Search for R-parity Violating SUSY in Run 2 at DØ

S. Banerjee, N.K. Mondal, V.S. Narasimham, and N. Parua
Tata Institute of Fundamental Research, Bombay, India

March 25, 1999

I PHYSICS MOTIVATION

Recent interest in R-parity violating (RPV) SUSY decay modes is motivated by the possible high-Q^2 event excess at HERA [1]. When interpretation of the excess through first-generation leptoquarks was excluded by the DØ [2] and CDF [3] experiments, it was suggested [4] that such an effect could be explained via the s-channel production of a charm or top squark decaying into the $e + jet$ final state. Both the production and the decay vertices would thereby violate R-parity. Although more recent data has not confirmed the previous event excess, and despite the combined analysis showed that the anomalous events reported by the H1 and ZEUS experiments were unlikely to originate from the production of a single s-channel narrow resonance [5], interest in RPV signatures has not abatted.

The CDF and DØ Collaborations have recently performed searches for RPV SUSY [7,8], and have set new mass limits on the RPV SUSY particles. Both experiments focussed their searches on the λ' couplings, as motivated by the high-Q^2 HERA event excess. The results of the DØ searches are extended to the Run 2 case and the expected sensitivity to the RPV couplings is discussed.

II DØ SEARCH FOR RPV NEUTRALINO DECAYS

The DØ search for RPV SUSY considered the case of neutralino LSP which decays into a lepton and two quarks due to a finite RPV λ' coupling (see Fig. 1). Both the electron and muon decay channels were considered, corresponding to what commonly referred to as λ'_{1ij} and λ'_{2ij} couplings, respectively. The corresponding final states contain either $2e$ or 2μ and at least four accompanying jets. Unlike at HERA, this search is not sensitive to the value of the RPV coupling, as long as it is large enough so that the neutralino decays within the DØ detector. That corresponds to $\lambda' \geq 10^{-3}$, which gives a lot of room, given current indirect constraints [6].

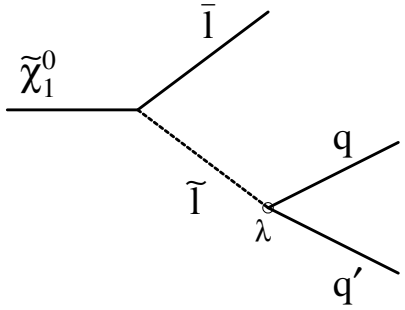

FIGURE 1. RPV decay of a neutralino LSP into a lepton and two quarks.

We assume that the neutralino (LSP) pairs are produced in cascade decays of other supersymmetric particles and use all SUSY pair production mechanisms when generating signal events.

Signal events were generated within the SUGRA framework with the following values of SUSY parameters: $A_0 = 0$, $\mu < 0$ and $\tan\beta = 2$ (the results are not sensitive to the value of A_0 .) Center of mass energy of the colliding beams was taken to be 2 TeV. ISAJET [9] was used for event generation. The acceptance and

resolution of the DØ detector were parametrized using the following resolutions: $\delta E/E = 2\% \oplus 15\%/\sqrt{E}$ [GeV] (electrons), $\delta(1/p)/(1/p) = 0.018 \oplus 0.008(1/p)$ (muons), and $\delta E/E = 3\% \oplus 80\%/\sqrt{E}$ [GeV] (jets) and found consistent with the full detector simulation based on GEANT [10].

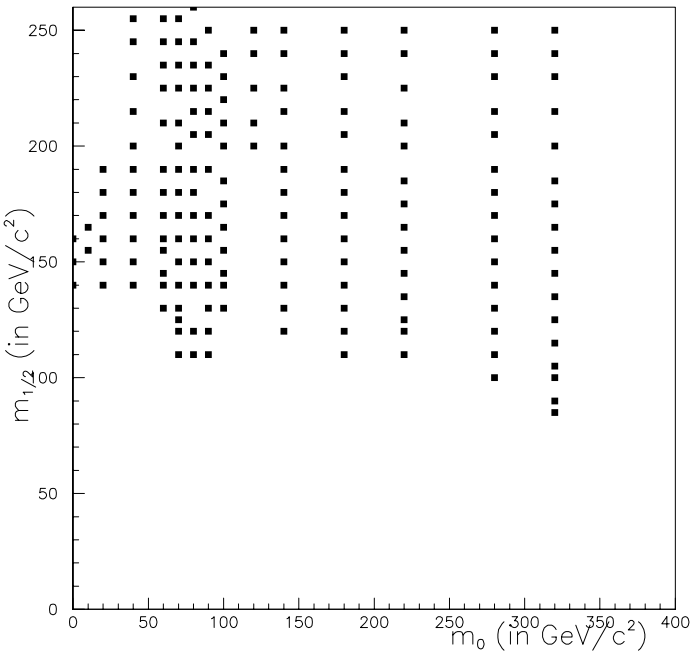

FIGURE 2. Points in the $(m_0, m_{1/2})$ SUGRA parameter space used to generate RPV events in the $ee+4$ jets channel.

Figure 2 shows the points in the $(m_0, m_{1/2})$ SUGRA parameter space where signal Monte Carlo events were generated for the electron channel. Similar points were studied for the muon-decay channel.

III SELECTION CRITERIA FOR THE DIELECTRON CHANNEL

A multijet trigger was used for the analysis of Run 1 data. It was found to be nearly 100% efficient for the typical RPV signal. Since Run 2 trigger list will include a similar trigger, we assume trigger efficiency of 100% and do not perform any trigger simulations for the Run 2.

The following offline selections were used:

- At least two good electrons, the leading one with $E_T(e) > 15$ GeV and the other one with $E_T(e) > 10$ GeV;
- Rapidity range $\mid \eta \mid \leq 1.1$ (central calorimeter), or $1.5 \leq \mid \eta \mid \leq 2.5$ (end calorimeters) for all the electrons;
- Energy isolation for the electrons: the EM energy in the R=0.2 cone about the center of gravity of the EM cluster, subtracted from the total energy in R=0.4 cone, should not exceed 15% of the EM energy in the R-0.2 cone.
- At least four jets with $E_T(j) > 15$ GeV and $\mid \eta \mid < 2.5$;
- The dielectron invariant mass (M_{ee}) should not be in the Z-mass interval, ie, $\mid M_{ee} - M_Z \mid > 15$ GeV/c^2.

In the present analysis we have dropped the requirement on $H_T = \sum E_T(e) + \sum E_T(j)$, but retained all other offline criteria that were used in the previous analysis of data from Run I [8].

IV SELECTION IN THE DIMUON CHANNEL

The following event selection requirements were used for the muon decay channel:

- Two muons, the leading one with $p_T > 15$ GeV, and the other one with $p_T > 10$ GeV.
- Rapidity range $|\eta| < 2.3$ for both muons.
- Energy isolation requirement for both muons, i.e. the calorimeter energy accompanying the muon in a $(\eta\ \phi)$ cone of 0.4 should be consistent with that from a minimum ionising particle.
- At least four jets with $E_T(j) > 15$ GeV and $|\eta| < 2.5$;

V SIGNAL EFFICIENCIES

The number of signal events expected can be written as: $\langle N \rangle = \mathcal{L} \cdot \sigma \cdot \epsilon$, where $\langle N \rangle$ is the expected number of events for luminosity $\mathcal{L}$, σ is the cross-section, and ϵ is the overall efficiency. The efficiency ϵ can be split into three terms: $\epsilon = \epsilon_{\rm trig} \cdot \epsilon_{\rm kin} \cdot \epsilon_{\rm id}$. Here $\epsilon_{\rm trig}$ is the trigger efficiency for the events that pass the offline cuts (assumed to be 100%), $\epsilon_{\rm kin}$ is the efficiency for offline criteria, which includes kinematic, fiducial and topological requirements, and $\epsilon_{\rm id}$ is the electron/jet identification efficiency.

The efficiency for identifying jets is very high ($> 95\%$) and is expected to stay the same in Run 2.

Electron identification efficiencies in Run 1 were $80 \pm 7\%$ in the central ($|\eta| < 1.1$) and $71 \pm 7\%$ in the forward ($1.5 < |\eta| < 2.5$) regions [8]. These efficiencies were calculated for electrons with $E_T(e) > 25$ GeV, It drops by about 30% for electrons with $E_T(e) = 10$ GeV.

The muon identification efficiencies used in Run 1 were $62 \pm 2\%$ in the central ($|\eta| < 1.0$) and $24 \pm 4\%$ in the forward ($1.0 < |\eta| < 1.7$) regions [11]. These were calculated for muons with $p_T > 15$ GeV. For muons with 10 GeV $< p_T < 15$ GeV the efficiencies were 80% smaller on average [12].

In the present analysis we have taken the overall particle identification efficiency to be 0.90 ± 0.09 in each channel, independent of lepton E_T, primarily due to the expectation of a better tracker and muon spectrometer for the upgraded DØ experiment.

VI BACKGROUNDS

The main backgrounds are expected to arise from Drell-Yan production in association with four or more jets, dilepton top-quark events, and QCD multijet events. The latter is the dominant background for the electron channel (followed by the Drell-Yan background). In the case of muons, the background is dominated by the Drell-Yan and top pair production. We used Monte Carlo to calculate background from the first two sources, and data to estimate background from QCD jets.

Background for the Run 1 analysis was estimated to be $1.8 \pm 0.2 \pm 0.3$ (with 1.27 ± 0.24 from QCD and $0.42 \pm 0.15 \pm 0.16$ from the other processes) for $\sim 100\ pb^{-1}$ of data. To extrapolate this number to the data set from Run 2, we have simply multiplied it by the ratio of luminosities to obtain $36 \pm 4 \pm 6$ events. However, it is expected that due to the central magnetic field in the upgraded DØ detector, the probability of jets to be misidentified as electrons will be reduced by a factor of ~ 2 in Run 2. We have therefore considered a second scenario with the smaller expected background of $15 \pm 1.5 \pm 1.5$ events.

For the muon channel, the expected background has been scaled directly from the Run 1 analysis. We expect $10 \pm 1 \pm 1$ background events in Run 2.

VII RESULTS

In order to obtain the sensitivity of Run 2 in to RPV decays, we calculated the efficiency for signal for all the mass points shown in Fig. 2. Typical efficiencies, the signal cross section in the $ee + 4$ jets channel, and the expected event yield in 2 fb^{-1} of data, for several representative $(m_0, m_{1/2})$ points, are given in Table VII. Similar numbers are obtained for the muon channel.

We use these efficiencies to obtain exclusion limits in the $(m_0, m_{1/2})$ plane at 95% CL, assuming that no excess of events will be observed above the predicted background. The exclusion contours for the electron

TABLE 1. Efficiency × BR (%), signal cross section and the expected event yield in 2 fb^{-1} of data, at various $(m_0, m_{1/2})$ parameter space points.

m_0 (GeV)	$m_{1/2}$ (GeV)	Efficiency × BR (%)	Cross section (pb)	$\langle N \rangle$ (in 2 fb^{-1})
60	235	7.9 ± 1.1	0.16	25.2 ± 3.4
60	245	8.3 ± 1.1	0.08	12.8 ± 1.7
60	255	8.3 ± 1.1	0.06	10.5 ± 1.4
100	220	6.1 ± 0.8	0.10	12.2 ± 1.7
100	230	7.0 ± 1.0	0.08	11.3 ± 1.5
180	240	7.0 ± 0.9	0.05	7.1 ± 1.0
320	240	7.1 ± 0.9	0.05	6.9 ± 1.0

and muon channel are shown in Fig. 3 and 4, respectively. Numerical values of the limits are summarized in Table VII.

TABLE 2. Lower limits on the squark and gluino masses from Run 2.

	Lower limit on $m_{\tilde{q}}$ (For any $m_{\tilde{g}}$)	Lower limit on $m_{\tilde{g}}$ (For any $m_{\tilde{q}}$)	Limit when $m_{\tilde{q}} = m_{\tilde{g}}$
Electrons			
Run 1	252 GeV	232 GeV	283 GeV
Run 2 (Scenario I)	430 GeV	490 GeV	490 GeV
Run 2 (Scenario II)	520 GeV	575 GeV	585 GeV
Muons			
Run 2	560 GeV	640 GeV	665 GeV

It's worth mentioning that our analysis provides a conservative estimate of the sensitivity achievable in Run 2, since no formal optimization of the signal vs. background has been performed. We expect that a formal optimization can improve the sensitivity in the mass reach by 15–20%.

REFERENCES

1. H1 Collaboration, C. Adloff *et al.*, Z. Phys. C **74**, 191 (1997); ZEUS Collaboration, J. Breitweg *et al.*, Z. Phys. C **74**, 207 (1997).
2. DØ Collaboration, B. Abbott *et al.*, Phys. Rev. Lett. **79**, 4321 (1997); Phys. Rev. Lett. **80**, 2051 (1998) .
3. CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **79**, 4327 (1997)
4. See, e.g., D. Choudhury, S. Raychaudhuri Phys. Lett. **B401**, 54 (1997); Phys. Rev. D **56** 1778 (1997); G. Altarelli, J. Ellis, S. Lola, G.F. Giudice, and M.L. Mangano, Nucl. Phys. **B506**, 3 (1997); H. Dreiner and P. Morawitz, Nucl.Phys. **B503**, 55 (1997).
5. U.Bassler, G.Bernardi, Z.Phys. **C76**, 223 (1997).
6. See, e.g., H. Dreiner, preprint `hep-ph/9707435`, to be published in "Perspectives on Supersymmetry", Edited by G.L. Kane, World Scientific.
7. CDF Collaboration, F. Abe *et al.*, *"Search for R-parity Violating Supersymmetry Using Like-sign Dielectrons at CDF,"* presented at the ICHEP 98 Conference, Vancouver, 1998.
8. N. Parua. *"Search for R-parity Violating Supersymmetry in $p - \overline{p}$ Collisions at $\sqrt{s} = 1.8$ TeV"*, Ph.D thesis, University of Mumbai, 1998 (unpublished).
9. F. Paige and S. Protopopescu, BNL Report No. 38034, 1986 (unpublished). We used ISAJET versions 7.13 and 7.22.
10. R. Brun and F. Carminati, CERN Program Library Writeup W5013, 1993 (unpublished). We used GEANT version 3.15.
11. T. Hu and P. Quintas, DØ Note # 2956 (unpublished).
12. D. Wirjawan. *"A search for Wino-Zino Associated Production via Trilepton final states"*. Ph.D. thesis, Texas A& M University, 1998 (unpublished).

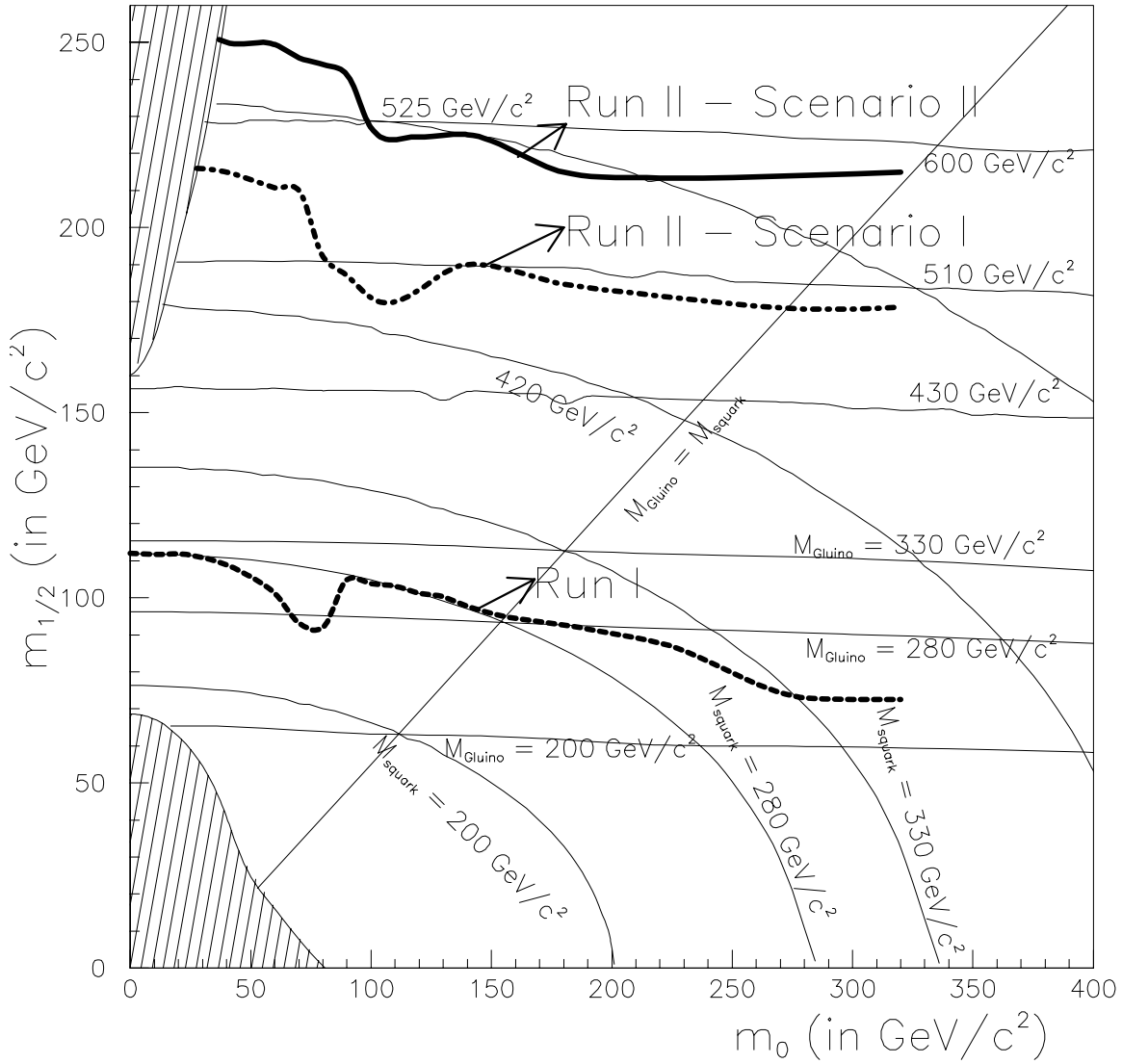

FIGURE 3. Estimated exclusion contour for Run 2 in the $(m_0, m_{1/2})$ plane for $tan\beta = 2$, $A_0 = 0$, $\mu < 0$, from the $ee + 4$ jets channel. Scenario I corresponds to a background of $36 \pm 4 \pm 6$ events (direct scaling from Run 1); scenario II uses the background of $15 \pm 1.5 \pm 1.5$ events (scaling, but with improvements in the detector taken into account).

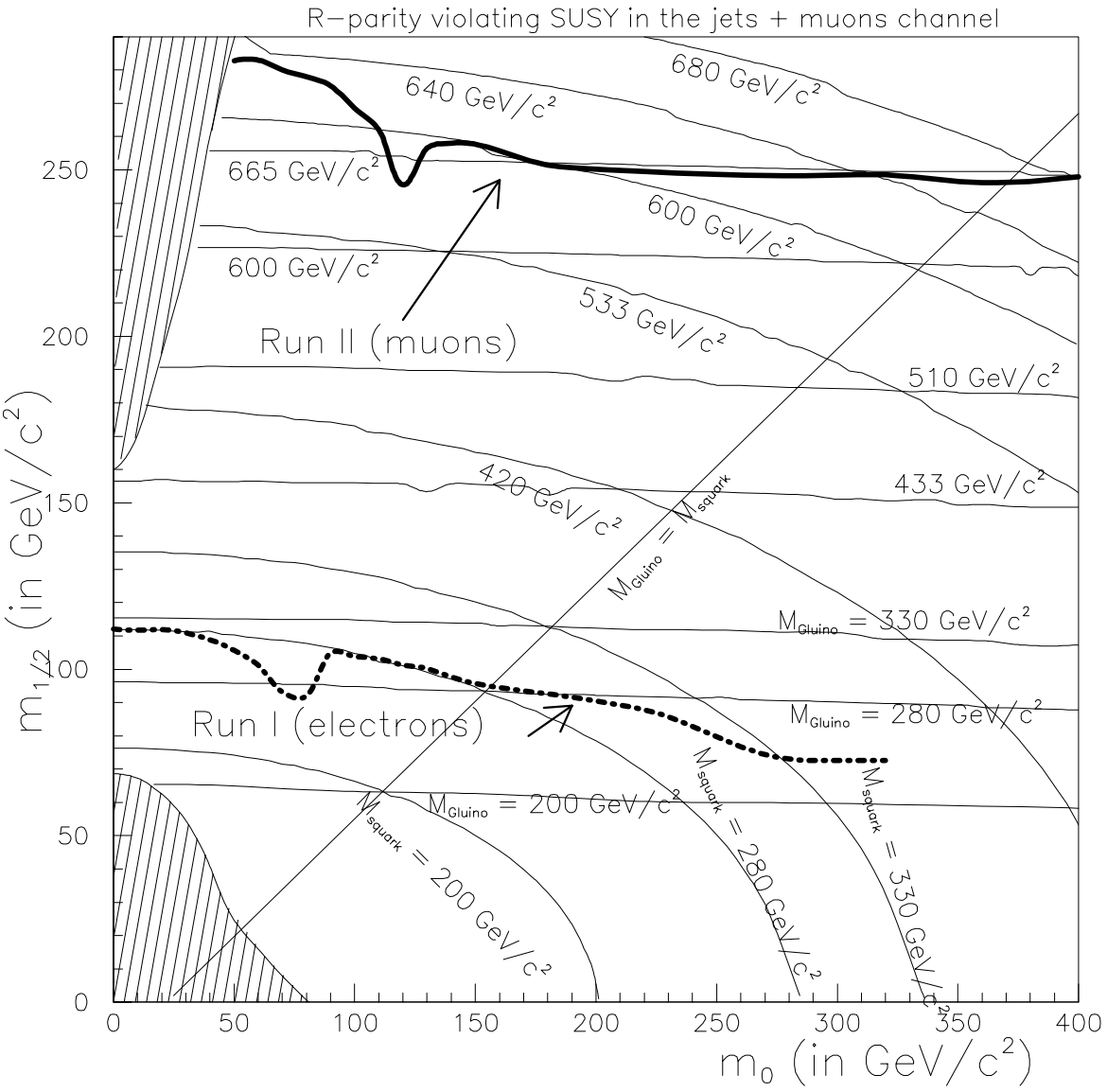

FIGURE 4. Estimated exclusion contour for Run 2 in the $(m_0, m_{1/2})$ plane for $tan\beta = 2$, $A_0 = 0$, $\mu < 0$, from the $\mu\mu + 4$ jets channel for background of $10 \pm 1.0 \pm 1.0$ (direct scaling from Run 1).