Signatures of the Light $\tilde{d}_R$ Scenario at the Upgraded Tevatron

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ABSTRACT

In scenarios with relatively light down squarks, motivated, e.g., by $SO(10)$ D terms, jets $+ \not{E}_T$ signals can be observed at the luminosity upgraded Tevatron even if the squarks are much heavier than the gluinos and the common gaugino mass ($M_{\frac{1}{2}}$) at M_G lies above the LEP allowed lower bound . In the conventional mSUGRA model with heavy squarks practically no signal is expected in this channel. The possiblity of distinguishing between various SUGRA motivated scenarios by exploiting the $\not{E}_T$ and jet p_T distributions, opposite sign dileptons $+$ jets $+ \not{E}_T$ events and clean trilepton signals have been discussed.

1   Introduction

The search for supersymmetry (SUSY) [1] has been going on at the leading high energy colliders, most notably at LEP and Tevatron (Run-I), for quite some time. From the negative results lower limits on various sparticle masses have been obtained [2]. The prospect of SUSY searches at Tevatron(Run-II) and at the large hadron collider (LHC) has also been studied in great details [3, 4]. The sparticle mass reach of these colliders in different channels have also been estimated.

In most of the analyses it is assumed, for the sake of economy in the number of parameters, that all the scalars in the model, i.e. the squarks, the sleptons and the Higgs bosons, have a common SUSY breaking mass (m_0) at the grand unified theory (GUT) scale (M_G). Moreover the gaugino masses and the trilinear soft breaking terms are also assigned common values $m_{\frac{1}{2}}$ and A_0 respectively, at M_G. The parameters at the energy scale of interest ($\sim$ few hundred GeV) is determined by the usual renormalisation group (RG) running.

The number of free parameters may be further reduced by requiring radiative $SU(2) \times U(1)$ breaking at the electroweak scale. This fixes the magnitude of the Higgsino mass parameter (μ). Thus m_0, $m_{\frac{1}{2}}$, A_0 along with the sign of μ and $\tan \beta$ (the ratio of the vacuum expectation values of the two neutral higgs bosons) define the model completely. This popular model is hereafter referred to as the conventional scenario.

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The above framework motivated by N=1 supergravity [5] is very attractive. However as there is no direct experimental information about physics at M_G, it is imprudent to restrict our attention to this model only. In this paper our goal is to re-examine the prospective SUSY signals at the Tevatron (Run-II) by relaxing some of the above assumptions. We shall, however, assume that the gaugino masses unify at M_G. This assumption is quite natural within the framework of any SUSY GUT, since it follows if the GUT symmetry is respected by the SUSY breaking mechanism at some high scale.

The assumption of a common soft breaking mass m_0 at M_G is undoubtably more model dependent. Unlike the gauginos different scalars in a SUSY GUT may belong to different representations of the GUT group. This is especially so for the light higgs scalars and the sfermions, which almost always reside in different multiplets. Even if we assume the validity of the supergravity model, the universal parameter m_0 may well be generated at a scale substantially different from M_G, say the Plank Scale (M_P). Then the running of the scalar masses, belonging to different multiplets of the GUT group, between M_P and M_G may lead to non-universality at M_G [6].

The following nonuniversal scenario is rather interesting from the phenomenological point of view. In this scenario the 'right - handed' down - type squarks ($\tilde{d}_R, \tilde{s}_R, \tilde{b}_R$), generically denoted by $\tilde{d}_R$, are significantly lighter than the other squarks. Then the gluino decays into three body final states mediated by virtual $\tilde{d}_R$ squarks will dominate. Further if the LSP is assumed to be dominated by the $U(1)$ gaugino ($\tilde{B}$), then practically all of these virtual $\tilde{d}_R$'s will decay into the LSP and a d-type quark. Thus the branching ratio (BR) of direct gluino decays into the LSP will be enhanced, while the cascade decays of the gluino will be correspondingly suppressed. In the special case $m_{\tilde{g}} > m_{\tilde{d}_R}$, while all other squarks are heavier than the gluino, practically all the gluinos will decay into the jets + $\not{E}_T$ channel with a remarkably hard $\not{E}_T$ spectrum. On the other hand gluino decays into leptons + jets + $\not{E}_T$ arising through cascade decays will be strongly suppressed. The signal from $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{d}_R$ and $\tilde{d}_R\tilde{d}_R$ production is likely to be observable, although the other squarks may be heavy to be of any consequence at Tevatron energies [7, 8].

Theoretically relatively light $\tilde{d}_R$'s can be naturally motivated within a SUSY GUT framework in a variety of ways. If the GUT group is $SU(5)$, then the $\tilde{d}_R$ squarks residing in the 5 - plet may be renormalized between M_P and M_G such that the resulting soft breaking mass at M_G is significantly smaller than that of the other squarks belonging to the 10 - plet [6]. The numerical results of ref. [6], though in the right direction, does not exhibit a large enough mass split.

In this paper we shall illustrate the signatures of a light $\tilde{d}_R$ scenario through an $SO(10)$ SUSY GUT to be discussed below. Such models are now much more popular than the good old $SU(5)$ SUSY GUT in view of the recent excitement about neutrino masses and mixings generated by the SUPERK and other experiments [9].

We, however, emphasize that the novel collider signatures are essentially consequences of the above squark - gluino mass hierarchy at low energies and are fairly insensetive to the details of GUT scale or Planck scale physics responsible for generating it. Moreover, in view of the large uncertainties involved in GUT scale - Plank scale physics the quantitative results need not be regarded as firm predictions. Therefore, keeping in mind that either of the above mechanisms or their combination can in principle generate the required mass hierarchy, one might as well discuss the resulting phenomenology in a model independent way.

We shall now focus our attention on an SO(10) SUSY GUT [10] containing all the quarks and leptons of a given generation in a 16 dimensional multiplet which includes the heavy right handed neutrino. In this model the non-universality at M_G due to running between M_P and M_G, is expected to be negligible for the first two generations of squarks and sleptons with small Yukawa couplings. In principle nonuniversal masses for the third generation sfermions with a large Yukawa coupling is also possible due to this mechanism. However we shall assume this intergeneration nonuniversility to be small compared to the nonuniversality due to D terms, which will be described below.

Running of the soft breaking masses between M_P and M_G may result in soft breaking masses of light higgs bosons at M_G significantly different from that in the sfermion sector. The light higgs doublets reside in a 10 dimensional representation of SO(10) and hence are renormalised differently. Moreover they have to couple to other super heavy GUT fields in order to implement the mass-split between the coloured higgs bosons and the colour neutral ones responsible for $SU(2) \times U(1)$ breaking. Unfortunately the magnitude of the resulting nonuniversility is not calculable without specifying all the couplings of the higgs bosons, which are not known presently. We, therefore, do not attempt to study directly the impact of nonuniversality on higgs phenomenology in this paper. Instead we shall restrict ourselves to the signature of the squark-glunio production and decays which are only weakly dependent on the characteristics of the higgs sector. However, the effect of nonuniversality in the higgs sector will be taken into account indirectly by treating μ as a free parameter.

In summmary we shall work with a SO(10) scenario in which the soft breaking masses of the squarks and sleptons are equal ($= m_0$) at M_G. Non-universality at this scale may still arise due to D-term contributions to the above masses which appear when SO(10) breaks into a group of smaller rank[11, 12]. In general such contributions could be different for different members of the 16-plet . However, these non-universal terms are generation independent, so that no additional problem due to flavour changing neutral currents arise.

As a specific example we shall consider the breaking of SO(10) directly to the SM gauge group [12]. The group $SO(10)$ contains $SU(5) \times U(1)$ as a subgroup. It is further assumed that the D-terms are linked to the breaking of this $U(1)$ only. The squark- slepton masses in this case are

$$m_{\tilde{u}_L}^2 = m_{\tilde{u}_R}^2 = m_{\tilde{e}_R}^2 = m_0^2 + 0.5 D m_0^2 \tag{1}$$

$$m_{\tilde{d}_R}^2 = m_{\tilde{e}_L}^2 = m_0^2 - 1.5 D m_0^2, \tag{2}$$

where the unknown parameter D can be of either sign. The mass differences arise because of the differences in the $U(1)$ quantum numbers of the sparticles concerned. As can be readily seen from the above formula for D > 0, the left handed sleptons ($\tilde{e}_L$) and right handed down type squark ($\tilde{d}_R$) are relatively light. In this paper we want to concentrate on the collider signatures of the light $\tilde{d}_R$. In principle the D term contributions to the light higgs masses lead to further mass splitting between the higgs bosons and the sfermions at M_G. This provides additional motivation for treating μ as a free parameter.

The phenomenology of the lighter $\tilde{d}_R$ have been studied by several authors [7, 8]. In this work we shall extend and complement these studies in several ways. In [8], the production cross-section of squark-glunio pairs and their decay branching ratios were studied. The effects of the kinematical cuts on the resulting SUSY signals, however, were not taken into

account. In this paper we study the jets + $\not{E}_T$ as well as opposite sign dileptons + jets + $\not{E}_T$ signals by using a parton level Monte Carlo. We use as a guide line the kinematical cuts given in [3], but our main conclusions are essentially consequences of the spectrum under study and are fairly independent of the precise choices of these cuts.

Moreover, we shall comment on the sensitivity of the signal on μ and $\tan\beta$. this important point was not addressed in the earlier works. Event generators requiring large amount of computer time, though essential for precise quantitative studies, are rather expensive as tools for studying the dependence of the signal on a large number of parameters. A parton level Monte Carlo on the other hand enables us to carry out a qualitative study relatively easily.

We shall concentrate on two main issues:
a) What are the mass reaches of the upgraded Tevatron in the nonuniversal scenario and how do they compare with that in the conventional scenario ?
b) If a signal is seen at the upgraded Tevatron, can one distinguish between the models with lighter $\tilde{d}_R$ and the conventional scenario ?

The plan of the paper is as follows. In section II we shall discuss regions of the parameter space which are motivated by various theoretical considerations and are interesting for SUSY searches at the Tevatron. In section III we present our result for the jet + $\not{E}_T$ signal. In section IV the discrimination of different models using the jet + dilepton + $\not{E}_T$ and the clean trilepton signal is presented. Finally in section V the conclusions are summarised.

2 The Choice of Parameters and the Overall Strategy

As has been stated in the introduction the model under study has the following parameters: $m_0, m_{1/2}, A_0, \mu, \tan\beta$ and D. In this set m_0 and $m_{\frac{1}{2}}$ are essentially free parameters.

The glunio mass reach via the jet + $\not{E}_T$ channel at the upgraded Tevatron has been studied by Baer *et al.* [3]. Adopting the conventional scenario, their results can be classified into two generic casess: i) squarks much heavier than the gluino ($m_0 >> m_{\frac{1}{2}}$) and ii) squarks roughly degenerate with the gluinos ($m_0 \leq m_{\frac{1}{2}}$; squarks much lighter than the gluinos are not allowed in the conventional scenario. Let us review the results in case i) for $m_0 \simeq 500$ GeV $>> m_{\frac{1}{2}}$. It was found that only $m_{\frac{1}{2}} \leq 75$ (100) GeV can be probed at the upgraded Tevatron provided the integrated luminosity accumulates to 2 fb^{-1} ($25fb^{-1}$) [3]. Unfortunately such low values of $m_{\frac{1}{2}}$ have already been ruled out by the direct chargino searches at LEP [2] and direct squark - gluino searches by the D0 collaboration [13]. Thus according to the conventional scenario direct squark gluino searches at the Tevatron in the jet + $\not{E}_T$ channel will draw a blank if the squarks indeed happen to be very heavy. This motivates us to focus our studies on choice i) in the nonuniversal scenario. In case ii) even the conventional scenario predicts observable signals at the upgraded Tevatron[3] and we shall not consider it further.

It may be worthwhile to mention that recent analyses of the precision elctroweak observables have produced additional evidence, albeit rather mild, in favour of scenario i). In [14] SUSY contributions to several of these observables were studied. Including the contributions from squarks, sleptons, gauginos and higgs bosons seperately, it was found that light squarks or sleptons (with all other sparticless rather heavy) just allowed by the current lower limits

from direct searches, always make the fit to 22 data points (Z width and partial widths, various assymmetries etc.) worse than that of the SM. On the otherhand relatively light charginos and neutralinos with heavy sfermions ($m_0 >> m_{\frac{1}{2}}$) improve the fit although the statistical significance of the improvement is rather modest.

Similar conclusions pertaining to the squark sector were obtained in [15]. However, it was also noted that even for comparatively light sbottoms and small mass of one of the stops, special values of $\tilde{t}_L - \tilde{t}_R$ mixing can make the fit as good as that in the SM.

Increasing the number of theoretical inputs the number of free parameters can be further reduced. Several authors have noted that [16], if Yukawa coupling unification at M_G is demanded for the third generation within an $SO(10)$ frame work, then $\tan\beta$ becomes practically fixed, since only high values of $\tan\beta$ (in a narrow range around 50) lead to such unification. The well known difficulty in accomodating the radiative $SU(2) \times U(1)$ breaking in this scenario [17] with universal soft breaking masses for the scalars, may be overcome by the nonuniversality induced by the $SO(10)$ D-terms [18].

We, however, note that the Yukawa coupling unification in SO(10) is a consequence of the assumption that the higgs sector is indeed minimal. In this case a single 10 dimensional higgs multiplet is assumed to contain both the higgs doublets required to generate the masses of the up and down type quarks and to trigger the radiative $SU(2) \times U(1)$ breaking. We, therefore, do not require full Yukawa unification for the third generation and the resulting large value of $\tan\beta$, since this crucially depends on the choice of the higgs sector.

From the phenomenological point of view the large $\tan\beta$ scenario in conjuction with the LEP lower bound $M_{\widetilde{\chi}_1^\pm} \geq 95$ GeV necessarily implies that $m_{\tilde{g}}$ is almost at the edge of or beyond the kinematical reach of the Tevatron collider. Thus direct squark- gluino search at the upgraded Tevatron is of little consequence in this scenario, in particular if the squarks are much heavier than the gluino.

Even if more general higgs multiplets are assumed, b - τ Yukawa unification is a desirable feature of the theory. The conventional wisdom is that this requires values of $\tan\beta$ smaller than that in the case of full Yukawa unification. Yet the favoured values of $\tan\beta$ are still too large to make gluinos sufficiently light to be produced copiously at Tevatron energies. Typical values required by unification are $\tan\beta > 30$. However in the presence of neutrino masses and , in particular, of large mixing in the lepton sector this conclusion may require revision [19, 20].

In the presence of large lepton mixing, as required by the SUPERK data on atmospheric neutrinos [9], b - τ unification can be achieved for relatively low values of $\tan\beta$ which were previously disfavoured. In fact it has been shown in [20] that for $2 \leq \tan\beta \leq 4$ and suitable fermion mass matrix textures at M_G, one can obtain large mixings in the lepton sector along with an acceptable CKM matrix, desired neutrino mass patterns and b - τ unification. From the point of view of Tevatron phenomenology this finding is important, since gluino masses well within the striking range of the Tevatron are not necessarily excluded by the LEP lower bound on $M_{\widetilde{\chi}_1^\pm}$ for such low values of $\tan\beta$. We shall, therefore, restrict ourselves to the above narrow range of $\tan\beta$.

The sign of the parameter μ is chosen to be negative since otherwise the gluino mass range allowed by the LEP lower bound on $M_{\widetilde{\chi}_1^\pm}$, turns out to be uninteresting for Tevatron phenomenology.

As has been discussed in the introduction, an attractive way of fixing the magnitude

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of μ is to require radiative $SU(2) \times U(1)$ breaking at the electroweak scale. The resulting numerical value, however, strongly depends on the choice of the higgs mass parameter at M_G. Since we wish to make our predictions largely free from the additional assumptions on the higgs sector we shall treat μ as a free parameter. In the context of Tevatron phenomenology this, however, does not make much of a difference since in any case magnitudes of μ can not be much beyond 450 GeV or so, if we require a gluino well within the striking range of the Tevatron and $M_{\widetilde{\chi}_1^\pm} > 95$ GeV. On the lower side μ is constrained by the requirement of a bino dominated LSP.

We shall denote the cross-section corresponding to the signal with n leptons + jets + $\not{E}_T$ by σ_n. First we shall consider the jet + $\not{E}_T$ signal (σ_0) arising from squark-gluino production.

In this work we shall reexamine the gluino mass reach at the upgraded Tevatron for large m_0 ($>> m_{\frac{1}{2}}$) in the non-universal scenario. We find that an interesting range of $m_{\frac{1}{2}}$ beyond the LEP-2 search limit can be probed. This is particularly so, if a high integrated luminosity ($\sim 30 \ fb^{-1}$) is available. We further study the distributions of various kinematical observables associated with the final states using conservative kinematial cuts given in [3] and compare and contrast them with the corresponding distribution in the conventional scenario.

The size of the signal is very sensitive to the squark, glunio masses or alternatively with m_0, D, and $m_{\frac{1}{2}}$. The dependence on the magnitude of μ and $\tan \beta$ is relatively mild but non trivial. This variation was not studied systematically in earlier works [8]. In this paper we shall check the sensitivity of our conclusions with respect to μ and $\tan \beta$.

If the signals for several values of D happen to be indistinguishable, we shall try to distinguish between them by considering the distributions of the final state observables and the corresponding dilepton (σ_2) and clean trilepton signals.

3   jet + $\not{E}_T$

In the conventional scenario Baer *et al.* [3] have considered the jet + $\not{E}_T$ signals in great details using the ISAJET-ISASUSY Monte Carlo. They have given the kinematical cuts and the SM background corresponding to these cuts. In our parton level Monte Carlo we have adopted the cuts and the background estimates of Baer *et al.* Although our numerical estimates based on a simple minded approach give approximate guide lines and should not be treated as firm predictions, the main conclusions drawn are expected to be valid.

Baer *et al.* have given the jet + $\not{E}_T$ cross-section for several representative choices of the SUSY parameters (see fig. 3 of ref. [3]). Since we are interested in the $m_{\tilde{q}} >> m_{\tilde{g}}$ case, we have focussed our attention on the choice $m_0 = 800$ GeV, $m_{\frac{1}{2}} = 120$ GeV, $\tan \beta = 2$, $A_0 = 0$ and sign of μ negative. They have also prescribed the following set of kinematical cuts $E_T(j_1)$, $E_T(j_2) > E_T{}^c$ and $\not{E}_T > E_T{}^c$, where $E_T{}^c$ is a variable which should be chosen appropriately for each point of the parameter space to optimise the signal to background ratio. $E_T(j_1)$ and $E_T(j_2)$ are the transverse energies of the two leading jets respectively. The other cuts from [3] are $|\eta_j| \leq 3$ for all jets and $\Delta R (\equiv \sqrt{\Delta \eta^2 + \Delta \phi^2}) > 0.7$. Subject to these cuts the SM background is $\sim 2 \ pb$. In most of the cases studied in ref. [3] higher values of $E_T{}^c$ improves the statistical significance of the signal.

Using these cuts our parton level calculation gives cross-sections which approximately

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agree with Baer *et al.* for $E_T{}^c \leq 50$ GeV. For example for $E_T{}^c = 50$ GeV we find $\sigma_0 \approx 35 \; fb$ where as Baer *et al.* obtain $\approx 25 fb$. A part of the discrepancy ($\sim 10 \%$) may be attributed to the use of different parton density functions. Baer *et al.* have used CTEQ2L [21] while we have used CTEQ4M [22]. For higher values of $E_T{}^c$,however, parton level calculation grossly over estimate the cross section compared to ISAJET result. This is understandable because the reduction in p_T of the parton jets due to fragmentation, final state radiation etc. which soften the jet p_T in general, is not taken into account in parton level calculations. Being conservative we shall use $E_T{}^c = 50$ GeV. For a reallistic estimate we scale our parton level cross-sections by a factor of $2/3$. We however note that our conclusions regarding the search limits are likely to improve to some extent by the use of harder cuts.

We next present the sparticle spectrum for D = i)0.0, ii)0.4, and iii)0.6 using equations (1) and (2). The details are given in Table 1. Our main interest will be restricted to D = 0.6 where $m_{\tilde{g}} > m_{\tilde{d}_R}$. However, we shall also comment on the D = 0.4 scenario.

	D=0.0	D=0.4	D=0.6
$\widetilde{u}_L$	550	593	614
$\widetilde{u}_R$	547	591	611
$\mathbf{\tilde{d}_R}$	**548**	**390**	**281**
$\mathbf{\tilde{e}_L}$	**507**	**328**	**180**
$\tilde{e}_R$	503	550	572
$\tilde{g}$	312	313	313
$\widetilde{\chi}_1{}^0$	46	46	46
$\widetilde{\chi}_2{}^0$	96	95	95
$\widetilde{\chi}_1^{\pm}$	96	95	95

Table 1: The mass spectrum in GeV at the weak scale for different values of D with $m_0 = 500$ GeV, $m_{\frac{1}{2}} = 105$ GeV, $\tan\beta = 3$, $A_0 = 0$, $\mu = -340$ GeV.

Further using the radiative $SU(2) \times U(1)$ breaking we find $\mu \approx$ -340 GeV in the universal scenario (D = 0.0). In principle μ can be determined from radiative $SU(2) \times U(1)$ breaking in the non universal scenario as well, if we make additional assumptions about the higgs masses at M_G. We shall, however, refrain from making such assumptions and, as has already been mentioned in the introduction, treat μ as a free parameter. In order to study the impact of light $\tilde{d}_R$ squarks on the jets + $\not{E}_T$ signal we shall first use $\mu = -340$ GeV even in the nonuniversal case. Later we shall comment on the sensitivity of the signal to μ.

For Tevatron Run II ($\mathcal{L} \sim 2 \; fb^{-1}$), where $\mathcal{L}$ indicates the integrated luminosity, we find that for $m_{\frac{1}{2}} \geq 100$ GeV, no observable signal is expected for D = 0.0 in agreement with Baer *et al.* For D=0.4 the conclusion remains more or less unchanged. For D=0.6 ($m_{\tilde{g}} > m_{\tilde{d}_R}$), however, a signal may be seen, provided $m_{\frac{1}{2}}$ is in a narrow range just beyond the LEP II limit. For example we find for $m_{\frac{1}{2}} = 110$ GeV, $\sigma_0 = 143 \; fb$ which corresponds to $\frac{\sigma}{\sqrt{B}} \approx 5$.

This may be understood from the following facts. The gluino decay channels and corresponding branching ratio (BR)s are given in the Table 2.

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	D=0.0	D=0.4	D=0.6
$\tilde{g} \to \tilde{\chi}^{\pm} + jets$	0.4657	0.3681	0.0006
$\tilde{g} \to \widetilde{\chi_1}^0 + jets$	0.1418	0.3311	0.0001
$\tilde{g} \to \widetilde{\chi_2}^0 + jets$	0.3925	0.3009	0.0005
$\tilde{g} \to \tilde{d}_R + jet$	0.0	0.0	0.998

Table 2: The glunio decay channels and corresponding branching ratios for different values of D.

For D = 0 case 3-body decay of the glunio dominates because all the squarks ($\tilde{q}_L$, $\tilde{q}_R$) are heavier than the glunio. $\tilde{\chi}^{\pm}$ and $\widetilde{\chi_2}^0$ decay through leptonic as well as hadronic modes. So BR($\tilde{g} \to jets+ \not{E}_T$) is somewhat suppressed. But for D = 0.4 this BR increases. This is due to the light $\tilde{d}_R$ propagator which is less suppressed. As a result BR($\tilde{g} \to \widetilde{\chi_1}^0 + jets$) is enhanced significantly ($0.14 \to 0.33$).

For D=0.6, BR ($\tilde{g} \to jets+ \not{E}_T$) increases rapidly. In this case $m_{\tilde{g}} > m_{\tilde{d}_R}$ and so the 2-body decay of glunio dominates. First we have the decay $\tilde{g} \to \tilde{d}_R$ d ($\tilde{d}_R \equiv \tilde{d}_R, \tilde{s}_R, \tilde{b}_R$) with BR = 0.998, followed by $\tilde{d}_R \to \widetilde{\chi_1}^0 d$ with 100 % BR as the $\widetilde{\chi_1}^0$ is $\tilde{B}$ dominated.

The observability of jets + $\not{E}_T$ signal may improve sgnificantly if higher $\mathcal{L}$ ($\sim 30 \ fb^{-1}$) is available at the upgraded Tevatron (see Table 3).

D=0.0			D=0.4			D=0.6		
$m_{\frac{1}{2}}$	σ_0	$\frac{S}{\sqrt{B}}$	$m_{\frac{1}{2}}$	σ_0	$\frac{S}{\sqrt{B}}$	$m_{\frac{1}{2}}$	σ_0	$\frac{S}{\sqrt{B}}$
105	53	6	105	62	7	105	203	25
-	-	-	-	-	-	125	53	6

Table 3: The $jets+ \not{E}_T$ cross-sections (in fb) and statistical significances for different values of $m_{\frac{1}{2}}$ and D with $m_0 = 500$ GeV, $\tan\beta = 3$, $A_0 = 0$, $\mu = -340$ GeV.

We find that if the chargino mass is just above the LEP lower limit corresponding to $m_{\tilde{g}} \simeq 312$ GeV, a signal may also be expected for D = 0.0 and 0.4. For the D = 0.0 case we obtain slightly enhanced $\frac{S}{\sqrt{B}}$ ratio compared to ref.[3] since we have used $\tan\beta = 3$. and $\mathcal{L}$ ($\sim 30 \ fb^{-1}$). For heavier charginos no signal is anticipated.

For D = 0.6, however, a range of $m_{\frac{1}{2}}$ 105 GeV $\leq m_{\frac{1}{2}} \leq$ 125 GeV can be probed. This is the consequence of the production of relatively light $\tilde{d}_R$ squarks along with the gluino and the enhanced BR ($\tilde{g} \to jets+ \not{E}_T$) for reasons discussed above.

We next study the variation of σ_0 with μ. For D = 0.6 the results hardly changes with μ. This is a consequence of the fact that in this case the decays $\tilde{g} \to \tilde{d}_R d$ and $\tilde{d}_R \to \widetilde{\chi_1}^0 d$ dominates the signal. The branching ratio of the former strong decay is insensitive to μ. The second decay has $\approx$100 % BR as long as the LSP is $\tilde{B}$ dominated.

For D = 0.0 and D = 0.4 the signal has some dependence on μ (see Table 4).

μ	$\sigma_0(\mathrm{D}=0.0)$	$\sigma_0(\mathrm{D}=0.4)$
-340	79	93
-400	82	80.5
-450	81	72
-500	80	66
-600	73	63.5
-700	65.5	58

Table 4: The sensitivities of the $jets+\not{E}_T$ cross-section with μ for different values of D. All cross-sections are in fb and μ in GeV.

However for $|\mu| > 450$ GeV, the chargino mass violates the LEP lower bound. Larger values of μ, therefore, require enhanced $m_{\frac{1}{2}}$ which makes the $m_{\tilde{g}}$ larger and the signal at the Tevatron is supressed below the observable limit.

We next study the variation of σ_0 with $\tan\beta$. It is once again found that σ_0 for D = 0.6 is not at all sensitive to this parameter. For D = 0.4 and D = 0.0 the signal show some sensitivity. However, for $\tan\beta \geq 4$, the chargino mass again violates the LEP lower bound unless $m_{\frac{1}{2}}$ and correspondingly $m_{\tilde{g}}$ is increased.
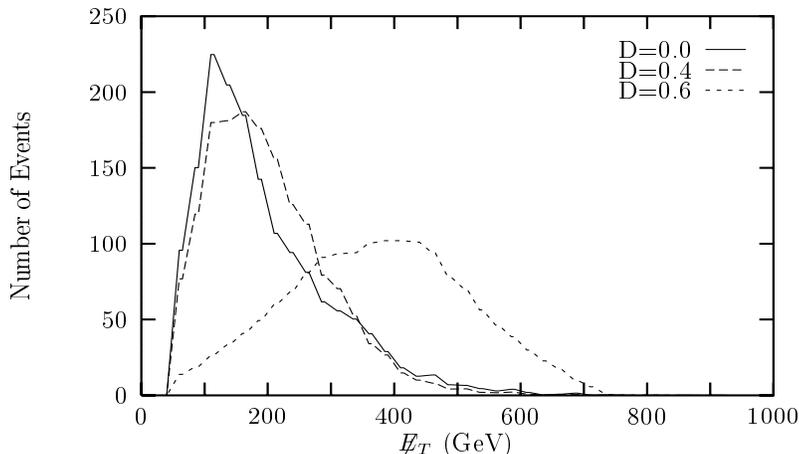

Fig. 1: *Missing E_T distribution of signal for three different values of D-parameter.*

From tables 3 and 4 it follows that the magnitudes of σ_0 is approximately the same in the following cases($m_0 = 500$, $A_0 = 0$, $\tan\beta = 3$):
a) $m_{\frac{1}{2}} = 105$ GeV, D = 0.0, $\mu = -340$ GeV
b) $m_{\frac{1}{2}} = 105$ GeV, D = 0.4, $\mu = -400$ GeV
c) $m_{\frac{1}{2}} = 105$ GeV, D = 0.6, $\mu = -340$ GeV

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We now explore the possiblity of distinguishing between these different scenarios by using the $\not{E}_T$ distribution and the p_T distributions of the leading jet. In fig.1 we present the $\not{E}_T$ distribution with the kinematical cuts given above. We find that already in D = 0.4 case the distribution is considerably harder than that in the mSUGRA scenario at least in the interval $150\,\text{GeV} \leq \not{E}_T \leq 300\,\text{GeV}$. A bin by bin analysis of this distribution may disentangle the two models, if a signal is seen.
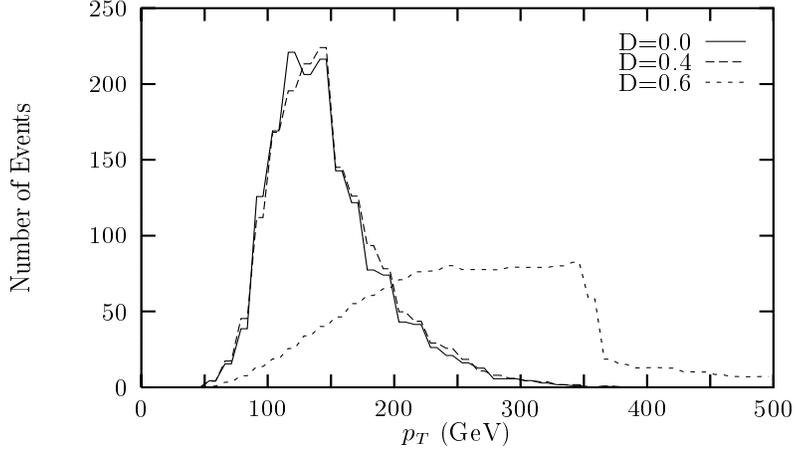

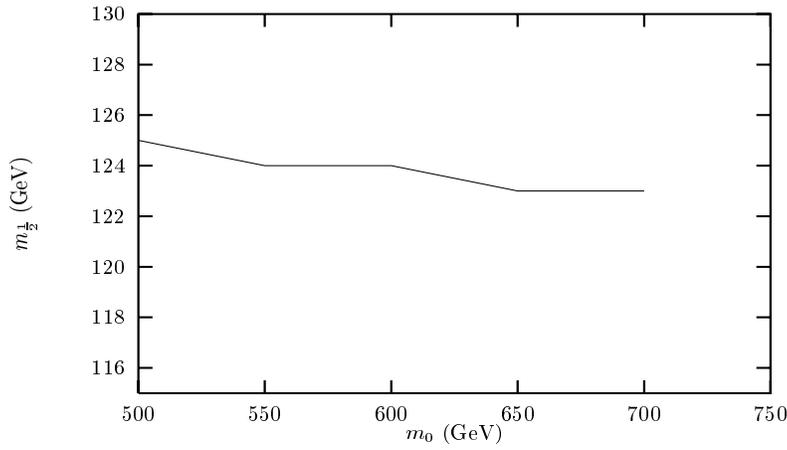**Fig. 2**: *Leading-jet P_T distribution of signal for three different values of D-parameter.*

Fig. 3: *Mass reach of jets + $\not{E}_T$ signal in $m_0 - m_{\frac{1}{2}}$ plane.*

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For the D = 0.6 case the signal has a very hard $\not{E}_T$ spectrum extending far beyond the distributions in the other two cases.

The p_T spectrum of the leading jet is presented in fig.2. It is clear that no distinction between parameter set a) and b) are possible. A much harder p_T spectrum for the leading jet, on the other hand, can easily identify the $m_{\tilde{g}} > m_{\tilde{d}_R}$ scenario (D = 0.6).

We next investigate the variation of σ_0 with m_0. As expected $m_{\tilde{d}_R}$ increases with m_0 and beyond a certain range we find $m_{\tilde{d}_R} > m_{\tilde{g}}$. Upto $m_0 \sim 700$ GeV a 5σ signal can be obtained for values of $m_{\frac{1}{2}}$ beyond the LEP limit (see fig.3).

4   OS-dileptons and clean Trileptons

We have also studied the consequence of nonuniversality in the opposite sign(OS) dilepton + jets + $\not{E}_T$ channel. For D=0.6, $m_0 = 500$ GeV, $m_{\frac{1}{2}} = 105$ GeV, $\tan\beta = 3$, $\mu < 0$, (i.e. $m_{\tilde{g}} > m_{\tilde{d}_R}$) the OS-dilepton cross-section vanishes since there is no cascade decay of the glunios. This coupled with a relatively large σ_0 makes this model totally distinct from the D = 0.0 case.

Baer *et al.* [3] have studied OS dilepton signal in great details. We have used the following cuts from [3]: $E_T(j_1)$, $E_T(j_2) \geq 50$ GeV, $\not{E}_T \geq 50$ GeV, $E_T(l_1)$, $E_T(l_2) \geq 10$ GeV, $|\eta_l| < 2.5$, and the lepton isolation criterion $R > 0.3$.

Using the above cuts we get for $m_0 = 800$ GeV, $m_{\frac{1}{2}} = 120$ GeV, $\tan\beta = 2$, $\mu < 0$, $\sigma_2 = 1.8 \; fb$ where as Baer *et al.* [3] have obtained $\sigma_2 \sim 2 \; fb$. Thus the aggrement is rather well. With harder cuts the signal/background ratio improves. But as discussed above realistic e2stimates may not be obtained from a parton level Monte Carlo with such strong cuts.

For $m_0 = 500$ GeV, $m_{\frac{1}{2}} = 105$ GeV and for $\tan\beta \simeq 2$ Baer *et al.* [3] have already analysed σ_2 in the conventional scenario. Their conclusion was that this signal is unobservable at the upgraded Tevatron. However, in their analyses they asumed $|\mu|$ to be a fixed number determined by the $SU(2) \times U(1)$ breaking condition, which may not be realistic due reasons discussed earlier.

We have re-examined the OS signal at the parton level for D = 0.0 case treating μ as a free parameter. We find that irrespective of the value of μ the cross section is unobservable even with $\mathcal{L} = 30 \; fb^{-1}$ in the conventional scenario.

But for m_0=500 GeV, $m_{\frac{1}{2}} = 105$ GeV , $\tan\beta = 3$ and D = 0.4 an observable signal may be achieved for favourable values of μ (see Table 5).

μ	σ_2	$\text{BR}(\widetilde{\chi}_2^0 \to l^+l^-\widetilde{\chi}_1^0)$	$\frac{S}{\sqrt{B}}$
-340	5.1	0.08	3
-400	7.4	0.12	4
-450	8.6	0.14	5

Table 5: The sensitivities of the *OS dilepton + jets+ $\not{E}_T$* cross sections with μ. Cross-sections are in fb and μ in GeV.

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It is clear from the Table 5 that in the non-universal case OS dilepton + $\not{E}_T$ may be observable for large $|\mu|$, using $\mathcal{L} = 30 \ fb^{-1}$. This happens since $|\mu|$ increases, $\widetilde{\chi_2}^0$ and $\widetilde{\chi_1}^0$ becomes more gaugino like and as BR $(\widetilde{\chi_2}^0 \to l^+l^-\widetilde{\chi_1}^0)$ increases. Incidentally the OS dilepton signal may be a convenient tool for distinguishing the D = 0.4 scenario (parameter set in section 3) from the others which predicts unobservable dilepton signals. The most appropriate tool for distinguishing the three parameter sets a, b, c presented in the previous section is ,however, the clean trilepton signal [23].

We again use the cuts of ref[3]; $|\eta_l| < 2.5$, $p_T(l_1) > 20$ GeV, $p_T(l_2) > 15$ GeV, $p_T(l_3) > 10$ GeV, $\not{E}_T > 25$ GeV and $|m(l\bar{l}) - M_Z| \geq 10$ GeV. In recent times it has been emphasised that the background from $W\gamma^*/Z^*$ is the most severe one in the channel [24]. In order to take care of this background we have introduced an additional invariant mass cut of $m_{l\bar{l}} > 12$ GeV. Using MADGRAPH[25] we estimate the SM background to be $\sim 5 \ fb$ subject to the above cuts. The clean 3l cross -section is presented in Table 6.

parameter set	$\sigma_{\widetilde{\chi_1}^{\pm}\widetilde{\chi_2}^0}$ in pb	BR($\widetilde{\chi_2}^0 \to l^+l^-$)	σ_{3l} in fb	$\frac{S}{\sqrt{B}}$
a	2.294	0.019	3.0	7
b	2.371	0.117	16.7	41
c	1.187	0.152	32.3	79

Table 6: The clean trilepton cross-sections in pb for different set of parameters.

From Table 6 it follows that the three scenarios can be conveniently distinguished by the clean 3l signal.

5 Conclusions

Within the framework of $N = 1$ SUGRA, it is quite possible that the $\tilde{d}_R$ squarks are significantly lighter than all other sfermions. We consider the case in which $\tilde{d}_R$ squarks have mass $\stackrel{<}{\sim} m_{\tilde{g}}$, while all other squarks are significantly heavier than the gluino, and outside the kinematical reach of the Tevatron. These light $\tilde{d}_R$ squarks have several distinctive features in comparison with the conventional MSUGRA scenario : 1) enhancement of $j + \not{E}_T$ cross-section, 2) suppression of multilepton $+ j + \not{E}_T$ cross-section and the cascade decays of the gluinos and 3)relatively hard missing energy spectrum.

Although in view of various uncertainties in Planck and GUT scale physics it is desirable to consider the scenario in a model independant way, we have considered a model based on $SO(10)$ D-terms to generate the mass spectra for the purpose of illustration.This model has only one extra parameter, namely the D-parameter, than the conventional MSUGRA model.

For $m_0 >> m_{\frac{1}{2}}$, which makes most of the squarks much heavier than the gluino, it is well known that MSUGRA does not yield an observable $j + \not{E}_T$ signal at the upgraded Tevatron for gluino masses consistent with LEP or Tevatron Run-I lower bounds [2, 13]. On the other hand if $m_{\tilde{d}_R} < m_{\tilde{g}}$, an observable signal can be seen even with anintegrated luminosity $\sim 2 \ fb^{-1}$ for $m_{\frac{1}{2}}$ just above the current lower bound. As the integratde luminosity accumulates

to $\sim 30 \ fb^{-1}$ at the upgraded Tevatron, asignificant range ($105 \ \text{GeV} \le m_{\frac{1}{2}} \le 125 \ \text{GeV}$) can be probed. The variation of this signal with $\tan \beta$ and μ is insignificant for reasons discussed in the text [4]. Although we have carried out most of the calculations for $m_o = 500$ GeV, similar signals can be achieved for any $m_o < 700$ GeV, even if $m_o >> m_{\frac{1}{2}}$.

We have also considered the possibilities of distinguishing between the various scenarios from the $j+$ $\not{E}_T$ signal at the Tevatron. We illustrate this with three values of the D-parameter: 1) $D = 0$ (conventional MSUGRA) 2) $D = 0.4$ ($m_{\tilde{d}_R} > m_{\tilde{g}}$, but $<< m_{\tilde{q}}$) and 3) $D = 0.6$ ($m_{\tilde{g}} > m_{\tilde{d}_R}$. We have chosen all other parameters such that the $j+$ $\not{E}_T$ cross-sections are comparable in all the three cases. As discussed in th text the missing energy spetrum in scenario 2) is already somewhat harder compared to that in scenario 1). This difference may observable depending on the value of the integrated luminosity. The $\not{E}_T$ spectrum in scenario 3) is much harder compared to that in 1) and 2) and extends far beyond the end point of the corresponding distributions and can be easily distinguished.

Multilepton $+j+$ $\not{E}_T$ signals may also help to distinguish between the three scenarios. In the scenario 3) the OS di-lepton $+j+$ $\not{E}_T$ is absent. In scenario 1) a slight enhancement above the SM background is possible for all values of μ, although this enhancement is not statistically significant to qualify as a genuine SUSY signal. In scenario 2) for suitable values of μ the OS di-lepton signal may be so large that it may be above the SM background in a staistically significant way.

Finally clean tri-lepton signal differ quite appreciably in the three cases. It is the largest in case 3 while in case 2 it is still muh larger than that in the conventional scenario.

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