What does the EMC-SRC Correlation tell us about isospin dependence (and origin) of the EMC Effect?

John Arrington
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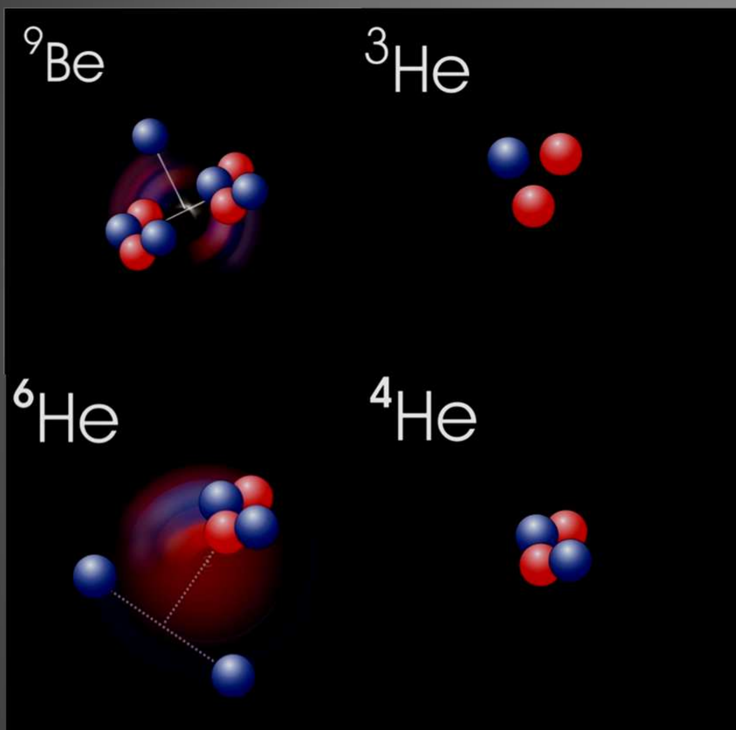
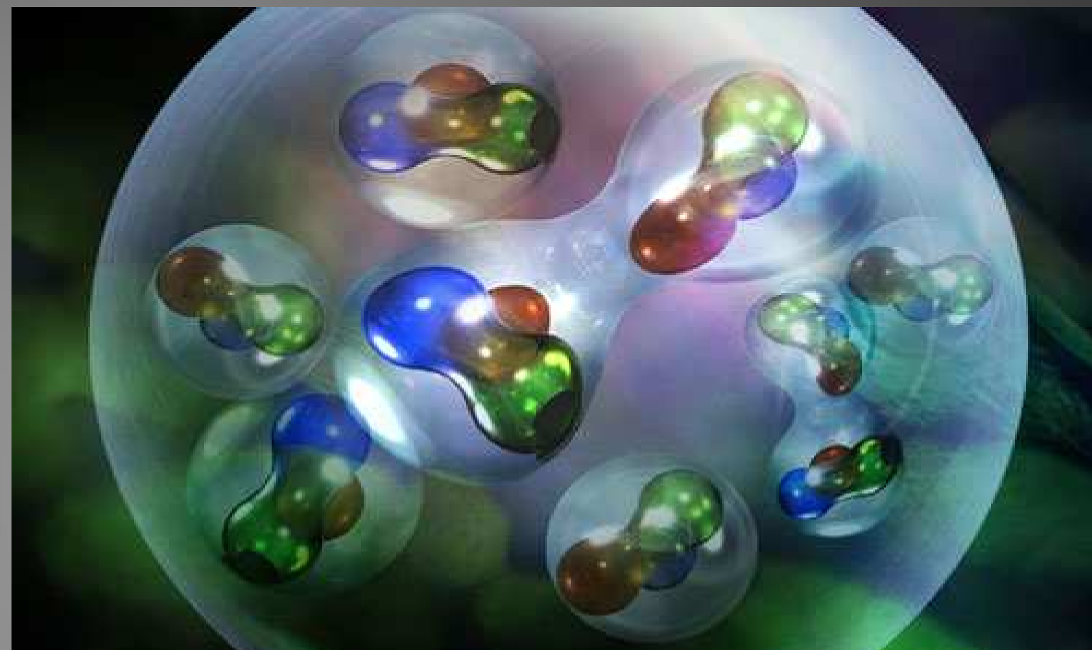
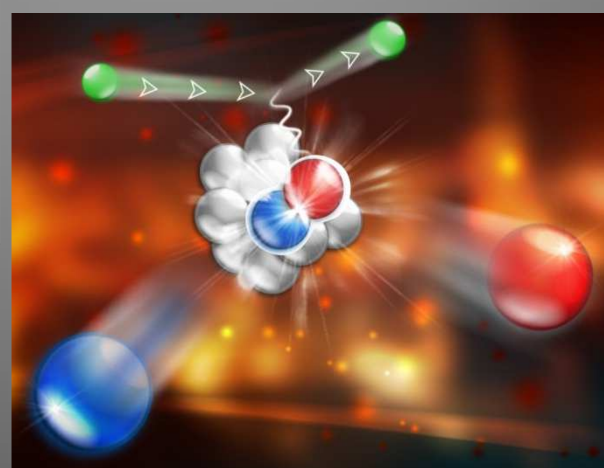
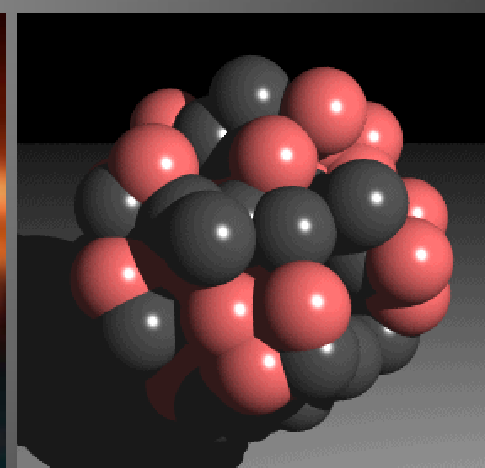








Second Workshop on Quantitative Challenges in SRC and EMC Research

EMC-SRC: First ~25 years

- EMC effect is a suppression of high-x part of nuclear quark distributions, whose shape is universal, but with a magnitude that depends on A

- High momentum nucleons, well above k_{Fermi}, are associated with Short-Range Correlations (SRCs) and have a universal two-body nature associated with the strong, short-range components of the N-N interaction
  - "Late" development: SRCs dominated by np pairs

- Both effects assumed (and observed) to scale with nuclear density

JLab EMC (SRC) Data

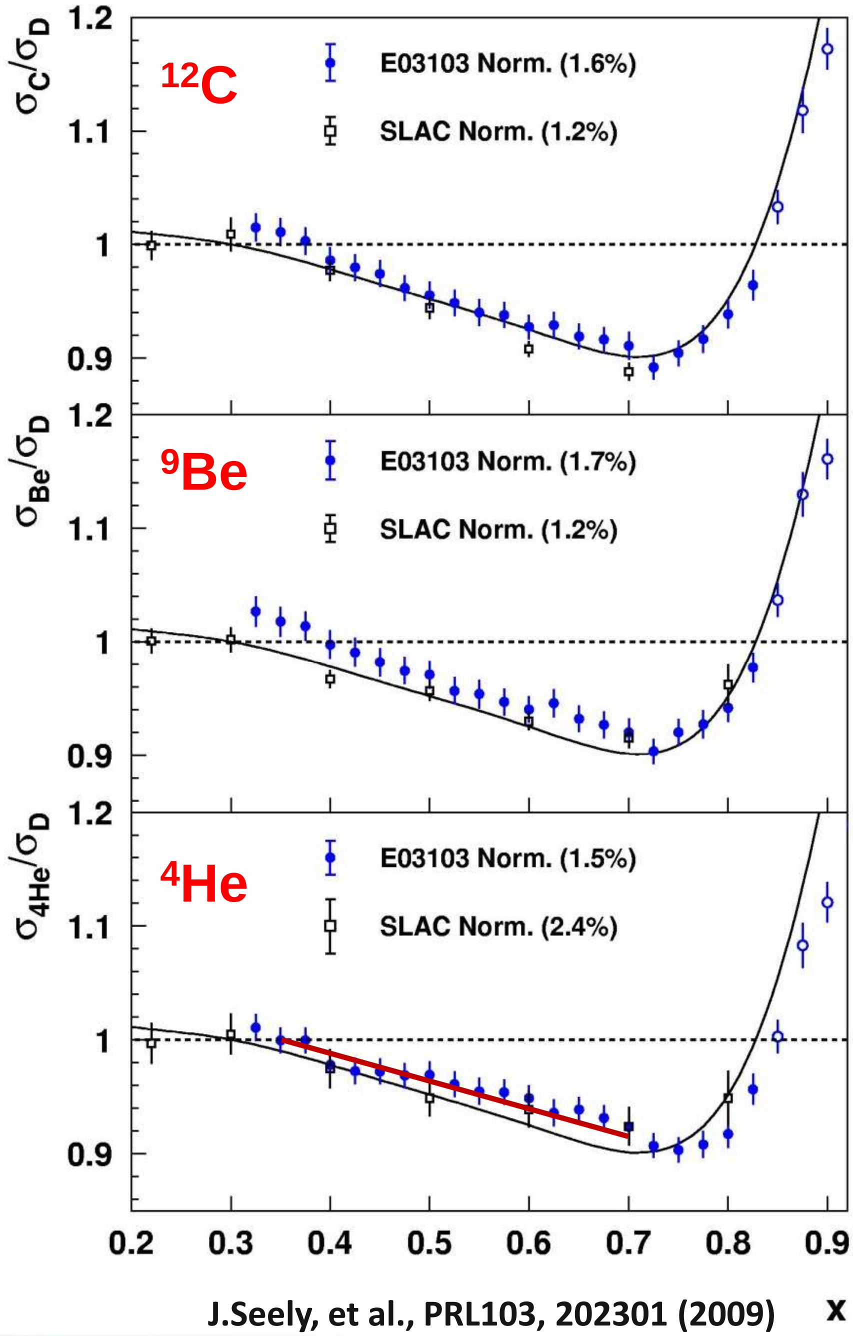
Consistent shape for all nuclei
(curves show shape from SLAC fit)

Measurements on **3He, 4He, 9Be, 12C**
JA, D. Gaskell, spokespersons

If shape (x-dependence) is same for all nuclei, the slope (0.35<x<0.7) can be used to study dependence on A

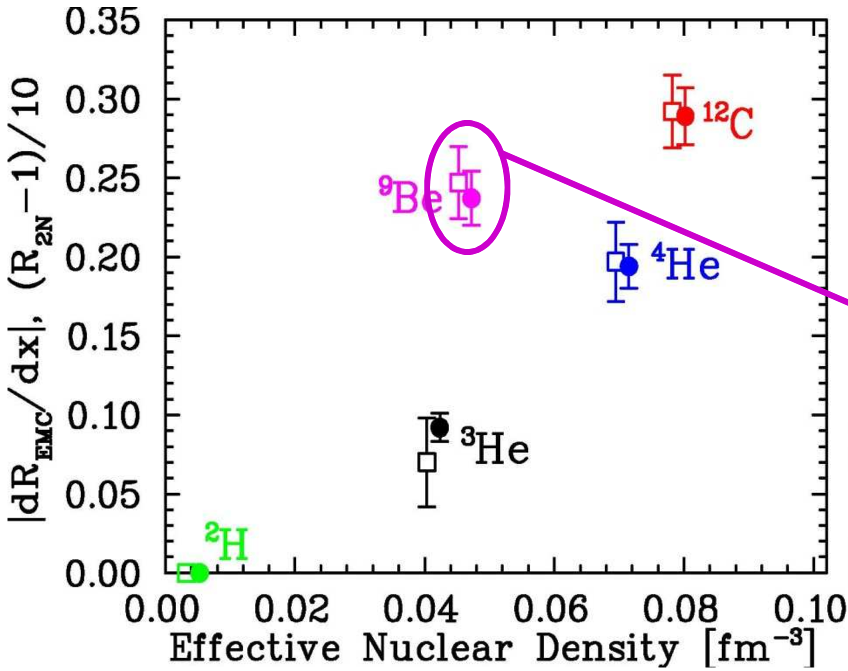
Alternative to using suppression at x=0.6; more sensitive to normalization, requires x=0.6 data

***Fractional** modification goes like slope divided by baseline (no-EMC) ratio; typically ignored because $R_{no\text{-}EMC}=1$*



J.Seely, et al., PRL103, 202301 (2009)

EMC-SRC correlation

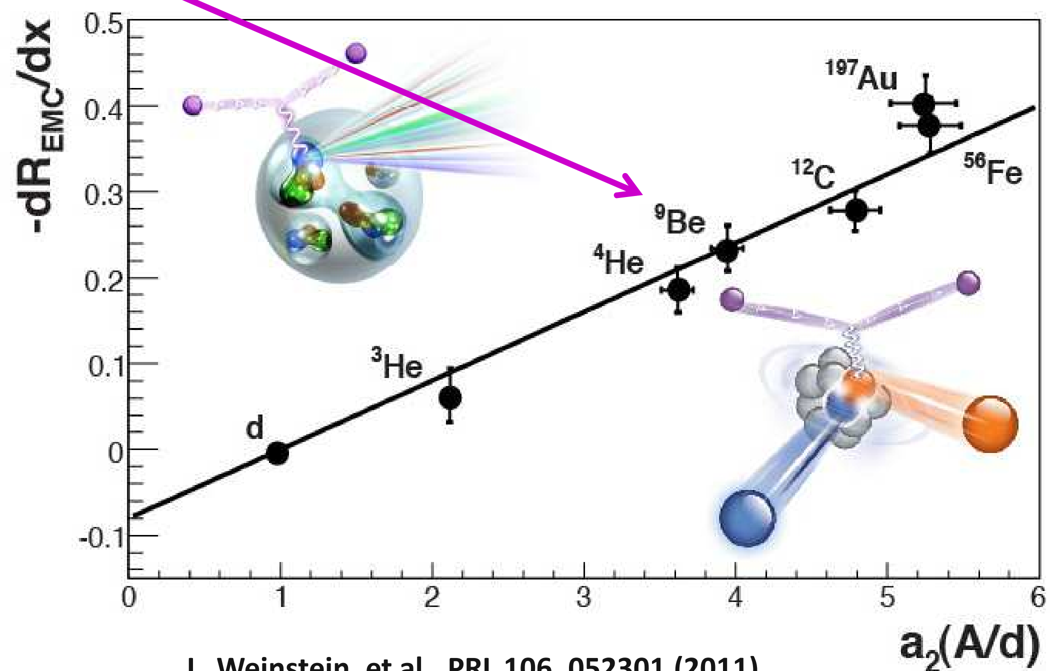


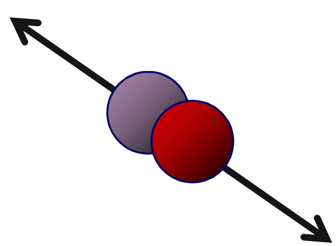
J. Seely, et al., PRL103, 202301 (2009)

N. Fomin, et al., PRL 108, 092052 (2012)

SRCs are both short-distance and high-momentum components

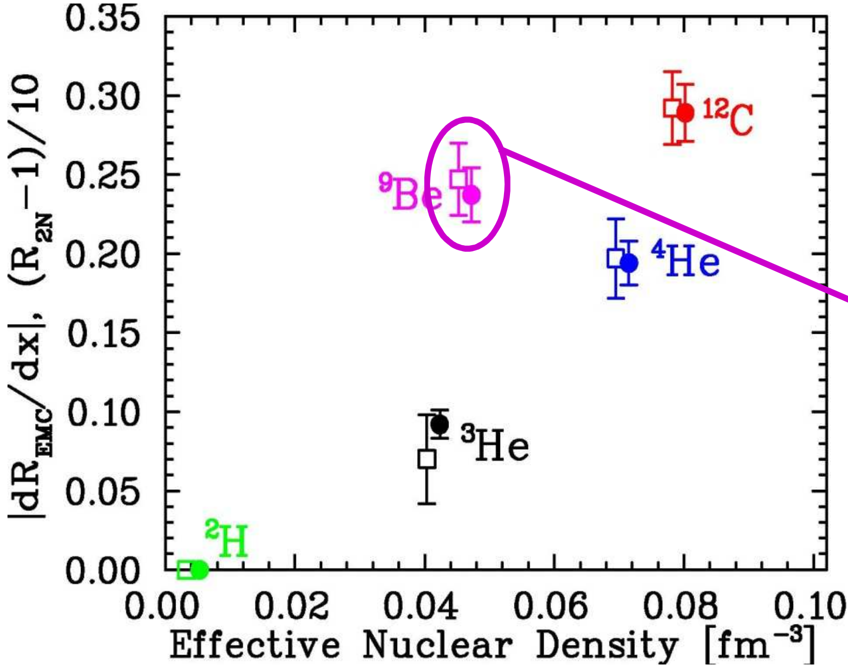
Which matters for EMC effect??
(or neither, or some combination?)





L. Weinstein, et al., PRL 106, 052301 (2011)
O. Hen, et al, PRC 85, 047301 (2012)
JA, A. Daniel, D. Day, N. Fomin, D. Gaskell, P. Solvignon, PRC 86, 065204 (2012)

EMC-SRC correlation



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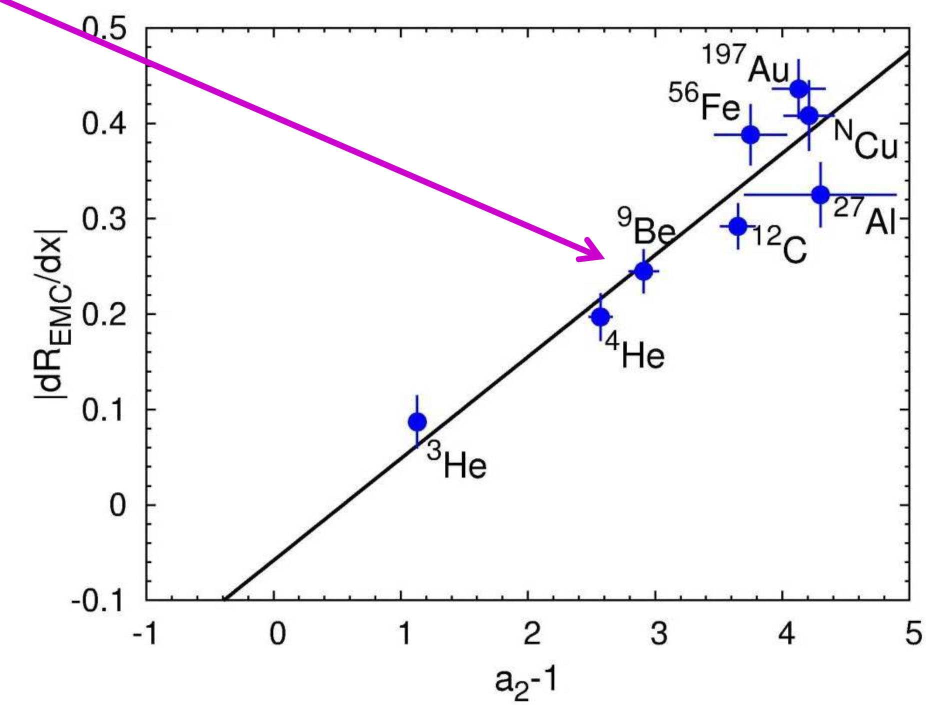

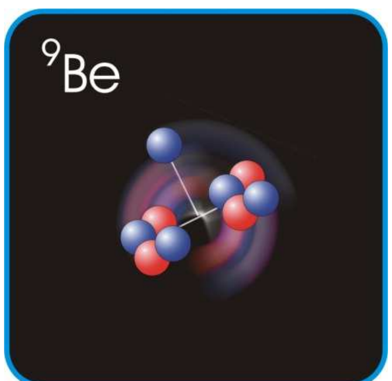

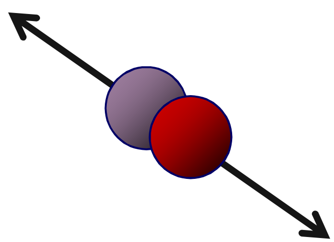

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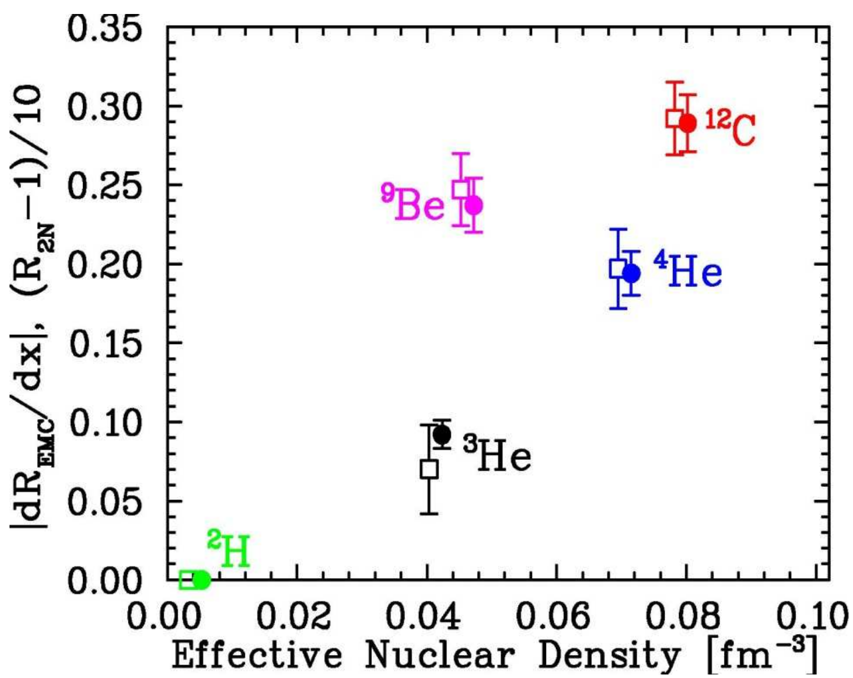
Short-distance behavior and the EMC effect

~~1. EMC effect driven by **average density** of the nucleons~~

~~[J. Gomez, et al., PRD 94, 4348 (1994), Frankfurt and Strikman, Phys. Rept. 160 (1988) 235]~~



If EMC effect and SRC contributions both scaled with density, it would explain the EMC-SRC correlation

It would not explain the anomalous result for 9Be

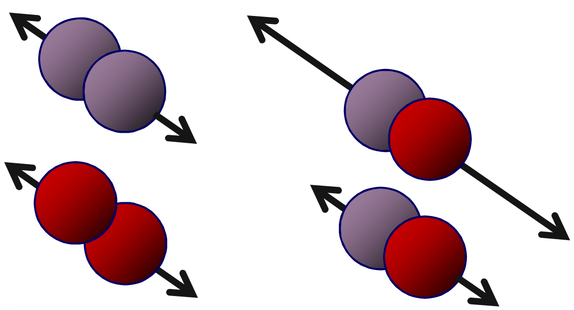
Note: in some cases, e.g. Frankfurt and Strikman review ('88), average density was used to represent probability of nucleon overlap – conceptually consistent with idea of large 9Be EMC effect

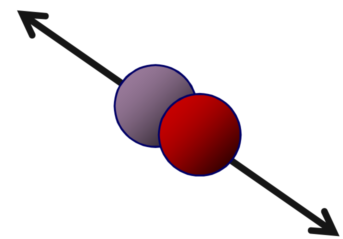
Short-distance behavior and the EMC effect

~~1. EMC effect, SRCs driven by **average density** of the nucleus~~
~~[J. Gomez, et al., PRD 94, 4348 (1994), Frankfurt and Strikman, Phys. Rept. 160 (1988) 235]~~

2. EMC effect is driven by **Local Density (LD)** – overlap of nucleons
[J. Seely et al., PRL 103, 202301, 2009]
SRC measurements probe high-momentum nucleons (np pairs)
EMC effect driven by high-density nucleon configurations (pairs, clusters)

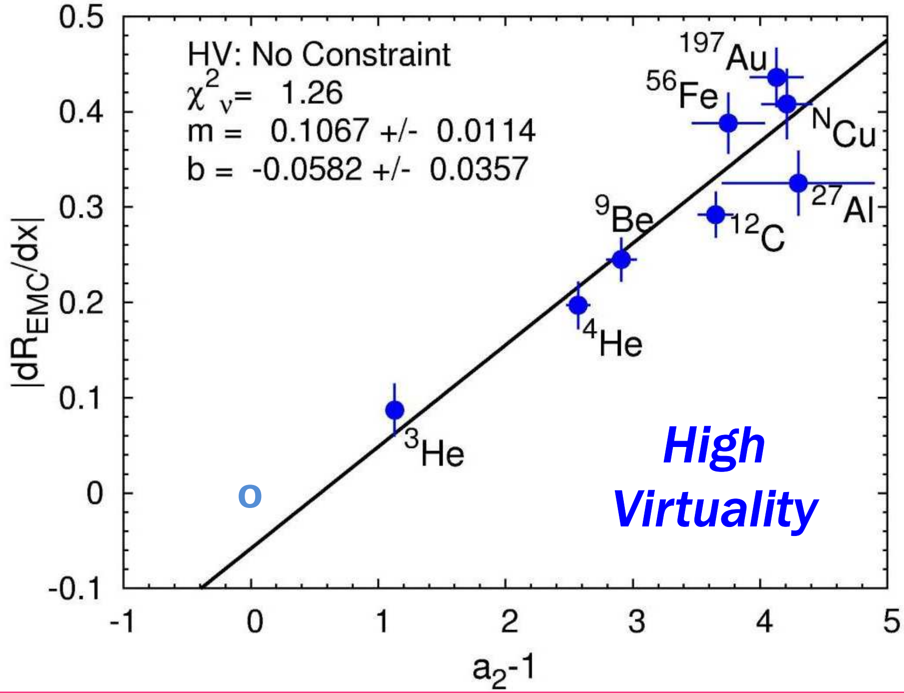
3. EMC effect driven by **High Virtuality (HV)** of the nucleons
[L. Weinstein et al, PRL 106, 052301,2011]
SRC measurements directly probe high-momentum nucleons
EMC effect driven by off-shell effects in high-momentum nucleons





Initial comparison of HV/LD explanations of EMC-SRC correlation:
JA, A. Daniel, D. Day, N. Fomin, D. Gaskell, P. Solvignon, PRC 86 (2012) 065204

Two Hypotheses for EMC-SRC correlation

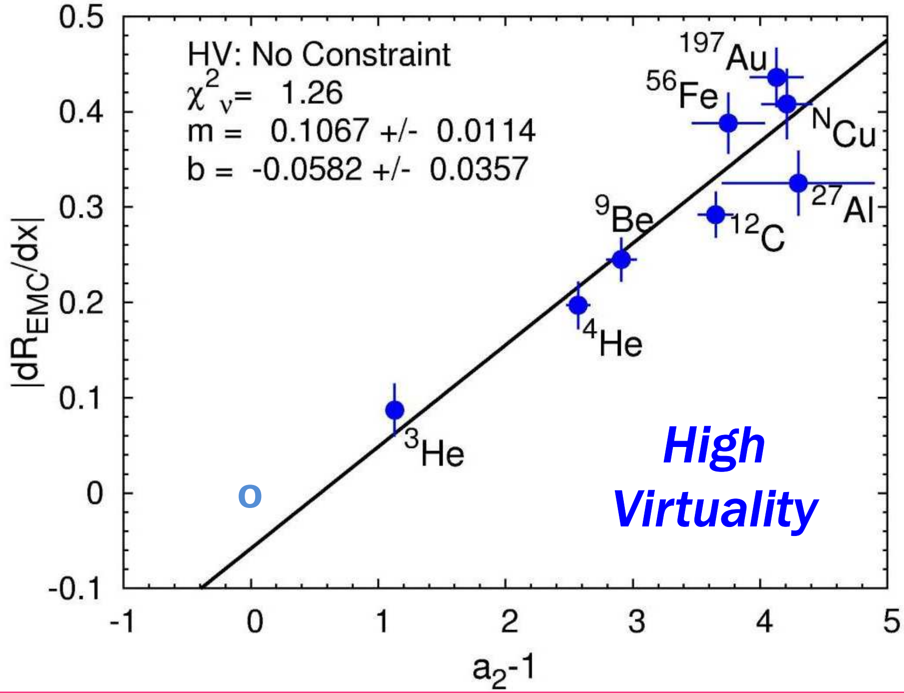


HV: OK linear correlation (χ_ν^2=1.26)
Fair extrapolation to deuteron:
EMC(^{2}H) = -0.058 ± 0.036

# of nucleons at high momentum (relative to ^{2}H)

JA, A. Daniel, D. Day, N. Fomin, D. Gaskell, P. Solvignon, PRC 86 (2012) 065204

Two Hypotheses for EMC-SRC correlation

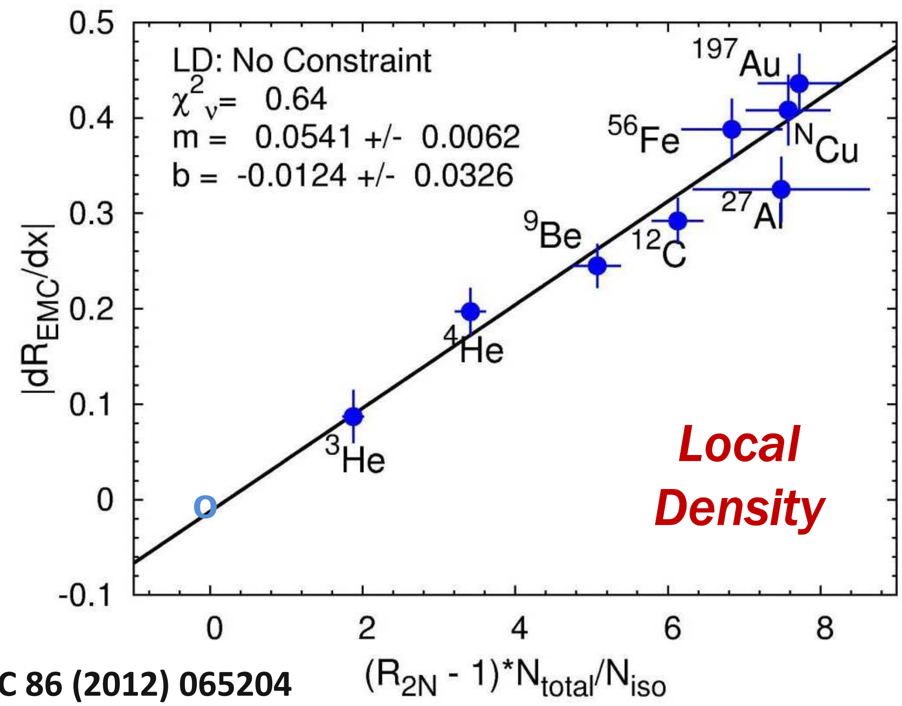


HV: OK linear correlation (χ_ν^2=1.26)
Fair extrapolation to deuteron:
EMC(^{2}H) = -0.058 ± 0.036

# of nucleons at high momentum (relative to ^{2}H)

LD: Good linear correlation (χ_ν^2=0.64)
Good extrapolation to deuteron:
EMC(^{2}H) = -0.012 ± 0.033

# of nucleons in small-sized configurations



JA, A. Daniel, D. Day, N. Fomin, D. Gaskell, P. Solvignon, PRC 86 (2012) 065204

LD picture: Estimate #/NN pairs based on measured np (SRC) pairs.
Better fit, but not conclusive. Want more light nuclei, better precision, larger N/Z range

New (but related) approach

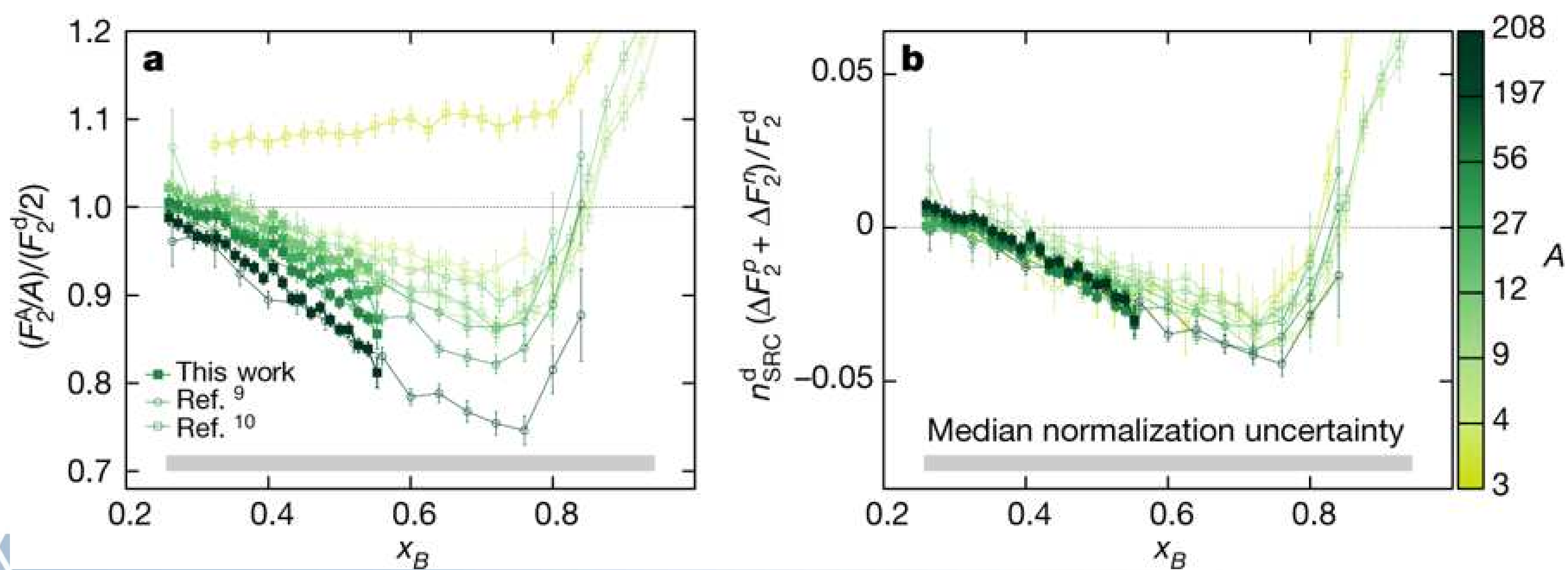
If EMC effect due to high-momenta (our HV hypothesis), can extract universal modification of (F2p+F2n)/F2d in a deuteron

B. Schmookler, et al., Nature 566 (2019) 345

$$F_{univ}^{HV} = \frac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$$

For isoscalar nuclei, simplifies to $(R_{EMC}-1)/(a_2-1)$

More detailed way of looking at EMC-SRC correlation (**and** isospin structure of EMC effect)



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$$F_{univ}^{HV} = \frac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$$

Observation of universal function shows data are consistent with the HV picture. But how much better is this than an isospin-independent picture?

Define similar function under assumption that all NN pairs contribute with no isospin dependence:

JA, N. Fomin, in preparation

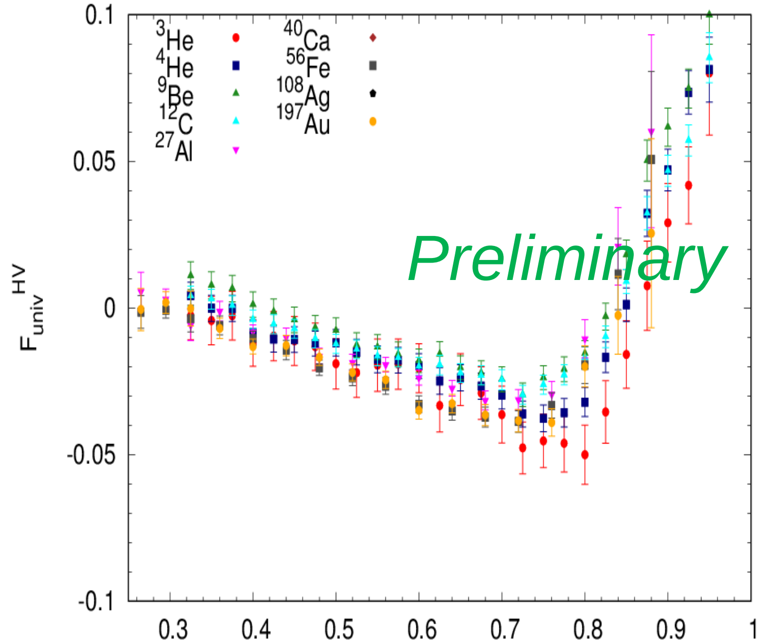
$$F_{univ}^{LD} = \frac{R_{EMC} - 1}{R_{2N}\frac{A(A-1)}{2ZN} - 1}$$

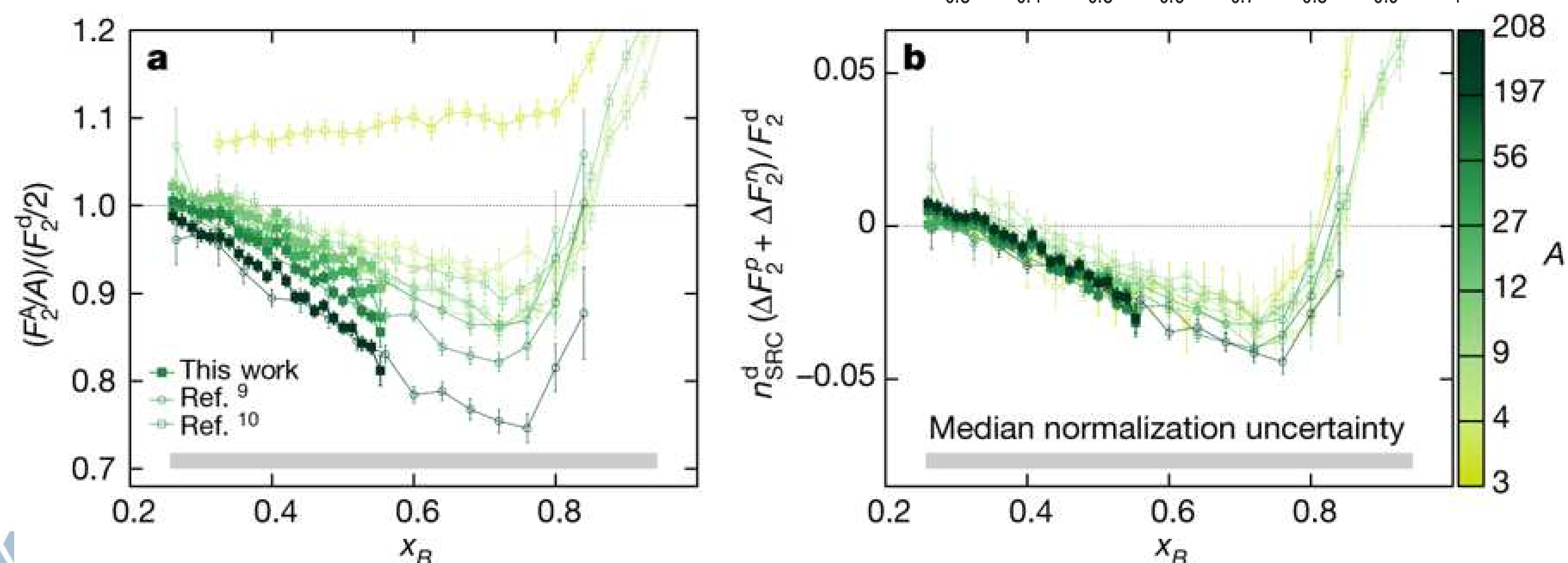
Note: As in B. Schmookler, et al., we removed isoscalar corrections from the data set and apply a unified correction [different from Barak's correction, but very similar for x<0.7]

We use SLAC+JLab (Hall C) data; have not included new CLAS results.

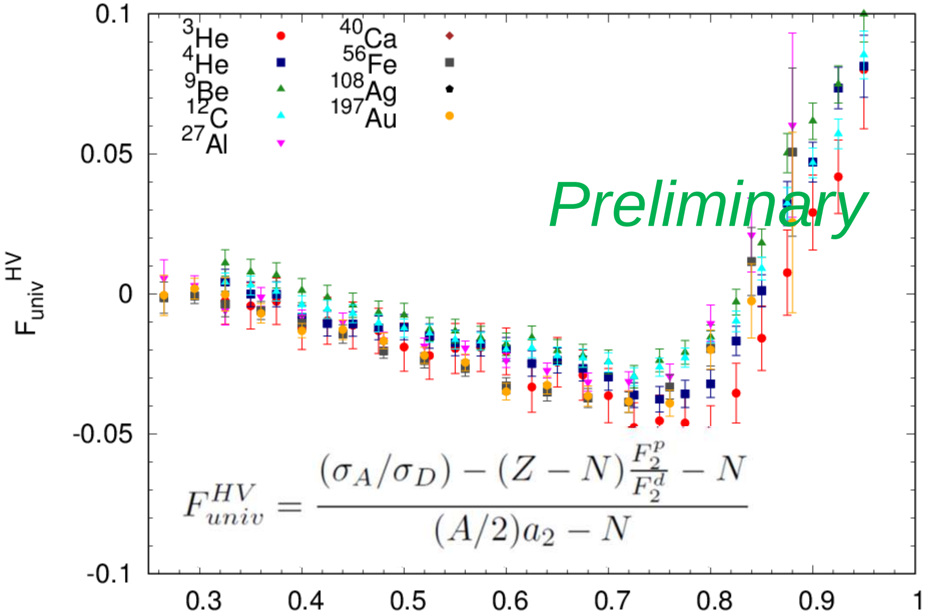
Comparison to Nature result

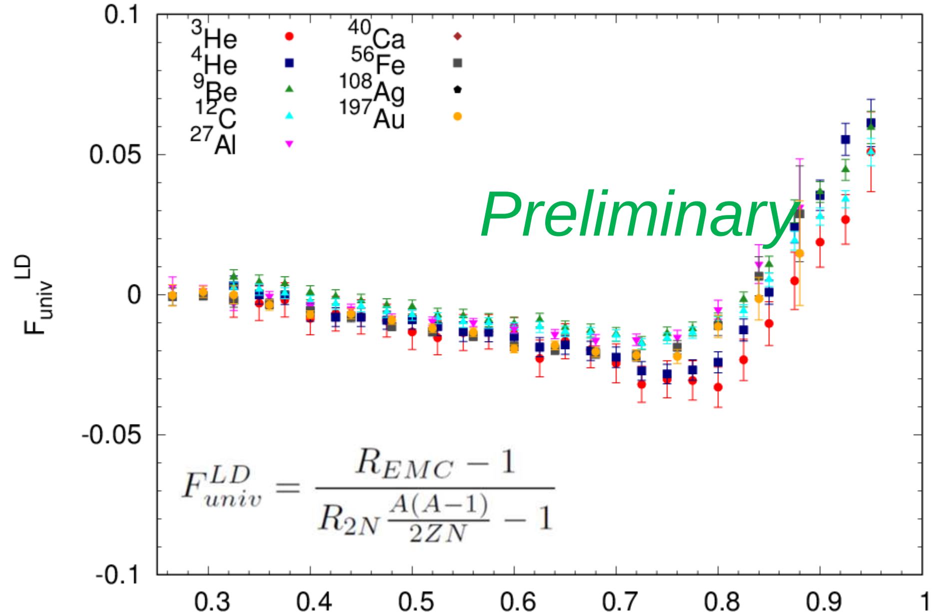
$$F_{univ}^{HV} = \frac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$$





B. Schmookler, et al., Nature 566 (2019) 345

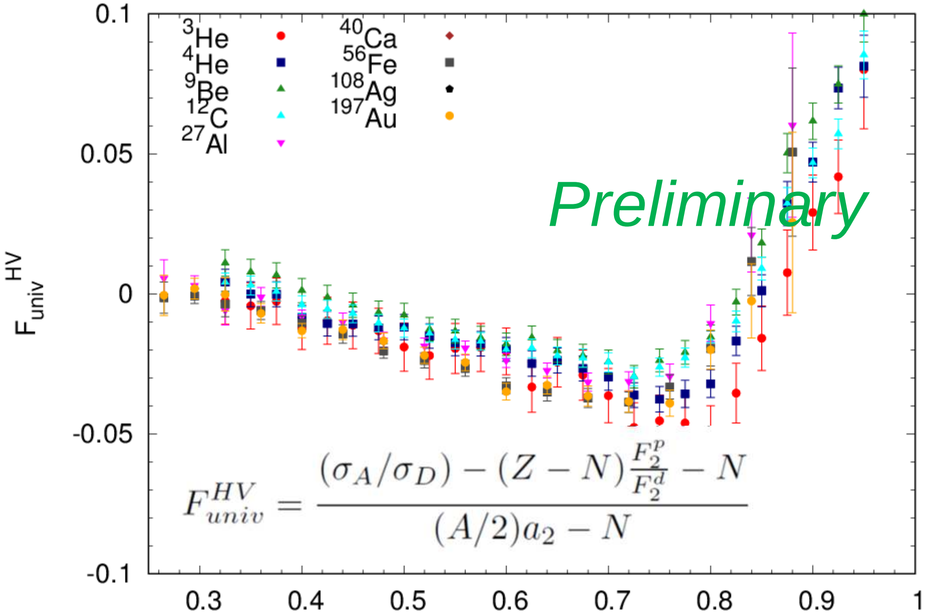


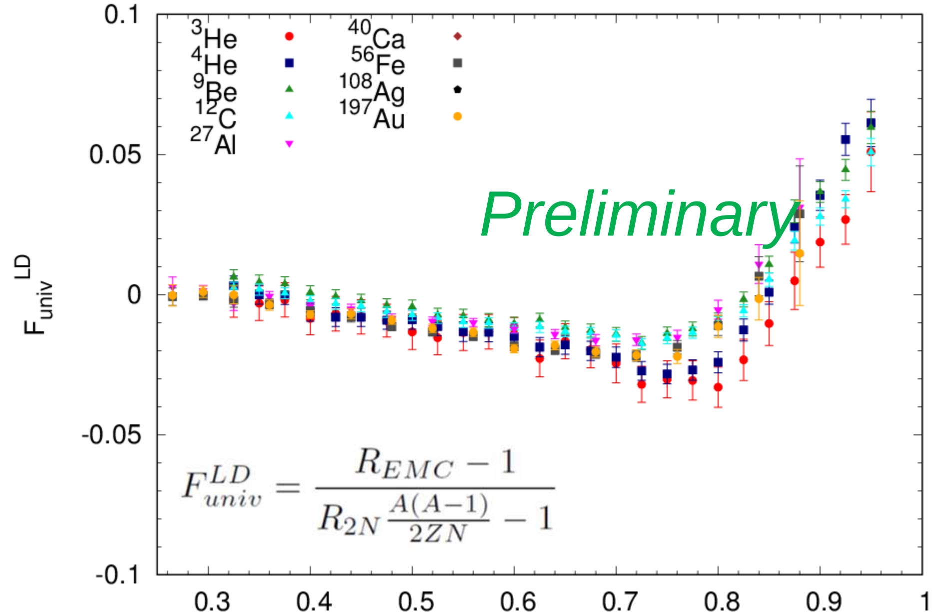


HV picture: np-dominance generates predicable isospin dependence of EMC effect

LD picture: EMC effect from short-distance pairs, assumed to be isospin independent

Both pictures give a good description of the data in terms of a universal modification

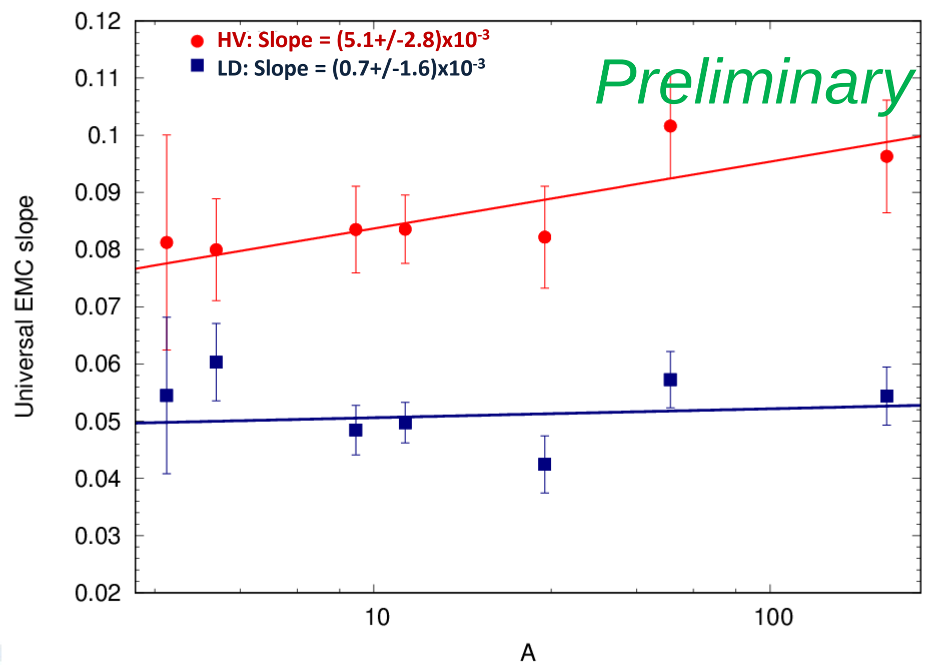




HV picture: EMC effect from np-SRC, generates known isospin dependence

LD picture: Driven by short-distance pairs, assumed to be isospin independent

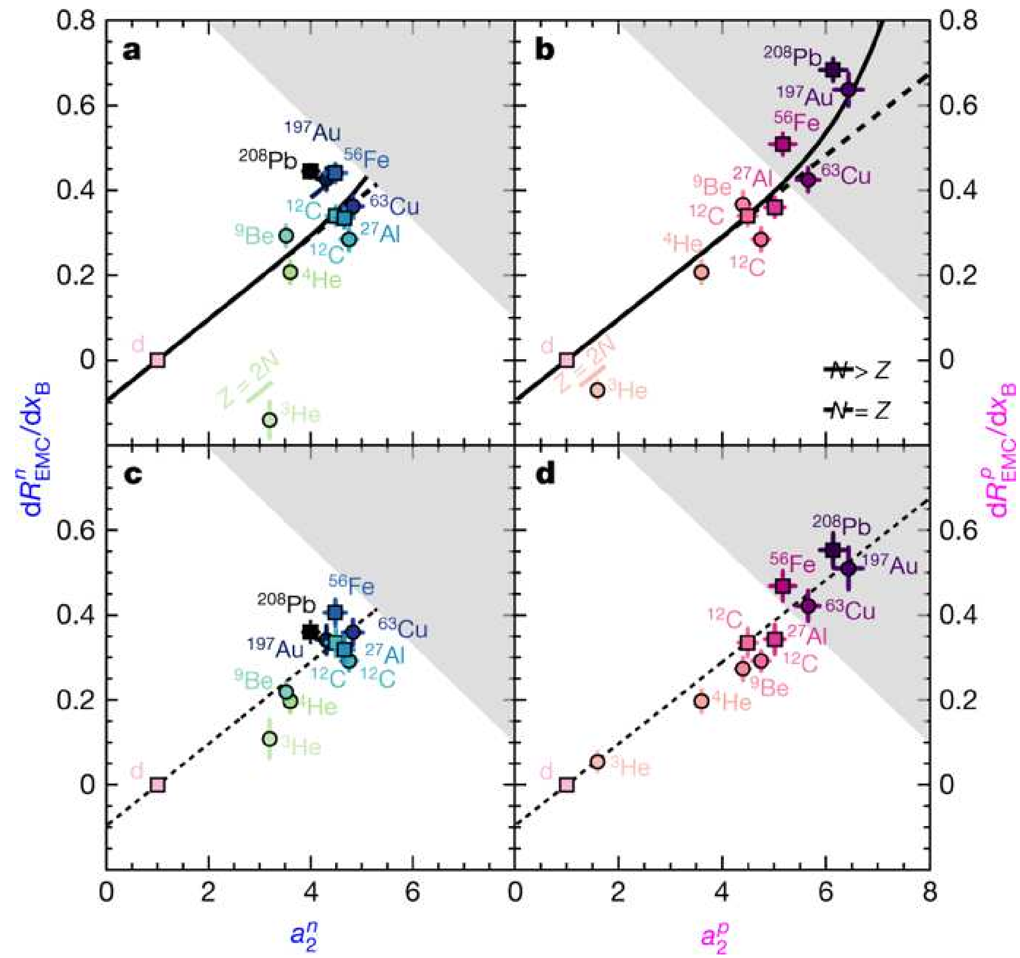
As in 2012 EMC-SRC test, somewhat better description in isospin-independent LD picture



Proton vs neutron EMC effect

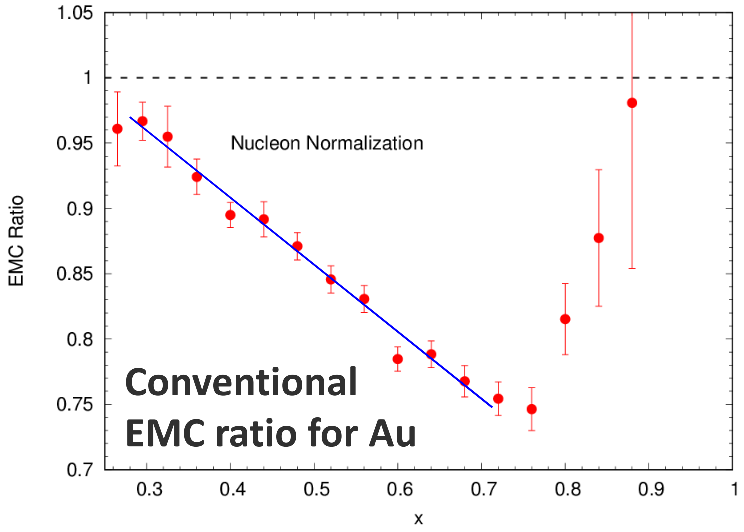
If np-dominated SRCs generate the EMC effect, then larger fraction of high-momentum protons in neutron-rich nuclei generate larger EMC effect for protons

Plot EMC and SRC ratios “per-proton” or “per neutron” rather than usual per-nucleon ratios: Saturation of neutron EMC effect and increase of proton EMC ratios taken as evidence for larger EMC effect in proton



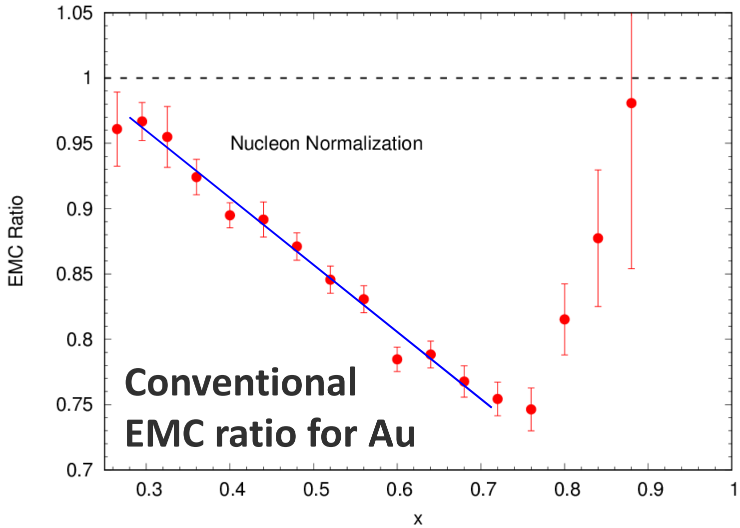
B. Schmookler, et al., Nature 566 (2019) 345

Definition of the EMC slope



Slope = 0.409

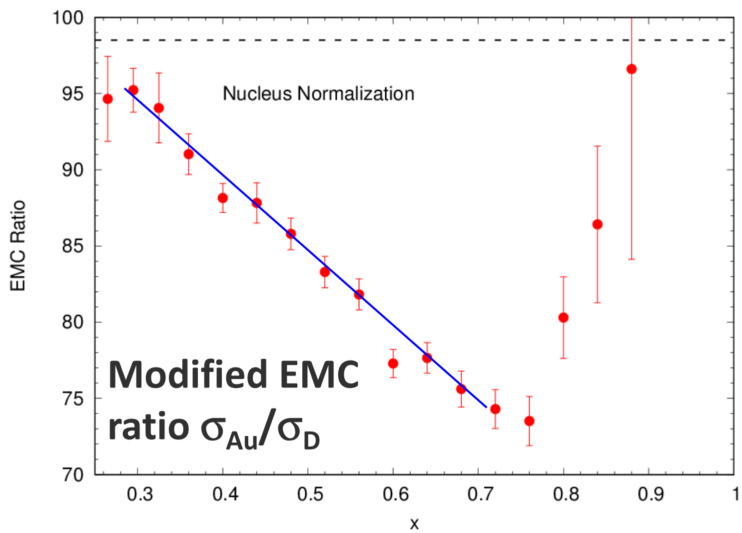
Definition of the EMC slope



Slope = 0.409

$R_{\text{no-EMC}}$ = 1

Slope/$R_{\text{no-EMC}}$ = 0.409 - "The EMC effect"



Cross section ratio (per nucleus)

Slope = 40.3

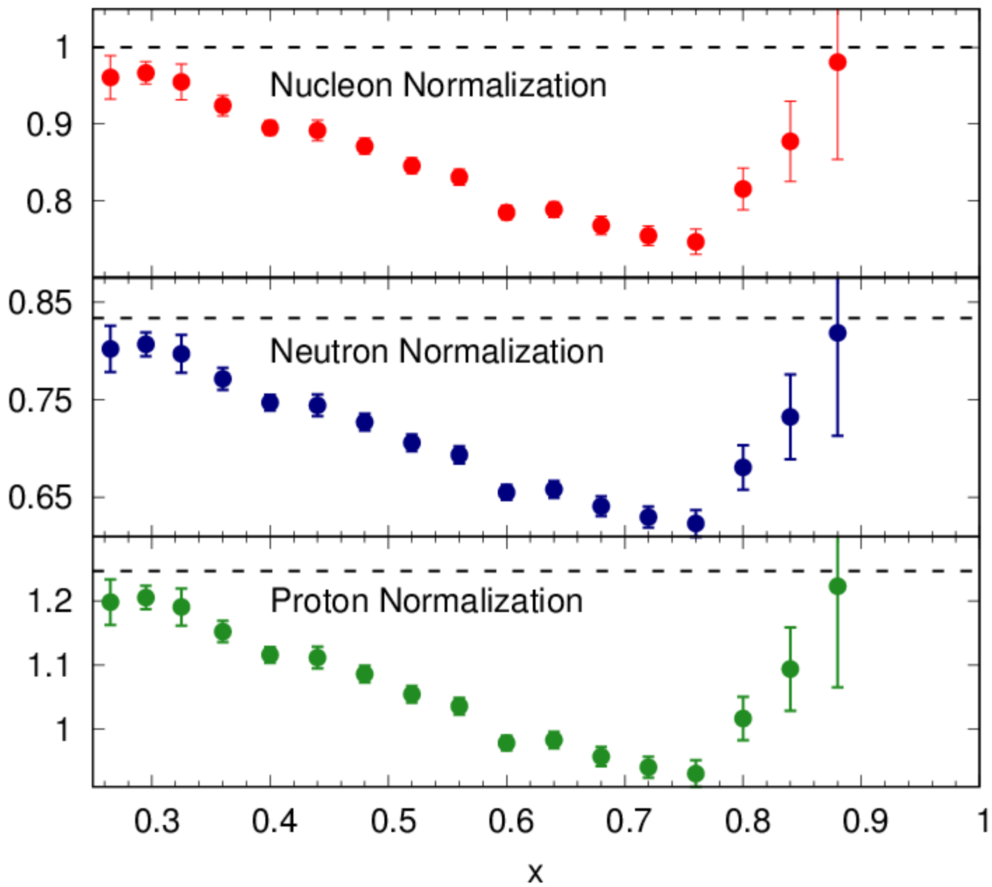
$R_{\text{no-EMC}}$ = 98.5

Slope/$R_{\text{no-EMC}}$= 0.409

20% drop at x=0.6 is same in both cases

Definition of the EMC slope

Different "EMC" ratios for Au



The conclusion that the EMC effect differs for protons and neutrons comes from changing the definition of the EMC ratios without updating the measure of the size of the effect

While the slope scales with the normalization, the EMC effect is generally taken as *fractional* modification of the nuclear pdf which does not change

Final issue on proton vs neutron EMC effect

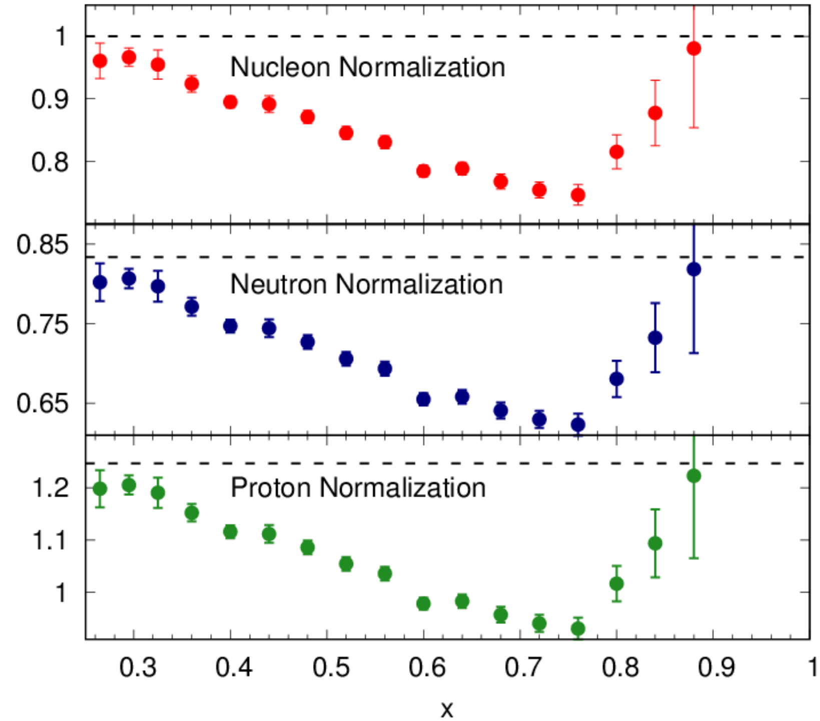
Nuclear cross section ratios, however normalized, yield the cross section for scattering from *all of the protons and neutrons*

Rescaling by N or Z instead of A is simply a renormalization. It's impact is completely independent of the physics of the EMC effect - isospin independent, driven by np pairs, or even coming entirely from protons or neutrons

Our conclusion from the EMC-SRC data:

- No indication that HV (isospin-dependent EMC) picture gives better explanation
- LD (isospin-independent) fits data somewhat better (~2 sigma level)

No data provide clear indication of isospin-dependence in the EMC effect



Flavor/Isospin dependence of the EMC effect?

- **Historically assumed that EMC effect is <u>identical for proton and neutron</u>**

- **Becoming hard to believe, at least for non-isoscalar nuclei**
  - **Recent calculations show difference for u-, d-quark, as result of scalar and vector mean-field potentials in asymmetric nuclear matter**
    [I. Cloet, et al, PRL 109, 182301 (2012); PRL 102, 252301 (2009)]
  - **EMC-SRC correlation + n-p dominance of SRCs suggests enhanced EMC effect in minority nucleons**
    - In ^{3}H, np-dominance suggests single proton generates same high-momentum component as two neutrons –> larger proton EMC effect in 'high-virtuality' picture
  - **^{48}Ca, ^{208}Pb expected to have significant neutron skin: neutrons preferentially sit near the surface, in low density regions**

All of these imply increased EMC effect in minority nucleons

- **The fact that the (limited) data show no indication of this is, in my mind, very puzzling**

A dependence (isospin dependence) of $R=\sigma_L/\sigma_T$??
(probably not)

A major caveat…

Discussion generally assumes a single origin for EMC effect

In the rest frame convolution formalism, the average removal energy, not just the overall binding energy, is relevant. The EMC effect scales with average removal energy, as does the contribution of SRCs which contribute a large part of the removal energy

JA et al, PRC 86 (2012) 065204
O. Benhar and I Sick, arXiv:1207.4595,

So it's not purely an exotic density- or virtuality-driven effect, but appears to be mix of binding corrections and something more exotic

The binding calculations of Kulagin & Petti explain half of the EMC effect, and the effect is correlated with the presence of SRCs. This suggests that the remaining half is also correlated with SRCs, although the evaluation of the removal energy is model dependent and uncertain

S. Kulagin and R. Petti, Nucl. Phys. A765 (2006) 126

NOTE: removal energy depends on n vs. p → should have same isospin dependence as "high-virtuality" model, approximately scale with <KE> estimates