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SOME BACKGROUND PROBLEMS IN PHOTON-PHOTON COLLISIONS IN ELECTRON-POSITRON STORAGE RINGS

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Résumé. — Considérant des réactions d’anneaux de collision, du type ee → eeX (X = μ- μ+ ; π- π+ ; K- K+ ; hadrons quelconques), nous comparons la contribution du bruit de fond (diagramme avec émission d’un photon lourd) à celle de l’effet principal (diagramme faisant intervenir une collision photon-photon) dans le cas où l’un des électrons sort à petit angle et l’autre à grand angle (θ > 2°). Pour une énergie de faisceau de 3 GeV, il s’avère, pour certaines valeurs ou régions particulières de la masse invariante totale produite, que le rapport bruit de fond/effet principal dépasse 100 % déjà à des valeurs modérément grandes de θ. Nous suggérons un moyen de réduire ce rapport. Nous montrons par ailleurs que le problème du bruit de fond est nettement moins critique à plus basse énergie des faisceaux.

Abstract. — For colliding beam reactions of the type ee → eeX (X = μ- μ+ ; π- π+ ; K- K+ ; any hadrons), we compare the contribution of the background (heavy-photon bremsstrahlung type diagram) with that of the main effect (photon-photon collision type diagram) in the case where one of the electrons comes out at small angle and the other one at large angle (θ > 2°). At a beam energy of 3 GeV, it appears, for some particular values or ranges of the total invariant mass produced, that the noise/signal ratio may exceed 100 % already at moderately large values of θ. A procedure is suggested in order to reduce this ratio. We also show that the background problem is much less critical at lower beam energies.

From the start of our work in 1969 [1], we have noticed that the idea of treating the colliding electron-positron or electron-electron beams — in reactions of the type ee' → ee' X — as colliding virtual photon spectra is subject to certain limitations. These restrictions are due to the background represented by the other diagrams of the same order in perturbation theory as the « photon-photon collision » diagram. We may call it the « theoretical background », in contradistinction to the experimental background which, according to the experimental conditions involved, may be provided by ordinary or radiative annihilation (in the electron-positron case), fortuitous coincidences, collisions with the residual gas, misidentification of particles and so on ; to handle this latter background is of course a matter for the experimentalists. Our problem is, since we are only interested in diagram (I) of figure 1, how to eliminate all the other diagrams, i. e. (II)-(VI) in the e- e+ case or (II), (III) and (I')-(III') in the e- e- case.

We have shown in our early work of 1969 that this background elimination can be performed very efficiently if both outgoing electrons are detected in their forward directions, i. e. at a few milliradians or at most at a few degrees with respect to the beam directions. Our qualitative argument was the following. Because of the photon propagators in $q^2$, both electrons in diagram (I) tend very strongly to come out in their forward directions ; in diagrams (II) and (III), this is true only for one of them ; in diagrams (IV)-(VI), for none of them. As for diagrams (I')-(III'), we can forget about them since they then involve backward scattering for both electrons, which means at least one enormous $q^2$ value. We made a quantitative check,

![Diagram](image-url)
evaluating the contributions of diagrams (II) and (III) under the conditions defined; we found them really negligible with respect to diagram (I), even when taking account of their resonant enhancements in the case of hadron production. We then assumed that the contribution of diagrams (IV)-(VI) (or (I')-(III')) can be neglected a fortiori.

It must be remarked that, due to the difference in charge conjugation number, diagrams (II) and (III) don’t interfere with diagram (I) if one averages over the charges of the particles produced. Among the other diagrams, only (VI) or (I') interfere with (I); however, we don’t have to worry about these interference terms since (VI) and (I') are particularly small under the conditions defined, due to the very large $q^2$ values involved.

Now, we knew from the start that, as soon as we would depart from this particular kinematic situation — i.e., both electrons scattered forward, the background problem might become dangerous. This danger has been stressed also by some other authors, in particular by Fujikawa [2] and Terazawa [3]. In the present work, we are considering the case where one of the electrons is scattered at large angle, the other one at small angle (Fig. 2). (As for the limit between

![Diagram](image)

FIG. 2. — Kinematic scheme.

«large angle» and «small angle», we fix it arbitrarily at 2°.) Such a situation will have to be considered in storage ring experiments where:

1) no detection at all is possible for electrons coming out in the forward direction; then only the large-angle outgoing electron is measured but the other one (scattered at about 0°) may possibly be reconstructed (in particular if X is only composed of two charged particles and their momenta are measured);

2) for some experimental reason, it may be easier to detect a forward-going electron only on one side rather than on both sides;

3) for theoretical reasons, one is really interested in this case: for instance, one wants to measure deep inelastic scattering on the photon as was suggested by Walsh [4] and by Brodsky, Kinoshita and Terazawa [5]; or one wants to measure various electromagnetic form factors of hadrons, as was suggested by us [6], [7];

4) or simply, one wants to analyze these events since, in any case, they will appear in addition to those where both electrons are scattered forward.

We thus compare, for a beam energy of 3 GeV, the differential cross section $d^4\sigma/dM^2 d(\cos \theta)$, where $M$ is the invariant mass of X and $\theta$ the scattering angle of the large-angle electron, for diagrams (I) and (II) or (III) respectively. (Let us suppose that the large-angle electron is the right-hand one; then only diagram (II), not (III), is taken into account.) In our calculation, the forward scattered electron’s angle was integrated over up to $2\theta$, and no other cut was made on angles and energies of outgoing particles.

Following reactions are considered:

\[
\begin{align*}
e e' & \rightarrow ee' \mu^- \mu^+ \\
e e' & \rightarrow ee' \pi^- \pi^+ \\
e e' & \rightarrow ee' K^- K^+ \\
e e' & \rightarrow ee' \text{ plus any hadrons } (M > 1 \text{ GeV}).
\end{align*}
\]

Before showing you the results, let me make the following remark. Only for process (1), both diagrams (I) and (II) can be calculated in a sure way (pure QED). For processes (2), (3), (4), only the calculation of diagrams (II) is a relatively sure one, since it was based on QED combined with existing experimental results on $e^- e^+$ annihilation. Actually, for $\pi^- \pi^+$ and $K^- K^+$ production, we used Renard’s formulae [8] which seem to fit the experimental data well; for «any hadron» production, with $M > 1$ GeV, we used existing data from Frascati and CEA [9]. On the contrary, for any process $\gamma\gamma \rightarrow \text{hadrons}$, we must rely on a model. For $\gamma\gamma \rightarrow \pi^- \pi^+$ and $K^- K^+$, we simply chose the Born term model, with the isovector Dirac form factor at the vertex where $q^2$ is large. Except for $\gamma\gamma \rightarrow \pi^- \pi^+$ in the low-energy region (below $M^2 \approx 0.5 \text{ GeV}^2$, where theorists think [10] that the Born term predictions should be more or less correct), such a calculation should be regarded as very rough. In general, it should be an overestimation (since field-theoretical models usually over-estimate hadronic processes), although on the other hand resonant enhancements may reinforce these processes (but again any estimation of these enhancements is model-dependent). As for $\gamma\gamma \rightarrow \text{any hadrons } (M > 1 \text{ GeV})$, we used the following procedure, based on VDM:

\[
\begin{align*}
\frac{d^4\sigma}{d^2q^2 dM^2 d(\cos \theta)} & \approx \frac{4 \pi a}{f_{\gamma p}^2} \sigma_T^{\gamma\gamma}(q^2, M^2) \\
& \approx 4 \frac{\pi a}{f_{\gamma p}^2} (0.6) \sigma_T^{\gamma\gamma}(q^2, M^2)
\end{align*}
\]

where the coefficient 0.6 is given by the quark model (see [4], [5]). For $\sigma_T^{\gamma\gamma}(q^2, M^2)$, we used the fit given by Brasse et al. [11] for virtual photoproduction (i.e. electroproduction data), where we made $\sigma_L/\sigma_T = 0.18$ (at any $q^2, M^2$) and replaced everywhere in the formu-
As the technique of calculation used, the only approximation we made was to use the Williams-Weizsäcker method at the left-hand vertex. Since we are limiting ourselves to small transfers at that vertex, we know that this approximation should give the correct order of magnitude.

I shall now show you the curves for the four processes considered, for various fixed values of $M$. The critical parameter will be the angle where the two curves pertaining to diagram (I) and (II) respectively intersect. Indeed, as long as (II) is small with respect to (I), it can in principle be properly subtracted. When it becomes comparable to or larger than (I), then — accounting also for experimental errors — the analysis in terms of $\gamma\gamma$ scattering becomes difficult and eventually meaningless.

(1) $\mu^-\mu^+$ production. — You notice (Fig. 3) that, slightly above threshold ($M = 250$ MeV), the crossing of the curves occurs at $36^\circ$; at $M = 400$ MeV, it occurs at $65^\circ$. At 800 MeV, the value of the intersection point was calculated to be about $120^\circ$. In conclusion, there is practically no background problem, except very near threshold.

(2) $\pi^-\pi^+$ production. — The intersection points are (Fig. 4): $37^\circ$ at $M = 300$ MeV; $25^\circ$ at 500 MeV; $16^\circ$ at 750 MeV; $40^\circ$ at 1 000 MeV; higher values are found at larger invariant masses. We thus notice that the background problem is essentially acute in the region of the $\rho$ (where one would like, precisely, to look for the $\sigma$ or $\epsilon$ in diagram (I)).

(3) $K^-K^+$ production. — Here the crossing between the curves occurs (Fig. 5) at $6^\circ$ for $M = 1 019$ MeV, and at $26^\circ$ for 1 050 MeV; and at increasing angles for increasing invariant masses. We thus see that the background problem is very critical around the $\phi$ mass shell.

(4) « Any hadron » production ($M > 1$ GeV). — The intersection point lies at (Fig. 6): $28^\circ$ for $M = 1 200$ MeV, $23^\circ$ at 1 400 MeV, $26^\circ$ at 1 600 MeV, $82^\circ$ at 2 000 MeV; and at higher angular values for larger invariant masses. Thus the background problem is acute in the region around 1.4 GeV where the bump ($\rho'$ ?) of multi-hadron production in heavy-photon decay is located.

As a conclusion, we may state that, generally speaking, the background becomes dangerous — already at not too large angles — wherever diagram (II) gets a (resonant or other) enhancement. Qualitatively, our conclusion would be the same for experiments where both outgoing electrons would be detected at large angle. Actually, the situation would be somewhat worse, since both diagrams (II) and (III) should then be considered. Roughly speaking (i.e. neglecting the interference between (II) and (III)), the noise/signal ratio should then be multiplied in the average by a factor of 2: thus the crossing of the curves would occur at somewhat smaller values than those shown above.

When the outgoing electron angles become very large (calling « very large ») an appreciable fraction of a radian or so), it might become necessary to consider also the neglected diagrams (IV) (V) or (I')-(III'). However, at the luminosities available at present or in the near future, very large electron angles are out of reach anyway because of the rapid drop of the differential cross sections with increasing $q^2$ values.
FIG. 4. \( X = \frac{d^2\sigma}{dM^2 d(\cos \theta)} \) in \( 10^{-34} \text{ cm}^2 \cdot \text{GeV}^{-2} \) vs \( \theta \) at \( E = 3 \text{ GeV} \), for ee' \( \rightarrow \) ee' \( \pi^- \pi^+ \)

diagram (I) --- diagram (II)

(a) \( M = 300 \text{ MeV} \)  (b) \( M = 500 \text{ MeV} \)  (c) \( M = 750 \text{ MeV} \)  (d) \( M = 1000 \text{ MeV} \).
Shift of intersection point with energy $E = 3$ GeV

<table>
<thead>
<tr>
<th>$\omega_{\text{min}}/E$</th>
<th>0</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{\pi^+\pi^-}$ = 750 MeV</td>
<td>16°</td>
<td>25°</td>
</tr>
<tr>
<td>$M_{K^+K^-}$ = 1 019 MeV</td>
<td>6°</td>
<td>13°</td>
</tr>
<tr>
<td>$M_{\text{hadrons}}$ = 1 400 MeV</td>
<td>23°</td>
<td>28°</td>
</tr>
</tbody>
</table>

We also show (Fig. 7), for the same three cases, both the shift of the intersection point and the reduction of the counting rate (the «price to pay») with increasing $\omega_{\text{min}}/E$.

To end with, let me remark that we chose the value of 3 GeV for the beam energy because this value is a sort of average for the three high-energy high-luminosity storage rings which will run in a near future: SPEAR, DORIS and DCI. In order to get an idea about the background problem at lower energies, we extended our calculations to the value $E = 1$ GeV for one case (20% production). As table II shows, the situation is considerably better at lower beam energies.

This work was performed by C. Carimalo, P. Kessler and myself.

### Table II

<table>
<thead>
<tr>
<th>$E$</th>
<th>1 GeV</th>
<th>3 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{\pi^+\pi^-}$</td>
<td>300 MeV</td>
<td>500 MeV</td>
</tr>
</tbody>
</table>

$X \rightarrow 2 \gamma$. It is based on the fact that, considering any process $ye \rightarrow eX$, where $\gamma$ is the quasi-real photon emitted by the forward-going electron, its cross section increases with the energy $\omega$ of this photon as far as diagram (I) is concerned, and decreases with $\omega$ as far as diagram (II) is concerned. The procedure we suggest thus consists in cutting the smaller $\omega$ values away by means of a cut-off $\omega_{\text{min}}$. In case the forward-scattered electron is measured, such a minimal value for $\omega$ may be imposed anyway to some extent by the apparatus; if this electron remains undetected, we must of course assume that the value of $\omega$ can be reconstructed, from the parameters measured, with enough precision.

In table I we show the effect of such a cut-off in the three critical cases considered before. Taking $\omega_{\text{min}} = 600$ MeV (i.e. 20% of the beam energy $E$), the point of intersection is shifted as you can see in this table.

Comming back to our problem of one small and one «moderately large» electron angle, there is a way to reduce the noise/signal ratio, at the price of losing some fraction of the counting rate. We already suggested [6] such a procedure in order to reduce the background, due to double bremsstrahlung, in $e^- e^+ \rightarrow e^- e^+ X$ (with $X = \pi^0, \eta$ or $\eta'$) followed by...
FIG. 6. — $X = \frac{d^3\sigma}{dM^2 \ d(\cos \theta)}$ in $10^{-34}$ cm$^2$.GeV$^{-2}$ vs $\theta$ at $E = 3$ GeV, for $ee' \rightarrow ee'$ plus any hadrons

(a) $M = 1200$ MeV (b) $M = 1400$ MeV (c) $M = 1600$ MeV (d) $M = 2000$ MeV.
**Fig. 7.** - Effects of the cut-off $\omega_{\min}/\varepsilon$ on the counting rate ($\gamma$ only for diagram (I)) at fixed $\theta$, vs $\omega_{\min}/\varepsilon$

(a) $\gamma = e^+ e^- \rightarrow \pi^- \pi^+$ $M = 750$ MeV

(b) $\gamma = e^+ e^- \rightarrow K^- K^+$ $M = 1019$ MeV

(c) $\gamma = e^+ e^- \rightarrow \gamma$ plus any hadrons $M = 1400$ MeV.

References


DISCUSSION

A. ZICHICHI. — I would like to point out what seems to me a very interesting feature of the calculations presented by Dr. Parisi. The measurement of the cross-over angle \( \theta \) is relatively simple and represents a very clear parameter to disentangle the contributions from the \( C = +1 \) and \( C = -1 \) states.

K. SUBBARAO. — You can calculate the cross-section for \( ee \rightarrow ee + \text{any hadrons} \) through \( C = -1 \) diagrams in terms of \( e^+ e^- \) annihilation cross-sections. How did you estimate this cross-section for \( C = +1 \) diagrams?

J. PARISI. — As I have shown, it was a model-dependent calculation, based on VDM (connecting the quasi-real photon with the \( \rho_0 \)), the quark model (relating the \( \rho_0 \) to the proton), and finally an analysis of existing electroproduction data on the proton. This kind of model was already used by Walsh, and also by Brodsky, Kinoshita and Terazawa, in their respective predictions for « deep inelastic scattering on the photon ».

K. STRAUCH. — Why are the curves you have shown for diagram (II) so sharply peaked in the backward direction?

J. PARISI. — That diagram contains virtual Compton scattering, and there you have a backward pole in the photon-electron center-of-mass frame, which gives you this sharp backward peak even in the lab frame. More precisely, the pole occurs in that one of the two Compton scattering diagrams where the electron is exchanged in the u-channel.

G. FELDMAN. — I want to be sure that I understand the directions of your calculation in terms of the proposed SPEAR experiment I described today. In that case the energy will be 3.8 GeV rather than 3 GeV and the minimum angle for the second electron will be \( 3.5^\circ \) rather than \( 2^\circ \). Will both of these factors make the situation worse?

J. PARISI. — Yes, they will.

G. FELDMAN. — Then the interpretation of the deep inelastic scattering in terms of the conventional diagram will be difficult.

J. PARISI. — I am afraid it will be.

H. TERAZAWA. — Fujikawa estimated the background coming from the diagram (II) to the deep inelastic \( \gamma \gamma \) cross section by assuming that \( \gamma^+ + \gamma \rightarrow \text{any hadrons} \) can be approximated by \( \gamma^+ + \gamma \rightarrow \text{quark + antiquark} \). He concluded that, if scattering angles are large (\( \approx 90^\circ \)), diagram (II) contributes substantially (\( \approx 20-40\% \)). I estimated the similar background to the process \( \gamma^+ + \gamma^+ \rightarrow \text{any hadrons} \) where both of the photons are highly virtual. My conclusion was that the contribution of diagram (II) is less than 20%.

J. PARISI. — Do you mean: less than 20% in the total cross section, or also in the differential cross section with respect to the invariant mass produced?

H. TERAZAWA. — Also in the differential cross section.

P. KESSLER. — So there is some disagreement between your (and Fujikawa’s) conclusions on the one hand, and ours on the other hand. It is obviously due to the difference in the models used.

C. BERNARDINI. — I have two questions:

1) How sensitive is the crossing angle of the \( C = + \) and \( C = - \) contributions to the models you use for the pions in the two cases?

2) Can the interference between \( C = + \) and \( C = - \) give a measurable charge asymmetry when the charges are detected?

P. KESSLER. — For \( C = - \), we used Renard’s fit — which seems quite good — of the Frascati results. As Parisi said, it is only the \( C = + \) term calculation which must rely upon a model. We used the Born-term model which, as Parisi stressed, is probably acceptable for the smaller invariant masses (as was shown by Lyth, for instance), but might provide a gross overestimation at the larger invariant masses. There may be resonant enhancements, but any attempt to calculate them is model-dependent, and indeed the various authors involved widely diverge on the values of the coupling constants for the vert \( \gamma \gamma \)-resonance (for instance, Kleinert, in contradistinction to others, finds that \( g_{\gamma\gamma} \approx 0 \)). Therefore, it may well be that our calculations are still overoptimistic, i. e. the crossing point might occur at smaller angles than was shown by Parisi.

As to the other question, it may indeed be interesting to get additional information by distinguishing between the charges and thus measuring the interference term in some physical regions.

T. F. WALSH. — In your calculations, you took into account the Born terms for \( \gamma \gamma^* \rightarrow \mu^+ \mu^- \), but used a form factor (decreasing with \( q^4 \)) for \( \gamma \gamma^* \rightarrow \pi^+ \pi^- \). If one accepts the parton model notions, than one expects \( \rho_0 \) form factor in the latter case. So the Born term calculations for the \( \pi^+ \pi^- \) final state, as
shown by Parisi, need not necessarily be an overestimation; they may be an underestimation.

A. ZICHICHI. — In the background calculation, why did you neglect diagram (III)?

P. KESSLER. — Yes, that is worth while to be explained. In diagram (III), the small-angle electron $e'$ comes out at the Compton-scattering vertex, and the large-angle electron $e$ comes out at the eee vertex. Thus, in comparison with diagram (II), the Compton scattering angle becomes smaller, and the scattering angle for the eee vertex becomes larger. From the first fact you may gain some factor in the cross-section, but you lose a much bigger one from the second fact. On the whole, the contribution of (III) is thus much smaller than that of (II). Similar considerations also show diagrams (II') and (III') (in the electron-electron case) to be negligible.

G. SALVINI. — I get the impression, from Dr. Parisi's talk that tagging of the outgoing electrons on both sides is really the fundamental problem in $\gamma\gamma$ collisions.

P. KESSLER. — Yes, it is the problem.