Search for charginos mass-degenerate with the LSP

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The search performed in the DELPHI experiment at LEP for charginos mass-degenerate with the lightest neutralino, assumed to be the Lightest Supersymmetric Particle (LSP), is described. Degeneracies below 3 GeV/c^2 are not considered so far in the standard searches, because of the loss of efficiency. Several search strategies are proposed here for the runs of LEP at high energy, each of which is able to explore a different range in the mass splitting between the chargino and the neutralino.

1. DEGENERATE CHARGINOS

In the Minimal Supersymmetric Standard Model (MSSM)[1], mass degeneracy between the lightest chargino ($\tilde{\chi}_1^{\pm}$) and the lightest neutralino ($\tilde{\chi}_1^0$) is allowed only in two regions of the space of the parameters:

Scenario I $|\mu| \ll M_2$: $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ are both higgsino-like;

Scenario II $|\mu| \gg M_2$, $M_1 \geq M_2$: $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ are both gaugino-like.

μ , M_1 and M_2 are respectively the higgsino mass parameter, the $U(1)$ and the $SU(2)$ gaugino masses. In the scenario II, which is foreseen in some SUSY-string theory [2], the GUT relation $M_1 \simeq \frac{1}{2}M_2$ must be released in order to have degeneracy.

The $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$ cross sections are shown in figure 1 as a function of the chargino mass at the four centre-of-mass energies explored by LEP in the years 1995-96. They have been computed for charginos with a mass degeneracy between 0.5 and 3 GeV/c^2 in the two scenarios above. In the gaugino case (upper bands) the sneutrino mass is set to be above 500 GeV/c^2 ; the allowed variation of the $\tilde{\nu}$ mass is the main responsible of the sizeable width of the band describing this cross section. In both scenarios also the variation of $\tan\beta$ (between 1 and 50) and of the SUSY parameters M_1, M_2 and μ (provided the mass and the degeneracies stay in the choosen ranges) are taken into account.

For both scenarios, as far as the sneutrino is heavy, chargino's lifetimes and branching ratios (BR) depend only on the mass splitting $\Delta M_\chi \equiv M_{\tilde{\chi}_1^{\pm}} - M_{\tilde{\chi}_1^0}$ and only weakly on the other parameters of the MSSM. Lifetime and branching ratios are shown in figure 2 as a function of ΔM_χ .

Events with pair production of mass-degenerate charginos would give rise to visible final states with a great amount of missing energy, associated to the LSP's, and with few soft SM particles coming from charginos decays. The usual selections used to search for charginos require a strong cut on the visible transverse momentum p_t , in order to reduce the contributions from the $\gamma\gamma$ background [3]. This cut results in a quite large inefficiency when ΔM_χ is below few GeV, because the visible energy of the final states is usually not sufficient to satisfy it.

2. SEARCH STRATEGIES

Ad hoc selections are needed for degenerate scenarios. The different search strategies applied or proposed for the DELPHI [4] experiment at LEP2 depend on the mass splitting between $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$, which is related to the lifetime and the decay length λ of the chargino.

According to the decay length the following analyses can be applied [5]:

- Heavy Stable Charged Particles;
- Visible Kinks inside the tracking devices;
- Displaced Vertices;

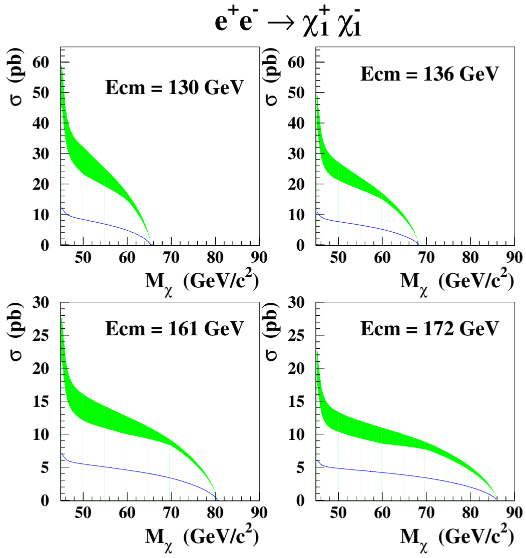

Figure 1. *Chargino cross sections as a function of the $\tilde{\chi}_1^{\pm}$ mass at four centre-of-mass energies. The lower bands refer to the scenario I, the upper ones to the scenario II. In scenario II $M_{\tilde{\nu}}$ is set to be above 500 GeV/c^2 , while it has no effect on the cross-section in scenario I. The plots refer to degeneracies ΔM_χ between 0.5 and 3 GeV/c^2 and to* $\tan\beta$ *in the range* $1 < \tan\beta < 50$.

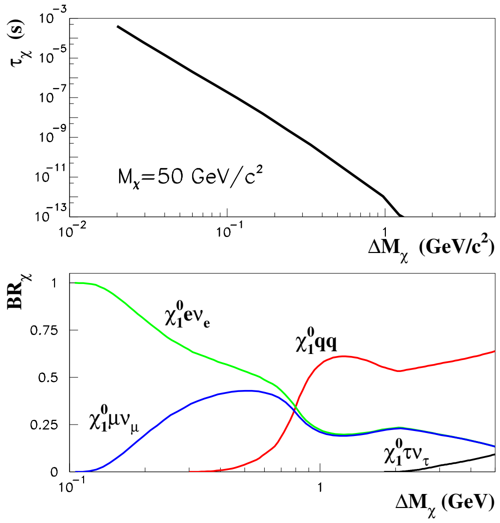

Figure 2. *Lifetime and branching ratios for mass-degenerate charginos as a function of the degeneracy. In the gaugino case they are valid only for heavy sneutrinos.*

- ISR Photon Tagging.

The chargino decay length is plotted in figure 3 as a function of the mass splitting ΔM_χ , for $\sqrt{s} = 184$ GeV and for chargino masses between 50 and 80 GeV/c^2 . The arrows show the interval in λ corresponding to each search strategy.

2.1. Heavy Stable Charged Particles

Massive particles with a long enough lifetime can decay outside the detector. These charged particles are identified in DELPHI by their anomalously high ionization (dE/dx) in the Time Projection Chamber and by the absence of the light cone in the Cherenkov counter (RICH), because of the low speed.

In DELPHI, stable charginos with mass below 84 (80) GeV/c^2 are excluded at 95% C.L. in the case of high (low) sneutrino mass [6].

2.2. Kinks and Displaced Vertices

If the chargino decays inside the tracking devices of DELPHI, a high $|\overrightarrow{p}|$ track coming from the interaction region ends up with a soft one and a kink is visible between them. This method has been already used to search for stau's decays ($\tilde{\tau} \rightarrow \tau\tilde{G}$) [7]; the efficiency is around 50-60% for staus decaying between 15 and 90 cm from the primary vertex. The corresponding efficiency for degenerate charginos is expected to be lower, because of the softness of the visible secondaries.

For lower decay lengths but still higher than the resolution on the impact parameter of the tracks, one could try to search for decay vertices slightly displaced from the interaction point.

No results will be presented here for the two methods above.

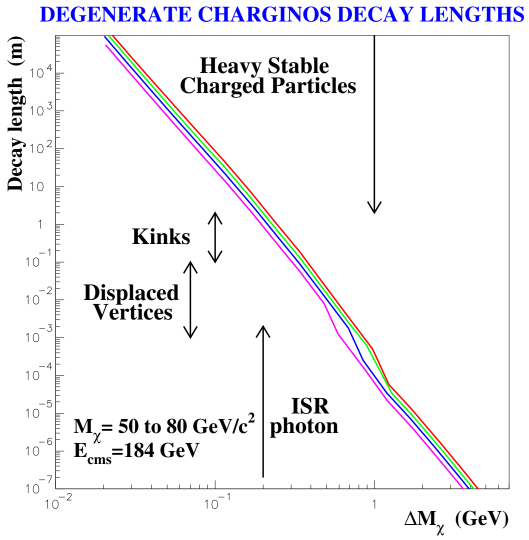

Figure 3. *Decay length for mass-degenerate charginos with mass between 50 and 80 GeV/c^2 at 184 GeV of energy in the centre of mass. In the gaugino case this behaviour is valid only for heavy sneutrinos. The arrows show the range of λ in which the corresponding technique can be applied.*

2.3. ISR Photon Tagging

If the decay length is too short to distinguish the decay vertices from the interaction point, a photon radiated from the initial state (ISR) can help the selection. This configuration, sketched in figure 4, has been used in DELPHI to look for charginos in the range of ΔM_χ comprised between 0.5 and 3 GeV/c^2 [8].

The visible energy of the decay products of the degenerate charginos is lower than few GeV: the presence of an ISR photon helps also with increasing the trigger efficiency.

Moreover, if the transverse energy of this photon satisfies the request

$$E_T^\gamma > \sqrt{s}\cdot\frac{\sin\theta_{min}}{1+\sin\theta_{min}} \qquad (1)$$

the overwhelming $\gamma\gamma$ background is strongly reduced by forcing one of the energetic electrons in the final state to be detected above the inner polar acceptance (θ_{min}) of the DELPHI luminometer, STIC.

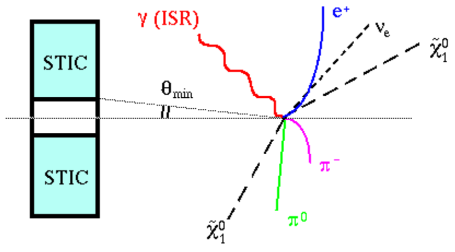

Figure 4. *Sketch of a possible degenerate chargino final state accompanied by the emission of an ISR photon.*

Other requirements applied to the events, in order to enhance the signal-to-noise ratio, can be qualitatively listed as:

- the recoil mass of the ISR photon must be above a certain threshold, to reduce the contribution from the radiative Z^0 decays;
- the total visible energy must be low enough to be compatible with the one expected in degenerate SUSY events;
- the photon must be isolated from the rest of the event;
- the fraction of energy at low polar angles must be below a threshold, in order to reduce the background from $\gamma\gamma$ events;
- the events at larger (> 2) multiplicity must be aplanar.

The selection efficiency is below 2-3%, since it takes into account the probability of radiating an ISR photon with the requested transverse energy.

The distributions of the data at $\sqrt{s} = 130$, 136, 161, 172 GeV have been compared with the expectations from the Standard Model at different stages of the selection process and they generally

Table 1
Results of the selection applied to the data and to the simulated background at the four centre-of-mass energies.

ISR photon search		
$\sqrt{s}$ (GeV)	Data	Background
130	0	~ 0
136	0	~ 0
161	0	$0.82 \pm .47$
172	1	$1.25 \pm .58$

agree with the SM. The results of the final selection on the real data and on the SM background are shown in table 1. Only one candidate, at 172 GeV, remains after the application of the selection cuts. It is compatible with being a hadronic $\gamma\gamma$ event, which represents the most sizeable part of the expected background.

The events with production of degenerate charginos are triggered by the logic sum of the single γ trigger and of the trigger components able to rescue the low p_t charged tracks. The resulting trigger efficiency depends on the energy of the photon (that is on the chargino mass) and on ΔM_χ. Anyhow, it has been computed to be always larger than 80% in the range of $M_{\tilde{\chi}_1^\pm}$ and ΔM_χ taken into account.

The agreement between data and SM predictions permits to set a lower bound on the mass of degenerate charginos. The low selection efficiency does not allow to set such a limit independently at each centre-of-mass energy: it is necessary to combine the results obtained at the four energies.

2.3.1. Results

Because of the not negligible relative errors on the efficiency (and its strongly asymmetric distribution), a MC program has been created [9] to compute the lower limit, at a given C.L. of the difference between the number of expected signal events (N_e) and the number of events compatible

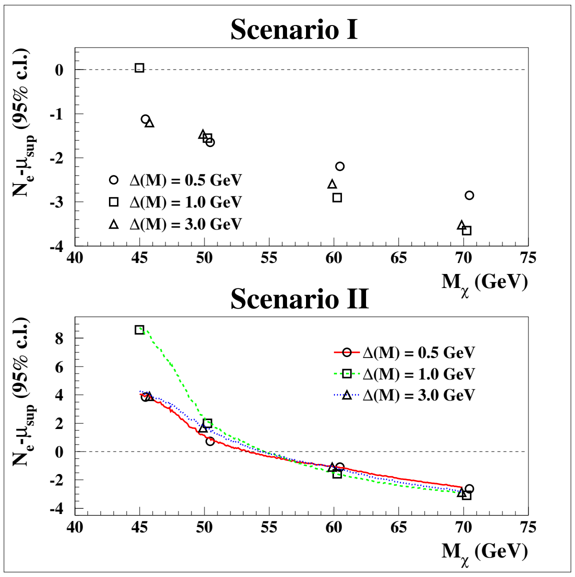

Figure 5. *Lower limit at the 95% C.L. on the difference between the expected signal events and the number of events compatible with the data and the background, as a function of the chargino mass, for the two degenerate scenarios.*

with the results of the search (μ_{sup}). Whenever this difference is positive, the corresponding value for the chargino mass and degeneracy can be discarded at the same C.L. The lower limit at the 95% C.L. on this difference is reported in figure 5 as a function of the mass of the chargino, for the two degenerate scenarios.

No lower limit can be set yet on the mass of the chargino when it is higgsino-like (scenario I), owing to the expected cross sections. For the gaugino-like case (scenario II) the limit is $M_{\tilde{\chi}_1^\pm} > 53.4$ GeV/c^2 at the 95% C.L., provided ΔM_χ is between 0.5 and 3 GeV/c^2, the sneutrino mass greater than 500 GeV/c^2 and $\tan\beta$ between 1 and 50.

These limits can be combined with those obtained by the standard search in the particular case in which $\Delta M_\chi = 3$ GeV/c^2. The resulting lower bounds at the 95% C.L. for the chargino mass are raised to 56.8 GeV/c^2 for higgsino-like charginos and to 66.9 GeV/c^2 for gaugino-like charginos [10]. Table 2 shows the improvement obtained with respect to each separate analysis.

Table 2
Lower limits at the 95% C.L. on the mass of the chargino for the two degenerate scenarios with $\Delta M_{\chi} = 3$ GeV/c^2. The standard search, the search using an ISR photon and the combination of the two are reported.

Search strategy	95% limit on $M_{\tilde{\chi}_1^\pm}$ (GeV/c^2) Higgsino	Gaugino
Standard	52.4	64.3
ISR γ	-	53.4
Stand. $\oplus$ ISR	56.8	66.9

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