PROCEEDINGS OF SCIENCE

Searches for heavy long-lived charged particles with the ATLAS detector in *p-p* collisions at $\sqrt{s}$ = 8 TeV

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Searches for heavy long-lived charged particles (LLP) [1] were performed on a 19.1 fb^{-1} data sample from p-p collisions at $\sqrt{s}$ = 8 TeV collected by the ATLAS detector at the LHC. No excess is observed above the estimated background and limits are placed on the mass of the LLPs in various supersymmetric models: R-hadrons, directly produced charginos, stable sleptons produced directly or in cascade decays in GMSB and LeptoSUSY models.

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1. Introduction

Heavy LLPs are predicted in many extensions to the Standard Model. R-parity conserving supersymmetry (SUSY) models, such as split SUSY [3-4], gauge-mediated SUSY breaking (GMSB) [5-12] and LeptoSUSY [13-14], as well as other scenarios allow for a variety of LLP states stable enough to be directly identified by the ATLAS detector [2].

We focuses on the search for charged LLPs at the reach of the Large-Hadron Collider (LHC) and under the SUSY theory.

The searches are based almost entirely on the characteristics of the LLP itself, but are further optimized for the different experimental signatures of sleptons, charginos and composite colorless states of a squark or gluino together with light SM quarks or gluons, called R-hadrons.

1.1 Analysis Strategy

When traveling with a speed measurably lower than the speed of light, charged particles can be identified and their mass (m) determined from their measured speed (β) and momentum (p), using the relation: m= $\frac{p}{\beta\gamma}$, where the momentum p can be deduced from the particle's track in the detector, γ is the Lorenz factor, and the velocity β can be estimated from the measured Time-of-Flight (ToF) and from specific ionization energy loss $\frac{dE}{dx}$ that measure βγ.

The measured ToF from hits generated by the charged particle track in the ATLAS electromagnetic and hadronic calorimeters, and in the muon spectrometer is used to estimate β, and correction to the hit-times for LHC-ATLAS phase difference (per run) and offsets by detector element is performed. Then smearing of hit-times in MC according to calibrated hit-times distribution in Z→μμ data (checked with Z→μμ MC) allow for a better estimation of the signal efficiency.

Quality and consistency requirements are applied on the β's and the individual sub-detector β measurements are combined in a weighted average as shown in Figure 1.

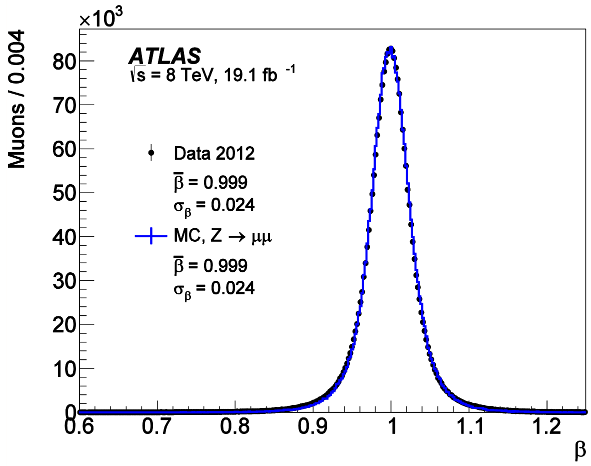

Figure 1: Combined β measurement (right) for selected $Z \rightarrow \mu\mu$ events in data (points) and MC simulation (line) [1].

The event selection includes only events that were triggered by either Muon or missing-transvers momentum (E_T^{miss}) trigger chains that have a good primary vertex. Then the candidates within the event are selected by reconstruction quality cuts and cuts on p_T, η, β and p. Last, a model dependent mass cut is applied.

The background, composed mostly of μ's with high-p_T and miss-measured β, is estimated entirely using data. Elimination of possible correlation between p and β by division into η regions, and random pairings between a candidate's momentum and β (or also $\beta\gamma$ for R-hadrons) is used to calculate the candidate's mass.

1.2 Signal Regions

Within the different searches different scenarios can occur, hence in order to cover all possibilities, a division into signal-regions is applied. Then the candidate selection is constructed and tuned per search and per signal-region and the background is estimated per search and signal region as well.

1.2.1 Sleptons

Within the GMSB the $\tilde{\tau}$ is considered the Next-to-Lightest SUSY Particle (NLSP) and the $\tilde{G}$ is the Lightest SUSY Particle (LSP), however in case of small coupling to the $\tilde{G}$, the NLSP is long-lived. GMSB sub-scenarios are considered here as well: either Electroweak ($\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0 \rightarrow \tilde{l} \rightarrow \tilde{\tau}$) or direct slepton production ($\tilde{l} \rightarrow \tilde{\tau}$ or DY $\tilde{\tau}$). Within the LeptoSUSY model either a $\tilde{g}$ or a $\tilde{q}$ is produced, decaying to jets and multiple leptons to a final state with stable $\tilde{l}$**.** For the slepton searches two muon-like LLPs are expected per event where the two signal regions considered are the Loose two-candidates (SR-SL-2C) SR or a Tight one-candidate (SR-SL-1C) SR, defined in order not to eliminate cases where one of the two candidates is badly reconstructed.

Mass distribution and background estimation for the two-candidate SR are shown in Figure 2.

1.2.2 Charginos

Simplified model predicting the $\tilde{\chi}_1^{\pm}$ to be nearly mass degenerate with $\tilde{\chi}_1^0$(LSP). 33% of the events are expected to be of a $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ i.e. two muon-like LLPs (Loose two-candidates (SR-CH-2C)) per event, and 67% are of $\tilde{\chi}_1^0\tilde{\chi}_1^{\pm}$, i.e. a final state with one LLP and a large reconstructed E_T^{miss} (Loose one-candidate+ E_T^{miss} (SR-CH-1LC)). The third SR is defined in order to include also badly reconstructed candidates (Tight one-candidate (SR-CH-1C)).

Mass distribution and background estimation for the loose one-candidate + E_T^{miss} SR are shown in Figure 3 (left).

1.2.3 R-hadrons

Long-lived $\tilde{g}$, $\tilde{t}$ or $\tilde{b}$ are produced at the interaction point, bounding to colored SM particles to form R-Hadron. Nuclear interactions between the light quarks and gluons in the hadron and the calorimeter material can result in either neutral or electric charge state. As a result the R-hadron‘s detector signature can not be anticipated. In this search we consider either a full track, i.e the R-hadron is electrically charged before and after the interaction with the calorimeter, or a half track (information from the Inner-Detector (ID) and the calorimeters (Calo) is the only one available) if the R-hadron is exiting the calorimeter as neutral.

To gain more signal efficiency in the R-hadron search, the cuts on β, $\beta\gamma$, p depend on

LLP mass. Two search strategies are applied: a full detector search (SR-RH-FD), where Muon Spectrometer (MS) information may or may not be used. And an MS-Agnostic search (SR-RH-MA) where only the track information from ID+Calo, and MS information is omitted.

Mass distribution and background estimation for a 500 GeV gluino in the full-detector search are shown in Figure 3 (right).

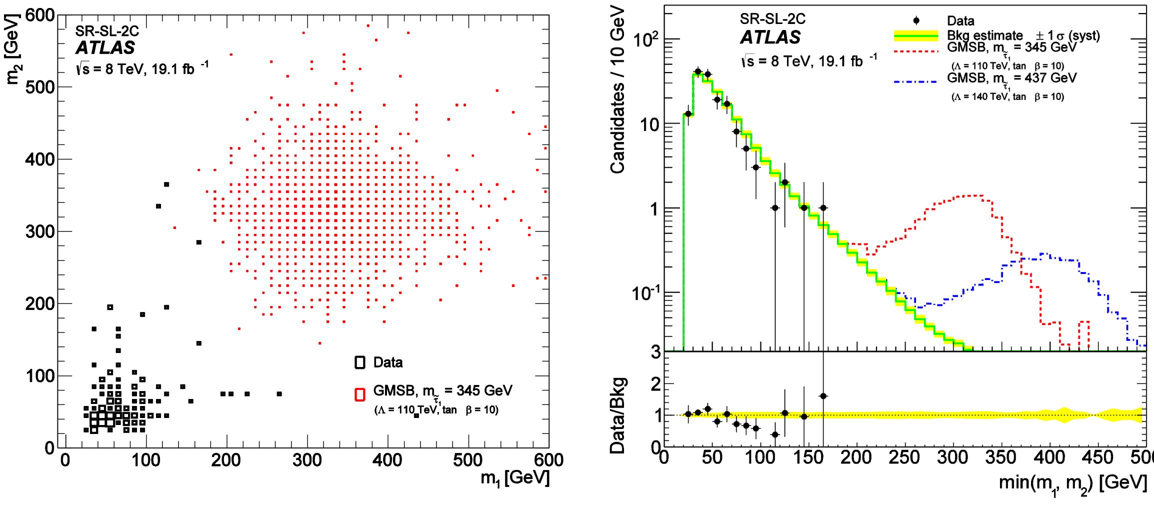

Figure 2: Reconstructed mass m_β of one candidate (m_2) vs. m_β of the other candidate (m_1) for observed data (black) and expected signal (red) in the GMSB slepton search in the two-candidate signal-region (left). Observed data, background estimate and expected signal (red/blue) in the slepton search for the lower of the two masses (m) in the two-candidate signal-region (GMSB τ_1 masses of 344.5 and 437 GeV)(right) [1].

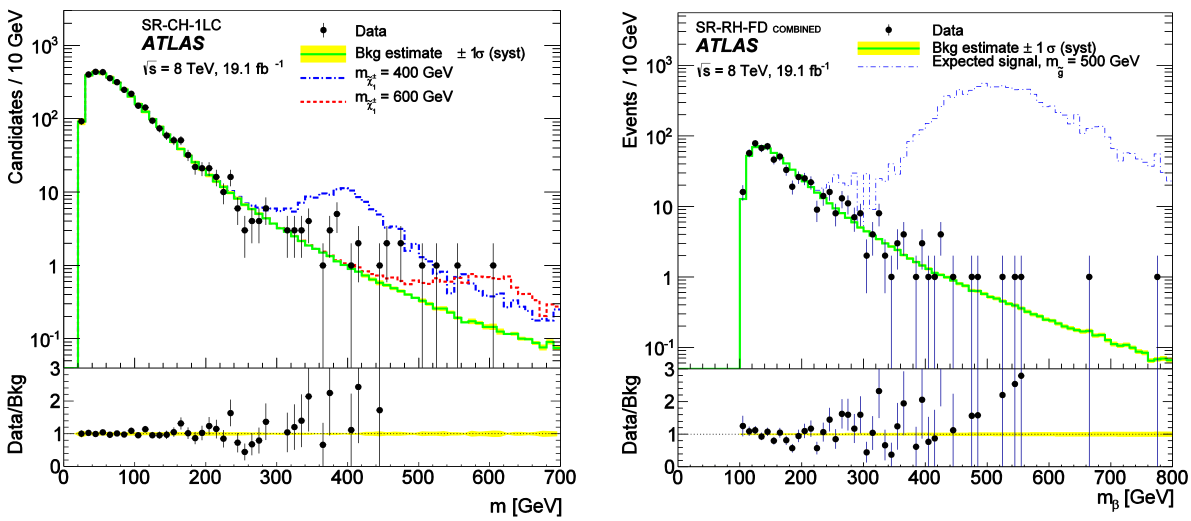

Figure 3: Reconstruction mass m_β in observed data, background estimate and expected signal in the chargino search (left) for the one-loose-candidate signal region ($\chi_1^\pm$ masses of 400 and 600 GeV), and of a 500 GeV gluino in the full-detector R-hadron search (right) [1].

1.3 Results

No excess was observed above the estimated background and limits were placed on the mass of long-lived particles in various supersymmetric models.

Long-lived tau sleptons in models with gauge-mediated SUSY breaking are excluded up to masses between 440 and 385 GeV for tan β between 10 (Figure 5 top-left) and 50. In the case of a direct slepton production $\tilde{\tau}_1$ masses of 373 to 330 GeV are excluded at 95% CL for models with slepton mass splitting of 2.7-93 GeV (Figure 4 left) and with a 290 GeV limit in the case where only direct tau slepton production is considered. In the context of LeptoSUSY models, where sleptons are stable and have a mass of 300 GeV, squark and gluino masses are excluded up to a mass of 1500 and 1360 GeV (Figure 4 right), respectively.

Directly produced stable charginos, that are nearly degenerate to the lightest neutralino, are excluded up to a mass of 620 GeV (Figure 5 top-right).

R-hadrons, composites containing a gluino (Figure 5 bottom), bottom squark and top squark, are excluded up to a mass of 1270, 845 and 900 GeV, respectively, using the full detector.

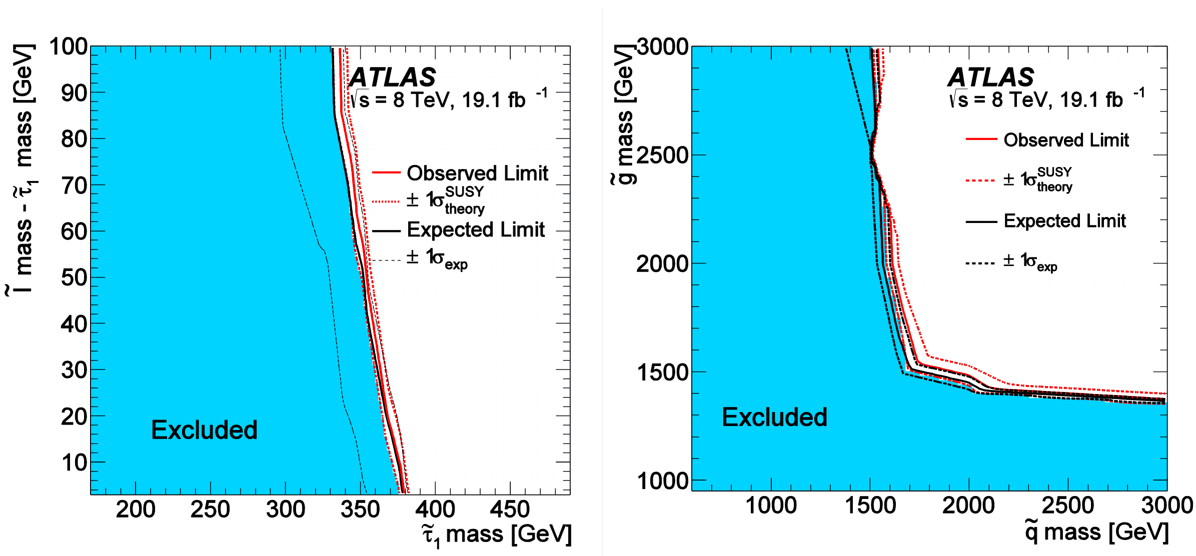

Figure 4: 95% CL excluded regions for squark and gluino mass in the LeptoSUSY models (right) and for directly produced sleptons in the plane $m_l - m_{\tau_1} vs.\ m_{\tau_1}$ (left). The excluded region is shown in blue. The expected limit is drawn as a solid black line with a ±1σ uncertainty band drawn in dashed black lines. The observed limit is shown as solid red line with a ±1σ uncertainty band drawn as dashed red lines [1].

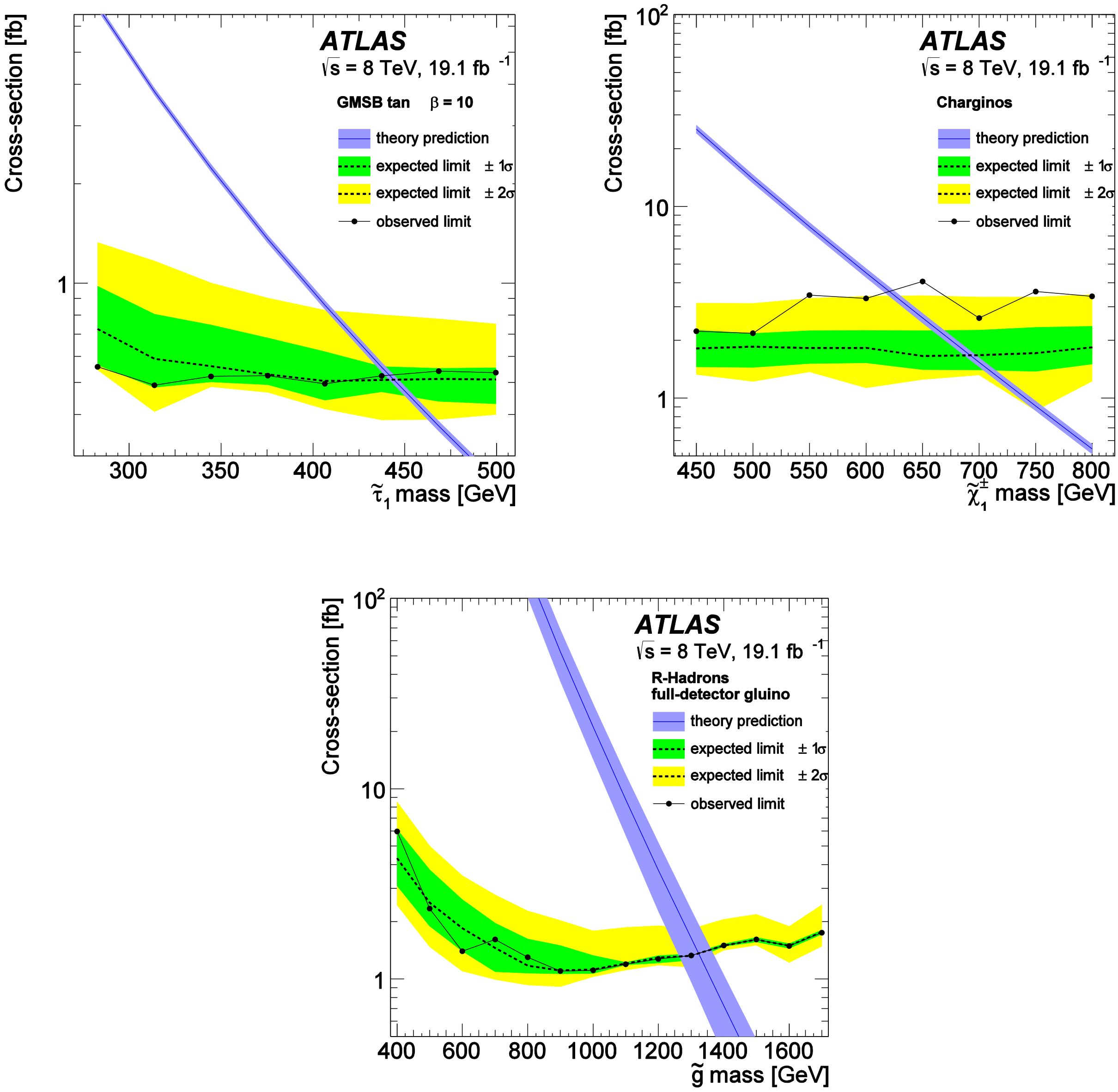

Figure 5: Cross-section upper limits as a function of the mass of the lightest stau for the GMSB models with $tan\beta = 10$ (top-left), for various chargino masses in stable-chargino models (top-right) and as a function of the gluino mass in the R-hadron full-detector search (bottom). The expected limit is drawn as a dashed black line with $\pm 1\sigma$ and $\pm 2\sigma$ uncertainty bands drawn in green and yellow, respectively. The observed limit is shown as solid black line with markers. The theoretical cross-section prediction is shown as a solid blue line with a dashed $\pm 1\sigma$ uncertainty band [1].

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