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MEASUREMENT OF ELECTROMAGNETIC SHOWER POSITION AND SIZE WITH A SATURATED AVALANCHE TUBE HODOSCOPE AND A FINE GRAINED SCINTILLATION HODOSCOPE*

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Summary

A hodoscope has been constructed from 100 μ m diameter wires and brass tubes (1.2 x 0.7 cm^2 cross section) filled with a mixture of argon, ethane and ethyl alchohol. It has been tested in the saturated avalanche mode in an SCG1-C electromagnetic shower detector to determine its properties for the measurement of the position and size of electromagnetic showers. Two of these tube hodoscopes were positioned 3.5 radiation lengths deep in the detector and the profiles of 1-25 GeV electromagnetic showers were measured. Simultaneous measurements were performed using a plane of twenty, 0.5 cm wide scintillation counters positioned immediately behind the gas tube hodoscope. In addition the transition between saturated avalanche and limited streamer modes has been measured for the tube hodoscopes.

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Introduction

In preparation for Tevatron Experiment 705 at Fermilab [1], where good photon position and energy resolution and two photon resolving power are required over a large detector (4m x 2m), two types of hodoscopes have been tested. The performance of a plane of 0.5 x 1.0 cm , 230 cm long scintillation counters is compared with that of two planes of gas filled tube hodoscopes operated in the saturated avalanche mode [2]. In addition to the obvious advantage of eliminating the problem of attenuation which is present in scintillator hodoscopes, these devices have the advantage that they are inexpensive, easy to construct and maintain, and can be constructed from conducting plastic which will limit the amount of material placed in the detector. The results are also compared with those obtained from a previously tested seven element (1 x 1 x 15 cm^3) scintillator hodoscope, where the position resolution was measured to be $\sigma(mm) = 0.7 + 5.6/\sqrt{E}$ (GeV) [3].

The ionization,shower shape and position resolution of these devices has been measured as a function of energy. Properties of the tube hodoscopes were studied as a function of high voltage and performance of the scintillator hodoscope was studied as a function of the position of the positron beam along the length of the scintillator.

Test Beam

This test was performed using the positron test beam 19 in the B end station at the Stanford Linear Accelerator Center (SLAC). The momentum of the beam was variable from 1 to 25 GeV/c and had a spread, $\Delta p/p$ (FWHM)

= 0.25%. Ninety per cent of the beam particles were contained within a radius of 1 mm. Details of the beam have been previously reported [4].

Experimental Apparatus

The experimental arrangement is shown in Fig. 1. The tube and scintillation hodoscopes were positioned 2.9,3.9 and 7.6 cm downstream of a 15 cm thick, 3.5 radiation length active converter composed of SCG1-C scintillation glass [5]. A 4 x 4 array of the same glass counters (15 x 15 x 89.2 cm^3) was located 2.5 cm downstream of the scintillator hodoscope. The scintillator hodoscope was composed of twenty 0.5 x 1 x 230 cm^3 elements made of Bicron BC416 scintillator coupled to 10 stage 1.9 cm diameter Amperex PM1911 phototubes. Pulses from the scintillator counters were digitized using LeCroy 2249A ADC's with a 60 ns gate and 0.25 pc/count sensitivity.

The tube hodoscopes were constructed from brass tubes 1.2 x 0.7 cm^2 in cross-section and 50 cm in length. Gold plated tungsten anode wires 100 μm in diameter were centered in the tubes. The brass tube cathodes were at negative high voltage. The anode wires were at ground potential and connected to 30 meter long RG58/U coaxial cables which carried the total charge to the ADC's. The signal was not amplified. Pulses from each wire of the tube hodoscopes were digitized by 12-bit LeCroy 2285 ADC's with a sensitivity of 0.1 pc/count and a 256 ns gate. The gas volumes of the individual brass tubes were connected to each other in series via 1.6 mm diameter tubing. The tube hodoscopes were flushed at atmospheric pressure with a gas mixture of 50% argon and 50% ethane bubbled through ethyl alchohol at 0^0 C, giving a final gas mixture of 49.3% argon, 49.3% ethane and 1.4% alchohol. The X hodoscope consisted of 13 vertical wires and the Y hodoscope consisted of 20 horizontal wires. The entire apparatus rested on a table which could be positioned vertically or horizontally to ± 1 mm.

Test Results

With the active converter removed each hodoscope element was positioned on the positron beam. For the scintillator hodoscope this was done with the beam at three positions along the counter approximately 40 cm, 100 cm [6] and 200 cm from the phototube. This scanning procedure determined the pulse amplitude of minimum ionizing particles hitting each hodoscope element. The average integrated charge for minimum ionizing particles in the scintillator was 10 pc when the beam was close to the phototube, 8 pc at the one meter position and 3 pc when the beam was nearly two meters away. The factor of three reduction in the total charge over the length of the counter is a result of the large attenuation factor of the scintillator.

The minimum ionizing pulse amplitude in the tube hodoscope was studied as a function of the high voltage applied to the tubes. Below 2250 V, all the minimum ionizing pulses produced charge comparable to that expected in saturated avalanche operation. At 2250 V pulses of approximately fifty times larger charge than saturated avalanche minimum ionizing pulses appeared. The fraction of these large (limited streamer) pulses increased from 2% at 2250 V to 13% at 2300 V and 56% at 2350 V.

These results are illustrated in Fig. 2. Above 2350 V, "double" streamers are also observed. For the purpose of the results presented here no distinction has been made between the two types of limited streamers. For the remainder of the tests the tube hodoscopes were operated at 2250 V. At this voltage the average integrated charge for minimum ionizing particles was 1.3 pc.

Once the minimum ionizing pulse amplitudes were determined, all results could be expressed in units of number of minimum ionizing particles and a normalization factor for each element was established. With the active converter in place scintillator counter 10 was the central element of the electron showers. For the tube hodoscopes, the centroid of the shower was between wires 6 and 7 for the X hodoscope and at wire 16 for the Y hodoscope. The energy of the beam was then varied from 1 to 25 GeV. The total ionization observed in the scintillator and X hodoscope is shown in Figs. 3a-b as a function of energy. The multiplicity predicted by an EGS Monte Carlo [7] is also shown on the figures. At 25 GeV a total multiplicity of approximately 60 times minimum ionizing was observed in both the scintillator and the tube hodoscopes. The bars on the data points in these figures are not errors in the determination of the centroid of the observed ionization distributions but rather the rms deviation of these distributions. Approximately 1000 showers were collected at each energy giving a negligible statistical error in the determination of the mean. The occurrence of limited streamers in the showers was observed. At 2250 V the ratio of limited streamer pulses to minimum ionizing saturated avalanche pulses was found to be essentially independent of energy and the intensity of the particles hitting the wire. The ratio 1.2±0.3 % is slightly lower, though not inconsistent with the ratio measured for single minimum ionizing particles. Events which were identified as having limited streamers (greater than 40 units of minimum ionizing particles on a single wire) were eliminated from the resolution analysis.

The shape of the electromagnetic showers was studied by observing the fraction of the total ionization in each of the elements. Figs. 4a-d show 25 GeV and 2 GeV ionization distributions for the finely segmented scintillation hodoscope, and the more coarsely segmented X tube hodoscope. Once again the bars on the data are the rms deviations of the ionization distributions. Shower profiles at each energy were fit to a shape $\exp[-|\mu-x|/\alpha]$ where μ is the centroid of the showers, x is the distance of an element from the shower mean, and α characterizes the width of the shower at a position of 3.5 radiation lengths. The value of α determined from the shower profiles in the scintillator and X tube hodoscope is shown as a function of energy in Fig. 5. The value of α shows that the width of the shower increases rapidly with energy below 4 GeV, while above 4 GeV the shower shape changes very slowly with energy.

For each of the hodoscopes a first moment calculation of the position of the positron was performed for each shower using the formula:

$$\bar{x} = \frac{\sum_{n_o}^{n_f} N_i x_i}{\sum_{n_o}^{n_f} N_i}$$

where N_i is the number of minimun ionizing particles observed in the i^{th} element, and x_i is the position of the center of the element. The indices n_o and n_f are the starting and stopping numbers of the element used in the calculation. They were chosen so that an active area of 70 mm about the shower mean was used. The distribution of x's for each beam energy was fit to a gaussian. The standard deviations (σ) of these distributions were found to be approximately linear in $1/\sqrt{E}$ as shown in Figs. 6a-b. The errors assigned to the data points are not the statistical errors in the determination of the σ 's, but the rms spread in the σ's when the first moment calculation was repeated with n and n independently changed by + 1.

These data are approximately described by $\sigma(\mathrm{mm}) = (0.5 \pm 0.1) + (9.0 \pm 0.3)/\sqrt{E}$ for the scintillator hodoscope and $(3.1 \pm 0.4) + (4.6 \pm 0.8)/\sqrt{E}$ for the X hodoscope. No difference in the resolution of the scintillator hodoscope was found for the data where the beam was at the position one meter from the phototube. Also no difference was found when the first moment analysis was performed with the counters grouped by two, simulating a 1 cm element hodoscope. However, there is an increase in the $1/\sqrt{E}$ term of the scintillator over the 1 cm element test. Effects which may contribute to the larger energy dependent term are a greater distance between the active converter and the hodoscope, and the reduction of the number of photoelectrons reaching the phototube due to the long length and fine segmentation of the counters in the current test. Contributions to the larger constant terms observed in the tube hodoscopes may come from the larger fluctuations observed in the ionization distributions of the tube hodoscopes. At energies of 10 GeV and above an improvement in the resolution in the tube hodoscope can be obtained by fitting the ionization in each event to the shower shape $\exp[-|x-\bar{x}|/\alpha\ ]$, where $\bar{x}$ and α are fitted parameters. The resolution can be improved by approximately a factor of two by this technique giving σ(mm) = 1.6% at 25 GeV.

Acknowledgments

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References

1. Fermilab Proposal E-705 (1981).
2. M. Atac, et. al., Nucl. Inst. Meth., 205 (1983) 113-124.
3. B. Cox, et. al., IEEE Trans. Nuc. Sci, NS-30, 131 (1983).
4. B. Cox, et. al., IEEE Trans. Nuc. Sci, NS-30, 127 (1983).
5. D. Wagoner, et. al., A Measurement of Energy Resolution and Related Properties of an SCG1-C Scintillation Glass Shower Counter Array for 1-25 GeV Positrons, Paper 3A2, 1983 Nuclear Science Symposium, San Francisco, CA.
6. This test was done using electrons in SLAC test beam 6 which has been described, B. Cox, et. al., A Measurement of the Response of an SCG1-C Scintillation Glass Array to 4-14 GeV/c Pions, Paper 3A3, 1983 Nuclear Science Symposium, San Francisco, CA.
7. R. L. Ford and W. R. Nelson, SLAC-210 (1978).

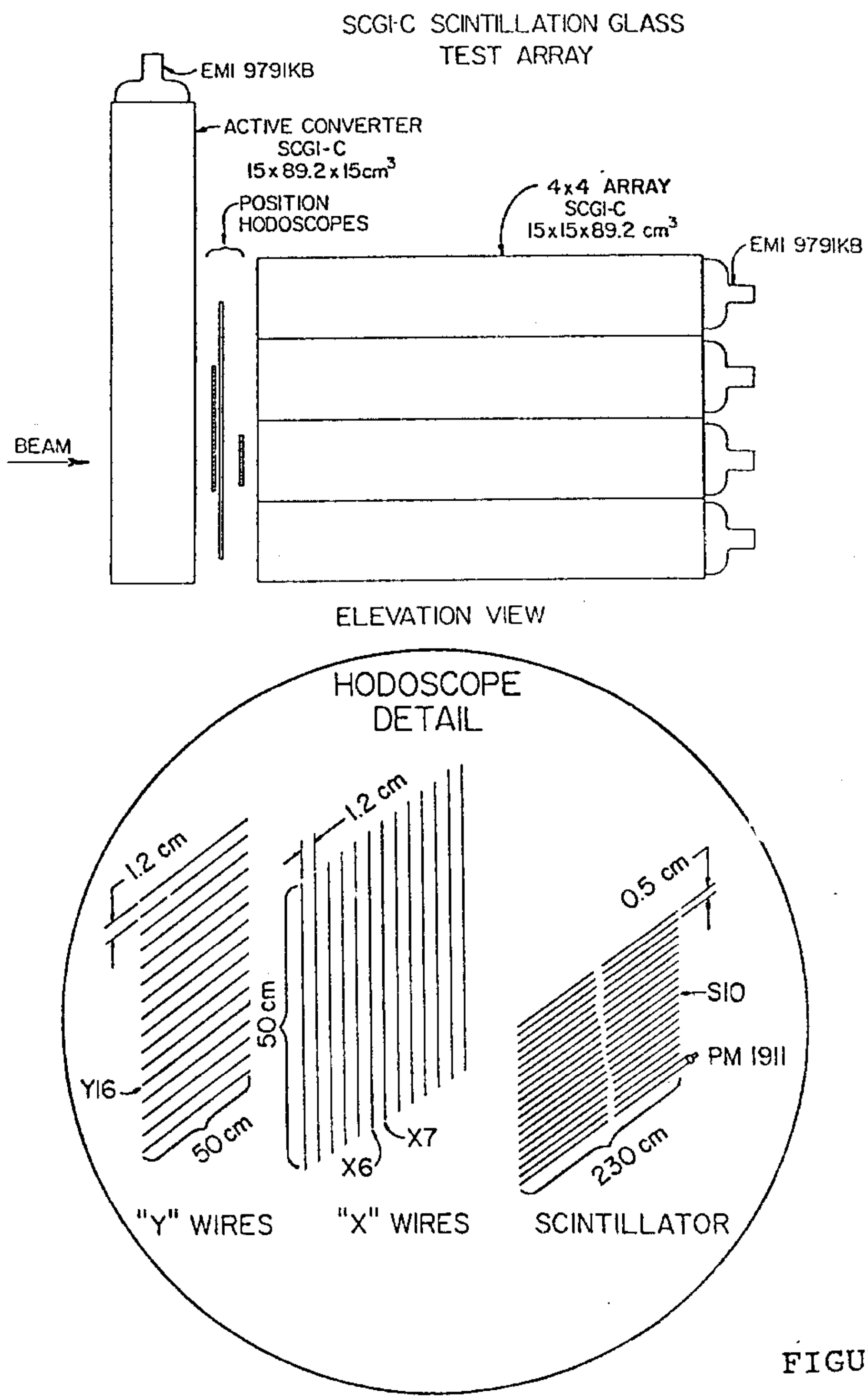
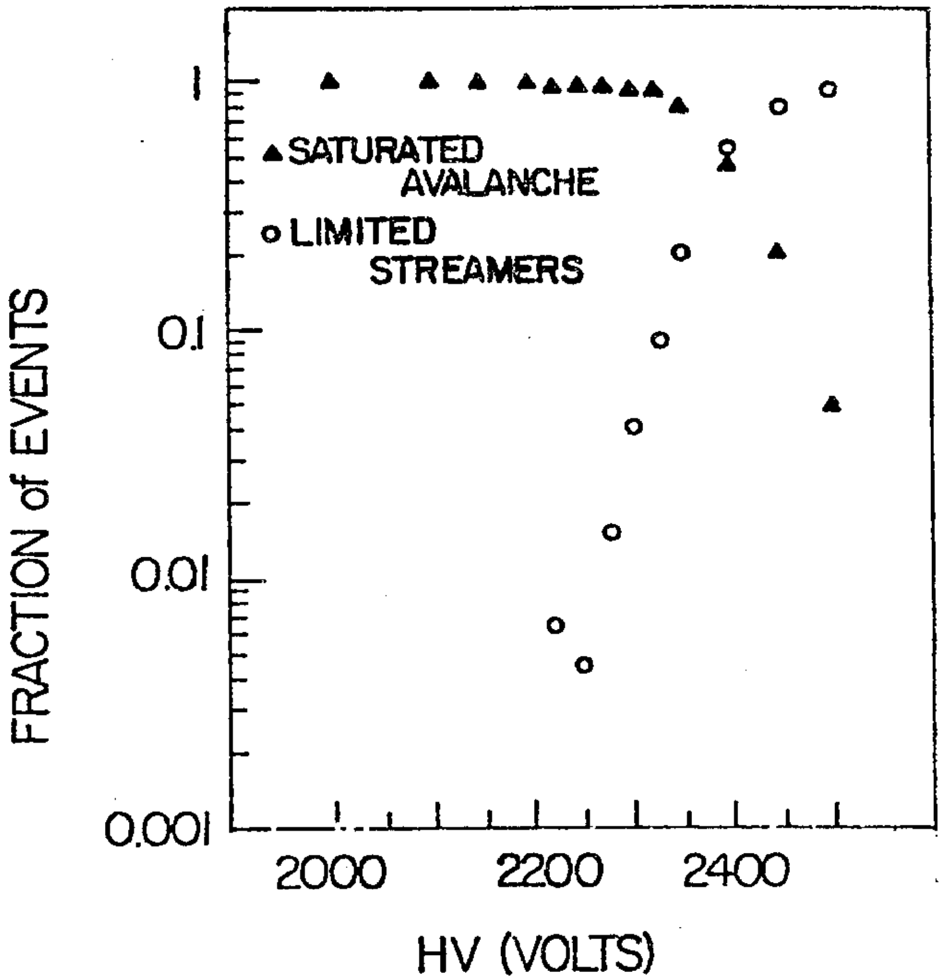

SCGI-C SCINTILLATION GLASS
TEST ARRAY
EMI 9791KB
ACTIVE CONVERTER
SCGI-C
15x89.2x15cm³
POSITION
HODOSCOPES
4x4 ARRAY
SCGI-C
15x15x89.2 cm³
EMI 9791KB
BEAM
ELEVATION VIEW
HODOSCOPE
DETAIL
1.2 cm
1.2 cm
0.5 cm
50 cm
S10
PM 1911
Y16
50 cm
X7
X6
230 cm
"Y" WIRES
"X" WIRES
SCINTILLATOR

FIGURE 1



FRACTION of EVENTS
1
0.1
0.01
0.001
SATURATED AVALANCHE
LIMITED STREAMERS
2000
2200
2400
HV (VOLTS)

FIGURE 2

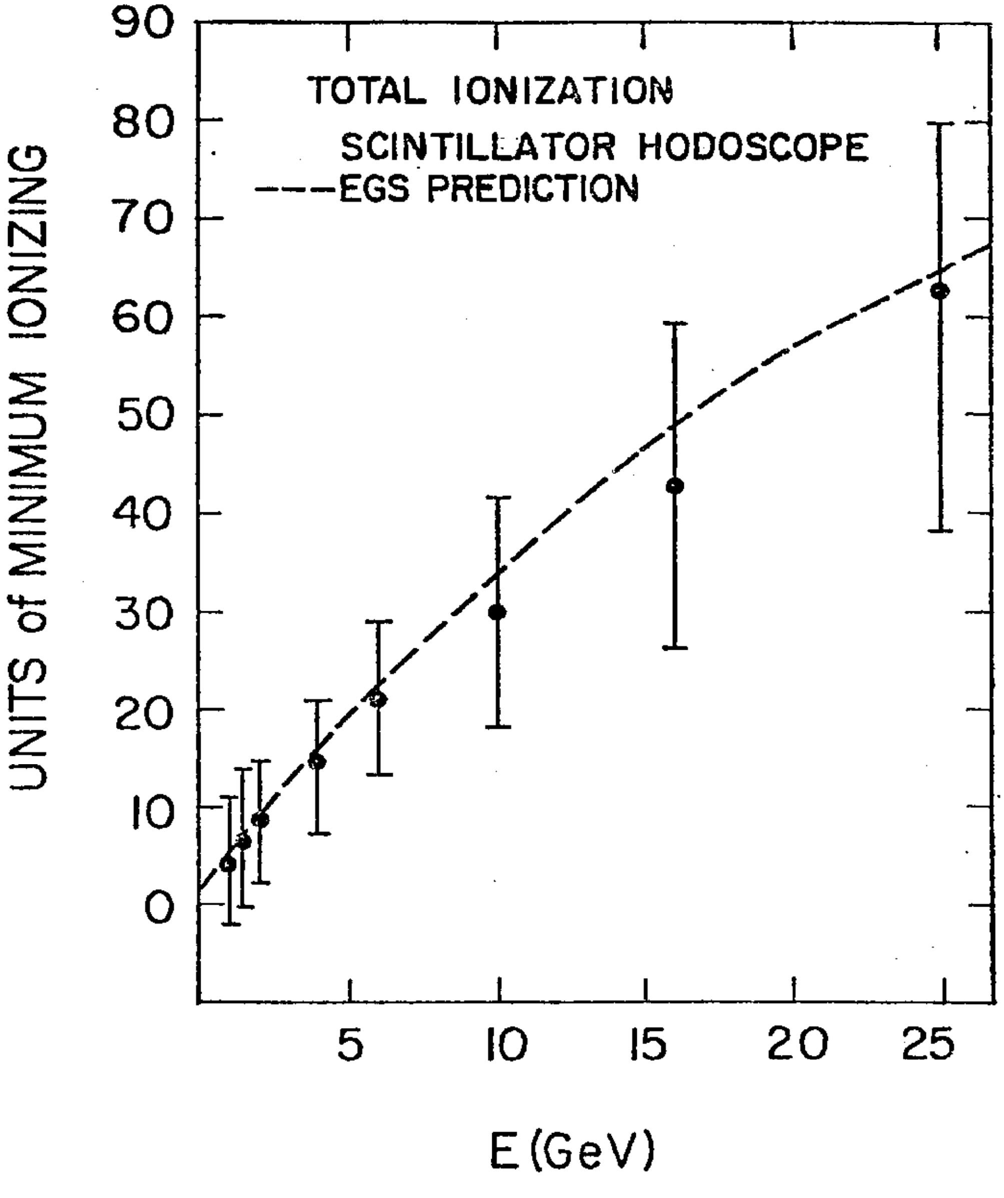
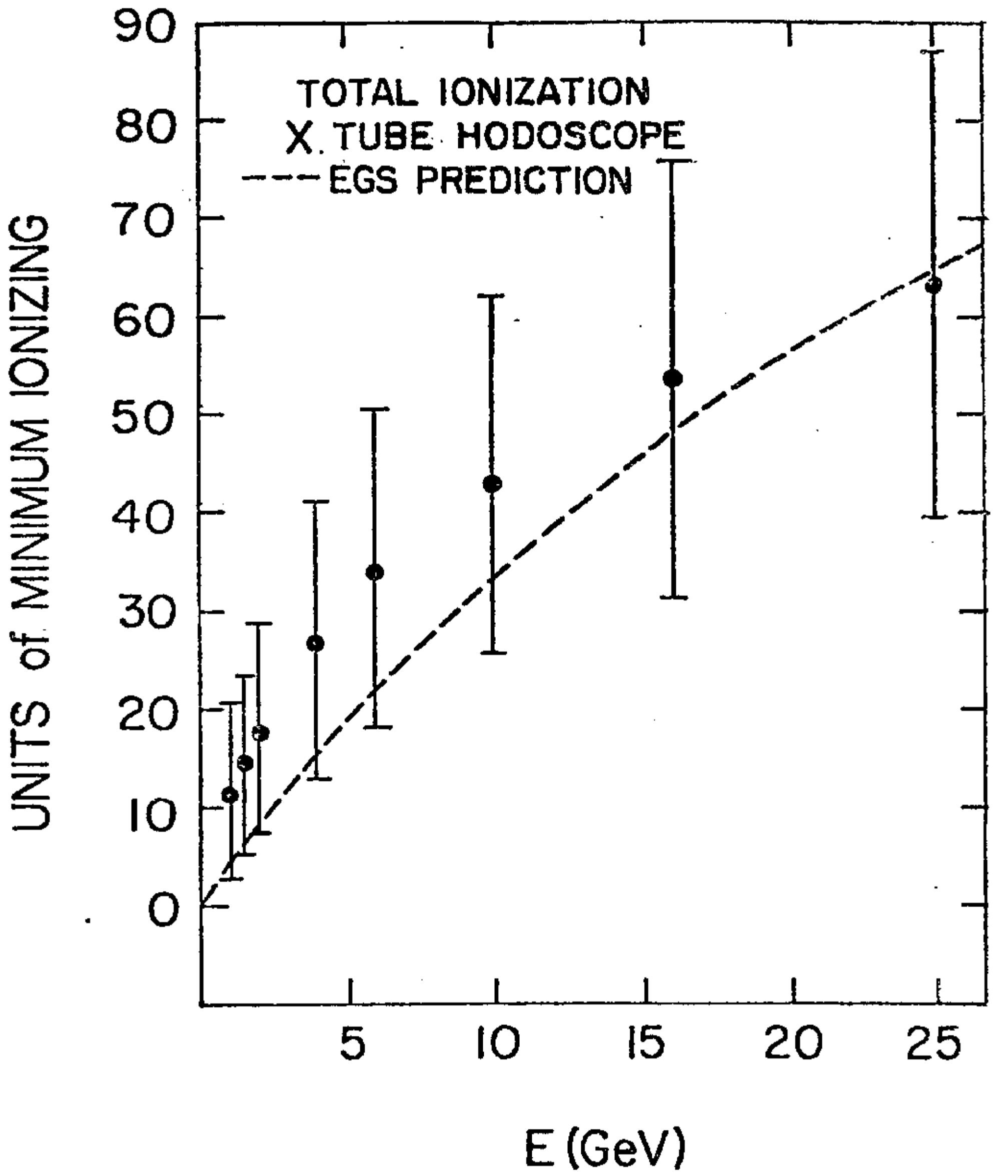

TOTAL IONIZATION
SCINTILLATOR HODOSCOPE
---EGS PREDICTION
UNITS of MINIMUM IONIZING
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
E(GeV)

FIGURE 3a



TOTAL IONIZATION
X TUBE HODOSCOPE
---- EGS PREDICTION
UNITS of MINIMUM IONIZING
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
E (GeV)

FIGURE 3b

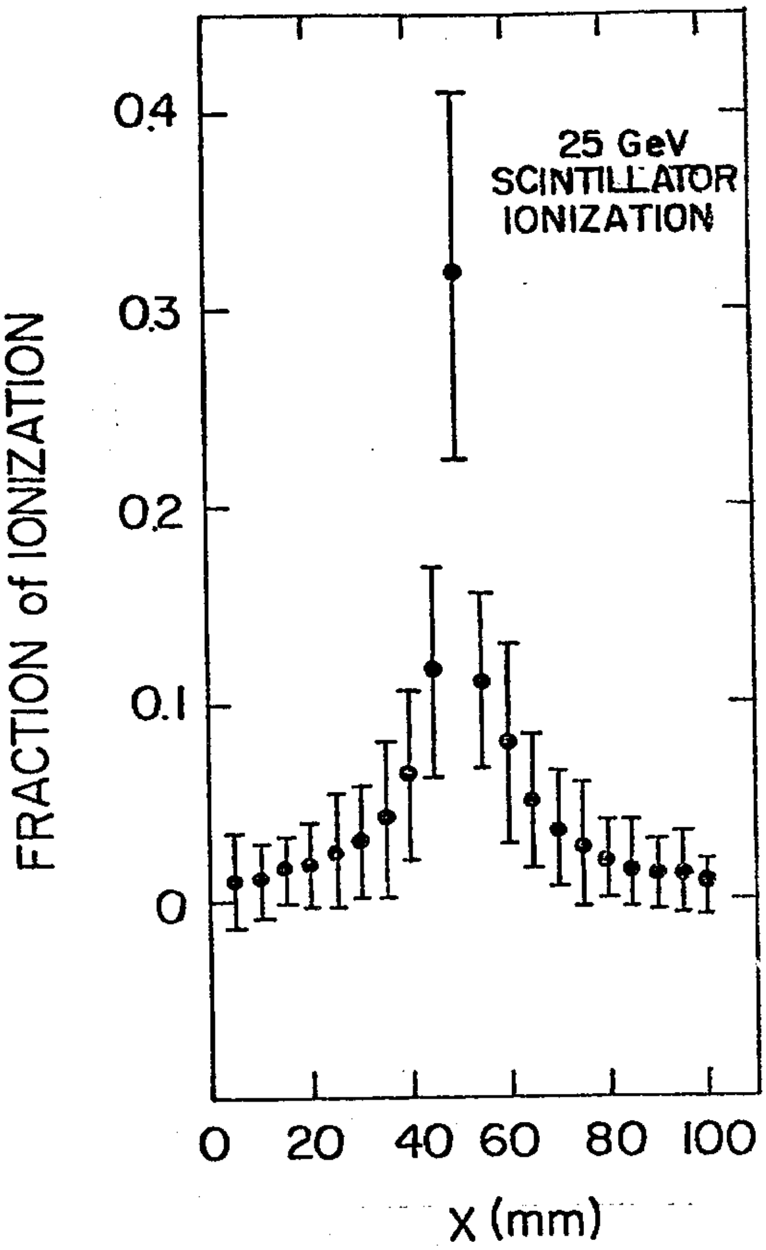

FRACTION of IONIZATION
0.4
0.3
0.2
0.1
0
25 GeV
SCINTILLATOR
IONIZATION
0
20
40
60
80
100
X (mm)

FIGURE 4a

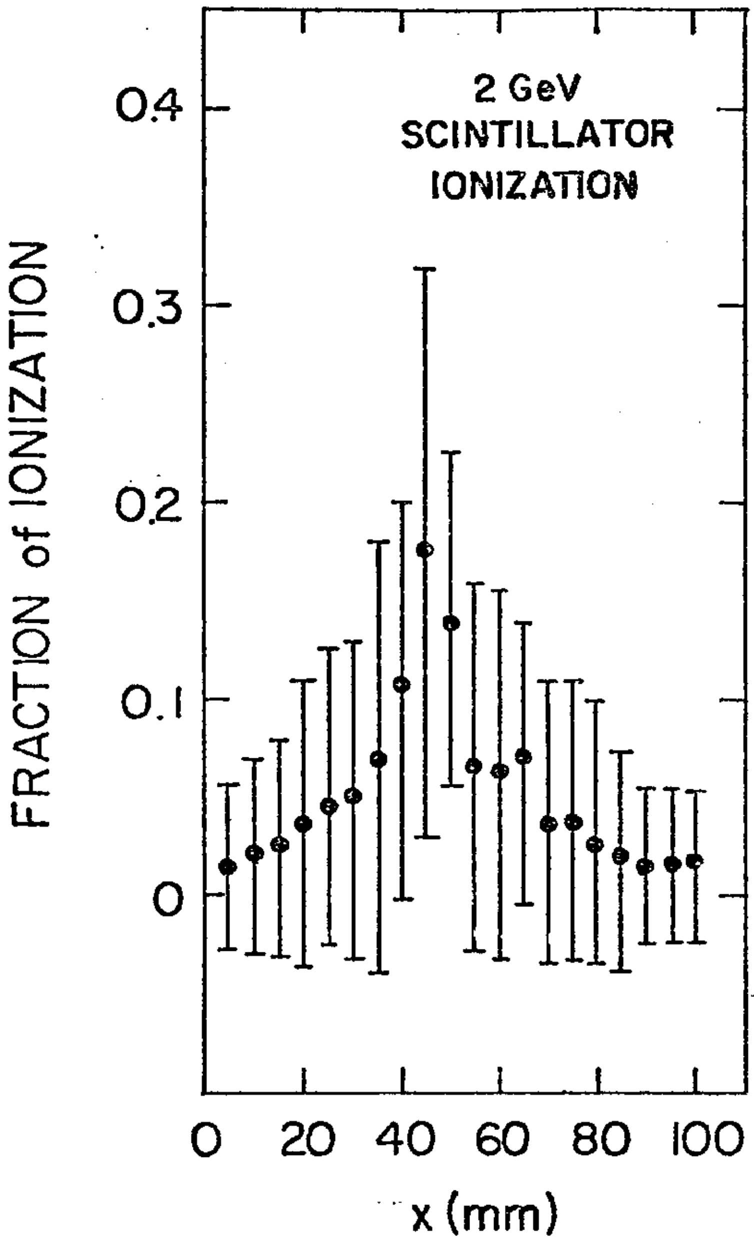

2 GeV
SCINTILLATOR
IONIZATION
FRACTION of IONIZATION
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
x (mm)

FIGURE 4b

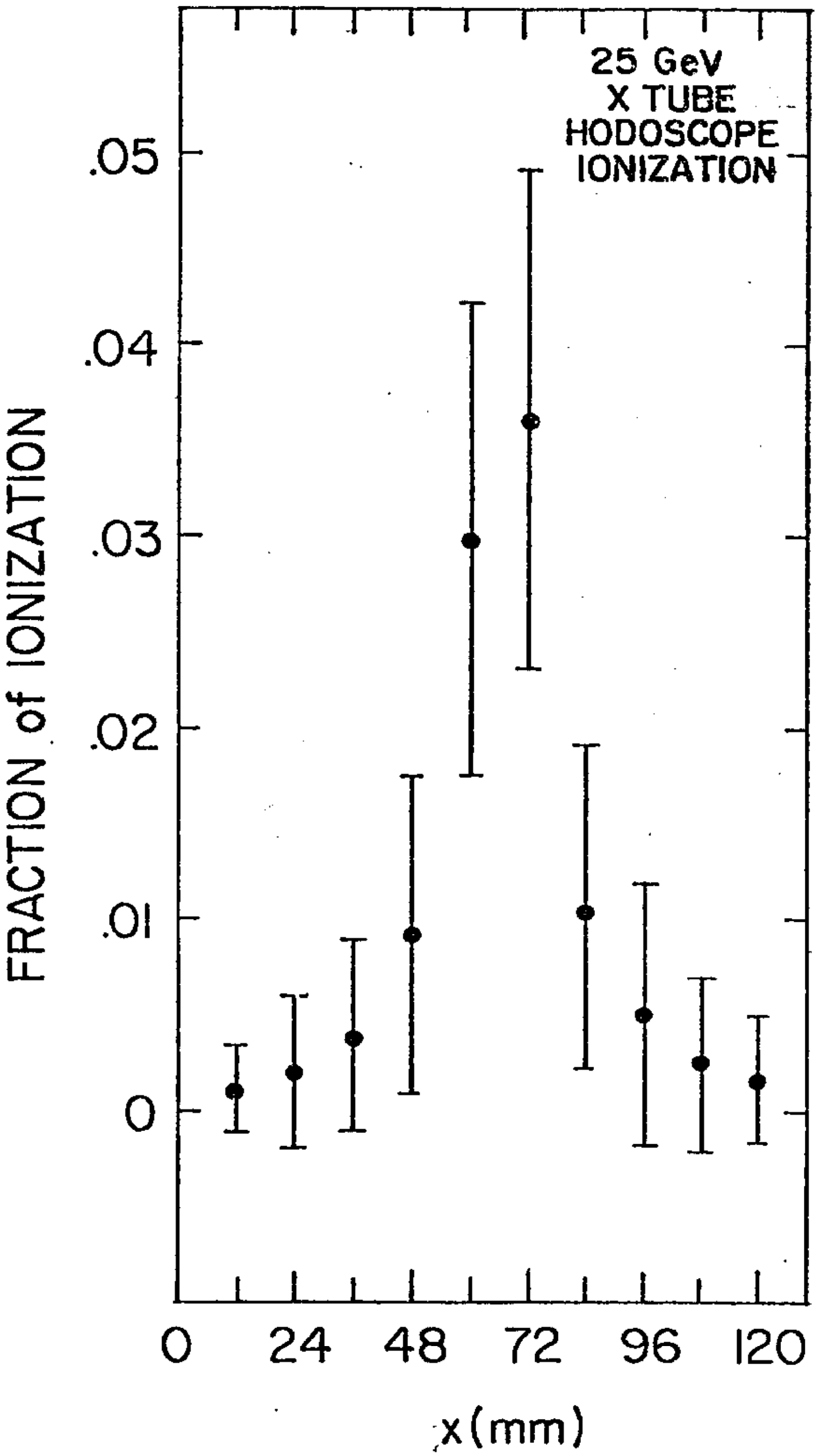

25 GeV
X TUBE
HODOSCOPE
IONIZATION
.05
.04
.03
.02
.01
0
FRACTION of IONIZATION
0
24
48
72
96
120
x(mm)

FIGURE 4c

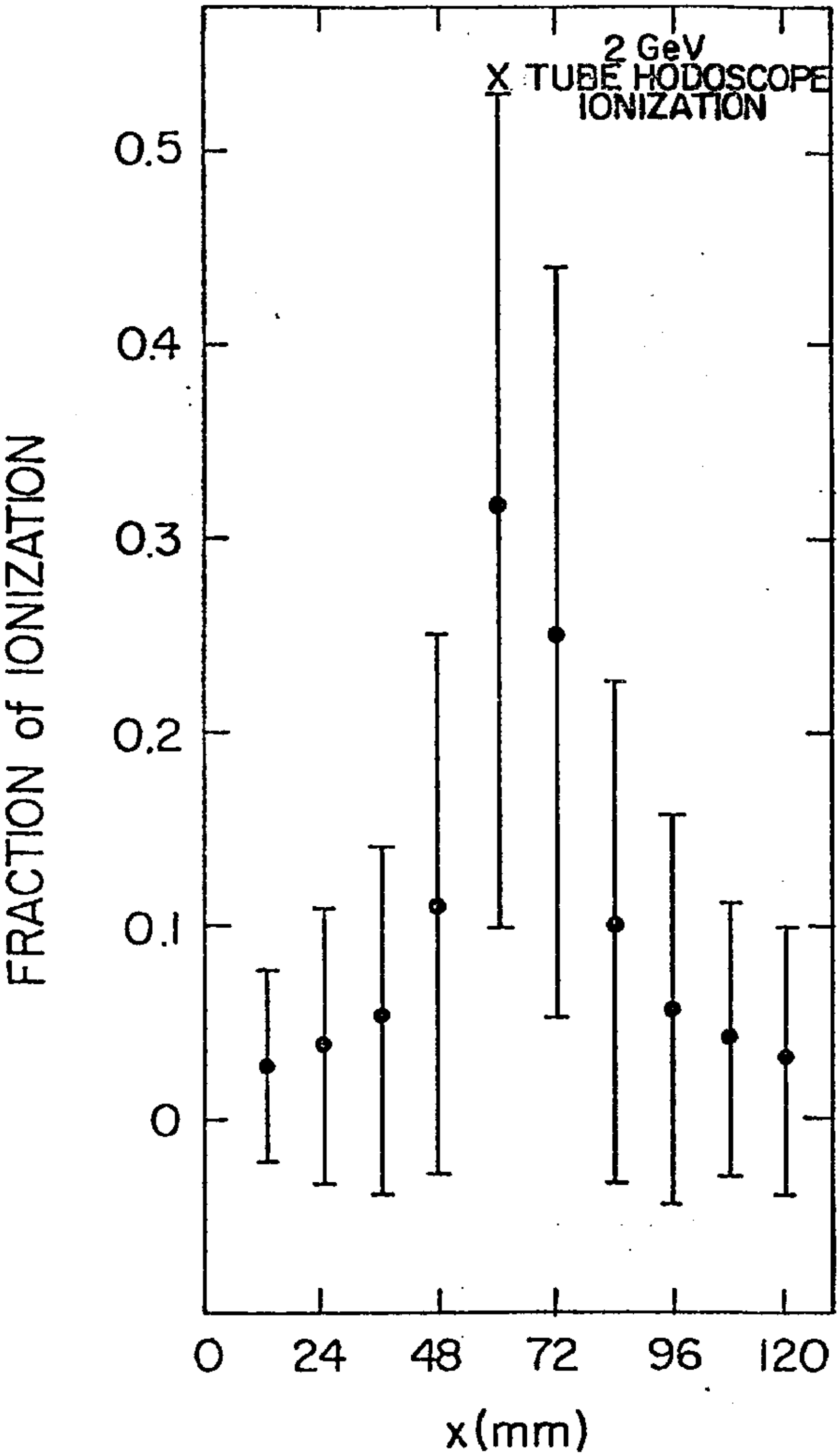
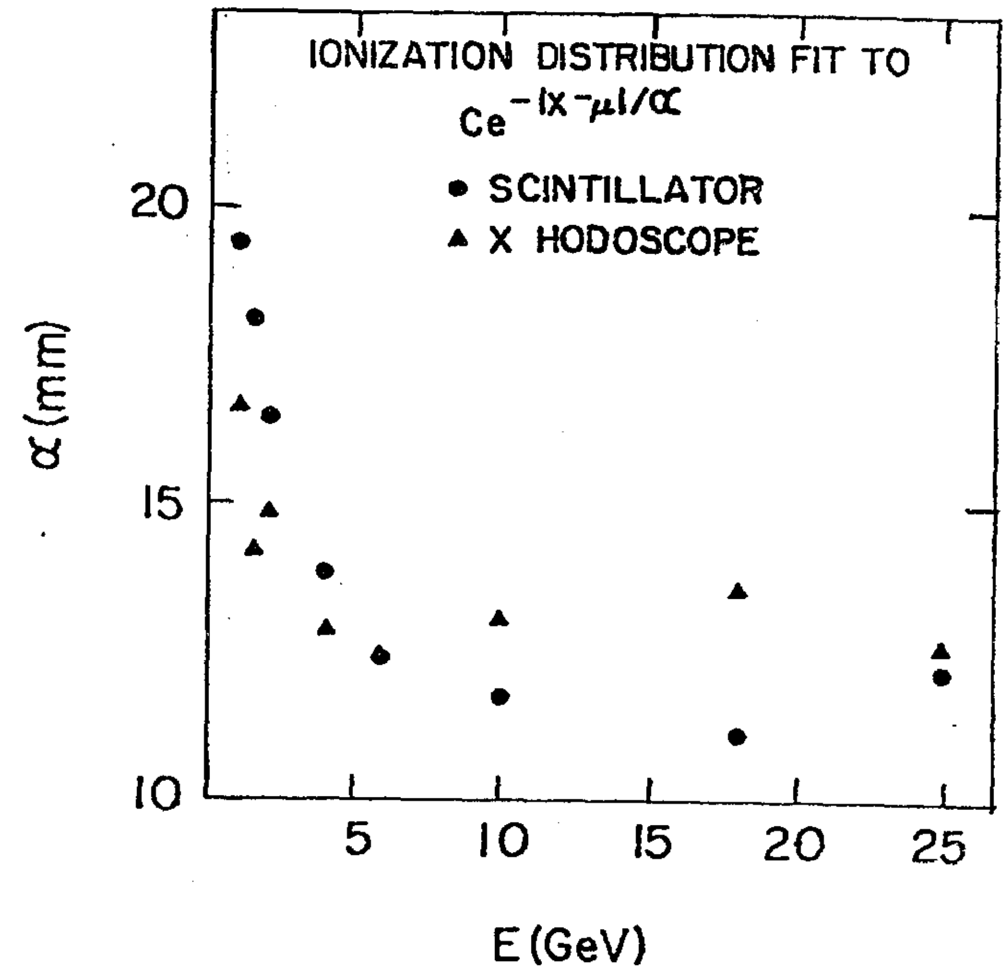
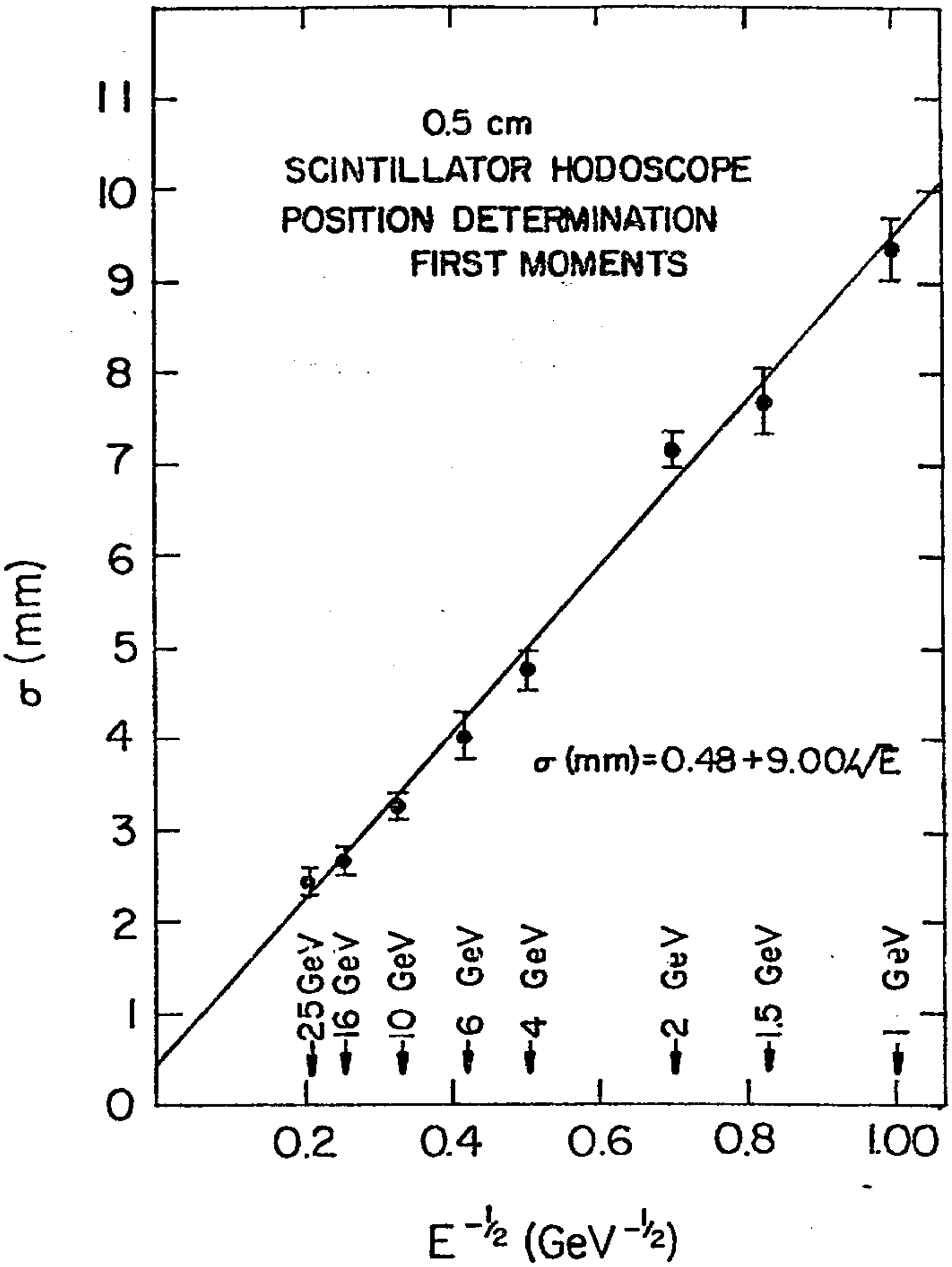

2 GeV
X TUBE HODOSCOPE
IONIZATION
FRACTION of IONIZATION
0.5
0.4
0.3
0.2
0.1
0
0
24
48
72
96
120
x(mm)

FIGURE 4d



IONIZATION DISTRIBUTION FIT TO
Ce^{-|x-μ|/α}
● SCINTILLATOR
▲ X HODOSCOPE
α (mm)
20
15
10
5
10
15
20
25
E (GeV)

FIGURE 5



0.5 cm
SCINTILLATOR HODOSCOPE
POSITION DETERMINATION
FIRST MOMENTS
σ (mm)=0.48+9.00/√E
σ (mm)
E^-½ (GeV^-½)
25 GeV
16 GeV
10 GeV
6 GeV
4 GeV
2 GeV
1.5 GeV
1 GeV
0
1
2
3
4
5
6
7
8
9
10
11
0.2
0.4
0.6
0.8
1.00

FIGURE 6a

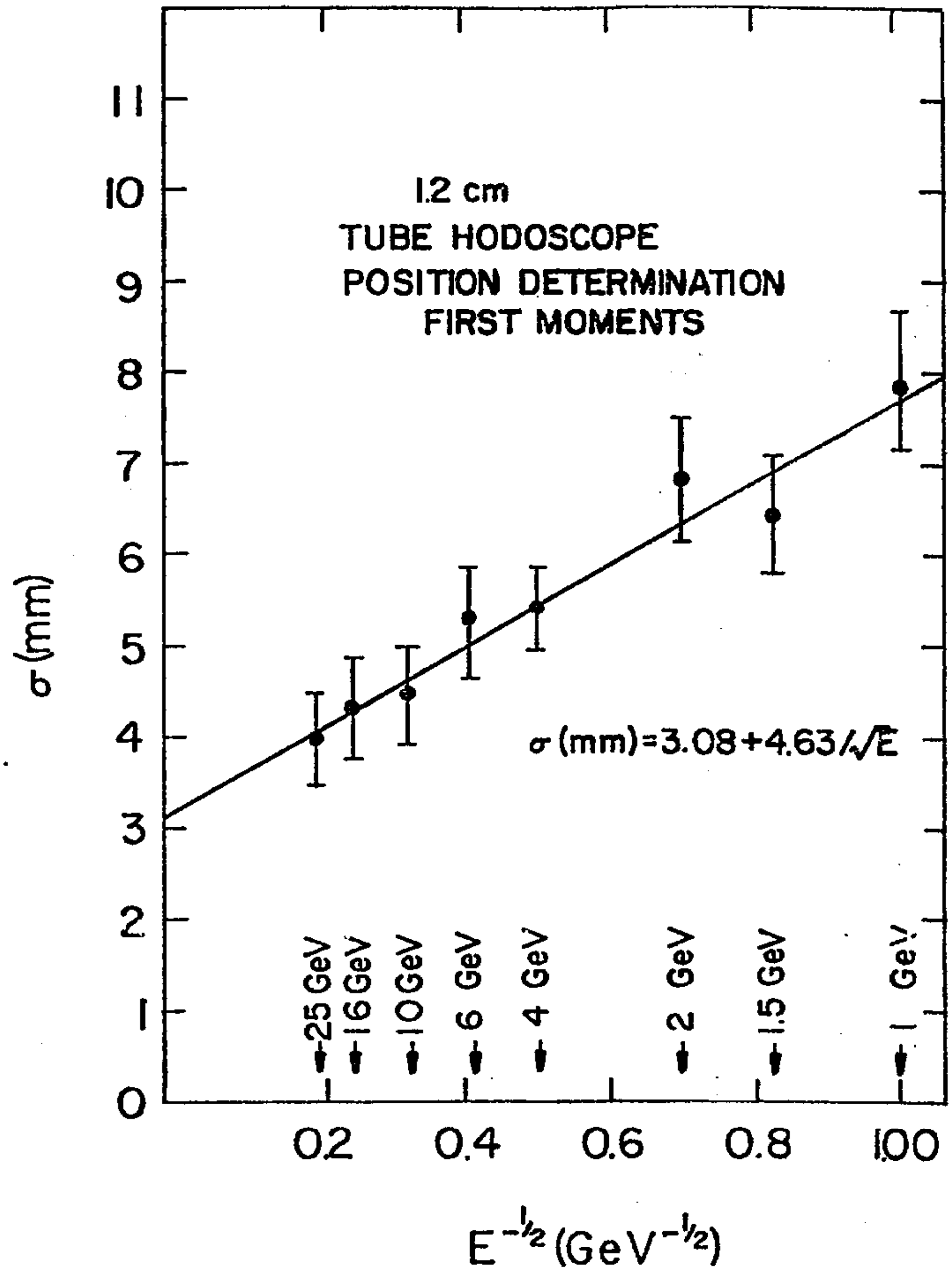

1.2 cm
TUBE HODOSCOPE
POSITION DETERMINATION
FIRST MOMENTS
σ (mm)=3.08+4.63/√E
σ (mm)
E^-½ (GeV^-½)
25 GeV
16 GeV
10 GeV
6 GeV
4 GeV
2 GeV
1.5 GeV
1 GeV
0.2
0.4
0.6
0.8
1.00
0
1
2
3
4
5
6
7
8
9
10
11

FIGURE 6b