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Extension of the search for the lightest chargino down to $M(\tilde{\chi}_1^+) - M(\tilde{\chi}_1^0) = 3$ GeV/c^2

S.Navas[1], S. Paiano[2], A. Perrotta[2], P. Rebecchi[3]

1 IFIC, Valencia-CSIC, and D.F.A.M.N., Univ. de Valencia, E-46100 Burjassot (Valencia), Spain

2 Dipartimento di Fisica dell'Università di Bologna, and INFN, I-40126 Bologna, Italy

3 Université de Paris-Sud, Lab. de l'Accélérateur Linéaire, IN2P3-CNRS, F-91405 Orsay Cedex, France

Abstract

This note extends the search for charginos pair produced in the e^+e^- collisions recorded by the DELPHI experiment at LEP down to mass differences with the LSP of 3 Gev/c^2. All the data collected in 1995 and 1996 at centre-of-mass energies between 130 and 172 GeV have been analized and no evidence of signal has been found. To compute the limits on the mass of the chargino two different analyses have been combined. In the standard SUSY-GUT scenario, charginos of mass below 56.8 GeV/c^2 can be excluded at the 95% confidence level. If the GUT condition $M_1 \simeq 1/2\, M_2$ is released, wino-like charginos can be excluded up to masses of 66.9 GeV/c^2 at the same confidence level, provided $M_1 \geq M_2$ and the sneutrino mass is above 500 GeV/c^2.

The search for sparticles mass-degenerate with the Lightest Supersymmetric Particle (LSP) is challenging because, if R-parity is conserved, the sparticle decays into an invisible and weakly interacting LSP plus few soft ordinary particles, which can be easily discarded by the selection criteria aimed at reducing the $\gamma\gamma$ background.

The higgs and gauge sector of the minimal SUSY [1] can be described in term of four parameters: the ratio $\tan\beta$ of the two Higgs vacuum expectation values; the Higgs mixing parameter μ; the $SU(2)$ gaugino mass M_2; and the $U(1)$ gaugino mass M_1. In the minimal SUSY, complemented with the gaugino mass unification condition at the GUT scale ($M_1 = 5/3 \tan^2\theta_W \cdot M_2 \simeq 1/2 \cdot M_2$), charginos can be mass-degenerate with the lightest neutralino, assumed to be the LSP, if $M_2 \gg |\mu|$; in that case the chargino is higgsino-like and its cross section, at a given degeneracy, only depends on its mass. If the GUT constraint is released, charginos can be mass-degenerate with the lightest chargino if $|\mu| \gg M_2$, provided $M_1 \geq M_2$; in that case the chargino is mostly wino like and its cross section in e^+e^- collisions is lowered by the destructive interference of the s-channel production diagram and the t-channel sneutrino exchange, the reduction being more important for low sneutrino masses. In figure 1 are plotted the $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ cross sections at the centre-of-mass energies of 130, 136, 161 and 172 GeV as function of the chargino mass in the two scenarios. In the figure the cross section of the gaugino is given for $M_1 \sim M_2$, but variations smaller than 6% have been calculated when moving M_1 between M_2 and $5M_2$.

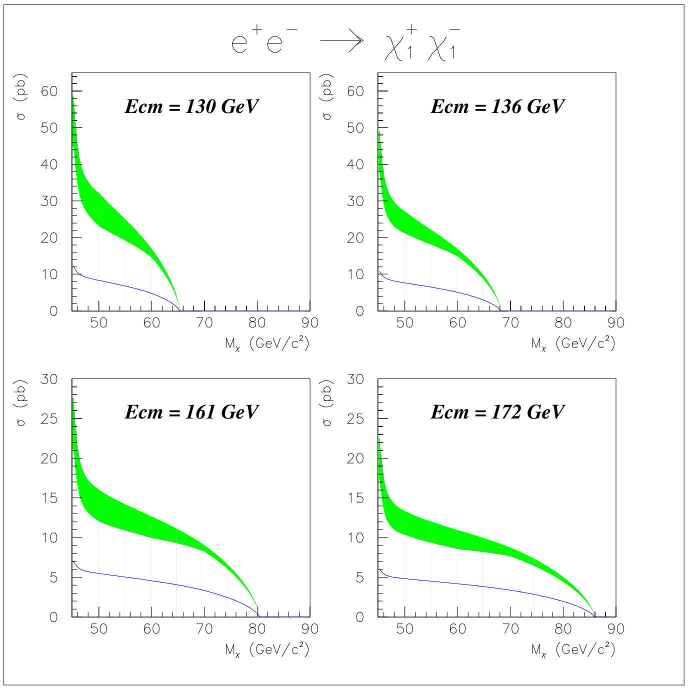

Figure 1: $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ *cross section at the centre-of-mass energies used in the analysis, as function of the chargino mass and for* $\Delta(M) = 3$ GeV/c^2. *The upper band referes to the* $|\mu| \gg |M_2|$ *wino-like scenario; the lower band to the* $|\mu| \ll M_2$ *higgsino-like one. The widths of the two bands allow for* $M(\tilde{\nu}) > 500$ GeV/c^2 *(wino) or* $M(\tilde{\nu}) > M(\tilde{\chi}_1^+)$ *(higgsino).*

In DELPHI, charginos have been searched for in the data collected in 1995-96 at the centre-of-mass energies of 130, 136, 161 and 172 GeV, with an overall integrated luminosity of about 26 pb^{-1}. Two analyses have been carried out: in [2] the selection criteria were tailored for the large $\Delta(M)$ region; in [3] the use of events radiating a photon from the initial state (ISR) permitted to explore degeneracies as low as $\Delta(M) = 500$ MeV/c^2. $\Delta(M) = 3$ GeV/c^2 is a point in which both searches are sensitive but with low efficiency. The reader can refer to the cited papers for the details of the two analyses.

The candidates found and the expected background are summarized in table 1, where, for the analysis in [2] it is only reported the 'degenerate search'. The two candidates found at $\sqrt{s} = 172$ GeV are not the same, neither are the same the events remaining in the simulated samples used to compute the backgrounds (at least at $\sqrt{s} = 172$ GeV).

	Large $\Delta(M)$ search		Rad. photon search	
$\sqrt{s}$ (GeV)	Data	Tot. bckg	Data	Tot. bckg
130	0	$0.20 \pm .03$	0	-
136	0	$0.15 \pm .02$	0	-
161	0	$1.51 \pm .13$	0	$0.82 \pm .34$
172	1	$0.87 \pm .08$	1	$0.92 \pm .35$

Table 1: *Number of candidates remaining in the 1995-96 data and total number of background events expected after the two independent selections used for the search.*

In [2] the search stops at $\Delta(M) = 5$ GeV/c^2 because at smaller $\Delta(M)$ the selection efficiency starts to be so low that it is not negligible any more its uncertainty due to the limited MC signal statistics (and, off course, if in the formulas used to compute the number of expected events are inserted the efficiencies reduced by one standard deviation, then the predictive power of the search is unnecessarily weakened). However, with the method explained in [4], which makes use of the bayesian approach and of the formula in [5] to combine more than one channel, it is possible to include the features of the statistical distribution of the efficiencies, computed with the MC samples, in the calculation of the limits on the chargino mass.

The selection criteria used for the 'degenerate' search in [2] have been applied to samples of charginos simulated at all energies with $\Delta(M) = 3$ GeV/c^2 and masses 45, 50, 60 and 70 GeV/c^2 and passed through a complete detector simulation [6]. The efficiencies obtained are reported in table 2. They are computed for chargino decay modes as modelled in the SUSY generator SUSYGEN [7]; an independent analytical calculation [8] gives similar results for the chargino branching ratios at a degeneracy of 3 GeV/c^2. In any case, small deviations from the expected decay rates would not modify the efficiencies obtained beside their statistical error, because the selection criteria have been found to have similar efficiencies in the lepton-lepton, *jet*-lepton and *jet-jet* final states [2].

In the same table there is an estimate of the trigger efficiency for the events passing the selection cuts. This estimate is derived from the data themselves, by looking at events having the same multiplicity and transverse energy distribution as the signal ones and

	$M_\chi = 45$	$M_\chi = 50$	$M_\chi = 60$	$M_\chi = 70$
$\sqrt{s} = 130$	$(1.95 \pm .31)\%$ 0.996	$(1.95 \pm .31)\%$ 0.995	$(0.75 \pm .19)\%$ 0.993	- -
$\sqrt{s} = 136$	$(2.10 \pm .31)\%$ 0.999	$(2.15 \pm .33)\%$ 0.998	$(1.05 \pm .23)\%$ 0.990	- -
$\sqrt{s} = 161$	$(3.45 \pm .42)\%$ 0.996	$(3.45 \pm .42)\%$ 0.996	$(1.90 \pm .31)\%$ 0.993	$(1.35 \pm .26)\%$ 0.985
$\sqrt{s} = 172$	$(3.75 \pm .43)\%$ 0.996	$(3.80 \pm .44)\%$ 0.988	$(2.85 \pm .39)\%$ 0.983	$(2.30 \pm .34)\%$ 0.989

Table 2: *Selection (above) and trigger (below) efficiencies for charginos having a mass difference of 3 GeV/c^2 with the lightest neutralino (LSP). They are computed with only the 'degenerate' selection criteria of the search for charginos at large $\Delta(M)$, at the different center-of-mass energies and as function of the chargino mass.*

independently triggered by the DELPHI luminometer (STIC) for the normalization [3]. The trigger efficiency is always above 98% also for this degenerate scenario. No error has been computed for the trigger efficiency because in the product with the selection efficiency its relative contribution is negligible.

In table 3 are reported the corresponding selection and trigger efficiency for the search of degenerate charginos with ISR photons. They are taken from [3]. The trigger efficiency is a bit lower than in the previous selection, because here are selected events with low visible charged energy. However, thanks to the ISR photon of high energy in the event, the trigger efficiency is always above 90%.

In table 4 are the combined efficiencies obtained by making a logical OR of the two criteria. One can see that the two selections are almost completely complementar one to each other so that the combined selection efficiency is very close to the sum of the two independent ones.

The absence of evidence of signal above the Standard Model expectations permits to set limits on the mass of the chargino. The limits are different in the two scenarios taken into account because so are the production cross sections (see figure 1). To interpolate between the chargino masses which are fully simulated, the efficiencies and the cross sections have been weighted with the results of a fast simulation at the generator level, which takes into account the reduced boost of the visible chargino decay products and the reduced phase space available for the photon radiation at the highest chargino masses.

With the present luminosity, charginos of 3 GeV/c^2 degeneracy with the LSP can be excluded at the 95% confidence level up to masses of 56.8 GeV/c^2 in the higgsino-like scenario and up to masses of 66.9 GeV/c^2 in the wino-like scenario. The limits in the wino-like scenario are valid provided the mass of the sneutrino is above 500 GeV/c^2.

	$M_\chi = 45$	$M_\chi = 50$	$M_\chi = 60$	$M_\chi = 70$
$\sqrt{s} = 130$	$(1.28 \pm .25)\%$ 0.988	$(1.00 \pm .22)\%$ 0.992	$(0.15 \pm .09)\%$ 0.983	- -
$\sqrt{s} = 136$	$(1.47 \pm .28)\%$ 0.988	$(1.30 \pm .25)\%$ 0.992	$(0.50 \pm .16)\%$ 0.983	- -
$\sqrt{s} = 161$	$(1.87 \pm .31)\%$ 0.973	$(1.99 \pm .32)\%$ 0.967	$(1.38 \pm .26)\%$ 0.955	$(0.65 \pm .18)\%$ 0.955
$\sqrt{s} = 172$	$(1.56 \pm .29)\%$ 0.958	$(1.75 \pm .30)\%$ 0.958	$(1.30 \pm .26)\%$ 0.938	$(0.70 \pm .19)\%$ 0.919

Table 3: *The same as table 2 but for the selection criteria used in the search for degenerate charginos accompanied by initial state photon radiation.*

As a comparison, the limits get by using only the large $\Delta(M)$ selection would be 52.4 GeV/c^2 in the higgsino scenario and 64.3 GeV/c^2 in the wino one; instead, by using the ISR selection alone, nothing could be excluded for the higgsino scenario inside the range of masses explored, while the limit for the wino would be at 53.4 GeV/c^2.

These limits can be safely extended toward $\Delta(M) = 5$ GeV/c^2: in fact, a MC study at the generator level shows that the combined efficiency is a function which grows with $\Delta(M)$, when $3 < \Delta(M) < 5$ GeV/c^2. For $\Delta(M) < 3$ GeV/c^2 the limits reported in [3] should be quoted.

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	$M_\chi = 45$	$M_\chi = 50$	$M_\chi = 60$	$M_\chi = 70$
$\sqrt{s} = 130$	$(3.23 \pm .40)\%$ 0.993	$(2.85 \pm .38)\%$ 0.994	$(0.85 \pm .21)\%$ 0.991	- -
$\sqrt{s} = 136$	$(3.57 \pm .43)\%$ 0.994	$(3.30 \pm .41)\%$ 0.996	$(1.45 \pm .27)\%$ 0.988	- -
$\sqrt{s} = 161$	$(5.12 \pm .51)\%$ 0.988	$(5.24 \pm .51)\%$ 0.985	$(3.23 \pm .40)\%$ 0.977	$(1.95 \pm .31)\%$ 0.975
$\sqrt{s} = 172$	$(5.26 \pm .52)\%$ 0.985	$(5.40 \pm .52)\%$ 0.979	$(3.93 \pm .46)\%$ 0.969	$(2.80 \pm .37)\%$ 0.973

Table 4: *Selection and trigger efficiencies for charginos having a mass difference of 3 GeV/c^2 with the lightest neutralino (LSP), computed with the logical OR of the two selections whose efficiencies are detailed in tables 2 and 3.*

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