Fermilab proposal # 599

Correspondent: Luke W. Mo

Tel: (703) 951-5423

Proposal

A Prompt Neutrino Experiment at Fermilab

Submitted by

A. Abashian, N.E. Booth, R.H. Heisterberg, L.W. Mo, and A. Skuja

University of Maryland, National Science Foundation, University of Oxford, and Virginia Polytechnic Institute and State University

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Abstract

We propose to do a "prompt" neutrino search experiment at Fermilab using the existing E-253 apparatus with minor additions. Using the D-decay as a guide to demonstrate the experimental feasibility, we believe that the proposed experiment is worthwhile pursuing. We request a running time of 1,000 hours at 400 GeV, 10^{13} protons/pulse, and a beam dump angle greater than 20 mr.

I. Introduction

It is intriguing to consider possible sources of neutrinos other than decays of secondary pions and kaons in pp collisions. These "prompt" neutrinos, if they exist, indicate production of new particles hitherto unobserved in hadronic reactions, or the presence of new mechanisms which have not been thought of.

In the first category, we may contemplate on pair production of charmed particles, or of heavy leptons. The neutrino decays of neutral vector bosons, such as ρ^o, ω^o, ϕ^o, $J/\psi \to \nu\bar{\nu}$, may be sources of "prompt" neutrinos. For definiteness we shall consider mainly pair production of charmed particles as a source of prompt neutrinos, making use of the $D(\bar{D})$ inclusive production cross section as a guide. In order to avoid the background due to the pion/kaon neutrinos, we shall agree that the best way to detect "prompt" neutrinos is to look for them at near 90^o in the center of mass system. We will demonstrate that the counting rate and the signal-to-background ratio are reasonable enough as to make the detection of prompt neutrinos feasible with the existing apparatus of E-253.

We should state here that, about one year ago, the late Professor Benjamin W. Lee was deeply interested in doing this experiment himself. He made most of the calculations and discussed the experiment with us many times. The proposal was drafted but not submitted then because of the scheduling of E-253 and the involvement of doing it at near 90^o in the center-of-mass system. Recently, CERN has generated a great deal of excitment by their 0^o beam-dump experiment, in which the charm production cross section is estimated to be bigger than ~100 μb if the "prompt" neutrinos they observed were due to charm decays. Also, W. Fry, et al, have presented a new "prompt" neutrino proposal to Fermilab for consideration. We believe that it is appropriate now for us to submit this proposal because we have the most suitable apparatus for experiments of this kind.

II. Estimate of Rate and Background

Bourquin and Gaillard (BG) have chosen the overall normalization of $D(\bar{D})$ inclusive production so as to account for the ratio $\ell/\pi \simeq 10^{-4}$ for $p_\perp \gtrsim 0.5$ GeV/c at 90° in CM system, when this source of prompt muons (electrons) is added to other known particle sources such as ρ, ω, ϕ, J/ψ, $K\bar{K}$, etc. Since other mechanisms for high-$p_\perp$ lepton production, such as the models proposed by Drell and Yan, Bjorken and Weisberg, Farrar and Frautschi, may very well be operating, the BG estimate can be considered as an upper limit. With this caveat, we proceed to use their estimate at face value.

Let us suppose that the neutrino detector is placed behind a beam dump along the incident proton direction. The probability for a pion decaying within the first few interaction lengths is approximately

$$P = \frac{\lambda}{\gamma_\pi c\tau_\pi} \simeq 0.02/\gamma_\pi \qquad \text{(in Fe)}$$

where λ is the absorption length in the beam dump which is assumed to be steel, and $\gamma_\pi \equiv E_\pi/m_\pi$. According to BG, the inclusive D production cross section is about 10 μb at Fermilab energies, so that the signal-to-(noise)$_\pi$ ratio is

$$\frac{\text{Signal}}{(\text{Noise})_\pi} \simeq \frac{10\mu\text{b x } 15\%}{<n_\pi>\text{x } 30 \text{ mb x } P} \simeq 1 \times 10^{-3}\ (\bar{E}_\pi/m_\pi)$$

where $\bar{E}_\pi$ is the average secondary pion energy; and $<n_\pi>$, the charged pion multiplicity which we take to be ~6. With a reasonable $\overline{E}_\pi$, the signal-to-(noise)$_\pi$ ratio is ~10%, which is a situation quite tolerable. However the major background is from the kaon decays.

Consider now that the detector is placed at 71 mr from the incident proton beam direction, which corresponds to ~90° in the C.M. system. The cross section for the reaction

$$p + p \to D + \text{----}$$
$$\quad\quad\quad\quad \hookrightarrow \overline{K} + e + \nu$$

can be parametrized, by assuming $(\frac{\nu}{\pi}) \simeq (\frac{e}{\pi}) \simeq 10^{-4}$ and is energy-independent, as

$$\left(\frac{d^3\sigma}{dydp_\perp d\phi}\right)^{(\text{prompt } \nu)}_{y_{C.M.}=0} \simeq \left(\frac{p_\nu}{GeV}\right) e^{-7(p^*_\nu-0.5)/GeV} \times 10^{-30}\ cm^2/GeV/rad$$

for $p^*_\nu = p_\perp \gtrsim 0.5$ GeV/c. The cross section for the background neutrinos from pion decays in the same kinematical region can be estimated as follows:

$$\left(\frac{d^3\sigma}{dydp_\perp d\phi}\right)^{(\nu_\pi)}_{y_{C.M.}=0} \simeq \frac{\lambda}{c\tau_\pi} \left(\frac{m_\pi}{14E^*_\pi}\right) \left(\frac{d^3\sigma}{dydp'_\perp d\phi}\right)^{(\pi)}_{y_{C.M.}=0}$$

$$\simeq 2 \times 10^{-4} \left(\frac{d^3\sigma}{dyd^2p'_\perp}\right)^{(\pi)}_{y_{C.M.}=0}$$

where $p'_\perp = p^*_\pi \simeq 2p_\perp$. A similar expression can also be written for the neutrinos from K-decay with $\sigma_{in}(K) \simeq 9\% \times \sigma_{in}(\pi^-)$. The spectra of neutrinos from the D-meson decays, π^- meson decays, and K meson decays are plotted in Figure 1. It can be seen that the experiment should be performed at $p_\perp \gtrsim 1$ GeV/c to overcome the background from K decays. Of course, if the CERN observation turns out to be correct, then the background due to K decays should not cause any problem.

The flux of the prompt neutrinos in the direction of 71 mr in the laboratory is given by

$$F_\nu(E_\nu) = F_p \rho L \left(\frac{d^3\sigma}{dy\,dp_\perp d\phi}\right)^{(\text{prompt } \nu)}_{y_{C.M.}=0} \Delta y\ \Delta\phi$$

where we have assumed the inclusive D-production cross sections on nuclei scale as A; E_ν is the neutrino energy:

$$E_\nu \simeq 14 p_\perp ;$$

F_p is the incident proton flux which we will take to be 10^{13} per pulse; ρ is the beam dump target density; L is the target length, which is taken to be approximately one absorption length. Then

$$F_p \rho L = 10^{13} \times 7.87 \times 6 \times 10^{23} \times 17.1 \simeq 10^{39}\ \text{cm}^{-2}/\text{pulse}$$

and

$$F_\nu(E_\nu) \simeq \left(\frac{E_\nu}{\text{GeV}}\right) e^{-(E_\nu - 7)/(2\text{GeV})} \Delta y\ \Delta\phi \times 10^8\ (\text{GeV})^{-1}$$

for $E_\nu \gtrsim 7$ GeV.

To estimate the event rate, we use the neutrino detector of E253 at Fermilab, approximately 1 m x 1 m x 5 m of aluminum, located 500 m away from the proton beam dump as suggested by W. Fry et al. Then the event rate per pulse, R, is given by

$$R = \int_7^\infty dE_\nu \, F_\nu(E_\nu) \times (10^{-38} E_\nu) \, (2.7 \times 500 \times 6 \times 10^{23})$$

$$\simeq 10^{-4} \text{ events}/10^{13} \text{ protons} \quad .$$

where we have used $\Delta y \simeq \Delta\theta/\sin\theta$; and $\Delta\theta \simeq 0.002$, $\theta = 0.71$, and $\Delta\phi \simeq 0.028$.

Thus we expect to detect about one ν_μ interaction giving a final state muon every 24 hours in the E-253 detector. From the D-decay process we expect a similar number of final state electrons. The CERN beam dump experiment in BEBC indicated that the number of final state electrons is about the same as the final state muons. It also indicated that this calculation underestimates the experimental rates by about a factor of ~10.

For practical reasons it may only be feasible to use a smaller beam dump angle, perhaps at most 20 mr. This gives an increase in rate by a factor ~10 due to the $1/\theta^2$ from the $\Delta y \Delta\phi$ factors for both D-decay and K-decay neutrinos, and an additional increase in the K-decay background due to its smaller mass and steeper $p_\perp$ dependence. In either case our detector is well suited to observe these events.

III. The Detector

The detector we propose to use for this "prompt" neutrino experiment is the same one we are currently using for E-253 in the Wonder Building. It is shown schematically in Figure 2. It has been demonstrated experimentally that this apparatus can detect muons with high efficiency and can measure the direction of energy flow of electromagnetic showers with good angular resolution.

Basically the detector consists of 48 MWPC's interlaced with ~1 r.l. thick aluminum plate and plastic scintillators. The exact size of the aluminum plates in each module is 42" x 42" x 9.2 cm. In each MWPC, the two cathode planes are equipped with delay-lines, of spacing 16 wires per inch, to measure the x- and y-coordinates of particles going through. The anode planes are used for individual pulse-height analysis and also for forming the experimental trigger. During October and November, 1977, E-253 had a short period of data-taking while the Main Ring was operating at 300 GeV. With 7×10^{17} 300 GeV protons on the target, we collected approximately 12,000 triggers on tape. Approximately 10% of these triggers are good neutral current events. We may anticipate to see ~20 $\nu_\mu e$ elastic scattering events. We are quite happy to see that the detector performs exactly as designed. It can identify muons and electromagnetic showers in a beautiful manner. The setup, one muon event, and one E.M. shower event are shown in Figures 3 through 5.

During the first shut-down period of Fermilab in 1978, the following major improvements will be made to our detector:

1. Muon spoilers, made of 6' dia. toroids and total length 32', will be installed at the end of the decay pipe to kill all the undesirable muons in the Wonder building. This background has prevented us from taking data at 400 GeV.
2. Scintillation counters, made of plastic NE 114, will be added to each MWPC module. This will tighten the time resolution from the current 100 nsec to ~15 nsec. Also, we will use them to form another set of triggers and pulse-height measurements, independent of the MWPC's. The counter installation work has already started.
3. A magnet will be installed behind the hadron shield to provide

momentum measurement of the muons. (The exact size of the magnet is still under negotiation with Fermilab).

IV. The Proposal

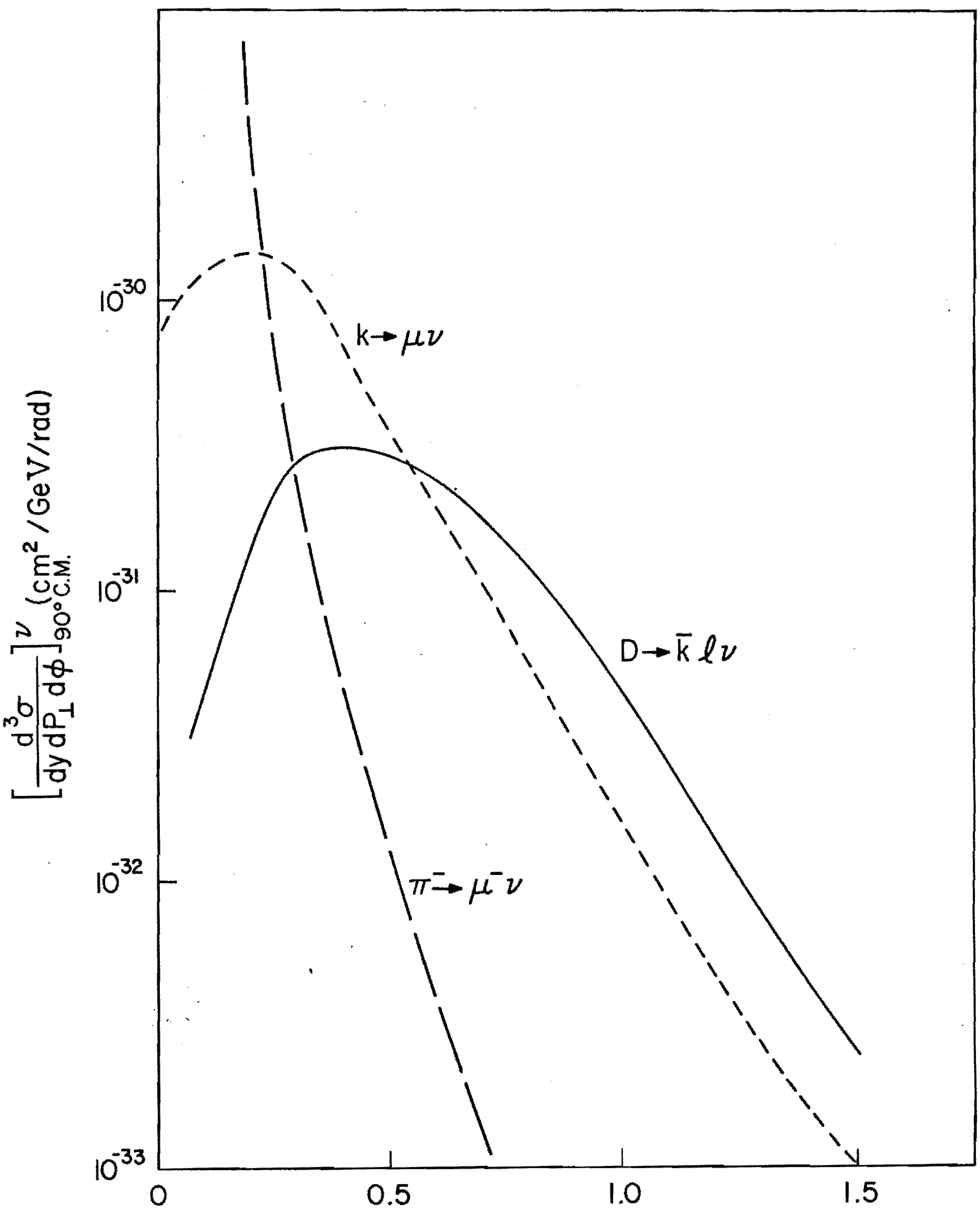
We propose to pursue the "Prompt" neutrino search experiment with the E-253 apparatus. Specifically, we have the following requests:

1. 1,000 hours of running time at 10^{13} protons per pulse;
2. Fermilab should construct a proton beam dump at the end of the present decay tunnel, very much like the design proposed by W. Fry et al;
3. We want to run the experiment near 90° in the C.M. system, where the background is the lowest. For 400 GeV protons, this dumping angle with respect to our apparatus is ~71 mr in the laboratory. Whether this can be achieved or not depends on the detailed construction plan of Fermilab. It is our strong opinion that at least we should be able to dump the 400 GeV proton beam at an angle greater than 20 mr;
4. We need an iron magnet behind the hadron shield to measure the momenta of the muons. We hope this magnet can be installed as soon as possible, because it is also needed to do the flux normalization for E-253 by monitoring the charged current events.

Finally, we would like to remark that with the high beam intensity and high $p_{\perp}$ values which can be reached at Fermilab, the neutrino beam dump experiments should provide exciting opportunities to search for new physics phenomena. By proper planning and coordination, all the existing neutrino detectors at Fermilab should be able to run simultaneously.

Figure Captions

Figure 1	Neutrino spectra from D-meson decays, π^- decays, and K decays in the proton beam dump as a function of the neutrino transverse momentum.
Figure 2	Schematic diagram of the present E-253 apparatus.
Figure 3	Photograph of part of the E-253 apparatus.
Figure 4	A muon track registered in the E-253 detector. The beam goes from left to right. The upper two pictures show the x- and y-view of the muon track. The bottom picture indicates the pulse height measured by each chamber. Numbers on the horizontal axis label the chambers.
Figure 5	An electromagnetic shower detected in the E-253 apparatus.



$\left[\frac{d^3\sigma}{dy\,dP_\perp d\phi}\right]^{\nu}_{90° C.M.}$ (cm² /GeV/rad)
10^{-30}
10^{-31}
10^{-32}
10^{-33}
$k \rightarrow \mu\nu$
$D \rightarrow \bar{k}\ell\nu$
$\pi^- \rightarrow \mu^-\nu$
0
0.5
1.0
1.5
$P_\perp$ (GeV/c)

Figure 1

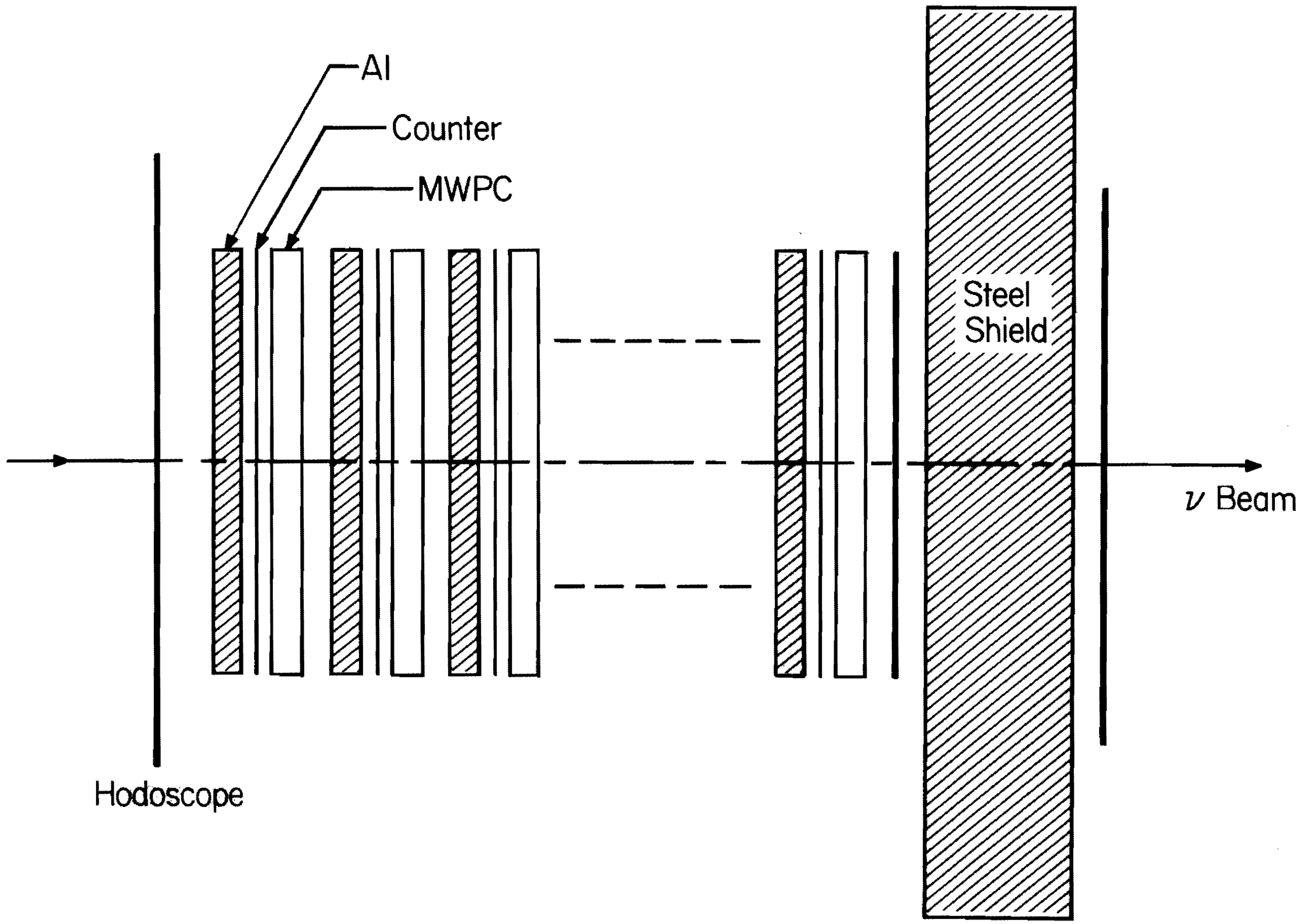


Figure 2

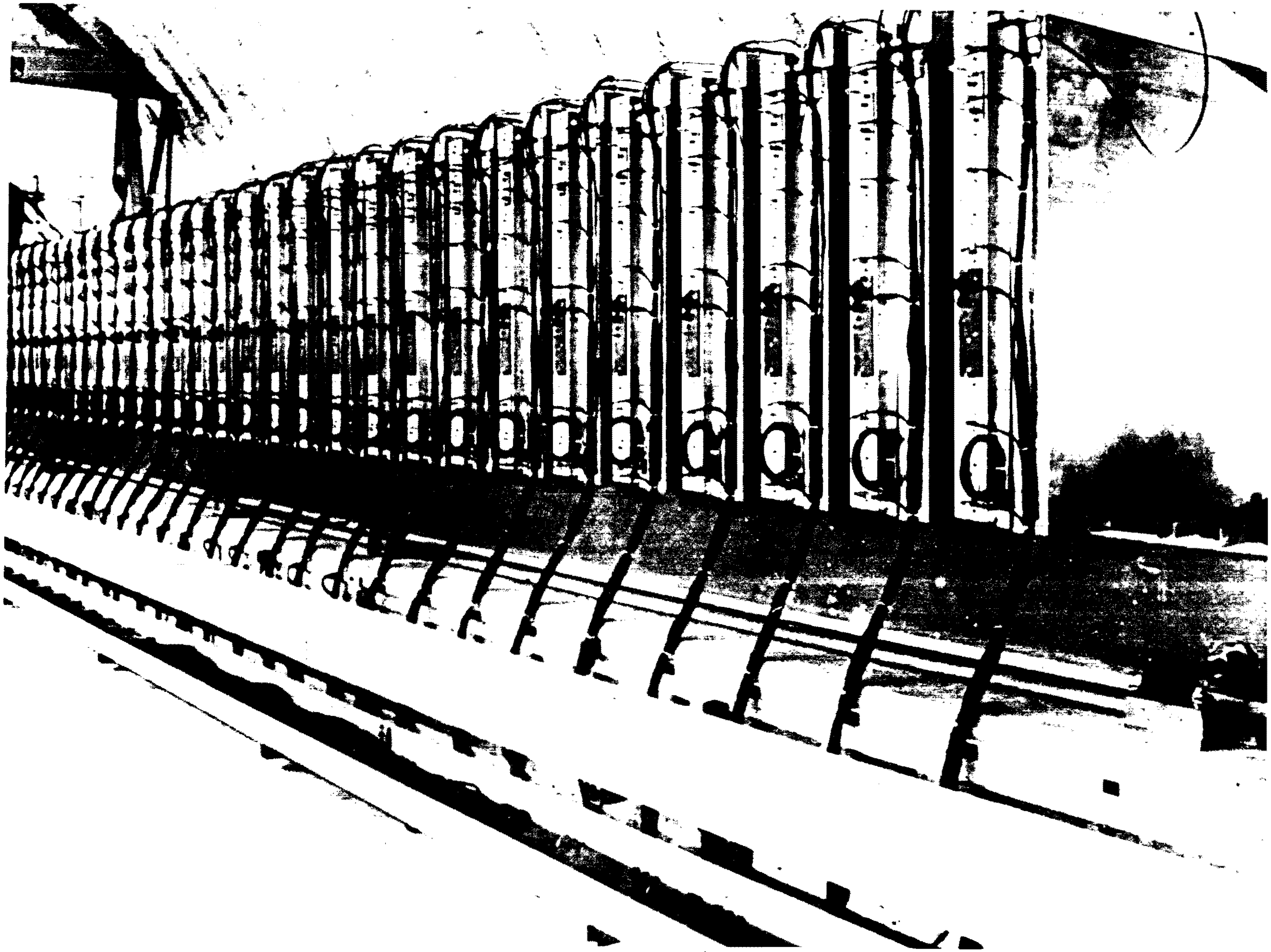
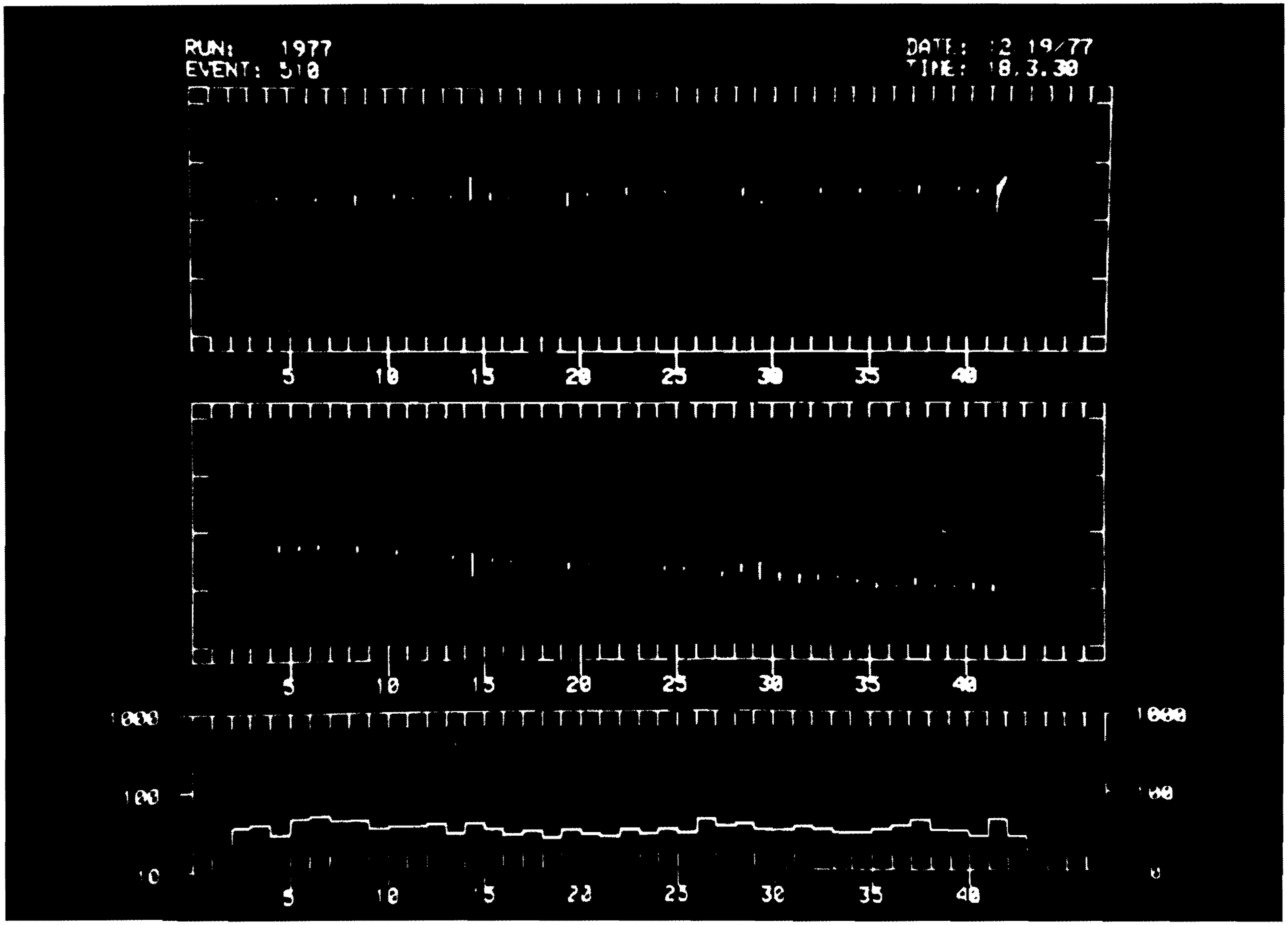


Figure 3



RUN: 1977
EVENT: 510
DATE: 12 19/77
TIME: 18.3.30
5
10
15
20
25
30
35
40
1000
100
10

Figure 4

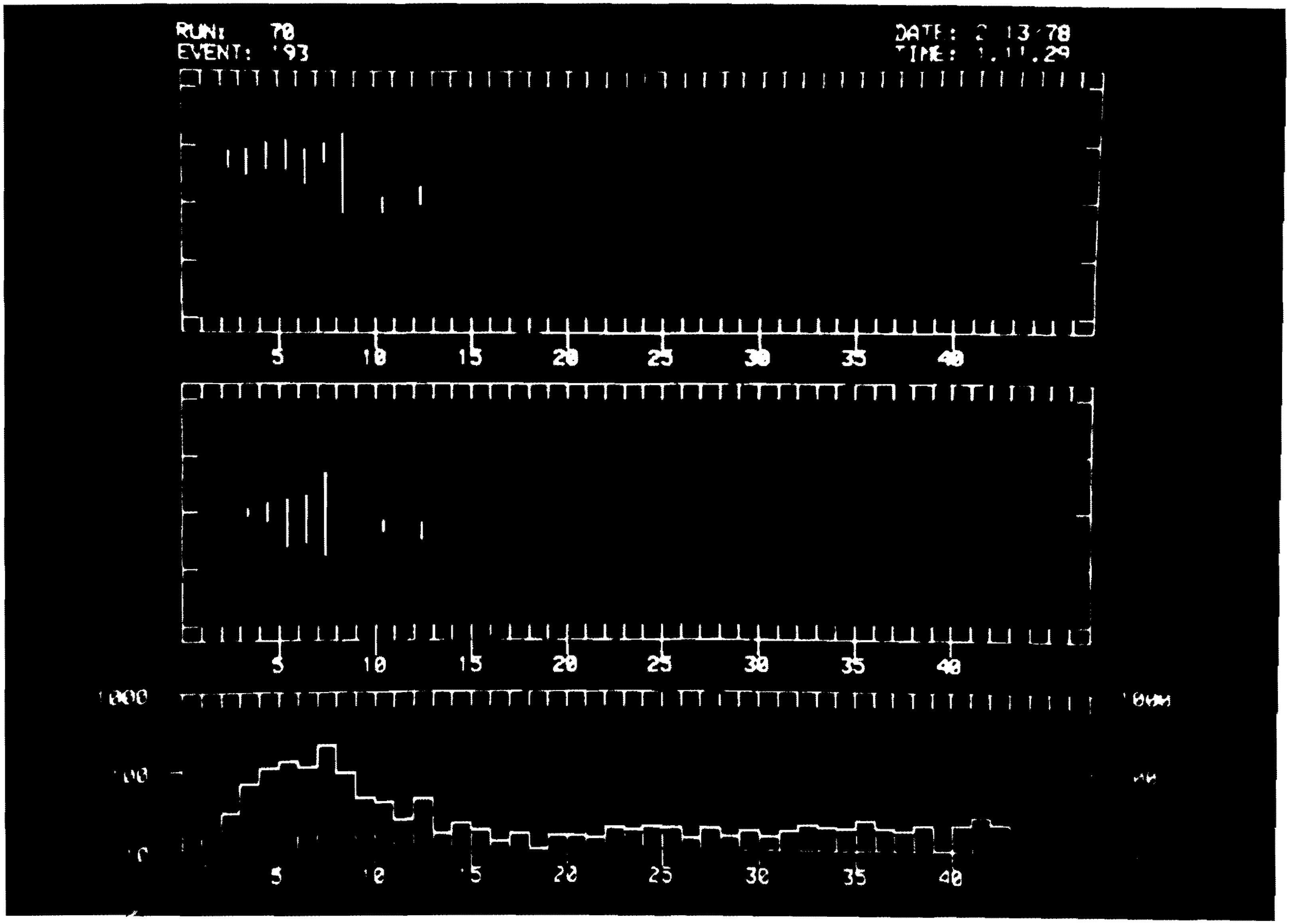


Figure 5

ADDENDUM TO P-599

Upon careful consideration, it gradually became clear to us that our proposed experiment on the search for prompt neutrinos should not be carried out in the present location of E-253, the Wonder Building. Instead, we are convinced that the M2 beam line of the Meson Laboratory is a good place to perform the proposed experiment properly. The reasons are the following:

I. Event Rate

In M2, the E-253 detector can be placed ~40 to 50 m from the beam dump target. In the Wonder Building, the corresponding distance is ~500 m. The M2 beam presently runs at 0.7×10^{12} protons per pulse. It appears that $2\text{-}5 \times 10^{12}$ is feasible without causing a radiation safety problem. Thus, we lose a factor of 4 to 10 in beam intensity, as compared to the Neutrino Area, but we gain a factor of ~100 in solid angle. The net gain in event rate is approximately a factor of 10, which will give ~1 event/hour assuming a 10 μb production cross section.

II. Production Angle

It is most desirable to measure the prompt neutrinos at 90° in the C.M. system where the background is minimum. For 400 GeV protons, this angle in the laboratory is approximately 71 mr. Such an angle is "too large" to produce in the present neutrino beam line. However, we can almost position our apparatus at any angle we want in the M2 beam line. This offers a great advantage in studying the production mechanism of a possibly new phenomenon.

III. Analysis Magnet

In the M2 beam line there will be space for us to install an analysis magnet of moderate size which is essential to the measurement of final state muons. In the Wonder Building this is now very difficult due to space limitations.

Since our main interest in physics is still E-253, the neutrino-electron scattering, we wish to take as much data as possible and as soon as possible on E-253. We want to run P-599 only during the period when E-253 cannot take data adequately (as during the dichromatic run in the Spring of 1979). This will involve the moving of apparatus back and forth between the Meson Laboratory and the Neutrino Laboratory. We do not regard this as a problem. During the period of March 27 to April 10, 1978, we moved 20% of our apparatus to the M5 beam line of the Meson Laboratory to carry out an energy calibration run. It took altogether 17 days to set up the apparatus and to complete the calibration run. We believe that we can put our apparatus into operational condition in the Meson Laboratory within a period of three weeks. This can be achieved by the following preparation work:

(1) New Cables

An identical set of new cables can be laid out first in the Meson Laboratory. This will constitute the major portion of the setup work. The old set of cables can be left untouched in the Wonder Building to allow a quick recovery in moving back to take more E-253 data.

(2) New Detector Stand

A new detector stand is needed in the Meson Laboratory. T. E. Toohig has informed us that an old stand is available which is even rotatable.

(3) Analysis Magnet

An analysis magnet is required to measure the final state muons. We prefer to have an iron core dipole magnet of active area ~2m x 2m to match our drift chambers which are under construction.

(4) New Target Steel

The present target material of E-253 is made of 50 layers of aluminum plates, 1 r.l. thick each. In the Meson Laboratory we would use 100 steel plates, approximately 1½ r.l thick, a total of 20 tons.

(5) Beam Dump

We need a copper beam dump. If time permits, we may want to change the dump material to allow an A-dependence study.

We believe that the M2 beam line offers a better option for performing the proposed prompt neutrino experiment, P-599. By combining the apparatus of E-253 and the flexibility of the M2 area, we anticipate an exciting physics outcome.

#599 - Revised

Correspondent: Luke W. Mo
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Proposal

A Prompt Neutrino Experiment in the Meson Laboratory of Fermilab

Submitted by

A. Abashian, N.E. Booth, R.H. Heisterberg, L.W. Mo, A. Skuja and T. Toohig

Fermilab, University of Maryland, National Science Foundation, University of Oxford, and Virginia Polytechnic Institute and State University

October 1978

Abstract

We propose to do a "prompt" neutrino search experiment in the M2 beam-line of the Meson Laboratory at Fermilab using the existing E-253 apparatus with the addition of an iron magnet and drift chambers for muon detection. Using the D-decay as a guide to demonstrate the experimental feasibility, we believe that the proposed experiment is worthwhile pursuing. Our equipment has the unique capability of detecting both electrons and muons in the final state. We request a running time of 1,000 hours at 400 GeV, 10^{12} protons/pulse, and a beam dump angle greater than 18 mr.

I. Introduction

It is intriguing to consider possible sources of neutrinos other than decays of secondary pions and kaons in pp collisions. These "prompt" neutrinos, if they exist, indicate production of new particles hitherto unobserved in hadronic reactions, or the presence of new mechanisms which have not been thought of.

In the first category, we may contemplate pair production of charmed particles, or of heavy leptons. The neutrino decays of neutral vector bosons, such as ρ°, ω°, ϕ°, $J/\psi \rightarrow \nu\bar{\nu}$, may be sources of "prompt" neutrinos. For definiteness we shall consider mainly pair production of charmed particles as a source of prompt neutrinos, making use of the $D(\bar{D})$ inclusive production cross section as a guide. In order to avoid the background due to the pion/kaon neutrinos, we shall agree that the best way to detect "prompt" neutrinos is to look for them at near 90° in the center of mass sytem. We will demonstrate that the counting rate and the signal-to-background ratio are reasonable enough to make the detection of prompt neutrinos feasible with the existing apparatus of E-253.

We should state here that, about one year ago, the late Professor Benjamin W. Lee was deeply interested in doing this experiment himself. He made most of the calculations and discussed the experiment with us many times. The proposal was drafted but not submitted then because of the scheduling of E-253 and the involvement of doing it at near 90° in the center-of-mass system. Recently, CERN has generated a great deal of excitement by their neutrino beam-dump experiment, in which the charm production cross section is estimated to be of the order of 40 μb if the "prompt" neutrinos they observed were due to charm decays. Also, the CDHS collaboration has indicated that their result is consistent with interactions of electron neutrinos from charm decay. We believe that this subject is worthwhile for further study at Fermilab and that we have the most suitable apparatus for experiments of this kind. Specifically, we have excellent capabilities in distinguishing electrons from hadrons and muons.

II. Estimate of Rate and Background

Bourquin and Gaillard (BG) have chosen the overall normalization of $D(\bar{D})$ inclusive production so as to account for the ratio $\ell/\pi \simeq 10^{-4}$ for $p \geq 0.5$ GeV/c at 90° in CM system, when this source of prompt muons (electrons) is added to other known particle sources such as ρ, ω, ϕ, J/ψ, $K\bar{K}$, etc. Since other mechanisms for high-p lepton production, such as the models proposed by Drell and Yan, Bjorken and Weisberg, Farrar and Frautschi, may very well be operating, the BG estimate can be considered as an upper limit. With this caveat, we proceed to use their estimate at face value.

Let us suppose that the neutrino detector is placed behind a beam dump along the incident proton direction. The probability for a pion decaying within the first few interaction lengths is approximately

$$p = \frac{\lambda}{\gamma_\pi c\tau_\pi} \simeq 0.02/\gamma_\pi \qquad \text{(in Fe)}$$

where λ is the absorption length in the beam dump which is assumed to be steel, and $\gamma_\pi \equiv E_\pi/m_\pi$. According to BG, the inclusive D production cross section is about 10 μb at Fermilab energies, so that the signal-to-$(\text{noise})_\pi$ ratio is

$$\frac{\text{Signal}}{(\text{Noise})_\pi} \simeq \frac{10\mu b \times 10\%}{\langle n_\pi \rangle \times 30 \text{ mb} \times p} \simeq 1\times10^{13} \; (\bar{E}_\pi / m_\pi)$$

where $\bar{E}_\pi$ is the average secondary pion energy; and $\langle n_\pi \rangle$, the charged pion multiplicity which we take to be ~6. With a reasonable $\bar{E}_\pi$, the signal-to-(noise)$_\pi$ ratio is ~10%, which is a situation quite tolerable. However the major background is from the kaon decays.

Consider now that the detector is placed at 71 mr from the incident proton beam direction, which corresponds to ~90° in the C.M. system. The cross section for the reaction

$$p + p \rightarrow D + \cdots\cdots$$
$$\quad D \longrightarrow \bar{K} + e + \nu$$

can be parametrized, by assuming $(\frac{\nu}{\pi}) \simeq (\frac{e}{\pi}) \simeq 10^{-4}$ and is energy-independent, as

$$\left(\frac{d^3\sigma}{dy dp_\perp d\phi}\right)^{(\text{prompt})}_{y_{C.M.}=0} \simeq \left(\frac{p_\nu}{\text{GeV}}\right) e^{-7(p_\nu^* - 0.5)/\text{GeV}} \times 10^{-30} \text{ cm}^2/\text{GeV/rad}$$

for $p_\nu^* = p_\perp \geq 0.5$ GeV/c. The cross section for the background neutrinos from pion decays in the same kinematical region can be estimated as follows

$$\left(\frac{d^3\phi}{dy dp_\perp d\phi}\right)^{(\nu_\pi)}_{y_{C.M.}=0} \simeq \frac{\lambda}{c\tau_\pi} \left(\frac{m_\pi}{14E_\pi^*}\right) \left(\frac{d^3\sigma}{dy dp'_\perp d\phi}\right)^{(\pi)}_{y_{C.M.}=0}$$

$$\simeq 2\times10^{-4} \left(\frac{d^3\sigma}{dy d^2p'_\perp}\right)^{(\pi)}_{y_{C.M.}=0}$$

where $p_\perp' = p_\pi^* \simeq 2p$. A similar expression can also be written for the neutrinos from K-decay with $\sigma_{in}(K) \simeq 9\% \times \sigma_{in}(\pi^-)$. The spectra of neutrinos from the D-meson decays, π^- meson decays, and K meson decays are plotted in Figure 1. It can be seen that the experiment should be performed at $p_\perp \gtrsim 1$ GeV/c to overcome the background from K decays. Of course, if the CERN observation turns out to be correct, then the ν flux due to D decay should be a factor of ~4 higher than that shown in Figure 1.

The flux of the prompt neutrinos in the direction of 71 mr in the laboratory is given by

$$F_\nu(E_\nu) = F_p \rho L \left(\frac{d^3\sigma}{dy dp_\perp d\phi}\right)^{(prompt)}_{y_{C.M.}=0} \Delta y\ \Delta\phi$$

where we have assumed the inclusive D-production cross sections on nuclei scale as A^1; E_ν is the neutrino energy:

$$E_\nu \simeq 14 p_\perp ;$$

F_p is the incident proton flux which we will take to be 10^{12} per pulse; ρ is the beam dump target density; L is the target length, which is taken to be approximately one absorption length. Then

$$F_p \rho L = 10^{12} \times 7.87 \times 6 \times 10^{23} \times 17.1 \simeq 10^{38}\ \text{cm}^{-2}/\text{pulse}$$

and

$$F_\nu(E_\nu) \simeq \left(\frac{E_\nu}{\text{GeV}}\right) e^{-(E_\nu-7)/(2\ \text{GeV})} \Delta y\ \Delta\phi \times 10^6\ (\text{GeV})^{-1}$$

for $E_\nu \gtrsim 7$ GeV.

To estimate the event rate, we use the neutrino detector of E-253 at Fermilab, approximately 1 m x 1 m x 5 m of aluminum, located 50 m away from a proton beam dump in the M2 beam line to be described later. The event rate per pulse, R, is given by

$$R = \int_{7\ \mathrm{GeV}}^{\infty} dE_\nu F_\nu(E_\nu) \times 6\mathrm{x}10^{23} \times (10^{-38} E_\nu\ \mathrm{cm}^2)$$

$$\times\ (2.7\ \mathrm{gram/cm}^3) \times 500\ \mathrm{cm} \simeq 2\mathrm{x}10^{-3}\ \mathrm{events/pulse}$$

where we have used $\Delta y \simeq \Delta\theta/\sin\theta$; and $\Delta\theta = 0.02$, $0 = 0.071$, and $\Delta\phi \simeq 0.28$.

Thus we expect to detect about one ν_μ interaction giving one final state muon every hour in the E-253 detector. From the D-decay process we expect a similar number of final state electrons. The CERN beam dump experiment in BEBC indicated that the number of final state electrons is about the same as the final state muons. It also indicated that this calculation under-estimates the experimental rates by about a factor of ~10.

III. Experimental Layout

We propose to perform a measurement of prompt neutrino production in the M2 beam line of the Meson Laboratory. The M2 400 GeV proton beam will be dumped in the Meson Laboratory specifically using a copper beam dump. The beam dump will be surrounded by adequate shielding to meet radiation safety requirements as well as to minimize muon backgrounds. The neutrino detector will be located 50 m behind the beam dump, sitting at 9 mr to the M2 zero degree line. The neutrino detector will be the E-253 detector augmented by an iron core dipole and drift chambers, for the detection of final state muons.

a. The Beam

The M2 400 GeV proton beam at intensities of $1\text{-}3\times10^{12}$ protons/pulse will be used. An additional dipole will be added to the M2 line just upstream of the beam dump to allow the beam targeting angle to be varied between ±9 mr. This new feature of the beam will allow us to take data at 0°, 9 mr and 18 mr, for instance, by steering the proton beam rather than moving the detectors. For data taking at larger angles, such as 71 mr, the detector will have to be moved. By the experience we have already acquired, it can be carried out without undue effort.

Two calibrated SEMS will have to be placed in the beam line with associated readout electronics to provide a measurement of the incident proton intensity.

b. The Beam Dump

We propose to use a beam dump made of copper blocks, 3 m in length (~20 absorption length) and 1'x1' in cross section. They can be stacked with 2" thick copper plates. This will allow us to check the contributions of the conventional neutrinos to the event rate simply by segmenting the beam dump.

c. The Detector

The detector we propose to use for this "prompt" neutrino experiment is the same one we are currently using for E-253 (ν_μe scattering) in the Wonder Building. It is shown schematically in Figure 2.

Basically the detector consists of 49 MWPC's interlaced with 1 r.l. thick aluminum plate and plastic scintillators. The exact size of the aluminum plates in each module is 42" x 42" x 9.2 cm. In each MWPC, the two cathode planes are equipped with delay-lines, of spacing 16 wires per inch, to measure the x- and y-coordinates of particles going through. The anode planes are used for individual pulse-height analysis and also for forming the experimental trigger. Scintillation counters, made of plastic NE114, placed between each MWPC module are also used to measure the energy deposition by individual pulse height analysis, as well as to form part of trigger requirement, independent of the MWPC's. They also tighten up the time resolution of the system.

During October and November of 1977, E-253 enjoyed a short running period with the main ring operating at 300 GeV. During that period we were able to confirm that the detector performed as designed. It demonstrated experimentally that our detector can identify electrons, muons, and hadrons quite unambiguously. Also it can measure the directions of the electromagnetic showers with good angular resolution. These goals are achieved because the apparatus is a fine track-measuring device; as well as being a fine grained shower detector which measures the energy in steps of every r.l. along the beam direction. Figure 3 shows a muon track in the apparatus. Figure 4 shows an EM shower. Figure 5 shows the angular resolution of measuring electrons. Figure 6 shows the pulse height spectra in 10 consecutive modules of our apparatus, induced by electrons and pions of the same energy, 10 GeV. They vividly illustrate how well we can do in particle identifications.

The present E-253 detector does not have an analysis magnet for the muons. In order to do the beam dump experiment properly, it is imperative to have a simple iron magnet, followed by a set of drift-chambers (2m x 2m in size) for the muon measurement. With this addition, we can measure the inclusive reactions of both ν_μ's and ν_e's originating from new sources. Therefore, we propose to change the detector arrangement to the configuration as shown in Figure 7. The function of each individual component is described briefly below:

1. Hodoscopes

   Hodoscope A is used to veto the muons. The downstream hodoscopes, B, C, and D, are used to measure the muons due to neutrino interactions.

2. MWPC and Scintillation Calorimeter

   This assembly is used as a fine-grained calorimeter as well as a track-measuring device in the same fashion as that in E-253. We propose to replace the E-253 standard module of Al-Scintillator-MWPC by a module consisting of Fe-Scintillator-Fe-MWPC to increase the counting rate by a factor of ~2.

3. Hadron Absorber and Iron Magnet

   The calorimeter will be followed by a steel hadron absorber. This could be instrumented to provide coarse hadron calorimetry if funding permits. The hadron absorber will be followed by a 2m x 2m iron dipole sandwiched between two sets of 6 drift chamber planes, also of

2m x 2m dimensions. The drift chambers are presently under construction. The iron dipole and drift chamber will be used to measure the energy of muons produced in neutrino interactions in the detector.

We should also add that:

1. It is preferred to mount the detector on a movable stand to allow a larger range of angles accessible, if results warrant it. We understand that a stand suitable for this purpose exists in the Meson Laboratory.
2. We plan to modify the delay-line readout electronics for the MWPC's, if funds permit, for the purpose of allowing the detection of multiple showers at each tap point (10 taps for each MWPC). This modification will make our detector truly powerful for doing the prompt neutrino experiment. The new electronics is already under development.

IV. Shielding and Muon Background

Muons from pion delay as well as "directly" produced muons from the beam dump could produce difficulty if no precautions were taken. Fortunately, two explicit measurements of the muon background have been made in the M2 beam line. One behind the E-439 apparatus by the E-439 collaboration, and the second behind the E-8 hyperon magnet by a University of Michigan group.

In Figure 8, we show the muon rate distribution as measured by E-439 in the M2 beam line with 400 GeV incident protons. Their experimental number has been scaled to 10^6 protons per pulse.

The number of muons increases away from the median plane because of a sweeping dipole magnet immediately after the beam dump. Using these numbers we calculate that we should expect $\sim 5\times10^5$ muons per 10^{12} protons in our apparatus, sitting at 18 mr, 40 m downstream of E-439.

However, using the measured muon flux of the University of Michigan group behind the E-8 hyperon magnet (20 feet of steel) an additional attenuation factor of 5 is observed so that only 10^5 muons / 10^{12} protons would be subtended by our apparatus.

We propose to add another 25 ft of steel just upstream of the hyperon magnet which further reduces the muon flux to an estimated 2×10^4 muons/10^2 protons on target.

Since the proposed experiment will run on slow spill, we expect no difficulty in vetoing triggers induced by this muon flux. In addition, the rate of 0.02 muons/μsec will cause no difficulty for our delay-line readout. Triggers due to muons can be vetoed easily to the level of 10^{-4} to 10^{-5}. The unvetoed muons will cause some triggers. We will record these events. Since the neutrino events can be unambiguously identified, these muon induced events can be completely rejected in the final data analysis using the information of tracks, timing, etc.

To absorb neutrons, that could contribute a fake neutrino rate, we require an additional 10 ft of concrete shielding immediately downstream of the hyperon magnet.

In addition to muon shielding in the forward direction, additional shielding around the target area will be needed for radiation safety requirements. We estimate that the shielding on either side of the target area should consist of 3 ft of steel, 6 ft of concrete (ρ = 2.4 gm(cm^3) and, 8 ft of PPA concrete (ρ = 3.76 gm/cm^3). Figure 9 shows the configuration of the proposed shielding arrangement.

V. Discussion on the Proposed Experiment

A. Charge Current and Neutral Current Interactions

The proposed prompt neutrino production experiment consists of the study of the following four reactions:

$$\nu_\mu + N \rightarrow \mu^- + \text{hadrons} \qquad (1)$$

$$\nu_e + N \rightarrow e^- + \text{hadrons} \qquad (2)$$

$$\nu_\mu + N \rightarrow \nu_\mu + \text{hadrons} \qquad (3)$$

$$\nu_e + N \rightarrow \nu_e + \text{hadrons} \qquad (4)$$

and their counterparts due to anti-neutrinos. We can clearly identify reaction of type (1) by measuring the final state muons. In addition, it is also clear that we cannot distinguish between the neutral current reactions (3) and (4). To separate reaction (2) from (3) and (4), we will rely on the fineness of our calorimeter - we sample pulse heights every radiation length. Charged current events, having electrons in the final state, will have large pulse heights in the first ~10 radiation lengths, irrespective of the electron energies. Neutral current events (type [3] and [4]), containing only hadrons and neutrinos in the final states, will generally have smaller pulse heights per radiation length. The difference in total energy deposited within the first 10 r.l., plus the dE/dx cuts one can make in the first 3 r.l. from the vertex, should allow a separation of pions from electrons to the level of 10^{-2}. The fact that the hadronic shower in the calorimeter normally extends far beyond 15 r.l. can help further the πe separation. We have this track information at our disposal. We also emphasize that the method we are using, in separating π's from e's by pulse height distributions, is a well-known technique, established a long time ago.

B. Triggers due to Conventional ν_μ's

The background due to neutrinos from pion and kaon decays as a function of p_t is shown in Figure 1 of our proposal. In estimating the prompt neutrino rate, we have used 10 μb as the $D\bar{D}$ production cross section, and 10% as the semi-leptonic decay branching ratio. This is quite conservative, because the CDHS experiment at CERN found that their data is consistent with a production cross section of 40 μb. The event rate we anticipate from the prompt neutrinos is ~4 per hour (one for detecting muons of each sign, and one for electrons). It will become 8 events/hour if the aluminum target in the E-253 detector is changed to steel plates as we proposed. The event rate due to pion and kaon neutrinos is about a factor of 3 less than that due to prompt neutrinos for $p_t \geq 0.5$ GeV/c (factor of 10 if using 40 μb as the $D\bar{D}$ production cross section instead of 10 μb). By performing the experiment at large angles we will be able to take advantage of the small background due to conventional neutrino sources, thus having to do only a 30% subtraction. We should also point out that the conventional neutrino rate can be easily measured with a segmented beam dump, if we wish.

C. More on the ν_e Interactions

We emphasize again that our detector has very fine granularity and thus a better capability than most of the experiments in identifying the electromagnetic showers. For example, we sample the shower in every r.l. of aluminum, while the CDHS experiment at CERN did it every 5 cm of steel (~3 r.l.). Therefore, we can study the ν_e interactions particularly well. During the past months, we have learned in great detail the characteristics of the longitudinal energy deposition of electrons and pions in our detector. As already described in (A) of this section, the CC events of ν_e interactions can be sorted out from the ν_μ NC event by their characteristics in energy distributions and longitudinal lengths. This separation is not expected to be complete, but we believe that we have a good chance of success, at least, for prompt ν_e's at the higher energy end of the spectrum. In CC interactions, the outgoing electron should carry most of the incident neutrino energy.

VI. The Proposal

We propose to pursue the "prompt" neutrino search experiment with the E-253 apparatus. The experimenter of this proposal will provide the E-253 MWPC's and scintillator planes for the neutrino detector, as well as scintillation counter hodoscopes for muon vetoing and tagging, and 12 planes of 2m x 2m drift chambers for the momentum analysis of final state muons. We request that Fermilab provide:

1. 1000 hours of running time with a minimum of 10^{12} protons/pulse in the M2 beam line of the Meson Laboratory;
2. A beam dump made of copper plates;
3. Shielding for the experiment to meet safety requirements as well as to reduce the muon backgrounds;
4. 100 steel plates, 42" x 42" x 1.76 cm in size, for the neutrino detector;
5. An iron shield behind the calorimeter, 2m x 2m x 1m in size;

6. A dipole iron magnet, 2m x 2m in cross section and 1 m in depth, for momentum analysis of the muons; and
7. A moveable stand for mounting our apparatus in the Meson Laboratory. We want to run the experiment initially at 9 and 18 mr. Later on, we would like to reposition the detector at an angle near 90° in the C.M. system, where the background is the lowest. For 400 GeV protons, this angle is ~71 mr in the laboratory.

Finally, we would like to remark that with the high beam intensity and high $p_\perp$ values which can be reached in the Meson Laboratory, the experiment we are proposing should provide exciting opportunities to search for new physics phenomena.

We should mention that a discussion has been initiated with physicists of the Institute of High Energy Physics at Peking on the possibility of collaboration on this proposal. If they agree upon the collaboration, we will report it to the Laboratory by a formal communication.

Figure Captions

Figure 1 Neutrino spectra from D-meson decays, π^- decays, and K decays in the proton beam dump as a function of the neutrino transverse momentum. The estimate is based on a $D\bar{D}$ production cross section of 10 μb.

Figure 2 Schematic diagram of the present E-253 apparatus.

Figure 3 A muon track registered in the E-253 detector. The beam goes from left to right. The upper two pictures show the x- and y- view of the muon track. The bottom picture indicates the pulse height measured by each chamber. Numbers on the horizontal axis label the chambers. Between the chambers are aluminum plates of 1 r.l. thickness.

Figure 4 An electromagnetic shower detected in the E-253 apparatus.

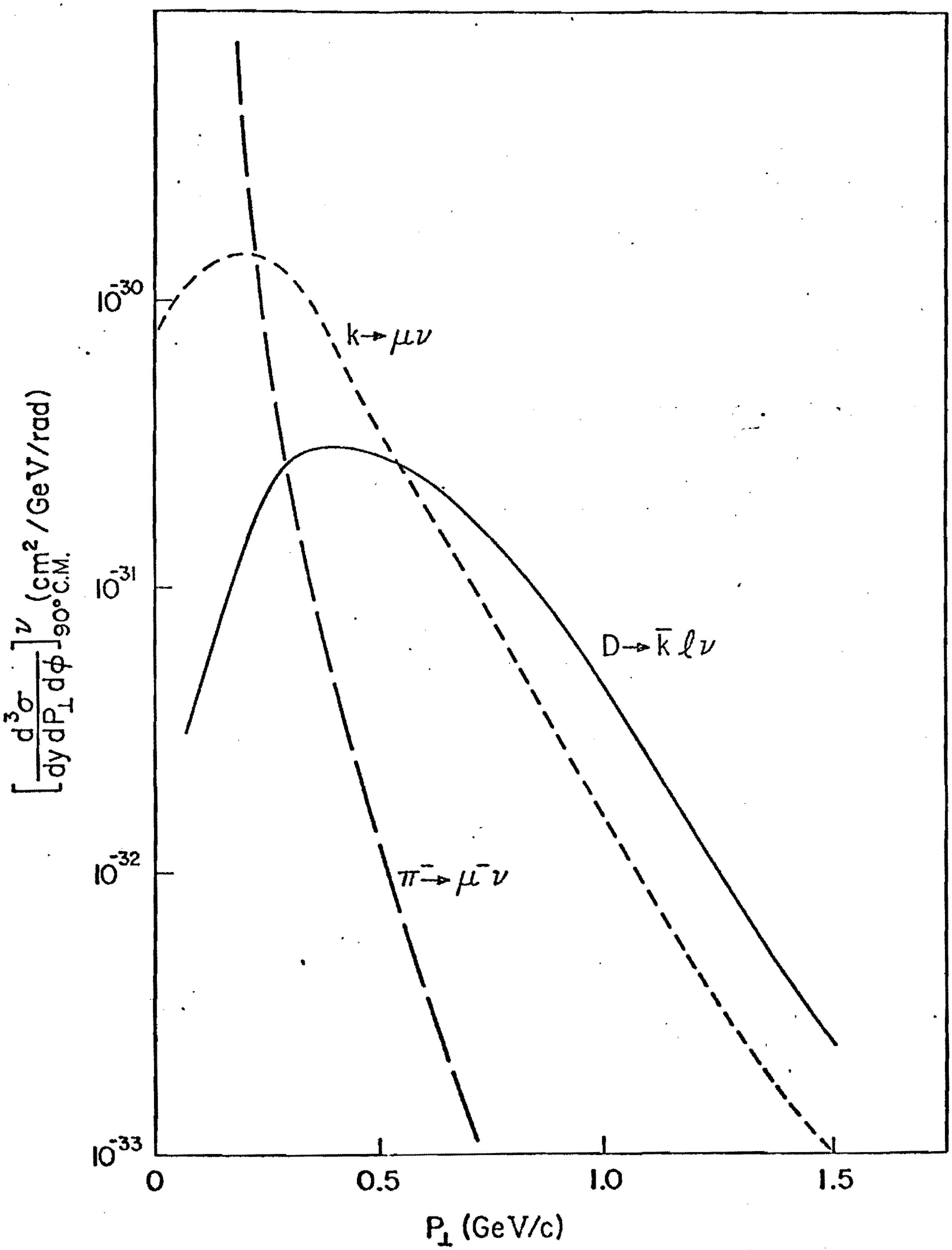
Figure 5 Angular resolution measured with 4 GeV electrons.

Figure 6 Pulse height spectra measured at Meson Laboratory with pions and electrons both of 10 GeV/c with 10 chambers. There are aluminum plates, 1 r.l. thick each, between the MWPC's.

Figure 7 Layout of the proposed experiment.

Figure 8 The muon background in the M2 beam line with 10^{12} p's/pulse at 400 GeV.

Figure 9 The shielding required near the beam dump.



10^{-30}
10^{-31}
10^{-32}
10^{-33}
0
0.5
1.0
1.5
$P_{\perp}$ (GeV/c)
$\left[\frac{d^3\sigma}{dy\,dP_{\perp}\,d\phi}\right]^{\nu}_{90^\circ C.M.}$ (cm^2/GeV/rad)
$k \to \mu\nu$
$D \to \bar{k}\ell\nu$
$\pi^- \to \mu^-\nu$

Figure 1

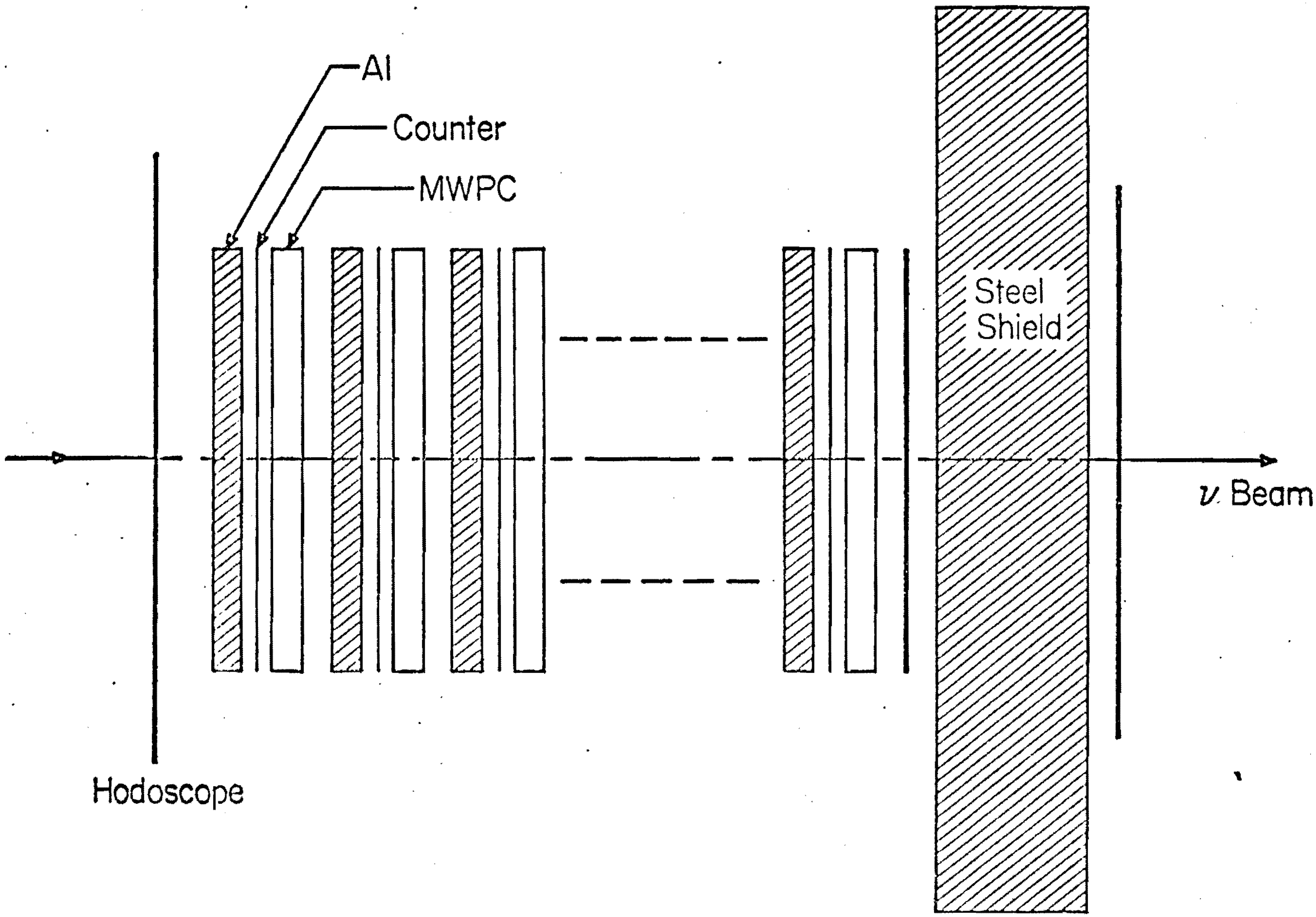


Figure 2.

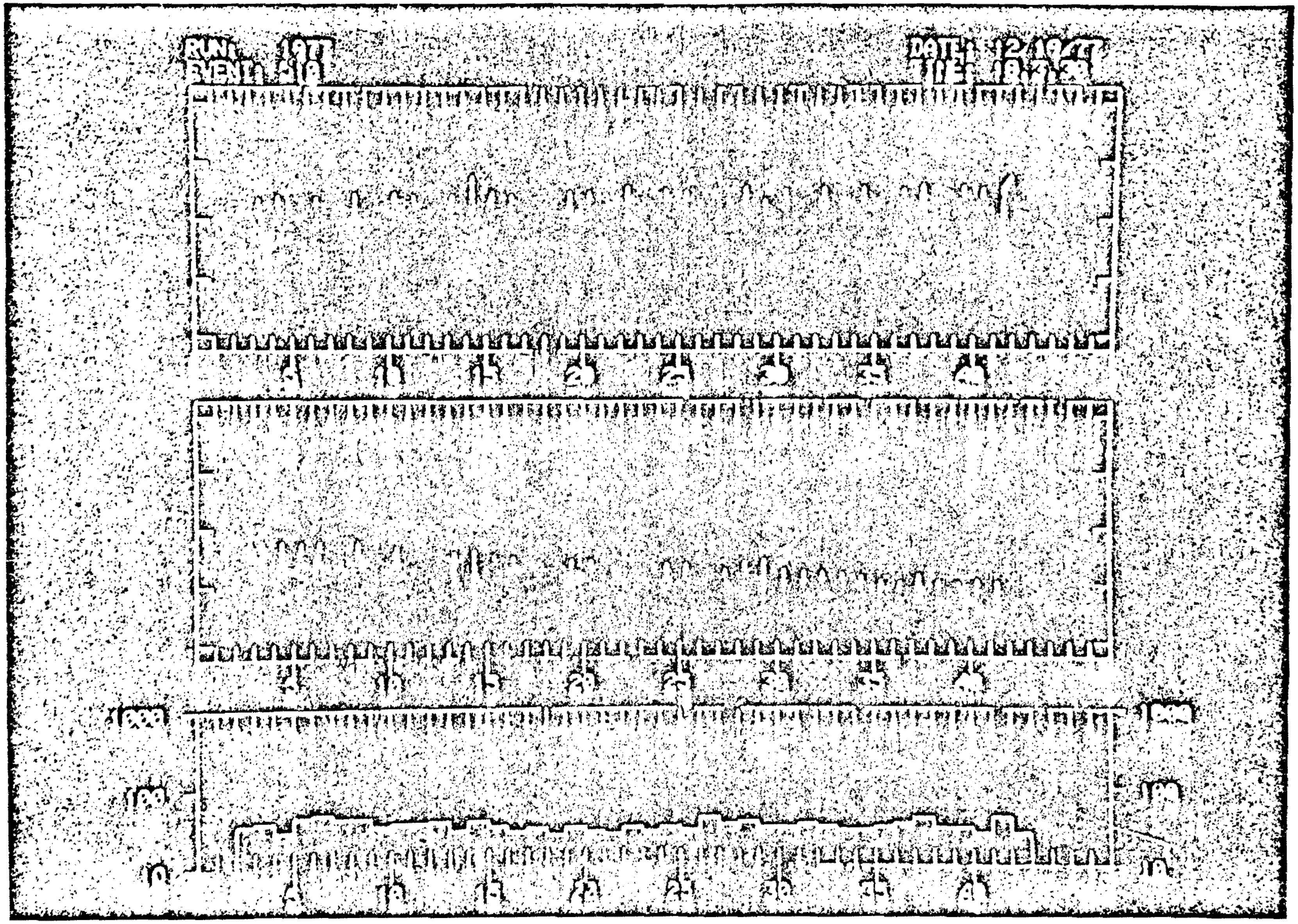
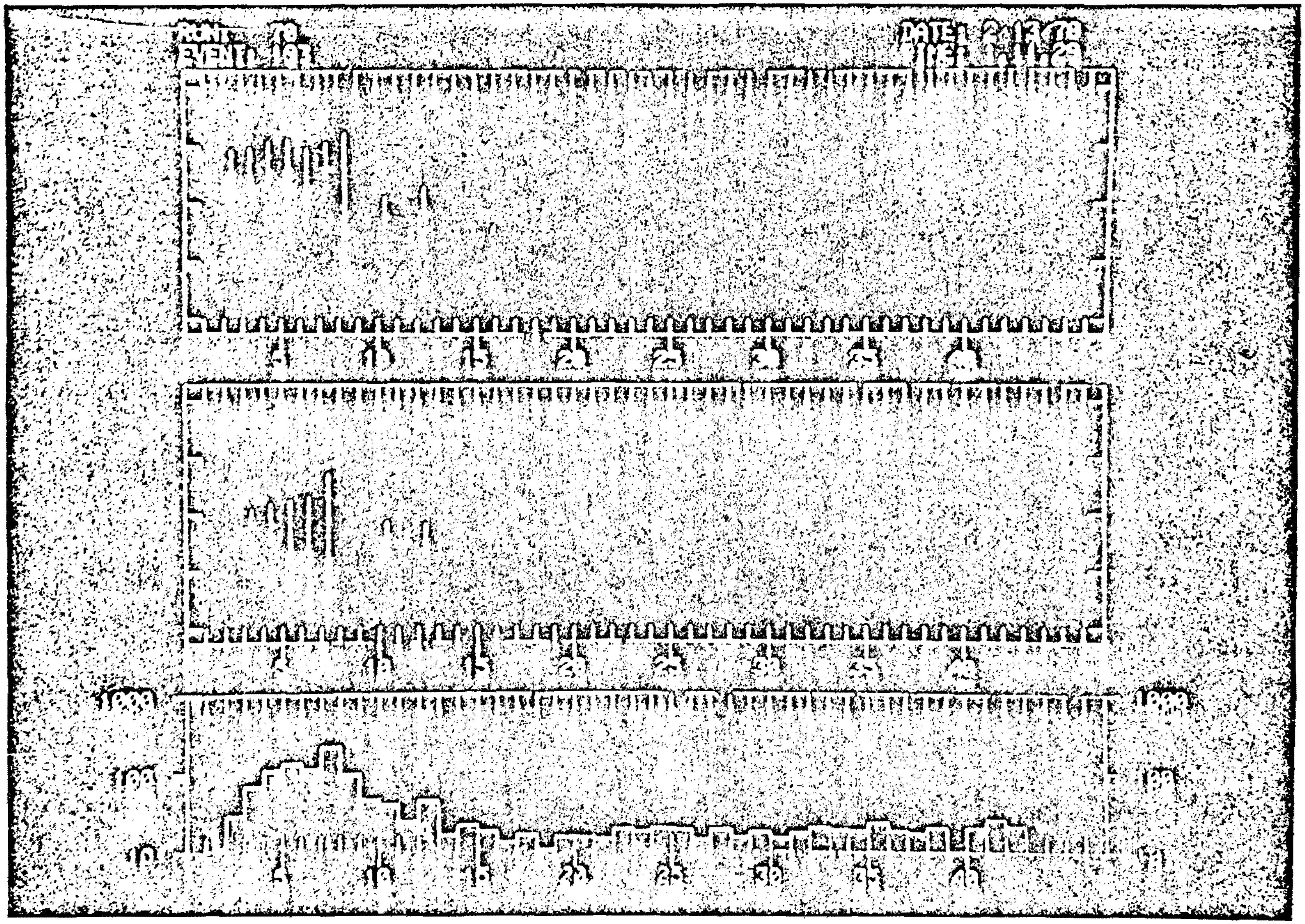


Figure 3.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EVENT:
DATE: 2-13-78
TIME:
5 10 15 20 25 30 35 40
5 10 15 20 25 30 35 40
1000
100
10
5 10 15 20 25 30 35 40
1000
100

Figure 4.

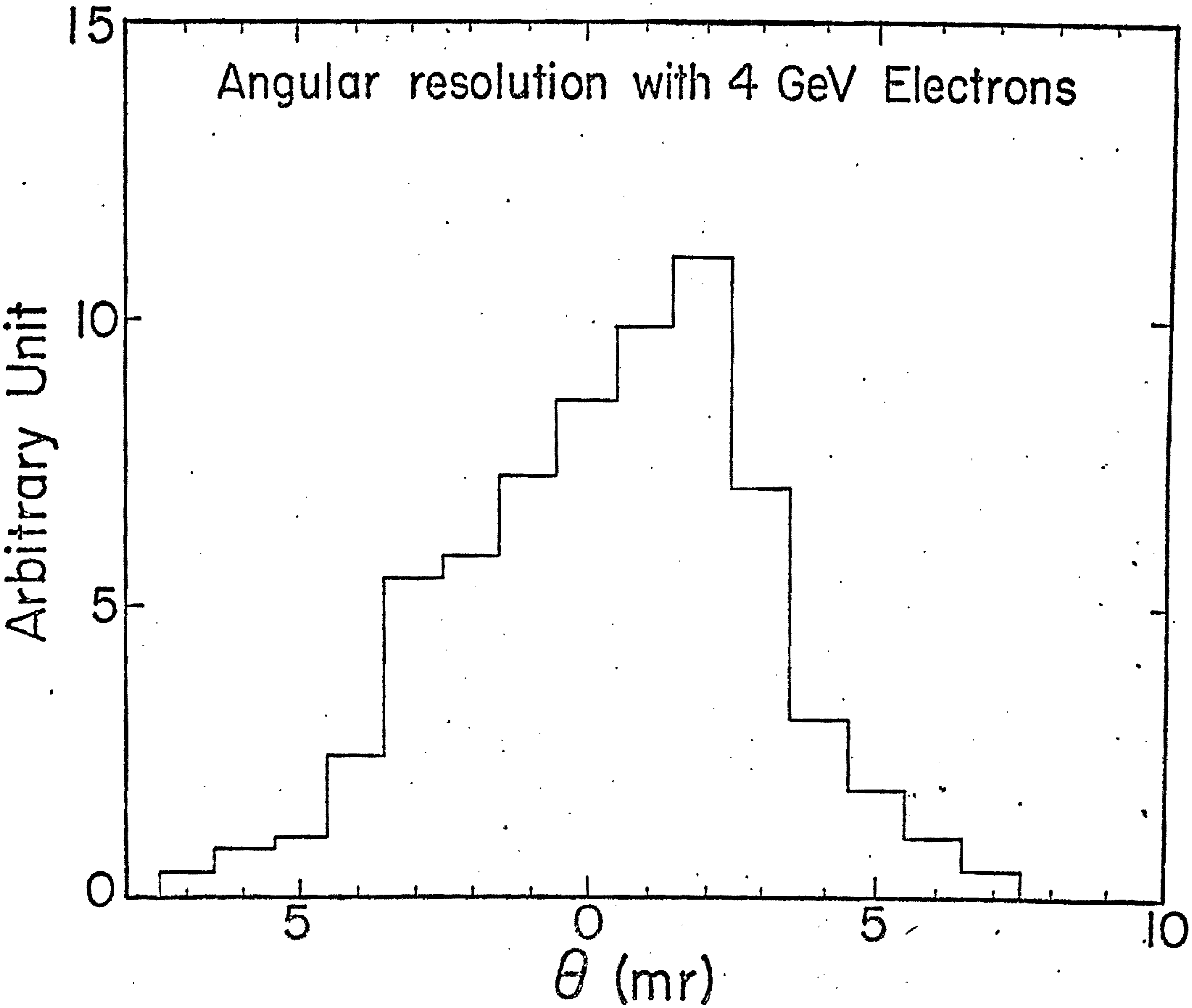
Angular resolution with 4 GeV Electrons
15
10
5
0
Arbitrary Unit
5
0
5
10
θ (mr)

Figure 5.

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Figure 6a.

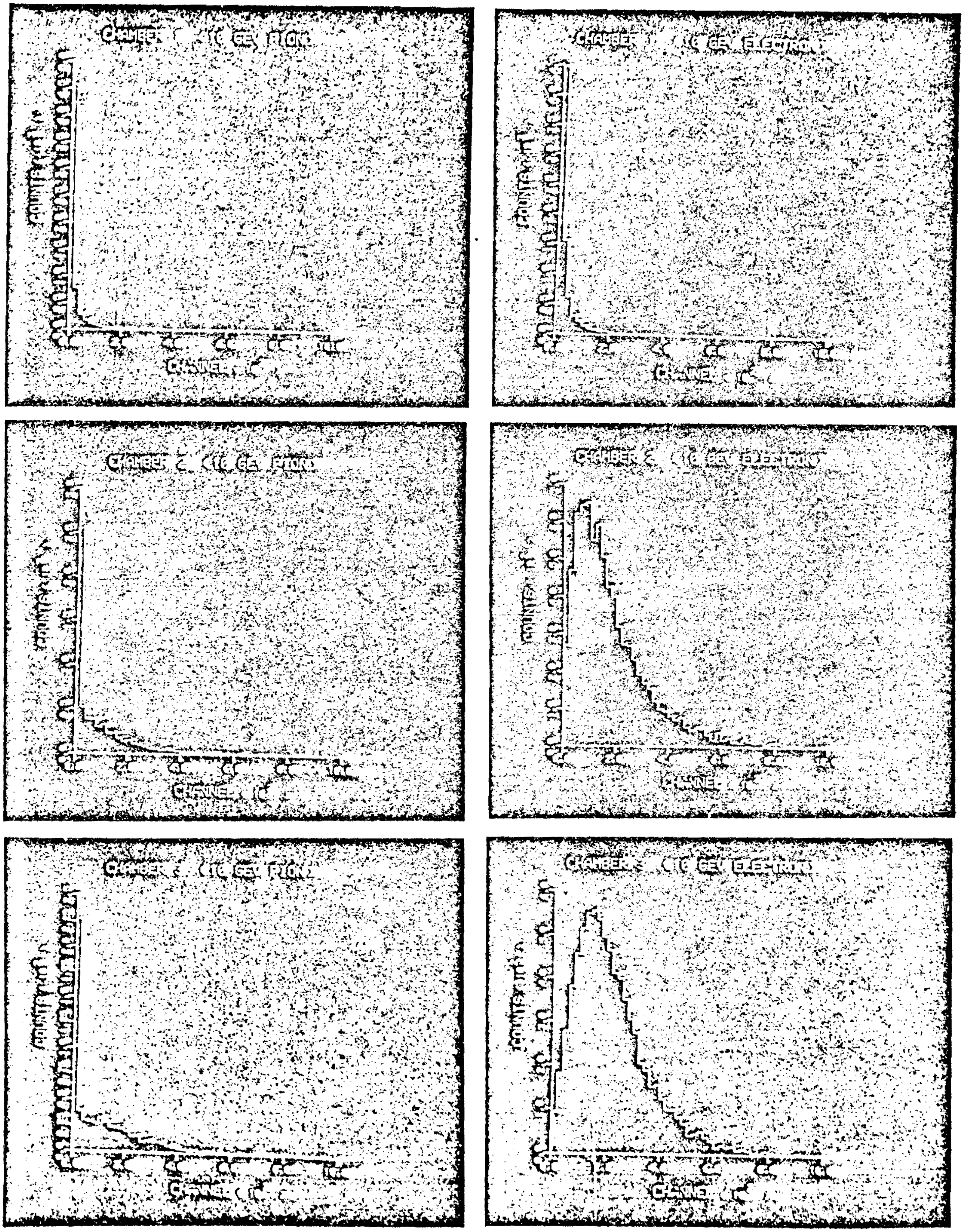

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Figure 6b.

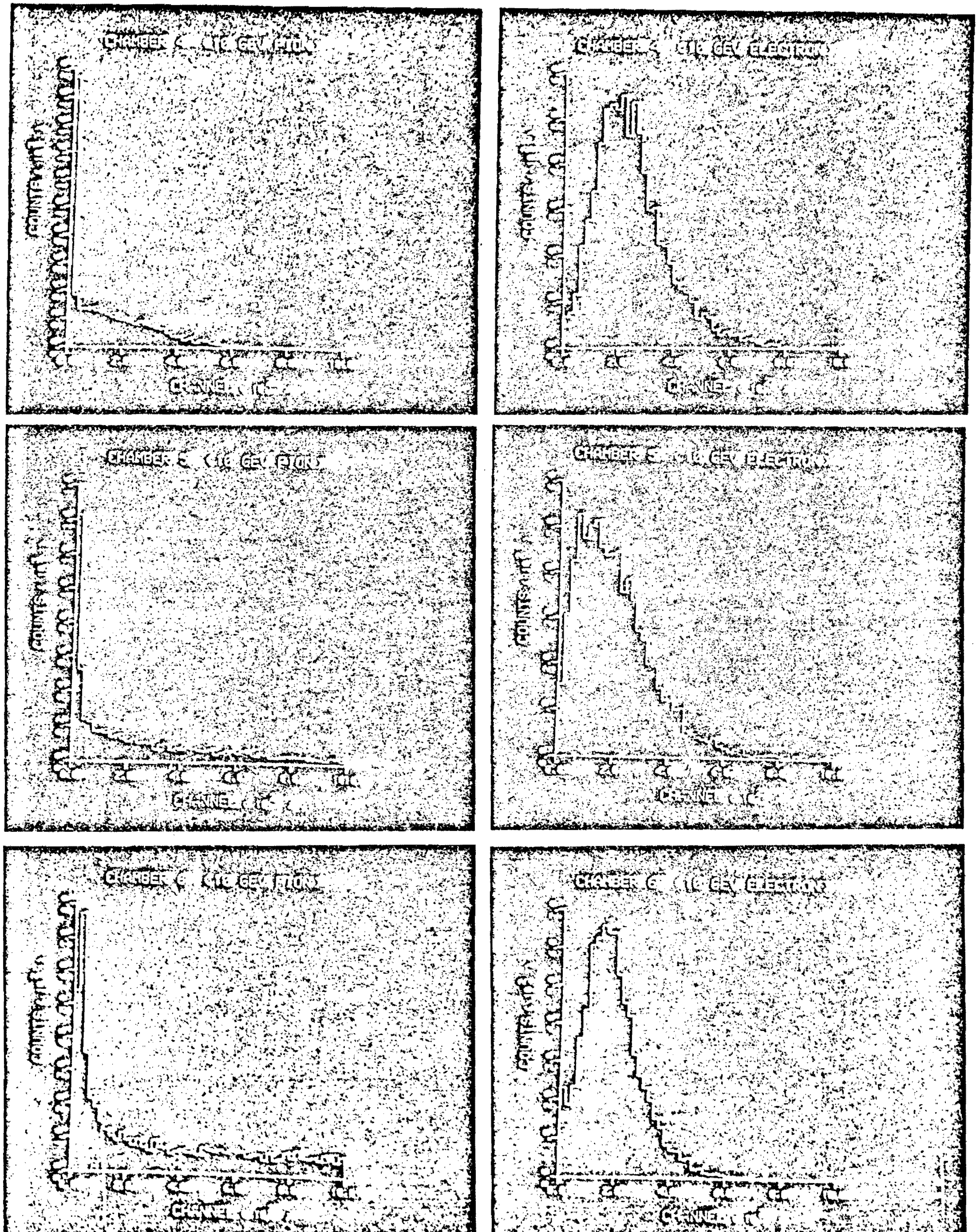

Figure 6c.

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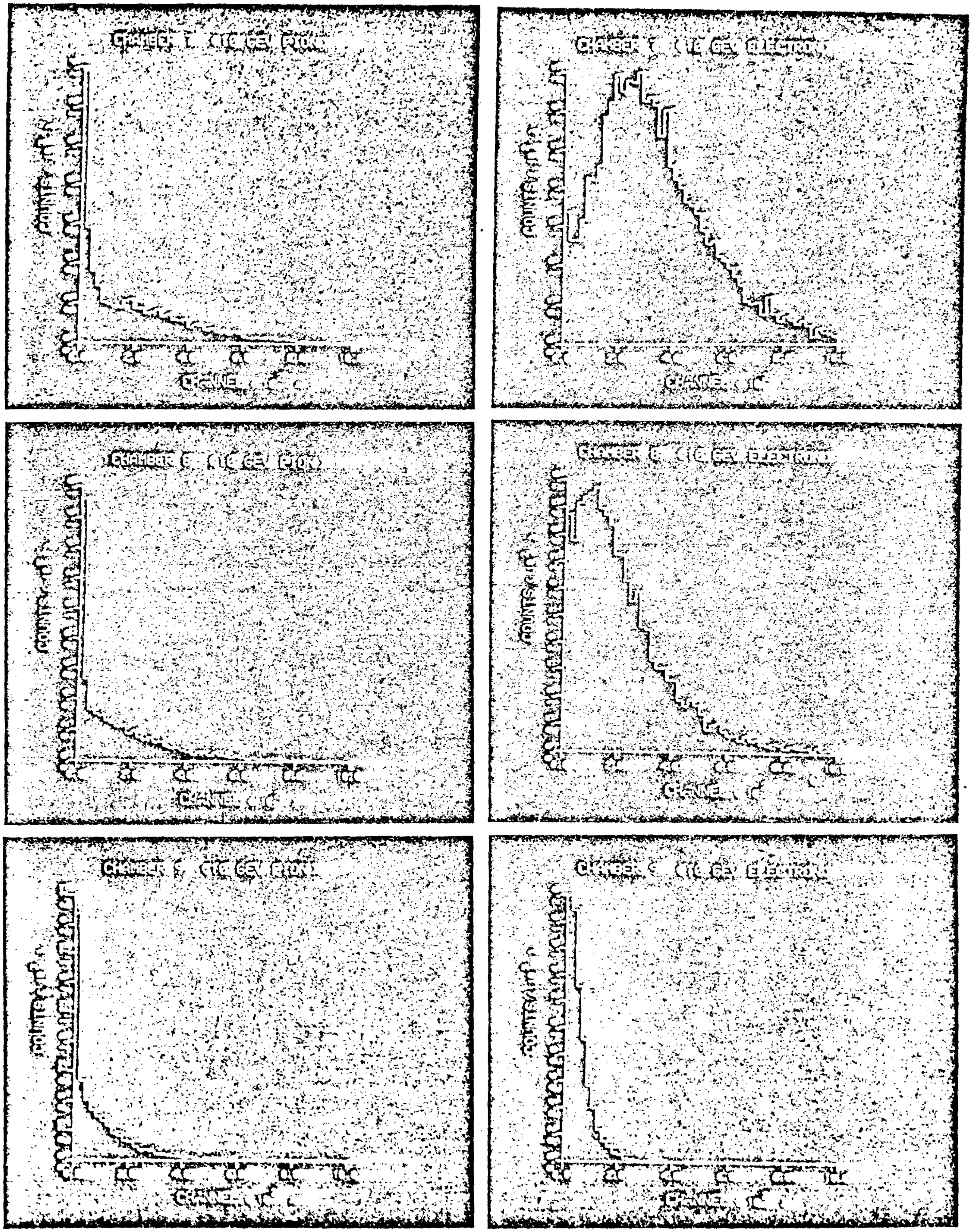

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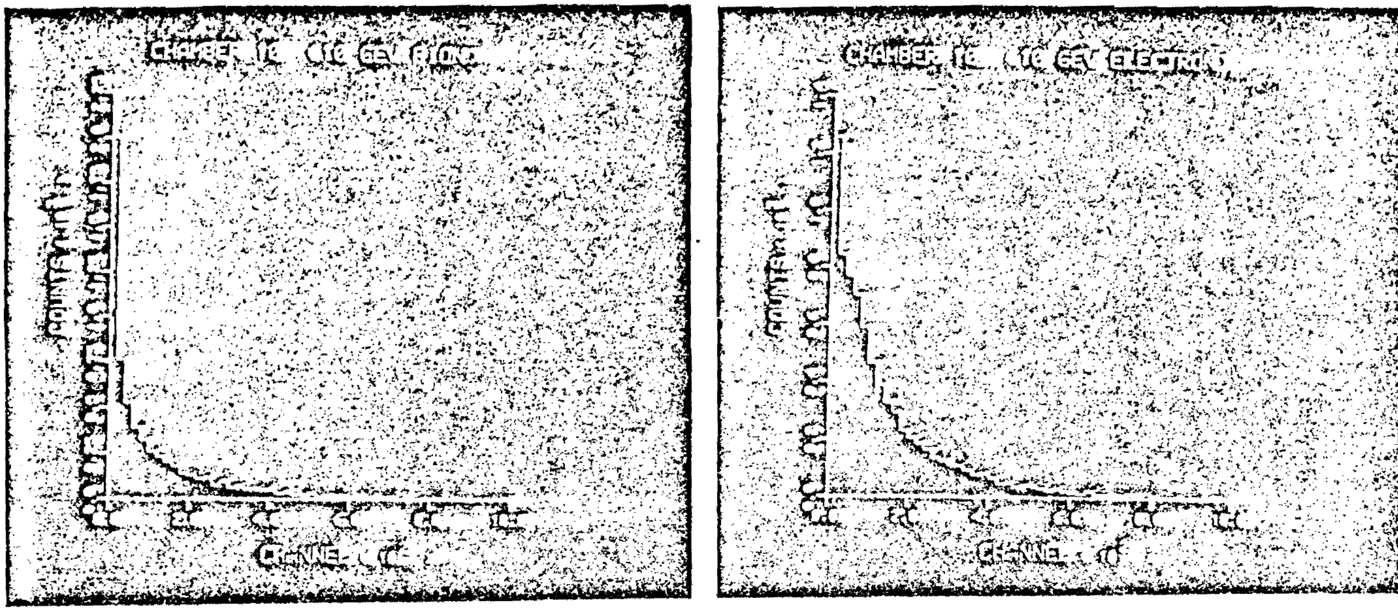
Figure 6d.



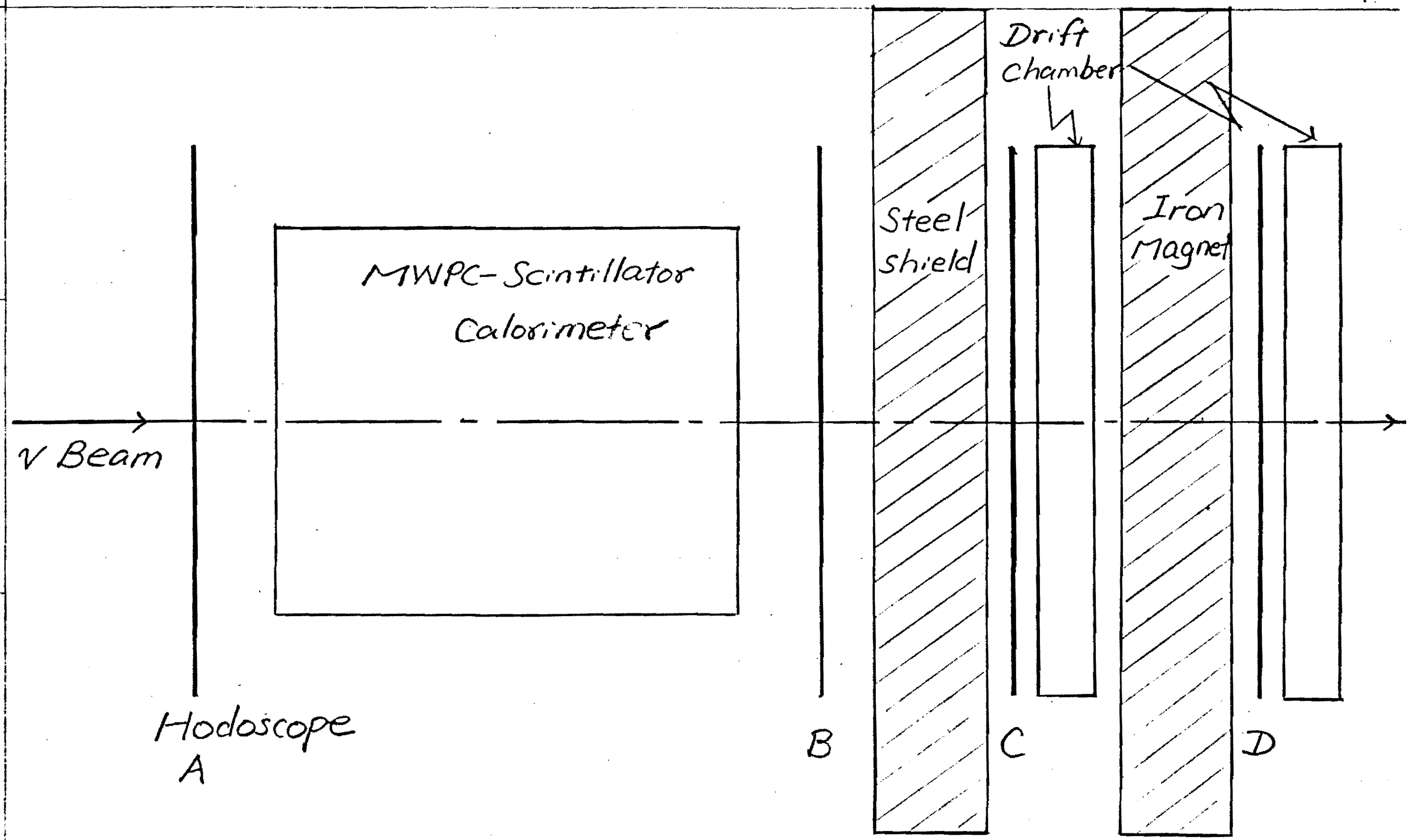

Drift
Chamber
MWPC-Scintillator
Calorimeter
Steel
shield
Iron
Magnet
ν Beam
Hodoscope
A
B
C
D

Figure 7.

Figure 8. Muon Background

The figure displays the number of muons per 10^6 protons incident on the beam dump in the E439 hodoscope 8.5m from the dump. The shaded area corresponds to the muon flux that will be intercepted by our apparatus at 18 mrad and 50m from beam dump without additional shielding.

VERTICAL PROJECTION

BEAM ℄ +

5.5cm	14.0cm	21.5cm	29cm	36.5cm	44.0cm	51.5cm	59.0cm	66.5cm	74.0cm	
2.142	0.982	0.795	0.611	0.474	0.404	0.283	0.241	0.162	0.151	41.25
1.359	0.650	0.516	0.392	0.322	0.277	0.186	0.166	0.123	0.100	33.75
0.906	0.410	0.340	0.281	0.277	0.185	0.136	0.122	0.092	0.074	26.25
0.713	0.278	0.278	0.235	0.182	0.151	0.106	0.102	0.075	0.063	18.75
0.356	0.152	0.152	0.121	0.100	0.083	0.062	0.063	0.049	0.037	11.25
0.313	0.143	0.116	0.092	0.079	0.065	0.050	0.050	0.042	0.032	3.75 cm
0.299	0.114	0.098	0.079	0.067	0.057	0.041	0.045	0.035	0.027	-3.75 cm
0.313	0.134	0.113	0.087	0.072	0.066	0.046	0.050	0.030	0.030	-11.25
0.413	0.175	0.146	0.113	0.091	0.085	0.055	0.059	0.039	0.035	-18.75
0.551	0.273	0.217	0.116	0.128	0.106	0.106	0.076	0.049	0.040	-26.25
0.881	0.454	0.331	0.246	0.194	0.164	0.117	0.110	0.075	0.056	-33.75
1.454	0.700	0.524	0.392	0.297	0.269	0.181	0.158	0.102	0.083	-41.25
1.941	0.966	0.713	0.532	0.429	0.342	0.240	0.218	0.131	0.107	

HORIZONTAL PROJECTION →

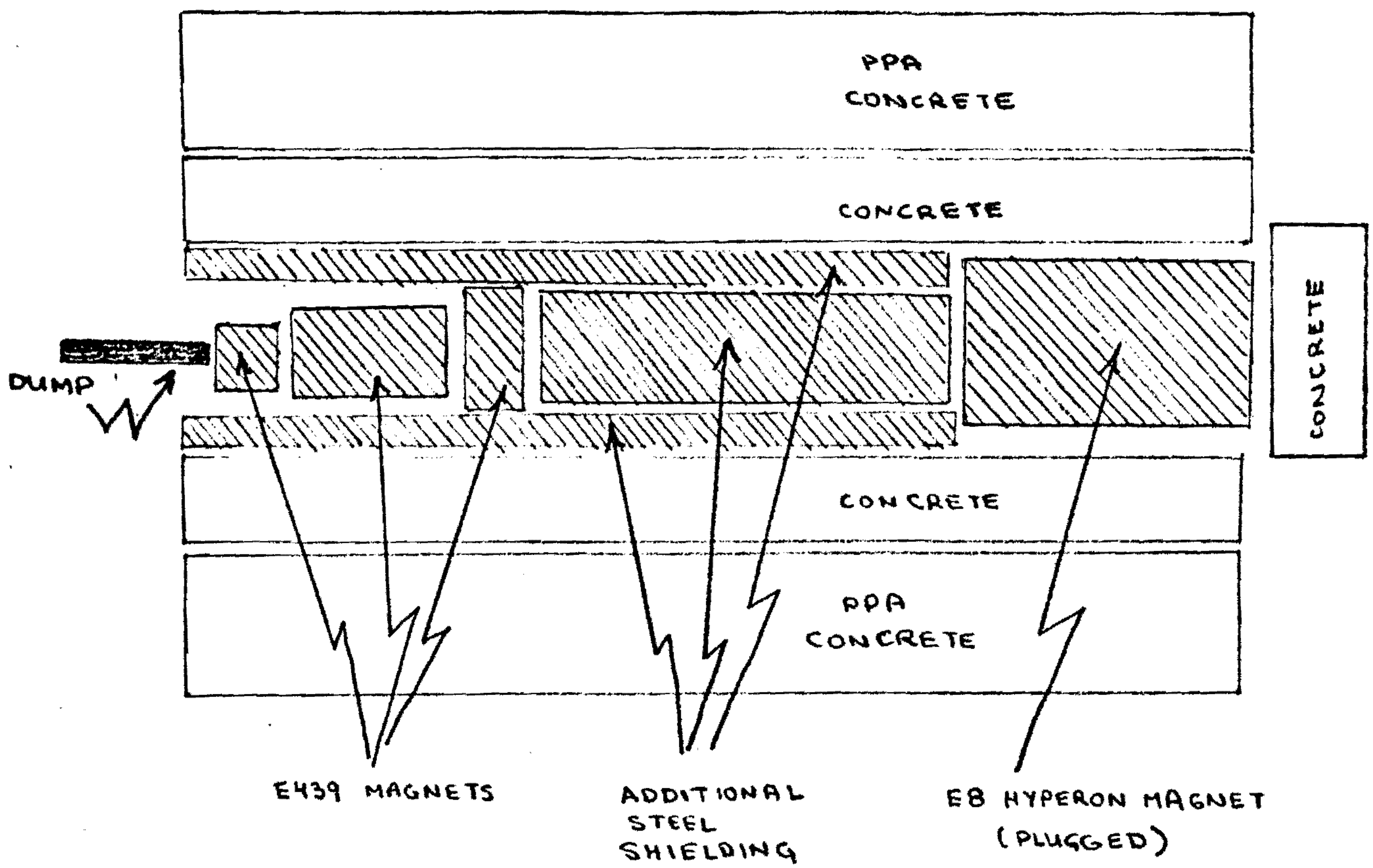

PPA
CONCRETE
CONCRETE
CONCRETE
DUMP
CONCRETE
PPA
CONCRETE
E439 MAGNETS
ADDITIONAL
STEEL
SHIELDING
E8 HYPERON MAGNET
(PLUGGED)

Figure 9.