

Short-range correlations and the EMC effect in an EFT approach

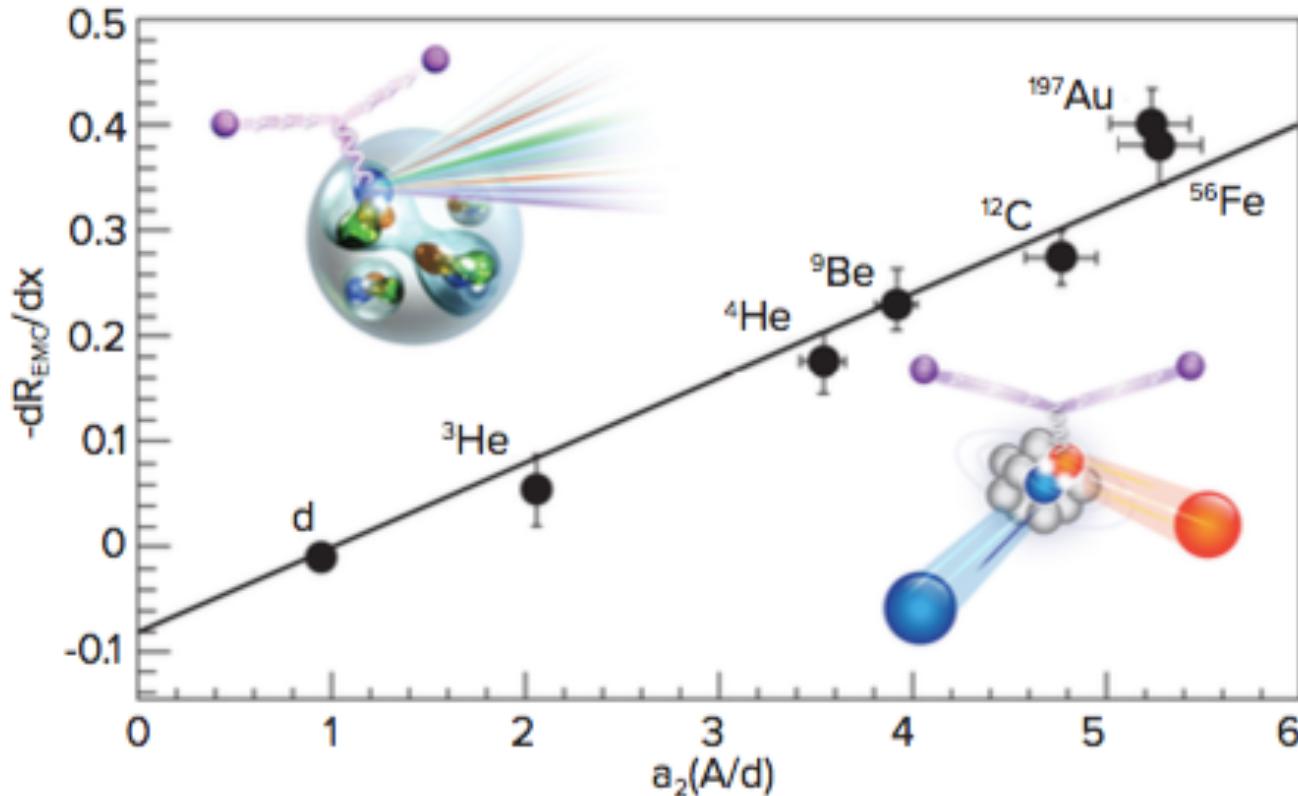
Jiunn-Wei Chen

National Taiwan U. & MIT

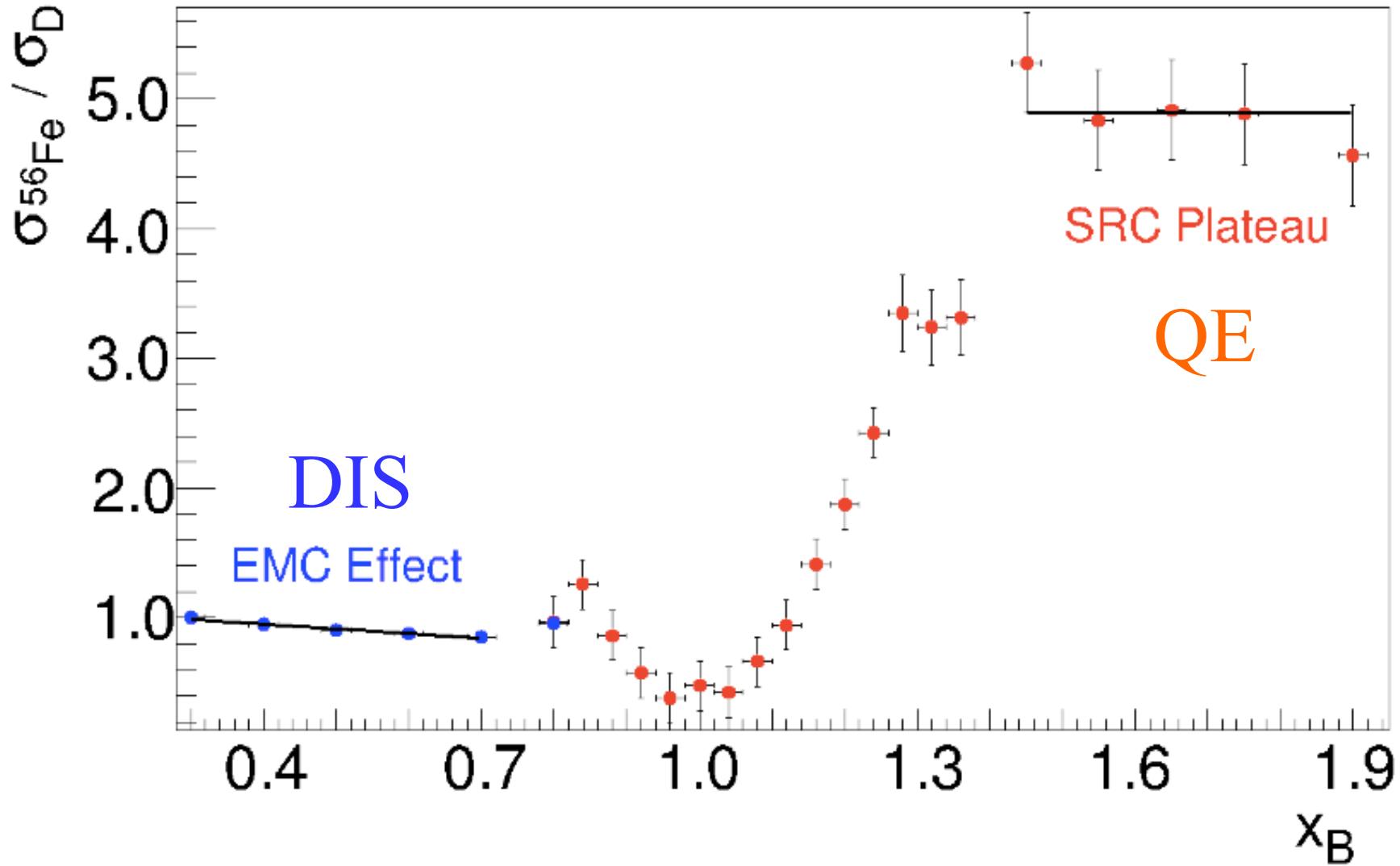
w/ William Detmold, Joel E. Lynn, Achim Schwenk,
1607.03065, Phys. Rev. Lett. 119 (2017) 262502

w/ William Detmold, hep-ph/0412119, Phys.Lett. B625
(2005) 165

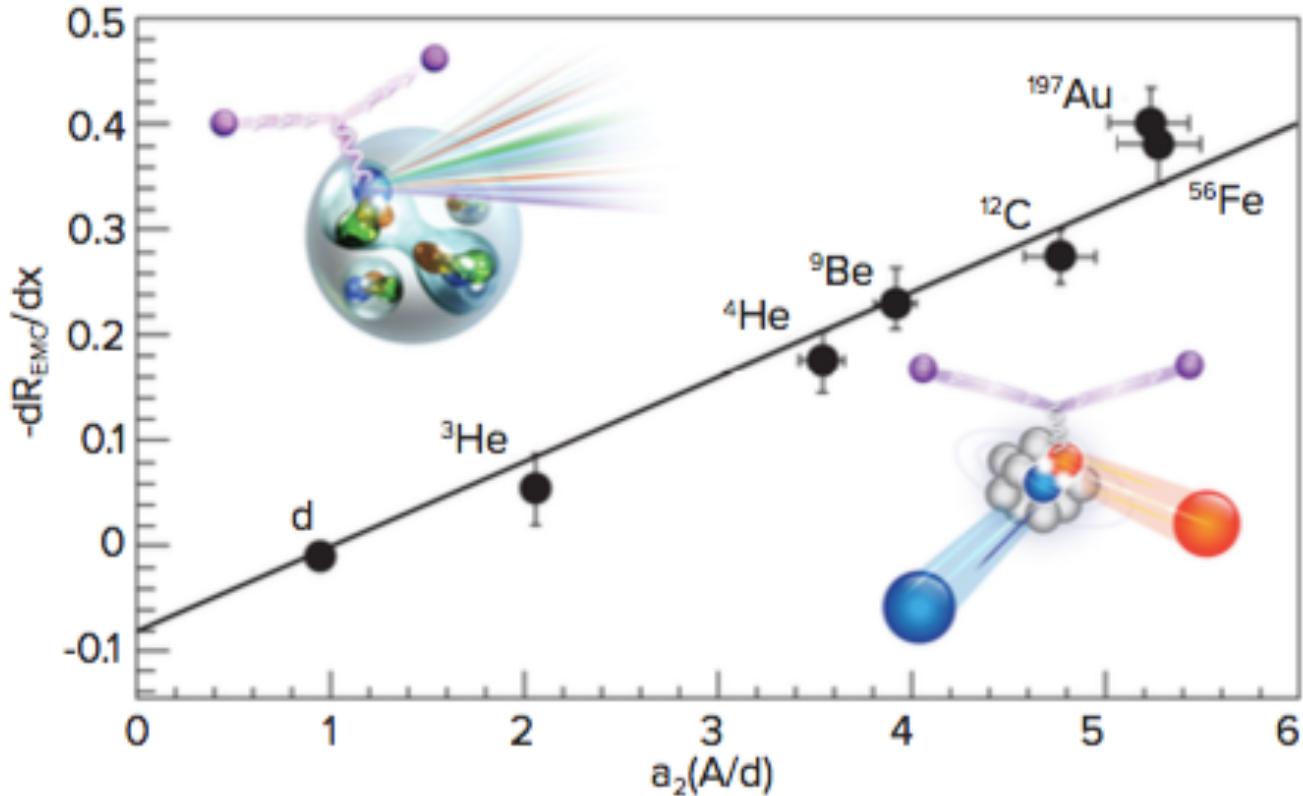
An Astonishing Empirical Result!



Weinstein et al., Phys. Rev. Lett. 106, 052301 (2011)

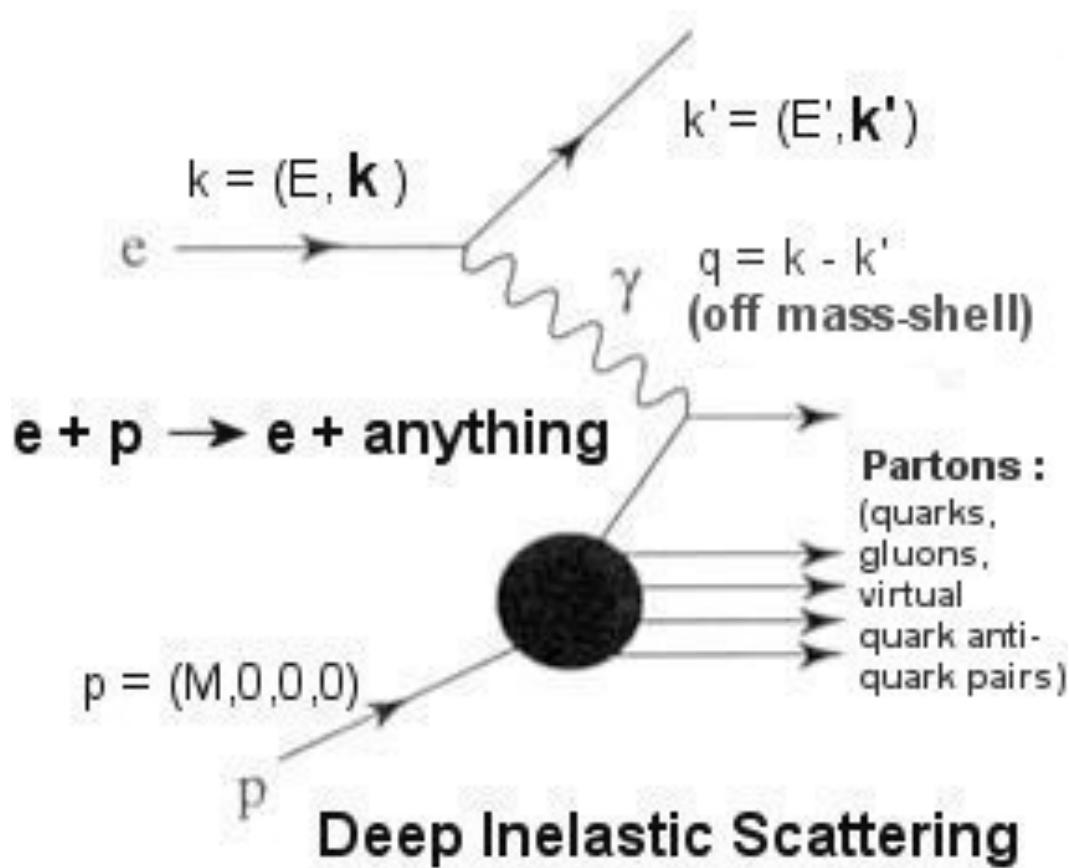


Promise from EFT

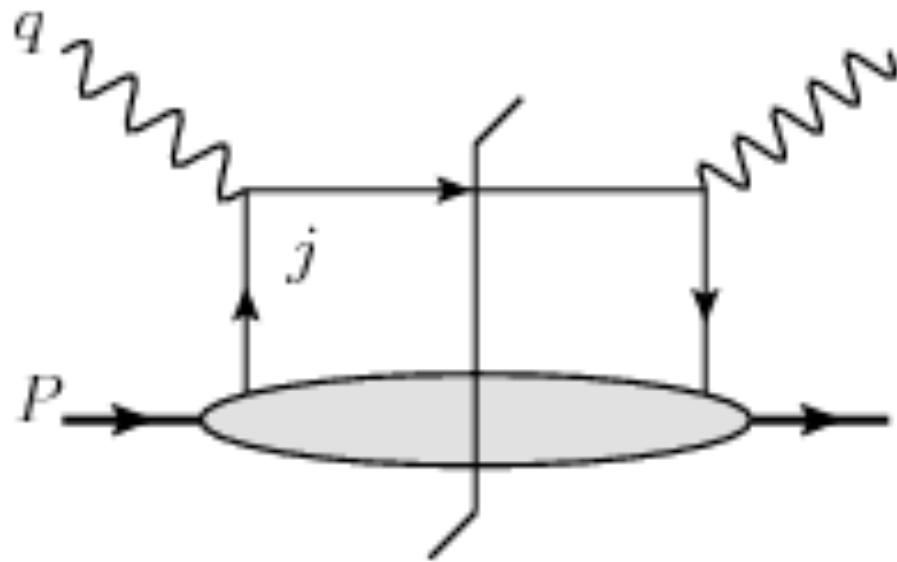


- EMC-SRC linear relation reproduced
- Some a_2 reproduced ab initio
- Remaining problem: EMC slope from LQCD
(only need deuteron)

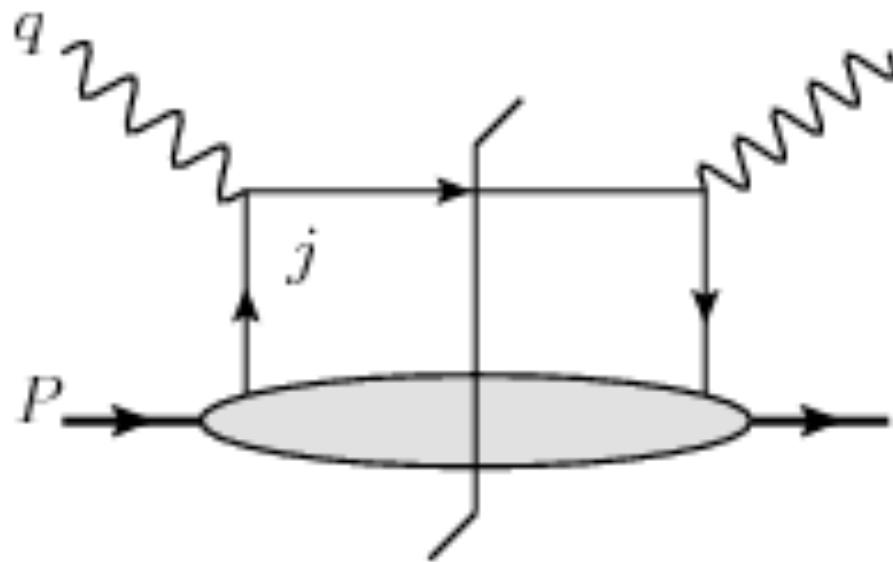
DIS



Parton Distribution Function (PDF) in QCD



Parton Distribution Function (PDF) in QCD



The struck parton moves on a light cone at the leading order in the twist-expansion.

$$q(x, \mu^2) = \int \frac{d\xi^-}{4\pi} e^{ix\xi^- P^+} \langle P | \bar{\psi}(0) \lambda \cdot \gamma \Gamma \psi(\xi^- \lambda) | P \rangle$$

PDF & Twist-2 operators

$$q(x, \mu^2) = \int \frac{d\xi^-}{4\pi} e^{ix\xi^- P^+} \langle P | \bar{\psi}(0) \lambda \cdot \gamma \Gamma \psi(\xi^- \lambda) | P \rangle$$
$$(\lambda^2 = 0)$$

- OPE yields

$$\bar{\psi} \lambda \cdot \gamma \Gamma (\lambda \cdot D)^n \psi = \lambda_{\mu_1} \lambda_{\mu_2} \cdots \lambda_{\mu_n} O^{\mu_1 \cdots \mu_n}$$

symmetric and traceless (twist-2) operators

$$(\lambda_{\mu_1} \lambda_{\mu_2} - g_{\mu_1 \mu_2} \lambda^2 / 4)$$

Twist-2 operator matching -standard procedure in ChPT

- JWC, Ji, Phys. Lett. B523 (2001) 107
Phys.Rev.Lett. 87 (2001) 152002
Phys.Rev.Lett. 88 (2002) 052003
- JWC, Stewart, Phys.Rev.Lett. 92 (2004) 202001
- Arndt, Savage, Nucl.Phys. A697 (2002) 429

Chiral Perturbation Theory: an Effective Field Theory of QCD

- QCD with three light flavors: “a theoretical paradise” (Leutwyler)
- Exhibits spontaneous and explicit chiral symmetry breaking
- Can be analyzed systematically in quark mass and momentum double expansions (Weinberg (1979) Gasser, Leutwyler (1984,1985))
- A model independent approach

Twist-2 operator matching -standard procedure in ChPT

$$\mathcal{O}_{u-d}^{\mu_1 \dots \mu_n} = \bar{u} \gamma^{(\mu_1} i D^{\mu_2} \dots i D^{\mu_n)} u$$

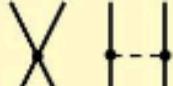
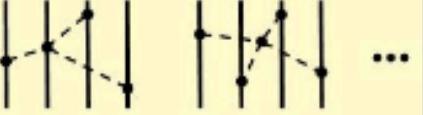
$$- \bar{d} \gamma^{(\mu_1} i D^{\mu_2} \dots i D^{\mu_n)} d .$$

$$\begin{aligned} \mathcal{O}_{u-d}^{\mu_1 \dots \mu_n} &= a_n \frac{f_\pi^2}{4} \left\{ \text{Tr} \left[\Sigma^\dagger \tau_3 i D^{(\mu_1} \dots i D^{\mu_n)} \Sigma \right] \right. \\ &\quad \left. + \text{Tr} \left[\Sigma \tau_3 i D^{(\mu_1} \dots i D^{\mu_n)} \Sigma^\dagger \right] \right\} \\ &\quad + b_n \bar{N} v^{(\mu_1} \dots v^{\mu_n)} (u \tau_3 u^\dagger + u^\dagger \tau_3 u) N , \\ &\quad + c_n \bar{N} S^{(\mu_1} v^{\mu_2} \dots v^{\mu_n)} (u^\dagger \tau_3 u - u \tau_3 u^\dagger) N \\ &\quad + \dots , \end{aligned}$$

$$u = \exp(i\pi^a \tau^a / 2f_\pi)$$

$$\Sigma = u^2$$

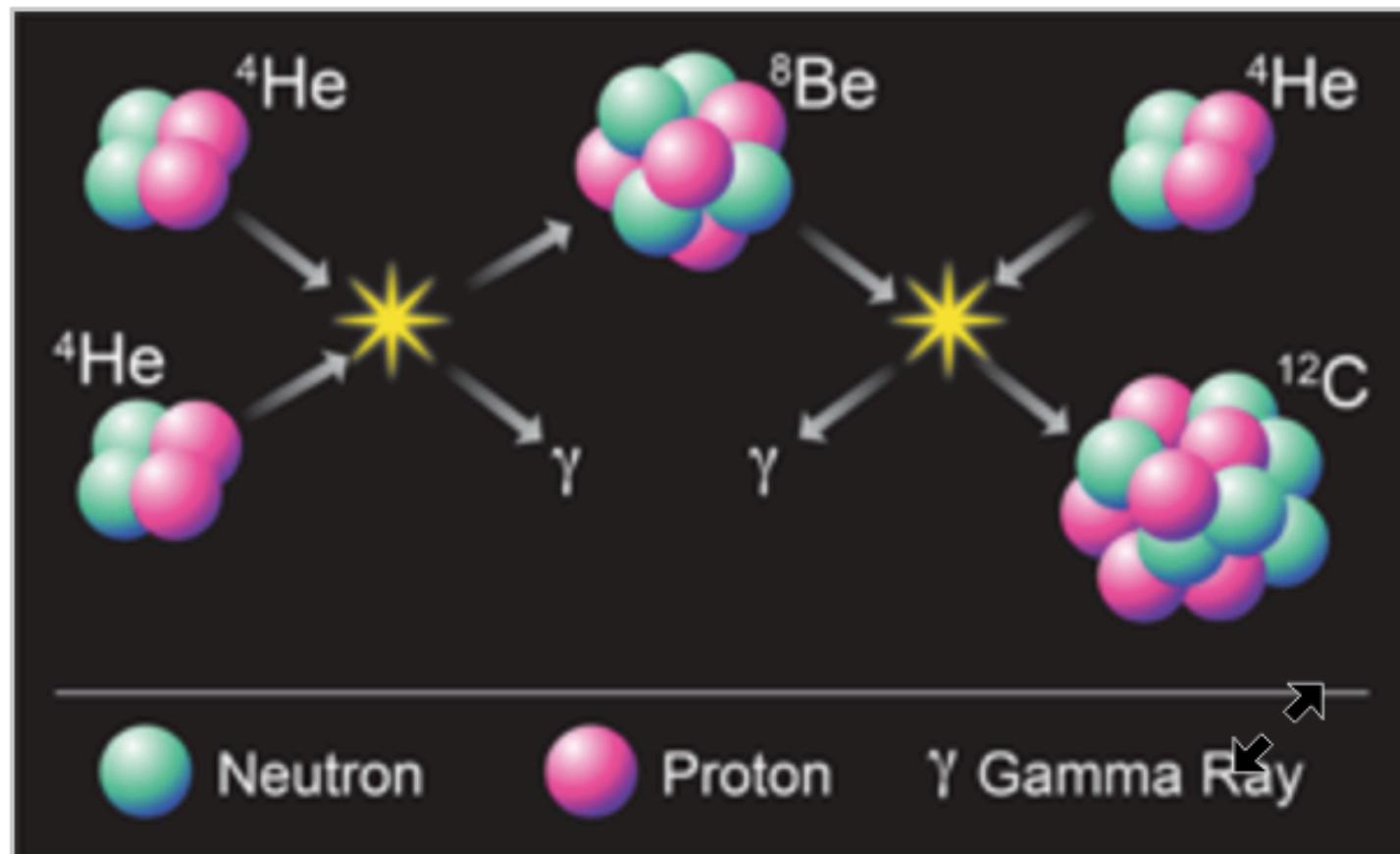
Applying ChPT to nuclear systems (Weinberg)

Two-nucleon force		Three-nucleon force	Four-nucleon force
LO	 2 LECs	—	—
NLO	 7 LECs	—	—
N ² LO		 2 LECs	—
N ³ LO	 15 LECs	 ...	 ...

Credit: U-G Meissner

Hoyle State Obtained

Epelbaum, Krebs, Lee, Meißner, Phys. Rev. Lett. 106, 192501 (2011)



Credit: Carin Cain

Twist-2 operator matching (isoscalar)

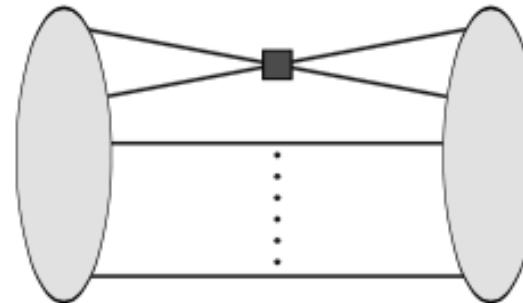
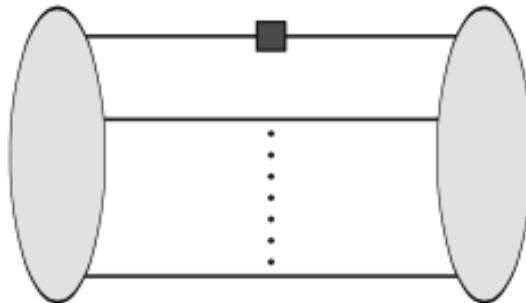
$$\mathcal{O}^{\mu_0 \dots \mu_n} = \bar{q} \gamma^{(\mu_0} i D^{\mu_1} \dots i D^{\mu_n)} q,$$

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

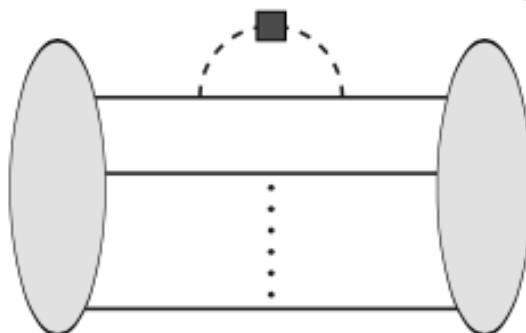
$$\langle x^n \rangle_A(Q) = \int_{-A}^A x^n q_A(x, Q) dx,$$

$$\begin{aligned} \mathcal{O}^{\mu_0 \dots \mu_n} &\rightarrow \langle x^n \rangle_N M^n v^{(\mu_0} \dots v^{\mu_n)} N^\dagger N [1 + \alpha_n N^\dagger N] \\ &+ \langle x^n \rangle_\pi \pi^\alpha i \partial^{(\mu_0} \dots i \partial^{\mu_n)} \pi^\alpha + \dots, \end{aligned} \quad ($$

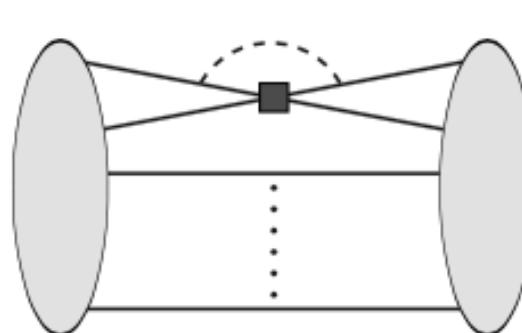
Using large Nc counting



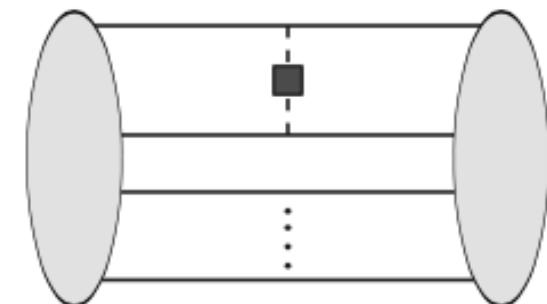
(a)



(c)



(d)



(e)

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

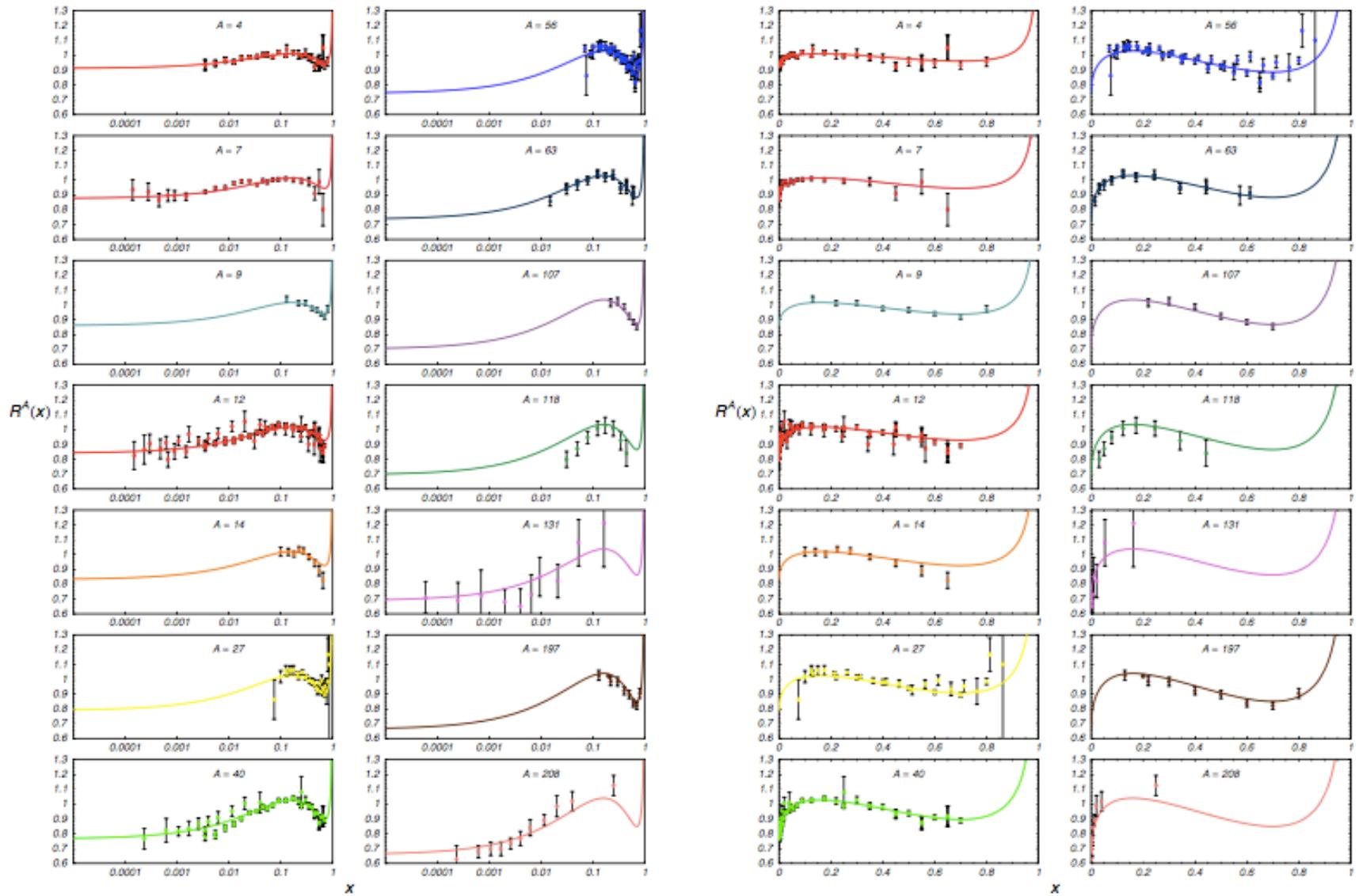
Factorization Implies prediction power!

$$q_A(x)/A = q_N(x) + g_2(A, \Lambda) \tilde{q}_2(x, \Lambda)$$

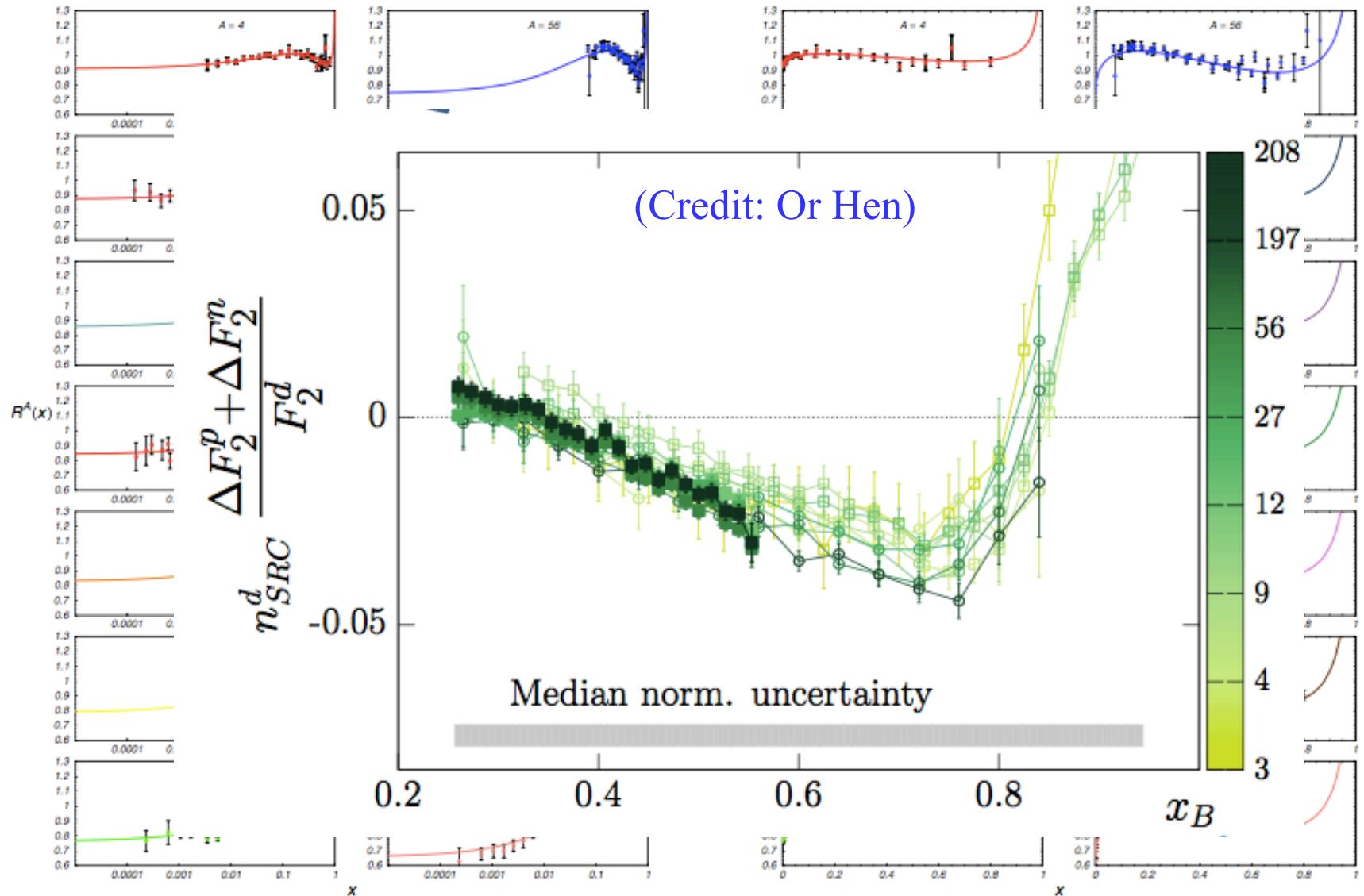
1-body op. 2-body op. determined
by deuteron

EFT predicts EMC $R_A(x) - 1 = f(A)\phi(x)$

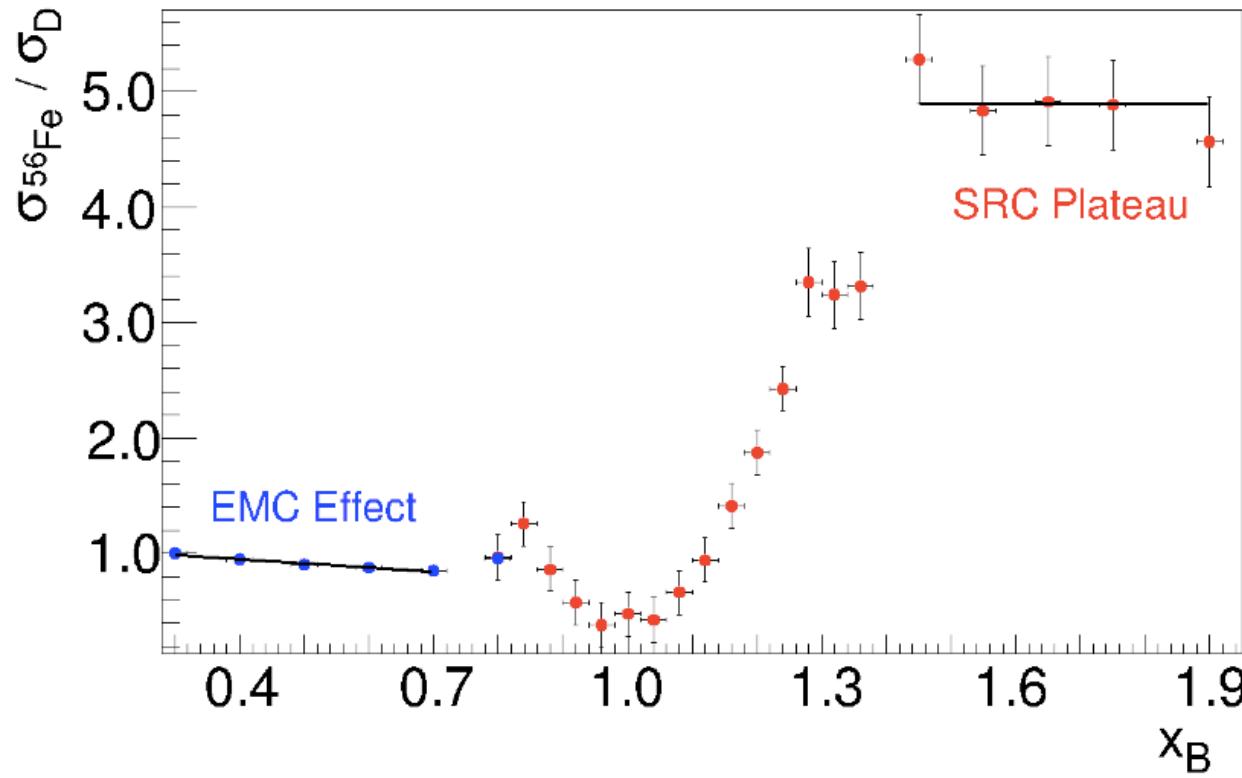
EFT predicts EMC $R_A(x) - 1 = f(A)\phi(x)$



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SRC scaling factor (same in QE)



$$q_A(x)/A = q_N(x) + g_2(A, \Lambda)\tilde{q}_2(x, \Lambda) \quad q_N(x > 1) = 0$$

Indep of scheme
& scale!

$$a_2(A, x > 1) = \frac{2q_A(x)}{Aq_d(x)} = \frac{g_2(A, \Lambda)\tilde{q}_2(x, \Lambda)}{g_2(2, \Lambda)\tilde{q}_2(x, \Lambda)} = \frac{g_2(A, \Lambda)}{g_2(2, \Lambda)}$$

a_2 : scheme and scale independent

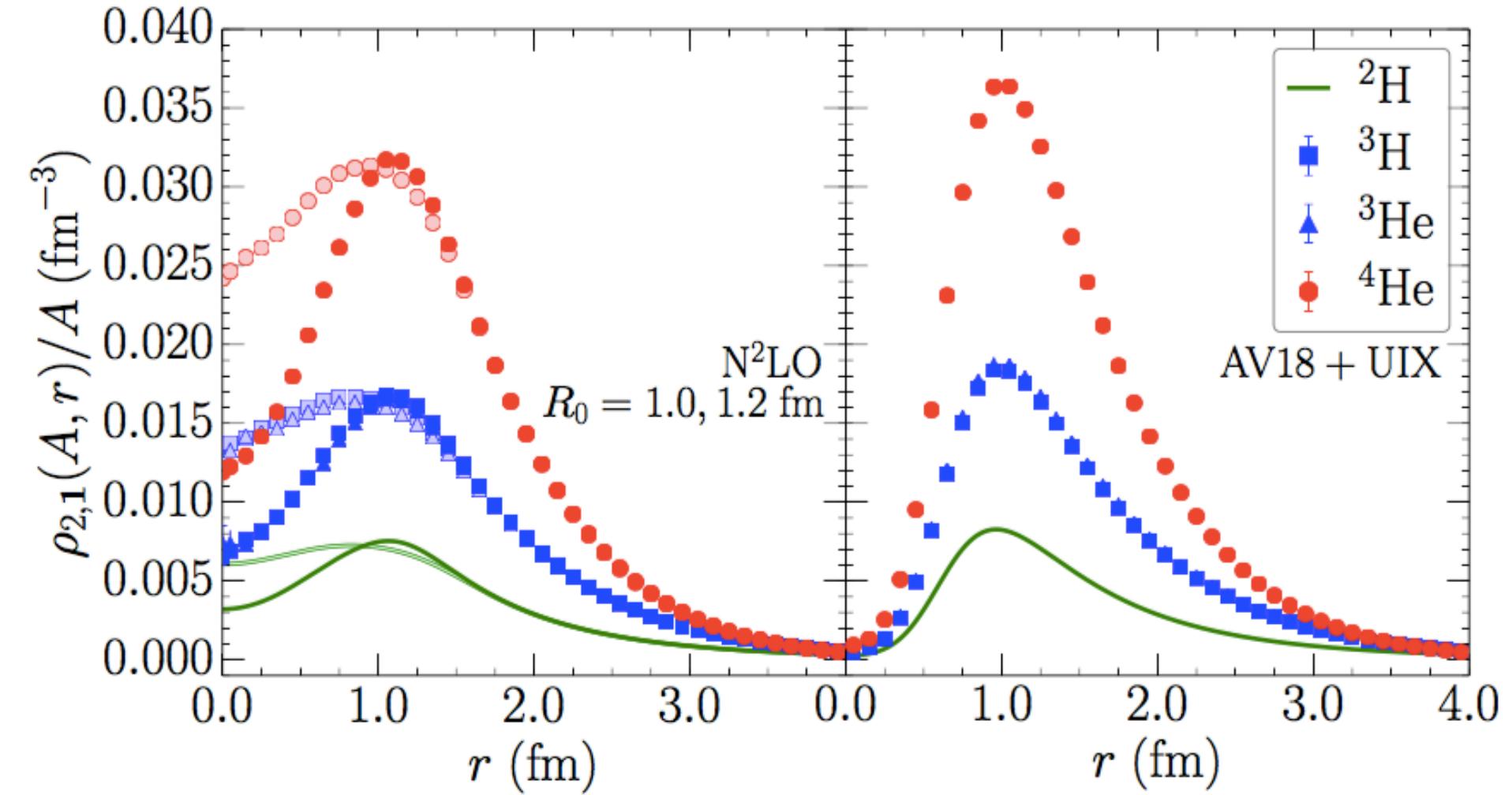
$$a_2(A, x > 1) = \frac{g_2(A, \Lambda)}{g_2(2, \Lambda)}.$$

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

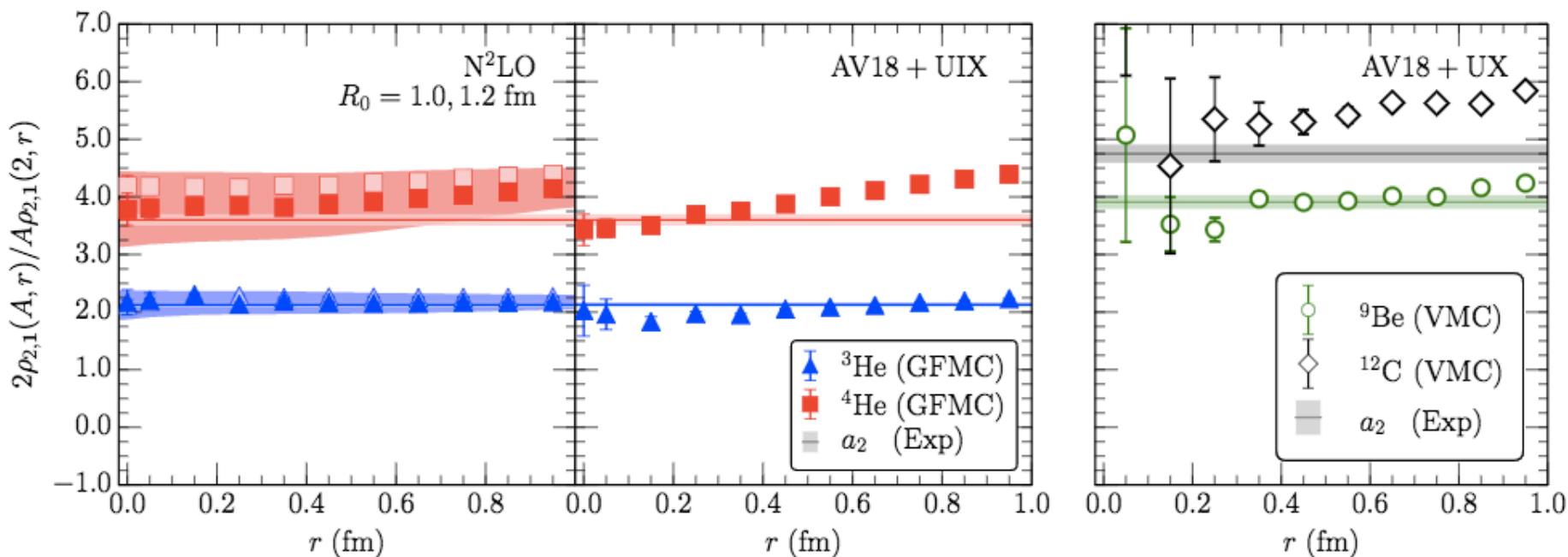
$$= \rho_{2,1}(A, r = 0)/A$$

$$\rho_{2,1}(A, r) = \frac{1}{4\pi r^2} \left\langle \Psi_0 \left| \sum_{i < j}^A \delta(r - |\mathbf{r}_i - \mathbf{r}_j|) \right| \Psi_0 \right\rangle$$

$\rho_{2,1}(A, r)/A$:scheme and scale DEPENDENT



a_2 : scheme and scale independent

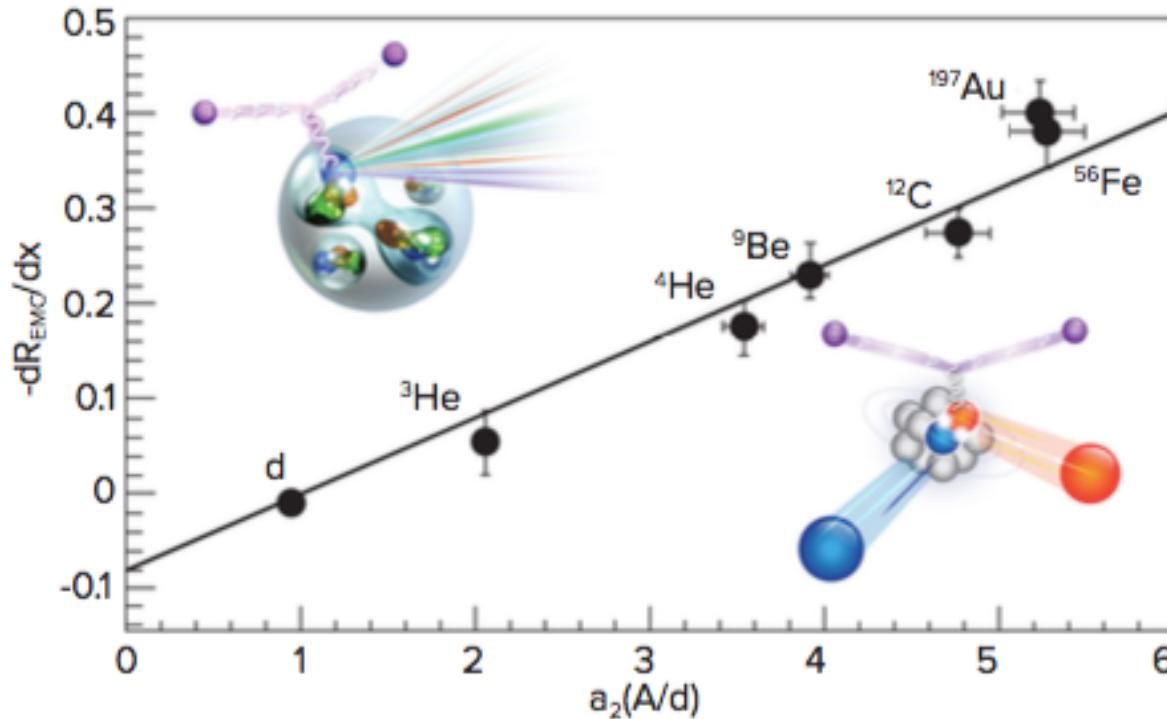


Limitation of EFT

- Describes physics below momentum cut-off (~500 MeV in ChEFT)
- Why useful for DIS & QE at several GeV? (a) optical theorem (**inclusive** processes) (b) OPE (Wilson coeff. PQCD (Q), ME of local op. LQCD (Λ, P))
$$Q \gg \Lambda \gg P$$
- Twist exp. Λ/Q ; chiral exp. $\epsilon \sim P/\Lambda \sim 0.2 - 0.3$

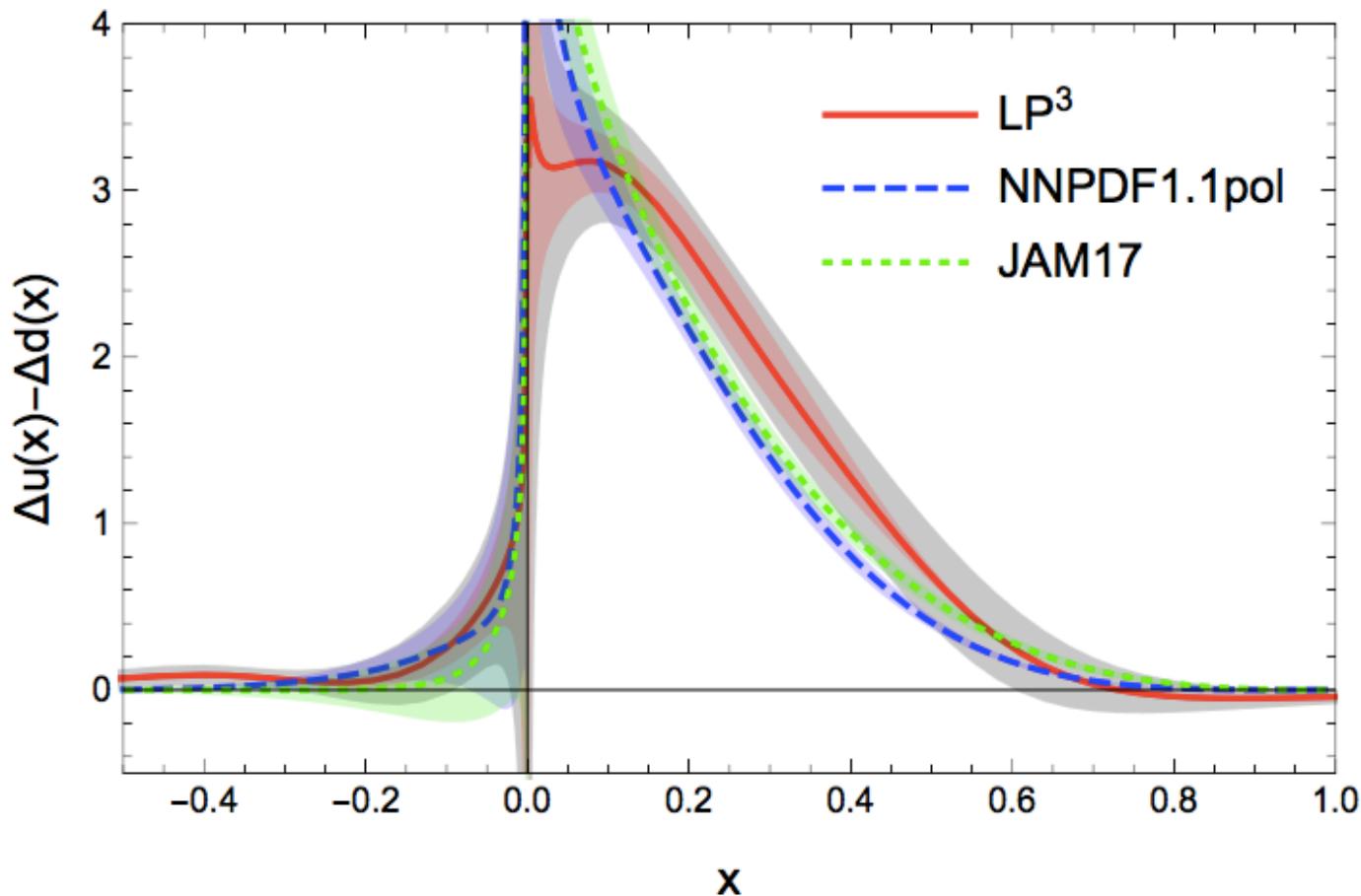
$$q_A(x)/A = q_N(x) + g_2(A, \Lambda)\tilde{q}_2(x, \Lambda)$$

Summary



- EMC-SRC linear relation reproduced
- Some a_2 reproduced ab initio
- Remaining problem: EMC slope from LQCD (only need deuteron)

Proton PDF by LP3 (1807.07431)



LQCD might get the EMC-SRC slope in 10 years to complete the picture!

- EMC-SRC relation: a simple and elegant empirical result explained by a simple, elegant, and predictive theory
- Applications:
 - (a) ν -A **inclusive** scattering for long baseline exp.
(Measurements from three unpol. targets (e.g. p, d, C) give predictions to all isoscalar targets.
 - (b) 3D imagining of nuclear PDFs

Backup