Chiral Extrapolation of Nucleon Properties from Lattice QCD ◇

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The chiral symmetry of QCD is spontaneously broken at low energies, leading to the appearance of Goldstone Bosons. For 2-flavor QCD we identify the resulting three Goldstone Bosons with the physical pion states, the lowest lying modes in the hadron spectrum. In addition to being spontaneously broken, chiral symmetry is also broken explicitly by the non-zero quark mass $\hat{m}$ in the QCD Lagrangian. This explicit breaking is responsible for the non-zero pion mass. At low energies QCD can be represented by a chiral effective field theory (ChEFT) with the dynamics governed by the Goldstone Bosons. The important aspect for this work is the fact that this ChEFT incorporates *both* the information on the spontaneous *and* on the explicit breaking of chiral symmetry.

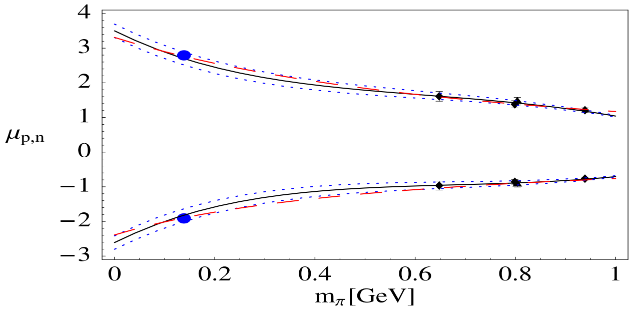

Fig. 1: Quark mass dependence of proton and neutron magnetic moments plotted as a function of the lowest lying Goldstone Boson mass. We show a comparison between the prediction from ChEFT [1] (solid line), lattice data and a Padé fit formula (dashed-line). The empirical values $\mu_p = 2.793$ and $\mu_n = -1.913$ are also shown.

In recent works [1,2] such a theory has been utilized to study the quark mass (pion mass) dependence of the magnetic moments and the axial-vector coupling constant of the nucleon. The aim has been to explore the feasibility of ChEFT methods for extrapolations of lattice QCD results—so far determined at relatively large quark masses corresponding to pion masses $m_\pi \geq 0.6$ GeV—down to physical values of m_π. Two versions of ChEFT have been compared: heavy-baryon chiral perturbation theory in its truncated form restricted to pion and nucleon degrees of freedom only, and an alternative approach which incorporates the $\Delta(1232)$ resonance as an explicit degree of freedom. It turns out that in order to approach the physical values of magnetic moments and the axial vector constant g_A already at low orders in perturbation theory the explicit Δ degrees of freedom are crucial in ChEFT. Stable chiral extrapolation curves for both quantities could be obtained, which extend from the chiral limit region over the physical point out to the region of present lattice data, as shown in Figs.(1,2). Further studies pertaining to the quark mass dependence of nucleon form factors [3] as well as to baryon masses [4] are in progress.

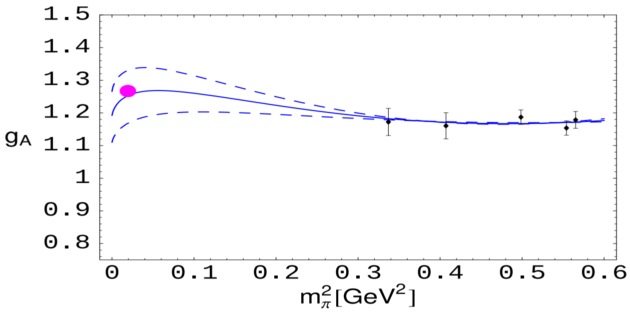

Fig. 2: Chiral extrapolation of the axial coupling of the nucleon g_A [2]. The dashed curves give an impression of the uncertainty arising from the limited knowledge of short distance physics. The empirical value $g_A = 1.267$ determined from neutron beta decay is also shown.

References

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◇ supported in part by BMBF project 06 TM 980 and DFG project We 655/14-3