MEASUREMENT OF THE REACTION $e^+e^- \to \gamma\gamma$ AT CMS ENERGIES FROM 9.4 TO 31.6 GeV

PLUTO Collaboration

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The differential cross section for the reaction $e^+e^- \to \gamma\gamma$ has been measured in the CMS energy range between 9.4 and 31.6 GeV. The results are found to be in agreement with the predictions of quantum electrodynamics up to momentum transfers-q^2 of 900 GeV^2. The data set lower limits of about 40 GeV on QED cut-off parameters. We have searched for the decay Υ (9 46) $\to \gamma\gamma$ and obtain an upper limit $\Gamma(\Upsilon \to \gamma\gamma)/\Gamma(\Upsilon \to \text{all}) < 1.4\%$ (95% c.l.).

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We report on a study of the reaction $e^+e^- \to \gamma\gamma$ at center of mass energies between 9.4 and 31.6 GeV. The experiment was performed at the e^+e^- colliding beam rings DORIS and PETRA at DESY. The two-photon annihilation process is particularly well suited for testing the validity of quantum electrodynamics at high energies, since contributions from electro-weak interference are expected to be absent in first order perturbation theory [1]. The analysis of $e^+e^- \to \gamma\gamma$ in the Υ region is of interest, because the $J^P = 1^-$ assignment of the Υ forbids the decay into two photons.

The experiment was carried out with the PLUTO detector which has been described in earlier publications [2,3]. The data analysis is closely linked to the study of Bhabha scattering [3] and will be described in detail only when relevant to the $\gamma\gamma$ final state. The essential parts of the PLUTO detector for this study are:

– barrel and endcap shower counters, endcap proportional chambers and 880 helix tubes for the cluster analysis and

– 13 cylindrical proportional wire chambers for pattern recognition of charged tracks.

Data were taken at the Υ region and at center of mass energies of 9.4, 12, 13, 17, 22, 27.6 and 30–31.6 GeV. For the selection of $\gamma\gamma$ events we required two back-to-back showers, containing more than 25% of the beam energy and being collinear within 20 degrees. The angle θ between the γ-rays and the electron beam was restricted to $|\cos\theta| < 0.75$. In a preselection the majority of Bhabha scattering events, $ee\gamma$ and hadronic final states were removed by rejecting events

– where at least one track could be associated with each of the clusters [‡1]

– where more than 5 tracks were observed in the inner detector or

– where the angle between any two reconstructed tracks exceeded 50°.

All events surviving these cuts were scanned visually. The subsample of events with *no* track in the central detector (~60% of the total) was found to be essentially free of background, in agreement with a Monte Carlo study.

The remaining events consisted of i) $\gamma\gamma$ final states with one converted photon (~30% of the expected $\gamma\gamma$ rate), ii) Bhabha scattering with one electron starting

‡1 This cut also excluded $\gamma\gamma$ final states with two converted photons.

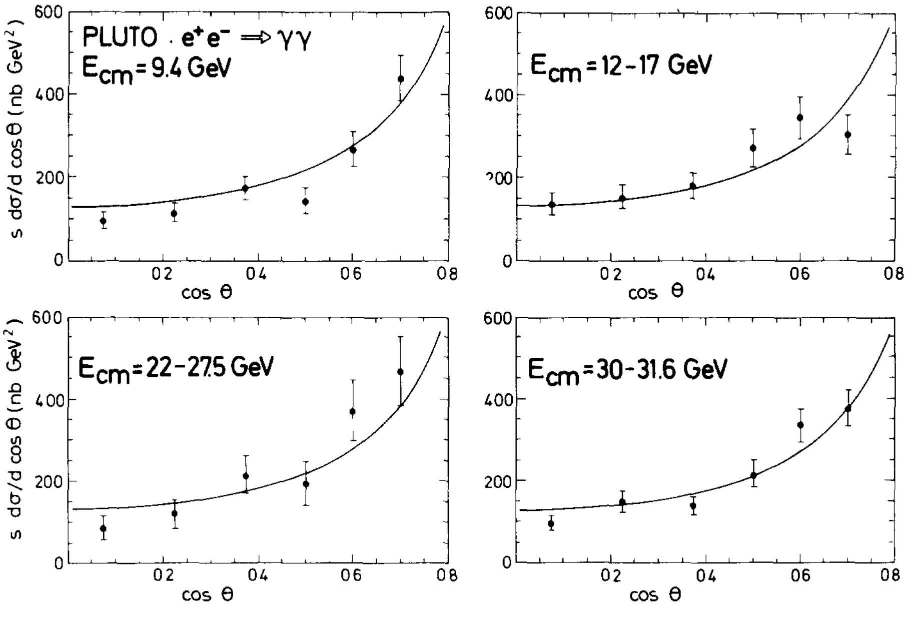

Fig. 1. Differential cross section $s\ d\sigma/d\cos\theta$ of the reaction $e^+e^- \to \gamma\gamma$ at different CMS energies as indicated in the figure. The curves are the QED predictions including the effects of radiation and angular resolution.

an early shower, iii) eeγ final states and iv) a negligible fraction of hadronic events. A total of 1034 events with an estimated background of (1 ± 1)% was accepted for the final analysis after the visual inspection of all candidates.

The fraction of events excluded by the cuts was estimated with a Monte Carlo program [4] to be (5 5 ± 1.1)%. The visual inspection showed that an additional 1.3% of events were lost due to incorrectly analysed shower patterns. Combining both values we obtain a detection efficiency of (93 ± 2)% which was applied as an overall correction

The differential cross sections were evaluated using the integrated luminosities as measured by the rate of large angle Bhabha scatters. Fig. 1 shows the angular distributions together with the QED expectations. The theoretical distributions (full curves) were folded with the angular resolution. The radiative corrections were estimated in the standard way [5] up to orders of α^3 and are incorporated into the theoretical curves. They range between 0% and −3% in the angular region under study. The agreement between the data and the QED predictions is good. The systematic uncertainty of the cross sections at 9.4 and 30–31.6 GeV is 3.5% (2% from event identification and 3% from the luminosity determination). The luminosity at the remaining energies has slightly higher statistical errors (up to 5%).

In fig. 2 the s-dependence of the cross section integrated over the measured angular range is displayed in a log-log plot. The straight line is the QED expectation and is seen to give a reasonable fit to our data.

The $e^+e^- \to \gamma\gamma$ cross section measured on the Υ resonance at 9.46 GeV was compared with data at

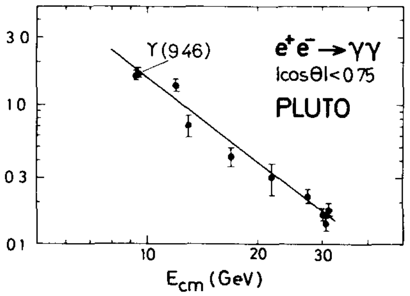

Fig. 2. The cross section for reaction $e^+e^- \to \gamma\gamma$ for $|\cos\theta| < 0.75$ The curve is the QED prediction including the effects of radiation and angular resolution.

adjacent energies in order to look for evidence of an $\Upsilon \to \gamma\gamma$ decay which is forbidden for a $J^P = 1^-$ vector meson. No enhancement in the $\gamma\gamma$ signal was found. The upper limit for the branching ratio $\Gamma(\Upsilon \to \gamma\gamma)/\Gamma(\Upsilon \to \text{all})$ is estimated to be 1.4% (95% c.l.). A test of QED was made using our data at the highest PETRA energies. We have applied two possible modifications of the standard QED cross section, which have been suggested in the literature·

– based on a vertex modification (sea-gull graph [7, 8]) the differential cross section can be written as [6]

$$\frac{d\sigma_V}{d\Omega} = \frac{\alpha^2}{2s}\left\{\frac{q'^2}{q^2}|F(q^2)|^2 + \frac{q^2}{q'^2}|F(q'^2)|^2\right\}(1+\delta_{rad})$$
$$= \frac{\alpha^2}{2s}\left\{\frac{q'^2}{q^2} + \frac{q^2}{q'^2} \pm \frac{4q^2q'^2}{\Lambda^4_{V\pm}}\right\}(1+\delta_{rad}) , \quad (1)$$

with $F(q^2) = 1 \pm q^4/\Lambda^4_{V\pm}$, $F(q'^2) = 1 \pm q'^4/\Lambda^4_{V\pm}$ (here δ_{rad} is the radiative correction, $q^2 = -s\cos^2\theta/2$ and $q'^2 = -s\sin^2\theta/2$, $\Lambda_{V\pm}$ is a cut-off parameter)

– on the other hand if one assumes the exchange of a hypothetical heavy electron e* [9] then:

$$\frac{d\sigma_{e^*}}{d\Omega} = \frac{\alpha^2}{2s}\left\{\frac{q'^2}{q^2} + \frac{q^2}{q'^2} \pm \frac{2s^2 - 4q^2q'^2}{\Lambda^4_{e^*\pm}}\right\}(1+\delta_{rad}). \quad (2)$$

The value of Λ_{e^*+} can be interpreted as the mass of a heavy electron assuming its coupling strength is the same as that of the electron. The parameter Λ_{e^*-} is theoretically less motivated. In both cases the relative modification is largest and of same magnitude at $\theta = 90°$.

Both expressions were fitted to the experimental differential cross sections at $30 \leqslant E_{cms} \leqslant 31.6$ GeV. The fit selected the sign of Λ^4 in eqs (1) and (2) required to describe the data. The fitted values of s^2/Λ^4 are given in table 1. Lower bounds for the cut-off parameters Λ_{V+}, Λ_{V-}, Λ_{e^*+} were obtained with standard χ^2_{min} techniques. In both parameterisations we find lower limits for the cut off parameters of about 40 GeV (95% c.l.). The results are compared in table 1 with those from other recent measurements. It can be seen that the new results of PLUTO and JADE at the highest PETRA energies have raised the lower bounds on Λ by a factor of 4 to 5.

In conclusion, our results show that the two-pho-

Table 1
Fitted values of s^2/Λ^4 and lower limits (95% c.l.) of the QED cut off parameters for the reaction $e^+e^- \to \gamma\gamma$. Everywhere $\epsilon = \pm 1$ represents the fitted sign in eq. (1) and (2) and $\Lambda_\pm$ corresponds to $\epsilon = \pm 1$. The statistical and systematic uncertainties of the luminosity determination have been taken into account in the fit.

ref.	E_{cm} (GeV)	$\epsilon \frac{s^2}{\Lambda_V^4}$	$\epsilon \frac{s^2}{\Lambda_{e^*}^4}$	Λ_{V+} (GeV)	Λ_{V-} (GeV)	Λ_{e^*} (GeV)
10	1.4– 2.4			⩾ 2.6	⩾ 2.4	–
11	4			–	–	⩾ 3.9
12	5.2			⩾ 6.2	⩾ 6.9	–
13	6.2– 7.4			⩾ 10 7	⩾ 9.0	–
13	27.7–31.6			–	–	⩾ 45
this exp	30 –31.6	−0.169 ±0.185	−0.083 ±0.145	⩾ 46	⩾ 36	⩾ 46

ton annihilation process is very well described by quantum electrodynamics up to $q^2 \approx -900$ GeV^2. The absence of $\Upsilon \to \gamma\gamma$ has been checked down to the 1% level.

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