FERMILAB-Proposal-0603

1978

Addendum to Proposal 603

Bubble Chamber Part of Proposal

W. F. Fry and R. Huson

The bubble chamber sub-group of the proponents strongly feel that the bubble chamber is the most decisive device for disentangling the complex nature of the various types of neutrino interactions. Specifically, the most important information is contained in the e^+ neutrino induced events. The incisive ability of the bubble chamber to separate e^+, e^-, μ^+, μ^- and measure their energies along with the detection of associated K_s^o decays makes the bubble chamber unique for exploratory beam dump experiments.

For these reasons we propose that the total flux for the experiment be increased to 5×10^{18} protons. This could be achieved in different modes such as

1. Dedicated single turn $\sim$4 weeks
2. $\sim 10^{13}$/pulse at 10 sec. cycle $\sim$3 months.

37 pgs.

603

A Search for the Production of Prompt Neutrinos in High Energy Proton Nucleus Collisions

D. D. Reeder, Spokesman

University of Wisconsin
Madison, Wisconsin
(Phone 608-262-2281)

E-310 Detector

D. B. Cline, P. Cooper, M. Duffy, M. Gilchriese, R. Loveless

M. Heagy, R. Imlay, T. Y. Ling, M. Merlin,

T. Trinko, and D. Winn

University of Wisconsin
University of Pennsylvania
Rutgers University
Ohio State University

15' Bubble Chamber

R. Benada, U. Camerini, B. Chrisman, W. F. Fry, A. Greene,

F. Huson, R. Loveless, R. March, T. Murphy, A. Roberts,

J. Schmidt, W. Smart, J. Wolfson, and M. Yee

Table of Contents

I. Introduction

We propose to detect neutrinos either produced directly in proton nucleus collisions or produced in the decay of the short lived parents (e.g. quarks with new flavors or new leptons) which are made in these collisions. The principle characteristics which permit the separation of these neutrinos from the more familiar sources that will constitute the background are:

i) The large Q value expected in the decays will produce neutrinos at large momentum transverse to the proton beam, whereas the flux from background sources is suppressed.

ii) The new sources are expected to produce roughly equal numbers of neutrinos and antineutrinos of both electron and muon lepton numbers; $\nu_\mu \sim \bar{\nu}_\mu \sim \nu_e \sim \bar{\nu}_e$. In contrast the background neutrinos are predominately muon neutrinos: $\nu_\mu > \bar{\nu}_\mu > \nu_e > \bar{\nu}_e$.

The specification of an appropriate detector must incorporate these and other characteristics. To optimize a single detector is very difficult. However, existing detectors with some modification can provide efficient and unbiased detection for particles with diverse characteristics. The addition of shower detectors to the E-310 apparatus provides electron sensitivity which, coupled with the proven calorimeter and muon spectrometer, can be an exceptionally complete detector. The neon bubble chamber has limited mass but is unrivaled in defining the details of the final states, recording strange particles (Vees) and the charge of electron in ν_e interactions.

We propose to modify the E-310 detector by installing the lead scintillator counters in place of the iron target. With the modified detector and the 15' Bubble Chamber filled with neon we request:

i) 10^{18} protons on beam dump at zero target angle

ii) 10^{18} protons on beam dump at 10 mr target angle

II. Physics Motivation

Since the first observation of the J/ψ[1] and its interpretation as evidence for a new flavor (charm), many experiments have been performed to search for the production of pairs of charmed particles produced in collisions of hadrons. Until recently, the confirmation of the hadronic production of charm has eluded these efforts. The beam dump experiment at CERN may have established it (or something else!). The difficult experimental problem of the detection of still more massive hadrons, as suggested by the observation of the upsilon,[2] has not even been seriously addressed.

These experiments can be classified by the "signature" or specific final state used to signal the charmed particle.

A. Hadronic final states

The search is handicapped because the branching ratio (BR) into a two body final state is only a few per cent.[3] Although the sensitivity to the product of cross section and branching ratio (σ.B) is much less than 1 μb/nucleon, the consequent limit on the cross section is rather poor. Typical results are:

$\sigma_{D\bar{D}}$ < 28 μb/nucl. 250 GeV neutrons	Ref. 4
$\sigma_{D\bar{D}}$ < 26 μb/nucl. 250 GeV protons	Ref. 5
σ_{CH} < 1.5 μb/nucl. 300 GeV protons (emulsion)	Ref. 6
$\sigma_{D\bar{D}}$ < 50 nb/nucl. 30 GeV protons	Ref. 7

The limit provided by the emulsion experiment is dependent on assumptions concerning the lifetime or angular distribution of the charmed particles.

The only search for particles more massive than charm was done by the Stony Brook, Columbia, FNAL collaboration[8] who report a limit for σ.B of 300 to 0.2 nb/nucleus in the mass range 4-10 GeV/c^2 for decay into charged hadrons.

B. Charged lepton production

The direct production of charged leptons in hadronic collisions has been known for some time. J. Cronin at the Lepton Photon Symposium at Hamburg has admirably reviewed the experimental situation.[9] In summary, although the direct production of single leptons for $p_\perp > 1$ GeV/c and rather small x_F is found to be about 10^{-4} of pion production, most of these single leptons are produced in pairs. Figure 1 taken from a review by B. Dolgoshein[10] shows the data at FNAL and at ISR energies. Perhaps 20-30 percent of the signal at large $p_\perp$ remains after subtraction of muon pair production. That is, for single prompt muons the ratio is at most

$$\left(\frac{\mu}{\pi}\right) \simeq 2 - 3 \times 10^{-5}.$$

However, the most striking feature of these data is the large μ/π ratio as small transverse momentum and high energy. It is of obvious importance to understand this anomaly and its relation to prompt neutrinos.

Searches for the hadronic production of charm using a single prompt muon as a trigger have failed to clearly establish charm production. The limits are:

$\sigma_{DD} < 90$ μb/nucleon	Ref. 15
$\sigma_{DC} < 44$ μb/nucleon	Ref. 15
$\sigma_{CHARM} < 15$ μb/nucleon	Ref. 16

However, the preliminary results from a recent calorimetric experiment, E-379, indicate that a signal which may be charm has been detected using a prompt muon and missing energy (presumably due to prompt neutrinos). Their result is

$$\sigma_{DD} \simeq 10 - 100 \text{ μb/nucleon}$$

C. Direct neutrino production

Although searches for sources of prompt neutrinos were proposed at Fermilab as early as 1970[17], for various reasons these experiments, colloquially known as "beam dump" experiments, were never completed. An early attempt to discover long lived particles which decay inside a massless detector was reported by the E1A collaboration in 1975.[18] Earlier an unsuccessful search for an anomalous source of positive muons (wrong sign) in a charge separated neutrino beam had been reported by Barish et al.,[19] and later by the CDHS collaboration at CERN.[20] Recently, a limit on the beam dump origin of trimuon events has been published by E-310.[21]

The first positive indication of prompt neutrino production was reported at Neutrino '77 by a Serpukhov group. They measure the rate of prompt neutrinos to be

$$\left(\frac{\nu}{\pi}\right) = (2.0^{+2.2}_{-2.0}) \times 10^{-5} \qquad \text{protons at 70 GeV}$$

They further extract a cross section assuming D meson production.

$$\sigma_{DD} \lesssim 18 \pm 20 \ \mu b/\text{nucleon} \qquad \text{Reference 22}$$

A serious attempt to observe direct production of neutrinos at high energy was made in the Autumn of 1977 by a consortium of detectors: the BEBC and GARGAMELLE Bubble Chambers and the CDHS massive counter apparatus. Recent publication of the results obtained in this pioneering experiment[23,24,25] indicate that, although the data are not consistent there is general agreement that direct neutrinos are produced with a cross section of 40-300 μb/nucleon. The experiment was performed at 0° with respect to the primary proton beam.

In summary, although an enormous experimental effort has been expended on the search for hadronically produced flavors, there are rather few well established conclusions. The results discussed above are presented graphically in Figure 2 together with a theoretical estimate of the charm production cross section.[26] There is an apparent inconsistency between the experiments using hadronic final states and the prompt neutrino experiments and E-379. Unfortunately, because of the model dependent corrections needed to extract a cross section from the prompt neutrino measurement at 0° and the poorly known hadronic branching ratios for charmed particles a definitive comparison is impossible.

The dependence on model calculation is removed if the angular dependence of the prompt neutrinos is measured. Thus it is very important to repeat the prompt neutrino experiment at another target angle. It is equally important to insure the systematic uncertainties are known and small.

III. Description of the Apparatus

A. Proton beam and dump

A sine qua non for a beam dump experiment is a well instrumented primary proton beam free of any significant accompanying halo which could produce background neutrinos. Dr. R. Stefanski and Dr. S. Mori of Fermilab have been studying these problems at length and have developed detailed plans to construct a satisfactory beam. A schematic diagram is shown in Figure 3.

The proton beam is collimated prior to its entry into Neuhall. It then is directed through the target tube into the decay pipe and thence through the muon beam aperture into Enclosure 100. The beam is in vacuum throughout. We estimate $\lesssim$ 75 milligm/cm^2 of material in the beam almost all due to the vacuum of 1 Torr in the decay pipe.

The beam is deflected in enclosure 100 using the four bending magnets installed on skids which can be remotely adjusted through the 20-30 cm needed to vary the target angle. Finally it is directed into a water cooled copper cylinder which absorbs the energy in the beam.

By tuning the beam to obtain a focus in target tube just before the decay pipe we maximize beam size at the target. The calculated beam size is 2.5 cm x 1.5 cm, small in relation to the 20 cm x 2 cm vacuum pipe and magnet aperture.

An important feature of the beam is the series of halo monitors. These are integrating proportional tube counters capable of accurate measurement of the intensity of the charge particle halo. We measure the K_L° or neutral hadronic component which might arise from upstream interactions by turning off the horizontal bending magnet in Neuhall. The primary proton beam is then directed on the beam dump at the end of the decay pipe. Counters are then inserted into the hole in the dump to measure the neutral component. The background due to halo interactions is expected to be $\lesssim 10^{-3}$ of the usual neutrino beam arrangement.

Materials necessary to modify the cover for the decay pipe are on hand and S. Mori has made detailed cost and manpower estimates. Except for the beam dump, which we estimate can be built for $150,000, no significant material acquisition or modification is required.

A novel means of further reducing the background due to meson decays is to provide a strong magnetic field at the target. A 3 kg field acting over 1 absorption length (15 cm) will deflect a 100 GeV/c particle through 1 milliradian. The transverse momentum provided by this field is 150 MeV. Since the solid angle subtended by the detector is $\sim 10^{-5}$ steradian the background due to pions is suppressed. The practicality of this idea involving considerations of the high radiation level environment, cost, power, etc. is under investigation.

The flux of background neutrinos and antineutrinos due to decay of π and K mesons has been calculated for the geometry here proposed by S. Mori of Fermilab.[27] In addition the signal from charm production has been calculated for a value of $\sigma . B = 8.8\ \mu b$.

B. E-310 Apparatus

The experimental apparatus used in E-31 can be subdivided into three parts; the liquid scintillator calorimeter, the iron-scintillator calorimeter, and the muon spectrometer. Each of these subsystems has been extensively exercised and tested during E-310.

To better approximate an optimal detector for the beam dump, we propose to modify this apparatus by removing none, a portion, or all of the liquid calorimeter and replacing it by the shower counters. (See Fig. 4) These lead-scintillator counters provide 13.6 each of radiation lengths and about 0.4 absorption length. The measured response and performance of these counters is detailed in Appendix A. The shower development in such an apparatus can thus distinguish the *direct electromagnetic component* (*e and* γ) from the charged hadronic component of neutrino interactions, in many cases on an event by event basis.

The principle parameters of the detector so configured are:

Electron Sensitive Target	120 T
Muon Neutrino Target	200 T
Electromagnetic Energy Resolution	$\frac{\delta E}{E} = \frac{50\%}{\sqrt{E}}$
Muon Momentum Resolution	$\frac{\delta p}{p} = 10\%$

All tubes, bases, scintillator and counters for the electron sensitive detector exist. No further acquisition or construction is necessary. The installation and check out can be completed in about 8-10 weeks. In addition to the existing detector and its accompanying electronics we would require 300 additional channels of CAMAC analoque to digital converters (a PREP standard item).

C. The 15' Bubble Chamber

The 15' bubble chamber filled with Neon has proven itself to be a very productive detector of neutrino interactions. Coupled with the External Muon Identifier (EMI), the bubble chamber records both muons and electrons with good efficiency and charge measurement. It is unexcelled in revealing details of neutrino interactions; strange particles, charged multiplicities, Z distributions, total energy measurement, etc. The major difficulty in employing the bubble chamber as a detector for prompt neutrinos is its limited mass ($\sim$20 Tons).

Nonetheless, because it has broad sensitivity and records almost all the information, it complements the massive but limited counter detector and balances the program.

IV. The Experimental Program

S. Mori has calculated the background neutrino flux in the beam dump and the flux from charmed mesons.[27] The charm (or other) signal is believed to provide about equal numbers of muon neutrinos and antineutrinos and electron neutrinos and antineutrinos. The background of electron neutrinos and antineutrinos is very small. To illustrate the excellent signal to noise in the electron channel we plot in Figure 5 the rate of electron neutrino background events and the rate of charmed D mesons. (In this and other rate calculations we use $\sigma_\nu = (0.6 \times 10^{-38})E_\nu$ and $\sigma_{\bar{\nu}}/\sigma_\nu = .5$). The value of $\sigma.B$ used in the calculation of the signal is 1 μb. Even if the background were twice as large we could detect a signal at this level.

The information provided by varying the target angle is illustrated in Figure 6, in which we plot the rate of muon antineutrino background events and that of the D signal for a $\sigma.B$ of 5 μb. Note the improvement in signal to noise as the angle is increased, characteristic of the large transverse momentum provided in the D decay. Also shown in Figure 6 is a measurement by a European group using BEBC and the dichromatic beam at CERN. Clearly better information must be obtained under controlled conditions.

We propose to measure the prompt neutrino flux at zero degrees target angle with 10^{18} 400 GeV protons incident on the beam dump. This measurement would resolve the question of rate raised by the inconsistency of the CERN groups. A further measurement at 10 mr with 10^{18} 400 GeV protons on the beam dump would provide good information on the angular dependence. For example, using Figure 6, the $\bar{\nu}_\mu$ alone would distinguish between the background and signal at the 3.5 σ level assuming the smallest CERN rate measurement.

In Table I the rates in the counter apparatus and the bubble chamber are shown calculated using $\sigma . B = 5\ \mu b$, roughly corresponding the result of the CDHS group. To obtain the expected rate using the CERN Bubble Chamber results multiply all rates by 2.5!

In comparison to previous or contemporary measurements this experiment is excellent. For example the lead scintillator detector can provide event by event separation of ν_e and ν_e events in about half the cases. The CERN-CDHS detector could only separate on a statistical basis in a restricted fiducial volume. The statistical precision of this experiment is adequate for this initial investigation. The experiment complements E-379 in that it measures the prompt neutrinos directly.

A Search for Production of Prompt Neutrinos in High Energy Proton Nucleus Collisions

Lab C Facility

D. D. Reeder, D. B. Cline, P. Cooper, M. Duffy,
M. Gilchriese, R. Loveless, M. Heagy, R. Imlay,
T. Y. Ling, M. Merlin, T. Trinko, and D. Winn

University of Wisconsin
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Fermi National Accelerator Lab.
University of Wisconsin

We propose to measure the flux of prompt neutrinos produced in a copper beam dump in Enclosure 100 for two target angles, zero and 10 mr. An integrated beam intensity of 10^{18} protons at 400 GeV will be required at each target angle. (2 x 10^{18} p in total) The detectors to be used are:

i) the 15' Bubble Chamber filled with Neon-hydrogen (the standard heavy mix)

ii) the E-310 facility in Lab C without the iron target but with the lead scintillator shower counters.

Approximately 8-10 weeks would be required to complete the modification of the detector. This experiment would also require an appropriate beam dump and modification to the decay tube cover plate.

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TABLE I

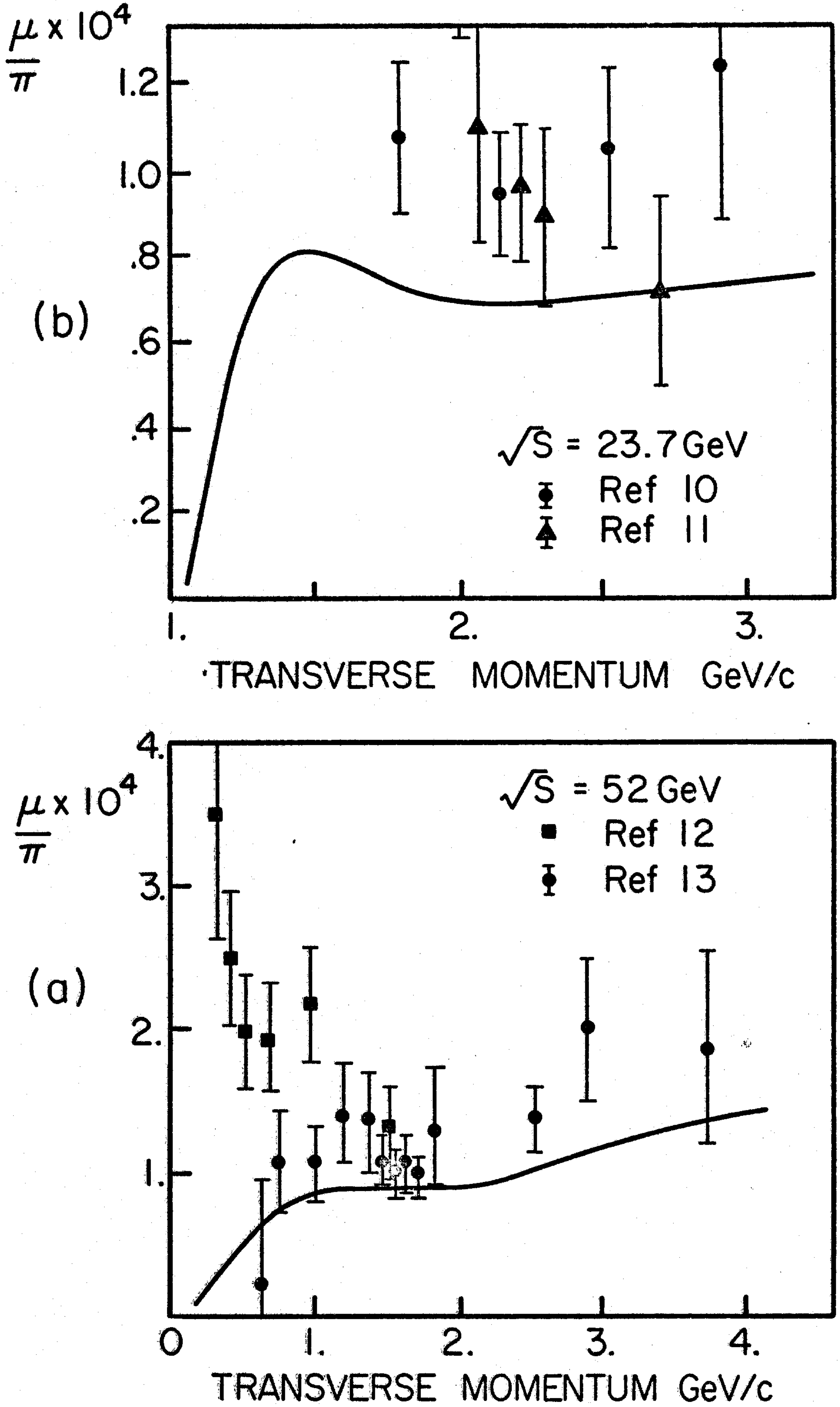
EVENT RATES FOR THE DETECTORS USED IN THIS EXPERIMENT. S/N IS THE SIGNAL TO NOISE RATIO, THE EVENT COLUMN IS THE NEW PARTICLE SIGNAL EXPECTED.

A. E-310 Apparatus ($\sigma \cdot B = 5\ \mu b$) ($10^{18}$ ppp)

E_ν (GeV)	θ_ν (mr)	ν_μ event	S/N	$\bar{\nu}_\mu$ event	S/N	$(\nu_e + \bar{\nu}_e)$	S/N
0-200	0	120	0.26	60	0.67	108	7.2
0-200	5	86	0.48	43	1.23	77	12.9
0-200	9	62	0.89	31	2.30	51	21.8
0-200	19	19	1.38	9	3.33	15	32.1

B. 15' Bubble Chamber ($\sigma \cdot B = 5\ \mu b$) ($10^{18}$ ppp)

		ν_μ	S/N	$\bar{\nu}_\mu$	S/N	ν_e	S/N	$\bar{\nu}_e$	S/N
0-200	0	12	0.3	6	0.7	12	6.0	6	12.
0-200	5	9	0.5	4	1.2	9	11.3	4	20.
0-200	9	6	0.9	3	2.3	6	19.4	3	39.



μ/π x 10^4
1.2
1.0
.8
(b)
.6
.4
.2
√S = 23.7 GeV
Ref 10
Ref 11
1.
2.
3.
TRANSVERSE MOMENTUM GeV/c
4.
μ/π x 10^4
√S = 52 GeV
Ref 12
Ref 13
3.
(a)
2.
1.
0
1.
2.
3.
4.
TRANSVERSE MOMENTUM GeV/c

Figure 1

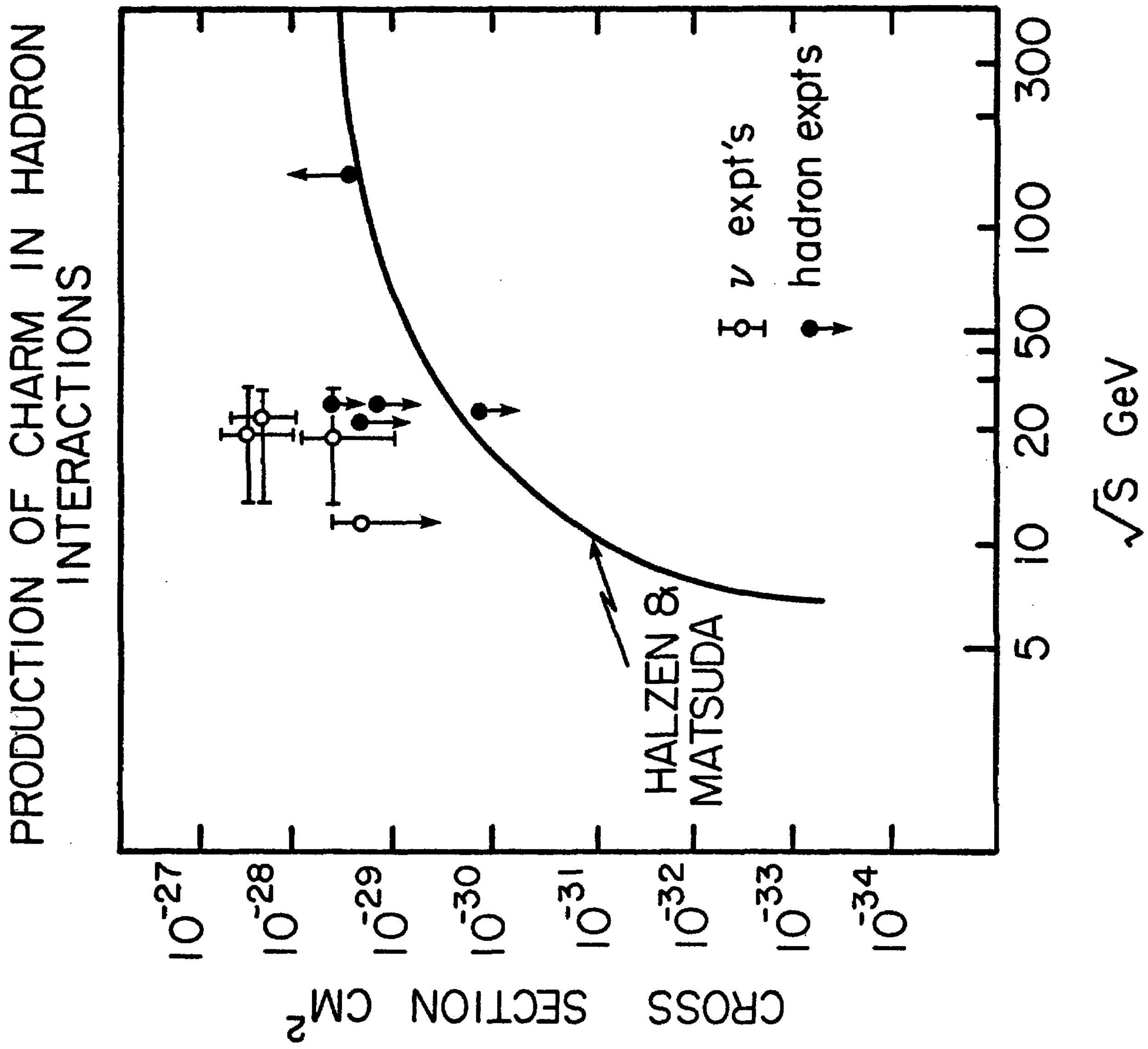

PRODUCTION OF CHARM IN HADRON INTERACTIONS
HALZEN & MATSUDA
ν expt's
hadron expts
5
10
20
50
100
300
√S GeV
10^-27
10^-28
10^-29
10^-30
10^-31
10^-32
10^-33
10^-34
CROSS SECTION CM^2

Figure 2

SCHEMATIC DIAGRAM

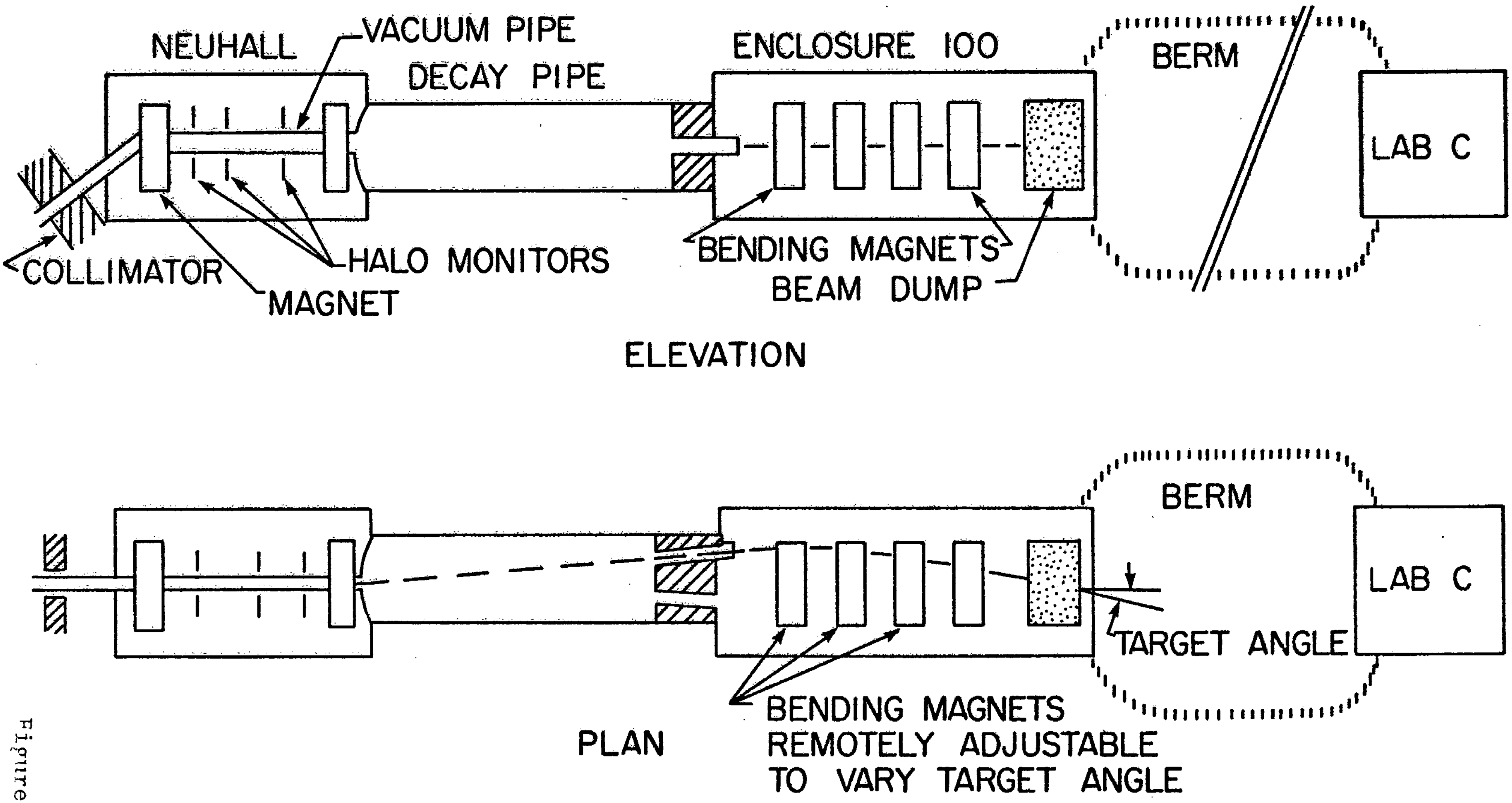


Figure 3

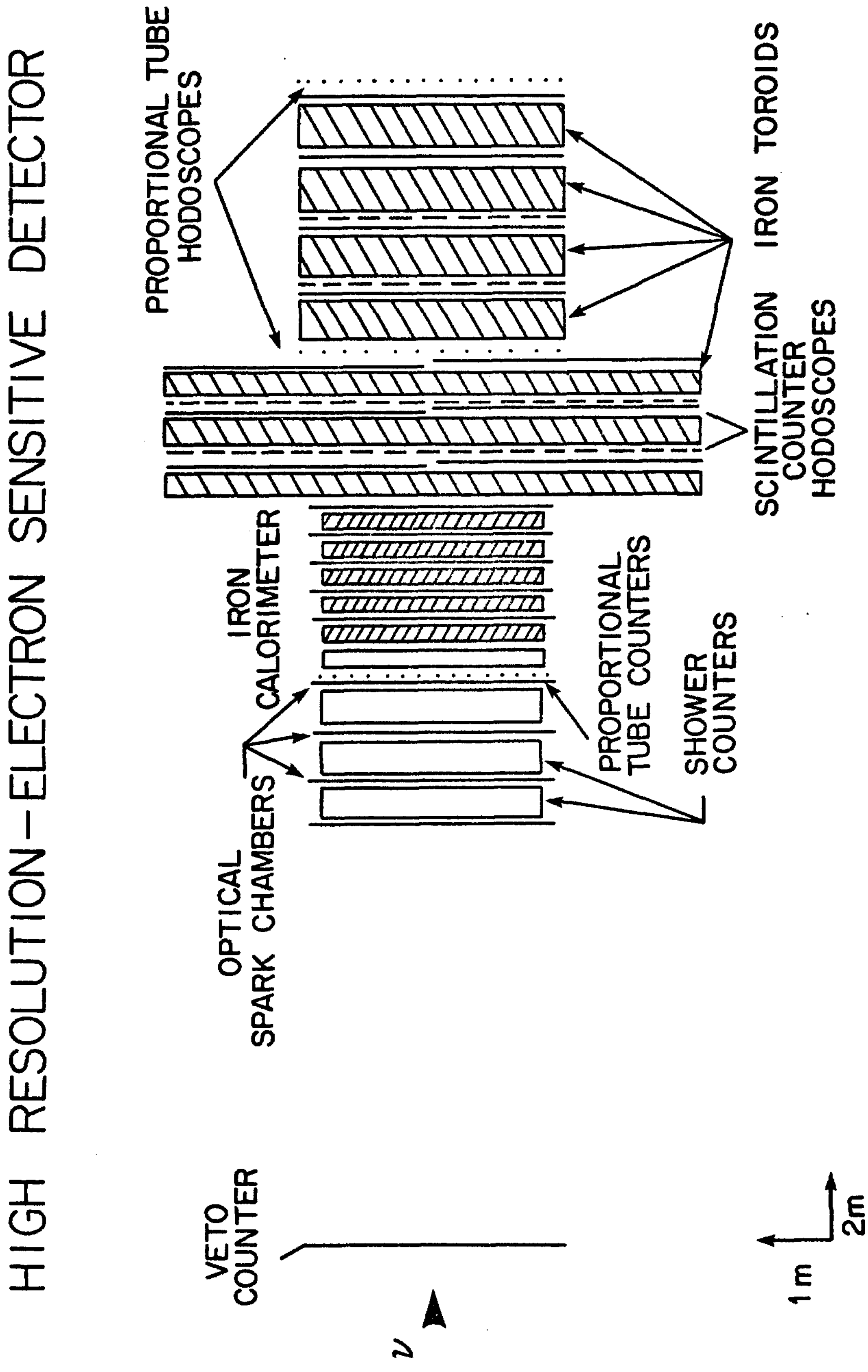

HIGH RESOLUTION-ELECTRON SENSITIVE DETECTOR
PROPORTIONAL TUBE HODOSCOPES
IRON TOROIDS
SCINTILLATION COUNTER HODOSCOPES
IRON CALORIMETER
PROPORTIONAL TUBE COUNTERS
SHOWER COUNTERS
OPTICAL SPARK CHAMBERS
VETO COUNTER
ν
1m
2m

Figure 4

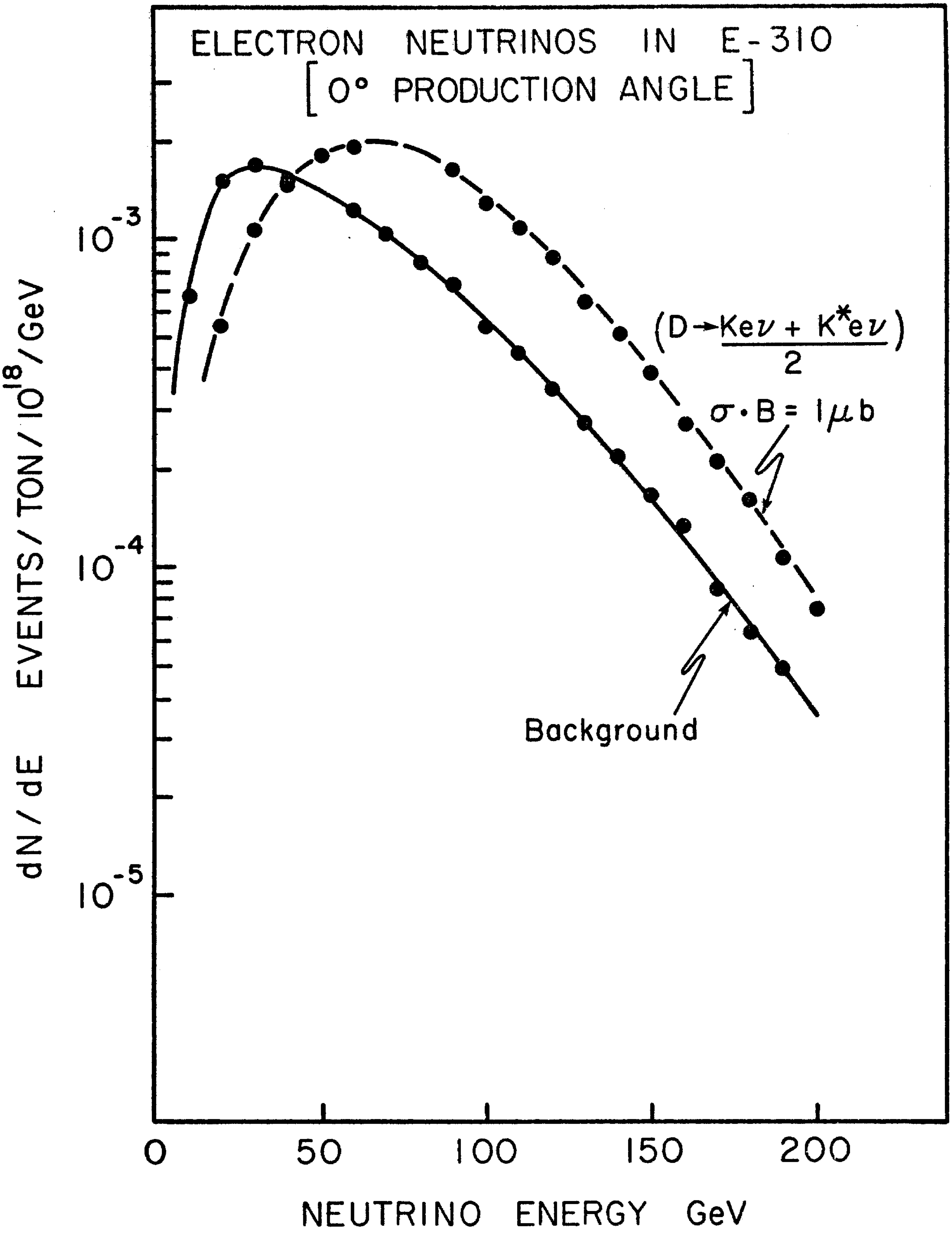

ELECTRON NEUTRINOS IN E-310
[0° PRODUCTION ANGLE]
$(D \rightarrow \frac{K e \nu + K^* e \nu}{2})$
σ·B = 1μb
Background
dN / dE EVENTS / TON / 10^18 / GeV
10^-3
10^-4
10^-5
0
50
100
150
200
NEUTRINO ENERGY GeV

Figure 5

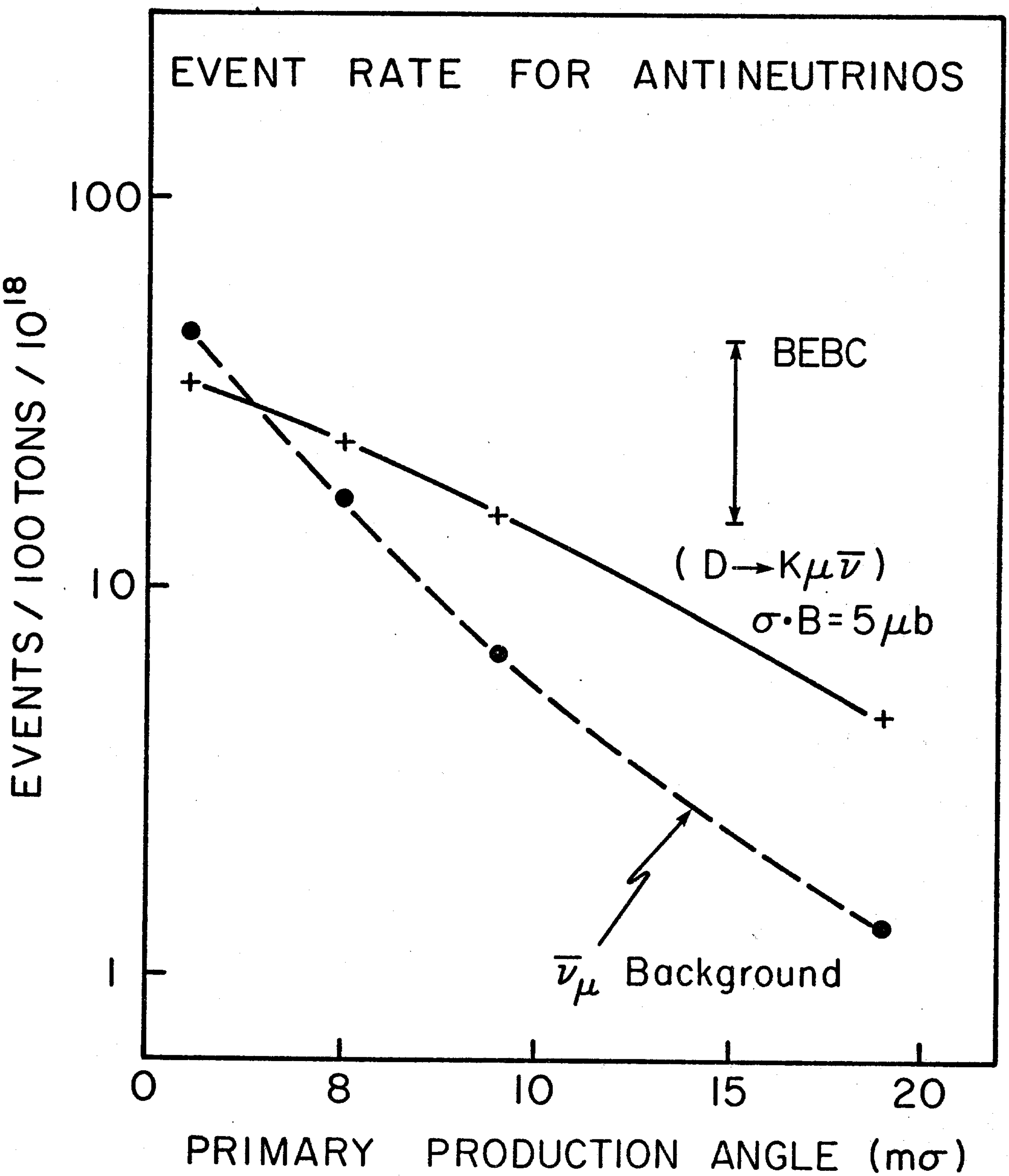

EVENT RATE FOR ANTINEUTRINOS
100
10
1
EVENTS / 100 TONS / 10^{18}
BEBC
(D→Kμ$\bar{\nu}$)
σ•B=5μb
$\bar{\nu}_\mu$ Background
0
8
10
15
20
PRIMARY PRODUCTION ANGLE (mσ)

Figure 6

Appendix A - Performance of the Lead-Scintillator Shower Counters.

We have tested one module of the lead-scintillator calorimeter in the M5 meson area beam. A drawing of one such shower counter is given in Fig. 1. Each module consists of five optically separate strips, 27 cm wide and 365 cm long, with 2" phototubes (RCA 6655 for these tests) mounted on each end. Within each strip there are 12 ¼" thick teflon coated lead plates (total of 13.6 radiation lengths) with ¼" gaps between plates filled with liquid scintillator (NE235A). The lead sheets extend to within 30 cm of the edge of the counter. The remaining space is taken up by reflectors to collect and channel light to the phototubes.

Tests were performed to determine the response of the counter to minimum ionizing particles and electrons. Electrons in the M5 beam (∿4% of the particles) were identified by a threshold Cerenkov counter. Two overlapping scintillation counters immediately upstream of the test module, in coincidence with beamline counters, defined the beam. LeCroy 2249A ADC's were used to record anode and inverted dynode signals from the photomultipliers. Data were recorded on magnetic tape and extensively analyzed on-line using a modified version of the E-310 data acquisition program resident in the Detector Development PDP 11/20 computer.

i) Response to Minimum Ionizing Particles

In order to test the response to minimum ionizing particles, one strip of the module was centered, vertically and horizontally, on the beam center line. The right (R) and left (L) phototube voltages were then adjusted to yield equal response from each tube. A typical distribution of the sum of the right and left pulse heights is shown in Fig. 2. Minimum ionizing particles are clearly visible with good efficiency.

The uniformity of response along the horizontal direction was also determined. The sum of the right and left tubes at the center of the counter is shown in Fig. 3 for various horizontal positions. The total pulse height increases by 80% at 120 cm and grows rapidly thereafter as the edge of the lead sheets (150 cm) is approached. Since a reasonable fiducial cut would be $\sim$ 120 cm, the observed response will be sufficiently uniform.

The response to movement of the beam in the vertical direction is shown in Fig. 4 for two different horizontal positions - center of the counter (X = 0) and x = 120 cm. The light output shows no variation with vertical position.

We have also determined the horizontal attenuation length in the counter. In Fig. 5 we plot the ratio of the right to left pulse heights (R/L) as a function of horizontal position. The observed ratios clearly suggest an exponential fall-off in light intensity for each tube with an attenuation length of 1.1 m.

ii) Response to Electrons

We have measured the response of the test module to 10, 20, 30 and 39.3 Gev electrons. The distribution for 30 Gev electrons is shown in Fig. 6a. In Fig. 7 we plot the measured electron energy vs the beam momentum assuming that the electron shower is totally contained in the counter at 10 Gev. A deviation from linear dependence is evident at 30 and 39.3 Gev, indicative of energy leakage from the counter.

The positional dependence of the light output for electrons is the same in the horizontal direction as for minimum ionizing particles and differ in the vertical direction only in the vicinity of the spacer bar between strips. This inactive region causes an apparent loss of energy as shown in Fig. 8 where we plot the energy response vs vertical position.

The shower energy resolution at 10, 20, 30 and 39.3 Gev was also determined. The full-width-at-half maximum (FWHM) at each energy was determined by doubling the half-width on the higher energy side of the shower peak. This was made necessary by a considerable radiative tail as a result of material in the M5 beam as may be seen in the logarithmic plot of Fig. 6b. Furthermore, the intrinsic momentum spread for electrons in the M5 is known to be larger than the calculated ± 1%. We therefore believe our measurements to be upper bounds on the electromagnetic energy resolution of a single calorimeter module.

The measured resolutions (FWHM) are plotted in Fig. 9. They vary from 23% at 10 Gev to 10% at 30 and 39.3 Gev.

iii) Summary

The tests described above have demonstrated that the lead-scintillation calorimeters respond with good efficiency to minimum ionizing particles with reasonable uniformity over the useful area of the counter. These counters should also be able to identify and measure electromagnetic showers with adequate resolution.

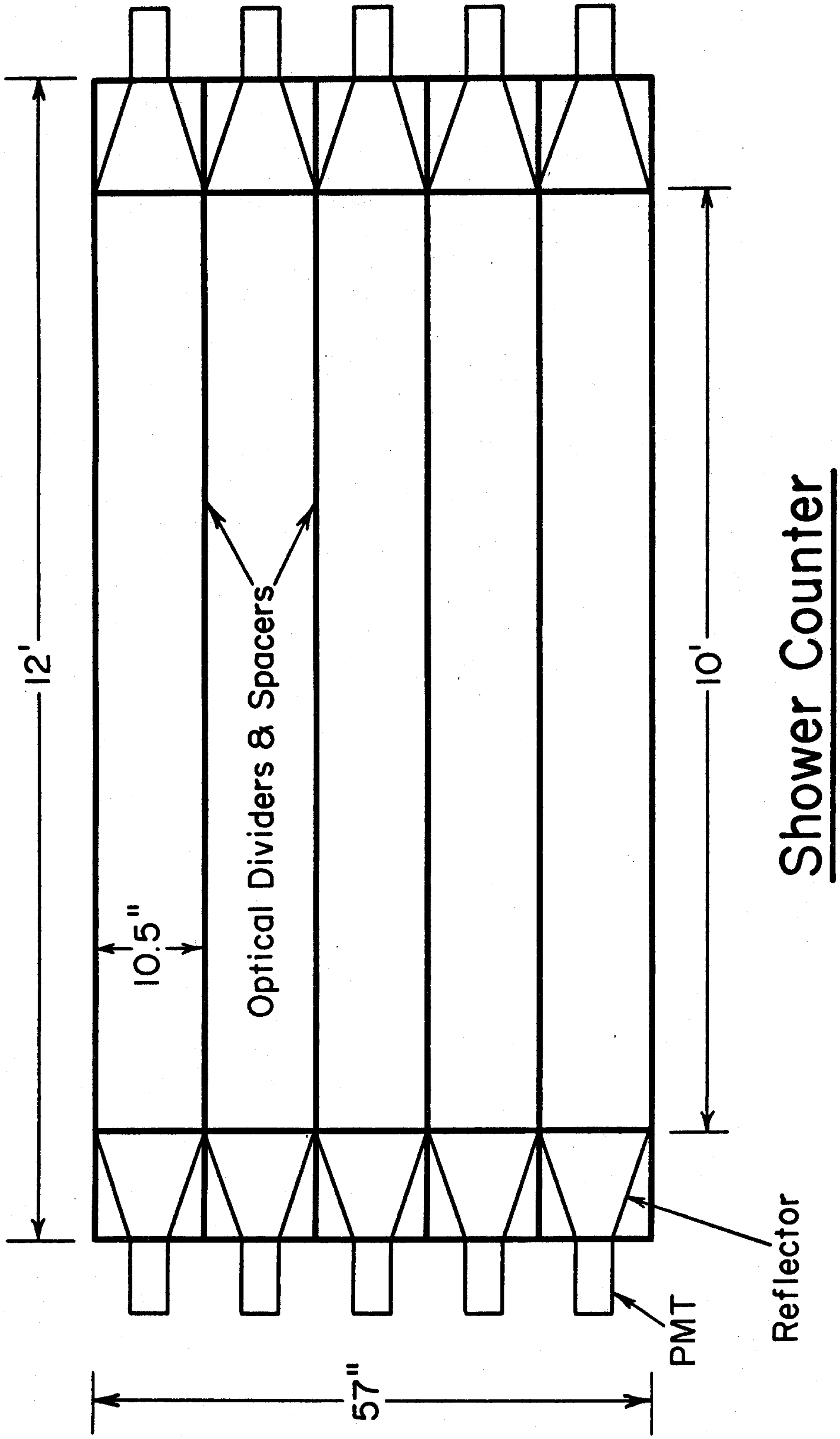

Shower Counter
12'
10'
57"
10.5"
Optical Dividers & Spacers
Reflector
PMT

Fig. 1

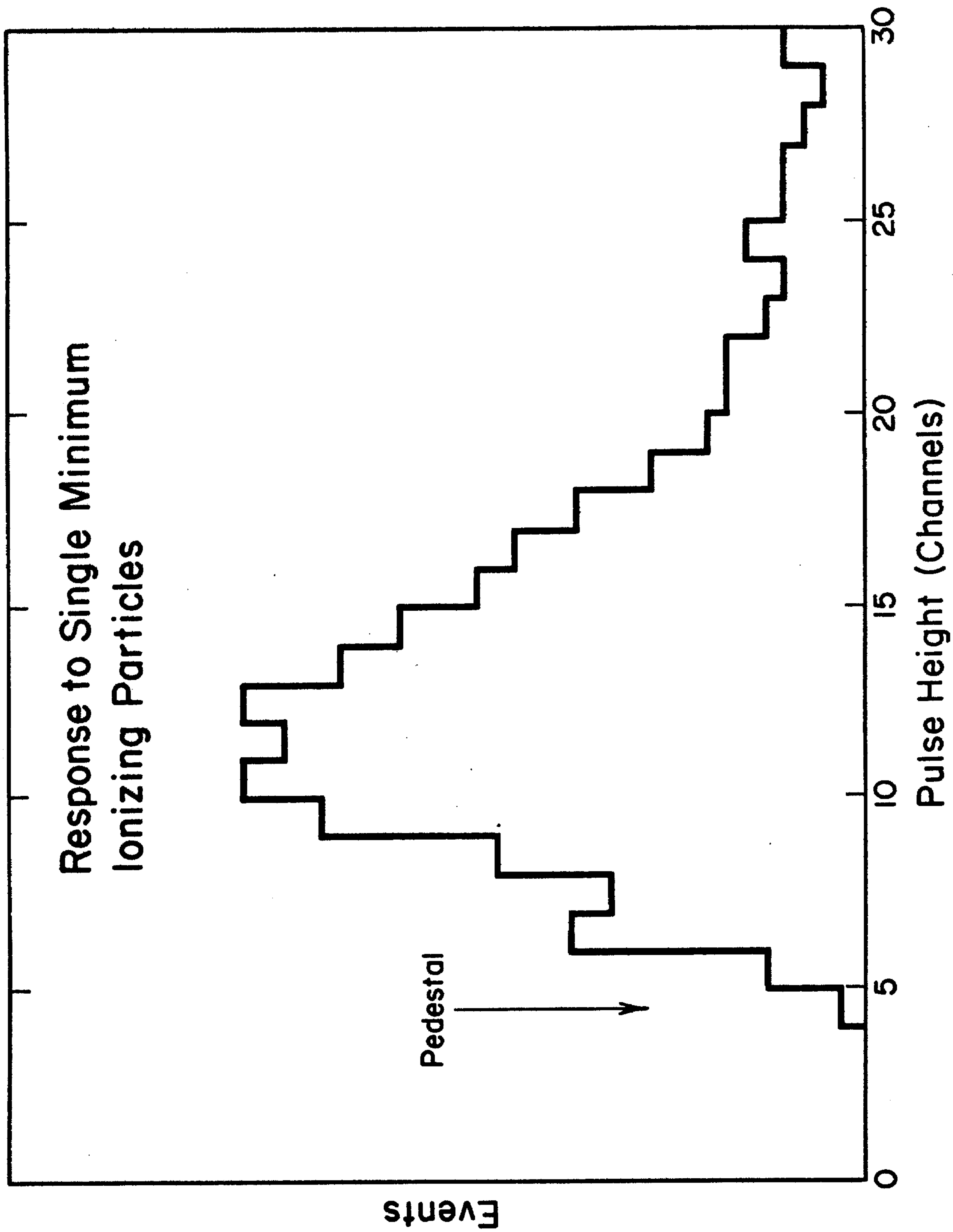

Response to Single Minimum
Ionizing Particles
Pedestal
Events
Pulse Height (Channels)
0
5
10
15
20
25
30

Fig. 2

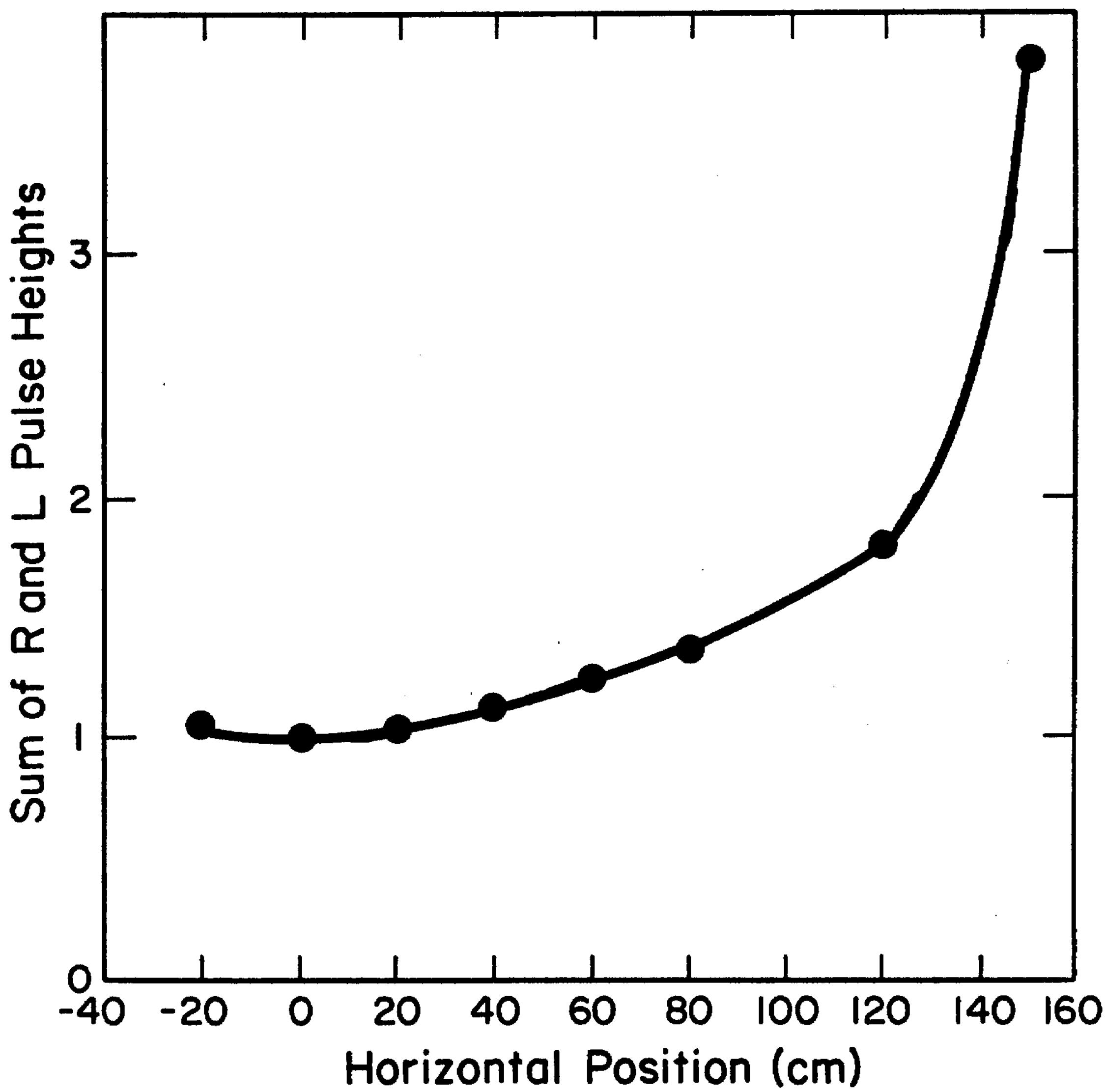

Sum of R and L Pulse Heights
0
1
2
3
-40
-20
0
20
40
60
80
100
120
140
160
Horizontal Position (cm)

Fig. 3

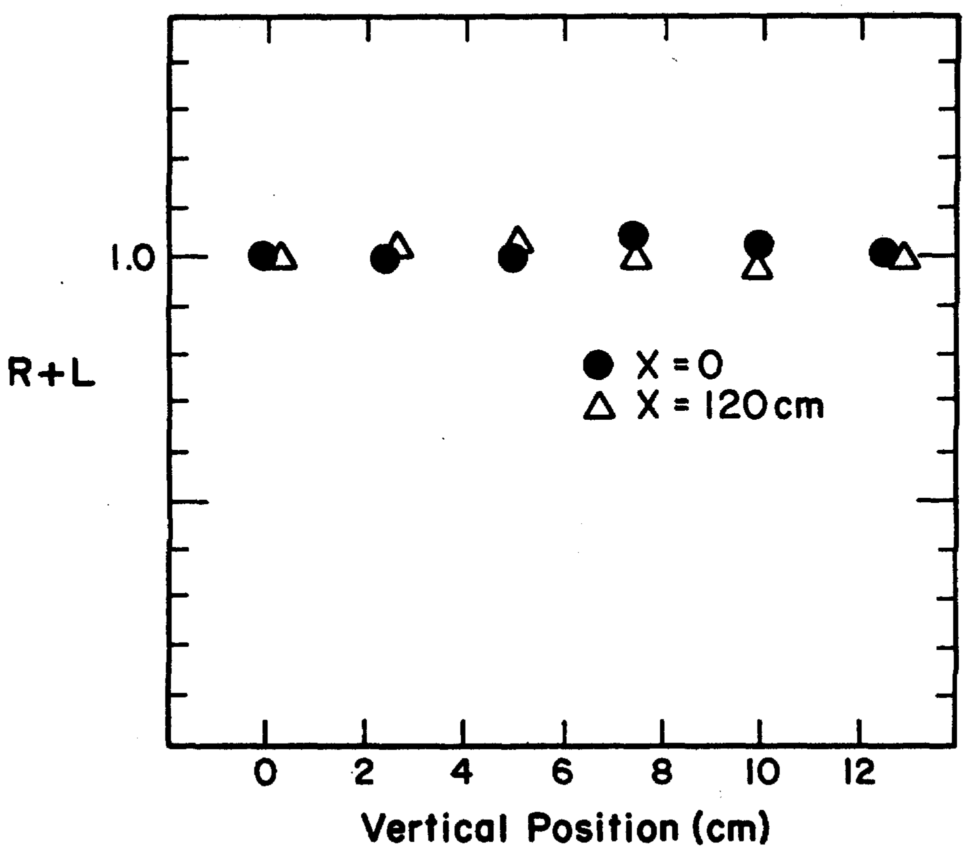


Fig. 4

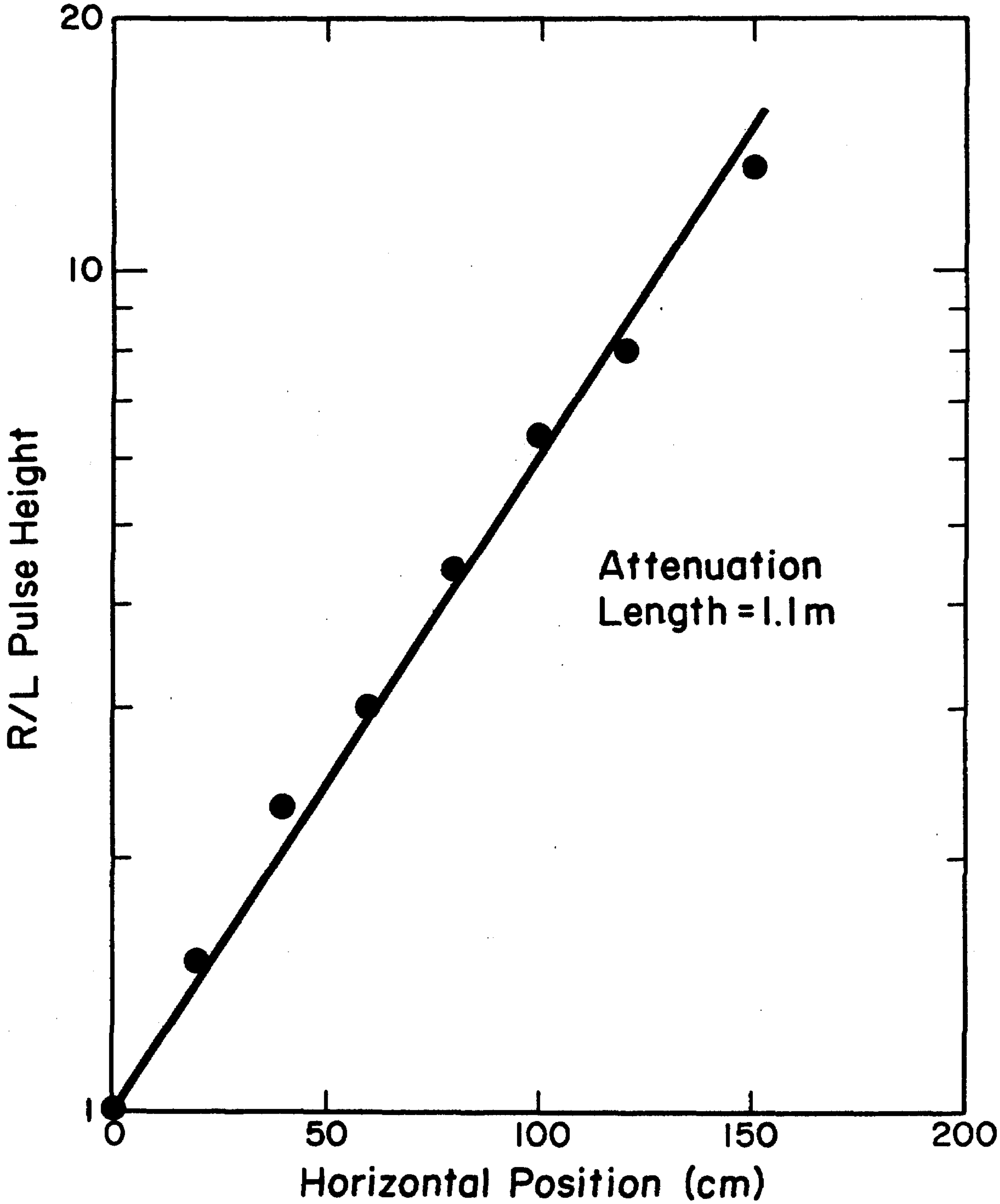
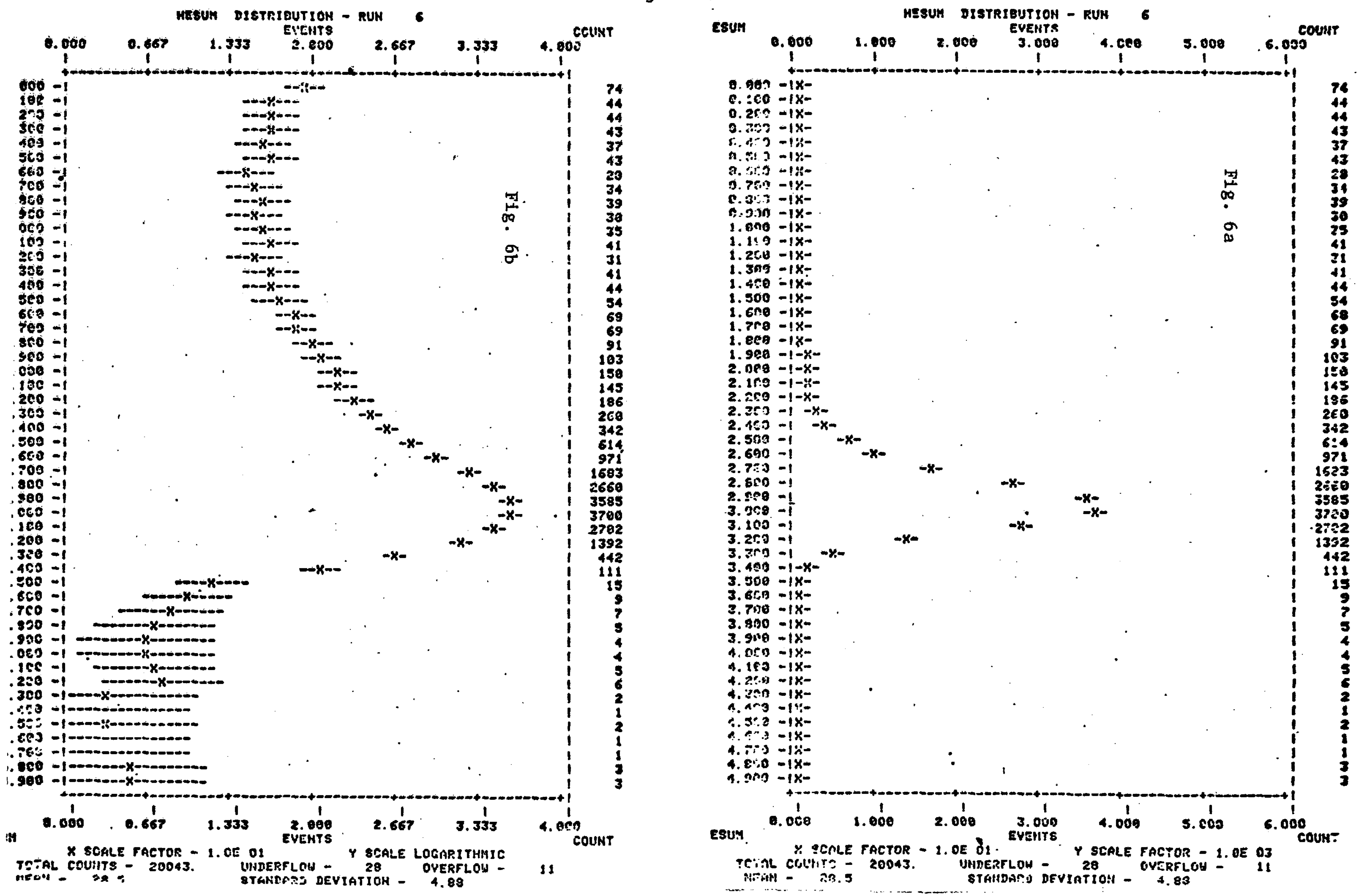
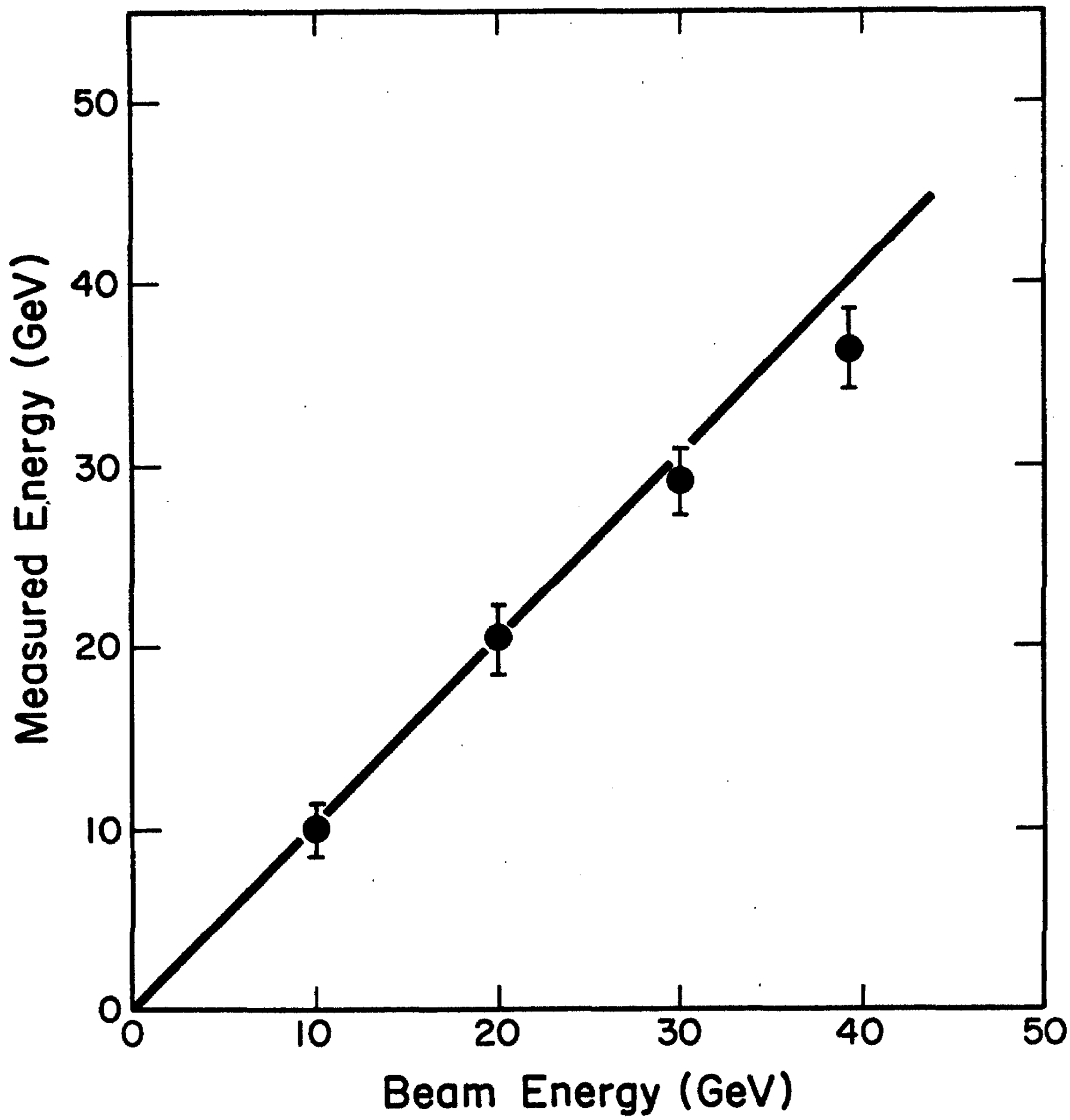

R/L Pulse Height
20
10
1
0
50
100
150
200
Horizontal Position (cm)
Attenuation
Length = 1.1m

Fig. 5

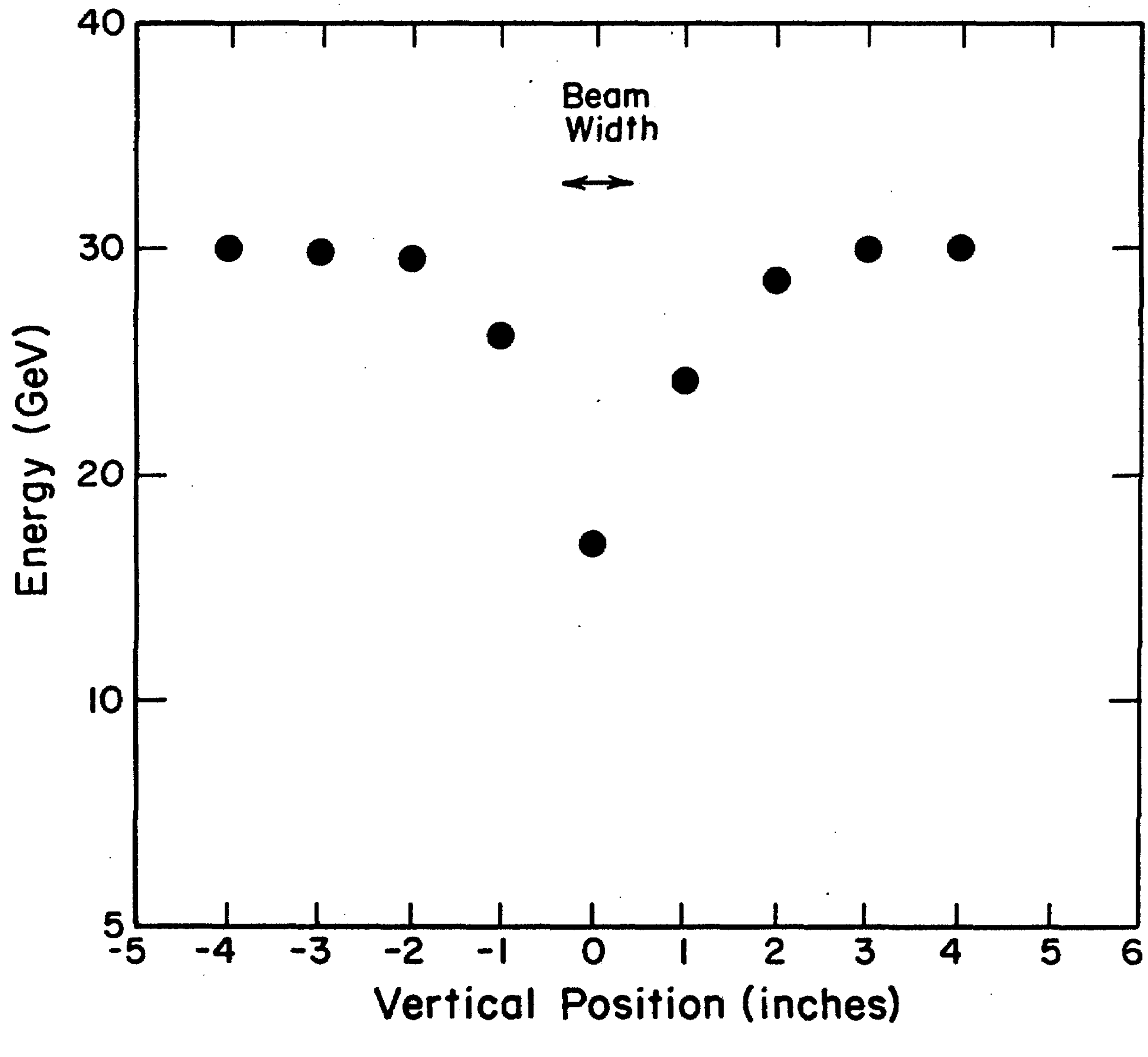
Figure 6


HESUM DISTRIBUTION - RUN 6
EVENTS
COUNT
Fig. 6b
X SCALE FACTOR - 1.0E 01
Y SCALE LOGARITHMIC
TOTAL COUNTS - 20043.
UNDERFLOW - 28
OVERFLOW - 11
STANDARD DEVIATION - 4.88
HESUM DISTRIBUTION - RUN 6
ESUM
EVENTS
COUNT
Fig. 6a
X SCALE FACTOR - 1.0E 01
Y SCALE FACTOR - 1.0E 03
TOTAL COUNTS - 20043.
UNDERFLOW - 28
OVERFLOW - 11
MEAN - 28.5
STANDARD DEVIATION - 4.83



Measured Energy (GeV)
50
40
30
20
10
0
0
10
20
30
40
50
Beam Energy (GeV)

Fig. 7



40
30
20
10
5
Energy (GeV)
Beam
Width
-5
-4
-3
-2
-I
0
I
2
3
4
5
6
Vertical Position (inches)

Fig. 8

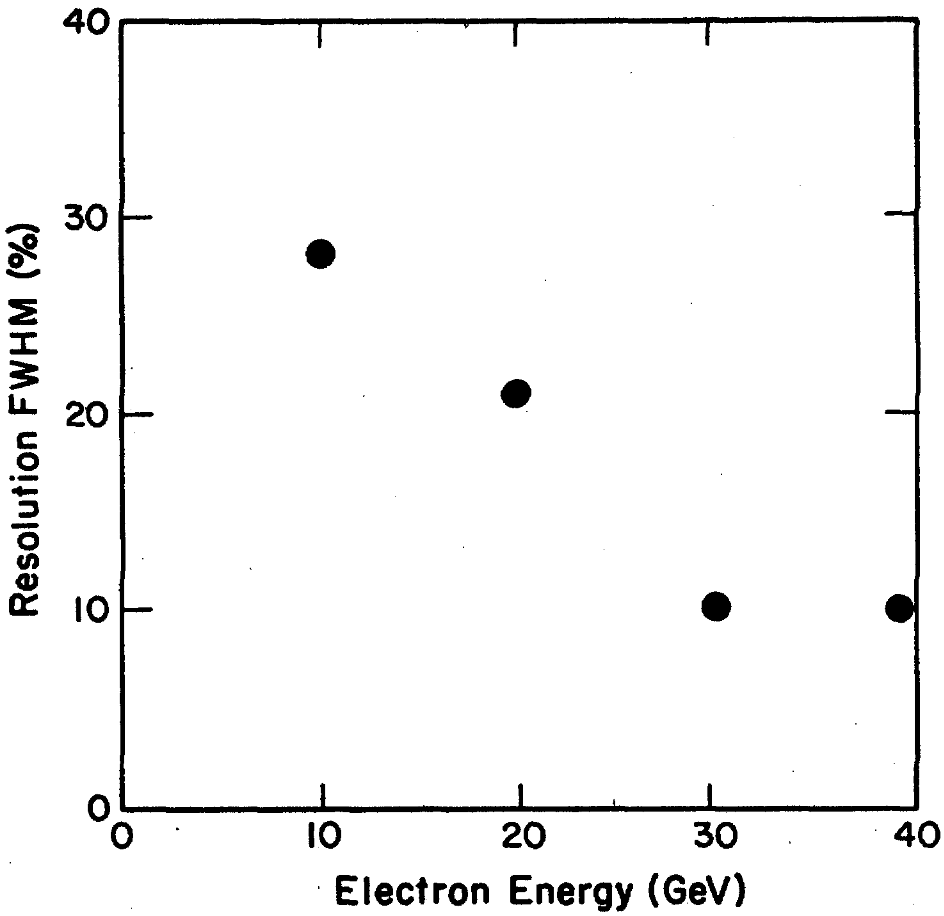


Fig. 9