Search for Singly Produced Supersymmetric Electrons in e^+e^- Interactions

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A search for supersymmetric electron production via the reaction $e^+e^- \to e^\pm\tilde{\gamma}\tilde{e}^\mp$ followed by the decay $\tilde{e}^\mp \to e^\mp\tilde{\gamma}$ has been performed with the MAC detector at the electron-positron storage ring PEP. No candidates were found in a sample corresponding to an integrated luminosity of 36.4 pb^{-1}. For a massless $\tilde{\gamma}$ this corresponds to a lower limit on the $\tilde{e}$ mass of 22.4 GeV/c^2 at the 95% confidence level.

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One of the most striking predictions of supersymmetric theories[1] is that for every familiar particle of the standard model there should be supersymmetric partners with spin differing by $\frac{1}{2}$ unit and, in the case of exact supersymmetry, identical mass. Since none of these particles has yet been found, the symmetry, if valid, is apparently broken at low energies. There is no universal agreement, however, about the mechanism responsible for supersymmetry breaking and it is therefore important to search for supersymmetric particles in current experiments. The spin-0 partners of the electron, muon, and tau ($\tilde{e}, \tilde{\mu}, \tilde{\tau}$) could be pair produced in e^+e^- annihilations if the beam energy exceeded their mass.[2] Their decay would lead to distinctive noncoplanar e^+e^- or $\mu^+\mu^-$ final states. Experiments conducted at the electron-positron storage rings PETRA[3] and PEP[4] have established upper bounds on these processes leading to lower limits on the mass of the $\tilde{e}$, $\tilde{\mu}$, and $\tilde{\tau}$. The most stringent limit on the $\tilde{e}$ mass using this technique[5] is $m_{\tilde{e}} > 17.8$ GeV/c^2. As suggested by several authors,[2,6] $\tilde{e}$'s with masses larger than the beam energy but smaller than the center-of-mass energy could be produced singly in e^+e^- interactions in the process $e^+e^- \to e^\pm\tilde{\gamma}\tilde{e}^\mp$, where $\tilde{\gamma}$ is the supersymmetric partner of the photon.

A search for this process has been completed using the MAC detector at PEP. The MAC detector has been described elsewhere.[7] The components of the detector used in this analysis are the central tracking chamber, the central electromagnetic calorimeter, and the end-cap scintillation counters and calorimeters. The central tracking chamber has a total of ten cylindrical layers of drift cells inside a common gas volume, providing charged-particle tracking to 17° from the beam axis. The electromagnetic calorimeter has a hexagonal geometry and consists of alternating planes of lead and proportional chambers totaling 14 radiation lengths of material. Each calorimeter sextant is segmented into 32 azimuthal sectors and three layers in depth. Charge division in each of the segments is used to measure the axial position of the showers. The energy resolution for electromagnetic showers has been measured with Bhabha events as $\delta E/E = 20\%/\sqrt{E}$. The end-cap calorimeters are made of alternating layers of steel and proportional chambers with electromagnetic energy resolution given by $\delta E/E = 45\%/\sqrt{E}$. A single plane of scintillators are located inside each end cap and around the central electromagnetic calorimeter.

The MAC trigger for single electron or photon showers uses energy sums from the central electromagnetic calorimeter. Sums corresponding to the three layers of radial readout and 30° azimuthal sectors are made and combined again to form sextant energy sums. A timing discriminator[8] on each sextant sum produces a pretrigger if that sum is greater than 2 GeV and within a 150-nsec timing gate. The full trigger further requires that at least two adjacent layers in any sector each have more than 0.3 GeV energy deposited. Only triggers with energy greater than 2.5 GeV in the central electromagnetic calorimeter were logged. The efficiency of this trigger was measured from the real data sample, with use of $e^+e^- \rightarrow e^+e^-\gamma$ events that have only one particle in the central section and satisfy other MAC triggers. The trigger efficiency increases with energy, rising from 92% at 3 GeV to greater than 99% above 6 GeV.

The cross section for the process $e^+e^- \rightarrow e^\pm\tilde{\gamma}\tilde{e}^\mp$ has been calculated by Gaillard, Hall, and Hinchliffe[6] when the $\tilde{\gamma}$ mass is much smaller than the $\tilde{e}$ mass. Their calculation assumes that the dominant contribution to the cross section comes from the interaction of one of the beam electrons with a quasireal photon radiated by the other beam electron, producing a $\tilde{\gamma}$ and a $\tilde{e}$. The beam electron that radiates the photon is scattered by a small angle and is therefore not observed in the detector.[9] The $\tilde{e}$ is assumed to decay promptly into an electron and a $\tilde{\gamma}$ with a 100% branching ratio. The decay electron has a nearly isotropic angular distribution and is fairly energetic. These characteristics reflect the fact that the $\tilde{e}$ is a heavy particle which decays isotropically in its rest frame and is moving slowly in the laboratory frame. The energy distribution of the electron, shown in the inset of Fig. 1 for our center-of-mass energy of 29 GeV and for several $\tilde{e}$ masses, was calculated for $|\cos\theta| < 0.75$, where θ is the angle of the electron with respect to the beam axis. Approximately 75% of the total cross section satisfies this cut. Under the assumption that the $\tilde{\gamma}$'s are undetected,[10] this electron is the only observed final-state particle.

The single-electron sample was obtained by selecting events with one and only one track in the central drift chamber, with $|\cos\theta| < 0.75$, and with associated calorimeter hits consistent with an electromagnetic shower of energy greater than 3 GeV. For this search region typically 95% of the electron's energy is deposited in the central shower chamber. Events with showers in the central or end-cap calorimeters greater than 1 GeV and not correlated with the electron track were removed from the sample. Events with end-cap scintillator hits were also removed. The energy and angular distribution of the final sample are shown in Figs. 1 and 2, respectively. The

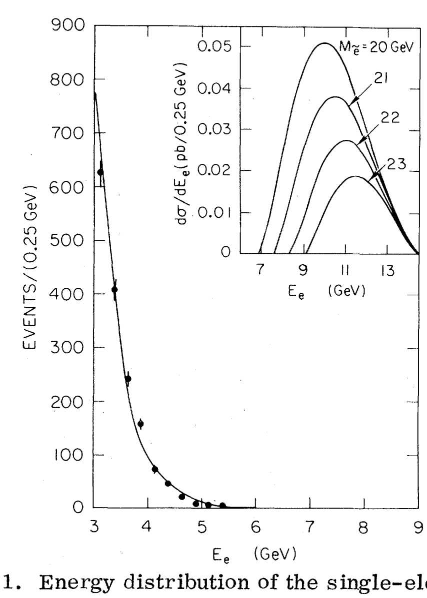

FIG. 1. Energy distribution of the single-electron sample selected as described in the text. The curve is the Monte Carlo prediction for single-electron events coming from the $ee\gamma$ final state. The inset shows the energy distribution of single electrons that would result from the $e^+e^- \rightarrow e^\pm\tilde{\gamma}\tilde{e}^\mp$ reaction.

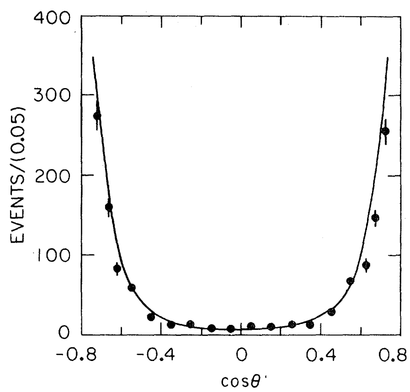

FIG. 2. Angular distribution of the single-electron events selected as described in the text. The curve is the Monte Carlo prediction for single-electron events coming from the $ee\gamma$ final state.

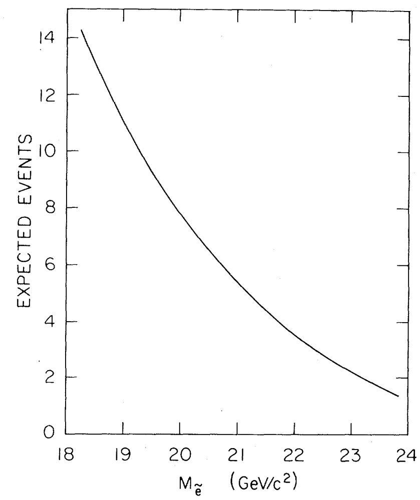

FIG. 3. Number of single-electron events with $|\cos\theta| < 0.75$ expected from the reaction $e^+e^- \rightarrow e^{\pm}\tilde{\gamma}\tilde{e}^{\mp}$ as a function of the scalar-electron mass. An overall detection efficiency of 95% was used.

total number of events is 1565 ± 40, where the error is only statistical. No event is observed with an electron energy of more than 6 GeV.

Background single-electron events come primarily from $e^+e^-\gamma$ final states where one electron and the photon are not seen in the detector. Two-photon processes and tau events can also contribute to the background. The MAC detector is very efficient at detecting energetic (> 2 GeV) electrons or photons over its entire angular range (98% of 4π). Although the detector has small dead regions between adjacent calorimeter segments, in the central part these regions are smaller than the shower size, thus ensuring very efficient detection of electromagnetic showers. In the end-cap regions the scintillation-counter layer located at a depth of 8 radiation lengths efficiently detects electromagnetic showers thus complementing the end-cap–calorimeter shower detection. As a result of the complicated detector geometry at small angles, the minimum polar angle at which showers can be detected varies from 9° to 12° depending on the azimuthal angle. Except for this low-polar-angle region the efficiency for detecting energetic electromagnetic showers is essentially 100%. All background processes then have at least two particles at small polar angles, severely restricting the energy of the electron observed in the search region.

The energy and angular distribution of single electrons from the $e^+e^- \rightarrow e^+e^-\gamma$ reaction was estimated by use of the Monte Carlo program of Berends and Kleiss[11] to generate $ee\gamma$ events. Those events which had only one electron in the central calorimeter were run through the detector simulation program[12] and subjected to the same cuts used to select the data sample. The resulting energy and angular distributions were corrected by folding in the trigger inefficiency as a function of energy. In addition a 5% loss of events due to the effect of dead channels in the energy measurement and a 1% loss due to accidental end-cap calorimeter and scintillator hits were included in obtaining the curves shown in Figs. 1 and 2. From the Monte Carlo analysis, the total number of single-electron events expected for the luminosity of 36.4 ± 0.6 pb^{-1} is 1640 ± 230. The error includes the statistical errors due to the finite number of Monte Carlo generated events, the uncertainties in the correction factors mentioned above, and an additional 10% error due to uncertainty in the absolute calorimeter energy calibration. Also included is an 8% error due to the uncertainty of modeling the detector geometry at small angles. Contributions due to $\tau^+\tau^-\gamma$, other tau events, and two-photon processes are negligible compared to the $e^+e^-\gamma$ contribution. The $e^+e^-\gamma$ final state entirely accounts for the observed single-electron events within errors. In particular, no events are predicted with electron energy above 6 GeV in agreement with our experimental observation.

The observation of no events in the region $E_e > 6$ GeV and $|\cos\theta| < 0.75$ corresponds to an upper limit on the cross section for $e^+e^- \rightarrow e^{\pm}\tilde{\gamma}\tilde{e}^{\mp}$ of 0.08 pb within our acceptance. Extrapolating to full acceptance by use of the angular dependence of Ref. 6, this limit becomes 0.11 pb. An overall detection and analysis efficiency of 95% in this region was used to correct for the losses previously mentioned. The number of single-electron events expected is shown in Fig. 3 as a function of the $\tilde{e}$ mass. At the 95% confidence level $\tilde{e}$ masses less than 22.4 GeV are excluded.[13] Comparable limits have recently been reported by the Mark II collaboration[14] based upon an analysis similar to the one presented here, and by this group[5] based upon the preliminary results of a search for the reaction $e^+e^- \rightarrow \tilde{\gamma}\tilde{\gamma}\gamma$,[15] where the experimental signature is a single photon in the final state.

In conclusion, we have measured the energy and angular distribution of single-electron events in the MAC detector at PEP. These distributions are consistent with the expected QED process $e^+e^- \rightarrow e^+e^-\gamma$ where only one electron is observed. No signal from the reaction $e^+e^- \rightarrow e^\pm\tilde{\gamma}\tilde{e}^\mp$ was found, which, under the assumption that the $\tilde{\gamma}$ is massless, allows us to set a new lower limit on the $\tilde{e}$ mass of 22.4 GeV/c^2 at the 95% confidence level.

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[10] The $\tilde{\gamma}$ mass and lifetime are very model dependent. For a $\tilde{\gamma}$ mass much less than the $\tilde{e}$ mass most models would give a $\tilde{\gamma}$ decay length too long to be observed in the detector.

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[13] The calculation of Ref. 6 assumes that the mass of the supersymmetric partners of the left-handed and right-handed components of the electron are identical. If only one of them has mass less than the center-of-mass energy, the expected number of events will be reduced by a factor of 2 and the limit would be $m_{\tilde{e}} > 20.7$ GeV/c^2.

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