COMMENTS ON NEUTRAL-CURRENT PHENOMENOLOGY

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Abstract: Some miscellaneous remarks are made on neutral-current phenomenology with emphasis on recent experimental developments.

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There are several reviews on neutral-current phenomenology which are fairly up-to-date[1]. In this written version I restrict myself to a few miscellaneous remarks to supplement the experimental talks presented at this meeting.

The most significant experimental development in neutral-current physics in the past year has been in the area of electron-positron collisions. No longer are we talking about "limits on", or "search for", weak interaction effects. A significant forward-backward asymmetry in

$$e^+e^- \to \mu^+\mu^- \tag{1}$$

has been established beyond any shadow of doubt. The combined PETRA results, reported by Steffen[2] at this meeting, show a 6.5 standard deviation effect !

Quite often it has been said that the observation of a forward-backward asymmetry in (1) demonstrates parity nonconservation in this process. This statement is false. For one thing, whenever we measure $d\sigma/d\Omega$ in collisions of two unpolarized beams, no quantities sensitive to pseudoscalars are detected. Even if the neutral-current interactions were purely parity-conserving, e.g.

$$\mathcal{L}_{NC} = -(2G/\sqrt{2})h_{AA}\ (\bar{e}\gamma_5\gamma_\mu e)(\bar{\mu}\gamma_5\gamma_\mu\mu) \tag{2}$$

with $h_{VV} = h_{VA} = 0$ as in the standard electroweak model with $\sin^2\theta_W$ set equal to 1/4, we would still expect a finite angular asymmetry due to weak-electromagnetic interference.

Another comment I wish to make on (1) concerns factorization, the hypothesis that the neutral-current couplings can be written as the interaction of a single current with itself, as in models with single-Z exchange. Some authors have related the $(\bar{e}e)(\bar{\mu}\mu)$ constants h_{VV}, h_{AA} to the $(\bar{\nu}\nu)(\bar{e}e)$ constants g_V and g_A as follows:

$$h_{VV} = g_V^2 \ , \quad h_{AA} = g_A^2 \ . \tag{3}$$

These are, however, not model-independent relations that follow from factorization and μe universality alone. The "correct" expressions, written nearly five years ago[3], are

$$h_{VV} = g_V^2/c_\nu^2 \ , \quad h_{AA} = g_A^2/c_\nu^2 \tag{4}$$

where c_ν characterizes the strength of elastic $\nu\nu$ scattering. The constant c_ν is one in a large class of gauge models; furthermore by combining νe scattering and parity violation in electron-deuteron scattering we can show that c_ν^2 is one to an accuracy of 15%. But it would be nice if we could study factorization in purely leptonic sector alone.

Fortunately there is a much more direct way to compare the colliding-beam reaction (1) with νe scattering. All we have to do is to deduce from (4)

$$h_{VV}/h_{AA} = g_V^2/g_A^2 \,. \tag{5}$$

Empirically h_{VV} is vanishingly small (< 0.05) because no deviation from the pure QED prediction has been observed in the integrated cross section for (1). In contrast, h_{AA} is sizable, $\sim 1/4$, as expected from the standard model. In νe scattering there is a well known VA ambiguity arising from the fact that, in experiments carried out at energies where the electron mass is negligible, all observable quantities are invariant under the substitution $g_V \leftrightarrow g_A$. The PETRA data, together with the factorization (5), now conclusively force us to choose the axial-vector dominant solution in νe scattering. Even though arguments in favor of $g_A^2 \gg g_V^2$ were obtained prior to the colliding-beam data by comparing the νe scattering data with the SLAC asymmetry etc., it is gartifying to obtain this conclusion based on purely leptonic data alone.

Another recent neutral-current experiment worthy of attention is a beautiful $\mu^\pm$ asymmetry measurement in deep inelastic muon-carbon scattering at CERN SPS performed by a Bologna-CERN-Dubna-Munich-Saclay collaboration. This experiment, reported for the first time at this meeting[4], has established a statistically significant cross section difference between the two reactions

$$\begin{aligned} \mu_R^- + C &\to \mu^- + \text{any}, \\ \mu_L^+ + C &\to \mu^+ + \text{any} \,. \end{aligned} \tag{6}$$

The observed asymmetry due to weak neutral currents (i.e. after correcting for purely electromagnetic two-photon effects etc.) is a 3.4 standard deviation effect with sign and magnitude in agreement with the standard model predictions.

It has sometimes been asked: After the SLAC parity, is there any point in performing an experiment of this kind ? There are two obvious remarks we may make. First, the q^2 range involved in this CERN effort is up to two orders of magnitude larger than the q^2 range covered by the SLAC experiment; as a result the actual magnitude of asymmetry is $\sim 10^{-4}$ at SLAC but up to about 1 % at CERN SPS. Second, the CERN experiment uses muon beams; we therefore have a new test of μe universality. Within the framework of $SU(2) \otimes U(1)$, just as the SLAC experiment has ruled out a weak-isospin doublet of the form

$$\begin{pmatrix} N^o \\ e^- \end{pmatrix}_R ,$$

the CERN experiment rules out a weak-isospin doublet of the form

$$\begin{pmatrix} M^o \\ \mu^- \end{pmatrix}_R ,$$

where N^o and M^o are heavy neutral leptons with no mass restrictions. A more important and subtle difference between the SLAC experiment and the CERN experiment is that, at a purely phenomenological level, they really explore different types of neutral-current interactions. The SLAC asymmetry arises predominantly from the parity-violating $A_{lept}V_{quark}$ interactions while the CERN asymmetry is predominantly due to the partiy-conserving $A_{lept}A_{quark}$ interactions. From this point of view the two experiments provide complementary information.

Of course, if you are a firm believer of μe universality and factorization (the single Z hypothesis), an experimental result like this obtained nearly four years after the SLAC asymmetry measurement is somewhat of an anticlimax. This leads to a more general question: Is it worth accumulating more experimental data in neutral-current physics at low energies ? (My definition of "low energies" is that the q^2 involved is much less than m_Z^2.) Isn't it expected, on the basis of factorization and μe universality, that any new data we obtain in the future will agree with the standard model ?

In the couplings involving ν_e, ν_μ, e, μ, u and d, the standard model has been checked to accuracies of 10 to 15 %[1]. Yet we can still accommodate contributions due to exchanges of additional weak bosons provided their effective couplings at low q^2 are not overwhelmingly strong. It is for this reason that precision data are still worth obtaining.

Specifically, by going through various theoretical papers we can make a catalog of theorists' expectations:

(a) right-left symmetric models with a higher mass scale for right-handed couplings.

(b) multiboson models with an additional coupling of the form $J^{em} \cdot J^{em}$.

(c) supersymmetry models with "extra U(1)".

(d) composite weak boson models with unusual space-time and/or isospin properties.

This list can go on indefinitely as long as the imaginations of model builders are unbounded.

Even if we work only within the framework of the standard model and its "orthodox" extension to grand unification, accurate data are still worth obtaining. Precise measurements of $\sin^2\theta_W$ are of interest for two reasons. First, it is hardly necessary to emphasize that an accurate value of $\sin^2\theta_W$ is needed for the W and Z mass predictions. Second, the "minimal" grand unification model based on SU(5) predicts a value of $\sin^2\theta_W$ tantalizingly close to the experimental value.

The experimenta error in $\sin^2\theta_W$, now in the neighborhood of $\pm$ 0.01, has reached the stage where the higher order corrections can no longer be ignored. To illustrate this point let us recall that by changing $\sin^2\theta_W$ from 0.23 to 0.22, the Z mass, computed according to the uncorrected Weinberg's mass formula, goes up from 88.9 GeV to 90.2 GeV. But the electroweak readiative corrections change the Z mass by a larger amount, by $\sim$4 GeV (upward)[5].

Also important is to note that the electroweak radiative corrections are process dependent; for example, they do not affect $\sin^2\theta_W$ determined from the SLAC parity asymmetry and $\sin^2\theta_W$ determined from deep inelastic neutrino scattering in the same way. Specifically, recent calculations by Llewellyn Smith and others[5] indicate that the radiative corrections alter the uncorrected values of $\sin^2\theta_W$ as follows:

$$\sin^2\theta_W\Big|_{\text{uncorrected}} = 0.230 \text{ (deep inelastic } \nu N) \rightarrow \sin^2\theta_W(m_W)_{\text{corrected}} = 0.219$$

$$\sin^2\theta_W\Big|_{\text{uncorrected}} = 0.224 \text{ (SLAC parity)} \rightarrow \sin^2\theta_W(m_W)_{\text{corrected}} = 0.217 \qquad (7)$$

In this talk I have emphasized some of the issues which are still remaining in low-energy neutral-current physics. The main developments within the next year will undoubtedly depend on the outcome of the current $\bar{p}$ collider search for W and Z. I hope that this is going to be the last talk I give on neutral-current phenomenology before the experimental discovery of the Z boson.

References

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