Nucleon axial charge in lattice QCD with nearly physical pion mass

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We report the status of lattice quantum chromodynamics (QCD) calculations of nucleon isovector axial and vector charges using the four recent domain-wall fermions (DWF) ensembles with 2+1 dynamical flavors jointly generated by the RIKEN-BNL-Columbia (RBC) and UKQCD collaborations[1)]: the strange-quark mass is set at physical value and degenerate up- and down-quark mass is varied with the pion mass of about 420, 330, 250 and nearly physical 170 MeV.

Spontaneously broken chiral symmetry drives the axial charge, g_A, of nucleon away from its chiral partner, the vector charge, g_V, to a larger value. The current experimental estimate of the ratio of these charges is $g_A/g_V = 1.2701(25)$[2)]. This ratio is an important quantity that not only determines neutron life time but also the interaction of pion and nucleon through the Goldberger-Treiman relation[3)], and hence nuclear stability, syntheses and abundance. Numerical lattice-QCD calculations underestimate the ratio by about 10 %[4–7)]. The cause of this deficit is not known: insufficient lattice volumes[4,7)] and excited-state contaminations[8)] have been discussed as possible cause.

We have improved the statistical accuracy[7)] of our calculations so the statistical errors now stand at around 4 %. The AMA method[9)] was important in achieving this for the pion mass of about 330 and 170 MeV. With these improved statistics we have now excluded excited-state contamination as the cause of the deficit[7)]. On the other hand, in the two cases with the pion mass of 170 MeV and 330 MeV the ratio has been found to suffer from very long-range autocorrelation[7)]. At 170 MeV the calculated charge ratio, g_A/g_V, starts with a value that is statistically consistent with the experiment at the beginning quarter of the calculation, but then monotonically decreases quarter by quarter to a value drastically low (see Fig. 1.) A similar but less drastic autocorrelation has been observed at 330 MeV as well. This results in the observed deficit, but we are yet to understand what causes this very long-range autocorrelation. We do not find such long-range autocorrelation at 250 and 420 MeV: the autocorrelation for these two cases are much shorter-ranged.

The absence of a long-range autocorrelation at lighter pion mass of 250 MeV in contrast to the presence at heavier 330 MeV suggests this peculiar autocorrelation is related to insufficient lattice spatial volume. The finite-size effect can be parametrized by a dimensionless product, $m_\pi L$, of the calculated pion mass, m_π, and linear spatial extent of the lattice, L[4)]: Indeed the autocorrelation is milder at 330 MeV with $m_\pi L$ of about 4.5 than at 170 MeV with $m_\pi L$ of about 4.0, and absent for 250- and 420-MeV with $m_\pi L$ of about 5.8[7)]. Thus the observed autocorrelations seem consistent with finite-size scaling in terms of $m_\pi L$: the nucleon as seen by its isovector axialvector current or interaction with pion may be much larger than its electric charge distribution indicates.

Though our statistics is still too low to conclude more definitely, we captured an important clue toward understanding the deficit, likely in its relation with the finite-size effect that may scale with $m_\pi L$.

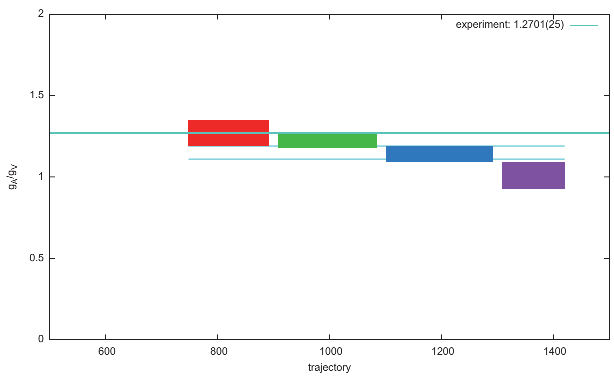

Fig. 1. Unusually long-range autocorrelation is seen in the isovector axial to vector charge ratio, g_A/g_V along the gauge-configuration generation history at $m_\pi = 170$ MeV and $m_\pi L$ of about 4.0, slowly moving from consistent with experiment to drastically low. Similarly long-range autocorrelation has been seen in at $m_\pi = 330$ MeV and $m_\pi L$ of about 4.5 as well, but not at 250 or 420 MeV that share $m_\pi L$ of about 5.8. No other observable shows such a long-range autocorrelation.

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References

1) R. Arthur et al. *Phys.Rev.*, D87:094514, 2013.
2) Particle Data Group, J. Beringer, et al. *Phys. Rev.*, D86:010001, 2012. and 2013 partial update for 2014.
3) M.L. Goldberger and S.B. Treiman. *Phys.Rev.*, 110:1178–1184, 1958.
4) T. Yamazaki et al. *Phys.Rev.Lett.*, 100:171602, 2008.
5) H. Wittig. *PoS*, LATTICE2011:025, 2011.
6) H.-W. Lin. *PoS*, LATTICE2012:013, 2012.
7) S. Ohta. *PoS*, LATTICE2013:274, 2013.
8) S. Capitani et al. *Phys.Rev.*, D86:074502, 2012.
9) T. Blum et al. *Phys.Rev.*, D88:094503, 2013.