PROCEEDINGS OF SCIENCE

Search for phenomena beyond the Standard Model in events with large b-jet multiplicity using the ATLAS detector at the LHC

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Events with a large number of high-p_{T} b-jets are rare in the Standard Model (SM); an excess of events with such topology would be a signal of phenomena beyond the SM. One phenomenon where a large excess is expected is a variant of Supersymmetry in which R-parity is violated, allowing baryon number violating decays of the super partners of the SM particles. This document presents the search for physics beyond the SM in events with at least eight jets and at least six b-jets. It was performed using Run 2 data collected by the ATLAS detector corresponding to an integrated luminosity of 139 fb^{-1} of pp collisions at a center-of-mass energy of $\sqrt{s}$ = 13 TeV. We consider specifically the production of a pair of heavy top squarks which decay to a b-quark and a chargino, which in turn decays into bbs via a virtual top squark. The most dominant source of background is multijet production, estimated using a data-driven technique. A fit is performed to estimate the expected sensitivity of the signal strength. Expected and observed 95% CL upper limits are set based on the top squark and chargino masses.

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1. Introduction

Supersymmetry (SUSY) provides an extension to the SM by predicting the existence of supersymmetric partners associated to each of the SM particles. A variant of SUSY in which R-parity is violated (RPV) [1] provides unstable lightest superpartners (LSP) and gives rise to a wide range of experimental signatures depending on which of the many RPV couplings are non-zero. The work presented in this document focuses on the search for RPV SUSY through a final state signature with large b-tagged multiplicities, small momentum imbalance and no leptons. Event topologies of this signature have not been covered by present searches at the LHC. The results are obtained from pp collision data collected by the ATLAS detector [2], corresponding to an integrated luminosity of 139 fb^{-1} at $\sqrt{s}$ = 13 TeV.

2. RPV decay of top squark pair production

One proposed SUSY RPV phenomenon where a large excess is expected can arise from the production of a pair of top squarks [3]. In the considered model, the LSP is assumed to be a triplet of two neutralinos ($\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$) and one chargino ($\tilde{\chi}^\pm_1$) states that are mass-degenerate and carry dominantly higgsino components (in the following collectively referred to as “higgsinos”). The top squark decays either to a bottom quark and a chargino with a subsequent decay $\chi^\pm_1 \rightarrow bbs$ via the non-zero baryon number violating RPV coupling $\lambda^{''}_{323}$ or into a top quark and a neutralino with a subsequent decay $\chi^0_{1,2} \rightarrow tbs$ via the $\lambda^{''}_{323}$ coupling as shown in Figure 1. When $m_{\tilde{t}} - m_{\tilde{\chi}^\pm_1, \chi^0_{1,2}} < m_{\text{top}}$,

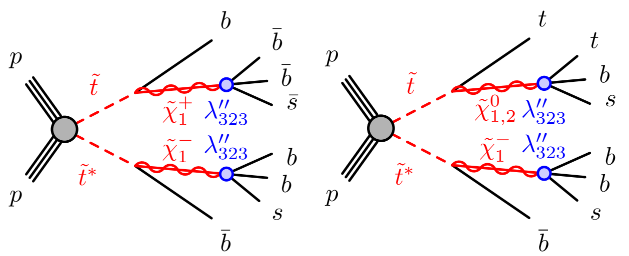

Figure 1: Signal diagrams involving pair production of top squarks $\tilde{t}$: (left) with the decay into a b-quark and the lightest chargino $\tilde{\chi}^+_1$ which subsequently decays into $\bar{b}\bar{b}\bar{s}$ and charge conjugate (c.c.), and (right) the decay into a top quark and the two lightest neutralinos $\tilde{\chi}^0_{1,2}$ which subsequently decay into tbs [4].

the $\tilde{t} \rightarrow t\tilde{\chi}^0_{1,2}$ decay is kinematically forbidden, therefore the $\tilde{t} \rightarrow b\tilde{\chi}^\pm_1$ (and c.c.) process saturates the branching ratio (BR). When $m_{\tilde{t}} - m_{\tilde{\chi}^\pm_1, \chi^0_{1,2}} > m_{\text{top}}$, the BR is assumed to be 50% between $\tilde{t} \rightarrow b\tilde{\chi}^\pm_1$ (and c.c.) and $\tilde{t} \rightarrow t\tilde{\chi}^0_{1,2}$ processes.

3. Event selection

The four leading jets in p_{T} are required to have $p_{\text{T}} \geq 120\,(140)$ GeV in 2015–2016 (2017–2018) data period and $|\eta| \leq 2.5$. Other jets present in the event must have $p_{\text{T}} \geq 25$ GeV and $|\eta| \leq 2.5$. At least two b-tagged jets are required using the MV2c10 tagger at 60% efficiency [5]. Events containing at least one lepton with $p_{\text{T}} \geq 10$ GeV are discarded.

The SM background processes that are relevant to the search of top-squark pair production include the multijet production as the main background, followed by the $t\bar{t}$+jets process. Other small contributions can come from the Wt single top quark background and the associated production of a $t\bar{t}$ pair with a vector boson or a Higgs boson. While the multijet background is estimated using a data-driven method presented in Section 4, the other backgrounds are generated by MC simulation.

The selected events are categorised according to the number of jets (N_j) and the number of b-tagged jets (N_b). This analysis exploits the difference in N_j and N_b between signal and SM background (multijet and top-quark production). While the event yields of SM background are mainly distributed at low b-tagged jet multiplicity, the signal distribution is accumulated at high N_j and N_b. Events with $N_j \geq 6$ and $N_b \geq 4$ are categorized into 8 signal regions for model-dependent hypothesis tests.

4. TRF$_{\mathrm{MJ}}$ data-driven method for multijet estimation

The TRF$_{\mathrm{MJ}}$ method is a data-driven technique which is developed in order to estimate the multijet background. It is based on the probability of b-tagging a jet in a multijet event which is extracted in data from regions rich in multijet events. The TRF$_{\mathrm{MJ}}$ method is validated in two different comparisons to data. The first validation is performed in the VR-MJ region, defined by requiring an upper value on the centrality-mass variable which is the ratio of the hadronic transverse energy and the invariant mass of jets ($C_{\mathrm{mass}} = H_{\mathrm{T}}/M_{\mathrm{jets}}$). The second validation is performed in a separate set of Z + jets-enriched events (VR-ZJ) selected by requiring exactly two opposite-sign leptons to have $p_{\mathrm{T}}>$ 27 GeV, and their invariant mass m_{ll} > 61 GeV. The validation results are presented in Figure 2. The prediction and data are in agreement within the systematic uncertainties.

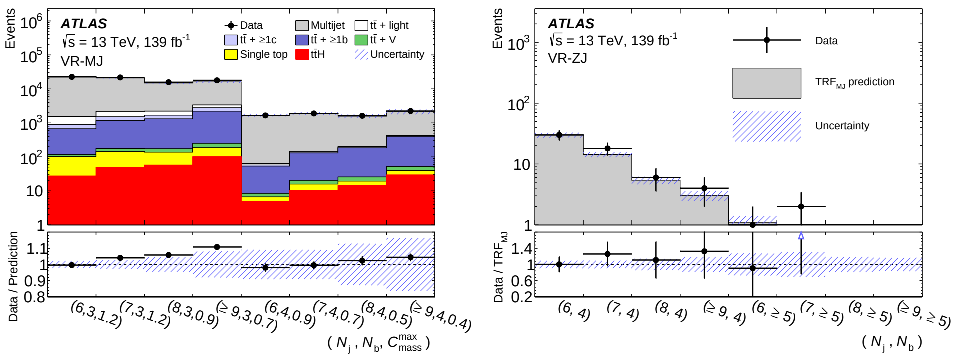

Figure 2: Comparison between data and the predicted number of events in (left) the VR-MJ validation region and (right) the VR-ZJ region. The systematic uncertainties are represented by the blue hatched area [4].

5. Systematic uncertainties

Several sources of systematic uncertainty are considered that can affect the normalization of simulated samples and/or the shape of their corresponding final discriminant distributions. Individual sources of systematic uncertainty are considered uncorrelated. Correlations of a given systematic uncertainty are maintained across processes and channels. The uncertainty on the normalization of the multijet background estimation is assessed using MC dijet events.

6. Results

For hypothesis testing of the signal model, a statistical data analysis technique using the profile likelihood fit [6] is performed. The TRF_{MJ} systematic uncertainty is treated as uncorrelated across regions because of its large statistical component. Other MC systematic uncertainties are correlated across N_j and N_b multiplicities. The fitted SM background under the background-only hypothesis is in agreement with data within the uncertainties. No significant excess over the SM expectation has been observed. Model-independent limits on the contribution of new phenomena to the signal-region yields are calculated at 95% Confidence Level (CL) as shown in Table 1.

Signal region	σ^{95}_{obs} [fb]	N^{95}_{obs}	N^{95}_{exp}	p_0 (Z)
$N_{\text{j}} \geq 8$, $N_{\text{b}} \geq 5$	0.76	105	85^{+30}_{-24}	0.24 (0.7)
$N_{\text{j}} \geq 9$, $N_{\text{b}} \geq 5$	0.54	75	52^{+20}_{-15}	0.11 (1.2)

Table 1: Observed 95% CL model-independent upper limits on σ^{95}_{obs}, obtained from the product of cross-section, acceptance and efficiency in two signal regions and the number of observed (expected) new phenomena events, N^{95}_{obs} (N^{95}_{exp}). The p_0 value and significance Z are also presented [4].

For the considered signal model, Figure 3 shows the exclusion limits in the mass phase space of top squark ($m_{\tilde{t}}$) and chargino/neutralino ($m_{\chi_1^\pm,\tilde{\chi}^0_{1,2}}$) in the top-squark production model when $\text{BR}(\tilde{t} \to b\chi_1^\pm)$ is assumed to be unity and when $\tilde{t} \to t\tilde{\chi}^0_{1,2}$ is included. In the case of higgsino LSP, the limits from a previous ATLAS search that analysed events characterised by the presence of a lepton plus jets [7] is represented by green lines. In the region $m_{\tilde{t}} - m_{\tilde{\chi}_1^+,\chi^0_{1,2}} > m_{\text{top}}$, the sensitivity of this analysis is reduced in comparison to Ref. [7] due to the large contribution of the multijet background. An observed 95% CL upper limit on top-squark mass is computed which excludes $m_{\tilde{t}}$ up to 950 GeV where this analysis has exclusive sensitivity.

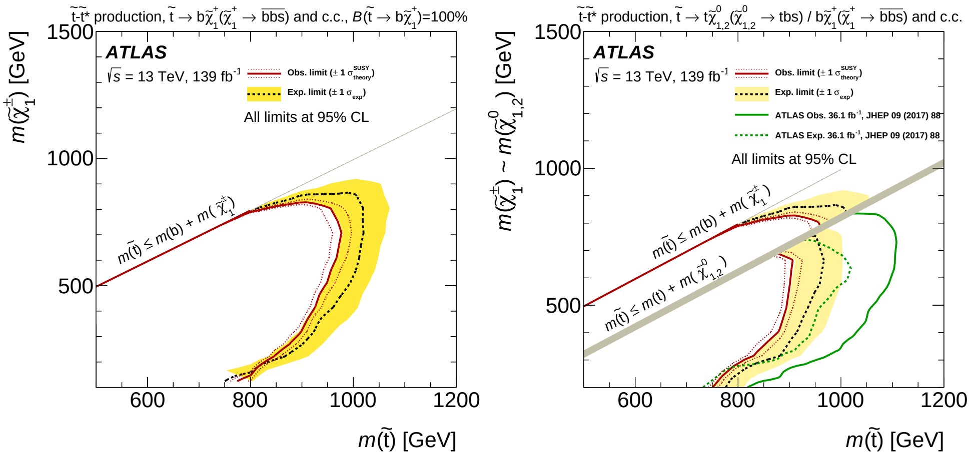

Figure 3: Observed and expected exclusion contours on the $\tilde{t}$ and $\chi_1^\pm/\chi^0_{1,2}$ masses in the context of top-squark production model with RPV decays of the $\chi_1^\pm$ and of the $\tilde{\chi}^0_{1,2}$. Limits are shown in the case of (left) $\text{BR}(\tilde{t} \to b\chi_1^\pm)$ equal to unity and (right) a higgsino LSP [4].

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PoS(LHCP2020)218