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Differential cross section for $\gamma d \to \omega d$ using CLAS at Jefferson Lab

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ABSTRACT

The cross section for coherent ω-meson photoproduction off the deuteron has been measured for the first time as a function of the momentum transfer $t = (P_\gamma - P_\omega)^2$ and photon energy E_γ using the CLAS detector at the Thomas Jefferson National Accelerator Facility. The cross sections are measured in the energy range $1.4 < E_\gamma < 3.4$ GeV. A model based on $\omega - N$ rescattering is consistent with the data at low and intermediate momentum transfer, $|t|$. For $2.8 < E_\gamma < 3.4$ GeV, the total cross-section of $\omega - N$ scattering, based on fits within the framework of the Vector Meson Dominance model, is in the range of 30–40 mb.

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1. Introduction

Vector meson photoproduction off protons at high energies is well described [1] theoretically using the phenomenological Vector Meson Dominance (VMD) model, in which the photon fluctuates into a virtual light vector meson (having the same quantum numbers as the photon) and then scatters off the target [2]. The VMD model has been very successful at predicting vector meson production at high energies. However, at photon energies closer to the production threshold, other diagrams, such as pseudoscalar meson exchange in the t-channel, can contribute [3]. This makes the reaction dynamics of vector meson photoproduction off proton targets more complex near threshold. Additional complexity near the threshold may come from nucleon resonances in the s-channel. Coherent ω-meson production off the deuteron avoids such complexities. Since both the deuteron and the final ωd state are isosinglets, exchange of non-isosinglet (e.g. pseudoscalar) mesons cannot contribute. Hence, natural parity exchange in the t-channel, usually described by Pomeron exchange (see Fig. 1a), is expected to dominate at low momentum transfer (low $|t|$, where $t = (P_\gamma - P_\omega)^2$ and P_i is the four-momentum of particle i) for vector meson photoproduction off deuterium, thus simplifying theoretical interpretations of the data.

At higher momentum transfer ($|t| > 0.5$ GeV$^2/c^2$) secondary scattering diagrams, where the ω is produced off one nucleon and scatters from the second, as shown in Fig. 1b, enable both nucleons to remain bound as a deuteron in the final state [4]. These diagrams provide an opportunity to extract the $\omega - N$ total scattering cross section, $\sigma_{\omega N}$, from comparisons of data and calculations. Similar studies were done for coherent ϕ-meson photoproduction from the deuteron [5,6], resulting in the first-ever estimates of the $\phi - N$ total cross section. Information on these vector meson–nucleon total cross sections is virtually impossible to extract cleanly via other methods, due to the short lifetimes of these mesons.

Experimental information on $\sigma_{\omega N}$ is of interest currently due to progress within lattice QCD, which can now extract meson–meson scattering phase shifts directly [7]. The Hadron Spectroscopy Collaboration [7] is working on extracting meson–nucleon scattering phase shifts, which are directly related to the total cross sections. This is a significant advance because it connects QCD calculations to experimental observables, such as the total cross sections. Such a direct connection between non-perturbative QCD and experiment has been rare until now. The ω meson is a particularly good choice for these studies, since it decays into three pions about 89% of the time. On the lattice, the light quark masses are inputs. Lattice results are often shown for pion masses heavier than in nature, as the lattice calculations are easier to compute there. The ω is thus a stable particle in lattice calculations where the pion mass is somewhat higher than its physical value. Scattering phase shifts of stable particles are easier to obtain on the lattice than for unstable particles. Hence, measurements of $\sigma_{\omega N}$ are timely and can soon be compared with predictions from lattice calculations.

Previous experimental data on coherent ω photoproduction are scarce. Bubble chamber measurements [1] have low statistical precision. The best data on this reaction are from the Weizmann Institute [8], using a photon beam of energy 4.3 GeV and at $|t| < 0.2$ GeV$^2/c^2$, which is too small to see the effect of double-scattering as shown in Fig. 1b. Data on coherent ρ photoproduction have been measured at higher $|t|$ at SLAC [9], which was used to extract $\sigma_{\rho N}$. No previous data exist that would allow an extraction of $\sigma_{\omega N}$.

Here, we present data on coherent ω photoproduction off deuterium at photon energies ranging from 1.4 to 3.4 GeV over a wide range in the momentum transfer t. The t-dependence of the cross section is measured out to $|t| \sim 2.0$ GeV$^2/c^2$, which is compared with theoretical calculations that include the double-scattering diagrams, allowing an extraction of the total scattering cross section $\sigma_{\omega N}$. This completes the measurement of scattering cross sections for the trio of vector mesons ($V = \rho, \omega, \phi$).

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