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

MARATHON

Hanjie Liu

Hall A Collaboration meeting, Jan 30

Columbia University

Motivation

- Measure the F_2^n/F_2^p at medium and large x
- Measure d/u at medium and large x
- Measure the EMC effect for ^3H and ^3He

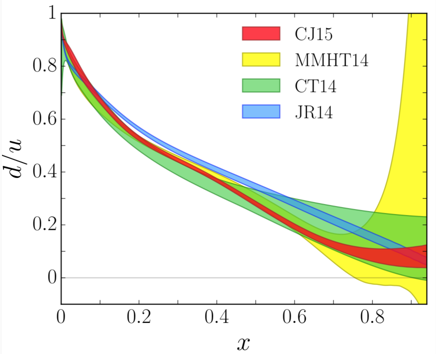
Why is it important to know distribution functions at high x?

- The distribution functions in the valence region is the key to hadron physics;
- Its accurate parametrization is crucial to high energy physics:
  - Need to completely understand QCD background
  - According to QCD evolution, with increasing center-of-mass energy, the distributions at large x evolves to small x

- In theory, the distribution functions are essentially non-perturbative
- Parametrization: the cross section is factorized into the product of short- and long-distance contributions

$x \to 1$

- $d/u \to \frac{1}{2}$ SU(6) symmetry
- $d/u \to 0$ Scalar diquark dominance
- $d/u \to \frac{1}{5}$ pQCD power counting



- pQCD choices
- The theoretical assumptions about the $x \to 1$ behavior

F_2^n/F_2^p is one of the best methods to determine the d/u ratio.

Quark-parton Model

$$F_2(x) = x \sum_i e_i^2 q_i(x) \tag{1}$$

- Assume isospin symmetry:

$$u^p(x) = d^n(x) = u(x) \qquad d^p(x) = u^n(x) = d(x)$$

- Proton structure function: $F_2^p(x) = x[\frac{4}{9}u(x) + \frac{1}{9}d(x) + \frac{1}{9}s(x)]$
- Neutron structure function: $F_2^n(x) = x[\frac{4}{9}d(x) + \frac{1}{9}u(x) + \frac{1}{9}s(x)]$

$$\frac{F_2^n(x)}{F_2^p(x)} = \frac{u(x) + 4d(x) + s(x)}{4u(x) + d(x) + s(x)} \tag{2}$$

The cross section for inelastic electron-nucleon scattering:

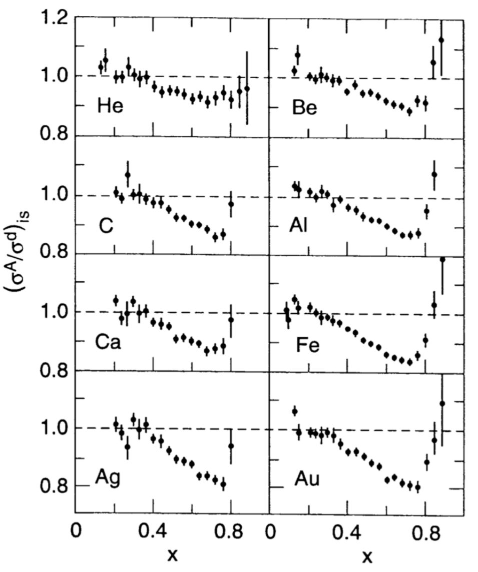
$$\sigma = \frac{4\alpha^2(E')^2}{Q^4} cos^2(\frac{\theta}{2}) F_2 [\frac{1}{\nu} + \frac{1 + Q^2/\nu^2}{xM(1+R)} tan^2(\frac{\theta}{2})] \tag{3}$$

where $R = \sigma_L/\sigma_T$

- Proton structure function is measured up to ~ 0.85 by electron/muon scattering on Hydrogen target
- Since there is no free neutron target, deuteron target is used to extract neutron structure function for decades

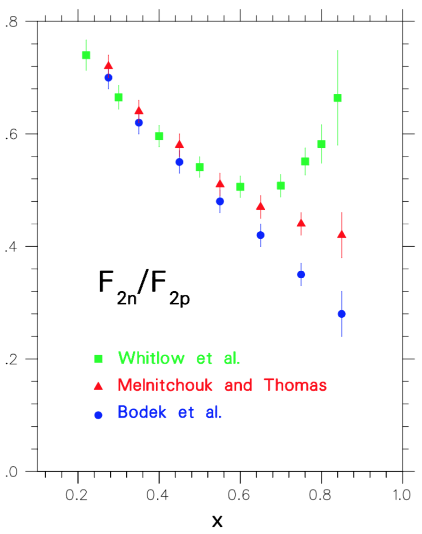
Why can't extract F_2^n from deuteron target at high x?

EMC effect



The nuclear structure function is not simply the sum of the nucleon structure functions

- Using different nuclear effect model, the F_2^n/F_2^p extracted from F_2^d/F_2^p could be different.



SLAC DIS Data revisited

Bodek *et al.*: Non-relativistic Fermi-smearing-only model with Paris N-N potential

Melnitchouk and Thomas: Relativistic convolution model with empirical binding effects

Whitlow *et al.*: Assumes EMC effect in deuteron (Frankurt and Strikman data-based Density Model)

Why could MARATHON avoid this issue?

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Perform inclusive electron deep inelastic scattering (DIS) on ^3H, ^3He, D_2

- If $R = \sigma_L/\sigma_T$ is the same for ^3H and ^3He,

$$\frac{F_2^{^3H}}{F_2^{^3He}} = \frac{\sigma(^3H)}{\sigma(^3He)} \tag{4}$$

- ^3H and ^3He EMC type ratios:

$$R(^3He) = \frac{F_2^{^3He}}{2F_2^p + F_2^n} \qquad R(^3H) = \frac{F_2^{^3H}}{F_2^p + 2F_2^n} \tag{5}$$

define the "super-ratio" of EMC ratios in ^3H and ^3He:

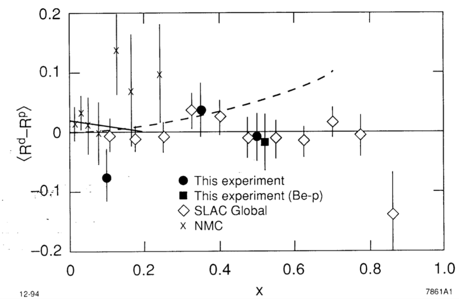
$$\mathcal{R} = \frac{R(^3He)}{R(^3H)} \tag{6}$$

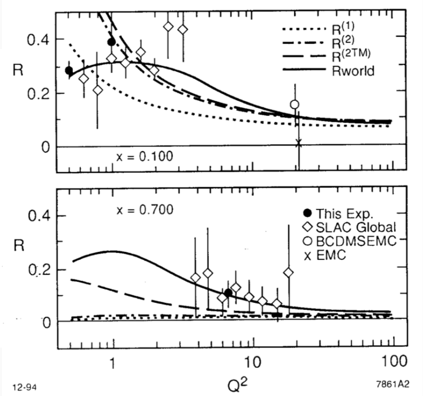
- Free neutron to proton structure functions:

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

$R = \sigma_L/\sigma_T$

SLAC E140X: Measurement of $R = \sigma_L/\sigma_T$ on H1, D2 and Be in DIS





L. H. Tao et al., Z. Phys. C70, 387 (1996).

Super ratio $\mathcal{R}$

- ^3H and ^3He are mirror nuclei. The nuclear effects should be similar.
- $\mathcal{R}$ has been calculated in theory to deviate from 1 up to 2% by taking into account all possible effects

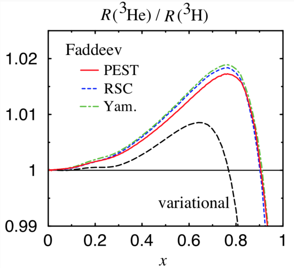


Figure 1: With different wave functions

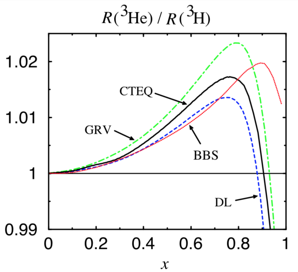


Figure 2: With different input nucleon structure functions parametrization

Super ratio $\mathcal{R}$

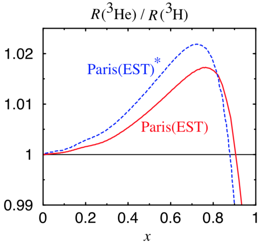


Figure 3: Include Coulomb interaction

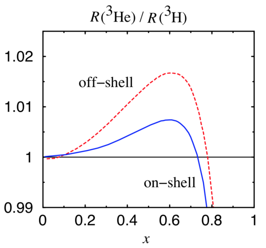


Figure 4: Include off-shell corrections

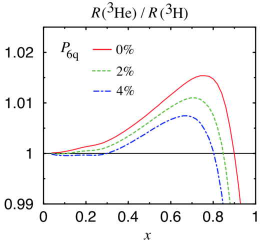


Figure 5: Include six-quark configurations

Recent discussions about off-shell corrections can be seen in arXiv:1811.07668 [nucl-th]

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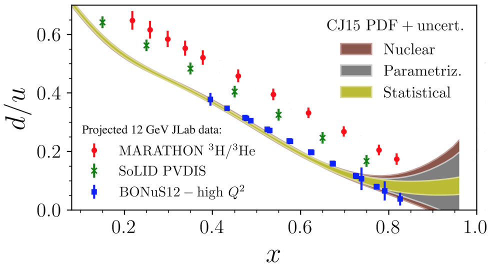
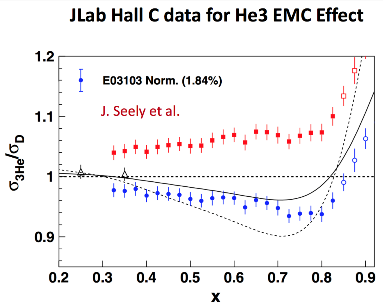


(Plot courtesy of Alberto Accardi)

MARATHON would have similar error bar as Hall C EMC effect

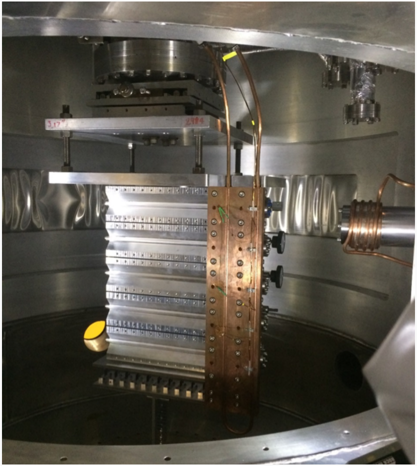


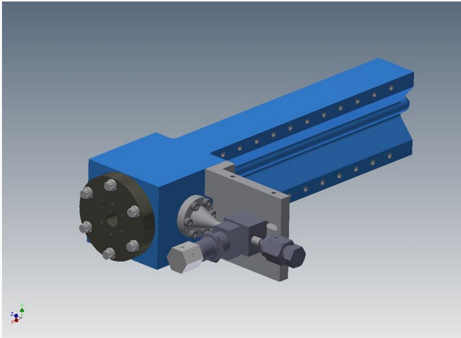
Experiments

- Run period: 2018 Jan 13 – Mar 5; Mar 24 – Apr 12;
- Beam energy $E_0 = 10.59 GeV$; beam current $I = 22.5 \mu A$
- Use both HRS to detect electrons
- 11 kinematics data on ^3H, ^3He, D_2
- Statistic error is supposed to be smaller than 1%

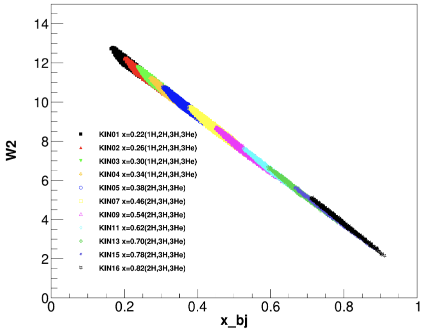
	x	E' (GeV)	θ (deg)
kin0	0.199	3.1	16.80
kin1	0.218	3.1	17.58
kin2	0.258	3.1	19.14
kin3	0.298	3.1	20.58
kin4	0.338	3.1	21.93
kin5	0.378	3.1	23.21
kin7	0.458	3.1	25.59
kin9	0.538	3.1	27.77
kin11	0.618	3.1	29.81
kin13	0.698	3.1	31.73
kin15	0.778	3.1	33.55
kin16	0.818	2.9	36.12

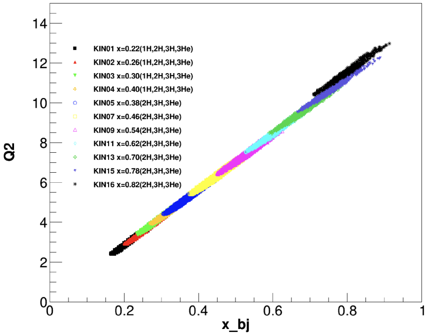
Target





Kinematics





plots from Tong Su

Data analysis

- Data yield:

$$Yield = \frac{N_e}{N_{tar} \times N_{beam}} \tag{7}$$

  - $N_e = N_e^{meas} \times C_e$
    C_e includes efficiencies correction, acceptance correction, dead time correction and background subtraction;
  - $N_{tar} = N_{tar}^0 \times C_{boiling}(I)$
    $C_{boiling}$ is the boiling effect correction
  - radiative correction
- **Yield ratio**: since the efficiencies and acceptance should have no difference between targets, we only consider dead time, charge-symmetric background, end-cup background, boiling effect and radiative correction

Data analysis status

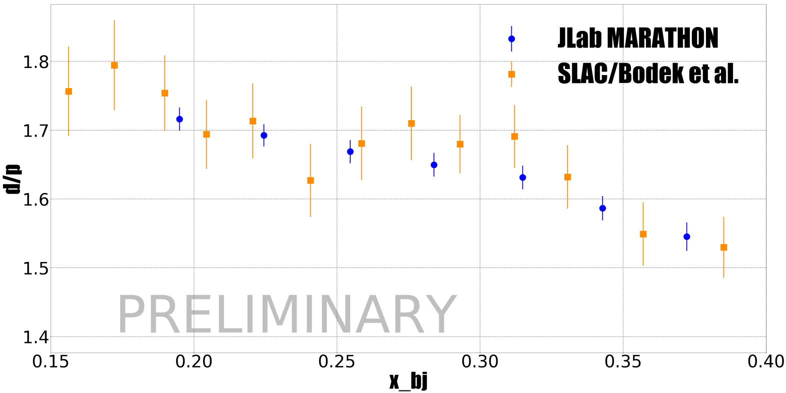
Pass I analysis:

- Detector calibrations $\surd$
- Beamline component calibrations $\surd$
- End-cup containmination $\surd$
- Charge-symmetric background $\surd$
- Gas target boiling effect $\surd$
  S. N. Santiesteban, S. Alsalmi arXiv:1811.12167 [physics.ins-det]
- Radiative correction (ongoing)

Preliminary yield ratios of $^3H/^3He$, $^3H/D_2$, $^3He/D_2$ and F_2^n/F_2^p are obtained. No significant deviations has been seen.

Start **Pass II analysis**. Will recheck everything and decide systematic errors.

σ_D/σ_p

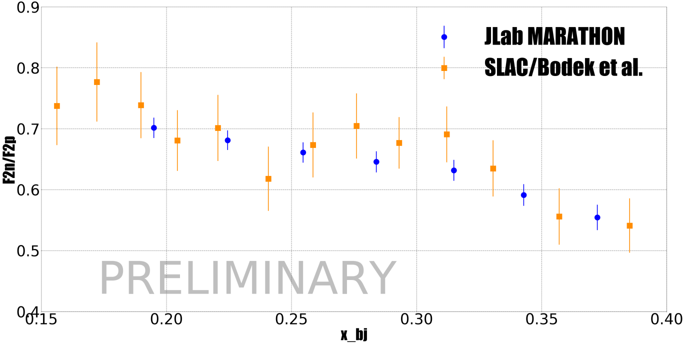


plots from Tong Su

F_2^n/F_2^p extracted from σ_D/σ_p

$$\frac{F_2^n}{F_2^p} = \frac{F_2^d}{F_2^p}\frac{1}{R_2} - 1$$

$R_2 = \frac{F_2^d}{F_2^p+F_2^n}$ is very colse to unity in the MARATHON d/p range. It's determined from a theoretical model by Kulagin and Petti. [1]



[1] S. A. Kulagin, R. Petti, Phys. Rev. 82C, 054614 (2010); and private communication, 2018.

Graduate students

Jason Bane	(University of Tennessee)	Tyler Hague	(Kent State University)
Tyler Kutz	(Stony Brook University)	Hanjie Liu	(Columbia University)
Mike Nycz	(Kent State University)	Tong Su	(Kent State University)

Postdoc

R. Evan McClellan Zhihong Ye Florian Hauenstein

Thank You!