REQUEST FOR EXTENSION OF E-310

D. Cline, P. S. Cooper, M. Gilchriese, M. Heagy, R. Imlay, T. Y. Ling,

A. K. Mann, M. Merlin, S. Mori, D. D. Reeder, T. Trinko, and H. H. Williams

Fermi National Accelerator Laboratory
P. O. Box 500
Batavia, Illinois 60510

Ohio State University
Department of Physics
Columbus, Ohio 43210

University of Pennsylvania
Department of Physics
Philadelphia, Pennsylvania 19104

Rutgers University
Department of Physics
New Brunswick, New Jersey 08873

University of Wisconsin
Department of Physics
Madison, Wisconsin 53706

CONTENTS

I. INTRODUCTION

A number of interesting events have occurred in particle physics, particularly in neutrino physics, just before or since Fermilab experiment E-310 began data-taking in late 1976. These pose new questions for neutrino experiments or, in some instances, sharpen old questions, which indicate that an extension of the running time of E-310 would be of value. The questions are concerned with the possible existence of new quarks beyond charm and new leptons. We anticipate that some of them are answered more or less definitively in the data already taken in E-310. Others need to be addressed through data obtained under different conditions than those utilized for the E-310 data in hand. Specifically, it is desirable to use different (and previously unavailable) ν and $\bar{\nu}$ beams, and also to modify the event trigger arrangement by adding new counters.

We propose the extension of E-310 to include use of long-spill, two-horn focussed beams for ν and $\bar{\nu}$. The long-spill property makes possible use of the high-intensity, low-energy features of these beams in our experiment. The modified trigger arrangement will aid in that use, and, more importantly, allow us to eliminate suspected trigger biasses in the detection of multimuons. We request 2×10^{18} protons on target (POT) with the horn system focussed for negative particles and another 2×10^{18} POT for positive particles. We prefer the horn system to be operated without a plug. The trigger modifications involve modest changes in the present E-310 apparatus and, therefore, we should be prepared to begin data-taking early in the long-spill horn run scheduled for mid-August, 1978, if this extension is approved.

II. FURTHER STUDY OF MULTIMUON EVENTS

Dimuon events of the type

$$\nu_\mu + N \rightarrow \mu^-\mu^+ X$$
$$\bar{\nu}_\mu + N \rightarrow \mu^+\mu^- X \qquad (1)$$

were first observed at Fermilab in 1974.[1] The rate of these events is about 10^{-2} relative to charge current (CC) events. Studies of the characteristics of the dimuons as well as the measurement of the relative rates in targets of different densities led to the conclusion that these events were largely due to the weak semi-leptonic decay of short-lived, massive new hadrons produced in the ν_μ N interaction.[2] Dimuon production detected in other neutrino experiments confirmed the early observation.[3] The detection of μe events

$$\nu_\mu + N \rightarrow \mu^- e^+ X$$
$$\bar{\nu}_\mu + N \rightarrow \mu^+ e^- X \qquad (2)$$

in bubble chamber experiments[4] provided further evidence supporting the above interpretation. Furthermore, the discovery at SPEAR of the charmed D-meson[5] made it clear that the new hadrons proposed to be responsible for the bulk of the dimuon events are indeed 'charmed' particles.

The nature of the like-sign dimuon events,

$$\nu_\mu + N \rightarrow \mu^-\mu^- + X$$
$$\bar{\nu}_\mu + N \rightarrow \mu^+\mu^+ + X \qquad (3)$$

also observed in counter experiments[2,3], is less well understood.

Since the observed rate for the like-sign events is about 10-15% of the $\mu^-\mu^+$ rates, background due to $\pi(K)$ decay could constitute a significant fraction of the observed events. Nevertheless, like-sign dimuons with two energetic muons, such as the event shown in Fig. 1, exist. It is unlikely that such an event can be due to $\pi(K)$ decay. A crude measurement of the rate relative to $\mu^-\mu^+$ events in targets of different density, shown in Fig. 2, suggests the existence of a 'prompt' source for the like-sign events.

The recent discovery at Fermilab of neutrino induced trimuon events[6]

$$\nu_\mu + N \rightarrow \mu^-\mu^+\mu^- X \qquad (4)$$

added a new dimension to the multimuon phenomenon. A total of twelve such events were detected in experiment 310 prior to the November 1977 run. All these events were observed at high neutrino energies ($E_\nu \geqslant 100$ GeV). The trimuon production rate appears to be a few percent of the $\mu^-\mu^+$ events above 100 GeV. Two of these events exhibit the outstanding characteristics that the muons are all high energy (> 30 GeV) while the hadrons share a relatively small fraction of the incident energy. Fig. 3 shows the sketch of one of these exceptional events.

Two tetramuon candidates of the kind

$$\nu_\mu N \rightarrow \mu^-\mu^+\mu^-\mu^+ X$$

have been found to date in Exp. 310. One such event was reported[9] recently by the CDHS collaboration.

These interesting observations have naturally raised the questions:

1) Can 'charm' account for all of the multimuon phenomenon?

2) Can the trimuons or the like-sign dimuons be explained by any other conventional mechanism?

Recent theoretical calculations[7] using QCD for associated charm production yield rates for $\mu^-\mu^-$ and $\mu^-\mu^+\mu^-$ too low (by a factor of 10-100) to account for the experimental data. Several calculations[8] on radiative μ-pair production in ordinary CC events predict a trimuon rate (10-30)% of the observed rate. Low invariant mass ($M_{\mu^-\mu^+} \leqslant 1$ GeV/c^2) for at least one of the $\mu^-\mu^+$ combinations is expected for the radiative process. This property appears to be exhibited by several, but not all, of the observed trimuon events. Furthermore, the properties of the two exceptional events do not fit the description of either of the above-mentioned mechanisms.

It is apparent that at this stage we are far from completely understanding the multimuon physics. The exciting possibility exists that new physics beyond charm could be learned from the data. In particular, the exceptionally energetic trimuon events are not very probable in any mechanisms considered and therefore may be the key to the most interesting physics to be learned. Further progress in understanding them requires data with higher statistics and free from systematic biasses.

We request an extension of E-310 with an improved trigger arrangement and additional target mass to enable us to collect further data on multimuon events ($\mu^-\mu^-$, $\mu^+\mu^+$, $\mu^-\mu^+$, $\mu^-\mu^-\mu^+$, $\mu^-\mu^-\mu^+\mu^+$, etc.) with special emphasis on improved trigger efficiency for events originating in the liquid and iron calorimeters. The improvement lies in the construction and installation of two planes of fine-grain proportional tube hodoscopes. These tubes will be constructed from 1" x 1" square aluminum tubes. Each tube has a 50 μm diameter gold plated tungsten wire centered in the square hole. The technology of construction and the performance of these counters is well developed. The hodoscope planes will cover 12' x 12' area. One of the planes is to be installed at the end of the Fe calorimeter and the other downstream of the last 12' toroid, as shown in Fig. 4. The proportional tube hodoscopes will provide clean and efficient multimuon triggers, hence reduce the number of pictures taken and thereby speed up the analysis of the data. The fine granularity (1" x 1" cell size) enables the trigger to be essentially free of angular bias down to very small (< 5 mr) opening angle between the muons.

All the mass upstream of the spectrometer (totaling 400 metric tons) and the iron of the three 24' toroid and the first 12' toroid (250 tons total) will be used as targets for multimuon events. The total mass of 650 tons or more taken together with the improved triggering efficiency more than doubles the effective target mass of E-310. The expected multimuon rates for a run of 2×10^{18} POT with the long-spill horn beam are given in Table I.

TABLE I

RATES FOR MULTIMUON FINAL STATES IN A LONG SPILL HORN FOCUSSED NEUTRINO BEAM (No Plug)

Energy	Dimuons					Trimuons				
GeV	Toroid	Fet	LiqC	FeC	Total	Toroid	Fet	LiqC	FeC	Total
> 50	2440	2160	600	1200	6400	49	43	12	24	128
> 100	1120	1000	260	520	2900	22	20	5	10	62
> 150	560	500	140	280	1480	11	10	3	6	30
> 200	220	200	56	112	588	5	4	1	2	12

Assumptions

2×10^{18} Protons on Target

$R(\mu\mu/\mu) = .005$

$R(\mu\mu\mu/\mu) = 10^{-4}$

REFERENCES

1. B. Aubert et al., "Experimental observation of $\mu^+\mu^-$ pairs produced by very high energy neutrinos", in proceedings of the Seventeeth International Conference on High Energy Physics, London, 1974.

2. A. Benvenuti et al., Phys. Rev. Lett. 34, 419 (1975); A. Benvenuti et al., Phys. Rev. Lett. 35, 1199 (1975) and 35, 1203 (1975).

3. B. C. Barish et al., Phys. Rev. Lett. 36, 939 (1976); M. Holder et al., Phys. Lett. 70B, 260 (1977).

4. J. Blietschau et al., Phys. Lett. 60B, 207 (1976); J. von Krogh et al., Phys. Rev. Lett. 38, 710 (1976); C. Baltay et al., Phys. Rev. Lett. 39, 62 (1977).

5. E. G. Cazzoli et al, Phys. Rev. Lett. 34, 1125 (1975); G. Goldhaber et al., Phys. Rev. Lett. 37, 255 (1976).

6. A. Benvenuti et al., Phys. Rev. Lett. 38, 1110 (1977); B. C. Barish et al., Phys. Rev. Lett. 38, 577 (1977).

7. H. Goldberg, Phys. Rev. Lett. 39, 1598 (1977).

8. J. A. M. Vermaseren and J. Smith, Stony Brook Report (to be published); V. Barger, T. Gottschalk and R. J. N. Phillips, Wisconsin Preprint COO-881-9 (to be published); T. Hagiwara (to be published).

9. J. Steinberger, Talk presented at the Irvine Conference, December, 1977.

III. INELASTIC ANTINEUTRINO-NUCLEON SCATTERING

A series of experiments on the inelastic scattering of high energy neutrinos (ν) and antineutrinos ($\bar{\nu}$) by nucleons was carried out at Fermilab during the past few years by physicists from Harvard, Pennsylvania, Wisconsin and Fermilab (FNAL E-1A). The relevant processes were

$$\nu_\mu(\bar{\nu}_\mu) + N \rightarrow \mu^-(\mu^+) + X \qquad (1)$$

where N is an isoscalar target and X is any hadron state. One result of the experiments was the observation of an apparent discrepancy when the $\bar{\nu}$ data were compared to theoretical predictions based on the body of weak interaction data in general and on lower energy ν and $\bar{\nu}$ scattering experiments in particular.[1,2,3] Within experimental error, the ν data showed no such discrepancy, which was taken as evidence for the correctness of the experimental method and data. Subsequently, because of the interest in this $\bar{\nu}$ discrepancy, it came to be called the "high-y anomaly" by some theoreticians, after the Bjorken scaling variable $y = (E_{\bar{\nu}} - E_\mu)/E_{\bar{\nu}}$ which is a measure of the inelasticity of an interaction.

Briefly, the simple theoretical framework with which the early data were compared is as follows. In terms of the variables $x = Q^2/2M_N E_H$ and $y = E_H/E_\nu$, the scale invariant differential cross section for process (1) can be written as

$$\frac{d\sigma^\nu}{dy} = K_\nu \left[1 - (1-B^\nu)y + (1-B^\nu)\frac{y^2}{2}\right]; \qquad (2)$$

$$\frac{d\sigma^{\bar{\nu}}}{dy} = K_{\bar{\nu}} \left[1 - (1+B^{\bar{\nu}})y + (1+B^{\bar{\nu}})\frac{y^2}{2}\right], \qquad (3)$$

where the Callan-Gross relation, $2xF_1(x) = F_2(x)$, was assumed. The parameters $K_{\nu,\bar{\nu}}$ and $B^{\nu,\bar{\nu}}$ are related to the structure functions F_2 and F_3, which are functions of x only, if Bjorken scaling is assumed, by the following definitions:

$$K_{\nu,\bar{\nu}} = \frac{G^2 M_N E_{\nu,\bar{\nu}}}{\pi} \int F_2^{\nu,\bar{\nu}}(x)dx \quad ; \tag{4}$$

$$B^{\nu,\bar{\nu}} = - \frac{\int xF_3^{\nu,\bar{\nu}}(x)dx}{\int F_2^{\nu,\bar{\nu}}(x)dx} \quad . \tag{5}$$

Charge Symmetry Invariance (CSI) means that when scattering on an isoscalar (I=0) target, $F_i^{\nu}(x) = F_i^{\bar{\nu}}(x)$; i = 1,2,3. Therefore, CSI implies that i) $K_\nu = K_{\bar{\nu}}$, ii) $B^\nu = B^{\bar{\nu}}$. Relation i) can be checked by comparing $d\sigma/dy$ at y = 0 between ν_μ and $\bar{\nu}_\mu$ data while relation ii) can be checked by studying the shape of y-distributions independent of normalization. In the limiting case $B^\nu = B^{\bar{\nu}} = 1$, equations (2) and (3) reduce to the well known forms

$$\frac{d\sigma^\nu}{dy} = K_\nu \quad ; \quad \frac{d\sigma^{\bar{\nu}}}{dy} = K_{\bar{\nu}} \; (1 - y)^2 . \tag{6}$$

In terms of the Quark Parton Model (QPM) this corresponds to the limits in which there is no antiparton ($\bar{Q}$) in the nucleon, as can be seen by the relation

$$\frac{\bar{Q}}{Q+\bar{Q}} = \frac{1}{2} \; (1-B) . \tag{7}$$

The y-anomaly can be summarized empirically by the following statements: i) a decrease with increasing energy of the value of $B^{\bar{\nu}}$ for the $\bar{\nu}_\mu N$ data,[2] manifesting the breakdown of scale invariance; and ii) inequality of B^ν and $B^{\bar{\nu}}$ at high energy, and in particular at low x, equivalent to an effective violation of charge symmetry invariance.[1] It was observed[1,2] that the shape of the y-distribution for $\bar{\nu}_\mu N$ scattering was flatter at high energy than at low energy.

Each of the new, more recent experiments on high energy ν and $\bar{\nu}$ interactions at Fermilab, and now at CERN, has sought to study the y-anomaly. For various reasons there have been insufficient data from these experiments to confirm or repudiate the effect. This situation is changing, and experiments using higher intensity proton beams as neutrino sources and a variety of experimental methods are now yielding data bearing directly on the y-anomaly.

The results of one of these investigations by the CDHS experiment at CERN has been published[4]. The authors of this paper conclude that there is no y-anomaly, and implicitly interpret their data are confirming scale invariance, charge symmetry invariance and the simple quark-parton model (QPM). Some of us in E-1A studied that paper and pointed out that there were several serious inconsistencies in the data of that paper which were relatively obvious, and which made its conclusions very doubtful.[5] These inconsistencies suggested-in view of the small statistical uncertainties of the CDHS data-that there were systematic errors in their experiment which they had failed to take into account.

It has turned out that our criticism was justified, and identified with good accuracy the nature of the errors in the initial results of the CDHS experiment. Corrected CDHS results which were given in recent talks by J. Steinberger at the Irvine Conference and at BNL now confirm the original HPWF results in the energy region in which they overlap. It appears that the high-y anomaly exists precisely as had been indicated in PRL papers[1,2] in 1974 and 1976. Indeed, the high-y anomaly is, if anything, more pointed now because there are three counter experiments showing that the value of $B^{\bar{\nu}}$, the parameter in the simple quark-parton model (eq. 3) that describes the shape of the antineutrino y-distribution, is significantly smaller above about 60 GeV antineutrino energy than it is at energies below 30 GeV. The lower energy data are from Gargamelle[6] and HPWF[2]. A summary of the data is shown in Fig. 5, which includes also old and new data from the CIT-FNAL experiment.[7,8] Note by how much (> 20 standard deviations if it were statistical) the CDHS data have changed since their PRL publication. Note also the relatively dramatic change in $B^{\bar{\nu}}$ in the energy region between about 20 GeV and 60 GeV. That was what was called attention to in references 1 and 2 and in other publications, and that is what came to be called the high-y anomaly.

An alternative direct comparison of the CDHS data with the earlier HPWF data may be made in a simple and quantitative way. The published HPWF data above 50 GeV (where apparatus acceptance corrections are less significant) yield an average value of y ($\langle y \rangle^{\bar{\nu}}$) of 0.38 ± 0.015, where the error is determined from the statistics on the points and an assumed systematic error of equal magnitude. Within errors these data are consistent with no dependence of $\langle y \rangle^{\bar{\nu}}$ on $E_{\bar{\nu}}$ for $E_{\bar{\nu}} > 50$ GeV. The new CDHS result given by Steinberger is 0.35 ± 0.01, and is also consistent with no energy dependence above 50 GeV. These data are summarized in Fig. 6, which includes new results from CITF.[8]

Furthermore, HPWF presented measured values of $\sigma^{\bar{\nu}}/\sigma^{\nu}$ as a function of neutrino energy[9] which were obtained by two methods of analysis because of normalization difficulties that were attendant on using the wide band neutrino beams in the early HPWF experiments. From the published HPWF data points above 50 GeV, one obtains $\sigma^{\bar{\nu}}/\sigma^{\nu} = 0.65 \pm 0.08$ by one method of normalization, and $\sigma^{\bar{\nu}}/\sigma^{\nu} = 0.58 \pm 0.05$ for the other method, where the errors are statistical only. No statistically significant energy dependence was observed above 50 GeV. Since there was concern that the systematic error in the normalization might be large, it was stated in the conclusion of that paper,[9] "A growing ratio of cross sections with energy is indicated by the data, with the ratio exceeding 0.5 above 50 GeV." (p. 191-2). The corrected CDHS value of $\sigma^{\bar{\nu}}/\sigma^{\nu}$, again from the same source, is 0.50 ± 0.05, consistent with no energy dependence above 50 GeV. Above about 100 GeV the CITF experiment[8] also yields $\sigma^{\bar{\nu}}/\sigma^{\nu} \geq 0.50$.

One sees therefore that within two standard deviations the revised CDHS data above 50 GeV are in agreement with the published HPWF results in that energy region. Below 30 GeV, there are no published CDHS data, but the HPWF and Gargamelle results are in agreement within one standard deviation.

Possible interpretations of the data in Fig. 5 are as follows. If the initial CDHS results were correct, the small difference between the $B^{\bar{\nu}}$ values below 30 GeV and above 60 GeV could be attributed entirely to charmed hadron production by antineutrinos. However, if the revised CDHS are taken as correct, then all of the data in the region $E_{\bar{\nu}} \geqslant 60$ GeV are in agreement within experimental errors, and the larger difference between the values of $B^{\bar{\nu}}$ at the lower and higher energies, if it persists, is unlikely to be explained solely by charmed hadron production. Among the additional mechanisms that may be adduced to account for that larger difference are (i) asymptotic freedom effects that break scale invariance, and (ii) the existence of a new, charge - 1/3 quark (for example, the b-quark) that gives rise to new hadrons of mass in the vicinity of 5 GeV/c^2.

It appears then that the high-y anomaly is alive and well-if the data in Figs. 5 and 6 are taken at face value. It is therefore of interest to study intensively charged current antineutrino scattering in the energy region from 10 GeV to about 60 or 80 GeV with high statistics and careful attention to systematic effects. New data will either confirm the data in Fig. 5 and delineate the nature of the energy dependence of $B^{\bar{\nu}}$ and, possibly, $\sigma^{\bar{\nu}}/\sigma^{\nu}$, or they may show that the low energy data (< 30 GeV) are in error. It is also possible, but unlikely in our opinion, that the energy dependence of, say, $B^{\bar{\nu}}$ is slow (logarithmic) as the result of asymptotic freedom effects noted above and suggested by the new CITF data.

Whatever the explanation, it is desirable to acquire additional data soon. A significant amount of new data have already been taken in E-310 using a bare target, sign selected antineutrino beam (BTSS $\bar{\nu}$). The results of analysis of these data will be presented in early Spring, 1978. Preliminary analysis shows that the E-310 detector has, as anticipated, good geometric acceptance of events over wide ranges of the scaling variables x and y at low as well as high antineutrino energies, and that no serious systematic effects are present in the acquired data.

We propose in the extension of E-310 to obtain additional data using a long-spill, two-horn antineutrino beam which enhances the low energy end of the antineutrino spectrum. This is because the physics emphasis has for the moment shifted from high antineutrino energy (where all experiments are in agreement within experimental errors) to lower antineutrino energy where the data are sparser, as shown in Fig. 5. The distributions of events in the BTSS $\bar{\nu}$ and 2-HORN beams are shown in Table II, where it is seen how differently events produced by the two beams are distributed in energy. Note that the predicted number of events for the 2-HORN beam is based only on the fiducial mass of the liquid scintillator calorimeter. Iron plate calorimeter data at low antineutrino energies may involve serious biasses. This is a significant advantage of E-310 in studying antineutrino charged current interactions relative to experiments which use only iron plate calorimeters.

TABLE II. Energy distributions of useful $\bar{\nu}$- events obtained with the E-310 detector in BTSS $\bar{\nu}$ beam and expected in 2-HORN beam for 2 x 10^{18} protons on target.

BTSS $\bar{\nu}$			2-HORN		
Energy Interval	Number of Events*	Fraction (%)	Energy Interval	Number of Events**	Fraction (%)
15-30 GeV	1050	14	15-30 GeV	3980	46
30-45	1570	21	30-45	2600	30
45-60	1720	23	45-60	1090	12.7
60-80	1270	17	60-80	680	8.1
80-100	900	12	80-100	350	4.0
TOTAL	6500		TOTAL	8700	

* Obtained with liquid scintillator calorimeter (fiducial mass = 27.5 metric tons) plus 10 cm thick iron plate calorimeter (fiducial mass = 50 metric tons).

** Expected in liquid scintillator calorimeter <u>only</u>. Events occurring in the iron plate calorimeter with energies less than about 30 GeV may be difficult to use without bias.

Note also that we expect a similar total of neutrino events between 15 and 100 GeV from the 2-HORN $\bar{\nu}$ beam if it is operated without a plug. We anticipate operation without a plug in the long-spill, 2-HORN $\bar{\nu}$ run to take place late next summer because the 15-foot bubble chamber will not have a neon filling during that run. The neutrino events allow a direct comparison of the shapes of ν and $\bar{\nu}$ y-distributions, as was done in E-1A. Furthermore, they also permit determination of $\sigma^{\bar{\nu}}/\sigma^{\nu}$ in the lower energy bins, 15-30, 30-45, and perhaps 45-60 GeV, by means of quasielastic events, again as was done in E-1A.

In summary, an extension of E-310 which utilizes 2 x 10^{18} protons onto the target of the long-spill, two-horn focussing system (focussed for π^-/K^-) should yield more than 8000 $\bar{\nu}$ events in the fiducial mass of the liquid calorimeter in the energy region 15 to 100 GeV and a similar number of ν events. This can be done without any modification of the E-310 apparatus. The events will be measured on the FNAL semi-automatic measuring machine (SAMM), on which the bulk of the E-310 data taken up to now have been measured, and for which all software exists. We anticipate measuring 30,000 events at 2 minutes per event for a total of 25 weeks at 40 hours per week utilization.

It is our expectation that the charged current data from E-310 and this extension-which will contain significant yields of antineutrino events from three different incident $\bar{\nu}$ spectra (quadrupole triplet, BTSS $\bar{\nu}$ and long-spill, two-horn), and two different types of calorimeter-would enable us to clarify the energy dependence of the parameters describing antineutrino-nucleon scattering in a definitive way. The data obtained in the extension would play a decisive role.

REFERENCES

1. B. Aubert et al., Phys. Rev. Lett. 33, 984 (1974).

2. A. Benvenuti et al., Phys. Rev. Lett. 36, 1476 (1976).

3. A. K. Mann, "New Pathways in High Energy Physics II", edited by A. Perlmutter (Plenum Press, 1976).

4. M. Holder et al., Phys. Rev. Lett. 39, 433 (1977).

5. A. Benvenuti et al., (talk presented by T. Y. Ling), Int'l Symp. on Lepton and Photon Interactions at High Energies, Hamburg, Germany, 1977; A. K. Mann, Proc. Banff Summer Institute (C.A.P.) on Particles and Fields, Banff, Canada, 1977; Proc. of the School on High Energy Physics and Relativistic Nuclear Physics, Gomel, USSR, 1977.

6. J. Blietschau et al., Nucl. Phys. B118, 218 (1977); D. C. Cundy, Proc. 17th Int'l Conf. on High Energy Physics, London, 1974 (p. IV - 131).

7. B. Barish et al., Phys. Rev. Lett. 38, 314 (1977).

8. F. Sciulli, talk at Int'l Symp. on Lepton and Photon Interactions at High Energies, Hamburg, Germany, 1977.

9. A. Benvenuti et al., Phys. Rev. Lett. 37, 189 (1976).

IV. SUMMARY

A summary of all runs to data in E-310 is given in Table III, which shows that we have utilized beams that yield relatively hard ν and $\bar{\nu}$ spectra in an effort to emphasize multimuon physics. Table IV summarizes the data collected so far in E-310. Dimuon and trimuon data taken prior to QT (II) have been presented at conferences and in PRL. All of the single muon data taken prior to QT (II) will be ready for presentation by April, 1978, as will the trimuons (and tetramuon) from QT (II). There remain to be measured and analyzed the dimuon data and a fraction of the single muon data from QT (II).

The long-spill, two-horn run requested here should complement the previous runs in E-310. This beam, which is essential to clean running conditions in our experiment, was previously not available at FNAL. The horn focussed $\bar{\nu}$ beam provides high intensity in the low energy region ($E_{\bar{\nu}} < 50$ GeV), and is therefore well suited to map out the energy dependence of any charge symmetry or scale breaking effects in $\bar{\nu}N$ scattering, as shown in Table II. The long-spill, two-horn ν and $\bar{\nu}$ beams also yield high energy fluxes ($E_\nu > 100$ GeV) comparable to or larger than those in the QT beam. Thus, multimuon studies at both low and high energies are fruitful, and a direct comparison of multimuon (particularly trimuon) production at $E_\nu < 100$ GeV and $E_\nu > 100$ GeV can be made.

TABLE III. E-310 Run Summary

Date	Beam	POT	Corrected[+] POT
Oct. 25, 1976 - Dec. 28, 1976	Quad Triplet (1)	1.12×10^{18}	0.58×10^{18}
Mar. 27, 1977 - Apr. 18, 1977	SSBT $\bar{\nu}$ (1)	0.79×10^{18}	0.44×10^{18}
May 30, 1977 - Jun. 25, 1977	SSBT $\bar{\nu}$ (2)	1.76×10^{18}	1.44×10^{18}
Jun. 27, 1977 - Jul. 4, 1977	SSBT ν	0.41×10^{18}	0.33×10^{18}
Oct. 22 - Present (Jan. 30, 1978)	Quad Triplet (2)	3.7×10^{18}	$\sim 3.0 \times 10^{18}$

+ Corrected for dead time and detector efficiency.

TABLE IV. E-310 Data Summary

Beam	Total Charged Current Events	Fid. Vol. Charged Current Events	Fid. Vol. Dimuons	Trimuons	Tetramuons
QT (I)	$9 \times 10^{3+}$	5×10^3	160	6	1
BTSS($\bar{\nu}$)	$14 \times 10^{3+}$	7.5×10^3	60	1	0
BTSS(ν)	$6 \times 10^{3+}$	3×10^3	100	6	0
QT (II)	$60 \times 10^{3+}$	33×10^3	2500	70	1

+ Prescaled events in the liquid and iron calorimeter only before ficucial cut.

FIGURE CAPTIONS

1. A like-sign dimuon event in the E-310 apparatus.

2. The rate for $\mu^-\mu^-$ to $\mu^-\mu^+$ for different density targets.

3. A higher trimuon event observed in E-310.

4. The proposed detector.

5. Plot of $B^{\bar{\nu}}$ vs $E_{\bar{\nu}}$ summarizing data from high energy counter neutrino experiments and Gargamelle.

6. Plot of average y vs $E_{\bar{\nu}}$ for high energy counter neutrino experiments.

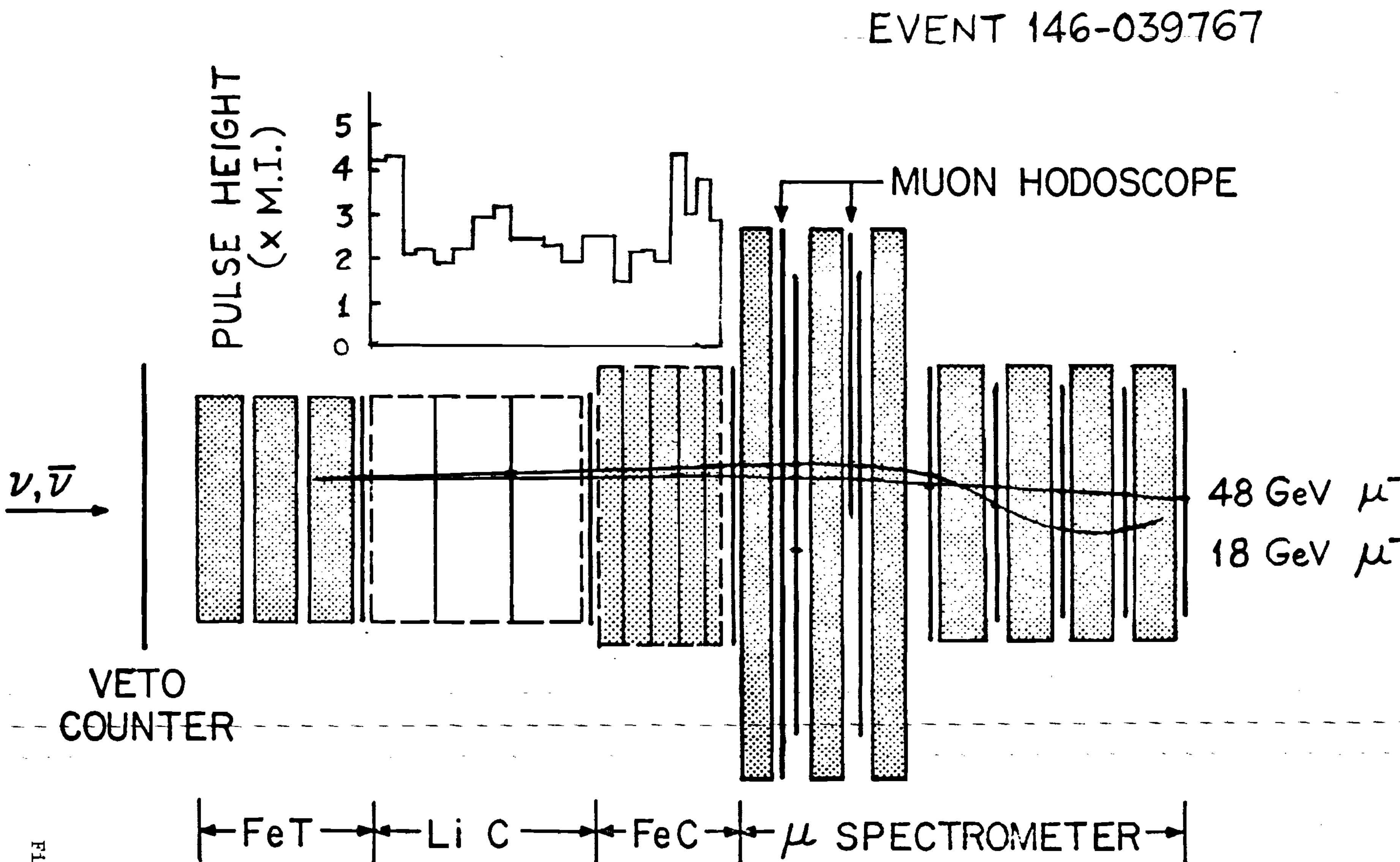

EVENT 146-039767
PULSE HEIGHT (x M.I.)
5
4
3
2
1
0
MUON HODOSCOPE
ν, ν̄
VETO COUNTER
48 GeV μ⁻
18 GeV μ⁻
FeT
Li C
FeC
μ SPECTROMETER

Fig. 1

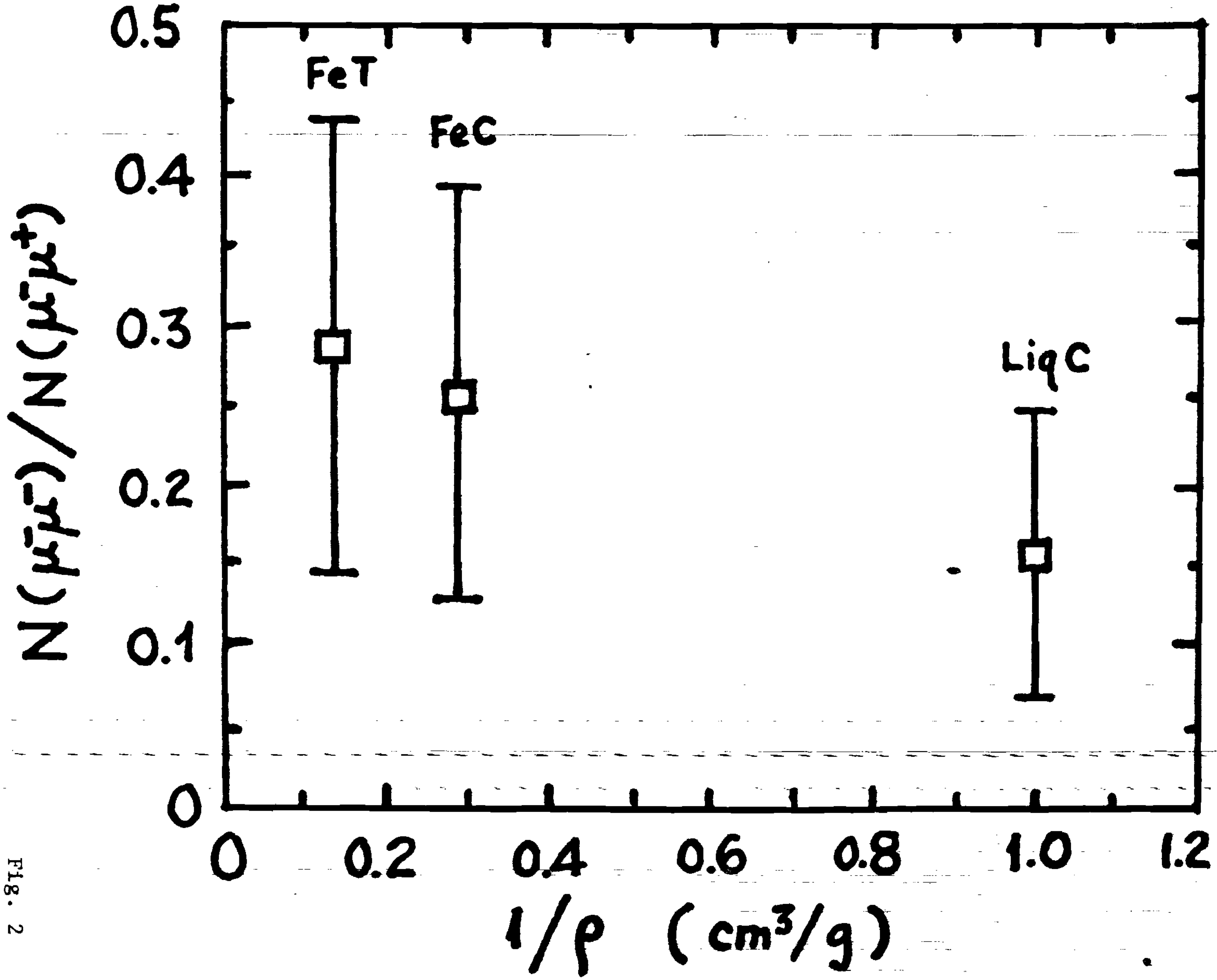


Fig. 2

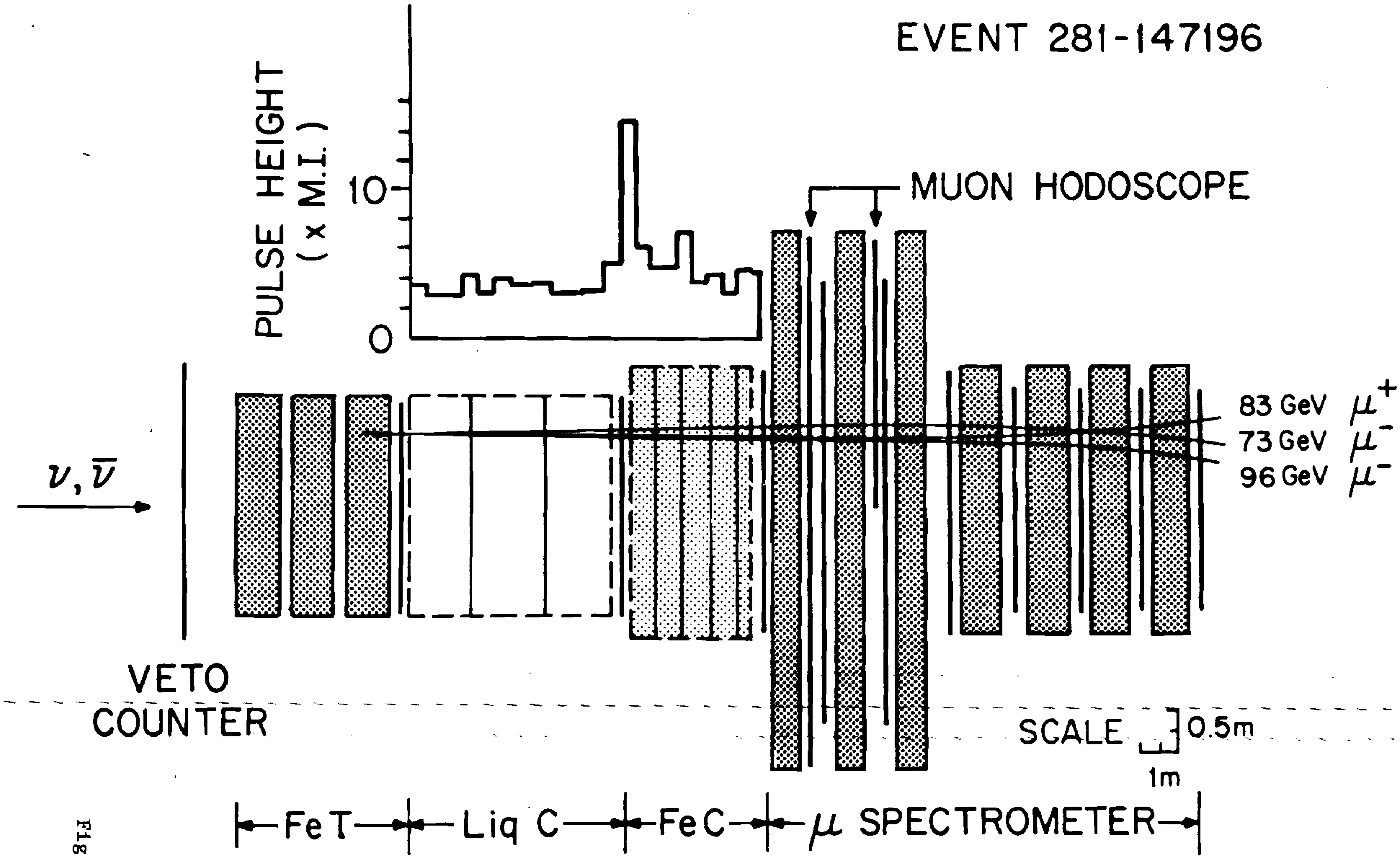
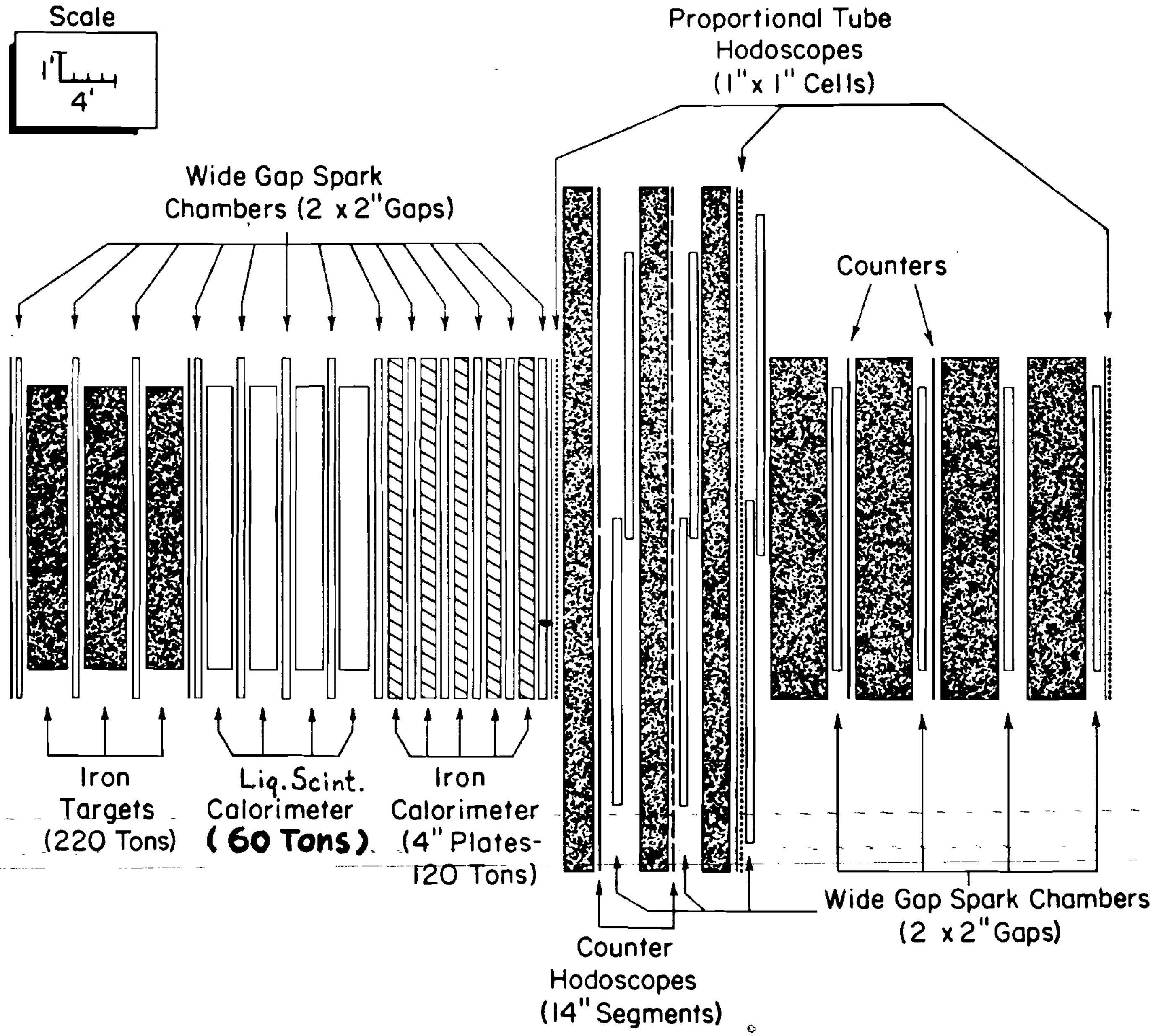

EVENT 281-147196
PULSE HEIGHT (x M.I.)
10
0
MUON HODOSCOPE
83 GeV μ^+
73 GeV μ^-
96 GeV μ^-
$\nu, \bar{\nu}$
VETO COUNTER
SCALE 0.5m
1m
FeT
Liq C
FeC
μ SPECTROMETER

Fig. 3



Scale
1'
4'
Proportional Tube
Hodoscopes
(1"x 1" Cells)
Wide Gap Spark
Chambers (2 x 2"Gaps)
Counters
Iron
Targets
(220 Tons)
Liq. Scint.
Calorimeter
(60 Tons)
Iron
Calorimeter
(4" Plates-
120 Tons)
Wide Gap Spark Chambers
(2 x 2"Gaps)
Counter
Hodoscopes
(14" Segments)

Fig. 4

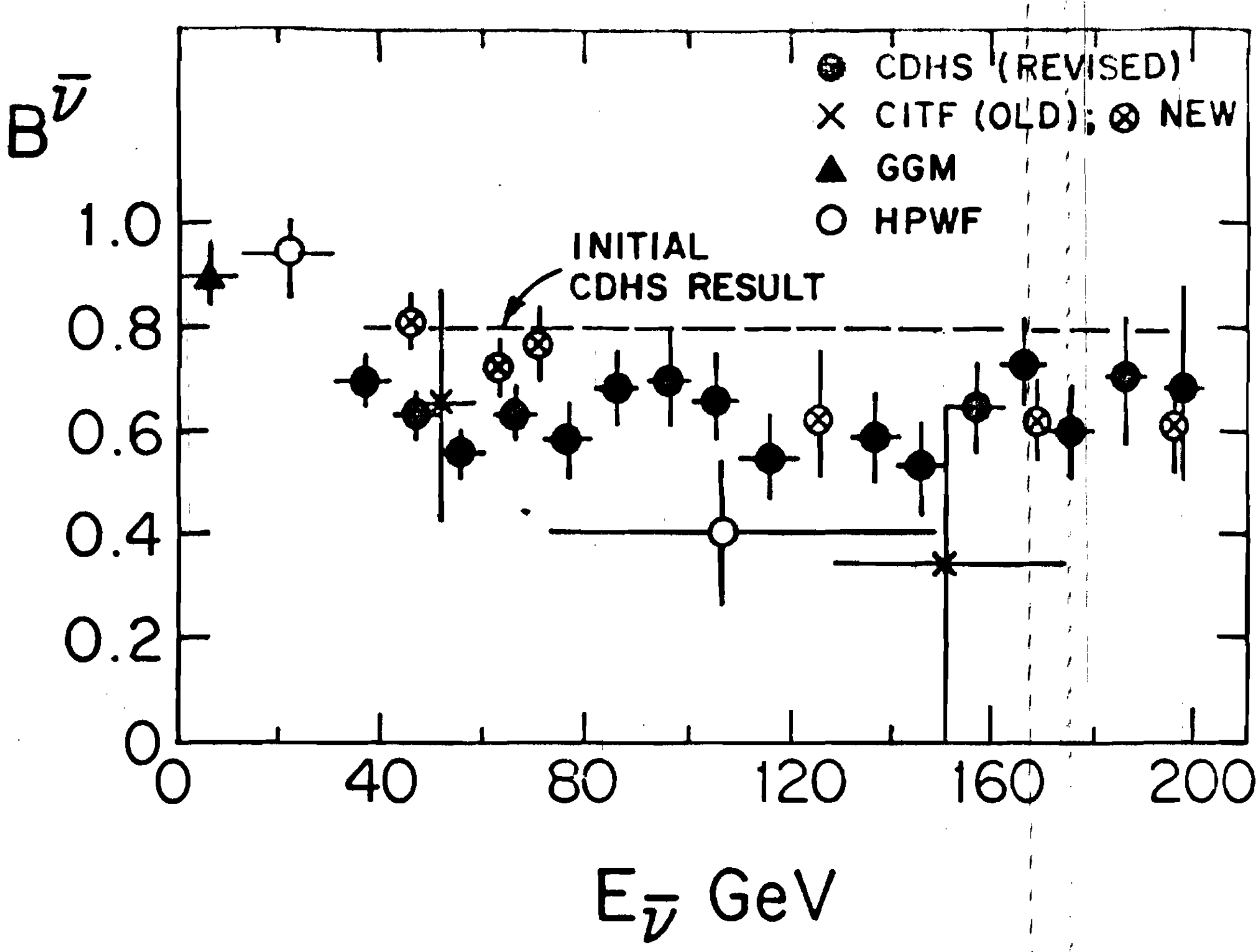


Fig. 5 Plot of $B^{\bar{\nu}} = -\int x F_3(x)dx / \int F_2(x)dx$ against antineutrino energy, showing data from three high energy ionization calorimeter experiments and a datum from Gargamelle. The HPWF data are from reference 2; the "old" CITF data are from PRL 38, 314 (1977); the "new" CITF data from F. Sciulli, talk at Int'l Symp. on Lepton and Photon Interactions at High Energies, Hamburg, 1977; the Gargamelle point is from reference 6. The initial CDHS data points [given in PRL 39, 433 (1977)] were centered about the dashed line marked INITIAL CDHS RESULT. The "revised" CDHS data points have been located by translating the original data so as to coincide with the values of $\langle y \rangle^{\bar{\nu}} = 0.35 \pm 0.01$ and $\sigma^{\bar{\nu}}/\sigma^{\nu} = 0.50 \pm 0.05$, presented by J. Steinberger at the Irvine Conference, December, 1977. This translation is also based on the statement at Irvine that the "revised" CDHS data show no dependence on $E_{\bar{\nu}}$.

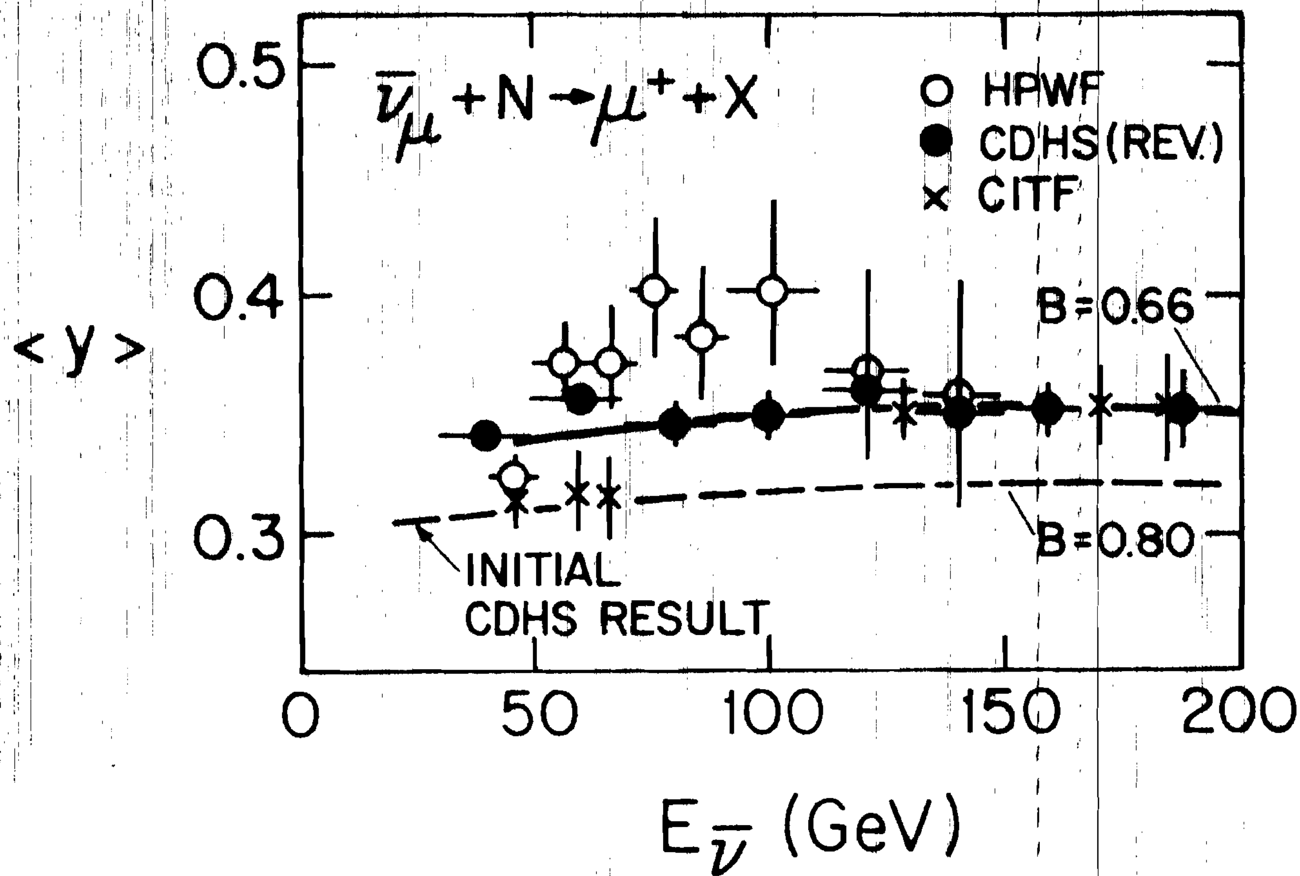


Fig. 6 Plot of average y for antineutrinos against antineutrino energy. Explanation given in the caption of Fig. 1 applies here also.