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RESEARCHES IN FRASCATI ON THE REACTIONS

\[ e^+ e^- \rightarrow e^+ e^- + X. \] THE RESULTS OF THE « \( \gamma \gamma \) GROUP»

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Résumé. — Nous donnons une revue générale des possibilités concernant les collisions photon-photon auprès de l'anneau ADONE à Frascati, ainsi que les appareillages correspondants. Nous considérons particulièrement les expériences déjà réalisées par le « groupe \( \gamma \gamma \) ». À une énergie de 1 400-1 500 MeV par faisceau, 46 événements du type \( e^- e^- \rightarrow e^+ e^- e^- e^- \) et quelques événements du type \( e^- e^- \rightarrow e^+ e^- \mu^+ \mu^- \) ont été analysés. En ce qui concerne les événements de production de paires d'électrons (avec détection, essentiellement, d'un seul des électrons primaires diffusés vers l'avant), plus de la moitié d'entre eux n'obéissent pas au mécanisme des collisions photon-photon (deux photons quasi réels), mais paraissent correspondre au mécanisme suggéré par Cabibbo et G. Parisi (un photon quasi réel et l'autre très virtuel).

Abstract. — A general survey is given of the possibilities for performing photon-photon collisions with the Frascati storage ring ADONE, and the corresponding set-ups used. The experiments already performed by the « \( \gamma \gamma \) group » are considered in particular. At beam energy 1 400-1 500 MeV, 46 events of the type \( e^- e^- \rightarrow e^+ e^- e^- e^- \) and a few events of the type \( e^- e^- \rightarrow e^+ e^- \mu^+ \mu^- \) were analyzed. More than half of the electron-pair production events (with tagging of only one forward-scattered primary electron) did not belong to the photon-photon collision mechanism (two quasi real photons), but to the mechanism suggested by Cabibbo and G. Parisi (one quasi real and one highly virtual photon).

In the present report I give a short summary of the activity of two research groups working in Frascati, with Adone, to the processes \( e^+ e^- \rightarrow e^+ e^- e^+ e^- \); \( e^+ e^- \rightarrow e^+ e^- \mu^+ \mu^- \); \( e^- e^- \rightarrow e^+ e^- \pi^+ \pi^- \).

These groups are :

— The « \( \gamma \gamma \) » group (works, in different occasions, of BACCI C., BALDINI CELIO R., CAPON G., DEI FABBRO R., MENCUCCINI C., MURTA G. P., PENO G., REALE A., SALVINI G., SPINETTI M., STELLA B., ZALLO A.)

— The « \( \mu \pi \) » group (work of BARBELLINI G., CERADINI F., CONTIVI M., d'ANGELO S., FERRER M. L., ORITO S., PAOLUZI L., SANTONICO R., TSURU T., VISENTIN R.).

After having made a general comment on the activity in Frascati, I shall particularly report in detail the results of the « \( \gamma \gamma \) » group. The results of the « \( \mu \pi \) » group will be reported in detail by SANTONICO R.

1. Introduction. — It is well known that the \( e^+ e^- \) storage rings have been built to the main aim of studying the annihilation processes :

\[ e^+ e^- \rightarrow \text{virtual time like photon} \gamma \rightarrow Y (1) \]

where \( Y \) is a physical object with the quantum number of a photon (for instance, \( Y \) may be the \( \rho \) meson, a group of hadrons, a pair of leptons with \( J^P = 1^- \), etc.).

But it was soon very clear, through the theoretical previsions of many authors [1], [2], that other kind of interactions could be also of high interest, that is

\[ e^+ e^- \rightarrow e^+ e^- + X \] (2)

where the microscopic system \( X \) may be a lepton pair (or a quadruplet of leptons) or a hadronic system with \( C = + 1 \).

The system \( X \) in reaction (2) may be obtained in many ways, and two have been certainly experimentally observed in the last two years [3], [4] :

A) The two electrons irradiate one photon each in a glimpsing collision (double bremsstrahlung) and the two quasi real photons interact and annihilate, giving rise to the system \( X \). This process may be considered, with good approximation, a \( \gamma \gamma \) annihilation process with quasi real photons, that is a process :

\[ e^+ e^- \rightarrow (e^+ e^-) + (\gamma \gamma) \rightarrow (e^+ e^-) + X \] (3)
which in a simple graph takes the forms:

\[ e^+ \quad (4) \]

\[ e^- \quad \text{forward} \]

\[ \text{wide angle} \]

\[ \text{wide angle} \]

\[ \text{forward} \]

This opens the way to the study of all X systems with 0.2 spin and \( C = + 1 \), for instance the \( e, \eta, \eta' \) particles.

It was established, through careful study [1], that it is possible to have \( \gamma \gamma \) interactions with quasi real photons \( (q^2 < \text{a few MeV}^2) \), if one detects the \( e^+ \) and the \( e^- \) when continuing on their direction of flight. In this case one may apply rather well and properly the William-Weizsacher method, and deduce \( \alpha \) directly from the experimental data. In fact each lepton \( (e^+ \) or \( e^- \) is equivalent to a beam of real transversely polarized photons (energy \( \kappa \)) with a spectrum

\[
\frac{\alpha E^2 + (E - \kappa)^2}{E^2} \ln \left( \frac{E}{m_e} \right) \frac{dk}{\kappa}.
\]

In addition we have the simplification that in case one detects both final \( e^+ \) and \( e^- \) travelling on their initial direction of flight all other Feynman diagrams of the same order become rather unimportant.

The experimental cross sections for process (3) with graphs (4) or (5) increase logarithmically at high energies [1]. For example:

\[
\sigma_{ee} \rightarrow ee + \pi^+ \pi^- \sim \frac{8}{3} \frac{\alpha^4}{\pi m_e^2} \left( \ln \frac{E}{m_e} \right)^2 \left( \ln \frac{E}{m_{\pi}} \right).
\]

\( E \) being the energy of each beam. We know on the contrary that the usual one photon cross section for hadron production must sooner or later, inevitably decrease with energy, perhaps as \( E^{-2} \).

B) One electron (positron) of the colliding beams emits a photon which converts into a group of particles (mostly but not necessarily a pair: \( e^+ e^- ; \mu^+ \mu^- ; \pi^+ \pi^- \)). One particle of the pair may scatter with the positron (electron) of the colliding beam. So in the final state we find again (in the case of a pair production) one electron and one positron, plus a pair \( e^+ e^- \) or \( \mu^+ \mu^- \) or \( \pi^+ \pi^- \); but in most cases two of the four final particles will be aligned with the beams but they will travel both in the same direction and two may be scattered at large angle [4], [5].

More in general, we can define this case B) as the case in which one of the photon propagators is the hard one. The graph (in case of pair production) is of type:

\[ \text{forward} \quad \text{forward} \]

\[ \text{wide angle} \quad \text{wide angle} \]

\[ \text{forward} \]

A mechanism of this type is not only a QED curiosity. In case it occurs in reaction \( e^+ e^- \rightarrow e^+ e^- \mu^+ \mu^- \); \( e^+ e^- \pi^+ \pi^- \) it can be used [6] in principle for investigating electron-muon and electron-pion scattering. If we represent by \( \kappa \) and \( \bar{\kappa} \) the 2 muons or the two pions, and by \( e, \bar{e} \) the two final electrons \( (e_0, \bar{e}_0 \) are the initial particles) we have mostly a situation of type

\[ \sigma_{\kappa \bar{\kappa}} \rightarrow ee + \kappa \bar{\kappa} \quad (7) \]

that is, two particles (in the figure \( e, \kappa \)) come out in the almost forward direction with respect to the incident particle, while \( \bar{e} \) and \( \bar{\kappa} \) are emitted at large angles respect to the beam axis. The virtual muon or pions exchanged in the diagram (7) should tend [6] to be close to its mass shell and approximately collinear with the beam axis. So we can consider this process as involving the scattering of an almost real muon or pion with one electron.

2. Researches at Frascati. — In the following we shall present in a short synthesis what has been done experimentally in Frascati until now, and shall briefly comment the future scientific perspectives of reactions (2). Reactions (2) have been particularly studied by two experimental groups, the so-called \( (\gamma \gamma ) \) group and the \( (\mu \pi ) \) group.

The \( (\gamma \gamma ) \) group was the first to distinguish experimentally between reactions of type [5] and reactions of type [6] when the final state is formed by four electrons. Their first partial results have been already published, and are reinforced to day from further experimental data. They have results of \( 2 \times 1000 \) and \( 2 \times (1400 - 1500) \) MeV.

The results of the \( (\mu \pi ) \) group [7] are very interest-
RESEARCHES IN FRASCATI ON THE REACTIONS $e^+ e^- \rightarrow e^+ e^- + X$

...for they could study with significant statistics also the processes

$$e^+ e^- \rightarrow e^+ e^- + \mu^+ \mu^- \quad (8)$$

and they have preliminary evidence of the process

$$e^+ e^- \rightarrow e^+ e^- + \pi^+ \pi^- \quad (9)$$

It is clear that with processes like (9) we enter into the kingdom of the hadronic facts; in fact the value of the cross section for reaction (9) shall depend on the $\pi\pi$ interaction, and on the existence of particular bodies ($\pi$) decaying $\pi^+ \pi^-$. The rate of reaction (9), for instance, increases with the width of the decay $\pi \rightarrow \gamma\gamma$. We perhaps do not have enough statistics, yet, but we are on a very promising way.

The two experiments «$\gamma\gamma$» and «$\mu\mu$» use similar techniques, but they cover different angles and energies of the particles emitted at large angles. We must remind that both apparatus had been originally designed to observe ordinary qed phenomena, with two particles in the final state.

Before going ahead it is convenient to give a glance to the values of the cross sections for the different processes $e^+ e^-$ which may be observed in colliding beams. Our figure 1 makes clear that in the same apparatus events of the type of reactions (2) may happen with a frequency comparable with that of the events of type (1), to start from energies $2E$ of a few GeV. It is therefore important to distinguish as clearly as possible between reactions (1) and (2).

This may be achieved making use of the fact that in all reactions (2), if they follow diagram (4) or (5), or (6), at least two particles have a large probability to remain, within one degree or so, along the line of the colliding beams. This is definitely not the case for reaction (1). It is therefore obvious to put counters on the line of the $e^+ e^-$ beams, and to use the magnetic field of the machine itself as a spectrometer to verify that we are involved with process (2), and to measure the energy of the electrons emitted along the beam line. This was done in 1971 by the «$\gamma\gamma$» group [3], by placing scintillation counters very close to the beam line. Let's look now to the experimental dispositions of the «$\gamma\gamma$» and the «$\mu\mu$» apparatus, also to see their basic similarities and differences.

3. The experimental dispositions in Frascati. —

3.1 One basic progress to detect reactions (2) is the use of the time of flight tagging counters, as suggested by Barbiellini and Orito [8]. This provides both a large acceptance and a good momentum resolution.

With this method the forward emitted electron and or positron are recorded by tagging counters, as also shown in figures 2 and 3. The adopted technique [8] utilizes the machine bending magnet as a momentum analyzer; the momentum of the $e^+$ and/or $e^-$ is determined with an accuracy of $\pm 4\%$ by measuring the propagation time of the light inside the long counters $T$.

The time of flight tagging counters $T$, as well as the other counters along the beams, are about the same in both Frascati groups and are prepared now in all new experimental set up's in Frascati.

3.2 The «$\gamma\gamma$» APPARATUS. — Respect to the description already given in [3] there is the presence of the tagging counters $T$ with time of flight. The experimental disposition is given in figure 2.

A fraction of the particles emitted along the beam line is bent by the magnets of the storage ring, and detected by the long counters $TP(TE)$ or/and by the counters $CP(CE)$, which are located beyond the counters $TP(TE)$. Clearly counter $CP(CE)$ takes care of the positron (electron) which lost less energy in the bremsstrahlung act.

Above and below the interaction region (Fig. 2) four similar telescopes $A$, $B$, $D$, $S$, each made of plastic scintillators, optical spark chambers and lead converters [3] allow to distinguish with good accuracy between showering and not showering particles.

As you notice the apparatus can detect particles (electrons, muons, ...) emitted at small angle ($\theta < 15^\circ$) and in this respect it is unique in Frascati. Its main limitation is instead in the fact that the trigger is rather hard: to trigger the apparatus a particle

![Fig. 1. — A comparison between total cross sections for processes $e^+ e^- \rightarrow e^+ e^- + X$ and the multihadronic total cross sections at the same energy, for the one-photon annihilation process $e^+ e^- \rightarrow$ multihadrons. The experimental points for multihadronic one-photon annihilation are represented with open circles. (Frascati and C. E. A.).]
entering one of the telescopes ABDS must have an initial range of at least 41 g/cm² of equivalent iron.

All these characteristics make our apparatus rather different (complementary) respect to the «μπ» apparatus, which we describe now.

3.3 THE «μπ» APPARATUS. — This apparatus is shown in figures 3, 4.

As you see from figure 3 the tagging system is substantially the same than in the «γγ» case.

The particles emitted at large angle are detected by a system of two wide angle (WA) telescopes, as sketched in figure 3. In figure 4 is given a cross sectional view of the WA apparatus. Near the machine vacuum chamber is a system of thin foil spark chambers, for kinematical reconstruction of the events. The other (thick plate) spark chambers are used to observe particle stops, nuclear interactions, or the development of em showers. I leave to the next speaker a proper description of the μπ apparatus.

![Diagram 1](image1.png)

**FIG. 2.** a) The straight section of Adone machine (top view) with wide-angle set-up, the tagging counters CE, TE, and CP, TP and the calibration Cerenkov counters C₁ and C₂. Q/: quadrupole; B/: bending magnet (experiment of groups «γγ»). b) The wide-angle apparatus; side view from the center of Adone ring. --- scintillation counter, □ spark chamber ⊙ lead (γγ group).

![Diagram 2](image2.png)

**FIG. 4.** Cross-sectional view of the WA telescopes («μπ» groups). The outer thick absorbers and track chambers are used for the simultaneous investigation of the one photon channel processes, not considered here.

In both «γγ» and «μπ» apparatusi, the basic requirements for the selection of the events are:

- presence of two single particles (track or shower), one in above and one below the spark chambers,
- time coincidence within 10 ns, from the instant of beam-beam collision,
- a coincidence pulse in at least one of the two tagging counters.

The penetration (minimum range) of the particles which is required to trigger the spark chambers is specified in table I, where the «γγ» and «μπ» apparatus are compared. In the same table we also gave the minimum angle θ_{min} under which a particle, or electron, may be observed. As we can see from table I the two

<table>
<thead>
<tr>
<th>Group</th>
<th>Event type</th>
<th>Penetration of one particle (g/cm²)</th>
<th>Penetration of the other particle (g/cm²)</th>
<th>θ_{min}</th>
</tr>
</thead>
<tbody>
<tr>
<td>«μπ»</td>
<td>DT-e</td>
<td>40</td>
<td>11</td>
<td>45°</td>
</tr>
<tr>
<td></td>
<td>ST-e</td>
<td>40</td>
<td>22</td>
<td>45°</td>
</tr>
<tr>
<td></td>
<td>DT-μ</td>
<td>40</td>
<td>11</td>
<td>45°</td>
</tr>
<tr>
<td></td>
<td>ST-μ</td>
<td>40</td>
<td>40</td>
<td>45°</td>
</tr>
<tr>
<td>«γγ»</td>
<td>DT-e</td>
<td>41</td>
<td>41</td>
<td>24°</td>
</tr>
<tr>
<td></td>
<td>ST-e</td>
<td>41</td>
<td>41</td>
<td>24°</td>
</tr>
<tr>
<td></td>
<td>DT-μ</td>
<td>41</td>
<td>41</td>
<td>24°</td>
</tr>
<tr>
<td></td>
<td>ST-μ</td>
<td>41</td>
<td>41</td>
<td>24°</td>
</tr>
</tbody>
</table>

Table I

**Requirements on minimum particle penetration (at 90° impact) and minimum angle θ_{min} (viewed from the center of the target) for the different experiments at Frascati.**

The two apparatusi have rather different characteristics in range (the detector of the γγ group is more hard, as we already said) and in θ_{min}. This may explain the rather different results of the two experiments, and make them rather complementary, considering that the phenomena we are studying depend very critically on θ_{min} and on the energy.
In both experiments the events are subdivided in two categories:

Singly tagged events (ST events) and Doubly tagged (DT events). The $e^+e^→e^+e^-e^+e^-$ events are searched among the events which exhibit two electron originated electromagnetic showers in the spark chambers; the $e^+e^-→e^+e^-μ^+μ^-$ events are searched among those which show two tracks with no shower or nuclear interaction in the spark chambers.

4. A short summary of the Frascati results. — Before going to the experimental detailed results, it may be convenient to synthetize them, since now. This synthesis is very simple:

A) Processes

$$e^+e^-→e^+e^-+e^+e^-$$

(10)

exist, and their rate agrees with the theoretical provisions in both cases, ST and DT. To get this agreement one must take into account both diagrams (5) and (6). The contribute of diagram (6) to events DT is negligible. These results confirm the first observations in Frascati by Bacci et al. [3].

B) Processes (8), (9)

$$e^+e^-→e^+e^-+μ^+μ^-$$

exist, and also in this case the rate agrees with the theory. Most of the evidence of these processes come from the $μπ$ group.

C) There is evidence from the $μπ$ group for processes (9)

$$e^+e^-→e^+e^-π^+π^-$$

and this rate seems to be lower (by a factor $≈ 6$) than the rate of reaction (8). This is an interesting still very preliminary information.

In fact the simple Born calculation (following q. e. d.) foresees a cross section for process (9) which is $≈ 1/8$ of process (8). The existence of an $e$ particle could easily enhance the pion pair production of a factor 2-6 [2]. This is one of the most interesting points opened to future investigations.

Now we enter in the details of the experimental results. I will do it for the $γγ$ group. Santonico for the $μπ$ group.

5. Experimental results of the $γγ$ group. — 5.1 We have extended our previous experimental study [3] of processes (2), with particular regard to reactions (10), (8)

$$e^+e^-→e^+e^-e^+e^-$$

$$e^+e^-→e^+e^-μ^+μ^-$$

using the same apparatus (plus improvements) which we used for the previous research [3] at $2 × 1000$ MeV.

The experimental disposition is given as we already said, in figure 3.

Respect to the previous disposition, we added as tagging counters the two long counters TE, TP, following the suggestion of Barbiellini and Orito [8].

The geometrical efficiency of the complete tagging system is given in figures 5, 6. By $(E - K)$ we mean the energy of the electron after the interaction, $E$ being the initial beam energy.

The efficiency and momentum calibration have been obtained:

1) by measuring the energy of the photons coming from beam-gas bremsstrahlung with a lead glass Cerenkev counter C (figure 2) in coincidence with TE, TP;

2) by use of process $e^+e^-→e^+e^-γ$, with γ emitted at wide angle.

Above and below the interaction region (Fig. 2) four similar telescopes A, B, D, S each made of plastic scintillators, optical spark chambers and lead converters [3], allow to distinguish with good accuracy between showering and not showering particles. The detection efficiency of the ABDS telescopes for incident electrons has been measured by
means of the pair spectrometer of the Frascati electron-
synchrotron [9]. The results are given in figure 7.
The trigger requires at least two particles at rather
wide angles (16° < θ < 140°) in the four telescopes,
in coincidence (within 10 ns) with at least one particle
in one at least of the counters CP, CE, TP, TE.
Č is a veto Cerenkov counter.

5.2 Numerical results. — As known, the results
we obtained in 1971 for reaction [10], were at first
in disagreement with the existing theoretical calcula-
tions, which had been based on the hypothesis of
two « quasi-real » photons (diagram (5)). The
addition to the previsions of diagram (6), made the
agreement between theory and experiment reasonably
good. It is impossible to expect more than this espe-
cially in the case of diagram (6), considering the still
large theoretical uncertainties. The calculations for
this diagram, proposed by Cabibbo and Parisi, are
still unpublished.

The explored energies are now 1 400 and 1 500 MeV,
and we add together the yield, to get some statistical
significance. The total luminosity in the present
experiment is:

\[ L = 118.5 \text{ at } 1 \, 400 \text{ MeV per beam} + 49.5 \text{ at } 1 \, 500 \text{ MeV} = 168 \, \text{nb}^{-1} \left(168 \times 10^{33} \text{ cm}^{-2}\right). \]

To avoid accidentals due to Bhabha scattering,
we selected the collected events by requiring that the
particles at wide angle should not be collinear within
less that 10°. With this cut we obtained a total of
46 events due to reaction \( e^+ e^- \rightarrow e^+ e^- + e^+ e^- \).
They can be divided as shown in table II. By ST(DT)
we indicate the events with one single (a double)
coincidence between the tagging counters.

Let us now analyse in more detail our 46 events
of reaction (10), the events ST first. We may safely
assume that the two electrons which do not appear
in the spark chambers go along the beam direction [3],
[4]. In this approximation the cm of the two electrons
emitted at wide angles moves also along the beam
direction, and its velocity \( \beta \) is determined [3] by
measuring the particle angles \( \theta_1 \) and \( \theta_2 \) with respect
to the beam (see Fig. 2):

\[ \beta = \frac{\sin (\theta_1 - \theta_2)}{\sin \theta_1 \sin \theta_2}. \]

The \( \beta \) distribution of our events ST in the two possible
cases of a coincidence with counter T or C is reported
in figures 8, 9. We define \( \beta \) as negative (positive)
when the cm moves in the same (opposite) direction
with respect to the particle detected by the tagging
counter T or C.

<table>
<thead>
<tr>
<th>Type of event</th>
<th>Expected number</th>
<th>Observed number</th>
<th>Lumin. (nb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-e</td>
<td>10.46 + 19.94 = 30.4</td>
<td>44</td>
<td>168</td>
</tr>
<tr>
<td>DT-e</td>
<td>1.4</td>
<td>2</td>
<td>168</td>
</tr>
</tbody>
</table>

As we already discussed in a previous paper, our
results cannot be explained by the single diagram (5),
but diagram (6) brings a large contribute (see Fig. 8, 9).
The events with \( \beta > 0 \) are mostly coming from di-
agram (6).
The events with \( \beta < 0 \) are mostly from diagram (5).
We have now a rather good agreement between
theory and experiment in this region also. Our results
have been compared with the Monte Carlo predictions.
By QRP and VP in the figures 8 and 9 we indicated

![Fig. 7. — Energy dependence of the electron detection effi-
ciency in wide-angle telescopes (γγ group).](image)

![Fig. 8. — Events ST (single tagging) detected by counter TE
or TP. The experimental distribution of the centre of mass
velocity \( \beta \) of two wide-angle electrons compared with the
absolute theoretical predictions. In the hystogram each square
represents one event. The open circles describe the absolute
« quasi-real photon » prediction and the dark triangles the
absolute « virtual photon » prediction (« γγ » group).](image)
RESEARCHES IN FRASCATI ON THE REACTIONS $e^+e^-\rightarrow e^+e^-+X$

![Diagram of reaction $e^+e^-\rightarrow e^+e^-+X$]

Fig. 9. — Events ST (single tagging) detected by counter CE or CP. The experimental distribution of the centre of mass velocity of two wide-angle electrons compared with the absolute theoretical predictions. In the histogram each square represents one event. The open circles describe the absolute « quasi-real photon » prediction and the dark triangles the absolute « virtual photon » prediction (« $\gamma\gamma$ » group).

The results with « quasi-real photons » (diagram (5)) and with a « virtual photon » (diagram (6)).

The Monte Carlo has been tested for the diagram (5), and we have found a good agreement between the Monte Carlo results of an ideal $4\pi$ and perfectly efficient apparatus and the total cross section previous of Arteaga-Romero et al. [10].

In figure 10 are also reported our previous experimental results [3], at $2 \times 1000$ MeV, compared with our present Monte Carlo predictions. Our previous Monte Carlo calculations agree very well on diagram (6) with our present ones. As for diagram (5), there is a discrepancy of a factor $\sim 3$ respect to present predictions, and we are studying the origin of it.

As for the DT-$\mu$ events, we have 2 cases, to be compared with a Monte Carlo prediction of 1.4.

In table II we have summarized our results for process (10).

5.3 We cannot give yet the number of ST-$\mu$ events (process (8)) $e^+e^-\rightarrow e^+e^-\mu^+\mu^-$ with a single tagging, due to the insufficient information on our background. Preliminary results indicate 8 events, in agreement with our Monte Carlo expectation.

The number of DT-$\mu$ events is two, to be compared with a Monte Carlo prediction of 1.7.

6. Conclusions. — In conclusion, the observations of the $\gamma\gamma$ group are in reasonable agreement with the theoretical predictions in the region from $2E=2\times1000$ to $2E=2\times1500$ MeV. Our results confirm that reactions (2), going through the channels of diagrams (4), (5) or (6), are at disposal for future original research when going to higher energies and luminosities.

As it shall appear in the reports of to-day and to-morrow, when going to the highest energies (2 $E > 3$ GeV) we must expect great difficulties and very interesting results. The difficulty is found in the nature of the $e^+e^-$ collision in to-day rings: the bunches of $e^+$ and $e^-$ are very narrow and dense, and to separate the $\gamma\gamma$ interaction events from ordinary bremsstrahlung and double bremsstrahlung shall be difficult.

The interest is immense: nature and width of $\pi, \eta, \eta'$, analysis of all positive C states; study of $e^-\mu, e^-\pi, e^-\kappa$ scattering, to quote only the most obvious. We are just beginning, like multi-hadronic production was at the beginning three years ago.

References

[1] A recent report of Kessler, P., in view of the 3-4 September 1973 Meeting in Paris on the $\gamma\gamma$ interactions contains a large bibliography on this subject.


[5] This particular aspect of the 2 photon diagram has been suggested by Cahnbo, N. and Parisi, G., to interpret the unexpected results of Bacci et al. [3].


K. Strauch (CEA). — Do you have any troubles with gas background or accidentals in single-tagged events?

Salvini. — For events $e^+ e^- \rightarrow e^+ e^- e^+ e^-$, no. For events $e^+ e^- \rightarrow e^+ e^- \mu^+ \mu^-$, yes. In fact, our number of $e^+ e^- \mu^+ \mu^-$ cases (or $e^+ e^- \pi^+ \pi^-$, we cannot distinguish) from single tagging, which I gave as being 8, is still uncertain, as I said, due to the uncertainty in background (single beam subtraction). Of course, I consider the double-tagging muon events (they are two) that we found as free from background effects.

S. Brodsky (SLAC). — Were the $C = -1$ ee $\rightarrow$ eeee diagrams included in the calculation of the single-tagged events? They can contribute a cross-section one power of $\log \frac{E}{m_e}$ smaller than the main cross section.

Salvini. — This contribution should be smaller by at least a factor of five. Anyway, we did not include it into our Monte Carlo calculations.

S. Orito (Frascati). — The contribution of the $C = -1$ diagram is negligible at least for the data of the $\mu \pi$ group. The $e^+ e^-$ invariant mass of this process goes down much faster than that of the photon-photon process. Since the $e^+ e^-$ mass threshold of our system is about 400 MeV and since our wide-angle telescopes are located at large angle, this contribution turns out to be very small.

W. Wallraff (Aachen). — Could you compare your results on ee $\rightarrow$ eeee(ee$\mu\mu$) to the theoretical predictions for the various diagrams, as given for example by Brodsky or Kessler?

Salvini. — We did, but only in first approximation. We used the results for quasi-real photons as given in the literature quoted, and the estimates of G. Parisi for the 2-photon diagram, type B. We did not make an extended analysis as now it starts becoming possible. Our statistics, anyway, are still very limited.

P. Kessler (Paris). — One may be surprised that the ratio between «virtual photon events» and «quasi-real photon events» is so high in the single-tagging analysis (about a factor of 2). I guess that this should be due to the fact that the energy loss of the tagged electron is quite high. Is that correct?

Salvini. — Yes, but the main effect comes from the fact that one wide-angle electron has high energy.

G. Barbiellini (Frascati). — From an experimental point of view, one important difference between the processes A and B mentioned by Salvini is that the two particles coming at wide angle from process B have at least a total energy $E$ (one beam energy), while for process A they are accumulated around the low energy cut. As a consequence, the ratio between events of type B and A is strongly dependent on the apparatus.

Salvini. — Yes. We are going to study systematically these kinematics, since our apparatus allows us to make some estimate of the electron energy.