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Araştırma Makalesi / Research Article

Standard Model Background Analysis for Single Lepton Channel

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Abstract

Since protons are not fundamental particles, they produce very large backgrounds in proton-proton collisions. Therefore, in supersymmetry searches, the main challenge is to differentiate supersymmetric signals from Standard Model background. Hence, extensive background analysis becomes an important probe to obtain information in the direction of supersymmetry searches. Among the variety of signatures in this direction, single lepton channel is one of the effective processes in which Standard Model background is obtained. In this work, starting from the generation of background emerging from various events, basic selections and cuts have been applied to obtain a homogenous and a clean sample. On the other hand, the magnitude of missing transverse energy and scalar sum of all transverse momentums are crucial to detect particles that can escape without leaving trace in the detector. Therefore, all necessary histograms have been plotted. Emerging the leading backgrounds from W-bosons + jets and top quark-antiquark + jets events, almost all energy regions, it is seen that W+jets have greater contribution to background. However, for the collisions that produce high number of jets top quark-antiquark + jets become more dominant. Final step of the work is the application of additional selections and cuts for the isolation of potential supersymmetry signals.

Tek Lepton Kanalında Standart Model Ardalan Analizi

Anahtar kelimeler
Süpersimetri; Standart Model; Tek lepton kanalı; Analiz

Öz

Protonlar temel parçacık olmadıkları için, proton-proton çarpışmalarında büyük bir ardalan üretirler. Dolayısıyla, süpersimetri arayışlarında ana problem, süpersimetrik sinyalleri bu Standart Model ardalanından ayırmaktır. Bu nedenle, kapsamlı bir ardalan analizi, süpersimetri arayışları yönünde bilgi edinebilmek için önemli hale gelir. Tek lepton kanalı, Standart Model ardalanının elde edildiği etkin süreçlerden biridir. Bu çalışmada, çeşitli olaylardan oluşan ardalan üretilmiş, homojen ve temiz bir ardalan oluşabilmesi için temel seçimler ve kesimler uygulanmıştır. Öte yandan, dedektörde iz bırakmadan kaçabilen parçacıkları tespit edebilmek için, kayıp enine enerjinin büyüklüğü ve tüm enine momentumlarım skaler toplamı oldukça önemlidir. Bu nedenle, gerekli tüm histogramlar çizilmiştir. Ardalan, büyük ölçüde W-bozonları + jetleri ve top kuark-antikuark + jetlerinden oluşmakla birlikte, neredeyse tüm enerji bölgelerinde en fazla katkı, W+jetlerinden gelmektedir. Ancak çok sayıda jet üreten çarpışmalar için top kuark-antikuark + jetleri daha baskın hale gelmektedir. Çalışmanın son adımı ise, potansiyel süpersimetri sinyallerinin izolasyonu için ek seçimler ve kesimlerin uygulanmasıdır.

1. Introduction

Supersymmetry (SUSY) is an essential theory to advance new physics Beyond Standard Model (BSM) (Ramond 1971, Golfand, and Likhtman 1971, Neveu and Schwarz 1971, Nilles 1984, Fayet 1975). Being one of the strongest tools for the solution of certain problems, like gauge hierarchy problem (Hooft 1980) and gauge coupling constant unification problem (Dimopoulos *et al.* 1981), which cannot be explained by the Standard Model (SM), it is also a leading candidate for the experimental work via proton-proton (pp) collisions. SUSY searches in collider experiments typically examine events with high transverse missing energy (E_T^{miss}) which can originate from the lightest supersymmetric particle, in the case of R-parity conserving SUSY. Indeed, this is the reason why the lightest SUSY particle could be a good candidate for viable dark matter (Farrar and Fayet 1978.). Recent results on searches for SUSY in single lepton channel are presented at the center of mass energy of 7 TeV (Chatrchyan et al. May. 2013, CMS Collaboration 2012, ATLAS Collaboration 2012), 8 TeV (CMS Collaboration 2013, ATLAS Collaboration 2014 and 2015.) and 13 TeV (Yildiz 2016, CMS Collaboration 2016, ATLAS Collaboration 2016, Khachatryan *et al.* 2017) at CERN LHC, by using data recorded in CMS and ATLAS experiments.

The main challenge in SUSY searches is to obtain sufficient sensitivity to collision data and signal while understanding the contribution of background. So, extensive background analysis has to be done, to isolate signal from the SM background. In this study, SM background for single lepton channel has been produced for future SUSY analysis. The leading backgrounds emerge from $\mathrm{W+jets}$ (W-boson) and $\mathrm{t\bar{t}+jets}$ (top quark-antiquark) events. While the longitudinal momentum of the partons is difficult to determine due to their composite structure, the missing transverse momentum ($\vec{p}_T^{miss}$) which is the negative vector sum of the transverse momenta could be reconstructed.

$$\vec{p}_T^{miss} = -\sum \vec{p}_T \quad (1)$$

The magnitude of missing transverse momentum is defined as in Equation (2) (Yildiz 2016).

$$|\vec{p}_T^{miss}| = E_T^{miss} \quad (2)$$

In addition to that, scalar sum of all transverse momentums (H_T) is also considered in Equation (3). The polar angle θ is the angle between beam pipe (z-axis). Instead of θ, pseudorapidity is often used as in Equation (4).

$$H_T = \sum |\vec{p}_T| \quad (3)$$

$$\eta \equiv -\ln \tan\left(\frac{\theta}{2}\right) \quad (4)$$

The background is produced for the gluino pair production T1tttt scenario and T5qqqqWW scenario (Chatrchyan *et al.* Sep. 2013, Alwall *et al.* 2009, Alves *et al.* 2012). Both SUSY scenarios lead to single lepton final state. In the first scenario gluino pair is produced after collision and it decays to top quark-antiquark and the lightest neutralino final state ($t\bar{t}+\tilde{\chi}_1^0$). In the second scenario, the gluino pair which is produced after collision, decay to quark-antiquark and W-boson ($q\bar{q}W^{\pm}\tilde{\chi}_1^0$) final state.

2. Computational Details

MadGraph5 (Alwall *et al.* 2011, the NNPDF Collaboration *et al.* 2014) is a groundwork that aims to implement all the tools required for SM and BSM theories. All the processes could be simulated to leading order (LO) accuracy for a given Lagrangian. In this study main SM backgrounds, $\mathrm{t\bar{t}+jets}$, $\mathrm{W+jets}$, $\mathrm{DY+jets}$ which refer to $q\bar{q} \to Z/\gamma^* \to l^+l^-$ events and single-top quark events in t-channel and tW process, are generated by using MadGraph5 event generator. In addition to that the results are analyzed with Root program package (Brun and Rademakers 1997.).

3. Results and Discussion

3.1 Basic selections and cuts

The dominant background for this search comes from $\mathrm{W+jets}$ whose contribution remains the greatest almost all energy regions and all event selections. In the region with four jets or higher, where BSM theories expected to be effective, $\mathrm{t\bar{t}+jets}$ should become more dominant (ATLAS Collaboration 2016, Khachatryan *et al.* 2017).

The aim of the event selections is to gather a homogenous and clean background sample. Since the analysis is carried out for one lepton channel, events should contain single electron or single muon as seen from the Table 1. Pseudorapidity for electron and muon has been chosen as $\eta^l < |2.1|$ and for the jets $\eta^j < |2.4|$. $E_T^{miss} > 80\ GeV$ requirement is implemented which further lower DY-backgrounds and multijet to a negligible level. Moreover, to avoid cross trigger an event $p_T^{l,j} > 30\ GeV$ is chosen for electron muon and jets.

Table 1. Basic event selections and cuts, where l and j refer to lepton and jets consecutively. $\mathrm{N_l}$ refers to number of leptons.

Basic Event Selections and Cuts
$\mathrm{N_l} = 1$
$\eta^l < |2.1|$

$p_T^{l,j} > 30$ GeV
$E_T^{miss} > 80$ GeV
$\eta^j < \|2.4\|$

The magnitude of missing transverse energy is crucial for detecting particles that can escape without leaving a trace in the detector, such as neutrinos and weakly interacting particles. In addition to that, high amount of missing transverse energy is expected for SUSY events. For those reasons, generating SM background for the magnitude of missing transverse energy E_T^{miss} and scalar sum of all transverse momentums H_T is important. Therefore, H_T and E_T^{miss} histograms after event selections and cuts are given in Figure 1a and 1b in which $W + \text{jets}$ and $t\bar{t} + \text{jets}$ dominant for all regions. However, the contribution of $DY + \text{jets}$ for $H_T < 120$ GeV region surpasses $t\bar{t} + \text{jets}$.

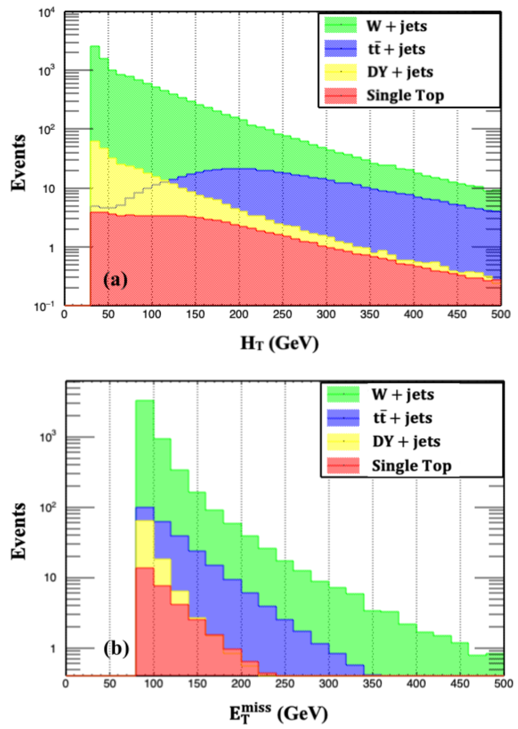


Figure 1. (a) H_T and (b) E_T^{miss} after event selections and cuts.

Many SUSY models lead to very large number of jets. For this reason, understanding the behavior of SM background, as a function of number of jets and of b-jets, is essential. In Figure 2a and 2b, number of jets and of b-jets after event selections and cuts have been plotted. It is clearly seen that if $N_{jets} < 6$ and $N_{bjets} < 3$ leading background is $W + \text{jets}$ otherwise $t\bar{t} + \text{jets}$.

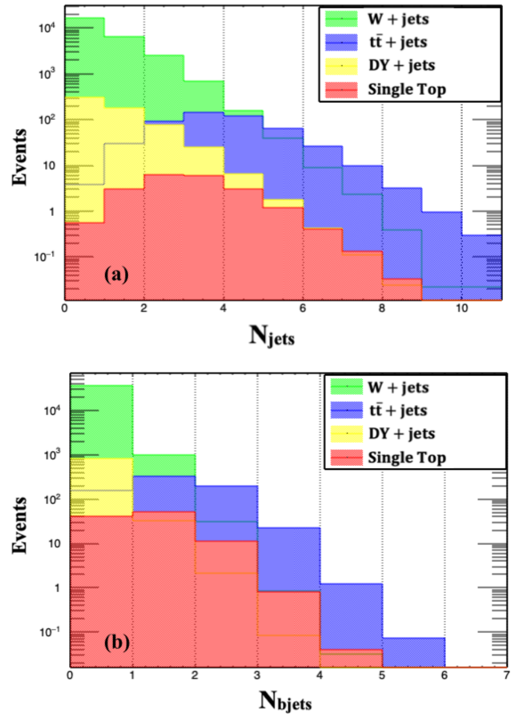
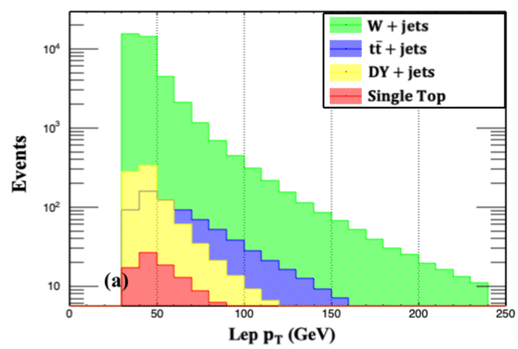


Figure 2. (a) Number of jets and (b) number of b-jets after event selections and cuts.

After applying event selections and basic cuts given at Table 1, transverse momentum (p_T) and pseudorapidity (η) of single lepton events are plotted Figure 3a and 3b. The largest contribution to background originates from $W + \text{jets}$ for all the region, as expected. In Figure 3a while in the region between 30 to 60 GeV $DY + \text{jets}$ has greater background, above 60 GeV $t\bar{t} + \text{jets}$ produces more events. Also, in Figure 3b, for the vertical axis (y) $t\bar{t} + \text{jets}$, and for the beam pipe axis (z) $DY + \text{jets}$ have generate more events.



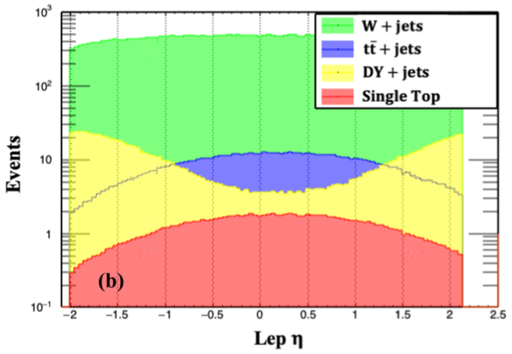


Figure 3. (a) Lepton p_T and (b) lepton pseudorapidity η after event selections and cuts.

3.2 Additional selections

Y_{MET} is defined as in Equation (5).

$$Y_{MET} = E_T^{miss}/\sqrt{H_T} \quad (5)$$

Both, Y_{MET} and H_T can discriminate potential SUSY signals from SM background (Yildiz 2016). In simulated events these two variables are found to be considerable uncorrelated. This fact gives one an advantage of differentiating T1tttt and T5qqqqWW signals (Chatrchyan et al. Sep. 2013, Alwall et al. 2009, Alves *et al.* 2012) from the SM background for selected region. For that reason, additional selections, $N_j > 4$, $H_T > 300$ GeV and $E_T^{miss} > 150$ GeV have been applied in Figure 4b. With those new cuts, 99.9% additional data cleaned as seen from Table 2.

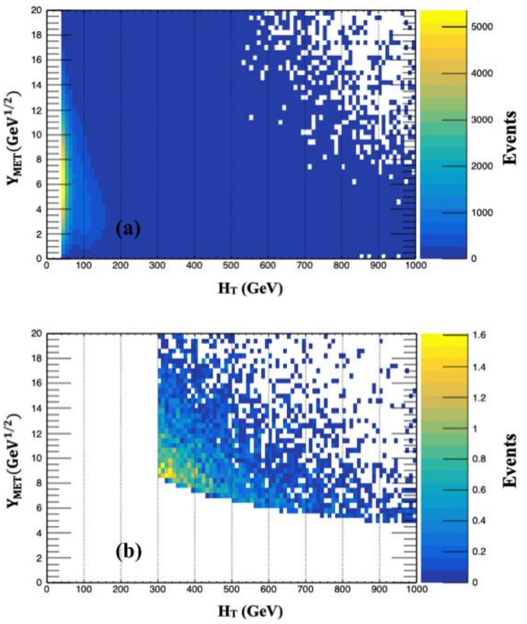


Figure 4. (a) Y_{MET} as a function of H_T with basic event selections and (b) with additional cuts $N_j > 4$, $H_T > 300$ GeV and $E_T^{miss} > 150$ GeV.

Table 2. Number of events after additional cuts. Basic selections and cuts from Table 1 normalized to 1.

Selections	Number of Events
Basic Selections and Cuts	1.00000
$N_j > 4$	0.01590
$E_T^{miss} > 150$ GeV	0.00124
$H_T > 300$ GeV	0.00107

4. Conclusion

In this study, SM backgrounds, W + jets, $t\bar{t}$ + jets, DY + jets and single top events have been generated for one lepton channel by using MadGraph5 event generator. The leading SM background emerges from W + jets whose contribution remains the highest almost among all regions. However, for the region with number of jets greater than 5 and number of b-jets greater than 2, the highest contribution comes from $t\bar{t}$ + jets. In order to isolate potential SUSY signals from background new cuts $N_j > 4$, $H_T > 300$ GeV and $E_T^{miss} > 150$ GeV have been applied and additional 99.9% background has been cleaned for potential SUSY signal region. To understand the effect of these new cuts Y_{MET} and H_T histograms are plotted and reduced background has been observed.

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