Observation of the process $e^+e^- \to \gamma\gamma\gamma\gamma$

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The quantum electrodynamic process $e^+e^- \to \gamma\gamma\gamma\gamma$ was studied with the VEPP-2M electron-positron storage ring in the energy interval $2E = 0.5$–1.4 GeV. The integrated cross section in the kinematic region of large momentum transfer, angular distribution of photons, energy spectra, and spectra of the effective masses of photon pairs were measured.

Among all of the quantum electrodynamic (QED) e^+e^- annihilation processes it is possible to single out those which have only photons in the final state. The distinctive feature of these processes is that they have only fermion propagators in the corresponding Feynman diagrams in lowest-order perturbation theory. Test of the applicability of QED for a fermion propagator, in contrast with a photon propagator, does not require the use of corrections for vacuum polarization and the Z-boson contribution, which greatly simplifies a comparison with experiment. Processes with only two or three final-state photons have so far been studied. In the present study we have detected for the first time a QED process of fourth order in α,

$$e^+e^- \to \gamma\gamma\gamma\gamma \quad . \tag{1}$$

In comparison with our preliminary results,[1] we have increased the integrated luminosity and expanded the energy range, making it possible to single out the region in which the background of the process we are studying is negligible.

Reaction (1) was observed in the VEPP-2M e^+e^- storage ring[2] with a neutral detector, which was described previously in Ref. 3. The principal part of the neutral detector is a calorimeter consisting of four layers of NaI(Tl) crystals which span 65% of the solid angle of 4π. To determine the angles of emission of the photons, we placed two layers of flat proportional chambers between the crystal layers. The experiment was carried out in the energy interval $2E = 0.5$–1.4 GeV with an integrated luminosity of $4.1\ \text{nb}^{-1}$ (Refs. 1–4).

The background of the process (1) gives the following reactions in different energy regions:

$$e^+e^- \to \rho, \omega \to \eta\gamma, \qquad \eta \to 3\pi^0, \tag{2}$$

$$e^+e^- \to \omega \to \pi^0\gamma, \tag{3}$$

$$e^+e^- \to \omega\gamma, \ \omega \to \pi^0\gamma, \tag{4}$$

$$e^+e^- \to \omega\pi^0, \ \omega \to \pi^0\gamma. \tag{5}$$

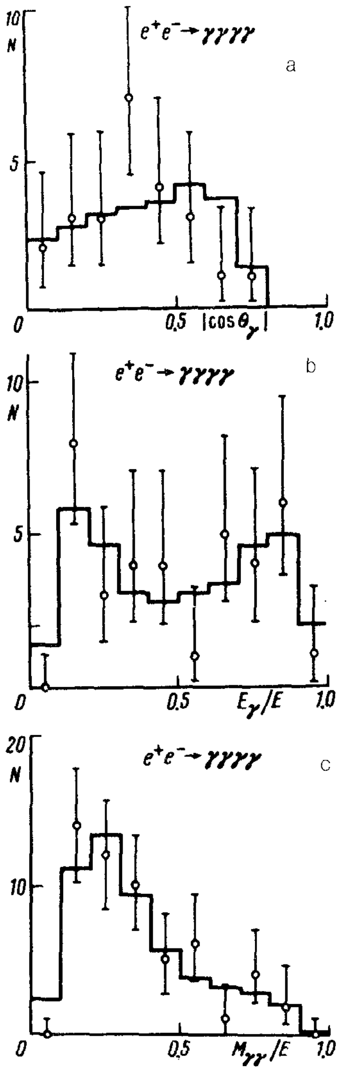

FIG. 1. Distributions for the process $e^+e^- \to \gamma\gamma\gamma\gamma$ at the energy $2E = 0.5$–0.75 GeV. Histogram—simulation; points—experiment; (a) from the angles of emission of photons; (b) photon spectrum; (c) spectrum of effective masses of photon pairs.

To identify the events in process (1) and to suppress the background, we stipulated that

•four photons should fall into the detector's solid angle;

•the energy-momentum conservation laws should hold within the instrumental resolution;

•the angle between the photons should be greater than 30°;

•the energy of each photon should be greater than 0.1 E.

In the energy region $2E < 0.75$ GeV, where the background is less than 10%, we detected nine events in process (1). Using the events from this region only, we can compare some of the distributions with the QED calculations. Figure 1 shows the measured distribution of the photon emission in the cosine of the polar angle and the distribution of the photon energy, as well as the spectum of the effect masses of the photon pairs in the energy region $2E = 0.5$–0.75 GeV. The experiment is found to be in agreement with a numerical simulation within the statistical error.

To reduce the contribution from the hadronic processes, we have also stipulated that in the energy region $2\,E = 0.75$–1.4 GeV the energy of the most energetic photon should exceed 0.7 E and the energy of the softest photon should be less than 0.3 E. The remaining contribution from processes (2)–(4), which is no greater than 30%, is subtracted.

In the energy region above 1.04 GeV, we considered the events in which we found no more than a single photon pair with an invariant mass in the range 90–180 MeV, consistent with the mass of a π^0 meson. From these events we selected events in which the recoil mass of the "π^0 meson" or the mass of the "π^0" γ system lies in the interval $M \pm 120$ MeV. By imposing these conditions we were able to suppress the contribution from process (5) by an order of magnitude and to completely suppress process (4). However, the efficiency of detecting process (1) in this case decreased approximately by a factor of 3. The remaining contribution from process (5) was subtracted using the cross section measured previously with the neutral detector.[5] After imposing all the constraints described above, we identified 87 events with four photons. Subtracting the background from processes (2)–(5), we find the number of events in process (1) to be 43 ± 12.

Monte-Carlo simulation of process (1) was carried out using the differential cross section[6] in the kinematic region

$$E_i > 20\text{ MeV} \quad 140^\circ > \theta_i > 40^\circ, \tag{6}$$

where E_i are photon energies, and θ_i are the angles between the photons and the beam axis. From the simulation we were able to determine the efficiency, i.e., the fraction of simulated events which satisfy the selection conditions described above. The efficiency was varied between 4% and 10% in the energy range $2\,E = 0.5$–1.4 GeV. To compare our results with the theory and with the results of other experiments, we converted the cross section for detection of process (1), measured under the selection conditions described above, into an integral cross section (Fig. 2) in the kinematic region (6). The line represents the calculated cross section in the same kinematic region. The

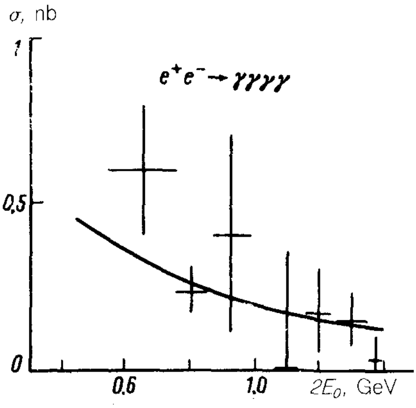

FIG. 2. Cross section for the quantum electrodynamic process $e^+e^- \to \gamma\gamma\gamma\gamma$ in the kinematic region of large momentum transfer. Line—calculated cross section; points—experimental data (including the errors).

theoretical curve in Fig. 2 has no adjustable parameters. We see from the figure that the experimental results are in agreement with the QED calculations.

A comparison with QED in the form of a restriction imposed on the parameter Λ has not yet been made, since such a comparison requires laborious calculations of the differential cross section for reaction (1), analogous to those carried out in Ref. 6, but with a modified fermion propagator.

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[1]S. I. Dolinskiĭ, V. P. Druzhinin, M. S. Dubrovin, *et al.*, Preprint IYaF 85-98, Novosibirsk, 1985.
[2]G. M. Tumaĭkin, Tenth International Conf. on High-Energy Charged Particle Accelerators, Serpukhov, 1977, p. 443.
[3]V. B. Golubev, V. P. Druzhinin, V. N. Ivanchenko, *et al.*, Nucl. Instr. Meth. **227**, 467 (1984).
[4]V. M. Aul'chenko, S. I. Dolinskiĭ, V. P.Druzhinin, *et al.*, Preprint IYaF 86-105, Novosibirsk, 1966.
[5]S. Dolinsky, V. P. Druzhinin, M. S. Dubrovin, *et al.*, Phys. Lett. **174B**, 453 (1986).
[6]F. A. Berends, P. De Causmaecker, R. Gastans, *et al.*, Nucl. Phys. **B239**, 395 (1984).

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