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Summary

An SCG1-C scintillation glass detector consisting of a 3.5 radiation length SCG1-C active converter followed by scintillation and gas tube hodoscopes and a 4x4 array of a 20.5 radiation length SCG1-C counters has been exposed to pions in the 4-14 GeV/c momentum range. The response of this detector to pions is compared with the response to electrons of the same momentum in order to distinguish between the two types of particles. Using only longitudinal and tranverse shower development criteria the electrons and pions can be separated such that on average $1.1x10^{-1}$ of all pions in the range of 4-14 Gev/c would be misidentified as electrons of any energy. If the

momentum of the incident particle is known and can be used in the identification technique, this average fraction is reduced to 6.4×10^{-3} of all pions misidentified as electrons of the same momentum.

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Introduction

In the test reported in this paper properties of showers produced by pions and electrons are measured in a 4x4 array of SCG1-C scintillation glass counters (Ohara Optical Glass Manufacturing Co., Ltd.). An SCG1-C scintillation glass active converter, plastic scintillator hodoscope, and a gas tube hodoscope were positioned in front of the 4x4 array of scintillation glass to complete the full detector.

Pion shower development at various energies was compared with electron showers using four variables: the ratio of the active converter energy (E_{ac}) to the energy deposited in the main 4x4 array (E_a), the ratio of the energy observed in the hit block of the 4x4 array (E_h) to the energy deposited in the 4x4 array, the total ionization observed in the gas tube hodoscope, and the second moment of the shower calculated from the distribution of ionization observed in the gas tube hodoscope. During these tests the beam was centered on the hit block. The response of the plastic scintillator hodoscope was recorded but gave information largely redundant to the gas tube hodoscope data. The mean and standard deviation of the distributions of each of these quantities were determined for 1-14 GeV/c electron showers. From these means and standard deviations a χ^2 was calculated for each pion shower with a given deposited energy in the detector by using parameters determined from electron showers at that same observed energy. The cut made on this χ^2 was set to retain 97% of all the electrons at that energy.

Beam

These tests were conducted with electrons and negative pions in test beam 6 at the Stanford Linear Accelerator Center (SLAC). The spot size of the beam containing 90% of the particles had a radius of 5 mm and the momentum spread was $\Delta p/p=2\%$ (FWHM). The beam momentum was varied between 4 and 14 GeV/c. The beam was operated at 10 pulses per second with an average intensity of 0.3 particles per 1.5 μs pulse. Beam pulses with multiple particles in the spot were tagged and later rejected in the off-line analysis. A pion beam was produced by placing 1.6 cm of lead in the beam to absorb electrons and by using a differential Cerenkov counter to tag the pions. An electron beam was produced by removing the lead absorber and using the same differential Cerenkov counter to tag the electrons. The electron beam had a pion component that varied with beam energy from 1% to 50%. This pion component was eliminated by the Cerenkov counter tag and an additional 3σ cut on the electron peak in the energy distribution measured in the scintillation glass detector. Electron showers below 4 GeV/c were measured with the same apparatus in a different SLAC test beam and the results are reported elsewhere.[1,2]

Experimental Apparatus

The detector (shown in Figure 1) was composed of an active converter and a 4x4 array of SCG1-C scintillation glass blocks. The blocks were 15x15x89.2 cm^3 (20.5 radiation lengths long). Between the active converter and the main array was placed a scintillator hodoscope and a gas tube hodoscope that was run in the saturated avalanche mode. Details on the calibration, energy resolution, and position resolution of this detector for electron showers are given elsewhere.[1,2] Pulse heights from the glass were digitized with LeCroy 2249W ADCs with a 256 ns gate. The data were collected by a LSI-11 mini-computer and written on magnetic tape for off-line analysis.

Energy Distributions of Pions and Electrons Measured by the SCG1-C Glass Detector

Figures 2a and 2b show the total energy deposited in the active converter and the main array by 4 and 14 GeV/c pions and electrons. Calibration constants are determined from the electron showers. More details on the determination of these calibrations constants are given in reference 1. The apparent energy deposited by pions extends up to and slightly beyond the incident pion momentum. The peak in the pion energy spectrum at low energies is due to noninteracting pions. These noninteracting pions deposit an apparent energy of 1.0±0.1 GeV independent of beam energy. The calculated minimum ionization energy loss through 104.2 cm of SCG1-C is 0.54 GeV. The calculated pion absorption length of 45.6 cm in scintillation glass is consistent with the observed ratio of noninteracting to interacting pion events. The ratio of apparent energy to beam energy for all pions is 0.58±0.01 throughout the energy range. The ratio of apparent energy to beam energy for interacting pions increases from 0.54 at 4 GeV to 0.67 at 14 GeV. The energy distributions for 4 and 14 GeV electrons are indicated by the cross hatched areas in Figures 2a and 2b. The electron energy distributions are clustered around the beam energy with the percentage energy spread decreasing with the square root of energy as discussed in reference 1.

Electron and Hadron Shower Shape

The energy and ionization deposited in the various elements of the detector have been used to determine the longitudinal and transverse shapes of pion and electron showers as a function of energy. Figure 3 shows the average shower shapes for pions and electrons at 4 and 14 GeV as measured in the gas tube hodoscope. As can be seen the pions interacting in the active converter produce showers that are broader on the average than the comparable electron showers and deposit much lower total ionization. This transverse peaking of the electron showers and the larger ionization deposited by the electrons relative to the pion showers are the most powerful discriminating factors between electron and pions in this detector. The transverse shower shapes are parameterized by the ratio E_h/E_a and the second moment of the distribution of ionization measured in the gas tube hodoscope. The distribution of these variables for 12 GeV/c electrons and pions showers are shown in Figures 4a and 5a. The most probable values and the extent of variation (each variance includes 68% of the events on either side of the most probable value) of the distributions as a function of incident momentum are shown in Figures 4b and 5b. As can be seen in Figure 4a the strong transverse peaking of the electromagnetic shower is also manifested in the distribution of E_h/E_a since on the average 90% of the observed electron energy is contained in the hit block. The pion showers by comparison have only 55% of the observed energy contained in the hit block on the average.

The longitudinal shower development is parameterized by E_{ac}/E_a and the total ionization observed in the gas tube hodoscope. Figures 6a and 7a show the distribution of these variables for 12 GeV/c pions and electrons and Figures 6b and 7b show the most probable value and the extent of variation of the two variables as a function of incident particle momentum. The distribution of E_{ac}/E_a is gaussian for electrons while the distribution for pions is strongly peaked toward low values because of the large fraction of pions events which do not interact in the active converter. The longitudinal variable E_{ac}/E_a does not allow a strong separation of interacting pions and electrons as can be seen from the overlap of the distributions shown in Figure 6. However pions which do not interact in the active converter are partially eliminated by the ionization distributions shown in Figure 7.

Electron-Pion Discrimination

Electrons and pions can be distinguished by comparing the transverse and longitudinal showers that are produced by pions that deposit a given energy with showers produced by electrons that deposited the same energy. No knowledge of the incident particle momentum is required since the observed deposited energy is used to select the electron showers of that same energy. This technique is appropriate to experiments in which the incident particle momentum is not measured independently of the calorimetric measurement (e.g., experiments which attempt to distinguish neutral hadrons from photons). If a particular experiment can determine the incident momentum in a way that is independent of the calorimetric measurment (e.g., experiments which make a magnetic measurement of electron momentum and make determination of E/p) then this independent knowledge of the incident momentum can be used to obtain an additional rejection of pions. Therefore, we quote a pion rejection factor based on shower shape criteria alone and a pion rejection factor assuming that independent knowledge of the incident particle momentum is available.

As mentioned in the previous section the four variables E_{ac}/E_a, E_h/E_a, total ionization in the gas tube hodoscope and the second moment of the distribution of ionization in the gas tube hodoscope were used to form a χ^2 which measures the probability that a particular shower is due to an electron. If a pion shower deposits a given energy the values of these four variables for that shower are used to calculate a χ^2 using the means and standard deviations of the distributions of electron showers at that energy. Cuts on this χ^2 were set to contain 97% of the electrons at all energies. Figure 8 shows the fraction of pion showers which survive this χ^2 cut as a function of deposited energy for the various incident momenta. As can be seen pions which deposit lower energies are harder to separate from electron showers than pions which deposit larger energies. The fraction of pions of a given incident momentum that survive the shape cuts is shown in Figure 9 as a function of incident momentum. In addition in the same figure the fraction of pions which survive a cut on a χ^2 which incorporates knowledge of the incident particle momentum is shown as a function of incident momentum. As can be seen both types of rejection factors are relatively independent of momentum. Knowledge of the incident momentum gives approximately an extra factor of 10 discrimination against pions.

Conclusions

An SCG1-C scintillation glass detector has been tested with pions in the 4-14 GeV/c range to determine its properties for discrimination between pions and electrons. The noninteracting pions deposit 1.0±0.1 GeV of energy in the array and are discriminated from electrons by their transverse shower properties and total ionization deposited in the gas tube hodoscope. Interacting pions are primarily rejected on the basis of their transverse shower shapes with the longitudinal shower shapes contributing to the discrimination factor to a lesser degree. Overall shower shape variables allow rejection of all but 1.1×10^{-1} of all pions in the 4-14 GeV/c range. Knowledge of the incident momentum decreases this rejection factor to 6.4×10^{-3}.

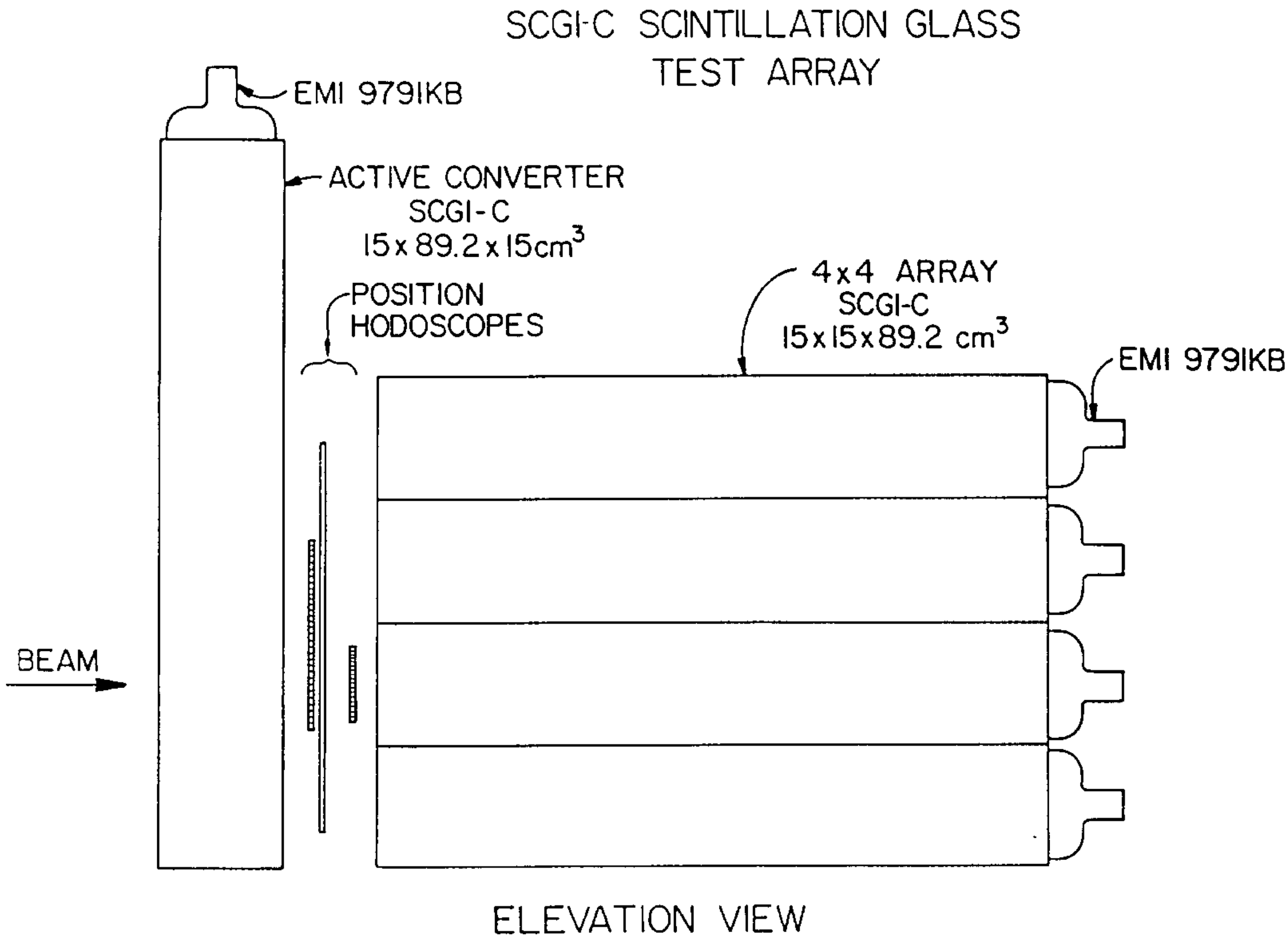
Acknowledgments

We wish to thank the SLAC operating staff. We would also like to acknowledge the U.S. Department of Energy, the Natural Sciences and Engineering Research Council of Canada, the Quebec Department of Education, and the Hellenic Science and Technology Agency for their support.

References

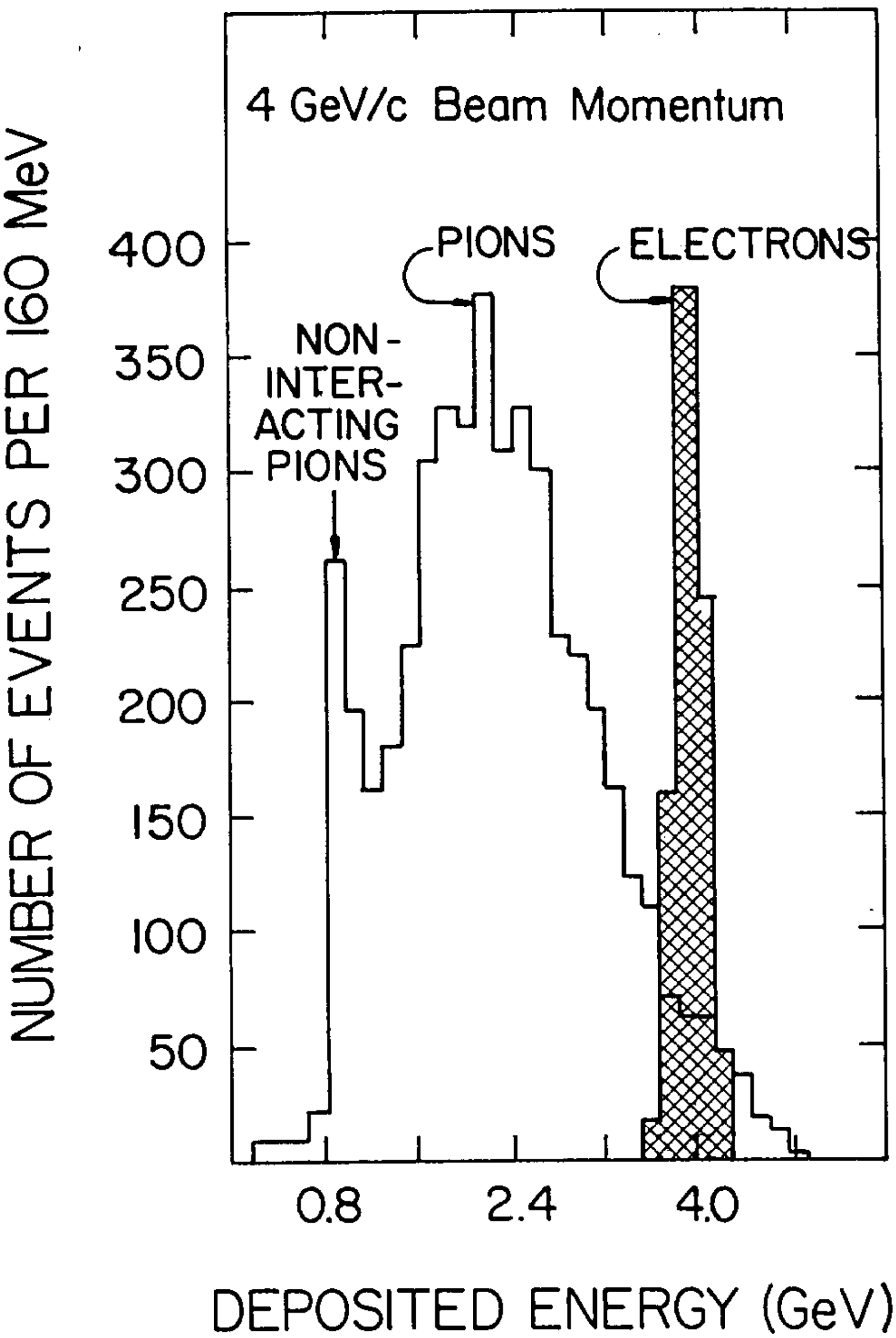
1. D.E. Wagoner, et al., A Measurement of the Energy Resolution and Related Properties of an SCG1-C Scintillation Glass Shower Counter Array for 1-25 GeV Positrons, Paper 3A2, 1983 Nuclear Science Symposium, San Francisco, CA.

2. R. Rameika, et al., Measurement of Electromagnetic Shower Position and Size with a Saturated Avalanche Tube Hodoscope and a Fine Grained Scintillation Hodoscope, Paper 3A5, 1983 Nuclear Science Symposium, San Francisco, CA.



SCGI-C SCINTILLATION GLASS
TEST ARRAY
EMI 9791KB
ACTIVE CONVERTER
SCGI-C
15 x 89.2 x 15cm³
POSITION
HODOSCOPES
4x4 ARRAY
SCGI-C
15 x 15 x 89.2 cm³
EMI 9791KB
BEAM
ELEVATION VIEW

FIGURE 1



4 GeV/c Beam Momentum
NUMBER OF EVENTS PER 160 MeV
400
350
300
250
200
150
100
50
PIONS
ELECTRONS
NON-INTER-ACTING PIONS
0.8
2.4
4.0
DEPOSITED ENERGY (GeV)

FIGURE 2a

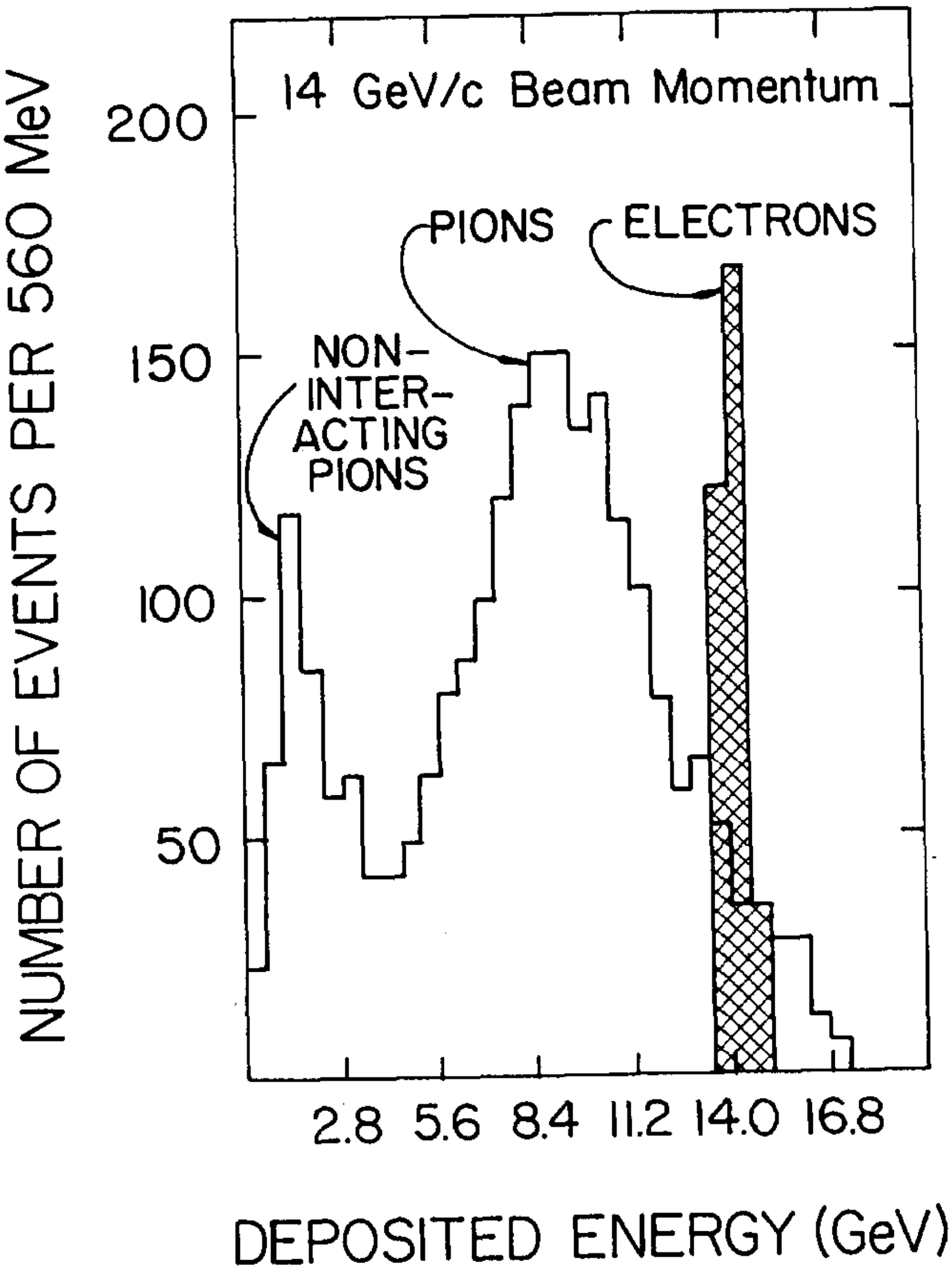
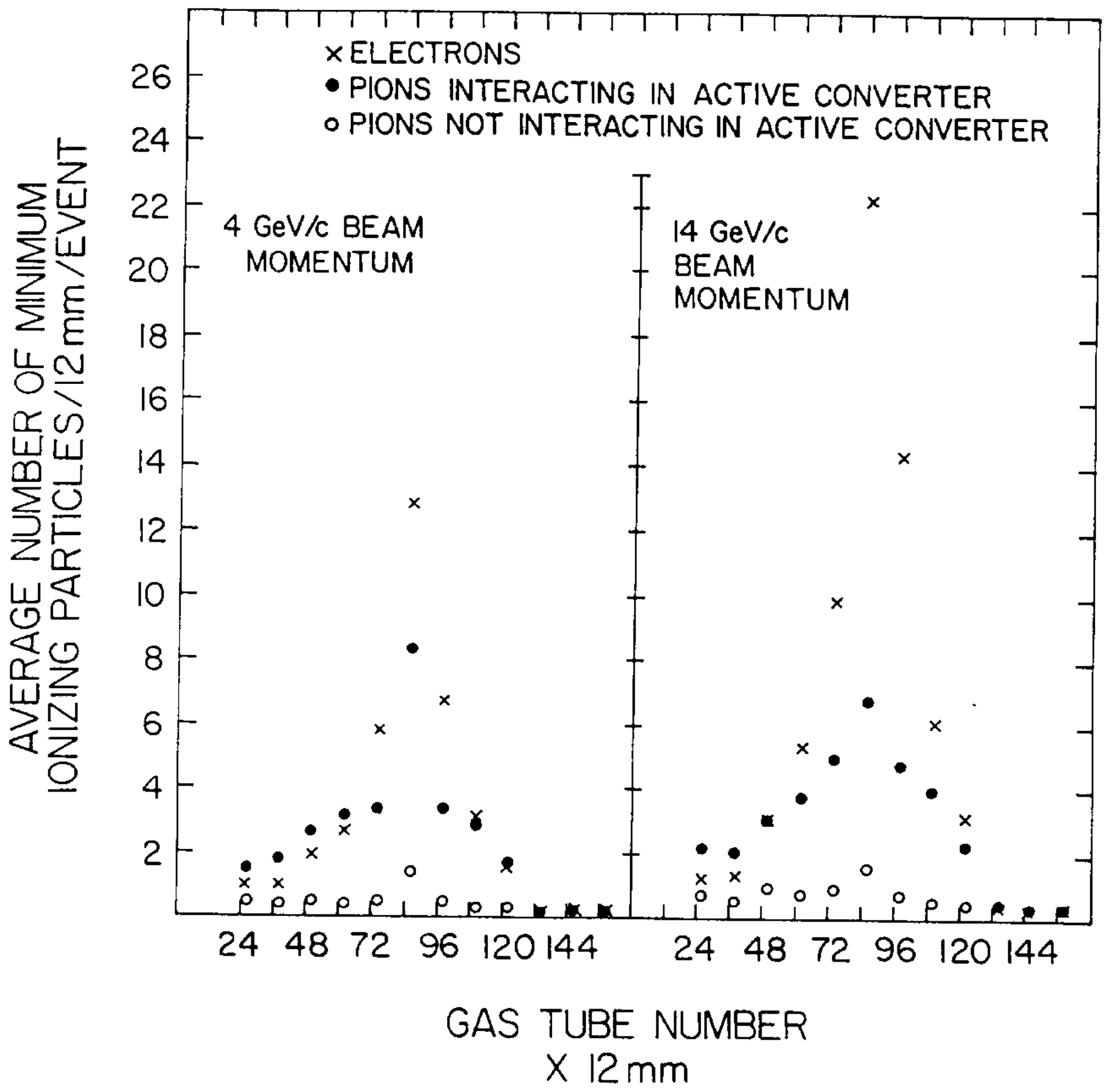
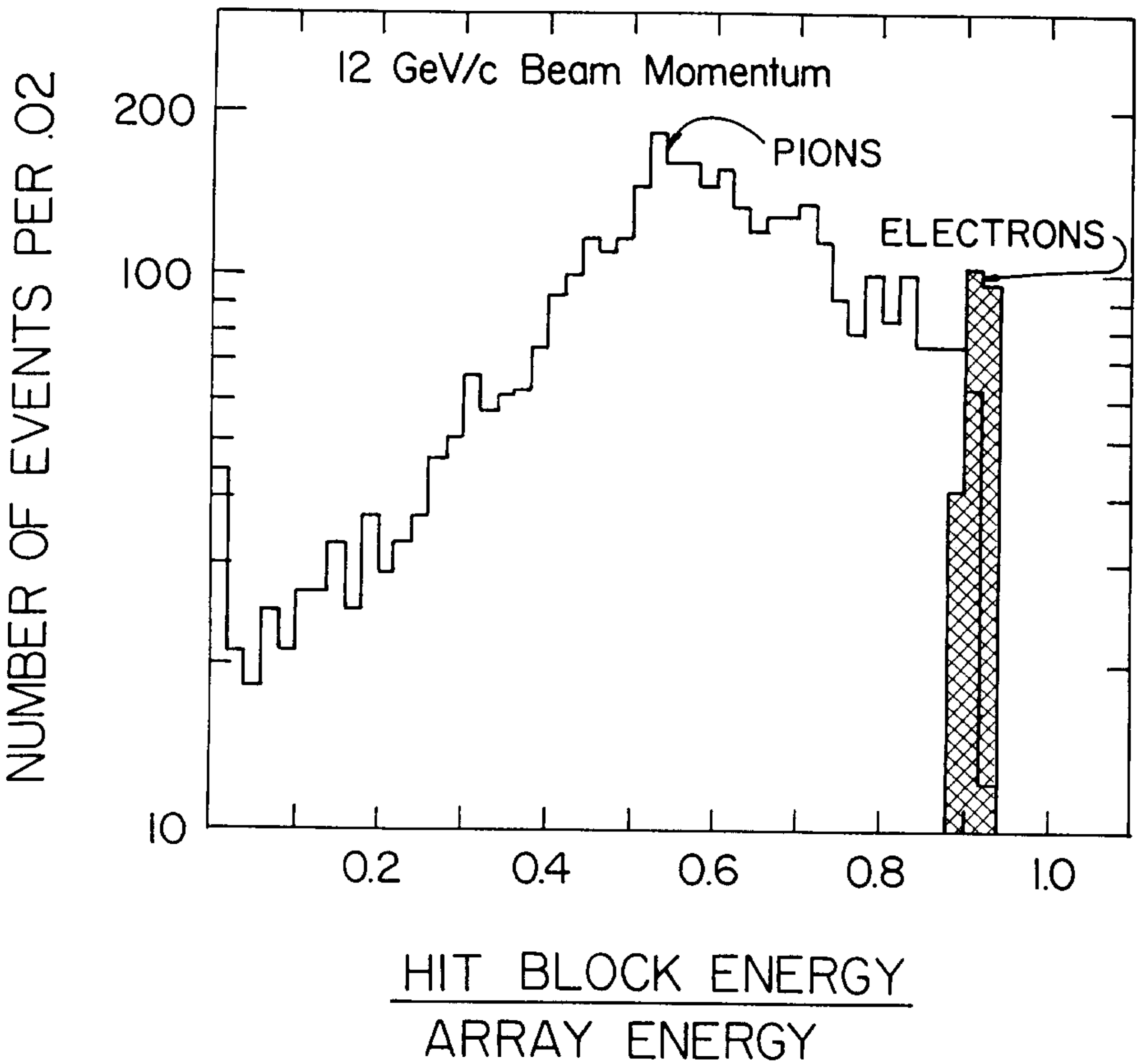

14 GeV/c Beam Momentum
NUMBER OF EVENTS PER 560 MeV
200
150
100
50
PIONS
ELECTRONS
NON-
INTER-
ACTING
PIONS
2.8
5.6
8.4
11.2
14.0
16.8
DEPOSITED ENERGY (GeV)

FIGURE 2b



× ELECTRONS
● PIONS INTERACTING IN ACTIVE CONVERTER
○ PIONS NOT INTERACTING IN ACTIVE CONVERTER
4 GeV/c BEAM MOMENTUM
14 GeV/c BEAM MOMENTUM
AVERAGE NUMBER OF MINIMUM IONIZING PARTICLES/12mm/EVENT
26
24
22
20
18
16
14
12
10
8
6
4
2
24
48
72
96
120
144
24
48
72
96
120
144
GAS TUBE NUMBER X 12mm

FIGURE 3



12 GeV/c Beam Momentum
PIONS
ELECTRONS
NUMBER OF EVENTS PER .02
200
100
10
0.2
0.4
0.6
0.8
1.0
HIT BLOCK ENERGY
ARRAY ENERGY

FIGURE 4a

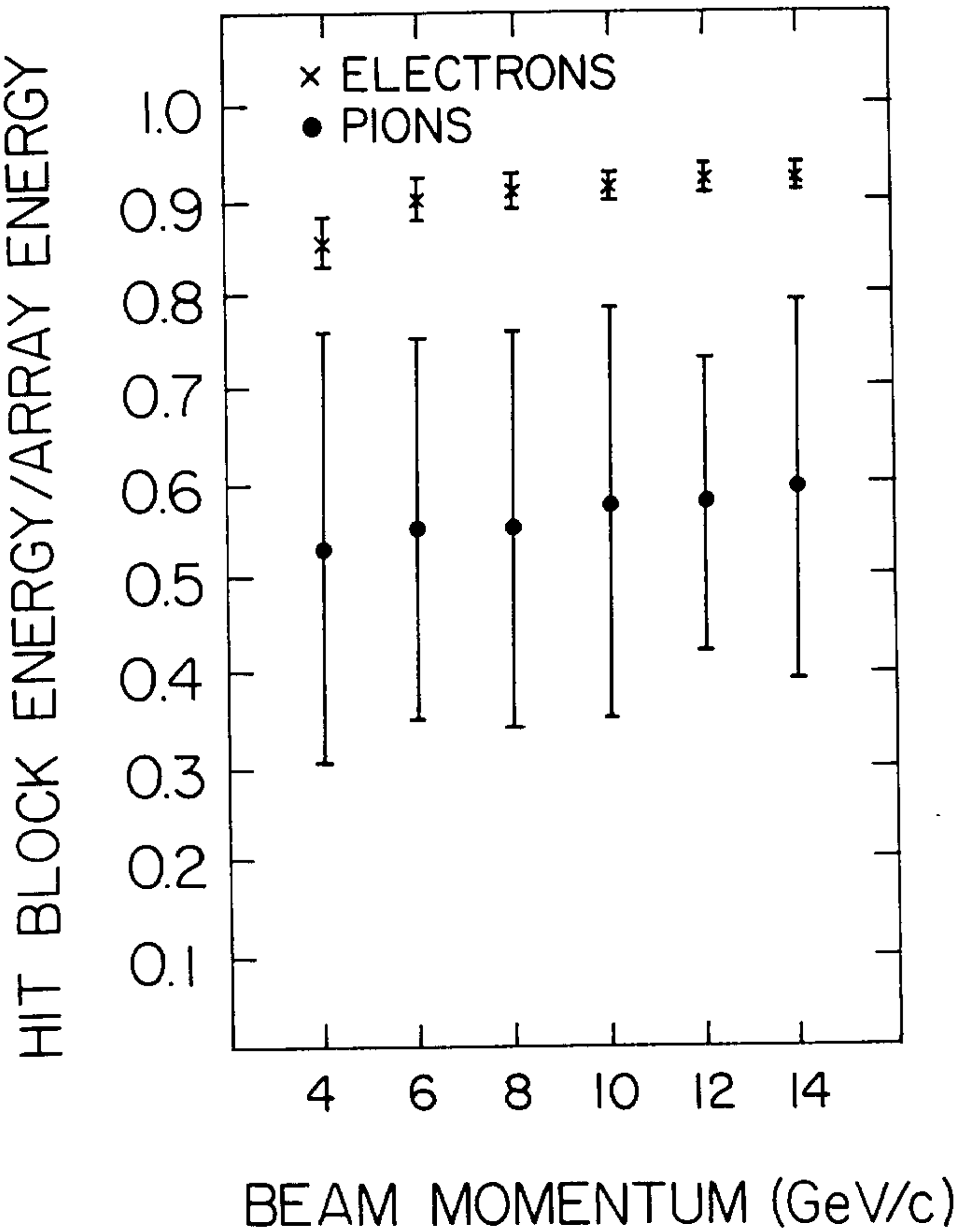

× ELECTRONS
● PIONS
HIT BLOCK ENERGY/ARRAY ENERGY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
6
8
10
12
14
BEAM MOMENTUM (GeV/c)

FIGURE 4b

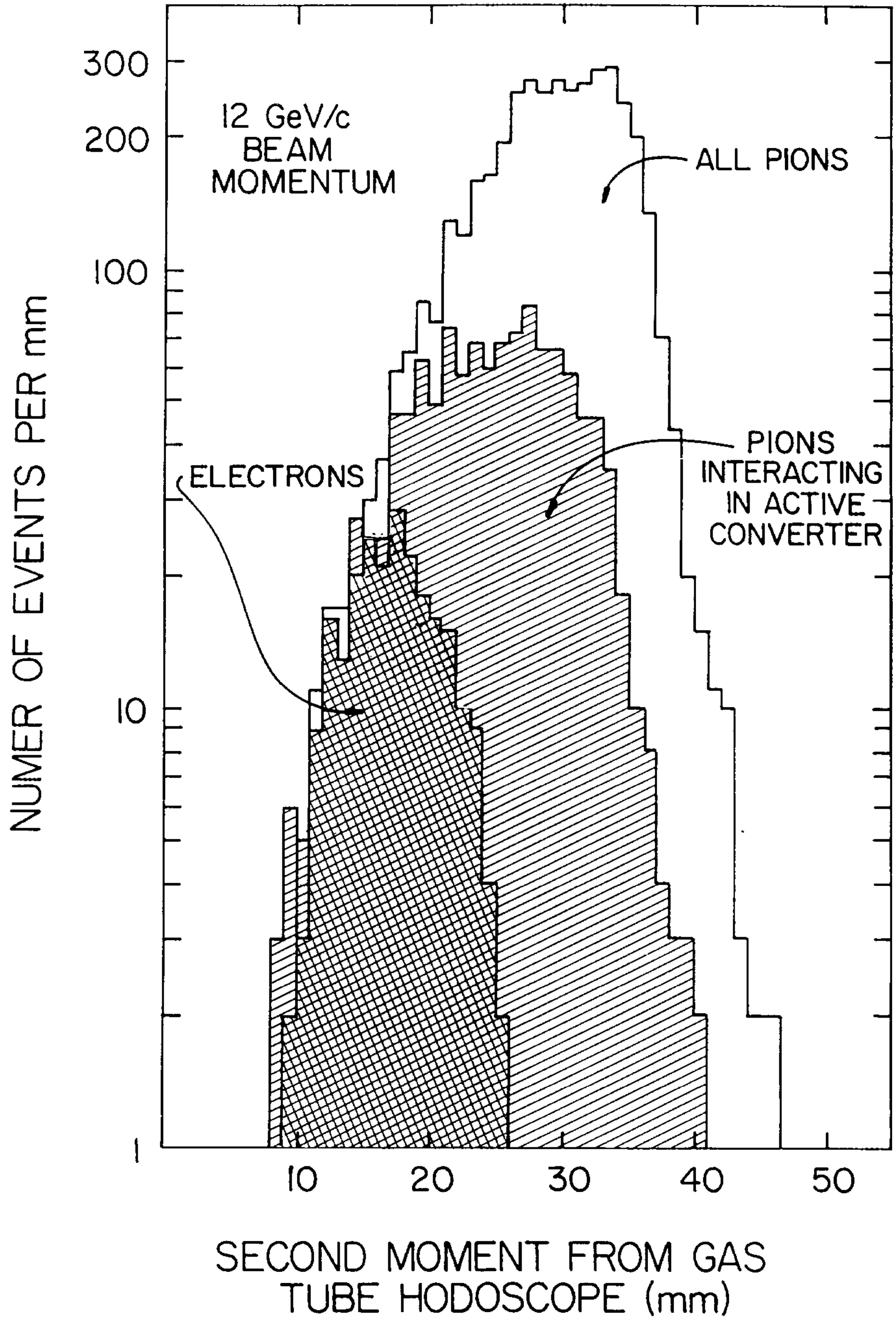

12 GeV/c
BEAM
MOMENTUM
ALL PIONS
PIONS
INTERACTING
IN ACTIVE
CONVERTER
ELECTRONS
300
200
100
10
1
10
20
30
40
50
NUMER OF EVENTS PER mm
SECOND MOMENT FROM GAS
TUBE HODOSCOPE (mm)

FIGURE 5a

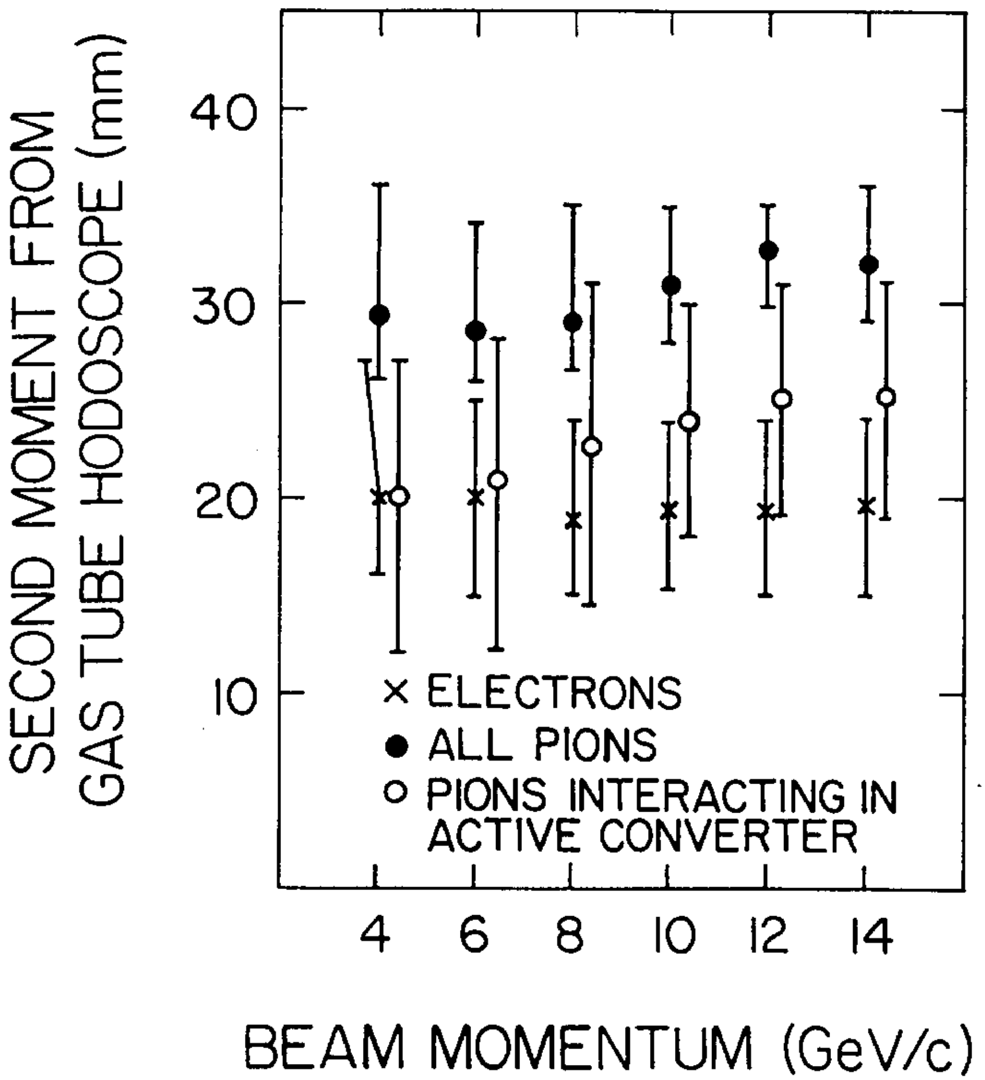

SECOND MOMENT FROM
GAS TUBE HODOSCOPE (mm)
40
30
20
10
× ELECTRONS
● ALL PIONS
○ PIONS INTERACTING IN
ACTIVE CONVERTER
4
6
8
10
12
14
BEAM MOMENTUM (GeV/c)

FIGURE 5b

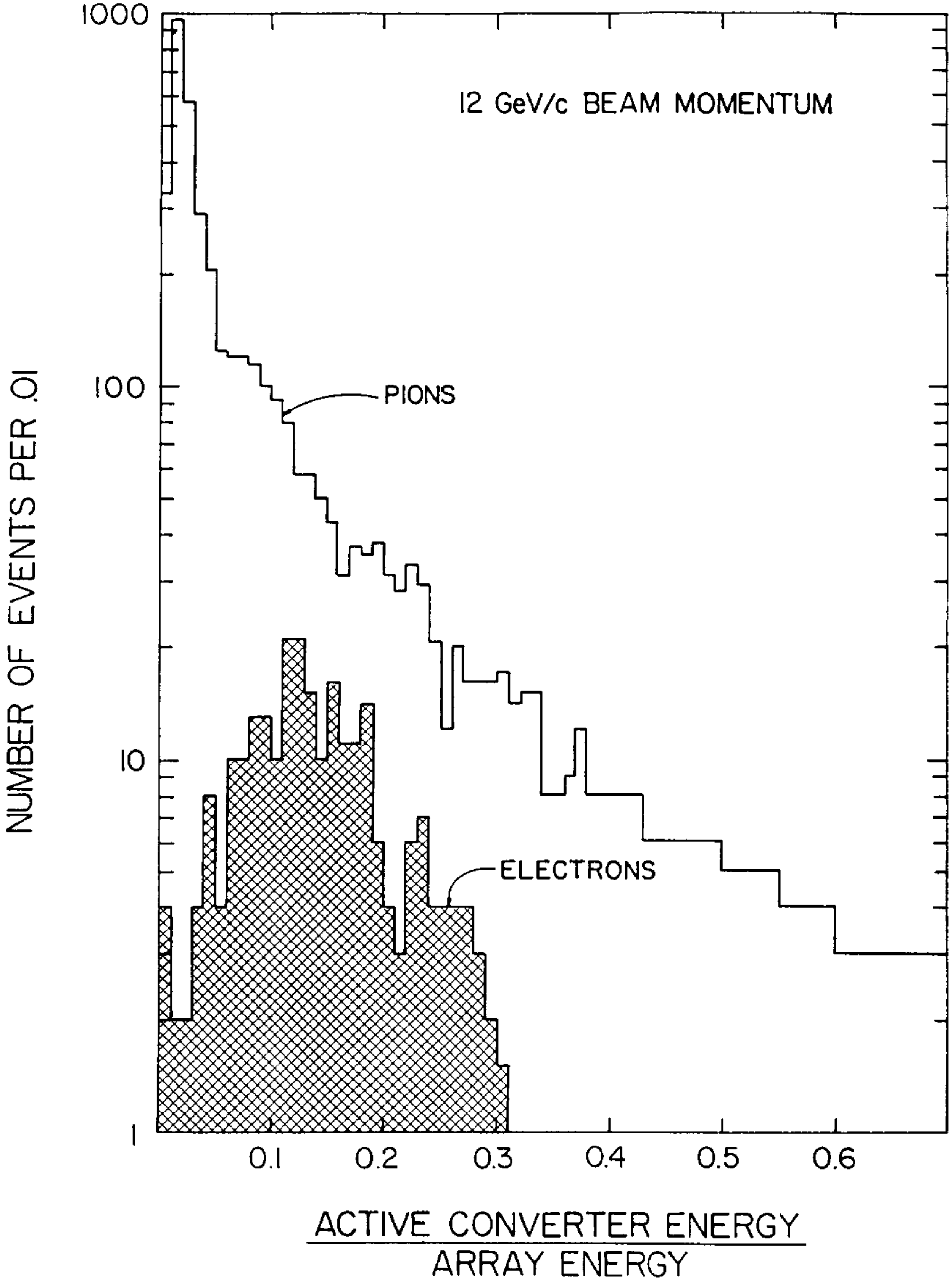
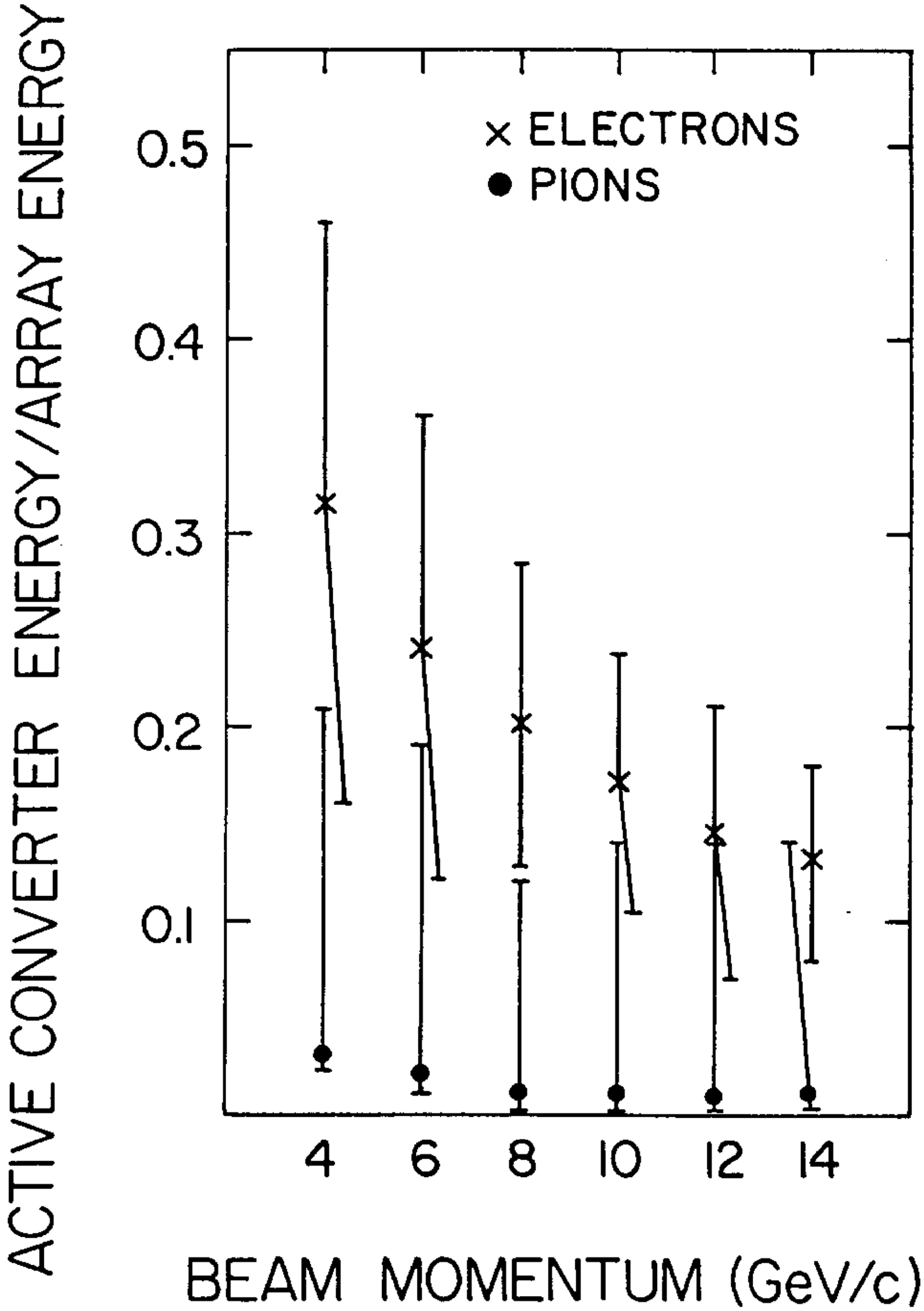

12 GeV/c BEAM MOMENTUM
PIONS
ELECTRONS
NUMBER OF EVENTS PER .01
1000
100
10
1
0.1
0.2
0.3
0.4
0.5
0.6
ACTIVE CONVERTER ENERGY
ARRAY ENERGY

FIGURE 6a



ACTIVE CONVERTER ENERGY/ARRAY ENERGY
0.5
0.4
0.3
0.2
0.1
× ELECTRONS
● PIONS
4
6
8
10
12
14
BEAM MOMENTUM (GeV/c)

FIGURE 6b

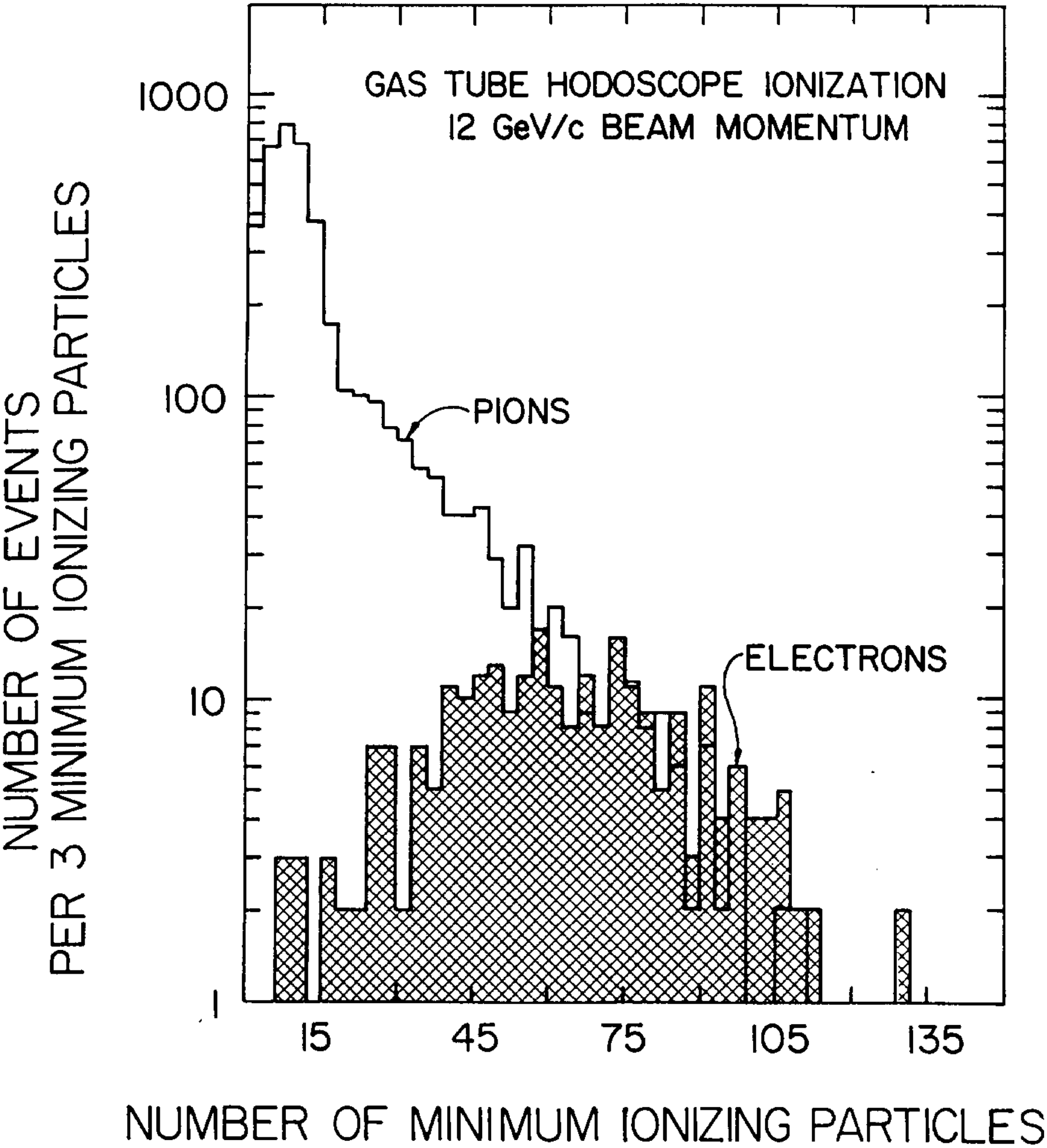
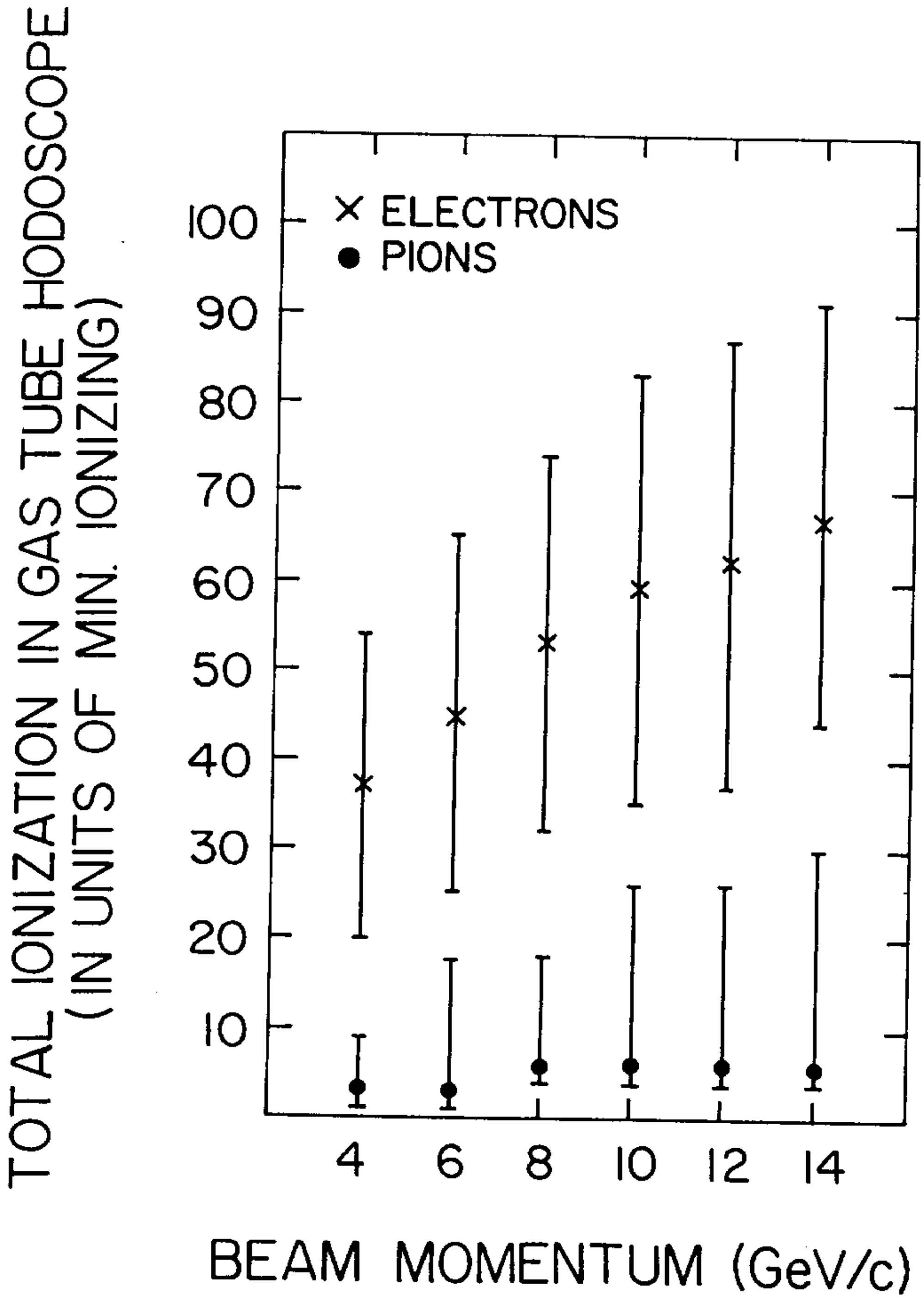

GAS TUBE HODOSCOPE IONIZATION
12 GeV/c BEAM MOMENTUM
NUMBER OF EVENTS
PER 3 MINIMUM IONIZING PARTICLES
1000
100
10
1
PIONS
ELECTRONS
15
45
75
105
135
NUMBER OF MINIMUM IONIZING PARTICLES

FIGURE 7a



TOTAL IONIZATION IN GAS TUBE HODOSCOPE
(IN UNITS OF MIN. IONIZING)
100
90
80
70
60
50
40
30
20
10
× ELECTRONS
● PIONS
4
6
8
10
12
14
BEAM MOMENTUM (GeV/c)

FIGURE 7b

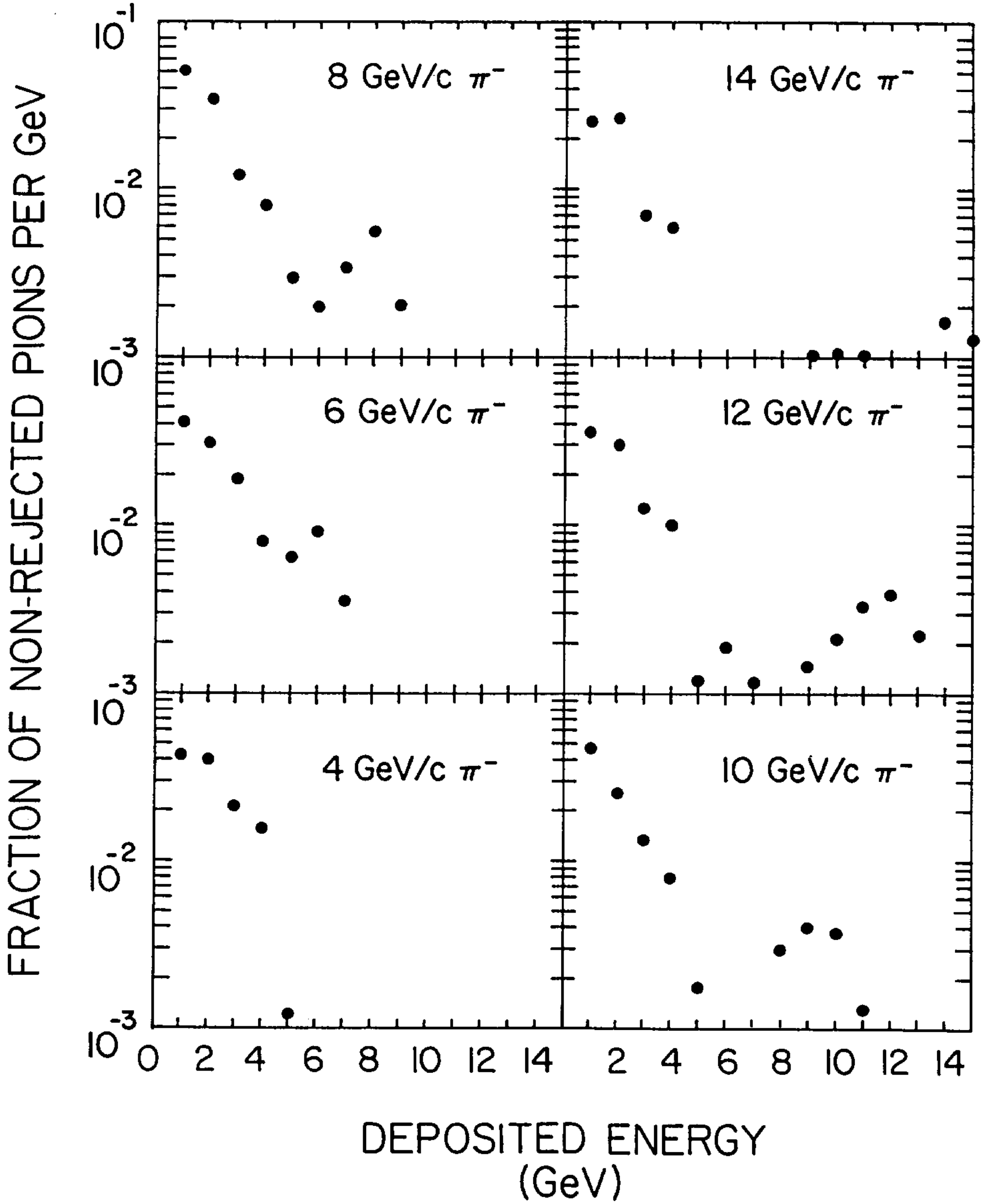

FRACTION OF NON-REJECTED PIONS PER GeV
8 GeV/c π⁻
14 GeV/c π⁻
6 GeV/c π⁻
12 GeV/c π⁻
4 GeV/c π⁻
10 GeV/c π⁻
10⁻¹
10⁻²
10⁻³
0 2 4 6 8 10 12 14
DEPOSITED ENERGY (GeV)

FIGURE 8

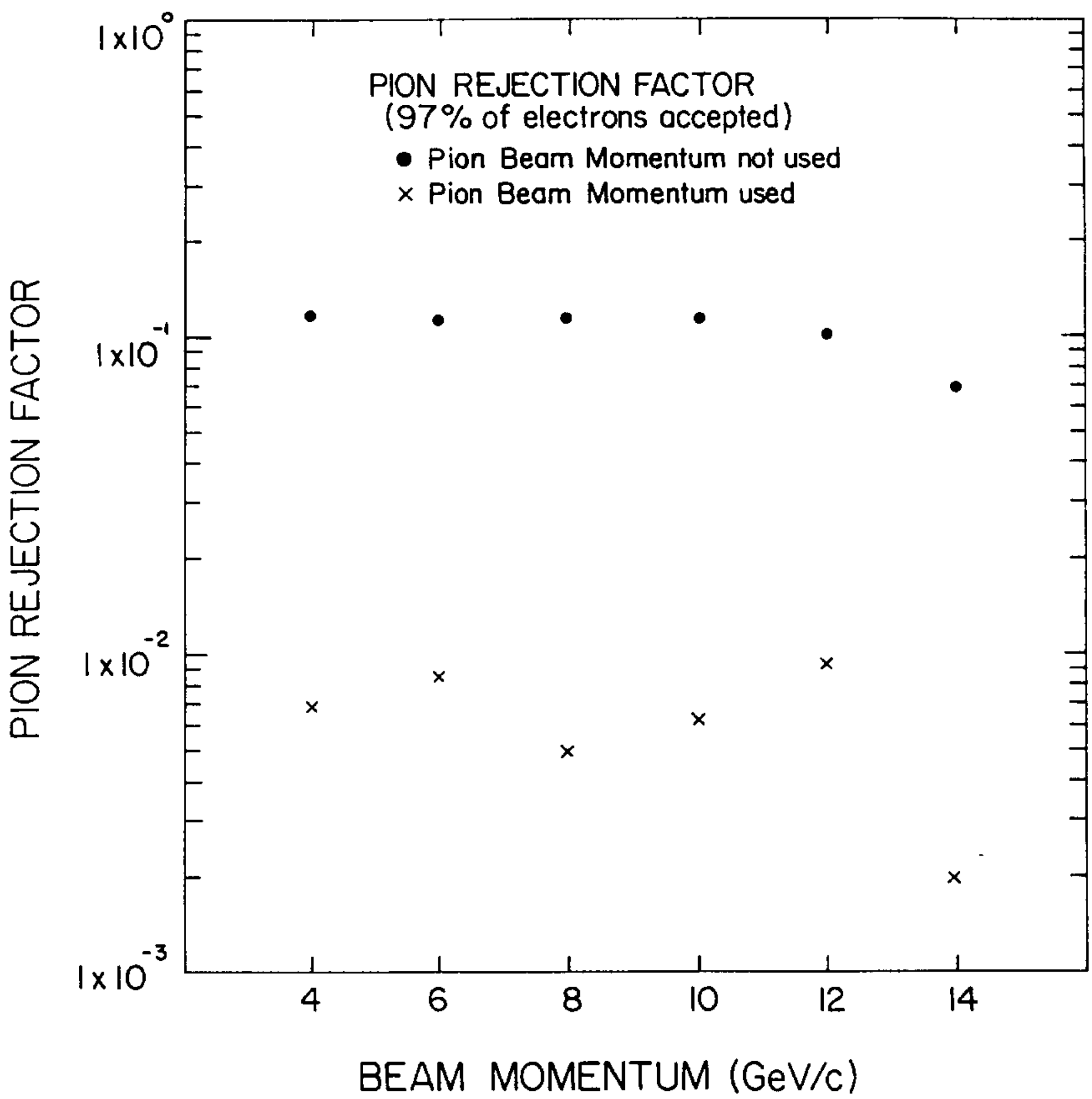

PION REJECTION FACTOR
(97% of electrons accepted)
● Pion Beam Momentum not used
× Pion Beam Momentum used
PION REJECTION FACTOR
BEAM MOMENTUM (GeV/c)
1x10°
1x10⁻¹
1x10⁻²
1x10⁻³
4
6
8
10
12
14

FIGURE 9