New Measurements of the EMC Effect in Very Light Nuclei and at Large x

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Quarks in the Nucleus

- Typical nuclear binding energies ~ MeV while DIS scales → GeV
- Naïve expectation:

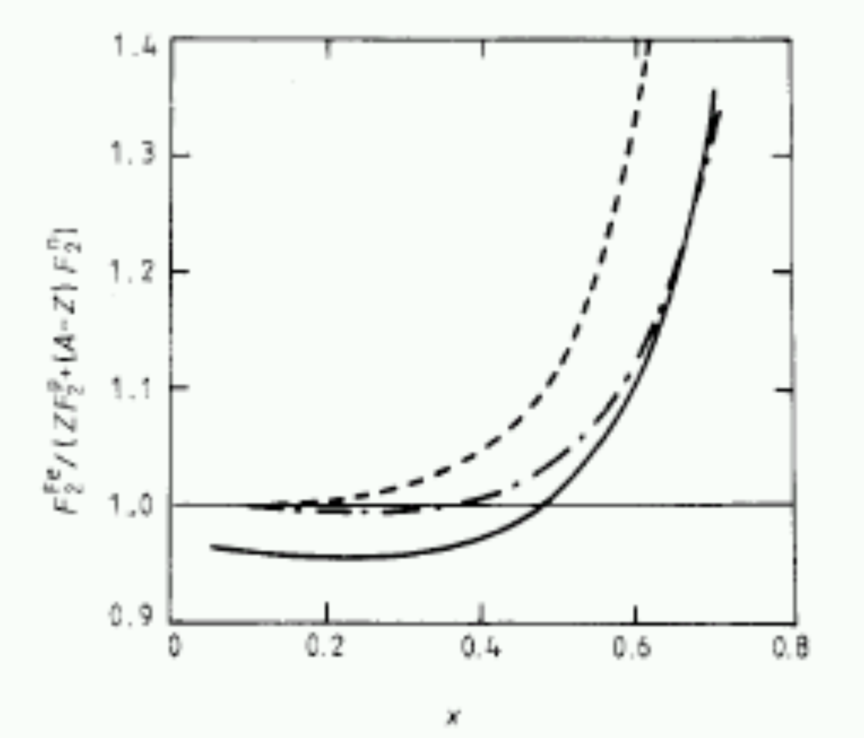
$$F_2^A(x) = ZF_2^p(x) + (A-Z)F_2^n(x)$$

- 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)

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



Bodek and Ritchie PRD 23, 1070 (1981)

EMC Effect and Quark Distributions in Nuclei

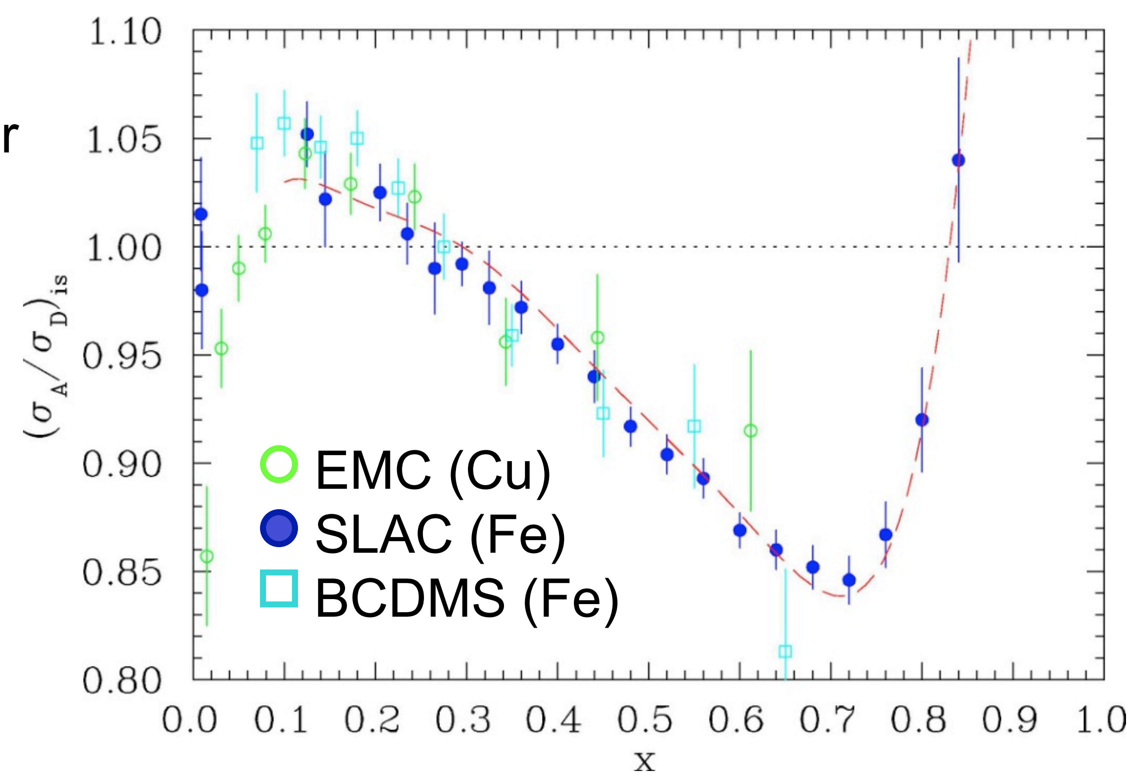
Measurements of F_2^A / F_2^D (EMC, SLAC, BCDMS,…) have shown the naïve expectation is *wrong* - quark distributions are modified in nuclei.

Observed properties:

1. x-dependence same for all A

Shadowing: *x<0.1*
Anti-shadowing: *0.1<x<0.3*
EMC effect: *x>0.3*

2. Size of EMC effect depends on A (i.e. minimum at x=0.7



EMC Effect Model Issues

1. Conventional nuclear physics based explanations (convolution calculations)
   - Fermi motion alone clearly not sufficient
   - Early attempts to combine Fermi motion effects and binding were fairly simplistic
   - Even more sophisticated approaches (spectral function) fail unless one includes "nuclear pions"

     Size of contributions from nuclear pions typically used in DIS calculations inconsistent with nuclear dependence of Drell-Yan

2. "Exotic" effects
   - Medium effects on quark distributions themselves → dynamical rescaling, multiquark clusters, etc.

→ Uncertainties in ***1*** make it difficult to determine what role mechanisms in ***2*** play in observed EMC effect

JLab Experiment E03-103

Measurement of the EMC Effect in light nuclei (^{3}He and ^{4}He) and at large *x*

→^{3}He, ^{4}He amenable to calculations using "exact" nuclear wave functions

→Large x dominated by binding, conventional nuclear effects

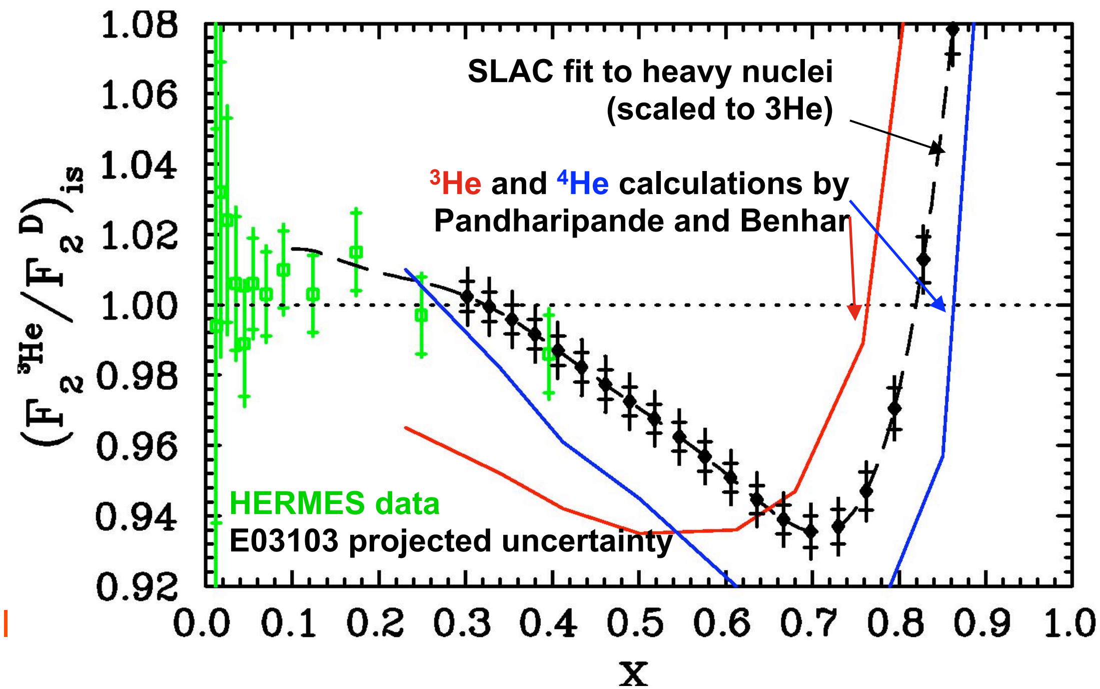
A(e,e') at 5.77 GeV in Hall C

→Targets: H, ^{2}H, ^{3}He, ^{4}He, Be, C, Cu, Au

→Six angles to measure Q^2 dependence

Spokespersons: DG and J. Arrington

Graduate students: J. Seely and A. Daniel

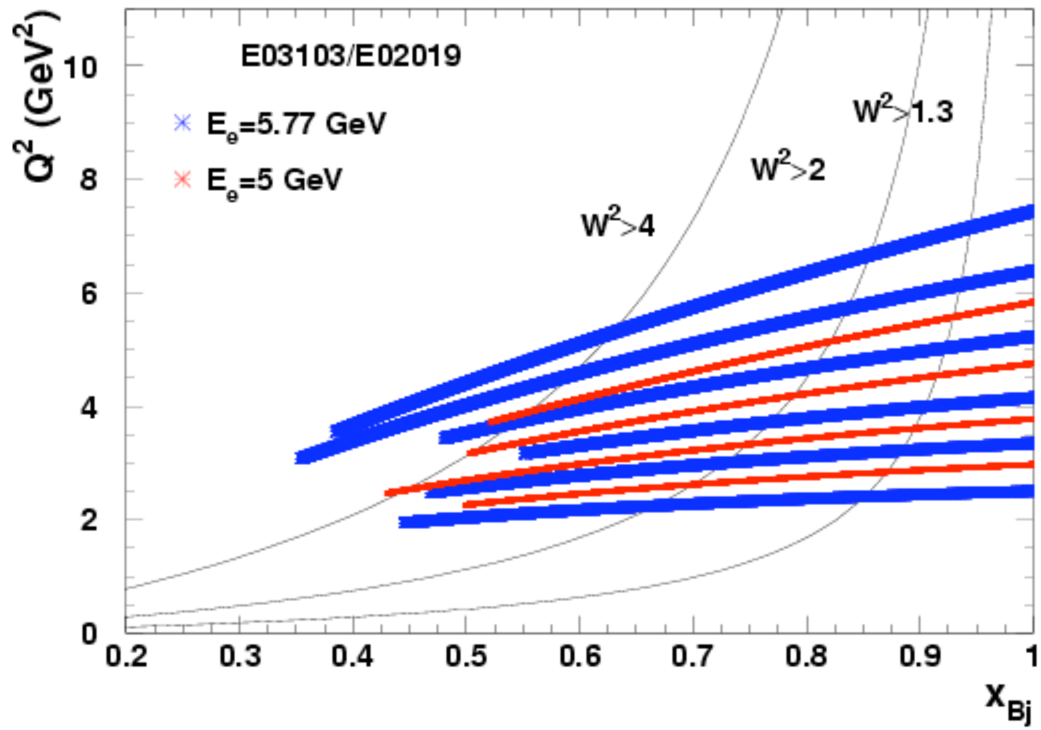


Deep Inelastic Scattering at low W

Canonical DIS regime:

$Q^2 > 1$ GeV^2 ***AND***
$W^2 > 4$ GeV^2

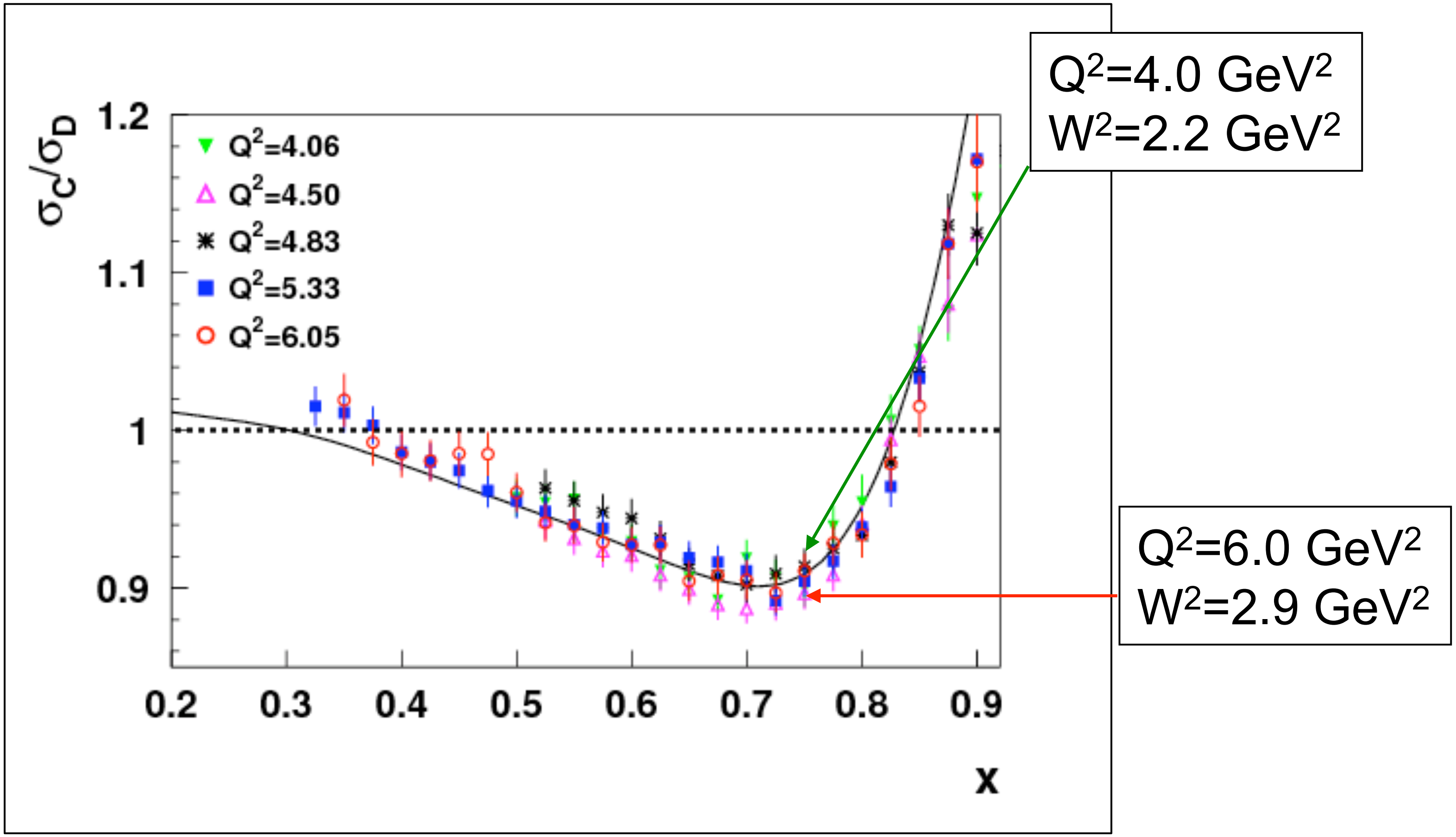
→ Scattering from "quarks" in the nucleon or nucleus



- At JLab, we have access to large Q^2, and $W^2>4$ GeV^2 up to $x=0.6$
- At x>0.6, we are in the "resonance region" → excited, bound states of the nucleon, but Q^2 is still large
- Are we really sensitive to quarks in this regime?

Carbon/^{2}H Ratio and Q^2 Dependence

E03-103 Results



At larger angles (Q^2) → ratio appears to scale to very large x

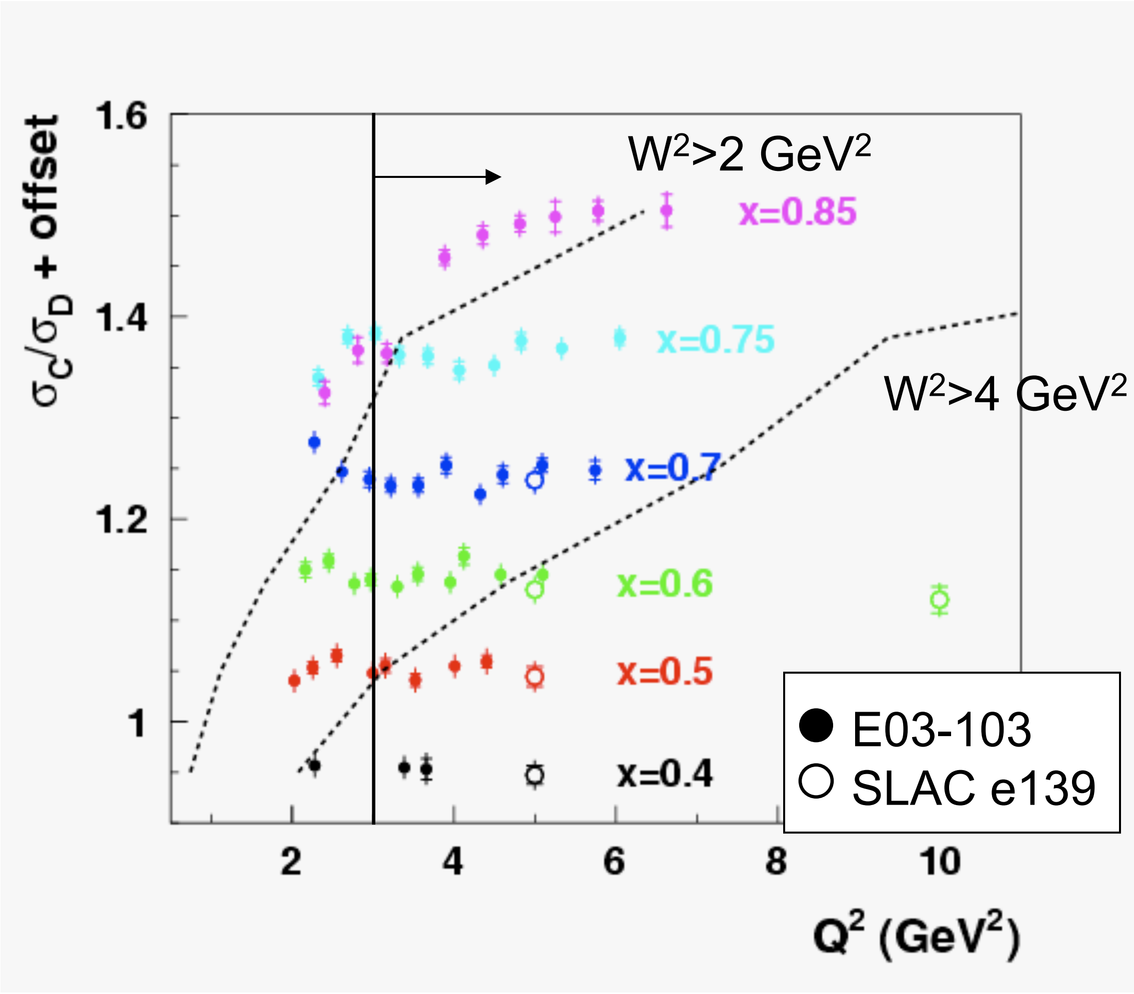
More detailed look at scaling

C/D ratios at fixed x are Q^2 independent for

$W^2>2$ GeV^2 and $Q^2>3$ GeV^2

Limits E03-103 coverage to x=0.85

Ratios at larger x will be shown, but should be taken cautiously



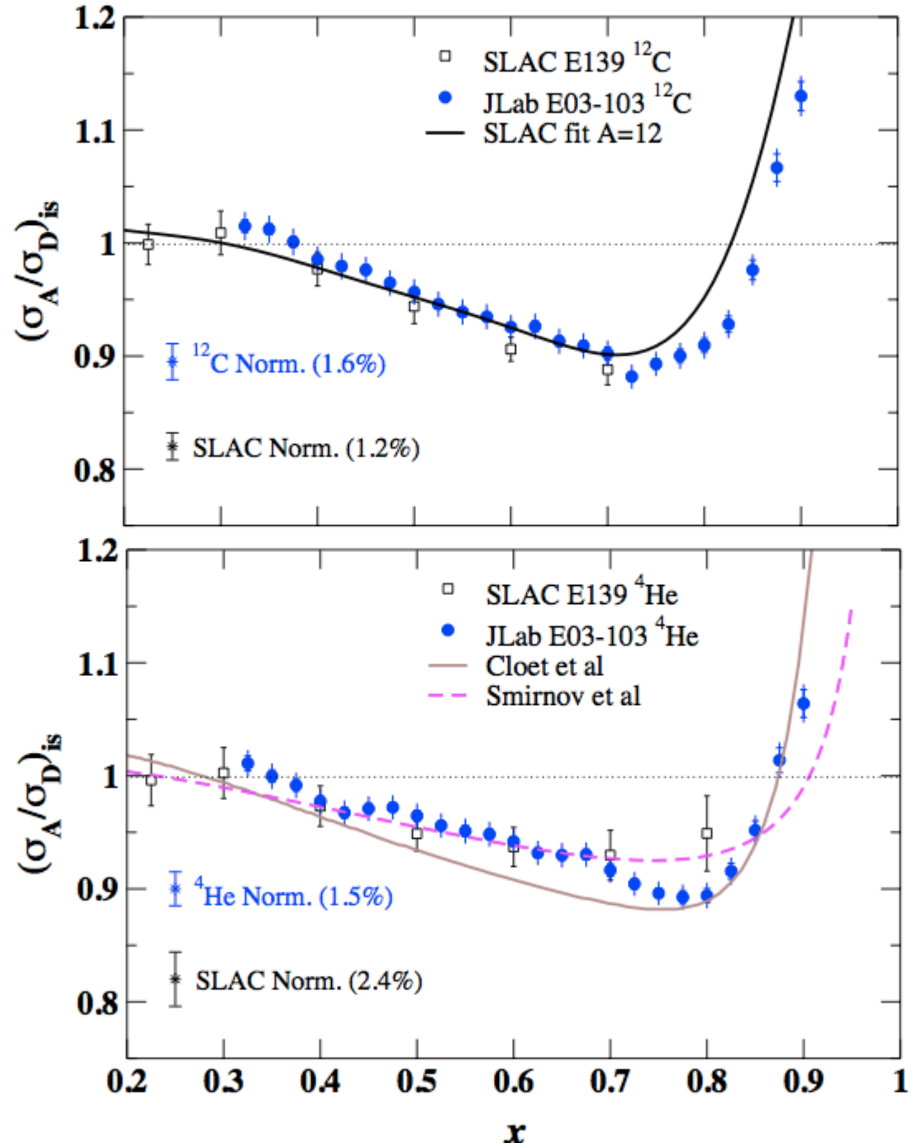
Results for C and ^{4}He

JLab results consistent with SLAC E139

→ Improved statistics (C and He) and systematic errors (He)

Models shown do a reasonable job describing the data.

But very few real few-body calculations
(most neglect structure, scale NM)

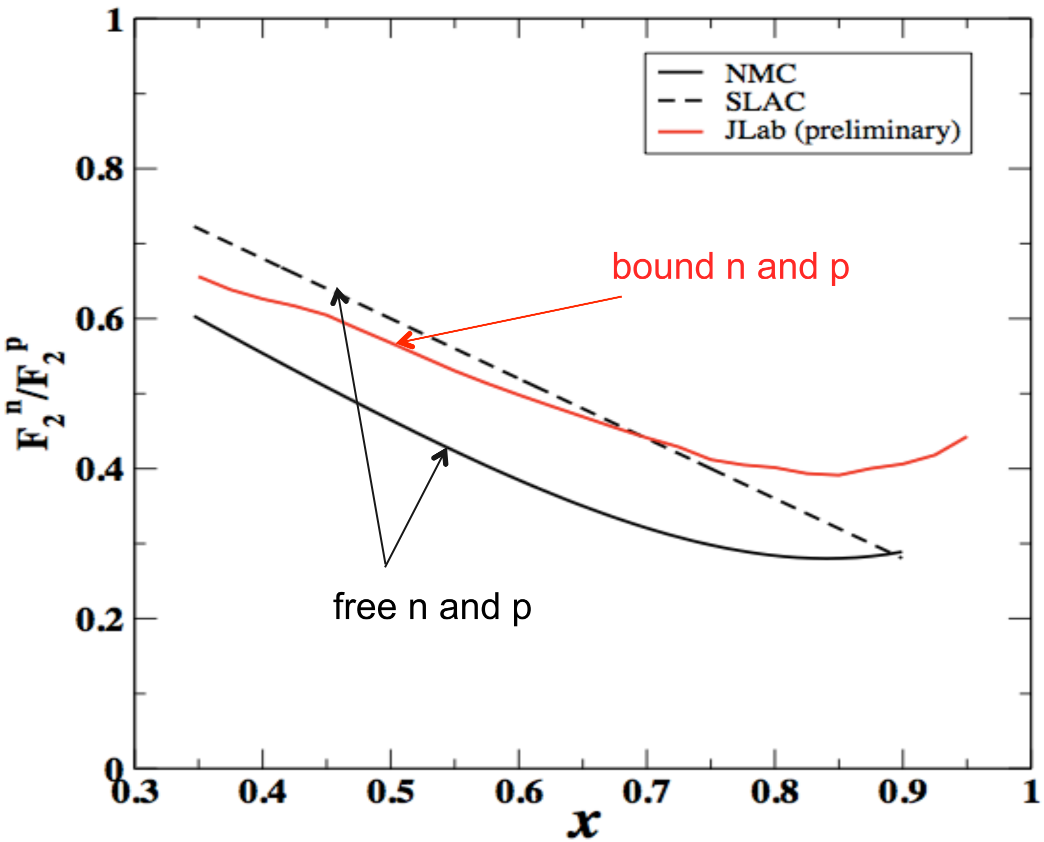


Isoscalar Correction

In the case of nuclei where N≠Z, need to remove the “trivial” change in nuclear cross section due to $\sigma_n \neq \sigma_p$

$$\left(\frac{\sigma_A}{\sigma_D}\right)_{ISO} = \left(\frac{\sigma_A}{\sigma_D}\right)_{MEAS} \frac{\frac{A}{2}\left(1+\frac{\sigma_n}{\sigma_p}\right)}{Z+(A-Z)\frac{\sigma_n}{\sigma_p}}$$

Historically, experiments have used “free” n/p
→ We use “bound” n/p, evaluated at our kinematics



New extraction from **J. Arrington, F. Coester, R.J. Holt, T.-S.H. Lee**, J.Phys.G36, 025005 (2009)

Isoscalar Correction

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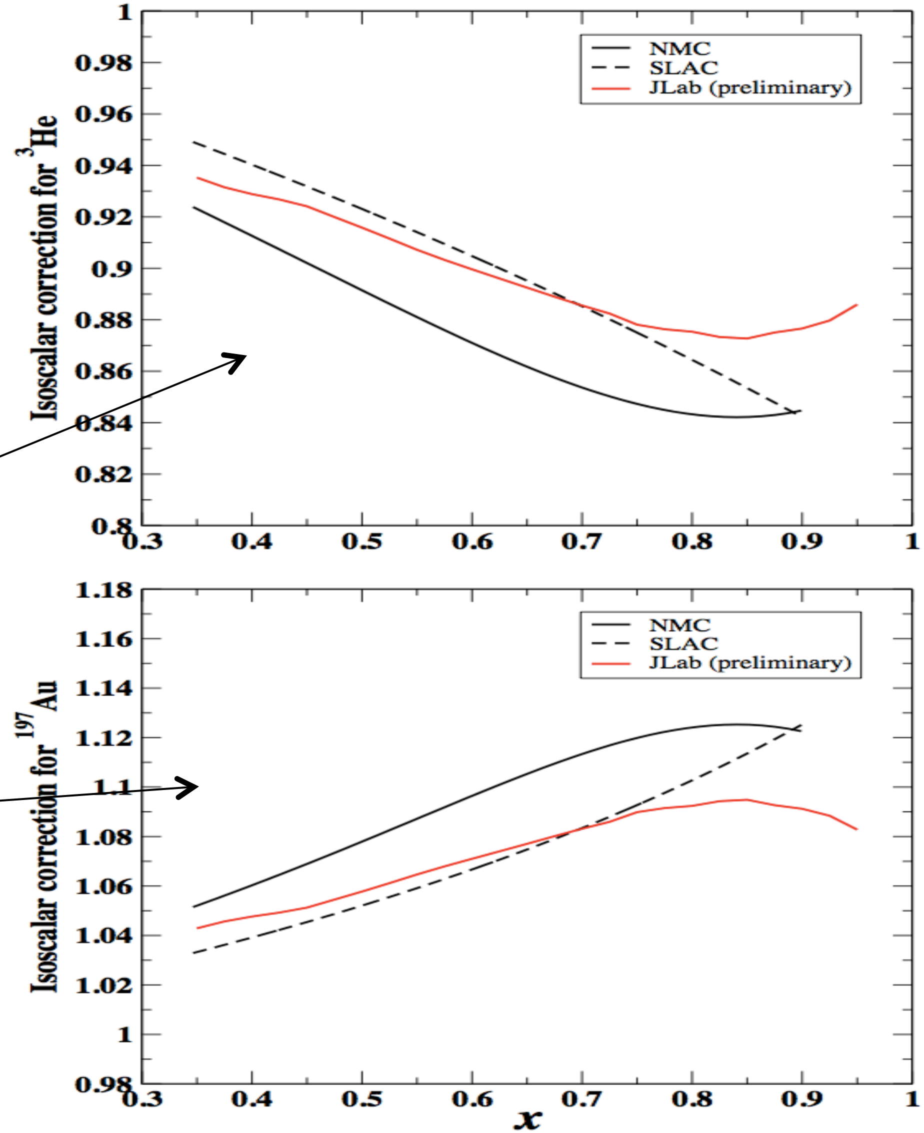
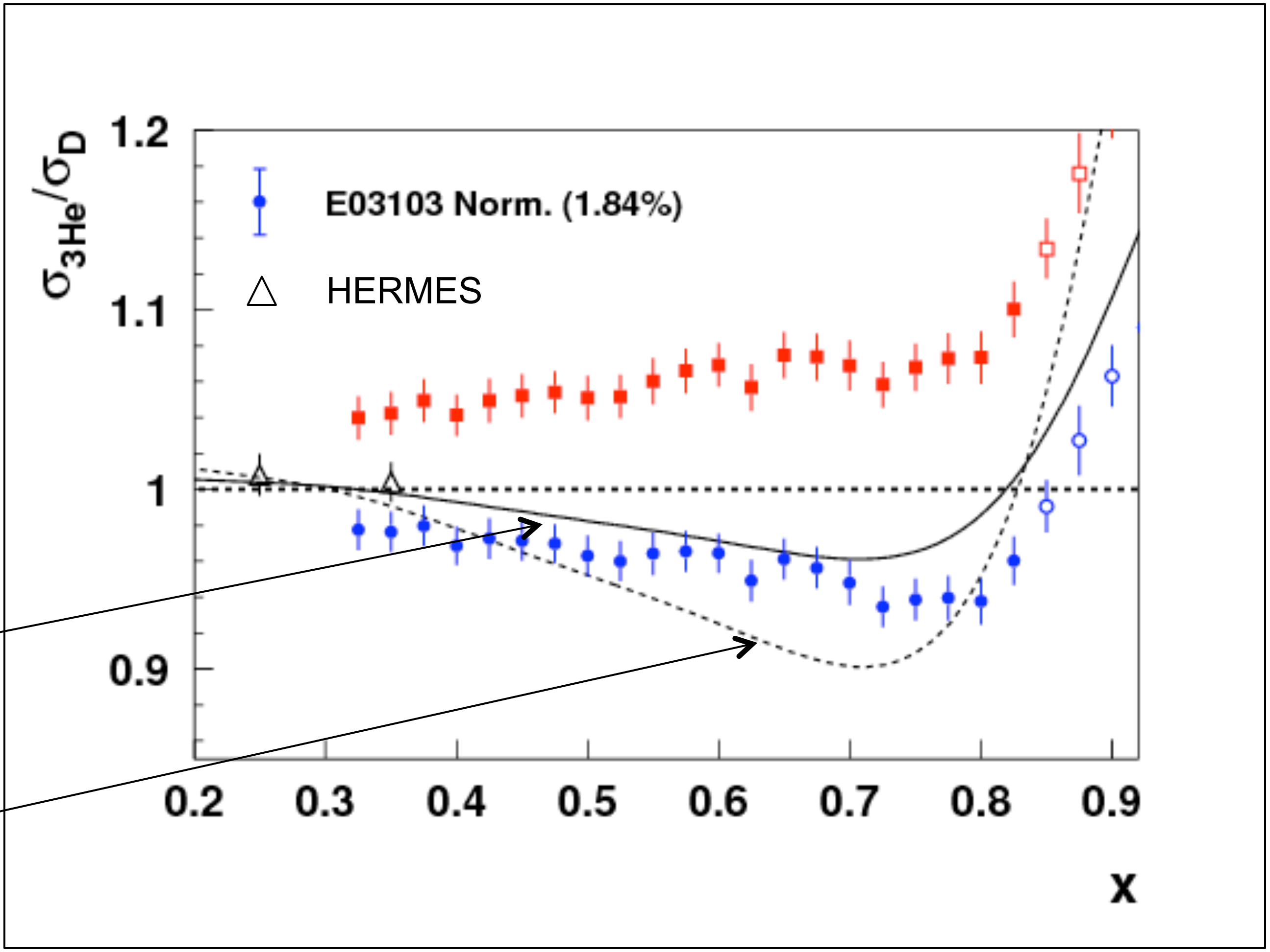
^3He

Au



EMC Effect in ^{3}He

Large correction due to "proton excess"



SLAC fit; A=3

SLAC fit; A=12

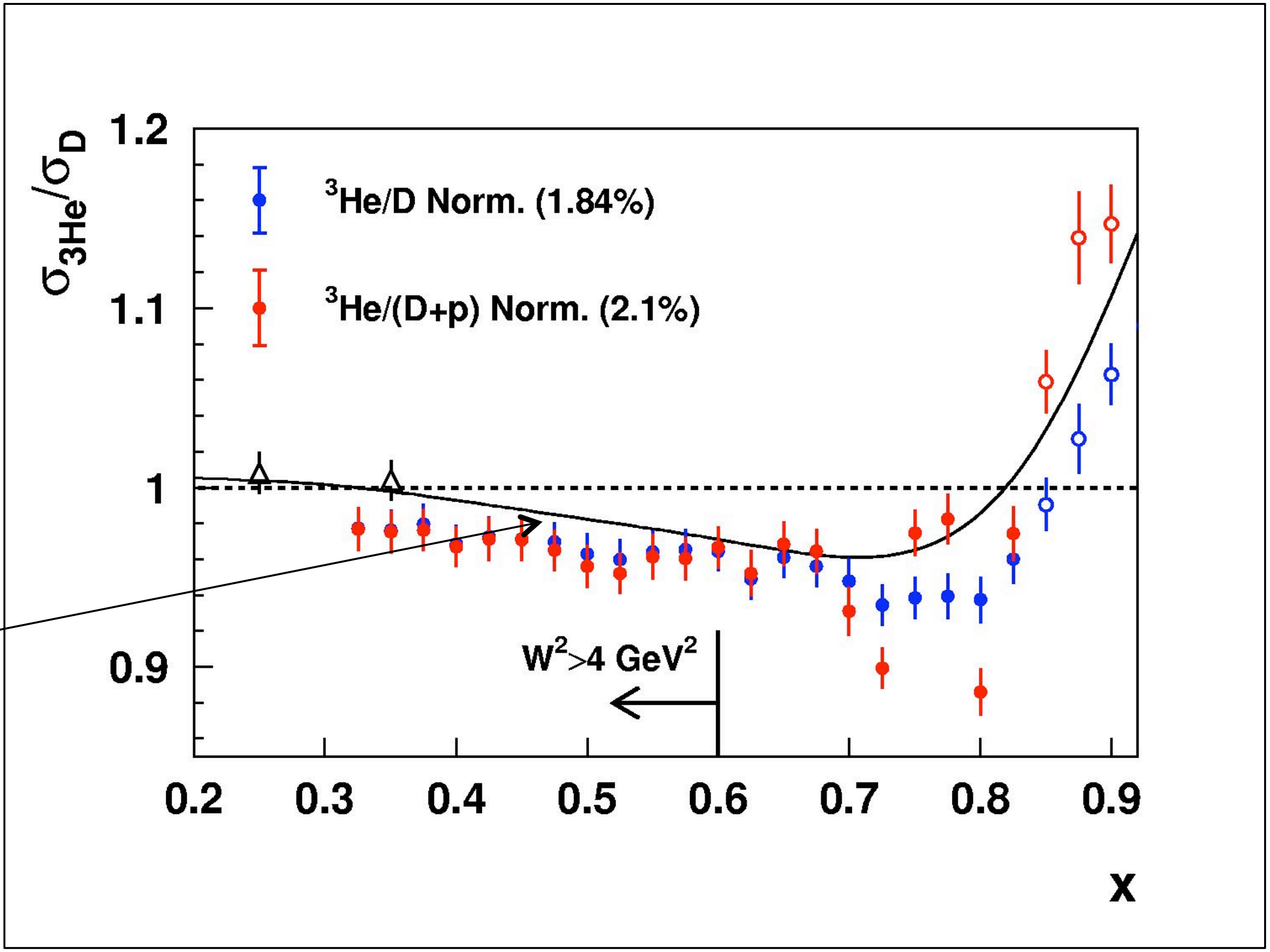
J. Seely et al, PRL 103, 202301 (2009)

EMC Effect in ^{3}He

Large correction due to "proton excess"

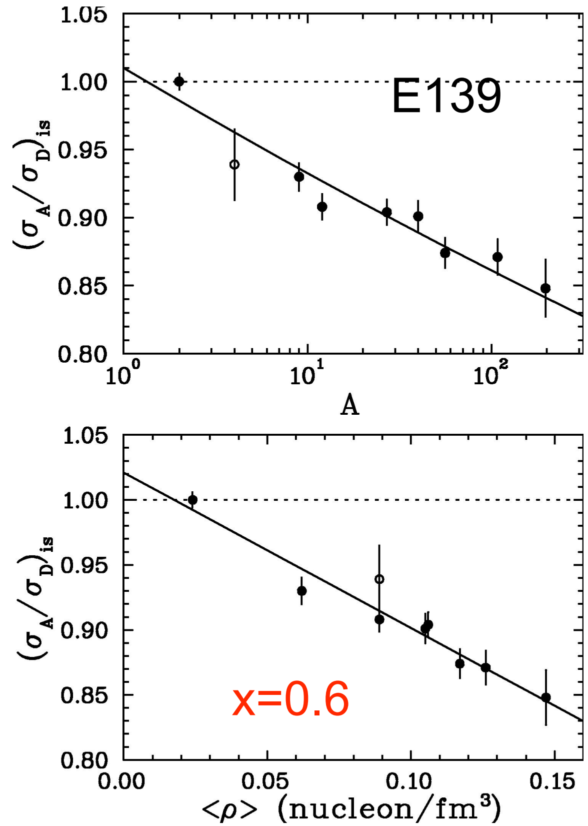
→ Test validity of isoscalar correction using ^{3}He/(D+p) for x<0.6

SLAC fit; A=3

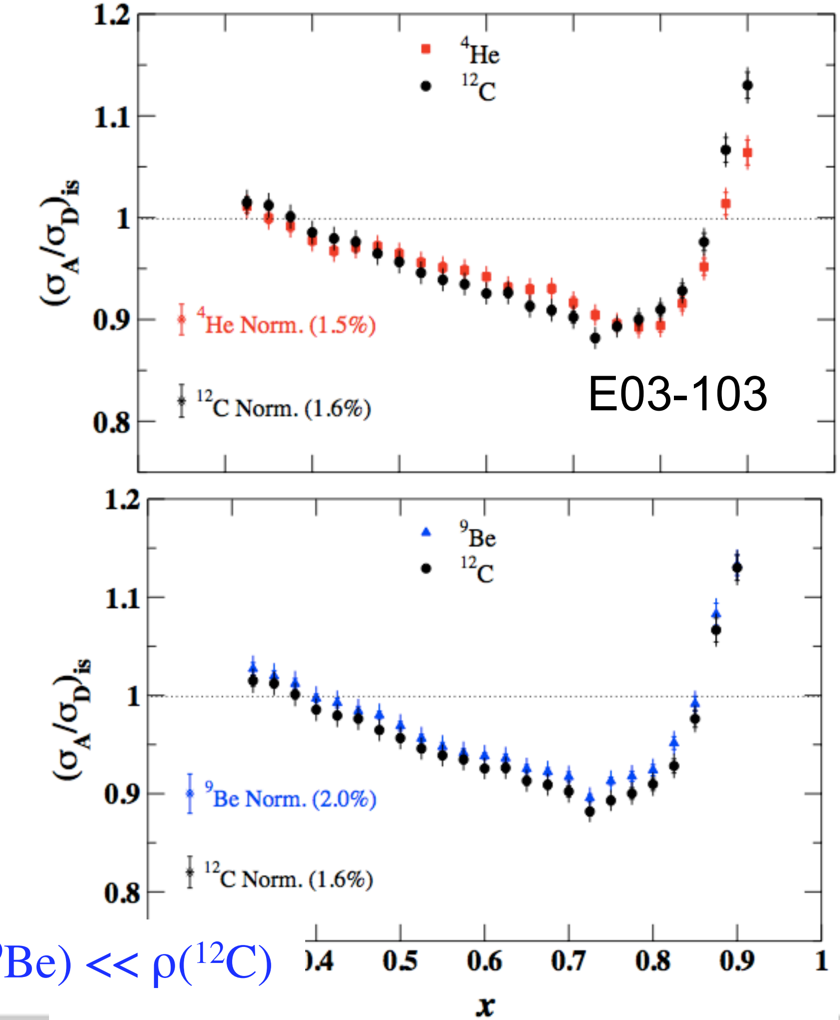


Nuclear Dependence

Does EMC effect scale with A ($A^{-1/3}$) or average nuclear density (ρ)?



Magnitude of the EMC effect for C and ^{4}He very similar, and $\rho(^4He) \sim \rho(^{12}C)$

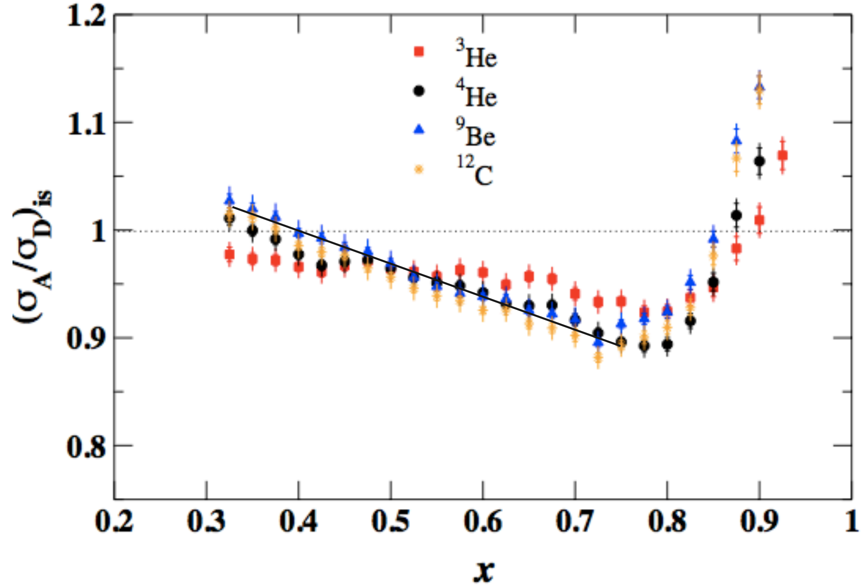


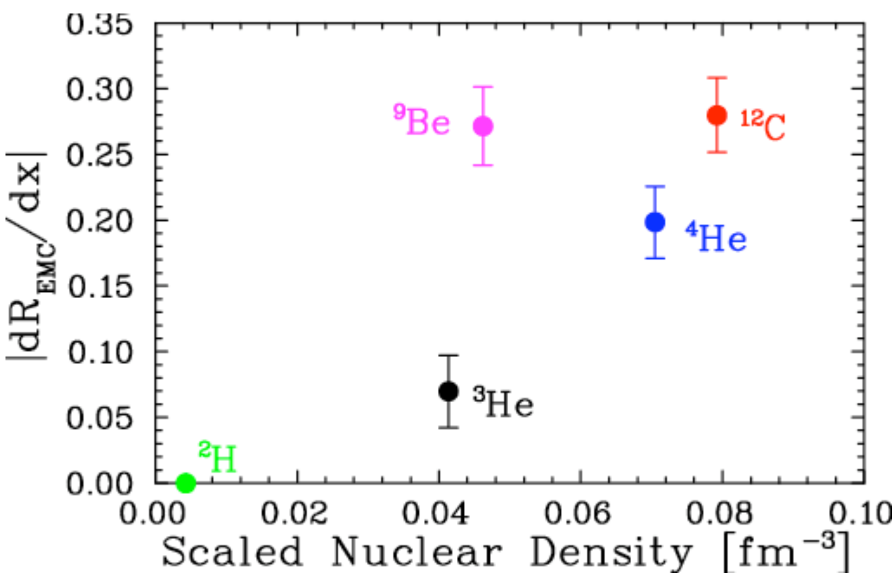
Also similar for Be and C, but $\rho(^9Be) << \rho(^{12}C)$

Nuclear Dependence

Scale uncertainties make it difficult to distinguish between A and ρ dependence at particular x

→ Fit slope between x=0.35-0.7 as another measure of the magnitude of the EMC effect





Density determined from ab initio few-body calculation
S.C. Pieper and R.B. Wiringa,,Ann. Rev. Nucl. Part. Sci 51, 53 (2001)]

Density scaled by (A-1)/A to remove contribution from struck nucleon

Data show smooth behavior as density increases…

except for ^{9}Be

Nuclear Dependence

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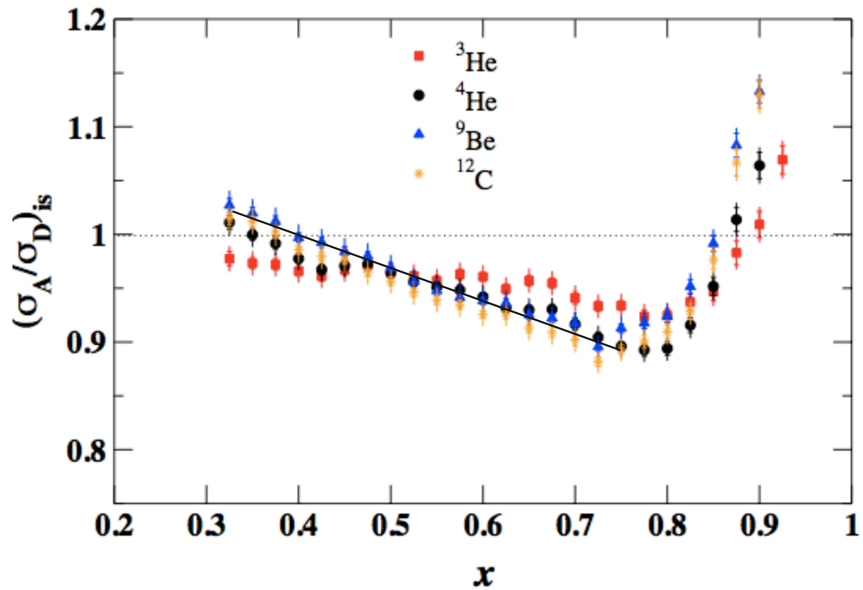
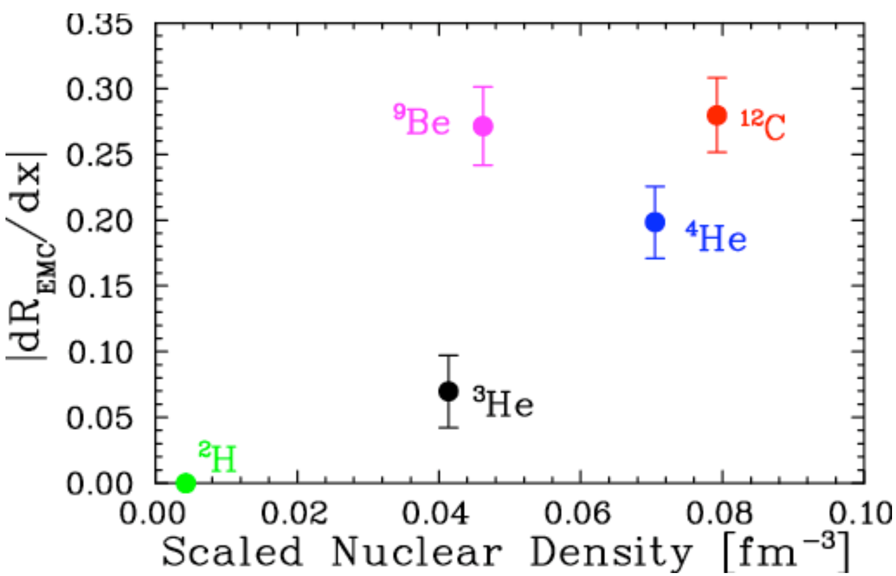
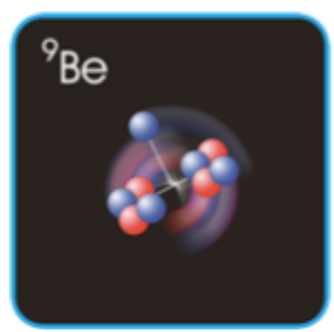
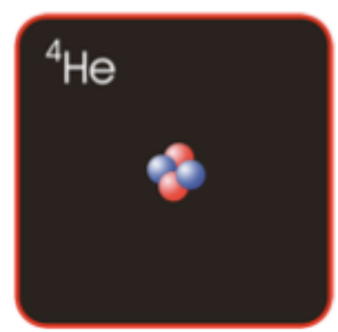




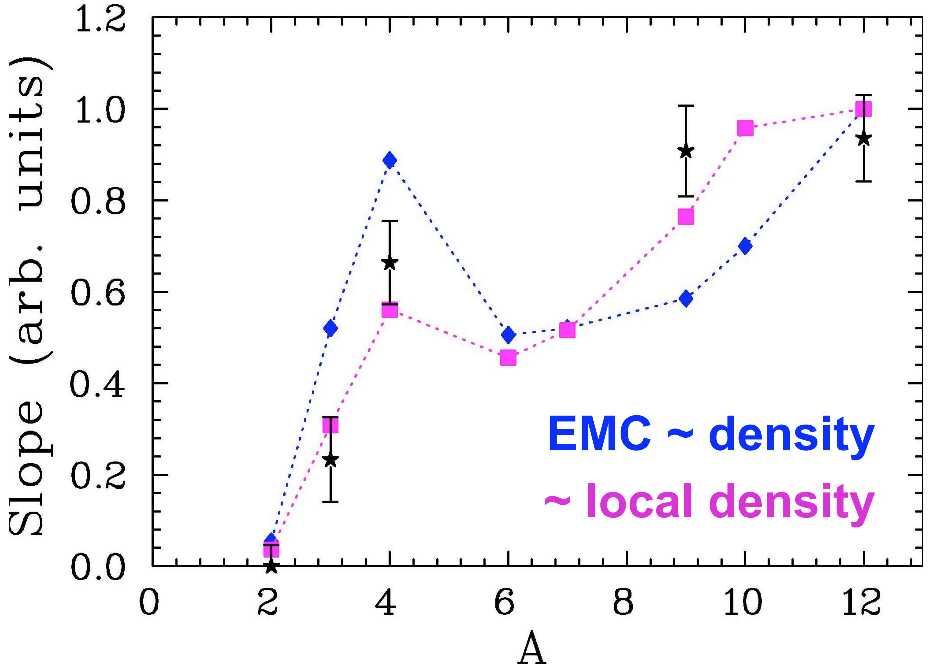
^{9}Be has low average density, but large component of structure is 2α+n most nucleons in tight, α-like configurations

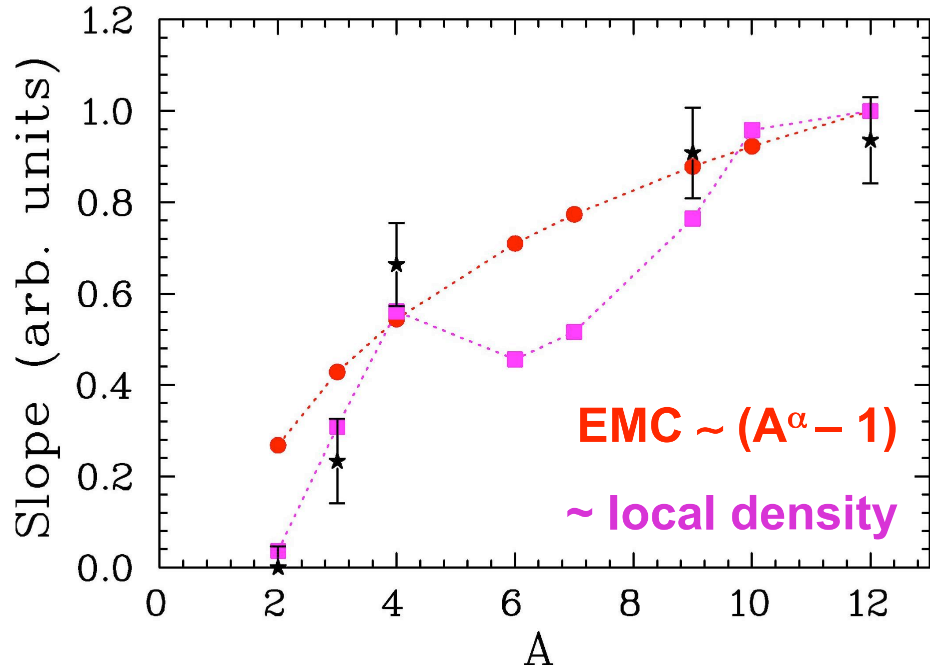




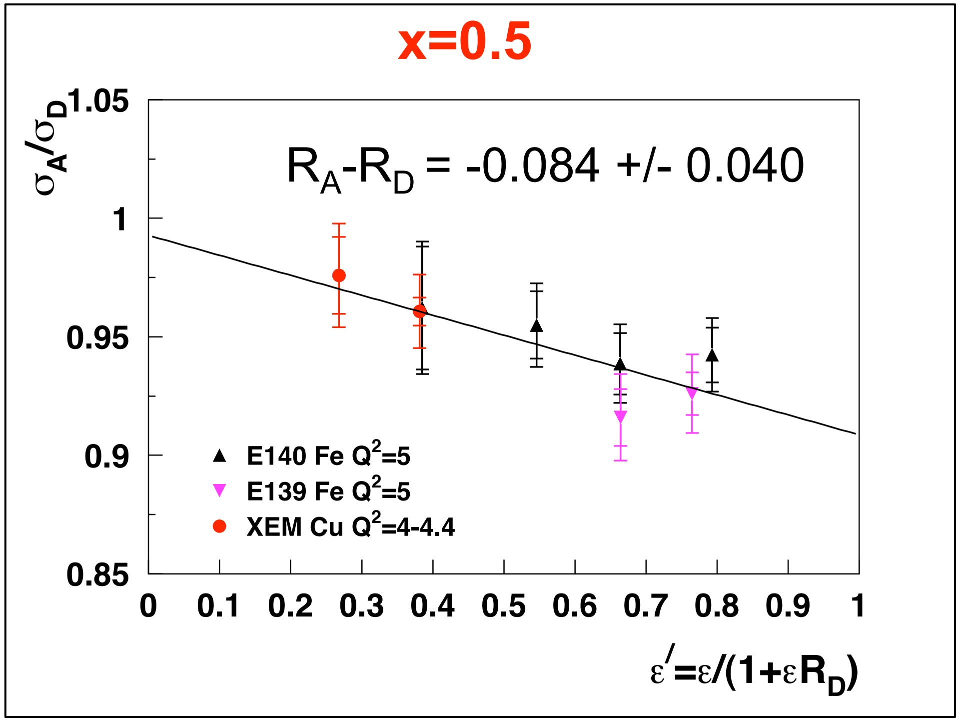
E10-008: Additional light nuclei

- 12 GeV experiment that will map out A-dependence in more detail
  - Very hard to explain large ^{3}He – ^{9}Be difference in ρ-dependent fit
  - Hard to explain large ^{3}He – ^{4}He difference in mass-dependent fit
    - Modified fit does somewhat better, but worse for heavier nuclei
  - "Local density" works well, provides different predictions
    - Use ab initio GFMC calc. of 2-body correlation function to calculate average nucleon 'overlap'





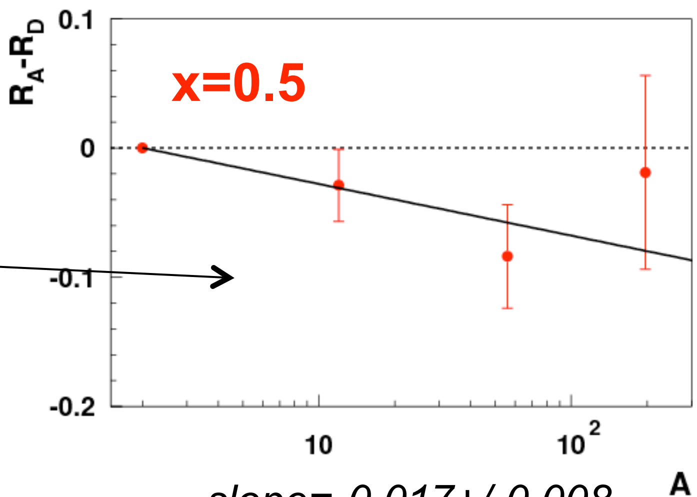
Nuclear Dependence of R?



SLAC E140 results demonstrated no evidence for nuclear dependence of $R=\sigma_L/\sigma_T$ at large x(>0.2)

→ Applying *Coulomb corrections* to SLAC data and combining with Hall C data suggest non-trivial nuclear dependence at large x

SLAC E139/E140, Hall C combined for carbon, Fe/Cu, gold



slope=-0.017+/-0.008

[P. Solvignon et al, arXiv:0906.2839 (AIP Conf. Proc.)]

→ longer publication in progress

Summary

- New data from E03-103 provide new precise data on EMC effect in light nuclei
  - Results suggest that EMC effect depends on ***local*** nuclear environment rather than “average” properties
- Few-body nuclei provide an excellent opportunity to attempt calculations incorporating detailed nuclear structure
- Precision at large x (where Fermi motion dominates) tests underlying model of nucleus
- Approved 12 GeV experiment will expand set to more few-body nuclei
- E03-103 heavy target data suggest some interesting effects as well – stay tuned

Acknowledgements

- Aji Daniel and Jason Seely (students)
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- Patricia Solvignon (former post-doc – now Hall C staff)
- Steve Pieper and Bob Wiringa for help with few-body nuclear density calculations