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A search for R-parity violating decays of the top squark in four-jet final state with the ATLAS experiment at $\sqrt{s} = 13$ TeV

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We present a search for direct production of pairs of top squarks, each decaying into a b- and an s-quark through R-parity violating couplings. The analysis uses 3.2 fb^{-1} of proton-proton collision data recorded at $\sqrt{s} = 13$ TeV by the ATLAS experiment at the LHC in 2015. Four jets, two of which are b-tagged, are selected and paired according to their angular separation. Signal regions are defined by imposing requirements on the masses of the two resonance candidates and their angular distribution. The average mass of the resonances is then used as the final discriminant. No significant excess is observed above the background prediction and a 95% confidence level lower limit on the mass of the top squark in the model considered is derived to be 345 GeV.

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1. Introduction

The ATLAS collaboration is conducting an extensive program to search for new phenomena using data collected during Run II of the Large Hadron Collider (LHC). Examples of searches in jet final states include those done in dijet, four-jet, multijet final states. The focus of this contribution will be the search for new particles in four-jet final state wherein we consider pair-production of resonances and their decay into two standard model quarks. We consider pair-production of top squarks (stops), and the subsequent decay of both stops to a b- and an s-quark as shown in Fig. 1. Details about signal generation and signal model as well as references to earlier ATLAS and CMS searches can be found in the ATLAS public note [1]. Details about the ATLAS detector can be found in Ref. [2]. We explore the mass range above 225 GeV.

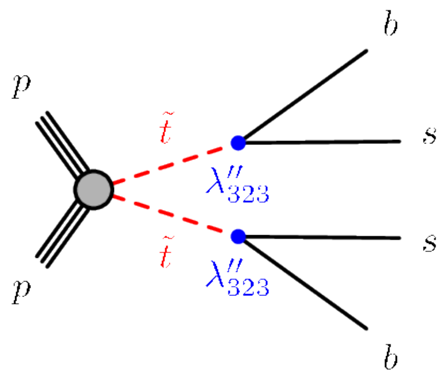

Figure 1: Direct pair-production of stops and their subsequent decay into a b- and an s-quark [1]

2. Online and offline selections

The analyzed data was collected using a four-jet trigger that requires four jets with $p_T > 85$ GeV in the event. The event is required to have a reconstructed primary vertex and to have at least four jets that each have $p_T > 150$ GeV and each are within $|\eta| < 2.4$. The leading four jets are then paired to form resonant candidates or stop candidates. The pairing is done according to their angular separation and is motivated by the decay topology being pursued in this search (Fig. 1). We iterate over all jet pairs and choose the one that minimizes the quantity, ΔR_{min} that is described in Eq. 2.1. To enhance signal and reduce background, it is required that ΔR_{min} be less than 1.6. Finally, one jet in each pair is required to be b-tagged [3]. All ATLAS Run II data collected in 2015, totaling to 3.2 fb^{-1}, were used to perform the search.

$$\Delta R_{min} = \sum_{i=1,2} |\Delta R_i - 1.0| \tag{2.1}$$

3. Variables of interest

Standard model multijet events are the dominant background for this search and their expected count is evaluated using a data-driven method (Sec. 4). There is a small contribution from $t\bar{t}$ that is obtained from simulation and is appropriately subtracted in the data-driven method.

To separate signal from background, and to obtain the expected background, a few variables of interest are defined. The distribution of these variables for data and signal simulation after all the offline selections have been applied (Sec. 2) are shown in Fig. 2. First is the mass asymmetry, A, defined in Eq. 3.1, which yields a measure of the relative mass difference for the two reconstructed resonances (m_1 and m_2 are the masses of the two reconstructed resonances). For signal events, A peaks at 0.0 while for data that largely consists of standard model multijet events, A is evenly distributed for most of the available spectrum. The second variable is the production angle of the resonance pair in the center-of-mass frame with respect to the beam axes, $|\cos(\theta^{\star})|$. Standard model multijet events are dominantly coming from t-channel gluon exchange and are preferentially produced in the forward region while pair-produced stops are expected to be majorly produced in the central region. For signals, both A and $|\cos(\theta^{\star})|$ variables are peaked at 0.0 while for backgrounds, the two distributions have much larger presence farther from 0.0. Thus, the two variables of A and $|\cos(\theta^{\star})|$ facilitate the separation of signal and background. The signal region corresponds to small values of A and $|\cos(\theta^{\star})|$.

$$A = \frac{|m_1 - m_2|}{m_1 + m_2} \tag{3.1}$$

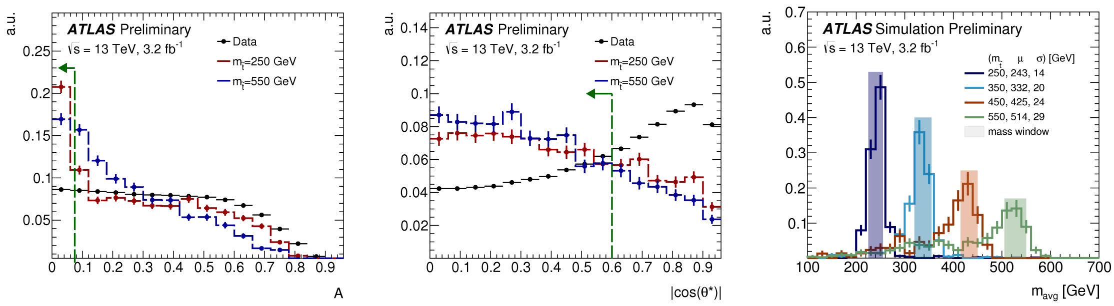

Figure 2: Normalized distributions of A (left) and $|\cos(\theta^{\star})|$ (middle) for data and simulation of stop with two different masses [1]. Normalized distribution of m_{avg} for stop simulation with different masses (right) [1].

The final variable used is the average mass of the two reconstructed resonances, m_{avg}, as defined in Eq. 3.2. For signal samples, we are able to reconstruct the stop candidates close to their true mass (Fig. 2). The search is done in a narrow window near the reconstructed signal mass obtained from simulation.

$$m_{avg} = \frac{m_1 + m_2}{2} \tag{3.2}$$

4. Background prediction

By choosing a selection on A and $|\cos(\theta^{\star})|$, data events can be divided into A, B, C, and D regions. Region A covers the space where events pass $|\cos(\theta^{\star})|$ selection and fail A selection while region C covers the space where events pass A selection and fail $|\cos(\theta^{\star})|$ selection. Events that pass (fail) both selections populate region B (D). The signal region (Sec. 3) corresponds to region D. The variables of A and $|\cos(\theta^{\star})|$ are uncorrelated for standard model multijet events and this can be used to make a data-driven prediction for the expected count of standard model multi-jet events in region D as shown in Eq. 4.1

$$\#(D) = \frac{\#(A) * \#(C)}{\#(B)} \tag{4.1}$$

where #(A), #(B), #(C), #(D) are the data counts in the regions A, B, C, and D respectively. The prediction for the expected number of standard model events in region D is done in bins of m_{avg}. The small contribution from $t\bar{t}$ that is obtained from simulation is subtracted from all four regions before the usage of Eq. 4.1.

Figure 3 shows the normalized m_{avg} distribution in background regions with zero, one, and two b-tags. Given m_{avg} shapes are similar across varying number of b-tags, we use Eq. 4.1 in high statistics zero b-tag region and make the prediction for two b-tag region using a scaling factor that is derived from regions A and C.

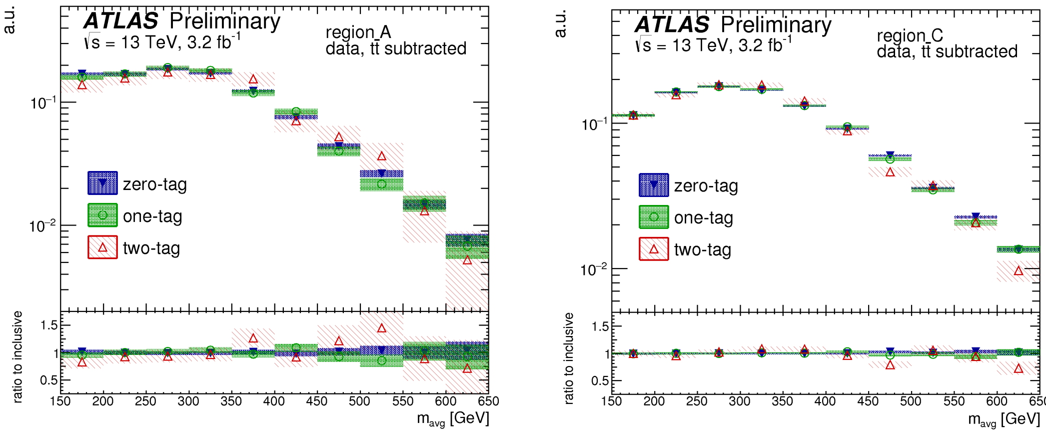

Figure 3: Normalized distributions of m_{avg} in data for region A (left) and region C (right) with varying b-tag multiplicities [1]

5. Results

We scan several selections of A and $|\cos(\theta^{\star})|$ and optimize the final selection for discovery. The final signal region selection of $A < 0.075$ and $|\cos(\theta^{\star})| < 0.6$ are used for all m_{avg} search windows. A counting experiment comparing expected and observed data counts is done in various m_{avg} search windows.

Figure 4 shows expected and observed m_{avg} spectrum in the signal region. Barring a small statistically insignificant discrepancy at around 340 GeV, the observed m_{avg} spectrum matches with that expected from the standard model. The expected and observed cross-section limits for the considered model are also shown in Fig. 4. Stop masses from 250-345 GeV are excluded at 95%

confidence level and this result stretches the previous ATLAS stop mass exclusion of 100-320 GeV that was obtained using Run I data. The CMS collaboration has excluded stop masses from 200-385 GeV using their Run I data [4].

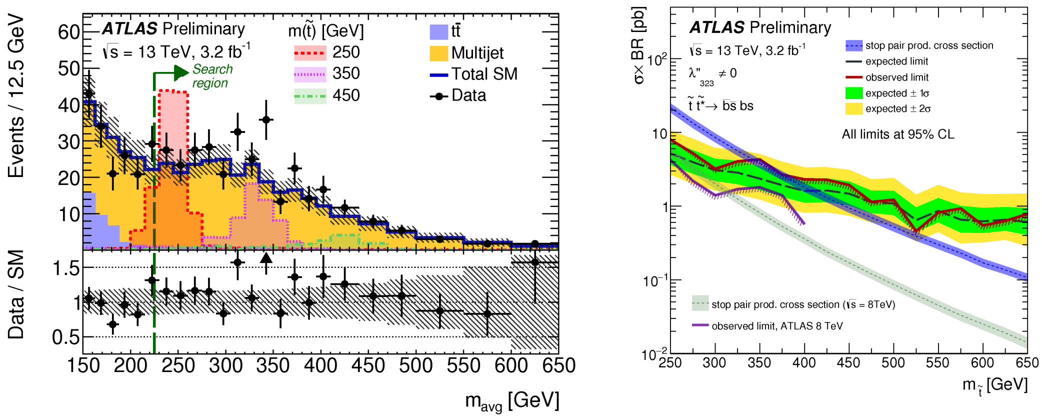

Figure 4: Expected and observed m_{avg} distributions in the signal region are shown in left. Expected and observed 95% confidence level upper limit on $\sigma \times BR$ for the signal region along with theoretical cross-section for direct stop pair-production with each stop decaying to a b- and an s-quark are shown in right [1].

6. Summary

With the LHC operating at a new center-of-mass energy, it is imperative that ATLAS have an extensive search program for new particles. I presented the search in four-jet final state that was done using 3.2 fb^{-1} of 13 TeV data collected with ATLAS detector during the 2015 LHC proton-proton run. We do not have statistical evidence for new particles in four-jet final state. Cross-section limits are placed for a SUSY model in which stops are pair-produced and each stop decays to a b- and an s-quark. For the considered model, stop masses from 250 to 345 GeV are excluded at 95% confidence level.

References

[1] ATLAS Collaboration, *A search for R-parity violating decays of the top squark in four jet final states with the ATLAS detector at $\sqrt{s} = 13$ TeV*, ATLAS-CONF-2016-022.

[2] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, 2008 JINST 3 S08003.

[3] ATLAS Collaboration, *Commissioning of the ATLAS b-tagging algorithms using $t\bar{t}$ events in early Run-2 data*, ATL-PHYS-PUB-2015-039.

[4] CMS Collaboration, *Search for pair-produced resonances decaying to jet pairs in proton-proton collisions at $\sqrt{s} = 8$ TeV*, 2015 Phys. Lett. B 747 98.