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A SHOWER POSITION DETECTOR INSIDE AN ELECTROMAGNETIC CALORIMETER

B.Aubert, P.Catz, J.Colas, M.Della-Negra, A.Gonidec, J.P.Lees, D.Linglin, M.N.Minard, M.Yvert

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ABSTRACT.

We present the results of a test in an electron-hadron beam (5-90 GeV) of the prototype of a position detector. This position detector consists of proportionnal tubes with charge division readout, giving the position and a coarse value of the shower energy. This detector will be used in the end cap electromagnetic calorimeter (bouchon) of the UA1 experiment (CERN $\bar{p}p$ Collider). We give results on the properties of the tubes and on the development of the shower in the lead-plastic sandwich.

INTRODUCTION.

We are currently building in Annecy the two electromagnetic end cap calorimeters of the UA1 experiment[1] (CERN $\bar{p}p$ collider). Each end cap calorimeter covers, at 3 meters from the interaction point, an angle θ between 5 and 25° with respect to the beam axis, the total thickness is 28 radiation lengths (X_o) of lead scintillator sandwich (4 mm Pb, 6 mm scintillator) divided into 4 stacks along the shower direction. The 2π ϕ angle is divided into 32 sectors (petals) of equal size, each stack of each petal being read out using BBQ light shifter technique.[1]

This arrangement is an upgraded solution with respect to the proposal : choosing the attenuation length of the scintillator to be ∿80 cm, we use the exponential attenuation of the light along the petal to obtain a pulse roughly proportional to $P_t = E \sin \theta$. We have tested this to be the case within 20 % over the length of a prototype stack.

This solution, which will allow us to have directly P_t , is welcome at the trigger level, but forces us to get (off line) the energy to measure the $\sin \theta$ factor, i.e. the position of the shower inside the calorimeter.

Furthermore, this end cap E.M. calorimeter will have to handle multishower events, the position detector should therefore give a redundant position information in order to remove ambiguities, it should also give a coarse measurement of the energy in order to resolve two showers in the same petal.

THE POSITION DETECTOR.

The solution we have adopted is to place at a depth of 11 X_o , that is after the two first stacks of scintillator-lead sandwiches, two planes of proportional tubes (one vertical, one horizontal) (fig. 1).

The tubes are extruded aluminium with a square cross-section (2×2 cm^2), 0.15 cm thickness. We use a Ni-Cr alloy wire of 25 µm diameter (R $\sim$ 3 kΩ/meters), the critical impedance[2] is :

$$Z_c = \frac{2600}{\ell} \quad (Z_c \text{ in ohms, } \ell \text{ in meters})$$

the electronics diagram is shown in fig. 2 : the positive high voltage is applied to the wire via a 1.5 MΩ resistor and the signal is collected at each end of the tube on a 1 nf capacitor. A 50 Ω, 6 meters long cable brings the signal to an amplifier[3] which is placed outside the calorimeter. This amplifier, using a high gain channel (750) and a low gain channel (25), has a better than 1 % linearity on a very large dynamic range. The aim of this is to cope with the large dynamic expected from the tubes, from a single muon at one end to a 200 GeV EM shower at the other end of the tube. Each output is analysed by an ADC (4 ADC channels per tube).

TEST OF A PROTOTYPE.

In October 1979 we have performed extensive tests of a 2×8 tubes prototype in the CERN SPS H1b beam. This beam can be tuned at will to pure hadrons or pure electrons up to 92 GeV/c. The aim of the test was to study the properties of the tubes when fired by high energy electromagnetic showers and the properties of the showers themselves.

The set up we have used is shown on fig. 3, the beam is defined by 3 scintillator counters and the incoming particle direction measured by two MWPC (2 mm wire spacing). The two modules of 8 tubes each were placed in front of a one-stack petal prototype the whole set up being placed on a movable chariot. In front of the tubes was placed a cradle in which we could place at will up to 32 plates of .4 cm Pb + .6 cm plastic in order to simulate the calorimeter. We have operated the tubes at 1650 volts with a gas mixture argon-ethane 50%-50% and an ADC gate of 800 ns.

At the analysis (off line) we have cut a spot of the beam of 1×1 cm^2 and rejected all events in which there was more than one cluster in one plane of the beam MWPC.

HARDWARE TESTS.

a) Uniformity : The aim of this test was to study if the response of a large system is uniform without sophisticated corrections. We have only calibrated the relative high/low gain of each amplifier and assumed all the low gain amplifiers identical, we have also assumed the same calibration for all ADC's (Lecroy 2249 during this test) using a pure pion beam without absorber in front of the tubes, we compute the total charge collected from 8 tubes :

$$Q = \sum_{i=1}^{8} q_{i\ left} + q_{i\ right}$$

and we fit the Landau like shape(4)

$$N(Q) = \frac{1}{\sqrt{2}} \frac{1}{\xi} \Delta Q\ N_T e^{-\frac{1}{2}(1+e^{-\lambda})}$$

with $\lambda = \frac{Q-Q_o}{\xi}$

where $N(Q)$ is the number of events in the bin ΔQ and N_T the total number of events. We adjust Q_o and ξ , Q_o gives the position of the maximum, the typical result of such a fit is shown on fig. 4. Moving the chariot in 20 different (x,y) positions we got a mean value of the Landau peak position

$$\langle Q_o \rangle = 0.116 \pm 0.008 \quad pc$$

which shows that even with almost no corrections to the data we got an uniform response within 7 %.

b) Saturation : Since an EM shower develops a large number of particles, we have studied the saturation of the tube n° 4, which was on the beam line, by comparing the total charge collected in the tube, varying the high voltage, for

i) a single incoming pion with no lead in front of the tubes,

ii) an electron shower produced by a 92 GeV electron traversing 11 X_0 of lead + plexi sandwich.

In both cases we plot the mean charge collected, normalized at the normal working point 1650 volts, as a function of V, V being the working voltage in volts. Fitting a dependence of the form :

$$\frac{\bar{Q}(V)}{\bar{Q}(1650)} = e^{\gamma(V-1650)}$$

we obtain for γ :

case i) $\gamma = (8.62 \pm 0.02)10^{-3}$ volts^{-1} Fig. 5.a

case ii) $\gamma = (8.9 \pm 0.5)10^{-3}$ volts^{-1} Fig. 5.b

We conclude that at 92 GeV we are far from saturation, the tubes can stand a factor of 2 more gain and consequently will not saturate even in a 200 GeV shower. But clearly we have to work with very low gain on the wire.

c) Charge collection inside the tubes : Since the cross section of the tubes is a square, the electric field if far from uniform inside the tube, we have studied how uniformly the charges are collected. Using incoming 92 GeV pions with no lead in front of the tubes and removing the 1×1 cm^2 cut on the beam spot, we use the beam MWPC information to locate the traversing track to ± 1 mm and plot the mean charge collected fig. 6. We conclude that the collection is uniform inside the whole cross section.

d) Position measurement : From one plane of tubes, we get the two coordinates X and Y. Using the horizontal tubes we define :

$$x^i_{CD} = \frac{\ell_{eff}}{2} \frac{q^i_{left} - q^i_{right}}{q^i}$$

$$q^i = q^i_{left} + q^i_{right}$$

where i stands for tube number i, $q_{left(right)}$ = charge collected on left (right) side, ℓ_{eff} = effective length of the tube. We have calibrated ℓ_{eff} by moving the chariot and we found a mean value of $\ell_{eff}/2$ = 99±6 cm for a real length $\ell/2$ = 72 cm. We take the center of gravity to get a mean value of the charge division coordinate by

$$X_{CD} = \frac{\sum_{i=1}^{8} x_{cd}^{i} q^{i}}{\sum_{i=1}^{8} q^{i}}$$

this because a shower develops on several tubes.

We have tested the linearity of this charge division measurement by moving the chariot along X for a 92 GeV electron beam with 11 X_0 of Pb-plexi sandwich in front of the tubes (maximum signal) fig.7.

Still using the horizontal tubes, we get the Y coordinate of the shower by :

$$Y_{WM} = \frac{\sum_{i=1}^{8} q_i y_i}{\sum_{i=1}^{8} q_i} \qquad \text{(WM = weighted mean)}$$

where y_i is the Y coordinate of tube i. We have studied the precision in position of the shower, as a function of the incoming electron energy, comparing the position obtained from the beam MWPC with the position obtained from the tubes. On fig.8 is shown the r.m.s. of the difference between these two measurements :

$$\Delta X = X_{MWPC} - X_{CD} \text{ (charge division)}$$

$$\Delta Y = Y_{MWPC} - Y_{WM} \text{ (weighted mean).}$$

The weighted mean measurement is always much better than the charge division one and both are giving a very satisfactory accuracy. Note that the 2 mm error we got at 92 GeV is largely due to the MWPC 1 mm precision on beam position.

E.M. SHOWERS PROPERTIES.

In order to study in more details the properties of electro magnetic showers, we have taken data changing both the electron beam energy and the number of pb+plexi plates in front of the tubes.

The charges collected in the tubes have not been corrected for small fluctuations in the gas amplification due to atmospheric pressure, gas mixture fluctuation, HV fluctuation... We estimate a ±10 % systematic error on the collected charge due to these fluctuations. Leaving as before a beam spot of 1×1 cm^2, we take as a good approximation of the transverse size of a shower (r.m.s.) the r.m.s. of the distribution of the tubes weighted by the mean charge deposited per accepted incident electron. By charge collected, we mean the charge at the input of the amplifiers[(5)].

a) Total charge per event : On fig. 9.a,b is shown the mean value of the total charge collected from the tubes at a depth of 11 X_o of pb+plexi sandwich as a function of the incident electron energy from 5 to 92 GeV (fig. 9.a) and at 10,30 and 92 GeV as a function of the depth from 0 to 23 X_o of sandwich (fig. 9.b). The data are compared to the phenomenological formula developped by Longo and al.[(6)] to describe E.M. showers in scintillator up to 5 GeV, the numerical parameters are from Saas and Spiro[(7)] who used this formula to describe also showers in a Pb-scintillator sandwhich, we have normalised the formula using the 92 GeV point of fig. 9.a :

$$Q(t,E) = 0.6\ t^{\alpha} e^{-bt}$$

with Q in picoloulomb

$\alpha = 2.+0.4343 \log E$, $b = 0.46$,

E in Gev, t in radiation length.

The agreement between the "scintillator formula" and our points is note-worthy if one considers the difference in the energy cut off of the two detection mecanisms.

b) Shape of showers : The mean shower profiles are shown on fig. 10 at 11 X_0 as a function of electron energy and on fig. 11 for 92 GeV electron for various depths. Fig. 12.a shows that the transverse width of the shower, (r.m.s.) at fixed depth is completely independant of the shower energy ; our data are in complete agreement with the result obtained by Breare and al.[8] who were using a flash tube device. We found a shower transverse width (r.m.s.) increasing linearly with the depth (fig. 12.b). We attribute the larger r.m.s. observed at $0X_0$ to the contribution of particles emitted backward by the shower when developping in the petal prototype placed dowstream, this is in qualitative agreement with Monte Carlo calculation and will be described in more details elsewhere.[9]

c) Energy resolution : Since the total charge collected grows almost linearly with energy at a depth of 11 X_0, we expect an error on Q growing like $\sqrt{E}$. We got (fig. 13) :

$$\frac{\sigma(Q)}{Q} = \frac{1.29}{\sqrt{E}} + 0.05 \qquad \text{(E in GeV)}$$

by only imposing the curve to pass through the 5 GeV and 92 GeV points.

CONCLUSION.

These results have shown that these tubes will be a good position detector for the UA1 end cap EM calorimeter. With almost no correction we can expect a good uniformity, and no saturation up to at least 200 GeV EM showers. We found a very uniform collection of the primary charge inside the tubes, a charge division measurement nicely linear for a 92 GeV EM shower and a very satisfactory accuracy in the EM shower position determination (down to 2 mm at 92 GeV).

We found that the development of an E.M. shower, seen by a gas detector is well described by a simple formula scaled from scintillator measurements and that the transverse "width" of an EM shower penetrating the calorimeter evolves as if the shower remain in a cone, the opening angle of this cone being completely independent of the shower energy up to 92 GeV.

We would like to thank Mr. J.Boniface, Mr.Ditta, Mr.J.C.Lacotte and Mr. J.C.Le Marec for building and testing the proportional tubes and the associated electronic.

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Aachen-Annecy-Birmingham-CERN-Collège de France-Queen Mary College-Riverside-Rutherford-Saclay Collaboration CERN/SPSC/78-06.

(2) V.Radeka and P.Rehak, BNL 25070 (1978).

(3) J.Colas and J.C.Lacotte,
A low noise, large dynamic range pulse amplifier.
Wire chamber Conference - Vienna - 1980.

(4) F.Sauli,
Principle of operation of multiwire proportional and drift chambers, CERN-77-09 (1977).

(5) To transform the charge into "minimum ionization equivalent signal" one should use the value of the maximum of the Landau distribution Q_o = .12 picocoulombs.

(6) E.Longo and I.Sestili, NIM 128 (1975) 283.

(7) J.Saas and M.Spizo, CERN $\bar{p}$p Tech. Note 78-32.

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(9) J.P.Lees, These of 3ème Cycle, University of Grenoble. To be published.

FIGURE CAPTION.

Fig.1 Schematic view of the position detector and its slot inside a half of a "bouchon" (UA1 end cap EM calorimeter).

Fig.2 Schematic arrangment of the electronic for one tube.

Fig.3 Experimental layout used for the tests.

Fig.4 Fit of a Landau like shape on the total charge collected with incident pions and no lead in front of the tubes.

Fig.5 Mean charge collected normalized to the charge at 1650 volts, versus high voltage
a) with incident pions and no lead in front of the tubes,
b) with 92 GeV incident electrons and 11 X_o of pb+plexi sandwich in front of the tubes.

Fig. 6 Charge collection inside the tubes.

Fig.7 Linearity of the charge division measurement when the tubes are find by a 92 GeV e^- shower, with 11 X_o in front of the tubes.

Fig.8 Accuracy in position measurement vs energy, using charge division and weighted mean.

Fig.9 Total charge collected (over 8 tubes)
a) at a depth of 11 X_o of pb+plexi sandwich from 5 to 92 GeV electrons, the error bars are indicating the width of the charge distribution.
b) at 10,30,92 GeV as a function of depth from 0 to 23 X_o of pb+plexi sandwich.

Fig.10 Electron shower profiles at a depth of 11 X_o of pb+plexi sandwich from 5 to 92 GeV.

Fig.11 92 GeV electron shower profile at depth varying from 0 to 23 radiation length.

Fig.12 Transverse width of the electron shower (RMS)
a) versus energy,
b) versus depth.

Fig.13 Resolution of the total change collected on eight tubes versus energy.

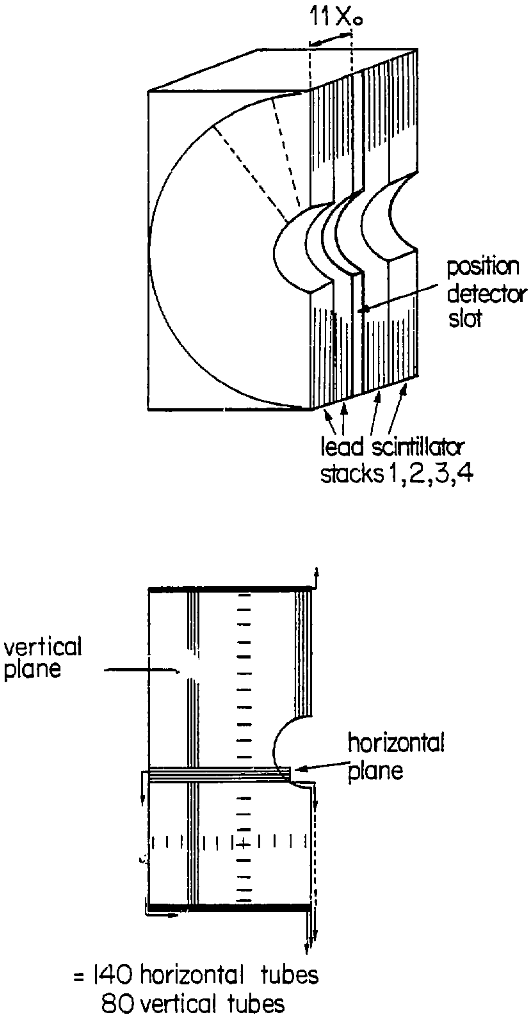

11 X₀
position
detector
slot
lead scintillator
stacks 1,2,3,4
vertical
plane
horizontal
plane
= 140 horizontal tubes
80 vertical tubes

Fig. 1

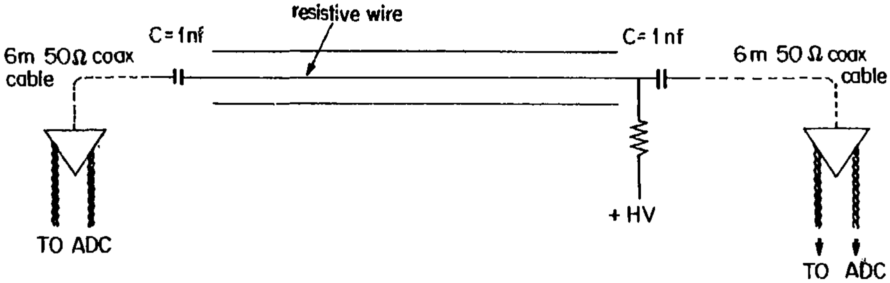

resistive wire
C=1nf
C=1nf
6m 50Ω coax
cable
6m 50Ω coax
cable
+HV
TO ADC
TO ADC

Fig. 2

LAYOUT OCTOBER 1979 TEST POSITION DETECTOR

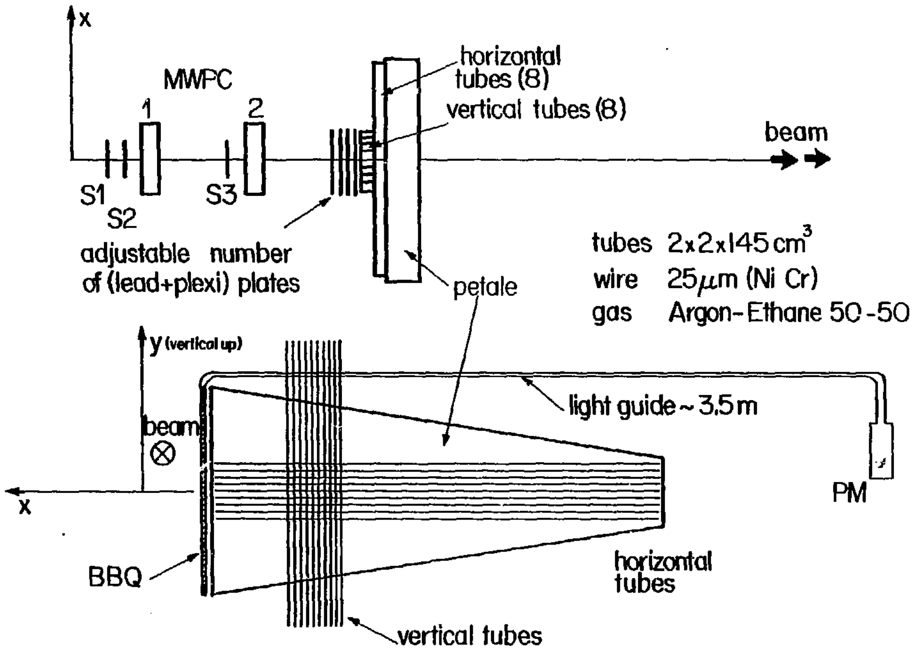


Fig.3

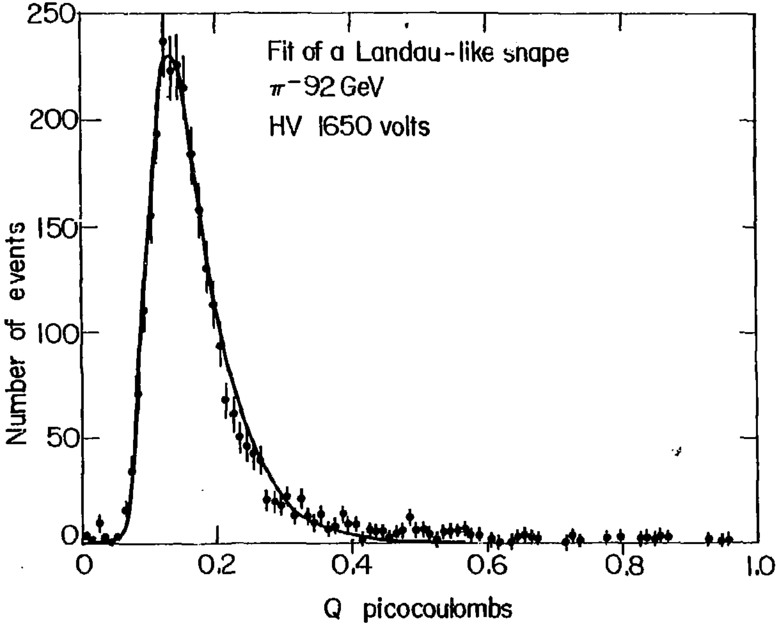
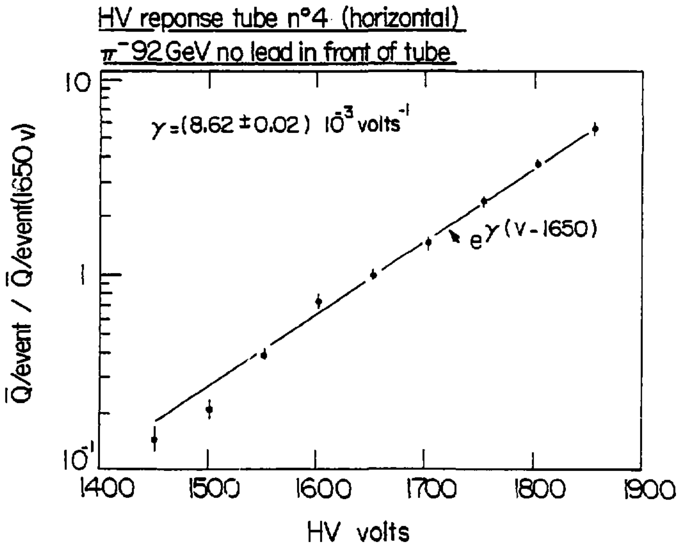
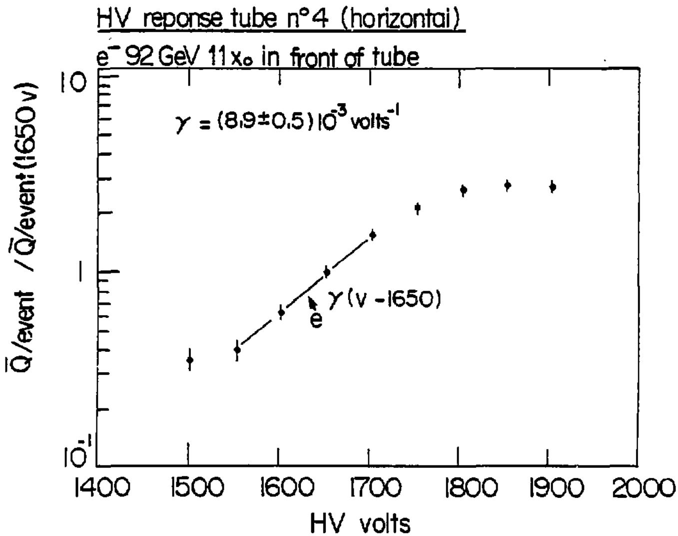

Fit of a Landau-like shape
π^- 92 GeV
HV 1650 volts
Number of events
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1.0
Q picocoulombs

Fig. 4



HV reponse tube n°4 (horizontal)
π⁻ 92 GeV no lead in front of tube
γ=(8.62±0.02) 10⁻³ volts⁻¹
eγ(V-1650)
Q̄/event / Q̄/event(1650 v)
10
1
10⁻¹
1400
1500
1600
1700
1800
1900
HV volts

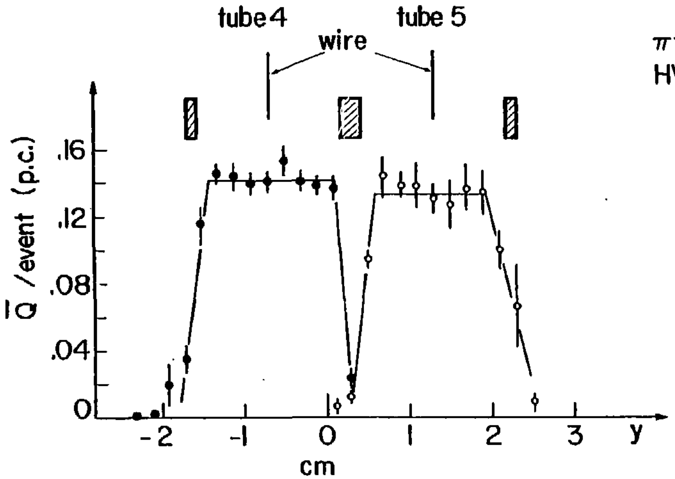
Fig.5.a



HV reponse tube n°4 (horizontal)
e⁻ 92 GeV 11 x₀ in front of tube
γ = (8.9±0.5) 10⁻³ volts⁻¹
γ(V -1650)
e
10
1
10⁻¹
1400
1500
1600
1700
1800
1900
2000
HV volts
Q̄/event / Q̄/event (1650 v)

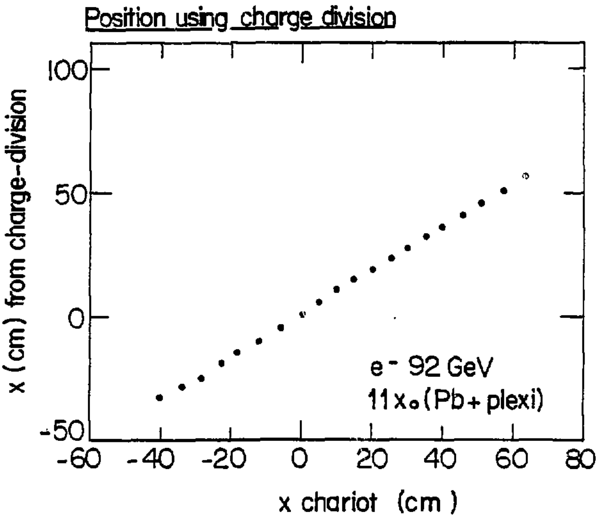
Fig.5.b

CHARGE COLLECTION INSIDE THE TUBES



π^- 92 GeV
HV= 1700 V

Fig. 6



Position using charge division
x (cm) from charge-division
100
50
0
-50
-60
-40
-20
0
20
40
60
80
x chariot (cm)
e⁻ 92 GeV
11 X₀ (Pb + plexi)

Fig.7

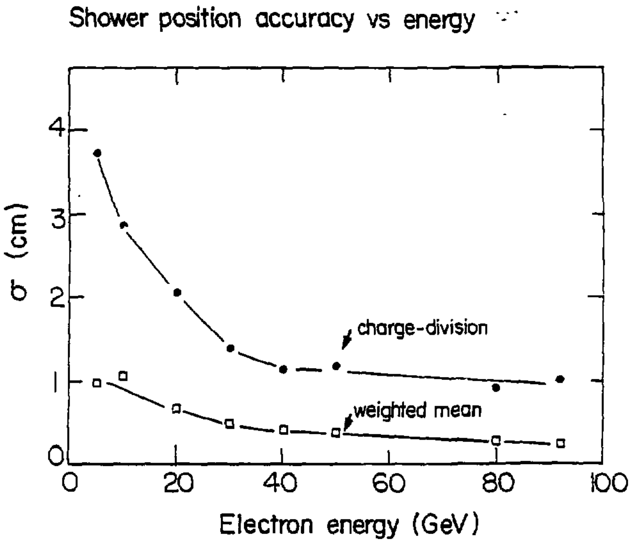
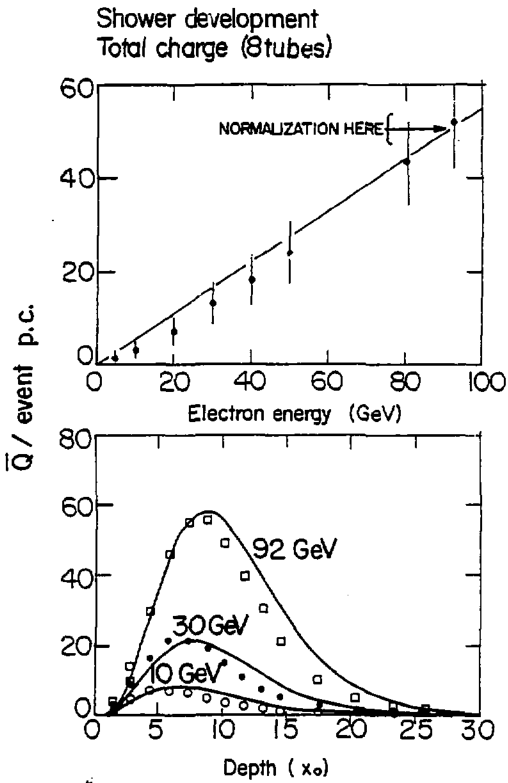

Shower position accuracy vs energy
4
3
2
1
0
σ (cm)
charge-division
weighted mean
0
20
40
60
80
100
Electron energy (GeV)

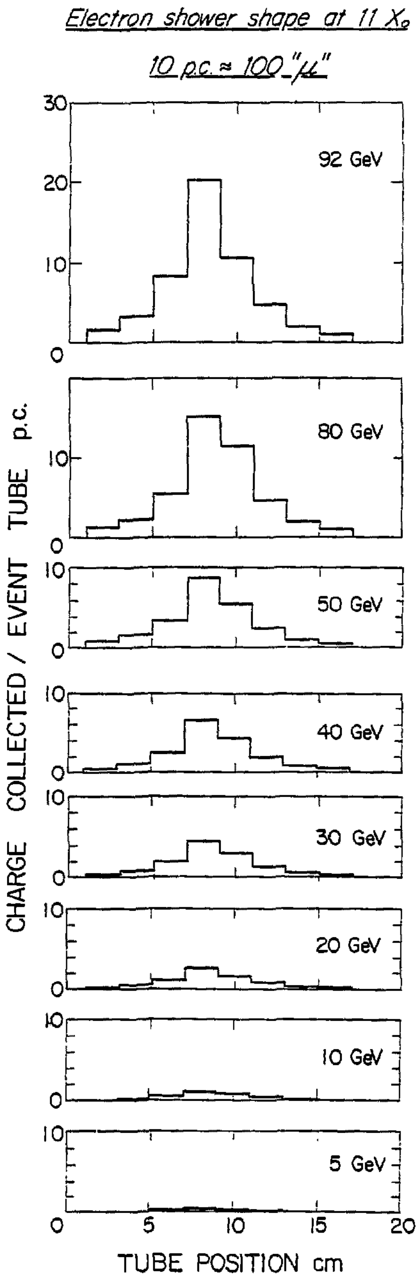
Fig.8



Shower development
Total charge (8tubes)
NORMALIZATION HERE
Q̄ / event p.c.
Electron energy (GeV)
0 20 40 60 80 100
0 20 40 60
92 GeV
30 GeV
10 GeV
0 20 40 60 80
0 5 10 15 20 25 30
Depth (x₀)

Fig.9.a

Fig.9.b



Electron shower shape at 11 X_0
10 p.c. ≈ 100 "μ"
92 GeV
80 GeV
50 GeV
40 GeV
30 GeV
20 GeV
10 GeV
5 GeV
CHARGE COLLECTED / EVENT TUBE p.c.
TUBE POSITION cm

Fig.10

92 e⁻ shower shape inside the sandwich (plexi-Pb)

1 plate = 4 mm Pb + 6 mm plexi.

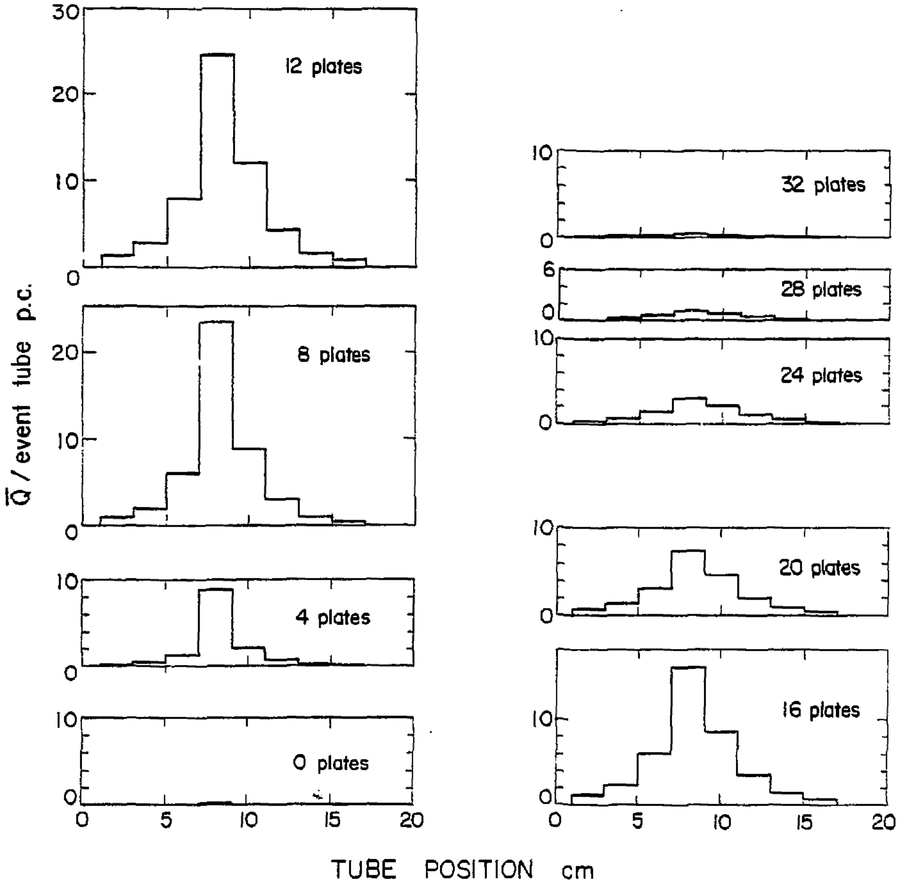
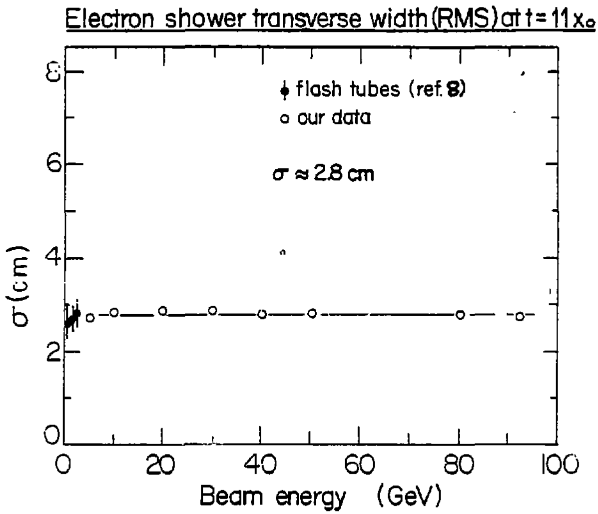
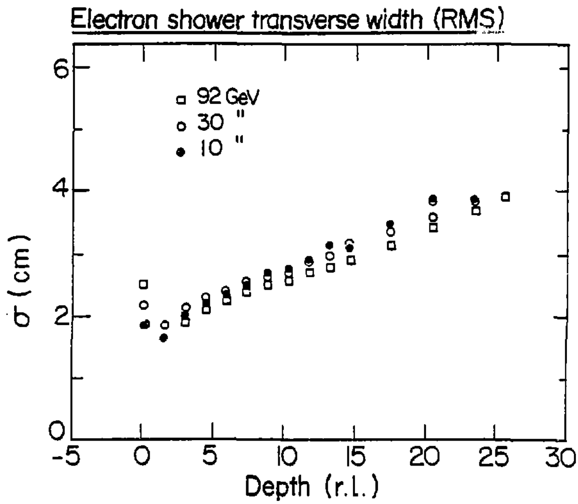


Fig.11



Electron shower transverse width (RMS) at t = 11 X_0
flash tubes (ref. 8)
our data
$\sigma \approx 2.8$ cm
σ (cm)
0
2
4
6
8
0
20
40
60
80
100
Beam energy (GeV)

Fig.12.a



Electron shower transverse width (RMS)
92 GeV
30 "
10 "
σ (cm)
0
2
4
6
-5
0
5
10
15
20
25
30
Depth (r.l.)

Fig.12.b

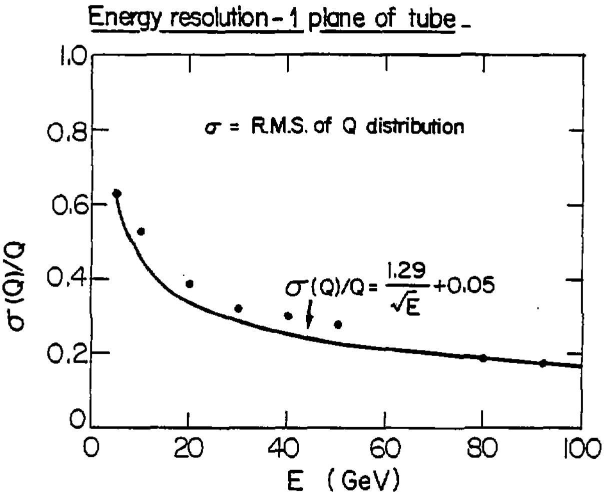

Energy resolution - 1 plane of tube -
1.0
0.8
0.6
0.4
0.2
0
σ (Q)/Q
σ = R.M.S. of Q distribution
σ(Q)/Q = 1.29/√E + 0.05
0
20
40
60
80
100
E (GeV)

Fig.13