EMC and SRC in EFT

1. Universality of the EMC effect
Jiunn-Wei Chen, William Detmold
Phys.Lett. B625 (2005) 165-170

2. Short Range Correlations and the EMC Effect in Effective Field Theory
Jiunn-Wei Chen, William Detmold, Joel E. Lynn, Achim Schwenk
arXiv:1607.03065

William Detmold, MIT

EMC and SRC in EFT

$$\frac{f^A(x)}{A} = f^N(x) + g_2(A) f_2(x)$$

- WD: sketch and consequences, $f_2(x)$ from LQCD
- Joel Lynn (after lunch): $g_2(A)$ from GFMC
- Jiunn-Wei Chen (Sunday): EFT details, extensions

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Effective field theory

- EFT provides rigorous description of low-energy QCD with quantifiable uncertainties
  - Hard partonic processes not naturally described
- Operator product expansion: moments of PDFs are matrix elements of local twist-2 operators

$$\mathcal{O}^{\mu_0 \cdots \mu_n} = \overline{q}\gamma^{(\mu_0} iD^{\mu_1} \cdots iD^{\mu_n)} q$$

$$\langle A; p | \mathcal{O}^{\mu_0 \cdots \mu_n} | A; p \rangle = \langle x^n \rangle_A(Q)\, p^{(\mu_0} \ldots p^{\mu_n)}$$

$$\langle x^n \rangle_A(Q) = \int_{-A}^{A} x^n q_A(x, Q) dx$$

Evaluate in rest frame, EFT methods applicable

Twist-two operators in EFT

- EFT: match QCD operators to **all** possible hadronic operators with same symmetries

- Used in π and N sectors to connect lattice PDF moments to experiment [Arndt & Savage; Chen & Ji; Detmold et al.,…]

- Isoscalar, spin independent operator matching:

$$\bar{q}\gamma^{\{\mu_1}D^{\mu_2}\dots D^{\mu_n\}}q \longrightarrow a_n \frac{1}{\Lambda^n}\mathrm{tr}\left[\Sigma^\dagger D^{\mu_1}\dots D^{\mu_n}\Sigma + h.c.\right]$$

LECs

$$+c_n N^\dagger \mathcal{V}^{\mu_1\dots\mu_n}N + c'_n N^\dagger S^{\{\mu_1}A^{\mu_2}\mathcal{V}^{\mu_3\dots\mu_n\}}N+\dots$$

$$+\alpha_n N^\dagger\mathcal{V}^{\mu_1\dots\mu_n}N\;N^\dagger N + \beta_n N^\dagger \mathcal{V}^{\mu_1\dots\mu_n}\tau_j^{\xi+}N\;N^\dagger\tau_j^{\xi+}+\dots$$

where

$$\mathcal{V}^{\mu_1\dots\mu_n} = \left(v + i\frac{D}{M}\right)^{\mu_1}\dots\left(v + i\frac{D}{M}\right)^{\mu_n} \qquad \tau_j^{\xi\pm} = \frac{1}{2}\left(\xi^\dagger\tau_j\xi \pm \xi\tau_j\xi^\dagger\right)$$

Twist-two matrix elements

- Nucleon matrix elements

$$v_{\mu_1}\dots v_{\mu_n}\langle N|\mathcal{O}^{\mu_1\dots\mu_n}|N\rangle = \langle x^n\rangle_q$$

Includes pionic and nucleonic terms

- Nuclear matrix elements

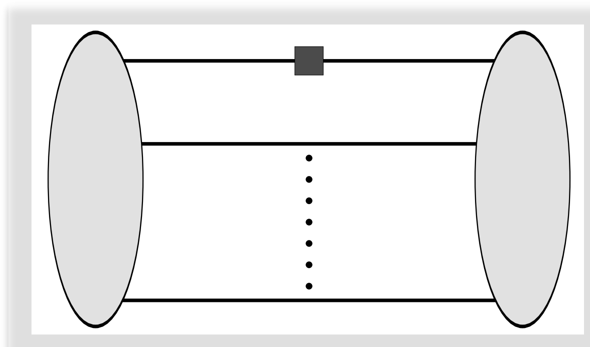
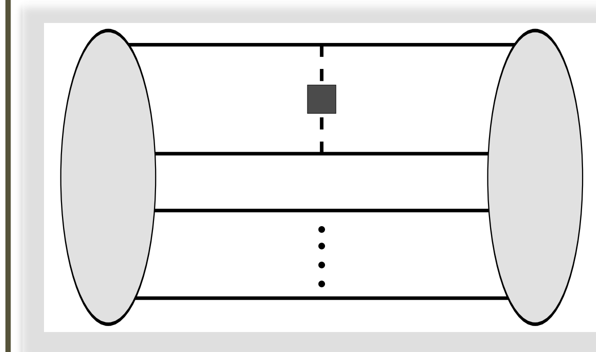
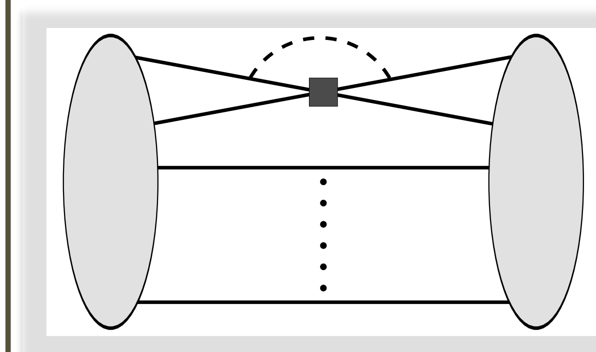
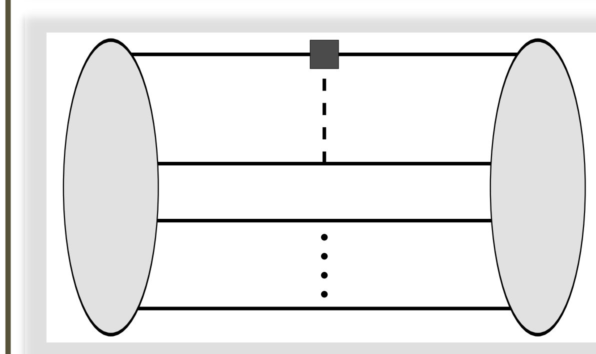
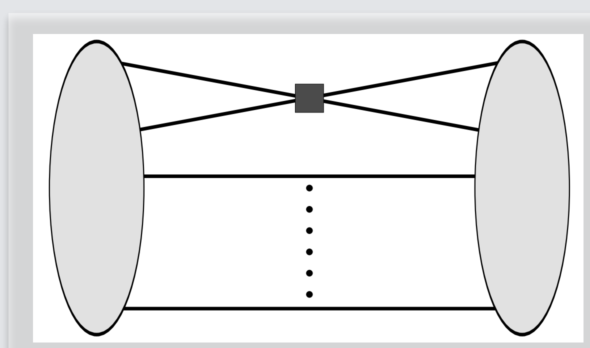
$$\langle x^n\rangle_{q|A} \equiv v_{\mu_1}\dots v_{\mu_n}\langle A|\mathcal{O}^{\mu_1\dots\mu_n}|A\rangle$$

$$= \langle x^n\rangle_q \left[A + \alpha_n\langle A|(N^\dagger N)^2|A\rangle + \beta_n\langle A|(N^\dagger\tau N)^2|A\rangle\right] + \dots$$

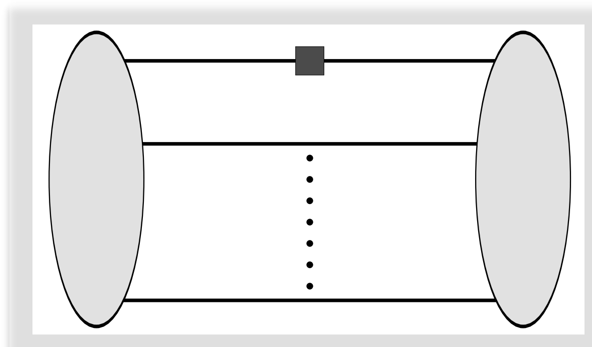
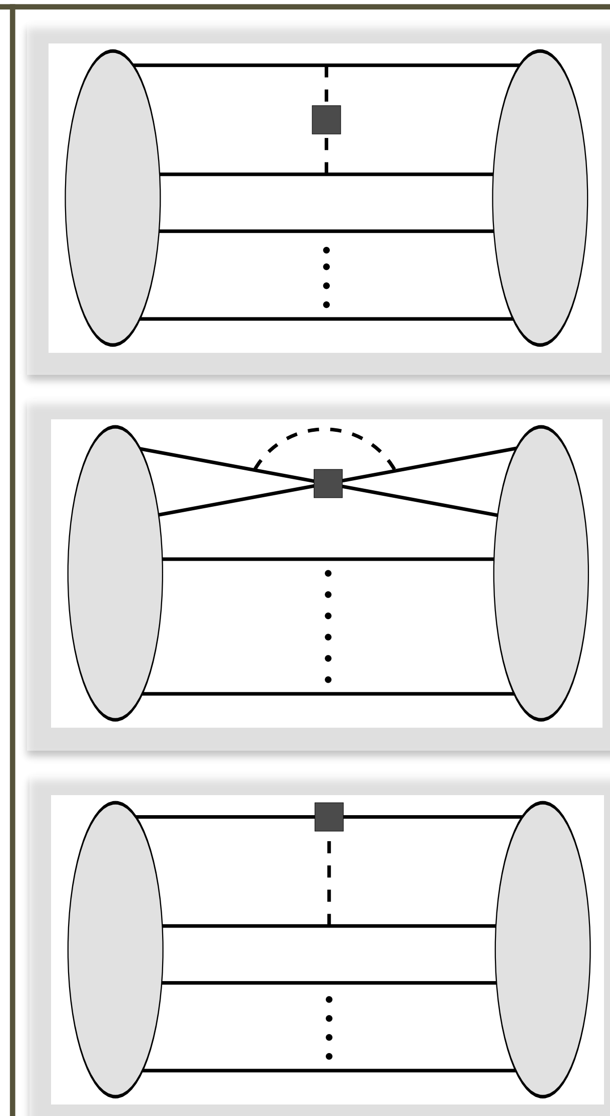
Dominant terms

- β_n term suppressed by N_c^2 [Kaplan & Savage 96; K & Manohar 97]

- Ellipsis includes higher-body operators, terms with derivatives: higher-order in power-counting

ε		higher orders	   ••• •••
ε			

Power counting

ε		higher orders	
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Twist-two matrix elements

- Inverse Mellin transform

$$\langle x^n \rangle_{q|A} = \langle x^n \rangle_q \left[A + \alpha_n \langle A|(N^\dagger N)^2|A\rangle\right.$$

➡ $$\frac{f^A(x)}{A} = f^N(x) + g_2(A) f_2(x)$$

with $g_2(A,\Lambda) = \frac{1}{A}\langle A|\left(N^\dagger N\right)^2|A\rangle_\Lambda$

and $\alpha_n = \frac{1}{\langle x^n \rangle_q} \int dx\, x^n f_2(x)$

- Factorisation of (x,Q^2) and A dependence: universality
  - Observed in data: [Daté et al. 84,..., Gomez et al. 95]
  - Requires there be only a single relevant non-trivial source of A dependence in EFT operator
  - Factorisation breaks: holds to O(**ε**) or N_c^2: expect ~20%

EMC and SRC

- Factorised form (also holds for QE cross section)

$$\frac{f^A(x)}{A} = f^N(x) + g_2(A) f_2(x)$$

- Simple manipulations imply

$$R(x,A) = \frac{2}{A}\frac{f^A(x)}{f^d(x)} = 1 + (a_2(A) - 1)\left(1 - \frac{f^p(x) + f^n(x)}{f^d(x)}\right)$$

where $a_2(A) = \frac{g_2(A,\Lambda)}{g_2(2,\Lambda)} = \frac{\langle A|(N^\dagger N)^2|A\rangle_\Lambda}{\langle d|(N^\dagger N)^2|d\rangle_\Lambda}$ (scheme indep.!)

- Consequently
  - $R(1 < x < 2, A) = a_2(A)$ as $f_p(x > 1) = f_n(x > 1) = 0$
  - EMC slope: $dR(x,A)/dx = (a_2(A) - 1)h(x)$
  - EMC-SRC relation !

Lattice QCD

- LECs α_n can be determined from experiment

OR

- Lattice QCD can probe EMC effect from first principles
  - Calculate $\langle N \; N|\mathcal{O}^{(n)}|N \; N\rangle$ to determine LECs
    - α_n can be extracted using background twist-2 fields
    - NPLQCD: Recent successful calculations of electroweak matrix elements in A=2,3,4 nuclei
    - Twist-2 matrix elements being calculated right now
  - With a few moments, reconstruct $f_2(x)$

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Nuclear EFT Lagrangian

- Pion and nucleon fields $\Sigma = \xi^2 = \exp\left[\frac{2i}{f}\begin{pmatrix}\pi^0 & \pi^+ \\ \pi^- & \pi^0\end{pmatrix}\right]$
- Heavy baryon formalism: $N_v(x) = e^{iMv\cdot x}N(x)$
- Δ -isobar omitted for simplicity

$$\mathcal{L} = \frac{f^2}{8}\mathrm{tr}[\partial^\mu\Sigma^\dagger\partial_\mu\Sigma] + \frac{\lambda f^2}{4}\mathrm{tr}[m_Q\Sigma^\dagger + m_Q\Sigma]$$

Velocity → v; Spin → S^μ

$$+N^\dagger i\, v\cdot D\ N + g_A N^\dagger S^\mu A_\mu\ N$$

$$+C_0(N^\dagger N)^2 + C_2(N^\dagger D_i N)^2 + \ldots$$

All possible operators constrained by symmetries

where

$$D^\mu = \partial^\mu + \frac{1}{2}\left(\xi^\dagger\partial^\mu\xi + \xi\partial^\mu\xi^\dagger\right) \qquad A^\mu = \frac{i}{2}\left(\xi^\dagger\partial^\mu\xi - \xi\partial^\mu\xi^\dagger\right)$$

- In detail

$$\frac{f^A(x)}{A} = f^N(x) + g_2(A) f_2(x),$$
$$a_2 = R(2 > x > 1, A) = g_2(A)/g_2(2).$$

$$\begin{aligned}\frac{f^A(x)}{A} &= \frac{f^d(x)}{2} + \left(g_2(A) - g_2(2)\right) f_2(x) \\ &= \frac{f^d(x)}{2} + \left(a_2(A) - 1\right) g_2(2) f_2(x) \\ &= \frac{f^d(x)}{2} + \left(a_2(A) - 1\right) \left(\frac{f^d(x)}{2} - f^N(x)\right)\end{aligned}$$