arXiv:hep-ph/9406248v1 7 Jun 1994

CTP-TAMU-19/94
June 1994

Supersymmetry at the DiTevatron

T. Kamon, J. L. Lopez, P. McIntyre, and J. T. White

Department of Physics
Texas A&M University
College Station, TX 77832–4242

Abstract

We study the signals for supersymmetry at the Tevatron and DiTevatron ($\sqrt{s} = 4\,\mathrm{TeV}$) in various well-motivated supersymmetric models. We consider the trilepton signature in the decay of pair-produced charginos and neutralinos, the missing energy signature in gluino and squark production, and the $b\bar{b}$ signal in the decay of the lightest supersymmetric Higgs boson produced in association with a W or Z boson. In each case we perform signal and background studies, using Monte Carlo and/or real data to estimate the sensitivity to these signals at the Tevatron and DiTevatron with the Main Injector, for short- and long-term integrated luminosities of $\mathcal{L} = 10$ and $25\,\mathrm{fb}^{-1}$, and 5σ statistical significance. We conclude that one could probe chargino masses as high as $m_{\chi_1^\pm} \sim 180\,(200)\,\mathrm{GeV}$, gluino masses as high as $m_{\tilde{g}} \sim 450\,(750)\,\mathrm{GeV}$, and lightest Higgs boson masses as high as $m_h \sim 110\,(120)\,\mathrm{GeV}$ at the Tevatron (DiTevatron). A high-luminosity option at the Tevatron ($10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$) may compensate somewhat for the higher reach of the DiTevatron, but only in the trilepton and Higgs signals. However, these gains may be severely compromised once the multiple-interaction environment of the high-luminosity Tevatron is accounted for.

1 Introduction

In the wake of the demise of the Superconducting Super Collider, the high energy physics community has been seeking the most cost-effective ways to extend the reach of present facilities for new science. Three new developments during the past year suggest a particular opportunity in this regard. First, the recent announcement at Fermilab of evidence for the top quark. Second, with the results on electroweak and strong gauge couplings from CERN's LEP experiments and the new result on the top quark, the models of supersymmetry have become far more predictive and require a spectrum of new particles in the mass range of 100-1000 GeV. Supersymmetry uniquely opens the possibility to directly connect the Standard Model with an ultimate unification of the fundamental interactions. Third, the now-mature magnet technology of the SSC opens an opportunity to double the energy of the Fermilab Tevatron and access most of this predicted spectrum [1]. The DiTevatron would have a collision energy of 4 TeV and a luminosity of $3 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. It could be realized by installing a single ring of SSC-type magnets in the existing tunnel, using the exisiting source and using the Tevatron as a high-energy injector. This DiTevatron design is summarized in Appendix A. It would require no new tunnel construction, no magnet R&D, and no new detectors.

Another approach to upgrading the Tevatron, increasing its luminosity to $> 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, has also been proposed [2]. Luminosity and energy trade off up to a point in extending the reach of a collider for new physics. The recent evidence for the top quark is an example, however, of the limit of that trade-off. The evidence became possible because of a series of successful upgrades of the Tevatron luminosity which finally brought sufficient event rate to possibly observe the top; but no luminosity upgrades would have sufficed to find the massive top quark with half the Tevatron energy. The ultimate limit for the mass reach of a hadron collider, resulting from the distribution functions of the constituent quarks and gluons, is $\sim 25\%$ of its collision energy. Thus the Sp$\bar{\mathrm{p}}$S approached its limit in the discovery of the W and Z, and the Tevatron is approaching its limit with the evidence for the top quark at 174 GeV.

The purpose of this paper is to analyze the discovery potential of energy and luminosity upgrades of the Tevatron. The key question is whether one of these modest upgrades could provide a major window on new physics during the coming decade while CERN's Large Hadron Collider (LHC) is being built.

One main motivation for considering an upgraded Tevatron is to study the physics of supersymmetry. The generic Minimal Supersymmetric Standard Model (MSSM) is described in terms of a large number of parameters (at least twenty), which makes experimental tests of such a model rather impractical. Alternatively, one may consider a theoretical "framework" to reduce the number of free parameters, *e.g.*, grand unification, supergravity, or superstrings. Clearly, the more theoretical assumptions one builds in, the less parameters the models have, and the more predictive they become. Even though it is not clear which framework one should consider, once such a framework is selected, the parameter spaces of these models can be tested experimentally, either directly through collider processes or in-

directly through rare processes. For concreteness we consider here a four-parameter "conservative" framework based on supergravity grand unified models with universal soft-supersymmetry-breaking and radiative electroweak symmetry breaking. We also study more "speculative" models (minimal $SU(5)$ supergravity and string-inspired no-scale $SU(5) \times U(1)$ supergravity) which have much smaller parameter spaces and where one finds an array of further phenomenological constraints.

Within the context of these models we study three signals for new physics: (a) the trilepton signature in the decay of pair-produced charginos ($\chi_1^\pm$) and neutralinos (χ_2^0) (section 3.1), (b) the missing energy signature in gluino ($\tilde{g}$) and squark ($\tilde{q}$) production (section 3.2), and (c) the $b\bar{b}$ signal in the decay of the lightest supersymmetric Higgs boson (h) produced in association with a W or Z boson (section 3.3). In each case we perform signal and background studies, using Monte Carlo and/or real data to estimate the sensitivity to these signals at the Tevatron and DiTevatron with the Main Injector, for a short- (long-) term integrated luminosity of $\mathcal{L} = 10\,(25)\,\mathrm{fb}^{-1}$ and 5σ statistical significance. These sensitivity results are realistic and largely model independent. We then obtain the corresponding reaches in chargino, gluino, and Higgs-boson masses in the models we consider.

Finally we contrast the discovery potential of the Tevatron versus the DiTevatron in the various luminosity scenarios being considered (section 4). We conclude that the energy upgrade to the DiTevatron is the most profitable alternative for the search for supersymmetry at Fermilab.

2 The models

2.1 Conservative framework

In this case we assume that the models contain the particle content of the MSSM: the Standard Model particles and their superpartners, plus two Higgs doublets. Convergence of the precisely-measured Standard Model gauge couplings (with a suitably normalized hypercharge) then occurs at a scale $M_U \sim 10^{16}\,\mathrm{GeV}$ [3]. From the theoretical point of view, the unification of the gauge couplings is built into the grand unified model and the actual experimental test is the predicted value of $\sin^2\theta_W$ in terms of the strong coupling. Alternatively one can predict the strong coupling given $\sin^2\theta_W$. All of these tests agree very well with the data. Supergravity is then invoked as the source of the supersymmetry breaking scalar and gaugino masses. The simplest assumption is that at the unification scale supersymmetry is broken in a hidden sector with all scalar masses degenerate (m_0), as are the gaugino masses ($m_{1/2}$), and the trilinear scalar couplings (A). The set of mass parameters is then evolved down to the electroweak scale via the renormalization group equations, and the whole supersymmetric and Higgs-boson spectrum is determined (*e.g.*, $m_{\tilde{g}} \propto m_{1/2}$, $m_{\tilde{q}}^2 \approx m_0^2 + c_{\tilde{q}} m_{1/2}^2$, and A contributes to the $\tilde{t}_L - \tilde{t}_R$ mass splitting). The final step is to enforce the radiative breaking of the electroweak symmetry, which allows the determination of the Higgs mixing parameter μ (up to a sign).(For recent reviews of this procedure

see Ref. [4].) The final parameter set also includes the ratio of the Higgs vacuum expectation values ($\tan\beta > 1$), and is constrained by the present experimental lower bounds on sparticle and Higgs-boson masses. Incidentally, for users of ISAJET V7.0x [5], two of the input parameters are determined in these models, namely $|\mu|$ and the pseudoscalar Higgs-boson mass (m_A). The ISAJET parameter A_t should not be confused with the parameter A, which is the value A_t takes at the unification scale. In what follows we take $A = 0$, which nonetheless implies a non-zero value for A_t.

The top-quark mass is an essential input in the calculations, although small variations do not affect the results significantly; we take $m_t^{\rm pole} = 174\,{\rm GeV}$ [6] in discussions of this model. Our exploration of the four-dimensional parameter space is necessarily a limited one: $\tan\beta = 2, 10$; $\xi_0 \equiv m_0/m_{1/2} = 0, 1, 2, 5$; $A = 0$, and a variable chargino (*i.e.*, $m_{1/2}$) mass. (As shown in Eq. (6) below, $\xi_0 = 0, 1, 2, 5 \leftrightarrow m_{\tilde{q}} \sim (0.8, 0.9, 1, 2) m_{\tilde{g}}$.)

2.2 More speculative models

We would also like to consider models with further theoretical and phenomenological constraints, which reduce the size of the allowed parameter space. These models are particular cases of the conservative models described above.

In the minimal $SU(5)$ supergravity model [7], specification of the GUT gauge group entails two new phenomenological constraints: (i) proton decay via $p \to \bar{\nu} K^+$ [8], which entails small values of $\tan\beta$ ($\lesssim 10$), relatively light charginos and gluinos, and relatively heavy squarks and sleptons (*i.e.*, $\xi_0 \gtrsim 3$); (ii) the relic density of the lightest neutralino should not be too large [9], which in conjunction with the proton decay constraint results in $m_{\chi_1^0} \sim \frac{1}{2} m_h$ or $\sim \frac{1}{2} m_Z$. $SU(5)$ symmetry also implies unification of the bottom and tau Yukawa couplings, which favors $\tan\beta \sim 1$ [10] (or $\tan\beta \gg 1$). We do not impose this condition here as it is sensitive to relatively small perturbations that could arise from Planck-scale physics. We choose here $m_t^{\rm pole} \approx 168\,{\rm GeV}$. The combined constraints of (i) and (ii) imply

$$m_{\chi_1^\pm} \lesssim 120\,{\rm GeV}, \quad m_{\tilde{g}} \lesssim 400\,{\rm GeV}, \quad m_h \lesssim 120\,{\rm GeV}. \tag{1}$$

In the string-inspired $SU(5) \times U(1)$ supergravity model [11] there are intermediate scale particles (at $\sim 10^6\,{\rm GeV}$ and $\sim 10^{12}\,{\rm GeV}$) which delay unification until the string scale ($M_{\rm string} \sim 10^{18}\,{\rm GeV}$). We also consider the no-scale supergravity [12, 13] universal soft-supersymmetry-breaking scenario with $m_0 = A = 0$ (*i.e.*, $\xi_0 = 0$). Thus, this is a two-parameter model ($\tan\beta$ and $m_{1/2} \leftrightarrow m_{\chi_1^\pm} \leftrightarrow m_{\tilde{g}}$), which has been studied in Refs. [13, 14], including additional indirect experimental constraints (*e.g.*, from $b \to s\gamma$ and $(g-2)_\mu$ processes). We note that in $SU(5) \times U(1)$ supergravity the proton decay mode $p \to \bar{\nu} K^+$ is automatically small, the cosmological relic density is always below cosmological limits, and no Yukawa unification condition is required by the $SU(5) \times U(1)$ gauge symmetry.

3 Signals for supersymmetry

We now discuss three typical signals for supersymmetry in the models discussed above at the upgraded Tevatron, namely chargino-neutralino production and decay via the trilepton channel, the missing energy signature in squark and gluino production, and associated production of the lightest Higgs boson. These are not the only possible signals, but we believe they are the most important ones. The analysis is facilitated considerably because of the definiteness of the parameters to be explored and the relationships among the various sparticle masses. The latter will be discussed in the following subsections as needed.

3.1 Charginos and neutralinos

In the models we consider, a simple relation among the lighter neutralino and chargino masses holds to varying degrees of accuracy, namely $m_{\chi_2^0} \approx m_{\chi_1^\pm} \approx 2m_{\chi_1^0}$ [15, 13]. The process of interest: $p\bar{p} \to \chi_2^0 \chi_1^\pm X$, where both neutralino and chargino decay leptonically ($\chi_2^0 \to \chi_1^0 \ell^+ \ell^-$, $\chi_1^\pm \to \chi_1^0 \ell^\pm \nu_\ell$, with $\ell = e, \mu$) was first treated for on-shell W's in Ref. [16]. The production cross section for off-shell s-channel W-exchange and t-channel squark-exchange (a small contribution for heavy squarks), was first studied at the Tevatron in Refs. [17, 18], and has also been explored in $SU(5) \times U(1)$ supergravity in Ref. [19]. In figures 1 ($\tan\beta = 2$) and 2 ($\tan\beta = 10$) we give the cross sections into trileptons (summed over all four channels: $eee, ee\mu, e\mu\mu, \mu\mu\mu$) at the Tevatron and DiTevatron, versus the chargino mass for the conservative models discussed above. In figures 3 and 4 we show the analogous results for the minimal $SU(5)$ and no-scale $SU(5) \times U(1)$ supergravity models. Before we can assess the discovery potential of these models via the trilepton signature, we have to discuss the experimental reach in various luminosity scenarios.

The CDF and D0 collaborations have collected about $20\,\mathrm{pb}^{-1}$ of data in the 1992–93 run. The data analysis on supersymmetry searches using trilepton events sets an upper limit of about 2 pb for $\sigma(\chi_1^\pm \chi_2^0) \times B$ into all four trilepton modes ($eee, ee\mu, e\mu\mu, \mu\mu\mu$) [20, 21]. The major backgrounds are $t\bar{t}$, ZW, ZZ, $Z + X$ and $\mathrm{DY} + X$, where X could be a real lepton or a fake lepton. Hereafter, the combined lepton contribution is called "fake". The acceptance for the events is calculated using ISAJET(V7.06) + QFL (a CDF detector simulation program). This includes the detector smearing effect, inefficiency due to uninstrumented regions of the detector, and lepton identification efficiency. We also assume that (a) the beam luminous region is a Gaussian distribution with a sigma of 30 cm and that (b) the coverage for leptons in the future upgraded detector will be the same as in the current detector. The P_t (E_t) cut for the leading muon (electron) in a trilepton event is required to be 10 GeV, and the minimum P_t (E_t) cut is 4 GeV (5 GeV) for muons (electrons). Additional cuts for the event selection [21] are required:

- $|Z_{\mathrm{vertex}}| < 60$ cm,
- $\Delta R(\ell\ell) > 0.4$ (for any two leptons),

- $Iso(R = 0.4) < 2\,\mathrm{GeV}$ (energy isolation around each lepton),
- Unlike-sign requirement (e^+e^- or $\mu^+\mu^-$),
- Resonance removal: Z (75–105 GeV), Υ (9–11 GeV), and J/ψ (2.9–3.3 GeV),
- $\Delta\phi(\ell_1, \ell_2) < 170^\circ$ (for the two leading P_t leptons).

The isolation energy cut (2 GeV) is determined by looking at the fluctuation of the energy flow within $R = 0.4$ around the lepton in the data. The $\Delta\phi$ (azimuthal opening angle) cut on the two leading leptons is found to be effective in reducing the DY events by a factor of 2, whereas $\sim 10\%$ of the signal events are rejected. Trigger efficiency for the trilepton event trigger is taken to be 90% [21]. We also assume the fake lepton rate in Z and DY to be 10^{-4}. The current CDF and D0 fake lepton rates are somewhat worse; they should be improved in the future upgraded detectors.

The background is estimated as follows:

$$N_{\mathrm{BG}} = \sigma \times B_{2\ell} \times \epsilon(\mathrm{MC})_{2\ell} \times \epsilon(\mathrm{trig}) \times f \times \mathcal{L}, \quad \text{for } Z \text{ and DY} \tag{2}$$

$$= \sigma \times B_{3\ell} \times \epsilon(\mathrm{MC})_{3\ell} \times \epsilon(\mathrm{trig}) \times \mathcal{L}, \quad \text{for } ZW \text{ and } ZZ \tag{3}$$

$$= \sigma \times B_{2\ell} \times \epsilon(\mathrm{MC})_{3\ell} \times \epsilon(\mathrm{trig}) \times \mathcal{L}, \quad \text{for } t\bar{t} \tag{4}$$

where $\sigma \times B$ is the cross section to produce dilepton or trilepton final states. The production cross sections are obtained from ISAJET + CTEQ2L structure functions with K-factors of 1.0 for $t\bar{t}$,[1] 1.3 for Z and DY, and 1.4 for ZZ and ZW. With these K-factors the cross sections at $\sqrt{s} = 1.8\,\mathrm{TeV}$ are consistent with the current CDF data for Z and DY [22, 23] and theoretical calculations for $t\bar{t}$ [24], and ZZ/ZW [25, 26]. Also, $\epsilon(\mathrm{MC})_{3\ell}$ ($\epsilon(\mathrm{MC})_{2\ell}$) is an acceptance for trilepton (dilepton) events with the above cuts and is determined by a Monte Carlo simulation (ISAJET + QFL), $\epsilon(\mathrm{trig})$ is an expected trigger efficiency (90%), f is the fake rate ($f = 10^{-4}$), and $\mathcal{L}$ is the integrated luminosity.

The $t\bar{t}$ dilepton events could be an important background to the trilepton signal [17]. The additional lepton might come from the b-quark leptonic decay, which cannot be rejected with an isolation cut at certain rate. The fraction of three isolated leptons (with $Iso < 2$ GeV) in top dilepton events is determined to be $0.63\,(0.54) \times 10^{-3}$ at 2 (4) TeV. Therefore we expect $(7 \times 10^3\,\mathrm{fb})(4.4\%)(0.63 \times 10^{-3})(1\,\mathrm{fb}^{-1}) = 0.19$ events with 1 fb^{-1} at $\sqrt{s} = 2$ TeV, and 1.0 events at 4 TeV. At 4 TeV we can reduce this background by a factor of 17 by requiring no jets with $E_t \geq 25$ GeV in $|\eta(\mathrm{jet})| < 2.4$. This cut keeps 70% of the signal, *i.e.*, a drop of 30% in the signal significance. Since, as we show below, the resulting $t\bar{t}$ background is only about 25% of the other backgrounds, it is better to not impose the jet cut. This entails a degradation of the significance by only 12%.

[1] The production cross sections for $t\bar{t}$ at $\sqrt{s} = 2$ and 4 TeV are 7 (15) pb and 42 (78) pb for $m_t = 170\,(150)$ GeV [5]. The branching ratio for the dilepton mode ($t\bar{t} \to ee + X,\ e\mu + X,\ \mu\mu + X$) is 4.4%.

Table 1: Number of background events expected in trilepton searches in $p\bar{p}$ collisions at center-of-mass energy of 2 and 4 TeV for $\mathcal{L} = 1\,\mathrm{fb}^{-1}$. X represents a fake lepton.

Process	$N_{\mathrm{BG}}(2\,\mathrm{TeV})$	$N_{\mathrm{BG}}(4\,\mathrm{TeV})$
ZW	0.21	0.49
ZZ	0.04	0.08
$(Z \to \ell\ell) + X$	0.13	0.24
$(Z \to \tau\tau \to \ell\ell) + X$	0.10	0.18
$(\mathrm{DY} \to \ell\ell) + X$	1.95	3.08
$(\mathrm{DY} \to \tau\tau \to \ell\ell) + X$	0.01	0.02
$t\bar{t}$	0.19	1.00
Total	2.63 events	5.09 events

Another possible source of background comes from three-jet events faking a trilepton signal. Based on the CDF measurements of jet fragmentation [27], the probability of one charged track carrying more than 80% of its jet energy is less than 10^{-4}. This can also be used for neutral particles (with a factor of 1/2). A rough estimate of the probability that such a particle fakes an $e^{\pm}$ or $\mu^{\pm}$ in a magnetic detector (*e.g.*, CDF) is about 1–5% (depending on the tightness of the selection criteria). Therefore, we take as a conservative estimate for the fake rate of a jet being misidentified as $e^{\pm}$ or $\mu^{\pm}$ the value 10^{-5}. Since the three-jet cross section is about 1 mb, the contribution to "trilepton" events is $1\,\mathrm{mb} \times (10^{-5})^3 = 10^{-3}\,\mathrm{fb}$.

The estimated number of background events at $\sqrt{s} = 2, 4\,\mathrm{TeV}$ with $\mathcal{L} = 1\,\mathrm{fb}^{-1}$ are given in Table 1.[2] From Table 1 we calculate the sensitivity (minimal observable signal cross section) for trilepton searches for a 5σ statistical significance:

$$\mathrm{Sensitivity}\,[\,\mathrm{fb}] = \frac{5 \times \sqrt{N_{\mathrm{BG}}}}{\mathcal{L} \times \epsilon(\mathrm{MC}) \times \epsilon(\mathrm{trig})}\ . \tag{5}$$

The value of ϵ(MC) depends on the chargino mass and on whether the leptonic decay is dominantly a two-body or a three-body process. For three-body decays, a typical value is $\epsilon(\mathrm{MC}) \times \epsilon(\mathrm{trig}) = 0.12\,(0.09)$ at 2 (4) TeV, which is valid for $m_{\chi_1^\pm} \approx 120\,\mathrm{GeV}$ and does not change much for $m_{\chi_1^\pm} \gtrsim 120\,\mathrm{GeV}$. We have found that the acceptance for two-body decays for $m_{\chi_1^\pm} \gtrsim 120\,\mathrm{GeV}$ is almost the same as that for the three-body decays. The reason is that our trigger lepton P_t threshold (10 GeV) is low enough to detect the highest P_t lepton in two- or three-body decays, and our minimum lepton P_t cuts (5 GeV for e and 4 GeV for μ) are low enough for unbiased detection of the other two leptons. Since the $\chi_1^\pm$ and χ_2^0 are relatively heavy, most leptons tend to be detected in the central region. Therefore, the acceptance

[2]Here we use $m_t = 170\,\mathrm{GeV}$. Using $m_t = 150\,\mathrm{GeV}$ instead increases the total number of background events by 8% (17%) at $\sqrt{s} = 2\,(4)\,\mathrm{TeV}$.

Table 2: Sensitivity at 5σ significance for trilepton searches into $eee, ee\mu, e\mu\mu, \mu\mu\mu$ at the Tevatron and DiTevatron, for expected short- and long-term integrated luminosities. We assume 0.12 (0.09) efficiency for trilepton detection at 2 (4) TeV. The sensitivity at the Tevatron at the end of Run IB (1994–95, $\mathcal{L} \sim 0.1\,\mathrm{fb}^{-1}$) is expected to be $\sim 400\,\mathrm{fb}$.

$\sqrt{s}$	$\mathcal{L}(\,\mathrm{fb}^{-1})$	N_{BG}	N_{S}	Sensitivity(fb)
2 TeV	10	26	25	21
	25	66	41	14
4 TeV	10	51	36	40
	25	127	56	25

for trilepton events is mainly limited by the detector coverage (fiducial region in η and ϕ). In what follows we use the typical value $\epsilon(\mathrm{MC}) \times \epsilon(\mathrm{trig}) = 0.12\,(0.09)$ at 2 (4) TeV.

The above discussion assumes that the leptons are hard enough to be detectable, but this may not always be the case when two-body decays dominate. Kinematically speaking, in the parent rest-frame the P_t cuts entail a minimum detectable daugther lepton energy (E_ℓ^{min}), and thus a minimum mass difference (Δm) between the chargino (neutralino) and the sneutrino (selectron) when the two-body decay $\chi_1^\pm \to \tilde{\nu} e^\pm$ ($\chi_2^0 \to \tilde{e}_R e$) is allowed and dominates the decay amplitude (*i.e.*, $\Delta m \gtrsim E_\ell^{\mathrm{min}}$ for parent masses in the range of interest). In the Lab frame these simple relations are smeared and a simulation is required to obtain the P_t distribution as a function of Δm. As an example, we studied a case (for $\xi_0 = 0$ and $\tan\beta = 2$) with $m_{\chi^\pm} = 112.6\,\mathrm{GeV}$ and $m_{\tilde{\nu}} = 111.2\,\mathrm{GeV}$ (*i.e.*, $\Delta m = 1.4\,\mathrm{GeV}$). In this case the efficiency for trilepton events was found to be $\frac{1}{4}$ of the 12% quoted above. This result is encouraging since such small values of Δm occur only rarely in the models we have studied, and only for $\xi_0 = 0$. (However, it is precisely for this value of ξ_0 that one gets the largest trilepton rates (see Figs. 1,2).)

In Table 2 we summarize the sensitivities for two integrated luminosity scenarios with and without the energy upgrade. We assume an instantaneous luminosity of $3 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, which could be achieved with the Main Injector (see Appendix A) and is the expected upper limit allowed by the present CDF and D0 detectors (including their planned Main-Injector-era upgrades). With a 50% duty cycle, one would accumulate $10\,\mathrm{fb}^{-1}$ in two years (short term) and $25\,\mathrm{fb}^{-1}$ in five years (long term). We do not consider the proposed luminosity upgrade (so-called T* Tevatron) to $10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ since that would require basically new expensive detectors and a time-line which is beyond the planned start-up time of the LHC.

Taking the sensitivities given in Table 2, we can determine the approximate reach in chargino masses for each of the (conservative) models in the various scenarios by examining figures 1 and 2. These reaches are given in Table 3. Note the many

Table 3: Reach for chargino masses at 5σ significance in $p\bar{p}$ collisions at the Tevatron and DiTevatron for $\mathcal{L} = 10\,(25)\,\mathrm{fb}^{-1}$ in the conservative models which we consider. All masses in GeV. An asterisk indicates that the whole allowed range of chargino masses is covered.

Parameters		Tevatron		DiTevatron	
$\tan\beta$	ξ_0	$\mu > 0$	$\mu < 0$	$\mu > 0$	$\mu < 0$
2	0	$125^*\,(125^*)$	$170\,(180)$	$125^*\,(125^*)$	$190^*\,(190^*)$
	1	$155\,(155)$	$160\,(170)$	$155\,(155)$	$175\,(185)$
	2	$140\,(150)$	$135\,(145)$	$150\,(155)$	$145\,(160)$
	5	$115\,(125)$	$115\,(125)$	$120\,(135)$	$115\,(130)$
10	0	$100\,(110^*)$	$115^*\,(115^*)$	$100\,(110^*)$	$115^*\,(115^*)$
	1	$125\,(135)$	$135\,(145)$	$135\,(145)$	$140\,(155)$
	2	$95\,(105)$	$105\,(115)$	$95\,(110)$	$110\,(125)$
	5	$95\,(105)$	$105\,(115)$	$95\,(110)$	$110\,(125)$

instances where the whole range of chargino masses is accessible (*i.e.*, the asterisks in Table 3). In the case of the minimal $SU(5)$ supergravity model, because of the model contraints in Eq. (1), basically the whole range of chargino masses should be accessible at the Tevatron and DiTevatron with $\mathcal{L} = 25\,\mathrm{fb}^{-1}$, as figure 3 shows. Note that the slope of the trilepton rate plots is comparable to the $\xi_0 = 5$ curves in Fig. 1, since in this model $4 \lesssim \xi_0 \lesssim 10$. This also implies that a limiting point is reached where increasing ξ_0 further does not change the slope of the plots anymore.

For the no-scale $SU(5) \times U(1)$ supergravity model (see Fig. 4), aymptotically the trilepton rates are comparable with the $\xi_0 = 0$ cases in Fig. 1, since in this model $m_0 = 0$. There are however some differences, especially for lighter values of the chargino mass. These are due to the somewhat different relationships among the sparticle masses compared to the conservative models (for $\xi_0 = 0$), because of the different unification scales. The reach in this case would be (for $\mu < 0$) $m_{\chi_1^\pm} \approx 190\,(200)\,\mathrm{GeV}$ at the Tevatron and $220\,(240)\,\mathrm{GeV}$ at the DiTevatron, for $\mathcal{L} = 10\,(25)\,\mathrm{fb}^{-1}$.

3.2 Gluino and squarks

The relationship between gluino and squark masses depends on the parameter ξ_0. In the conservative models discussed above, the average squark mass is approximately given by (for $\alpha_3 = 0.120$)

$$\begin{aligned} m_{\tilde{q}} &\approx m_{\tilde{g}} \left(\frac{\sqrt{6+\xi_0^2}}{2.9} \right) \\ &\approx 0.84\, m_{\tilde{g}} \qquad \text{for } \xi_0 = 0 \end{aligned} \tag{6}$$

$$
\begin{aligned}
&\approx 0.91\, m_{\tilde{g}} \qquad \text{for } \xi_0 = 1 \\
&\approx 1.09\, m_{\tilde{g}} \qquad \text{for } \xi_0 = 2 \\
&\approx 1.91\, m_{\tilde{g}} \qquad \text{for } \xi_0 = 5
\end{aligned}
$$

In order to determine the reach of the Tevatron and DiTevatron for squarks and gluinos, we studied the two extreme cases: (i) gluino pair production with significantly heavier squarks, *i.e.*, the limit $\xi_0 \gg 1$ in Eq. (6) (also expected in the minimal $SU(5)$ supergravity model), and (ii) all gluino squark production channels such that $m_{\tilde{q}} \approx m_{\tilde{g}} - 10\,\text{GeV}$, as expected for $\xi_0 \lesssim 1$ (also expected in the no-scale $SU(5) \times U(1)$ model). For case (i), events were generated using ISAJET (V7.06) for different gluino masses with $m_{\tilde{q}} = m_{\tilde{b}} = m_{\tilde{t}} = 1\,\text{TeV}$. For case (ii), all squarks were given masses 10 GeV less than the gluino mass while sleptons and sneutrinos were left at 1 TeV. In both cases, the following additional parameters were chosen: $\tan\beta = 2$, $\mu = -500\,\text{GeV}$, $A_t = -100\,\text{GeV}$, and $m_A = 500\,\text{GeV}$.

The events were processed through a toy calorimeter using energy smearing with D0 resolution and jet finding algorithm with a cone with $R = 0.7$. A variety of cuts based on missing P_t and the number of jets above a given threshold were studied to achieve a reasonable signal-to-background ratio. Other more refined cuts (such as the direction of the missing P_t vector relative to the leading jets) were not considered. The following selection criteria were then applied:

- Tevatron: missing $P_t > 100\,\text{GeV}$, 3 jets with $P_t > 40\,\text{GeV}$
- DiTevatron: missing $P_t > 150\,\text{GeV}$, 4 jets with $P_t > 40\,\text{GeV}$

For the background estimate, only the dominant $Z \to \nu\nu$ channel was generated (using ISAJET).[3] For selections with large missing P_t, and with the upgraded detectors, it was assumed that contributions from leptonic W decays with missed electrons and muons will be no larger than the $Z \to \nu\nu$ background, and that QCD backgrounds are negligible. To account for these and any other backgrounds, and for any inefficiencies from additional cuts, the $Z \to \nu\nu$ background was multiplied by a factor of five. This should provide a conservative estimate of the reach based on current CDF and D0 experience.

An estimate of the reach with $\mathcal{L} = 10\,\text{fb}^{-1}$ for these two cases is shown in Fig. 5 for the Tevatron and in Fig. 6 for the DiTevatron, in terms of the statistical significance $N_S/\sqrt{N_{BG}}$. For other values of $\mathcal{L}$, simply multiply the significance by a factor of $(\mathcal{L}/10\,\text{fb}^{-1})^{1/2}$. The reaches that could be achieved with $\mathcal{L} = 10\,(25)\,\text{fb}^{-1}$ are summarized in Table 4.

Note that in the minimal $SU(5)$ supergravity model (where $m_{\tilde{q}} \gg m_{\tilde{g}}$), the whole range of allowed gluino masses (see Eq. (1)) could be explored at the DiTevatron. For the case consistent with $\xi_0 \lesssim 1$ (*i.e.*, $m_{\tilde{q}} \approx m_{\tilde{g}}$), the DiTevatron could explore ultimately roughly 75% of the parameter space.

[3] We have also studied the possible $t\bar{t} \to \ell\nu + n - \text{jets}$ background, where the lepton from W decay is lost. For $m_t = 170\,\text{GeV}$ we found the $t\bar{t}$ background to be no larger than the $Z \to \nu\nu$ background. For completeness, a detector-dependent discussion is given in Appendix B.

Table 4: Reach for gluino masses at 5σ significance in $p\bar{p}$ collisions at the Tevatron and DiTevatron for $\mathcal{L} = 10$ and $25\,\mathrm{fb}^{-1}$ in the two extreme scenarios: (i) $m_{\tilde{q}} \gg m_{\tilde{g}}$ and (ii) $m_{\tilde{q}} = m_{\tilde{g}} - 10\,\mathrm{GeV}$. The ranges indicate the allowed uncertainty in the background: $(Z \to \nu\bar{\nu})$ up to $5 \times (Z \to \nu\bar{\nu})$. All masses in GeV.

	Tevatron		DiTevatron	
$\mathcal{L}$	$m_{\tilde{q}} \gg m_{\tilde{g}}$	$m_{\tilde{q}} = m_{\tilde{g}} - 10$	$m_{\tilde{q}} \gg m_{\tilde{g}}$	$m_{\tilde{q}} = m_{\tilde{g}} - 10$
$10\,\mathrm{fb}^{-1}$	330–370	400–430	540–590	670–720
$25\,\mathrm{fb}^{-1}$	360–400	410–440	560–610	690–750

3.3 Lightest Higgs boson

For the models we consider in this paper the lightest Higgs boson is very much Standard-Model–like, and thus the LEP limit on the Standard Model Higgs-boson mass ($m_H \gtrsim 65\,\mathrm{GeV}$) applies as well here. The mass of the lightest supersymmetric Higgs boson (h) is bounded above by an m_t-dependent limit: $m_h \lesssim 120\,(130)\,\mathrm{GeV}$ for $m_t = 150\,(170)\,\mathrm{GeV}$. Therefore, signatures for the difficult intermediate-mass Higgs boson need to be explored. We consider the associated production mechanism $p\bar{p} \to W^*, Z^* \to Wh, Zh$ [28, 29], which has been recently revisited in Ref. [30]. The decays of the Higgs boson in this mass range are dominantly to $b\bar{b}$ final states, except when the supersymmetric $h \to \chi_1^0\chi_1^0$ mode is kinematically allowed (in a small region of parameter space).

Higgs searches will be in the mainstream of any future collider program. At the moment only the planned LHC supercollider at CERN could possibly explore the largest range of Higgs parameter space. However, this will require ultimate luminosity ($> 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$) and any detector will suffer from numerous multiple interactions. This makes background (physics, fake, and maybe a combination of both) analyses difficult. In light of the proposed Tevatron upgrades [1, 2], two analyses have appeared dealing with associated Higgs production and detection [31, 32]. Moreover, it has been pointed out that double b-tagging reduces the $W+jj/Z+jj$ background substantially, but $W + bb/Z + bb$ and $W + jj/Z + jj$ remain the main background sources [31, 32]. Since the lightest Higgs boson in the models of interest here looks very much like the Standard Model Higgs boson, in what follows we concentrate on the latter.

We have studied the event topology of $H \to b\bar{b}$ decay using the PYTHIA Monte Carlo program [33] to see if any further useful cuts (beyond those imposed in Refs. [31, 32]) may exist that enhance the signal-to-background ratio. We found that a cut in $\cos(\theta^*)$, where θ^* is the polar angle with respect to the $2b$ (or $2j$) direction in the $b\bar{b}$ (or jj) center-of-mass system, reduces the QCD background while keeping a large fraction of the signal. A plot of this distribution is shown in Fig. 7. In our study we considered $Z + H \to ee + b\bar{b}$ and $Z(\to ee) + b\bar{b}$ with a smearing of electron and jet energies: $\sigma/E = 15\%/\sqrt{E} \oplus 1\%$ for electrons and $\sigma/E = 80\%/\sqrt{E} \oplus 5\%$ for jets. After the smearing the following kinematical and geometical cuts were imposed:

Table 5: Improvement factor of $Z + (H \to b\bar{b})$ signal over $Z + b\bar{b}$ background in the presence of the $\cos(\theta^*)$ cut discussed in the text. Results are for $p\bar{p}$ collisions at center-of-mass energy of 4 TeV. For the signal, we get an average $\langle R_{\rm S}\rangle = 0.75$. The improvement factor is defined as $I = \langle R_{\rm S}\rangle / [R_{\rm BG}]^{1/2}$.

$M_{b\bar{b}}$(GeV)	$R_{\rm BG}$	$R_{\rm S}$	I
100 ± 20	0.46	0.724	1.11
110 ± 20	0.40	0.750	1.19
120 ± 20	0.36	0.749	1.25
140 ± 20	0.35	0.744	1.27

- For b: $|\eta(b)| < 2,\ P_t(b) > 15\,{\rm GeV}$
- For ℓ: $|\eta(\ell)| < 2,\ P_t(\ell) > 20\,{\rm GeV}$
- Topology cuts: $\Delta R(b\bar{b}) > 0.7,\ \Delta R(b\ell) > 0.7$

After the event selection, the $\cos(\theta^*)$ cut is imposed

$$\cos(\theta^*) < 0.7 \tag{7}$$

in the $b\bar{b}$ center-of-mass system. This cut accepts 75% of the signal (mass-independent) and 35%-46% (depending on the Higgs-boson mass) of the background. Table 5 summarizes the ratio of event acceptance,

$$R = \frac{\#\text{events with the } \cos(\theta^*) \text{ cut}}{\#\text{events without the } \cos(\theta^*) \text{ cut}}\ , \tag{8}$$

for background and signal. We also define the improvement factor of the significance as

$$I = \langle R_{\rm S}\rangle / \sqrt{R_{\rm BG}}, \tag{9}$$

where $\langle R_{\rm S}\rangle$ is the average value of $R_{\rm S}$. These numbers are also listed in Table 5.

We see that the significance of the signal is improved by 10%–30% for Higgs-boson masses in the range $(100 - 140)\,{\rm GeV}$, when adding the $\cos(\theta^*)$ cut. This improvement factor can also be used for $W+H$ over $W+jj/W+b\bar{b}$. If we can assume a similar improvement factor for all other backgrounds ($t\bar{t}, Wg \to t\bar{b}, q\bar{q} \to t\bar{b}$, WZ [4]) then we can push up somewhat the Higgs-boson mass reaches at the DiTevatron. We start from Table 1 of Ref. [31], where the signal, background, and statistical significance are given for $m_H = (60 - 130)\,{\rm GeV}$ at the DiTevatron with $\mathcal{L} = 30\,{\rm fb}^{-1}$;

[4]For $M_{b\bar{b}} \gtrsim 110\,{\rm GeV}$ this background is smaller than all the others (see Table 2 in Ref. [32] or Fig. 2 in Ref. [31]). On the other hand, for $M_{b\bar{b}} \approx 90 \pm 20\,{\rm GeV}$, this background is the dominant one and the $\cos(\theta^*)$ cut is not as effective (*i.e.*, we find $R_{\rm BG} = 0.65$).

Table 6: Number of signal ($N_{\rm S}$) and background ($N_{\rm BG}$) events at the DiTevatron with $\mathcal{L} = 10\,{\rm fb}^{-1}$ for associated Higgs-boson production and decay through the $b\bar{b}$ mode. We also show the statistical significance (Sig $= N_{\rm S}/(N_{\rm BG})^{1/2}$), the improvement factor (I) from Table 5, the corresponding improved signicance (Sig$^{\rm I}$), and the required integrated luminosity for discovery (5σ).

m_H	$N_{\rm S}$	$N_{\rm BG}$	Sig	I	Sig$^{\rm I}$	$\mathcal{L}(5\sigma)$
110	32	110	3.1	1.19	3.6	$19\,{\rm fb}^{-1}$
120	23	87	2.4	1.25	3.1	$26\,{\rm fb}^{-1}$

we use the double b-tagging option. For $m_H = 110, 120\,{\rm GeV}$, in Table 6 we show the rescaled values for $\mathcal{L} = 10\,{\rm fb}^{-1}$, along with the improved values using the I-factor in Table 5, and the required integrated luminosity for discovery (5σ). We can see that the DiTevatron would see evidence (3σ) for Higgs-boson masses up to $m_H = 120\,{\rm GeV}$ with $\mathcal{L} = 10\,{\rm fb}^{-1}$ (short-term) and would discover Higgs bosons (5σ) up to the same mass with $\mathcal{L} = 25\,{\rm fb}^{-1}$ (long-term). For comparison, at the Tevatron the significance of the $m_H = 120\,{\rm GeV}$ signal is 1.7 before the $\cos(\theta^*)$ cut and 2.1 after the cut. Therefore, $57\,{\rm fb}^{-1}$ would be required to achieve a 5σ significance.

We should add that in addition to the $H \to b\bar{b}$ mode, it has been recently pointed out [35] that the $H \to \tau^+\tau^-$ mode could be used to increase the significance of the Higgs signal. We have also studied this mode and find the signal to be small once currently available experimental data are used to determine the expected dectection efficiencies. Moreover, the expected backgrounds are large and it appears difficult to reduce them enough to obtain a statistically meaningful result. A summary of this analysis is given in Appendix C.

As we have indicated above, the above mass reach ($m_H \lesssim 120\,{\rm GeV}$) applies to the lightest Higgs boson (h) in the supergravity models also. Moreover, in this case there is an upper limit on m_h which depends on m_t: $m_h \lesssim 120\,(130)\,{\rm GeV}$ for $m_t = 150\,(170)\,{\rm GeV}$. Therefore, Higgs searches at the DiTevatron would probe a large fraction (if not all) of the parameter space of the various models which we have considered. In contrast, the reach of LEPII for Higgs-boson searches is roughly $\sqrt{s} - 95\,{\rm GeV}$ [34]. With a beam energy of $\sqrt{s} = 190\,{\rm GeV}$, the mass reach would be $m_h \lesssim 95\,{\rm GeV}$.

4 Discussion and conclusions

Let us now contrast the potential of the Tevatron versus the DiTevatron for probing the parameter space of the models we consider. For trileptons searches, the $\xi_0 = 0$ case of the conservative models gives the largest rates, which decrease for increasing values of ξ_0. The reaches for various values of ξ_0 and $\tan\beta$ are summarized in Table 3. Generally speaking, unless the Tevatron can already reach all of the allowed range

of chargino masses, the DiTevatron results in an increase of 5–15 GeV in the reach for chargino masses, for the same integrated luminosity. The increases are larger for $\tan\beta = 2$ and the smaller values of ξ_0.

In the minimal $SU(5)$ supergravity model the rates are smaller (since $\xi_0 \gtrsim 3$), but a much smaller range of chargino masses needs to be explored (see Eq. (1)), and both the Tevatron and DiTevatron would explore *all* of the allowed parameter space with $\mathcal{L} = 25\,\mathrm{fb}^{-1}$. The no-scale $SU(5)\times U(1)$ supergravity model, essentially a $\xi_0 = 0$ model, predicts somewhat larger trilepton rates than its $\xi_0 = 0$ conservative model counterpart, and likely constitutes the upper limit for trilepton rates in supergravity models. The reach in this case would be (for $\mu < 0$) $m_{\chi_1^\pm} \approx 190\,(200)\,\mathrm{GeV}$ at the Tevatron and $220\,(240)\,\mathrm{GeV}$ at the DiTevatron, for $\mathcal{L} = 10\,(25)\,\mathrm{fb}^{-1}$.

We should point out that the sensitivity of the DiTevatron for trileptons would be enhanced if the tracking and calorimeter coverage are improved relative to those in the present CDF detector. This effect is reflected in the analysis by the drop in acceptance from 12% down to 9% when going from 2 to 4 TeV.

For gluino and squark searches, the reaches are summarized in Table 4 for the two extreme scenarios of heavy squarks, and comparable squark and gluino masses. We conclude that at the Tevatron the reach for gluinos would not exceed $\sim 430\,(440)\,\mathrm{GeV}$ with $\mathcal{L} = 10\,(25)\,\mathrm{fb}^{-1}$. Considering that squarks and gluinos can be as massive as $\sim 1\,\mathrm{TeV}$, this is a modest ($\sim 45\%$) reach into parameter space. At the DiTevatron the reach would improve significantly: $m_{\tilde{g}} \approx m_{\tilde{q}} \sim 720\,(750)\,\mathrm{GeV}$ with $\mathcal{L} = 10\,(25)\,\mathrm{fb}^{-1}$, *i.e.*, $\sim 75\%$ of the parameter space. Equation (1) shows that *all* of the parameter space of minimal $SU(5)$ model could be explored for both machines. Note that the reach for gluinos and squarks at the DiTevatron is considerably larger than the corresponding reach at the Tevatron. This significant improvement is due to that the Tevatron is at the phase space limit for squark and gluino production.

For Higgs searches through the $b\bar{b}$ mode the reaches are summarized in Table 6. Incorporating our $\cos(\theta^*)$ cut, at the DiTevatron one could see evidence (3σ) for Higgs boson masses as high as 120 GeV with $\mathcal{L} = 10\,\mathrm{fb}^{-1}$ (short-term) and discover (5σ) Higgs bosons up to 120 GeV with $\mathcal{L} = 25\,\mathrm{fb}^{-1}$ (long-term). In the supergravity models that we consider, these results also apply to the lightest supersymmetric Higgs boson, whose mass is however, bounded above by $m_h \lesssim 120 - 130\,\mathrm{GeV}$.

In summary, we conclude that the DiTevatron with the luminosity level provided by the Main Injector is a superior machine compared to the Tevatron for the same luminosity, *as far as the search for supersymmmetry is concerned*. To make this point apparent in a concise way, we have tabulated all the relevant physics results in Table 7. In this table we also show numbers of events for some interesting Standard Model processes which have a bearing in the search for supersymmetry for practical purposes, *i.e.*, calibration and precise determination of backgrounds.

Acknowledgments

This work has been supported in part by DOE grant DE-FG05-91-ER-40633. We would like to thank Dick Arnowitt for many suggestions and comments and for reading the manuscript. We would also like to thank Howie Baer and Xerxes Tata for useful discussions.

Table 7: Detected signal (background) for processes of major physics interest at the Tevatron and DiTevatron. $\mathcal{L} = 10\,\text{fb}^{-1} = 3 \times 10^{32} \times 2\,\text{years}\,@\,50\%$. Note: $r = \sigma(4\text{TeV})/\sigma(2\text{TeV})$. A asterisk indicates that the CDF detector coverage is assumed.

$\sqrt{s}$ $(p\bar{p})$	2 TeV	4 TeV	Comments
•Top quark (∗):			
$t\bar{t}$ ($m_t = 170$ GeV)	7.6 K (3.8 K)	46 K (23 K)	$r = 6$ based on Ref. [6]
•Higgs boson:			
$W + H \to \ell\nu + b\bar{b}$			
$m_H = 100$ GeV	27 (120)	44 (142)	Refs. [30, 31, 32]
$m_H = 120$ GeV	14 (71)	23 (87)	Refs. [30, 31, 32]
$m_H = 120$ GeV	11 (25)	17 (30)	Refs. [30, 31, 32] with $\cos(\theta^*_{bb})$ cut
•Weak bosons (∗):			
$W \to \ell\nu$	13.1 M	28.8 M	$r = 2.2$
$Z \to \ell\ell$	1.4 M	3.1 M	$r = 2.2$
•Dibosons (∗):			
$WW \to 2\ell + 2\nu$	156	452	$r = 2.9$
$WZ \to 3\ell + 1\nu$	106	297	$r = 2.8$
$ZZ \to 4\ell$	16	42	$r = 2.6$
$W\gamma \to \ell\nu + \gamma$	13.6 K (6.2 K)	29.9 K (13.6 K)	$r = 2.2$; $E_t^{\gamma} > 7$ GeV, $\Delta R_{\ell\gamma} > 0.7$
$Z\gamma \to \ell\ell + \gamma$	6.4 K (0.4 K)	12.2 K (0.8 K)	$r = 1.9$; $E_t^{\gamma} > 7$ GeV, $\Delta R_{\ell\gamma} > 0.7$
•Supersymmetry:			
$W + h \to \ell\nu + b\bar{b}$			
$m_h = 120$ GeV	11 (25)	17 (30)	Ref. [30, 31, 32] with $\cos(\theta^*_{bb})$ cut SM-like couplings
$\chi_1^{\pm}\chi_2^0$ $(\to \ell\ell\ell X)$ $(*)$			
$m_{\chi_1^{\pm}} = 150$ GeV	32 (26)	68 (51)	$\xi_0 = 1;\ \mu < 0, \tan\beta = 2$
$m_{\chi_1^{\pm}} = 170$ GeV	16 (26)	39 (51)	$\xi_0 = 1;\ \mu < 0, \tan\beta = 2$
$m_{\chi_1^{\pm}} = 190$ GeV	6 (26)	17 (51)	$\xi_0 = 1;\ \mu < 0, \tan\beta = 2$
$\tilde{g}\tilde{g},\ \tilde{g}\tilde{q},\ \tilde{q}\tilde{q}$	$3j + \not\!\!E_t$	$4j + \not\!\!E_t$	Jet $P_t > 40$ GeV
$(\to n\text{-jets} + \not\!\!E_t)$	> 100 GeV	> 150 GeV	
(a) $m_{\tilde{q}} = m_{\tilde{g}} - 10$ GeV			
$m_{\tilde{g}} = 400$ GeV	270 (3700)	11300 (4350)	$N_{\text{BG}} = 5 \times N_{Z\to\nu\nu}$
$m_{\tilde{g}} = 700$ GeV	20 (3700)	195 (4350)	$N_{\text{BG}} = 5 \times N_{Z\to\nu\nu}$
(b) $m_{\tilde{q}} = 1000$ GeV			
$m_{\tilde{g}} = 300$ GeV	602 (3700)	5600 (4350)	$N_{\text{BG}} = 5 \times N_{Z\to\nu\nu}$
$m_{\tilde{g}} = 400$ GeV	79 (3700)	2170 (4350)	$N_{\text{BG}} = 5 \times N_{Z\to\nu\nu}$
$m_{\tilde{g}} = 500$ GeV	5 (3700)	580 (4350)	$N_{\text{BG}} = 5 \times N_{Z\to\nu\nu}$

A The DiTevatron

The Tevatron is the highest energy collider in the world today. The recently reported evidence for the top quark was only possible because of the energy reach of the Tevatron: its discovery at a lower collision energy would have been unthinkable, even with arbitrarily high luminosity. The Tevatron's single magnet ring produces collisions of protons and antiprotons at $\sqrt{s} = 1.8\,\mathrm{TeV}$. The superconducting magnets of the ring operate at a field strength of 4.1 Tesla at the peak beam energy of 900 GeV. The Tevatron is itself an upgrade of the original Main Ring at Fermilab, which accelerated beams of protons to 400 GeV for fixed target experiments. The luminosity of the Tevatron is currently being upgraded to $10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.

The crowning success of the ill-fated Superconducting Super Collider was the development to production readiness of a 6.5 Tesla superconducting dipole and corresponding quadrupole. A string of these magnets were operated successfully at this field at 4.2°K, validating the magnet technology required for SSC. The same magnets were also operated at 2°K, producing a field of 8.8 Tesla. A ring of such magnets, placed in the existing Fermilab tunnel, could use the same source and the Tevatron as injector, and produce collisions at $\sqrt{s} = 4\,\mathrm{TeV}$ - the DiTevatron. The beams adiabatically damp as they are accelerated, so that the DiTevatron luminosity would be $3 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The DiTevatron makes it possible to envision doubling the energy of the Tevatron, with no new tunnel construction, no magnet R&D, and no new detectors. It is estimated to cost $250 million, and would require ~ 4 years to build.

This remarkable opportunity is the result of four happy circumstances. First, the Tevatron magnet ring and the DiTevatron ring could be situated in the existing tunnel compatibly. Figure 8 shows the tunnel cross section in which the Tevatron has been moved up; the DiTevatron is located on the tunnel floor, preserving the same beam elevation through the collider experiments; and the magnet elements required for transfer of beams for fixed-target physics are routed over the two rings.

Second, the Tevatron can be used to advantage as a high-energy injector for the new ring. Many of the most challenging requirements on the superconducting magnets concern its field quality at injection energy E_0. Figure 9(a) shows the measured field distribution in the superconducting magnets of the Tevatron. Its effective full aperture for colliding beams is 5 cm. Figure 9(b) shows the measured field distribution in the superconducting magnets for the SSC. The sextupole term in B_y was introduced by design and can be removed straightforwardly. By the same criteria of field quality, the effective full aperture of the SSC magnet for colliding beams is 3 cm. The beam size damps as $1/\sqrt{E_0}$, so the higher the injection energy the less is the required aperture of the magnets. Thus, with injection to DiTevatron at 400 GeV compared to injection to Tevatron at 150 GeV, the 5 cm Tevatron aperture maps to a DiTevatron aperture requirement of $\sqrt{150/400} \times 5\,\mathrm{cm} = 3\,\mathrm{cm}$. The SSC magnets are thus adequate for DiTevatron use substantially as-is.

Also at injection, the persistent currents in the superconducting cables of the magnet produce error multipole fields which can dilute the beams' brightness before they can be accelerated. Figure 10 shows the magnitude of these multipoles for the

magnets of the Tevatron. As indicated, these multipoles would be negligible at the field strength corresponding to 400 GeV injection to the DiTevatron.

Third, the forces on the conductors in the SSC magnets are still under suitable levels of preload compression at a field strength of 8.8 Tesla. Figure 11 shows the measured stress in the conductor package, as a function of field strength. The coils of superconducting magnets are assembled with a preloaded compressive stress which must be greater than the maximum Lorentz stress produced at full field; otherwise coil motion and quenching would occur when the direction of net stress reversed. Although the SSC magnets were designed to operate at 6.5 Tesla, its mechanical design contains sufficient prestress to support operation at 8.8 Tesla.

Lastly, the cryogenic requirement to operate the DiTevatron ring at 2°K would require an additional refrigeration loop in the current Fermilab cryogenic plant (which operates at 4°K), but would not pose a major additional overall refrigeration load. The present Tevatron magnets have a heat load which is ~ 10 times greater than that of the SSC magnets. The additional load of the DiTevatron, cooling at 2°K, would present a $\sim 20\%$ increase in the aggregate cooling power.

B $t\bar{t}$ background in $\tilde{g}, \tilde{q}$ searches

We have studied the missing E_t ($\not\!\!E_t$) signal with multi-jets from $t\bar{t} \to \ell\,\nu + n$-jets and $Z \to \nu\nu$ for the signal events ($\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, $\tilde{q}\tilde{q}$). We used ISAJET V7.06 to generate the signal events; Table 8 summarizes the cross sections obtained by ISAJET.

Table 8: Cross sections at $\sqrt{s} = 4$ TeV

Physics Process	σ [pb]	Comments
$B1$: $Z \to \nu\nu$	152	$P_t(Z) \geq 40$ GeV
$B2$: $t\bar{t} \to \ell\nu + n$-jets	12	$m_t = 170$ GeV; $\ell = e, \mu$ (cf. $\sigma_{t\bar{t}}^{tot} = 42$ pb)
$S1$: $\tilde{g}\tilde{g}$	0.54	$\tan\beta = 4, \mu = -400, m_A = 500, A_t = -100$
$S2$: $\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$	5.8	$\tan\beta = 4, \mu = -400, m_A = 500, A_t = -100$

Note: $S1$: $m_{\tilde{g}} = 400$ GeV and $m_{\tilde{q}} = 800$ GeV; $S2$: $m_{\tilde{g}} = 400$ GeV and $m_{\tilde{q}} = 390$ GeV. $m_{\tilde{b}} = m_{\tilde{t}} = m_{\tilde{q}}$ for both cases.

We use a CDF detector simulation package (QFL) and a set of the CDF off-line codes for the lepton/jet finding and $\not\!\!E_t$ calculation. Thus, the $\not\!\!E_t$ calculation includes the effect of uninstrumented regions of the detector as well as the detector smearing. Figure 12(a) shows the $\not\!\!E_t$ distributions for $Z \to \nu\nu$ (solid line), $t\bar{t}$ (dashed line), $\tilde{g}\tilde{g}$ (dotted line) with $m_{\tilde{g}} = 400$ GeV and $m_{\tilde{q}} = 800$ GeV, and $\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$ (dash-dotted line) with $m_{\tilde{g}} = 400$ GeV and $m_{\tilde{q}} = 390$ GeV. Since $\not\!\!E_t$ values above $\sim$70 GeV are reliable without detailed correction from experience in the CDF experiment, we simply set the $\not\!\!E_t$ cut at 100 GeV.

In order to reduce the background, we choose an optimized selection criteria for jets: (i) $N_{\rm jet} \geq 4$ and (ii) $\Sigma E_t({\rm jet}) \geq 300$ GeV, where $E_t^{min}({\rm jet}) = 20$ GeV. We note that the identified leptons are not used in the above jet selection, nor are they used to veto the event. This should give us a conservative estimate on the $t\bar{t}$ background size. Figure 12(b) shows the $\not\!\!E_t$ distributions for signals and backgrounds after the event selection. The cross section ($\not\!\!E_t \geq 100$ GeV) and its significance for each physics process are listed in Table 9.

Table 9: Significance

Physics Process	σ [fb] (after cuts)	N_{event} @10 fb^{-1}	$N_{\rm S}/\sqrt{N_{\rm BG}}$ (BG = $B1 + B2$)
$B1$: $Z \to \nu\nu$	97	970	n/a
$B2$: $t\bar{t} \to \ell\nu + n$-jets	142	1420	n/a
$S1$: $\tilde{g}\tilde{g}$	220	2200	45
$S2$: $\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$	922	9220	189

As one can see, the $t\bar{t}$ background is comparable to the $Z \to \nu\nu$ background, even without the lepton removal. Therefore, our conservative background estimate in the text, *i.e.*, $5 \times N_{Z\to\nu\nu}$, is fairly safe.

If we require to remove the events where the leptons are lost, *i.e.*, isolated ($Iso < 4$ GeV) leptons in a CDF fiducial detector region with $P_t(\ell) \geq 15$ GeV

($|\eta(\ell)| < 1.2$), then the $t\bar{t}$ background reduces by 24% – not a major improvement. Here the isolation variable (Iso) is defined to be the sum of the transverse energy (excluding the lepton E_t) within a cone of $R = 0.4$ around the lepton. The two main reasons for the smaller than expected reduction in the $t\bar{t}$ background are:

(a) The lepton from W decay ($t \to Wb \to l\nu_l b$) is relatively soft after the jet activity selection and $\not\!\!E_t$ cut;

(b) The pseudorapidity region for e and μ is not wide because we assumed the specifics of the present CDF detector (*i.e.*, the CDF central tracking volume).

In summary, $t\bar{t}$ events are not really the major background for the squark and gluino signals, even if we take the worse case scenario where the present CDF detector is used without any improvements on the tracking, and the muon and electron detection coverage.

C The $H \to \tau^+\tau^-$ signal at the DiTevatron

We have studied the Standard Model Higgs signals in $p\bar{p} \to W+H\ (Z+H) \to jj+\tau\tau$ at $\sqrt{s} = 4$ TeV. We are especially interested in $m_H = 120\,\text{GeV}$, because the discovery sensitivity at 120 GeV is the minimum detectable one and it could be enhanced by adding the $\tau\tau$ mode. In what follows we fix $m_H = 120\,\text{GeV}$. The cross sections for the associated production of Higgs, $W + H$ and $Z + H$, are $\sigma_{WH} = 440$ fb and $\sigma_{ZH} = 230$ fb [31]. The branching ratios are:

- $B(H \to \tau\tau) = 7\%$
- $B(\tau \to \text{hadrons}) = 63.9\%, \quad B(\tau \to \ell) = 36.1\%\ (\ell = e,\ \mu)$
- $B(W \to jj) = 68.5\%, \quad B(Z \to jj) = 69.8\%$

We apply the following kinematical and geometical cuts:

- $P_t(\tau) \geq 20$ GeV, $|\eta(\tau)| < 2$
- $P_t(j) \geq 20$ GeV, $|\eta(j)| < 2$
- $\Delta R(\tau\tau) > 0.7$
- $\Delta R(\tau j) > 0.7$

Note that $\sigma/E(j) = 80\%/\sqrt{E} \oplus 5\%$ and $\sigma/E(\tau) = 30\%/\sqrt{E} \oplus 3\%$. The geometical and kinematical acceptance ($\mathcal{A}$) is obtained to be 19% using PYTHIA [33].

As for τ identification ($P_t(\tau) \geq 20$ GeV), we simply refer to the selection in the CDF data analyses:

<u>$\tau \to$ hadrons</u> [36]

- τ reconstruction efficiency: 94%
  - Seed track $P_t \geq 5$ GeV
  - Clustering based on tracks ($P_t \geq 1$ GeV) within a 30° cone around the seed track
  - $E_t \geq 15$ GeV with $E_{em}/(E_{em} + E_{had}) < 0.95$
- ΣP_t cut efficiency: 86%
  - $\Sigma P_t = \Sigma P_t(tracks) + \Sigma E_t(\pi^0\text{'s})$
  - $\Sigma P_t \geq 17.5$, 20 or 22.5 GeV for 1, 2 or 3 prong.
- Isolation cut efficiency: 84%
  - No tracks between 10 and 30° from the seed track.

- This efficiency is estimated from $W \to e\nu_e$ data. The loss is because underlying event tracks overlap with the electron.

- $N(tracks)$ cut efficiency: 98%
  - Number of tracks should be ≤ 3 in the 10° cone.

The total efficiency is 67% per τ. In this analysis we use

$$\epsilon^{ID}_{\tau\to h} = 70\% \tag{10}$$

The probability for a QCD jet to satisfy the τ selection is estimated to be 0.7% [36].

<u>$\tau \to \ell\nu\nu$</u>

- ℓ (from τ) identification efficiency: 62%
  - Kinematical acceptance is 69% [33] with $E_t(e) \geq 10$ GeV or $P_t(\mu) \geq 10$ GeV for $P_t(\tau) \geq 20$ GeV.
  - Electron and muon quality cut efficiency is 90%.

- Isolation cut efficiency: 84% [36]
  - No tracks between 10 and 30° from the seed track.
  - This efficiency is estimated from $W \to e\ \nu$ data. The loss is because underlying event tracks overlap with the electron.

- $N(tracks)$ cut efficiency: 98% [36]
  - Number of tracks should be 1 in the 10° cone.

The total efficiency is 51% per τ. In this analysis we use

$$\epsilon^{ID}_{\tau\to \ell} = 50\% \tag{11}$$

The number of events is calculated as follows:

$$\begin{aligned} N_{VH} &= \sigma_{VH} \times \mathcal{L} \times B(V \to jj) \times B(H \to \tau\tau) \times \mathcal{A} \\ &\quad \times B(\tau \to x) \times B(\tau \to y) \times N_{xy}(combination) \times \epsilon^{ID}_x \times \epsilon^{ID}_y \end{aligned} \tag{12}$$

where V is W or Z; $\mathcal{L}$ is the integrated luminosity; $\mathcal{A}$ is the geometical and kinematical acceptance; x (y) refers to τ leptonic or hadronic decay mode; N_{xy} is the number of combinations for a choice of x and y decay modes; ϵ^{ID} is the τ identification efficiency. Table 10 summarizes the number of events expected at an integrated luminosity of 10 fb^{-1}. It should be noted that these numbers are obtained for a fully instrumented detector in $|\eta| < 2$ and 100% trigger efficiency, *i.e.*, they are slightly optimistic.

Table 10: Number of events for $m_H = 120\,\text{GeV}$ with 10 fb^{-1}

Mode $(x,\, y)$	N_{xy}	$W+H$	$Z+H$	Total
$\tau \to$ hadrons, $\tau \to$ hadrons	1	8.0	4.3	12
$\tau \to$ hadrons, $\tau \to \ell$	2	6.5	3.4	10
$\tau \to \ell, \tau \to \ell$	1	1.3	0.7	2

At this level, the expected sizable Standard Model backgrounds are: QCD 4 jets ($\to$ "$\tau\tau$" + $j\ j$), $Z(\to \tau\tau)$ + 2-jets, $WZ \to jj + \tau\tau$, $ZZ \to jj + \tau\tau$ ($\tau\tau + jj$), $t\bar{t} \to \tau^+\nu b + \tau^-\bar{\nu}\bar{b}$, Drell-Yan $\tau\tau$ + 2-jets, *etc.*

In the decay of $H \to \tau\tau$, the azimuthal opening angle of two τ's is often near 180°. Therefore, the missing E_t ($\not\!\!E_t$) is soft. A further cut on M_{jj} ($60 < M_{jj} < 110$ GeV) can reduce the QCD and $t\bar{t} \to \tau^+\nu b + \tau^-\bar{\nu}\bar{b}$ (460 fb just in cross section times branching ratio) backgrounds while keeping most of the signals in Table 10.

Now let us consider the remaining backgrounds for each signal mode and give a simple estimate of their sizes and possible cuts to reduce them:

- $\tau \to$ hadrons, $\tau \to$ hadrons
  This mode will be the best to determine the mass of the Higgs boson. However, it suffers from QCD jets background. The QCD dijet cross section is 27 μb for $30 < P_t < 70$ GeV [5], where the dijet invariant mass is near the weak boson masses. By requiring two more jets ($E_t > 20$ GeV), the cross section is about 1% of 27 μb ($\mathcal{O}(\alpha_s^2)$), *i.e.*, 270 nb. The fake rate is determined to be 0.7% by CDF [36]. By taking into account 6 combinations (2 out of 4 jets) in misidentification of 2 jets as 2 τ's, the cross section for "$\tau\tau$" + jj-like events is 79×10^3 fb. With 10 fb^{-1}, we have to reduce the background (790 K events) to 16 (6) events for a 3σ (5σ) significance. It should be noted that the $\not\!\!E_t$ in the events is not hard. Therefore, the most efficient requirement is a mass cut, $M_{\tau\tau} \geq 100$ GeV, which will keep a large fraction of the signal. Though the cut reduces Z, WZ and ZZ backgrounds substantially, the QCD jet events as well as $t\bar{t}$ events will remain as the major backgrounds because the mass distributions in those backgrounds are continuum and broad. If we want to reduce the QCD background, the $\not\!\!E_t$ cut should be applied ($\not\!\!E_t \geq 20$ GeV). This will kill the signal. If we want to reduce the $t\bar{t}$ background, the $\not\!\!E_t$ cut should be $\not\!\!E_t \leq 20$ GeV, and we suffer then from the QCD background. Thus, we find that it would be very hard to see a statistically significant Higgs signal at 10 fb^{-1}.

- $\tau \to$ hadrons, $\tau \to \ell$
  This event topology (ℓ + τ-jet+ 2 jets) is expected from 4 jets (at least one jet contains heavy flavours, *e.g.*, $g \to b\bar{b}$), Z + 2 jets, WZ/ZZ, and $t\bar{t}$ events. To reduce the QCD 4-jet background we need to require a higher $P_t(\ell)$ cut (*e.g.*, 20 GeV) and $\not\!\!E_t$ cut at 20 GeV. The higher lepton P_t cut will reduce the signal by ∼35% in 120-GeV Higgs-boson decay, that is, down to 6-7 events. The $\not\!\!E_t$ cut reduces the signal further. We also need a cut on the transverse mass

distribution of the $\ell + \tau$-jet $+\not\!\!E_t$ system (*e.g.* ≥ 90 GeV) to remove $Z + 2$ jets and WZ/ZZ events. As for $t\bar{t}$ events, cuts on $P_t(\ell), \not\!\!E_t$, and the transverse mass will not be efficient to reduce this background. Since the mass spectrum is very wide, the determination of the Higgs-boson mass is difficult with 10 fb^{-1} even if we can achieve **zero** background without loosing any signal events from the transverse mass cut.

- $\underline{\tau \to \ell, \tau \to \ell}$
  This mode is expected to be cleaner (2 isolated leptons + 2 jets). However, this event topology is also expected from Drell-Yan ($\to \ell^+\ell^-$) + 2 jets, $Z(\to \ell^+\ell^-)$ + 2 jets, bb + 2 jets, WZ/ZZ events, and $t\bar{t}$ events. To reduce the backgrounds we need to select $e\mu$ events with higher $P_t(\ell)$ cut (*e.g.*, 20 GeV). The higher P_t cut for lepton is estimated to accept 42% of signals in Table 10, so that the signal is reduced by a factor of $\sim$4 by excluding the ee and $\mu\mu$ modes. Therefore, we will see no signal with 10 fb^{-1}.

In conclusion, we expect it to be very difficult to get a significant signal above the background in the $\tau\tau$ mode with 10 fb^{-1}.

Since a track isolation cut is essential for τ identification, we should operate an accelerator machine with as few interactions per beam crossing as possible. The current CDF data indicates 84% in its efficiency, and the loss is because underlying event tracks overlap with τ tracks [36]. Therefore, in any high luminosity operation such as at the LHC (6 interactions per crossing even at 10^{33} cm^{-2}s^{-1}) or T*, this efficiency is expected to be lower.

References

[1] "A vision for high energy physics", T. Kamon, J. L. Lopez, P. McIntyre, and J. White, CTP-TAMU-11/94 (February 1994).

[2] "Conceptual design for a Tevatron upgrade to 2 TeV beams and luminosity $> 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$", G. Jackson, J. Strait, D. Amidei, G. W. Foster, D. Baden, S. Holmes, D. Finley, and J. Theilacker (March 1994).

[3] J. Ellis, S. Kelley, and D. V. Nanopoulos, Phys. Lett. B **249** (1990) 441; P. Langacker and M.-X. Luo, Phys. Rev. D **44** (1991) 817; U. Amaldi, W. de Boer, and H. Fürstenau, Phys. Lett. B **260** (1991) 447; F. Anselmo, L. Cifarelli, A. Peterman, and A. Zichichi, Nuovo Cim. **104A** (1991) 1817.

[4] R. Arnowitt and P. Nath, in Proceedings of the VII J. A. Swieca Summer School (World Scientific, Singapore, 1994); J.L. Lopez, D.V. Nanopoulos, and A. Zichichi, Nuovo Cimento, **17**(1994) 1; V. Barger, M. Berger, and P. Ohmann, MAD/PH/826 (March 1994).

[5] F. Paige and S. Protopopescu, in Supercollider Physics, p. 41, ed. D. Soper (World Scientific, 1986); H. Baer, F. Paige, S. Protopopescu amd X. Tata, in Proceedings of Workshop on Physics at Current Accelerators and the Supercollider, ed. J. Hewett, A. White and D. Zeppenfeld, (Argonne National Laboratory, 1993).

[6] The CDF Collaboration, "Evidence for top quark production in $\bar{p}p$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$", Fermilab-Pub-94/097-E (April 1994).

[7] A. Chamseddine, R. Arnowitt, and P. Nath, Phys. Rev. Lett. **49** (1982) 970. For reviews see *e.g.*, R. Arnowitt and P. Nath, *Applied N=1 Supergravity* (World Scientific, Singapore 1983); H. P. Nilles, Phys. Rep. **110** (1984) 1.

[8] R. Arnowitt and P. Nath, Phys. Rev. Lett. **69** (1992) 725, Phys. Rev. D **49** (1994) 1479; P. Nath and R. Arnowitt, Phys. Lett. B **287** (1992) 89; J. L. Lopez, D. V. Nanopoulos, and H. Pois, Phys. Rev. D **47** (1993) 2468; J. L. Lopez, D. V. Nanopoulos, H. Pois, and A. Zichichi, Phys. Lett. B **299** (1993) 262, and references therein.

[9] R. Arnowitt and P. Nath, Phys. Lett. B **299** (1993) 58 and **307** (1993) 403(E); P. Nath and R. Arnowitt, Phys. Rev. Lett. **70** (1993) 3696; J. L. Lopez, D. V. Nanopoulos, and K. Yuan, Phys. Rev. D **48** (1993) 2766.

[10] See *e.g.*, J. Ellis, S. Kelley, and D. V. Nanopoulos, Nucl. Phys. B **373** (1992) 55; H. Arason, *et al.*, Phys. Rev. Lett. **67** (1991) 2933; S. Kelley, J. L. Lopez, and D. V. Nanopoulos, Phys. Lett. B **274** (1992) 387; V. Barger, M. Berger, and P. Ohman, Phys. Rev. D **47** (1993) 1093; P. Langacker and N. Polonsky,

Phys. Rev. D **49** (1994) 1454; C. Kolda, L. Roszkowski, J. Wells, and G. Kane, UM-TH-94-03 (February 1994).

[11] For a recent review see "Status of the Superworld: From Theory to Experiment", J.L. Lopez, D.V. Nanopoulos, and A. Zichichi, CERN preprint CERN-TH.7136/94 (to appear in Progress in Particle and Nuclear Physics).

[12] For a review see A. B. Lahanas and D. V. Nanopoulos, Phys. Rep. **145** (1987) 1.

[13] J. L. Lopez, D. V. Nanopoulos, and A. Zichichi, Phys. Rev. D **49** (1994) 343.

[14] J. L. Lopez, D. V. Nanopoulos, G. Park, X. Wang, and A. Zichichi, Texas A & M University preprint CTP-TAMU-74/93 (to appear in Phys. Rev. D).

[15] P. Nath and R. Arnowitt, Phys. Lett. B **289** (1992) 368.

[16] J. Ellis, J. Hagelin, D. V. Nanopoulos, and M. Srednicki, Phys. Lett. B **127** (1983) 233; A. H. Chamseddine, P. Nath, and R. Arnowitt, Phys. Lett. B **129** (1983) 445; H. Baer and X. Tata, Phys. Lett. B **155** (1985) 278; H. Baer, K. Hagiwara, and X. Tata, Phys. Rev. Lett. **57** (1986) 294, Phys. Rev. D **35** (1987) 1598.

[17] P. Nath and R. Arnowitt, Mod. Phys. Lett. A **2** (1987) 331; R. Arnowitt, R. Barnett, P. Nath, and F. Paige, Int. J. Mod. Phys. A **2** (1987) 1113; R. Barbieri, F. Caravaglios, M. Frigeni, and M. Mangano, Nucl. Phys. B **367** (1991) 28.

[18] See also, H. Baer and X. Tata, Phys. Rev. D **47** (1993) 2739; H. Baer, C. Kao, and X. Tata, Phys. Rev. D **48** (1993) 5175.

[19] J. L. Lopez, D. V. Nanopoulos, X. Wang, and A. Zichichi, Phys. Rev. D **48** (1993) 2062.

[20] J. T. White (D0 Collaboration) to appear in Proceedings of the 9th Topical Workshop on Proton-Antiproton Collider Physics, Tsukuba, Japan, October 1993.

[21] Y. Kato (CDF Collaboration) to appear in Proceedings of the 9th Topical Workshop on Proton-Antiproton Collider Physics, Tsukuba, Japan, October 1993; The CDF Collaboration, "Search for Supersymmetry at CDF", Fermilab-Conf-94/149-E (1994), submitted to the 27th International Conference on High-Energy Physics (Glasgow, Scotland).

[22] The CDF Collaboration, Phys. Rev. D **44** (1991) 29.

[23] The CDF Collaboration, submitted to Phys. Rev. D (Rapid Comm.), Fermilab-Pub-93/133-E.

[24] E. Laenen, J. Smith, and W. L. van Neerven, Phys. Lett. B **321** (1994) 254.

[25] K. Hagiwara, J. Woodside, and D. Zeppenfeld, Phys. Rev. D **41** (1990) 2113.

[26] J.Ohnemus, Phys. Rev. D **44** (1991) 1403; J. Ohnemus and J.F. Owens, Phys. Rev. D **43** (1991) 3626.

[27] The CDF collaboration, Phys. Rev. Lett. **65** (1990) 968.

[28] S. Glashow, D. V. Nanopoulos, and A. Yildiz, Phys. Rev. D **18** (1978) 1724.

[29] R. Kleiss, Z. Kunszt, and W. J. Stirling, Phys. Lett. B **253** (1991) 269; T. Han and S. Willenbrock, Phys. Lett. B **273** (1990) 167; J. Ohnemus and W. J. Stirling, Phys. Rev. D **47** (1993) 2722; H. Baer, B. Bailey, and J. Owens, Phys. Rev. D **47** (1993) 2730.

[30] A. Stange, W. Marciano, and S. Willenbrock, Phys. Rev. D **49** (1994) 1354.

[31] J.F. Gunion and T. Han, UCD-94-10 (April 1994).

[32] A. Stange, W. Marciano, and S. Willenbrock, ILL-TH-94-8 (April 1994).

[33] H.-U. Bengtsson and T. Sjostrand, PYTHIA V5.6 manual.

[34] See *e.g.*, A. Sopczak, L3 note 1543 (November 1993).

[35] G. Kane and S. Mrenna, to appear.

[36] The CDF collaboration, Phys. Rev. Lett. **68** (1992) 3398.

[37] G. Jackson, "Aperture Requirements for DiTevatron".

Figure 1: Trilepton yield ($\sigma \times B$) versus chargino mass in chargino production in $p\bar{p}$ collisions. The lines define the range of parameters allowed within the most conservative supergravity model with universal soft-supersymmetry-breaking and radiative electroweak symmetry breaking. Results are shown for $\xi_0 = m_0/m_{1/2} = 0, 1, 2, 5$ ($\leftrightarrow m_{\tilde{q}} \sim (0.8-2)m_{\tilde{g}}$); $A = 0$, $\tan\beta = 2$, and both signs of the Higgs mixing parameter μ (we use $m_t^{\rm pole} = 174\,{\rm GeV}$). The upper (lower) plots show the limits which could be reached at the Tevatron (DiTevatron). The estimated sensitivity limit at the Tevatron (DiTevatron) for $\mathcal{L} = 10\,{\rm fb}^{-1}$ is 21 (40) fb, and for $\mathcal{L} = 25\,{\rm fb}^{-1}$ is 14 (25) fb.

Figure 2: Trilepton yield ($\sigma \times B$) versus chargino mass in chargino production in $p\bar{p}$ collisions. The lines define the range of parameters allowed within the most conservative supergravity model with universal soft-supersymmetry-breaking and radiative electroweak symmetry breaking. Results are shown for $\xi_0 = m_0/m_{1/2} = 0, 1, 2$; $A = 0$, $\tan\beta = 10$, and both signs of the Higgs mixing parameter μ (we use $m_t^{\rm pole} = 174\,{\rm GeV}$). (The corresponding curves for $\xi_0 = 5$ are not shown since they largely overlap with those for $\xi_0 = 2$.) The upper (lower) plots show the limits which could be reached at the Tevatron (DiTevatron). The estimated sensitivity limit at the Tevatron (DiTevatron) for $\mathcal{L} = 10\,{\rm fb}^{-1}$ is 21 (40) fb, and for $\mathcal{L} = 25\,{\rm fb}^{-1}$ is 14 (25) fb.

Figure 3: Trilepton yield ($\sigma \times B$) versus chargino mass in chargino production in $p\bar{p}$ collisions. The dots define the range of parameters allowed within the minimal $SU(5)$ supergravity model (for $m_t^{\rm pole} = 168\,{\rm GeV}$ and $\tan\beta = 2 - 10$). Results are shown for each sign of the Higgs mixing parameter μ. The upper (lower) plots show the limits which could be reached at the Tevatron (DiTevatron). The estimated sensitivity limit at the Tevatron (DiTevatron) for $\mathcal{L} = 10\,{\rm fb}^{-1}$ is 21 (40) fb, and for $\mathcal{L} = 25\,{\rm fb}^{-1}$ is 14 (25) fb.

Figure 4: Trilepton yield ($\sigma \times B$) versus chargino mass in chargino production in $p\bar{p}$ collisions. The dots define the range of parameters allowed within the string-inspired no-scale $SU(5) \times U(1)$ supergravity model (for $m_t^{\rm pole} = 178\,{\rm GeV}$). Results are shown for each sign of the Higgs mixing parameter μ. The upper (lower) plots show the limits which could be reached at the Tevatron (DiTevatron). The estimated sensitivity limit at the Tevatron (DiTevatron) for $\mathcal{L} = 10\,{\rm fb}^{-1}$ is 21 (40) fb, and for $\mathcal{L} = 25\,{\rm fb}^{-1}$ is 14 (25) fb.

Figure 5: Statistical significance for gluino and squark events at the **Tevatron** with $\mathcal{L} = 10\,\mathrm{fb}^{-1}$. (The significance scales with $\mathcal{L}^{1/2}$.) These events were selected by the criteria $P_t > 100\,\mathrm{GeV}$, and 3 jets with $P_t > 40\,\mathrm{GeV}$. Bands are shown for signal S from gluino pairs ($m_{\tilde{q}} = 1\,\mathrm{TeV}$), and squark/gluino combinations ($m_{\tilde{q}} = m_{\tilde{g}} - 10\,\mathrm{GeV}$). These two cases bracket the range of possibilities in the conservative supergravity models which we consider. The background BG is calculated from $Z \to \nu\bar{\nu}$; the bands provide for a factor of 5 deterioration of $N_\mathrm{S}/N_\mathrm{BG}$ ratio due to additional backgrounds or inefficiencies.

Figure 6: Statistical significance for gluino and squark events at the **DiTevatron** with $\mathcal{L} = 10\,\mathrm{fb}^{-1}$. (The significance scales with $\mathcal{L}^{1/2}$.) These events were selected by the criteria $P_t > 150\,\mathrm{GeV}$, and 4 jets with $P_t > 40\,\mathrm{GeV}$. Bands are shown for signal S from gluino pairs ($m_{\tilde{q}} = 1\,\mathrm{TeV}$), and squark/gluino combinations ($m_{\tilde{q}} = m_{\tilde{g}} - 10\,\mathrm{GeV}$). These two cases bracket the range of possibilities in the conservative supergravity models which we consider. The background BG is calculated from $Z \to \nu\bar{\nu}$; the bands provide for a factor of 5 deterioration of $N_\mathrm{S}/N_\mathrm{BG}$ ratio due to additional backgrounds or inefficiencies.

Figure 7: The $\cos(\theta^*_{bb})$ distributions (before any event selection) for $Z + H(\rightarrow bb)$ ($m_H = 120\,\mathrm{GeV}$) and QCD $Z + bb$ ($30 < M_{bb} < 200\,\mathrm{GeV}$) events. The variable θ^*_{bb} is the opening angle between the two b-quarks in the center of mass system, where the z axis is defined as the direction of $\vec{p}_{b_1} + \vec{p}_{b_2}$. Note that the vertical scale is shown as the fraction of events per 0.01.

Figure 8: Cross section of Tevatron tunnel, showing arrangement of SSC magnet (inverted from SSC design), Tevatron magnet, and transfer line magnet.

Figure 9: Field distribution in Collider magnets and relation to effective aperture: (a) rms deviations in full production run of Tevatron magnets; (b) rms deviations in 8 Fermilab-built SSC magnets. B_y contains a sextupole term which was built in by design, which would be removed for DiTevatron magnets.

Figure 10: Persistent-current sextupole field for a Tevatron magnet, as a function of current. 400 GeV injection field is indicated.

Figure 11: Net mechanical stress (sum of preload and Lorentz stress) as a function of current^2. Peak field of 8.8 Tesla is indicated.

Figure 12: The $\not\!\!E_t$ distributions before (a) and after (b) event selection for $Z \to \nu\nu$ (solid line), $t\bar{t}$ (dashed line), $\tilde{g}\tilde{g}$ (dotted line) with $m_{\tilde{g}} = 400$ GeV and $m_{\tilde{q}} = 800$ GeV, $\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$ (dash-dotted line) with $m_{\tilde{g}} = 400$ GeV and $m_{\tilde{q}} = 390$ GeV. We set the $\not\!\!E_t$ cut at 100 GeV.