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Searches for Squark and Gluino Production at the Tevatron

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Abstract. This paper reviews some of the most recent results from CDF and DØ experiments on searches for supersymmetry (SUSY) at the Tevatron. We focus on searches for squark and gluino pair production on data samples up to ~ 2 fb^{-1}. No signal was observed, and constraints are set on the SUSY parameter space.

Keywords: supersymmetry, squark, gluino, missing transverse energy
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INTRODUCTION

Supersymmetry is an extension to the standard model (SM) of particle physics that overcomes some of the theoretical problems in the SM by introducing a new symmetry between fermions and bosons. The symmetry in SUSY is believed to be broken, and several models (mSUGRA, GMSB, AMSB,...) have been developed to describe the breaking mechanism. Some SUSY models assume the conservation of the $R-$parity [1] quantum number. In this case SUSY particles must be produced in pairs, and the lightest SUSY particle (LSP) is stable. Cosmological constraints require the LSP to be neutral and colorless [1]. Thus, the LSP interacts only weakly and escapes detection leading to the experimental signature of missing transverse energy ($\not\!\!E_T$). In this paper we report on recent squark and gluino search results from CDF and DØ based on $\sim 1-2$ fb^{-1} of $p\bar{p}$ collision data at $\sqrt{s} = 1.96$ TeV. In all these searches the $R-$parity is assumed to be conserved and the LSP is assumed to be the lightest neutralino ($\tilde{\chi}_1^0$). The limits presented in this paper are all obtained at 95% confidence level (C.L.) .

SEARCHES FOR SQUARKS AND GLUINOS IN MISSING TRANSVERSE ENERGY AND JETS

At the Tevatron, squark and gluino pairs ($\tilde{q}\bar{\tilde{q}}$, $\tilde{g}\tilde{g}$, $\tilde{q}\tilde{g}$, $\tilde{q}\tilde{q}'$) can be copiously produced. They will decay into SM particles and, possibly through cascades, into LSPs. Thus, the final state signature will consist of multiple jets and large missing transverse energy due to the escaping LSPs. The relative contributions from each pair production process depends on the correlation between the the squark and gluino masses. If gluinos are lighter (heavier) than squarks, gluino pair $\tilde{g}\tilde{g}$ (squark pair $\tilde{q}\bar{\tilde{q}}$, $\tilde{q}\tilde{q}'$) production will dominate. Squark-gluino ($\tilde{q}\tilde{g}$) production dominates when squark and gluino masses are comparable. A gluino can decay into two quarks and a LSP. A squark can decay into a quark and a LSP. Therefore, in gluino (squark) pair production the final state signature will consist of at least four (two) jets from the hadronization of the quarks and large $\not\!\!E_T$. The final state signature from the gluino-squark pair production will be three or more jets and large $\not\!\!E_T$.

The main sources of SM background are from the productions of $W(\to l\nu)+$jets, $Z(\to \nu\bar{\nu})+$jets, single top quark, $t\bar{t}$, and di-bosons. In these productions, the $\not\!\!E_T$ comes mostly from the neutrinos escaping detection. The QCD multi-jet production is also another source of SM background. In this case the $\not\!\!E_T$ is due to mismeasurement of the energy of one or more jets. The direction of the $\not\!\!E_T$ will point in the direction of the mismeasured jet.

CDF and DØ search for squark and gluino pair production in three separate final states ($\not\!\!E_T+2$jets, $\not\!\!E_T+3$jets, $\not\!\!E_T+4$jets) so that the searches are most optimal for each production channel. The searches are conducted in the context of the mSUGRA framework. The common SUSY parameter values employed by both CDF and DØ are $A_0 = 0$ and $\mu < 0$. CDF (DØ) has chosen to perform the search with $\tan\beta = 5$ ($\tan\beta = 3$) and assumes that the squark masses are degenerate up to four (five) favors. A_0 is the universal trilinear coupling constant, μ is the higgsino mass parameter, and $\tan\beta$ is the ratio of the vacuum expectation values of the two Higgs fields. The total integrated luminosity of the data sample used by each experiment is about 2 fb^{-1}. To select the signal events cuts are first applied to remove background from non-collision sources (e.g. cosmic muons, beam-halo). A minimal azimuthal distance between the $\not\!\!E_T$ and jets is required to suppress the QCD multi-jet background. Events with identified charged lepton (electron or muon) candidates are vetoed to reduce the contributions from

[1] $R-\text{parity} = (-1)^{3(B-L)+2s}$

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TABLE 1. The number of observed data events and expected SM background events in the search for squark and gluino pair production.

	CDF (2 fb^{-1})		DØ (2.1 fb^{-1})	
Ch.	Events Expected	Events Observed	Events Expected	Events Observed
2jets	16 ± 5	8	$11\pm1^{+3}_{-2}$	11
3jets	37 ± 12	38	$11\pm1^{+3}_{-2}$	9
4jets	48 ± 17	45	$18\pm1^{+6}_{-3}$	20

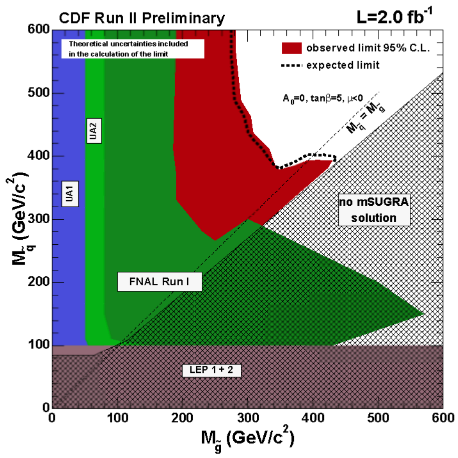

FIGURE 1. Region in the $m(\tilde{q})$ and $m(\tilde{g})$ plane excluded by CDF in the search for squark and gluino pair production.

electroweak and top quark productions. Cuts on the jets' transverse energy, $\not{E}_T$ and H_T (scalar sum of the jets' transverse energy) are applied to further reduce the SM background.

The number of observed data events and expected SM background events, after applying all selection cuts, are shown in Table 1. The results indicate no evidence of SUSY signal. Thus both experiments set limits in the mSUGRA framework as a function of squark and gluino masses. The region excluded by CDF in the $m(\tilde{q})$ and $m(\tilde{g})$ plane is shown in Figure 1. The results can also be interpreted as a function of the mSUGRA parameters at the GUT scale. Figure 2 [2] shows the region excluded by DØ in the $m_{1/2}$ and m_0 plane. m_0 is the universal scalar mass and $m_{1/2}$ is the universal gaugino mass.

SEARCHES FOR SQUARKS IN MISSING TRANSVERSE ENERGY, JETS AND TAU FINAL STATE

In SUSY there can be large mixing between the left and right handed super-partners of the third generation

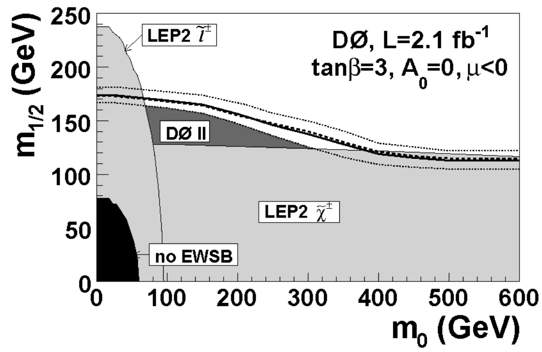

FIGURE 2. Region in the $m_{1/2}$ and m_0 plane excluded by DØ in the search for squark and gluino pair production.

fermions. In the case of stau ($\tilde{\tau}$), large mixing may occur at high $\tan\beta$ and thus the lighter stau ($\tilde{\tau}_1$) may be the lightest slepton. At the Tevatron $\tilde{\tau}_1$ can originate from the cascade decays of squarks that are pair produced. The stau then decays directly to a tau lepton and a neutralino ($\tilde{\tau}_1 \to \tau\tilde{\chi}^0_1$). The final state signature will consist of at least two jets, large $\not{E}_T$ and a tau lepton. DØ performs a search for squarks in this channel on a 0.96 fb^{-1} data sample, using selection cuts that are similar to the ones used in the searches for squark and gluino pair production. In this search it also requires that there is at least one hadronic tau candidate with $E_T > 15$ GeV in the final state. The hadronic tau candidate is identified as a narrow isolated jet with low track multiplicity. The cuts on $\not{E}_T$ and $JJTHT$ ($JJTHT$ is the scalar sum of the transverse energy of the first and second leading jets and the hadronic tau candidate) are optimized to further enhance the signal over the background. The dominating SM background contributions are the $W(\to l\nu)+$jets and $t\bar{t}$ productions. DØ observes two events in the data sample after applying all selection cuts and expects $1.7\pm0.2(\text{stat})^{+0.6}_{-0.3}(\text{syst})$ background events. These results are interpreted in a mSUGRA model ($\tan\beta = 15$, $A_0 = -2m_0$, $\mu < 0$) and obtains an exclusion region in the m_0 vs $m_{1/2}$ plane shown in Figure 3.

SIGNATURE BASED SEARCH IN MISSING TRANSVERSE ENERGY AND DI-JET SIGNATURE

The $\not{E}_T$ and jets final state signature is predicted in many new physics models. Therefore, CDF has performed a generic search for new physics in the $\not{E}_T$ and exclusive di-jet signature (events with three or more jets are vetoed), without optimizing the search to any specific model. The search is performed in two kinematic regions

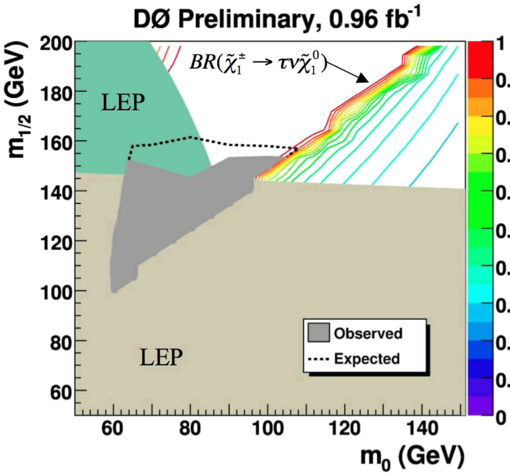

FIGURE 3. Region excluded by DØ in the search for squarks production in the final state with $\not{E}_T$, jets and tau lepton.

TABLE 2. Number of observed and predicted background events in the $\not{E}_T$+di-jet signature based search.

	Kinematic Regions	
	Low	High
Events Expected	2312 ± 140	196 ± 29
Events Observed	2506	186

in order to have good sensitivity over a wide range of new physics. For the low kinematic region search CDF requires that the $\not{E}_T$ is greater than 80 GeV and the scalar sum of the transverse energy of the first and second leading jets (H_T) is greater than 125 GeV. For the high kinematic region search, the selection cuts are $\not{E}_T > 100$ GeV and $H_T > 225$ GeV. The number of observed events and predicted background events are shown in Table 2 for the two kinematic regions. The two largest background contributions are from the productions of $Z(\to \nu\bar{\nu}) + \text{jets}$ and $W(\to l\nu) + \text{jets}$. The H_T distribution of the search in the low kinematic region is shown in Figure 4.

As there is no evidence of new physics beyond the SM, CDF interprets these null results in the minimum supersymmetric extension of the SM (MSSM). In this model CDF assumes that $\tilde{\chi}_1^0$ is the LSP and the first and second generation squarks ($\tilde{u}$,$\tilde{d}$,$\tilde{c}$,$\tilde{s}$) are degenerate in mass. The other SUSY parameter values that CDF has chosen are $\tan\beta = 3$, $A_T = -500$ and $\mu = -800$ (A_T is the trilinear coupling constant of the Top quark). Under these assumptions and with the chosen SUSY parameters, CDF selects four SUSY mass points, as shown in Table 3, to test its search sensitivity for this signature based search. The decision of choosing which kinematic region search cuts to be applied on each of the four SUSY mass points is based on which set of cuts gives the lowest a priori cross section upper limit. Thus, the low kinematic region search cuts are used on the SUSY mass point that has m($\tilde{q}$)=120 GeV/c^2, m($\tilde{g}$)=550 GeV/c^2 and m($\tilde{\chi}_1^0$)=89 GeV/c^2. The high kinematic region search cuts are applied to the other three SUSY mass points. The expected and observed 95% C.L. upper limit cross sections for all the four SUSY mass points are given in Table 4. By comparing the observed upper limit cross sections to the predicted leading order (LO) production cross sections, CDF excludes two (SUSY mass point 2 and 3) of the four SUSY mass points at 95% C.L. .

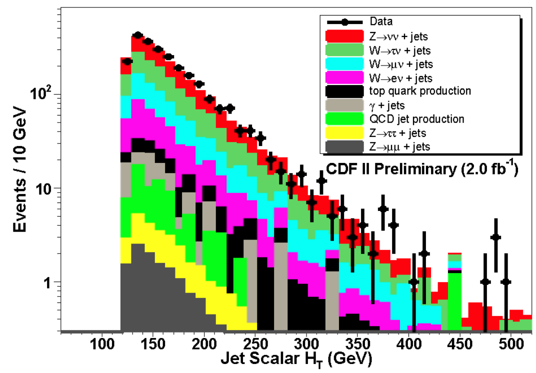

FIGURE 4. H_T distribution of the search in the low kinematic region.

TABLE 3. SUSY mass points to test search sensitivity.

SUSY	mass (GeV/c^2)		
mass points	$\tilde{q}$	$\tilde{g}$	$\tilde{\chi}_1^0$
1	320	390	60
2	250	450	72
3	220	520	85
4	120	550	89

TABLE 4. Expected and observed 95% C.L. upper limit cross sections of the signature based search conducted at four SUSY mass points and their corresponding predicted LO production cross sections.

SUSY	Limits (pb)		Pythia LO
mass points	Expected	Observed	cross section (pb)
1	0.52	0.46	0.36
2	0.88	0.77	1.73
3	1.82	1.60	3.21
4	75.9	122.3	57.4

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