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A Study of Single Photon Production in e^+e^- Annihilation at $\sqrt{s}$ = 58 GeV

VENUS Collaboration

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Abstract

We have studied a single photon production process in e^+e^- annihilation based on a data sample corresponding to an integrated luminosity of 164.1 pb^{-1} at $\sqrt{s}$ = 58 GeV. The single photon yield is consistent with the prediction by the standard model with three light neutrino species. No anomalous signal has been observed leading to an upper limit on the mass of supersymmetric particles under the assumption of radiative pair production of photinos. Left- and right- handed scalar electrons in the mass degenerate case are excluded below 44.4 GeV/c^2 for massless photinos at 90 % CL.

1. Introduction

The known electroweak process of single photon production in e^+e^- annihilation is light neutrino pair production accompanied by one initial state radiation of photon, $e^+e^- \to \gamma\nu\bar{\nu}$ [1]. Since the neutrino pair production is one of the most fundamental processes of the standard model, it is very important to study the process precisely. If any excess of signal beyond this process is found, it means a sign of new physics.

Recently three experimental groups at LEP reported studies of the single photon production for the direct determination of the invisible width of the Z boson [2]. All experiments at LEP conclude that the single photon cross section is consistent with the prediction by the standard model. The cross section in the TRISTAN energy region is expected to be much lower than that at the Z pole. This is, however, an advantage to observe a small signal from new physics beyond the standard model.

The most interesting process that we expect is radiative pair production of lightest neutral supersymmetric particles. Supersymmetry (SUSY) is the symmetry between bosons and fermions, and the only known symmetry which naturally eliminates the quadratic divergence of scalar mass parameters. In most theories the lightest SUSY particle is considered to be stable and interacts only weakly with matter [3,4]. In the present analysis, we assume that the lightest SUSY particle is the photino, the SUSY partner of the photon. Therefore, a single photon event relevant to SUSY is assumed to be produced by the radiative production of photino pair via t-channel scalar electron exchange.

This paper reports a study of the single photon production process based on a data sample corresponding to an integrated luminosity of 164.1 pb^{-1} at $\sqrt{s}$= 58 GeV with the VENUS detector at TRISTAN. The data were accumulated after the VENUS detector upgrade in 1990.

2. VENUS detector and trigger

The VENUS detector has an electromagnetic calorimeter consisting of three parts; barrel, endcap and forward [5]. For this analysis the barrel part is used to detect a single photon, and the endcap and forward parts are used to veto events which have one or more extra tracks.

The barrel calorimeter (LG) is a cylindrical array of lead-glass counters located between the superconducting magnet and the return yoke. The LG consists of 120 counters in azimuth and 43 counters along the beam direction, covering the polar angle range from 37° to 143° with the complete azimuth coverage. A typical lead-glass counter is 12 x 11.6 cm^2 in cross section corresponding to 3° x 3° in angle and 30 cm in length corresponding to 18 radiation lengths. The energy resolution of the LG is $\Delta E / E = \left[7.0/\sqrt{E[\mathrm{GeV}]} + 2.5\right]$ %.

The endcap calorimeter (LA) is a lead-liquid argon sampling calorimeter which covers polar angle regions from 8.5° (171.5°) to 37.5° (142.5°), with the energy resolution of $\Delta E / E = \left[10.2/\sqrt{E[\mathrm{GeV}]} + 1.6\right]$ %. The average surface granularity is about 10 cm x 10 cm and the total thickness including liquid argon is 20.3 radiation lengths.

In the forward region there is a pair of upgraded small angle calorimeters, Active Mask (AM) [6], which fulfills the mask function to protect our vertex chamber against synchrotron lights from the beam. The AM consists of 0.5 mm-diameter plastic scintillation fibers interleaved between 1-mm thick lead sheets and covers the polar angle regions from 2.6° (177.4°) to 8.6° (171.4°). The AM is divided into 8 segments in azimuth. The energy resolution is $\Delta E / E = 17$ % for 29 GeV electrons.

The other elements of the VENUS detector of interest for the present study are those used for tracking; the central drift chamber (CDC), time of flight counter (TOF), barrel streamer tubes (BST), and barrel muon chamber (MU). The information from these devices is useful for the background event rejection.

The detector was triggered if the total sum of energy deposited in the LG was greater than 3.0 GeV. The LG trigger efficiency was determined as a function of the photon energy using $e^+e^- \to e^+e^-\gamma$ events which were found with charged track triggers. The efficiency is 99.9 ± 0.1 % in the energy range greater than 3.7 GeV.

3. Selection and background

The single photon production process is detected as an event that nothing except only one photon is observed by the detector. Background sources that imitate the single photon event are electronics noises, cosmic rays and QED processes. Especially, the $e^+e^- \to e^+e^-\gamma$ and $e^+e^- \to \gamma\gamma\gamma$ reactions have to be taken into consideration when e^+e^- or two photons in the two respective reactions escape along the beam pipe and are thus undetected. In this case, however, the detected photon is kinematically constrained to have low transverse energy. Then, if the detector is hermetic except for a small dead space for the beam pipe, these backgrounds can be removed by requiring X_t $(=E_{t\gamma}/E_{\mathrm{beam}}) > 2\sin\theta_{\mathrm{veto}} / (1+\sin\theta_{\mathrm{veto}})$, where X_t is the photon transverse energy normalized to the beam energy and θ_{veto} is the maximum polar angle of particles escaping undetected down the beam pipe.

Candidates for single photon events were selected by applying the following criteria:

1) Single cluster in the calorimeters:

A single LG cluster was required with energy greater than 3 GeV in the region, $50.0^\circ \leq \theta \leq 130.0^\circ$. The LG cluster size was required to be within $2 \leq N_\theta$ $(N_\phi) \leq 5$, where N_θ (N_ϕ) is the number of modules over which the cluster spreads in the θ (ϕ) direction. There should be no other cluster with energy greater than 0.2 GeV in the LG and LA, and no signal greater than 5.0 GeV in the AM.

2) No charged particle:

It was required that no CDC track be reconstructed in the region $|\cos\theta| \leq 0.8$, and that no MU track be connected to the cluster. Also, it was required that no track be reconstructed toward the off-vertex direction by the LG cluster, TOF and BST.

3) Proper timing:

It was required that the time of the LG trigger satisfy $|\Delta T_{LG}| \leq 2\sigma_t$, where ΔT_{LG} is the difference between a signal time and an expected one from the beam crossing time, and σ_t (2.4 nsec) is the measured standard deviation.

4) Proper shower profile:

The lateral distribution of the shower in the LG cluster was required to be consistent with an electromagnetic shower profile produced by a single photon from the interaction point.

5) Photon transverse energy:

$X_t > 0.13$.

In selection 1) only information from the calorimeters was used. In order to suppress background from electronics noise and cosmic-ray showers, we required that the LG cluster spread over at least two and less than 6 modules in the θ and ϕ directions. The cluster size of the photon from the interaction point was studied using photons in $e^+e^- \to e^+e^-\gamma$ events. Generally the spread of a shower produced by a photon lies within the cut with negligible energy dependence. The efficiency of this cut is 94.3 ± 0.5 %. The selection that requires no other cluster in the calorimeters leads a loss of the real single photon events because of unexpected extra signals from electronics noises or cosmic rays. The accidental veto rate due to these signals was estimated using events collected by the random trigger and found to be 9.6 ± 0.8 %.

Selection 2) removes events with charged tracks. We required that no tracks were found in the CDC. By this requirement, the event was rejected that the photon converted into an electron-positron pair before entering the CDC. The loss rate due to the photon conversion was estimated to be 8.2 ± 1.4 % for $\theta > 50^\circ$ using a full detector simulation program. Most of cosmic-ray events were rejected by requiring that no MU tracks were reconstructed. This selection also leads a loss of single photon events because of unexpected noises in the chambers or accidental coincidence with cosmic rays. The rate was studied using Bhabha events and found to be 7.6 ± 0.2 %. Finally z and ϕ information of the TOF and BST was used in conjunction with the position of the LG cluster to reject cosmic-ray events not already removed by the CDC and MU signals. The minimum distance of each BST hit from the line connecting the TOF hit and the cluster position was calculated for all combinations of hits in the BST and TOF. If there was a combination in which the distance was less than 10 cm, it was considered to be a cosmic-ray track. However, care must be taken to save good single photon events. The TOF signal produced by a photon from the interaction point is expected to have $|\Delta Z| \leq 15$ cm and 3 nsec < T_{TOF} < 13 nsec, where ΔZ is the difference between the position of the signal in the TOF counter and the position expected from the cluster and the interaction point. T_{TOF} is the time of flight measured by the TOF. Therefore, we accepted the events that satisfied the above condition for the TOF signal. The loss rate of the single photon events from this cut was studied using $e^+e^- \rightarrow \gamma\gamma$ and $e^+e^- \rightarrow e^+e^-\gamma$ events whose photons struck the LG and was estimated to be 2.7 ± 0.6 %.

The LG trigger timing requirement in Selection 3) was imposed to further eliminate the backgrounds from cosmic rays. The standard deviation σ_t of the time difference ΔT_{LG} were determined to be 2.4 nsec using photons in $e^+e^- \rightarrow e^+e^-\gamma$ events. The efficiency of this timing cut is 95.9 ± 0.8 %.

In selection 4), the lateral shower profile in the LG was required to be consistent with the shape expected for an electromagnetic shower. Assuming the lateral distribution of the electromagnetic shower is characterized by a double exponential form, we calculated the expected energy deposition for each module in a 5 x 5 array as described in our previous study [7]. The χ^2 is defined as follows:

$$\chi^2 = Min\sum_{i=1}^{N}\left[\frac{E^i_{obs} - E^i_{exp}(\theta_{in}, \phi_{in})}{\sigma^i}\right]^2 / N_{dof} \, , \tag{1}$$

where E^i_{obs} and E^i_{exp} are the observed and expected energies for each module, θ_{in} and ϕ_{in} the production angles of the photon, σ^i the resolution of each counter, N_{dof} the degrees of freedom and N the number of modules whose measured or expected energies are greater than 10 MeV. We minimized the χ^2 for the two free parameters θ_{in} and ϕ_{in}. Figure 1 shows log χ^2 distributions for photons in $e^+e^- \rightarrow e^+e^-\gamma$ events and selected data before the shower profile test. We required $\chi^2 < 6$ for this shower profile test. The efficiency was studied using the photons in $e^+e^- \rightarrow e^+e^-\gamma$ events and estimated to be 84.0 ± 0.7 %.

In order to eliminate the QED backgrounds, in selection 5), we finally applied the conservative X_t cut taking into account the inefficiency of the AM edge. We determined the cut value by studing single electron events from the $e^+e^- \rightarrow e^+e^-\gamma$ process. After all the cuts, 8 events remained as the candidates of single photon events. Figure 2 shows the X_t distribution of the remaining events together with the expected one from the Monte Carlo event generator NNGG03 that makes an exact calculation of the $O(\alpha^2)$ correction with exponentiation of the soft photon spectrum [8]. The overall selection efficiency was estimated to be 56.6 ± 2.1 % within the detector acceptance.

In our data sample the most serious background was from cosmic rays that sneaked into the detector through the endcap holes for the beam pipe leaving no signal except for the LG. We estimated the contamination using off-timing events that were rejected by selection 3). Also, we independently estimated the background by extrapolating the event distribution with $\chi^2 > 6$ into the lower χ^2 region. We obtained consistent results in both methods and estimated the contamination of the cosmic rays to be $4.0^{+2.4}_{-1.7}$ events. The contamination from $ee\gamma$, $\gamma\gamma\gamma$ and $\mu\mu\gamma$ events was estimated considering the small detector gaps, dead modules and detector inefficiencies [9]. The background from $e^+e^- \rightarrow e^+e^-\gamma$ events were found to be 0.1 ± 0.1 events, while the other two processes were negligible.

4. Results and Limits on SUSY particle

We obtained 8 candidate single photon events, while the number of the expected background events is $4.1^{+2.4}_{-1.7}$. Therefore, the number of the background subtracted single photon events is $3.9^{+4.2}_{-2.8}$. From this, we deduce the observed cross section as:

$$\sigma \text{ (Single photon production)} = 42.0^{+45.3}_{-30.2} \text{ fb},$$

for the production of the single photon with $X_t > 0.13$ in the polar angle region $50.0° \leq \theta\gamma \leq 130.0°$, where the error includes the uncertainties in the estimation of selection efficiencies discussed in the previous section and the luminosity determination (2.6 %). The cross section is consistent with the expectation of 36.4 fb which is calculated by NNGG03. Figure 3 shows the present result at $\sqrt{s} = 58$ GeV and the expected yield as a function of CM energy.

From this result, a new limit is placed on the photino mass-scalar electron mass plane. The cross section of $e^+e^- \rightarrow \gamma\tilde{\gamma}\tilde{\gamma}$ is calculated using the formulae in reference [10]. The limit on the mass of the degenerate scalar electron is 44.4 GeV/c^2 at 90 % CL, when we assume a massless photino. The updated VENUS limit is 51.9 GeV/c^2 after being combined with our previous result based on the 60.4 pb^{-1} data that was accumulated before the detector upgrade [7].

Since all the results at TRISTAN/PETRA/PEP are statistically limited, it is worth while combining our result with other published studies from ASP, CELLO and MAC [11]. Figure 4 shows the excluded region thus obtained on the photino mass-scalar electron mass plane including the result from the search using acoplanar charged particles by ALEPH collaboration [12]. The mass degenerate scalar electron is excluded below 72.6 GeV/c^2 at 90 % CL, when we assume a massless photino.

5. Summary

We have studied the single photon production process at $\sqrt{s}$ = 58 GeV with the VENUS detector. The observed single photon cross section is $42.0^{+45.3}_{-30.2}$ fb in the acceptance of $X_t > 0.13$ and $50.0° \leq \theta\gamma \leq 130.0°$. The result is consistent with the prediction by the standard model with three light neutrino species. No anomalous single photon events are observed to suggest SUSY particle pair production.

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References

[1] K.J.F. Gaemers, R. Gastmans and F.M. Renard, Phys. Rev. D 19 (1979) 1605.
[2] OPAL Collab., M. Z. Akawy et al., Z. Phys. C50 (1991) 373.
L3 Collab., O. Adriani et al., Phys. Lett. B275 (1992) 209.
ALEPH Collab., D. Buskulie et al., Phys. Lett. B313 (1993) 520.
[3] G. Farrar and P. Fayet, Phys. Lett. B 76 (1978) 575.
[4] J. Ellis et al., Nucl. Phys. B 238 (1984) 453.
[5] VENUS Collab., H. Yoshida et al., Phys. Lett. B198 (1987) 570.
[6] F. Takasaki et al., Nucl. Instr. and Meth. A322 (1992) 211.
[7] VENUS Collab., K. Abe et al., Phys. Lett. B232 (1989) 431.
Y. Narita, Ph. D. Thesis Tokyo Metropolitan University (1991).
[8] R. Miquel, C. Mana and M. Martinez, Z. Phys. C 48 (1990) 309.
[9] D. Karlen, Nucl.Phys. B289 (1987) 23.
J. Fujimoto, M. Igarashi and Y. Shimizu, Prog. Theor. Phys. 77 (1987) 118.
VENUS Collab., K. Abe et al., Z. Phys. C 45 (1989) 175.
VENUS Collab., Y. Yonezawa et al., Phys. Lett. B264 (1991) 212.
[10] K. Grassie and P. N. Pandita, Phys. Rev. D 30 (1984) 30.
[11] ASP Collab., C. Hearty et al., Phys. Rev. D 39 (1989) 3207.
CELLO Collab., H. -J. Behrend et al., Phys. Lett. B215 (1988) 186.
MAC Collab., W. T. Ford et al., Phys. Rev. D33 (1986) 3472.
[12] ALEPH Collab., D. Decamp et al., Phys. Lett. B236 (1990) 86.

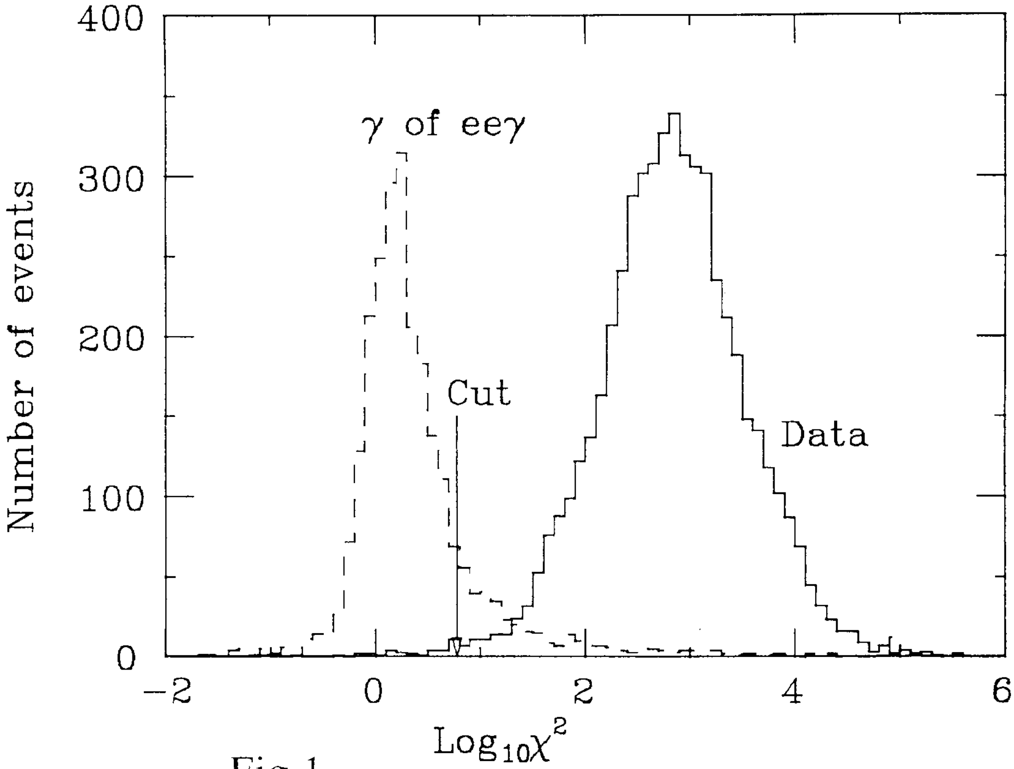
Figure captions

Fig. 1. Distribution of log χ^2 for remaining events before the shower profile cut.
Dashed histogram shows the distribution for the photon in $e^+e^- \rightarrow e^+e^-\gamma$ events.

Fig. 2. X_t distribution of the candidate events together with the expectation by NNGG03.

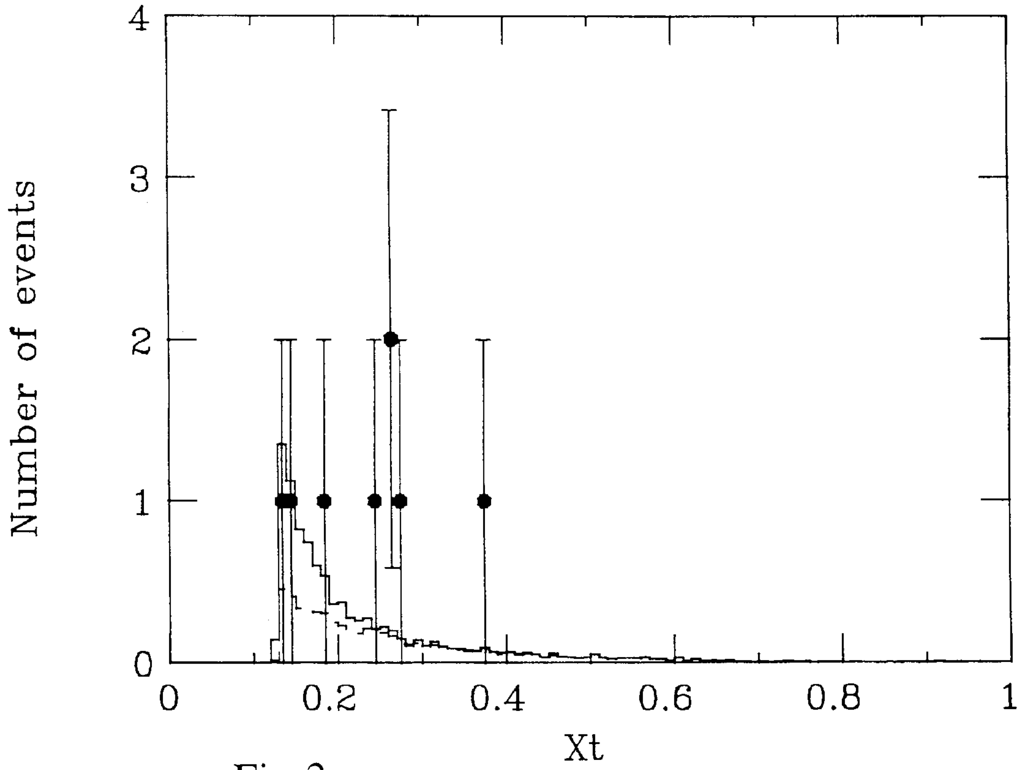
Fig. 3. Observed single photon cross section at $\sqrt{s} = 58$ GeV and the expected yield from $e^+e^- \rightarrow \gamma\nu\bar{\nu}$ process calculated using NNGG03.

Fig. 4. Excluded region on photino mass - scalar electron mass plane.
VENUS (90%CL, solid line), ASP (90%CL, dashed line), CELLO(90%CL, dotted line), ALEPH (95%CL, dot-dashed line) and combined single photon result (90%CL, solid line).



400
300
200
100
0
−2
0
2
4
6
Number of events
γ of eeγ
Cut
Data
Log10χ2

Fig.1



4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
Number of events
Xt

Fig.2

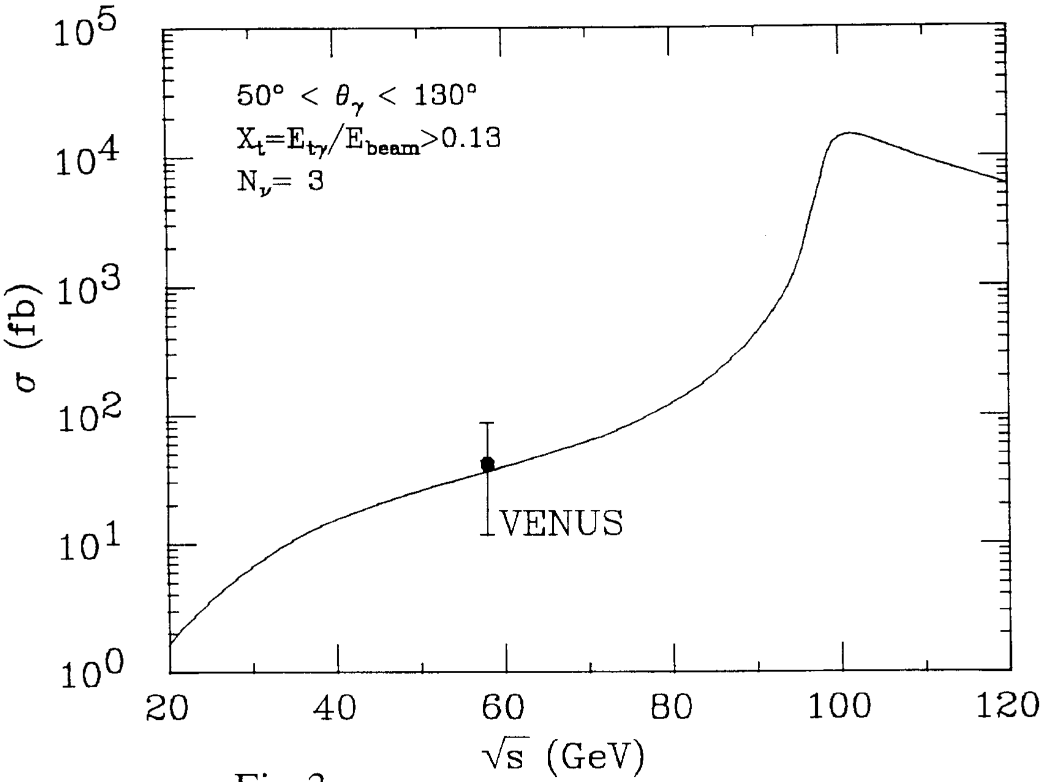

50° < θ_γ < 130°
$X_t=E_{t\gamma}/E_{beam}>0.13$
$N_\nu= 3$
VENUS
σ (fb)
√s (GeV)

Fig.3

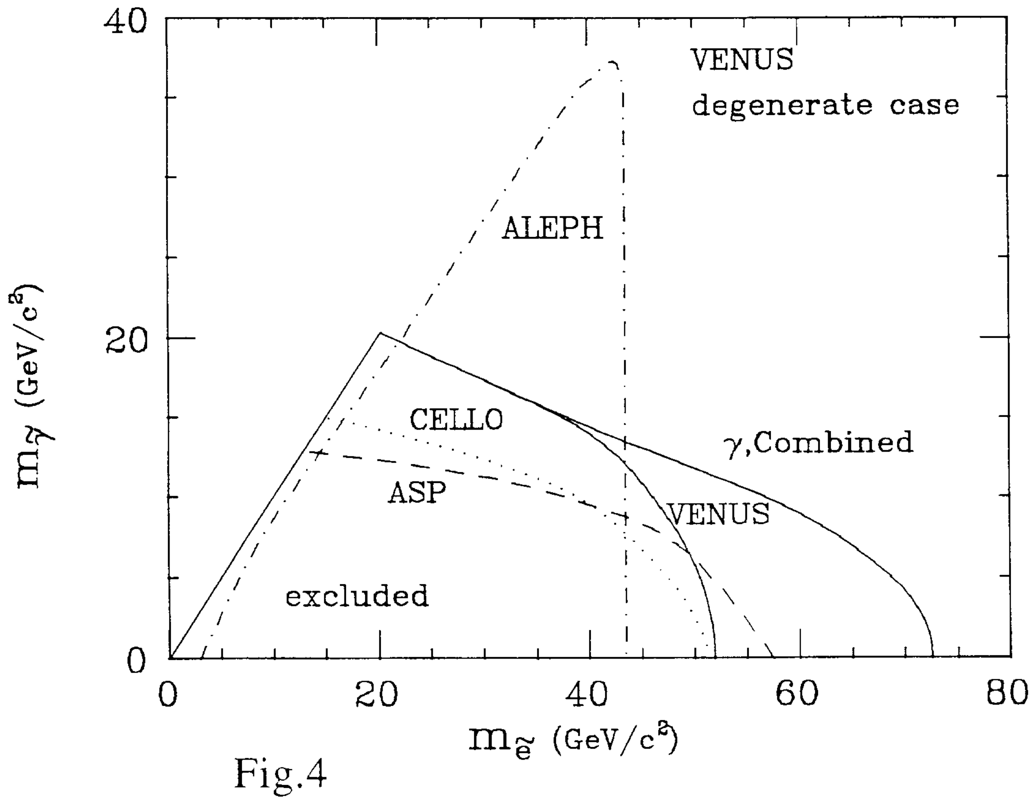

VENUS
degenerate case
ALEPH
CELLO
γ,Combined
ASP
VENUS
excluded
$m_{\tilde\gamma}$ (GeV/c²)
$m_{\tilde e}$ (GeV/c²)

Fig.4