THE FIRST APPLICATION OF THE CHIRAL SMS NUCLEON–NUCLEON INTERACTION TO THE DEUTERON PHOTODISINTEGRATION PROCESS*

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A chiral nucleon–nucleon potential has been recently further improved by employing a semi-local regularization in momentum space. As such, a potential has not been tested yet in an electromagnetic process, we apply it to the deuteron photodisintegration reaction with photon energies up to 100 MeV. Results of our calculations show a weaker dependence of a selected observable on the cut-off parameter and a faster convergence with respect to the chiral expansion order compared to older chiral potentials.

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1. Introduction

Recently, the Bochum group has presented a new chiral potential with a semilocal regularization in momentum space [1] (the so-called SMS model). The resulting model allows for representing the nucleon–nucleon (NN) interaction up to the fifth order ($\mathrm{N^4LO}$) in the chiral expansion. Unlike the old models (see, for example, [2]), the new regularization leads to a weaker dependence on the cut-off parameter of the model and a better description of experimental data in the two-nucleon ($2N$) sector. Note that a semi-local regularization was proposed already in Ref. [3], but it was applied in the coordinate space.

Any model of the NN interaction has to be tested in various nuclear structures and reaction calculations to verify its reliability. Up to now, the chiral model of [1] has not been applied to an electromagnetic process. In this work, we will show the first application of this model to the deuteron photodisintegration reaction. We will discuss how results of calculations

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depend on the order of the chiral expansion and on the cut-off parameter values. It is especially interesting because from previous studies (see, for example, [4, 5]), one could conclude that non-local regularization of the chiral potential has a big flaw — corresponding results strongly depend on the regulator parameters. On the other hand, in Ref. [6], we already saw that using a semi-local regularization, albeit in the coordinate space, reduces the finite cut-off artefacts and led to a faster convergence in chiral order. In the present contribution, we investigate the behaviour of the SMS potential. It is interesting to check if the improvement observed in [6] is also valid for the SMS interaction from Ref. [1].

2. Theoretical approach

We provide the reader only with the crucial elements of our theoretical formalism and do not discuss the details of our framework, since one can find them in previous papers (see, for example, [5, 6]).

In order to calculate observables for deuteron photodisintegration, the crucial nuclear matrix elements $N^{\mu}_{\rm deu}$ have to be obtained. They are defined in the following way:

$$N^{\mu}_{\rm deu} \equiv \left\langle \Psi^{2N}_{\rm scatt} \right| j^{\mu}_{2N} \left| \Psi^{2N}_{\rm bound} \right\rangle \,, \tag{1}$$

where $|\Psi^{2N}_{\rm scatt}\rangle$ and $|\Psi^{2N}_{\rm bound}\rangle$ are proton–neutron scattering (final) and deuteron bound (initial) states, and the full $2N$ electromagnetic current operator is denoted as j^{μ}_{2N}. In the momentum space, the deuteron wave function is obtained from a simple eigenvalue problem and a more challenging task of finding the $2N$ scattering state is accomplished by solving the Lippmann–Schwinger equation for the t-operator,

$$t = V + tG_0V \tag{2}$$

with the $2N$ potential V and the free $2N$ propagator G_0. Using the t-operator, Eq. (1) is written as

$$N^{\mu}_{\rm deu} = \langle \vec{p}_0 | \, (1 + tG_0) \, j^{\mu}_{2N} \left| \Psi^{2N}_{\rm bound} \right\rangle \,, \tag{3}$$

where $|\vec{p}_0\rangle$ denotes the eigenstate of the relative proton–neutron momentum.

At the moment, we do not have at our disposal an explicit $2N$ current operator consistent with the NN potential. Since it is well-known that contributions from the single-nucleon current operator are not sufficient, providing a very poor description of data, we decided to include implicitly $2N$ parts of the current operator by employing the Siegert theorem. This allowed us to go beyond the single-nucleon current approximation but definitely leaves room for improvement. The detailed expressions for our treatment of the Siegert approximation can be found in Refs. [7–9].

3. Results of calculations

We present our results for the deuteron photodisintegration process using the new SMS potential [1] and treating the $2N$ current via the Siegert theorem. The predictions have been obtained for two photon energies: 30 and 100 MeV.

Figures 1 and 2 show the final proton polarization for the two photon energies $E_\gamma = 30$ MeV and $E_\gamma = 100$ MeV, respectively. The results of our calculations reveal a very fast convergence with respect to the chiral order and only a small dependence on the cut-off parameter. Since there are no experimental data for this deuteron photodisintegration observable, we com-

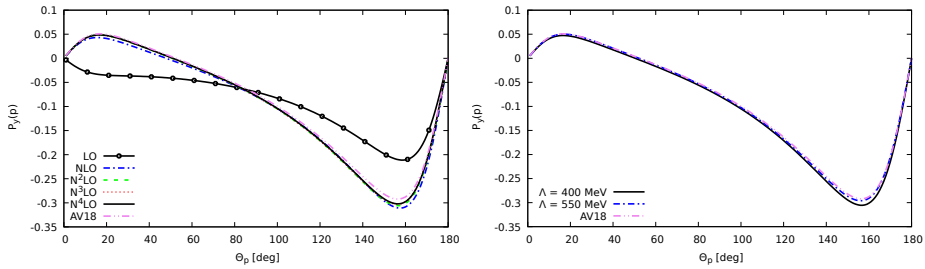

Fig. 1. The final proton polarization $P_y(p)$ in the deuteron photodisintegration reaction for the photon energy $E_\gamma = 30$ MeV as a function of the photon scattering angle θ_p. Predictions at different chiral orders are presented in the left panel for the fixed cut-off parameter $\Lambda = 450$ MeV. In the right panel, N^{4}LO results obtained with two different regulator values Λ are displayed. In the two panels, results based on the Argonne V18 (AV18) potential are also added. In the calculations, $2N$ contributions in the current operator are included via the Siegert theorem.

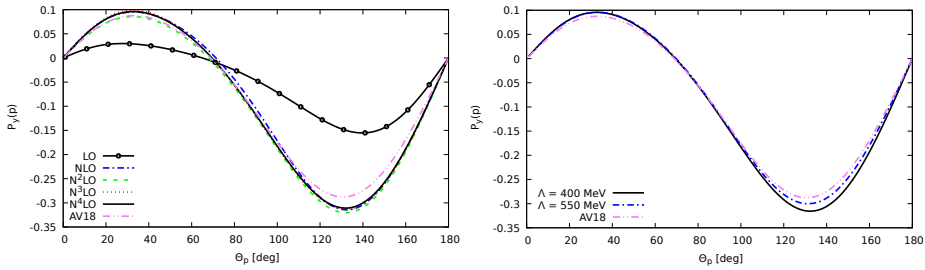

Fig. 2. The final proton polarization $P_y(p)$ in the deuteron photodisintegration reaction for the photon energy $E_\gamma = 100$ MeV as a function of the photon scattering angle θ_p. Predictions at different chiral orders are presented in the left panel for the fixed cut-off parameter $\Lambda = 450$ MeV. In the right panel, N^{4}LO results obtained with two different regulator values Λ are displayed. In the two panels, results based on the Argonne V18 (AV18) potential are also added. In the calculations, $2N$ contributions in the current operator are included via the Siegert theorem.

pare the SMS-based predictions with the ones obtained with the standard AV18 NN force model [10], which has been widely used to describe many electromagnetic processes. The agreement between the converged SMS results and the predictions based on the AV18 NN force is very good. Thus, one can infer that the current order (N^4LO) of the chiral expansion is sufficiently high for the deuteron photodisintegration process at the considered here energies and substantial contributions from higher orders should not be expected. This observation follows from already small differences between N^3LO and N^4LO predictions (visible in the left panels of Figs. 1 and 2). A weak dependence of the prediction (see the right panels of Figs. 1 and 2) is definitely due to various regulator values, also a very welcome feature of these SMS potential based results.

4. Conclusions

In the present contribution, we have tested the new chiral potential regularized in the semi-local way in the momentum-space [1]. We have applied it to the deuteron photodisintegration reaction in order to calculate a selected polarization observable. For the final proton polarization P_y, studied in this contribution, the results of our calculations show a good convergence with respect to the chiral order and a weak dependence on the cut-off parameter.

This confirms a high quality of the SMS model of the NN potential and opens the path to detailed studies of the electromagnetic processes in few-nucleon and many-nucleon systems as soon as the single-nucleon and many-nucleon currents consistent with the SMS interaction are available.

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