MeAsurement of F_2^n/F_2^p, d/u RAtios and $A=3$ EMC Effect in Deep Inelastic Electron Scattering Off the Tritium and Helium MirrOr Nuclei

JLab Experiment E12-10-103 - Update

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for the JLab MARATHON Collaboration

Tritium Collaboration Meeting

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Deep Inelastic Scattering and Quark Parton Model

- DIS cross section - Nucleon structure functions F_1 and F_2:

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

$$R = \frac{\sigma_L}{\sigma_T} = \frac{F_2 M}{F_1 \nu}\left(1 + \frac{\nu^2}{Q^2}\right) - 1$$

$$\nu = E - E'$$

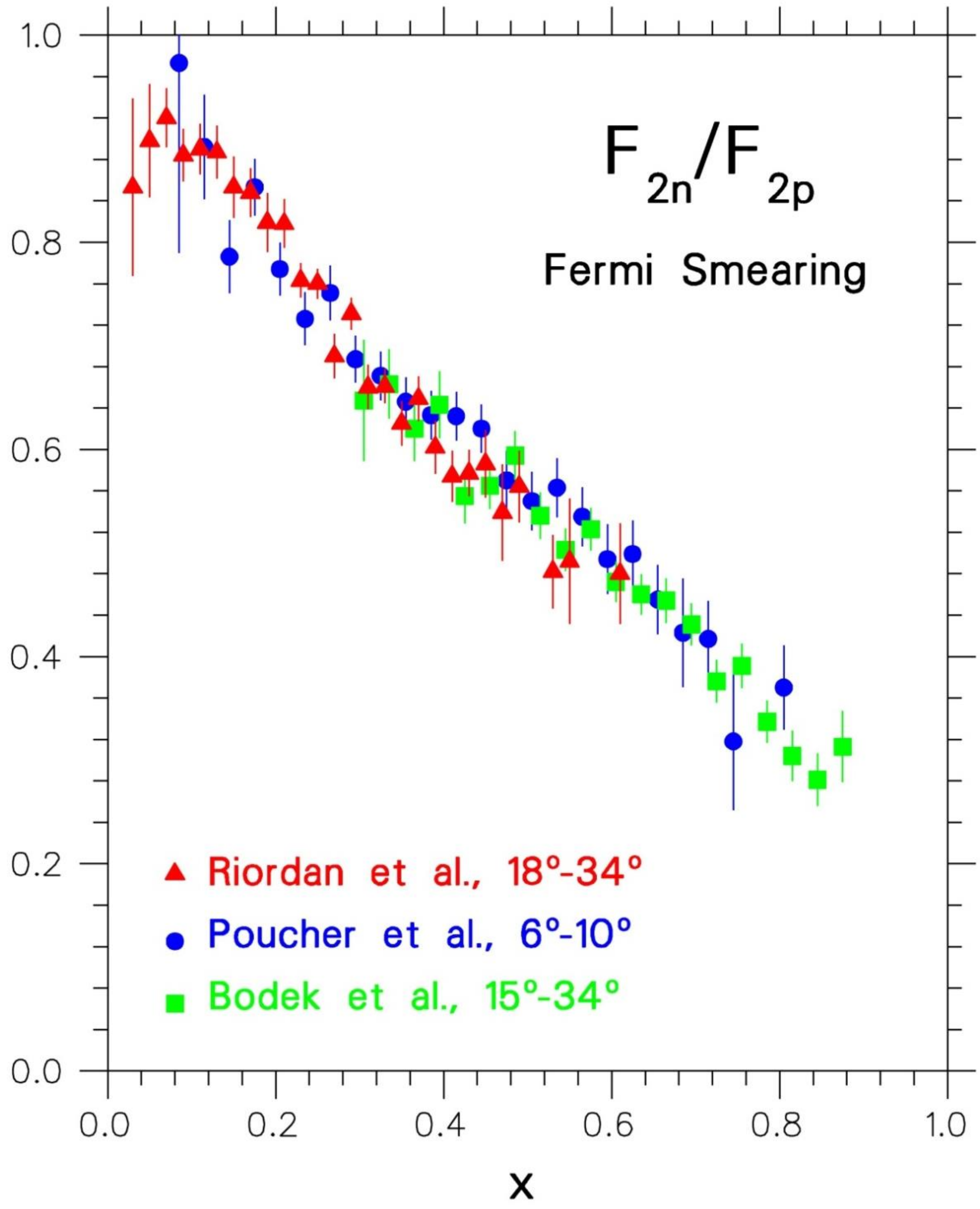
$$Q^2 = 4EE' \sin^2(\theta/2)$$

- QPM interpretation in terms of quark momentum probability distributions $q_i(x)$ (large Q^2 and ν, fixed x):

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 q_i(x) \qquad F_2(x) = x\sum_i e_i^2 q_i(x)$$

- Bjorken x: fraction of nucleon momentum carried by struck quark:

$$x = Q^2 / 2M\nu$$



SLAC 1968-1972

Friedman, Kendall, Taylor

Nobel 1991

F_2^n/F_2^p extracted from *p* and *d* DIS using a Fermi-smearing model and a non-relativistic *N*-*N* potential

Data in disagreement with *SU(6)* prediction: 2/3=0.67!

High momentum quarks in *p(n)* are *u(d)* valence quarks

There are no high momentum strange quarks in *p* and *n*

Sea quarks dominate at small *x*

Data consistent with di-quark model by Feynman and others

F_2^n / F_2^n, d/u Ratios and A_1 Limits for $x \to 1$

	F_2^n/F_2^p	d/u	A_1^n	A_1^p
SU(6)	2/3	1/2	0	5/9
Diquark/Feynman	1/4	0	1	1
Quark Model/Isgur	1/4	0	1	1
Perturbative QCD	3/7	1/5	1	1
Quark Counting Rules	3/7	1/5	1	1

A_1: Asymmetry measured with polarized electrons and nucleons. Equal in QPM to probability that the quark spins are aligned with the nucleon spin.

A_1^p, A_1^n: Extensive experimental programs at CERN, SLAC, DESY and JLab (6 GeV and 12 GeV Programs)

Structure Function Ratio Problem !

- **Convolution model:**

  Fermi motion and binding, covariant deuteron wave function, off-shell effects :

$$F_2^d(x,Q^2) = \int dy \rho(y)[F_2^p(x/y,Q^2)+F_2^n(x/y,Q^2)]$$

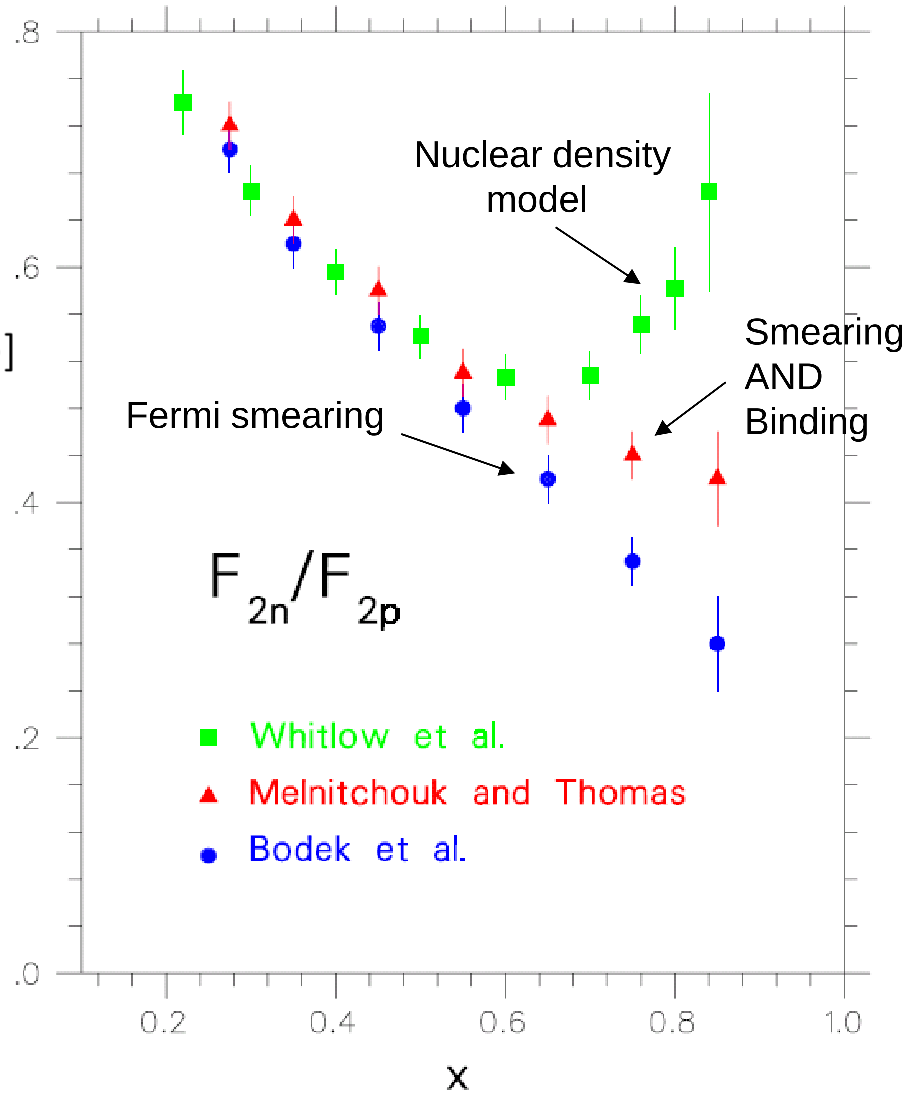
[Melnitchouk and Thomas (1996)]

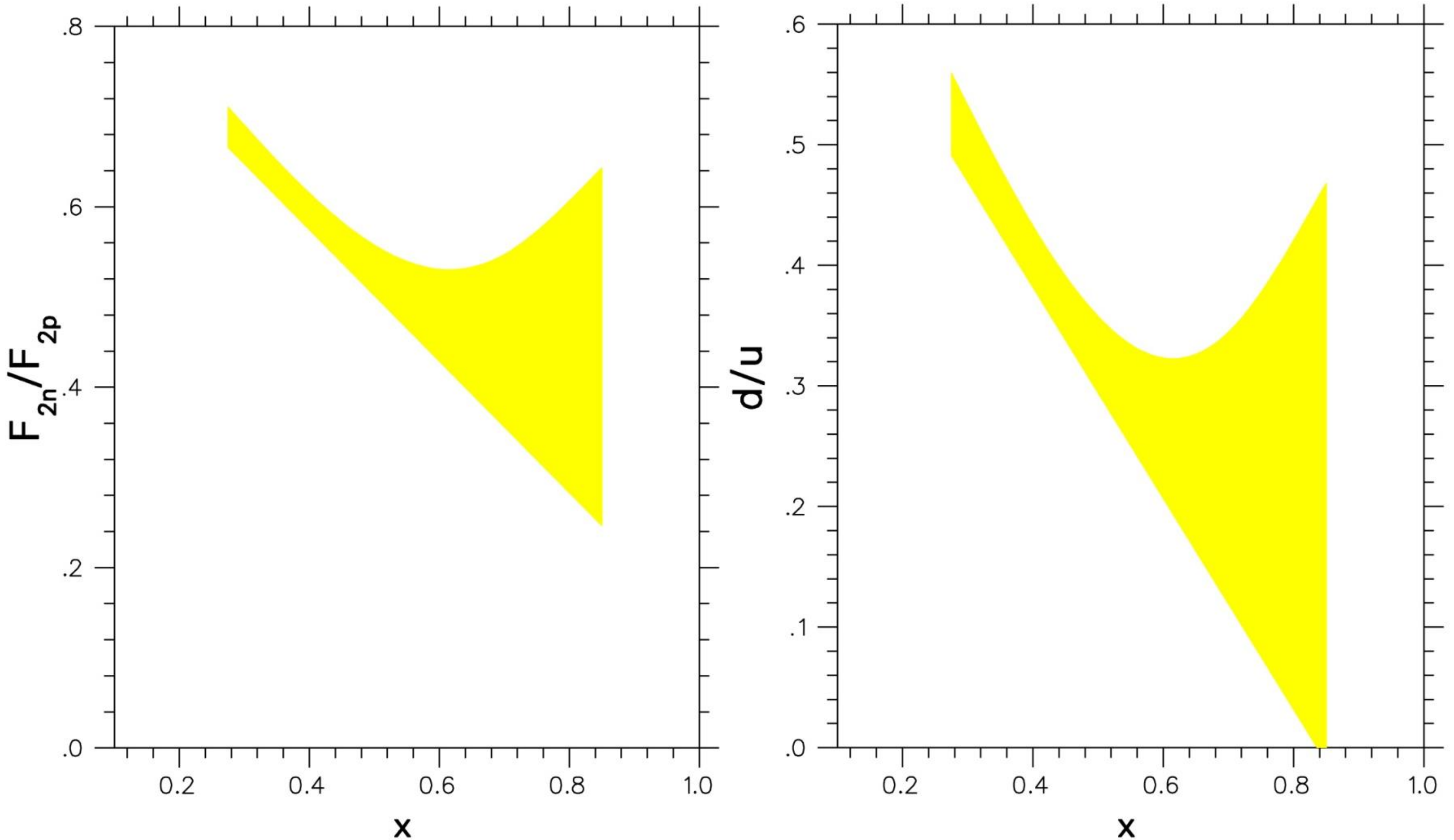
- **Nuclear density model:**

  EMC effect for deuteron scales with nuclear density:

$$\frac{F_2^d}{F_2^p+F_2^n} = 1 + \frac{\rho_d}{\rho_A-\rho_d}\left[\frac{F_2^A}{F_2^d} - 1\right]$$

[Frankfurt and Strikman (1988)]

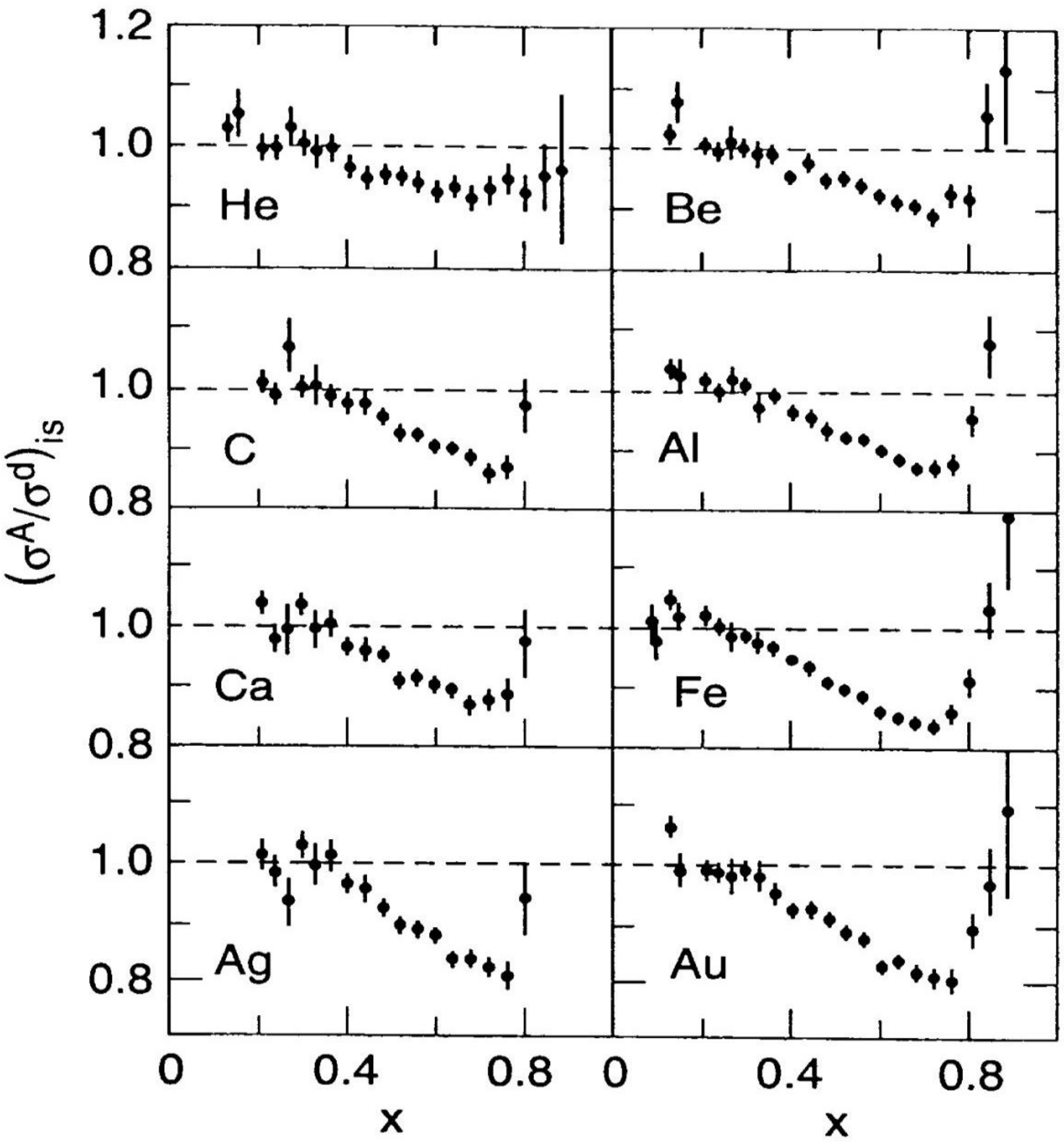




The three analysis methods indicate tremendous uncertainties in high-*x* behavior of F_2^n/F_2^p and *d/u* ratios … *d/u* essentially unknown at large *x*!

EMC Effect

- Nuclear F_2 structure function per nucleon is different than that of deuterium: large Bjorken x and nuclear mass A dependence.
- Quark distribution functions modified in the nuclear medium.
- Possible explanations include:
  - Binding effects beyond nucleon Fermi motion
  - Enhancement of pion field with increasing A
  - Influence of possible multi-quark clusters
  - Change in the quark confinement scale in nuclei
- No universally accepted theory for the effect explanation.
- A=3 data will be pivotal for understanding the EMC effect.
- Theorists: Ratio of EMC effect for ^{3}H and ^{3}He is the best quantity for quantitative check of the theory, free of most uncertainties.

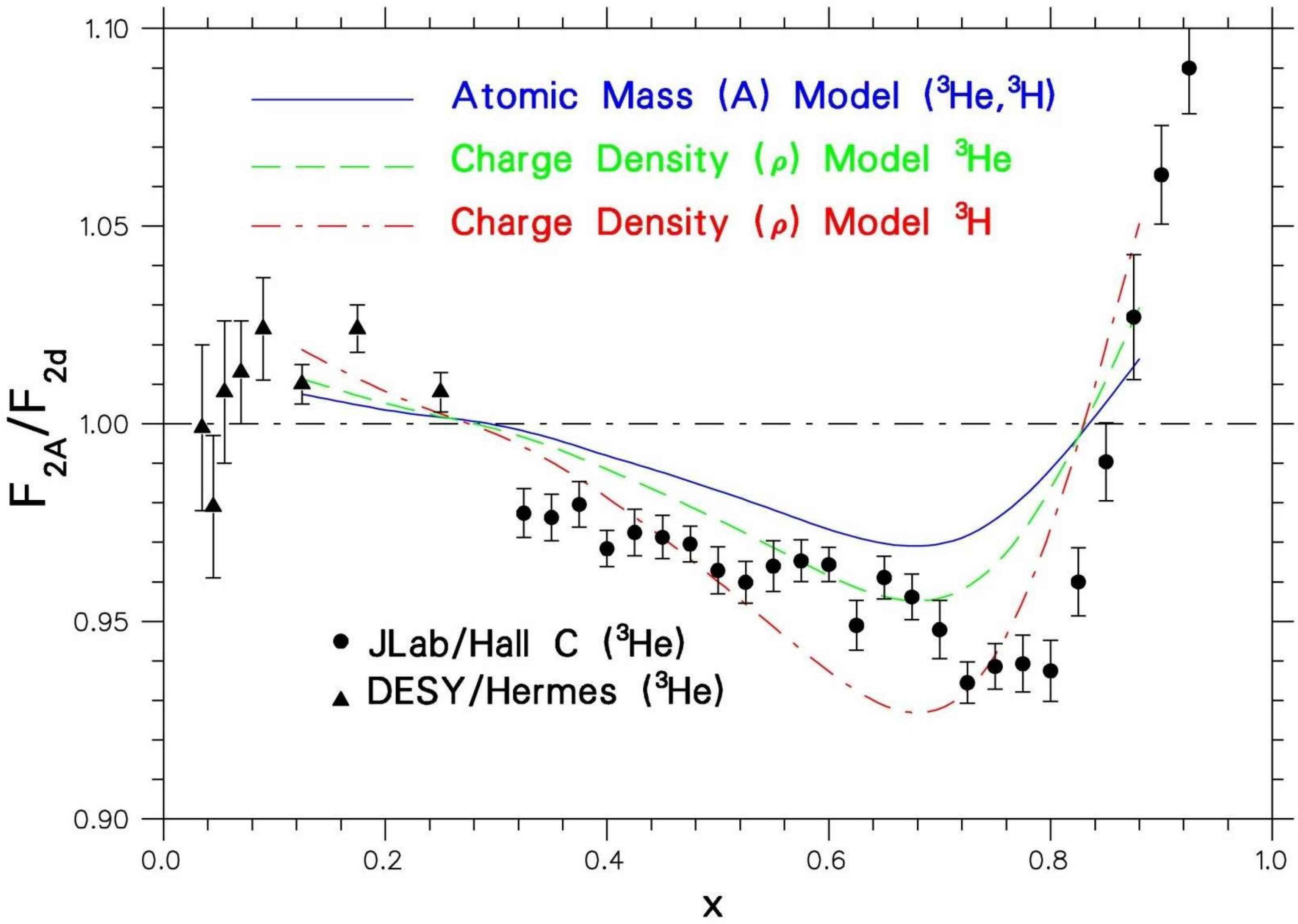


A Dependence
EMC Effect

SLAC E-139, 1984
J. Gomez et al.

Nucleon momentum probability distributions in nuclei different from those in deuterium. Effect increases with mass number *A*.

EMC Effect for *A=3* Mirror Nuclei



Nucleon F_2 Ratio Extraction from ^{3}He/^{3}H

- Just perform DIS from ^{3}He and ^{3}H. Binding of nucleons in the two nuclei is of same nature. Differences between bound and free nucleons in the two nuclei is calculable, summarized, for their ratio, by some parameter R^* (W. Melnitchouk *et al.*).

- If $R=\sigma_L/\sigma_T$ is the same for ^{3}He and ^{3}H, measured DIS cross section ratio must be equal to the F_2 structure function ratio as calculated using R^*:

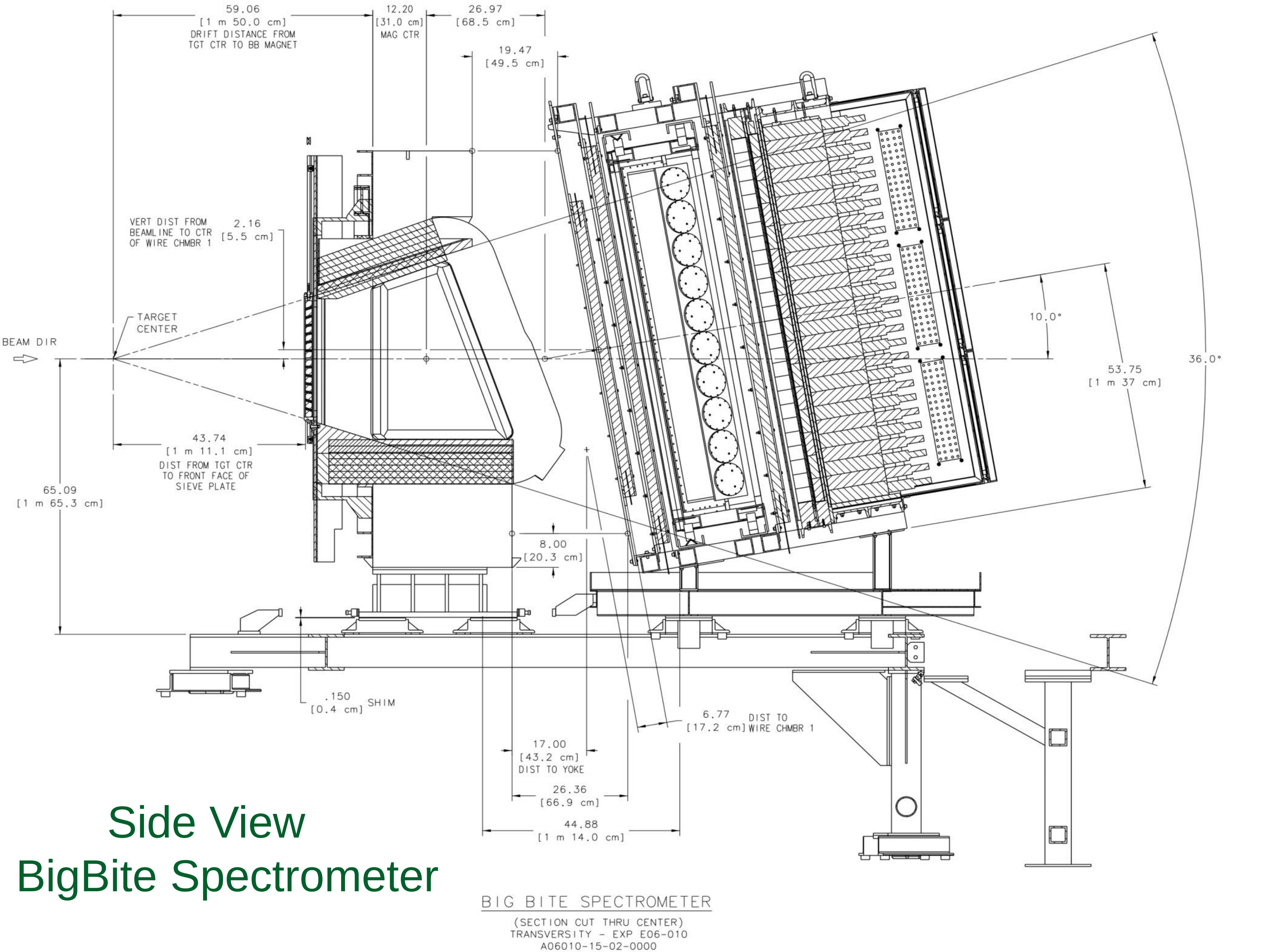
$$\frac{\sigma^{^3He}}{\sigma^{^3H}} = \frac{F_2^{^3He}}{F_2^{^3H}} = R^* \frac{2F_2^p + F_2^n}{F_2^p + 2F_2^n}$$

- Determine nucleon F_2 ratio using A=3 DIS cross section data and R^*($\approx$1) from theory:

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

Experimental Plan and Requirements

- ^{3}He/^{3}H DIS measurements approved to run in Hall A:
  - Beam Energy: 11.0 GeV – Beam Current: 25 μA
  - Small angles (15^o - 23^o): Left HRS system
  - Large angles (4 settings: 42^o , 47^o , 52^o, 57^o): BigBite system
  - ~700 hours for *d/u* measurement (@ 100% efficiency)
- Desirable to check that the ratio $R=\sigma_L/\sigma_T$ is the same for ^{3}He and ^{3}H: Rosenbluth separation of DIS cross section. Need dedicated 3.3, 4.4, 5.5, 6.6, 7.7, 8.8 GeV energies.
  - Wide angular range (13^o - 68^o): Left HRS system
  - ~300 hours for $R=\sigma_L/\sigma_T$ measurement (@ 100% efficiency)
- Need target system with helium/tritium/deuterium/hydrogen high pressure cells: 25 cm long, 1.25 cm diameter, 14 atm (^{3}H), 30 atm (^{1}H, ^{2}H, ^{3}He). Must collimate cell end caps.
- (See presentations by R. Holt, D. Meekins, P. Solvignon).



Side View
BigBite Spectrometer

The BigBite Spectrometer – Special Issues

- 40-50 msr solid angle, ~1.0% momentum resolution
- Successfully employed in previous Hall A experiments
  - Drift Chamber set and Scintillator (trigger) Hodoscope package
  - Pb-glass Calorimeter and Gas Threshold Cerenkov Detector
- **BUT** need to **IMPROVE** Cerenkov Detector: i) ~double radiator length (from 40 to 70 cm) and ii) recoat all mirrors and Winston cones, <u>or</u> **REUSE** mirrors and phototubes to build a new one that focuses light towards one side only, away from the beam. Cerenkov Sum signal must be part of the trigger.
- (See N. Sparveris/M. Paolone, Temple U. presentation)
- To minimize background through dipole (dominant source): install lead collimator in front of dipole magnet?
- To develop reliable Monte Carlo model: set up TOSCA model and cross check it with basic magnetic measurements?

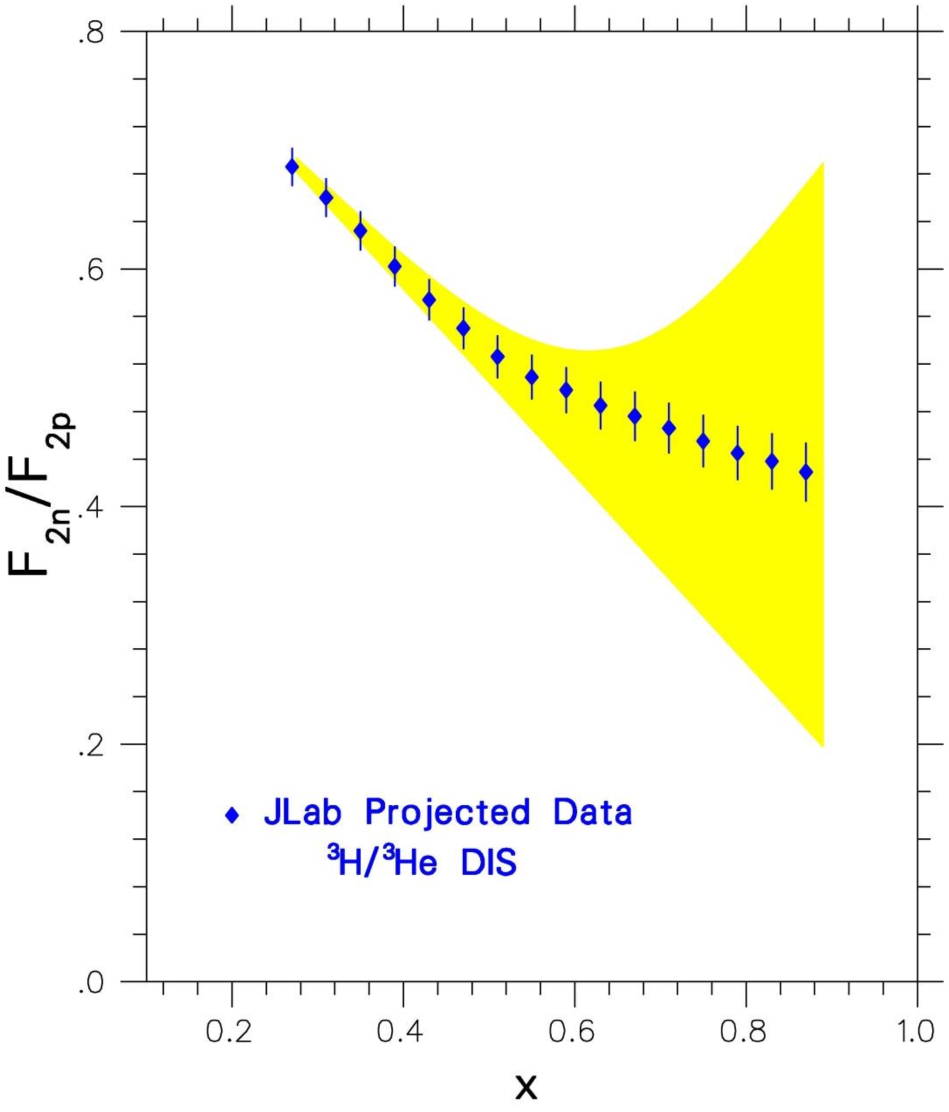
BB System – Special Issues (Continued)

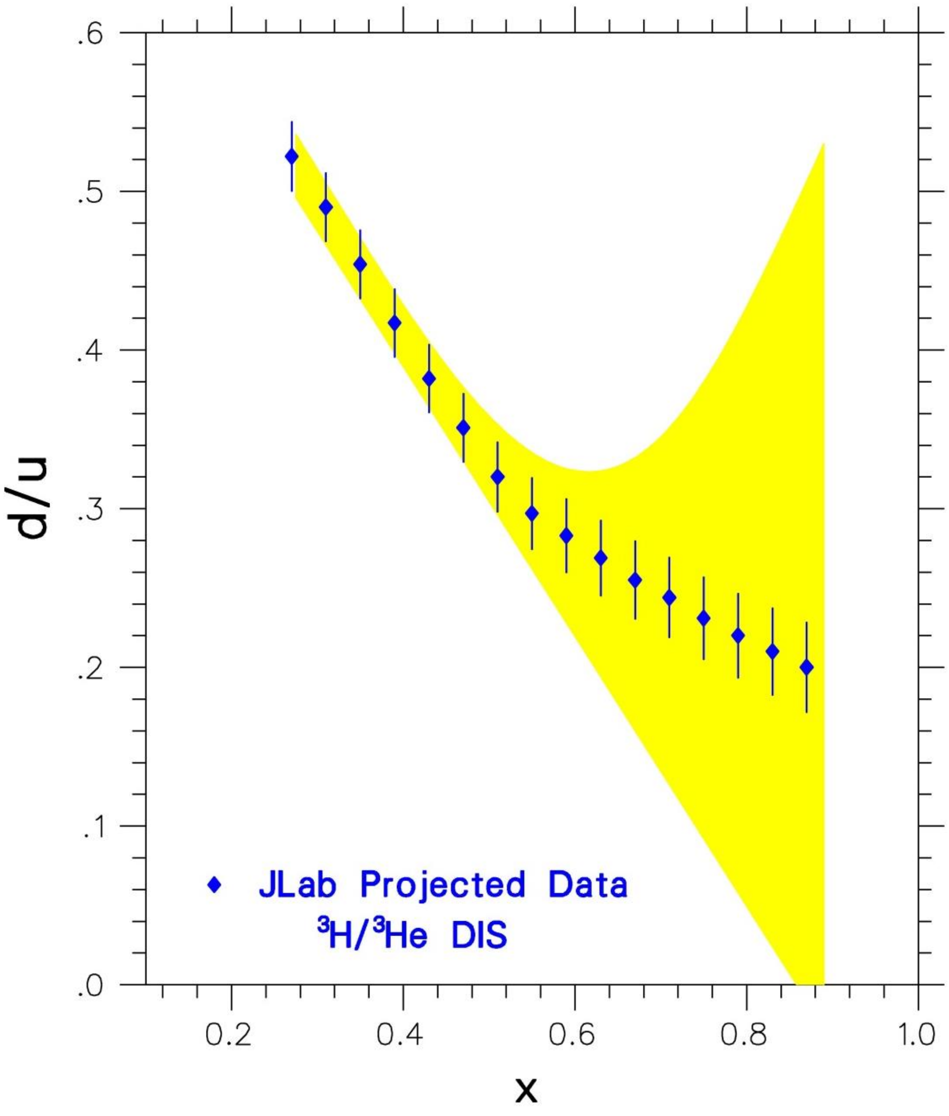
- What is the level of the current understanding of the magnet optical properties? A cross section measurement needs better understanding than an asymmetry measurement!
- Proposal assumed that the target to spectrometer distance will change with every angular setting (will be getting closer to target with increasing angle). Plan for a survey mechanism.

The Left HRS System – Special Issues

- Is this spectrometer well understood at the level of a precision Rosenbluth measurement of $R=\sigma_L/\sigma_T$? Do we need a new sieve slit calibration at several central momenta?
- Are any Left HRS detector changes/upgrades planned for the 12 GeV Program? Would the existing detector package be fine? What does the so far accumulated experience tell us?

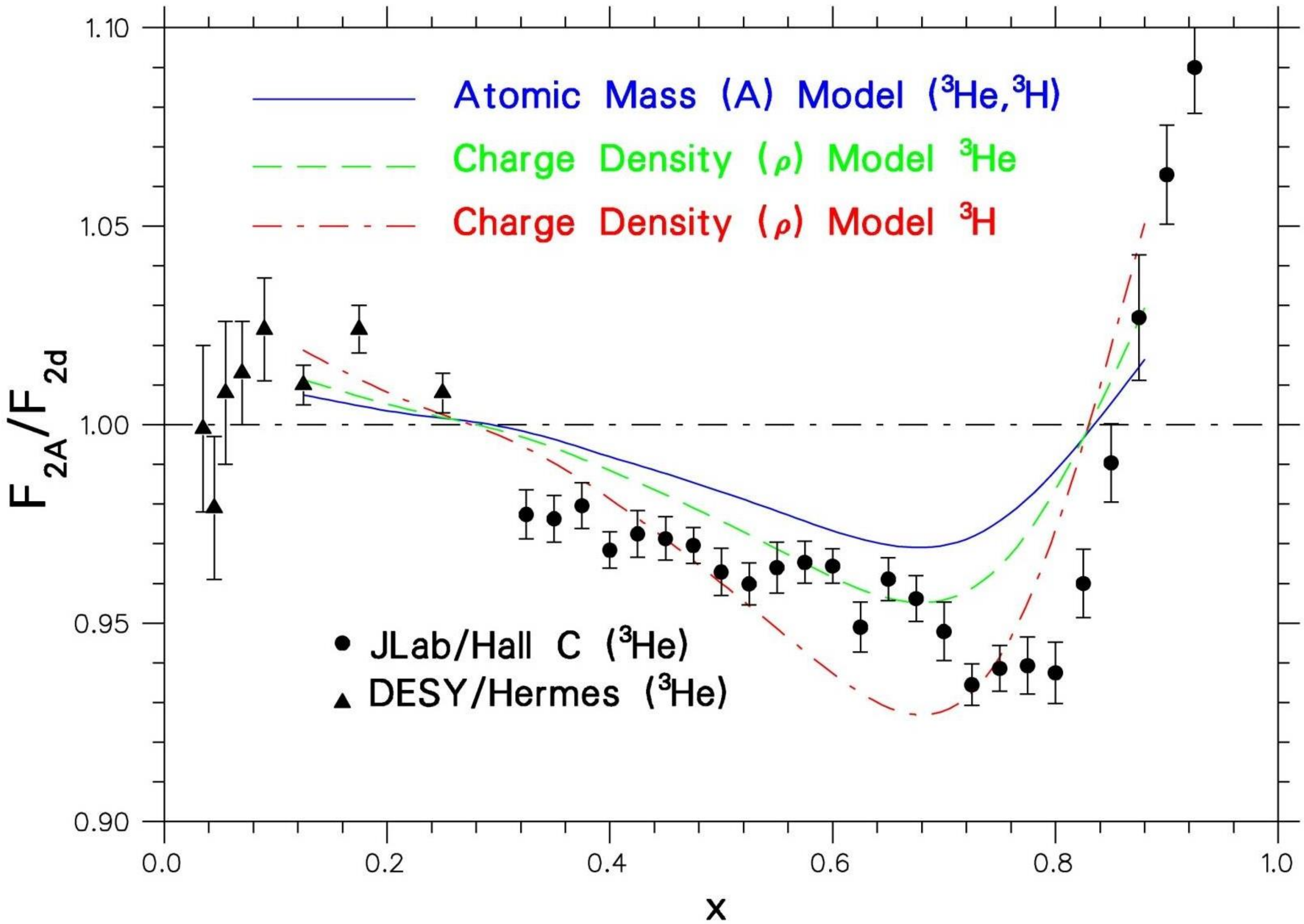
Possible Jlab - Hall A Data for F_2^n/F_2^p and d/u Ratios





HIGHEST Bjorken x DIS measurements

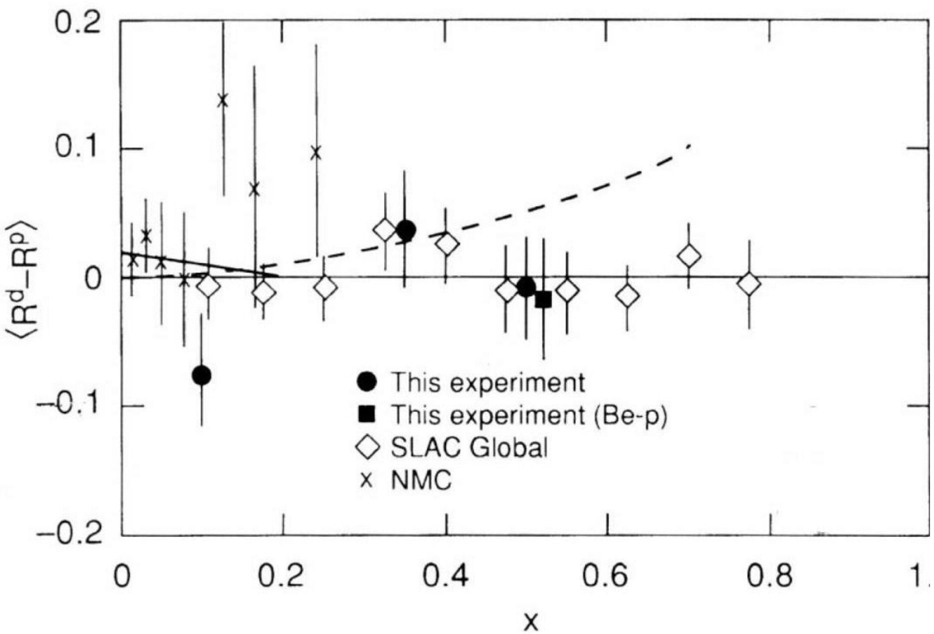
EMC Effect for *A=3* Mirror Nuclei

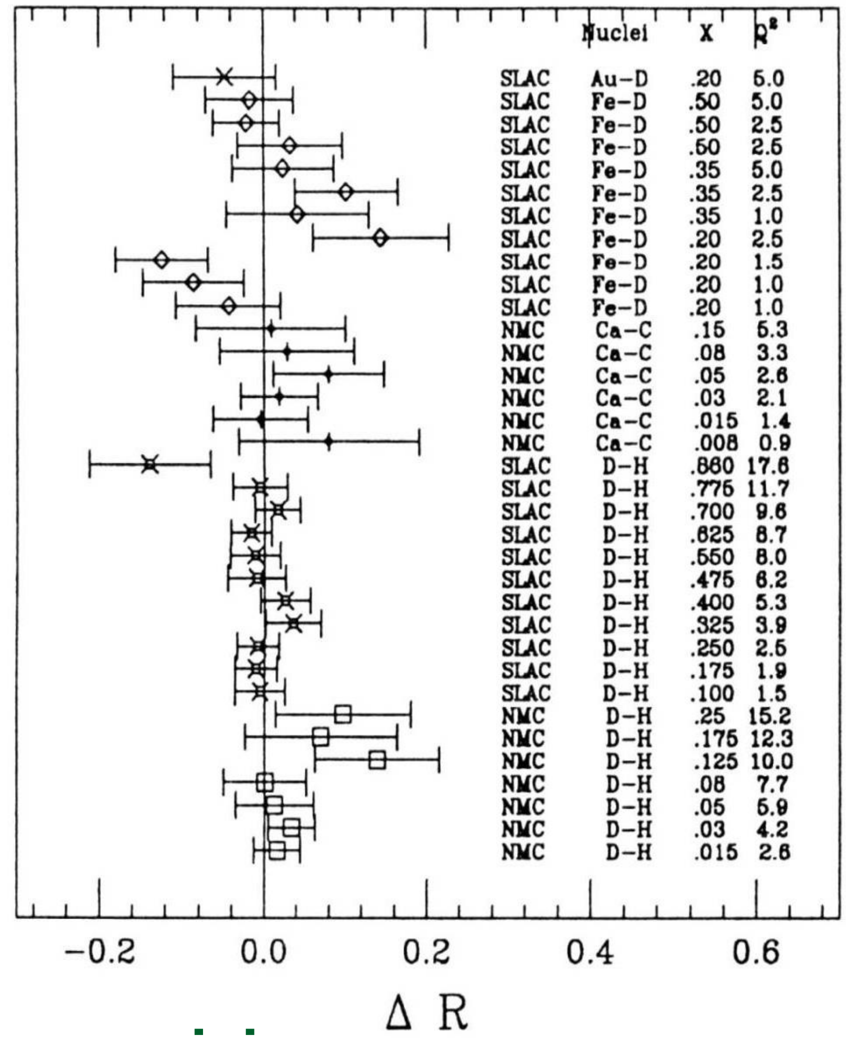


Hall A data on ^{3}H, ^{3}He will be of similar precision to Hall C data

$R=\sigma_L/\sigma_T$ Measurements

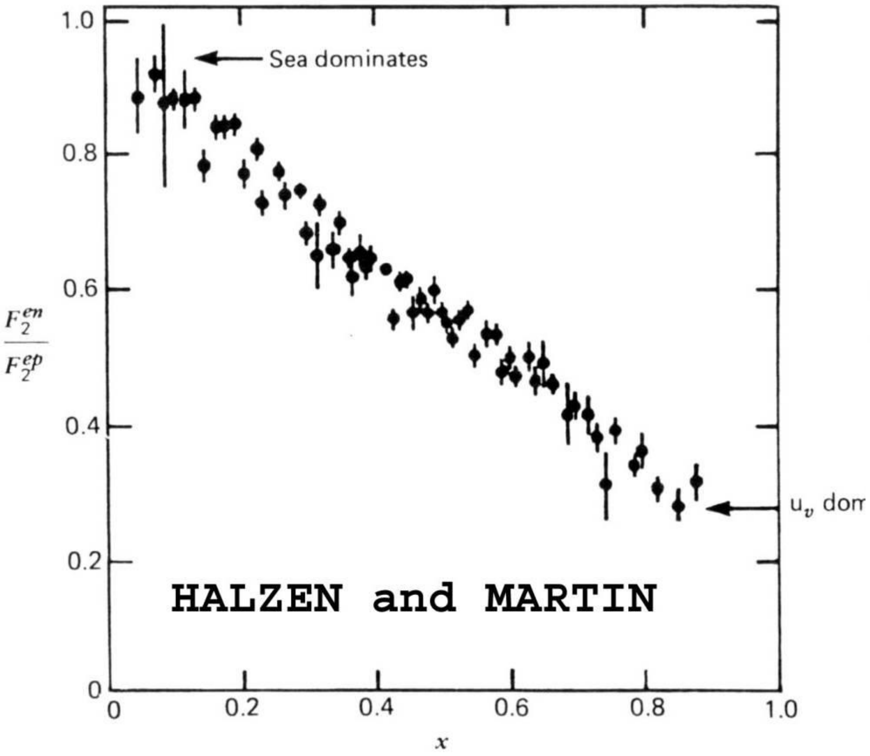
SLAC/CERN data show that the ratio $R=\sigma_L/\sigma_T$ is the same for all nuclei within experimental errors

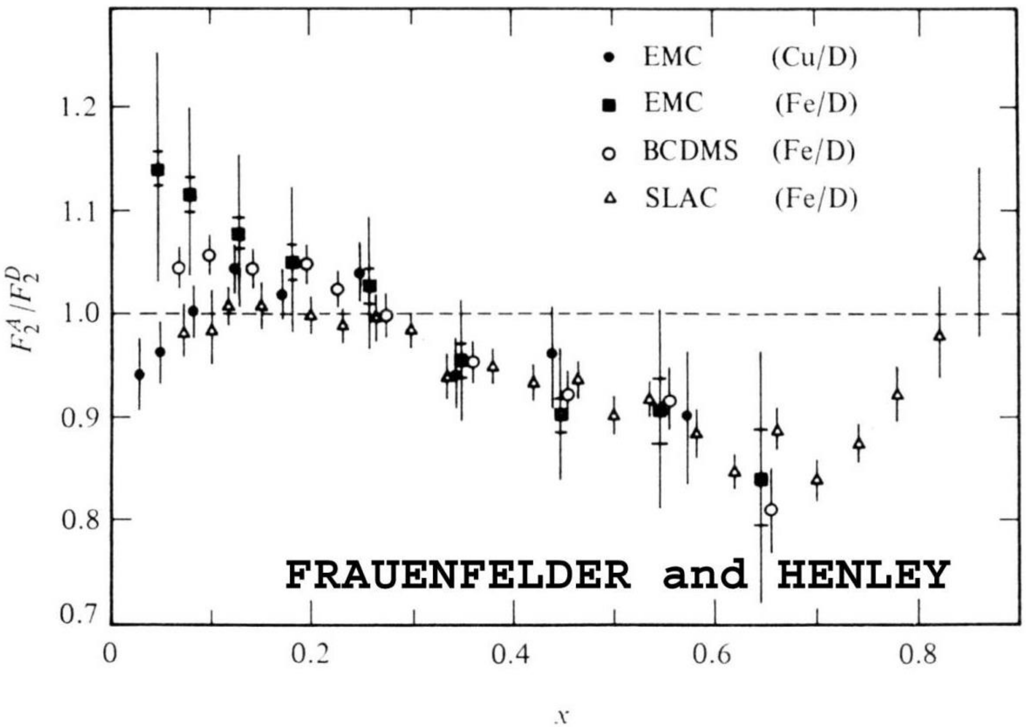




$^3He/^3H$ JLab data will be of better precision than SLAC data [wider angular range!]

F_2^n/F_2^p Ratio and EMC Effect are Elementary Undergraduate Nuclear-Particle Textbook Physics!





Summary - Issues

- E12-10-103 experiment on DIS from ^{3}He and ^{3}H in will provide:
  - The world's highest-*x* measurements of F_2^n/F_2^p and *d*/*u* ratios
  - Crucial unique EMC effect data for both *A*=3 systems
  - Important input to light-nuclei structure theory, and

    to nucleon structure function parametrizations
- Must resolve the issue of BigBite Cerenkov detector
- Must plan on required BigBite movements and surveys
- Make sure Left HRS is ready for the challenge of DIS data
- Start looking into (wo)manpower issues. Collaboration to grow after tentative scheduling of experiment.
- Are we ready to attract PhD dissertation students?
- Tritium target remains the most crucial project of experiment.
- Many thanks to Roy Holt and Dave Meekins!