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BRANCHING RATIOS OF SCALAR LEPTONS AT THE TESLA PHOTON COLLIDER*

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We report a Monte Carlo study of the $\gamma\gamma \to \tilde{\mu}^{\pm}_{\rm R,L}\tilde{\mu}^{\mp}_{\rm R,L}$ reactions. The case of the left-handed scalar lepton is of particular interest because their main decay channel can be measured with a high precision. Final states containing up to 4 leptons and missing energy are also investigated. There, exotic shapes of the energy distributions appear as a consequence of cascade decay which would give a hint to recognize supersymmetric processes by observing the shape of such distributions.

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1. Introduction

The Photon Collider [1] offers an excellent opportunity to study a variety of reactions beyond Standard Model which could be unaccessible at the LHC and e^+e^- collisions [2]. Superymmetric reactions constitute an interesting example. In fact, if these particles are observed at the LHC or ILC, the proposed TESLA Photon Collider could give more information of the supersymmetric Lagrangian by measuring their branching ratios. Thus, photon collisions are a suitable arena to analyze, for instance, $\tilde{\chi}^0_1\mu^+\tilde{\chi}^0_1\mu^-$ final states to be expected from $\gamma\gamma \to \tilde{\mu}^{\pm}_{\rm R,L}\tilde{\mu}^{\mp}_{\rm R,L}$ reactions.

Because the TESLA detector can isolate muons with a high efficiency, final states containing these leptons are logically the best option. In this report the right-handed and left-handed scalar leptons will be treated.

A minimal Supergravity model is assumed. In this model, scalar leptons could be seen at the LHC or e^+e^- collisions, leading to their identification. However, the number of events per year is not enough to carry out precision measurements such as branching ratio determination.

The TESLA Photon Collider could give us that opportunity, basically due to two reasons. Firstly, QED is the responsible mechanism to produce scalar leptons. Secondly, the cross section production is remarkably higher in comparison with e^+e^- collisions.

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The aim of this study is precisely to give a quantitative as well as qualitative analysis of the lepton spectrum to be expected due to scalar leptons decay. The branching ratio error of decays $\tilde{\mu}^{\pm}_{\rm L} \to \tilde{\chi}^0_1\mu^{\pm}$ and $\tilde{\mu}^{\pm}_{\rm L} \to \tilde{\chi}^0_2\mu^{\pm}$ are estimated.

2. Production and detection of $\tilde{\mu}^+_{\rm R}\tilde{\mu}^-_{\rm R}$

The production of $\tilde{\mu}^+_{\rm R}\tilde{\mu}^-_{\rm R}$ pairs is a t-channel type. A crude estimate of the cross section for $\sqrt{s}_{e^-e^-} = 500\,{\rm GeV}$ when the photons are monochromatic and without polarization effects and $m = 144\,{\rm GeV}$ (SPS1a scenario [3]) gives 386 fb. On the other hand, to create high energetic photons with an energy comparable to the electron beam energy can be done only inside a Compton scenario by which additional quantum subprocesses take place. As a clear consequence of that, the effective cross section is reduced by a factor of 2.5, being still notoriously comparable to e^+e^- collisions.

In order to calculate the effective cross section of the right-handed scalar muon production, the full photon spectrum including all possible effects is considered. It means that the real cross section comes from a convolution mechanism. To simulate the cross section as well as to generate events under realistic conditions the programme SHERPA [4] was used. Thus, the convoluted cross section to produce $\tilde{\mu}^+_{\rm R}\tilde{\mu}^-_{\rm R}$ pairs gives a peak $\sigma_{\rm eff}$=80 fb when $\sqrt{s}_{e^-e^-}$=480 GeV. $J = 0$ as well as 80 % of electron beam polarization was assumed.

The production of $\mu^+\tilde{\chi}^0_1\mu^-\tilde{\chi}^0_1$ final states was simulated by using the SHERPA programme interfaced with ISAJET [5], while the TESLA detector is simulated via SIMDET [6]. A center-of-mass energy of 500 GeV in the e^-e^- system and a luminosity of $100\,{\rm fb}^{-1}$ was assumed. It gives an effective cross section of $75\,{\rm fb}^{-1}$. Thus 7.5×10^3 events were simulated. There is a significant amount of background events coming from the Standard Model and supersymmetric reactions. We summarize the reactions which contribute with the same topology as the signal, $e^-\gamma \to e^-Z^0 \to e^-\mu^+\mu^-$ (41.79 fb); $e^-\gamma \to \nu W^- \to \nu\nu_\mu\mu^-$ (258.12 fb); $\gamma\gamma \to W^-W^+ \to \mu^+\nu\mu^-\bar{\nu}$ (202.56 fb); $\gamma\gamma \to W^-W^+ \to \tau^{\pm}\nu\mu^{\mp}\bar{\nu} \to \mu^{\pm}\bar{\nu}\nu\nu\mu^{\mp}\bar{\nu}$ (70.23 fb); $\gamma\gamma \to \tilde{\chi}^+_1\tilde{\chi}^-_1 \to \mu^+\tilde{\chi}^0_1\nu\nu\nu\mu^-\tilde{\chi}^0_1\nu\nu\nu$ (10.00 fb); $\gamma\gamma \to \mu^+\mu^-$ (2500 fb); $\gamma\gamma \to \tau^+\tau^- \to \mu^+\nu\nu\mu^-\nu\nu$ (72.5 fb). Coplanarity turns out to be an important variable. The purity is enhanced by a factor of 6 when a cut close to π is applied. A cut on the energy distribution was also applied, and it was posed on the expected endpoints of the signal. This cut improves the purity by a factor of 3. The cut applied on the variable $(E_{\mu^+} - E_{\mu^-})/P_{\rm missing}$ increases the purity around 60 %. In the present analysis it should be emphasized that changing of binning has no influence on the final statistics. Turning now to Fig. 1 (right), it is easy to note a peaked distribution of signal at 400 GeV that appears contrarily to the total background distribution. Mainly, it displays an the manner the $\gamma\gamma \to \tilde{\mu}^+_{\rm R}\tilde{\mu}^-_{\rm R}$ events which were created close to the peak of

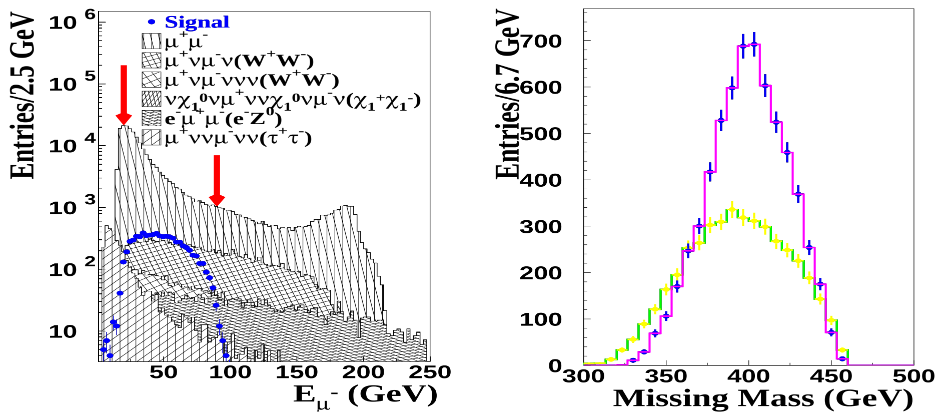

Fig. 1. Left: Histograms of signal (error bars) and background before cuts. Right: After cuts, the missing mass of signal and total background is plotted. It can be noted that the signal presents a peak near to 400 GeV.

luminosity spectrum. The gained statistics of signal against background, as reflected in Fig. 1 (right), gives a first impression of an efficient reconstruction of the supersymmetric signal with a remarkable statistics. The relative statistical error is connected with the product efficiency×purity, through the relation

$$\frac{\Delta N_s}{N_s} = \frac{1}{\sqrt{N_s \text{ eff} \times \text{pur}}}\,. \tag{1}$$

where N_s is the number of events before cuts. Finally an efficiency and purity of 84.9 % and 59.6 %, respectively, was achieved. A relative statistical error of 1.63 % was obtained. These numbers show a negligible variation for different binning.

3. Production and detection of $\tilde{\mu}_{\mathrm{L}}^+\tilde{\mu}_{\mathrm{L}}^-$

In the SPS1a scenario, at least one part of the lepton spectrum must be similar to those of the right-handed scalar muons because the branching ratio $\tilde{\mu}_{\mathrm{L}} \to \mu\tilde{\chi}_1^0$ is 54.96 %. In addition, $\mathrm{BR}(\tilde{\mu}_{\mathrm{L}} \to \mu\tilde{\chi}_2^0) = 16.88\,\%$ and $\mathrm{BR}(\tilde{\mu}_{\mathrm{L}}^\pm \to \nu_\mu\tilde{\chi}_1^\pm) = 28.15\,\%$ according to `ISAJET`. Since the mass is approximately 204 GeV, a center-of-mass energy of 600 GeV is required.

Because left-handed scalar muons are coupled to charginos and neutralinos, complex topologies are expected [7]. The simulation was done with pile-up events, which are expected to have a relative influence on the hadronic channels.

The effect of variable center-of-mass energy on the energy distribution is manifested by the presence of well-defined distorted peaks. This circumstance is of great importance for branching ratio determination because it allows us to disentangle the supersymmetric signal from Standard Model reactions in a direct way. Thus, 3×10^4 $\tilde{\mu}_{\mathrm{L}}^+ \tilde{\mu}_{\mathrm{L}}^-$ pairs were generated. Each smuon is allowed to decay according to their predicted branching ratios. The preselection already assumes the left-handed scalar muon and neutralino masses, then one can impose the cuts precisely around the predicted end-points, between 41 and 145 GeV for both $\mu^\pm$. It leads to selecting 8344 events. A supersymmetric background is the cascade decay $\tilde{\mu}_{\mathrm{L}}^\pm \to \nu \tilde{\chi}_1^\pm \to \nu\nu\tilde{\tau}_1 \to \nu\nu\tilde{\chi}_1^0 \tau^\pm \to \nu\nu\tilde{\chi}_1^0 \nu\nu\mu^\pm$. Concerning the selection cuts, the signal shows no intensive cos(coplanarity) distribution, so that a cut on -0.8 was applied while cos(collinearity) shows a different behavior in comparison with the background. The optimum value to reject background events should be just around cos(collinearity) $= 0.5$. Furthermore, an important amount of the Standard Model events can be rejected if events with $P_{\mathrm{missing}} > 100$ GeV and $P_{\mathrm{T}} > 90$ GeV. As last step, the cut on the invariant mass was applied. It reduces the $e^-\gamma \to \nu Z^0$ processes, incrementing the purity up to 74 %. It has to be noted that the applied cut was posed between a region equal to $M_{Z^0} \pm \mathit{\Gamma}_{Z^0}$. Stability of the product efficiency×purity near the cut values was verified. Finally in Fig. 2 (right) the energy spectrum after the selection is plotted. At present, purely statistical errors are considered. The branching ratio error depends on the number of events after cuts, efficiency and purity. Because the branching ratio enters quadratically in the total cross section, the relative error $\Delta\mathrm{BR}/\mathrm{BR} = 1/2\Delta N_s/N_s = 0.98\%$.

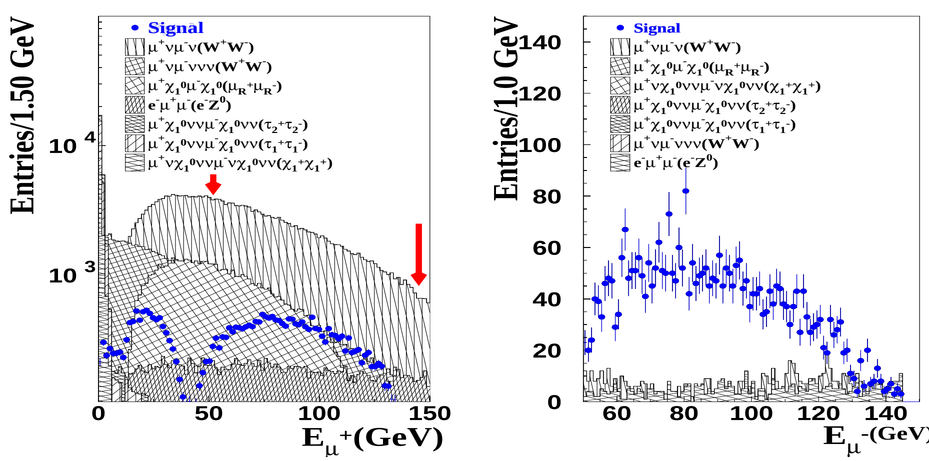

Fig. 2. Left: Histograms of signal (error bars) and background before cuts. Right: The lepton energy of signal (error bars) and background after cuts.

4. Study of the reaction $\tilde{\mu}^+_{\mathrm{L}}\tilde{\mu}^-_{\mathrm{L}} \to \mu^+ e^- \tilde{\chi}^0_1 e^+ \mu^- \tilde{\chi}^0_1$

At the TESLA photon collider, $\gamma\gamma \to \tilde{\mu}^+_{\mathrm{L}}\tilde{\mu}^-_{\mathrm{L}}$ and $\gamma\gamma \to \tilde{e}^+_{\mathrm{L}}\tilde{e}^-_{\mathrm{L}}$ events can be produced up to 6×10^4 events, for a luminosity of $10^3 \mathrm{fb}^{-1}$ (1 year) the number of signal events is roughly $\approx 1.21\%$. In order to simulate the signal events N_{4l}, we have to multiply the total number of events by its corresponding branching ratio as follows:

$$\begin{aligned} N_{4l} \;=\; \mathcal{L}\Big(& 4\,\sigma_{\gamma\gamma\to\tilde{\mu}^+_{\mathrm{L}}\tilde{\mu}^-_{\mathrm{L}}}\,\mathrm{BR}(\tilde{\mu}^-_{\mathrm{L}} \to \mu^-\chi^0_1)\,\mathrm{BR}(\tilde{\mu}^+_{\mathrm{L}} \to \mu^+\chi^0_2) \\ & \times \mathrm{BR}(\tilde{\chi}^0_2 \to \tilde{e}^+_{\mathrm{R}} e^-)\,\mathrm{BR}(\tilde{e}^+_{\mathrm{R}} \to e^+\chi^0_1) \\ & + 4\,\sigma_{\gamma\gamma\to\tilde{e}^+_{\mathrm{L}}\tilde{e}^-_{\mathrm{L}}}\,\mathrm{BR}(\tilde{e}^-_{\mathrm{L}} \to e^-\chi^0_1)\mathrm{BR}(\tilde{e}^+_{\mathrm{L}} \to e^+\chi^0_2) \\ & \times \mathrm{BR}(\tilde{\chi}^0_2 \to \tilde{\mu}^+_{\mathrm{R}}\mu^-)\,\mathrm{BR}(\tilde{\mu}^+_{\mathrm{R}} \to \mu^+\chi^0_1)\Big)\,. \end{aligned} \tag{2}$$

Due to the universality of s-leptons as it is postulated in the minimal supergravity model, left-handed scalar muons and left-handed scalar electrons are treated in an indistinguishable way. Thus, the kinematical limits of the lepton energy of the decay $\tilde{l} \to \tilde{\chi}^0_1 l$, give $41.94\,\mathrm{GeV} < E_l < 152.88\,\mathrm{GeV}$, while the channel $\tilde{l} \to \tilde{\chi}^0_2 l$ present a lepton energy range between 11.39 and 41.51 GeV. Due to these kinematical constrains, the lepton energy will be composed of parts showing a well-defined shape.

In the real experiment one expects a superposition of all leptonic energy spectra. When the simulation is done for both processes $\tilde{\mu}^+_{\mathrm{L}}\tilde{\mu}^-_{\mathrm{L}}$ and $\tilde{e}^+_{\mathrm{L}}\tilde{e}^-_{\mathrm{L}}$ energy distributions seem to be very similar. In other words, the shape of the energy distribution for each lepton contains three peaks, as a logical consequence of the superposition of electron and muon energy distributions.

The background process $\gamma\gamma \to \mu^+\mu^- e^+ e^-$ was simulated with the package `WHIZARD` [8] where a few cuts at the generator level were imposed: $-0.99 < \cos(\theta_{\mu^\pm}) < 0.99$, $-0.99 < \cos(\theta_{e^\pm}) < 0.99$, and $P_{\mathrm{T},l} > 1.$ GeV, where $\cos(\theta)$ denote the angle between the lepton and the beam pipe, and $P_{\mathrm{T},l}$ is the transversal momentum of each lepton. The cross section after these cuts is 217.6 fb. This background is easily rejected due to angular requirements. It means that the geometry of each lepton of the background differs substantially from those of the signal events. After cuts, a lepton energy containing three peaks is noted (Fig. 3 (left)). A nice lego plot shows the exotic nature of the signal energy distribution displaying four well-defined peaks (Fig. 3 (right)). The final statistics is inserted into Eq. (2). There one can estimate the limits of $\delta\mathrm{BR}(\tilde{\mu}^\pm_{\mathrm{L}} \to \mu^\pm\tilde{\chi}^0_2)$. It is interesting to note that the δBR could reach up to 20 %. It should be noted that this error could be reduced up to 2 % if the errors on $\sigma_{\tilde{\mu}^+_{\mathrm{L}}\tilde{\mu}^-_{\mathrm{L}}}$ and $\delta\,\mathrm{BR}(\tilde{\mu}^\pm_{\mathrm{L}} \to \mu^\pm\tilde{\chi}^0_1)$ are below 1 % and 1.8 %, respectively. It is noteworthy that so far errors due to energy calibration as well as polarization errors are not considered.

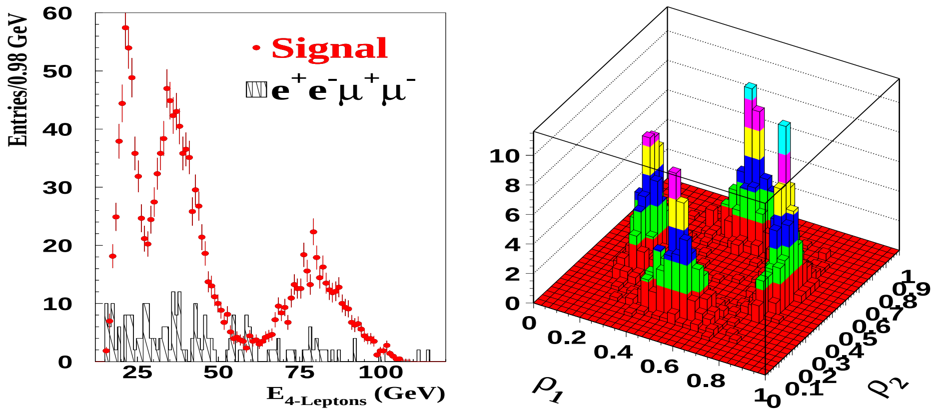

Fig. 3. Left: Final lepton spectrum after cuts. Note three well-defined peaks of signal events (error bars). Right: A lego plot of kinematical variables which uses only lepton energy information is displayed.

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