Exploring Supersymmetry signatures with two leptons, jets, and low missing transverse energy with the ATLAS detector

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September 2, 2016

Sensitivity estimations using simulated samples of R-parity violated SUSY inspired model, where little or no expected missing transverse energy, are performed. It was found that with an integrated luminosity of 30 fb^{-1} of $\sqrt{s}$=13 TeV data recorded by the ATLAS experiment, it would be possible to exclude gluino masses up to 1.55 TeV covering most of the lightest neutralino mass phase-space when looking at $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ with $\tilde{\chi}_1^0 \rightarrow 3q$(UDD) simplified pair production models.

1 Introduction

I have participated in the CERN Summer Student Programme 2016. My project concentrated on Supersymmetry (SUSY) searches where little or no Missing Transverse Energy (MET) is present. This is inspired by R-Parity Violating (RPV) models, where the lightest SUSY particle can decay into Standard Model (SM) particles. The final state explored uses signatures with a pair of same electric charge electrons and/or muons, to which I refer as leptons. These studies are based on the published SUSY same sign leptons searches of the ATLAS Colaboration [1].

The ATLAS experiment is a multipurpose detector of CERN's Large Hadron Collider. It is described in detail in reference [2].

2 Search strategy

2.1 Signal model

Supersymmetry is an extension of the SM which fundamentally relates fermions and bosons. This study looks for SUSY signatures with two same-sign leptons, large number of jets, and little/no MET. It relies on the simplified signal benchmark gluino pair production, where each gluino decaying into $t\bar{t}$ plus a neutralino final state. The top quark mostly decays into a W boson and a b quark. The W boson decays into a charge lepton and neutrino with branching ratio of about 33%. In the RPV SUSY model conciderd, the lightest neutralino decays into three SM light quarks (see Fig.1). Therefore, a final state with leptons, at least 10 jets (light and heavy) is expected.

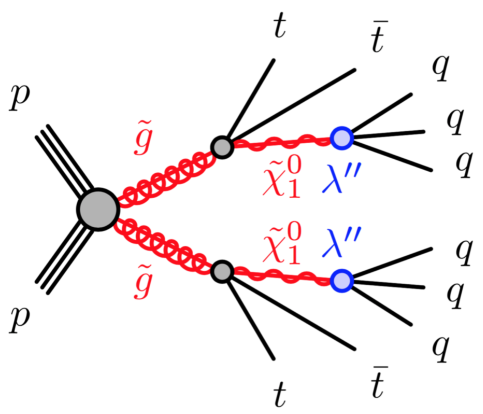

Figure 1: Feynman diagram of RPV SUSY model explored in this project

2.2 Background processes

Expected signal yields are very rare when compared with the large expected background processes. The dominant background processes are $t\bar{t}$, tW, W+jets, Z+jets, diboson, Higgs and $t\bar{t}V$ production. This study relays on Monte Carlo (MC) simulations for all background processes. These are described in reference [1]. The final goal is to evaluate and maximize the expected sensitivity of the signal by optimizing different kinematic requirements.

2.3 Kinematic distribution

The simulated events used on this study rely on preselection requirements as described in reference [1]. At least two same sign leptons with transverse momentum, $P_{\mathrm{T}} > 20$ GeV, within the fiducial acceptance of the ATLAS are required. Similarly, only preselected jets with $P_{\mathrm{T}} > 20$ GeV are considered.

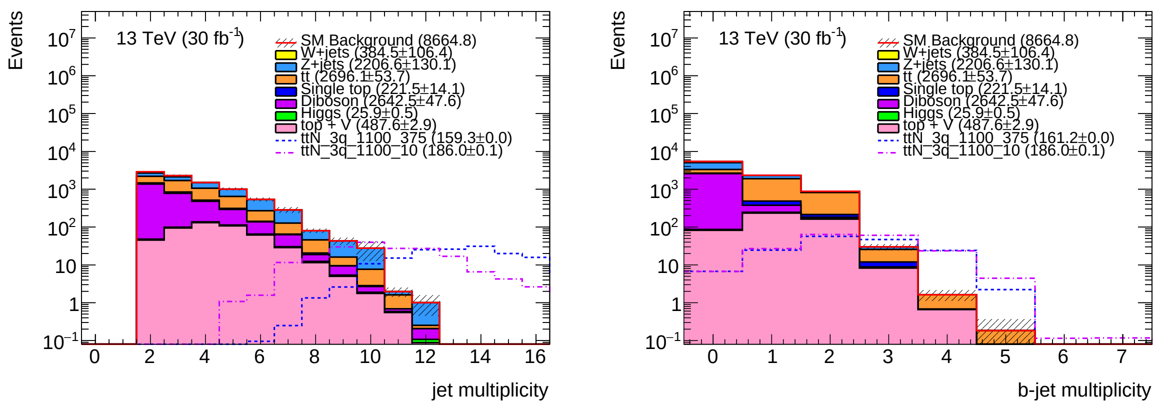

Figure 2: Distribution of number of jets (left), b-jets (right)

Figure 2 shows the expected distributions of number of jets and number of b-jets. For these plots, requirements of at least two same-sign leptons and at least two jets are imposed. As expected, the exploded RVP signal model has more jets and b-jets than the SM backgrounds.

This indicates that requirements of large jets and b-jets multiplicities can be effective to reduce backgrounds while keeping a high signal efficiency.

2.4 Sensitivity estimation

Signal sensitivities for different requirements are estimated by using a gaussian approximation formula of statistical significance:

$$\sigma_{\mathrm{Gaussian}} = N_{\mathrm{signal}} / \sqrt{N_{\mathrm{BG}} + (\Delta N_{\mathrm{BG}})^2} \tag{1}$$

where N_{signal} is the expected number of signal events, N_{BG} is the expected total number of SM background events and ΔN_{BG} is systematic uncertainty of expected background. An uniform conservative systematic uncertainty for the expected background of 30% is assumed. The gaussian formula is known to over performed for small expected yields. On the contrast, binomial estimators as defined in reference [3], allows us to calculate statistical significance incorporating background uncertainty. With more robustness in the low statistical regime. Table 1 compares calculated statistical significances using these two methods. The results on this study where all obtain using $\sigma_{Binomial}$.

$m\tilde{\chi}_1^0$ [GeV]	10	50	287	563	840
Number of signal events	53.0	54.7	46.4	34.9	16.4
$\sigma_{\mathrm{Gaussian}}$ without uncertainty	15.2	15.7	13.3	10.0	4.7
$\sigma_{\mathrm{Gaussian}}$ with uncertainty	10.5	10.9	9.2	6.9	3.2
$\sigma_{\mathrm{Binomial}}$ with uncertainty	5.6	5.9	5.1	4.3	2.5

Table 1: Comparison sensitivity between difference significance estimators for the signal of $m_{\tilde{g}}$ is 1.2 TeV. The expected number of background events is 12.15

3 Results

Expected signal yields are different for each gluino-neutralino mass configuration. This is driven by the gluino production cross section as a function of mass and the efficiency dependency given by the kinematic effect of the neutralino mass.

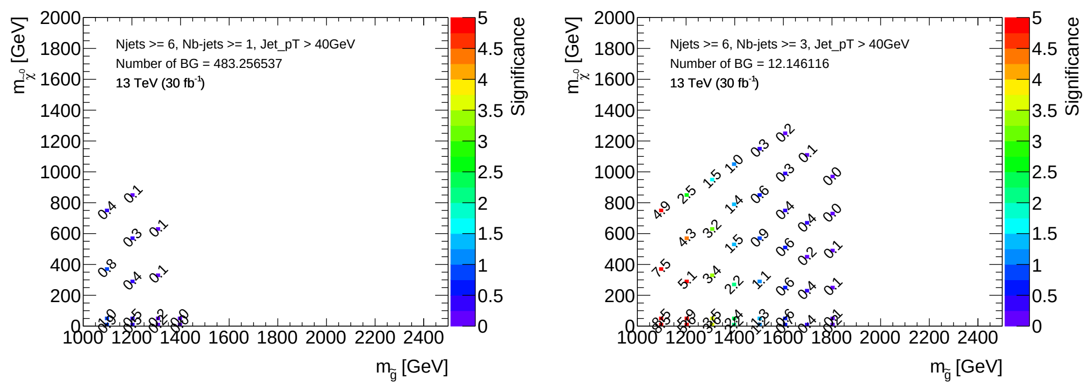

Figure 3: Expected statistical significance in the gluino - neutralino mass plane including at least one b-jet (left), and at least three b-jets(right)

Figure 3 (left) shows the sensitivity when requiring at least 6 jets of $P_{\mathrm{T}} > 40$ GeV and at least one b-jet. On the other hands, Fig.3 (right) shows a similar case but imposing a requirement of at least three b-jets. It is confirmed that a cut on the b-jet multiplicity is effective to make sensitivity better.

Three sigma significance was used as benchmark to estimate sensitivity for observation of this RPV SUSY model.

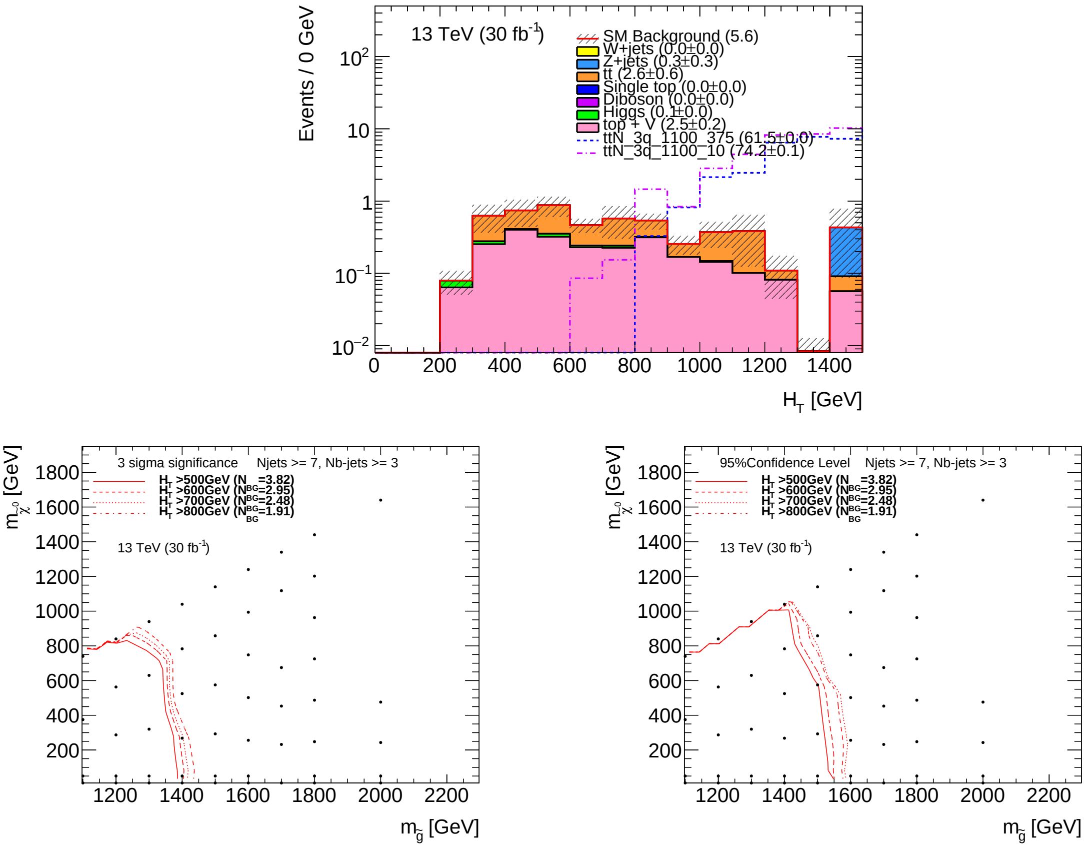

Figure 4: Distribution of h_{T}(top), expected 3 sigma sensitivity (bottom left) and 95% CL expected exclusion limits (bottom right)

H_{T} is defined as the scalar sum of P_{T} of all jets and leptons in each event. Figure 4 (top) shows the h_{T} distribution when requiring at least 7 jets and at least three b-jets. Figure 4 (bottom left) shows the expected sensitivity reach of three sigma significance for four different additional selections of H_{T} : 500 GeV, 600 GeV, 700 GeV and 800 GeV. Figure 4 (bottom right) shows the corresponding 95% CL expected exclusion limits.

Similarly Fig 5 shows the 3 sigma significance and 95% CL expected exclusion for the same common selection but instead requiring four different selection leading jet's P_{T} : 100 GeV, 120 GeV, 140 GeV and 160 GeV. Figure 5 (top) shows the distribution of the leading jet's P_{T}.

It is confirmed that for tighter requirement, the sensitivity improves. Nevertheless, if there requirement is very tight, it leads to very low background yields (minimum of three total expected background events for $30 fb^{-1}$ is enforced) An attempt to find the best requirements which keeps a not too small expected background was found to be Njets $>$ 7 , Nb-jets 3 , and P_{T} of leading jet is more than 160 GeV. A requirement Njets $>$ 7 , Nb-jets 3 , and H_{T} is more than 800 GeV has better sensitivity than an optimal one, but it has less than 3 expected number of background events. Therefore it was not adopted.

When requiring an optimal selection, a gluino in the SUSY model studied whose mass is less than 1.4 TeV may be observed with integrated luminosity of 30 fb^{-1} of data. It is confirmed that the region with the largest neutralino mass (compressed/diagonal) are well covered by this signature. Otherwise, it could be possible to exclude at 95% CL gluino masses up to 1.55 TeV.

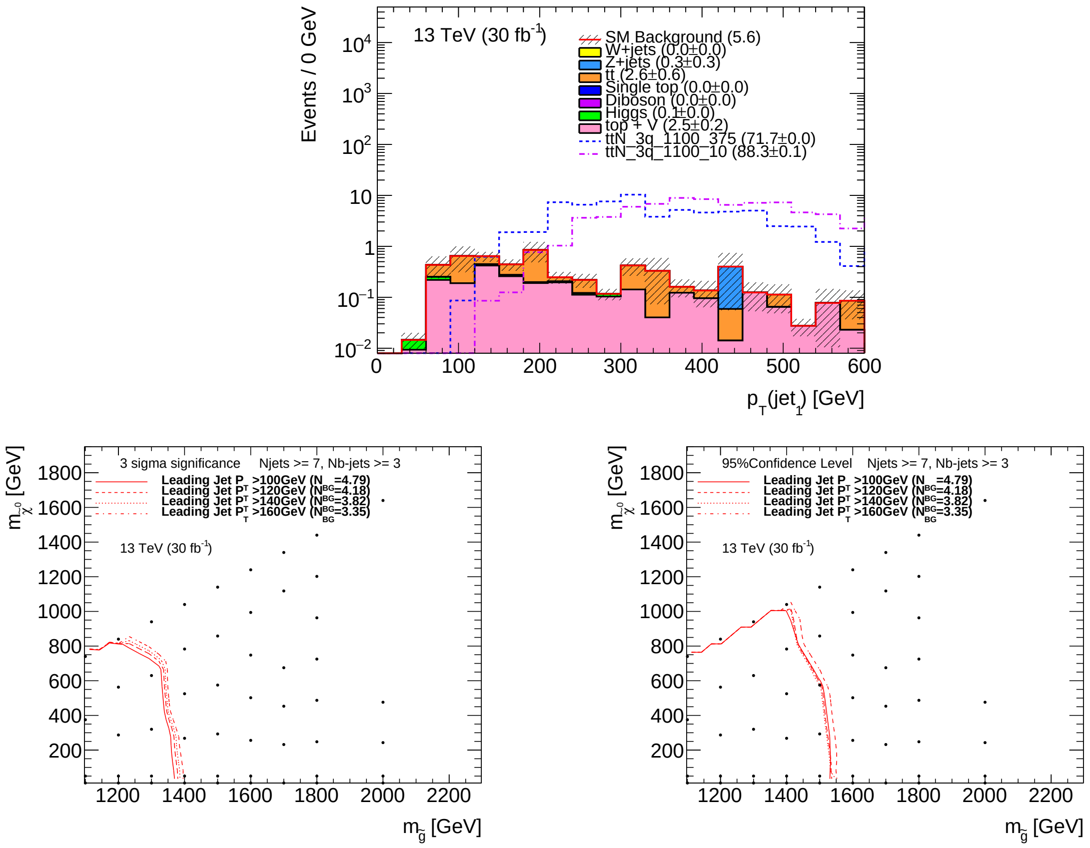

Figure 5: Distribution of leading jet's P_{T}(top), expected 3 sigma sensitivity (bottom left) and 95% CL expected exclusion limits (bottom right)

4 Conclusion

Sensitivity estimations using simulated samples of RPV SUSY inspired model, where little or no expected missing E_{T}, were performed. Since this signal model has large number of jets and b-jets, it is confirmed that a cut on large light and b-jet multiplicities are effective to make sensitivity better. An optimal requirement of Njets $>$ 7 , Nb-jets 3 , and P_{T} of leading jet is more than 160 GeV was found. As a result, with an integrated luminosity of 30 fb^{-1} of $\sqrt{s}$=13 TeV data recorded by the ATLAS experiment, it could be possible to exclude gluino masses up to 1.55 TeV in the absence of an excess, or observe it up to masses of 1.4 TeV, covering most of the lightest neutralino mass phase-space when looking at $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ with $\tilde{\chi}_1^0 \rightarrow 3q$(UDD) simplified pair production models.

References

[1] ATLAS Collaboration, *Search for supersymmetry at $\sqrt{s}$=13 TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector*, Eur. Phys. J. C (2016) 76: 259

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

[3] Robert D. Cousins *et al. Evaluation of three methods for calculating statistical significance when incorporating a systematic uncertainty into a test of the background-only hypothesis for a Poisson process*, J.NIMA 2008.07.086