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Quasifree pion photoproduction from the deuteron in the energy region from threshold up to the Δ(1232)-resonance including polarization observables

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Abstract

Quasifree pion photoproduction from the deuteron including polarization observables is studied in the energy region from threshold up to the Δ(1232)-resonance with inclusion of all leading πNN effects. For the elementary pion photoproduction operator, a realistic effective Lagrangian approach is used which displays chiral symmetry, gauge invariance, and crossing symmetry, as well as a consistent treatment of the spin-3/2 interaction. The interactions in the final two-body subsystems are taken in separable form. The sensitivity of the results to the elementary N(γ,π)N operator is investigated. A considerable dependence on the elementary amplitude of the target asymmetry for the d(γ,π)NN case is found. This indicates that this observable can serve to test different choices of elementary operators .

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1. Introduction

Since the advent of high duty-factor accelerators, such as MAMI at Mainz and ELSA at Bonn (Germany), MAX-Lab at Lund (Sweden), JLab at Newport News and LEGS at Brookhaven (USA), the study of single pion production at intermediate energies has been getting increasing attention [1-15] within the context of hadron structure in the non-perturbative domain of Quantum Chromo-Dynamics (QCD). This is relevant for the study of the nature of the strong interaction and the investigation of the resonance excitations of the nucleon and their photodecay amplitudes. In addition, this reaction serves as a test of our understanding of the chiral pion-nucleon dynamics. A well-known example is the accurate description given by Chiral Perturbation Theory (ChPT) of the very precise data on the S-wave amplitude E_{0+} and the P-wave amplitudes of π^0-photoproduction on the nucleon in the threshold region [16].

Rescattering effects on pion photoproduction from the deuteron were treated approximately by including hadronic rescattering in the final NN- and πN-subsystems [5]. The method of Ref. [5] was applied to the computation of the spin asymmetry with respect to circular photon polarization [6], which determines the Gerasimov-Drell-Hearn (GDH) sum rule [17]. This approach was limited to the Δ(1232)-resonance region because of the employed elementary pion production operator from [2]. This work was improved in Refs. [8,10] (and also in [9] where the model was extended to virtual photons), in which a better elementary production operator from the MAID model [18] was taken, and the role of final-state interaction (FSI) effects on cross sections and polarization observables was studied. More recently, incoherent pion photoproduction on the deuteron has been studied in the Δ(1232)-resonance region [12] using the elementary production operator from the MAID [18] and SAID [19] multipole analyses and including NN-FSI effect. In [14] we have reported on a theoretical prediction for polarization observables of the exclusive π^0 photoproduction from the deuteron in the Δ(1232) resonance region. For the elementary pion photoproduction amplitude, the model of Sato and Lee (SL) [20] was taken.

In this paper we present results for both the charged and neutral pion photoproduction channels of the semi-inclusive reaction γd→πNN in the energy region from threshold up to the Δ(1232)-resonance. Here, in this work, we are extending the work in the preceding papers [5,14]. The extension includes the following important aspects: (i) An enhanced elementary pion photoproduction operator taken from Ref. [21] is used, and (ii) we investigate the sensitivity of the spin-dependent and spin-independent observables to the elementary pion photoproduction operators. The calculation is of theoretical interest because it provides an important test of our understanding of the πNN dynamics, which is a prerequisite for reliable extraction of the pion photoproduction amplitude on the neutron.

This paper is structured as follows: in the next section we briefly outline the electromagnetic and hadronic two-body elementary reactions which we include in our treatment of pion photoproduction on the deuteron. In section 3, a brief review of the framework for the reaction d(γ,π)NN in which the transition matrix elements are calculated [5] is presented. Results and discussion are presented in section 4, focusing in the sensitivity of our results to the elementary pion photoproduction operator. Throughout the paper we use natural units $\hbar = c = 1$.

2. Elementary Reactions

In this section we will collect the necessary ingredients for the various elementary reactions which govern the process of pion photoproduction from the deuteron. These are the pion photoproduction reaction from free nucleons γN→πN, which plays the central part in the reaction, and hadronic two-body scattering reactions, namely NN and πN scattering, which constitute the rescattering effects in the final state.

To study the γd→πNN processes we first need a model for the elementary reaction γN→πN. The model we use for this elementary process is the one elaborated in Ref. [21], which has been applied successfully from threshold up to 1 GeV photon energy in the laboratory reference system and succeeds to reconcile [22] pion photoproduction experiments in the Δ(1232) region [23,24] with the latest Lattice QCD calculations of the quadrupole deformation of the Δ(1232) [25]. Recently, the model has also been applied successfully to eta photoproduction from the proton [26].

The model is based upon an effective Lagrangian approach (ELA), which from a theoretical point of view is a very appealing, reliable, and formally well-established approach in the energy region of the mass of the nucleon. The model includes Born terms (diagrams (A)-(D) in Fig. 1), vector-meson exchanges (ρ and ω, diagram (E) in Fig. 1) and all the four star resonances quoted in by the Particle Data Group (PDG) [24] up to 1.7 GeV and up to spin-3/2: Δ(1232), N(1440), N(1520), N(1535), Δ(1620), N(1650), and Δ(1700) (diagrams (F) and (G) in Fig. 1).