Flavor dependent nPDFs via A=3 SIDIS $\pi^{\pm}$ production & Diquark-SRC Model Projections with DIS Constraints

Jennifer Rittenhouse West
INFN Turin
Electron-Ion Collider Users Group & ePIC Meeting
Glasgow, Scotland
13-17 July 2026

Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

EIC Center at Jefferson Lab

Proposed Theory Foundation for A=3 SIDIS Experiments

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Outline for talk:

1. Nuclear Response Functions for A=3 SIDIS
2. Diquark-SRC Model of EMC Effect
3. Diquark-SRC Projections
4. Check for flavor dependent nPDFs from A=3 DIS MARATHON results

Future: EIC fixed target projections

nPDFs in terms of the EMC effect

- Predicted structure function $F_2(x)$ ratio in disagreement with theory
- nPDFs inside of $F_2(x)$
- Quark confinement at QCD energy scales ~200 MeV
- Nucleons bound at BE $\geq$ 2.2 MeV
- Reason for these nuclear environment effects on quarks unknown after 43 years

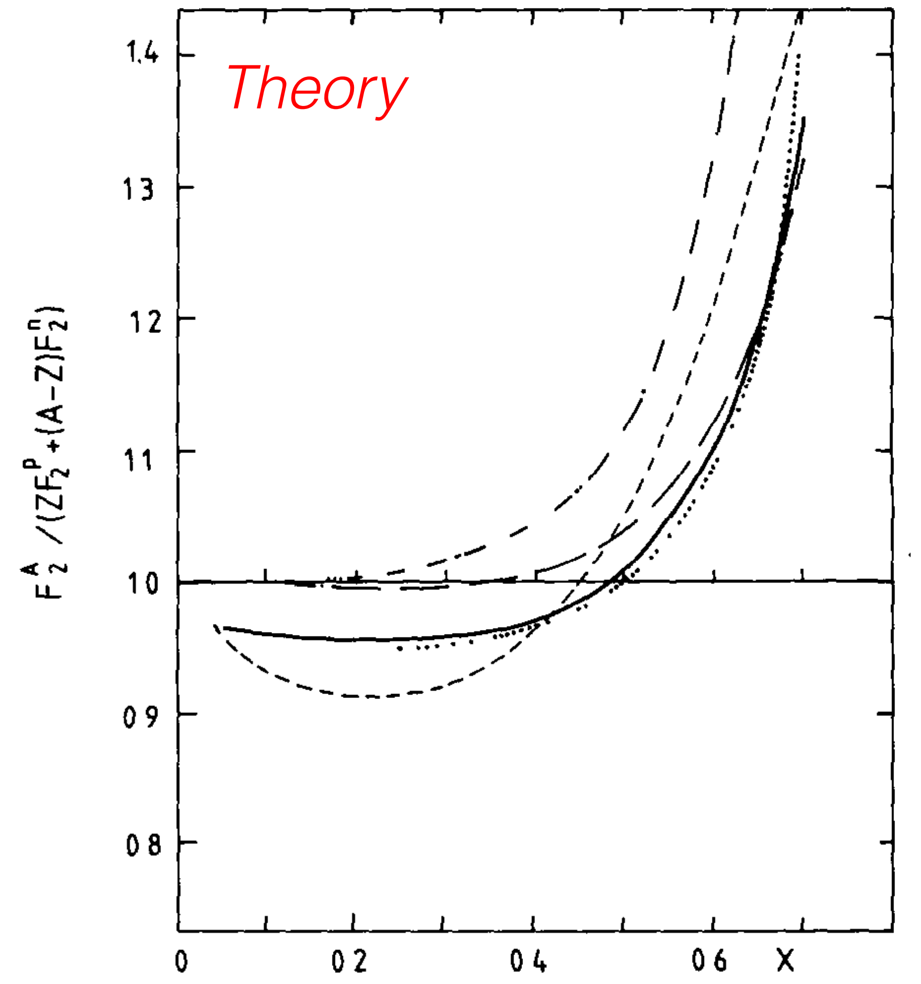


Fig. 1. Theoretical predictions for the Fermi motion correction of the nucleon structure function F_2^N for iron. Dotted line Few-nucleon-correlation-model of Frankfurt and Strikman [9]. Dashed line. Collective-tube-model of Berlad et al. [10] Solid line Correction according to Bodek and Ritchie [8]. Dot–dashed line. Same authors, but no high momentum tail included. Triple-dot–dashed line Same authors, momentum balance always by a $A - 1$ nucleus. The last two curves should not be understood as predictions but as an indication of the sensitivity of the calculations to several assumptions which are only poorly known.

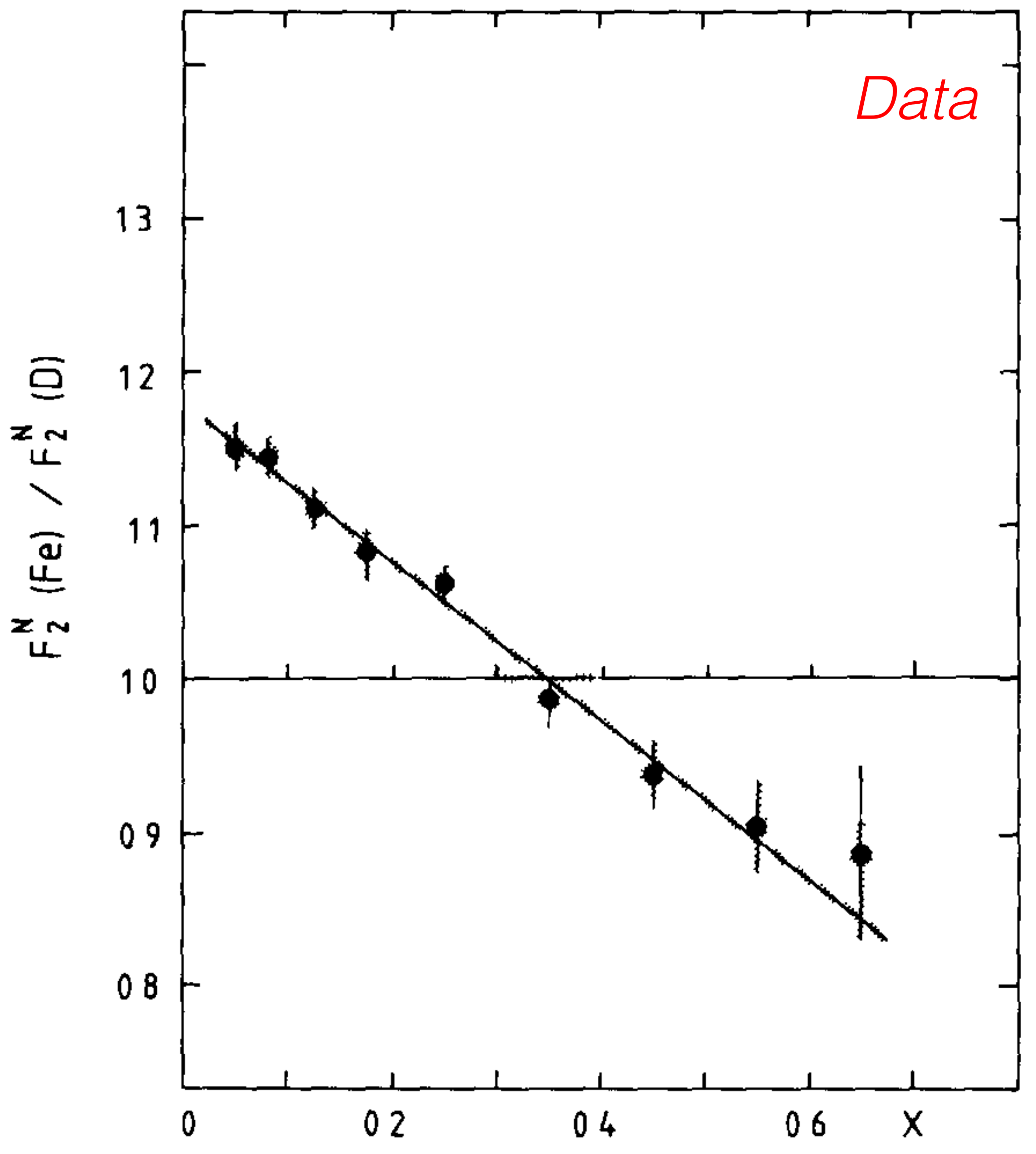


Fig. 2. The ratio of the nucleon structure functions F_2^N measured on iron and deuterium as a function of $x = Q^2/2M_p\nu$. The iron data are corrected for the non-isoscalarity of $^{56}_{26}$Fe, both data sets are not corrected for Fermi motion. The full curve is a linear fit $F_2^N(\mathrm{Fe})/F_2^N(\mathrm{D}) = a + bx$ which results in a slope $b = -0\ 52 \pm 0.04$ (stat.) $\pm$ 0.21 (syst) The shaded area indicates the effect of systematic errors on this slope.

“THE RATIO OF THE NUCLEON STRUCTURE FUNCTIONS F_2 FOR IRON AND DEUTERIUM “
The European Muon Collaboration, J.J. AUBERT et al. 1983

Flavor Dependent nPDF search

- The idea is to search for nuclear modifications to u quark and d quark separately
- Possible discovery path for EMC effect solution
- An example of a flavor-dependent nPDF search (now defunct):

An update to C12-21-004 for PAC54, 2026

Semi-Inclusive Deep Inelastic Scattering Measurements of $A = 3$ Nuclei with CLAS12 in Hall B

New nuclear response functions for nPDFs

Motivation: In analogy to pieces of the AV18 NN potential

$$V_{\mathrm{NN}} = \sum_{p=1}^{18} V_p(r)\, \mathcal{O}_p$$

specifically the scalar and tensor spin terms

$$\sigma_1 \cdot \sigma_2,\ S_{12} = 3(\sigma_1 \cdot \hat{r})(\sigma_2 \cdot \hat{r}) - \sigma_1 \cdot \sigma_2,$$

the search is for functions that turn on and off in the presence of flavor-dependent nuclear environmental modifications.

II. NUCLEAR RESPONSE FUNCTIONS

The fractional modifications to the up and down quark PDFs in a bound proton inside nucleus A are defined to be

$$r_u \equiv 1 - \frac{u^{p/A}}{u}, \quad r_d \equiv 1 - \frac{d^{p/A}}{d}, \tag{1}$$

where $u \equiv u^p$ and $d \equiv d^p$ are the free proton PDFs. All variables carry quark momentum fraction (Bjorken-x) and Q^2 dependence which is suppressed for visual clarity.

The flavor-asymmetric and flavor-averaged nuclear response functions are defined as the linear combinations

$$\varepsilon_{\mathrm{a}} \equiv \frac{r_u - r_d}{2}, \quad \varepsilon_{\mathrm{avg}} \equiv \frac{r_u + r_d}{2}. \tag{2}$$

These definitions are chosen such that nuclear modifications that act equally on both u and d quarks ($r_u = r_d$) force the flavor-asymmetric function to vanish $\varepsilon_{\mathrm{a}} = 0$, thereby supplying the condition for a quark flavor-independent nuclear modification. It also provides $\varepsilon_{\mathrm{a}} \neq 0$ as the necessary and sufficient condition for a flavor-dependent nuclear modification. In addition, in the case of no nuclear modifications, both functions are zero $\varepsilon_{\mathrm{a}} = \varepsilon_{\mathrm{avg}} = 0$.

The inverse relations $r_u = \varepsilon_{\mathrm{avg}} + \varepsilon_{\mathrm{a}}$ and $r_d = \varepsilon_{\mathrm{avg}} - \varepsilon_{\mathrm{a}}$ may be substituted into Eq.1 in order to write the bound proton PDFs in terms of the nuclear response functions,

$$u^{p/A} = u(1 - \varepsilon_{\mathrm{avg}} - \varepsilon_{\mathrm{a}}), \quad d^{p/A} = d(1 - \varepsilon_{\mathrm{avg}} + \varepsilon_{\mathrm{a}}). \tag{3}$$

Assuming charge symmetry (i.e., the double isospin swap $u \leftrightarrow d$ and $p \leftrightarrow n$), the bound neutron PDFs are related to the bound proton PDFs by $u^{n/A} = d^{p/A}$ and $d^{n/A} = u^{p/A}$. Therefore the full nuclear PDFs for a nucleus with Z protons and $N = A - Z$ neutrons can be obtained by summing over the bound nucleon content

$$u^A = Zu^{p/A} + (A-Z)d^{p/A}, \quad d^A = Zd^{p/A} + (A-Z)u^{p/A}. \tag{4}$$

Substituting the expressions for the bound proton PDFs in terms of the nuclear response functions (from Eq. 3) gives the general nPDF expressions for nucleus A,

$$u^A = (Zu + (A-Z)d) - (Zu - (A-Z)d)\,\varepsilon_{\mathrm{a}} - (Zu + (A-Z)d)\,\varepsilon_{\mathrm{avg}}, \tag{5}$$

$$d^A = (Zd + (A-Z)u) + (Zd - (A-Z)u)\,\varepsilon_{\mathrm{a}} - (Zd + (A-Z)u)\,\varepsilon_{\mathrm{avg}}. \tag{6}$$

Cross sections in terms of nPDFs

A=3 SIDIS cross sections:

$$\frac{d\sigma_A^h}{dx\,dQ^2\,dz} = \frac{4\pi\alpha^2}{Q^4}\left(1 - y + \frac{y^2}{2}\right)\sum_q e_q^2\, q^A(x, Q^2)\, D_q^h(z, Q^2)$$

which will always be used in ratios such that

$\frac{d\sigma_A^h}{dx\,dQ^2\,dz} \propto \sum_q e_q^2\, q^A(x, Q^2)\, D_q^h(z, Q^2)$ can be used without loss of generality

To leading order in terms of nPDFs q^A:

$$\sigma_A^{\pi^+} \propto \frac{4}{9}\, u^A D^+ + \frac{1}{9}\, d^A D^-,$$

$$\sigma_A^{\pi^-} \propto \frac{4}{9}\, u^A D^- + \frac{1}{9}\, d^A D^+,$$

written in terms of favored and unfavored FFs (the fragmenting quark is a valence constituent of the produced pion, D^+, or not, D^-) and where $D_u^{\pi^+} = D_d^{\pi^-}$ is assumed due to (isospin) charge symmetry $u \leftrightarrow d,\ \pi^+ \leftrightarrow \pi^-$, just as for nPDFs $u \leftrightarrow d,\ p \leftrightarrow n$. CSV effects must be considered (they are small).

nPDFs in terms of flavor-dependent functions

A=3 SIDIS cross sections to leading order,

$$\sigma_A^{\pi^+} \propto \frac{4}{9} u^A D^+ + \frac{1}{9} d^A D^-,$$

$$\sigma_A^{\pi^-} \propto \frac{4}{9} u^A D^- + \frac{1}{9} d^A D^+$$

Substituting nPDFs on the right into the xsecs above yields the cross sections in terms of $\varepsilon_a, \varepsilon_{avg}$

$$u^A = Zu^{p/A} + (A-Z)d^{p/A}, \quad d^A = Zd^{p/A} + (A-Z)u^{p/A}. \tag{4}$$

Substituting the expressions for the bound proton PDFs in terms of the nuclear response functions (from Eq. 3) gives the general nPDF expressions for nucleus A,

$$u^A = (Zu + (A-Z)d) - (Zu - (A-Z)d)\,\varepsilon_{\mathrm{a}} - (Zu + (A-Z)d)\,\varepsilon_{\mathrm{avg}}, \tag{5}$$

$$d^A = (Zd + (A-Z)u) + (Zd - (A-Z)u)\,\varepsilon_{\mathrm{a}} - (Zd + (A-Z)u)\,\varepsilon_{\mathrm{avg}}. \tag{6}$$

For helion ^{3}He ($Z=2$, $N=1$) and triton ^{3}H ($Z=1$, $N=2$) specifically, these become

$$u^{^3\mathrm{He}} = (2u+d) - (2u-d)\,\varepsilon_{\mathrm{a}} - (2u+d)\,\varepsilon_{\mathrm{avg}}, \tag{7}$$

$$d^{^3\mathrm{He}} = (u+2d) - (u-2d)\,\varepsilon_{\mathrm{a}} - (u+2d)\,\varepsilon_{\mathrm{avg}}, \tag{8}$$

$$u^{^3\mathrm{H}} = (u+2d) - (u-2d)\,\varepsilon_{\mathrm{a}} - (u+2d)\,\varepsilon_{\mathrm{avg}}, \tag{9}$$

$$d^{^3\mathrm{H}} = (2u+d) - (2u-d)\,\varepsilon_{\mathrm{a}} - (2u+d)\,\varepsilon_{\mathrm{avg}}. \tag{10}$$

For the deuteron ($Z=1$, $N=1$), the nPDFs are

$$u^{^2\mathrm{H}} = (u+d) - (u-d)\,\varepsilon_{\mathrm{a}}^{^2\mathrm{H}} - (u+d)\,\varepsilon_{\mathrm{avg}}^{^2\mathrm{H}}, \tag{11}$$

$$d^{^2\mathrm{H}} = (u+d) + (d-u)\,\varepsilon_{\mathrm{a}}^{^2\mathrm{H}} - (u+d)\,\varepsilon_{\mathrm{avg}}^{^2\mathrm{H}}, \tag{12}$$

New nPDFs in ratios of cross sections I

From Eqn.23, setting the flavor-asymmetric $\varepsilon_a = 0$ response function to zero forces ε_{avg} to cancel out, leaving

$$\mathscr{R}(x)\Big|_{\varepsilon_\mathrm{a}=0} = \frac{(7u+2d)(1-\varepsilon_\mathrm{avg})}{(2u+7d)(1-\varepsilon_\mathrm{avg})} = \frac{7u+2d}{2u+7d} \equiv \mathscr{R}_0(x),$$

where the ratio depends only on free proton PDFs.

This means that any deviations from the curve $\mathscr{R}_0(x)$ imply, within errors and assumptions, that ∃ a nonzero ε_a, i.e., a flavor-dependent nuclear modification,

$$\frac{u^{p/A}}{u} \neq \frac{d^{p/A}}{d}.$$

For visual clarity, take $\mathscr{R}_0(x)_{data}$ divided by $\mathscr{R}_0(x)_{PDFs}$, and search for deviations from unity.

Taking the difference of the π^+ and π^- cross sections for a general nucleus A, the favored and unfavored fragmentation functions combine into the flavor non-singlet (i.e., flavor-carrying) combination $\Delta D \equiv D^+ - D^-$, giving

$$\Delta\sigma_A^\pi \equiv \sigma_A^{\pi^+} - \sigma_A^{\pi^-} \propto \frac{1}{9}(4u^A - d^A)\,\Delta D. \tag{17}$$

Substituting the nuclear PDFs derived above for helion and triton yields

$$\Delta\sigma^\pi_{^3\mathrm{He}} \propto \frac{1}{9}\left[(7u+2d)(1-\varepsilon_\mathrm{avg}) - (7u-2d)\,\varepsilon_\mathrm{a}\right]\Delta D, \tag{18}$$

$$\Delta\sigma^\pi_{^3\mathrm{H}} \propto \frac{1}{9}\left[(2u+7d)(1-\varepsilon_\mathrm{avg}) - (2u-7d)\,\varepsilon_\mathrm{a}\right]\Delta D. \tag{19}$$

while for the deuteron

$$\Delta\sigma^\pi_D \propto \frac{1}{3}\left[(u+d)(1-\varepsilon^D_\mathrm{avg}) - (u-d)\,\varepsilon^D_\mathrm{a}\right]\Delta D. \tag{20}$$

Under the assumption that the deuteron has negligible nuclear modifications, $\varepsilon^D_\mathrm{avg} = \varepsilon^D_\mathrm{a} = 0$, this reduces to

$$\Delta\sigma^\pi_D\big|_{\varepsilon=0} \propto \frac{1}{3}(u+d)\,\Delta D. \tag{21}$$

This assumption can be tested experimentally by forming the ratio

$$\frac{\Delta\sigma^\pi_D}{\frac{1}{3}(u+d)\,\Delta D} = (1-\varepsilon^D_\mathrm{avg}) - \frac{(u-d)}{(u+d)}\,\varepsilon^D_\mathrm{a}, \tag{22}$$

which equals unity if both $\varepsilon^D_\mathrm{avg} = 0$ and $\varepsilon^D_\mathrm{a} = 0$. Deviation from unity in the measured ratio constitutes evidence for nuclear environment modifications in the deuteron.

The ratio of the mirror nuclei $\Delta\sigma^\pi$ is

$$\mathcal{R}(x) \equiv \frac{\Delta\sigma^\pi_{^3\mathrm{He}}}{\Delta\sigma^\pi_{^3\mathrm{H}}} = \frac{(7u+2d)(1-\varepsilon_\mathrm{avg}) - (7u-2d)\,\varepsilon_\mathrm{a}}{(2u+7d)(1-\varepsilon_\mathrm{avg}) - (2u-7d)\,\varepsilon_\mathrm{a}}, \tag{23}$$

where the fragmentation function combination ΔD cancels between numerator and denominator under the assumption of nucleus-independent fragmentation. This cancellation is a primary motivation for using cross section ratios as the experimental observables because it eliminates the need for a precise theoret-

New nPDFs in ratios of cross sections II

From Eqn.23, setting the flavor-asymmetric $\varepsilon_a = 0$ response function to zero forces ε_{avg} to cancel out, leaving

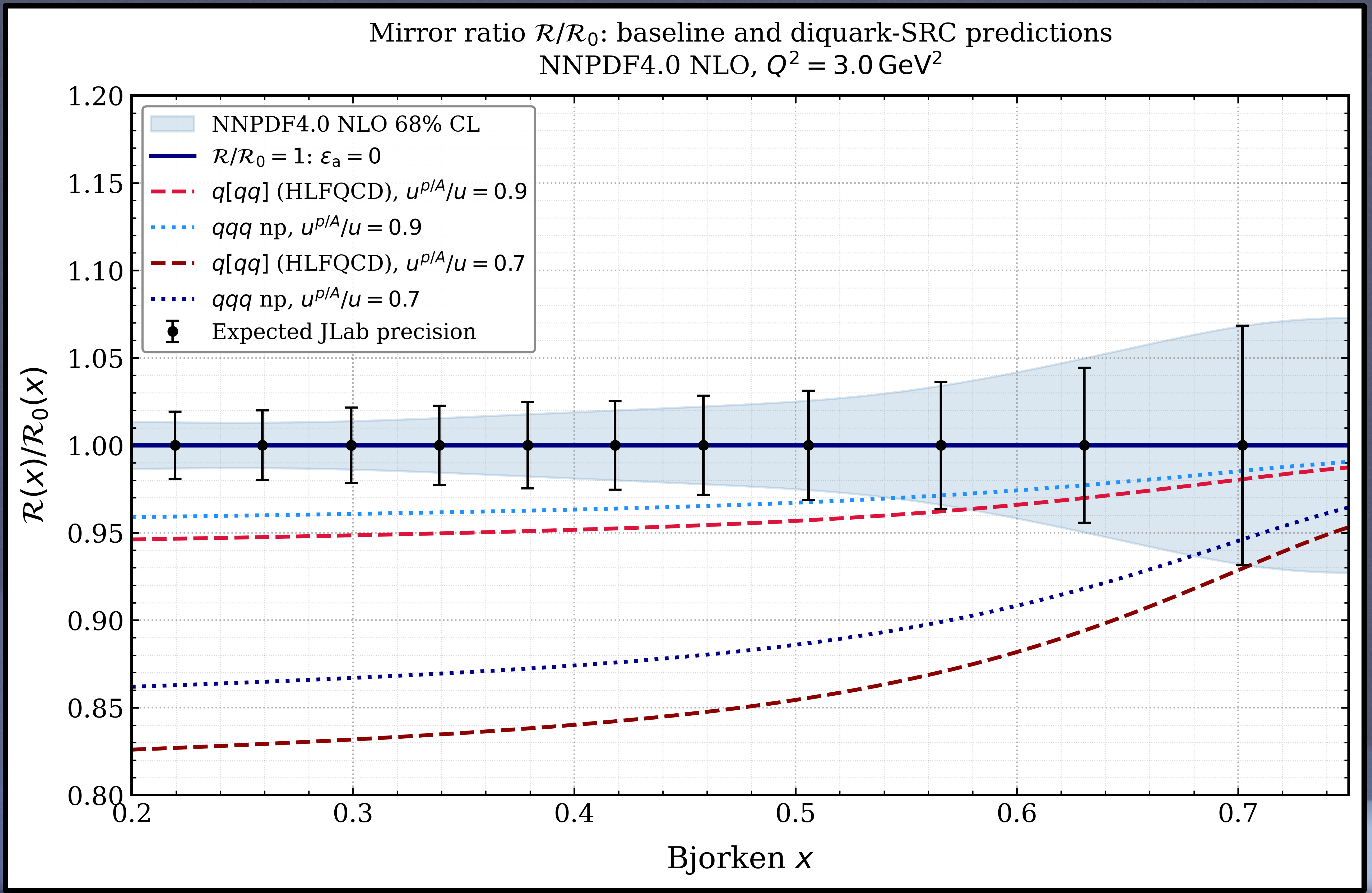
$$\mathscr{R}(x)\Big|_{\varepsilon_a=0} = \frac{(7u+2d)(1-\varepsilon_{\rm avg})}{(2u+7d)(1-\varepsilon_{\rm avg})} = \frac{7u+2d}{2u+7d} \equiv \mathscr{R}_0(x),$$

where the ratio depends only on free proton PDFs.

This means that any deviations from the curve $\mathscr{R}_0(x)$ imply, within errors and assumptions, that ∃ a nonzero ε_a, i.e., a flavor-dependent nuclear modification,

$$\frac{u^{p/A}}{u} \neq \frac{d^{p/A}}{d}.$$

For visual clarity, take $\mathscr{R}_0(x)_{data}$ divided by $\mathscr{R}_0(x)_{PDFs}$, and search for deviations from unity.



Plot to be updated: Lower dashed lines not viable

New nPDFs in sums/diffs of ratios to ^{2}H

Determination of the nuclear response functions for each value of x:

IV. DETERMINATION OF NUCLEAR RESPONSE FUNCTIONS

In order to determine the values of $\varepsilon_{\rm a}$ and $\varepsilon_{\rm avg}$, the ratios $R^{\Delta}_{^3{\rm He}/D}$ and $R^{\Delta}_{^3{\rm H}/D}$ are formed by dividing the helion and triton charge difference cross sections by the deuteron charge difference cross section of Eq. 21,

$$R^{\Delta}_{^3{\rm He}/D} \equiv \frac{\Delta\sigma^{\pi}_{^3{\rm He}}}{\Delta\sigma^{\pi}_{D}} = \frac{(7u+2d)(1-\varepsilon_{\rm avg}) - (7u-2d)\,\varepsilon_{\rm a}}{3(u+d)}, \tag{26}$$

$$R^{\Delta}_{^3{\rm H}/D} \equiv \frac{\Delta\sigma^{\pi}_{^3{\rm H}}}{\Delta\sigma^{\pi}_{D}} = \frac{(2u+7d)(1-\varepsilon_{\rm avg}) - (2u-7d)\,\varepsilon_{\rm a}}{3(u+d)}. \tag{27}$$

The sum and difference of these ratios are

$$R^{\Delta}_{^3{\rm He}/D} + R^{\Delta}_{^3{\rm H}/D} = 3(1-\varepsilon_{\rm avg}) - \frac{3(u-d)}{(u+d)}\,\varepsilon_{\rm a}, \tag{28}$$

$$R^{\Delta}_{^3{\rm He}/D} - R^{\Delta}_{^3{\rm H}/D} = \frac{5(u-d)}{3(u+d)}(1-\varepsilon_{\rm avg}) - \frac{5}{3}\,\varepsilon_{\rm a}. \tag{29}$$

These two equations constitute a linear system in the unknowns $\varepsilon_{\rm avg}$ and $\varepsilon_{\rm a}$, with coefficients determined by the free proton PDFs $u(x)$ and $d(x)$ at each value of x. The system may be solved analytically at each x, providing a model independent extraction of the nuclear response functions from the measured ratios without requiring a global fit, with the resulting expressions

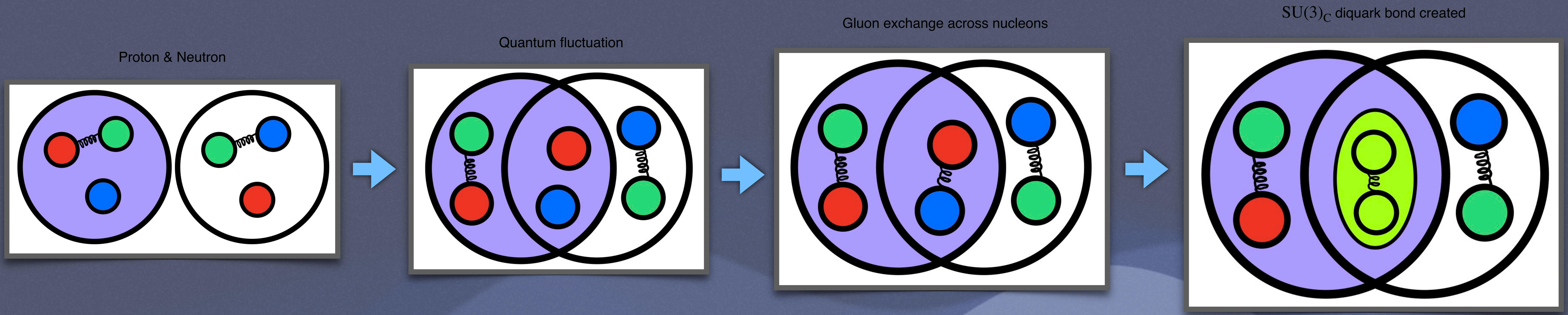
$$\begin{aligned} \varepsilon_{\rm a} &= \frac{(u+d)\,[5(u-d)R_{\Sigma} - 9(u+d)R_{\Delta}]}{60ud} \\ \varepsilon_{\rm avg} &= 1 - \frac{(u+d)\,[5R_{\Sigma}(u+d) - 9(u-d)R_{\Delta}]}{60ud} \end{aligned} \tag{30}$$

Diquark-Induced SRC Model of EMC Effect

Diquark-Induced SRC Model

Nuclear structure: $\sim 80\,\%$ of nucleons in nuclear shell structure, $\sim 20\,\%$ of nucleons in Short-Range Correlated NN pairs ($\sim 20\,\%$ of nucleon wavefunction in SRC state) with large p_{relative}.

Quantum fluctuations in spatial proximity or in relative momentum can create such overlap - how do they “stick” together?



Cross-nucleon diquark formation: Attractive QCD potential $V(r) = -\frac{2}{3}\frac{g_s^2}{4\pi r}$

Constituent quark-quark binding energy ~ 150 MeV, via color-hyperfine mass model, De Rujula, Georgi, Glashow 1979

“Diquark induced short-range nucleon-nucleon correlations & the EMC effect” JRW, Nuc.Phys.A 2023

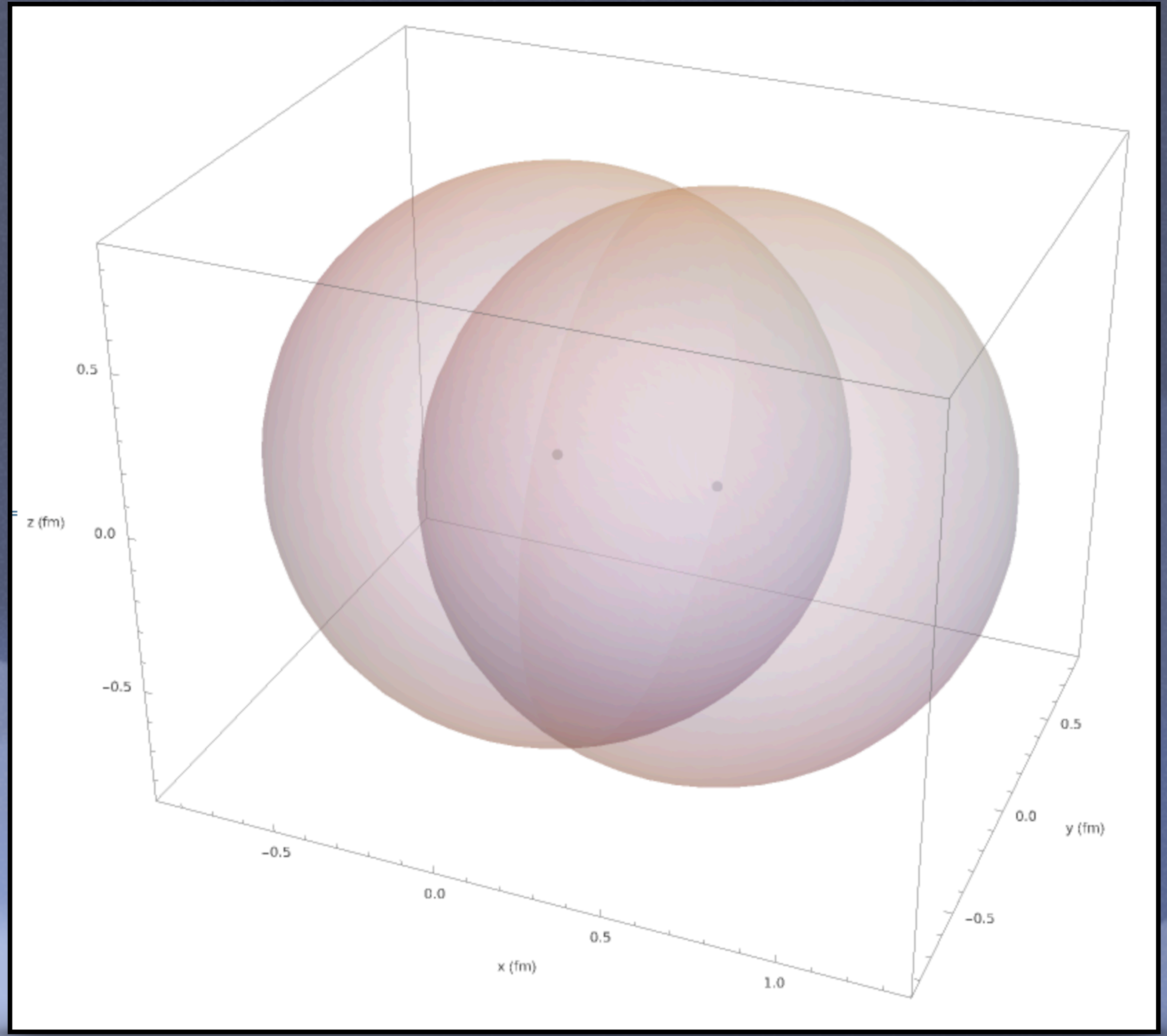
NN Overlap & Diquark-SRC Model

Nuclear structure: $\sim 80\,\%$ nuclear shell structure, $\sim 20\,\%$ Short-Range Correlated NN with large p_{relative}

Measurements of p_{rel} by CLAS 2019:

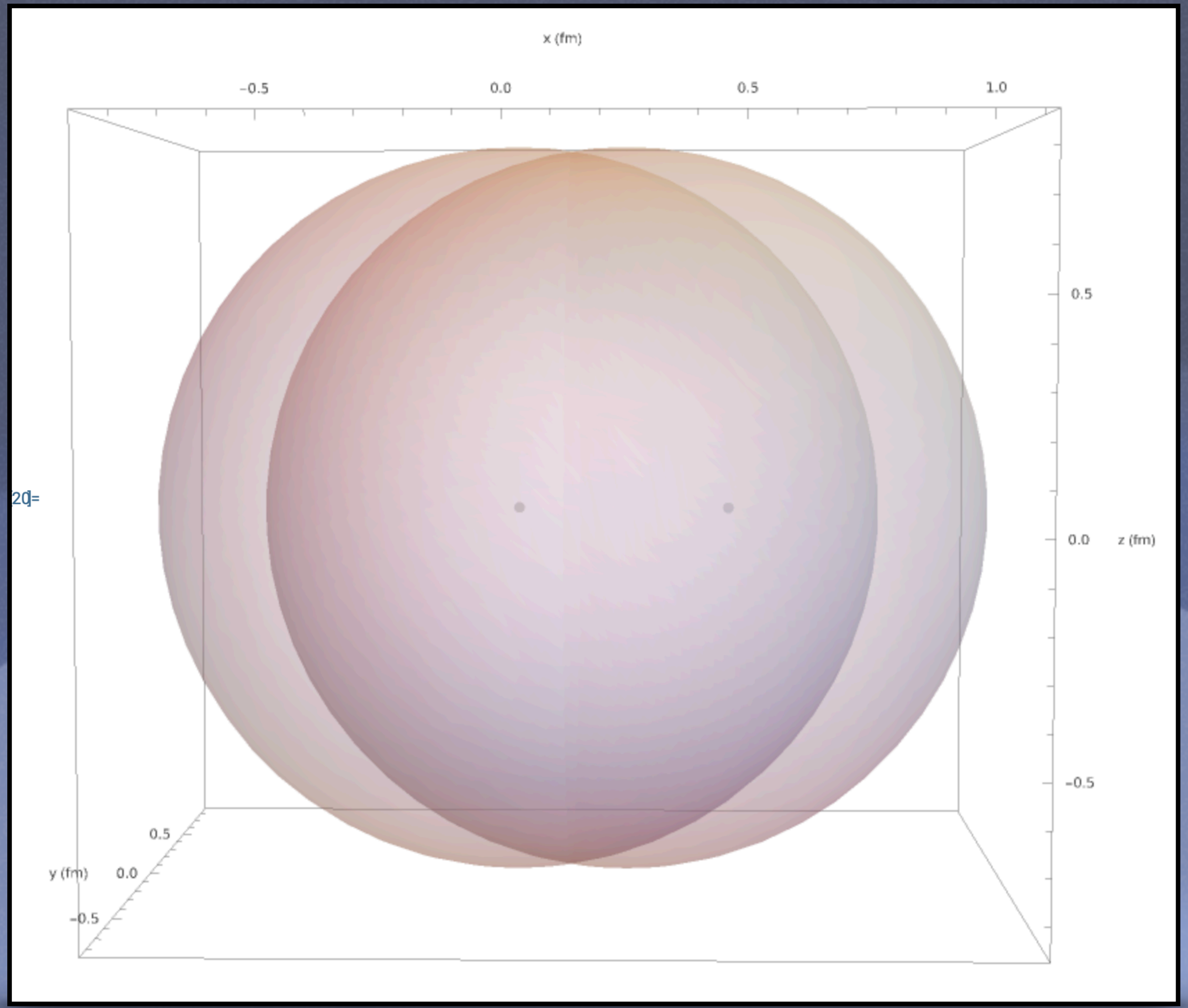
SRC Plot 1: Tensor-scalar transition in ^{12}C measurements from 2021 CLAS. **NN tensor force dominates at 400 MeV/c relative momenta**. Natural unit conversion gives 0.49 fm = 400 MeV/c.

57% of nucleon volume in the overlap region



SRC Plot 2: Tensor-scalar transition in ^{12}C measurements from 2021 CLAS. **NN scalar force is included at 800 MeV/c relative momenta**. Natural unit conversion gives 0.25 fm = 800 MeV/c .

78% of nucleon volume in the overlap region



"Diquark induced short-range nucleon-nucleon correlations & the EMC effect" JRW, Nuc.Phys.A 2023

Diquark-Induced SRC Model $\varepsilon_a, \varepsilon_{avg}$ relations

A. Proton: Quark-Diquark Internal Configuration

In the $u[ud]$ configuration, the d quark is already bound in the internal $[ud]$ diquark and cannot participate in cross-nucleon diquark formation. Only the free u quark can participate, and it can only pair with a d quark in the partner nucleon. For a pp SRC pair, the partner proton also has its d quark bound in an internal diquark, so no cross-nucleon diquark can form and the contribution is zero. For an np SRC pair, the neutron has a free d quark available, so cross-nucleon diquark formation proceeds. In both cases,

$$r_d = 0, \qquad r_u = 1 - \frac{u^{p/A}}{u}, \tag{34}$$

giving

$$\varepsilon_{\text{avg}} = \frac{r_u + r_d}{2} = \frac{1}{2}\left(1 - \frac{u^{p/A}}{u}\right), \tag{35}$$

$$\varepsilon_{\text{a}} = \frac{r_u - r_d}{2} = \frac{1}{2}\left(1 - \frac{u^{p/A}}{u}\right). \tag{36}$$

The diquark-SRC model therefore predicts

$$\varepsilon_{\text{a}} = \varepsilon_{\text{avg}} \tag{37}$$

for the $u[ud]$ configuration, independently of the value of $u^{p/A}/u$.

B. Proton: 3-Quark Internal Configuration

In the uud configuration, all three valence quarks are available for cross-nucleon diquark formation. The number of available $[ud]$ diquark microstates depends on the identity of the SRC partner nucleon.

1. pp Pairing

For a pp SRC pair, the bound proton uud partners with another proton uud. The available cross-nucleon $[ud]$ combinations are: u_{1a} with d_2 and u_{1b} with d_2, giving 2 combinations for the u quarks in the first proton; and d_1 with u_{2a} and d_1 with u_{2b}, giving 2 combinations for the d quark. The u and d quarks therefore participate with equal probability, giving $r_u = r_d$, and therefore

$$\varepsilon_{\text{a}} = 0, \qquad \varepsilon_{\text{avg}} = 1 - \frac{u^{p/A}}{u}. \tag{38}$$

2. np Pairing

For an np SRC pair, the bound proton uud partners with a neutron udd. There are 5 total available cross-nucleon $[ud]$ microstates, where $p \supset u_{11}u_{12}d_1$ and $n \supset d_{21}d_{22}u_2$: $u_{11}d_{21}$, $u_{11}d_{22}$, $u_{12}d_{21}$, $u_{12}d_{22}$, and d_1u_2. The proton's u participates in 4/5 microstates and d in 1/5 microstates. The fractional modification of the u quark PDF is therefore 4 times that of the d quark PDF.

$$r_u = 4\,r_d, \tag{39}$$

giving $r_d = (1 - u^{p/A}/u)/4$, and therefore

$$\varepsilon_{\text{avg}} = \frac{r_u + r_d}{2} = \frac{5}{8}\left(1 - \frac{u^{p/A}}{u}\right), \tag{40}$$

$$\varepsilon_{\text{a}} = \frac{r_u - r_d}{2} = \frac{3}{8}\left(1 - \frac{u^{p/A}}{u}\right). \tag{41}$$

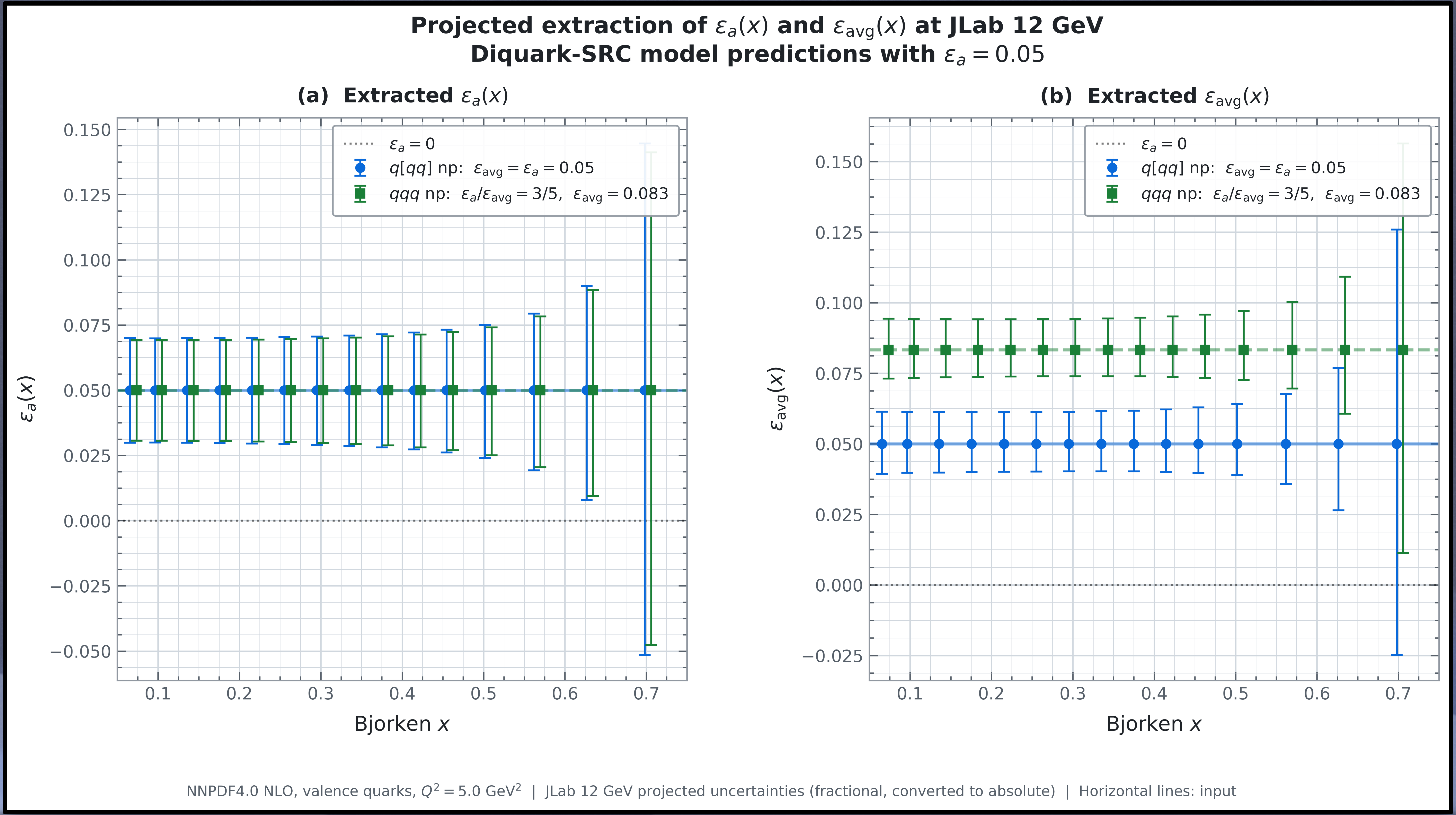
The ratio $\varepsilon_{\text{a}}/\varepsilon_{\text{avg}} = 3/5$ is a parameter-free prediction of the diquark-SRC model for the uud np-pairing case.

Diquark formation across NN pair dependent upon internal structure of the proton & partner nucleon. Leading order 3-quark Fock states:

$$|p\rangle \propto a_1\ u[ud] + a_2\ |uud\rangle$$

$\Longrightarrow$Diquark-SRC predictions for flavor-dependent nuclear response functions also depend upon the internal structure of the proton & partner nucleon identity.

Diquark-Induced SRC Model Projections

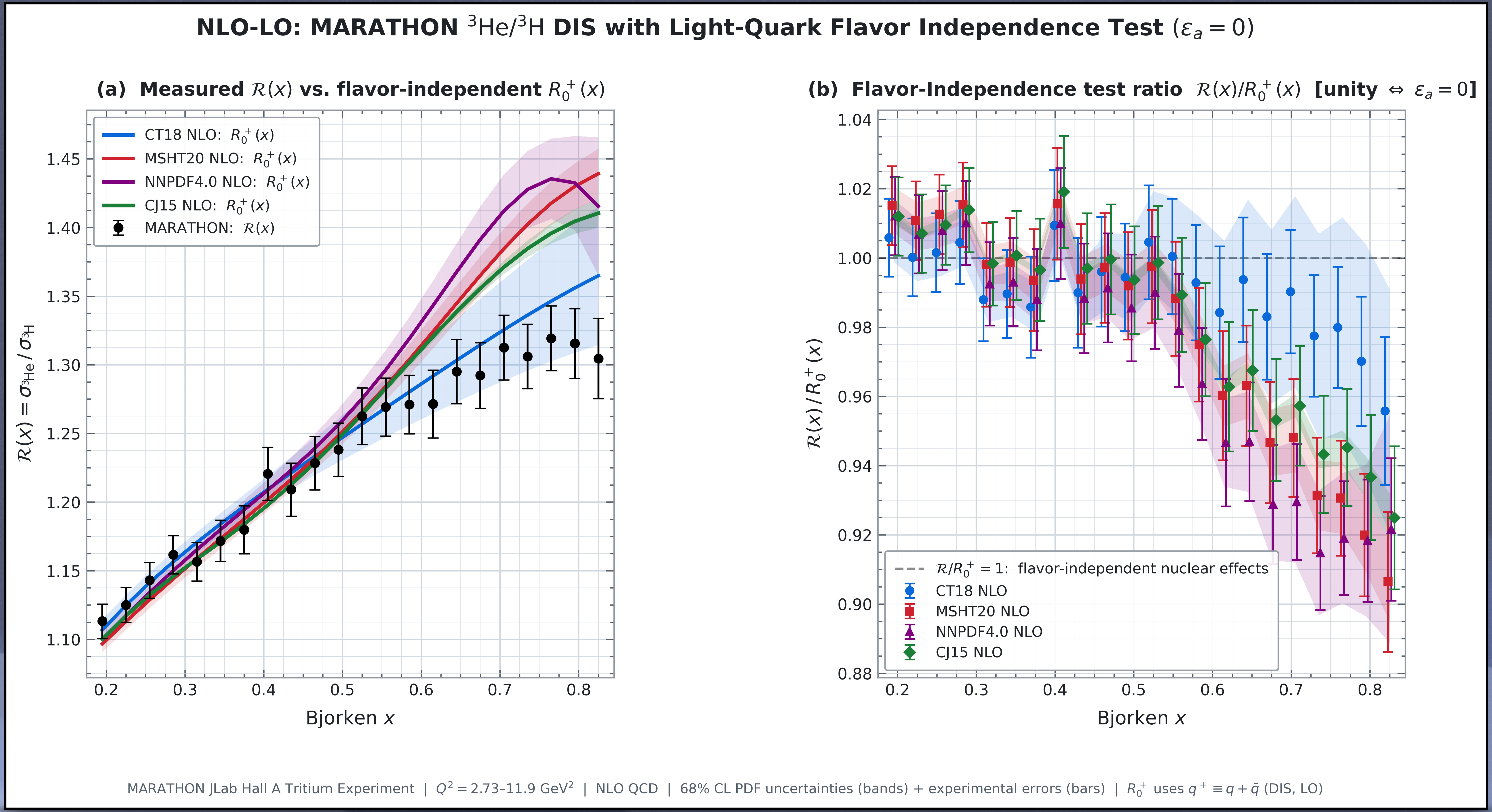


Values of $\varepsilon_a, \varepsilon_{avg}$ to be extracted from data but may be projected using DIS constraints from MARATHON 2025. Guess & plot:

$$\varepsilon_a = 0.05$$

Quark Flavor Dependence in DIS: Constraints I

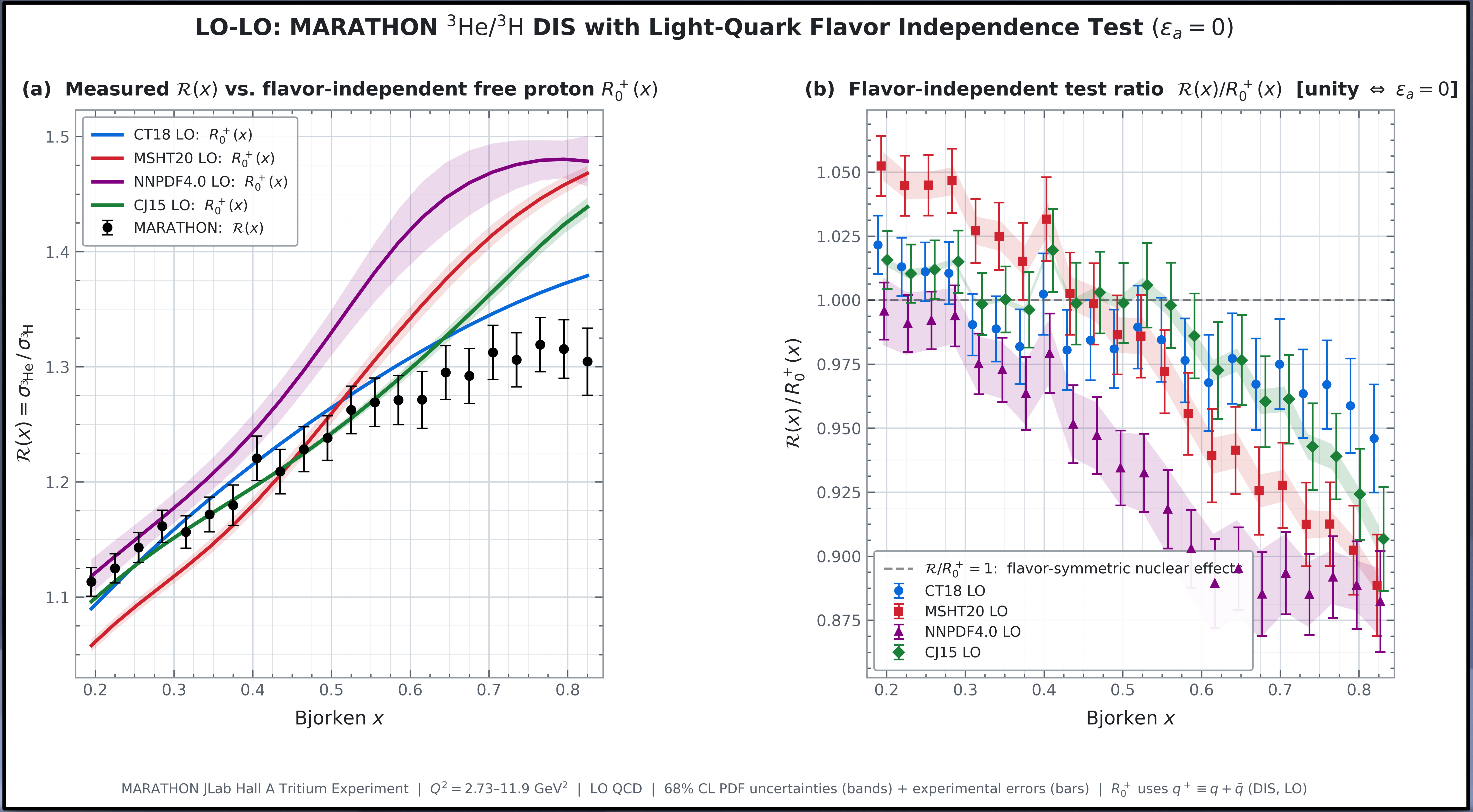
"EMC Effect of Tritium and Helium-3 from the JLab MARATHON Experiment," 2025 PRL (grazie Holly Szumila-Vance)



Data from deep inelastic scattering experiment at Jefferson Lab: $e\ ^3\mathrm{H} \to e'X$ and $e\ ^3\mathrm{He} \to e'X$ with four PDF sets from LHAPDF. Left: Helion/Triton xsec ratio, data vs. free PDFs. Right: Xsec ratio/free proton PDFs for $\epsilon_a = 0$.

Quark Flavor Dependence in DIS: Constraints II

LO-LO: Leading order PDFs, leading order F_2 vs. NLO-LO in Constraints I



Data from deep inelastic scattering experiment at Jefferson Lab: $e\ {}^3\mathrm{H} \to e'X$ and $e\ {}^3\mathrm{He} \to e'X$ with four PDF sets from LHAPDF. Left: Helion/Triton xsec ratio, data vs. free PDFs. Right: Xsec ratio/free proton PDFs for $\epsilon_a = 0$.

DIS: Quantifying the LO vs NLO coefficient uncertainty in $F_2(x, Q^2)$ built from NLO PDFs

Testing the LO-NLO hybrid in DIS against a proper NLO-NLO calculation using a toy model with no nuclear modification at all (i.e., $\varepsilon_a = \varepsilon_{avg} = 0$)

$$R_0^+(x,Q^2) = [\,3(u+\bar{u}) + 2(d+\bar{d})\,] \,/\, [\,2(u+\bar{u}) + 3(d+\bar{d})\,] \quad \textit{(LO } F_2 \textit{ coefficient, NLO PDFs)}$$

Method

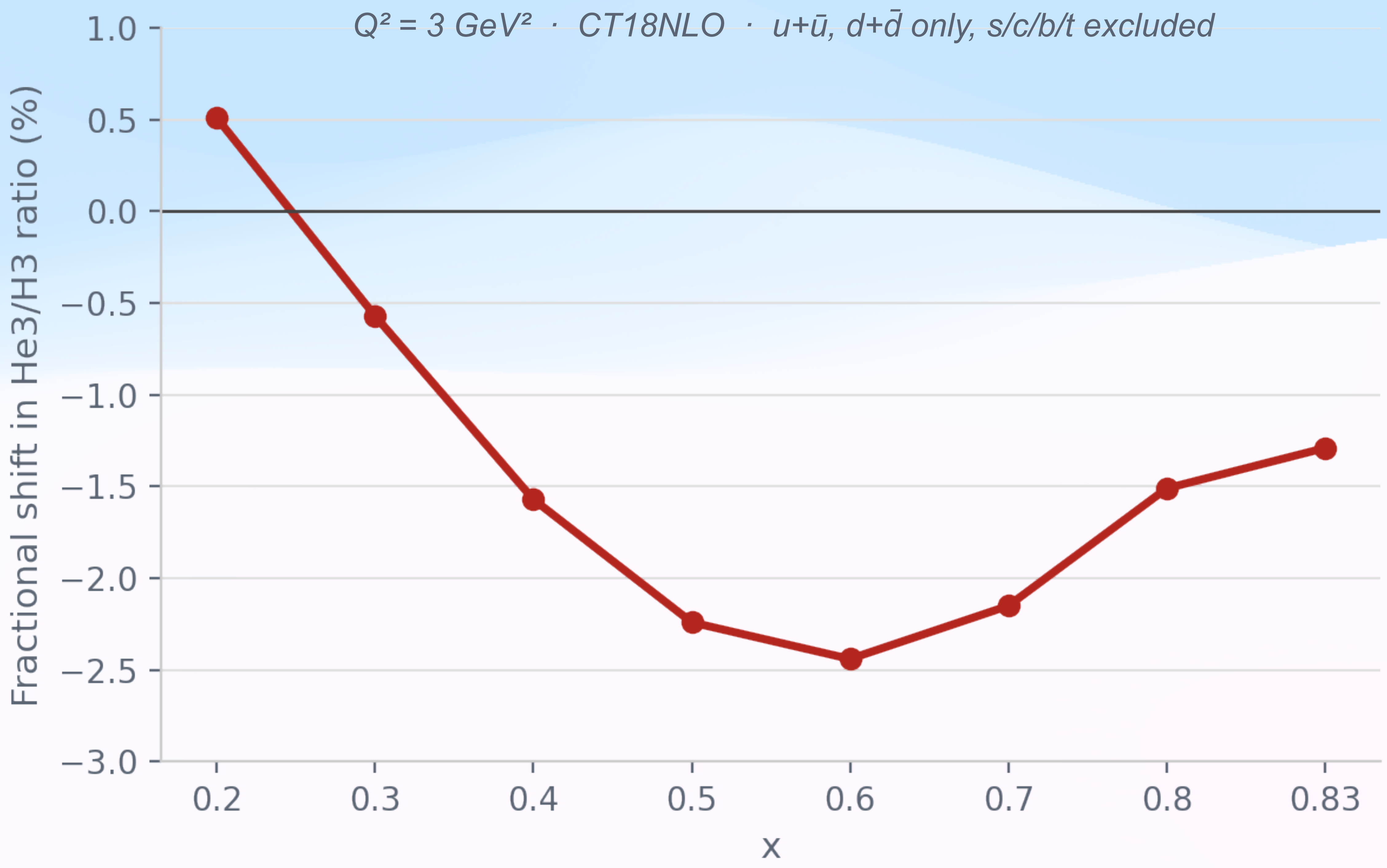
- R_0^+ ratio of $^3\mathrm{He}/^3\mathrm{H}$ DIS cross sections built from free proton PDFs (CT18NLO), evaluated at LO in F_2
- $^3\mathrm{He}$ = 2p+1n, $^3\mathrm{H}$ = 1p+2n via (isospin) charge symmetry
- Same NLO PDFs throughout, only the F_2 coefficient order changes from LO to NLO (via **APFEL++** software library, Bertone & Carrazza 2017, github.com/vbertone/apfelxx)
- Compared: genuine LO, hybrid (NLO PDF + LO coefficient), genuine NLO

Result

Individual F_2 pieces shift ~30–50% at large x, but the $^3\mathrm{He}/^3\mathrm{H}$ **ratio shifts by only 0.3–2.4%** across x = 0.20–0.83.

$\Longrightarrow$ *R_0^+=1 is an accurate test of flavor dependent nuclear modification, $\varepsilon_a = 0$*

LO-LO → NLO-NLO shift in the ratio



APFEL++ APFEL 4.8.0 A PDF evolution library in C++

DIS: What does the hybrid (LO coefficient + NLO PDF) approximation cost, relative to full NLO?

Same NLO PDF (CT18NLO) throughout. Isolating the F_2 coefficient function order.

Hybrid = F_2 *with NLO PDF, LO coefficient* *Genuine NLO* = F_2 *with NLO PDF, NLO coefficient*

Method

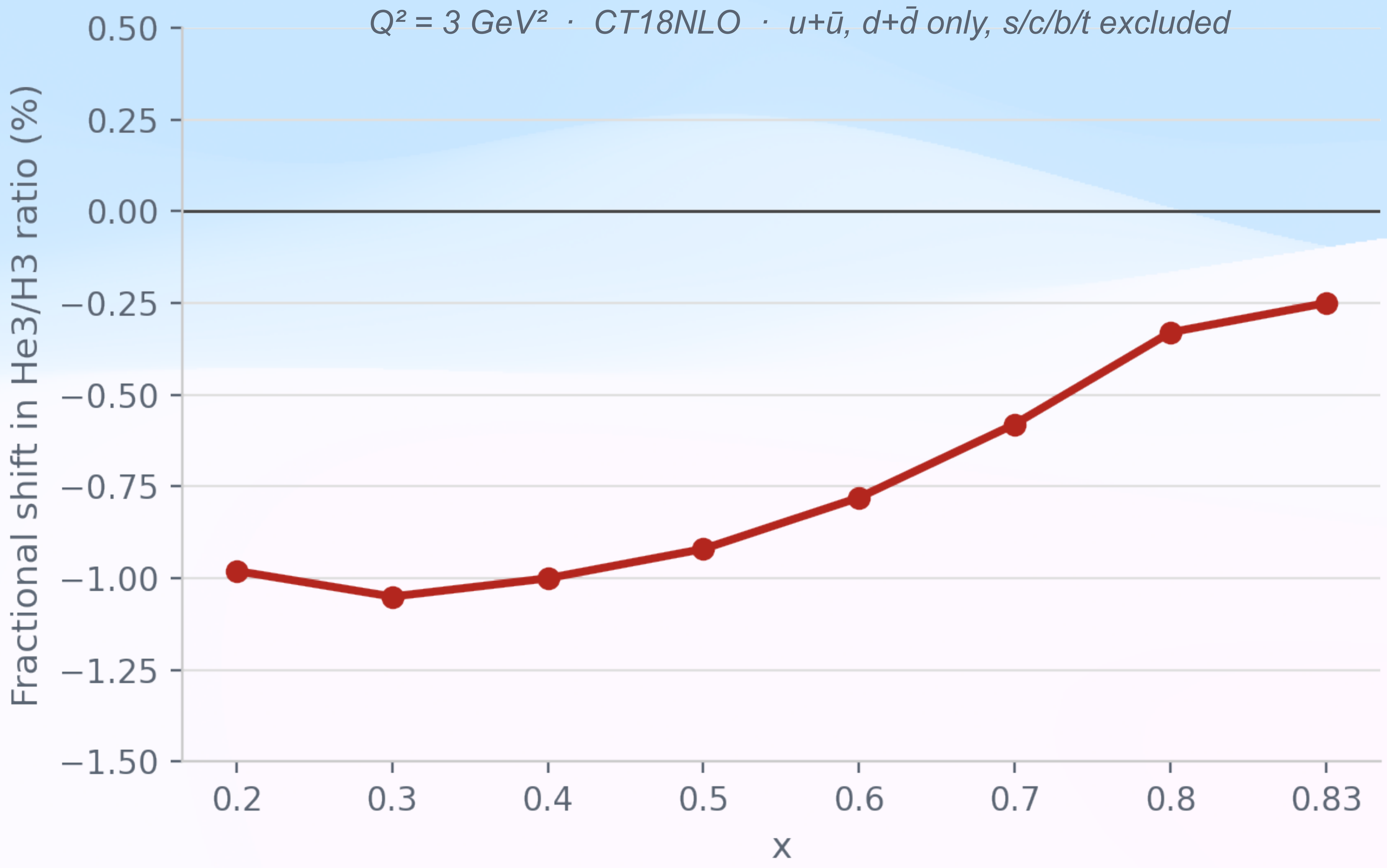
- Same $^3\mathrm{He}/^3\mathrm{H}$ setup as before (charge symmetry, u+ū, d+d̄ only)
- Both cases use the same NLO PDF, only the coefficient function's order changes (LO vs NLO), calculated via **APFEL++** software library, Bertone & Carrazza 2017, github.com/vbertone/apfelxx
- The approximation used in the extraction scheme: an NLO PDF paired with an LO structure function coefficient. This allows a simple extraction of flavor dependent functions ε_a, ε_{avg} from data.

Result

The hybrid ratio stays within **−1.05% to −0.25%** of the genuine NLO ratio across x = 0.20–0.83.

→ The LO-coefficient approximation costs under 1.1% in the cross section ratio

Hybrid → NLO shift in the ratio



Future

- EIC Fixed Target Support Proposal
- EIC study of polarized/unpolarized SIDIS ratios for $^3\mathrm{He}$
- Light nuclei nPDF inclusion into nPDF LHC Collaborations
- Flavor-Dependent nTMDs in A=3 feasibility study

Summary

1. Nuclear Response Functions for A=3 SIDIS proposed:

$$\varepsilon_{\mathrm{a}} \equiv \frac{r_u - r_d}{2}, \quad \varepsilon_{\mathrm{avg}} \equiv \frac{r_u + r_d}{2}$$

with fractional modification functions given by

$$r_u^{p/A} \equiv 1 - \frac{u^{p/A}}{u}, \quad r_d^{p/A} \equiv 1 - \frac{d^{p/A}}{d}.$$

2. Diquark-SRC Projections

3. Uncertainties on Nuclear Decomposition Functions for A=3 SIDIS then done!

4. Wish list: EIC fixed target uncertainties for new nuclear modification functions!

Fin…grazie!

Jennifer Rittenhouse West
INFN Turin
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Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

EIC Center at Jefferson Lab