NEUTRINO COUNTING WITH THE CELLO DETECTOR AND SEARCH FOR SUPERSYMMETRIC PARTICLES

CELLO Collaboration

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A search for single photons, produced in e^+e^- collisions together with particles interacting only weakly with matter, has been performed using the CELLO detector at the PETRA storage ring. We report on results from data taken at 35 GeV$<\sqrt{s}<$ 46.57 GeV. An upper limit of 8.7 (90% CL) on the number of light neutrino species is set. Combining our result with published results from other e^+e^- experiments the number of light neutrinos is limited to $N_\nu<4.6$ at 90% CL. We also set lower limits on the masses of supersymmetric particles.

In the standard SU(2)⊗U(1) gauge theory of electroweak interaction the number of fermion generations is not predicted. However, within this framework any new generation will have its own neutrino and the decay width of the Z^0 boson into neutrino pairs can be used to count the number of light neutrino species N_ν. It has been suggested [1,2] to use the reaction $e^+e^-\to\gamma\nu\bar{\nu}$ to tag the process $Z^0\to\nu\bar{\nu}$. Since neutrinos interact only weakly with matter and escape the detector unobserved, the signature for this process is a single photon.

In addition to the pair production of all neutrino species via Z^0 exchange, in e^+e^- collisions the production of electron-neutrinos receives a contribution from W exchange and from the interference between W and Z_0 exchange diagrams. The cross section for $e^+e^-\to\gamma\nu\bar{\nu}$, assuming massless neutrinos, reads [3]

$$\frac{d\sigma(e^+e^-\to\gamma\nu\bar{\nu})}{dx\,dy} = \frac{\alpha G_F^2 s(1-x)}{6\pi^2 x(1-y^2)}\left[(1-\tfrac{1}{2}x)^2+x^2\tfrac{1}{4}y^2\right] \times\left(2+\frac{N_\nu(g_v^2+g_a^2)+2(g_v+g_a)(1-s(1-x)/M_Z^2)}{[1-s(1-x)/M_Z^2]^2+\Gamma_Z^2/M_Z^2}\right),$$

where x is the energy of the photon divided by the beam energy, $\sqrt{s}$ is the center of mass energy, $y=\cos\theta$, θ is the polar angle of the photon with respect to the beam axis, g_v and g_a are the vector and axial vector couplings of the electron and the total width of the Z^0 is

$$\Gamma_Z=(M_Z^3 G_F/12\pi\sqrt{2}) \times(21+N_\nu-48\sin^2\theta_W+64\sin^4\theta_W)$$

where a decay into three charged leptons, six quarks and N_ν neutrinos is assumed.

Besides the process $e^+e^-\to\gamma\nu\bar{\nu}$, any other radiative production of weakly interacting particles can contribute to the measured total cross section for $e^+e^-\to\gamma X$, Where X stands, for an undetected final state. In most supersymmetric theories the lightest supersymmetric particle (LSP) is stable because of R-parity conservation [4]. From cosmological arguments [5] the LSP is expected to be colourless and neutral and it turns out that it interacts only weakly with matter because of the exchange of a heavy supersymmetric particle. Thus the LSP behaves like a neutrino. Candidates for the LSP are the photino $\tilde{\gamma}$, the zino $\tilde{z}$, the higgsino $\tilde{h}$ or a mixture of these. The LSP could also be the scalar neutrino $\tilde{\nu}$. In this paper we only consider the simple case where the LSP is a pure photino $\tilde{\gamma}$. This assumption is practically valid for a large class of supergravity models. It has been suggested [6] to use the process $e^+e^-\to\gamma\tilde{\gamma}\tilde{\gamma}$ to tag the pair production of photinos. The signature for radiative pair production of LSP's is the same as for $e^+e^-\to\gamma\nu\bar{\nu}$. The cross section for $e^+e^-\to\gamma\tilde{\gamma}\tilde{\gamma}$ has been given in ref. [7].

A common feature of all these processes is that the photon spectrum is of the bremsstrahlung type, peaked at small polar angles θ and at low energies. Therefore a large acceptance for photon tagging and a low energy threshold for the single photon trigger are needed. In addition to ensure that only weakly interacting particles are produced in association with the tagged photon, the veto capability of the detector

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must be extended to the largest possible solid angle. However, in e^+e^- storage rings a hole is unavoidable left in the detector for the beam pipe. This causes the reaction $e^+e^- \to \gamma e^+e^-$ to be the major experimental background, when both electrons are scattered at small polar angles. If θ_{veto} is the minimum veto angle, this background is kinematically totally eliminated as soon as the fractional transverse momentum $x_\perp = x \times \sin\theta_\gamma$ of the photon is $x_\perp \geqslant 2\theta_{veto}$ (for small θ_{veto}).

In the CELLO detector [8], charged particles are detected for $|\cos\theta| \leqslant 0.98$ by a system of cylindrical proportional and drift chambers, completed by two planes of proportional chambers placed perpendicular to the beam in the forward and backward directions (end cap chambers).

Electrons and photons are detected and measured in the 20 radiation lengths (X_0) deep barrel ($|\cos\theta| < 0.86$) and end cap ($0.92 < |\cos\theta| < 0.99$) lead liquid argon calorimeters. The energy resolution of the barrel calorimeter is $\Delta E/E = 5\% + 10\%/\sqrt{E}$ for electromagnetic showers. The fine lateral segmentation of the seven longitudinal samplings provides good determination of the shower direction in projections into a plane containing the beam axis and transverse to it. This feature is used to identify cosmic showers which do not point to the interaction region. For this purpose, we define the quantity d, the distance of closest approach of the extrapolated shower direction to the interaction point. The resolution in d varies from $\sigma = 16$ cm at 1–2 GeV to $\sigma = 5$ cm at energies > 10 GeV and is essentially the same for both projections.

The acceptance gap between the barrel and end cap calorimeters is covered by a simple lead scintillator sandwhich array, the so-called "hole tagger". With only two samplings after 4 and 8 X_0, the energy resolution is poor, but efficient veto capability is ensured in this angular range. This allows the elimination of a large potential background coming from $e^+e^- \to \gamma\gamma\gamma$ with one photon remaining inside the beam pipe, another going into the hole tagger region, and only detected in the barrel calorimeter.

A lead-glass array closes the acceptance from 130 mrad (lower limit of the angular coverage of the end cap calorimeter) to a minimum veto angle of $\theta_{veto} = 50$ mrad.

High energy muons can be identified over 92% of the solid angle in large proportional chambers which surround the detector beyond an 80 cm thick iron absorber.

Single photon events were triggered by the energy deposited in any of the 16 modules of the barrel calorimeter. Signals from cosmic showers and from electronic noise not in time with the beam crossing were efficiently rejected by the following method: The liquid-argon pulse is sampled at a set of four times fixed with respect to the beam crossing. Comparing the four amplitudes to the known shape of the liquid argon pulse, the time t at which the signal is initiated can be derived with a resolution of $\sigma_t = 25$ ns at energies above 4 GeV, degrading to $\sigma_t = 45$ ns at 2 GeV. The time information was already used in a crude way at the trigger level, allowing an energy threshold (at 50% efficiency) as low as 1.75 GeV in most of the experiment [#1].

The data used for this analysis were taken at center of mass energies between 35.0 GeV and 46.57 GeV. The total integrated luminsosity is $\int L\,dt = 122.6$ pb^{-1} (table 1). The analysis of the high energy data ($\sqrt{s} \geqslant 38.28$ GeV) has been reported previously [9]. Here we present the results obtained with the total sample.

Single-photon event candidates were selected with the following criteria:
– A single shower with energy > 1.75 GeV, well within the acceptance of the barrel calorimeter given by $|\cos\theta| < 0.83$ (this cut corresponds to an implicit $x_\perp$-cut of $x_\perp > 0.05$), no additional shower with energy > 500 MeV within the fiducial volume of the calorimeter.

[#1] The energy threshold of the trigger was 3 GeV for most of the high energy data $\sqrt{s} \geqslant 38.28$ GeV) reported in ref. [9].

Table 1
Summary of the data sample used in this analysis.

$\sqrt{\langle s \rangle}$ (GeV)	$\int L\,dt$ [pb^{-1}]
35.00	85.0
38.28	8.9
43.45	1.4
43.60	17.0
44.20	9.2
46.57	1.1

– No reconstructed track with $|\cos\theta| < 0.83$.

Cosmic showers were rejected by the following requirements:

– Time coincidence with the beam crossings within $\Delta t < 2\sigma_t$.

– No string of at least five hits in the central drift chambers within a cone of 2° around the fitted shower direction.

– Lateral and longitudinal shower development compatible with that of an electromagnetic shower coming from inside the detector.

Events due to QED processes, such as $e^+e^- \to e^+e^-\gamma$ and $e^+e^- \to \gamma\gamma\gamma$, were rejected by applying the additional cuts:

– No energy in any of the hole tagger modules away from the single photon shower.

– No energy in the forward lead-glass array.

– No energy in the liquid-argon end cap calorimeter.

– No string of two or more hits in the central detector between the interaction point and any end cap chamber hit.

– No hit in the end cap wire chambers with an azimuth opposite to that of the single photon shower.

These last two cuts were primarily applied to veto electrons or photons in the angular range 100–130 mrad. In this range 20 X_0 long copper cones, installed to shield the central detector from synchrotron radiation, absorb most of the energy of a particle scattered into this direction but some lateral leakage is expected to cause hits in the end cap chambers.

The losses due to the various cuts were determined using event samples triggered independently. The efficiencies of the trigger and timing cut were obtained using $e^+e^-\gamma$ events with a single electron in the barrel calorimeter and triggered independently by a high energy electron or photon in the end cap region. The single-photon trigger efficiency is shown in fig. 1. The shape of electromagnetic showers and the related cut efficiency were determined from a sample of $e^+e^-\gamma$ events, where all particles are reconstructed in the barrel calorimeter and the photon is well separated from the electrons. The losses introduced by the other cuts to reject cosmic ray events and to veto QED events were determined from events triggered at randomly selected beam crossings.

The average detection efficiency of single-photon events within $|\cos\theta| < 0.83$, $x_\perp > 0.1$ and $x < 0.75$ weighted with a bremsstrahlung spectrum varies from

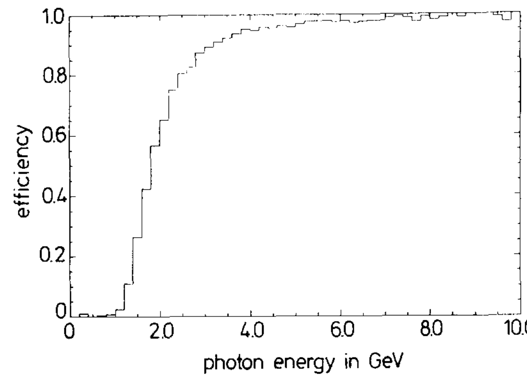


Fig. 1. Single-photon trigger efficiency as a function of energy.

37% to 51%, depending on the running conditions. The inefficiency of the detector components used to veto $e^+e^-\gamma$, $\gamma\gamma\gamma$ events was determined with single electrons from radiative Bhabha scattering. It is found to be less than 10^{-5}.

From the 77 events surviving the cuts all but 12 could be removed because of matching hits in the muon chambers (efficiency 95.5%) indicating their cosmic origin. The losses of single-photon events due to that cut is 2%. This sample of 12 events may still contain background events from:

– $e^+e^-\gamma$ events with a transverse momentum of the photon of $0.05 < x_\perp < 0.1$, where both undetected electrons contribute to the $x_\perp$ balance.

– $\gamma\gamma\gamma$ events, where one photon stays in the beam-pipe, and one photon escapes in the cracks between the calorimeter modules.

– cosmic rays which do not point to the interaction point, and do not leave hits in the central detector nor in the muon chambers.

Events from $e^+e^- \to e^+e^-\gamma$ were studied using the Monte Carlo program of Mana and Martinez [10]. Within our acceptance we expect 1.7 single-photon events with a transverse momentum of the photon of $0.05 < x_\perp < 0.1$ in our data sample. One out of the 12 single-photon events has $x_\perp = 0.07$ and the photon is pointing to the interaction point within 1σ. This event is therefore interpreted as an $e^+e^-\gamma$ event candidate.

From a Monte Carlo study of $e^+e^- \to \gamma\gamma\gamma$ we expect 1.1 detected events, where one photon escapes through the cracks between the calorimeter modules, one photon stays in the beam-pipe and one photon is observed. A kinematical calculation shows that observed photons from such a process must have an energy $x>0.75$. One event with $x=0.8$ is observed in our data sample.

Thus to exclude both these types of background events, photons from $e^+e^-\to\gamma\nu\bar{\nu}$ are required to have

$$x_\perp>0.1, \quad x\leqslant 0.75\ .$$

Background from cosmic ray events left in the data sample of ten single-photon candidates is rejected using the distribution of the distance of closest approach d to the interaction point. The d-distribution for the single-photon events (signal events) is obtained from photons of $e^+e^-\gamma$ final states, where all particles are well reconstructed. In order to reproduce the proper d-distribution the $e^+e^-\gamma$ event sample is weighted with the energy spectrum expected from $e^+e^-\to\gamma\nu\bar{\nu}$ (fig. 2a). The d-distribution for background events (fig. 2b) is obtained from a sample of cosmic ray events, which pass all cuts of the single-photon selection, but have a hit pattern in the central detector. The azimuthal distribution of the cosmic rays causes the d-distribution measured in the barrel to be depressed around $d=0$. The energy distribution for bremsstrahlung photons from cosmic rays is similar to the one from $e^+e^-\to\gamma\nu\bar{\nu}$. Moreover, since cosmic rays in general do not pass through the interaction point, the d-distribution of photons originating from cosmic rays is independent of the photon energy.

Two alternative methods to estimate the number of single-photon events were applied:

– Single-photon candidates are required to point to the interaction region within $d<18$ cm in the two orthogonal projections of a calorimeter module (pointing cut).

– A maximum likelihood analysis is performed using the d-distributions for signal and cosmic ray background events to estimate the number of signal events.

After applying the pointing cut, only one event is left, which has $x=0.18$, $|\cos\theta|=0.23$ and $x_\perp=0.175$ (fig. 2c). This event is shown in fig.3. From the process $e^+e^-\to\gamma\nu\bar{\nu}$ we expect to observe 1.6 events for three neutrino species. With one observed event the 90% (95%) CL upper limit is 3.9 (4.7). This can be turned into an upper limit for the number of neutrino species N_ν:

$$N_\nu<10(13) \text{ at } 90\%\ (95\%)\ \text{CL}\ .$$

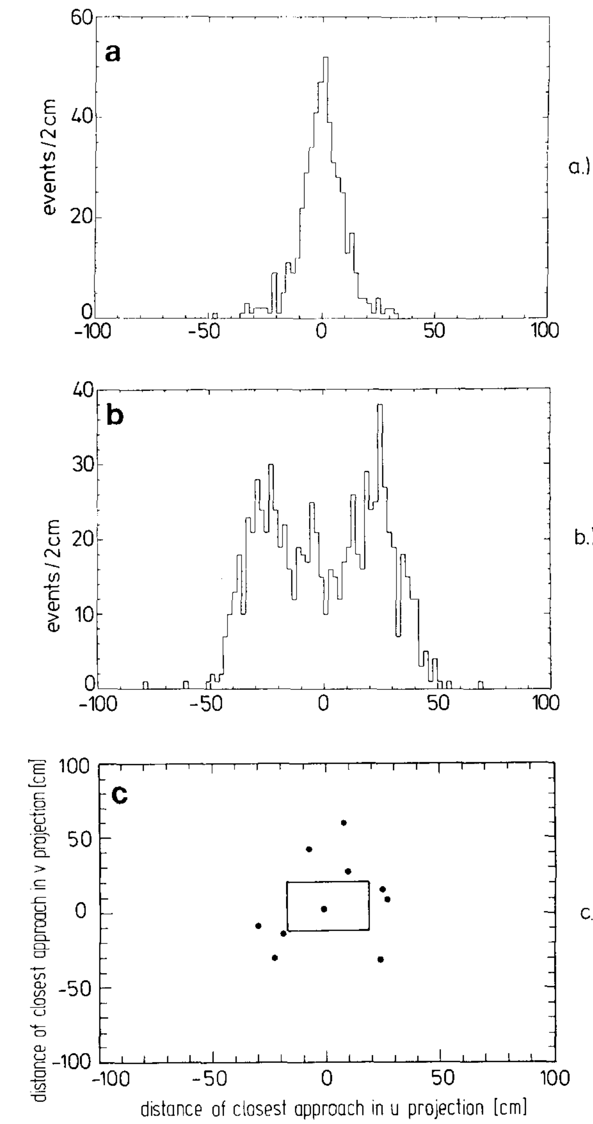
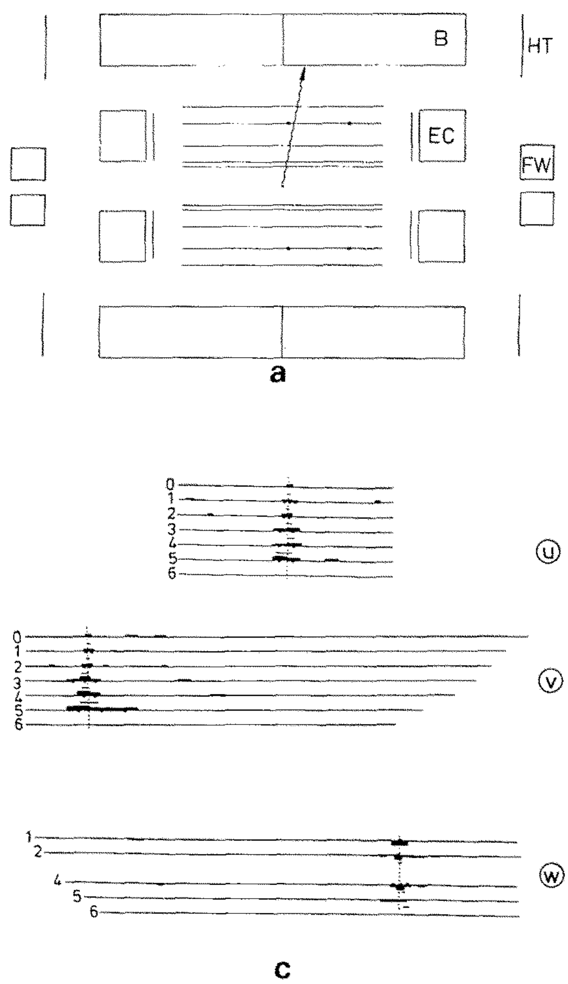


Fig. 2. Distribution of the distance of closest approach to the interaction point in a projection into the plane transverse to the beam axis for photons from $e^+e^-\to e^+e^-\gamma$ (a) and for photons from background (cosmic ray) events (b). (c) shows the positions of closest approach in the two perpendicular projections for the ten single-photon event candidates. The pointing cut is indicated by the full line.

A statisticaly more powerful analysis can be performed when the probability distributions for signal and background events (p_S and p_B respectively) are known. A generalized likelihood function [11] is defined by



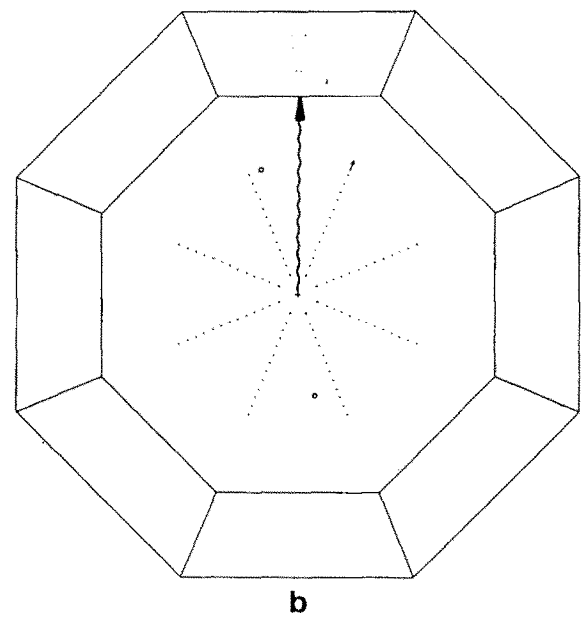


Fig. 3. Single-photon candidate: $x=0.18$, $|\cos\theta|=0.23$ and $x_\perp=0.175$. In (a) and (b) the projections into planes containing the beam axis and transverse to it are shown. The various components of the calorimetric coverage are indicated: barrel (B) and end cap (EC) lead–liquid-argon calorimeter, hole tagger (HT) and forward lead-glass array (FW). The data in the calorimeter module containing the shower are displayed in (c). The lead strips of the seven layers in u direction run parallel to the beam, those of the seven layers in the v direction transverse to it, and those of the five layers in the w direction at 45° with respect to u and v. The magnification varies with the depth so that a shower pointing to the interaction vertex always appears perpendicular to the layers.

$$L=\frac{\exp[-(S+B)](S+B)^N}{N!}\times\prod_{i=1}^{N}\frac{p_{S_i}S+p_{B_i}B}{S+B},$$

where S (B) is the estimate for signal (background), N is the total number of observed events. The d-distributions shown in figs. 2a, 2b are used to determine the probabilities $p_{S_i}(p_{B_i})$ for event i to be signal (background). With these probabilities the maximum of the likelihood function is reached at:

$$\hat{S}=1.26,\quad \hat{B}=8.74,$$

for $N=10$ observed events. Without imposing the pointing cut to the photons we expect 1.87 events from $e^+e^-\to\gamma\nu\bar{\nu}$ for three neutrino species.

Since the d-distribution of the single-photon events was derived from $e^+e^-\to e^+e^-\gamma$ events after properly weighting for the expected bremsstrahlung spectrum from $e^+e^-\to\nu\bar{\nu}\gamma$ no additional systematic uncertainty is expected for the determination of the central value $\hat{S}$ with the above method. Nevertheless we have studied the dependence of $\hat{S}$ on different assumptions for the expected energy distributions of single-photon events. With the rather extreme assumptions of restricting the bremsstrahlung spectrum to $E_\gamma<2.5$ GeV ($E_\gamma>6$ GeV) we find the values $\hat{S}=2.01$ (0.95).

With 1.26 observed events we calculate the central value for N_ν:

$N_\nu = 1.3^{+6.7}_{-1.2}$,

The errors given are the statistical 1σ errors of a Poisson distribution.

The upper limit on S for a given confidence level is calculated by a Monte Carlo method. A number of signal (background) events $N_S(N_B)$ is generated from a parent Poisson distribution with mean $\mu_S(\mu_B)$. The numbers N_S and N_B are then used to simulate an experiment like the one we have performed (equivalent experiment).

Cosmic ray events in the final sample of ten events are only present due to the 4.5% inefficiency of the muon chambers. From the number of single-photon events with matching hits in the muon chambers indicating their cosmic origin, the mean μ_B of the parent Poisson distribution for cosmic background events is calculated to be $\mu_B = 6.13$.

A confidence level for a given μ_S is calculated by counting the number of equivalent experiments giving a maximum likelihood estimate S greater than $\hat{S}$.

The 90%(95%) CL upper limit is realized with our experimental conditions for $\mu_S = 3.9(4.7)$. This value is independent of μ_B for $\mu_B > 3.0$. The limits are only by accident the same as in the case when exactly one event is observed. They can be turned into upper limits for the total number of neutrino species N_ν:

$$N_\nu < 8.7(11.3) \quad \text{at } 90\%(95\%) \text{ CL} .$$

The result on N_ν obtained from the maximum likelihood method is more stringent than that obtained with the previous method using the pointing cut, because the latter reduces the photon detection efficiency by 15%. Both results agree with the standard model prediction for the three known neutrino species. In the following we refer to the maximum likelihood result only.

An upper limit for an additional contribution to the single-photon yield when 1.87 events are expected from $e^+e^- \to \gamma\nu\bar{\nu}$ for three neutrino species is 3.0(3.9) events at 90%(95%) CL for our experimental conditions, using a bayesian probability interpretation [12] with a uniform a priori probability distribution for the mean value. This can be turned into an upper limit on the number of additional neutrino species ΔN_ν in excess of the three known neutrinos:

$$\Delta N_\nu < 8.2(10.9) \quad \text{at } 90\%(95\%) \text{ CL} .$$

The search for single photons can also be used to set limits on the radiative production of the LSP. For the calculation of limits on supersymmetric particles we treat the expected number of 1.87 events from $e^+e^- \to \gamma\nu\bar{\nu}$ for three neutrino species as background. Assuming the photino to be the LSP we get with the cross section given in ref. [7] for mass-degenerate scalar electrons ($m_{\tilde{e}_R} = m_{\tilde{e}_L}$) and a massless photino

$$m_{\tilde{e}} \geq 51.5(47.5) \text{ GeV} \quad \text{at } 90\%(95\%) \text{ CL} .$$

The dependence of the lower limits $m_{\tilde{e}}$ on the photino mass $m_{\tilde{\gamma}}$ is shown in fig. 4.

Using the method described in ref. [13], we combine our result with those obtained by ASP [14] and MAC [15] at PEP and MARK J [16] at PETRA, as summarized in table 2. In total, the single-photon experiments have seen 3.86 events.

The expected single-photon yield, calculated for each experiment, is

$$N = \sum_i \mathcal{L}_i \bar{\epsilon}_i \sigma_i$$

where $\mathcal{L} = \int L\, dt$ is the integrated luminosity, $\bar{\epsilon}$ is the averaged detection efficiency for photons from a bremsstrahlung spectrum and σ is the cross section integrated over the search region. For three neutrino species a total number of 6.11 single-photon events is expected.

The central value for N_ν using the 3.86 events observed by all e^+e^- single-photon experiments is

$$N_\nu = 1.0^{+2.9}_{-1.0} .$$

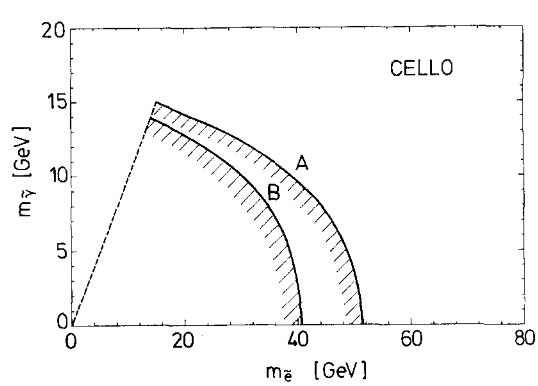


Fig. 4. 90% CL domains in the $\tilde{\gamma}$–$\tilde{e}$ mass plane excluded by this analysis for mass degenerate scalar electrons (A), and for the case of a very heavy scalar electron (B). The dashed line corresponds to the assumption that the photino be the LSP.

Table 2
Single-photon searches and limits obtained. The experimental acceptance is given by $\sigma(e^+e^- \to \gamma\nu\bar{\nu})\cdot\bar{\epsilon}/\sigma(e^+e^- \to \nu\bar{\nu})$. The expected yields are calculated for the three known neutrino species. All limits are at the 90% CL.

Search	$\sqrt{s}$ [GeV]	Acceptance cuts		Experimental acceptance	$\int L\,dt$ [pb^{-1}]	Yield		N_ν	$m_{\tilde{e}}$ [GeV]
		$E_{\perp\gamma}$[GeV]	θ_γ[deg]			expected	observed		
CELLO 1	42.6	>2.13	>34	0.004	37.6	0.66	1.26	<8.7	>51.5
CELLO 2	35.0	>1.75	>34	0.005	85.0	1.21			
MARK J	39.0	>3.90	>20	0.003	35.5	0.39	0	<26	
ASP	29.0	>0.8	>20	0.012	115.0	2.7	1.6	<7.50	>58
MAC 1	29.0	>4.5	>40	0.0015	36.0	0.11	0		
MAC 2	29.0	>2	>40	0.004	80.0	0.64	1	<17.0	>48
MAC 3	29.0	>2.6	>40	0.003	61.0	0.40	0		
combined						6.11	3.86	<4.6	>68.5

The 90%(95%) CL upper limit with 3.86 events observed, is 7.8(9.0). This gives a limit on N_ν:

$$N_\nu < 4.6(5.8) \quad \text{at } 90\%(95\%) \text{ CL} .$$

Treating the 6.11 events expected from $e^+e^- \to \gamma\nu\bar{\nu}$ for three neutrino species as a source of background for an additional contribution, and still with a bayesian probability interpretation, the 90%(95%) CL upper limit is 4.0(5.0). The upper limit on the number of additional neutrino species ΔN_ν in excess of the three known neutrinos is

$$\Delta N_\nu < 3.7(4.7) \quad \text{at } 90\%(95\%) \text{ CL} .$$

All values on N_ν obtained from e^+e^- experiments and for comparison the results from $p\bar{p}$ experiments [17] are summarized in table 3. The $p\bar{p}$ results depend on the unknown mass of the top quark and on the Q^2 evolution of the proton structure functions up to the collider energies. Since the electron-neutrino plays a special role in e^+e^- experiments (with its W-exchange contribution), the limit on additional neutrino species ΔN_ν is less stringent than the result of the $p\bar{p}$ experiments, whereas the situation is reversed for the limits on N_ν. The e^+e^- limits on N_ν are valid up to possible neutrino masses of a few GeV. Radiative corrections to $e^+e^- \to \gamma\nu\bar{\nu}$ including virtual, soft and hard photon corrections as given in ref. [18], result in a decrease of the cross section of 3% for the center of mass energies used in this analysis and will not change our limits.

In the search for SUSY particles the 6.11 events expected from $e^+e^- \to \gamma\nu\bar{\nu}$ are treated as background. This gives the combined result for mass-degenerate scalar electrons ($m_{\tilde{e}_R} = m_{\tilde{e}_L}$) and a massless photino:

$$m_{\tilde{e}} \geq 68.5(64.0)\,\text{GeV} \quad \text{at } 90\%(95\%) \text{ CL} .$$

Table 3
Summary of the limits on the number of neutrinos obtained by e^+e^- and $p\bar{p}$ [17] experiments.

		N_ν at 90%(95%) CL	ΔN_ν at 90%(95%) CL	N_ν (central value)	
e^+e^- experiment	CELLO	<8.7 (11.3)	<8.2 (10.9)	$1.3^{+6.7}_{-1.2}$	
	combined	<4.6(5.8)	<3.7(4.7)	$1.0^{+2.9}_{-1.0}$	
$p\bar{p}$ experiment	UA1+UA2	<5.7	<2.9	$1.8^{+2.0}_{-1.5} \pm 0.6$ [a)]	$-0.1^{+1.7}_{-1.3} \pm 0.6$ [b)]

[a)] $m_t = 44$ GeV. [b)] $m_t = 80$ GeV.

To summarize, we have searched for single-photon events produced in e^+e^- collisions at $35.0<\sqrt{s}<46.57$ GeV with a total time integrated luminosity $\int L\,dt=122.6\ pb^{-1}$. With tight cuts to eleminate the background one event is observed, where 1.6 events are expected for three neutrino species. Relaxing the pointing requirement to the interaction region, ten candidate events are observed. From a likelihood fit to the distance of closest approach to the interaction region, we obtain a signal of 1.26 events, in good agreement with the expectation of 1.9 events for three neutrino species. An upper limit of $N_\nu=8.7$ at 90% CL is set on the total number of light neutrino species and the allowed mass range for supersymmetric particles has been restricted. Combining our data with those from other e^+e^- experiments, the 90% CL upper limit on N_ν is 4.6 and the lower limit on the mass $m_{\tilde{e}}$ of degenerate scalar electrons is 68.5 GeV (90% CL) for a massless photino.

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