Search for Gluino and Squark Cascade Decays at the Fermilab Tevatron Collider

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We report on a search for supersymmetry using dilepton events which complements the classic missing E_T plus multijet analyses. Using $19\,\mathrm{pb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$ recorded with the Collider Detector at Fermilab we have searched for squarks and gluinos decaying into charginos and producing events with two leptons. We observe one candidate event. In comparison, the expected number of background events from standard model processes is $2.39 \pm 0.63(\mathrm{stat})^{+0.77}_{-0.42}(\mathrm{syst})$. Hence we set limits on gluino and squark production based on predictions from the supergravity inspired minimal supersymmetric extension of the standard model.

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Supersymmetry (SUSY) is one of the most appealing theories as a next step towards grand unification. In the minimal supersymmetric extension of the standard model (MSSM) all known fermions of the standard model have bosons as supersymmetric partners, while all bosons acquire fermions as superpartners. Conservation of R parity, a multiplicative quantum number, requires these new particles to be produced in pairs and prevents decays of the lightest supersymmetric particle (LSP). From cosmological considerations [1], the lightest neutralino is normally assumed to be this LSP. Light gluinos decay preferentially into a quark-antiquark pair and an LSP. However, decays into charginos will dominate as soon as they are kinematically allowed [2]. Since the gluino is a Majorana particle, the charge of the chargino can be either $+1$ or -1. Subsequent chargino decays can yield leptons and, in the case of gluino pair production, a distinctive like-sign dilepton signature [3]. Although the search reported here was motivated by this like-sign dilepton signature, we will not apply a like-sign requirement but rather search for SUSY based on any dilepton events from gluino and squark pair production [4]. Lepton based SUSY searches will become more important at high luminosity hadron colliders. This analysis is the first of its kind. It not only demonstrates the feasibility of this approach but already reaches a sensitivity comparable to the classic missing E_T plus multijet searches [5,6].

In addition to this search, several other searches for supersymmetry with the Collider Detector at Fermilab (CDF) are underway: a search for charginos and neutralinos decaying into leptons and yielding a distinctive trilepton signature [7]; searches for the supersymmetric partner of the top quark (stop); and a search for squarks and gluinos in the classic missing E_T plus multijet channel [6]. Although all of those analyses aim to detect supersymmetry, each one addresses a different SUSY particle or signature, probing complementary regions in SUSY parameter space.

The CDF detector [8] is well suited to search for such new supersymmetric particles. The following components are relevant to this analysis: The central tracking chamber which is inside a 1.4 T superconducting solenoidal magnet measures the momentum of charged particles with a resolution of $\delta p_T/p_T = 0.002 p_T$ (p_T in GeV/c) [9]. The electromagnetic and hadronic calorimeters cover the pseudorapidity region $|\eta| < 4.2$ and are used to identify jets and electrons, and to measure the missing transverse energy ($\not{E}_T$), which can indicate the presence of undetected energetic LSPs or neutrinos. An outer layer of drift chambers provides muon identification in the region $|\eta| < 1.0$.

Events for this analysis are selected by requiring a central electron ($|\eta| \leq 1.1$) or central muon ($|\eta| \leq 0.6$) with transverse momentum $p_T \geq 12$ GeV/c. For the second lepton, a lower transverse momentum cut of $p_T \geq 10$ GeV/c and less stringent electron and muon identification criteria are used. Electron candidates in the region $|\eta| \leq 2.4$ and muon candidates in the region $|\eta| \leq 1.0$ are accepted as second leptons. Electron or muon pairs with opposite electric charge and an invariant mass between 75 and 105 GeV/c^2 are removed as possible Z bosons.

In addition to the lepton from the chargino, quarks originate from each gluino or squark cascade decay. We require one jet [10] in the central region ($|\eta| \leq 1.1$) and a second jet with $|\eta| \leq 2.4$, both of which carry at least 15 GeV of transverse energy. Jets and leptons are not allowed to overlap in η-ϕ space.

The LSPs as well as the neutrinos from the chargino decays escape the apparatus without detection. The missing E_T measured by the calorimeter is corrected if either of the two leptons is a muon. Events are then required to have $\not{E}_T \geq 25$ GeV.

In the 19 pb^{-1} of data collected with CDF during 1992–93, 2265 events fulfill the above dilepton requirements, 130 events fulfill the dilepton and dijet requirements, and 17 events fulfill the dilepton, dijet, and $\not{E}_T$ requirements.

A background calculation shows that the majority of the events originate from heavy flavor production, mainly $b\bar{b}$ and $c\bar{c}$, and misidentified leptons. Leptons from these processes are expected to be nonisolated, while leptons from chargino decays are expected to be isolated. We require $I_{\text{lepton 1}} + I_{\text{lepton 2}} \leq 8$ GeV, where I is a measure of the amount of energy surrounding each lepton, using a combination of tracking and calorimeter information [11].

In a significant fraction of the remaining background, the $\not{E}_T$ originates from jet mismeasurement. In these events, the jet and the $\not{E}_T$ are close in azimuthal angle. Events are rejected if the central jet and the $\not{E}_T$ are closer in $\Delta\phi$ than 90°.

Much of the remaining background is expected to come from Drell-Yan plus multijet production. The azimuthal angle between the two leptons ($\Delta\phi_{ll}$) and the transverse momentum of the dilepton system [p_T(dilepton)] allow good separation of background and signal. We reject events with $\Delta\phi_{ll} > 60°$ and $p_T(\text{dilepton}) > 40$ GeV/c and events with $\Delta\phi_{ll} > 120°$ and $p_T(\text{dilepton}) > 20$ GeV/c.

With these additional cuts the signal region is defined. Of the 17 events passing the dilepton, dijet, and $\not{E}_T$ cuts, only one passes all these additional cuts. This event has two unlike-sign muons with transverse momenta of 73 and 70 GeV/c.

The standard model background with two genuine leptons is calculated with the help of Monte Carlo programs. We have used ISAJET [12] with a CDF detector simulation. The cross sections for top production and Drell-Yan processes have been set to the CDF measured values [13,14]. Cross sections for diboson processes are taken from theoretical calculations [15]. The contribution from misidentified leptons is calculated from CDF single lepton data. We expect a total of $2.39 \pm 0.63(\text{stat})^{+0.77}_{-0.42}(\text{syst})$ background events in the signal region.

Possible signals from supersymmetry are generated with the ISAJET Monte Carlo generator [16] and passed through detector simulation programs, analogously to the background Monte Carlo generator. Because the supersymmetric parameter space is very large, we reduce the number of parameters by relating gaugino masses to gauge couplings as in supergravity grand unified theories [17]. As a result of this the gluino has to be lighter than the five degenerate squarks. We have generated and analyzed Monte Carlo samples with gluino masses between 60 and 350 GeV/c^2, squark masses between 90 and 500 GeV/c^2, ratios of the vacuum expectation value of the two Higgs doublets $\tan\beta$ between 2 and 8, and higgsino mass parameters μ between ± 1 TeV/c^2. We have used next-to-leading order gluino

TABLE I. Systematic uncertainties associated with the signal simulation.

Integrated luminosity	3.6%
Lepton identification	10.0%
Calorimeter energy scale	4.7%
Trigger simulation, Monte Carlo	2.5%
Total	11.9%

and squark production cross sections [19] calculated with MRS(A′) parton distribution functions.

For example, using $m_{\tilde{g}} = 160\,\mathrm{GeV}/c^2$, $m_{\tilde{q}} = 192\,\mathrm{GeV}/c^2$, $\tan\beta = 4$, and $\mu = -400\,\mathrm{GeV}/c^2$ we expect 15.5 events from gluino and squark production [20]. The statistical uncertainty in the signal simulation is better than 10%. Table I lists the systematic uncertainties in the signal simulation, totalling 11.9% when added in quadrature.

Using a Monte Carlo program to convolute the uncertainties of both signal and background expectations, we calculate the number of signal events that plus background would yield more than the one event observed at a 95% confidence level. Figure 1 shows the region in the gluino mass versus squark mass plane (with $\tan\beta = 4.0$ and $\mu = -400\,\mathrm{GeV}/c^2$) that would yield more than 4.6 events from gluino and squark production and is thus excluded at the 95% confidence level by this analysis. Also shown is CDF's previous limit [18], which has now been significantly extended. This result is comparable to limits reported by D0 [5] and to preliminary CDF results [6] using the missing E_T plus multijet channel with a similar amount of data. This analysis, however, is complementary to these analyses: While the missing E_T plus multijet analysis is degraded by cascade decays [21], the dilepton analysis is based upon them.

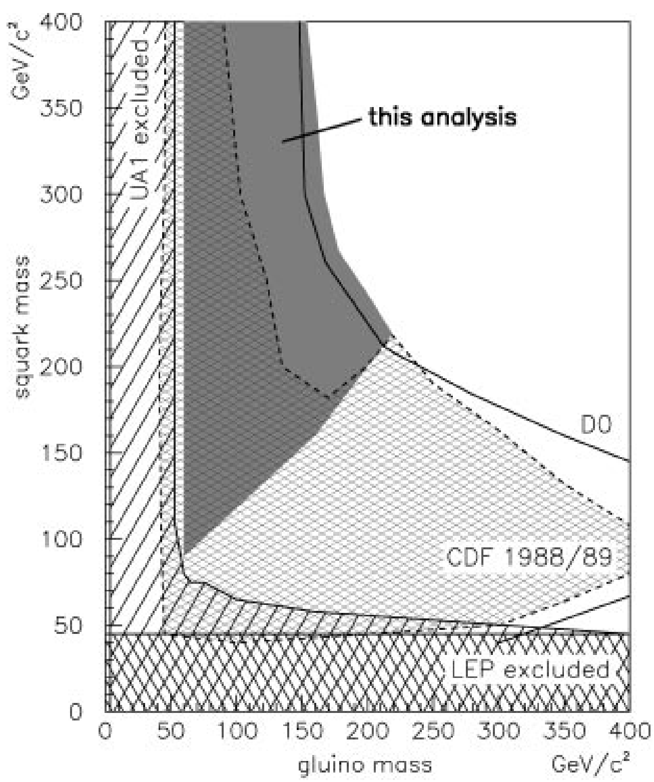

FIG. 1. Excluded region in the gluino–squark mass plane ($\tan\beta = 4.0$, $\mu = -400\,\mathrm{GeV}/c^2$). The SUGRA constraints used restrict the analysis to the region of $m_{\tilde{q}} > m_{\tilde{g}}$. Also shown are the UA1, LEP, D0, and previous CDF limits, some of which have slightly different parameters.

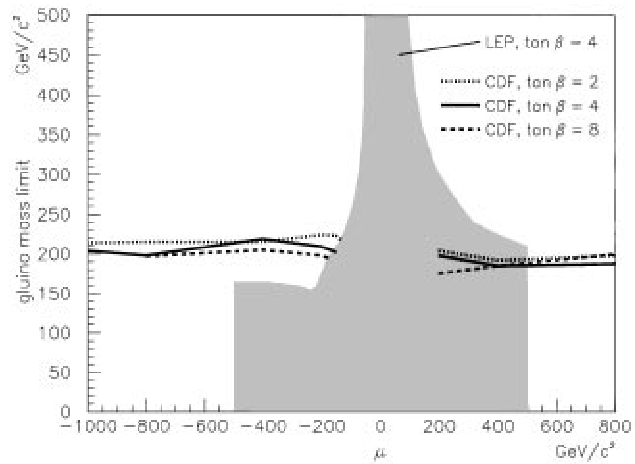

FIG. 2. The 95% confidence level mass limit ($m_{\tilde{q}} = m_{\tilde{g}}$) as a function of μ for $\tan\beta$ values of 2.0, 4.0, and 8.0 compared to the LEP limit [22]. The $m_{\tilde{\chi}^{\pm}} > 45\,\mathrm{GeV}/c^2$ limit of LEP corresponds to a gluino mass of 154 (176) GeV/c^2 for $\mu = -1000$ (800) GeV/c^2 and $\tan\beta = 4.0$.

Figure 2 shows the 95% confidence level mass limit as a function of μ for different $\tan\beta$ values. For squark mass equal to the gluino mass, we exclude gluinos up to $224\,\mathrm{GeV}/c^2$. For heavy squarks, $m_{\tilde{q}} = 400\,\mathrm{GeV}/c^2$, we exclude gluinos up to $154\,\mathrm{GeV}/c^2$ ($\tan\beta = 4.0$ and $\mu = -400\,\mathrm{GeV}/c^2$).

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