Brief Reports

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Search for single electrons from supersymmetric-particle production

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A search for single electrons produced by the decay of singly produced supersymmetric electrons ($\tilde{e}$) or W's ($\tilde{W}$) within the MAC detector at the SLAC storage ring PEP has been performed in e^+e^- annihilations at $\sqrt{s}=29$ GeV. No evidence of supersymmetric-particle production is observed in a data sample with an integrated luminosity of 206 pb^{-1}. Limits on possible masses of supersymmetric electrons and photons ($\tilde{\gamma}$) are presented. The $\tilde{e}$ mass limit is $m_{\tilde{e}}>24.5$ GeV/c^2 at the 90% confidence level if $m_{\tilde{e}_L}=m_{\tilde{e}_R}$ and $m_{\tilde{\gamma}}=0$. If $m_{\tilde{e}_L}\gg m_{\tilde{e}_R}$, the corresponding limit is $m_{\tilde{e}_R}>23.3$ GeV/c^2. Limits on possible masses of supersymmetric W's and neutrino's ($\tilde{\nu}$) are also presented. The $\tilde{W}$ mass limit is $m_{\tilde{W}}>22.0$ GeV/c^2 at the 90% confidence level if $m_{\tilde{\nu}}=0$.

Searches for the associated production of supersymmetric (SUSY) electrons ($\tilde{e}$) and photons ($\tilde{\gamma}$) (Refs. 1—3) via the reaction

$$e^+e^-\to e^\pm\tilde{e}^\mp\tilde{\gamma} \tag{1}$$

were the first to extend mass limits on the $\tilde{e}$ beyond the limitations of beam energy. Another example of associated production

$$e^+e^-\to e^\pm\tilde{W}^\mp\tilde{\nu} \tag{2}$$

has been used to search for supersymmetric W's ($\tilde{W}$) and neutrinos ($\tilde{\nu}$) (Ref. 4). A signature for both reactions is the observation of a final state with only one observed electron and large missing $p_\perp$. Previous searches[1–4] for reactions (1) and (2) used approximate calculations[5] of these reactions which may have lead to an overestimate of the cross sections. This paper uses recent precise calculations of these processes,[6,7] valid for all $e^\pm$ scattering angles and nonzero $\tilde{\gamma}$ or $\tilde{\nu}$ masses, to model the detector acceptance accurately. Including all first-order Feynman diagrams and the effects of the $e^{\pm}$ scattering angle reduces the $e^{\pm}\tilde{e}^{\mp}\tilde{\gamma}$ cross section by 40% for the cuts and masses used in our previous publication.[1] This search covers a data sample with an integrated luminosity of 206 pb^{-1}, six times larger than our previous search. Background from radiative Bhabha scattering has been reduced by the addition of small angle detectors, allowing the present search to be extended to lower electron energies and larger $\tilde{\gamma}$ or $\tilde{\nu}$ masses.

In many supersymmetric (SUSY) models either the $\tilde{\gamma}$ or $\tilde{\nu}$ is the lightest SUSY particle (LSP) (Ref. 8). The LSP is neutral, stable, and interacts only weakly and thus cannot be directly observed in the detector. In both reactions (1) and (2) the electron is usually scattered along the beam axis and is often not detected. In reaction (1) the $\tilde{e}$ is assumed to decay via $\tilde{e}^{\mp}\to e^{\mp}\tilde{\gamma}$. For heavy $\tilde{e}$'s the decay electron has a nearly isotropic angular distribution and roughly half of the $\tilde{e}$ energy. The expected energy distributions of electrons from $\tilde{e}$ decay are shown in Fig. 1 for two combinations of $\tilde{e}$ and $\tilde{\gamma}$ masses. As seen in Fig. 1 sensitivity to electrons with energies less than $E_{\mathrm{beam}}/2$ is essential if the search is to include $\tilde{\gamma}$ masses ≈ 10 GeV/c^2. In reaction (2) we assume that the $\tilde{\nu}$ is the LSP and that the $\tilde{W}$ decays via $\tilde{W}^{\pm}\to l^{\pm}\tilde{\nu}_l$ with a branching fraction into electrons of $\frac{1}{3}$. The energy and angular spectra of the decay electrons from $\tilde{W}$ decay are similar to those expected from $\tilde{e}$ decay.

QED processes which could contribute background to the $\tilde{e}$ or $\tilde{W}$ signal are $e^+e^-\to e^+e^-\gamma$, $\tau^+\tau^-(\gamma)$, and $e^+e^-\tau^+\tau^-$ where a single electron is observed and all other particles escape detection. The MAC detector covers $>98\%$ of 4π sr with calorimetric and tracking chambers restricting the unseen e's or γ's from $e^+e^-\gamma$ to small angles about the beam axis. If θ_{veto} is the maximum polar angle of the undetected particles then the $p_\perp$ of the observed electron is $p_\perp \le (\sqrt{s}-E_e)\sin\theta_{\mathrm{veto}}$. Thus a kinematical region in $p_\perp$, or equivalently E_e and θ, can be chosen with a negligible background from $e^+e^-\gamma$. No kinematic cut can completely eliminate backgrounds from τ decays since the observed $p_\perp$ can be balanced by neutrinos. If the other charged particles in the final state are very soft or escape down the beam pipe the event may be indistinguishable from $\tilde{e}$ or $\tilde{W}$ decays. Good veto angular coverage and discrimination between electrons and hadrons considerably reduce the number of τ decays satisfying the single electron criteria. The rate of the remaining background may be calculated by Monte Carlo simulation.

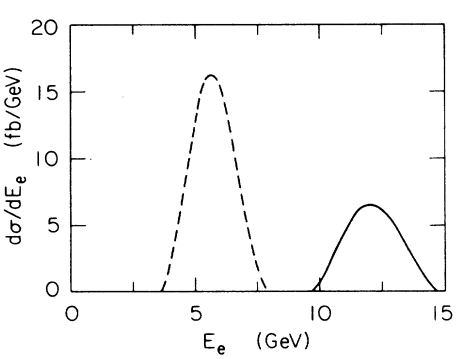

FIG. 1. Energy spectra of single electrons from $\tilde{e}$ decay in $e^+e^-\to e^{\pm}\tilde{e}^{\mp}\tilde{\gamma}$ at $\sqrt{s}=29$ GeV for the cases $m_{\tilde{e}}=24$ GeV/c^2, $m_{\tilde{\gamma}}=0$ (solid curve) and $m_{\tilde{e}}=17$ GeV/c^2, $m_{\tilde{\gamma}}=10$ GeV/c^2 (dashed curve).

More detailed descriptions of the MAC detector may be found elsewhere.[9] The sections of the detector of particular importance to this experiment are the central drift chamber (CD) in which the momentum and angles of the electrons are measured, the electromagnetic shower calorimeter (SC) in which the electron energy is measured, and the calorimeters at small angles which determine θ_{veto}. The ten-layer CD inside a solenoid with a 0.57-T axial magnetic field has a momentum resolution of $\sigma_p/p^2=0.065\sin\theta$ and angular resolutions of 0.2° in azimuth (ϕ) and 0.7° in polar angle (θ). Additional track information was available from a precision vertex chamber installed after half of the data were recorded. The 14-radiation-length SC, constructed from lead and proportional wire chamber planes, has an energy resolution of $\sigma_E/E \simeq 20\%/\sqrt{E\,(\mathrm{GeV})}$ and angular resolutions of 1.3° and 1.7° in θ.

The data included in this paper were accumulated over three years during which several changes were made to the small angle detectors. In data sample I with an integrated luminosity of 68 pb^{-1}, θ_{veto} was set by the endcap calorimeters which covered polar angles greater than 10° with steel and proportional wire planes and by scintillators providing coverage to $\theta \approx 12°$. In data sample II (76 pb^{-1}) small-angle-veto calorimeters (SAV) were installed covering polar angles $3.8° < \theta < 17.5°$. In data sample III (62 pb^{-1}) shielding for the vertex chamber blocked portions of the SAV. To recover most of the lost veto coverage, calorimeters made from bismuth germanate crystals (BGO) were added. The SAV and BGO detectors cover the angular region $4.5° < \theta < 17.5°$.

Single-electron candidates were collected using an energy trigger requiring ≥ 1 GeV of energy in a SC sextant with significant energy deposition in at least two of the three SC layers. Candidates were required to have exactly one reconstructed CD track with $|\cos\theta| \le 0.75$ and momentum $p \ge 1.0$ GeV/c. Showers in the electromagnetic and hadronic calorimeters were recognized by a clustering algorithm which combined nearby hits and calculated an energy vector for each cluster. Only events with one cluster of energy greater than 2.0 GeV (≥ 3.0 GeV in data sample I) were kept. Further cuts on drift chamber, scintillator, BGO, and veto calorimeter activity ensured that candidate events had no evidence of other particles in the detector. To minimize $\tau^+\tau^-(\gamma)$ backgrounds, stringent cuts ensured that the energy deposition in the SC was consistent with an electron shower and that the θ and ϕ determined from the calorimeter shower agreed well with those determined from the CD track. The energy distributions of single electrons satisfying these requirements are shown in Fig. 2 for the three data samples.

The efficiencies of the trigger and analysis requirements were determined from studies of radiative-Bhabha-scattering events with two final-state particles observed. The net efficiency was determined to have a weak energy

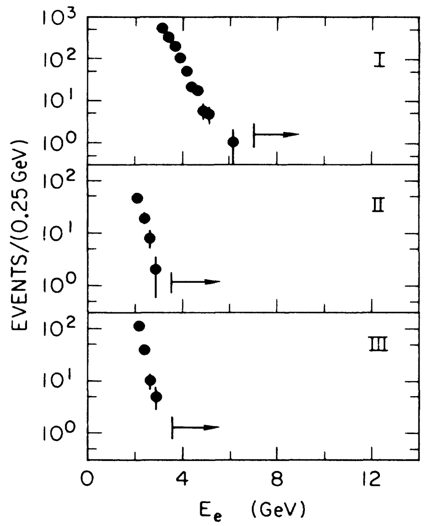

FIG. 2. Energy spectra of observed single electrons for data sample I with $\theta_{\rm veto} \approx 10°$ and search region $E_e > 7.0$ GeV/c^2, for data sample II with $\theta_{\rm veto} \approx 3.8°$ and search region $E_e > 3.5$ GeV/c^2, and for data sample III with $\theta_{\rm veto} \approx 4.5°$ and search region $E_e > 3.5$ GeV/c^2. These data samples have integrated luminosities of 68, 76, and 62 $\rm pb^{-1}$, respectively.

dependence, rising from 78% at 3 GeV to 82% at 12 GeV.

Search regions for single electrons from $\tilde{e}$ or $\tilde{W}$ decay were chosen for each of the running periods to be free of background from $e^+e^-\gamma$. To determine these regions a Monte Carlo generator[10] produced simulated $e^+e^-\gamma$ events which were then subjected to the trigger and analysis cuts and corrected for resolution and efficiency effects. These simulated events were compared to the data for different assumed values of $\theta_{\rm veto}$. In all cases the $\theta_{\rm veto}$ determined from this procedure agreed well with the angle expected from the detector geometry for that data period and with the $\theta_{\rm veto}$ determined by a separate analysis of single-photon events[11] from $e^+e^-\gamma$. The search regions for the different running periods are (I) $E_e > 7.0$ GeV and (II and III) $E_e > 3.5$ GeV. A small background of 2 ± 1 events is expected from $\tau^+\tau^-\gamma$. However, as seen in Fig. 2, no single electrons are observed in the search region of any running period.

The total number of events expected in the search regions I—III as a function of the $\tilde{e}$ and $\tilde{\gamma}$ masses was calculated by Monte Carlo simulation[6] including corrections for trigger and analysis efficiencies. Some of the events from $e^+e^- \to e^\pm \tilde{e}^\mp \tilde{\gamma}$ or $e^\pm \tilde{W}^\mp \tilde{\nu}$ would have two electrons visible in the detector and would fail the analysis requirements. The fraction of $\tilde{e}$ decays producing an electron in the search region and satisfying all other analysis cuts is 47% in data sample I, 40% in data sample II, and 41% in data sample III if the $\tilde{\gamma}$ is massless. An upper limit of 26 pb is placed on the total $\tilde{e}$ cross section if $m_{\tilde{\gamma}} \le 6$ GeV/c^2. Regions of excluded $\tilde{e}$ and $\tilde{\gamma}$ masses were determined and are shown in Fig. 3 for degenerate ($m_{\tilde{e}_L} = m_{\tilde{e}_R}$) and nondegenerate ($m_{\tilde{e}_L} \gg m_{\tilde{e}_R}$) mass assumptions. For $m_{\tilde{\gamma}} = 0$ the limits are $m_{\tilde{e}} > 24.5$ GeV/c^2 for the degenerate case and $m_{\tilde{e}_R} > 23.3$ GeV/c^2 for the nondegenerate case, both at the 90% confidence level. The corresponding limits at the 95% confidence level are $m_{\tilde{e}} > 24.1$ GeV/c^2 and $m_{\tilde{e}_R} > 22.8$ GeV/c^2. From a similar calculation,[7] limits on $\tilde{W}$ and $\tilde{\nu}$ masses were determined and are shown in Fig. 4. For $m_{\tilde{\nu}} = 0$ the limit is $m_{\tilde{W}} > 22.0$ GeV/c^2 at the 90% confidence level. These mass limits on nondegenerate $\tilde{e}$ slightly exceed those obtained by other published searches for $e^+e^- \to e^\pm \tilde{e}^\mp \tilde{\gamma}$. The $\tilde{W}$ mass limits represent the first search for $e^+e^- \to e^\pm \tilde{W}^\mp \tilde{\nu}$ in which the $\tilde{W}$ decays to an electron.

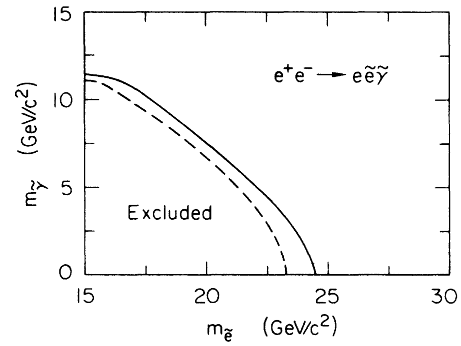

FIG. 3. Experimental limits on $m_{\tilde{e}}$ and $m_{\tilde{\gamma}}$. Mass combinations inside the contours are excluded at the 90% confidence level. The solid and dashed curves represent the limits of this search for single $\tilde{e}$'s for degenerate ($m_{\tilde{e}_L} = m_{\tilde{e}_R}$) and nondegenerate ($m_{\tilde{e}_L} \gg m_{\tilde{e}_R}$) masses, respectively.

We thank M. Martinez for providing calculations of the $e^\pm \tilde{e}^\mp \tilde{\gamma}$ and $e^\pm \tilde{W}^\mp \tilde{\nu}$ cross sections for the MAC detector acceptance. We also thank N. Erickson, J. Escalera, M. J. Frankowski, and J. Schroeder for technical assistance, and the SLAC staff for continued reliable operation of the PEP storage ring. This work was supported in part by the U.S. Department of Energy under Contracts Nos. DE-

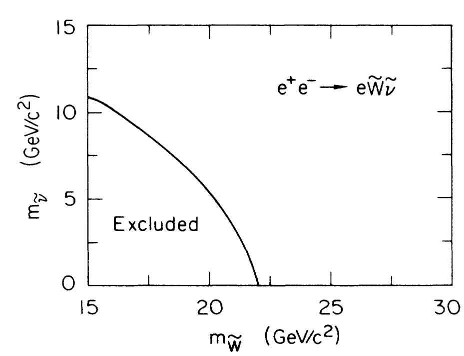

FIG. 4. Experimental limits on $m_{\tilde{W}}$ and $m_{\tilde{\nu}}$ from this search for single $\tilde{W}$'s from $e^+e^- \to e^\pm \tilde{W}^\mp \tilde{\nu}$. Mass combinations inside the contour are excluded at the 90% confidence level.

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