Chargino Production in Different
Supergravity Models
and the Effect of the Tadpoles

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Abstract

If the lightest chargino is discovered at LEP2, the measurement of its mass and cross section together with the mass of the lightest neutralino, enables the determination of the parameters that define the theory and the entire supersymmetric and Higgs spectrum. Within this context, we: (i) study the effect of the one–loop tadpoles in the minimization condition of the Higgs potential, by comparing the RGE–improved Higgs potential approximation with the calculation of the minimum including the effect of the one–loop tadpoles, and (ii) compare the prediction of two different supergravity models, namely, the model based on $B = 2m_0$ and motivated by the solution of the $\mu$–problem, and the minimal supergravity model, based on $A = B + m_0$. 
1 Introduction

Chargino searches at LEP1.5 at 130 GeV < \sqrt{s} < 140 GeV center of mass energy have been negative, and new exclusion regions in the $m_{\chi^\pm} - m_{\chi^0_1}$ plane have been published [1]. For example, if $m_{\chi^0_1} = 40$ GeV and if $m_{\tilde{\nu}_e} > 200$ GeV, the chargino mass satisfy $m_{\chi^\pm_1} > 65$ GeV at 95% C.L. Nevertheless, this bound on the chargino mass is relaxed if the lightest neutralino mass is close to the chargino mass, or if the sneutrino is lighter than 200 GeV.

In Global Supersymmetry with universal gaugino masses, i.e., without assuming scalar mass unification and without imposing radiative breaking of the electroweak symmetry, it was shown how the discovery of the lightest chargino at LEP2 and the measurement of $m_{\chi^\pm_1}$, $\sigma(e^+e^- \rightarrow \chi^+_1\chi^-_1)$, and $m_{\chi^0_1}$, will enable the determination of the basic parameters $m_{\tilde{g}}$ (or $M_{1/2}$), $\mu$, and $\tan \beta$ [2]. A similar line was follow by ref. [3], without assuming gaugino unification.

The idea of determining the supersymmetric parameters using the measurements mentioned above, was extended to Supergravity models [4]. The predictive power of these models is greater, thus not only the basic parameters of the theory can be determined, but also the entire spectrum. The model analyzed in ref. [4] satisfies the condition $B = 2m_0$, where $B$ is the bilinear soft mass and $m_0$ is the unified scalar mass. These models are motivated by the solution of the $\mu$–problem [5].

In ref. [4], the radiative breaking of the electroweak symmetry was found by minimizing the RGE improved Higgs potential, i.e., using the tree level condition

\[
(m_{1H}^2 + \frac{1}{2}m_Z^2 \cos 2\beta)(1 + \cos 2\beta) = (m_{2H}^2 - \frac{1}{2}m_Z^2 \cos 2\beta)(1 - \cos 2\beta)
\]

but with running parameters evaluated at $Q = m_Z^2$. In the above equation, $m_{1H}^2$ and $m_{2H}^2$ are the mass parameters of the two Higgs doublet $H_1$ and $H_2$ respectively, and the effect of the one–loop tadpoles have been neglected.

The purpose of this letter is two folded. First, we include the one–loop tadpoles and study the effect on the determination of the supersymmetric parameters from chargino observables. And second, keeping the one–loop tadpoles, we study the differences between the supergravity model based on the relation $B = 2m_0$, and the Minimal Supergravity Model, based on the relation $A = B + m_0$.

2 The Effect of Tadpoles

At tree level, the tadpole equations which define the minimum of the Higgs potential are [1]

\[
t_{01} = m_{1H}^2 v_1 - m_{12}^2 v_2 + \frac{1}{8}(g^2 + g'^2)v_1(v_1^2 - v_2^2),
\]

\[
t_{02} = m_{2H}^2 v_2 - m_{12}^2 v_1 + \frac{1}{8}(g^2 + g'^2)v_2(v_2^2 - v_1^2).
\]

where $g$ and $g'$ are the gauge coupling constants, $v_1$ and $v_2$ are the vacuum expectation values of the two Higgs doublets, and $m_{1H}^2$, $m_{2H}^2$ and $m_{12}^2$ are three arbitrary parameters with units of mass squared. The minimum of the Higgs potential is defined by $t_{01} = t_{02} = 0$. Using this latest condition, eq. [1] can be derived from eq. [2] by eliminating $m_{12}^2$ and noting that $\tan \beta = v_2/v_1$. 

At one–loop level, and working with Dimensional Reduction (DRED) in the $\overline{MS}$ scheme, the tree level quantities depend implicitly now on the arbitrary scale $Q$. On the other hand, one–loop contributions to the tadpoles depend explicitly on that scale, such that the renormalized tadpoles are scale independent at the one–loop level:

$$t_1 = \left[ m_{1H}^2 v_1 - m_{12}^2 v_2 + \frac{1}{8} (g^2 + g'^2) v_1 (v_1^2 - v_2^2) \right] (Q) + \tilde{T}_{1}^{\overline{MS}}(Q),$$

$$t_2 = \left[ m_{2H}^2 v_2 - m_{12}^2 v_1 + \frac{1}{8} (g^2 + g'^2) v_2 (v_2^2 - v_1^2) \right] (Q) + \tilde{T}_{2}^{\overline{MS}}(Q). \tag{3}$$

In the last equation, $\tilde{T}_{i}^{\overline{MS}}(Q)$ are the renormalized one–loop tadpoles, i.e., the counterterms have subtracted the infinite pieces.

Imposing that the renormalized tadpoles are equal to zero and eliminating the running parameter $m_{12}^2(Q)$, we find the corrected minimization condition

$$\left[ m_{1H}^2 + \frac{1}{v_1} \tilde{T}_{1}^{\overline{MS}} + \frac{1}{2} m_Z^2 c_2^2 \right] c_2^2 = \left[ m_{2H}^2 + \frac{1}{v_2} \tilde{T}_{2}^{\overline{MS}} - \frac{1}{2} m_Z^2 c_2^2 \right] s_2^2 \tag{4}$$

where the dependence on the arbitrary scale $Q$ has been omitted from all the parameters and tadpoles. Here we calculate the one–loop tadpoles including loops with top and bottom quarks and squarks.

The difference between including or not including the one–loop tadpoles into the minimization condition can be appreciated in Fig. 1 and 2. In Fig. 1 we plot the total light chargino pair production cross section as a function of the lightest neutralino mass. Three scenarios are considered according to the value of the chargino and gluino masses: $(m_\chi^\pm, m_{\tilde{g}}) = (70, 320), (80, 350),$ and $(90, 390) \text{ GeV}$. The calculation of the radiative breaking of the electroweak symmetry without the one–loop tadpoles [Eq. (1)] is represented by dashed lines, and the same calculation with one–loop tadpoles [Eq. (4)] is represented with solid lines. We can appreciate that the RGE–improved Higgs potential is not a bad approximation in this light chargino scenario, introducing an error typically of 0.1 pb (3%) in the cross section, and 0.5 GeV (1%) in the neutralino mass in the most disfavored regions.

In Fig. 2 we plot the total light chargino production cross section as a function of (a) the universal scalar mass $m_0$, (b) the trilinear coupling $A$, (c) the ratio of the two vacuum expectation values $\tan \beta$, and (d) the supersymmetric Higgs mass parameter $\mu$, for the same cases as in Fig. 1. With Fig. 2 we see how the fundamental parameters of the theory can be determined from the discovery of the chargino and the measurement of its mass and cross section, together with the mass of its decay product, the lightest neutralino mass. It is clear from the figure that the RGE–improved Higgs potential in the light chargino scenario is better in the chargino/neutralino sector where the errors in the determination of the parameters $\tan \beta$ and $\mu$ are small (Figs. 1c and 1d). The exception occurs in the large $\tan \beta$ region: when the one–loop tadpoles are included, large values of $\tan \beta$ are allowed resulting in longer (solid) curves. Errors in the determination of $m_0$ and $A$ are larger (Figs. 1a and 1b) what implies the introduction of larger errors in the determination of sfermion masses (typically 5–10% in the disfavored regions).

3 Two Supergravity Models

Supergravity models considered here involve the following universal soft parameters: $m_0, M_{1/2}, A,$ and $B$. Our input parameters are (i) the gluino mass $m_{\tilde{g}}$, which fixes the
value of $M_{1/2}$, (ii) $\mu$, and (iii) the lightest chargino mass $m_{\tilde{\chi}^\pm_1}$, which together with $\mu$ fixes the value of $\tan \beta$. The value of $m_0$ is chosen such that the minimization condition in eq. (4) is satisfied. Similarly, up to now, the value of $A$ has been chosen such that the relation $B = 2m_0$ is satisfied.

An immediate question arises: how do the predictions change if we consider a different supergravity model? For this purpose we compare the previous model ($B = 2m_0$) with Minimal Supergravity, where the boundary condition at the unification scale is $A = B + m_0$.

In Fig. 3 we plot the total light chargino pair production cross section as a function of the lightest neutralino mass. The values of the light chargino and gluino masses are the same as in Fig. 1. The model $B = 2m_0$ is represented with solid lines and minimal supergravity, with $A = B + m_0$, is represented with dashed lines. In the case of $B = 2m_0$ the sign of $\mu$ is unambiguous (positive, in our convention) because the product $B\mu$ is related to the CP–odd Higgs mass $m_{A_1}^2$. On the contrary, in minimal supergravity, $\mu$ can take either sign, nevertheless, in Fig. 3 only $\mu > 0$ is present because it is not possible to find a solution with $\mu < 0$ for the displayed choices of $m_{\tilde{\chi}^\pm_1}$ and $m_{\tilde{g}}$. Lighter values of $m_{\tilde{g}}$ are needed in order to find a solution with $\mu < 0$. We do not show them. In the three cases presented here, the two models coincide at the upper left corner of the curves; this is because in those cases $A \approx 3m_0$, and both type of boundary condition are satisfied simultaneously. This occurs at small values of $\tan \beta$ ($\sim 2$) and large values of $\mu$ ($\sim 300$ GeV). We can notice also that in these models the lightest neutralino mass satisfy $m_{\tilde{\chi}^0_2} \approx \frac{1}{2} m_{\tilde{\chi}^\pm_1}$, which is important for chargino searches, considering that the bounds are not applicable if $m_{\tilde{\chi}^\pm_1} - m_{\tilde{\chi}^0_2} < 10$ GeV.

The differences between the two models can be also appreciated in the prediction of the masses of the supersymmetric partners, as it is displayed in the next figure. In Fig. 4 we plot the total light chargino pair production cross section as a function of (a) the second lightest neutralino mass $m_{\tilde{\chi}^0_2}$, (b) the sneutrino mass $m_{\tilde{\nu}}$, which for all practical purposes is degenerate for the three flavors, (c) the lightest charged slepton mass $m_{\tilde{l}^\pm_1}$, which is always the stau, and (d) the lightest up–type squark mass $m_{\tilde{q}^u_1}$, which is mostly stop. The prediction of the $\tilde{\chi}^0_2$ mass is quite similar in both models, as it can be appreciated from Fig. 4a, and this mass satisfy $m_{\tilde{\chi}^0_2} \approx m_{\tilde{\chi}^\pm_1}$. On the contrary, differences are more pronounced in the sfermion sector, and the general trend is that sneutrinos, staus and stops are lighter in the $B = 2m_0$ model compared with Minimal Supergravity (Figs. 4b–4d). It is worth to notice that in the light chargino scenario, most of the time the sneutrino mass is smaller than 200 GeV (Fig. 4b). This is important for chargino searches, because it is common to assume a sneutrino heavier that 200 GeV in quoting chargino mass bounds.

4 Conclusions

The discovery of a light chargino at LEP2 and the measurement of its mass and cross section, as well as the mass of the lightest neutralino, enable the determination of the basic parameters of the theory and, in supergravity models, the prediction of the entire supersymmetric and Higgs spectrum. Within this light chargino context, we have shown that the RGE improved Higgs potential approximation, i.e., the omission of the one–loop tadpoles contributions, introduce an error of a few percent in the
determination of the parameters and masses of the chargino/neutralino sector. With the exception of large $\tan \beta$ region, where errors are larger. The error is also larger in the sfermion sector (typically of 10%).

At the same time, we have shown how the predictions change in different supergravity models. We compared a model based on the boundary condition $B = 2m_0$ and motivated by the solution of the $\mu$–problem, with Minimal Supergravity based on the boundary condition $A = B + m_0$. When the same sign of $\mu$ is considered, predictions are quite different except in the large $\tan \beta$ region where the two models tend to coincide ($A \approx 3m_0$). Nevertheless, minimal supergravity accepts the other sign of $\mu$, and that class of solutions has no counterpart in the $B = 2m_0$ model.

Acknowledgements

The author is indebted to Prof. Steve King for his input in the subject. Part of this work was done in the University of Southampton, Southampton, England.

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Figure Captions

Fig. 1: Total light chargino pair production cross section as a function of the lightest neutralino mass for three different values of the chargino and gluino masses: $(m_{\chi^\pm}, m_\tilde{g}) = (70, 320), (80, 350), (90, 390)$ GeV. We take the boundary condition at the unification scale to be $B = 2m_0$. The dashed lines are found neglecting the effect of the tadpoles, while the solid lines include this effect.

Fig. 2: For the same cases as in Fig. 1, the total light chargino pair production cross section is plotted as a function of (a) $m_0$, (b) $A$, (c) $\tan \beta$, and (d) $\mu$. Solid lines include one–loop tadpoles and dashed lines do not.
**Fig. 3:** Total light chargino pair production cross section as a function of the lightest neutralino mass for three different values of the chargino and gluino masses: $(m_{\chi^\pm}, m_{\tilde{g}}) = (70, 320), (80, 350), \text{ and } (90, 390) \text{ GeV (same as in Fig. 1). In solid lines, the } B = 2m_0 \text{ boundary condition is used, while } A = B + m_0 \text{ is used in the dashed lines. In all curves the effect of one–loop tadpoles is included.}

**Fig. 4:** For the same cases as in Fig. 3, the total light chargino pair production cross section is plotted as a function of (a) $m_{\chi_2^0}$, (b) $m_{\tilde{\nu}}$, (c) $m_{\tilde{l}^\pm}$, and (d) $m_{\tilde{q}_{u1}}$. Solid lines correspond to $B = 2m_0$ and dashed lines correspond to $A = B + m_0$. All curves include the effect of one–loop tadpoles.
\( \sigma(e^+e^- \rightarrow \gamma^*, \gamma^* \rightarrow \chi_1^+ \chi_1^-) \) (pb)
\[ \sigma(e^+e^- \rightarrow \gamma^*,Z^*,\bar{\nu}^* \rightarrow \chi_1^+\chi_1^-) \text{ (pb)} \]
\( \sigma(e^+e^- \rightarrow \gamma^*, Z^*, \bar{\nu}_e \rightarrow \chi_1^+\chi_1^-) \ (pb) \)