SEARCH AT LEP FOR $\tilde{\chi}_1^{\pm}$ MASS-DEGENERATE WITH THE $\tilde{\chi}_1^0$.

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This article describes the key points of the chargino search at LEP, when the mass difference between the chargino and the LSP is between a few hundred MeV and a few GeV. DELPHI results for $\sqrt{s}$ up to 189 GeV and preliminary L3 results for $\sqrt{s}$ up to 202 GeV are given.

1 $\tilde{\chi}_1^{\pm}$ search

Supersymmetry (SUSY) is one of the most appealing extensions of the Standard Model[1]. In SUSY theories with minimal particle content (MSSM), in addition to the ordinary particles, there is a supersymmetric spectrum of particles with spins which differ by one half with respect to their Standard Model partners.

In this article the hypothesis of R-parity conservation is made. R-parity is a quantum number which distinguishes ordinary particles from supersymmetric particles. If R-parity is conserved supersymmetric particles are pair-produced and their decay chain always contains, besides standard particles, two Lightest Supersymmetric Particles (LSP). The LSP, which is stable and weakly-interacting, escapes detection. The LSP can be the lightest neutralino ($\tilde{\chi}_1^0$), a mixture of the supersymmetric partners of Z, γ, and neutral Higgs bosons, or the scalar neutrino.

Charginos ($\tilde{\chi}_1^{\pm}$), which are a mixture of the supersymmetric partners of $W^{\pm}$, (gaugino state) and $H^{\pm}$ (higgsino state), are pair produced via s-channel γ/Z exchange. The production cross section can be reduced by an order of magnitude when the t-channel scalar neutrino ($\tilde{\nu}$) exchange is significant.

As long as charginos are sufficiently heavier than the LSP, their decay products can be detected with high trigger and selection efficiencies. This kind of search (hereafter referred as standard) has been done by the 4 LEP experiments[2]. When the mass difference ($\Delta M = M_{\tilde{\chi}_1^{\pm}} - M_{\tilde{\chi}_1^0}$) is smaller than 4 GeV, this standard search becomes very inefficient, because in that range the signal and the photon-photon interaction background are indistinguishable.

2 Low ΔM phenomenology

Chargino decay branching ratios in the low ΔM region change according to the opening of the various decay channels[5]. Assuming that all scalar leptons and scalar quarks are sufficiently heavy to be able to neglect their contribution in $\tilde{\chi}_1^{\pm}$ decay, the following picture can be drawn. For $\Delta\mathrm{M} < 1.5$ GeV, the hadronic decay channel in one or two pions is enhanced and the decay spectrum is more similar to $\tau^{\pm}$ decays than to $\mathrm{W}^{\pm}$ decays.

The $\tilde{\chi}_1^{\pm}$ decay length increases with decreasing ΔM[5]. For $\Delta\mathrm{M} \gtrsim 300$ MeV, the $\tilde{\chi}_1^{\pm}$ decays near the interaction vertex within 1 cm. For $m_{\pi^{\pm}} < \Delta\mathrm{M} \lesssim 300$ MeV, the $\tilde{\chi}_1^{\pm}$ decays often inside the detector but a few centimetres away from the interaction vertex. For ΔM less than the $\pi^{\pm}$ mass, the $\tilde{\chi}_1^{\pm}$ decays outside the detector and appears as a heavy stable charged particle.

The latter configuration has also been covered by the 4 LEP experiments[3].

3 ISR search

For ΔM between a few hundred MeV and a few GeV, charginos decay near the interaction vertex and the energy carried by the visible decay products is so small that trigger inefficiencies become substantial. In addition, such a signal is overwhelmed by the photon-photon interaction background, which is rapidly increasing for decreasing masses of the photon-photon system. The trigger efficiency and the signal to background ratio can be improved by requiring in the event an Initial State Radiation (ISR) photon with high transverse momentum. Therefore, in this paper, the searched-for process is

$$\mathrm{e}^+\mathrm{e}^- \;\rightarrow\; \gamma\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm} \;\rightarrow\; \gamma\tilde{\chi}_1^0\tilde{\chi}_1^0\mathrm{X}$$

where X stands for low energy standard model charged particles.

The search for low ΔM charginos accompanied by an ISR photon does not suffer from the large photon-photon interaction background if the transverse momentum of the photon is large enough. While in signal events the missing momentum is due to weakly interacting neutralinos, in photon-photon interactions it is due to electrons' escaping in the beam pipe. In the latter case, if a high transverse momentum photon is present, at least one of the two final state electrons should be deflected into the detector. To suppress the photon-photon interactions, the following requirement on the photon transverse momentum is applied :

$$E_{T\gamma} \geq 2E_{\mathrm{beam}}\frac{\sin\theta_d}{1+\sin\theta_d} \tag{1}$$

where θ_d is the minimum detection angle for the deflected electron and $E_{\rm beam}$ is the beam energy. For a LEP detector, $\theta_d \sim 2^\circ$ resulting in $E_{T\gamma} \gtrsim 6$ GeV. With this requirement the photon energy is large enough to trigger the detector.

This method was previously used in the Mark II experiment[4] in the search for a fourth lepton doublet, whose members are close in mass. It was then suggested[5] for the search at LEP for charginos nearly mass-degenerate with the LSP.This search has been done up to now by DELPHI[6] and L3[7].

Besides the photon-photon interaction, the other backgrounds are $\mathrm{e^+e^-} \to \tau^+\tau^-\gamma(\gamma)$, $\mathrm{e^+e^-} \to \mu^+\mu^-\gamma(\gamma)$, $\mathrm{e^+e^-} \to \nu\bar{\nu}\gamma(\gamma)$ and $\mathrm{e^+e^-} \to \mathrm{W^+W^-}\gamma(\gamma)$.

4 Analyses

No Monte-Carlo generator describes completely the photon-photon interactions in the presence of ISR. The analyses are thus tailored on the signal distributions only. The first stage of both analyses is a preselection which has 3 main points :

- The signal must contain an ISR photon : its transverse momentum should be compatible with equation (1). This photon should be isolated in a 15° (resp. 30°) cone for L3 (resp. DELPHI). For a given hypothesis of $\tilde{\chi}_1^\pm$ mass, the recoil mass of the photon should be greater than twice the $\tilde{\chi}_1^\pm$ mass.

- The $\tilde{\chi}_1^\pm$ decay products contain few low energy particles with at least 2 charged ones : discarding the photon, the visible energy should be small (< 12 GeV in L3, $< 0.06\sqrt{s}$ in DELPHI). The event multiplicity should be low and there must be at least 2 tracks in the inner tracking system.

- photon-photon interaction rejection : photon-photon events with a photon compatible with equation (1) are expected to have an electron deflected in the low-angle region of the detector. It is thus required that this low-angle region contain no energy deposit. There is also a specific cut against photon-photon interactions reflecting the transverse energy balance of this process. This cut is $E_{Tvis}/E_{vis} > 0.1$ in L3 and $P_{Tmiss}/E_{Tvis} > 0.4$ in DELPHI (See Figure 1).

The preselection is then divided in 3 selections : one for ΔM ~ 3 GeV, one for ΔM ~ 1 GeV and one for ΔM ~ 300 MeV. Those selections reflect the fact that when ΔM is decreasing, the event multiplicity is also decreasing due to the closure of decay channels. The $\tilde{\chi}_1^\pm$ decay product energy is also decreasing

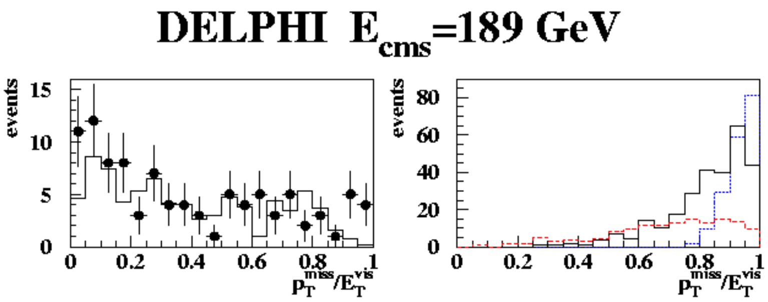

Figure 1. P_{Tmiss}/E_{Tvis} distribution at $\sqrt{s}$ = 189 GeV for left : data (dots) and background (solid line) and right : signal with ΔM = 300 MeV (dotted line), ΔM = 1 GeV (solid line) and ΔM = 3 GeV (dashed line).

Table 1. Number of recorded and expected events for the ISR analyses.

	L3		DELPHI	
energy	luminosity	observed/expected	luminosity	observed/expected
130-183 GeV			81.3 pb^{-1}	5/2.8
189 GeV	176 pb^{-1}	8/3.1	152.9 pb^{-1}	8/5.5
192-202 GeV	232 pb^{-1}	9/3.8		
All	408 pb^{-1}	17/6.8	234.2 pb^{-1}	13/8.3

and so their contributions to the visible energy are smaller. Also, the value of the specific cut against photon-photon interactions can be increased (See Figure 1).

For ΔM $\sim$ 3 GeV and ΔM $\sim$ 1 GeV selections, tracks should come from the interaction point while for ΔM $\sim$ 300 MeV selection, high impact parameter tracks are allowed to take into account the possible $\tilde{\chi}_1^\pm$ long lifetime.

5 Results

The number of selected and expected events for the OR of the 3 selections is shown in table 1 for L3 and DELPHI. In case of L3, the photon-photon processes are not included in the background estimation while DELPHI includes them but with incomplete phase space and without ISR for some of them.

The typical efficiency for detecting the signal $e^+e^- \rightarrow \tilde{\chi}_1^\pm\tilde{\chi}_1^\pm\gamma$ with a photon of more than 4 GeV and above 10° with respect to the beam is around 30%. The ISR requirement is then included in a global efficiency to compare

Table 2. Preliminary 95% C.L. $\tilde{\chi}_1^{\pm}$ mass lower limits for the case of heavy sleptons and heavy squarks.

	DELPHI 130 − 189 GeV	L3 189 − 202 GeV
gaugino-like $\tilde{\chi}_1^{\pm}$		$M_{\tilde{\chi}_1^{\pm}} > 82.8$ GeV
any field content	$M_{\tilde{\chi}_1^{\pm}} > 59.8$ GeV	$M_{\tilde{\chi}_1^{\pm}} > 76.7$ GeV
higgsino-like $\tilde{\chi}_1^{\pm}$ assuming gaugino mass unification at GUT scale	$M_{\tilde{\chi}_1^{\pm}} > 62.4$ GeV	$M_{\tilde{\chi}_1^{\pm}} > 83.2$ GeV

this search with the standard search and the search for stable heavy charged particles. For the process $e^+e^- \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, the obtained global efficiency is of order of 1%.

The ISR energy spectrum in signal events depends on the relative contribution of the s-channel Z exchange, which in turn depends on the $Z\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ coupling. A softer photon spectrum is expected in the case of higgsino-like charginos than in the case of gaugino-like charginos[7]. In addition, when scalar neutrinos are as light as charginos the t-channel diagram becomes important for gaugino-like charginos and the shape of the ISR energy spectrum is modified.

Efficiencies are thus computed for the following cases : higgsino-like $\tilde{\chi}_1^{\pm}$, gaugino-like $\tilde{\chi}_1^{\pm}$ with heavy $\tilde{\nu}$ and gaugino-like $\tilde{\chi}_1^{\pm}$ with light $\tilde{\nu}$.

6 Excluded regions

By combining the results of the standard search and of the heavy stable charged particles search, an excluded region in the $(M_{\tilde{\chi}_1^{\pm}}, \Delta M)$ plane can be derived. An example for the L3 analysis is given in Figure 2. If the scalar leptons and scalar squarks are heavy, this excluded region allows the derivation of $\tilde{\chi}_1^{\pm}$ mass limits independant of ΔM(95% C.L). These limits are listed in table 2.

Acknowledgments

We express our gratitude to the CERN accelerator divisions for the excellent performance of the LEP machine. We also acknowledge and appreciate the effort of the engineers, technicians and support staff who have participated in the construction and maintenance of the LEP experiments.

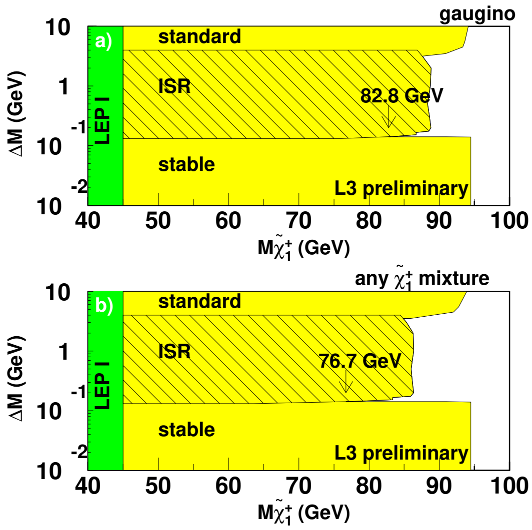

Figure 2. Preliminary excluded region in the $(M_{\tilde{\chi}_1^\pm}, \Delta M)$ plane with the data collected by L3 for 189 GeV $\leq \sqrt{s} \leq$ 202 GeV.

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