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... for a brighter future

Coulomb distortion in the inelastic regime

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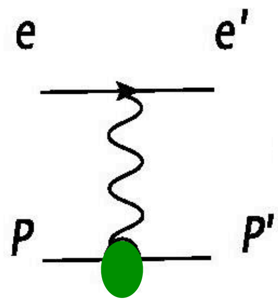
Work done in collaboration with
Dave Gaskell (JLab) and John Arrington (ANL)

International Workshop on Positrons at Jefferson Lab
JPOS09
March 25-27 2009

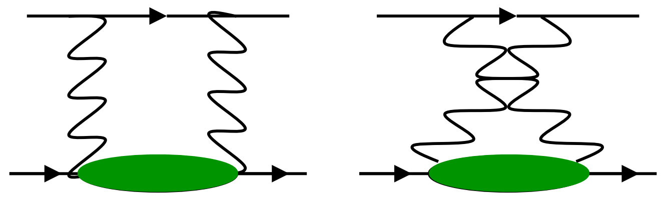
Coulomb distortion and two-photon exchange

OPE



TPE

Exchange of 2 (hard) photons with a single nucleon

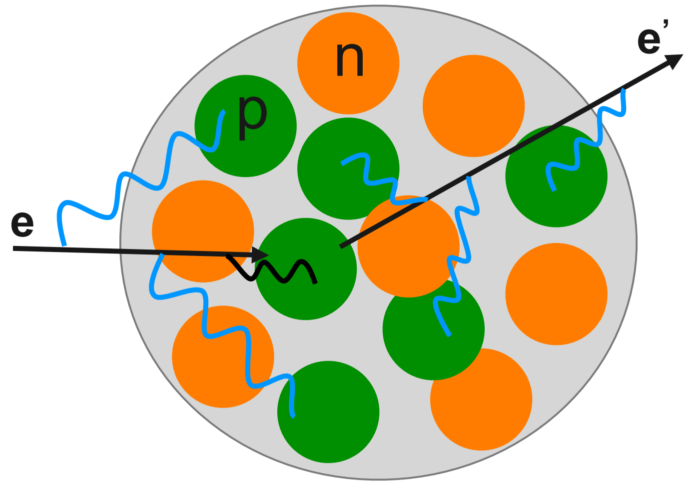


Coulomb distortion

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)

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

<u>1st method</u>

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

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

⇔

<u>2nd method</u>

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

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

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

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

How to correct for Coulomb distortion ?

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1st method | 2nd method

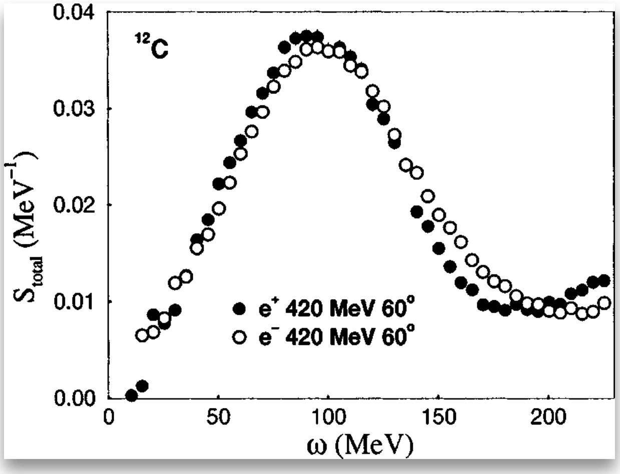
$S_{tot}^{PWBA}(|\vec{q}|, \omega,$ ...

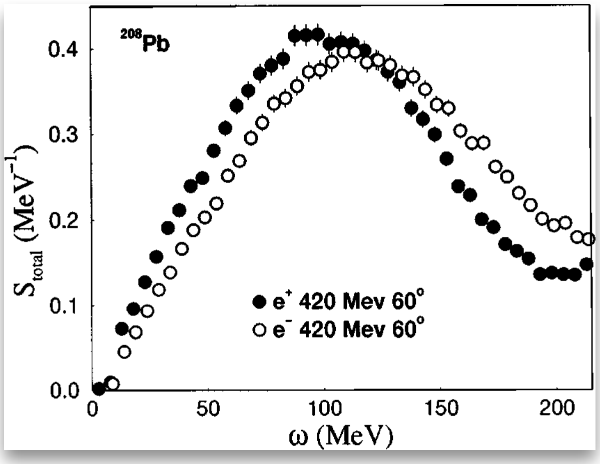
$F^i_{foc} = \frac{\ldots}{E}$

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

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

Coulomb distortion measurements in quasi-elastic scattering





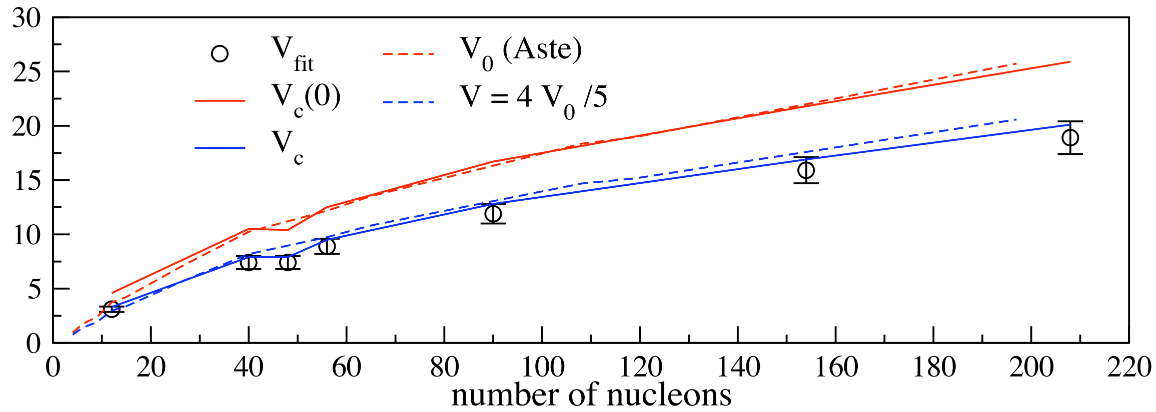
Gueye *et al.*, PRC60, 044308 (1999)

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

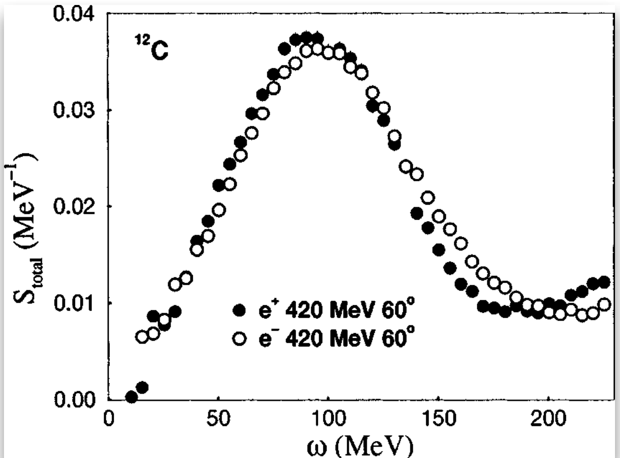
$$V(r) = -\frac{3\alpha(Z-1)}{2R} + \frac{\alpha(Z-1)}{2R}\left(\frac{r}{R}\right)^2$$

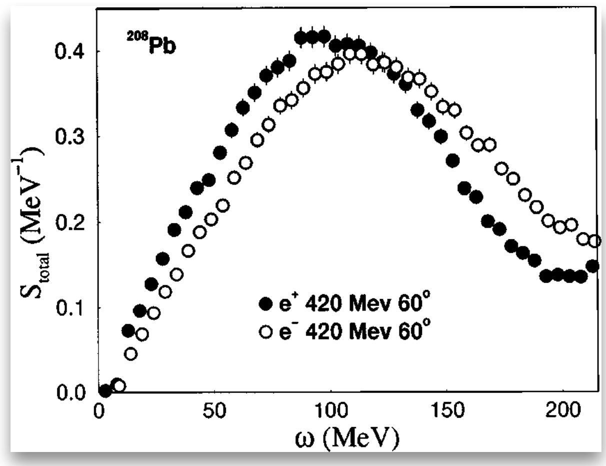
$$R = 1.1A^{1/3} + 0.86A^{-1/3}$$

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



Coulomb distortion measurements in quasi-elastic scattering





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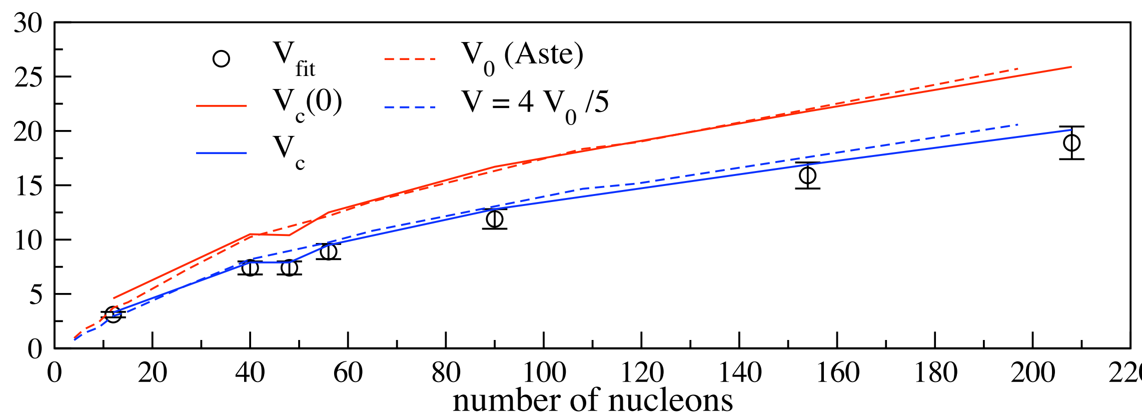

Coulomb potential established in Quasi-elastic scattering regime !

Physics sensitive to Coulomb distortion

Coulomb distortion:

- Not accounted for in typical radiative corrections
- Usually, not a large effect at high energy machines
- Important for $E_p << E$

x>1 experiments
L/T experiments
EMC effect
Color transparency
In-medium modification on the nucleon FF

About every experiments that used nuclei with A>12

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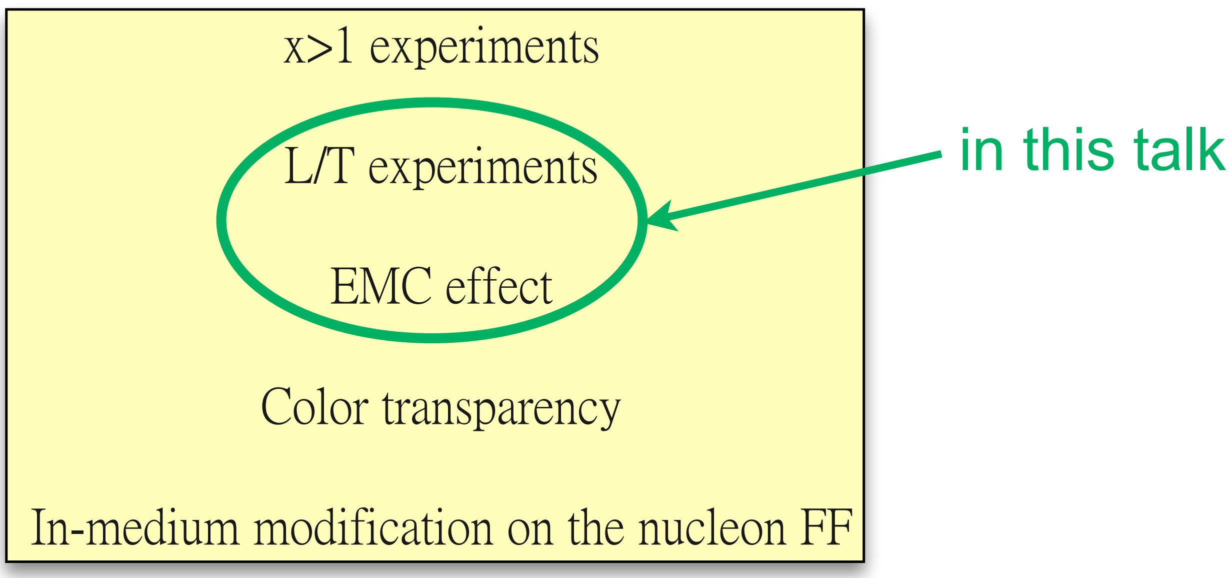
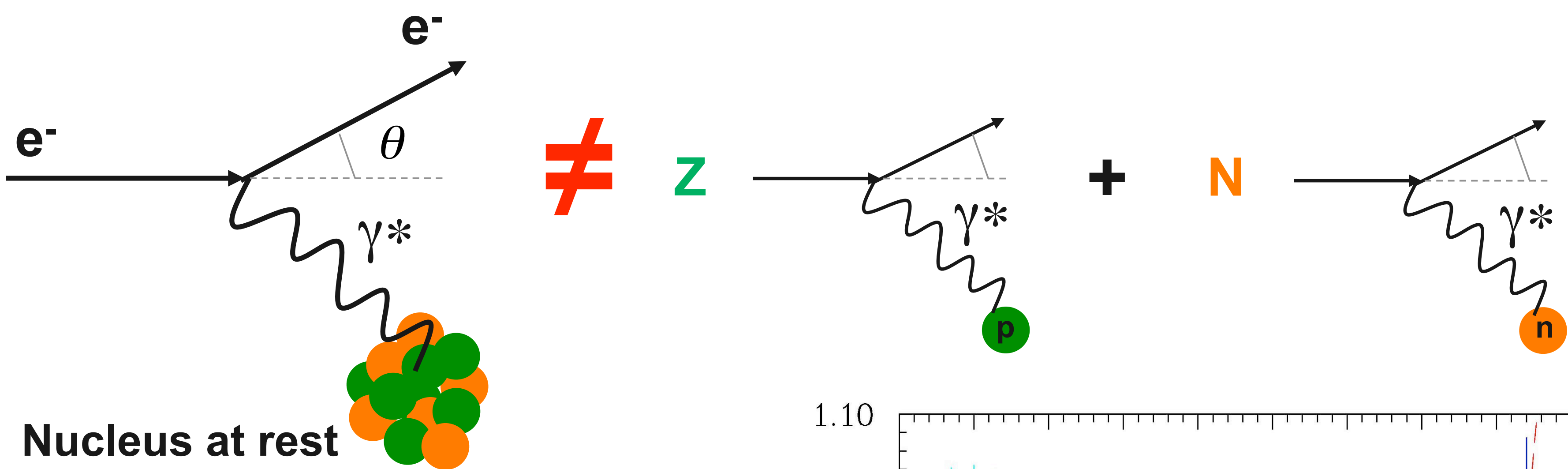
- ➡ Important for $E_p << E$

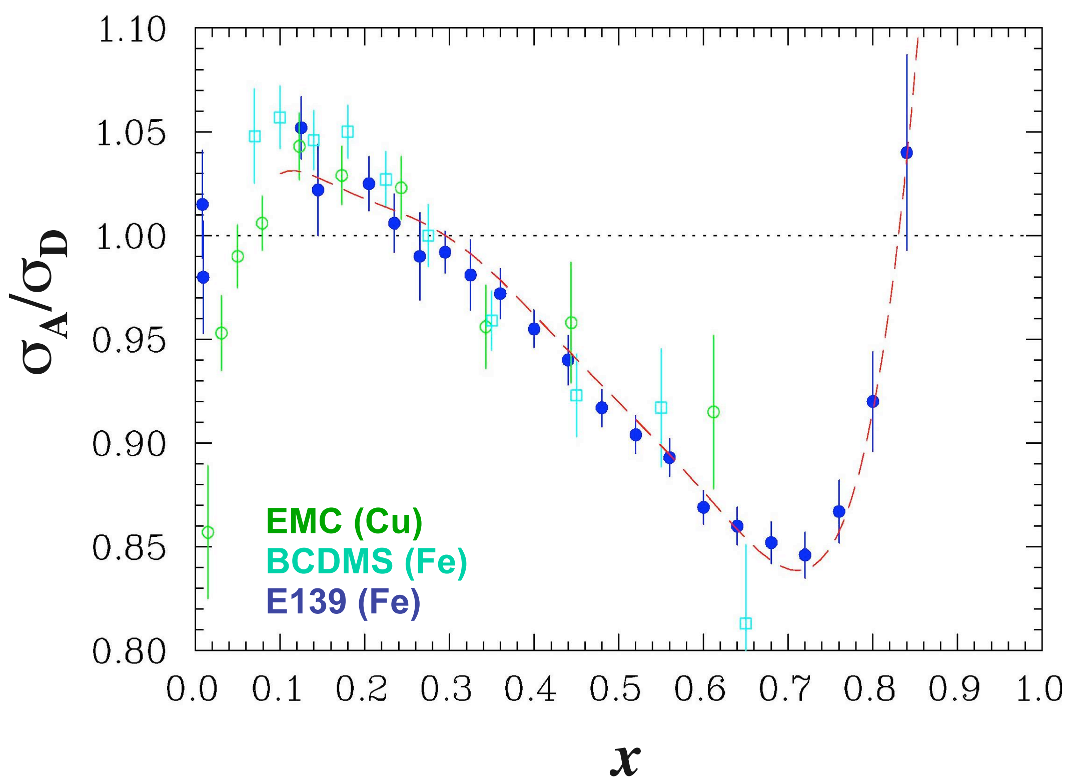


About every experiments that used nuclei with A>12

The EMC effect



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

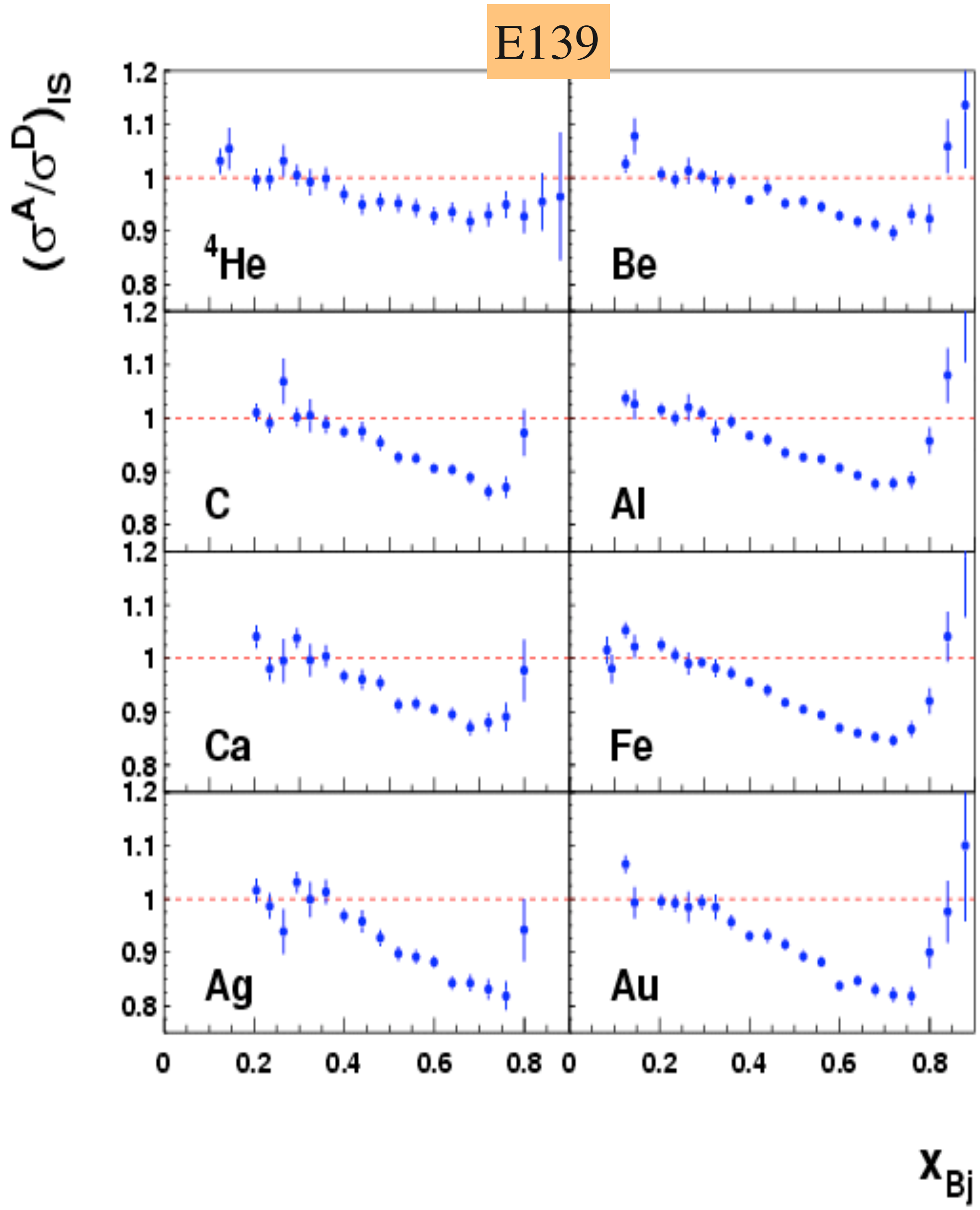


Effects found in several experiments at CERN, SLAC, DESY

SLAC E139 results on the EMC effect

SLAC E139:

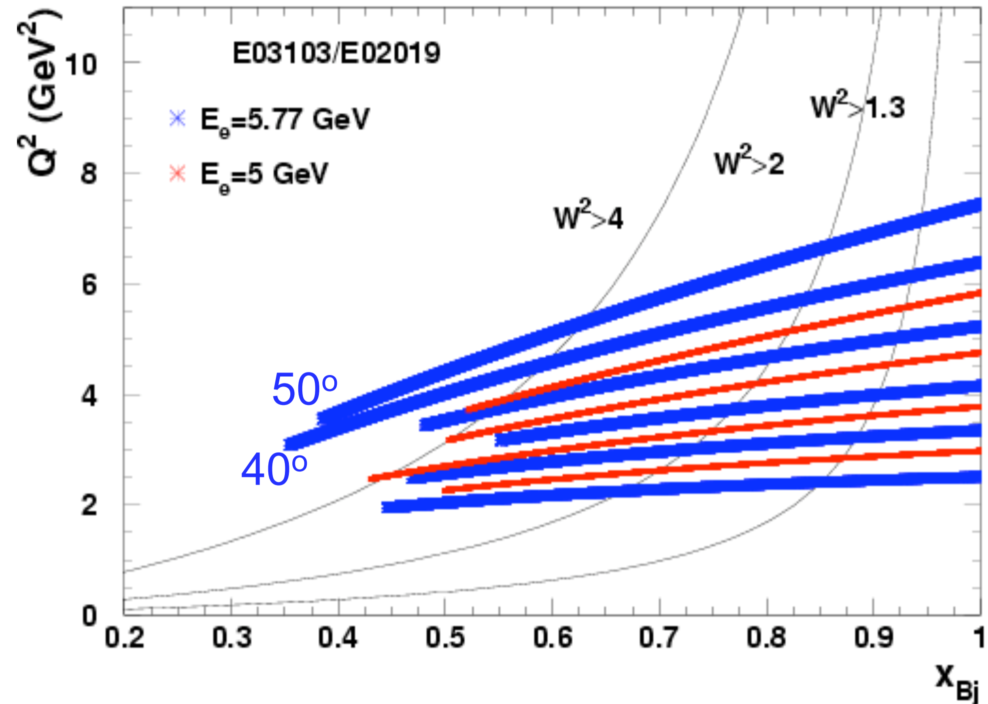
- Most complete data set: A=4 to 197
- Most precise at large x
  - → Q^2-independent
  - → universal shape
  - → magnitude dependent on A

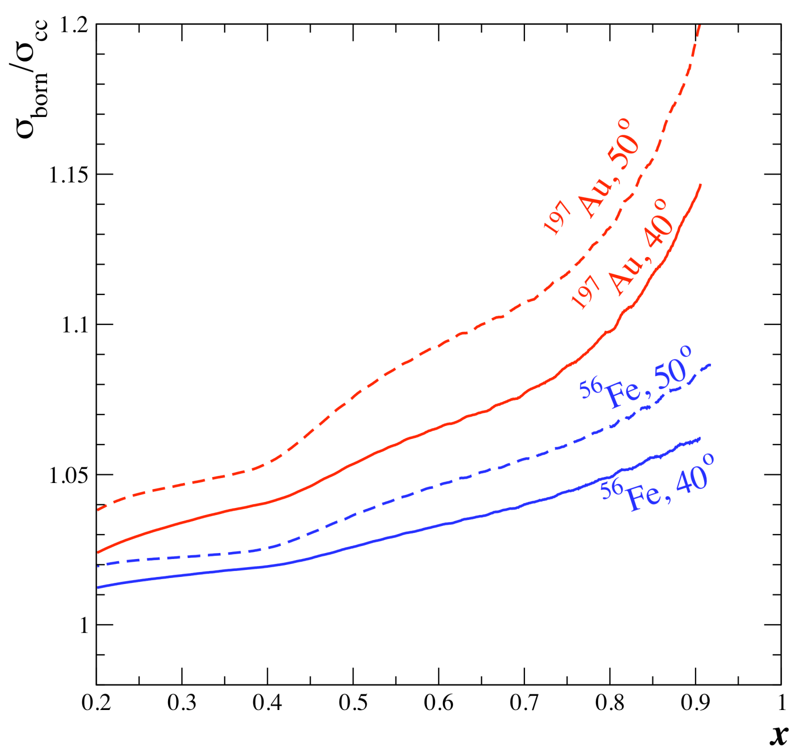


Effect of Coulomb distortion on JLab E03-103 results

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

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





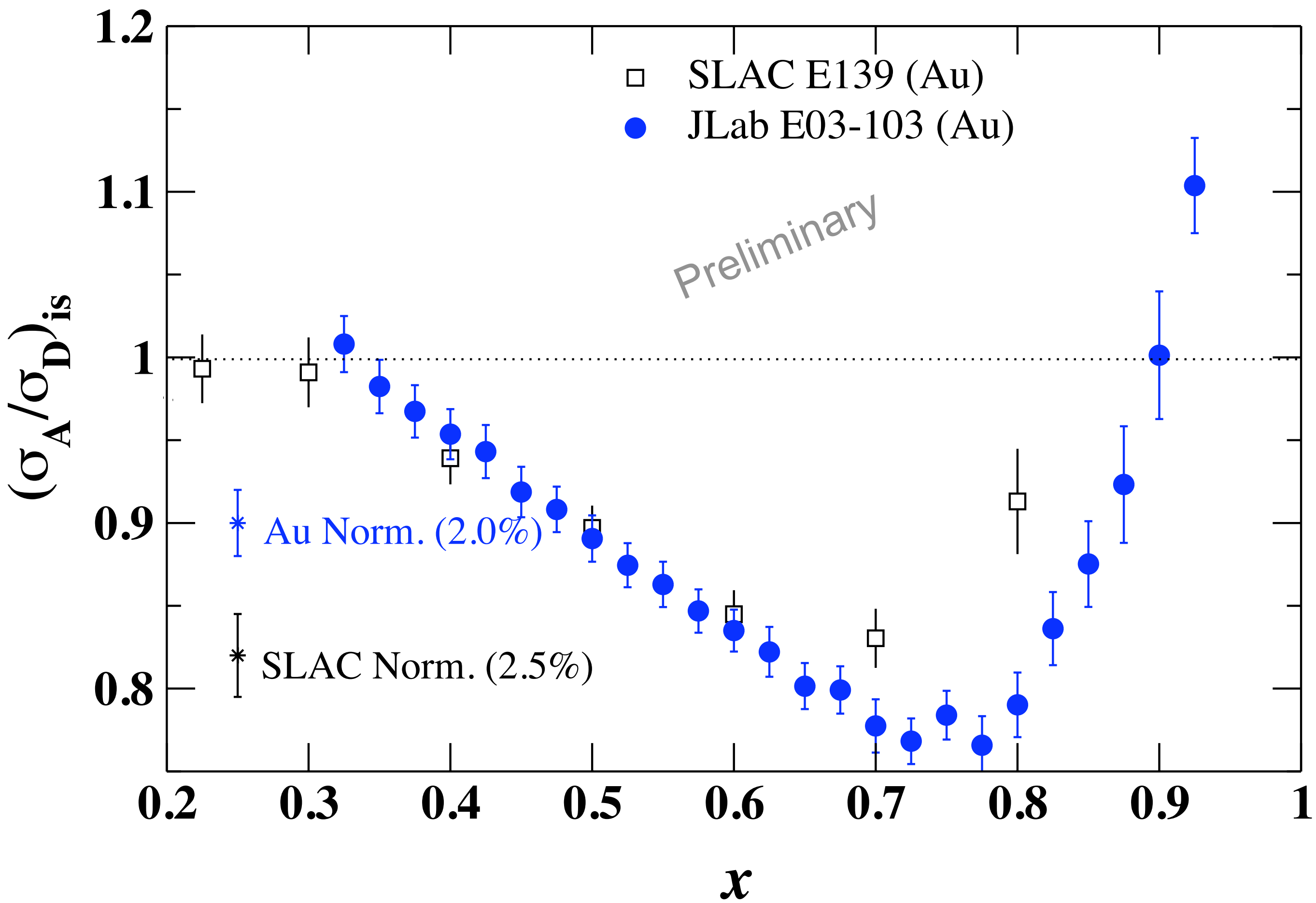
JLab is at lower energy than SLAC but the luminosity is much higher.

We obtain similar or larger Q^2 values in many cases by going to larger angles such that E_p is smaller.

So Coulomb distortion effects are 'doubly' amplified: lower beam energy and lower fractional E_p.

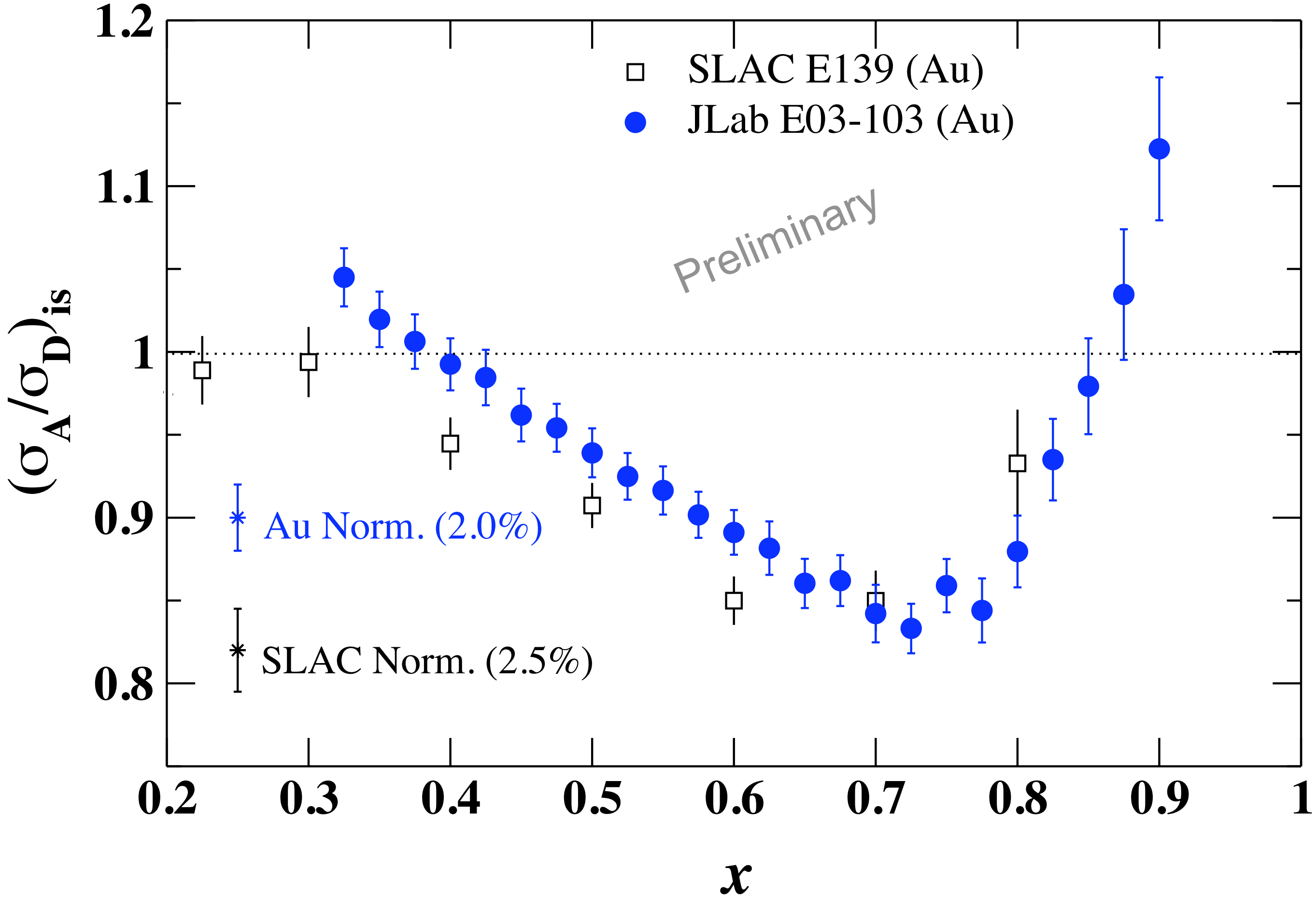
E03-103 heavy target results

no Coulomb corrections applied



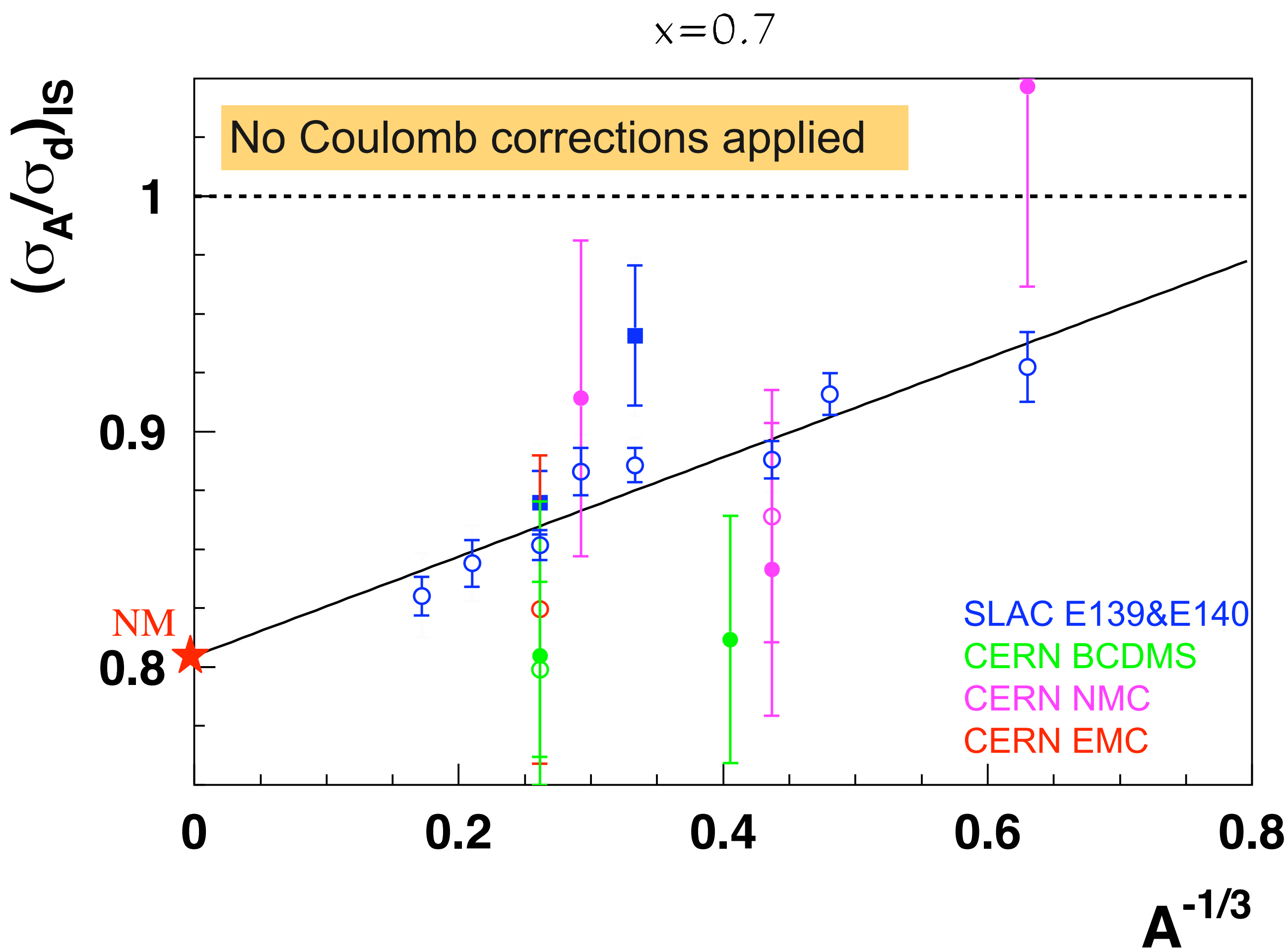
E03-103 heavy target results

Coulomb corrections applied



Extrapolation to nuclear matter

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



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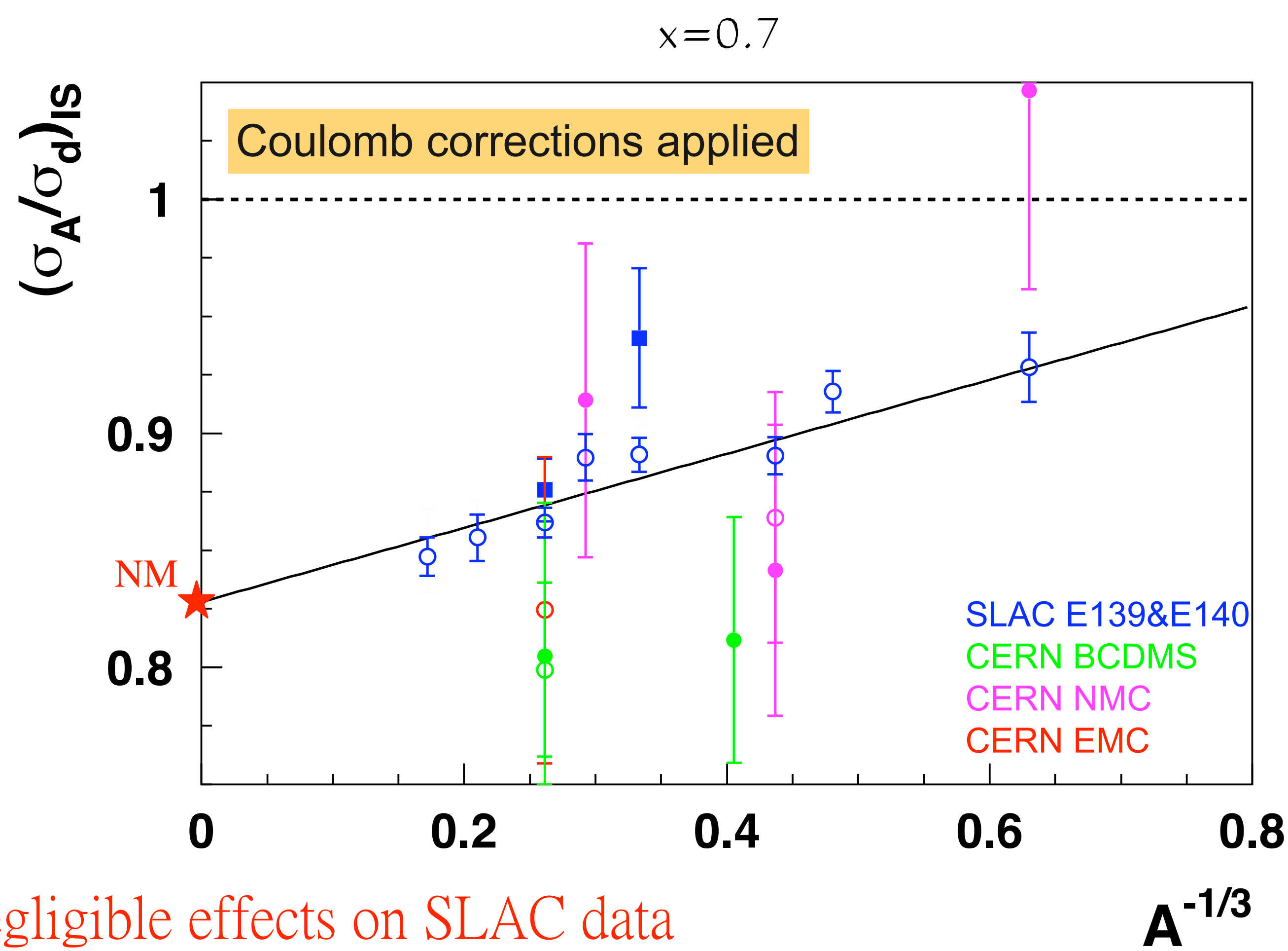
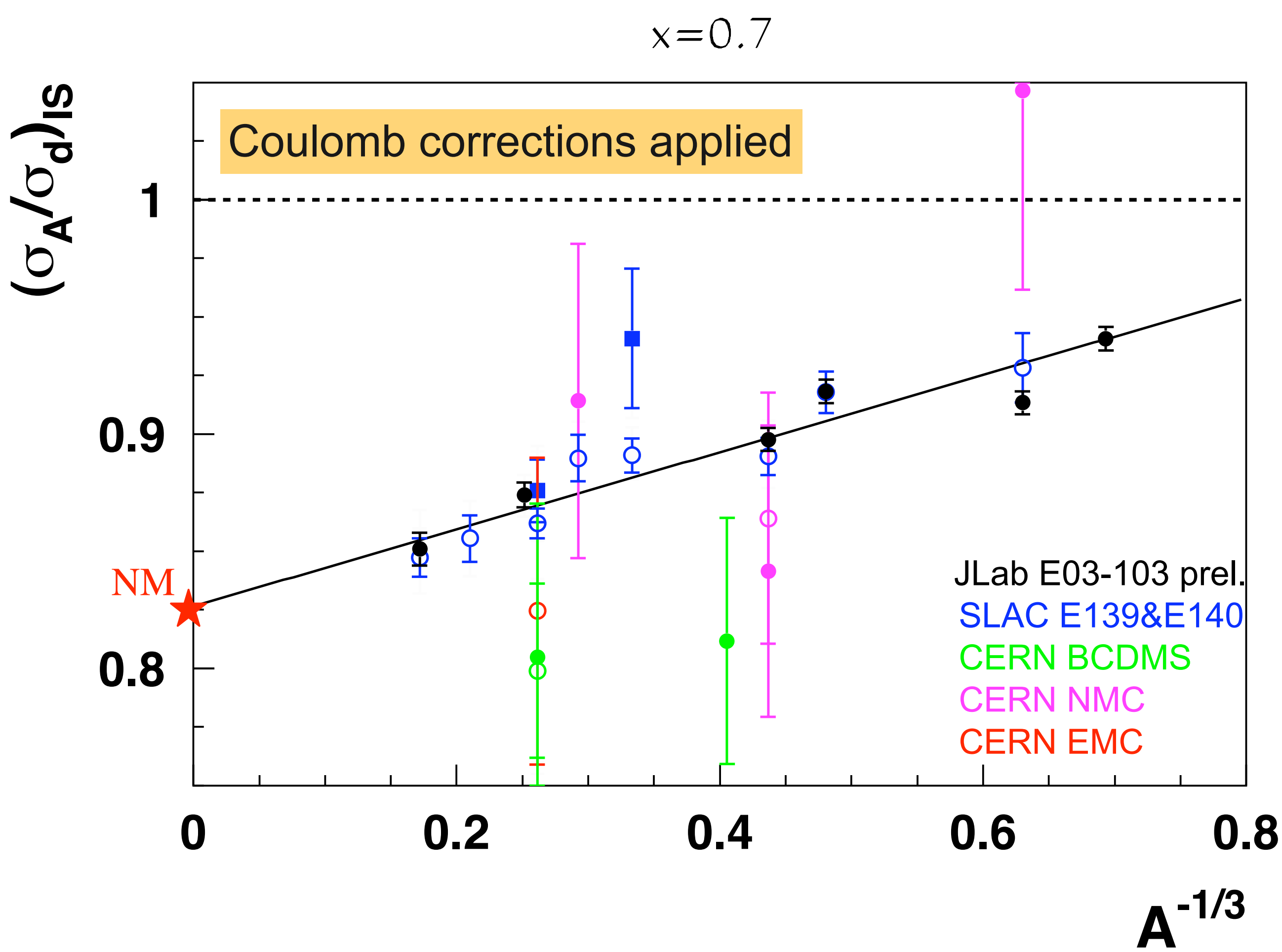


Non-negligible effects on SLAC data

Extrapolation to nuclear matter

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



R(x,Q²)

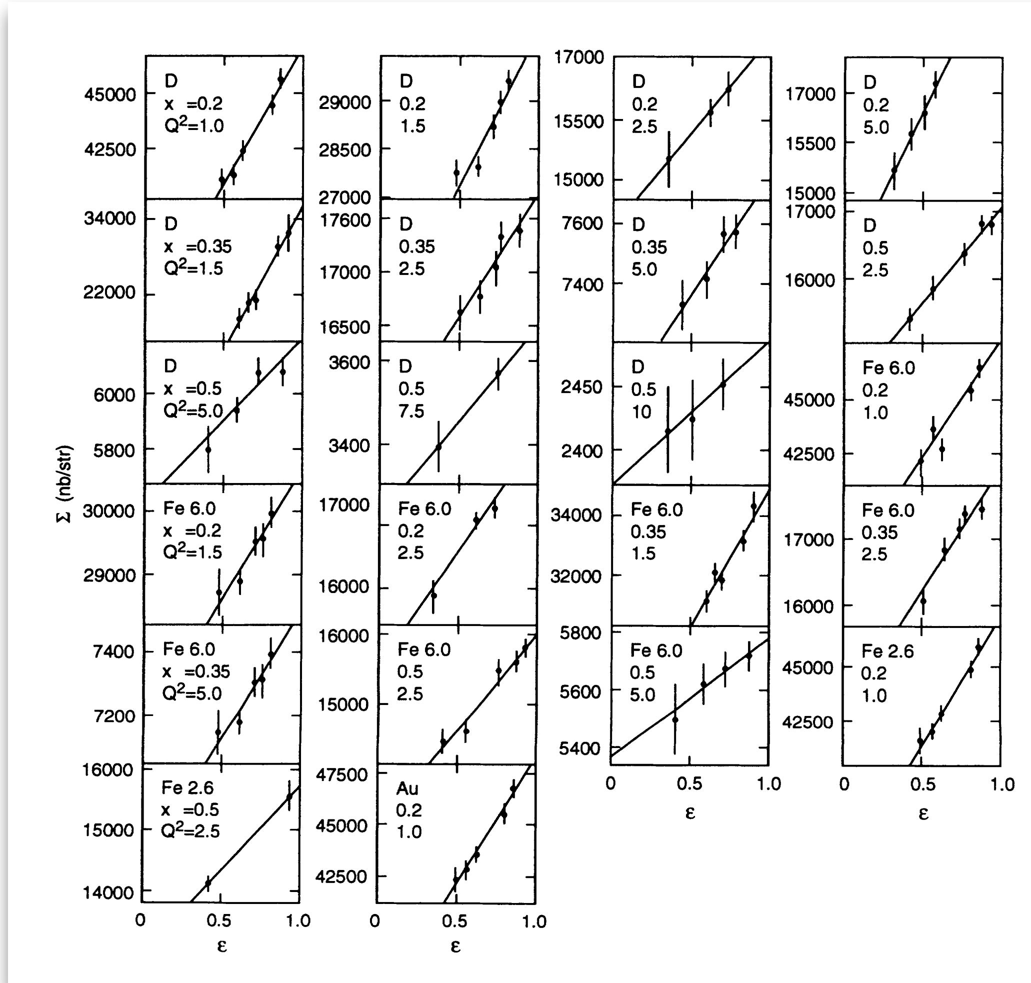
$$\frac{d\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T(x,Q^2) + \varepsilon\sigma_L(x,Q^2)\right]$$

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

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)



Meaning of R

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

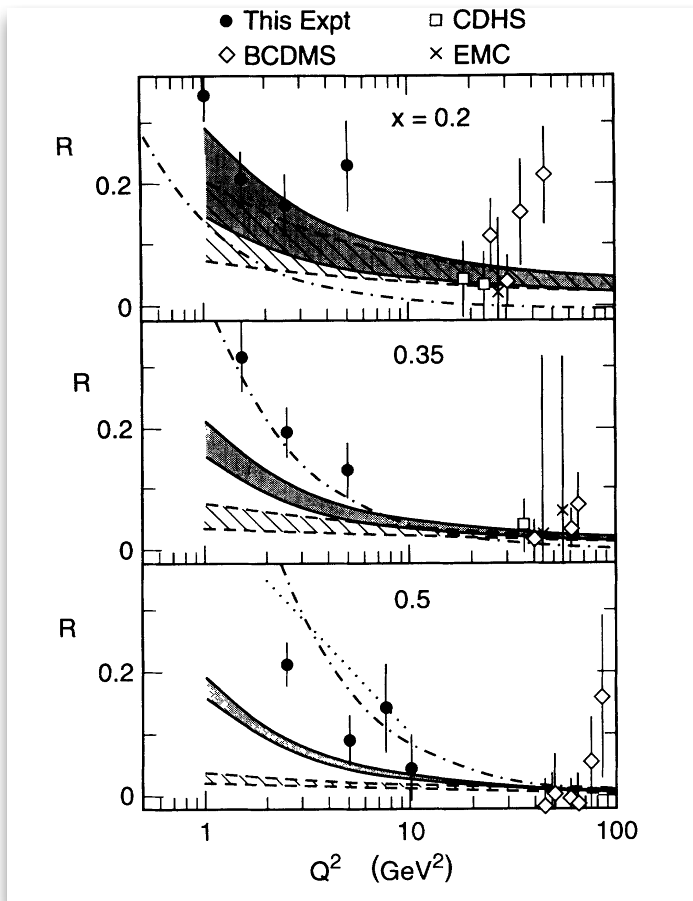
$$R(x,Q^2) = \frac{\sigma_L(x,Q^2)}{\sigma_T(x,Q^2)}$$

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

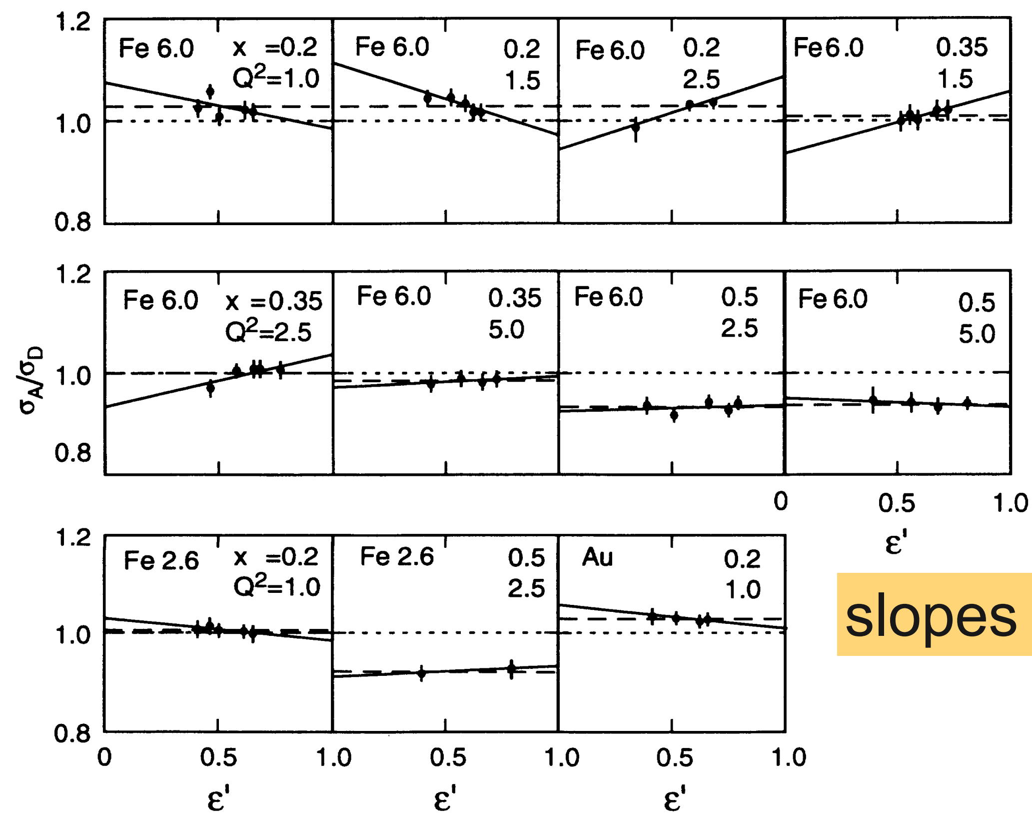


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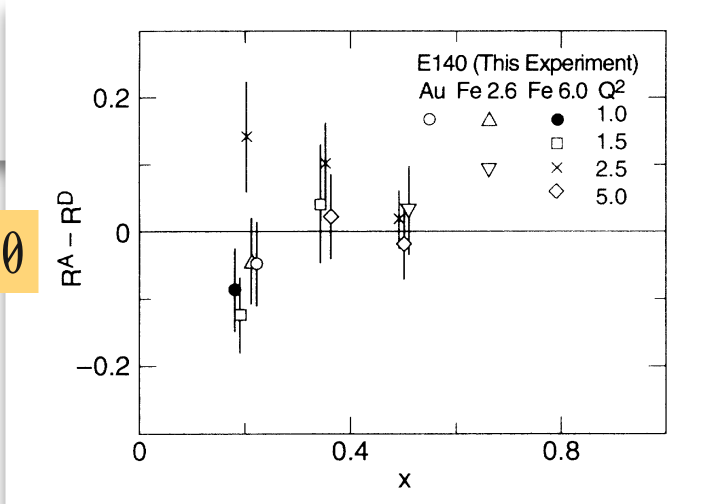
FIG. 13. The fits to the differential cross section ratio σ_A/σ_D versus $\epsilon' = \epsilon/(1+R^D)$ are shown for each (x, Q^2) point. The errors on the cross section include statistical and point-to-point systematic contributions added in quadrature.

slopes $\Rightarrow$ R_A-R_D

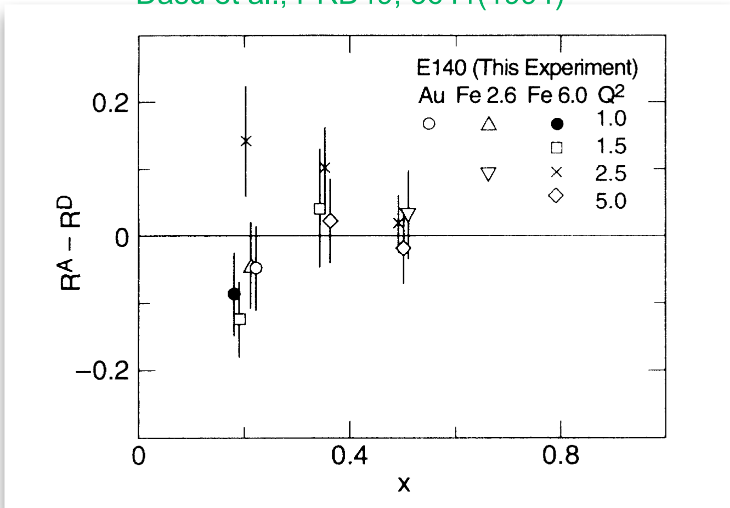


Nuclear higher twist effects and
spin-0 constituents in nuclei:
same as in free nucleons

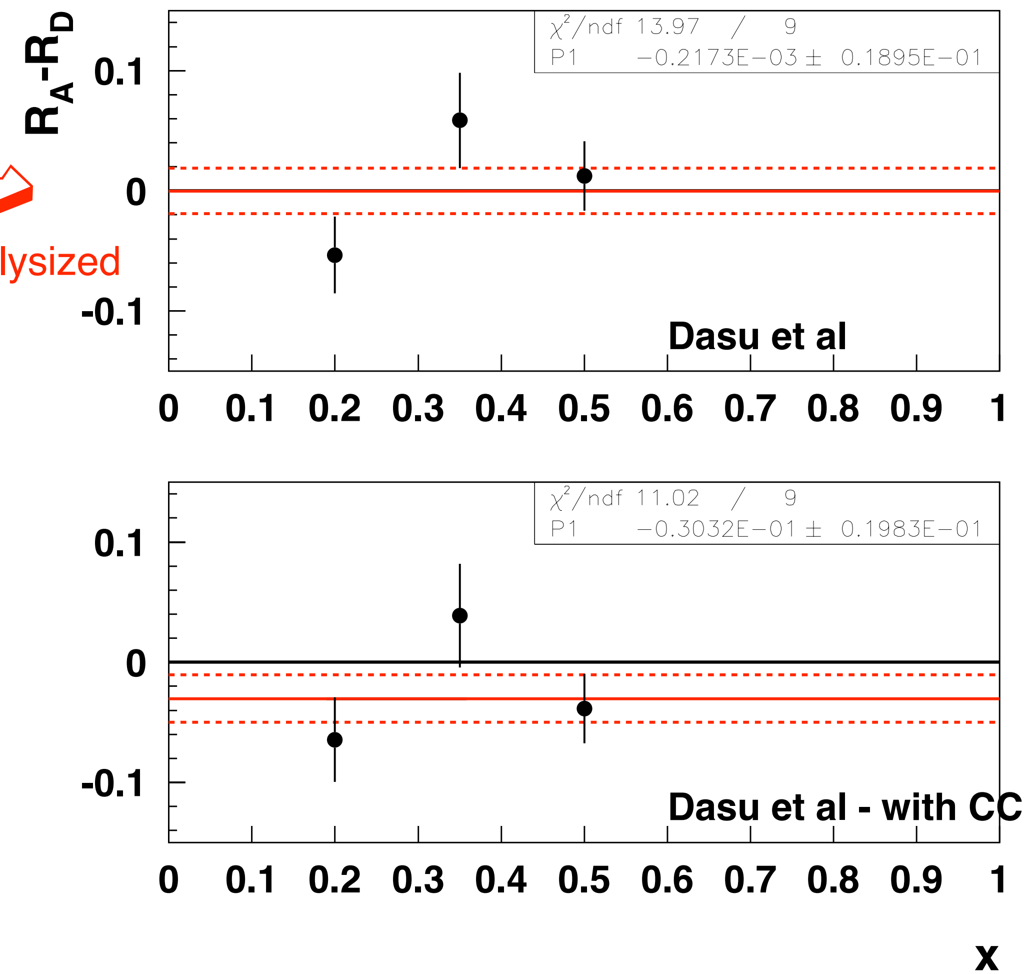
$\Leftarrow$ R_A-R_D=0

Access to nuclear dependence of R

Dasu et al., PRD49, 5641(1994)



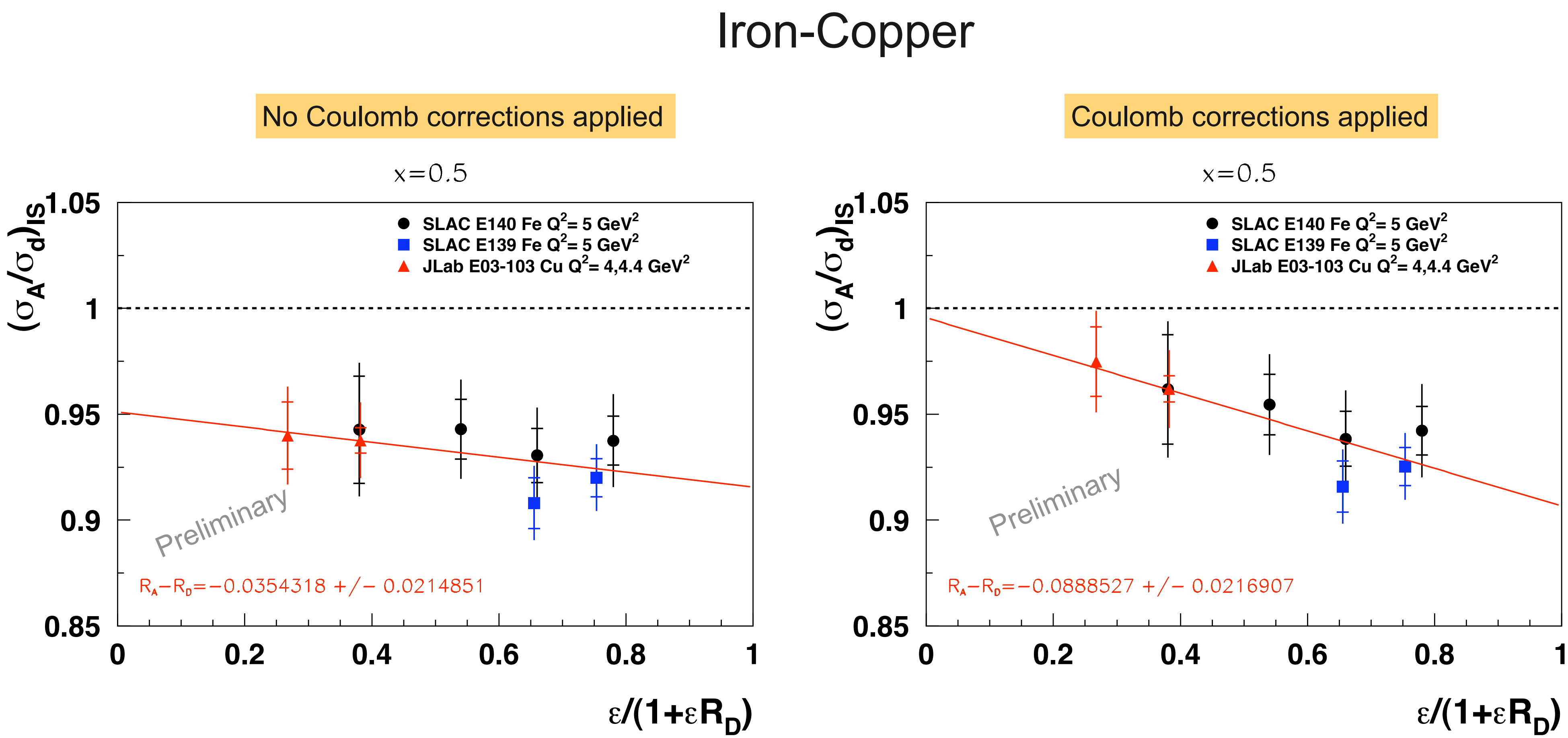
re-analyzed



A non-trivial effect in R_A-R_D arises after applying Coulomb corrections

Access to nuclear dependence of R

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



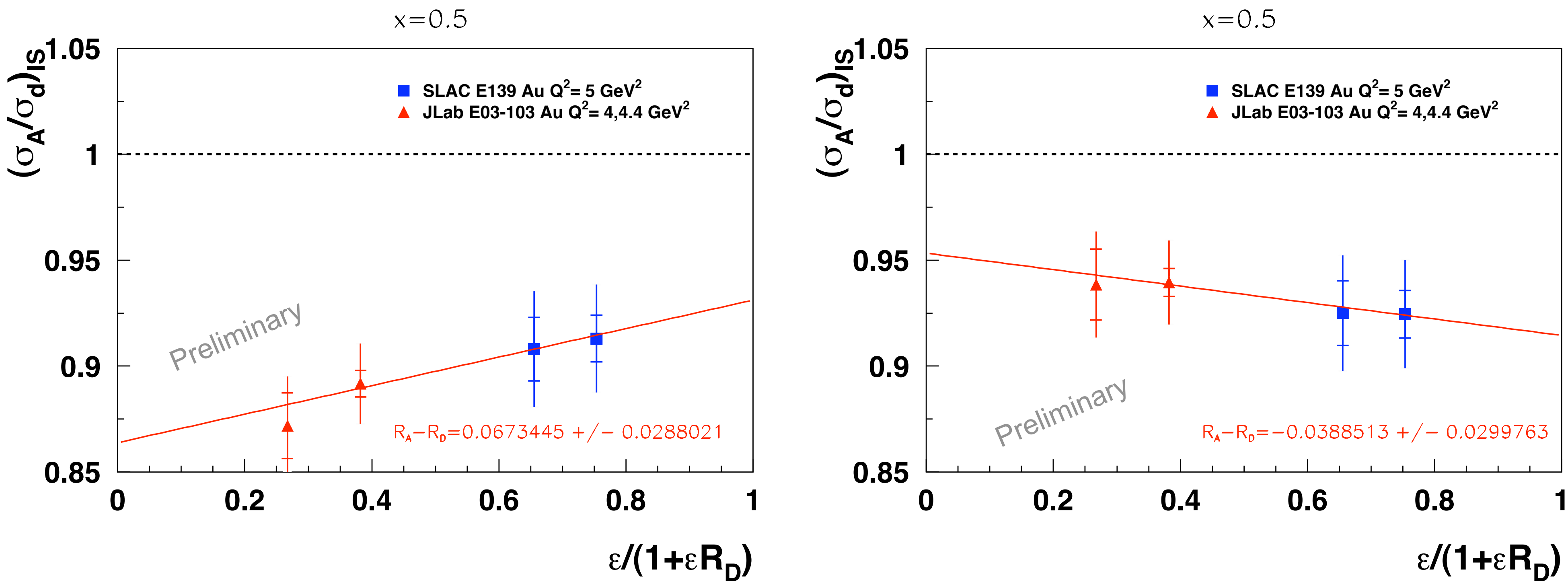
Access to nuclear dependence of R

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

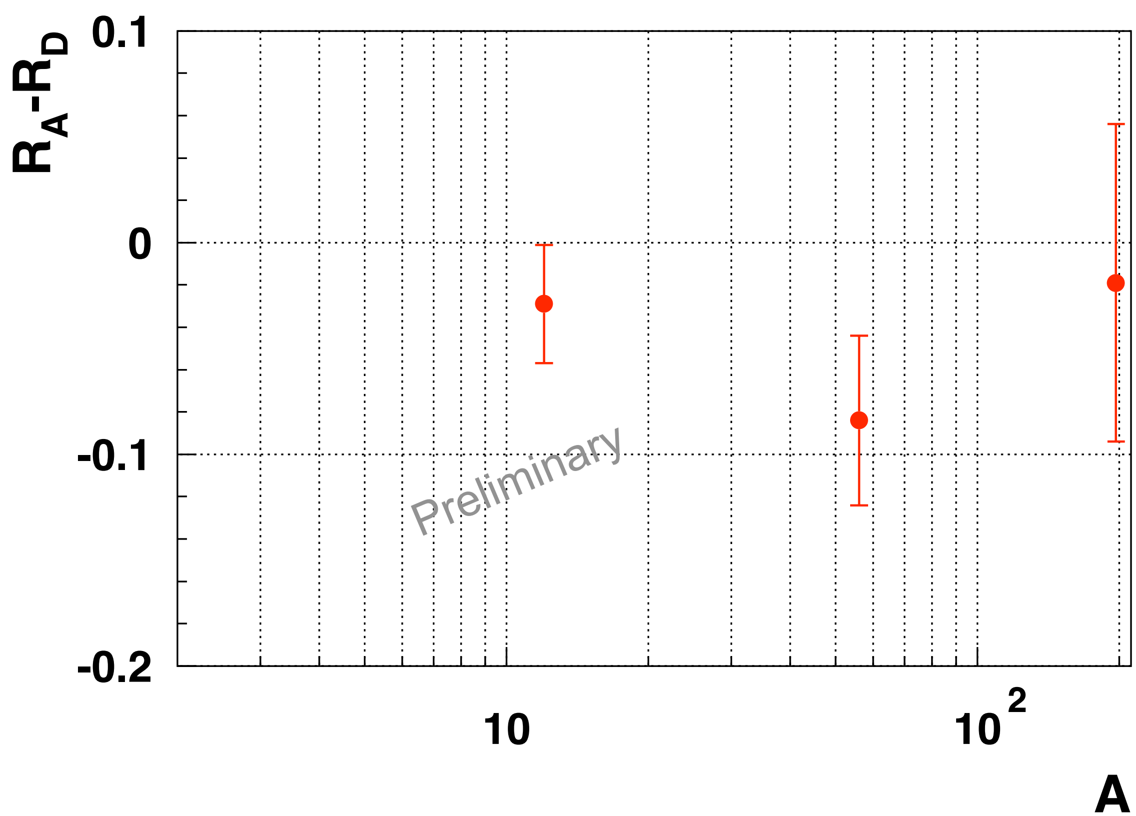
Gold

No Coulomb corrections applied

Coulomb corrections applied



Access to nuclear dependence of R

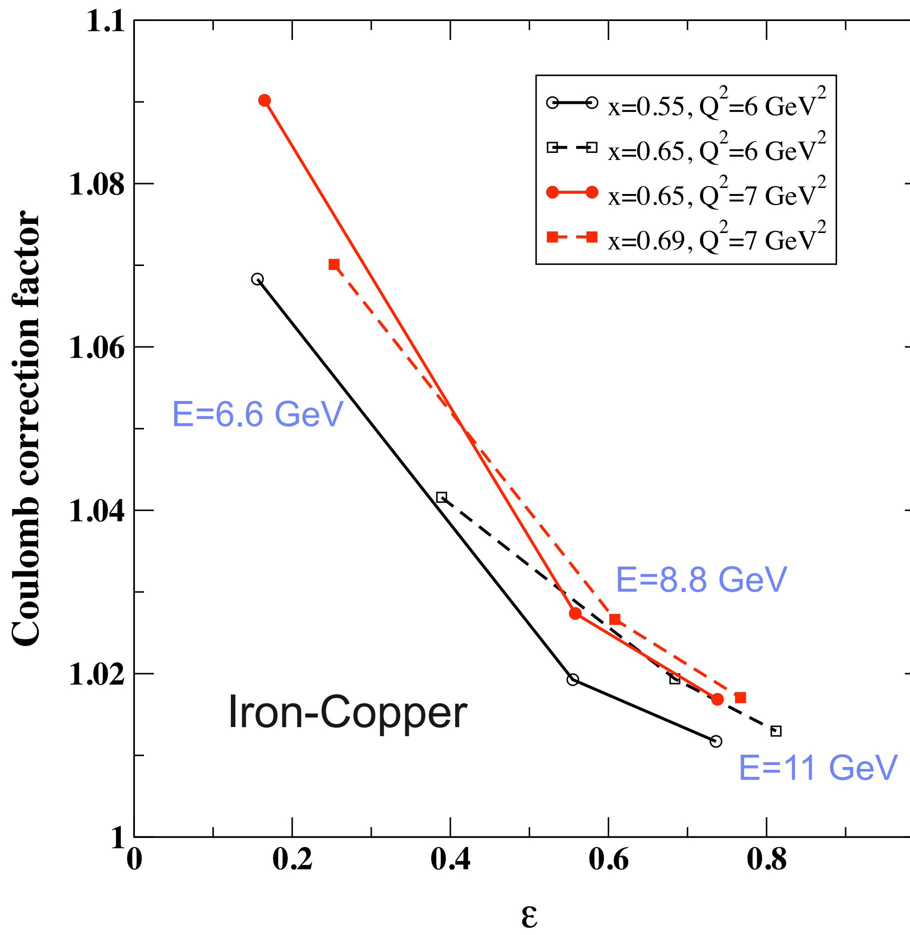


After taking into account the normalization uncertainties from each experiment

Hint of an A-dependence in R in Copper-Iron

ε dependence of the Coulomb distortion

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



Summary

- At present, corrections for Coulomb distortion in inelastic regime are done using a prescription for quasi-elastic scattering regime

  ➡ need a measurement of the amplitude of the effect in the inelastic regime
  ➡ need a prescription in the inelastic regime

- Coulomb distortion affects the extrapolation to nuclear matter which is key for comparison with theoretical calculations

- Coulomb distortion has a real impact on the A-dependence of R: clear ε -dependence

  ➡ hint of an A-dependence of R: could impact many experiments which used R_p or R_D for R_A
  ➡ could change our conclusion on the spin-0 constituent contents and higher twist effect in nuclei versus free nucleons.

Back-ups

Nucleon only model

Assumptions on the nucleon structure function:

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

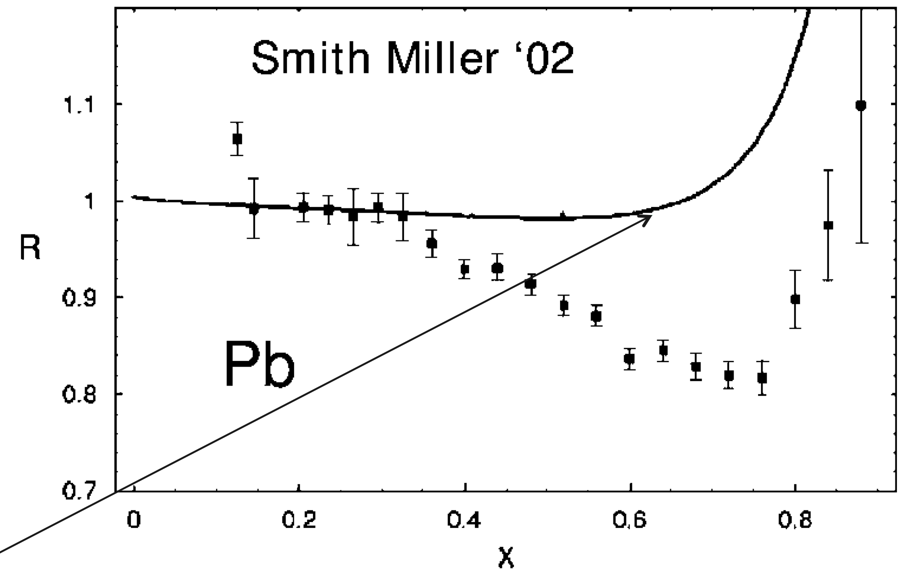
$$\frac{F_2^A(x_A)}{A} = \int_{x_A}^{A} dy \cdot f_N(y) F_2^N(x_A / y)$$

Fermi momentum << $\mathbf{M_{nucleon}}$

➔ $f_N(y)$ **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 cloud is enhanced and pions carry an access 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

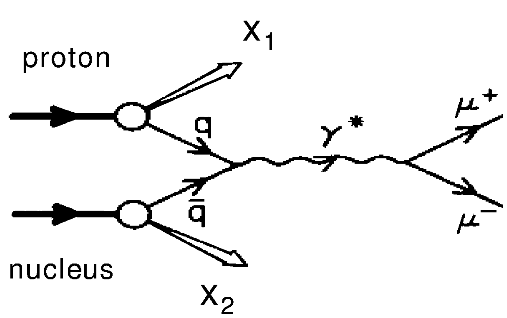
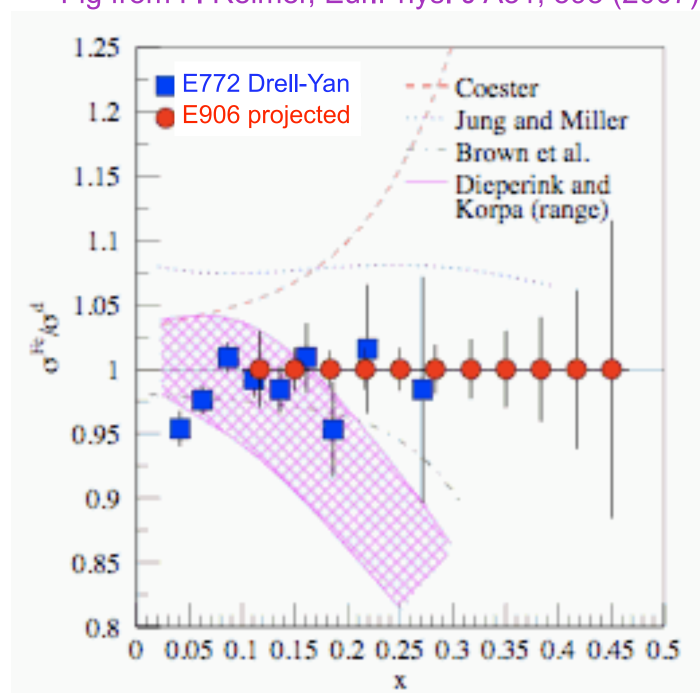


Fig from P. Reimer, Eur.Phys. J A31, 593 (2007)



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

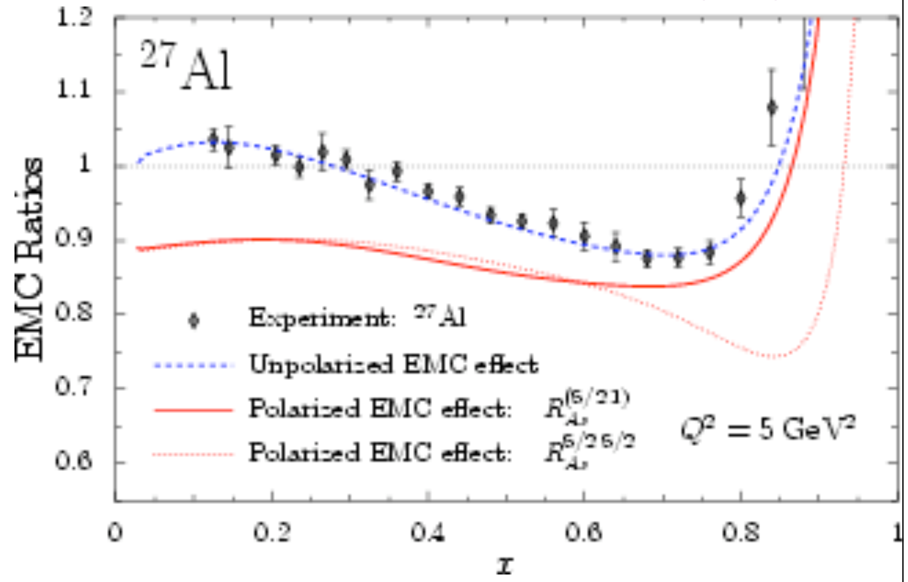
Another class of models

- Interaction between nucleons

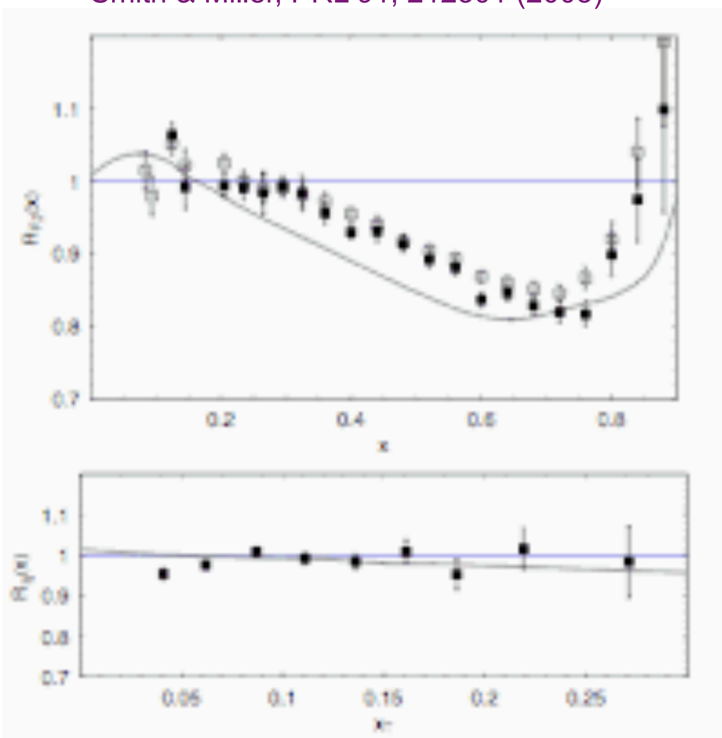
Model assumption:

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

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



Smith & Miller, PRL 91, 212301 (2003)

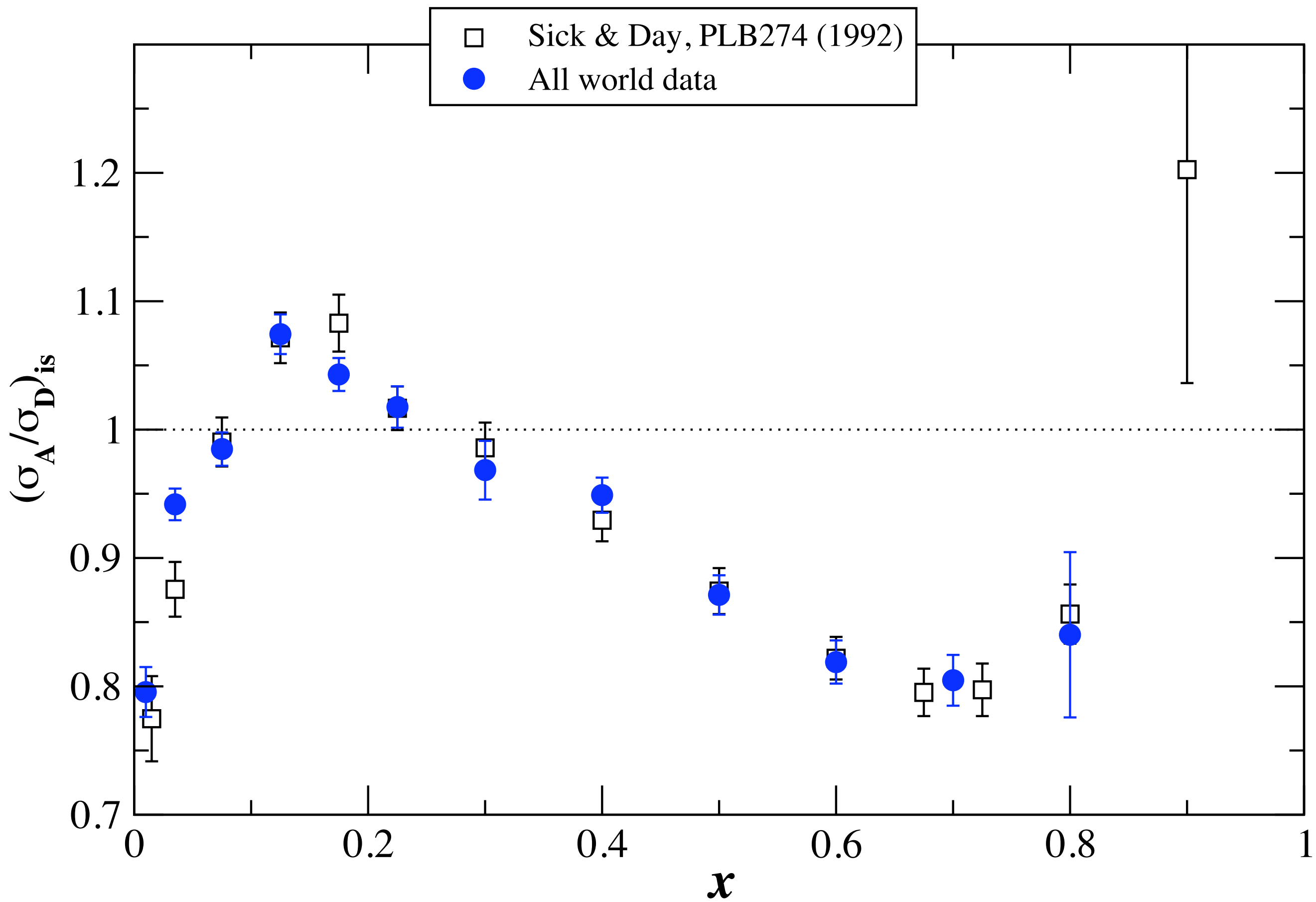


Model requirements:

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

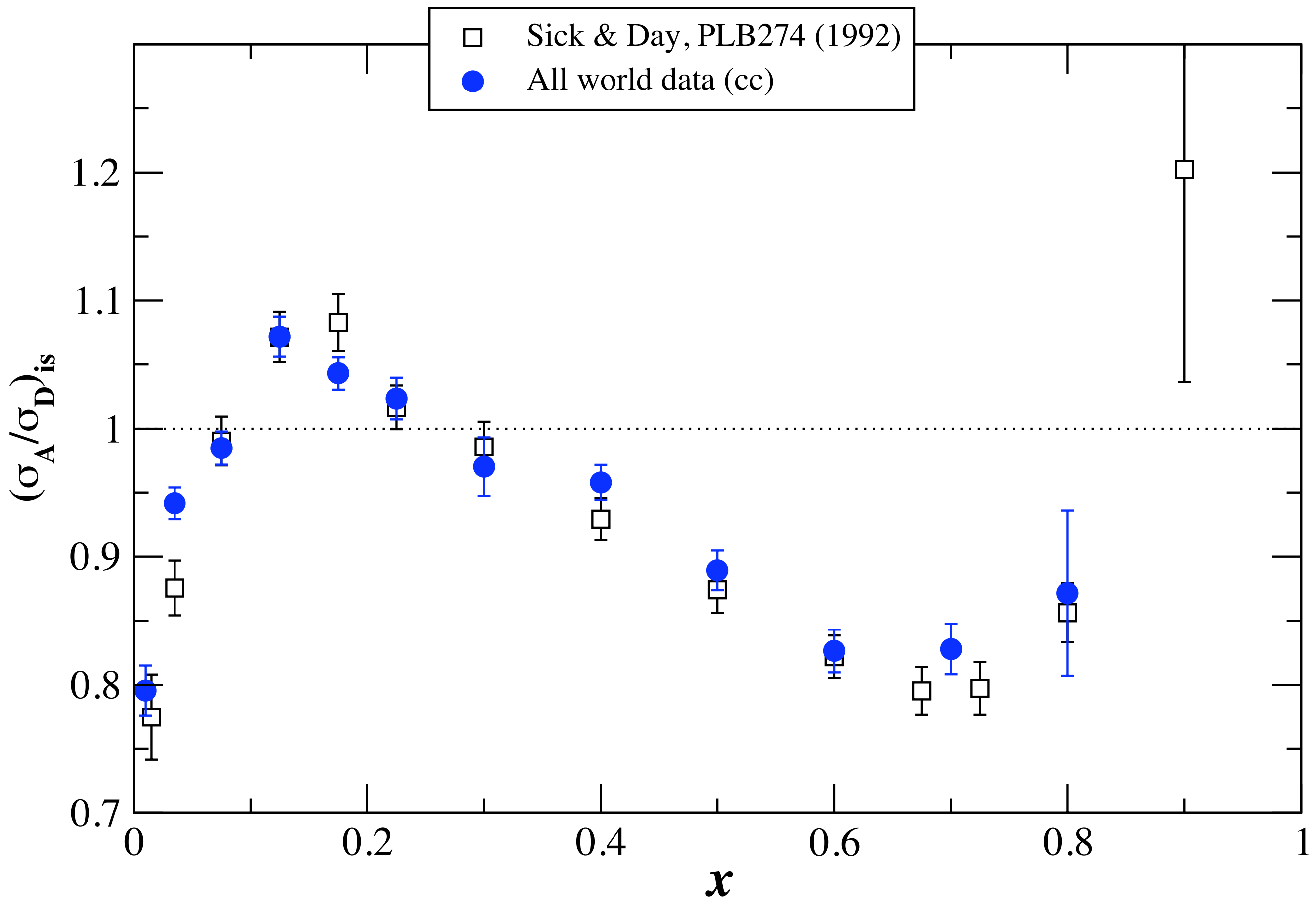
EMC effect in nuclear matter

No Coulomb corrections applied



EMC effect in nuclear matter

Coulomb corrections applied



EMC effect in nuclear matter

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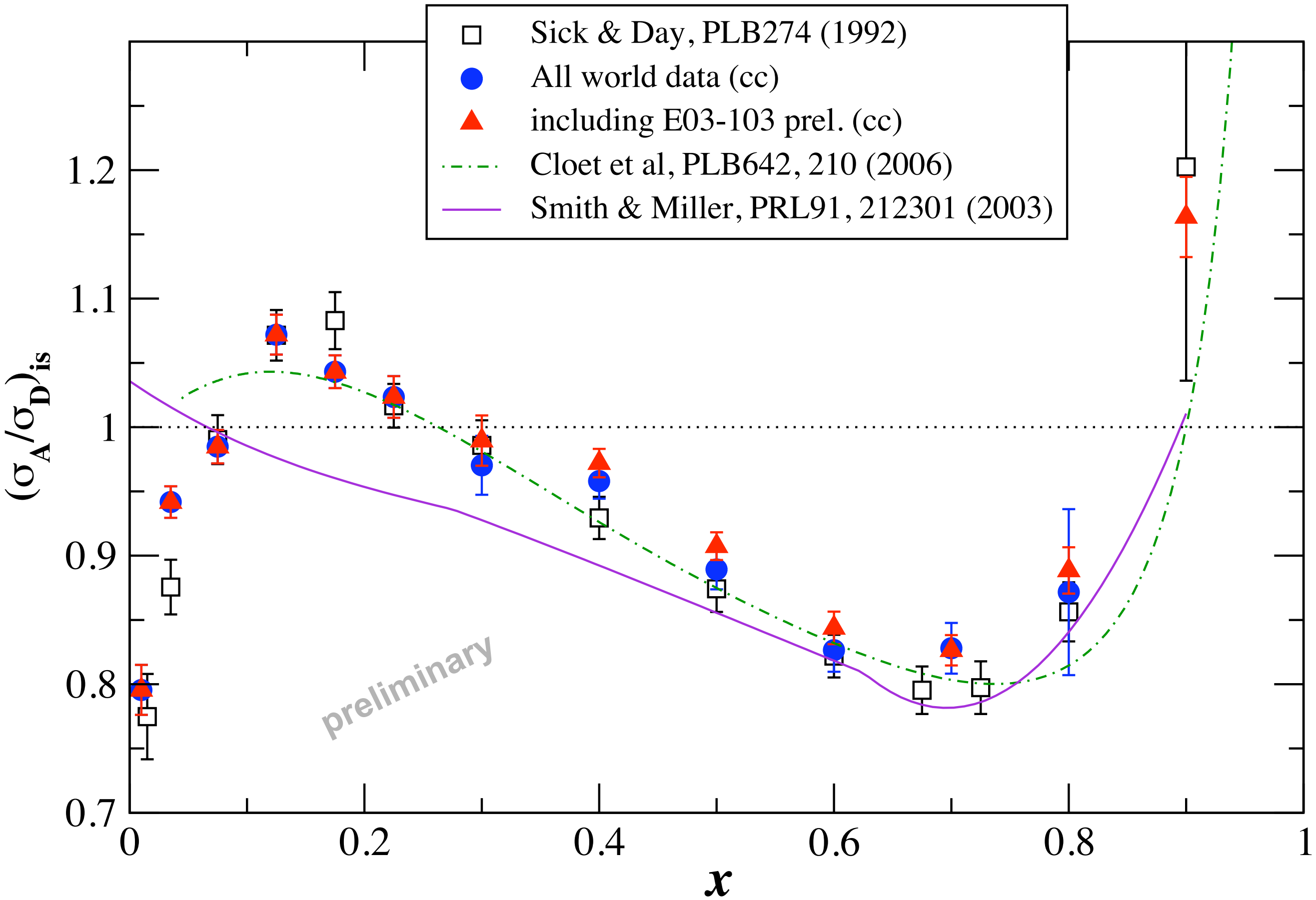
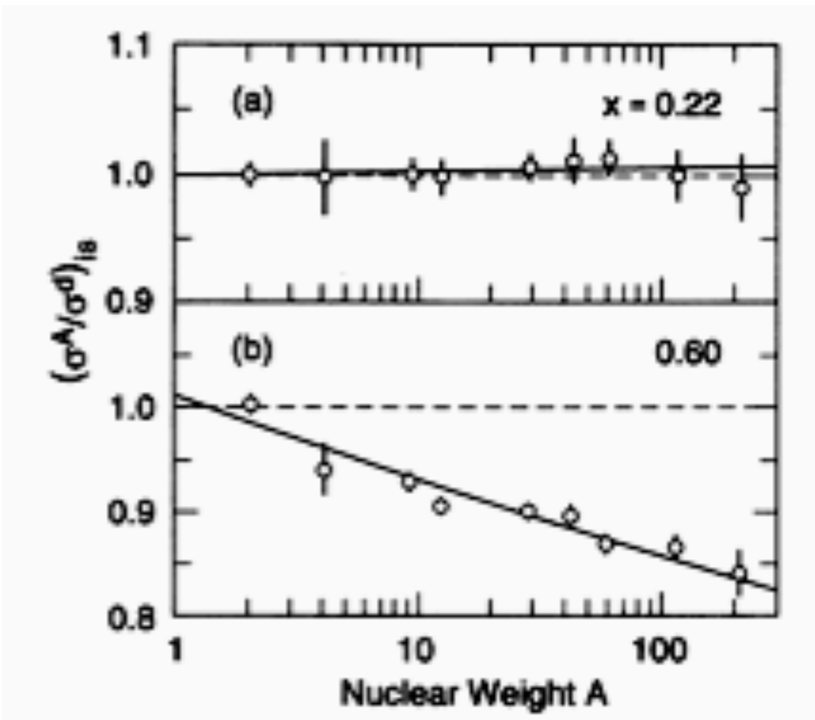


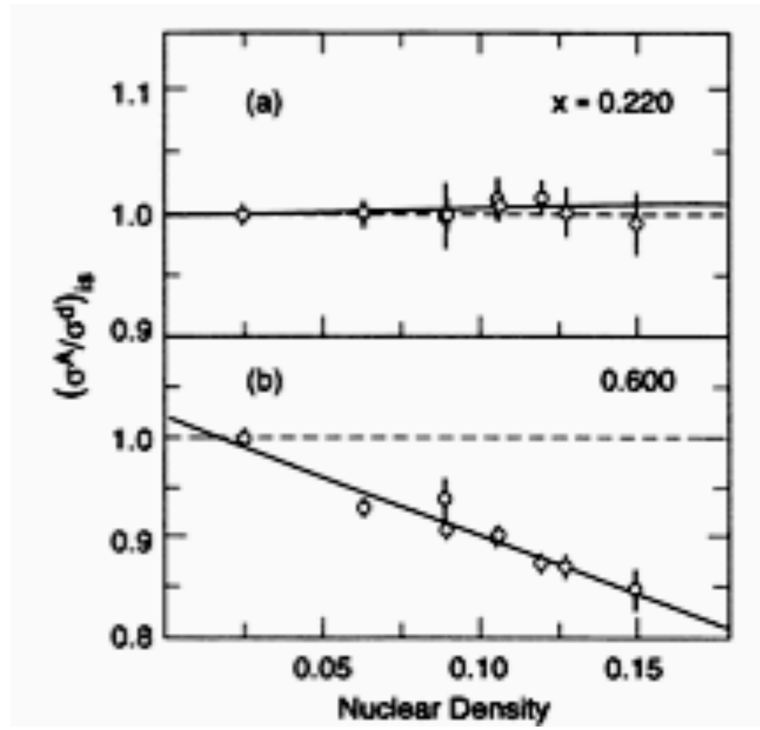
World data re-analysis

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

A or density dependence ?

Figs from J. Gomez, PRC49, 4348 (1994))

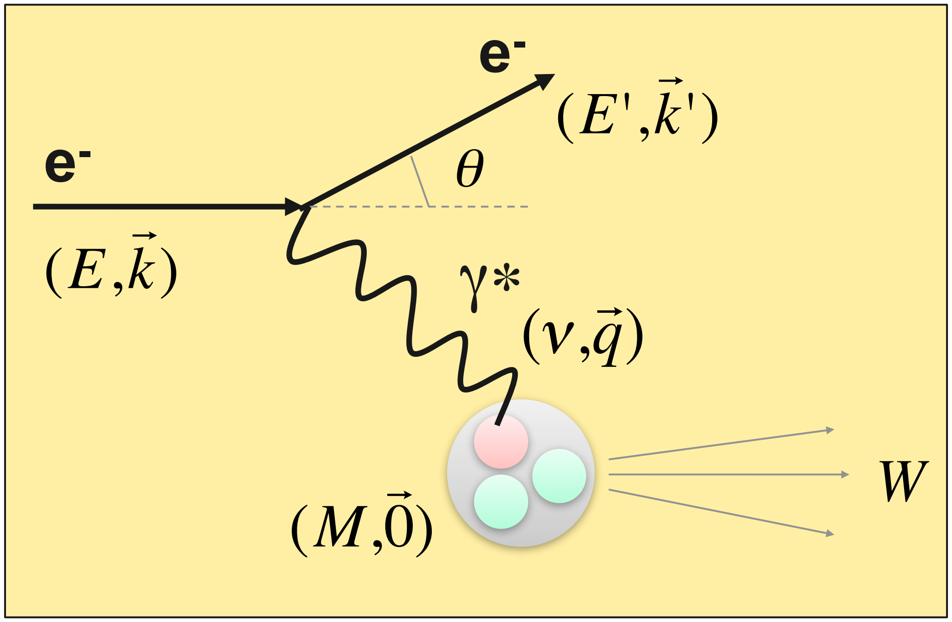




Density calculated assuming a uniform sphere of radius: $R_e\ (r=3A/4pR_e^{3})$

The structure of the nucleon

Deep inelastic scattering: probe the constituents of the nucleon, i.e. the quarks and the gluons



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

$$x = \frac{Q^2}{2M\nu}$$

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