Nucleon scalar charge with overlap fermions

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Lattice 2019
Jun. 16-22, Wuhan, China

Outline

- Introduction.
- Numerical details.
- Results.
- Summary and outlook.

Motivation

- Fundamental property of hadron structure.
- Probe new physics beyond standard model.
- Not well known experimentally.
- Need accurate lattice determination.

Lattice setup

- Gauge configurations generated by the RBC/UKQCD collaboration with 2+1 flavor domain-wall fermion.

Ensemble ID	$L^3 \times T$	a^{-1}(GeV)	m_π^{sea} (MeV)	N_{conf}
24I	$24^3 \times 64$	1.747	337	203
32I	$32^3 \times 64$	2.310	302	309
48I	$48^3 \times 96$	1.730	139	81
32ID	$32^3 \times 64$	1.3709	171	200
32Ifine	$32^3 \times 64$	3.148	371	459

Overlap fermions

- Overlap fermion action for the valence quark.
- Chiral symmetry at finite lattice spacing via the Ginsparg-Wilson relation.
- Has better control of the systematic error, but more costly.

The overlap Dirac operator is

$$D(m) = \rho D_{ov}(\rho) + m(1 - \frac{D_{ov}(\rho)}{2}),$$

where $D_{ov} = 1 + \gamma_5 \epsilon(\gamma_5 D_w(\rho))$, we use the parameter $\rho = -1.5$.
The effective propagator is

$$D_{eff}^{-1} = \frac{1}{D_c + m},$$

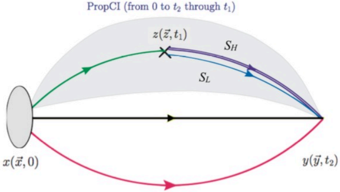
where $D_c = \frac{\rho D_{ov}}{1 - D_{ov}/2}$ is exactly chiral, i.e. $\{\gamma_5, D_c\} = 0$.

Computational strategies

- Low-mode substitution(LMS): Use the low lying eigenvalues and eigenvectors of D_c to speed up the inversion and separate the propagators into its low-mode and high-mode parts.

$$S(y,x) = S_L(y,x) + S_H(y,x), \qquad S_L(y,x) = \sum_{|\lambda_i|<\epsilon} \frac{1}{\lambda_i + m} |i\rangle_y \langle i|_x$$

- Z_3 noise grid source: Tie the sources of the three quark propagators stochastically to each point so that one can have multi-to-all propagator from one inversion.
- Stochastic sandwich method with LMS: all-to-all low mode + noise many-to-all high mode



Correlation functions

- To extract the scalar charge, we compute the two- and three-point functions:

$$C_{2pt}(t_2) = \sum_{\vec{x}} \Gamma^e_{\alpha\beta} < 0|\chi_\alpha(t_2,\vec{x})\bar{\chi}_\beta(0,\vec{0})|0 >,$$
$$C^{u,d}_{3pt}(t_2,t) = \sum_{\vec{x},\vec{x}'} \Gamma^e_{\alpha\beta} < 0|\chi_\alpha(t_2,\vec{x})\mathcal{O}^{u,d}(t,\vec{x}')\chi_\beta(0,0)|0 >,$$

  where χ is the proton interpolating operator $\chi_\alpha = \epsilon^{abc}[u^{a^T}C\gamma_5 d^b]u^c$.

- Only the connected insertion is computed for isovector scalar charge.

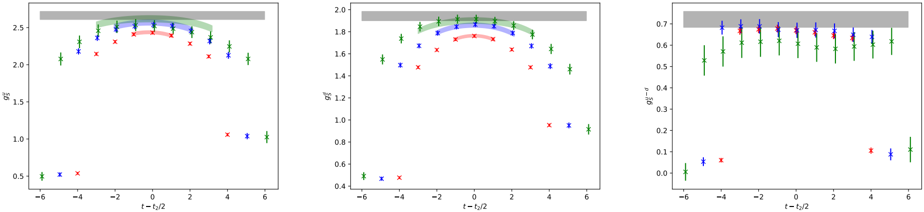
- For each ensemble, the correlation function are computed for several values of valence quark mass (use multi-mass algorithm) and source-sink separation.

Ensemble ID	m_π^{sea} (MeV)	$m_\pi^{valence}$(MeV)	$t_{sink} - t_{source}$
24I	337	$282 \sim 389$	8, 10, 12
32I	302	$295 \sim 410$	12, 14, 15
48I	139	$134 \sim 372$	8, 10 ,12
32ID	171	$146 \sim 325$	7, 8, 9, 10, 11
32Ifine	371	$344 \sim 485$	14, 16, 18

Two-state fit

$$R^q(t_2, t) = \frac{C^q_{3pt}(t_2, t)}{C_{2pt}(t_2)} = g^q_S + C^q_1 e^{-\Delta M t_2} + C^q_2 e^{-\Delta M (t_2 - t)} + C^q_3 e^{-\Delta M t},$$

Joint fit of $R^u(t, t_s)$ and $R^d(t, t_s)$:



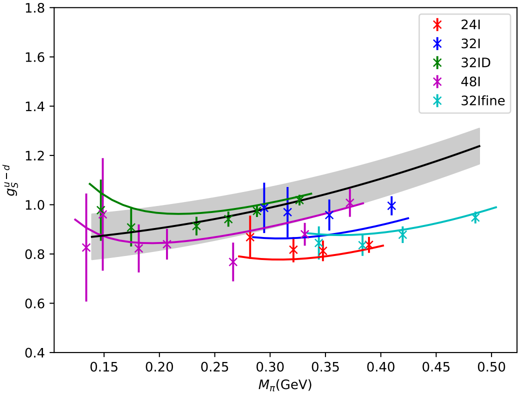
Renormalization factor Z_S (Z. Liu et al. Phys. Rev. D 90, 034505 (2014)):

24I	32I	32ID	48I	32Ifine
1.1272	1.0563	1.2355	1.1272	0.9539

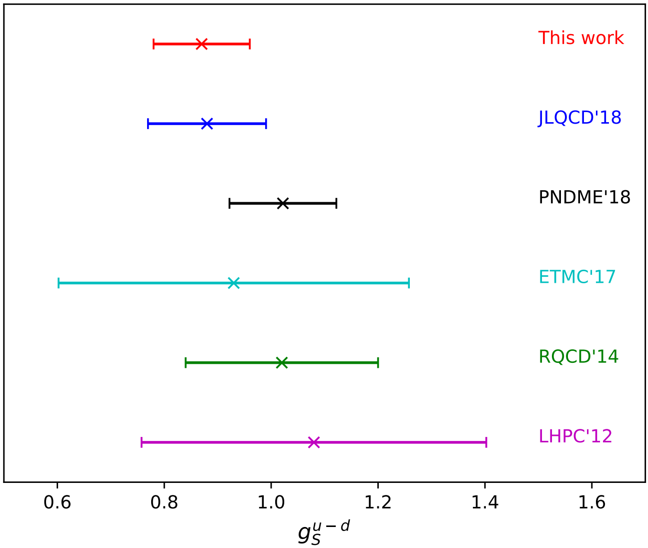
$$g_S(m_{\pi,vv}, m_{\pi,vs}, a, L) = c_0 + c_1 m_{\pi,vv}^2 + c_2 m_{\pi,vs}^{mix\ 2} + c_3(c_4)a^2 + c_5 e^{-m_{\pi,vv}L}$$

c_0	c_1	c_2	c_3	c_4	c_5	χ^2/dof
0.88(0.10)	4.03(0.62)	-4.71(1.00)	-1.11(5.42)	3.13(3.79)	4.83(2.05)	1.06

$g_S^{u-d} = 0.87(9)$



Results


This work
JLQCD'18
PNDME'18
ETMC'17
RQCD'14
LHPC'12
0.6
0.8
1.0
1.2
1.4
1.6
g_S^{u-d}

Outlook

- More statistics on the physical ensemble.
- Systematic error needs further investigation.
- Axial, tensor charges, disconnected insertion.
- σ-terms, Form factors.