Diminishing "charginos nearly degenerate with the lightest neutralino" slit using precision data

M. Maltoni$^{a,b,c}$ and M. I. Vysotsky$^{c,d}$

$^a$ Dipartimento di Fisica, Università di Ferrara, I-44100, Ferrara, Italy
$^b$ Istituto TeSRE/CNR, Via Gobetti 101, I-40129 Bologna, Italy
$^c$ INFN, Sezione di Ferrara, I-44100, Ferrara, Italy
$^d$ ITEP, Moscow, Russia

Abstract

Though LEP II direct searches still cannot exclude a chargino nearly degenerate with the lightest neutralino if their mass is only slightly above half of the Z boson mass, it can be excluded indirectly analyzing precision data. In this particular limit simple analytical formulas for oblique electroweak radiative corrections are presented.

1 Introduction

LEP II is very effective in bounding from below masses of charginos which, if this is kinematically allowed, should be produced in a pair in $e^+e^- \rightarrow \chi^+\chi^-$ annihilation. The present bounds are $m_{\tilde{\chi}^{\pm}} \gtrsim 90$ GeV for the higgsino-dominated case and $m_{\tilde{\chi}^{\pm}} \gtrsim 70$ GeV for the gaugino-dominated case if sneutrino is not too heavy [1, 2]. However, when the lightest chargino and neutralino (the latter being the LSP) are almost degenerate in mass, the charged decay products of the light chargino are very soft, and the above quoted bounds are no longer valid. Special search for such light charginos has been performed recently by DELPHI collaboration, and the case of $\Delta M^{\pm} \equiv m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0} \lesssim 100$ MeV is now excluded [3]. However, still in the case of $\Delta M^{\pm} \sim 1$ GeV LEP II does not provide a lower bound and charginos as light as 45 GeV are allowed (this bound comes from the measurements of Z decays at LEP I and SLC). The case of almost degenerate chargino and
neutralino can be naturally realized in SUSY and the possibilities to find such particles are discussed in literature [3].

In this letter we investigate the radiative corrections to $m_W$ and to $Z$ boson decay parameters generated by such almost degenerate particles. When their masses are close to $m_Z/2$ radiative corrections are large and they spoil the perfect description of experimental data by the Standard Model. Due to the decoupling property of SUSY models, when $m_{\tilde{\chi}^{\pm,0}} \gg m_Z$ the radiative corrections are power suppressed.

2 Discussion

In the simplest supersymmetric extensions of the Standard Model the chargino-neutralino sector is defined by the numerical values of four parameters: $M_1, M_2, \mu$ and $\tan \beta$. The case of nearly degenerate lightest chargino and neutralino naturally arise when:

1. $M_2 \gg \mu$: in this case the particles of interest form an $SU(2)$ doublet of Dirac fermions, whose wave functions are dominated by higgsinos;

2. $\mu \gg M_2$: in this way we get an $SU(2)$ triplet of Majorana fermions, with the wave functions dominated by winos.

In this way we get higgsino- and gaugino-dominated scenarios, correspondingly. Let us start from case (1).

2.1 Higgsino-dominated case

The degenerate Dirac doublet produces the following corrections to the three functions $V_i$ which determine the values of radiative corrections (for definitions of functions $V_i$ and further details about electroweak radiative corrections see [4]):

$$\delta h V_m = \frac{16}{9} \left[ \left( \frac{1}{2} - s^2 + s^4 \right) \left( 1 + 2\chi \right) F(\chi) - \left( \frac{1}{2} - s^2 \right) \left( 1 + 2\chi^2 \right) F \left( \frac{\chi}{c^2} \right) - \frac{s^4}{3} \right], \quad (1)$$

$$\delta h V_A = \frac{16}{9} \left\{ \frac{1}{2} - s^2 + s^4 \right\} \left[ \frac{12\chi^2 F(\chi) - 2\chi - 1}{4\chi - 1} \right], \quad (2)$$

$$\delta h V_R = \frac{16}{9} c^2 s^2 \left[ 1 + 2\chi \right] F(\chi) - \frac{1}{3}, \quad (3)$$

where $\chi \equiv (m_{\tilde{\chi}^{\pm,0}}/m_Z)^2$, the function $F$ is defined in Appendix B of Ref. [4], and $s^2 (c^2)$ is the sine (cosine) squared of the electroweak mixing angle $\theta$. 

2
Comparing the experimental data with Standard Model formulas [4], we obtain that the $\chi^2$ for the new physics contributions to $V_i$ can be computed in the following way:

$$
\chi^2 = C_{ij} \left( \delta_{\text{NP}} V_i - \delta V_i \right) \left( \delta_{\text{NP}} V_j - \delta V_j \right)
$$

(4)

$$
\begin{pmatrix}
C_{mm} & C_mA & C_mR \\
C_mA & C_{AA} & C_AR \\
C_mR & C_AR & C_{RR}
\end{pmatrix} =
\begin{pmatrix}
7.28 & 0 & 0 \\
0 & 7.24 & 2.54 \\
0 & 2.54 & 23.03
\end{pmatrix};
\begin{pmatrix}
\delta V_m \\
\delta V_A \\
\delta V_R
\end{pmatrix} =
\begin{pmatrix}
-0.07 \\
-0.33 \\
+0.01
\end{pmatrix}.
$$

(5)

In Fig. 1 the functions $\delta h V_i$ are plotted against the chargino-neutralino mass $m_{\tilde{\chi}^{\pm,0}}$. Comparing this graph with formulas (4) and (5), we see that at 95% C.L. the bound $m_{\tilde{\chi}^{\pm,0}} \gtrsim 54$ GeV should be satisfied. Note that the main contribution to $\chi^2$ comes from $\delta h V_A$, which is singular at $m_{\tilde{\chi}^{\pm,0}} = m_Z/2$. This singularity is not physical and our formulas are valid only for $2m_{\tilde{\chi}^{\pm,0}} \gtrsim m_Z + \Gamma_Z$; the existence of $\chi^\pm$ with a mass closer to $m_Z/2$ will change $Z$-boson Breit-Wigner curve, therefore it is also not allowed. The importance of the $Z$ wave function renormalization for the case of light charginos was emphasized in [5].

Figure 1: Dependence of the $\delta h V_i$ functions (left Y-axis) and of the confidence level (right Y-axis) on the light gaugino mass $m_{\tilde{\chi}^{\pm,0}}$, in the limit $M_2 \gg \mu$ (higgsino-dominated case).
2.2 Wino-dominated case

For case $2$ (gaugino dominated states) the expressions for the $\delta \tilde{w}_i$ functions are:

\[
\delta \tilde{w}_V m = \frac{16}{9} c^4 \left( 1 + 2 \chi \right) F(\chi) - \left( 1 - 2 s^2 \right) \left( 1 + 2 \frac{\chi}{c^2} \right) F\left( \frac{\chi}{c^2} \right) - \frac{s^4}{3},
\]

(6)

\[
\delta \tilde{w}_V A = \frac{16}{9} c^4 \left[ \frac{12 \chi^2 F(\chi) - 2 \chi - 1}{4 \chi - 1} \right],
\]

(7)

\[
\delta \tilde{w}_V R = \frac{16}{9} c^2 s^2 \left[ \left( 1 + 2 \chi \right) F(\chi) - \frac{1}{3} \right].
\]

(8)

The values of these functions are shown in Fig. 2 and at 95% C.L. we get $m_{\tilde{\chi}^{\pm,0}} \gtrsim 60$ GeV.

Let us remark that, although this and the previous bounds have been obtained respectively in the limits $|\mu| \to \infty$ and $|M_2| \to \infty$ (in which case the mass splitting $\Delta M^{\pm}$ is exactly zero), we have verified numerically using equations from Ref. [6] that they are still valid for values of $|M_2|$ and $|\mu|$ small enough to allow for $\Delta M^{\pm} \sim 1$ GeV.

![Figure 2](image-url)  

Figure 2: Dependence of the $\delta \tilde{w}_V i$ functions (left Y-axis) and of the confidence level (right Y-axis) on the light gaugino mass $m_{\tilde{\chi}^{\pm,0}}$, in the limit $\mu \gg M_2$ (wino-dominated case).
3 Conclusions

Since there are a number of new additional particles in SUSY extensions, we will briefly discuss their contributions to the functions $V_i$. In the considered limits the remaining charginos and neutralinos are very heavy, so they simply decouple and produce negligible contributions. The contributions of the three generations of sleptons (with masses larger than 90 GeV) into $V_A$ are smaller than 0.1, so they can be safely neglected. The contributions of squarks of the first two generations are also negligible since they should be heavier than Tevatron direct search bounds; taking $m_{\tilde{q}} \gtrsim 200$ GeV, we have $|\delta \bar{V}_i| \lesssim 0.1$. Concerning the contributions of the third generation squarks, they are enhanced by the large top-bottom mass difference and are not negligible. However, being positive and almost universal, they do not affect our analysis: compensating negative contributions of chargino-neutralino into $V_A$ they will generate positive contributions to $V_R$ and $V_m$, and $\chi^2$ will not be better. When squarks are heavy enough (for $m_{\tilde{b}} \gtrsim 300$ GeV), they simply decouple and their contributions become negligible as well.

The last sector of the theory to be discussed is Higgs bosons. Unlike the case of Standard Model now we have one extra charged higgs and two extra neutral higgses. Their contributions to radiative corrections were studied in detail in [8]. According to Fig. 2 from that paper it is clear that the contributions of MSSM higgses (and $SU(2) \times U(1)$ gauge bosons) equal with very good accuracy those of the Standard Model with the mass of SM higgs being equal to that of the lightest neutral higgs in SUSY generalization. That is why the contributions from the gauge-Higgs sector of the theory also cannot compensate those of the light chargino-neutralino.

Apart from oblique corrections (those arising from vector bosons self energies) which have been considered in this letter, there are process dependent vertex and box corrections. However, due to LEP II and Tevatron low bounds on squarks and sleptons masses they are small.

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