Abstract. A \( t \)-channel factorization model is used to estimate cross sections for the processes \( \gamma \gamma \rightarrow V_1 V_2 \). Whenever \( V = \rho \), the width of the \( \rho \) has been included in the calculations. The channels \( \gamma \gamma \rightarrow \rho^0 \rho^0 \), \( \rho^0 \varphi \), \( \omega \omega \), \( \rho^0 \alpha \) and \( \rho^+ \rho^- \) are calculated for two quasi-real photons. Predictions are also given for the process \( \gamma \gamma \rightarrow \rho^0 \rho^0 \) for virtual photon mass squared \( Q^2 < 5 \text{GeV}^2 \). Our results are consistent with all available experimental data.

I. Introduction

A large cross section for the quasi-real photons (no tag) reaction \( \gamma \gamma \rightarrow \rho^0 \rho^0 \) near threshold has been observed \([1-3]\). This threshold enhancement is considerably bigger than a simple asymptotic VDM prediction \([1]\) and therefore has triggered several interpretations. Among them are those studies which attempted to understand the large \( \rho^0 \rho^0 \) cross section as a signature of a new phenomena in the direct \( \gamma \gamma \) channel: the production of a new resonance \([4]\) or the exotic formation of interfering four-quark bound states with \( I=0 \) and \( I=2 \) \([5, 6]\). A more conservative approach has been to accommodate the observed \( \rho^0 \rho^0 \) enhancement by the factorization properties of the hadron-like (VDM) two photon interaction \([7]\). The relevance of this approach is self-evident. If it does provide, as indeed we claim, satisfactory estimates for the observed rates of vector meson production in \( \gamma \gamma \) collisions, then it defines a large background over which any signal of a more exotic nature should be verified.

In this paper we wish to elaborate on the factorization model defined in \([7]\). The model assumptions remain unchanged. We apply the factorization relation for the crossed \( t \)-channel natural and unnatural parities at fixed outgoing c.m. momenta, correcting for the flux factors (denoted by \( F_{ij} \)) arising from the different masses involved. Thus we get:

\[
\sigma(\gamma \gamma \rightarrow V_1 V_2) = \sum_i \sigma(\gamma N \rightarrow V_1 N) \sigma(\gamma N \rightarrow V_2 N) F_{iN}^2 \frac{F_{\gamma N}^2}{F_{\gamma \gamma}}
\]

where the summation is over the various \( t \)-channel processes contributing to \( \gamma \gamma \rightarrow V_1 V_2 \). As we shall see the actual processes of interest are the diffractive and the one pion exchange (OPE) contributions. Thus our summation is equivalent to summing over the isoscalar and isovector photon components. Equation (1) has the advantage that it approaches the standard asymptotic factorization relation in the high energy limits, while providing a sensible low energy continuation close to threshold.

The applicability of this model crucially depends on several elements:

a) that the quality of the input data is satisfactory,

b) that a reliable separation of the input data to \( t \)-channel contributions with well defined quantum numbers is possible,

c) that our main assumption is viable, i.e. that a \( t \)-channel model, when continued to the low energy limit, provides nevertheless a reasonable average description of the data.

In the following we shall apply the model to estimate the diffractive production of \( \rho^0 \rho^0 \), \( \varphi \varphi \) and \( \rho^0 \rho^0 \) by two quasi-real photons. We improve on our previous calculation \([7]\) by taking the \( \rho \) width into account. We proceed to predict the \( \rho^0 \rho^0 \) cross sections when one of the initial photons is off shell. The model is then applied to estimate the cross sections of \( \gamma \gamma \rightarrow \omega \omega \) and \( \gamma \gamma \rightarrow \rho^0 \rho^0 \). We conclude by discussing the estimate of \( \gamma \gamma \rightarrow \rho^+ \rho^- \).
II. Diffractive Production of Vector Mesons

The reactions $\gamma\gamma \rightarrow \rho^0\rho^0$, $\gamma\gamma \rightarrow \phi\phi$ and $\gamma\gamma \rightarrow \rho^0\phi$ are very suitable for the application of (1). The input reactions are either purely or predominantly diffractive for which we have reliable cross sections close to threshold [8–10]. There is, however, a certain ambiguity with regard to the $\rho^0$ photo-production input data resulting from different model dependent handlings of the $\rho^0$ resonance. The cross sections obtained with a standard Breit-Wigner analysis, the Söding [11] or Ross-Stodolsky [12] models differ by as much as 15%. This together with the statistical errors are the sources of uncertainty in our input reflected in the wide band of our $\rho^0\rho^0$ cross section output.

Our earlier estimate neglected the $\rho^0$ width, which may affect the results for $W_{\gamma\gamma} \leq 1.7$ GeV. Following [1], we present here a simple Breit-Wigner procedure to unfold the $\rho^0$ width:

\[
\sigma(\gamma\gamma \rightarrow \rho^0\rho^0) = \left\{ \frac{M}{m_1} \left[ \sigma(\gamma\gamma \rightarrow \rho^0\rho^0)^F_{p\rho} \right] \{\text{BW}(m)\}^2 dm \right\}^2 \left\{ \frac{M}{m_1} \left[ \{\text{BW}(m)\}^2 dm \right] \right\}^2
\]

(2)

where $m_1 = 0.6$ GeV, $m_2 = 0.9$ GeV and $M = \min \left( \frac{W_{\gamma\gamma}}{2}, 0.9 \text{ GeV} \right)$. The numerical results are insensitive to our particular choice of $m_1$ and $m_2$. The Breit-Wigner amplitude is given by

\[
\text{BW}(m) = \frac{V m_\rho F_{p\rho}}{\pi (m_\rho^2 - m^2 - i m_\rho F_{p\rho})}
\]

with

\[
\Gamma_\rho = \Gamma_0 \frac{p^*^3}{p_0^*^2 + p^*^2}, \quad p^* = \sqrt{m^2 - 4 m^2_x}
\]

The $\rho^0$ nominal parameters used are $m_\rho = 0.776$ GeV and $\Gamma_0 = 0.155$ GeV. To compare our prediction with the data below $W_{\gamma\gamma} = 1.5$ GeV we have followed [1] and have subtracted 50 MeV from the input $m_\rho$ for every decrease of 100 MeV in $W_{\gamma\gamma}$.

For the actual application of (2), we have used numerical extrapolations, including error propagations, through the data points of [8–10]. Our results for $\gamma\gamma \rightarrow \rho^0\rho^0$ in the final state are shown in Fig. 1 where we compare our estimates with the no-tag data of TASSO [11], CELLO [2] and TPC [3]. As can be seen, we reproduce the observed threshold enhancement of $\gamma\gamma \rightarrow \rho^0\rho^0$ including the observation [1] of a big cross section below the nominal $\rho^0\rho^0$ threshold. We predict a very small cross section for $\gamma\gamma \rightarrow \phi\phi$. For $2 < W_{\gamma\gamma} < 5$ GeV our predicted cross sections range from 0.001 to 0.05 nb respectively. This estimate is far below the current experimental upper limits [13, 14], where $\phi + 2$ charged tracks are observed in the final state, but no $\phi\phi$ signal has been detected thus far. Our prediction for $\sigma(\gamma\gamma \rightarrow \rho^0\phi)$ in the energy range $2 < W_{\gamma\gamma} < 3$ GeV is 0.4–0.5 nb. Once again no $\rho^0\phi$ signal has been detected in the $\phi + 2$ charged tracks sample and the published upper limits [13, 14] are well above our estimate.

III. The Reaction $\gamma^*\gamma \rightarrow \rho^0\rho^0$

It is of interest to check the predictions of our model for single tag production of $\rho^0\rho^0$. Whereas our treatment of the no-tag, almost real photons, as hadron-like is rather sensible, one may, however, question the validity of this treatment for off mass photons. We rely here on a similar model [15] applied to deep inelastic $e^-\gamma$ scattering which was compared with the data [10]. The conclusions of that comparison are that whereas a factorizable estimate reproduces the data at small $Q^2$, it is severely deficient when compared with the high $Q^2$ data. This conclusion is not surprising in view of the fact that the point-like photon contribution increases with $Q^2$.

Our estimates are thus confined to $Q^2 < 5\text{ GeV}^2$, where we have taken the $e\rho \rightarrow e\rho^0\rho$ input data from [17]. Our results for two representative $W_{\gamma\gamma}$ values are displayed in Fig. 2. An interesting point should be noted. If we compare our results with a $\rho$-domin