Abstract: Measurements of the total hadronic cross section in $e^+e^-$ annihilation are shown to be capable of severely limiting the possibility that gauginos have negligible tree level masses. A combined analysis of 1997 and earlier LEP data, considering simultaneously conventional SUSY signatures and purely hadronic final states, should achieve a 95% cl sensitivity to the case that the SU(2) and U(1) gauginos are massless. If integrated luminosity targets are achieved, it should also be possible to exclude the case that the wino or wino and gluino are light while the bino is heavy, except possibly for a small region of $\mu$, $\tan\beta$. The analysis applies whether or not R-parity is conserved, and can also be used to reduce the model-dependence of conventional SUSY searches.

1Research supported in part by NSF-PHY-94-23002
An important prediction of SUSY breaking scenarios which give small or negligible mass, $m_2$, to the SU(2) gauginos (winos) is that the lighter physical chargino has mass $\lesssim m_W$. If the U(1) gaugino (bino) also has negligible mass, $m_1$, then the lightest neutralino is a nearly massless photino. When gaugino masses are negligible at tree level, radiative corrections give a gluino mass of $\sim 100$ MeV and a somewhat larger photino mass, depending on parameters. The photino can account for the observed dark matter if it is lighter than the gravitino and $R$-parity is conserved.

In such scenarios, the cross section for production of charginos and neutralinos is determined essentially completely by $\mu$, the higgsino mixing parameter, $\tan\beta \equiv v_U/v_D$, and $m(\tilde{\nu}_e)$. $\mu$ and $\tan\beta$ determine the masses and couplings of the charginos and neutralinos; the sensitivity to $m(\tilde{\nu}_e)$ is due to destructive interference between the $s$-channel poles and $t$-channel $\tilde{\nu}_e$ exchange. Figures 1 and 2 show the chargino and neutralino masses as a function of $\mu$, for several values of $\tan\beta$ and $m_1 = m_2 = 0$. It is easy to see analytically that when $m_1$ and $m_2$ are negligible and $\mu$ obeys $\mu \ll m_Z$, the second lightest neutralino is mainly higgsino and has mass approximately $\mu$.

The important feature to extract from Figs. 1 and 2 is that $m(\chi^0_2) + m(\chi^0_3)$ is smallest at low $\mu$ while $2m(\chi^0_1)$ is smallest at large $\mu$. Therefore for any value of $\mu$ either neutralino or chargino production is kinematically favorable. The purpose of this paper is to point out that the entire parameter space of any scenario with approximately massless electroweak gauginos leads to rates for either $e^+e^- \rightarrow \chi^0_2\chi^0_{3,4}$ or $e^+e^- \rightarrow \chi^+_i\chi^-_j$ which are accessible with existing LEP data. Scenarios with a heavy bino but approximately massless wino are potentially also fully accessible with the planned 183 GeV and 192 GeV data acquisition.

Depending on the relative mass of squark and $W$, whether the gluino is light or not, whether $R$-parity is violated and if so how, chargino and

\[ 2M^2_{\chi^\pm} = \mu^2 + 2m_W^2 \pm \sqrt{\mu^4 + 4m_W^4 \cos^2 2\beta + 4m_W^2 \mu^2} \] at tree level.
neutralino (ino) pair production will contribute mainly to the hadronic cross section or to conventional SUSY signatures (missing energy, plus leptons and/or multiple jets\textsuperscript{3}). However in all cases, some anomaly in comparison to SM predictions will be experimentally observable.

If the gluino is heavy and short-lived and \( R \)-parity is conserved, the standard phenomenology with missing energy applies\cite{4} so the gluino mass must be greater than 154 GeV\textsuperscript{3}. In this scenario charginos and neutralinos are too light to decay via a gluino. For their conventional chargino and neutralino analysis, LEP experiments place a limit on excess events of the types

- \( E_T^{\text{miss}} \) and hadronic activity in four or more jets.
- \( E_T^{\text{miss}} \), two or more jets, and a charged lepton.
- \( E_T^{\text{miss}} \) and two oppositely charged leptons, possibly of different flavor.

These signatures are sensitive to the chargino decays

\[
\chi^\pm \rightarrow [\chi_0^0 W^\pm] \rightarrow \chi_0^0 f \bar{f}; \quad \chi^\pm \rightarrow [\tilde{\nu} l \text{ or } l \nu \bar{l}] \rightarrow \chi_0^0 l \nu
\]  

and the analogous neutralino decays.

When these are the only decay modes, \( m_1, m_2 \approx 0 \) is already excluded\cite{6}. For small bino and wino mass, the mass gap between the neutralinos \( \chi_2^0 \) and \( \chi_1^0 \) is about \( \mu \). Thus when \( \mu \) is larger than a few GeV the experimental acceptance for the conventional decay modes (1) is good\cite{7,6} and the sensitivity is sufficient to exclude \( m_1, m_2 \approx 0 \). When \( \mu, m_1, m_2 \) are all of order GeV’s, the analysis of Feng, Polonsky, and Thomas\cite{3} applies. This window has now been excluded, again assuming the modes (1) are the only important decay channels\cite{3}.

\textsuperscript{3}Or, in a window around \( m_1 \approx m_2 \approx \mu \approx 0 \), to apparent excess \( W^\pm \) pair production\cite{3}. 

2
However other decay modes are possible, and indeed may dominate, if the gluino is light or $R$-parity is violated. In the light gluino case these are:

$$\chi^\pm \rightarrow [\tilde{q}\bar{q} \text{ or } \tilde{q}\bar{q}] \rightarrow g\tilde{q}\bar{q}.$$  \hspace{1cm} (2)

In the $R$-parity violating case the intermediate squark could produce quark pairs. High energy quarks and gluinos hadronize to produce jets, so squarks decaying to quark and gluino or to quark pairs produce two jets, with little missing energy. $R$-parity and lepton number violating decays $\tilde{q} \rightarrow q + l$ are included in the hadronic event sample, as long as the missing energy is small.

The branching fractions to the various final states depend critically on the relative masses of ino, sneutrino or slepton, squarks and $W$. Two-body on-shell decays dominate three body decays, except at the extreme edge of phase space. At present, selectron and sneutrino mass limits (about 60 GeV and 45 GeV respectively) are compatible with the possibility that the two-body decays $\chi^{\pm 0} \rightarrow \tilde{\nu}l$, $\tilde{l}\nu$, $\tilde{\nu}\tilde{l}$ are kinematically allowed. Limits on squark masses are compatible with the possibility that on-shell $\chi^{\pm 0} \rightarrow \tilde{q}\bar{q}$ is kinematically allowed. If both types of two-body decays are allowed, the color multiplicity of the $q\bar{q}$ final state causes hadronic decays.

$^4$Light, long-lived gluinos escape detection by conventional means such as beam dump experiments or limits on missing energy. Most of the interesting range of mass and lifetime has yet to be directly explored experimentally. Nor are indirect tests capable of excluding light gluinos due to QCD uncertainties. For instance, when the theoretical uncertainty associated with scale dependence and hadronization models are included as in other experiments, the recent ALEPH limit $m_{\tilde{g}} > 6.3$ GeV becomes instead compatible with a massless gluino. Also, the systematic uncertainties in $\alpha_s$ at both low and high $Q^2$ are still too large to use the $Q^2$ dependence to probe the light gluino possibility. Ref. shows that the uncertainty in $\alpha_s(m_t)$ is much larger than previously assumed so that the $Q^2$ dependence of $\alpha_s$ only slightly (70% cl) disfavors a light gluino. Note Added: See for a review of these and other recent experimental constraints.

$^5$Up and down squark masses must either be larger than $\sim 600$ GeV or in the range $\sim 50 - 130$ GeV. The lower limit is to ensure compatibility with the $Z$ width and the upper limit to avoid dijet mass peaks above QCD background at the FNAL collider.
to dominate, as for $W$ decay. If no two-body decay modes are allowed\cite{15},

$$\Gamma(\chi^{\pm} \rightarrow q\bar{q}g)/\Gamma(\chi^{\pm} \rightarrow \chi_1^0W^{\pm}) \sim 5\left(\frac{m_W}{m(\tilde{q})}\right)^4.$$  

(3)

Thus, for a substantial part of the allowed squark mass range, the hadronic channels \cite{2} dominate chargino and neutralino decay.

While the decay modes \cite{2} preferentially populate the multijet ($n \geq 4$) sample, the best way to put limits on \textit{ino}'s which decay through these modes is to use limits on an excess in the \textit{total} hadronic cross section. The total hadronic cross section is far less sensitive to QCD uncertainties than are individual $n$-jet cross sections. QCD predictions for experimental observables which involve definition of jets require resummation of the large logarithms of the small parameter $y_{cut}$ used to define the jets. Furthermore QCD predictions for $n$-jet cross sections are very sensitive to $\alpha_s$ and its running, to the hadronization model, and to the scale dependence from truncation of the perturbation series. Thus being able to use the total cross section greatly reduces the theoretical uncertainty of the SM prediction.

When one of the two \textit{inos} decays via \cite{(2)} and the other via \cite{(3)}, the events would often be picked up by the conventional search, with somewhat modified efficiency. However let us begin by analyzing the simplest limit, when \textit{inos} other than the lightest neutralino decay hadronically 100% of the time. This phenomenology has not previously been explored. The treatment of the more general case of decay both through \cite{(3)} and \cite{(2)} is discussed afterward.

Our experimental constraints come from the very high statistics measurement of the total hadronic cross section on the $Z^0$ peak, and lower statistics measurements at higher energy. The PDG value for the total hadronic cross section on the $Z^0$ peak is $\sigma^0_{\text{had}} = 41.54 \pm 0.14$ nb\cite{3}. Assuming no deviation from the SM prediction, this error corresponds to a 95\% confidence level upper limit on any new physics contribution of $1.64 \times 140$ pb = 230 pb. Due to higher order QCD corrections to the $e^+e^- \rightarrow q\bar{q}$ rate, the theoretical prediction for $\sigma^0_{\text{had}}$
has an irreducible fractional uncertainty of \( \frac{\delta(\alpha_s)}{\pi} \approx 0.003 \), but this produces an uncertainty of less than \( \pm 0.1 \) pb in \( \sigma_{\text{had}}^0 \).

According to OPAL results, uncertainties in the cross sections of some 2 pb per experiment can be obtained with the current data collected in the high energy running of LEP. At present, the error in estimating the feedthrough for the \( s'/s \) cut dominates the systematic error. The systematic uncertainty in the \( W^+W^- \) contribution to the hadronic cross section, which must be included to obtain the SM prediction, is negligible at this level. One can expect that when all four LEP experiments combine their results, the final statistical and systematic error can be reduced by a factor of two from the preliminary OPAL values. Then if no excess signal is observed, the 95% cl upper limits will be about 2 pb or slightly better. With 100 pb\(^{-1} \) per experiment at 183 GeV, one can anticipate an error bar of \( \approx 0.5 \) pb, and thus a \( \approx 0.8 \) pb 95% cl upper limit.

For a given \( \mu, \tan\beta \), find the sneutrino mass (consistent with experimental limits) which minimizes the total cross section for \( e^+e^- \to (\chi_0^i\chi_0^j + \chi_1^i\chi_1^j) \) summed over all ino species \( i, j \) except the lightest neutralino. Denote this cross section \( \sigma_{\text{min}}(\mu, \tan\beta) \), or \( \sigma_{\text{min}} \) when minimizing over \( \mu, \tan\beta \) as well. At 172 GeV, \( \sigma_{\text{min}} = 2.0 \) pb; it is realized for \( \mu = 0, \tan\beta = 1.2 \), and \( m_{\tilde{\nu}_e} \approx 85 \) GeV. If a combined analysis of the existing LEP 172 GeV data can produce a 95% cl upper limit on a deviation from the SM hadronic cross section of 2 pb or lower, the all-gauginos-massless scenario would be excluded, assuming purely hadronic decay of the inos. If some hint of a signal is seen in the existing data, it should be unambiguously confirmed or excluded with a high statistics run at 183 GeV, where the cross section for

---

\( ^6 \)The best determination of \( \alpha_s(m_Z) \) which does not employ \( \sigma_{\text{had}}^0 \) makes use of event shape variables, but results of this method display a large dispersion.

\( ^7 \)I am grateful to P. Mattig for help with this estimate and those below.

\( ^8 \)Throughout, cross sections include initial state radiation and the cut \( s'/s \geq 0.8 \) as in the OPAL analysis. They are calculated using the programs of M. Mangano, G. Ridolfi et al \[23\] with minor modifications.
$e^+e^- \rightarrow (\chi^0\chi^0 + \chi^+\chi^-)$ with $\mu = 0$, $\tan\beta = 1.2$ is 4 pb. Indeed, at 183 GeV $\sigma_{\text{min}} = 2$ pb, for $\mu = 0$, $\tan\beta = 1.4$; this is significantly above the 95\% cl sensitivity estimated above.

The generic case with decay to both hadronic and conventional-SUSY final states can be approached in two ways. The “brute force” method is to generalize the usual SUSY analysis to allow for the possibility of squarks decaying hadronically\(^\text{9}\) and then compare the predicted to observed number of events in suitable classes of events, including purely hadronic final states as well as those used in conventional SUSY analyses. This analysis is quite complex, because the relative number of events in the various samples will depend on squark masses. Thus the limits will depend on having assumed some squark mass spectrum. Including the possibility of two body decays to sneutrinos, $R$-parity violation, etc, makes the analysis even more complicated and model dependent.

A more elegant approach, if feasible, would be to put limits on the excess total $e^+e^-$ cross section, including purely hadronic as well as conventional SUSY channels and mixed channels. This would reduce the model dependence of the analysis even in the case of purely conventional decays. For instance it removes the model dependent systematic uncertainty associated with the efficiency for a signal event to pass the cuts (e.g., missing energy) defining a particular class of events. In particular, the limit of small splitting between $ino$ mass eigenstates is no more difficult to treat than large mass splitting. However this approach requires computing the cross section for “radiative returns” ($e^+e^- \rightarrow \gamma's + Z^0$) with a systematic uncertainty which is small compared to the desired $\approx 2$ pb limit on excess cross section. If this is possible, the approach suggested here will provide a new and potentially more powerful strategy for $ino$ searches, which is applicable whether or not gauginos are light and only depends on an increase in total cross section.

\(^9\)And decaying to lepton and quark, if it is desired to allow for lepton-number-$R$-parity violation.
which is larger than the systematic (and statistical) uncertainties.

Finally, an intermediate approach can work if limits on the excess cross section in conventional SUSY final states ($\sigma_{\text{conv}}^{\text{min}}$) and in purely hadronic final states ($\sigma_{\text{had}}^{\text{min}}$) are good enough. If the linear combination $b\sigma_{\text{had}}^{\text{min}} + (1-b)\sigma_{\text{conv}}^{\text{min}}$ is lower than $\sigma_{\text{min}}^{\text{min}}(\mu, \tan\beta)$ for any $b$ satisfying $0 \leq b \leq 1$, that value of $\mu$, $\tan\beta$ is ruled out if $m_1$, $m_2 \approx 0$. At present, the limits are not good enough to exclude all values of $\mu$, $\tan\beta$ except for $b \approx 0$ or 1. However the anticipated integrated luminosity of the next two LEP runs should put this test within reach. Assuming no anomaly is found, this would exclude $m_1$, $m_2 \approx 0$ for any value of squark, sneutrino, and gluino mass and without any assumption about the size of $R$-parity violating couplings.

It is interesting to consider the possibility that some but not all of the gaugino masses are negligible. This does not occur in the simplest gravity-mediated SUSY breaking, but can arise in more general SUGRA models. Moreover when SUSY breaking is communicated to the visible sector through particles with standard model gauge interactions, some, none or all of the gauginos obtain masses at leading order, depending on the gauge quantum numbers of the messengers. For instance binos, but not gluinos and winos, have large masses if the messengers have only hypercharge interactions\cite{24}. One can also consider the possibility of small $m_1$ and $m_3$ but large $m_2$, or $m_3 << m_1$ and $m_2$\cite{25}.

The cross section limits anticipated here would severely restrict scenarios in which large $m_1$ pushes neutralinos out of reach, yet charginos are pair produced because $m_2 \approx 0$. This is illustrated in Fig. 3. The area below and to the left of the dash-dot curve is the region in the $\mu$, $\tan\beta$ plane which is compatible with the requirement that $\Gamma(Z^0 \rightarrow \chi^+ \chi^-) < 230$ pb, i.e., $m(\chi_1^\pm) = 45$ GeV. The area below the solid curve in Fig. 3 is the $\mu$, $\tan\beta$ region which would be consisten with a 1.9 pb limit on $\sigma_{\text{had}}$ at 172 GeV, for $b = 1$. However one can do better than this. From Fig. 4 one sees that $\chi_1^+ \chi_1^-$ production is kinematically allowed even at 133 GeV for the larger
$\tan\beta$ values in the allowed region of Fig. 3. Furthermore, the value of $m(\tilde{\nu}_e)$ which minimizes the cross section is a relatively strong function of $E_{cm}$. Thus demanding that predicted cross sections are above the experimental limits at all three energies, for a common value of $m(\tilde{\nu}_e)$, will improve the limits indicated in Fig. 3.

Overall, the previous discussion indicates that analysis of data at and below 172 GeV will allow the parameter space for $m_2 \approx 0$ to be limited to $\mu \lesssim 30$ GeV, $1.1 \lesssim \tan\beta \lesssim 2$, for $b = 1$. At 183 GeV, the minimal total cross section for $e^+e^- \rightarrow \chi^\pm \chi^\mp$ is 0.6 pb, for $\mu \lesssim 1$ GeV, $\tan\beta = 1.4$, and $m(\tilde{\nu}_e) \approx 85$ GeV. Combining with the lower energy limits, this is on the borderline of being excludable with 183 GeV data, again for $b = 1$.

The dotted curve in Fig. 3 corresponds to $m(\chi^\pm_1) = 53$ GeV. This is well within the allowed region anticipated for existing data. Thus the possibility that the anomalous 4-jet events observed by ALEPH are due to chargino pair production cannot be ruled out with present data.

If it is established that $m_2$ is not small, cross section predictions become much less constrained and ruling out the small $m_1$ but large $m_2$ case may be difficult. One interesting, albeit fine-tuned possibility is the case that both $m_1$ and $m_2$ are large, but related in such a way that the lightest neutralino mass is about 1 GeV. This is of interest because the $\chi^0_1$ may then be a good dark matter candidate if it is the LSP and $R$-parity is conserved.

Another interesting phenomenological possibility is $m_1 \approx m_2 > \mu$, so that $\chi^0_1$ is higgsino-like while $\chi^0_2$ is photino-like. In this case $\chi^0_2$’s produced in selectron decay via $\chi^0_2 \rightarrow \chi^0_1 + \gamma$.

In performing the analyses proposed here, the changes in efficiency for detecting the excess events predicted in the light gaugino scenario ought to be modeled for completeness. It should be straightforward to make the

---

10Note added: No anomaly in 4-jet events was observed in a repeat run at 130 and 133 GeV with total luminosity of about 5 pb$^{-1}$ per experiment. M. Schmitt, private communication.
(presumably small) correction coming from the fact that QCD produces dominantly 2- and 3-jet events whereas the excess hadronic events would have \( \geq 4 \) jets. Gluino jets may also be “fatter” than a typical light quark jet, but this should make little difference to the efficiency. A more subtle complication is that the \( R \)-hadron in each gluino jet, typically the gluino-gluon bound state denoted \( R^0 \), may decay (dominantly to \( \pi^+\pi^-\tilde{\gamma} \)) before the hadronic calorimeter. The corresponding \( < p^\text{miss} > \) carried by each photino would be \( \lesssim p(R^0)/2 \). (We will see below that \( E(R^0) \approx p(R^0) \).) We can get a rough upper limit on \( < p(R^0) > \) as follows. Since the \( R^0 \) has light constituents, its production should be softer than is typical for the charm quark, so we take \( < x_{R^0} > < 0.4 \).\(^{11}\) For pair produced \( inos \) with mass \( \approx E_{\text{cm}}/2 \), the momentum of the gluino jet is typically 1/3-1/2 of the \( ino \) mass, giving \( < p(R^0) > \lesssim 0.4 \times (\frac{1}{6} - \frac{1}{4})E_{\text{cm}} \approx 15 \text{ GeV} \) for each gluino jet. Hence if the \( R^0 \) lifetime is shorter than \( \sim 3 \times 10^{-10} \text{ sec} \), it will on average decay before reaching the hadronic calorimeter and the photino energy (bounded by \( \approx 7 \text{ GeV} \) by the reasoning above) would be lost. This effect reduces the probability for the event to pass the \( s'/s \) cut and should be modeled more carefully in a final analysis. See \( \cite{8} \) for experimental constraints on \( R^0 \) decay.

If some excess hadronic cross section is observed and is due to hadronically decaying \( inos \), the \( ino \)-containing events can be identified as follows. They will have a large jet multiplicity: in principle 6 jets, however if the intermediate squark is close in mass to the parent \( ino \), it may be difficult to resolve all 6 jets. Two of the jets (not the soft ones) will be gluinos. If an \( R^0 \) decays in the detector, that jet will contain a “vee” from the decay \( R^0 \rightarrow \pi^+\pi^-\tilde{\gamma} \). This can in principle be distinguished from the decay of a kaon by the missing \( p_t \) carried by the photino and possibly by the invariant mass of the \( \pi^+\pi^- \) pair.\(^\text{12}\) Even if the \( R^0 \) lifetime is such that it rarely

\(^{11}\)A crude estimate rather than upper limit would be \( < x_{R^0} > \approx < x_K > \). I am grateful to P. Nason for a helpful discussion on this point.\(^{12}\)See ref. \( \cite{8} \) for limits on the \( R^0 \) lifetime.
decays in the detector, gluino jets are distinguishable from ordinary quark jets by having $Q = 0$ and possibly looking more gluon-like than expected for quark jets. Reconstructing the invariant masses of systems of jets should in principle produce mass peaks corresponding to the ino masses, but it is not obvious that kinematic reconstruction of jets in high-multiplicity events can be accurate enough for this to be practical.

To summarize: If gluinos are light or $R$-parity is violated, the phenomenology of charginos and neutralinos can differ dramatically from the conventional scenario. Ino final states can be purely hadronic, with negligible missing energy. Nevertheless, we have seen that by combining limits on both conventional modes and excess hadronic cross section the entire parameter space for models with light electroweak gauginos can be explored, independent of their decay mode.

Note added: OPAL has now implemented the analysis we have proposed. As anticipated by the estimates given above, combining all their 130-172 GeV data allows them to exclude the possibility that both bino and wino are light for any values of $\mu$, $\tan\beta$, $m_{\tilde{\nu}}$, assuming inos decay purely hadronically ($b = 1$). The integrated luminosity of that data set is not sufficient to extend the analysis to arbitrary $b$, except over a portion of $\mu$, $\tan\beta$ space. The possibility of a heavy bino but light wino is only viable for $b = 1$ in a small range of $\mu$, $\tan\beta$, roughly consistent with our estimate shown in Fig. 3. The extent of the analysis to arbitrary $b$, conceivably also for arbitrary $m_{2}$, may be possible in the near future.

Until the possibility of a light gluino or $R$-parity violation is definitively excluded, experimental limits on squarks and inos should routinely address the possibility that some fraction of their final states are purely hadronic. This will ensure limits with the greatest possible range of validity.

It was also noted that if the systematic uncertainty on the standard model prediction for the total $e^+e^-$ cross section (including radiative returns) can be reduced to a low enough level, less model-dependent limits on new physics
should be possible. This is because assumptions about final states and efficiency of certain cuts are irrelevant to determining the total production rate of the new particles.

Acknowledgements: I am especially indebted to P. Mattig and M. Mangano for informative correspondence and discussions, as well as to B. Gary, S. Komamiya, H. Neal, and M. Schmitt.

References

[1] R. Barbieri and L. Maiani, *Nucl. Phys.*, B243:429, 1984; G. R. Farrar and A. Masiero, Technical Report RU-94-38, [hep-ph/9410401], Rutgers Univ., 1994; D. Pierce and A. Papadopoulos, *Nucl. Phys.*, B430:278, 1994; G. R. Farrar, Technical Report RU-95-26 and [hep-ph/9508292], Rutgers Univ., 1995.

[2] G. R. Farrar and E. W. Kolb, *Phys. Rev.*, D53:2990, 1996; D. J. Chung, G. R. Farrar, and E. W. Kolb, Technical Report FERMILAB-Pub-96-097-A, RU-97-13 and [astro-ph/9703143], FNAL and Rutgers Univ, 1997.

[3] J. Feng and N. Polansky and S. Thomas, *Phys. Lett.*, 370B:95, 1996.

[4] G. R. Farrar and P. Fayet, *Phys. Lett.*, 76B:575–579, 1978 and *Phys. Lett.*, 79B:442–446, 1978.

[5] Particle Data Group. *Phys. Rev.*, D54:1, 1996.

[6] The OPAL Collaboration. Technical Report PPE 97-083 (hep-ex/9708018) CERN, 1997.

[7] The ALEPH Collaboration. *Phys. Lett.*, 373B:246-260, 1996.

[8] G. R. Farrar, *Phys. Rev. Lett.*, 53:1029–1033, 1984 and *Phys. Rev. Lett.*, 55:895, 1985.
[9] G. R. Farrar. *Phys. Rev.*, D51:3904, 1995.

[10] G. R. Farrar. *Phys. Rev. Lett.*, 76:4111, 1996.

[11] The Aleph Collaboration. *Z. Phys.*, C76:191-199, 1997.

[12] G. R. Farrar. Invited talk, La Thuile, 1997. RU-97-22, hep-ph/9707467.

[13] B. Chibisov et al. Technical Report hep-ph/9605464, TPI Minnesota, 1996.

[14] F. Csikor and Z. Fodor. *Phys. Rev. Lett.*, 78:4335, 1997.

[15] G. R. Farrar. Invited review, SUSY97, Technical Report RU-97-21, hep-ph/9710277.

[16] D. Choudhury and D. P. Roy. *Phys. Rev.*, D54:6769, 1996. See also H. Dreiner et al. *Phys. Lett.*, B389:62, 1996.

[17] G. R. Farrar. *Phys. Rev. Lett.*, 76:4115, 1996.

[18] G. R. Farrar, Technical Report RU-96-71 and hep-ph/9608387, and Invited talk Warsaw ICHEP96, RU-96-93 and hep-ph/9612353, Rutgers Univ., 1996.

[19] L. Clavelli et al, *Phys. Lett.*, B291:426, 1992; G. Bhattacharyya and A. Raychaudhuri, *Phys. Rev.*, D49:1156, 1994.

[20] I. Terekhov and L. Clavelli, Technical Report UAHEP964 (hep-ph/9603390), U. Alabama, 1996; J. Hewitt, T. Rizzo, and M. Doncheski, Technical Report SLAC-PUB-7372 and hep-ph/9612377, 1996.

[21] P. N. Burrows. Technical Report SLAC-0UB-7328, MIT-LNS-96-213, hep-ex/9612008, MIT, 1996.

[22] The OPAL Collaboration. Technical Report PN 280, CERN, 1997.
[23] M. Mangano, G. Ridolfi, et al. Technical Report CERN 96-01, Vol. 2, hep-ph/9602203.

[24] R. Mohapatra and S. Nandi, Technical Report UMD-PP-97-082 and hep-ph/9702291, 1997; Z. Chacko et al, Technical Report UMD-PP-97-102 and hep-ph/9704307, 1997.

[25] S. Raby. Technical Report OHSTPY-HEP-T-97-002 and hep-ph/9702293, 1997.

[26] The Aleph Collaboration. Z. Phys., C71:179-198, 1996.

[27] S. Ambrosanio et al, Phys. Rev., D55:1372, 1997.

[28] The KTeV Collaboration. Technical Report RU-97-26, 1997. Phys. Rev. Lett. to be published.

[29] The OPAL Collaboration. Technical Report PPE 97-101 (hex-ex/970802) CERN, 1997.
Figure 1: Chargino masses versus $\mu$ in GeV, for $\tan\beta = 1$ (solid) and 1.5 (dashed).
Figure 2: Masses of $\chi^0_2$, $\chi^0_2$ and $\chi^0_4$ versus $\mu$ (GeV), for $\tan\beta = 1$ (solid) and 1.5 (dashed).
Figure 3: Curves of constant $m(\chi^\pm)$: 45 GeV (dash-dot), 53 GeV (dot). Chargino production alone is inconsistent with the $Z^0$ width in the region to the right of the dash-dot curve and with the anticipated 172 GeV sensitivity limit above the solid curve.