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The large hadronic production in high energy e^+e^- collisions observed both at Frascati(1) and CEA(2) has recently been confirmed at SPEAR-SLAC(3), where the energies covered by the experiments range continuously from $\sqrt{s} = 2E = 3$ GeV to 5 GeV. The most salient features of these results can be summarized as follows:

(i) The total cross section for multihadron production is approximately flat in the incident energy and of the order of 2×10^{-32} cm^2.

(ii) Depending on the momentum of the particle the single inclusive distributions of the observed charged hadrons behave quite differenly. More explicitly, at low momenta ($q \lesssim 1$ GeV/c) the inclusive cross section $d\sigma/q\,dq$ behaves similarly to what is observed in purely hadronic reactions. For high momenta on the other hand, or for $x \gtrsim 0.5$, where $x \equiv 2q_0/\sqrt{s}$, the quantity $s\,d\sigma/dx$ seems to be purely a function of x.

(iii) The total energy carried away by neutral particles is approximately equal to that of the charged ones.

If we accept that all the observed events come from the one photon channel, the above features not only raise serious troubles for various models, but also contrast with our theoretical aspectations based on what has been learnt from deep inelastic electron and neutrino scattering. On the other hand, before changing drastically our ideas and think about new types of phenomena, we have to be sure that these results cannot be understood in the light of our present knowledge of electromagnetic processes.

In this connection we observe that a possible explanation of the data, which is suggested by (ii), can come quite simply from the occurence of two different mechanisms which only incidentally give rise to a flat total cross section in this energy range. The first would preserve Bjorken scaling, give $\sigma^{1\gamma}_{tot} = R\,\sigma_{\mu\bar{\mu}}$ and be responsible for the high energy tail of the single particle distributions. The second one in addition would be mostly responsible for the production of lower energy particles, with a purely hadronic behaviour. A possible identification of this mechanism with $\gamma\gamma$ processes is suggested by (iii), in the sense that the unobserved final leptons would carry away a fraction of the total energy at their disposal, behaving as undected neutral particles. In order to take this possibility seriously one has of course to estimate, with reasonable accuracy, the background from $\gamma\gamma$ interactions.

The importance of the two photon mechanism of hadron production in colliding beam experiments has been emphasized by many authors[(4)]. As well known, in the case where the leptons are not detected, the production cross section is approximately given by :

$$(1)\qquad \sigma_{ee\to ee\,had} \simeq \left(\frac{\alpha}{\pi}\right)^2 \ln^2\left(\frac{E}{m}\right) \int_{s_o}^{4E^2} \frac{ds}{s}\,\sigma^{had}_{\gamma\gamma}(s)\, f\left(\frac{s}{4E^2}\right),$$

with $f(y) = -(2+y)^2 \ln y - 2(1-y)(3+y)$, where m, E are the mass and energy of the colliding electrons and $\sigma^{had}_{\gamma\gamma}(s)$ is the cross section for production of hadrons by two real photons of total c.m. energy squared s with threshold s_o.

The total hadronic $\gamma\gamma$ cross sections have been estimated by many authors[(4)] using the usual tools of hadronic physics, either by evaluating the detailed contributions of resonant states coupled to two photons, or using an overall smooth contribution obtained using Regge and duality ideas[5, 6]. For example one can estimate[4, 5]

$$\sigma^{had}_{\gamma\gamma}(s) = \sigma_o + \frac{\sigma_1}{\sqrt{s}} = 0.24\ \mu b + \frac{0.27}{\sqrt{s}}\ \mu b\ GeV\ , \tag{2}$$

corresponding to Pomeron and normal Regge exchanges. Although the total hadronic contribution at the highest energy achieved is about 15 nbs, having used $\sqrt{s_o} = 0.3$ GeV in eq. (1), a reasonable estimate of possible backgrounds can be of the order of 3-4 nbs, with $\sqrt{s_o} \approx 1$ GeV and without any experimental cuts on energy and angles.

On the other hand it has to be realized that these expectations, based on the simple extrapolation of hadron physics to $\gamma\gamma$ scattering, could not give the whole answer. For example the presence of a fixed pole in Compton scattering reflects itself in the imaginary part of the amplitude for $\gamma\gamma$ scattering, and this term has no counter part in a pure hadron-like behaviour of $\sigma^{had}_{\gamma\gamma}(s)$[7].

With these considerations in mind, we shall study in the following the contributions to $\gamma\gamma \rightarrow$ hadrons coming from diagrams of the type shown in Fig. 1, where an elementary pion can be exchanged

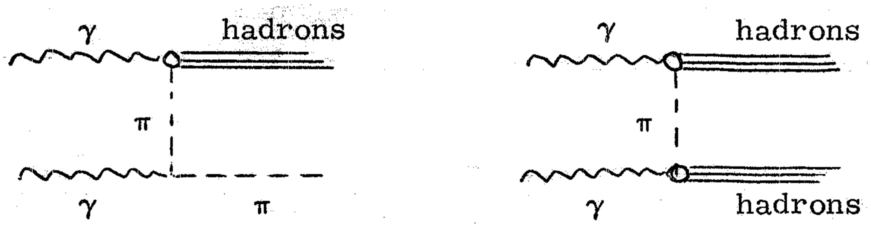

FIG. 1

between the two photon lines. The hadrons can be produced either as a decay of a resonance or by a non-resonating mechanism. In addition to the reaction $\gamma\gamma \rightarrow \pi^+\pi^-$, which has been extensively studied[4] and experimentally observed[8], simple processes such as $\rho\pi$, $A_1\pi$, $B\pi$,

$\rho\rho$, $\omega\omega$, etc., can in principle give a non-negligeable contribution to the total cross section, particularly if the radiative decays of these mesons into $(\pi\gamma)$ is strongly enough, as in the case of $\omega \to \pi^0\gamma$[9].

Let us first consider the process $\gamma\gamma \to \pi^+\rho^-$. Define

(3) $$g\,\varepsilon_{\alpha\beta\gamma\delta}\; k^{\alpha}\,\varepsilon^{\beta}\,q^{\gamma}\,\rho^{\delta} ,$$

as the vertex γ-π-ρ, where (k, ε) and (q, ρ) are the momenta and polarization of the photon and the ρ meson respectively, and the coupling constant g is such that the decay width of $\rho \to \pi\gamma$ is given by

(4) $$\Gamma_{(\rho \to \pi\gamma)} = g^2 \frac{(m_\rho^2 - \mu^2)^3}{96\,\pi\, m_\rho^3} .$$

The most important contribution to the cross section is given by

(5) $$\frac{d\sigma^{\gamma\gamma\to\pi\rho}}{d\cos\theta} \simeq \frac{g^2\alpha}{8}\,\frac{p^3}{s^{3/2}}\,(m_\rho^2 - t)^2\,\frac{1}{(t-\mu^2)^2}\,\sin^2\theta + (\theta \to \pi+\theta) ,$$

where θ is the production angle in the $\gamma\gamma$ center of mass frame, p the final momentum and $t = \mu^2 - E_\pi s\,(1 - \beta_\pi \cos\theta)$. By neglecting all t dependence in the numerator of (5) we get :

(6) $$\sigma_{\gamma\gamma \to \pi^+\rho^-} \simeq \frac{2\alpha}{\pi}\,\frac{p}{\sqrt{s}}\,\frac{m_\rho^2}{s^2}\left\{\frac{1}{\beta_\pi}\ln\frac{1+\beta_\pi}{1-\beta_\pi} - 2\right\}\left\{\frac{24\pi^2\,\Gamma_{(\rho\to\pi\gamma)}}{m_\rho}\right\}$$

This cross section can be simply generalized to estimate the more general process $\gamma\gamma \to \pi^+ + S_1^-$ where S_1^- is a hadronic system of mass $\sqrt{s_1}$:

(7) $$\frac{d\sigma_{\gamma\gamma\to\pi^+S_1^-}}{ds_1} \simeq \frac{2\alpha}{\pi}\,\frac{s_1}{s^2}\,\frac{s-s_1}{2s}\,\beta_\pi\left\{\frac{1}{\beta_\pi}\ln\frac{1+\beta_\pi}{1-\beta_\pi} - 2\right\}\left\{\sigma_{\gamma\pi\to S_1}(s_1)\right\}$$

We can therefore estimate either the production of final states like πR, where R is a resonance like A_1, A_2, ..., by evaluating through simple ρ dominance their radiative decay widths, or, more generally, put in eq. (7) an expression for the total pion-photon cross section. Using asymptotically the quark model relation $\sigma(\gamma\pi) \simeq \frac{2}{3}\sigma(\gamma N)$ and by factorization of Regge residues one can estimate:

$$\sigma_{\gamma\pi}(s) = a + \frac{b}{\sqrt{s}} \simeq 65\ \mu b + \frac{35}{\sqrt{s}}\ \mu b\ \text{GeV}; \tag{8}$$

Inserting eq. (8) into (7) one obtains, approximately:

$$\sigma_{\gamma\gamma \to \pi^{\pm} S_1^{\mp}} \simeq \left\{ 14\ \mu b + \frac{13.5}{\sqrt{s}}\ \mu b\ \text{GeV} \right\} \left\{ \ln 2 \frac{\overline{E}_\pi}{\mu} - 1 \right\} 10^{-2}, \tag{9}$$

where $\overline{E}_\pi$ is an average energy of the outgoing pion.

Similarly we consider the process $\gamma\gamma \to \omega\omega$. Using the same definitions of eqs. (3) and (4) we get

$$\frac{d\sigma^{\gamma\gamma\to\omega\omega}}{dt} = \frac{\pi}{16}\left(\frac{g^2_{\omega\pi\gamma}}{4\pi}\right)^2 \frac{1}{s^2}(m_\omega^2 - t)^4 \frac{1}{(\mu^2 - t)^2} + (t \to u) + \text{int. terms}, \tag{10}$$

where $t = m_\omega^2 - \frac{s}{2}(1 - \beta_\omega \cos\theta)$, $u = m_\omega^2 - \frac{s}{2}(1 + \beta_\omega \cos\theta)$ and the interference terms add positively to the cross section. The minimum value of t is given by $t_{min} = - m_\omega^2(1-\beta_\omega)/(1+\beta_\omega)$. From (10), one gets at threshold

$$\sigma^{\gamma\gamma\to\omega\omega}(s \sim 4m_\omega^2) = \frac{3\pi}{32}\left(\frac{g^2_{\omega\pi\gamma}}{4\pi}\right)^2 \beta_\omega\, s\ . \tag{11}$$

This rising cross section is not reliable at high energies, where a form factor in the $\omega\pi\gamma$ coupling is supposed to operate and damp the cross section. In this hypothesis, for $s \gg 4m_\omega^2$, one would get from (10)

$$\sigma^{\gamma\gamma\to\omega\omega}(s) \gtrsim \frac{\pi}{8}\left(\frac{g^2_{\omega\pi\gamma}}{4\pi}\right)^2 \frac{m_\omega^8}{s^2}\frac{1}{\mu^2} = \frac{\pi}{8}\frac{1}{\mu^2}\left[\frac{24\Gamma(\omega\to\pi\gamma)}{m_\omega}\right]^2 \left(\frac{m_\omega^2}{s}\right)^2, \tag{12}$$

where we have neglected the contribution arising from interference terms. At intermediate energies the order of magnitude of the cross section is still given by eq. (12). Because we are interested only in the rough estimate of this kind of effects, we generalize eq. (12) to the process $\gamma\gamma \rightarrow R_1 + R_2$ as follows:

$$\sigma_{\gamma\gamma \rightarrow R_1 R_2} \simeq \frac{\pi}{8} \frac{1}{\mu^2} \left[\frac{8\Gamma(R_1 \rightarrow \pi\gamma)(2J_1+1)}{m_1} \right] \left[\frac{8\Gamma(R_2 \rightarrow \pi\gamma)(2J_2+1)}{m_2} \right] \cdot \left(\frac{m_1 m_2}{s} \right)^2 \tag{13}$$

We can therefore estimate $\sigma_{\rho^+\rho^-} = 2\sigma_{\rho^0\rho^0} \simeq 3 \times 10^{-2}\, \sigma_{\omega\omega}$, $\sigma_{\rho\omega} \simeq$ $\simeq 10^{-1}\, \sigma_{\omega\omega}$, $\sigma_{A_1^+ A_1^-} \simeq 10^{-1}\, \sigma_{\omega\omega}$, $\sigma_{A_2^+ A_2^-} \simeq 0.5 \times 10^{-1} \sigma_{\omega\omega}$, having used $\Gamma(A_{1,2} \rightarrow \pi\gamma) \simeq e^2/f_\rho^2\, \Gamma(A_{1,2} \rightarrow \pi\rho)$.

More generally one could in principle use eq. (8) at both γ-π-hadrons vertices to estimate the total hadronic production via pion exchange. This procedure would give total $\gamma\gamma$ cross sections rising with s and therefore indicate that the hypothesis of single pion exchange cannot be pushed too far. On the other hand this could also indicate that the extrapolation of eq. (2) to moderate energies cannot be completely reliable.

By substituting eq. (9) into (1) and using $\sqrt{s_0} = 0.6$ GeV one gets a cross section for $e\bar{e} \rightarrow e\bar{e}$ + hadrons of about 2 nb s and 1 nb for the constant and the $1/\sqrt{s}$ terms respectively, at E = 2.5 GeV. These contributions are a factor of two smaller at E = 1.5 GeV. Similarly, from eqs. (12) and (13), one gets about 2.5 nbs and 1.5 nbs at E = 2.5 and E = 1.5 respectively. These estimates are of the same order of those deduced from eq. (2).

Recalling that at E = 1.5 GeV and 2.5 GeV the cross section for $e\bar{e} \rightarrow \mu\bar{\mu}$ is 9.7 nbs and 3.5 nbs respectively, it follows that it is not unconceivable, in the light of our present knowledge of the couplet $\gamma\gamma$ amplitude, to have a pure one-photon scaling cross section $\sigma_{tot}^{1\gamma} = R\sigma_{\mu\bar{\mu}}$, with R of the order of 2-3, also at the highest energies.

Note added in proof. - When this work was completed the author was informed by Prof. S.D. Drell that a possible $\gamma\gamma$ background in SPEAR has been experimentally estimated to be less than 20%.

REFERENCES. -

(1) - B. Bartoli, F. Felicetti, H. Ogren, V. Silvestrini, G. Marini, A. Nigro and F. Vanoli, Phys. Rev. D6, 2374 (1972); C. Bacci, G. Penso, G. Salvini, B. Stella, R. Baldini Celio, G. Capon, C. Mencuccini, G. P. Murtas, M. Spinetti and A. Zallo, Phys. Letters 44B, 533 (1973); F. Ceradini, M. Conversi, S. D'Angelo, L. Paoluzi, R. Santonico and R. Visentin, Phys. Letters 47B, 80 (1973); M. Grilli, E. Iarocci, P. Spillantini, V. Valente, R. Visentin, B. Borgia, F. Ceradini, M. Conversi, L. Paoluzi, B. Santonico, M. Nigro, L. Trasatti and G. T. Zorn, Nuovo Cimento 13A, 593 (1973); M. Bernardini, D. Bollini, P. L. Brunini, E. Fiorentino, T. Massam, L. Monari, F. Palmonari, F. Rimondi and A. Zichichi, presented to the Meeting of the Italian Phys. Society, Firenze (1973). For a review see also K. Strauch, ref. (2).

(2) - A. Litke, G. Hanson, A. Hofman, J. Kock, L. Low, M. E. Law, J. Leong, R. Little, R. Madaras, H. Newman, J. M. Paterson, R. Pordes, K. Strauch, G. Tornopolsky and R. Wilson, Phys. Rev. Letters 30, 1189 (1973); K. Strauch, Proceedings of the 1973 Intern. Symp. on Electron and Photon Interaction at High Energies, Bonn (1973).

(3) - B. Richter, Invited talk presented to the Irvine Conference on Lepton Induced Reactions, Irvine, Cal. (1973).

(4) - For a recent review see : S. J. Brodsky, Invited talk presented to the Intern. Colloquium on Photon-Photon Collisions in Electron-Positron Storage Rings, College de France, Paris (1973), and SLAC-PUB 1322 (1973).

(5) - J. Rosner, BNL preprint CRISP 71-26 (1971).

(6) - R. Gatto and G. Preparata, University of Roma preprint N. I. 479 (1973).

(7) - The importance of seagull contributions in the process $\gamma\gamma \to$ $\to$ hadrons, in the framework of the parton model, has been unphasized by S. J. Brodsky, F. E. Close and J. F. Gunion, Phys. Rev. D6, 177 (1972).

(8) - G. Barbiellini, F. Ceradini, M. Conversi, S. D'Angelo, M. L. Ferrer, S. Orito, L. Paoluzi, R. Santonico, T. Tsuru and R. Visentin, Frascati preprint LNF-73/63 (1973), to be published; S. Orito, M. L. Ferrer, L. Paoluzi and R. Santonico, Two photon annihilation into pion pairs, to be published.

(9) - The possibility of a strong contribution to the total cross section from $\gamma\gamma \to \omega\omega$ has been emphasized by S. D. Drell (private communication).