Slepton Production in Polarized $\gamma\gamma$ Scattering

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In this talk I have summarized the potential of supersymmetric searches in $e^-e^-$, $e^-\gamma$ and $\gamma\gamma$ scattering. Detailed studies have already been published for $e^-e^-$ and $e^-\gamma$ collisions. I therefore do not repeat these results here, but rather report an as yet unpublished analysis of slepton pair-production in polarized $\gamma\gamma$ scattering. It is an extension of what was presented in Ref.\cite{1}, where discovery limits were derived for unpolarized backscattered laser photon beams. Here I show that the combined use of polarization and angular correlations, can greatly enhance the resolving power of the $\gamma\gamma$ reaction. Chargino pair-production in polarized $\gamma\gamma$ scattering has also been studied recently\cite{2}.

![Feynman diagrams](image)

**Figure 1:** Feynman diagrams.

The lowest order Feynman diagrams for slepton pair-production are shown in Fig. 1. It is followed by the decays of the sleptons into their corresponding leptons and neutralinos. In the framework of the minimal supersymmetric standard model the latter escape detection. The signal is thus an acoplanar lepton pair and missing energy. Obviously, this analysis applies as well to selectrons as to smuons, and to a less clean extent to staus.

The differential and total cross sections for this process are

$$\frac{d\sigma}{dt} = \frac{\pi\alpha^2}{s} \left\{ 1 + \left( 1 + 2\frac{m^2}{t-m^2} + 2\frac{m^2}{u-m^2} \right)^2 \right. $$

$$+ 2 P_1 P_2 \left( 1 + 2\frac{m^2}{t-m^2} + 2\frac{m^2}{u-m^2} \right) \right\} \quad (1)$$

$$\sigma = \frac{\pi\alpha^2}{s} \left\{ (1+x)\sqrt{1-x} - x \left( 1 - \frac{x}{2} \right) \ln \frac{1 + \sqrt{1-x}}{1 - \sqrt{1-x}} \right. $$

$$+ P_1 P_2 \left( \sqrt{1-x} - x \ln \frac{1 + \sqrt{1-x}}{1 - \sqrt{1-x}} \right) \right\} \quad (2)$$

where $s, t, u$ are the Mandelstam variables, $m$ is the slepton mass, $x = 4m^2/s$ and $P_{1,2}$ are the polarizations of the photon beams.

At a linear collider of the next generation operating in the TeV range, hard and intense photon beams can be obtained by backscattering an intense laser on the incoming electron beams.\cite{3} The cross sections (1,2) must thus be folded up with the resulting photon spectra. There is also an unavoidable loss of luminosity which is taken into account here as in Ref.\cite{1}. I also assume 100% polarized lasers and 95% polarized electron beams.

To warrant a high photon luminosity one must live with $\sqrt{s_{\gamma\gamma}} \leq 0.83\sqrt{s_{ee}}$. Therefore this collider mode is in general not suited for discoveries. However, because the initial state photons only couple to the charge of the produced particles, there is also little room left for any model dependence and the $\gamma\gamma$ mode is thus ideally suited for studying their properties. This is also the case for supersymmetric studies: by the time the $\gamma\gamma$ mode is turned on, the sleptons would have already been discovered and their masses determined in either $e^-e^-$ or $e^+e^-$ collisions; the $\gamma\gamma \rightarrow \ell^+\ell^-$ cross section would then be accurately predicted and the measurement of the $\gamma\gamma \rightarrow \ell^+\ell^- + E_{\text{mis}}$ cross section would provide a direct determination of the $\ell \rightarrow \ell\chi_0^0$ branching ratio. The situation is rendered slightly more complicated by possible cascade decays of the sleptons, but these small corrections can only be taken seriously into account with a complete detector simulation.

![Energy dependence](image)

**Figure 2:** Energy dependence of a 200 GeV slepton signal and its $W$ background uncut cross sections.

The only background which cannot be rendered harmless by a simple cut on the $p_\perp$ of the emerging leptons, originates from $W^+W^-$ pair-production and sub-
sequent leptonic decay. The energy dependence of the cross sections of this background and the signal of a 200 GeV slepton are displayed in Fig. 3. Clearly, the best signal to background ratio is obtained in the threshold region when the two photon beams have opposite average polarizations. It turns out that the highest cross sections are obtained when the electron beams’ centre of mass energy is approximately three times the slepton mass. This remains true for any reasonable slepton mass.

The signal to background ratio can be further enhanced by using the information undoubtedly gathered in previous $e^-e^-$ or $e^+e^-$ experiments: the energies of the observed leptons which originate from the supersymmetric signal are confined between

$$E_\ell \in \frac{E}{4} \left[ 1 - \frac{m_{\tilde{\chi}_0^0}^2}{m_\ell^2} \right] \left[ 1 \pm \sqrt{1 - \frac{4m_\ell^2}{E^2}} \right], \quad (3)$$

where $E = 0.83\sqrt{s_{ee}}$ is the maximum attainable $\gamma\gamma$ centre of mass energy. Imposing this cut on the data significantly reduces the $W^+W^-$ background at no cost for the supersymmetric signal.

Furthermore, as can be gathered from Fig. 3, the supersymmetric leptonic events are rather uniformly distributed at all angles with a slight dominance in the transverse direction. On the other hand, the leptons which originate from the decays of the $W$’s are mostly emitted at small angles from the beampipe.

![Figure 3: Angular distributions of the events from a 300 GeV slepton signal and its $W$ background. The collider’s $e^\pm e^\mp$ energy and luminosity are 1 TeV and 80 fb$^{-1}$. No cuts are applied.](image)

To estimate the resolving power of the $\gamma\gamma$ mode, one can therefore divide the $(\theta_{e^-}, \theta_{e^+})$ angular range into $3 \times 3$ equal size two-dimensional bins and perform a least squares test for different values of the relevant supersymmetry parameters. Demanding $\chi^2 \geq 6$, one obtains in Fig. 3 contours in the $(\mu, M_2)$ plane of supersymmetry parameters for 300 and 350 GeV sleptons produced at a 1 TeV collider with 80 fb$^{-1}$ of $e^\pm e^\mp$ luminosity. The following cuts have been implemented in addition to Eq. (3):

$$10^\circ < \theta_{e^\pm} < 170^\circ \quad p_{T\ell^\pm} > 10 \text{ GeV} \quad \phi_{acopl} > 2^\circ . \quad (4)$$

These cuts very efficiently remove the potential backgrounds from the standard model lepton pair-production mechanisms and their electroweak Bremsstrahlung.

![Figure 4: Contours of observability of two slepton signals for $\tan\beta = 4$. The collider’s $e^\pm e^\mp$ energy and luminosity are 1 TeV and 80 fb$^{-1}$. The cuts (3,4) are applied.](image)

As it turns out, the two contours in Fig. 4 delimit very precisely the regions of parameter space where the branching ratio $\tilde{\ell} \rightarrow \ell\tilde{\chi}_0^0$ is .02 or .035 for the sleptons of mass 300 and 350 GeV respectively. The branching ratios become smaller inside the contours. Clearly, this direct measurement of the slepton branching ratios will provide invaluable information about the nature of supersymmetry breaking.

To conclude, the $\gamma\gamma$ operating mode of a linear collider of the next generation can be advantageously used to constrain the parameter space of supersymmetry by providing an accurate measurement of the branching ratio of sleptons into their leptonic partners and the lightest neutralino.

References

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