LEFT-RIGHT SYMMETRIC GAUGE THEORIES

G. Senjanovic, University of Maryland

These models were suggested originally in order to understand the origin of parity violation in low-energy weak interactions,[1] the nonconservation of parity being attributed to spontaneous symmetry breaking. Parity violation is then a low-energy phenomenon which ought to disappear at sufficiently high energies.

The minimal scheme which implements such an idea is based on gauge group $SU(2)_L \times SU(2)_R \times U(1)$[1]. Its properties were recently discussed[2] at length so I will only briefly mention some of the basic features of the model. The main characteristic of the theory is the fact that both left-handed and right-handed fermions are placed in $SU(2)_L$ and $SU(2)_R$ doublets (as is dictated by parity being a good symmetry of an unbroken Lagrangian). The non-invariance of the vacuum under space reflection results in $M_{W_R} \gg M_{W_L}$ and, as a consequence, all low-energy weak processes appear the same as in the $SU(2)_L \times U(1)$ theory, with small corrections [proportional to $(M_{W_L}/M_{W_R})^2$], undetectable in experiments done up to date. What actually happens is that, when the dust settles, the physical gauge mesons turn out to be left-handed light bosons $W_L^{\pm}$ and Z_L (the familiar $W^{\pm}$ and Z^0 of the standard model) and right-handed heavy bosons $W_R^{\pm}$ and Z_R, lower bounds on their masses being:[2]

$$M_{Z_R} \gtrsim 300 \text{ GeV}$$
$$M_{W_R} \gtrsim 240 \text{ GeV} \qquad (1)$$

At high energies one expects deviations from the predictions of the standard model in the sense that parity will become a good symmetry once we reach energies beyond the masses of W_R and Z_R.

I now turn to the predictions of the theory relevant for this workshop, namely what we can expect to observe if we go to higher energies. In order to do that I have to say a couple of words about the properties of neutrinos in this theory. Since both ν_L and ν_R are present, the neutrino naturally has a mass. However, there are two distinguishing possibilities:

(i) Neutrinos are Dirac particles: ν_L and ν_R are combined into a single massive state through the mass term:

$$m_\nu(\bar{\nu}_L \nu_R + \bar{\nu}_R \nu_L).$$

(ii) Neutrinos are Majorana particles[3]: ν_L and ν_R are separately massive two-component Majorana spinors with mass terms: $m_\nu \nu_L^T C \nu_L$ and $M \nu_R^T C \nu_R$ with $M > m_\nu$. This case is particularly appealing since such models can naturally account for the smallness of m_ν. Also, ν_R becomes extremely heavy with $M \approx 100$ GeV.

Now, as far as neutrino-related phenomena are concerned it is clear that there is a drastic difference between cases (i) and (ii). In case (ii) neutrinos interact only with W_L and Z_L and will never know about the existence of W_R and Z_R directly. We would therefore expect full agreement between the standard theory and this model in neutrino interactions, even at very high energies ($E > M_{W_R}$).

Case (i) is quite different in this aspect, since now neutrinos, being Dirac particles, will interact with W_R and Z_R. This has no relevance for neutrino scattering, however, since the prepared initial beam of neutrinos is purely left-handed and will not interact with W_R or Z_R. For the purpose of physics at the Tevatron we may conclude that left-right symmetric models will not be distinguishable from the standard theory in neutrino-charged and neutral-current interactions. I should add, though, that right-handed neutrinos may and will be produced through the exchange of right-handed gauge bosons. A test has been suggested[4] to find the (V,A) structure of hadronic current by analyzing for example, $D \to \bar{K}\pi\ell\nu$ and $D \to K\pi\ell\bar{\nu}$ decays. With perhaps 10^6 D's per day at Tevatron II, such tests may be possible.

To conclude, as far as neutrino beams are concerned, energies in the TeV region will not help unravel the nature of parity nonconservation. Fortunately, the same is not true for muon beams. I will discuss now how one could discover parity restoration at deep inelastic muon capture at very large momentum transfer.

Imagine the process $\mu p \to \nu_\mu X$. Again the situation depends on the nature of neutrinos.

(i) **Dirac ν's.** In this case there exists an interaction $\bar{\mu}_R \gamma_\mu \nu_{\mu R} W^{\mu -}$, where ν_R is the right-handed component of a light neutrino. Parity restoration could be observed by measuring the difference in differential cross sections of polarized muons.[7]

$$\Delta = \frac{d\sigma(\mu_L) - d\sigma(\mu_R)}{d\sigma(\mu_L) + d\sigma(\mu_R)}$$

Of course, one would have competing neutral current processes, which would be distinguished by observing a muon in the final state.

It is a simple exercise to derive the expression for Δ:

$$\Delta = \frac{(m^2_{W_R} - q^2)^2 - (m^2_{W_L} - q^2)^2}{(m^2_{W_R} - q^2)^2 + (m^2_{W_L} - q^2)^2}.$$

Parity becomes an exact symmetry when $q^2 \to \infty$, so at high q^2, we should start seeing effects indicating such phenomena. We give some estimates, taking $m^2_{W_L}/m^2_{W_R} = 1/10$:

$$q^2 = -m^2_{W_L}/10 \qquad |\Delta| \simeq 1-(m_{W_L}/m_{W_R})^4 \simeq 99/100$$
$$q^2 = -2m^2_{W_L} \qquad |\Delta| \simeq 0.88$$
$$q^2 = -10\ m^2_{W_L} \qquad |\Delta| \simeq 0.55$$

As we see, for enormous q^2 one would see dramatic effects of parity restoration: but even at $q^2 \simeq -2M^2_{W_L}$ we see appreciable decrease of Δ compared to the value given by the standard model ($\Delta = 1$). I believe that this process is the most exciting candidate to test the ideas discussed above.

(ii) Majorana ν's. In this case, of course, light neutrinos do not interact with W_R; but heavy ν_R's (called N hereafter) do. Therefore, by capturing a right-handed muon one may actually produce heavy right-handed neutrinos and therefore directly confirm such models (I would like to emphasize again that understanding the smallness of m_ν heavily favors this class of theories.) Since m_N is estimated ~ 100 GeV, even muon beams available at Tevatron energies do not suffice to produce them, but there could be surprises. It is important to work out the details of the production of N's. I would like to conclude by repeating the importance of the use of polarized beams of muons at the Tevatron. These experiments could provide the crucial confirmation of left-right symmetric models which occur so naturally in theories.

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References

1. J. C. Pati and A. Salam, Phys. Rev. **D10**, 275, (1976); R. N. Mohapatra and J. C. Pati, Phys. Rev. **D11**, 566, 2558 (1975); G. Senjanovic and R. N. Mohapatra, Phys. Rev. **D12**, 1502 (1975).

2. G. Ecker, Univ. of Vienna preprint (1973).

3. See R. N. Mohapatra and G. Senjanovic, Fermilab preprint FERMILAB-Pub-80/61-THY, July 1980.

4. G. L. Kane, K. Stowe, and W. B. Rolnick, Nucl. Phys. **B152**, 390 (1979).

5. M. A. B. Beg, R. V. Budny, R. N. Mohapatra, and A. Sirlin, Phys. Rev. Lett. **38**, 1252 (1977).

6. J. C. Pati, S. Rajpoot, and A. Salam, Phys. Rev. **D17**, 131 (1978).

7. G. Senjanovic, Nucl. Phys. **B153**, 334 (1978).