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

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Outline

- The EMC Effect
  - Review of measurements
  - Limitations of the existing data
- JLab Experiment E03-103
  - Motivation
  - "Preliminary" results

jeffy lab

"Beam in 30 minutes or it's free"

Quarks in the Nucleus

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

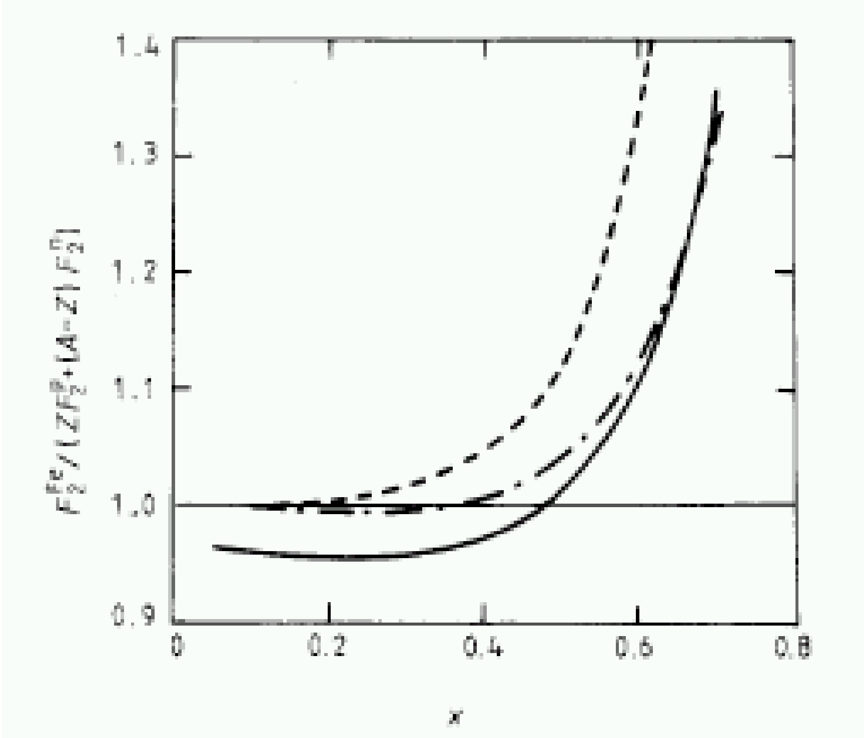
$$F_2^A(x) = ZF_2^p(x) + (A-Z)F_2^n(x)$$

- 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

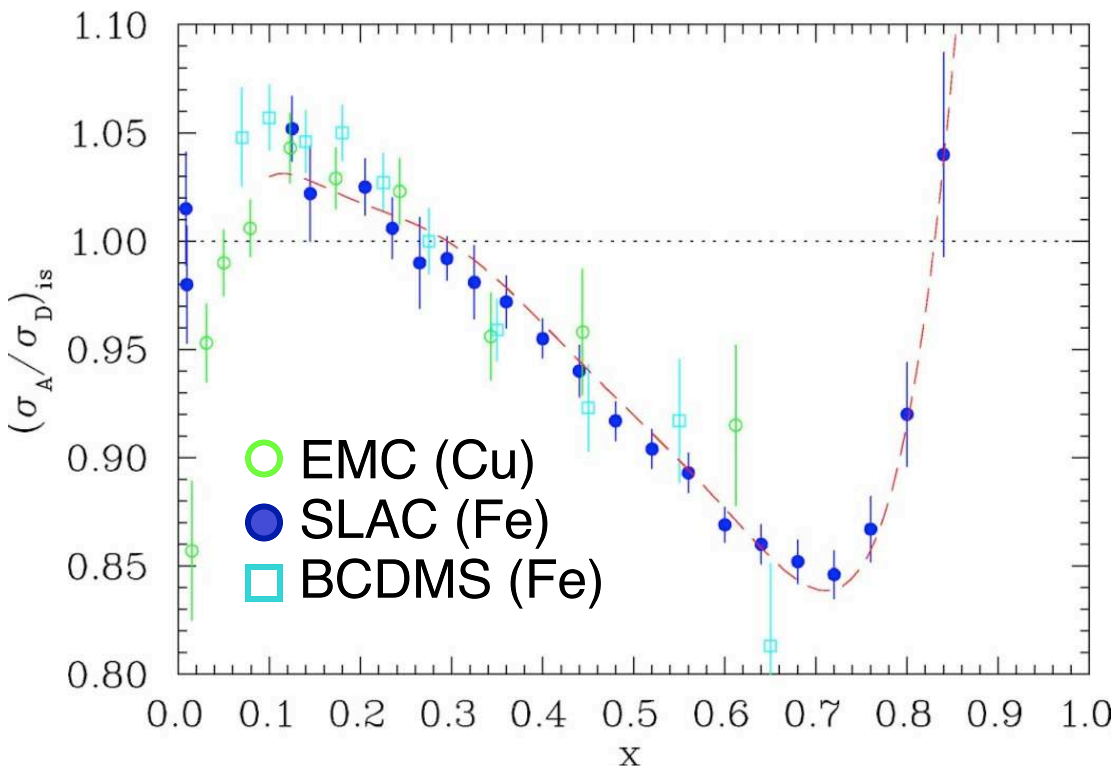
Measurements of F_2^A / F_2^D (EMC, SLAC, BCDMS,…) have shown the naïve expectation is *wrong* - quark distributions are modified in nuclei.

Observed properties:

1. *x*-dependence is the same for all A

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

2. Size of the effect depends on *A* (i.e., minimum at *x=0.7*)



EMC Effect Measurements at Large x

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

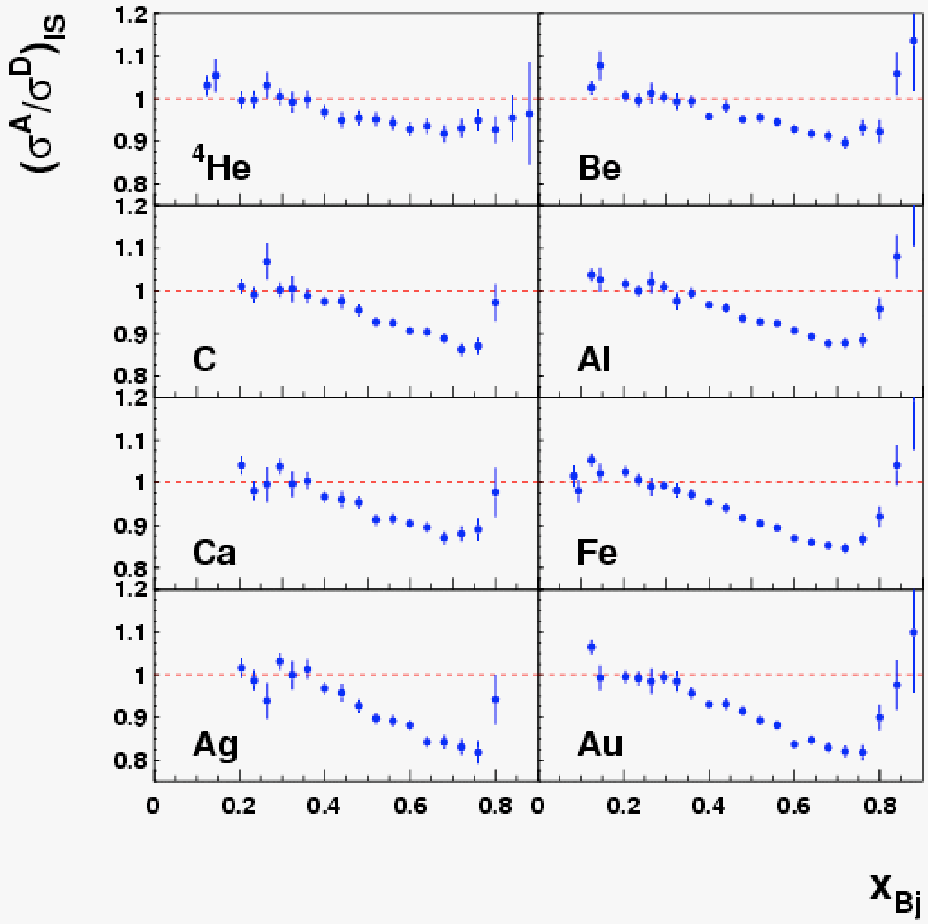
Measured σ_A/σ_D for A=4 to 197
^{4}He, ^{9}Be, C, ^{27}Al, ^{40}Ca, ^{56}Fe, ^{108}Ag, ^{197}Au

Size at fixed *x* varies with *A*, but shape (*x* dep.) nearly constant

Potential improvements to existing data

- →Higher precision data for ^{4}He
- →Addition of ^{3}He data
- →Precision data at large *x*

SLAC E139



EMC Effect Model Issues

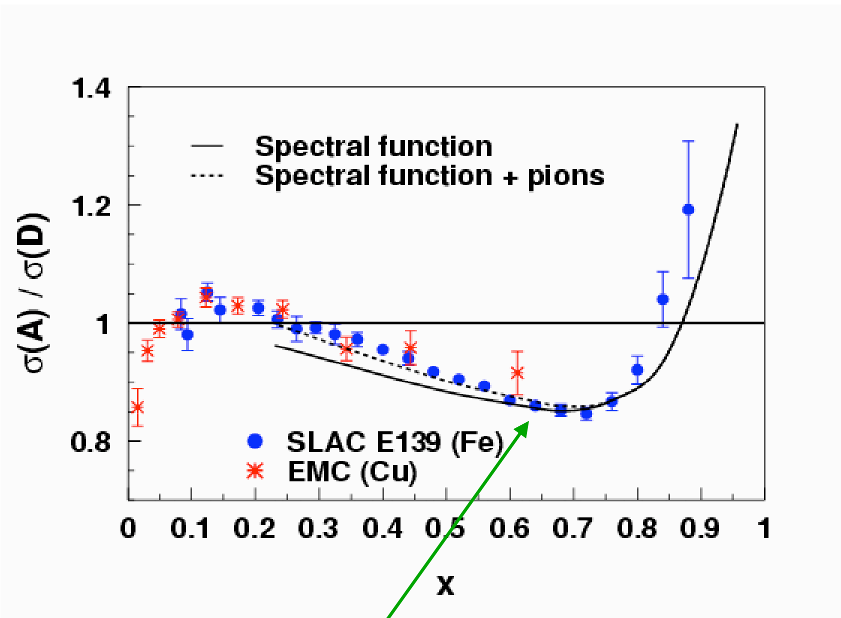
1. Conventional nuclear physics based explanations (convolution calculations)
   - Fermi motion alone clearly not sufficient
   - Early attempts to combine Fermi motion effects and binding were fairly simplistic
   - Even more sophisticated approaches (spectral function) fail unless one includes "nuclear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

EMC Effect Calculations

Benhar, Pandharipande, and Sick
Phys. Lett. B410, 79 (1997)

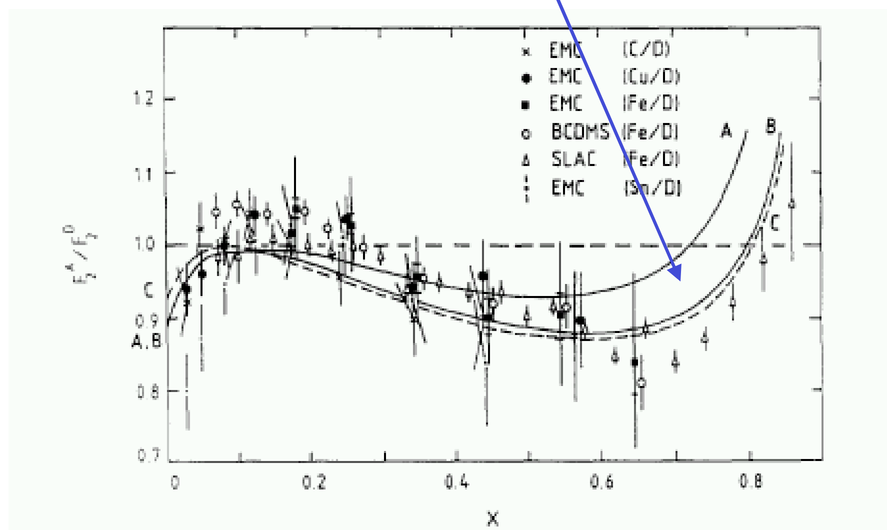


Conventional Models

- Some combination of Fermi motion and binding
- Fermi motion + binding + nuclear pions

Exotic Models

- Dynamical rescaling
- Multiquark clusters



K.E. Lassila and U.P. Sakhatme
Phys. Lett. B209, 343 (1988)

JLab Experiment E03-103

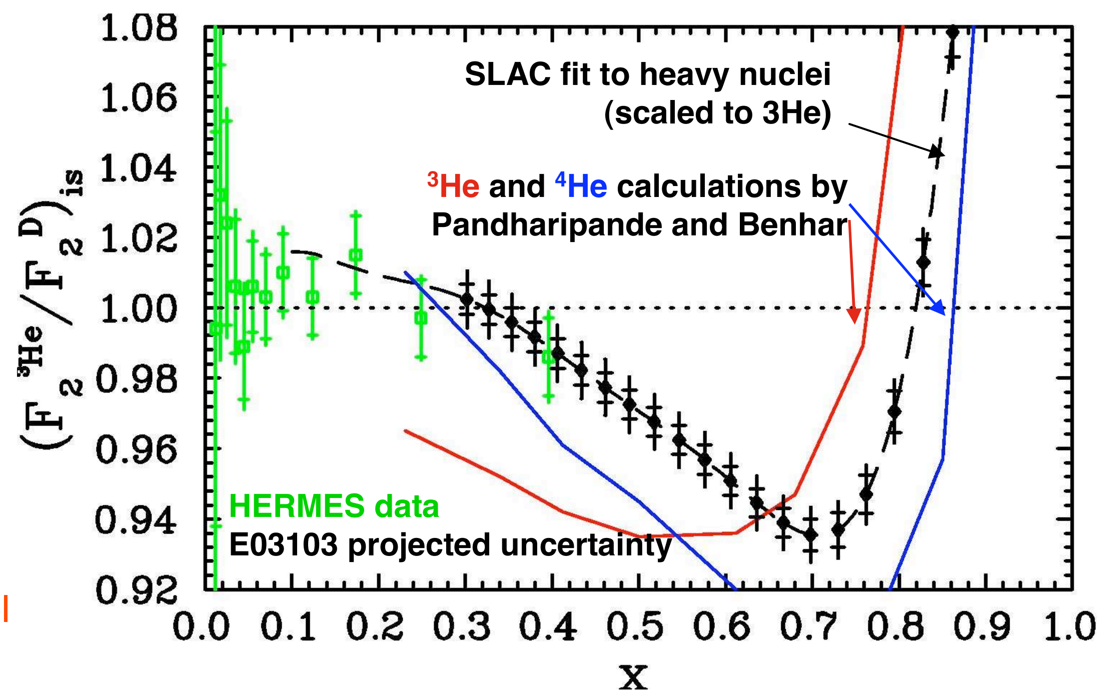
Measurement of the EMC Effect in light nuclei (^{3}He and ^{4}He) and at large *x*

→^{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

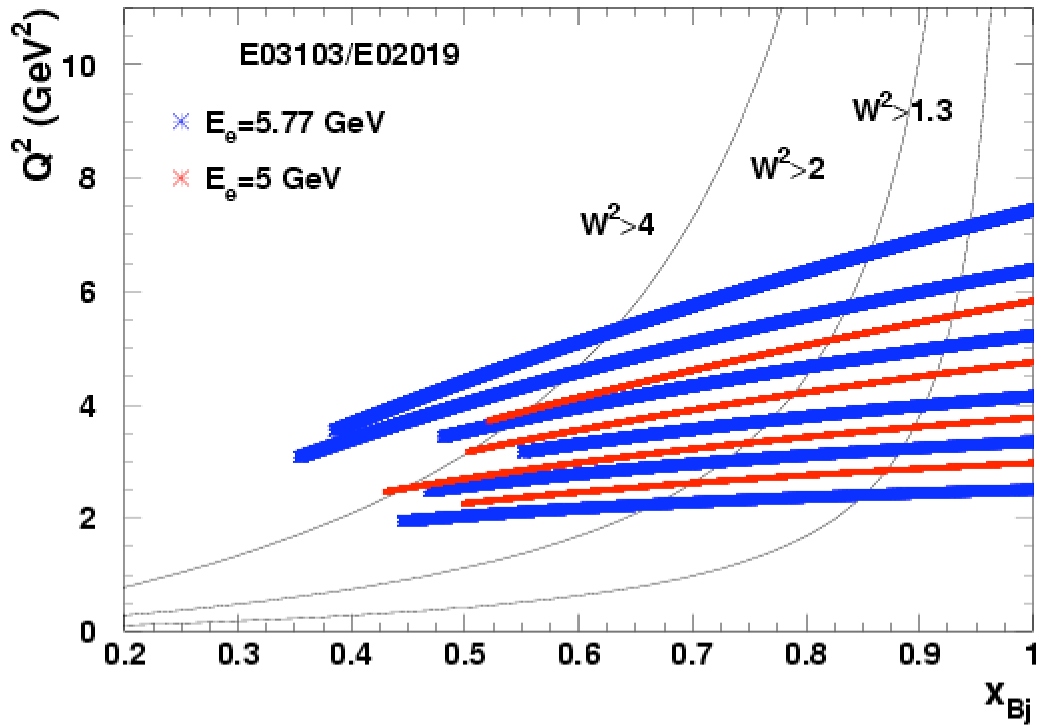


Deep Inelastic Scattering at low W

Canonical DIS regime:

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

→ Scattering from "quarks" in the nucleon or nucleus

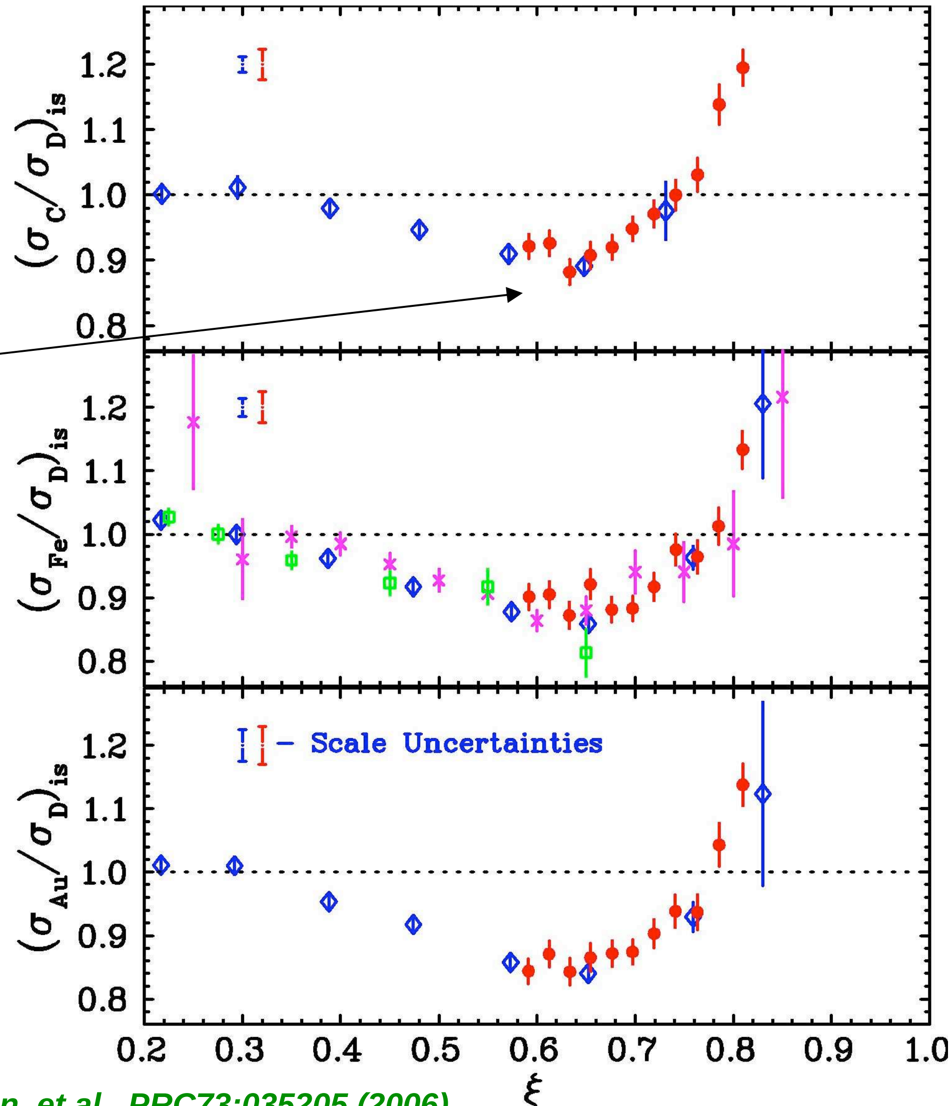


- At JLab, we have access to large Q^2, and $W^2>4$ GeV^2 up to $x=0.6$
- At x>0.6, we are in the "resonance region" → excited, bound states of the nucleon, but Q^2 is still large
- Are we really sensitive to quarks in this regime?

EMC Effect in Resonance Region

JLab E89-008:
Q^2 ~ 4 GeV^2
1.3<W^2<2.8 GeV^2
data in the resonance region
→ In region of overlap agrees well with DIS data

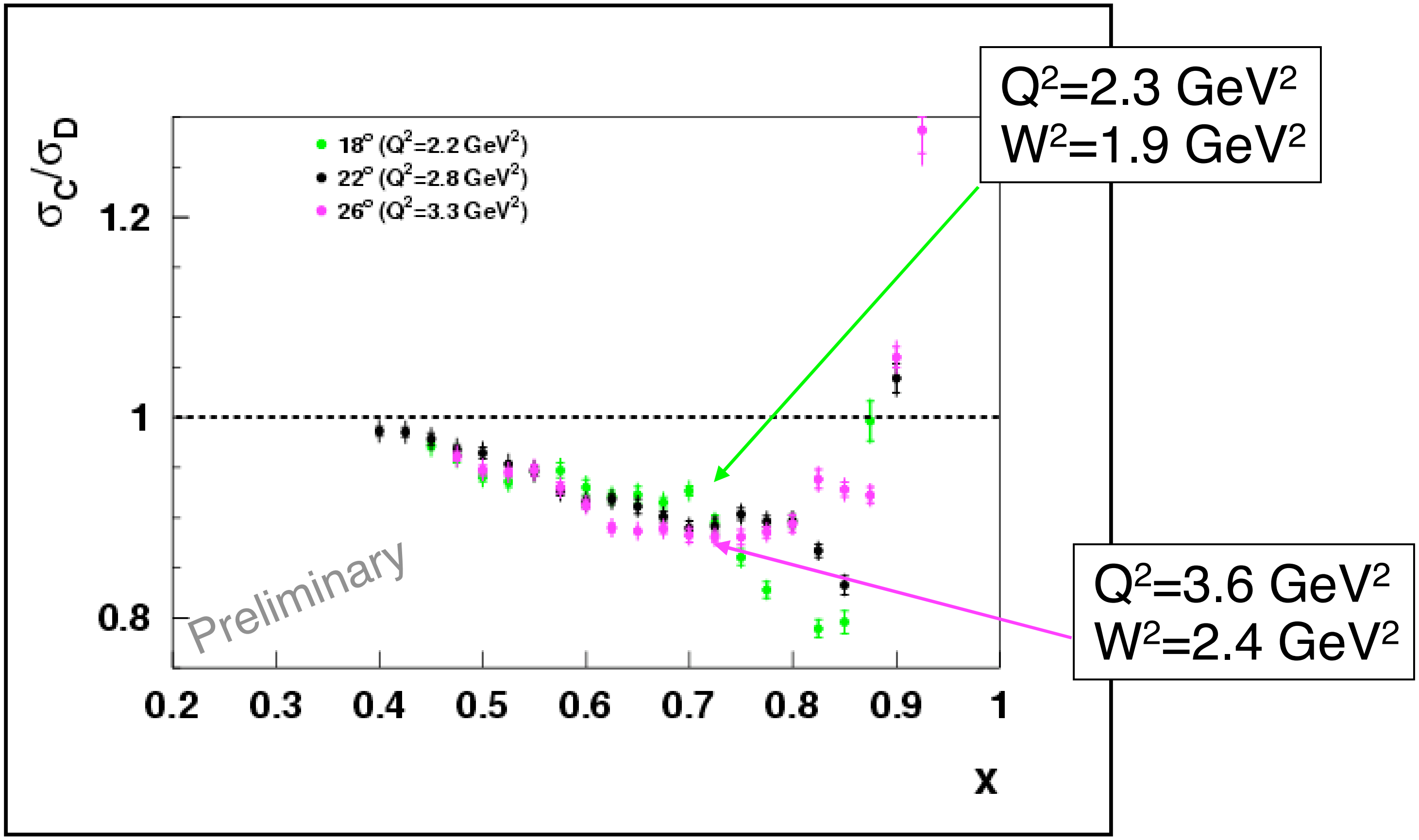
E03-103 data are at higher Q^2, will test scaling with precise measurement of Q^2-dependence



J. Arrington, et al., PRC73:035205 (2006)

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

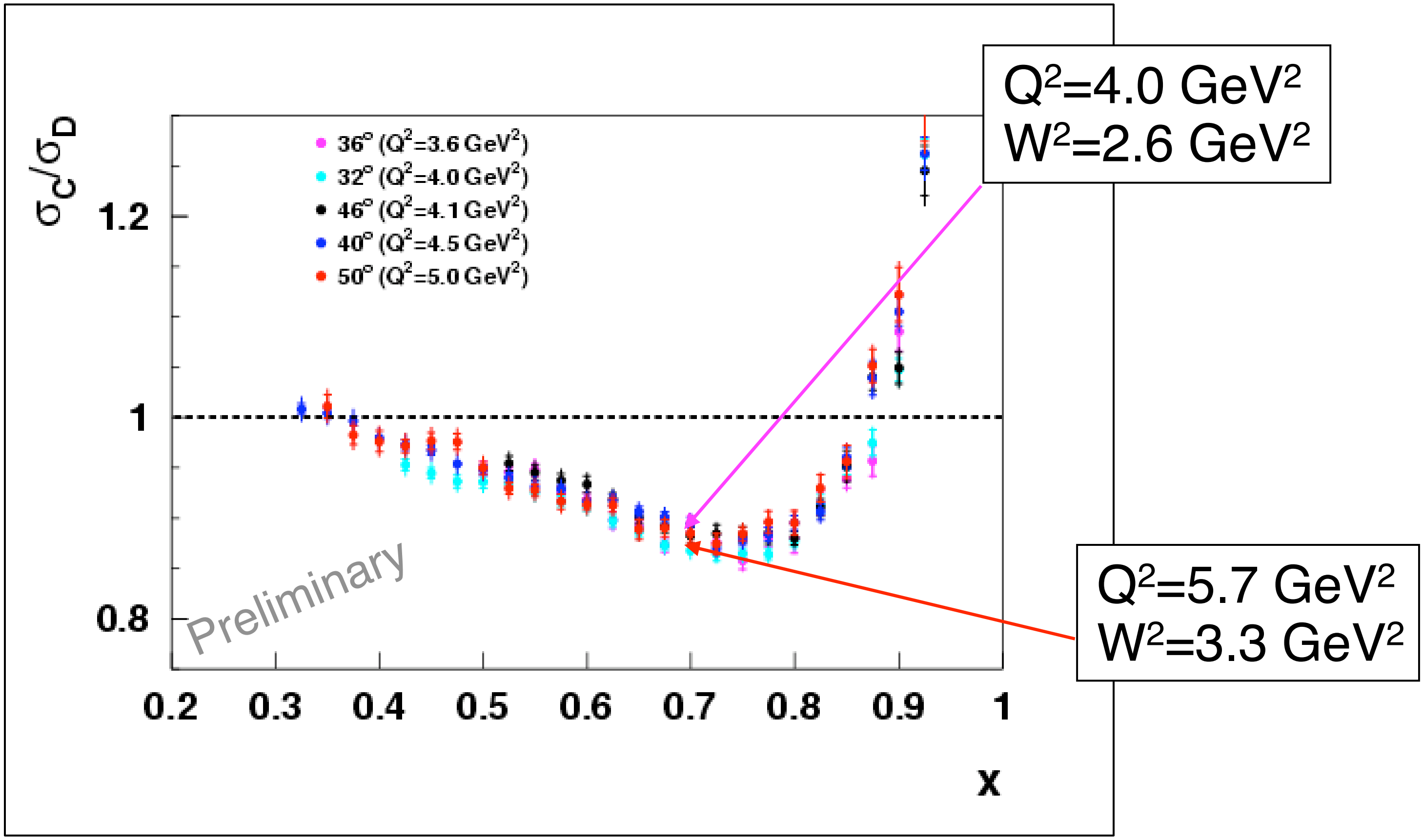
E03-103 Results



Small angle, low Q^2 → clear scaling violations for $x>0.7$, but surprisingly good at lower x

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

E03-103 Results



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

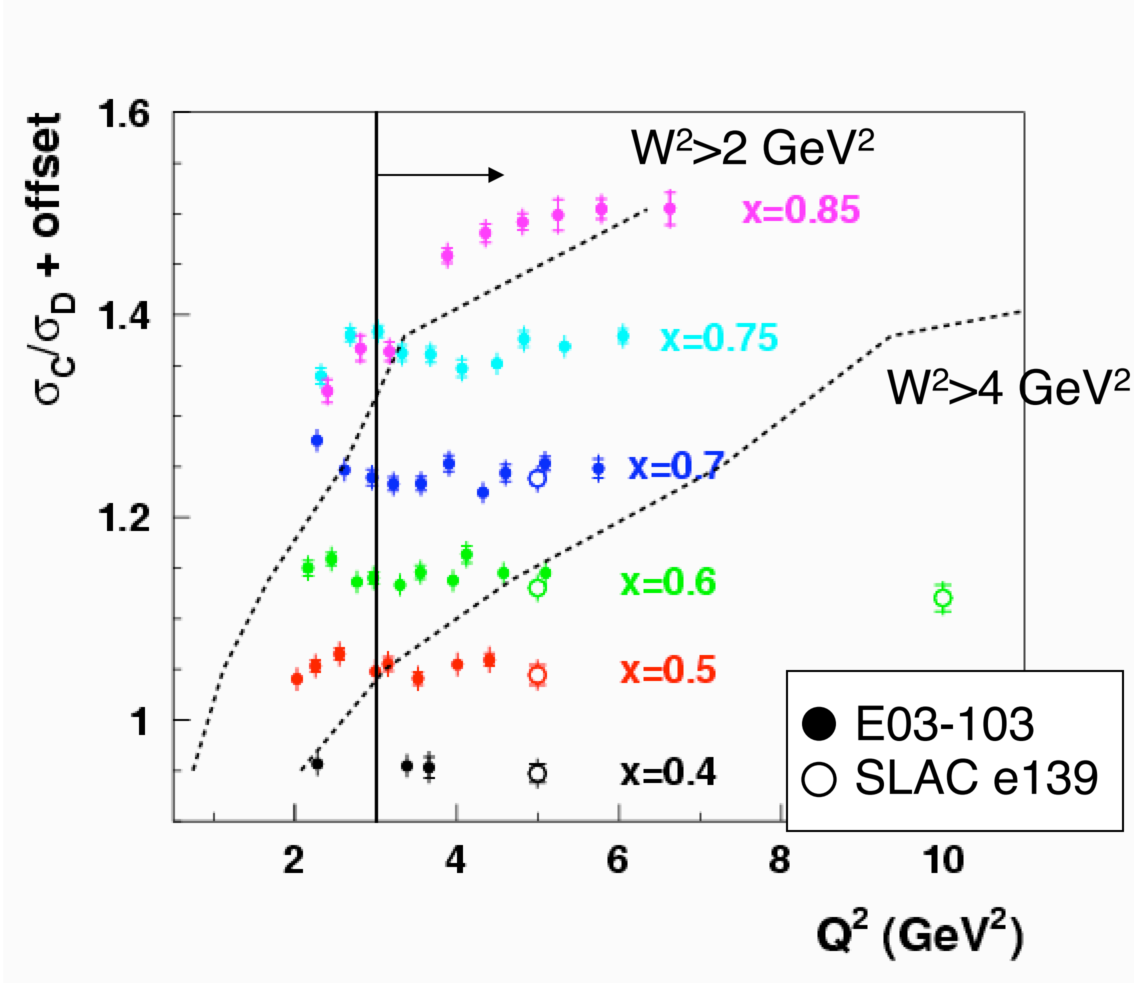
More detailed look at scaling

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

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

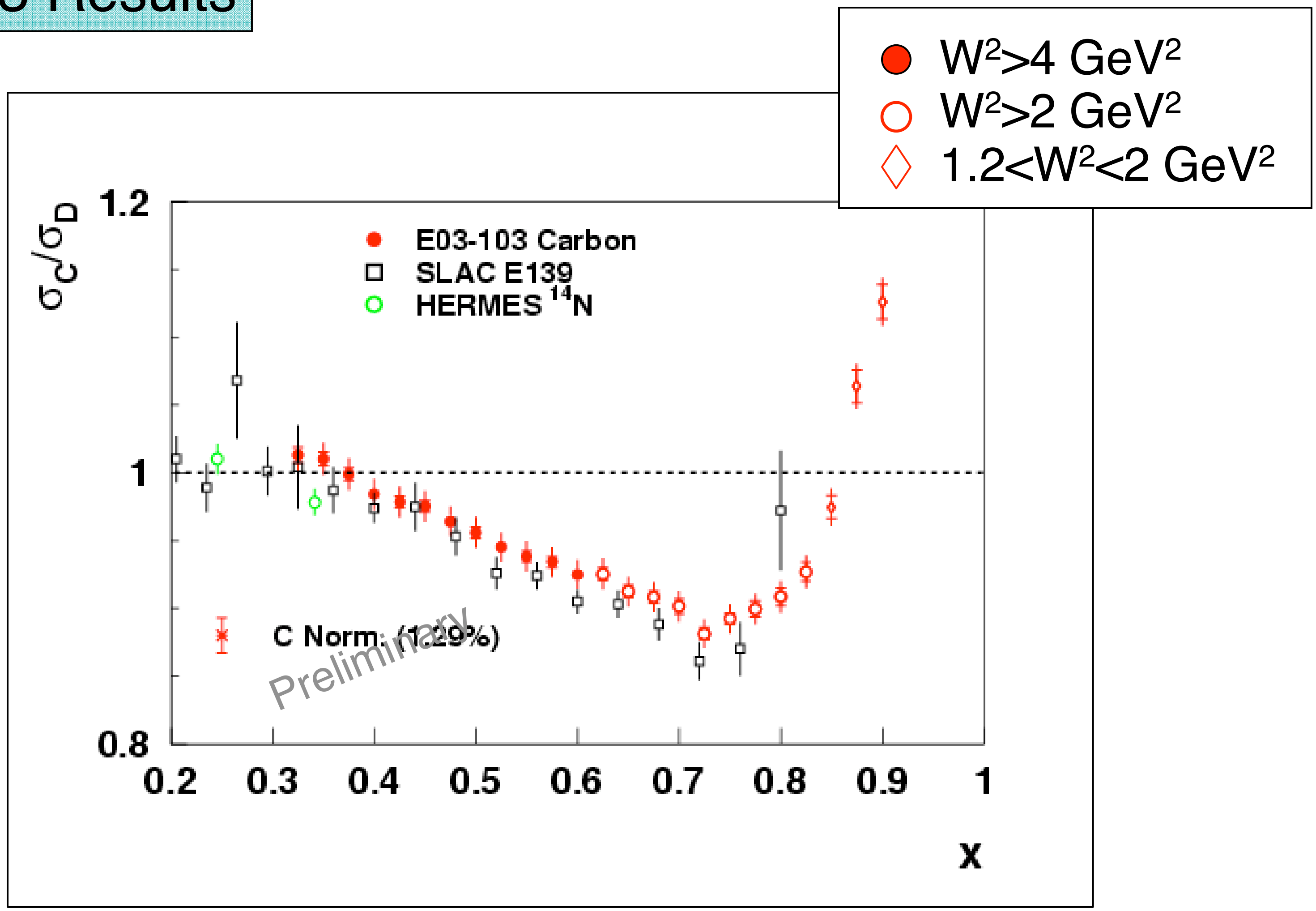
Limits E03-103 coverage to x=0.85

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



Carbon/^{2}H Ratio

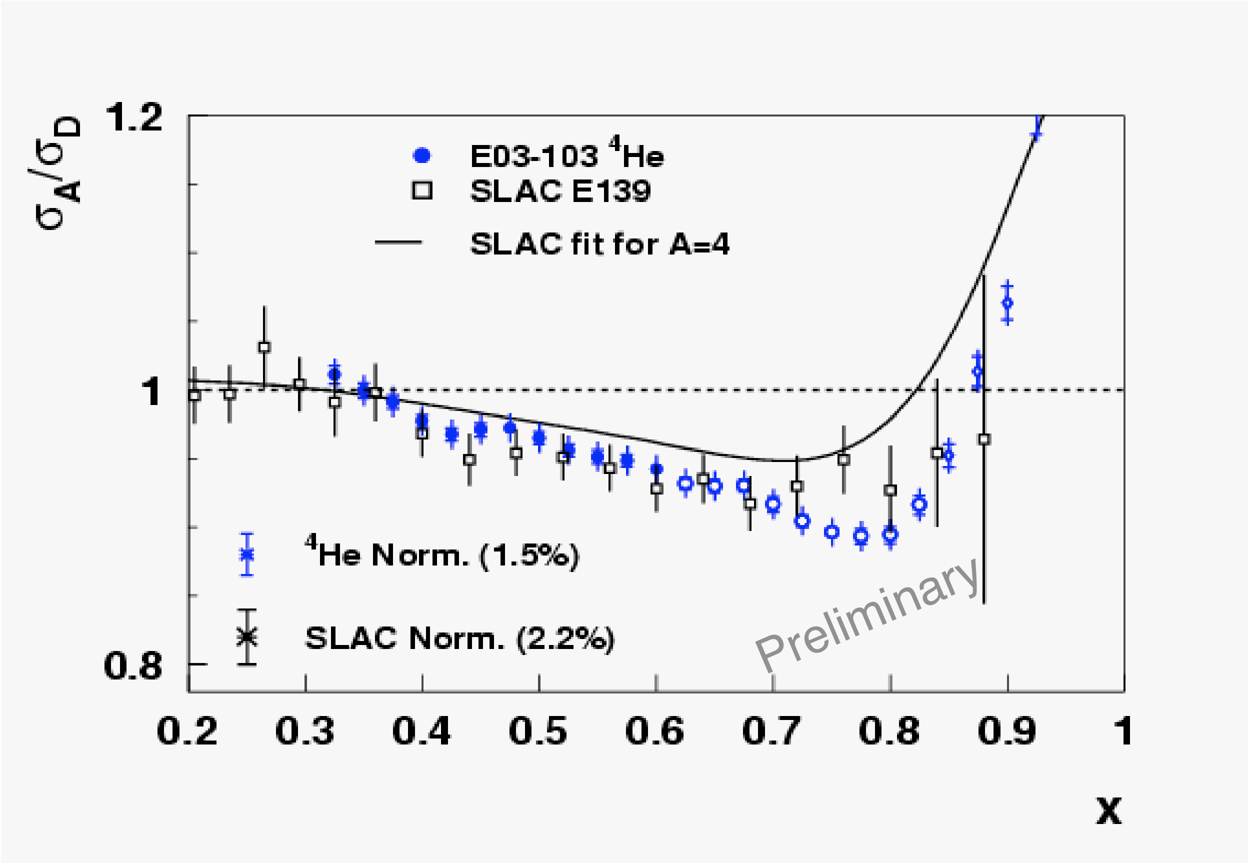
E03-103 Results



Light Nuclei: EMC Effect in ^4He

JLab results consistent with SLAC E139
→Improved statistics and systematic errors

Large x shape more clearly consistent with heavier nuclei

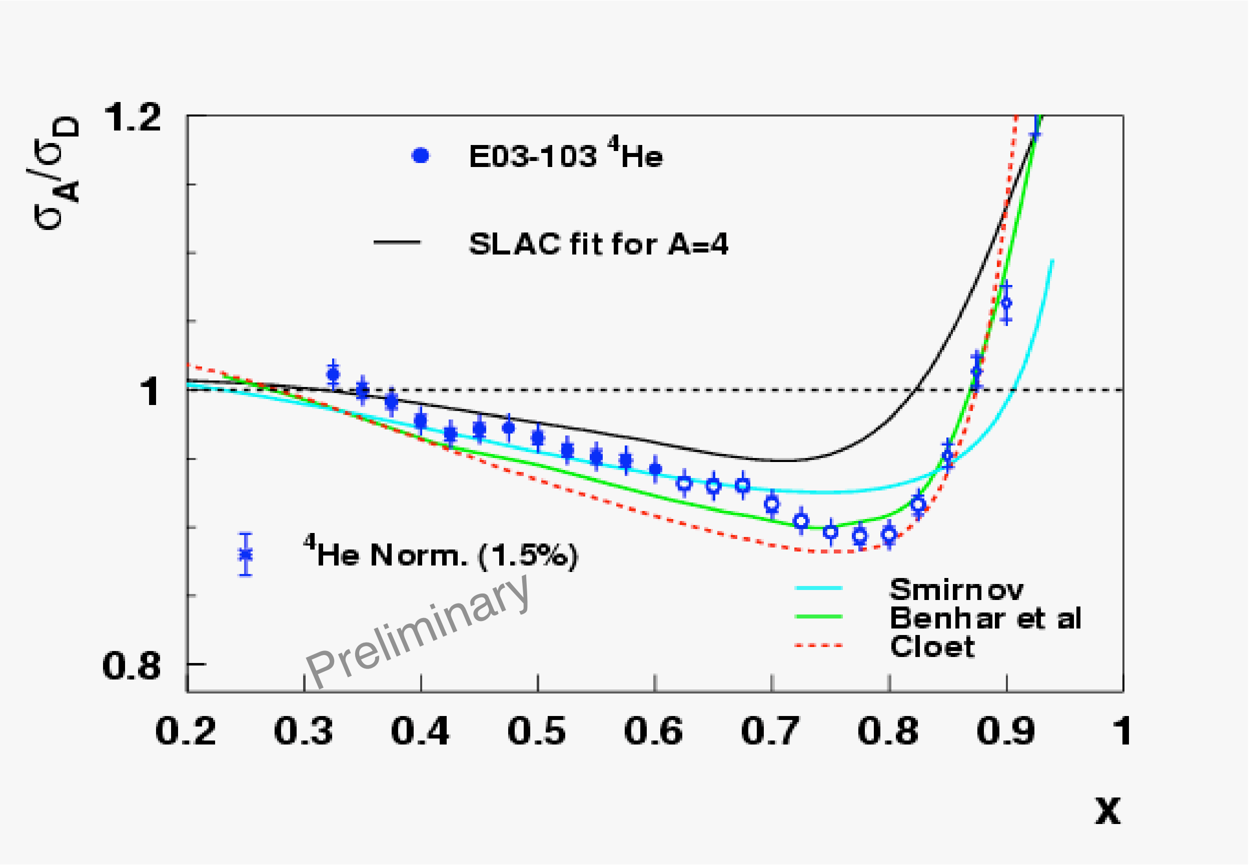


EMC Effect in ^{4}He

JLab results consistent with SLAC E139
→Improved statistics and systematic errors

Large x shape more clearly consistent with heavier nuclei

Models shown do a reasonable job describing the data, but there is room for improvement



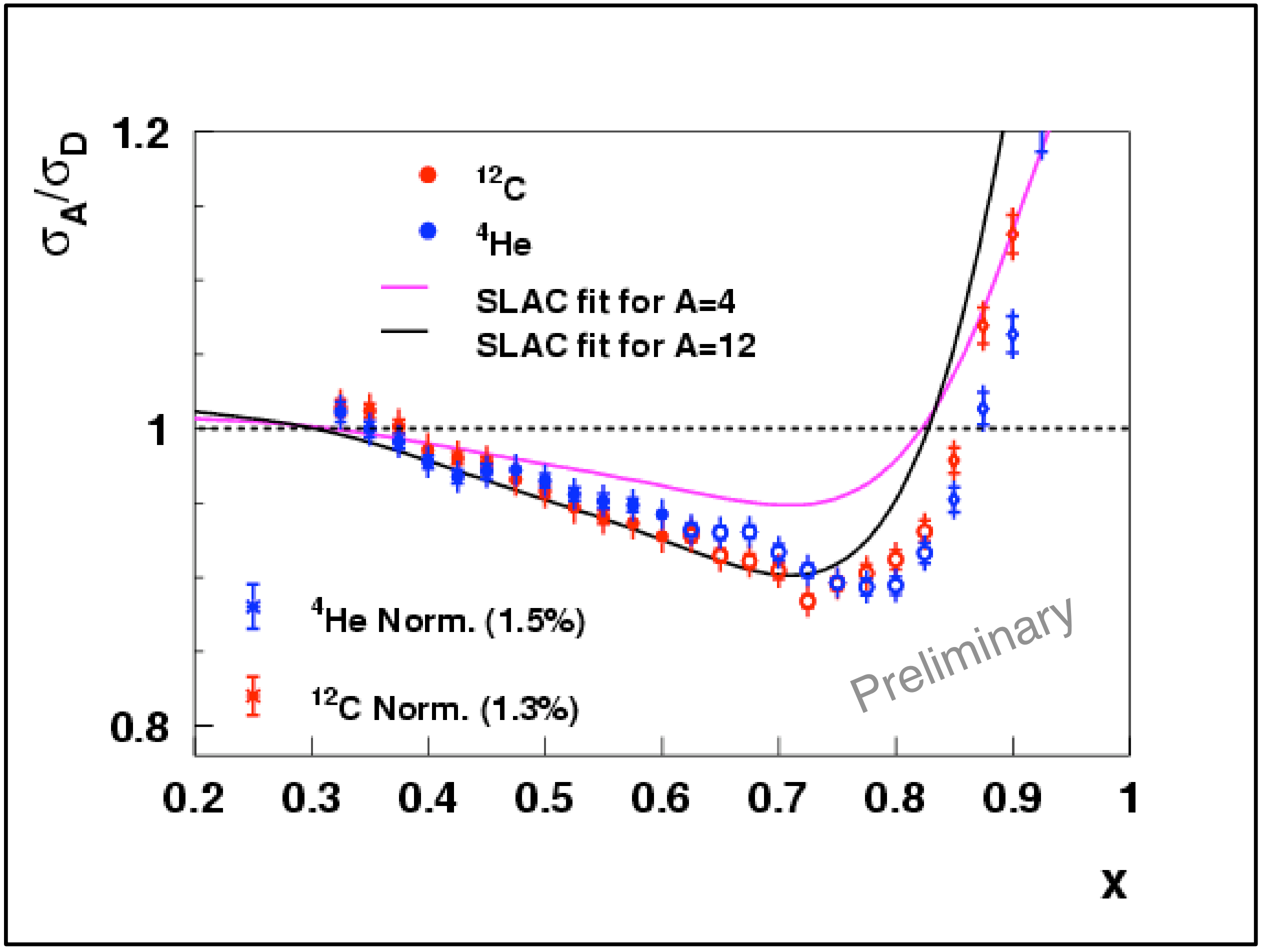
Cloet = *private communication, "QMC"-inspired model [see PLB 642, 210 (2006)]*
Smirnov = *Burov, Molochkov and Smirnov [PLB 466, 1 (1999)]*
Benhar = *private communication, Argonne v_{14} + Urbana VII 3N*

Carbon to ^{4}He Comparison

Magnitude of the EMC Effect for C and ^{4}He very similar

^{4}He more consistent with SLAC A=12 fit than A=4

→ ^{4}He acts like a "real nucleus"



Some hint of difference in shape, but hard to tell with existing errors

Isoscalar Corrections

- When extracting cross section ratios, want to compare a nucleus with *Z=N* protons and neutrons to deuterium (*Z=1*, *N=1*)
- In some cases, nature is kind enough to provide this for us (^{4}He, Carbon)
- As *A* gets large, typically have more neutrons than protons (^{3}He more protons than neutrons)
- σ_A/σ_D must be corrected for non-isoscalarity of nucleus

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

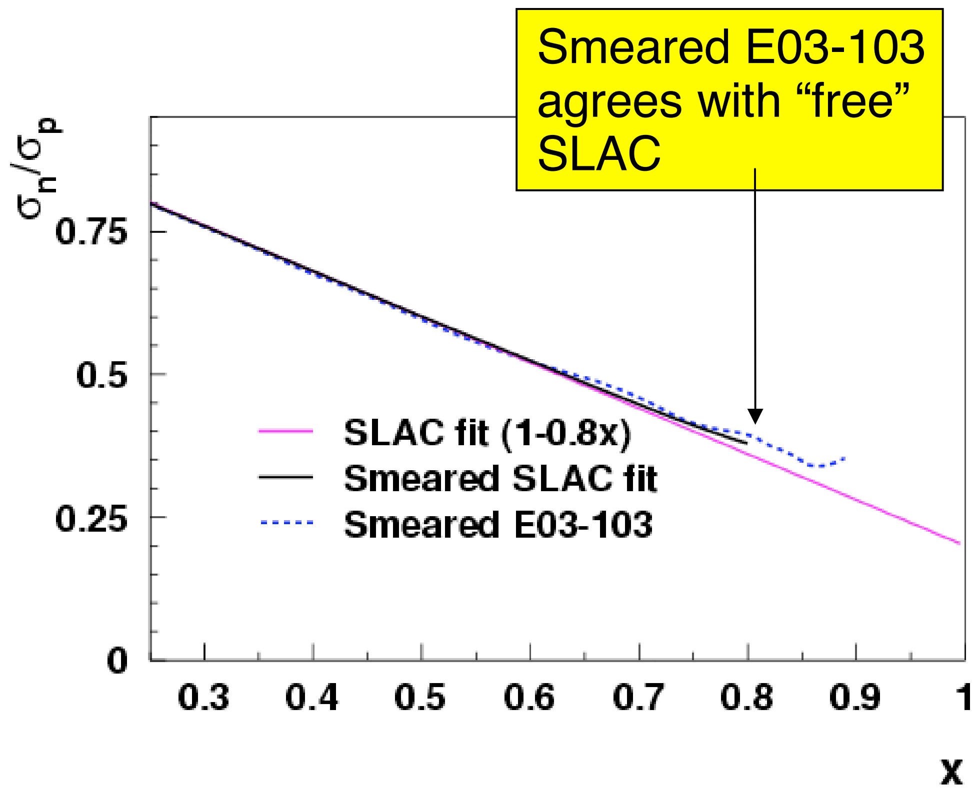
Smeared σ_n/σ_p

- Previous experiments used "free" σ_n/σ_p for isoscalar correction
- However, we are correcting nuclei – don't want "free" n/p
  → Ideally we'd like "bound" n/p for relevant nucleus

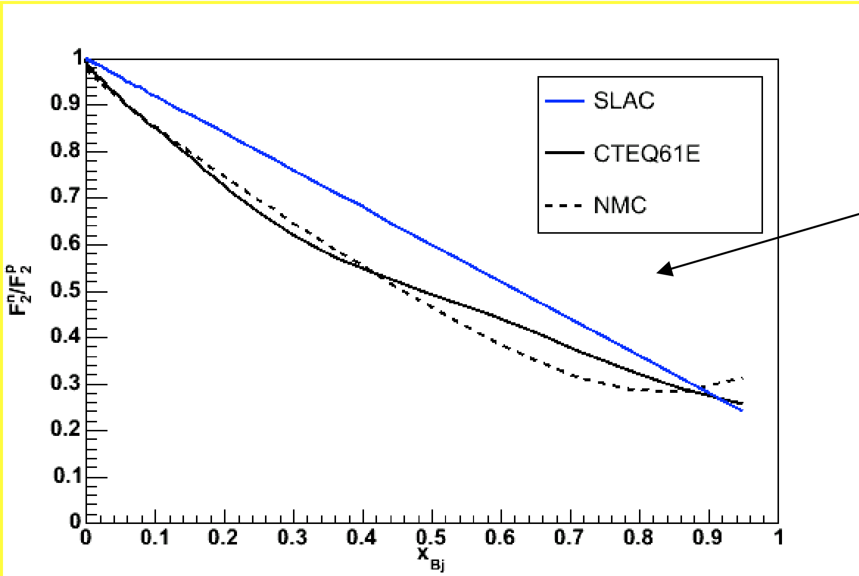
•This is difficult – start with "bound" n/p in deuterium in first approximation

•Smeared n/p from fit to D and p cross sections consistent with SLAC fit:

σ_n/σ_p=1-0.8x



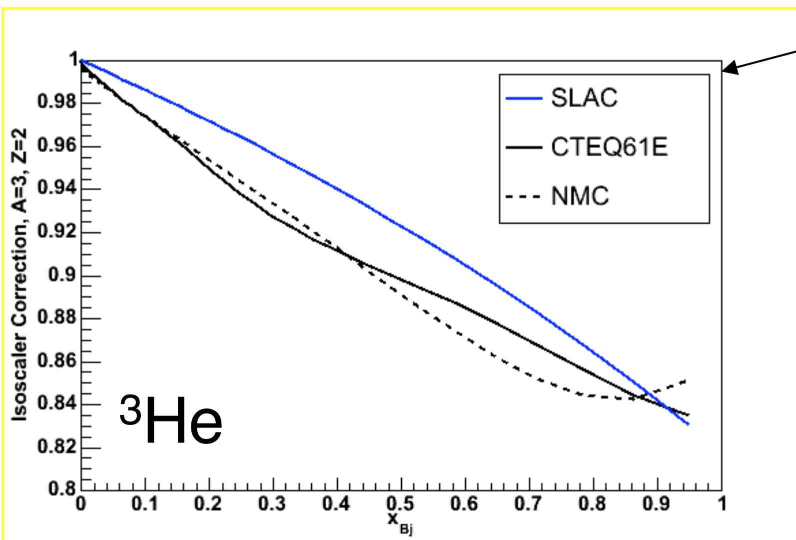
Effect of Isoscalar Corrections

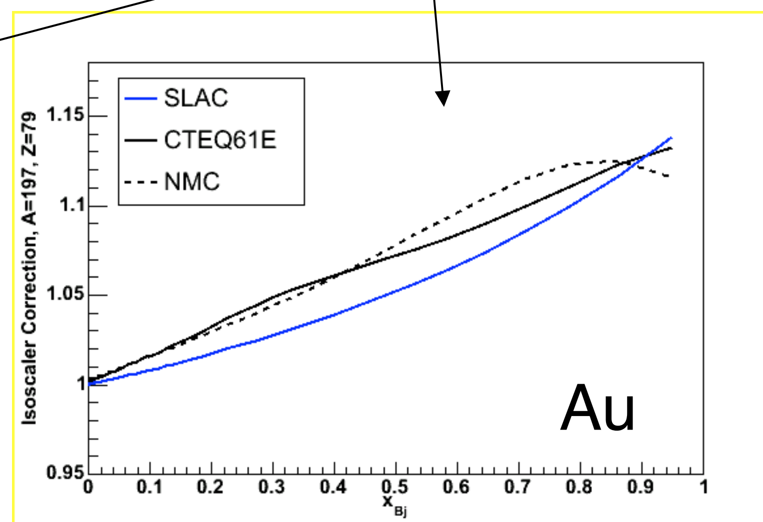


$$\frac{F_2^{\,n}}{F_2^{\,p}}$$

- SLAC param. *(1-0.8x)*
- CTEQ
- NMC fit

Isoscalar correction applied to data

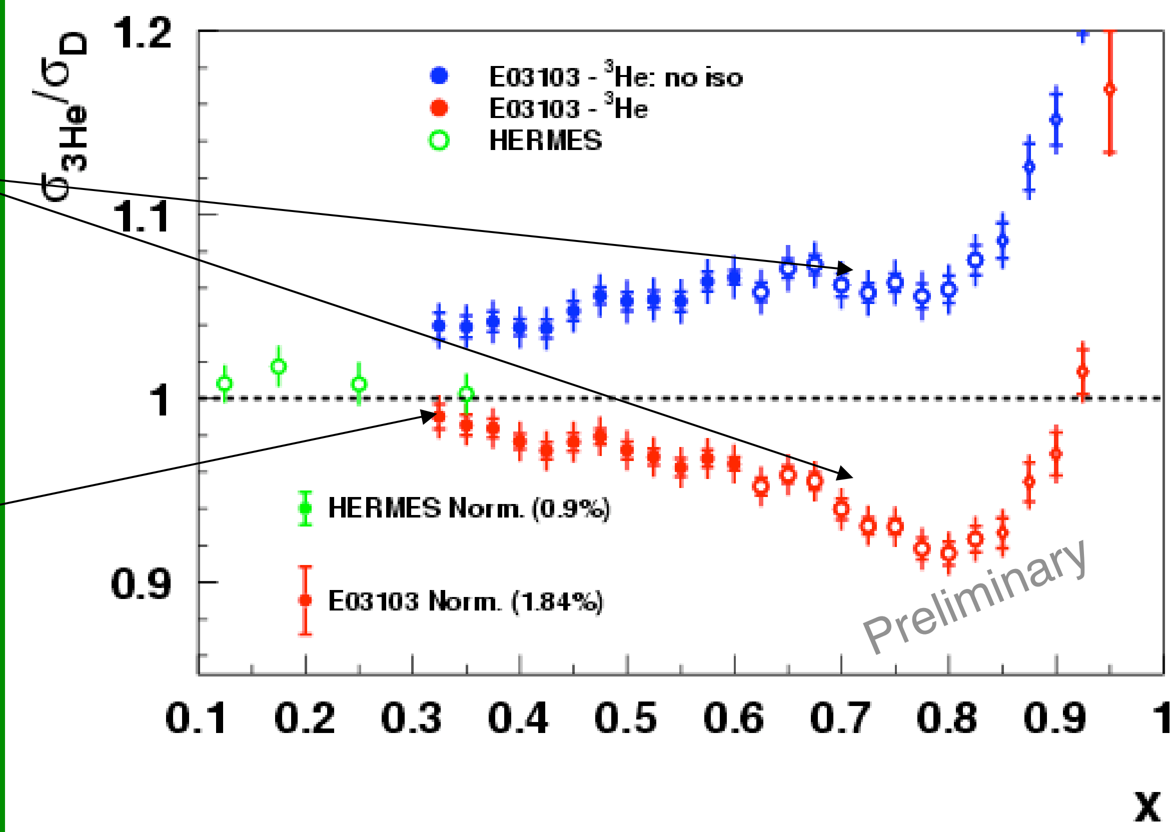




EMC Effect in ^{3}He

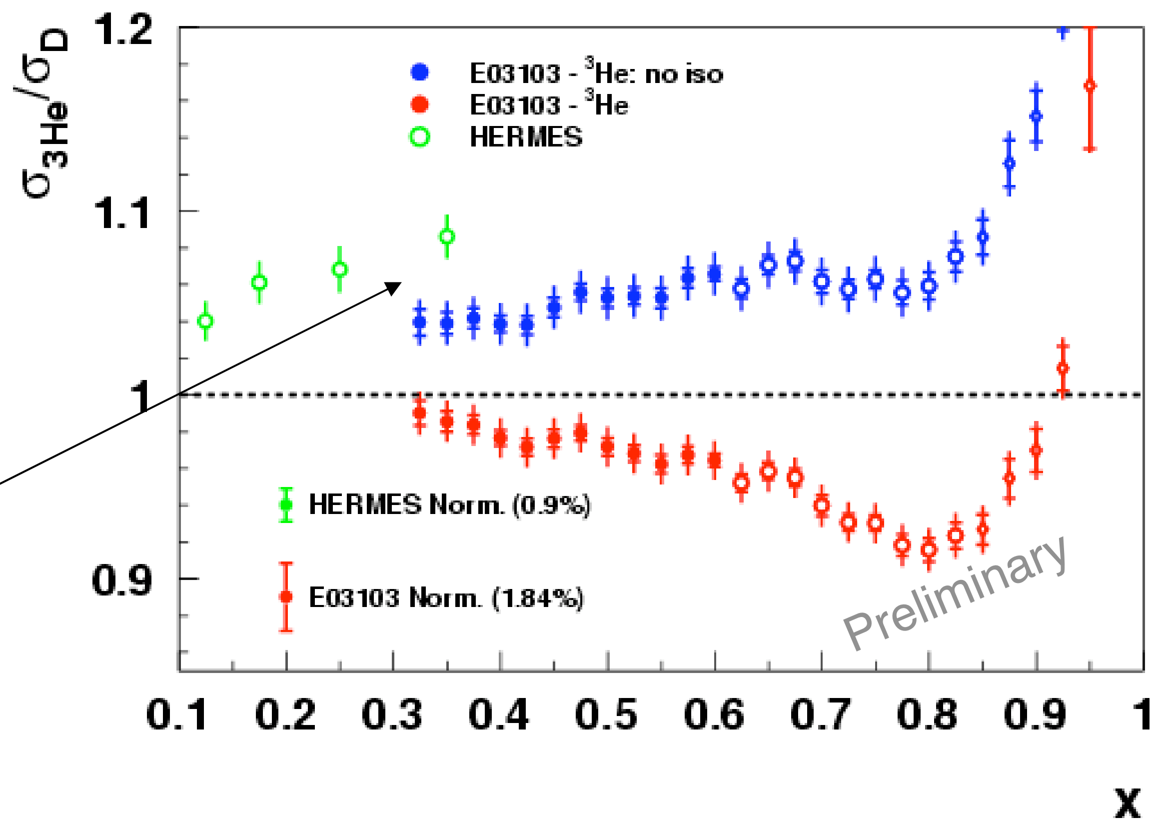
Large proton excess correction

Good agreement with HERMES in overlap region



^{3}He EMC Ratio – HERMES Comparison

Fair
~~Good~~ agreement with HERMES in overlap region



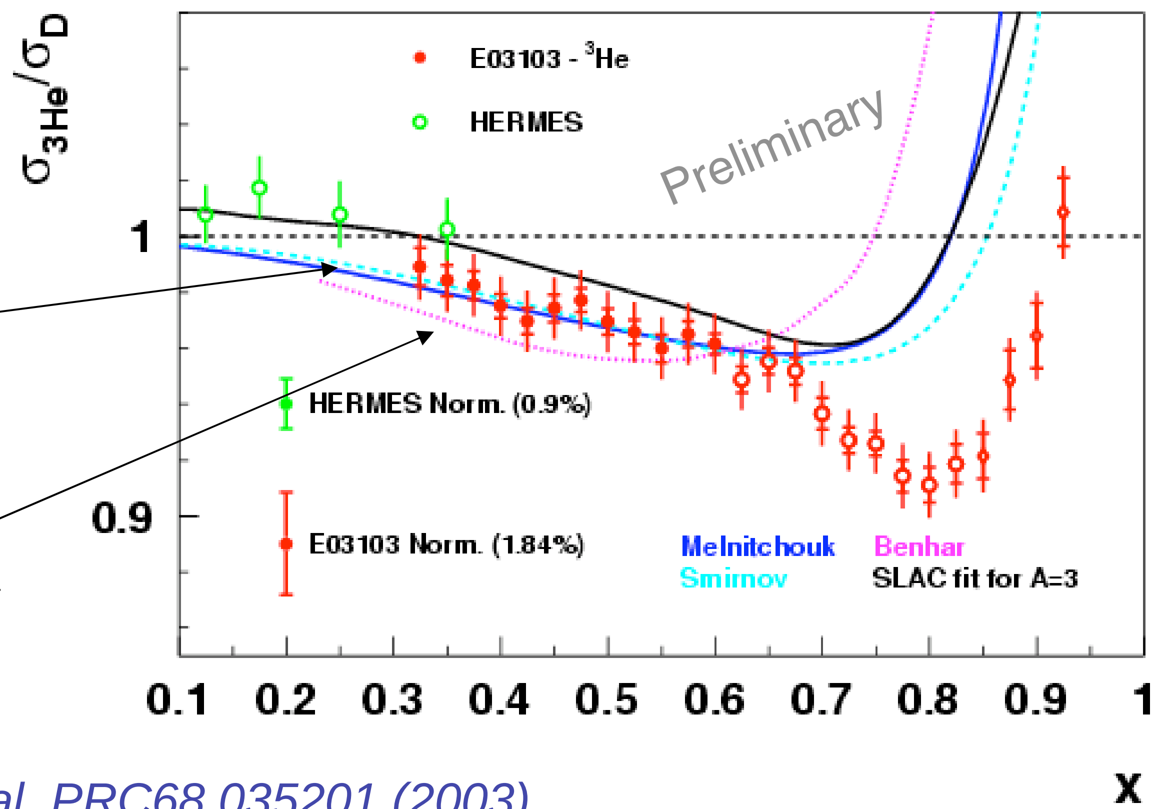
HERMES uses different param. for isoscalar correction!

EMC Effect in ^{3}He - Models

All calculations shown use convolution formalism at some level

$$\frac{F_2^{\,^3He}}{(F_2^D + F_2^p)}$$

$$\frac{F_2^{\,^3He}}{(2F_2^p + F_2^n)}$$



Melnitchouk = *Afnan et.al. PRC68 035201 (2003)*
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EMC Effect in ^3He

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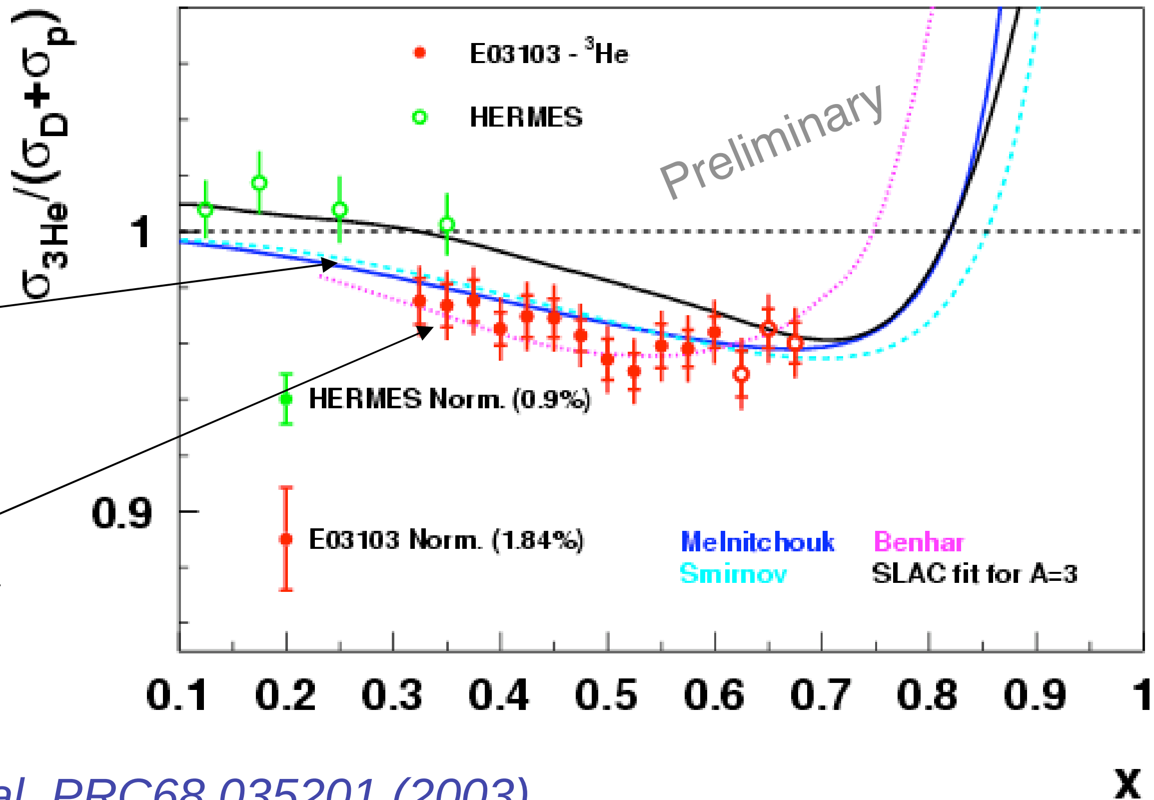

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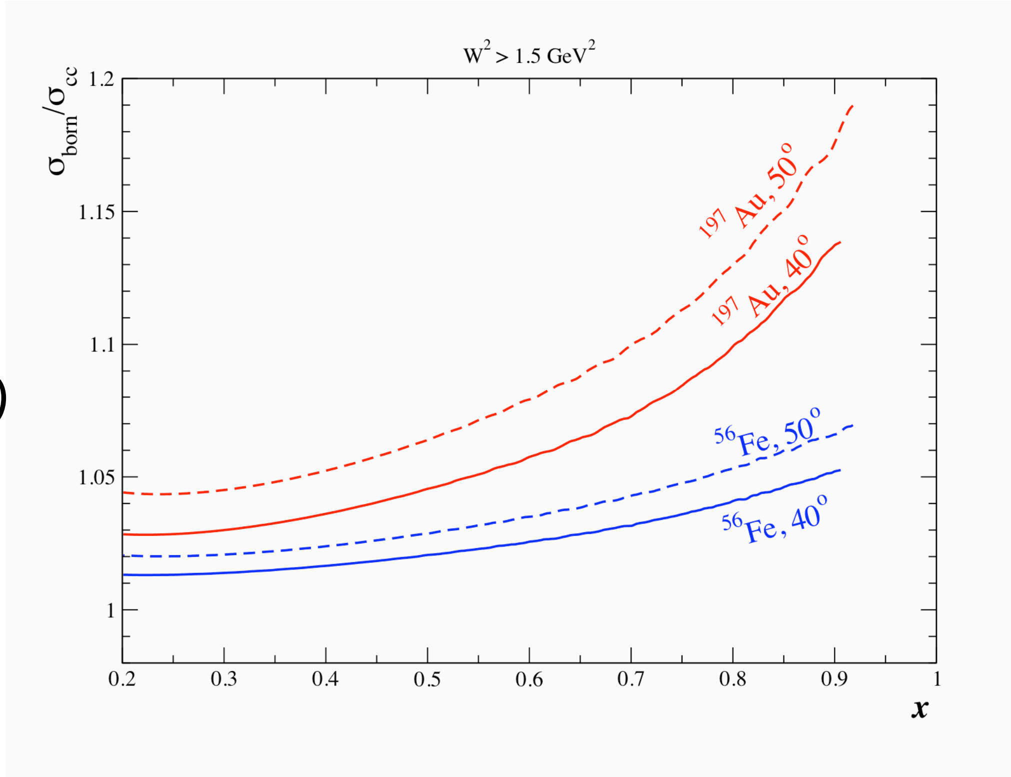
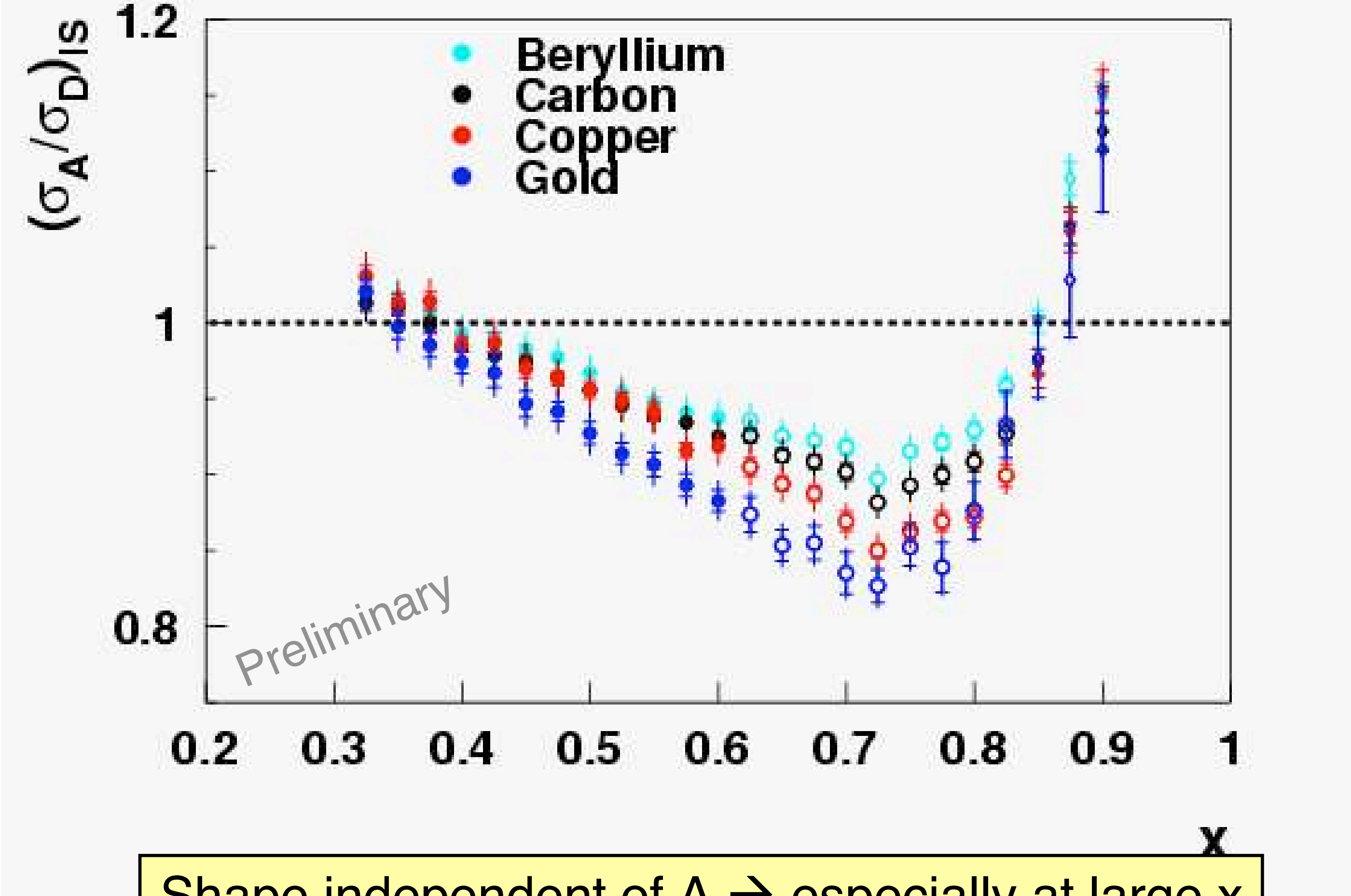
Coulomb Corrections

- Initial (scattered) electrons are accelerated (decelerated) in Coulomb field of nucleus with *Z* protons
  - Not accounted for in typical radiative corrections
  - Usually, not a large effect at high energy machines – ***not true at JLab (6 GeV!)***
- E03-103 uses modified Effective Momentum Approximation (**EMA**), ***Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)***
  - $E \rightarrow E+\Delta$, $E' \rightarrow E'+\Delta$
  - $\Delta = -\frac{3}{4} V_0$, $V_0 = 3\alpha(Z-1)/(2r_c)$
- EMA tested against DWBA calculation for QE scattering
  → *application to inelastic scattering appropriate?*



EMC Measurements for Heavy Nuclei

E03-103 data corrected for coulomb distortion

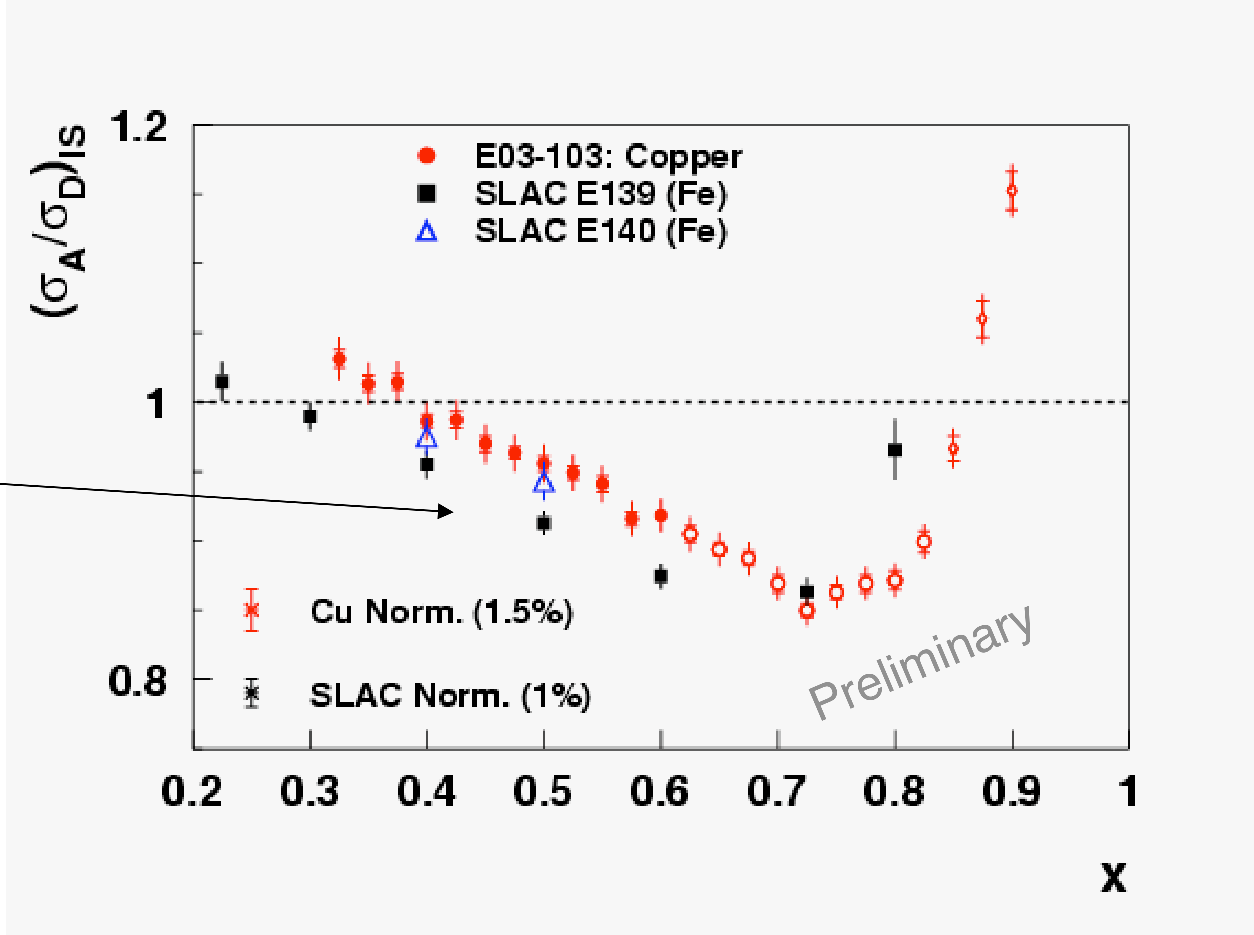


Shape independent of A → especially at large x

EMC Effect in Heavy Nuclei - Cu

E03-103 data corrected for coulomb distortion

E03-103 Copper data roughly agree with Coulomb Corrected Fe data from SLAC

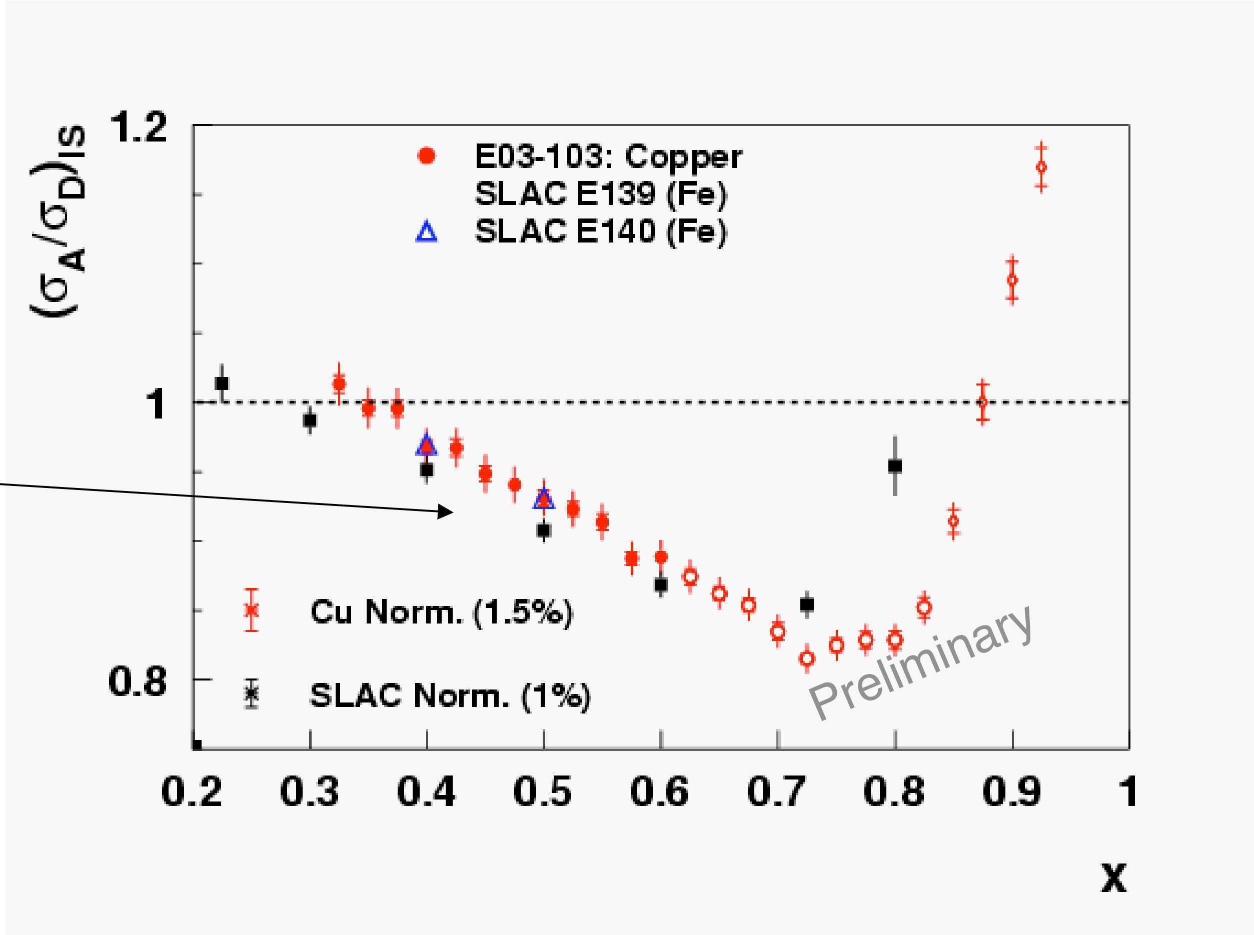


EMC Effect in Heavy Nuclei - Cu

E03-103 data corrected for coulomb distortion

E03-103 Copper data roughly agrees with Coulomb Corrected Fe data from SLAC

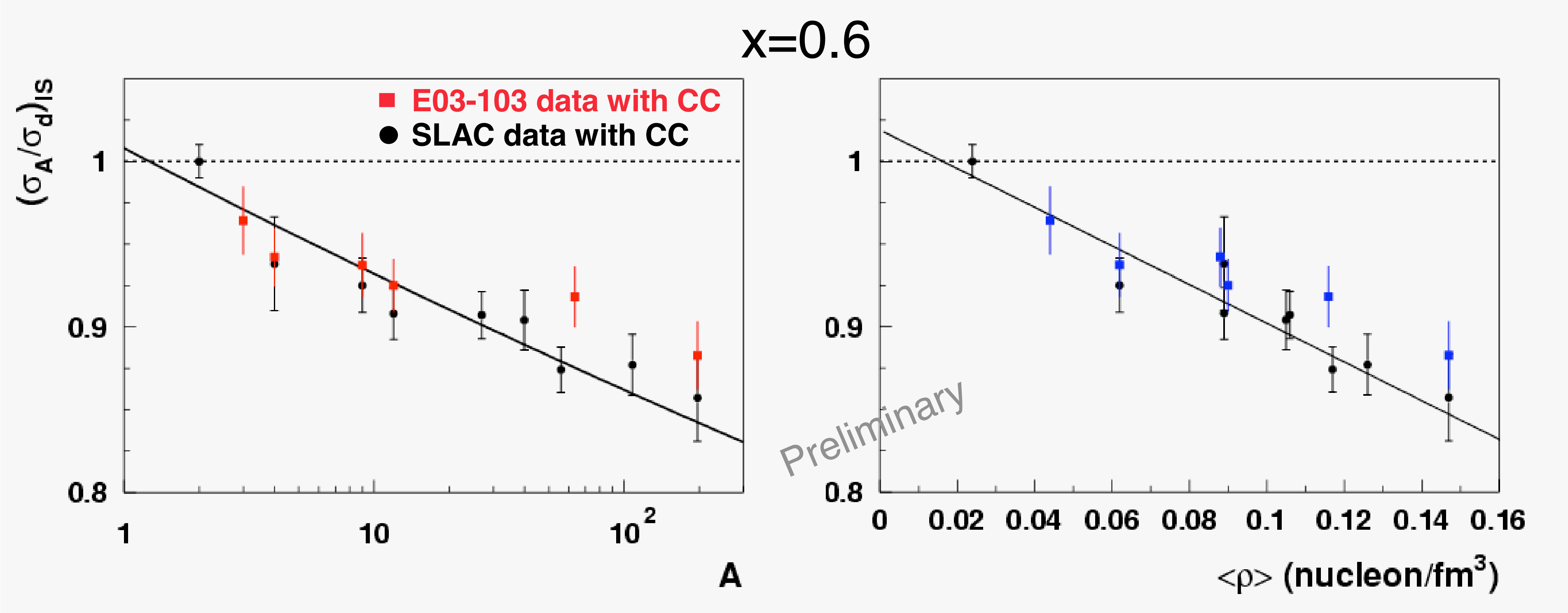
→ Agreement seems to improve if we ignore Coulomb corrections



Nuclear Dependence of the EMC Effect

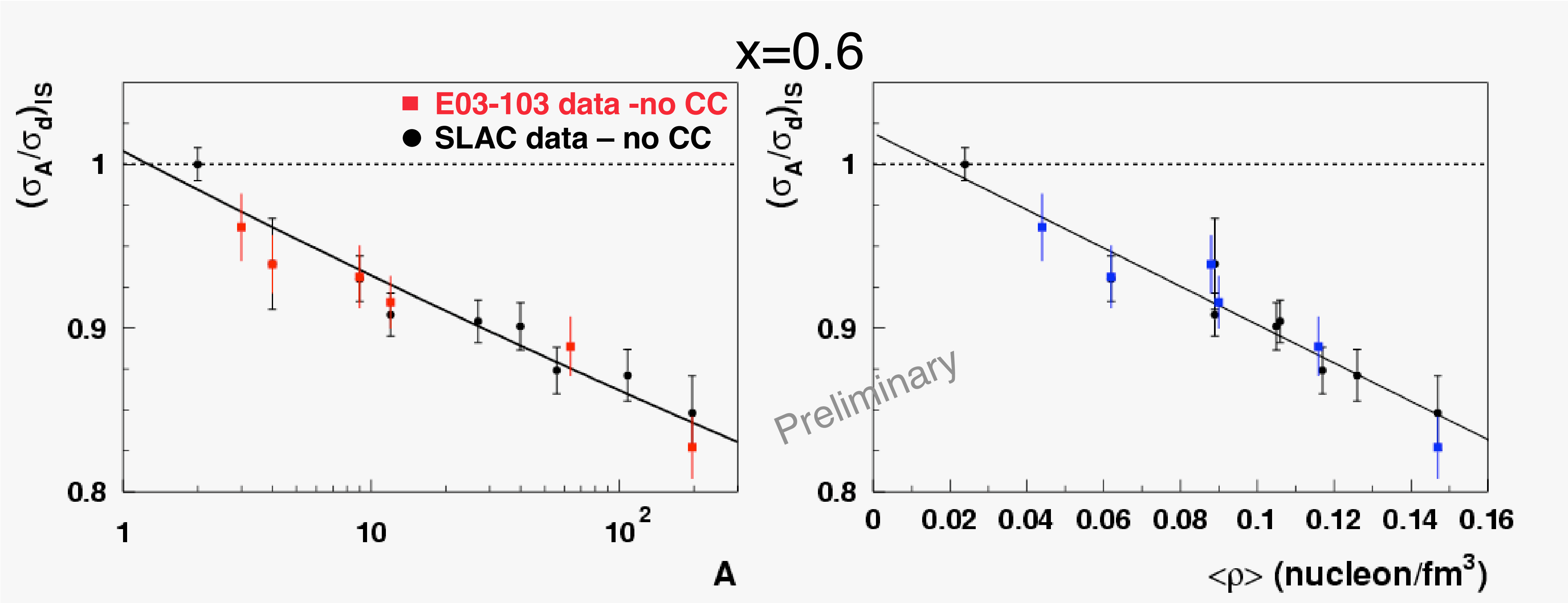
• Original e139 paper parameterized in terms of *A* or ρ=nuclear density assuming uniform sphere of radius R_e ($\rho=3A/4\pi R_e^3$)

• After correction for Coulomb effects, e139 and E03-103 data show reasonable agreement



Nuclear Dependence of the EMC Effect

- Ignoring Coulomb effect in JLab data appears to yield slightly better agreement with e139 data – Coulomb corrections overestimated?
- Resolving this issue important as it affects extrapolation to nuclear matter (even when just using SLAC data: 1-2% effect for gold).



E03-103 Impact

- Measurements from light nuclei
  - First measurement of EMC effect in ^{3}He above x=0.4
  - Improved ^{4}He measurement
  - These results will serve as excellent testing ground for convolution calculations → virtually no uncertainty in nuclear wave function
- Measurements at large x
  - Assuming one believes in scaling for W^2<4 GeV^2, our heavy target data improve the precision for x>0.75 where Fermi motion, binding dominate
- Both of the above combined should help settle to what degree conventional nuclear physics plays a role in the EMC effect
- Once this is understood, we are in a better position to quantify to what extent we must introduce additional mechanisms

Future of the EMC Effect

- Will E03-103 data settle all the questions relating to modification of quark structure functions in nuclei?
  - No
- What else is there to learn?
  - Flavor dependence → u(x) changed in the same way as d(x)? (in other words, n/p nuclear dependent?)
  - Anti-quarks → how the “sea” quarks are affected
  - Spin dependence → how will the polarized quark distributions change in the nucleus?