Nucleon structure in lattice QCD near physical mass

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The RIKEN-BNL-Columbia (RBC) collaboration continue numerical lattice-QCD investigations of nucleon structure[1–6]. Here, I report results obtained from ensembles[7–9] generated jointly with the UKQCD collaboration near the physical pion mass. In these ensembles the strange quark mass is set very close to its physical value while the degenerate up and down quark is varied toward the physical mass, resulting in pion mass ranging from about 420 to 170 MeV. Isovector observables such as vector- and axialvector-current form factors and some low moments of structure functions are calculated.

The isovector axial charge, g_A, is about the most important observable concerning nucleon structure. It determines the neutron life and pion-nucleon interaction through the celebrated Goldberger-Treiman relation. And as such it determines nuclear abundance and much of nuclear physics. Lattice-QCD calculations have experienced difficulty reproducing this quantity: they generally underestimate the experimental value of 1.2723(23)[10]. Our latest results do not escape this problem, as summarized in Fig. 1: About 10% deficit

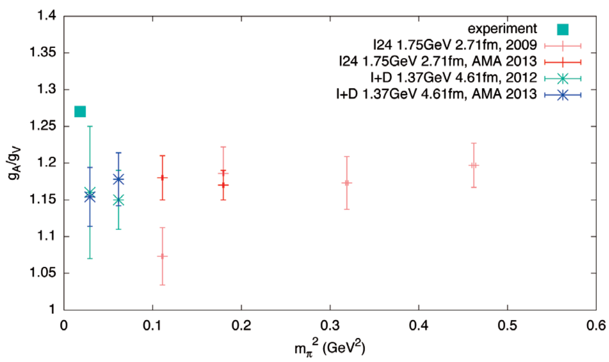

Fig. 1. The ratio, g_A/g_V, of isovector axia chargel, g_A, to isovector vector charge, g_V, calculated in our recent lattice-QCD ensembles plotted against calculated pion mass squared, m_π^2[6]

is persistent across the mass range investigated, and possibly worsens toward the physical mass.

Much of our efforts during the past year were concentrated in understanding this[11], starting with the long-range autocorrelation observed at the lightest-mass ensemble at pion mass $m_\pi = 170$ MeV. This ensemble is at the smallest finite-size scaling parameter, $m_\pi L = 3.9$, where L is the linear extent of the lattice volume. That weaker but similar auto-correlation was seen at heavier mass, $m_\pi = 330$ MeV, with the second smallest finite-size scaling parameter, $m_\pi L = 4.6$, but not at a lighter mass of 250 MeV with larger $m_\pi L = 5.8$, hints this autocorrelation may be related to too small lattice volume.

We found weaker but similar autocorrelation in isovector transversity, $\langle 1\rangle_{\delta u-\delta d}$, that differs by only one extra Dirac γ matrix factor from the axialvector current. This, together with the axial charge observation, suggests the virtual pion cloud around the nucleon may not be well contained within the lattice volume. The other observables, including the isovector vector-current form factors and isovector quark momentum fraction, $\langle x\rangle_{u-d}$, and isovector quark helicity fraction, $\langle x\rangle_{\Delta u-\Delta d}$ do not show such autocorrelation at any mass.

A possible cause for such a long-range autocorrelation is interference from the gauge-field topology that is known to have long autocorrelation. However the axial charge and topological charge are not found to be correlated[11].

We also looked at how the axial charge fluctuates spatially by dividing the volume into halves with lower and higher $x-$, $y-$, or $z-$coordinates[11]: we found that it fluctuates rather wildly.

At the pion mass of about 170 MeV the virtual pion cloud around the nucleon may not be well contained in our lattice box with linear extent of about 4.5 fm.

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