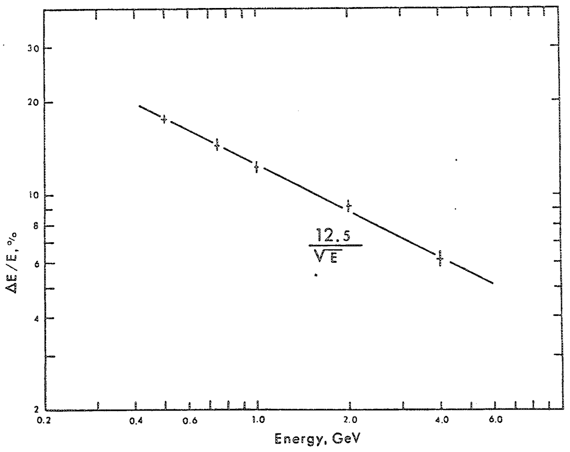

Fig. 8 The energy resolution $\Delta E/E$ as a function of the electron energy.

7. Conclusions

It has been shown that the High density Projection Chamber can be used as an electromagnetic calorimeter with a relative energy resolution of $12.5\%/\sqrt{E}$, with an excellent particle tracking capability. Its mechanical and electronic properties makes it very well suited as a calorimeter for experiments like those envisaged for the electron positron storage rings LEP.

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