Expected Performance of the ATLAS Detector in GMSB Models with Tau Final States

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Gauge Mediated Supersymmetry Breaking (GMSB) models provide a possible mechanism to mediate Supersymmetry to the visible sector. In these models the lightest supersymmetric particle (LSP) is usually the gravitino, while the next-to-lightest supersymmetric particle (NLSP) is either a neutralino or a slepton. In the case of a stau NLSP events with large missing transverse energy, highly energetic jets and up to four τ leptons are expected in pp-collisions at the LHC. A study of the expected performance of the ATLAS detector in GMSB scenarios with a stau NLSP for a LHC center-of-mass energy of $\sqrt{s}$ = 10 TeV is presented. A cut-based selection has been optimised using a typical GMSB scenario and a scan of the GMSB parameter space has been performed to determine the discovery reach as a function of the integrated luminosity. In addition, the invariant mass distribution of two τ leptons has been used to study the measurement of masses of supersymmetric particles with larger event samples.

XXth Hadron Collider Physics Symposium
November 16 – 20, 2009
Evian, France

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PoS(HCP2009)073

1. GMSB Models

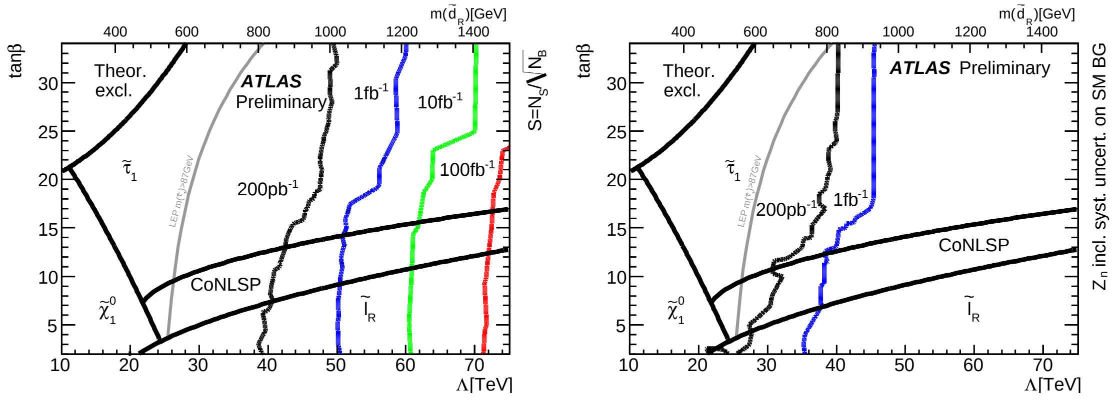
In GMSB models Supersymmetry is communicated from the secluded sector to the visible sector through a flavor-blind SM gauge interaction via messenger fields at a scale M_m small compared to the Planck mass. Squarks, sleptons and gauginos obtain their masses radiatively from the gauge interactions with the massive messenger fields. The minimal GMSB model ist characterised by six fundamental parameters: the effective SUSY breaking scale Λ, the mass of the messengers M_m, the number of messenger SU(5) supermultiplets N_5, the ratio of the Higgs vacuum expectation values $\tan\beta$, the sign of the Higgsino mass term sgnμ and the scale factor of the gravitino coupling C_{grav}which determines the NLSP lifetime. If R-parity is assumed to be conserved the lightest supersymmetric particle (LSP), the gravitino $\widetilde{G}$, is stable. In large parts of the parameter space the next-to-lightest supersymmetric particle (NLSP) is the $\tilde{\tau}$. An example is the scenario called GMSB6 with Λ=40 TeV, M_m=250 TeV, N_5=3, $\tan\beta$=30, sgnμ=+ and C_{grav}=1, where $m_{\tilde{\tau}_1}$=102.8 GeV. GMSB models with $\tilde{\tau}_1$ NLSP have been searched for at LEP [1]. For prompt decays, $\tilde{\tau}_1$ NLSPs with masses below 87 GeV have been excluded.

2. Study of the Discovery Potential in the GMSB Parameter Space

In regions of the GMSB parameter space where the NLSP is the $\tilde{\tau}_1$, long cascade decays of the initial squarks and gluinos lead to many highly energetic jets, many τ leptons, and a significant amount of missing transverse energy (E_T^{miss}) due to the escaping $\widetilde{G}$. For this reason the following preselection is applied: events must pass the trigger selection containing at least one jet with $p_T >$ 70 GeV and $E_T^{\text{miss}} > 30$ GeV, two or more reconstructed jets have to be found (leading jet $p_T >$ 100 GeV, second-leading jet $p_T > 50$ GeV), at least one hadronically decaying τ lepton has to be found (leading $\tau\, p_T > 20$ GeV), E_T^{miss} has to exceed 60 GeV and the azimuthal angle between the leading jet and the direction of E_T^{miss} needs to exceed 0.2. This selection yields a signal efficiency of 43% for the GMSB6 scenario. The remaining SM background mainly consists of $t\bar{t}$ and W events. For further suppression of this SM background a two-dimensional optimisation of $S = N_S/\sqrt{N_B}$, where N_S (N_B) is the number of signal (background) events, has been performed. The maximum significance S can be achieved for $E_T^{\text{miss}} > 280$ GeV and $N_\tau \geq 2$ yielding 20.4 ± 0.7 signal events for the GMSB6 scenario and 2.5 ± 1.5 expected background events for $\mathscr{L} = 200\,\text{pb}^{-1}$ [2].

The discovery potential in the GMSB parameter space is studied in the (Λ-$\tan\beta$)-plane for $M_m = 250$ TeV, $N_5 = 3$, sgn$\mu = +$ and $C_{\text{grav}} = 1$. These parameter values restrict the analysis to specific, promptly decaying NLSPs. The number of selected signal events in the $(\Lambda - \tan\beta)$-plane for $200\,\text{pb}^{-1}$ and the expected number of background events can be translated into a signal significance as a function of the integrated luminosity $\mathscr{L}$. The corresponding results are shown in Fig. 1(a). However, this simple definition neglects the influence of systematic uncertainties on the background expectation. These relative uncertainties have been estimated to be 50% for a centre-of-mass energy of 10 TeV. A more appropriate calculation of the significance Z_n including these systematic uncertainties [3] (p.1590) provides a more conservative estimate of the signal significance as displayed in Fig. 1(b). This significance definition reduces the parameter region for a 5σ discovery with $\mathscr{L} = 200\,\text{pb}^{-1}$ ($1\,\text{fb}^{-1}$) from $\Lambda \sim 50$ TeV (60 TeV) to $\Lambda \sim 40$ TeV (45 TeV). The discovery reach is limited by the systematic uncertainty of the background.

PoS(HCP2009)073



(a) (b)

Figure 1: Integrated luminosity needed for a signal significance of $S = 5$ or $Z_n = 5$, respectively, in the (Λ-tanβ)-plane for $M_m = 250\,TeV$, $N_5 = 3$, sgn$\mu = +$ and $C_{\rm grav} = 1$ using (a) the simple calculation of the significance S and (b) Z_n properly including the systematic uncertainties.

3. Study of the Invariant Di-Tau Mass Distribution

After a possible SUSY discovery the determination of the masses of SUSY particles is vital. In the presence of two undetected LSP only kinematic end points of invariant mass distibutions can be measured, mostly sensitive to differences of SUSY masses. For the study of the kinematic end-point of the invariant mass of two τ leptons larger datasets ($8\,\mathrm{fb}^{-1}$) are considered. The selection is slightly loosened compared to the one mentioned in the previous section to allow for sufficient statistics [2]. Due to the unmeasured neutrinos in τ decays the characteristic triangular shape and therefore the kinematic end-point of the di-tau invariant mass distribution is lost impeding its direct extraction. For this reason the combined OS-SS distribution of the GMSB signal and the SM background is fitted to extract the inflection point $m_{\tau\tau}^{\rm IP}$ of the distribution which is translated into the end-point $m_{\tau\tau}^{\rm max}$ using a linear calibration curve following the method proposed in [3] (p. 1617). The determination of the end-point is subject to several sources of systematic uncertainty. Combining all systematic uncertaintinties the following kinematic endpoint is obtained:

$$m_{\tau\tau}^{\rm max} = \big(135 \pm 4\,(\mathrm{stat.})\,^{+13}_{-9}\,(\mathrm{sys.}) \pm 13\,(\mathrm{SUSY\,model})\big)\ \mathrm{GeV}\,. \tag{3.1}$$

This result demonstrates that a measurement of the end-point of the invariant di-tau mass spectrum might be possible in the GMSB6 scenario with a small bias from additional SUSY background.

References

[1] LEPSUSYWG, ALEPH, DELPHI, L3 and OPAL Experiments, *Combined LEP GMSB stau/smuon/selectron results, 189-208 GeV*, *LEPSUSYWG/02-09.2*, 2002.

[2] The ATLAS Collaboration, *Expected performance of the ATLAS detector in GMSB models with tau final states*, *ATL-PHYS-PUB-2009-089*, 2009.

[3] The ATLAS collaboration, *Expected performance of the ATLAS experiment - Detector, trigger and physics*, *CERN-OPEN-2008-020*, 2009.