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A SEARCH FOR SUPERSYMMETRIC ELECTRONS*

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ABSTRACT

A search for single electrons from the decay of singly produced selectrons has been made at the PEP storage ring at SLAC. No events of this type have been found in 123 pb^{-1} of data, resulting in a cross section limit of less than 2.4×10^{-2} pb within the detector acceptance, and a 95% confidence level lower limit on the selectron mass of 22.2 Gev/c^2 .

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Supersymmetric theories[1] postulate a symmetry between fermions and bosons such that all known particles have supersymmetric partners whose spins differ from ordinary particles by $\pm\frac{1}{2}$. Each supersymmetric particle has the same electromagnetic and weak couplings as its partner, although its mass may be different (the exact nature of the symmetry breaking is model dependent). The cancellation between the fermion and boson loops of a particle and its supersymmetric partner alleviates the hierarchy problem of the standard gauge theories[2] , and softens some of the divergences of quantum gravity[3] . However, all searches for supersymmetric particles have so far yielded negative results. In particular, previous searches for pair production of scalar electrons (selectrons) in e^+e^- collisions have excluded the selectron mass range below 16.8 GeV[4–6] .

We report here on the results of a search for selectrons, $\tilde{e}$, singly produced in association with photinos, $\tilde{\gamma}$ (the spin-$\frac{1}{2}$, neutral partner of the photon), through the reaction $e^+e^- \rightarrow e^\pm + \tilde{e}^\mp + \tilde{\gamma}$. The selectron and the photino are produced by the interaction of an incident electron with a virtual photon. The largest contribution to the production cross section comes from the case where the photon is almost real, and one electron is scattered through a small angle and remains unobserved. The produced selectron is assumed to decay rapidly, with a 100% branching ratio, into a photino and an electron. The photinos are assumed to be massless and noninteracting, and so remain undetected. These events have a distinct experimental signature; only one charged prong is detected with large transverse momentum relative to the beam axis[7] . This search uses the above single selectron production mechanism to extend the mass limit to approximately 75% of the center of mass energy[8] . In contrast, searches involving the production of a pair of selectrons provide limits no greater than 50% of the center of mass energy.

The data used for this search were taken with the Mark II detector at the PEP storage ring. This detector has been described elsewhere[9] , and only those properties relevant to this analysis are discussed here. Surrounding the beam pipe is a high precision drift chamber, known as the vertex chamber[10] . This chamber is divided into an inner and outer band of tracking layers, with four and three layers of wires respectively. Charged particles can be detected to within 10° of the beam axis with the inner band of wires. Surrounding the vertex chamber is the main drift chamber (DC), consisting of 16 layers of wires. Both tracking chambers are immersed in a solenoidal magnetic field (2.3 kG). The electromagnetic calorimetry is divided between three different systems, the liquid argon (LA) barrels, the endcaps, and the forward shower counters, or small angle tagging (SAT) system. The LA system consists of eight rectangular modules which surround the magnet coil and have an acceptance of $|\cos\theta| < 0.70$ relative to the beam axis. These modules are approximately 14 radiation lengths ($14\,X_o$) thick and provide an energy resolution of $14\%/\sqrt{E}$. The endcaps have an acceptance of $0.75 < |\cos\theta| < 0.92$ and are approximately 5 X_o thick, however, there is a substantial break in azimuthal coverage due to their support stand. Finally, the SAT system consists of four semi-circular modules, with two on either side of the main detector. This calorimeter covers the forward and backward cones between 2° and 4° from the beam axis, and is 15 X_o thick.

The Mark II trigger system was modified for this search to include a trigger for single charged tracks which deposit at least 1 GeV in a single LA module. The following criteria were applied to all events obtained with this trigger. First, the detected prong was required to fall within the active area of the LA calorimetry to ensure that its energy could be reliably measured. Thus, the particle was required to have $|\cos\theta| < 0.70$ and to miss the azimuthal gaps between the modules by at least 2.7°. The LA energy, rather than the track momentum, was used in all studies of event kinematics. To ensure that the detected track was an electron and to eliminate background from two-photon production of low energy electrons, we required the detected track to deposit at least 6 GeV in a LA shower module. To eliminate cosmic ray showers we required the total number of hit drift chamber wires in the event to be less than 50 ; a single track typically has between 14 and 18 hits in the DC. The track was required to originate from the interaction point, with $R_m < 5$ cm, $Z_m < 15$ cm (where R_m, Z_m are the distances of closest approach to the interaction point in the plane perpendicular to the beam direction, and along the beam direction, respectively). Single electron events with photons were eliminated unless the photons were within 10° of the electron track. This requirement eliminated events which were obviously inconsistent with the singly produced selectron hypothesis, but retained events in which the electron radiated in the detector material (3% of a radiation length) between the interaction point and the LA calorimeter. We made two further cuts to eliminate events with additional charged tracks at low angles. We required the vertex detector to show no evidence of low angle tracks, and the SAT shower counters to have less than 3 GeV in any module.

The cuts mentioned above confined all particles other than the detected charged prong either to uninstrumented regions of the detector or the 2° cone around the beam axis in the forward and backward regions, and yielded 763 events. One further cut, to be described below, was applied to these events. This cut was determined by studying the major background sources and the gaps in the electromagnetic calorimetry.

The major sources of background in this search are QED processes, in particular, $ee\gamma$ events (from the reaction $e^+e^- \rightarrow e^+ + e^- + \gamma$) where only one electron is detected, the other electron goes down the beam axis, and the gamma falls into a gap in the electromagnetic calorimetry or a region with significant inefficiency for detecting photons. The three body kinematics of these events, together with the confinement of the unseen electron to within 2° of the beam axis, allows the gamma direction to be constrained once the energy and direction of the one detected prong is determined. The ambiguity concerning the unseen electron's direction down the beam pipe can be resolved by comparing the detected electron's direction with its incident direction. If the detected electron is scattered in the forward (backward) direction, the largest QED matrix element is for the other electron to be going in the opposite (same) direction. The uncertainty in the gamma direction was determined from the known measurement errors on the detected electron and the 2° uncertainty in the direction of the unseen electron.

The accuracy of the above method in predicting the photon direction was checked with a sample of events containing both a detected electron and a detected photon. This sample was selected with the same cuts as the search sample, with the exception that one photon was required in addition to the charged track. A study of the deviation of the measured position of the gamma from that predicted using only the seen electron's direction and energy was used to check the three body hypothesis. The polar angle deviations agreed with those expected from experimental uncertainties. Figure 1 shows a plot of χ_{cos}, the normalized error distribution in the cosine of the gamma polar angle, with a gaussian fit superimposed. The gaussian fit shown in the figure excludes the tail of the distribution and is consistent with a mean of zero and unit width. The tail arises from soft radiative corrections and nongaussian tails in experimental resolutions. The distribution of deviations in azimuthal angle was found to have a FWHM of 0.02 radians.

As stated above, events from the lowest order QED processes ($ee\gamma$ events) can mimic the singly produced selectron topology when the photon falls into an uninstrumented or inefficient region of the detector and one electron is within the 2° forward or backward cones. To eliminate these events we treated all single electron candidates as if they were $ee\gamma$ events. Thus, the recoil direction of the hypothetical gamma was determined for each event by assuming the unseen electron was scattered at 0°. The observed distribution of recoil angles is shown in fig. 2 and is consistent with being predominately from $ee\gamma$ events. The distribution for $ee\gamma$ events is expected to rise rapidly above a cosine of 0.70 for three reasons: there is an uninstrumented region between the LA and endcap calorimeters; the endcap calorimeter has a break in azimuthal coverage; and, there is a significant probability (2.5% as determined by a Monte Carlo simulation) that a photon will pass through the endcap undetected.

The feedthrough of events into the data sample from the above sources can be eliminated by requiring that the recoil angle from the three body hypothesis be located well within the LA calorimeter. This final cut on the recoil angle ($\cos\theta_\gamma$) was determined by studying the sample of events which had both a detected electron and a detected photon. From the angular distribution of the detected photons in these events, the number of events with an undetected photon falling in the region between the LA and endcap calorimeters ($\cos\theta$ between 0.715 and 0.750) was determined to be 266 for 123 pb^{-1}. This number and the resolution from the fit shown in fig.1 ($\sigma_{cos\theta} = 0.045$) were used to determine that the $ee\gamma$ process would contribute a background of less than one event provided that $|\cos\theta_\gamma|$ was required to be less than 0.54. Although this cut severely reduces the $ee\gamma$ background, the efficiency for high mass selectrons remains approximately 41 %, since their angular distribution tends to be more uniform.

Additional backgrounds are expected from higher order QED processes, for example $ee\gamma\gamma$ events. These were also studied with the single prong plus photon background sample, since these events would, like the $ee\gamma$ events, become single prong candidates if the seen photon had fallen into an uninstrumented region. Since $ee\gamma\gamma$ events do not have 3-body kinematics, they are expected to populate the tails of the χ_{cos} distribution (fig. 1), and also have a large missing mass. Background sample events which had a missing mass greater than 10 GeV/c^2 were called $ee\gamma\gamma$ events. An interpolation over the angular distribution of events of this type which passed the $\cos\theta_\gamma$ cut indicated a background for the selectron sample of 0.6 ± 0.5. A similar treatment applied to events with $|\chi_{cos}|$ between 2.5 and 6.0 and with missing mass less than 10 GeV/c^2 (presumably mismeasured events and $ee\gamma\gamma$ final states with one soft photon) predicted a background of 0.3 ± 0.2 events from this source. Finally, the backgrounds from two photon processes and tau production were determined by Monte Carlo studies to be 1.2 ± 1.5 and less than 0.6 respectively.

The effect of all the cuts used in this analysis is to constrain the single measured prong to lie within the contour shown in fig.3. The acceptance shown is for negative charged prongs and is the same for positive charged prongs except that $\cos\theta$ must be replaced by $-\cos\theta$. From the data points shown in fig.3, we conclude that all single prong events are consistent with the known background processes. The search yielded no final candidate events for an integrated luminosity of 123 pb^{-1} . This yields a 95% confidence level upper limit on the cross section within the acceptance of fig.3 of 2.4×10^{-2} pb.

The double differential cross section of ref.7 was integrated over this acceptance to yield a corrected cross section for selectron production as a function of the selectron mass. The upper limit on the cross section gives a 95% confidence level lower limit on the mass of the selectron of

$$M_{\tilde{e}} > 22.2\ \mathrm{GeV}/c^2.$$

This mass limit is set with the assumption that the photino is unobservable in our detector and that the partners of right-handed and left-handed electrons are degenerate. If one of the partners is infinitely heavy then the production cross section is halved and the mass limit for the lighter selectron becomes 19.4 GeV/c^2. Both limits are well in excess of the beam energy (14.5 GeV) and substantially exceed previously published limits on the selectron mass[4–6].

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Figures

1. Distribution of $(\cos\theta_{predicted} - \cos\theta_{measured})/\sigma_{\cos\theta}$ for events with one seen electron and one seen photon. The solid curve is the best fit to the data as described in the text.
2. Angular distribution of hypothetical gammas in the single electron event sample.
3. Mark II acceptance for single negative prongs. Also shown is a scatter plot of single prong events. Positive-charge prongs have $\cos\theta$ replaced by $-\cos\theta$.

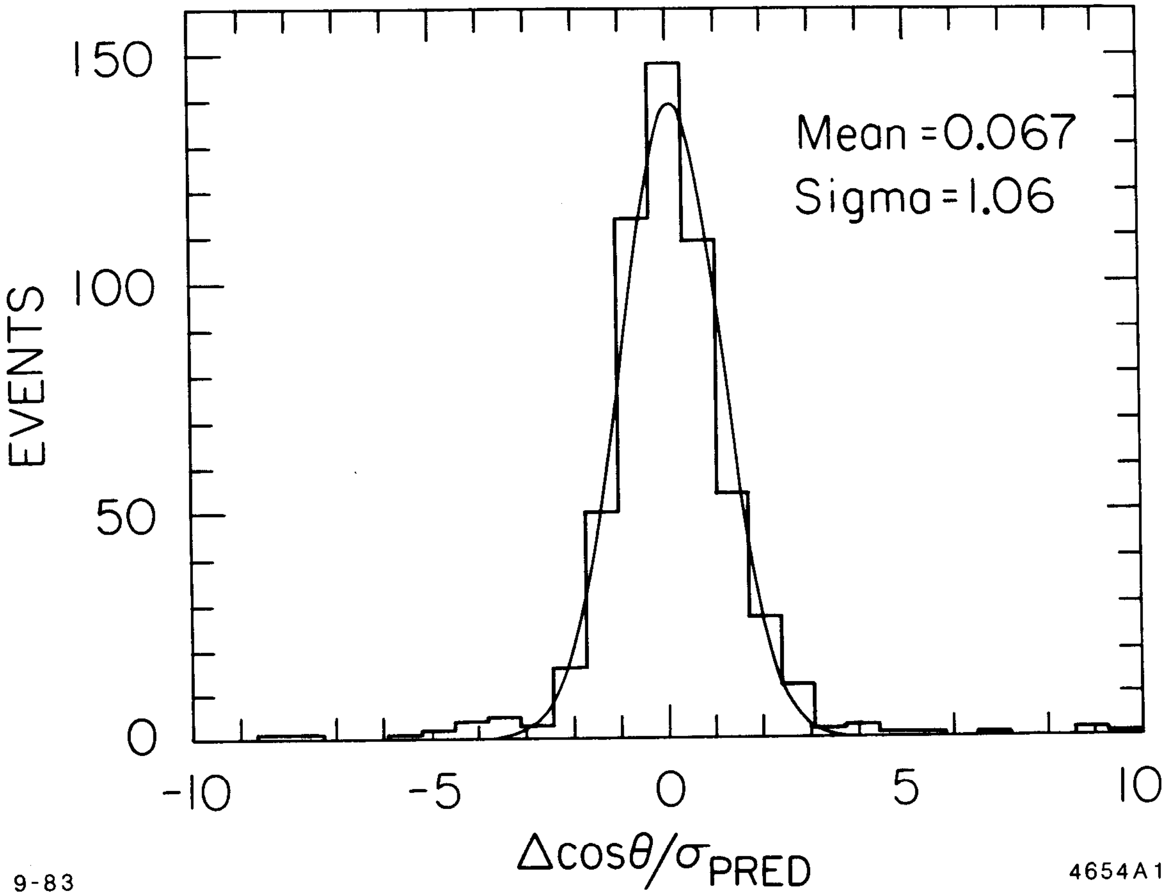
150
100
50
0
EVENTS
Mean =0.067
Sigma=1.06
-10
-5
0
5
10
$\Delta\cos\theta/\sigma_{PRED}$
9-83
4654A1

Fig. 1

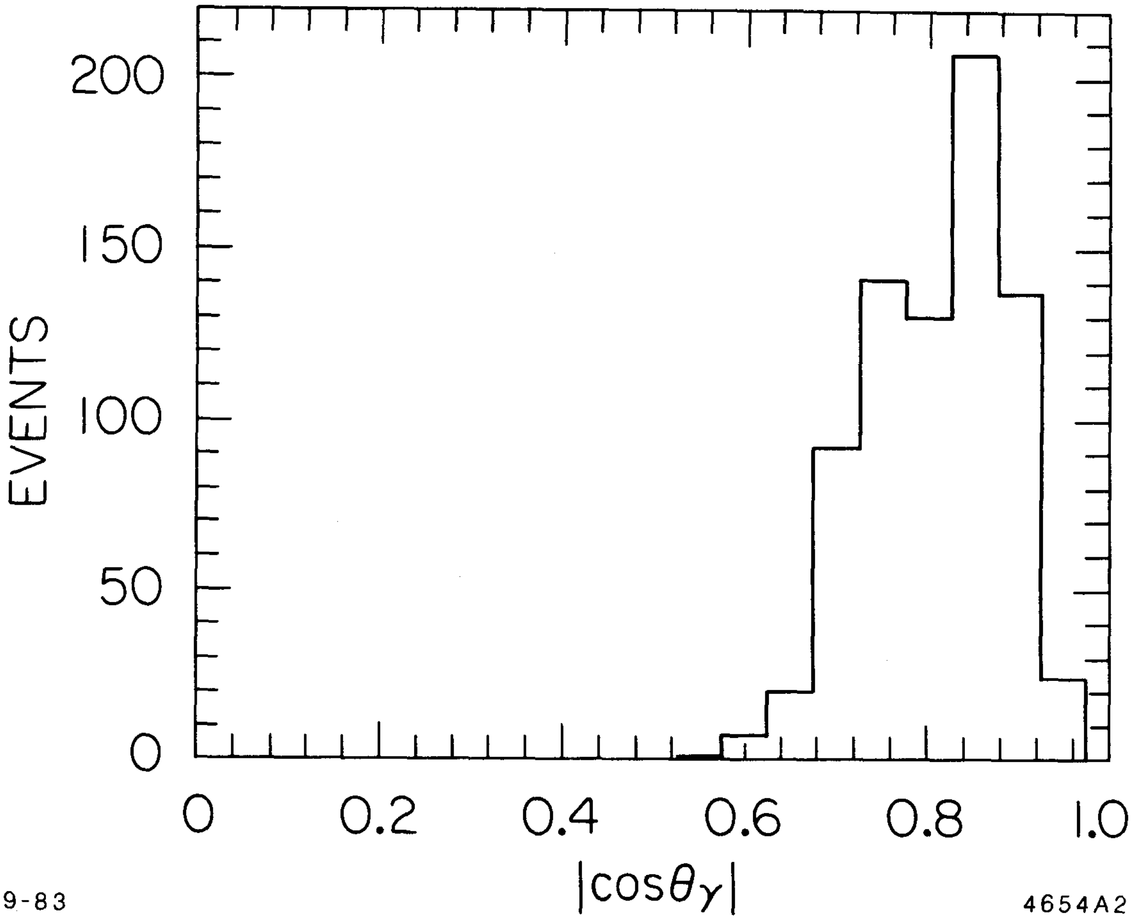
200
150
100
50
0
EVENTS
0
0.2
0.4
0.6
0.8
1.0
$|\cos\theta_\gamma|$
9-83
4654A2

Fig. 2

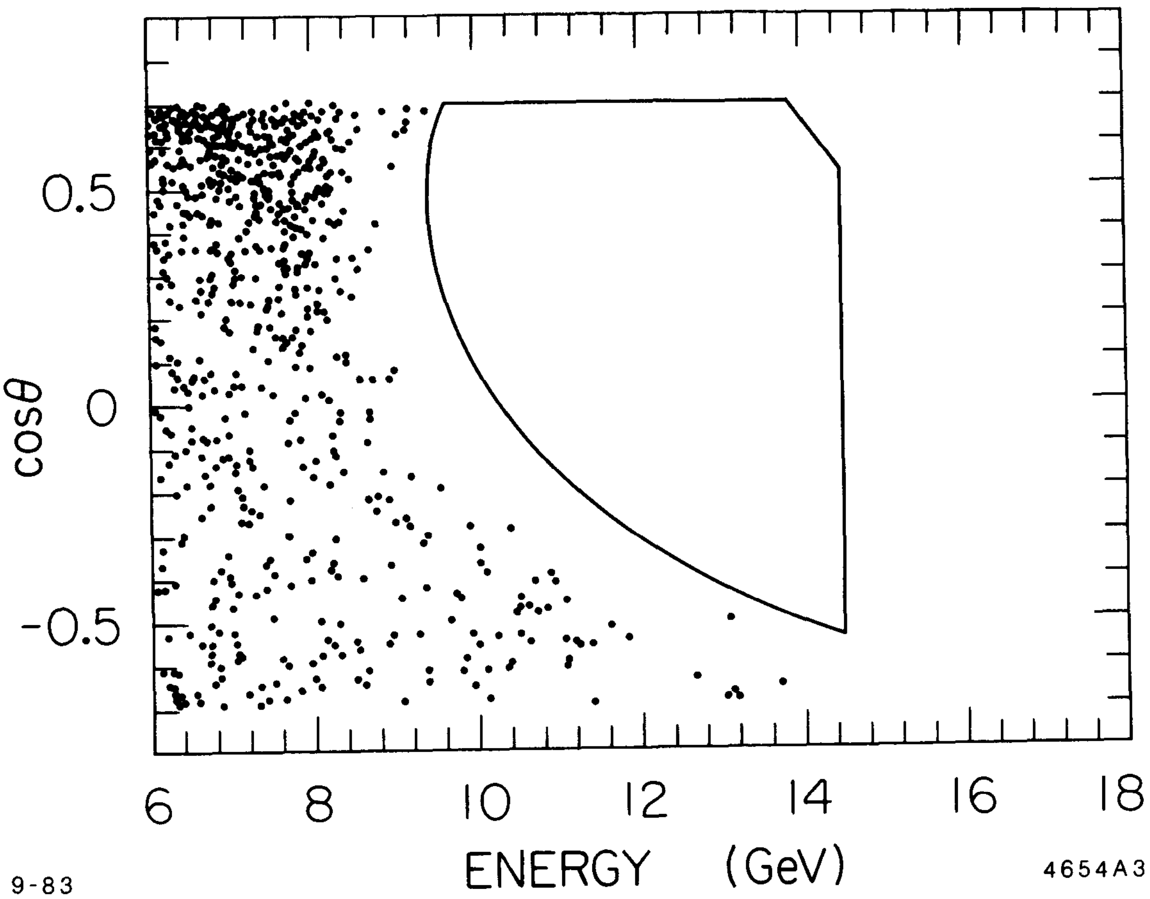

Fig. 3