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Tevatron Proposal No. 745

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Muon Neutrino Experiment Using the Tohoku High Resolution One Meter Bubble Chamber

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Summary

We propose to carry out a muon neutrino experiment using the Tohoku High Resolution One Meter Freon Bubble Chamber during the scheduled wide band and narrow band neutrino run periods beginning some time after September 1984. A total of 8800 neutrino charged current events is expected in a restricted fiducial volume region for the wide band (1×10^{18}p) and narrow band (1×10^{18}p) runs. Physics aims are the further investigation of (a) the production and properties of charmed particles, for which 500-900 charmed particles will be analyzed by the holographic optics, and (b) neutrino interactions in the high Q^2 region above 100 $(GeV)^2$, to be reached for the first time by the TEVATRON. A mini-detector system, which consists of the Tohoku one meter freon bubble chamber with holographic optics, superconducting magnet of 28.5 kG, an interaction triggering system, and a muon detector system, will be used. In Appendix I a detailed procedure is presented for charm analysis, based on our experience in a charm photo-production experiment, SLAC BC 72/73. In Appendix II the measurement error of the muon momentum and the resolution of relevant quantities in our analysis for the high Q^2 region are discussed, based on our experience from the neutrino-deuterium experiment, FNAL E 545.

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Proposal

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Spokesman: T. Kitagaki, Tohoku University

1. Introduction

The collaboration is currently preparing for the beam dump experiment E-636 scheduled for late 1986. The main component of the detector, the Tohoku one meter Freon Bubble Chamber with high spatial resolution, will be installed at LAB-F in the N_O-beam line and will be ready to operate by May 1984. Meanwhile the muon-neutrino experiments at the TEVATRON are scheduled in N_O - beam line beginning in fall 1984. During this running period our chamber will be in the beam line and exposed to the muon-neutrino beam. We note here the capability of our detector system for the muon-neutrino experiment and expected fruitful physics on charm and neutrino interactions in high Q^2 region. The crucial elements of this experiment consist only of the chamber and the muon detector. Other elements will be added to the system and tested during the run. Most groups in our collaboration have had extensive experience working on charm meson decays[1)] and one group has been concentrating on the analysis of muon-neutrino interactions[2,3)]. Therefore, it is natural for the collaboration to propose a concurrent neutrino experiment taking 200,000 pictures using the one meter Freon Bubble Chamber system to take place during the scheduled wide band and narrow band neutrino run periods beginning after September 1984.

2. Physics Aims

The physics aims of this proposal are divided in the following two categories; first, production and properties of charmed particles and second, neutrino interactions in high Q^2 region. The first is made possible by the high spatial resolution available with holographic techniques, and the e, μ identification capability of our detector. The second is characterized by the new high Q^2 region made available by the TEVATRON neutrino beam.

A. Production and Properties of Charmed Particles

From the sample of 500-900 charmed particles produced in the experiment we expect to:

1) Measure the charm production cross section over the energy spectrum of the neutrino beam and to roughly observe the E_ν, Q^2, W dependence of the cross section at least for D mesons.
2) Utilize the muon detector and the sensitivity of the bubble chamber to electrons to measure semileptonic branching ratios and to examine charm particle production mechanisms by searching for like-sign dileptons, D* production, D^- production, etc.
3) Measure the lifetimes of D^+,D° mesons and possibly F^+ and Λ_c^+ with accuracy and statistics 1.5 to 3 times better than the major experiments underway at the present time.
4) Search with good efficiency for undiscovered or unconfirmed short lived mesons or baryonic states produced in high energy neutrino interactions e.g. the long lived baryon state reported by E-531.[4)]
5) Although we expect only a few B mesons in this experiment, the recently measured long lifetime, high decay multiplicity and large transverse momenta may permit their detection.

Estimates of charmed particle production and detection efficiencies are given in Appendix I.

B. Neutrino Interactions in High Q^2 Region

One group of the present collaboration has been working on E-545, ν_μ-D experiment in the 15 foot bubble chamber at 350 GeV proton energy. Fig. 2 compares the event rate vs. E_ν in E-545 and the proposed exposure. E 545 had 15,900 events, the proposed exposure would have 8,800 events. It is seen that E-545 is essentially an experiment with E_ν below 50 GeV and the present proposal is for E_ν > 50 GeV. In spite of the low energy, experiment E-545 was a fruitful experiment[2,3]. Therefore, all the subjects developed in E-545 will be extended to a higher energy region. The structure functions, the P_T distribution of jets and the presence of gluon jets in neutrino interactions will be investigated in the new region of high Q^2 with good separation of the jets.

The asymmetries of hadrons in neutrino interactions provide important checks for QCD[5]. However the available energy was not sufficiently high to investigate this problem in past experiments and this exposure will be a good place to investigate them. The observation of a cos ϕ term, the forward-backward asymmetry of hadrons in the lepton plane, is a first order effect of QCD and the sin ϕ term, the left/right asymmetry against the lepton plane, is a second order effect of QCD and gives a direct proof of the non-Abelian character of gluons, the presence of the three gluon coupling.

Quantitatively, about 8,800 charged current events are expected in the fiducial volume of 347 ℓ (70%) for total of 2×10^{18} protons at 1000 GeV, 1×10^{18} protons for each of the wide band and narrow band run. The corresponding low energy exposure in the 15 foot bubble chamber produced 15,900 charged current events in E-545. However, in the high Q^2/W region, e.g. this exposure supplies more events than E-545 by a factor of 8 for Q^2 > 100 GeV and of 12 for W > 17 GeV, as in Figs. 3 and 4, which show the numbers of events above cut values of Q^2 and W for E-545 and for the proposed exposure. The improvement of the statistics for high Q^2/W region by the narrow band is important for the QCD studies. Some examples are shown in Appendix II. Moreover an important role of the narrow band part is to give a good calibration for the evaluation of $E_\nu/Q^2/W$ in the high value region.

3. Experimental Layout

A. Beam

We propose to take pictures by using the Tohoku one meter Freon bubble chamber system at LAB-F with the muon-neutrino beam passing through the chamber. Naively one might think that a 1 meter bubble chamber is too small for neutrino experiments. However, this is not true for TEVATRON energies. The contraction of neutrino flux by the Lorentz factor is effective at this energy. Fig. 5 shows the radial distribution of neutrino event rate at LAB-F for a wide band and narrow band beam[6)] and the effective length of fiducial volume of the Tohoku one meter chamber. It is seen that a major portion of dense part of flux passes through the fiducial volume.

The Quadrupole Triplet System was proposed for the wide band neutrino beam run in the fall 1984. Also, the Sign Selected Triplet system is discussed for the wide band beam. Fig. 1 is a comparison of both systems. Fig. 2 shows the charged current event rates for the three cases of the SST (1000 GeV, 1 x 10^{18} protons), NCI (1 x 10^{18} protons) and single horn (E-545, 350 GeV, 4.8 x 10^{18} protons). The curves were calculated by using the Monte Carlo simulation NUADA[6)] and normalized to E-545 data. Table I is the best estimation of events for the 347 liter fiducial volume in the Tohoku one meter Freon Bubble

Chamber. All numbers are based on the assumption of 1×10^{18} protons in each of wide band and narrow band runs and those are reasonable expectations for TEVATRON. The numbers of charged current events, 7.65 K events and 1.14 K events in Table I, compare with 15.9 K events in E-545. However, all the events in this proposal are in high E_ν, Q^2 and W region, see Table I, and Fig. 2, 3 and 4, where the figures are normalized to 4.8×10^{18}, 1×10^{18}, 1×10^{18} protons for E-545, present wide band and narrow band runs, respectively. It is clear that they will bring us to a new region of QCD study not previously accessible.

B. Mini-Detector System

Fig. 6 shows the minimum system required for the experiment which consists of the Tohoku one meter Freon bubble chamber with holographic optics, super conducting magnet of 28.5 kG, a triggering system for holographic systems and a muon detector. The Mini-system is a closed system which provides all necessary features for this muon-neutrino experiment. Namely, high spatial resolution of 30-50 μm for short decay detection, fast interaction triggering by neutrino interactions in the chamber Freon for the hologram, electron and gamma identification by the Freon, downstream muon detection, and all logic and data logging systems. Space is allowed for testing of CRISIS and the downstream wire chambers of E-636.

C. High Resolution Bubble Chamber

The Tohoku one meter bubble chamber has been constructed and successfully tested in Tokyo in two periods of June and August in 1983 (total 100 K expansions). Fig. 7 shows a track picture taken in the test run.

The chamber provides three normal optics camera (35mm film) and one holographic camera (70mm film). The prototype test of holography shows that

30-50 μm spatial resolution is obtainable everywhere in the bubble chamber volume of 83cm dia x 100cm depth. Holograms created at Tohoku have been successfully reconstructed by groups in the U.S. Other important factors in achieving the high spatial resolution are the stable operation of bubble chamber to ensure high bubble density and fast triggering for holography. We have studied the high bubble density operation of reon chambers using the Tohoku 14cm Freon bubble chamber at Fermilab in May 1982. (Fig. 8.) For the fast interaction triggering a barrel type scintillation hodoscope will be provided. It surrounds the chamber body and triggers on neutrino interactions inside chamber. Also, a Nd-YAG laser system which can send a light pulse 80μs after the triggering was specially made (80μs is approximately the time required for growth of bubbles to 30-50μm diameter). If there is no interaction trigger, a picture is taken at the end of the beam spill. The chamber is operated in the magnetic field of 28.5 KG produced by superconducting coils.

D. Muon Detector

A simplified muon detector system will be used initially. This system consists of one y counter plane, (y_3), two sets of y, z counter planes, (y_1, z_1 and y_2, z_2) and two layers of iron of 1.5m and 0.5m thickness. Each 2m x 2m counter plane consists of limited streamer cylindrical tubes filled with Ar-Isobutane. In the configuration of fig. 6, the muon acceptance is 92.5% for charged current events. The y counter planes read track position with a resolution of ± 1mm. The position reading will be used for the hybridization of fast muons. In the present system we estimate $\Delta p_\mu/p_\mu$ of 8-10% for the yoke window part, and 27-28% for the yoke iron part, respectively, for 100-200 GeV. This system has its own closed logging system. Any element of the E-636 detectors that are completed during the run will be used in parallel.

4. Operation and Analysis

A. Operation Manpower

The operation of the bubble chamber, optics, development of film, trigger counters and muon detector will be carried out by 18 personnel, 5 bubble chamber key people, 5 technicians and 8 physicists. The superconducting coil is required through the entire experimental period of nine months. Cryogenic operation will be provided by Fermilab.

B. Analysis

We have normal three view pictures in addition to a hologram. The normal pictures will be handled in each laboratory by means of standard bubble chamber picture analysis. The neutrino events will be visually scanned, measured and recorded on magnetic tape. Next, the region near the vertices of selected events will be examined in the holographic image. The Tohoku holographic reconstruction machine, Fig. 9, locates a vertex automatically using the magnetic tape information. Tohoku has the capacity to handle more than 100 K pictures (30 K events) per year and the other laboratories have also a capacity of 100 K pictures per year in total. Therefore, 200 K pictures expected for 2×10^{18} protons will be analysed within one year.

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Table I

Number of charged current events	Wide Band SST	Narrow Band NCI
NUADA CALCULATION (R < 37.5cm, RAW)/(10^{13}p)(100 ton)	18.68 events	2.78 events
Normalization by E-545, x 1/1.27	14.71 events	2.19 events
For Tohoku BC fiducial volume, 347ℓ x 1.5 = 0.520 ton 10^{18}p	7.65 K events	1.14 K events
Q^2 bin		
$Q^2 < 50$, $(GeV)^2$ unit	5,949 events	705 events
$50 < Q^2 < 100$	1,059 events	212 events
$100 < Q^2 < 200$	494 events	146 events
$200 < Q^2$	147 events	77 events
Charm Production		
Assuming 7.5 % rate of CC	574 events	86 events

FIGURE CAPTIONS

Fig. 1 Neutrino event rates for Quadrupole Triplet and Sign Selected Triplet.

Fig. 2 Comparison of event rates vs. E_ν. This proposal; 1000 GeV wide band (1×10^{18}p) and narrow band (1×10^{18}p). E-545; 350 GeV, wide band single horn (4.8×10^{18}p).

Fig. 3 Comparison of event rates vs. Q^2
This proposal and E-545.

Fig. 4 Comparison of event rates vs. W
This proposal and E-545.

Fig. 5 Radial dependence of event rate/unit area and the effective length of fiducial volume in the Tohoku 1m bubble chamber.

Fig. 6 Layout, Mini-detector system

Fig. 7 Cosmic ray picture in Tohoku 1 m Freon Bubble Chamber, Tokyo, July 1983.

Fig. 8 High bubble density operation of Freon bubble chamber, Tohoku 14 cm bubble chamber, FNAL, May 1982.

Fig. 9 A holography reconstruction machine, Mark III, Tohoku, Aug. 1983. Virtual image type. The reconstruction machine points a vertex inside the bubble chamber volume automatically using the vertex coordinate given by the conventional measurement in normal pictures. The reconstructed image on TV is immediately hard copied.

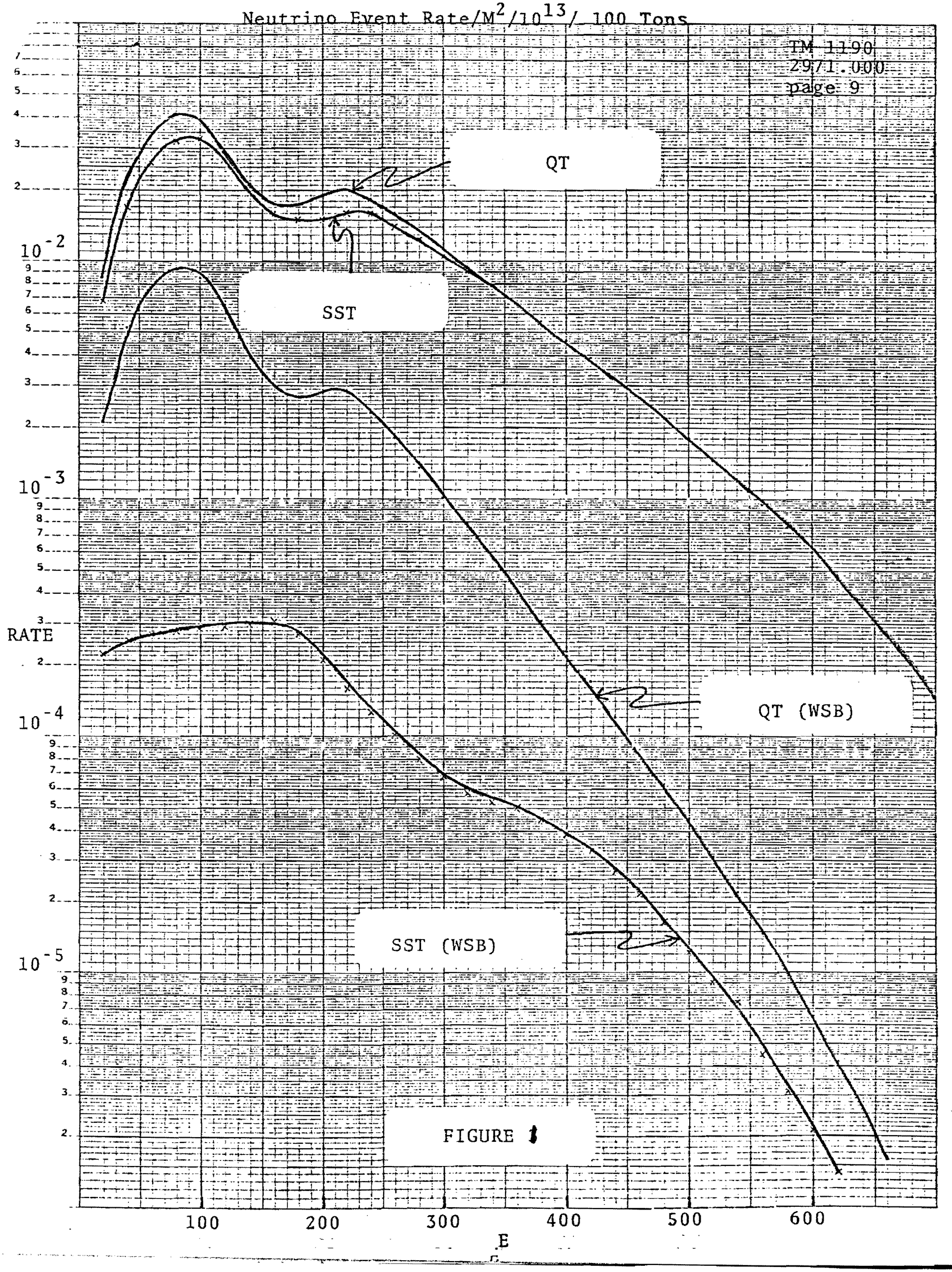

Neutrino Event Rate/M²/10¹³/ 100 Tons
RATE
E
QT
SST
QT (WSB)
SST (WSB)
10⁻²
10⁻³
10⁻⁴
10⁻⁵
100
200
300
400
500
600

FIGURE 1

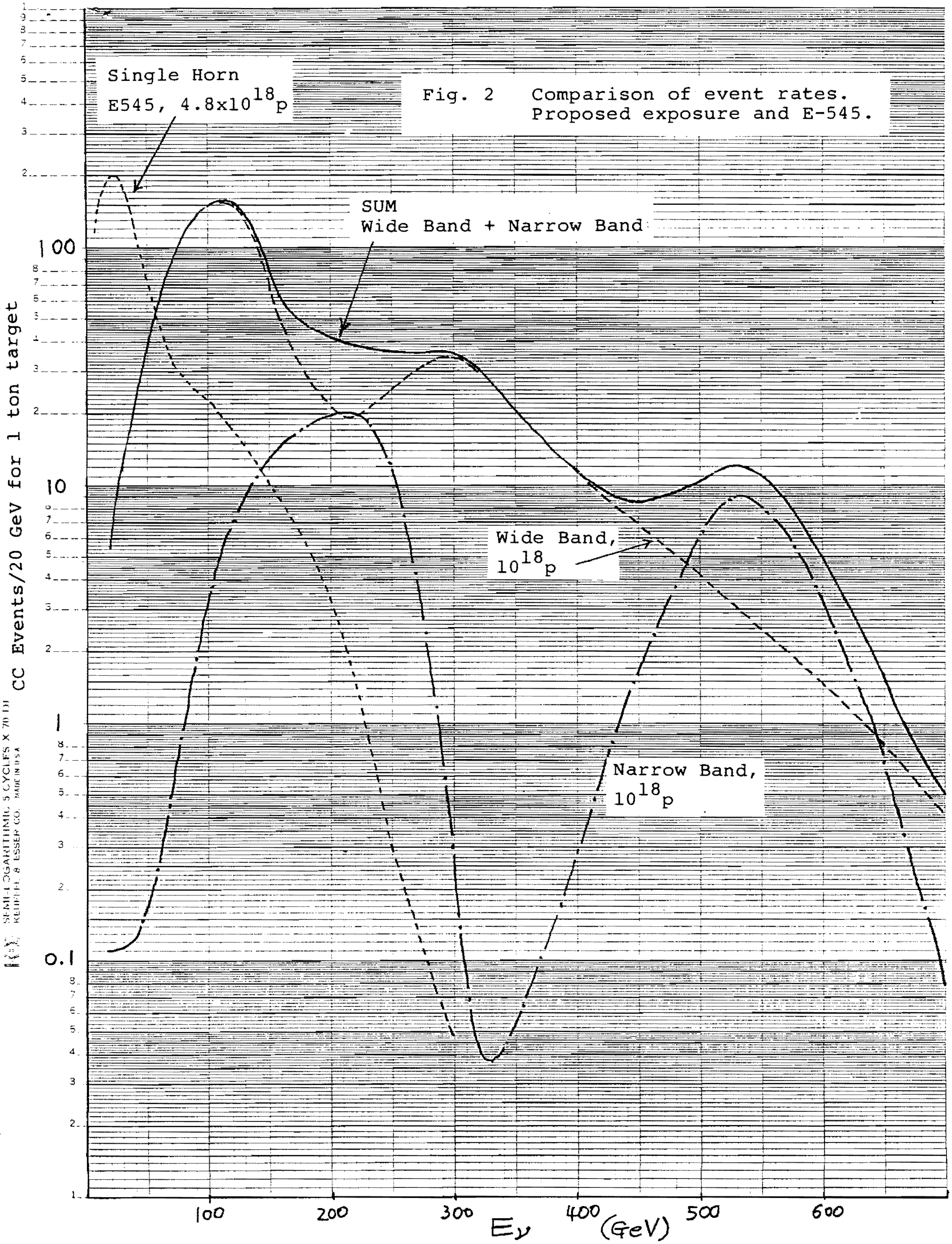
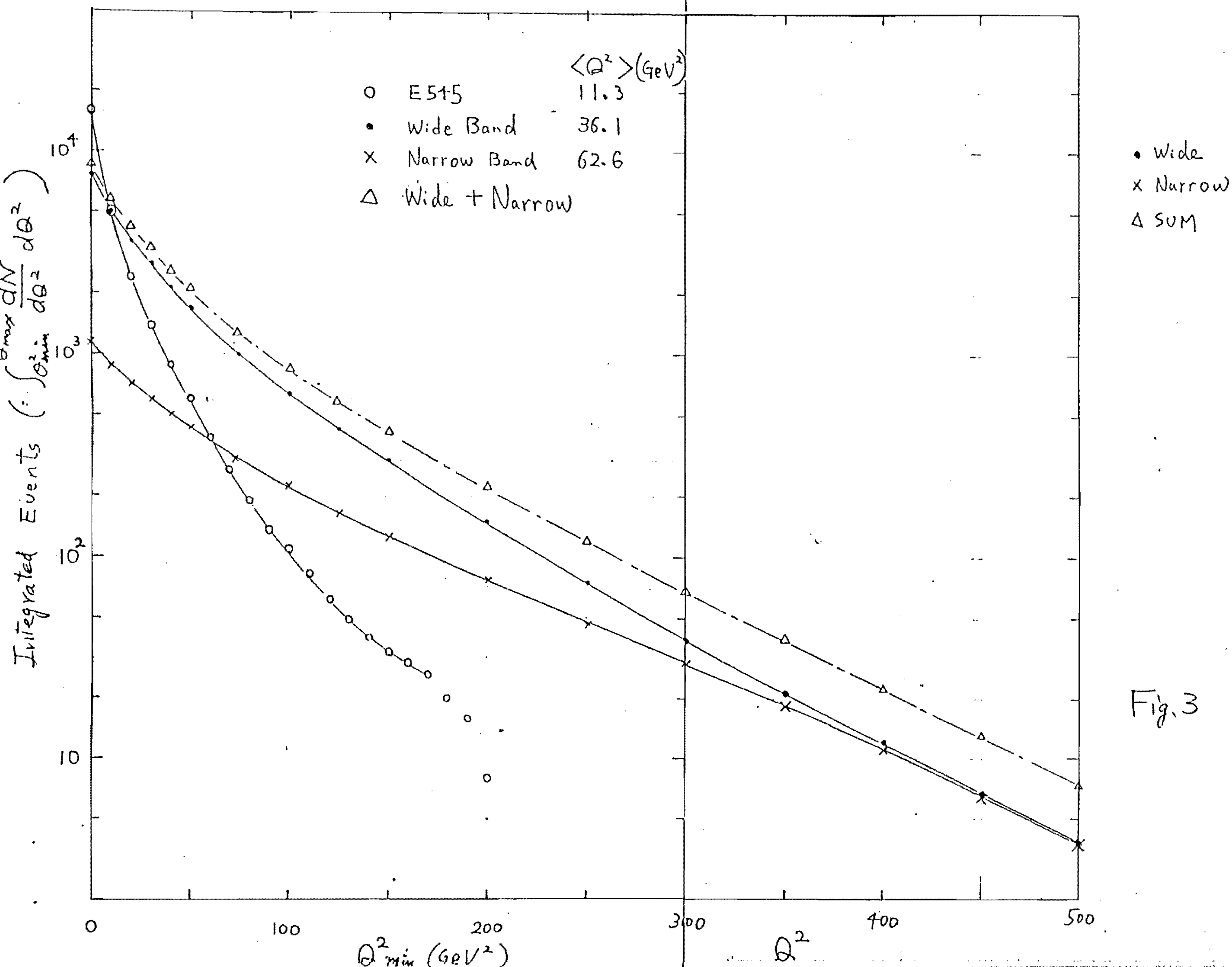


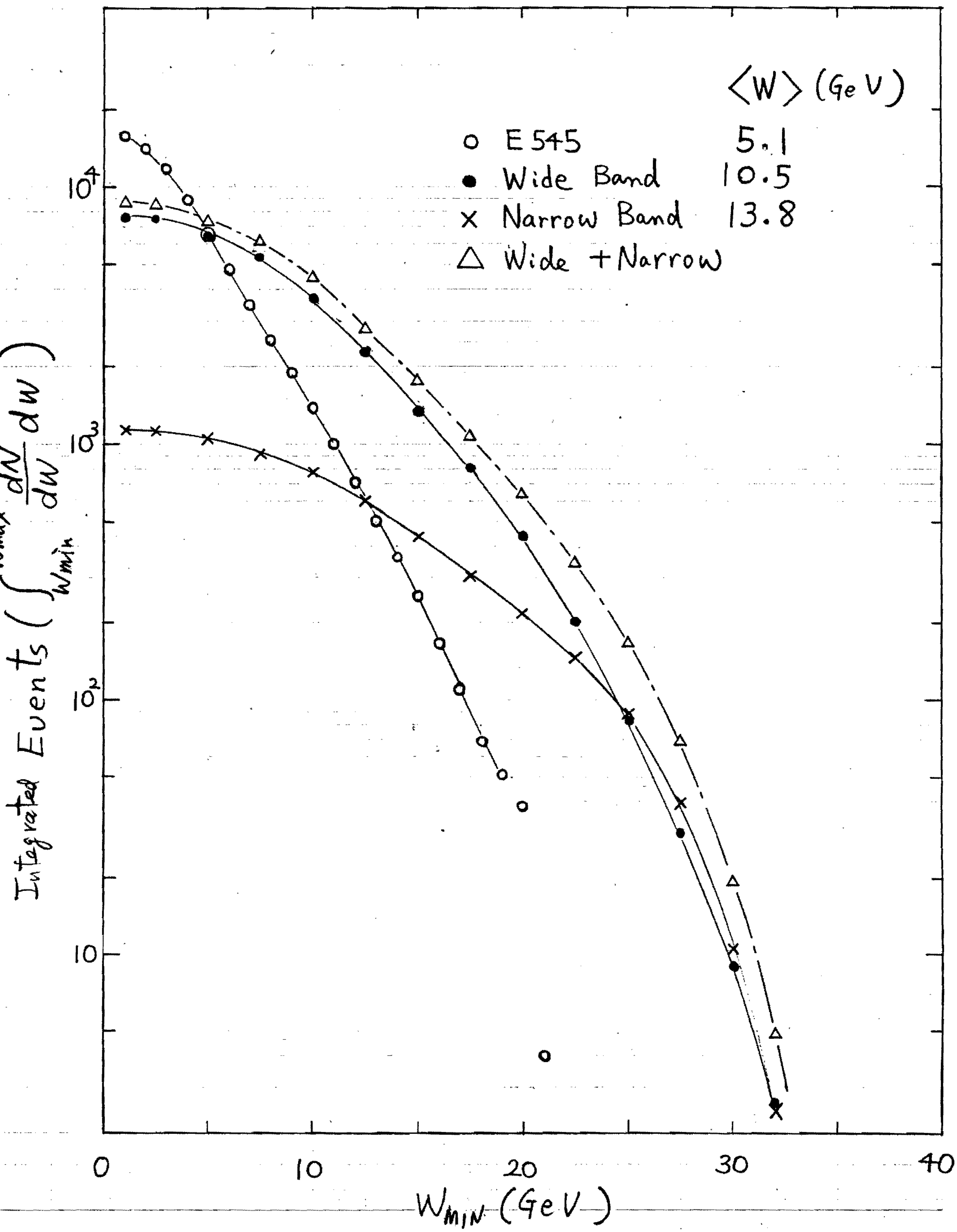
Fig. 2 Comparison of event rates. Proposed exposure and E-545.



<Q² >(GeV²)
o E515 11.3
• Wide Band 36.1
× Narrow Band 62.6
Δ Wide + Narrow
• Wide
× Narrow
Δ SUM
Integrated Events (∫ dN/dQ² dQ²)
10⁴
10³
10²
10
0
100
200
300
400
500
Q²min (GeV²)
Q²

Fig. 3

Fig. 4



⟨W⟩ (GeV)
○ E545 5.1
● Wide Band 10.5
× Narrow Band 13.8
△ Wide + Narrow
10⁴
10³
10²
10
Integrated Events $\left(\int_{W_{min}}^{W_{max}} \frac{dN}{dW} dW\right)$
0
10
20
30
40
W_{MIN} (GeV)

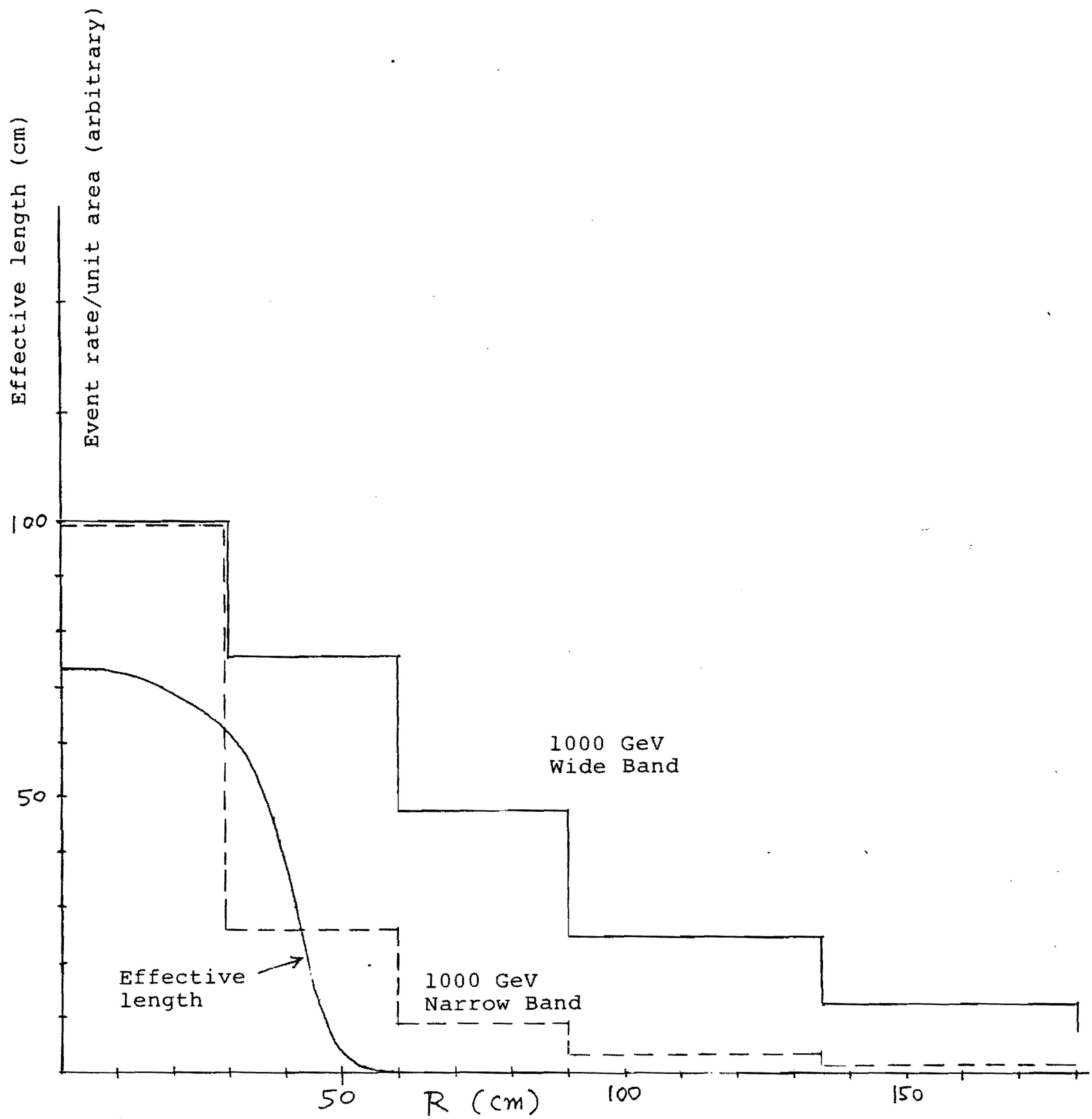


Fig. 5 Radial dependence of (Event rate/unit area) and the effective length of fiducial volume in the Tohoku 1m bubble chamber.

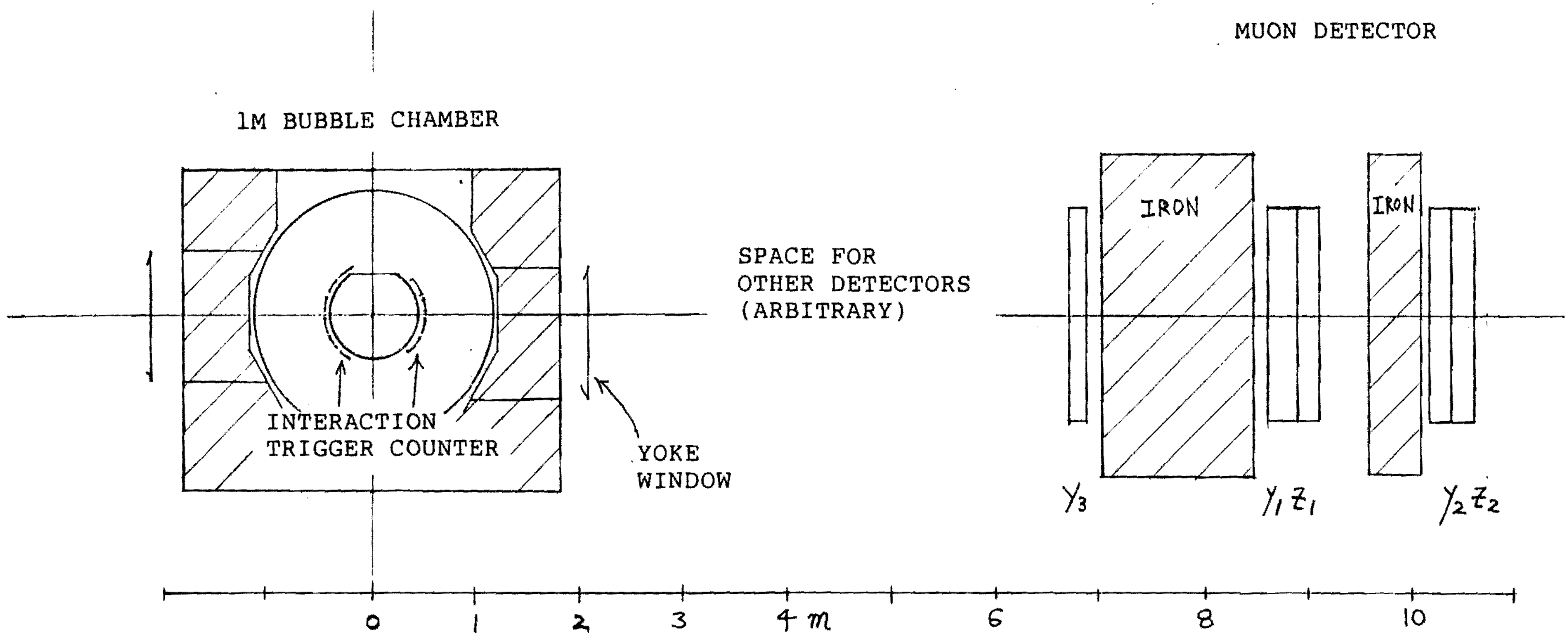


Fig. 6 Mini-Detector System

Appendix I

Charm Production Estimates

As discussed in the previous section, we expect 7650 charged current events per 10^{18} protons in the wide band Tevatron beam and 1140 per 10^{18} protons in the narrow band beam.

In neutrino charged current events, 5-10% of the events contain charms. We assume 7.5% charm particle production in these events yielding an estimated 660 events with a charmed particle. If we further assume production ratios of 30% for charmed baryonic production, and that 14% of mesonic production is F production, we expect

198 charmed baryons

64 F mesons

398 D mesons.

This number of charmed particles gives a data sample for lifetime and production cross section and branching ratio measurements, which is comparable to the largest samples available from major high resolution bubble chamber experiments, e.g. BC 72-73 at SLAC, NA-16 and NA-27 at CERN, and high resolution emulsion experiments such as E-531 at FNAL. The groups involved in this proposal have had extensive experience in high resolution studies of charmed particles in BC 72-73-75 (charm photoproduction at 20 GeV/c) and NA-27 (π^- and p on protons at 360 GeV/c) and recognize that for purposes of physics analysis the important numbers are those for detection and analysis of charm decays, not number of particles produced. These numbers, of course, are crucially dependent on particle parameters such as lifetimes, decay modes and production mechanisms, and on experimental conditions, particularly, in the case of a high resolution bubble chamber, bubble diameter, bubble density, and the optical resolution. For the Tohoku chamber the resolution is projected to be aproximately 30 μ and comparable with the bubble width. These expectations are supported by test photographs and holographic reconstruction thereof but have not yet been demonstrated under production conditions.

To establish truly realistic estimates of the number of analyzable events, we make here a detailed comparison with BC 72-73 at the SLAC hybrid facility, a 2.4 x 10^6 picture exposure of 20 GeV photons which yielded 580,000 hadronic interactions and 146 ± 22 charmed particle events. That experiment exhibits many similarities to the experiment proposed here, and as most of our groups (Tohoku, Tennessee, Brown, MIT) participated in BC 72-73, we feel that the experience gained in analyzing these data enables us to make accurate estimates of usable events rather than optimistic speculations.

The program to be followed for these estimates is to present cuts used and efficiencies determined in that experiment. A Monte Carlo program has been developed which matches these data exceedingly well. The Monte Carlo program has been altered to conform with the high energy experimental conditions of this experiment, and rerun, first for chamber resolution identical to the SLAC chamber, and then for the resolution expected in the Tohoku chamber.

In BC 72-73 146 ± 22 charm events were produced in the charm fiducial volume with approximately 51 charmed baryons and 241 mesons (primarily D^+, D° with an undetermined admixture of $F^\pm$ mesons). From this sample 72 charmed decays in 62 events were detected of which 51 decays in 49 events passed cuts designed to remove biases and permit quantitative study of detection efficiencies. Thus an overall detection efficiency of 21% was observed for the D, F admixture (no uniquely identified Fs were seen) and an efficiency consistent with zero for Λ_c.

This drastic reduction primarily arises from the removal of events with one prong (or zero prong for neutrals) decays. For $D^{\pm}$, e.g., this removes 65% of the decays, for D°, 13%, and an unknown fraction of F and Λ_C. To eliminate strange particle backgrounds, two-prong decays were required to have a π-π effective mass greater than the K° mass (> 550 MeV/c^2), a π-p effective mass greater than the Λ° (> 1130/MeV/c^2) and to have an appropriate effective mass more than 5 standard deviations from either particle. These cuts, of course, removed good D° events.

Finally, a series of cuts dependent on the high resolution optics resolution were implemented. The magnitudes of these cuts were chosen to reduce ambiguities in interpretation of decays and to insure that reasonable variations did not change conclusions on lifetimes or cross section. These cuts required [1] a minimum decay length of 500 μ, [2] an impact distance (d max) greater than 110 μ (2 track widths) for at least one track, and [3] an impact distance d_2 greater than 40 μ for a 2nd track from the same vertex. (See Figure A1). The cut [1] is necessary to reduce charged neutral ambiguities and the cut [3] ensures that a detected decay is indeed a multiprong decay. Fig. A2 shows the combined effect of these cuts as estimated with a Monte Carlo program.

We are convinced that any charm experiment of this type must incorporate similar cuts and that, in particular, cuts [1], [2] and [3] will scale linearly with resolution. Thus for the Tohoku chamber we expect appropriate cuts to be at $d_{max} \cong 60$ μm, $d_2 \cong 20$ μm and $\ell_{min} = 250$ μm. Of course for some special purpose cuts might be reduced below these limits but our experience would indicate that in general they represent good criteria for unbiased results.

Given branching ratios, detection efficiencies and a given set of cuts, if one assumes a production model so that a laboratory momentum distribution is known for each particle, then for any assumed lifetime one can calculate the expected laboratory distributions of the parameters d_{max}, d_2 and ℓ. Figure A3 shows the data of BC 72-73 compared with the Monte Carlo prediction as a function of each of these parameters when the values of the other two are fixed at the nominal cut value. We have thus developed considerable confidence in our Monte Carlo program's ability to predict efficiencies for given lifetimes, experimental cuts, and production momenta.

We have carried out a similar Monte Carlo analysis for the present experiment. In the absence of a full simulation of neutrino interactions, we have used a momentum spectrum which for the charmed mesons is similar to the spectrum observed in E-531 scaled by a factor of approximately 2.5, corresponding to the higher energy of the SST neutrino beam. The results are shown in Figures A4 and A5. Figure A4(a) contains the generated length distribution for D^+ mesons assuming a lifetime of 7.2×10^{-13} sec. Figures A4(b) and A4(c) show the number of events passing the SLAC cuts and the Tohoku cuts. The efficiency of the Tohoku cuts for multiprong decay is 64%. Since our best estimate of the multiprong rates is actually 35%, our overall efficiency is 22% for charged D decay. A similar run for D°s gives an overall efficiency of 40%.

We have done a similar analysis for F mesons assuming a lifetime of 2.2×10^{-13} sec. The results are shown in Fig. A5 for both cuts. The efficiency for multiprongs is 33% f_F where f_F is the branching ratio to multiprongs.

For Λ_c^+ we have assumed $\tau_{\Lambda_c} = 2.2 \times 10^{-13}$sec, and a momentum distribution ranging from 2 to 10 GeV/c with an average momentum of 7 GeV/c. (E-531 observes p_{av} of 6 GeV/c) We find for the Tohoku cuts an efficiency of 20% x f_{Λ_c}. This lower efficiency is due primarily to the low production momentum and the short lifetime. Therefore we find as a conservative estimate

Produced		Multiprong decays detected and passing cuts
Λ_c	198	$39 \times f_{\Lambda_c}$
F	64	$21 \times f_F$
D	398	126

where we have assumed equal numbers of D^+ and D° produced. Therefore we see a number of detected charmed particles passing cuts, and therefore suitable for lifetime and cross section measurements, which surpasses at least by a factor of two a typical recent large experiment.

In 129 one prong decays of D^+, decays with visible K° or identified e/μ are usable in this proposal in addition to the above multiprong decays. We estimate 20 for $\pi^+ K^\circ X^\circ$, 12 for $e^+ X^\circ$, 12 for $\mu^+ X^\circ$, 8 for $K^\circ \ell^+ X^\circ$ and the total, 52, where we assumed the e/μ detection efficiency of 60%. The leptonic decays of charmed particles are particularly important when compared with their lifetimes.

The background from the secondary interactions near the production vertex is expected for the charm study. We estimate approximately 171 such background events within 2mm distance of the primary vertex for Freon 13B1 (interaction length = 82cm). However, our experimental data in the Tohoku 14cm Freon Bubble chamber at FNAL, May 1982, shows that the background rate for the short decay is reduced to 21/117 by the removal of secondary interactions with clear nuclear signatures (not using charge information) and another factor of 1/2 by a further kinematical cuts. Therefore the background level is 10% for this level of cuts. Furthermore such background is spacially uniformly distributed, and can be subtracted from the charm signal.

We do not expect to be very sensitive to the production of B mesons although the expected rate of 1 to 5 particles in the exposure, the recently measured long lifetime and the expected high decay multiplicity, and the enormous transverse momenta might permit their detection. At the same level there is a faint hope of seeing a single example of top quark production.

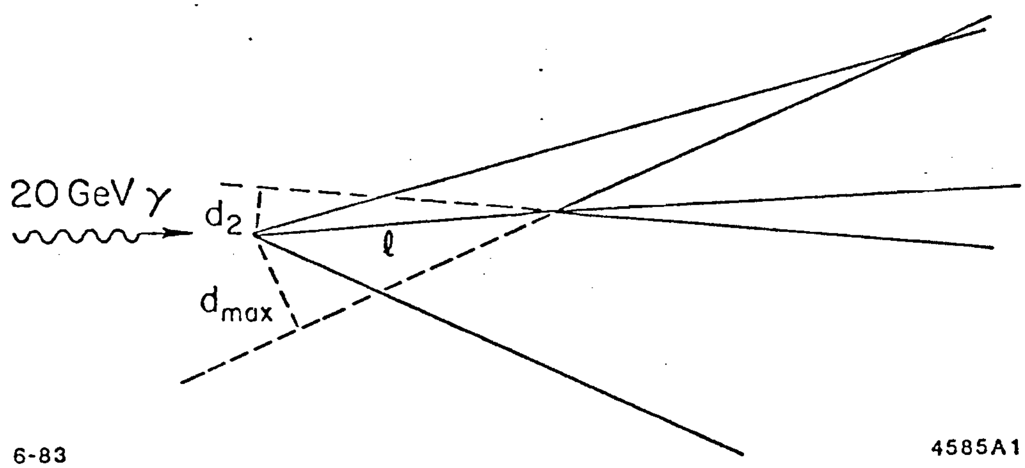
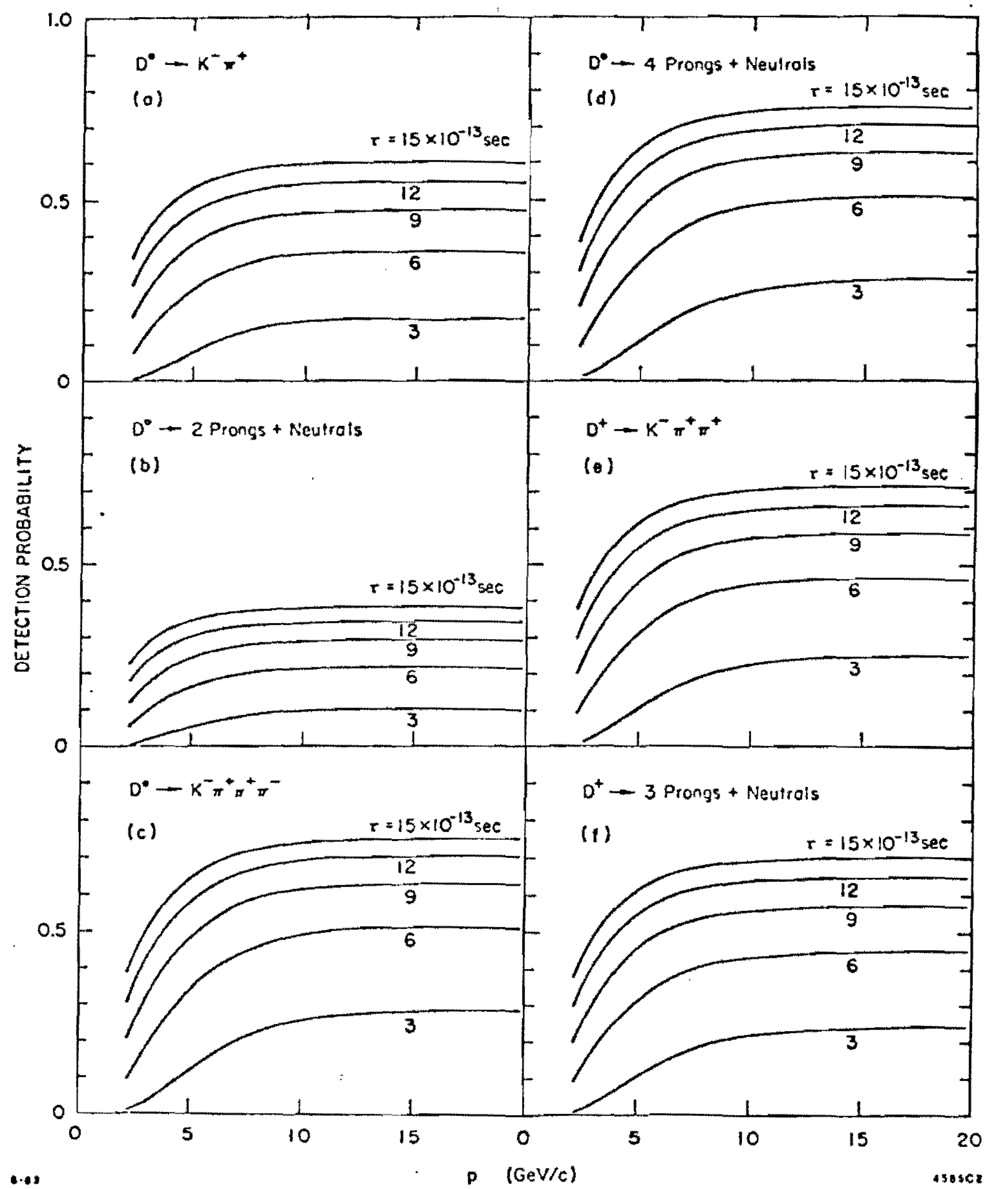


FIGURE A 1



DETECTION PROBABILITY
p (GeV/c)
$D^0 \to K^-\pi^+$
(a)
$\tau = 15\times10^{-13}$sec
12
9
6
3
$D^0 \to$ 4 Prongs + Neutrals
(d)
$D^0 \to$ 2 Prongs + Neutrals
(b)
$D^+ \to K^-\pi^+\pi^+$
(e)
$D^0 \to K^-\pi^+\pi^+\pi^-$
(c)
$D^+ \to$ 3 Prongs + Neutrals
(f)
0
0.5
1.0
5
10
15
20

FIGURE A 2

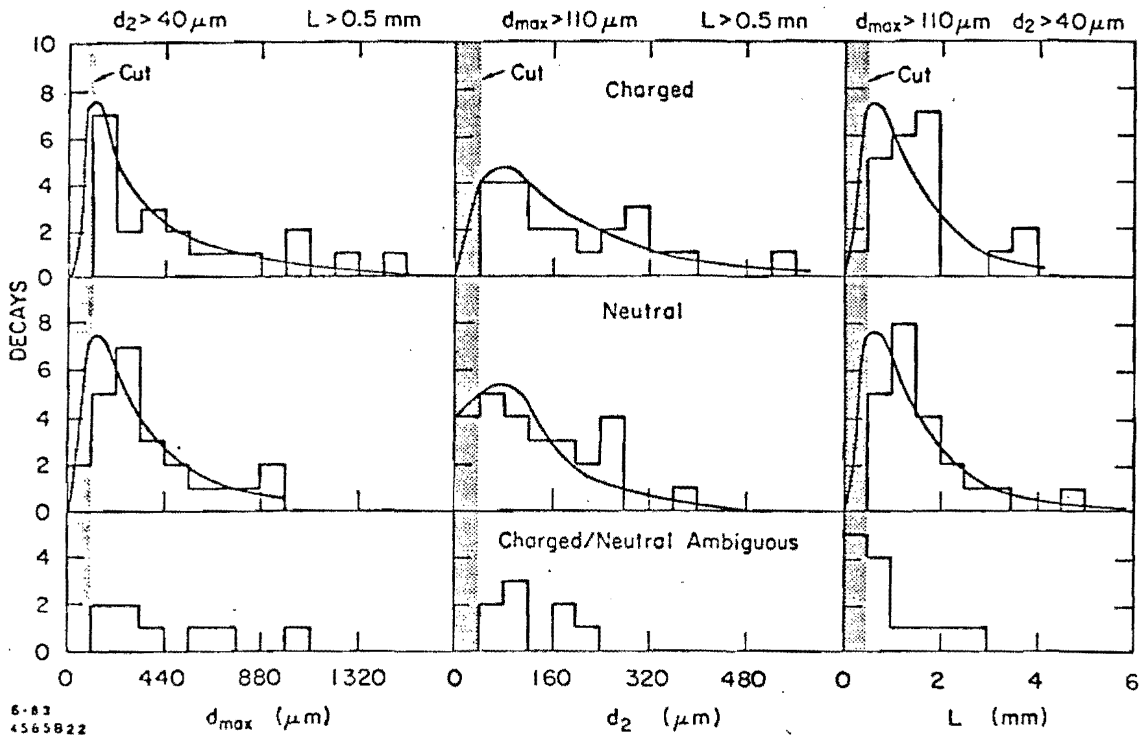
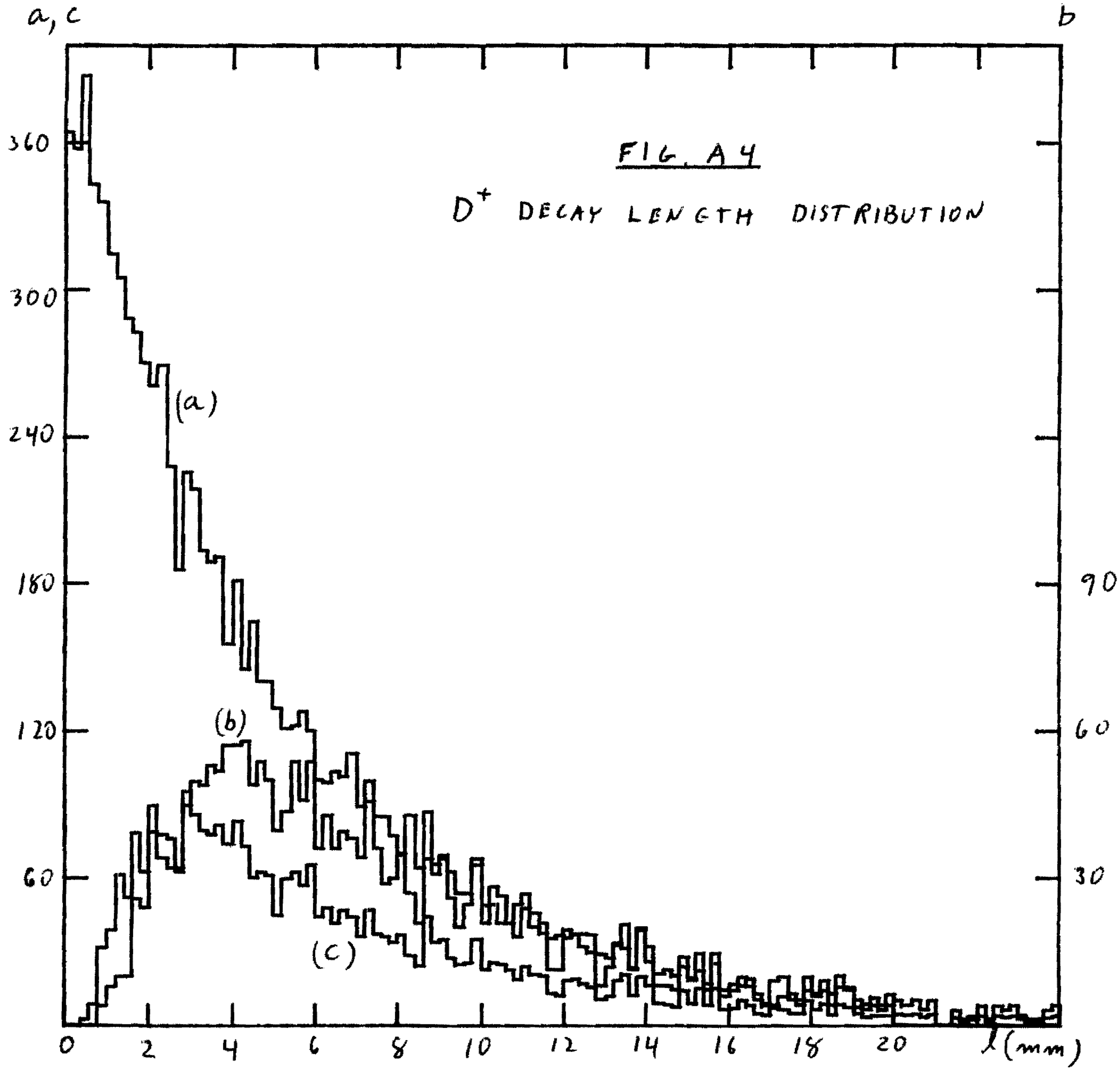

d2 > 40 μm
L > 0.5 mm
dmax > 110 μm
L > 0.5 mn
dmax > 110 μm
d2 > 40 μm
Cut
Cut
Cut
Charged
Neutral
Charged/Neutral Ambiguous
DECAYS
10
8
6
4
2
0
0
440
880
1320
160
320
480
2
4
6
6-83
4565B22
dmax (μm)
d2 (μm)
L (mm)

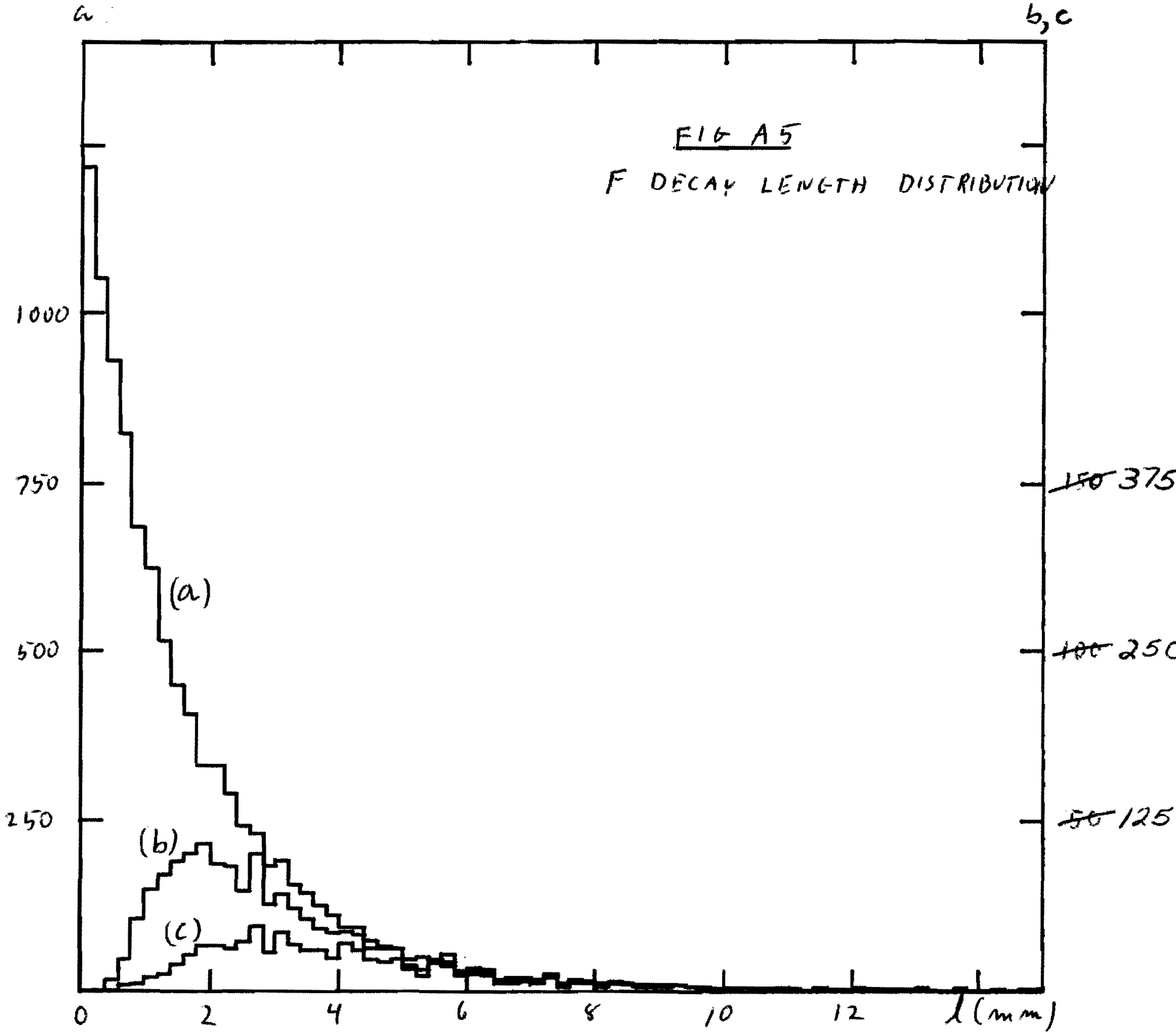
FIGURE A 3



(a) TOTAL MULTIPRONG EVENTS

c ~~(b)~~ WITH TOHOKU CUTS; $d_{MAX} > 60 \mu m$, $d_2 > 20 \mu m$
Scale on left

b ~~(c)~~ WITH SLAC CUTS; $d_{MAX} > 110 \mu m$, $d_2 > 40 \mu m$
Scale on right



(a) TOTAL MULTIPRONG EVENTS

(b) WITH TOHOKU CUTS; $d_{MAX} > 60\ \mu m$, $d_2 > 20\ \mu m$.
Scale on right

(C) WITH SLAC CUTS; $d_{MAX} > 110\ \mu m$, $d_2 > 40\ \mu m$.
Scale on right

Appendix II

Analysis of High Q^2 Events

One of the major aims in this proposal is to extend the neutrino event analysis to the high Q^2 region above 100 $(GeV)^2$ in Q^2. In this Appendix, we will discuss (1) a possible Q^2 bin size, (2) statistics, (3) measurement error of muon momentum, and (4) the deviations from the true values in the relevant quantities, E_ν, Q^2 and W, due to the expected measurement errors. We will use two examples of studies of the structure function $F_2(X)$, and the left-right asymmetry of hadrons against the ν-μ lepton plane. Both problems are controversial, and new data above 100 $(GeV)^2$ in Q^2 will be important to reach firm conclusions.

The event rate decreases rapidly as Q^2 increases, and therefore it is important not to take too small a bin size. We believe that two Q^2 bins above 100 $(GeV)^2$, $100 < Q^2 < 200$ and $200 < Q^2$ are reasonable for the studies mentioned above, as shown in Figs. B1 and B2. Fig. B1 is the Q^2 dependence of $F_2(X)$. The data are those from EMC[7]. The points with square marks show the expected statistical errors in this experiment. Fig. B2 shows the expected statistical errors in the sin ϕ asymmetry (not the asymmetry itself) for each region of Q^2. The dark circles are the E-545 data, and the square marks are the simulation for this experiment. The asymmetry predicted by QCD is the order of a few percent[5], therefore errors less than 2% are to be desired. In both Figs. B1 and B2, errors are shown separately for the wide band beam run, and for the sum of wide band and narrow band beam runs. In the case of the asymmetry, errors are directly given by the number of tracks. The statistics are considerably improved by the narrow band beam run (also, see Table I of the proposal).

Fig. B3 shows the distributions of E_ν and P_μ corresponding to each Q^2 region of the charged current events produced by a 1000 GeV wide band beam. The high Q^2 requires a relatively high E_ν and small P_μ and the momenta of the muons to be measured are predominantly below 200 GeV for our Q^2 region of interest, above 50 $(GeV)^2$.

Slow muons below 50 GeV are primarily analysed by the track measurement inside the bubble chamber, and the fast muons by the hybridization between the bubble chamber and the muon detector. Background stray muons which have track length of 80 cm inside bubble chamber will be used for the calibration of the hybrid system. Our estimate shows that the $\Delta p_\mu/p_\mu$ in the muon hybrid system is 8-10% for the yoke window part, and 27-28% for the yoke iron part, for 100-200 GeV.

Fig. B4 shows the Monte Carlo results of the ratios R = (Exp. value/Monte Carlo input) for (I)p_μ, (II)E_ν, (III)Q^2 and (IV)W, comparing the deviations of these quantities from the true values for (A) the bare chamber, (B) the proposed muon hybrid system, (C) the ideal case of no measurement error for all charged tracks and (D) the deuterium filled 15' bubbld chamber (E545). The proposed hybrid system (B) improves the resolution compared with the bare chamber case (A). However, as indicated in case (C), the primary source of such deviations comes from the method used to evaluate E_ν, as described later. In the Monte Carlo simulation, the bubble chamber fiducial volume is taken to have track lengths larger than 30 cm. The measurement errors (Δp, $\Delta\phi$, $\Delta\lambda$) are included for all charged tracks. Fig. B4 shows that the expected deviations, (B), are slightly worse than the E545 case, (D) but tolerable in our studies.

A standard method of neutrino event analysis in the bubble chamber is to estimate the missing (not measured) momenta by the momentum balance method using the visible (measured) momenta, and to evaluate E_ν, Q_1^2 and other quantities. It is not a rigorous solution, and the resolution of E_ν, Q^2, and W thus suffer, as shown in Fig. B4(C). In addition, several experimental cuts are applied in the selection of the event sample in order to reduce the background. For these reasons, a Monte Carlo simulation is always used to evaluate the correction efficiencies. In this proposal the heavy liquid in the bubble chamber often produces secondary interactions and gamma conversions. These are included in the visible momenta. It is noted that an important role of the narrow band run is to obtain a good correction factor for the efficiency evaluation.

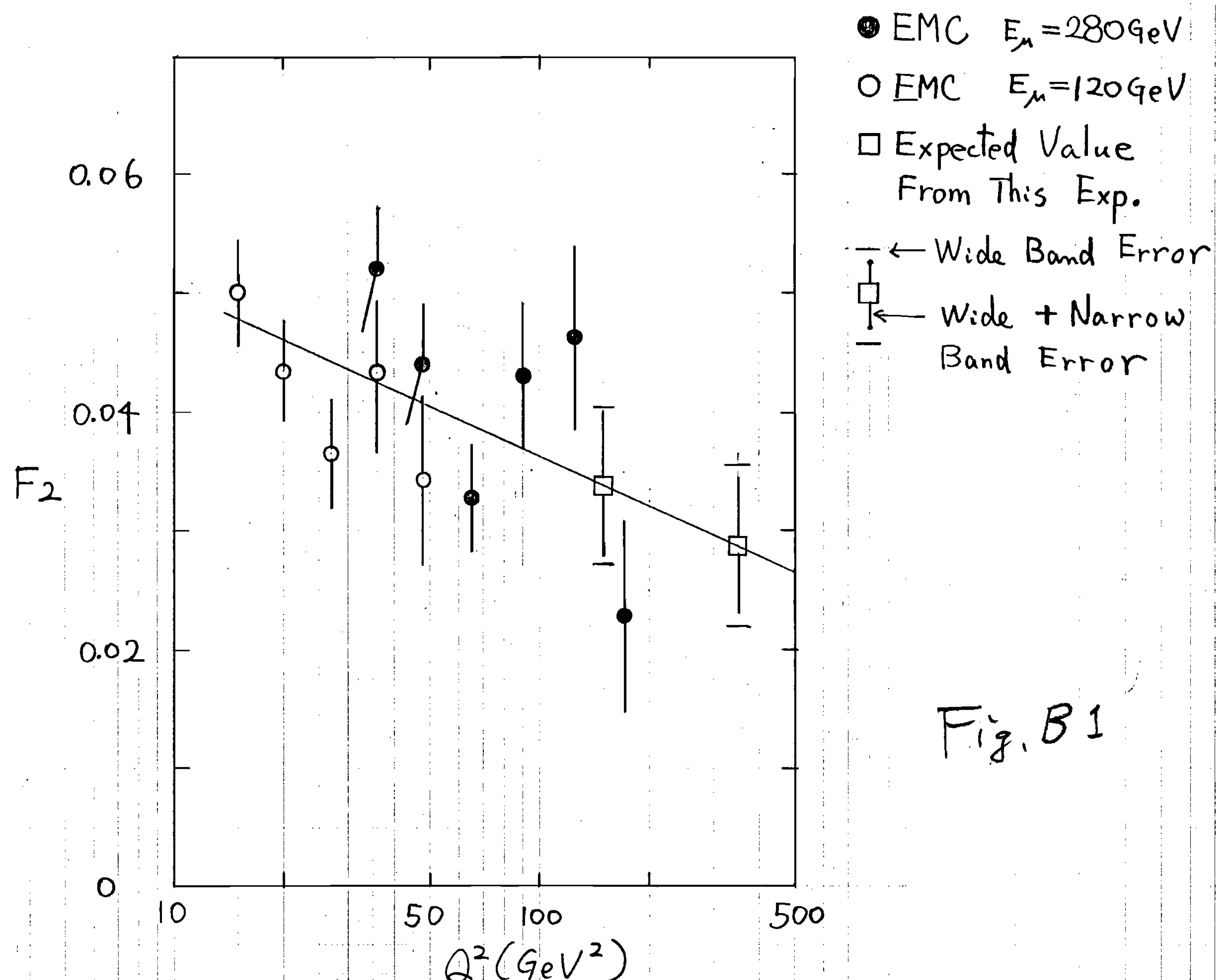

EMC $E_\mu = 280$ GeV
EMC $E_\mu = 120$ GeV
Expected Value From This Exp.
Wide Band Error
Wide + Narrow Band Error
0.06
0.04
0.02
0
F_2
10
50
100
500
Q^2 (GeV^2)

Fig. B1

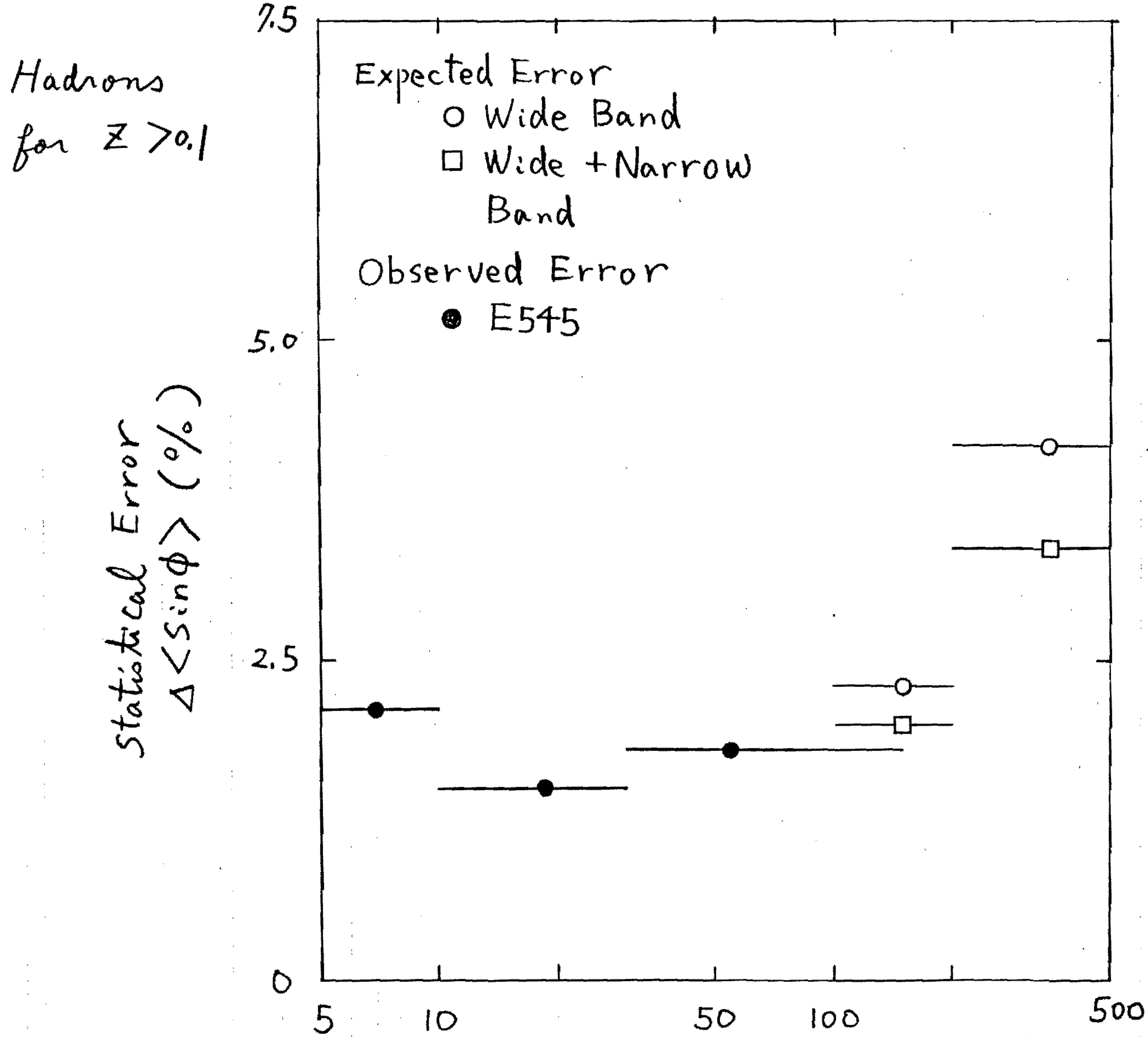
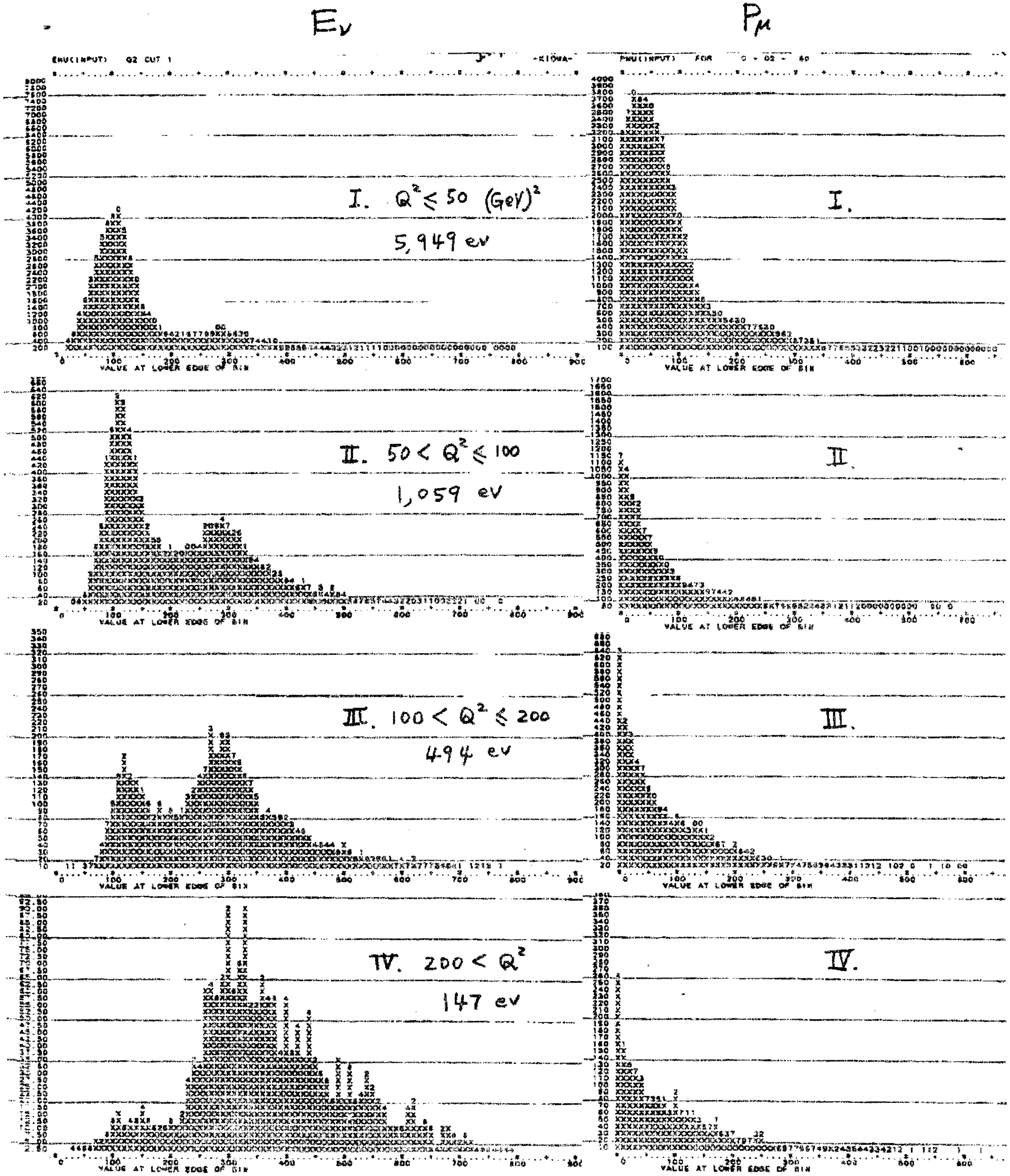

Hadrons
for Z >0.1
7.5
5.0
2.5
0
Statistical Error
Δ<sinφ> (%)
Expected Error
○ Wide Band
□ Wide + Narrow Band
Observed Error
● E545
5
10
50
100
500

Fig. B2

Fig. B3 E_ν and P_μ distributions for each Q^2 region.
Monte Carlo for 1000 GeV Wide band beam.



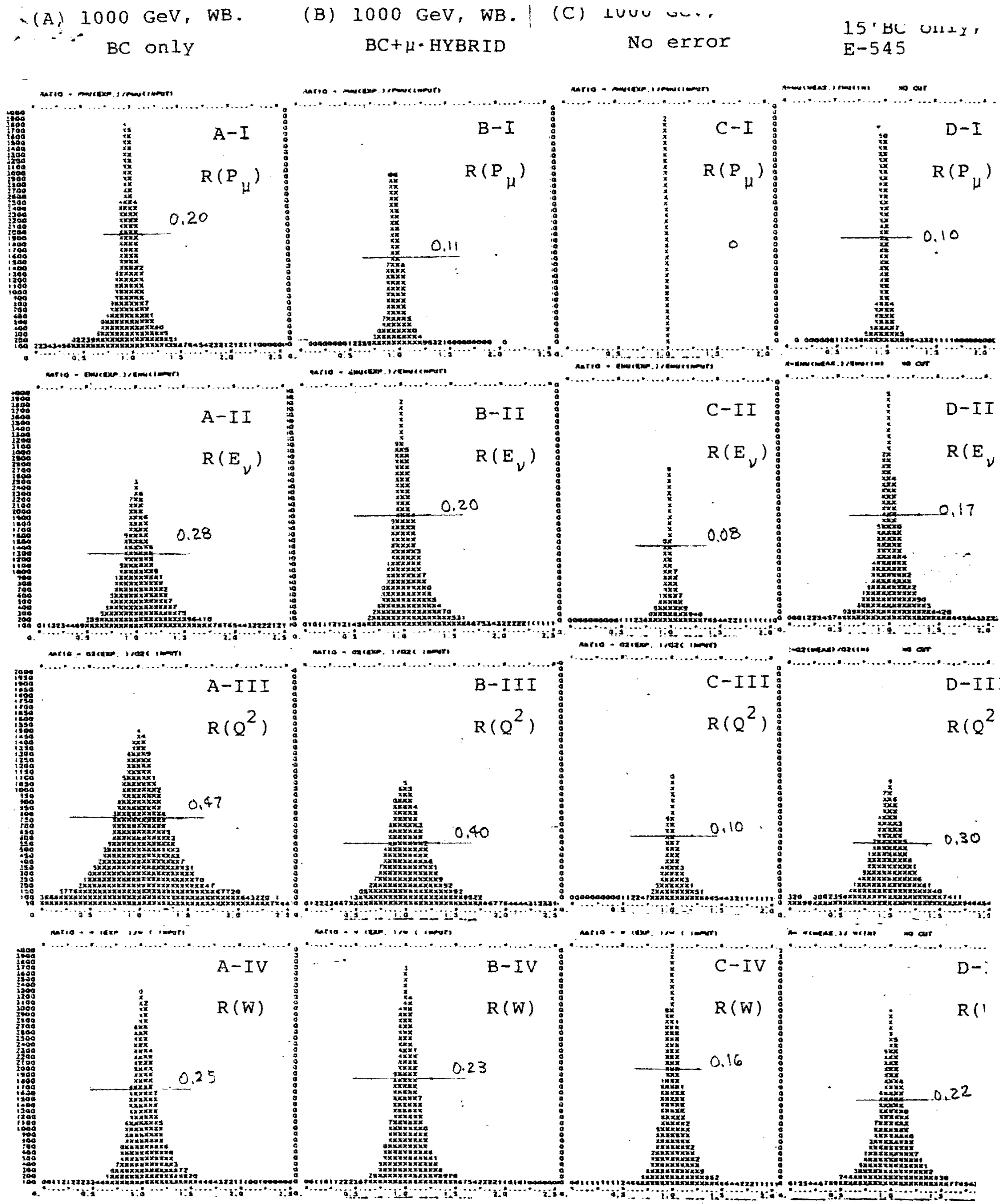


Fig. B4 Deviations of quantities from the true values; in the ratio of R=(exp. value/Input value). (I) P_μ, (II) E_ν, (III) Q^2 and (IV) W. Numerical figures show FWHM.