Polarization Effects in Chargino Production at High Energy $\gamma\gamma$ Colliders

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ABSTRACT

We investigate the chargino production process $\gamma\gamma \rightarrow \tilde{W}^+\tilde{W}^-$ at high energy $\gamma\gamma$ colliders in the framework of the minimal supersymmetric standard model (MSSM). Here the high energy $\gamma$ beams are obtained by the backward Compton scattering of the laser flux by the electron in the basic linear TeV $ee$ colliders. We consider the polarization of the laser photons as well as the electron beams. Appropriate beam polarization could be effective to enhance the cross section and for us to extract the signal from the dominant background $\gamma\gamma \rightarrow W^+W^-$. 
We call generally a class of the laws of nature standard model (SM). The SM explains almost perfectly interactions between elementary particles at energy scale less than about 100 GeV. However, it is known that the gauge hierarchy problem exists in the model. Now, we know, there are supersymmetric (SUSY) models which could solve the gauge hierarchy problem. The supersymmetry is a symmetry between fermions and bosons and the quadratic divergence can be cancelled out owing to both contributions of bosons and fermions. However, we should note that in the exact SUSY limit fermions and bosons must be degenerate in mass and there appears to be no evidence in nature for such a situation. Therefore, in order to apply supersymmetry to particle physics, we must consider models in which supersymmetry is broken. In this case masses of SUSY partners must be less than about 1 TeV in order to solve the hierarchy problem.

In this paper, we investigate $\gamma\gamma \rightarrow \tilde{W}_1^+ \tilde{W}_1^-$, where $\gamma$ should be polarized. Here $\tilde{W}_1$ is the lighter chargino which is one of mixing states of the wino $\tilde{W}$ and the charged higgsino $\tilde{h}$. We should note that the lighter chargino $\tilde{W}_1$ could be the lightest charged SUSY particles in the minimal SUSY standard model (MSSM). So there is a possibility that $\tilde{W}_1$ would be discovered first at some high energy colliders.

The possibility for realization of $e\gamma$ and $\gamma\gamma$ colliders have been discussed in detail by Ginzburg et al. Here the high energy photon beams will be obtained by the backward Compton scattering of the laser flush by one of electron beam in the basic linear $ee$ colliders. We consider polarized circular photons characterized by a four vector,

$\epsilon = \frac{1}{\sqrt{2}}(0, \xi_2, -i, 0),$

where $\xi_2$ denotes the Stokes parameter of the circular polarized photon beam. In principle we can get laser photons and initial electron beams with proper helicity. As a result, circular polarization of the back-Compton scattered photon could be controlled.

Some SUSY particle production processes at the $e\gamma$ and $\gamma\gamma$ colliders have already been discussed. Particularly, analysis for the process $\gamma\gamma \rightarrow \tilde{W}_1^+ \tilde{W}_1^-$ have been given in [4], where only unpolarized initial beams are considered. Here we focus our attention
to the physical consequence of the initial beam polarization.

Formulae for the polarized differential cross sections of our process are obtained as follows;

\[
\frac{d\hat{\sigma}}{d \cos \theta}[\gamma_{\pm} \gamma_{\pm} \to \tilde{W}_i^+ \tilde{W}_i^-] = \frac{4\pi \alpha^2}{\hat{s}(1 - \hat{\beta}^2 \cos^2 \theta)^2} \hat{\beta}(1 - \hat{\beta}^4),
\]
\[
\frac{d\hat{\sigma}}{d \cos \theta}[\gamma_{\pm} \gamma_{\mp} \to \tilde{W}_i^+ \tilde{W}_i^-] = \frac{4\pi \alpha^2}{\hat{s}(1 - \hat{\beta}^2 \cos^2 \theta)^2} \hat{\beta}^3 \sin^2 \theta(2 - \hat{\beta}^2 \sin^2 \theta),
\]

where \( \hat{s} \equiv s_{\gamma\gamma} \) and \( \hat{\beta} \equiv \sqrt{1 - 4m_{\tilde{W}_i}^2/\hat{s}} \). Total cross sections are given by

\[
\hat{\sigma}[\gamma_{\pm} \gamma_{\pm} \to \tilde{W}_i^+ \tilde{W}_i^-] = \frac{2\pi \alpha^2}{\hat{s}} \left[ 2\hat{\beta}(1 + \hat{\beta}^2) + (1 - \hat{\beta}^4) \ln \frac{1 + \hat{\beta}}{1 - \hat{\beta}} \right],
\]
\[
\hat{\sigma}[\gamma_{\pm} \gamma_{\mp} \to \tilde{W}_i^+ \tilde{W}_i^-] = \frac{2\pi \alpha^2}{\hat{s}} \left[ -2\hat{\beta}(5 - \hat{\beta}^2) + (5 - \hat{\beta}^4) \ln \frac{1 + \hat{\beta}}{1 - \hat{\beta}} \right],
\]
\[
\hat{\sigma}[\text{unpol}] = \frac{2\pi \alpha^2}{\hat{s}} \left[ -2\hat{\beta}(2 - \hat{\beta}^2) + (3 - \hat{\beta}^4) \ln \frac{1 + \hat{\beta}}{1 - \hat{\beta}} \right].
\]

Total energy dependence of each sub-process cross section \( \hat{\sigma} \) is shown in Fig.1, where we take \( m_{\tilde{W}} = 100 \text{GeV} \). When \( \sqrt{s} \gtrsim 400 \text{GeV} \), \( \hat{\sigma}(\pm, \pm) \) is larger than any other sub-process cross section. Since \( \hat{\sigma}(\pm, \pm) \) has the \( s \)-wave contribution. On the other hand, \( \hat{\sigma}(\pm, \mp) \) becomes a most predominant for \( \sqrt{s} \lesssim 400 \text{GeV} \).

\( \hat{\sigma}(\text{unpol}) \) takes an average of \( \hat{\sigma}(\pm, \pm) \) and \( \hat{\sigma}(\pm, \mp) \), where \( \hat{\sigma}(\pm, \pm) \equiv \hat{\sigma}[\gamma_{\pm} \gamma_{\pm} \to \tilde{W}_i^+ \tilde{W}_i^-] \), etc.

Only arbitrary SUSY parameter which appears in Eqs.(1) and (2) is the chargino mass. Since our process is a pure SUSY QED process, we can get results for both charginos \( \tilde{W}_1 \) and \( \tilde{W}_2 \) with the formulae Eqs.(1) and (2). For completeness, we also give the formulae for \( \gamma\gamma \to W^+ W^- \), which will be needed in the discussion of background suppression;

\[
\frac{d\hat{\sigma}}{d \cos \theta}[\gamma_{\pm} \gamma_{\pm} \to W^+ W^-] = \frac{2\pi \alpha^2}{\hat{s}(1 - \hat{\beta}^2 \cos^2 \theta)^2} \hat{\beta}'(3 + 10\hat{\beta}'^2 + 3\hat{\beta}'^4),
\]
\[
\frac{d\hat{\sigma}}{d \cos \theta}[\gamma_{\pm} \gamma_{\mp} \to W^+ W^-] = \frac{2\pi \alpha^2}{\hat{s}(1 - \hat{\beta}^2 \cos^2 \theta)^2} \hat{\beta}'[16 - 16\hat{\beta}'^2 + 3\hat{\beta}'^4 + 2\hat{\beta}'^2(8 - 3\hat{\beta}'^2) \cos^2 \theta + 3\hat{\beta}'^4 \cos^4 \theta],
\]
where $\hat{\beta}' \equiv \sqrt{1 - 4m_W^2/s}.$

The polarized cross section in Fig.1 for the sub-process $\gamma\gamma \rightarrow X$ is expressed as

$$\hat{\sigma}(\xi_2(z_1), \xi_2(z_2)) = \frac{1}{4}[(1 + \xi_2(z_1))(1 + \xi_2(z_2))\hat{\sigma}[\gamma_+\gamma_+] + (1 + \xi_2(z_1))(1 - \xi_2(z_2))\hat{\sigma}[\gamma_+\gamma_-]$$

$$+ (1 - \xi_2(z_1))(1 + \xi_2(z_2))\hat{\sigma}[\gamma_-\gamma_+] + (1 - \xi_2(z_1))(1 - \xi_2(z_2))\hat{\sigma}[\gamma_-\gamma_-]].$$

(4)

If the incident gamma beams were monochromatic, the formulae (2), (3) and (4) would give just the cross section. However, since each gamma is the secondary beam, the experimental cross section are obtained by folding the sub-process cross section $\hat{\sigma}$ with the photon energy spectra $D_{\gamma/e}(z_i)$. Experimental cross section $\sigma$ is given by

$$\sigma = \int_{z_i^{\text{max}}_1}^{z_i^{\text{max}}_1} dz_1 \int_{z_i^{\text{max}}_2}^{z_i^{\text{max}}_2} dz_2 D_{\gamma/e}(z_1) D_{\gamma/e}(z_2) \hat{\sigma}(z_1, z_2).$$

(5)

Here $z_i$ (i=1, 2) denotes the energy fraction of each high energy gamma beam;

$$z_i = \frac{E_\gamma}{E_e}.$$

In the following we take the upper limit on $z_i$ as $z_i < 0.83$, which guarantees a good conversion efficiency in the backward Compton scattering [4].

Next we show the numerical results for the experimental cross section Eq.(5).

The chargino mass dependence of the polarized and the unpolarized cross section is shown in Fig.2, where we set $\sqrt{s}_{ee} = 1$ TeV. We also plotted the total cross section for $e^+e^- \rightarrow \tilde{W}_1^+\tilde{W}_1^-$ in Fig.2, where we take $m_{\tilde{\nu}} = 500$ GeV and consider two extreme cases; a) the lighter chargino is almost Wino ($\tilde{W}$) and b) almost Higgsino ($\tilde{h}$).

First, we find that the polarized initial beams could enhance the cross section for $m_{\tilde{W}_1} \gtrsim 250$ GeV. Second, polarized $\gamma\gamma$ cross section dominates over the $e^+e^-$ one for $m_{\tilde{W}_1} \lesssim 350$ GeV. It should be noted that $\tilde{W}_1 = \tilde{h}$ case gives the maximum value of $\sigma(e^+e^- \rightarrow \tilde{W}_1^+\tilde{W}_1^-)$. Third, we could know the mass of chargino in terms of a measurement of the total cross section $\sigma(\gamma\gamma \rightarrow \tilde{W}_1^+\tilde{W}_1^-)$ only. This is because the cross section depends on $m_{\tilde{W}_1}$ but not on any other arbitrary SUSY parameters as mentioned above. On the other hand, $\sigma(e^+e^- \rightarrow \tilde{W}_1^+\tilde{W}_1^-)$ depends not only $m_{\tilde{W}_1}$ but also on the chargino mixing angles and the mass of sneutrino.
Now we should discuss the experimental signature and the background. For simplicity, we consider the case, \( m_W < m_{\widetilde{W}_1} < m_f \). In this case the chargino will dominantly decay into \( W \widetilde{Z}_1 \), where \( \widetilde{Z}_1 \) denotes the lightest neutralino and experimental signatures of our process would be \( W \)-boson pair plus large missing energies. Therefore, the most serious background will be \( \gamma\gamma \rightarrow W^+W^- \). We have already given the formula Eq.(3) for the \( \gamma\gamma \rightarrow W^+W^- \) cross section. Since the \( W \)-bosons come from the background process are emitted to the back-to-back in the initial \( \gamma\gamma \) CMS, a cut on the acoplanarity \( \phi_{acop} \) of the \( W \)-boson pair will be effective to suppress the background processes. In Fig.3 we show the transvers momentum \( P_{T}^{q,q} \) distribution of expected number of events, where we impose a cut on acoplanarity, \( \phi_{acop}^{q,q} > 90^\circ \), where \( q\)'s denote the quarks originated from the hadronic decays of the \( W \)-bosons. Here we take \( \sqrt{s} = \sqrt{s_{ee}} = 1\) TeV, \( m_{\widetilde{W}_1} = 300 \) GeV, \( m_{\widetilde{Z}_1} = 150 \) GeV and the luminosity \( L = 1\) fb\(^{-1}\). We see that if we take the polarization \( (\lambda_{1,2}, P_{1,2}^c) = (+\frac{1}{2}, -1) \), the signal events could be distinguished from the background.

We have investigated the chargino production and focused our attention to the physical consequence of the initial beam polarization. It has been shown that appropriate beam polarization could be useful to enhance the cross section for the chargino with the mass \( m_{\widetilde{W}} \sim 0.4\sqrt{s} \). We have explicitly shown that the most serious \( WW \) background can be suppressed by the cuts on the acoplanarity and the choice of polarization. Another good property of the process is the simple dependence of the cross section on the arbitrary SUSY parameters. This could be enable us to measure the mass of chargino and in turn to check the GUT relations among the gaugino masses.

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Figure Captions

Figure 1: $\sqrt{s}$ dependence of total sub-process cross section for each photon polarization ($\xi_2(z_1), \xi_2(z_2)$). We take $\sqrt{s_{\gamma\gamma}}=1\text{TeV}$.

Figure 2: Chargino mass dependence of total cross sections for each initial beam polarization ($\lambda_1, P_1^c$) and ($\lambda_2, P_2^c$). We take $\sqrt{s_{ee}}=1\text{TeV}$.

Figure 3: Monte-Carlo event generation for $\gamma\gamma \rightarrow \tilde{W}^+_1 \tilde{W}^-_1$ and $\gamma\gamma \rightarrow W^+W^-$ with cut $\phi_{acop} > 90^\circ$. We take $\sqrt{s_{ee}}=1\text{TeV}$, $m_{\tilde{W}_1} = 300\text{GeV}$, $m_{\tilde{Z}_1} = 150\text{GeV}$, $(\lambda_{1,2}, P_{1,2}^c) = (\frac{1}{2}, -1)$ and the luminosity $L = 1\text{fb}^{-1}$. 
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