Brief Reports

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Addendum to "Production of flavor-changing gauge bosons from E_6 at e^+e^- and hadron colliders": Single production in e^+e^- annihilation

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We extend our previous analysis of the production of neutral, non-Hermitian, flavor-changing gauge bosons (W_I) to include single, associated production in e^+e^- collisions. Such gauge degrees of freedom are associated with the $SU(2)_I$ subgroup of E_6 which can lead to new low-energy electroweak interactions and produce distinct decay signatures.

Superstring-inspired E_6 models may lead to an enrichment of the phenomenology of the electroweak sector at relatively low energies.[1] One of the most interesting possibilities is the extension of the usual electroweak gauge group of the standard model (SM) by an additional SU(2) factor whose generators commute with the electric charge Q: $SU(2)_I$. Under $SU(2)_L \times U(1)_Y \times SU(2)_I$, the fermions in the **27** of E_6 transform as

$$\begin{bmatrix} \nu & N \\ e & E \end{bmatrix}_L, \quad \begin{bmatrix} u \\ d \end{bmatrix}_L, \quad (d^c, h^c)_L \,, \qquad \begin{bmatrix} E^c \\ N^c \end{bmatrix}_L, \quad (\nu^c, S^c)_L, \quad h_L, \quad e_L^c, \quad u_L^c \,, \tag{1}$$

with $SU(2)_{L(I)}$ acting vertically (horizontally). Some discussion of the phenomenology of these new $SU(2)_I$ interactions has been given in the literature[2] and in our earlier work.[3] One of the most important new ingredients in this scenario is the existence of new neutral, yet non-Hermitian, gauge bosons (W_I) which couple the ordinary and exotic fermions in the $SU(2)_I$ doublets. In our earlier paper, hereafter referred to as I (Ref. 3), we considered the pair production of W_I's in e^+e^- colliders and single, associated production at hadron colliders. In this addendum, we wish to consider single-W_I production at e^+e^- colliders. This process is especially important in looking for W_I's with masses too large to be pair produced at a given e^+e^- collider energy. W_I carries lepton number ($L=-1$) as well as negative R parity so that it needs to be either pair produced or produced in association with another negative-R-parity state. Present bounds on the *Hermitian* $SU(2)_I$ gauge boson Z_I, together with the rather constrained Higgs sector in E_6 models [containing only doublets and singlets of $SU(2)_I$] restricts $M(W_I) = M(Z_I) = M \gtrsim 200$–$250$ GeV when the mixing of Z_I with the SM Z is ignored.

Turning now to the problem of single-W_I production we consider the reactions $e^+e^- \to W_I E^- e^+$ ($W_I^\dagger E^+ e^-$) and make use of the effective-photon approximation[4] for which the subprocess $\gamma e^- \to W_I E^-$ (and $\gamma e^+ \to W_I^\dagger E^+$) needs to be considered and is shown in Fig. 1. We then find, summing over W_I and $W_I^\dagger$ production,

$$\sigma_{W_I + W_I^\dagger} = 2 \int_{(M+m)^2/s}^{1} dx \, P_{\gamma/e}(x, \sqrt{s}/2) \times n \int_{t_1}^{t_2} dt' \left[\frac{d\hat{\sigma}}{dt'} \right] , \tag{2}$$

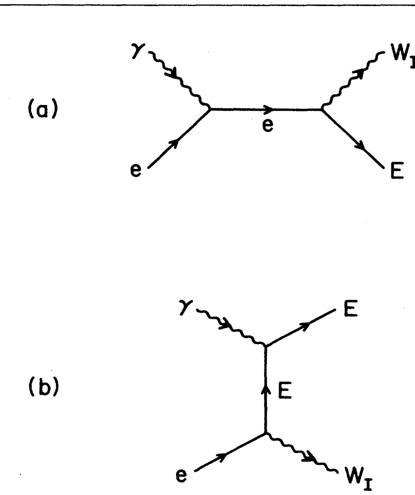

FIG. 1. Diagrams for the process $\gamma e \to W_I E$.

where m is the mass of the exotic fermion E, $P_{\gamma/\epsilon}$ is the photon structure function of the electron, $t'=\hat{t}-m^2$, and

$$t_{1,2}=-\tfrac{1}{2}(\hat{s}-M^2+m^2) \mp \tfrac{1}{2}[(\hat{s}-M^2+m^2)^2-4m^2M^2]^{1/2}\ , \quad (3)$$

with $\hat{s}=xs$, and (using $\alpha^{-1}\simeq 128.0$ and $x_W=0.230=\sin^2\theta_W$) the parton-level cross section is given by

$$\frac{d\hat{\sigma}}{dt'}=\frac{\pi\alpha^2}{4x_W}\frac{1}{\hat{s}^2}\left[\frac{|A|^2}{\hat{s}^2}+\frac{|B|^2}{t'^2}+\frac{2AB^*}{\hat{s}t'}\right], \quad (4)$$

where we have defined

$$\begin{aligned}|A|^2 &= \hat{s}^3M^{-2}+\hat{s}^2t'M^{-2}-\hat{s}^2(1+m^2M^{-2}) \\ &\quad -\hat{s}\hat{t}'(2+m^2M^{-2})\ , \\ |B|^2 &= \hat{s}\,t'^2M^{-1}+\hat{s}t'(m^2M^{-2}-2)+t'^3M^{-2} \\ &\quad -t'^2(1+m^2M^{-2})-2t'm^2(1+2m^2M^{-2}) \\ &\quad +2m^2(2M^2-m^2-m^4M^{-2})\ , \quad (5) \\ AB^* &= -\hat{s}^2t'M^{-2}-\hat{s}^2m^2M^{-2}-\hat{s}t'^2M^{-2}+\hat{s}t' \\ &\quad +\hat{s}(m^4M^{-2}+2M^2)+t'(2M^2-m^2-m^4M^{-2}) \\ &\quad -m^6M^{-2}+3m^2M^2-2M^4\ .\end{aligned}$$

Figures 2 and 3 show the results of our calculation for the total cross section as a function of M for different m values at $\sqrt{s}=1$ and 2 TeV, respectively. For both $\sqrt{s}=1$ and 2 TeV e^+e^- colliders we will assume an integrated luminosity of 30 fb^{-1} in accord with the work in Ref. 5. Since the W_I (and E) must be reconstructed from a final state consisting of one ordinary plus one exotic fermion which also subsequently decays, a reasonably large number of events (N) will be needed before one can claim that W_I has been found. We will take $N=30$ in our discussion below so that (when combined with the assumed integrated luminosity of 30 fb^{-1}) this would imply cross sections as small as 10^{-3} pb will produce W_IE final states at observable rates. Figures 2 and 3 show that it is the combination $m+M$ which is actually constrained; for $\sqrt{s}=1$ (2) TeV we find that the W_IE final state occurs at an observable rate for $m+M \lesssim 920$ (1800) GeV.

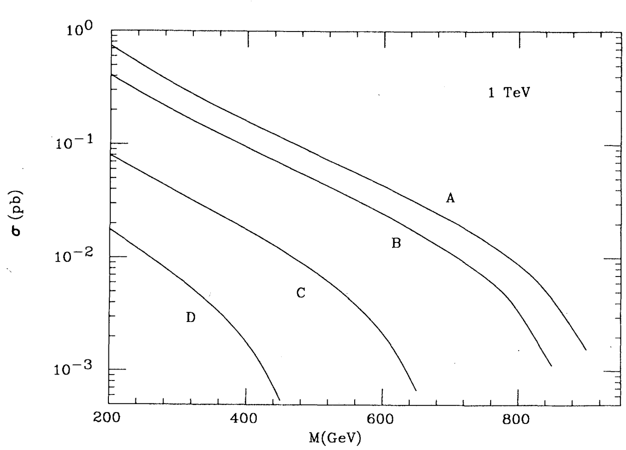

FIG. 2. Total cross section for $W_I+W_I^\dagger$ production in e^+e^- collisions at $\sqrt{s}=1$ TeV as a function of the mass M for different values of m: A, $m=50$ GeV; B, $m=100$ GeV; C, $m=300$ GeV; D, $m=500$ GeV.

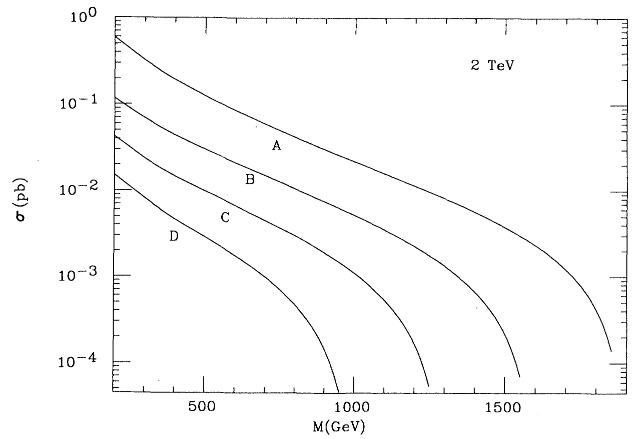

FIG. 3. Same as Fig. 2 but for $\sqrt{s}=2$ TeV. A, $m=100$ GeV; B, $m=100$ GeV; C, $m=300$ GeV; D, $m=500$ GeV.

From the W_I associated-production mechanism discussed above it is clear that single-W_I production will be quite different than single production of other gauge bosons. W_I itself will have a large branching fraction into the $\bar{e}E$ and $\bar{h}d$ modes with $\bar{e}E$ providing the cleanest signature since there is an additional jet in the $\bar{h}d$ case. Once produced, the E from the W_I (and the $\bar{E}$ on the opposite side) will decay into $d\tilde{\bar{u}}$ ($\tilde{d}u$) and $e\tilde{\bar{\nu}}$ ($\tilde{e}\nu$) with the dominance of either mode being sensitive to the relative sizes of the corresponding Yukawa couplings in the superpotential. For example, the leptonic E decay chain results in

$$\text{E}\rightarrow\begin{cases} e\tilde{\bar{\nu}} \\ \tilde{e}\nu \end{cases} \quad (6a)$$

followed by

$$\tilde{\nu}\rightarrow\begin{cases} e\tilde{W} \\ \quad \hookrightarrow \tilde{\gamma}W \\ \qquad\quad \hookrightarrow e\nu\ , \\ \nu\tilde{Z} \\ \quad \hookrightarrow l^+l^-\tilde{\gamma} \end{cases} \quad (6b)$$

$$\tilde{e}\rightarrow\begin{cases} \nu\tilde{W} \\ \quad \hookrightarrow \tilde{\gamma}W \\ \qquad\quad \hookrightarrow e\nu\ . \\ e\tilde{\gamma} \end{cases} \quad (6c)$$

W_I decay thus involves a final state with several charged leptons as well as missing p_T from $\tilde{\gamma}$'s and/or ν's. W_I decay into the $\bar{h}d$ will result in a similar final state with additional jets which in either case results in a final state with a very large effective mass. It is thus clear that the W_I production and decay is sufficiently unique to distinguish it from any conventional SM background due to other processes.

In conclusion we have examined the cross section for and decay signatures of single-W_I production in e^+e^- annihilation. This mechanism leads to the production of an exotic fermion (E) in addition to the W_I in the final states so the production search limits we obtain are for the sum of the masses of both particles. The W_I and E decays lead to a final state which is very distinctive with leptons, missing p_T, and (possibly) jets.

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[3]T. G. Rizzo, Phys. Rev. D **38**, 71 (1988).
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