Scaling models for the EMC effect in light and non-isoscalar nuclei

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Examining the role of nuclear structure in nuclear quark distributions, and looking at potential impact of the isospin-dependent structure of nuclei to find the flavor.

NOTES/OVERALL AIMS

- Use microscopic models to evaluate A and isospin dependence of the EMC effect. [include isospin from EMC-SRC models]
- Make projections for 48Ca/40Ca and PVEMC based on HV and LD models, and the scaling models.
- Probably a separate paper: consistency of high-p and low-r in QMC calculations (scale the same way with A, what distance corresponds to k>275 or 300 (where cut dependence is small), quantify pn dominance from structure calculations, updated EMC-SRC analyses?

INTRODUCTION [DG/NF/JA]

VERY brief intro/overview of EMC effect; JLab measurements showing importance of detailed nuclear structure.

Brief introduction of EMC-SRC correlation. "Recent" measurement: (1) light nuclei tells us nuclear structure is important, (2) EMC-SRC shows connection to SRCs. Question of flavor/isospin dependence. *These first 2 paragraphs motivate the A dependence and flavor dependence studies.*

Underlying physics/explanations (HV/LD) and how they tie in to EMC-SRC. Brief summary of recent comparisons of HV and LD, but only to say it's an open question.

Another approach is to take underlying pictures (short distance vs large momenta) and evaluate directly from detailed structure calculations. We present both here and discuss implications for upcoming and proposed measurements.

EMC-SRC ANALYSES [NF/JA]

Present EMC-SRC analyses in terms of slope, first in words. Give overall conclusion about previous results.

Present universal EMC function and conclusions. Note that HV is almost identical to naive, LD is identical to LD from slope, so not independent checks, but LD gives better 'visualization' in terms of universal function.

HV and naive nearly the same. HV and LD differ mainly by pair counting, not explicit "flavor dependence" assumed. *This is the only thing we'd miss if we don't discuss updated universal function, but easy enough to say if desired.*

PREDICTIONS FROM NUCLEAR STRUCTURE CALCULATIONS [SL/NF/JA]

EMC effect scaling was tested using a number of quantities derived from nuclear structure calculations, such as nuclear density, kinetic energy, fraction of nucleons at high momentum and others. These quantities were obtained from single and two-nucleon densities as well as single and two-nucleon momentum distributions from [1]. The distributions are the result of variational Monte Carlo calculations (VMC) using the v18 two-nucleon and Urbana X three nucleon potentials. For isoscalar nuclei, the proton and neutron distributions are identical, but they differ in the non-isoscalar cases.

Density

The most natural quantity to consider is the average density of protons only, given by:

$$\langle\rho\rangle_p = \frac{4\pi\int \rho_p^2(r) r^2 dr}{4\pi\int \rho_p(r) r^2 dr} \tag{1}$$

We calculate the average density of nucleons as sampled by protons,$\langle\rho\rangle_p$, as:

$$\langle\rho\rangle_p^p = \frac{4\pi\int [\rho_p(r)+\rho_n(r)]\rho_p(r) r^2 dr}{4\pi\int \rho_p(r) r^2 dr} \tag{2}$$

The average density of neutrons, $\langle\rho\rangle_n$ is defined analogously. Additionally, we define the average density of other nucleons (not including itself) *as seen* by a proton, $\langle\rho'\rangle_p$, as:

$$\langle\rho'\rangle_p^p = \frac{4\pi\int [\rho_p(r)\times\frac{Z-1}{Z}+\rho_n(r)]\rho_p(r) r^2 dr}{4\pi\int \rho_p(r) r^2 dr} \tag{3}$$

with the average density of neutrons *as seen* by a neutron, $\langle\rho'\rangle_p$, defined analogously, as before. The effect of including the additional $(Z-1)/Z$ scaling is shown in Fig.1.

2-body Density

2-body densities are also calculated in Ref. [1]. For isoscalar nuclei, the distributions are provided for pn and pp pairs, with nn distributions to be taken the same as the latter. For non-isoscalar nuclei, nn distributions are also calculated. We consider several scenarios, such as probablity of a proton to be within 1 fm of a neutron (the threshold for SRC pair), P_{pn} given by:

$$P_{pn} = \frac{4\pi\int_0^1 \rho_{np}^2(r) r^2 dr}{4\pi\int \rho_{np}(r) r^2 dr} \tag{4}$$

with analogous expressions for P_{pp} and P_{nn} probabilities. EMC effect assuming scaling vs: Average density, overlap (LD), virtuality (HV), high-p component

EMC effect scaling models:

- Density

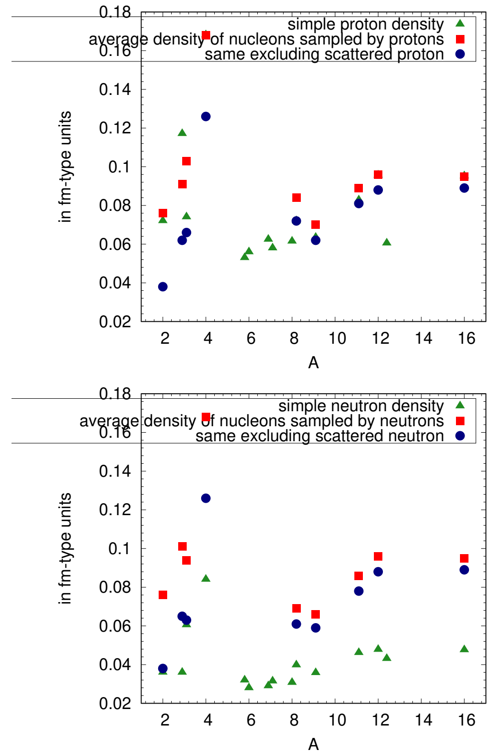

FIG. 1. **Proton and neutron densities, as described above.**

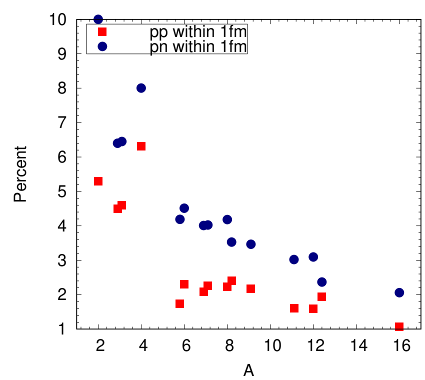

FIG. 2. **Pairs within 1 fm of each other**

- Local density (estimate variation with cuts)
- Kinetic energy
- Fraction at high momentum (estimate variation)

Show A dependence; comment on upcoming experiments (requires separate evaluation of protons and neutrons, with cross section weighted average). Maybe show ratios and projected uncertainties??? *this could be part of a later section on future experiments.*

Momentum Distributions We used the momentum distributions for kinetic energy calculations as well as to estimate the numbers of high-momentum protons

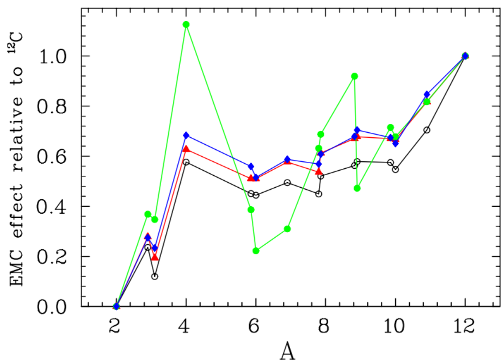

FIG. 3.

and neutrons. The latter (defined with a threshold of 1.0 fm^{-1} or 2.0 fm^{-1}) are obtained with:

$$Blah = \frac{\frac{4\pi}{8\pi^3}\int_{1.0}^{\infty} n_p(k)k^2dk}{\frac{4\pi}{8\pi^2}\int n_p(k)k^2dk} \tag{5}$$

Kinetic energy calculations are done for the whole distribution (to get the average) as well as for only protons (in cases of non-isoscalar nuclei) as well as given certain momentum thresholds:

$$\langle K\rangle = \frac{\frac{4\pi}{8\pi^3}\int_{1.5}^{\infty} n_p(k)k^2dk}{\frac{4\pi}{8\pi^2}\int n_p(k)k^2dk} \tag{6}$$

Show proton vs neutron to predict isospin for these scaling model. Show flavor dependence vs N/Z, and add curve for LD and HV.

EMC effect (JRA notes)

So the EMC effect is something like modified F2p + F2n divided by unmodified. So if f_p and f_n are the modification of the slope due to the EMC effect for protons and neutrons, you'd have something like:

$$R_{EMC} \approx \frac{ZF_{2p}(1-f_px)+NF_{2n}(1-f_nx))}{ZF_{2p}+NF_{2n}} \tag{7}$$

$$= \frac{Z(1-f_px)+NR_{n/p}(1-f_nx))}{Z+NR_{n/p}} \tag{8}$$

$$= \frac{(1-f_px)+N/ZR_{n/p}(1-f_nx))}{1+N/ZR_{n/p}} \tag{9}$$

where $R_{n/p} = F_{2n}/F_{2p}$. Then you'd take R_{EMC} and fit it to extract the "overall" f_A, so this only works well if f is small so that things stay approximately linear. Since the scaling functions are arbitrarily normalized, you'll have to convert them to "small numbers" for this. For some cases, fraction of high-momentum nucleons or fraction of short-distance nucleons, you can probably set f_p to be the proton high-p or low-r fraction directly. For average KE, you'll just have to scale down by some arbitrary factor so that that factor time KE$_p$ and KE$_n$ are at the 5 or 10% level.

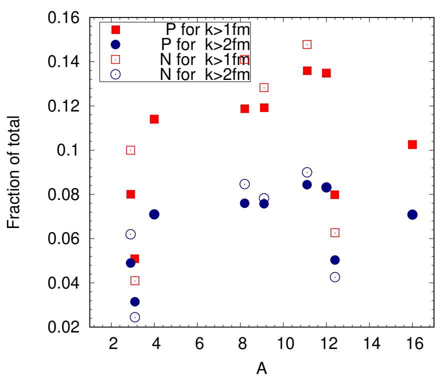

FIG. 4. **Fraction of p, n at momenta above 1 and 2 fm.**

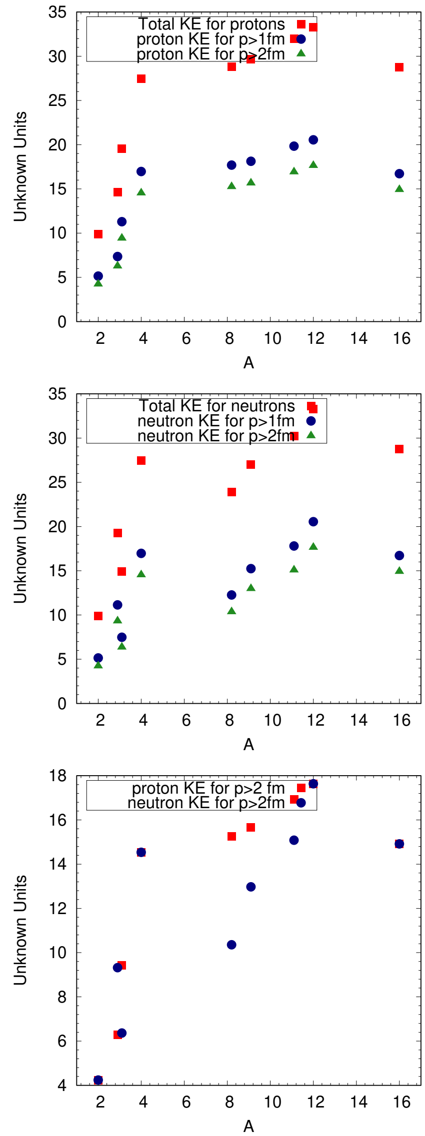

FIG. 5. **KE of protons, neutrons, cuts applied.**

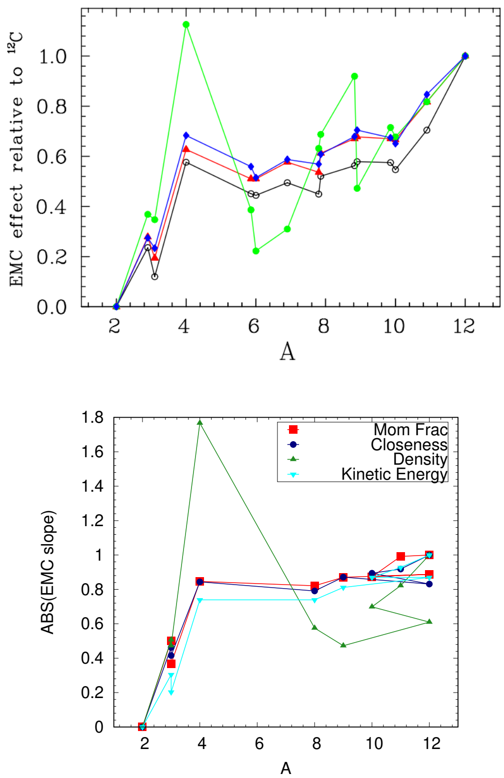

FIG. 6. **JRA: For this paper, we should pick an n/p parameterization (simple) and actually calculate nuclear pdf, not just weighted sum of proton and neutron EMC effect!**

Nadia's results The EMC effect has been constructed in two ways: (1) looking at the fraction of protons or neutrons whose momentum exceeded 2 fm^{-1} (labeled "mom frac") and (2) fraction of protons or neutrons within 1 fm of another nucleon (labeled "closeness").

$$f_{p,close} = \frac{f_{np} \times N + f_{pp} \times (Z-1)}{10} \tag{10}$$

The factor of 10 is included to keep $f_{p,close}$ sufficiently small. $f_{n,close}$ is calculated in an analogous way.

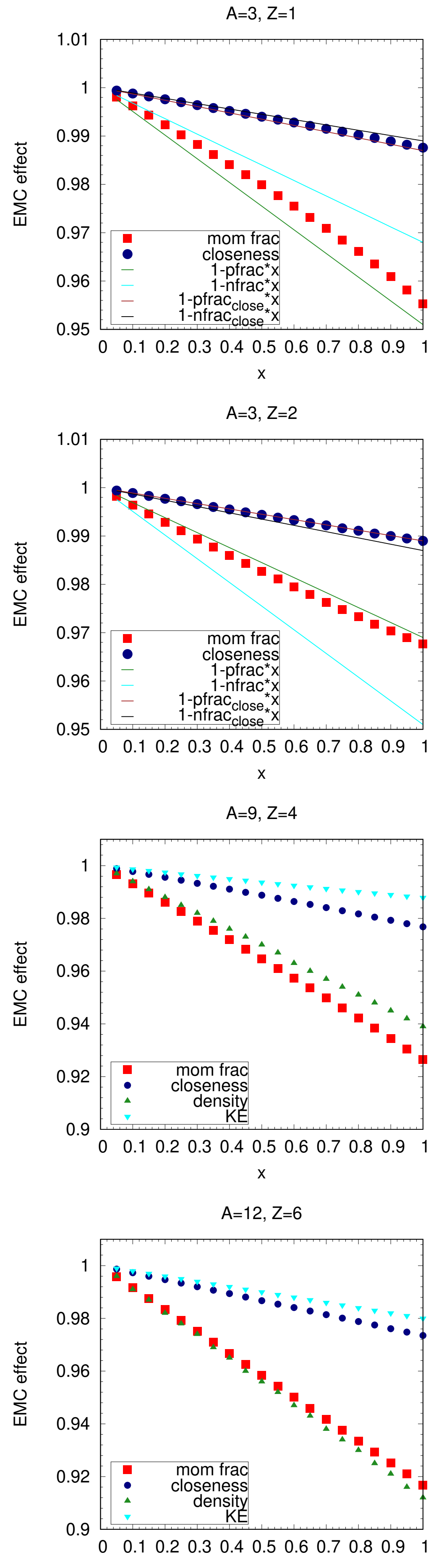

FIG. 7. Nadia's plots. Pfrac and Nfrac refer to f for mo-

PREDICTIONS AND FUTURE EXPERIMENTS [DG/JA]]

Use those to predict 48/40Ca ratio, note sensitivity and range ot targets

Predictions of 48Ca PVEMC (maybe also 9Be PVEMC - good at higher energy!).

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[1] R. B. Wiringa, R. Schiavilla, S. C. Pieper, and J. Carlson, Nucleon and nucleon-pair momentum distributions in $a \leq 12$ nuclei, Phys. Rev. C **89**, 024305 (2014).