BRIEF REPORTS

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Limit on flavor-changing neutral currents from a measurement of neutrino-electron elastic scattering

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From a measurement of the absolute cross section in $\nu_e e^-$ elastic scattering we have set a limit on flavor-changing neutral currents in the neutrino sector. We find that an off-diagonal, flavor-changing coupling is limited to $1-f_{ee}<0.35$ (90% C.L.).

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Consideration of weak neutral currents has been central to the development of the standard model of electroweak interactions. Much of the formal structure of the standard model derives from the necessity to eliminate flavor-changing neutral currents (FCNC) at the tree level since such currents have not been observed experimentally. It is especially intriguing to investigate flavor changing in the neutrino-lepton current as has been emphasized by Okun' [1]. The occurrence in the Sun of such FCNC has been proposed [2] in connection with the apparent deficit of solar neutrinos. In particular, the elastic scattering of electron neutrinos by electrons, $\nu_e+e^-\rightarrow\nu_e+e^-$, would be affected by the presence of FCNC. We report here a limit on FCNC from a $\nu_e e^-$ experiment [3,4] performed at the Clinton P. Anderson Meson Physics Facility (LAMPF) of the Los Alamos National Laboratory.

Because the $\nu_e e^-$ scattering is mediated by the exchange of both W and Z bosons, the cross section depends upon interference between the two exchange amplitudes. This interference effect requires the outgoing neutrino to be the same type, i.e., ν_e, as the incoming neutrino. If the neutrino flavor has been changed for at least part of the incoming flux, for example $\nu_e\rightarrow\nu_\mu$, the amplitude for the interference effect will be reduced, and the resultant $\nu_e e^-$ scattering cross section changed. A convenient way to search for such a phenomenon would be to compare the measured $\nu_e e^-$ cross section with that expected in the standard model, or equivalently, to compare the measured value of the weak-mixing angle from $\nu_e e^-$ scattering, $\overline{\Theta}_W$, with that extracted from non-neutrino processes. A framework in which to discuss flavor changing in neutrino-lepton currents begins with the introduction [1] of purely phenomenological terms in the weak interaction Lagrangian:

$$\begin{aligned}\mathcal{L}_{\rm int}=&f_{ee}\overline{\nu}_e Z\nu_e+f_{\mu\mu}\overline{\nu}_\mu Z\nu_\mu+f_{\tau\tau}\overline{\nu}_\tau Z\nu_\tau\\&+f_{e\mu}(\overline{\nu}_e Z\nu_\mu+\overline{\nu}_\mu Z\nu_e)+f_{\mu\tau}(\overline{\nu}_\mu Z\nu_\tau+\overline{\nu}_\tau Z\nu_\mu)\\&+f_{e\tau}(\overline{\nu}_\tau Z\nu_e+\overline{\nu}_e Z\nu_\tau)\ ,\end{aligned}\tag{1}$$

that allow for flavor-changing amplitudes. Here the operator $Z=Z_\alpha\gamma_\alpha(1+\gamma_5)$, and to maintain agreement

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with experiment the couplings are normalized to

$$1=f_{ee}^2+f_{e\mu}^2+f_{e\tau}^2=f_{\mu\mu}^2+f_{\mu\tau}^2+f_{e\mu}^2=f_{\tau\tau}^2+f_{\tau\mu}^2+f_{e\tau}^2 . \quad (2)$$

The standard model is recovered by setting $f_{e\mu}=f_{\mu\tau}=f_{e\tau}=0$.

Allowing for flavor-changing amplitudes, the cross section for $\nu_e e$ elastic scattering is given by [1]

$$\sigma(\nu_e e)=G_F^2\frac{s}{\pi}[(\tfrac{1}{2}+\sin^2\Theta_W)^2+\tfrac{1}{3}\sin^4\Theta_W +(1-f_{ee})(1-2\sin^2\Theta_W)] . \quad (3)$$

G_F is the Fermi constant and s is the square of the total energy in the center of mass. From the normalization requirements of Eq. (2), the existence of flavor-changing couplings $f_{e\mu}$ or $f_{e\tau}$ would cause the diagonal coupling f_{ee} to be less than one; thus, effects due to FCNC would be manifest in a nonzero value for the last term.

If we label the weak mixing angle extracted from $\nu_e e^-$ elastic scattering as $\overline{\Theta}_W$, and the weak mixing angle derived from the W-boson and Z-boson mass measurements as Θ_W, we can compare the standard model cross section with Eq. (3) to get

$$1-f_{ee}=(\sin^2\overline{\Theta}_W-\sin^2\Theta_W)[1+\tfrac{4}{3}(\sin^2\overline{\Theta}_W+\sin^2\Theta_W)] \times(1-2\sin^2\Theta_W)^{-1} . \quad (4)$$

Explicit limits can be placed upon the right-hand side of Eq. (4) by the use of current experimental results.[1]

A range of values for $\overline{\Theta}_W$ can be inferred from our measured [3] absolute cross section for $\nu_e e^-$ elastic scattering. As part of a search [4] for a neutrino charge radius, limits were set from this experiment for the weak-neutral-current vector coupling constant, g_V, to be $-0.177 < g_V < 0.187$ at a 90% confidence limit (C.L.). We can now use the standard-model relationship $g_V=-\frac{1}{2}+2\sin^2\overline{\Theta}_W$ and these limits to produce values for $\sin^2\overline{\Theta}_W$. The value $\sin^2\Theta_W=0.227 \pm 0.0057$ is derived from the $W^\pm$ and Z^0 boson masses [7].

These values for $\sin^2\overline{\Theta}_W$ and $\sin^2\Theta_W$ were inserted into Eq. (4) to obtain limits on FCNC. Equation (4) then was solved as a Monte Carlo problem by choosing input values from Gaussian distributions with the appropriate widths. The calculated probability distribution of f_{ee},

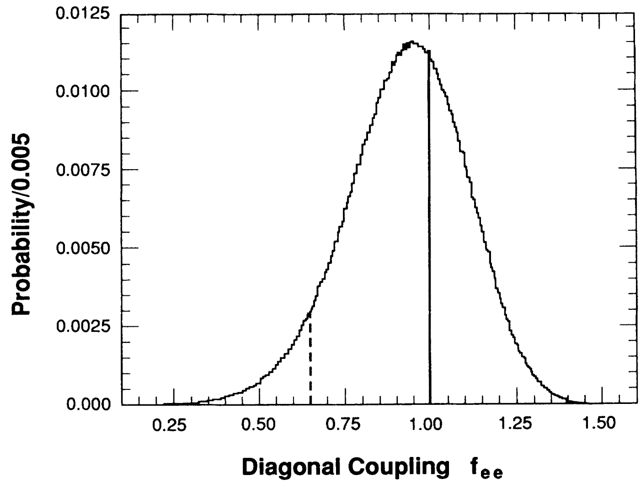

FIG. 1. Probability distribution for f_{ee} measured by the Monte Carlo method described in the text. The central value for f_{ee} is 0.93 ± 0.13; the 90% confidence lower limit, for the allowed region, is given by the dashed line.

where $f_{ee}(x)$ is the probability of obtaining $f_{ee}=x$, is shown in Fig. 1 for a total of 10^6 trials. As seen in Fig. 1, the mean value occurs at $f_{ee}=0.93$. We define the 90% confidence region, for allowed values $f_{ee}<1$, so that the lower limit (LL) of the integral over the probability distribution satisfies

$$\int_{\rm LL}^{1} f_{ee}(x)dx=0.90 . \quad (5)$$

The resultant value for LL is shown in Fig. 1 by the dashed line; it defines the lower limit of f_{ee} to be $f_{ee}>0.65$ (90% CL). This minimum value for the diagonal lepton coupling can be restated as a limit for an off-diagonal, flavor-changing coupling, as

$$1-f_{ee}<0.35 \text{ at } 90\% \text{ C.L.} \quad (6)$$

Alternatively, through use of the normalization relation in Eq. (2), we have a limit on the total strength of flavor-changing transitions of $f_{e\mu}^2+f_{e\tau}^2<0.58$ (90% C.L.). Similar limits on FCNC have been obtained by LoSecco [8] in a model-dependent analysis of atmospheric neutrino rates observed in large water Čerenkov detectors.

In summary, measurement of the absolute cross section for the process $\nu_e+e^-\rightarrow\nu_e+e^-$ has enabled experimental limits to be placed upon flavor-changing neutral currents in the neutrino sector.

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[1] Limits on FCNC derived from preliminary results of this experiment were given in Ref. [1]; limits were also presented in Ref. [1] from a $\overline{\nu}_e e^-$ scattering experiment [5]; however, those limits are no longer valid due to a recent reevaluation [6] of the reactor flux for that experiment.

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