Comments and Addenda

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Experimental Limit on $\nu_\mu+e^- \rightarrow \nu_\mu+e^-$ and the Existence of Weakly Coupled Neutral Lepton Currents

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A recent analysis by Steiner of the CERN neutrino spark-chamber experiment is employed to derive an upper limit on the elastic cross section for ν_μ-e^- scattering. The limit obtained is just at a level consistent with the theoretical cross section predicted for neutral lepton currents coupled to form a weak isospin-invariant Hamiltonian.

RECENTLY, Steiner[1] has placed an upper limit of

$$\sigma_{\text{expt}}<40\sigma_{V-A} \tag{1}$$

on the cross section for

$$\nu_e+e^- \rightarrow \nu_e+e^-, \tag{2}$$

from an analysis of the 1963–64 CERN neutrino spark-chamber experiment.[2] This result is of great interest, since a recently reported result[3] indicates an anomalously large cross section for the related scattering of electrons by electron-type antineutrinos. The purpose of this note is to point out that an upper limit can also be placed on the cross section for

$$\nu_\mu+e^- \rightarrow \nu_\mu+e^- \tag{3}$$

by the same type of analysis. The limit here is of interest, for (3) can proceed in lowest order directly only through weakly coupled neutral currents by virtue of muon-number conservation or through weakly coupled charged currents mediated by second-order electromagnetic interactions. The result derived below for (3) is, in fact, much more restrictive than that given in (1) since the muon-type neutrino flux is considerably larger than the electron-type neutrino flux as shown[4] in Fig. 1.

The analysis of Steiner[1] indicates that of the 30 electron events observed with $E_e>1$ GeV, which are compatible with the quasielastic process

$$\nu_e+n \rightarrow p+e^-, \tag{4}$$

one event may possibly be identified with process (2). From the universal $V-A$ charged-current theory[5] and a knowledge of the detection efficiency of the experimental setup and the ν_e flux from the K_{e3} decays, Steiner finds that 0.11 ± 0.04 events of type (2) were expected. Poisson statistics then lead him to the upper limit on the experimental cross section quoted in (1) with 90% confidence.

We now note that the one event in 30 singled out is also compatible with process (3), so the same argument is applicable here. Comparison of the neutrino fluxes in Fig. 1 leads to an average ν_μ flux 120 times greater than the average ν_e flux for $E_\nu>1$ GeV and to a rate for (3) 100 times that for (2) if the matrix elements for the two processes are assumed to have the same form.[6] Hence 11 ± 4 events would have been expected, whereas only at most one was seen. With 90% confidence, we

[1] H. J. Steiner, Phys. Rev. Letters **24**, 746 (1970).

[2] J. K. Bienlein, A. Bohm, G. von Dardel, H. Faissner, F. Ferrero, J.-M. Gaillard, H. J. Gerber, B. Hahn, V. Kaftanov, F. Krienen, M. Reinharz, R. A. Salmeron, P. G. Seiler, A. Staude, J. Stein, and H. J. Steiner, Phys. Letters **13**, 80 (1964). See also Ref. 1, footnotes 4 and 6 therein.

[3] F. Reines and H. S. Gurr, University of California at Irvine Report No. UCI 10, pp. 19–28 (unpublished). A revised version of this report has been published by F. Reines and H. Gurr, Phys. Rev. Letters **24**, 1448 (1970), in which a new upper limit of $\sigma_{\text{expt}}<4\sigma_{V-A}$ is quoted for the antineutrino process corresponding to (2).

[4] The neutrino fluxes pictured in Fig. 1 are obtained from Ref. 1 and M. Holder, A. Staude, A. Bohm, H. Faissner, H. J. Steiner, J. K. Bienlein, G. von Dardel, F. Ferrero, J.-M. Gaillard, H. J. Gerber, V. Kaftanov, F. Krienen, C. Manfredotti, M. Reinharz, and R. A. Salmeron, Nuovo Cimento **57A**, 338 (1968).

[5] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958); E. C. G. Sudarshan and R. E. Marshak, *ibid.* **109**, 1860 (1958).

[6] On the basis of a contact interaction between the two lepton currents, one expects a cross section which rises linearly with the incident neutrino energy.

can then place the upper limit

$$\sigma_{\rm expt}(\nu_\mu+e^-\rightarrow\nu_\mu+e^-)<0.40\sigma_{V-A}. \qquad (5)$$

It is interesting to speculate what kinds of neutral lepton currents may exist. For example, if the neutral currents couple only charged leptons (electrons or muons) or only neutrinos, elastic ν_μ-e^- scattering will occur in lowest-order weak interactions only through terms of order Ge^2. On the other hand, it is reasonable to guess that the charged and neutral lepton currents couple so as to form an isospin-invariant Hamiltonian according to

$$H_W{}^l=(G/\sqrt{2})\sum_{l,l'=e,\mu}[l_\lambda{}^{(+)}l_\lambda'{}^{(-)}+l_\lambda{}^{(3)}l_\lambda'{}^{(3)}], \qquad (6)$$

where the lepton current is just $l_\lambda{}^{(k)}=\frac{1}{2}\bar{\psi}_l\tau^{(k)}\gamma_\lambda(1+\gamma_5)\psi_l$, and ψ_l is a two-component isospinor. The first term in (6) contains the charged-current contribution to muon decay, while the second term contributes to the process (3). On the basis of this model, $\sigma_{\rm th}(\nu_\mu+e^-\rightarrow\nu_\mu+e^-)=\frac{1}{4}\sigma_{V-A}$, and the limit in (5) becomes

$$\sigma_{\rm expt}(\nu_\mu+e^-\rightarrow\nu_\mu+e^-)<1.6\sigma_{\rm th} \qquad (5')$$

with 90% confidence. This model is quite consistent[7] with the present information.

If neutral currents exist and (6) is correct, one should note that elastic ν_e-e^- scattering can occur by both charged and neutral currents. The weak leptonic Hamiltonian of (6) predicts that $\sigma_{\rm th}(\nu_e+e^-\rightarrow\nu_e+e^-)=\frac{1}{4}\sigma_{V-A}$. Hence if we reattribute the one possible electron event to (2), the upper limit (1) can be restated as

$$\sigma_{\rm expt}(\nu_e+e^-\rightarrow\nu_e+e^-)<160\sigma_{\rm th} \qquad (1')$$

with 90% confidence. On the other hand, if the one event in question should be identified with (3) rather than (2), the above is reduced to

$$\sigma_{\rm expt}(\nu_e+e^-\rightarrow\nu_e+e^-)<100\sigma_{\rm th}. \qquad (1'')$$

It is rather remarkable that this analysis indicates that the present experimental upper limits are within one order of magnitude of testing the predictions of the weak isospin-invariant Hamiltonian stated in (6). The next generation of neutrino experiments should clarify the matter decisively in the near future.

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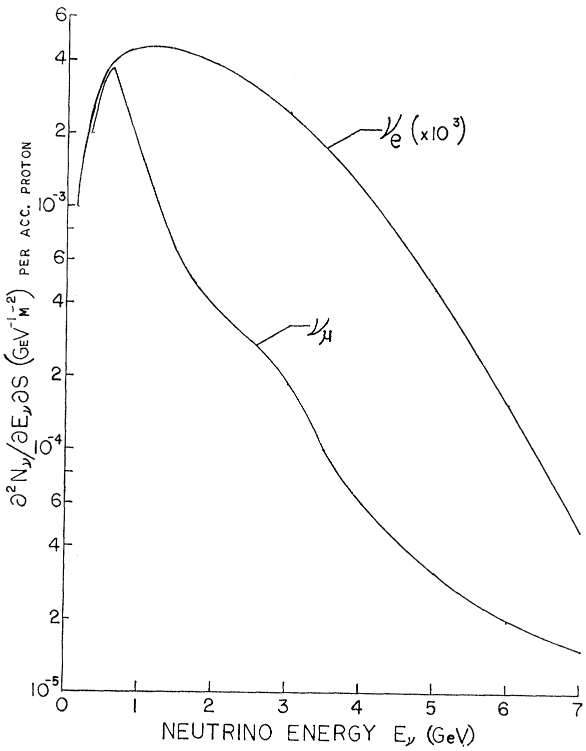

FIG. 1. Energy spectra of muon-type neutrinos and electron-type neutrinos in the CERN neutrino spark-chamber experiment.

[7] We should point out that if it were known that no events of process (3) have really been observed, the upper limit in (5') would become $\sigma_{\rm expt}<1.0\sigma_{\rm th}$ with 90% confidence.