"Double Chargino Production in e^-e^- scattering"

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We point out the production of the charginos and neutralinos in electron-electron process in several supersymmetric models, in order to show that the International Linear Collider can discover double charged charginos if these particles really exist in nature.

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1. Introduction

The full symmetry of the so called Standard Model (SM) is the gauge group $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$. This model describes the observed properties of charged leptons and quarks it is not the ultimate theory. However, the necessity to go beyond it, from the experimental point of view, comes at the moment only from neutrino data. If neutrinos are massive then new physics beyond the SM is needed. From the theoretical point of view, the SM cannot be a fundamental theory since it has so many parameters and some important questions like that of the number of families do not have an answer in its context.

On the other side, it is not clear what the physics beyond the SM should be. Probably, the SM is an effect of grand unified scenarios and/or their supersymmetric extensions, the Minimal Supersymmetric Standard Model (MSSM) [1].

There are two Higgs doublets in the MSSM, the Higgs' Mass spectrum was studied at[2,3]. The Higgs sector of the MSSM is established by the charged Higgs bosons ($H^{\pm}$), the neutral Higgs bosons H^0, h^0 and A^0 and finally the charged ($G^{\pm}$) and neutral Goldstone bosons (G^0). The upper limit on the mass of the lightest neutral scalar is lighter than M_Z at the tree level but radiative corrections rise it to 130 GeV [4].

By another hand, the main motivation to study Left-Right Models (LR) is to

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explain the lightness of neutrinos masses. On the literature there are two different Left-Right models. They differ in their $SU(2)_R$ breaking fields: one uses $SU(2)_R$ triplets (LRT) and the other $SU(2)_R$ doublets (LRD).

However, on the technical side, the LR has a problem similar to that in the SM: the masses of the fundamental Higgs scalars diverge quadratically. Terefore, we can impose supersymmetry in order to stabilize the scalar masses and cure this hierarchy problem, as we have done in MSSM.

The supersymmetric versions of these models, are known as (SUSYLR), have the additional appealing characteristics of having automatic R-parity conservation. Of course, there are two differents kind of model, the first one is the SUSYLRT [5], which is the supesymmetric version of LRT model, and the SUSYLRD [6].

Some other possibility of physics beyond the SM, at energies of a few TeVs, is that the gauge symmetry may be $SU(3)_c \otimes SU(3)_L \otimes U(1)_N$ (3-3-1 for shortness). There are two main versions of the 3-3-1 models as far as lepton sector is concern. In the minimal version, the charge conjugation of the right-handed charged lepton for each generation is combined with the usual $SU(2)_L$ doublet left-handed leptons components to form an $SU(3)$ triplet $(\nu, l, l^c)_L$. No extra leptons are needed in this model, and we shall call such model as minimal 3-3-1 model. We want to remind that in this model there is no right-handed (RH) neutrino. There exists another interesting possibility, where we add a left-handed anti-neutrino to each usual $SU(2)_L$ doublet to form an $SU(3)$ triplet $(\nu, l, \nu^c)_L$, and this model is called the 3-3-1 model with RH neutrinos.

The 3-3-1 models [7,8,9] provide possible solutions to some puzzles of the standard model (SM) such as the generation number problem, the electric charge quantization [10]. Since one generation of quarks is treated differently from the others this may lead to a natural explanation for the large mass of the top quark [11]. There is also a good candidate for self-interacting dark matter (SIDM) since there are two Higgs bosons, one scalar and one pseudoscalar, which have the properties of candidates for dark matter like stability, neutrality and that it must not overpopulate the universe [12], etc.

As happens with the SUYLR models, again, we have two kind of supersymmetrics model. The first one is the Minimal Supersymmetric 3-3-1 model (MSUSY331), the supersymmetric version of the minimal 3-3-1 model. The second model is the susy331rh, wchich contains right handed neutrinos.

The models 3-3-1 can be embedded in a model with 3-4-1, its mean $SU(3)_c \otimes SU(4)_L \otimes U(1)_N$ gauge symmetry. The $SU(3)_L$ symmetry is possibly the largest symmetry involving the known leptons (and $SU(4)_L$ if right-handed neutrinos do really exist). This make 3-4-1 model interesting by its own. Someyears ago was presented the supersymmetric version of these models listed above [13,14,15].

By another hand, the Linear colliders would be most versatile tools in experimental high energy physics. A large international effort is currently under way to study the technical feasibility and physics possibilities of linear e^+e^- colliders in the TeV range. A number of designs have already been proposed (NLC, JLC,

TESLA, CLIC, VLEPP, ...) and several workshops have recently been devoted to this subject. They can provide not only e^+e^- collisions and high luminosities, but also very energetic beams of real photons. One could thus exploit $\gamma\gamma$, $e^-\gamma$ and even e^-e^- collisions for physics studies. Thus it has been proposed to build a new electron-positron collider, the International Linear Collider (ILC) [16,17].

The last exciting prospects have prompted a growing number of theoretical studies devoted to the investigation of the physics potential of such e^-e^- accelerator experiments. Of course, in the realm of the Standard Model this option is not particularly interesting because mainly Møller scattering, the total cross section to this process is $\sigma \approx 10^{-3}nb$ at $\sqrt{s} = 500$ GeV [18], and bremsstrahlung events are to be observed.

However, it is just for that reason that e^-e^- collisions can provide crucial information on exotic processes, in particular on processes involving lepton and/or fermion number violation. Therefore, new perspectives emerge in detecting new physics beyond the Standard Model in processes having non-zero initial electric charge (and non-zero lepton number) like in electron-electron e^-e^- process.

The goal of this article is to review the mecanism of production of double charged charginos and neutralinos in electron-electron process on the supersymmetric models listed above.

2. Charginos Production

The Left-Right models may have doubly charged Scalars [19]. It means that, when we construct their supersymmetric version, we get double charged charginos. There are another kinds of model, where similar situation occur. Models with $SU(3)$ (or $SU(4)$) electroweak symmetry may have doubly charged vector bosons. This means that in some supersymmetric extensions of these kind of models we will have double charged charginos [20,15].

By another way, there are not so many studies about this kind of particle. Due this fact there are not experimental studies to detect this kind of particle. Due this fact, here I want to summarize the main results in the literature concerning the production of double charged charginos.

In order to start this study, it is useful to review the particle content of which model we have discussed above. Instead to present all the particles of each model, on the table 1, we list the particle content of the chargino's and neutralino's sector at some supersymmetric models. In parenthesis we show the number of states that they appear in each models. Therefore we can distinguish the differents models with base in the numbers of particles.

As we mentioned above, because of low level of SM backgrounds, the total cross section $\sigma \approx 10^{-3}nb$ at $\sqrt{s} = 500GeV$ [18], e^-e^- collisions are a good reaction for discovering and investigating new physics at linear colliders. With this process is possible to study reactions that violate both lepton and/or fermion number, and this kind of reaction are expected in supersymmetric models, as we will briefelly

model	charginos and neutralinos
MSSM [1]	$\tilde{\chi}^{\pm}(2)\ \tilde{\chi}^{0}(4)$
SUSYLRT [5]	$\tilde{\chi}^{\pm\pm}(1)\ \tilde{\chi}^{\pm}(5)\ \tilde{\chi}^{0}(9)$
SUSYLRD [6]	$\tilde{\chi}^{\pm}(6)\ \tilde{\chi}^{0}(11)$
MSUSY331 [13]	$\tilde{\chi}^{\pm\pm}(5)\ \tilde{\chi}^{\pm}(8)\ \tilde{\chi}^{0}(13)$
SUSY331RN [14]	$\tilde{\chi}^{\pm}(6)\ \tilde{\chi}^{0}(15)$
SUSY341 [15]	$\tilde{\chi}^{\pm\pm}(5)\ \tilde{\chi}^{\pm}(16)\ \tilde{\chi}^{0}(25)$
NMSSM [21]	$\tilde{\chi}^{\pm}(2)\ \tilde{\chi}^{0}(5)$

Table1: Spectrum of Charginos and Neutralinos in several SUSY models

present next.

Before, we present our review, it is useful to remeber that [21] "Sleptons are likely to be among the ligther sparticles whose early discovery is anticipated. As already shown, a knowledge of the mass parameters $m_{\tilde{l}_L}$, $m_{\tilde{l}_R}$ and $m_{\tilde{\nu}_L}$ will be of great use in studying signals of charginos and neutralinos". Selectron pair-production takes place in e^-e^- collisions via the exchange of the neutralinos $\tilde{\chi}^0$ in a t-channel contribution was studied at [22,23]. This production depends very crucially on the properties of the exchanged neutralinos, *i.e.* their masses and their couplings to electrons, because strong interferences can take place between the different channels and dramatically influence the production cross section.

It is important to note that, this reaction violates fermion number conservation, which comes as no surprise since the neutralinos are Majorana fermions. On these references cited above, the authors studied the cross section to produce the sleptons. Some of their results are depicted in Fig.(1,2). From this figure, we can notice that the cross section to the selectron production are of the same magnitude as the cross section to the Møller production.

However, after impose rapidity, energy and acoplanarity cuts [23] the background from Møller scattering is entirely eliminated. The supersymmetric signal, on the other hand, is not significantly reduced by these mild cuts, which roughly simulate a typical detector acceptance. Therefore, we can conclude that the e^-e^- machine is ideal for discovering and studying selectrons.

In the realm of the MSSM, chargino pairs can be produced in e^-e^- collisions by the u- and t-channel exchange of a sneutrinos, as shown at [22,24]. This production depends very crucially on the properties of the exchanged sneutrinos, *i.e.* their masses and their couplings to electrons-charginos. On this works, the authors calculate the total cross section of the reaction $e^-e^- \to \chi_1^-\chi_1^-$ in the MSSM. The main results are show on Fig.(2,3) for unpolarized beams. From Fig.(3), that the cross section of the production of the charginos are bigger than cross section to the Møller production for several values of charginos masses.

While in the case of the supersymmetric 331 and 341 model, the Feynmann diagrams contributing to $e^-e^- \to \tilde{\chi}^-\tilde{\chi}^-$ is shown in Fig(4). The Feynmann diagram
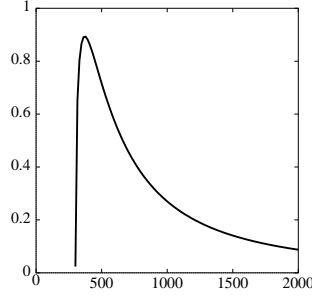
Fig. 1.   The total cross section to the selectron production (σ [pb]) in $e^- e^-$ collisions as function of the energy ($\sqrt{s_{ee}}$ [GeV]).
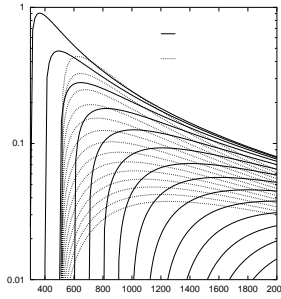
Fig. 2.   Energy dependence of the unpolarized production cross sections of $e^- e^- \rightarrow \tilde{e}^- \tilde{e}^-$ (full curves) and $e^- e^- \rightarrow \tilde{\chi}_1^- \tilde{\chi}_1^-$ (dotted curves) for $m_{\tilde{e}} = m_{\tilde{\nu}} =$150, 200, ... 800 GeV, assuming $\tan \beta = 10$, $\mu = -300$ GeV and $M_2 = 300$ GeV. For this choice of parameters, $m_{\tilde{\chi}_1^-} = 255$ GeV.
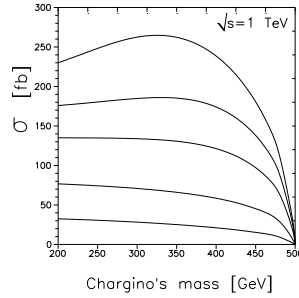
Fig. 3.   Cross section for the process $e^- e^- \rightarrow \tilde{\chi}_1^- \tilde{\chi}_1^-$ as a function of the chargino mass and sneutrino masses (downwards) $m_{\tilde{\nu}} = 100, 200, 300, 500, 800$ GeV and $\sqrt{s} = 1$ TeV.

that contribute to the $e^- e^- \rightarrow \tilde{\chi}^{--} \tilde{\chi}^0$ is show in the Fig.(6). We must stress that in the MSSM the chargino pairs can be produced in $e^- e^-$ collisions by the u- and t- channel exchange of a sneutrino. In both model, susy331 and susy341, we have beyond this possibility, the s- channel contributing with the exchange of a bilepton
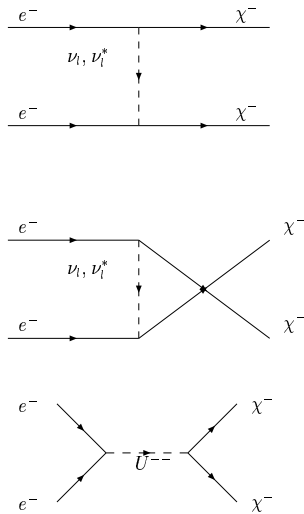
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Fig. 4.   Lower Diagram Contributing to $e^-e^- \to \chi_1^- \chi_1^-$ in the SUSY331 and SUSY341.

U^{--}, because of this new contribution we have on peak at $\sqrt{s} \simeq M_U$, where M_U is the bilepton mass is expected. The total cross section outside the U's resonance has the same order of magnitude than the cross section in the MSSM.

The cross section of these process was calculated on [20], and the total cross section is show in the Fig.(5). The results is that outside the U resonance, the total cross section is of order of pb, like in the MSSM, and near the U resonance we have very nice peak. Due to this fact we expect that there will be an enhancement in the cross section of production of these particles in e^-e^- collisors, such as the ILC [20].
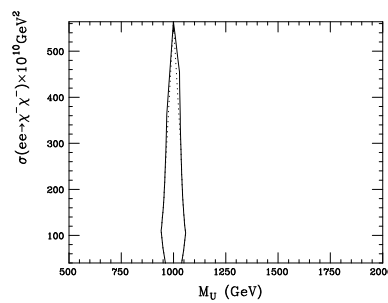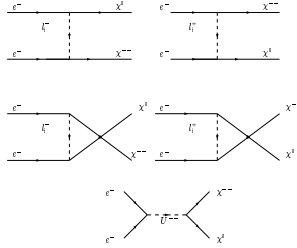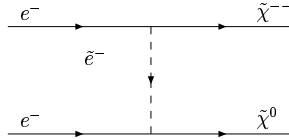

Fig. 5.   Total Cross Section $e^-e^- \to \tilde{\chi}^- \tilde{\chi}^-$ at $\sqrt{s} = 1.0$TeV in susy331 and susy341 models.

The production of double charged chargino in e^+e^- collision occurs through the diagrams presented in Fig.(6) on the models susy331 and susy341. While on Fig.(7) we present the Feynmann diagram to this process on SUSYLRT. Comparing

Fig. 6.   Lower Diagram Contributing to $e^- e^- \to \chi_1^{--} \chi_1^0$ in the SUSY331 and SUSY341.

Fig. 7.   Lower Diagram Contributing to $e^- e^- \to \chi_1^{--} \chi_1^0$ in the SUSYLRT.
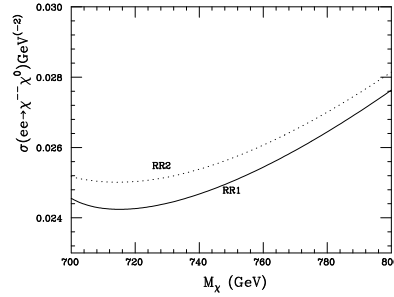
Fig. 8.   Total cross section to $e^- e^- \to \chi_1^{--} \chi_1^0$ in the SUSY331 and SUSY341 as fuction of the double charged mass.

Figs.(6,7) we notice that in the models, susy331 and susy341, have one contribution on s-channel that don't appear on the SUSYLRT.

The total cross section to this process was calculated on [25], and we show on Fig(9) the cross section as function of the mass of the double charged chargino. The results on both, susy331 and susy341 models, are presented at Fig.(8). We notice that allways the cross section in susy331 and susy341 model is greater than the ones get at SUSYLRT.

We have considerate the double chargino mass in the range $700 \leq M_{\tilde{\chi}^{++}} \leq 800$ GeV, and we could get cross section of the order of pb outside the U resonance, while in the resonance we have an enhancement in the cross section. We believe that these new states can be discovered, if they really exist, in linear colliders
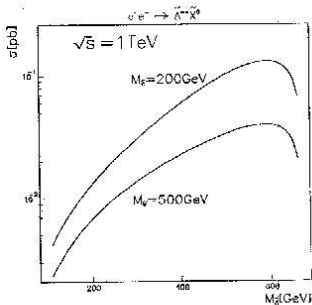
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Figure 5:

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Fig. 9.   Total cross section to $e^- e^- \to \chi_1^{--} \chi_1^0$ in the SUSYLRT as fuction of the double charged mass.

3. Conclusions

We believe that the charginos and neutralinos production can be very well studied in the international linear colliders (ILC). Due the fact that the differents models presented here have differents predictions, on the mechanism production, they can distinguish at ILC. Another exciting search, can be done in discover the double charged charginos, due the fact that there are very few models that predict these kind of particle, and if they really exist the ILC can detect them.

4. acknowledgements

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