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The EMC Effect and The Quest for High x Quark Distributions

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Nathan Isgur Distinguished Postdoctoral Fellowship Seminar

Jefferson Lab

June 23, 2009

U.S. Department of Energy

UChicago ▸ Argonne LLC

Office of Science
U.S. DEPARTMENT OF ENERGY

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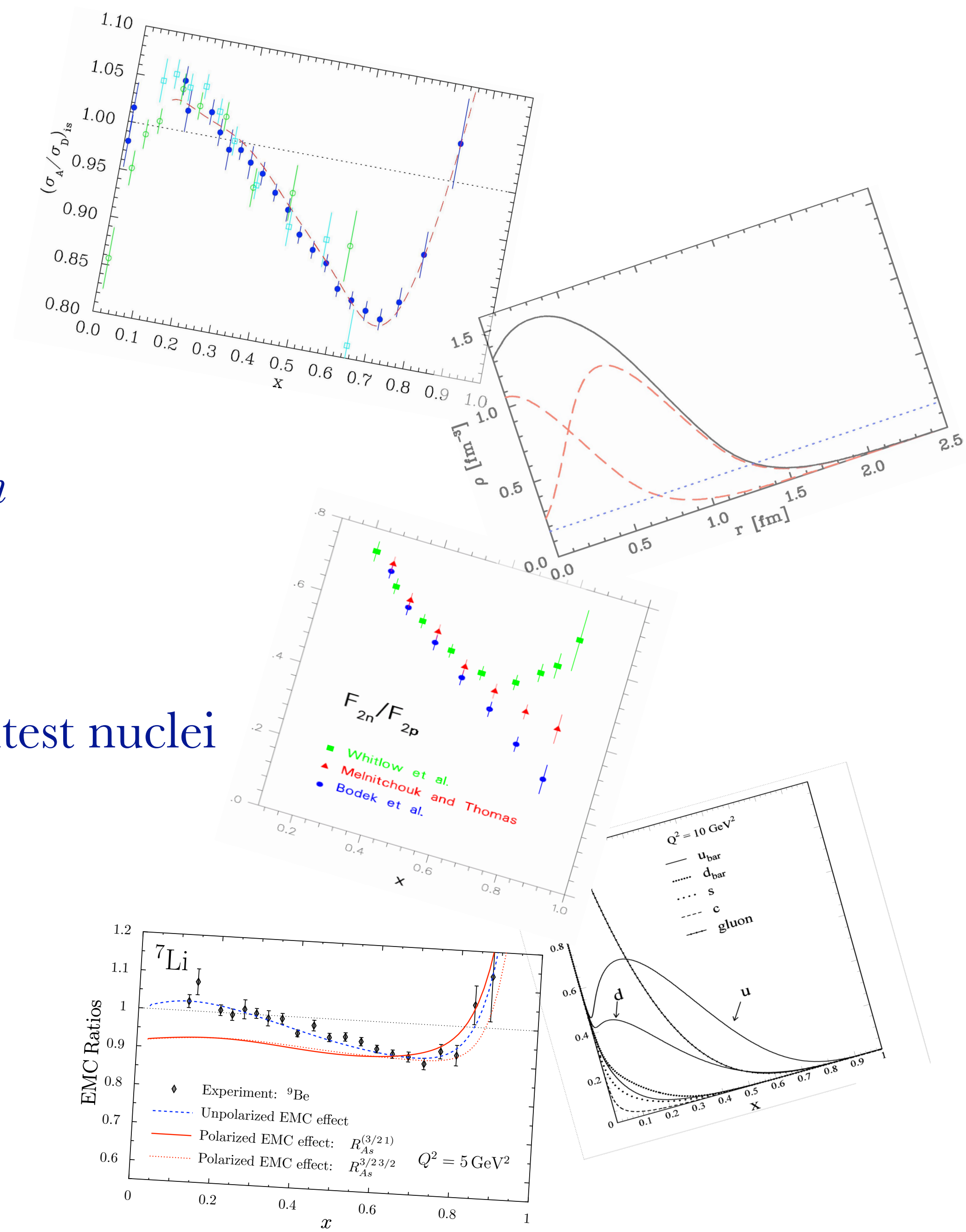
Outline

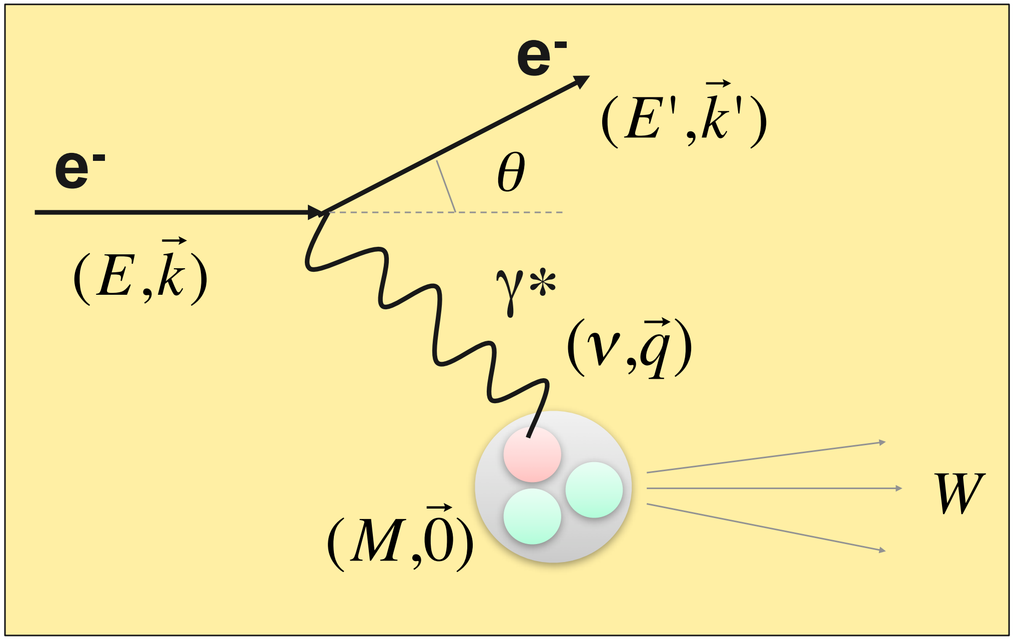
- The EMC effect
  - Short introduction
  - JLab Hall C E03-103 results:
    - *Light nuclei*
    - *Heavy nuclei and Coulomb distortion*

- What's next ?
  - $F_2(^3H)/F_2(^3He)$: EMC effect on lightest nuclei
  - F2n/F2p and d/u at high x
  - Polarized EMC effect

- Summary and Outlook



Deep inelastic scattering



4-momentum transfer squared

$$Q^2 = -q^2 = 4EE'\sin^2\tfrac{\theta}{2}$$

Invariant mass squared

$$W^2 = M^2 + 2M\nu - Q^2$$

Bjorken variable

$$x = \frac{Q^2}{2M\nu}$$ = *quark momentum fraction*

DIS scattering measures structure function $F_2(x)$

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\tfrac{\theta}{2}\right]$$

In the parton model, $F_2(x)$ related to parton momentum distributions (pdfs)

$$F_1(x) = \frac{1}{2}\sum_i e_i^2[q_i^{\uparrow}(x) + q_i^{\downarrow}(x)] = \frac{1}{2x}F_2(x)$$

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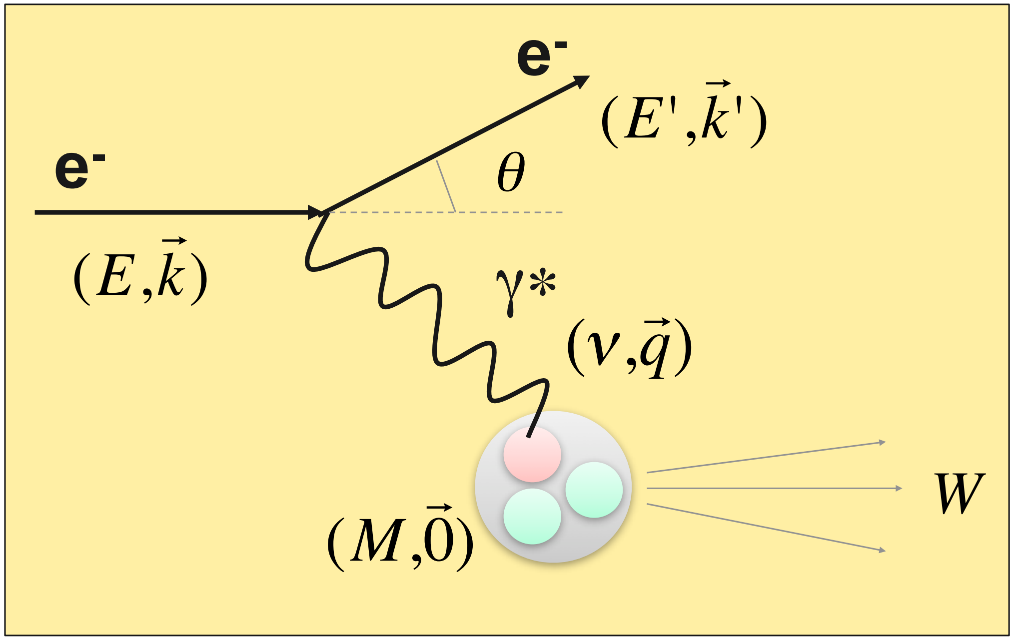
The quest for higher precision data

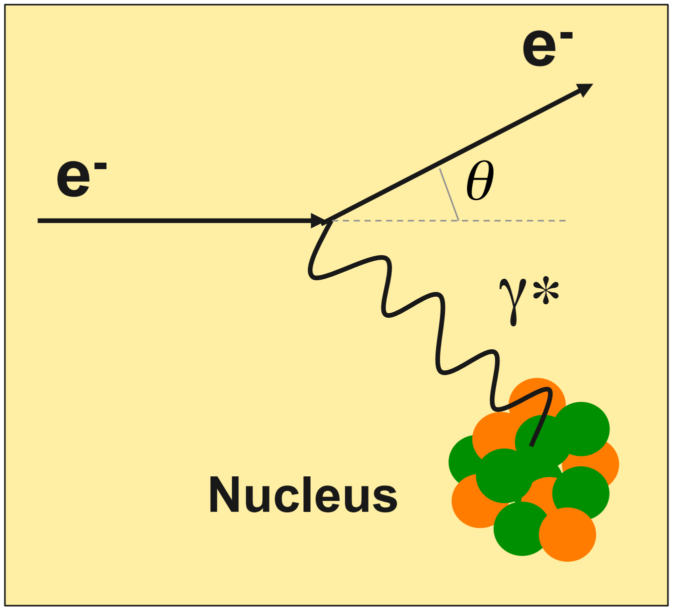


To increase the luminosity, physicists decided to use heavy nuclei to study the structure of the proton instead of a hydrogen target.

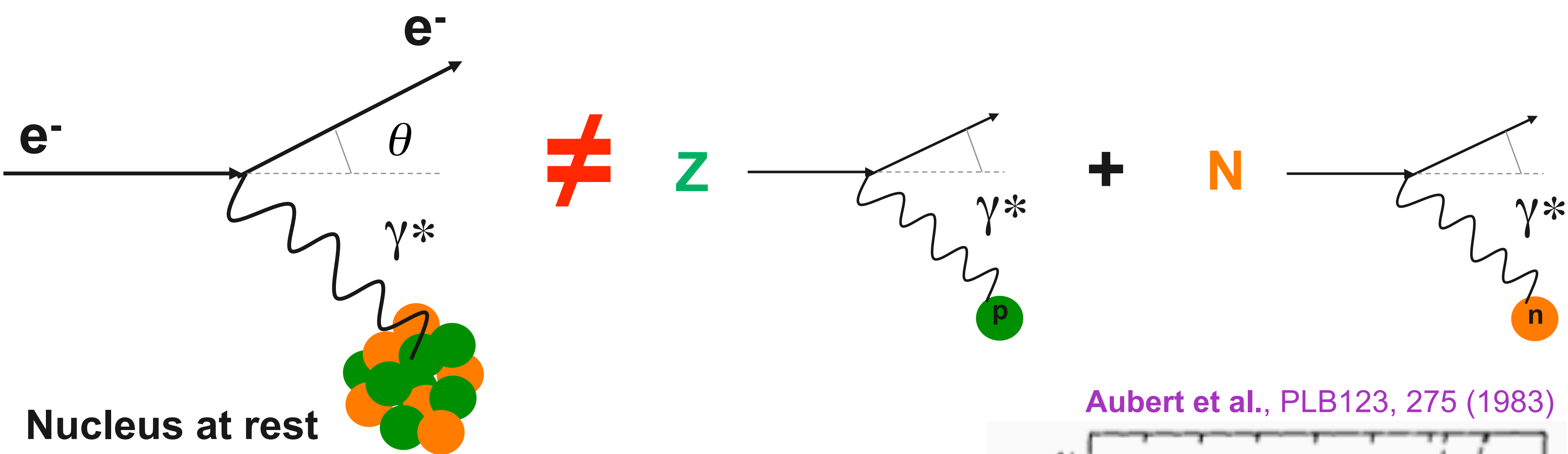
For nuclei,
binding energies << energy scale of the probe

Expected

$$F_2^A(x) \approx Z\, F_2^p(x) + N\, F_2^n(x)$$

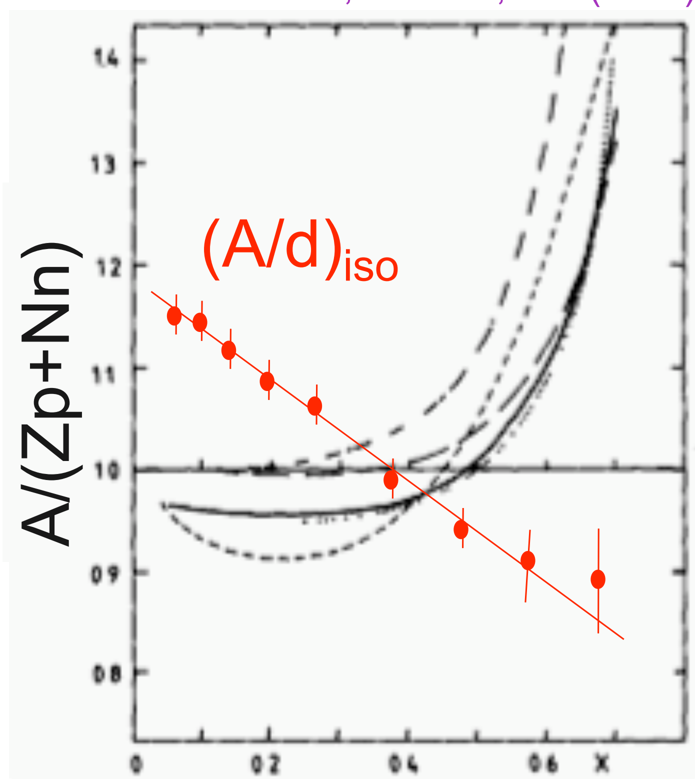


The EMC effect



Nucleus at rest
(**A** nucleons = **Z** protons + **N** neutrons)

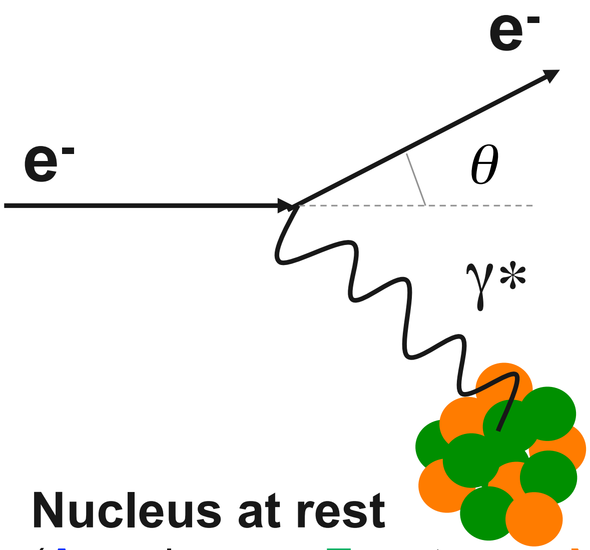
Aubert et al., PLB123, 275 (1983)

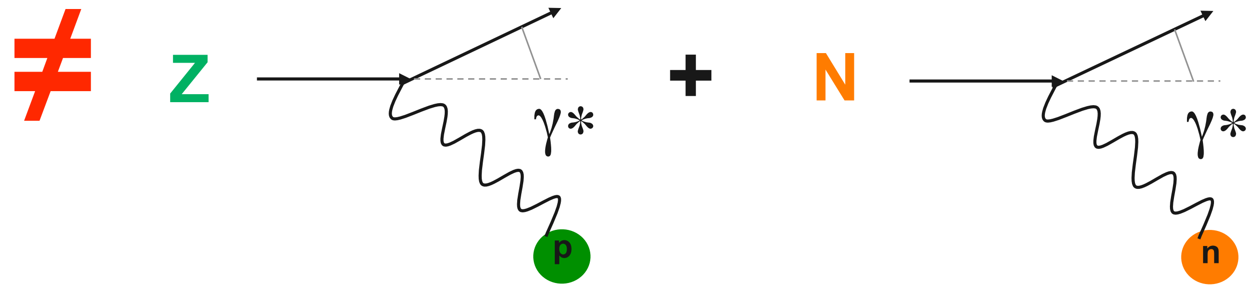


First measurement by the EMC collaboration (1983) found an excess of low-x quarks, deficit of high-x quarks in heavy nuclei

Nuclear structure: $F_2^A \neq ZF_2^p + NF_2^n$

The EMC effect





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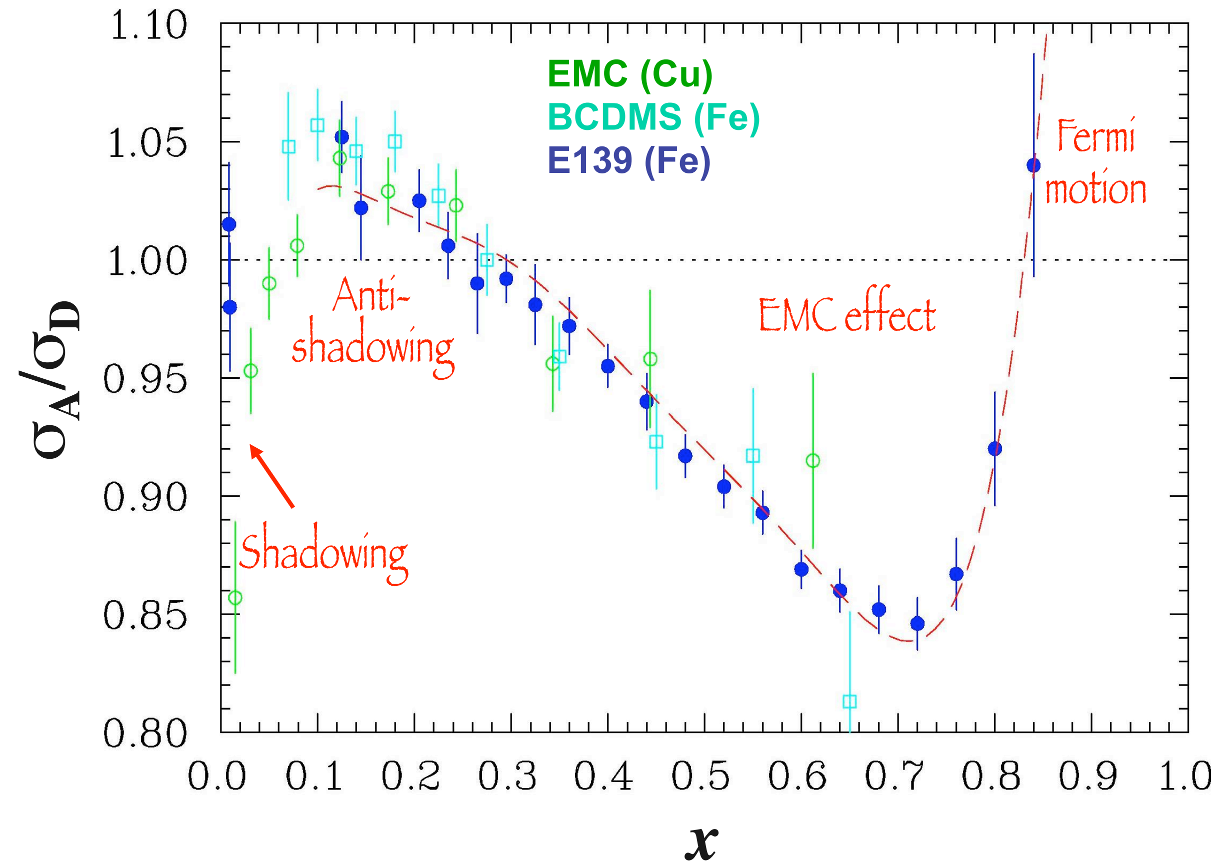


Effects found in several experiments at CERN, SLAC, DESY

Nucleon only model

Assumptions on the nucleon structure function:

- not modified in medium
- the same on and off the energy shell

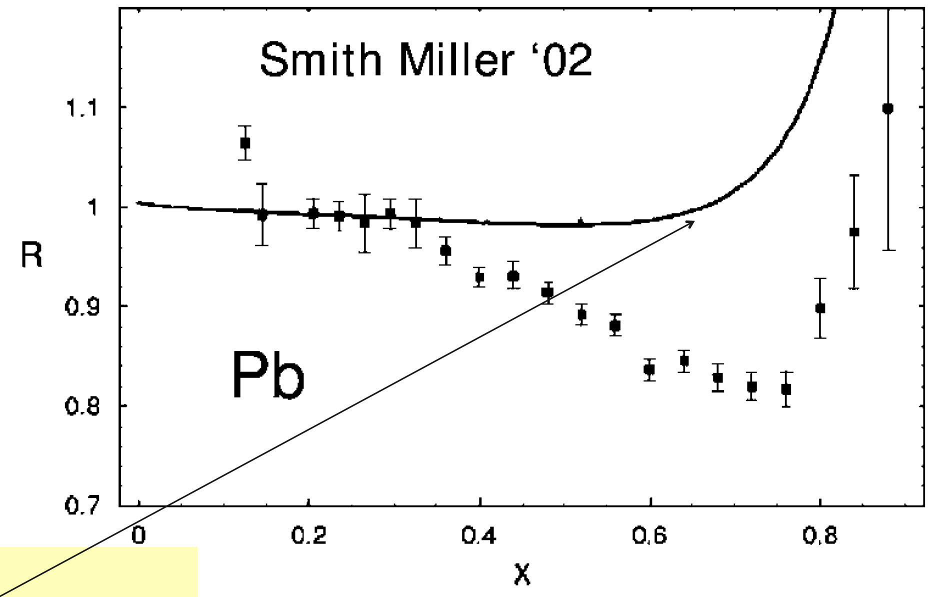
$$\frac{F_2^A(x_A)}{A} = \int_{x_A}^{A} dy \cdot f_N(y) F_2^N(x_A / y)$$

Fermi momentum << $M_{nucleon}$

➔ $f_N(y)$ **is narrowly peaked and** $y \approx 1$

$$\frac{F_2^A}{A} \approx F_2^N$$ ➔ no EMC effect

Smith & Miller,
PRC 65, 015211 and 055206 (2002)



"… some effect not contained within the conventional framework is responsible for the EMC effect." **Smith & Miller**, PRC 65, 015211 (2002)

Nucleons and pions model

Pion field is enhanced and pions carry an excess of plus momentum:

$$P^+ = P_N^+ + P_\pi^+ = M_A$$

and using $P_\pi^+ / M_A = 0.04$ is enough to reproduce the EMC effect.

But excess of nuclear pions
↓
enhancement of the nuclear sea

However this enhancement was not seen in nuclear Drell-Yan reaction

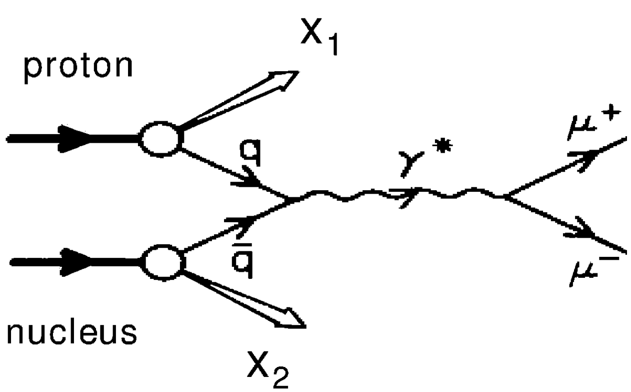
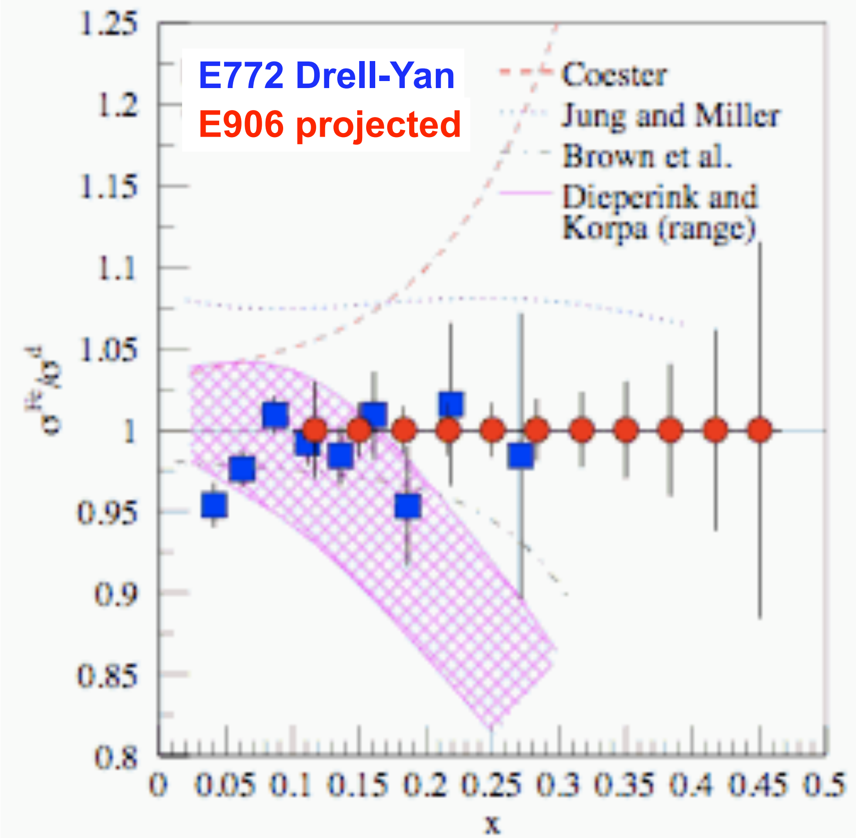


Fig from **P. Reimer**, Eur.Phys. J A31, 593 (2007)



Another class of models

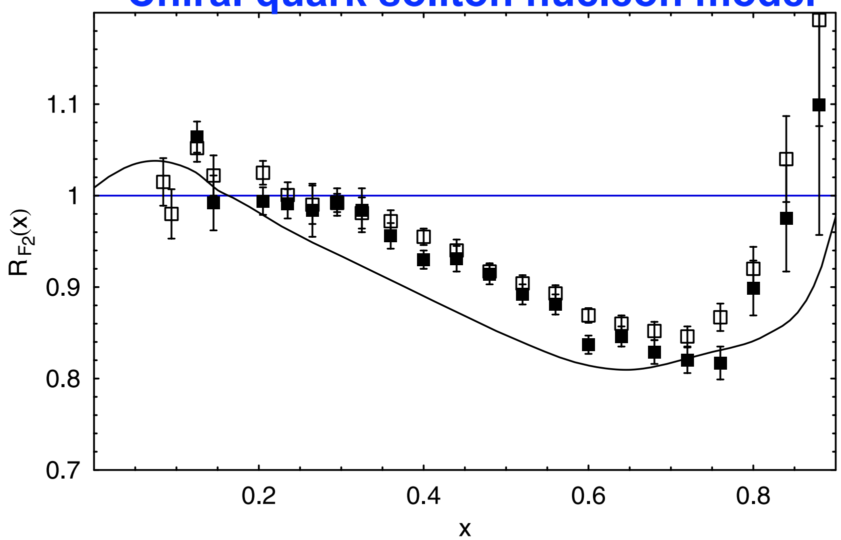
Interaction between nucleons

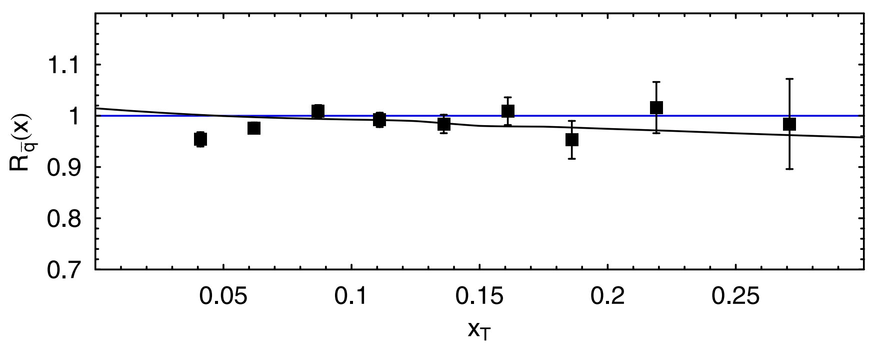
Model assumption:

nucleon wavefunction is changed by the strong external fields created by the other nucleons

Smith & Miller, PRL 91, 212301 (2003)

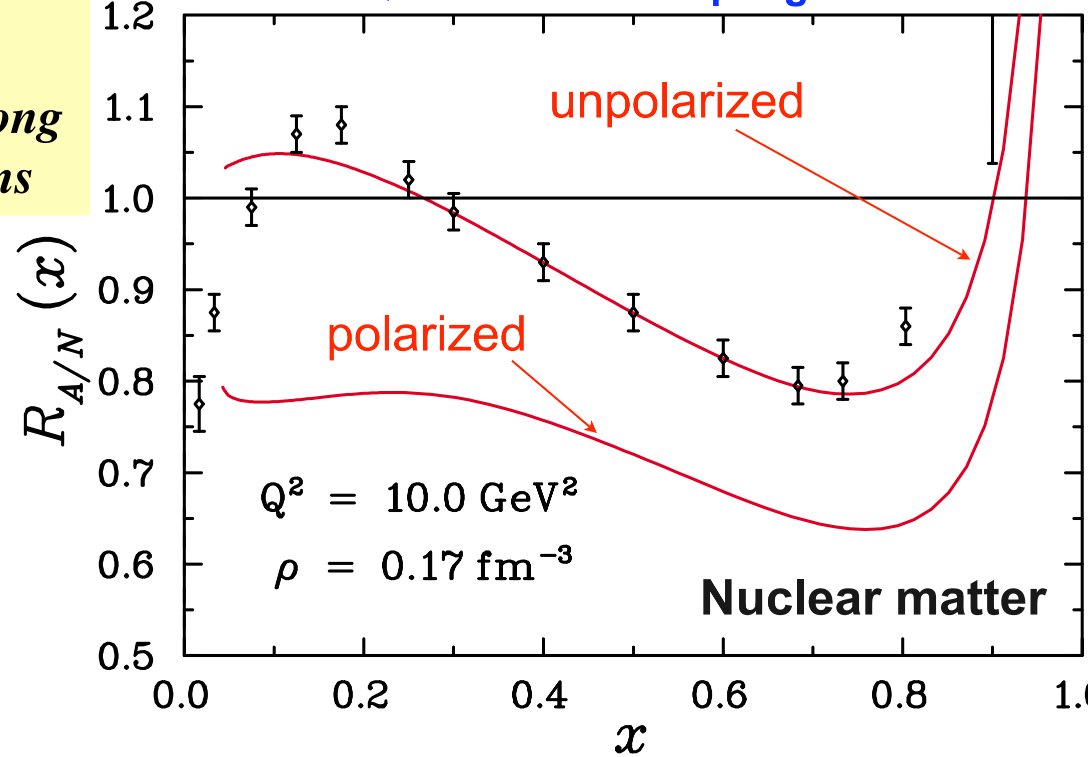
Chiral quark soliton nucleon model





Cloet, Bentz, and Thomas, PLB 642, 210 (2006)

Quark-meson coupling model



Model requirements:

- *Momentum sum rule*
- *Baryon number conservation*
- *Vanishing of the structure function at x<0 and x>A*
- *Should describe the DIS and DY data*

Existing EMC Data

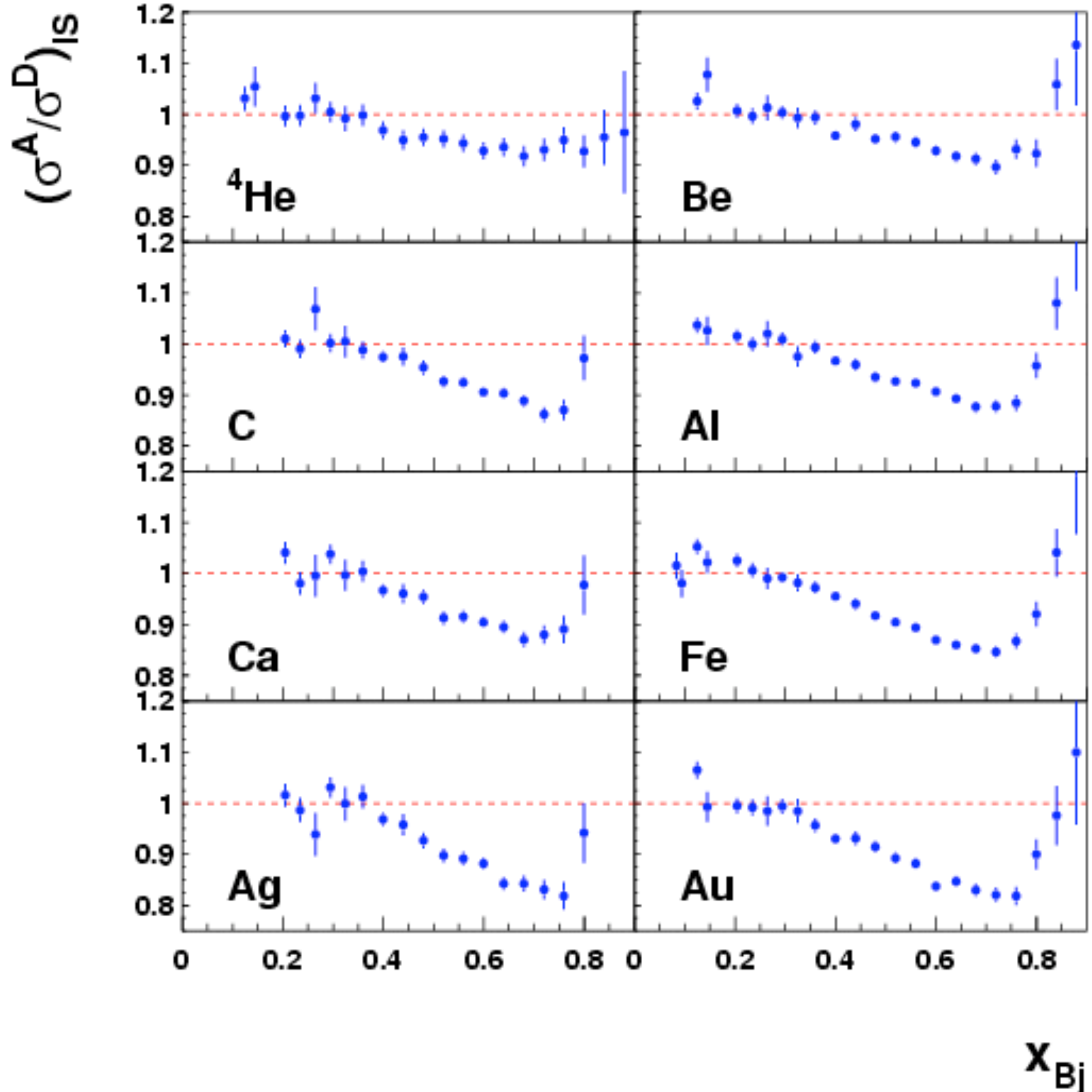
SLAC E139:

- Most precise large x data
- Nuclei from A=4 to A=197

Observations:

- Universal x-dependence shape

J. Gomez et al, PRC49, 4348 (1994)



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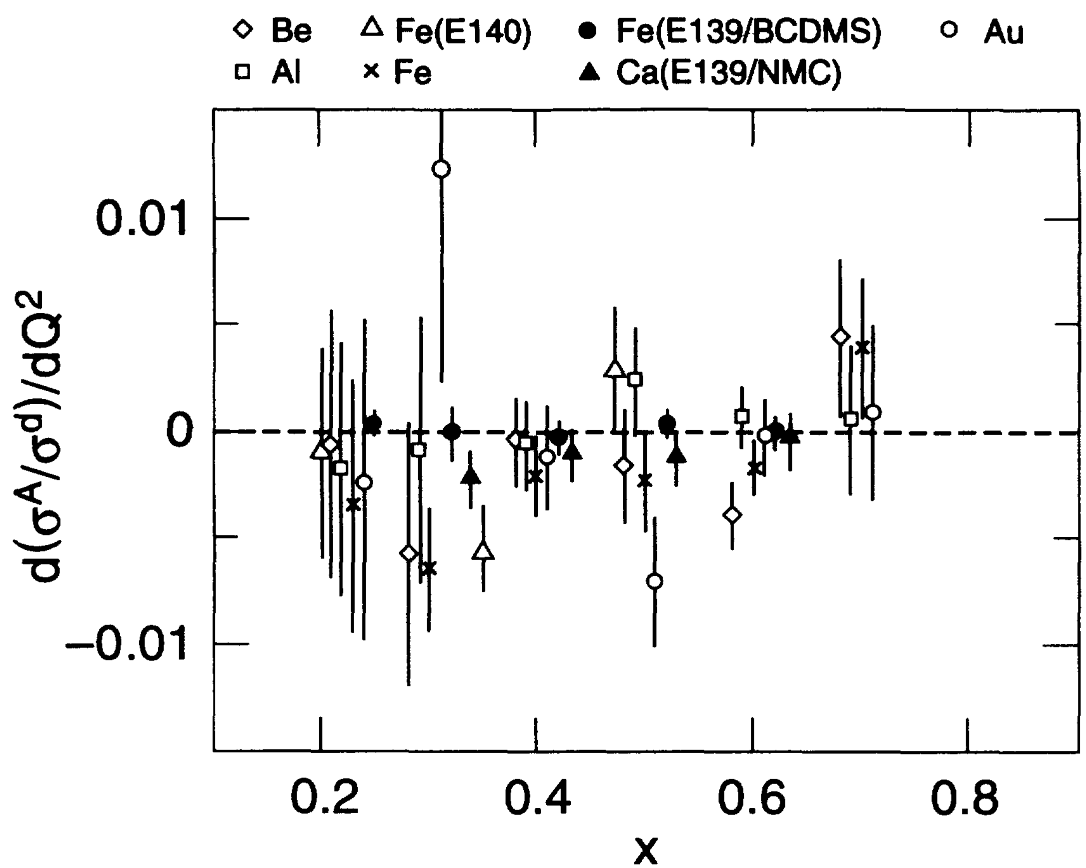

Observations:

- Universal x-dependence shape
- Q^2-independent

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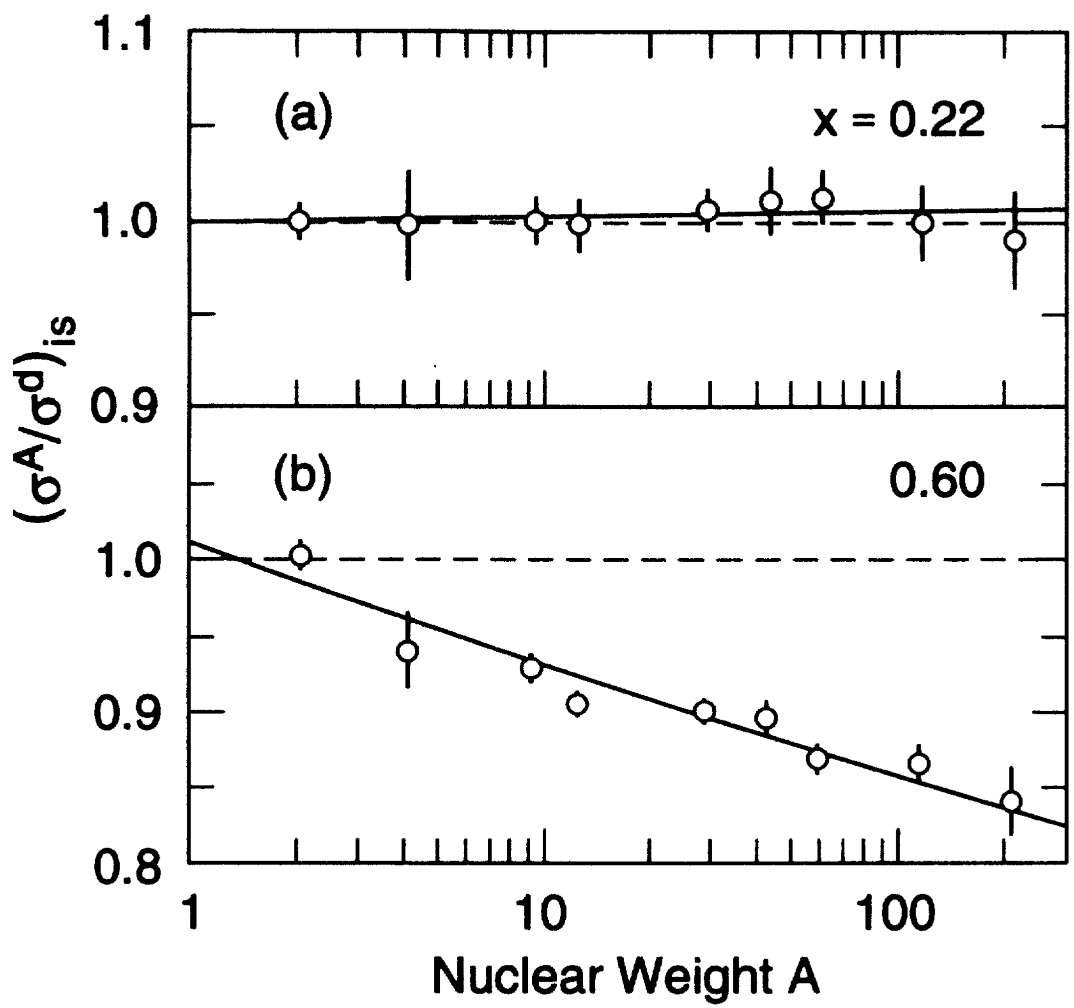

Observations:

- Universal x-dependence shape
- Q^2-independent
- Magnitude varies with A:
  - Scale with $A^{-1/3}$

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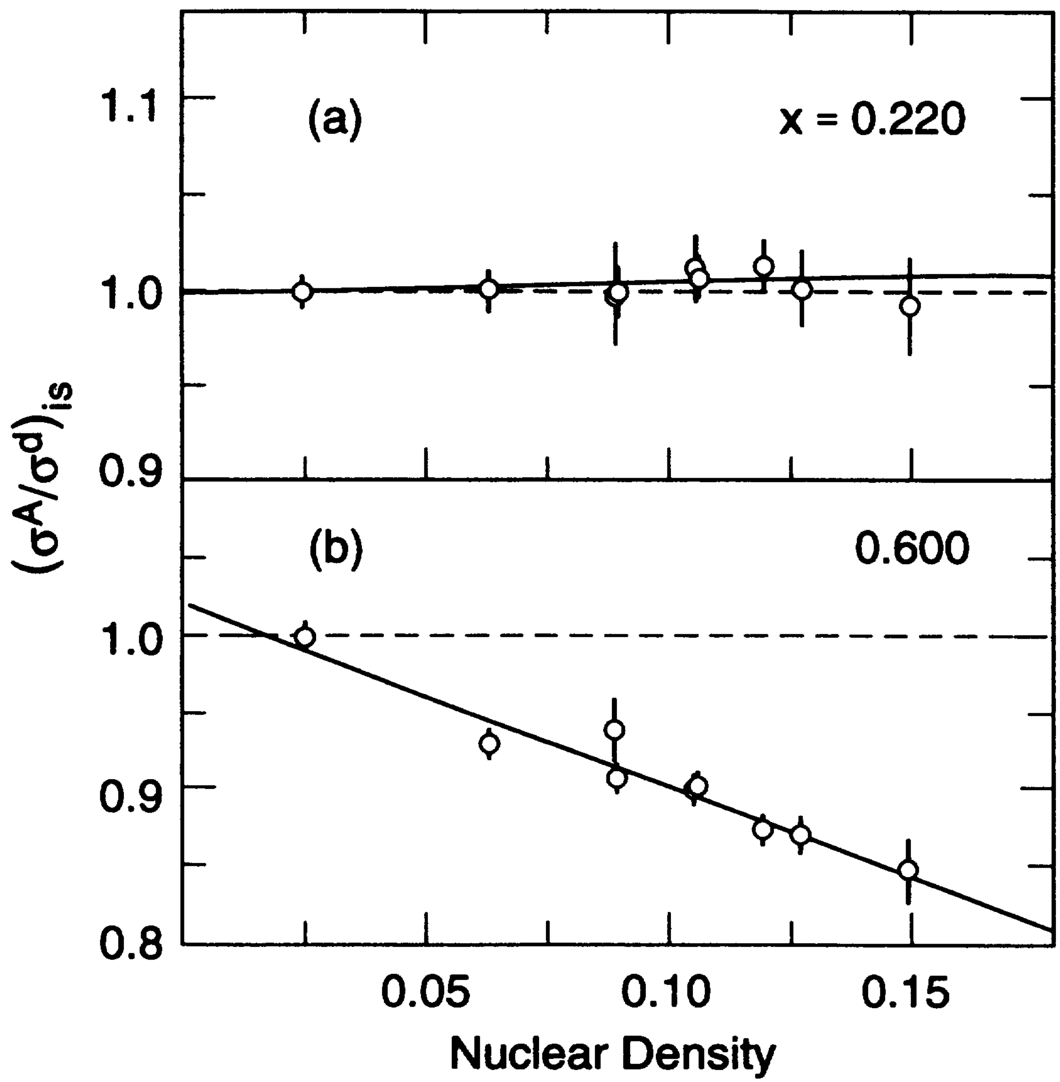

SLAC E139:

- Most precise large x data
- Nuclei from A=4 to A=197

Observations:

- Universal x-dependence shape
- Q^2-independent
- Magnitude varies with A:
  - Scale with $A^{-1/3}$
  - Scale with average density

    Density calculated assuming a uniform sphere of radius:

    $R_e (r=3A/4pR_e^3)$

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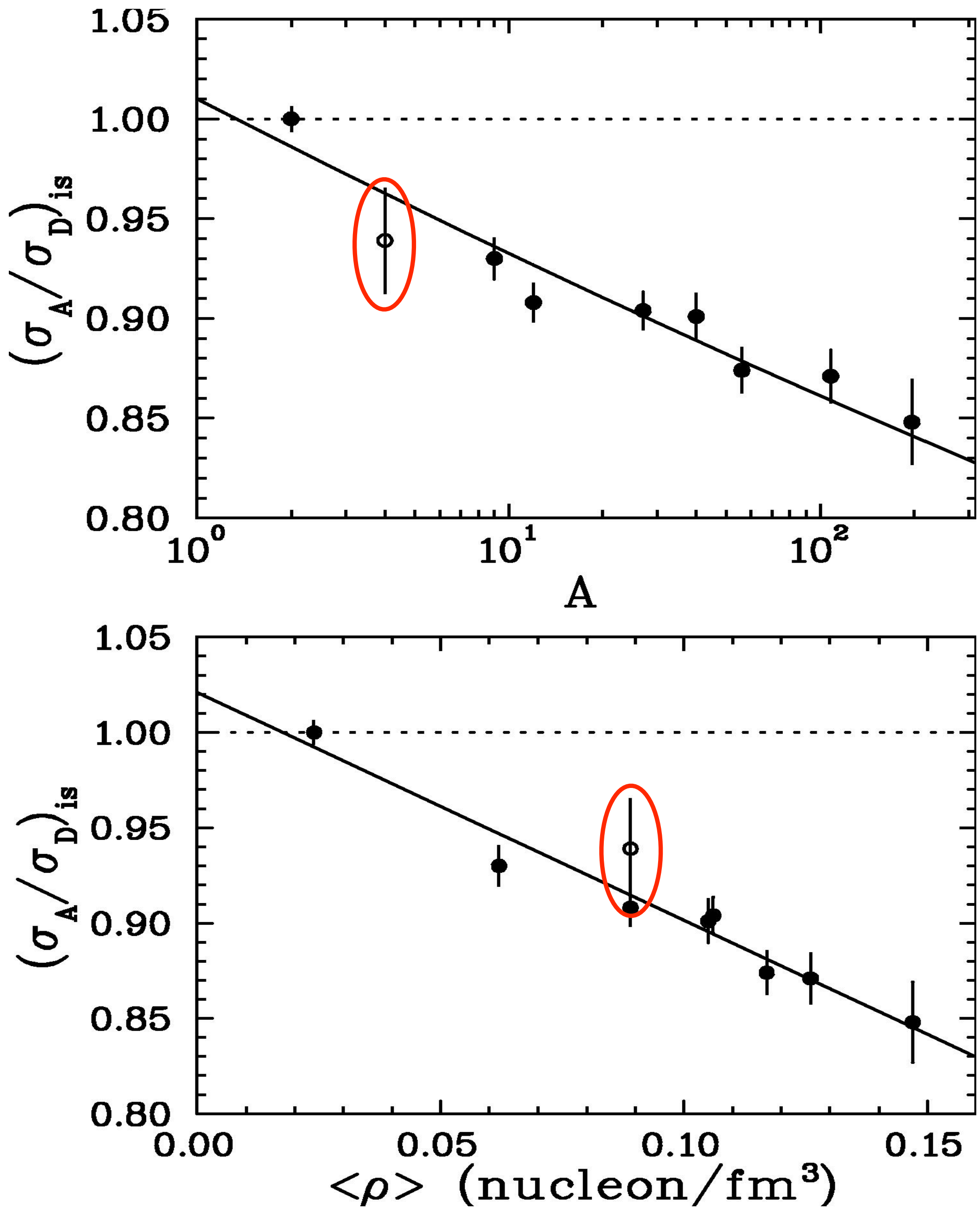
Limits of EMC Data



- ^{4}He much lighter than ^{12}C, but has similar average density

  Compare A vs <ρ>

- ^{3}He has low A and low density; expect smaller EMC effect

- Both nuclei allow for precise, few-body calculations

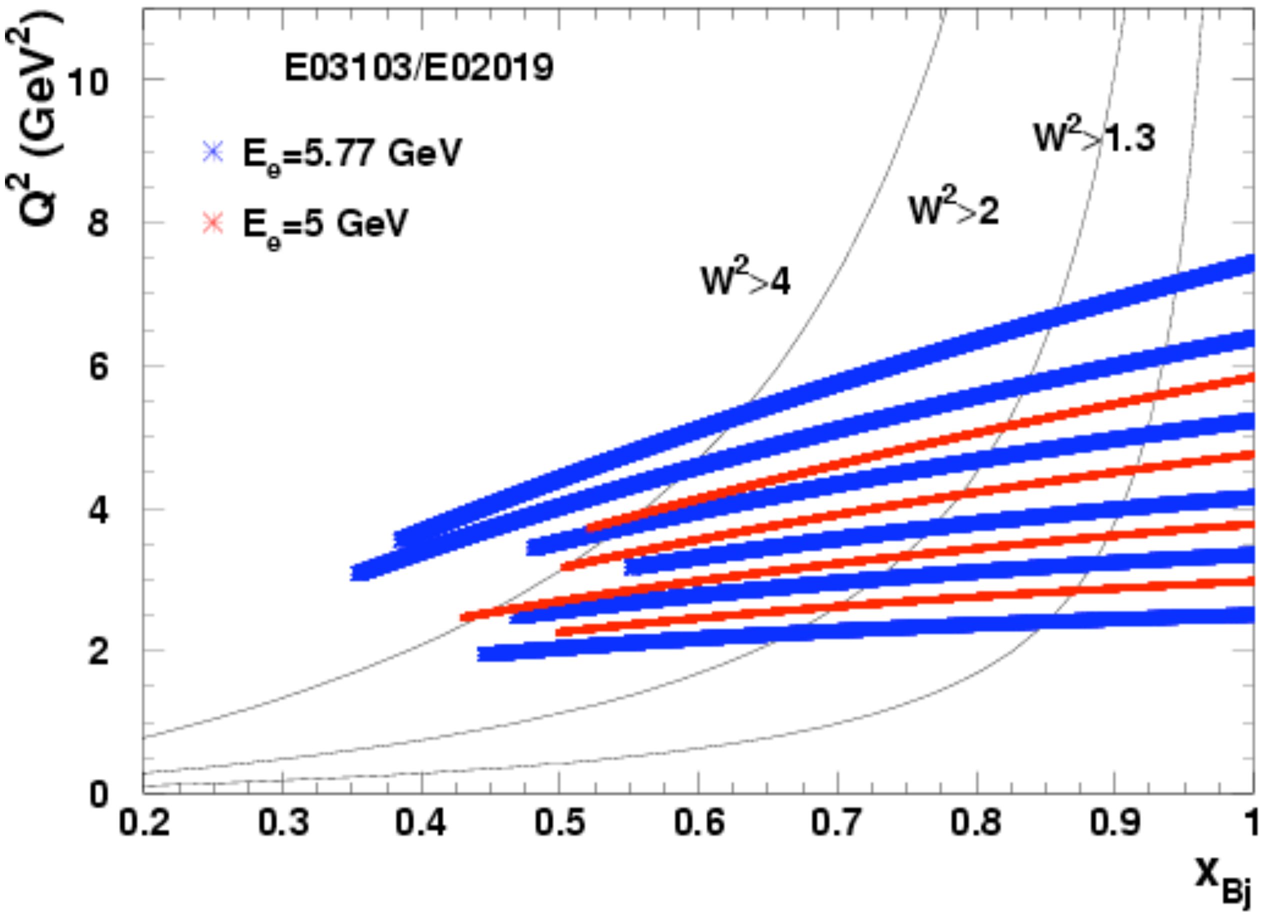
JLab Experiment E03-103

JLab E03-103, "*EMC effect in few-body nuclei*"
J. Arrington and D. Gaskell: spokespersons
J. Seely, A. Daniel, (N. Fomin): Ph.D. students

A(e,e') at 5.0 and 5.8 GeV in Hall C

10 angles to measure Q^2-dependence

Targets: H, ^{2}H, ^{3}He, ^{4}He, ^{9}Be, ^{12}C, ^{63}Cu, ^{197}Au



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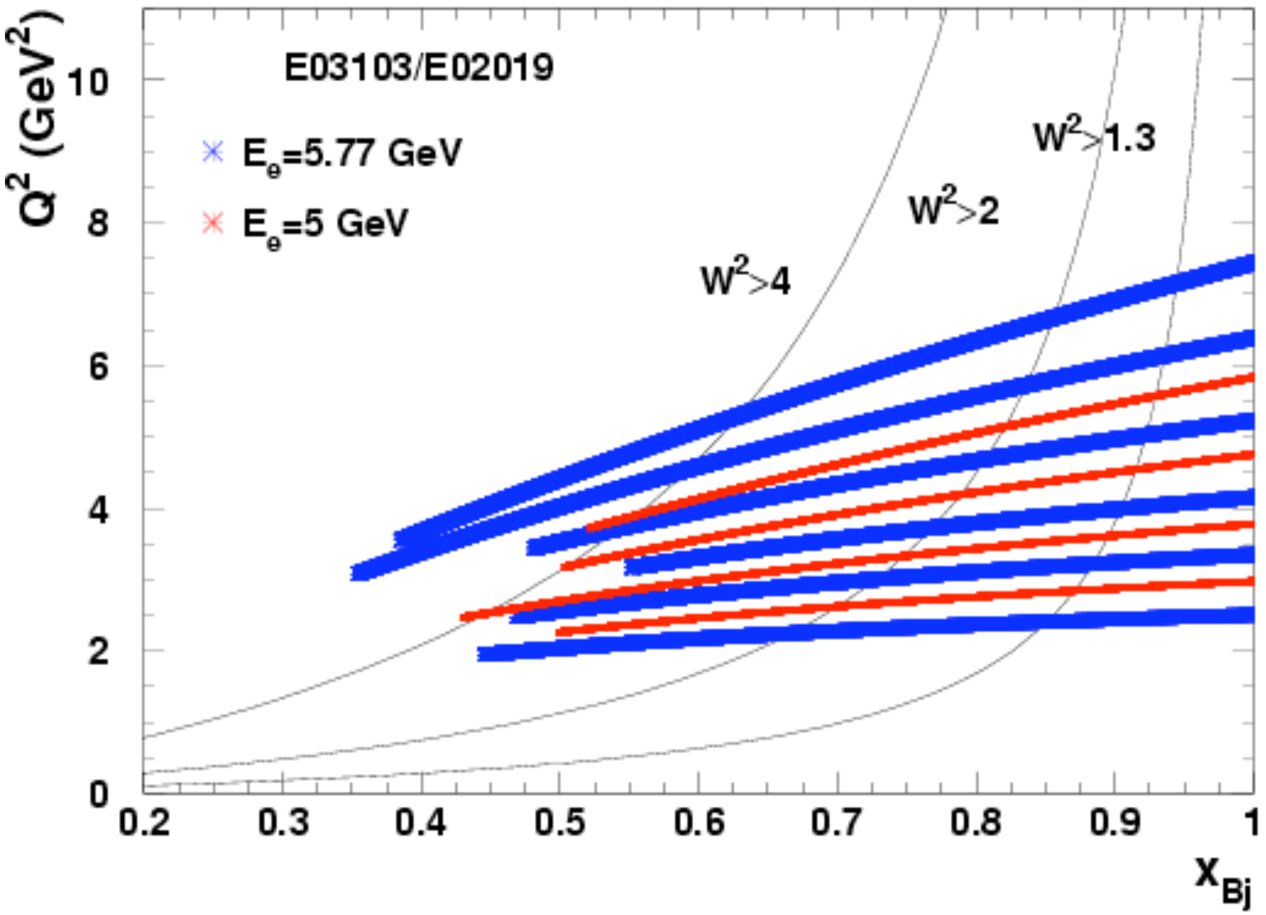
Isoscalar correction



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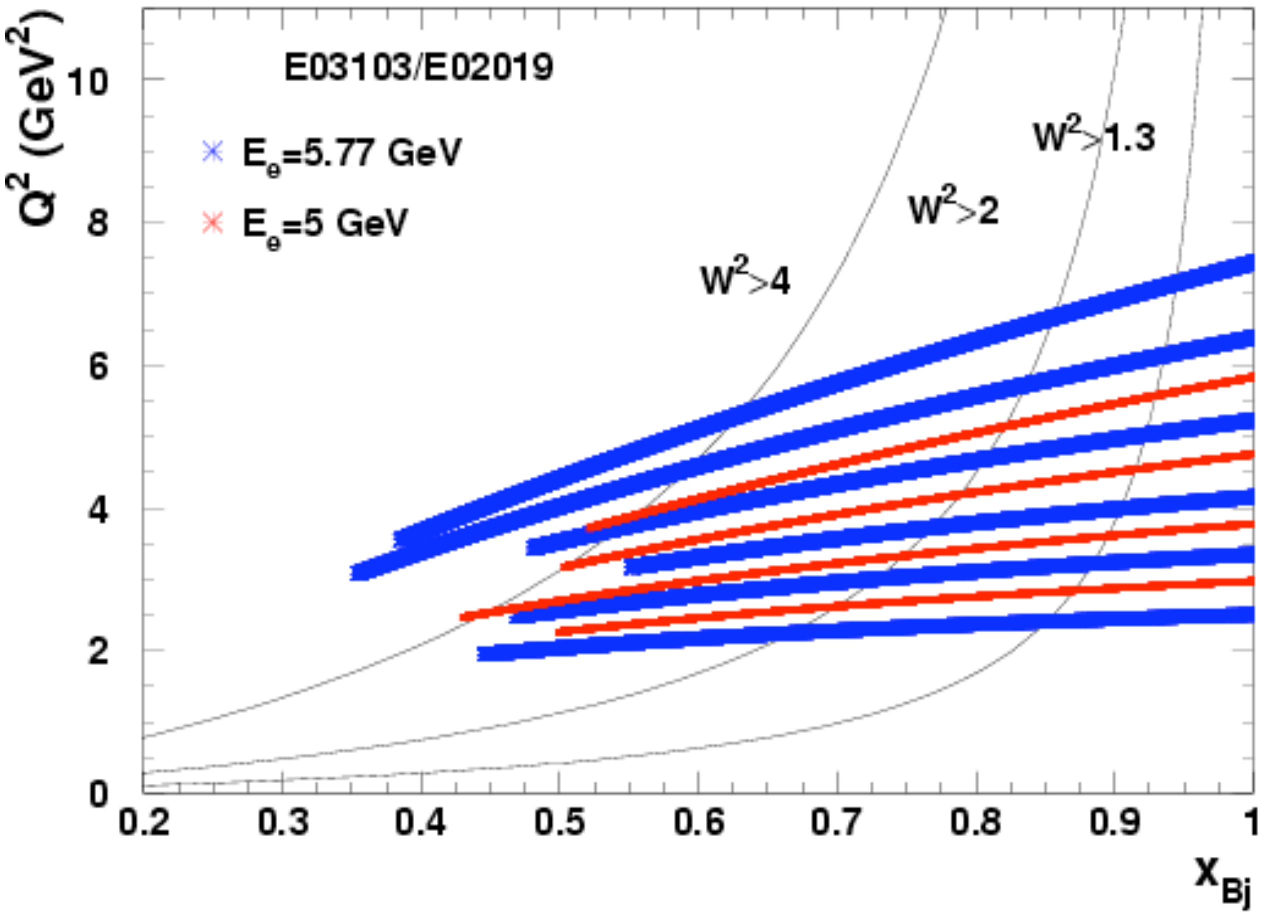
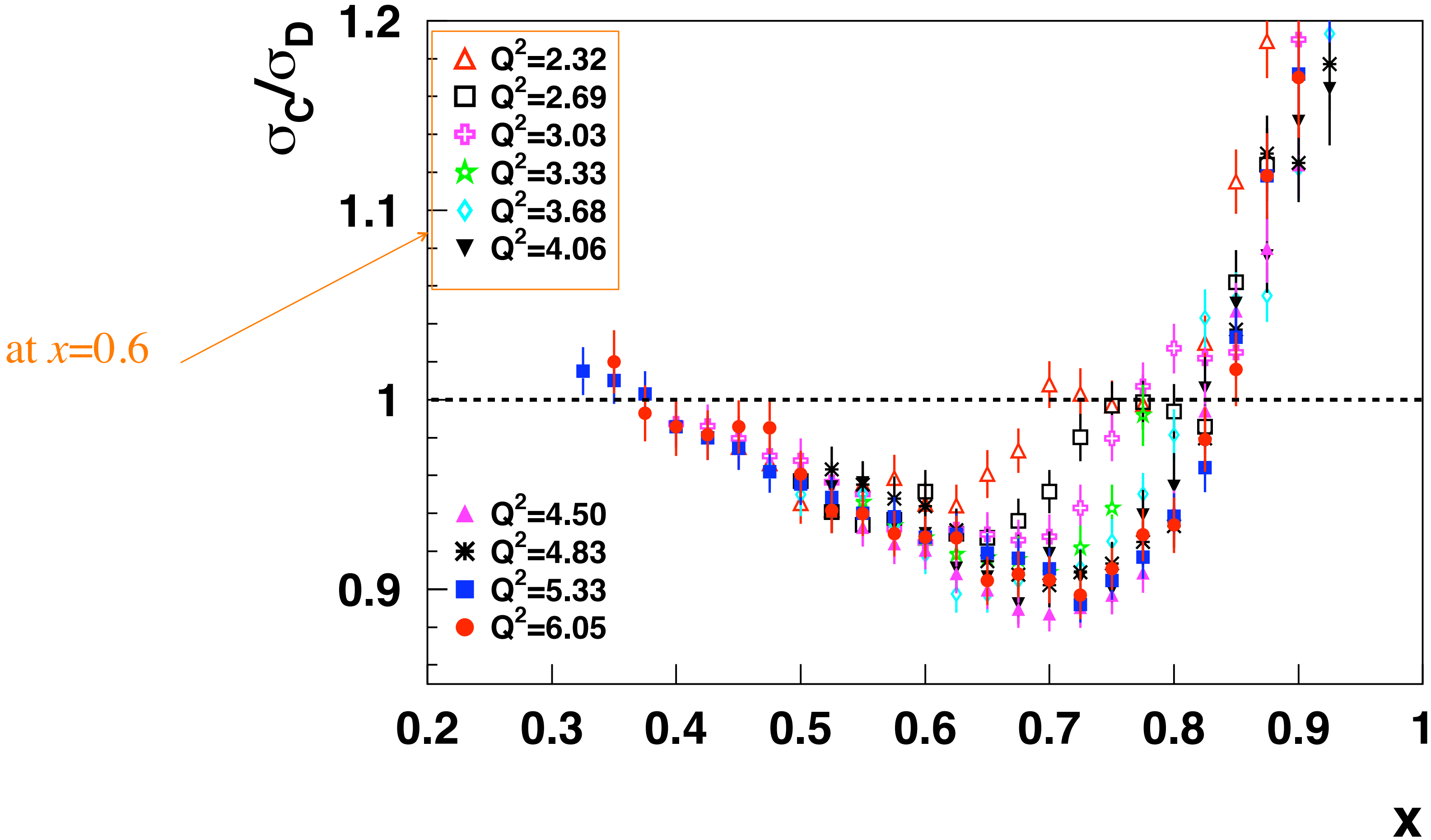
Isoscalar correction

Coulomb correction



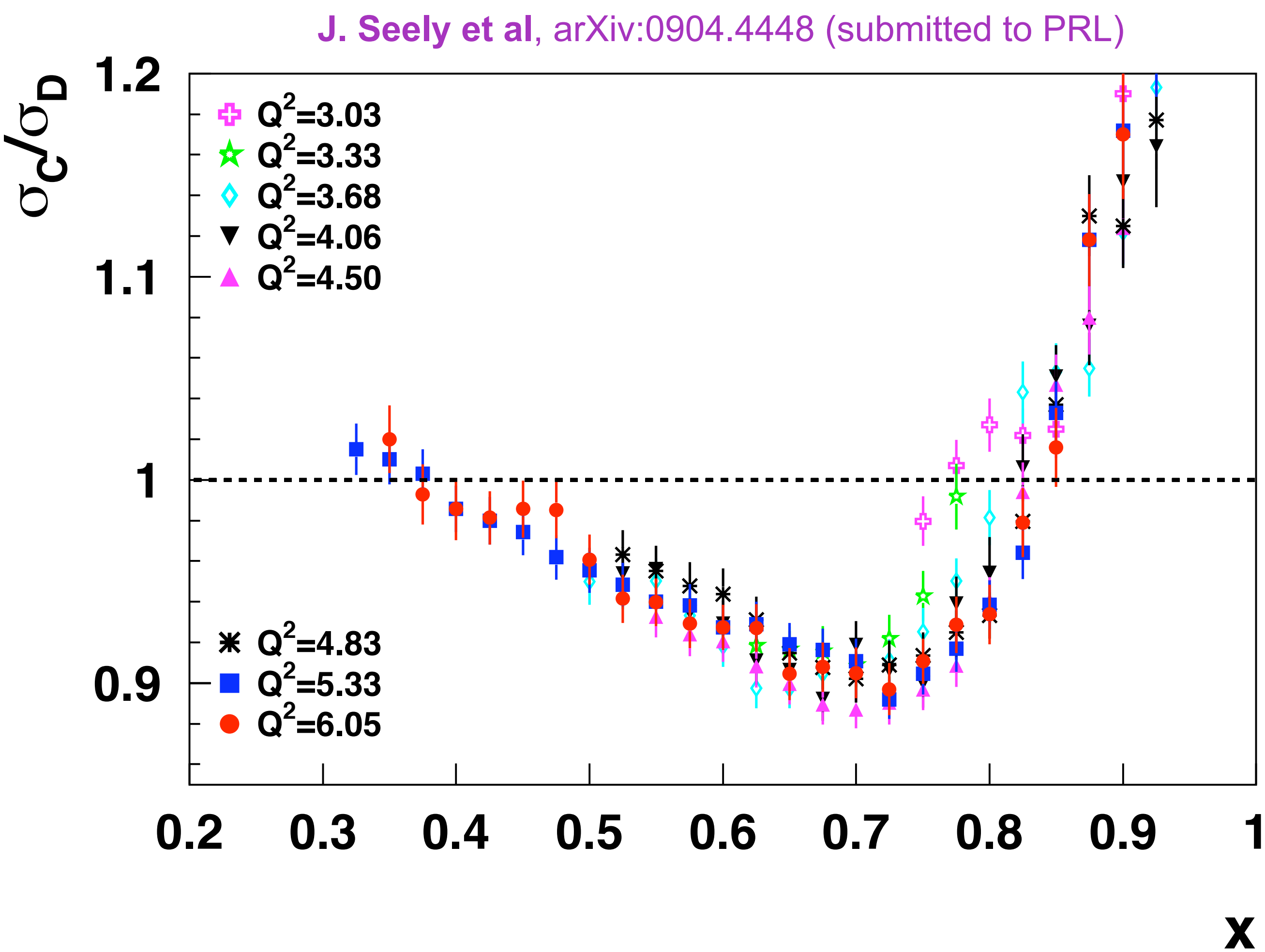
E03-103: Carbon EMC ratio and Q^2-dependence

J. Seely et al, arXiv:0904.4448 (submitted to PRL)



Small angle, low Q^2 ➔ clear scaling violations for $x>0.6$-0.7

E03-103: Carbon EMC ratio and Q^2-dependence



At larger angles ➔ indication of scaling to very large *x*

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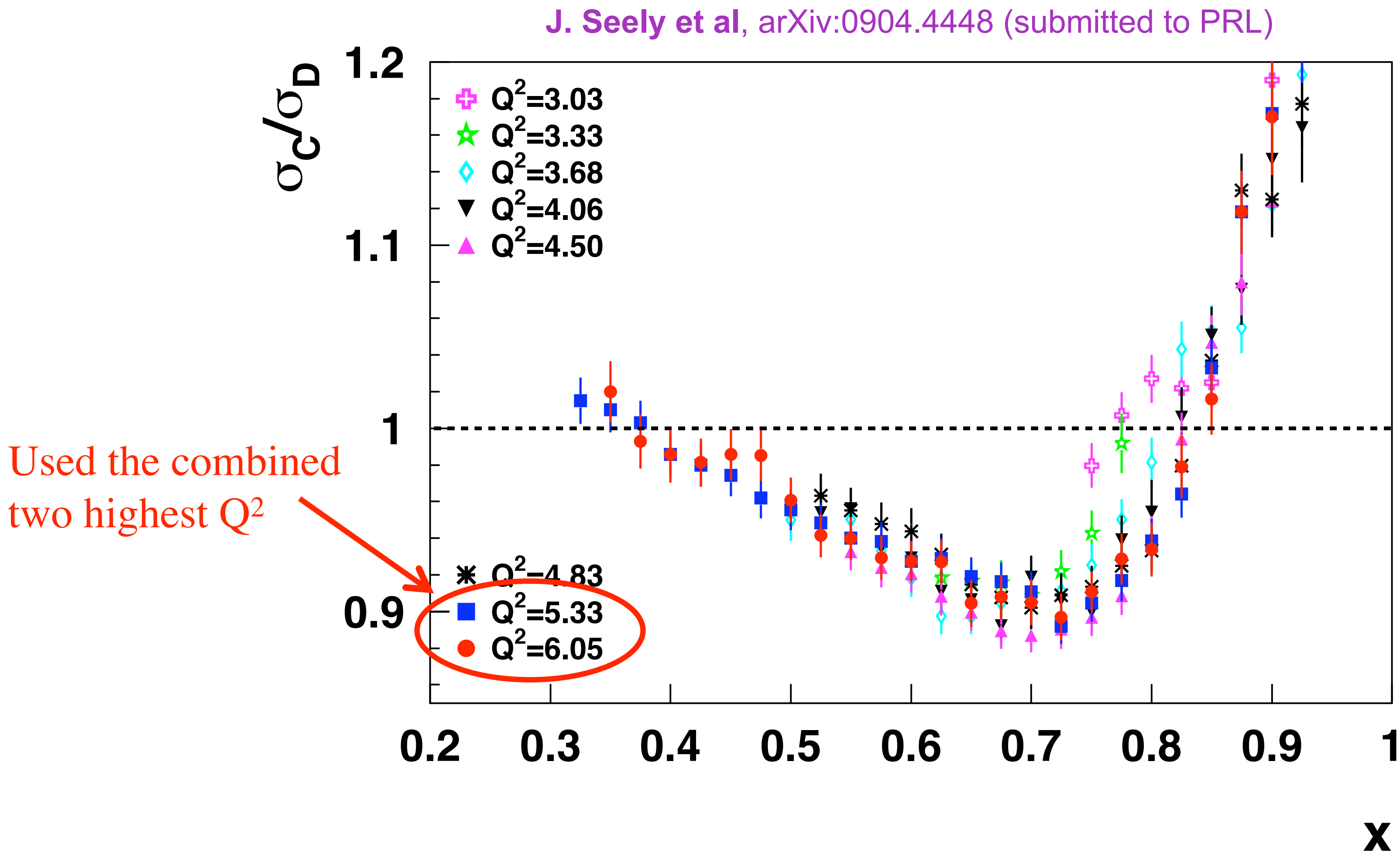

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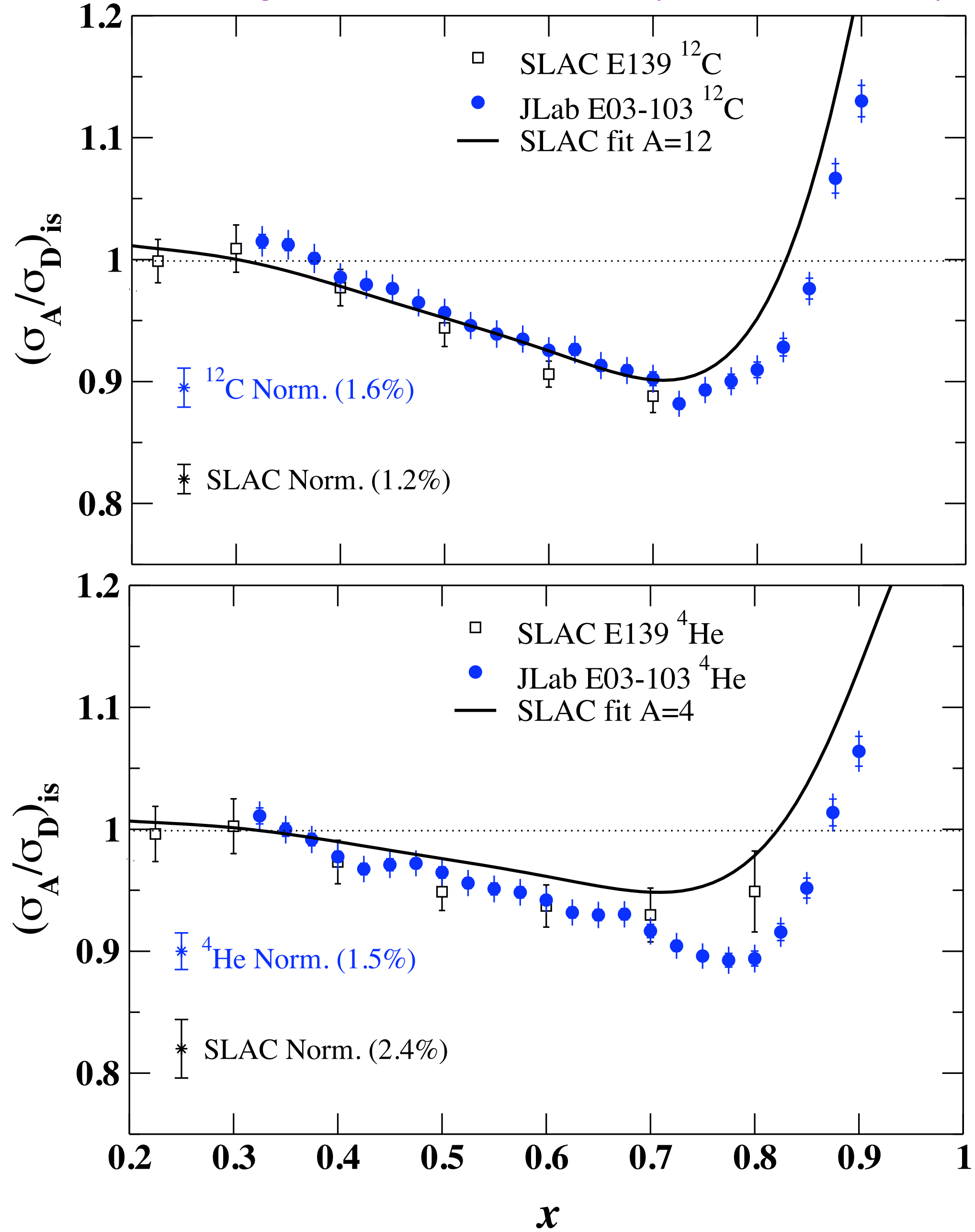
JLab results consistent with SLAC E139

→ Improved statistics and systematic errors



E03-103: ^{12}C and ^{4}He EMC ratios

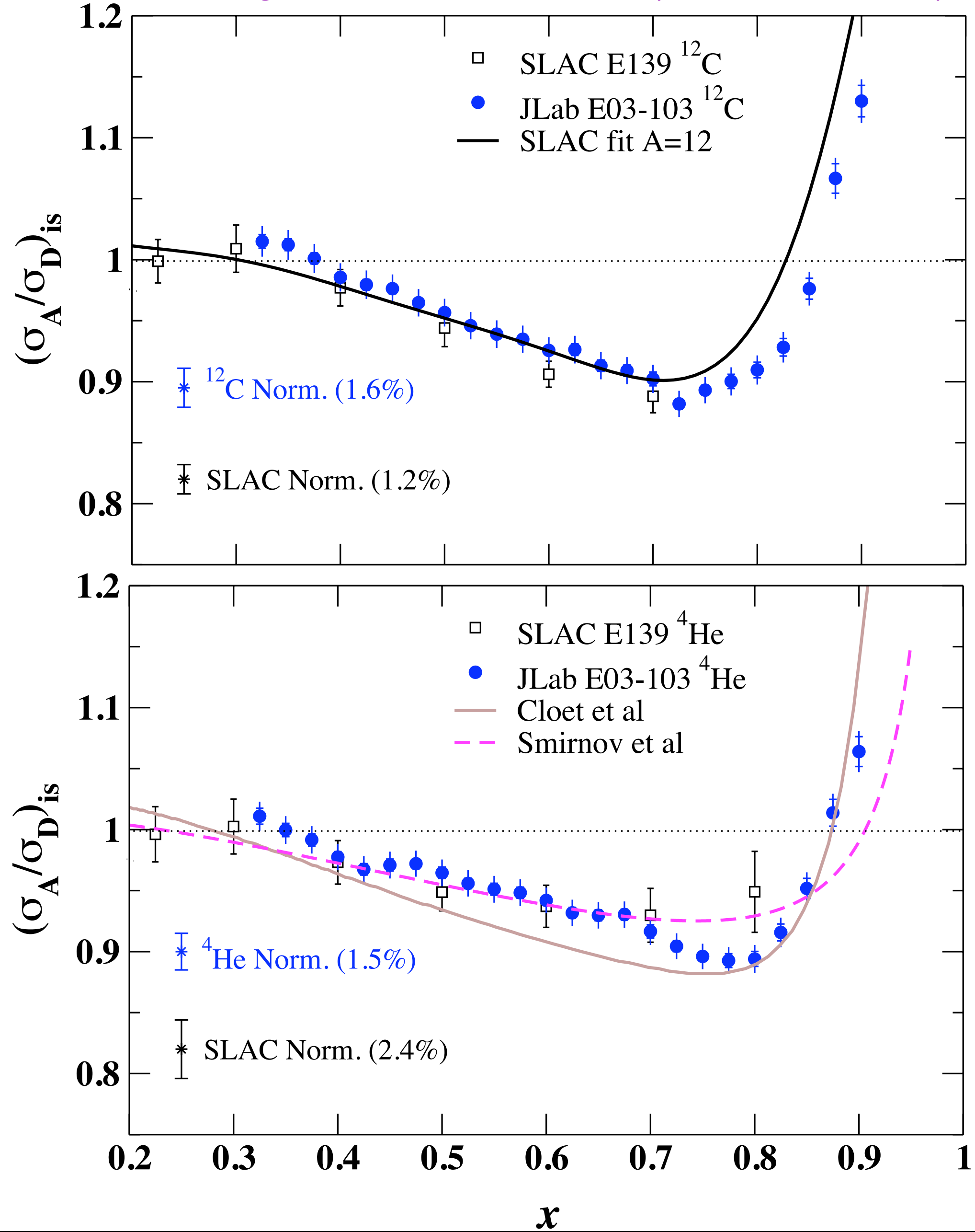
JLab results consistent with SLAC E139

→ Improved statistics and systematic errors

Models shown do a reasonable job describing the data.

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

J. Seely et al, arXiv:0904.4448 (submitted to PRL)



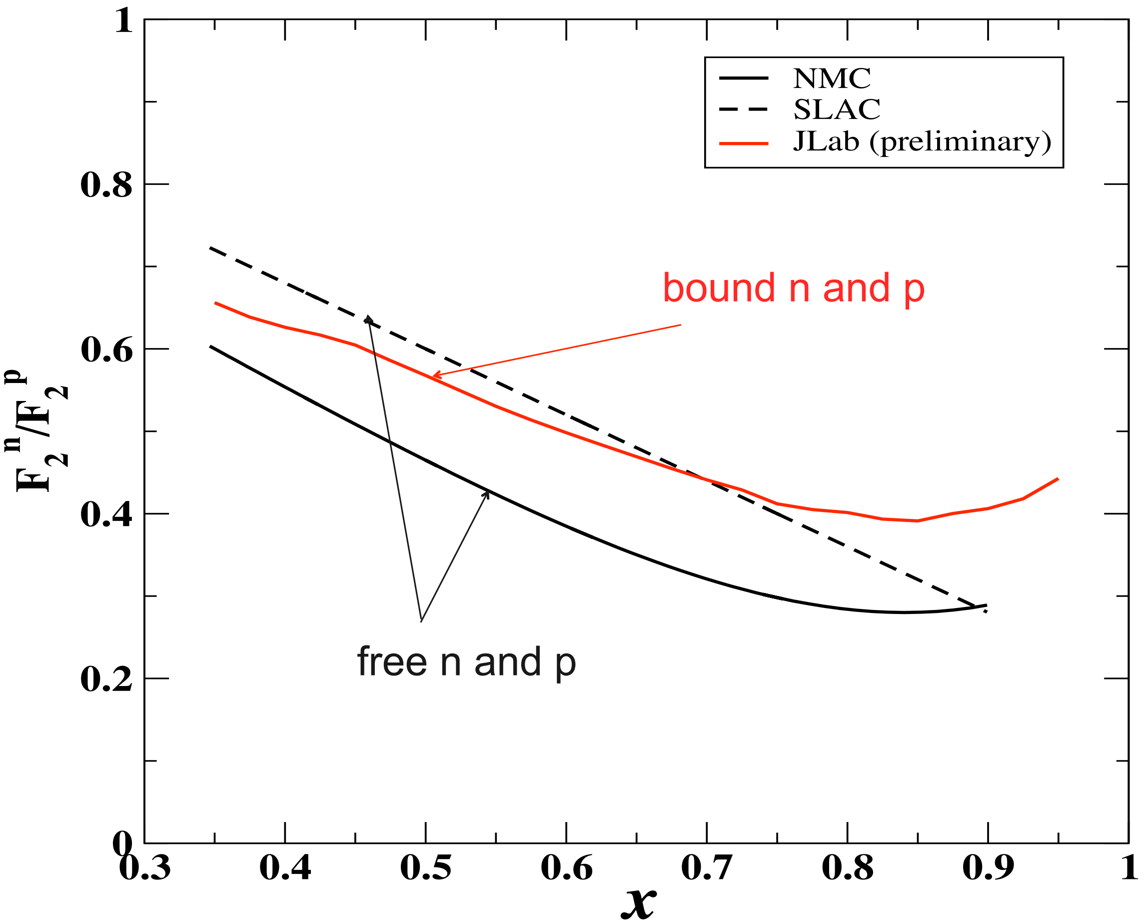
Isoscalar correction

$$Zp + Nn \rightarrow A/2(p+n)$$

Smeared n/p at the kinematics of the experiment

vs.

high Q^2 free n/p

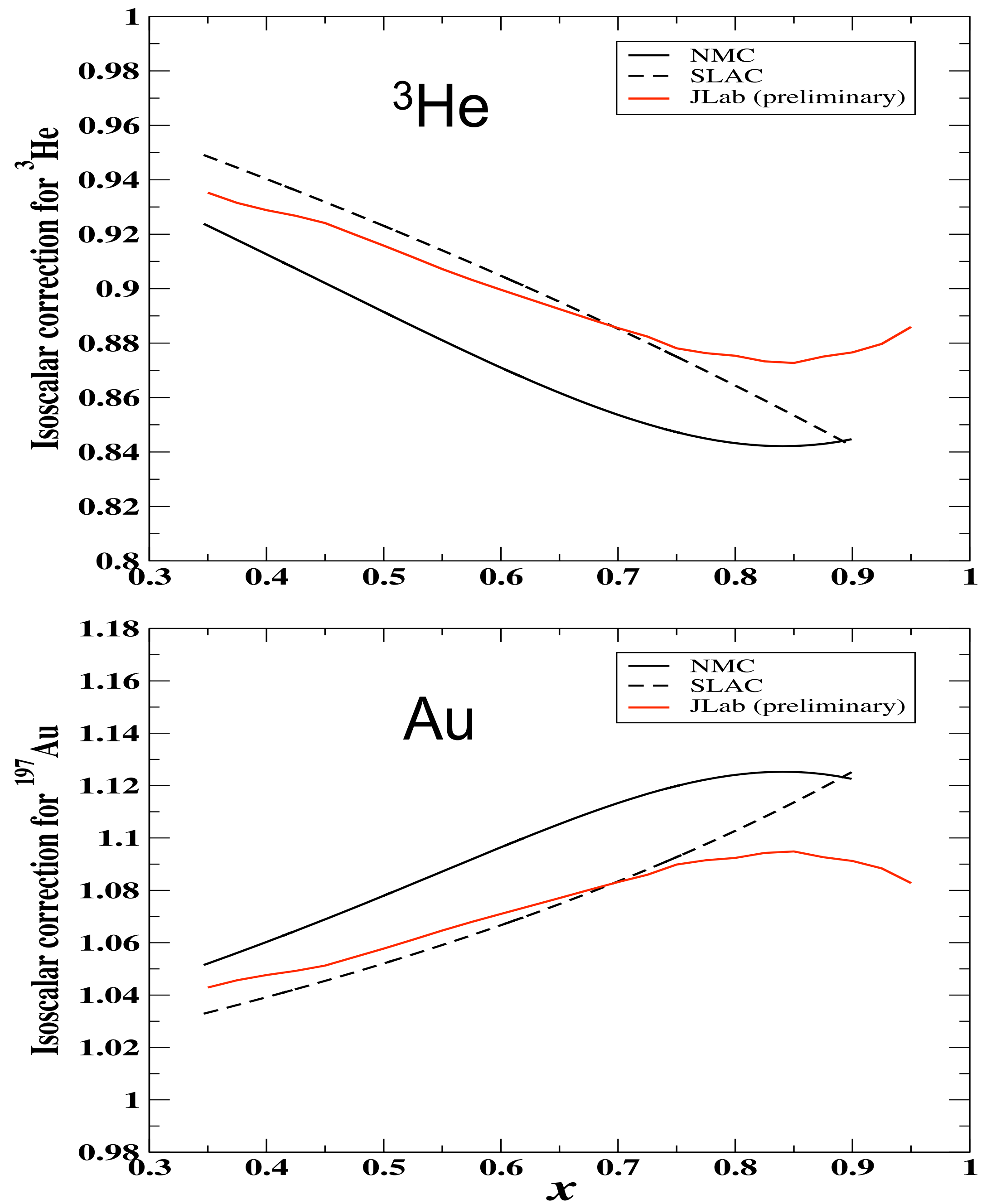


J. Arrington, F. Coester, R.J. Holt, T.-S.H. Lee, J.Phys.G36, 025005 (2009)

Isoscalar correction

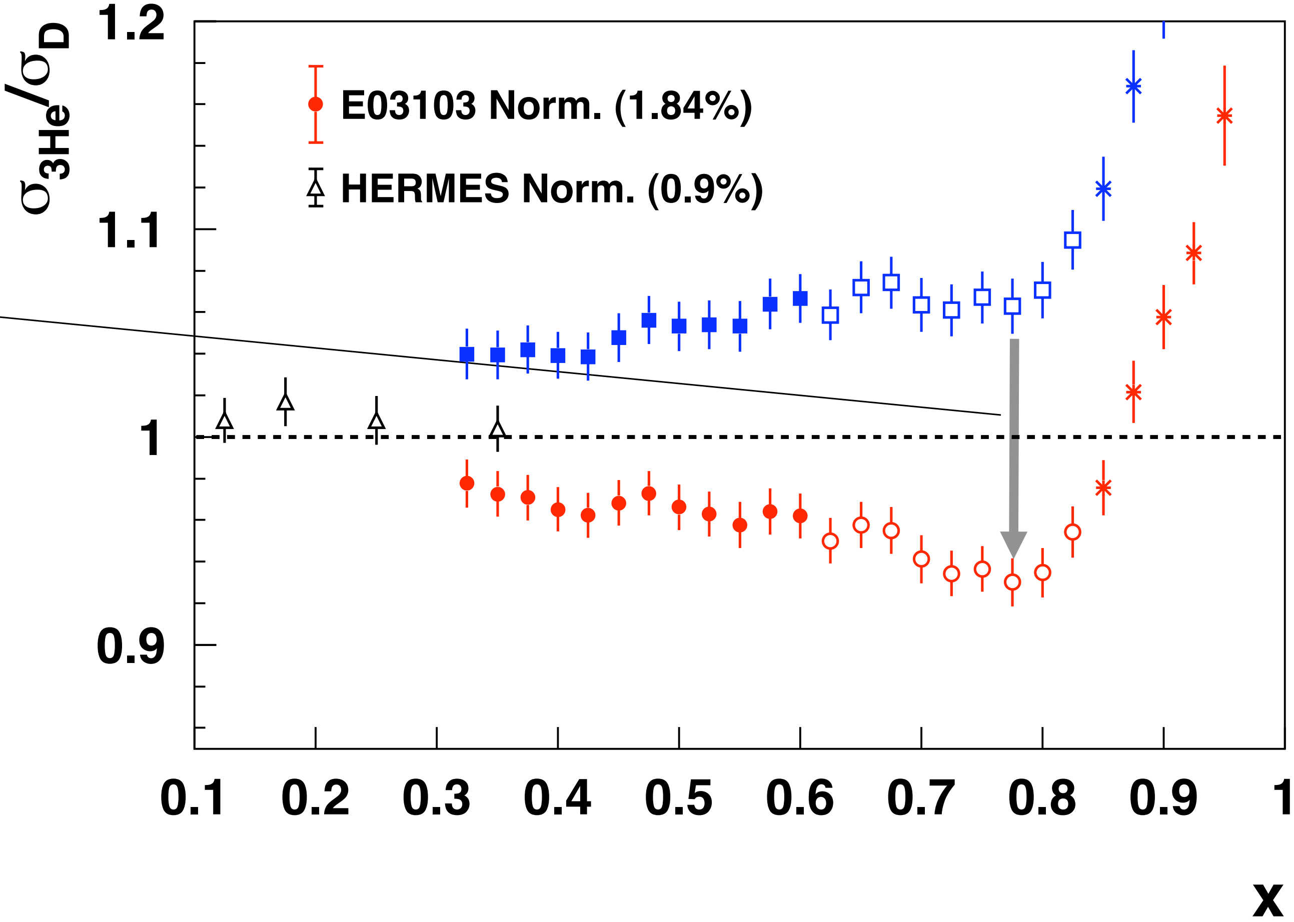
$$R_{EMC} = \frac{\sigma_2^A / A}{\sigma_2^D / 2} \cdot \frac{(p+n)/2}{(Zp+Nn)/A}$$

Isoscalar correction



E03-103: ^{3}He EMC ratio

J. Seely et al, arXiv:0904.4448 (submitted to PRL)



Large proton excess correction

Isoscalar correction done using ratio of bound neutron to bound proton at E03-103 kinematics

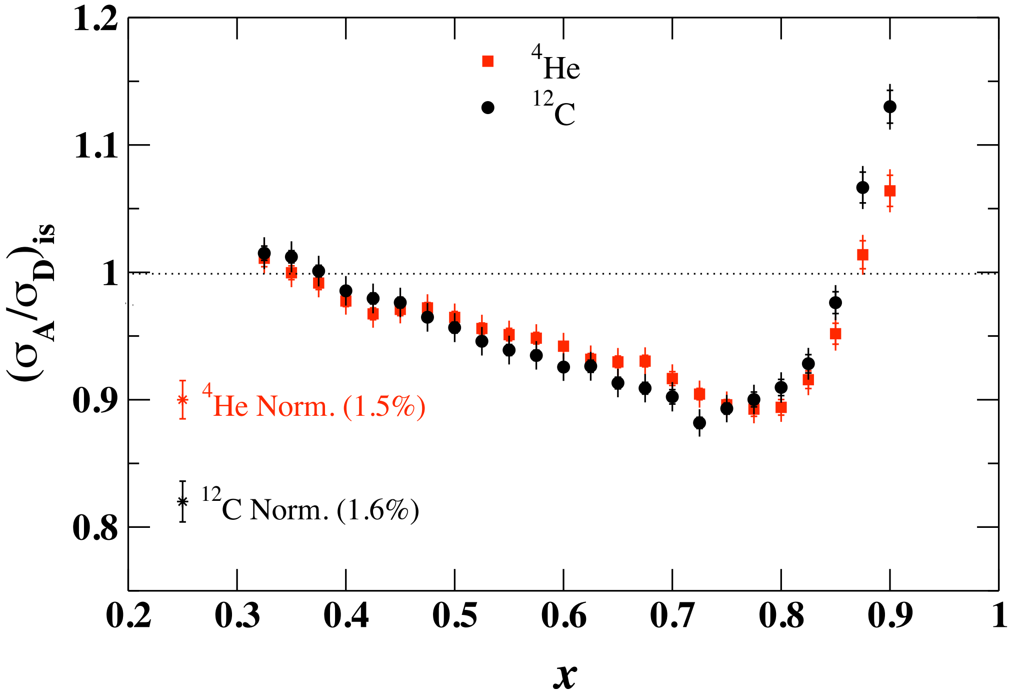
A or ρ-dependence ?

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

$\rho(^4He) \sim \rho(^{12}C)$

^{4}He suggests ρ–dependent

J. Seely et al, arXiv:0904.4448 (submitted to PRL)



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

$\rho(^{4}He) \sim \rho(^{12}C)$

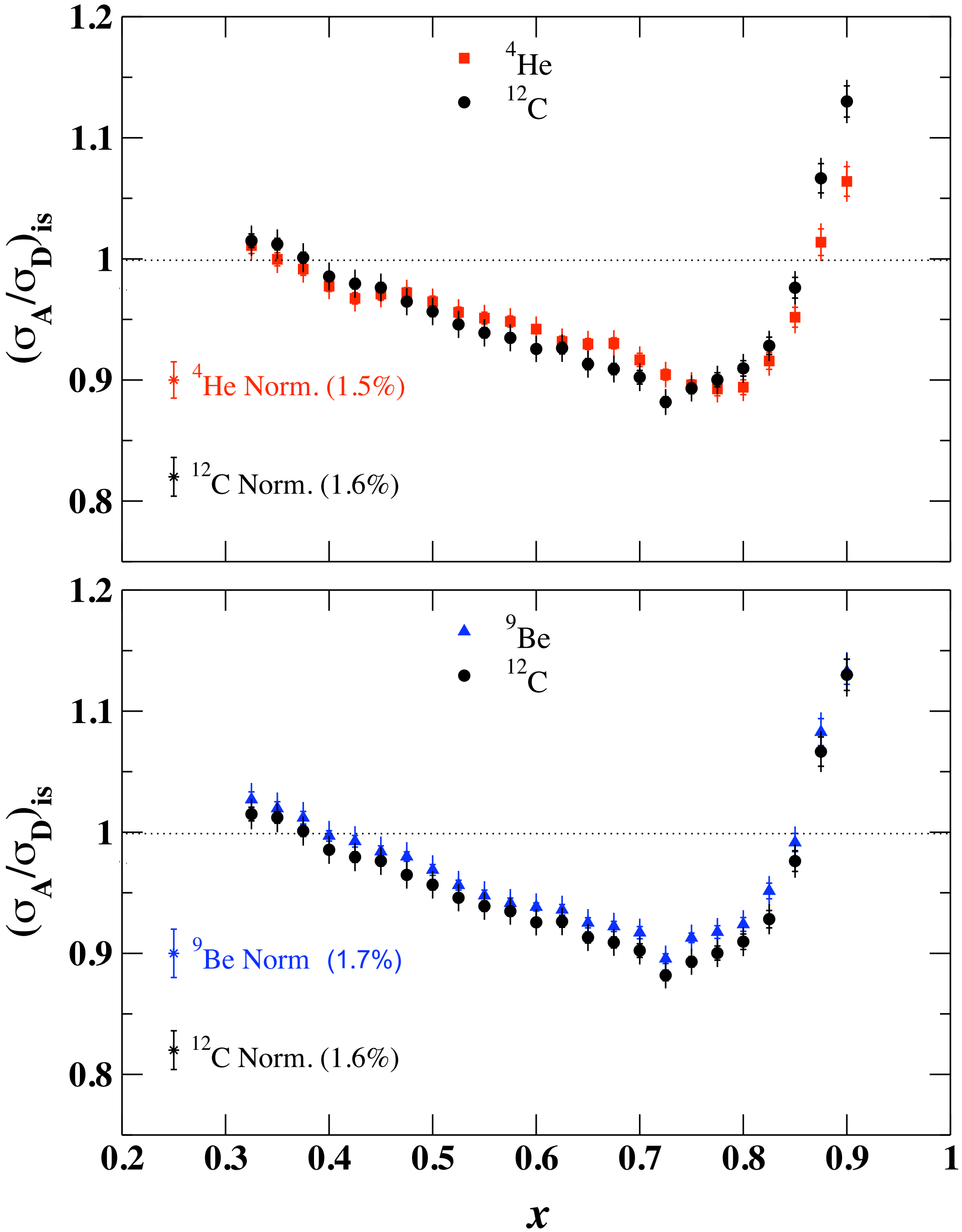
^{4}He suggests ρ–dependent

Magnitude of the EMC effect for C and ^{9}Be very similar, but

$\rho(^{9}Be) << \rho(^{12}C)$

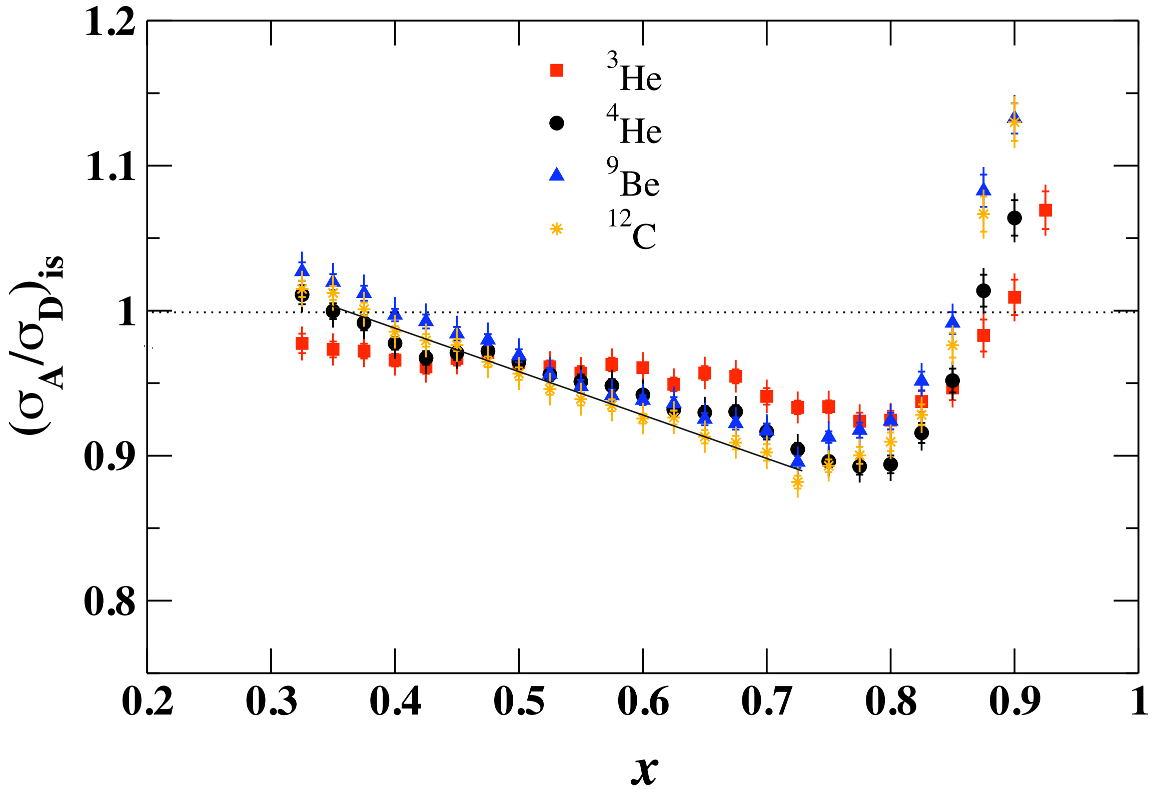
^{9}Be suggests A-dependent

J. Seely et al, arXiv:0904.4448 (submitted to PRL)



A or ρ-dependence ?

Fit of the EMC ratio for 0.35<x<0.7 and look at A- and density dependence of the slope



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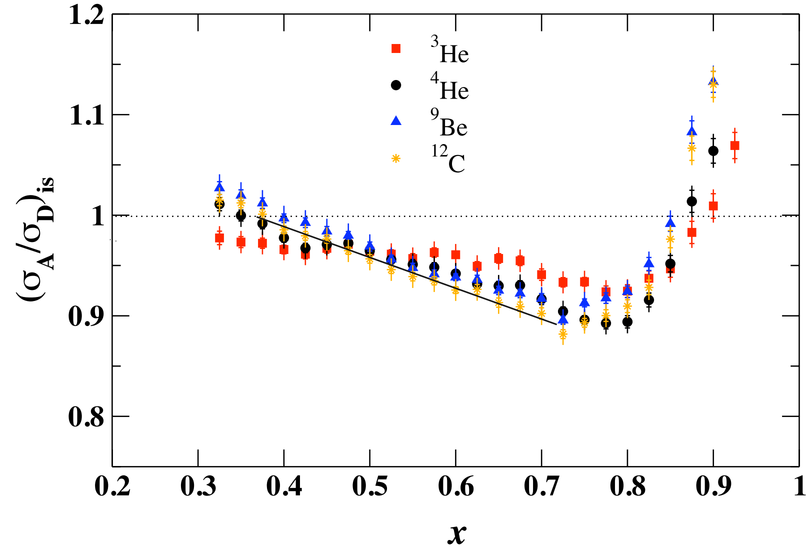

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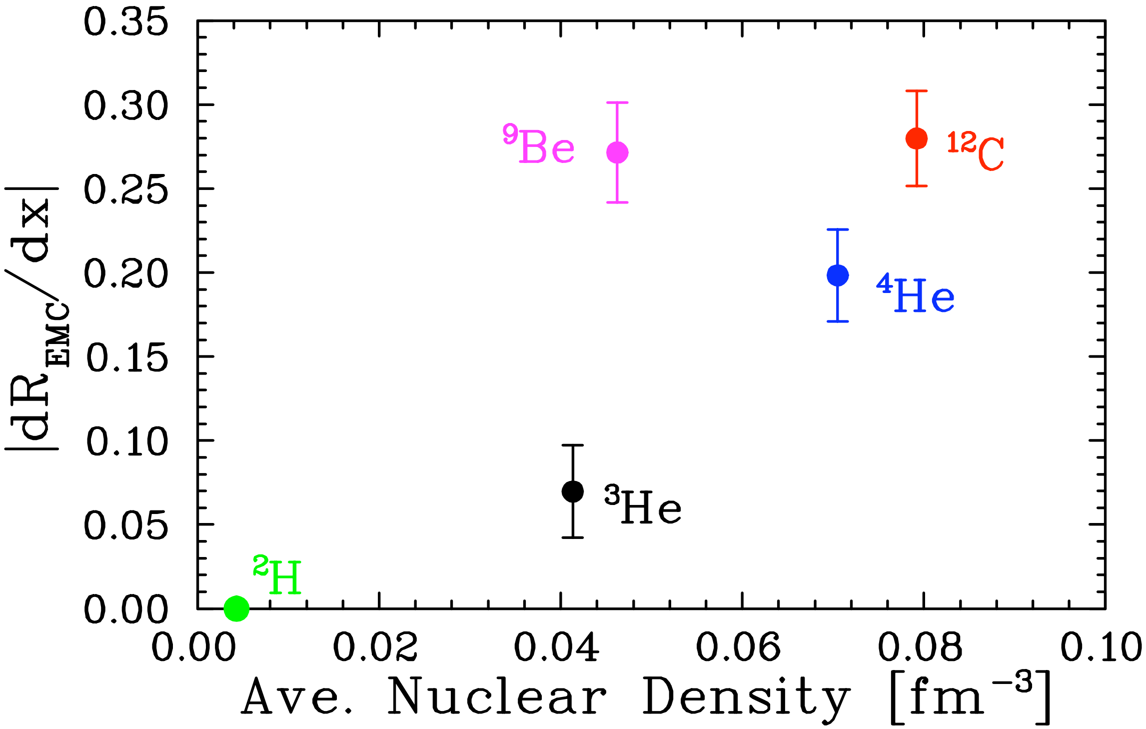

Density determined from ab initio few-body calculation

S.C. Pieper and R.B. Wiringa, Ann. Rev. Nucl. Part. Sci 51, 53 (2001)

To remove struck nucleon's contribution, scale density by (A-1)/A

Data show smooth behavior as density increases…
except for ^{9}Be

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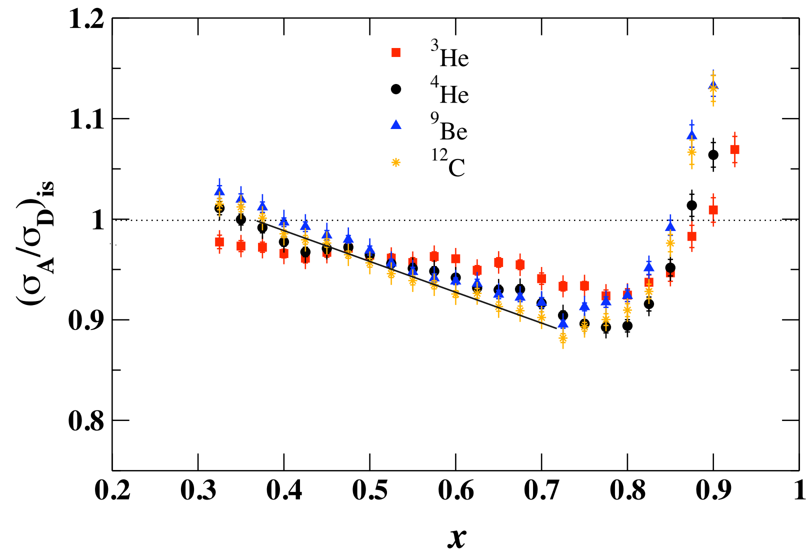

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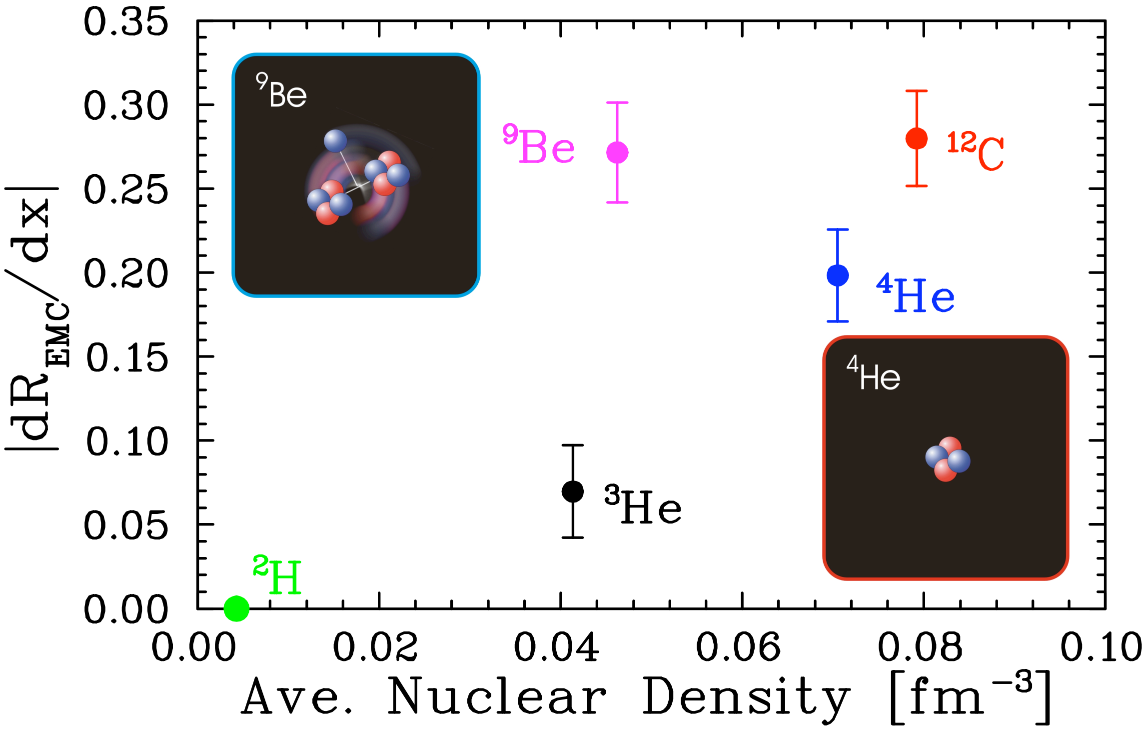
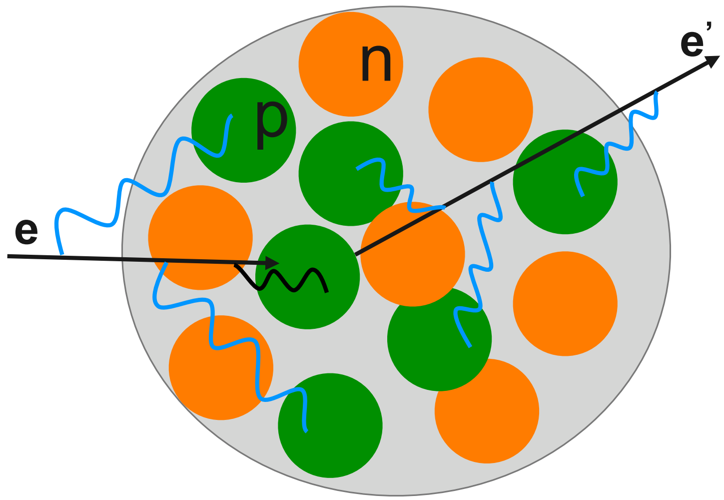


^{9}Be has low average density, but large component of structure is 2α+n most nucleons in tight, α-like configurations

Heavy nuclei
and
Coulomb distortion

Coulomb distortion



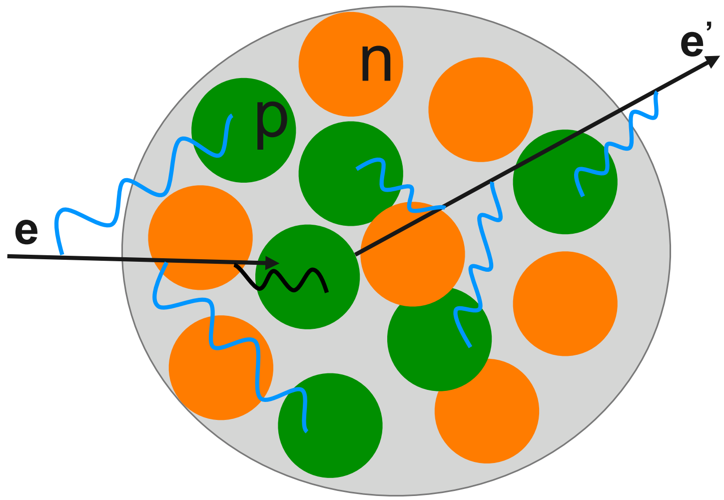
Exchange of one or more (soft) photons with the nucleus, in addition to the one hard photon exchanged with a nucleon

Incident (scattered) electrons are accelerated (decelerated) in the Coulomb well of the nucleus.

Opposite effect with positrons

$$\sigma_{tot}^{PWBA} = \sigma_{Mott}\, S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta)$$

Coulomb distortion



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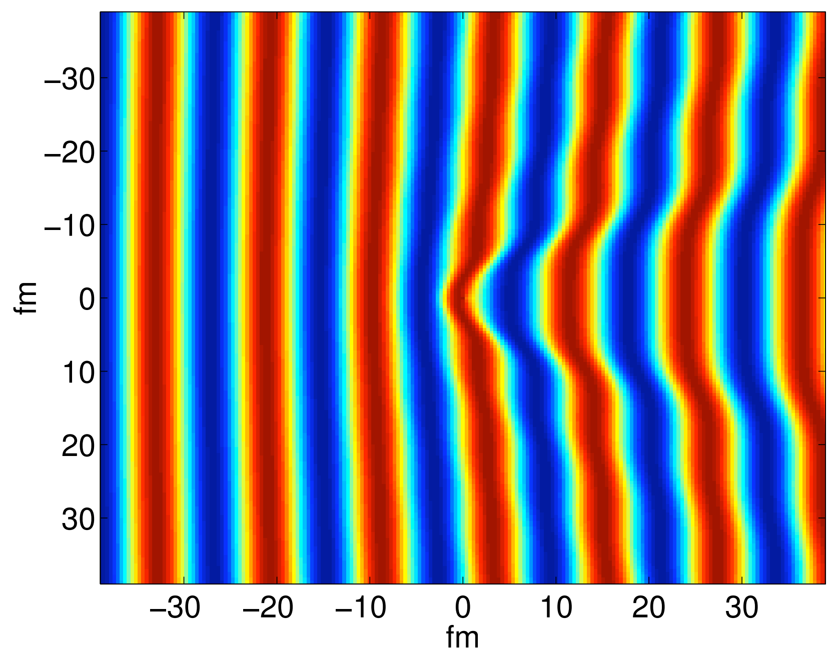
$$\sigma_{tot}^{PWBA} = \sigma_{Mott}\, S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta)$$

$$\Downarrow$$

$$\sigma_{tot}^{DWBA}$$

- Focusing of the electron wave function
- Change of the electron momentum

Fig. from **A. Aste** at Mini-Workshop on Coulomb Distortion, JLab May 2005



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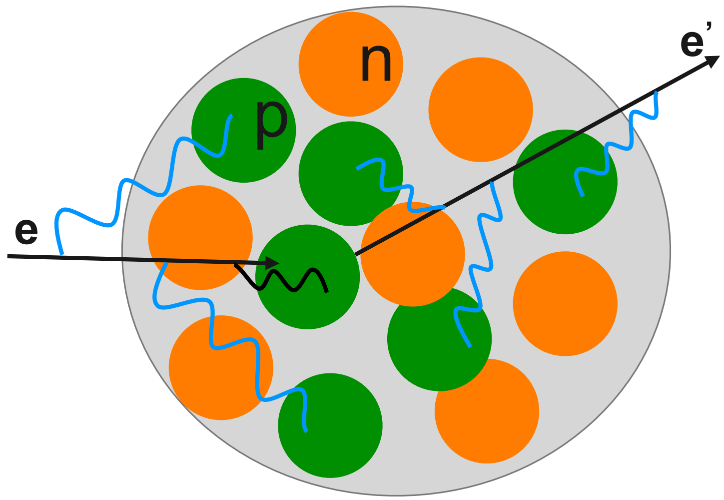

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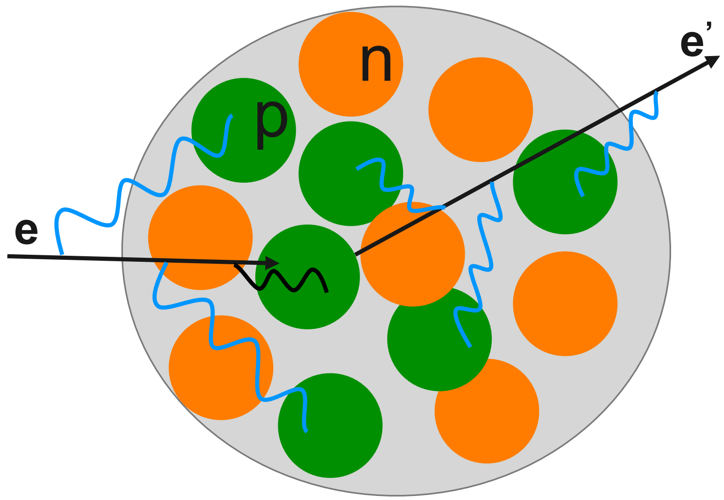
Opposite effect with positrons

Effective Momentum Approximation (**EMA**)

$$\left.\begin{array}{l} E \rightarrow E + \bar{V} \\ E_p \rightarrow E_p + \bar{V} \end{array}\right\} \quad Q^2_{eff} = 4(E + \bar{V})(E_p + \bar{V})\sin^2(\frac{\theta}{2})$$

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)

Coulomb distortion



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Incident (scattered) electrons are accelerated (decelerated) in the Coulomb well of the nucleus.

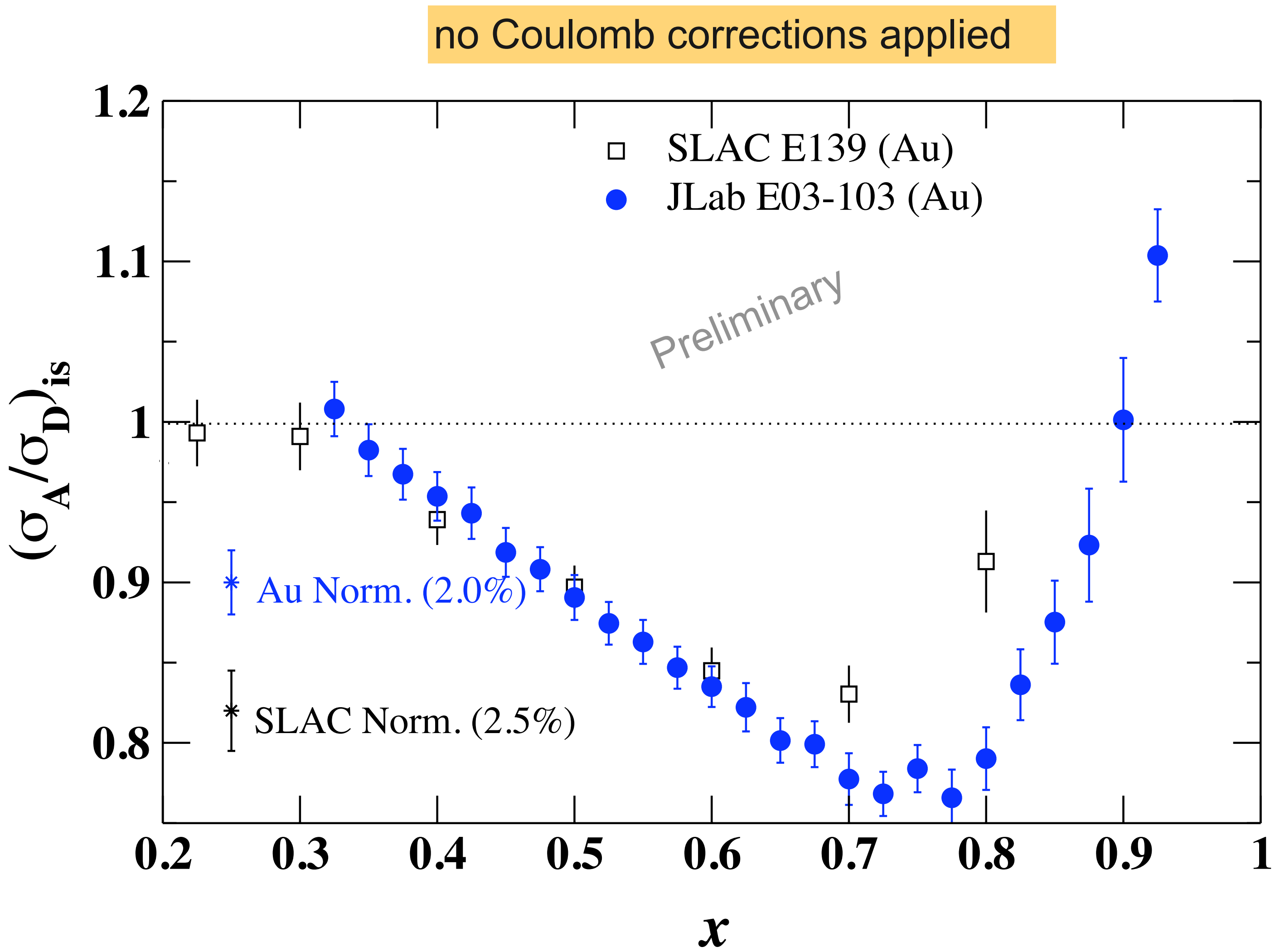
Opposite effect with positrons

Effective Momentum Approximation (**EMA**)

One-parameter model depending only on the effective potential seen by the electron on average.

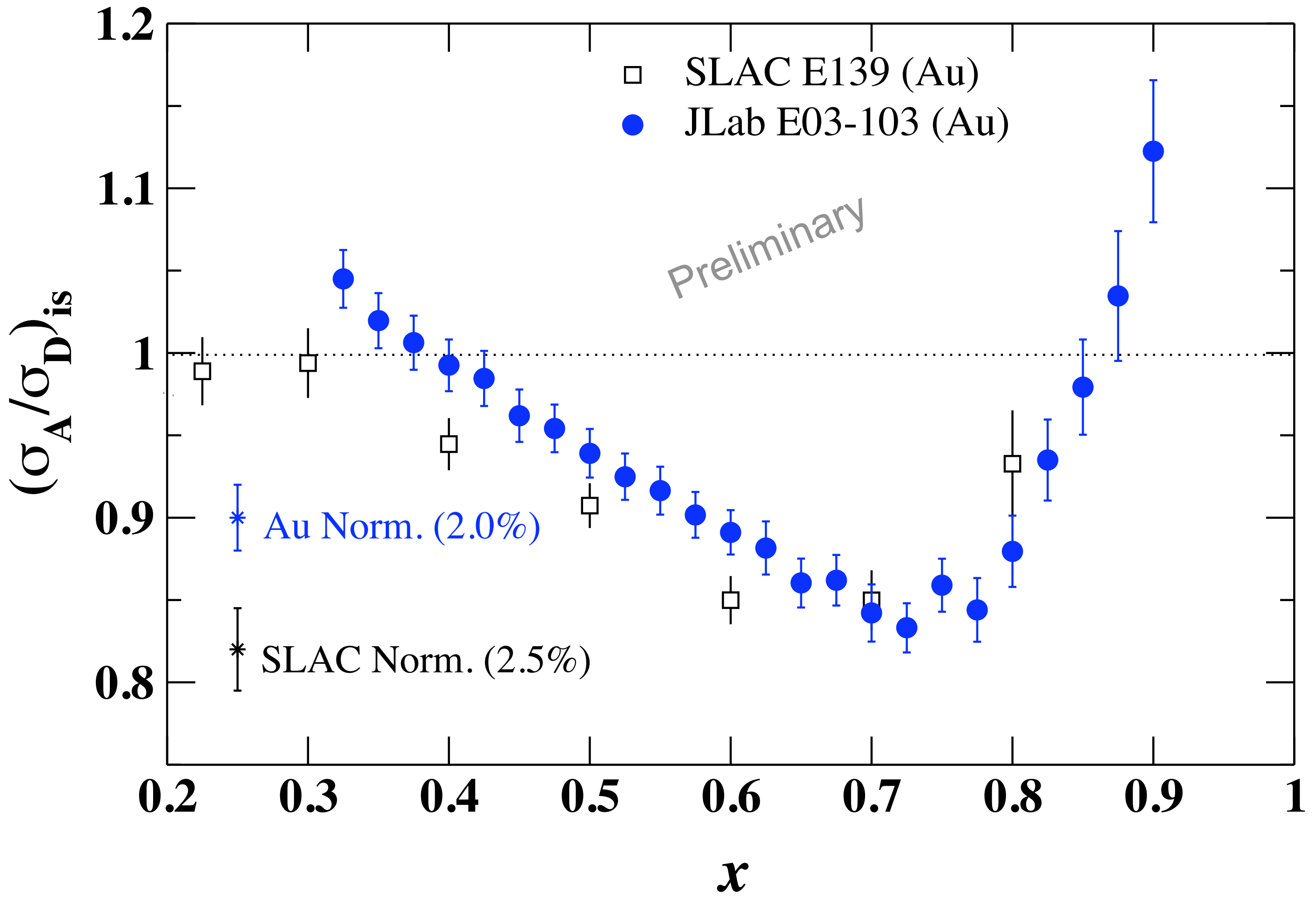
Coulomb potential established in Quasi-elastic scattering regime !

Coulomb distortion effect on E03-103



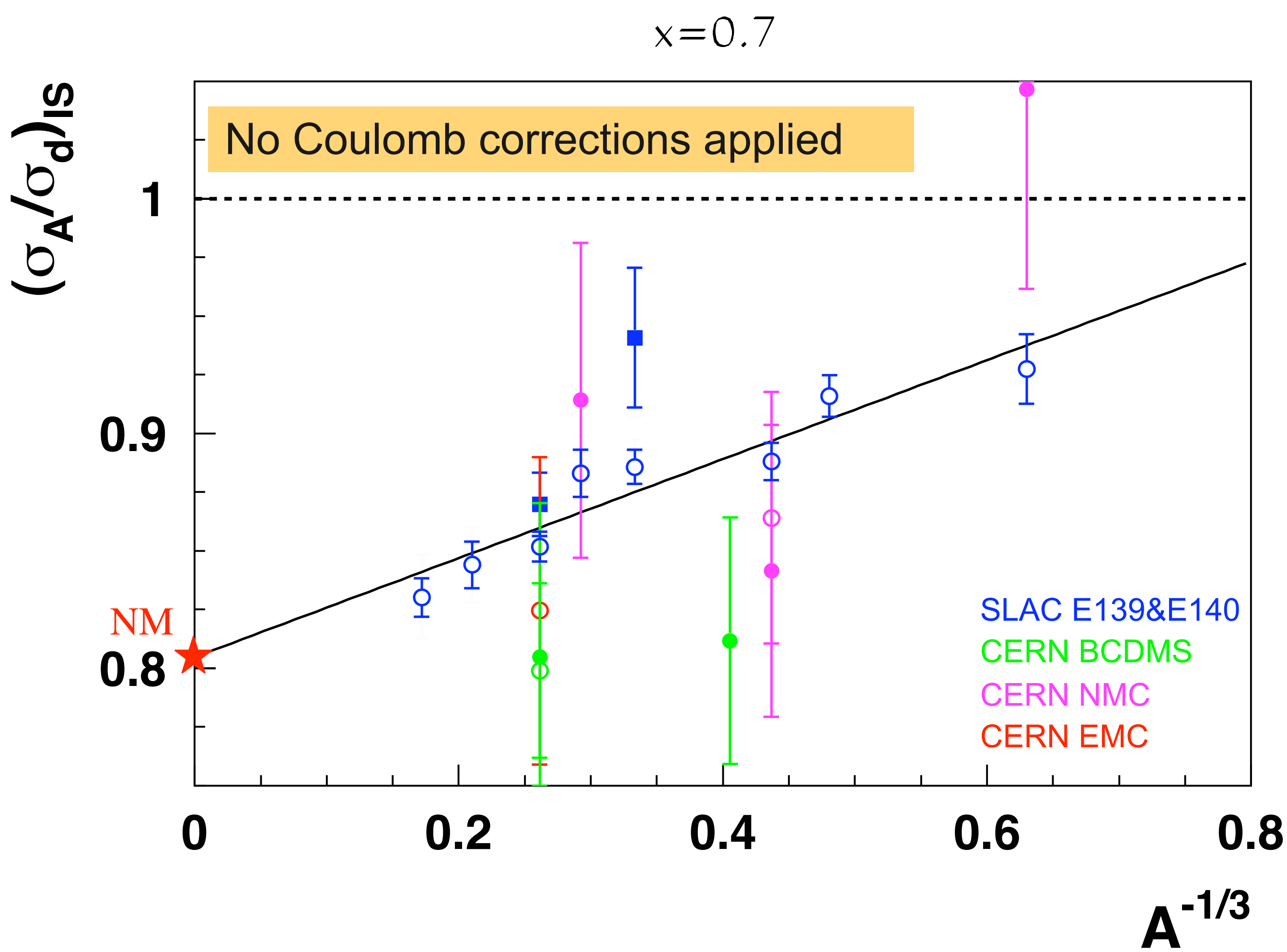
Coulomb distortion effect on E03-103

Coulomb corrections applied



Extrapolation to nuclear matter

Exact calculations of the EMC effect exist for light nuclei and for nuclear matter.



Extrapolation to nuclear matter

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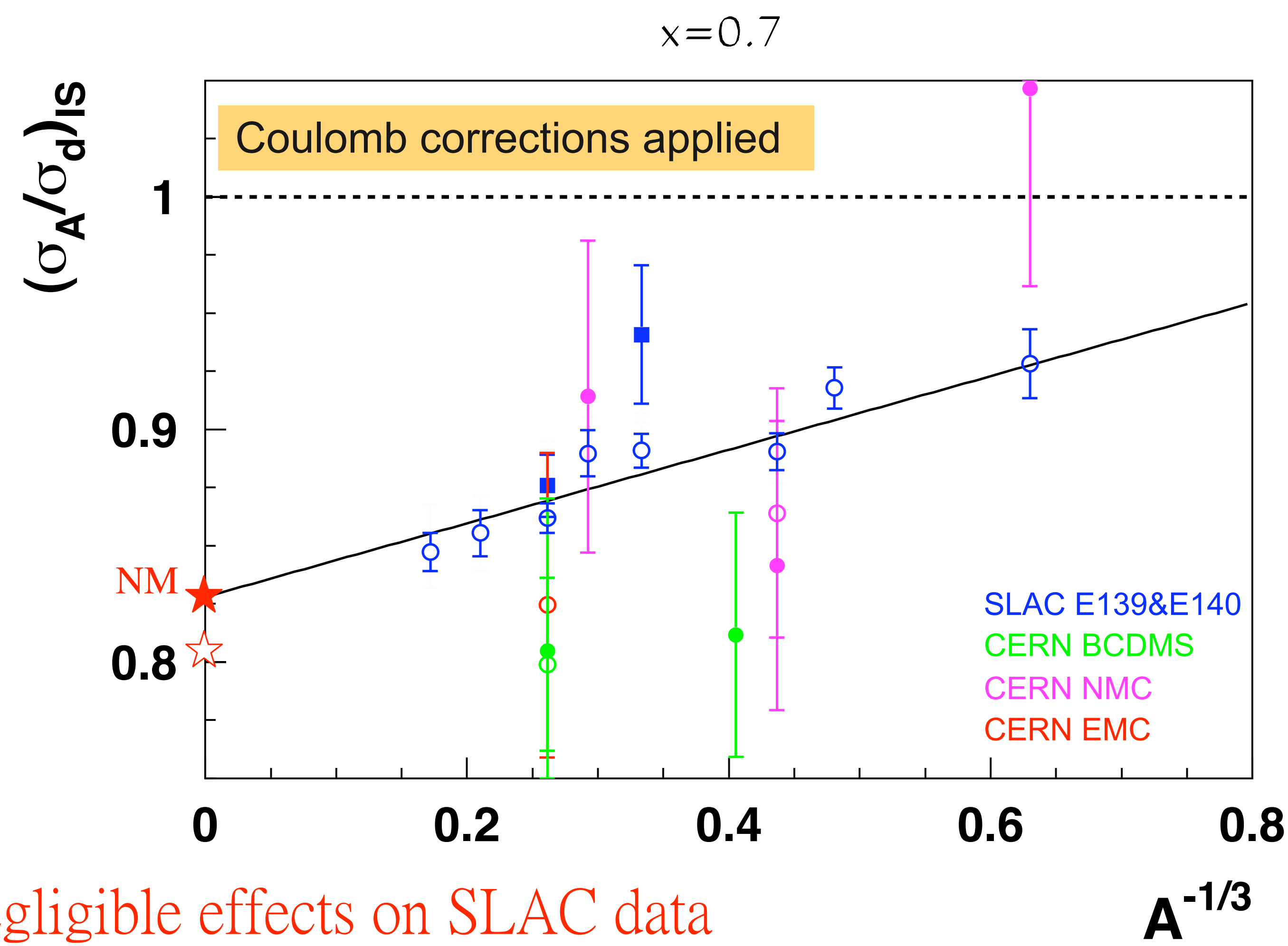
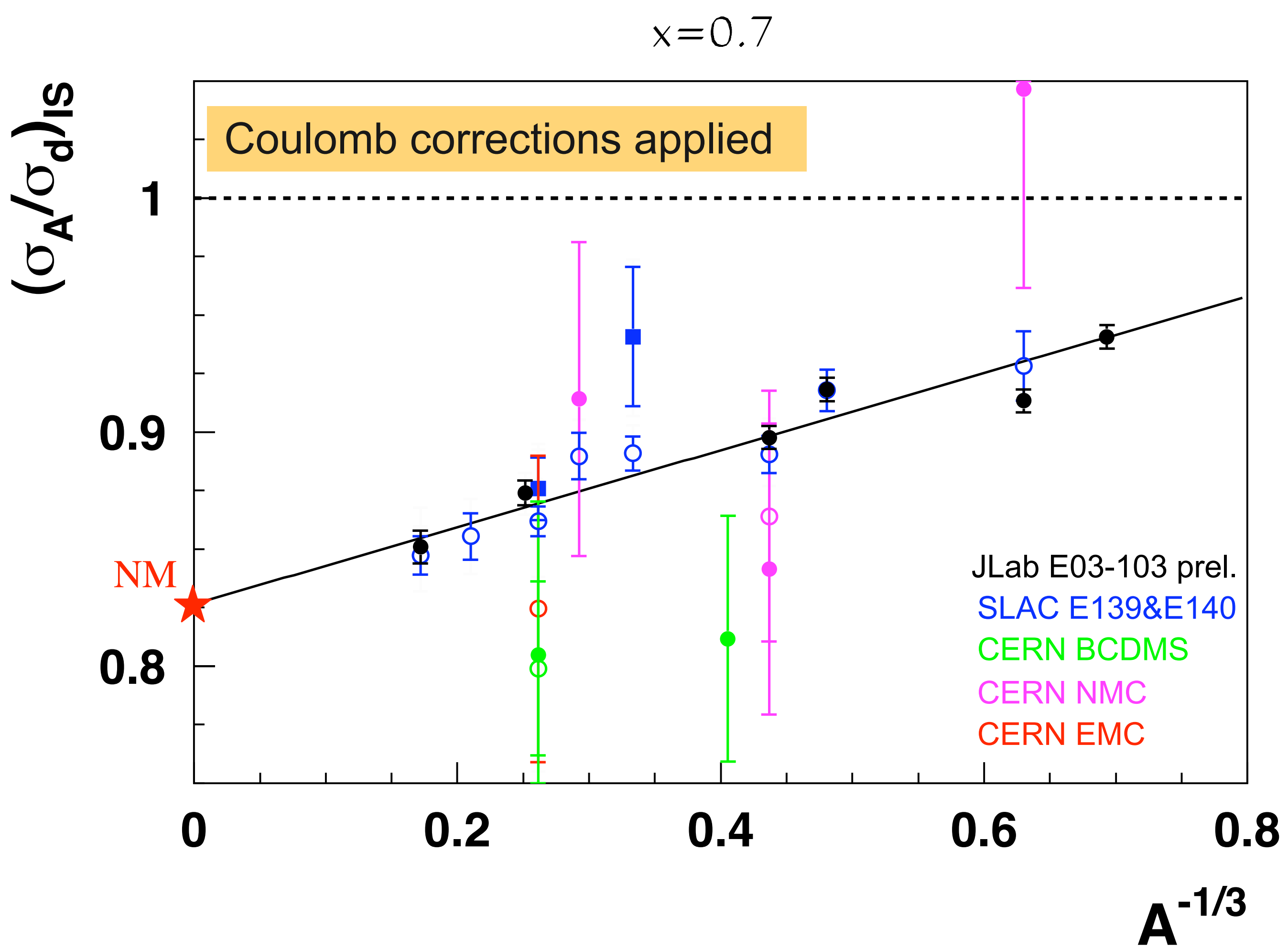


Non-negligible effects on SLAC data

Extrapolation to nuclear matter

Exact calculations of the EMC effect exist for light nuclei and for nuclear matter.

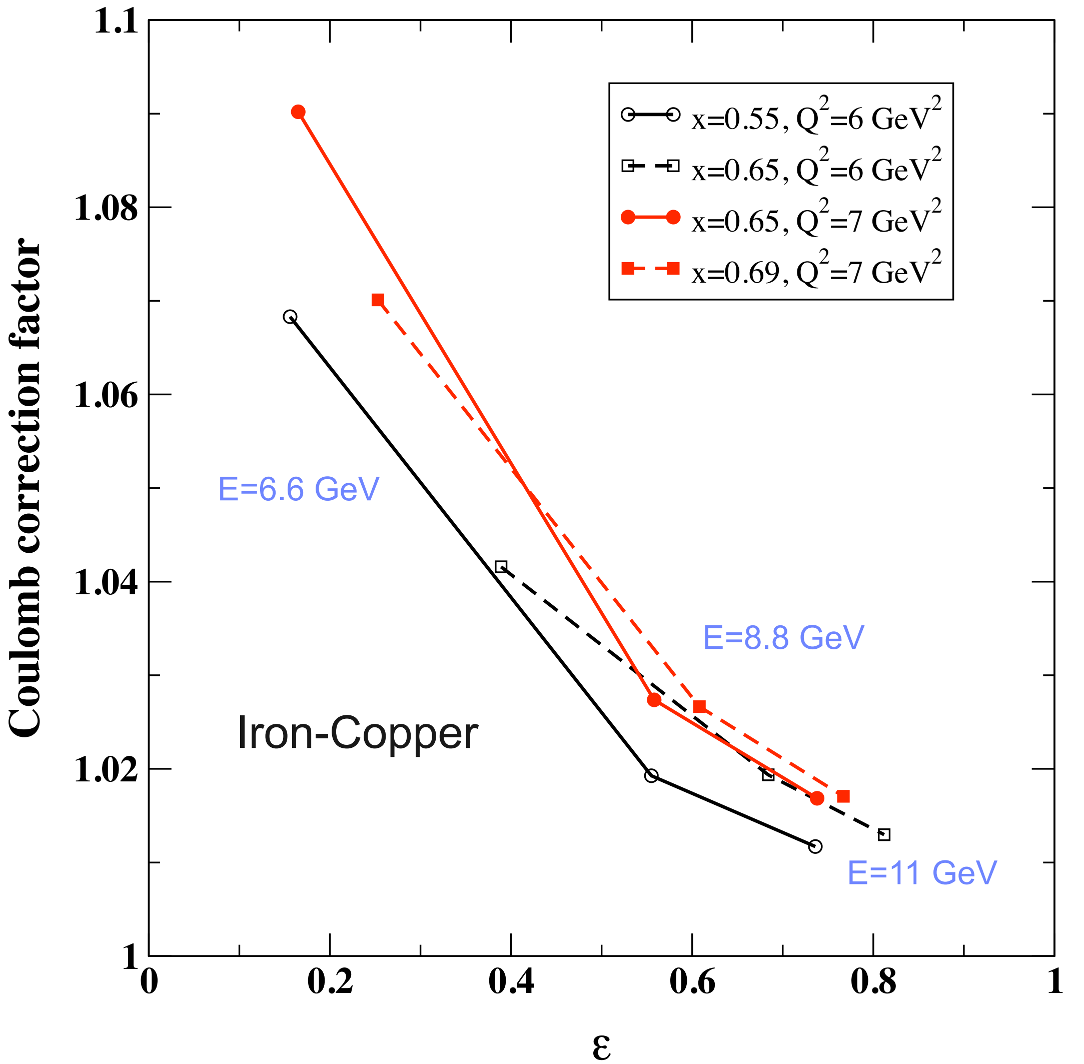


Coulomb distortion: ε-dependence

The ε-dependence of the Coulomb distortion has effect on the extraction of R in nuclei.

$$\epsilon = \frac{1}{1 + 2\left[1 + \frac{\nu^2}{Q^2}\tan^2(\frac{\theta}{2})\right]}$$

$$\theta = 0^\circ \rightarrow \epsilon = 1$$
$$\theta = 180^\circ \rightarrow \epsilon = 0$$



$R(x,Q^2)$

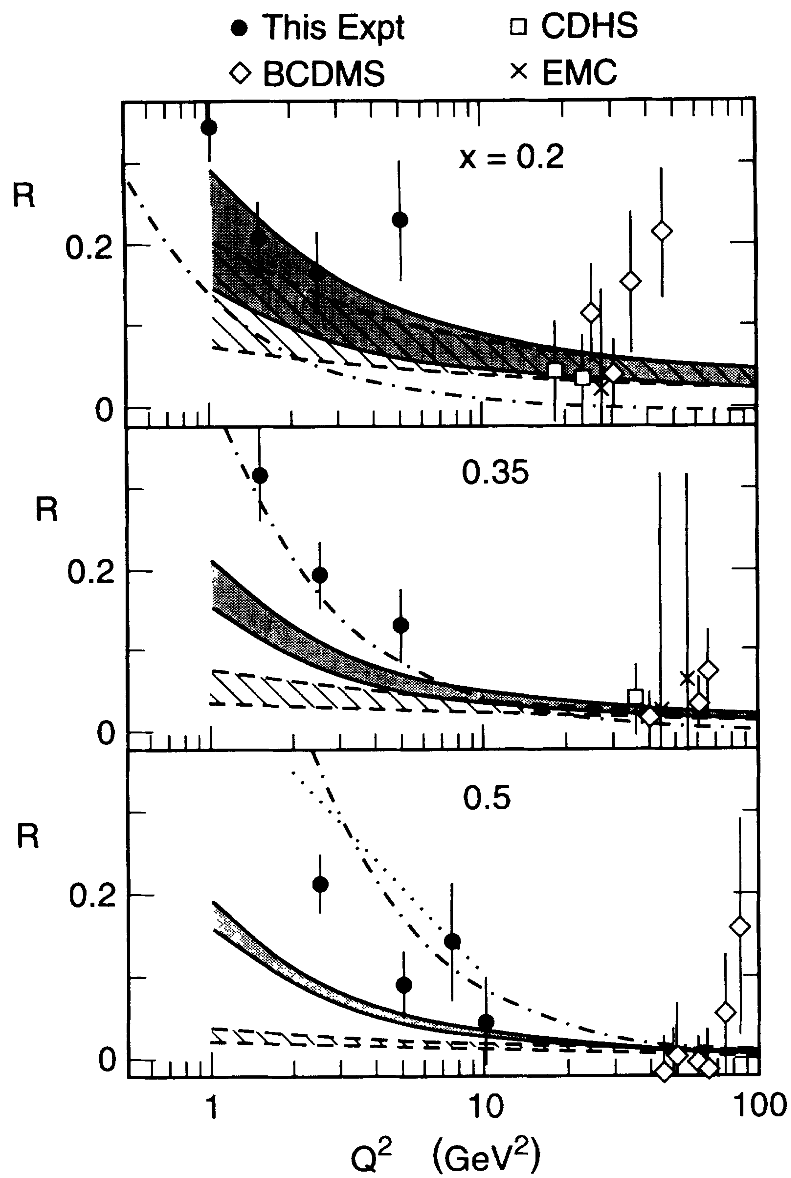
$$\frac{d\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T(x,Q^2) + \varepsilon\sigma_L(x,Q^2)\right]$$

$$R(x,Q^2) = \frac{\sigma_L(x,Q^2)}{\sigma_T(x,Q^2)}$$

In a model with:

a) spin-1/2 partons: R should be small and decreasing rapidly with Q^2

b) spin-0 partons: R should be large and increasing with Q^2

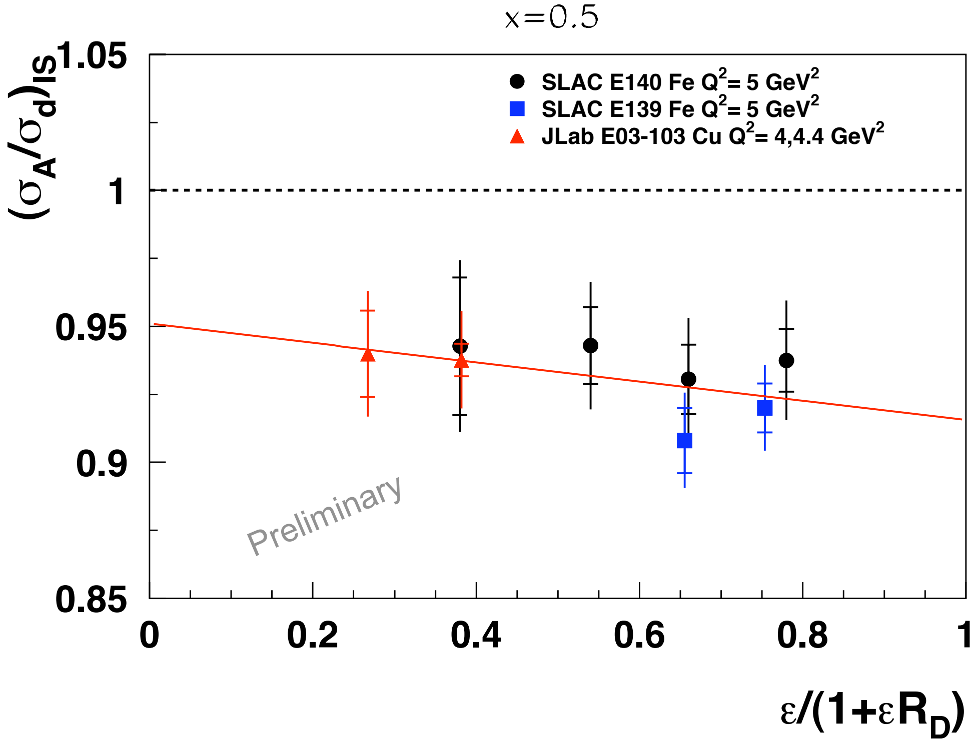


Dasu et al., PRD49, 5641(1994)

Access to nuclear dependence of R

Iron-Copper

No Coulomb corrections applied

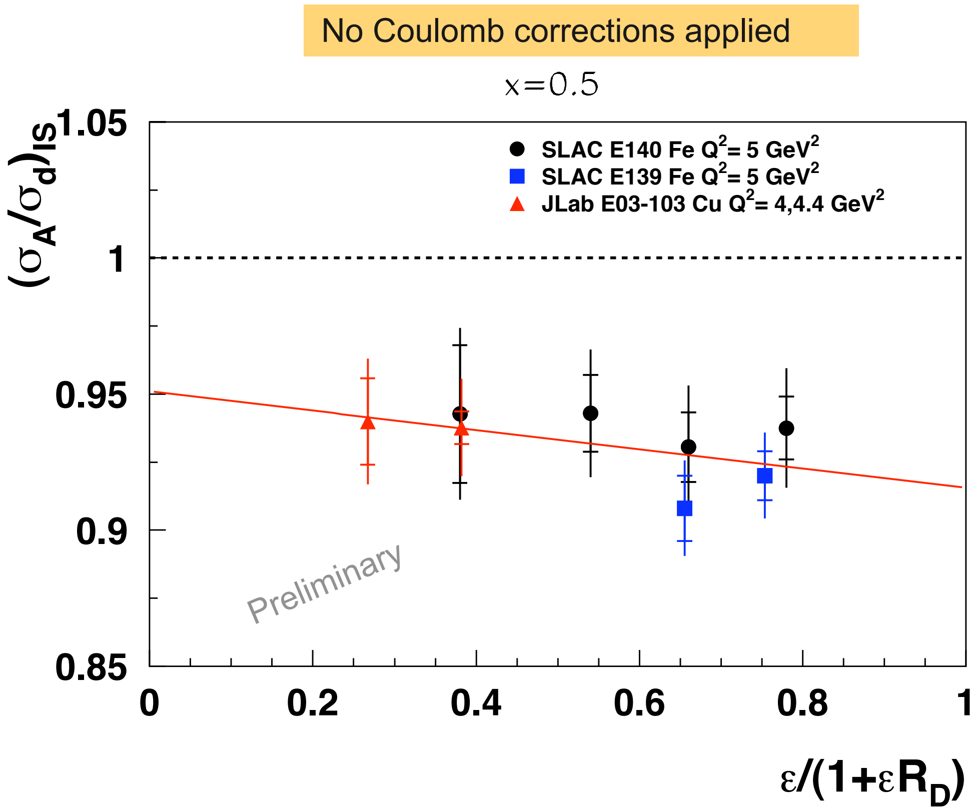


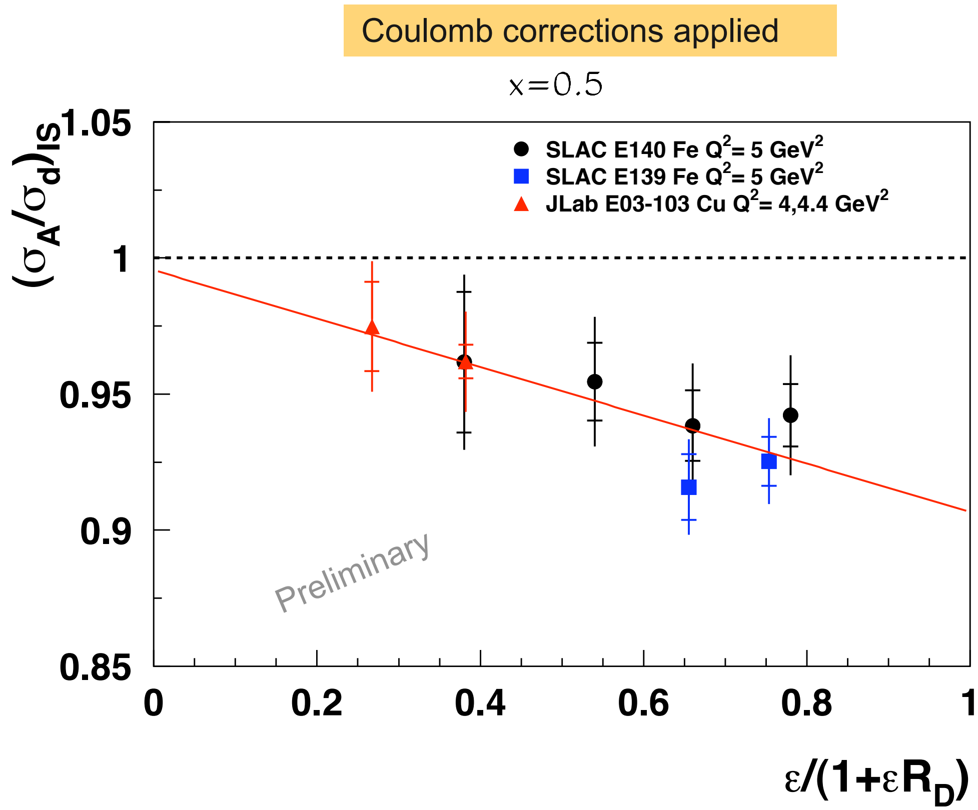
slopes $\Rightarrow R_A - R_D$

$R_A - R_D = 0 \Rightarrow$ **Nuclear higher twist effects and spin-0 constituents in nuclei: same as in free nucleons**

Access to nuclear dependence of R

Iron-Copper





New data from JLab E03-103: access to lower ε

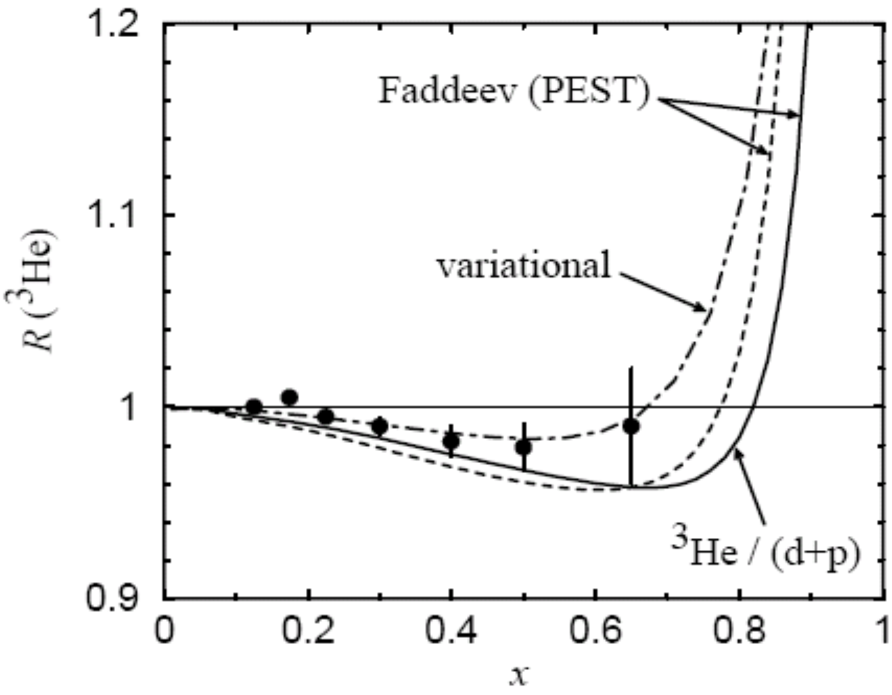
After coulomb corrections: R_A-R_D=−0.08±0.04

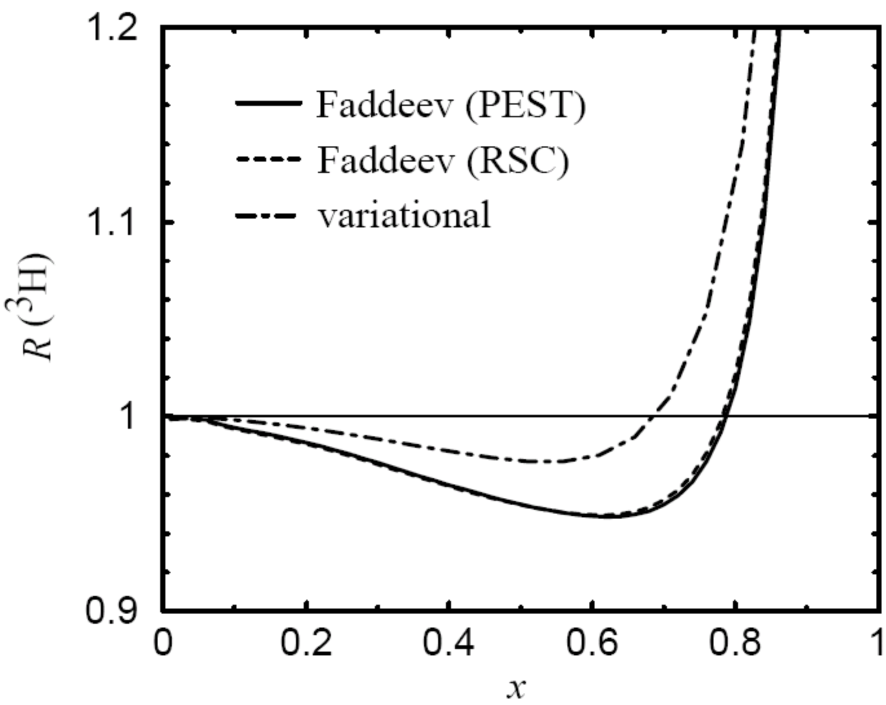
What's next ?

The EMC effect in ^3H and ^3He

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

$$R(^3H) = \frac{F_2^{^3H}}{F_2^p + 2F_2^n}$$





I. Afnan et al, PRC 68 (2003)

Ratio of ^{3}He, ^{3}H: JLab E12-06-118

A way to get access to F_2^n

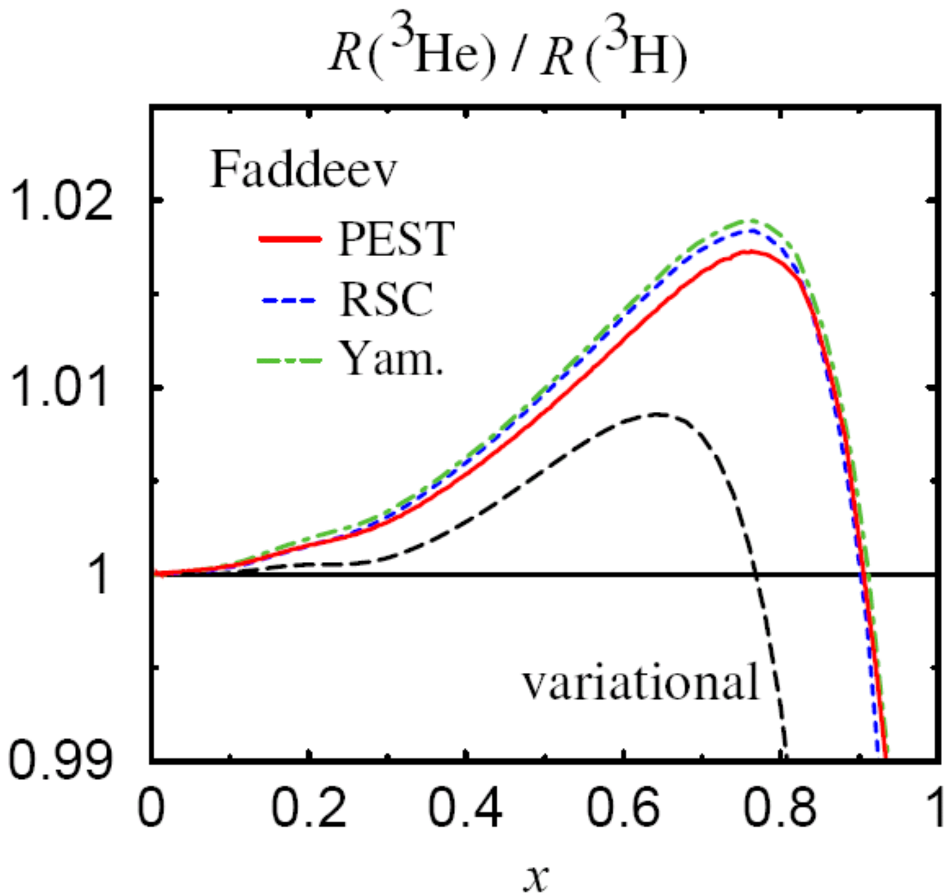
- Measure F_2's and form ratios:

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

- Form "super-ratio", r, then

$$\frac{F_2^n}{F_2^p} = \frac{2r - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - r}$$

where $\quad r \equiv \dfrac{R(^3He)}{R(^3H)}$



I. Afnan et al, PRC 68 (2003)

Why is the F_2^n/F_2^p ratio so interesting?

SU(6)-symmetric wave function of the proton in the quark model (spin up):

$$|p\uparrow\rangle = \frac{1}{\sqrt{18}}\left(3u\uparrow[ud]_{S=0} + u\uparrow[ud]_{S=1} - \sqrt{2}u\downarrow[ud]_{S=1} - \sqrt{2}d\uparrow[uu]_{S=1} - 2d\downarrow[uu]_{S=1}\right)$$

- *u and d quarks identical, N and Δ would be degenerate in mass.*
- *In this model: d/u = 1/2, F_2^n/F_2^p = 2/3.*

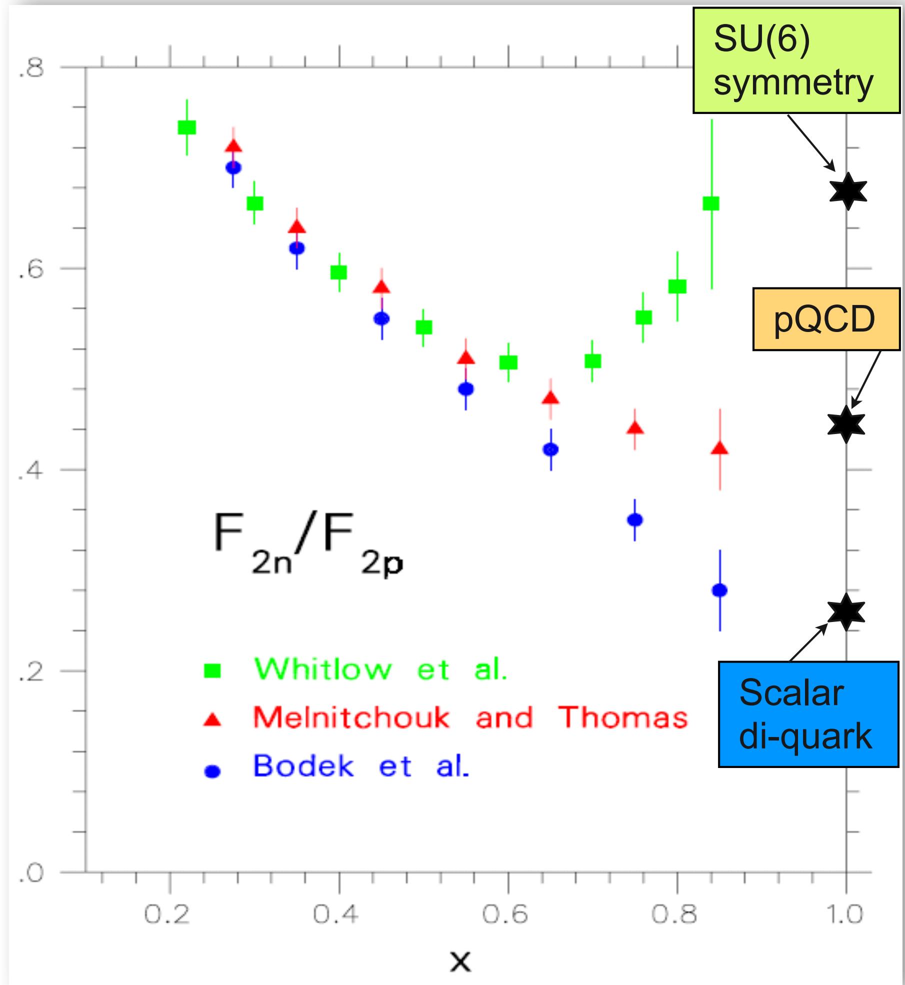
pQCD: helicity conservation (q↑↑p)

=> *d/u =2/(9+1) = 1/5, F_2^n/F_2^p = 3/7 for x ->1*

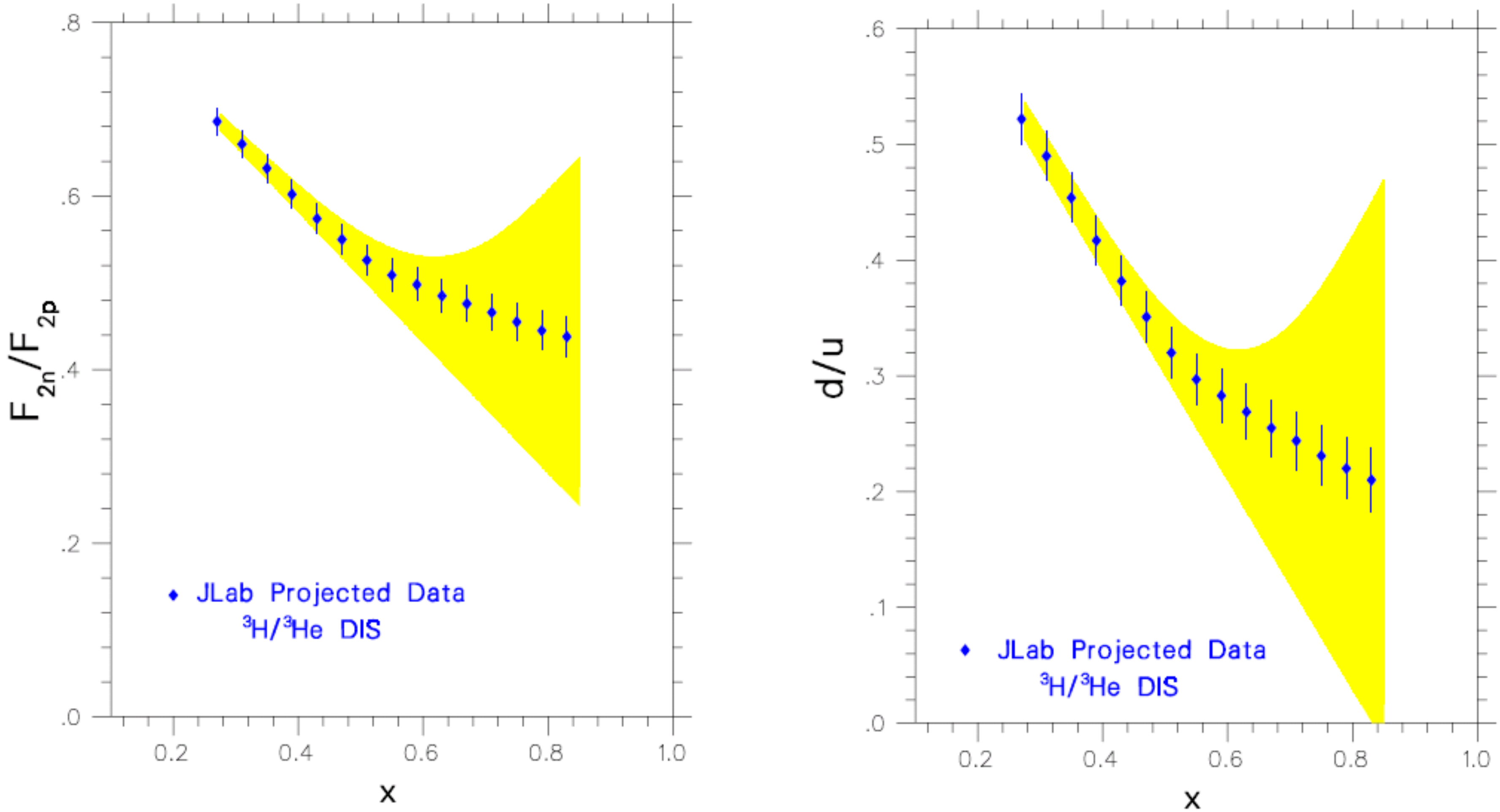
SU(6) symmetry is broken: N-Δ Mass Splitting

- *Mass splitting between S=1 and S=0 diquark spectator.*
- *symmetric states are raised, antisymmetric states are lowered (~300 MeV).*
- *S=1 suppressed*

=> d/u = 0, F_2^n/F_2^p = 1/4, for x -> 1



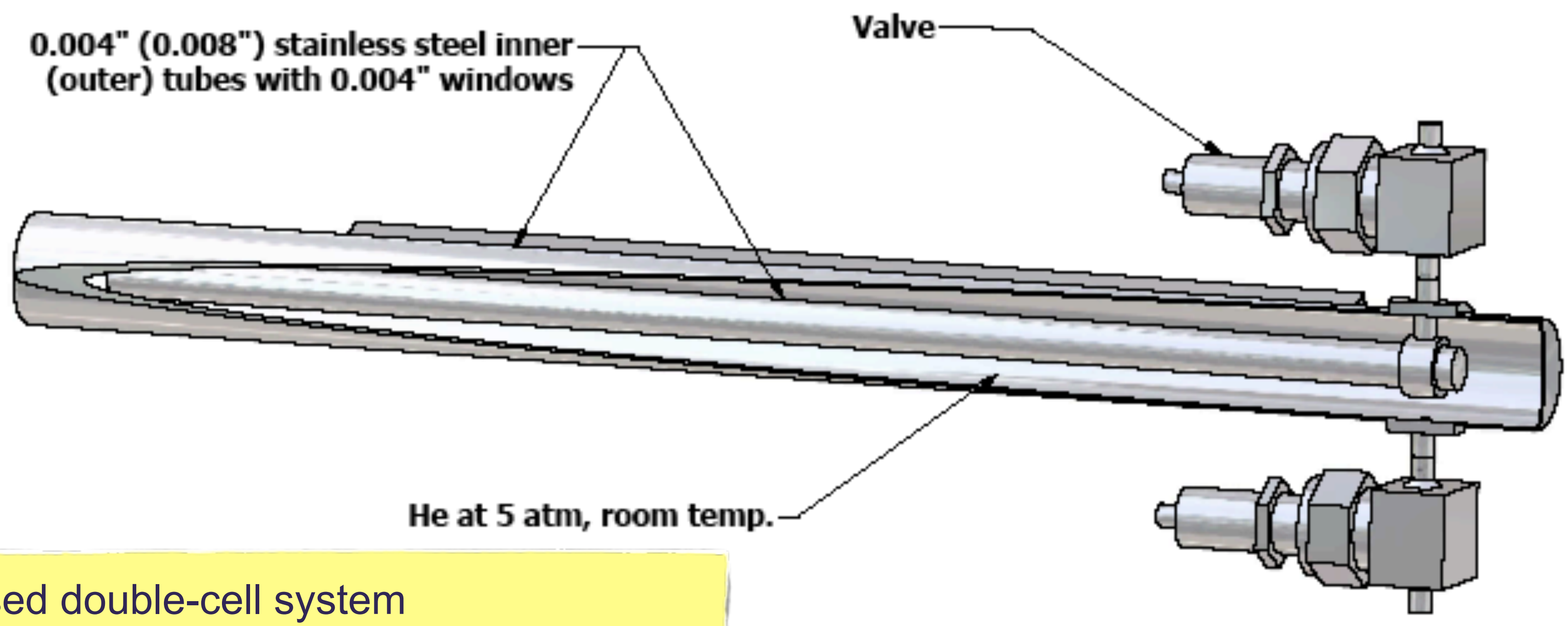
E12-06-118 Projected Results



- PAC30: "conditionally approved"
- 5000 Ci T target, 31 days
- JLab E12-06-118, G. Petratos, J. Gomez, R. J. Holt, R. Ransome *et al*

The tritium target conceptual design

E. J. Beise (U. of Maryland), R. J. Holt (Argonne), W. Korsch (U. of Kentucky),
T. O'Connor (Argonne), G. G. Petratos (Kent State U.), R. Ransome (Rutgers U.),
P. Solvignon (Argonne), and B. Wojtsekhowski (Jefferson Lab)
Tritium Target Task Force



- ❖ Closed double-cell system
- ❖ Density: 2.5mg/cm^3
- ❖ Target length/diameter: 40cm/1.25cm
- ❖ Activity ~ 1500 Ci
- ❖ He for heat conduction

Polarized EMC effect

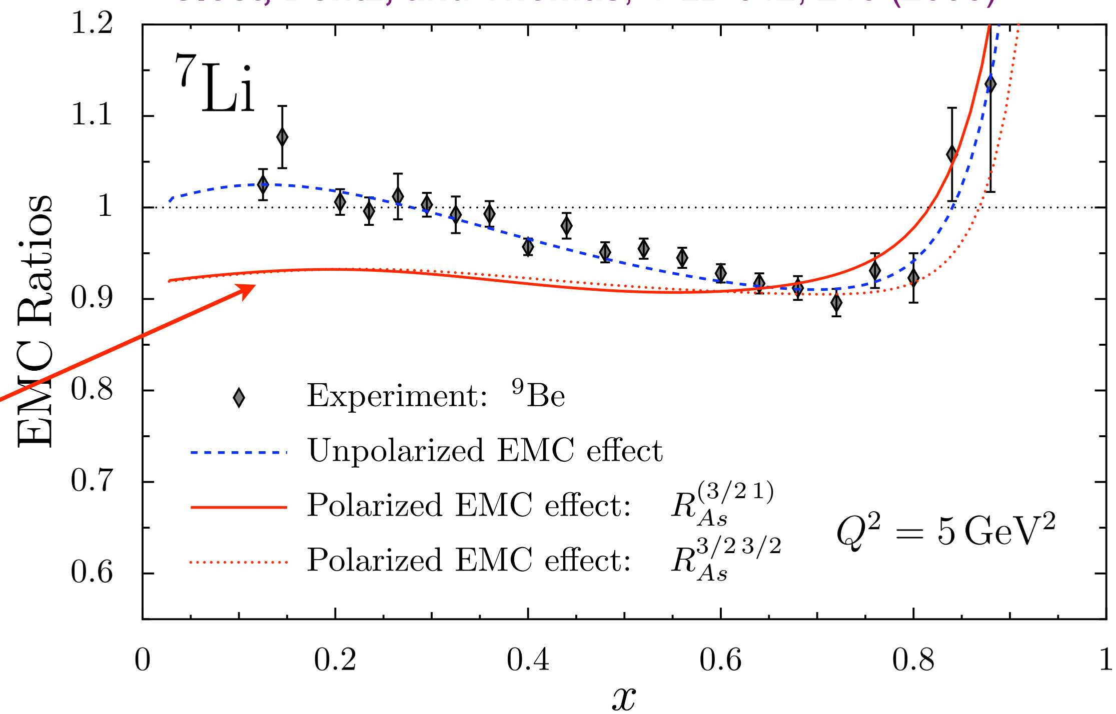
- Best target to do this type of measurement would be polarized tritium

- Most probable measurement will be with ^{7}Li at this time

- Calculation on the size of the effect exists in the modified NJL model.

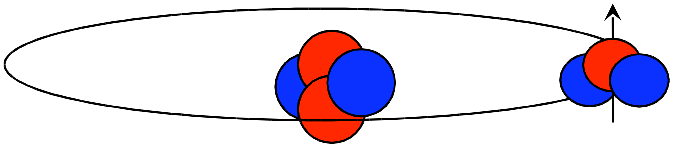
- State-of-the-art calculation from GFMC are available for ^{7}Li

Cloet, Bentz, and Thomas, PLB 642, 210 (2006)



Different sensitivity to the components of the valence quark wave function ⇒ could bring promising insights in the origin of the EMC effect

Polarized EMC effect



- From cluster model: ^{7}Li = $\boldsymbol{\alpha}$ + triton

"^{7}Li is most of the time in the cluster configuration." *R. Wiringa, Private Comm.*

- From JLab E03-103 results on light nuclei (A ≤12), EMC effect depends on the local density:

  ➡ the polarized proton "feels" dominantly the two neutrons part of the same cluster

  ➡ the $\boldsymbol{\alpha}$ cluster dilutes the asymmetries

  ➡ at first approximation, polarized ^{7}Li could be seen as an effective polarized tritium target !

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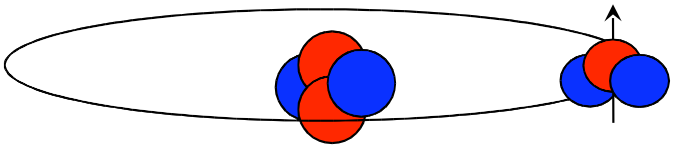
Polarized EMC effect



- From cluster model: ^{7}Li = α + triton

"^{7}Li is most of the time in the cluster configuration." *R. Wiringa, Private Comm.*

- From JLab E03-103 results on light nuclei (A ≤12), EMC effect depends on the local density:

  ➡ the polarized proton "feels" dominantly the two neutrons part of the same cluster

  ➡ the α cluster dilutes the asymmetries

  ➡ at first approximation, polarized ^{7}Li could be seen as an effective polarized tritium target !

- Therefore the use of polarized ^{7}Li could be handy for several physics goal:

  ➡ the polarized EMC effect in ^{7}Li

  ➡ If cluster model assumptions are right: access to the polarized EMC effect in triton and also the Bjorken Sum Rule for mirror nuclei:

$$\Gamma_1^{(^3\mathrm{H})} - \Gamma_1^{(^3\mathrm{He})} = \frac{g_A^{tri}}{6} \cdot C_{\mathrm{NS}}(\alpha_s)$$

axial vector coupling constant of the triton measured in tritium decay

R. Jaffe & A. Manohar, Nucl. Phys. B321, 343 (1989)

Summary

JLab experiment E03-103 brings a wealth of new results:

- Light nuclei:
  - *contain key information on the EMC effect*
  - *hint of local density dependence of the EMC effect*
  - *can be compared to realistic calculations*

- Heavy nuclei and Coulomb distortion:
  - *affects the extrapolation to nuclear matter which is key for comparison with theoretical calculations*
  - *has a real impact on the A-dependence of R: clear ε-dependence*
  - *need a measurement of the amplitude of the effect in the inelastic regime*

Outlook

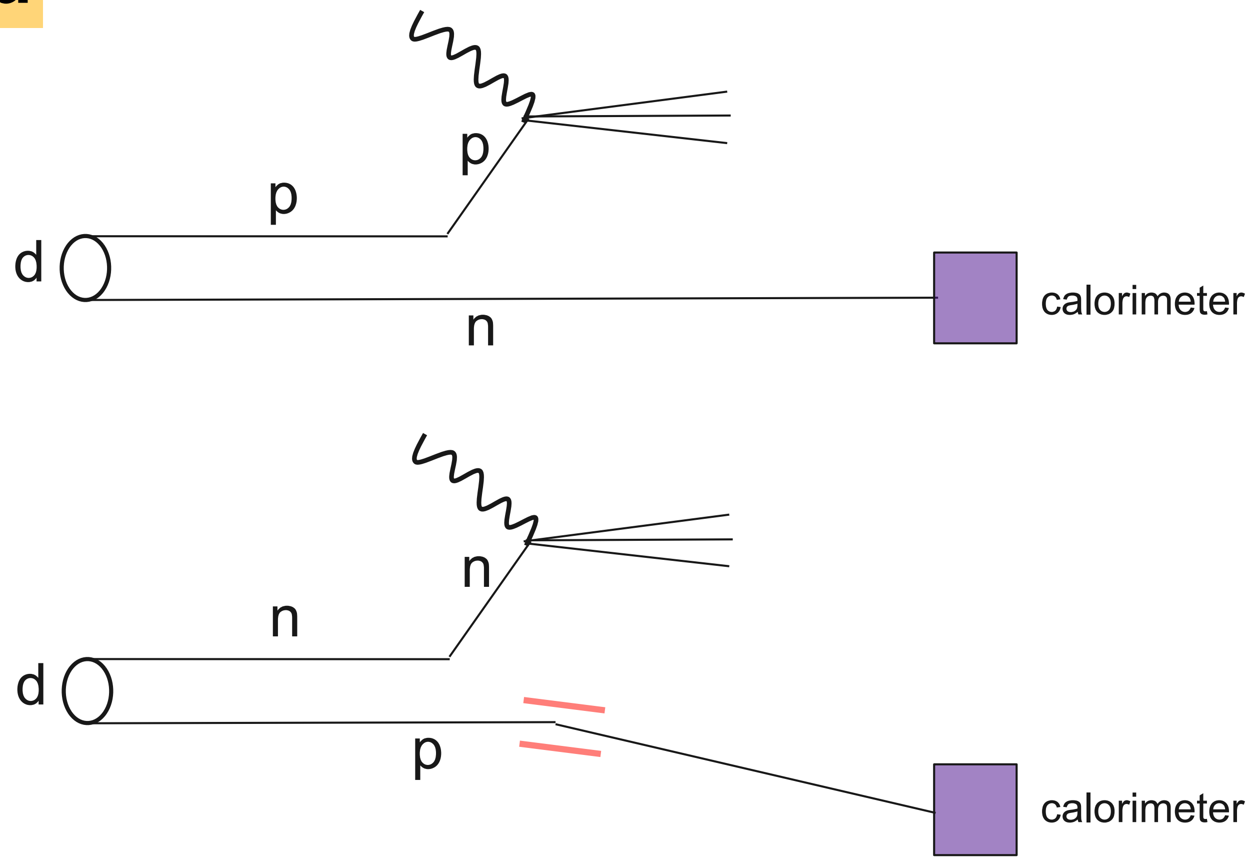
- $F_2(^3He)/F_2(^3H)$: Hall A E12-06-118 *(conditionally approved)*
  - EMC effect in light nuclei
  - n/p at high x in DIS
  - getting to the d-quark distribution
- Coulomb distortion measurement in DIS *(require a positron beam)*
- Precision measurement of R in medium weight nuclei in DIS *(proposal in preparation)*
- Polarized EMC *(discussion-stage about a possible proposal)*
- (Short-range correlations and super-fast quarks: *approved measurements*)
- EIC ...

What about a measurement at the EIC ?

F2n/F2p at EIC:

high W so no need to worry about target mass correction

e^- ➞ ⇐ d



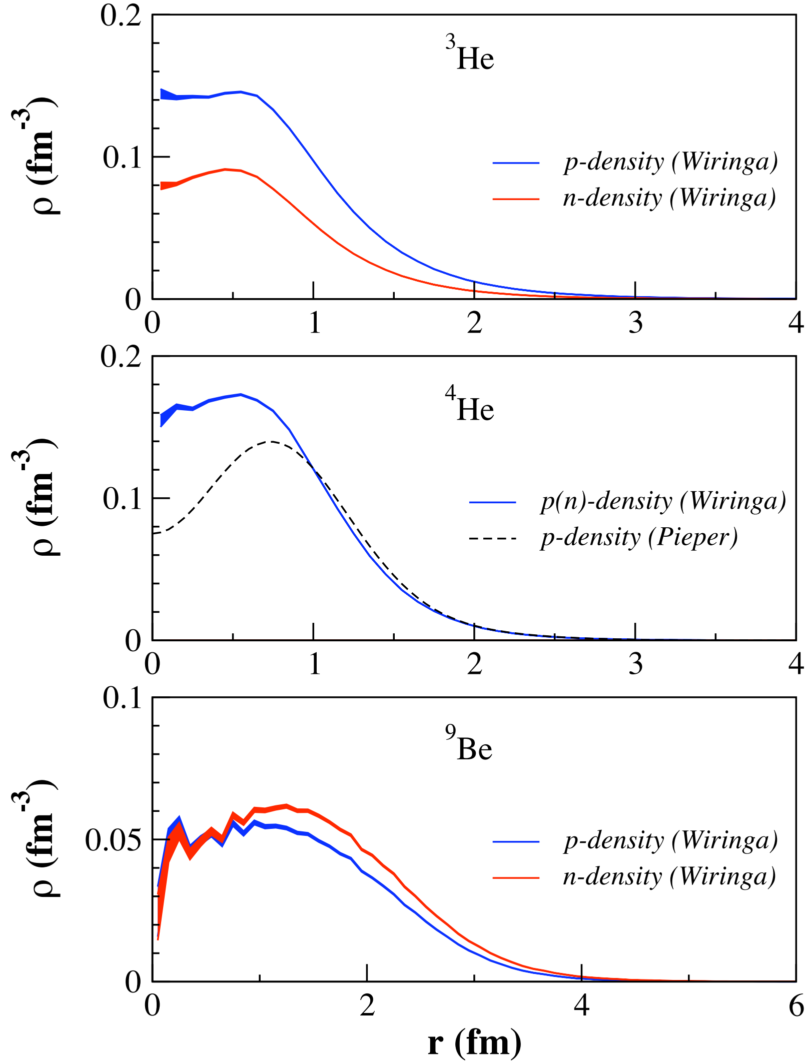
Extra slides

World data re-analysis

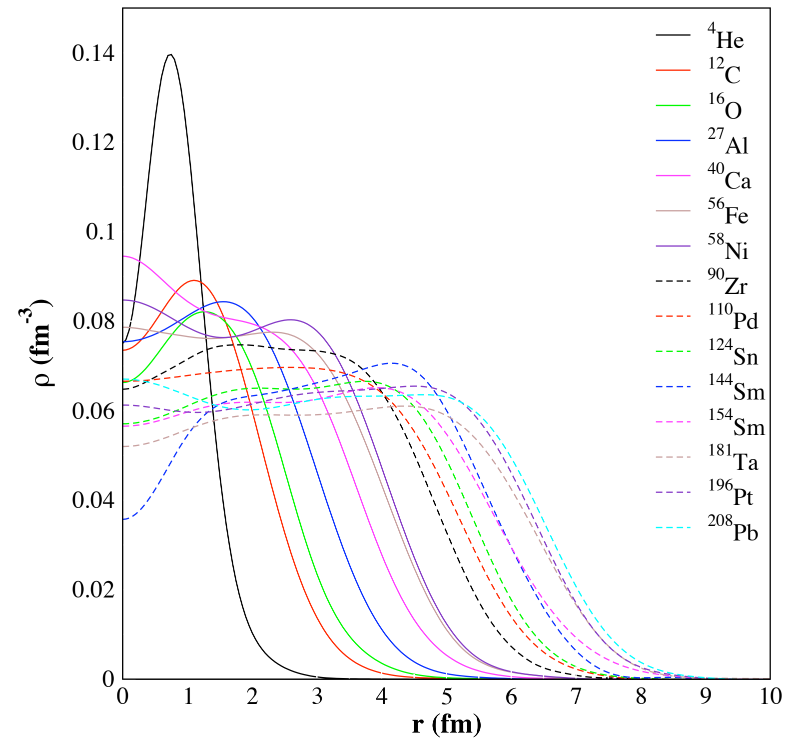
Experiments	E (GeV)	A	x-range	Pub. 1st author
CERN-EMC	280	56	0.050-0.650	Aubert
		12,63,119	0.031-0.443	Ashman
CERN-BCDMS	280	15	0.20-0.70	Bari
		56	0.07-0.65	Benvenuti
CERN-NMC	200	4,12,40	0.0035-0.65	Amaudruz
	200	6,12	0.00014-0.65	Arneodo
SLAC-E61	4-20	9,27,65,197	0.014-0.228	Stein
SLAC-E87	4-20	56	0.075-0.813	Bodek
SLAC-E49	4-20	27	0.25-0.90	Bodek
SLAC-E139	8-24	4,9,12,27,40,56,108,197	0.089-0.8	Gomez
SLAC-E140	3.7-20	56,197	0.2-0.5	Dasu
DESY-HERMES	27.5	3,14,84	0.013-0.35	Airapetian

Density calculations

Calculation from R. Wiringa & S. Pieper



Calculation from S. Pieper



Average density:

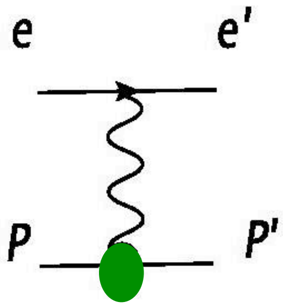
$$\langle \rho_{n,p} \rangle = \frac{\int \rho_{n,p}^2 d^3r}{\int \rho_{n,p} d^3r}$$

$$\langle \rho_p \rangle + \langle \rho_n \rangle = \langle \rho_A \rangle \xrightarrow{\textit{finite proton size correction}} \langle \rho_A \rangle \cdot \left(\frac{\langle r \rangle}{r_{eff}} \right)^3$$

with $r_{eff} = \sqrt{\langle r \rangle^2 + 0.9^2}$

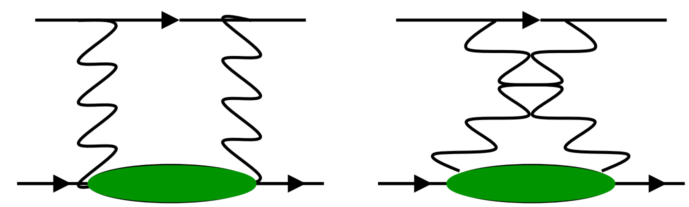
Coulomb distortion and two-photon exchange

OPE



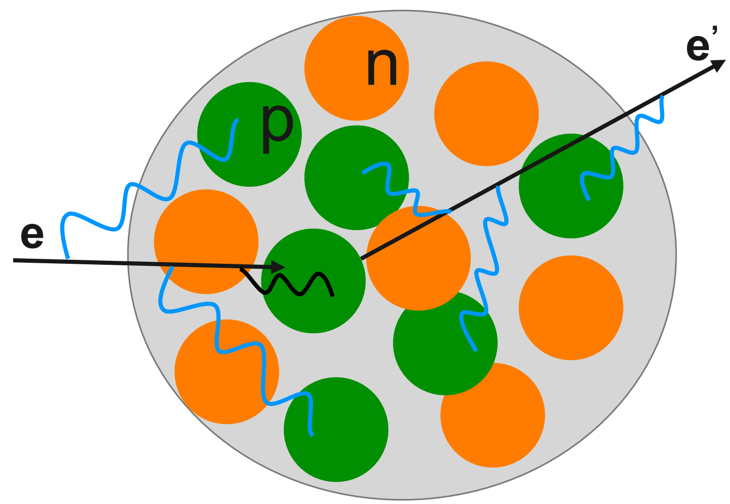
TPE

Exchange of 2 (hard) photons with a single nucleon



Coulomb distortion

Exchange of one or more (soft) photons with the nucleus, in addition to the one hard photon exchanged with a nucleon



Incident (scattered) electrons are accelerated (decelerated) in the Coulomb well of the nucleus.

Opposite effect with positrons

How to correct for Coulomb distortion ?

~~$$\sigma_{tot}^{PWBA} = \sigma_{Mott}\, S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta)$$~~ ⇨

σ_{tot}^{DWBA}

- Focusing of the electron wave function
- Change of the electron momentum

Effective Momentum Approximation (EMA)

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)

$E \rightarrow E + \bar{V}$
$E_p \rightarrow E_p + \bar{V}$

$$Q^2_{eff} = 4(E+\bar{V})(E_p+\bar{V})\sin^2(\frac{\theta}{2})$$

1st method

$$S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta) \longrightarrow S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)$$

$$\sigma_{tot}^{CC} = \sigma_{Mott} \cdot S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)$$

⇔

2nd method

$$S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta) \longrightarrow S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)$$

$$\sigma_{Mott}^{eff} = 4\alpha^2\cos^2(\theta/2)(E_p+\bar{V})^2/Q^4_{eff}$$

$$F^i_{foc} = \frac{E+\bar{V}}{E}$$

$$\sigma_{tot}^{CC} = (F^i_{foc})^2 \cdot \sigma_{Mott}^{eff} \cdot S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)$$

How to correct for Coulomb distortion ?

~~$\sigma_{tot}^{PWBA} = \sigma_{Mott} \, S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta)$~~ ⇨

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Effective Momentum Approximation (EMA)

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)

$$\left.\begin{array}{l} E \rightarrow E + \bar{V} \\ E_p \rightarrow E_p + \bar{V} \end{array}\right\} \quad Q_{eff}^2 = 4(E+\bar{V})(E_p+\bar{V})\sin^2(\frac{\theta}{2})$$

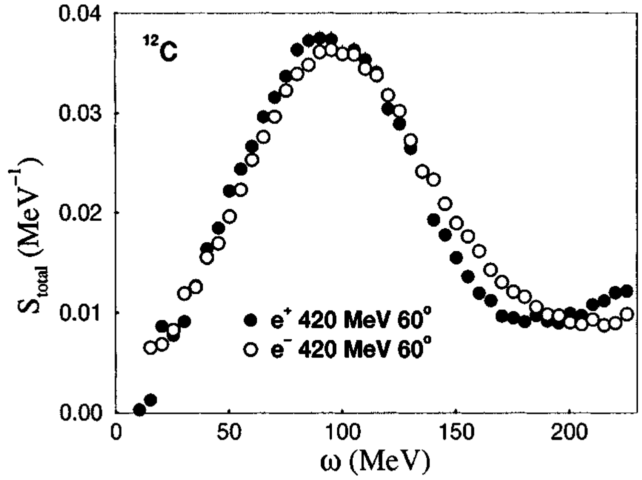
One-parameter model depending only on the effective potential seen by the electron on average.

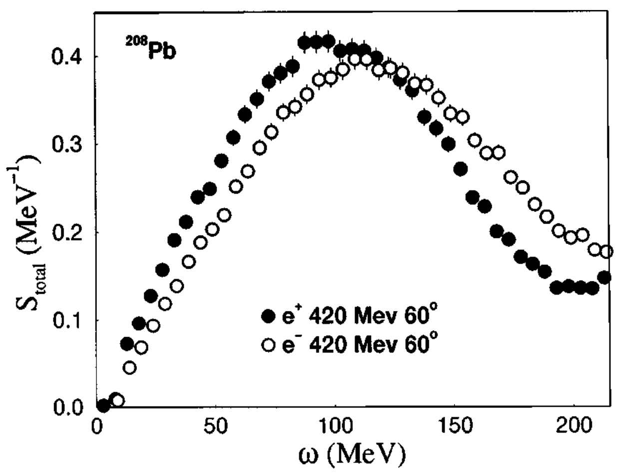
S_{tot}^{PWB}

$$F_{foc}^i = \frac{E+\bar{V}}{E}$$

$$\sigma_{tot}^{CC} = \sigma_{Mott} \cdot S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta) \Leftrightarrow \sigma_{tot}^{CC} = (F_{foc}^i)^2 \cdot \sigma_{Mott}^{eff} \cdot S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)$$

Coulomb distortion measurements in quasi-elastic scattering





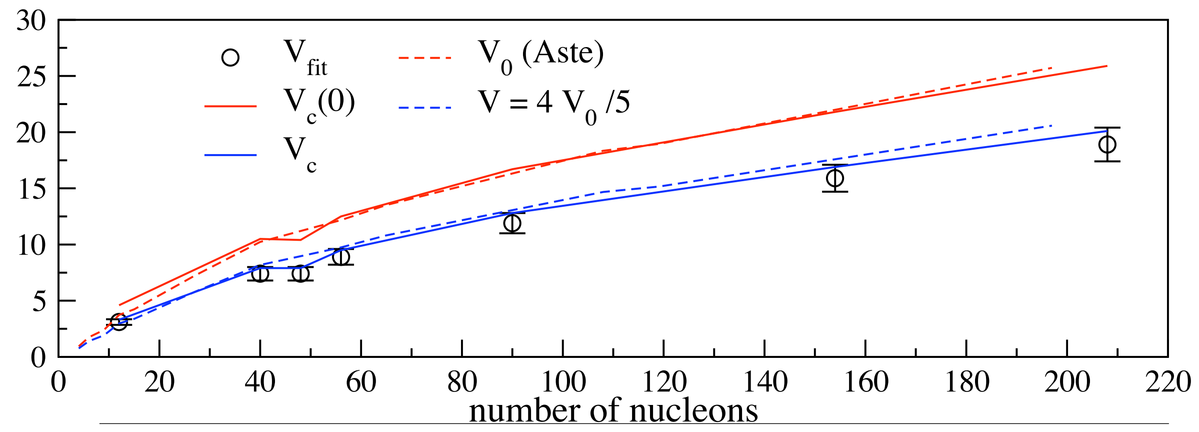
Gueye *et al.*, PRC60, 044308 (1999)

$$\tilde{k} = k - V(z)$$

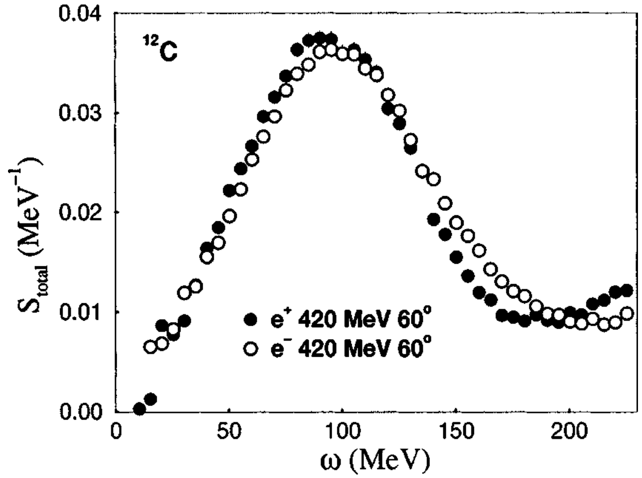
$$V(r) = -\frac{3\alpha(Z-1)}{2R} + \frac{\alpha(Z-1)}{2R}\left(\frac{r}{R}\right)^2$$

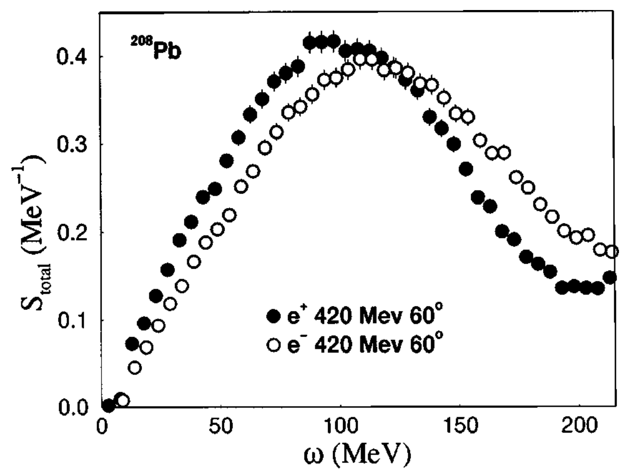
$$R = 1.1A^{1/3} + 0.86A^{-1/3}$$

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)



Coulomb distortion measurements in quasi-elastic scattering





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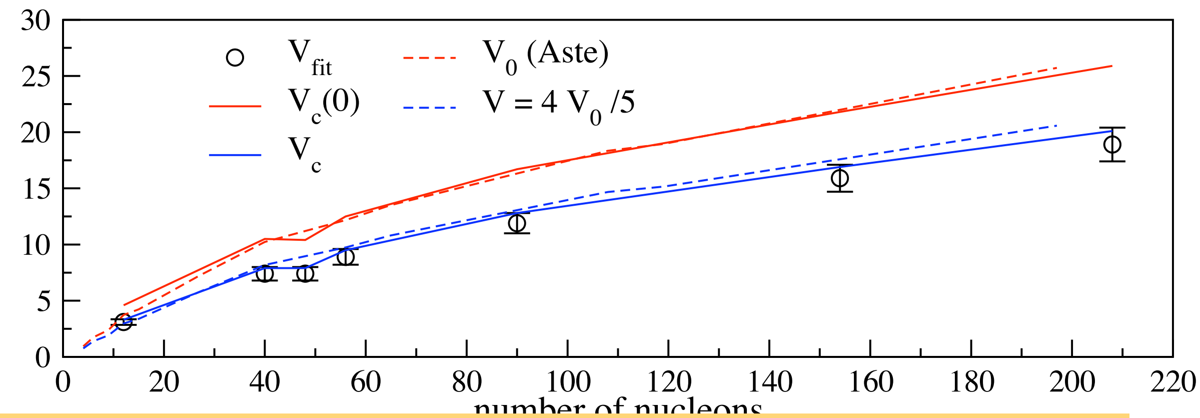
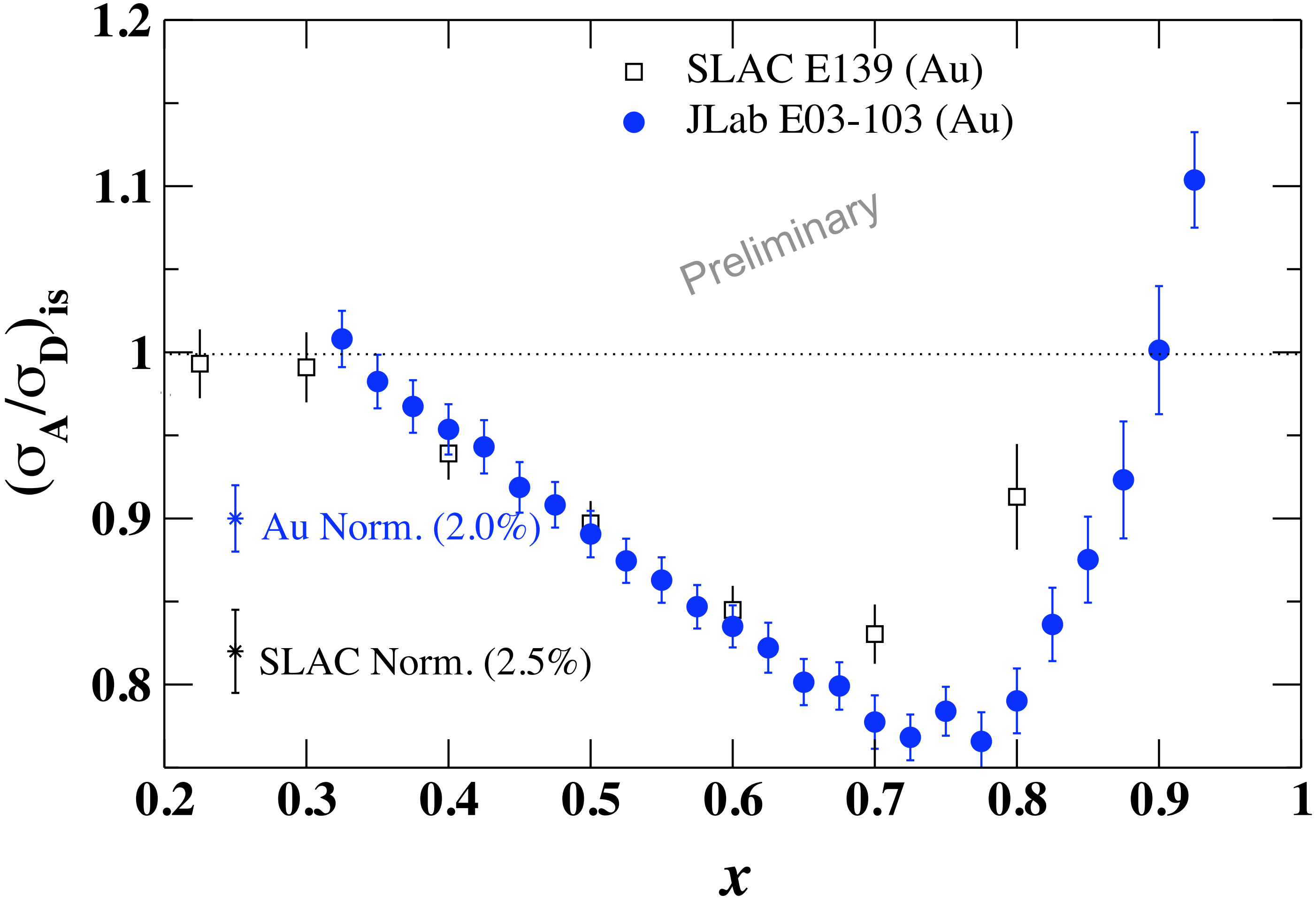
Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)



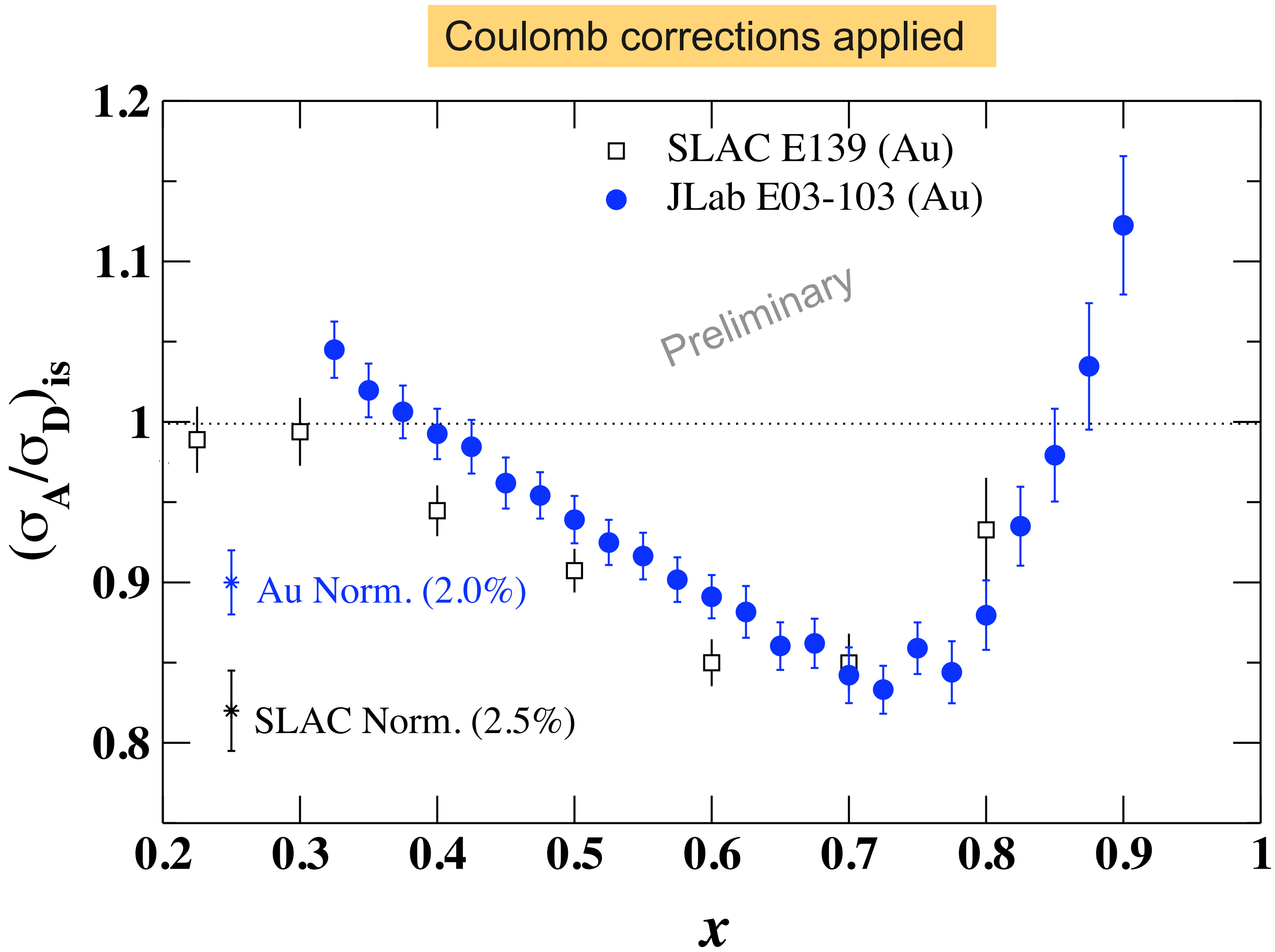
Coulomb potential established in Quasi-elastic scattering regime !

E03-103 heavy target results

no Coulomb corrections applied



E03-103 heavy target results



$R(x, Q^2)$

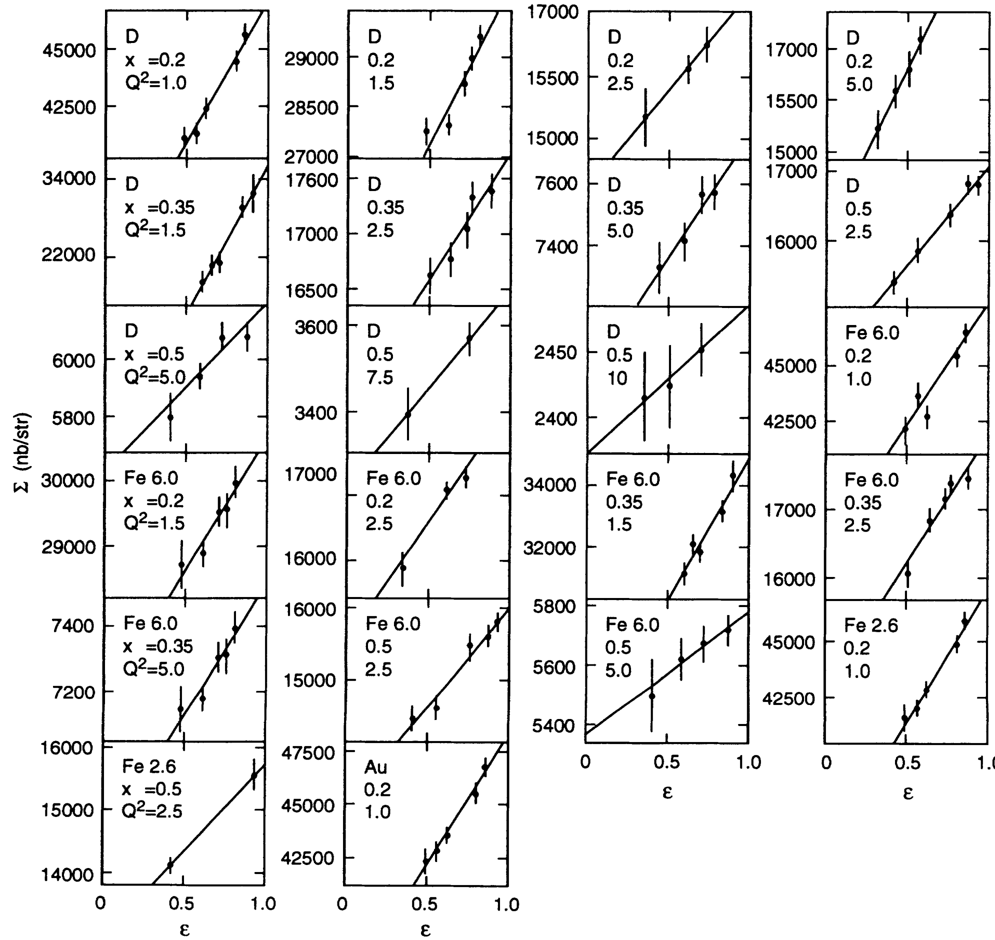
$$\frac{d\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T(x,Q^2) + \varepsilon\sigma_L(x,Q^2)\right]$$

$$R(x,Q^2) = \frac{\sigma_L(x,Q^2)}{\sigma_T(x,Q^2)}$$

TPE can affect the ε dependence (talk of E. Christy on Thursday)

Coulomb Distortion could have the same kind of impact as TPE, but gives also a correction that is A-dependent.

Dasu et al., PRD49, 5641(1994)



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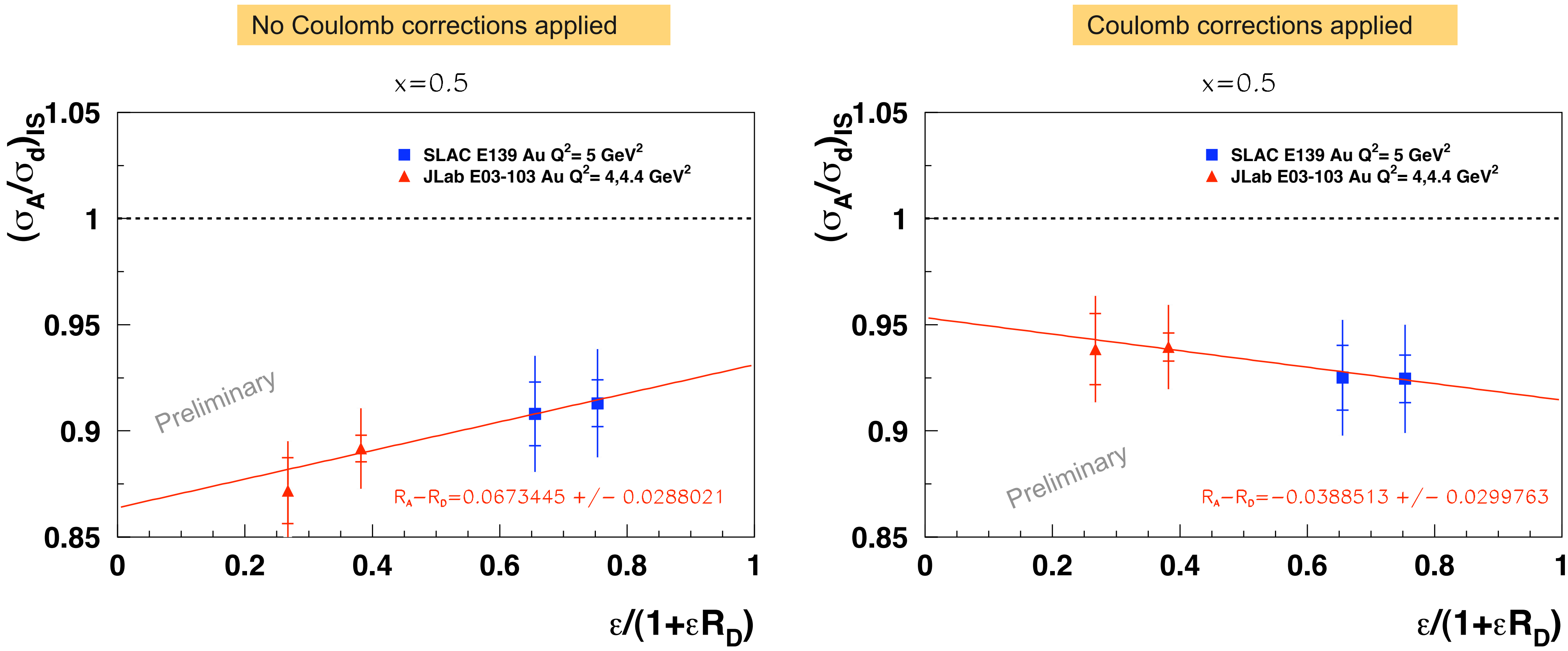
Access to nuclear dependence of R

New data from JLab E03-103: access to lower ε

Gold



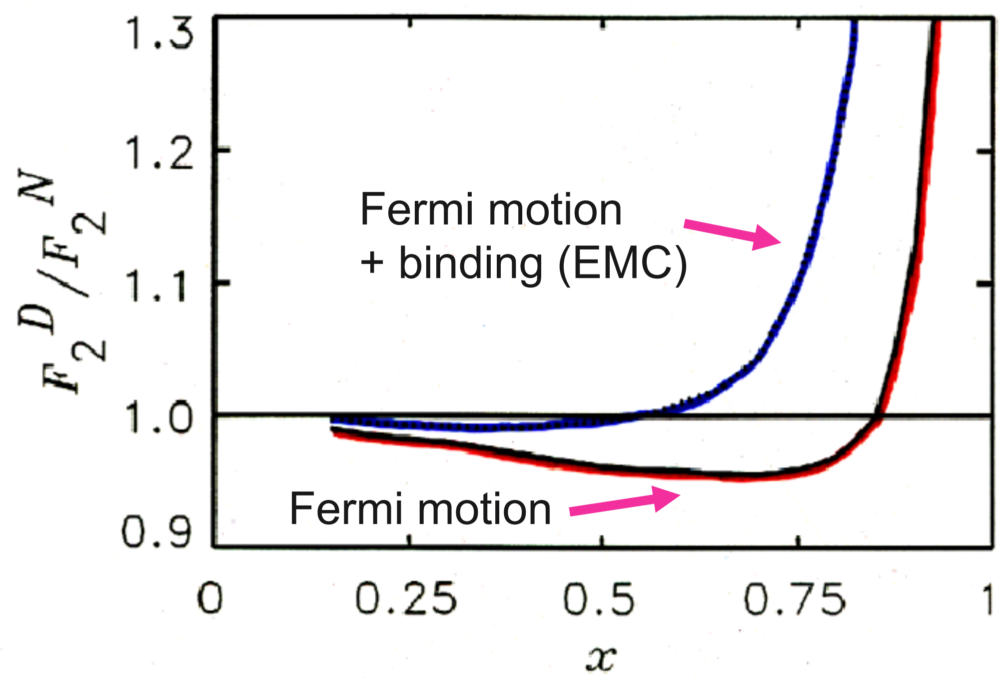
Why don't we know the ratio at high x?

The deuteron is used as "poor person's" neutron target.

$$F_2^D = \frac{1}{2}\sum_N \int_x^{M_D/M} dy\rho(y)F_2^N\left(\frac{x}{y}, Q^2\right) + \delta^{off}F_2^D$$

Off-shell

Probability of N of momentum y
(Fermi smearing + binding)



- Subtract off-shell corr from deuteron data
- Smear the proton data and subtract
- Remainder is smeared neutron struc fn.
- Unsmear the neutron structure function

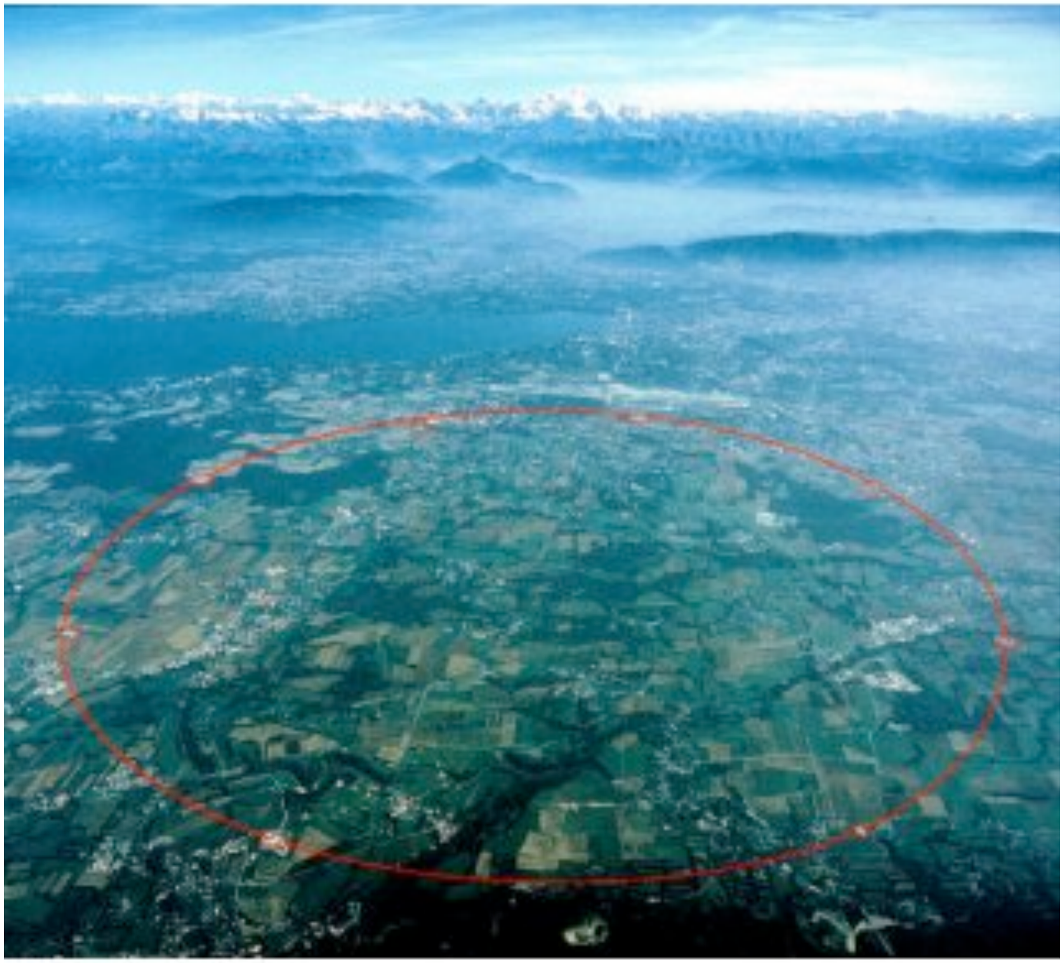
$$F_2^n = S_n(F_2^{D(conv)} - \tilde{F}_2^p)$$

- Iterate

A. W. Thomas and W. Melnitchouk, NP A 631 (1998) 296

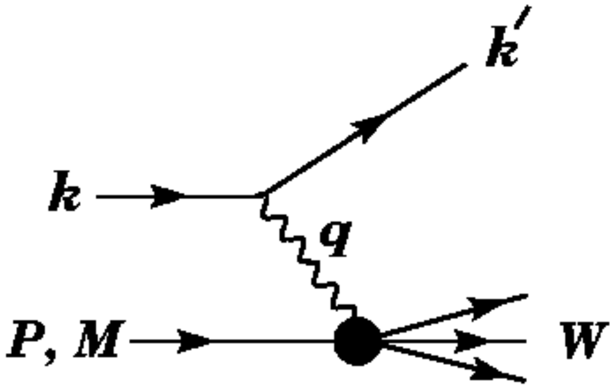
Large x is essential for particle physics

- **Parton distributions at large x are important input into simulations of hadronic background at colliders, *eg* the LHC.**
  - High x at low Q^2 evolves into low x at high Q^2.
  - Small uncertainties at high x are amplified.
- **HERA anomaly: (1996): excess of neutral and charged current events at $Q^2 > 10{,}000$ GeV^2**
  - Leptoquarks
  - ~0.5% larger u(x) at x > 0.75
    S. Kuhlmann et al, PLB 409 (1997)



LHC era is approaching.

Why do we need high energy electrons?



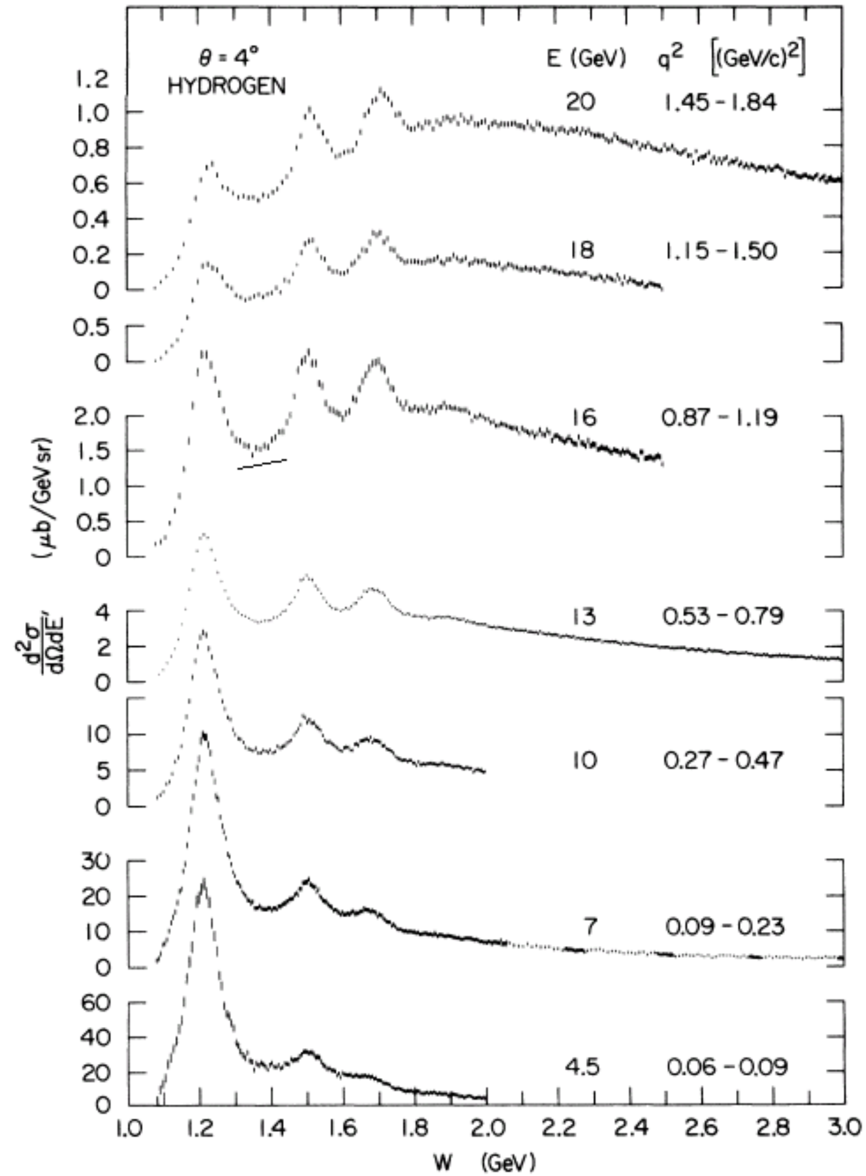
$$Q^2 > 1 \text{ GeV}^2$$
$$W > 2 \text{ GeV}$$

$$W^2 = (p+q)^2 = M^2 + 2M\nu - Q^2$$

$$W^2 = M^2 + \frac{1-x}{x}Q^2$$

eg. if x =0.9, then Q^2 = 27 GeV^2

Practical limit at JLab12: x = 0.8



S. Stein *et al*, PRD 12 (1975)

Ratio: Neutron to Proton Structure Function

- Proton structure function:

$$F_2^p = x\left[\frac{4}{9}(u+\overline{u}) + \frac{1}{9}(d+\overline{d}) + \frac{1}{9}(s+\overline{s})\right]$$

- Neutron structure function (isospin symmetry): $u_p(x) = d_n(x) \equiv u(x)$

$$F_2^n = x\left[\frac{4}{9}(d+\overline{d}) + \frac{1}{9}(u+\overline{u}) + \frac{1}{9}(s+\overline{s})\right]$$

- Ratio:

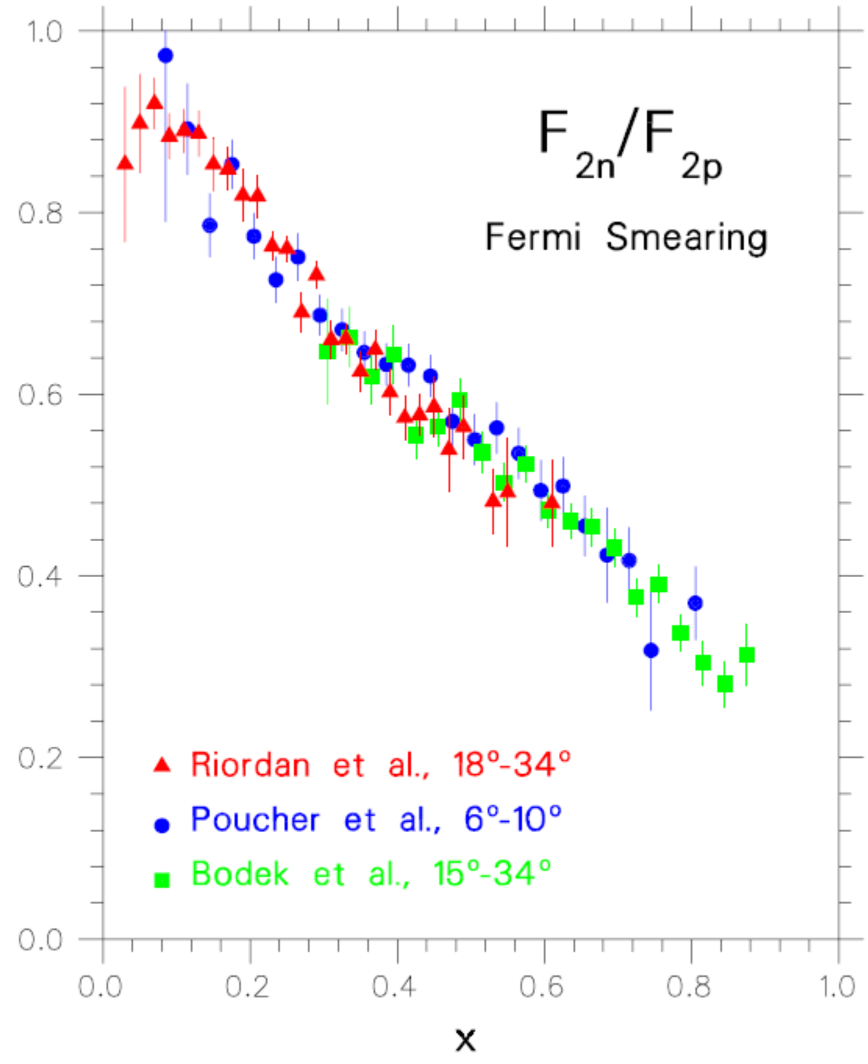
$$\frac{F_2^n}{F_2^p} = \frac{u+\bar{u}+4(d+\bar{d})+s+\bar{s}}{4(u+\bar{u})+d+\bar{d}+s+\bar{s}}$$

- Nachtmann inequality:

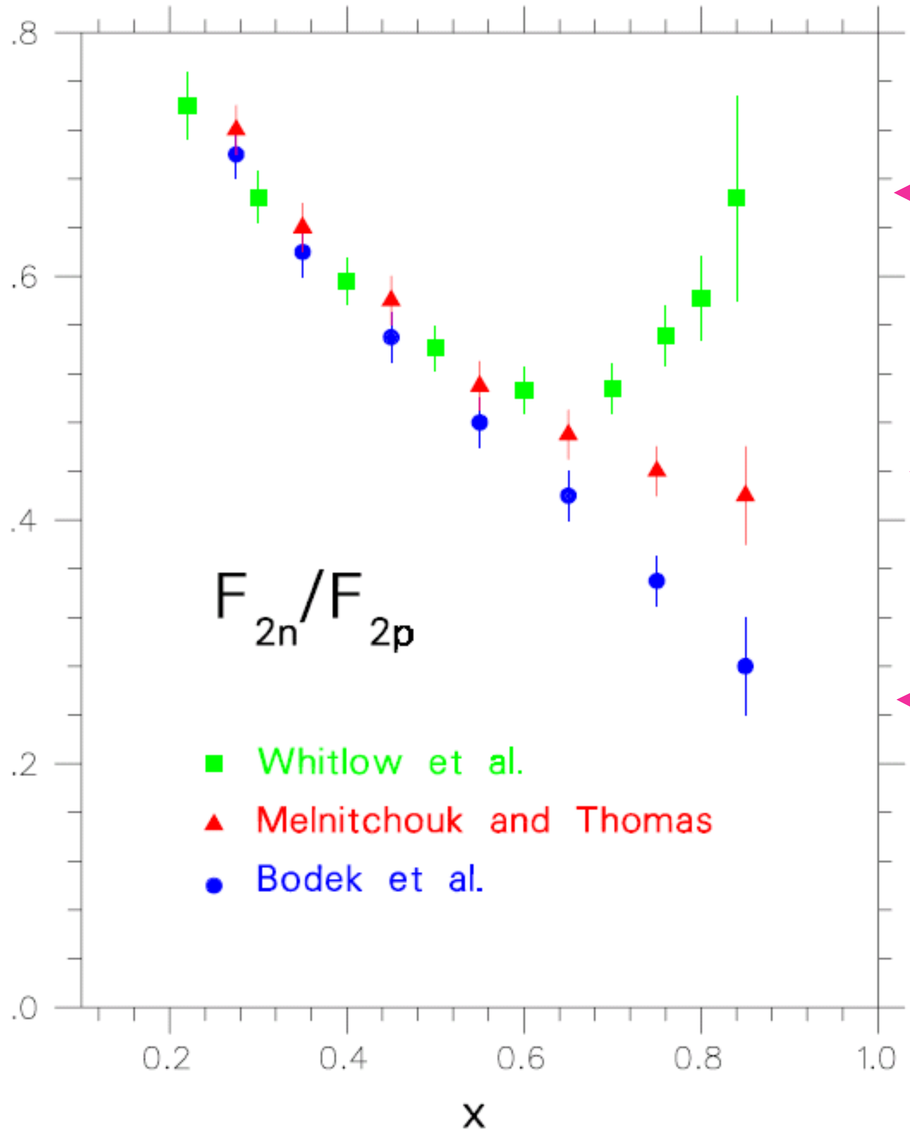
$$\frac{1}{4} \le \frac{F_2^n}{F_2^p} \le 4$$

- Focus on high x:

$$\frac{F_2^n}{F_2^p} = \frac{[1+4(d/u)]}{[4+(d/u)]}$$



Structure Function Ratio



SU(6) symmetry

pQCD

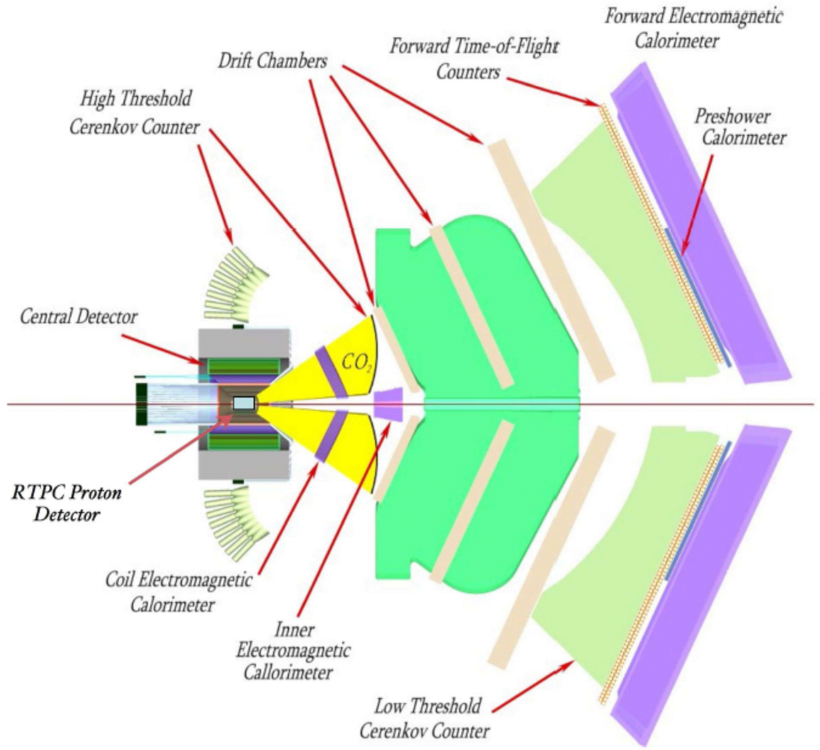
Scalar di-quark

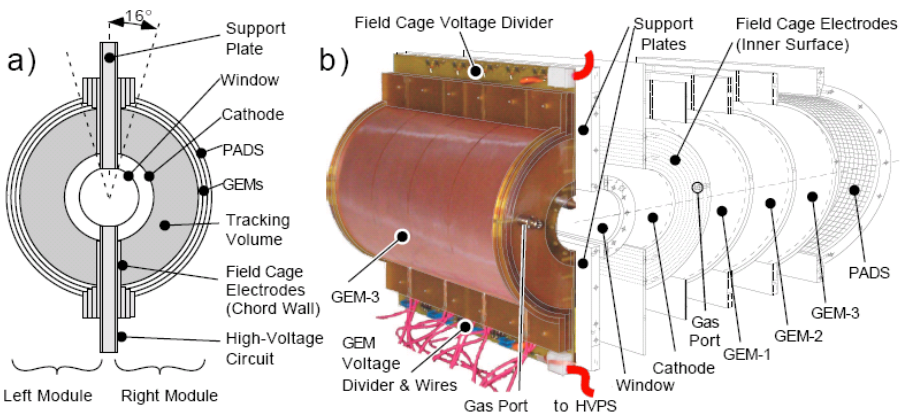
Reviews:

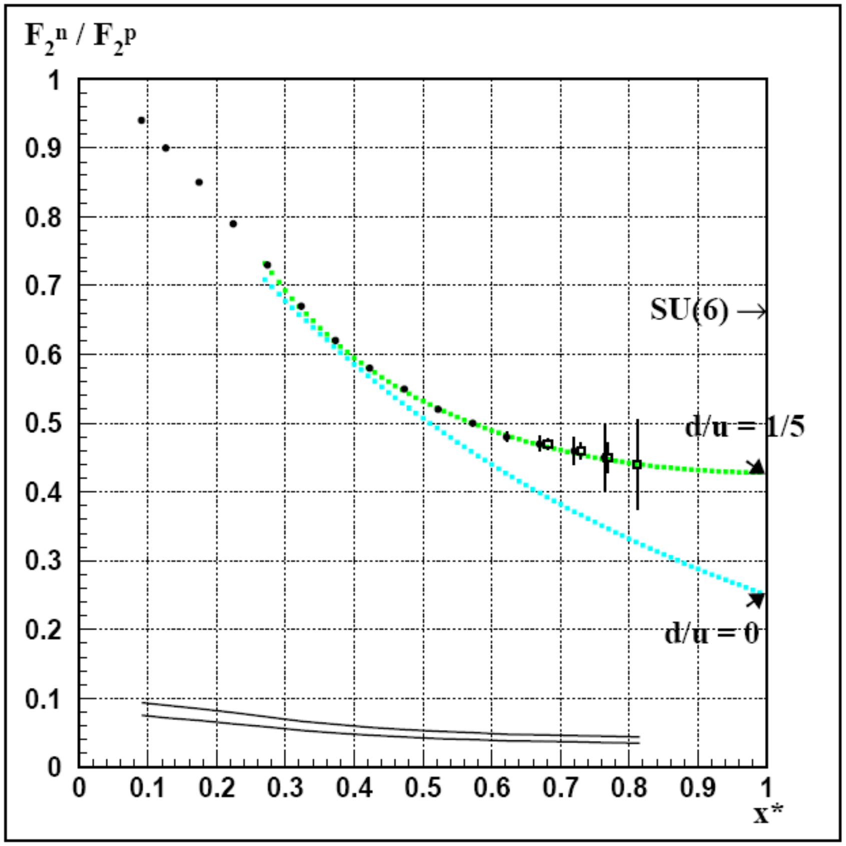
N. Isgur, PR**D 59** (1999),
S Brodsky et al NP **B441** (1995),
W. Melnitchouk and A. Thomas PL **B377** (1996) 11.

Craig Roberts: "a top priority"

Tagged Neutron in the Deuteron – BONUS + CLAS12

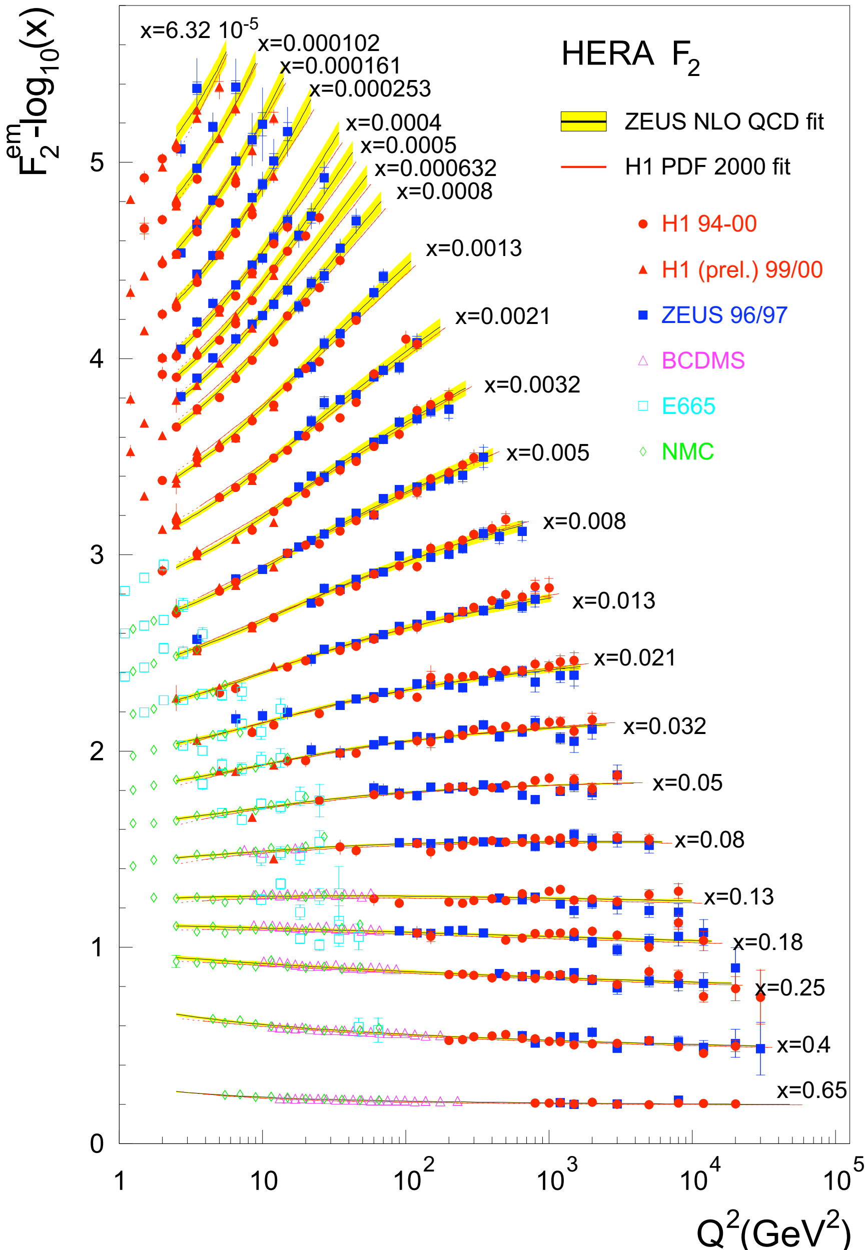


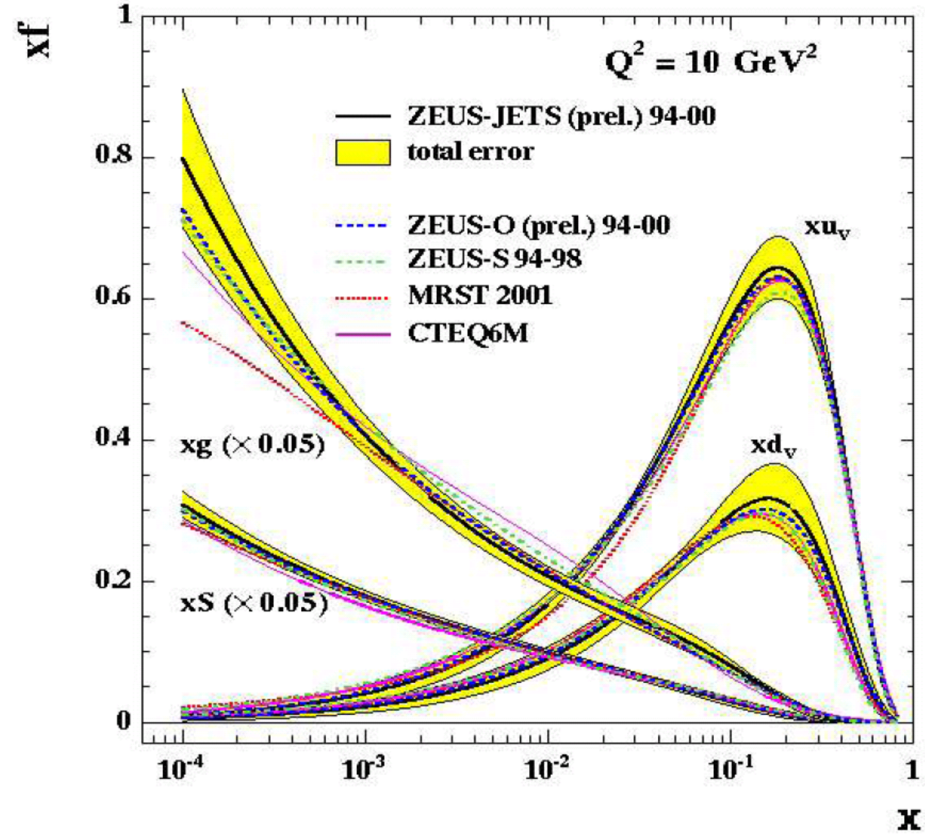




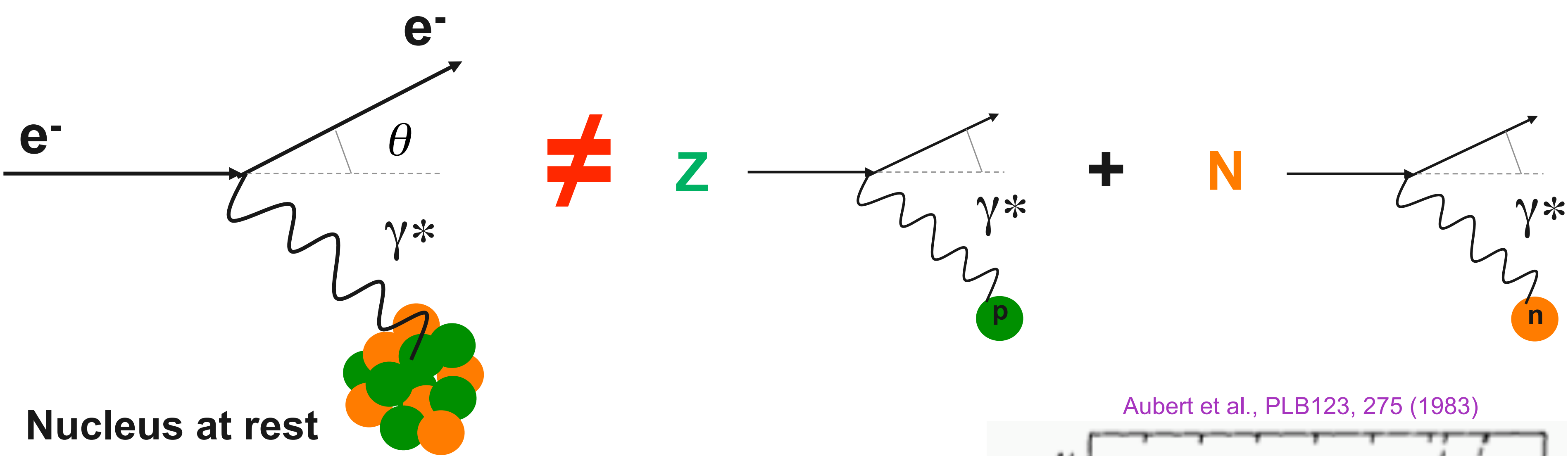
- PAC30: "conditionally approved"
- JLab E12-06-113, S. Bueltmann, H. Fenker, M. Christy, C. Keppel *et al*

F2p and parton distributions





The EMC effect



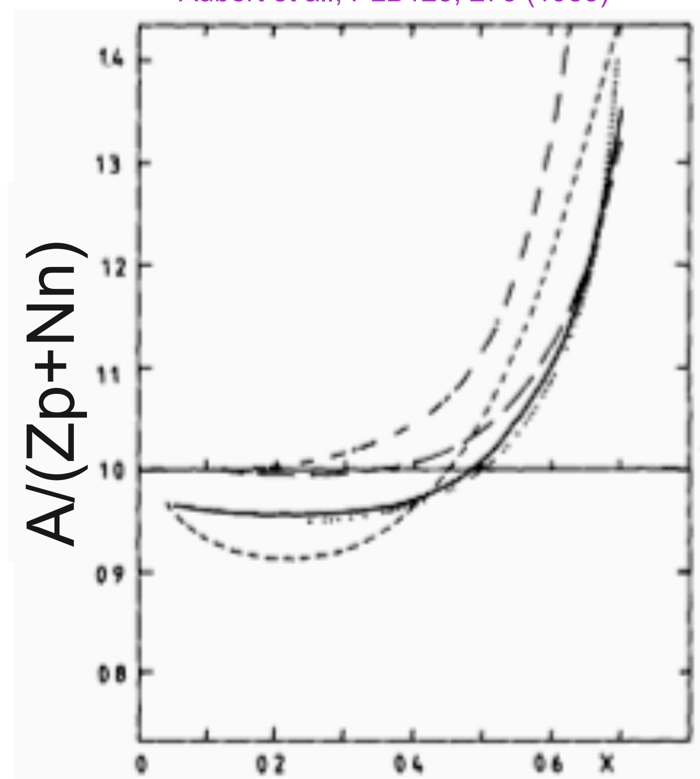
Nucleus at rest
(**A** nucleons = **Z** protons + **N** neutrons)

Theoretical prediction:

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

after corrections due to the motion of the nucleons in the nucleus (slowly moving nucleons weakly bound)

Aubert et al., PLB123, 275 (1983)



Polarized EMC effect

- Why is it important to measure it ?
- Experimental requirements for a baseline measurement
- Will the extraction of g1(7Li)/g1p be model independent ?

- A1n extraction only considered unpolarized EMC effect. Need calculation of g1(3He)/g1n.
- ...