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An estimate of exchange contributions to the reaction $\gamma\gamma \to \rho^0\rho^0$ near threshold

H. Kolanoski*

Institut für Physik, Universität Dortmund, D-4600 Dortmund 50, Federal Republic of Germany

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Abstract. The large cross section for $\gamma\gamma \to \rho^0\rho^0$ below and near the nominal $\rho^0\rho^0$ threshold cannot be accounted for by t-channel exchange contributions as estimated using a factorisation model.

The cross section for the two-photon reaction

$\gamma\gamma \to \rho^0\rho^0$

is large at the nominal $\rho^0\rho^0$ threshold (i.e. at a $\gamma\gamma$ invariant mass, $W_{\gamma\gamma}$, of twice the peak mass of the ρ) and stays large below the threshold down to $W_{\gamma\gamma} \lesssim 1.3$ GeV (Fig. 1 [1,2]). Since the available phase space for $\rho^0\rho^0$ production becomes very small below the nominal threshold the behaviour of the observed cross section means that the matrix element is extremely fast rising towards smaller $W_{\gamma\gamma}$. The energy dependence of the squared matrix element was estimated by the TASSO group to follow $W_{\gamma\gamma}{}^{-11.4}$ [1].

A theoretical model for two-photon production of $\rho^0\rho^0$ has to explain this strong energy dependence of the matrix element. Resonance formation seems to be an obvious possibility. However, models with one resonance had to be discarded because $\rho^+\rho^-$ production has been measured to be much smaller than $\rho^0\rho^0$ production [3]. By isospin invariance a $q\bar{q}$ resonance decaying into $\rho\rho$ has to be in an $I=0$ state with a decay branching ratio $B(\rho^+\rho^-)$: $B(\rho^0\rho^0)=2$. A resonance interpretation can be maintained assuming interference of different resonances. It has been suggested that an $I=0$ and an exotic $I=2$ state could interfere constructively in the $\rho^0\rho^0$ channel and destructively in the $\rho^+\rho^-$ channel thus explaining the small $\rho^+\rho^-$ cross section [4, 5].

Alexander et al. [6] have argued that it should be checked whether the threshold enhancement cannot be explained conventionally before resorting to exotic explanations. They calculated the contributions from t-channel exchanges by applying factorization rules to photoproduction and nucleon–nucleon scattering data. To determine the two-photon cross section for the production of a vector meson pair $V_1 V_2$ they used the following relation:

$$\sigma(\gamma\gamma \to V_1 V_2) = \sum_i \frac{\sigma^i(\gamma N \to V_1 N)\cdot\sigma^i(\gamma N \to V_2 N)}{\sigma^i(NN \to NN)} \frac{F^{(1)}_{\gamma N}\cdot F^{(2)}_{\gamma N}}{F_{NN}\cdot F_{\gamma\gamma}}. \quad (1)$$

The sum accounts for different exchanges (pomeron, pion, etc.). In principle such a factorization formula relates matrix elements. Near threshold it is not a priori defined at what kinematical point and with what kinematical corrections cross sections should be compared. How these problems are solved is more a question of intuition rather than stringent arguments. In [6, 7] it was suggested as a sensible solution to take all cross sections at fixed center-of-mass momenta, p^*, of the outgoing particles. The factors F_{ij} in (1) correct for the different fluxes of the incoming particles i and j. Using ρ photoproduction and pp elastic scattering data the authors of [7] derived from relation (1) a cross section estimate for $\gamma\gamma \to \rho^0\rho^0$ which approximately reproduces the observed threshold enhancement.

In the following we estimate the $\gamma\gamma \to \rho^0\rho^0$ cross section using essentially the same formalism as in [6, 7]. Particularly, the $\gamma\gamma \to \rho^0\rho^0$ cross section will be related to the $\gamma p \to \rho^0 p$ and $pp \to pp$ cross sections at fixed p^*. Furthermore, it will be assumed that the $\gamma\gamma \to \rho^0\rho^0$ and $\gamma p \to \rho^0 p$ cross sections are dominated by pomeron exchanges and only these contributions will be considered. Here the problem arises that the pomeron exchange contribution to the pp elastic cross section near threshold is not known. Two different estimates for this contribution will be used below.

The formalism applied here differs from that in [6, 7] in the way the width of the ρ is accounted for. However, the difference is only significant very close to the nominal $\rho^0\rho^0$ threshold ($W_{\gamma\gamma} = 1.55$ GeV) and below.

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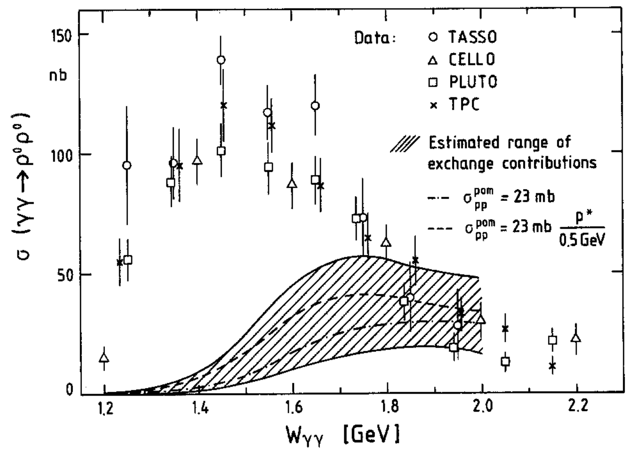

Fig. 1. Cross section for the reaction $\gamma\gamma\to\rho^0\rho^0$. The experimental data are compared to an estimate of t-channel exchange contributions. For the two curves different assumptions about the pomeron exchange contribution to the pp cross section are used; the hatched band indicates the range of the estimate including the uncertainty from the photoproduction cross section

The ρ production cross sections will be folded with Breit–Wigner functions in the following way:

$$\sigma_{\gamma\gamma\to\rho\rho}=\frac{1}{\pi^2}\int dm_1^2\int dm_2^2\,\frac{m_1\Gamma_\rho(m_1)}{D_\rho^2(m_1)}\,\frac{m_2\Gamma_\rho(m_2)}{D_\rho^2(m_2)}\cdot\sigma'_{\gamma\gamma\to\rho\rho}(W_{\gamma\gamma},m_1,m_2) \qquad (2)$$

$$\sigma_{\gamma p\to\rho p}=\frac{1}{\pi}\int dm^2\,\frac{m\Gamma_\rho(m)}{D_\rho^2(m)}\,\sigma'_{\gamma p\to\rho p}(W_{\gamma p},m).$$

The integrals run over the allowed kinematical range and are normalized to 1 for a unit cross section ρ' if there are no kinematical restrictions. The W_{ij}'s are the invariant masses of the particles i and j. The centre-of-mass momentum p^* of the outgoing particles depends on the actual mass the ρ can acquire. $\Gamma_\rho(m)$ is the energy dependent ρ width and $D_\rho^2(m)=(m^2-m_\rho^2)^2+m^2\Gamma_\rho^2(m)$ is the Breit–Wigner denominator.

Separating the flux and phase space factors from the dynamics the cross sections can be written as:

$$\sigma'_{ij}=\frac{p^*}{4\pi F_{ij}W_{ij}}A_{ij}. \qquad (3)$$

The F_{ij}'s are the flux factors and the functions A_{ij} correspond to the squared matrix elements. For constant A_{ij} one can summarize the flux and phase space dependencies together with the effect of the ρ width in the following formulae:

$$C_{\gamma\gamma}=\frac{1}{8\pi^3W_{\gamma\gamma}^2}\int dm_1^2\int dm_2^2\cdot\frac{m_1\Gamma_\rho(m_1)}{D_\rho^2(m_1)}\,\frac{m_2\Gamma_\rho(m_2)}{D_\rho^2(m_2)}\,\frac{p^*(m_1,m_2)}{W_{\gamma\gamma}}$$

$$C_{\gamma p}=\frac{1}{8\pi^2(W_{\gamma p}^2-M_p^2)}\int dm^2\,\frac{m\Gamma_\rho(m)}{D_\rho^2(m)}\,\frac{p^*(m)}{W_{\gamma p}}$$

$$C_{pp}=\frac{1}{16\pi W_{pp}^2}. \qquad (4)$$

Assuming that the matrix element for two-photon production of $\rho^0\rho^0$ depends only on p^*, the $\gamma\gamma\to\rho^0\rho^0$ cross section is obtained from the formula:

$$\sigma_{\gamma\gamma\to\rho\rho}=\frac{1}{8\pi^3W_{\gamma\gamma}^3}\int dm_1^2\int dm_2^2\,\frac{m_1\Gamma_\rho(m_1)}{D_\rho^2(m_1)}\,\frac{m_2\Gamma_\rho(m_2)}{D_\rho^2(m_2)}\cdot p^*(m_1,m_2)A_{\gamma\gamma}(p^*) \qquad (5)$$

where $A_{\gamma\gamma}(p^*)$ is obtained from the fixed-p^* factorization relation:

$$A_{\gamma\gamma}(p^*)=\frac{(A_{\gamma p}(p^*))^2}{A_{pp}^{\text{pom}}(p^*)}. \qquad (6)$$

In this formula it is assumed that the pomeron exchange dominates the $\gamma\gamma$ and γp processes. A_{pp}^{pom} is related to the pomeron contribution of the pp elastic cross section by:

$$A_{pp}^{\text{pom}}=\frac{\sigma_{pp}^{\text{pom}}}{C_{pp}}. \qquad (7)$$

To get an estimate for σ_{pp}^{pom} we note that below the inelastic threshold the elastic cross section goes through a minimum of about 23 mb around $p^*=0.35$ GeV and then rises very steeply towards the elastic threshold. This rise is supposed to be due to pion exchanges. Lacking other experimental information we use two different assumptions for the pomeron exchange contribution:

1) $\sigma_{pp}^{\text{pom}}=23$ mb (constant)

2) $\sigma_{pp}^{\text{pom}}=23\,\text{mb}\,\frac{p^*}{0.5\,\text{GeV}}$ for $p^*<0.5$ GeV

$\quad=23$ mb for $p^*>0.5$ GeV.

Note that the combined flux and phase space factor has a s^{-1} dependence, so that a constant cross section implies that the squared matrix element is proportional to s as expected for diffractive scattering at high energies.

The relevant photoproduction data [8] are plotted in Fig. 2 versus the photon laboratory energy, E_γ^{lab}. The data points above $E_\gamma^{\text{lab}}=1.4$ GeV are an average of two analysis methods applied in [8] (taken from [9]). The nominal threshold for ρ-production is at $E_\gamma^{\text{lab}}=1.1$ GeV corresponding to $W_{\gamma\gamma}=1.55$ GeV for the same p^*, while $E_\gamma^{\text{lab}}=2.0$ GeV corresponds to $W_{\gamma\gamma}=1.95$ GeV. The dashed curve in Fig. 2 shows the E_γ^{lab} dependence of the flux and phase space factor $C_{\gamma p}$ (in arbitrary units). Dividing the measured cross section by $C_{\gamma p}$ yields the crosses in Fig. 2 (again in arbitrary units) which indicate that the underlying matrix element is roughly constant.

Assuming that the matrix element is independent of E_γ^{lab} and p^* one obtaines from the average below

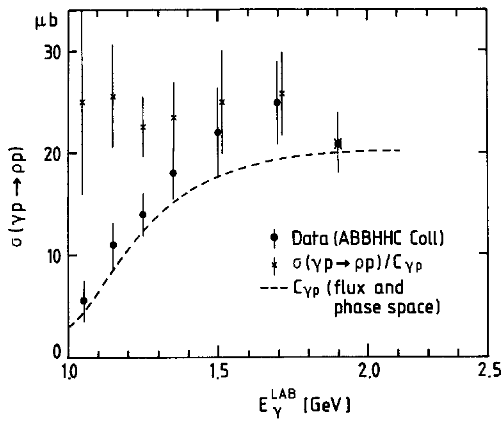

Fig. 2. Cross section for photoproduction of ρ^0 mesons measured by [8] (open circles). The crosses are obtained by correcting for the flux and phase space dependence which is plotted as the dashed curve. This curve and the corsses are given in arbitrary units

$E_\gamma^{\mathrm{lab}} = 2.0\,\mathrm{GeV}$:

$$A_{\gamma p} \approx \left\langle \frac{\sigma_{\gamma p}}{C_{\gamma p}} \right\rangle. \tag{8}$$

Rather than taking the relatively small statistical error we assume for the following that this number has a 20% uncertainty. Figure 1 shows the estimate for the $\gamma\gamma \to \rho^0\rho^0$ cross section using the two assumptions for the pomeron contribution to the pp elastic cross section with $A_{\gamma p} = 23.3$. The shaded band in Fig. 1 includes also an assumed 20% uncertainty in $A_{\gamma p}$.

According to our estimate the pomeron exchange cannot account for the experimentally observed enhancement in the $\gamma\gamma \to \rho^0\rho^0$ cross section at threshold. A better description of the data can only be achieved if one assumes either that the photoproduction cross section does not fall to zero at threshold or that the pomeron contribution to the pp elastic cross section goes much faster to zero at threshold than proportional to p^*. There is no experimental support for either assumption. Note that an infinite $\rho^0\rho^0$ cross section would result from the assumption that $\sigma_{pp}^{\mathrm{pom}}$ is related to the absorptive part of the pp cross section and thus vanishes below the inelastic threshold. Such a procedure is clearly extremely dependent on the kinematical point chosen to relate the different processes in the factorization formula. In the presence of thresholds the choice of fixed p^* appears even more arbitrary.

In conclusion, an estimate for the pomeron exchange contribution to the reaction $\gamma\gamma \to \rho^0\rho^0$ was derived using a factorization formalism as proposed in [6, 7]. Setting aside the basic problems connected with the application of factorization to threshold processes our estimate suggests that the $\rho^0\rho^0$ threshold enhancement cannot be accounted for by the pomeron exchange mechanism. The opposite conclusion was drawn in [6, 7]. A detailed study indicates that the main difference does not come from different kinematical corrections. The origin of the difference is not clear.

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