Extracting SUSY Parameters from Selectron and Chargino Production†

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Abstract

We review the extraction of fundamental supersymmetric parameters from experimental observables related to the detection of charginos and selectrons at $e^+e^-$ colliders. We consider supergravity models with universal scalar and gaugino masses and radiatively broken electroweak symmetry. Two scenarios are considered: (a) The lightest chargino is light enough to be produced at LEP2, and (b) the right handed selectron is light enough to be produced at LEP2. We show how the validity of supergravity models can be tested even if experimental errors are large. Interesting differences between the spectrum in the two scenarios are pointed out.

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1 Introduction

One of the main problems in particle physics today is the mass generation mechanism. The Higgs mechanism [1] was proposed as a way of generating mass to the gauge bosons and fermions, nevertheless, within the Standard Model (SM) the mass of the Higgs scalar is unstable under radiative corrections. Supersymmetry (SUSY) [2] is a symmetry which protects the scalar masses against the quantum corrections, although, this symmetry must be broken to be in agreement with the experimental observations. The most popular supersymmetric extension of the SM is the Minimal Supersymmetric Standard Model (MSSM) whose particle content includes a scalar partner of all known fermions, a fermionic partner of all known gauge bosons, and two Higgs doublets plus their fermionic partners [3]. The MSSM conserves the $R$–parity, which means susy particles are always produced in pairs at the accelerators, and that all susy particles eventually decay into the lightest supersymmetric particle (generally the lightest neutralino), which is stable.

Presently at LEP an extensive search of supersymmetric particles is been performed. Negative searches impose a lower bound on the mass of the susy particles. In this way, $m_{\tilde{e}^\pm} > 58$ GeV if $m_{\tilde{e}^\pm} - m_{\tilde{\chi}^0_1} > 3$ GeV [4, 5] is the latest published bound on the right selectron, and $m_{\tilde{\chi}^\pm} > 75$ GeV if $m_{\tilde{\chi}^\pm} - m_{\tilde{\chi}^0_1} > 10$ GeV [5, 6] is the latest published bound on the lightest chargino. In this talk I will concentrate in the last two particles. In particular, I want to investigate the problem of extracting the supersymmetric parameters out of the experimental observables associated with the discovery of charginos and selectrons.

2 Supergravity Models

The supergravity (SUGRA) motivated version of the MSSM is particularly interesting because of its predictability. In general it is assumed the universality of scalar and gaugino masses at the unification scale ($M_X \approx 10^{16}$ GeV), where the gauge coupling constants unification is achieved, and these masses evolve differently down to the electroweak scale. One of the Higgs masses squared is driven towards negative values, due to the heaviness of the top quark, and in this way, the electroweak symmetry is broken radiatively. Imposing that the renormalised tadpoles are equal to zero we can find the one–loop corrected minimisation condition of the Higgs potential [7]

$$\left[ m_{1H}^2 + \frac{1}{v_1} T_{1}^{MS}(Q) + \frac{1}{2} m_Z^2 c_{2\beta} \right] c_{\beta}^2 = \left[ m_{2H}^2 + \frac{1}{v_2} T_{2}^{MS}(Q) - \frac{1}{2} m_Z^2 c_{2\beta} \right] s_{\beta}^2 \quad (1)$$

where $T_i^{MS}(Q)$ are the one–loop tadpoles, and the dependence on the arbitrary scale $Q$ has been omitted from all the running parameters. We include in the loops contributions from top and bottom quarks and squarks.

The independent parameters defined at the unification scale which specify the model are the scalar mass $m_0$, the gaugino mass $M_{1/2}$, the trilinear mass $A$, the bilinear mass $B$, and the supersymmetric Higgs mass $\mu$. In Minimal Supergravity it is a common practice to impose the relation $A = B + m_0$ at the unification scale, and we use this relation in the study of selectron pair production. Nevertheless, the relation $B = 2m_0$ at the unification scale appears in models proposed to solve the $\mu$–problem [8], and we
adopt it in the study of the chargino production. These kind of boundary conditions eliminates the bilinear soft mass $B$ from the group of independent parameters.

In Fig. 1 we show the running of different mass parameters with the arbitrary mass scale in Minimal Subtraction ($\overline{MS}$). In solid lines we have some scalar masses, which are degenerated at the unification scale and equal to $m_0$. Squark and slepton soft masses are represented by $3 \times 3$ mass matrices, and we plot the third diagonal element corresponding to the third generation. We have the left squark mass $M_Q$, the right up–type squark mass $M_U$, the right down–type squark mass $M_D$, the left slepton mass $M_L$, and the right charged slepton mass $M_R$. Due to strong interactions, the squark masses are typically larger than slepton masses. The value of $m_0$ has been chosen to produce a selectron with $m_{\tilde{e}_R}^\pm = 75$ GeV. In dashed lines we plot the gaugino masses $M_3$, $M_2$, and $M'$ corresponding to the groups $SU(3)$, $SU(2)$, and $U(1)$ respectively. They are also degenerated at the unification scale and equal to $M_{1/2}$. Again, strong interactions make evolve the gluino mass $M_s$ to higher values compared to the wino and bino masses. Thus, in supergravity, the best candidates to be found first at the accelerators are the sleptons, the charginos, and the neutralinos. Finally, in dot–dashed lines we plot the Higgs masses $m_{1H}$ and $m_{2H}$, which have the common value of $\sqrt{m_0^2 + \mu^2}$ at $M_X$. In the case of the latest mass parameter, $m_{2H}^2$ is driven to negative values as we approach to the electroweak scale. In that case, we plot $-\sqrt{|m_{2H}^2|}$. For this figure we adopt the relation $A = B + m_0$ valid at the unification scale and consider $\mu < 0$. 

Figure 1: Scale evolution of the different soft supersymmetry breaking terms in the supergravity lagrangian.
Figure 2: Relation between the lightest neutralino mass and the total production cross section of a pair of right selectrons for different choices of $\tan \beta$ and the sign of $\mu$. Two values of the center of mass energy are displayed: (a) 175 GeV and (b) 192 GeV.

3 Selectron Production

In this section we assume that the right selectron $\tilde{e}_R^\pm$ is light enough to be produced at LEP2, and study the determination of the fundamental parameters of the supergravity model from the experimental determination of the selectron mass, its total production cross section, and the mass of the lightest neutralino [9]. We consider the relation $A = B + m_0$ at the unification scale. We calculate the total production of a pair of right selectrons including the contribution from $Z-$boson and photon in the $s-$channel, and from neutralinos in the $t-$channel.

In Fig. 2 we plot the relation between the lightest neutralino mass $m_{\tilde{\chi}_1^0}$ and the total production cross section of a pair of right selectrons $\sigma(e^+e^- \rightarrow \gamma^*,Z^*,\chi_j^0 \rightarrow \tilde{e}_R^\pm\tilde{e}_R^\mp)$ for a constant value of the selectron mass $m_{\tilde{e}_R^\pm} = 85$ GeV. Curves with $\tan \beta = 2.5, 10, 25$, and both signs of $\mu$ are displayed. The center of mass energy is (a) $\sqrt{s} = 175$ GeV and (b) $\sqrt{s} = 192$ GeV. It is obvious from the figure that the allowed points in the $m_{\tilde{\chi}_1^0} - \sigma$ plane are restricted to a narrow region. This implies that the observation of a pair of selectrons at LEP2 will validate or ruled out the supergravity model depending on whether the experimental results lie in the allowed region or not. It is interesting to notice that the neutralino mass can be close to the selectron mass selected here, specially for low $\tan \beta$ and $\mu < 0$. This small mass difference decrease the efficiency of the detection of selectrons, and therefore, mass lower bounds become weaker in the
Figure 3: Relation between the lightest neutralino mass $m_{\tilde{\chi}^0_1}$ and the fundamental parameters of the theory: (a) the universal scalar mass $m_0$, (b) the universal trilinear coupling $A$, (c) the universal gaugino mass $M_{1/2}$, and (d) the supersymmetric Higgs mass $\mu$.

The case of non-observation. It can also be appreciated from the figure that it is harder to distinguish different values of $\tan \beta$ when $\mu > 0$. The way of using this figure is simple: once a selectron is observed, the measurement of its mass, its production cross section, and the mass of the lightest neutralino coming from its decay, will single out a point over one of the curves in Fig. 2. This in turn will enable the determination of $\tan \beta$ and the sign of $\mu$.

For the scenario described in Fig. 2, we can relate to any point in one of the curves, the value of any of the fundamental parameters of the theory. In Fig. 3, we choose to plot the relation between the lightest neutralino mass and the following parameters: (a) the universal scalar mass $m_0$, (b) the universal trilinear coupling $A$, (c) the universal gaugino mass $M_{1/2}$, and (d) the supersymmetric Higgs mass $\mu$. The advantage of choosing to plot the lightest neutralino mass instead of the cross section is that we make Fig. 3 independent of the center of mass energy, i.e., Fig. 3 and the following two are valid for any center of mass energy. The scalar mass $m_0$ is rather low $0 \leq m_0 < 80$ GeV, and $m_0 = 0$ can be accommodated if $\tan \beta$ is small and $M_{1/2}$ is large. An inverse relation can be appreciated between $m_0$ and $M_{1/2}$, and this is because the selectron mass receive contributions from scalar masses as well as from gaugino masses. Large values of the gaugino mass are allowed: $60 < M_{1/2} < 200$ GeV. Both signs of $A$ are obtained, and it is mildly correlated with the sign of $\mu$. Low values of $|\mu|$ are not
Figure 4: Relation between the lightest neutralino mass \( m_{\tilde{\chi}_1^0} \) and the following sparticle masses: (a) lightest chargino \( m_{\tilde{\chi}_1^\pm} \), (b) lightest charged slepton \( m_{\tilde{l}_1} \) (the stau), (c) gluino \( m_{\tilde{g}} \), and (d) the lightest up–type squark \( m_{\tilde{q}_{u1}} \) (mainly stop).

allowed because either the chargino mass or the stau mass is too low.

In Fig. 4 we plot as a function of the lightest neutralino mass (a) the lightest chargino mass \( m_{\tilde{\chi}_1^\pm} \), (b) the lightest charged slepton mass \( m_{\tilde{l}_1} \) (the stau), (c) the gluino mass \( m_{\tilde{g}} \), and (d) the lightest up–type squark mass \( m_{\tilde{q}_{u1}} \) (mainly stop). It is clear from the figure that \( \tilde{\chi}_1^\pm, \tilde{g}, \) and \( \tilde{t}_1 \) are strongly correlated with \( M_{1/2} \). The lightest chargino can be as heavy as 170 GeV. The gluino satisfy \( 180 < m_{\tilde{g}} < 560 \) GeV. We do not consider the light gluino scenario because it is ruled out in this class of supergravity models [10]. The top squark is bounded by \( 170 < m_{\tilde{t}_1} < 380 \) GeV. It is interesting to see the stau mass in Fig. 4b, because it is strongly correlated with the value of \( \tan \beta \). Since its mass is smaller than 90 GeV, it can be pair produced at LEP2 and a measurement of its mass can be used to determinate the value of \( \tan \beta \).

The Higgs sector is analysed in Fig. 5. The lightest CP-even Higgs mass \( m_h \) include one–loop radiative corrections which have been proved to be very important [11]. Here it is calculated using the method developed in [12]. This mass satisfy \( 64 < m_h < 110 \) GeV, therefore, if it is light enough it may be detected at LEP2, specially if the center of mass energy \( \sqrt{s} = 200 \) GeV is achieved. If the Higgs is detected first, the value of its mass can be used to distinguish the supergravity model from the SM, since a gap emerges between the upper limit of \( m_h \) in the first model and the lower limit of \( m_{H_{SM}} \) in the second model [14]. In addition, it can be seen a strong dependence of \( m_h \) on \( \tan \beta \) if this parameter is small. Therefore, if \( m_h \) is measured in addition to selectron
Figure 5: Relation between the lightest neutralino mass $m_{\tilde{\chi}_0^1}$ and the following parameters of the Higgs sector: (a) lightest CP–even Higgs mass $m_h$, (b) CP–odd Higgs mass $m_A$, (c) charged Higgs mass $m_{H^\pm}$, and (d) the parameter $-\cos(\beta - \alpha)$.

detection, it can be useful to determine the value of $\tan \beta$ in a region ($\tan \beta \gtrsim 2$) where the stau mass is less sensible to this parameter. In Fig. 5b we have the CP-odd Higgs mass $m_A$, which is the pole mass, and it is determined with the relation

$$m_A^2 = \frac{B_{\mu}}{s_\beta c_\beta}(Q) - \frac{s_\beta^2}{v_1} T_{1}^{MS}(Q) - \frac{c_\beta^2}{v_2} T_{2}^{MS}(Q) + A_{AA}^{MS}(m_A^2, Q)$$

where $A_{AA}^{MS}(m_A^2, Q)$ is the finite self energy of the CP–odd Higgs $A$ in the $\overline{MS}$ scheme, evaluated at external momenta $p^2 = m_A^2$. This self energy depends on the arbitrary scale $Q$, but the overall dependence of the pole mass $m_A$ cancels at the one–loop level. The allowed range of the CP–odd Higgs mass in this scenario is $120 < m_A < 400$ GeV. The charged Higgs mass is plotted in Fig. 5c and satisfy $150 < m_{H^\pm} < 410$ GeV. It includes radiative corrections [13], nevertheless, for the values of $\tan \beta$ allowed in this scenario, quantum corrections are small. In Fig. 5d we plot the parameter $-\cos(\beta - \alpha)$. We note that $\sin(\beta - \alpha)$ is the $ZZh$ coupling relative to the SM coupling $ZZH_{SM}$, therefore, $\cos(\beta - \alpha)$ close to zero implies the lightest CP–even Higgs $h$ has SM–like couplings. In this scenario, $|\cos(\beta - \alpha)| < 0.3$. 

![Figure 5: Relation between the lightest neutralino mass $m_{\tilde{\chi}_0^1}$ and the following parameters of the Higgs sector: (a) lightest CP–even Higgs mass $m_h$, (b) CP–odd Higgs mass $m_A$, (c) charged Higgs mass $m_{H^\pm}$, and (d) the parameter $-\cos(\beta - \alpha)$.](image-url)
Figure 6: Total production cross section of a pair of light charginos in electron positron annihilation as a function of the lightest neutralino mass.

### 4 Chargino Production

In this section we assume that the lightest chargino $\tilde{\chi}^\pm_1$ is light enough to be produced at LEP2, and study the determination of the fundamental parameters of the supergravity model from the experimental determination of the chargino mass, its total production cross section, and the mass of the lightest neutralino [15, 16]. We consider the relation $B = 2m_0$ at the unification scale. A comparison between this choice and the minimal supergravity relation $A = B + m_0$ is made in ref. [7]. We calculate the total production of a pair of light charginos including the contribution from $Z$–boson and photon in the $s$–channel, and from electron–sneutrino $\tilde{\nu}_e$ in the $t$–channel.

Total production cross section of a pair of light charginos in electron positron annihilation as a function of the lightest neutralino mass is plotted in Fig. 6. We take a constant value of the chargino mass: $m_{\chi^\pm_1} = 80$ GeV (solid lines) and 90 GeV (dashed lines), in a supergravity model based in the boundary condition $B = 2m_0$ valid at the unification scale. This implies that only one sign of $\mu$ is allowed, $\mu > 0$, because $m_A^2$ must be positive. Different curves of the same type are labelled by the gluino mass, and the center of mass energy is $\sqrt{s} = 192$ GeV. As in the case with selectrons, given the chargino mass, the allowed region is small. Therefore, the observation of a pair of charginos at LEP2 will validate or ruled out this supergravity model depending on whether the experimental results lie in the allowed region or not. Contrary to the selectron case, the lightest neutralino mass cannot be close to the chargino mass. In fact,
Figure 7: Relation between the total production cross section of two charginos $\tilde{\chi}^\pm_1$ and the fundamental parameters of the theory (a) the universal scalar mass $m_0$, (b) the universal trilinear coupling $A$, (c) $\tan \beta$, and (d) the supersymmetric Higgs mass $\mu$.

$m_{\tilde{\chi}^0_1}$ is about one half of $m_{\tilde{\chi}^\pm_1}$, and this implies that in this class of models the the region of parameter space with low efficiency for the detection of charginos is avoided. The way to use Fig. 6 is simple. A measurement of the chargino mass, its productions cross section, and the mass of the neutralino mass, which comes from the $\tilde{\chi}^\pm_1$ decay mode, will single out a curve in Fig. 6, and therefore a value of $m_{\tilde{g}}$. Of course, experimental errors will translate into errors in the determination of the gluino mass.

For the scenario described in Fig. 6 we plot in Fig. 7 the relation between the total production cross section of two charginos and the fundamental parameters of the theory (a) the universal scalar mass $m_0$, (b) the universal trilinear mass parameter $A$, (c) the ratio between vacuum expectation values $\tan \beta$, and (d) the Higgs mass parameter $\mu$. In Fig. 7a we see that the scalar mass can take large values: $50 < m_0 < 330$ GeV while the gaugino mass $M_{1/2}$ is kept low in order to have a light chargino. In this sense, the light chargino scenario is complementary to the light selectron scenario presented in the previous section. In Fig. 7b we plot the parameter $A$, and appreciate that only solutions with positive $A$ are obtained. We see that the smaller the gluino mass the larger the $A$ parameter, which can be as large as 1 TeV. The parameter $\tan \beta$ is given in Fig. 7c, whose allowed values are $2 \lesssim \tan \beta \lesssim 30$. Most of the time, the chargino production cross section decreases when $\tan \beta$ increases. The last fundamental parameter we plot is the supersymmetric Higgs mass $\mu$ in Fig. 7d. Only positive values are allowed with
Figure 8: Relation between the total production cross section of two charginos $\tilde{\chi}_1^\pm$ and the following sparticle masses: (a) second lightest neutralino $m_{\tilde{\chi}_2^0}$, (b) sneutrino mass $m_{\tilde{\nu}}$ (the three sneutrino spices are practically degenerated), (c) lightest charged slepton (stau) mass $m_{\tilde{\tau}_1}$ (the stau), and (d) the lightest up–type squark $m_{\tilde{t}_1}$ (mainly stop).

$180 < \mu < 400$ GeV. In general, we appreciate that the total cross section increases when $\mu$ increases. The way to use Fig. 7 and the following two figures is as follows: once the chargino and the gluino masses are known, a curve is singled out, and with it and the value of the total cross section, any parameter can be read from its corresponding figure.

In Fig. 8a we plot as a function of the total production cross section of a pair of light charginos (a) the second lightest neutralino mass $m_{\tilde{\chi}_2^0}$, (b) the sneutrino mass $m_{\tilde{\nu}}$, (c) the lightest charged slepton (stau) mass $m_{\tilde{\tau}_1}$, and (d) the lightest up–type squark $m_{\tilde{t}_1}$. From Fig. 8a we appreciate that the second lightest neutralino $\tilde{\chi}_2^0$ has a mass low enough to be produced at LEP2, either in association with $\tilde{\chi}_1^0$ or pair produced. Furthermore, in this plot the different curves labelled by the gluino mass are well differentiated, and therefore, a measurement of $m_{\tilde{\chi}_2^0}$ can help to determine $m_{\tilde{\nu}}$, which is essential for the determination of the fundamental parameters of the model. The three sneutrino spices are in practice degenerated, and in Fig. 8b we plot this common mass $m_{\tilde{\nu}}$. It is strongly correlated with $m_0$, and it is clear from the figure that the electron–sneutrino contribution to the cross section is negative, and the lighter the sneutrino is the smaller the cross section becomes. The lightest stau mass $m_{\tilde{\tau}_1}$ is plotted in Fig. 8c. It is the lightest of the charged sleptons and its mass decreases when $\tan \beta$ increases. This is due to the fact that stau mixing grows with $\tan \beta$. Many of
Figure 9: Relation between the total production cross section of two charginos $\tilde{\chi}_1^\pm$ and the following parameters of the Higgs sector: (a) lightest CP–even Higgs mass $m_h$, (b) CP–odd Higgs mass $m_A$, (c) charged Higgs mass $m_{H^\pm}$, and (d) the parameter $-\cos(\beta-\alpha)$.

The curves are truncated because $\tilde{\tau}_1^\pm$ is too light. In Fig. 8d we have the mass of the lightest up–type squark, which is mainly top–squark with a very small component of charm–squark. Contrary to the previous case, the stop mass $m_{\tilde{t}_1}$ decreases when $\tan \beta$ decreases. This effect appears because the stop mixing grows when $\tan \beta$ decreases and at the same time $\mu$ increases.

The Higgs sector is represented in Fig. 9. The lightest CP–even Higgs mass is plotted in Fig. 9a and satisfy $84 < m_h < 103$ and may be detected at LEP2 if the center of mass energy $\sqrt{s} = 200$ GeV is achieved. In this case, if in addition to chargino detection we have a measurement of the lightest Higgs mass, we can determine the gluino mass with the aid of this figure. The CP–odd Higgs is heavier than in the light selectron scenario of the previous section. We plot $m_A$ in Fig. 9b, and it satisfy $170 < m_A < 580$ GeV. Strongly correlated with $m_A$ is the charged Higgs mass $m_{H^\pm}$ in Fig. 9c, which is slightly heavier: $200 < m_{H^\pm} < 580$ GeV. Consistent with the heaviness of the CP–odd Higgs, we find that the Higgs sector is close to the decoupling limit, that is, the Higgs boson $h$ behaves like the SM Higgs boson: $|\cos(\beta-\alpha)| < 0.07$ as it can be appreciated from Fig. 9d.
5 Conclusions

In Supergravity models, with either the minimal SUGRA relation at the unification scale $A = B + m_0$ or the relation $B = 2m_0$ motivated by solutions to the $\mu$-problem, we have shown that all the fundamental parameters of the theory can be determined by the observation of a pair of right–selectrons or a pair of light charginos. The necessary experimental measurements are the mass of the observed particle, its total production cross section, and the mass of the lightest neutralino which come from the decay of the observed particle. In the light selectron scenario $m_0$ is small and $M_{1/2}$ may be large. On the contrary, in the light chargino scenario, $M_{1/2}$ is small and $m_0$ may be large. In this sense, the two scenarios complement each other.

In the light selectron scenario the neutral Higgs with $64 < m_h < 110$ GeV, and the lightest stau with $45 < m_{\tilde{\tau}_1^\pm} < 85$ GeV, may be also produced at LEP2. Therefore, a measurement of their masses can help in the determination of $\tan \beta$ due to the strong dependence of these masses on $\tan \beta$. Analogously, in the light chargino scenario the neutral Higgs with $84 < m_h < 103$ GeV, and the second lightest neutralino with $80 < m_{\tilde{\chi}^0_2} < 94$ GeV, may be also produced at LEP2. And a measurement of their masses can help in the determination of the gluino mass, and with it the fundamental parameters of the theory.

In both scenarios, the allowed region in parameter space is rather small, as it can be appreciated from Figs. 2 and 3. Therefore, the detection of either right–selectrons or light charginos will validate or ruled out the class of supergravity models analysed here.

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