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HIGH ENERGY ELECTROMAGNETIC SHOWER POSITION MEASUREMENT BY A FINE GRAINED SCINTILLATION HODOSCOPE*

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Summary

We have measured the centroids of high energy electromagnetic showers initiated by positrons in the energy range 2 to 17.5 GeV with a fine grained scintillation hodoscope composed of seven 1 cm wide elements placed behind a 3.6 radiation length (15 cm) converter composed of SCG1-C scintillation glass. A simple first moment calculation using the ionization observed in each element of this hodoscope yields a shower position resolution as a function of energy of: $\sigma(\mathrm{mm}) \approx 0.7 \pm 5.6/\sqrt{E(\mathrm{GeV})}$. We present results on the energy dependence of the shower profiles and the ionization measured by this hodoscope.

Introduction

The determination of the position of a photon by measurement of the profile of its shower in an electromagnetic shower detector is a critical requirement of any experiment which attempts to reconstruct photon energies and directions. In preparation for Tevatron Experiment 705[1] at Fermilab we have tested a fine grained (1 cm wide elements) scintillation hodoscope positioned 3.6 radiation length deep in electromagnetic showers initiated by 2 to 17.5 GeV positrons. We have determined the position resolution attainable by this device as a function of energy. In addition, we have measured the shower shapes and ionization seen by the hodoscope as a function of energy. Comparisons of the measured shower shapes with the EGS electromagnetic shower Monte Carlo[2] have been performed.

Test Beam

This test was performed using the positron test beam 19 in the B end station at Stanford Linear Accelerator Center. The small phase space of the beam (90% of the positrons included within a $\sigma \sim 1$ mm spot) allowed us to make a relatively precise determination of the position resolution of the scintillation hodoscope. The momentum of the beam was tunable from 2 to 17.5 GeV and the contamination of the beam by hadrons and muons was less than 10^{-5}. The beam was typically operated at 10 pulses per second with less than 0.3 positrons per 1.6 μsec pulse. Beam pulses with two or more positrons were tagged and later rejected in the off-line analysis.

Experimental Apparatus

The arrangement of the scintillation hodoscope, active converter and SCG1-C scintillation glass/lead glass array[3] used in this test is shown in Fig. 1. The incident positron beam showered in a 15 cm thick (3.6 radiation lengths) SCG1-C scintillation glass active converter. A finger hodoscope composed of seven 1 x 1 x 15 cm^3, NE114 scintillators coupled to 12 stage, 2 inch diameter EMI 9807B phototubes was placed 3 cm downstream of the active converter. Pulse heights from these counters were digitized using a LeCroy 2249W ADC. The main shower detector array, which was composed of a central 15 x 15 x 80 cm^3 SCG1-C scintillation glass shower counter surrounded by eight 15 x 15 x 45 cm^3 SF5 lead glass counters, was positioned approximately 4 cm downstream of the finger hodoscope. The entire apparatus rested on a table which could be positioned vertically or horizontally to ± 1 mm.

Test Results

With the active converter removed, the positron beam was scanned horizontally through each of the elements of the hodoscope to locate the hodoscope edges and to determine the pulse height of minimum ionizing particles in each of the finger hodoscope elements. With the minimum ionizing pulse heights determined, all results could be expressed in units of the average pulse height for a minimum ionizing particle. After normalization of the gain of each counter, a 17.5 GeV positron beam was centered in the central finger hodoscope element (F4). Effects of backscatter from the main array were then studied. Less than 5% of the showers had greater than one unit of minimum ionization pulse height in either of the adjacent counters (F3 and F5). This did not significantly change when 2.5 cm of polyethylene absorber was inserted between the main array and the finger hodoscope.

The active converter was then inserted in front of the finger hodoscope. In this configuration we searched for possible effects of a wide angle, low energy electron component of the 17.5 GeV showers by examining the average pulse heights seen in F1 and F7 (the finger counters most distant from the shower center) as a function of polyethylene thickness inserted between the active converter and the hodoscope. The average pulse height for a 17.5 GeV shower in either extreme counter was approximately 1.5 times minimum ionizing. In comparison, pulse heights averaging approximately 25 times minimum ionizing were observed in the central counter, F4. These results were essentially independent of polyethylene absorber thickness.

The energy of the beam was then varied from 2 to 17.5 GeV. The total ionization observed in the hodoscope is shown in Fig. 2a as a function of energy. The bars on the data points in this figure are not errors in the determination of the centroid of the observed ionization distributions but rather the full width at half maximum of these distributions. Figure 2b shows the ionization in the central counter, F4, as a function of energy. Figure 3 shows the shower profile as seen by this hodoscope for 2.0, 6.0, 10.0 and 17.5 GeV showers. As shown, the shower profiles at a depth of 3.6 radiation lengths are narrow with full widths of less than one centimeter. The shape of the shower was slowly changing with energy. This can be seen in Fig. 3 in the slight tendency of the 2 GeV showers to be less collimated than the 17.5 GeV showers. Figure 4 shows the 17.5 GeV shower ionization distribution together with an EGS Monte Carlo[2] prediction of the ionization that the finger hodoscope should detect. As shown the data is consistent with the EGS prediction. The bars on the 17.5 GeV/c data once again are the width of the ionization distributions seen in the various finger counters.

We have performed a first moment calculation of the position of the positron for each shower using the formula

$$\langle X \rangle = \frac{\sum_{k=1}^{7} P_i X_i}{\sum_{k=1}^{7} P_i}$$

where P_i is the pulse height in the i^{th} finger counter and X_i is the position of the center of the counter. The distribution of $\langle X \rangle$ for a set of 2 GeV and 17.5 GeV showers is shown in Fig. 5a and 5b. The σ of the distributions of first moment is approximately linear with $1/\sqrt{E(\mathrm{GeV})}$ as shown in Fig. 6. These data are approximately described by σ (mm) = $0.7 + 5.6/\sqrt{E}$. This σ contains the $\sigma \sim 1$ mm phase space of the incident positron beam which contributes to the energy independent term. The errors assigned to these data points are not the statistical error in the σ of the distributions of first moments but rather the spread in the σ's of these distributions when repeated measurements of the positron showers are done under different experimental conditions.

Conclusions

A fine grained (1 cm) scintillation hodoscope of the type described can be used to determine with precision the centroid of electromagnetic showers when placed behind 3 to 4 radiation lengths of converting material even if the material has a relatively long radiation length (r_ℓ = 4.35 cm in the case of the SCG1-C scintillation glass). The position resolution which contains the finite size ($\sigma \sim 1$ mm) of the positron beam position is observed to be σ (mm) $\simeq 0.7 + 5.6/\sqrt{E(\mathrm{GeV})}$. The shower shape is less than 1 cm full width at this depth and is slowly varying with energy. The ionization observed in this hodoscope varies linearly with energy with half the ionization appearing in the central element. At 17.5 GeV a total pulse height of approximately 50 times minimum ionizing is observed.

Acknowledgments

We wish to thank Fermilab Physics Department and to acknowledge the considerable efforts of the SLAC operating staff. We would also like to thank the U.S. Department of Energy, the Natural Sciences and Engineering Research Council of Canada and the Quebec Department of Education for their support.

References

1. M. Binkley, et al., Fermilab Proposal E-705, 1981.
2. R.L. Ford and W.R. Nelson, SLAC-210 (1978).
3. B. Cox, et al., A Measurement of the Response of an SCG1-C Scintillation Glass Shower Detector to 2-17.5 GeV Positrons, Paper 2H7, 1982 Nuclear Science Symposium, Washington, D.C.

FINGER HODOSCOPE TEST APPARATUS

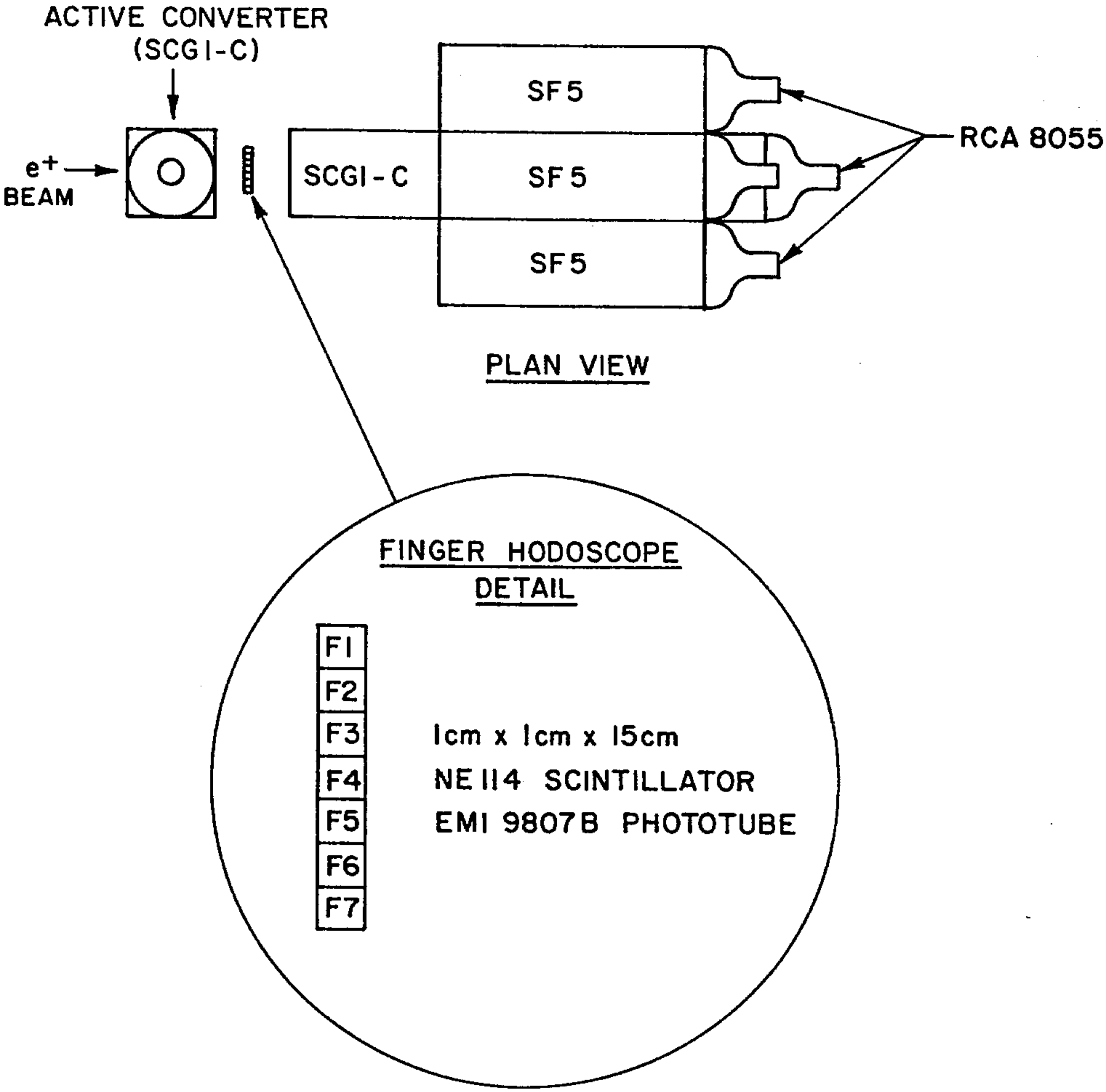


FIGURE 1

FIGURE 2a

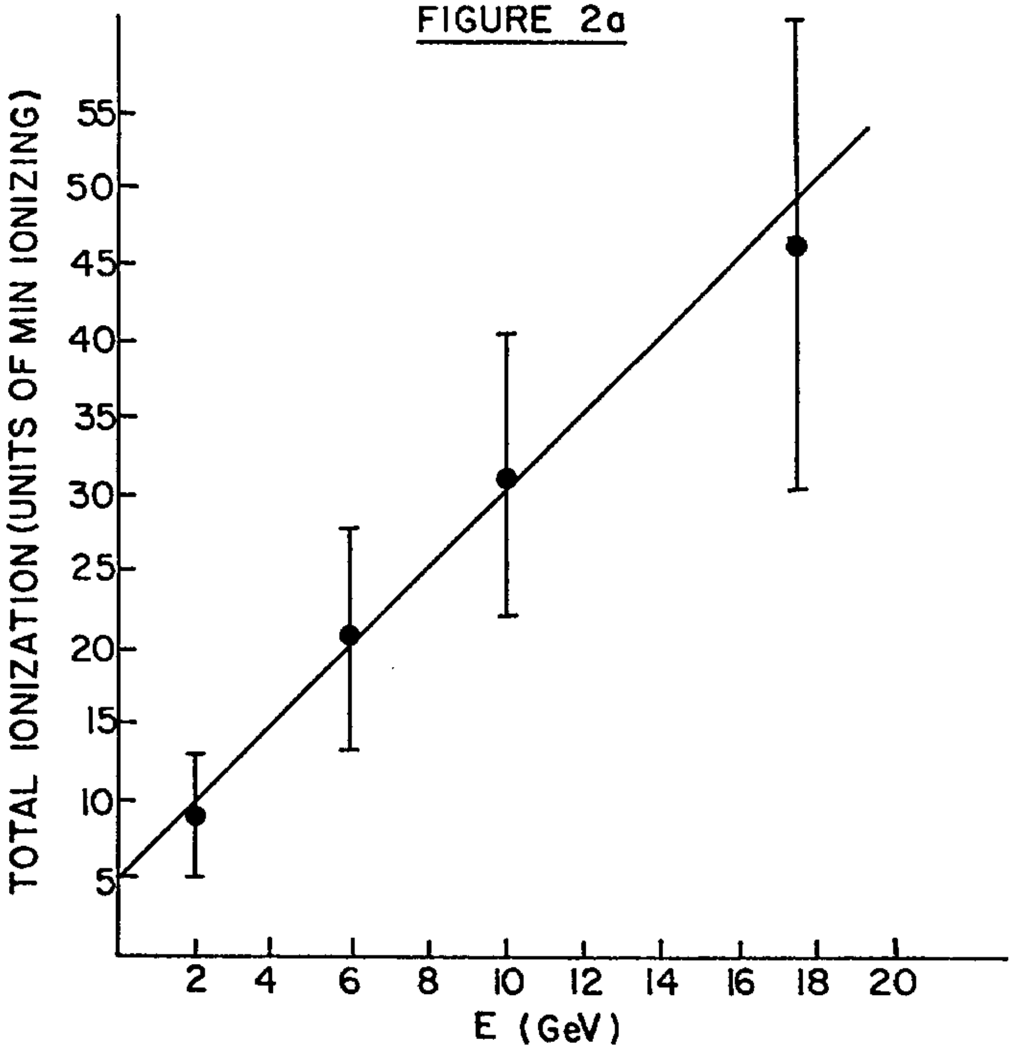
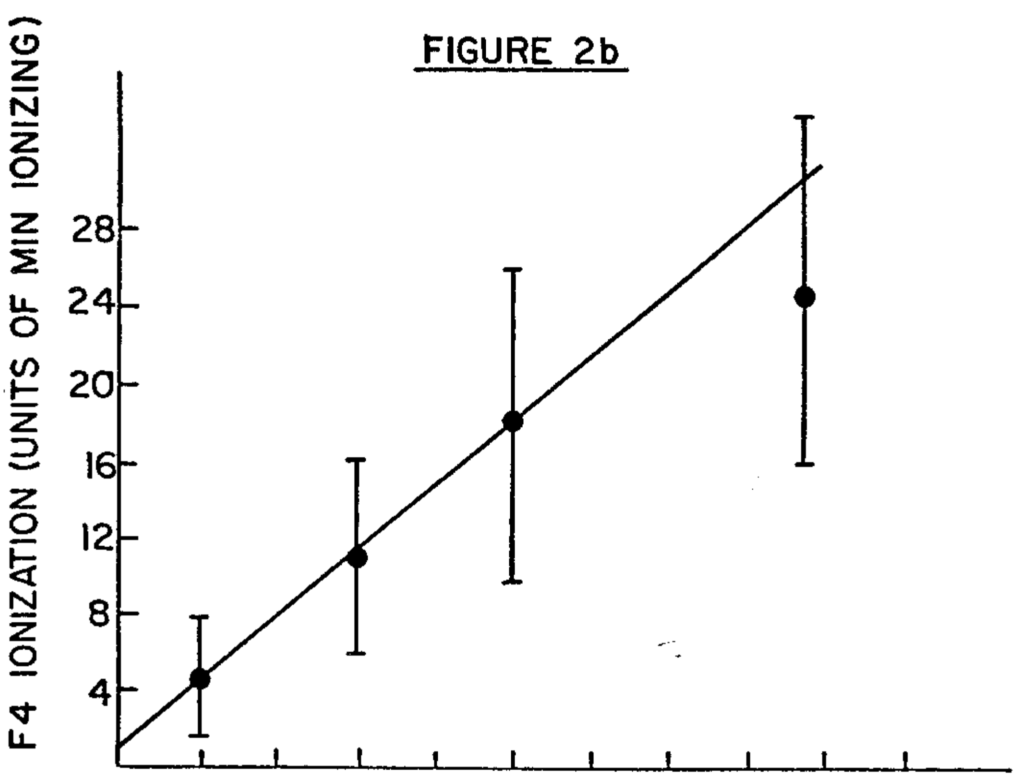


FIGURE 2b



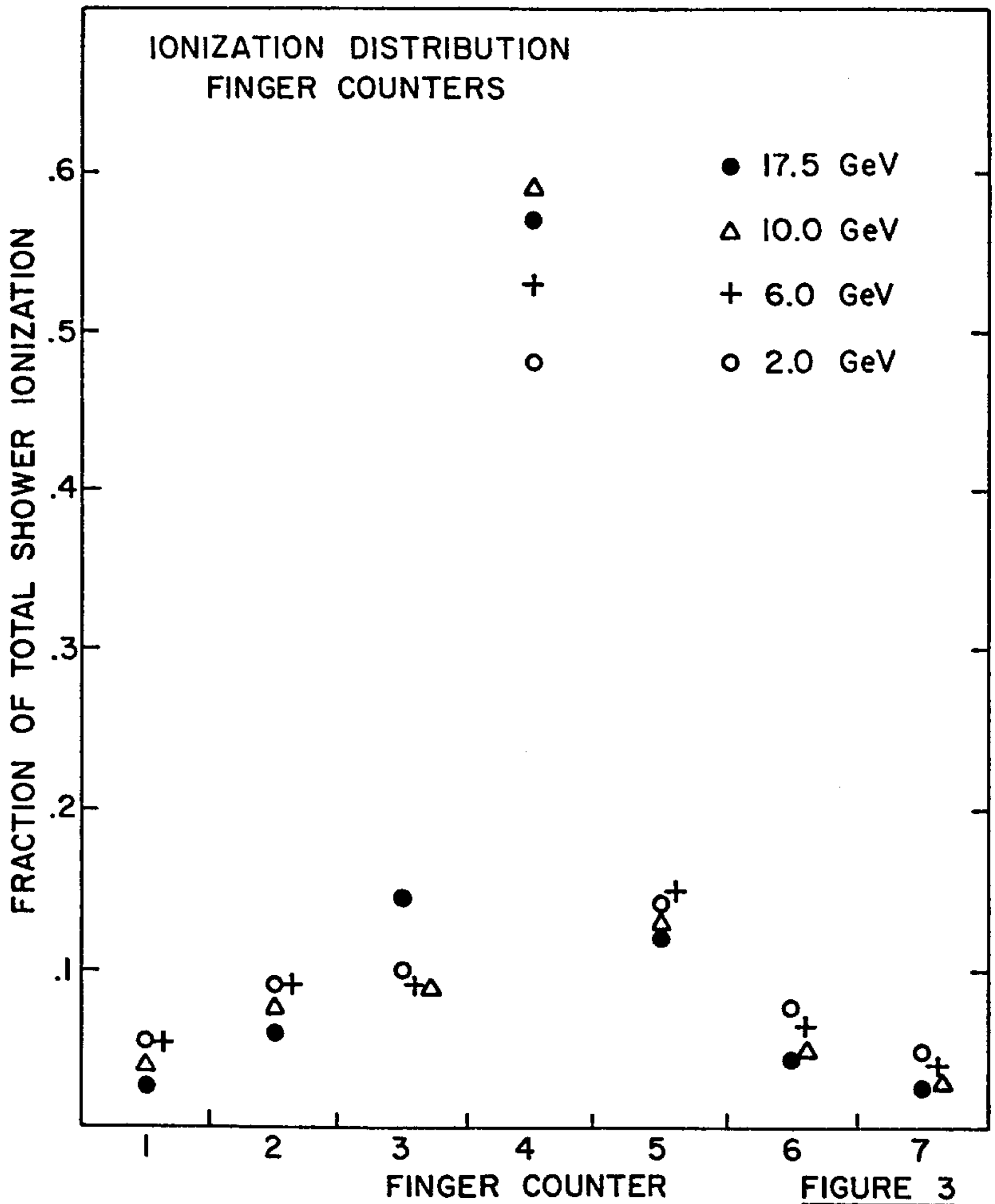

IONIZATION DISTRIBUTION
FINGER COUNTERS
17.5 GeV
10.0 GeV
6.0 GeV
2.0 GeV
FRACTION OF TOTAL SHOWER IONIZATION
.1
.2
.3
.4
.5
.6
1
2
3
4
5
6
7
FINGER COUNTER

FIGURE 3

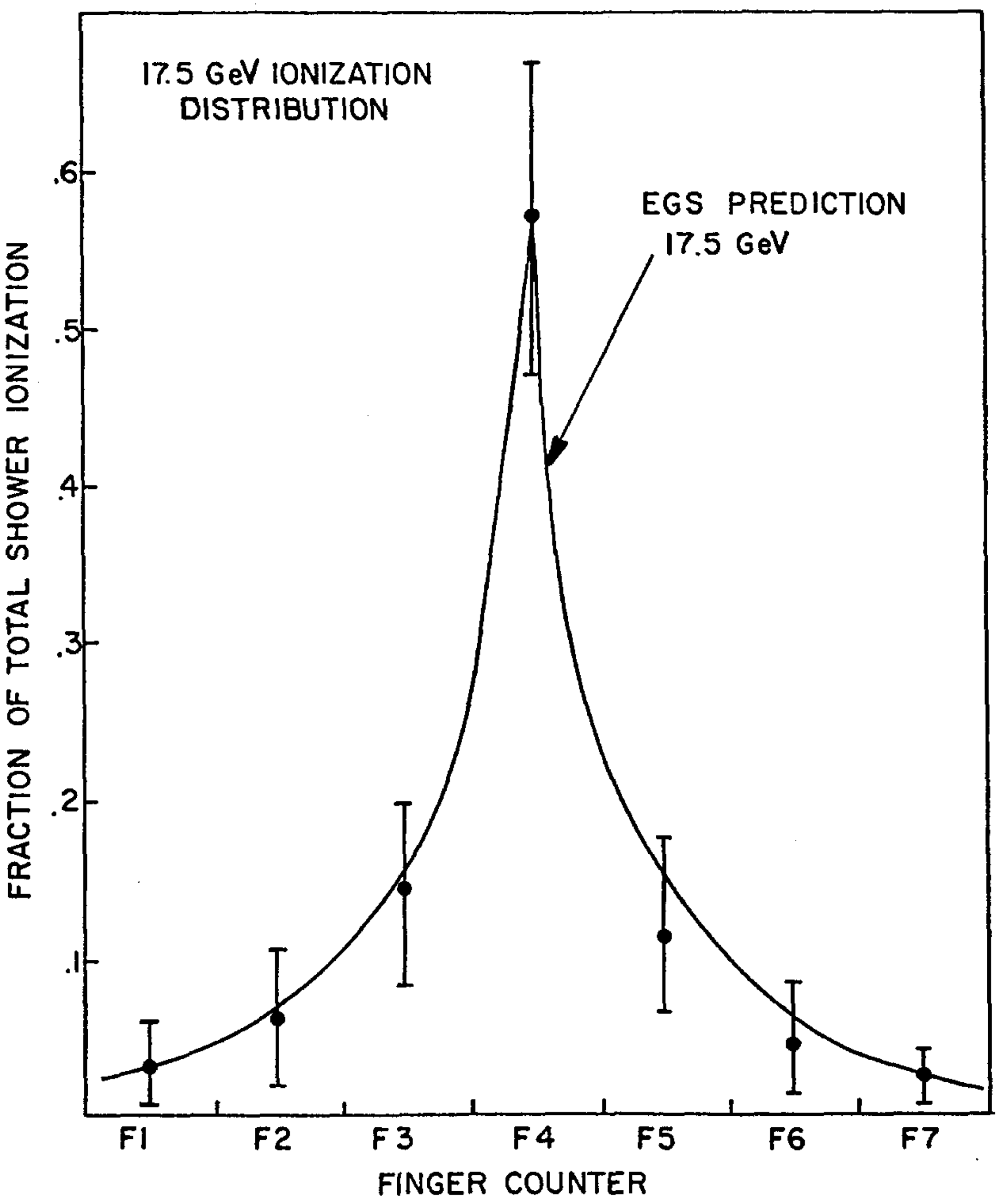

17.5 GeV IONIZATION
DISTRIBUTION
EGS PREDICTION
17.5 GeV
FRACTION OF TOTAL SHOWER IONIZATION
.6
.5
.4
.3
.2
.1
F1
F2
F3
F4
F5
F6
F7
FINGER COUNTER

FIGURE 4

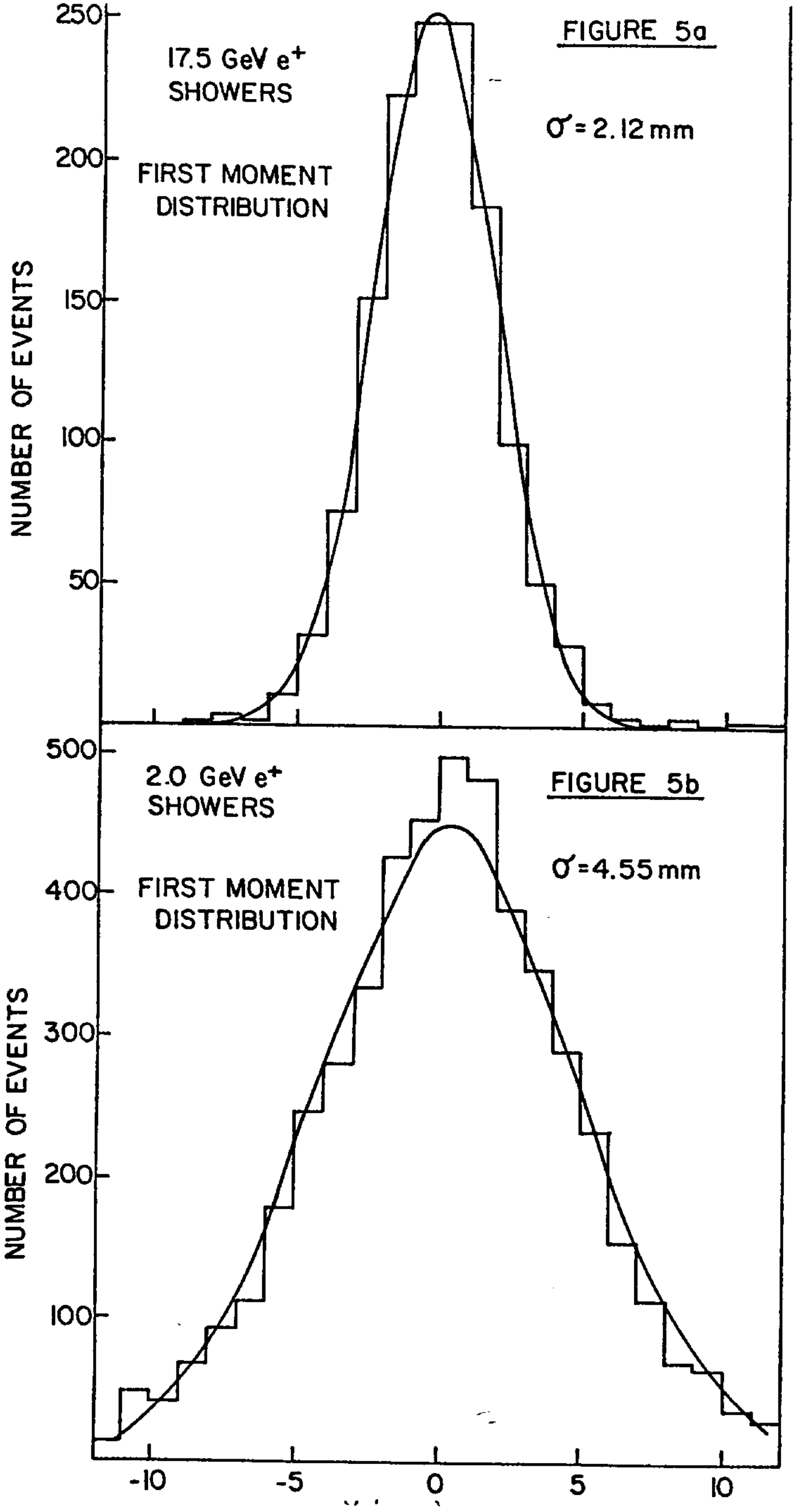


FIGURE 5a
17.5 GeV e+
SHOWERS
FIRST MOMENT
DISTRIBUTION
σ = 2.12 mm
NUMBER OF EVENTS
250
200
150
100
50
FIGURE 5b
2.0 GeV e+
SHOWERS
FIRST MOMENT
DISTRIBUTION
σ = 4.55 mm
NUMBER OF EVENTS
500
400
300
200
100
-10
-5
0
5
10

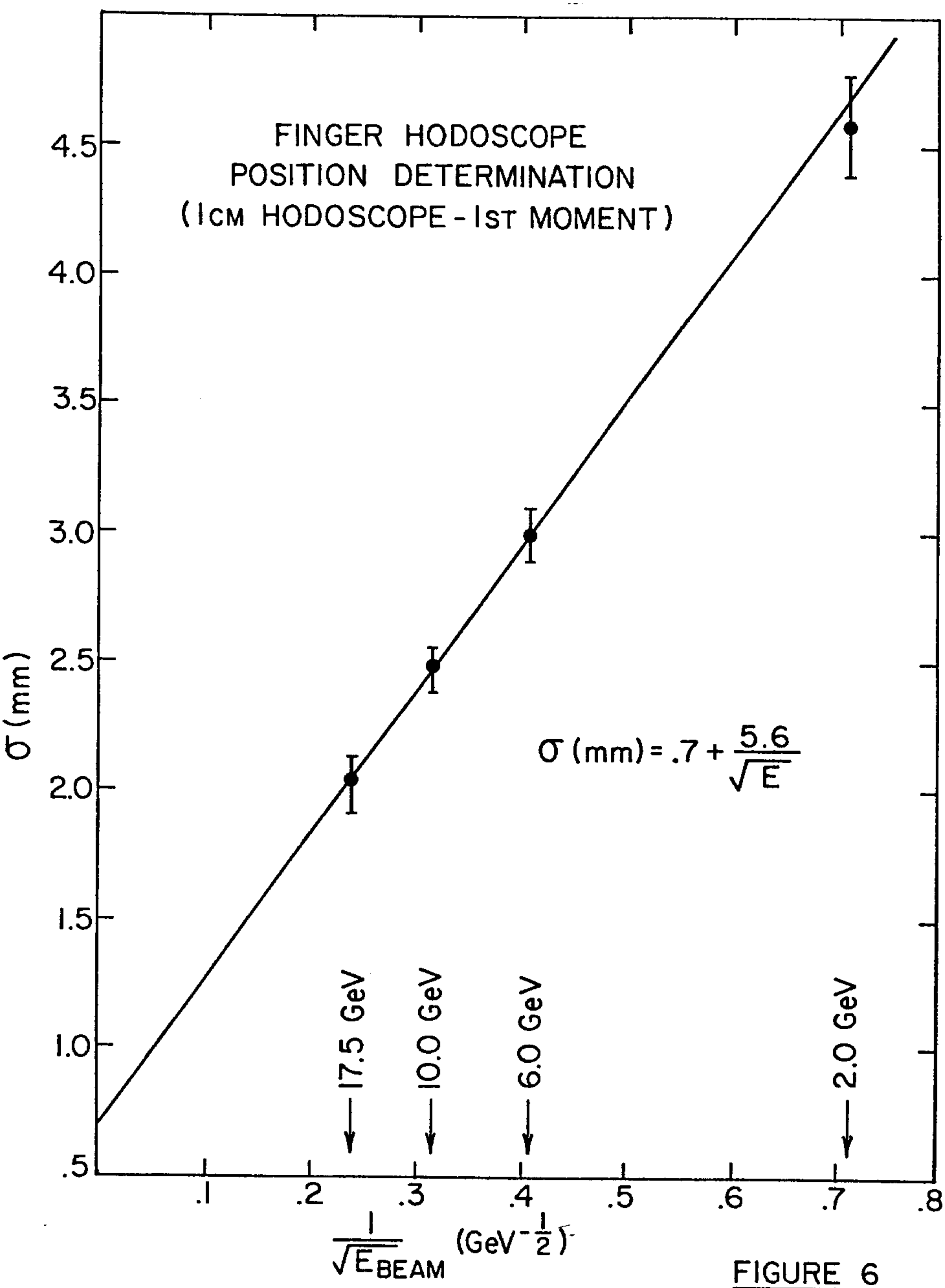

FINGER HODOSCOPE
POSITION DETERMINATION
(1CM HODOSCOPE - 1ST MOMENT)
σ (mm) = .7 + 5.6/√E
σ (mm)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
17.5 GeV
10.0 GeV
6.0 GeV
2.0 GeV
.1
.2
.3
.4
.5
.6
.7
.8
1/√E_BEAM (GeV^-1/2)

FIGURE 6