A SEARCH FOR MASSIVE PHOTINOS AT PETRA

JADE Collaboration

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We have searched for the supersymmetric partner of the photon, the photino, by investigating two-photon and single photon final states in e^+e^-collisions. No significant signals were observed, which excludes the existence of the photino in the mass range 0.08–18 GeV/c^2 at the 95% confidence level, subject to the assumptions d = (100 GeV)^2 and $m_{\tilde{e}}$ = 40 GeV/c^2, where d is the supersymmetry breaking scale parameter and $m_{\tilde{e}}$ is the scalar electron mass.

The supersymmetry theory [‡1] predicts the existence of a spin-1/2 partner of the photon, called the photino ($\tilde{\gamma}$). In e^+e^- collisions, a pair of photinos could be produced by the exchange of a scalar electron, $\tilde{e}$, which is the spin-0 partner of the electron. Although the photino mass is expected to be small, the theory does not firmly exclude the existence of a massive photino. If the photino has a finite mass, it will decay into a photon and a gravitino, $\tilde{G}$ [2]. We report here on a search for this process, where we have assumed the gravitino mass to be negligible compared to the photino mass [3]. If such unstable photinos are produced, the following three types of events are expected, depending on the photino mass and lifetime:

(1) Heavy photino:
If the photino is relatively heavy ($\gtrsim$ a few GeV/c^2), its decay into a photon and a gravitino would be nearly isotropic in the e^+e^- centre of mass system. Therefore, the photino events would appear as acoplanar photon pairs.

(2) Light photino with short lifetime:
In this case, collinear photon pairs would be observed if both photinos decay within the detector ($\gamma\tau \lesssim$ ns). The photon energies, however, would not be peaked at the beam energy but distributed over a wide range. Therefore, we would expect to see some collinear photon pairs with low energies.

(3) Light photino with long lifetime:
In cases (1) and (2), the lifetime of the photino must be short enough in order to detect two photons in the detector. If the lifetime is relatively long (i.e. $\gamma\tau \simeq$ ns), it could be expected that only one photino will decay within the detector, resulting in an event with only one observed photon in the final state.

Data were collected by the JADE detector at the e^+e^- colliding beam machine PETRA. A description of the JADE detector can be found in previous publications [4]. The essential part of the detector for the present analysis is an array of 2712 lead glass shower counters, which covers the polar angle regions $|\cos\vartheta| \leqslant 0.82$ (barrel) and $0.89 \leqslant |\cos\vartheta| \leqslant 0.97$ (end-caps). The cylindrical drift chamber (jet-chamber) inside the lead glass array is used to distinguish photons from electrons/positrons. The experiment was carried out at centre of mass energies ranging from 12 GeV to 43 GeV. Only the high energy data, $\sqrt{s} \geqslant 32$ GeV, were used for the present analysis. The corresponding total integrated luminosities were 79.1 pb^{-1} for cases (1) and (2) above, and 46.2 pb^{-1} for case (3). The events which are relevant for this study were recorded by the shower energy trigger, which required at least a 4 GeV shower deposit in the lead glass counters for cases (1) and (2) and at least 2 GeV in the barrel part for case (3).

The selection criteria for case (1) were as follows:

(a) No charged tracks were allowed in the jet-chambers.

(b) Two shower energy clusters observed in the barrel lead glass counters ($|\cos\vartheta| \leqslant 0.76$) were required to have energies greater than 25% of the beam energy.

(c) Besides the two energetic shower clusters, any residual shower energy in the whole lead glass array had to be less than 500 MeV, in order to remove the process $e^+e^- \to \gamma\gamma\gamma$.

(d) Cosmic ray events were rejected by using the muon chamber information and by investigating the shower cluster shape in the lead glass array.

(e) If the missing energy exceeded 20% of the beam energy, the missing momentum vector had to point inside the fiducial volume of the barrel part: i.e. $|\cos\vartheta(\text{missing})| \leqslant 0.78$. This requirement reduced backgrounds from the process $e^+e^- \to \gamma\gamma\gamma$ where one photon escaped into the beam direction.

(f) The acoplanarity angle between the two energetic shower clusters had to be greater than 10°. The acoplanarity angle is defined in the following way:

$$\cos\vartheta_{\text{acop}} = \frac{-(\boldsymbol{n}_1 \times \boldsymbol{z}) \cdot (\boldsymbol{n}_2 \times \boldsymbol{z})}{|\boldsymbol{n}_1 \times \boldsymbol{z}| \cdot |\boldsymbol{n}_2 \times \boldsymbol{z}|} ,$$

‡1 References to other theoretical works on supersymmetry can be found in refs. [1,2].

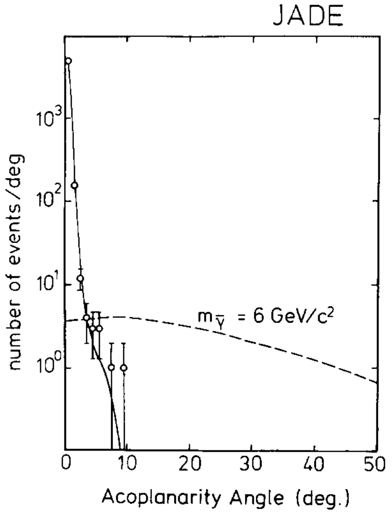

Fig. 1. The acoplanarity angle distribution of the reaction $e^+e^- \to \gamma\gamma$ for the events selected by criteria (a)–(e) in case (1) in the text. The solid curve shows the expectation from the Monte Carlo simulation of the process $e^+e^- \to \gamma\gamma$ with radiative corrections of order α^3. The dashed line indicates the Monte Carlo expectation of the process $e^+e^- \to \tilde{\gamma}\tilde{\gamma}$ with the parameters, $m_{\tilde{\gamma}} = 6$ GeV/c^2, $m_{\tilde{e}} = 40$ GeV/c^2 and $d = (100$ GeV$)^2$.

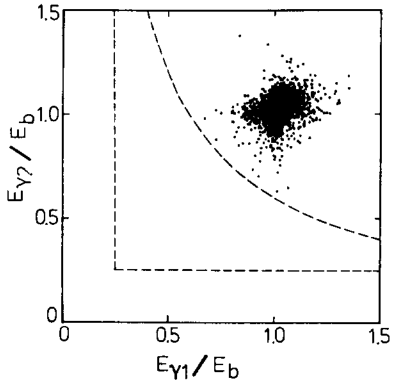

Fig. 2. The correlation plot of the two-photon energies normalised to the beam energy for the events selected by criteria (a)–(f) in case (2) in the text. The dashed lines show the cuts $E_\gamma/E_b \geq 0.25$ and $E_\gamma(1) \cdot E_\gamma(2) \leq 0.6\, E_b^2$.

where n_1 and n_2 are the unit vectors pointing in the directions of the two energetic shower clusters, and z is the unit vector parallel to the beam direction.

The acoplanarity angle distribution of the events selected before application of cut (f) is shown in fig. 1 together with the prediction of a Monte Carlo simulation of the process $e^+e^- \to \gamma\gamma$ [5], where radiative corrections up to order α^3 are included. None of the events survived cut (f).

The selection criteria (a)–(d) for case (1) were common to case (2). The following further cuts were applied:

(e) The acollinearity angle between the two energetic clusters had to be less than 10°.

(f) Shower clusters near dead counters or near the small azimuthal gaps between the lead glass counters were rejected.

(g) The shower energies were required to satisfy the condition

$$E_\gamma(1) \cdot E_\gamma(2) \leq 0.6\, E_b^2 \,.$$

For the events selected by the cuts (a)–(f) in this case, the correlation plot of the two-photon energies (normalised to the beam energy) is shown in fig. 2. The cluster of events at $E_\gamma/E_b = 1$ is due to events of the type $e^+e^- \to \gamma\gamma$. No candidate events remained after applying cut (g).

The single photon events of case (3) were selected according to the following criteria:

(a) No charged tracks were allowed.

(b) The transverse energy of the highest energy photon, $E_\gamma \sin\vartheta_\gamma$, was required to be greater than 25% of the beam energy.

(c) The shower cluster had to be well inside the fiducial volume of the barrel lead glass counters. Explicitly, we required $|\cos\vartheta_\gamma| \leq 0.70$.

(d) The residual shower energy other than that of the shower cluster defined in (b) and (c) had to be less than 500 MeV.

(e) Cosmic ray backgrounds were rejected with the help of muon chamber information, cluster shape analysis in the lead glass array, and time-of-flight information of the shower counters.

A total of 84 events remained after the above cuts. These events were mainly explained by the higher order QED process, $e^+e^- \to \gamma\gamma\gamma$, where one photon escaped into the beam direction and another into the gap between the barrel and end-cap lead glass arrays, resulting in an event with only a single observed photon. To remove this background, a further cut on the transverse photon energy was applied; we required $E_\gamma \sin\vartheta_\gamma/E_b \geq 0.6$, after which no candidate events were left.

The cross section for massive photino production in e^+e^- collision has been derived by Ellis and Hagelin [2] as follows:

$$d\sigma/dx = \frac{1}{4}\pi\alpha^2 s\beta^3 \times \frac{K^2(1+x^2) - s(2K - m_{\tilde{\gamma}}^2 - s/4)x^2 + s^2\beta^2 x^4/4}{(K^2 - s^2\beta^2 x^2/4)^2}$$

where $K = m_{\tilde{e}}^2 - m_{\tilde{\gamma}}^2 + s/2$, $\beta^2 = 1 - 4m_{\tilde{\gamma}}^2/s$, and $x = \cos\vartheta_{\tilde{\gamma}}$. There are two conjectured types of scalar electrons; s_e and t_e associated with the left-handed and right-handed electrons, respectively. We assumed their masses to be the same and the cross section given above should therefore be multiplied by 2. The lifetime of the photino is given by [6] ‡2

$$\tau = 8\pi d^2/m_{\tilde{\gamma}}^5 ,$$

where the parameter d has a dimension of $(\text{mass})^2$ and measures the scale of supersymmetry breaking. Monte Carlo events were generated according to the cross section given above for various values of $m_{\tilde{\gamma}}$, $m_{\tilde{e}}$ and d. They were subjected to the same selection criteria as the data. One of the expected acoplanarity angle distributions for massive photino production is indicated by a dashed line in fig. 1.

‡2 A new cosmological constraint on the photino mass as a function of scalar fermion mass is presented in ref. [7].

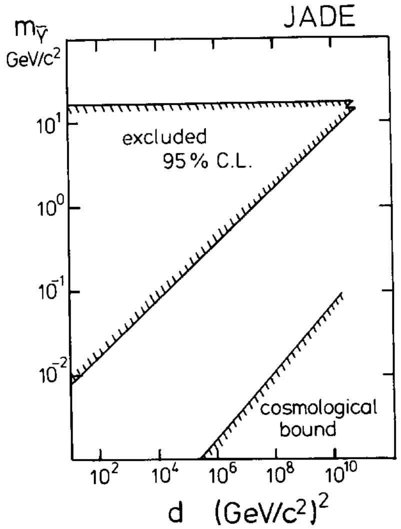

Fig. 3. The excluded region in the $m_{\tilde{\gamma}}$–d plane with $m_{s_e} = m_{t_e} = 40$ GeV/c^2. The cosmological bound was taken from ref. [6].

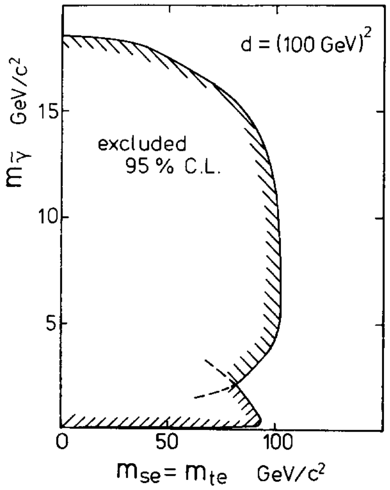

Fig. 4. The excluded region in the $m_{\tilde{\gamma}}$–$m_{\tilde{e}}$ plane with d fixed by (100 GeV)^2. The higher (lower) $m_{\tilde{\gamma}}$ region was excluded by the investigation of case (1) (case (2)) in the text.

The region excluded with 95% confidence level is shown in fig. 3 in terms of photino mass $m_{\tilde{\gamma}}$ and the parameter d, with the scalar electron mass fixed to 40 GeV/c^2 ‡3. The limit obtained from cosmological observations [6] is also shown. If we take $d = (100\ \text{GeV})^2$, we exclude the photino mass region 0.08 GeV/$c^2 \leqslant m_{\tilde{\gamma}} \leqslant 18$ GeV/c^2 by the present analysis. The upper mass limit is mainly determined by the kinematical limit, whereas the lower mass limit is determined by the detector size due to the requirement that at least one photino must decay within the detector. The excluded region is also shown in fig. 4 in terms of $m_{\tilde{\gamma}}$ and $m_{\tilde{e}}$, with d fixed to (100 GeV)^2. For $m_{\tilde{\gamma}}$ between 0.15 and 15 GeV/c^2, the scalar electron mass region below 80 GeV/c^2 is excluded. A very narrow region near $m_{\tilde{\gamma}} = 0$ is not excluded in the present investigation. A similar analysis has been done by the CELLO collaboration with lower statistics (7 pb^{-1}) [9], where only two-photon final states were investigated and the photino mass range between 0.1 GeV/c^2 and 13 GeV/c^2 was excluded with the assumptions $m_{\tilde{e}} = 40$ GeV/c^2 and $d = (100\ \text{GeV})^2$.

To summarize, we have searched for massive un-

‡3 The experimental lower limit on the scalar electron mass is around 22 GeV/c^2. This was obtained by investigating a single electron/positron final state in e^+e^- collisions, assuming the photino to be massless [8].

stable photinos produced in e^+e^- collisions by investigating the two-photon and single photon final states. No evidence for them was found and the photino mass region $0.08\ \mathrm{GeV}/c^2 \leqslant m_{\tilde{\gamma}} \leqslant 18\ \mathrm{GeV}/c^2$ was excluded with 95% CL, when $\tilde{d}$ and $m_{\tilde{e}}$ were fixed to $(100\ \mathrm{GeV})^2$ and $40\ \mathrm{GeV}/c^2$, respectively. The excluded region extended to $m_{\tilde{e}} = 100\ \mathrm{GeV}/c^2$ in the $m_{\tilde{\gamma}}$–$m_{\tilde{e}}$ plane.

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