Analyzing chargino-neutralino production in mSUGRA scenario @ATLAS with 10 TeV

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Abstract

At the ATLAS SU3 benchmark point of the minimal supergravity (mSUGRA) model, it is possible to produce chargino ($\tilde{\chi}_1^{\pm}$) neutralino ($\tilde{\chi}_2^0$) pairs at a energy scale below the maximal LHC energy. This offers an interesting possibility to detect supersymmetric particles in the initial stage of the LHC. In this report we study a chargino neutralino pair, produced at 10 TeV, that decays into leptons and the lightest supersymmetric particle (LSP), which for SU3 is the lightest neutralino ($\tilde{\chi}_1^0$). We present several cuts, in order to suppress SM background and other SUSY channels as good as possible and discuss the possibility for an observation of this signal at the ATLAS detector.

1 Introduction

Supersymmetry (SUSY) is an attractive extension of the SM that solves some of the shortcomings of the Standard Model in a quite natural way, e.g. the unification of the couplings at the GUT scale and the hierarchy problem. Additionally it provides a good candidate for dark matter, assuming R-Parity to be conserved. Under this symmetry supersymmetric particles can only be produced in pairs and the LSP is stable and thus a good dark matter candidate. In supersymmetric models a so called superpartner is imposed for every Standard Model (SM) particle, with same quantum numbers but with spin differing by 1/2. So the superpartners of fermions are bosons and vice versa. A sketch of SM and SUSY particles can be seen in Figure 1. The higgsinos and the electroweak gauginos mix with each other and form mass eigenstates. The neutral higgsinos ($\tilde{H}_u^0$ and $\tilde{H}_d^0$) and the neutral gauginos ($\tilde{B}$ and $\tilde{W}^0$) combine to four neutralinos while the charged higginos ($\tilde{H}_u^+$ and $\tilde{H}_d^-$) mix with the charged gauginos ($\tilde{W}^+$ and $\tilde{W}^-$) into two charginos. If Supersymmetry would be exact, the superpartners would have the same mass as the SM particles. But since no SUSY particles (sparticles) have been observed yet, Supersymmetry must be broken.

In this report we study a chargino ($\tilde{\chi}_1^{\pm}$) neutralino ($\tilde{\chi}_2^0$) process in the mSUGRA model that is described briefly in section 2. In this section we also introduce one particular ATLAS benchmark point SU3 in the bulk region of the mSUGRA parameter space in which this process is analyzed. In section 3 we show the investigated process and analyze possible final states, before looking at the background in the following sections. We present two types of cuts we use to suppress the background. In the last section we discuss the results and draw conclusions regarding to possible further studies in this SUSY channel. The analysis is done using the Root based program SFrame.

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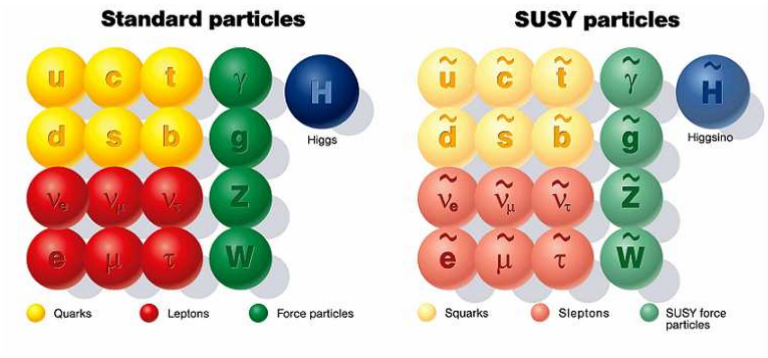

Figure 1: SM and SUSY particles

2 mSUGRA benchmark point SU3

The breaking mechanism is described by several models (mSUGRA, GMSB, ...). Our study is done in the minimal supergravity model (mSUGRA). In this model gravity mediates the SUSY breaking from GUT scale to EW scale. Assuming R-Parity conservation mSUGRA can be completely characterized by five parameters:

- common mass of all scalar particles at GUT scale: m_0
- common mass of gauginos and higgsinos at GUT scale: $m_{1/2}$
- common trilinear (Higgs - Sfermion - Sfermion) coupling: A_0
- ratio of the vevs of the two Higgs doublets: $\tan\beta$
- sign of the Higgsino mass parameter: μ

Our Investigation is done for one particular point - the benchmark point SU3 in the bulk region of the mSUGRA parameter space. The five mSUGRA parameters for SU3 are given in Table 1. The phenomenology at this point is determined by the mass spectrum, which can be seen in Figure 2. The LSP is the lightest neutralino ($\tilde{\chi}_1^0$). Most relevant for this study, are the second lightest neutralino ($\tilde{\chi}_2^0$) and the lightest chargino ($\tilde{\chi}_1^{\pm}$). Both particles decay mainly into leptons. The branching ratios for decays into taus, muons and electrons (relating to all leptonical decays) are given in table 2. In 76% of the cases the $\tilde{\chi}_2^0$ decays into two taus and only 12% decay into electrons and muons. The suppression of electron and muon decays becomes clear by noting that the $\tilde{\chi}_2^0$ is mainly Wino like and thus couples mainly to left handed particles. Also in the chargino ($\tilde{\chi}_1^{\pm}$) decays taus are favored, since the chargino can decay into a stau (which decays into a tau and a neutralino ($\tilde{\chi}_1^0$)) but decays into left handed selectrons and smuons are energetically forbitten, as one can see in the mass spectrum (Figure 2)

Table 1: SU3 Parameters

Parameter	m_0	$m_{1/2}$	A_0	$\tan\beta$	sgnμ
Value	100 GeV	300 GeV	-300 GeV	6	+

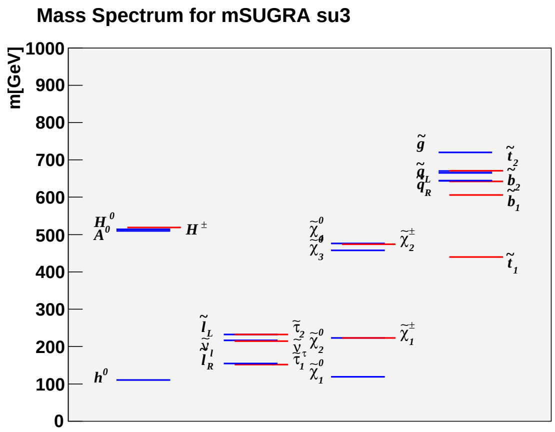

Figure 2: Mass spectrum of the mSUGRA SU3 benchmark point

Table 2: Branching ratios for leptonically decaying neutralinos and charginos

Decay	BR [%]	Decay	BR [%]
$\tilde{\chi}_2^0 \to \tau^+\tau^-\tilde{\chi}_1^0$	≈ 76	$\tilde{\chi}_1^\pm \to \tau^\pm\nu_\tau\tilde{\chi}_1^0$	≈ 74
$\tilde{\chi}_2^0 \to e^+e^-\tilde{\chi}_1^0$	≈ 12	$\tilde{\chi}_1^\pm \to e^\pm\nu_e\tilde{\chi}_1^0$	≈ 13
$\tilde{\chi}_2^0 \to \mu^+\mu^-\tilde{\chi}_1^0$	≈ 12	$\tilde{\chi}_1^\pm \to \mu^\pm\nu_\mu\tilde{\chi}_1^0$	≈ 13

3 Investigated process

The Feynman diagram for the chargino - neutralino process decaying into tau final states can be seen in Figure 3. The signal we look for consists of three leptons in the final state plus missing transverse energy from the neutrino and the neutralinos. There are many background events, from other SUSY processes and from SM processes (e.g. Di-jet, W, Z, Di-boson, $t\bar{t}$, ...), with the same final states. Later in this work we show possible cuts in order to suppress the background events and to see the signal above the remaining background. Before looking at the background we want to focus here on the different combinations of leptons in the final state of the given process. As we have seen, we have taus in the final state more often than muons and electrons. Detecting taus is more difficult than other leptons, since they are not stable. Taus can decay leptonically or hadronically - the branching ratios for both decays is given in Table 3. Leptonical decaying taus are detected as electrons or muons and the information that they come from τ decays is lost due to the fact that ν cannot be detected. Only hadronical decaying taus can be detected, using special τ reconstruction mechanisms. And also in this case the detection is complicated, because it is difficult differentiate between hadronically decaying taus and QCD jets. The τ reconstruction efficiency lies around $50 - 60\%$ depending on the scenario. Considering the different τ decay modes we have 40 possible final states. The $\tilde{\chi}_1^\pm$ can decay into one electron, one muon or one tau, which can then decay into a electron, a muon or hadronically and analogous the $\tilde{\chi}_2^0$ can decay in two electrons, two muons or two taus, which decay into electrons, muons or hadronically. Figure 4 shows the fraction of the different final states in our sample (the colored boxes can be disregarded here. They will be important for later purposes). The 10 TeV mSUGRA

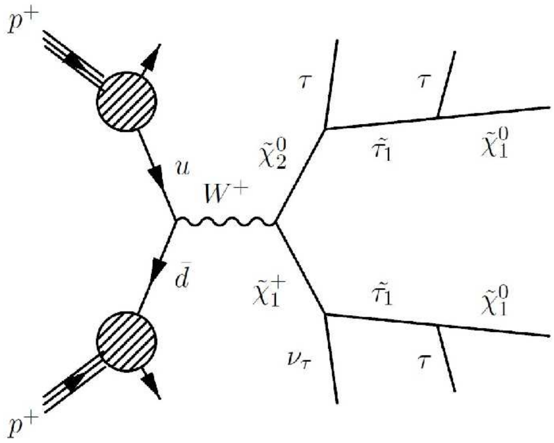

Figure 3: Feynman graph of chargino - neutralino process

sample is produced with the Herwig MC generator.

4 Background: Distribution and cuts

Besides other SUSY events the background containts many SM events, we investigate in this section. The generators used to produce the background samples are: MC@NLO ($t\bar{t}$, single t, di boson), Alpgen (Z plus jet, W plus jet), Pythia (di jet, photon jet).

4.1 Event selection

Figure 5 shows the missing E_T, the number of jets, the p_T of jet1 (highest energetic jet) and $|\Delta\phi|$ (jet1,MET) of the signal and SM backgrounds. These variables are often used for standard cuts. The number of events relates to a luminosity of 1.8fb^{-1}. It can clearly be seen that the signal is overwhelmed by SM background, in which the di-jet background is dominating. The distributions of many (other) SUSY events differ considerably from the SM distribution, so that cuts on these variables can be used to suppress a lot of the SM background. Unfortunately that is not the case for the initial chargino - neutralino process. The shape of all these distributions is very similar for the signal and the background, so that it is difficult to find sufficient event selection cuts. The cuts we used are:

Table 3: Branching ratios for τ decays

Leptonically	
$e\nu_e\nu_\tau$	17.8%
$\mu\nu_\mu\nu_\tau$	17.4%
Hadronically	
$\pi^\pm\nu_\tau$	46.8%
$\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	13.8%

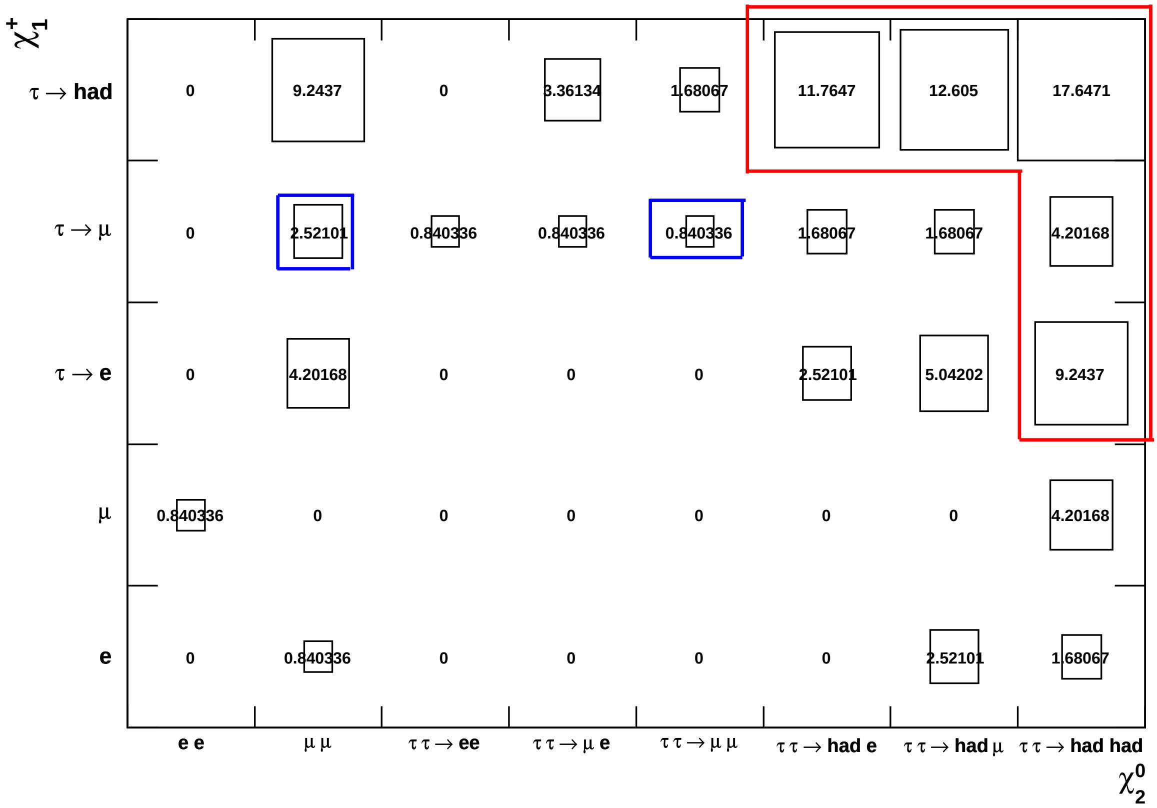

Figure 4: Fraction of different final states in our sample

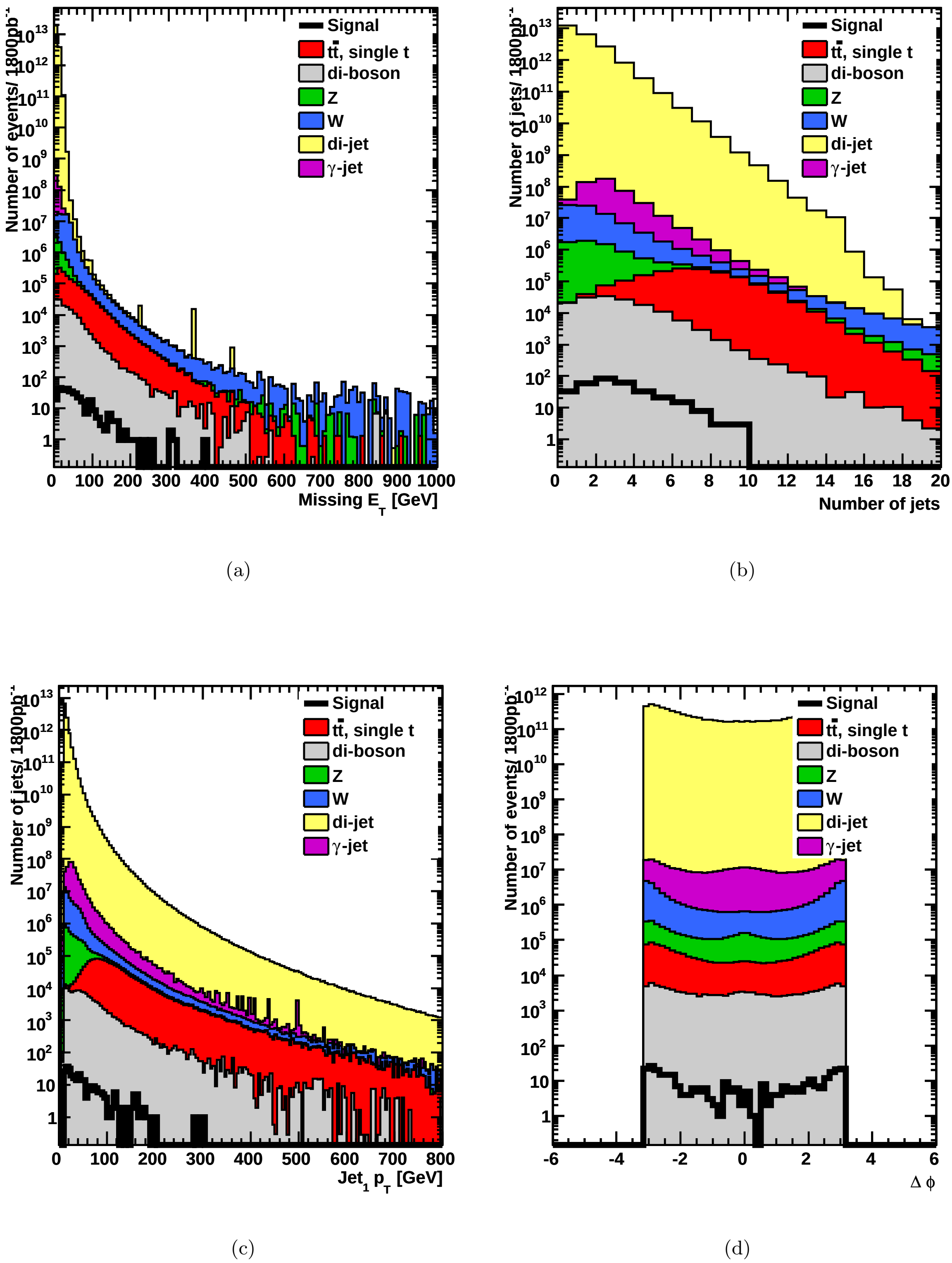

Figure 5: Distribution of standard cut variables: MET, # of jets, p_T of jet1 (highest energetic jet) and $|\Delta\phi|$ (jet1,MET)

1. missing E_T < 200 GeV
2. missing E_T > 20 GeV
3. # Jets < 8
4. Jet1 p_T < 100 GeV
5. $|\Delta\phi|$ (jet1, MET)> 0.2

The five cuts are applied successively and the number of signal and background events after each cut is shown in the first six bins of the cutflow plot in Figure 6. The first bin of this plot (without any cuts applied yet) points out what has be seen before: The background is many magnitudes larger than the signal. While we have around 300 signal events, the background is of the order 10^{13}. Applying the standard cuts we get rid of some background, but still the background is far to large. Using only standard cuts it will not be possible to detect our signal above the SM background.

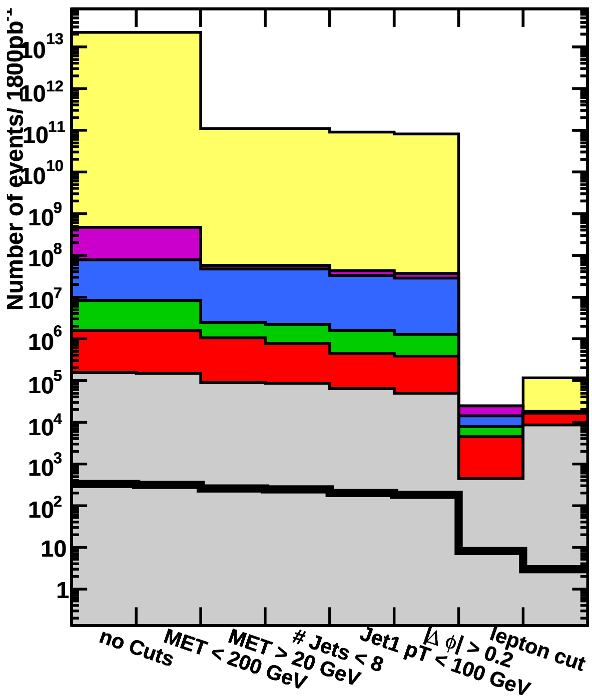

Figure 6: Cutflow

4.2 Leptoncuts

The results, after the use of the standard cuts, expose that additional cuts are needed. The final state of the signal with exactly three leptons suggests to cut on the lepton number. Since τ decays are favored, we try cutting on taus, although detection of taus is more challenging than the detection of other leptons. In Figure 4 it can be seen that 17.6 % of the chargino-neutralino events in our sample have three (hadronically decaying) taus in the final state. To enrich our signal we look not only at

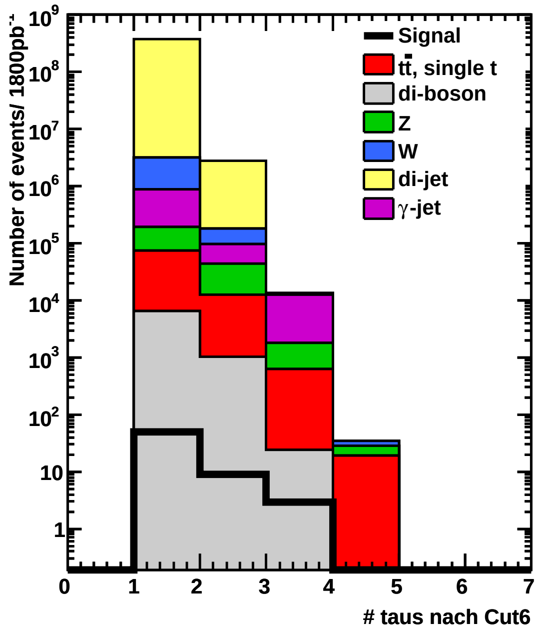

Figure 7: number of taus after standard cuts and cut on tau p_T.

events with three taus in the final state, but also at events with two taus and one additional lepton. So our signal contains all final states within the red box in Figure 4. Before carrying out the cut on the τ number, we demand that the highest energetical τ should have a $p_T < 100$ GeV. In Figure 7 the number of taus for the selected events, after the cut on the tau p_T, can be seen. The cut on two taus plus one lepton contains three different cases. Three taus or two taus and one muon or two taus and one electron are possible. Figure 8 shows the number of electrons and muons after executing the τ cut. By this cut a lot of the background is removed but anyhow we have to notice that the background is still magnitudes larger than the signal and a detection will be difficult.

Alternatively one can look for muons or electrons in the final state. The advantage is clearly that these leptons are easier to see in the detector than taus. There are no events with 3 electron final states in our sample, so that cutting on the electron number would be pointless. The blue box in Figure 4 marks the final states of three muons. The muons can come directly from chargino - neutralino decays or from a leptonically decaying τ. Figure 9 shows the number of muons for events that survive the standard cuts and contain only muons with $p_T < 100$ GeV. Cutting on three muons only the events in the fourth bin remain. In this case there are no electrons and taus in the final state as one can see by plotting the electron and tau number after applying the μ cut (Figure 10). We can compare the two cuts by looking at the last two bins of the cutflow plot in Figure 6. For the τ cut (second last bin) we have more signal events and less background events than for the μ cut (last bin). Even though the detection of taus is more challenging it is worth looking for taus to detect the chargino - neutralino events.

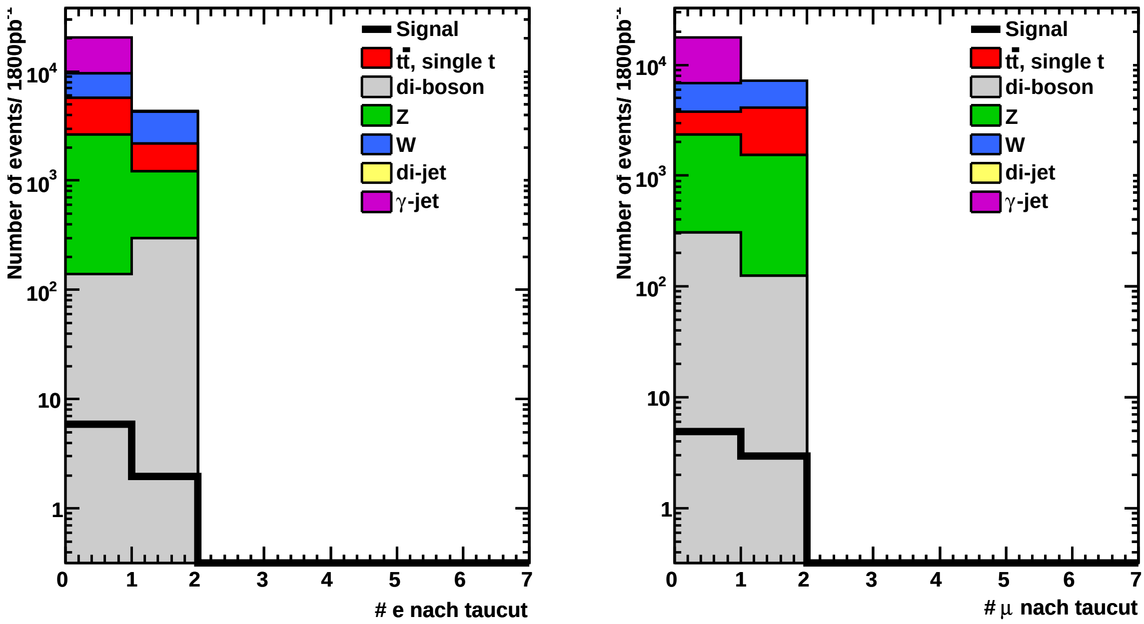

Figure 8: number of electrons and muons after the τ cut

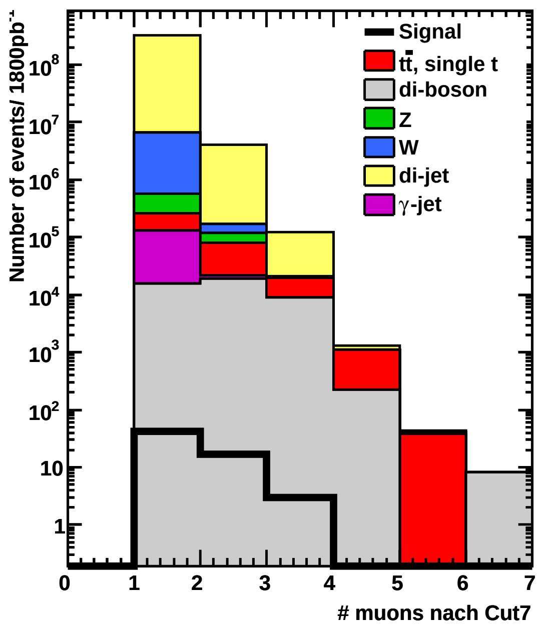

Figure 9: number of muons after standard cuts and cut on mu p_T.

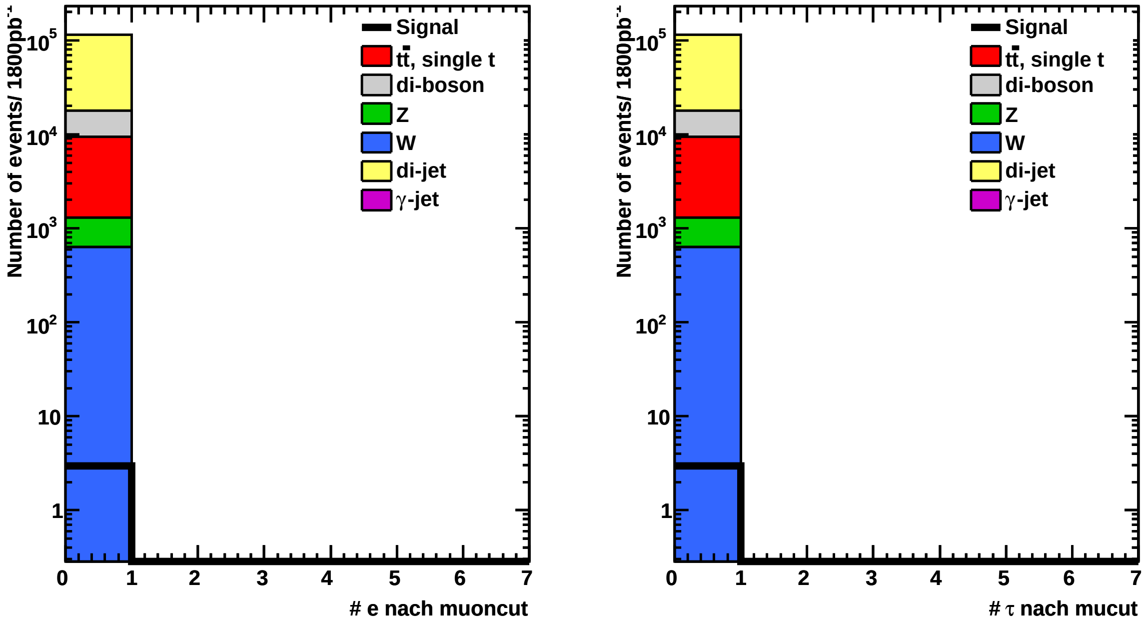

Figure 10: number of electrons and taus after the μ cut

5 Conclusions

In this report we studied chargino - neutralino production in mSUGRA. The chargino - neutralino pair decays into leptons (in favor taus) which gives an interesting channel for SUSY detection in the initial phase of the LHC. Different cuts were analyzed to suppress the high SM background. We saw that using only standard cut variables, it is not possible to remove a sufficient amount of background events. Also the search for three muons or electrons seems futile. Despite additional difficulties in the tau detection, we consider to look at taus in the final state. With the τ cut we suppressed a lot SM background. Though we have to assert that the background is still magnitudes larger than our signal and a detection of the chargino - neutralino signal will be difficult. But since this process gives new and promising detection prospects especially in the beginning phases of the LHC, further investigations should be done. With better statistics, other cuts (e.g. ΔR, Sum E_T, Invariant mass) could be tried to suppress the remaining SM background.

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