SEARCHING FOR LEFT-RIGHT HIGGS PARTICLES AT THE SSC

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ABSTRACT

The left-right symmetric model predicts ten physical Higgs bosons, some of which are very unusual particles. Findings of an analysis of the prospects for detecting several of these bosons at the SSC are described. It appears that, with some good fortune, detection will be possible, but it is by no means assured.

The Higgs bosons predicted by the left-right symmetric model are an interesting example of the new particles which could be sought with the Superconducting Super Collider (SSC). The feasibility of producing and detecting these bosons at the SSC has been analyzed by a working group which formed at the 1986 Summer Study on the Physics of the SSC, held in Snowmass, Colorado. After very briefly introducing the left-right symmetric (LR) model, I shall describe this analysis and a number of its findings.[1)]

The LR model [2)] contains two weak isospins. The first of them, the left-handed isospin I_L, is caried by the known 82 GeV W boson, which in this model is referred to as W_L. The W_L couples to left-handed quarks and leptons, which are in doublets of I_L. The second isospin, the right-handed isospin I_R, is carried by a so-far undiscovered W boson, W_R. The W_R, whose mass is constrained by the $K_L - K_S$ mass difference to exceed $\sim$ 1.6 TeV,[3)] couples to right-handed quarks and leptons, which are in doublets of I_R. It is worth noting that the neutral leptons to which W_R couples are somewhat special. They are not the right-handed partners of the ordinary light neutrinos, but much heavier particles generally pictured as having masses of (10-1000) GeV. In addition to the two charged gauge bosons, the model also contains two neutral gauge bosons, the known 93 GeV boson "Z_L", and a so-far undiscovered, heavier boson "Z_R". Finally, the model contains a rich Higgs sector.

The Higgs sector must give W_L and Z_L their known masses, and W_R and Z_R their unknown but significantly larger masses. In addition, this sector is designed to provide a natural explanation for the relative lightness of the ordinary neutrinos. Not surprisingly, the Higgs sector which accomplishes these various tasks is more complicated than that of the standard model. The minimal Higgs sector of the LR model consists of three multiplets. First, there is the "bidoublet"

$$\begin{array}{cccc} I_{3R}: & -\frac{1}{2} & \frac{1}{2} & \underline{I_{3L}} \\ & \left(\begin{array}{c} \varphi^o \\ \varphi^- \end{array}\right. & \left.\begin{array}{c} \varphi^{+'} \\ \varphi^{o'} \end{array}\right) & \begin{array}{c} \frac{1}{2} \\ -\frac{1}{2} \end{array} \end{array} , \tag{1}$$

whose members are simultaneously in a doublet of I_L and one of I_R, with the indicated I_{3L}, I_{3R} quantum numbers. Secondly, there is a pair of triplets, one (Δ_L) with $I_L = 1$, and one (Δ_R) with $I_R = 1$:

$$\Delta_L = \begin{pmatrix} \Delta_L^{++} \\ \Delta_L^{+} \\ \Delta_L^{o} \end{pmatrix} , \quad \Delta_R = \begin{pmatrix} \Delta_R^{++} \\ \Delta_R^{+} \\ \Delta_R^{o} \end{pmatrix} . \tag{2}$$

When the gauge symmetry is spontaneously broken, some of the Higgs states become the longitudinal polarization states of the gauge bosons, but no fewer than *ten* physical Higgs particles remain. Neglecting mixing, these are:

$$\Delta_L^{++}\ ,\ \Delta_R^{++}\ ;\ \Delta_L^{+}\ ,\varphi^{+'}\ ;\ Re\varphi^o\ ;\ Re\Delta_R^o\ ,\ Re\varphi^{o'}\ ,\ Im\varphi^{o'}\ ,\ Re\Delta_L^o\ ,\ Im\Delta_L^o\ . \qquad (3)$$

The $Re\,\varphi^o$ is the analogue of the Higgs particle of the standard model. As usual in a gauge theory, the masses of the Higgs particles are not predicted, but in our analysis we pictured them as being between 50 GeV and 2 TeV. We focussed attention on the Higgs bosons $\Delta_{L,R}^{++}$, $\varphi^{+'}$, and $Re\,\Delta_R^o$. What can be said about searching for these particles?

$\underline{\Delta_{L,R}^{++}}$

Being doubly-charged, the Δ_L^{++} and Δ_R^{++} are the most unusual Higgs particles predicted by the LR model. These particles have the further unusual property of being unable to couple to quarks, since no two quarks (nor quark and antiquark) have charges that add up to two. The $\Delta_{L,R}^{++}$ do couple to leptons, and have the highly-distinctive decays $\Delta_{L,R}^{++} \to e^+e^+$ *or* $\mu^+\mu^+$ *or* $\tau^+\tau^+$. These decay modes may well be the only ones, depending on some unknown boson masses. (Note that to detect the unusual ***like-sign*** dilepton decay, one must have a magnet capable of determining the charge of a very energetic e or μ.)

Of course, the fact that that the $\Delta_{L,R}^{++}$ do not couple to quarks makes them hard to produce at the SSC, whose beams consist of protons, which are made of quarks. Nevertheless, the $\Delta_{L,R}^{++}$ can be produced in pp collisions by the Drell-Yan process quark + antiquark $\to$ virtual photon $\to$ $\Delta_{L,R}^{++} + \Delta_{L,R}^{--}$. We assume, as usual, that a standard SSC operating year will yield 10^4 events per picobarn. Then, the Drell-Yan mechanism will produce more than ten $\Delta_{L,R}^{++}\Delta_{L,R}^{--}$ pairs/year if the mass $m_{\Delta_{L,R}^{++}} <$ 100 GeV. Owing to the distinctive like-sign dilepton decay, ten events should suffice for discovery of the Δ_L^{++} or Δ_R^{++}. However, if the mass of one of these Higgs bosons exceeds 100 GeV, the Drell-Yan cross section is no longer sufficient to permit its discovery at SSC.

$\underline{\varphi^{+'}}$

This singly-charged Higgs boson does couple to quarks through the Lagrangian

$$\mathcal{L}_{\varphi^{+'}} = 2^{3/4}\,G_F^{1/2}\,\varphi^{+'}\sum_{f,f'=1}^{3}\Big\{\overline{u_{fL}}M_{ff'}^{u}d_{f'R} - \overline{u_{fR}}M_{ff'}^{d\dagger}d_{f'L}$$

$$+\overline{\nu_{fL}}M_{ff'}^{\nu^D}\ell_{f'R} - \overline{N_{fR}}M_{ff'}^{\ell\dagger}\ell_{f'L}\Big\} + h.c. \qquad (4)$$

Here G_F is the Fermi constant, u_f runs over the three quarks u, c, t, and similarly for d_f, ν_f, ℓ_f (which refers to the charged leptons), and N_f (which refers to the heavy neutral leptons). The 3×3 matrices M^u, M^d, M^ℓ, and M^{ν^D} are, respectively, the up-quark, down-quark, and charged lepton mass matrices, and the neutrino Dirac mass matrix. The matrix M^u is dominated by the large top quark mass, m_t, so that $\sum \overline{u_{fL}} M^u_{ff'} d_{f'R} \approx m_t \bar{t}_L b_R$, and $\sum \overline{u_{fR}} M^{d\dagger}_{ff'} d_{f'L}$ is negligible by comparison. Now, considerations based on $SO(10)$ grand unified theory suggest that $M^{\nu^D} \approx \frac{1}{3} M^u$ and $M^\ell \approx \frac{1}{3} M^d$. (The second of these relations is the origin of the fairly well-satisfied prediction that $m_\tau \approx \frac{1}{3} m_b$.) *We assume that these mass-matrix relations hold*, so that $\sum \overline{\nu_{fL}} M^{\nu^D}_{ff'} \ell_{f'R} \approx \frac{1}{3} m_t \overline{\nu_{\tau L}} \tau_R$, and $\sum \overline{N_{fR}} M^{\ell\dagger}_{ff'} \ell_{f'L}$ is negligible. Then,

$$\mathcal{L}_{\varphi^{+'}} \approx 2^{3/4} G_F^{1/2} \varphi^{+'} \left\{ m_t \bar{t}_L b_R + \frac{1}{3} m_t \overline{\nu_{\tau L}} \tau_R \right\} + h.c. \tag{5}$$

As this discussion illustrates, in our analysis we must make certain simplifying assumptions, so that our results should be considered to be *illustrative* of what might plausibly happen if the LR model is right. However, these results are not completely independent of specific details.

Given its couplings in Eq. (5), the $\varphi^{+'}$ can be produced in pp collisions via $t\bar{b}$ fusion. In this process, a gluon in each of the colliding protons produces a heavy quark pair; a $t\bar{t}$ pair in one proton and a $b\bar{b}$ pair in the other. Then the t joins the $\bar{b}$ to make the $\varphi^{+'}$. Assuming that the bosonic channels into which $\varphi^{+'}$ could in principle decay are not kinematically allowed, the $\varphi^{+'}$ will decay back into $t\bar{b}$ or into $\tau^+\nu$. From Eq. (5) we find, including color factors, that

$$\varphi^{+'} \rightarrow \begin{cases} t\bar{b} & 96\% \text{ of the time} \\ \tau^+\nu & 4\% \text{ of the time} \end{cases} \quad \text{if } m_{\varphi^{+'}} >> m_t \,, \tag{6}$$

and

$$\varphi^{+'} \rightarrow \tau^+\nu \qquad 100\% \text{ of the time if } m_{\varphi^{+'}} < m_t \,.$$

Searches for the $\varphi^{+'}$ through its $t\bar{b}$ decays would be impractical due to enormous backgrounds from QCD two-jet production. Therefore, one would look for the $\tau^+\nu$ decays. Now if, for example, $m_{\varphi^{+'}} = 1$ TeV, and m_t (which influences the production cross section) is 40 GeV, we estimate very conservatively that there will be more than 100 events of the type $pp \rightarrow \varphi^{+'} (\hookrightarrow \tau^+\nu) + \cdots$ per standard SSC operating year.

The principal background will be from $pp \rightarrow W_L (\hookrightarrow \tau^+\nu) + \cdots$. By triggering only on events which contain a high-$p_\perp$ lepton, which would frequently be produced in the decay of the $\bar{t}$ left behind when a t and $\bar{b}$ combine to make a $\varphi^{+'}$, one can reduce this background by a factor of order 70 while retaining approximately half of the $\varphi^{+'}$ signal.[4] After further cuts, one is left with a conservatively estimated 14 signal events and 10 background events. With luck, this $\varphi^{+'}$ signal would be detectable, and the situation will be more favorable if m_t is actually greater than

40 GeV. However, the $\varphi^{+'}$ is not quite so distinctive as the $\Delta^{++}_{L,R}$. In particular, it can be mimicked by Higgs particles from supersymmetrized versions of the standard model.

Δ^o_R

Due to the weak-isospin invariance of the model, the fact that Δ^{++}_R couples to leptons but not to quarks implies that the same is true of any member of the Δ_R triplet. In particular, the $Re\,\Delta^o_R$, which we shall now refer to simply as Δ^o_R, does not couple to quarks, even though it is electrically neutral. This property makes it both unusual, and difficult to produce at the SSC. Now, it *can* be produced at a rate exceeding 3000/year by $Z_R Z_R$ fusion *if* the mass of Z_R is not much larger than the current empirical bound of 0.3 TeV,[5] *and* the mass of Δ^o_R is not much larger than 0.5 TeV. Once produced, if the Δ^o_R is heavy enough to decay back into $Z_R Z_R$, it can be sought through the decay chain

$$\begin{array}{llll} \Delta^o_R \rightarrow & Z_R & + \; Z_R & \\ & \hookrightarrow \ell^+\ell^- & \hookrightarrow N_{\ell' R} & + \; N_{\ell' R} \\ & & \quad | & \quad \hookrightarrow \ell'^{\pm} \; + \text{hadrons} \\ & & \quad \hookrightarrow & \longrightarrow \ell'^{\pm} \; + \text{hadrons} \end{array} \quad . \tag{7}$$

Here $\ell, \ell' = e$ or μ, and $N_{\ell' R}$ is the heavy neutral lepton predicted by the LR model. Since $N_{\ell' R}$ is a Majorana particle, it is "confused" about whether it is a lepton or an antilepton, and half the time the two $N_{\ell' R}$ particles in (7) will decay, as shown, into leptons of the *same* sign, yielding a rather distinctive final state. Now, the Δ^o_R decay channels which potentially compete with $Z_R Z_R$ contain pairs of Higgs particles. If these channels are kinematically closed, the net branching ratio for the decay chain (7) is approximately 0.75%. Then, more than 20 such unusual decays will occur if 3000 Δ^o_R bosons are produced.[6] On the other hand, if the Higgs pair channels are open, then we might see the very distinctive decay chain

$$\begin{array}{lll} \Delta^o_R \rightarrow & \Delta^{++}_R & + \; \Delta^{--}_R \\ & \hookrightarrow \ell^+\ell^+ & \hookrightarrow \ell'^-\ell'^- \end{array} \quad . \tag{8}$$

This chain, which would have an appreciable branching ratio, would serve to reveal the presence of both the Δ^o_R and the Δ^{++}_R, even if the latter is too heavy to be produced via the Drell-Yan mechanism.

If the Z_R is too heavy for Δ^o_R bosons to be produced at a significant rate through $Z_R Z_R$ fusion, these Higgs bosons will still be produced at such a rate if they mix appreciably with the $Re\varphi^o$. The latter is the analogue in the LR model of the usual Higgs particle in the standard model, and has a promising production cross section. Of course, if the Δ^o_R mixes appreciably with the usual Higgs particle, then it inherits the decay modes of the latter, and so is less distinctive than it otherwise might be. Nevertheless, the observation of a decay such as (8) would still point towards the LR model as the underlying theory.

In summary, if the LR model is correct, then with some luck the $\varphi^{+'}$ will be detectable at the SSC. With additional luck, the more distinctive $\Delta^{++}_{L,R}$ and Δ°_{R} will be detectable too.

REFERENCES

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