Search for Supersymmetry in Trilepton Final States with the DØ Detector.

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Abstract. Data taken by the DØ experiment at the proton-antiproton collider at Tevatron has been analyzed to search for signatures consistent with decay of Charginos and Neutralinos. The search is performed in final states with three leptons and missing transverse energy. No excess above the Standard Model expectation is observed and limits on the production cross section times Branching fraction are set.

PACS. 13.85.Rm Limits on production of particles – 14.80.Ly Supersymmetric partners of known particles

1 Introduction

The proton-antiproton collider Tevatron delivers at present the world's highest center of mass energies with $\sqrt{s}$ = 1.96 TeV. The DØ experiment, one of the two experiments at the Tevatron, has collected data corresponding to an integrated luminosity of close to 3.0 fb^{-1} in RunIIa and RunIIb. Here one analysis based on the RunIIb dataset and four analyses based on the RunIIa dataset will be described. The search for Supersymmetry (SUSY) is one of the main goals at DØ . The Charginos ($\tilde{\chi}^{\pm}$) and Neutralinos ($\tilde{\chi}^{0}$), the superpartners of the Standard Model (SM) gauge and Higgs bosons, are of particular interest because the decay mode into three charged leptons and missing transverse energy provides a clean signature with small SM background expectations.

2 Supersymmetric model and decay

Supersymmetry postulates a symmetry between bosons (integer spin) and fermions (half integer spin). For every particle in nature there is a supersymmetric partner that differs in spin with $\frac{1}{2}$. No evidence has so far been found for the existence of SUSY particles and limits have been set by previous experiments [1]. The analyses presented here describe a search for the SUSY partners of the charged and neutral electroweak gauge and Higgs bosons. The search is performed in final states with two identified leptons (e or μ), a third track and large missing transverse energy. The analysis is based on the Minimal Supersymmetric extension of the Standard Model (MSSM) with R-parity conservation [2]. R is given by $(-1)^{3(B-L)-2s}$. R parity conservation leads to a stable Lightest Supersymmetric Particle (LSP), in this case the lightest Neutralino. More specifically, the results are interpreted using minimal supergravity (mSUGRA) models. mSUGRA models are characterized by five parameters: m_0, the common fermion mass at GUT scale, $m_{1/2}$, the common scalar mass at GUT scale, A_0, the trilinear coupling, tanβ, the ratio of vacuum expectation values of the two Higgs fields and sign(μ), the Higgs(ino) mass parameter. At the Tevatron, the dominant channel for producing Charginos and Neutralinos is the s-channel via an off-shell W boson [3]. The t-channel production takes place via squark exchange and this diagram interferes destructively with the s-channel. The t-channel is suppressed at higher squark masses. See Fig. 1 for an example of production and decay of Charginos and Neutralinos. The branching fraction of Charginos and Neutralinos into leptons depends on the slepton mass. At high slepton mass W/Z exchange is dominant which leads to small branching fraction into leptons (large m_0 scenario). The leptonic branching fraction for 3-body decays is at maximum when $m_{\tilde{\ell}}$ is just above $m_{\tilde{\chi}_2^0}$ (3l-max scenario). The result is interpreted in a scenario without slepton mixing and the masses of the right handed sleptons are assumed degenerated.

Table 1. SUSY parameters for three reference signal points ordered by decreasing masses. All points have tanβ = 3, $A_0 = 0$, $\mu > 0$. All masses are in GeV.

Point	$m_{\tilde{\chi}^{\pm}}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$\sigma \times$ BR(3ℓ)
High mass	150	152	82	0.0366
Medium Mass	125	127	69	0.123
Low mass	115	118	63	0.1984

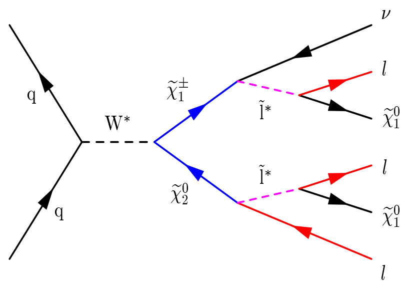

Fig. 1. An example of production and decay modes for the signal points considered in the analyses.

3 Search strategy

3.1 General

The trilepton final states are characterized by three charged leptons and missing transverse energy, ($\not\!\!E_{\rm T}$), due to the presence of neutrinos and neutralinos in the final state. One of the leptons in the final state has in general very low p_T. To increase the efficiency of the selection, only two fully identified leptons (e or μ) are required while a high quality, isolated track is required instead of the third lepton. This approach keeps the efficiency high and is sensitive to tracks from electrons, muons and taus.
In some parts of the parameter space, however, this strategy breaks down. When $m_{\tilde{\ell}}$ is just below $m_{\tilde{\chi}_2^0}$, the third lepton is extremely soft and the trilepton analyses lose their sensitivity. Instead of requiring two charged leptons and an isolated track, a pair of like-sign leptons of the same flavour (muons) is required. This is enough to suppress the SM background to an acceptable level. Signal parameter combinations have been generated with tanβ=3 and Chargino masses in the range of 115-150 GeV using the Les Houches Accords (LHA) [4]. See Table 1. The main background components are vector boson pair production, (WW, WZ, ZZ) and Z/γ^* and W production. In the case of the Like Sign muon analysis, QCD multijet production is the most important background. All background processes are generated with PYTHIA [5], except QCD multijet background which is taken directly from data by inverting lepton identification variables. The main focus in the following will be on the final state with two identified electrons and a third track. This analysis was newly updated with RunIIb data. Three other RunIIa analyses with final states with two muons and a third track, one electron, one muon and a third track and finally the Like Sign muon analysis are also discussed in some detail. In the following the following notation will be used to label the different analyses: $ee+\ell$ for the final state with two electrons and a third track, $e\mu+\ell$ for the final state with one electron, one muon and a third track and $\mu\mu+\ell$ for the final state with two muons and a third track.

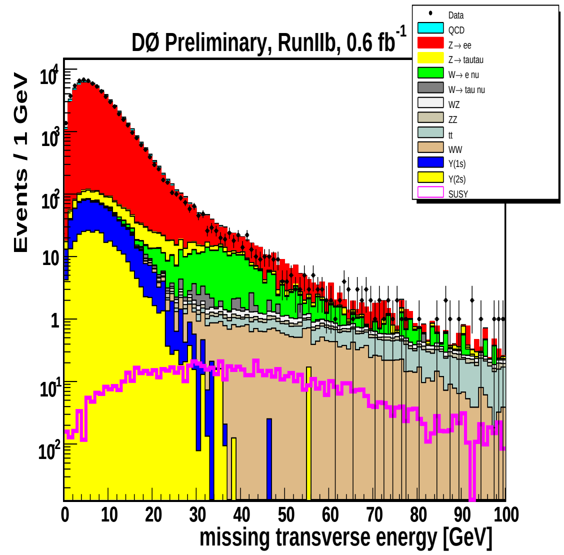

Fig. 2. Distribution of the missing transverse energy, $\not\!\!E_{\rm T}$, at preselection level in the $ee+\ell$ analysis based on RunIIb data.

3.2 $ee+\ell$ selection

The selection requires two electrons with $p_T > 8, 12$ GeV. The electrons have to be isolated and to match a reconstructed track in η and ϕ. Both electrons must stem from the primary vertex and events with both electrons in detector regions with poor resolution are rejected. To supress the large contribution from $Z \to ee$ events, several cuts are made. The invariant mass of the two electrons is required to be less than 60 GeV and above 18 GeV. Furthermore, the opening angle in the transverse plane has to be below 2.9 rad, $\Delta\phi < 2.9$. Events with large jet activity are rejected to reduce the contribution from $t\bar{t}$. Z/γ^* and QCD events have small values of $\not\!\!E_{\rm T}$ and an important cut to reject these backgrounds is to require $\not\!\!E_{\rm T}$ to be greater than 22 GeV. See Fig. 2 for the $\not\!\!E_{\rm T}$ distribution at preselection level. Mismeasurements of the lepton energies lead to small values of the quantity transverse mass. Transverse mass is defined as $m_T = \sqrt{p_T \not\!\!E_{\rm T}(1-\Delta\phi(e,\not\!\!E_{\rm T}))}$ and is required to be greater than 20 GeV for both electrons. Larger values of $\not\!\!E_{\rm T}$ can also be produced due to fluctuations of the jet energy depoistions. To address this fact, the quantity Sig($\not\!\!E_{\rm T}$) is required to be in excess of 8. Sig($\not\!\!E_{\rm T}$) is defined by dividing the $\not\!\!E_{\rm T}$ by the jet resolution projected onto the direction of the $\not\!\!E_{\rm T}$ $\sigma_{E_T^j \| \not\!\!E_{\rm T}}$. See Fig. 3 and Fig. 4 for the distributions of m_T and Sig($\not\!\!E_{\rm T}$) at preselection level.
The third track is required to come from the same vertex as the two electrons but also to be well separated from them ($\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ >0.4). The tracks are also required to have a p_T greater than 4. Isolation both in calorimeter and tracker is required. See Fig. 5 for the p_T distribution of the leading isolated track in events where an isolated track is found. The final cut in the selection is to require the product of track p_T

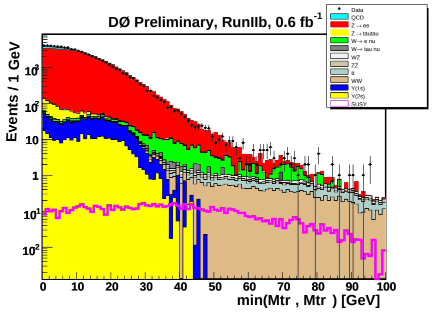

Fig. 3. The distribution of the minimum transverse mass at preselection level.

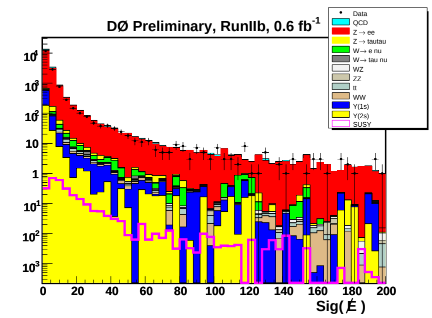

Fig. 4. The distribution of the scaled missing transverse energy, Sig($\not\!\!E_{\rm T}$), at preselection level.

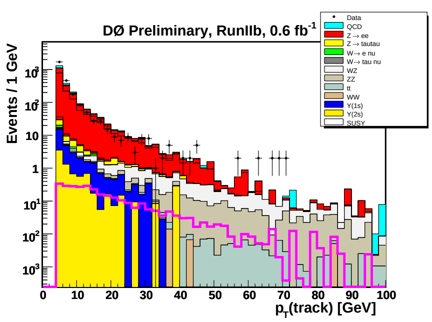

Fig. 5. The isolated track transverse momentum, $p_T^{\ell 3}$, at preselection level.

and $\not\!\!E_{\rm T}$ to be greater than 220 GeV^2. See Table 2 for expected number of signal and background events as well as observed events.

3.3 Likesign $\mu\mu$ selection

The preselection in the like sign di-muon channel requires two muons of the same charge with transverse momenta $p_T > 5$ GeV which are not back to back ($\Delta\phi$ <2.9). Three muons events with opposite sign pairs of invariant mass above 65 GeV are discarded. As in the other analyses a set of cuts related to $\not\!\!E_{\rm T}$ are applied. The missing transverse energy must be in excess of 10 GeV while the transverse mass is required to be in the range between 15 GeV and 65 GeV. The significance of $\not\!\!E_{\rm T}$ must be greater than 12. See Table 2 for signal and background expectation as well as events observed in data. A more detailed description can be found in [6].

3.4 $e\mu + \ell$ and $\mu\mu + \ell$ selection

A detailed description of the $e\mu+\ell$ and $\mu\mu+\ell$ analyses can be found in [7]. In the following a brief summary of the two selections will be given. For both analyses, the requirement of a third, isolated track is the same as in the $ee+\ell$ discussed above. In the $e\mu+\ell$ analysis the events selected have at least one electron with $p_T > 12$ GeV and one muon with $p_T > 8$ GeV and the invariant mass of the electron and the muon must be greater than 15 GeV and smaller than 100 GeV. Both the electron and the muon must stem from the primary vertex. To remove potential WZ background, events with either two muons or two electrons are removed if the their invariant mass is larger than 70 GeV. The $\not\!\!E_{\rm T}$ is required to be in excess of 10 GeV and Sig($\not\!\!E_{\rm T}$) must be above 8 GeV. The transverse mass with $\not\!\!E_{\rm T}$ must be above 20 GeV and below 90 GeV for both the electron and the muon. The transverse mass of the third track and $\not\!\!E_{\rm T}$ must be greater than 8 GeV and the invariant mass between either the electron or muon and the third track must be below 70 GeV. The $\mu\mu+\ell$ selection requires two isolated muons stemming from the primary vertex with $p_T > 12$ and 8 GeV. The invariant mass is required to be at least 24 GeV and not greater than 60 GeV and the angle between the two muons in the transverse plane, $\Delta\phi$, has to be below 2.9 radians. Again several cuts related to $\not\!\!E_{\rm T}$ are applied: $\not\!\!E_{\rm T} > 20$ GeV, Sig($\not\!\!E_{\rm T}$) > 8 and the transverse mass is required to be above 20 for both muons and $\not\!\!E_{\rm T}$. For the track, the transverse mass with $\not\!\!E_{\rm T}$ must be above 8 GeV and events where the invariant mass between the leading muon and $\not\!\!E_{\rm T}$ is above 80 GeV are rejected. A summary of expected number of signal and background events as well as observed events can be found in Table 2.

4 Results

The numbers of observed candidate events as well as the expectation for signal and background are shown in Table 2. No evidence for the production of Charginos and Neutralinos is observed and therefore an upper limit on the product of cross section and leptonic branching fraction, $\sigma\times\mathrm{BR}(3\ell)$, is set. To avoid double counting between the analyses, events found by more than one analysis are assigned to the analysis with best signal to background ratio and removed from all others. Systematic uncertainties are small compared to statistical uncertainties due to limited MC statistics. The expected and observed limit range between 0.75 and 0.11 pb. Assuming the 3ℓ-max scenario, see Section 2, the cross section limit can be translated into

Table 2. Number of events expected and observed in data and signal predictions for the different final states. The integrated luminosity is also given.

Final state	$\mathcal{L}_{int}$ [fb^{-1}]	Background	Data	Signal
$ee+\ell$	0.6	1.0 ± 0.3	0	0.5-2.1
$ee+\ell$	1.1	0.76 ± 0.67	0	1.0-5.3
$\mu\mu+\ell$	1.0	$0.32\pm^{0.78}_{0.08}$	2	1.5-1.8
$e\mu+\ell$	1.1	$0.94\pm^{0.40}_{0.18}$	0	2.0-2.6
$\mu^{\pm}\mu^{\pm}$	0.9	1.1 ± 0.4	1	0.5-2.0

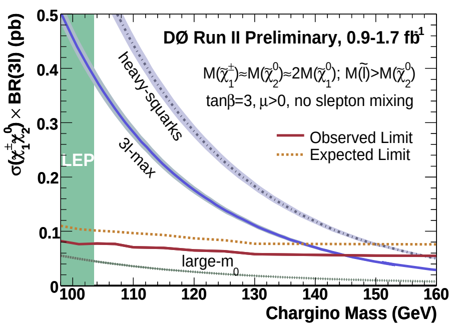

Fig. 6. Limit on $\sigma \times \mathrm{BR}(3\ell)$ as a function of $\tilde{\chi}^{\pm}_1$ mass, in comparison with the expectation for several SUSY scenarios. The red line corresponds to the observed limit. PDF and renormalization/factorization scale uncertainties are shown as shaded bands.

a mass limit of 140 GeV. See Fig. 6 for the limit of $\sigma \times \mathrm{BR}(3\ell)$as a function of the Chargino mass. If sleptons are light so that two body decay of Charginos and Neutralinos can take place and the mass difference between the sleptons and next to lightest neutralino is small, the Like Sign muon analysis remains the only sensitive because of the low p_T of the third lepton. This leads to higher limits in this region of parameter space. See Fig. 7 for the limit of $\sigma \times \mathrm{BR}(3\ell)$as a function of the mass difference between sleptons and next to lightest neutralino.

5 Conclusion and Outlook

A search for Charginos and Neutralinos has been performed in final states with three charged leptons and missing transverse energy. No evidence for SUSY has been found and limits on $\sigma \times \mathrm{BR}(3\ell)$ have been set. With prospects of up to 8 fb^{-1} of integrated luminosity the limits will continue to improve. More difficult regions of phasespace will also be probed. For high Chargino masses, the decay of Charginos and Neutralinos can go via an on shell Z boson, making the search more challenging since the current mass cuts have to

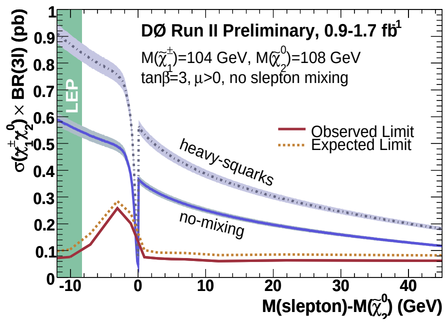

Fig. 7. Limit on $\sigma \times \mathrm{BR}(3\ell)$ as a function of the mass difference between sleptons and $\tilde{\chi}^0_2$, in comparison with the expectation for the MSSM (no mixing) and the heavy-squarks scenario (see text). PDF and renormalization/factorization scale uncertainties are shown as shaded bands.

be changed and the background from Z bosons will increase significantly.

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