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Search for SUSY in gauge mediated and anomaly mediated supersymmetry breaking models

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Abstract. In this note, recent results on the search for Gauge Mediated Supersymmetry Breaking (GMSB) and Anomaly Mediated Supersymmetry Breaking (AMSB) at the LEP and Tevatron colliders are summarized. We report on DØ's search for GMSB in di-photon events with large missing transverse energy and discuss the sensitivity of similar searches based on future Tevatron integrated luminosities.

1 Introduction

If Supersymmetry (SUSY) would be an exact symmetry, SUSY particles would have the same masses as their Standard Model (SM) partners. The required breaking of SUSY is generally assumed to occur in a *hidden* sector at some very high energy, and to be mediated to the *visible* sector at scales $\mathcal{O}(1\,\text{TeV})$ by means of a known interaction. In contrast to Super Gravity (SUGRA), where SUSY is broken at a very high scale and is mediated by gravity, in GMSB models, it is assumed that at scales as low as $\mathcal{O}(10\,\text{TeV})$ the hidden sector is coupled to a messenger sector, which by itself is coupled to the visible sector through standard SM gauge interactions [1].

Since those gauge interactions are flavour blind, GMSB models do not generate unwanted Flavour Changing Neutral Currents (FCNC). Another attractive feature of GMSB models is their predictiveness having a minimal set of only five parameters in addition to the SM ones: the SUSY breaking scale Λ, the messenger mass scale M_{mess}, the number of messenger fields N_{mess}, the ratio of the Higgs vacuum expectation value $\tan\beta$, and the sign of the Higgs mass term $|\mu|$.

GMSB models have a very distinctive phenomenology. The gravitino $\tilde{G}$ is typically light ($\lesssim 1\,\text{keV}$) and is the lightest SUSY particle (LSP). The next-to-lightest SUSY particle (NLSP) is usually either the lightest neutralino $\tilde{\chi}_1^0$, decaying into $\gamma\tilde{G}$, or the lightest charged slepton (mostly $\tilde{\tau}_1$), decaying into $l\tilde{G}$.

In Anomaly Mediated SUSY Breaking (AMSB) models [2], the rescaling of anomalies in the supergravity Lagrangian gives rise to soft mass parameters at the visible scale. AMSB models are defined by only three parameters and the sign of the Higgs mass term in addition to the SM. The LSP can be either the $\tilde{\chi}_1^0$, which is nearly mass degenerate with the $\tilde{\chi}_1^\pm$, or the $\tilde{\nu}$, or the $\tilde{\tau}$.

This note briefly reviews searches for both GMSB and AMSB signatures at LEP and reports on DØ's preliminary search for GMSB in $\gamma\gamma$ events with large missing transverse energy ($\not{E}_t$).

2 Searches for GMSB topologies at LEP

Depending on the mass of the LSP and its own mass, the NLSP could have any decay length relative to detector dimensions. Thus, not only the nature of the NLSP, but also its lifetime is crucial for the wealth of topologies which can be generated by GMSB models.

2.1 Topologies with $\tilde{\chi}_1^0$ as NLSP

If the first generation neutralino $\tilde{\chi}_1^0$, which can be pair-produced at LEP via $\tilde{e}$ exchange, is short-lived, the event topology will consist of two acoplanar photons and missing energy. The main SM background contribution to this channel is neutrino production with photon radiation. Since no anomalies in the mass distribution of the system recoiling against the photons were observed at LEP, limits on the neutralino mass $m_{\tilde{\chi}_1^0}$ as function of $m_{\tilde{e}}$ were set [3] and the GMSB interpretation of CDF's $ee\gamma\gamma\not{E}_t$ event [5] was excluded[1] (see Fig. 1). The LEP collaborations have also searched for $\tilde{\chi}_1^0$ production with medium lifetimes by studying topologies with non-pointing photons, where one of the neutralinos decays within the detector at large distances away from the interaction point. In the case of long-lived neutralinos, searches in the indirect production channels via slepton-pair or chargino-pair production have been performed [6].

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[1] All exclusion limits mentioned in this paper are 95% C.L.

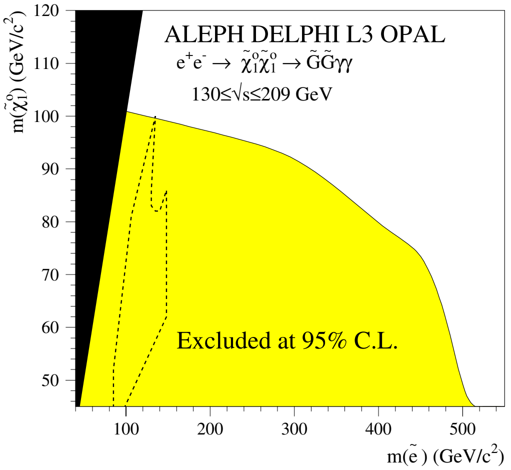

Fig. 1. 95% exclusion limit for GMSB derived from acoplanar di-photon analyses at LEP

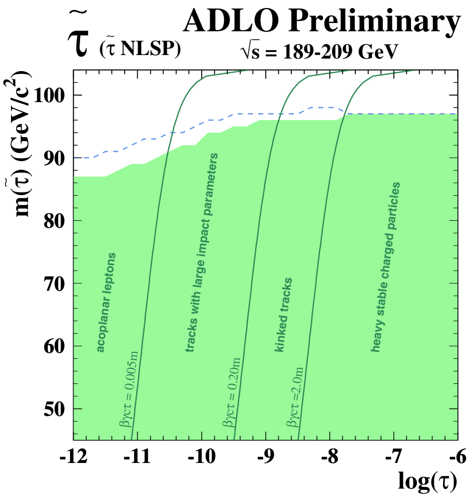

Fig. 2. Excluded mass as a function of $\tilde{\tau}_1$ lifetime. Expected limit and lines of equal $\beta\gamma c\tau$ are shown, the latter to indicate the different lifetime regimes

2.2 Topologies with $\tilde{\tau}$ or $\tilde{l}$ as NLSP

The LEP collaborations have extensively studied scenarios where the stau or a slepton is the NLSP. Depending on the NLSP lifetime, different search strategies have been applied. The combination of those searches covers the entire range of possible lifetimes [3,6]. For the $\tilde{\tau}_1$ NLSP scenario, the mass limit as a function of the stau lifetime is shown in Fig. 2, where the sensitivities for the various channels are also indicated. In order of increasing lifetime, searches for the following final states have been performed: acoplanar leptons, tracks with large impact parameter, kinked tracks, and heavy stable charged particles [3,7]. Combining the results from all four LEP collaborations, a lifetime independent lower mass limit for the stau mass of $m_{\tilde{\tau}_1} > 86.9\,\text{GeV}$ was set [3]. The combination of searches for all NLSP scenarios was used by OPAL to perform a complete scan over the parameters of the minimal model of GMSB [6].

3 Searches for AMSB topologies at LEP

A characteristic feature of AMSB is the small mass difference between the first-generation chargino and neutralino, which are mostly gaugino-like. All LEP experiments have searched for signatures of this model [3].

For mass differences $\Delta m = m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \lesssim 200\,\text{MeV}$, the lifetime can be so long that the chargino could be identified through detection of a heavy stable charged particle or through a kink corresponding to its decay, similar to the searches for GMSB signatures. For larger Δm those lifetime tags are no longer effective. Since the visible products of the chargino decay carry little momentum, those events are both difficult to trigger on and to distinguish them from the large two-photon background. However, a tag on a photon with large transverse energy coming from initial state radiation improves both trigger efficiency and separation from background. Thus, this method achieves the highest sensitivity in the mass range $200\,\text{MeV} \lesssim \Delta m \lesssim 3\,\text{GeV}$. For even larger values of Δm a standard search for chargino decays can be applied.

Delphi has performed a parameter scan of AMSB models using a combination of the small Δm chargino search together with the search for $\tilde{\chi}_1^\pm \to \tilde{\nu} l^\pm$, the searches for SM-like or invisible Higgs, and the constraints coming from LEP I measurements at the Z pole [8].

4 Searches for GMSB signatures at Tevatron

The dominating production channels for SUSY particles at Tevatron are $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ and $\tilde{\chi}_1^+\tilde{\chi}_1^-$ pair production.

4.1 Inclusive search for $\gamma\gamma\not{E}_t$

If the neutralino is the NLSP and it has a short lifetime, the final state will contain two photons and large missing transverse energy $\not{E}_t$.

The DØ collaboration has done a preliminary search for this GMSB signature based on an integrated luminosity of $L = 128\,\text{pb}^{-1}$ collected since the start of Run II. The measurement of the $\not{E}_t$ spectrum in di-photon events requires two isolated reconstructed photons with transverse energy $E_T > 20\,\text{GeV}$ within the acceptance of the central calorimeter. Two different types of background contributions, with and without true $\not{E}_t$, have been estimated. The background without true $\not{E}_t$ (i.e. where the measured $\not{E}_t$ is due to resolution effects) are dominantly QCD processes like di-photon or jet production, where the latter are mis-identified as photons (due to leading π^0's within the jets). Their contribution is estimated using a fake $\gamma\gamma$ sample, where at least one photon candidate fails the shower shape requirement.

The background with true $\not{E}_t$ (from ν's) originates from W production accompanied by a photon or a jet, where the electron from the W decay and the potential jet are misidentified as photons. This contribution is estimated using an electron-photon sample and the $e \to \gamma$ mis-identification probability derived from data.

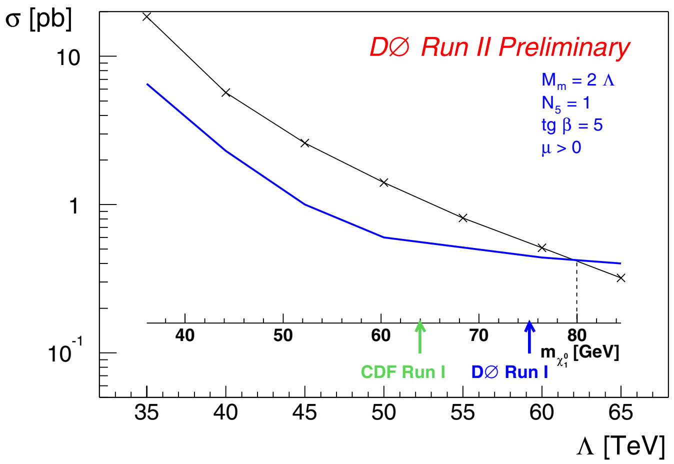

Fig. 3. Upper cross section limit compared to the GMSB prediction for the sum of $\tilde\chi_1^\pm\tilde\chi_2^0$ and $\tilde\chi_1^+\tilde\chi_1^-$ pair production and derived lower mass bound. For comparison the limits obtained at Run I are indicated

Signal acceptance and selection efficiencies have been estimated for various parameter sets of GMSB using a full simulation of the DØ detector and the photon identification efficiency, which was determined from data.

Since no excess in the $\not\!\!E_t$ distribution has been observed, upper limits on cross sections are calculated based on expected and observed event rates with $\not\!\!E_t > 35\,\mathrm{GeV}$ using a Bayesian approach. By comparing the derived upper limits for the cross sections with their theoretical predictions (shown in Fig. 3), a lower limit on the SUSY breaking scale $\Lambda > 62.5\,\mathrm{TeV}$ has been derived within the parameter set indicated in the figure. This limit corresponds to lower bounds on the neutralino and chargino mass of $m_{\tilde\chi_1^0} > 80\,\mathrm{GeV}$ and $m_{\tilde\chi_1^\pm} > 144\,\mathrm{GeV}$, respectively.

Earlier exclusions interpreted as lower limits on the neutralino mass within this parameter set are 65, 75, and 100 GeV from CDF [5], DØ [9], and combined LEP (see Sect. 2.1) respectively.

A similar preliminary study has been performed by CDF [10].

4.2 Prospects for Tevatron Run II

The discovery reach of the $\gamma\gamma\not\!\!E_t$ channel has been studied in Ref. [11] for a similar set of GMSB parameters. With an integrated luminosity of $L = 2\,\mathrm{fb}^{-1}$, GMSB with prompt $\tilde\chi_1^0$ decays can be discovered with a C.L. of 5σ up to neutralino masses $m_{\tilde\chi_1^0} \approx 165\,\mathrm{GeV}$, in excess of the current LEP exclusion limit. For intermediate neutralino lifetimes the sensitivity drops as the $\tilde\chi_1^0$ decays outside the detector, but it can be partly recovered by including final states with one photon, jets, and missing transverse energy.

Also for the $\tilde\tau$ NLSP scenario, Tevatron has a discovery reach beyond the current LEP limits as shown in Fig. 4 [11]. In case of a short-lived NLSP the analysis follows a standard search for a tri-lepton or like-sign dilepton signature. If the NLSP is quasi-stable, so that it escapes the detector, the two staus in the final state can be identified as two muon-like objects with large ionization energies $\mathrm{d}E/\mathrm{d}x$.

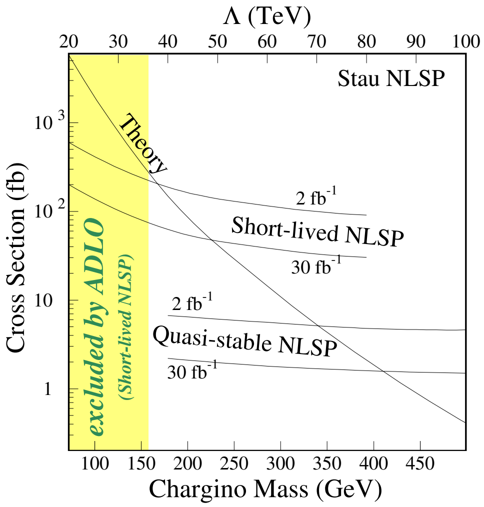

Fig. 4. LEP exclusion limits for chargino masses compared to prospects for Tevatron Run II

5 Conclusions

No evidence for the production of SUSY particles have been observed at LEP or Tevatron. At LEP many different topologies as predicted by GMSB and AMSB have been studied. The combination of many search channels is used to set limits for all NLSP lifetimes and to cover most of the kinematically accessible parameter space for both GMSB and AMSB models. DØ's preliminary results from Run II are already superseding the GMSB limits obtained from Run I. For certain regions of the GMSB parameter region, the experiments at Tevatron have the potential to significantly improve lower limits on SUSY particle masses.

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