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On the convergence of the chiral expansion for the baryon ground-state masses

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Abstract

We study the chiral expansion of the baryon octet and decuplet masses in the isospin limit. It is illustrated that a chiral expansion of the one-loop contributions is rapidly converging up to quark masses that generously encompasses the mass of the physical strange quark. We express the successive orders in terms of physical meson and baryon masses. In addition, owing to specific correlations amongst the chiral moments, we suggest a reordering of terms that make the convergence properties more manifest. Explicit expressions up to chiral order five are derived for all baryon masses at the one-loop level. The baryon masses obtained do not depend on the renormalization scale. Our scheme is tested against QCD lattice data, where the low-energy parameters are systematically correlated by large-N_c sum rules. A reproduction of the baryon masses from PACS-CS, LHPC, HSC, NPLQCD, QCDSF-UKQCD and ETMC is achieved for ensembles with pion and kaon masses smaller than 600 MeV. Predictions for baryon masses on ensembles from CLS as well as all low-energy constants that enter the baryon masses at $\mathrm{N^3LO}$ are made.

Keywords: Chiral symmetry; Large-N_c QCD; Lattice QCD; Flavor SU(3)

Contents

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1. Introduction

By now there is large set of QCD lattice data on the lowest baryon masses composed of up, down and strange quarks and with $J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$ [1–10]. The recent and unexpected success of a quantitative description of this data set based on the chiral three-flavor Lagrangian [11–15] makes it paramount to unravel further the chiral convergence domain of this sector of QCD. It is an important question how small the quark masses have to be chosen as to render a chiral expansion framework meaningful in the flavor $SU(3)$ case. Based on two flavor studies of the nucleon mass the power-counting domain (PCD) was estimated in various studies to be as low at $m_\pi < 200$ MeV–300 MeV [16–23]. Due to the important role played by the baryon decuplet fields it is not quite straight forward to conduct such studies in the three flavor case. In the two-flavor case there are different power counting schemes as to incorporate the spin three half field in a consistent manner [24–28]. It is an open challenge how to adapt such schemes to the flavor $SU(3)$ case.

A strict chiral expansion for the baryon masses following the rules of heavy-baryon χPT appears futile. Applications to current QCD lattice data do not seem promising [1–8]. In oder to make progress we have to leave the safe haven of conventional χPT. State of the art chiral extrap-