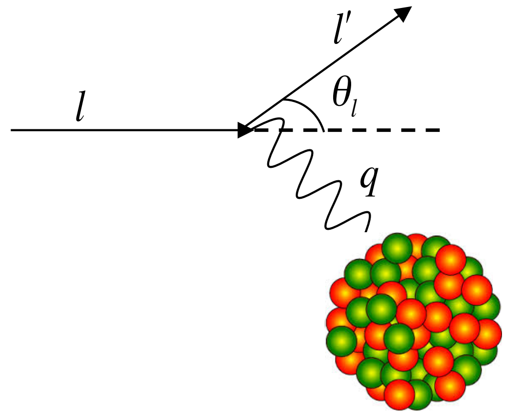


Q^2 dependence at large x and impact on EMC studies

N. Kalantarians (Virginia Union Univ.)

NDNN-NUSTEC: 16 Mar. 2021

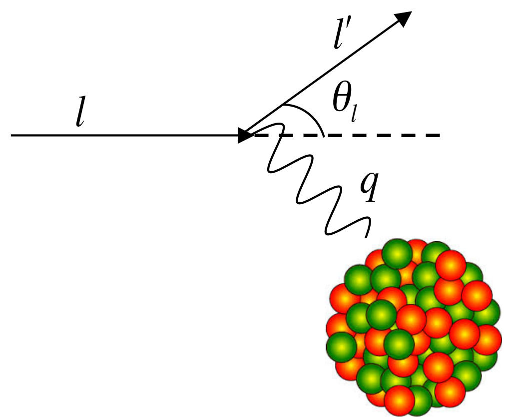
For *S. Escalante, C. Keppel,* and *H. Szumila-Vance*

*Work supported by NSF Award 2000108

Jefferson Lab

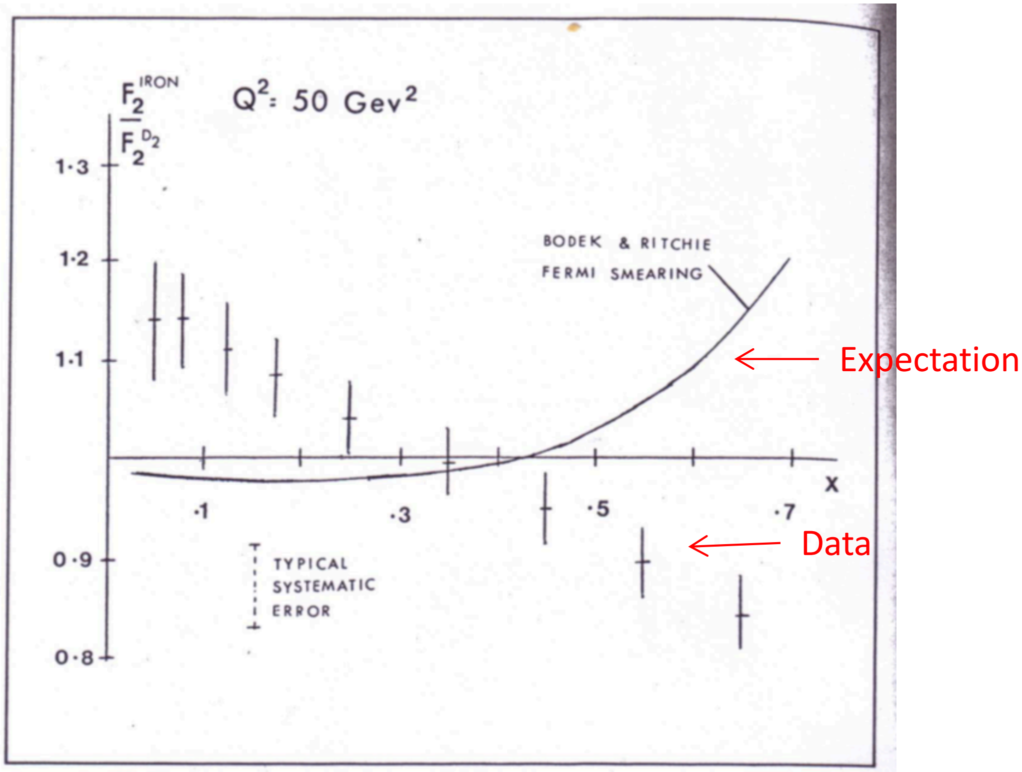
Overview

- Goal: Explore quark flavor dependence of EMC Effect via Structure Functions *(F_2^A)*, which characterize quark content of nuclei.
- Made possible with F_2^n (neutron) data from DIS world data analysis (S. Li UNH), using CTEQ-Jefferson Lab (CJ) deuteron nuclear corrections.
- Physical Review C **103** 015201 - with a VUU UG as an author (S. Escalante)!



EMC* Effect

- CERN Courier, Nov. 1982 (shown) and then Phys. Lett. B **123** (1983) 275.



*Eur. Muon Collab.

Effect Reproduced many times

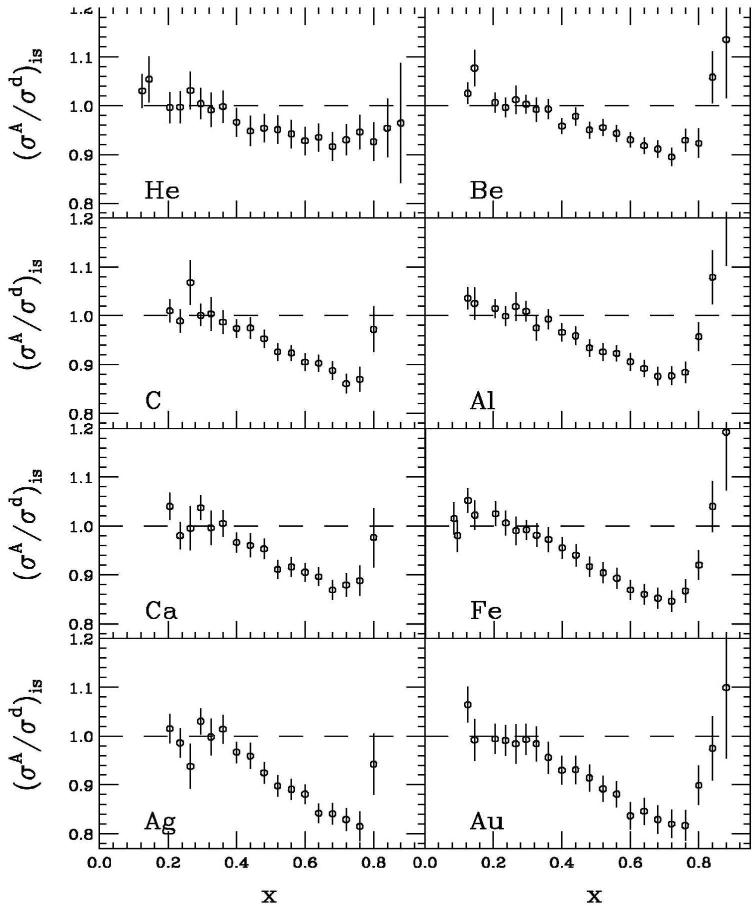
- PLB **123** (1983) 275.
- Simple Parton Counting Expects One
- **MANY Explanations**

SLAC E139

- Phys. Rev. D **49** (1994) 4348.
- Precise large-x data
- Nuclei from A=4 to 197

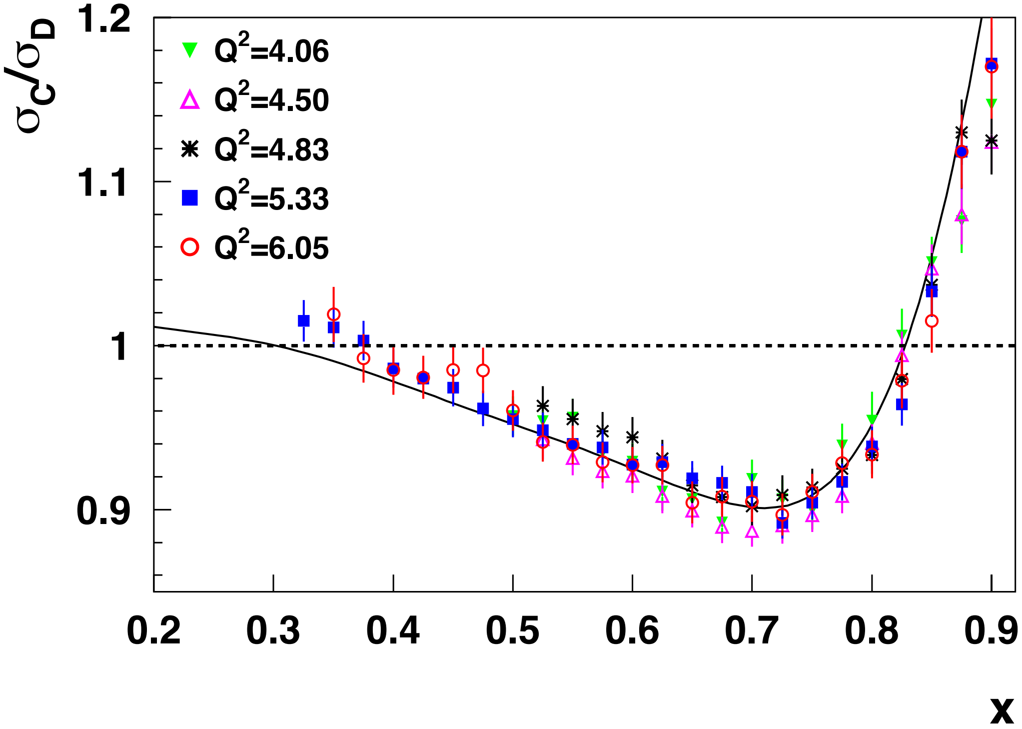
Conclusions from SLAC data

- Nearly Q^2-independent
- Universal x-dependence (shape)
- Some A dependence



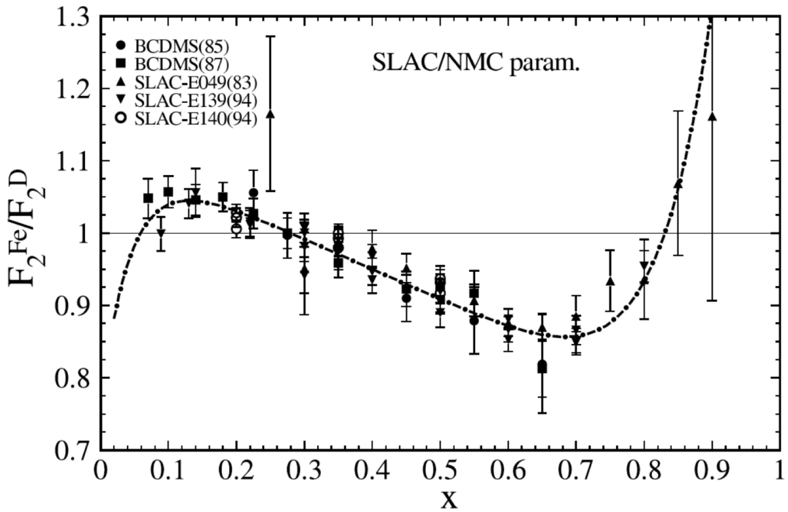
JLab EMC Data

Phys, Rev. Lett. **103** (2009) 202301.

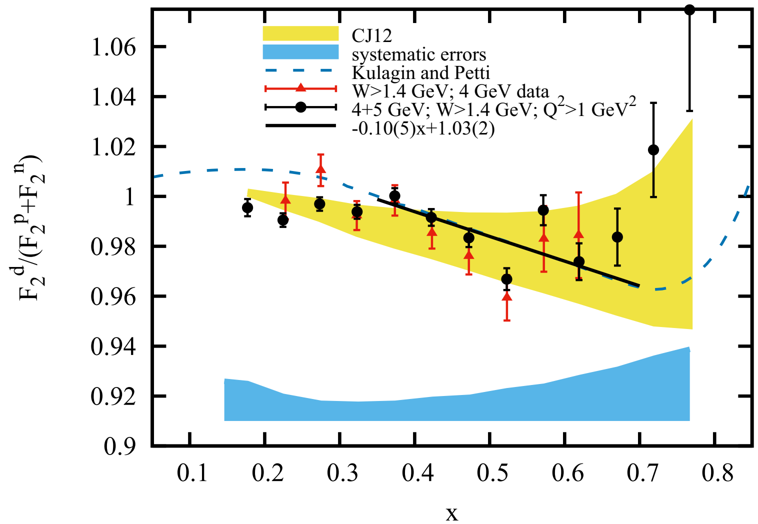


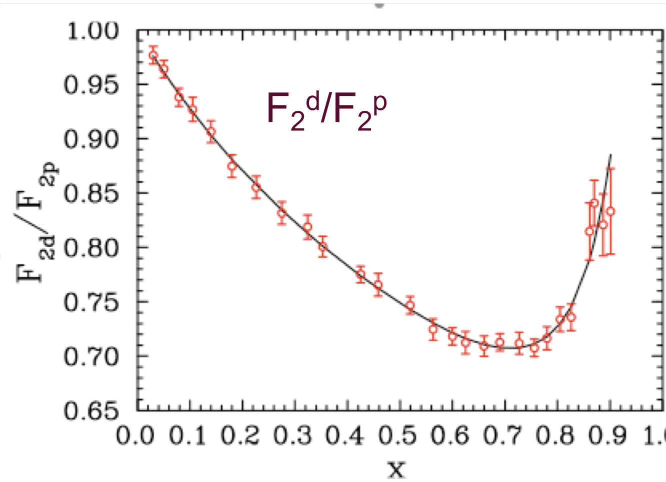
EMC Effect and Nuclear Dependence

Representative EMC Ratio



Phys. Rev. C **92** 015211 (2015)





J. Arrington et al., J.Phys. G36 (2009) 025005

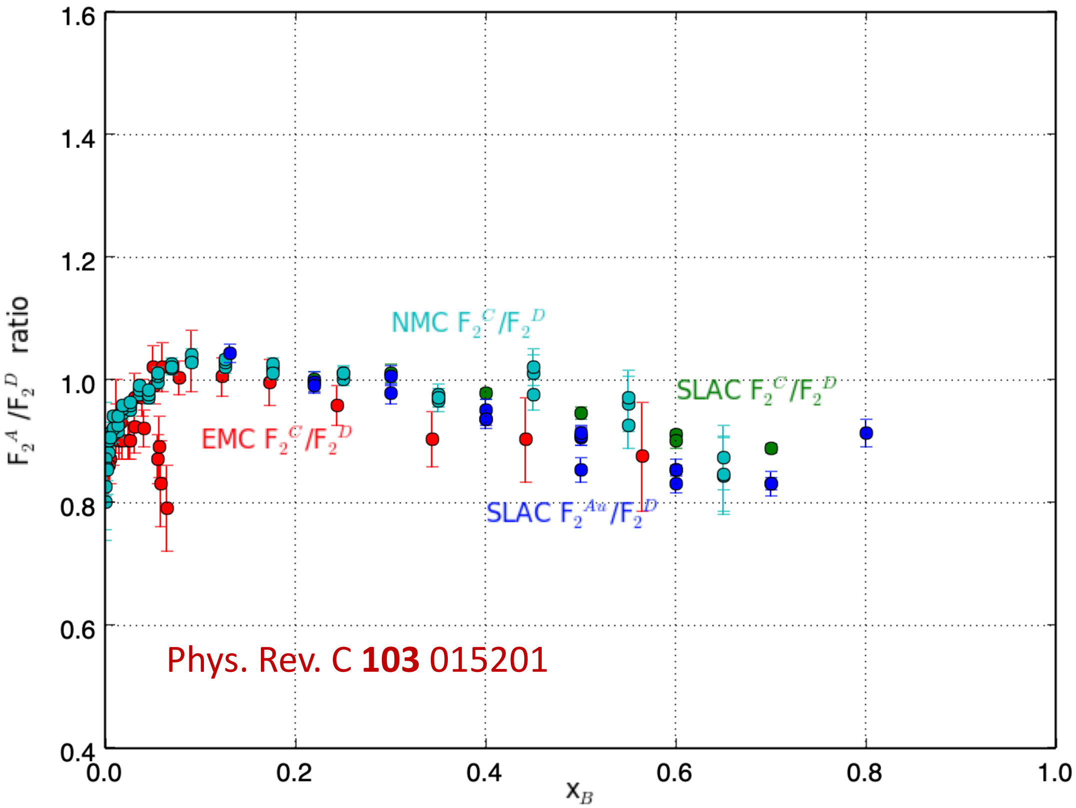
- *Seen numerous times.*
- Deuteron also has a nuclear dependence

EMC data-mining effort

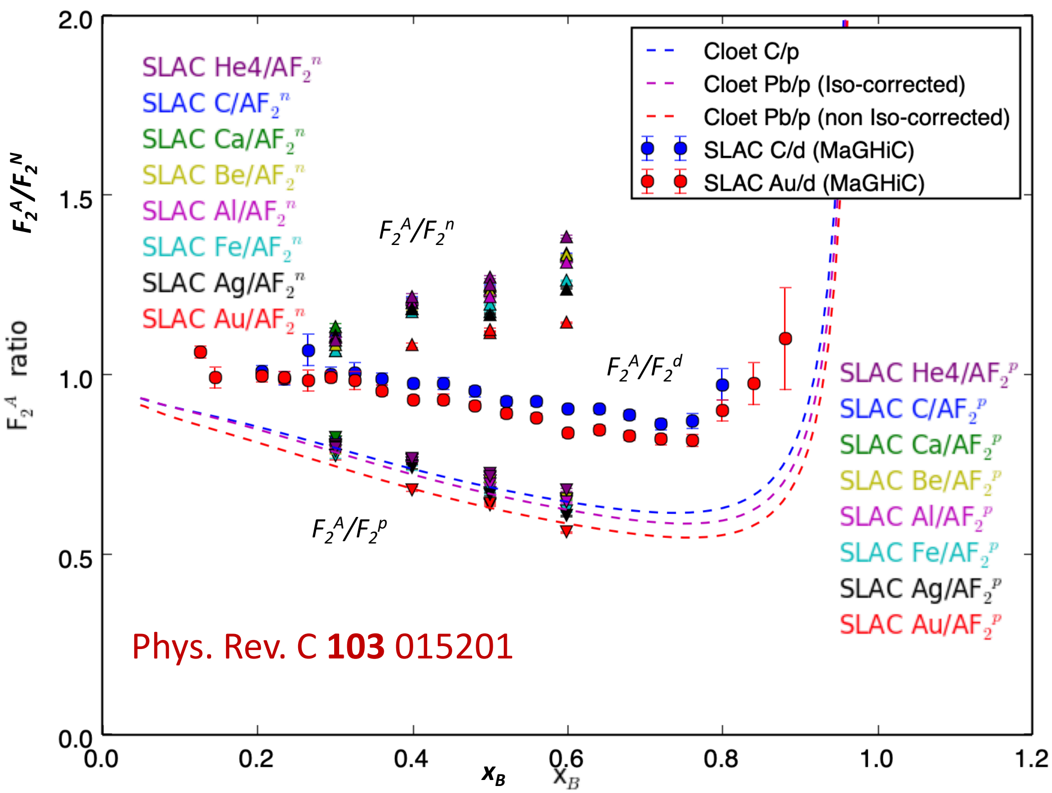
- SLAC (E139) published cross-sections – Phys. Rev. D **49** 4348 (1994).
- Used R1990* parameterization (assumes no nuclear dependence of R) to obtain F_2^A.

** L. Whitlow, et al., Phys.Lett.B 282 (1992)*

Cuts: $Q^2 > 2$ GeV/c^2, $W^2 > 4$ GeV^2

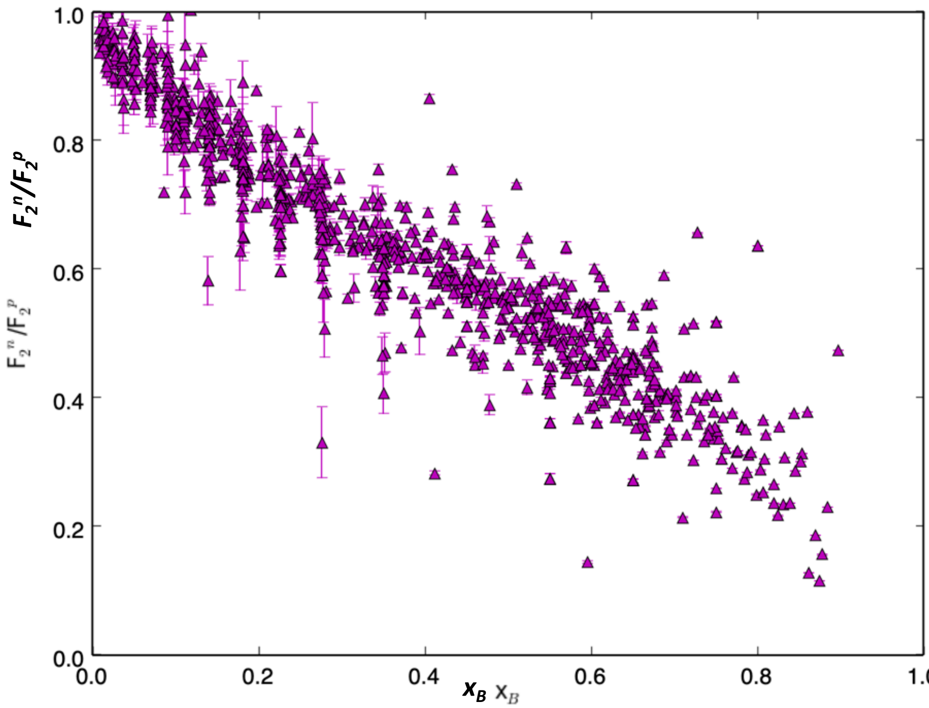


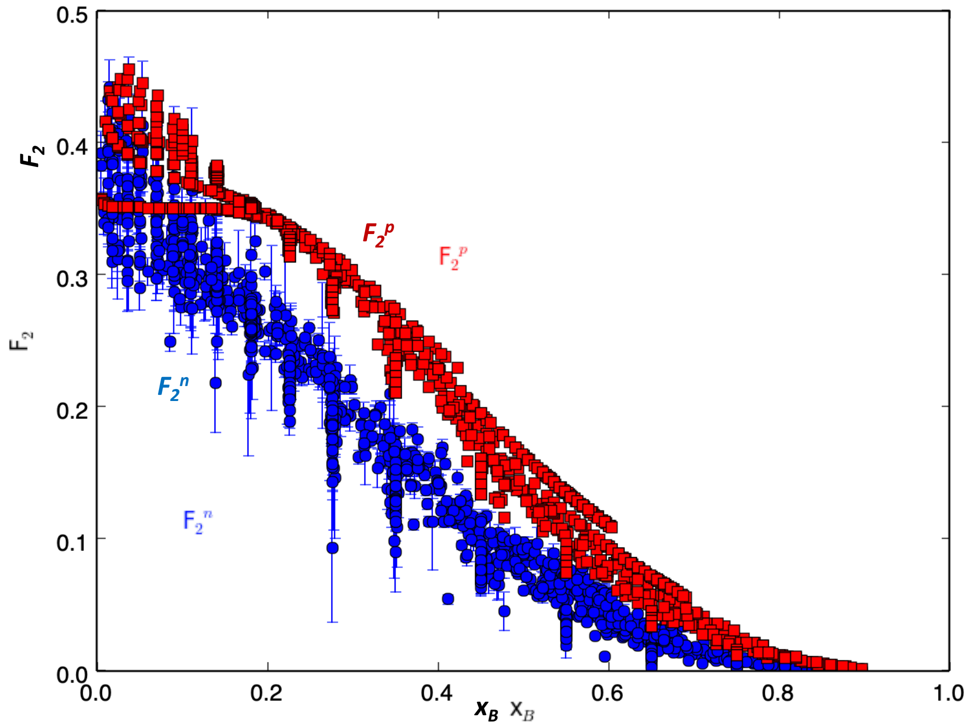
F_2^A/F_2^N ratios per nucleon



- We don't apply iso-scalar corrections for this analysis.
- Theory curves from I. Cloet.
- F_2^p from NMC parameterization. Checked with CJ15 fit.
- F_2^A/ F_2^p seem to agree with theory.
- F_2^A/ F_2^n seem to have broader spread between nuclei.
- Expect some spread with nuclear asymmetry.
- "MaGHiC" Intl. Journ. Mod. Phys. E **23** 8 (2014).

Looking at F_2^n/F_2^p via data

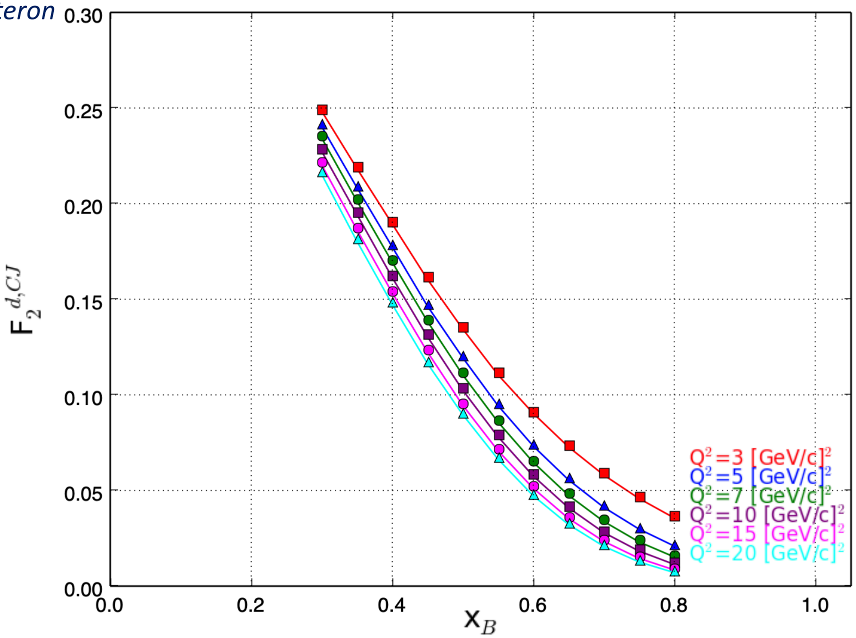




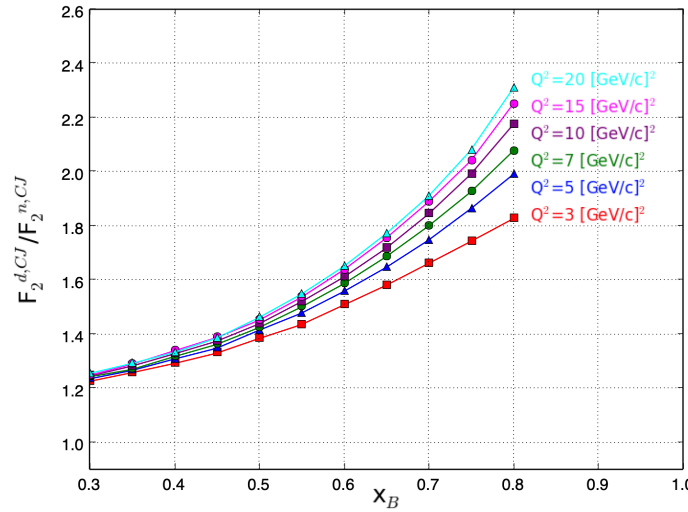
- F_2^n from world data: S. Li's analysis using CJ15 nuclear corrections for deuteron Phys. Rev. D **93** 114017 (2016). Data publication being drafted.
- F_2^p (at same x and Q^2) using SFTM - J. Phys. G **35** 053101 (2008).

Looking at $F_2^D/F_2^{n,p}$ via CJ15

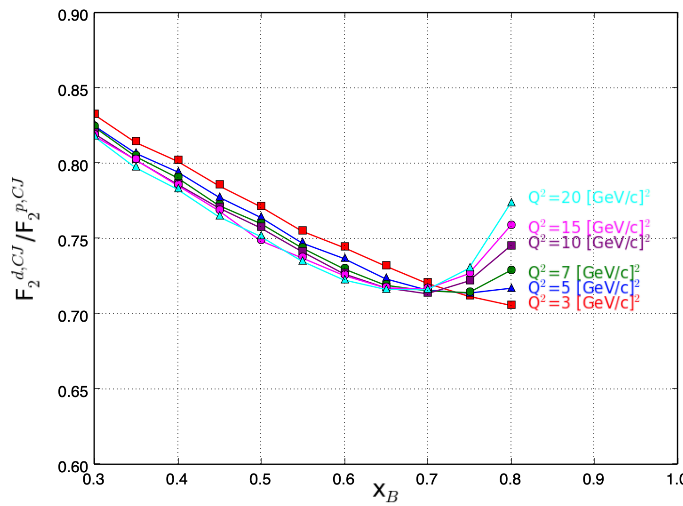
Deuteron



D/n



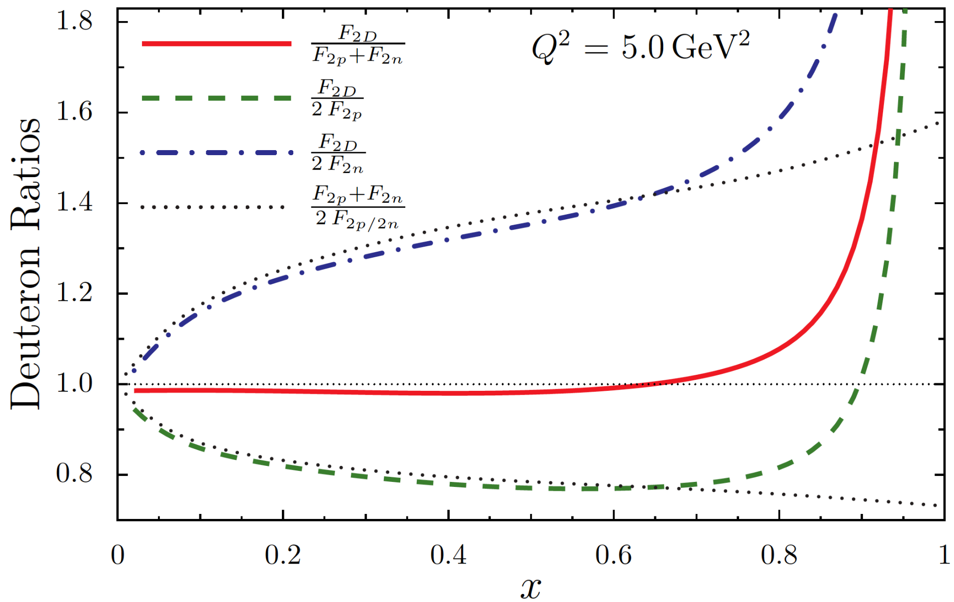
D/p



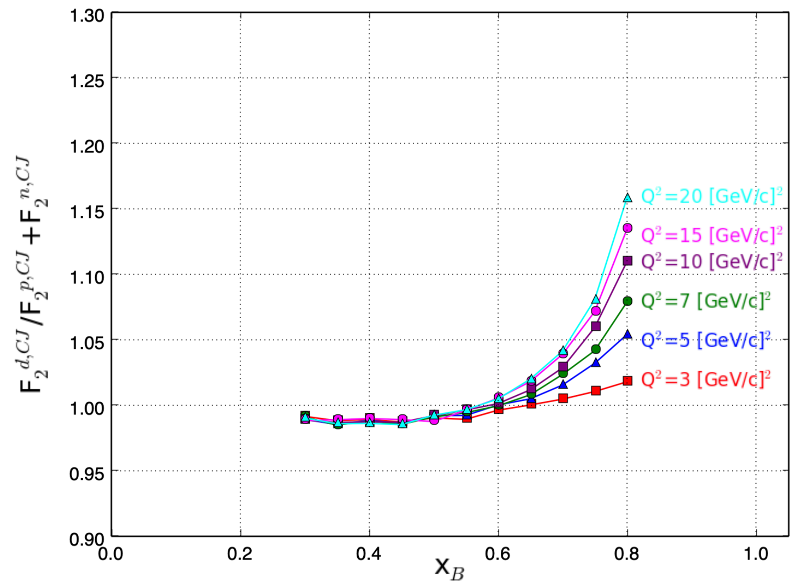
- Neglecting uncertainties on purpose to highlight behavior in the plot.
- There is Q^2 dependence, in particular at large *x.*
- Phys. Rev. D **93** 114017 (2016)

Looking at F_2^D/F_2^{n+p}

Theory-driven

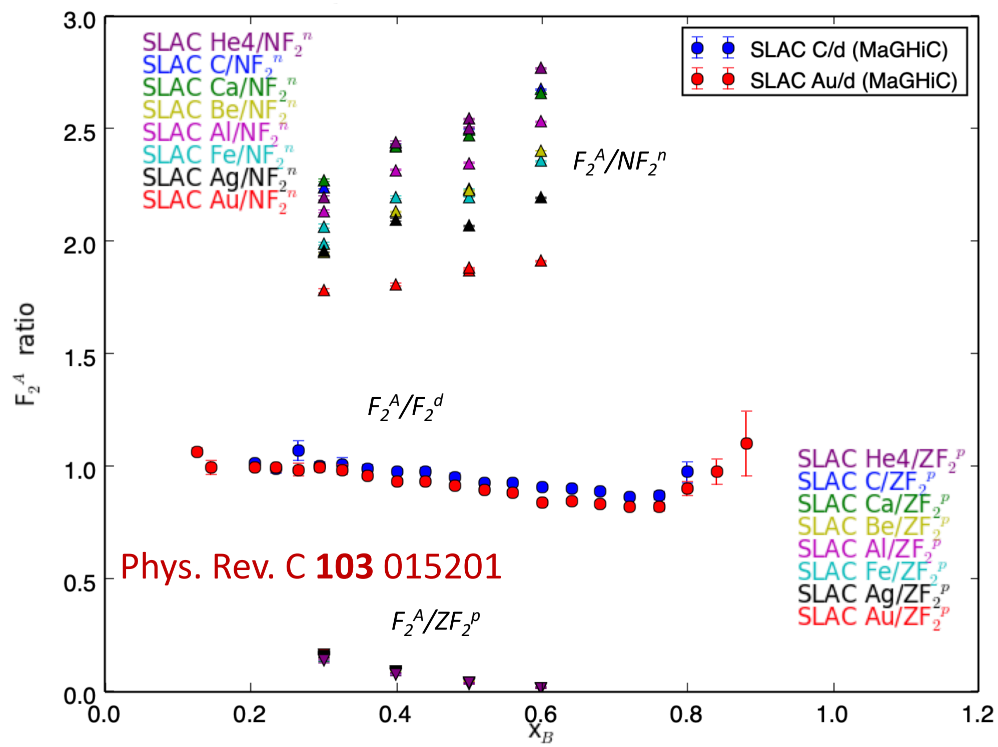


CJ15



- Theory-driven deuteron to sum of free neutron and proton ratio (in red) dips just below unity in EMC region.
- $F_2^D/2F_2^p$ well below unity with similar shape. $F_2^D/2F_2^n$ well above unity with positive slope.
- Phys. Rev. D **93** 114017 (2016)

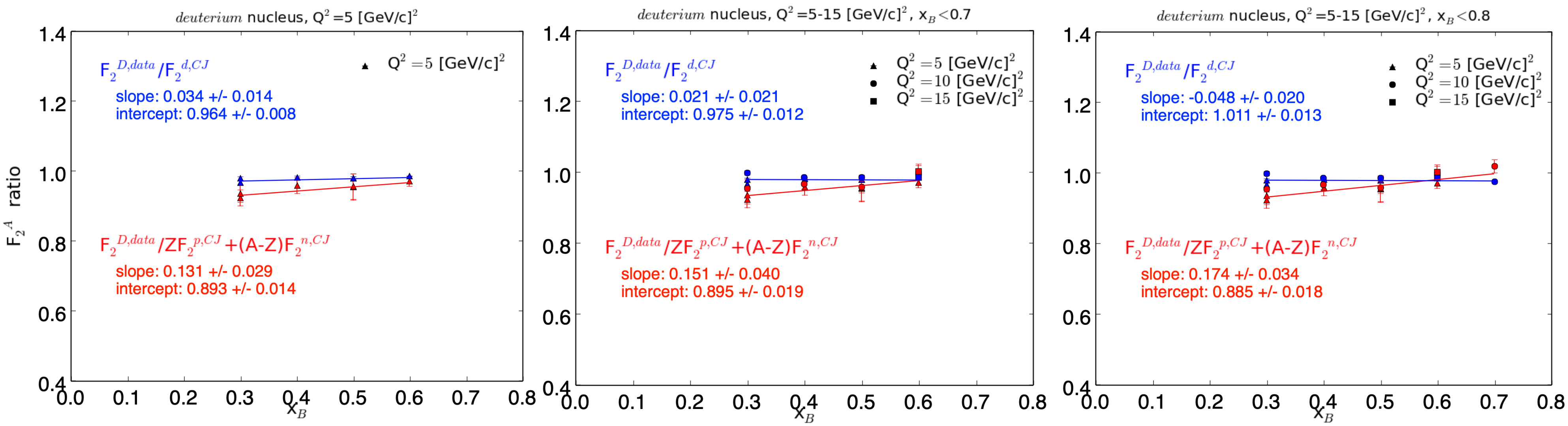
Comparing F_2^A per free neutron, proton.



- Typically observed nucleon spread.
- Starts below 1; approximately 10%.
- Large spread in A/n compared to A/p
- Expect some spread with nuclear asymmetry.
- “MaGHiC” Intl. Journ. Mod. Phys. E **23** 8 (2014).

N = A - Z

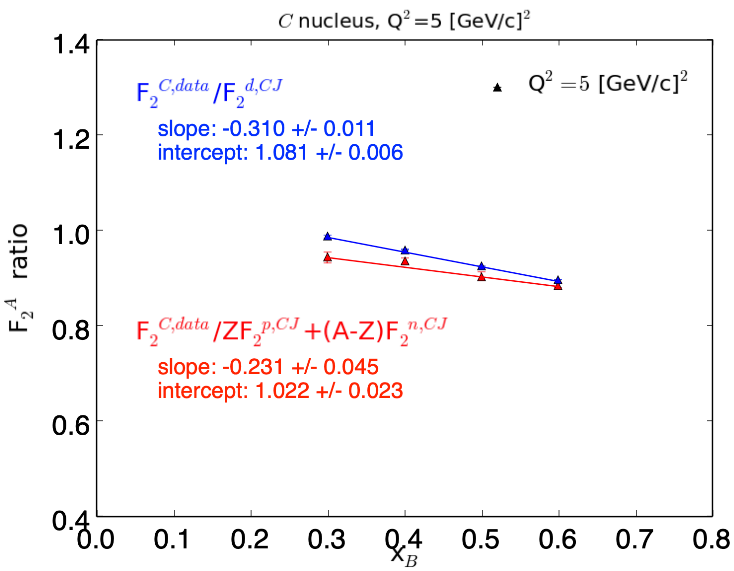
Fitting Slopes of Ratios: Deuteron

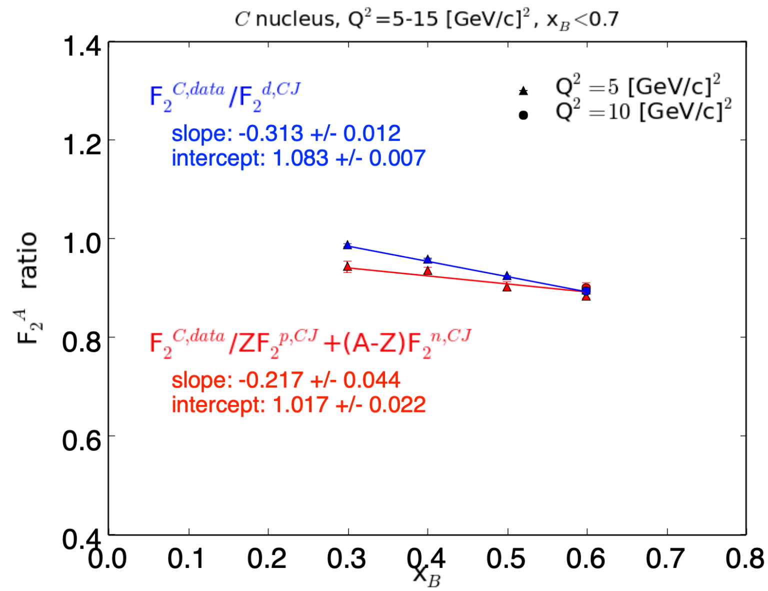


- Linear fits to deuterium data, with cuts on Q^2 and x_B.
- Blue points are ratio of E139 data to deuterium from CJ15.
- Red points are ratio of E139 data to sum of free (CJ15) neutron and proton, without nuclear effects.

Fitting Slopes of Ratios: Carbon

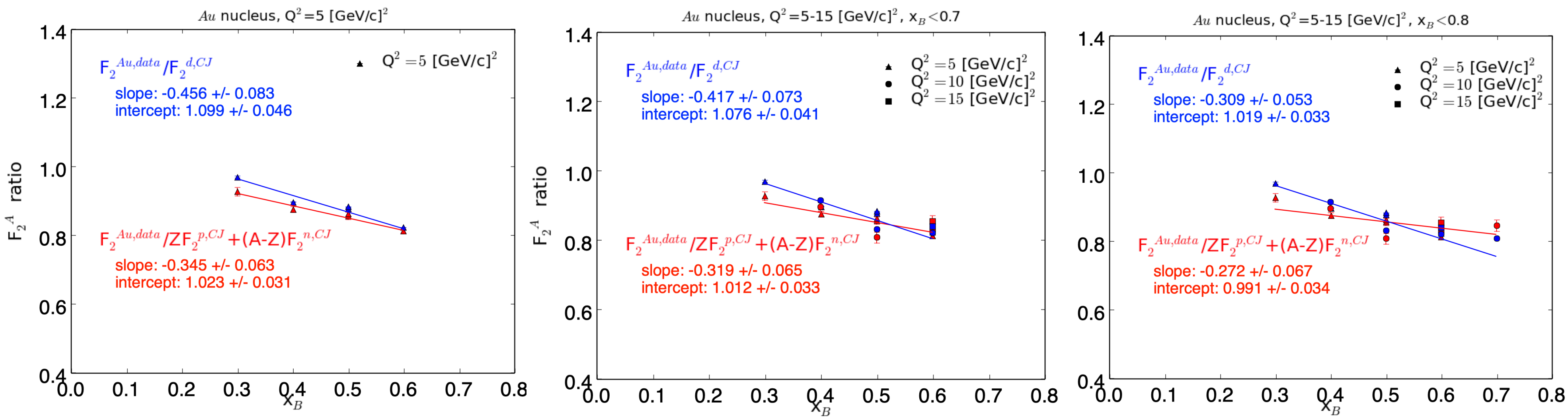
F_2^A/F_2^N





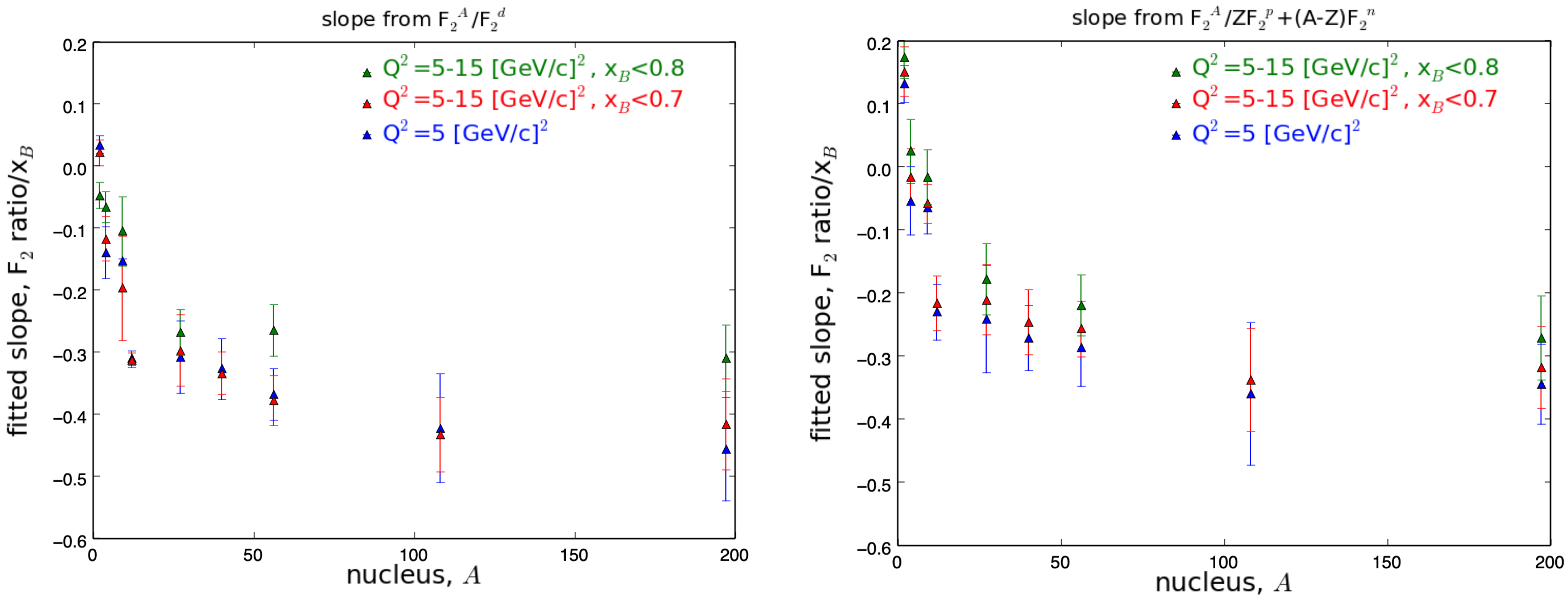
- Linear fits to deuterium data, with cuts on Q^2 and x_B.
- Blue points are ratio of E139 data to deuterium from CJ15.
- Red points are ratio of E139 data to sum of free (CJ15) neutron and proton, without nuclear effects.
- E139 Carbon data didn't go to $x_B > 0.6$.

Fitting Slopes of Ratios: Gold



- Linear fits to deuterium data, with cuts on Q^2 and x_B.
- Blue points are ratio of E139 data to deuterium from CJ15.
- Red points are ratio of E139 data to sum of free (CJ15) neutron and proton, without nuclear effects.

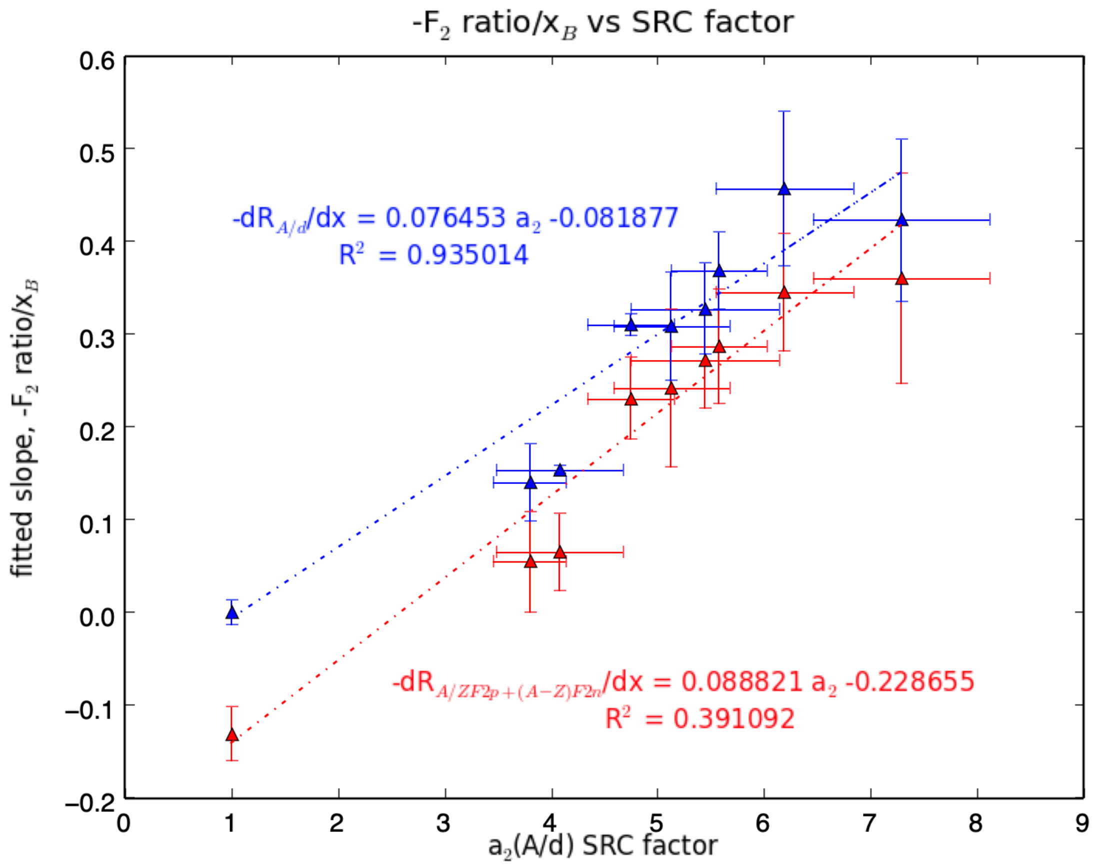
Fitting Slopes of Ratios.



- Fits done in region 0.3 < x < 0.6, with 0.7 included
- Non-negligible nuclear effects in x 0.6-0.7 for extracting EMC Effect in meaningful way.
- Not trivial to disentangle between x and Q^2.
- Inclusion of higher x and Q^2 generates somewhat shallower slopes from rise in nuclear effects.

Comparison of $F_2^A/F_2^{n,p}$ to SRC factor a_2 (A/d)

- a_2(A/d) scaling factor: PRL **106** 052301 (2011). Blue points are for A/d; Red points are for A/n+p.
- Slope of near -0.08 (with deuteron point set to 0) consistent with previous studies.
- Difference in these 2 sets seems to come from nuclear effects from deuteron.
- R^2 orth. distance regression (goodness of fit).

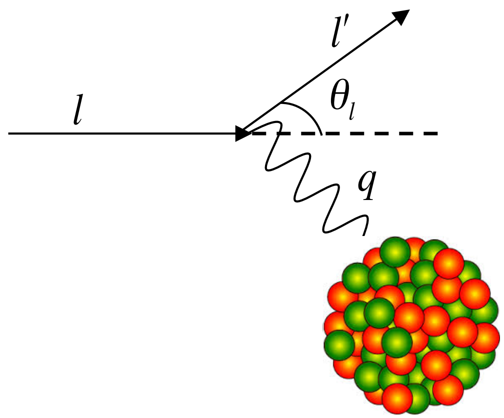


a_2 probability nucleon belongs to a pair (represented as ratio for A/d)

Summary

- Study of nuclear modifications using F_2^n and F_2^p.
- F_2^n made possible with world data set driven CJ15.
- F_2^A / F_2^n seem to have broader spread between nuclei than F_2^A / F_2^p.
- F_2^A / F_2^{n+p} shows relative magnitude of (non-negligible) nuclear effects in deuteron.
- Some of the traditional EMC observation, as well as the correlation with SRC, may be deuteron nuclear effects and Q^2 dependence - especially at large *x.*
- *Collaborative effort between VUU and JLab – with a VUU student as an author on the publication.*

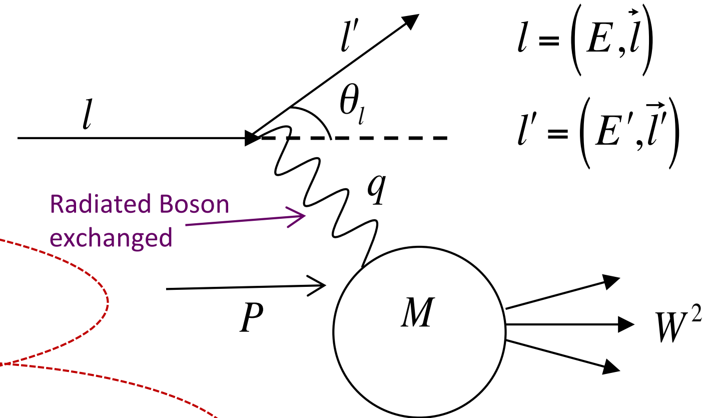
Backup Slides



Inclusive Lepton Scattering

Only detecting the scattered lepton:

Physics Reports **406** 127 (2005)



$$l = \left(E, \vec{l}\right)$$

$$l' = \left(E', \vec{l}'\right)$$

Virtuality
(Resolving power) [GeV²]

$$q = l - l'$$

$$Q^2 = -q^2 = 4EE'\sin^2\left(\frac{\theta_l}{2}\right)$$

~ λ microscope

Bjorken scaling variable *x*
(dimensionless)

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

Momentum carried by quarks

Energy transferred to target

$$\nu = E - E'$$

Invariant mass
of final states [GeV²]

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

Inelasticity: $y = \dfrac{\nu}{E}$

Inclusive Lepton Scattering

Physics Reports **406** 127 (2005)

Structure Functions; Observable of Interest is F_2

Incl. Cross-Section:

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

Mott: Scattering from a point particle:

$$\sigma_{Mott} = \frac{4x^2E'^2}{Q^4}\cos^2\frac{\theta}{2}$$

Callan-Gross Relation:

$$F_2(x) = 2xF_1(x) = x\sum_q e_q^2 f_q(x)$$

$f_q(x)$ Quark probability distribution *i.e.* **Parton Distr. Fn. (PDF)**

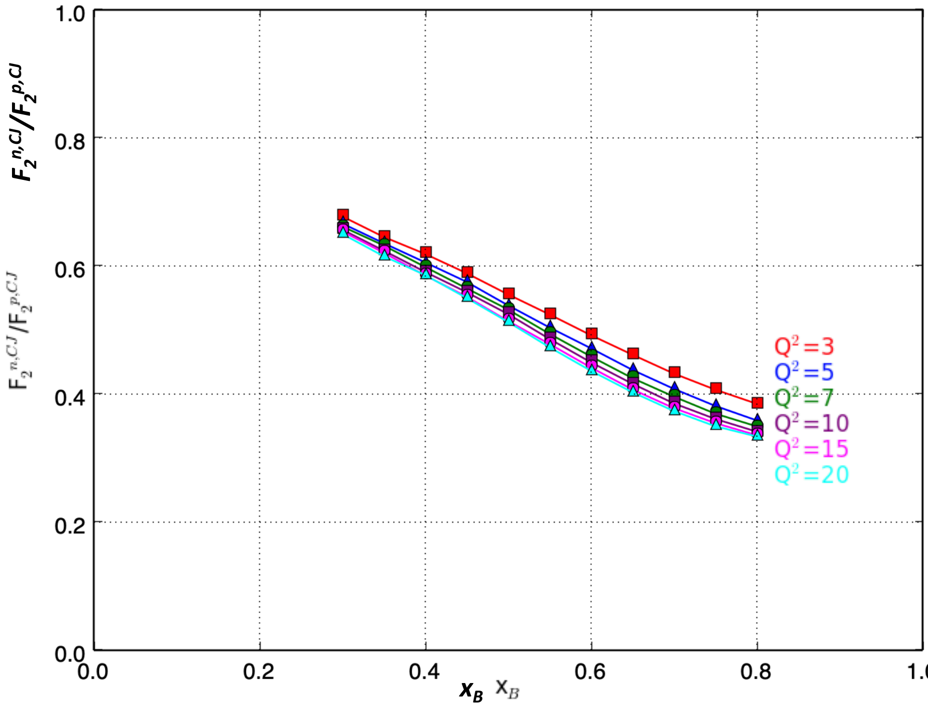
e_q Quark charge

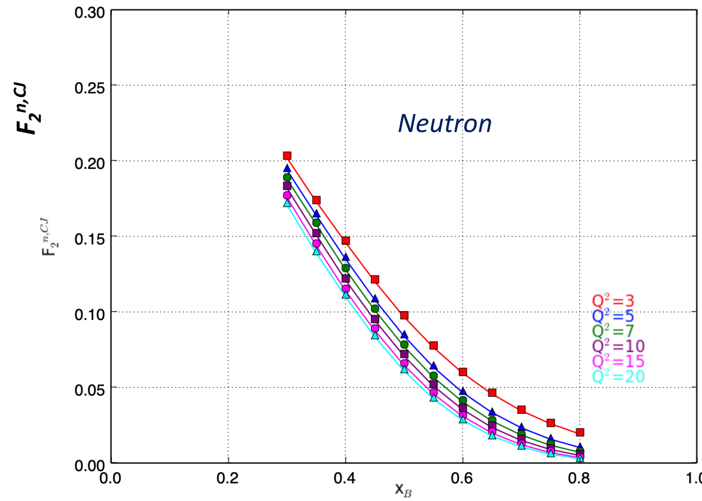
Nuclear Ratios

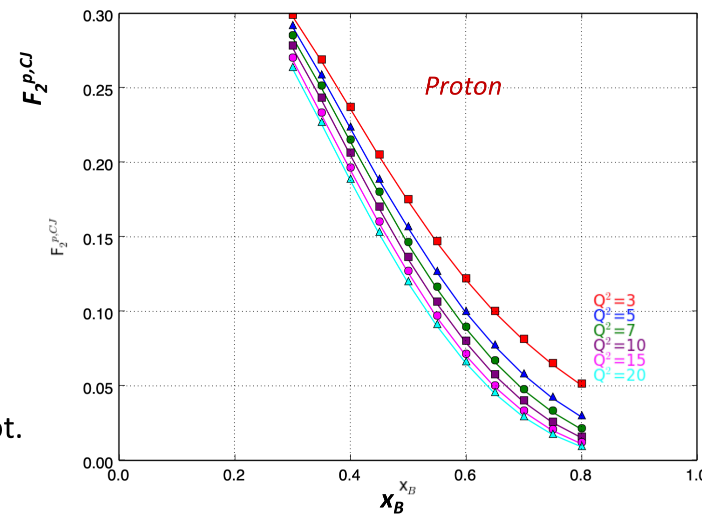
- Take the ratio of F_2 of a near isoscalar (#n = #p) target to simplest nucleus (deuteron).
- Are there changes in the medium?
- Is F_2 universal?
- If nuclei are (only) composed of neutrons and protons then, normalizing by nucleon number (A), such a ratio should be unity.

$$\frac{2}{A}\frac{F_2^A(x)}{F_2^d(x)} = 1$$

Looking at F_2^n/F_2^p via CJ15



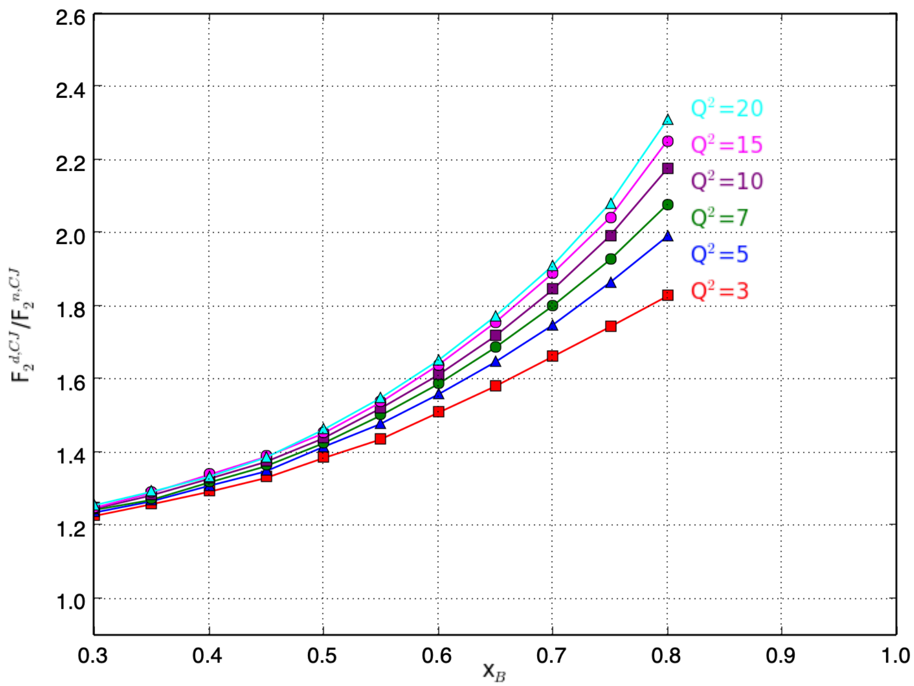




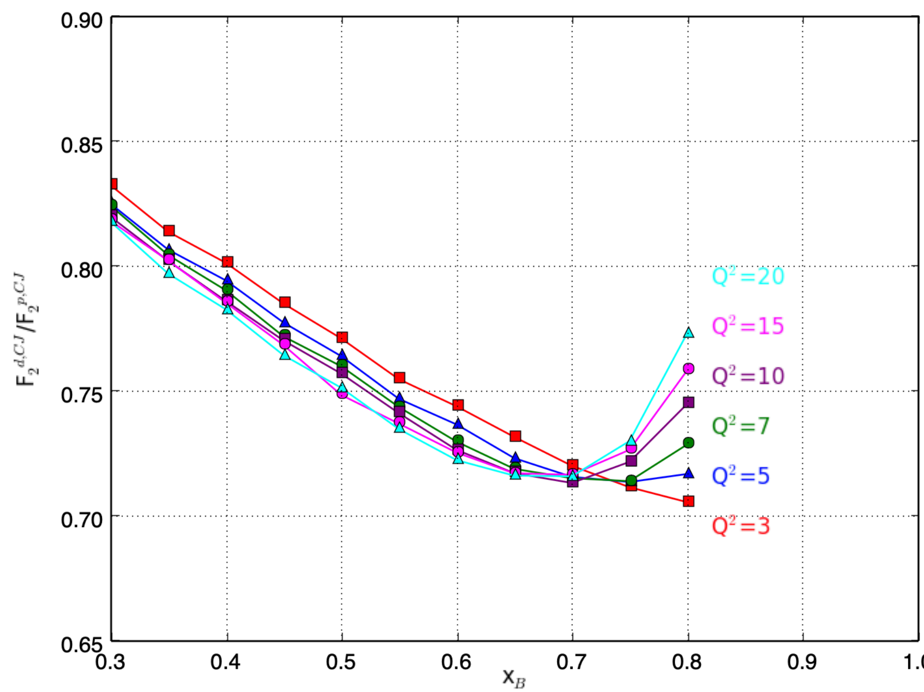
- Neglecting uncertainties on purpose to highlight behavior in the plot.
- There is Q^2 dependence, in particular at large x and low Q.
- Phys. Rev. D **93** 114017 (2016)

Looking at $F_2^d/F_2^{n,p}$ via CJ15

d/n

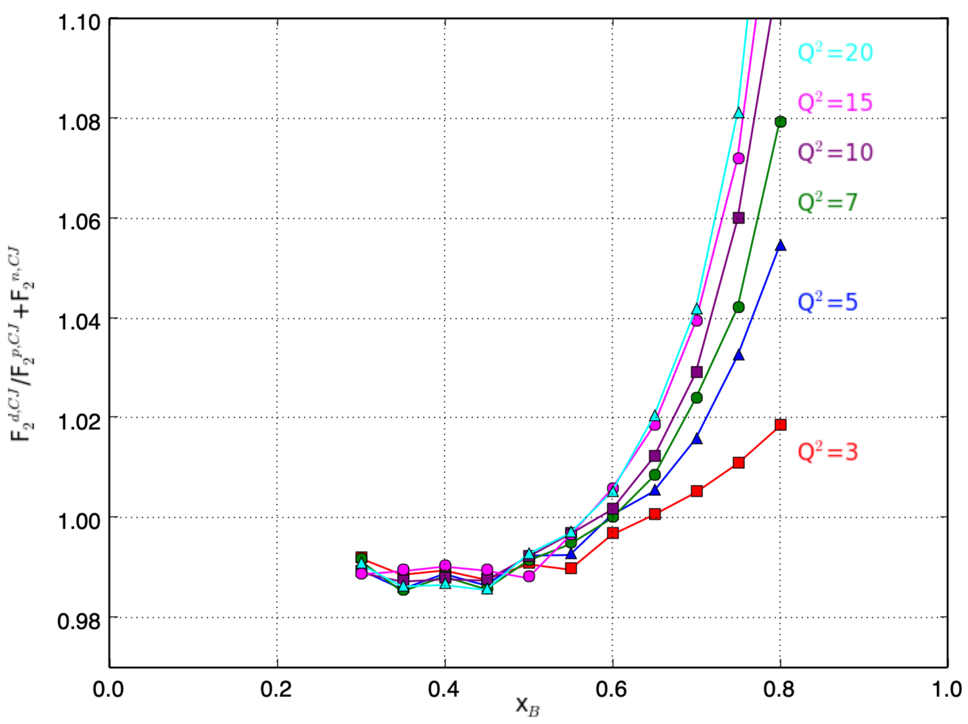


d/p



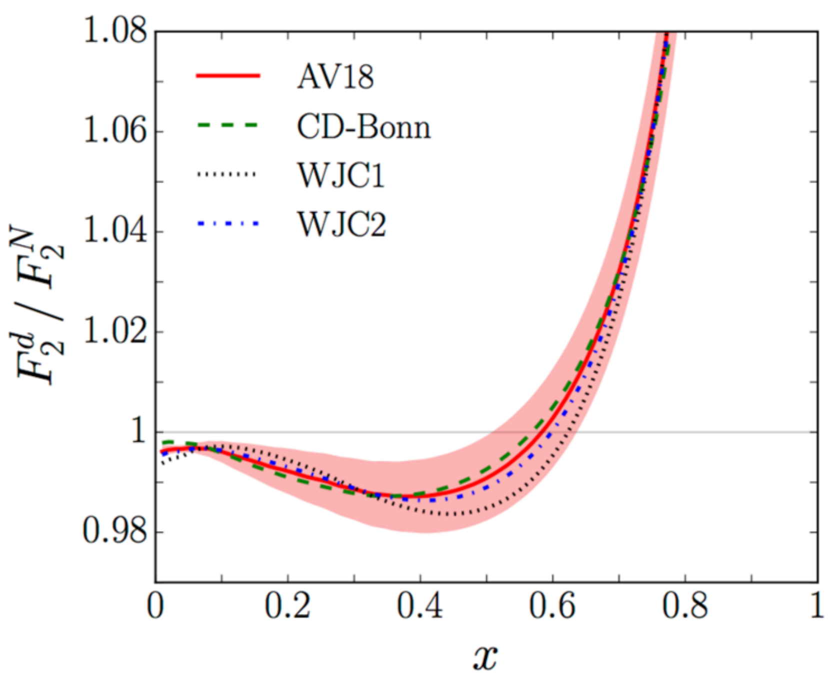
- Phys. Rev. D **93** 114017 (2016)

Looking at F_2^d/F_2^{n+p} via CJ15



- Phys. Rev. D **93** 114017 (2016)

Looking at F_2^d/F_2^N Theory



- Theoretical extraction of F_2^d/F_2^N.
- Some x dependence -> ~2% effect in 0.3-0.7 x region.
- Phys. Rev. D **93** 114017 (2016)

EMC data-mining effort

SLAC (E139) published cross-sections. Used R1990* parameterization (assumes no nuclear dependence of R) to obtain F_2^A.

**Whitlow's thesis*

$$F_2 = \frac{d^2\sigma}{d\Omega dE'} \frac{1+R}{1+\varepsilon R} \times kinem.$$

$$\varepsilon = (1 + 2\frac{\nu^2 + Q^2}{Q^2} tan^2 \frac{\theta}{2})^{-1}$$

$$kinem. = \frac{K\nu}{4\pi^2\alpha} \frac{1}{\Gamma} \frac{1}{1+\nu^2/Q^2}$$

$$K = (W^2 - M^2)/(2M)$$

$$\Gamma = \frac{\alpha K}{2\pi^2 Q^2} \frac{E'}{E} \frac{1}{1-\varepsilon}$$