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The Influence of ηN and NN Interactions on Incoherent η Electroproduction from the Deuteron

Mahmoud Tammam *

Department of Physics, Faculty of Science, Al-Azhar University, Assiut Branch, Egypt.

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Abstract: The influence of ηN and NN rescattering interactions in the final state for incoherent η electroproduction from the deuteron near threshold is studied. Their effects on the semi-exclusive structure functions are invistgated.

Keywords: Photo- and electroproduction, meason production and nucleun-nucleun interactions

1 Introduction

Photo- and electroproductions of η-mesons are very important because of its spcial features, it has a zero isospin state, thus only the resonances with isospin 1/2 contributes in the s and u channel and it also has a neutral charge so that the contact (seagull) term [1] plays a dominant role in the charged meson production does not contribute, thus enhances the role of resonances. The S-wave is dominant in photo- and electroproductions of η-mesons because the mass of the resonance $S_{11}(1535)$ is just above the ηN threshold. There are considerable theoretical and experimental interests in studying the η photoproduction off protons and deuteron [2,3,4,5,6,7,8, 9,10,11], but there is a chortge in studying η electroproduction [12,13,14]. Photo- and electroproduction of η on the proton in the $S_{11}(1535)$ resonance region is intensively studied, see for example references [15,16,17,18,19].
An investigation of incoherent η electroproduction off the deuteron is given in [14].

The present work is devoted to study the effects of rescattering in the final state of the $\gamma^* + d \to \eta + n + p$ process. One can expect that such effects become important near threshold region because in this region the excitation energy in the final np-system is small and the large momentum transfer (which is about the η mass in the γd c.m. frame) lead to a kinematical situation, where two final nucleons move primarily together with a large total, but small relative momentum[20]. For this situation, in case of using the spectator model one expect to has a very small cross section since the momenta of thw two outgoing nucleons are large and the corrections due to the strong NN-interaction may be significant. Also, as has been shown in [21], the η-rescattering can also visibly change the $\gamma d \to \eta np$ cross section near threshold.
In the next section the construction of the reaction matrix for η electroproduction from the deuteron with final state interactions as will as the expressions of structure functions and cross section are briefly presented. The results will be presented and discussed in Sect. 3 and we will close with a summary and an outlook.

2 The T-Matrix

Incoherent electroproduction of η from the deuteron is described according to the next equation:

$$\gamma^*(q) + d(p_d) \to \eta(p_\eta) + N_1(p_1) + N_2(p_2)\,, \qquad (1)$$

where:
$q = (q_0, \mathbf{q})$, $p_d = (E_d, \mathbf{p}_d)$, $p_\eta = (E_\eta, \mathbf{p}_\eta)$ and $p_i = (E_i, \mathbf{p}_i)$. are the four-momenta for the virtual photon, the deuteron, the produced η-meson, and the outgoing nucleons (i = 1, 2). The electron kinematics will be considered in the laboratory frame, while the evaluation of the reaction matrix will be done in the center-of-momentum frame (c.m.) of virtual photon and deuteron.

As in pion electroproduction from the deuteron, see Fig. 1, the matrix element we use in our caculations

* Corresponding author e-mail: mmamt@yahoo.com

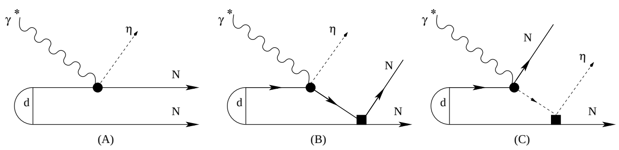

Fig. 1: Diagrammatical representation of the amplitude for $\gamma^* d \to \eta np$: (A) Impulse (spectator) approximation (IA), (B) NN rescattering, (C) ηN rescattering

consistis of impulse approximation (IA) T^{IA} which is calculated using the spectator model, two-body rescattering contribution T^{NN} and $T^{\eta N}$ subsystems[22].

$$T = T^{IA} + T^{NN} + T^{\eta N}, \qquad (2)$$

For the IA contribution, where the final state is described by a plane wave, antisymmetrized with respect to the two outgoing nucleons, one has

$$\begin{aligned} T^{IA}_{sm_s\mu m_d} &= \langle \mathbf{p}\, sm_s, \mathbf{p}_\eta \,|\left[j_{\gamma^*\eta,\mu}(1) + j_{\gamma^*\eta,\mu}(2)\right] |\, 1\, m_d\rangle \\ &= \sqrt{2}\sum_{m_s'}\Big(\langle sm_s\,|\,\langle \mathbf{p}_1| j_{\gamma^*\eta,\mu}(W_{\gamma^* N_1}, Q^2)| \\ &\quad \mathbf{p}_d - \mathbf{p}_2\rangle \phi_{m_s' m_d}(\frac{1}{2}\mathbf{p}_d - \mathbf{p}_2)\,|\, 1\, m_s'\rangle \\ &\quad -(1 \leftrightarrow 2)\Big), \end{aligned} \qquad (3)$$

where $W_{\gamma^* N_1}$ is the invariant energy of the $\gamma^* N_1$ system, $\mathbf{p}_{1/2} = (\mathbf{q} + \mathbf{p}_d - \mathbf{p}_\eta)/2 \pm \mathbf{p}$ and $j_{\gamma^*\eta,\mu}$ denotes the elementary η electroproduction operator which is taken from the isobar model EtaMAID [23], it includes contributions from Born terms, vector meson exchanges in the t-channel, and s-channel resonances $D_{13}(1520)$, $S_{11}(1535)$, $S_{11}(1650)$, $D_{15}(1675)$, $F_{15}(1675)$, $D_{13}(1700)$, $P_{11}(1710)$, and $P_{13}(1680)$. This model provides a reasonable description of the available data on η photo- and electroproduction on the nucleon in the energy region up to a total c.m. energy $W = 2$ GeV, which corresponds to a lab photon energy $E^*_\gamma lab = 1650$ MeV.

The two rescattering contributions have a similar structure

$$\begin{aligned} T^{NN}_{sm_s\mu m_d} &= \langle \mathbf{p}\, sm_s, \mathbf{p}_\eta \,|\, T_{NN} G_{NN}[j_{\gamma^*\eta,\mu}(W_{\gamma^* N_1}, Q^2) \\ &\quad + j_{\gamma^*\eta,\mu}(W_{\gamma^* N_2}, Q^2)]\,|\, 1\, m_d\rangle, \end{aligned} \qquad (4)$$

$$\begin{aligned} T^{\eta N}_{sm_s\mu m_d} &= \langle \mathbf{p}\, sm_s, \mathbf{p}_\eta \,|\, T_{\eta N} G_{\eta N}[j_{\gamma^*\eta,\mu}(W_{\gamma^* N_1}, Q^2) \\ &\quad + j_{\gamma^*\eta,\mu}(W_{\gamma^* N_2}, Q^2)]\,|\, 1\, m_d\rangle, \end{aligned} \qquad (5)$$

where T_{NN} and $T_{\eta N}$ denote respectively the NN and ηN scattering matrices and G_{NN} and $G_{\eta N}$ the corresponding free two-body propagators.

The semi-exclusive structure functions are calculated using the same way given in [22].

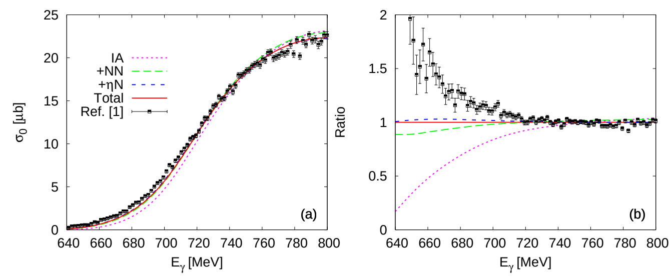

Fig. 2: Left panel (a): Unpolarized total cross section σ_0 for $\gamma^* d \to \eta np$. The dotted, long-dashed and short-dashed curves correspond to the impulse approximation (IA) and successive inclusion of NN and ηN rescatterings, respectively. Experimental data from Ref. [24]. Right panel (b): Ratios of the various approximations with respect to the "Total" one.

3 Results and discussion

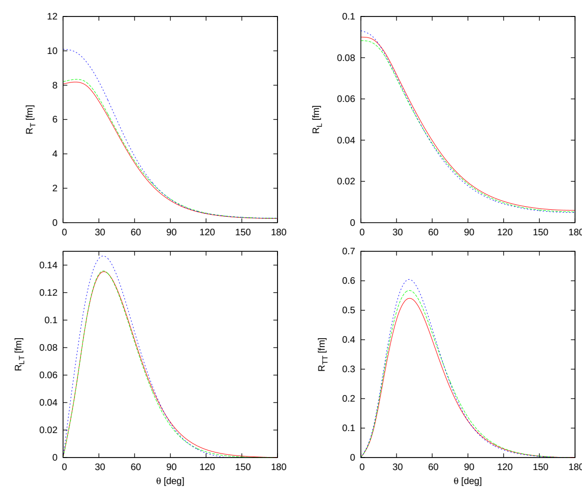

Fig. 3: Angular dependence of the four unpolarized semi-exclusive structure functions of $d(e,e^{'}\eta)np$ at k_0^{lab} =800 MeV and squared four-momentum transfer $K^2 = 0.1(GeV)^2$, The solid lines indicate IA, dashed ones for $IA+NN$ where the dotted lines for $IA+NN+\eta N$.

In this section, the effect of the final state interactions on the unpolarized semi-exclusive structure functions for η electroproduction from the deuterion is presented. As already mentioned, the realistic isobar model EtaMAID model [23] has been used for the evaluation of the elementary eta electroproduction operator on the free nucleon.

Scince there is no experimental data for eta

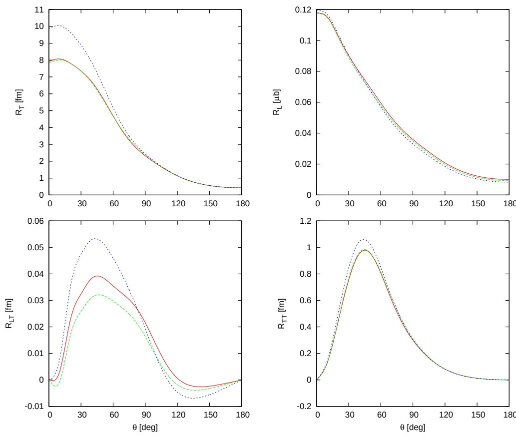

Fig. 4: Notation as in Figure (3) at $k_0^{lab} = 850$ MeV.

electroproduction from the deuteron to compar with the results of this work, a comparison of the total unpolarized cross section for eta photoproduction from the deuteron is shown in Fig. 2, where the theoretical results for the different approximations together with available experimental data are presented in the left panel of Fig. 2 whereas the right panel shows the ratios with respect to the complete calculation.

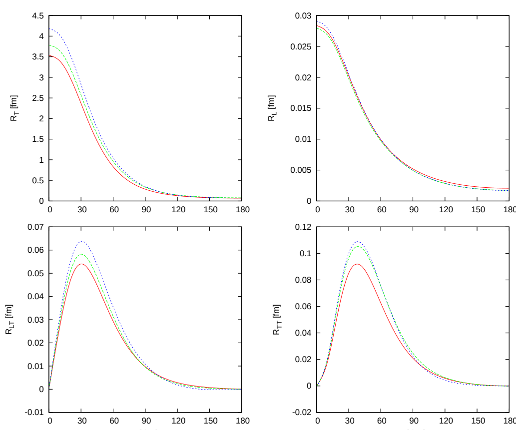

Fig. 5: Notation as in Figure (3) at $K^2 = 0.2GeV^2$

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Back to electroproduction case, In Figures (3-8), the angular distribution for the four unpolarized semi-exclusive structure functions (R_L, R_T, R_{TT} and R_{LT}) at different values for the squared four momentum transfer K^2 and the virtual photon lab k_0^{lab} are shown. The solid lines indicate IA, dashed ones for $IA + NN$ where the dotted lines for $IA + NN + \eta N$.

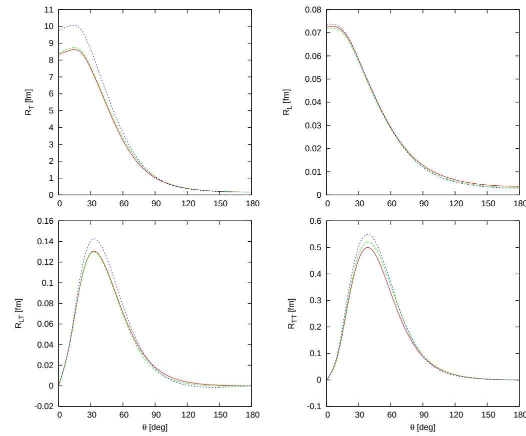

Fig. 6: Notation as in Figure (4) at $K^2 = 0.2GeV^2$

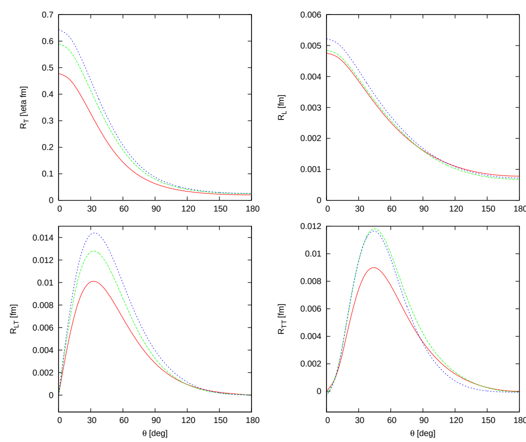

Fig. 7: Notation as in Figure (3) at $K^2 = 0.3GeV^2$.

In Fig.3, $K^2 = 0.1\,GeV^2$ and $k_0^{lab} = 800\,MeV$, the effect of NN interaction is almost neglagable where there is a notciable effect for ηN interaction espicially for R_T at the forward angles. Increasing k_0^{lab} to 850 MeV and keeping K^2 at $0.1\,GeV^2$, Fig.4, still the the effect of ηN is much clear than the effect of NN.

At $K^2 = 0.2\,GeV^2$ and $k_0^{lab} = 800\,MeV$, Fig.5,the magnitudes of all the structure functions are reduced and the effect of NN is start to be clear, the effect of ηN still bigger.

Increasing k_0^{lab} to 850 MeV and keeping K^2 at 0.2 GeV^2, Fig.6, the magnitudes of the four structure functions are increased and the effect of NN is reduced.

Fig.7 show the situation for k_0^{lab} equal to 800 MeV and $K^2 = 0.3\,GeV^2$, again the effect of NN interaction appears at the forward angles where still the effect of ηN is bigger.

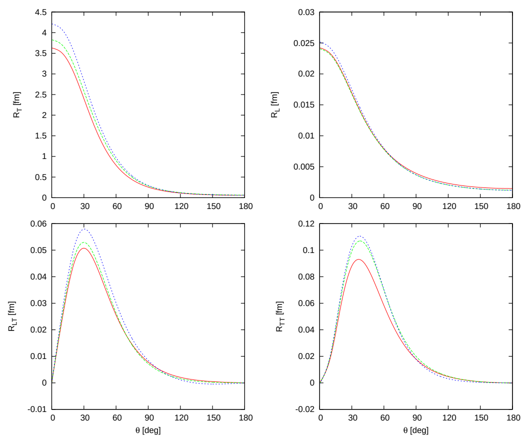

Fig. 8: Notation as in Figure (4) at $K^2 = 0.3GeV^2$

Finally, keeping $K^2 = 0.3\,GeV^2$ and increasing k_0^{lab} to 850 MeV, still the effect of ηN bigger than the effect of NN.

4 Conclusion

In the persent work, the incoherent η meson electroproduction from the deuteron is considered. The effect of the NN and ηN final state interaction are studied at different values for the virtual photon laboratory energy, k_0^{lab}, and the squared four momentum transfer K^2.

Three values for K^2 and two for,k_0^{lab}, were selected in this study. The results show that, the effect of ηN interaction is bigger than the effect of NN interaction. This effect is more clear at the forward angles.

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