Searching for SUSY at the upgraded LHC

CERN Work Project Report
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Abstract

We investigate the pair production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ followed by a subsequent decay into the W and the Higgs SM bosons using events with 3 leptons and missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) coming from proton-proton collision data produced by the LHC at 14 TeV center-of-mass energy and collected by the ATLAS detector. A cut-and-count analysis is presented with the assumption of 3000fb^{-1} of data. The results are interpreted as discovery and exclusion reaches.

1 Searching for SUSY

Supersymmetry (SUSY) is one of the most promising theories for physics beyond the standard model (SM). The ATLAS detector at the LHC has a wide range of ongoing searches looking for SUSY. It has already searched for strongly produced sparticles (e.g. squarks, gluinos, stops, sbottoms) [1] [2] and for weakly produced sparticles (e.g. charginos, neutralinos, sleptons). The most up-to-date results of the ATLAS searches for SUSY can be found at [3]. So far, no excess of events has been found. The LHC has ran up to 8 TeV center-of-mass energy over the past few years, and has collected more than 20 fb^{-1} of data. There is a planned upgrade in 2020 that will bring the center-of-mass energy up to 14 TeV and will allow researchers to collect over 3000 fb^{-1} of data.

2 Signal

The focus of this study is centered around searching for weakly produced SUSY. More specifically, we will investigate the pair production of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$. The particular channel presented in this document is the pair production of a $\tilde{\chi}_1^{\pm}$ and a $\tilde{\chi}_2^0$, with the $\tilde{\chi}_1^{\pm}$ decaying into a W boson and a $\tilde{\chi}_1^0$, and the $\tilde{\chi}_2^0$ decaying into a Higgs boson and a $\tilde{\chi}_1^0$ (see figure 1). The long sought after Higgs boson has a variety of decay modes (i.e. different ways to decay). The probability of these decays occuring (i.e. the branching ratios of the processes) is dependent on the mass of the Higgs boson. In this study, our leptons are electrons and muons, not taus. Figure 2 shows the different branching ratios for the SM Higgs boson. We know that the mass of the Higgs is around 125 GeV [4]. Hence, we see that the main decay mode for the Higgs is by far $b\bar{b}$ (note the log scale on figure 2). However, the Higgs also decays into WW and ZZ with non-negligible branching ratios. Combining this with the fact that leptons are extremely "clean" compared to quarks (i.e. can be well identified and reconstructed in the ATLAS detector), we realize that it is important to search for these processes, despite the minuscule branching ratio of the Higgs decaying into WW (21.5%) or into ZZ (2.64%) [5]. Finally, in the final state, we are left with 3 stable leptons, and missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$).

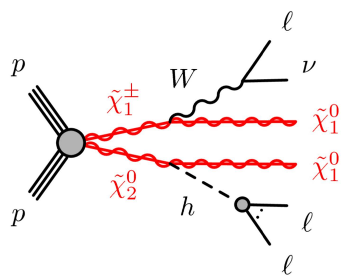


Figure 1: Feynmann diagram of a proton-proton collision at the LHC pair producing a $\tilde{\chi}_1^{\pm}$ and a $\tilde{\chi}_2^0$, which then decay into $W\tilde{\chi}_1^0$ and $h\tilde{\chi}_1^0$, respectively.

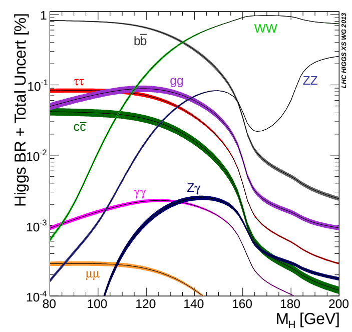


Figure 2: Standard Model Higgs boson decay branching ratios.

3 Backgrounds

There are many SM backgrounds to this signal (i.e. other SM processes with the same signature of 3 leptons and $E_{\mathrm{T}}^{\mathrm{miss}}$). The main SM backgrounds are WZ and WH diboson production, triboson production, and $t\bar{t}$ and $t\bar{t}W$ production. The cross sections of the SM backgrounds vary greatly. Looking at these various cross sections, we see that the dominant background is by far the $t\bar{t}$.

4 Event selection

Preselection Considering each and every object in an event would require way too much CPU time. To concentrate our efforts only on interesting particles, a preselection is firstly applied. We only consider electrons with $p_{\mathrm{T}} > 5$ GeV, muons with $p_{\mathrm{T}} > 5$ GeV, and jets with $p_{\mathrm{T}} > 10$ GeV.

Smearing After preselection, we use the `TruthToRecoFunctions` RootCore packages to smear the lepton p_{T} and the $E_{\mathrm{T}}^{\mathrm{miss}}$. This is done to emulate as accurately as possible the detector resolution, since we only have truth based event generations, and not reconstructed objects.

Object definition The next step is to select leptons and jets that meet certain requirements. Our signal mainly contains electrons and muons with $p_{\mathrm{T}} > 10$ GeV, so there is no need to keep events with lower p_{T} leptons. Note that we do not consider taus in this study. We define our objects such that electrons have $p_{\mathrm{T}} > 10$ GeV and $|\eta| < 2.47$, muons have $p_{\mathrm{T}} > 10$ GeV and $|\eta| < 2.50$, and jets: $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 2.50$.

Trigger We define a set of "easy to check" criteria that allow us to reject most LHC collisions prior to storage on tape. For this study, these criteria are one of the following: an electron with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.47$, or a muon with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.40$.

5 Signal regions

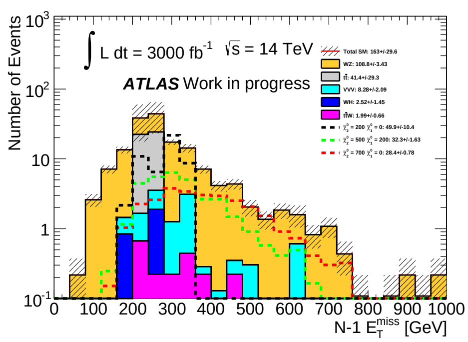
In this study we define two signal regions. The first signal region optimization has a same flavour opposite sign (SFOS) lepton pair veto. This signal region focuses mainly on the selection criteria optimization for low $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ mass points. The second signal region optimization does not have the SFOS veto applied, and focuses on optimizing the selection criteria for higher $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ mass points.

5.1 Common selection criteria

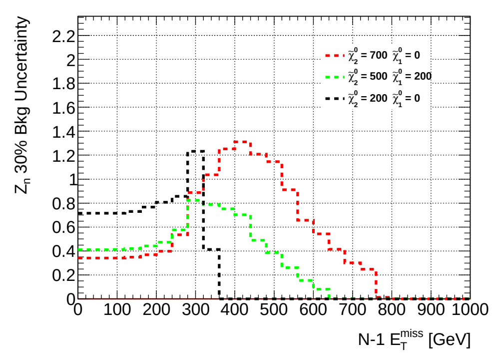
The signal region optimizations have a set of basic selection criteria that are common to both of them. These selection criteria are listed below. We start by selecting events with 3 leptons in the final state. This is the decay signature we are looking for. Then, we apply a b-jet veto. The 3 leptons in our signal should be coming from W or Z bosons. Assuming these bosons decay fully leptonically, there should not be any b-quarks in the signals' signature. So if there is a b-jet in the event, this event is most likely a background event. Next, we require that $\Delta\phi_{min} < 1.0$. Two out of the 3 leptons of our signal are expected to come from the decay of a Higgs boson. If this is the case, these two leptons should be well collimated in the ATLAS detector, and hence have a small $\Delta\phi$. The two leptons should be well collimated mainly because the Higgs has spin-0. Since both linear and angular momentum are conserved, when the Higgs decays into two W bosons, the W bosons have opposite momenta and opposite spin, hence the same helicity. In both cases (i.e. either both W bosons are right-handed, or both bosons are left-handed), the leptons coming from the two W bosons will be going in the same direction. Finally, in this study, we assume that at the time of the HL-LHC, a lepton isolation algorithm with efficiency comparable to the one currently used in the 8 TeV analysis will be available. So, to account for lepton isolation, we multiply the weight of the $t\bar{t}$ sample by a factor of 0.2, which is the efficiency of the isolation requirement as measured in the 8 TeV data.

5.2 Optimization

The optimization for the signal region selection criteria was done in two ways. First of all, we sequentially go through all the selection criteria, one by one, and before each selection criteria, look if the next selection criteria is optimal. Secondly, we use what are called the "N-1" plots. These are plots of a certain variable in which all selection criteria are applied except the selection criteria on the variable being plotted. This is done to make sure that all selection criteria are at their optimal value and helps take into account correlations between the selection criteria themselves. Figure 3 show an example of an N-1 plot.



(a) N-1 plot of the $E_{\mathrm{T}}^{\mathrm{miss}}$ for the large electro-weakino mass signal region optimization.



(b) Significance for the N-1 plot of the $E_{\mathrm{T}}^{\mathrm{miss}}$ for the large electro-weakino mass signal region optimization.

Figure 3: Example of an N-1 plot for the large electro-weakino mass signal region optimization.

5.3 Significance (Z_n)

The way to go about searching for SUSY is by trying to detect an excess of events passing certain requirements (i.e. selection criteria) when comparing data to background predictions. If no excess is found, as is currently the case, then one can set limits on the mass of the SUSY particles. The significance Z_n is a value calculated for each combination of the $\tilde{\chi}_1^{\pm} = \tilde{\chi}_2^0, \tilde{\chi}_1^0$ masses. It is roughly equal to the number of signal events divided by the square root of the number of background events left after all of our selection criteria have been applied. However, we use a more complex calculation which takes into account effects such as systematic uncertainties, etc., to which we specify a systematic uncertainty of 30%. If the Z_n value is greater than 1.645, we can exclude the existence of the $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ at the HL-LHC, assuming we collect the 3000 fb^{-1} of data; the given mass scenario is excluded at 95% CL. If the Z_n value is greater than 3, we expect evidence for the given mass scenario. Finally, if the Z_n value is greater than 5, we expect discovery for the given mass scenario.

5.4 Signal region optimization for low mass electro-weakinos

For the time being, we focus on the $h \to WW$ decay process (and not $h \to ZZ$). This is because we require exactly 3 leptons in our final state, and considering the $h \to ZZ$ would give us more than 3 leptons in the final state. So, for this signal region, we firstly apply a SFOS veto to suppress the WZ background; if an event has a pair of leptons with the same flavour and opposite sign, the pair most likely came from the decay of the Z boson. Then, we require that $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV. Finally, we apply selection criteria on the transverse mass m_{T} calculated with each of the 3 signal lepton such that $m_{\mathrm{T}}^1 > 150$ GeV, $m_{\mathrm{T}}^2 > 150$ GeV, and $m_{\mathrm{T}}^3 > 200$ GeV.

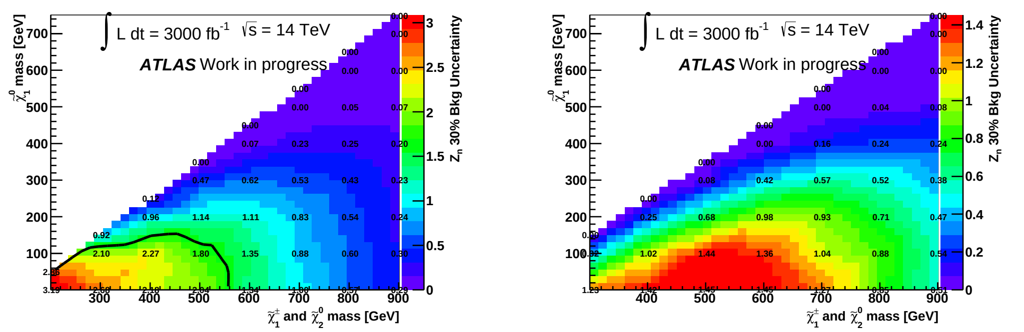
5.5 Signal region optimization for large mass electro-weakinos

For this signal region, we firstly veto events having a pair of leptons with a mass within 10 GeV of the Z boson mass. Possible lepton pairs are two electrons (regardless or their charge), or two muons with opposite charge. Then, we veto events having a pair of leptons with a mass smaller than 15 GeV. Possible lepton pairs are two electrons (regardless or their charge), or two muons with opposite charge. Next, we require that $E_{\mathrm{T}}^{\mathrm{miss}} > 380$ GeV. Finally, we apply selection criteria on the transverse mass m_{T} calculated with each of the 3 signal lepton such that

$m_{\mathrm{T}}^{1} > 300$ GeV, $m_{\mathrm{T}}^{2} > 200$ GeV, and $m_{\mathrm{T}}^{3} > 150$ GeV.

6 Conclusion

Figure 4 shows the sensitivity obtained for both signal region optimizations. The x-axis is the input mass of the $\tilde{\chi}_1^{\pm}$, which is equal to the mass of the $\tilde{\chi}_2^0$. The y-axis is the mass of the $\tilde{\chi}_1^0$. The z-axis is the sensitivity. The black line in the plot is the "exclusion" line. We see that the low electro-weakino mass optimization is sensitive to a smaller portion of the grid, but get much higher Z_n values for the points which it is sensitive to (able to exclude up to about 550 GeV). On the other hand, the large electro-weakino mass optimization has lower Z_n values in general, but covers much more of the 2D grid.



(a) Sensitivity obtained in the low electro-weakino mass signal region optimization.

(b) Sensitivity obtained in the large electro-weakino mass signal region optimization.

Figure 4: Sensitivity for both signal regions with exclusion limits being represented by the black line.

In summary, we investigated the pair production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ with a final state of 3 leptons and missing transverse momentum $E_{\mathrm{T}}^{\mathrm{miss}}$ at the LHC with the assumption of 3000 fb^{-1} of accumulated data and 14 TeV center-of-mass energy. We achieved 3 sigma for the 200 GeV $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ mass point and excluded masses below 550 GeV if the $\tilde{\chi}_1^0$ is massless. This study will be finalized once tha latest high statistics MC samples are available.

List of Figures

References

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