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Leptoquarks and R-parity Violating Supersymmetry Search at CDF

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Leptoquarks and R-parity Violating Supersymmetry Search at CDF[1]

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Abstract. We present results from direct searches for leptoquarks and R-parity violating SUSY particles by the CDF experiment. These results strongly constrain the interpretation of the recently reported high Q^2 event excess at HERA as leptoquark or R-parity violating SUSY production.

1 Search for Leptoquarks

Leptoquarks (LQ) refer to a general class of particles that couple both to leptons and quarks. They are bosons possessing both lepton numbers and color. These particles arise in many extensions to the SM where a new lepton-quark symmetry is assumed, for example GUT, technicolor, compositeness and SUSY models. The specific $qlLQ$ couplings are model dependent but in order to be compatible with many low energy measurements these couplings are severely constrained. To avoid Flavor Changing Neutral Currents which are not observed experimentally, LQ's at the 100-1000 GeV/c^2 range are assumed to couple only within one generation [1].

There is recent strong interest in leptoquarks with masses around 200 GeV/c^2 due to the observation of an excess of events at high Q^2 at HERA [2] which can be speculated as the production of a first generation leptoquark [3].

At hadron colliders, gluon fusion and $q\bar{q}$ annihilation can produce pairs of leptoquarks. This is a strong process, thus its cross section can be calculated with perturbative QCD, independent of the $qlLQ$ coupling. All three generations of leptoquarks can be produced at hadron colliders. In general leptoquark decays are assumed to conserve both lepton and baryon numbers in order to avoid rapid proton decay. Therefore there are two possible decay channels for a leptoquark: either to a quark and a charged lepton, or to a quark and a neutrino. Defining the charged lepton branching ratio as β, for the leptoquark pair produced the branching ratio of two charged lepton final state is β^2, while that of the one charged lepton plus neutrino state is $2\beta(1-\beta)$.

CDF has searched for all three generation leptoquarks in its data. Search results are summarized in Table 1. In this note we present the details of the analysis of the first two generation leptoquarks. The third generation leptoquark search has been published in [4].

[1] Presented at the International Europhysics Conference on High Energy Physics, 19-26 August, 1997, Jerusalem, Isreal.

generation	first	first	second	third
channel	$eejj$	$e\nu jj$	$\mu\mu jj$	$\tau\tau jj$
95% CL limit (GeV/c^2)	213 (β=1)	180 (β=0.5)	195 (β=1)	99 (β=1)
status	published [5]	preliminary	preliminary	published [4]

Table 1. Summary of CDF scalar leptoquark search results.

1.1 Search for first generation leptoquarks with $eejj$

The analysis begins with selecting events with two high energy electrons ($E_T > 25$ Gev) and 2 jets ($E_T > 30$ and $E_T > 15$ GeV). Z^0 events are removed by a cut on M_{ee}: $M_{ee} < 76$ or $M_{ee} > 106$ GeV/c^2 . To reduce the background from Drell-Yan dilepton continuum, the sum E_T of two electrons and the sum E_T of two jets are required to be greater than 70 GeV. The electrons are then paired with jets to reconstruct two leptoquarks. Two parings are possible. The paring that gives closer ej masses are chosen. To select candidate events that are consistent of leptoquark pair production of a mass M_{LQ}, the mass difference of two ej masses, ΔM_{ej}, is required to be less than $0.2M_{LQ}$, and the average of the two ej masses within 3σ of M_{LQ}.

With these requirements, only one event passed the selection for $140 < M_{LQ} < 170$ GeV/c^2 in a data sample of 110pb^{-1}, which is consistent of the background expectation. Acceptance for the signal is evaluated by the PYTHIA program and a full detector simulation. The result of this analysis is interpreted as a 95% CL limit on leptoquark pair production cross section derived from Poisson statistics, taking into account systematic uncertainties (13.4% in total) on the acceptance, but without background subtraction. Figure 1 shows this limit, as function of M_{LQ}, compared to the NLO QCD calculation [6]. From this comparison, a first generation leptoquark with $\beta = 1$ is excluded for $M_{LQ} < 213$ GeV/c^2 at 95%CL.

1.2 Search for first generation leptoquarks with $e\nu jj$

If $\beta < 1$, leptoquark pairs can decay to $e\nu jj$ final states. The maximum braching ratio occurs at $\beta = 0.5$.

The analysis selects events with one high energy electron, ($E_T > 20$ GeV), large missing energy ($\not\!\!E_T > 35\ GeV$) and 2 jets ($E_T > 30$ and $E_T > 15$ GeV). The main background in this case is W plus multi-jets and they are rejected by the following cuts: the sum E_T of two jets must be greater than 80 GeV and the transverse mass of electron and neutrino must be greater than 120 GeV/c^2 .

Using the paring that gives closer M_{ej} and $M^T_{\nu j}$, a 3σ cut around a nominal M_{LQ} on the M_{ej} vs $M^T_{\nu j}$ plane is applied to select candidate events that are consistent with leptoquark pair production. One candidate with $100 < M_{LQ} < 130$ GeV/c^2 is selected from 110 pb^{-1} data.

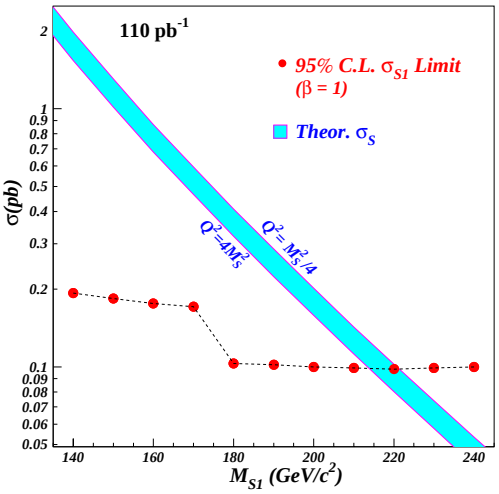

Fig. 1. 95 % C.L. cross section limit for the first generation LQ.

Acceptance for the signal is evaluated by the PYTHIA program and a full detector simulation. The total systematics uncertainty is 15%. Using a Poisson probability distribution without background subtraction, a conservative 95%CL limit on first generation leptoquark production cross section with $\beta = 0.5$ is derived.This gives a lower mass limit of 180 GeV/c^2 comparing to the NLO QCD cross section calculation.

1.3 Search for second generation leptoquarks with $\mu\mu jj$

This analysis is very similar to that of the dielectron channel. Events with two high energy muons ($P_T > 30$ and 20 GeV/c) and 2 jets ($E_T > 30$ and $E_T > 15$ GeV) are selected. Z^0 and J/ψ events are removed by a cut on $M_{\mu\mu}$: $M_{\mu\mu} < 76$ or $M_{\mu\mu} > 106$ GeV/c^2 , and $M_{\mu\mu} > 11$ GeV/c^2 . Using the paring that gives closer μj masses, a 3σ cut around a nominal M_{LQ} on the $M_{LQ}(1)$ vs $M_{LQ}(2)$ plane is used to select candidate events that are consistent of leptoquark pair production. Two candidates with $100 < M_{LQ} < 140$ GeV/c^2 and one candidate with $M_{LQ} > 220$ GeV/c^2 are selected from 110 pb^{-1} data, with 3.8 and 0.09 background expected, respectively.

Acceptance for the signal is evaluated by the PYTHIA program and a full detector simulation. The total systematics uncertainty is 20%. Using a Poisson probability distribution without background subtraction, a conservative 95%CL limit on second generation leptoquark production cross section is derived, as shown in Figure 2 in comparison with the NLO QCD calculation. We exclude a second generation leptoquark with $\beta = 1$ below 195 GeV/c^2 .

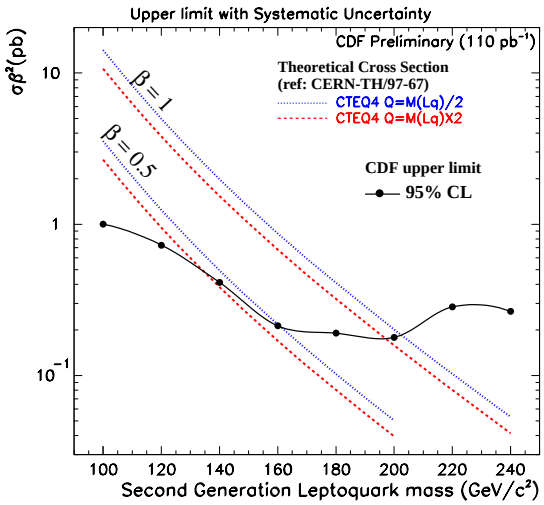

Fig. 2. 95 % C.L. cross section limit for the second generation LQ.

2 Search for R-parity violating SUSY particles

In the Minimal Supersymmetric Standard Model, R parity is assumed to be conserved to avoid rapid proton decay. However this requirement can be relaxed: either baryon number or lepton number is conserved, but R parity can be violated. This gives rise to new decay channels for SUSY particles. In fact, one of the interpretations for the HERA high Q^2 events is the R parity violating production and decay of a squark: $e^+d \to \tilde{c}_L, \tilde{t}_L \to e^+d$.

We have studied two complementary R-parity violating SUSY processes:

$$p\bar{p} \longrightarrow \tilde{g}\tilde{g} \longrightarrow (\bar{c}\tilde{c}_L)(\bar{c}\tilde{c}_L) \xrightarrow{\not{R}_p} \bar{c}(e^{\pm}d)\bar{c}(e^{\pm}d) \quad (1)$$

$$p\bar{p} \longrightarrow \tilde{c}_L\bar{\tilde{c}}_L \longrightarrow (c\tilde{\chi}_1^0)(\bar{c}\tilde{\chi}_1^0) \xrightarrow{\not{R}_p} c(q\bar{q}'e^{\pm})\bar{c}(q\bar{q}'e^{\pm}) \quad (2)$$

Process 1 is important when $M_{\tilde{\chi}_1^0} > M_{\tilde{c}_L}$ and $\mathrm{Br}(\tilde{c}_L \to e^{\pm}d)$ is large, while process 2 is important when $M_{\tilde{\chi}_1^0} < M_{\tilde{c}_L}$ and $\mathrm{Br}(\tilde{c}_L \to c\tilde{\chi}_1^0)$ is large. In the second case, the $\tilde{\chi}_1^0$ decay is R-parity violating.

These final states have the distinct feature of two lepton of same charge (like sign) and multiple jets, with little missing energy. Like sign dilepton signature have the benefit of low SM background.

CDF has conducted a search in $\sim$105 pb^{-1} of data. Events are required to have two electrons of the same charge, both with $E_T > 15$ Gev, and two jets with $E_T > 15$ GeV. A cut on the missing energy significance, $S \equiv \not{E}_T/\sqrt{\Sigma E_T} < 5$, is used to remove events with large missing energy. No event passed these cuts. This null result is then used to derive limits on SUSY parameters for the above two R parity violating processes.

2.1 Limit on $\tilde{g}\tilde{g} \longrightarrow (\bar{c}\tilde{c}_L)(\bar{c}\tilde{c}_L) \longrightarrow \bar{c}(e^{\pm}d)\bar{c}(e^{\pm}d)$

This process is studied with $M_{\tilde{c}_L}$=200 GeV/c^2 and $M_{\tilde{q}\neq\tilde{c}_L}$=400 GeV/$c^2$ ($M_{\tilde{s}_L}$ is fixed by the mass relation in MSSM). The acceptance is then evaluated with ISAJET for $M_{\tilde{g}}$ of 210-400 GeV/c^2 . The dependance on $M_{\tilde{g}}$ is not strong so the average acceptance of 15.8%±2.4% is used. This gives a result of $\sigma Br(\tilde{g}\tilde{g} \longrightarrow e^{\pm}e^{\pm}X) < 0.19$ pb at 95% CL. The NLO calculation [8] of $\sigma(p\bar{p} \to \tilde{g}\tilde{g})$, with the above fixed $M_{\tilde{c}_L}$ and $M_{\tilde{q}\neq\tilde{c}_L}$ values, is a function of $M_{\tilde{g}}$. Therefore for a given $Br(\tilde{g}\tilde{g} \longrightarrow e^{\pm}e^{\pm}X)$, the above cross section limit can be used to derive a limit on $M_{\tilde{g}}$, as presented in Figure 3. The result is that for $Br(\tilde{g}\tilde{g} \longrightarrow e^{\pm}e^{\pm}X) = 0.5$, $M_{\tilde{g}}$ must be heavier than 270 GeV at 95% CL.

Limits are also set on one particular scenario [7] of this process proposed to explain the HERA events.

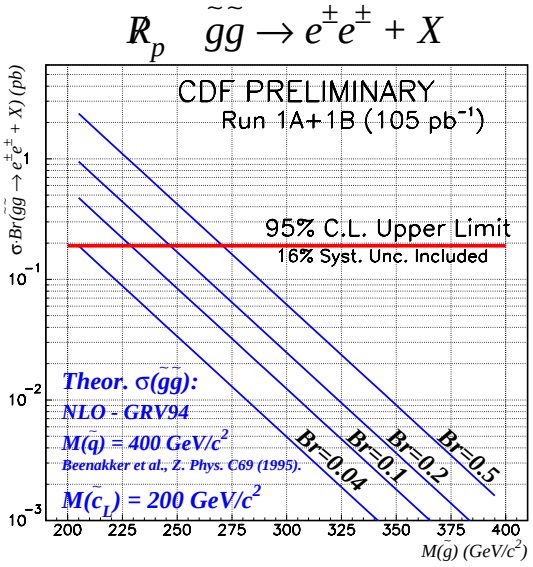

Fig. 3. 95 % C.L. limit on $M_{\tilde{g}}$ for $\tilde{g}\tilde{g} \xrightarrow{R\!\!\!/_p} e^{\pm}e^{\pm}X$

2.2 Limit on $\tilde{c}_L\bar{\tilde{c}}_L \longrightarrow (c\tilde{\chi}_1^0)(\bar{c}\tilde{\chi}_1^0) \longrightarrow c(q\bar{q}'l^{\pm})\bar{c}(q\bar{q}'l^{\pm})$

The acceptance for this process is a strong function of $M_{\tilde{\chi}_1^0}$ and $M_{\tilde{c}_L}$ so the null search result can be used to derive a limit on $\sigma(p\bar{p} \to \tilde{c}_L\bar{\tilde{c}}_L)Br(\tilde{c}_L\bar{\tilde{c}}_L \to e^{\pm}e^{\pm} + X)$ as function of $M_{\tilde{\chi}_1^0}$, $M_{\tilde{c}_L}$.

Assuming $Br(\tilde{c}_L \to c\tilde{\chi}_1^0) = 1$ and $Br(\tilde{\chi}_1^0\tilde{\chi}_1^0 \to LSee) = 1/8$, one can exclude regions of $M_{\tilde{\chi}_1^0}$-$M_{\tilde{c}_L}$ by comparing to $\sigma(p\bar{p} \to \tilde{c}_L\bar{\tilde{c}}_L)$ calculation.

One can also consider the case where $M_{\tilde{q}}$ is degenerate except for $\tilde{t}$, and then compare the experimental limit with NLO calculation of $\sigma(p\bar{p} \to \tilde{q}\bar{\tilde{q}})$ to set exclusion areas in $M_{\tilde{\chi}_1^0}$, $M_{\tilde{q}}$ and $M_{\tilde{g}}$, since the NLO $\sigma(p\bar{p} \to \tilde{q}\bar{\tilde{q}})$ is a function of $M_{\tilde{g}}$. The result for $M_{\tilde{q}}/2 < M_{\tilde{\chi}_1^0} < M_{\tilde{q}} - Mq$ is shown in Figure 4.

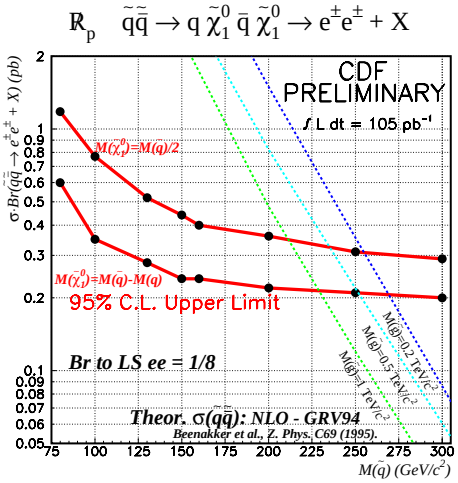

Fig. 4. 95 % C.L. limit on $\tilde{q}\bar{\tilde{q}} \longrightarrow (q\tilde{\chi}_1^0)(\bar{q}\tilde{\chi}_1^0) \xrightarrow{\not{R}_p} c(q\bar{q}'e^{\pm})\bar{c}(q\bar{q}'e^{\pm})$

3 Conclusions

The latest direct searches from CDF result in better lower mass limits for three generations of leptoquarks. R-parity violating SUSY particles have also been searched by the CDF experiment. The interpretation of the recently reported high Q^2 event excess at HERA as leptoquarks is excluded for $\beta = 1$. The R-parity violating SUSY interpretation is strongly constrained.

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