Nucleonic resonance excitations and " missing resonances" in the ω meson photoproduction

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In this work, an improved quark model approach to the ω meson photoproduction with an effective Lagrangian is reported. The t-channel *natural* parity exchange is consistently taken into account through the Pomeron exchange, while the *unnatural* parity exchange is described by the π^0 exchange. With very limited number of parameters, the available data in the low energy regime can be consistently reproduced in this framework. Effects from the intermediate nucleonic resonances are investigated in several polarization observables. The sensitivities of these observables to the resonance effects are probably the best way for identifying those so-called "missing resonances" in the baryon spectrum.

1. INTRODUCTION AND THE MODEL

The non-relativistic constituent quark model (NRCQM) predicts a much richer baryon spectrum than that observed in $\pi N \to \pi N$ scatterings. This arises the question of the existences of the "missing resonances". Alternatively, it is argued that the "absence" of those resonances might originate from their weak couplings to the πN channel. Therefore, efforts are also made to search for signals of those "missing resonances" in other decay channels, for instance, γN, ηN, $K\Sigma$, $K\Lambda$, ωN, ρN, etc. This revives the study of vector meson (ω, ρ^0, $\rho^\pm$, ϕ and K^*) photo- and electroproduction near threshold in both experiment and theory.

The main feature in vector meson photoproduction is the dominant diffractive phenomenon at small momentum transfer. In the ω meson photoproduction, the *unnatural* parity exchange contribution plays a dominant role over the *natural* parity exchange from threshold $E_\gamma = 1.12$ GeV to $E_\gamma \approx 3.$ GeV. Meanwhile, deviations from the pure diffractive phenomenon are expected since contributions from the non-diffractive intermediate resonance excitations become important.

In this work, a π^0 exchange mechanism is introduced to account for the *unnatural* parity exchange, while a Pomeron exchange model by Donnachie and Landshoff [1] is included to describe the *natural* parity exchange. The commonly used couplings, $g^2_{\pi NN}/4\pi = 14$ and $g^2_{\omega\pi\gamma} = 3.315$ are employed for the πNN and $\omega\pi\gamma$ vertices, respectively, while an exponential form factor $e^{-(\mathbf{q}-\mathbf{k})^2/6\alpha^2_\pi}$ comes from the integrals over the spatial wavefunctions in the harmonic oscillator basis for these two vertices. $\mathbf{k}$ and $\mathbf{q}$ are the momenta of the incoming photon and outgoing ω meson, respectively, in the c.m. system. $\alpha_\pi = 200$ MeV is the only

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parameter introduced for the π^0 exchange terms. In the *natural* parity exchange model, the Pomeron mediates the long range interaction between a confined quark and a nucleon, and behaves rather like a $C = +1$ isoscalar photon. The only parameter $\beta_0 = 1.27$, which describes the coupling strength of the Pomeron to the constituent quark, is determined by experimental data at high energies. In this way, we believe that the *natural* and *un-natural* parity exchanges have been reasonably estimated. We emphasize that a reliable description of the non-resonance contributions at forward angles is the prerequisite for studying roles played by the s- and u-channel resonances.

For the s- and u-channel resonance contributions, an effective Lagrangian is introduced into the quark-vector-meson coupling in the quark model [2,3]:

$$L_{eff} = -\overline{\psi}\gamma_\mu p^\mu \psi + \overline{\psi}\gamma_\mu e_q A^\mu \psi + \overline{\psi}(a\gamma_\mu + \frac{ib\sigma_{\mu\nu}q^\nu}{2m_q})\phi^\mu_m \psi, \tag{1}$$

where ψ and $\overline{\psi}$ represent the quark and antiquark fields, respectively, and ϕ^μ_m denotes the vector meson field. The two parameters, a and b represent the vector and tensor couplings of the quark to the vector meson, respectively, and $m_q = 330$ MeV is the constituent quark mass.

In the $SU(6) \otimes O(3)$ symmetry limit, those low-lying contributing states with $n \leq 2$ in the harmonic oscillator basis are listed in Table 1, while those excited states with $n > 2$ are safely treated degenerate with n. It should be noted that the Moorhouse selection rule [4] has eliminated those states belonging to NRCQM representation [$\mathbf{70}$,$^4\,\mathbf{8}$] from contributing.

Table 1
Resonances in the s-channel, with their assignments in the $SU(6) \otimes O(3)$ symmetry limit. M_R and Γ_T are the masses and total widths of resonances which are taken from Ref. [5].

Resonances	$SU(6) \otimes O(3)$	M_R (MeV)	Γ_T (MeV)
$S_{11}(1535)$	$N(^2P_M)_{\frac{1}{2}^-}$	1535	150
$D_{13}(1520)$	$N(^2P_M)_{\frac{3}{2}^-}$	1520	120
$P_{13}(1720)$	$N(^2D_S)_{\frac{3}{2}^+}$	1720	150
$F_{15}(1680)$	$N(^2D_S)_{\frac{5}{2}^+}$	1680	130
$P_{11}(1440)$	$N(^2S'_S)_{\frac{1}{2}^+}$	1440	350
$P_{11}(1710)$	$N(^2S_M)_{\frac{1}{2}^+}$	1710	100
$P_{13}(1900)$	$N(^2D_M)_{\frac{3}{2}^+}$	1900	250
$F_{15}(2000)$	$N(^2D_M)_{\frac{5}{2}^+}$	2000	250

The constraint on the two parameters, a and b, for the resonance contributions comes from the large angle behavior in the differential cross sections. At large angles, it is the s- and u-channel resonance contributions that play dominant roles over the t-channel contributions. To reproduce the bump structures observed in experiments [6–8], we find that $a = -0.8$ and $b = -1.6$ give an overall fitting for all the data available [9].

2. OBSERVABLES

In Fig. 1, the total cross section (full curve) calculated in this model is presented. The *unnatural* parity exchange contribution is accounted for by the π^0 exchange (dashed curve) over a large energy regime. With the energy increasing, the Pomeron exchange (dot-dashed), which accounts for the *natural* parity exchange contributions, becomes more and more important, and finally dominates the cross sections at high energies. The inclusion of the Pomeron exchange terms improves the previous calculations [10,3] significantly when the photon energies are above the resonance region (from threshold to about 2.2 GeV). The most interesting feature from the resonance contributions (dotted curve) is that, although the π^0 exchange plays a dominant role over a large energy regime, it is the resonance contributions that definitely dominate over the other two processes from threshold to about $E_\gamma = 1.5$ GeV. This feature accounts for the flattened angular distributions near threshold observed in CLAS experiment [11].

In Fig. 2, the angular distributions for different energy scales are presented. Explicitly, it shows that the s- and u-channel resonance contributions (dotted curves) produce the bump structures at large angles, while the π^0 plus Pomeron exchange (dashed curves) account for the forward angle diffractive behaviors. The energy evolution of the large angle behavior is quite sensitive to the relative sign and strength between a and b, which makes the model prediction absolutely non-trivial. We find that the predicted angular distributions are in good agreement with the preliminary CLAS data [11].

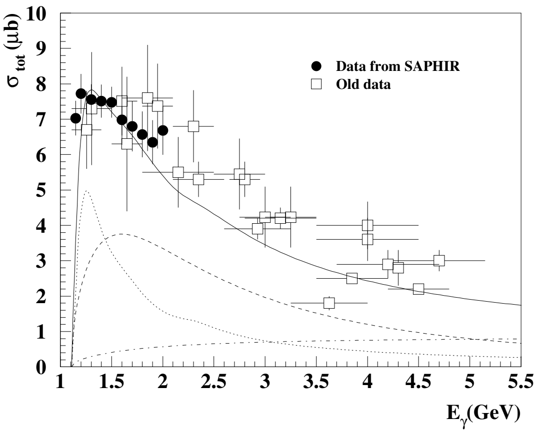

Figure 1. Total cross section. Notations are given in the text.

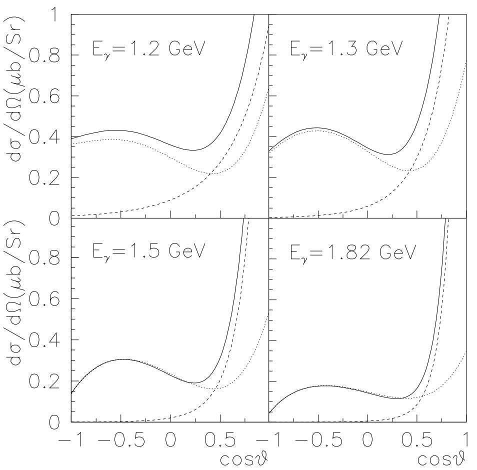

Figure 2. Angular distributions predicted by this model.

Our predictions for the beam polarization asymmetry Σ are presented in Fig. 3. The dashed curves represent the asymmetries with only the t-channel exchange terms (π^0 plus Pomeron). It can be justified that pure *unnatural* or *natural* parity exchanges produce no asymmetries (zero) in Σ. This rule also holds for the π^0 plus Pomeron exchanges in this model. since here the π^0 and Pomeron exchanges contribute to the real and imaginary amplitudes, respectively. Thus, no interfering terms (real-imaginary components) appear in the Σ (Σ only involves the real-real or imaginary-imaginary interfering components). Although the Pomeron exchange is not a rigorous *natural* parity exchange model, it has been good enough to reproduce the main characters. This feature makes the beam polarization asymmetry interesting since the s- and u-channel resonance interferences can be reflected by the obvious deviation from zero. With the resonance contributions included, the asymmetries are shown by the full curves. We find that a clear nodal structure appears at about 90°. Also, a flattened behavior with very small asymmetries is also found in the forward angles between 0° and 60°. Similar feature has been observed in the preliminary data from GRAAL. The energy evolution of the asymmetries will provide a challenge for a model prediction.

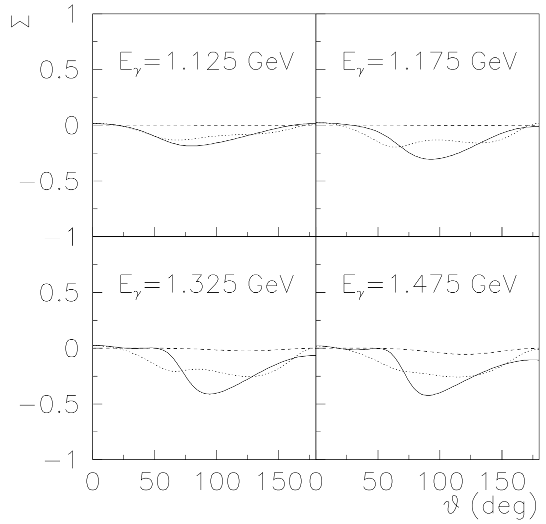

Figure 3. Beam polarization asymmetry within GRAAL energy scope. Notations are given in the text.

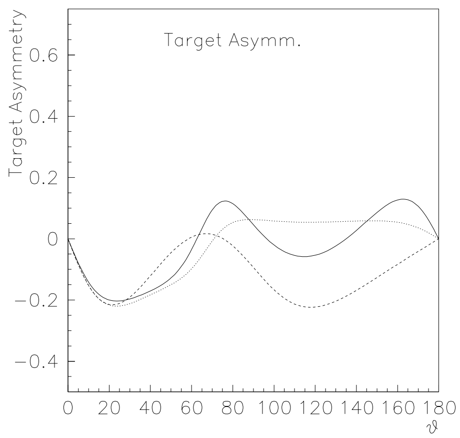

Figure 4. Target polarization asymmetry predicted at $E_\gamma = 1.6$ GeV. Notations are given in the text.

In the $SU(6) \otimes O(3)$ symmetry limit, it shows that two resonances $P_{13}(1720)$ and $F_{15}(1680)$, which are assigned to representation $[\mathbf{56},^2\mathbf{8}]$ with $n = 2$, play dominant roles over other states. The dotted curves in Fig. 3 show the effects without $P_{13}(1720)$. This dominating behavior can be accounted for by the non-vanishing longitudinal, and electro-like transitions at the meson coupling vertex. In comparison with $P_{13}(1720)$ and $F_{15}(1680)$, the contributions from $P_{13}(1900)$ and $F_{15}(2000)$, which belong to representation $[\mathbf{70},^2\mathbf{8}]$ with $n = 2$, turn out to be quite small. In the quark model symmetry limit, only the magnetic-like transition is permitted for these two states.

In Fig. 4, the target polarization asymmetries (full curve) are shown at $E_\gamma = 1.6$ GeV. The dashed curves represent the asymmetries from the t-channel exchanges (π^0 plus Pomeron). In comparison with the full curve in which the resonance contributions are taken into account, we find that the resonance contributions play significant roles at large angles. Interestingly, with the energy increasing, the interference between the π^0 and Pomeron exchange determines the asymmetries at small angles while at large angles it is the resonance interference that plays a dominant role. The dotted curve shows the effects when the two "missing resonances" are eliminated from contributing. In Fig. 4, it shows that the nodal structures at intermediate and large angles come from the interferences of the two "missing resonances". The target polarization asymmetry measurement might be able to provide signals for their existences.

3. CONCLUSION

In summary, we report an improved quark model approach to the ω meson photoproduction. With very limited number of parameters, all the available data in the low-energy region can be consistently reproduced. Such a framework shows great potential in the study of the resonance effects in vector meson photoproduction. We expect that with the final results from GRAAL and CLAS, the parameters in this model can be precisely determined. More detailed results will be reported elsewhere [9].

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