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CDF

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Abstract

We present results of a search for like-sign dielectron plus multijet events using 107 pb^{-1} of data at $\sqrt{s}$ = 1.8 TeV collected by the CDF experiment. Finding no events that pass our selection criteria, we set 95% confidence level upper limits on gluino-gluino ($\tilde{g}\tilde{g}$) and squark-squark ($\tilde{q}$-$\bar{\tilde{q}}$) production with R parity violating decays of the charm squark ($\tilde{c}_L$) in $\tilde{g} \to c\tilde{c}_L$ and of the lightest neutralino ($\tilde{\chi}_1^0$) in $\tilde{q} \to q\tilde{\chi}_1^0$ via a non-zero λ'_{121} coupling. We compare our results to NLO calculations of gluino and squark production cross sections and set lower limits on the masses $M(\tilde{g})$, $M(\tilde{t}_1)$, and $M(\tilde{q})$.

Introduction

The minimal supersymmetric standard model (MSSM) [1] is an extension of the standard model (SM) that adds a supersymmetric (SUSY) partner for each SM particle, and is constructed to conserve R parity (R_p) [2]: for a particle of spin S, the multiplicative quantum number $R_p \equiv (-1)^{3B+L+2S}$ distinguishes particles ($R_p = +1$) from SUSY particles ($R_p = -1$). Here B and L are baryon and lepton number, respectively. The R_p conservation requires the lightest supersymmetric particle (LSP) to be stable. This leads to experimental signatures with appreciable missing transverse energy ($\not\!\!E_T$).

In general, however, the superpartners of the quarks and leptons can undergo R_p violating ($\not\!\!R_p$) interactions [3]. Various $\not\!\!R_p$ models can be built by adding explicitly B or L violating terms to the SUSY Lagrangian. These additional $\not\!\!R_p$

couplings allow for the decay of the LSP and eliminate the $\not\!\!E_T$ signature seen in the MSSM.

Events with a positron and a jet at high Q^2 values, detected at the HERA experiments [4], have sparked interest in R_p violating SUSY, since such events can be explained by the production and decay of a charm squark ($\tilde{c}_L$): $e^+ + d \rightarrow \tilde{c}_L \rightarrow e^+ + d$, where R_p is violated at both vertices. For this scenario, $\tilde{c}_L$ with mass $M(\tilde{c}_L) \simeq 200$ GeV$/c^2$ is the preferred squark flavor, because its associated coupling λ'_{121} [5, 6] is less constrained by experiment than the other couplings. Another possibility to explain the excess is the production and decay of a first-generation leptoquark; DØ and CDF have ruled out this explanation [7].

Two $\not\!R_p$ processes that involve the same λ'_{121} coupling can be tested in $p\overline{p}$ collisions: (i) $p\overline{p} \rightarrow \tilde{g}\tilde{g} \rightarrow (c\,\tilde{c}_L)\,(c\,\tilde{c}_L) \Rightarrow c\,(\mathrm{e}^{\pm}d)\,c\,(\mathrm{e}^{\pm}d)$ "gluino analysis" ; and (ii) $p\overline{p} \rightarrow \tilde{q}\bar{\tilde{q}} \rightarrow (q\tilde{\chi}^0_1)\,(\bar{q}\tilde{\chi}^0_1) \Rightarrow q\,(dc\mathrm{e}^{\pm})\,\bar{q}\,(dc\mathrm{e}^{\pm})$ "neutralino analysis". Here, the $\not\!R_p$ decays are indicated by "$\Rightarrow$." For process (i) we assume $M(\tilde{g}) > M(\tilde{c}_L) = 200$ GeV$/c^2$. The masses of all other squarks are given in a MSSM scenario in Ref. [5]. For process (ii), we consider $\tilde{q}\bar{\tilde{q}}$ production (5 degenerate squark flavors) and $\tilde{t}_1\bar{\tilde{t}}_1$ production separately. We also make the mass assumptions: $M(\tilde{\chi}^{\pm}_1) > M(\tilde{q}) > M(\tilde{\chi}^0_1)$, $M(\tilde{\chi}^{\pm}_1) \approx 2\,M(\tilde{\chi}^0_1)$, and $M(\tilde{\chi}^{\pm}_1) > M(\tilde{t}_1) - M(b)$, where the first relation suppresses $\tilde{q} \rightarrow \tilde{\chi}^{\pm}_1$, the second relation arises from gaugino mass unification, and the third ensures that $Br(\tilde{t}_1 \rightarrow c\tilde{\chi}^0_1) = 100\%$ for $M(\tilde{t}_1) < M(t)$. Given the Majorana nature of the gluino and neutralino, these reactions yield like-sign (LS) and opposite-sign (OS) dielectrons with equal probability. Since LS dilepton events have the benefit of small SM backgrounds, we search for events with LS electrons plus two or more jets.

We present results of the search for $e^{\pm}e^{\pm} + \geq 2$ jet events from $p\overline{p}$ collisions at a center of mass energy of $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. The analysis is based on two data samples of 18.6 pb^{-1} and 88.6 pb^{-1} collected by the Collider Detector at Fermilab (CDF) during the 1992-93 and 1994-95 runs, respectively.

CDF Detector

The CDF detector is described in detail elsewhere [8]. The components of the detector relevant to this analysis will be described briefly here. The location of the $p\overline{p}$ collision event vertex (z_{vertex}) is measured along the beam direction with a time projection chamber. The transverse momenta (p_T) of charged particles are measured in the pseudorapidity region $|\eta| < 1.1$ by the central tracking chamber, which is located in a 1.4 T solenoidal magnetic field. Here $p_T = p\sin\theta$, $\eta = -\ln\tan(\theta/2)$, and θ is the polar angle with respect to the proton beam direction. The electromagnetic and hadronic calorimeters surround the tracking chambers. They are segmented in a projective tower geometry and cover the central ($|\eta| < 1.1$) and plug ($1.1 < |\eta| < 2.4$) regions.

Event Selection

Dielectron+$\geq$2-jet candidates are selected from a initial sample of events that fired the inclusive central electron triggers with $E_T > 9.2$ GeV in the 1992-93 run and with $E_T > 8$ GeV or 16 GeV in the 1994-95 run. We require at least two electrons with $E_T > 15$ GeV in central electromagnetic calorimeter. Each electron must exhibit lateral and longitudinal shower profiles consistent with an electron, and be well matched to a charged track [9] with $p_T \geq E_T/2$. The tracks must originate at the same vertex, where $|z_{vertex}| \leq 60$ cm. The η-ϕ distance $\Delta R_{ee} \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ between two electrons must be greater than 0.4. Each electron must pass an isolation cut which requires the total calorimeter E_T in an η-ϕ cone of radius $\Delta R = 0.4$ around the electron, excluding the electron E_T, to be less than 4 GeV. Jets are identified in the electromagnetic and hadronic calorimeters using a fixed cone algorithm [10] with cone size $\Delta R = 0.7$ for clustering and within $|\eta_j| < 2.4$. There must be at least two jets with $E_T > 15$ GeV, $\Delta R_{jj} > 0.7$, and $\Delta R_{ej} > 0.7$. We further require no significant $\not\!\!E_T$ in the event: $\not\!\!E_T/\sqrt{\sum E_T} < 5$ GeV$^{1/2}$. No LS ee events survive our selection, while we are left with 166 OS ee events.

Two dominant SM backgrounds for this search are $t\bar{t}$ and $b\bar{b}/c\bar{c}$ productions. For example, $t\bar{t} \to (W^+b)(W^-\bar{b}) \to (e^+\nu b)(q\bar{q}'\bar{c}e^+\nu)$. We find the total background in 107 pb^{-1} is consistent with zero events.

Setting Limits

We exclude the two processes if:

$$\sigma(p\bar{p} \to \tilde{g}\tilde{g}/\tilde{q}\bar{\tilde{q}}) \cdot Br(\tilde{g}\tilde{g}/\tilde{q}\bar{\tilde{q}} \to e^{\pm}\, e^{\pm} + \;\geq 2j) \;\geq \frac{N_{95\%}}{A \cdot \epsilon_{trig} \cdot \int \mathcal{L}\; dt} \qquad (1)$$

where no subtraction of the background events is performed.

For the gluino analysis, the 95% confidence level (C.L.) upper limit is $N_{95\%} =$ 3.1 events for zero observed events combined with a Gaussian 10% systematic uncertainty. The event acceptance is a very weak function of $M(\tilde{g})$ in the range $A =$ 16.0% - 16.6%. The trigger efficiency for dielectrons (with $E_T\; > 15$ GeV) is determined to be $\epsilon_{trig} = (98.4 \pm 1.3)\%$. The total integrated luminosity is $\int \mathcal{L}\; dt = (107.2 \pm 7.1)$ pb^{-1}. We exclude $\sigma \cdot Br \geq 0.18$ pb independent of $M(\tilde{g})$.

In Figure 1 are plotted the results for the gluino analysis in the gluino-squark mass plane. Contours are shown for two values of the branching ratio $Br(\tilde{c}_L \to ed)$, where we have compared our results to the NLO $\tilde{g}\tilde{g}$ production cross section [11] multiplied by the branching ratio to LS ee from Ref. [6]. Our sensitivity vanishes for $M(\tilde{q}) < 260$ GeV/c^2 where $\tilde{q}$ denotes the degenerate up type and right-handed down type squark flavors. This is because $M(\tilde{b}_L)$ is lighter than 200 GeV/c^2 when $M(\tilde{q}) \lesssim 260$ GeV/c^2 due to the large top quark mass, where we use the mass relation in Ref. [6] which includes mixing for the left-handed,

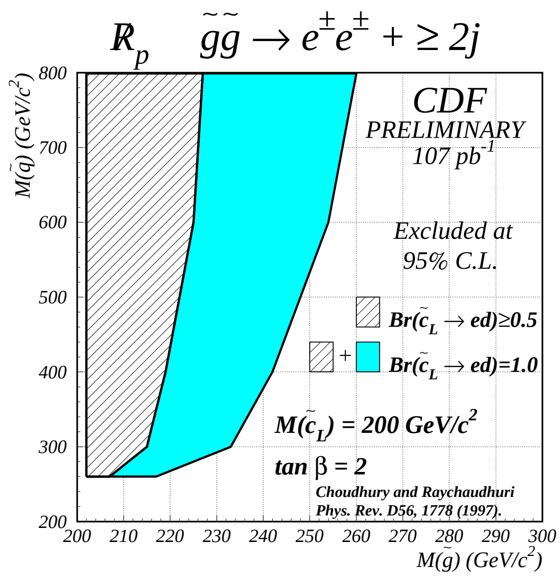

Figure 1: Exclusion region in the $M(\tilde{q})$-$M(\tilde{g})$ plane at 95% C.L. The combined hatched plus shaded region is excluded for $Br(\tilde{c}_L \rightarrow ed) = 1.0$, while the hatched region alone is excluded for $Br(\tilde{c}_L \rightarrow ed) \geq 0.5$.

down-type squarks. For $M(\tilde{q}) = 200$ GeV$/c^2$, $M(\tilde{b}_L) = 115$ GeV$/c^2$ so the decay $\tilde{g} \rightarrow \bar{b}\tilde{b}_L$ (and its charge conjugate mode) dominates and $\tilde{g} \rightarrow \bar{c}\tilde{c}_L$ (and its charge conjugate mode) $\rightarrow e^+d(e^-\bar{d})$ is supressed. Since our analysis assumes a non-zero $R\!\!\!/_p$ coupling only for $\tilde{c}_L$, the LS with zero $E\!\!\!/_T$ signal disappears in this region of parameter space.

For the neutralino decay analysis, the 95% C.L. upper limit is $N_{95\%} = 3.1$ events for zero observed events and a Gaussian systematic uncertainty in the range 10% - 16%. The event acceptance A is determined for each squark and neutralino mass and ranges from 3.7% - 15.2%. In this case, the trigger efficiency is $\epsilon_{trig} = (96.5 \pm 0.2)\%$. This is slightly lower than for the gluino analysis because these lower p_T electrons (especially for the second leg) can be accepted by a lower-threshold trigger (in the 1994-95 run) that was prescaled by 1.2 due to rate limitations of the CDF data acquisition system. We calculate for each squark and neutralino mass combination the upper limit on the cross section times branching ratio to LS ee, and we exclude $\sigma \cdot Br$ in the range 0.81 pb - 0.20 pb as a function of the masses.

Figure 2 shows the results of the neutralino analysis for $\tilde{t}_1\bar{\tilde{t}}_1$ and five flavor degenerate $\tilde{q}\bar{\tilde{q}}$ production. Plotted are our upper limits on the cross section times branching ratio, compared with the NLO predictions for $\tilde{t}_1\bar{\tilde{t}}_1$ [12] and $\tilde{q}\bar{\tilde{q}}$ [13]. We assume $Br(\tilde{\chi}_1^0 \to q\overline{q}'e^{\pm}) = Br(\tilde{\chi}_1^0 \to q\overline{q}'\nu)$ (although the actual branching ratios are a function of the SUSY parameters). Since each neutralino can decay to e^+ or e^- with equal probability, the branching ratio to LS ee is 1/8. The variation with neutralino mass is shown: for a heavy neutralino at the kinematic limit for the reaction, we set a better limit on $M(\tilde{t}_1)$ or $M(\tilde{q})$ than for a light neutralino, because the acceptance is increased due to harder electron E_T spectra. This analysis excludes $M(\tilde{t}_1)$ below 120 (135) GeV/c^2 for a light (heavy) neutralino and $M(\tilde{q})$ below 200 - 260 GeV/c^2 depending on the masses of the gluino and neutralino.

The HERA experiments' data collected in 1997 do not appear to confirm the excess of high Q^2 events seen in previous data [14]. However, only with more data will this question be answered definitively as the total data sets (1994-97) still exhibit slight deviations from SM predictions.

Conclusion

We find no evidence for $\not{R}_p$ SUSY yielding LS dielectron events passing our selection in 1.8 TeV $p\overline{p}$ collisions and set limits on $\sigma \cdot Br$ for two processes. In the gluino analysis, we exclude the scenario of a 200 GeV/c^2 $\tilde{c}_L$ as a function of $M(\tilde{g})$ and $M(\tilde{q})$. In the neutralino analysis we set mass limits of $M(\tilde{t}_1) > 135$ GeV/c^2 for a heavy neutralino, and the degenerate squark $M(\tilde{q}) > 260$ GeV/c^2 for a heavy neutralino and 200 GeV/c^2 gluino.

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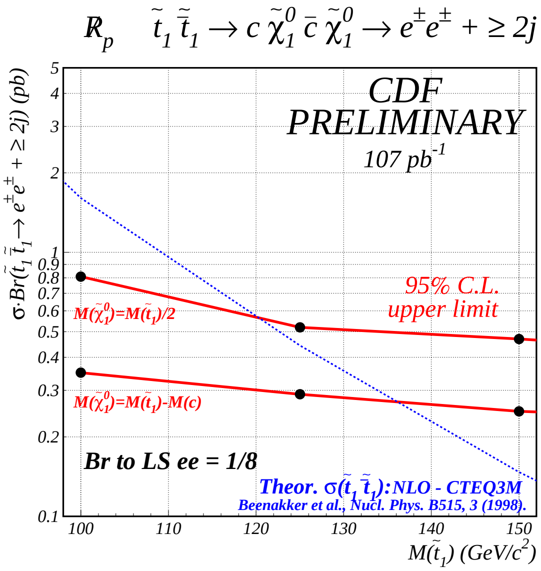

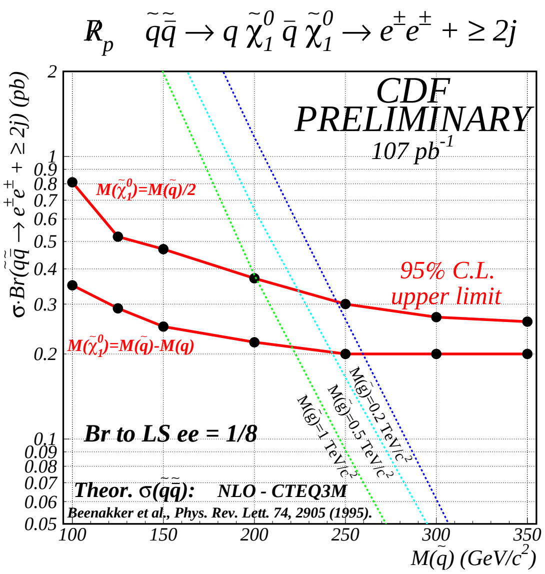

Figure 2: Upper limits on cross section times branching ratio at 95% C.L. for $\tilde{t}_1\bar{\tilde{t}}_1$ production (top) and five-flavor degenerate $\tilde{q}\bar{\tilde{q}}$ production (bottom). The theoretical curves are the NLO cross sections multiplied by a branching ratio to LS ee of 1/8 with assumption of $Br(\tilde{t}_1 \to c\tilde{\chi}_1^0) = Br(\tilde{q} \to q\tilde{\chi}_1^0) = 1.0$.

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