We present a quark model study of the $\omega$ meson photoproduction near threshold. With a limited number of parameters, all the data in history are reproduced. The roles played by the $s$- and $u$-channel processes (resonance excitations and nucleon pole terms), as well as the $t$-channel natural (Pomeron) and unnatural parity (pion) exchanges are clarified. This approach provides a framework for systematic study of vector meson photoproduction near threshold.

1 Introduction

For a long time, the experimental study of the neutral vector meson ($\omega$, $\rho^0$, and $\phi$) photoproduction was concentrated on high energy regions, where the diffractive process played a dominant role and could be accounted for by a soft Pomeron exchange model. Recently, the availabilities of high intensive electron and photon beams at JLAB, ELSA, ESRF, and SPring-8 give access to excite nucleons with the clean electromagnetic probes. Thus, vector meson production via resonance excitations provides an ideal tool to study the non-diffractive mechanisms in vector meson photoproduction near threshold. Concerning the resonance excitations in this reaction, the other essential motivation is to search for “missing resonances”, which were predicted by the nonrelativistic constituent quark model (NRCQM) but not found in $\pi N$ scatterings. Vector meson photoproduction near threshold might provide supplementary knowledge of those missing resonances and their couplings to vector mesons.

In this proceeding, a quark model approach to vector meson photoproduction near threshold is applied to the $\omega$ meson photoproduction. Our purpose is to provide a framework on which a systematic study of resonance excitations becomes possible. Our model consists of three processes: (i) $s$- and $u$-channel vector meson production with an effective Lagrangian (S+U); (ii) $t$-channel Pomeron exchange ($P$) for $\omega$, $\rho^0$, and $\phi$ production; (iii) $t$-channel light meson exchange. Namely, in the $\omega$ meson photoproduction, the $\pi^0$ exchange is taken into account.

In the $SU(6) \otimes O(3)$ symmetry limit, the constituent quark $\psi$ couples to
a vector meson $\phi^\mu_m$ via an effective Lagrangian

$$L_{\text{eff}} = \bar{\psi}(\alpha\gamma_\mu + \frac{ib\sigma_{\mu\nu}q^\nu}{2m_q})\phi^\mu_m\psi,$$

where $a$ and $b$ are the overall parameters introduced at quark level for baryon states. In this way, all the $s$- and $u$-channel resonances and nucleon pole terms can be included. The $t$-channel vector meson exchange and contact term from the Lagrangian will only contribute in the charged vector meson photo-production. In $\gamma p \to \omega p$, eight low-lying resonances: $P_{11}(1440)$, $S_{11}(1535)$, $D_{13}(1520)$, $P_{13}(1720)$, $F_{15}(1680)$, $P_{11}(1710)$, $P_{13}(1900)$, and $F_{15}(2000)$, with quark harmonic oscillator shell $n \leq 2$ are explicitly included while higher mass states are treated degenerate with $n$. We refer the readers to Ref. 3, 4 for details of this approach.

![Figure 1. Differential cross section for $\gamma p \to \omega p$.](image1)

![Figure 2. Total cross section for $\gamma p \to \omega p$.](image2)

2 Analysis

In Fig. 1, differential cross sections for four energy bins, $E_\gamma = 1.225, 1.450, 1.675$ and 1.915 GeV, are presented and compared with the SAPHIR data. Results for exclusive processes are also presented. It shows that near threshold the $\pi^0$ exchange plays a dominant role over the other two processes, in particular at small angles. With the increasing energy the natural parity Pomeron exchange becomes more and more important which will produce interesting interfering effects in polarization observables. In Ref. 4 we show that the natural and unnatural parity exchanges can be constrained well by the measurement of forward angle parity asymmetries. The dotted curves in Fig. 1...
represent the exclusive calculations of the $s$- and $u$-channel processes. They account for the large angle behavior in the differential cross sections, but have only a small impact on the small-angle cross sections. This feature justifies the method we constrain the $t$-channel processes.

In Fig. 2, the total cross section for $\gamma p \to \omega p$ is given. Interestingly, it shows that the dominant process near threshold is the $S+U$, although it falls down rapidly with the increasing energy. The Pomeron exchange becomes dominant over the pion exchange above $E_\gamma \sim 3.5$ GeV, which is consistent with the experimental results [7]. Note that in Ref. [9], a phenomenological model with parameters predicted by the $^3P_0$ quark-pair-creation model [10] obtains quite different results for exclusive processes.

For the purpose of investigating individual resonance excitations, we have to turn to polarization observables in which small effects from individual resonances might be picked up. Following the convention of Ref. [11], in Fig. 3 we present predictions for $\Sigma \equiv (2\rho^{11}_{11} + \rho^{11}_{00})/(2\rho^{00}_{11} + \rho^{00}_{00})$, where $\rho^1$ and $\rho^0$ are density matrix elements in the helicity space [12]. One of the most important features of $\Sigma$ is that large asymmetries cannot be produced by the $P$ or $P+\pi^0$. As shown by the solid curves, large asymmetries are produced by the interferences between the $P+\pi^0$ and $S+U$ processes.

In this study, we find that the $P_{13}(1720)$ and $F_{15}(1680)$, which are classified to $[56,^28,2,2,J]$ quark model representation, play a strong role in this reaction. The $S_{11}(1535)$ and $D_{13}(1520)$ of $[^70,^28,1,1,1,J]$ have also relatively large effects. In Fig. 3, we show that without the $P_{13}(1720)$, the asymmetry will be significantly changed (see the dotted curves). The predictions can be compared to the preliminary data from GRAAL collaboration [13].

Another interesting observable with polarized photon beam is, $\Sigma_A \equiv (\rho^{11}_{11} + \rho^{11}_{-11})/(\rho^{00}_{11} + \rho^{00}_{-11}) = (\sigma_\parallel - \sigma_\perp)/(\sigma_\parallel + \sigma_\perp)$, where $\sigma_\parallel$ and $\sigma_\perp$ represent the pion decay cross sections of the $\omega$ meson with the pions submerged
in or perpendicular to the photon polarization plane. As found in Ref. 4, this observable is more sensitive to small contributions from individual resonances.

Summarily, we present a quark model study of vector meson photoproduction near threshold by applying it to $\gamma p \rightarrow \omega p$. It provides a framework on which a systematic investigation of resonance excitations in vector meson production can be done. Our predictions should be confronted with the forthcoming data from GRAAL and JLAB in the near future.

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