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C. Bacci, R. Baldini-Celio, G. Capon, C. Mencuccini, G. P. Murtas, G. Penso, A. Reale, G. Salvini, M. Spinetti and B. Stella : GAMMA-GAMMA INTERACTION PROCESSES AT ADONE e^+e^- STORAGE RING. MEASUREMENT OF THE REACTION $e^++e^- \to e^++e^-+e^++e^-$.

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C. Bacci[(x)], R. Baldini-Celio, G. Capon, C. Mencuccini, G. P. Murtas, G. Penso[(x)], A. Reale, G. Salvini[(x)], M. Spinetti, and B. Stella[(o)]: GAMMA-GAMMA INTERACTION PROCESSES AT ADONE e^+e^- STORAGE RING. MEASUREMENT OF THE REACTION $e^+ + e^- \rightarrow e^+ + e^- + e^+ + e^-$. -

The study of interactions

(1) $$e^+ + e^- \rightarrow e^+ + e^- + \text{(hadrons, leptons)}$$

is an interesting field of research with e^+e^- storage rings. These processes have recently received considerable interest[(1)], when they proceed through the diagram of Fig. 1a), that is through virtual photon-photon interaction; in particular cases one can extract from them the real photon--photon cross section $\gamma + \gamma \rightarrow$(hadrons, leptons).

The most usual interpretation[(1, 2)] of reaction (1) has been therefore based on the assumption that the two initial electrons pick up a very small transverse momentum, and continue on the same line as the beams. This immediately suggests selecting events (1) by detecting the

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surviving electron emitted at zero angle.

We have carried out on these lines an experimental investigation of reaction (1) at the Frascati storage ring Adone; some preliminary results have already been presented[3,4]

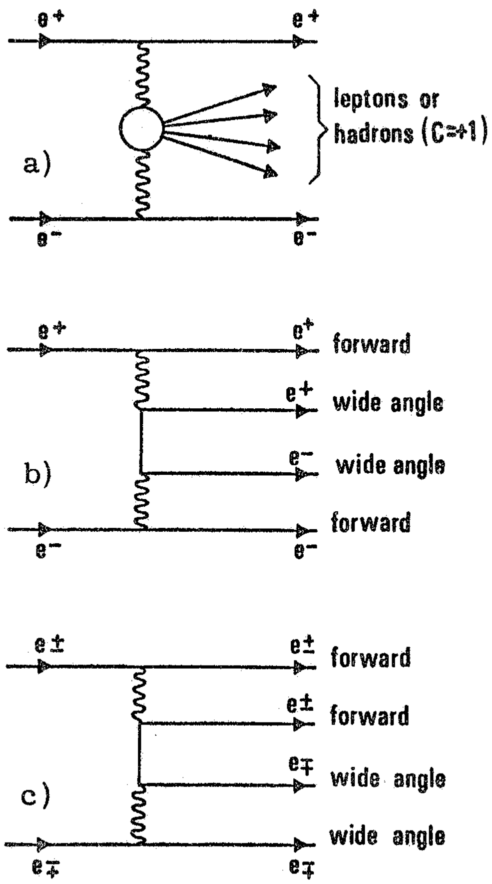


FIG. 1 - a) General diagram of virtual γ - γ interaction from e^+e^- colliding beams; b) Leading diagram of the process $e^+ + e^- \rightarrow e^+ + e^- + e^+ + e^-$, with a hard electron propagator; c) Same diagram as in b), with a hard photon propagator.

In the present paper we report in particular on the reaction

(2) $$e^+ + e^- \rightarrow e^+ + e^- + e^+ + e^-$$

which has been analyzed at an average total incident energy of 2 GeV, and we compared our experimental results with the available theoretical calculations. Results on reaction (2) at lower energies have been already reported[5] from the Novosibirsk e^+e^- storage ring.

The exact cross section for reaction (2) can be evaluated by standard QED methods. But until now this calculation has been performed under the previously mentioned assumption that both final electrons carry out negligible transverse momentum.

The results we obtained were rather unexpected and difficult to understand on the basis of this assumption. In fact, to explain our results we had to reconsider in a more complete way the 4th order diagram (Fig. 1b and 2c) which describes reaction (2).

The experimental results on reaction (2), the theoretical interpretation, and its possible practical consequences for future research on γ - γ interactions are the main purpose of this letter.

The experimental apparatus is shown in Fig. 2 and it is in part the same described in detail in Ref. (6) for the $e^+ + e^- \rightarrow \gamma + \gamma$ reaction. The forward emitted electrons or positrons are bent by the magnets of the storage ring and a fraction of them are detected by the counters C_e or C_p respectively, located at the extreme end of these magnets. The energy of the electrons and positrons accepted by the C_e, C_p counters covers the range $(0.7 \div 0.9)E$ (E=single beam energy). Therefore the corresponding virtual photons have energies in the interval $(0.1 \div 0.3)E$.

Due to the walls of the doughnut and to the fringing fields of the bending magnets, we have a $\sim 15\%$ loss in detection efficiency. The momentum acceptance[7] and detection efficiency of counters C_e, C_p has been calibrated by measuring the energy of the photons coming from beam--gas bremsstrahlung, with a lead glass Cerenkov counter $C_1(C_2)$ (Fig. 2a)), in coincidence with $C_e(C_p)$.

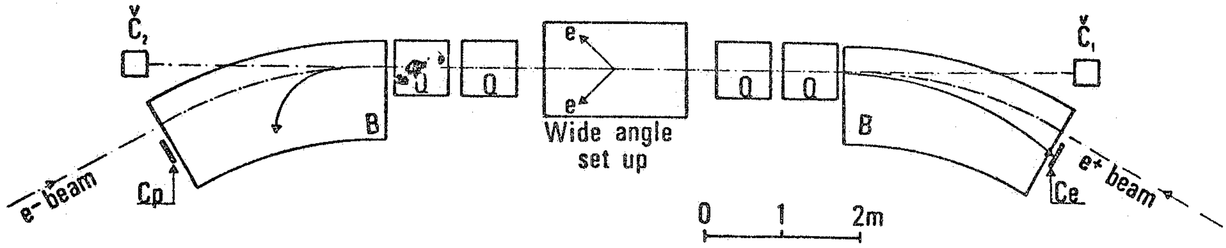
Above and below the interaction region (Fig. 2b)) four similar telescopes A, B, D, S each made of plastic scintillators, optical spark chambers and lead converters, allow us to distinguish with good accuracy between showering and not showering particles.

The spatial reconstruction of tracks and showers is achieved with an angular resolution of the order of 1.5°. The detection efficiency of the telescopes for incident electrons has been measured by means of the pair spectrometer of the Frascati electron synchrotron.

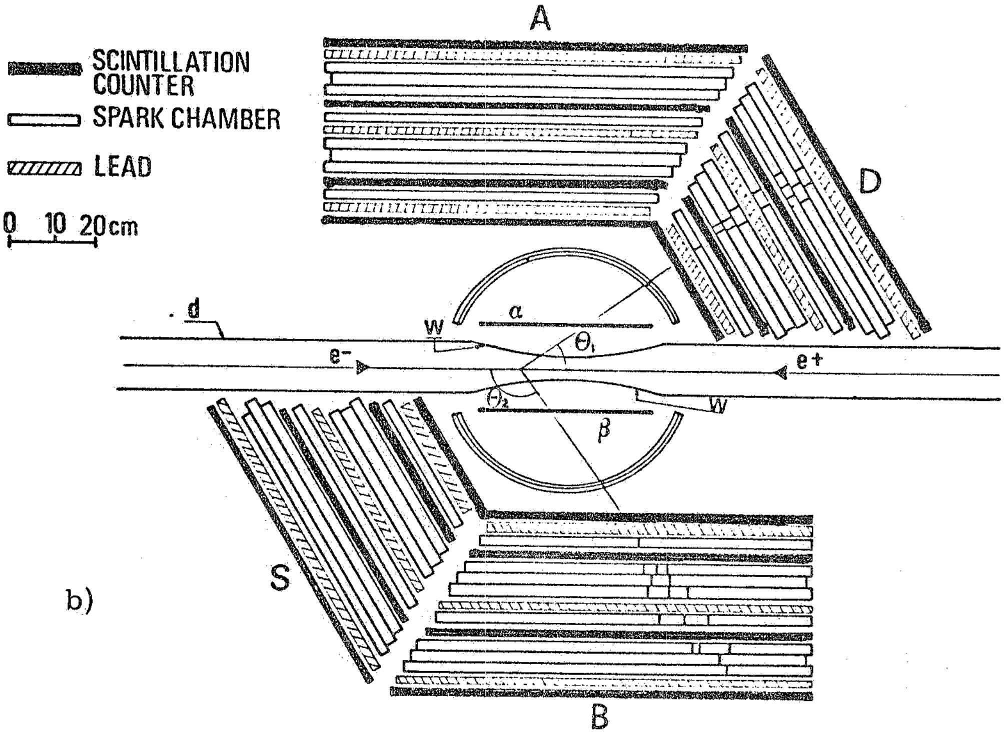
The trigger requires at least two particles at wide angles ($15^\circ \lesssim \theta \lesssim 140^\circ$) in the four telescopes, in coincidence with a particle in counter C_e or C_p.

The explored energies were 950, 970, 1050 MeV per beam with a total luminosity 1.23×10^{35} cm^{-2}.

To avoid accidentals, due for instance to e^+e^- Bhabha scattering, we selected the collected events by requiring that the detected particles at wide angle should not be collinear within 10°. With this cut we obtained 29 events, identified as coming from reaction (2). All these events are coplanar with the beams within $\pm 10^\circ$. We did not find any event with both counters C_e and C_p in coincidence. We have verified that the contribution to our events due to beam-gas interaction is negligible.



a)



b)

FIG. 2 - a) The straight section of Adone machine (top view) with the wide angle set up, the "tagging" counters C_e and C_p and the calibration Cerenkov counters $\check{C}_1$ and $\check{C}_2$. Q = quadrupole; B = Bending magnet; b) The wide angle apparatus; side view from the center of the Adone ring.

Let us now analyze in more detail our 29 events. We may safely assume, on the basis of the existing theoretical approaches, that the two electrons of reaction (2) which do not appear in the spark chambers go along the beam direction. In this approximation the c.m. of the two electrons emitted at wide angle moves along the beam direction, and its velocity is determined by measuring the particle angles θ_1 and θ_2 with respect to the beams (Fig. 2b)); in fact

$$|\beta| = \frac{\sin|\theta_1 - \theta_2|}{\sin\theta_1 + \sin\theta_2} \qquad (3)$$

The β distribution of our events is reported in Fig. 3. We define β as negative (positive) when the c.m. moves in the same (opposite) direction with respect to the particle detected by the counter C_e or C_p.

We have compared our experimental results with a Montecarlo distribution based on the theoretical prediction for process (2).

Since we require two high energy electrons at wide angle, at least one of the three propagators in Figs. 1b), 1c) must be hard. The first step in this direction was to assume for the cross section of process (2) the value predicted on the basis of diagram 1b): this theoretical case corresponds to assuming that the electron propagator is the hard one, so that the two created electrons are emitted at a large angle. This is the case most commonly considered in the literature[1,2], which has been treated by Landau and others in the double Fermi approximation[8]. As we already said, our results do not agree with the predictions when we take into account this contribution alone. The Montecarlo prediction of this contribution is reported in Fig. 3 (dashed line ε_2). The fact that we do not observe events with $\beta < 0$ (left side of Fig. 3) could be in itself not very significant. In fact the events with $\beta < 0$ have the electrons at large angles with the lowest energies, and the predictions become critically dipendent on the efficiency of the four telescopes for the electrons below ~ 150 MeV. As an indication we give in Fig. 3 (dashed line ε_3) the Montecarlo prediction obtained when assuming an efficiency ε_3 for the electrons which is somewhat lower than our experimental calibration ε_2, and (dashed line ε_1) the prediction in the extreme case of 100% efficiency. The energy dependence of these efficiencies are reported in Fig. 4.

The situation for the events with $\beta > 0$ is more definite. In fact (see Fig. 3) for $\beta > 0$ the results do not depend critically on the efficiency of our apparatus. It remains clear that the larger part of our events must have a different origin than the contribution from Fig. 1b). So we considered[9] the case in which one of the photon propagators is the hard one (Fig. 1c). This contribution has been recently calculated by G. Parisi[10] with several approximations : in this case the two electrons or positrons with small transverse momentum are mostly emitted in the same direction, and the events must concentrate in the region with positive values of β.

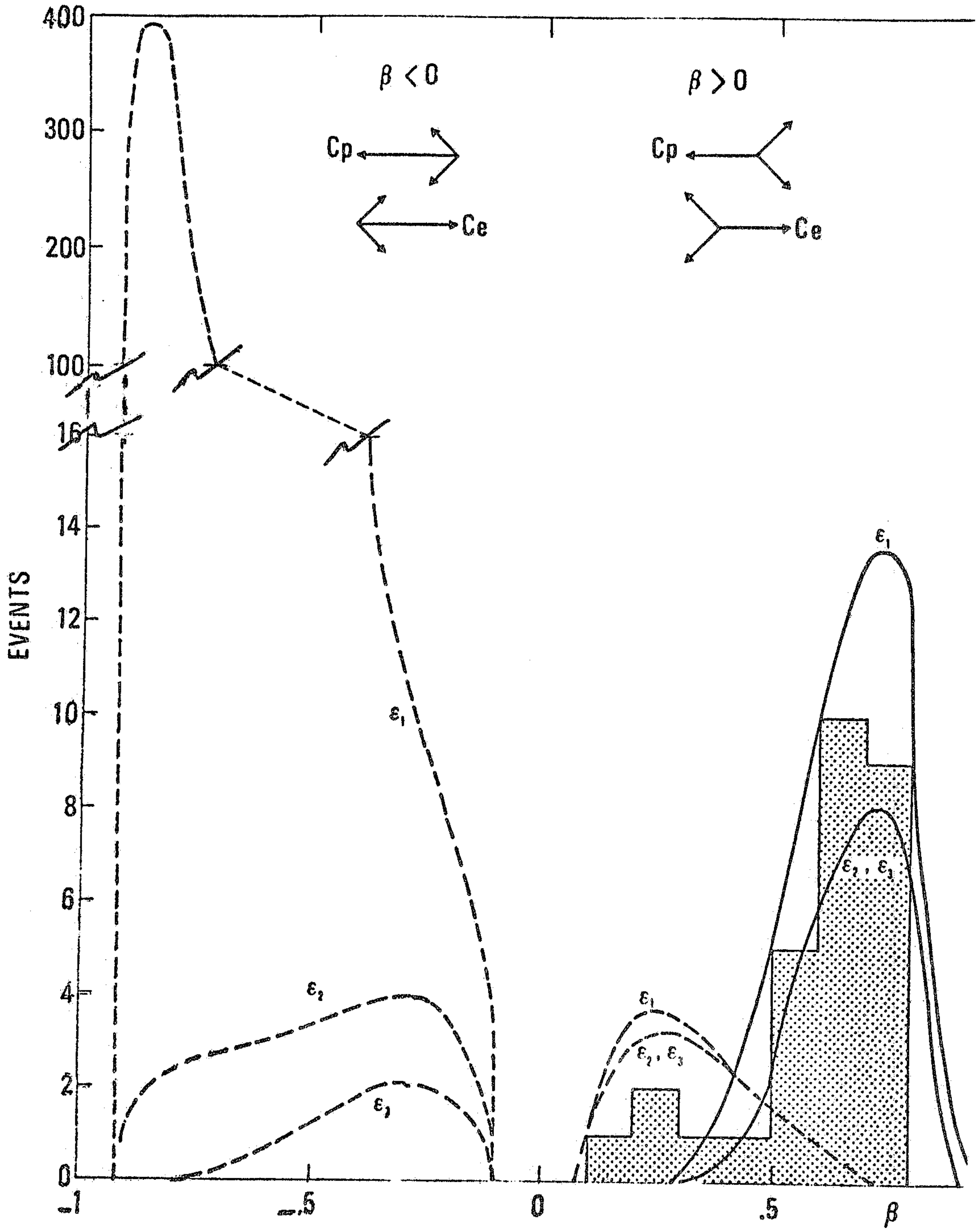


FIG. 3 - Experimental distribution of β (velocity of the center of mass of the two electrons emitted at wide angle) compared with the absolute theoretical prediction. Dashed (solid) lines are the predictions based on the contribution of Fig. 1b, 1c. The different lines ε_1, ε_2, ε_3 refer to different efficiencies of telescopes A, B, D, S, ε_2 being the efficiency experimentally measured (See Fig. 4). Arrows on top give the configuration of the detected electrons in the case $\beta < 0$ (left) and $\beta > 0$ (right). The behaviour for different efficiences ε_1, ε_2, ε_3, make clear that in the case $\beta < 0$ the predictions are very uncertain, while in the case $\beta > 0$ they are more certain (See text).

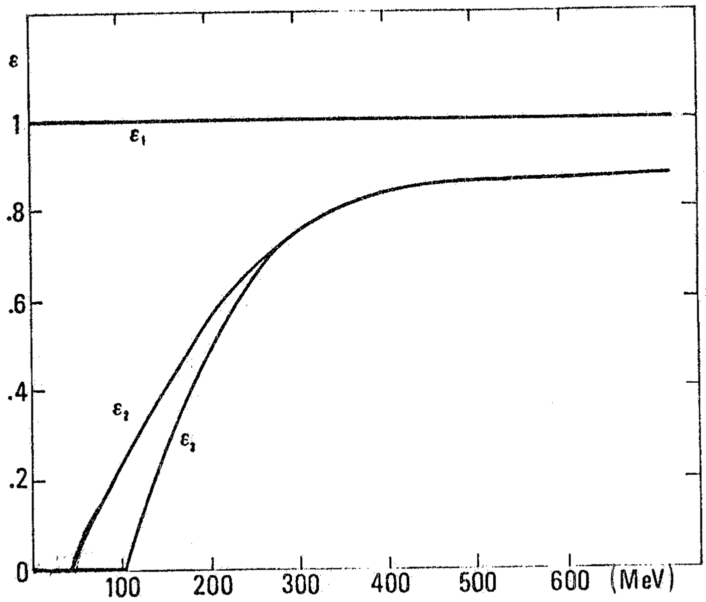


FIG. 4 - Energy dependence of the electron detection efficiency in telescopes A, B, D, S, as used in Fig. 3; ε_1: full (100%) efficiency; ε_2: experimental efficiency measured at the electron pair spectrometer; ε_3 reference lower efficiency.

It is clear that the contribution from Fig. 1c) to the total cross section of reaction (2) is rather small, but considering our experimental selection of the events, it may become rather important. The absolute predictions for different detection efficiencies ε_1, ε_2, ε_3 is reported in Fig. 3 (solid lines) and it is clearly in good agreement with our experimental results.

In summary, the results of Fig. 3 indicate that we can consider the theoretical prediction in satisfactory agreement with the experiment on the $\beta > 0$ side. The prediction is still rather unsatisfactory on the $\beta < 0$ side.

As we said, reaction $e^+ + e^- \rightarrow e^+ + e^- + e^+ + e^-$ has been observed at 510 MeV per beam at Novosibirsk[5]. In this case the experiment has been performed by detecting only the particles at wide angles and the reaction was recognized through the coplanarity angle distribution. This fact, together with much lower experimental cuts in the energy of the electrons, reduces the contribution of Fig. 1c) in this case.

In conclusion:

- We have observed the reaction $e^+ + e^- \rightarrow e^+ + e^- + e^+ + e^-$ by using the technique of requiring at least one forward emitted-electron. This result ensures us of the possibility of using this technique when investigating reactions (1).
- To explain our experimental results we must reconsider in a more complete way the diagrams of Fig. 1. In particular we have shown that in our experimental disposition the contribution of diagram c) (Fig. 1) (hard

photon propagator) is more important than that of diagram b) (hard electron propagator).

- It is of general interest, in connection with the future physics of γ-γ interactions, to perform an accurate theoretical analysis on the process (2) and in general on reactions (1).

Before closing, we wish to mention that we have also observed during this measurements a few events with two non-showering tracks in the spark chambers. These events could be interpreted as due to the reactions $e^+ + e^- \rightarrow e^+ + e^- + \mu^+ + \mu^-$ or $e^+ + e^- \rightarrow e^+ + e^- + \pi^+ + \pi^-$. Further analysis and theoretical calculations, are in progress to compare these results with theory.

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