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G. P. Murtas, G. Penso, G. Salvini, M. Spinetti, B. Stella and A. Zallo:
FURTHER RESULTS ON REACTIONS $e^+e^- \rightarrow e^+e^-e^+e^-$ AND $e^+e^- \rightarrow$
 $e^+e^- \mu^+ \mu^-$ WITH ADONE STORAGE RING AT 1400-1500 MeV. -

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1. - INTRODUCTION. -

The study of the interactions

$$(1) \quad e^+e^- \rightarrow e^+e^- + X$$

is an interesting field of research, whose importance has been recently emphasized by some experimental results and verifications^(1,2) and by several theoretical analysis^(3,4).

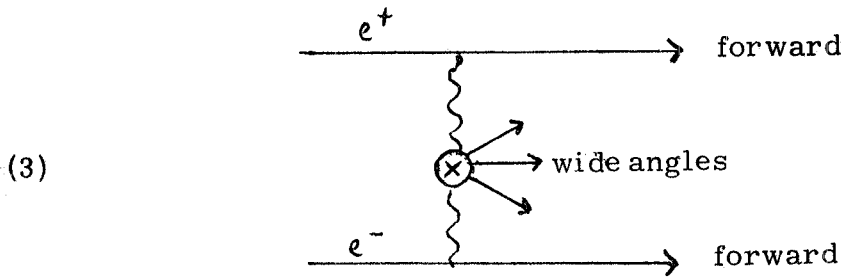
The system X may be obtained in many ways, and two have been certainly observed in the last two years:

1a) The two initial electrons irradiate one photon each⁽³⁾ in a glimp sing 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, that is a process:

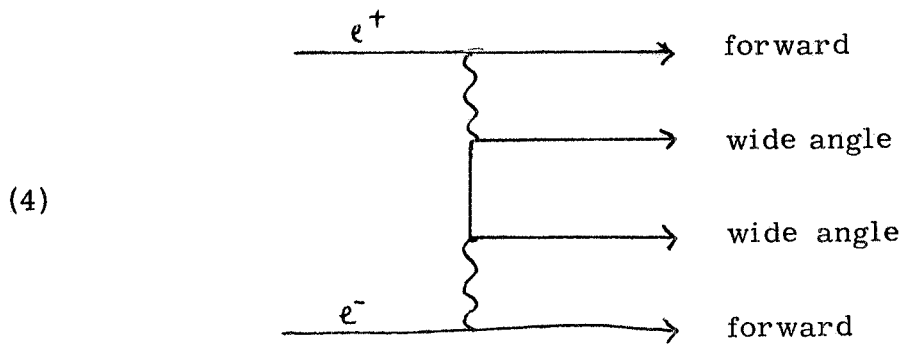
$$(2) \quad e^+e^- \rightarrow (e^+e^-) + (\gamma\gamma) \rightarrow (e^+e^-) + X \quad \text{which in simple graph takes the general form:}$$

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2.



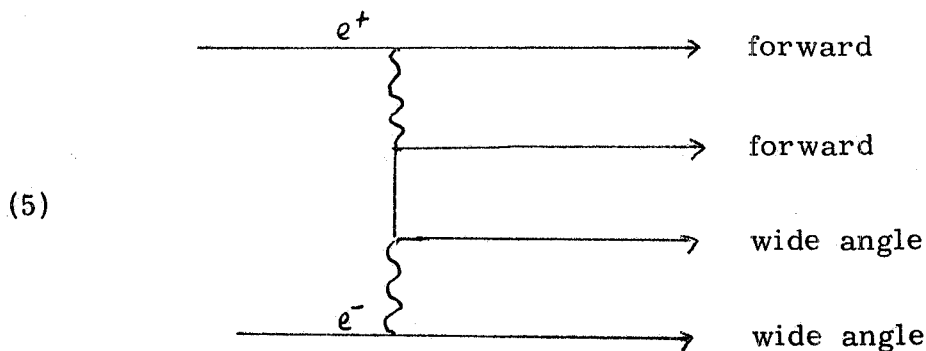
and more specifically, in case of pair production, the form:



This opens the way to the study of all X systems with even spin and $C=+1$, for instance the ξ , η , η' particles.

1b) One electron (positron) of the colliding beams emits a photon which converts into a group of particles (mostly a pair, e^+e^- ; $\rho^+\rho^-$; $\pi^+\pi^-$; k^+k^-). One particle of the pair may interact by elastic scattering, with the positron (electron) of the colliding beam⁽⁵⁾. So in the final state we find again (in the case of a pair production) one electron and one positron, plus e^+e^- or $\rho^+\rho^-$, $\pi^+\pi^-$, but in most cases two of the four particles will be aligned with the beam and travel both on the same side, and two may be scattered at large angle.

The corresponding graph (in case of pair production) is of the type:



The two scattered particles may be identical or not.

Of course events of the type of diagr.(5), where one of the photons is deeply virtual, are in principle very interesting, for they still may be the best way to study directly the scattering electron-unstable particle, for instance the strongly wanted interaction $e-\mu$, or $e-\pi$ (6).

2. - EXPERIMENTAL DISPOSITION. -

We have extended our experimental study of processes (1), with particular regard to reactions:

$$(6) \quad e^+e^- \rightarrow e^+e^-e^+e^-$$

$$(7) \quad e^+e^- \rightarrow e^+e^- \mu^+ \mu^- ,$$

with the same apparatus (plus improvements) which we used for a previous research(2).

The experimental disposition is given in Fig. 1a, b.

In our previous work around 2×1000 MeV c.m. the forward emitted electrons or positrons were bent by the magnets of the storage ring and a fraction of them were detected by the counters CE, CP respectively (Fig. 1a). In the present disposition we added as tagging counters two long counters TE, TP, following a suggestion by Barbiellini and Orito(7).

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 counters.

The geometrical efficiency of the complete tagging system is given in Figg. 2, 3. 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 Cerenkov counter \check{C}_1 (\check{C}_2) (Fig. 2a), in coincidence with TE, TP;

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

Above and below the interaction region (Fig. 2b) four similar telescopes A, B, D, S, each made of plastic scintillators, optical spark

" $\gamma\gamma$ " GROUP EXPERIMENT

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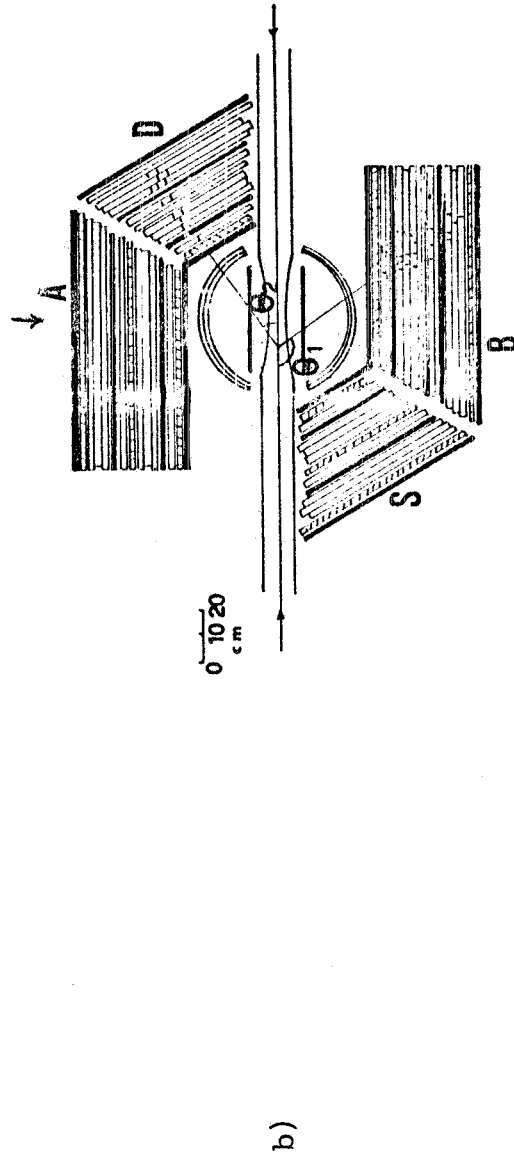
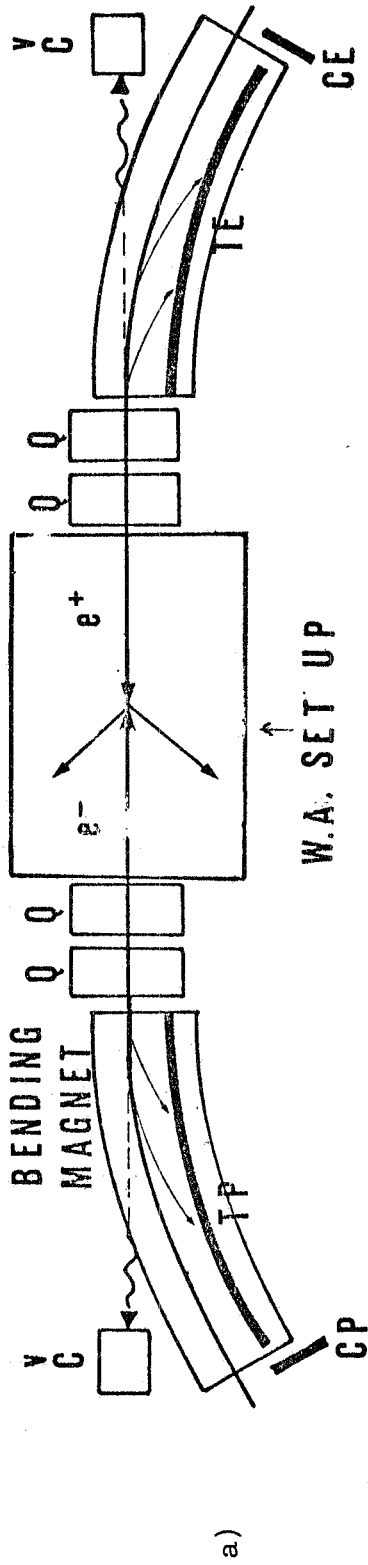


FIG. 1 - a) The straight section of Adone machine (top view) with wide-angle set-up, the tagging counters Ce and Cp and the calibration Čerenkov counters C₁ and C₂. Q : quadrupole; B: bending magnet. b) The wide-angle apparatus; side view from the center of Adone ring. ▨ : scintillation counter; ▭ : spark chamber; ▩ : lead.

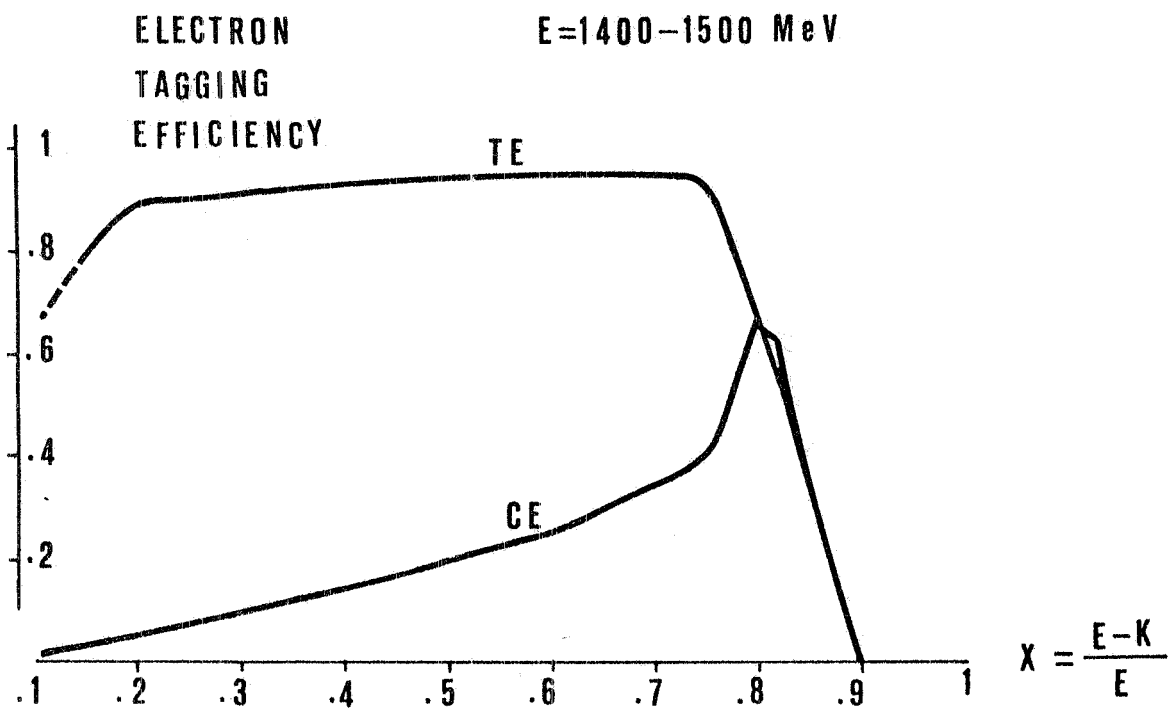


FIG. 2 - Efficiency behaviour, of the TE and CE tagging telescopes as a function of the tagged electron energy beam unit.

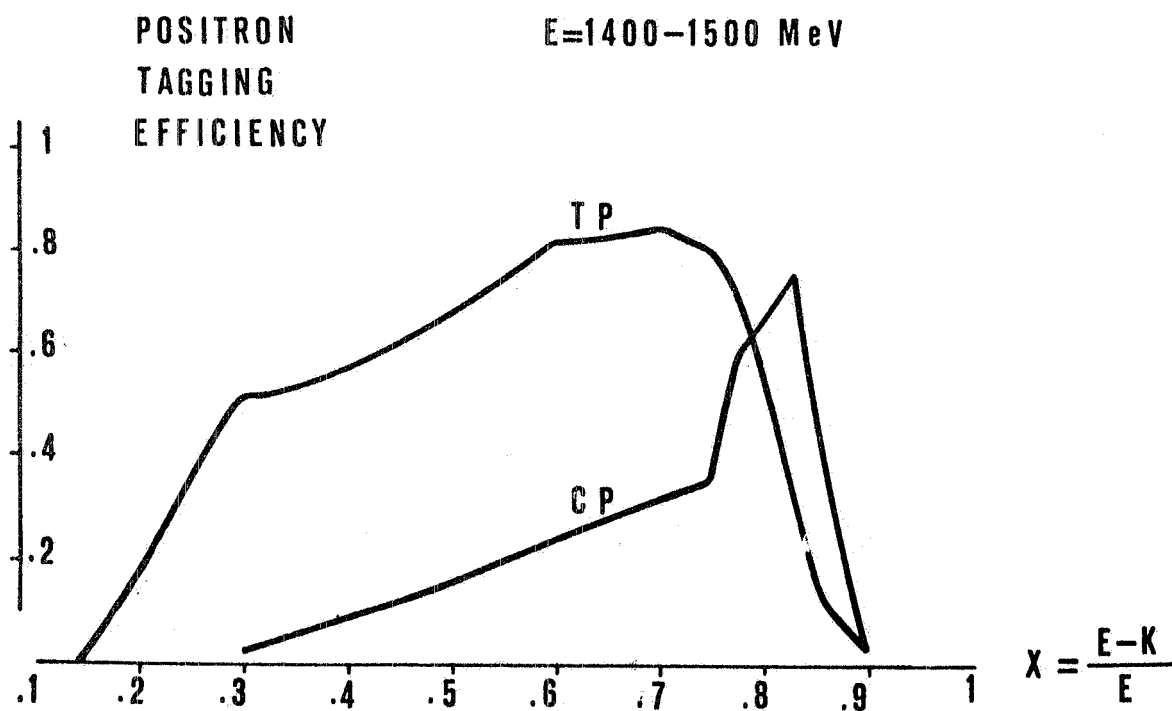


FIG. 3 - Efficiency behaviour, of the TP and CP tagging telescopes as a function of the tagged positron energy in energy beam unit.

chambers and lead converters⁽²⁾, 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⁽⁸⁾. The results are given in Fig. 4.

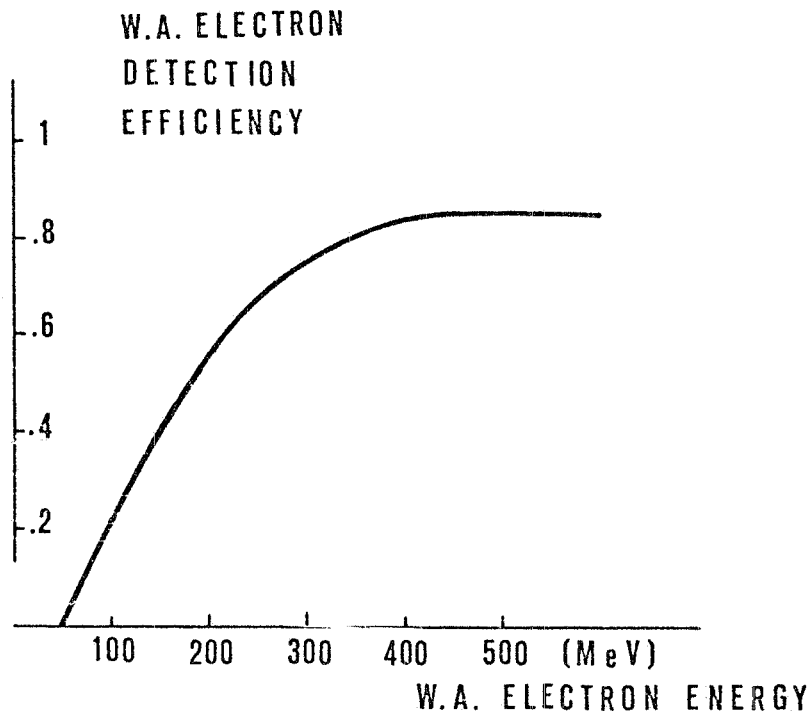


FIG. 4 - Energy dependence of the electron detection efficiency in wide-angle telescopes.

The trigger requires at least two particles at rather wide angles ($16^\circ \leq \theta \leq 140^\circ$) in the four telescopes, in coincidence (within 10 nsec) with at least one particle in one at least of the counters CP, CE, TP, TE. \checkmark is a veto Cerenkov counter.

As you notice the apparatus can detect particles (electrons, muons,) emitted at small angle, 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 entering one of the telescopes ABDS must have an initial range of at least 41 g/cm^2 of equivalent iron.

3. - EXPERIMENTAL RESULTS. -

3.1. - As known, the results we obtained⁽²⁾ were at first in disagreement with the existing theoretical calculations, which had been based on the hypothesis of two "quasi-real" photons (diagram (4)). The addition to the previsions of diagram (5), made the agreement between theory and experiment reasonably good. It is impossible to expect more than this especially in the case of diagram (5), considering the still large theoretical uncertainties. The calculations for this diagram, proposed by Cabibbo and Parisi, are still unpublished.

The explored energies are now 1400 and 1500 MeV, and we add together the yield, to get some statistical significance. The total luminosity in the present experiment is:

$$L = 118.5 \text{ at } 1400 \text{ MeV per beam} + 49.5 \text{ at } 1500 \text{ MeV} = 168 \text{ nb}^{-1} (168 \times 10^{33} \text{ cm}^{-2})$$

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 than 10^0 . 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 1. 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 (6), the events ST first. We may safely assume that the two electrons which do not appear in the spark chamber go along the beam direction^(3,4). In this approximation the c.m. of the two electrons emitted at wide angles

TABLE I

Number of observed and expected events ($E = 1400 - 1500 \text{ MeV}$) in process $e^+e^- \rightarrow e^+e^-e^+e^-$. The expected number is the addition of diagram (4) and (5) respectively. Interference between the diagrams (4) and (5) has been disregarded.

Type of event	Expected number	Observed number	Lum. (nb ⁻¹)
ST	10.46 + 19.94 = 30.4	44	168
DT	1.4	2	168

8.

moves also along the beam direction, and its velocity β is determined⁽²⁾ by measuring the particle angles θ_1 and θ_2 with respect to the beam (see Fig. 1b):

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

The β distribution of our events ST in the two possible cases of a coincidences with counter T or C is reported in Figg. 5, 6. We define β as negative (positive) when the c.m. moves in the same (opposite) direction with respect to the particle detected by the tagging counter, T or C.

As we already discussed in a previous paper, our results cannot be explained by the single diagram (4), but diagram (5) brings a large contribute (see Figg. 5, 6). The events with $\beta > 0$ are mostly coming from diagram (5).

The events with $\beta < 0$ are mostly from diagram (4). We have now a rather good agreement between theory and experiment in this region also. Our results have been compared with the Montecarlo predictions. By Q.R.P. and VP in the figures (5) and (6) we indicated the results with "Quasi Real photons" (diagram 4) and with a "virtual Photon" (diagram (5)).

The M.C. has been tested for the diagram (4), and we have found a good agreement between the M.C. results of an ideal 4π and perfectly efficient apparatus and the total cross section previsions of Arteaga-Romero et.al.⁽⁹⁾

The lack of complete theoretical calculations forbids an analogous test for the diagram (5), nevertheless the agreement of the forward peaked angular distribution, typical of this diagram, has been considered by us a first qualitative check.

We have also confidence on the M.C. subroutines simulating the experimental set up; in fact these subroutines have been used successfully in the past for the analysis of our e.m. processes.

A further analysis and comparison of our Montecarlo programs is in progress.

As for the DT-e events, we have 2 cases, to be compared with a Montecarlo prediction of 1.4.

In Table I we have summarized our results for process (6).

3.2. - We cannot give yet the number of ST- μ events (process (7) $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ with single tagging), due to the insufficient information on our background.

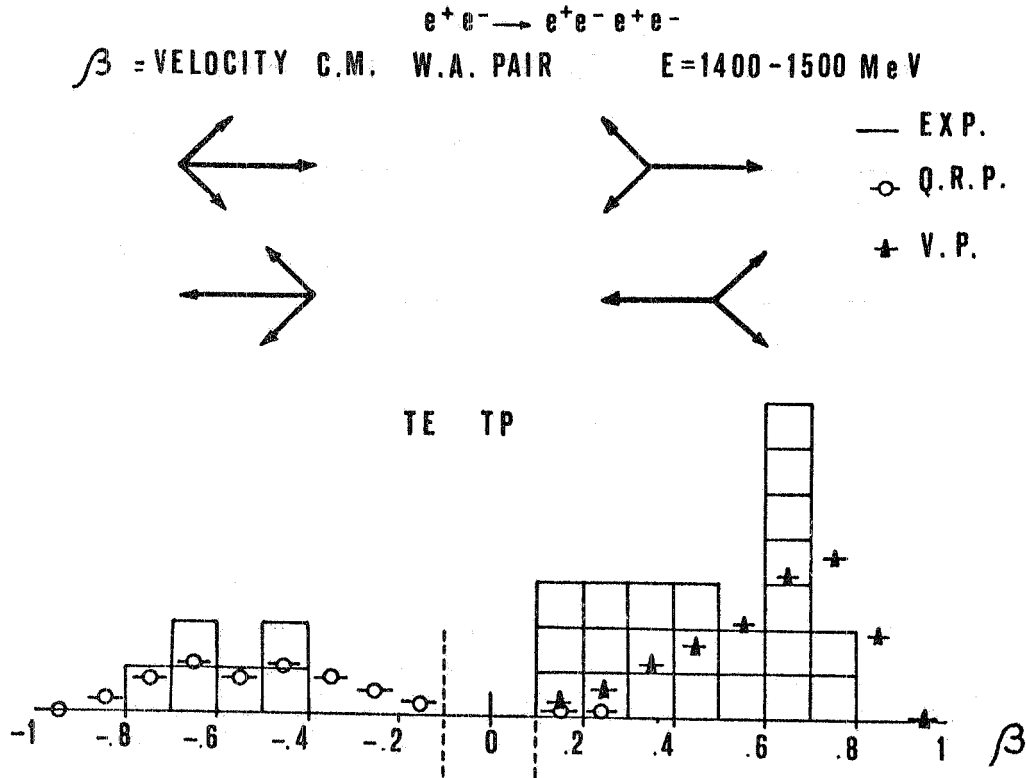


FIG. 5 - Events ST (single tagging) detected by counter TE or TP. The experimental distribution of the centre of mass velocity of two wide-angle electrons compared with the absolute theoretical predictions. In the histogram each square represents one event. The open circles describe the absolute "quasi real photon" prediction and the dark triangles the absolute "virtual photon" prediction.

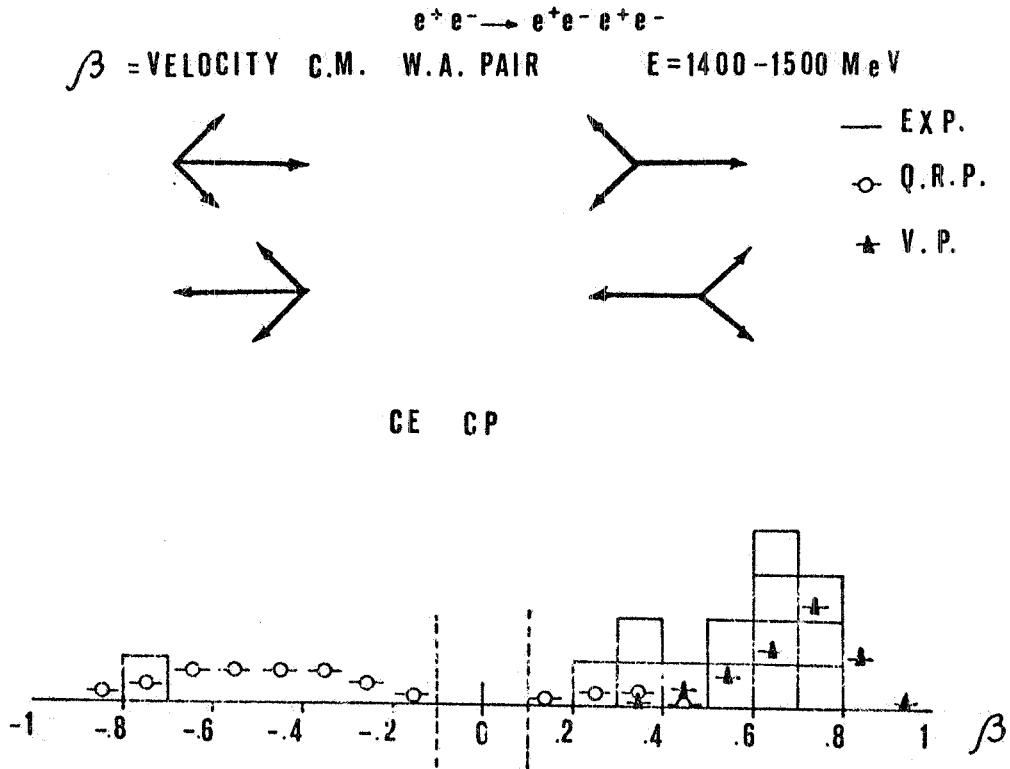


FIG. 6 - Events ST (single tagging) detected by counter CE or CP. The experimental distribution of the centre of mass velocity of two wide-angle electrons compared with the absolute theoretical predictions. In the histogram each square represents one event. The open circles describe the absolute "quasi real photon" prediction and the dark triangles the absolute "virtual photon" prediction.

The number of DT- μ events is two, to be compared with a Montecarlo prediction of 1.7.

4. - CONCLUSIONS. -

In conclusion, all our observations are in reasonable agreement with the theoretical predictions at 1400 and 1500 MeV. Our results confirm that reactions(1), going through the channels of diagrams (4) on (5), are at disposal for future original research when going to higher energies and luminosities.

We are very grateful to G. Parisi for many illuminating discussions.

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