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PRECISION ELECTROWEAK TESTS WITH $\bar{\nu}_e e$ SCATTERING[1]

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Measurements of the cross section for $\bar{\nu}_e e^-$ elastic scattering with unprecedented precision have recently been proposed. The impact of these experiments for detecting possible deviations from the standard electroweak theory is analyzed and compared with that of several other measurements.

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Precise tests of the electroweak theory are able to determine the presence of "oblique corrections" affecting vacuum polarization of the photon, Z, and W bosons through new particles in loops. A language for dealing with these effects has been developed by Peskin and Takeuchi [1] in terms of two parameters S and T, upon which observables depend linearly. $S = T = 0$ may be defined to correspond to "no new physics," given nominal values of the top quark and Higgs boson masses m_t and M_H. Both S and T depend logarithmically on M_H, while T depends quadratically on m_t. Constraints on S and T thus can provide information on the mass of the as-yet-undiscovered Higgs boson as well as restricting the types of new particles that may enter into gauge boson vacuum polarization loops.

Every new experiment can be analyzed in terms of the constraints it imposes on S and T. Thus, for example, it was discovered that the weak charge Q_W measured in parity-violation experiments on heavy atoms such as cesium [2, 3] is sensitive almost exclusively to S.

Recently a measurement of the total cross section for $\bar{\nu}_e e^-$ elastic scattering with unprecedented accuracy has been proposed [4]. In the present note I analyze the potential constraints on S and T following from such a measurement at the proposed 1.3% level. The measurement is found to have much more dependence on S than on T, and to restrict S more closely than measurements of atomic parity violation in the best-studied cesium [5] case. Its impact is compared with those of several other measurements, including the direct W mass determination from hadron and e^+e^- colliders, $M_W = 80.425 \pm 0.034$ GeV/c^2 [6], and the NuTeV measurement of the ratio of neutral-current to charged-current cross sections in deeply inelastic neutrino scattering [7].

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The differential cross section for $\bar{\nu}_e e^- \to \bar{\nu}_e e^-$ may be written as a function of recoil electron kinetic energy T [4] in the standard electroweak theory as

$$\frac{d\sigma}{dT} = \frac{G_F^2 m_e}{2\pi}\left[(g_V+g_A)^2 + (g_V-g_A)^2\left(1-\frac{T}{E_\nu}\right)^2 + (g_A^2-g_V^2)\frac{m_e T}{E_\nu^2}\right] \quad , \qquad (1)$$

where $G_F = 1.16639(1)\times 10^{-5}$ GeV^{-2} is the Fermi coupling constant, m_e is the electron mass, E_ν is the energy of the incident $\bar{\nu}_e$, and the couplings in the lowest-order electroweak theory are $g_A = -1/2$, $g_V = 1/2 + 2x$, with $x \equiv \sin^2\theta$, where θ is the weak mixing angle. The combination $g_V + g_A = 2x$ is due entirely to Z exchange, while the combination $g_V - g_A = 1 + 2x$ contains a contribution of $+2$ from W exchange in the direct channel and $-1+2x$ from Z exchange. One can then write down the S and T dependence of these combinations by noting that they become

$$g_V + g_A = 2x\rho \ , \quad g_V - g_A = 2 + (-1+2x)\rho \ , \quad g_V = 1 + (2x - \frac{1}{2})\rho \ , \quad g_A = -1 + \frac{\rho}{2} \qquad (2)$$

when oblique corrections are included, where [1, 2, 8]

$$x = x_0 + 0.0036S - 0.0026T \quad , \quad \rho = 1 + \alpha T = 1 + 0.0078T \quad , \qquad (3)$$

where x_0 is the nominal value of $\sin^2\theta$ at $S = T = 0$. The parameter $\sin^2\theta$ in this discussion is to be interpreted as $\sin^2\theta_{\rm eff}$, the effective value of $\sin^2\theta$ as measured via leptonic vector and axial-vector couplings: $\sin^2\theta_{\rm eff} \equiv (1/4)(1 - [g_V^\ell/g_A^\ell])$. Its latest value in one analysis [10] is $\sin^2\theta_{\rm eff} = 0.23150 \pm 0.00016$. One can then substitute Eq. (3) into Eq. (2) and linearize in S and T to find

$$g_V = 1/2 + 2x_0 + 0.0073S - 0.0055T \quad , \quad g_A = -1/2 + 0.0039T \qquad (4)$$

The number of expected events in the proposal of Ref. [4] depends on the coupling constants in the following manner [11]:

$$N = 45950(g_V+g_A)^2 + 2277(g_V-g_A)^2 + 4424(g_A^2 - g_V^2) \quad , \qquad (5)$$

where the large disparity between the first two coefficients arises from the fact that the experiment tends to be sensitive to high electron recoil energies, for which the second term in Eq. (1) is small. Taking the expressions (4) for the couplings, one then finds

$$N = 11727 + 297S - 101T \quad . \qquad (6)$$

If N is measured to $\pm 1.3\%$, and if a central value consistent with $S = T = 0$ is found, a band $\pm 152 = 297S - 101T$, or

$$\pm 1 = 1.95S - 0.66T \qquad (7)$$

is found. The results of this constraint are compared with several others in Fig. 1. The ellipses are based on a previous fit [8] to electroweak data, which have not changed greatly subsequently.

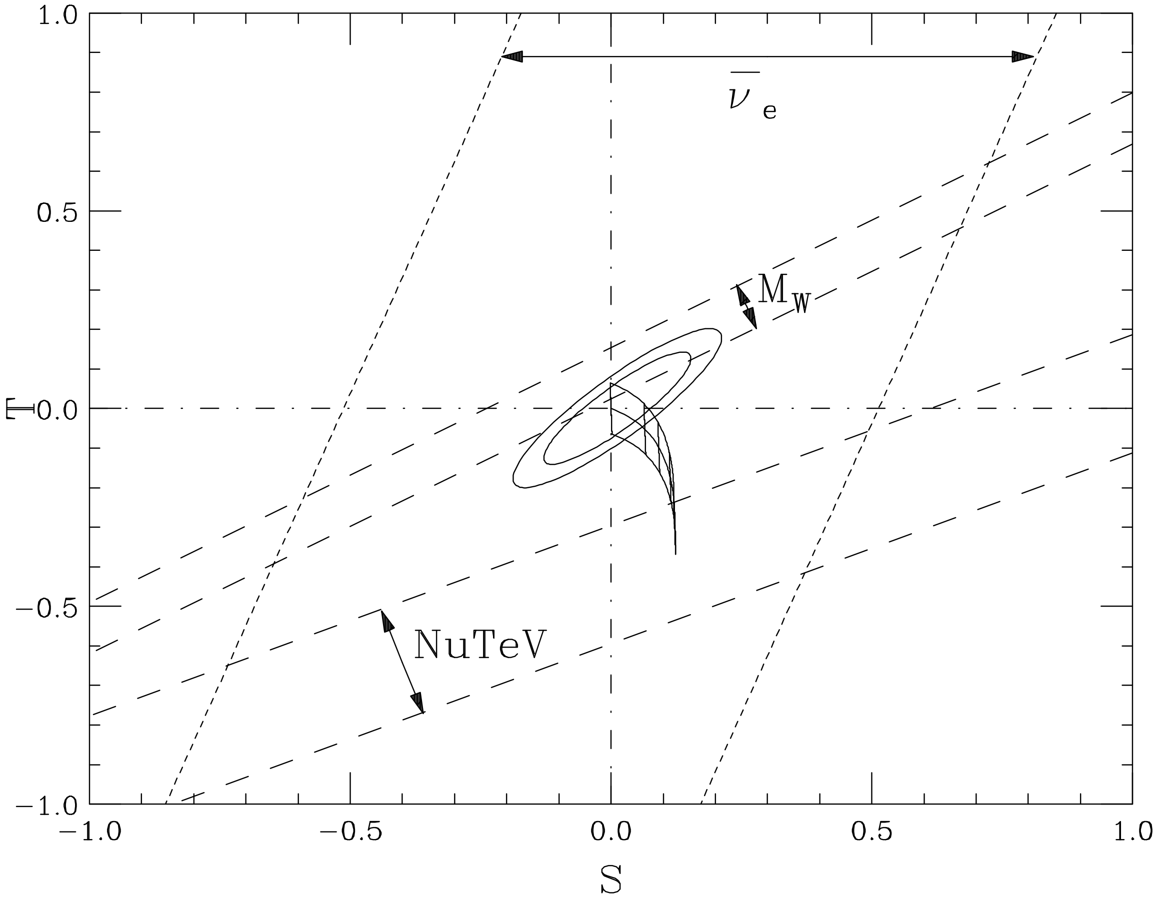

Figure 1: Regions of 68% (inner ellipse) and 90% (outer ellipse) confidence level values of S and T based on comparison of theoretical and experimental electroweak observables [8]. Dash-dotted lines denote the axes $S = 0$ and $T = 0$. Diagonal long-dashed lines denote the constraints from M_W [6] (above the ellipses) and NuTeV [7] (below the ellipses). Diagonal short-dashed lines denote the constraints from the proposed measurement of $\sigma(\bar{\nu}_e e^- \to \bar{\nu}_e e^-)$, assuming a central value entailing $S = T = 0$. Curves emerging from the center of the ellipses denote Standard Model predictions. Nearly vertical lines correspond, from left to right, to Higgs boson masses $M_H = 100$, 200, 300, 500, 1000 GeV; drooping curves correspond, from top to bottom, to $+1\sigma$, central, and -1σ values of m_t.

To put the constraints from $\sigma(\bar{\nu}_e e^- \to \bar{\nu}_e e^-)$ in perspective, no other electroweak observable aside from atomic parity violation has such a large ratio of S to T dependence. For comparison, the latest determination of the weak charge Q_W in cesium finds [5] $Q_W(\mathrm{Cs}) = -72.84 \pm 0.49$, to be compared with the Standard Model prediction [2, 9] $Q_W(\mathrm{Cs}) = -(73.19 \pm 0.13) - 0.800S - 0.007T$, thus entailing $S = -0.45 \pm 0.61$, a band so wide that it cannot be fully displayed in Fig. 1.

Thus, though a measurement of $\sigma(\bar{\nu}_e e^- \to \bar{\nu}_e e^-)$ at the percent level is not likely to restrict the ellipses in precision electroweak fits to S and T, it provides unique information in much the same spirit as atomic parity violation at levels superior to those currently obtained.

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