

Estimation of SM backgrounds to SUSY searches in the 1-lepton + jets + E_T^{miss} channel

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The ATLAS Collaboration has reported the first results of the search for SUSY particles in 1-lepton + ≥ 3 jets + E_T^{miss} final states for $\int L dt = 35 \text{ pb}^{-1}$. An essential ingredient for these results is a reliable background estimation in the signal region, in particular of the $t\bar{t}$, W +jets and QCD backgrounds. The estimation of these three backgrounds is explained in this paper. The $t\bar{t}$ and W +jets backgrounds are obtained from a background dominated control region and extrapolated to the signal region, whereas for the estimation of the QCD background a matrix method is used.

1 Introduction

Supersymmetric extensions (SUSY) to the Standard Model (SM) predict the existence of supersymmetric particles which could be produced in the proton-proton collisions at a center-of-mass energy of 7 TeV at the LHC ¹. The search for SUSY is one of the main aims of the ATLAS experiment ².

The main production channels of SUSY particles at the LHC are squark-(anti)squark, gluino-squark and gluino-gluino pairs if these sparticles are light enough. Typical squark and gluino decays contain isolated leptons, quarks and gluons (which result in jets) and end with the stable Lightest Supersymmetric Particle (LSP) if a R-parity conserving SUSY model is assumed. As the LSP escapes the detector undetected, missing transverse energy (E_T^{miss}) will be observed. Therefore, the typical experimental signature consists of multiple jets, isolated leptons and E_T^{miss} . Here only final states with one isolated muon or electron, at least three jets and E_T^{miss} are considered (1-lepton + ≥ 3 jets + E_T^{miss} channel).

However, other physical processes can have similar experimental signatures, in particular:

- $t\bar{t}$ events with a semileptonic decay topology, where each top quark decays into a W -boson and a b-quark, with one of the W -bosons decaying into an isolated charged lepton and a neutrino (E_T^{miss}).
- W +jets events where the W -boson decays into a neutrino and the corresponding charged lepton.
- QCD events, like heavy flavor (b or c quarks) decays, events with photon conversions or jets which were reconstructed as isolated leptons.

A signal region rich in SUSY signal events but poor in background events (BG) which was motivated by studies on Monte Carlo event samples is defined as follows. Hereby, the channel

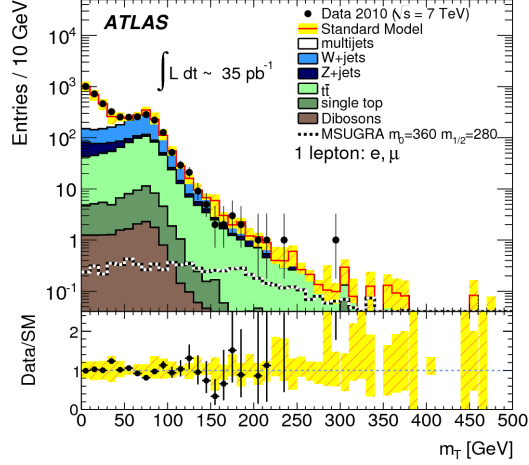


Figure 1: The m_T distribution after the lepton and the jets criteria. The ratio of data to SM expectations is given in the ratio plot below. The uncertainties on the MC predictions are indicated by the yellow bands.

itself is defined by asking for exactly one isolated lepton being in the event with a transverse momentum of $p_T > 20$ GeV which already reduces the QCD BG. Furthermore, the event must contain at least three jets with $p_T^{\text{leading jet}} > 60$ GeV and $p_T^{\text{second,third jet}} > 30$ GeV. In addition to these cuts, various cuts are applied to reject background events: a further reduction of the QCD background is achieved by asking for the three leading jets and E_T^{miss} not to point in the same direction^a. Furthermore, only events with $E_T^{\text{miss}} > \max(125 \text{ GeV}, 0.25M_{\text{eff}})$ ^b and a high transverse mass with $m_T > 100$ GeV^c are selected. The last cut reduces the W +jets and $t\bar{t}$ backgrounds considerably as illustrated in figure 1. Finally, a cut on the effective mass with $M_{\text{eff}} > 500$ GeV is applied. After applying these cuts, $t\bar{t}$ events are the main background and QCD events are heavily suppressed.

The estimation of the three most important backgrounds in the signal region is discussed in the following.

2 W and top backgrounds

The magnitude of the backgrounds is estimated with the help of background dominated control regions. In figure 2, various control regions - one for each of the main backgrounds (QCD, $t\bar{t}$, W +jets) in the $E_T^{\text{miss}} - m_T$ plane are defined. All other cuts for these control regions correspond to the usual selection cuts presented above except the cut on M_{eff} which is not applied. For example, the QCD region (QR) which is defined by $E_T^{\text{miss}} < 40$ GeV and $m_T < 40$ GeV is rich in QCD events. The control region with medium E_T^{miss} and m_T values ($30 < E_T^{\text{miss}} < 80$ GeV and $40 < m_T < 80$ GeV) is dominated by top and W +jets events. This control region is further divided into two control regions dominated by $t\bar{t}$ events (top region, TR) or W +jets events (W region, WR), respectively, by the requirement of finding at least one b-tagged jet (TR) or no b-tagged jet (WR) in the three leading jets. The QR is only used to estimate the QCD contamination in the TR or in the WR, whereas the QCD BG in the signal region itself is obtained with the method described in the next section. In contrast, the $t\bar{t}$ and W +jets BG in the signal region is obtained by extrapolating the number of measured W and top events in W and T control regions (other backgrounds were subtracted) into the signal region. For

^a $\Delta\phi(\text{jet}_i, \vec{E}_T^{\text{miss}}) > 0.2$ ($i = 1, 2, 3$)

^b the effective mass is defined as $M_{\text{eff}} = p_T^l + E_T^{\text{miss}} + \sum_{i=1}^3 p_T^{\text{jet}_i}$

^c the transverse mass is defined as $m_T = \sqrt{2 \cdot p_T^l \cdot E_T^{\text{miss}} \cdot (1 - \cos(\Delta\phi(l, E_T^{\text{miss}})))}$

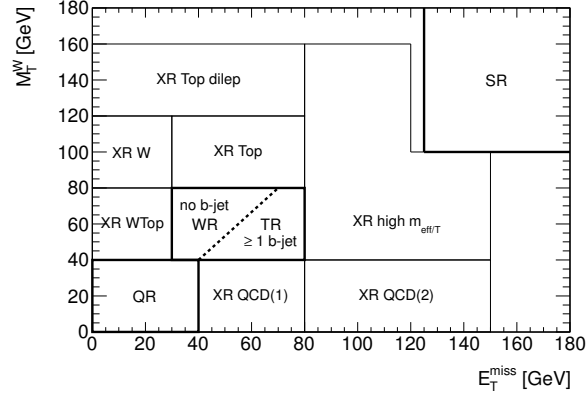


Figure 2: The positions of the signal region (SR) and of the main control regions (as QR, WR and TR, defined in the text) are indicated in the $E_T^{\text{miss}} - m_T$ -plane. Control regions which are not mentioned in the text (XR) are used to cross check the background estimation techniques presented in the text.

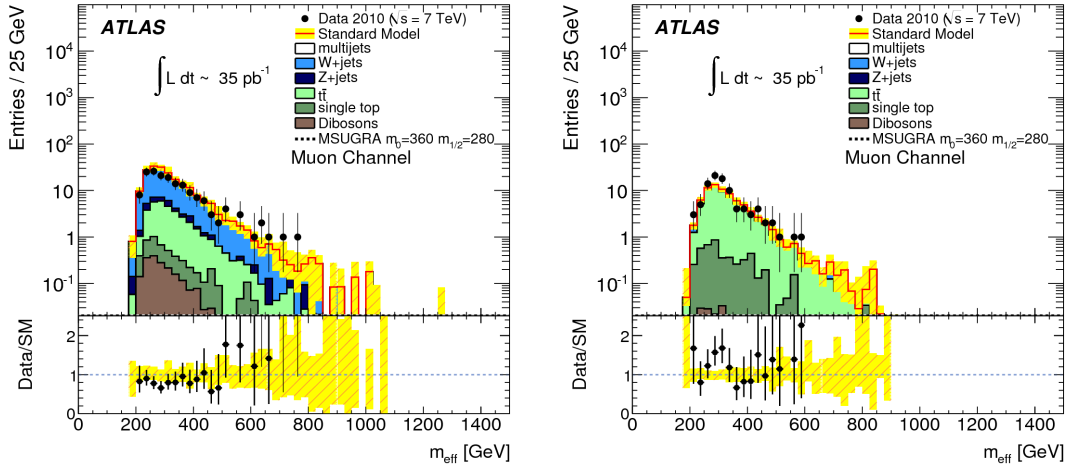


Figure 3: The M_{eff} distributions in the W region (left) and in the top region (right) in the muon channel. The yellow bands indicate the uncertainties on the MC predictions.

this an extrapolation factor which is obtained from Monte Carlo is used. The extrapolation is illustrated in equation 1 for the top background.

$$\underbrace{N(\overline{t\bar{t}} \text{ pred.}, \text{ SR})}_{\text{predicted events in signal region}} = \underbrace{N(\overline{t\bar{t}}(\text{data}), \text{ CR})}_{\text{measured events in control region - other BG}} \times \underbrace{\frac{N(\overline{t\bar{t}}(\text{MC}), \text{ SR})}{N(\overline{t\bar{t}}(\text{MC}), \text{ CR})}}_{\text{extrapolation factor CR to SR}} \quad (1)$$

This method is validated by comparing data to MC in the relevant distributions for the extrapolation. Figure 3 shows for example the M_{eff} distributions in the TR and in the WR in the muon channel. The good agreement between data and MC gives confidence in the method.

3 QCD background

In contrast to the W and top backgrounds, the QCD background is estimated by a matrix method. As mentioned above, the signal selection cuts (tight selection cuts) choose only events with exactly one isolated lepton. By relaxing the isolation requirement for the lepton a loose control sample enriched with QCD events can be defined. The events passing the tight selection

Table 1: The number of observed events in $\int Ldt = 35 \text{ pb}^{-1}$ is compared to the total number of background events expected. The contribution of $t\bar{t}$, W and Z events and QCD events to the total number of background events is given.

channel	observed events	sum estimated BG events	estimated top	estimated WZ	estimated QCD
muon	1	2.25 ± 0.94	1.76 ± 0.67	0.49 ± 0.36	$0.0^{+0.5}_{-0.0}$
electron	1	1.81 ± 0.75	1.34 ± 0.52	0.47 ± 0.40	$0.0^{+0.3}_{-0.0}$

cuts can be expressed as the sum of QCD events (“fake”) and non-QCD events (“real”) as in equation 2.

$$N_{\text{tight}}^{\text{obs}} = N_{\text{tight}}^{\text{real}} + N_{\text{tight}}^{\text{fake}} \quad (2)$$

In the same way, the events passing the loose but not the tight selection cuts can be written as the sum of QCD and non-QCD events. By defining two efficiencies by $\epsilon^{\text{real/fake}} = \frac{N_{\text{tight}}^{\text{real/fake}}}{N_{\text{loose}}^{\text{real/fake}}}$ this sum can be written as:

$$N_{\text{loose not tight}}^{\text{obs}} = (1/\epsilon^{\text{real}} - 1)N_{\text{tight}}^{\text{real}} + (1/\epsilon^{\text{fake}} - 1)N_{\text{tight}}^{\text{fake}} \quad (3)$$

Both equations 2 and 3 are solved for the QCD events passing the tight selection cuts in equation 4. The result gives the QCD events in the SUSY signal region.

$$N_{\text{tight}}^{\text{fake}} = \frac{N_{\text{loose not tight}}^{\text{obs}} - (1/\epsilon^{\text{real}} - 1)N_{\text{tight}}^{\text{obs}}}{1/\epsilon^{\text{fake}} - 1/\epsilon^{\text{real}}} \quad (4)$$

This method was applied to the whole dataset of 2010 of 35 pb^{-1} in the electron and in the muon channel, respectively. Thus, $\epsilon^{\text{fake}} \sim 0.2 - 0.3$ was obtained in a QCD dominated control region with $E_{\text{T}}^{\text{miss}} < 40 \text{ GeV}$ and $M_{\text{T}} < 40 \text{ GeV}$, whereas $\epsilon^{\text{real}} \sim 0.9 - 1.0$ was taken from Monte Carlo. Only an upper limit on the QCD background in the signal region could be derived with < 0.5 events in the muon channel and < 0.3 events in the electron channel due to low statistics in the loose-but-not-tight events.

4 Outlook

The QCD, $t\bar{t}$ and W +jets backgrounds in the signal region are estimated with the methods presented. Other backgrounds are taken from simulation. The final results are detailed in table 1. The top background is with 1.76 ± 0.67 (muon channel) and 1.34 ± 0.52 (electron channel) the most dominant background in the signal region. In total, 2.25 ± 0.94 background events are expected in the muon channel and 1.81 ± 0.75 background events in the electron channel, but only 1 event passes all the signal selection cuts presented above in each of the electron and the muon channels. An interpretation of the results in terms of limits is given elsewhere³.

References

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3. The ATLAS Collaboration. Search for supersymmetry using final states with one lepton, jets, and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7 \text{ TeV}$ pp collisions. Phys. Rev. Lett. 106, 131802 (2011)