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NEUTRINO LEPTON SCATTERING

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ABSTRACT

The four-fermion interactions which can be produced by muon and electron neutrino beams at 200 GeV are studied. The reaction cross sections, neutrino fluxes, and event rates are presented. The only reaction which it appears reasonable to study in a five-ton liquid hydrogen detector is $\nu_\mu + e^- \rightarrow \nu_e + \mu^-$. The backgrounds encountered in studying this reaction are discussed.

I. INTRODUCTION

From time immemorial the four-fermion point interaction has eluded experimental study[1-3] in the energy and momentum transfer region above that accessible from muon decay. Since the four-fermion cross sections given by present theories exceed the unitarity limit for center-of-mass energies above about 300 GeV, a study of these reactions at high energies is necessary to guide the development of a correct weak interaction theory. The neutrino-lepton scattering reactions are in principle the best way to study the nature of the weak interaction since they do not involve the complications of a strong interaction.

The four-fermion interactions allowed by lepton-number and muon-number conservation are:

$\nu_\mu + e^- \rightarrow \nu_e + \mu^-$ Reaction 1

$\nu_e + e^- \rightarrow \nu_e + e^-$ Reaction 2

$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$ Reaction 3

$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_\mu + \mu^-$ Reaction 4

$\nu_\ell + \nu_{\ell'} \rightarrow \ell + \ell'$ Reaction 5

The reactions involving muon and positron targets have been excluded. The neutrino-neutrino colliding beam reaction 5 will not be considered further since the collision of two NAL neutrino beams produces an event rate of less than one pico-event per millennium. Neutrino-induced muon pair production in a coulomb field will also not be discussed since it is the topic of another Aspen study.[4] The resonances [5] produced by the intermediate boson in the antineutrino-electron scattering reactions 3 and 4 will not be discussed. The cross sections and event rates for the above reactions will now be discussed.

II. REACTION CROSS SECTIONS

All energies will be expressed in units of GeV. Let E represent the incident neutrino energy and E^0 the threshold neutrino energy for a given reaction. The cross sections will be given in units of $\sigma_0 = 1.7 \times 10^{-41}$ cm^2/electron-neutrino. The cross sections[6-8] for reactions 1-4 are given in Table I, along with their high-energy approximations and thresholds. These cross sections are presented on Fig. 1. For comparison purposes the total muon-neutrino cross section and the "elastic" $\nu_\mu + n \to \mu^- + p$ cross section are presented. Several observations can be made from Fig. 1; at E = 30 GeV the ratio of total four-fermion cross section to "elastic" cross section is 0.14. The ratio at E = 30 GeV of the cross section for reaction 1 to the total cross section is 7×10^{-3} assuming the total cross section saturates at E = 10 GeV. Note also that sufficiently above the energy threshold of 10.8 GeV one has the same cross sections for the neutrino reactions 1 and 2 and for the antineutrino reactions 3 and 4. The neutrino and antineutrino cross sections in this "saturation region" differ by a factor of three which results from the fact that the charged lepton angular distribution in the center-of-mass is isotropic for the neutrino reactions and $(1 - \cos\theta)^2$ for the anti-neutrino reactions.

III. NEUTRINO FLUXES

The muon-neutrino flux and muon-antineutrino flux were taken from Kang and Nezrick.[9] The neutrino fluxes were obtained from the FANC particle production model.[10, 11] The physical parameters of the neutrino beam are those presented by NAL.[12] The electron-neutrino and antineutrino fluxes were obtained from the muon-neutrino and antineutrino fluxes by the method derived by G. Kalbfleisch.[13]

The muon-neutrino, electron-neutrino, and electron-antineutrino fluxes are presented on Fig. 3. We note that the electron-neutrino fluxes are of the order of 0.6% of the muon-neutrino fluxes. Larger fluxes by a factor of ~2.5 could have been estimated[11] by using the CKP particle production model.

IV. EVENT RATES

The event rates for the various four-fermion reactions were calculated using the following assumptions:

Fiducial Volume of Detector	- 70 m^3 liquid hydrogen (5 tons liquid hydrogen) (2.5×10^{30} electrons)
Interacting protons/pulse in ν target	- 1.6×10^{13}
Time unit of experiment	- 10^6 proton bursts
Detection efficiency of events	- 100%

This set of assumptions can represent "one unit of neutrino experiment." Figure 3 presents for the reactions 1-4 the number of events per GeV per unit of neutrino experiment. The total number of events per unit of neutrino experiment for reactions 1-4 are 215, 2.5, 0.8, and 0.02 respectively. Unless it would be possible to obtain many units of neutrino experiment only reaction 1 appears amenable to detailed experimental study. It is somewhat unfortunate that the reaction which can be studied is not a diagonal term reaction and hence is less important at these lower neutrino energies in helping to resolve the normalization problem.[14]

V. BACKGROUNDS

What are the important backgrounds encountered in studying reaction 1?

1. $\nu + p \rightarrow N^{*++} + \mu^-$. While this channel is copious, the probability of charge-exchanging the pion in less than 500μ and also having a proton of momentum less than 80 MeV/c, thus simulating a single muon event, is negligible.

2. $\bar{\nu} + p \rightarrow n + \mu^+$. Because of the antineutrino contamination in the neutrino beam this production rate is appreciable, but those events which have short muons and therefore a $\mu^+ - \mu^-$ ambiguity can simply be rejected.

3. $\nu + n \rightarrow p + \mu^-$. Assuming a deuterium-to-hydrogen ratio of 0.02% in the detector, about 10 events will be obtained per unit of neutrino experiment. If a minimum detectable proton has a momentum of 80 MeV/c (1.5 mm in liquid hydrogen) then approximately 3.5% of the events[15] will appear as single muon events. This background amounts to only 0.35 events and therefore is negligible, but it has some interesting properties. It is often stated that reaction 1 can be distinguished from the background, since the muon direction is nearly the neutrino direction: $\theta(\nu\mu) = \sqrt{2m_e/E_\nu} = 7.8$ mrad for $E_\nu = 17$ GeV. However, for the reaction $\nu + n \rightarrow p + \mu^-$, when the proton has a momentum of ~80 MeV/c the muon direction is $\theta_\mu \approx 8$ mrad for a 10-GeV neutrino. Considering also that the neutrino beam has a divergence of about 2.5 mrad it is not apparent that the signature of reaction 1 is unique.

4. Other backgrounds. The other backgrounds considered are from interactions around the detector which produce secondaries that enter the detector. Those particles which enter the detector from most of its surface can be rejected since the event signature is a negative secondary born in the detector with $\langle\theta_\mu\rangle \approx 7$ mrad. The important background is then entering positive tracks which stop in the detector without producing prongs and with a "stopping angle" of less than about 7 mrad to the muon-neutrino direction. This background rate has not been calculated but should be small when consideration is given to the increased ionization of stopping protons, bremsstrahlung of electrons, direction by delta rays, and direction by changes of curvature of the track.

VI. CONCLUSION

It appears reasonable to study the four-fermion point interaction $\nu_\mu + e^- \rightarrow \nu_e + \mu^-$ in the hydrogen bubble chamber. The event rate is on the order of a few hundred per million photographs. This yield is about the same as the total yield obtained on "free protons" in present day neutrino bubble-chamber experiments. The backgrounds do not appear to be large. The same reaction studied in spark chambers would have a considerable (if not overwhelming) background.

The yields of the other four fermion interactions are truly minuscule. In addition the background problems even in a bubble chamber approach the impossible. These two facts coupled with the physics interest in the "diagonal" interactions present a noteworthy challenge to the experimentalist.

REFERENCES

[1] J. Chadwick, D. Lea, Proc. Cambridge Phil. Soc. 30, 59 (1934).

[2] E. Wollan, Phys. Rev. 72, 445 (1947).

[3] J. Barrett, Phys. Rev. 79, 907 (1950).

[4] C. Baltay and H. W. Wachsmuth, Lepton Pair Production by Neutrinos, National Accelerator Laboratory 1969 Summer Study Report SS-133, Vol. II.

[5] S. L. Glashow, Phys. Rev. 118, 316 (1960).

[6] R. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

[7] J. N. Bahcall, Phys. Rev. 136, B1164 (1964).

[8] L. Heller, LAMS-3013, VC-34, Los Alamos (1964).

[9] Y. Kang and F. A. Nezrick, Neutrino and Anti-Neutrino Flux Using The Empirical π^+, $K^{\pm *}$, National Accelerator Laboratory 1969 Summer Study Report SS-142, Vol. I.

[10] G. Coconni, Empirical Estimates of Secondary Fluxes Produced By 200-BeV Protons, National Accelerator Laboratory 1969 Summer Study Report SS-61, Vol. I.

[11] F. A. Nezrick, Empirical Pion and Kaon Fluxes From 200-GeV Proton Interactions, National Accelerator Laboratory 1969 Summer Study Report SS-134, Vol. I.

[12] Y. W. Kang and F. A. Nezrick, Neutrino Beam Design, National Accelerator Laboratory 1969 Summer Study Report SS-146, Vol. I.

[13] G. R. Kalbfleisch, Electron Neutrinos ν_e, National Accelerator Laboratory 1969 Summer Study Report SS-121, Vol. I.

[14] M. Gell-Mann et al., Phys. Rev. 179, 1518 (1969).

[15] M. Derrick, T. O'Halloran, and R. Kraemer, FAKE Studies on Some Strong and Weak Interactions in the 12-Ft and 25-Ft Bubble Chambers, National Accelerator Laboratory 1968 Summer Study Report A.1-68-89-I, Vol. I, p. 29.

[16] D. D. Jovanovic, Muon Background in the 25-Foot Chamber, National Accelerator Laboratory 1969 Summer Study Report SS-81, Vol. II.

Table I. Neutrino-Lepton Scattering Cross Sections.

Reaction	Threshold E^o (GeV)	Cross section all E	Cross section in limit
(1) $\nu_\mu + e^- \to \nu_e + \mu^-$	10.8	$\sigma_1 = \sigma_0 E \left(1 - \frac{E^o}{E}\right)$	$\sigma_1 = \sigma_0 E$ for $E \geq 100$ GeV
(2) $\nu_e + e^- \to \nu_e + e^-$	0	$\sigma_2 = \sigma_0 E^2 \left(m_e^2 + 2\ me\ E\right)^{-1}$	$\sigma_2 = \sigma_0 E$ for $E > m_e$
(3) $\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$	0	$\sigma_3 = \sigma_0 \left(\frac{E}{6\ m_e}\right) \left[1 - \left(1 + \frac{2E}{m_e}\right)^{-3}\right]$	$\sigma_3 = \frac{\sigma_0}{3} E$ for $E > m_e$
(4) $\bar{\nu}_e + e^- \to \bar{\nu}_\mu + \mu^-$	10.8	$\sigma_4 = \sigma_0 \left(\frac{E}{3}\right)\left(1 - \frac{E^o}{E}\right)\left(1 + \frac{E^o}{2E}\right)$	$\sigma_4 = \frac{\sigma_0}{3} E$ for $E > 100$ GeV

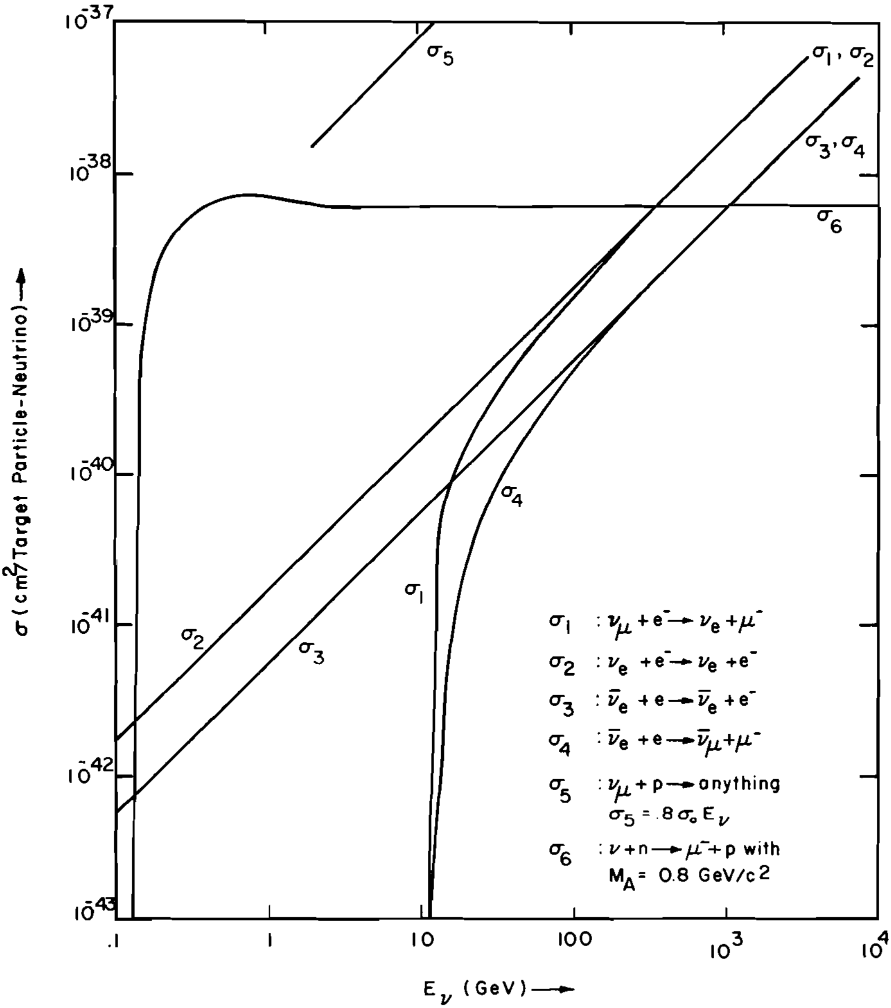

Fig. 1. Energy dependence of the neutrino-lepton scattering cross sections.

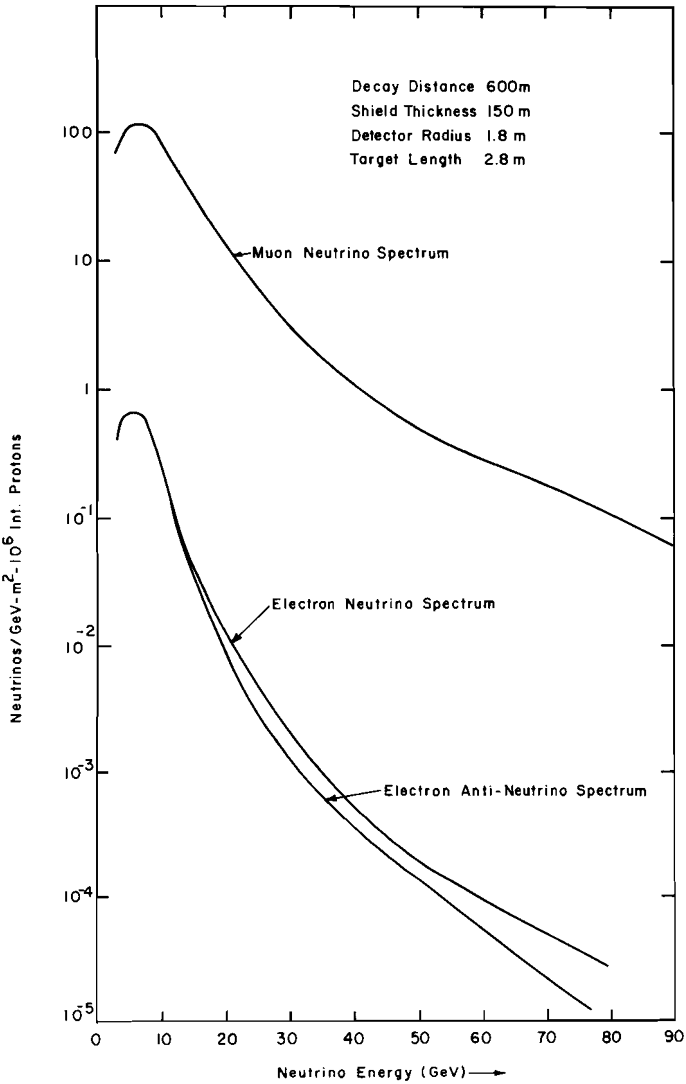

Fig. 2. Energy spectra of muon-neutrinos, electron-neutrinos, and electron-antineutrinos.

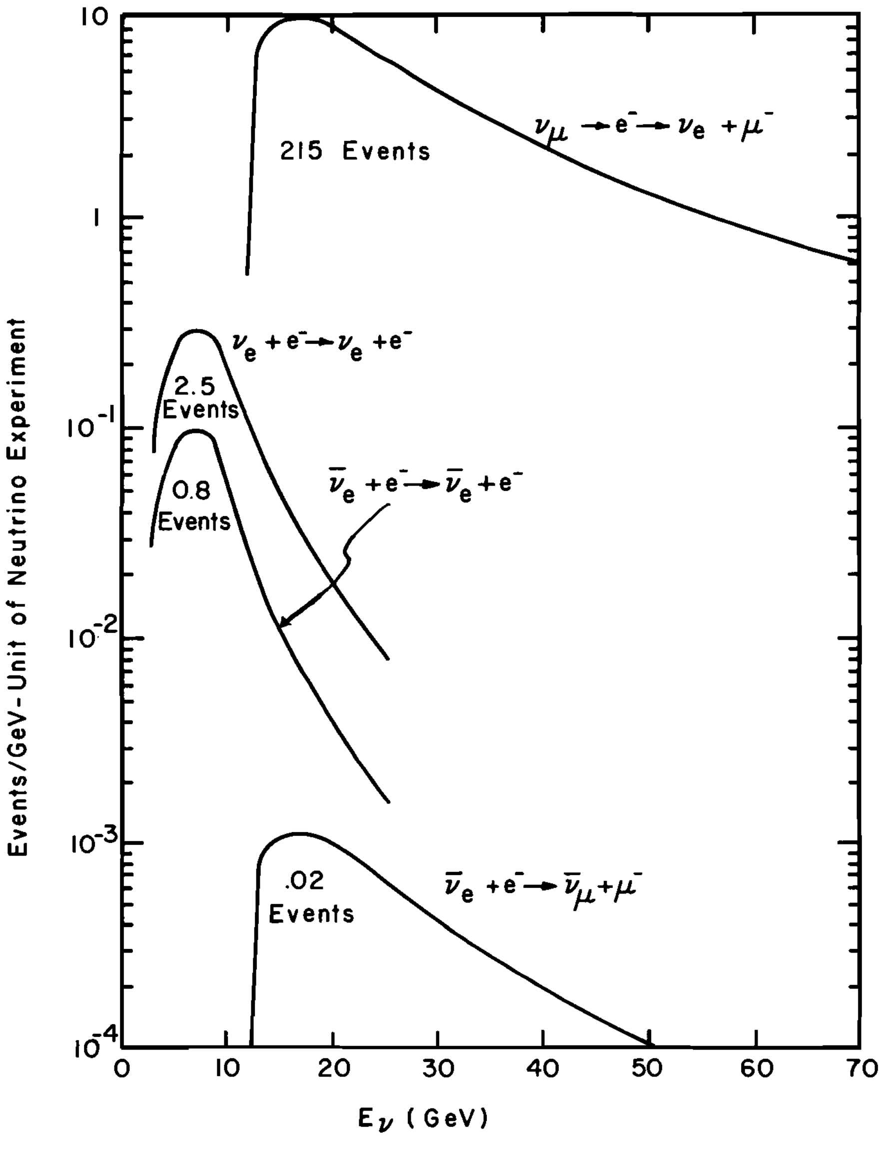

Fig. 3. Event rates of neutrino-lepton scattering reactions.