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THE HPC MILESTONE PROTOTYPE

The DELPHI Collaboration

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1. INTRODUCTION

Early in 1983 we decided to adopt the High Density Projection Chamber (HPC) technique for our barrel electromagnetic calorimeter, because of its excellent granularity in the three space dimensions. At the end of the year the technique to provide the drift field shaping and the sampling material was chosen, amongst different options, to be the lead wires ribbon technique. The HPC Group planned in '84 the construction of two prototypes based on this technique.

The first prototype was built with a lead wire 1 mm thick, the same as used for the first feasibility tests, and has shown the capability of the lead wire technique to shape the required homogeneous electric drift field. The response of the 1 mm prototype to electrons and pions has been investigated with the DESY and CERN test beam facilities and compared both with theoretical expectations and with previous experimental results obtained with the early work on the first HPC prototype built in 1982 and called in the following the "Hamburg prototype".

The experience gained in the construction of this first prototype has been essential in the preparation for the production of the Milestone prototype.

The construction of the Milestone prototype, with a lead wire thickness of 1.7 mm to give the 0.5 X_o/sample, and with a drift length of more then 60 cm started in Spring '84.

The prototype is ready since December '84 to be tested in a beam with and without magnetic field as required by the LEPC.

Unfortunately no test beams have been available since January. For this reason the Milestone prototype has been extensively studied using cosmic ray muons and the preliminary results show that the response of the module to minimum ionizing particles agree quite well with the expected one. At the same time we have learned that cosmic rays provide an important tool for the calibration of all HPC modules.

Since the CERN beam and the large volume magnetic field, which is needed, will not be available before April '85 we have built a one-metre long drift channel with a geometry similar to that of the Milestone prototype to measure the attenuation length with different gas mixtures in a solenoid available to the Collaboration. The results of this measurement are in good agreement with expectation and provide direct information on the charge transmission along the drift channels of the Milestone prototype in magnetic field.

Moreover the behaviour of the trigger counters, to be inserted in the special gap of the HPC modules, has been investigated in the DESY electron beam test and in the CERN beams and compared with expectation.

Beam tests of the Milestone prototype in magnetic field will be performed next summer to fulfil all the requirements of the LEPC.

We will conclude at the end of this report that the correct response of the Milestone prototype to minimum ionizing particles, the observed value of the attenuation length in magnetic field, and the response in magnetic field of the small scale prototypes to electron and pion provide us with enough elements to be sure that the Milestone tests which are going on in DESY, without magnetic field, and can start in CERN with magnetic field only in May will be positive.

2. BEAM TEST RESULTS ON THE FIRST PROTOTYPES

2.1 Description of the Prototypes

The Hamburg prototype is described in detail in the paper NIM 225(1984). Here we shall recall briefly the main characteristics.

The module is 15 radiation length deep with 61 gas sampling channels, each 10 mm wide. The drifted charge was read by 48 cathode pads. The total drift length was 134 mm. The main part of the data was collected at the DESY Electron Synchrotron with a beam energy from 0.25 to 6 GeV. The module was placed inside a magnet which could go up to 1.4 T. The magnetic field was parallel to the electric field. The gas mixture was 80% Ar/20% CO_2 and the electric field was typically 220 V/cm.

The module was also tested at CERN in a high energy e, μ and π beam.

The "1 mm" prototype was the first HPC detector built using the lead wire ribbon technique. The lead wire ribbon contains two layers of 20 wires and it is supported by one steel plate on each side. There are 40 gas sampling slots 9 mm wide for a total radiation length of 10.5 X_o. The maximum drift length is 270 mm. The detector plane is a multiwire proportional chamber with cathode pads and a field decoupling grid. There are in total 252 pads, each covering an area of 33 x 33 mm^2. A picture of the assembled "1 mm" prototype is shown in fig. 1.

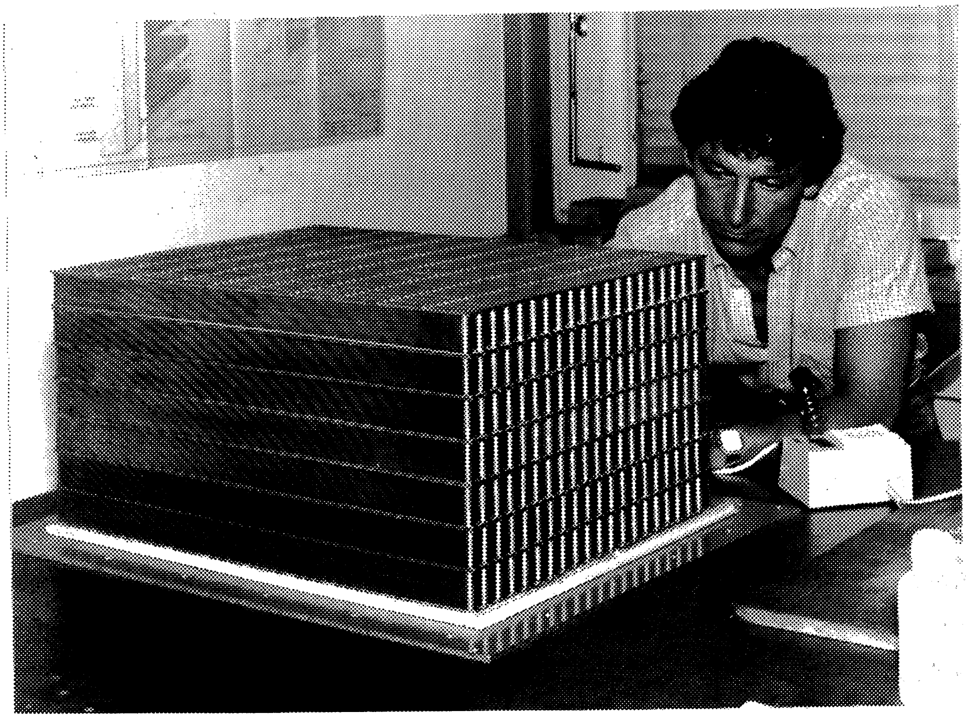


Fig. 1 - Assembled lead structure of the "1 mm" prototype.

This prototype was tested using two different electronic chains, a multiplexing integrator system and a CCD read out system. The pad layout used for the two electronics is shown in fig. 2.

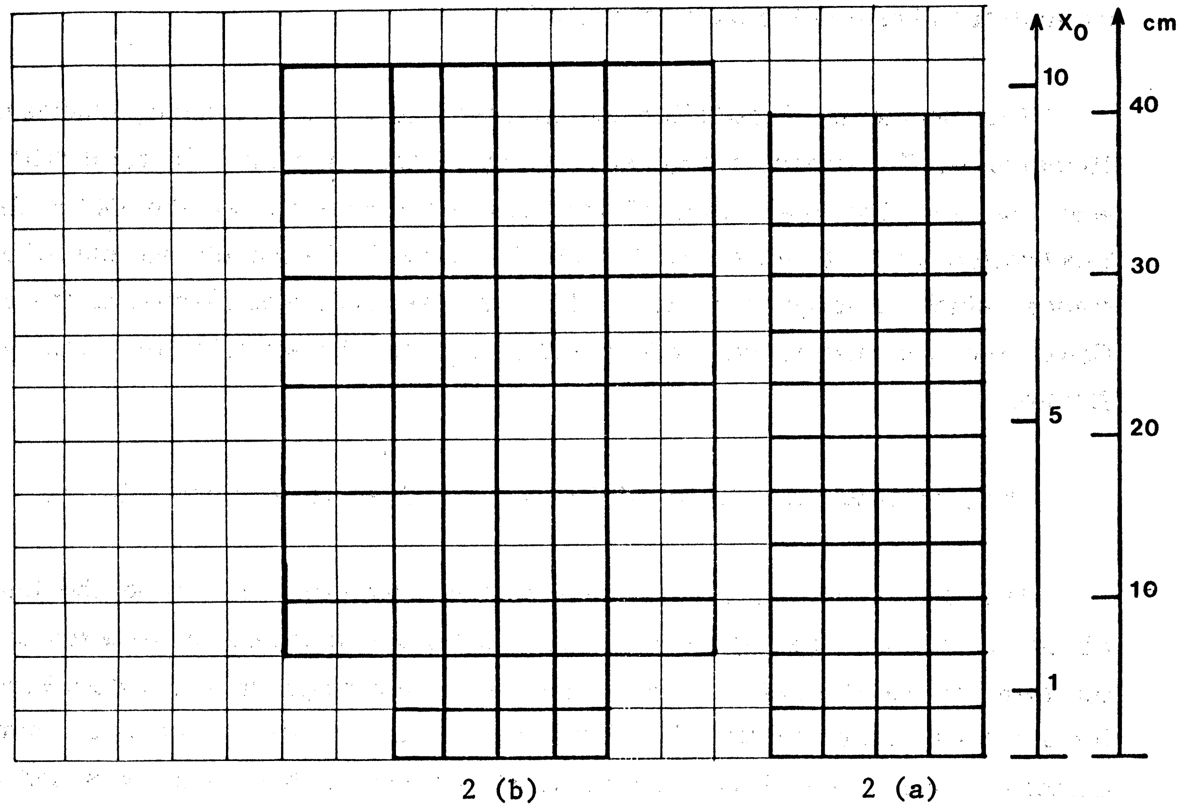


Fig. 2 - Pad layout for the "1 mm" prototype. The thick lines show the pad grouping used for the different tests, the pad dimension is 33 x 33 mm².

The construction and tests of the 1 mm prototype have allowed our group to gain considerable experience. Several technical problems were found and solved during the construction and first tests were successfully performed.

2.2 Space distribution of the shower development

This section is devoted to a presentation of the results on the energy density of the shower development as measured in the Hamburg and 1 mm HPC prototypes.

The intrinsic granularity of the detector allows a longitudinal (x) sample length as fine as $0.8\,X_o$ or $1.6\,X_o$ and the transverse dimension cell in the core of the shower is 33 mm for the y projection. The most accurate information on the transverse shape of the shower is given by measuring the coordinate along the drift direction (z) with a space resolution of ~ 1mm.

Most of the results on the space distribution refer to the 1 mm prototype. The data taken with the Hamburg prototype are presented to show the effect of the magnetic field on the space distribution and on the energy resolution.

Fig. 3 shows the x-y projection of a single event at 1 GeV. The pulse height has been integrated on the z (time) projection for each of the 48 pads in which the cathode plane is subdivided; the pad layout is shown in fig. 2(a). A much better resolution is achieved along the z direction by sampling the drift in time.

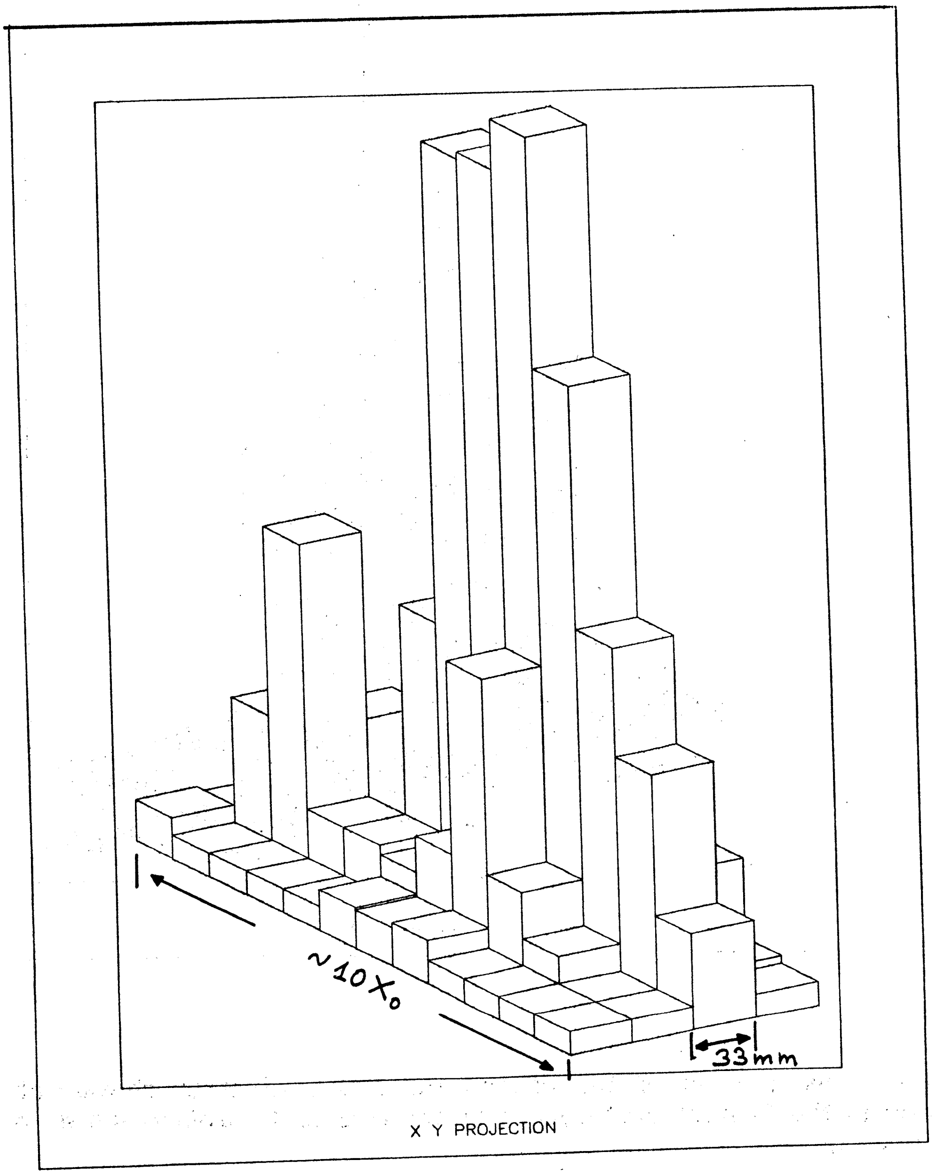


Fig. 3 - x-y projection of the e.m. shower for 1 GeV electron incident on the "1 mm" prototype.

The transverse shower profile distribution was determined along the drift direction (z) by measuring the charge deposited as a function of time.

The charge deposited on pads at the same depth in the detector is added together. An example of a shower produced by 1 GeV electron is shown in fig. 4.

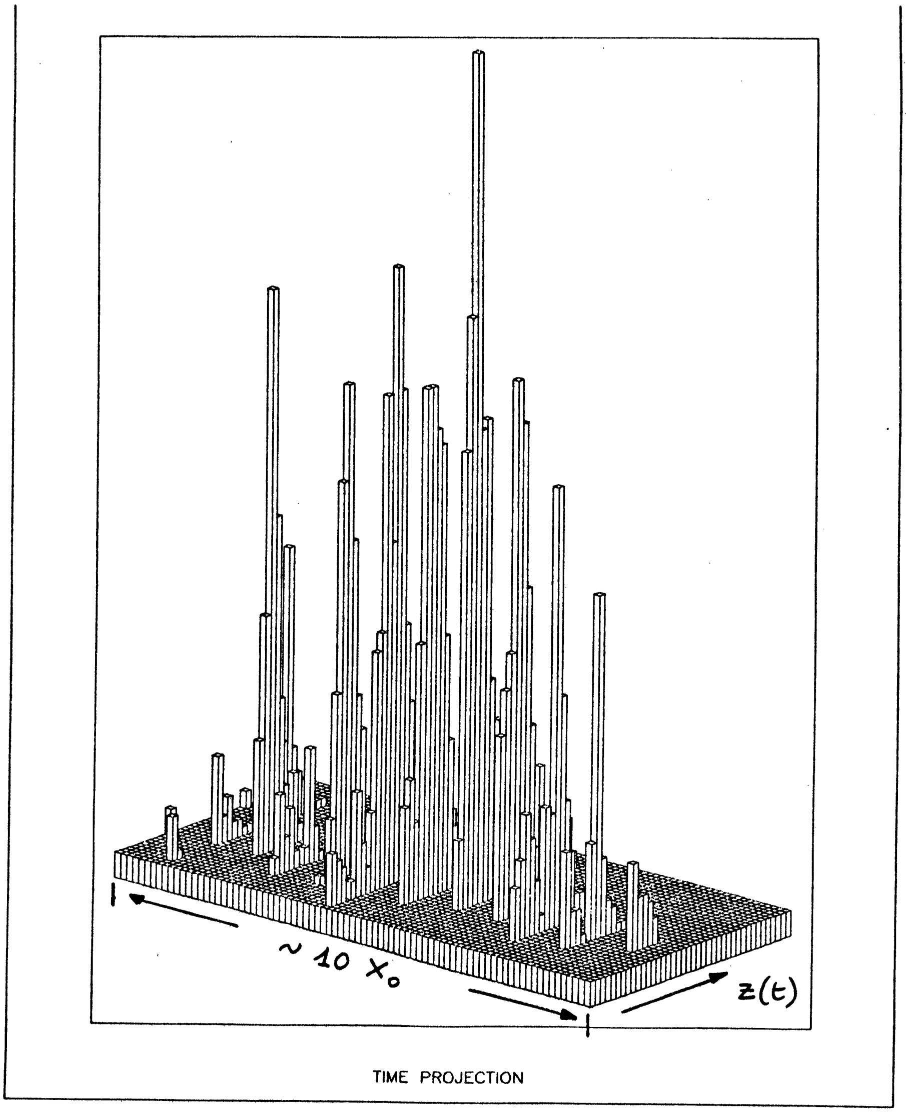
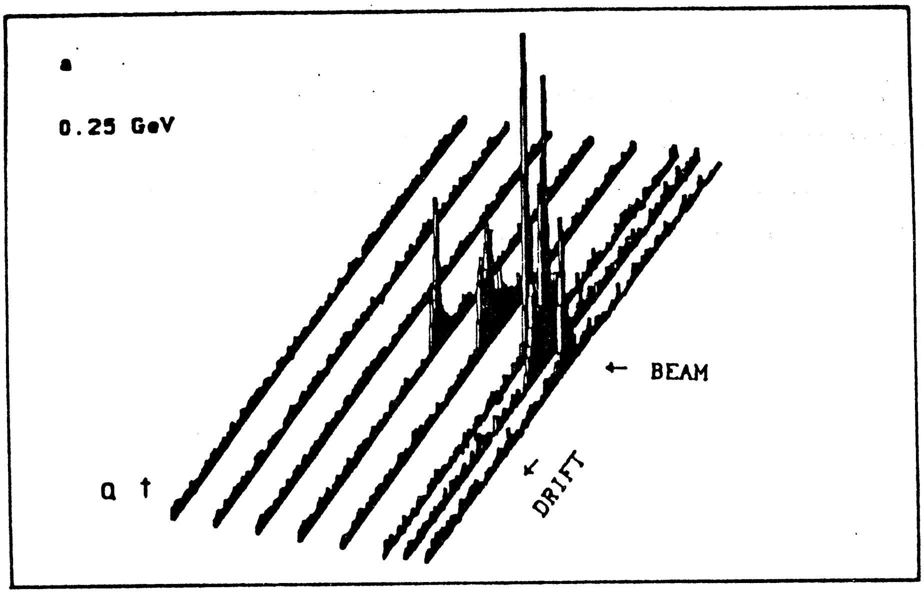
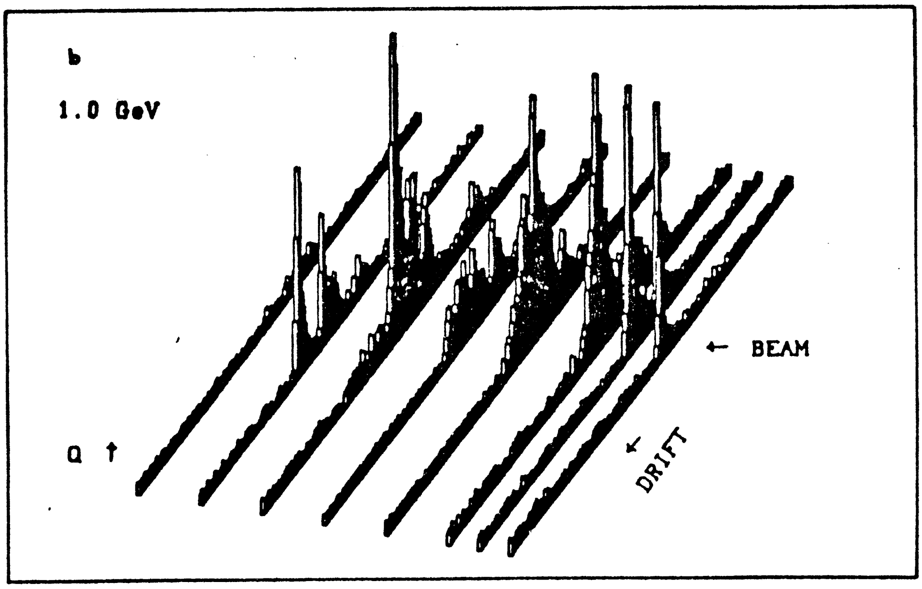


Fig. 4 - z distribution of the charge for 1 GeV electron shower at 12 x samples measured in the "1 mm" prototype with the pad configuration shown in fig. 2(a). The bin in z is 4 mm.

For this event the charge had been recorded via a multiplexing integration method. The same z distribution for three events with electron energies of 0.25 GeV, 1 GeV, 6 GeV are shown in fig. 5(a), (b), (c) respectively. The charge was sampled using the CCD method, and the pad layout of fig. 2(b).





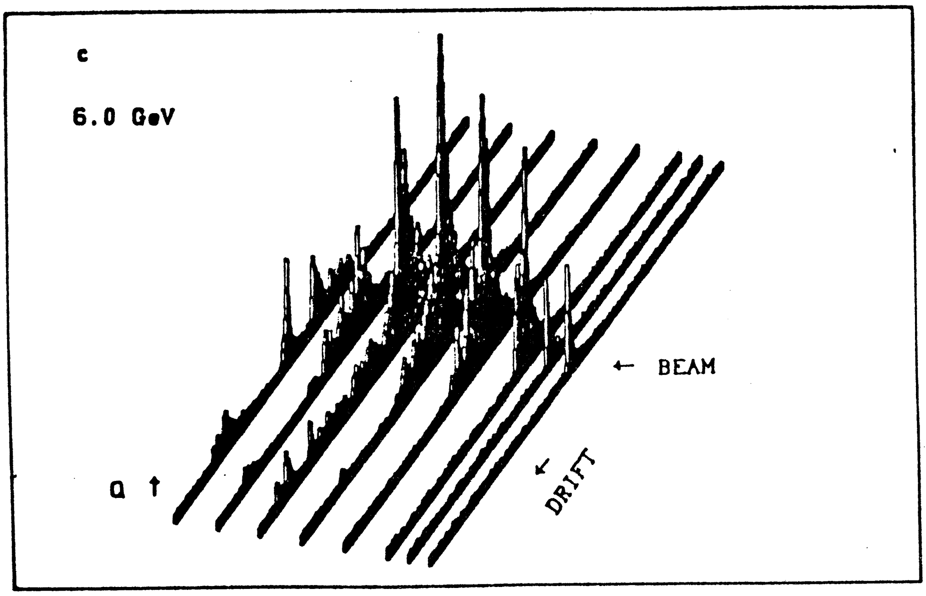
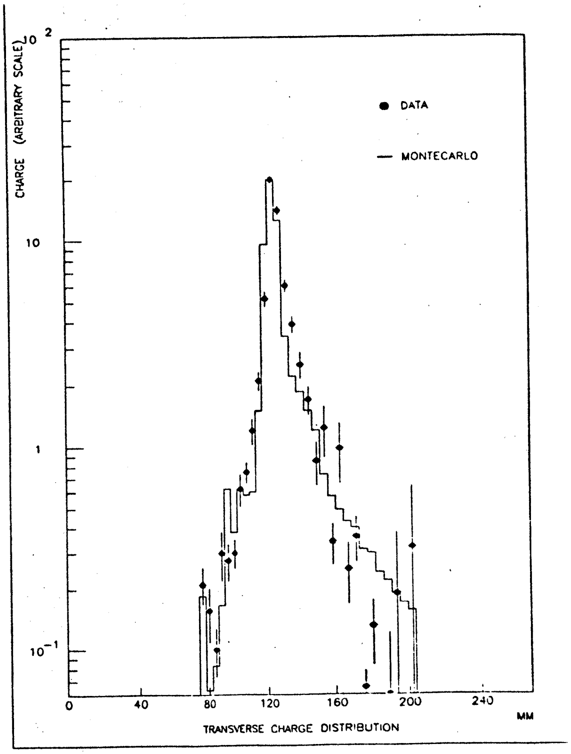
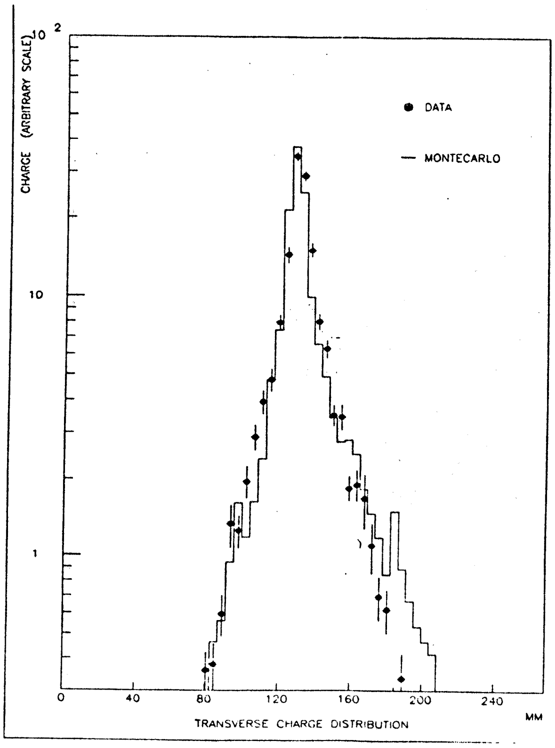


Fig. 5 - z distribution of the charge at 8 x samples for 0.25, 1.0, 6.0 GeV electron energy measured in the "1 mm" prototype. Data had been recorded with the pad layout as in fig. 2(b). The z bin is 1 mm.

Transverse (z) distributions for a large number of events are compared at three shower depths to the shower profile produced by Monte-Carlo calculations. Fig. 6(a), (b), (c) show the shower profile measured and predicted at an average depth of 0.78 X_o, 1.56 X_o and 3.9 X_o respectively.





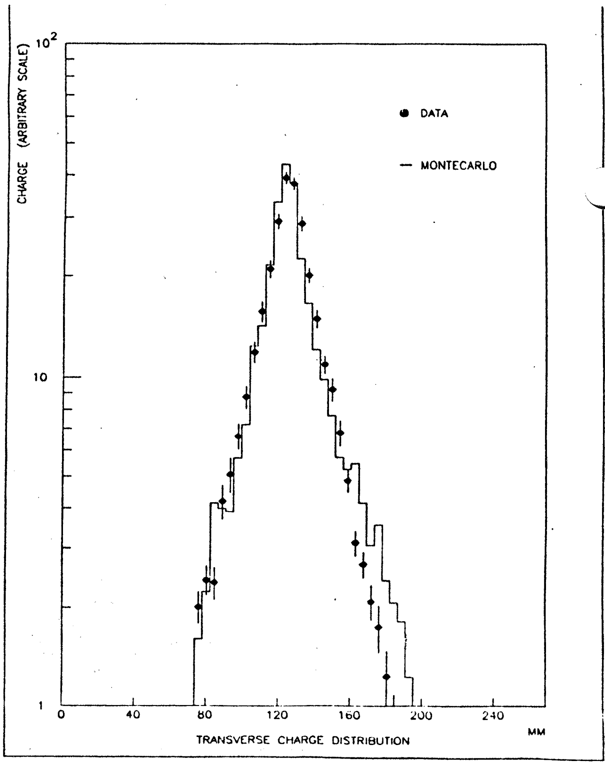


Fig. 6(a,b,c) - Transverse z charge distributions for 1 GeV electrons generated showers at 3 different longitudinal depths (0.78, 1.56, 3.9) X_o (a), (b), (c) for the "1 mm" prototype. The experimental data are compared with Monte-Carlo calculations (full line).

The electromagnetic showers were generated with the Monte-Carlo program EGS4 with an energy cut-off of 40 keV. The effects of the δ-rays, charge diffusion and charge amplification in the proportional chamber response were included. The pulse shaping of the electronics is also taken into account. This causes the visible asymmetry in the distribution of charge along the drift direction.

The excellent agreement between measured and simulated charge distributions indicates that the shower development and the charge collection in the HPC are well understood.

The effect of the magnetic field on the response of the HPC to the electrons has been studied with the Hamburg prototype. The magnetic field was of 1.2 T and parallel to the electric field as will be in the DELPHI experiment.

The transverse (z) distribution measured at 1.2 X_o with and without magnetic field are compared in fig. 7. It is clear that the transverse charge distribution is not changed by the presence of the magnetic field.

A broadening of the shower profile would indicate a spiralling of δ-rays around the direction of the magnetic field. The experimental results show that this phenomenon is not visible within the statistics.

The longitudinal development for a 1 GeV electron of showers is shown in fig. 8 and compared to the EGS4 calculation.

The total energy deposited in one single drift channel is also in good agreement with Monte-Carlo predictions (fig. 9).

Fig. 9 refers to 1 GeV data taken with the Hamburg prototype, in which it was possible to study the behaviour of the incoming electrons in the first drift slot. The tail at high charge depositions, which is caused by δ-electrons, is well reproduced in the Monte-Carlo simulation.

The energy resolution of the HPC improves when the detector is placed in a strong magnetic field as shown by the measurement presented in figs 10 and 11.

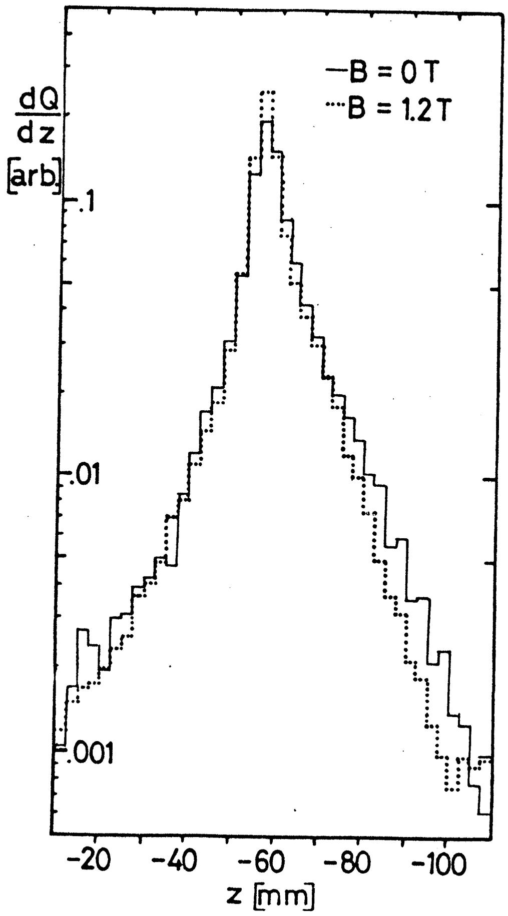


Fig. 7 - Comparison of transverse shower profiles for 1 GeV electrons with and without magnetic field (Hamburg prototype), at a depth of 1.2 X_o.

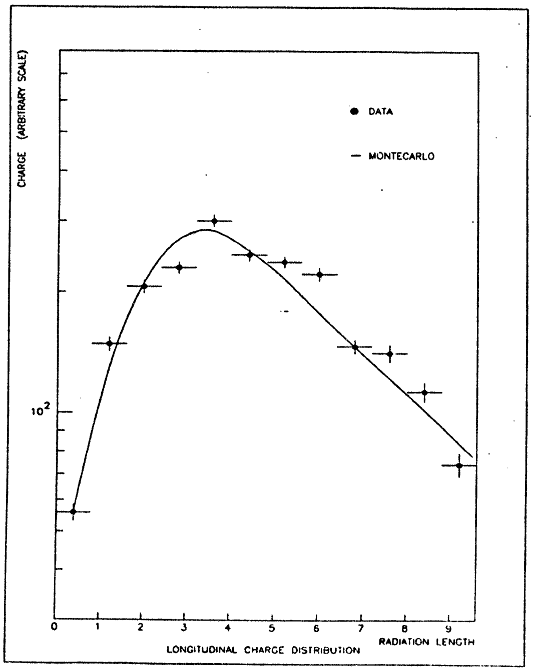


Fig. 8 - Comparison of the longitudinal profile of 1 GeV electron showers with Monte- Carlo (Hamburg prototype).

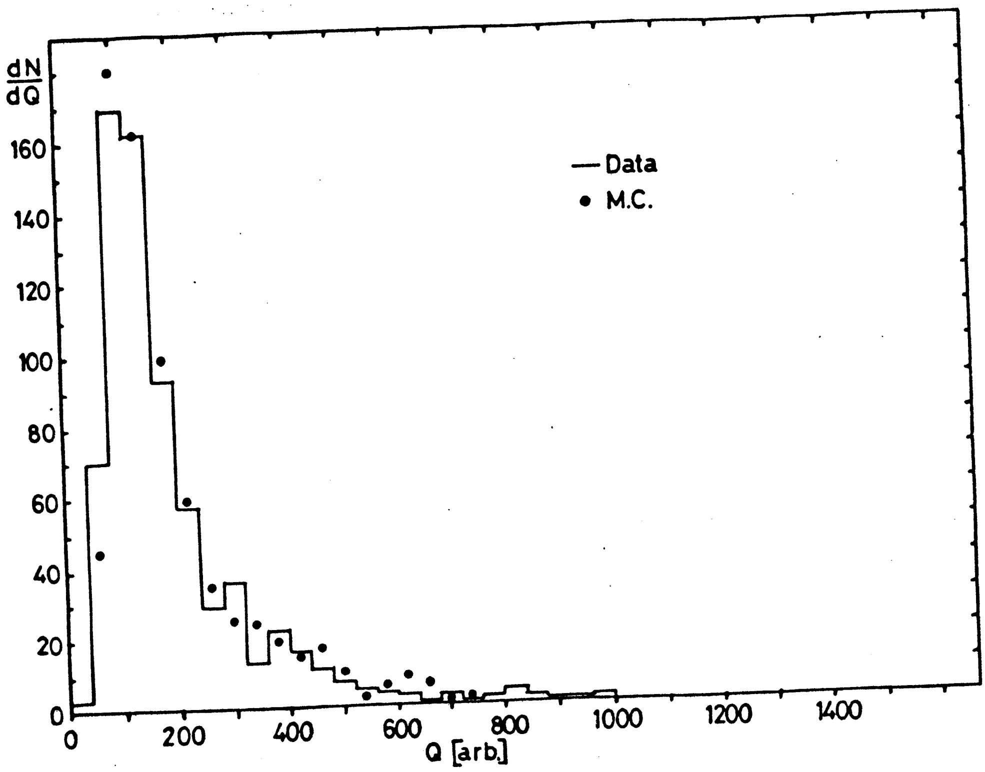


Fig. 9 - The energy deposited in the first drift channel by 1 GeV electrons (Hamburg prototype).

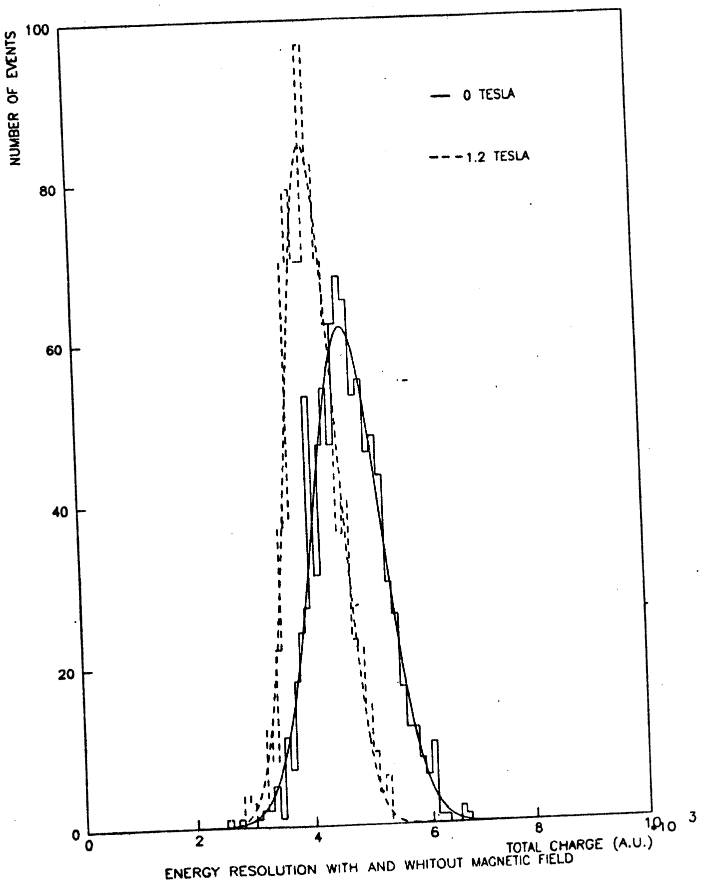


Fig. 10 - Total charge deposited in the HPC by 1 GeV electron with and without magnetic field parallel to the drift E field (Hamburg prototype).

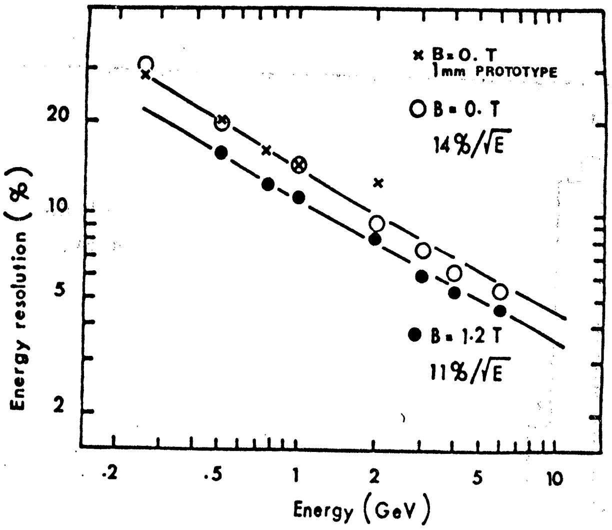


Fig. 11 - The energy resolution as a function of the electron energy with and without magnetic field.

The energy resolution of the Hamburg prototype is compatible with a parametrization of the form $\Delta E/E = 14\%/\sqrt{E}$ without magnetic field and decreases to $11\%/\sqrt{E}$ in a magnetic field of 1.2 T parallel to the electric drift field. Preliminary results on $\Delta E/E$ obtained with the "1 mm" prototype are also shown in fig. 11. The 1 mm data (crosses) shows at 2 GeV a deviation from the parametrization $14\%/\sqrt{E}$ since the shower energy is leaking at the end of the 10 X_o.

The angular resolution of the z projection is not affected by the presence of B as shown in fig. 12 where the data taken with the Hamburg prototype in an electron beam at DESY are compared with Monte-Carlo predictions.

The energy dependence of the projected angular resolution is parametrized by the formula $\sigma_\phi = 38/\sqrt{E}$ mrad.

2.3 π/E separation

Some tests with the "1 mm" prototype were performed with pions beams to measure the probability $P(\pi \rightarrow e)$ of misidentifying a pion as an electron in the HPC module.

The data were taken with the PS beam in the East Hall at CERN. The pion energy ranges between 1 and 5 GeV, but only at 3 and 5 GeV the beam is practically uncontaminated by electrons (a lead glass block of 10 radiation lengths was in front of the module and absorbed the electrons present in the beam).

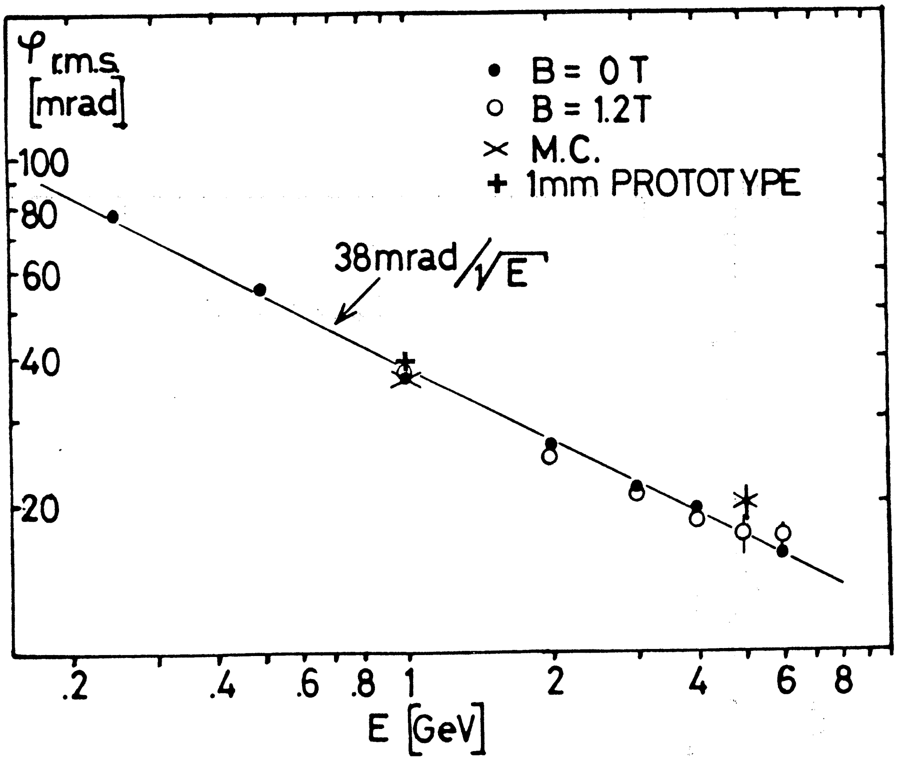


Fig. 12 - Angular resolution for reconstructed e.m. showers measured for different energies (Hamburg prototype 0,●), (1 mm prototype +), (Monte-Carlo, x).

Fig. 13 shows the total charge deposited from pions of 2 GeV.

The beam is composed by e/π = .40, and one can see clearly the electron component well separated from the peak of the minimum ionizing particles.

An attempt was made to find an algorithm capable to reject pions and, at the same time, to identify electrons with good efficiency. This was done by defining a procedure to check that the shape of the shower is consistent with the electron hypothesis. The algorithm to separate π's from e's uses the longitudinal segmentation of the HPC module, and is based on the observed longitudinal and transverval shape of the e.m. showers ("electron" data). It asks that the charge is deposited at each step (pad row) according to the longitudinal evolution and with the time structure expected from an e.m. shower. However, the available pion data have been taken in sligthly different conditions than the electron data (which were collected in DESY) and a comparison was only possible between pions and electrons of lower energy, where the data had been taken with pure pion beams. This decreases the pion rejection of the algorithm. The measured probability is (assuming 0 electron contamination in the beam) $P(\pi \rightarrow e) = (1 \div 0.2)\%$, between 2 and 5 GeV pion energy, and must be considered at this stage only an upper limit. The electron acceptance for this value of $P(\pi \rightarrow e)$ is ≃ 85%.

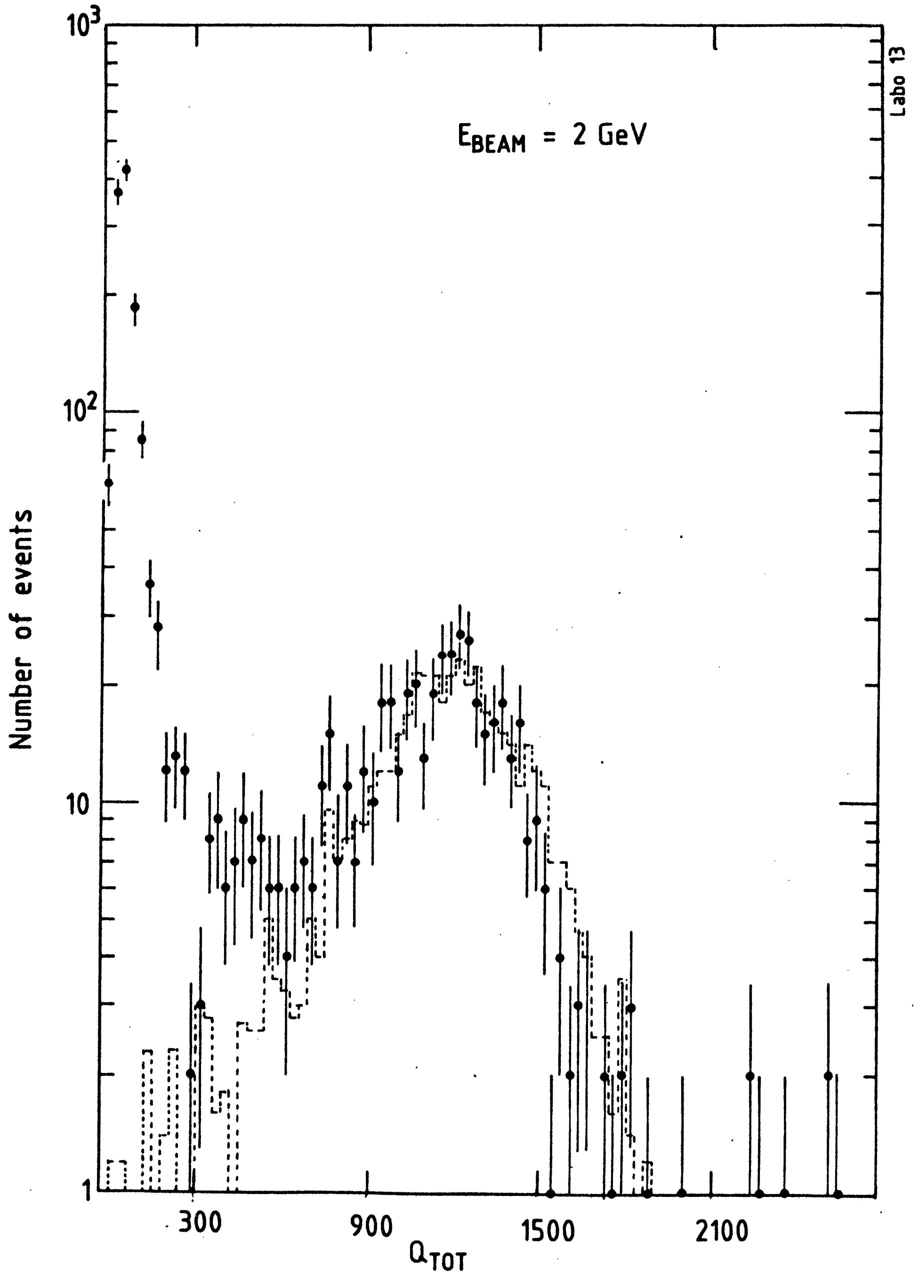


Fig. 13 - Total deposited charge from a beam composed by pions and electrons in the proportion of e/π = .40 (the dotted line shows data taken in a pure 2 GeV electron beam). The charged deposited Q_{TOT} is not corrected for impact position.

3. THE MILESTONE PROTOTYPE

3.1 Description of the Prototype

This prototype was designed as close as possible to the proposed final unit. It was built by assembling together 18 submodules. Each submodule is made by a ribbon of 20 lead wires of trapezoidal cross section, 1.7 mm thick and glued on the two sides of a glass fiber/epoxy substrate 0.1 mm thick. The trapezoidal shape of the lead wire and the interwire gap gives a lead filling factor of 80%. The ribbons are bent into an "accordion" like shape and then glued to two stainless steel plates (0.7 mm thick) which provide the necessary mechanical stability. The design of these plates had been optimized for maximum stability and minimum dead area. The submodules have a trapezoidal cross section as shown in fig. 14: the bases of the trapezoid are 65 and 53 cm long and the sides make an angle of 15°.

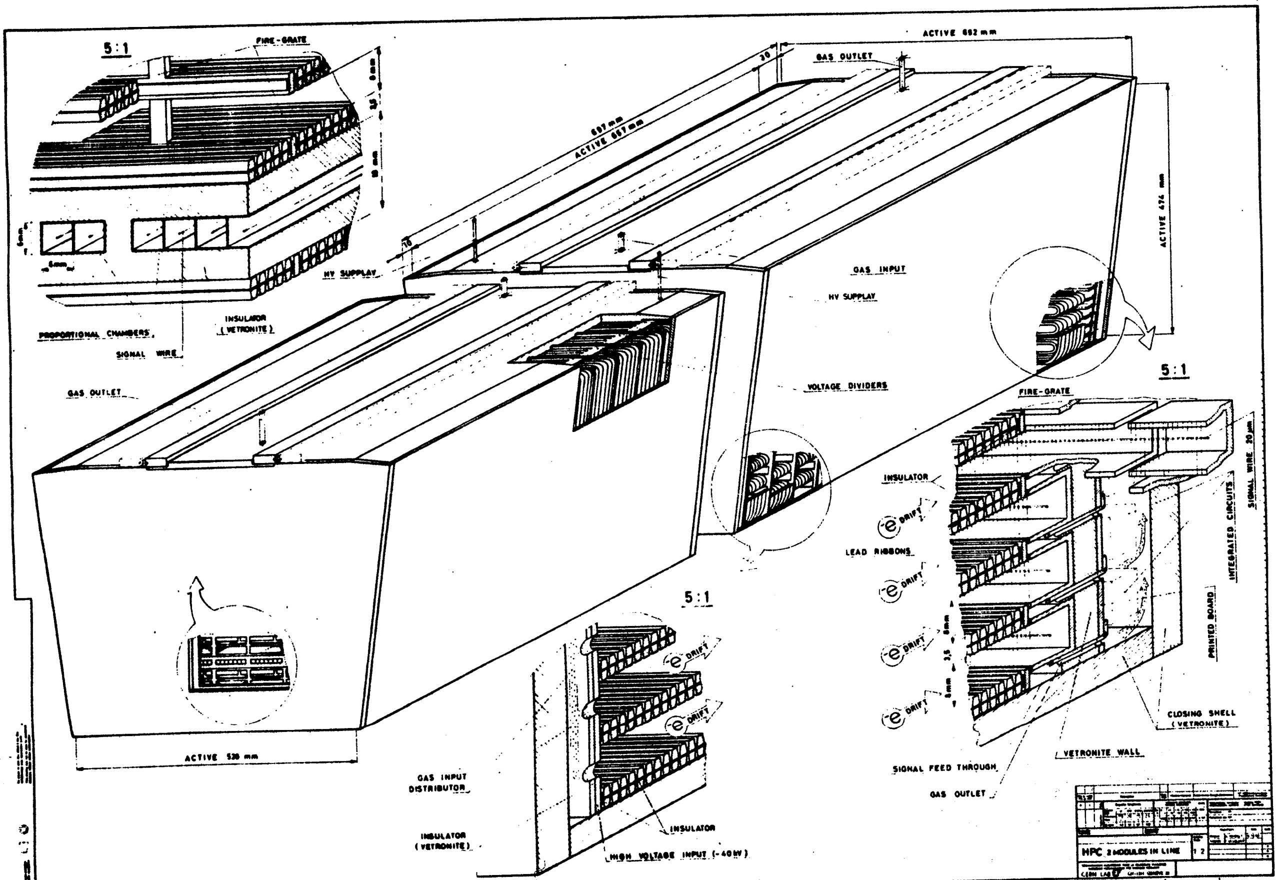


Fig. 14 - Design of an HPC module.

18 submodules are assembled to form the module, resulting in a drift channel length of 660 mm. The total radiation length for the 18 submodules is 19 X_o. The accordions have 40 gaps, the width of the drift channel being 8 mm for all the sampling slots except for the tenth, which is 20 mm wide to house the fast trigger detector consisting of a set of proportional tubes orthogonal to the drift channel.

Fig. 14 shows the design of two modules and some construction details of their structure.

A picture of the assembled module is reproduced in fig. 15.

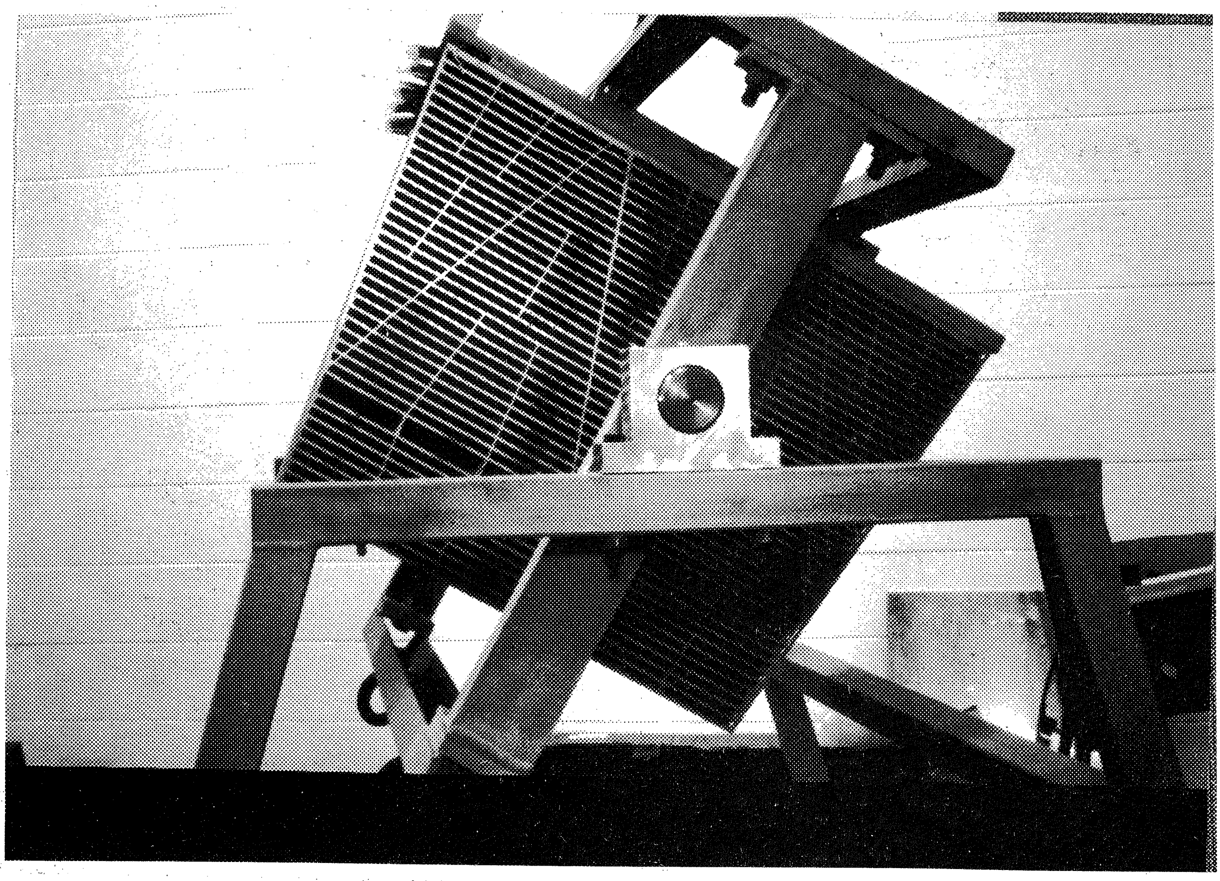


Fig. 15 - The assembled Milestone prototype before being inserted in the gas container.

At the end of the drift region a wire proportional chamber collects the drifted ionization electrons. The chamber is made up of a set of proportional tubes 8 mm wide and 17 to 41 mm long. There is a decoupling grid facing the drift region. The proportional wire is common to all the tubes facing the same drift gap. Signals are read through pads made up by grouping together the cathodes of the proportional tubes. The pad size can be selected by properly grouping the tubes to form a pad, thus offering great flexibility in the tests to optimize the pad design structure. The actual layout of the present pad structure is shown in fig. 16.

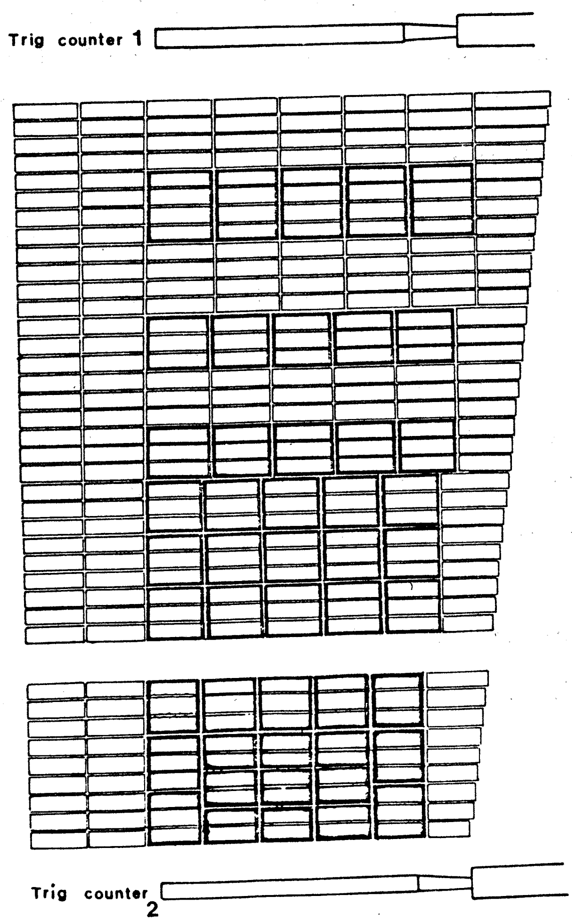


Fig. 16 - The pad structure of half of the read-out chamber. The thick lines rectangles show the 48 pads being read in the cosmic ray test of the milestone prototype.

3.2 The test set-up

During the tests performed until February 85, 48 pads distributed over 10 rows were read out. The information from all 48 pads was read in coincidence with a trigger signal from a cosmic ray counter telescope, covering the full length of the module (70 cm) and the cross section which was equipped with electronics. The trigger rate over this area was about 20 events/min.

The proportional readout chamber was operated at voltages between 1.60 and 1.65 kV in order to avoid saturation. After amplification the signals were sampled 255 times at an interval of 200 ns for an integration time of 10 nsec. The samplings were digitized by means of a FADC (7 bits plus overflow) which could cover a range of 4 V. With the preamplifiers the sensitivity was 3.5 V/pC and the chamber gain was adjusted to approximately $3\ 10^4$ to collect the charge of m.i.p. without saturating. The pedestal level was regularly monitored and was found stable during the data taking.

The HPC was operated with an Ar(80%)-CO_2(20%) gas mixture due to the known longer attenuation length of Ar/CO_2 compared to the Ar/CH_4 mixture in the absence of a magnetic field. The O_2 content at the exit was permanently monitored, and typical O_2 readings ranged between 8 and 20 ppm.

The temperature and the pressure inside the HPC active volume were permanently monitored by means of several gauges.

The high voltage applied to the drift channel was 25 kV, corresponding to an average electric field of about 380 V/cm, for nearly all the data taking. In these conditions the electron drift velocity was measured to be 1.2 ± .1 cm/µsec, well compatible with previously measured values.

3.3 Results of the cosmic ray tests

A typical cosmic ray charge distribution is shown in fig. 17.

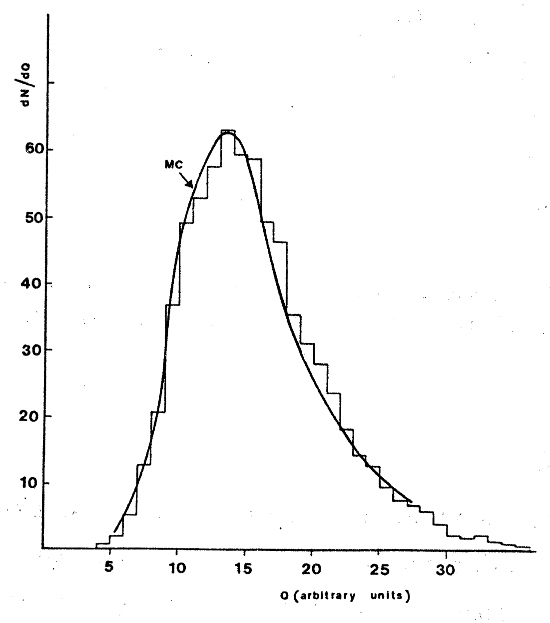


Fig. 17 - Typical energy deposit by cosmic muons in one gap of the HPC.

As a consequence of the inclination of the muon tracks, the primary ionization left by cosmic muons was on the average deposited in 5 or 6 time buckets. The evaluation of the centroid of the charge deposition provided the track position along the drift coordinate, and the area is directly proportional to the energy deposited in the gap.

The picture of an event display showing a cosmic ray crossing the milestone prototype is shown in fig. 18. About 6×10^4 cosmic triggers have been analyzed in total.

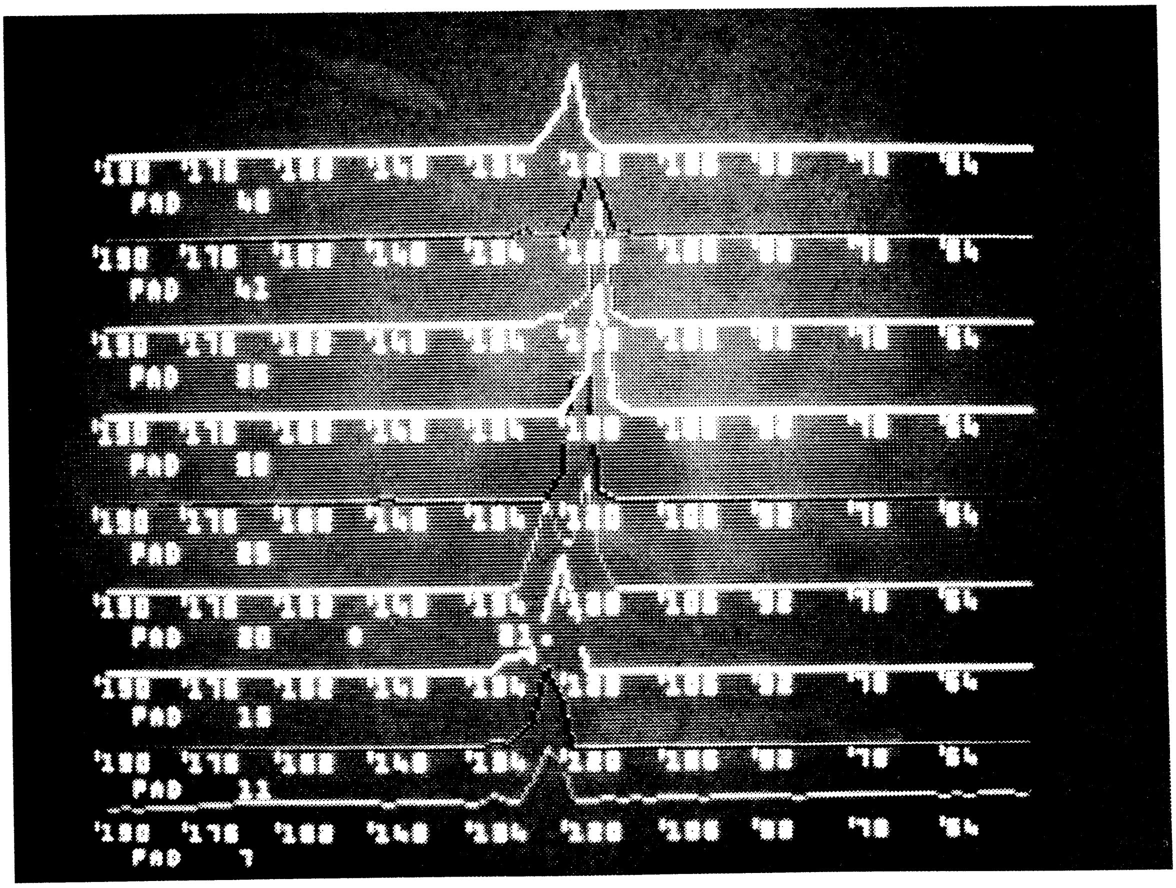


Fig. 18 - A cosmic ray crossing the milestone prototype.

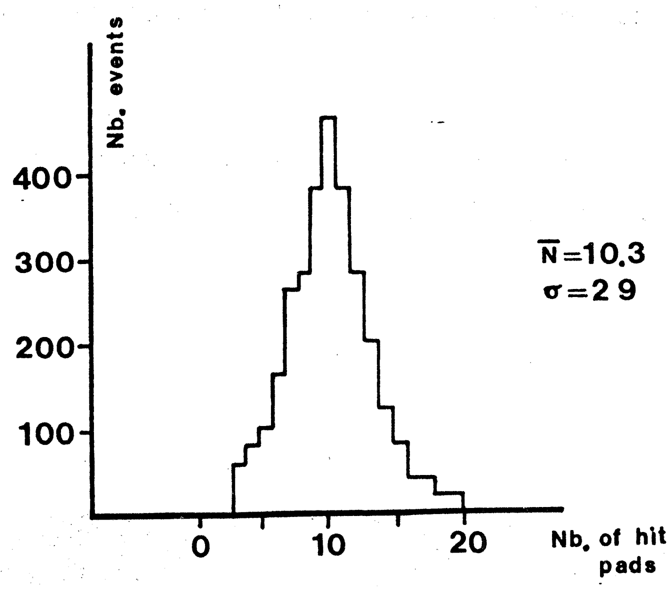


Fig. 19 - Distribution of the number of pads hit per event.

Fig. 19 shows the distribution of the number of pads hit per event.

It is peaked at 10 as expected since pads are arranged over 10 rows, and the width is consistent with a cosmic muon often giving signal on 2 or 3 adjacent pads. The lower side tail, corresponding to events with less than 10 pads hit, is due to track topology and geometrical inefficiencies.

The angular distribution of cosmic muons in the plane defined by the vertical axis and the drift direction is shown in fig. 20 where the solid curve is the expected distribution of the cosmic rays folded with the detector acceptance.

Fig. 21 shows the obtained spatial resolution along the drift direction calculated for single particle tracks incident normally to the drift direction.

Typical values of the spatial resolution are about 2.7 mm as expected from the time resolution of the electronics and the drift velocity.

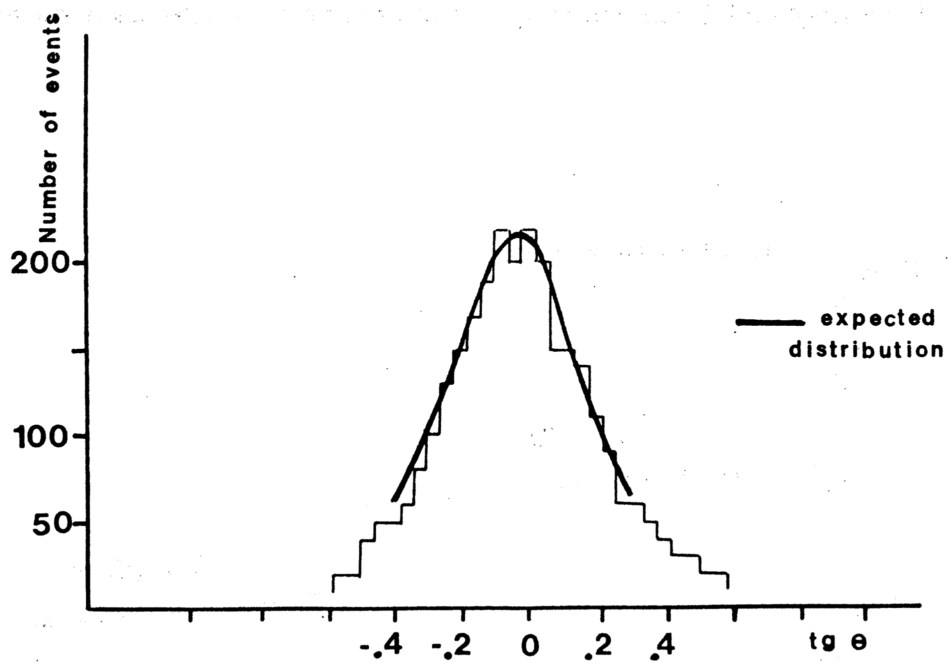


Fig. 20 - Angular distribution of events in the cosmic ray test. The solid line is the expected distribution from the known cosmic ray angular distribution folded with the geometrical acceptance of the detector.

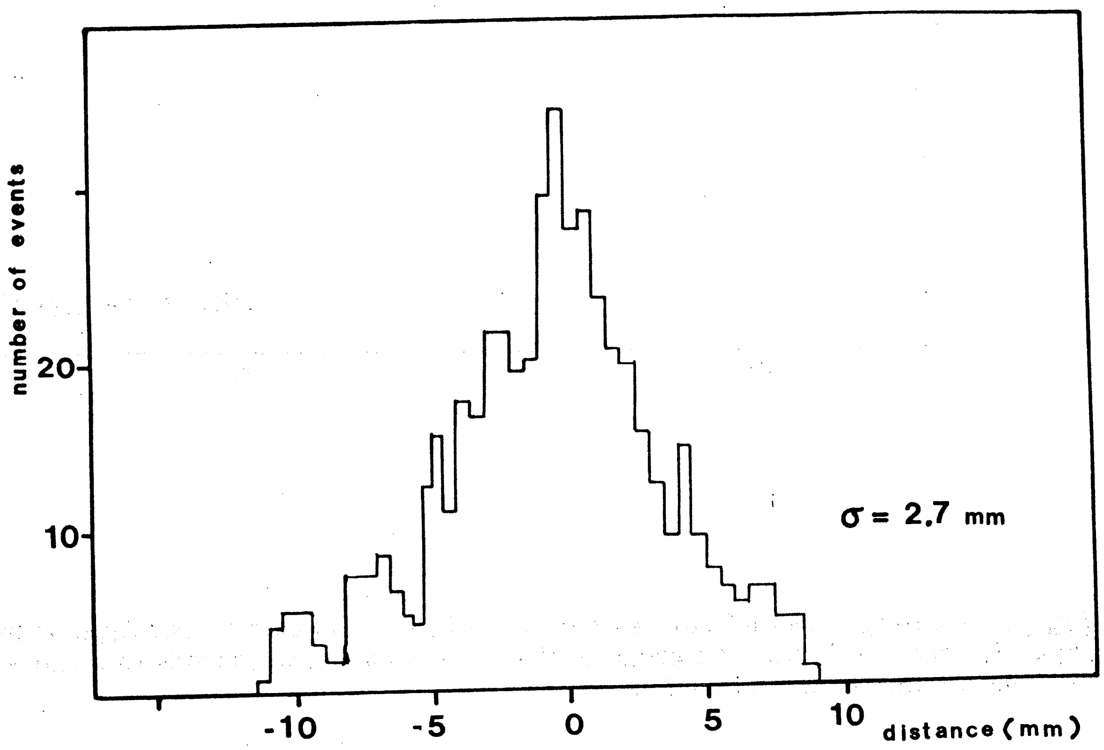


Fig. 21 - Space resolution along the drift direction of one pad for a cosmic ray track as reconstructed by the other 9 pads on the track.

The charge transmission along the drift channels has also been measured. The average charge deposited as a function of distance (drift time) from the collecting wire for a single minimum ionizing particle at normal incidence is shown in fig. 22.

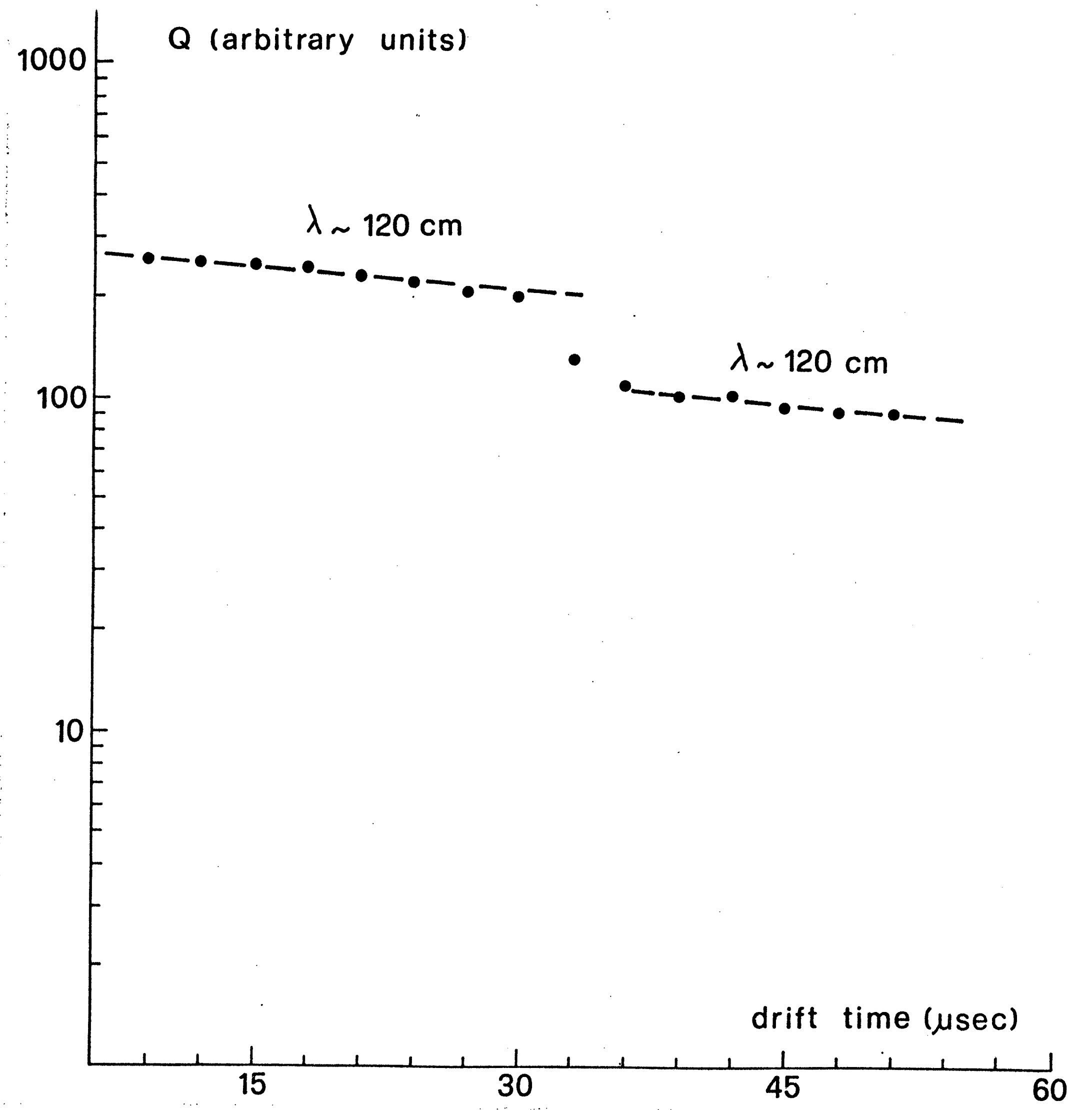


Fig. 22 - Charge transmission as measured in the milestone prototype with cosmic rays. 1 μ sec ≡ 1.2 cm. The break in the transmission corresponds to a concentration of short circuits in one submodule.

The break in the charge attenuation data can be traced to the short circuits, concentrated in one of the submodules.

At the end of the cosmic ray test the module has been opened and most of the short circuits have been eliminated using a method tested successfully on the 1 mm prototype. The short is eliminated by passing a current pulse between the wire.

A fit to the two sets of points, before and after the break, gives the same value for the attenuation length: $\lambda \sim 120$ cm, quite consistent with the known values at the present O_2 contamination in the Ar/CO_2 gas mixture used for these tests.

3.4 Test of the trigger counter

We have built and tested a set of 6 prototype fast trigger chambers which consist of 9 cells, 5×6 mm^2 each, enclosed in an epoxy/dolomite casting 6 mm thick, simulating the trigger gap environment of the Milestone prototype.

Chamber castings were tested for corona discharge by applying a 60 kV tension at the castings ends.

After initial checks on a single wire, the 9 wires of one chamber were passively ored together and the signal sent to a preamplifier.

Three of these chambers were tested in the DESY electron beam in October 1984 with electrons of 1, 2, 3, 4, 5 and 6 GeV of energy. The chamber was calibrated with single particle behaviour and with electron showers after 6 X_o lead stacks simulating the HPC radiator before the trigger gap.

Fig. 23 shows the distribution of the collected charge at energies of 2 and 5 GeV, compared to Monte-Carlo.

The chamber behaviour is found to be uniform and to compare reasonably well with the expectations and allows a good and efficient trigger for 5 GeV photons. From the above distributions one can evaluate an efficiency for shower detection as large as 95% at 5 GeV.

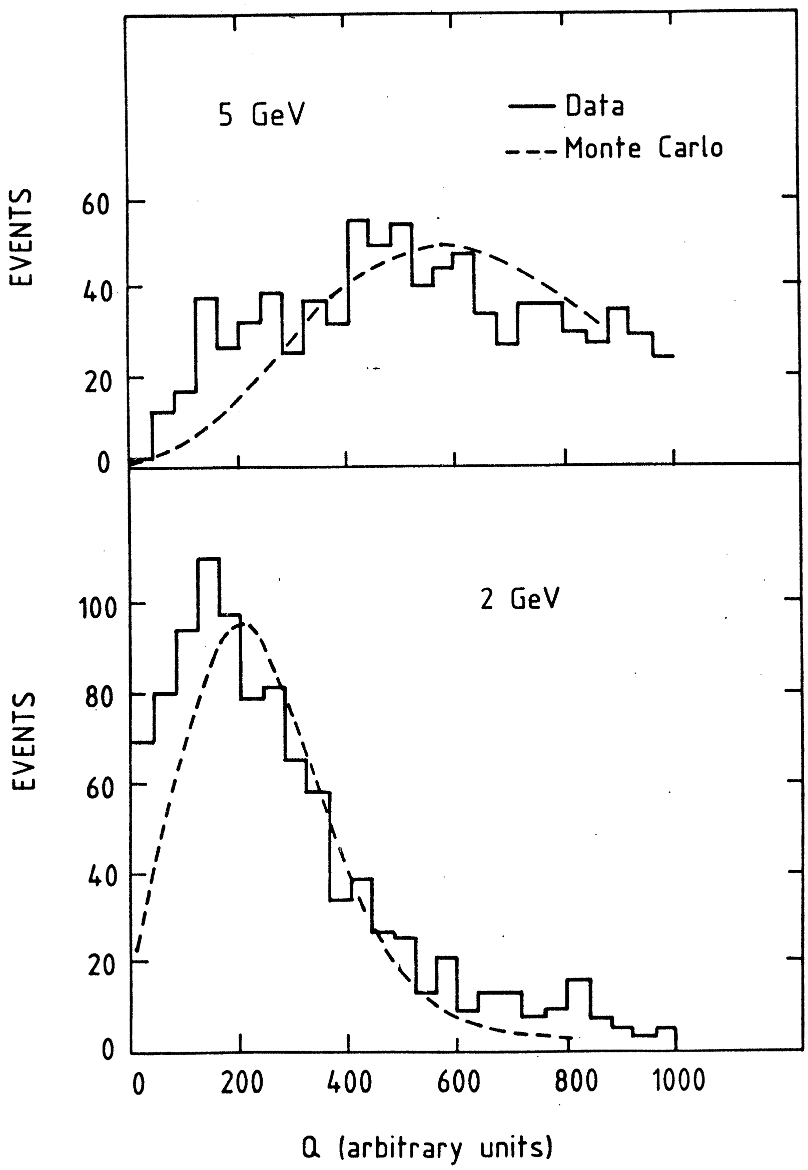


Fig. 23 Charge collected by the trigger chamber after 6 X_o for 2 and 5 GeV electrons.

4. MEASUREMENT OF THE ATTENUATION LENGTH IN MAGNETIC FIELD

Measurements of the attenuation length of electrons in a confined channel were carried out in various experimental conditions.

The principle of the measurement was as follows:

- An ^{241}Am source was placed at distance x from the proportional tube, α particles were shot into the drift channel through 0.5 mm diameter holes.
- The pulse height distribution was then measured for different values of x.

We used two test channels whose parameters are given in table 1. The lead wire ribbons used for channels 1 and 2 are the same as for the 1 mm and for the milestone prototype, respectively.

TABLE 1

	Channel 1	Channel 2
Channel length (b) [mm]	500	960
Channel width (a) [mm]	9	8
Lead wire thickness [mm]	1.0	1.7
# of wires/ribbon	20	30
Gas mixture	Ar + 20% CO_2	Ar + 20% CH_4

The ribbon is bent in a form of a U and held in position by a precisely machined plexiglass structure. The cross section of the drift channels is identical to that of a channel of the prototypes and differs only by the width, that is approximately 10 cm instead of 60 cm.

The first drift channel was filled with an Ar/CO_2 (20%) gas mixture and operated at a drift field value of 360 V/cm to minimize transverse diffusion.

The results of the charge transmission are presented in fig. 24, where the effect of two short circuits that developed between lead wires is also shown. A fit to the data in the region before the short circuits gives $\lambda \sim 200$ cm which corresponds to a transverse diffusion coefficient $\sigma_t = 250\ \mu m/\sqrt{cm}$.

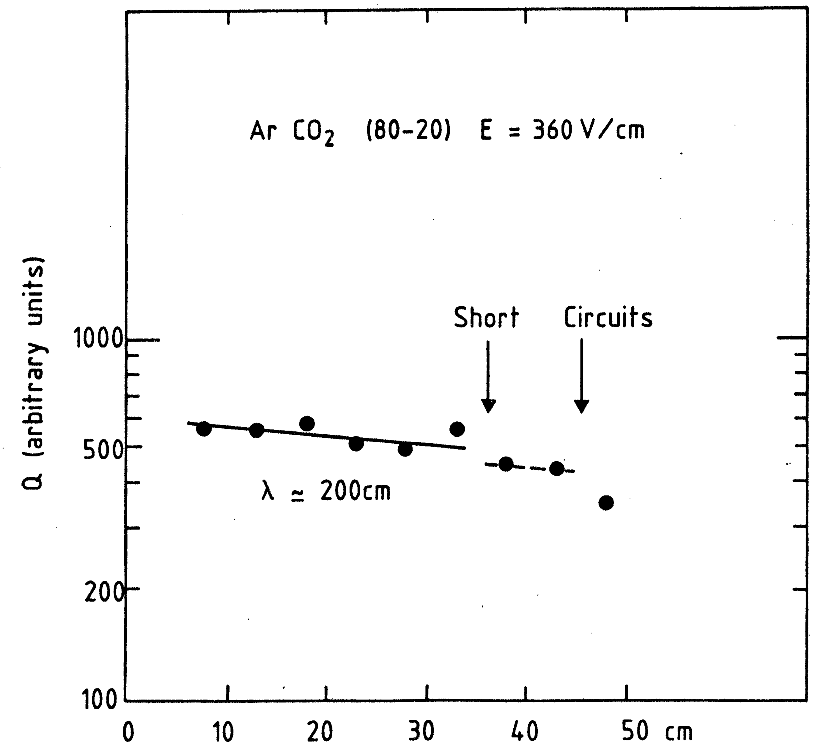


Fig. 24 Charge transmission in $ArCO_2$ for the drift channel 1. The attenuation length (λ) of the drift channel corresponds to a $\sigma_t = 250\ \mu m/\sqrt{cm}$. The effect of field deformation due to 2 adjacent wires in short circuit (the location is indicated by arrows) is visible.

The second drift channel was filled with an Ar/(20 %) CH_4 gas mixture and operated at a drift field of 200 V/cm, with and without a magnetic field of 1.2 T parallel to the electric drift field.

Results are presented in fig. 25 corresponding to $\sigma_t = 420\ \mu m/\sqrt{cm}$ ($100\ \mu m/\sqrt{cm}$) without (with) magnetic field. A fit to the data yields $\lambda = 65$ cm (390 cm). The ratio $\sigma_t(B = 0)/\sigma_t\ (B = 1.2\ T) = 4.2$, corresponds to the expected value of $\omega\tau$ for the gas mixture.

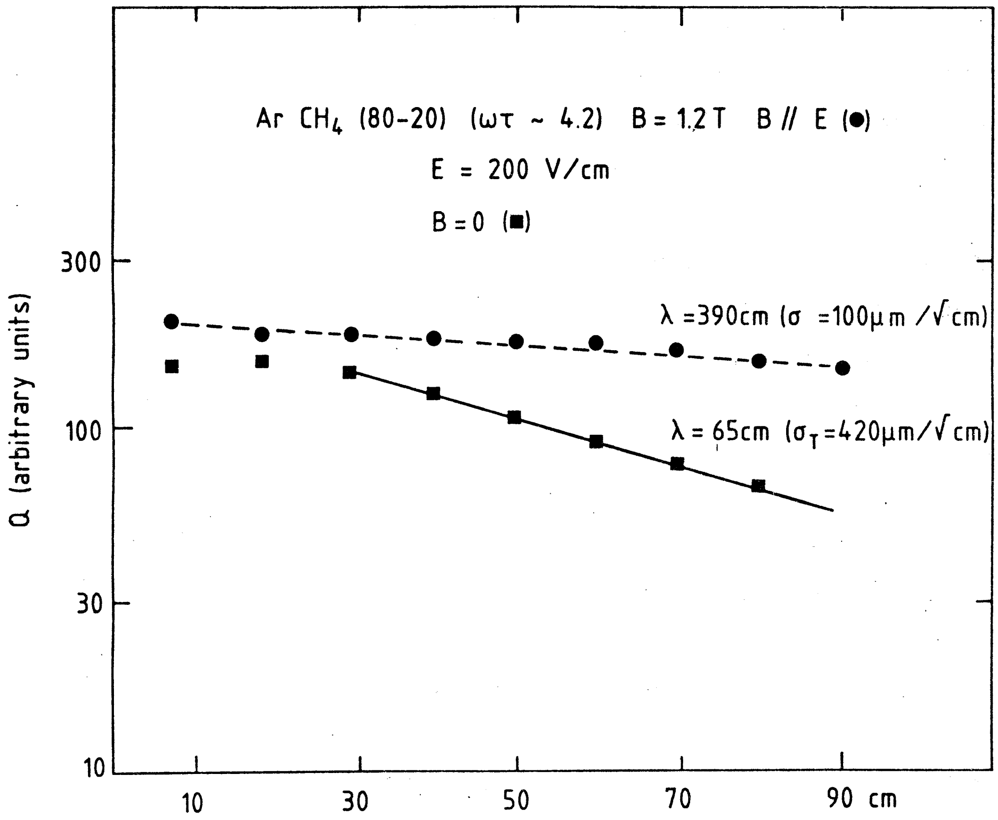


Fig. 25 - Charge transmission in $ArCH_4$ for the drift channel 2. The two data sets have been measured with and without magnetic field: note the improvement in attenuation length in presence of a 1.2 T magnetic field.

It has also been possible to study the effect of misalignement between B and E, within the limits of a few milliradians and to confirm that the transverse displacements behave as expected.

5. CONCLUSIONS AND FUTURE PLANNING

We have measured the physics response of the Hamburg and the 1 mm HPC prototypes to electron and pion beams between 0.25 and 6 GeV, with and without magnetic field. The results obtained compare satisfactorily in all cases with Monte-Carlo calculations.

A full scale module has been built and, because of lack of test beams, tested with cosmic rays. The measurements of the charge deposited, space resolution and charge transmission agree with expectations. Problems due to the preliminary production of the lead wire ribbon will be cured in the future with the new wiring machine.

The behaviour of electrons drifting in a confined region in a magnetic field has been measured with single channels, with have the same structure as the final detector. The expected improvement in Ar CH_4 (80%; 20%) when passing from zero to 1.2 T magnetic field has been quantitatively verified.

We plan to start a production of a small series of HPC modules within mid 1985 with the new machines, which are at present almost completed, concentrating our effort on the production of high quality lead wire ribbon as required for the construction of large series.

6. REQUEST TO LEPC

All these tests point to the conclusion that the HPC behaves as expected. The milestone HPC has been tested with cosmic muons. The LEP Committee requirement of a test in a magnetic field was met by the small scale prototypes; for the full scale prototype module no beam with a magnet has been available. Although we plan to perform these tests by mid 1985 we request the LEPC to agree that the milestone has been reached.