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Dedicated to Vladimir KISLIK,
our imprisoned colleague from Kiev,
as an expression of our sympathy,
solidarity and support

Inverse Photon-Photon Processes

C. Carimalo, M. Crozon, P. Kessler and J. Parisi +)

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+) Talk given at the Orsay $\gamma\gamma$ Seminar (7/8 Oct. 1981).
Speaker: C. Carimalo

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Abstract

We here consider inverse photon-photon processes, *i. e.* $AB \rightarrow \gamma\gamma X$ (where A, B are hadrons, in particular protons or antiprotons), at high energies. As regards the production of a $\gamma\gamma$ continuum, we show that, under specific conditions, the study of such processes might provide some information on the subprocess $gg \leftrightarrow \gamma\gamma$, involving a quark box. It is also suggested to use those processes in order to systematically look for heavy C = + structures (quarkonium states, gluonia, etc.) showing up in the $\gamma\gamma$ channel. Inverse photon-photon processes might thus become a new and fertile area of investigation in high-energy physics, provided the difficult problem of discriminating between direct photons and indirect ones can be handled in a satisfactory way.

Résumé

Nous considérons les processus photon-photon inverses, c'est à dire $AB \rightarrow \gamma\gamma X$ (où A et B sont des protons ou antiprotons, notamment), aux hautes énergies. Pour ce qui concerne la production d'un continuum $\gamma\gamma$, nous montrons que, dans certaines conditions, l'étude de ces processus pourrait permettre d'obtenir des informations sur le sous-processus $gg \leftrightarrow \gamma\gamma$, *faisant intervenir une boîte* de quarks. Nous suggérons également d'utiliser ces processus pour une recherche systématique des structures lourdes C = + (états de quarkonium, gluonia, etc.) apparaissant dans la voie $\gamma\gamma$. Les processus photon-photon inverses pourraient ainsi devenir un domaine nouveau et fertile de recherches en physique des hautes énergies, à condition que l'on soit en mesure de résoudre de façon satisfaisante le problème de la séparation expérimentale entre photons directs et indirects.

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1. Introduction

Inverse photon-photon processes, i. e. processes of the type $AB \rightarrow \gamma\gamma X$ (where A, B are hadrons; in particular, we mean pp or $p\bar{p}$ collisions) (fig. 1) should be able, in principle, to provide informations similar to those obtained from direct photon-photon processes, i. e. $ee \rightarrow eeX$. Generally speaking, they are less powerful as a tool of investigation than the latter, where a large variety of different exclusive hadronic channels may be experimentally studied. Nevertheless - as we shall show - in some specific cases the information desired on two-photon interactions with matter may be easier or better obtained through the inverse process than through the direct one; actually, as will appear below, those two modes of investigation are complementary to some extent.

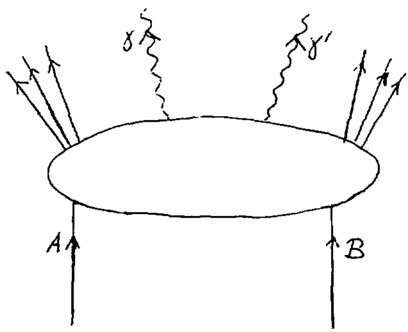


Fig. 1

The experimental signature of the processes here considered is the observation of two direct photons. In this Report we shall not go into a discussion of experimental details. Let us only remark that apparently it has become possible to measure direct photons - i. e. to discriminate between direct and indirect ones, the latter being due to bremsstrahlung from quarks, to fragmentation of quarks and gluons, and particularly to the radiative decay of π^0, η etc. - in high-energy experiments at $p_T^{(\gamma)}$ values of a few GeV [1]. Therefore we shall assume that one may get a good signal/noise ratio by selecting events with two photons emitted at large angle with respect to the incoming colliding beams (in their c. m. frame) and characterized by large, mutually opposite and equal transverse momenta; in addition, those photons should be unaccompanied by any hadrons.

2. Production of a $\gamma\gamma$ continuum

The basic process for the production of a $\gamma\gamma$ continuum, at high energy, is the one involving the subprocess $q\bar{q} \to \gamma\gamma$ (fig. 2). Obviously that process is very similar to the Drell-Yan effect (fig. 3) from the point of view of the dynamical mechanism involved; therefrom one may conclude that it is of comparable physical interest; finally, it may be easily checked (see farther below) that it is of the same order of magnitude.

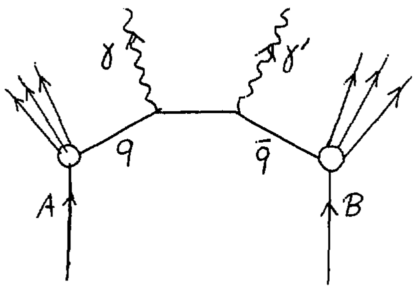


Fig. 2

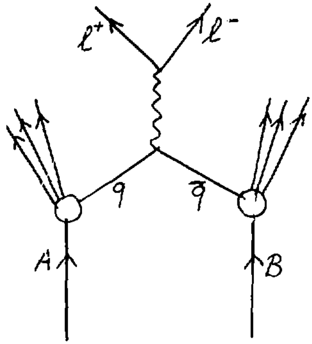


Fig. 3

Historically the subprocess $q\bar{q} \to \gamma\gamma$ was first considered, among other "hard-scattering" processes, ten years ago in the fundamental paper of Berman, Bjorken and Kogut [2]. In the last years, several authors suggested that it should be investigated experimentally in order to obtain various physical informations. Soh et al. [3] proposed that the ratio α_s/α should be determined through an experimental comparison between $q\bar{q} \to g\gamma$ and $q\bar{q} \to \gamma\gamma$. Krawczyk and Ochs [4] remarked that, since $q\bar{q} \to \gamma\gamma$ involves the factor e_q^4, it should be used for checking the quark charges. Hemmi [5] suggested that one should analyze the angular distribution of the photons produced, which would be a way of checking the quark propagator; he even considered the possibility that, going down to small angles (which would however be difficult), a hint on the quark masses might be obtained.

Another aspect of $AB \to \gamma\gamma X$ was recently considered by Combridge [6] and independently, somewhat later, by the authors [7] (here we will give some details on the latter work). That aspect concerns the contribution of the quark-box diagram shown in fig. 4. (We here systematically assume permutations of lines to be implicitly included in our diagrams.)

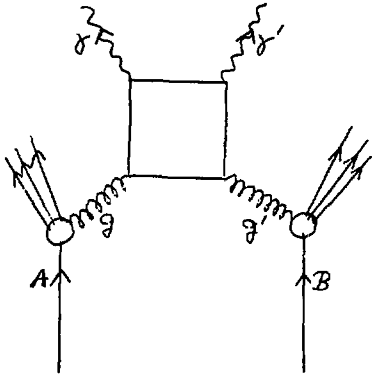
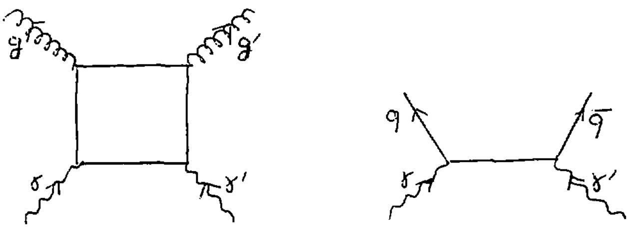


Fig. 4

On the basis of a QED calculation performed many years ago by De Tollis [(8)], it has been shown by Cahn and Gunion [(9)] and independently by Kajantie and Raitio [(10)] that, considering jet-pair production in photon-photon collisions, the contribution of the quark-box diagram of fig. 5 (a) is not as negligible as one might believe a priori, when compared to that of the basic diagram of fig. 5 (b). Actually the ratio of $d\sigma/d\Omega(\gamma\gamma \rightarrow gg)$ to $d\sigma/d\Omega(\gamma\gamma \rightarrow q\bar{q})$ at 90° in the $\gamma\gamma$ c. m. frame has been computed to be $\simeq \alpha_s^2$, i. e. 5 - 10 %.



(a) (b)

Fig. 5

Going over to the inverse processes, i. e. specifically to those represented in fig. 2 and 4, and calling $R(gg/q\bar{q})$ the ratio of the contributions of both mechanisms involved in photon-pair production, in the configuration where both photons are emitted at 90° in the overall c. m. frame, that ratio is derived from the above-mentioned result as follows:

$$\mathcal{R}(gg/q\bar{q}) \simeq \alpha_s^2 \cdot 2 \cdot 9/64 \, \frac{(\Sigma e_q^4)\, g_A(x)\, g_B(x')}{\Sigma\{e_q^4[q_A(x)\,\bar{q}_B(x') + \bar{q}_A(x)\, q_B(x')]\}}$$

$$\approx 0.02 \, \frac{(\Sigma e_q^4)\, g_A(x)\, g_B(x')}{\Sigma\{e_q^4[q_A(x)\,\bar{q}_B(x') + \bar{q}_A(x)\, q_B(x')]\}}$$

where in the upper line the factor 2 takes account of Bose statistics, and the factor 9/64 of colour. For simplicity, we here assume quark and gluon distribution functions to scale; actually, in the configuration considered, one has $x = x'$.

In the lower line the numerical factor 0.02 appears extremely small, but may (occasionally) be compensated or even over-compensated - as we are going to show - by the factor at right-hand, involving the ratio between gluon and quark distribution functions. The latter factor may indeed become large in two different configurations:

(i) $x = x'$ very small, i. e. in the range where practically valence quarks don't contribute, while gluons are largely predominating over sea-quarks.

(ii) $x = x'$ large, provided one has: $2\, n_g < n_q + n_{\bar{q}}$, defining those various parameters through

$g(x) \sim (1 - x)^{n_g}$; $q(x) \sim (1 - x)^{n_q}$; $\bar{q}(x) \sim (1 - x)^{n_{\bar{q}}}$

(again assuming that the distribution functions are scaling).

The authors have computed numerically, for both mechanisms considered, the differential cross section $d\sigma/[dM\, dy\, d(\cos\theta)]$ at $y = 0$ and $\theta = 90°$ for the reaction $pN \rightarrow \gamma\gamma X$. Here M (= 2 p_T) is the $\gamma\gamma$ invariant mass, y the rapidity of the $\gamma\gamma$ system and θ the emission angle of either photon in the overall (or $\gamma\gamma$ c. m. frame). The differential cross section thus obtained was normalized to the corresponding one computed for the Drell-Yan effect (fig. 3). Such a normalization appears very convenient since, as we checked, the ratio of $\gamma\gamma$ to $\ell^+\ell^-$ production, when the former is computed according to the diagram of fig. 2 alone, remains practically model-independent, i. e. independent of the parametrization chosen +) for the quark distribution functions; in addition, obviously, part of the higher-order QCD corrections vanish from that ratio.

On the other hand, we shall see that, when considering $\gamma\gamma$ production through the mechanism shown in fig. 4, its ratio to the Drell-Yan effect strongly depends on the model used for quark and gluon distribution functions.

We here chose the following models:

+) (provided, of course, the same one is used in both processes)

Model I a. Here we used scale-conserving distribution functions, namely: $g(x) \sim x^{-1} (1-x)^4$, and quark distribution functions taken from the recent experimental literature (11).

Model I b: Same as model I a, except that here we chose: $g(x) \sim x^{-1} (1-x)^6$.

Model II: Scale-violating distribution functions (12) were used for both quarks and gluons. The variable Q^2, on which those functions depend, was chosen as: $Q^2 = M^2/3 = 4\ p_T^2/3$. For coherence, we here used a running quark-gluon coupling constant $\alpha_s = 12\pi/[25 \ln(Q^2/\Lambda^2)]$ with $\Lambda = 0.5$ GeV +) (whereas with model I a and I b we simply took $\alpha_s = 0.3$).

The results of our computations are shown in fig. 6 for $\sqrt{s} = 30$ GeV and for an isoscalar target (i. e. we set: $N = (n + p)/2$), and in fig. 7 for a pp collision at $\sqrt{s} = 600$ GeV. Obviously fig. 7 corresponds to the configuration (i) defined above, whereas in fig. 6 we see the effects of the situation defined in (ii) (with $n_q \simeq 3$, $n_{\bar{q}} \simeq 9$ in model I a or I b).

We thus conclude that inverse $\gamma\gamma$ processes might indeed allow one to perform a crucial test of higher-order QCD, namely showing the contribution of the quark-box diagram. Let us notice that the counting rates to be expected in such an experiment should not be too small, since the basic process, involving the $q\bar{q}$ mechanism, is by itself of the same order as the Drell-Yan effect.

+) The authors are aware that at present somewhat lower values of Λ, and correspondingly of α_s, tend to be preferred. Using those new values would change our results to some extent (the relative contribution of the gg mechanism would become smaller), but not too drastically. Anyhow, it seems that the value of Λ is still a controversial matter.

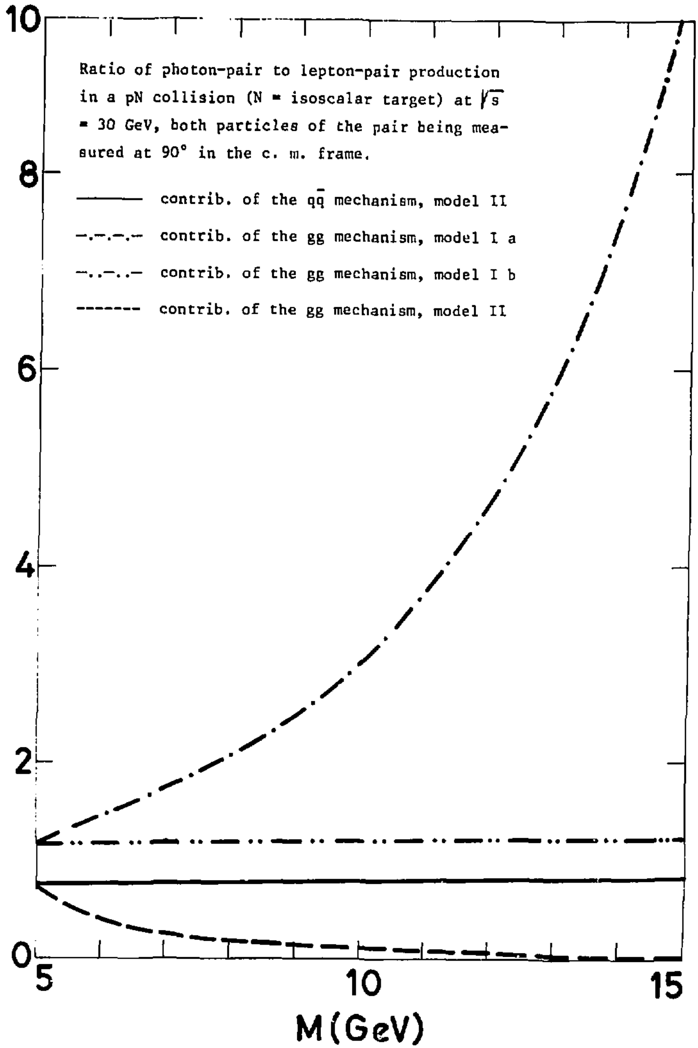
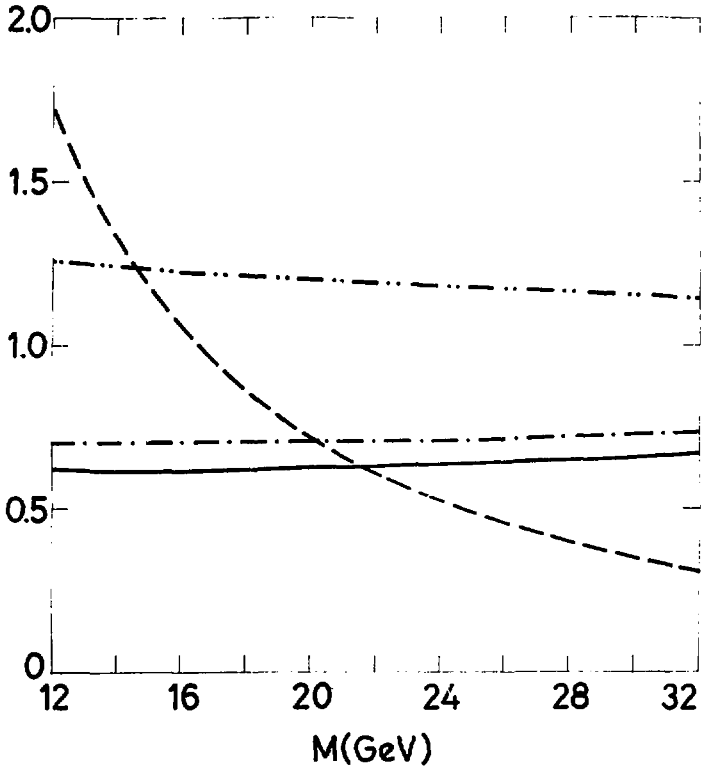

Ratio of photon-pair to lepton-pair production in a pN collision (N = isoscalar target) at √s = 30 GeV, both particles of the pair being measured at 90° in the c. m. frame.
——— contrib. of the $q\bar{q}$ mechanism, model II
-.-.-.- contrib. of the gg mechanism, model I a
-..-..- contrib. of the gg mechanism, model I b
------ contrib. of the gg mechanism, model II
10
8
6
4
2
0
5
10
15
M(GeV)

Fig. 6



Ratio of photon-pair to lepton-pair production in a pp collision at $\sqrt{s}$ = 600 GeV, both particles of the pair being measured at 90° in the c. m. frame.

——— contribution of the $q\bar{q}$ mechanism, model II

—.—.—.— contribution of the gg mechanism, model I a

—..—..— contribution of the gg mechanism, model I b

------- contribution of the gg mechanism, model II

Fig. 7

3. Production of resonant structures

Another interesting - perhaps even more interesting - aspect of inverse processes would be the search for structures: quarkonium states (0^{++}, 0^{-+}, 2^{++} ...) and glueballs coupled with two photons, and perhaps other yet unknown structures (Higgs particles, etc.). +)

Using the nowadays well-accepted gluon-fusion model of Einhorn and Ellis [13], we may assume that the main mechanism for the reactions here considered is that given by fig. 8.

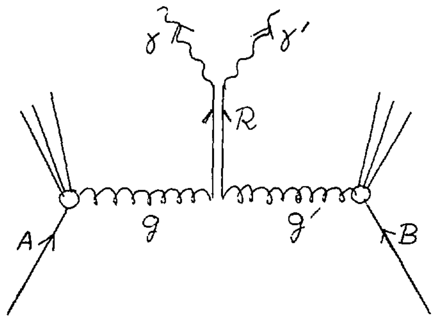


Fig. 8

In the following we shall be concerned with pp or p$\bar{p}$ collisions at very high energy ($s \gtrsim 10^5 - 10^6$ GeV), giving rise to massive structures (of at least a few GeV). We are going to show that

(i) cross sections to be expected appear not too low;

(ii) there are good chances that such resonant structures (at least, some of them) would show up above the $\gamma\gamma$ continuum;

(iii) inverse $\gamma\gamma$ processes should be a much more efficient way to look for such structures than direct ones;

(iv) there is no better way to investigate those structures; in particular, looking for gluon (jet) pairs instead of photon pairs, as has been suggested [14], seems hopeless because of the overwhelming non-resonant background.

+) That aspect, as well, was already considered by Combridge [6]. See also ref. (14).

(i) Cross section of pp $(p\bar{p}) \longrightarrow \gamma\gamma X$

Applying the usual factorization procedure, one gets:

$$\sigma = \int dx\, dx'\, g(x)\, g(x')\, \sigma_{gg\to R}(m_R^2) \frac{\Gamma(R\to\gamma\gamma)}{\Gamma_{tot}(R)} \qquad (3.1)$$

where for simplicity we assume the gluon distribution function to scale. Setting $\tau_R = m_R^2/s \simeq x\,x'$, one has (accounting for a colour factor 1/64):

$$\sigma_{gg\to R}(m_R^2) = \frac{\pi^2(2J_R+1)}{8\, m_R\, s} \Gamma(R\to gg)\, \delta(\tau_R - x x') \qquad (3.2)$$

For C = + quarkonium states, as well as for gluonia made up from two gluons, it is presumably reasonable to assume: $\Gamma(R \rightarrow gg) \approx \Gamma_{tot}(R)$. One thus gets:

$$\sigma \simeq \frac{\pi^2 (2J_R+1)\, \Gamma(R\to\gamma\gamma)}{8\, m_R\, s} \int_{\tau_R}^{1} \frac{dx}{x} g(x)\, g\left(\frac{\tau_R}{x}\right) \qquad (3.3)$$

Taking, as usual, $g(x) = \frac{n+1}{2\,x}(1-x)^n$ and choosing n = 5, assuming on the other hand that τ_R is extremely small with respect to 1, the integral over x becomes:

$$\int_{\tau_R}^{1} \frac{dx}{x} g(x)\, g\left(\frac{\tau_R}{x}\right) \simeq \frac{9}{\tau_R}\left(\ln\frac{1}{\tau_R} - \frac{137}{30}\right) \qquad (3.4)$$

Finally we get:

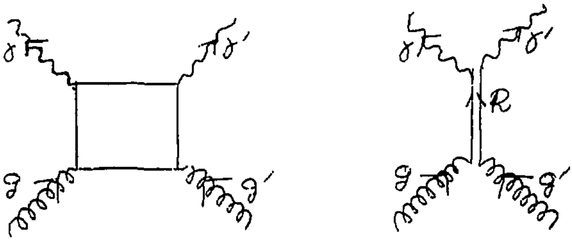
$$\sigma \simeq \frac{9\pi^2 (2J_R+1)\, \Gamma(R\to\gamma\gamma)\left(\ln\frac{1}{\tau_R} - \frac{137}{30}\right)}{8\, m_R^{\,3}} \qquad (3.5)$$

Assuming: $s = 10^6$ GeV^2; m_R= 10 GeV; $\Gamma(R \rightarrow \gamma\gamma)$ = 1 keV (which, generally speaking, should be a rather conservative assumption); $J_R = 0$, one gets: $\sigma \simeq 2\; 10^{-35}$ cm^{2}. Thus fairly high counting rates may be expected with pp or $p\bar{p}$ colliding-beam machines in the energy range considered, if the luminosity reaches $L \simeq 10^{32}$ cm^{-2} s^{-1} (as in the ISABELLE project), even accounting for acceptance cuts.

(ii) Resonant production vs. continuum

For simplicity we shall here assume y = 0, i. e. $x = x' = \sqrt{\tau_R}$. In addition, let us assume again that τ_R is extremely small: as regards the continuum, the gg mechanism (fig. 4) should then tend to predominate over the $q\bar{q}$ mechanism (fig. 2) or at least be of the same order (see fig. 7) +). Therefore we shall proceed as follows: We shall compute the non-resonant photon-pair production by considering the gg mechanism alone, but we shall multiply by 2 the cross section thus obtained; that procedure should provide us with a higher limit for the continuum. We are thus led to compare the subprocesses shown in fig. 9.

+) for photon emission angles close to 90°



(a) (b)

Fig. 9

For the process represented by diagram (a) above, one gets [7]:

$$\frac{d\sigma^{(a)}}{d(\cos\theta)} \leq \frac{25}{648}\,\frac{\pi\alpha^2\alpha_s^2}{M^2}\,\tilde{g}(\theta)\cdot 2 \qquad (3.6)$$

where the first numerical factor is due to colour and charge; M is the total energy of the subprocess in its c. m. frame, and θ the emission angle of either photon in that frame (which, in the configuration chosen, is also the c. m. frame of the full process shown in fig. 4). $\tilde{g}(\theta)$ is a complicated function, the expression of which is given in ref. (9); going from small angles to 90°, its value steadily goes down to $\tilde{g}(90°) \simeq 1$. As for the factor 2, it stands for security, as we explained.

On the other hand, one gets for the diagram of fig. 9 (b) (assuming R to decay isotropically into 2 photons):

$$\frac{d\sigma^{(b)}}{d(\cos\theta)} \simeq \frac{\pi^2(2J_R+1)}{16\, m_R}\,\Gamma(R\to\gamma\gamma)\,\delta(M^2-m_R^2) \qquad (3.7)$$

where account has been taken of a colour factor 1/64.

The δ function is related to the resolution involved in the measurement, as follows:

$$\delta(M^2-m_R^2) = \frac{1}{2m_R}\,\delta(M-m_R) \simeq \frac{1}{2m_R\,\Delta M} = \frac{1}{4\,m_R\,\Delta k} \qquad (3.8)$$

where k is the energy of either photon in the c. m. frame of the subprocess (or as well of the full process; we shall identify that latter frame with the lab frame). Thus we get:

$$\frac{d\sigma^{(b)}}{d(\cos\theta)} \simeq \frac{\pi^2(2J_R+1)\,\Gamma(R\to\gamma\gamma)}{64\,m_R^2\,\Delta k} \qquad (3.9)$$

Defining $r_{a/b} = \left(\frac{d\sigma^{(a)}}{d(\cos\theta)}\right)_{M=m_R} \Big/ \frac{d\sigma^{(b)}}{d(\cos\theta)}$, we get for that ratio:

$$r_{a/b} \lesssim \frac{400\,\alpha^2 \alpha_s^2\, \tilde{g}(\theta)\, \Delta k}{81\,\pi\,(2J_R+1)\,\Gamma(R\to\gamma\gamma)} \qquad (3.10)$$

Setting $\alpha_s = 0.25$, and assuming $J_R = 0$, $\Gamma(R\to\gamma\gamma) = 1$ keV, one obtains:

$$r_{a/b} \lesssim 5\, \tilde{g}(\theta)\, \Delta k\,(\mathrm{GeV}) \qquad (3.11)$$

With the conventional value of the photon's energy resolution, $\Delta k \simeq 0.1 \sqrt{k}$ (k, Δk in GeV), assuming that one performs the measurement in some range near $\theta = 90°$ (where $g(\theta) \gtrsim 1$), one gets at $m_R = 10$ GeV ($k = 5$ GeV): $r_{a/b} \lesssim 1$. One may thus conclude that at least some of the structures looked for should appear above the continuum.

(iii) Inverse vs. direct process

Let us now consider, for comparison, the direct $\gamma\gamma$ process shown in fig. 10.

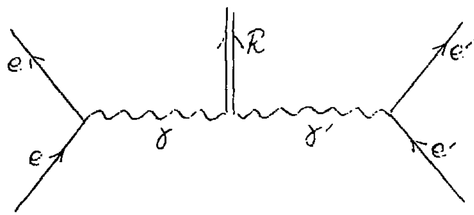


Fig. 10

Using the double equivalent-photon approximation and following the procedure applied by Low many years ago [15], one here obtains (assuming $\tau_R = m_R^2/s \ll 1$):

$$\sigma \simeq 8\alpha^2 (2J_R+1) \frac{\Gamma(R\to\gamma\gamma)}{m_R^3} \left(\ln \frac{s}{4\, m_e^2}\right)^2 \left(\ln \frac{1}{\tau_R} - \frac{3}{4}\right) \qquad (3.12)$$

Assuming $s \simeq 2\ 10^4$ GeV^2 (LEP project), $m_R = 10$ GeV, $\Gamma(R\to\gamma\gamma) = 1$ keV, $J_R = 0$, one gets: $\sigma \simeq 4\ 10^{-37}$ cm^2; this is almost two orders of magnitude less than the cross section found above for the inverse process in pp ($p\bar{p}$) collisions at $s \simeq 10^6$ GeV^2 with otherwise similar assumptions. At lower resonance masses, e. g. $m_R \simeq 3$ GeV, the ratio between both processes would remain about the same, although of course the absolute cross section of the $\gamma\gamma$ collision process would become much larger.

Actually the situation is even more unfavourable as regards resonance production in $\gamma\gamma$ collisions. If one wishes to identify a resonance through its decay particles in a given channel (according to the procedure commonly used in present measurements, searching for resonant structures in some range around 1 GeV [16], the decay channel chosen should obviously be a simple one, i. e. involve a small number of particles. For heavy structures, it may be expected that such simple channels will have small branching ratios; in other words, the cross section found would be further reduced by one or two orders of magnitude.

One might a priori imagine another procedure for identifying resonant structures, namely a missing-mass measurement through tagging of both electrons. Since in a superhigh-energy ee machine like LEP tagging will be performed only at finite angles, here again about two orders of magnitude will be lost. Furthermore the effect - as can be easily checked - will be totally buried below the continuum due to the general process $\gamma\gamma \rightarrow$ hadrons. Using the expression [17]

$$\sigma_{tot}\ (\gamma\gamma \rightarrow \text{hadrons}) \simeq (240 + 270/M(\text{GeV}))\ \text{nb}\ ,$$

that background should be expected to predominate over a resonant effect (computed with the same assumptions as before), in the mass range 3-10 GeV, by 2 or 3 orders of magnitude.

(iv) Photon-pair vs. gluon-pair production

It has been suggested [14] to use gluon-pair production for the investigation of high-mass C = + resonant structures. If the mass looked for is high enough, one may indeed expect that either gluon would show up as a relatively well defined particle-jet. The corresponding cross sections would be about three orders of magnitude larger than for emission of photon pairs; since the same mechanism would be involved in producing the C = + structures (see fig. 11), the ratio between both types of reactions would indeed simply be $\Gamma(R \rightarrow gg)/\Gamma(R \rightarrow \gamma\gamma) \approx \alpha_s^2/\alpha^2$.

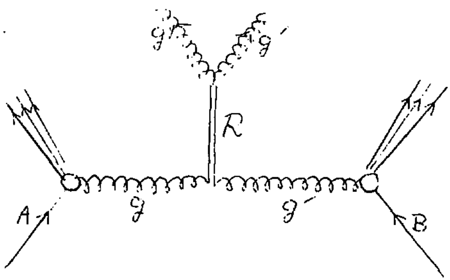


Fig. 11

However it would be difficult to reconstruct accurately the structure's mass from two particle jets, even if they are well defined. Moreover, as we are going to show, even if the mass resolution is not too bad, the resonant effect looked for would be dominated by an overwhelming QCD non-resonant background [+)].

We shall compare the subprocesses shown in diagrams (a) and (b) of fig. 12 (in diagram (a) the open circle stands for gluon exchange in the s, t and u channels). Notice that we are neglecting all subprocesses other than $gg \rightarrow gg$, contributing to the 2-jet continuum. In order to further minimize that continuum, we shall assume that the gluon scattering angle is fixed at 90° in the gg c. m. frame.

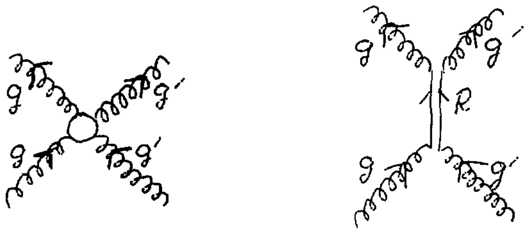


Fig. 12

For diagram (a) we get [(18)]:

$$\left(\frac{d\sigma^{(a)}}{d(\cos\theta)}\right)_{\theta=90^\circ} = \frac{243\,\pi\,\alpha_s^2}{16\,M^2} \tag{3.13}$$

whereas for diagram (b) we get (assuming R to decay isotropically into 2 gluons):

$$\left(\frac{d\sigma^{(b)}}{d(\cos\theta)}\right)_{\theta=90^\circ} \simeq \frac{\pi^2(2J_R+1)\,\Gamma(R\rightarrow gg)}{32\,m_R^2\,\Delta M} \tag{3.14}$$

Defining $r_{a/b} = \left(\frac{d\sigma^{(a)}}{d(\cos\theta)}\right)_{\theta=90^\circ,\,M=m_R} \Big/ \left(\frac{d\sigma^{(b)}}{d(\cos\theta)}\right)_{\theta=90^\circ}$,

we get for that ratio:

$$r_{a/b} \simeq \frac{486\,\alpha_s^2\,\Delta M}{\pi\,(2J_R+1)\,\Gamma(R\rightarrow gg)} \tag{3.15}$$

Assuming $\alpha_s = 0.25$, $J_R = 0$, $\Gamma(R\rightarrow gg) = 5$ MeV, $\Delta M = 1$ GeV, one obtains: $r_{a/b} \simeq 2000$!

+) We are a bit surprised that the authors of ref. (14) did not reach the same conclusion.

6. Conclusion

The purpose of this Report was to show that inverse photon-photon processes, i. e. direct-photon pair production, might become a new and fertile area of investigation in high-energy physics. As far as the 2-photon continuum is concerned, the physical interest of those reactions should be comparable to that of the Drell-Yan effect. In addition, they should allow one to perform a crucial check of higher-order QCD, regarding the contribution of the quark-box diagram.

A perhaps still more important aspect of inverse $\gamma\gamma$ processes would be the systematic investigation of C = + heavy resonant structures (quarkonium states, glueballs ...). We have shown that the corresponding counting rates might be not too small; that at least some of those structures should be expected to show up above the non-resonant background; and finally, that measuring inverse photon-photon processes should really be the best way (if not the only one) to look for such structures. The significance of such a systematic investigation of C = + structures through inclusive direct-photon pair measurements might become comparable to that of the famous Lederman-Ting type of experiments on lepton-pair production, where the J/ψ and the Υ were discovered.

One major problem, however, is not yet completely solved, namely discriminating with sufficient accuracy between direct photons and indirect ones, the latter being mainly due to π^0's. The physical interest of inverse photon-photon processes would certainly justify a major effort of the physicists involved in order to solve that problem once and forever.

To finish, let us mention (without going into details) that there are also some interesting applications of inverse photon-photon processes at low energy, i. e. in $p\bar{p} \to \gamma\gamma$ near the $p\bar{p}$ threshold [19] or in the charmonium range [20].

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(17) See for instance M. Greco, in Proceedings of the International Workshop on $\gamma\gamma$ Collisions (Amiens 1980), Lecture Notes in Physics 134, p. 311. Notice that available experimental data *from the TASSO and PLUTO groups at* PETRA seem to indicate a somewhat higher total cross section for hadron production, especially in the smaller-M range (see Ch. Berger, in Proceedings of

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