Search for Chargino and Neutralino Production in Gauge-Mediated Supersymmetry Breaking Models

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Abstract

We search for inclusive high E_T diphoton events with large missing transverse energy in $p\bar{p}$ collisions at $\sqrt{s}$=1.8 TeV. Such events are expected from pair production of charginos and neutralinos within the framework of the minimal supersymmetric standard model with a light gravitino. No excess of events is observed. In that model, and assuming gaugino mass unification at the GUT scale, we obtain a 95% CL exclusion region in the supersymmetry parameter space and lower mass bounds of 150 GeV/c^2 for the lightest chargino and 75 GeV/c^2 for the lightest neutralino.

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I. INTRODUCTION

Supersymmetric models with low energy gauge-mediated supersymmetry breaking, first proposed by Fayet [1], have generated recent theoretical interest [2,3]. These models are characterized by a supersymmetry breaking scale Λ as low as 100 TeV. Consequently the gravitino ($\tilde{G}$) is nearly massless and is naturally the lightest supersymmetric particle (LSP). In contrast to these light-gravitino models, the supersymmetry breaking scale of gravity-mediated models is $\Lambda \approx 10^9$ TeV, resulting in a massive gravitino which has no role in low energy supersymmetry. In light-gravitino models, the lightest superpartner of a standard model particle, assumed here and in most analyses to be the lightest neutralino ($\tilde{\chi}_1^0$), is the next-to-lightest supersymmetric particle (NLSP). If $\tilde{\chi}_1^0$ has a non-zero photino component, it is unstable and decays into a photon plus a gravitino ($\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$).

In this Letter, we present a direct search for supersymmetry with a light gravitino in the framework of the minimal supersymmetric standard model (MSSM). In this framework the gaugino-higgsino sector is described by four parameters: M_1, M_2, μ, and $\tan\beta$, where M_1 and M_2 are the $U(1)$ and $SU(2)$ gaugino mass parameters, μ is the higgsino mass parameter, and $\tan\beta$ is the ratio of the vacuum expectation values of the two higgs doublets [4]. With the assumption of gaugino mass unification at the GUT scale, $M_1 = \frac{5}{3} M_2 \tan^2\theta_W$. There are four neutralinos ($\tilde{\chi}_i^0$, $i = 1,2,3,4$) and two charginos ($\tilde{\chi}_j^{\pm}$, $j = 1,2$) whose masses and couplings are fixed by M_2, μ and $\tan\beta$. We assume $\tan\beta > 1$ in this analysis.

We search for neutralino and chargino pair production in $\sqrt{s}$=1.8 TeV $p\bar{p}$ collisions at the Fermilab Tevatron. The $\tilde{\chi}_1^0$ is assumed to be short-lived, decaying within the detector to $\gamma\tilde{G}$ with a branching ratio of 100%. R-parity conservation is assumed so that supersymmetric particles are pair produced and the LSP is stable and non–interacting. Thus pair production of charginos and neutralinos yields $\gamma\gamma\not\!\!E_T$ events with high transverse energy (E_T) photons and large missing transverse energy ($\not\!\!E_T$), with or without jets. The high E_T photons and large $\not\!\!E_T$ provide a powerful tool for suppressing backgrounds.

Recently DØ reported a search [5] for $\gamma\gamma\not\!\!E_T$ events based on supersymmetry models with $\tilde{\chi}_1^0$ as the LSP. In this analysis, we present the first experimental study of $p\bar{p} \rightarrow \gamma\gamma\not\!\!E_T + X$ based on the MSSM with a light gravitino as the LSP. Using this model and more efficient photon identification and event selection criteria than in Ref. [5], we set the strongest limits to date in the supersymmetry parameter space, exceeding those from LEP experiments.

II. THE ANALYSIS

The data used in this analysis were collected with the DØ detector during the 1992–1996 Tevatron run at $\sqrt{s}$=1.8 TeV and represent an integrated luminosity of 106.3 ± 5.6 pb^{-1}. A detailed description of the DØ detector can be found in Ref. [6]. The trigger requires one electromagnetic cluster with transverse energy $E_T > 15$ GeV, one jet with $E_T > 10$ GeV, and $\not\!\!E_T > 14$ GeV ($\not\!\!E_T > 10$ GeV for about 10% of the data). The jets in the trigger include non-leading electromagnetic clusters. Photons are identified through a two-step process: the selection of isolated electromagnetic energy clusters and the rejection of electrons. The electromagnetic clusters are selected from calorimeter energy clusters by requiring (i) at least 95% of the energy to be deposited in the electromagnetic section of the calorimeter,

(ii) the transverse and longitudinal shower profiles to be consistent with those expected for an electromagnetic shower, and (iii) the energy in an annular isolation cone from radius 0.2 to 0.4 around the cluster in $\eta - \phi$ space to be less than 10% of the cluster energy, where η and ϕ are the pseudorapidity and azimuthal angle. Electrons are removed by rejecting electromagnetic clusters which have either a reconstructed track or a large number of tracking chamber hits in a road between the calorimeter cluster and the event vertex. $\not\!\!E_T$ is determined from the energy deposition in the calorimeter for $|\eta| < 4.5$.

To be selected as $\gamma\gamma\not\!\!E_T$ candidates, events are required to have two identified photons, one with $E_T^{\gamma_1} > 20$ GeV and the other with $E_T^{\gamma_2} > 12$ GeV, each with pseudorapidity $|\eta^\gamma| < 1.2$ or $1.5 < |\eta^\gamma| < 2.0$. We require $\not\!\!E_T > 25$ GeV with at least one reconstructed vertex in the event to ensure good measurement of $\not\!\!E_T$. No requirement on jets is made. Two events satisfy all requirements. We denote the 28 events passing all photon requirements as the $\gamma\gamma$ sample.

The principal backgrounds are multijet, direct photon, $W + \gamma$, $W +$ jets, $Z \to ee$, and $Z \to \tau\tau \to ee$ events from Standard Model processes with misidentified photons and/or mismeasured $\not\!\!E_T$. The background due to $\not\!\!E_T$ mismeasurement is estimated using events with two electromagnetic-like clusters selected such that at least one of the two fails the electromagnetic cluster requirements. In addition, these events must pass the photon kinematic requirements. These events, called the QCD sample, are similar to those of the $\gamma\gamma$ sample and are expected to have similar $\not\!\!E_T$ resolution. By normalizing the number of events with $\not\!\!E_T < 20$ GeV in the QCD sample to that in the $\gamma\gamma$ sample, we obtain a background of 2.1 ± 0.9 events due to $\not\!\!E_T$ mismeasurement for $\not\!\!E_T > 25$ GeV.

Other backgrounds are due to events with genuine $\not\!\!E_T$ such as those from $W+$'γ' (where 'γ' can be a real or a fake photon), $Z \to \tau\tau \to ee$, and $t\bar{t} \to ee +$ jets production. These events would fake $\gamma\gamma\not\!\!E_T$ events if the electrons were misidentified as photons. We estimate their contribution using a sample of e'γ' events passing the kinematic requirements, including that on $\not\!\!E_T$. Electrons are selected from the identified electromagnetic clusters with matched tracks. Applying the electron rejection factor from the photon identification results in an estimated background of 0.2 ± 0.1 events. Adding the two background contributions together yields 2.3 ± 0.9 events. The $\not\!\!E_T$ distributions of the $\gamma\gamma$ sample and the background sample are compared in Fig. 1. Also shown are the expected distributions from supersymmetry for two representative points in the (μ, M_2) parameter space.

Chargino and neutralino pair production and decay are modeled using the SPYTHIA program [7], a supersymmetric extension of the PYTHIA 5.7 program [8]. Squarks and sleptons are assumed to be heavy so that the decays of charginos and neutralinos to the lightest neutralino (the NLSP) proceed through intermediate W and Z/γ exchanges, but our results are not sensitive to this assumption. To explore the parameter space, we choose to work in the (μ, M_2) plane while keeping $\tan\beta$ fixed. We generate $\tilde{\chi}_i^0\tilde{\chi}_j^0$, $\tilde{\chi}_i^0\tilde{\chi}_j^\pm$ and $\tilde{\chi}_i^\pm\tilde{\chi}_j^\pm$ events for a large number of points in the (μ, M_2) parameter space. Table I shows the resulting theoretical cross sections σ_{th} for several representative points, calculated using the CTEQ3L parton distribution function [9]. To determine the signal efficiencies, Monte Carlo events are run through a GEANT [10] based DØ detector simulation program, a trigger simulator, and the same trigger requirements, reconstruction, and analysis as the data. The total signal efficiency ϵ (including efficiencies of the trigger, reconstruction, photon identification, and kinematic requirements) varies greatly, from $\sim 0.01\%$ to $\sim 26\%$, depending largely on the

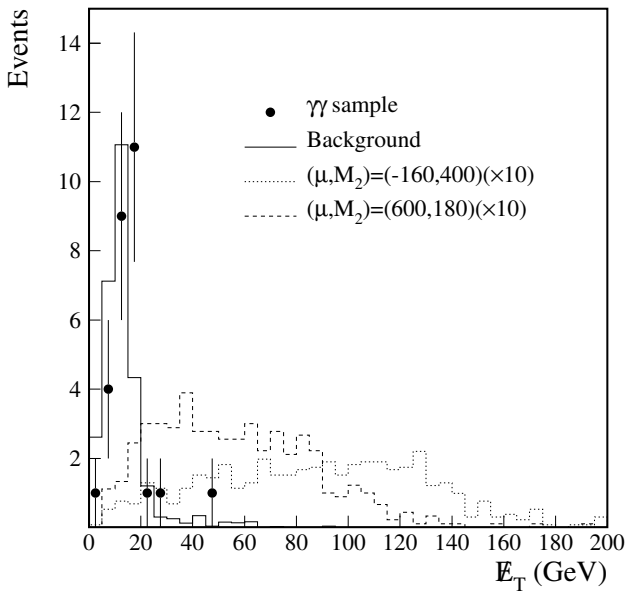

FIG. 1. The $\not\!\!E_T$ distributions of the $\gamma\gamma$ and background samples. The number of events with $\not\!\!E_T <$ 20 GeV in the background sample is normalized to that in the $\gamma\gamma$ sample. Also shown are the expected distributions (multiplied by 10) from two representative points in the supersymmetry parameter space, with $\tan\beta = 2$.

masses of $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ and their mass difference. For large masses such as those in Table I, the total efficiency $\epsilon > 17\%$. The estimated systematic error on the total efficiency is 7%.

III. THE RESULTS

With two events observed and 2.3 ± 0.9 events expected from background, we observe no excess of events. We compute 95% CL upper limits on the cross section σ for the Monte Carlo sampled points in the (μ, M_2) plane using a Bayesian approach [11] with a flat prior distribution for the signal cross section. The calculation takes into account the errors on the luminosity, the efficiency, and the number of background events. Depending on the values of the supersymmetry parameters, the 95% CL upper limits on the total cross section vary widely from several hundred pb for light charginos/neutralinos to $\sigma \sim 0.18$ pb for heavy charginos/neutralinos. For masses like those in Table I, which are near our 95% CL bounds, $\sigma < 0.32$ pb. Table I also gives a less model-dependent upper limit σ_D for observing chargino/neutralino production resulting in final states which satisfy the kinematic selection given in the table caption.

To derive bounds in the (μ, M_2) plane, the values of μ and M_2 are varied around the sampled points until the theoretical cross sections σ_{th} exceed the upper limits σ. The interpolated bounds in the (μ, M_2) plane are shown in Fig. 2 for $\tan\beta = 1.05, 2, 100$. The regions below the lines are excluded by this analysis. The bounds depend on the value of $\tan\beta$ slightly, becoming stronger in the $\mu < 0$ half-plane and weaker in the other half-plane as $\tan\beta$ is increased.

Figure 3 compares the bounds in the (μ, M_2) plane for $\tan\beta = 2$ with those estimated

μ	M_2	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_1^\pm}$	σ_{th}	Efficiencies (%)		Limits (pb)	
GeV	GeV	GeV/c^2		(pb)	ϵ	ϵ_D	σ	σ_D
-160	300	143.9	167.8	0.12	26.0±1.4	36.4	0.18	0.13
-600	140	72.5	146.4	0.36	17.2±1.2	32.1	0.28	0.15
-800	165	84.7	170.0	0.20	15.1±1.1	26.4	0.32	0.18
200	300	118.1	160.2	0.15	21.3±1.3	31.9	0.23	0.15
400	190	89.4	166.4	0.19	20.1±1.3	32.5	0.24	0.15
800	170	83.2	161.6	0.25	19.6±1.3	33.4	0.25	0.14

TABLE I. Representative points in the (μ, M_2) plane for $\tan\beta = 2$ with GEANT simulation. These points are chosen to be near our 95% CL bounds, where the experimental 95% CL cross section σ equals the theoretical cross section σ_{th}. ϵ is the efficiency for observing the total cross section σ, while ϵ_D and σ_D are the efficiency and cross section for observing the detectable events, those which satisfy the kinematic cuts $E_T^{\gamma_1} > 20$ GeV, $E_T^{\gamma_2} > 12$ GeV, $|\eta^\gamma| < 1.2$ or $1.5 < |\eta^\gamma| < 2.0$, and $\not\!\!E_T > 25$ GeV.

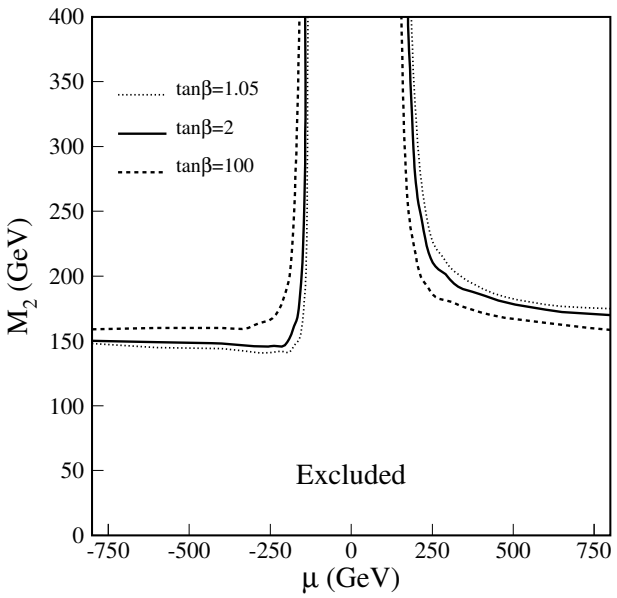

FIG. 2. 95% CL bounds in the (μ, M_2) plane for $\tan\beta = 2$ (solid line), $\tan\beta = 1.05$ (dotted line), and $\tan\beta = 100$ (dashed line).

in Ref. [3] from LEP data. These bounds exclude the region of parameter space suggested in Ref. [3] for the chargino interpretation of an event candidate shown by the CDF Collaboration [12]. Also shown are the contours of constant mass for $m_{\tilde{\chi}_1^\pm} = 150$ GeV/c^2 and $m_{\tilde{\chi}_1^0} = 75$ GeV/c^2. Since these are the largest masses for which the mass contours lie entirely in the excluded region, we obtain 95% CL lower mass limits of 150 GeV/c^2 for the lightest chargino and 75 GeV/c^2 for the lightest neutralino. This 75 GeV/c^2 lower mass limit also rules out a large part of the parameter space suggested for the scalar electron interpretation of the CDF event candidate in the model [3]. These mass limits are insensitive to the choice of $\tan\beta$, varying less than 2 GeV/c^2 over the range $1.05 < \tan\beta < 100$, as long as our

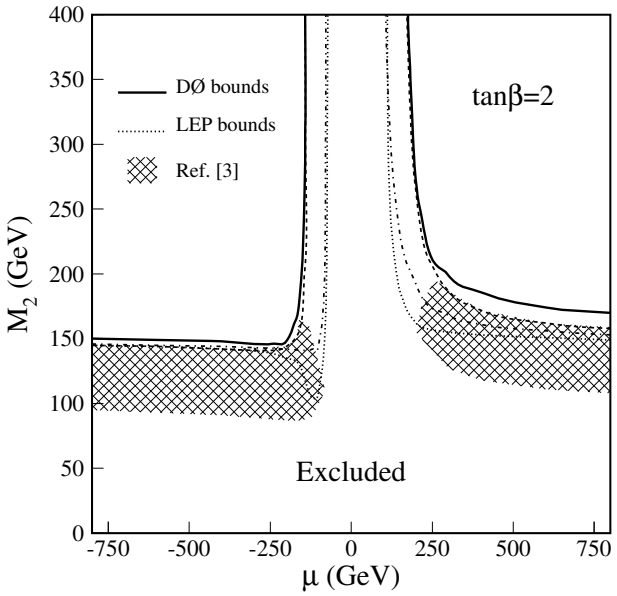

FIG. 3. Bounds in the (μ, M_2) plane for $\tan\beta = 2$. The region below the two solid lines is excluded at 95% CL. Also shown are the bounds estimated in Ref. [3] from the LEP data for $m_{\tilde{e}} = 75$ GeV/c^2 (dotted line) and the contours of constant $m_{\tilde{\chi}_1^\pm} = 150$ GeV/c^2 (dashed line) and $m_{\tilde{\chi}_1^0} = 75$ GeV/c^2 (dot-dashed line). The hatched areas are suggested in Ref. [3] for the chargino interpretation of the CDF event candidate in the model.

assumption that $\tilde{\chi}_1^0$ is the NLSP is satisfied.

Since most of the theoretical cross section is due to $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ production, we can place limits on these individual leading processes, similar to what is done for gravity mediated models [13]. For a large part of the parameter space ($|\mu| > M_2$), $m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_2^0} \approx 2 \times m_{\tilde{\chi}_1^0}$ so that we can express our cross section limits as a function of $m_{\tilde{\chi}_1^\pm}$. These 95% CL upper limits are compared with the theoretical limits in Fig. 4. The efficiencies and theoretical cross sections assume $\tan\beta = 2$ and $\mu = -500$ GeV. The efficiencies and 95% CL limits are insensitive to the choice of $\tan\beta$ and μ while the theoretical cross section varies slightly with this choice. These 95% CL cross section upper limits are below the theoretical cross sections for masses below ≈ 137 GeV, assuming $|\mu| > M_2$ and $\tan\beta = 2$.

IV. CONCLUSIONS

In summary, we have searched for inclusive high E_T diphoton events with large missing transverse energy. Such events are predicted in supersymmetric models with low energy gauge-mediated supersymmetry breaking. No excess of events is found. The null result is interpreted in the minimal supersymmetric standard model with a light gravitino. In that model, and with the assumption of gaugino mass unification at the GUT scale, we obtain 95% CL lower mass limits of 150 GeV/c^2 for the lightest chargino and 75 GeV/c^2 for the lightest neutralino.

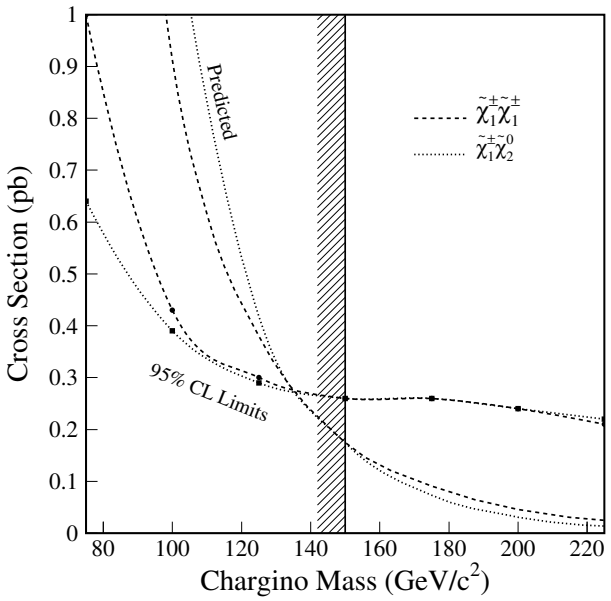

FIG. 4. Measured 95% CL upper limits and predicted theoretical cross sections for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ production as a function of $m_{\tilde{\chi}_1^{\pm}}$, assuming $m_{\tilde{\chi}_1^{\pm}} \approx m_{\tilde{\chi}_2^{0}} \approx 2\times m_{\tilde{\chi}_1^{0}}$. The vertical hatched line is the 95% CL lower limit on $m_{\tilde{\chi}_1^{\pm}}$ determined using the total cross section for all chargino/neutralino pair production and all possible μ values, as discussed in the text.

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