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Gaugino searches and constraints on supersymmetry

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Abstract. The negative outcome of gaugino searches at LEP has been one of the most disappointing results for fans of supersymmetric models. In the framework of minimal supersymmetric models with GUT unification assumptions, the combined absence of supersymmetry and Higgs signals in the LEP data, sets stringent constraints on the models parameter space, and lower limits on the mass of the lightest neutralino and of other supersymmetric particles. All limits are given at 95% Confidence Level.

PACS. 11.30.Pb Supersymmetry – 12.60.Jv Supersymmetric models – 13.66.Hk Production of non-standard model particles in e-e+ interactions – 14.80.Ly Supersymmetric partners of known particles

1 Gaugino searches

The production of gauginos in e^+e^-collision has certainly been the most expected signal of supersymmetry (SUSY) during the last ten years. In Minimal Supersymmetric extensions of the Standard Model (MSSM models [1]), gauginos are the fermionic superpartners of Standard Model (SM) gauge and Higgs bosons, making up two charged gauginos (charginos $\chi^{\pm}_{1,2}$) and four neutral gauginos (neutralinos $\chi^0_{1,2,3,4}$). In models where SUSY breaking is mediated by gravity, and with unification assumptions at the GUT scale, the lightest neutralino (χ^0_1), is the natural lightest SUSY particle (LSP). When R-parity further conserves lepton and baryon number, the LSP is stable and weakly interacting, and is of interest as a possible cosmological component of non-baryonic cold dark matter. The SUSY models considered in the following will assume a neutralino-LSP, GUT unification in all sectors and conservation of R-parity, implying that SUSY particles can only be produced in pairs.

1.1 Chargino-pair searches

In chargino-pair productions each produced chargino will decay to a fermion-pair and a LSP according to the chain

$$e^+e^-\to\chi^+\chi^-\to f\bar{f}'\chi^0_1 f\bar{f}'\chi^0_1. \qquad (1)$$

The χ^0_1 pair will carry away undetected energy while the two fermion-pairs ($f\bar{f}'f\bar{f}'$) can give rise to three main topologies with *(i)* two leptons ($\ell\nu\ell\nu$), *(ii)* one lepton and two jets ($qq\ell\nu$), or *(iii)* multi-jets (qqqq). The relative amount of visible and missing energy will depend mainly on the mass difference ΔM between the chargino and the LSP. For large ΔM values the main SM backgrounds for the searches come from four-fermion events as W-pairs,Z-pairs, Weν and Zee. In the case of low ΔM, main backgrounds arise from two photon collisions as $\gamma\gamma\to\tau\tau$, hadrons [2].

In scenarios where ΔM is smaller that $3\text{GeV}/c^2$ the $\gamma\gamma$ background can only be reduced by requiring the presence of an initial state radiation (ISR) photon with large transverse momentum, that will also ensure the signal triggering, but at the expense of a signal selection efficiency lower than 3%. Finally when ΔM is below the pion production threshold, charginos can be detected as heavy stable charged particles [3]. A very nice chargino-pair candidate is shown in Fig. 1.

1.2 Neutralino-pair searches

Signal topologies arising from pair productions of heavy neutralinos can be quite different due to a variety of decay channels and to possible cascade processes. The main searched topology arises from

$$e^+e^-\to\chi^0_i\chi^0_1\to f\bar{f}\chi^0_1\chi^0_1 \qquad (2)$$

and gives final states with acoplanar jets and acoplanar leptons. When two fermion pairs are produced as from

$$e^+e^-\to\chi^0_i\chi^0_j\to f\bar{f}f\bar{f}\chi^0_1\chi^0_1 \qquad (3)$$

the searched final states are multi-leptons or multi-jets with missing energy. Finally to cope also with possible radiative $\chi^0_i\to\chi^0_j\gamma$ decays signals as

$$e^+e^-\to\chi^0_i\chi^0_j\to f\bar{f}\gamma\chi^0_1\chi^0_1 \qquad (4)$$

are also searched for, with jets, photons and missing energy. Again different searches are performed according to

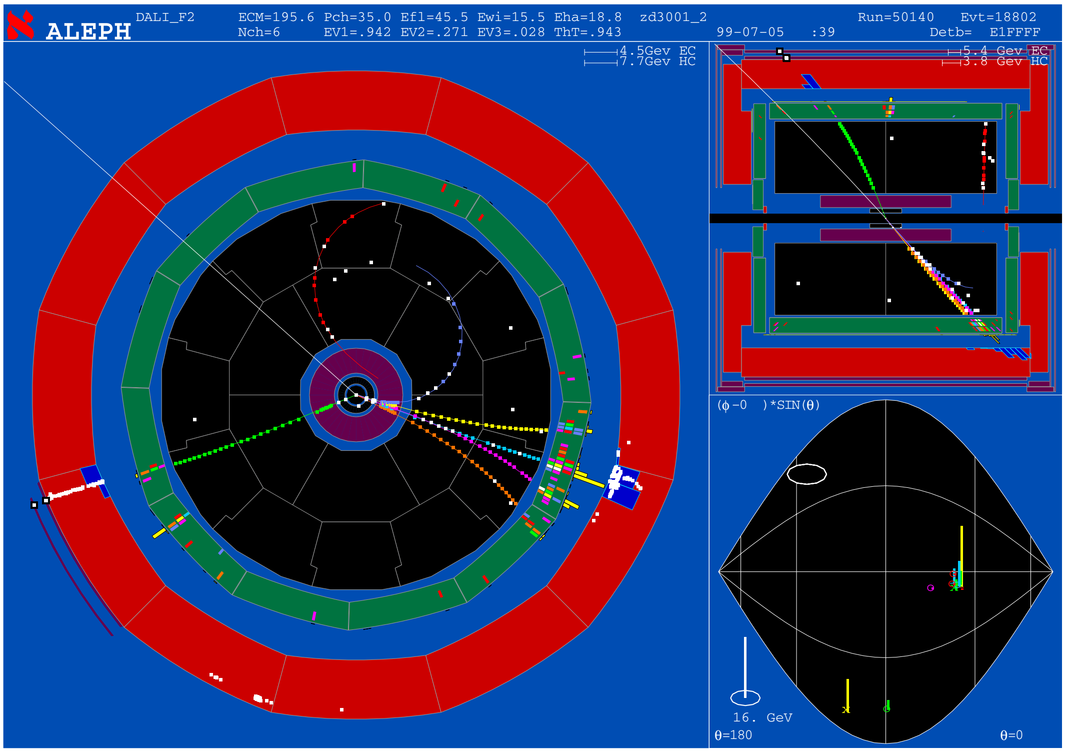

Fig. 1. A perfect chargino-pair candidate event recorded by ALEPH at $\sqrt{s}$=196 GeV. The event display shows an isolated muon with 8.5 GeV/c momentum and an hadronic monojet with a 16 GeV/c^2 invariant mass. The total missing invariant mass in the event amounts to 148 GeV/c^2, with a transverse missing energy component of 21 GeV. The possible Standard Model source of such an event is a W-pair decay $\mathrm{WW}^* \rightarrow \tau(\rightarrow \mu\nu\nu)\nu\mathrm{q}\bar{\mathrm{q}}$, where the hadronic decay of the second W is extremely off-shell

possible ΔM mass differences between the heavy neutralinos and the χ^0_1-LSP, with SM backgrounds arising mainly from four-fermion processes at large ΔM, and from two-photon collisions at small ΔM [2].

2 Lower LSP mass limits

In the LEP data up to $\sqrt{s}$=209 GeV none of the SUSY searches has revealed an excess of signal events over the expected SM processes. Therefore upper limits on gaugino pair production cross sections have been set at the level of less than a pb for all main topologies, when kinematically accessible. These cross section limits can be translated in exclusion domains in the constrained MSSM parameter space ($\tan\beta, \mu, M_2, m_0$), and from here in lower mass limits on the LSP and other SUSY particles.

2.1 Limits with heavy sfermions

When sfermions are heavier than electroweak bosons they do not interfere with the gaugino production and decay. In this scenario the expected gaugino production cross sections are in the 1-10 pb range. The excluded parameter space corresponds roughly to domains where the chargino mass is within the kinematic production limit, i.e. $m(\chi^+) \leq \sqrt{s}/2 \approx$100 GeV/$c^2$. The corresponding limit on the LSP mass can be set at $m(\chi^0) > 39$ GeV/c^2, at $\tan\beta \approx 1$ [2].

2.2 Limits with light sfermions

The effects of light sfermions (with a GUT unified mass m_0) are significant both in the production and decay of gauginos. Using dedicated searches of different decay topologies and direct sfermion searches, the MSSM parameter space can, however, be covered in a way similar to the case of heavy sfermions, and the LSP limit still holds at $m(\chi^+) > 39$ GeV/c^2, with $\tan\beta \approx 1$ [2].

2.3 Exclusions from Higgs boson searches

The negative outcome of Higgs boson searches [4] allows to exclude MSSM regions with $\tan\beta < 2-3$, bringing the LSP mass limit at $m(\chi^0) > 50$ GeV/c^2 with $\tan\beta \approx 3$ in the case of heavy sfermions, and at $m(\chi^0) > 45$ GeV/c^2 with $\tan\beta \geq 10$ in the case of light sfermions, where possible sneutrino-chargino mass degeneracies limit the exclusion reach [2].

2.4 Effects of sfermion mixing

The possible effects of mixing in the third family of sfermions $(\tilde{\tau}, \tilde{\mathrm{b}}, \tilde{\mathrm{t}})$ have also been considered, and open more mass degenerate scenarios where standard searches lose their sensitivity. The sensitivity is recovered with more dedicated searches, in particular for light $\tilde{\tau}_1$ signals in gaugino cascade decays, and the final LSP mass limits are only slightly deteriorated to $m(\chi^0) > 37$ GeV/c^2 at $\tan\beta \approx 1$, and are maintained at $m(\chi^0) > 45$ GeV/c^2 at large $\tan\beta$, including Higgs exclusions [2].

A summary of LSP mass limits in the constrained MSSM is shown in Table 1, with different hypothesis and constraints.

Table 1. Summary of lower mass limits on the LSP

$m(\chi_1^0)$ limit	any $\tan\beta$	with Higgs constraints
heavy sfermions	>39 GeV/c^2	>50 GeV/c^2
any m_0	>39 GeV/c^2	>45 GeV/c^2
with $\tilde{\mathrm{f}}$ mixing	>37 GeV/c^2	>45 GeV/c^2

2.5 Limits in minimal supergravity

In the framework of minimal supergravity (mSUGRA) the MSSM parameters are further reduced and the LSP mass limits, with light sfermions, mixing and Higgs constraints, improves to $m(\chi^0) > 50 - 60$ GeV/c^2, depending on the top quark mass [5], as shown in Fig. 2.

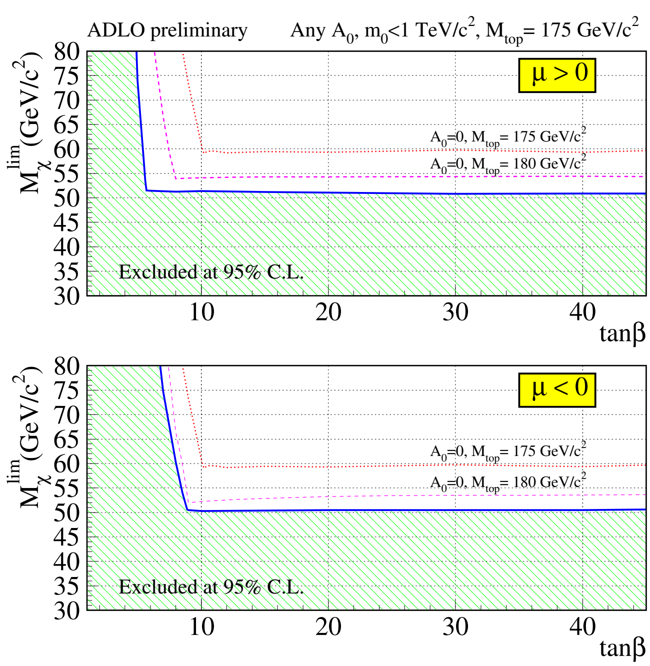

Fig. 2. Combined LSP lower mass limits in mSUGRA, as a function of $\tan\beta$ for $\mu > 0$ (*top*), and $\mu < 0$ (*bottom*)

2.6 Radiative corrections

Radiative corrections to the gaugino unification relation $\frac{M_1}{M_2} = \frac{5}{3}\tan^2\theta_W^2 \approx \frac{1}{2}$ and to the tree level gaugino masses are at the level of 5% and are not taken into account in the derivation of the mass limits. The proper inclusion of these corrections could deteriorate the LSP mass limits at the level of 1-2 GeV/c^2, that sets the level of precision of the quoted results.

3 Lower mass limits on other SUSY particles

Using the same exclusions of the constrained MSSM parameter space used to derive the LSP limits, lower mass limits on other SUSY particles can be derived, and are shown in Table 2, again under the assumption of unified light sfermions and using the constraints from Higgs searches [2].

Table 2. Other lower mass limits on SUSY particles

SUSY particle	lower mass limit with any m_0 and Higgs constraints
chargino	$m(\chi^+) > 90 - 100$ GeV/c^2
sneutrino	$m(\tilde{\nu}) > 85 - 95$ GeV/c^2
right selectron	$m(\tilde{\mathrm{e}}_R) > 75 - 95$ GeV/c^2
left selectron	$m(\tilde{\mathrm{e}}_L) > 110$ GeV/c^2

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