MASS LIMITS FOR SCALAR MUONS, SCALAR ELECTRONS, AND WINOS FROM e^+e^- COLLISIONS NEAR $\sqrt{s}=91$ GeV

L3 Collaboration

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We have searched for scalar muons $\tilde{\mu}$, scalar electrons $\tilde{e}$, and winos $\tilde{W}$ from the reactions $e^+e^- \to \tilde{e}^+\tilde{e}^-$, $\tilde{\mu}^+\tilde{\mu}^-$, $\tilde{W}^+\tilde{W}^-$ at $\sqrt{s} \approx 91$ GeV with an integrated luminosity of 157 nb^{-1}. We have searched for $\mu^+\mu^-$, e^+e^-, or e–μ final states with missing transverse momentum $P_T > 6$ GeV. These final states are signatures for the production of $\tilde{e}$, $\tilde{\mu}$, and $\tilde{W}$. We found no events. Our results are $M_{\tilde{\mu}} > 41$ GeV, $M_{\tilde{e}} > 41$ GeV, and $M_{\tilde{W}} > 44$ GeV at the 95% confidence level.

1. Introduction

The standard model [1] has been very successful in describing all data concerning electroweak interactions, including our latest data on Z^0 production at LEP and on Z^0 partial widths into hadrons, muon pairs, electron pairs and into invisible particles [2]. However, the standard model leaves many fundamental parameters unexplained, such as the magnitude of particle masses, the charged-current weak mixing angles, the number of fermion generations, the electroweak mixing parameter $\sin^2\theta_W$, as well as the large mass scale differences between the light particles, the electroweak scale, and the grand unification or gravitational mass scales. To find the origin for these parameters one must look beyond the standard model. One such model is the supersummetry model (SUSY) [3], which predicts many new particles with spin differing from the known particles by half a unit.

The large e^+e^- collider, LEP, is ideal for the study of the production of new particles, since the initial state consists of pointlike particles and the production mechanism is purely electroweak. Reliable calculations based on the SUSY model, where the Z^0 couples to all leptons and quarks, and their supersymmetric partners, are therefore possible. Because of its heavy mass (91.13 ± 0.07 GeV) and large total

[1] Deceased.
[2] Also at KEK, Ibaraki-ken 305, Japan.
[3] Also at Nanjing, P.R. China.
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production cross section (43 nb) [2], the Z^0 could provide a uniquely copious source of new particles at $\sqrt{s} \approx M_Z$. In this report we describe our searches for scalar muons, scalar electrons, and the supersymmetric partner of the $W^{\pm}$, the wino.

2. Signal and background for scalar leptons

SUSY particles are always produced in pairs. The lowest mass SUSY particles are expected to be neutral and stable, and like neutrinos, they will only interact weakly with normal matter. The signature of their production is very large missing momentum and energy from the undetected lowest mass SUSY particles, such as photinos or scalar neutrinos.

We search for scalar leptons which could be produced by the following reactions:

$$e^+e^- \to Z^0 \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\gamma}\tilde{\gamma} \text{ (acoplanar muons)}$$

and

$$e^+e^- \to Z^0 \to \tilde{e}^+\tilde{e}^- \to e^+e^-\tilde{\gamma}\tilde{\gamma} \text{ (acoplanar electrons)},$$

with large missing P_T.

The background to the above processes comes from

(1) radiative e, μ or τ pair production,

(2) two photon processes such as $e^+e^- \to e^+e^-\mu^+\mu^-$ or $e^+e^- \to e^+e^-e^+e^-$, where all but two particles are produced at small angles and are thus undetected. In order to eliminate these backgrounds, we look for acoplanar lepton pairs with large missing P_T.

3. Data

The data used in these searches were taken with the L3 detector at LEP. The detector and its performance in the detection of muons, electrons, photons and hadronic jets have been described elsewhere [2,4]. The total integrated luminosity used in this analysis is 157 nb^{-1}, corresponding to a total of 2538 hadronic events observed at seven energies between 89.26 and 93.27 GeV during the first energy scans over the Z^0 peak at LEP.

4. Search for scalar leptons

We identify scalar muons and electrons by the presence of acoplanar dimuons or dielectrons with large missing P_T. The missing P_T is defined as the product of the energy of the second most energetic particle and $\sin\phi$, where ϕ is the azimuthal angle between the two most energetic particles.

Dimuon events are selected according to the following criteria:

(1) Each of the two muons is reconstructed in at least two sets of chambers in the bending (xy) plane and one set in the non-bending (rz) plane.

(2) The momentum sum of the two muons is above 15 GeV.

(3) The total energy measured in the calorimeters is less than 30 GeV. Criteria (2) and (3) are used to reject all backgrounds including residual cosmic rays and hadronic events.

Dielectron events are selected according to the following criteria:

(1) There are two or three energy clusters in the calorimeters in the angular range $42° < \theta < 138°$, whose longitudinal and transverse shower distributions are consistent with being of electromagnetic origin.

(2) The energies of the two most energetic clusters are above 5 GeV.

(3) The total hadron calorimeter energy is less than 20% of the energy measured in the electromagnetic calorimeter. Criteria (2) and (3) are used to reject hadronic events.

Fig. 1 shows a typical $\mu^+\mu^-$ event and fig. 2 shows a typical e^+e^- event. The missing P_T spectra for dimuons and dielectrons are shown in figs. 3 and 4, respectively. The radiative dilepton events, with one or more energetic photons observed in our detector have been removed from the data since they clearly cannot be SUSY candidates. There were four such events observed with $P_T > 4$ GeV, while six events are expected from Monte Carlo simulation [5]. As seen from figs. 3 and 4, there are no pure dilepton events in either distribution with P_T greater than 6 GeV. The predicted P_T distributions for scalar muons or electrons were calculated using Monte Carlo methods [6]. The resultant spectra for 41 GeV mass scalar muons and 40 GeV mass scalar electrons are shown in figs. 3 and 4, respectively. We see that the scalar

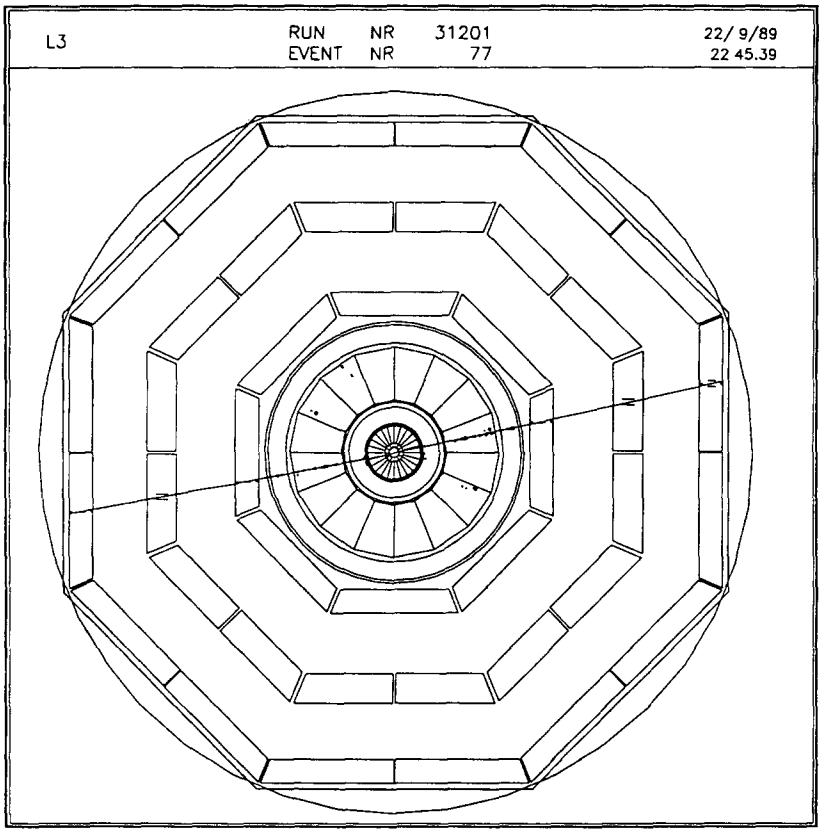

Fig. 1. Typical $e^+e^- \to \mu^+\mu^-$ event reconstructed in the L3 detector. The muon tracks are cleanly fitted in the precision muon chambers.

leptons are expected to cover a region in P_T between 6 and 26 GeV. No data events are observed in this region of P_T.

We compute the expected number of dimuon and dielectron events resulting from SUSY particle production, $N_{\tilde{\ell}\tilde{\ell}}$ by normalizing them to the observed colinear dimuon and dielectron events, $N_{\ell\ell}$, due to the Z^0 decays:

$$N_{\tilde{\ell}\tilde{\ell}} = N_{\ell\ell}\sigma_{\tilde{\ell}\tilde{\ell}}/\sigma_{\ell\ell} ,$$

where $\sigma_{\tilde{\ell}\tilde{\ell}}$ and $\sigma_{\ell\ell}$ are the accepted dilepton cross sections for scalar lepton pairs and for normal lepton pairs respectively, computed from Monte Carlo. The events from scalar lepton production satisfy the cuts described above, and a cut on the missing P_T greater than 6 GeV, while the normal lepton pairs satisfy the cuts described in ref. [2]. The acceptance for a pair of 41 GeV scalar muons is 40%, and the acceptance for a pair of 41 GeV scalar electrons is 41%. Assuming a photino mass of 10 GeV, we find that $\sigma_{\tilde{\mu}\tilde{\mu}}/\sigma_{\mu\mu} = 0.036$ for 41 GeV scalar muons and $\sigma_{\tilde{e}\tilde{e}}/\sigma_{ee} = 0.039$ for 41 GeV scalar electrons. Using $N_{\mu\mu} = 97$ and $N_{ee} = 95$ [2], we get the expected number of dimuon events, $N_{\tilde{\mu}\tilde{\mu}} = 3.5$ and the expected number of dielectron events, $N_{\tilde{e}\tilde{e}} = 3.7$. Since no acoplanar dimuon or dielectron events are observed above $P_T > 6$ GeV, we set lower mass limits of 41 GeV for scalar muons and 41 GeV for scalar electrons at the 95% confidence level. This result is insensitive to the photino mass up to 20 GeV.

5. Search for winos

Winos can be pair-produced in e^+e^- annihilation through the reaction

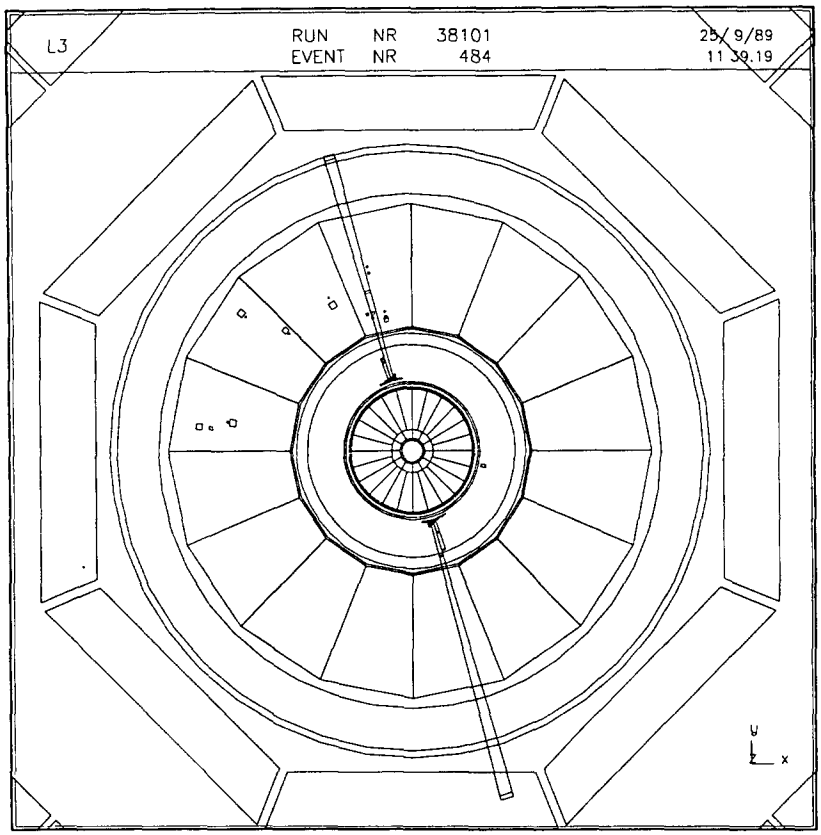

Fig. 2. Typical $e^+e^- \to e^+e^-$ event reconstructed in the L3 detector. The electron showers are cleanly identified and measured in the precision electromagnetic calorimeter.

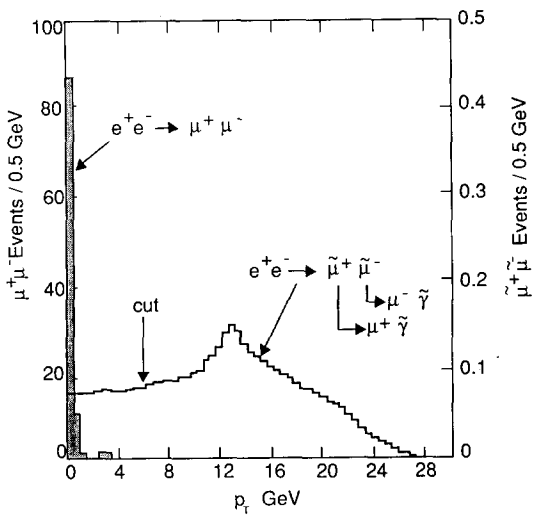

Fig. 3. Left scale: The missing P_T spectrum for the reaction $e^+e^- \to Z^0 \to \mu^+\mu^-$. The observed events are represented by the dark histogram. Right scale: The Monte Carlo prediction for the missing P_T spectrum in dimuon events from the reaction $e^+e^- \to Z^0 \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\gamma}\tilde{\gamma}$, for a mass of the scalar muon of 41 GeV and a photino mass of 10 GeV. The arrow indicates the $P_T > 6$ GeV cut used in the analysis.

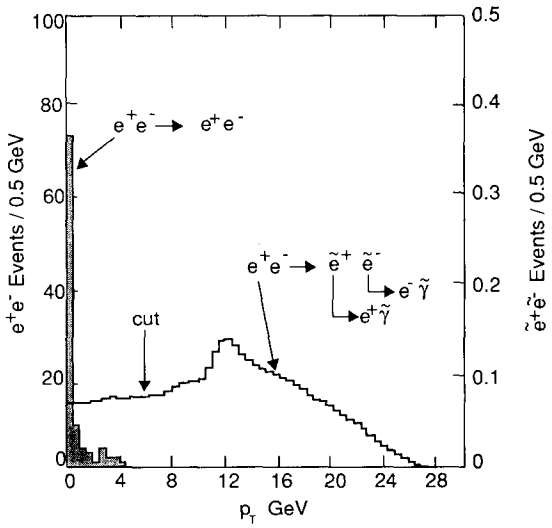

Fig. 4. Left scale: The missing P_T spectrum for the reaction $e^+e^- \to e^+e^-$. The observed events are represented by the dark histogram. Right scale: The Monte Carlo prediction for the missing P_T spectrum in dielectron events from the reaction $e^+e^- \to \tilde{e}^+\tilde{e}^- \to e^+e^-\tilde{\gamma}\tilde{\gamma}$, for a mass of the scalar electron of 41 GeV and a photino mass of 10 GeV. The arrow indicates the $P_T > 6$ GeV cut used in the analysis.

$e^+e^- \to \tilde{W}^+\tilde{W}^-$

From the above analysis we conclude that the scalar lepton masses must be above 41 GeV. It is natural to assume the scalar quarks cannot be lighter than the scalar leptons. Winos with mass less than 41 GeV could therefore decay into an ordinary lepton accompanied by a scalar neutrino:

$\tilde{W} \to \ell\tilde{\nu}$,

or if $M_{\tilde{\nu}} > M_{\tilde{W}}$, the $\tilde{W}$ also could decay into an ordinary lepton, a neutrino, and a photino:

$\tilde{W} \to \ell\nu\tilde{\gamma}$,

where we have used a branching ratio of 11% for each lepton flavor.

In either case there would be a large amount of missing energy, due to the scalar neutrino or photino which escapes undetected.

The signature of wino pair production can be either acoplanar dimuon, dielectron, or muon–electron [7] events. The first two channels are already ruled out by the above analysis. The muon–electron sample is selected according to the following criteria:

(1) One and only one muon is reconstructed in at least two sets of chambers in the xy plane and one set in the rz plane. There must be no other detected muons.

(2) The momentum of the muon is above 5 GeV.

(3) The total energy measured in the hadron calorimeters is less than 10 GeV.

(4) There are one or two clusters, whose longitudinal and transverse shower distributions are consistent with being of electromagnetic origin.

(5) The energy of the most energetic cluster is above 5 GeV.

Criteria (2) and (3) are used to reject hadronic events.

A total of nine eμ events are observed in our data sample while eight are expected from τ pair production. There are no events with a P_T greater than 1 GeV.

For the case of two-body decay, we assume a scalar neutrino mass of 10 GeV. Normalizing to the observed dimuon and dielectron events, we expect a total of 96 acoplanar ee, eμ and μμ events with $P_T > 6$ GeV for a wino mass of 42 GeV. In the case of three-body wino decay, we expect 7.4 events for a wino mass of 42 GeV and a photino mass of 10 GeV. For a wino mass of 44 GeV, we expect 64 events for the case of two-body decay, and five events for the case of three-body decay. We therefore are able to set a lower limit of 44 GeV for the wino mass. This result is again insensitive to the photino mass up to 20 GeV.

6. Conclusion

By searching for acoplanar dimuon, dielectron and μe events, with a large missing P_T, we have obtained new limits on the mass of scalar electrons, muons and Winos. We find, for a photino mass up to 20 GeV:

$$M_{\tilde{\mu}} > 41 \text{ GeV}, \quad M_{\tilde{e}} > 41 \text{ GeV}, \quad M_{\tilde{W}} > 44 \text{ GeV},$$

at the 95% confidence level. These limits are higher than those obtained in previous searches at PETRA [8], PEP [9] and TRISTAN [10]. A comparable mass limit for the wino has been obtained by the UA2 Collaboration [11], under the assumption that the wino decays only into the two-body final state.

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