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Multiparticle production in photon-photon collisions

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The relationship between multiparticle production in photon-photon collisions and that in hadron-hadron collisions is discussed.

Photon-photon collisions have been studied[1] at electron-positron storage rings via the process

$$e^- + e^+ \rightarrow e^- + e^+ + \gamma + \gamma \rightarrow e^- + e^+ + X \ , \qquad (1)$$

where X stands for the final state of the two interacting photons, denoted by the γ's in (1). By measuring the energy and the scattering angle of the outgoing lepton (e^-, e^+), one can "tag" the corresponding photon by determining its energy $\omega_i = p_{i0} - p'_{i0}$, and its squared mass $q_1^2 = -Q_1^2 = (p_i - p'_i)^2$. Here, p_i and p'_i are the four-momenta of the corresponding incoming and outgoing leptons $(i = 1,2)$, respectively. We denote the lepton-beam energy by E and the total center-of-mass-system (c.m.s.) energy of the photon-photon system by $\sqrt{s}$ (Ref. 2).

While at low energies the final state X consists of a lepton pair, or a hadron pair, or some hadronic resonances, it becomes more complex when such experiments are carried out at larger storage rings with more energetic beams. We are thus led to study multiparticle production processes in high-energy photon-photon collisions. Although not very much is known about such processes at this moment, it is hoped that much data will be available in the future.

One of the interesting points which should be studied in more detail in this connection is the similarities and the differences between photons and hadrons in multiparticle production processes in high-energy photon-photon and hadron-hadron collisions. This is because, based on the vector-dominance-type models[1,3] which are very successful at lower energies, it is envisaged that virtual photons have a kind of "dual nature," and that they are more "hadronlike" than "pointlike" when their masses are not too different from that of real photons. It is clear that such a picture implies a close relationship between the phenomena associated with multiparticle productions in high-energy photon-photon processes with those in hadron-hadron collisions at comparable energies. It is this relationship that we would like to discuss in the present paper. In fact, as a first step, we shall use the equivalent-photon approximation[4] and assume that all photons with not too large Q^2 can simply be considered as hadrons. We then insert the hadron-hadron multiparticle production data[5] at the corresponding incident energies in our ansatz and compare the calculated result with the experimental finding in the photon-photon case. In order to check the proposed ansatz and to examine the similarities and the differences between photons and hadrons in high-energy multiparticle production processes in the small-Q^2 region, several other tests are also suggested.

Consistent with the equivalent-photon approximation,[4] we propose the following ansatz for the case in which the squared masses of the photons are known (through double tagging): The probability for $F(n|Q_1^2, Q_2^2)$ producing n charged hadrons in collisions between two photons of squared masses Q_1^2 and Q_2^2 is the convolution of the hadron production probabilities $P(n,s)$ at a given total c.m.s. energy $\sqrt{s}$ and the probabilities of having photons with energies ω_1 and ω_2 and squared masses Q_1^2 and Q_2^2, respectively:

$$F(n|Q_1^2,Q_2^2) = \frac{\int d\omega_1 \int d\omega_2 \Gamma(\omega_1, Q_1^2)\Gamma(\omega_2, Q_2^2) P(n,s)}{\int d\omega_1 \int d\omega_2 \Gamma(\omega_1, Q_1^2)\Gamma(\omega_2, Q_2^2)} \ . \qquad (2)$$

Here, the ranges of ω_i $(i=1,2)$ in the functions $\Gamma(\omega_i, Q_1^2)$ are of course such that the total c.m.s. energy of the two-photon system is $\sqrt{s}$, given in $P(n,s)$. In fact, for relatively small Q^2 we use the Weizsäcker-Williams approximation[4]

$$\Gamma(\omega, Q^2) = \frac{\alpha}{4\pi E^2} \left[\frac{(2E-\omega)^2}{\omega^2 + Q^2} + 1 - \frac{4m^2}{Q^2} \right] \frac{\omega}{Q^2} \ , \qquad (3)$$

where α is the fine-structure constant $\frac{1}{137}$ and m is the electron mass.

For single-tagging experiments, in which the squared mass of only one of the two colliding photons is known, while the scattering angle of the other is kept in the neighborhood of zero degrees ($\theta_2 \approx 0$, say) and the total c.m.s. energy $\sqrt{s}$ has a given value, the corresponding probability can be obtained from Eqs. (2) and (3) as

$$F^{(1)}(n|Q_1^2|\theta_2\approx 0;s)=\frac{\int_{s/4E}^{E}d\omega_2(E-\omega_2)\Gamma\left[\omega_2,\frac{m^2\omega_2^2}{E(E-\omega_2)}\right]\Gamma\left[\frac{s+Q_1^2}{4\omega_2+Q_1^2/E},Q_1^2\right]P(n,s)}{\int d\omega_1\int d\omega_2(E-\omega_2)\Gamma\left[\omega_2,\frac{m^2\omega_2^2}{E(E-\omega_2)}\right]\Gamma(\omega_1,Q_1^2)} \quad (4)$$

To obtain Eq. (4) we have used

$$s=4\omega_1\omega_2-(E-\omega_2)Q_1^2/E \quad (5)$$

and

$$Q_1^2=4E(E-\omega_i)\sin^2\frac{\theta_i}{2}+\frac{m^2\omega_i^2}{E(E-\omega_i)} . \quad (6)$$

First, we check the quality of the ansatz by summing over n in Eq. (4) and compare the result with the measured number of hadron production events as a function of the observed invariant mass W_{vis}. Such data are available from the single-tag experiments of the PLUTO Collaboration.[6] We note that, because of the normalization $\sum_n P(n|s)=1$, by performing the summation over n, we are checking the quality of our product ansatz and the usefulness of the Weizsäcker-Williams approximation for this purpose. The above-mentioned data and our calculated result are shown in Fig. 1. Here we have taken into account that the measured invariant mass W_{vis} is smaller than the total invariant mass $\sqrt{s}$ by about 27%, and we have scaled our *probability* curve to obtain the experimental *number of events* by adjusting to a single experimental data point at $W_{\text{vis}}=4$ GeV.

Next, we calculate the multiplicity distribution. Since the photons are treated as hadrons, we insert into Eq. (2) the charged hadron multiplicity distributions $P(n,s)$ obtained from hadron-hadron experiments. In carrying out the calculations, we used the following parametrizations[7] for the experimental data:[5]

$$P(n,s)=\frac{16}{5\langle n\rangle}\left[\frac{3n}{\langle n\rangle}\right]^5 \exp\left[-\frac{6n}{\langle n\rangle}\right] . \quad (7)$$

Here, $\langle n\rangle$ is the mean multiplicity, which can either be taken directly from the data[8] or obtained from the parametrization

$$\langle n\rangle=a+b\ln s+c(\ln s)^2 , \quad (8)$$

with $a=0.88$, $b=0.44$, and $c=0.118$, where s is given in GeV^2.

We note that, since hadron production in photon-photon collisions is enhanced at low $\sqrt{s}$ values, it is important to check the quality of the above-mentioned parametrizations in these kinematical regions. As an example we show in Fig. 2 a comparison of Eq. (7) with experimental data down to $\sqrt{s}\approx 2$ GeV. It is interesting to see that Eqs. (7) and (8) taken together indeed give a reasonable description of these data.

The only low-Q^2 multiplicity distribution data in photon-photon collisions now available are those obtained by the PLUTO Collaboration.[6] Comparison between these data and our calculated result is shown in Fig. 3. The agreement between the existing low-Q^2 data[6]

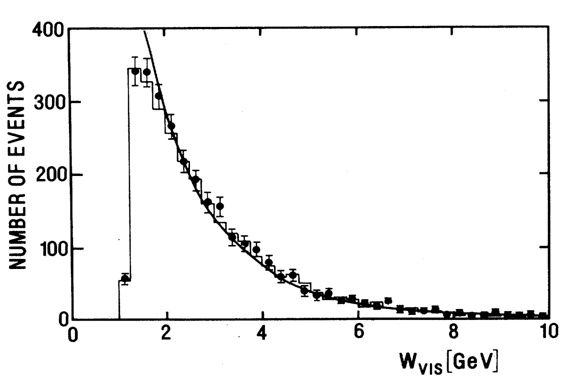

FIG. 1. Number of multihadron production events as functions of measured invariant mass W_{vis}, which should be equal to $\sqrt{s}$ when the experimental corrections are taken into account. The curve is the calculated result. (See text for details.)

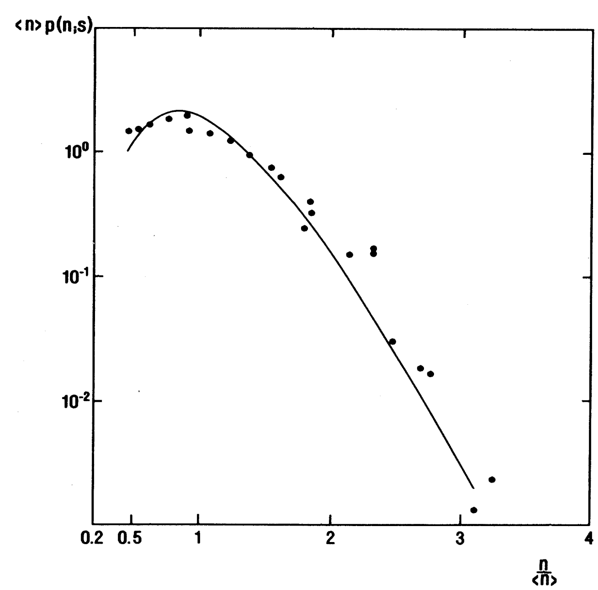

FIG. 2. Comparison between data on the hadron-hadron multiplicity distribution for $2.2<\sqrt{s}<7.1$ GeV (taken from Ref. 5) and the parametrization [Eq. (7)] used in this paper.

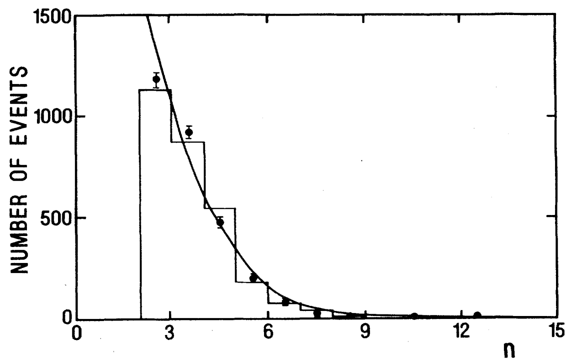

FIG. 3. Multiplicity distributions of charged particles in photon-photon collisions. Data are taken from Ref. 6. The curve is the calculated result.

and the calculated results seems to suggest that photons in multiparticle production processes in high-energy photon-photon collisions can indeed be considered as hadrons, and that it is worthwhile to study the similarities and the differences between photons and hadrons in such reactions in further detail. In experimental studies[9] of high-p_t (transverse-momentum) jet formation in untagged photon-photon collisions, it has been observed[9] that events with two-jet topology can be well described by the sum of Born and vector-dominance-model (VDM) terms alone, when the p_t of the jet is less than 3 GeV/c. But for jet transverse momenta greater than this value, there is evidence for an excess of events above the Born and VDM terms. In this connection, it should be of considerable interest to see whether such excesses are associated with QCD multijet formation and/or whether the low-p_t-jet and high-p_t-jet events in photon-photon collisions are related in the same way as that between low-E_t (transverse energy) and high-E_t events in hadron-hadron collisions.[10,11]

It would also be interesting to measure multiplicity distributions in no-tag and in double-tag experiments. In both cases the distributions can be readily calculated by using the equations and data parametrizations given in this paper in a straightforward manner. Furthermore, it would also be interesting to measure the forward-backward charge-multiplicity correlations in the double-tag case; this is because the existence of such long-range correlations is one of most characteristic features of hadron-hadron multiparticle production processes.

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[1]See, for example, H. Kolanoski, in *Two-Photon Physics at e^+e^- Storage Rings,* edited by G. Höhler (Tracts in Modern Physics, Vol. 105) (Springer, Berlin 1984), and the papers cited therein.

[2]As a function of the masses and the momenta of the photons, it can of course be expressed in terms of the energies and momenta of the leptons which are directly measured. The explicit expression is omitted here.

[3]See, for example, V. Maor and E. Gotsman, Phys. Rev. D **28**, 2149 (1982); see also R. P. Feynman, *Photon-Hadron Interactions* (Benjamin, New York, 1972), p. 82; B. L. Joffe, V. A. Khoze, and L. N. Lipatov, *Hard Processes* (North-Holland, Amsterdam, 1984), Vol. 1, p. 153, and the references therein.

[4]E. J. Williams, Proc. R. Soc. London **139**, 163 (1933); Phys. Rev. **45**, 729 (1934); K. F. von Weizsäcker, Z. Phys. **88**, 612 (1934); see also V. M. Budnev, I. F. Ginzburg, G. V. Meledin, and V. G. Serbo, Phys. Rep. **15**, 181 (1975); C. Carimalo, P. Kessler, and J. Parisi, Phys. Rev. D **21**, 669 (1980), and the references therein.

[5]See, for example, E. Bracci *et al.,* Report No. CERN/HERA **72-1**, 1972, and the papers cited therein.

[6]PLUTO Collaboration, Ch. Berger *et al.,* Phys. Lett. **149B**, 421 (1984).

[7]Liu Lian-sou and Meng Ta-chung, Phys. Rev. D **27**, 2640 (1983). Note that, for our purpose, we merely use the formulas given in Eqs. (11a) and (11b) as a parametrization of the data.

[8]W. Thromé *et al.,* Nucl. Phys. **B129**, 365 (1977); UA5 Collaboration, K. Alpgard *et al.,* Phys. Lett. **107B**, 315 (1981).

[9]See, for example, L. Poggioli, in *Proceedings of the XXIII International Conference on High Energy Physics,* Berkeley, California 1986, edited by S. C. Loken (World Scientific, Singapore, 1986), p. 1193, and the papers cited therein, as well as other contributions on this subject constituted to this conference.

[10]Chao Wei-quin, Meng Ta-chung, and Pan Ji-cai, Phys. Rev. Lett. **58**, 1399 (1987); Meng Ta-chung and Pan Ji-cai, Phys. Rev. D **37**, 243 (1988), and the papers cited therein.

[11]P. Darriulat, in *Proceedings of the International Europhysics Conference on High Energy Physics,* Uppsala, Sweden, 1987, edited by D. Botner (European Physical Society, Geneva, Switzerland, 1987), Vol. II, p. 738, and the papers cited therein.