TWIST-FOUR EFFECTS IN NEUTRAL CURRENT NEUTRINO SCATTERING AND $\sin^2\theta_W$

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ABSTRACT. We have calculated the twist-four, spin-two corrections to neutral current neutrino scattering on isoscalar targets using the operator product expansion, determining the coefficients, which obey the renormalization group equation, from perturbative Quantum Chromodynamics and evaluating the nucleon matrix elements of the operators in the MIT Bag Model. We find these higher twist effects decrease $\sin^2\theta_W$ by about 1 %, considerably less than the present experimental uncertainty, but comparable to the electroweak radiative corrections, which also decrease $\sin^2\theta_W$ by a few percent.

Our result for the neutrino neutral current cross section, including twist-four, spin-two effects is

$$\sigma_{NC}/\sigma_{CC}^{parton} = \frac{1}{2} + \left[-\frac{424}{27}\frac{I_1}{M} + \frac{320}{27}\frac{I_2}{M}\right]\frac{\alpha_s(Q_0^2)}{Q_0^2} + \left(-1 + \left[\frac{1360}{27}\frac{I_1}{M} - \frac{7040}{81}\frac{I_2}{M}\right]\frac{\alpha_s(Q_0^2)}{Q_0^2}\right)\sin^2\theta_W + \left(\frac{20}{27} + \left[-\frac{4192}{81}\frac{I_1}{M} + \frac{256}{3}\frac{I_2}{M}\right]\frac{\alpha_s(Q_0^2)}{Q_0^2}\right)\sin^4\theta_W,$$

where we have integrated over all x and values of $Q^2 \gg Q_0^2$.

To numerically illustrate the effect of the twist-four, spin-two corrections on $\sin^2\theta_W$, we shall assume that all other corrections have already been included in σ_{NC}. That is, we shall equate $\sigma_{NC}/\sigma_{CC}^{parton}$ to the naive result $1/2 - \sin^2\theta_W + \frac{20}{27}\sin^4\theta_W$ evaluated at $\sin^2\theta_W = 0.229 \pm 0.010$, the world average. One then finds $\sigma_{NC}/\sigma_{CC}^{parton} = 0.310$. Using the MIT Bag Model values for integrals $I_1 = 20.36\times10^{-4}$ GeV^3 and $I_2 = 3.21 \times 10^{-4}$ GeV^3 one finds, including the twist-four, spin-two corrections, that $\sin^2\theta_W = 0.226$ for $\alpha_s(Q_0^2) = 0.27$ and $Q_0^2 = 2$ GeV^2.

We conclude that the effect of twist-four, spin-two corrections to the neutral current neutrino cross section on isoscalar targets is to decrease $\sin^2\theta_W$ by about 1 %.

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NON-STANDARD MODELS OF NEUTRAL CURRENTS

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ABSTRACT: Suggestions are made for observation of extra Z bosons and neutral leptons in U(1) symmetries beyond electroweak SU(2)×U(1).

In standard $SU(2)_L\times U(1)_Y$, the electric charge is $Q = I_{3L}+Y/2$. The photon and Z° are mixtures of neutral bosons coupled to I_{3L} and Y. In many theories, $Y = 2I_{3R} + B-L$. If I_{3L}, I_{3R}, and B-L are all gauged, the resulting physical bosons are γ, Z° (in general non-standard), and a new boson Z_χ.

While a "generation" of quarks and leptons $(u,d,e,\nu)_L + (u,d,e)_R$ is anomaly-free in the standard model, the latter must be replaced by $(u,d,e,N)_R$ when I_{3R} is gauged as well. N is a "right-handed neutrino", in general massive. If we normalize charges Q_i so that $\Sigma Q_i^2 = 2$ over members of a generation, define "orthogonality" of charges by $\Sigma Q_\gamma Q_\chi = 0$, and require Q_γ and Q_χ to be linear combinations of I_{3R} and B-L, then[1]

$$Q_\chi = \frac{1}{\sqrt{10}}\left[5I_{3R} + 3(I_{3L} - Q)\right]. \quad (1)$$

In many models it is this charge to which an extra Z couples.

An unmixed Z_χ can be given mass in SU(2)×U(1)×

U(1) by an appropriate choice of Higgs bosons[2]. Define $x = \sin^2\theta$ and $y \equiv (g_\chi^2/[g_L^2+g'^2])(M^2_{Z^\circ}/M^2_{Z_\chi})$. Then neutral current parameters near $Q^2 = 0$ can be fitted for a range of x and y, with the result that $y < 0.11$. When $SO(10) \to SU(5)\times U(1)$[3], one has $g_\chi^2/[g_L^2+g'^2] \gtrsim 1/4$. Then $M^2_{Z^\circ}/M^2_{Z_\chi} \lesssim 0.45$, or $M_{Z_\chi} \gtrsim 140$ GeV/c^2. For smaller g_χ, M_{Z_χ} can be even less.

A light Z_χ can affect electroweak interference in e^+e^- annihilations. We express

$$\frac{d\sigma}{d\Omega}(e^+e^- \to f\bar{f}) \sim (1+2h^f_{VV}\xi)(1+\cos^2\theta) + 4h^f_{AA}\xi\cos\theta, \quad (2)$$

where

$$\xi \equiv -\sqrt{2}\,G_F\, s\,/e^2, \quad (3)$$

and find

$$h^\nu_{VV} = (-\tfrac{1}{2}+2x)^2 + \tfrac{2}{5}y \quad (4)$$

$$h^\nu_{AA} = \tfrac{1}{4}(1+\tfrac{2}{5}y) \quad (5)$$

$$h^u_{VV} = (-\tfrac{1}{2}+2x)(\tfrac{1}{2}-\tfrac{4}{3}x)/(-\tfrac{2}{3}) \quad (6)$$

$$h^u_{AA} = -\tfrac{1}{4}(1+\tfrac{2}{5}y) \quad (7)$$

$$h^d_{VV} = [(-\tfrac{1}{2}+2x)(-\tfrac{1}{2}+\tfrac{2}{3}x)-\tfrac{2}{5}y]/(\tfrac{1}{3}) \quad (8)$$

$$h^d_{AA} = \tfrac{1}{4}(1+\tfrac{2}{5}y) \quad (9)$$

The strongest dependence on y (due to Z_χ) occurs in h^d_{VV}, and can lead to an observable rise in the total cross-section for hadron production. If $\sqrt{s} \approx M_{Z_\chi}$ but $\sqrt{s} \ll M_{Z^\circ}$, one should replace y by $y\,M^2_{Z_\chi}/(M^2_{Z_\chi}-s)$, thereby obtaining an enhancement.

A virtual light Z_χ of mass 50-70 GeV/c^2 can account for an unusual event seen in e^+e^- annihilations by the CELLO collaboration[4] by giving right-handed neutrino pairs. It could have been missed up to now if coupled sufficiently weakly. However, if coupled strongly enough to account for the CELLO event it would lead to $h^\mu_{VV} \gtrsim 0.07$ and $\Delta R \gtrsim 0.14$ at $\sqrt{s} = 44$ GeV.

Searches are possible for several types of neutral leptons ν_H. Their decays in general will take place via mixing with other neutrinos. If neutral current decays are not suppressed, one finds[5]

$$B(\nu_H \to \nu\nu\bar{\nu}) = 10\% \quad (10)$$

$$B(\nu_H \to \nu + \text{hadrons}) = 20\% \quad (11)$$

$$B(\nu_H \to \ell\ell'\nu) = 20\% \quad (12)$$

$$B(\nu_H \to \ell + \text{hadrons}) = 50\% \quad (13)$$

for a wide range of ν_H masses.

1. - Right-handed neutrinos N couple in pairs to Z_χ [the charge (1) is particularly favourable]. If they are not to be an appreciable source of Z_χ mass through $Z_\chi \to N\bar{N} \to Z_\chi$ loops, their masses must be $\lesssim O(M_{Z_\chi}/g_\chi)$. If they are of Dirac type, their masses can be unconstrained, while if of Majorana type they often obey $M_N m_\nu$ = (typical Dirac mass)^2.

2. - Fourth generation neutrinos, belonging to a left-handed isodoublet, should be produced in Z° decays: $B(Z^\circ \to \nu_H\bar{\nu}_H) \simeq 6\%$. Their neutral-current decays will be suppressed by the GIM mechanism.

3. - Mirror neutrinos[6] belong to an $SU(2)_L$ doublet but couple according to $\gamma^\mu(1+\gamma_5)$. Again, $B(Z^\circ \to \nu_H\bar{\nu}_H) \simeq 6\%$, but these objects can have neutral-current decays at the level (10) and (11) because the GIM mechanism is frustated.

The best limits on neutral heavy leptons, coming from analysis of $D \to Ne$ in a beam dump experiment[7], are restricted to a narrow range of mixing amplitudes at the highest mass (≈2 GeV/c^2). Above this mass, few limits exist. (Limits in one recent search are based on full-strength charged current couplings[8].)

The CELLO event mentioned above[4] is compatible with production of a pair of neutral leptons of mass 20.5±1 GeV/c^2: via a virtual Z° (cases 2 or 3 above) or virtual Z_χ (case 1)[2].

The UA1 collaboration sees single jets with unbalanced transverse momentum[9] which may be interpreted as decays $Z^\circ \to \nu_H\bar{\nu}_H$ or (for the most energetic jet) $Z_\chi \to N\bar{N}$[10]. One lepton decays with an all-neutral mode (10); the other decays via (11)-(13) leading to the jet.

To conclude, extra low-mass Z's are possible[11]. For neutral leptons, there are wide gaps in present experimental bounds above 2 GeV/c^2.

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REFERENCES

1) N. Deshpande and D. Iskandar, Nucl.Phys. B167 (1980) 223.
2) J.L. Rosner, CERN-TH. 3894 (1984), submitted to Nucl.Phys.B.
3) R. Robinett and J. Rosner, PR D25 (1982) 3036.
4) H.J. Behrend et al. Phys.Lett. 141B (1984) 145.
5) M. Gronau et al., Phys.Rev. D29 (1984) 2539.
6) G. Senjanovic et al., NSF-ITP-84-28 (1984).
7) F. Bergsma et al., Phys.Lett. 128B (1983) 361.
8) W. Bartel et al., Phys.Lett. 123B (1983) 353.
9) G. Arnison et al., Phys.Lett. 139B (1984) 115.
10) L. Krauss, Harvard Preprint HUTP-84/A021 (1984); M. Gronau and J.L. Rosner, CERN-TH. 3911 (1984), to appear in Phys.Lett.B.
11) See also: V. Elias and S. Rajpoot, paper N° 107.