LOOKING FOR SUPER SYMMETRY SIGNALS IN „NEUTRINO--ELECTRON SCATTERING"

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The processes sneutrino-electron scattering and photino-electron scattering are considered. The expressions for the recoil electron energy distribution and the longitudinal polarization asymmetry are given and these are different from the corresponding expression for the neutrino-electron scattering. Hence detailed study of these observables is suggested as a test for "contamination" of light super symmetric particles in a neutrino beam.

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1. *Introduction*

There has been considerable interest in looking for super symmetric signals for the last few years. The interpretation of UA2 anomalous events [1], by invoking supersymmetric partner of quarks and gluons [2] has further accelerated the interest in these theories. In addition to being theoretically appealing and a piece of data consistent with these theories, the susy theories provide a guide to look for physics beyond standard model.

Most models that are consistent with experimental data assume conservation of R-parity. In these models, the lightest super-symmetric particle (LSP) is stable. In many models, sneutrino or the lightest eigen state of neutral gauge-higgs fermion sector is taken as LSP. The present day experiments does not exclude zero mass for sneutrino and photino [3]. There are experimental limits on masses and interaction strengths of supersymmetric particles from the studies of $e^+e^- \to e+$missing energy, $e^+e^- \to \gamma+$missing energy and $a \to b+$missing energy [4]. In Ref. [3] the analysis of Adeva et al. allows $M_{\tilde{\nu}} = 0$ if $M_{\tilde{W}} > 40$ [GeV] and $M_{\tilde{\gamma}} = 0$ if $M_{\tilde{e}} > 36$ [GeV]. Similarly the analysis of $\mu^- \to e^-+$missing energy, $\tau^- \to e^-$ or μ^-+missing energy can limit $M_{\tilde{W}}$ [5]. However, using K, π, decays in limiting $M_{\tilde{W}}$ involves assumptions regarding squark sector. In all the above analysis, one can only exclude some regions in SUSY parameter space. Using the value of SUSY parameters from the allowed regions in the parameter space one can see that $\tilde{\gamma}$e, $\overset{(\tilde{-})}{\gamma}$e scattering have comparable cross sections to that of νe e.g. $\tilde{\gamma}$e scattering cross section is an order of magnitude higher to that of νe, if $M_{\tilde{\gamma}} = 0$, $M_{\tilde{e}} = 40$ [GeV]. Hence if $\tilde{\gamma}$e, $\overset{(\tilde{-})}{\nu}$e scatterings could be determined from νe scattering by using Y-distribution of polarizations of final electron then it is possible to detect contamination of γ, $\overset{(-)}{\tilde{\nu}}$ in a $\overset{(-)}{\nu}$ beam.

The contamination of sneutrino in a laboratory neutrino beam can occur due to K, π, μ decays. In these decays sneutrino emission is not negligible if W-ino and squark masses are not very high. In hadron-hadron machines (e.g. Tevatron, where the most efficient production of highly energetic neutrino beams are obtained). $\tilde{\gamma}$ or $\tilde{\nu}$ could be produced along with some very heavy susy particles. This may considerably reduce the energy of $\tilde{\nu}$ or $\tilde{\gamma}$ and it could be an order of magnitude less than that of neutrinos. However as pointed out earlier in susy models with $M_{\tilde{e}} = M_W/2$ the $\tilde{\gamma}$ cross section is an order of magnitude higher than νe elastic cross section. The neutrino beams at Z^0, $W^\pm$ "factories", which may become possible in future, can contain $\tilde{\nu}$ or $\tilde{\gamma}$. In addition, the cosmic neutrino beams and the neutrinos coming from supernowa-II could contain contamination of $\tilde{\nu}$ or $\tilde{\gamma}$. For example the neutrinos in supernovae are produced in rapid cooling of the star preceding explosion and in that photinos can also be produced with comparable strength. The ultra high energy ($\gtrsim$ 1 [Tev]) astrophysical neutrino flux associated with γ-ray point sources like cygnus X-3 may also contain contamination of LSP's such as neutrinos and photinos. In literature the supersymmetric particle contamination of ultra high energy cosmic rays has been considered [6].

In this note we study the electron recoil energy distribution and longitudinal polarization of final electron in photino and sneutrino electron scatterings, to suggest a way to find contamination of sneutrinos and photino in a beam of neutrinos. This is a signal for supersymmetry. Our test involving average value of Y is independent of parameters of susy models and this is the advantage of using these tests to detect contamination of $\tilde{\gamma}$, $\tilde{\nu}$ in a neutrino beam.

2. *Sneutrino-electron scattering*

In our analysis, we consider the sneutrinos to be light susy particles and neglect the terms proportional to their masses and electron mass. The Feynmann diagrams that contribute to this scattering are given in Fig. 1. Using Fig. 1, in the high energy limit the

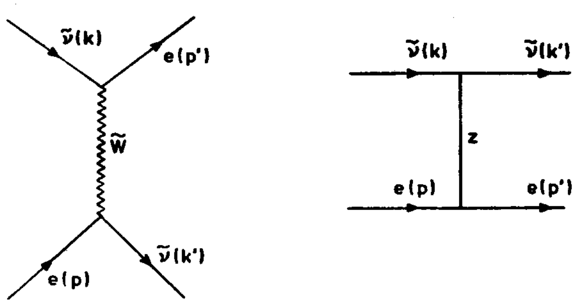

Fig. 1. The diagrams contributing to the amplitude given in Eq. (2.1). The symbol ~ on a particle stands for supersymmetric partner of the particle. The symbols in parentheses indicate their momenta

amplitude for the scattering can be written as,

$$M_{fi} = \left\{ \frac{gA}{M_Z^2} (\bar{u}(p')(\not{k}+\not{k}')(d_V - d_A\gamma_5)u(p)] + \frac{gB}{M_Z^2} [\bar{u}(p')(\not{k}-\not{k}')(d_V - d_A\gamma_5)u(p)] + \frac{h}{M_{\tilde{W}}^2} [\bar{u}(p')(\not{p}-\not{k}')(g_S - g_P\gamma_5)u(p)] \right\}. \tag{2.1}$$

The terms in the first two square brackets are the contributions due to Z-boson exchange and these are kept general. In the last square bracket is the contribution of W-ino exchange. The symbols M_Z and $M_{\tilde{W}}$ are masses of Z-boson and W-ino, respectively. In many supersymmetric models the possible couplings are restricted. The second term in the expression for the amplitude does not contribute in the high energy limit, since these terms are proportional to electron mass. If the coupling of $\tilde{W}$-e-$\tilde{v}$ is assumed to be flavour diagonal then the third term does not contribute to $\overset{(\tilde{-})}{\nu}_{\mu,\tau}$ e^-scatterings.

Using the expression for amplitude given in Eq. (2.1), the recoil energy distribution of unpolarized electrons can be written as

$$\frac{d\sigma}{dY'} = \left\{ \frac{ME_{\tilde{v}}}{2\pi} \left[\frac{g^2A^2}{2M_Z^4}(d_V^2 + d_A^2) + \frac{h^2(g_S^2+g_P^2)}{4M_{\tilde{W}}^4} - \frac{gAh(d_V g_S + d_A g_P)}{M_Z^2 M_{\tilde{W}}^2} \right] \right\}. \tag{2.2}$$

The symbol Y' is the ratio of the energy of final electron to the energy of initial sneutrino, $E_{\tilde{v}}$. The dependence of recoil electron energy spectrum on only the first powers of Y' is expected, since it is scalar fermion scattering. The average value of recoil electron energy is 1/3 and independent of coupling strengths and masses of intermediate particles. Even with flavour non-diagonal terms, (some susy models have flavour non-diagonal terms) and for an arbitrary mixture of different types of incident sneutrinos the average value of Y does not change. This is very important in looking for sneutrino contamination in a neutrino beam, because one does not know the flux of different types of sneutrinos in a neutrino beam. In general, contamination of sneutrino will bring down the value of $\langle Y \rangle$ in neutrino-electron scattering.

3. Photino-electron scattering

We consider the photinos to be light supersymmetric particles. As in sneutrino — electron scattering we do not keep the masses of photino or electron. The diagram which contribute to this process are given in Fig. 2. The amplitude for this reaction can be written as,

$$M_{fi} = f \left\{ \left[\bar{u}(p')(1-\gamma_5)u(k') \frac{1}{(p+k)^2 - M_{\tilde{e}_R}^2} \bar{u}(k)(1-\gamma_5)u(p) \right] \right.$$

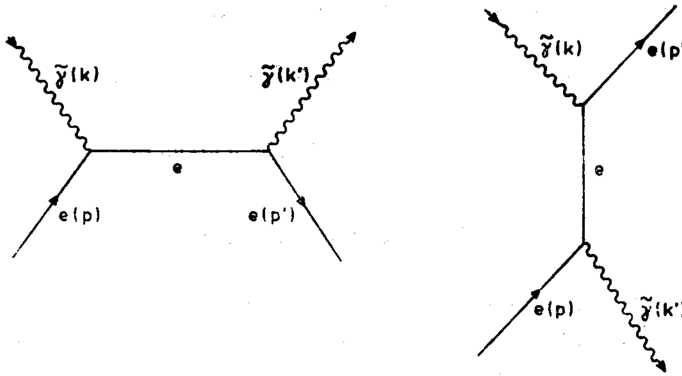

Fig. 2. The diagrams contributing to the amplitude given in Eq. (3.1)

$$+\left[\bar{u}(p')\,(1+\gamma_5)u(k')\,\frac{1}{(p+k)^2-M^2_{\tilde{e}_L}}\,\bar{u}(k)\,(1+\gamma_5)u(p)\right]+[k\leftrightarrow k']\Big\}\,. \tag{3.1}$$

For writing down Eq. (3.1), the vertex term for spinor-spinor-scalar was allowed to be general (but not derivative). The masses of left and right handed scalar electrons are allowed to be different.

Using the amplitude given in Eq. (3.1), the differential energy distribution of recoiled electrons can be written as

$$\frac{d\sigma}{dY''}=\frac{fME_{\tilde{\nu}}}{4\pi}\left(\frac{1}{M^2_{\tilde{e}_R}}+\frac{1}{M^2_{\tilde{e}_L}}\right)[1+(1-Y'')]. \tag{3.2}$$

The symbol $E_{\tilde{\nu}}$ is the initial photino energy and "Y" is the ratio between the recoil electron energy and the initial photino energy. The average value of recoil electron energy is a fixed value 7/16, independent of coupling strength and mass of scalar electron. Using the susy parameters as given in Ref. [5] the total cross section of $\tilde{\gamma}$e scattering is 3.574 $(M_W/M_{\tilde{e}})^4$ times the total cross section of $\nu_{\mu,\tau}$e scattering. If $M_{\tilde{e}} = 1/2\ M_W$ (see Ref. [3]) then the factor is as large as 57.184.

4. *Polarization of final electron*

Using Eqs. (2.1) and (3.1) the final electron longitudinal polarization asymmetry can be written as

$$\left(\frac{\sigma_L-\sigma_R}{\sigma_L+\sigma_R}\right)_{\tilde{\nu}e}=\frac{-\left[\frac{g^2A^2}{M_Z^4}(4d_Vd_A)+\frac{h^2}{M_W^4}(2g_Sg_P)+\frac{gAh}{M_Z^2M_{\tilde{W}}^2}(d_Vg_P+d_Ag_S)\right]}{\left[\frac{g^2A^2}{M_Z^4}2(d_V^2+d_A^2)+\frac{h^2}{M_{\tilde{W}}^4}(g_S^2+g_P^2)-\frac{gAh}{M_Z^2M_W^2}4(d_Vg_S+d_Ag_P)\right]} \tag{4.1}$$

$$\left(\frac{\sigma_L-\sigma_R}{\sigma_L+\sigma_R}\right)_{\tilde{\gamma}e}=\frac{f^2ME_{\tilde{\nu}}}{4\pi}\,\frac{7}{16}\left(\frac{M^4_{\tilde{e}_L}-M^4_{\tilde{e}_R}}{M^4_{\tilde{e}_L}+M^4_{\tilde{e}_R}}\right) \tag{4.2}$$

The observable, longitudinal polarization asymmetry in the case of photino electron scattering depends on the masses of left and right handed electrons. Its magnitude is maximum when the couplings are either purely left or right handed, and it is minimum when the masses of right and left handed selectrons are same. The magnitude of asymmetry is equal for sneutrinos ($\tilde{\nu}$e) and neutrino (νe) electron scatterings, and it is small for the experimentally determined values of d_V and d_A. For electronic type sneutrino the magnitude depends on $M_{\tilde{W}}$. Photino contamination in a neutrino beam can considerably change longitudinal polarization asymmetry if masses of left handed and right handed selectrons are different.

5. *Comments and discussion*

Neglecting the masses of neutrinos electrons in V, A model one can write the recoil electron energy distribution of neutrino electron scattering as [7]

$$\frac{d\sigma}{dY} = \frac{MG^2E_\nu}{2\pi}[A+B(1-Y)^2],$$

where

$$A = (d_V+d_A)^2$$
$$B = (d_V-d_A)^2 \tag{5.1}$$

and $d_{V,A}$ are defined in Eq. (2.1).

The recoil electron energy distribution of neutrino scattering (Eq. (2.2)) is different from the neutrino electron scattering (Eq. (5.1)). Hence the first moment of

$$\langle Y \rangle = \int_0^1 Y \frac{d\sigma}{dY}dY \Big/ \int_0^1 \frac{d\sigma}{dY}dY \tag{5.2}$$

is 1/3 for sneutrino electron scattering, independent of any parameter of supersymmetric theories. Using the experimentally [8] determined value of $\sin^2\theta = 0.226$ the corresponding observables in different types of neutrino electron scatterings are:

$$\langle Y \rangle_{\nu_e e} = 0.49590; \quad \langle Y \rangle_{\bar{\nu}_e e} = 0.28257;$$
$$\langle Y \rangle_{\nu_{\mu,\tau} e} = 0.41491; \quad \langle Y \rangle_{\bar{\nu}_{\mu,\tau} e} = 0.45377.$$

Hence comparison of experimentally determined value of $\langle Y \rangle$ in neutrino-electron scattering can set a limit on sneutrino contamination in a neutrino beam. Ideally, one need to use the values of $d_{V,A}$ extracted from the data of $e^+e^- \to e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$ etc.

For example consider the neutrino flux coming from an astrophysical object such as SN 1987A in which neutrinos are mainly produced in annihilation process [9]. The neutrino — electron scattering due to such a neutrino flux containing mixture of different types of neutrinos will have $\langle Y \rangle = 0.39545$ sneutrino contamination can alter this value considerably. Hence, experimental detection of lower values of $\langle Y \rangle$ than the expected value will indicate sneutrino contamination. Similarly if an $\bar{\nu}_e$ beam is contaminated with photinos or sneutrinos the observable $\langle Y \rangle$ can have larger values than expected. Needless to say, before making such comparisons, one needs to take into account radiative corrections and it may be done within standard model.

The photino electron scattering has Y-distribution similar to neutrino electron scattering with $A = B$ in Eq. (5.1). This is because the interference of $M_{\tilde{e}_R}$ and $M_{\tilde{e}_L}$ terms vanishes. Since experimentally determined global values of $d_{V,A}$ seem to satisfy $A = B$, Y-distribution is not suitable to find out contamination of photinos in a neutrino beam. However, the final electron longitudinal polarization asymmetry can be large if the masses of $\tilde{e}_R$ and $\tilde{e}_L$ are different, and it is between -1 and $+1$. For neutrino ($\neq \bar{\nu}_e$) electron scattering it is -0.4 0.575 and for ν_e scattering it is -0.952 0.225 using the data from $e^+e^- \to e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$ to calculate $d_{V,A}$ [8]. For sneutrino ($\tilde{\nu}_e$) scattering the value is the same as neutrino (ν_e) scattering. For $\bar{\nu}_e$ scattering the value is dependent on $M_{\tilde{W}}$ and $g_{S,P}$. Hence deviation of these observable from the expected values can be used to find out contamination of photinos in a neutrino beam.

As pointed out earlier, sneutrino contamination could be there in laboratory beams due to π, K, μ-decays. Both sneutrino and photino contamination could be there in neutrino flux from extragalactic sources, such as supernovae etc. and Z^0 factories. In all these cases the initial beam energy of sneutrino or photino is unknown. Hence for comparison with experimental data the Eq. (2.2) and (3.2) will not be useful. However experimentally one can determine electron recoil energy moments and the longitudinal polarization asymmetry. As pointed out earlier these observables are different for the cases when initial beams are neutrino, sneutrino, photino. The determination of the polarization asymmetry is experimentally difficult, however this provides a signal of supersymmetry.

The strength of the processes we have considered, is more than $e^+e^- \to \gamma +$missing energy and comparable to that of μ and τ-decay. This could be an advantage in this process to look for supersymmetric signals. The study of various reactions to set bounds on various unknown parameters of SUSY models only exclude certain regions in parameter space [3]. Since unknown parameters are many (even within a model), such an exercise may not be very useful.

Because of this reason, the fact that our tests can not be used to set limits on any parameter of SUSY models may not be a disadvantage.

Our tests involve purely leptonic reactions and hence are more clean.

Our amplitudes Eq. (2.1) and (3.1) are model independent. Our way to look for sneutrino contamination by comparing experimental $\langle Y \rangle$ with expected $\langle Y \rangle$ in neutrino-electron scattering is valid even for flavour non diagonal couplings of $\tilde{W}$-$\tilde{\nu}_e$-e and Z-ν_i-ν_j. This test is also valid for arbitrary mixture of different flavours of sneutrinos. The way to look for photino contamination by using longitudinal polarization asymmetry is model dependent since the observable will have large value only if the $M_{\tilde{e}_R}$ differs significantly from $M_{\tilde{e}_L}$.

In our analysis we neglected the mass of electron and masses of photinos and sneutrinos. This is justified only if the incident neutrino sneutrino and photino energy is much larger than the beam energy. At a hadron-hadron machine (e.g. Tevatron) if $\tilde{\gamma}$ and $\tilde{\nu}$ are produced at the same stage as meson production, then (in R-parity conserving thecries) these have to be produced along with a heavy susy particle. This considerably reduces $\tilde{\gamma}$ and $\tilde{\nu}$ energy. Even this energy cold be much larger than electron mass. However the lower $\tilde{\gamma}$ or $\tilde{\nu}$ energy causes considerable reduction in the cross section in comparison to νe cross section.

In models which are direct supersymmetrization of standard model, the sneutrino or supersymmetric partner of bosons are the lightest supersymmetric particles [5]. Similarly, superstring inspired E(6) models also allow a light sneutrino. The supersymmetric partner of gauge bosons could be photino or higgsino like states [5]. In all the cases our conclusions hold good, since our result do not depend on restrictive form and strength of interaction.

Editorial note. This article was proofread by the editors only, not by the authors.

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