Search for Single Photons from Supersymmetric Particle Production

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A search in e^+e^- annihilation for final states which contain only a single energetic photon has been performed at $\sqrt{s} = 29$ GeV with the MAC detector at PEP. The upper limit on an anomalous signal has been interpreted in terms of mass limits for supersymmetric particles under the assumption of radiative pair production of either supersymmetric photons or neutrinos. For the supersymmetric electron ($\tilde{e}$) this limit is $m_{\tilde{e}} > 37$ GeV/c^2 at the 90% confidence level if $m_{\tilde{e}_L} = m_{\tilde{e}_R}$ and the supersymmetric photon ($\tilde{\gamma}$) has $m_{\tilde{\gamma}} = 0$.

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The method of using a radiative photon to identify e^+e^- interactions producing weakly interacting neutral particles was first proposed by Ma and Okada[1] to count the number of light neutrino families via the reaction

$$e^+e^- \longrightarrow \nu\bar{\nu}\gamma. \qquad (1)$$

The experimental signature of this reaction is a final state containing only a single photon. Several authors[2] have suggested that this technique could be used to discover light neutral supersymmetric particles such as the photino ($\tilde{\gamma}$) and the supersymmetric partner of the neutrino (s-neutrino, $\tilde{\nu}$) in the reactions

$$e^+e^- \longrightarrow \tilde{\gamma}\tilde{\gamma}\gamma \qquad (2)$$

and

$$e^+e^- \longrightarrow \tilde{\nu}\tilde{\bar{\nu}}\gamma. \qquad (3)$$

A previous search[3] for the photino required that it decay into another supersymmetric particle and a photon. Whether photinos or s-neutrinos decay or are stable depends on the choice of a particular supersymmetric model.[4] In most models, the photino or s-neutrino is stable and only weakly interacting with matter,[5] and therefore not directly observable. We make the assumption that the photino and s-neutrino are stable and that only the radiative photon is detected in Reactions (2) and (3). This report describes a search with the MAC detector for single-photon final states produced by e^+e^- annihilation in the PEP storage ring at

SLAC.

Reaction (2) proceeds by the exchange of either a virtual $\tilde{e}_L$ or $\tilde{e}_R$ which are the supersymmetric partners of the left- and right-handed electrons, respectively. The cross section is a function of the masses $m_{\tilde{\gamma}}$, $m_{\tilde{e}_L}$, and $m_{\tilde{e}_R}$, and is sensitive to $m_{\tilde{e}} > \sqrt{s}$. Similarly, the cross section for Reaction (3) is a function of both $m_{\tilde{\nu}}$ and $m_{\tilde{W}}$. $\tilde{W}$ is the supersymmetric partner of the W boson. Searches for real $\tilde{e}$ [6–8] or $\tilde{W}$ [9] production have been limited to masses less than $\sqrt{s}$. Photons from Reactions (1)–(3) have similar energy and angular distributions and cannot be distinguished on an event-by-event basis. The total cross section for Reaction (1) [1,10] is proportional to $(1+N_\nu/4)$, where N_ν is the number of light neutrino families. For $N_\nu = 3$ and $m_{\tilde{e}} = 50$ GeV/c^2 the cross sections for Reactions (1) and (2) are comparable. Since Reaction (2) has a cross section which decreases roughly as $m_{\tilde{e}}^{-3}$ at $\sqrt{s} = 29$ GeV, it is difficult to differentiate from Reaction (1) for $m_{\tilde{e}} > 50$ GeV/c^2. A strong signal at present sensitivities would indicate either $m_{\tilde{e}} < 50$ GeV/c^2 or $N_\nu >> 3$.

Experimental backgrounds to the photon search arise from processes with a large-angle photon and other particles produced at angles outside the detector acceptance. The processes $e^+e^- \rightarrow e^+e^-\gamma$, $\gamma\gamma\gamma$, and $\mu^+\mu^-\gamma$, with unobserved particles escaping either down the beam pipe or into inefficient regions of the detector, can produce such backgrounds. However, the transverse energy $E_{\perp\gamma}$ of the observed photon in these cases must be balanced by that of the unobserved particles. If efficient particle detection extends to within a small angle from the beam axis, then $E_{\perp\gamma}$ is kinematically limited by $E_{\perp\gamma} \leq (\sqrt{s} - E_\gamma)\sin\theta_{\text{veto}}$. E_γ is the energy of the detected photon and θ_{veto} is the maximum polar angle of undetected particles. A veto angle $\theta_{\text{veto}} = 5°$ limits $E_{\perp\gamma} < 2.3$ GeV for the above backgrounds. Other single-photon backgrounds result from beam-gas and beam-halo interactions. A search region in $E_{\perp\gamma}$ for the photon was chosen that was well removed from the above backgrounds. Results from two data samples are presented here. The first sample of 36 pb^{-1} had $\theta_{\text{veto}} \simeq 10°$ with the search region chosen as $E_{\perp\gamma} > 4.5$ GeV. The second data sample of 80 pb^{-1} had $\theta_{\text{veto}} = 5°$, expanding the search region to include $E_{\perp\gamma} > 3.0$ GeV.

With nearly 4π-sr coverge from both tracking and calorimetric detectors, and minimal dead regions, the MAC detector[11] is well suited for the identification and study of reactions with missing energy. The detector consists of a central drift chamber (CD) with ten layers of drift cells covering polar angles more than 17° from the beam axis with at least five layers. Surrounding the CD is a hexagonal barrel of electromagnetic shower calorimeters (SC), scintillation counters, and hadronic calorimeters (HC). Planar end-cap calorimeters and scintillation counters extend the coverage to $\theta \simeq 10°$. Several layers of drift tubes outside the central and end-cap calorimeters provide muon identification and tracking. Position information for calorimeter showers is determined in the SC and HC from 1.9° segmentation in azimuthal angle ϕ and 4-cm resolution in the axial coordinate, obtained from charge division, and in the end-cap calorimeters from 5° segmentation in both θ and ϕ. The 14-radiation-length SC is segmented radially into three layers. Studies of photons and electrons from radiative Bhabha scattering determine an absolute energy calibration within 3% and an energy resolution $\sigma_E/E = 20\%/[E(\text{GeV})]^{1/2}$ in the SC.

After the first data sample of 36 pb^{-1} was taken, small-angle veto calorimeters, constructed from proportional chamber planes and 8.5 radiation lengths of lead, were installed between the CD and end-cap calorimeters in order to reduce θ_{veto} from 10° to 5°. The inefficiency of the veto calorimeter was measured to be $\leq 1\times 10^{-4}$ by studying $e^+e^-\gamma$ final states.

The trigger for this search has been described elsewhere.[6] The photon must deposit energy > 2.0 GeV in one of the SC sextants. At least two of the three radial layers must have energy > 0.3 GeV. These thresholds were lowered to 1.5 and 0.25 GeV for the second data sample. The trigger efficiency is measured to be $> 95\%$ for photons with energy > 3 GeV by studying $e^+e^-\gamma$ final states.

The data analysis searches for events with a single photon unaccompanied by other particles. The photon is required to be more than 40° from the beam axis. This requirement ensures that the photon shower is contained in the SC, the calorimeter with best energy and angular resolution. Signals from each component of the detector are used to reject events with additional charged or neutral particles. Calorimeter showers are identified and reconstructed from hits in the SC, HC, and end-cap calorimeters. The reconstruction procedure allows showers to contain energy hits from adjacent calorimeters, and can efficiently identify both single photons and additional low-energy showers. Each shower is assigned energy E, and angles θ and ϕ computed from the vector sum of the energy vectors of its hits.

Candidate showers are required to have energy-deposition depth, width, and pointing consistent with showers produced by photons from the interaction point. Hits in showers from beam-related sources far from the interaction point, such as scattering from an upstream mask, beam-halo, or beam-gas interactions, have a wider spread of polar angles than those from single photons. Hits in showers from cosmic rays or bursts of electronic noise have a wider spread of azimuthal angles. Cuts on the width of each shower retain events with showers narrow enough to be single photons from the interaction point. A straight line is fitted without vertex constraint to the hits in each shower. Its point of intersection z_0 with the beam axis in the plane containing the beam axis and the shower centroid, and its distance of closest approach r_{min} to the interaction point in the plane transverse to the beam axis are measured with resolution $\sigma_{z_0} = 12$ cm and $\sigma_{r_{\text{min}}} = 3.3$ cm. Showers are required to have $|z_0| < 30$ cm and $r_{\text{min}} < 15$ cm. Showers passing through these cuts are identified as single photons.

The detection and analysis efficiency was studied as a function of E_γ, $E_{\perp\gamma}$, and θ_γ by use of radiative Bhabha scattering, and was found to rise with increasing $E_{\perp\gamma}$, from $(67 \pm 5)\%$ at $E_{\perp\gamma} = 3$ GeV to $(73 \pm 5)\%$ at $E_{\perp\gamma} = 10$ GeV. Losses are due to trigger, detector, and event-selection inefficiencies, and photon conversions in the beam pipe. An average efficiency in the search regions was calculated for Reaction (1) by folding the expected $E_{\perp\gamma}$ dependence with the detection and analysis efficiency determined above. The average efficiency was 71% for the first data sample with search region $E_{\perp\gamma} > 4.5$ GeV, and 69% for the second data sample with search region $E_{\perp\gamma} > 3.0$ GeV. For Reactions (2) and (3), the average efficiencies differ from those for Reaction (1) by less than 2%.

The $E_{\perp\gamma}$ distributions of the selected single photons from the two data samples are shown in Fig. 1. No events are observed in the search region of the first data sample. One event with $E_{\perp\gamma} = 5.3$ GeV is observed in the search region of the second data sample. The $E_{\perp\gamma}$ spectrum below each search region is consistent with that of the reaction $e^+e^- \rightarrow e^+e^-\gamma$ with a small contribution from other beam-related background processes.

An estimate was made of the number of events expected from QED and other backgrounds in the search regions. Photons from $e^+e^- \rightarrow e^+e^-\gamma$ and $\gamma\gamma\gamma$ populate these regions only through photon energy mismeasurement or veto inefficiency. On the basis of the experimental energy resolution and veto efficiency less than 0.05 event is expected from these sources. Another background is $e^+e^- \rightarrow \tau^+\tau^-\gamma$ in which most of the energy is carried by decay neutrinos, leaving a photon and two charged tracks which may disappear down the beam pipe. Monte Carlo simulations of this process give an estimate of 0.05 event in the search regions. The estimate of the background from $e^+e^- \rightarrow \mu^+\mu^-\gamma$ is less than 0.1 event. Remaining backgrounds are beam-gas or beam-halo interactions which mimic single photons originating from the interaction point, and multiple photon events with very soft undetected photons. Both sources were studied by selecting background events consistent with these origins and extracting an $E_{\perp\gamma}$ dependence. These sources are estimated to contribute less than 0.1 event in the search regions. The probability that the observed event was produced by any of the backgrounds discussed above is small. If $N_\nu = 3$ is assumed, 0.5 event from Reaction (1) is expected in the search regions, consistent with the observed event. The reactions which produce supersymmetric particles cannot be excluded as the source of the event.

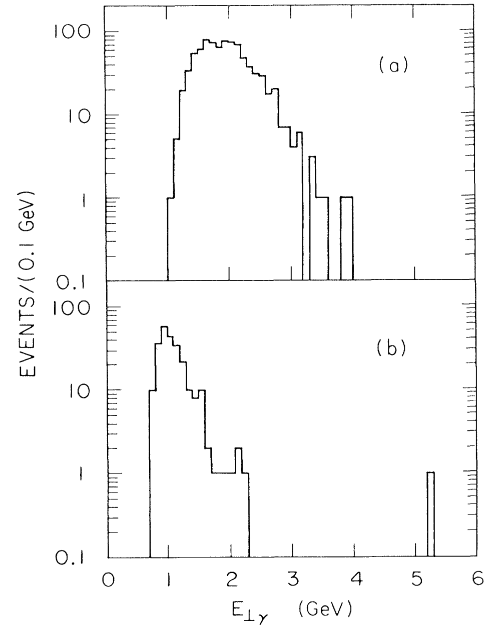

FIG. 1. (a) The observed $E_{\perp\gamma}$ spectrum for the first data sample of 36 pb^{-1} with $\theta_{\text{veto}} = 10°$ and search region $E_{\perp\gamma} > 4.5$ GeV. (b) The observed $E_{\perp\gamma}$ spectrum for the second data sample of 80 pb^{-1} with $\theta_{\text{veto}} = 5°$ and search region $E_{\perp\gamma} > 3.0$ GeV.

The observed event, regardless of interpretation, limits the single-photon–production cross section in the detector acceptance to < 57 fb at the 90% confidence level. In the absence of Reactions (2) and (3), this corresponds to a limit of $N_\nu < 41$ at the 90% confidence level. This is the first limit from e^+e^- collisions on the number of neutrino families. The cross section for radiative photino pair production has been calculated by several authors[12] and is used to obtain limits for the $\tilde{e}$ and $\tilde{\gamma}$ masses. The results at the 90% confidence level is shown in Fig. 2. For $m_{\tilde{\gamma}} = 0$ and $m_{\tilde{e}_L} = m_{\tilde{e}_R}$, the limit is $M_{\tilde{e}} > 37$ GeV/c^2. For $m_{\tilde{e}_L} >> m_{\tilde{e}_R}$, the limit is $m_{\tilde{e}_R} > 30$ GeV/c^2. These limits are significantly higher than those obtained from searches for either single-$\tilde{e}$ production[6,7] or $\tilde{e}^+\tilde{e}^-$ pair production.[8] The calculation by Ware and Machacek[13] of the radiative supersymmetric-neutrino pair-production cross section is used to obtain a limit for the $\tilde{\nu}$ mass. For the range of $\tilde{W}$ masses assumed in this calculation, $29 < m_{\tilde{W}} < 20$ GeV/c^2, the limit $m_{\tilde{\nu}} > 10$ GeV/c^2 is obtained at the 90% confidence

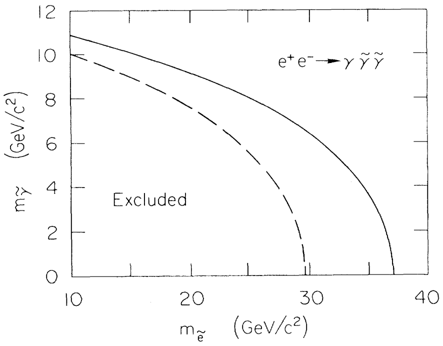

FIG. 2. The lower limit for $m_{\tilde e}$ as a function of $m_{\tilde\gamma}$. The solid curve is for $m_{\tilde e_L} = m_{\tilde e_R}$. The dashed curve is for $m_{\tilde e_L} >> m_{\tilde e_R}$. The limits are at the 90% confidence level.

level.

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