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TEST RESULTS OF THE STREAMER-TUBE SYSTEM OF THE CHARM II NEUTRINO DETECTOR

CHARM II Collaboration

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ABSTRACT

The CHARM II Collaboration is building a massive, fine-grained and low-density detector for the study of neutrino–electron scattering. Its target calorimeter consists of 441 detector planes with 155,232 plastic streamer tubes with digital readout of the wires and analog readout of external pick-up strips. At the time of this report, about 25% of the calorimeter planes were equipped with electronics. Results on the performance of these tubes are presented as obtained with cosmic-rays and with electron and pion beams. We have also investigated the use of water vapour as an additive to the gas to suppress coating of the anode wires. The use of water would be of particular importance when using the tubes in a high-rate environment.

1. INTRODUCTION

The CHARM Collaboration is at present building a new and dedicated detector to continue the study of the neutrino–electron scattering. Its physics aim is a precise determination of the electroweak mixing angle $\sin^2\theta_w$, the single parameter of the standard model of the electroweak interaction [1].

The construction of this CHARM II neutrino detector is based on the accumulated experience of the Collaboration with the instrumentation and the analysis of data from massive, fine-grained, and low-density electronic calorimeters. It consists of a modular target calorimeter of 35.7 m length, instrumented with streamer tubes and scintillators, followed by an 8.6 m long muon spectrometer*) made of magnetized iron, with scintillators and drift chambers as active elements.

The total mass of the target calorimeter is 692 t. The streamer tube system contains 155,232 digital and 9,240 analog channels, and there are 1,560 analog channels forming the scintillator system.

2. THE CONSTRUCTION OF THE CHARM II TARGET CALORIMETER

The calorimeter is composed of 420 modules of $3.70 \times 3.70\ m^2$ active area, which are grouped into 21 identical units. Each module consists of a 48 mm thick target plane made of glass, corresponding to one-half radiation length followed by a plane of 352 plastic streamer tubes of about 1 cm wire spacing. The streamer tubes are of the type used in the Mont Blanc experiment [2], but with direct readout of the wire signal in a digital mode and with analog readout on pick-up cathode strips of 21 mm spacing in the projection orthogonal to the wires. The wire orientation of consecutive modules is alternatively rotated by 90°. Successive planes with the same wire direction are shifted in the direction orthogonal to the wire by ± one-half wire spacing and orthogonal to the pick-up strips by ± one-half strip spacing. After 5 target modules one plane of 20 scintillators with $3 \times 3\ m^2$ sensitive area is added. Each group of 20 target modules is followed by one plane of streamer tubes, with wires inclined by $\pm 7°$ with respect to the vertical axis. The basic modules of the calorimeter arrangement is shown in fig. 1.

The streamer tubes are used to measure the vertex position, the hit multiplicity in the plane following the vertex, and the shower width, as well as its direction and energy. The central position of a track can be reconstructed with ± 2 mm accuracy from the cathode strips with the help of the analog electronics. Electromagnetic showers are characterized by a narrow lateral profile containing 95% of the energy within a range of ± 10 cm from the shower axis.

The pulse height observed in the scintillator plane following the glass plane in which the event occurred gives additional information about the fraction of showers initiated by a single electron and of those initiated by a photon. This information is required to distinguish the signal from background arising from electron-neutrinos of the beam and from photons of muon-neutrino interactions.

3. THE STREAMER-TUBE SYSTEM OF THE CALORIMETER AND THE TESTS

The need for a target calorimeter of fine granularity and high modularity suggested the use of plastic tubes operated in the limited streamer mode. They consist of extruded PVC profiles

*) The spectrometer was kindly made available to us for the duration of the experiment by the CDHS Collaboration.

with 8 open cells, each of 9 × 9 mm^2 inner dimensions with a 100 μm silver-plated Cu-Be wire in its centre. The cells are closed with a PVC cover sheet. Two 8-cell profiles, closed with two such covers, are mounted in one gas-tight PVC envelope and form one single chamber unit. The centring of the wire over the whole length is ensured by inserting wire holders, made of polyethylene, every 47.5 cm. The position of the wire holders is shifted along the wire by 10–15 cm in respect to the foregoing plane with the same wire direction. This arrangement repeats itself only after 10 planes; it assures a uniform detection efficiency for traversing particles over the whole detector. The inner surfaces of both the profile and the cover are coated with a layer of low conductivity. This allows the detection of the streamer signal with pick-up strips, placed outside the PVC envelope that contains the streamer cells. The conducting layer of the profiles is produced by graphite paint; its resistivity varies between 20 kΩ per square and 20 MΩ per square. The covers are coated with a mixture of carbon black in PVDC*). Its resistivity, of about 1 MΩ per square, varies only a few per cent. The analog strips face the covers, whose uniform resistivity guarantees a constant transparency for streamer signals.

In the CHARM II detector one coordinate of the streamer signal is read out directly from the wire as digital information; the other coordinate is determined from analog signals read from the pick-up strips orthogonal to the wire direction. To avoid high-voltage capacitors on each wire the high voltage is applied to the conducting layer on the cell walls of each tube so that the wire signals can be transmitted directly via connectors to the shaper cards. The gas mixture chosen is argon:isobutane in a ratio of 1:2.4. The working voltage under these conditions is about 4.3 kV with a width of the plateau of 400 V.

The digital electronics of the wire readout can be seen in fig. 2. Figure 2a shows the front-end electronics with a comparator used for the discrimination of the wire signal; there are 32 channels on one shaper card. Figure 2b gives the logical connection of the shaper cards for one plane to the readout.

The analog electronics of the system is sketched in the block diagram of fig. 3. Each plane has 176 pick-up strips made of 18 mm wide Al bands, separated from one another by 3 mm wide gaps. To reduce the number of analog channels, the charge of 8 strips of one plane, each spaced 22 strips (46 cm) from the next, is summed up by mixing transistors into one analog bus line, resulting in 22 bus lines per plane. The charge on each of these bus lines is integrated, amplified, and fed to a peak detector. The content of the peak detector is converted twice in the analog to digital converter (ADC) by switching the reference voltage from 5 V to 1 V, thereby giving a high- and a low-sensitivity range for the pulse-height analysis.

After production each chamber is tested. Only chambers with a dark current below 1 μA at a high voltage of 4.55 kV are retained for plane assembly. During the development of the test procedure we found that the chambers can be damaged by the collection of large quantities of charge. This can happen, for example, during the high-voltage conditioning period, where some chambers draw currents of several microamperes for several hours prior to settling down. These currents can produce localized insulating deposits on the anode wire. These insulating layers were found to contain large amounts of chlorine.

To investigate the coating rate more thoroughly, tests were done with a ^{90}Sr source and various fractions of water vapour in the gas. Water was chosen because it had been previously

*) This coating was done by the firm Aerni-Leuch at Berne, Switzerland.

seen to inhibit depositions on wires of proportional tubes [3]. The source gave a rate of 2×10^4 Hz on approximately 1 cm of wire. Singles rates were measured by discriminating the wire output signal at a threshold of 30 mV. The charge collected per count in the limited streamer mode was about 10^{-10} C. Thus in about 15 h the wire received a dosage of about 0.1 C/cm, corresponding to several hundred years of cosmic-ray exposure.

The results of several measurements are displayed in fig. 4. The addition of water at the level of a few $\times 10^{-3}$ parts has only a small influence on the plateau curve for the singles rate; it shifts the onset of the plateau by about 20 V for 2×10^{-3} parts of water vapour. With this amount of water it has a negligible effect on the streamer pulse height, so the effect is presumably chemical. In fig. 4 the relative counting rate on a wire, normalized to its initial value, is shown as a function of the irradiation time. With no water or a few $\times 10^{-4}$ parts of water, radiation damage begins after about 10^{-2} C/cm of collected charge. The inhibition of damage due to water sets in for greater than 10^{-3} parts of water, and at 4×10^{-3} parts radiation damage is very strongly suppressed. The addition of water to the chamber gas would be particularly crucial in an experiment where rates of more than 10 Hz/cm of wire are expected, while for a neutrino experiment the rate is essentially given by cosmic-rays.

4. TEST RESULTS OBTAINED WITH COSMIC-RAYS

The streamer tubes and their readout system were tested with cosmic-rays in a full-size prototype plane and in the calorimeter of the CHARM II detector. Some preliminary results were already reported [4].

The measurements with the pick-up strips on the prototype plane show that for a hit centred on a strip, the two neighbouring strips each contain about 30% of the charge of the central strip. This is sketched in fig. 5a together with the definition of the cluster threshold as a fraction of the charge of the strip with the highest ADC content in this cluster.

The cluster charge is defined as the sum of the charge of those strips in a cluster which have a content above threshold. Figure 5b displays, for cosmic-rays, the distribution of the cluster charge in ADC channels for a cluster threshold set at 1/4 of the highest strip content; its resolution is about 40% of the mean charge, $\sigma/Q_m \approx 40\%$. The resolution of the cluster charge depends only weakly on the choice of the cluster threshold, as can be seen in fig. 6; there σ/Q_m varies from 52% to 37% for a threshold change from 0.05 to 0.35.

To measure the position resolution of the analog strips, a set of wire chambers, together with a scintillator, was mounted above and below the prototype plane. With this arrangement, the trajectories of traversing cosmic particles and their impact point on the streamer tubes could be determined.

To compute from the charge distribution of a cluster the impact coordinate of the traversing particle, an interpolation by a Gaussian function was applied to the strip with the highest charge content and the two neighbouring ones. In addition, a constant background level, determined from the next neighbouring strips, is subtracted. This reduces the systematic error in the centroid determination in the case of asymmetric charge distributions, i.e. for particles which do not traverse the centre of a strip or the gap between two strips. The position resolution of the strips obtained with this method is $\sigma \approx 2.1$ mm, as can be seen in fig. 7.

The partly-assembled calorimeter was also tested with cosmic-rays. Figure 8 shows the efficiency of streamer tubes averaged over 8 planes as a function of the high voltage. This efficiency was determined using 4 reference planes for the reconstruction of cosmic-ray tracks; between 4300 and 4500 V the efficiency is practically independent of the voltage. In figs. 9a and b the hit multiplicity of the tubes and the average tube efficiency are displayed as a function of the projected impact angle for cosmic-ray tracks. For orthogonal impact the tube efficiency reaches the geometrical value. Tracks at about 0° can produce more than one hit through delta-ray production. The efficiency increase with increasing angle is due to tracks crossing more than one cell; the minimum detected track length is about 1 mm.

5. PRELIMINARY TEST-BEAM RESULTS

The incomplete calorimeter was exposed for a short period to a test beam of electrons and pions. Typical electron and pion showers are shown for one projection in fig. 10. The number of wires hit in each 8-cell profile is displayed. The horizontal axis gives the number of the streamer tube profile; the vertical axis gives the plane number in the detector for streamer tubes with a vertical-wire arrangement. The high density and narrow shower profile of the electron-induced shower is clearly visible.

Test-beam data were taken only with the digital readout of the wires; the effective sampling step was thus 1 radiation length in each projection. Figure 11 displays the distribution of the projected angle of 6 GeV electrons reconstructed from this information. The angular resolution measured in these conditions can be parametrized by

$$\sigma(\Theta_e) \approx 20\ \mathrm{mrad}/\sqrt{E},$$

making us confident that a combined analysis of the digital and analog information will provide a resolution of

$$\sigma(\Theta_e) \approx 16\ \mathrm{mrad}/\sqrt{E},$$

as stated in the proposal of the experiment.

Acknowledgments

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REFERENCES

[1] CHARM II Collaboration, Proposal to study neutrino-electron scattering at the SPS, CERN/SPSC/83-24, 28 April 1983.

[2] G. Battistoni et al., Nucl. Instrum. Methods **176** (1980) 297.
E. Iarocci, Nucl. Instrum. Methods **217** (1983) 30.

[3] CHARM Collaboration, A. N. Diddens et al., Nucl. Instrum. Methods **176** (1980) 189.
W. Schmidt-Parzefall (private communication): The central drift chamber of the ARGUS Collaboration showed, after some running time, growing regions where a few cells had abnormally high current due to radiation damage. These effects could be suppressed by adding constantly 0.2% of water vapour to the chamber gas. Increasing the water content led to reduced cell efficiency; when lowering it the regions with high current re-appeared.

[4] CHARM II Collaboration, Contributed paper to Gas Sampling Calorimetry Workshop, Fermilab, 1985.

Figure captions

Fig. 1 Basic modules of the target calorimeter.

Fig. 2 Digital readout of the streamer tubes and planes.

Fig. 3 Block diagram of the analog electronics for the pick-up strips.

Fig. 4 Relative counting rate on a wire irradiated by ^{90}Sr as a function of time, compared to initial counting rate for different amounts of water vapour added to the chamber gas.

Fig. 5 Charge distribution on pick-up strips (a) and distribution of the cluster charge (b) for cosmic-ray particles.

Fig. 6 Cluster charge and its r.m.s. width as a function of the threshold setting.

Fig. 7 Distribution of the cluster centroid for analog strips for cosmic-ray particles.

Fig. 8 Average efficiency of eight planes as a function of the high voltage of the tube.

Fig. 9 Dependence of the tube multiplicity (a) and its efficiency (b) on the projected impact angle of cosmic-ray tracks.

Fig. 10 Test beam events for an electron-induced shower and for a pion-induced shower.

Fig. 11 Distribution of the reconstructed angle in one projection (vertical wires) with 6 GeV electrons from the test beam.

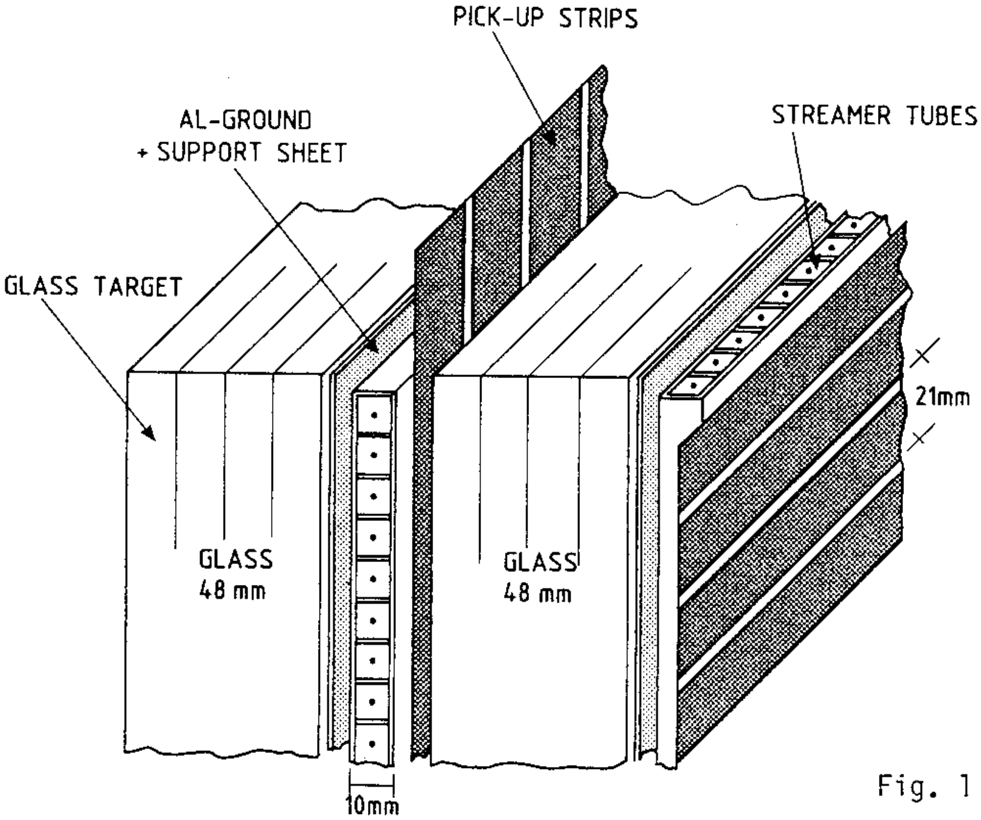
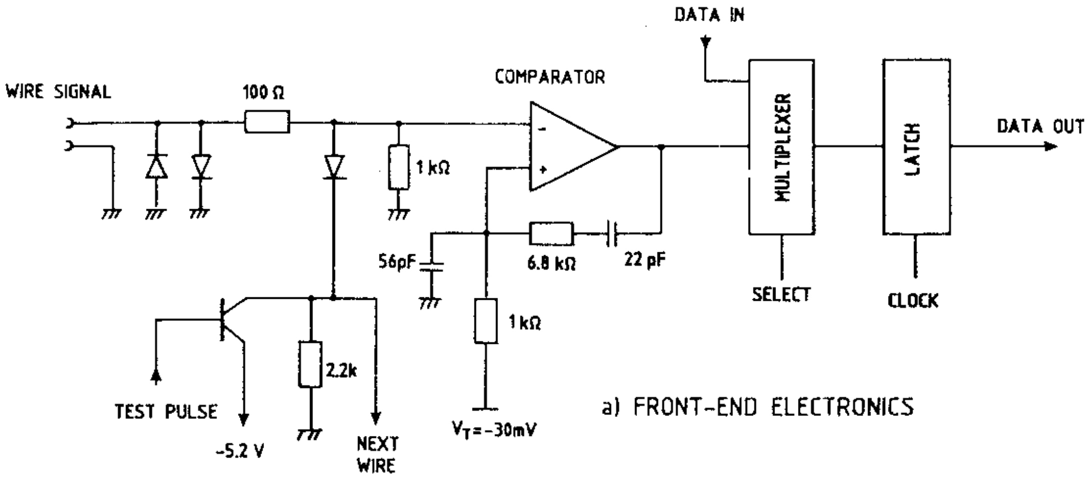
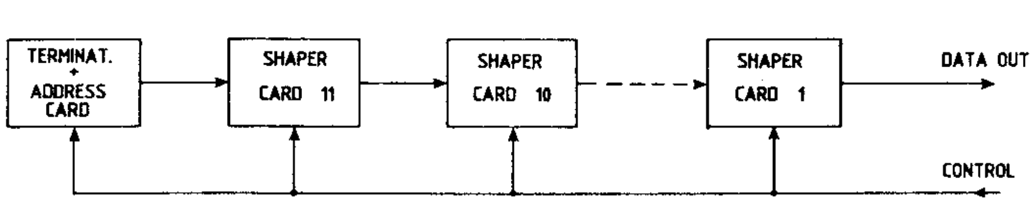


Fig. 1

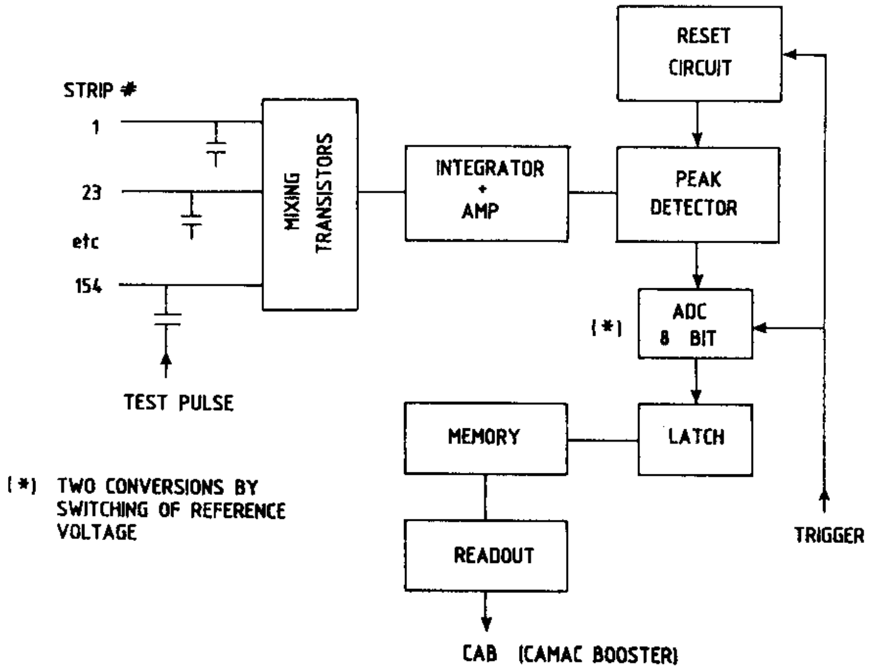


a) FRONT-END ELECTRONICS



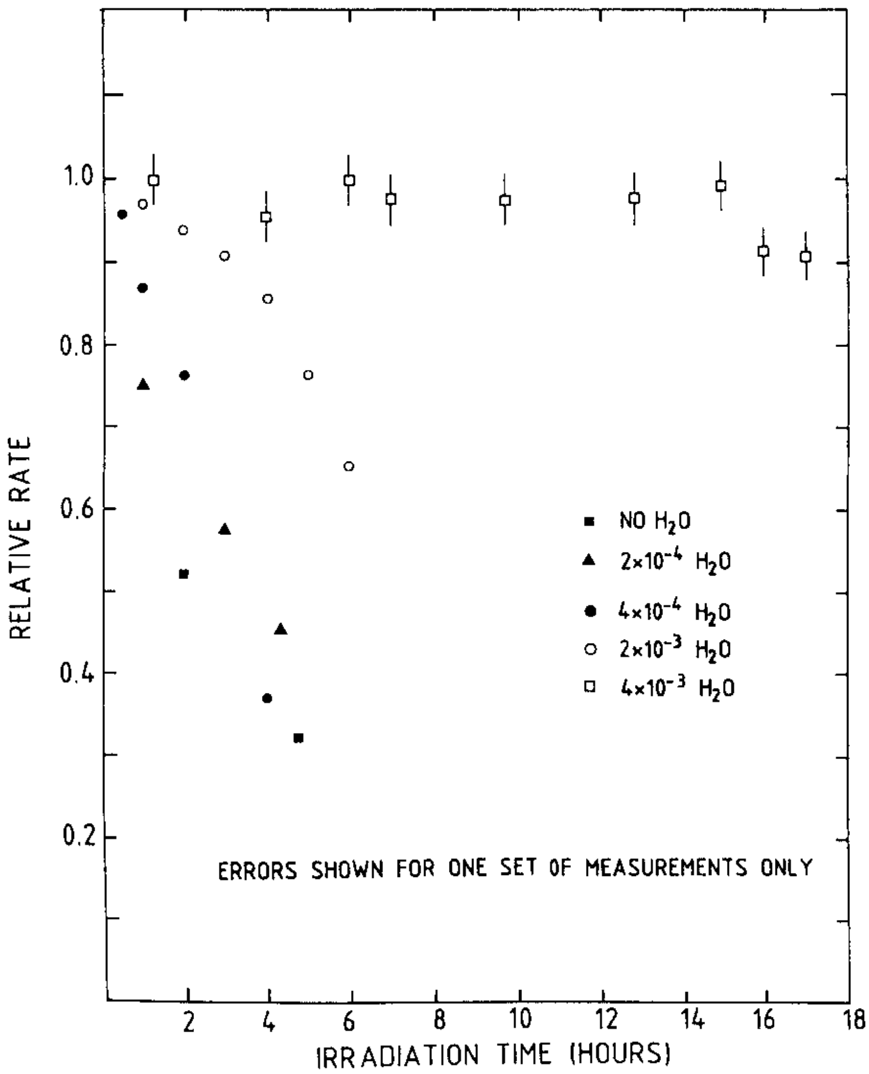
b) PLANE READ-OUT (EACH SHAPER CARD READS 32 WIRES)

Fig. 2



STRIP #
1
23
etc
154
TEST PULSE
MIXING TRANSISTORS
INTEGRATOR + AMP
RESET CIRCUIT
PEAK DETECTOR
ADC 8 BIT
(*)
LATCH
MEMORY
READOUT
CAB (CAMAC BOOSTER)
TRIGGER
(*) TWO CONVERSIONS BY SWITCHING OF REFERENCE VOLTAGE

Fig. 3



RELATIVE RATE
IRRADIATION TIME (HOURS)
NO H_2O
2×10^{-4} H_2O
4×10^{-4} H_2O
2×10^{-3} H_2O
4×10^{-3} H_2O
ERRORS SHOWN FOR ONE SET OF MEASUREMENTS ONLY

Fig. 4

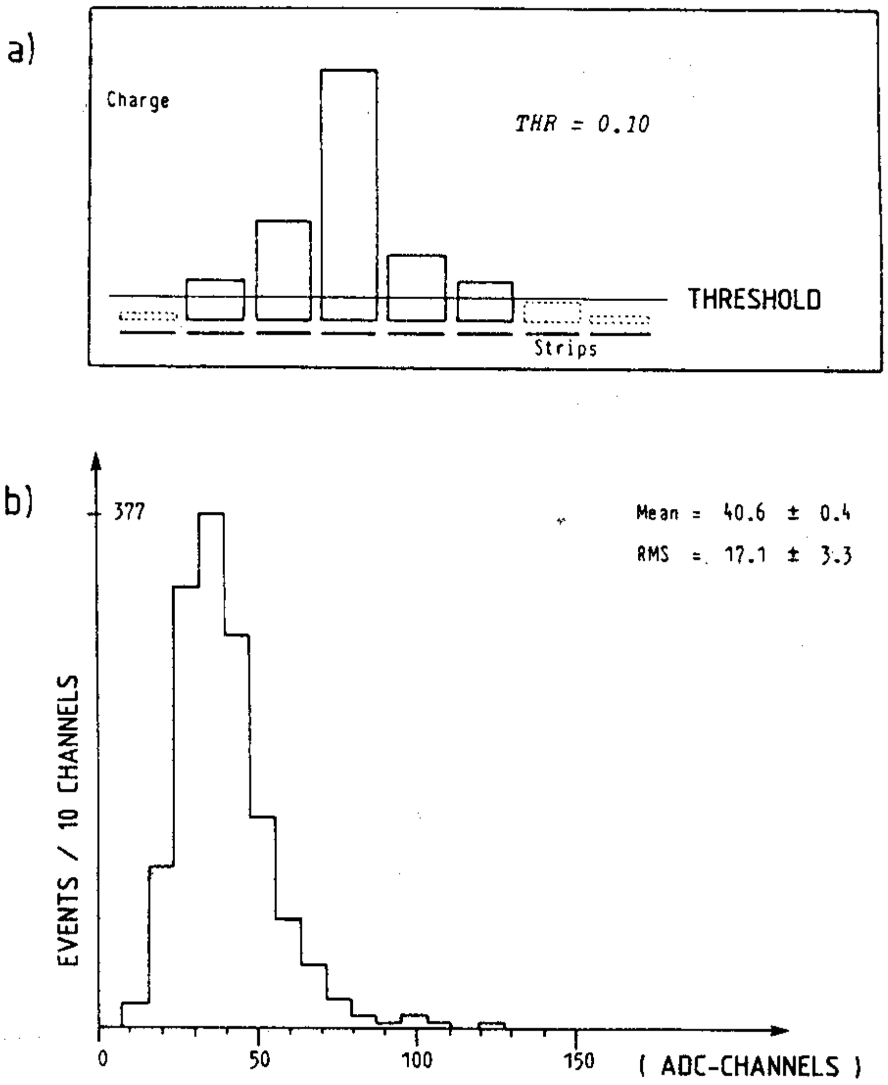

a)
Charge
THR = 0.10
THRESHOLD
Strips
b)
377
Mean = 40.6 ± 0.4
RMS = 17.1 ± 3.3
EVENTS / 10 CHANNELS
0
50
100
150
(ADC-CHANNELS)

Fig. 5

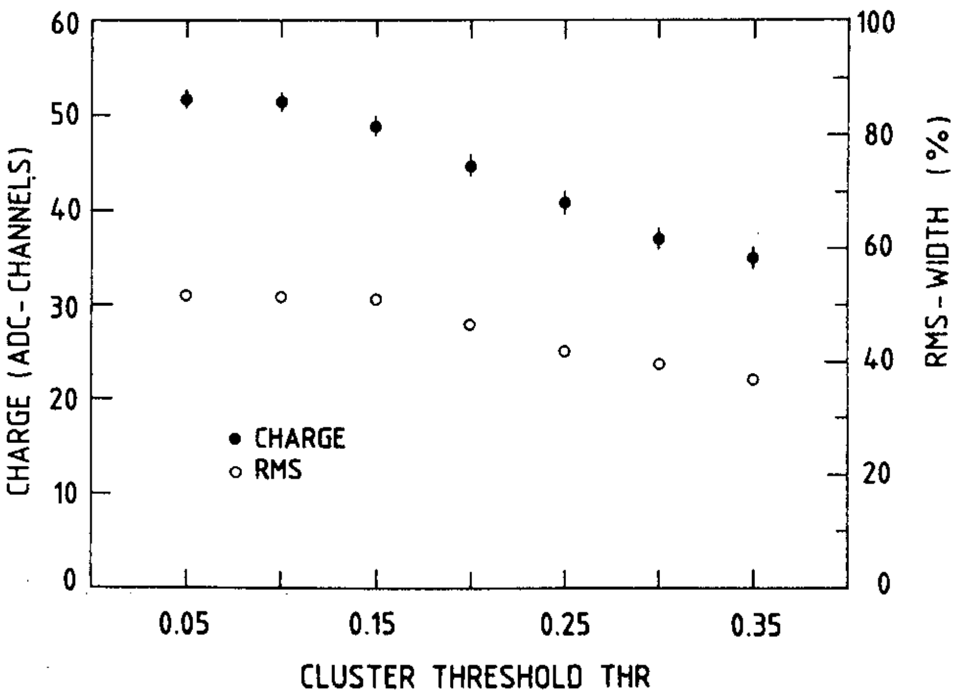
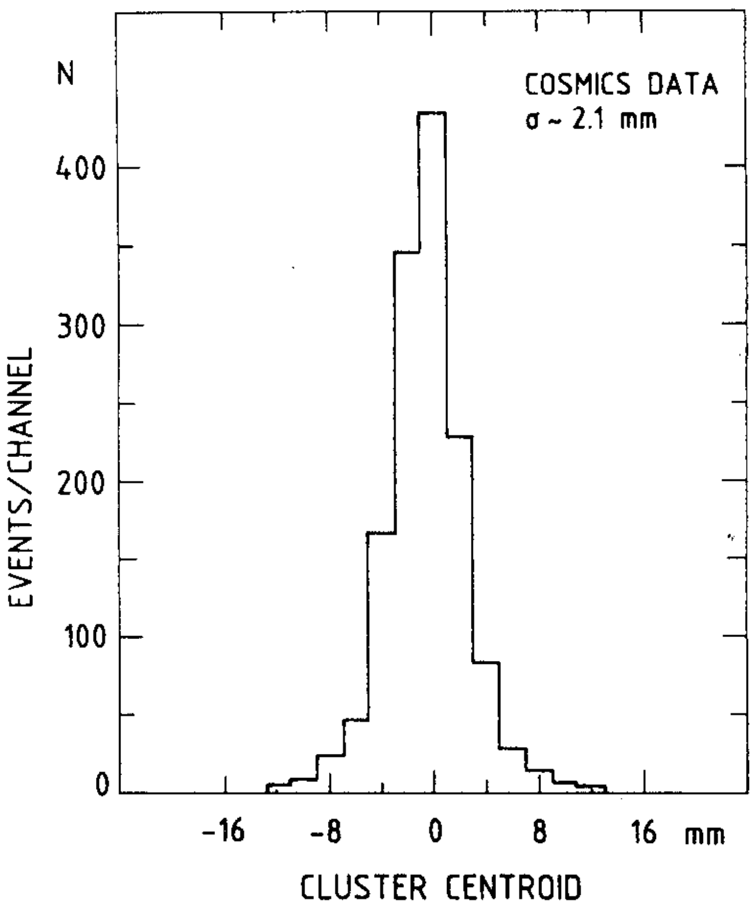
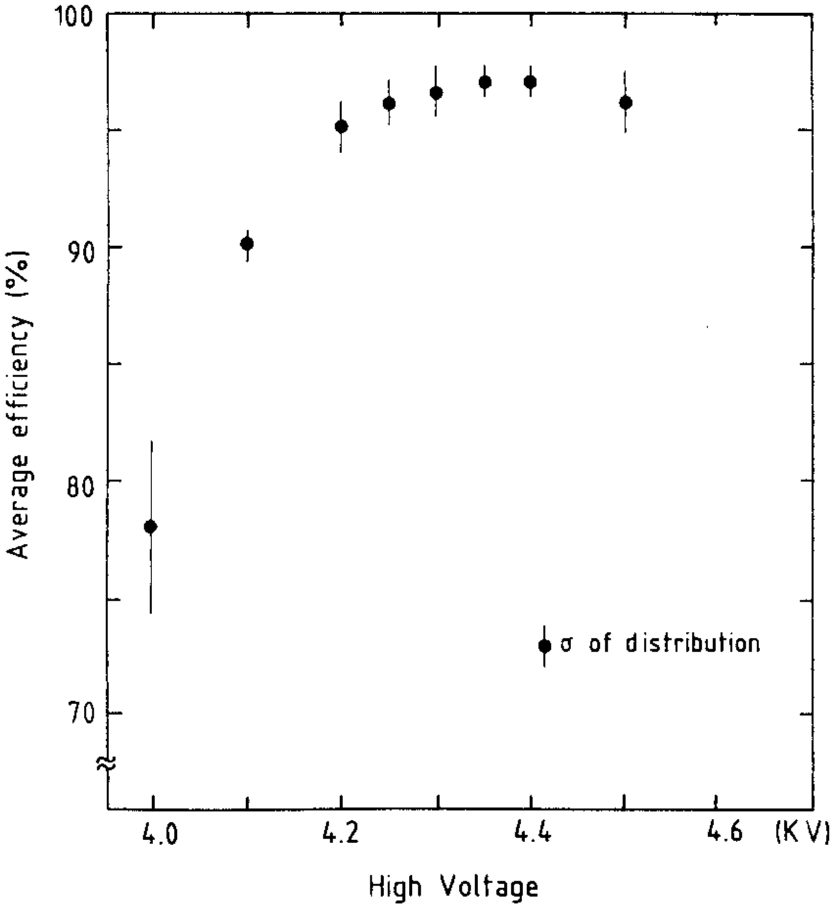

CHARGE (ADC-CHANNELS)
RMS-WIDTH (%)
● CHARGE
○ RMS
0.05
0.15
0.25
0.35
CLUSTER THRESHOLD THR

Fig. 6



N
COSMICS DATA
σ ~ 2.1 mm
400
300
200
100
0
EVENTS/CHANNEL
-16
-8
0
8
16 mm
CLUSTER CENTROID

Fig. 7



100
90
80
70
Average efficiency (%)
σ of distribution
4.0
4.2
4.4
4.6 (KV)
High Voltage

Fig. 8

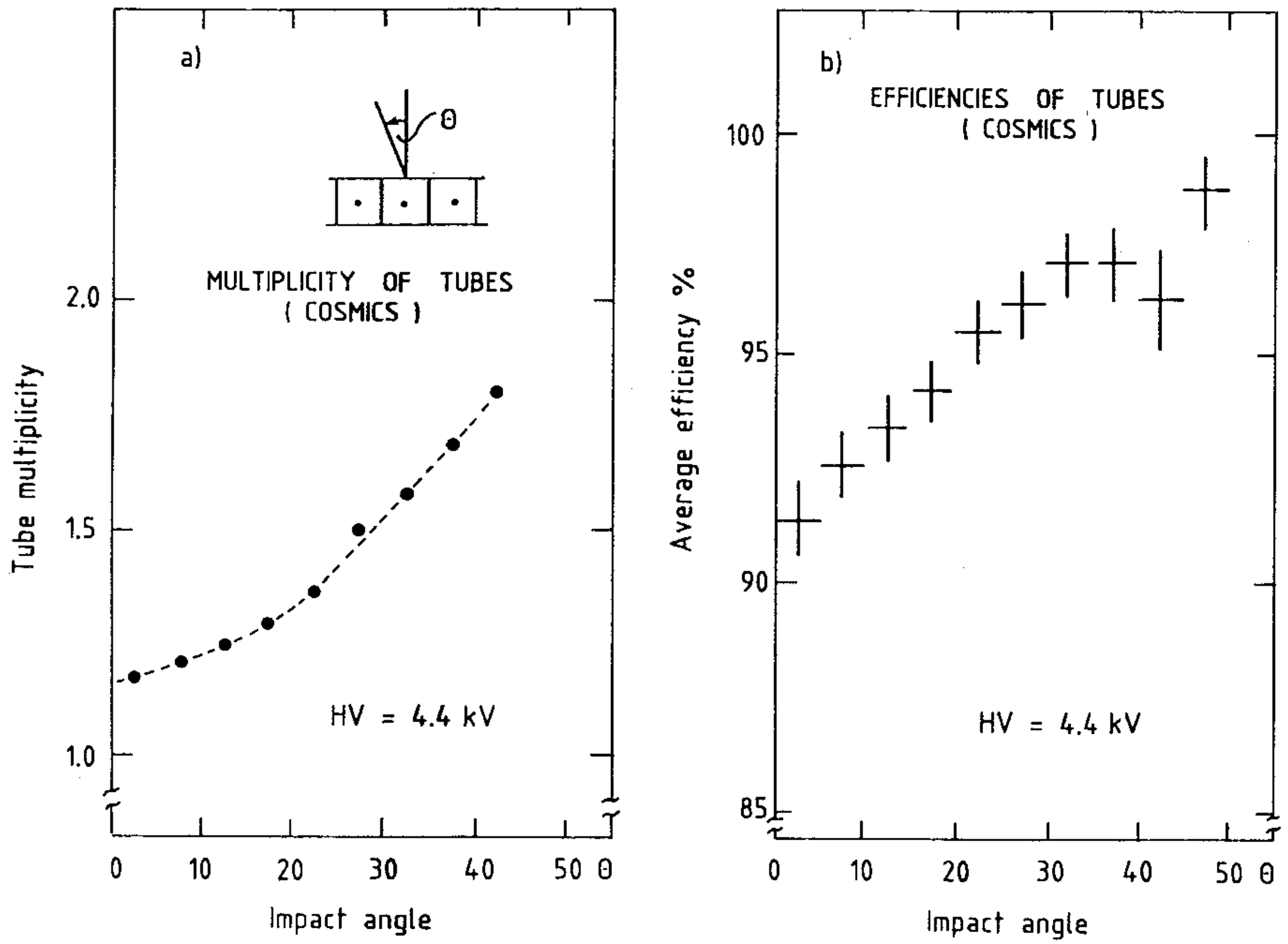

a)
θ
MULTIPLICITY OF TUBES
(COSMICS)
HV = 4.4 kV
Tube multiplicity
2.0
1.5
1.0
0
10
20
30
40
50 θ
Impact angle
b)
EFFICIENCIES OF TUBES
(COSMICS)
HV = 4.4 kV
Average efficiency %
100
95
90
85
0
10
20
30
40
50 θ
Impact angle

Fig. 9

ELECTRON SHOWER

BEAM : 45 GeV/c

PLANE # ↓

```
VERT TUBES           EVNT          79

               1111111111222222222233333333334444
     12345678901234567890123456789012345678901234
225                          1
227                          3
229                        1**1
231                        3*76
233                       3 **
235                       57**
237                    21 1***5
239                         7*1
241                       1**7
243                        277 3
245                        **4
247                       167125
249                        3*   2
251                       567*
253                        57 1
255                       434
               1111111111222222222233333333334444
     12345678901234567890123456789012345678901234
```

PROFILE # →

PION SHOWER

BEAM : 25 GeV/c

PLANE # ↓

```
VERT TUBES           EVNT          88

               1111111111222222222233333333334444
     12345678901234567890123456789012345678901234
225                          1
227                          2
229                          3 2
231                         773
233                        2477 6
235                      5 6*173 1
237                   16 447**43   1
239                   2   333231  5 .  6
241                  1  52 1612 1           1
243                       36*74   1
245                2         2    2
247              51        2 2    11
249                         ***6     1 3
251                          32 2     2 12
253                         652        76
255
               1111111111222222222233333333334444
     12345678901234567890123456789012345678901234
```

PROFILE # →

Fig. 10

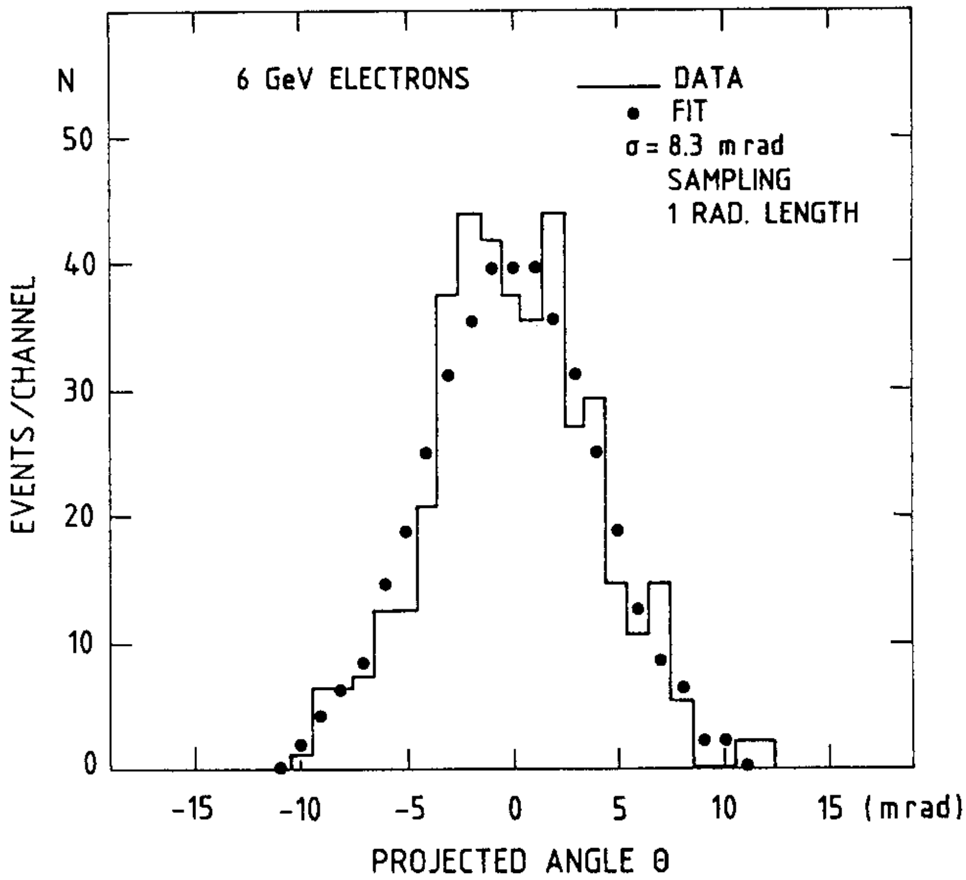

N
6 GeV ELECTRONS
DATA
FIT
σ = 8.3 m rad
SAMPLING
1 RAD. LENGTH
EVENTS /CHANNEL
50
40
30
20
10
0
-15
-10
-5
0
5
10
15 (m rad)
PROJECTED ANGLE θ

Fig. 11