Recent and Future Measurements of the EMC Effect with Inclusive Electron Scattering

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Exposing Novel Quark and Gluon Effects in Nuclei

April 16-20, 2018

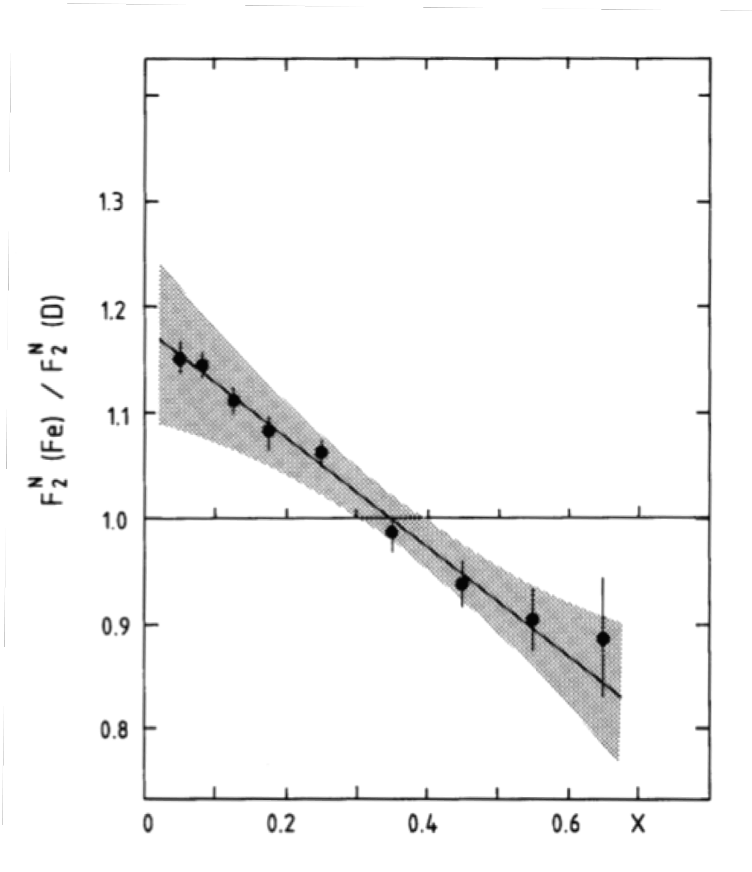
Outline

- Overview of EMC Effect Measurements
  - Discovery and dedicated measurements
  - Known properties of EMC effect from inclusive data
- Recent inclusive results from JLab
  - Local density dependence
  - EMC and SRC
  - Nuclear dependence of R?
- Open questions
  - Establish origin of EMC-SRC correlation
  - Flavor dependence of EMC effect
- Future measurements (interspersed)

EMC Effect approaches Middle Age

- The EMC Effect has been with us for 35 years
- While the source of intense experimental and theoretical study, we have not yet achieved consensus on the origin of this effect. Why?
  - Nuclear physics isn't simple: early calculations that attempted to incorporate "trivial" nuclear physics used simple pictures (mean field, no high-momentum wave function components)
  - Modern calculations can use better nucleon distributions, but it's unclear how to treat binding, off-shell effects
- In the end, we want to understand the EMC effect in terms of the fundamental constituents (quarks and gluons) – this is even harder since our picture of the free nucleon is incomplete
- Experimentalist's job: Gather as much information as possible to learn about general properties of EMC Effect, look for ties to other nuclear effects

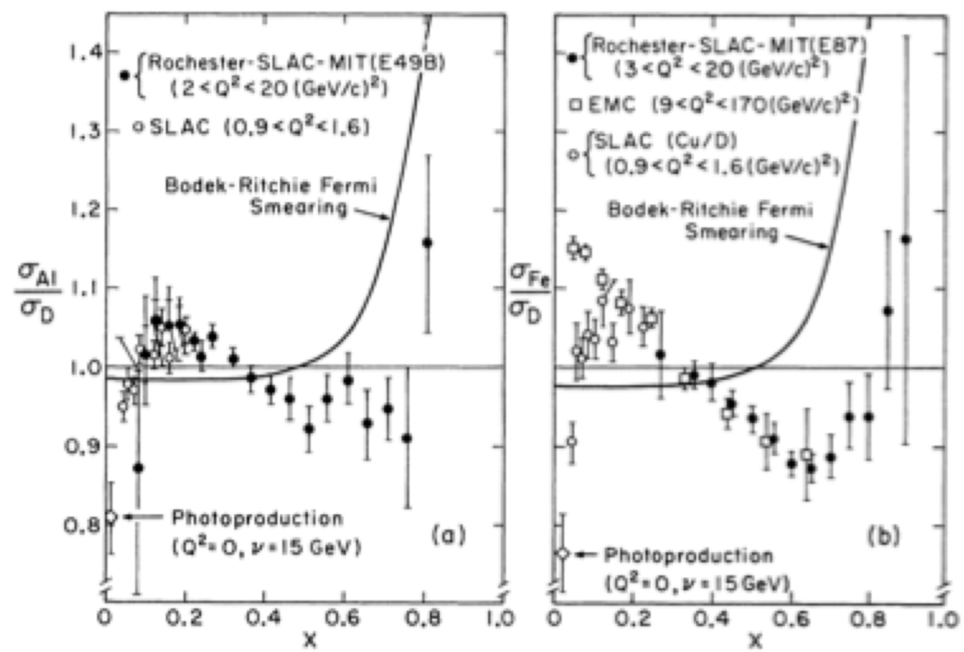
EMC Effect: Discovery and Confirmation



Aubert et al, Phys. Lett. B123, 275 (1983)

Original discovery by EMC collaboration
→ Rise observed at small x emphasizes potential pitfalls in making first measurement

Confirmation from "data mining" early SLAC data already hinted at important property of effect → minimal Q^2/energy dependence



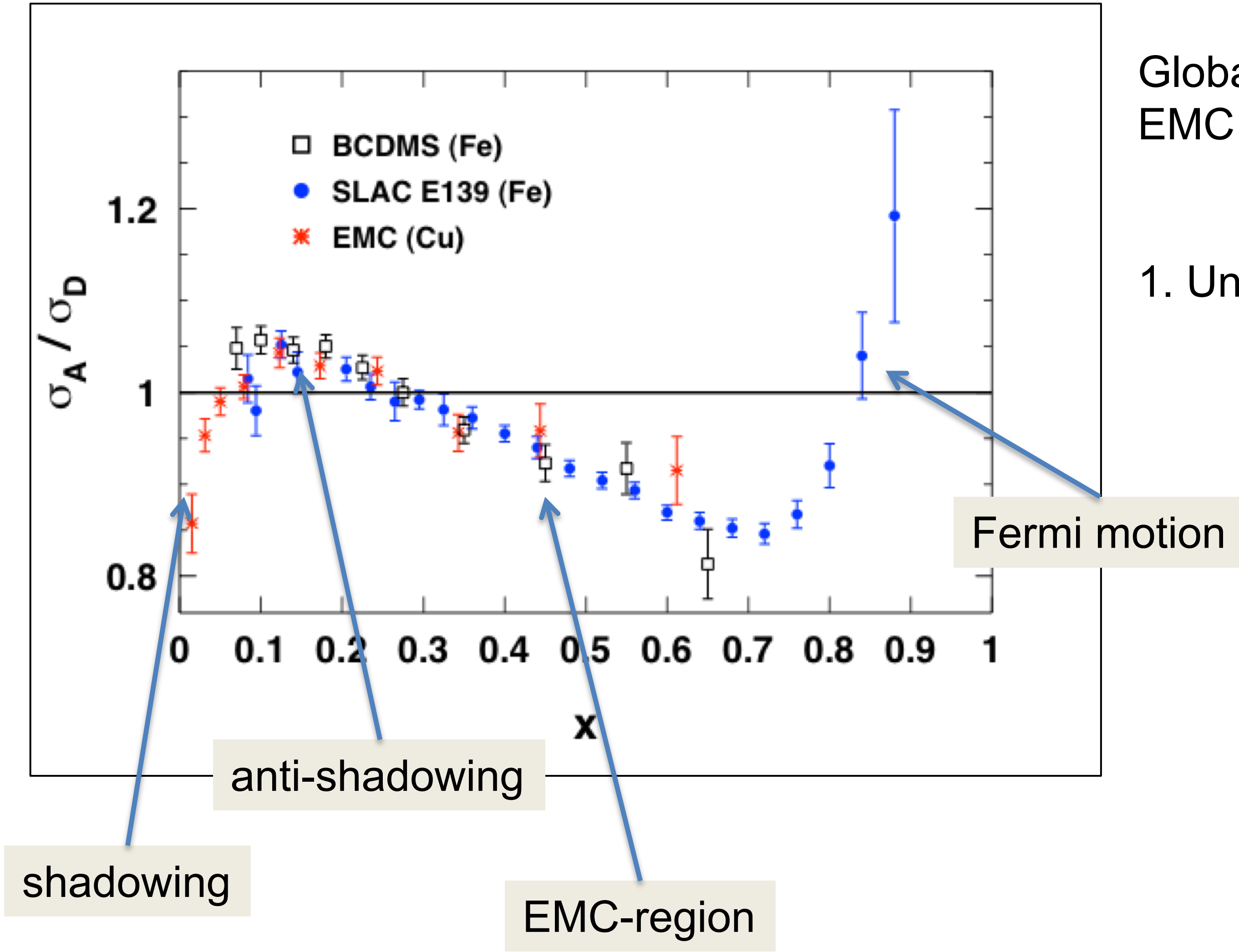
Bodek et al, PRL 50, 1431 (1983) and PRL 51, 534 (1983)

EMC Effect Measurements

Laboratory/collaboration	Beam	Energy (GeV)	Target	Year
SLAC E139	e	8-24.5	***D***, ^{4}He, Be, C, Ca, Fe, Ag, Au	1994,1984
SLAC E140	e	3.75-19.5	***D***, Fe, Au	1992,1990
CERN NMC	μ	90	***^{6}Li***, ^{12}C, ^{40}Ca	1992
	μ	200	***D***, ^{4}He, C, Ca	1991, 1995
	μ	200	Be, ***C***, Al, Ca, Fe, Sn, Pb	1996
CERN BCDMS	μ	200	***D***, Fe	1987
	μ	280	***D***, N, Fe	1985
CERN EMC	μ	100-280	***D***, Cu	1993
	μ	280	***D***, C, Ca	1988
	μ	100-280	***D***, C, Cu, Sn	1988
	μ	280	H, ***D***, Fe	1987
	μ	100-280	***D***, Fe	1983
FNAL E665	μ	490	***D***, Xe	1992
	μ	490	***D***, Xe	1992
DESY HERMES	e	27	***D***, ^{3}He, N, Kr	2000, 2003
Jefferson Lab	e	6	***D***, ^{3}He, ^{4}He, Be, C, Cu, Au	2009
	e	6	***D***, C, Cu, Au	2004 (thesis)

Geesaman, Saito, and Thomas, Ann. Rev. Nucl. Sci. 45, 337 (1995) – updated

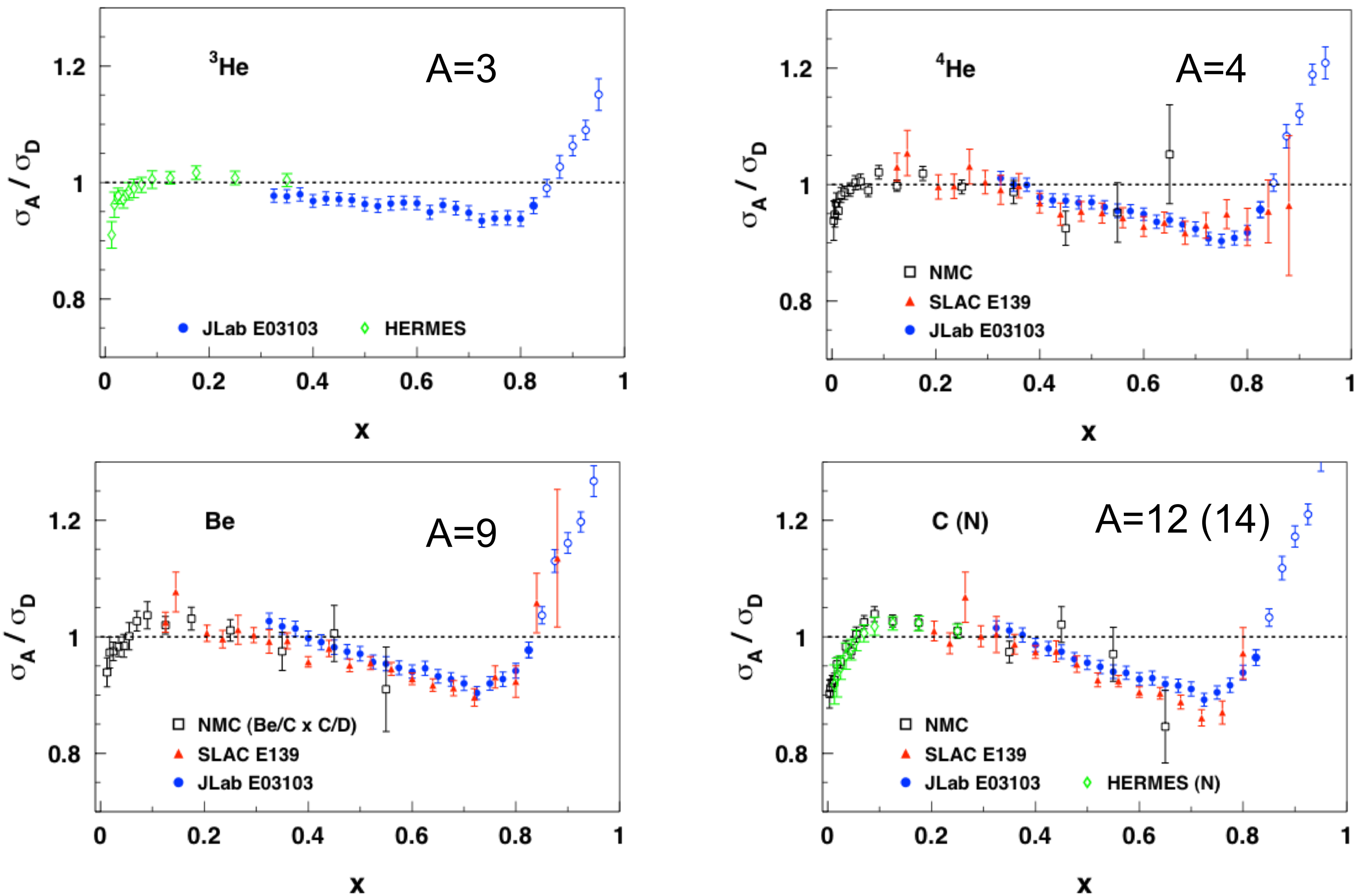
Properties of the EMC Effect



Global properties of the EMC effect

1. Universal x-dependence

x Dependence



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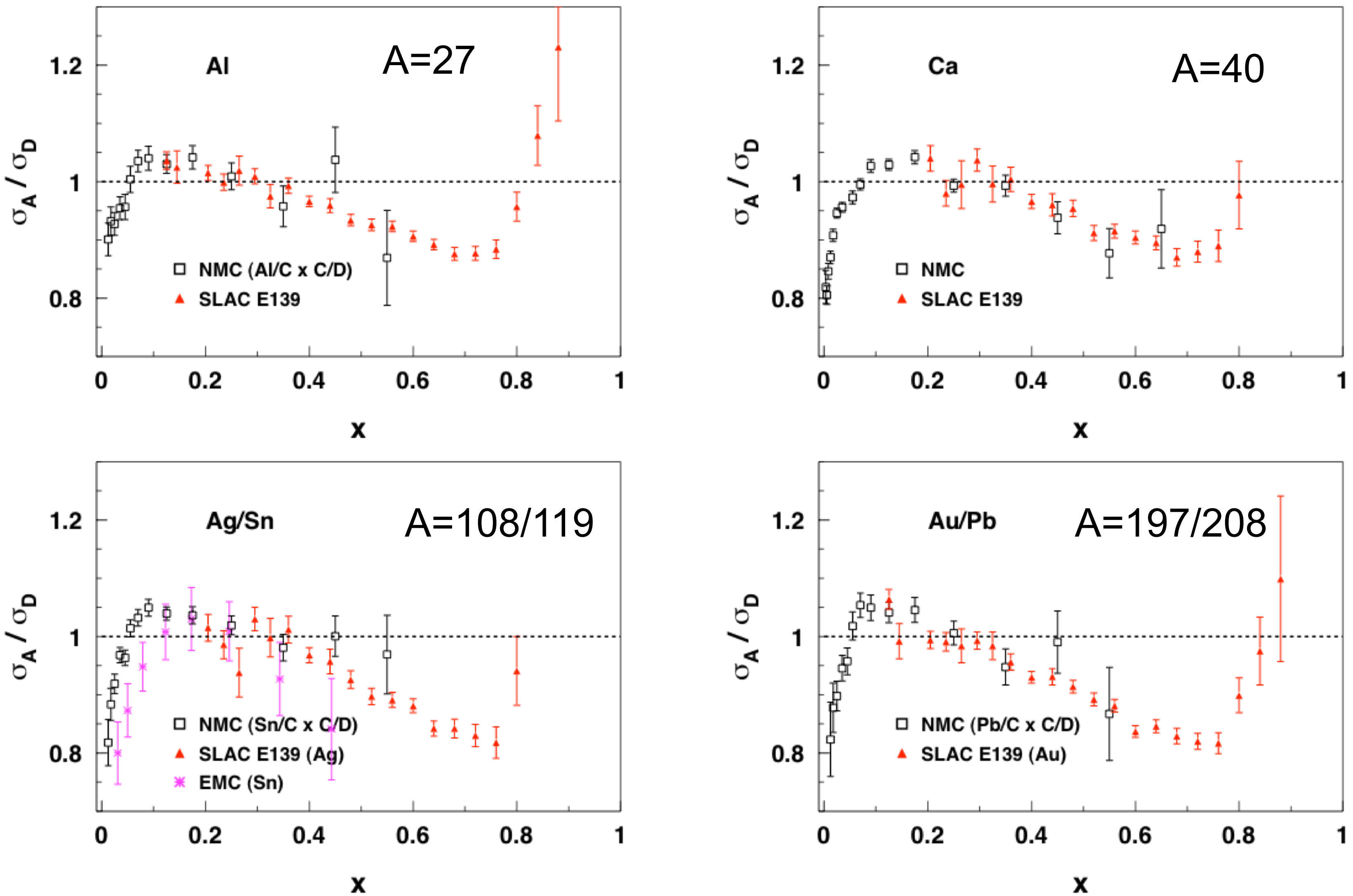
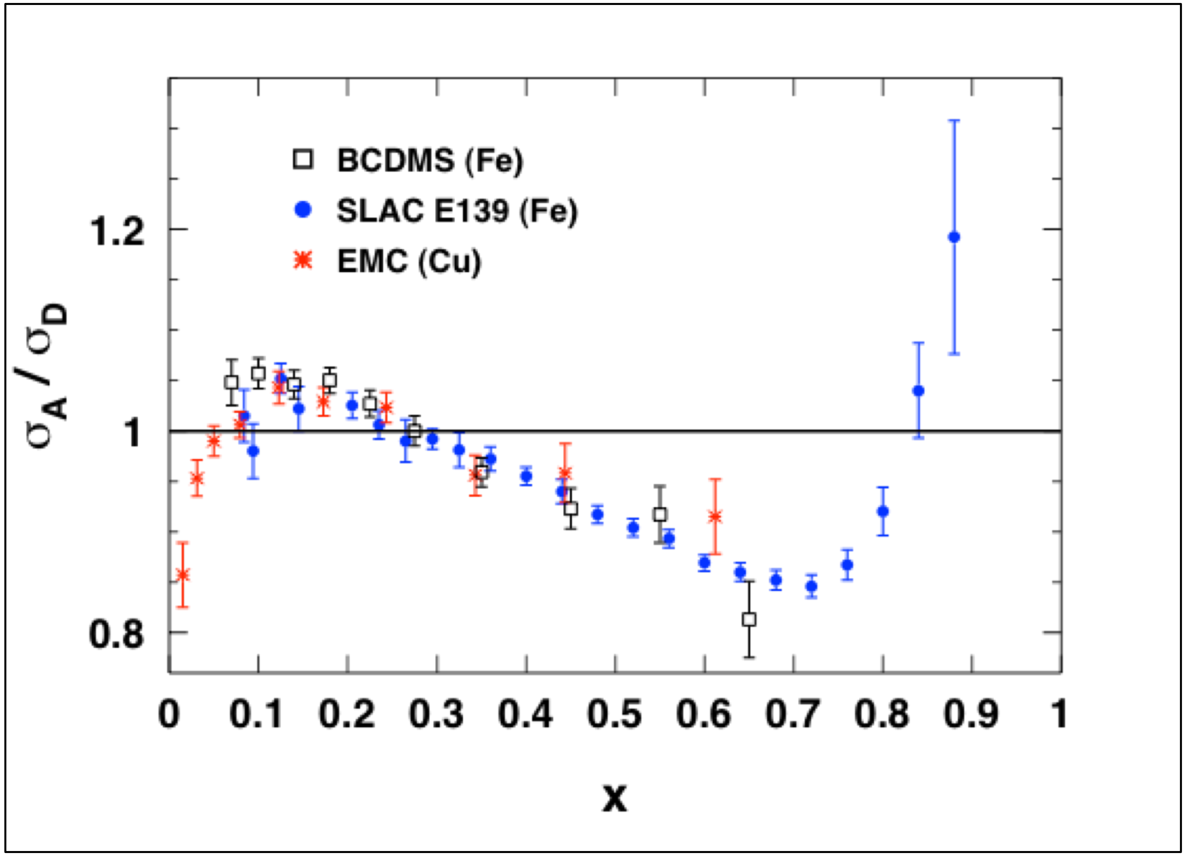
x Dependence



Properties of the EMC Effect



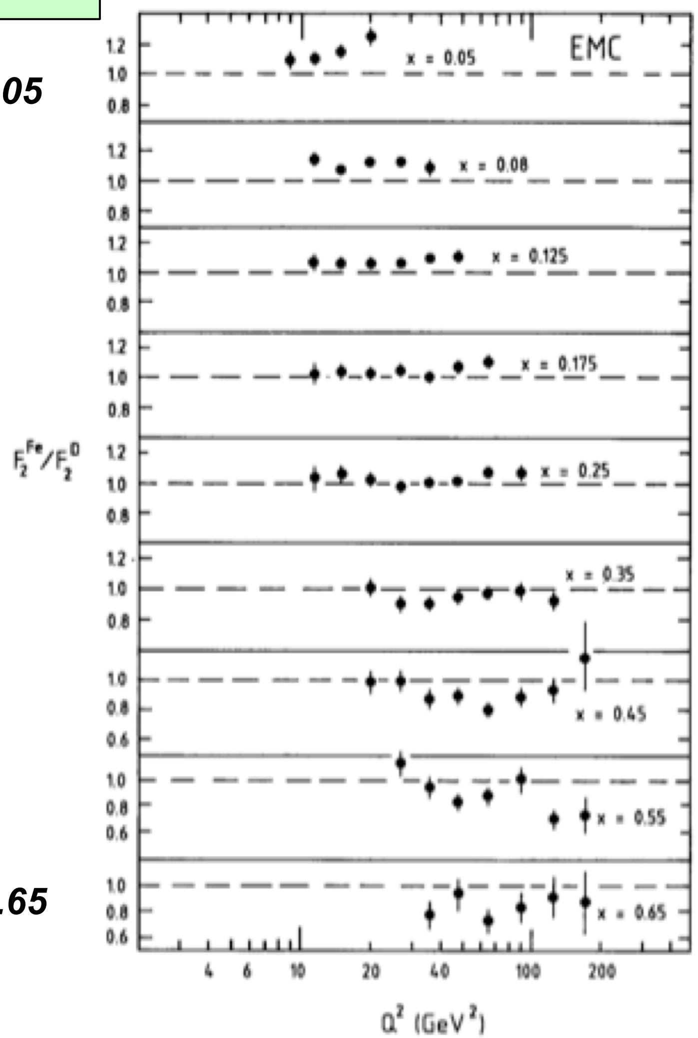
Global properties of the EMC effect

1. Universal x-dependence
2. Little Q^2 dependence*

Q^2 Dependence of the EMC Effect

EMC Q^2=10-200 GeV^2

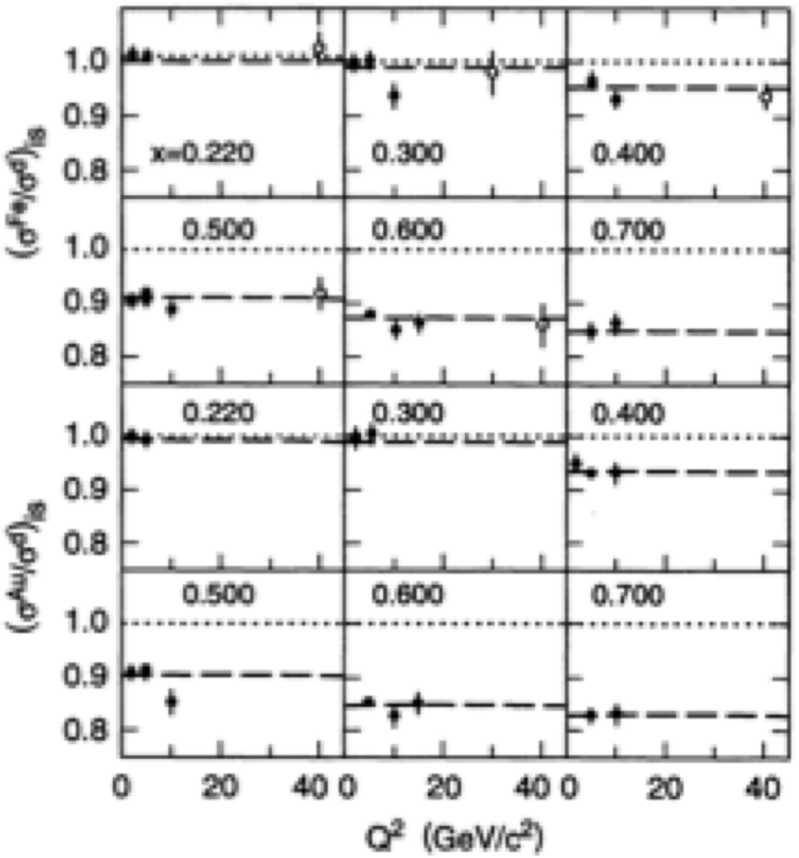
x=0.05



x=0.65

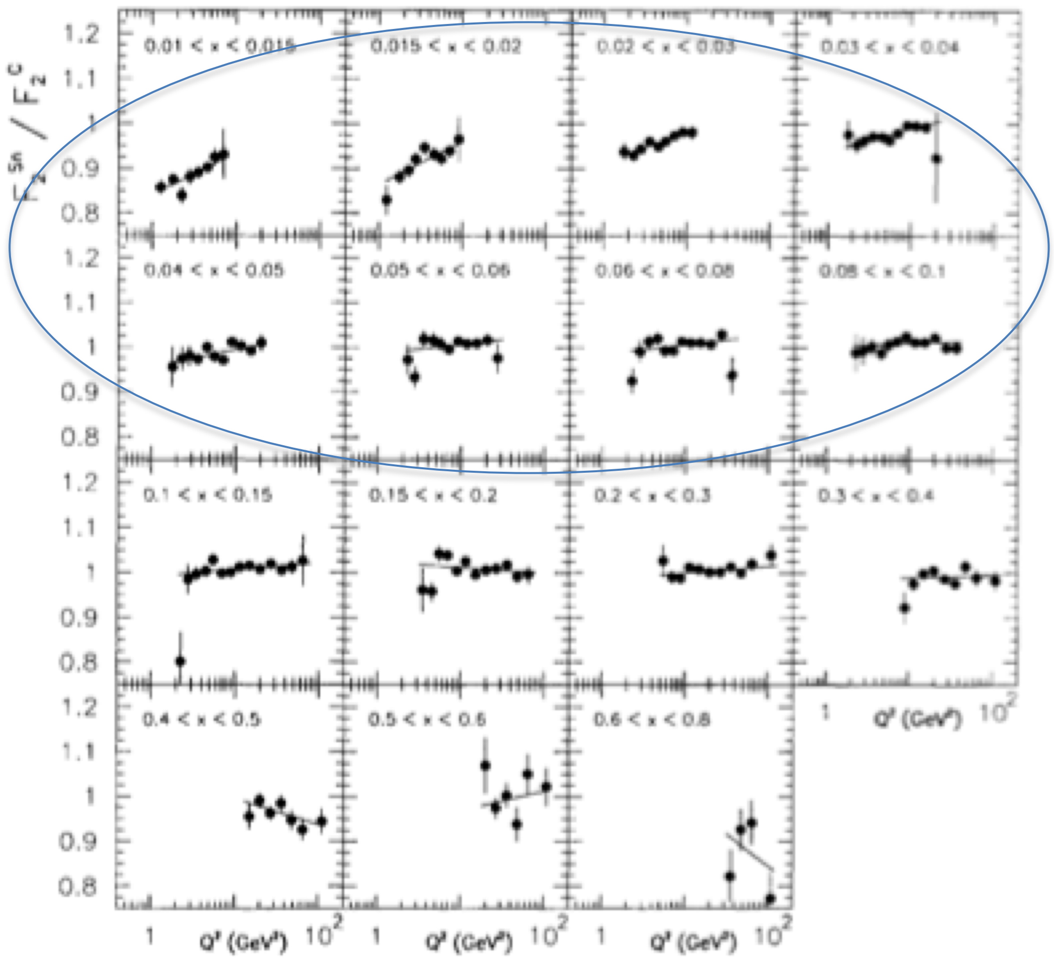
Aubert et al, Nucl. Phys. B293, 740 (1987)

SLAC E139 Q^2=1-10 GeV^2



Gomez et al, Phys. Rev. D 49, 4348 (1994)

(*) Q^2 Dependence of Sn/C



NMC measured non-zero Q^2 dependence in Sn/C ratio at low x

→ This result is in some tension with other NMC C/D and HERMES Kr/D results

Arneodo et al, Nucl. Phys. B 481, 23 (1996)

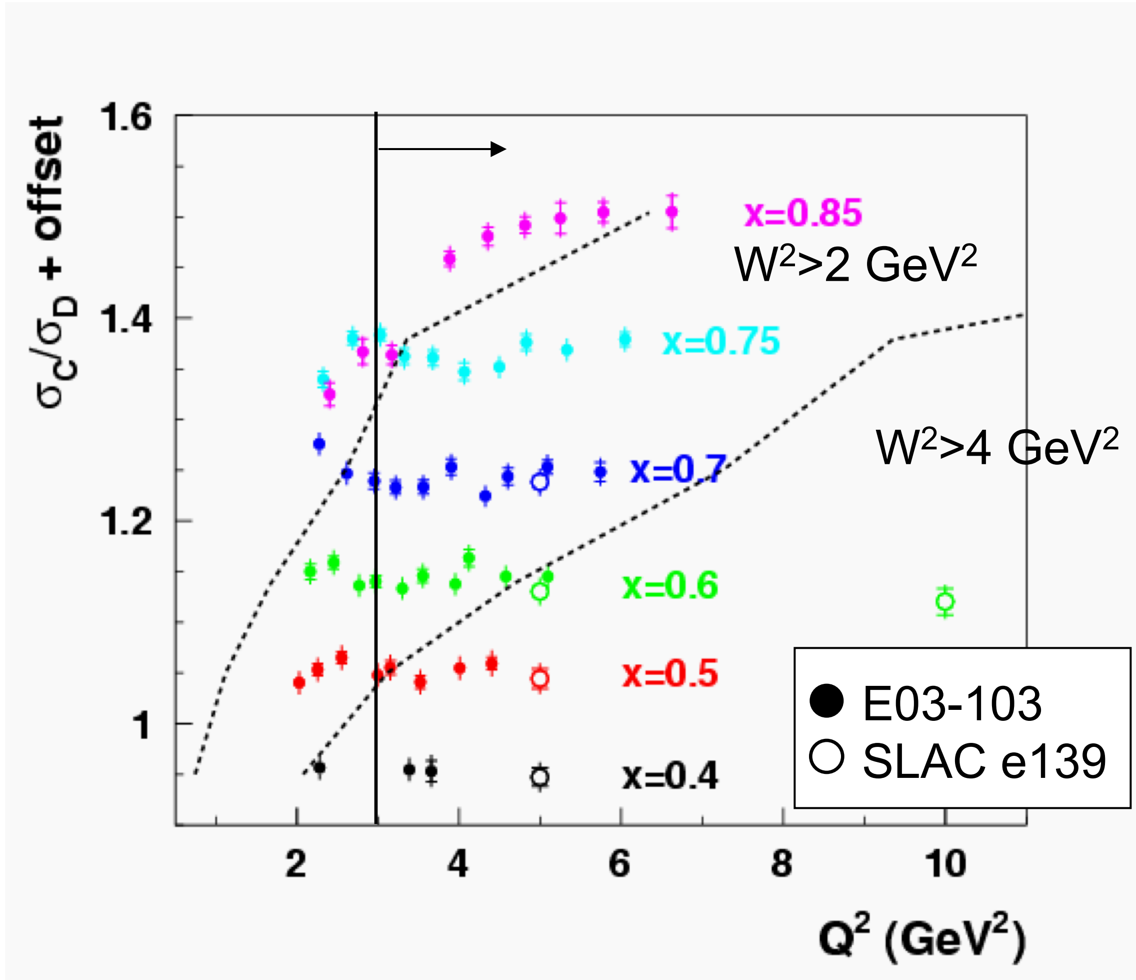
Q^2 Dependence at Large x, Low W

JLab found A/D ratios independent of Q^2 to surprisingly low W

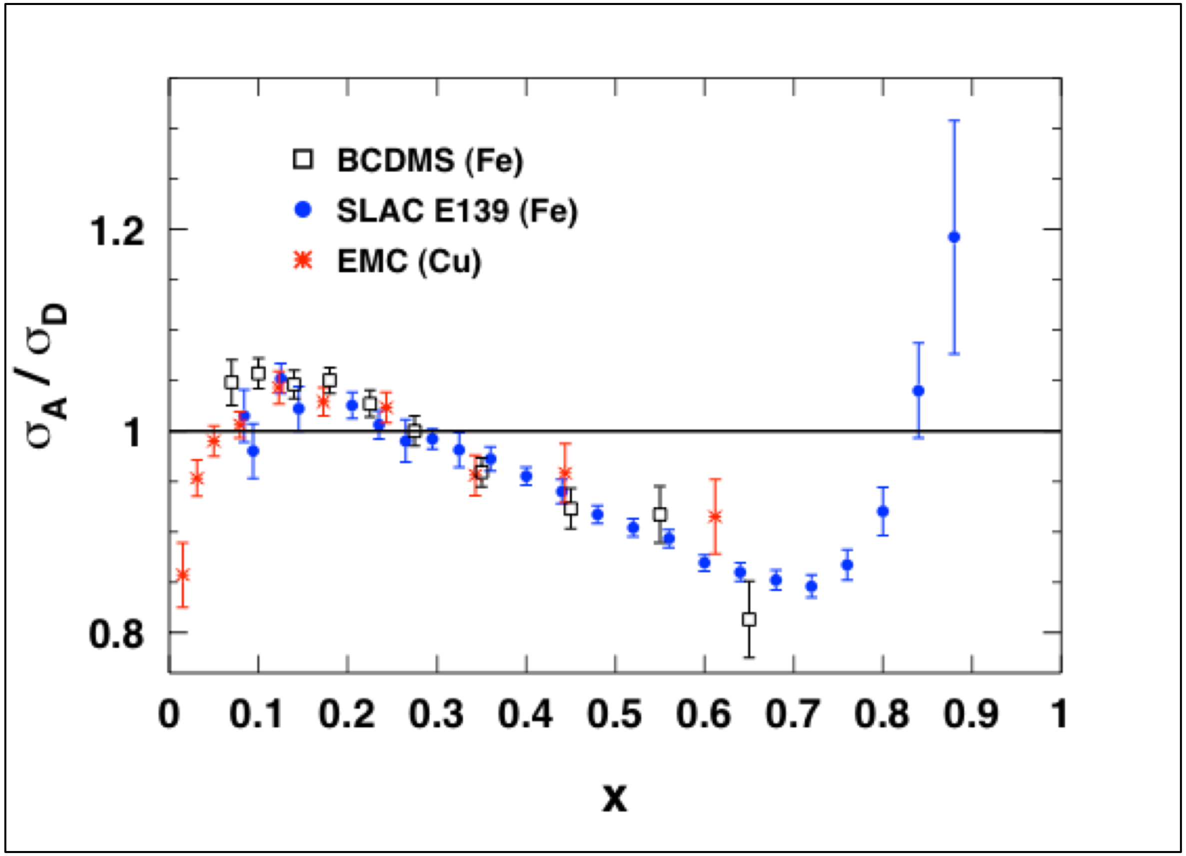
C/D ratios at fixed x are Q^2 independent for

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

For E03-103, this extends to x=0.85



Properties of the EMC Effect

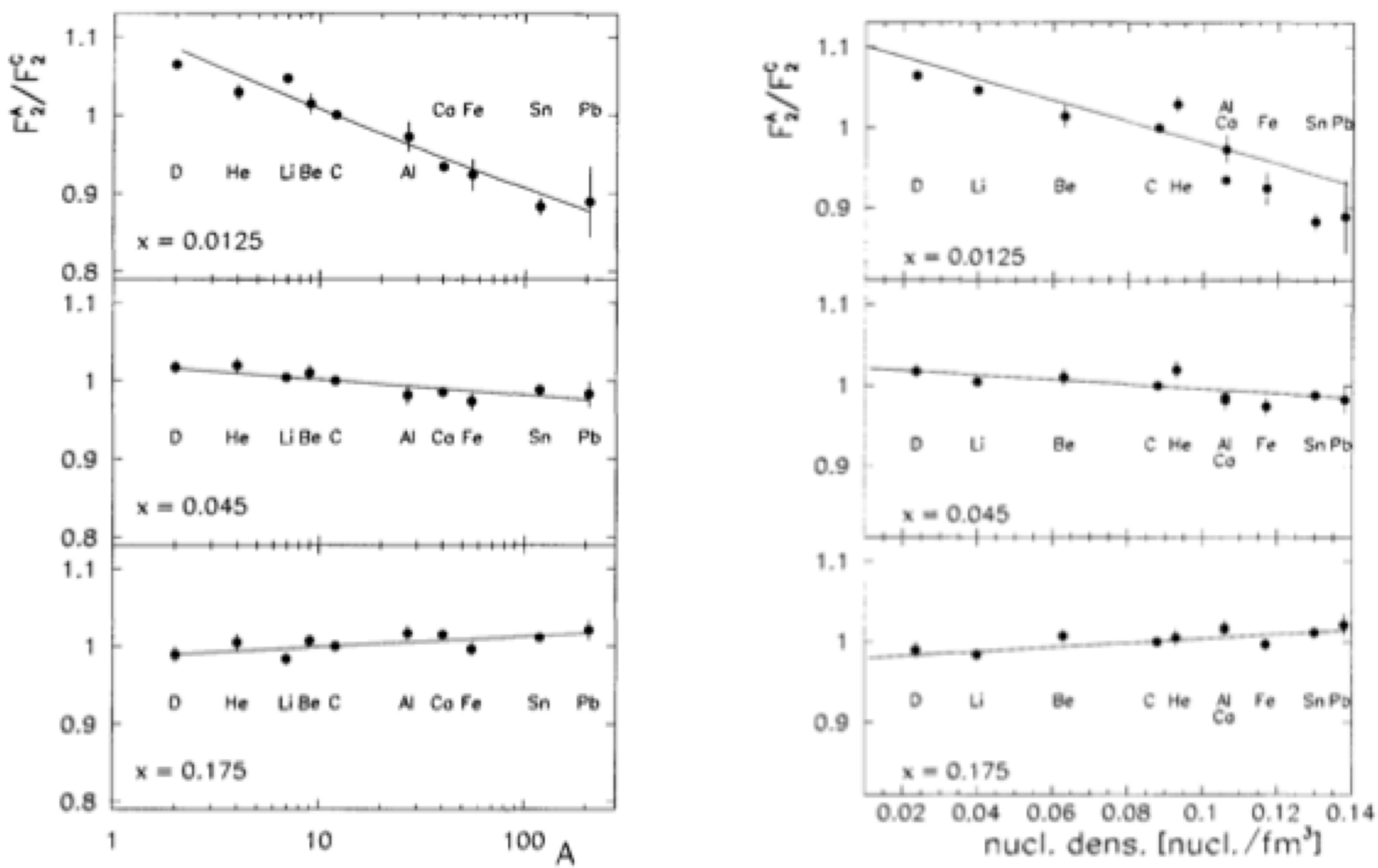


Global properties of the EMC effect

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

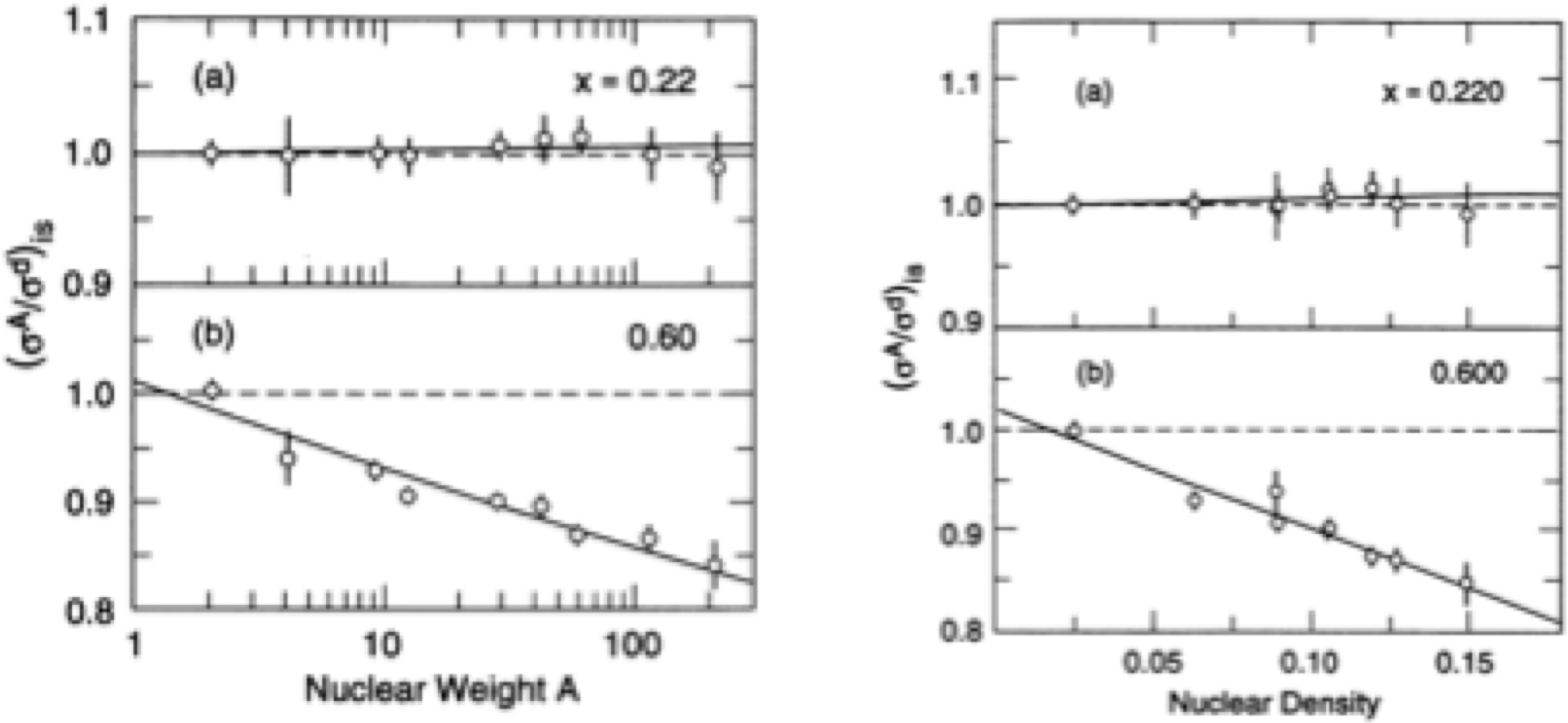
→ *Anti-shadowing region shows little nuclear dependence*

A-Dependence of EMC Effect



NMC: *Arneodo et al, Nucl. Phys. B 481, 3 (1996)*

A-Dependence of EMC Effect



$\rho=3A/4\pi R_e^3$ $\quad R_e^2=5\langle r^2\rangle/3$

$<r^2>$=RMS electron scattering radius

SLAC E139: *Gomez et al, PRD 49, 4348 (1992)*

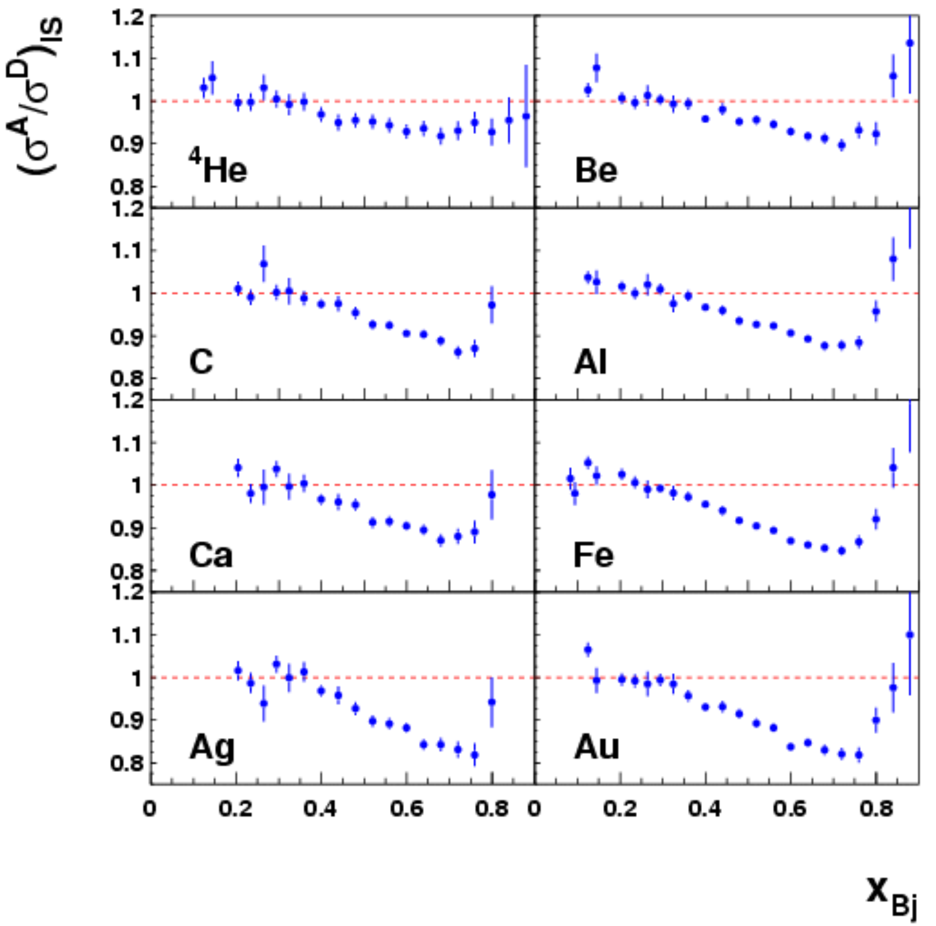
EMC Effect Measurements at Large x

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

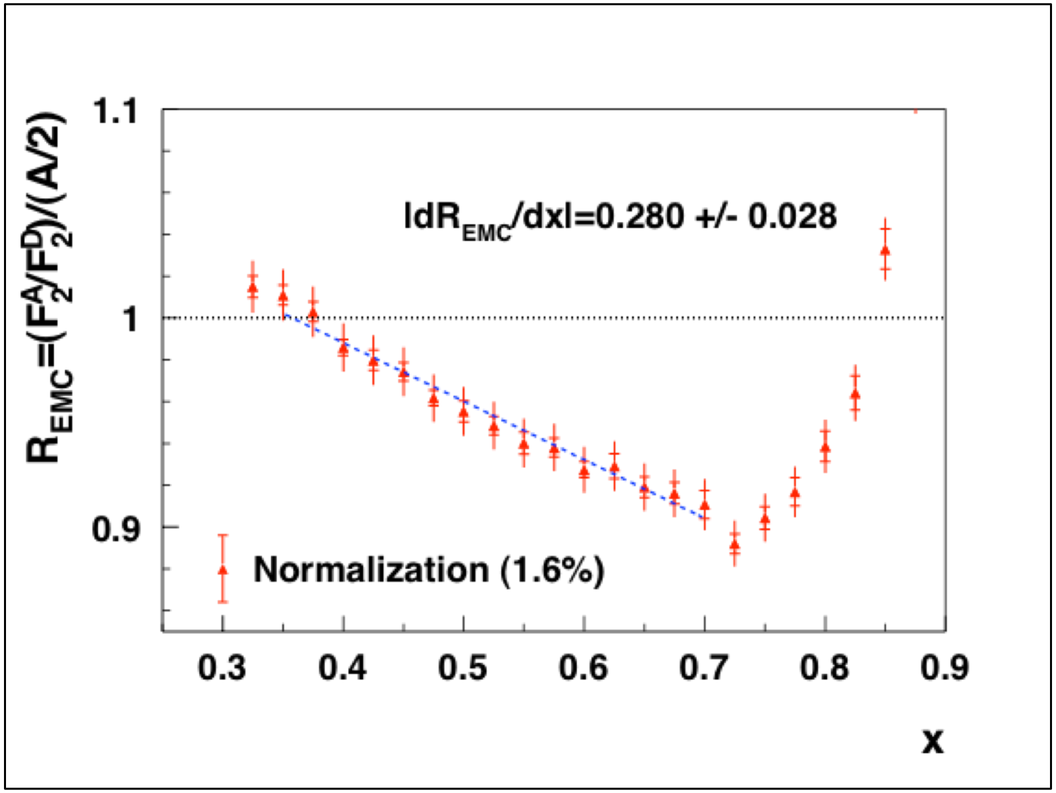
Building on the SLAC data
→ Higher precision data for ^{4}He
→ Addition of ^{3}He
→ Precision data at large *x*

SLAC E139



JLab E03103

E03103 in Hall C at Jefferson Lab ran Fall 2004
→ Measured EMC ratios for light nuclei (^{3}He, ^{4}He, Be, and C)
→ Results consistent with previous world data
→ Examined nuclear dependence a la E139



New definition of "size" of the EMC effect
→Slope of line fit from x=0.35 to 0.7

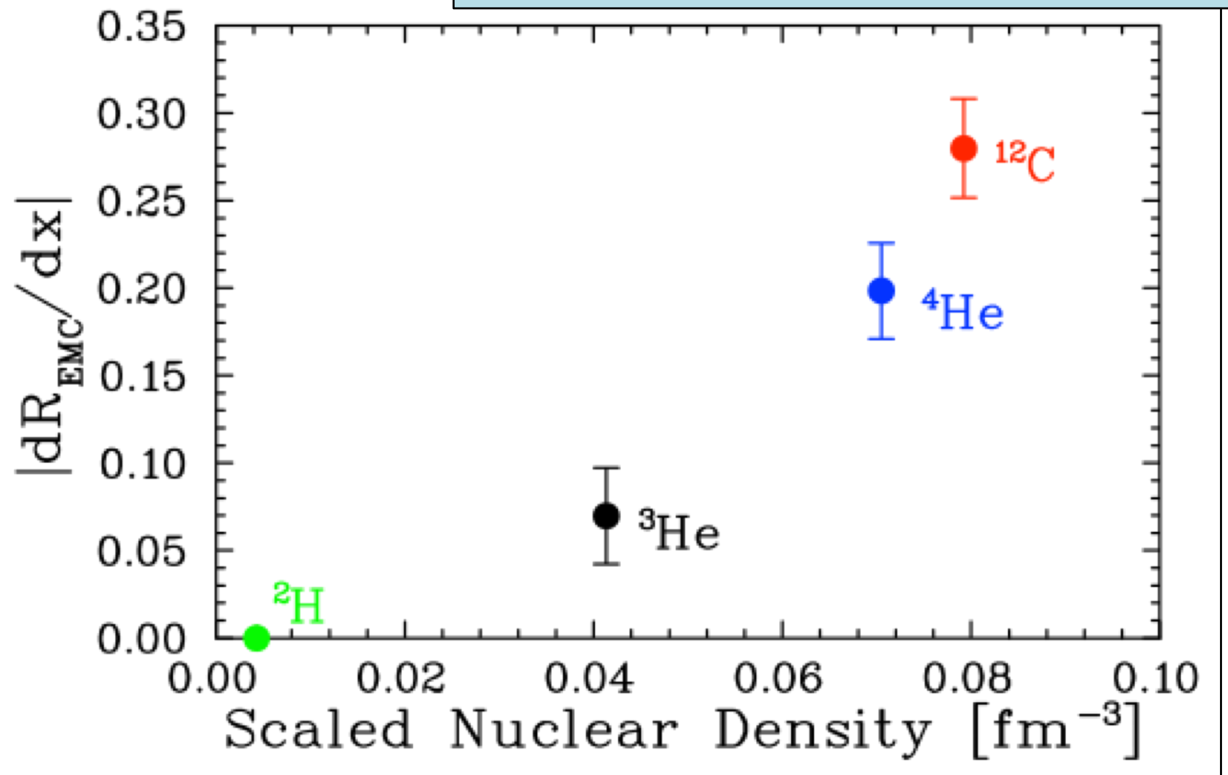
Definition assumes shape of the EMC effect is universal for nuclei
→Data *not inconsistent* with this assumption
→ Normalization errors mean we can only confirm this at 1-1.5% level

JLab E03103 Results

E03103 measured σ_A/σ_D for ^{3}He, ^{4}He, Be, C

→ ^{3}He, ^{4}He, C, EMC effect scales well with density

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



Scaled nuclear density = *(A-1)/A <ρ>*
→ remove contribution from struck nucleon

<ρ> from ab initio few-body calculations

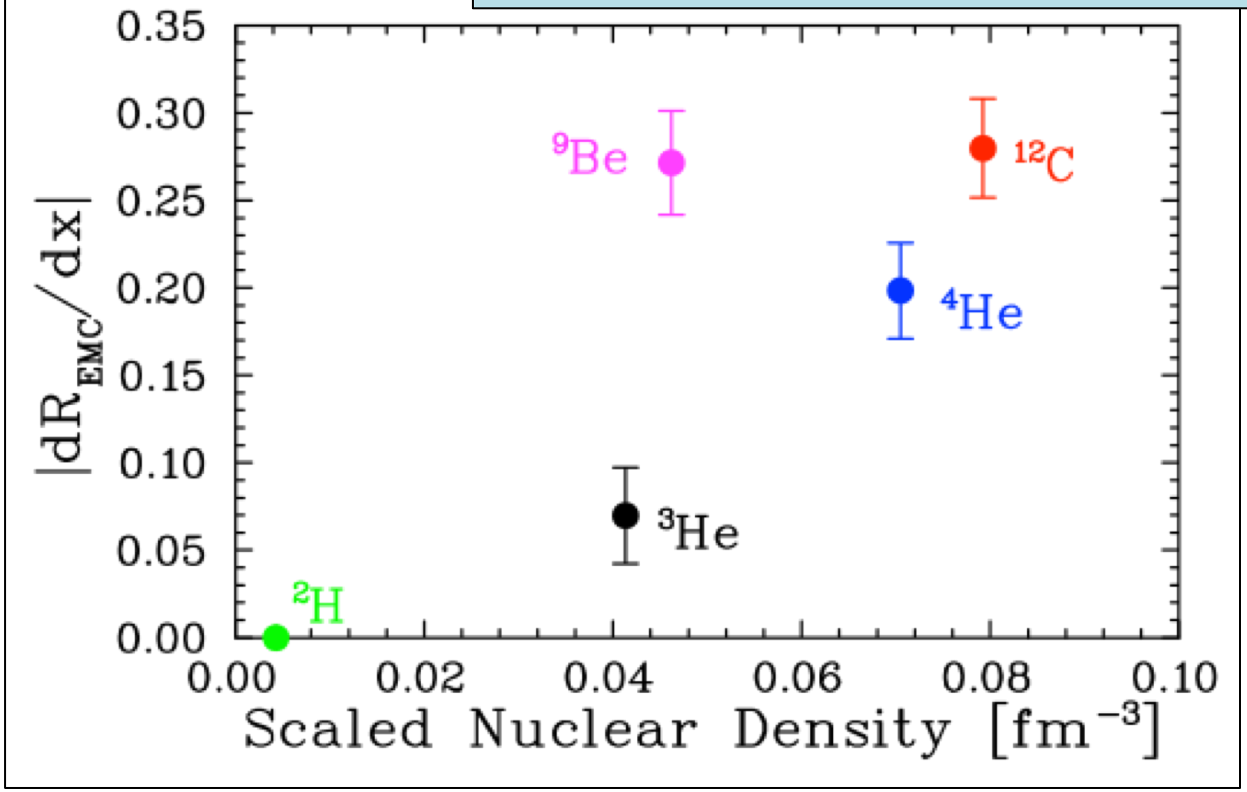
→ ***[S.C. Pieper and R.B. Wiringa**, Ann. Rev. Nucl. Part. Sci 51, 53 (2001)]*

JLab E03103 Results

E03103 measured σ_A/σ_D for ^3He, ^4He, Be, C

→ ^3He, ^4He, C, EMC effect scales well with density
→ Be does not fit the trend

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



Scaled nuclear density = *(A-1)/A <ρ>*
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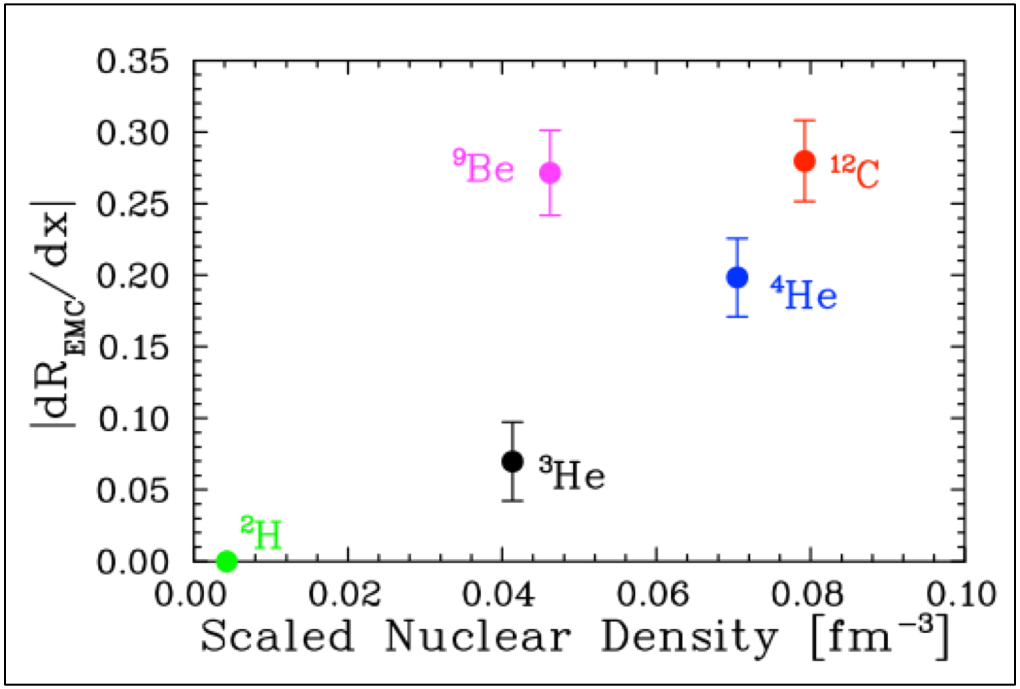
<ρ> from ab initio few-body calculations

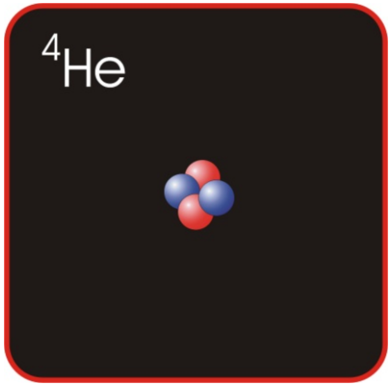
→ ***[S.C. Pieper and R.B. Wiringa**, Ann. Rev. Nucl. Part. Sci 51, 53 (2001)]*

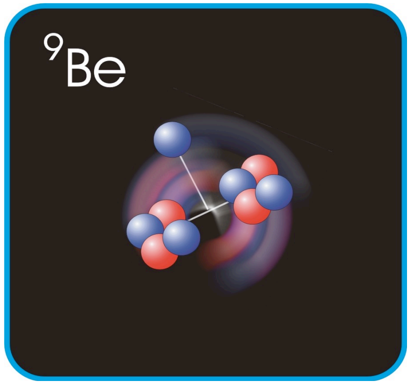
EMC Effect and Local Nuclear Density

^{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

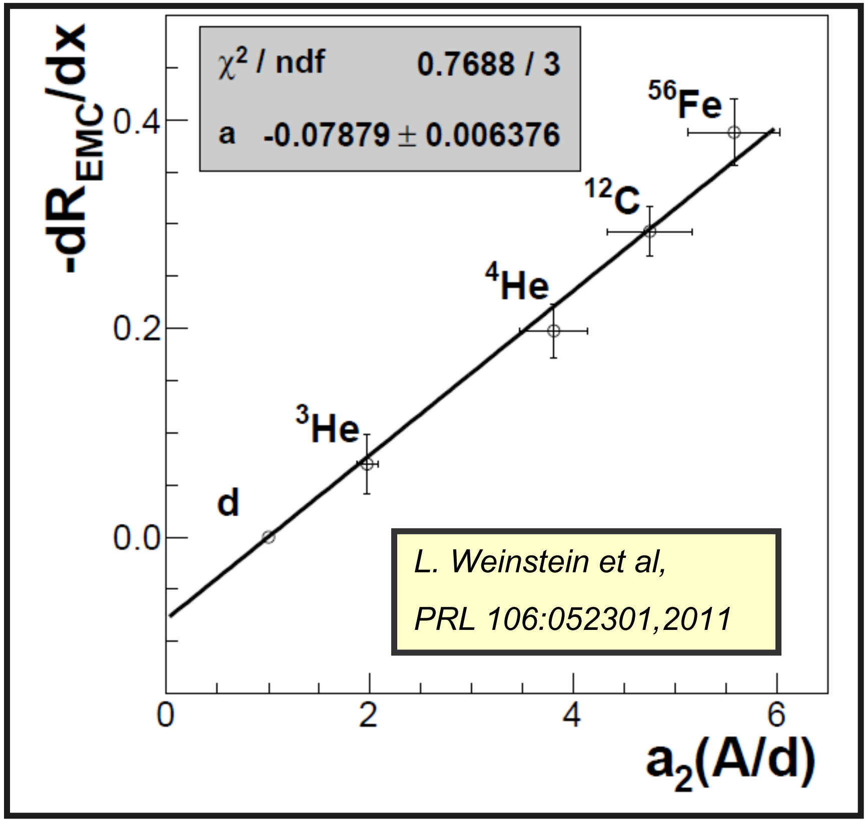






"Local density" is appealing in that it makes sense intuitively – can this be tied to other observables?

EMC Effect and Short Range Correlations

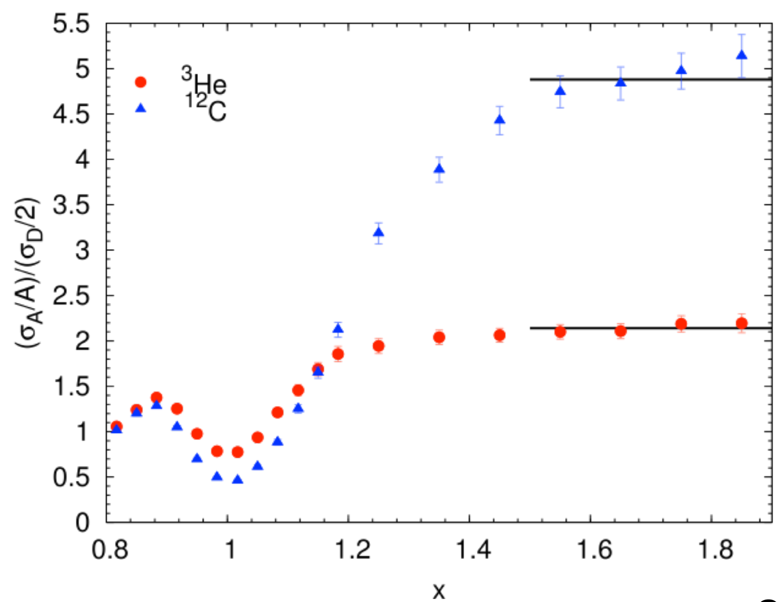


Weinstein *et al* observed linear correlation between size of EMC effect and Short Range Correlation "plateau"

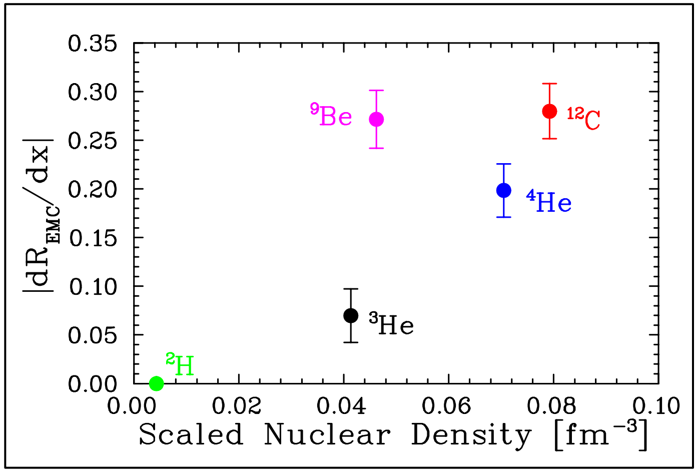
→Observing Short Range Correlations requires measurements at $x>1$

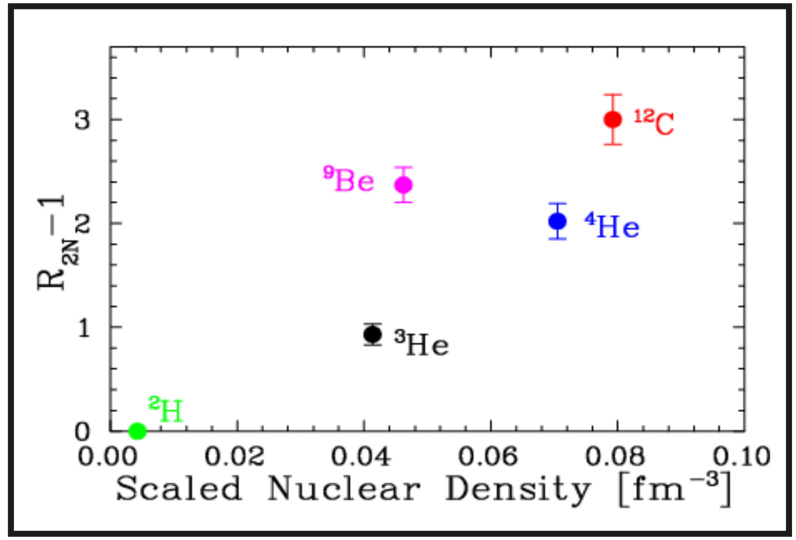
→ Reaction dynamics very different – DIS vs. QE scattering, why the same nuclear dependence?

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

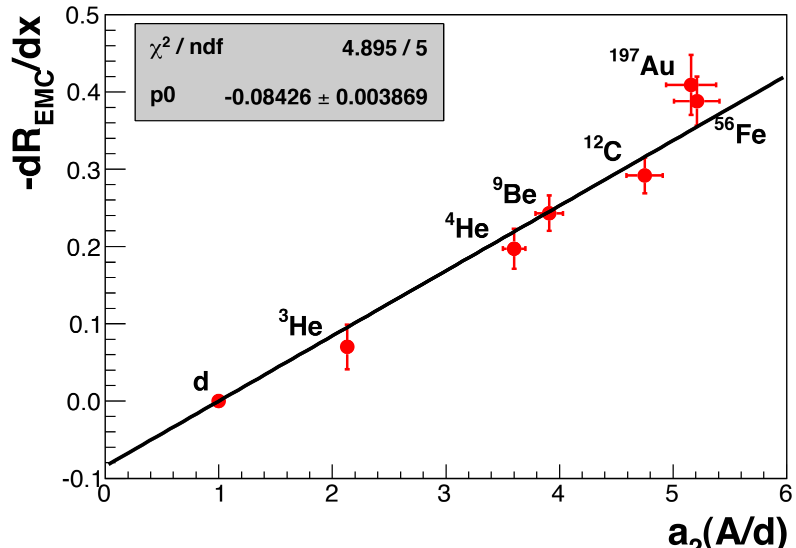


EMC Effect and SRC





EMC-SRC connection became more intriguing with the addition of Be SRC data
→ Both EMC and SRC display similar dependence on nuclear density



O. Hen et al, Phys.Rev. C85 (2012) 047301

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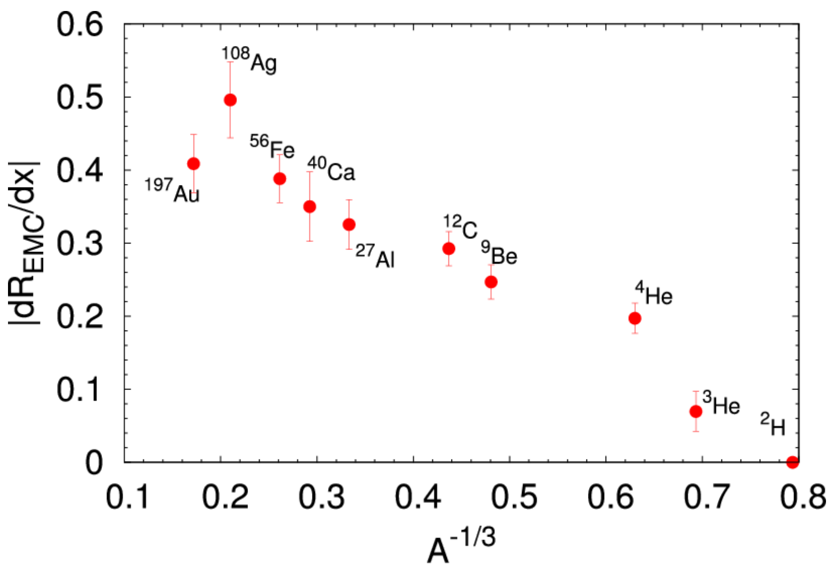
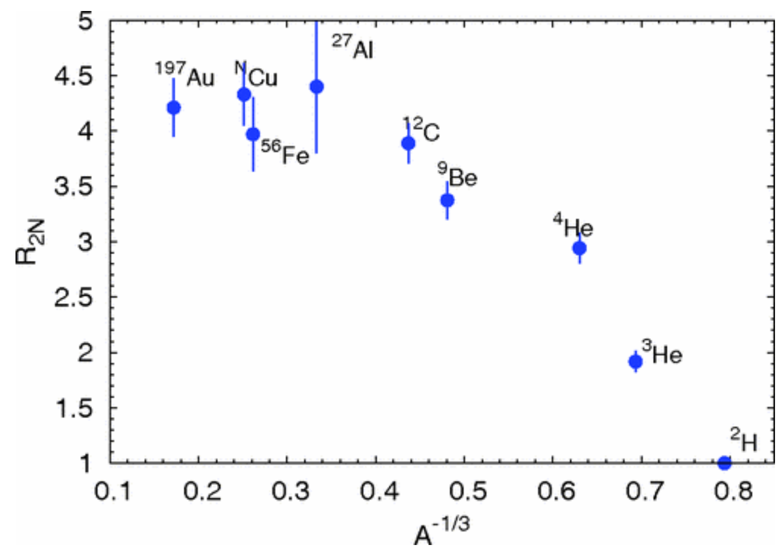
Nuclear Dependence of EMC and SRCs

Interesting to look for common independent variable that is correlated with both EMC Effect and SRCs

→ Various combinations of A-dependence
→ Average nuclear density
→ Separation energy

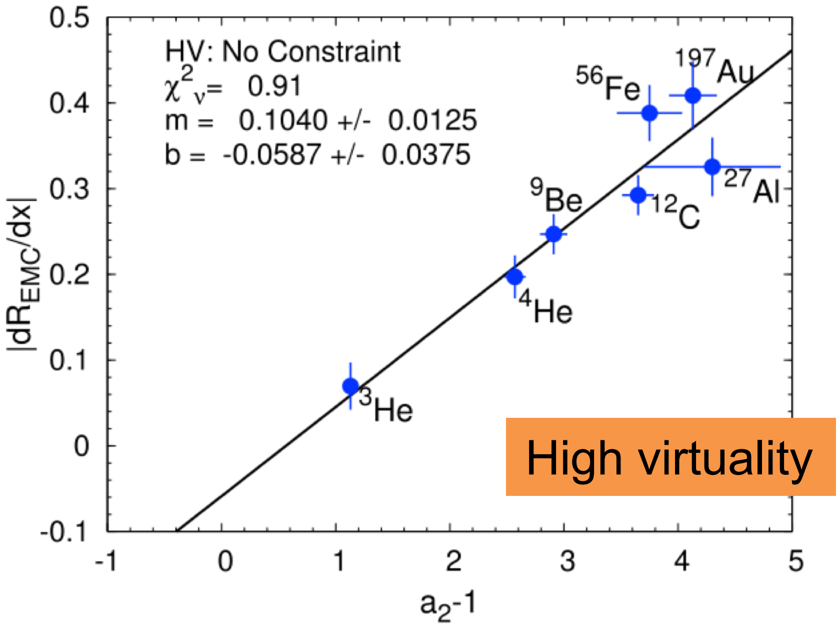
No clear, definitive common independent variable (with available data)



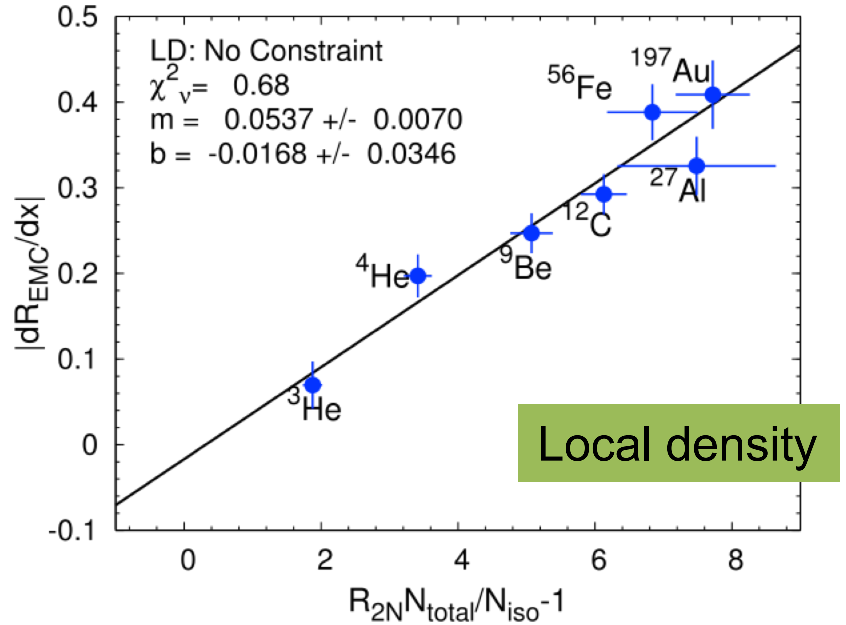


Arrington et al, PRC 86, 065204 (2012)

Nuclear Dependence of EMC and SRCs



a_2 ~ number of high momentum nucleons



R_{2N} ~ number of nucleons “close” together

Can also try to examine/distinguish “high virtuality” (np-correlated pairs only) hypothesis, or “local density” (all pairs participate) hypothesis
→ Data do not favor one or the other strongly

Arrington et al, PRC 86, 065204 (2012)

Further Studies of the EMC Effect with Inclusive Electron Scattering

EMC effect has been studied extensively with inclusive electron scattering – what more can we learn?

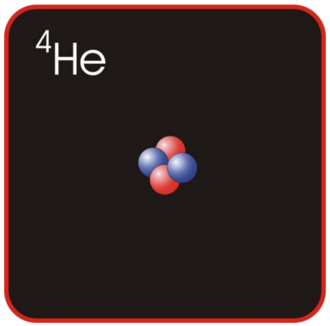
→ Improve precision for heavy targets at large *x*
→ Additional light nuclei – amenable to calculations with “exact” nuclear wave functions
→ Explore EMC-SRC connection further; A dependence at fixed N/P, N/P dependence at fixed A
→ Flavor dependence
→ n/p ratio in nuclei at large x

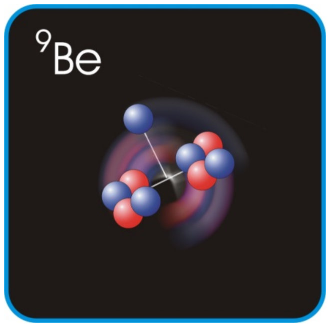
E12-10-008: EMC effect in light→ heavy nuclei

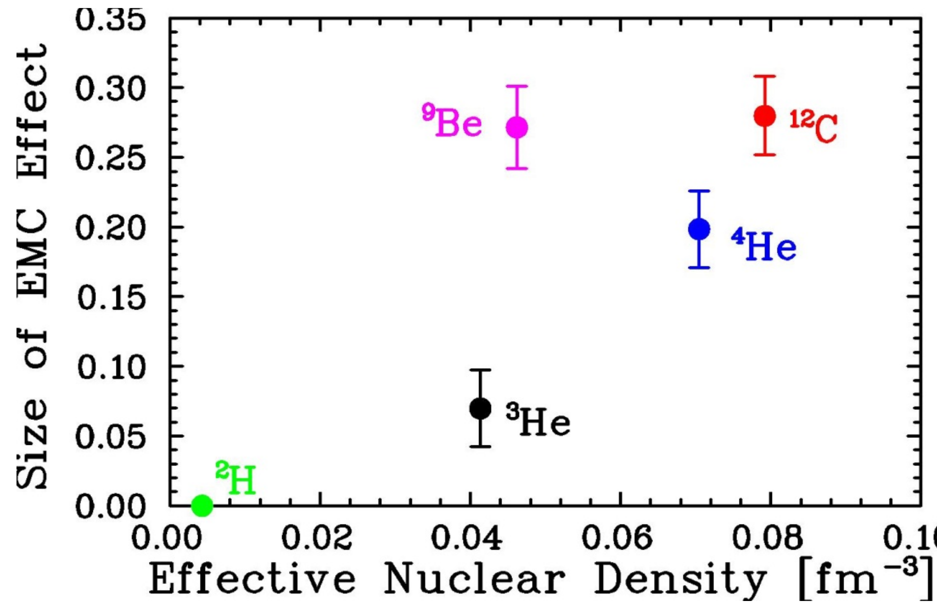
Spokespersons: J. Arrington, A. Daniel, N. Fomin, D. Gaskell

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 include ^{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

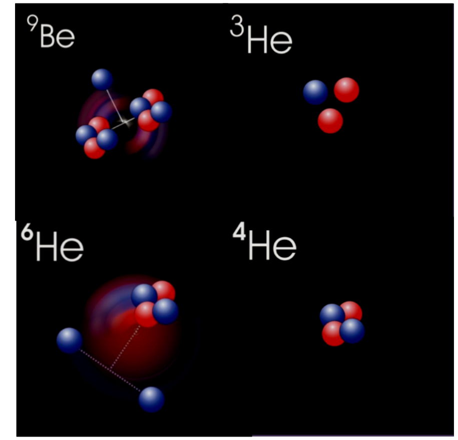
E12-10-008 (EMC effect) and E12-06-105 (x>1)

- Both experiments use wide range of nuclear targets to study impact of cluster structure, separate mass and isospin dependence on SRCs, nuclear PDFs

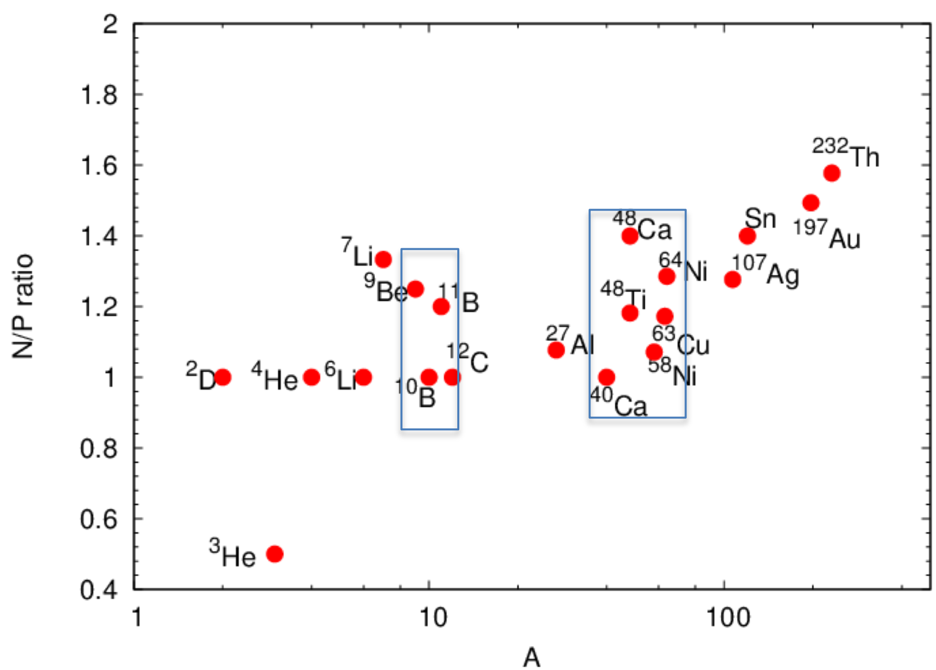
- Experiments will use a common set of targets to provide more information in the EMC-SRC connection

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



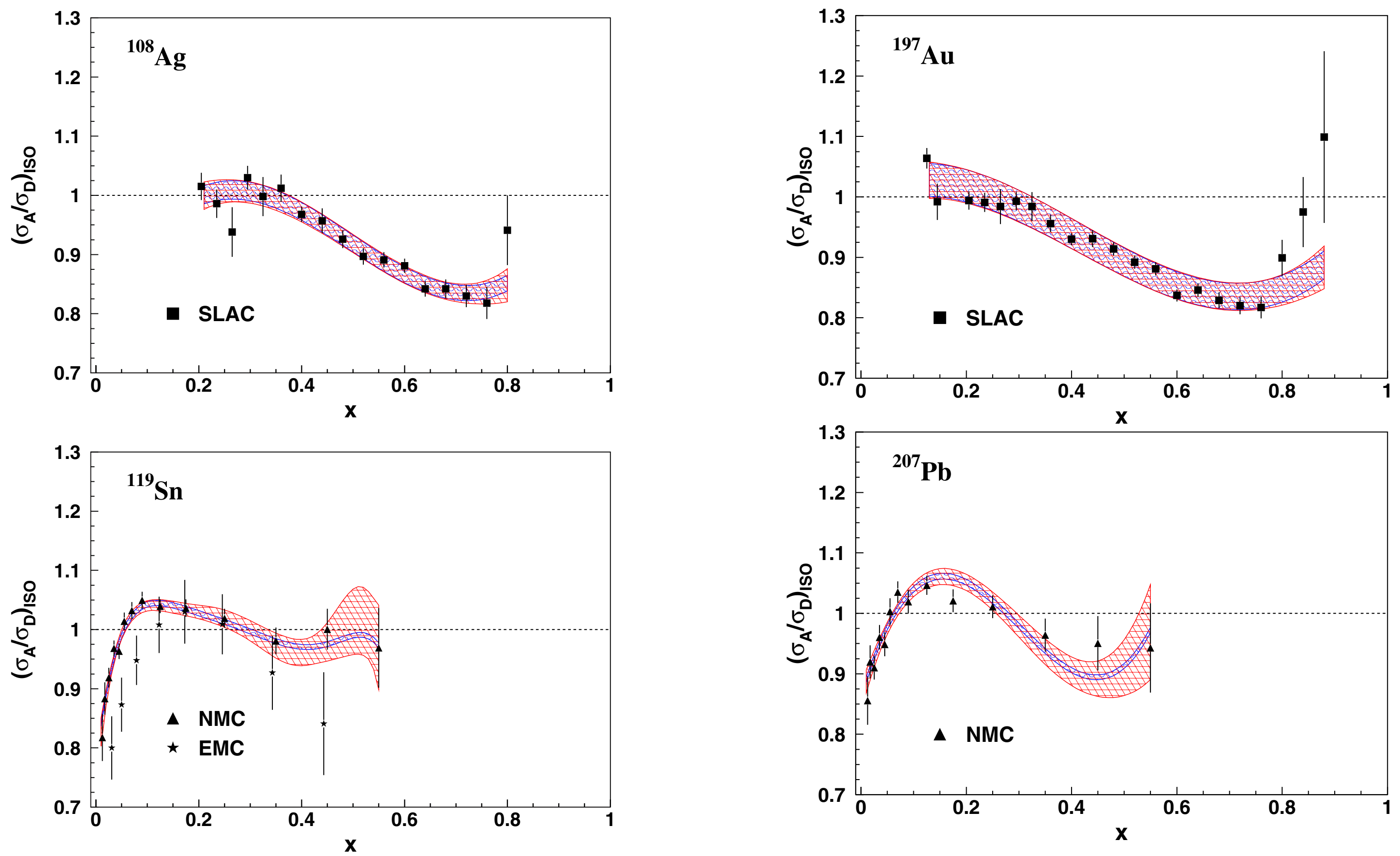
^{27}Al	^{64*}Cu
^{40*,48}Ca	^{108*}Ag
^{48}Ti	^{119*}Sn
^{54}Fe	^{197*}Au
^{58,64}Ni	^{232}Th



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

Heavy Nuclei at Large x

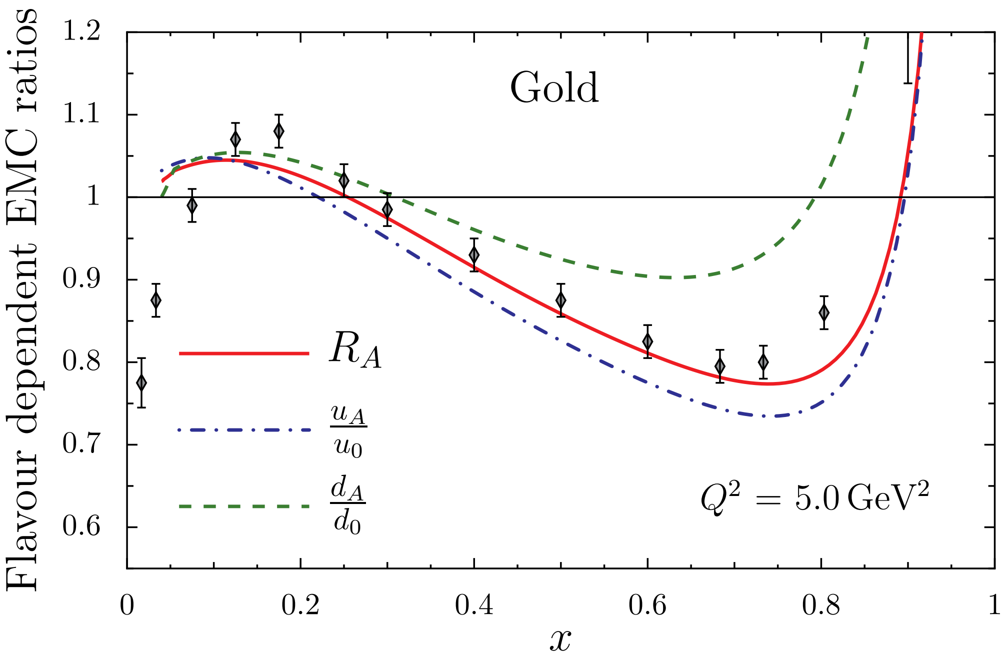
Precision for heavier nuclei at large *x* could be improved – NMC provides precision at low *x*, but poor statistics above *x*=0.2



S. Malace et al, Int.J.Mod.Phys. E23 (2014) no.08, 1430013

Flavor Dependence of the EMC Effect

Mean-field calculations predict a flavor dependent EMC effect for *N≠Z* nuclei



Isovector-vector mean field (ρ) causes u (d) quark to feel additional vector attraction (repulsion) in *N≠Z* nuclei

Cloët, Bentz, and Thomas, PRL 102, 252301 (2009)

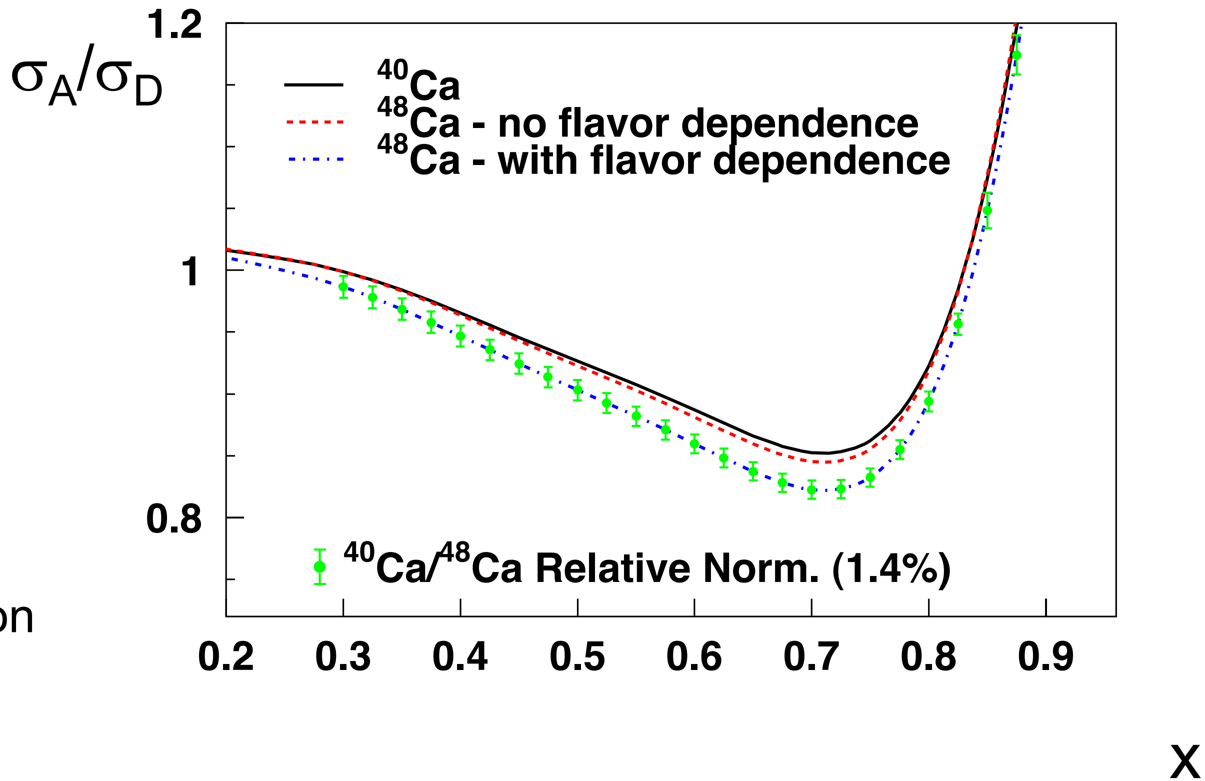
Experimentally, this flavor dependence has not been observed directly

Flavor dependence could be measured using PVDIS, pion Drell-Yan, SIDIS, unpolarized EMC Effect…

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*

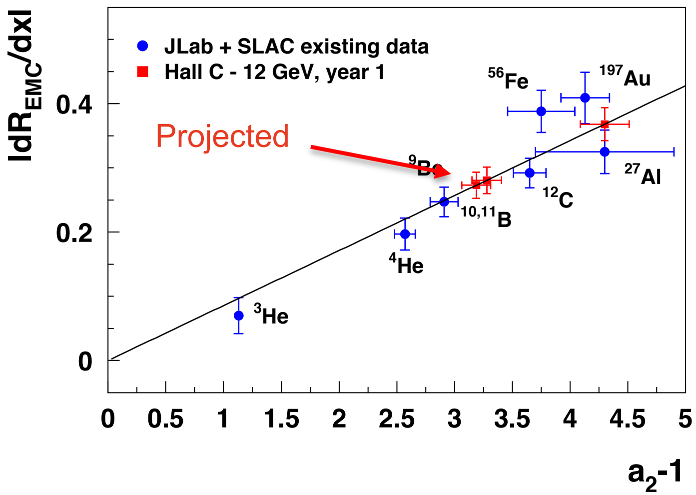
Assuming no flavor dependence, difference between ^{40}Ca and ^{48}Ca should be less than 1% assuming SLAC E139 A-dependent parametrization

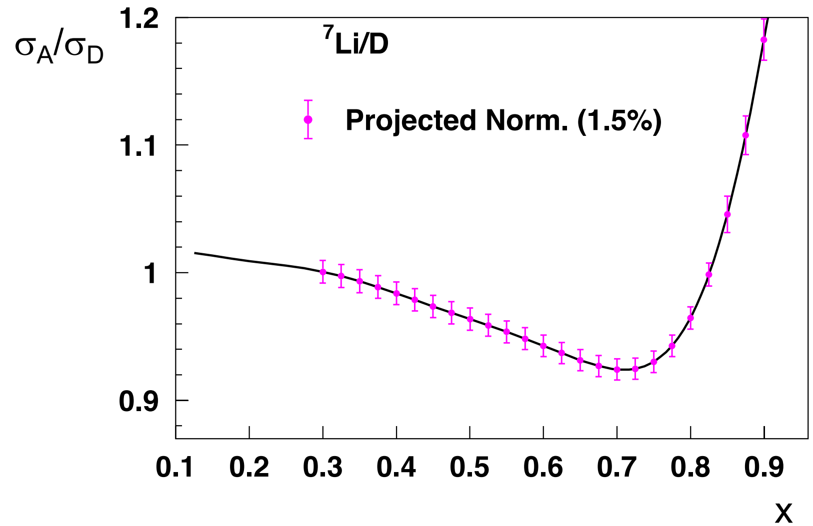


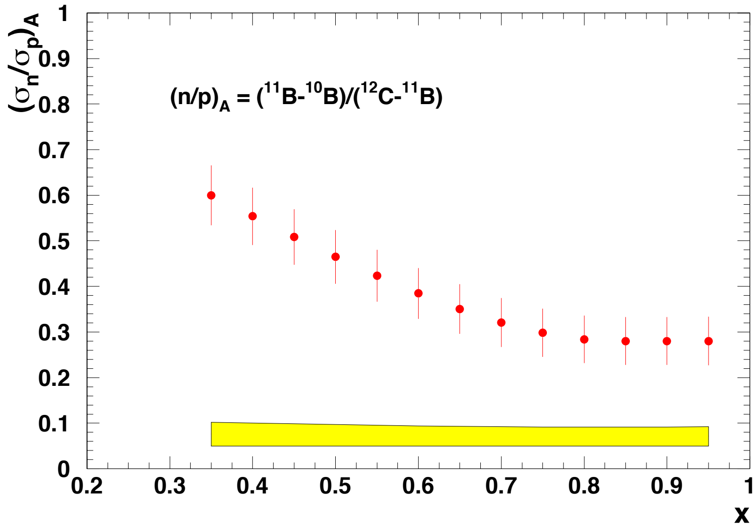
Measurement of unpolarized EMC effect in ^{40}Ca and ^{48}Ca provides some sensitivity to possible flavor dependent effect

E12-10-008: Physics Reach

^{10}B, ^{11}B data taken as part of Hall C Commissioning





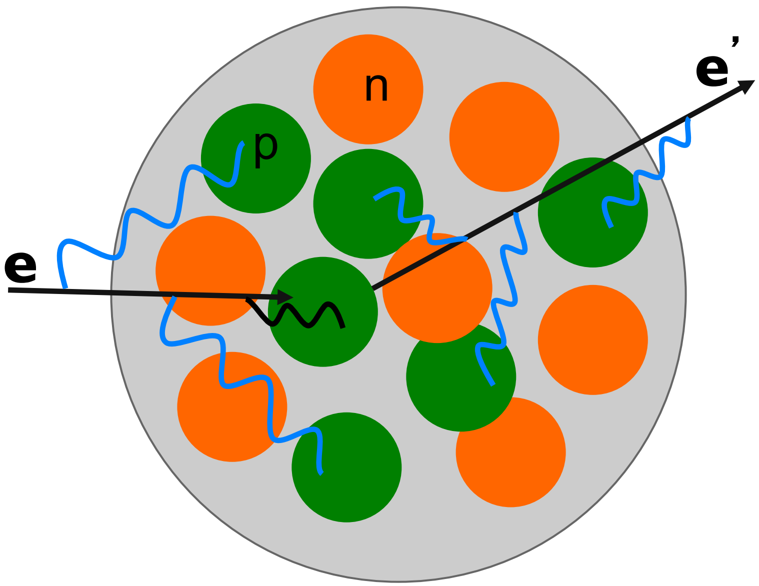


<u>E12-10-008 outcomes</u>

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

JLab E03103 (6 GeV) – Heavy Targets

E03-103 also measured EMC ratios for Cu and Au – analysis at the relatively low 6 GeV beam energy complicated by ***Coulomb Corrections***



Electrons scattering from nuclei can be accelerated/decelerated in the Coulomb field of the nucleus

→ This effect is NOT part of the hadronic structure of the nucleus we wish to study
→ Important to remove/correct for apparent changes in the cross section due to Coulomb effects

In a very simple picture – Coulomb field induces a change in kinematics in the reaction

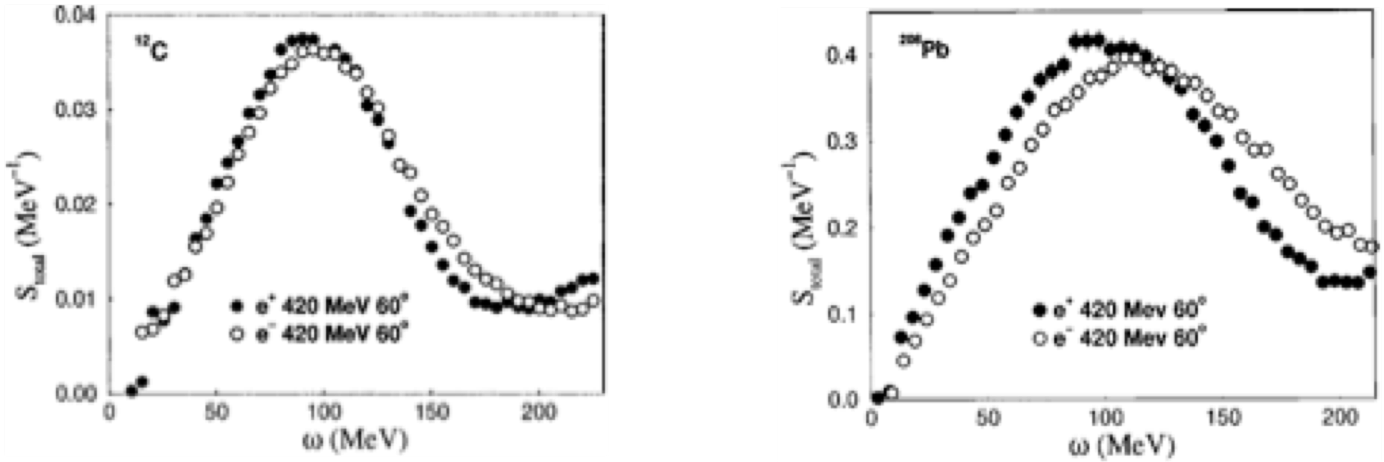
$$E_e \rightarrow E_e + V_0$$

$$E_e' \rightarrow E_e' - V_0$$

$$V_0 = 3\alpha(Z-1)/2R$$ ← *Electrostatic potential energy at center of nucleus*

Coulomb Corrections in QE Processes

Importance of Coulomb Corrections in quasi-elastic processes well known



Gueye et al., PRC60, 044308 (1999)

Distorted Wave Born Approximation calculations are possible – but difficult to apply to experimental cross sections

→Instead use ***E***ffective ***M***omentum ***A***pproximation (***EMA***) tuned to agree with DWBA calculations

EMA: $E_e \to E_e + V_0$ $E_e' \to E_e' - V_0$ with "focusing factor" $F^2 = (1-V_0/E)$

$V_0 \to (4/5)V_0$, $V_0 = 3\alpha(Z-1)/2R$ V_0 = 10 MeV for Cu, 20 MeV for Au

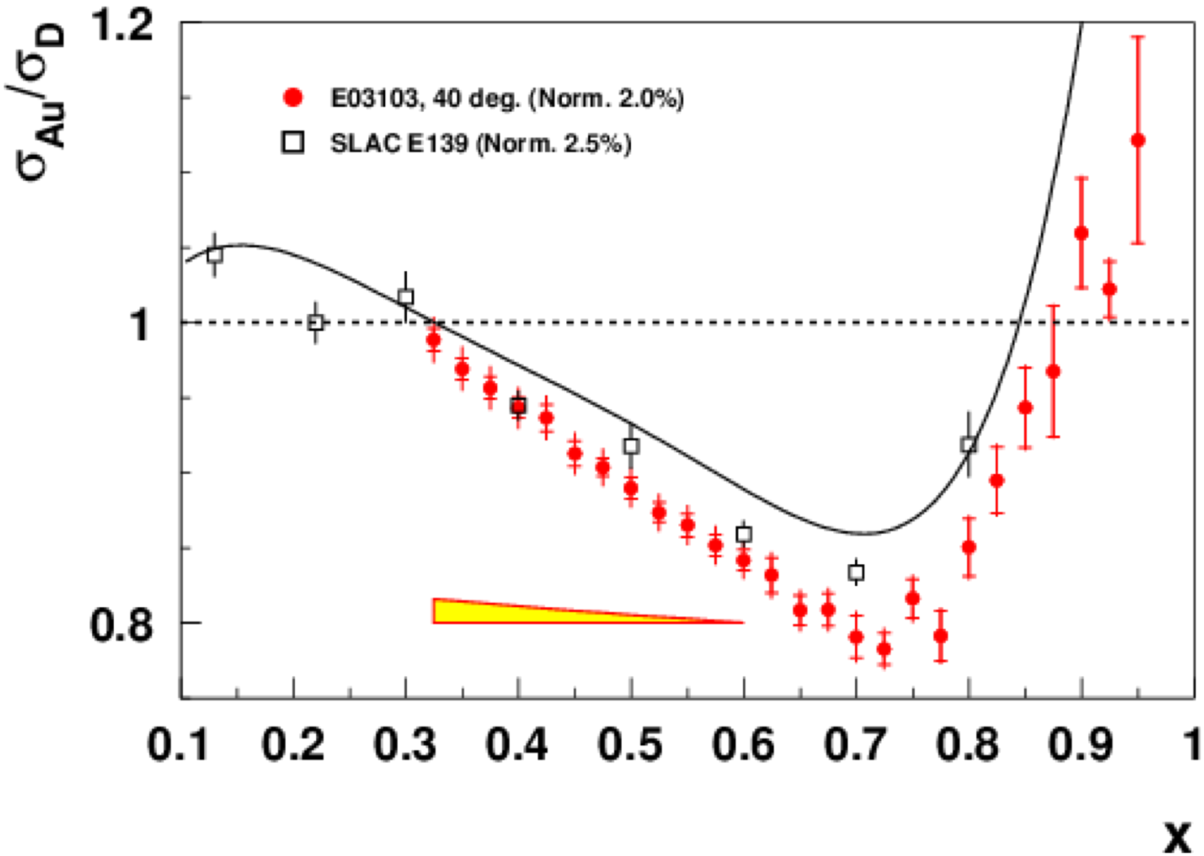
[Aste et al, Eur.Phys.J.A26:167-178,2005, Europhys.Lett.67:753-759,2004]

E03103: EMC Effect in Gold

σ_A/σ_D for Gold
A=197 Z=79

SLAC E-139
E_e ~ 8-25 GeV
E_e' ~4-8 GeV

JLab E03-103
E_e ~ 6 GeV
E_e' ~1-2 GeV



No Coulomb Corrections applied

E03103: EMC Effect in Gold

Coulomb corrections significantly larger for JLab data → 5-10%, SLAC → 1-2%

σ_A/σ_D for Gold
A=197 Z=79

<u>SLAC E-139</u>
E_e ~ 8-25 GeV
E_e' ~4-8 GeV

<u>JLab E03-103</u>
E_e ~ 6 GeV
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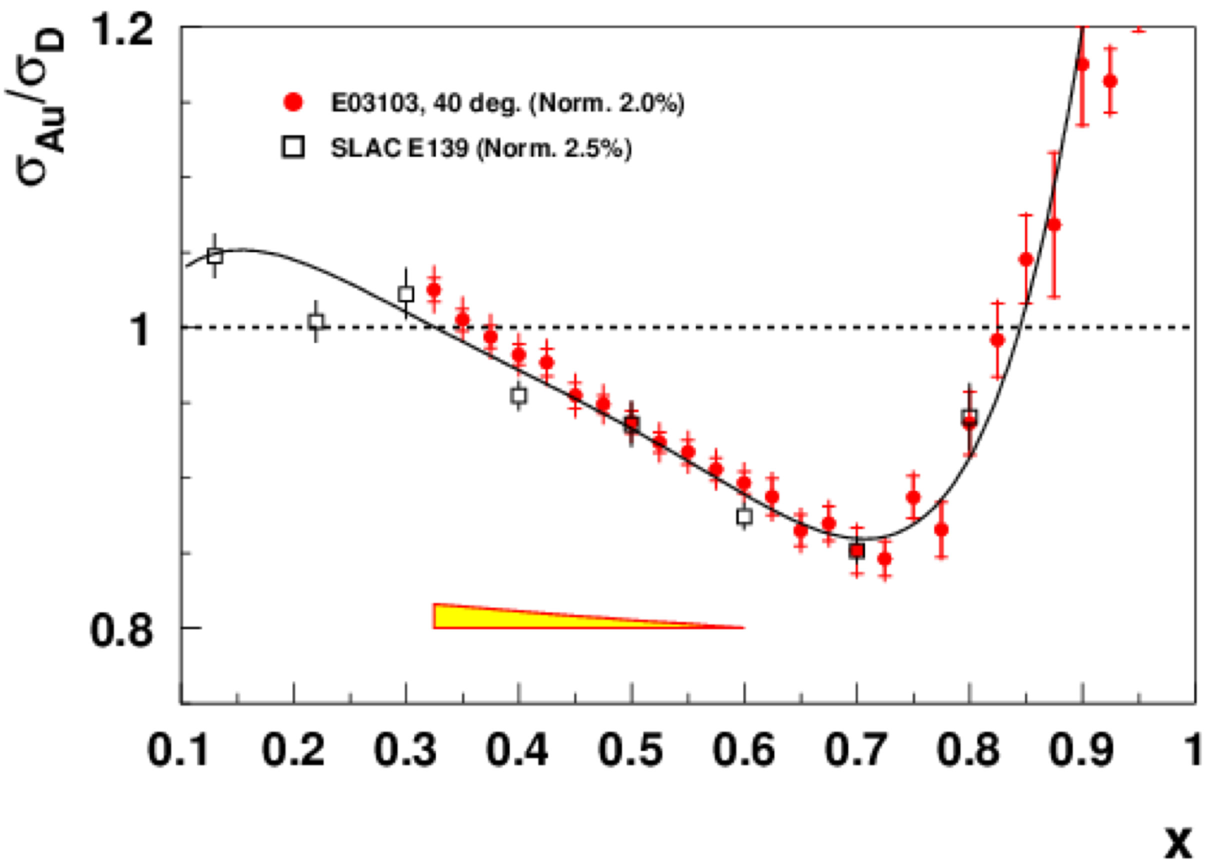


with Coulomb Corrections (both data sets)

R_A-R_D

E03103 shows good agreement with E139 data for smaller *A*
→ agreement not as good for heavier targets. Why?

$$\frac{d\sigma}{d\Omega dE'} = \frac{4\alpha^2 (E')^2}{Q^4 \nu}\left[F_2(\nu,Q^2)\cos^2\frac{\theta}{2} + \frac{2}{M\nu}F_1(\nu,Q^2)\sin^2\frac{\theta}{2}\right]$$

$F_2(x) = \sum_i e_i^2 x q_i(x)$ ⟵ Quark distribution functions

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

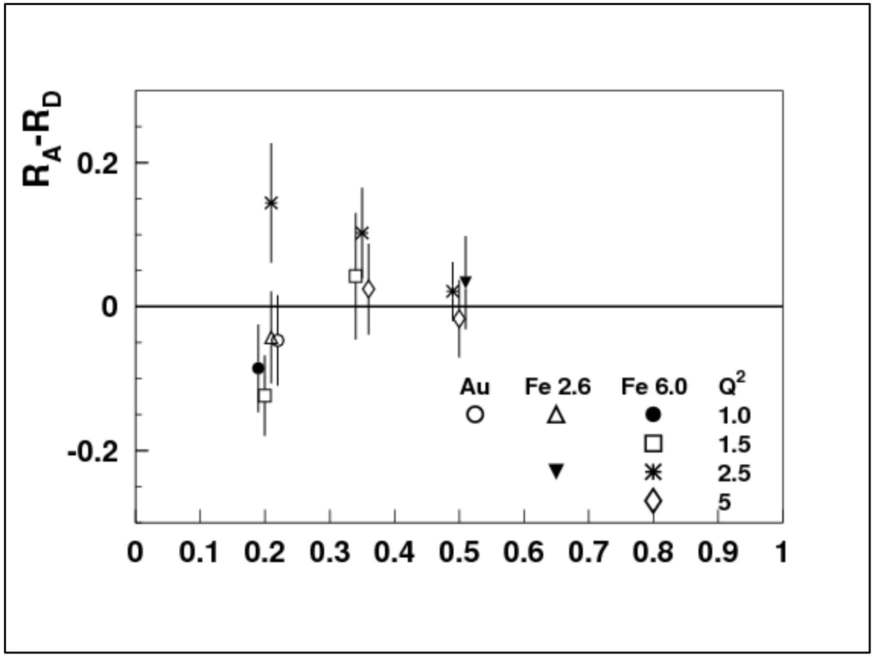
$F_1 \propto \sigma_T$ F_2 linear combination of σ_T and σ_L

Measurements of EMC effect often assume $\boldsymbol{\sigma_A/\sigma_D = F_2^A/F_2^D}$
→ this is true if $R=\sigma_L/\sigma_T$ is the same for A and D

E139 data mostly at large ε – JLab data at small ε → if $R_A \neq R_D$, this might explain the difference

→ Motivated us to re-examine earlier experiments that measured nuclear dependence of *R*

SLAC E140: R_A-R_D



[E140 Phys. Rev. D 49 5641 (1993)]

E140 measured ε dependence of cross section ratios σ_A/σ_D for

x=0.2, 0.35, 0.5
Q^2 = 1.0, 1.5, 2.5, 5.0 GeV^2
Iron and Gold targets

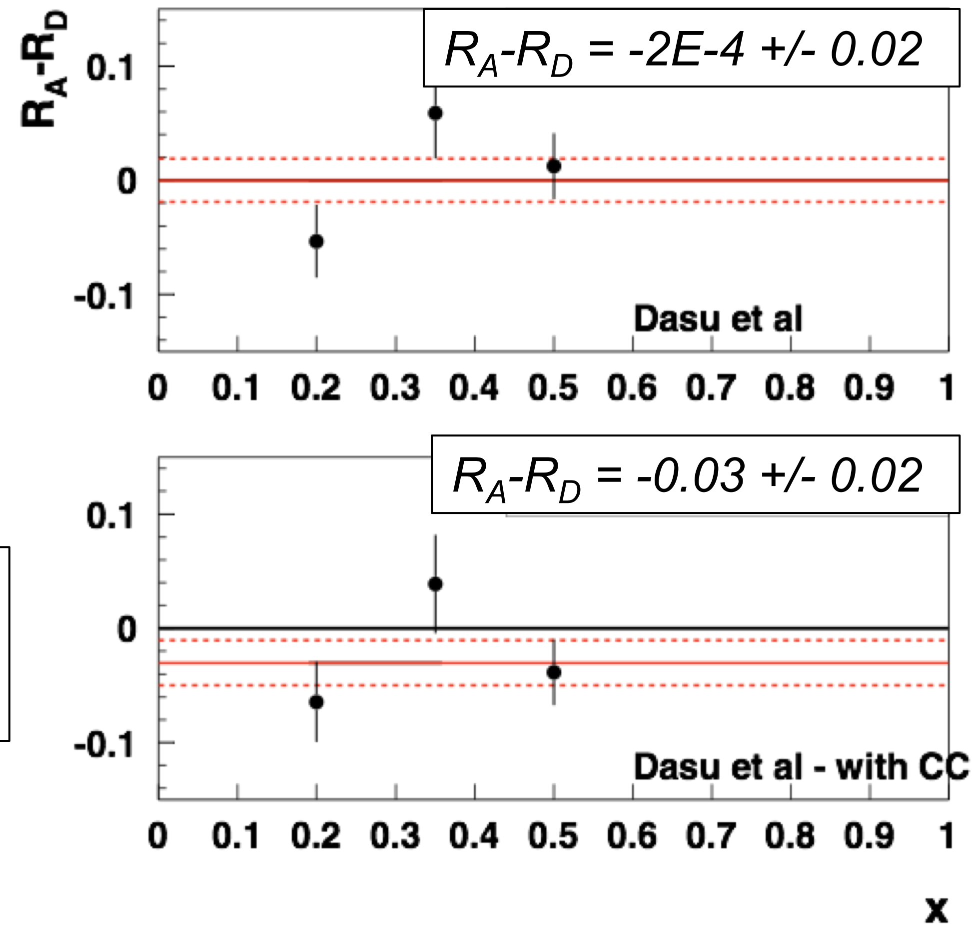
$R_A - R_D$ consistent with zero within errors

No Coulomb corrections were applied

Large ε data: E_e ~ 6-15 GeV E_e' ~ 3.6-8 GeV
Low ε data: E_e ~ 3.7-10 GeV   **E_e' ~ 1-2.6 GeV**

R_A-R_D: E140 Re-analysis

Re-analyzed E140 data using Effective Momentum Approximation for published “Born”-level cross sections
→ Total consistency requires application to radiative corrections model as well



Including Coulomb Corrections yields result 1.5 σ from zero when averaged over ***x***

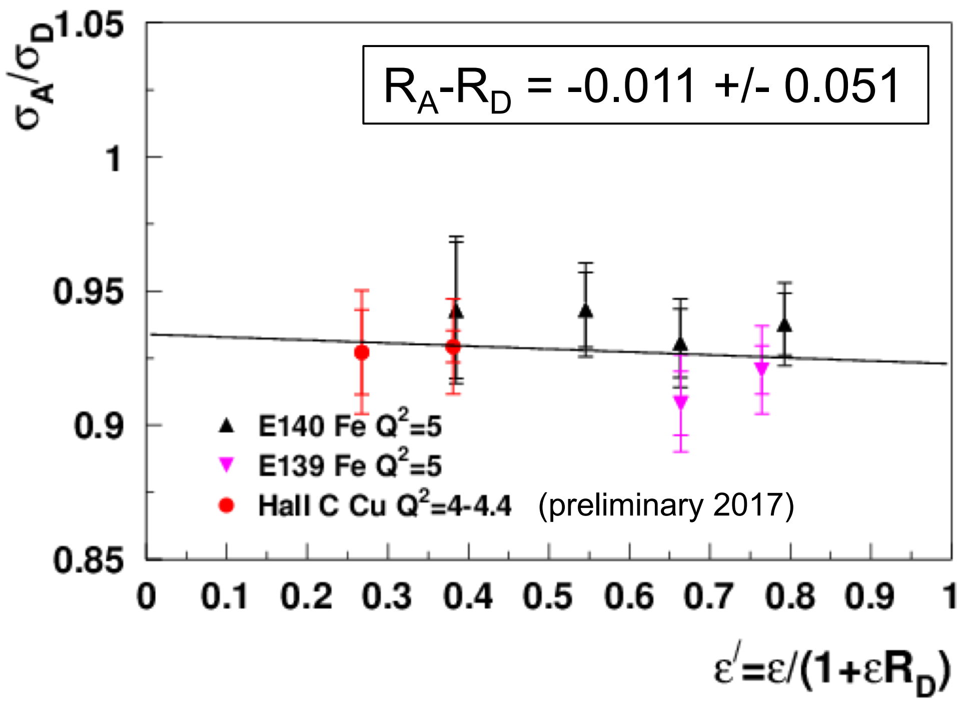
R_A-R_D at x=0.5

Interesting result from E140 re-analysis motivated more detailed study
→ $x=0.5$, $Q^2=5$ GeV^2

→ Include E139 Fe data
→ Include JLab data
Cu, $Q^2=4\text{-}4.4$ GeV^2

Normalization uncertainties between experiments treated as extra point-to-point errors

No Coulomb Corrections → combined analysis still yields R_A-R_D ~ 0



No Coulomb Corrections

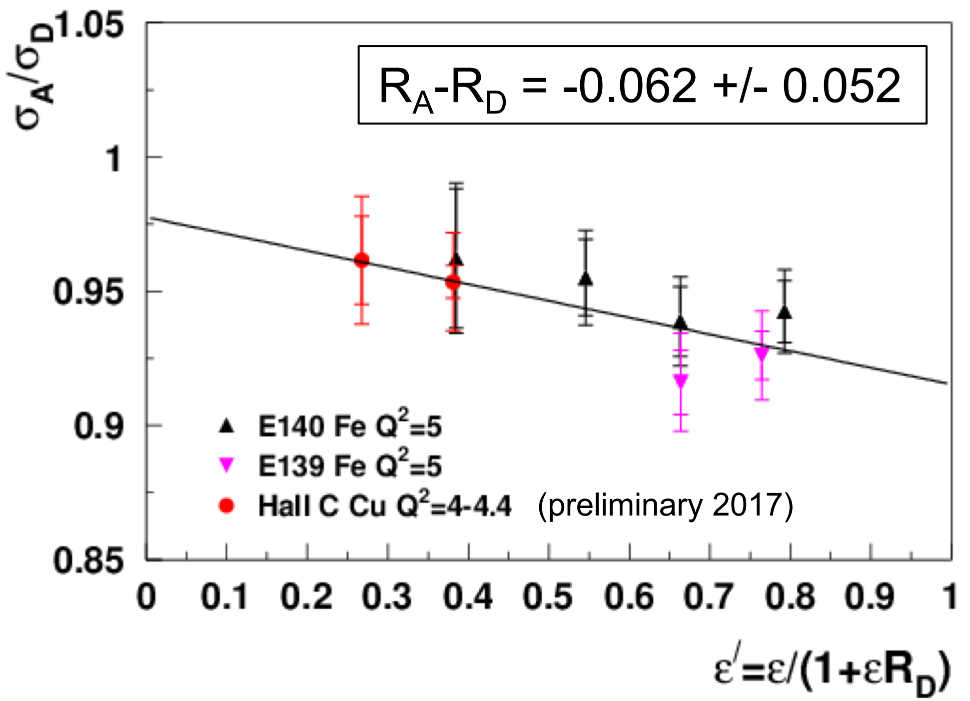
Jefferson Lab

R_A-R_D at x=0.5

Interesting result from E140 re-analysis motivated more detailed study
→ $x=0.5$, $Q^2=5$ GeV^2

→ Include E139 Fe data
→ Include JLab data
Cu, $Q^2=4\text{-}4.4$ GeV^2

Normalization uncertainties between experiments treated as extra point-to-point (between data sets) errors

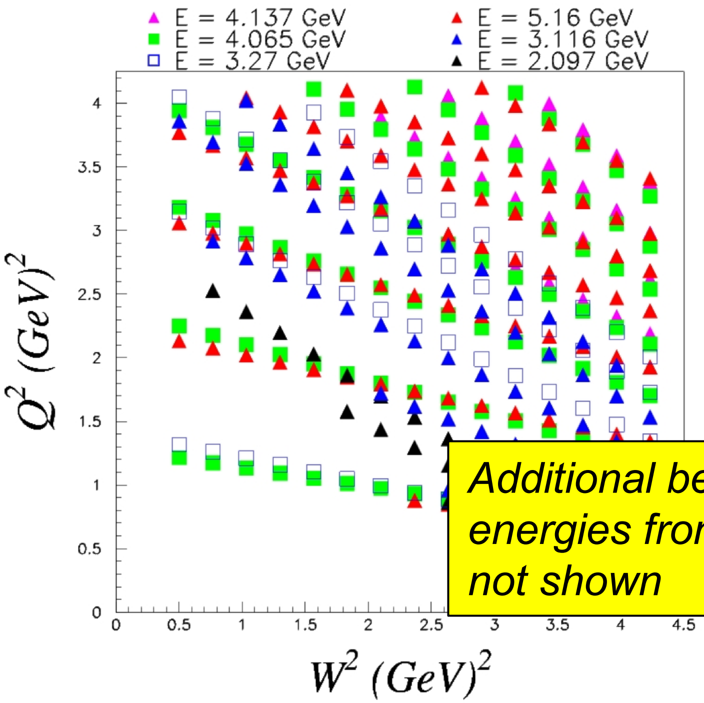


with Coulomb Corrections

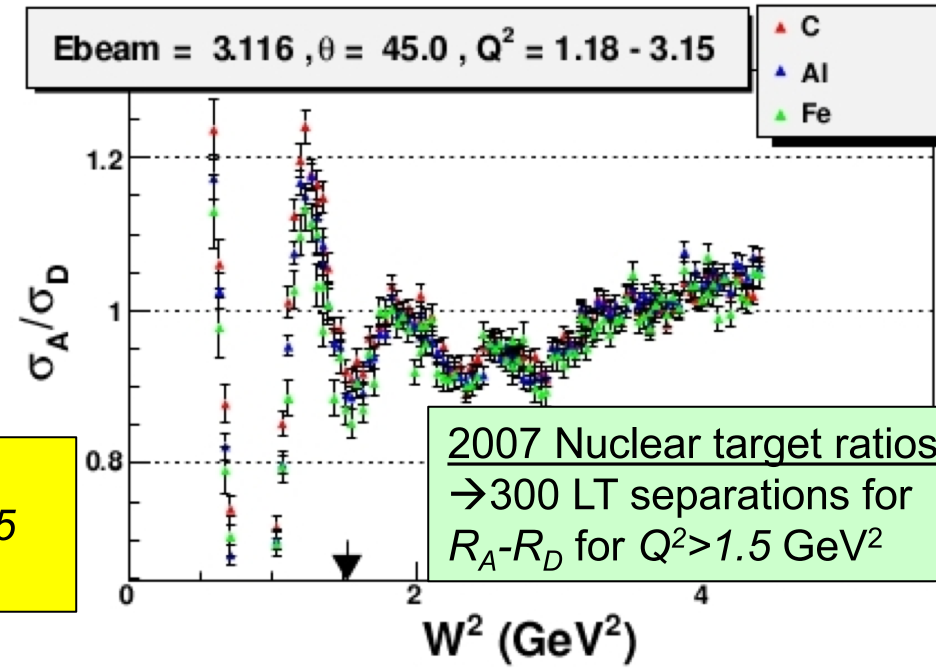
Application of Coulomb Corrections → R_A-R_D 1.2 σ from zero

Uncertainties amplified due to need to combine data from different experiments

JLab Hall C E02-109/E04-001/E06-009



Additional beam energies from 2005 not shown



2007 Nuclear target ratios
→300 LT separations for R_A-R_D for Q^2>1.5 GeV^2

→ Precision extraction of separated structure functions on D, Al, C, Fe/Cu
→ Search for nuclear effects in F_L, R
→ Neutron and p-n moment extractions (compare to lattice calculations)
→ Allow study of quark-hadron duality for neutron, nuclei separated structure functions

F_2, F_L, R on Deuterium and heavier targets

R_A-R_D at Large x

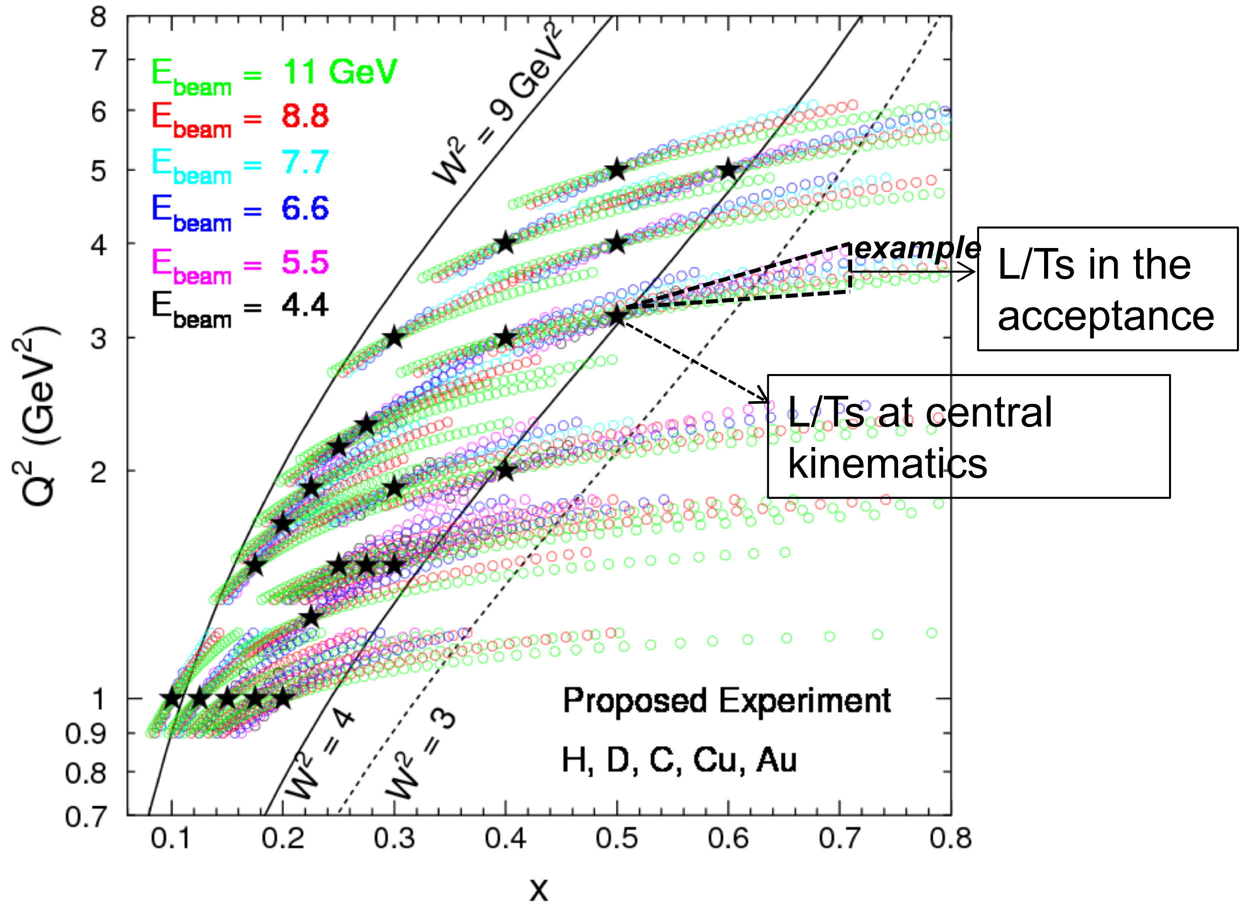
- Evidence is suggestive that R_A-R_D < 0 at large x
  - Effect is not large – depends on precision of the experimental data
  - Coulomb Corrections are crucial to observation/existence of this effect → CC has significant dependence on electron energy, varies between ε settings
- Implications of R_A-R_D < 0
  - F_1, F_2 not modified in the same way in nuclei
  - What does this mean for our understanding of the EMC effect?
  - Parton model: $R=4\langle K_T^2\rangle/Q^2$, $\langle K_T^2\rangle$ smaller for bound nucleons? [*A. Bodek, PoS DIS2015 (2015) 026*]
- **Additional data (dedicated measurement) in DIS region required**

JLab Experiment 12-14-002

Precision Measurements and Studies of a Possible Nuclear Dependence of $R=\sigma_L/\sigma_T$

[S. Malace, M.E. Christy, D. Gaskell, C. Keppel, P. Solvignon]

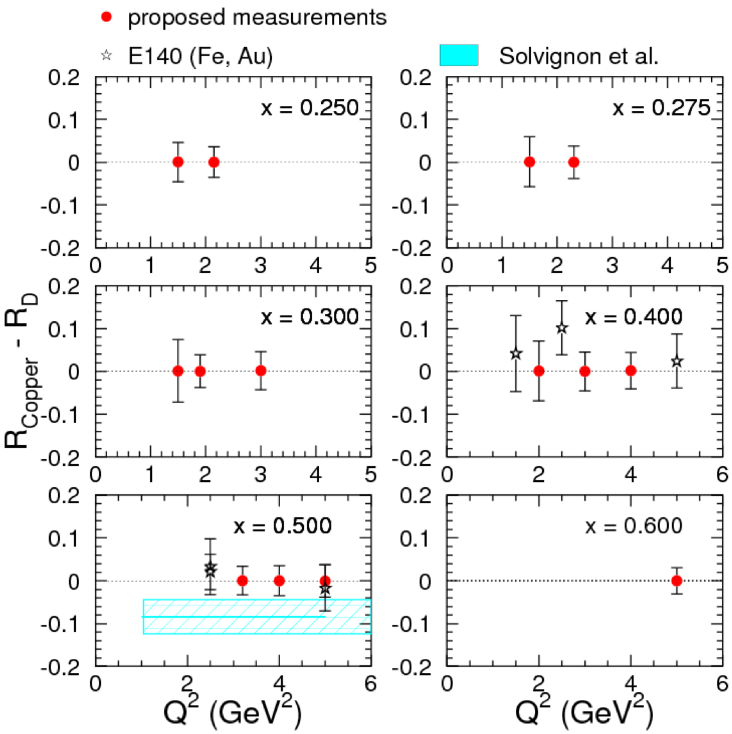
Measurements of nuclear dependence of structure functions, R_A-R_D via direct L-T separations

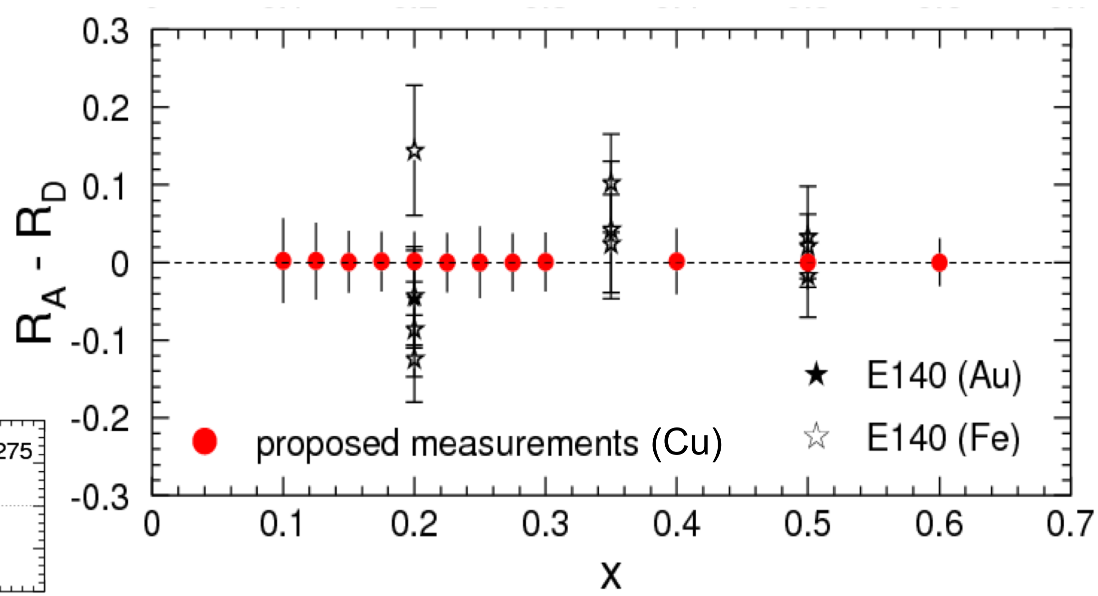


Detailed measurements of *x* and Q^2 dependence for Copper target
→ A dependence at select kinematics using C and Au

JLab Experiment 12-14-002

Experiment will study R_A-R_D in both the EMC effect and anti-shadowing regions





Projections shown at central kinematics only; enhanced coverage by adding L/Ts from spectrometers acceptance

Overlap previous L-T separated data but will extend to both smaller and larger *x*

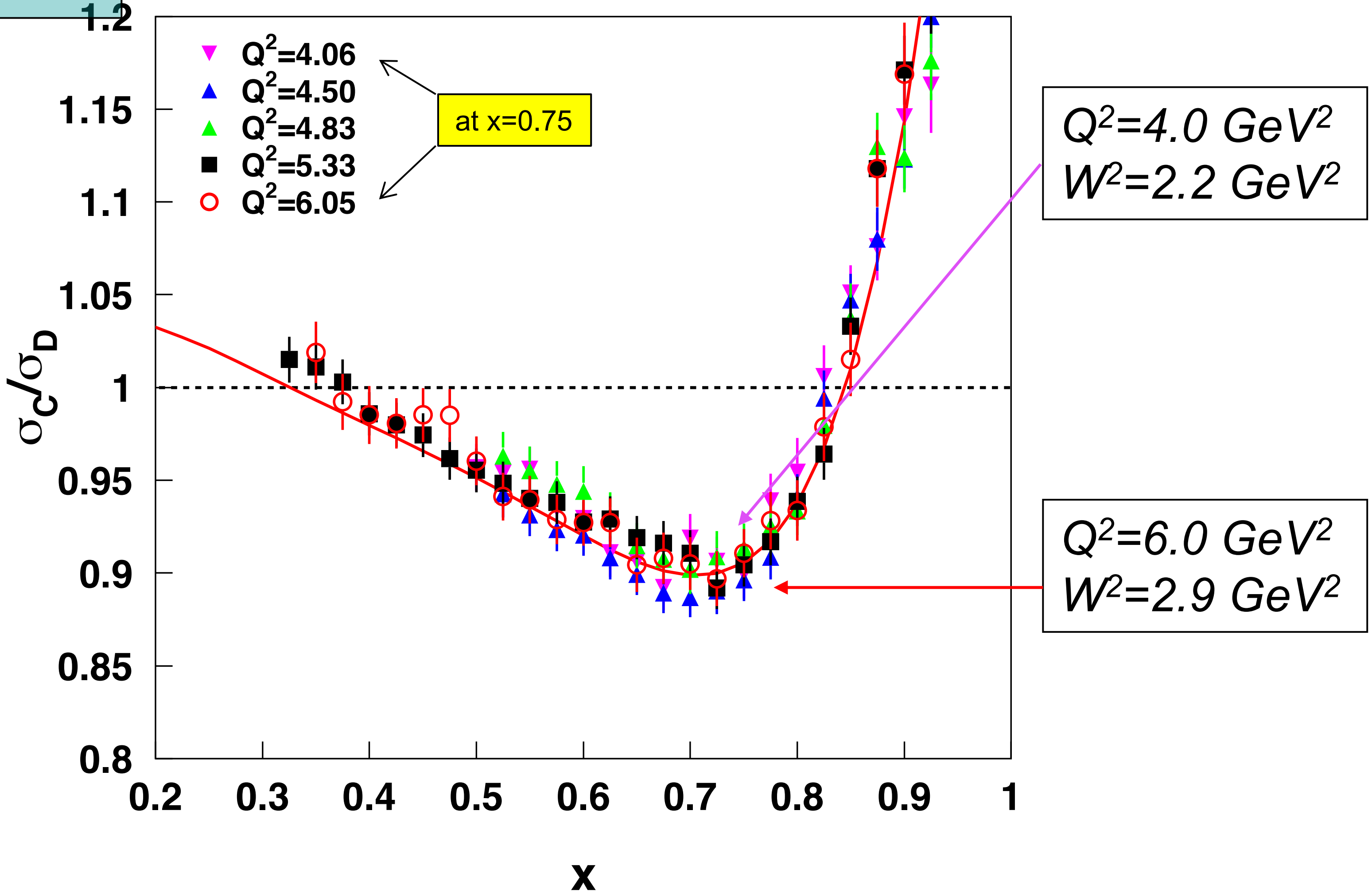
Summary

- 35 years of inclusive experiments have provided a lot of information about the properties of the EMC Effect
- Recent results (experimental and theoretical) have provided a roadmap for future studies (JLab-12 GeV)
  - Additional light nuclei, where exact nuclear wave functions are available
  - Further exploration of the EMC-SRC connection
  - Flavor dependence
- Nuclear dependence of R at large x also needs a second look
  - Effects do not appear to be large, but re-analysis of existing data suggests that the assumption $R_A=R_D$ may not be valid for all kinematics
  - Investigation requires L-T separation experiment with good control of systematic uncertainties

EXTRA

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

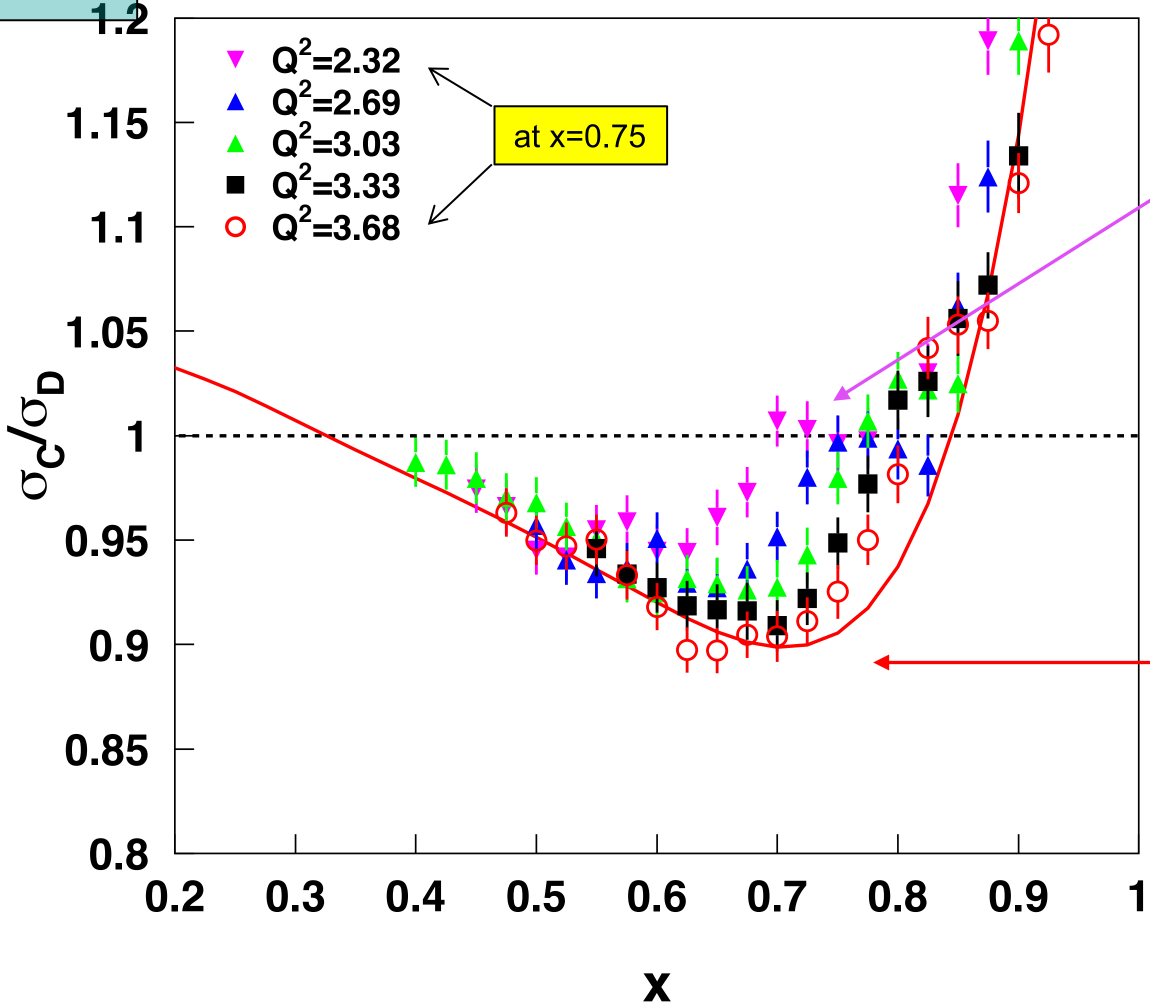
E03-103 Results



At larger angles (Q^2) the ratio appears to scale to very large x
→ $W^2 > 2$ GeV^2 and $Q^2 > 3$ GeV^2

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

E03-103 Results



Q^2=2.3 GeV^2
W^2=1.65 GeV^2

Q^2=3.68 GeV^2
W^2=2.1 GeV^2

Clear deviation from scaling at W^2<2.2 GeV^2

Sensitivity to flavor dependence

Extracting the flavor dependence from the inclusive ratio relies on comparing the measured to the "expected" EMC effect in ^{48}Ca relative ^{40}Ca
→ Can measure "size" of the EMC effect either at fixed x, or via "slope"

Ratio	R @ x=0.6	dR/dx (x=0.3-0.7)
$^{48}Ca/^{40}Ca$ (no flavor dep.)	0.993	1.050
$^{48}Ca/^{40}Ca$ (w/flavor dep.)	0.970 +/- 0.013 +/- 0.014	1.115 +/- 0.057 +/- 0.016

stat + random sys

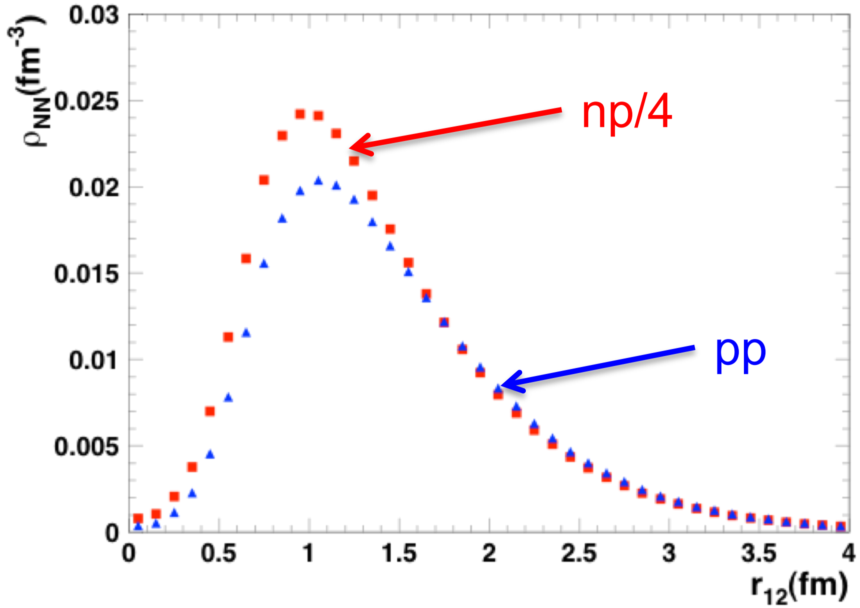
normalization

The "no flavor dependence" ratio above uses the nuclear dependence of the EMC effect from SLAC E139 A-dependent fit

→ Other, plausible nuclear dependencies (e.g. $A^{-1/3}$) yield similar results, change the expected ratio by < 0.5% at fixed x=0.6, or by 2.5% for the slope

Flavor dependence and SRCs

^{4}He 2-body density from



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

High momentum nucleons from SRCs emerge from tensor part of *NN* interaction <u>– *np* pairs dominate</u>

→ Probability to find 2 nucleons "close" together nearly the same for *np, nn, pp*

For $r_{12} < 1.7$ fm:

$$P_{pp} = P_{nn} \approx 0.8 P_{np}$$

If EMC effect due to ***high virtuality***, flavor dependence of EMC effect emerges naturally

→ If EMC effect from ***local density***, *np/pp/nn* pairs all contribute (roughly) equally

Flavor dependence and SRCs

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

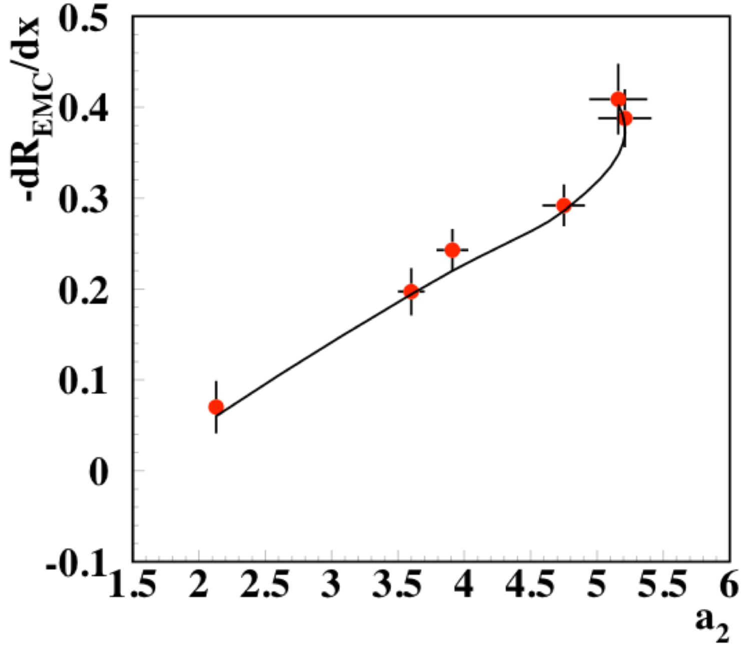
→The relative probability to find a high momentum proton is larger than for neutron for *N>Z* nuclei

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

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

Probability to find SRC

$$u_A = \frac{Z\tilde{u}_p + N\tilde{d}_p}{A} \qquad d_A = \frac{Z\tilde{d}_p + N\tilde{u}_p}{A}$$



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]

Testing Coulomb Corrections with Electrons

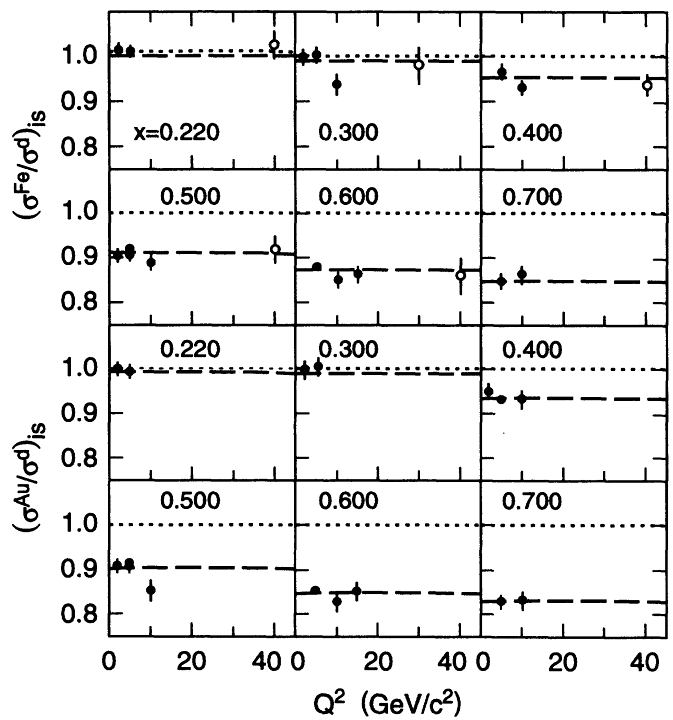
Coulomb corrections can be tested by measuring target ratios at fixed ***x*** and **ε**
→ Varying Q^2 allows us to change E/E' and hence size of CC

Fixed ***x*** required due to EMC effect

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^A(1+\epsilon R_A)(1+R_D)}{F_2^D(1+R_A)(1+\epsilon R_D)}$$

Fixed **ε** eliminates potential dependence on R_A-R_D

EMC effect measurements have shown little or no dependence on Q^2



E12-14-002 Coulomb Corrections Test

Gold target x=0.5

ε	Q^2 (GeV^2)	E (GeV)	E' (GeV)	θ (deg.)	W (GeV)	$C_{Coulomb}$
0.2	3.48	4.4	0.69	64.6	2.08	11.6%
0.2	9.03	11.0	1.38	45.5	3.10	6.2%
0.7	2.15	4.4	2.11	27.9	1.74	3.5%
0.7	5.79	11.0	4.83	19.0	2.58	1.9%

CC test will measure precise Au/D ratios
→ 2 shifts (16 hours) at 60 μA

Statistics goals: 100k events for deuterium, 50k for gold
→ 0.55% uncertainty in ratio (statistics)
→ Effect is potentially large at these kinematics, but want to test to high precision to minimize contribution to point-to-point uncertainties

E12-14-002 Coulomb Corrections Test

Gold and Deuterium targets x=0.5

ε	Q^2 (GeV^2)	E (GeV)	E' (GeV)	θ (deg.)	W (GeV)	$C_{Coulomb}$
0.2	3.48	4.4	0.69	64.6	2.08	11.6%
0.2	9.03	11.0	1.38	45.5	3.10	6.2%
0.7	2.15	4.4	2.11	27.9	1.74	3.5%
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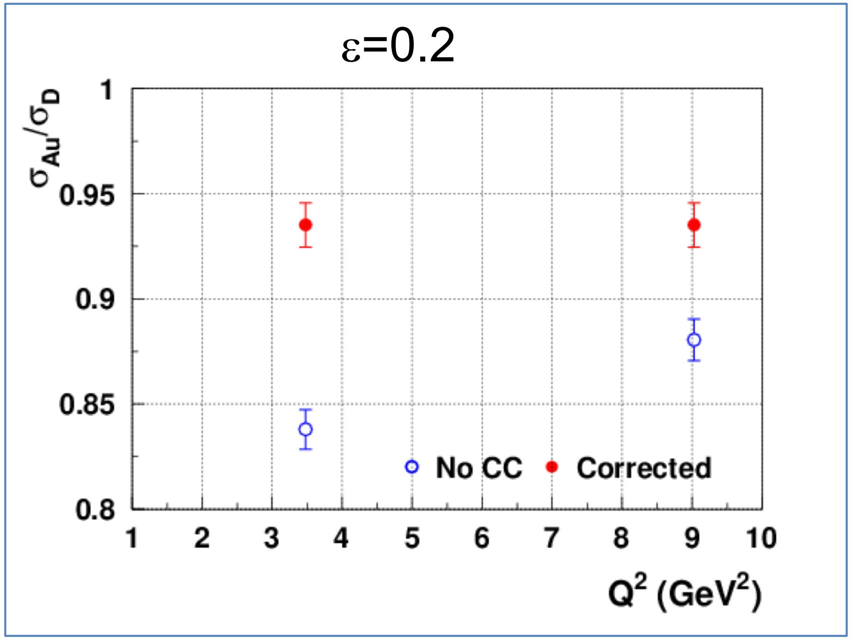
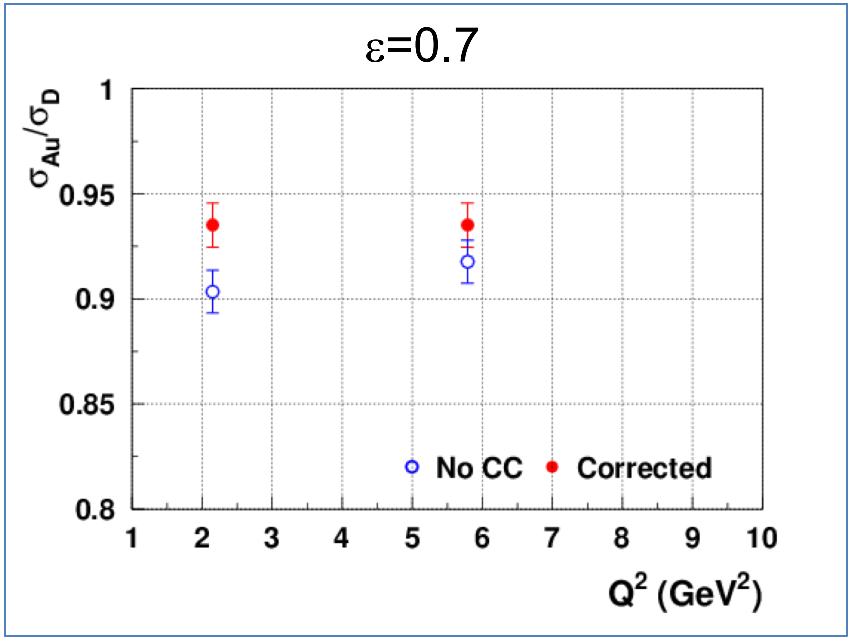
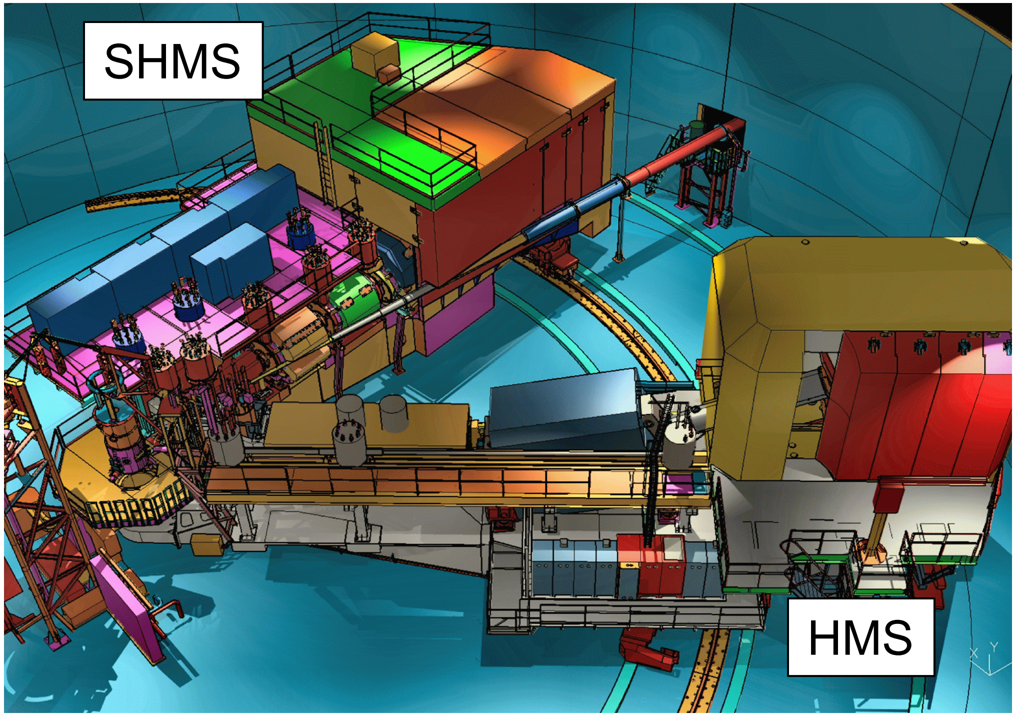




Jefferson Lab

Assume point-to-point uncertainty ~ 1% - normalization uncertainty not shown

E12-10-008 in Experimental Hall C



Spectrometers

HMS:
dΩ ~ *6* msr, P_0= *0.5 – 7 GeV/c*
θ_0=*10.5 to 80 degrees*
e ID via calorimeter and gas Cerenkov

SHMS:
dΩ ~ *4* msr, P_0= *1 – 11 GeV/c*
θ_0=*5.5 to 40 degrees*
e ID via heavy gas Cerenkov and calorimeter