Flavor decomposition of the nucleon axial and tensor charges from lattice QCD

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1 Introduction

We present our calculation of the nucleon axial and tensor charges at the continuum limit using lattice QCD simulations.

- We analyze four $N_f = 2 + 1 + 1$ twisted mass fermion ensembles with all quark masses tuned to approximately their physical values.
- We perform the full flavor decomposition to obtain the individual up, down, strange and charm contributions.

2 Motivation

- The nucleon axial and tensor charges describe how quarks contribute to the properties of protons and neutrons (collectively called nucleons), providing important tests of the Standard Model.
- The axial charge is a key input to the rate of neutron $\rightarrow$ proton decay, a process that plays a key role in nuclear reactions inside stars. Its precise value is also important for interpreting nuclear decays that could reveal physics beyond the Standard Model.
- The proton carries an intrinsic angular momentum, its spin, but how this spin is distributed among its quark constituents is still not fully understood. The flavor-diagonal axial charges, g_A^f, quantify the contributions of up, down, strange, and charm quarks. Upcoming experiments at the Electron-Ion Collider (EIC) will provide new information on these contributions.
- Tensor charges, g_T^f, describe a different aspect of quark polarization inside the nucleon. They are essential for interpreting experiments searching for a tiny electric dipole moment of the neutron, which would provide evidence for new sources of CP violation and physics beyond the Standard Model.

3 Methodology

- The nucleon charges for each quark flavor f, denoted as $g_{\mathrm{A,T}}^f$, are extracted from the matrix elements of the corresponding axial and tensor operators at zero momentum transfer:

$$\langle N|\bar{\psi}^f \Gamma_{\mathrm{A,T}} \psi^f|N\rangle = g_{\mathrm{A,T}}^f \bar{u}_N \Gamma_{\mathrm{A,T}} u_N$$

- Nucleon charges are extracted by combining two- and three-point nucleon correlation functions.
- There are both connected and disconnected contributions to the nucleon three-point function. These are illustrated in Fig.1.

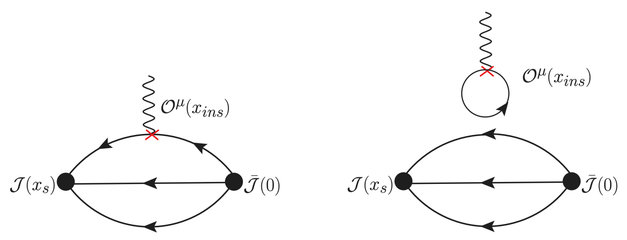

Figure 1. Connected (left) and disconnected (right) contributions of a baryon three-point function.

- For the axial charge, for example, we consider the ratio of the three- to two-point correlation functions at $\vec{p} = \vec{q} = 0$:

$$R_\mu^A(t_s, t_{ins}) = \frac{C_\mu^{3pt}(\Gamma_k; t_s, t_{ins})}{C^{2pt}(t_s)} \xrightarrow[t_{ins}\to\infty]{t_s - t_{ins}\to\infty} g_A$$

- In the large time separation limit, the ratio converges to the corresponding charge, e.g., g_A.
- All quantities are computed at the physical point, eliminating the need for chiral extrapolation.

Reference

C. Alexandrou, S. Bacchio, A. Evangelista, C. Iona, F. Pittler, and G. Spanoudes, Flavor decomposition of the nucleon axial and tensor charges from lattice QCD, In preparation.

4 Results

- The calculated nucleon matrix elements are renormalized nonperturbatively by employing the RI′/MOM scheme followed by perturbative conversion to the $\overline{\mathrm{MS}}$ scheme at the reference scale of 2 GeV.
- We obtain final results via a model-averaged continuum extrapolation ($a \to 0$), combining linear and constant fits in a^2 with weights reflecting lattice spacing dependence.
- In Figs. 2 and 3 we show the continuum extrapolations of the non-singlet and the singlet quark combinations in the left panels and the flavor decomposition in the right panels.
- In Figs. 4 and 5 we compare our results for the isovector and flavor diagonal charges with other lattice QCD determinations, observing good overall agreement.

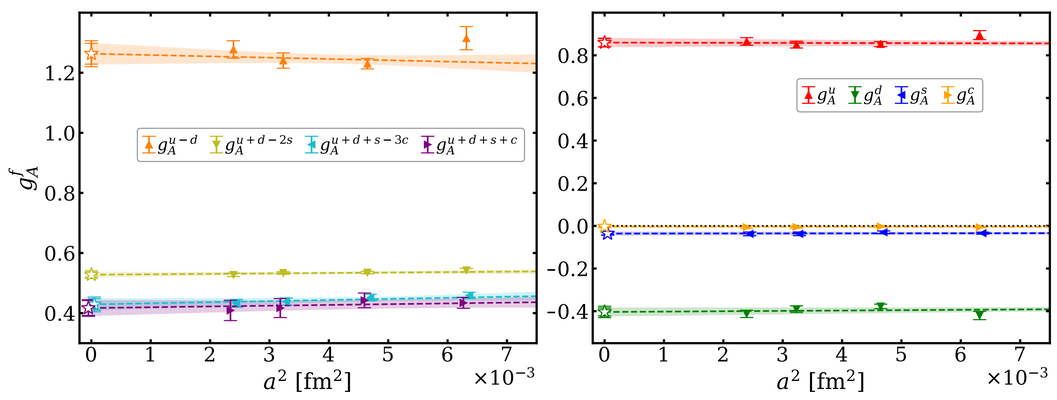

Figure 2. Continuum extrapolations of the non-singlet and the singlet quark combinations (left) and the flavor decomposition (right) for the axial charge. The stars show the values at $a = 0$, where the inner error is the statistical and the outer the total uncertainty after adding the systematic error in quadrature.

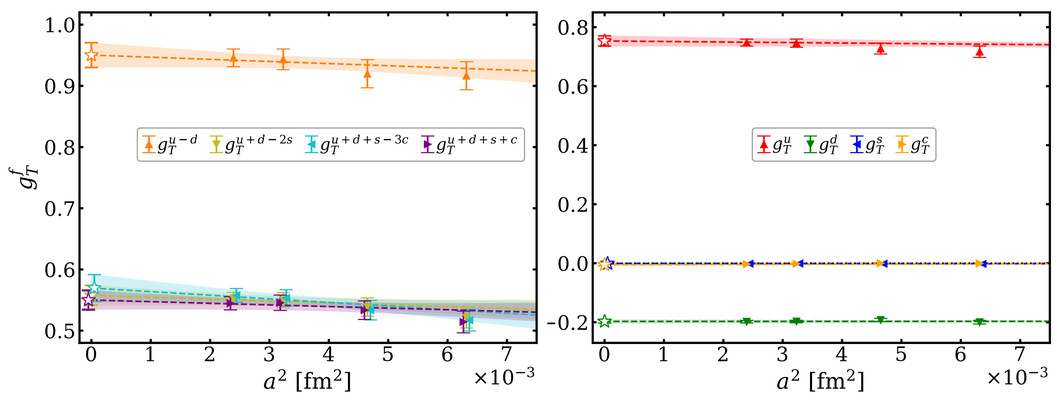

Figure 3. Continuum extrapolations of the non-singlet and the singlet quark combinations (left) and the flavor decomposition (right) for the tensor charge. The notation is the same as in Fig. 2.

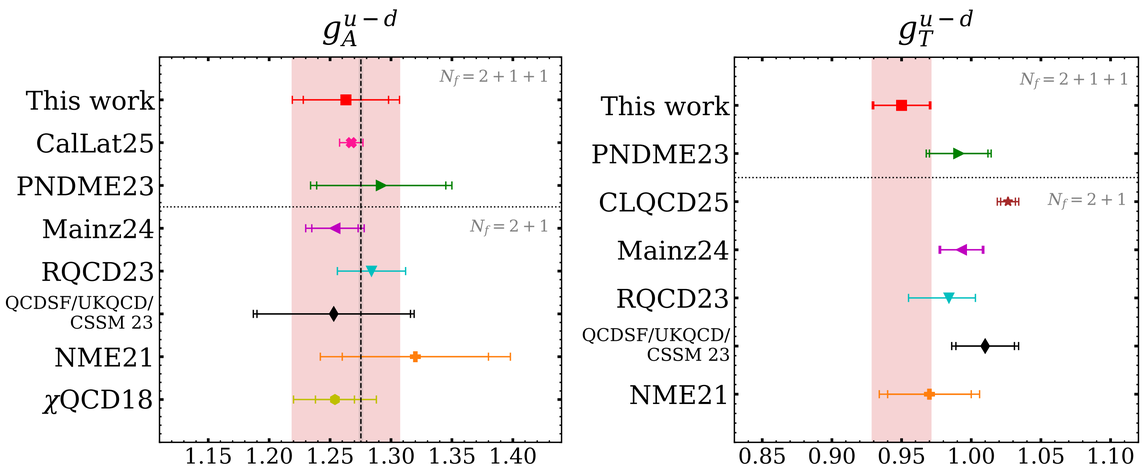

Figure 4. Comparison of the results of this work with other lattice QCD results, for the isovector axial and tensor charges. Our results are shown with the red square and red error band. For g_A^{u-d}, the dashed line and gray band represent the PDG value.

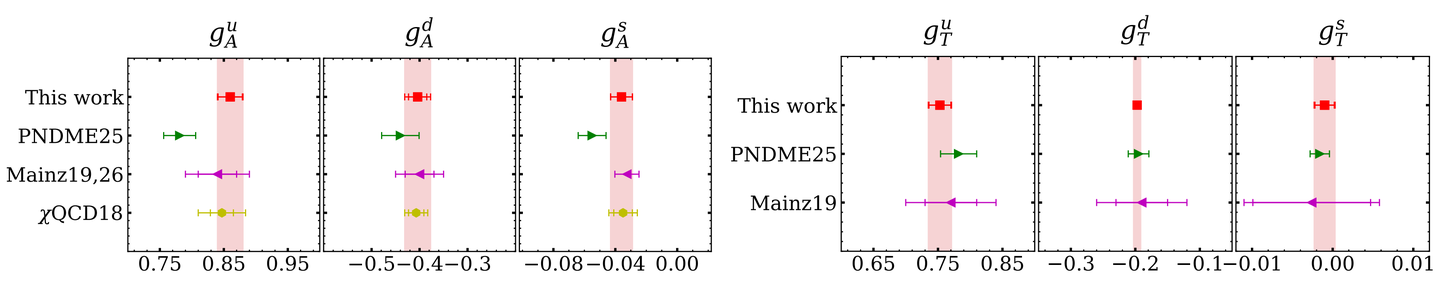

Figure 5. Comparison of the results of this work with other lattice QCD results, for the single flavor axial and tensor charges. Our results are shown with the red square and red error band.

5 Summary and Conclusions

- In this work we calculate the nucleon axial and tensor charges, at the continuum limit, using only physical point ensembles, thus avoiding chiral extrapolations.
- Our results are in agreement with results from other collaborations. The value we obtain for the isovector axial charge also agrees with the experimental value.
- The complete flavor decomposition of the axial and tensor charges provides a first-principles determination of the individual quark contributions to these nucleon observables, useful for applications in studies of nucleon structure and phenomenology beyond the Standard Model.

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