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SEARCHING FOR GAUGINOS AT THE CERN $p\bar{p}$ COLLIDER

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A B S T R A C T

Production at the Collider and detection of gauginos, the supersymmetric spin $\frac{1}{2}$ partners of gauge bosons, are discussed. In particular, the processes of associated production of a gluino together with another gaugino (a photino, a w-ino or a z-ino) are studied and the production cross-sections are compared with other supersymmetric particle channels and with conventional processes. The decay widths of weak gauginos are discussed and complete analytic results are derived. Depending on the masses of supersymmetric particles, different channels offer the best chances for detection. For light gluinos and scalar quarks, the associated production of photino and gluino is found to be the most prominent channel that contributes to events with an unbalanced hadronic jet at large p_T . Light w-inos can be detected in W and Z^0 decays, while w-inos and z-inos with masses close to the W and Z^0 masses can be produced in association with a gluino.

1. - Introduction -

A considerable effort is being devoted to the construction of realistic realizations of broken supersymmetry (SUSY) /1/ at accessible energies. It is of great importance to search for experimental clues on these theories. At present the $p\bar{p}$ Collider at CERN offers the best opportunity for an experimental study of these problems.

An appealing class of models is that where SUSY breaking is induced by gravitational interactions /2,3/. In these models one of the two w -inos ($\tilde{w}^+$: charged spin 1/2 partner of the W^+) is probably lighter than the W itself. Similarly, there is a z -ino ($\tilde{z}$) with mass smaller than the Z^0 . Presumably photinos ($\tilde{\gamma}$), gluinos ($\tilde{g}$), $\tilde{w}^-$ and $\tilde{z}$ could all be copiously produced at the Collider, while the scalars associated with quarks and leptons are not necessarily at sufficiently small masses. One is then led to the problem of studying practical signatures for an experimental search of these SUSY particles. Three classes of events are particularly relevant for these purposes:

- a) isolated charged leptons with large transverse momentum p_T plus missing E_T ;
- b) one or more unbalanced hadronic jets at large p_T plus missing E_T ;
- c) isolated charged leptons at large p_T on one side, hadronic jets on the other side plus missing E_T .

Particular attention has been recently devoted to the possibility /4,5,6,7/ of observing the $\tilde{w}$ in W decays:

$$p + \bar{p} \rightarrow W + X \rightarrow \tilde{w} + \tilde{\gamma} + X \quad (1)$$

The produced $\tilde{w}$'s can decay into leptonic or non leptonic modes:

$$\tilde{w}^+ \rightarrow l^+ + \nu + \tilde{\gamma} \quad (2)$$

$$\rightarrow \text{hadrons} + \tilde{\gamma} \quad (3)$$

where the $\tilde{\gamma}$ can either arise directly or through $\tilde{g}$ decays. The leptonic modes lead to events of type (a), while the non leptonic ones lead to events of type (b).

A sufficiently light $\tilde{w}$ is demanded in order to obtain a reasonable branching ratio for $W \rightarrow \tilde{w} + \tilde{\gamma}$. In the class of models we are considering a relatively light $\tilde{w}$ in general corresponds to heavier scalar quarks and leptons. Then $\tilde{w}$'s are expected to decay into

$$\tilde{w}^+ \rightarrow l^+ + \nu + \tilde{\gamma} \quad (4)$$

$$\rightarrow q + \bar{q}' + \tilde{\gamma} \quad (5)$$

$$\rightarrow q + \bar{q}' + \tilde{g} \quad (6)$$

through virtual exchange of W's and of scalar quarks and leptons (fig.1). If $\tilde{g}$'s are sufficiently light the hadronic mode is largely dominant, the leptonic signature is not detectable and the $\tilde{w}$'s from W decays can only be observed in events of type (b).

We point out in this paper that for light $\tilde{g}$'s and relatively light scalars the associated production of $\tilde{g}$ and $\tilde{\gamma}$ (fig.2):

$$p + \bar{p} \rightarrow \tilde{g} + \tilde{\gamma} + X \quad (7)$$

becomes the most prominent SUSY channel contributing to events of type (b). Thus if $\tilde{g}$'s are light and/or the $\tilde{w}$ is close in mass to the W, the process (7) is definitely more

suitable for detection than $W \rightarrow \tilde{W} + \tilde{\gamma}$. The process of scalar quarks production with an associated $\tilde{\gamma}$:

$$p + \bar{p} \rightarrow \tilde{s}_q + \tilde{\gamma} + X \quad (8)$$

analogous to (7) is in general found to be much suppressed in comparison.

In the following we compare in detail the cross sections and the p_T distributions for events of type (b) arising from all the SUSY processes just mentioned as well as from the conventional channels:

$$\begin{array}{lcl}
 p + \bar{p} \rightarrow W + X & & \\
 \quad \downarrow & & \\
 \quad \tau + \bar{\nu}_\tau & & (9) \\
 \quad \quad \downarrow & & \\
 \quad \quad \text{hadrons} + \nu_\tau & &
 \end{array}$$

$$\begin{array}{lcl}
 p + \bar{p} \rightarrow Z^0 + g + X & & (10) \\
 \quad \downarrow & & \\
 \quad \nu \bar{\nu} & &
 \end{array}$$

All channels arising from direct production are easily distinguished from the products of W decays by the absence of the characteristic Jacobian peak. For example while the W decays into $\tau + \nu_\tau$ or $\tilde{W} + \tilde{\gamma}$ are in many cases very difficult to be experimentally disentangled, on the contrary these modes can never be confused with the $\tilde{g} + \tilde{\gamma}$ production channel.

We then considered the SUSY processes that can lead to events of type (c). In particular we considered the production of two $\tilde{W}$'s from Z^0 decays [5,6]:

$$p + \bar{p} \rightarrow Z^0 \rightarrow \tilde{W}^+ + \tilde{W}^- \quad (11)$$

Events of type (c) correspond to one $\tilde{W}$ decaying into leptons and the other one into hadrons. We also studied the

associated production channels for gauginos (fig.2)

$$p + \bar{p} \longrightarrow \tilde{g} + \tilde{W} + X \quad (12)$$

$$p + \bar{p} \longrightarrow \tilde{g} + \tilde{Z} + X \quad (13)$$

followed by leptonic $\tilde{W}$ or $\tilde{Z}$ decays. These SUSY channels are compared with the conventional modes

$$p + \bar{p} \longrightarrow g + W + X \quad (14)$$

$$p + \bar{p} \longrightarrow g + Z^0 + X \quad (15)$$

and

$$p + \bar{p} \longrightarrow Z^0 \longrightarrow \nu^+ + \nu^- \quad (16)$$

which can also contribute to events of type (c).

The rates of the associated production channels (12) and (13) increase, at fixed p_T of the gluinos, with the $\tilde{W}$ or $\tilde{Z}$ masses, due to the corresponding decrease of the exchanged scalar quark masses. Thus, if the $\tilde{W}$ and $\tilde{Z}$ masses are close to the W and Z^0 masses respectively, it becomes interesting to study the possibility of detecting the weak gauginos in these channels, in addition and complementary to a search for the $\tilde{W}$ in W and Z^0 decays. Actually we find that the signals from the SUSY processes (12) and (13) only become comparable to those from the conventional channels (14) and (15) at quite large values of p_T , where all cross sections are very small. Thus the observation of heavy $\tilde{W}$'s and $\tilde{Z}$'s from these production modes is difficult but the good leptonic signature for $\tilde{Z}$'s could be detectable. On the other hand for light $\tilde{W}$'s the signal from $Z^0 \longrightarrow \tilde{W}^+ + \tilde{W}^-$ is large and the detection of this signal is possible. In particular the

separation from the potentially dangerous background from $Z^0 \rightarrow \tilde{\nu}^+ + \tilde{\nu}^-$ fortunately turns out to be quite feasible.

The plan of the paper is as follows. In sect.2 we describe an admittedly schematic pattern for the SUSY particle spectrum, which we adopt for definiteness in the subsequent analysis. In sect.3 we study the production and decays properties of $\tilde{W}$'s and $\tilde{Z}$'s. Some results are new, as for example the complete analytic expressions for the partial decay widths of weak gauginos. Sect.4 is devoted to an analysis of the processes of associated production of gauginos and of $\tilde{\gamma} + s_q$ production. The signals arising from the SUSY channels in events of type (b) and (c) are compared among them and with the competing conventional channels. In Sect.5 we draw our conclusions. Some detailed formulae and integrals are reported in Appendix 1.

2. - A schematic SUSY particle spectrum -

In the following analysis for definiteness we shall adopt an indicative pattern of masses for the SUSY spectrum. This level scheme in a simplest form takes into account some mass correlations /7/ which are in general expected in the class of models under study.

In terms of the gravitino mass $m_{3/2}$, the masses of the two scalars s_f associated to each quark or lepton f will be taken as:

$$m_{s_f} = | m_{3/2} \pm m_f | \quad (17)$$

Then $m_{3/2}$ must be heavier than about 20 GeV in order to accommodate the non observation of charged scalars at PETRA and PEP. Correspondingly the $\tilde{W}$ and $\tilde{Z}$ masses are assumed of the form:

$$m_{\tilde{W}, \tilde{Z}} = \sqrt{m_{W, Z^0}^2 + \frac{1}{4} m_{3/2}^2} \pm \frac{1}{2} m_{3/2} \quad (18)$$

For the light $\tilde{W}$ and $\tilde{Z}$, which we are particularly interested in, one equivalently has:

$$m_{3/2} = \frac{m_W^2 - m_{\tilde{W}}^2}{m_{\tilde{W}}} = \frac{m_{Z^0}^2 - m_{\tilde{Z}}^2}{m_{\tilde{Z}}} \quad (19)$$

Note that, with these mass formulae, the light $\tilde{W}$ would reach 20 GeV of mass when $m_{3/2}$ is increased up to about 300 GeV. Thus the allowed range for $m_{3/2}$ is restricted to be $20 \text{ GeV} \leq m_{3/2} \leq 300 \text{ GeV}$.

One more ingredient is the projection coefficient of the physical $\tilde{W}$ or $\tilde{Z}$ over the corresponding gaugino component, as opposed to the higgsino component, which will be taken as

$$\cos^2 \Phi_{\tilde{W}, \tilde{Z}} = \frac{m_{W, Z^0}^2}{m_{W, Z^0}^2 + m_{\tilde{W}, \tilde{Z}}^2} \quad (20)$$

With these admittedly schematic positions, once the photino mass $m_{\tilde{\gamma}}$ is neglected, the whole spectrum of SUSY particles is specified in terms of the masses of the ordinary particles and of two new parameters which can be chosen as $m_{3/2}$ and $m_{\tilde{g}}$.

3. - Properties of weak gauginos -

In this section we discuss a number of properties of weak gauginos, in particular their decay modes, which are important for the following analysis. Some results are new, as for example the complete analytic expressions for the $\tilde{W}$ and $\tilde{Z}$ decay widths.

The photino mass $m_{\tilde{\gamma}}$ is assumed to be negligible throughout this paper. Gluinos are expected to decay mainly into $q\bar{q}\tilde{g}$ /8/ with possibly a small partial width into $g\tilde{g}$ /9/, so that they can be observed as hadrons plus missing energy.

The decays of $\tilde{W}$'s and $\tilde{Z}$'s into a final state containing a real scalar quark or lepton are forbidden by phase space for most of the possible range of their masses. If the indicative spectrum given by eq.(17) and (18) is assumed this applies for $m_{\tilde{W}} \leq 57$ GeV and $m_{\tilde{Z}} \leq 64$ GeV. Then the widths are given by the diagrams in figs.1 and 3 with virtual exchange of W 's and scalars.

A direct evaluation of the $\tilde{W}$ decay rates into the channels listed in (4 - 6) leads to the following results. The partial width into the final state containing a gluino is given by:

$$\Gamma(\tilde{W} \rightarrow q\bar{q}\tilde{g}) = \frac{\alpha_W \alpha_S e s^2 \phi_{\tilde{W}} N_C C_F}{8\pi} M I\left(\frac{m_{S_q}^2}{M^2}, \frac{\mu^2}{M^2}\right) \quad (21)$$

where

$$I\left(\frac{m_{S_q}^2}{M^2}, \frac{\mu^2}{M^2}\right) = \frac{1}{2} \int_{\mu^2}^{M^2} \frac{du}{M^2} \int_{\frac{M^2\mu^2}{u}}^{M^2 + \mu^2 - u} \frac{dt}{M^2} \left[\frac{(t-\mu^2)(M^2-t)}{(t-m_{S_q}^2)^2} + \right. \\ \left. + \frac{M\mu s}{(t-m_{S_q}^2)(u-m_{\tilde{g}}^2)} + t \leftrightarrow u \right] \quad (22)$$

with $t = (P_{\tilde{w}} - P_q)^2$, $u = (P_{\tilde{w}} - P_{\tilde{q}})^2$, $s = M^2 + \mu^2 - u - t$

and $M \equiv m_{\tilde{w}}$, $\mu = m_{\tilde{g}}$, $\alpha_w = \frac{\alpha}{\sin^2 \theta_w}$,

α_s is the QCD coupling, $\cos^2 \Phi_{\tilde{w}}$ is given by eq.(20), N_c and C_F being colour factors given by $N_c = 3$, $C_F = 4/3$. This width corresponds to a single q or $\bar{q}$ flavour of the up type in the final state and consequently summing over quark flavours implies adding a factor of $(\frac{N_f}{2})$, N_f being the number of accessible generations ($N_f = 2$ in the following numerical estimates). The correct spectra can also be directly read out from eqs.(21) and (22) in that at this stage we did not make use of the symmetry in t and u of the phase space for the integrated width in order to simplify the integrand. The explicit expression of the integral I in eq.(22) is given in Appendix 1, eq.(A1).

With the same notations the widths into a final state containing a photino are given by:

$$\Gamma(\tilde{w} \rightarrow q \bar{q}' \tilde{\gamma}) = \frac{\alpha_w \alpha \cos^2 \Phi_{\tilde{w}} N_c}{16 \pi} M \int_0^{M^2} \frac{du}{M^2} \int_0^{M^2-u} \frac{dt}{M^2} \times$$

$$\times \left[\frac{1}{9} \frac{t(M^2-t)}{(t-m_{sq}^2)^2} + \frac{4}{9} \frac{u(M^2-u)}{(u-m_{sq}^2)^2} + \frac{u(M^2-u)+t(M^2-t)}{(s-m_w^2)^2} + (23) \right.$$

$$\left. + \frac{2}{3} \frac{t(M^2-t)}{(t-m_{sq}^2)(s-m_w^2)} + \frac{4}{3} \frac{u(M^2-u)}{(u-m_{sq}^2)(s-m_w^2)} \right]$$

and

$$\Gamma(\tilde{w} \rightarrow l \nu \tilde{\gamma}) = \frac{\alpha_w \alpha \cos^2 \phi_{\tilde{w}}}{16\pi} M \int_0^{M^2} \frac{du}{M^2} \int_0^{M^2-u} \frac{dt}{M^2} \times$$

$$\times \left[\frac{t(M^2-t)}{(t-m_{s_e}^2)^2} + \frac{u(M^2-u)+t(M^2-t)}{(s-m_w^2)^2} + \frac{2t(M^2-t)}{(t-m_{s_e}^2)(s-m_w^2)} \right] \quad (24)$$

The integrated expressions are given in eqs.(A3) and (A4).

For small values of the gluino mass $\Gamma(\tilde{w} \rightarrow q\bar{q}' \tilde{g})$, given in eq.(21), is large and the $\tilde{w}$ leptonic branching ratio $B_L(\tilde{w})$ is small. On the other hand, when the $\tilde{g}$ mass is increased, the three body phase space rapidly suppresses the gluino in comparison to the assumed massless (or nearly so) photino, and $B_L(\tilde{w})$ increases. On the other hand, when the $\tilde{w}$ mass is larger than the mass of scalar quarks and leptons the decays $\tilde{w} \rightarrow s_f + \bar{f}$ and $\tilde{w} \rightarrow f + \bar{s}_f$ become dominant with rates given by

$$\Gamma(\tilde{w} \rightarrow s_f + \bar{f}) \simeq \Gamma(\tilde{w} \rightarrow f + \bar{s}_f) = N \alpha_w \cos^2 \phi_{\tilde{w}} \frac{(M^2 - m_{s_f}^2)^2}{8 M^3} \quad (25)$$

where $N = N_c = 3$ for quarks and $N = 1$ for leptons. The resulting branching ratio $B_L(\tilde{w})$ is clearly independent of the $\tilde{g}$ mass in this case and $B_L(\tilde{w})$ is exactly equal to $B(W \rightarrow e \nu)$ in the limit of degenerate scalar quarks and leptons.

Finally we recall the well known /4,7/ expressions for $\Gamma(W \rightarrow \tilde{w} \tilde{\gamma})$ and $\Gamma(Z^0 \rightarrow \tilde{w} \tilde{w})$ which are also important in the following:

$$r \equiv \frac{\Gamma(W \rightarrow \tilde{W} \tilde{\gamma})}{\Gamma(W \rightarrow e \nu)} = 4 \sin^2 \theta_w \cos^2 \Phi_{\tilde{W}} \left(1 - \frac{m_{\tilde{W}}^2}{m_W^2}\right)^2 \left(1 + \frac{m_{\tilde{W}}^2}{2 m_W^2}\right) \quad (26)$$

$$r' \equiv \frac{\Gamma(Z^0 \rightarrow \tilde{W} \tilde{W})}{\Gamma(Z^0 \rightarrow e^+ e^-)} = \frac{2 \left(\sin^2 \theta_w - \cos^2 \Phi_{\tilde{W}} - \frac{1}{2} \sin^2 \Phi_{\tilde{W}} \right)^2}{\left(\sin^2 \theta_w - \frac{1}{2} \right)^2 + \sin^4 \theta_w} \times$$

$$\times \left(1 + 2 \frac{m_{\tilde{W}}^2}{m_Z^2} \right) \times \sqrt{1 - 4 \frac{m_{\tilde{W}}^2}{m_Z^2}} \quad (27)$$

The main results on $\tilde{W}$ properties as obtained from the previous analysis are summarised in Table 1. The mass spectrum of SUSY particles as given in eqs.(17,18) was assumed, so that the gravitino and the gluino masses are the only free parameters. We have taken $\alpha_s \approx 0.15$ and $\sin^2 \theta_w \approx 0.215$. Our results are in general agreement with the numerical results of ref./6/ for comparable mass assignments for the relevant SUSY levels.

One sees from Table 1 that in order to have:

$$\frac{\Gamma(W \rightarrow \tilde{W} \tilde{\gamma})}{\Gamma(W \rightarrow e \nu)} B(\tilde{W} \rightarrow e + X) \gtrsim 0.05 \quad (28)$$

it is necessary that $m_{\tilde{W}} \lesssim 40$ GeV, with a sufficiently large gluino mass. This implies that the leptonic signature for detecting $\tilde{W}$'s from W decays is reasonably pronounced only in this range of mass. Otherwise one must rely on the hadronic signature. In the next section we shall discuss the relative importance in this channel (events of type (b)) of $\tilde{W}$'s from W decays and of the photino - gluino associated production

process, together with other relevant SUSY or conventional channels.

We now consider $\tilde{Z}$ decays. The main decay modes of a light $\tilde{Z}$, when $\tilde{Z} \rightarrow f \bar{s}_f$, $s_f \bar{f}$ are kinematically forbidden, are

$$\tilde{Z} \longrightarrow \tilde{\gamma} + l^+ + l^- \quad (29)$$

$$\longrightarrow \tilde{g} + q + \bar{q} \quad (30)$$

$$\longrightarrow \tilde{g} + q + \bar{q} \quad (31)$$

and

$$\tilde{Z} \longrightarrow \tilde{W}^\pm + l^\mp + \nu \quad (32)$$

$$\longrightarrow \tilde{W}^\pm + q + \bar{q}' \quad (33)$$

The corresponding partial widths, as obtained from the diagrams in fig.3 a,b, are given as follows:

$$\begin{aligned} \Gamma(\tilde{Z} \rightarrow \tilde{\gamma} f \bar{f}) &= \frac{\alpha \alpha_w \omega^2 \phi_{\tilde{Z}} N}{16 \pi} \frac{1 - 4 |Q_f| s_w^2 + 8 Q_f^2 s_w^4}{c_w^2} Q_f^2 \\ &\times M I\left(\frac{m_{J_f}^2}{M^2}, 0\right) \end{aligned} \quad (34)$$

where $N = N_c$ for quarks and $N = 1$ for leptons,

$$\Gamma(\tilde{z} \rightarrow \tilde{g} q \bar{q}) = \frac{\alpha_w \alpha_s \cos^2 \Phi_{\tilde{z}} N_c C_F}{16\pi} \frac{(1 - 4|Q_f|s_w^2 + 8Q_f^2 s_w^4)}{c_w^2} \times$$

$$\times M I\left(\frac{m_{sq}^2}{M^2}, \frac{\mu^2}{M^2}\right)$$

In these expressions $M \equiv M_{\tilde{z}}$, $\mu = m_{\tilde{g}}$, $s_w \equiv \sin \theta_w$, $c_w \equiv \cos \theta_w$, $\cos^2 \Phi_{\tilde{z}}$ is given by eq.(20), the integral I is defined in eq.(22) and its explicit expression is in eq.(A1). The partial widths refer to a single lepton or quark flavour in the final state.

For the decay modes leading to a $\tilde{w}$ in the final state we find:

$$\Gamma(\tilde{z} \rightarrow \tilde{w} f_1 \bar{f}_2) = \frac{\alpha_w^2 \cos^2 \Phi_{\tilde{w}} \cos^2 \Phi_{\tilde{z}}}{16\pi c_w^2} N M \int_0^{M^2} \frac{du}{M^2} \int_{\frac{M^2 \mu^2}{M^2 + \mu^2 - u}}^{M^2 + \mu^2 - u} \frac{dt}{M^2} \times$$

$$\times \left\{ c_w^4 \frac{(t - M^2)(\mu^2 - t) - \mu M s}{(s - m_w^2)^2} + \frac{1}{4} (1 - 2|Q_{f_1}|s_w^2) \frac{(t - M^2)(\mu^2 - t)}{(t - m_{sf}^2)^2} + \right.$$

$$+ c_w^2 (1 - 2|Q_{f_1}|s_w^2) \frac{(t - M^2)(\mu^2 - t) - \mu M s}{(s - m_w^2)(t - m_{sf}^2)} -$$

$$- \frac{1}{4} (1 - 2|Q_{f_1}|s_w^2) (1 - 2|Q_{f_2}|s_w^2) \frac{\mu M s}{(t - m_{sf}^2)(\mu - m_{sf}^2)} +$$

$$\left. + \left(\begin{array}{c} t \leftrightarrow \mu \\ f_1 \leftrightarrow f_2 \end{array} \right) \right\}$$

In this last formula $\mu \equiv m_{\tilde{w}}$, and as usual one single quark ($N = N_c$) or lepton ($N = 1$) pair was considered. The results of the phase space integrations are given in eqs.(A5).

On the other hand, if the $\tilde{z}$ is sufficiently heavy, it will predominantly decay into a fermion and the correspon-

ding scalar. The partial widths for these decay modes are then given by:

$$\Gamma(\tilde{z} \rightarrow f \bar{s}_f) = \Gamma(\tilde{z} \rightarrow \bar{f} s_f) = \frac{\alpha_W \cos^2 \theta_{\tilde{z}}}{16} N \times$$

$$\times \left[\frac{(1 - 2|Q_f|s_W^2)^2 + 4Q_f^2 s_W^4}{C_W^2} \right] \frac{(M^2 - m_{sf}^2)^2}{M^3} \quad (37)$$

This partial width refers to the sum of the two scalars associated with each lepton ($N = 1$) or quark ($N = N_c$) flavour, in the limit where their mass difference is neglected.

The resulting leptonic branching ratio $B(\tilde{Z} \rightarrow e^+e^-+X)$ is shown in Table 2 for different values of $m_{3/2}$ (which fixes $m_{\tilde{Z}}$, $m_{\tilde{W}}$ and m_{sf} in the model of eqs.(17,18) for the SUSY spectrum) and of $m_{\tilde{g}}$. One sees that $B(\tilde{Z} \rightarrow e^+e^-+X)$ varies very much in the explored range of masses. This is due to the presence of many competing decay channels (see (29-33)). Also in the $\tilde{Z}$ case, as was true for the $\tilde{W}$, the leptonic branching ratio tends to increase with $m_{\tilde{g}}$, unless the $\tilde{Z}$ mass is sufficiently heavy for the decay into a final state with a real scalar to be possible. In this case the $\tilde{Z}$ leptonic branching ratio is clearly independent of $m_{\tilde{g}}$ and is identical to $B(Z \rightarrow e^+e^-)$.

4. - Gaugino Production and Detection -

We now consider the cross sections for associated production of two gauginos. In particular we study the parton sub - processes:

$$q + \bar{q} \rightarrow \tilde{g} + \tilde{\gamma} \quad (38)$$

$$q + \bar{q} \rightarrow \tilde{g} + \tilde{w} \quad (39)$$

$$q + \bar{q} \rightarrow \tilde{g} + \tilde{z} \quad (40)$$

The relevant diagrams are shown in fig.2 We always consider left and right scalar quarks as degenerate mass eigenstates with mass m_{sq} . Then one readily obtains:

$$\frac{d\sigma_i}{dt} = \frac{2\pi\alpha_s}{s^2} \frac{C_F}{N_c} \times \left\{ \gamma_i \times \left[\frac{(m_{\tilde{g}}^2 - t)(\mu_i^2 - t)}{(t - m_{sq}^2)^2} - \frac{\mu_i m_{\tilde{g}} s}{(t - m_{sq}^2)(u - m_{sq}^2)} + t \leftrightarrow u \right] \right\}^{(41)}$$

where μ_i is the gaugino mass ($\mu_i = m_{\tilde{g}} = 0, m_{\tilde{W}}, m_{\tilde{Z}}$), $s = (P_q + P_{\bar{q}})^2$, $t = (P_q - P_{\tilde{g}})^2$, $u = (P_{\bar{q}} - P_{\tilde{g}})^2$ and γ_i is given by

$$\begin{aligned} \gamma_i &= Q_q^2 \quad (\tilde{\gamma}) \\ &= \cos^2 \Phi_{\tilde{W}} / (4 \sin^2 \theta_w) \quad (\tilde{W}) \\ &= \frac{(\tau_3 - 2Q_q \sin^2 \theta_w)^2 + (2Q_q \sin^2 \theta_w)^2}{8 \cos^2 \theta_w \sin^2 \theta_w} \cdot \cos^2 \Phi_{\tilde{Z}} \quad (\tilde{Z}) \end{aligned} \quad (42)$$

As usual $C_F = 4/3$, $N_c = 3$.

Similarly from the diagrams in fig.4 we obtain the cross section for the process:

$$\bar{q} + g \rightarrow \tilde{\gamma} + \bar{s}_q \quad (43)$$

which is given by:

$$\frac{d\sigma}{dt} = \frac{\pi\alpha_s Q_q^2}{N_c s^2} \left[-\frac{u}{s} + \frac{t(t + m_{sq}^2)}{(t - m_{sq}^2)^2} - \frac{t(s - 2m_{sq}^2)}{s(t - m_{sq}^2)} \right] \quad (44)$$

where this expression refers to the production of both scalars associated with a single quark flavour. Here

$$s = (P_q + P_g)^2, \quad t = (P_q - P_{\tilde{\gamma}})^2, \quad u = (P_q - P_{S_q})^2.$$

We first concentrate on the signature based on events of type (b), defined in the introduction, with one or more hadronic jets at large p_T on one side (with respect to a plane containing the beams) and nothing on the other side. The main SUSY processes which contribute to this type of events are $\tilde{\gamma} + \tilde{g}$ and $\tilde{\gamma} + s_q$ associated production as well as $W \rightarrow \tilde{W} + \tilde{\gamma}$ with the $\tilde{W}$ decaying into hadronic channels. The signals from SUSY particles are to be compared with the background of the conventional processes $W \rightarrow \tau \nu$ with hadronic τ decay and $Z^0 + g$ associated production followed by Z^0 decay into any of the possible $\nu\bar{\nu}$ pairs (see (9.10)). We also considered other channels, as for example associated production of $\tilde{\gamma} + \tilde{W}$ (off the W peak) but found them to be negligible in comparison.

After convolution with the indicative quark and gluon densities in protons and antiprotons as specified in ref. /10/ one obtains the results displayed in figs.5-10. Fig.5 is intended to offer a general comparison of the relative size of the cross sections for the processes under study. We plot the differential cross sections in p_T for central production at $\theta \simeq 90^\circ$ for the different channels of interest. p_T and θ always refer to the particle that produces the visible hadronic jet. The gluino mass is fixed to $m_{\tilde{g}} \simeq 10$ GeV. For $m_{\tilde{W}} = 40$ GeV (which corresponds by eq.(18) to $m_{3/2} \simeq 124$ GeV) the signal from $W \rightarrow \tilde{W} \tilde{\gamma} \rightarrow \text{hadrons} + \tilde{\gamma} + \tilde{\gamma}$ is stronger than that arising from $\tilde{\gamma} + \tilde{g}$ production, although the Jacobian peak for the former process is partially superimposed to the larger peak from $W \rightarrow \tau \nu \rightarrow \text{hadrons} + \nu + \bar{\nu}$. On the other hand for $m_{\tilde{W}} = 60$ GeV (corresponding to $m_{3/2} \simeq 49$ GeV), the $\tilde{\gamma} + \tilde{g}$ production signal is dominant and its p_T distribution is clearly distinguishable from that of $W \rightarrow \tau \nu$. This shows that, as a function of $m_{3/2}$, as soon as the signal from $W \rightarrow \tilde{W} \tilde{\gamma}$ tends to disappear, it is gradually replaced by that of $\tilde{\gamma} + \tilde{g}$ production which eventually becomes very pro-

minent. Thus the interest of searching for this type of events is reinforced by the present analysis.

In figs.6,7 the differential cross sections for $\tilde{\gamma} + \tilde{g}$ production are plotted for different values of $m_{3/2}$ and $m_{\tilde{g}}$. In fig.8 the angular distributions for $\tilde{\gamma} + \tilde{g}$ production at fixed $p_T = 40$ GeV are shown for $m_{\tilde{g}} = 10$ GeV and different values of $m_{3/2}$. One sees that the results at $\theta = 90^\circ$ for this process are actually representative of a large range of values for θ . In fig.9 the p_T distributions at $\theta = 90^\circ$ for $W \rightarrow \tilde{W} \tilde{\gamma} \rightarrow \text{hadrons} + \tilde{\gamma} + \tilde{\gamma}$ are shown for different values of $m_{3/2}$. Finally in fig.10 we display the ratio of the differential cross sections for the channels $\tilde{\gamma} + s_q$ and $\tilde{\gamma} + \tilde{g}$ for different values of $m_{3/2}$ and $m_{\tilde{g}}$. We see that scalar quark production is always considerably suppressed with respect to gluino production unless $m_{\tilde{g}}$ is particularly large and m_{s_q} is as small as possible.

We now discuss the class (6) of events where a charged lepton (or alternatively a pair of oppositely charged leptons) is detected with large (total) p_T , partially balanced by a hadronic jet on the other side.

Two oppositely charged leptons and one hadronic jet can arise from the SUSY channel $\tilde{\gamma} + \tilde{Z}$ as well as from $g + Z^0$ production, followed by $\tilde{Z}$ or Z^0 leptonic decays. The p_T distributions at $\theta = 90^\circ$ for the two processes are shown in fig.1 for $m_{\tilde{g}} = 10$ GeV. The $\tilde{Z}$ production cross section increases with $m_{\tilde{Z}}$ because of the corresponding decrease of the mass of the exchanged scalar quark. Furthermore, as can be seen from Table 2, there is a large increase of the leptonic branching ratio for $m_{\tilde{Z}} \gtrsim 70$ GeV, where, according to our model for the mass spectrum the decays $\tilde{Z} \rightarrow f + s_f$ are allowed. This effect is clearly seen in fig.11. For large $\tilde{Z}$ mass, $m_{\tilde{Z}} \gtrsim 50$ GeV, and large p_T the SUSY signal is comparable to the production of Z^0 with large p_T . However in that region both cross sections are small, so that high statistics is necessary. On the other hand the signature is

very sharp in this case, because of the invariant mass of the two leptons, which obviously peaks at the Z^0 mass in one process and is distributed over quite smaller values in the other process. Thus, owing to its good signature, this channel is interesting in spite of its small production cross section.

Similarly one charged lepton and one hadronic jet can be obtained from the SUSY channels $\tilde{g} + \tilde{W}$ or $Z^0 \rightarrow \tilde{W}^+ \tilde{W}^-$ and from the standard processes $g + W$ and $Z^0 \rightarrow e^+ e^-$. The p_T distributions at $\theta = 90^\circ$ for $m_{\tilde{g}} = 10$ GeV obtained for all these processes are compared in fig.12. The $Z^0 \rightarrow \tilde{W}^+ \tilde{W}^-$ signal for $20 \text{ GeV} \leq m_{\tilde{W}} \leq 40 \text{ GeV}$ emerges quite well from the continuum of W production at large p_T . It is also important to observe that the distribution arising from $Z^0 \rightarrow e^+ e^-$ is less prominent and can be disentangled from the $\tilde{W}$ decay channel of the Z^0 . For heavier $\tilde{W}$'s the $Z^0 \rightarrow \tilde{W} \tilde{W}$ mode disappears and one can consider the associated production of $\tilde{g}$ and $\tilde{W}$. However even in the most favourable case the $\tilde{W}/W$ ratio is still rather small. Thus the detection of $\tilde{W}$'s produced in association with $\tilde{g}$'s requires high statistics and one has to rely on the difference between the lepton spectrum which is softer for $\tilde{W}$'s than for W 's in order to extract the $\tilde{W}$ signal from the background of W production at large transverse momentum.

5. - Conclusion -

The main purpose of our analysis was to discuss the SUSY processes of associated production of a gluino together with a photino or a $\tilde{W}$ or a $\tilde{Z}$. We find that the most promising channel is the $\tilde{\gamma} + \tilde{g}$ production mode. This process leads to events with an unbalanced hadronic jet at large p_T . For light gluinos and scalar quarks the production cross section is sufficiently large for detection. We have shown

that the conditions for a large signal from $\tilde{\gamma} + \tilde{g}$ production are complementary to those for detecting $\tilde{W}$'s from W decays. In fact the latter is visible for light $\tilde{W}$'s, which correspond to heavy scalar quarks. Furthermore light gluinos in general make the leptonic branching ratio of $\tilde{W}$'s to be small. This smallness in turn prevents detection by the leptonic signature of the $\tilde{W}$'s from W decays. Thus for light gluinos and/or heavy $\tilde{W}$'s the associated production of $\tilde{\gamma} + \tilde{g}$ is the most interesting channel for detection of a gaugino.

We also studied the associated production of $\tilde{g} + \tilde{W}$ and of $\tilde{g} + \tilde{Z}$. We have shown that the production cross sections become comparable to those of $g + W$ and of $g + Z^0$ only at large values of p_T where the cross sections are small. $\tilde{Z}$ production is the most interesting of the two, because of its more favourable signal to background ratio and its good signature. We have also shown that for light $\tilde{W}$'s the process $Z^0 \rightarrow \tilde{W} + \tilde{W}$ offers the best possibilities of detection in the channel of one lepton plus a jet at large p_T .

The next generation of runs at the Collider is thus expected to set stringent bounds on the masses of gauginos. The discovery of these SUSY particles would open a new horizon in particle physics.

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- Appendix 1 -

We report here the explicit results on the phase space integrations relevant to the calculation of the $\tilde{w}$ and $\tilde{z}$ partial widths given in sect.3.

The integral $I(x,y)$ defined in Eq.22 (which appears in eqs.21,34,35) leads to the expression:

$$\begin{aligned}
 I(x,y) = & (1-y) \left(3x + \frac{y}{x} + 2\sqrt{y} - \frac{5}{2}(1+y) \right) + \\
 & + \frac{y}{x} \left(2\sqrt{y} - \frac{y}{x} \right) \ln y + \ln \left(\frac{x-1}{x-y} \right) \left\{ \left[2 \left(2 + \frac{\sqrt{y}}{x} \right) (x-y) - \right. \right. \\
 & - \left. \left(1 - \frac{y^2}{x^2} \right) (1+x) \right] (x-1) + \sqrt{y} (2x-y-1) \ln \frac{x^2-y}{x(2x-y-1)} \right\} + \\
 & + \sqrt{y} (2x-y-1) \left[\text{Li}_2 \left(\frac{x-1}{x} \right) - \text{Li}_2 \left(\frac{x-y}{x} \right) + \right. \quad (A.1) \\
 & + \text{Li}_2 \left(\frac{x(x-y)}{x^2-y} \right) - \text{Li}_2 \left(\frac{x(x-1)}{x^2-y} \right) + \text{Li}_2 \left(\frac{x-1}{2x-y-1} \right) - \\
 & - \left. \text{Li}_2 \left(\frac{x-y}{2x-y-1} \right) \right]
 \end{aligned}$$

where /11/

$$Li_2(x) = - \int_0^x \ln(1-z) \frac{dz}{z} \quad (A.2)$$

The explicit results for the remaining $\tilde{w}$ and $\tilde{z}$ partial widths are given in the following.

From eq.23 one obtains:

$$\begin{aligned} \Gamma(\tilde{w} \rightarrow q \bar{q} \tilde{\gamma}) &= \frac{\alpha_w \alpha \cos^2 \phi_{\tilde{w}} N_c M}{16 \pi} \left\{ 2W - 1 - \frac{1}{3W} + 2W(W-1) \times \right. \\ &\times \ln\left(\frac{W-1}{W}\right) + \frac{5}{9} \left[3q - \frac{5}{2} + (q-1)(3q-1) \ln\left(\frac{q-1}{q}\right) \right] + \\ &+ 2q - W - \frac{1}{2} + (W-1)(2q-W-1) \ln\left(\frac{W-1}{W}\right) + 2q(1-q) \left[\ln\frac{W+q-1}{W} \ln\frac{q-1}{q} \right. \\ &\left. \left. + Li_2\left(\frac{q}{W+q-1}\right) - Li_2\left(\frac{q-1}{W+q-1}\right) \right] \right\} \\ \text{where } W &= \frac{m_w^2}{M^2} \quad \text{and } q = \frac{m_{sq}^2}{M^2} \end{aligned} \quad (A.3)$$

Similarly from Eq.(24) one finds:

$$\begin{aligned} \Gamma(\tilde{w}^+ \rightarrow l^+ \nu_l \tilde{\gamma}) &= \frac{\alpha_w \alpha \cos^2 \phi_{\tilde{w}}}{16 \pi} M \left\{ W - \frac{1}{3W} + 5l - 4 + \right. \\ &+ (W-1)(2l+W-1) \ln\frac{W-1}{W} + (l-1) \left[(3l-1+2l \times \right. \\ &\times \ln\left(\frac{W}{W+l-1}\right) \ln\left(\frac{l-1}{l}\right) + 2l Li_2\left(\frac{l-1}{W+l-1}\right) - \\ &\left. \left. - 2l Li_2\left(\frac{l}{W+l-1}\right) \right] \right\} \end{aligned} \quad (A.4)$$

with $l = \frac{m_{se}^2}{M^2}$.

Finally, from Eq.36 one obtains:

$$\Gamma(\tilde{z} \rightarrow \tilde{w}^- f_1 \bar{f}_2) = \frac{\alpha_{\tilde{w}}^2 \cos^2 \phi_{\tilde{w}} \cos^2 \phi_{\tilde{z}}}{32 \pi c_{\tilde{w}}^2} N M \left\{ 2 c_{\tilde{w}}^4 A_1 + \right. \\ \left. + (1 - 2 s_{\tilde{w}}^2 + 2 s_{\tilde{w}}^4 F_1) A_2 + 4 c_{\tilde{w}}^4 A_3 - (1 - 2 s_{\tilde{w}}^2 + 4 s_{\tilde{w}}^4 F_2) A_4 \right\} \quad (A.5)$$

where $F_1 = \frac{5}{9}$, $F_2 = \frac{2}{9}$ for quarks, $F_1=1$, $F_2=0$ for leptons and:

$$A_1 = (1 - \tilde{w}) \left[2W + 4\sqrt{\tilde{w}} - 1 - \tilde{w} - \frac{1}{3W} (1 - \tilde{w})^2 \right] + \left[W(W - (1 - \sqrt{\tilde{w}})^2) - \right. \\ \left. - \sqrt{\tilde{w}} (1 + \tilde{w}) \right] \ln \tilde{w} - \left\{ (W - \tilde{w} - 1) \left[\sqrt{\tilde{w}} (1 + \tilde{w}) - W(W - (1 - \sqrt{\tilde{w}})^2) \right] + \right. \\ \left. + 2\tilde{w}(W + 2\sqrt{\tilde{w}}) \right\} \cdot \frac{1}{2} \ln \left(\frac{W - 1 + \tilde{w}(W - \tilde{w} + 2) + (1 - \tilde{w})2}{W - 1 + \tilde{w}(W - \tilde{w} + 2) - (1 - \tilde{w})2} \right) \quad (A.6)$$

$$A_2 = (1 - \tilde{w}) \left[3f - \frac{5}{2} (1 + \tilde{w}) + \frac{\tilde{w}}{f} \right] - \frac{\tilde{w}^2}{f^2} \ln \tilde{w} + \\ + (f - 1) \left[4(f - \tilde{w}) - \left(1 - \frac{\tilde{w}^2}{f^2} \right) (f + 1) \right] \ln \left(\frac{f - 1}{f - \tilde{w}} \right) \quad (A.7)$$

$$\begin{aligned}
 A_3 = & \frac{1}{2} (1-\tilde{w}) \left(2f - w - \frac{\tilde{w}}{2} - \frac{1}{2} + 2\sqrt{\tilde{w}} \right) + \frac{\sqrt{\tilde{w}}}{f} (f-1)(f-\tilde{w}) \times \\
 & \times \ln \left(\frac{f-1}{f-\tilde{w}} \right) + \frac{1}{4} \left[(1+\tilde{w}-w)(w+\tilde{w}-2f+1) + \tilde{w} \times \right. \\
 & \times \left. \left(1 + 4 \frac{\sqrt{\tilde{w}}}{f} \right) \right] \ln \tilde{w} + \frac{1}{4} (2f-w-\tilde{w}-1) r \times \\
 & \times \ln \frac{(1-b_+)(\tilde{w}-b_-)}{(1-b_-)(\tilde{w}-b_+)} + \left[(1-f)(f-\tilde{w}) - \sqrt{\tilde{w}} w \right] \times \\
 & \times \left[\ln \left(\frac{f-1}{f-\tilde{w}} \right) \ln \left(1 + \frac{(f-1)(f-\tilde{w})}{wf} \right) + \text{Li}_2 \left(\frac{f-\tilde{w}}{f-b_+} \right) - \text{Li}_2 \left(\frac{f-1}{f-b_+} \right) + \right. \\
 & \left. + \text{Li}_2 \left(\frac{f-\tilde{w}}{f-b_-} \right) - \text{Li}_2 \left(\frac{f-1}{f-b_-} \right) + \text{Li}_2 \left(\frac{f-1}{f} \right) - \text{Li}_2 \left(\frac{f-\tilde{w}}{f} \right) \right]
 \end{aligned} \tag{A.8}$$

$$\begin{aligned}
 A_4 = & \sqrt{\tilde{w}} \left\{ 2 \left[\frac{1}{f} (f-1)(f-\tilde{w}) \ln \left(\frac{f-1}{f-\tilde{w}} \right) + \frac{\tilde{w}}{f} \ln \tilde{w} + 1 - \tilde{w} \right] + \right. \\
 & + (2f-\tilde{w}-1) \left[\ln \left(\frac{f-\tilde{w}}{f-1} \right) \ln \frac{f(2f-\tilde{w}-1)}{(f^2-\tilde{w})} + \text{Li}_2 \left(\frac{f-1}{f} \right) - \right. \\
 & - \text{Li}_2 \left(\frac{f-\tilde{w}}{f} \right) + \text{Li}_2 \left(\frac{f-1}{2f-\tilde{w}-1} \right) - \text{Li}_2 \left(\frac{f-\tilde{w}}{2f-\tilde{w}-1} \right) + \text{Li}_2 \left(\frac{f(f-\tilde{w})}{f^2-\tilde{w}} \right) - \\
 & \left. \left. - \text{Li}_2 \left(\frac{f(f-1)}{f^2-\tilde{w}} \right) \right] \right\}
 \end{aligned} \tag{A.9}$$

$$\text{with } r = \sqrt{(w - \tilde{w} - 1)^2 - 4\tilde{w}}$$

$$b_{\pm}^{\pm} = -\frac{1}{2} (w - \tilde{w} - 1) \pm \frac{1}{2} r$$

and

$$w = \frac{m_W^2}{M^2}, \quad \tilde{w} = \frac{m_{\tilde{W}}^2}{M^2}, \quad f = \frac{m_{sq}^2}{M^2} \text{ for quarks, } f = \frac{m_{sl}^2}{M^2} \text{ for leptons.}$$

- References -

- /1/ For a recent review see for example: S.Ferrara in Proc. of the Int. Europhysics Conf. on High Energy Phys. Brighton, England, 1983 (Rutherford Lab., 1983, p.522).
- /2/ E.Cremmer, S.Ferrara, L.Girardello, A.Van Proyen, Phys. Lett. 116 B (1982) 231.
R.Barbieri, S.Ferrara, A.Savoy, Phys. Lett. 119 B (1982) 343.
R.Arnowitz, A.H.Chamseddine, P.Nath, Phys. Rev. Lett. 49 (1982) 970; 50 (1983) 232.
S.Ferrara, D.V.Nanopoulos, C.Savoy; Phys. Lett. 123 B (1983) 214.
E.Cremmer, P.Fayet, L.Girardello; Phys. Lett. 122 B (1983) 41.
H.P.Nilles, M.Srednicki, D.Wyler, CERN-TH 3432 (1982).
- /3/ L.E.Ibanez, Phys. Lett. 118 B (1982) 73;
L.E.Ibanez, C.Lopez, Phys. Lett. 126 B (1983) 54;
J.Ellis, D.V.Nanopoulos, K.Tamvakis, Phys. Lett. 121 B (1983) 123;
L.Alvarez Gaumè, I. Polchinski, M.B. Wise, Nucl. Phys. B 221 (1983) 495;
J.Ellis, J.Hagelin, D.V.Nanopoulos, K.Tamvakis SLAC-PUB 3042 (1983);
J.Ellis, S.Rudaz, Phys. Lett. 128 B (1983) 248.
- /4/ S.Weinberg, Phys. Rev. Lett. 50 (1983) 387.
- /5/ J.Ellis, J.Hagelin, D.V.Nanopoulos, M.Srednicki, Phys. Lett. 127 B (1983) 233;
D.Dicus, S.Nandi, X.Tata Phys. Lett. 129 B (1983) 451;
D.Dicus, S.Nandi, W.Repko, X.Tata, Univ. of Texas at Austin Preprint, 1983;
B.Grinstein, I.Polchinski, M.Wise, Phys. Lett. 130 B (1983) 285;
M.Mangano, CERN-TH 3717 (1983).
- /6/ A.H.Chamseddine, P.Nath, R.Arnowitz, Harvard Univ. preprints HUTP - 83/A040 and HUTP - 83/A077.
- /7/ P.Fayet, Phys. Lett. 125 B (1983) 178 and Proceedings of the Int. Europhysics Conf. on High Energy Phys., Brighton, England, 1983 (Rutherford Lab., 1983, P.33).
- /8/ G.L.Kane, J.P.Leveille, Phys. Lett. 112 B (1982) 227;
E.Franco, Univ. of Rome Preprint n.332 (1983).
- /9/ H.E.Haber, G.L.Kane, Nucl. Phys. Rev. B 232 (1984) 333.
- /10/ G.F.Owens, E.Reya, Phys. Rev. D 17 (1978) 3003.
- /11/ L.Lewin, Dilogarithms and Associated Functions, Mc Donald 1958.

TABLE 1

$m_{\tilde{g}}$	20	25	30	35	40	45	50	60	65	70
$m_{3/2}$	308	237	189	152	124	101	81	49	36	24
r	0.74	0.67	0.60	0.52	0.44	0.36	0.28	0.14	0.09	0.05
r'	8.86	8.35	7.66	6.73	5.41	3.24				
m_g										
0	12.2 (%) (8.8)	10.8 (%) (7.2)	8.8 (%) (5.3)	6.4 (%) (3.4)	4.3 (%) (1.9)	2.6 (%) (0.9)	1.5 (%) (0.4)			
10	12.9 (9.3)	12.0 (8.0)	10.1 (6.0)	7.4 (3.9)	4.8 (2.1)	2.8 (1.0)	1.6 (0.4)			
20	13.1 (9.5)	13.1 (8)	12.9 (7.7)	11.7 (6.1)	8.9 (3.9)	5.5 (2.0)	2.8 (0.8)	13.1% (1.8)	13.1% (1.2)	13.1% (0.66)
30	13.1 (9.5)	13.1 (8.7)	13.1 (7.9)	13.2 (6.9)	13.0 (5.7)	11.3 (4.1)	7.1 (2.0)			
40	13.1 (9.5)	13.1 (8.7)	13.1 (7.9)	13.2 (6.9)	13.3 (5.9)	13.6 (4.9)	13.3 (3.8)			
50	13.1 (9.5)	13.1 (8.7)	13.1 (7.9)	13.2 (6.9)	13.3 (5.9)	13.6 (4.9)	14.0 (4.1)			

- Caption to Table 1 -

$\tilde{W}$ properties. For each value of $m_{\tilde{W}}$ the corresponding values of $m_{3/2}$, according to eq.19, of r and r' defined in eqs.26 and 27 respectively, are given in the first lines. Then, for each stated value of the gluino mass $m_{\tilde{g}}$ the values of $B_L(\tilde{W}) = B(\tilde{W} \rightarrow e + X)$, the branching ratio into electrons (with electrons from $\tilde{W}$ decays also included) and (in parenthesis) the quantity $\kappa_{B_L}(\tilde{W})$ are shown. For $m_{\tilde{Z}} = 60$ GeV $\tilde{W}$ decays into a final state with a real scalar are dominant.

Table 2

$m_{\tilde{Z}}$	25	30	35	40	45	50	55	60	70	75	80	85
$m_{\tilde{W}}$	19	22	26	30	35	39	43	48	57	62	66	71
$m_{3/2}$	336	271	223	186	156	130	109	90	59	45	33	21
$m_{\tilde{g}}$	0	.57 (%)	.46 (%)	.29 (%)	.22 (%)	.19 (%)	.19 (%)	.18 (%)	.18 (%)	↑	↑	↑
	10	1.0	.70	.40	.27	.21	.19	.18	.18	↑	↑	↑
	20	2.1	2.0	1.5	.90	.55	.41	.33	.27	3.5 %	3.5 %	3.5 %
	30	2.1	2.3	3.1	3.7	2.9	1.6	.98	.64	↓	↓	↓
	40	2.1	2.3	3.1	4.5	7.8	8.0	5.0	2.5	↓	↓	↓
	50	2.1	2.3	3.1	4.5	7.9	9.9	11.4	10.6	↓	↓	↓

- Caption to Table 2 -

$\tilde{Z}$ leptonic branching ratio. For each value of $m_{\tilde{Z}}$ the corresponding values of $m_{3/2}$ and $m_{\tilde{W}}$ are given, according to eq.19, in the first lines. Then, for each stated value of the gluino mass $B_L(\tilde{Z}) = B(\tilde{Z} \rightarrow e^+e^- + X)$ is shown. For $m_{\tilde{Z}} \geq 70$ GeV the decay into a final state with a real scalar is assumed to be dominant.

Figure Captions

- 1) Diagrams for $\tilde{w}$ decays. Top line: $\tilde{w} \longrightarrow l \bar{\nu}_l \tilde{\gamma}$;
middle: $\tilde{w} \longrightarrow q \bar{q}' \tilde{\gamma}$;
bottom: $\tilde{w} \longrightarrow q \bar{q}' \tilde{g}$.
- 2) Diagram for associated production of gluino-gaugino.
- 3) Diagrams for $\tilde{z}$ decays.
a) $\tilde{z} \longrightarrow l^+ l^- \tilde{\gamma}$ and $\tilde{z} \longrightarrow q \bar{q} \tilde{\gamma}$, $\tilde{z} \longrightarrow q \bar{q} \tilde{g}$.
b) $\tilde{z} \longrightarrow \tilde{w} f \bar{f}'$ where f is either a quark or a lepton.
- 4) Diagrams for associated production of a photino and a scalar quark.
- 5) Differential cross section at $\theta = 90^\circ$ of several processes contributing to events with one or more unbalanced hadronic jets at large transverse momentum p_T plus missing E_T . The relevant branching ratios are included. p_T and θ refer to τ for $W \longrightarrow \nu \tau$, to g for $g + Z^0$ production, to $\tilde{g}$ for $\tilde{\gamma} + \tilde{g}$ and to $\tilde{w}$ for $W \longrightarrow \tilde{\gamma} \tilde{w}$. The gluino mass, which also enters in the determination of the hadronic branching ratio of the $\tilde{w}$, is taken as $m_{\tilde{g}} = 10$ GeV. For small values of the $\tilde{w}$ mass, the process $W \longrightarrow \tilde{\gamma} \tilde{w}$ is the most important Susy channel. As $m_{\tilde{w}}$ increases, the associated production of $\tilde{\gamma} + \tilde{g}$ becomes dominant, due to the corresponding decrease of the exchanged scalar quark masses, according to eqs. 17 and 18 of the text.
- 6) Differential cross sections at $\theta = 90^\circ$ for $\tilde{\gamma} + \tilde{g}$ production for different values of the exchanged scalar quark mass. p_T and θ are the total transverse momentum and angle of the gluino.
- 7) Differential cross sections at $\theta = 90^\circ$ for $\tilde{\gamma} + \tilde{g}$ production for different values of the gluino and the exchanged scalar masses. p_T and θ are the total transverse momentum and angle of the gluino.
- 8) Angular distribution at fixed p_T for $\tilde{\gamma} + \tilde{g}$ production, as functions of the exchanged scalar quark masses. p_T and θ are the total transverse momentum and angle of the gluino.

- 9) Differential distributions at $\theta = 90^\circ$ for $W \rightarrow \gamma \tau$ and $W \rightarrow \tilde{\gamma} \tilde{W}$ (for τ and $\tilde{W}$ hadronic decays) for several values of $m_{\tilde{W}}$. p_T and θ are the total transverse momentum and angle of τ or $\tilde{W}$. The relevant hadronic branching ratios (see Table 1) are included.
- 10) Ratios of production rates for $s_q + \tilde{\gamma}$ versus $\tilde{\gamma} + \tilde{g}$ as functions of gluino and scalar quark masses. p_T and θ are the total transverse momentum and angle of s_q or $\tilde{g}$.
- 11) Differential distributions at $\theta = 90^\circ$ for the SUSY channels $\tilde{g} + (\tilde{Z} \rightarrow e^+ e^- \tilde{\gamma})$ compared with the conventional process $g + (Z \rightarrow e^+ + e^-)$ for different values of $m_{\tilde{g}}$ and $m_{\tilde{Z}}$. The relevant leptonic branching ratios are included. p_T and θ refer to the total transverse momentum and angle of g or $\tilde{g}$.
- 12) Differential distributions at $\theta = 90^\circ$ of various processes contributing to events with one electron and one or more hadronic jets at large transverse momentum. p_T and θ are the total transverse momentum and angle of the particle which produces the hadronic jet.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12