Addendum to "Doubly charged Higgs bosons and lepton-number-violating processess"

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We consider the process $e^{\pm} \rightarrow \Delta e^{\mp}$, where Δ is a doubly charged Higgs boson associated with Majorana neutrino masses and lepton-number-violating processes. This reaction can be examined at $\sqrt{s} \simeq 100$ GeV using the Stanford linear collider with a measurable cross section. Subsequent Δ decay produces a lepton-number-violating reaction which is clean without any large backgrounds. This would help us to study the Higgs sector and the nature of neutrino masses.

Recently, Renard[1] has considered the phenomenology of $\gamma e^{\pm}$ collisions at the Stanford linear collider[2] (SLC) with total energies $\sqrt{s} \simeq 100$ GeV in the center of mass. One of the reactions not discussed in this work is the single production of doubly charged Higgs bosons which are associated with Majorana neutrino masses and lepton-number violation in the standard model[3] and in extended models such as the left-right-symmetric model.[4] In an earlier work,[5] hereafter referred to as I, we considered the detailed phenomenology of such exotic Higgs bosons. Here, we would like to extend this previous analysis in I to include the reactions

$$\gamma e^{\pm} \rightarrow \Delta^{\pm\pm} e^{\mp} . \tag{1}$$

The three amplitudes contributing to this process are shown in Fig. 1; neglecting the electron mass these can be written as

$$\begin{aligned}
\mathfrak{M}_{(a)} &= \bar{u}(k_2)\, ieQ\gamma_\mu \frac{i}{\not k_1 + \not k_2}\kappa(1+a\gamma_5)u(l)\epsilon^\mu , \\
\mathfrak{M}_{(b)} &= \left[\bar{u}(k_2)\kappa(1+a\gamma_5)\frac{i}{\not k_2 - \not P} - ieQ\gamma_\mu u(l)\right]\epsilon^\mu , \\
\mathfrak{M}_{(c)} &= \bar{u}(k_2)\kappa(1+a\gamma_5)u(l)\frac{i}{(k_1-P)^2 - M^2} \\
&\quad \times 2ieQ(k_2 - l + P)_\mu \epsilon^\mu ,
\end{aligned} \tag{2}$$

where Q is the charge of the initial $e^{\pm}$ and M is the Δ mass. The $ee\Delta$ coupling is given by

$$\kappa(1+a\gamma_5) \tag{3}$$

with $a = \pm 1$ depending on whether the neutrinos are left or right handed; κ is a constant of order g^2 in the left-right-symmetric model[4,5] (LRSM).

The differential cross section for the process can be written as

$$\frac{d\sigma}{dz} = \alpha\kappa^2 \frac{1}{s^2}(s-M^2)\left\{-\left[\frac{1}{s}-\frac{1}{u}\right]^2 (u-M^2)(s-M^2) + tM^2\left[\left[\frac{1}{s^2}+\frac{1}{u^2}\right] + 4\left[\frac{1}{u}+\frac{1}{s}\right](t-M^2)^{-1} + 8(t-M^2)^{-2}\right]\right\} , \tag{4}$$

where $\sqrt{s}$ is the center-of-mass energy and

$$u \equiv -\tfrac{1}{2}(s-M^2)(1-z) , \quad t \equiv -\tfrac{1}{2}(s-M^2)(1+z) , \tag{5}$$

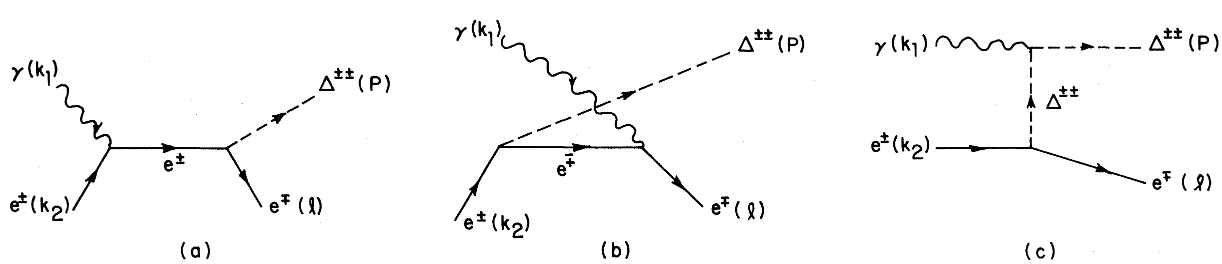

FIG. 1. Three subprocesses which contribute to the process $\gamma e^{\pm} \rightarrow \Delta^{\pm\pm} e^{\mp}$.

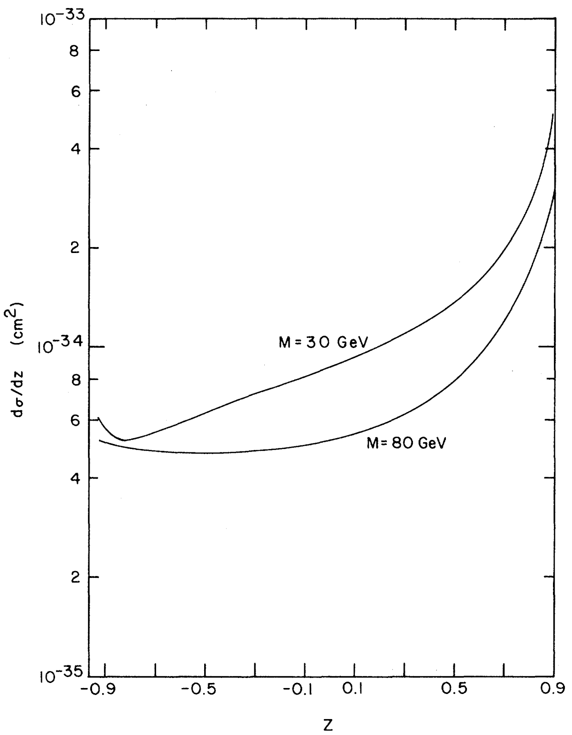

FIG. 2. Differential cross section $d\sigma/dz$ for $\sqrt{s}=100$ GeV for $M=30$ and 50 GeV with $\kappa^2=0.1$.

with $z=\cos\theta$. θ is the angle between the incoming $e^{\pm}$ beam and the outgoing Δ. Figure 2 shows $d\sigma/dz$ as a function of z for $M=30$ and 80 GeV with $\sqrt{s}$ $=100$ GeV; note the cross-section maximum occurs in the forward direction due to the u-channel pole but is relatively flat in z for moderate z values. We have taken $\kappa^2=0.1$ for these curves.

Figure 3 shows the integrated cross section as a function of the Δ mass for $\kappa^2=0.1$; note $\sigma \gtrsim 3$ $\times 10^{-34}$ cm^2 for most values of M considered. This result is independent of whether the initial beam is e^+ or e^- and independent of whether $a=\pm 1$ as is also true for $d\sigma/dz$. With a luminosity of 2×10^{30} cm^{-2} sec^{-1} we find a production rate of $\gtrsim 52$ events/day of this kind.

The Δ in this mass range would then decay into a like-sign lepton pair, say $\mu^{\pm}\mu^{\pm}$ or $\tau^{\pm}\tau^{\pm}$:

$$\gamma e^{\pm} \rightarrow \Delta^{\pm\pm} e^{\mp} \searrow \mu^{\pm}\mu^{\pm},\ \tau^{\pm}\tau^{\pm} \qquad (6)$$

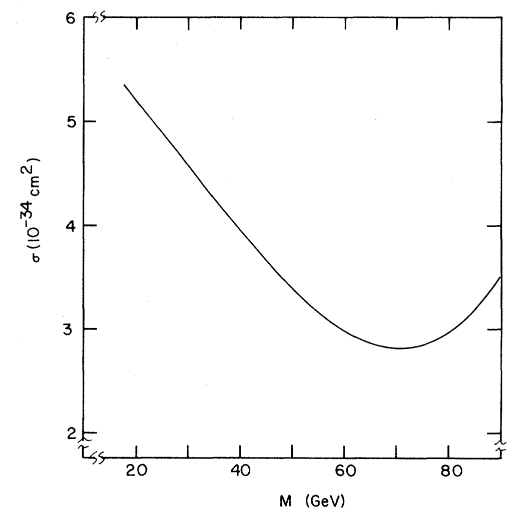

FIG. 3. Total cross section for $\sqrt{s}=100$ GeV as a function of M with $\kappa^2=0.1$.

which signals a lepton-number violation by two units. Note the Δ decay into an $e^{\pm}e^{\pm}$ pair would have a large background from Dalitz pair production while these other modes are clearly lepton-number violating and provide a unique signal.

We have chosen κ^2 large, since in the LRSM we find (as shown in I)

$$\kappa \simeq M_N/V_R\ , \qquad (7)$$

where M_N is the mass of the right-handed Majorana neutrino $\simeq 100$ GeV and V_R is the vacuum expectation value associated with the breaking of the right-handed mass scale $\simeq 250$ GeV. Within this model $\kappa \approx g^2$ and so we take $\kappa^2 \simeq 0.1$; other values of $d\sigma/dz$ and σ can be obtained from these results simply by rescaling the value of κ.

Observation of events of this kind would clearly indicate the existence of lepton-number-violating couplings and strongly indicate that neutrinos are of the Majorana variety. For reasonable Δ masses it appears that single-Δ production may be possible at the SLC with measurable rates.

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