Comment on “ΛcN interaction in leading order covariant chiral effective field theory”

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Song et al. [Phys. Rev. C 102, 065208 (2020)] presented results for the ΛcN interaction based on an extrapolation of lattice simulations by the HAL QCD Collaboration at unphysical quark masses to the physical point via covariant chiral effective field theory. We point out that their predictions for the 3D1 partial wave disagree with available lattice results. We discuss the origin of that disagreement and present a comparison with predictions from conventional (non-relativistic) chiral effective field theory.

Due to the lack of any experimental information, at present results from lattice QCD simulations provide the only model-independent estimate for the strength of the interaction of charmed baryons with nucleons. Corresponding lattice calculations for the ΛcN and ΣcN systems have been published by the HAL QCD Collaboration [1, 8], though for unphysical quark masses corresponding to pion masses of mπ = 410 – 700 MeV. Evidently, in order to draw conclusions on the physics implications and to allow for predictions for future experiments an extrapolation of the HAL QCD results to the physical point is required. Such an extrapolation was performed by us in Ref. [4] for ΛcN and in [5] for ΣcN. We used as guideline conventional (non-relativistic) chiral effective field theory (χEFT) [9] up to next-to-leading order (NLO). With regard to the ΣcN interaction, another extrapolation of the HAL QCD results was performed in Ref. [8] using heavy baryon chiral perturbation theory and taking into account heavy quark spin symmetry.

In this comment we critically discuss results for the ΛcN interaction of yet another and very recent extrapolation done by Song et al. [8] which utilizes covariant χEFT. The corresponding work is based on a potential at leading-order (LO) in the chiral expansion. Song et al. [8] found that in the case of the 1S0 partial wave the lattice QCD data at unphysical masses (mπ = 410, 570 MeV) can be quite well reproduced within covariant χEFT. At the physical point, the predicted phase shifts are rather similar to those we obtained in Ref. [4].

For the coupled 3S1–3D1 partial waves the situation is quite different. Here the 3S1 phase shifts from covariant χEFT are only in fair agreement with the lattice QCD data, see Fig. 4 (left side) in Ref. [8]. Specifically for mπ = 570 MeV the energy dependence suggested by the HAL QCD results is not properly reproduced. Moreover, the extrapolation to the physical point yields rather different results as compared to the predictions in Ref. [8]. While conventional χEFT suggests a moderately attractive 3S1 interaction, with phase shifts almost identical to the one in the 1S0 partial wave, the covariant approach leads to a predominantly repulsive result which, in addition, exhibits a strong energy dependence.

As a byproduct of their study, Song et al. provided also predictions for the 3D1 phase shifts and the mixing angle ε1 – at the physical point and for the pion masses of the HAL QCD simulation – with the intention that those can be checked by future lattice QCD calculation. Interestingly, such results are already available. They have been presented in the PhD thesis by Takaya Miyamoto [3] which can be accessed via Inspire. We show the lattice results for 3D1 in Fig. 4(a) together with the predictions from covariant χEFT. Obviously, there is a strong mismatch. While lattice QCD suggests a weakly attractive interaction, the results by Song et al. are strongly repulsive. Corresponding results of our ΛcN interaction [4], which are likewise predictions, are displayed in Fig. 4(b).

Evidently, in case of conventional χEFT there is a remarkable qualitative agreement with the lattice simulation. Specifically, the results for mπ = 410 MeV are rather well in line with those by the HAL QCD Collaboration. This gives us confidence that our extrapolation to the physical point is plausible and reasonable, for 3D1 as well as for 3S1.

For understanding the origin of the difference let us discuss briefly the main features of the two approaches. For further details, specifically how the pion-mass dependence is implemented, we refer the reader to Ref. [8] with regard to the extrapolation based on covariant χEFT and to Ref. [4] for the conventional approach. In either frameworks the potential is given in terms of pion exchanges and a series of contact interactions with an increasing number of derivatives. The latter represent the short-range part of the baryon-baryon force and are parameterized by low-energy constants (LECs), that need to be fixed by a fit to data [3]. The essential difference in the corresponding potentials occurs in the contact terms and arises from the circumstance that in the co-
variant formulation the potential is derived with the full Dirac spinor of the baryons included. As a consequence, while in conventional \( \chi \)EFT based on the Weinberg counting, contributions to the contact interaction of chiral power \( \nu \) are proportional to \( p^{\nu} \) (with \( p \) being the modulus of the baryon-baryon center-of-mass momentum) and, thus, are uniquely related to the order of the chiral expansion, this no longer the case for the covariant version. Moreover, in the conventional \( \chi \)EFT a partial wave expansion of the contact interaction with the involved spin- and momentum-dependent operators allows one to rewrite the various contributions in terms of suitably defined LECs that then contribute only to single partial waves. This is not possible in the covariant power counting, in which already the LO contact term contributes to all \( J = 0, 1 \) partial waves and the potential strengths in the various partial waves, characterized by the LECs, are interrelated. That aspect impacts the extrapolated results in Ref. [8]. Specifically, there is a contribution to the \( 3D_1 \) potential from the contact interactions already at LO where the corresponding LECs are those that appear likewise in the \( 1S_0 \) and \( 3S_1 \) partial waves, cf. Eq. (7) in Ref. [8]. Apparently, fixing those LECs solely from the \( S \)-wave phase shifts of the lattice simulations leads to wrong results for the \( 3D_1 \). In the Weinberg counting a \( 3D_1 \) contact interaction arises first at next-to-next-to-next-to-leading order (N\(^3\)LO) and it is independent of the LECs in the \( S \)-waves!

In summary, conventional \( \chi \)EFT (up to NLO) employed in Ref. [4] seems to provide a more reliable tool for representing lattice QCD results by the HAL QCD Collaboration for the \( \Lambda_c N \) interaction at \( m_\pi = 410, 570 \) MeV [3] and for extrapolating them to the physical point. In covariant \( \chi \)EFT as utilized by Song et al. [8] (at LO) it is obviously more difficult to account for unphysical pion masses on a quantitative level, specifically for the spin triplet case, i.e. in situations where coupled-channel effects could be important. As a consequence, extrapolations are more unstable. In any case, lattice simulations for quark masses closer to the physical point would be rather useful to shed further light on the issue of extrapolation and, of course, direct experimental constraints [10] would be helpful too.

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