SEARCHES FOR SUPERSYMMETRY IN GAUGE-MEDIATED SUSY BREAKING MODELS AT LEP

ANDREA SCIABÀ
Department of Physics, Imperial College,
London SW7 2BZ, United Kingdom

Searches for evidence of production of supersymmetric particles in gauge-mediated SUSY breaking models have been performed by all the LEP collaborations on the data collected at centre-of-mass energies up to 189 GeV. Almost all the relevant topologies have been covered, and negative results have been found in all cases. Preliminary limits on the masses of the sparticles and on the model parameters for a minimal model have been derived.

1 Introduction

Supersymmetry (SUSY) is the most promising extension of the Standard Model (SM), as it solves the "naturalness" problem [1]; it assumes the existence of partners for every SM particle, with spin differing by 1/2, and masses below the TeV scale. Since SUSY must be a broken symmetry, a proper explanation of the origin of SUSY breaking should be given; this is usually done by assuming the existence of a "hidden sector" of new particles where SUSY is spontaneously broken, and a "mediating" interaction which communicates the symmetry breaking to the visible part of the particle spectrum. Apart from the common hypothesis of gravity mediation [2], one possibility is that an additional set of "messenger" particles is coupled at tree level to the hidden sector and through the usual gauge interactions to the visible sector; this scenario is referred to as "gauge-mediated SUSY breaking" (GMSB). Gauge-mediated theories automatically explain the observed absence of flavour-changing neutral currents, since the gauge interactions are flavour-blind, they are highly predictive, and they have a very distinctive phenomenology [3].

2 Phenomenology at LEP

In a minimal GMSB model, the unknown parameters are the SUSY mass scale (Λ), the number of messenger pairs (N_5), the messenger mass scale (M_{mess}), the SUSY breaking scale ($\sqrt{F}$), the ratio between the vacuum expectation values of the two Higgs doublets ($\tan\beta$), and the sign of μ (the Higgs mass term in the superpotential). The most distinctive phenomenological features of GMSB models are: *a*) the gravitino ($\widetilde{G}$) is the lightest supersymmetric particle (LSP), and its mass is related to $\sqrt{F}$ ($m_{\widetilde{G}} \simeq 2.4 \cdot 10^{-2} \left(\frac{\sqrt{F}}{10\ \mathrm{TeV}}\right)^2$ eV); *b*) the next-to-lightest supersymmetric particle (NLSP) is the lightest neutralino ($\widetilde{\chi}^0_1$) or the lightest stau ($\widetilde{\tau}_1$); *c*) the NLSP lifetime can be very large if $\widetilde{G}$ is heavy; *d*) squarks and gluinos are much heavier than the other sparticles [4].

At LEP, sparticles are expected to be produced in pairs and to eventually decay into gravitinos (which do not interact) and SM particles; decays can take place on macroscopic distances

Table 1: GMSB topologies at LEP.

Process	Final state topology	References
Neutralino NLSP		
$e^+e^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1$ $\tilde{\chi}^0_1 \rightarrow \gamma\tilde{G}$	single photon, acoplanar photons	9, 10, 11, 12
$e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^-$ $\tilde{\ell}^+ \rightarrow \ell^+\tilde{\chi}^0_1$	acoplanar leptons + ≥ 0 photons	5, 6, 7
$e^+e^- \rightarrow \tilde{\chi}^+_1\tilde{\chi}^-_1$ $\tilde{\chi}^+_1 \rightarrow \tilde{\chi}^0_1 W^{+(*)}$	acoplanar jets/leptons + ≥ 0 photons	7, 8
$e^+e^- \rightarrow \tilde{\chi}^0_2\tilde{\chi}^0_1$ $\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 Z^{0(*)}$	acoplanar jets/leptons + ≥ 0 photons	7
Stau NLSP		
$e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^-$ $\tilde{\ell}^+ \rightarrow \ell^+\tilde{G}$	stable heavy charged particles, acoplanar leptons with kinks, acoplanar leptons	7, 9, 13, 14
$e^+e^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1$ $\tilde{\chi}^0_1 \rightarrow \ell^\pm(\ell^\mp\tilde{G})$	four leptons and missing energy	9, 13
$e^+e^- \rightarrow \tilde{\chi}^+_1\tilde{\chi}^-_1$ $\tilde{\chi}^+_1 \rightarrow \tilde{\tau}^+\nu_\tau$	acoplanar taus	15

if the lifetime is large. Most of the decay topologies relevant at LEP have been examined by at least one of the LEP collaborations, and they are summarized in table 1.

If the neutralino is the NLSP, $\tilde{\chi}^0_1 \rightarrow \gamma\tilde{G}$ decays will happen; nevertheless, the resulting topologies will be essentially the same to be found in gravity-mediated SUSY breaking models, apart from the possible presence of photons coming from the $\tilde{\chi}^0_1$ decay, if the $\tilde{\chi}^0_1$ decay length is sufficiently small. Searches for production of sleptons, charginos and associated production of the second lightest and lightest neutralino have been performed for the entire range of neutralino lifetimes [5,6,7,8]. In this scenario, the "discovery mode" is expected to be the production of $\tilde{\chi}^0_1\tilde{\chi}^0_1$ pairs, which typically lead to an acoplanar photon pair and missing energy [9,10,11,12]; events with single photons, not originating from the interaction vertex, are expected for long lifetimes.

If the $\tilde{\tau}_1$ is the NLSP, completely different topologies are expected. When $\tan\beta \lesssim 10$, stau mixing is small, and all sleptons will act as co-NLSP; decays such $\tilde{\ell} \rightarrow \ell\tilde{G}$ will be the only ones allowed. Otherwise, "cascade" decays like $\tilde{\ell} \rightarrow \ell\tau\tilde{\tau}$ ($\ell = \mathrm{e}, \mu$) could be possible. Therefore, for relatively small values of $\tan\beta$, events with production of slepton pairs will consist of pairs of stable heavy charged particles, of pairs of charged particles with kinks or displaced vertices, or of acoplanar lepton pairs, depending to the value of their lifetime [7,9,13,14]. Production of neutralino pairs, where $\tilde{\chi}^0_1 \rightarrow \tilde{\ell}\ell \rightarrow \ell^+\ell^-\tilde{G}$, would give four leptons in the final state (two energetic and two soft) and missing energy. The flavours and charges of the most energetic leptons are uncorrelated, thus giving an especially striking signature [9]; for large $\tan\beta$, four taus are expected in the final state [13]. The $\tilde{\chi}^0_1\tilde{\chi}^0_1$ production could be relevant, if allowed, due to the much larger cross section with respect to slepton production. Finally, chargino pairs would decay into two staus and two neutrinos, thus leading to a final state similar to the case of stau pair production [15].

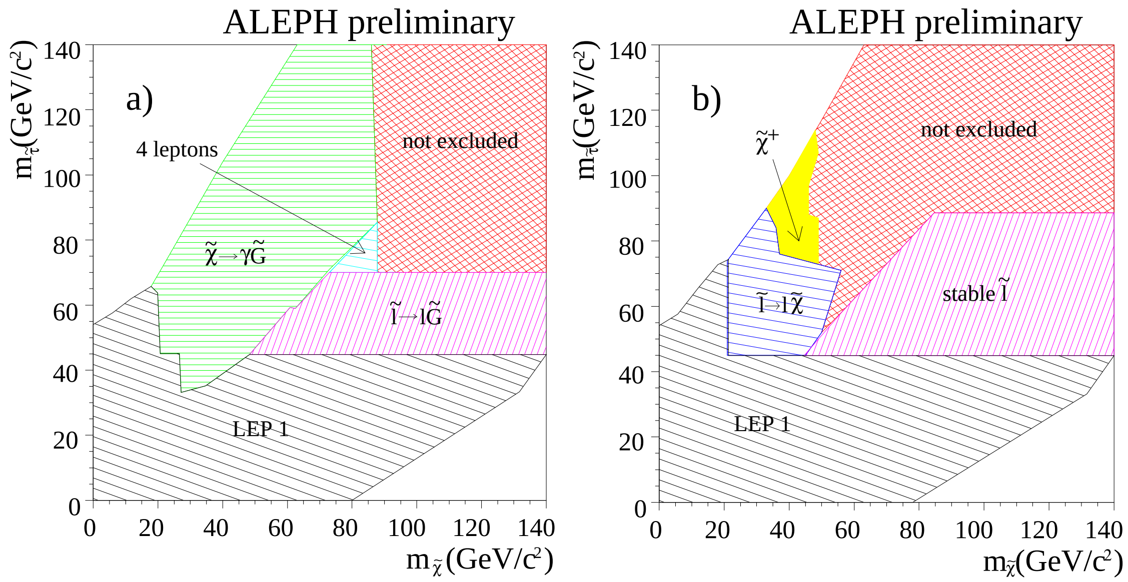

Figure 1: Region excluded at a 95% confidence level in the $\tilde{\tau}$ mass vs. $\tilde{\chi}_1^0$ mass plane for a) short and b) long NLSP lifetimes from the ALEPH data[9].

3 Interpretation and Conclusions

Data taken until 1998 at centre-of-mass energies up to 189 GeV have been analysed in a preliminar way by the LEP collaborations and no evidence of signal has been found. Upper limits on the cross section for production of SUSY particles can be translated into lower limits on their masses, depending on the specific GMSB model. They can also be used to constrain the parameter space of the GMSB model discussed earlier: ALEPH has combined the exclusion power of all their searches and an absolute lower limit on the NLSP mass of 45 GeV/c^2 has been derived. In figure 1, the contributions of each search to the excluded region in the $\tilde{\tau}$ mass vs. $\tilde{\chi}_1^0$ mass plane is shown, together with the contribution of the indirect limits from the measurement of the Z invisible width at LEP 1. From a scan of the parameter space, with $M_{\mathrm{mess}} < 10^{12}$ GeV, $\tan\beta < 38$ and $N_5 \leq 5$, a lower limit on Λ of 9 TeV has been found[9].

References

1. J. Wess and B. Zumino, *Nucl. Phys.* B **70**, 39 (1974)
2. R. Barbieri, *Riv. Nuovo Cimento* **11**, 1 (1988)
3. G. F. Giudice and R. Rattazzi, preprint hep-ph/9801271, submitted to *Phys. Rep.*
4. S. Ambrosanio, G. D. Kribs and S. P. Martin, *Phys. Rev.* D **56**, 1761 (1997)
5. R. Barate *et al* (ALEPH Coll.), *Phys. Lett.* B **433**, 176 (1998)
6. L3 Coll., L3 Note 2433, contribution # 6-243 to HEP99
7. OPAL Coll., OPAL Physics Note PN370 (1998)
8. DELPHI Coll., DELPHI 99-82 CONF 269, contribution # 7-213 to HEP99
9. ALEPH Coll., ALEPH 99-006 CONF 99-002, contribution # 7-420 to HEP99
10. DELPHI Coll., DELPHI 99-77 CONF 264, contribution to HEP99
11. L3 Coll., L3 Note 2426, contribution # 6-241 to HEP99
12. OPAL Coll., OPAL Physics Note PN386, contribution # 7-85 to HEP99
13. DELPHI Coll., DELPHI 99-89 CONF 276, contribution # 7-372 to HEP99
14. M. Acciarri *et al* (L3 Coll.), *Phys. Lett.* B **456**, 283 (1999)
15. DELPHI Coll., DELPHI 99-90 CONF 277, contribution # 7-373 to HEP99