Searches for GMSB at $\sqrt{s} = 189$ GeV at LEP

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Searches for Gauge Mediated Supersymmetry Breaking topologies are performed on 170 pb^{-1} of data collected at a centre of mass energy of 188.6 GeV by each of the four LEP experiments. No evidence for such processes is found, allowing 95% C.L. lower limits to be set on the masses of various particles in the context of GMSB. In particular, it is found that the lightest neutralino must be heavier that $90\,\mathrm{GeV}/c^2$, the right-handed stau must be heavier than $76\,\mathrm{GeV}/c^2$ and the gravitino must be heavier than $1.1 \times 10^{-5}\,\mathrm{eV}/c^2$.

I. INTRODUCTION

This note reports on searches for topologies characteristic of Gauge Mediated Supersymmetry Breaking theories [1]. In these theories supersymmetry is broken by gauge interactions at an energy scale close to the electroweak scale, rather than by gravitational interactions at the Plank scale. This supersymmetry breaking is conveyed to the visible sector by N generations of messenger multiplets.

Phenomenologically, GMSB theories differ from gravity mediated theories in that the gravitino $\tilde{\mathrm{G}}$ is naturally the lightest supersymmetric particle. The coupling of the gravitino to other particles is suppressed compared to the other SM couplings. This can give rise to search topologies which are significantly different for those of conventional SUSY. Pairs of SUSY particles which are produced in $\mathrm{e^+e^-}$ collisions will decay to the next to lightest supersymmetric particle NLSP via standard model processes. The NLSP will then decay into a gravitino together with its Standard Model partner. The nature of the NLSP depends largely on the number of generations of messenger multiplets. If there is only a single generation the lightest neutralino is generally the NLSP and it decays into a gravitino and a photon. If there are more than one generation the right-handed stau is generally the NLSP and it decays into a gravitino and a tau.

The neutralino NLSP scenario can result in standard SUSY topologies with the additional presence of a pair of energetic photons. This scenario provides a natural explaination (via the process $\mathrm{q\bar{q}} \to \tilde{\mathrm{e}}\tilde{\mathrm{e}} \to \mathrm{ee}\chi_1^0\chi_1^0 \to \mathrm{ee}\tilde{\mathrm{G}}\tilde{\mathrm{G}}\gamma\gamma$ [2]) for an unusual event with two high energy electrons, two high energy photons, and a large amount of missing transverse energy [3] observed by the CDF collaboration. In this framework, the best channel for discovery at LEP2 is $\mathrm{e^+e^-} \to \chi_1^0\chi_1^0 \to \tilde{\mathrm{G}}\tilde{\mathrm{G}}\gamma\gamma$. Limits derived from the LEP data are compared to the regions favoured by the CDF event within these models. In particular, in the case of GMSB theories, the data are compared to the predictions of the Minimal Gauge-Mediated MGM model of Ref. [2] which assumes that the lightest neutralino is pure bino, that the right-selectron mass is 1.1 times the neutralino mass and that the left-selectron mass is 2.5 times the neutralino mass.

The mass of the gravitino is related to the SUSY breaking scale $\sqrt{F}$. For $\sqrt{F} < 10$ TeV the gravitino is essentially massless. For a large SUSY breaking scale it is possible that the NLSP can decay inside the detector volume or can even traverse the detector without decaying leading to unmistakable characteristic signatures. In the case of a super-light gravitino [4] it is possible that the process $\mathrm{e^+e^-} \to \tilde{\mathrm{G}}\tilde{\mathrm{G}}\gamma$ can have an appreciable cross section leading to the production of events with photons and missing energy.

Searches for these topologies have been carried out by the four LEP experiments on the data samples of around 170 pb^{-1} of data collected at a centre of mass energy of 188.6 GeV. The searches performed follow closely those performed at lower centre of mass energies [5–8]. All the results given in this note are preliminary.

II. NEUTRALINO NLSP SCENARIO

In GMSB theories where the neutralino is the NLSP, the process $e^+e^- \to \chi_1^0\chi_1^0 \to \tilde{G}\tilde{G}\gamma\gamma$ is expected to provide the main experimental signature. If the neutralino has a short lifetime this gives rise to a topology involving two acoplanar photons and missing energy. Searches are performed for both neutralino and chargino pair production in this scenario.

A. Neutralino pair production

A search for neutralino pair production in the neutralino NLSP scenario has already been performed by the ALEPH collaboration at lower centre of mass energies [5]. The same analysis is applied with the energy of the least energetic photon required to be at least 36 GeV (the optimal value in the MGM [2] when the additional integrated luminosity is taken into account).

With this selection no candidates are found in the 189 GeV data while 1.00 events are expected from background processes. Applying this increased E_2 cut to the previously analysed data taken at 161 GeV to 183 GeV one event is observed in the data while 0.36 are expected from background processes. The upper limit on the production cross section at 189 GeV, obtained without performing background subtraction, is in the range of 0.037–0.061 pb for a 100% $\chi_1^0 \to \tilde{G}\gamma$ branching ratio and χ_1^0 masses in the range 45 GeV/c^2 to 94 GeV/c^2.

The mass limit obtained for the MGM model is

$$\mathrm{M}_{\chi_1^0} \geq 90\,\mathrm{GeV/c^2}$$

at 95% C.L., for a neutralino with lifetime < 3 ns.

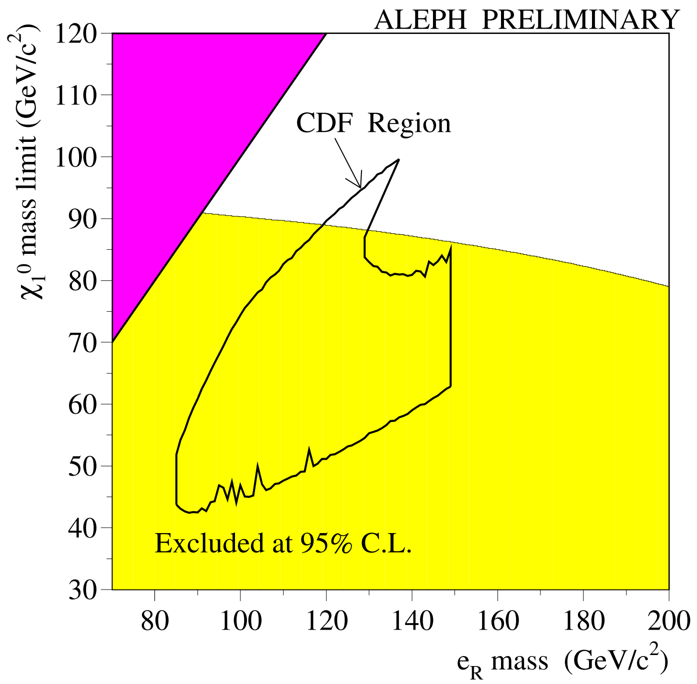

FIG. 1. The excluded region in the neutralino, selectron mass plane at 95% C.L. for a pure bino neutralino (light shaded area). Overlayed is the CDF region determined from the properties of the CDF event assuming the reaction $q\bar{q} \to \tilde{e}_R\tilde{e}_R \to ee\chi_1^0\chi_1^0 \to ee\tilde{G}\tilde{G}\gamma\gamma$ (taken from the Ref. [9]). The dark shaded region corresponds to a topology not covered by this analysis.

At LEP2 the production of bino neutralinos would proceed via t-channel selectron exchange. Right-selectron exchange dominates over left-selectron exchange. Thus, the cross section for $\mathrm{e^+e^-} \rightarrow \chi_1^0\chi_1^0$ depends strongly on the right-selectron mass. The experimentally excluded region in the neutralino, selectron mass plane is shown in Figure 1. Overlayed is the "CDF region", the area in the neutralino, selectron mass plane where the properties of the CDF event are compatible with the process $\mathrm{q\bar{q}} \rightarrow \mathrm{\tilde{e}_R\tilde{e}_R} \rightarrow \mathrm{ee}\chi_1^0\chi_1^0 \rightarrow \mathrm{ee\tilde{G}\tilde{G}}\gamma\gamma$ (taken from Ref. [9]). Most of the CDF region is excluded at 95% C.L. by this analysis.

B. Chargino pair production

A general search for chargino pair production in the neutralino NLSP scenario is performed by the OPAL collaboration following the selection criteria used at lower centre of mass energies [7]. Such chargino production would result in topologies similar to those of chargino searches in the MSSM but with the additional presence of one or more photons coming from the $\chi_1^0 \rightarrow \tilde{\mathrm{G}}\gamma$ decays. To keep the search efficient for longer neutralino lifetime, where one neutralino may decay outside the detector, the presence of only one additional photon is required. To cover efficiently the different possible final states produced in the chargino decay two different searches are made; depending on whether the photon and missing energy are accompanied by either a high multiplicity or a low multiplicity final state. These high and low multiplicity searches select 8 and 21 events in the data, respectively, while 13.8 ± 3.4 and 13.6 ± 1.6 events, respectively, would have been expected from SM background. Since no excess above SM predictions are observed, upper limits on the chargino production cross section can be obtain as a function of chargino and neutralino mass as shown in Figure 1. These limits are given in the case of negligible neutralino lifetime and 100% branching ratios for the decays $\chi^+ \rightarrow \chi_1^0\mathrm{W}^{+*}$ and $\chi_1^0 \rightarrow \tilde{\mathrm{G}}\gamma$.

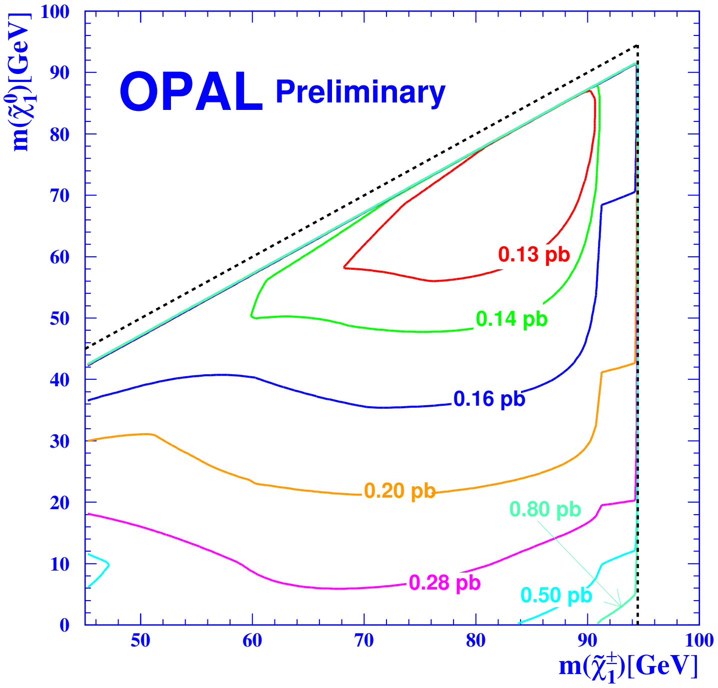

FIG. 2. The 95% C.L. upper limits on the chargino production cross section as a function of chargino and neutralino mass. These limits are given in the case of negligible neutralino lifetime and 100% branching ratios for the decays $\chi^+ \rightarrow \chi_1^0\mathrm{W}^{+*}$ and $\chi_1^0 \rightarrow \tilde{\mathrm{G}}\gamma$.

III. $\tilde{\tau}_R$ NLSP SCENARIO

In GMSB theories where the $\tilde{\tau}_R$ is the NLSP, the process $e^+e^- \to \tilde{\tau}_R^+\tilde{\tau}_R^- \to \tilde{G}\tilde{G}\tau^+\tau^-$ is expected to provide the main experimental signature. A variety of searches are performed for this final state in order to be sensitive to the full range of $\tilde{\tau}_R$ lifetimes. A further search is made for neutralino pair production which, in the case of a $\tilde{\tau}_R$ NLSP, may provide the best experimental signature for GMSB.

A. $\tilde{\tau}_R$ pair production

A search for $\tilde{\tau}_R$ pair production is performed by the DELPHI Collaboration using the same selection criteria which they employed at lower centre of mass energies [6]. The full range of possible $\tilde{\tau}_R$ lifetimes is covered by employing four separate searches. For short $\tilde{\tau}_R$ lifetimes the topology of interest involves two acoplanar taus and missing energy. Events of this type are searched for using the acoplanar tau search developed in the context of the MSSM. If the $\tilde{\tau}_R$ lifetime is long the $\tilde{\tau}_R$ will traverse the detector without decaying. Events of this type may be identified via the high specific ionization or the characteristic Cherenkov radiation associated with the passage of heavy particles through the detector volume. In the case of intermediate $\tilde{\tau}_R$ lifetimes searches are made for taus with large impact parameter and for $\tilde{\tau}_R$ which decay inside the tracking volume producing reconstructible decay vertices. No excess of events compared with SM expectation is observed for any of these searches, allowing a large region of the $(m_{\tilde{G}}, m_{\tilde{\tau}_R})$ plane to be excluded, as shown in Figure 3. From this analysis it is possible to set a lifetime-independent lower limit of $76\,\mathrm{GeV}/c^2$ on the mass of the $\tilde{\tau}_R$ at 95% C.L..

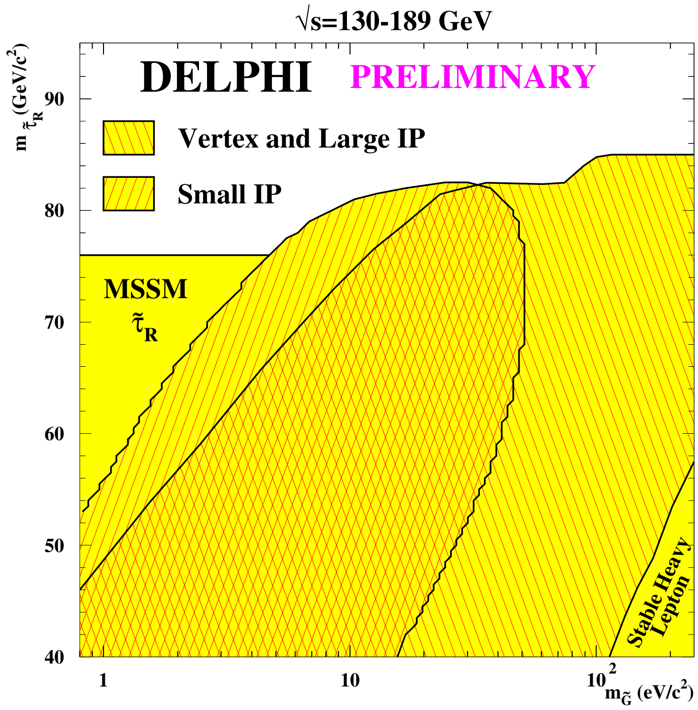

FIG. 3. Excluded region of the $(m_{\tilde{G}}, m_{\tilde{\tau}_R})$ plane from the four separate searches for $\tilde{\tau}_R$ pair production.

B. Neutralino pair production

In the $\tilde{\tau}_R$ NLSP scenario, direct $\tilde{\tau}_R$ pair production may not provide the best experimental signature due to the low cross section and irreducible background coming for W pair production. If the χ_1^0 is the NNLSP and is below threshold then the process $e^+e^- \to \chi_1^0\chi_1^0 \to \tilde{\tau}_R^+\tau^-\tilde{\tau}_R^-\tau^+ \to \tilde{G}\tilde{G}\tau^+\tau^-\tau^+\tau^-$ which gives rise to four τ's and missing energy in the final state may provide the best experimental signature. In general, two of the τ's will be energetic and the other two τ's will be soft. Furthermore, half of the time the two energetic τ's will have the same sign giving rise to a striking experimental signature. A search for such events is made by the DELPHI collaboration using a set of selection criteria which they developed at lower centre of mass energies [6]. No events are selected allowing an additional region of the $(m_{\tilde{\tau}_R}, m_{\chi_1^0})$ plane to be excluded, as compared to the searches for acoplanar photons and acoplanar taus, as shown in Figure 4.

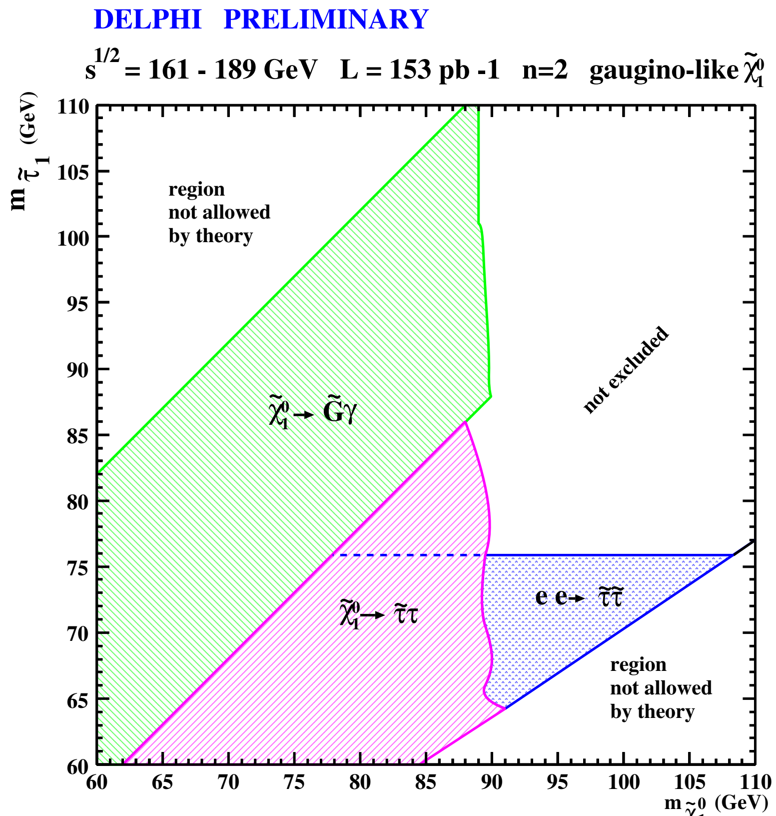

FIG. 4. Excluded region of the $(m_{\tilde{\tau}_R}, m_{\chi_1^0})$ plane from the searches for the acoplanar photon, acoplanar tau and four-tau final states

IV. SEARCH FOR THE PROCESS $e^+e^- \to \tilde{G}\tilde{G}\gamma$

If the gravitino $\tilde{G}$ is very light the cross section for the process $e^+e^- \to \tilde{G}\tilde{G}\gamma$ can become appreciable. This gives rise to a topology where only a single photon and missing energy are observed. This topology has an irreducible SM background from the process $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$.

The selection of events with one photon and missing energy follows that of a previous ALEPH analyses [5]. When this selection is applied to the 189 GeV data, 484 one-photon events are found. The KORALZ [10] Monte Carlo predicts that 492 events would be expected from Standard Model processes. The missing mass and polar angle distributions of the selected data events are in good agreement with the Monte Carlo expectations as shown in Figure 5.

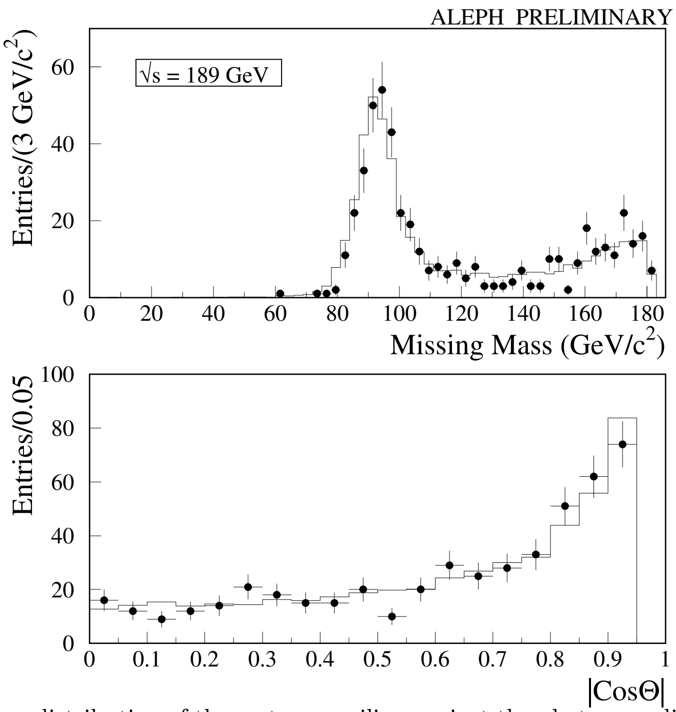

FIG. 5. a) The invariant mass distribution of the system recoiling against the photon candidate is shown for the data (points with error bars) and Monte Carlo (histogram). b) The polar angle distribution is shown for the data (points with error bars) and Monte Carlo (histogram).

In order to search for the process $e^+e^- \to \tilde{G}\tilde{G}\gamma$, a two-dimensional binned maximum likelihood fit is performed to these distributions. The missing mass and polar angle distributions of the signal, together with the cross section dependence on the centre of mass energy, are calculated from the differential cross section given in Ref. [4]. From the fit a cross section limit of 0.14 pb at $\sqrt{s} = 188.6\,\mathrm{GeV}$ is obtained at 95% C.L. This results in a 95% C.L. lower limit of $1.1 \times 10^{-5}\,\mathrm{eV}/c^2$ for the mass of the gravitino. In the same paper a more general approach gives a mass limit dependent on two free parameters. In the worst case this would lead to a limit on the gravitino mass lower by a factor of two.

V. CONCLUSIONS

A variety of searches for Gauge Mediated Supersymmetry Breaking topologies are performed on 170 pb^{-1} of data collected at a centre of mass energy of 188.6 GeV by each of the four LEP experiments. No evidence for such processes is found, allowing 95% C.L. lower limits of $90\,\mathrm{GeV}/c^2$, $76\,\mathrm{GeV}/c^2$ and $1.1 \times 10^{-5}\,\mathrm{eV}/c^2$ to be set on the mass of the lightest neutralino, the right-handed stau and the gravitino, respectively.

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