π and ρ loop corrections to ω photoproduction in the resonance region

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One-loop corrections due to the intermediate πN and ρN states are studied in ω photoproduction near threshold. Our results show that the coupled-channel effects should be taken into account in extracting reliable nucleon resonance parameters from the forthcoming vector meson photoproduction data in the resonance region.

1. INTRODUCTION

The study of photoproduction of light vector mesons such as ω, ρ and φ is expected to be useful to resolve the so-called “missing resonances” problem and experimental data are now being accumulated at various experimental facilities [1, 2, 3, 4]. The extracted N* parameters can then be used to test existing hadron models for the baryon resonance structure. There are some theoretical progress to understand the role of nucleon resonances in ω photoproduction at the resonance region [5, 6], where the nonresonant amplitudes are computed from the tree diagrams of the model Lagrangian. This is, however, obviously not satisfactory by neglecting the hadronic final state interactions and the coupled-channel effects. The importance of those effects has been well-known, e.g., in pion photoproduction, and the first trial to account for the coupled-channel effects in vector meson photoproduction has been made in late 1960’s [7]. In this work we make an attempt to reinvestigate this problem in the model of Ref. [5] with the dynamical formulation developed in Ref. [6].

It is the most ideal approach to construct a coupled-channel model by satisfying the unitarity condition [8]. However, because of the lack of experimental information which constrains the transitions between relevant hadronic meson-baryon channels, we first consider the effects due to intermediate πN and ρN channels only [9]. We also simplify the calculations by only considering the one-loop corrections which are the leading order terms in a perturbation expansion of a full coupled-channel formalism. Thus we can estimate the coupled-channel effects only qualitatively, but it will be sufficient to test the importance of the coupled-channel effects in ω photoproduction near threshold.
2. MODEL

In the considered energy region, the $\gamma N$ reaction is a multichannel multiresonance problem. In this work, following the formalism of Sato and Lee [8] we calculate the one-loop corrections to $\omega$ photoproduction which is represented in Fig. 1. Then its matrix element in the center of mass frame becomes [10]

$$ t_{\gamma N,\omega N}(k, q; E) = \sum_{M=\pi,\rho} \int d k' B_{\gamma N,MN}(k, k'; E) G_{MN}(k', E) v_{MN,\omega N}(k', q; E), $$

where $k$ and $q$ are the momenta of the incoming photon and the outgoing vector meson, respectively. $G_{MN}$ is the propagator for the meson-nucleon system, which reads

$$ G_{\pi N}(q', E) = \frac{1}{E - E_{\pi}(q') - E_{\pi}(q') + i\epsilon}, $$

$$ G_{\rho N}(q', E) = \frac{1}{E - E_{\rho}(q') - E_{\rho}(q') + i\frac{\Gamma(q', E)}{2}\theta[\omega^2(q', E) - 4M^2]} $$

by taking into account the $\rho$ meson width [11], where $\theta$ is the step function [10].

We assume that all nonresonant amplitudes $B_{\gamma N,MN}$ (except pion photoproduction amplitude) and $v_{MN,\omega N}$ can be calculated from the tree diagrams defined by the effective Lagrangian [14] and the Pomeron exchange. Therefore the tree diagram model for $\omega$ photoproduction includes the Pomeron, $\pi$ and $\eta$ exchanges as well as the nucleon exchanges [12, 13]. For the one-loop corrections due to the $\pi N$ channel, we need to know the amplitudes $B_{\gamma N,\pi N}$ and $v_{\pi N,\omega N}$. Since there is no tree diagram model for $B_{\gamma N,\pi N}$ in the considered energy region, we construct the amplitude by subtracting the resonance contribution from the empirical multipole amplitudes of the SAID program [14]. Therefore, $B_{\gamma N,\pi N}$ for $\gamma p \rightarrow \pi^0 p$ and $\gamma p \rightarrow \pi^+ n$ are calculated as in Ref. [14] except that we

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use the resonance parameters from PDG \cite{16}. For the $\pi N \to \omega N$ amplitude, we consider the $\rho$ and $b_1(1235)$ exchanges in $t$-channel and the nucleon exchange in $s$- and $u$-channel. We found that the contribution of the $b_1$-meson exchange is suppressed in the considered energy region and our results are consistent with the nonresonant amplitudes of Ref. \cite{17}.

Next we consider the one-loop corrections due to the $\rho N$ channel. The very limited data show that $\rho^+N$ and $\rho\Delta$ photoproduction processes are much weaker than $\rho^0$ photoproduction. Therefore, we keep $\rho^0p$ only in the loop calculation \cite{14}. The $\rho^0$ photoproduction amplitudes are constructed by the Pomeron, $\sigma$, $\pi$ and $\eta$ exchanges together with the nucleon exchange \cite{14} \cite{12} \cite{13}. The $pp \to \omega p$ amplitude includes the $\pi$ and nucleon exchanges. This amplitude is related with the tree diagrams of $\omega$ photoproduction in the vector dominance model, except that the $pp \to \omega p$ amplitude does not allow the Pomeron and $\eta$ exchanges because of their quantum numbers. Form factors are included for each process and fitted by available experimental data. The details on the amplitudes and comparison with the data can be found in Refs. \cite{14} \cite{13}.

3. RESULTS AND DISCUSSION

With the amplitudes constructed above, we can now investigate the one-loop corrections due to the intermediate $\pi N$ and $\rho N$ channels in $\omega$ photoproduction. In the left panel of Fig. 2 we show the results of differential cross sections of $\omega$ photoproduction. This shows that the role of the intermediate meson-baryon channels is very important to understand the production process near threshold. Although the magnitudes of the one-loop corrections are small compared with the tree diagram ones, their interference makes the contribution of the intermediate meson-baryon channels nontrivial. However, because of the uncertainties and the approximations made in the amplitudes, the results should be regarded as a qualitative indication for the role of the coupled-channel effects.

In addition to the differential cross sections, various spin polarization asymmetries have been suggested to identify the role of nucleon resonances \cite{14} \cite{13}. It is thus legitimate to test the coupled-channel effects within such asymmetries. Given in the right panel of Fig. 2 are the predictions for the single photon asymmetry \cite{18}. This result confirms that the coupled-channel effects are very important in polarization asymmetries.

In summary, we investigate the one-loop corrections to $\omega$ photoproduction near threshold as a step toward developing a coupled-channel model for vector meson photoproduction. This calculation was performed by assuming that all relevant nonresonant amplitudes can be calculated from tree diagrams of effective Lagrangians. Together with the fact that the experimental information is not sufficient to constrain the relevant transition amplitudes, the computed one-loop corrections are just the leading terms of a perturbative expansion for a full coupled-channel model. Therefore our results should be taken as a qualitative indication of the importance of the coupled-channel effects. However the results show that the coupled-channel effects should be carefully taken into account in extracting the resonance parameters from the forthcoming experimental data, especially the data of polarization observables.
Figure 2. Differential cross section (left panel) and single photon asymmetry $\Sigma_x$ (right panel) for $\gamma p \rightarrow \omega p$ at $E_\gamma =$ (a) 1.125 GeV, (b) 1.23 GeV, (c) 1.45 GeV and (d) 1.68 GeV. The dotted lines are from the tree diagrams only and the dashed lines include the tree diagrams and the intermediate $\pi N$ channel. The solid lines are the full calculations including the $\rho N$ channel in addition. The experimental data are from Refs. [1, 3].

ACKNOWLEDGMENTS

The work of Y.O. was supported by Korea Research Foundation Grant (KRF-2002-015-CP0074). T.-S.H.L. was supported by U.S. DOE Nuclear Physics Division Contract No. W-31-109-ENG-38.

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