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Study of Hyperon-Nucleon Interactions with $d(e, e'K)$ Reactions

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Abstract

The dependence of the $d(e, e'K^+)$ reaction cross sections on the hyperon-nucleon interactions is investigated. It is shown that the data obtained with Longitudinal-Transverse separation or polarized photons can distinguish a class of Nijmegen models of hyperon-nucleon interactions which are χ^2 -equivalent in fitting the existing 35 data points of hyperon-nucleon reactions.

The study of hypernuclei has been mainly based on the phenomenological shell model[1]. This is highly unsatisfactory for exploring the question concerning how hyperons behave in nuclear medium, an interesting and fundamental question often raised in the study of QCD effects in nuclear medium as well as in the study of relativistic heavy-ion collisions. To make progress, it is necessary to develop a many-body approach starting with realistic hyperon-nucleon and hyperon-hyperon interactions.

Obviously, the success in this direction depends entirely on the accuracy of the starting hyperon-nucleon and hyperon-hyperon interactions. The SU(3) flavor symmetry has been the guiding principle in developing [2,3] theoretical models for these interactions. The data for testing these models are however very limited. While using the SU(3) symmetry, it is still possible to generate many hyperon-nucleon potentials which give equally good descriptions of the existing 35 data points of hyperon-nucleon reactions. To develop a many-body approach to hypernuclear physics, we clearly need to use more reaction data to distinguish these models. In this work we consider $d(e, e'K^+)$ reaction which has been the focus of a recent experiment at TJNAF, as reported by J. Reinhold at this conference.

In our calculations, the amplitude for the $d(e, e'K^+)$ reaction is written as

$$T(E) = T^{(imp)}(E) + T^{(fsi)}(E) \quad (1)$$

where $T^{(imp)}$ is due to the production of K^+Y on one of the nucleons in the deuteron,

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$T^{(fsi)}$ contains the effects due to the final YN scattering. For a given final hyperon-nucleon state YN , these two amplitudes are calculated from the following matrix elements

$$T^{(imp)}(E) = \langle YN | \sum_{i=1,2} M_{K+Y,\gamma^*N}(i) | \Psi_d \rangle, \quad (2)$$

and

$$T^{(fsi)}(E) = \sum_{Y'N'} \langle YN | t_{YN,Y'N'}(E) G_{Y'N'}(E) \left[\sum_{i=1,2} M_{Y'N',\gamma^*N}(i) \right] | \Psi_d \rangle, \quad (3)$$

where M_{YN,γ^*N} is the kaon production amplitude, Ψ_d is the deuteron wave function, G_{YN} is the propagator of the intermediate YN state, and $t_{YN,Y'N'}$ is the hyperon-nucleon scattering t-matrix. The deuteron wave function can be generated accurately from the well-developed nucleon-nucleon potentials. The Kaon production amplitude can be determined from the data of $\gamma N \rightarrow KY$ and $N(e, e'K)Y$ reactions. In this work we employ the model developed by a Saclay-Lyon collaboration[5]. In addition to imposing the SU(3) symmetry, the unknown parameters of this model are determined from a global fit to *all* existing data. This model is currently being refined by introducing the off-shell effects to account for the new data from TJNAF and Bonn. With these two theoretical inputs fixed in the calculation of Eqs. (1)–(3), we can explore how the data of the $d(\gamma, K)YN$ reaction can be used to distinguish the constructed hyperon-nucleon models.

We have carried out calculations for five YN models recently constructed by Rijken and Stoks[4] using the approach developed by the Nimegen group[2]. These five models yield the same $\chi^2 \sim 16$ in fitting the existing 35 data points of YN reactions. However, they predict very different phase shifts and are very different in the short-range parts of the potentials.

Figure 1. The differential cross section (in unit of $\mu b/\text{GeV}^2\text{-Sr}^2$) of $d(e, e'K^+)$ at $Q^2 = 0.367 (\text{GeV}/c)^2$, $\theta_k = 1.5^\circ$ as a function of Λn invariant mass (GeV). The solid (dotted) curve is from full (impulse approximation) calculation.

In this short contribution we will only present results for Λ productions calculated from two of the constructed χ^2 -equivalent potentials. The calculations including Σ production are in progress. All results are for the experiment at TJNAF at $\theta_K = 1.5^\circ$, $Q^2 = 0.376$ (GeV/c) 2 . The predicted observables are plotted as functions of the invariant mass M_x of the outgoing Λn system.

In Fig. 1, we illustrate the importance of the Λn final state interaction. As expected, it generates the cusp structure due to the opening of the ΣN channel. However the difference between the full calculation (solid curve) and the impulse approximation calculation (dotted curve) is not large enough for distinguishing the considered χ^2 -equivalent YN models. Here, we observe that the predicted magnitudes are about 20% lower than the preliminary data report by J. Reinhold at this conference. This discrepancy could be reduced if the Σ production is included in the calculation.

The progress in determining YN interactions can be made if we can separate the longitudinal parts of the cross sections in the measurements. This is illustrated in Fig. 2. Here we see that the differences between two considered YN models are very striking, in particular at energies near the Σ production threshold.

Figure 2. The longitudinal differential cross section (in unit of $\mu b/\text{GeV}^2\text{-Sr}^2$) at $Q^2 = 0.367$ (GeV/c) 2 , $\theta_k = 1.5^\circ$ as a function of Λn invariant mass (GeV). The solid (dotted) curve is from using YN Mode III (V) of Ref. 4.

For possible future experiments with polarized photons at the newly constructed SPring-8 facility in Japan, we have also made predictions for the photon asymmetry at $Q^2 = 0$ and $\theta_K = 0^\circ$. The results are shown in Fig. 3. Again, we see the striking differences between the considered two YN models.

In summary, we have developed an approach to investigate the YN interactions using the $d(e, e'K)$ and $\bar{\gamma} + d \rightarrow K + Y + N$ reactions. It is shown that the data for Longitudinal-Transverse separation and photon asymmetries will be very useful in distinguishing χ^2 -equivalent YN models. This is a necessary step in developing a many-body approach to hypernuclear physics starting with realistic hyperon-nucleon and hyperon-hyperon interactions.

Figure 3. Same as Fig. 2 except for photon asymmetry at $Q^2 = 0$, $\theta_k = 1.5^\circ$.

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