PR-05-016

Me**A**surement of the F_2^n/F_2^p and d/u **RA**tios in Deep Inelastic Electron Scattering off the **T**ritium and **H**elium Mirr**O**r **N**uclei.

Jefferson Lab PAC27 Proposal

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Goals of Experiment

Measure the absolute cross section for inclusive scattering from ^3H and ^3He in the DIS region

Extract the F_2^n/F_2^p ratio from the $^3He/^3H$ ratio, then extract the u/d ratio for *x* from .25 to .77

Determine the magnitude and *x* dependence of the EMC effect in ^3H and ^3He

Physics Introduction

DIS and Quark Parton Model

- Cross Section - Nucleon Structure Functions

$$\sigma_{eN} = \frac{\alpha^2}{4E^2 \sin^4\left(\frac{\theta}{2}\right)} \left[\frac{F_2}{\nu} \cos^2\left(\frac{\theta}{2}\right) + \frac{2F_1}{M} \sin^2\left(\frac{\theta}{2}\right) \right]$$

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

$$\nu = E - E'$$

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

Quark-parton model

- Quark Parton Model

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

$$F_2(x) = x\sum_i e_i^2 q_i(x)$$

$$Q^2 \to \infty,\ \nu \to \infty,\ x = \tfrac{Q^2}{2M\nu}\ \text{fixed}$$

Structure functions depend only on x if scattering is from pointlike partons, and F_1 and F_2 are simply related – $2xF_1=F_2$

Relation of Structure functions and distribution functions

F_2^n/F_2^p in Quark Parton Model

- Assume isospin symmetry:

$$\begin{aligned} u^p(x) &\equiv d^n(x) \equiv u(x) \\ d^p(x) &\equiv u^n(x) \equiv d(x) \\ s^p(x) &\equiv s^n(x) \equiv s(x) \end{aligned}$$

(Similarly for antiquarks)

- Proton and neutron structure functions:

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

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

Structure functions and u/d

$F_2^n/F_2^p = (1+4(D/U) / (4+(D/U)$, where

$U= (u+u\text{-bar})$ and $D=(d+d\text{-bar})$

The ratio is bounded by the limits of ¼ and 4.

Ratio has been extracted from scattering on proton and deuteron at SLAC with corrections for Fermi-motion in the nucleons.

However, extraction depends on model of nuclear corrections in deuterium.

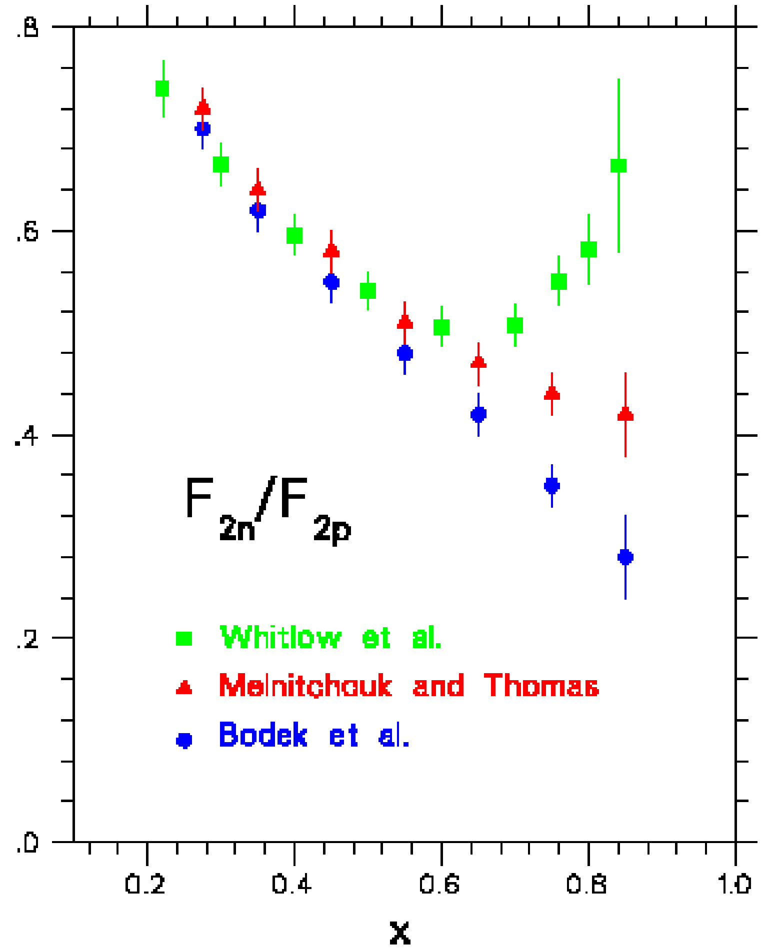


Figure 3: The F_2^n/F_2^p ratio extracted from proton and deuteron DIS measurements [11] with a) a Fermi-smearing model (Bodek *et al.* [12]), b) a covariant model that includes binding and off-shell effects (Melnitchouk and Thomas [34]), and c) the "nuclear density model" that also incorporates binding and off-shell effects (Frankfurt and Strikman [36, 35, 39]).

Theoretical expectations at high x

SU(6) Symmetry

- Wave function for a polarized proton:

$$
\begin{aligned}
p\uparrow &= \frac{1}{\sqrt{2}}u\uparrow(ud)_{S=0} + \frac{1}{\sqrt{18}}u\uparrow(ud)_{S=1} \\
&- \frac{1}{3}u\downarrow(ud)_{S=1} - \frac{1}{3}d\uparrow(uu)_{S=1} \\
&- \frac{\sqrt{2}}{3}d\downarrow(uu)_{S=1}
\end{aligned}
$$

S indicates total spin of diquark partner of quark

$d/u = ½$ for perfect SU(6) symmetry

Theoretical expectations

SU(6) is broken – if S=1 is suppressed relative to S=0 as x → 1, d/u → 0

Predictions of pQCD models of Farrar & Jackson, and a similar treatment by Brodsky, in which $S_Z = 1$ terms are suppressed gives d/u → 1/5

These substantially different predictions are all allowed by the current data due to the large uncertainty due to nuclear corrections in the deuteron.

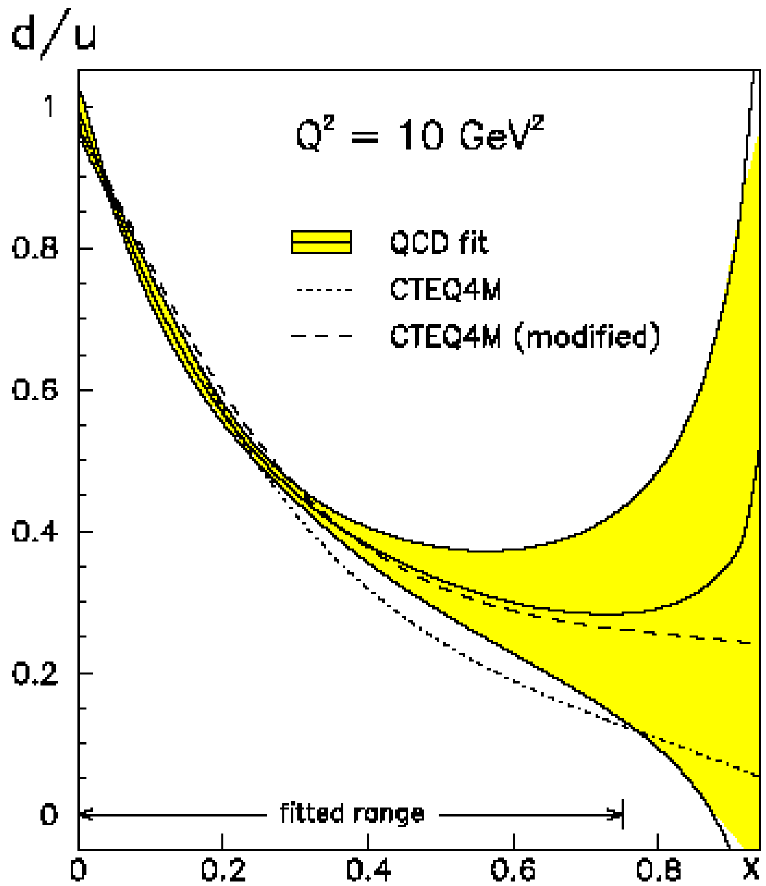


Figure 4: A typical uncertainty in the determination of the quark d/u distribution ratio by the QCD fit of Botje [40] on DIS cross section data. The solid curve is a QCD fit, and the shaded area shows the uncertainty in the fit. The dot-dashed curve represents the standard CTEQ4 fit [41], while the dashed curve corresponds to the CTEQ4 fit with a modified d quark distribution with $d/u \to\approx 0.2$ as $x \to 1$.

EMC Effect

The EMC effect refers to the change in quark distribution functions in nuclei compared to the deuteron.

Although it was discovered 20 years ago, there is still no complete theory for the effect at all *x*.

The size of the effect in the lightest nuclei (^3He and ^3H) is still unknown. A precision measurement of this is considered essential to understanding the EMC effect.

EMC Effect

Defining the EMC-type ratios for the F_2 structure functions of ^{3}He and ^{3}H (weighted by corresponding isospin factors) by:

$$R(^3\mathrm{He}) = \frac{F_2^{^3\mathrm{He}}}{2F_2^p + F_2^n} \ , \qquad R(^3\mathrm{H}) = \frac{F_2^{^3\mathrm{H}}}{F_2^p + 2F_2^n} \ , \tag{14}$$

one can write the "super-ratio", $\mathcal{R}$, of these as:

$$\mathcal{R} = \frac{R(^3\mathrm{He})}{R(^3\mathrm{H})} \ . \tag{15}$$

Inverting this expression directly yields the ratio of the free neutron to proton structure functions:

$$\frac{F_2^n}{F_2^p} = \frac{2\mathcal{R} - F_2^{^3\mathrm{He}}/F_2^{^3\mathrm{H}}}{2F_2^{^3\mathrm{He}}/F_2^{^3\mathrm{H}} - \mathcal{R}} \ . \tag{16}$$

DIS with 3H and 3He

In the absence of the Coulomb interaction and if isospin symmetry applied exactly, the properties of the proton in 3H would be identical to the neutron in 3He.

Of course, 3He and 3H are not identical. However, they are similar. Thus, if we take the ratio of cross sections, the nuclear effects largely cancel.

For example, the ratio of the EMC effects is predicted to be less than 2% for $x<0.8$

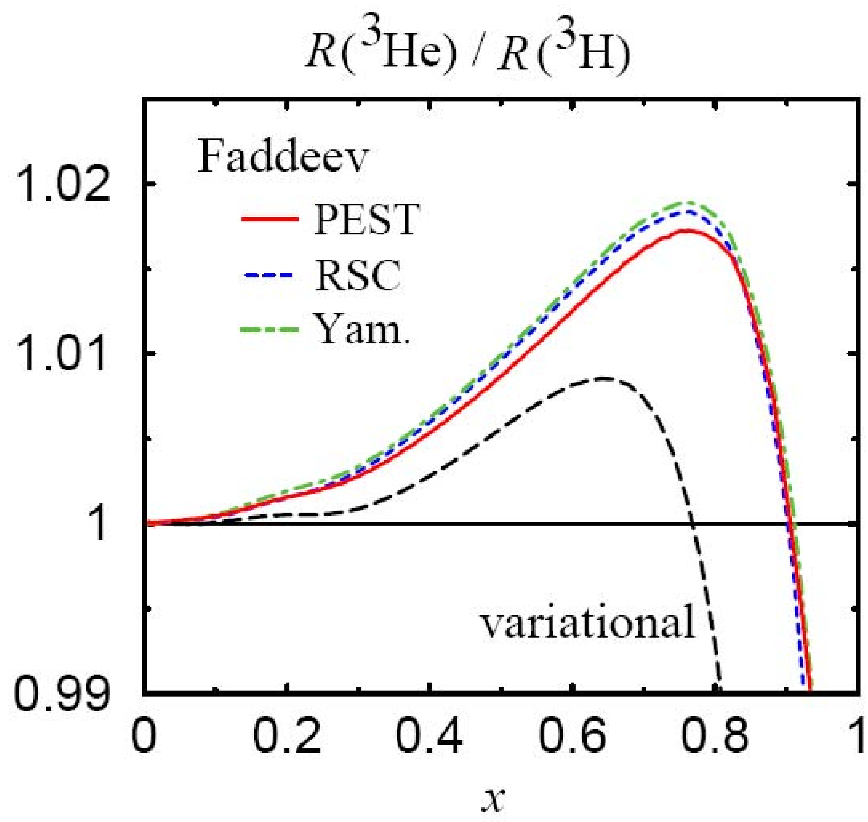


Figure 5: The "super-ratio" $\mathcal{R}$ of nuclear EMC ratios for ^{3}He and ^{3}H nuclei, with the nucleon momentum distribution calculated from the Faddeev (PEST, RSC, Yamaguchi) and variational (RSC) wave functions [43].

Experiment

Beam – 6 GeV at 100 μA

Targets – 11 atm, 300 K 3He and 3H

Spectrometer – Hall C HMS or Hall A HRS

Measure at W = 2.0 GeV

The tritium target

Target will be stainless steel cylinder:

Diameter 1.5 cm, Length 12 cm

11 atm ^3H at room temperature

Target density 9.6 x 10^{-4} g/cm^3, activity is 190 Ci

Acts as ideal gas to 10^{-4} level – can calculate density.

Activity is 700 times lower than safely used at Bates, 100 times lower than cold high pressure target investigated at tritium workshop.

APPENDIX II

Cross Sections and Counting Rates for the F_2^n/F_2^p and d/u Extraction

x	$\sigma(^3He)$ (nb/sr/GeV)	$\sigma(^3H)$ (nb/sr/GeV)	^{3}He Rate (Events/h)	^{3}H Rate (Events/h)	^{3}He Time (h)	^{3}H Time (h)
0.77	0.0721	0.0553	390	152	38	99
0.73	0.125	0.0957	718	280	28	71
0.69	0.0791	0.0606	320	125	78	199
0.65	0.360	0.279	2380	941	10	27
0.61	1.09	0.858	9010	3610	3	7
0.57	2.73	2.19	25600	10400	1	3
0.53	6.09	4.95	61900	25600	0.5	1
0.49	12.7	10.5	136000	57300	0.5	0.5
0.45	25.0	21.0	278000	119000	0.5	0.5
0.41	46.6	39.8	527000	229000	0.5	0.5
0.37	85.1	73.8	963000	425000	0.5	0.5
0.33	152	134	1690000	759000	0.5	0.5
0.30	232	207	2500000	1140000	0.5	0.5
0.27	351	317	3610000	1660000	0.5	0.5
0.24	535	489	5100000	2370000	0.5	0.5

Table 2: Inelastic cross sections, counting rates and beam times for the different Bjorken x kinematics of the proposed ^{3}He and ^{3}H inelastic cross sections measurements for the extraction of the F_2^n/F_2^p and d/u ratios. The counting rates assume 12 cm, 11 atm gas ^{3}He and ^{3}H targets, a beam current of 100μA and a spectrometer solid angle of 6 msr.

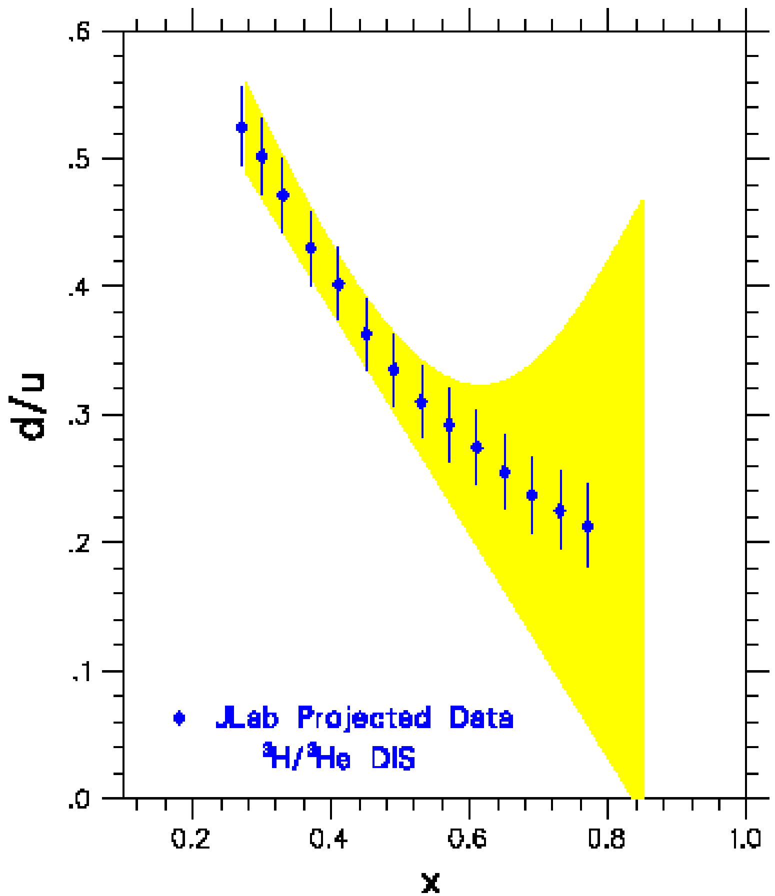
Time Requirements

Primary measurement – 24 days

Calibrations etc – 11 days

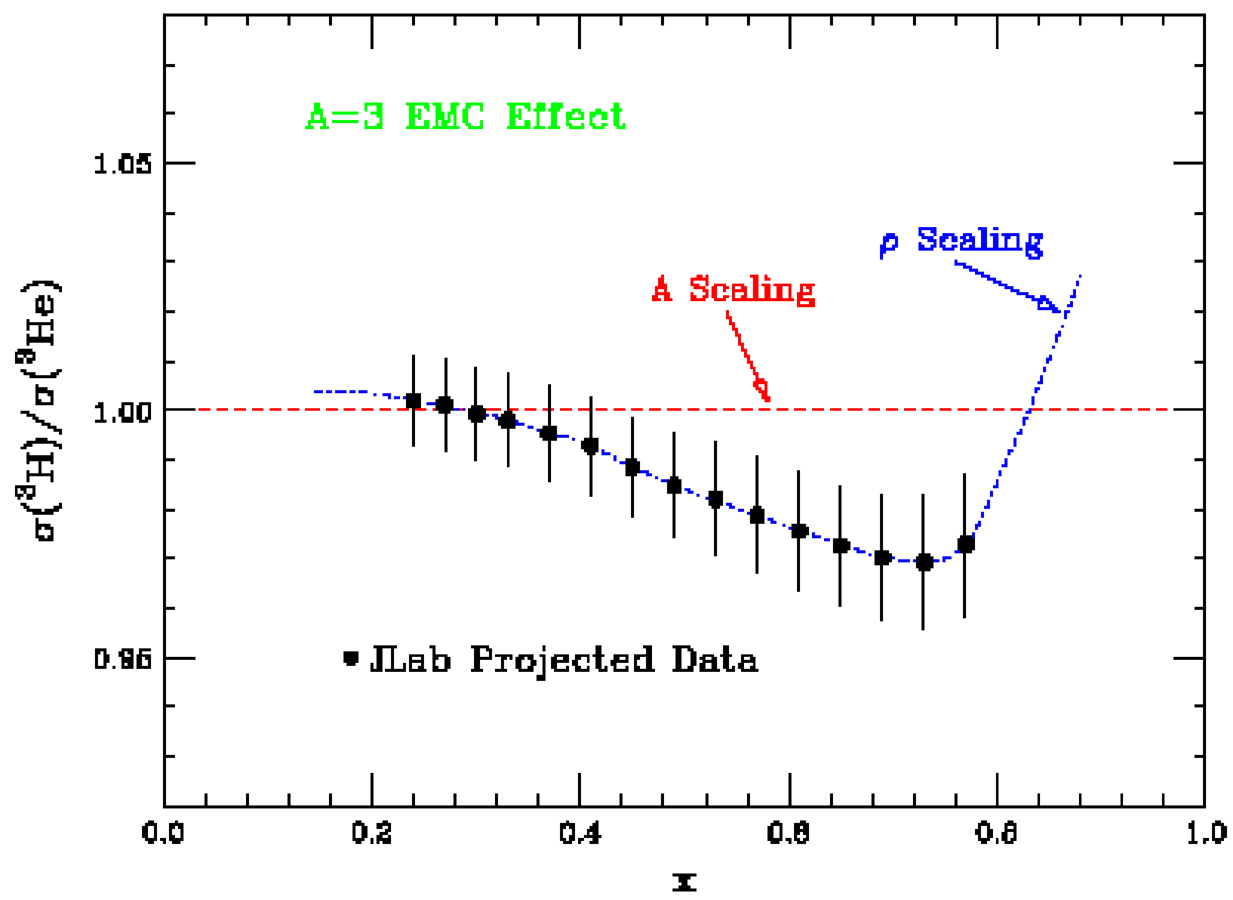
Systematic control requires measurement of elastic cross sections at low momentum transfer where cross sections are well known.

Anticipated Results u/d



Hall A Collaboration Dec 17, 2004

Anticipated results EMC effect



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Comparison with BoNuS

BoNuS will measure u/d by measuring the neutron structure function in deuterium by tagging the very low momentum proton.

Statistical precision comparable, but BoNuS has larger overall and point-to-point systematic errors than this experiment.

Experiments are complementary – provide two ways to measure this important quantity.

Conclusions

The u/d ratio can be determined from x = .24-.77 with high precision

Determine EMC effect in ^3He and ^3H

Requires only low activity target (190 Ci)

Total running time – 35 days