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Search for New Phenomena Associated with High Energy Neutrinos Using the Quadrupole Triplet Beam

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Abstract

We propose to take 100,000 pictures of high energy neutrinos in an approximately 20% mixture of Neon and Helium using the FNAL 15 foot bubble chamber exposed to the quadrupole triplet focussed neutrino beam with the EMI. Our experience in E-28A has shown that the capability of recording and analyzing high multiplicity, multiple gamma conversions, secondary neutrino interactions, and high energy electrons makes this instrument uniquely useful in searching for new phenomena in neutrino interactions.

The principle advantage in using the quadrupole triplet beam is that a greater proportion of the events occur at high energy (i.e. >60 GeV) allowing a fast and more effective analysis of the characteristics at high energy.

This experiment allows a sensitive and bias-free search for the following:

1. phenomena with electrons in the final state.
2. phenomena with muons in the final state. The EMI is an important adjunct to this study.

3. multiple leptons (μe, $\mu\mu$, ee, μee, $\mu\mu e$, $\mu\mu\mu$, eee) in the final state.

4. possible anamalies in scaling distributions of charged current events.

5. possible anomalies in distributions of neutral current events.

6. other anomalous phenomena which may occur at high energy.

7. comparison of characteristics of events produced by $\nu_e(\nu_\mu)$ to those by $\nu_e(\bar{\nu}_\mu)$.

Search for New Phenomena Associated with High Energy Neutrinos Using the Quadrupole Triplet Beam

I. Introduction

This proposal is for an exploratory experiment concentrating on new phenomena at high energies, consisting of 100,000 pictures of the 15' bubble chamber filled with 20% Ne/H_2 and exposed to a quadrupole triplet neutrino beam optimized for an energy range of 30-200 GeV.

For the investigation of these phenomena the quadrupole triplet focussed neutrino beam (QTB) is optimal, at least until the "long spill" horn becomes operational. A major reason is that satisfactory operation of the EMI with the horn requires the maximum primary proton intensity to be limited to $\sim 5\text{-}6 \times 10^{12}$ protons per burst. Higher intensities result in an unacceptably high rate of random accidentals. Since the QTB can be used with a spill 1 msec in length the random rate is 50 times smaller than that with the horn. As a result there is no limitation on primary proton intensity with the QTB. We will assume 1.5×10^{13} protons per pulse in calculating rates.

The large number of low energy neutrino events produced by a double horn beam provide a "background" to the search for high energy phenomena. This is particularly apparent in the case of neutral currents where events with small visible energy are produced by high energy neutrinos. The QTB suppresses this effect, about half the events have energies greater than 60 GeV compared to about 25% in the horn beam.

It is readily apparent that search for new phenomena must be as unbiased and as sensitive as possible. We have studied in detail the effect of the radiation length on the detection of direct electrons and on the "analyzability" of events. The results are presented in Appendix I and II. We conclude about 12-17% of the events can not be analyzed because of an early shower or secondary interaction which obscures the vertex or the detection and measurement of neutral strange particles. An event is considered unanalyzable if its energy cannot be measured, or the presence of a direct electron cannot be determined, or if the number of hadrons is so great because of secondary interactions that the EMI contributes no information. The blind region caused by the analyzability problem is obviously biased against large hadron energy and high energy direct electrons (such as those from $\bar{\nu}_e$ interactions) although the extent of the bias has yet to be determined. Above about 30 GeV we think that neither the momentum nor even the sign of the charge of an electron can be determined for more than about one half of the electrons in heavy mix.

The detection of muons using the EMI (1 plane) is difficult to evaluate because no experience has been gained with long spill (1 msec). Nonetheless with the usual increased collimation expected at high energies the utility of the EMI will be enhanced by suppression of accidentals. The detection of multiple muons has proved difficult with the horn beam (E-28). The primary reasons are that only muons with energies greater than $\sim$3 GeV can be identified with good efficiency and that the accidental rate in EMI with horn beam further degrades identificaiton efficiency.

Both these restrictions are minimized by use of the Quad Triplet Beam with its high energy and long spill.

In Table I we present a detailed comparison of the advantages and disadvantages of the various ν beam-detector combinations for several topics of current physics interest. Grades are awarded based on our quantitative studies of electron detection and backgrounds for direct electron identification and on our qualitative estimates of the utility of the sample with respect to the physics goals. For completeness we also present in Table II a similar comparison for $\bar{\nu}$ beam-detector combinations. Note that the QTB allows both ν and $\bar{\nu}$ studies to be made simultaneously under identical beam conditions.

Summary and Conclusions.

The main emphasis of this experiment is to search for new phenomena at high ν energies (E_ν > 60 GeV). As illustrated in the tables a 100,000 picture exposure of the 15' Bubble chamber filled with 20% mixture of Neon and Hydrogen exposed to the Quadrupole Triplet Neutrino Beam is an ideal combination for this investigation. Specifically, we propose to make an unbiased sensitive search for:

1. phenomena at high energies producing direct electrons.
2. phenomena at high energies producing direct muons.
3. electron neutrino and electron anti-neutrino interactions and comparisons between them.
4. phenomena at high energies involving multiple direct leptons (μe, ee, $\mu\mu$, $e\mu\mu$, μee, $\mu\mu\mu$, eee).

5. anomalous characteristics of neutral currents at high energies such as increased production strange particle production.

6. new phenomena in charged current neutrino interactions, particularly when compared to $\bar{\nu}_\mu$.

7. anomalous energy dependence of charm production.

Appendix I

STUDY OF EFFECTS OF RADIATION LENGTH ON THE ANALYSIS OF NEUTRINO EVENTS

We have experimentally studied the effects of radiation length on the detection and analysis of neutrino events. The data were obtained from an examination of about 2000 events in a light mixture of Neon in hydrogen (20% Ne by volume, λ_R = 116 cm) and about 100 events in a heavy mixture of Neon in hydrogen (70% Neon by volume, λ_R = 40 cm).

A. Analyzability of events

We catagorize an event an unanalyzable if the energy cannot be measured, or the presence of direct electrons cannot be determined, or the multiplicity of tracks entering the EMI make the interpretation of EMI data questionable. By these criteria we find no unanalyzable events in 20% mix and 17±4 % of the events in 70% mix c nnot be analyzed. The reasons are: early development of the electromagnetic cascade which obscures the vertex and makes measurement of other hadrons very difficult; an energetic hadron which interacts close to the vertex; and occasionally the unmeasurability of an otherwise useful event because it is superimposed in one stero view on an energetic shower from a ν event in the wall.

This problem is exacerbated when direct electrons are present, in that case the electro magnetic cascade starts at the vertex. Electron neutrino interactions will be particularly difficult to study although the extent of the difficulty has not been quantitatively determined.

B. Measurement of momentum of hadrons.

The measurement error due to multiple coulomb scattering depends inversely on the square root of the radiation length. At low and intermediate energies this is the dominant error. As a result the identification of K_S° amd Λ will be less precise. The K/Λ ambiguity is less than 10% in light mix but increases to about 25% in heavy mix even with 3c fitting.

The interaction mean free path is about 1 meter in heavy mix. The secondary interaction of energetic hadrons will limit the track length available for momentum measurement in an appreciable fraction of the events. This is not a problem in light mix.

C. Measurement of Electron energy

Because the radiative energy loss greatly exceeds ionization energy loss at electron energies above 800 MeV the effect of radiation length on electron energy measurement is linear. Thus the energy resolution of the measurement of a high energy electromagnetic cascade in heavy mix will be substantially inferior to light mix despite the increased detection probability.

D. Measurement of Neutrals

The smaller mean free path for hadrons in the heavy mix will increase substantially the detection of neutrons and K_L°. However, on the average a small fraction of the energy is carried by these particles. We estimate 85-90% of the average total energy will be measured in the light mix and 90-96% in the heavy mix.

Appendix II

A study was made to determine the effect of the radiation length of the bubble chamber fluid on the identification and measurement of direct electrons. The comparison was made using film taken in E-28 (20% Ne) and E-53 (70% Ne). The study is still in progress, preliminary results will be presented here.

There are two major aspects to the problem of the detection of direct electrons. The first deals with the detection of the electron, as well as a determination of its charge and its energy. The second deals with the background due to conventional electromagnetic processes which simulate direct electron production but which cannot be distinguished event by event. It will be seen that these different aspects make conflicting requirements on the properties of the liquid and a compromise will be necessary.

1. Detection Efficiency

a. 20% Ne

In this study, electrons were identified exclusively by electromagnetic processes. A track was considered identified as an electron if it showed any one of the following signatures:

- a rapid energy loss consistent with beamsstrahlung
- a converted e^-e^+-pair pointing tangentially to the track, and not to the main vertex
- the presence of a e^-e^+ pair directly on the track, pointing tangentially along the track.

The detection efficiency was calibrated with external e^-e^+ pairs, as a function of the momentum. It was measured in the region up to about 5 GeV/c. That the extrapolation to high energies up to 100 GeV is reasonable is confirmed by our observation of the expected number of electron-neutrinos ν_e, at high energies.

An electron gets detected in about 50%, as expected from the radiation length. From our experience in E-28 we have established that for every detected electron both the charge and the energy can be reliably determined. In 20% Ne, there also is no problem with electromagnetic showers of high energy π°'s making events unmeasurable. Hence there is no loss of electrons due to measurement problems.

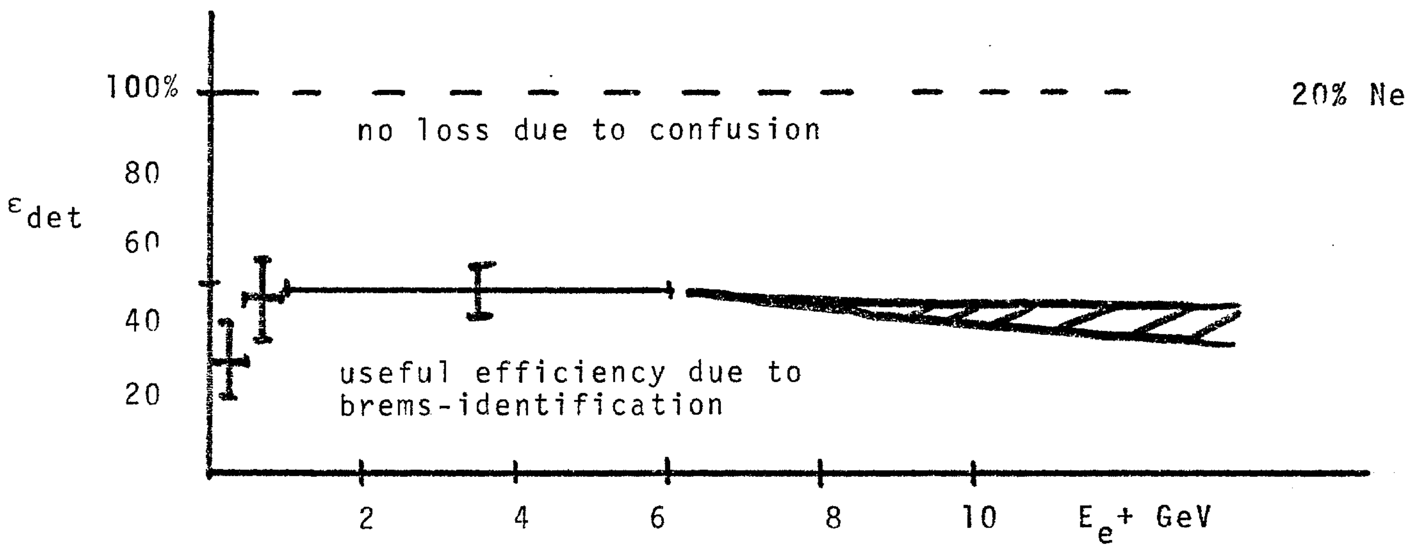

Fig. 1

b. <u>70% Ne</u>

In order that a particle is identified as an electron, two of the electromagnetic signatures of section (a) was required. Since the radiation length for the heavy mixture is X° = 40 cm, this, in principle, leads to a high efficiency, close to 100%. Unfortunately, the short radiation length also has disadvantages, which

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partly cancels the increase in efficiency, especially at high energies: Due to conversion of photons from neutral pions close to the vertex with its accompanying electromagnetic shower, in about 12% of the cases a direct electron will not be recognized as such due to the confusion of its shower with the shower from the neutral pion. Studies of film from E-53 indicate, that (12 ± 3)% of the total events will be unanalyzable due to dense showers.

At higher energies, there is the additional problem of an early onset of a shower from the electron itself, which often renders a determination of charge or energy impossible. Hence the useful detection efficiency is smaller than 100%, especially at high energies.

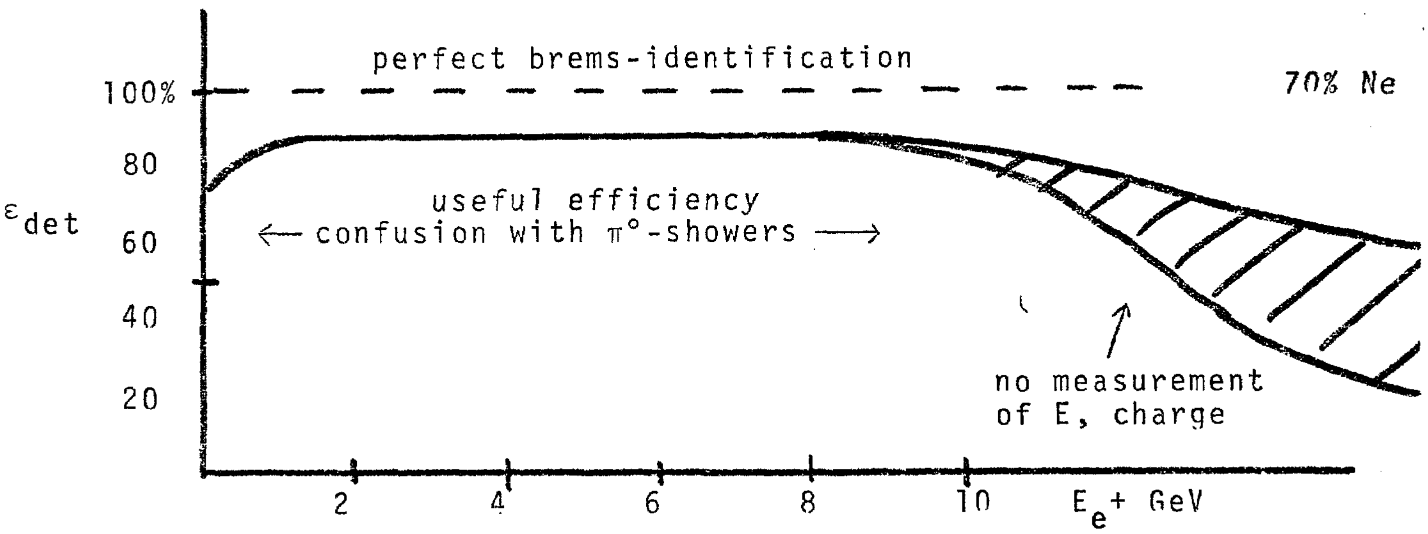


Fig. 2

2. Background to direct electrons from conventional sources

Obviously, there are conventional reactions which will result in electrons or positrons, which seem to come from the interaction vertex. In this section, we do not want to discuss the more obvious background as from ν_e, $\bar{\nu}_e$, and symmetric Dalitz-pairs, which can be eliminated by cuitable cuts or by the use of the EMI. Rather we would like to concentrate on the limitations after such cuts, the "irreducible", undetectable background.

a. The major source of such background comes from asymmetric Dalitz pairs, where e.g. the e^- is of such low energy that it cannot be observed. For this background, an operational definition of the term "Dalitz pair" has to be used. It includes real Dalitz pairs, as well as external pairs, close enough to be mistakenly taken as coming from the vertex.

This background depends very much on the energy spectrum of photons, the energy cut off for the e^+ and e^- as well as on the radiation length of the liquid. It is given by the integral (or sum) over all photon energies $E_i > E_+^0$

$$\frac{1}{N_{tot}} \sum_i \frac{E_-^0 \, N_i}{E_i}$$

where:

E_-^0 is the upper limit, below which electrons will not be observed.

E_+^0 is the lower limit for the positron to be accepted.

N_i is the number of "Dalitz pairs" in the i^{th} energy bin.

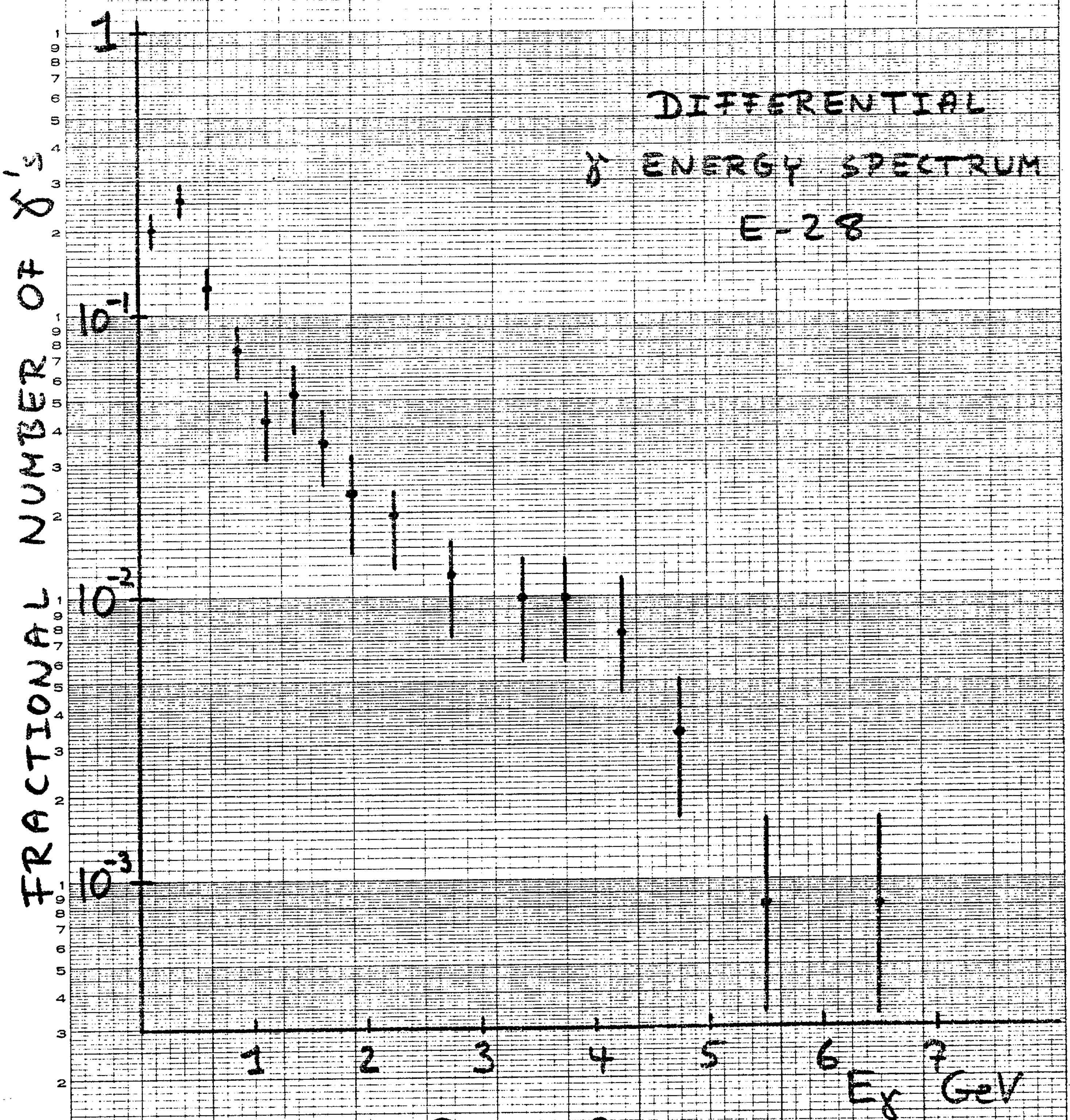
It turns out that N_i is approximately inversely proportional to the radiation length, since a large contribution comes from external pairs close to the vertex.

This background rate was evaluated using the observed photon energy spectrum in the neutrino experiment E-28, which is given in Fig. 3. An electron energy cut off of 5 MeV for 20% Ne and 10 MeV for 70% Ne was used. These values are based on a preliminary study of frequency distributions of low energy δ-rays.

background	20% Ne $E^0_- < 5$ MeV	70% Ne $E^0_- < 10$ MeV
$E^0_+ > 300$ MeV	4.3×10^{-4}	26.0×10^{-4}
$E^0_+ > 1$ GeV	0.55×10^{-4}	3.3×10^{-4}

These background rates have to be compared with an observed $\mu^- e^+$ signal rate.

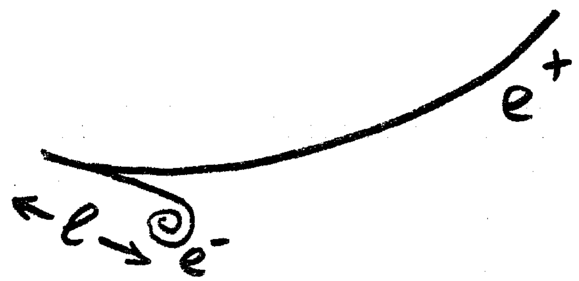
	20% Ne	70% Ne
signal rate ($\mu^- e^+$) =	40.0×10^{-4} (measured)	70.0×10^{-4} (not measured, estimated from E-28)



DIFFERENTIAL
γ ENERGY SPECTRUM
E-28
FRACTIONAL NUMBER OF γ's
1
10⁻¹
10⁻²
10⁻³
1
2
3
4
5
6
7
Eγ GeV

figure 3

b. For short radiation lengths, there is a second contribution which comes from a close symmetric "Dalitz pair" with a subsequent large energy loss due to bremsstrahlung of the negative electron.



If the brems process of the e^- is close to the vertex of the pair, the e^- will appear like a δ-ray on the positron, since the tracks have not separated sufficiently. Much of this background can be eliminated by requiring that the positron not have a δ ray above a certain momentum close to the vertex. There remains, however, a irreducible contribution, even after a δ-ray cut. It is given by

$$\frac{1}{N_{tot}} \frac{\ell}{X^{\circ}} \sum_i E^{o}_{-} \frac{N_i}{E_i} \ln \left(\frac{E_i - E^{\circ}_{+}}{E^{\circ}_{-}}\right)$$

where ℓ is the distance along the track of the e^- to the brems-point.

background 2	20% $E^o_- < 5$ MeV $l = 4$cm $X^o = 110$cm	70% $E^o_- < 10$ MeV $l = 4$cm $X^o = 40$cm
$E^o_+ > 300$ MeV	0.5×10^{-4}	7.2×10^{-4}
$E^o_+ > 1$ GeV	0.01×10^{-4}	1.3×10^{-4}

For light mixtures it can be neglected, this is not true for the heavy mix, however.

In the following table, the combined background is expressed as a percentage of the observed signal.

total Dalitz background	20% $E^o_- < 5$ MeV	60% $E^o_- < 10$ MeV
$E^o_+ > 300$ MeV	12%	47%
$E^o_+ > 1$ GeV	1.6%	7%

c. <u>*Background from particle decays*</u>.

Semileptonic decays of hadrons can simulate direct electrons. The largest contribution of this kind comes from the process $K^+ \rightarrow e^+\pi^\circ\nu_e$. The background from this source has been estimated to be 1.4×10^{-4} for positron energies $E_{e^+} > .5$ GeV, using the measured momentum spectrum for kaons in E-28. All other decays give smaller contributions.

100 K Pictures
Light mix = 20% Neon } By volume
Heavy mix = 70% Neon

TABLE
ANTI-NEUTRINO

	2 ELEMENT HORN 5×10^{12} p (5×10^{12} p on target) LIGHT MIX	HEAVY MIX	QUAD - TRIP (1.5×10…) LIGHT MIX
Exploration at High Energy and H. E. anomalies $E\nu_\mu > 60$ Gev	**C** — 300 events Has a high ν_μ background (~100%) 10% anomalies probably not observable.	**C-** — 900 events Has a high ν background. Problems of Heavy Mix ν_μ background high ~ 100%.	**C** — 500 events Useful for certain restri[…] signals e.g. $\mu^+ e^+ e^-$.
Neutral Currents	**B+** — 900 events Background of H.E. ν - Good for study at low neutrino energies.	**B** — 2700 events Measurement problems will bias distributions.	**F** — 700 events (ν[…] (no s[…]
Electron Anti Neutrinos ($\bar{\nu}_e$	**A** — 40 events observed Sensitivity limited only by statistics of 40 events More film required.	**F** — 210 events About 35 events only can be measured also with large biases	**A** — 30 events $\bar{\nu}_e$ observed Measurement of $\sigma_{\bar{\nu}e}/\sigma_{\nu e}$ in beam conditions minimize s[…] matic errors in compariso[…] ν_e events along with 30 $\bar{\nu}$[…]
[C]harm Studies	**B** — 10 events observed A low energy measurement of μe prod. More film required. Technique should be O.K.	**C** — 42 events All the normal problems of backgrounds from heavy mix. Rates can not be measured because of necessity of severe energy cuts.	**B** — 8 events observed (700% ν back[…] More film desirable. Tec[…] O.K. Look at higher ener[…] prod. compared to horn.
[D]i Muon [S]tudies	**F** — 2 events Statistics	**F** — 6 events Statistics	**F** — 12 events (700% ν bac[…] probably wi[…]
[Q]ua[…]ive [C]onventional [S]tudies […] W Prod etc.	**A** — 2000 events Predominantly low energy phenomena.	**A-** — 6000 events Visibility problems viz Y distrib. difficult.	**A** — 1500 events Permits comparison of $\bar{\nu}_\mu$ w[…] ν_μ in same film. (EMI […]arates $\bar{\nu}_\mu$ from ν_μ).

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STUDIES Wisconsin

2 Horn $5x10^{12}$ ppp
Q.T. and SSBT $1.5x10^{13}$ ppp

)UAD TRIPLET LIGHT MIX	1.5x10^13 P HEAVY MIX	SIGN SELECTED BARE TARGET 1.5x10^13 LIGHT MIX	HEAVY MIX
) 5200 events total ı energy ν flux without . "Background" bove ;eV > 100 GeV more than imes better than horn.	C 15,600 events Analyzability and related problems of heavy mix for exploration offsets advantage of higher statistics.	B 1100 events Augmented H.E. ν flux with good analyzability. Good H.E. electron measurements etc.	D 3300 events At high energies the confusion due to e.m. shower plus poor mom. and space resolution makes it less desirable for exploration.
) 3100 events 15% contamination of $\bar{\nu}$ in ν beam) (high energy component of considerable interest) →	B- 9300 events	A 1000 events Can study NC at H.E. Since ν not seen, L.E. and H.E. easier to separate than in horn run.	B- 3000 events H.E. not as analyzable loose advantage of augmented H.E. ν flux. Increased hadron int. prob. makes possible a sample without EMI.
) 150 events Light mix permits ν_e and $\bar{\nu}_e$ seperation even up to highest energies. Direct comparison can be made. ~30 $\bar{\nu}_e$ events.	F 1100 events? Due to short rad. length for electrons at H.E. neither mom. or charge can be measured. Some confusion of π° with single electrons at H.E.	C 30 events Light mix permits H.E. electron studies but statistics are poor	F 300 events? Problems of ... tron identification and measurement at H.E. Can not utilize increased ν_e flux at H.E.
) 55 events ı energy measurement ıared to horn may give ght into production ›ss at high energy.	B+ 130 events Problems of background in heavy mix.	D 18 μ^-e^+ events Limited by statistics	C 50 μ^-e^+ events Relatively poor statistics. Backgrounds relatively high. Difficulty in utilizing H.E. ν flux which is main advantage of this beam.
) 80 events ɛvents are after only ·gy cuts. Statistics low to permit many ; to be made. ←	C 240 events (Unknown performance of EMI with long spill)	F ~ 20 events Statistics poor	D ~ 60 events Problems same as Q.T. heavy mix but with lower ν_μ flux. →
) 10,200 events look at variable X,Y,W at higher energies compare ν and $\bar{\nu}$ data ... f...	A- 31000 events Problems of hadron int. and e.m. cascades. Statistics not much help at high energies.	B+ 2800 events Can look at X, Y and W distributions at high energies.	B- 8400 even... Increased statistic... offset by analyzing ... blems at high energy.

Light mix ≡ 20% by Volume Neon (Single Plane EMI)
Heavy Mix ≡ 70% Neon by Volume
EVENT NUMBER IN BOX FOR 100K PICTURES

TABLE NEUTRINO

	2 ELEMENT HORN LIGHT MIX	5×10¹² EMI LIMITED HEAVY MIX	C...
Exploration at High Energy $E_\nu > 60$ GeV High Energy Anomalies	A- 4100 events. All benefits of light mix for detailed studies high "background" of L.E. ν events EMI limited	C- 12,300 events. Problems of visibility and analyzability particularly with H.E. electrons overcome statistics.	A Hig L.E 60 2 t
Neutral Current Studies	B+ 3100 events. All advantages of light mix. L.E. and H.E. events more mixed than in SSBT beam.	B 11,100 events. Increased statistics not very important. Limited by analyzabilities. Catches more neutrals.	B ←
...ron Neutrino Studies	A 130 events. Nearly all ν_e events are measurable One half of events have $E_{\nu_e} > 60$ GeV.	F 1300 events. About 200 events can be measured with large biases.	A
Charm Studies ($\mu^- e^+ k^0 \ldots$)	A 70 $\mu^- e^+$ events after cuts. (Lower background than with heavy mix) less k-Λ ambig. etc.	B+ 200 $\mu^- e^+$ events. Cuts must be made to get background down. Event number after estimated cuts.	A Hig com ins pro
Dileptons	F 10 events with energy only. Limited by statistics and punch through in 1 plane EMI. using time coincidence. Not clear if exp. can be done.	D ~30 events. Heavy flux helps lower no. of hadrons into EMI. Statistics. Not sure that exp. can be done with 1 plane EMI.	C 80 ene too cut
...itative ...vention- Studies , W Dist. ...nge Part. ...c. etc.	A ~12,300 cc. Statistics enough for several cuts. Good analyzing power of light mix important.	A- 37000 cc events. Although statistics are higher analyzability has problems especially for high energies.	A Can etc can in