SOME PROPERTIES OF THE STREAMER TUBE SYSTEM OF THE CHARM NEUTRINO DETECTOR

(CERN-Hamburg-Amsterdam-Rome-Moscow Collaboration)

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ABSTRACT

The fine-grain and low-density neutrino calorimeter of the CHARM Collaboration has been designed to measure the energy and the direction of particle showers. To further improve the spatial resolution the calorimeter has been upgraded by adding 20,000 aluminium tubes, working in the limited streamer mode. Each subunit is now equipped with crossed wire planes. Results of a new energy calibration of the upgraded detector using electron and pion beams from 5 to 140 GeV/c, and on the angular and spatial resolution are presented. The use of the streamer tube system to discriminate between electromagnetic and hadronic showers is discussed.

INTRODUCTION

The CHARM detector was designed for the study of different reactions induced by high-energy neutrinos, in particular for a kinematically complete measurement of the neutral-current scattering of ν_μ ($\bar{\nu}_\mu$) on nucleons and electrons. This requires a clear separation of the neutral-current reactions from the charged current ones with an outgoing muon, a precise measurement of the energy and of the direction of the shower initiated in the process, and efficient discrimination between hadronic and electromagnetic showers.

The CHARM Collaboration has constructed a fine-grain and low-density sampling calorimeter of low-Z material ($\langle Z \rangle \simeq 13$) in a modular construction; the average density is 1.38 g/cm^3. It is followed by a muon spectrometer. The calorimeter is built up of 78 equal subunits with marble plates

of 1 radiation length thickness (8 cm) as target material. Each plate is surrounded by a magnetized iron frame for muon identification with large solid angle acceptance. The energy and the direction of the particle showers, as they develop in the target plates, are measured with hodoscopes of scintillation counters and proportional drift tubes. The CHARM detector has been described in detail elsewhere[1].

To improve the spatial resolution of the measurement of the direction of electromagnetic showers -- as, for example, in the study of $\nu_\mu e$ elastic scattering -- 77 subunits of the calorimeter were completed by a plane of 256 streamer tubes each. Its wires are oriented at 90° with respect to the proportional tube wires, thereby providing accurate lateral sampling in two orthogonal projections[2,3] in each subunit.

In this paper we report on the construction of these tubes and on some results of the new energy calibration of the upgraded detector in a test beam containing negative pions and electrons, together with data on the angular and spatial resolution of shower measurements.

THE STREAMER TUBE SYSTEM

Some details of the construction of the streamer tube system are shown in Fig. 1. Two extruded Al profiles of eight cells each are glued together to form one chamber; sixteen chambers make one plane of about 265 cm × 265 cm sensitive area. The cell size is 1 cm × 1 cm. Each end of a chamber is sealed by a plastic cap, which also contains a wire blocking system with conic pins. A 50 μm stainless-steel anode wire was chosen. It is centred by mylar spacers every 50 cm. The presence of the spacers did not create

any electrical problems, discharges or dead zones. Because of restrictions in the available space, the high voltage is fed in via 125 cm long, 50 Ω, coaxial cables, which serve simultaneously to transmit the signal from the wire to the electronics.

A gas mixture of argon + isobutane in a ratio of 1:3 is used. This leads to a working anode voltage of about 3.7 kV, with a width of the plateau of at least 500 V.

The streamer tube system works under these conditions in the limited streamer mode, characterized by very large and rather uniform signals. Fig. 2 shows a charge distribution for cosmics traversing one single streamer tube. The mean charge is about 30 pC for an integration time of 500 ns and an anode voltage of 3.7 kV. The trigger also accepted very inclined tracks, thereby extending the charge distribution to very high values. These large signals allow simple comparators to be used for the front-end electronics.

THE CALIBRATION OF THE CHARM DETECTOR AND ITS STREAMER TUBE SYSTEM

The CHARM calorimeter, upgraded with the planes of streamer tubes, was calibrated in a test beam of negative pions and electrons, in an energy range of 5 to 140 GeV. Bending magnets allowed the beam to be deflected horizontally to hit the detector at different points and with different impact angles. For this calibration, 36 of the 78 identical subunits of the target calorimeter were used.

For beam energies between 5 and 30 GeV, the electrons could be tagged by a 20 m long helium-filled threshold Čerenkov counter; 50 GeV electrons were identified by the width of their shower profile. Above 50 GeV the

electron component of the beam was less than 1%. For measurements with a pure pion beam, a lead filter was placed in the beam. The beam intensity was around 50 particles per pulse in a 30 ms spill. The central beam momentum was known to ±1%; the fractional momentum spread was less than 1%.

Figure 3 shows a scatterplot for beam particles at 20 GeV. Appropriate cuts in the Čerenkov pulse height and the shower width allowed us to distinguish between electrons and pions. This could then be used to develop some algorithms for the separation of electron- and pion-induced showers.

THE ENERGY RESPONSE AND RESOLUTION

An estimator for the energy of the incoming particles is the total number of streamer tubes fired, N_{tot}. The dependence of N_{tot} on the beam energy for electrons and pions is shown in Fig. 4. Because of the digital mode of operating the streamer tubes, the response is not proportional to the energy over the whole energy range; if more than one particle hits a tube they are counted as one hit. This saturation effect is most pronounced for electron-induced showers, because of their higher track density.

The non-linear response of the streamer tubes produces a deviation from the $1/\sqrt{E}$ dependence of the resolution. Figures 5a and 5b show for comparison the resolution $[\sigma(E)/E]\cdot\sqrt{E_b}$ for the streamer tubes and the scintillation counters as a function of the beam energy for pions and electrons. For linear response the resolution would be constant in this representation. The parametrization of the scintillator resolution gives

i) for pions

$$\frac{\sigma(E_\pi)}{E_\pi} = \frac{0.46}{\sqrt{E_b}} + 0.01 \qquad (7.5\ \text{GeV} \le E_\pi \le 140\ \text{GeV})$$

ii) for electrons

$$\frac{\sigma(E_e)}{E_e} = \frac{0.20}{\sqrt{E_b}} \qquad (5\ \text{GeV} \leq E_e \leq 50\ \text{GeV})\ .$$

However it should be noted that the resolution of the streamer tubes for incident pions below 20 GeV is only 20% worse than for scintillation counters; for electrons the resolution is worse owing to the stronger saturation.

The energy resolution of the detector for hadronic showers can be further improved by combining the scintillator and streamer tube information; as seen in Fig. 6 the improvement is about 20% at 140 GeV and less at lower energies. The combined resolution is

$$\frac{\sigma(E_\pi)}{E_\pi} = \frac{0.47}{\sqrt{E_b}} \qquad (7.5\ \text{GeV} \leq E_\pi \leq 140\ \text{GeV})\ .$$

The reason for this reduction can be understood as follows. The response of the scintillation counters to electromagnetic energy is higher than to hadronic energy[1]; for streamer tubes the opposite behaviour occurs, as can be seen in Fig. 4. The combined response function to electromagnetic and hadronic energy is therefore closer to equality. Hence, the fluctuations of these two components of hadronic showers have a reduced influence on the combined resolution, as shown in Fig. 6.

SEPARATION OF ELECTRON- AND PION-INDUCED SHOWERS

The target material of the CHARM detector was chosen such that approximately equal lengths were obtained for hadronic and electromagnetic showers,

thus minimizing the fluctuations in the length of the showers induced by semileptonic neutrino interactions. This makes it difficult to use the shower length to distinguish between electromagnetic and hadronic showers. Owing to the fine granularity of the detector, several methods of separation, based on the lateral shower profile, have been developed.

Figures 7a and 7b show the distribution of the width of 20 GeV electron- and pion-induced showers, as measured by the scintillators and the proportional drift tubes of the target calorimeter, respectively. The half width Γ of a Cauchy distribution fitted to the measured profiles is plotted for the scintillation counters, the r.m.s. width σ for the proportional drift tubes. Both distributions show a clear separation of electron- and pion-induced showers. A selection of events with $\Gamma < 1.6$ cm and $\sigma < 9$ cm gives a rejection factor of nearly 100 for pion-induced showers and an efficiency of $(85 \pm 5)\%$ for electrons.

The CHARM Collaboration has developed another algorithm, which uses the streamer tube system for the separation of electromagnetic and hadronic showers. It counts for a certain fraction of the shower length the number of non-fired tubes ("holes") between the extremes of the lateral shower width. A clear distinction for electron- and pion-induced showers can be seen in Fig. 8, where the mean number of holes as a function of the plane distance from the vertex is displayed.

Estimators for the separation are derived

a) by using only the digital information of the streamer tubes, in this case the maximum number of holes in a certain shower length,

b) by combining the streamer tube information (N_{tot}) and the visible shower energy deposited in the scintillators (E_{vis}); here the variable E_{vis}/N_{tot} is used.

In method (a) two estimators for electromagnetic showers are defined: the maximum number of holes in a plane i, $H_i^{max}(E)$, and the maximum of the total number of holes in the first 8 planes of the shower, $H_{tot}^{max}(E)$. They are fixed by appropriate cuts so that at least 90% of electron-induced events are recognized as being of electromagnetic origin. Applying these estimators to pion-induced showers of the same energy, only a few percent of them are declared as electron-induced events. This can be seen in Fig. 9.

An additional rejection can be obtained using the ratio between the energy seen in the scintillators and the number of streamer tube hits in the first part of the shower [method (b)]. In the first planes of the shower electrons not only deposit more visible energy than pions, but also give fewer hits, owing to the higher track density and hence larger tube saturation. Figure 10 gives the distribution of E_{vis}/N_{tot} for 20 GeV shower energy. A suitable cut together with the previously defined estimators allows for further pion rejection [method (b) in Fig. 9].

IMPROVEMENTS OF THE (LATERAL) VERTEX AND ANGULAR RESOLUTION

Due to the addition of the streamer tubes, two orthogonal coordinates can be measured in each calorimeter subunit. This improves both the vertex and the angular resolution.

a) For hadronic showers

The vertex resolution is mainly improved at low energy (by about a factor of 2); at 140 GeV the improvement is still about 20%. This brings the vertex resolution down to $\sim$ 3 cm at 7.5 GeV and to $\sim$ 2 cm at 140 GeV.

For measuring the shower direction the vertex and the barycentre of the shower have to be known. The better determination of the vertex and the barycentre using the streamer tubes also imply a better angular resolution. The largest improvements will again be at low energies.

b) For electromagnetic showers

Several improvements in the resolution of the direction measurement of electromagnetic showers can be obtained using the additional information from the streamer tubes. The vertex resolution in the close projection is obtained using the drift-time measurement of the proportional drift tube plane following the target plate in which the interaction occurred and the streamer tube hit-position to lift the left-right ambiguity. Figure 11 shows the corresponding angular resolution $\Delta\theta_1$ [4]. Another improvement is the vertex resolution in the far projection. Using the streamer tube plane following the target plate in which the interaction occurred instead of the proportional drift tube plane behind the next target plate (see $\Delta\theta_2$ in Fig. 11), a resolution similar to the one obtained in the close projection can now be achieved. Further improvement in the resolution of the shower direction is expected because of the additional sampling of the shower profile by the streamer tube planes.

References

1) A.N. Diddens et al. (CHARM Collaboration), Nucl. Instrum. Methods 178 (1980) 27.

M. Jonker et al. (CHARM Collaboration), Nucl. Instrum. Methods 200 (1982) 183.

2) M. Jonker et al., Phys. Scripta 23 (1981) 677.

References to the earlier literature can be found therein.

3) M. Jonker et al., The limited streamer tube system of the CHARM Collaboration, to be published in Nucl. Instrum. Methods (1982).

4) M. Jonker, PhD Thesis, University of Amsterdam (1983).

Figure captions

Fig. 1 : Some construction details of the streamer tubes.

Fig. 2 : Charge distribution for cosmics traversing one tube with wide angular spread.

Fig. 3 : Scatter plot of the Č-pulse height of beam particles and their shower width.

Fig. 4 : The response of the streamer tube system for pions and electrons.

Fig. 5 : The energy resolution of the streamer tube system for a) pions and b) electrons.

Fig. 6 : The energy resolution of the scintillation counters and its improvement with the streamer tubes.

Fig. 7 : Distribution of the width of 20 GeV electron and pion showers, as measured by a) the scintillators and b) the proportional drift tubes.

Fig. 8 : The mean number of holes between streamer tube hits for pions and electrons as a function of the distance from the vertex.

Fig. 9 : Efficiencies for electron and pion separation using the streamer tubes.

Fig. 10 : Distribution of the ratio of the visible energy in the scintillators and the streamer tube hits for electron- and pion-induced showers.

Fig. 11 : The angular resolution for electromagnetic showers in the close ($\Delta\theta_1$) and far ($\Delta\theta_2$) projection as a function of the energy.

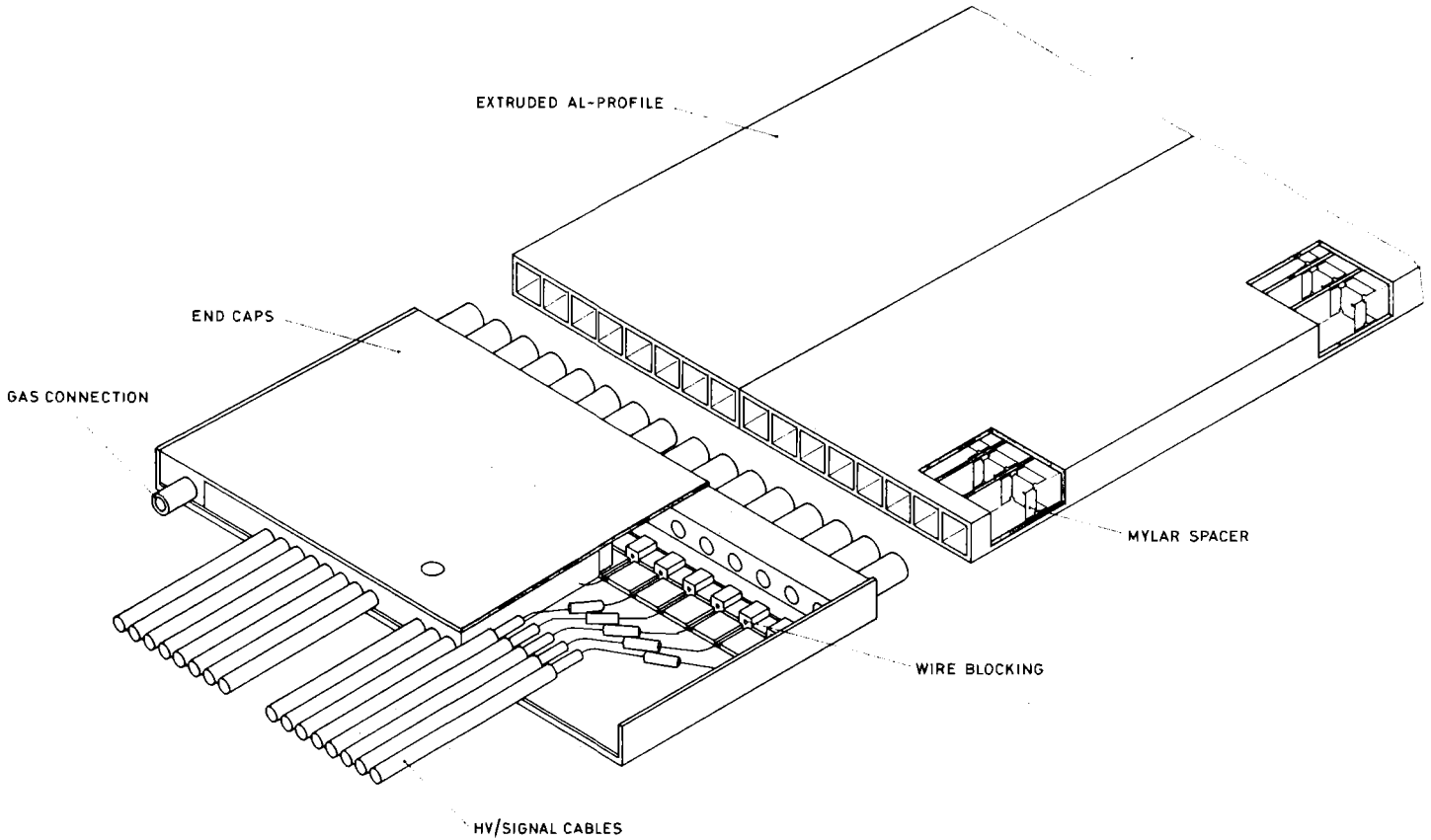

EXTRUDED AL-PROFILE
END CAPS
GAS CONNECTION
MYLAR SPACER
WIRE BLOCKING
HV/SIGNAL CABLES

Fig. 1

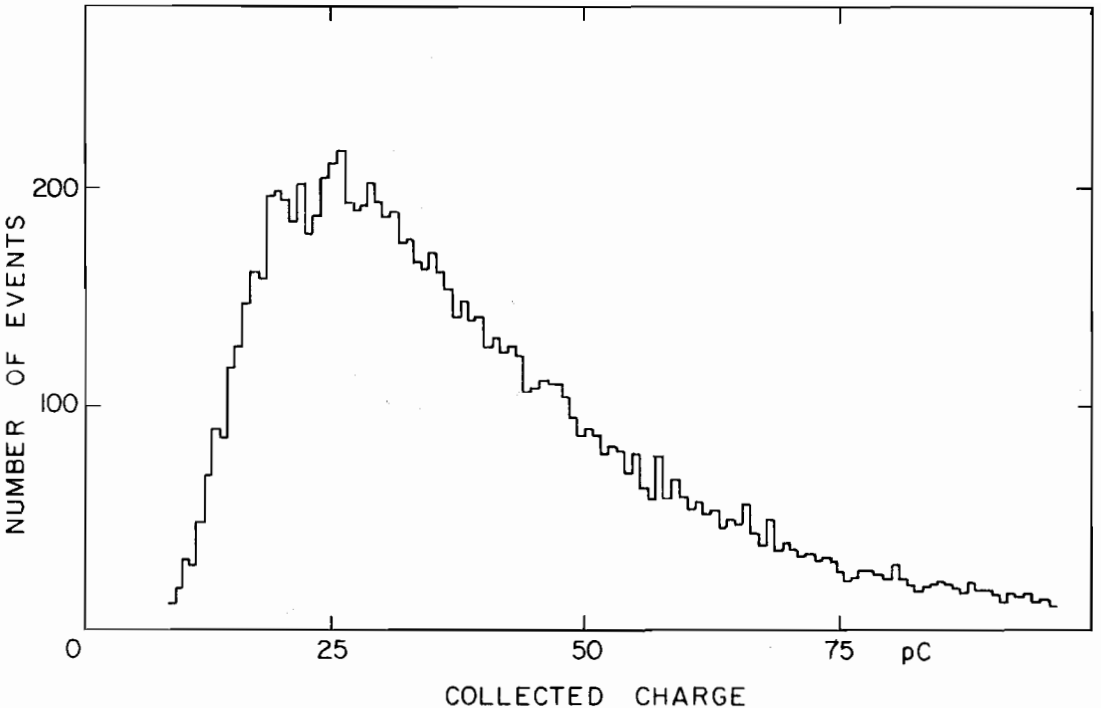


Fig. 2

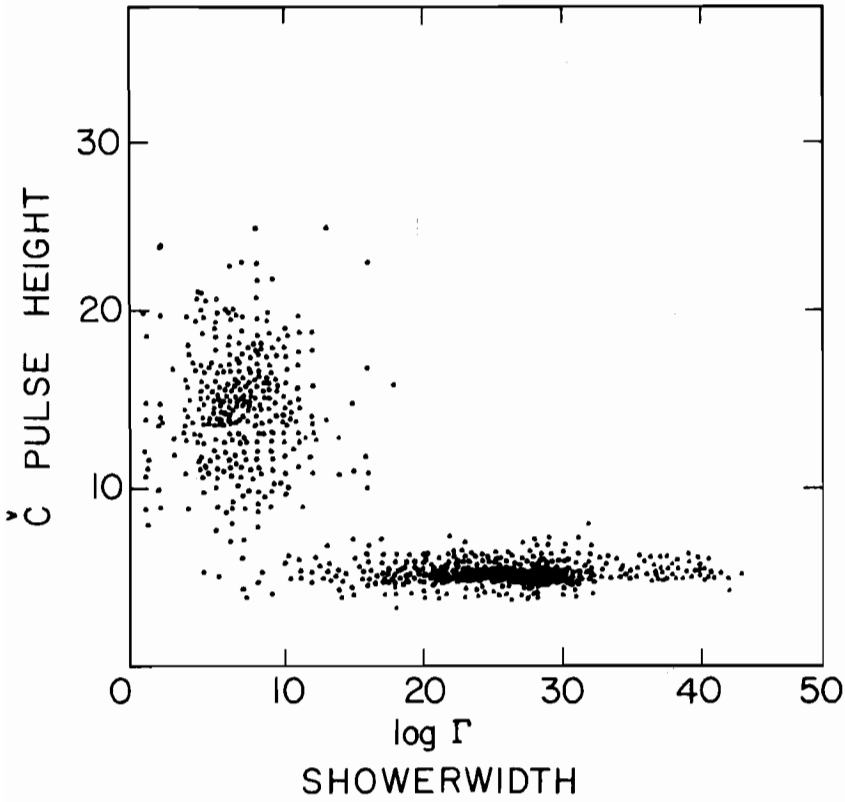


Fig. 3

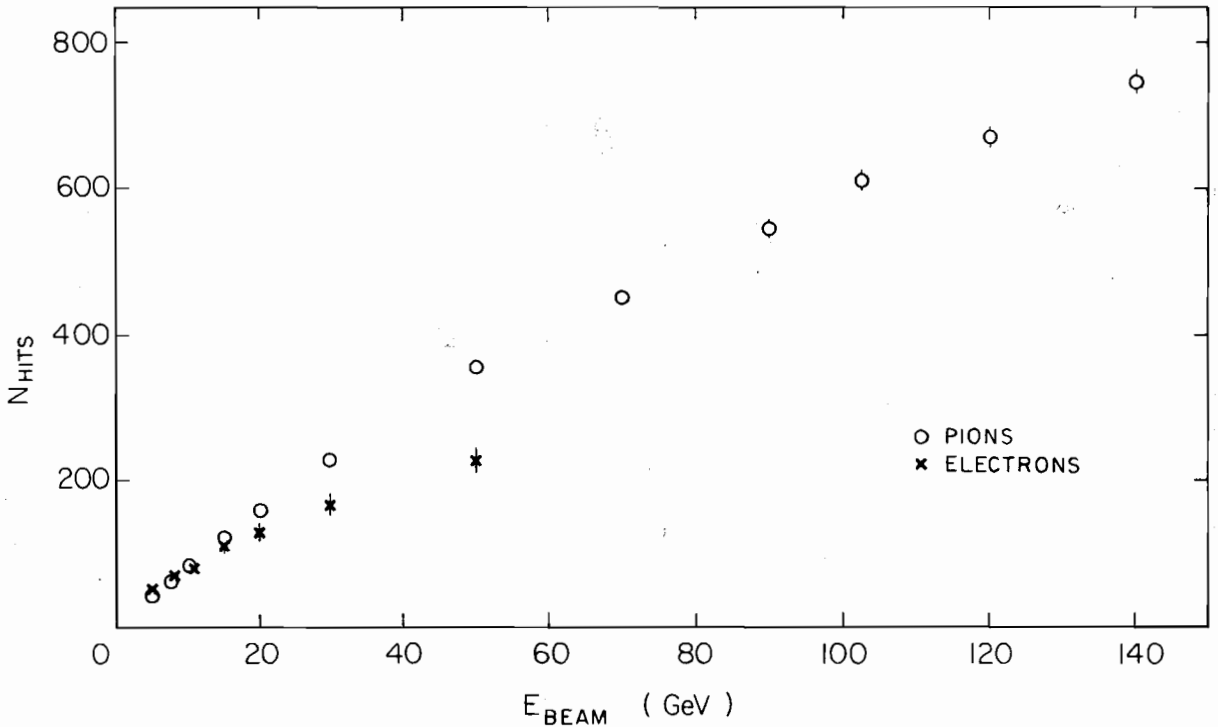
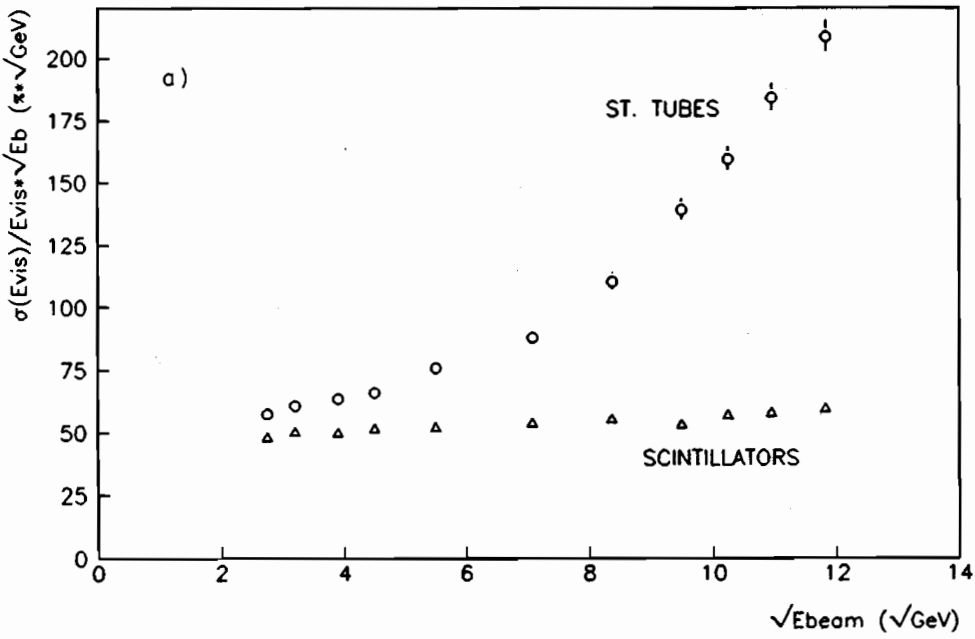

800
600
400
200
N_{HITS}
0
20
40
60
80
100
120
140
E_{BEAM} (GeV)
O PIONS
× ELECTRONS

Fig. 4


a)
ST. TUBES
SCINTILLATORS
σ(Evis)/Evis*√Eb (%*√GeV)
√Ebeam (√GeV)
0
25
50
75
100
125
150
175
200
0
2
4
6
8
10
12
14

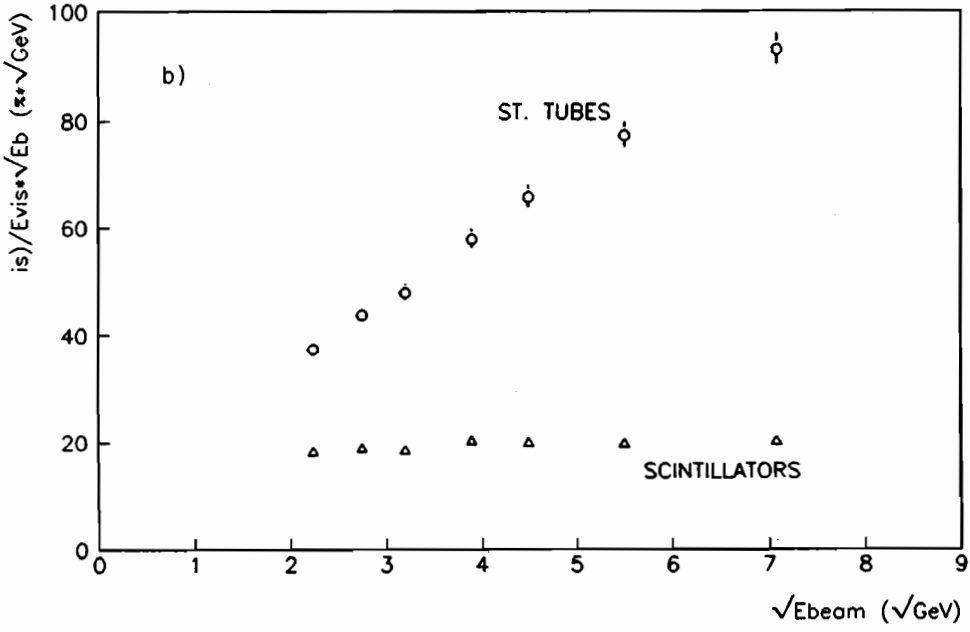

b)
ST. TUBES
SCINTILLATORS
is)/Evis*√Eb (%*√GeV)
√Ebeam (√GeV)
0
20
40
60
80
100
0
1
2
3
4
5
6
7
8
9

Fig. 5

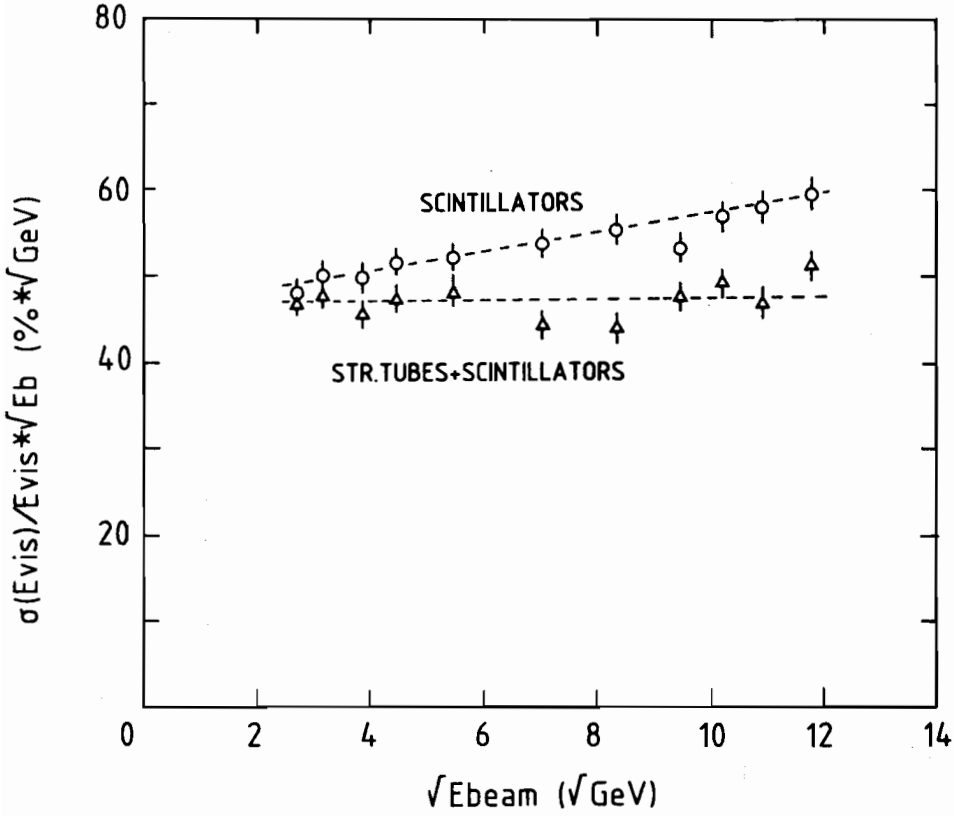

80
60
40
20
0
2
4
6
8
10
12
14
SCINTILLATORS
STR.TUBES+SCINTILLATORS
σ(Evis)/Evis*√Eb (%*√GeV)
√Ebeam (√GeV)

Fig. 6

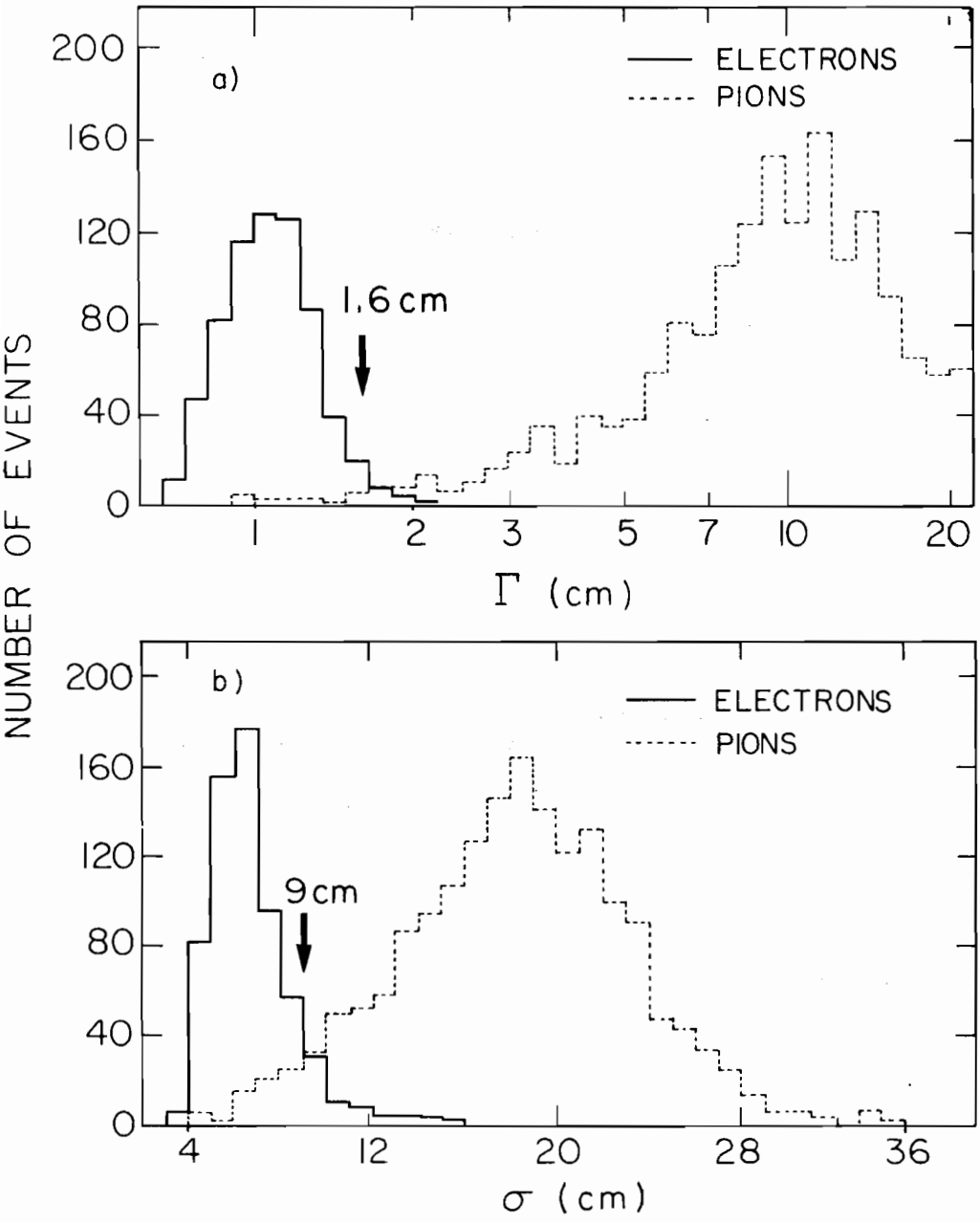

NUMBER OF EVENTS
a)
ELECTRONS
PIONS
1.6 cm
200
160
120
80
40
0
1
2
3
5
7
10
20
Γ (cm)
b)
ELECTRONS
PIONS
9 cm
200
160
120
80
40
0
4
12
20
28
36
σ (cm)

Fig. 7

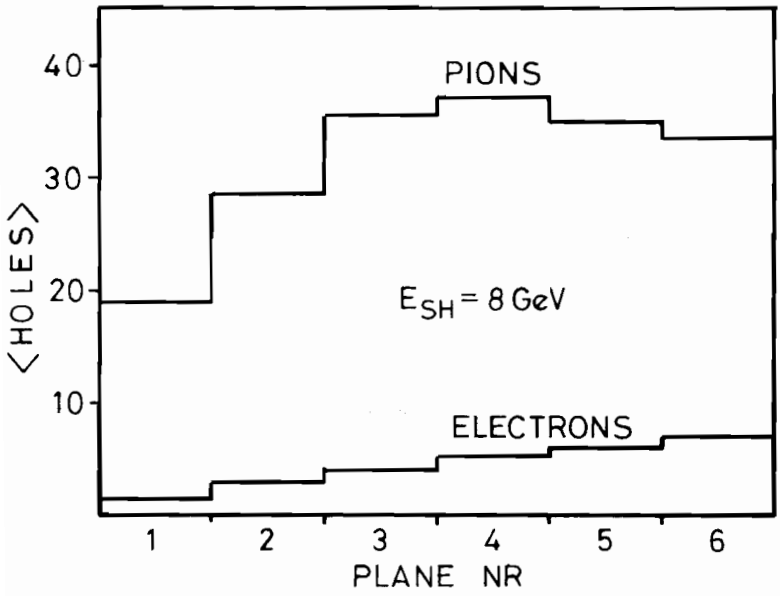


Fig. 8

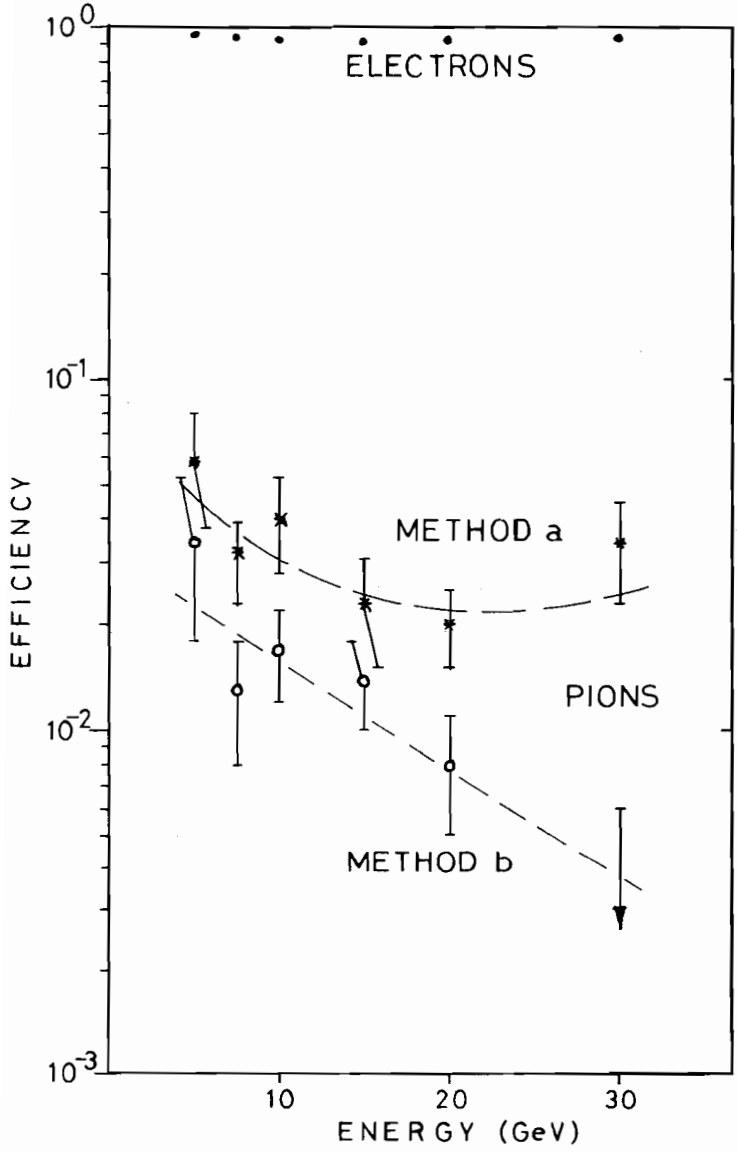

ELECTRONS
METHOD a
PIONS
METHOD b
EFFICIENCY
ENERGY (GeV)
10^0
10^{-1}
10^{-2}
10^{-3}
10
20
30

Fig. 9

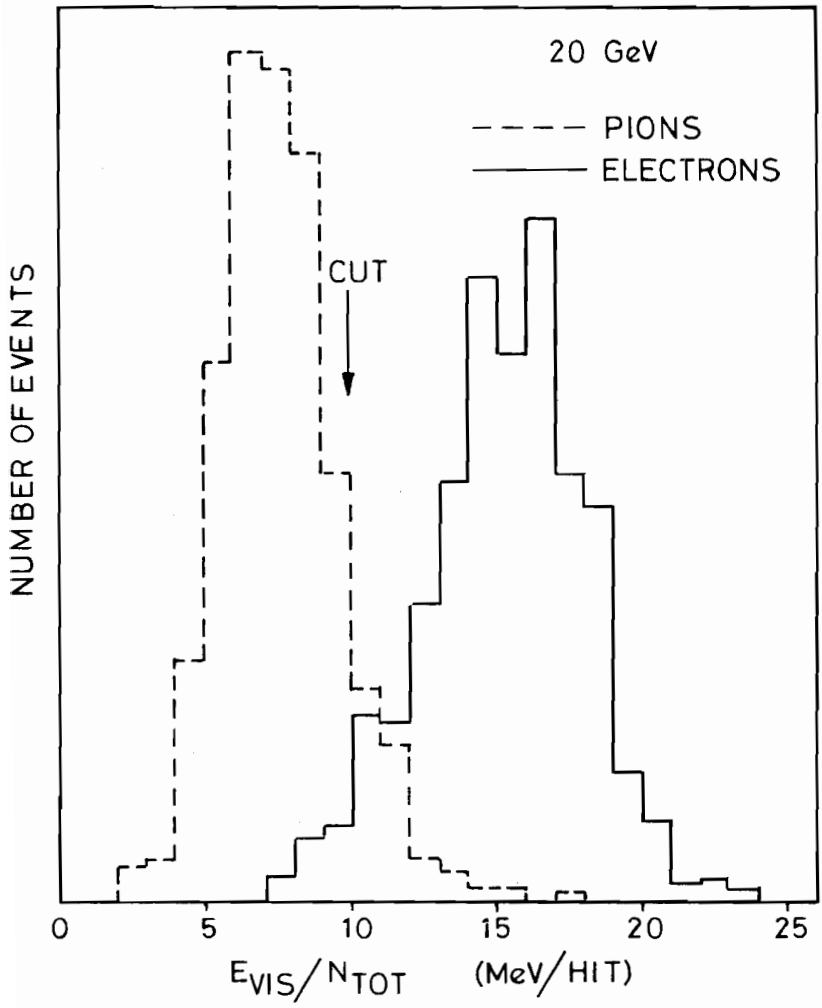

20 GeV
PIONS
ELECTRONS
CUT
NUMBER OF EVENTS
0
5
10
15
20
25
E_{VIS}/N_{TOT} (MeV/HIT)

Fig. 10

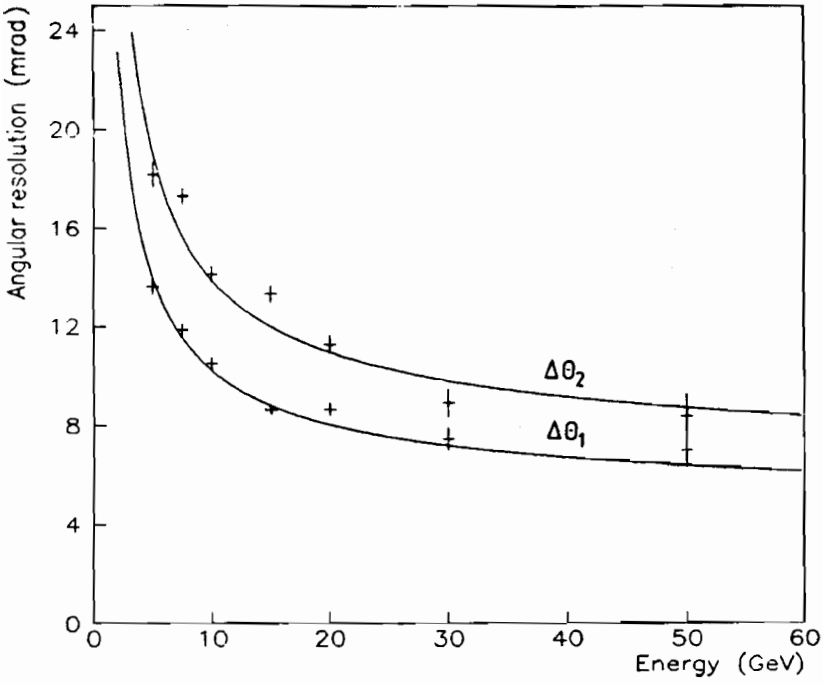

Angular resolution (mrad)
24
20
16
12
8
4
0
0
10
20
30
40
50
60
Energy (GeV)
$\Delta\theta_2$
$\Delta\theta_1$

Fig. 11