CERN Summer Student Program – 2016

Search for Supersymmetry in ATLAS with two or three leptons: background studies

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August 18, 2016

A study of the modeling of $t\bar{t}V(V = W$ or $Z)$ production at $\sqrt{s} = 13$ TeV has been conducted. This is one of the main backgrounds in the search for Supersymmetry with same-sign dileptons or three leptons final state.

1 Introduction

Supersymmetry (SUSY) is one of the most extensively studied theories beyond the Standard Model (SM) of particle physics. It introduces a new particle for each SM particle and a new concept known as R-parity. A search for SUSY signals using final states of two leptons with same-sign electric charge or three leptons has been performed by the ATLAS collaboration at the begining of 2016 and no significant excess over SM background was observed [1, 2]. The search performed by ATLAS targets four benchmark scenarios of R-parity conserving SUSY (Fig. 1). One of the main SM backgrounds in this search is the $t\bar{t}V(V = W$ or $Z)$ process, illustrated in Fig. 2, which currently is poorly constrainted by experiments. This summer project aims to improve the understanding and modelling of this background using Monte Carlo simulations. In particular, we wish to devise a set of cuts which could isolate the $t\bar{t}V$ processes from other SM backgrounds and thus facilitate selecting $t\bar{t}V$ events for background validation and measurements in similar final states as those in SUSY. This report is organized as follows: Section 2 describes the ATLAS detector, Section 3 describes the cuts dedicated to isolating the $t\bar{t}V$ processes. The work is summarised in Section 4.

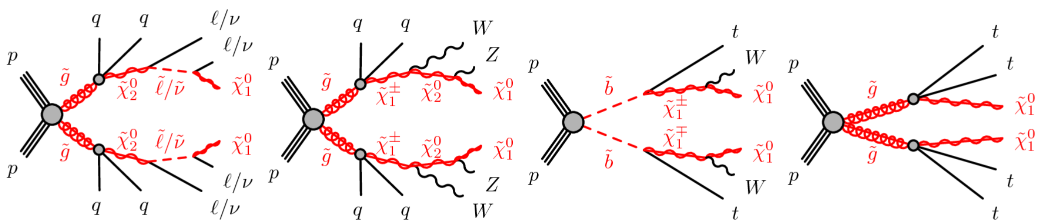


Figure 1: Feynman diagrams illustrating the benchmark scenarios of R-parity conserving SUSY targeted by the search performed by ATLAS collaboration.

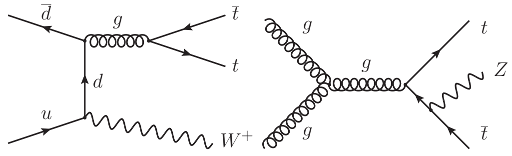


Figure 2: Feynman diagrams of the $t\bar{t}W$ (left) and $t\bar{t}Z$ (right) production processes, which are the main SM backgrounds in the search for the benchmark SUSY scenarios in Fig. 1.

2 The ATLAS detector

The ATLAS experiment is a general purpose detector with a cylindrical geometry and provides a nearly 4π angular coverage in solid angle[1]. The interaction region of the detector where proton-proton collisions occur is surrounded by an inner detector, a calorimeter system and a muon spectrometer. The inner detector is submerged in an axial magnetic field and provides momentum measurements and tracking of charged particles. The calorimeter system measures the energy of a wide variety of different particles, including electrons, photons, hardons. The muon spectrometer measures momentum of muons. The ATLAS detector is not sensitive to neutrinos and their presence is inferred from the energy-momentum imbalance in the transverse plane.

3 Study of $t\bar{t}V$ background process

A set of baseline cuts are first implemented for the $t\bar{t}W$ and $t\bar{t}Z$ process. Further kinematic constraints are then imposed according to the resultant purity of $t\bar{t}W$ and $t\bar{t}Z$ events, where the purity is defined as the ratio between the number of $t\bar{t}V$events over the number of other SM background events. In this section, results of both baseline and further analysis on top of the baseline selection are presented.

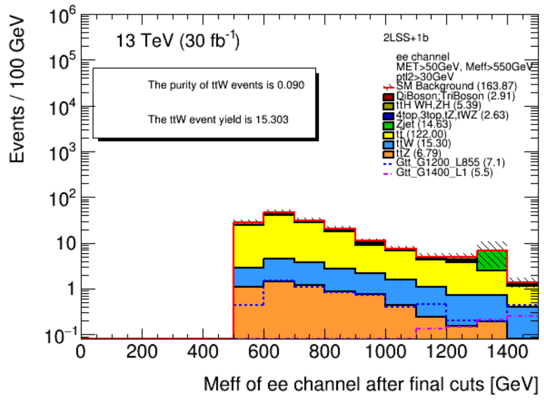
3.1 $t\bar{t}W$ Analysis

The baseline selection is similar to the $t\bar{t}V$ validation region in the search for SUSY performed by ATLAS [1, 2]. Events are required to satisfy the criteria shown in Table 1, where p_{T} denotes transverse momentum and $E_{\mathrm{T}}^{\mathrm{miss}}$ denotes missing transverse energy. The sub-leading lepton is the lepton with the second highest p_{T}. Since events are required to have exactly two same-sign leptons, they can be categorised into three flavour channels ($e\mu$, $\mu\mu$ and ee) and all results of the $t\bar{t}W$ analysis will be presented in this format hereafter. The resultant distributions of the effective mass (m_{eff}), defined in Table 1, are shown in Fig. 3.

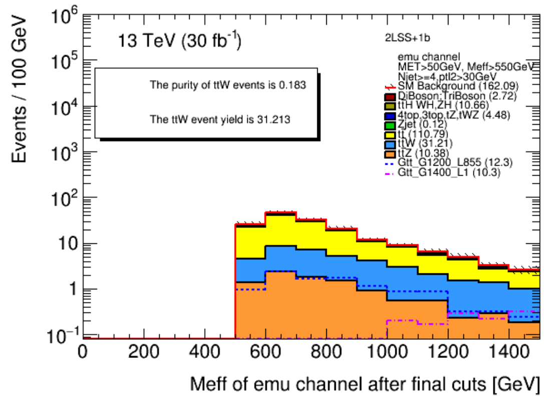
exactly two same sign leptons
Number of jets with $p_{\mathrm{T}} > 20$ GeV $\geqslant 3$ if the flavour of the two leptons are $e\mu$
Number of jets with $p_{\mathrm{T}} > 20$ GeV $\geqslant 4$ if the flavour of the two leptons are $\mu\mu$
Number of $b-$jet with $p_{\mathrm{T}} > 20$ GeV $\geqslant 1$
$E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV; $m_{\mathrm{eff}} > 550$ GeV where $m_{\mathrm{eff}} = \sum_{\mathrm{leptons}} p_{\mathrm{T}} + \sum_{\mathrm{jets}} p_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$
p_{T} of the sub-leading lepton > 30 GeV

Table 1: Baseline cuts for the $t\bar{t}W$ analysis.

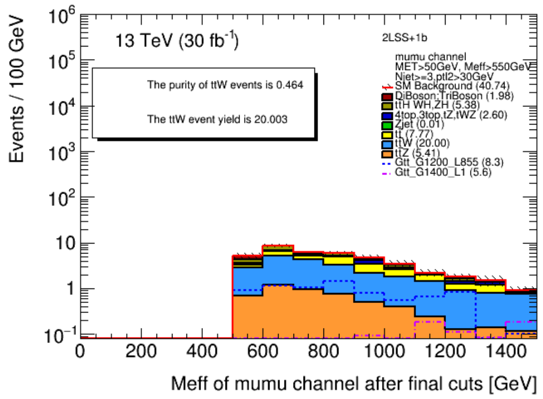
[1]ATLAS uses a right-handed coordinate system. The nominal interaction point is taken to be the origin. The z-axis points along the direction of the beampipe. The x-axis points to the center of the LHC ring and the y-axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane. The polar angle, θ, is measured with respect to the posive z-axis and the pseudorapdity η is defined as -ln $\tan(\frac{\theta}{2})$.



(a) ee channel



(b) $e\mu$ channel



(c) $\mu\mu$ channel

Figure 3: The distributions of m_{eff} of the three flavour channels resulting from the cuts listed in Table 1.

As shown in Fig. 3, the resultant purity of $t\bar{t}W$ in ee channel is very low (only 9%), in comparison with the other flavour channels. Further constraints on the pseudorapididity of the electrons $-1.37 < \eta_e < 1.37$ are imposed on top of the baseline cuts in order to reject backgrounds due to charge misidentification and the resultant distribution of $E_{\mathrm{T}}^{\mathrm{miss}}$ and m_{eff} of the $e\mu$ channel after applying the constraints are shown in Fig. 4. As shown, a fair increase of $t\bar{t}W$ purity was achieved in $e\mu$ channel after imposing the η_e constraints.

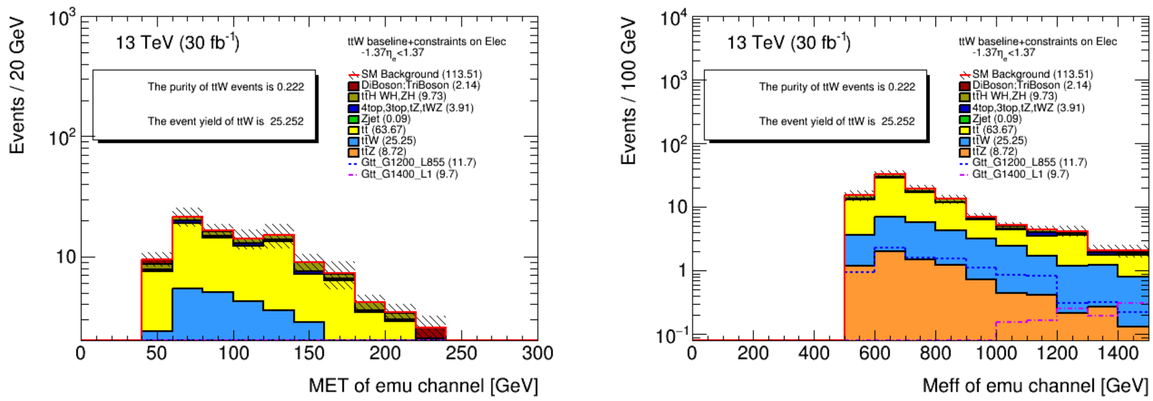


Figure 4: The distribution of $E_{\mathrm{T}}^{\mathrm{miss}}$ (left) and m_{eff} (right) of the $e\mu$ channel after imposing constraints on $-1.37 < \eta_e < 1.37$ on top of the cuts listed in Table 1.

3.2 $t\bar{t}Z$ Analysis

The baseline selection for $t\bar{t}Z$ requires the events to satisfy the criteria listed in Table 2. The resultant distributions of $E_{\mathrm{T}}^{\mathrm{miss}}$ and m_{eff} are shown in Fig. 5. After the baseline selection, the events are categorised into two channels according to the b-jet multiplicity. Events having exactly one b-jet are denoted by "1b channel" and events with b-jet multiplicity $\geqslant 2$ are denoted by "2b channel". The distributions of jet multiplicity of the two $t\bar{t}Z$ channels after the baseline selection is shown in Fig. 6. As shown, the 2b channel is much cleaner than the 1b channel and the distributions of jet multiplicity suggest that higher $t\bar{t}Z$ purity in the 1b channel could be achieved by cutting on jet multiplicity. The purity of the 1b channel increased from 0.527 to 0.591 after requiring at least four jets with $p_{\mathrm{T}} > 20$ GeV in the event.

At least three letpons
At least one pair of leptons with opposite-sign electric charge, same flavour and invariant mass m_{ll} between 80 GeV and 100 GeV
$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV
Number of jets with $p_{\mathrm{T}} > 20$ GeV $\geqslant 3$
p_{T} of sub-leading lepton > 25 GeV
Number of b-jets with $p_{\mathrm{T}} > 20$ GeV $\geqslant 1$

Table 2: Baseline cuts for $t\bar{t}Z$ analysis.

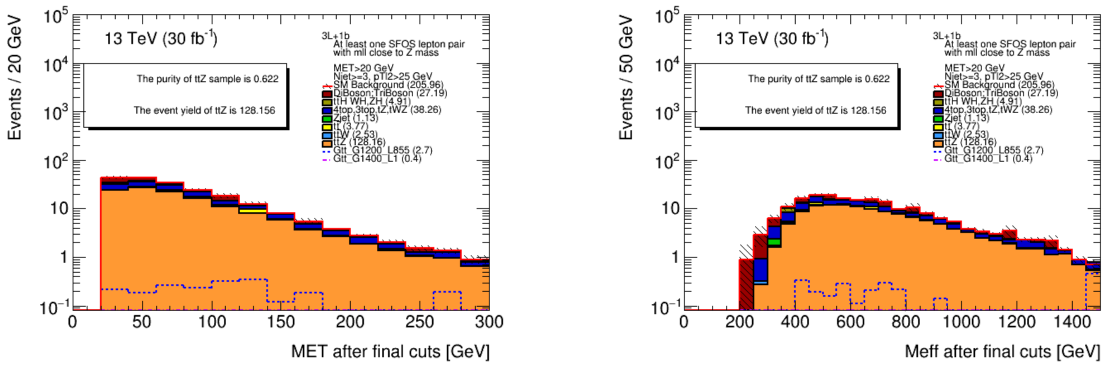


Figure 5: The distribution of $E_{\mathrm{T}}^{\mathrm{miss}}$ (left) and m_{eff} (right) of resulting from the cuts listed in Table 2.

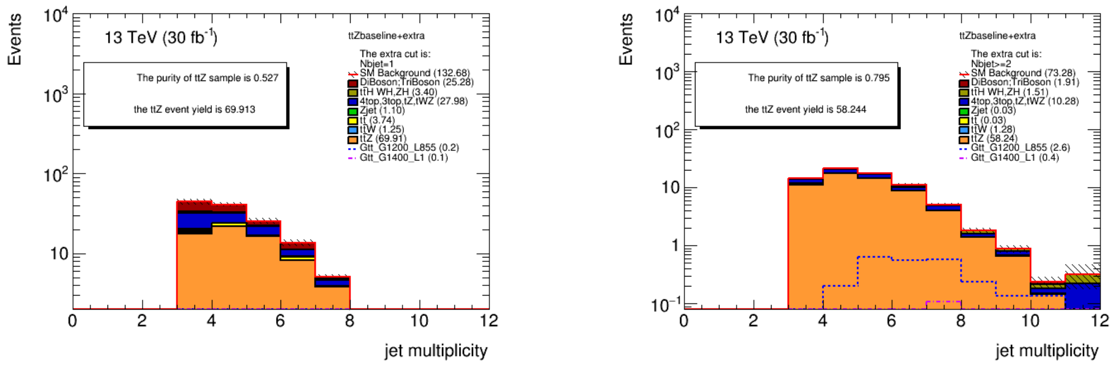


Figure 6: The distribution of jet multiplicity of 1b channel (left) and 2b channel (right) after the baseline selection.

4 Conclusion

A study of $t\bar{t}V (V = W$ or $Z)$ process aiming at separating it from other SM backgrounds in the search for R-parity conserving SUSY using same-sign dileptons or three leptons has been presented. A set of kinematic cuts which could efficiently separate $t\bar{t}Z$ from other SM backgrounds has been found and the resultant $t\bar{t}Z$ purity is 0.622. The purity can be further improved by splitting the events surviving from baseline selection into 1b channel and 2b channel and cutting on the jet multiplicity in the 1b channel. Separating $t\bar{t}W$ from other SM backgrounds still remains a challenge. Among the three channels of $t\bar{t}W$, the $\mu\mu$ channel was found to have the highest purity (0.464), the purity of $e\mu$ channel is 0.183 and the purity of ee channel is 0.090. The results are summarized in Table 3. This work is useful for future selection of $t\bar{t}V$ events for background validation and measurement in relevant SUSY analysis.

	baseline	baseline + η_e constraints
$t\bar{t}W_{e\mu}$	0.183 (31.213)	0.222 (25.252)
$t\bar{t}W_{\mu\mu}$	0.464 (20.003)	
$t\bar{t}W_{ee}$	0.090 (15.303)	0.131(9.749)
	baseline	baseline + multiplicity of jet with $p_{\mathrm{T}} > 20$ GeV $\geqslant 4$
$t\bar{t}Z_{\mathrm{inclusive}}$	0.622 (120.156)	
$t\bar{t}Z_{1b}$	0.527 (69.913)	0.591 (52.109)
$t\bar{t}Z_{2b}$	0.795 (58.244)	

Table 3: Summary of $t\bar{t}V$ event purity. The number in the bracket represents the corresponding $t\bar{t}V$ event yields for an integrated luminosity of 30 fb^{-1} of data.

5 Acknowledgement

I would like to express my gratitude to Dr. Ximo POVEDA TORRES and Dr. German CARRILLO MONTOYA for their kind assistance and support throughout this work.

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 **76** (2016) no.5, 259 doi:10.1140/epjc/s10052-016-4095-8 [arXiv:1602.09058 [hep-ex]].

[2] ATLAS collaboration, "Search for supersymmetry with two same-sign leptons or three leptons using 13.2 fb^{-1} of $\sqrt{s} = 13$ TeV pp collision data collected by the ATLAS detector," ATLAS-CONF-2016-037, http://cds.cern.ch/record/2205745.