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Low-energy vector-dominance-model description of $\gamma\gamma$ reactions

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The threshold enhancement of $\gamma\gamma \to \rho\rho$ is reexamined. We claim that factorization, when explicitly evaluated for low energies, does account for most, if not all, of the reported cross-section data. Our analysis indicates an important low-energy isoscalar-photon contribution yielding a large $\omega\omega$ production cross section. Our approach implies that the vector-dominance model is the major low-energy $\gamma\gamma$ mechanism. This is supported by the preliminary available information on $\gamma\gamma$ total cross sections.

Recently published data[1] provide relatively detailed knowledge of the reaction $\gamma\gamma \to \rho^0\rho^0$ at low photon energies. The most striking phenomenon observed is a very strong cross-section enhancement at threshold which is stated to be an order of magnitude above an estimated vector-dominance-model (VDM) contribution to this reaction. This situation is compatible with the first reported results on the $\gamma\gamma$ total cross sections, where both the PLUTO and TASSO collaborations[2] have reported a large increase of the total cross section at the same low-energy range. Even though there are differences between these two reported cross sections and the actual $\sigma_{\gamma\gamma}^{\rm tot}$ estimates may be model dependent,[3] it is believed that their values are also much bigger than the VDM estimates. These discrepancies have led to quite a few speculations that low-energy $\gamma\gamma$ physics, and, in particular, the exclusive $\rho^0\rho^0$ channel, exhibit a strong signature for a new non-VDM process, be it the production of a new exotic resonance in the direct $\gamma\gamma$ channel,[4] or the manifestation[5] of the pointlike γ-q coupling.[6] Common to these speculations is the claim that the suggested new component has a large signal as compared with the VDM background. In the following we shall reexamine the low-energy $\gamma\gamma$ data. We conclude that the hadronlike (VDM) photon sector does comfortably account for most, if not all, of the data, and, in general, the low-W, low-Q^2 $\gamma\gamma$ interactions data. This being the case, the relevant ratio of signal to VDM background in recent speculations[4,5] is probably small, and therefore rather elusive to experimental verification.

The so-far-reported VDM estimates[1,7] of the low-energy $\gamma\gamma \to \rho\rho$ total cross sections are based on the extrapolation of the high-energy photoproduction (asymptotic) $d\sigma/dt$ parametrization to the relevant low-energy domain. The high-energy parametrization includes only the isovector-photon (Pomeron t-channel exchange) contribution where factorization is explicitly assumed, that is

$$\sigma(\gamma\gamma \to \rho\rho) = [\sigma(\gamma p \to \rho p)]^2/\sigma(pp \to pp) \quad . \quad (1)$$

The small value of the low-energy integrated cross sections are then a direct consequence of two effects:

(1) The asymptotic cross-section estimates are not adequate to account for the larger cross section observed at low energies. This is very similar to the situation known in the analysis[8] of $\sigma_{\rm tot}(\pi^+\pi^-)$ just above the ρ-f resonance region. The asymptotic estimate

$$\sigma_{\rm tot}(\pi^+\pi^-) = \sigma_{\rm tot}(\pi^-p)\,\sigma_{\rm tot}(\pi^+p)/\sigma_{\rm tot}(pp) \simeq 14 \text{ mb} \quad (2)$$

is by far lower than the actual cross section which is measured to be about 35 mb. We note that an improved estimate of $\sigma_{\rm tot}(\pi^+\pi^-)$ is obtained once the factorization relation (2) is evaluated at the actual low-energy $E_{\rm c.m.}$ range under consideration.

(2) When integrating $d\sigma/dt(\gamma\gamma \to \rho\rho)$ at low ener-

gies, one obtains very low integrated values due to the relatively high $|t_{\min}|$ and the smallness of $|t_{\max}-t_{\min}|$. This problem relates to the well known uncertainties as to which is the appropriate variable to extrapolate with from high to low energies. At low energies, in particular, when treating a t-channel unequal-mass problem such as ours, the choice of an appropriate variable is crucial. We note that $\sigma_{\text{tot}}(\pi^+\pi^-)$ estimates are improved if one chooses to evaluate relation (2) at fixed $P_{\text{c.m.}}$ rather than fixed $E_{\text{c.m.}}$ values. Furthermore, we recall that low-energy data comparison with SU(3) relations involving unequal-mass channels were substantially improved[9] once they were evaluated at fixed excitations rather than fixed total c.m. energies.

We thus suggest modifying the procedure by which VDM cross sections were evaluated[1] in the low-energy $\gamma\gamma$ region close to the vector-resonance pair-production threshold. In our opinion, relation (1) should be applied directly at fixed $P_{\text{c.m.}}$ without additional extrapolations and integrations. Our variable choice does not change the high-energy limit of the factorization relation but provides what we consider a better low-energy limit, in particular, for a t-channel unequal-mass problem such as $\gamma\gamma\to\rho\rho$. We also note that factorization relates transition matrix elements, which means that our particular choice of variable requires a flux correction to be introduced into (1). Clearly, our estimates can produce only very approximate results. Nevertheless, even as crude an estimate as ours should distinguish between the two options; i.e., is VDM just a small fraction of the observed $\gamma\gamma$ cross sections,[1,2] or does it approximate the experimental data as indeed we claim.

The factorization relation (1) was applied at fixed final $P_{\text{c.m.}}$ neglecting the ρ width with input taken from Refs. 10 and 11. Our results are shown against the published TASSO data[1] in Fig. 1. We note that more recent results of the same experiment[12] produce a somewhat higher cross section at $W=2.0-2.5$ GeV, which fits nicely with our calculations.

Clearly, our ability to produce meaningful estimates depends crucially on the quality and reliability of our input. We have to clarify therefore some questions relating to this input. Our estimates were taken without a separation between the isovector- and isoscalar-photon sectors. This is perfectly legitimate for the $\rho\rho$ final state where the isoscalar-photon contribution is know to be exceedingly small.[13,14] This is not the case for other channels such as $\omega\omega$, which we shall discuss later on. There is also the problem of whether and how to add the direct-channel contribution to $\gamma\gamma\to\rho\rho$ without double counting. The isovector- and isoscalar-photon contributions to vector-meson photoproduction are associated at higher energies with Pomeron and pion exchanges.[13,14] Once this association is made the direct channel can be added, as we note that the Pomeron

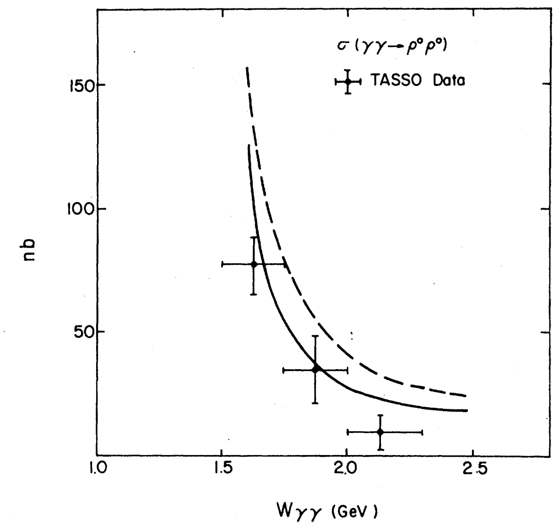

FIG. 1. $\gamma\gamma\to\rho^0\rho^0$ cross sections as function W. Data points are taken from Ref. 1. Solid curve presents our calculations. Dashed curve presents the same calculation with direct-channel contribution added.

is dual to the nonresonant background and the one-pion exchange (OPE) is almost real. In reality, such an addition is not reliable at all. To begin with, our input is not purely peripheral and both the "Pomeron" and "pion" contributions contain many more nonleading contributions such as cuts. For the sake of illustration we present in Fig. 1 also a prediction in which the contribution[4] of the direct f or ϵ is added to our factorized results. It has also been pointed out[15] that η-η' exchanges may play an important role in $\gamma\gamma\to\rho\rho$, due to their large coupling to $\rho\gamma$. However, the determination of such a contribution requires additional input and is dual to the direct-channel resonance production just mentioned. We have therefore preferred to neglect this mechanism.

To conclude: with essentially the isovector photon and factorization we can obtain a plausible estimate of the surprisingly large $\rho\rho$ cross section without the need to appeal to any new production mechanism. Of course some new effects may be present in some small degree in the data, but we do not believe they are evident just because of the low-energy cross-section enhancement. We also note that the preliminary data[1,12] on the ρ center-of-mass angular and decay distributions does not show any dramatic structure as indeed we expect, since factorization suggests a very modest forward angular peak and an almost flat ρ decay distribution as inferred from the low-energy ρ photoproduction. Our predictions are perfectly compatible with VDM which provides a good reproduction of the photoproduction input data.

We now turn to estimates of some other channels and, in particular, $\gamma\gamma \to \omega\omega$. For that purpose we have to adopt a procedure to separate the isovector- and isoscalar-photon sectors. Both sectors are known to play an important role in ω photoproduction.[13,14] To this end we use the published fits[14] of vector-meson photoproduction data as a sum of a weakly dependent term associated with the diffractive (Pomeron exchange) channel, and a strongly energy-dependent term associated with OPE which plays a dominant role in low-energy ω photoproduction,

$$\sigma(\gamma p \to \omega p) = C_1 E^{-\alpha_1} + C_2 E^{-\alpha_2} \ , \tag{3}$$

with $C_1 = 1.20 \pm 0.45$, $\alpha_1 = 0.08$, $C_2 = 22 \pm 4$, and $\alpha_2 = 1.6$. Factorization is then employed for each of these two terms. The pp elastic cross section[11] is assumed to be diffractive and corresponds to Pomeron exchange (isoscalar t-channel quantum numbers). The OPE contribution (which corresponds to isovector t-channel quantum numbers) is obtained from pn charge-exchange data,[16] corrected for isospin coefficients. Our predictions for both $\omega\omega$ and $\omega\rho$ final states are shown in Fig. 2, which contains also the overall estimate for $\gamma\gamma \to VV$ and the preliminary data on total $\gamma\gamma$ cross sections.[2]

An alternative approach to the $\gamma\gamma \to VV$ reactions is to use the t-channel notations for Pomeron (P) and OPE (π) and use VDM and SU(3) relations[17] between the noninterfering components

$$\begin{aligned} \sigma(\gamma p \to \rho p) &= \sigma^P + \sigma^\pi \ , \\ \sigma(\gamma p \to \omega p) &= \tfrac{1}{9}\sigma^P + 9\sigma^\pi \ , \end{aligned} \tag{4}$$

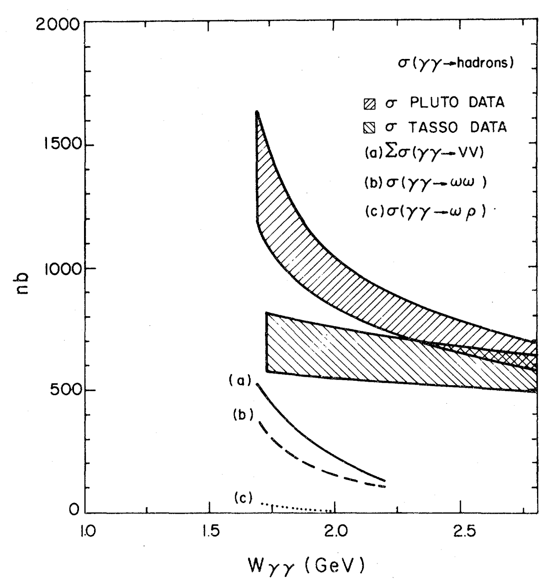

FIG. 2. Calculated cross sections for (a) $\gamma\gamma \to VV$, (b) $\gamma\gamma \to \omega\omega$, and (c) $\gamma\gamma \to \omega\rho$. Also shown are the PLUTO and TASSO preliminary total cross sections for $\gamma\gamma \to$ hadrons.

neglecting the overconstraints ambiguities involved once ϕ photoproduction data are included in the analysis. The most remarkable aspect of such an analysis follows from the use of the rather small OPE contribution to $\rho\rho$ production and VDM to obtain

$$\begin{aligned} \sigma(\gamma\gamma \to \omega\omega) &= 81\sigma^\pi(\gamma\gamma \to \rho\rho) + \tfrac{1}{81}\sigma^P(\gamma\gamma \to \rho\rho) \\ &\simeq 81\sigma^\pi(\gamma\gamma \to \rho\rho) \ . \end{aligned} \tag{5}$$

We discover that the $\omega\omega$ cross section may be as large as 150 nb at $W = 1.65$ GeV, corresponding to the estimates shown in Fig. 2. One should note that relations (3) and (4) are only approximately compatible for low-energy photoproduction. Had we used relation (4) we would have obtained estimates for $\gamma\gamma \to \omega\omega$ which are about 20% lower than those shown in Fig. 2, but with quite a larger error margin. Whichever estimate one chooses, a measurement of $\gamma\gamma \to \omega\omega$ provides a crucial test of our proposal. It appears that such a measurement is both feasible and likely.

Let us next turn to the problem of the large $\gamma\gamma$ total cross sections at low energies. Although there are some significant differences between the two sets of PLUTO and TASSO preliminary reports,[2,3] they both give an unexpectedly large hadronic production cross section at low energies which falls quite rapidly until, above $W = 3.5$ GeV, it coincides with the VDM prediction of

$$\sigma_{\gamma\gamma}^{\mathrm{VDM}}(\gamma\gamma) = \sigma^P + \frac{\sigma^R}{W\ (\mathrm{GeV})} \ , \tag{6}$$

with $\sigma^P \simeq \sigma^R \simeq 250$ nb. It has been noted[3] that the different low-energy results reported by PLUTO and TASSO can be accounted for in part by their different energy-dependent reconstruction of cross-section values from the raw data.

Let us examine if our estimated $\gamma\gamma \to VV$ cross sections constitute a reasonable fraction of the total cross section reported at low energies. Our results are compared in Fig. 2 with the PLUTO and the TASSO data estimates. We remember that for low-energy photoproduction, the vector mesons in the final states make up about 25% of the total cross section.[10,13,14] If a similar proportion of the $\gamma\gamma$ total cross section comes from the VV channels, then we need an $\omega\omega$ cross section between 100 and 150 nb in order to explain the $\sigma_{\mathrm{tot}}(\gamma\gamma)$ observations. This lies comfortably within our previous estimates for the $\omega\omega$ channel. We note of course that $\sigma(\gamma\gamma \to VV)$ falls much more rapidly than $\sigma_{\mathrm{tot}}(\gamma\gamma)$, but one should be aware of the massive opening of many more resonance and nonresonance channels just above the VV threshold.

Another approach to the description of $\sigma_{\mathrm{tot}}(\gamma\gamma)$ would be to apply factorization to the total cross section directly. If we lump the isovector- and isoscalar-photon sectors together we obtain, for example, at $W=2$ GeV, $\sigma_{tot}(\gamma\gamma)\sim 550$ nb, which is too small. However, OPE plays a more important role in low-energy photoproduction than in pp reactions. Let us assume, for example that $\sigma^{\pi}_{tot}(\gamma p)=0.2\sigma_{tot}(\gamma p)$, whereas $\sigma^{\pi}_{tot}(pp)=0.05\sigma_{tot}(pp)$. We then obtain a significant enhancement:

$$\sigma_{tot}(\gamma\gamma)=\frac{[\sigma_{tot}(\gamma p)]^2}{\sigma_{tot}(pp)}\left(\frac{0.2^2}{0.05}+\frac{0.8^2}{0.95}\right)\simeq 810 \text{ nb} \ . \tag{7}$$

Once again we conclude that the quoted VDM low-energy total-cross-section estimates[2,7] are inadequate as they are derived from the asymptotic quark-model relation $\sigma_{el}(\rho\rho)=(\frac{4}{9})^2\sigma_{el}(pp)$. We suggest that there is nothing unexpected in the large low-energy cross-section data provided account is taken of the specific low-energy isoscalar-photon contribution associated with OPE. A parametrization of the energy dependence based on these ideas would therefore contain an energy-independent Pomeron term, a $1/W$ term from Regge exchanges and a low-energy enhancement $1/W^2$ term from OPE:

$$\sigma^{\gamma\gamma}_{tot}(W)=\sigma^P+\frac{\sigma R}{W}+\frac{\sigma^{\pi}}{W^2} \ . \tag{8}$$

This parametrization is perfectly compatible with VDM and provides thus an understanding of the persistent low-energy ρ-pole dependence of the Q^2 distributions observed experimentally.[2] Finally, we note that the last enhancement term comes from a contribution associated with the real OPE and therefore has no dual counterpart in the direct $\gamma\gamma$ channel. This provides an elegant way to avoid problems encountered in low-energy $\gamma\gamma$ duality analysis[5] and replaces the need to introduce the quark-loop term[5] which is very sensible for high-Q^2 phenomena, but whose introduction to solve our low-Q^2 problems always seemed[18] artificial.

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