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GAUGINOS FROM $p\bar{p}$ COLLISIONS*

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ABSTRACT

We investigate signals for winos ($\tilde{W}$) and zinos ($\tilde{Z}$) when the decays $W \to \tilde{W}\gamma$, $Z \to \tilde{W}\bar{\tilde{W}}$ and $W \to \tilde{W}\tilde{Z}$ are allowed at $p\bar{p}$ colliders. These processes lead to i) monojet and dijet plus missing transverse momentum ($\not{p}_T$) events, ii) various di- and tri-lepton events with little accompanying hadronic activity, and iii) events containing jets plus leptons plus $\not{p}_T$. Absence of such signals may allow new limits to be placed on $m_{\tilde{W}}$ and $m_{\tilde{Z}}$ of at least $m_{\tilde{W}} + m_{\tilde{Z}} \gtrsim m_W$, from CERN collider data.

1. INTRODUCTION

John Ellis has told you all about the *reasons physicists love* SUSY.[1] Supersymmetry solves the hierarchy problem, it is aesthetically appealing, it provides an avenue for unification with gravity, and, of course, it should manifest itself as the low energy limit of the superstring. So far we have no experimental indication of supersymmetry; we only know roughly where the supersymmetric

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particles don't live.[2] Recent work on production of strongly interacting SUSY particles at $p\bar{p}$ colliders seems to indicate that[3]

$$\begin{aligned} m_{\tilde{q}} &> 65 - 80 \text{ GeV} \\ m_{\tilde{g}} &> 60 - 80 \text{ GeV} , \end{aligned} \tag{1}$$

but this doesn't really bother theorists--the SUSY mass gap, and hence, the sfermion masses are expected to be O(100-500 GeV) if SUSY is to provide a solution to the hierarchy problem. Most theorists professing devotion to SUSY favor models with light [~O(few GeV)] photinos ($\tilde{\gamma}$) with $\tilde{\gamma}$ as the lightest SUSY particle. In this case it is also expected on fairly general grounds that one of the supersymmetric counterparts of the gauge bosons--the wino ($\tilde{W}_1$) and zino ($\tilde{Z}_1$)--should have the following mass restrictions:[4]

$$\begin{aligned} m_{\tilde{W}_1} &< m_W \\ m_{\tilde{Z}_1} &< m_Z . \end{aligned} \tag{2}$$

These sparticles may then be accessible to detection by the currently operating $p\bar{p}$ colliders! In the following calculations, we assume a small $\tilde{\gamma}$ mass, so the mass eigenstates $\tilde{W}_1$ and $\tilde{Z}_1$ contain large gaugino, but small higgsino, components. We also assume heavy ($\gtrsim$O(100) GeV) sfermion masses, and a ratio $r = v_1/v_2 = 1$ of Higgs field vacuum expectation values (this is the preferred choice of a wide class of SUSY models[5]). This talk is a summary of results presented in Ref. 6

2. PRODUCTION AND DECAY OF GAUGINOS

In $p\bar{p}$ colliders, gauginos can be produced via the decay of vector bosons,[7] e.g.

$$W \rightarrow \tilde{W}\tilde{\gamma}\ ,\ \tilde{W}\tilde{Z}$$
$$Z \rightarrow \tilde{W}\bar{\tilde{W}}\ . \qquad (3)$$

These channels dominate gaugino production if the above decays are kinematically allowed; t-channel production also occurs, but at very low rates. The gaugino-gaugino'-gauge boson coupling strengths are large. This leads to the substantial production cross-sections illustrated in Fig. 1.

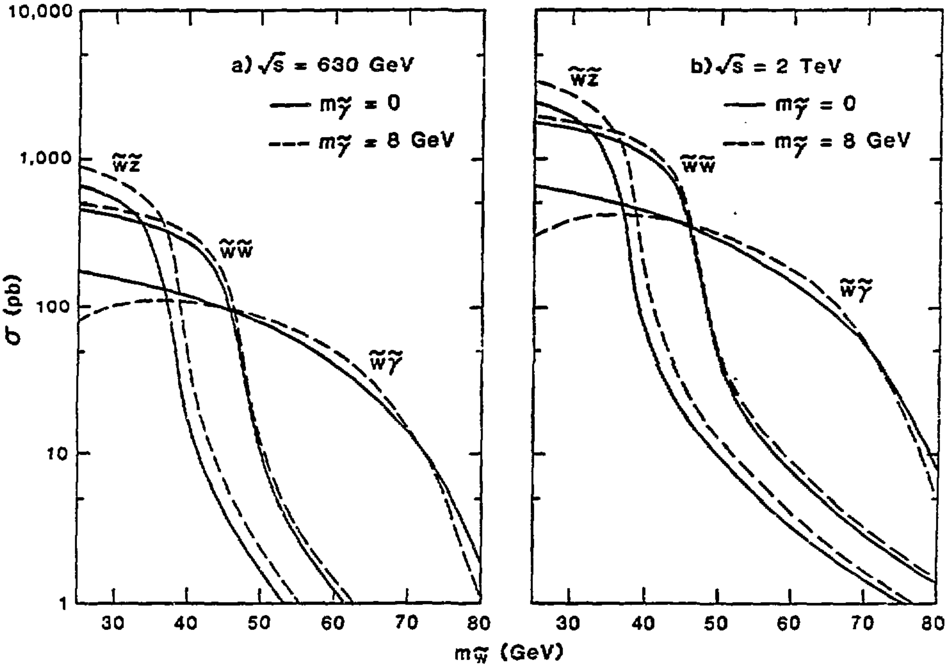

Fig. 1. Production cross-sections for $p\bar{p} \rightarrow \tilde{W}\tilde{\gamma}$, $\tilde{W}\bar{\tilde{W}}$, and $\tilde{W}\tilde{Z}$ versus $\tilde{W}$ mass at a) 630 GeV and b) 2 TeV for two choices of photino mass: $m_{\tilde{\gamma}} = 0$ and 8 GeV. The $\tilde{Z}$ mass is fixed by the other gaugino mass choices.

Assuming heavy sfermions, the gauginos have the following decay modes:

$$\tilde{W} \to q\bar{Q}\tilde{\gamma}\ (67\%) \quad \text{or} \quad \ell\bar{\nu}\tilde{\gamma}\ (11\%)$$

$$\tilde{Z} \to q\bar{q}\tilde{\gamma}\ (46\text{-}61\%) \quad \text{or} \quad \ell\bar{\ell}\tilde{\gamma}\ (13\text{-}18\%)\ . \tag{4}$$

The decay of $\tilde{Z}$ into $\tilde{W}$ is also allowed, but is small unless $m_{\tilde{q}} \gtrsim$ 300 GeV.[6] Calculation of gaugino production and decay maintaining gaugino spin correlations requires the evaluation of many lengthy Feynman diagrams; we make the calculation manageable by evaluating each helicity amplitude as a complex number[8] and summing over final state helicities in our Monte Carlo programs.

A wide variety of spectacular signatures can be expected from gaugino production. All three modes, $\tilde{W}\gamma$, $\tilde{W}\bar{\tilde{W}}$ and $\tilde{W}\tilde{Z}$, lead to mono- and multi-jet events plus $\not{p}_T$.[9] The $\tilde{W}\bar{\tilde{W}}$ mode can give acollinear dilepton pairs (ee, $\mu\mu$ and $e\mu$), and $\tilde{W}\tilde{Z}$ can lead to trileptons (eee, $e\mu\mu$, $ee\mu$ and $\mu\mu\mu$) and same or opposite sign dileptons if one of the above threesomes is lost or mis-identified. The size of these signals depends, in part, on the experimental cuts and selection criteria used. In our calculations, we don't try to match any particular year's cuts used by, say, UA1, but instead show that these signals can be observable if some set of typical cuts are used. We require

$$\begin{aligned} &|p_{T_e}| > 10 \text{ GeV}\ ; && |\eta_e| < 3.0 && \\ &|p_{T_\mu}| > 3 \text{ GeV}\ ; && |\eta_\mu| < 2.0 && \\ &|p_{T_{j_1}}| > 25 \text{ GeV}\ ; && |p_{T_{j_2}}| > 12 \text{ GeV}\ ; && |\eta_j| < 2.5\ , \end{aligned} \tag{5}$$

and coalesce partons within $\Delta r = (\Delta\eta^2 + \Delta\phi^2)^{1/2} < 1$. More stringent electron cuts are used if final state quarks are present. We trigger on events with jets only when

$$\not{p}_T > \text{Max}(15,4\sigma)\ , \quad \sigma = .7\ \text{GeV}^{1/2}\Big(\sum_{\text{partons}} E_T + E_T^S\Big)^{1/2} \tag{6}$$

where E_T^S is distributed according to[10]

$$\frac{dN}{dE_T} \sim \frac{4E_T}{\langle E_T\rangle^2} \exp\left(-\frac{2E_T}{\langle E_T\rangle}\right) \qquad (7)$$

with $\langle E_T\rangle \approx 45$ GeV.

3. RESULTS

In Fig. 2, we plot the monojet and dijet plus $\not{p}_T$ cross-sections expected when both gauginos $\tilde{W}$ and $\tilde{Z}$ decay hadronically, as a function of $m_{\tilde{W}}$ ($m_{\tilde{Z}}$) on the lower (upper) scale.

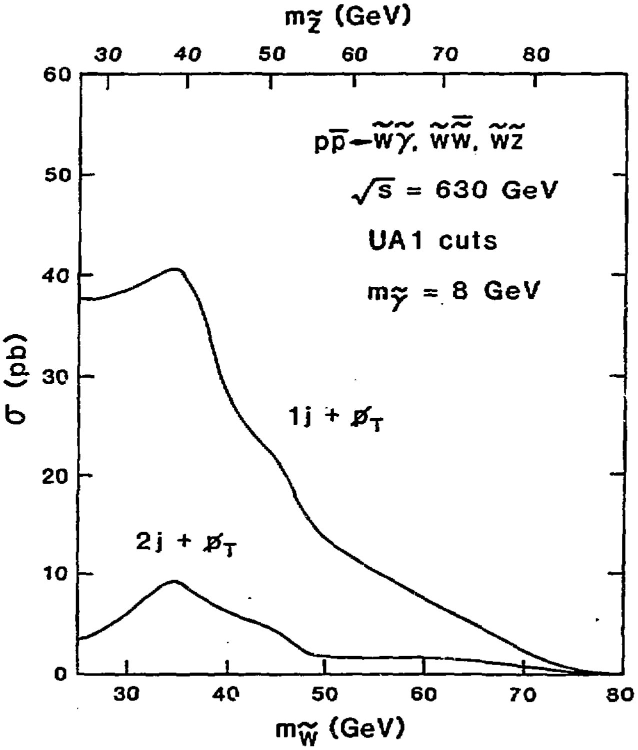

Fig. 2 Monojets and dijets + $\not{p}_T$ signals from gauginos.

We find monojet dominance for all values of wino mass, with a fairly constant monojet signal of ~39 pb for $m_{\tilde{W}} < 38$ GeV. This is in contrast to the case of heavy (> 40 GeV) squark or gluino production where dijets dominate.[1,3] At this point $W \to \tilde{W}\tilde{Z}$ phase space is saturated and the monojet signal drops to ~20 pb at $m_{\tilde{W}} = 45$ GeV, where the decay $Z \to \tilde{W}\bar{\tilde{W}}$ cuts off. The signal for $m_{\tilde{W}} \gtrsim 46$ GeV comes almost entirely from $W \to \tilde{W}\tilde{\gamma}$; in this region it would be difficult to tell $W \to \tilde{W}\tilde{\gamma}$ from $W \to L\nu_L$, where L is a new fourth generation heavy lepton.

Fig. 3 illustrates signals expected when both gauginos decay leptonically.

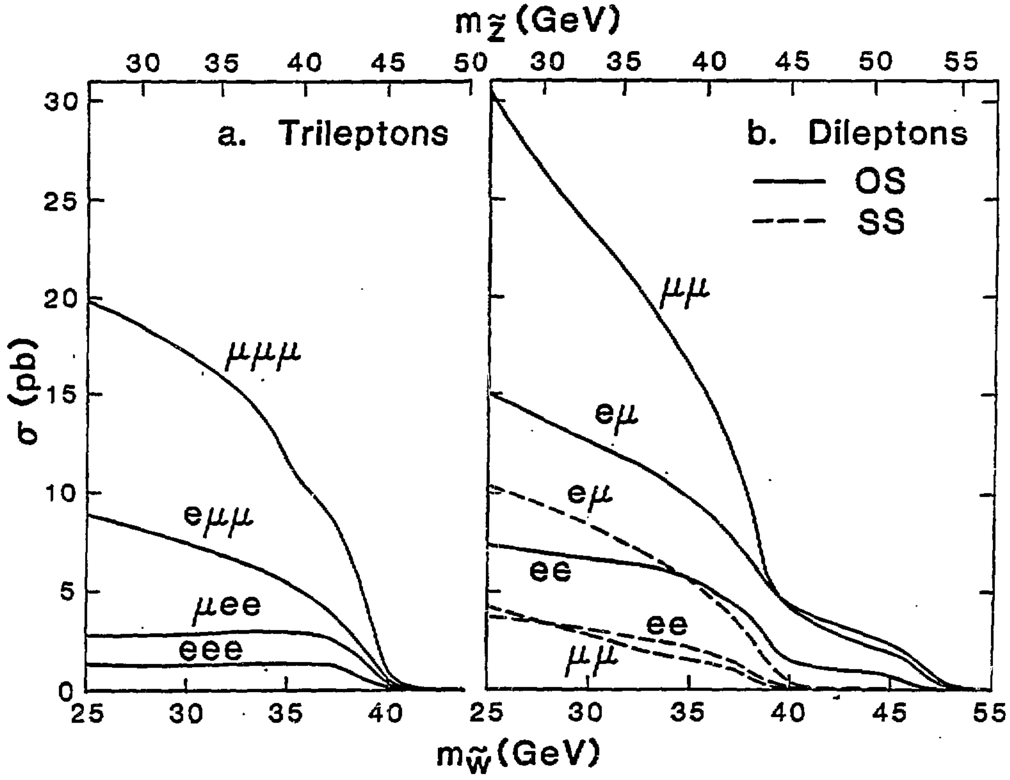

Fig. 3 Signals from $\tilde{W}\bar{\tilde{W}}$ and $\tilde{W}\tilde{Z}$ production when both $\tilde{W}$ and $\tilde{Z}$ decay leptonically. $m_{\tilde{\gamma}} = 8$ GeV.

In this case, we require no $\not{p}_T$ cut because the hard multi-leptons plus $\not{p}_T$ in association with only small amounts of hadronic debris (from W and Z production) are easily distinguishable from standard model backgrounds.[11] Isolated hard tri-leptons events (accompanied by $\not{p}_T$)

are a clear signal for $\tilde{W}\tilde{Z}$ production, and occur with substantial rates if the decay $W \to \tilde{W}\tilde{Z}$ is allowed. These would be accompanied by same and opposite sign dileptons plus $\not{p}_T$, where the azimuthal opening angle $\phi_{\ell\ell}$ would be distributed between $10° < \phi_{\ell\ell} < 170°$. Non-observation of these multi-lepton events could be used to easily rule out the decay $W \to \tilde{W}\tilde{Z}$ in the theoretical framework in which we work. For $38 \text{ GeV} < m_{\tilde{W}} < 46 \text{ GeV}$, one could still expect a few acollinear eμ and

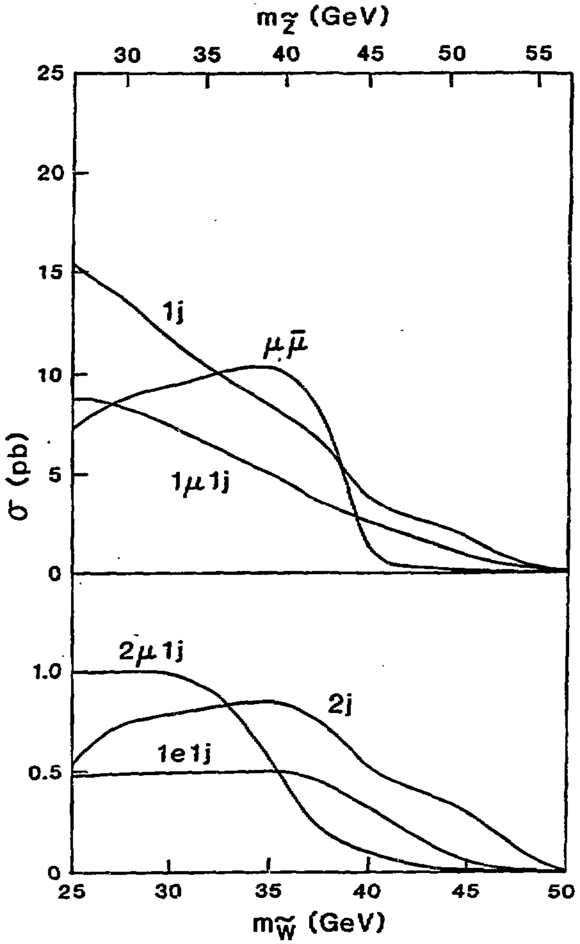

Fig. 4. Largest n jet + m lepton + $\not{p}_T$ signals from $p\bar{p} \to \tilde{W}\tilde{Z}, \tilde{W}\bar{\tilde{W}}$ when one gaugino decays leptonically and one hadronically, and $\sqrt{s} = 630$ GeV. Other signals are also present but at much smaller levels.

$\mu\mu$ pairs from $Z \to \tilde{W}\bar{\tilde{W}}$, not yet enough to set rigorous (once detection efficiencies are taken into account) limits from the present accumulated $p\bar{p}$ collider data.

Finally, a set of n jet + m lepton + $\not{p}_T$ events would be expected in the data sample from the case where one gaugino decays leptonically, and one hadronically (see Fig. 4). Such events would have background problems from heavy flavor production ($t\bar{t}$, $t\bar{h}$,...).

4. CONCLUSION

We have performed detailed calculations of gaugino signals expected from $N = 1$ supergravity when sfermions are heavy $[\sim O(100\ \text{GeV})]$ and $\tilde{\gamma}$ is light ($m_{\tilde{\gamma}} < 10$ GeV), when $r = v_1/v_2 = 1$. Substantial monojets, trileptons, and acollinear dileptons are expected if $W \to \tilde{W}\tilde{Z}$ is allowed, and it is likely current collider experiments are probing at least $m_{\tilde{W}} = 38$ GeV and $m_{\tilde{Z}} = 43$ GeV. If $m_{\tilde{W}} >$ 46 GeV, then the best channel for searching for gauginos is in $W \to \tilde{W}\tilde{\gamma}$ decays, where fat monojet + $\not{p}_T$ events offer the cleanest signal.

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