A Search for Acoplanar Pairs of Leptons or Jets in Z^0 Decays: Mass Limits on Supersymmetric Particles

The OPAL Collaboration

M.Z. Akrawy¹¹, G. Alexander²¹, J. Allison¹⁴, P.P. Allport⁵, K.J. Anderson⁸, J.C. Armitage⁶, G.T.J. Arnison¹⁸, P. Ashton¹⁴, G. Azuelos¹⁶, J.T.M. Baines¹⁴, A.H. Ball¹⁵, J. Banks¹⁴, G.J. Barker¹¹, R.J. Barlow¹⁴, J.R. Batley⁵, G. Bavaria¹⁶, F. Beck⁷, K.W. Bell¹⁸, G. Bella²¹, S. Bethke¹⁰, O. Biebel³, I.J. Bloodworth¹, P. Bock¹⁰, H. Breuker⁷, R.M. Brown¹⁸, R. Brun⁷, A. Buijs⁷, H.J. Burckhart⁷, P. Capiluppi², R.K. Carnegie⁶, A.A. Carter¹¹, J.R. Carter⁵, C.Y. Chang¹⁵, D.G. Charlton⁷, J.T.M. Chrin¹⁴, I. Cohen²¹, J.E. Conboy¹³, M. Couch¹, M. Coupland¹², M. Cuffiani², S. Dado²⁰, G.M. Dallavalle¹³, O.W. Davies¹⁴, M.M. Deninno², A. Dieckmann¹⁰, M. Dittmar⁴, M.S. Dixit¹⁷, D. Duchesneau¹⁶, E. Duchovni²⁴, I.P. Duerdoth^{7,a}, D. Dumas⁶, H. El Mamouni¹⁶, P.A. Elcombe⁵, P.G. Estabrooks⁶, E. Etzion²¹, F. Fabbri², P. Farthouat¹⁹, H.M. Fischer³, D.G. Fong¹⁵, M.T. French¹⁸, C. Fukunaga²², B. Gandois¹⁹, O. Ganel²⁴, J.W. Gary¹⁰, N.I. Geddes¹⁸, C.N.P. Gee¹⁸, C. Geich-Gimbel³, S.W. Gensler⁸, F.X. Gentit¹⁹, G. Giacomelli², W.R. Gibson¹¹, J.D. Gillies¹⁸, J. Goldberg²⁰, M.J. Goodrick⁵, W. Gorn⁴, D. Granite²⁰, E. Gross²⁴, P. Grosse-Wiesmann⁷, J. Grunhaus²¹, H. Hagedorn⁹, J. Hagemann⁷, M. Hansroul⁷, C.K. Hargrove¹⁷, J. Hart⁵, P.M. Hattersley¹, D. Hatzifotiadou⁷, M. Hauschild⁷, C.M. Hawkes⁷, E. Heflin⁴, J. Heintze¹⁰, R.J. Hemingway⁶, R.D. Heuer⁷, J.C. Hill⁵, S.J. Hillier¹, P.S. Hinde¹⁴, C. Ho⁴, J.D. Hobbs⁸, P.R. Hobson²³, D. Hochman²⁴, B. Holl⁷, R.J. Homer¹, S.R. Hou¹⁵, C.P. Howarth¹³, R.E. Hughes-Jones¹⁴, P. Igo-Kemenes¹⁰, M. Imori²², D.C. Imrie²³, A. Jawahery¹⁵, P.W. Jeffreys¹⁸, H. Jeremie¹⁶, M. Jimack⁷, E. Jin^{4,b}, M. Jobes¹, R.W.L. Jones¹¹, P. Jovanovic¹, D. Karlen⁶, K. Kawagoe²², T. Kawamoto²², R.G. Kellogg¹⁵, B.W. Kennedy¹³, C. Kleinwort⁷, D.E. Klem¹⁷, G. Knop³, T. Kobayashi²², L. Köpke⁷, T.P. Kokott³, M. Koshihara²², R. Kowalewski⁶, H. Kreutzmann³, J. von Krogh¹⁰, J. Kroll⁸, P. Kyberd¹¹, G.D. Lafferty¹⁴, F. Lamarche¹⁶, W.J. Larson⁴, M.M.B. Lasota¹¹, J.G. Layter⁴, P. Le Du¹⁹, P. Leblanc¹⁶, D. Lellouch⁷, P. Lennert¹⁰, L. Lessard¹⁶, L. Levinson²⁴, S.L. Lloyd¹¹, F.K. Loebinger¹⁴, J.M. Lorah¹⁵, B. Lorazo¹⁶, M.J. Losty¹⁷, J. Ludwig⁹, N. Lupu²⁰, J. Ma^{4,b}, A.A. Macbeth¹⁴, M. Mannelli⁷, S. Marcellini², G. Maringer³, J.P. Martin¹⁶, T. Mashimo²², P. Mättig⁷, U. Maur³, T.J. McMahon¹, A.C. McPherson⁶, F. Meijers⁷, D. Menszner¹⁰, F.S. Merritt⁸, H. Mes¹⁷, A. Micheli⁷, R.P. Middleton¹⁸, G. Mikenberg²⁴, D.J. Miller¹³, C. Milstene²¹, M. Minowa²², W. Mohr⁹, A. Montanari², T. Mori²², M.W. Moss¹⁴, A. Muller¹⁹, P.G. Murphy¹⁴, W.J. Murray⁵, B. Nellen³, H.H. Nguyen⁸, M. Nozaki²², A.J.P. O'Dowd¹⁴, S.W. O'Neale^{7,c}, B. O'Neill⁴, F.G. Oakham¹⁷, F. Odorici², M. Ogg⁶, H. Oh⁴, M.J. Oreglia⁸, S. Orito²², G.N. Patrick¹⁸, S.J. Pawley¹⁴, A. Perez²⁴, J.E. Pilcher⁸, J.L. Pinfold²⁴, D.E. Plane⁷, B. Poli², A. Possoz^{8,d}, A. Pouladdeh⁶, T.W. Pritchard¹¹, G. Quast⁷, J. Raab⁷, M.W. Redmond⁸, D.L. Rees¹, M. Regimbald¹⁶, K. Riles⁴, C.M. Roach⁵, F. Roehner⁹, A. Rollnik³, J.M. Roney⁸, A.M. Rossi^{2,e}, P. Routenburg⁶, K. Runge⁹, O. Runolfsson⁷, S. Sanghera⁶, R.A. Sansum¹⁸, M. Sasaki²², B.J. Saunders¹⁸, A.D. Schaile⁹,

O. Schaile⁹, W. Schappert⁶, P. Scharff-Hansen⁷, H. von der Schmitt¹⁰, S. Schreiber³, J. Schwarz⁹, A. Shapira⁻²⁴, B.C. Shen⁴, P. Sherwood¹³, A. Simon³, G.P. Siroli², A. Skuja¹⁵, A.M. Smith⁷, T.J. Smith¹, G.A. Snow¹⁵, E.J. Spreadbury¹³, R.W. Springer¹⁵, M. Sproston¹⁸, K. Stephens¹⁴, J. Steuerer⁹, H.E. Stier⁹, R. Ströhmer¹⁰, D. Strom⁸, H. Takeda²², T. Takeshita²², T. Tsukamoto²², M.F. Turner⁵, G. Tysarczyk¹⁰, D. Van den plas¹⁶, G.J. VanDalen⁴, C.J. Virtue¹⁷, A. Wagner¹⁰, C. Wahl⁹, H. Wang^{4,b}, C.P. Ward⁵, D.R. Ward⁵, J. Waterhouse⁶, P.M. Watkins¹, A.T. Watson¹, N.K. Watson¹, M. Weber¹⁰, S. Weisz⁷, N. Wermes¹⁰, M. Weymann⁹, G.W. Wilson⁷, J.A. Wilson¹, I. Wingerter⁷, V.-H. Winterer⁹, N.C. Wood¹³, S. Wotton⁷, B. Wuensch³, T.R. Wyatt¹⁴, R. Yaari²⁴, H. Yamashita²², Y. Yang^{4,b}, G. Yekutieli²⁴, W. Zeuner⁷, G.T. Zorn¹⁵, S. Zylberajch¹⁹.

¹School of Physics and Space Research, University of Birmingham, Birmingham, B15 2TT, UK

²Dipartimento di Fisica dell' Università di Bologna and INFN, Bologna, 40126, Italy

³Universität Bonn, D-5300 Bonn 1, FRG

⁴Department of Physics, University of California, Riverside, CA 92521 USA

⁵Cavendish Laboratory, Cambridge, CB3 0HE, UK

⁶Carleton University, Dept of Physics, Colonel By Drive, Ottawa, Ontario K1S 5B6, Canada

⁷CERN, European Organisation for Nuclear Research, 1211 Geneva 23, Switzerland

⁸Enrico Fermi Institute and Dept of Physics, University of Chicago, Chicago Illinois 60637, USA

⁹Fakultät für Physik, Albert Ludwigs Universität, D-7800 Freiburg, FRG

¹⁰Physikalisches Institut, Universität Heidelberg, D-6900 Heidelberg, FRG

¹¹Queen Mary and Westfield College, University of London, London, E1 4NS, UK

¹²Birkbeck College, London, WC1E 7HV, UK

¹³University College London, London, WC1E 6BT, UK

¹⁴Department of Physics, Schuster Laboratory, The University, Manchester M13 9PL, UK

¹⁵Dept. of Physics and Astronomy, University of Maryland, College Park, Maryland 20742, USA

¹⁶Laboratoire de Physique Nucleaire, Universite de Montreal, Montreal, Quebec, H3C 3J7, Canada

¹⁷National Research Council, Herzberg Institute of Astrophysics, Ottawa, Ont. K1A 0R6, Canada

¹⁸Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX, UK

¹⁹DPhPE, CEN Saclay, F-91191 Gif-sur-Yvette France

²⁰Department of Physics, Technion-Israel Institute of Technology, Haifa 32000, Israel

²¹Department of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

²²Int. Center for Elementary Particle Phys. and Dept. of Phys., Univ. of Tokyo, Tokyo 113, and Kobe University, Kobe 657, Japan

²³Brunel University, Uxbridge, Middlesex, UB8 3PH, UK

²⁴Nuclear Physics Department, Weizmann Institute of Science, Rehovot, 76100, Israel

^aOn leave from Manchester University

^bOn leave from Harbin Institute of Technology, Harbin, China

^cOn leave from Birmingham University

^dPresent address: EPFL, Lausanne

^ePresent address: Dipartimento di Fisica, Università della Calabria, 87036 Rende, Italy

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Abstract

We have searched for Z^0 decays into acoplanar pairs of leptons or jets. The data were recorded with the OPAL detector during an energy scan around the Z^0 peak and correspond to about 17000 produced Z^0 's. We have determined model independent limits on branching ratios for the Z^0 to decay into pairs of heavy particles with subsequent decays leading to the above topologies. In the context of supersymmetric models, mass bounds close to the kinematic limit were obtained for the scalar leptons, $\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$, and for the chargino, $\tilde{\chi}^\pm$.

1 Introduction

We describe a general search for Z^0 decays into pairs of massive particles that decay promptly to conventional quarks or leptons and undetected neutrino-like particles. Such events would be characterised by large missing energy and momentum. In the background to this signature from conventional sources the missing momentum vector points either along the e^+e^- beam direction (for initial state bremsstrahlung or two-photon interactions) or along the flight direction of the detected particles (e.g. in τ decays). We therefore searched for events in which the observed particles or jets are acollinear in the plane perpendicular to the beam direction (acoplanar).

Although our search for events containing acoplanar leptons (e, μ, τ) or jets was motivated primarily by supersymmetric models [1][2], similar signatures can be produced by other sources of new physics [3]. The absence of a signal allows us to set model independent limits on the rate of Z^0 decays of this kind and, within the supersymmetric framework, to place bounds on the masses of supersymmetric particles.

2 Apparatus and Trigger

The data were collected with the OPAL detector at LEP during an energy scan of the Z^0 resonance, at centre of mass energies between 88.3 and 94.3 GeV. We recorded over 10^6 events, measured an integrated luminosity of about 550 nb^{-1} , and observed approximately 12000 hadronic Z^0 decays (corresponding to 17000 produced Z^0 's). About 10% of the luminosity was obtained at centre of mass energies above 93 GeV.

The components of the OPAL detector relevant to this analysis are described below. The trajectories and momenta of charged particles are measured in a central tracking chamber with jet chamber geometry. The chamber is located inside a solenoidal coil and provides up to 159 space points on a track; it covers the polar angle range $|\cos \theta| < 0.97$. The coil is surrounded by a scintillator counter array with 160 azimuthal segments for time-of-flight (TOF) measurement. This is followed by the electromagnetic calorimeter, which consists of 11704 lead glass blocks and covers the angular range $|\cos \theta| < 0.98$. The iron return yoke of the magnet is instrumented with 9 layers of streamer tubes, which provide hadron calorimetry and muon identification over nearly the whole solid angle. Muons are also identified in four layers of drift chambers surrounding the hadron calorimeter. Two identical lead-scintillator calorimeters are placed around the beam pipe in the forward and backward directions. They are used to measure the luminosity by tagging small angle Bhabha scattering events and they complement the electromagnetic calorimeter by extending the geometrical coverage down to a polar angle of 40 mrad.

The trigger of the OPAL experiment has a high degree of redundancy for all types of events. The trigger conditions relevant to this search were as follows:

1. More than 6 GeV was deposited in the barrel electromagnetic calorimeter.

2. At least 2 tracks with $|\cos\theta| < 0.7$ were found by the central detector trigger processor.
3. Hits were found in at least 3 of the 4 layers of muon chambers and were associated in azimuthal angle with either a track or a TOF counter hit.
4. More than 4 GeV was deposited in the barrel electromagnetic calorimeter and at least one track or one TOF counter was hit.

The redundancy of the various triggers allowed us to determine the efficiencies of the individual triggers directly from the data using samples of e , μ , τ pairs and hadronic events from conventional sources. The efficiency of the total energy trigger, trigger 1, as measured from events with e^+e^- pairs and hadrons, was larger than 99% above 8 GeV (see also [4]). The 2-track trigger efficiency of $86 \pm 2\%$ was determined from e^+e^- pairs with $|\cos\theta| < 0.7$ which had satisfied trigger 1. To obtain the efficiency for the single muons (trigger 3) we used the μ pair events according to ref. [5] and obtained $85 \pm 1\%$. Finally, using τ pair candidates, trigger 4 had an efficiency of $80 \pm 8\%$ near threshold and of greater than 98% above 7 GeV. The quoted errors are statistical only and dominate systematic effects.

3 Analysis

We describe four separate searches for events containing acoplanar pairs of (a) electromagnetic clusters (b) muons (c) low multiplicity jets and (d) hadronic jets. For the searches (a) (b) and (c) the selection criteria followed the same pattern, namely first to select events containing two energetic particles or jets, then to demand that there was no other significant activity in the event and finally to require that the particles or jets were acoplanar. These criteria were chosen to give negligible background from standard processes. The searches (b) (c) and (d) started from a sample of 10^5 events that had been selected by an online filter as annihilation candidates (for details see refs. [5]) and for which the central tracking chamber was at full operating voltage. This latter requirement reduced the total integrated luminosity by about 10%. We determined the combined trigger and filter efficiencies for events that would have passed the selection criteria (detailed below) for (a) and (d) to be above 99%, for (b) $96 \pm 2\%$, and $93 \pm 1\%$ for (c).

In order to be considered in the searches a track was required to have at least 50 hits (which limits the acceptance to $|\cos\theta| < 0.9$) and to have a momentum transverse to the beam direction larger than 0.2 GeV. Its distance of closest approach to the interaction point in the transverse plane (d_0) had to be less than 1 cm and the distance along the beam direction less than 50 cm. A cluster in the electromagnetic calorimeter was considered if it contained at least two adjacent lead glass blocks with energy above 20 MeV and if the total cluster energy exceeded 100 MeV. In the endcap region, $0.81 < |\cos\theta| < 0.98$, we further demanded that a cluster contained at least 3 blocks if its total energy was greater than 2 GeV.

(a) In the *search for events with acoplanar electromagnetic clusters* the following selection criteria were applied:

1. At least two clusters with energy greater than 10% of the beam energy had to satisfy the requirement $|\cos \theta| < 0.7$.
2. The number of clusters had to be less than 15 and the total electromagnetic energy outside cones with a half-width of 10° around the two most energetic clusters had to be less than 2 GeV.
3. It was required that the event contained no tracks that were separated by more than 20° in azimuth from the two most energetic clusters.
4. At least one of the two most energetic clusters was required to be matched with a TOF counter hit within 5° in azimuth, and the measured time had to be within 8 ns of the expected time-of-flight from the interaction point.
5. After excluding the first layer, the number of hits in the remaining 8 layers of the barrel hadron calorimeter was required to be less than 6 (For a pair of muons the number is typically 12.).
6. The two most energetic clusters had to have an acollinearity angle greater than 10° .
7. The acoplanarity angle between the two most energetic clusters had to exceed 20° .

Cut 1 favoured events containing two energetic electrons (or photons). Cuts 2 and 3 removed hadronic events, cuts 4 and 5 removed cosmic rays, while most e^+e^- and $\tau^+\tau^-$ events were rejected by cut 6. After the first six cuts 12 events remained. The acoplanarity distribution for these events is shown in Fig. 1a. The sample of 12 events that passed all but the final cut was scanned and found to consist of 9 radiative e^+e^- pairs, 1 radiative $\tau^+\tau^-$ pair and 2 two-photon interactions. After the final cut on the acoplanarity angle no candidates survived. For comparison, the curve in the figure represents the distribution expected from supersymmetric electron pairs and will be discussed later.

In order to check the reliability of the selection procedure, events corresponding to more than 1pb^{-1} were generated by Monte Carlo for e^+e^- [6], $\tau^+\tau^-$ pairs [7], and two-photon events [8]. The generated events were passed through the detector simulation [9] and the selection cuts applied. The number of surviving events, as well as the acoplanarity distribution, were consistent with the data, except for 3 double-radiative e^+e^- events which were not simulated in the Monte Carlo.

(b) In our *search for events with acoplanar muons* we applied the following selection criteria:

1. The events had to contain exactly two tracks, one of which had to satisfy $d_0 < 0.5$ cm.
2. Both tracks had to have a momentum greater than 4 GeV and to satisfy $|\cos \theta| < 0.7$.
3. At least one track had to be found in the muon chambers, with hits in 3 out of 4 layers.
4. The energy in electromagnetic clusters outside cones with 20° half-width around the two tracks was required to be less than 2 GeV.

5. The acoplanarity angle between the two tracks had to exceed 20° .

After requiring cuts 1 to 4 we were left with 383 events for which the distribution of the acoplanarity angle is shown in Fig. 1b. The observed number of events is consistent with the expectation from Z^0 decays to $\mu^+\mu^-$ and $\tau^+\tau^-$ pairs. After the acoplanarity cut no candidates survived.

(c) We now describe the *search for events with acoplanar low multiplicity jets* (e.g. τ decays). Most multihadronic and cosmic ray events were removed by requiring that the track multiplicity be less than 9 and that the events contained at least one track with $d_0 < 0.5$ cm. This reduced the sample size to 6039 events. These events were analysed in terms of low multiplicity jets. In this context a “jet” could be a single charged or neutral particle or a narrow jet of a few charged or neutral particles, as produced by τ decays. The jets were defined by the following algorithm:

- Starting with the highest momentum track we searched in a cone of 20° half-width for another track. If a track was found, the sum of the momenta of the two tracks was used to define the centre of a new cone. This procedure was repeated until no more tracks could be added. Of the remaining tracks the one with the largest momentum was used as the centre for a new cone and the above method was repeated until all tracks were assigned to a jet.
- The same technique was used to combine electromagnetic clusters into jets. However, in this case the half-width of the cone was extended to 25° to increase the acceptance for τ decays with low momentum π^0 ’s. Neutral jets with final energies less than 1 GeV were ignored.
- The jets obtained from tracks and those obtained from clusters were combined if the angle between them was smaller than 20° .

In order to estimate the energy of a combined jet, the momenta of the tracks and the clusters were added separately. To avoid double counting, the larger of the two sums was taken as the energy of the jet. With the jets defined in this way the following selection criteria were applied:

1. Exactly 2 jets were required and each of them had to contain at least one track.
2. At least one jet was required to be within $|\cos\theta| < 0.8$.
3. The energy of each jet was required to be greater than 3 GeV.
4. The missing transverse momentum calculated from the two jets had to be greater than 3 GeV.
5. The energy deposited in the forward detector was required to be less than 10 GeV.
6. The acoplanarity angle between the two jets had to exceed 20° .

Cuts 1 through 3 selected pairs of jets with little other activity in the event. Cut 4 eliminated two-photon events which would not be tagged by the forward detector due to the acceptance cutoff at 40 mrad in polar angle. Cut 5 discriminated against two-photon interactions which

did deposit energy in the forward detectors. After cuts 1 to 5 we were left with 1008 events consistent with the expectation for lepton pair production. In Fig. 1c we show the acoplanarity distribution for these events. No events were found after applying the acoplanarity cut 6. A single event with an acoplanarity angle larger than 20° which had survived after cut 4 was scanned even though it did not pass the next cut, cut 5. The event was then found to be a tagged two-photon interaction.

d) In the *search for acoplanar hadron jets* the events had to satisfy the following requirements:

1. The number of tracks had to exceed five.
2. In both hemispheres defined by the plane normal to the beam axis the electromagnetic energy had to be greater than 2 GeV.
3. The total electromagnetic energy had to exceed 7.5 GeV.
4. In order to ensure good containment of the events, the thrust axis (calculated from the electromagnetic clusters) had to satisfy $|\cos\theta| < 0.86$.
5. The event was divided into two hemispheres using the plane normal to the thrust axis. Two directions were obtained by adding the vector momenta of the clusters, separately in each hemisphere. The acoplanarity angle was then calculated from these directions and was required to be greater than 50° .

After applying cuts 1 to 4 a sample of 9837 events remained. The distribution of the acoplanarity angle for these events is shown in Fig. 1d. The expectation from hadronic decays of the Z^0 was obtained using the Jetset Monte Carlo [10]. The distribution is also shown in the figure and agrees well with our data. Only 11 events have an acoplanarity angle larger than 50° . This number is in agreement with the simulation which yielded 12 ± 4 . We also considered separately the sample of 755 hadronic events collected at centre of mass energies above 93 GeV to increase the kinematical range for our search. In this subsample no events remained after the above cuts.

4 Limits on Supersymmetric Particle Masses and on Topological Z^0 Branching Ratios

We now proceed to place limits on branching ratios for the Z^0 to decay into a pair of massive particles which subsequently decay into leptons or quarks and undetected neutral particles. Such events are expected to be a signature for the production of supersymmetric (SUSY) particles. In SUSY models [2] all fermions and bosons have partners with identical couplings. The SUSY particles carry a multiplicative quantum number which in most models is conserved in their production and decay. They differ in their spin by half a unit from the corresponding standard particles. The SUSY partners ($\tilde{l}$) of the charged leptons have spin 0 and are denoted by $\tilde{e}$, $\tilde{\mu}$ and $\tilde{\tau}$. We assume that the photino ($\tilde{\gamma}$), the partner of the photon, is the lightest stable SUSY particle. With this assumption, the $\tilde{l}$ would decay promptly to the corresponding lepton and a $\tilde{\gamma}$. The partners of the left- and righthanded leptons are denoted by $\tilde{l}_L$ and $\tilde{l}_R$.

In most SUSY models the $\tilde{l}_R$ are lighter than the $\tilde{l}_L$. The partners of the charged bosons ($W^\pm, H^\pm$) are called charginos ($\tilde{\chi}^\pm$). The unknown mixing between these states leads to some model dependence in the production cross section and decay branching ratio of the $\tilde{\chi}^\pm$. The $\tilde{\chi}^\pm$ decay is expected to have leptonic modes $\tilde{\chi}^\pm \rightarrow l\nu\tilde{\gamma}$, and hadronic modes, $\tilde{\chi}^\pm \rightarrow q\bar{q}\tilde{\gamma}$. Masses below 25 GeV have already been excluded for most of the supersymmetric unstable charged particles [11]. The ASP experiment has excluded the $\tilde{e}_R$ with a mass below 48 GeV for the case of a small $\tilde{\gamma}$ mass [12].

The production cross sections of SUSY particles were obtained in the Born approximation from refs. [13] and [14]. Initial state bremsstrahlung was taken into account according to the formalism of ref. [15] which reduced the cross section by about 30% relative to the Born approximation.

We generated Monte Carlo events according to refs. [13] and [14] to determine the selection efficiencies for the various SUSY processes. The fragmentation of the quarks and the decays of the $\tau^\pm$ were included using the Jetset Monte Carlo [10]. The events were then passed through a full simulation of the OPAL detector [9]. The cross sections and selection efficiencies were calculated as a function of the masses of the various supersymmetric particles. Combining the trigger and filter efficiencies with the selection efficiencies as determined from the Monte Carlo's with $m_{\tilde{\gamma}} = 20$ GeV and a mass of 40 GeV for the $\tilde{l}$, we obtained efficiencies for the $\tilde{e}$ of $45 \pm 2\%$, for the $\tilde{\mu}$ of $44 \pm 2\%$, for the $\tilde{\tau}$ of $44 \pm 2\%$. However, these efficiencies dropped off rapidly when the mass difference between the decaying SUSY particle and the $\tilde{\gamma}$ became small. For a $\tilde{\chi}^\pm$ with a mass of 40 GeV and $m_{\tilde{\gamma}} = 0$ GeV an efficiency of $15 \pm 1\%$ was obtained. The efficiency was reduced to about 6% for $m_{\tilde{\gamma}} = 20$ GeV. In general, for $\tilde{\chi}^\pm$ and $\tilde{l}$ masses greater than 40 GeV the detection efficiencies of these events are independent of spin and basically determined by the decay kinematics. The expected distributions for the relevant SUSY particles, after the corresponding cuts, are shown as smooth curves in figs. 1a-d.

We now derive lower limits on the masses of supersymmetric particles. We considered the cases where the $\tilde{l}_L$ and $\tilde{l}_R$ have different masses and also the case where they have equal mass. For the $\tilde{e}$ the limits were derived from the search for acoplanar electromagnetic clusters, for $\tilde{\mu}$ from the search for acoplanar muons, and for $\tilde{\tau}$ from the analysis based on low multiplicity jets. For a $\tilde{\gamma}$ mass less than 20 GeV we obtain the 95% CL lower mass limits summarized in Table 1. The excluded mass range (95% CL) as a function of the $\tilde{\gamma}$ mass is shown in Figs. 2a-c for each $\tilde{l}_R$. For comparison, the ASP result [12] is also shown in Fig. 2a.

For the chargino ($\tilde{\chi}^\pm$) we calculated mass limits as a function of the hadronic branching ratio $Br(\tilde{\chi}^\pm \rightarrow q\bar{q}\tilde{\gamma}) = \Gamma(\tilde{\chi}^\pm \rightarrow q\bar{q}\tilde{\gamma}) / \{\Gamma(\tilde{\chi}^\pm \rightarrow l\nu\tilde{\gamma}) + \Gamma(\tilde{\chi}^\pm \rightarrow q\bar{q}\tilde{\gamma})\}$ assuming equal values for each leptonic channel. We assumed that the $\tilde{l}$ and the associated scalar neutrinos are heavy. Otherwise, the $\tilde{\chi}^\pm$ would decay predominately as $\tilde{\chi}^\pm \rightarrow l\tilde{\nu}_l$ or $\tilde{\chi}^\pm \rightarrow \tilde{l}\nu_l$, a case which is covered by our search for acoplanar leptons. The cross section for the production of $\tilde{\chi}^\pm$ pairs was calculated according to the minimal SUSY model and the parametrisation of ref.[14]. On the Z^0 resonance and for a $\tilde{\chi}^\pm$ mass of 40 GeV this model leads to a Born cross section of about 8.5 nb for the range of parameters studied [14]. Treating the hadronic branching ratio as a free parameter, Fig. 3 shows the region of the $\tilde{\chi}^\pm$ mass that is excluded by our searches for acoplanar electromagnetic clusters and quark jets. The regions are given for two choices of the $\tilde{\gamma}$ mass. Combined limits from the two searches are obtained from the

crossing points of the curves in Fig. 3. For photino masses of 0 (20) GeV, we exclude the $\tilde{\chi}^\pm$ with a mass less than 45.7 (45.0) GeV irrespective of the hadronic branching ratio. For the hadronic $\tilde{\chi}^\pm$ branching ratio of 64% as determined in ref.[14], similar to that suggested by $W^\pm$ decays, we obtain mass limits of 46.2 GeV for a photino mass of 0 GeV, and 44.8 GeV for a photino mass of 20 GeV. A summary of the results is presented in Table 2. In general, different SUSY models and different parametrisations can give other $\tilde{\chi}^\pm$ production cross sections than the one used above. Therefore, we show in Fig. 4 the variation in the mass limits (independent of the hadronic branching ratio) if the cross section, as given by ref.[14], is scaled by an overall reduction factor.

From the observation that the selection efficiencies, typically 40% for heavy particles (mass greater than 40 GeV) decaying into leptons and 15% for decays into jets, are largely model independent, we calculated limits on topological Z^0 decays, without reference to any particular model. The limits were obtained using the relation $Br < N_0/(\epsilon \cdot N_Z)$, where N_0 is the expected number of events at 95% CL, ϵ the detection efficiency, and N_Z the total number of produced Z^0 's. We observed no events with pairs of acoplanar electromagnetic clusters, muons or taus. From the corresponding efficiencies we calculated the following 95% CL upper limits for Z^0 decays into pairs of massive particles that decay promptly to a lepton or photon plus undetected neutrino-like particles. The limits are 4.4×10^{-4} for electron or photon pairs and 5.0×10^{-4} for μ or τ pairs. We observed 11 events with a pair of acoplanar hadronic jets. The corresponding upper limit on the branching ratio for Z^0 to acoplanar hadronic jets is then 8.0×10^{-3} and is independent of the details of fragmentation models. These numbers are summarized in Table 3.

5 Summary

We found no evidence for the decay of the Z^0 into acoplanar pairs of leptons or hadronic jets. We used this signature to set upper limits on Z^0 decays into pairs of massive particles that decay promptly to conventional quarks, leptons, or photons and undetected neutrino-like particles. For the leptonic final states we obtained upper limits on the branching ratios of 5×10^{-4} and for the hadronic final states 8×10^{-3} . These limits are essentially model independent. For righthanded scalar leptons, assuming that the photino mass is below 20 GeV, the lower mass limits of 41 GeV were obtained. For the chargino we excluded the mass range below 45.0 GeV, regardless of its hadronic branching ratio. All the above numbers are given at 95% confidence level. Recently similar limits were obtained by other experiments at LEP [16].

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 This model was used for the calculation of the chargino production cross section and the chargino decay matrix elements. The vacuum expectation values of the two Higgs doublets were taken to be equal, $v_1/v_2 = 1$, and $M' = (5/3) M \tan^2 \theta_w$ was assumed to be valid. Here we used the notation of the above references. We considered the two cases: $m_{\tilde{\chi}} = 0$ GeV, corresponding to $M = 0$, and $m_{\tilde{\chi}} = 20$ GeV, and varied the chargino mass in the range 30-45 GeV through a suitable combination of μ and M . Note that $M = 0$ means that there is no mixing in the neutral sector but always mixing in the charged sector. Although the above choice of parameters fixes the hadronic branching ratio for the chargino, we retain the branching ratio as a variable in the analysis.
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SUSY particle	Photino mass	Mass degenerate	Righthanded only	Lefthanded only
$\tilde{e}$	0-30	43.4	41.5	42.3
$\tilde{\mu}$	0-30	43.0	41.0	41.9
$\tilde{\tau}$	0-23	43.0	41.0	41.9

Table 1: Lower mass limits for $\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$ at 95% CL for the given ranges of the $\tilde{\gamma}$ mass (all numbers are in GeV)

$Z^0 \rightarrow \tilde{\chi}^+ \tilde{\chi}^-$	Photino mass (GeV)	Mass limit (GeV)
$\rightarrow e\nu\tilde{\gamma} e\nu\tilde{\gamma}$	0-20	45.3
$\rightarrow jets \tilde{\gamma}\tilde{\gamma}$	0	46.2
$\rightarrow jets \tilde{\gamma}\tilde{\gamma}$	20	44.8
combined limit	0	45.7
	20	45.0

Table 2: Lower $\tilde{\chi}^\pm$ mass limits at 95% CL for specific $\tilde{\chi}^\pm$ decay modes. The combined limit is independent of the branching ratio.

Signature	Mass of the undetected particle	Number of produced Z^0	Efficiency	Limit on Z^0 branching ratio
Acoplanar clusters	0-20 GeV	17 k	40%	4.4×10^{-4}
Acoplanar muons	0-20 GeV	15 k	40%	5.0×10^{-4}
Acoplanar low multiplicity jets	0-20 GeV	15 k	40%	5.0×10^{-4}
Acoplanar hadronic jets	0 GeV	15 k	15%	8×10^{-3}
	20 GeV	15 k	6%	2×10^{-2}

Table 3: Upper limits at 95% CL for the Z^0 branching ratio to final state topologies as described in the text.

FIGURE 1: Acoplanarity distributions for a) clusters in the electromagnetic calorimeter b) 2-track events with at least one μ candidate c) 2 low multiplicity jets d) hadronic jets. In figs. a)-c) the data are represented by the hatched histograms and in fig. d) by the points with error bars. The curves in a)-c) are the Monte Carlo expectations for $\tilde{l}_R$ with a mass of 40 GeV and a $\tilde{\gamma}$ mass of 10 GeV. In fig. d) the expectation for the $\tilde{\chi}^\pm$ with a mass of 43 GeV is given by the curve and the expectation for hadronic Z^0 decays, as simulated by the Jetset7.1 Monte Carlo [10], by the histogram (normalized to the number of events).

FIGURE 2: The 95% CL lower mass limit contour plots for right handed $\tilde{e}$ (a), $\tilde{\mu}$ (b), $\tilde{\tau}$ (c) pairs as a function of the $\tilde{\gamma}$ mass. The boundaries of the excluded regions are shaded. In a) we have included the 90% CL result of the ASP experiment[12] (dashed curve).

FIGURE 3: Contour plot (95% CL) of the hadronic $\tilde{\chi}^\pm$ branching ratio versus the $\tilde{\chi}^\pm$ mass. Curves (a) and (c) correspond to $m_{\tilde{\gamma}} = 0$ GeV, curves (b) and (d) to $m_{\tilde{\gamma}} = 20$ GeV. The excluded regions from the analysis based on electromagnetic clusters are given by the interior of the curves (a) and (b). The interior of curves (c) and (d) are the excluded regions as determined from the hadronic jet analysis. The boundaries of the combined excluded regions are shaded. The region below about 25 GeV has been excluded by the TOPAZ collaboration for $m_{\tilde{\gamma}} = 0$ GeV[17] and is marked by the dash-dotted curve.

FIGURE 4: The $\tilde{\chi}^\pm$ mass limit (branching ratio independent) as a function of a reduction factor applied to the production cross section. The reduction factor is 1 for the parametrisation defined in [14]. The curves are obtained from the combined limit of the hadronic jet analysis and the electromagnetic cluster analysis.

Figure 1

Figure 2

Figure 3

Figure 4