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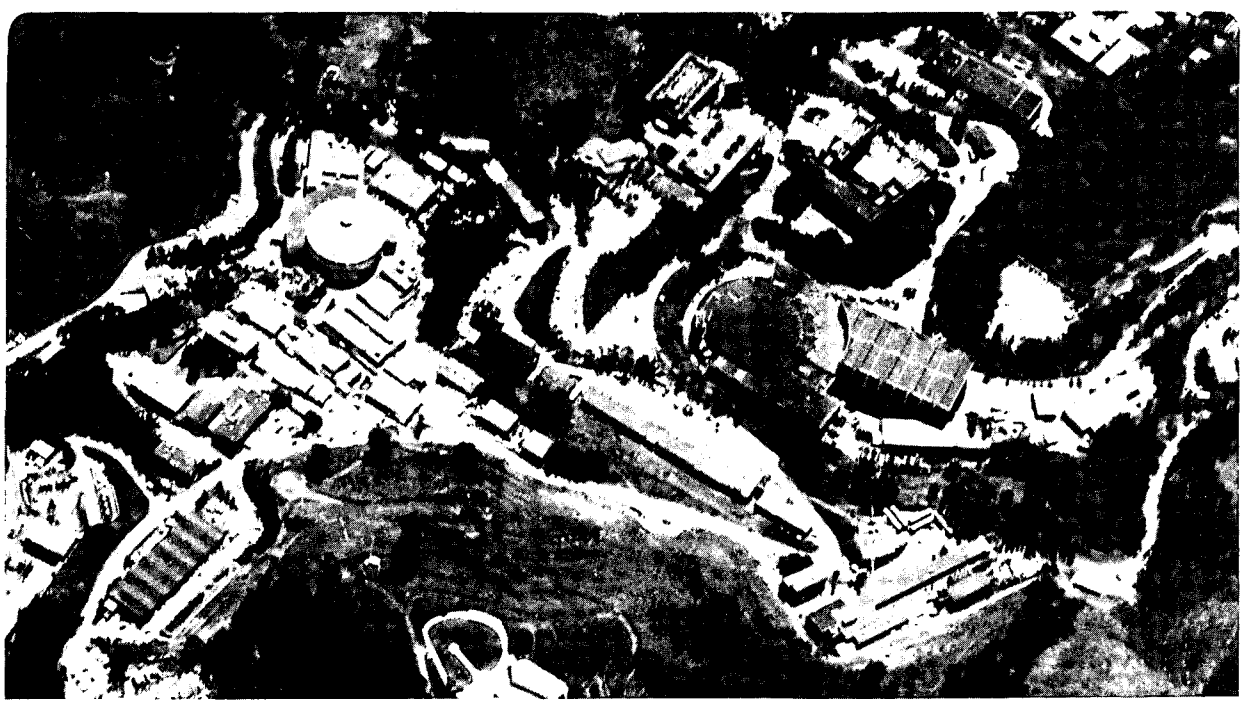
SUPERSYMMETRY AT THE SSC

S. Dawson

September 1985



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SUPERSYMMETRY AT THE SSC

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ABSTRACT

We consider the production of SUSY particles at the SSC, focusing mainly on gluino pair production. We also discuss the assumptions and uncertainties involved in calculating SUSY production rates.

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1 INTRODUCTION

The search for supersymmetry at the SSC is compelling for a number of reasons. Supersymmetry is the only known way of understanding the hierarchy problem (why is $M_W \ll M_P$?) and of regulating the quartic divergences of scalar masses.[1,2] In addition, the recent discovery that superstring theories can be anomaly free in ten dimensions has fueled renewed interest in effective low energy supersymmetric theories.[3] Hopefully, these theories will eventually predict the masses of the SUSY particle spectrum. At present, little is known about the expected masses of the SUSY particles – unfortunately, it is possible to build models where the gluino mass ranges anywhere from 1 MeV to 1 TeV (or higher!).

Low energy supersymmetric theories allow the calculation of production rates and event characteristics in terms of a relatively small number of unknown parameters.[4] Most SUSY theories have the feature that they possess a conserved quantum number (R parity) which guarantees that SUSY particles are always pair produced and that there is a lightest stable SUSY particle into which all others decay. This particle is usually taken to be the $\tilde{\gamma}$. Since the photino interaction strength is extremely weak, it will escape from the detector and the generic signal for SUSY particle production will be jets with missing transverse energy. The observation of events with large missing p_T at the $Sp\bar{p}S$ collider has thus increased interest in the signals for supersymmetry .[5] Many of the problems associated with the search for supersymmetry have become clear through the study of these events .[6]

There have been many studies of supersymmetric particle production at the SSC [7,8,9] and in this work we discuss some of the important issues which have not yet been studied. Most of this paper will be concerned with the search for gluino pair production. We consider this process because it has a large cross section, distinctive event shapes, and so is probably the easiest SUSY process to observe. In Section 2, we discuss the event characteristics of gluino pair production at the SSC and demonstrate that heavy gluinos ($m_{\tilde{g}} \gtrsim$ 500 GeV) may be easier to identify than light gluinos. Although the cross sections for producing heavy gluinos are small, if appropriate kinematic cuts are applied to discriminate against the large QCD background, the event shapes are quite different from those of the background. We also review the

current limits on light gluinos ($m_{\tilde{g}} \lesssim 5$ GeV) and discuss the difficulties of untangling different SUSY particle production mechanisms from each other.

In Section 3, we discuss the problems associated with finding intermediate mass gluinos, ($m_{\tilde{g}} \sim 100$ GeV). In this mass range, the background to gluino pair production from heavy quark decays and from W and Z decays is severe. A more promising channel to look for intermediate mass gluinos is through the process $pp \rightarrow \tilde{g}\tilde{\gamma}$ which has a smaller cross section, but a distinctive signature.

Finally, in Section 4, we discuss the model dependent assumptions usually made when calculating SUSY particle production and attempt to estimate the uncertainties in the production rates due to these factors. In some models, the lightest SUSY particle is not the $\tilde{\gamma}$ and we show that in this case the missing p_T signal is drastically degraded.

2 LOOKING FOR GLUINOS

In this section, we discuss some of the features of gluino pair production at the SSC. The cross sections for making gluino pairs are quite large : ~ 10 pb. for $m_{\tilde{g}} = 1$ TeV and 50 nb. for $m_{\tilde{g}} = 100$ GeV.[9] (These numbers assume $| y_{\tilde{g}} | \leq 1.5$). We will not treat gluinos which are ligher than 100 GeV, since if this is the case they will presumably be discovered at the $Sp\bar{p}S$ or Tevatron Colliders. Here we consider the problems associated with extracting the signal from the (formidable) background. We consider only the decay $\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$, although for light squarks $\tilde{g} \rightarrow \tilde{q}^* q$ may dominate. In either case, the signal for gluino pair production will be multi-jets with missing p_T .

2.1 The Case for Light Gluinos

It is important for SUSY phenomenology at the SSC to determine if very light gluinos ($m_{\tilde{g}} \lesssim 5$ GeV) are allowed by current experiments. Clearly, if such a light gluino exists it will be copiously produced and all of our previous conclusions on SUSY particle production at the SSC must be rethought. The limits on SUSY particle masses are discussed in Ref. (2) and we briefly summarize the limits on light gluino masses here.

Results on events with missing p_T from UA1 can probably rule out a gluino mass between about 40 and 5 Gev if the gluino decays within the detector ($\tau_{\tilde{g}} \lesssim 10^{-8}$ sec.).[10] Since the bulk of the gluino pair production cross section comes from gluon fusion, these limits are independent of the squark mass. However, the analysis for lighter gluinos is extremely dependent upon the assumptions made about gluino fragmentation and the energy resolution of the detector. For $m_{\tilde{g}} \lesssim 5$ GeV, the total cross section for gluino pair production at $\sqrt{s} = 630$ GeV is large ($\gtrsim 10^5$ nb.). However, the UA1 trigger and experimental cuts impose such severe restrictions that a large fraction of the signal is lost. As the gluino mass is lowered, fewer and fewer events pass the cuts and it becomes exceedingly difficult to generate statistically reliable rate estimates. By including the contributions of processes such as $p\bar{p} \rightarrow \tilde{g}\tilde{g}g$[11], which are important for light gluinos , it may be possible to push the limit on the gluino mass slightly lower than 5 GeV.

Beam dump experiments are sensitive to gluinos with $\tau_{\tilde{g}} \lesssim 10^{-10}$ or 10^{-11}

sec. and place limits on light gluinos which depend sensitively on the squark masses.[12] The gluino is assumed to decay to $q\bar{q}\tilde{\gamma}$ and then the $\tilde{\gamma}$ travels through the dump and interacts in the target. For $m_{\tilde{q}} \lesssim 300$ GeV, they typically rule out gluinos in a mass range between 1 GeV and 6 GeV. Unfortunately, for heavier squarks, beam dumps are unable to place any limits on gluino masses. It is of interest to see for how light a gluino mass beam dump experiments can obtain restrictions.

Quite stringent limits on light gluinos may be derived under the assumption that the gluino is stable and is confined in stable R hadrons. If the gluino is confined in the same manner as quarks and gluons are, it will combine with quark-antiquark pairs to form hadrons with charges 0 and ± 1. MIT-bag model calculations [13] suggest that these states should have masses near 1 GeV if the gluino is massless and that their masses should approach

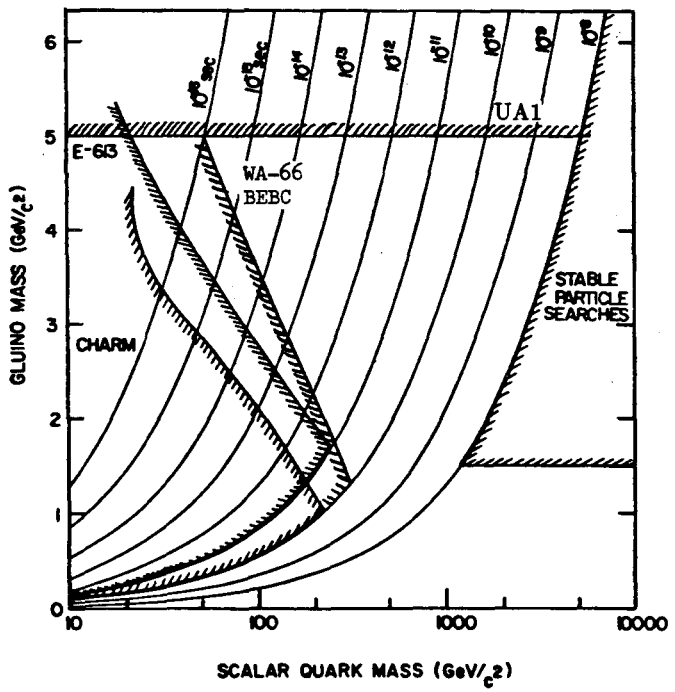


Fig 1. Limits on the gluino mass as a function of the lightest squark mass. The limits are from the beam dump experiments of Ref. 11 and from the analysis of Ref. 10 of missing p_T events at UA1.

the gluino mass if the gluino is heavy. Charged stable particle searches rule out the existence of R hadrons with lifetimes greater than 10^{-8} sec. in the mass range between 1.5 and 9 GeV.[2] (For a 2 GeV gluino, a lifetime of 10^{-8} sec. corresponds to a squark mass of about 2 TeV if $\tilde{g} \to q\bar{q}\tilde{\gamma}$).

If the gluinos are bound into neutral hadrons (or unconfined), neutral particle search experiments are relevant. Unfortunately, only gluinos with masses between 2 and 4 GeV and with lifetimes exceeding 10^{-7} sec. are excluded.[2] The limits from beam dumps and from stable particle searches depend on using perturbative QCD for very light gluino masses. However, perturbative QCD typically underestimates production cross sections for light objects and so the limits produced in this way should be conservative.

It may be possible to obtain limits by looking at the spectrum of $\tilde{g}\tilde{g}$ bound states. Haber and Goldman [14] have argued that the lightest $\tilde{g}\tilde{g}$ state ($\tilde{\eta}$) has the quantum numbers $J^{PC} = 0^{-+}$ and should have been seen in the decay $\psi \to \gamma\tilde{\eta}$. They conclude that this rules out zero mass gluinos. Zero mass gluinos are also forbidden by chiral symmetry arguments which require that for $m_{\tilde{g}}=0$ there be a pseudoscalar meson lighter than the pion.[15]

The limits on light gluino masses are shown in Fig. 1 under the assumption that $\tilde{g} \to q\bar{q}\tilde{\gamma}$. Many of these limits depend upon the squark masses and vanish for some range of parameters. The question of whether gluinos with masses less than 5 GeV are experimentally allowed remains open. Qualitative arguments against such light gluinos exist but the situation is murky. Clearly, careful study is needed!

2.2 Multi-jet Signals

We turn now to a study of the jets arising from gluino pair production. For light gluinos, the $q\bar{q}$ from the $\tilde{g}$ decay will tend to coalesce to form a single jet, while for heavier gluinos the jets from the $q\bar{q}$ will remain distinct. The analysis presented in this paper defines a jet by adding up all the energy within a cone described by $\Delta\phi^2 + \Delta\eta^2 \leq 1$. Also, unless otherwise stated, a jet is required to have a transverse energy greater than 30 GeV. With no hadronization or detector simulation in the Monte Carlo, the average number of jets produced at the SSC in the reaction $pp \to \tilde{g}\tilde{g}$ is 2 for $m_{\tilde{g}} = 100$ GeV, while for $m_{\tilde{g}} = 1$ TeV it is 4 .

The question of which kinematic cuts are appropriate for use at the SSC is vital for understanding the physics results. In Figs. 2 and 3, we demonstrate the effect of modifying the definition of a jet on the gluino signal. (There is no hadronization or detector simulation in these figures and a jet is defined simply to be the outgoing quark or gluon.) Both Fig. 2 and Fig. 3 have $p_T^{missing} \geq 100$ GeV. In Fig. 2, we show the 2-, 3-, and 4- jet cross sections obtained with $p_T^{jet} \geq 30$ GeV. For $m_{\tilde{g}} \gtrsim 200$ GeV, the 3- and 4- jet cross sections are significantly larger than the 2- jet cross section. Even for $m_{\tilde{g}} \sim 1$ TeV, however, the 4- jet cross section is only marginally larger than the 3-jet cross section. If we change the definition of a jet so that $p_T^{\text{jet } 1} \geq 25$ GeV and $p_T^{\text{other jets}} \geq 12$ GeV, we obtain the results shown in Fig. 3.

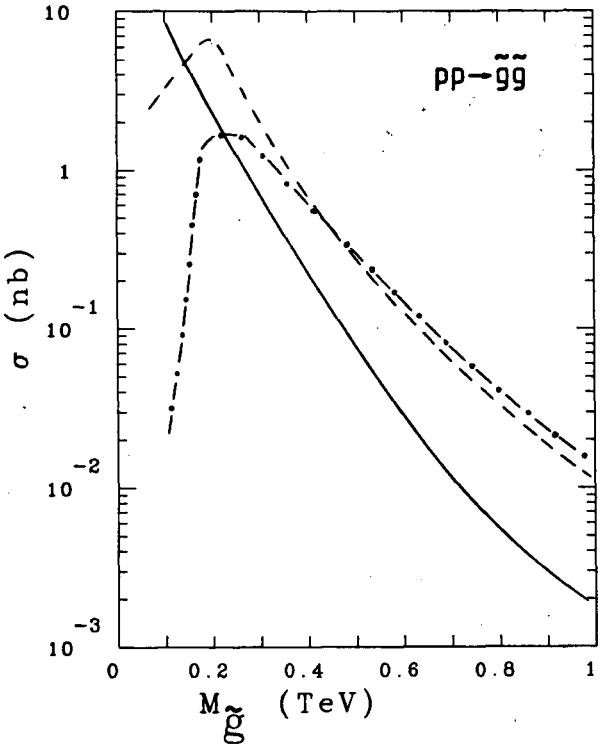


Fig 2. Jet cross sections for $pp \to \tilde{g}\tilde{g}$ at $\sqrt{s} = 40$ TeV with $p_T^{missing} \geq 100$ GeV and $p_T^{jet} \geq 30$ GeV. The solid, dashed, and dot-dashed lines are the 2-, 3-, and 4-jet cross sections, respectively. We assume $\tilde{g} \to q\bar{q}\tilde{\gamma}$.

For $m_{\tilde{g}} \gtrsim 300$ GeV, the results are nearly identical to those shown in Fig. 2, while for lighter gluino masses the differences are dramatic. The question of which are the best kinematic cuts to use to maximize the gluino signal at the SSC has not been adequately studied yet.

2.3 QCD Background

The most pernicious background to gluino pair production is from the QCD production of heavy quarks where one of the quarks decays semi- leptonically. In order to efficiently reject this background it would be useful to be able to veto leptons within a hadronic jet. At $\sqrt{s} = 800$ GeV, the QCD background to $pp \to \tilde{g}\tilde{g}$ was found to decrease by a factor of 10 when events

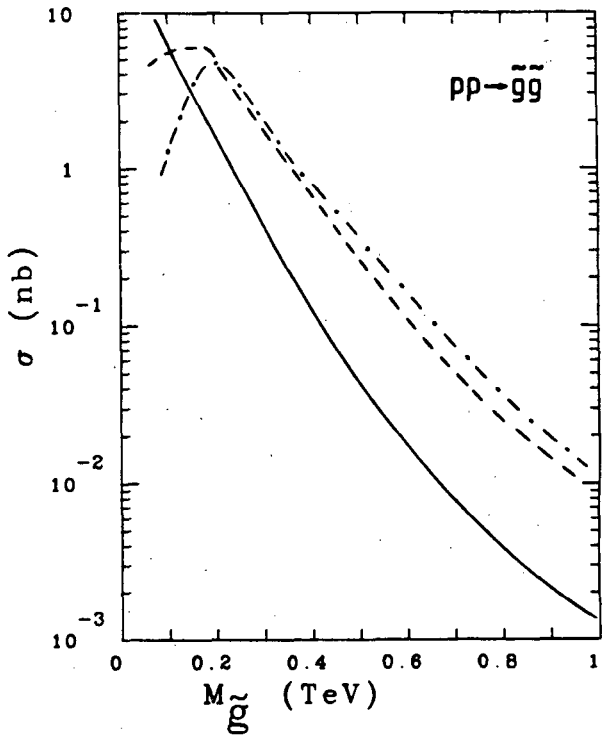


Fig 3. Jet cross sections for $pp \to \tilde{g}\tilde{g}$ at $\sqrt{s} = 40$ TeV with $p_T^{missing} \geq 100$ GeV and $p_T^{\text{jet } 1} \geq 25$ GeV and $p_T^{\text{other jets}} \geq 12$ GeV. The solid, dashed, and dot-dashed lines are the 2-, 3-, and 4-jet cross sections, respectively. We assume $\tilde{g} \to q\bar{q}\tilde{\gamma}$.

with leptons with energy $\geq$ 2 GeV were omitted.[16] It is clear that lepton identification would greatly enhance our chances of discovering supersymmetry.

Fig. 4 shows the missing p_T spectra for the $\tilde{g}\tilde{g}$ signal for $m_{\tilde{g}}$ = 1 TeV and for the QCD background.[8] The QCD background contains contributions from $pp \to qq$, where q = (u,d,s,c,b,t,or g) and we have taken the top quark mass to be 40 GeV. This background includes only events with a lepton with p_T greater than 5 percent of the p_T of the fast jet. This cut gives a signal to background ratio of approximately 1 : 10. A comparison of Figs. 4a and 4b shows that a simple $p_T^{missing}$ cut will not be sufficient to eliminate the QCD background.

For light gluinos, the $p_T^{missing}$ cut is even less effective in discriminating against the background. Fig. 5 shows the $p_T^{missing}$ spectra for 100 GeV gluino pair production. While the cross section is large ($\sigma(pp \to \tilde{g}\tilde{g}) \sim 50$ nb. for $m_{\tilde{g}}$ = 100 GeV and $|\, y_{\tilde{g}} \,| \leq 1.5$), the signal and the QCD background not

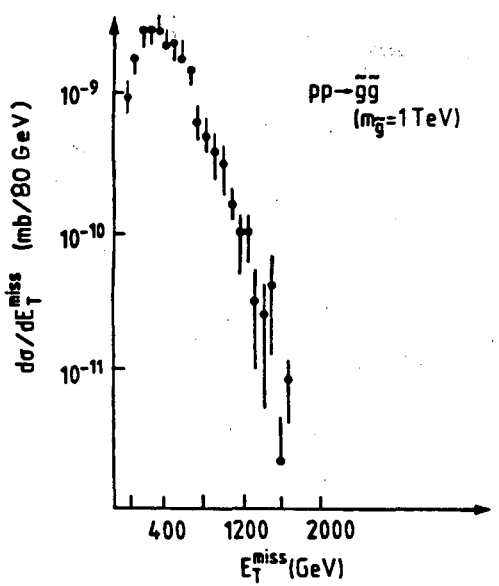


Fig 4a. Missing p_T spectra for $pp \to \tilde{g}\tilde{g}$ at $\sqrt{s}$ = 40 TeV with $m_{\tilde{g}}$ = 1 TeV. We assume $\tilde{g} \to q\tilde{q}\tilde{\gamma}$.

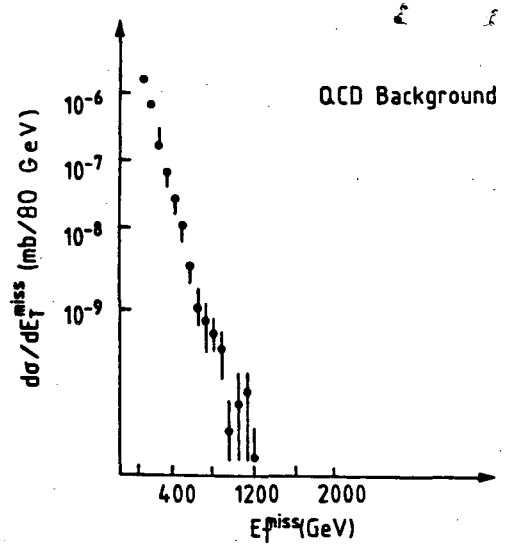


Fig 4b. QCD background from $pp \to qq$. This background includes only events with a lepton with p_T greater than 5 percent of the jet p_T .

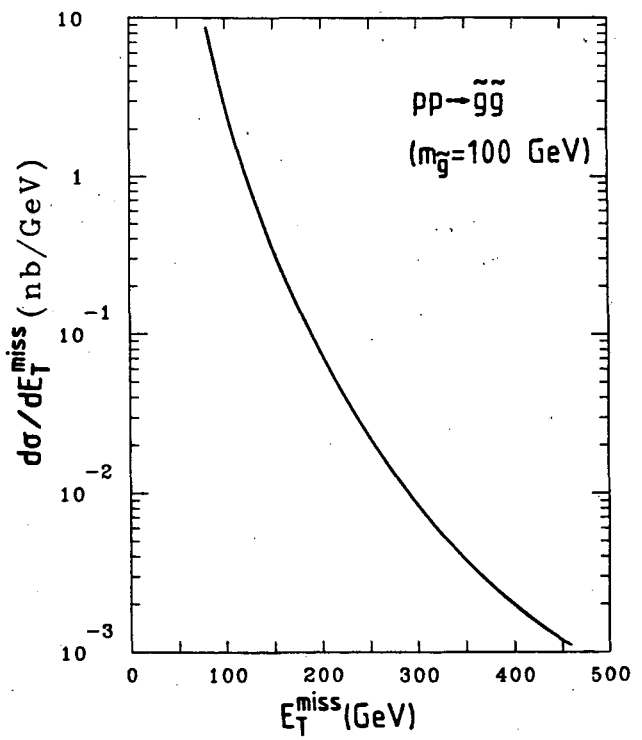


Fig 5. Missing p_T spectra for $pp \to \tilde{g}\tilde{g}$ at $\sqrt{s}$= 40 TeV with $m_{\tilde{g}}$ = 100 GeV. We assume $\tilde{g} \to q\tilde{q}\tilde{\gamma}$ .This figure has a cut $p_T^{missing} \geq 50$ GeV and requires that there be at least one jet with $p_T^{jet} \geq 30$ GeV .

only have comparable magnitudes, but also have a similar distribution in $p_T^{missing}$. If a cut $p_T^{missing} \geq 100$ GeV is made on the $m_{\tilde{g}} = 100$ GeV sample, there is only a 2 per cent acceptance rate.

For heavy gluinos, the QCD background can be efficiently rejected by the use of an x_{OUT} cut. x_{OUT} is defined,

$$x_{OUT} = \frac{\vec{p}_T^{\,missing} \cdot \hat{e}}{E_T^{TOT}} \tag{2.1}$$

where $\hat{e}$ is the unit vector perpendicular to the axis of the highest energy jet in the plane formed by the jet axis and the beam axis. For back-to-back jets $x_{OUT} = 0$. The x_{OUT} distribution for a 1 TeV gluino is compared to that of the QCD background in Fig. 6. A cut $x_{OUT} \geq .2$ retains 25 per cent of the signal. Unfortunately as the gluino mass decreases, the x_{OUT} cut becomes less effective in discriminating against the QCD background.

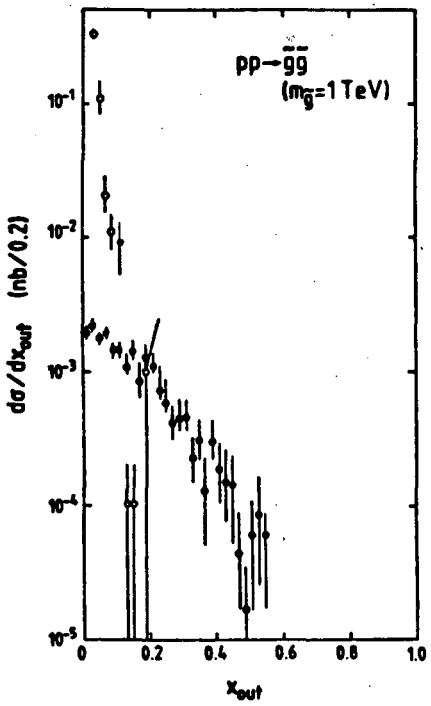


Fig 6. x_{OUT} spectrum for $pp \to \tilde{g}\tilde{g}$ (solid circles) and QCD background (open circles). We assume $\tilde{g} \to q\bar{q}\tilde{\gamma}$.

To separate gluino pair production from the QCD background for gluinos of an intermediate mass($m_{\tilde{g}} \sim 100$ GeV) it will probably be necessary to impose additional kinematic cuts. A good variable is,

$$x_E = \frac{\vec{p}_T^{\,missing} \cdot \hat{e}_l}{E_T^{TOT}} \tag{2.2}$$

where $\hat{e}_l$ is the direction of the largest jet. For a 1 TeV gluino, the signal to background ratio can be optimized by taking $x_E \gtrsim .25$ and $x_{OUT} \gtrsim .08$.[8] What needs to be done is a systematic study of the effects of varying the x_E and x_{OUT} cuts on the QCD background and on the gluino pair production cross section for a range of gluino masses between 100 GeV and 1 TeV. In this way it should be possible to make firm conclusions about what mass gluinos can be seen at the SSC.

Also, it remains to be seen whether tagging multi-jet cross sections can be an effective signal for gluino production. For $m_{\tilde{g}} \gtrsim 150$ GeV, the 3- and 4- jet cross sections dominate the $\tilde{g}$ pair production rate. The appropriate kinematic cuts for separating the 3- and 4-jet signal from the background have not been studied.

2.4 Other Backgrounds

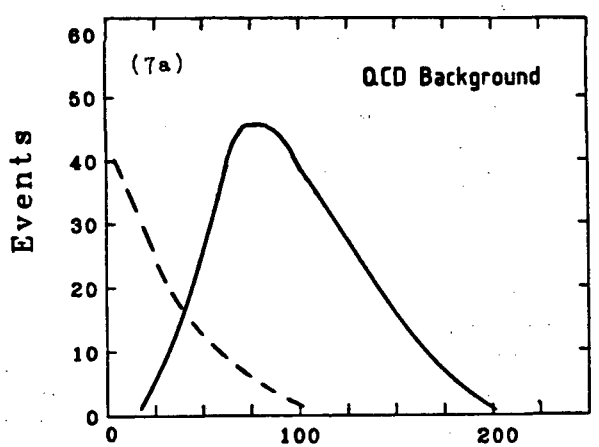
There are significant backgrounds to gluino pair production from $pp \to W^+W^-$, $pp \to$ W X, and $pp \to$ Z X, where the (W) Z decays (semi) leptonically. Again, an efficient lepton veto would help to discriminate against these backgrounds. The processes $pp \to$ W X or Z X will have $p_T^{missing} \lesssim M_W/2$ (or $M_Z/2$) and hence will be primarily a background for gluinos of mass $\lesssim$ 100 GeV. The reaction $pp \to W^+W^-$ can be a background to the production of all mass gluinos. However, for $m_{\tilde{g}} \lesssim 700$ GeV, the gluino signal is larger than the background from W pair production.

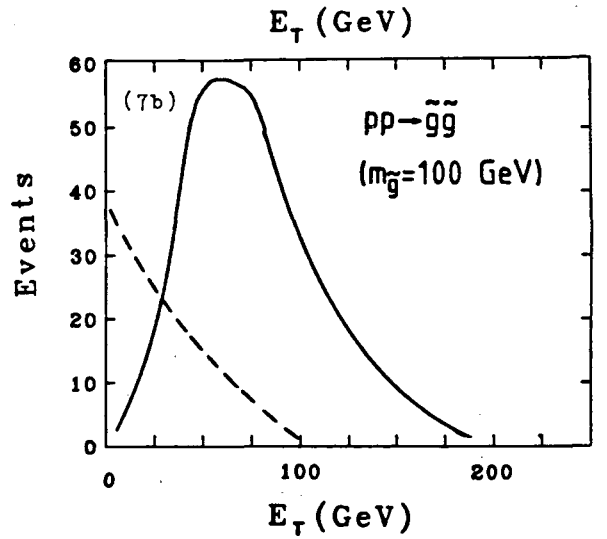
These backgrounds can be easily handled since they can be calibrated from measured events. For example, the background from $pp \to$ Z X; Z $\to \nu\bar{\nu}$ can be determined by measuring $pp \to$ Z X; Z $\to e^+e^-$ and multiplying by the branching ratio into neutrino pairs. With enough statistics, it should be straightforward to separate the gluino signal from the W and Z backgrounds.

2.5 Event Shapes for Gluino Production

Since it appears possible to defeat the backgrounds to gluino pair production by some combination of x_{OUT} and x_E cuts (perhaps combined with a lepton veto) we turn to the question of event shapes as distinctive signatures for gluino decays. The figures in this section are from the supersymmetry group at Snowmass '84.[8] They use events generated by ISAJET which are then fed through a CDF type detector simulation or a simple 4π calorimeter simulation. We have fit smooth curves through the Monte Carlo data points to aid in comparing generic event shapes.

We first consider the transverse energy of the jets produced in the decay of the $\tilde{g}$. When the gluino is heavy enough that it dissociates into 2 jets, ($m_{\tilde{g}} \gtrsim 400$ GeV), the difference in transverse energy between the two jets tends to be large ($\sim m_{\tilde{g}}/2$). On the other hand, when the $\tilde{g}$ is light and the $q\bar{q}$ pair from its decay fuses into a single jet this signal is less dramatic. In Fig. 7 we show the event shapes for the jet transverse energies for $m_{\tilde{g}} = 1$ TeV, $m_{\tilde{g}} = 100$ GeV, and for the QCD background. For the heavy $\tilde{g}$, the event shape is clearly distinctive from the background, while for $m_{\tilde{g}} = 100$ GeV, the signal and the background have quite similar event shapes.





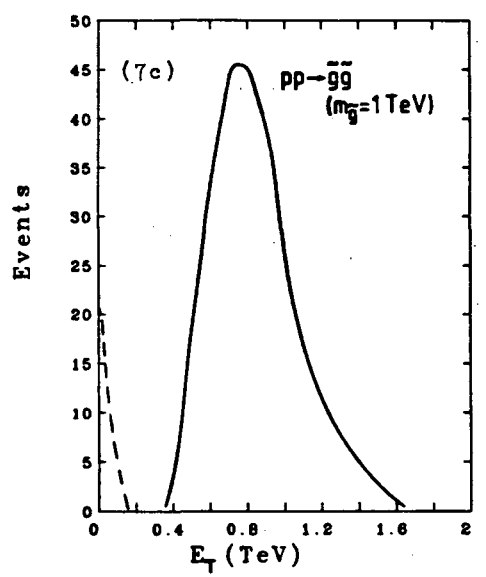
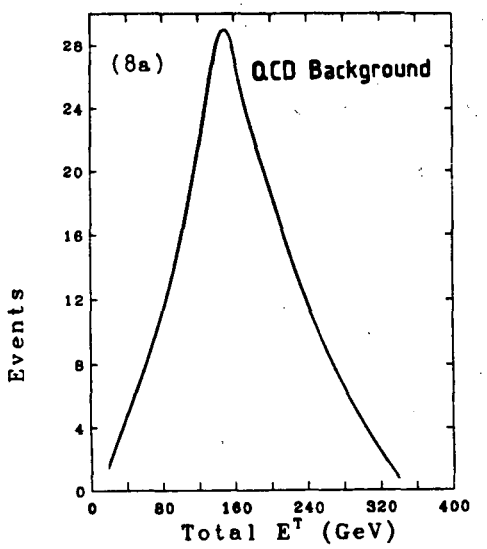
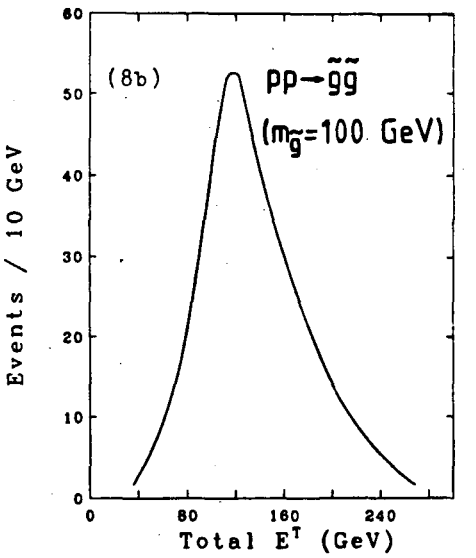


Fig 7. Transverse energy of the most energetic jet for the QCD background (Fig. 7a) and for $pp \to \tilde{g}\tilde{g}$ at $\sqrt{s} = 40$ TeV. Fig. 7b has $m_{\tilde{g}} = 100$ GeV and Fig. 7c has $m_{\tilde{g}} = 1$ TeV. We assume $\tilde{g} \to q\bar{q}\tilde{\gamma}$.

The total E^T distribution is also a distinctive signature for heavy gluino production. This distribution tends to peak near the mass of the gluino. Unfortunately, the total E^T of the QCD background peaks near 100 GeV, making it hard to tag intermediate mass gluinos. Fig. 8 illustrates this effect.

Hence, we see that event shapes form a distinctive signature for heavy $\tilde{g}$ production if the QCD background can be overcome. The Snowmass '84 group [8] estimated that the event shapes could be useful in tagging gluino pair production for $m_{\tilde{g}} \gtrsim 500$ GeV. It would be useful to see if this feature remains when the crucial x_E and x_{OUT} cuts are incorporated in the analysis.





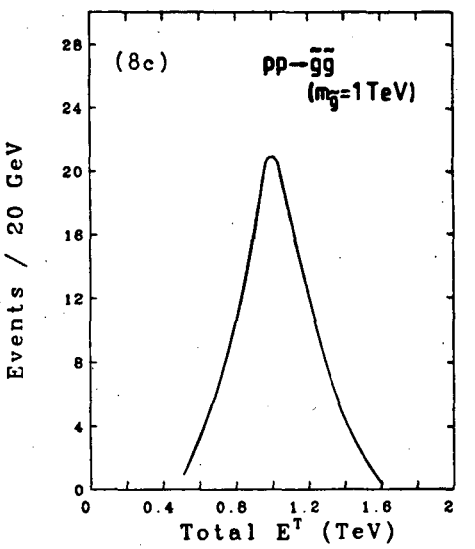


Fig 8. Total transverse energy for the QCD background (Fig. 8a) and for $pp \to \tilde{g}\tilde{g}$ at $\sqrt{s} = 40$ TeV. Fig. 8b has $m_{\tilde{g}} = 100$ GeV and Fig. 8c has $m_{\tilde{g}} = 1$ TeV. We assume $\tilde{g} \to q\bar{q}\tilde{\gamma}$.

2.6 Other SUSY Processes

Finally, we note the difficulty of untangling the different SUSY scenarios from each other. The total cross sections for $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, and $\tilde{q}\tilde{q}$ are similar for equal SUSY particle masses (as seen in Fig. 9) although the event characteristics may be different. Unfortunately, many of the distributions have qualitatively similar shapes. At $\sqrt{s} = 630$ GeV, Ellis and Kowalski [17] found that the p_T distributions of secondary jets gave the most characteristic differences between squark and gluino processes. A similar study of this type should be done for SSC energies.

In order to determine the physics, it is necessary to examine complete scenarios of masses and calculate the contributions of all SUSY processes to

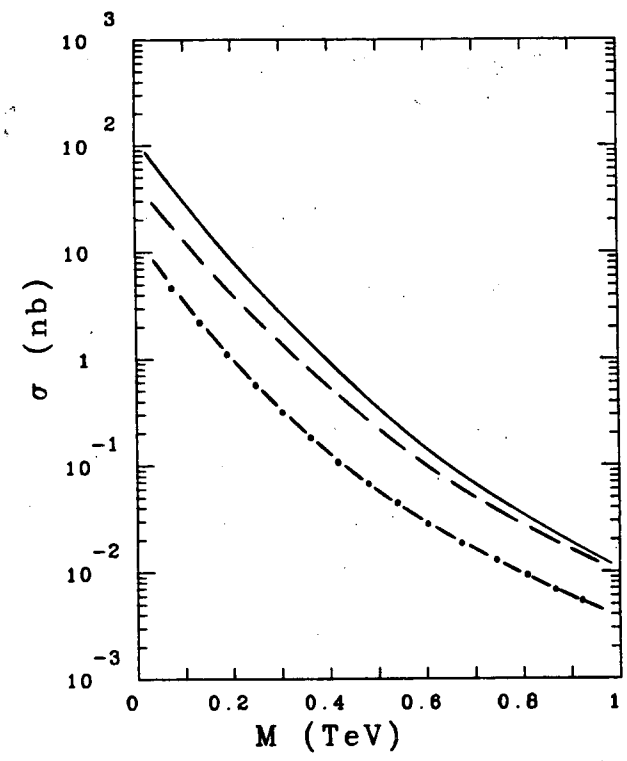


Fig 9. Total cross sections at $\sqrt{s} = 40$ TeV for $pp \to \tilde{g}\tilde{g}$ (solid), $pp \to \tilde{g}\tilde{q}$ (dashed), and $pp \to \tilde{q}\tilde{q}$ (dot- dashed) with $|y_i| \leq 1.5$. The squark curves sum over $\tilde{q}_L, \tilde{q}_R, \bar{\tilde{q}}_L$, and $\bar{\tilde{q}}_R$ and over all flavors.

a given distribution. This is obviously impractical at this point. What is really needed are better low energy SUSY models that can predict the masses of the SUSY particles.

3 FINDING THE INTERMEDIATE MASS GLUINO

We saw in the last section that gluinos with masses near 100 GeV have event shapes which are similar to those of the QCD background. It will probably be necessary to search for gluinos in this mass range by looking for the process $pp \to \tilde{g}\tilde{\gamma}$. The cross section for this process is small ($\sim 10^{-2}$ nb. for SUSY masses on the order of 100 GeV) but the signature is distinctive. This process has an energetic jet in one hemisphere and a large amount of missing p_T in the other. The most significant background is probably from $pp \to Z$ + jet; $Z \to \nu\bar{\nu}$. Using the total cross sections with $|y_i| \leq 1.5$, the signal to background ratio is about 10^{-3} for $m_{\tilde{g}} = m_{\tilde{\gamma}} = m_{\tilde{q}} = 100$ GeV. However, the situation should be drastically improved by applying kinematic cuts on the missing p_T distribution . Also, if the photino is very light, the signal to background ratio will obviously be much larger.

4 AMBIGUITIES IN CALCULATING SUSY RATES

The pair production rates of SUSY particles can unfortunately not be calculated in a model independent manner. The only exception to this is gluino pair production—all other cross sections involve model dependent mixing angles. In this section we describe the sources and effects of these ambiguities.

Mass mixing occurs between the fermionic partners of the W and the two charged Higgs bosons, between the fermionic parners of the γ, Z, and the 2 neutral Higgs, and between the scalar partners of the left- and right-handed quarks and leptons. This mixing depends upon the ratio of vacuum expectation values of the two Higgs bosons, v_1/v_2,and upon the possible soft supersymmetry breaking terms in the Lagrangian, μ_i.[1,2]

Unfortunately, this mixing does not enter in as an overall scale factor but multiplies different terms in the cross section in different manners so as to change the angular distributions. As an example, consider wino-gluino production. There are two charged gauge fermion mass eigenstates, $\tilde{\omega}_1^{\pm}$ and $\tilde{\omega}_2^{\pm}$, which are linear combinations of the gauge fermion eigenstates $\tilde{W}^{\pm}$ and the Higgsinos, $\tilde{H}$ and $\tilde{H}'$,

$$\begin{aligned} \tilde{\omega}_1^+ &= -i\cos\theta_1\tilde{W}^+ + \sin\theta_1\tilde{H}^+ \\ \tilde{\omega}_2^+ &= i\sin\theta_1\tilde{W}^+ + \cos\theta_1\tilde{H}^+ \\ \tilde{\omega}_1^- &= -i\cos\theta_2\tilde{W}^- + \sin\theta_2\tilde{H}'^- \\ \tilde{\omega}_2^- &= i\sin\theta_2\tilde{W}^- + \cos\theta_2\tilde{H}'^-. \end{aligned} \tag{4.1}$$

In a given model, the mixing angles, θ_1 and θ_2 can be calculated in terms of v_1/v_2 and the μ_i. The resulting cross section can be written as,

$$\frac{d\sigma}{dt}(pp \to \tilde{\omega}_1^+\tilde{g}) = \cos^2\theta_1 A_t + cos^2\theta_2 A_u + \cos\theta_1\cos\theta_2 A_{tu}, \tag{4.2}$$

where A_t, A_u, and A_{tu} represent the contributions from the t-channel, u-channel , and the t-u interference respectively. The cross section for producing $\tilde{\omega}_2^+\tilde{g}$ is found by making the substitution $\cos\theta_{1,2} \to \sin\theta_{1,2}$ in Eq. (4.2).

We see that the angular distribution can be changed by changing the relative magnitudes of θ_1 and θ_2. This effect is most important for wino masses near M_W. If the soft supersymmetry breaking terms μ are equal and much larger than M_W, then $m_{\tilde{\omega}1} = m_{\tilde{\omega}2} = \mu$ and $\theta_1 = \theta_2$. In this limit,

$$\frac{d\sigma}{dt}(pp \to (\tilde{\omega}_1 + \tilde{\omega}_2)\tilde{g}) = A_t + A_u + A_{tu} \tag{4.3}$$

and so the mass mixing is irrelevant for $m_{\tilde{\omega}} \gg M_W$.

In the neutral gauge fermion sector, the mixing has more important consequences. If R parity is conserved, there is a lightest, stable neutral (LSN) SUSY particle which is usually assumed to be the photino. All other SUSY particles will eventually decay into the LSN particle. (The lightest stable SUSY particle must be neutral, since there are extremely stringent limits on the abundance of stable charged particles.)

The LSN particle is not necessarily the photino. The mass matrix in the

neutral sector is,

$$\begin{bmatrix} M_1 & M_2 & 0 & 0 \\ M_2 & M_3 & -M_Z & 0 \\ 0 & -M_Z & \mu_2\sin 2\theta & \mu_2\cos 2\theta \\ 0 & 0 & \mu_2\cos 2\theta & -\mu_2\sin 2\theta \end{bmatrix} \tag{4.4}$$

where M_1, M_2, and M_3 are arbitrary soft mass terms, μ_2 is the coefficient of the $\tilde{H}\tilde{H}'$ term in the Lagrangian and $\tan\theta = -v_2/v_1$. (The notation is that of Ref. 2). The mass matrix acts on the states,

$$\begin{pmatrix} -i\tilde{\gamma} \\ -i\tilde{Z} \\ \tilde{h} \equiv \tilde{H}^o\cos\theta + \tilde{H}'^o\sin\theta \\ \tilde{h}' \equiv \tilde{H}'^o\cos\theta - \tilde{H}^o\sin\theta \end{pmatrix} \tag{4.5}$$

It is clear that the photino will only be a mass eigenstate for $M_2 = 0 \equiv e(\mu_1 - \mu_3)$ where

$$\mathcal{L} = \frac{1}{2}\mu_1\tilde{W}_3\tilde{W}_3 + \frac{1}{2}\mu_3\tilde{B}\tilde{B} \tag{4.6}$$

and $\tilde{W}_3$ and $\tilde{B}$ are the neutral $SU(2)_L$ and $U(1)_Y$ gauge fermions. In many of the hidden sector supergravity models [18] it is possible to arrange that all of the soft supersymmetry breaking terms are equal and M_2 is indeed 0.

It is straightforward,however, to construct examples where the LSN particle is not the photino. Consider, for example, $\mu_2 = 0$. In this case the LSN particle is the $\tilde{h}'$ which remains massless. This has important implications for the detection of SUSY particles. The Higgsino coupling to quarks and squarks is proportional to the quark mass and so is small. Thus the gluino decay chain will be,

$$\tilde{g} \to q\bar{q}\tilde{\chi}_2, \quad \tilde{\chi}_2 \to \gamma\tilde{h}' \tag{4.7}$$

where $\tilde{\chi}_2$ is the second lightest neutral SUSY fermion. The $\tilde{\chi}_2$ lifetime is approximately,[19]

$$\tau(\tilde{\chi}_2 \to \tilde{h}'\gamma) \sim 10^{-12}\ \text{sec.} \left(\frac{\tilde{m}_t}{m_t}\right)^4 \left(\frac{1\ \text{GeV}}{m_{\tilde{\chi}_2}}\right)^3 \tag{4.8}$$

where $\tilde{m}_t$ is the scalar partner of the top quark. For many values of the parameters $\tilde{\chi}_2$ will decay within the detector and the final state will then

have a soft photon and a degraded $p_T^{missing}$ signal. In Figure 10, we show the 2- and 3- jet cross sections for $\tilde{g}$ pair production at the SSC for the case where the photino is the LSN SUSY particle and for the case where the LSN particle is the $\tilde{h}'$. For heavy gluinos, the effects are insignificant, while for intermediate mass gluinos ($m_{\tilde{g}} \lesssim 400$ GeV) the effects can be large.

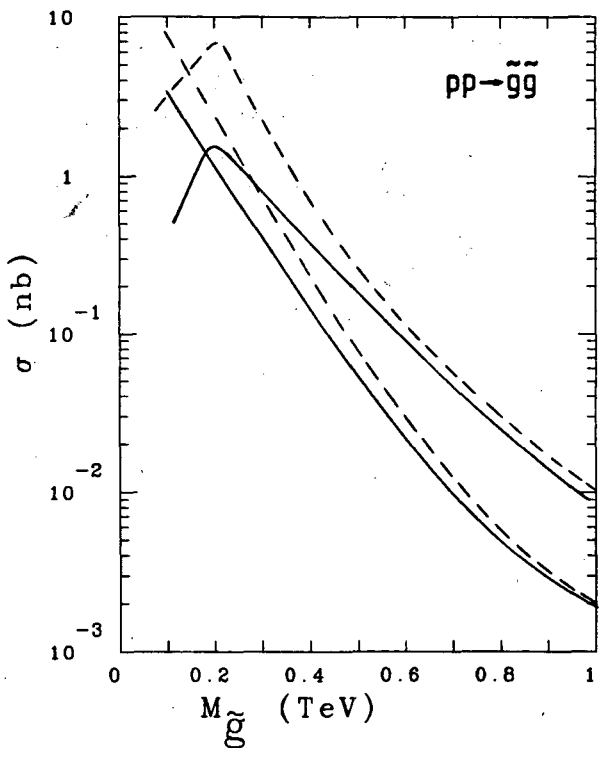


Fig 10. 2- and 3- jet cross sections for $pp \to \tilde{g}\tilde{g}$ at $\sqrt{s} = 40$ TeV. The solid lines have $\tilde{g} \to q\bar{q}\tilde{\chi}_2$; $\tilde{\chi}_2 \to \gamma\tilde{h}'$, while the dashed lines have $\tilde{g} \to q\bar{q}\tilde{\gamma}$ and a stable $\tilde{\gamma}$. We require that $p_T^{missing} \geq 100$ GeV and $p_T^{jet} \geq 30$ GeV.

5 CONCLUSION

The search for supersymmetry at the SSC will be difficult, but not impossible. By using the appropriate kinematic cuts it should be possible to have the SUSY signals stand out above the backgrounds. For gluinos with masses above about 500 GeV, the event shapes will be useful in tagging gluino pair production events. Much of this paper consists of a catalogue of work which should be done in order to facilitate the search for supersymmetry at the SSC. On the theoretical side, more SUSY model building needs to be done to narrow the allowed range of SUSY masses to a more tractable level. On the experimental side, a systematic study of the effects of various cuts on SUSY production rates and event shapes for a range of SUSY masses and processes is needed.

The requirements that SUSY puts on detectors are clear. The detector must be a 4π detector with finely segmented calorimetry in order to measure missing transverse energy and to distinguish between the q and $\bar{q}$ jets coming from the gluino decays. In addition, the ability to veto leptons within a hadronic jet would greatly improve the rejection of the QCD background.

A great deal of work on supersymmetry at the SSC has already been done, but much more remains!

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