E12-10-008:
Detailed Studies of the Nuclear Dependence of F_2 in Nuclei

Dave Gaskell
Jefferson Lab

Hall C Users Meeting
January 22, 2018

Quarks in the Nucleus

Typical nuclear binding energies ~ MeV
while DIS scales ~ GeV

(super) Naïve expectation:

$$F_2^A(x) = ZF_2^p(x) + (A-Z)F_2^n(x)$$

More sophisticated approach includes effects from Fermi motion

$$F_2^A(x) = \sum_i \int_x^{M_A/m_N} dy f_i(y) F_2^N(x/y)$$

Quark distributions in nuclei were not expected to be significantly different (below x=0.6)

$$F_2^{Fe} / \left(ZF_2^p + (A-Z)F_2^n \right)$$

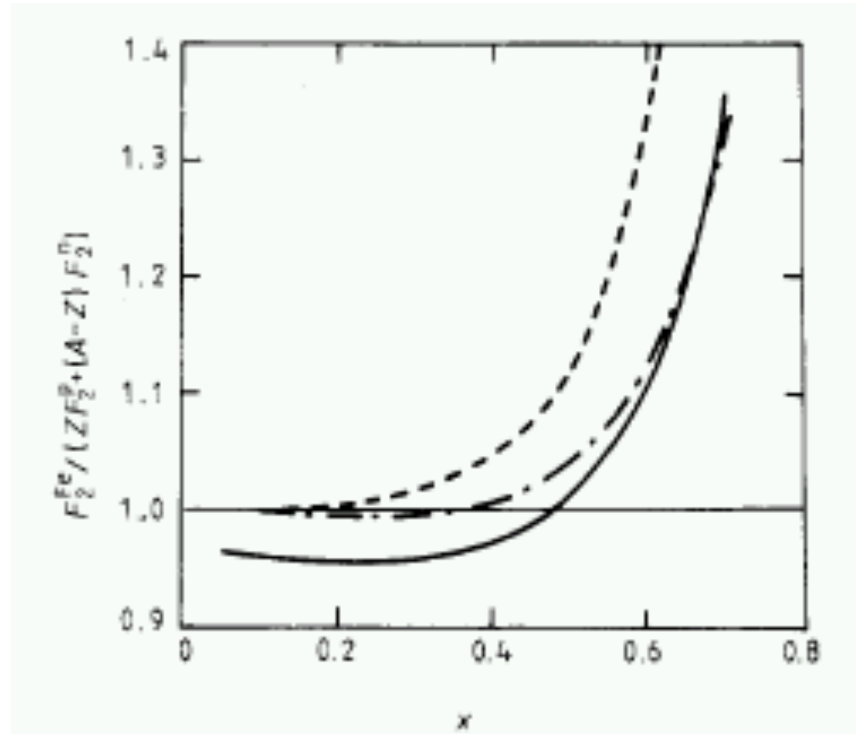
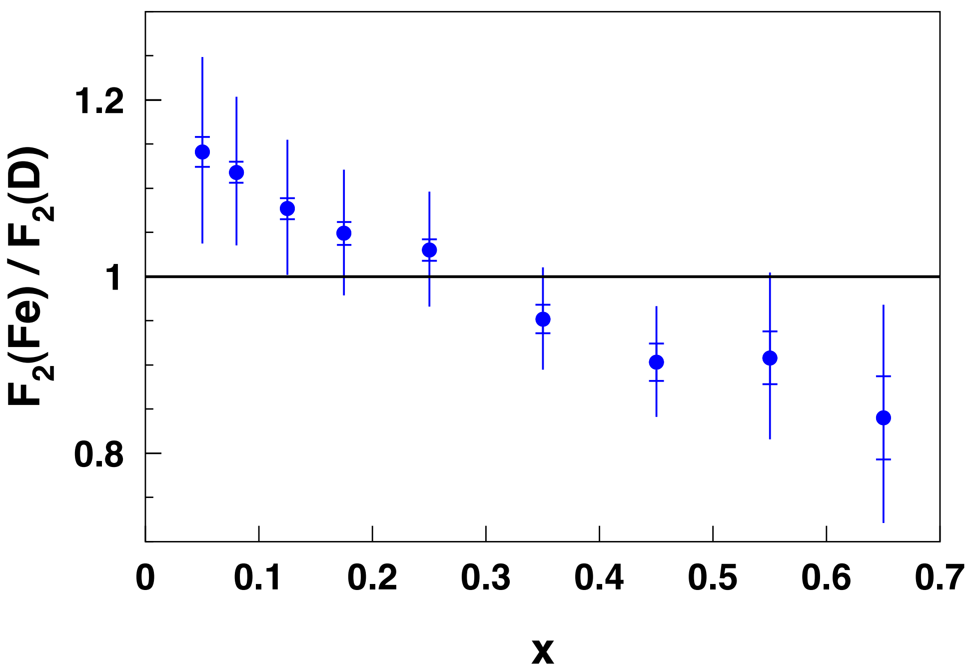


Figure from Bickerstaff and Thomas, J. Phys. G 15, 1523 (1989)
Calculation: Bodek and Ritchie PRD 23, 1070 (1981)

Discovery of the EMC Effect

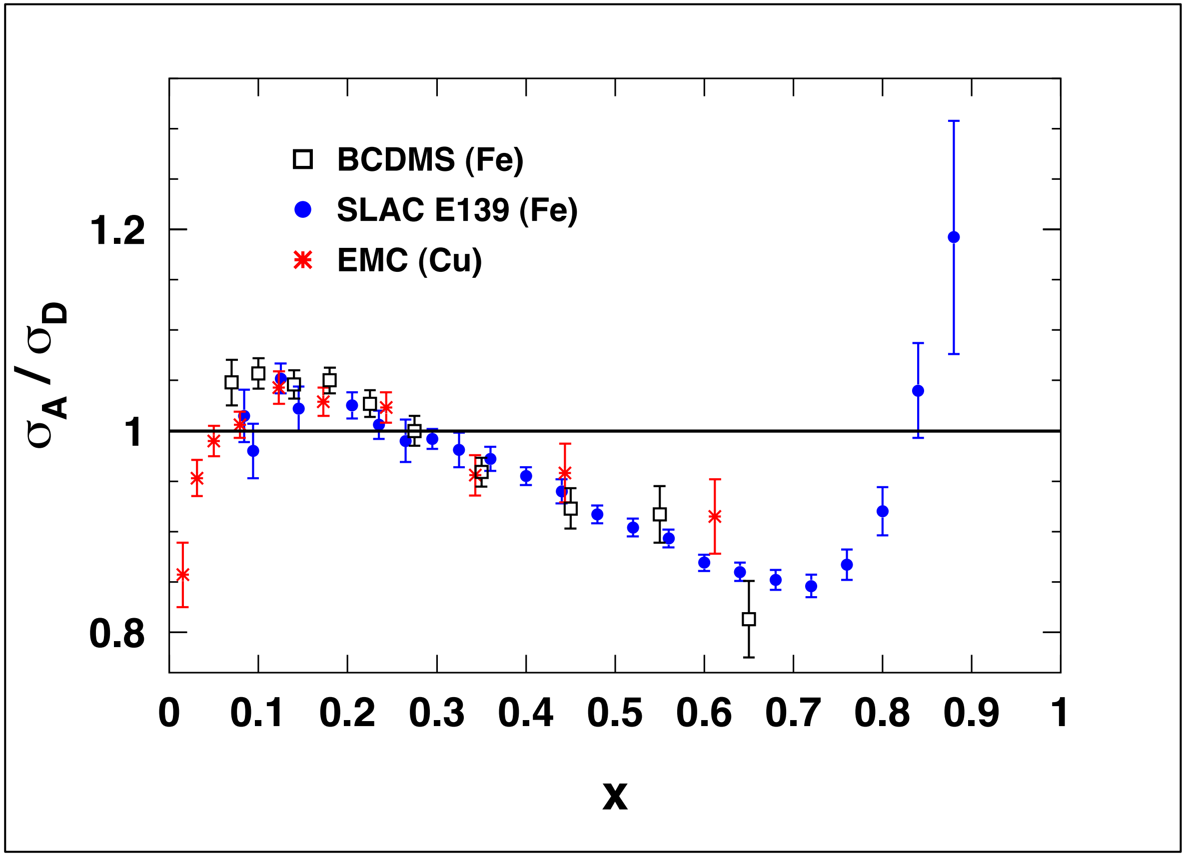
- First published measurement of nuclear dependence of F_2 by the European Muon Collaboration in 1983

- Observed 2 mysterious effects
  - Significant enhancement at small x → Nuclear Pions! (see my thesis)
  - Depletion at large x → the "EMC Effect"



Aubert et al, Nucl. Phys. B293, 740 (1987)

Properties of the EMC Effect



Large program of measurements at many labs followed the initial discovery of the EMC effect

Global properties of the EMC effect:

1. Universal x-dependence
2. Little Q^2 dependence
3. EMC effect increases with *A*

→ *Anti-shadowing region shows little nuclear dependence*

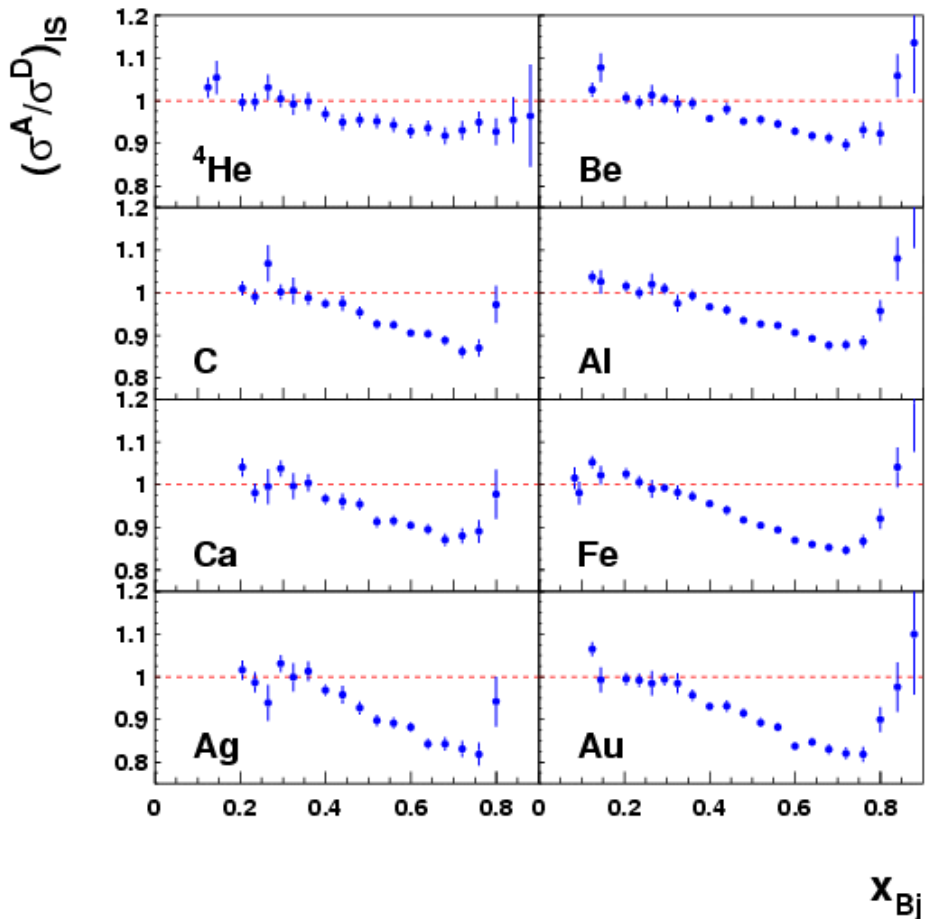
EMC Effect Measurements at Large x

SLAC E139 provided the most extensive and precise data set for *x>0.2*

Measured σ_A/σ_D for A=4 to 197
→ ^{4}He, ^{9}Be, C, ^{27}Al, ^{40}Ca, ^{56}Fe, ^{108}Ag, and ^{197}Au
→ Best determination of the *A* dependence
→ Verified that the *x* dependence was roughly constant

Building on the SLAC data
→ Higher precision data for ^{4}He
→ Addition of ^{3}He
→ Precision data at large *x*

SLAC E139



J. Gomez et al, Phys.Rev. D49 (1994) 4348-4372

Nuclear Dependence of the EMC Effect

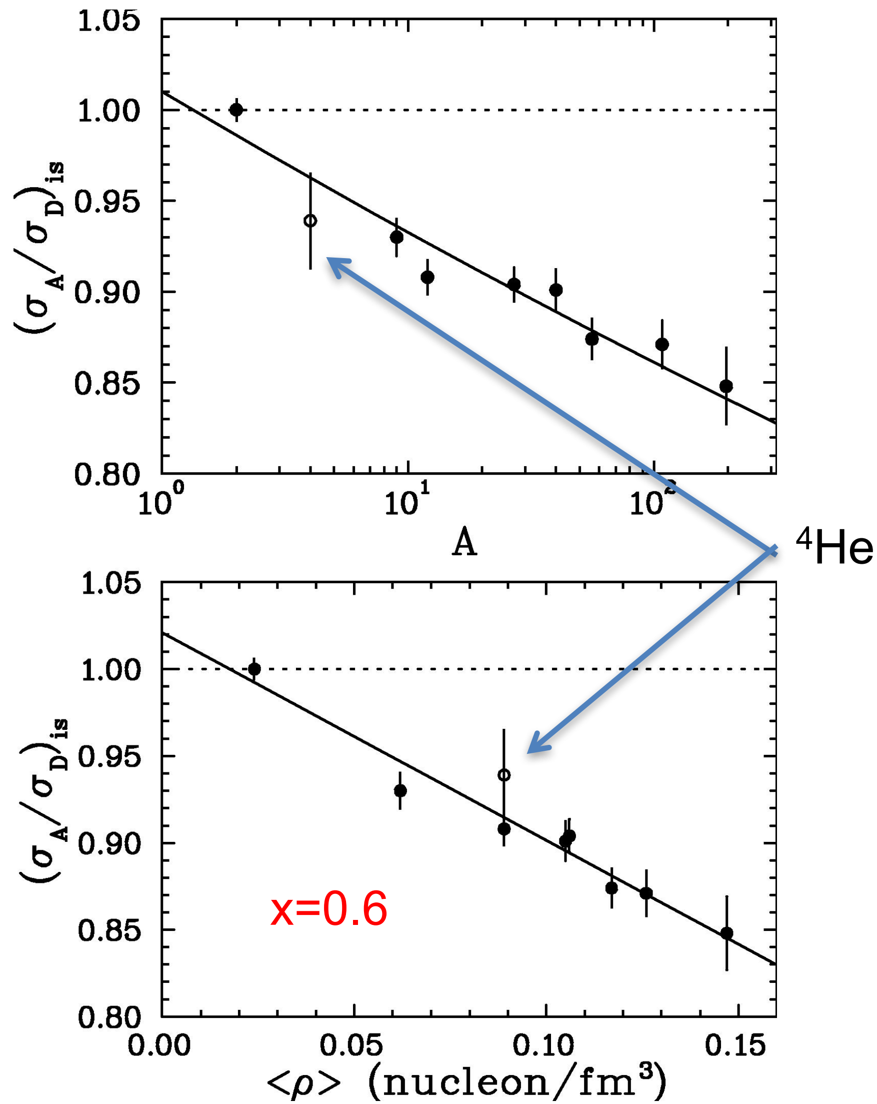
SLAC E139 studied the nuclear dependence of the EMC Effect at fixed *x*

Results consistent with
→Simple logarithmic A dependence
→Average nuclear density*

*uniform sphere with radius R_e,
$R_e^2 = 5/3 \langle r^2 \rangle$ → charge radius of nucleus

Many models of the EMC effect either implicitly or explicitly assume the size of the EMC effect scales with average nuclear density

→ Constraining form of nuclear dependence can confirm or rule out this assumption



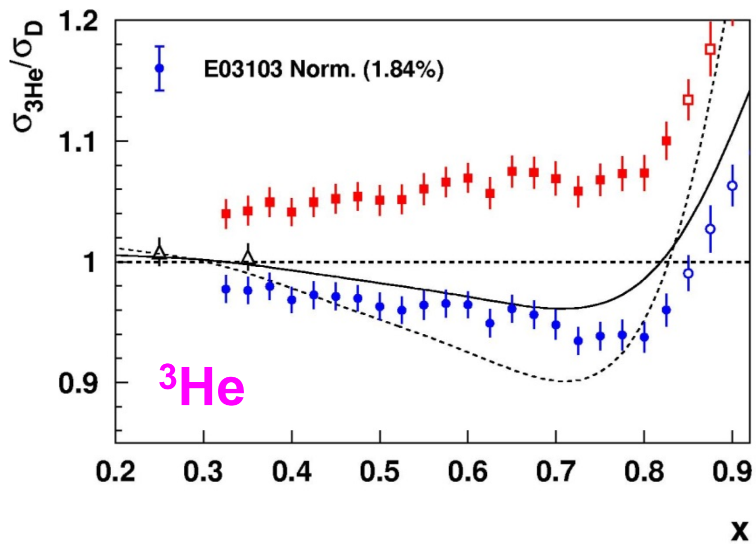
Gomez et al, PRD 49, 4348 (1994)

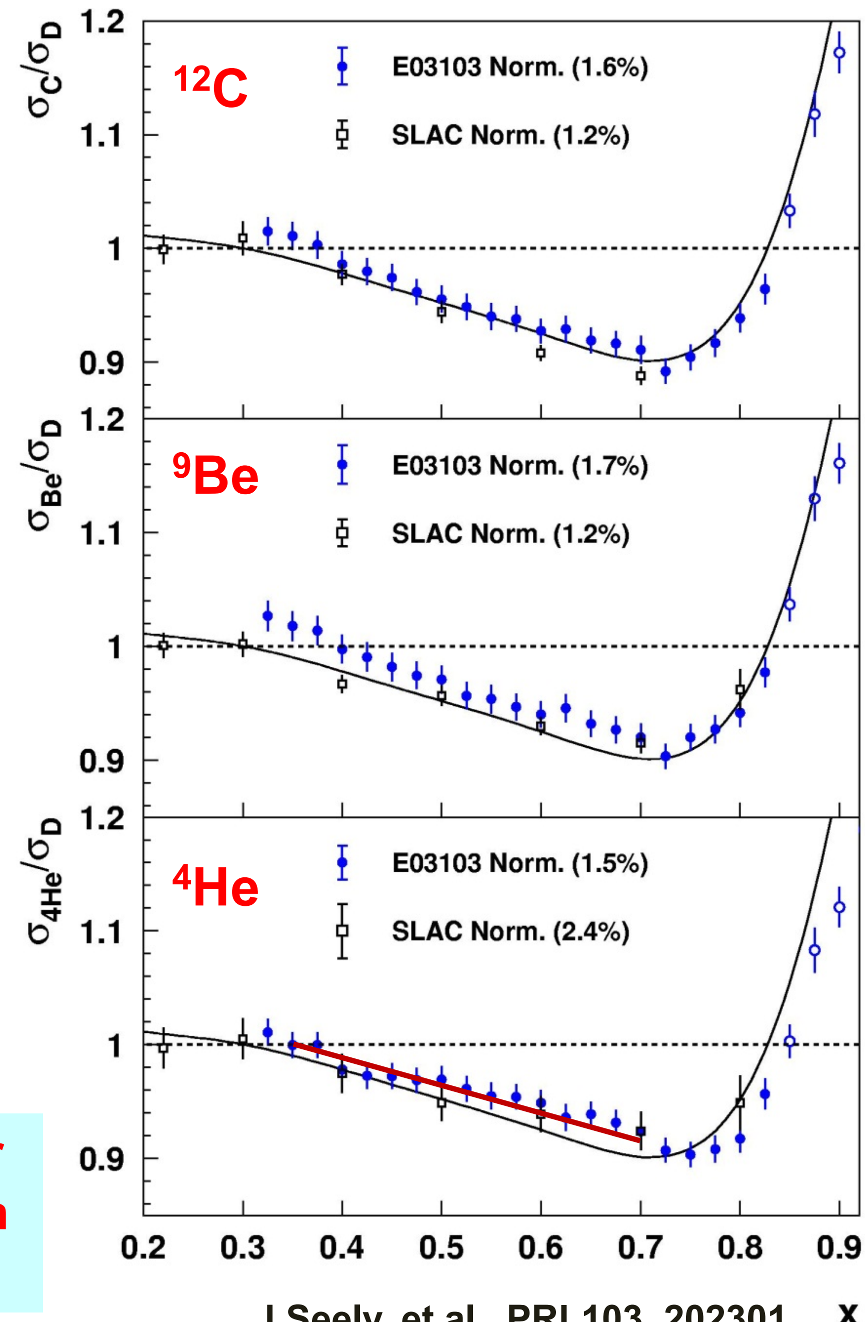
JLab E03-103 Results

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

Measurements on ^{3}**He,** ^{4}**He,** ^{9}**Be,** ^{12}**C**

JA, D. Gaskell, spokespersons

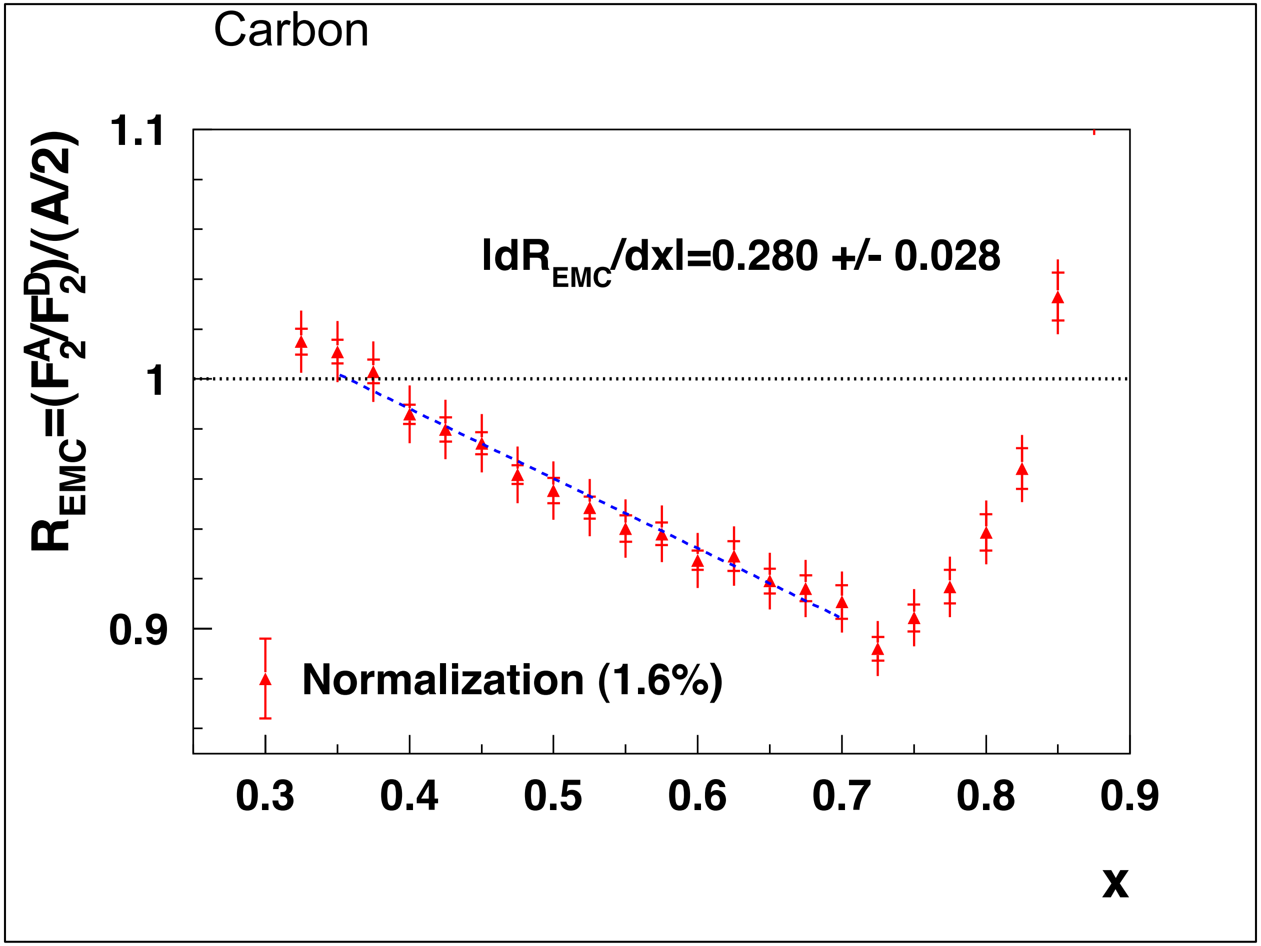




If shape (x-dependence) is same for all nuclei, the slope (0.35<x<0.7) can be used to study dependence on A

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

JLab E03-103 and the Nuclear Dependence of the EMC Effect



New definition of "size" of the EMC effect

→Slope of line fit from x=0.35 to 0.7

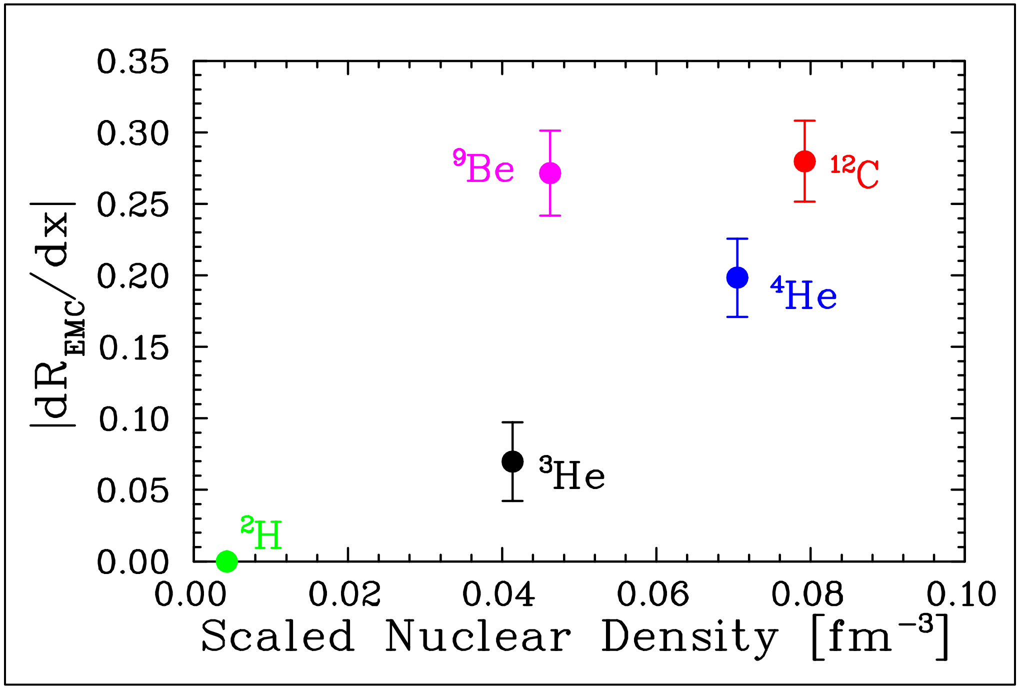
Assumes shape is universal for all nuclei

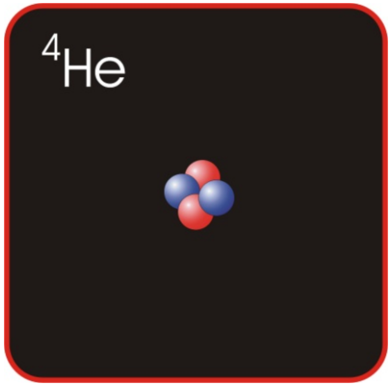
→Normalization uncertainties a much smaller relative contribution

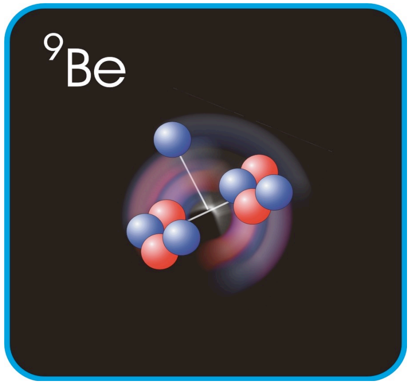
EMC Effect and Local Nuclear Density

^{9}Be has low average density
→ Large component of structure is ***2α+n***
→ Most nucleons in tight, *α*-like configurations

EMC effect driven by ***local*** rather than *average* nuclear density



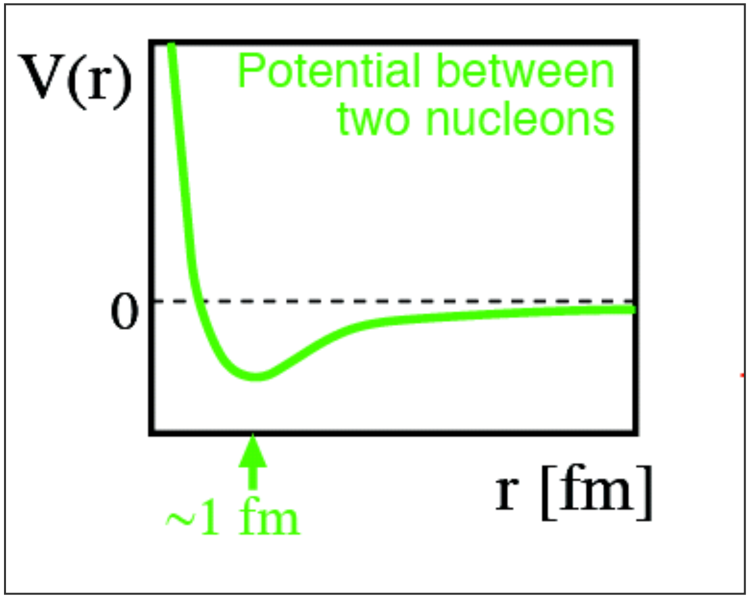


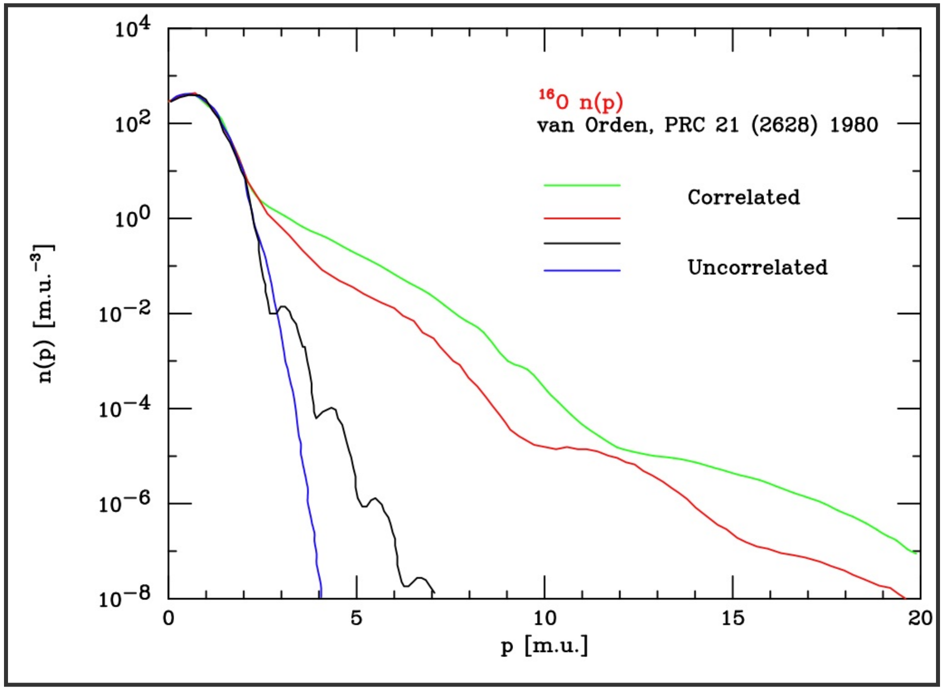


"Local density" is appealing in that it makes sense intuitively – can we make this more quantitative?

Local Density → Short Range Correlations

What drives high "local" density in the nucleus?



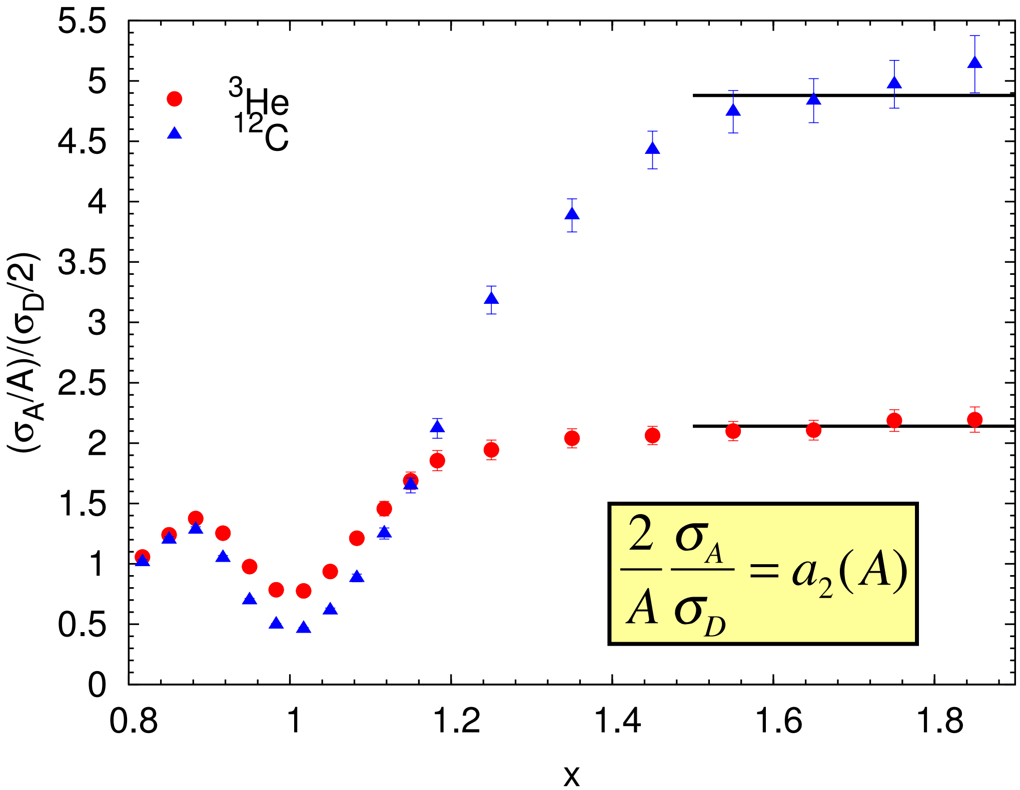


Tensor interaction and short range repulsive core lead to high momentum tail in nuclear wave function → correlated nucleons

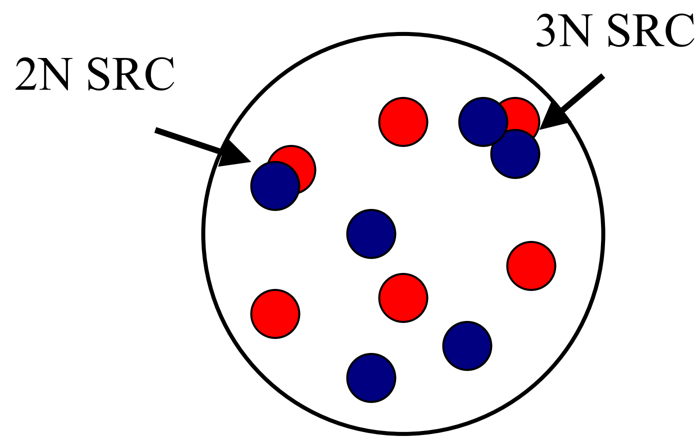
Measuring Short Range Correlations

To measure the (relative) probability of finding a correlated pair, ratios of heavy to light nuclei are taken at ***x>1*** → QE scattering

If high momentum nucleons in nuclei come from correlated pairs, ratio of A/D should show a plateau (assumes FSIs cancel, etc.)



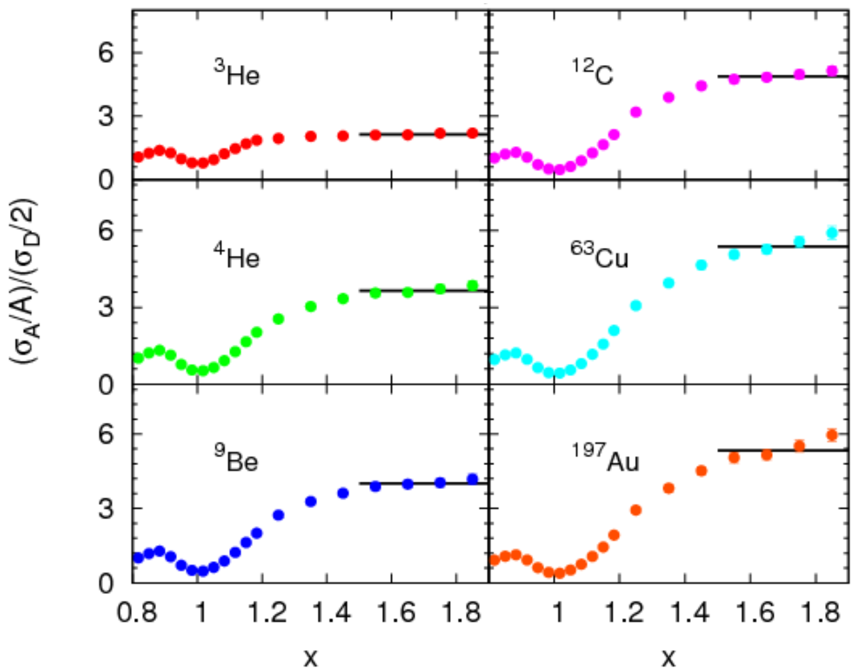
$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} = a_2(A)$$



1.4<x<2 => 2 nucleon correlation

2.4<x<3 => 3 nucleon correlation

SRCs and Nuclear Density



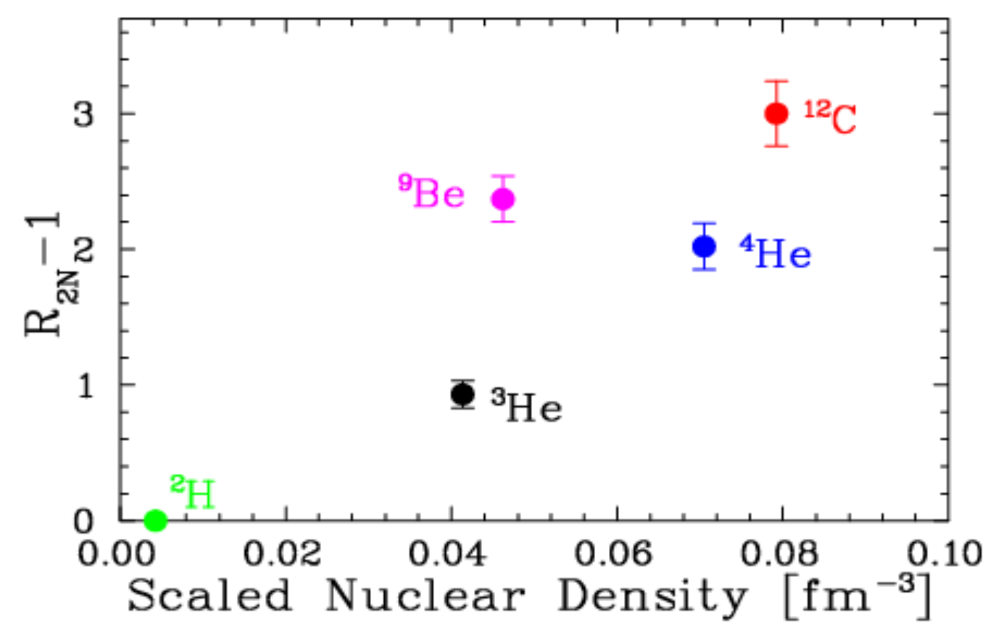
N. Fomin et al, Phys.Rev.Lett. 108 (2012) 092502

Hall C data on ratios at *x>1*

a_2 ratios for:

→Additional nuclei (Cu, Be, Au)

→Higher precision for targets with already existing ratios

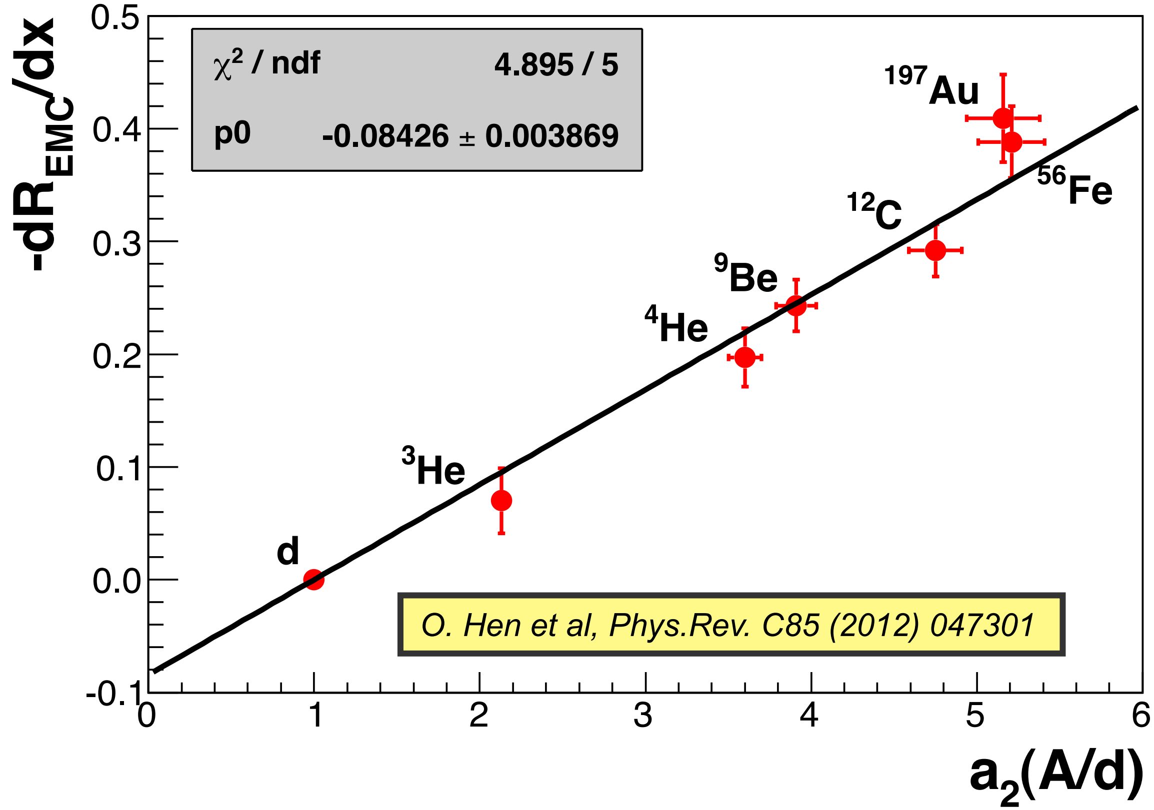


→ Relative probability to find SRC shows similar dependence on nuclear density as EMC effect

EMC Effect and SRC

Weinstein *et al* first observed linear correlation between size of EMC effect and Short Range Correlation "plateau"

Correlation <u>strengthened</u> with addition of Beryllium data



This result provides a ***quantitative*** test of level of correlation between the two effects

E12-10-008: EMC effect in light→ heavy nuclei

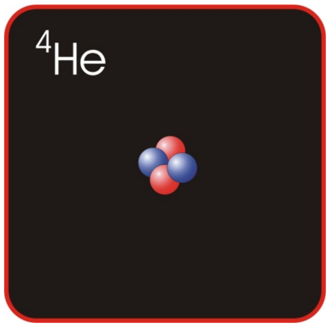
Spokespersons: J. Arrington, A. Daniel, N. Fomin, D. Gaskell

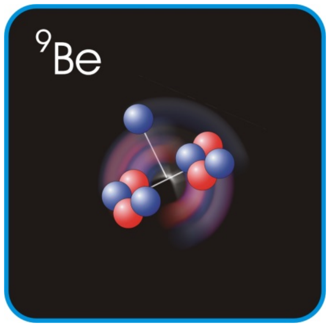
E03-103: EMC at 6 GeV

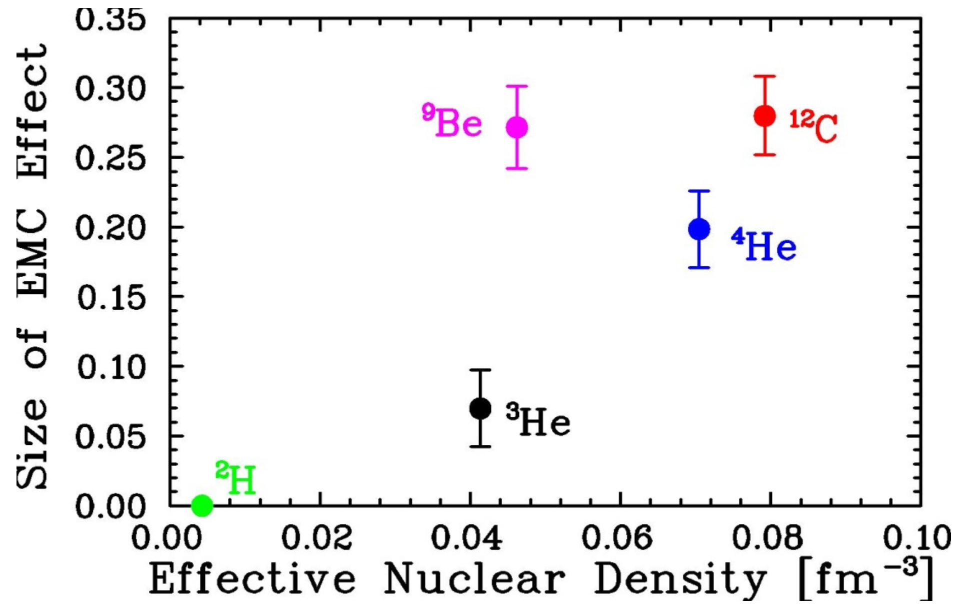
→ Focused on light nuclei

→ Large EMC effect for ^{9}Be

→ Local density/cluster effects?







J. Seely, et al., PRL 103, 202301 (2009)

E12-10-008: EMC effect at 12 GeV

→ Higher Q^2, expanded range in x (both low and high x)

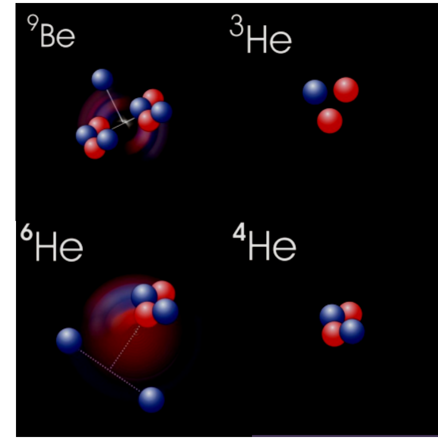
→ Light nuclei includes ^{1}H, ^{2}H, ^{3}He, ^{4}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C

→ Heavy nuclei include ^{40}Ca, ^{48}Ca and Cu and additional heavy nuclei of particular interest for EMC-SRC correlation studies

E12-10-008 (EMC effect) and E12-06-105 (x>1)

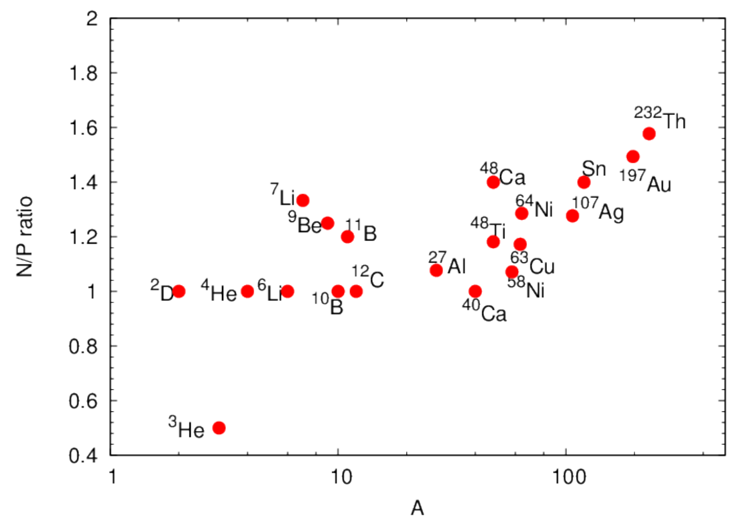
Light nuclei: Reliable calculations of nuclear structure (e.g. clustering)

^{1}H	$^{6,7}Li$
^{2}H	^{9}Be
^{3}He	$^{10,11}B$
^{4}He	^{12}C



- Both experiments use wide range of nuclear targets to study impact of cluster structure, separate mass and isospin dependence on SRCs, nuclear PDFs
- Experiments will use a common set of targets to provide more information in the EMC-SRC connection

^{27}Al	$^{64*}Cu$
$^{40*,48}Ca$	$^{108*}Ag$
^{48}Ti	$^{119*}Sn$
^{54}Fe	$^{197*}Au$
$^{58,64}Ni$	^{232}Th



Heavier nuclei: Cover range of N/Z at ~fixed values of A

Flavor Dependence of the EMC Effect and Short Range Correlations

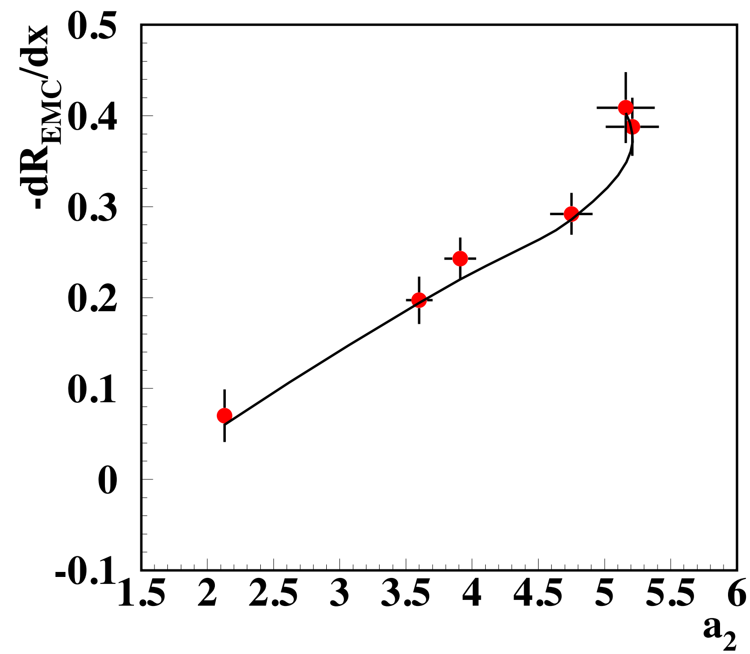
High momentum nucleons in the nucleus come primarily from *np* pairs

→The relative probability to find a high momentum proton is larger than for neutron for *N>Z* nuclei

$$n_p^A(p) \approx \frac{1}{2x_p} a_2(A,y) n_d(p) \qquad x_p = \frac{Z}{A}$$

$$n_n^A(p) \approx \frac{1}{2x_n} a_2(A,y) n_d(p) \qquad x_n = \frac{A-Z}{A}$$

Probability to find SRC



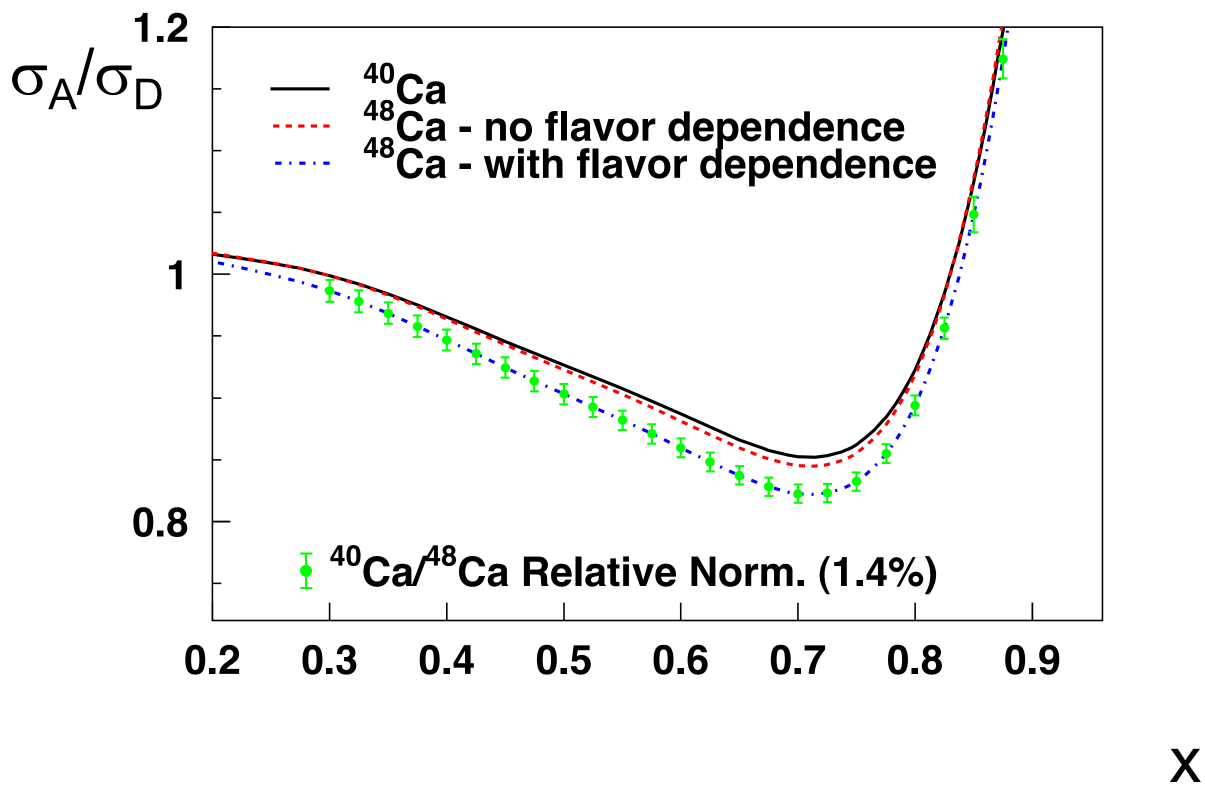
Under the assumption the EMC effect comes from "high virtuality" (high momentum nucleons), effect driven by protons (u-quark dominates) → similar flavor dependence is seen in some "mean-field" approaches

M. Sargsian, arXiv:1209.2477 [nucl-th] and arXiv:1210.3280 [nucl-th]

Flavor dependence from ^{40}Ca and ^{48}Ca

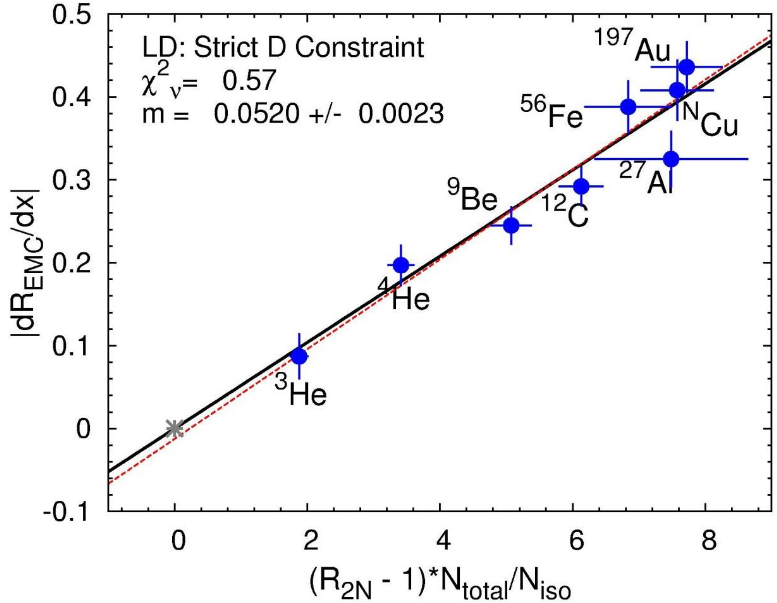
CBT model predicts a ~3% effect for ^{48}Ca at *x=0.6*
→*N/Z = 1.4*

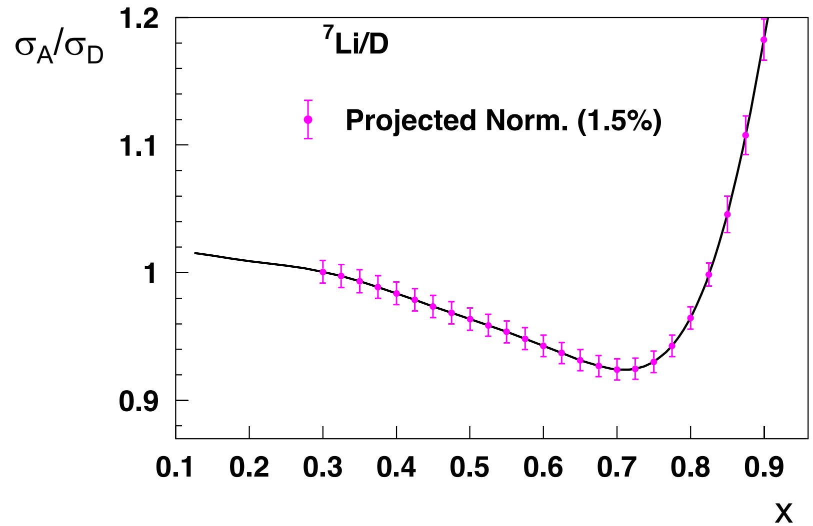
Assuming no flavor dependence, difference between ^{40}Ca and ^{48}Ca should be less than < 1% assuming SLAC E139 A-dependent parametrization

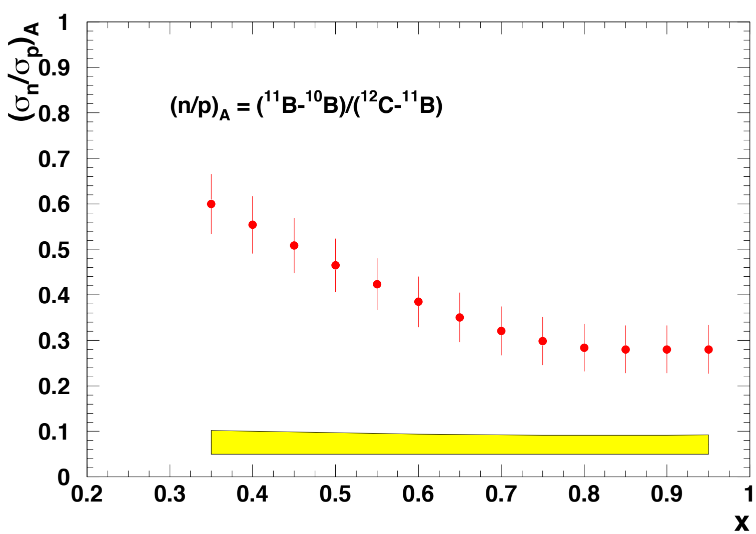


Measurement of unpolarized EMC effect in ^{40}Ca and ^{48}Ca provides some sensitivity to possible flavor dependent effect

E12-10-008: Physics Reach







E12-10-008 outcomes

1. EMC Ratios of a variety of previously unmeasured nuclei
2. Additional nuclei to explore the EMC-SRC correlation in more detail (when combined with E12-06-105)
3. Sensitivity to flavor dependence of EMC effect via measurements of ^{40}Ca and ^{48}Ca
4. n/p ratio in nuclei

E12-10-008: Commissioning running

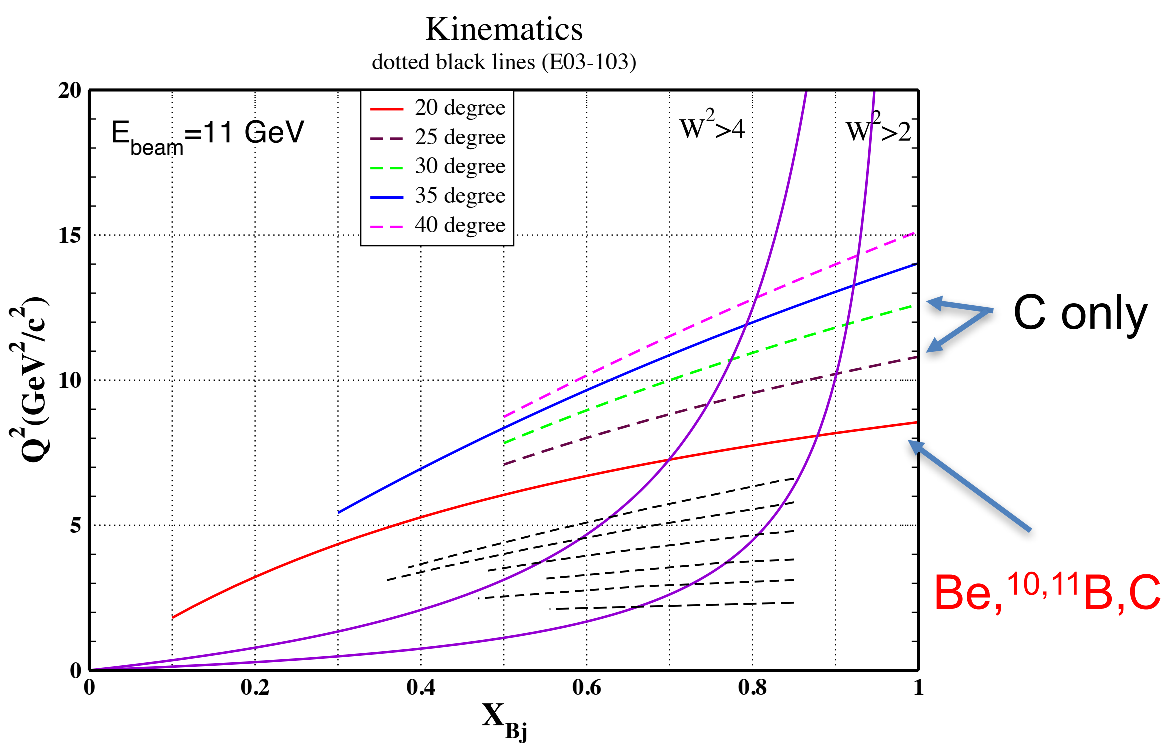
→ Will run with E12-10-002 at part of commissioning experiment run to make some initial EMC effect measurements

→ 2 PAC days will be used to:

1. Measure Q^2 dependence of EMC effect over range of x to check scaling of EMC ratio → carbon target
2. Obtain data on a few light nuclei at a single Q^2/angle (^{9}Be, ^{10}B, ^{11}B, C)

Targets:
10 cm H, D cryotargets with Al dummy, ^{9}Be, ^{10}B4C, ^{11}B4C, C solid targets

SHMS:
Theta = 20-30 degrees, P=2-5.5 GeV
→ Good pion rejection (worst case pi/e ~ 100:1)



Summary

- The EMC effect clearly demonstrates that quark distributions are modified in the nucleus
- More than 30 years after the initial discovery of the EMC effect, there is no universally accepted explanation
  - Recent JLab data combined with observation of EMC-SRC correlation has provided an intriguing clue
  - High density in local nuclear environment? Highly virtual nucleons?
- E12-10-008 (and E12-06-105) will provide new data on a several nuclei
  - Explore N/Z dependence at fixed A and A dependence at fixed N/Z
- 2018 data will provide first EMC measurements on ^{10}B and ^{11}B, initial measurements of Q^2 dependence at large x