Real and Virtual Nucleon Structure in the MARATHON Experiment

NSD Seminar

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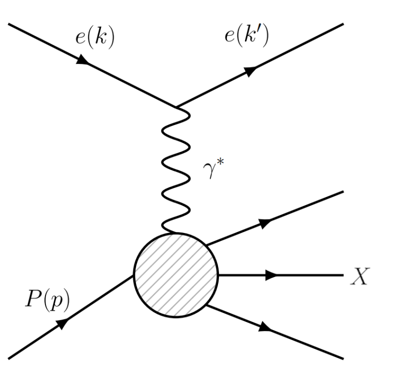
Tools of the Trade

Deep Inelastic Scattering



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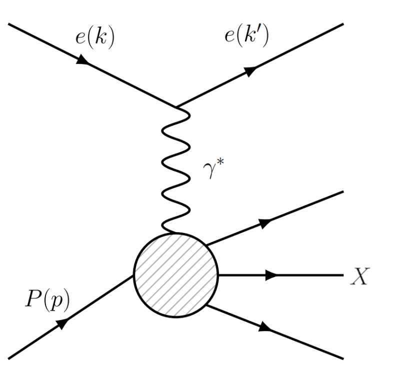
- At sufficient four-momentum transfer (Q^2), the virtual photon effectively scatters from a constituent quark

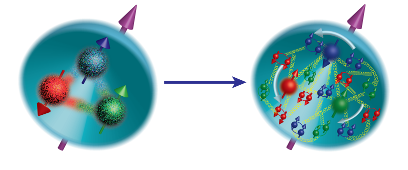
Deep Inelastic Scattering



- Deep Inelastic Scatter (DIS) allows us to probe the internal structure of nucleons
- At sufficient four-momentum transfer (Q^2), the virtual photon effectively scatters from a constituent quark

$$\frac{d^2\sigma}{d\Omega dE'}(E,E',\theta) = \frac{4\alpha^2 (E')}{Q^4}\cos^2\left(\frac{\theta}{2}\right) F_2\left[\frac{1}{\nu} + \frac{(1+Q^2/\nu^2)}{xM(1+R)}\tan^2\left(\frac{\theta}{2}\right)\right]$$

Bjorken x and the F_2 Structure Function

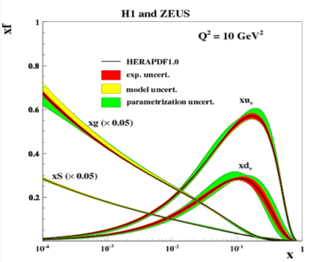


The Bjorken scaling variable, x, is the longitudinal momentum fraction of the struck quark

$$x = \frac{Q^2}{2M\left(E - E'\right)}$$

F_2 describes the longitudinal momentum distribution of partons within the nucleon

$$F_2\left(x\right) \equiv \sum_{i}^{u,d,s,\ldots} x e_i^2 q_i\left(x\right)$$



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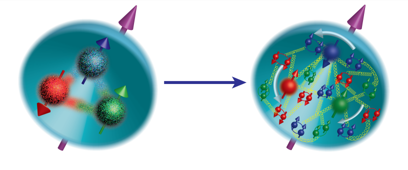

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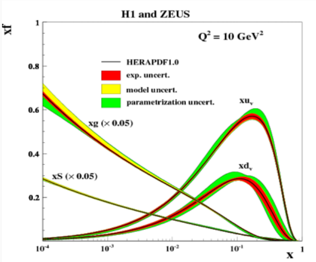
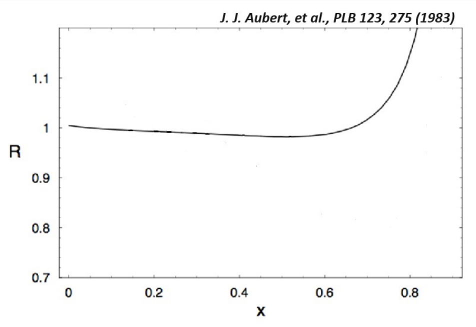


The EMC Effect

All is not well in the nucleus

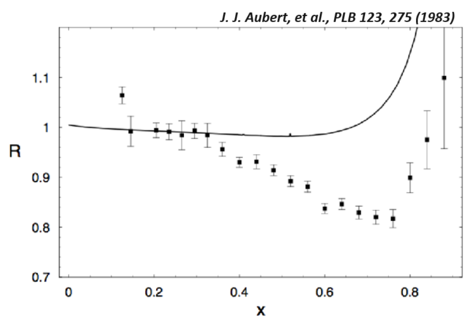
History

Nuclei are a composite system of nucleons, leading to an assumption that $F_2^A \approx ZF_2^p + (A - Z)\, F_2^n$ with deviations at high x due to Fermi smearing



The European Muon Collaboration (*EMC*) planned to use this assumption as a luminosity check in their experiment to study the structure functions of *H*, *D*2, and *Fe*...

???



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That doesn't seem right...

[1] Aubert et al., "The ratio of the nucleon structure functions $F2_n$ for iron and deuterium".

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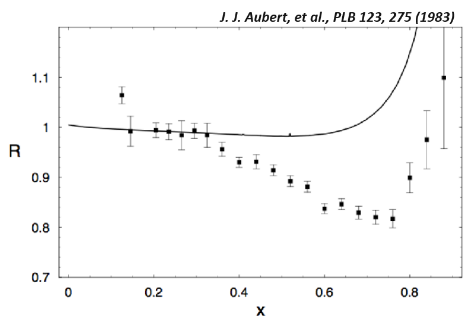

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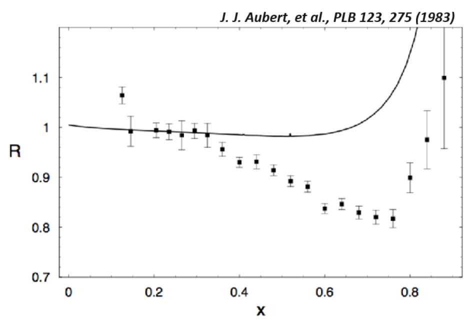

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This unexplained structural difference in nuclei became known as the EMC effect

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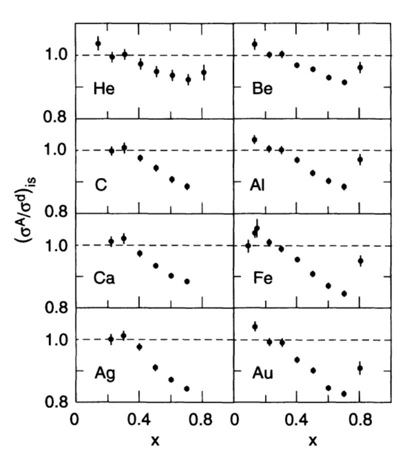
Further Studies at SLAC[2]



- SLAC went to work mapping the EMC effect over a large *A* range
- "Strength" of the EMC effect (slope of downturn) highly correlated with *A*

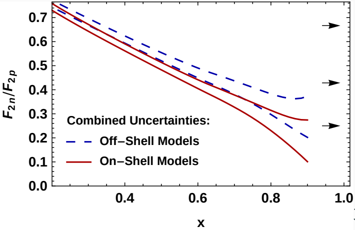
[2] Gomez et al., "Measurement of the *A* dependence of deep-inelastic electron scattering".

Nucleon Modification

Nucleons are modified when bound in a nuclear medium!

This leads to many open questions, including

- What causes the modification?
- Is the modification flavor dependent?



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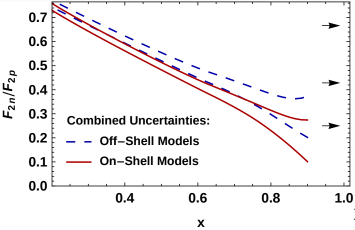

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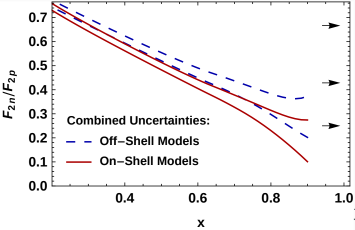

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The MARATHON Experiment

Mapping the $A = 3$ EMC Effect

Why do a new experiment?

A very large range of nuclei have been studied and we have learned many things, why do this experiment?

- $A = 3$ is the smallest system with mirror nuclei to study the difference between proton and neutron modification
- Assumed that the difference in nuclear effects of ^{3}He and ^{3}H is small to assess "free" nucleon structure function ratio F_2^n/F_2^p
- Free neutron structure is poorly constrained by prior data and is necessary for effective analysis of EMC data

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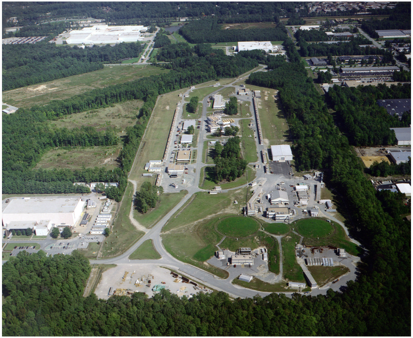
F_2^n/F_2^p Predictions as $x \to 1$

SU(6)	Diquark /Feynman	Quark Model/Isgur	Pert. QCD	Quark Counting
$2/3$	$1/4$	$1/4$	$3/7$	$3/7$

A Quick Tour of the Experiment

The CEBAF Accelerator



- The Continuous Electron Beam Accelerator Facility (CEBAF) is a racetrack accelerator at JLab
- Electrons are accelerated by $\sim$ 1.1 GeV per LINAC with up to 5 round trips (passes)
- MARATHON ran with 5 pass beam at 10.6 GeV

The Tritium Target

- MARATHON used 4 gas targets (^{3}H, ^{2}H, H, and ^{3}He)
- Specially designed aluminum cell to accommodate Tritium
- Safety procedures surrounding Tritium use limit the beam current on target to 22.5μA

The Hall A High Resolution Spectrometers

The HRSs use a QQDQ magnet setup to a detector stack with tracking, PID, and calorimetry

Extracting F_2^n/F_2^p

If nucleons are modified… How are we getting free nucleon structure functions?

If we assume the modification will be similar in each target, we can use a model to remove the differences

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

$\mathcal{R}$ is the “super-ratio” of “EMC-type” ratios

These “EMC-type” ratios predict how much the nuclei differ from being a simple sum of their nucleons

MARATHON chose to use the Kulagin-Petti (KP) model for its analysis

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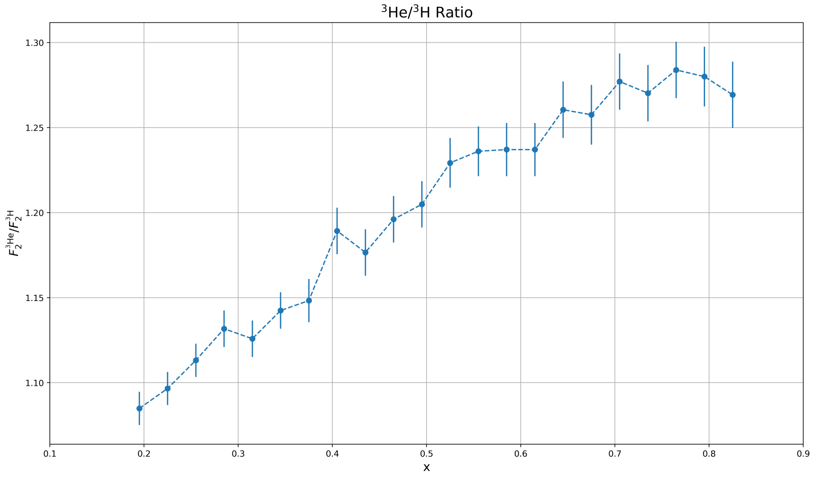
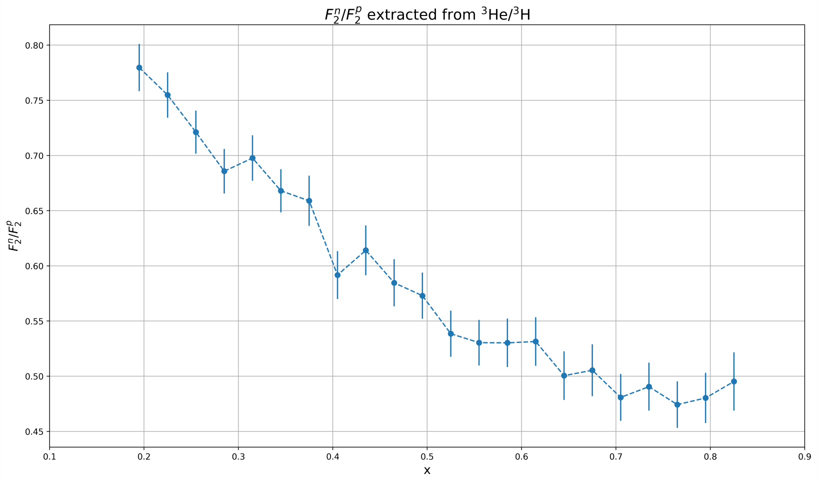
Results

$^3He/^3H$ Ratio



³He/³H Ratio
1.30
1.25
1.20
1.15
1.10
F2^3He/F2^3H
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x

F_2^n/F_2^p from ^{3}He/^{3}H



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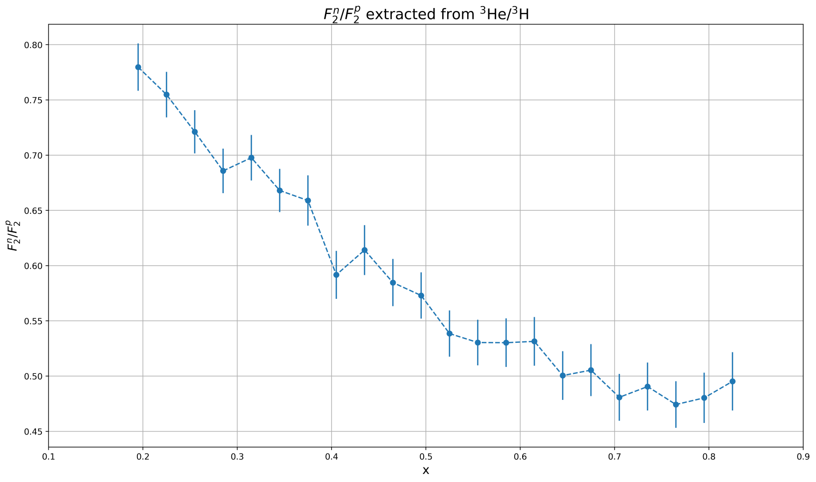

Is that it?

σ_D/σ_p

The MARATHON experiment also recorded a limited set of data on Hydrogen to use the ^{2}D/p ratio as a normalization check

[4] Abrams et al., "Measurement of the Nucleon F_2^n/F_2^p Structure Function Ratio by the Jefferson Lab MARATHON Tritium/Helium-3 Deep Inelastic Scattering Experiment".

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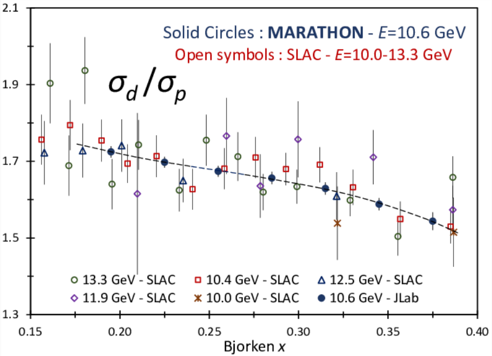

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F_2^n/F_2^p extractions from both data sets ought to agree, allowing an assessment of the normalization of the $A = 3$ targets

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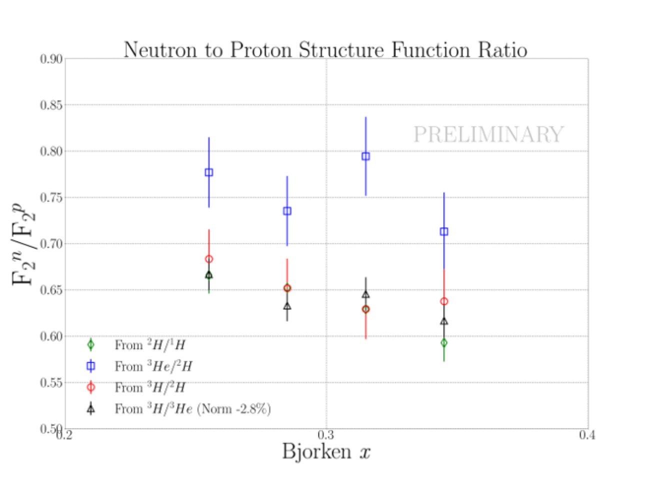

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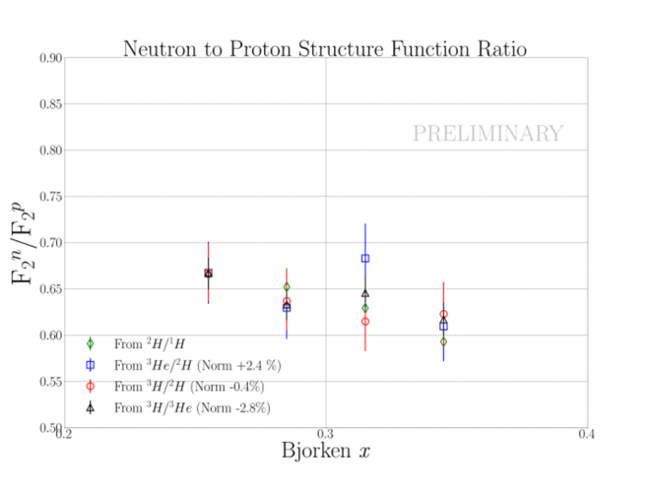

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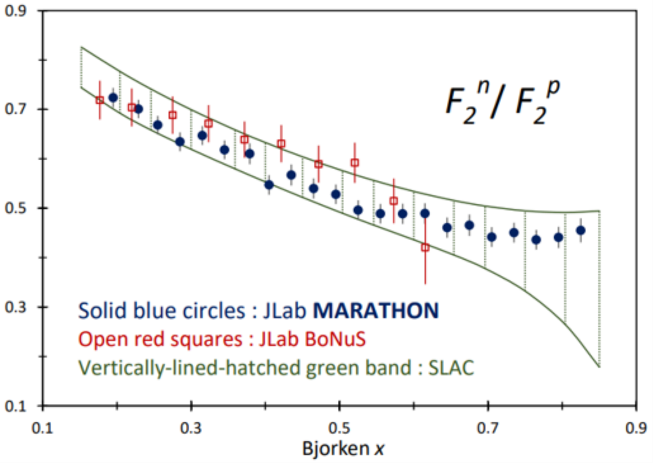

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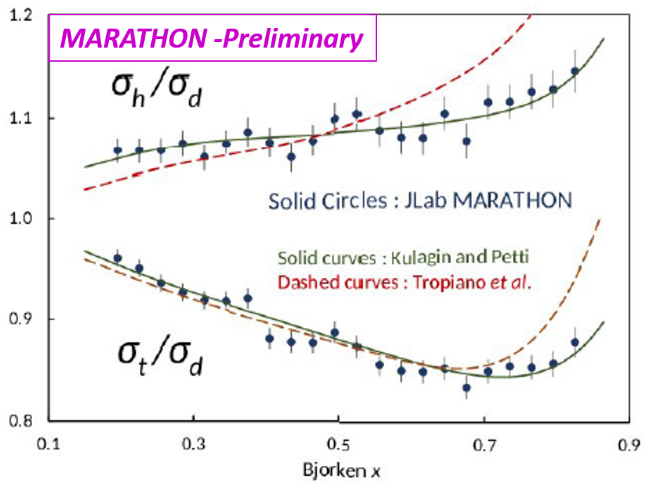
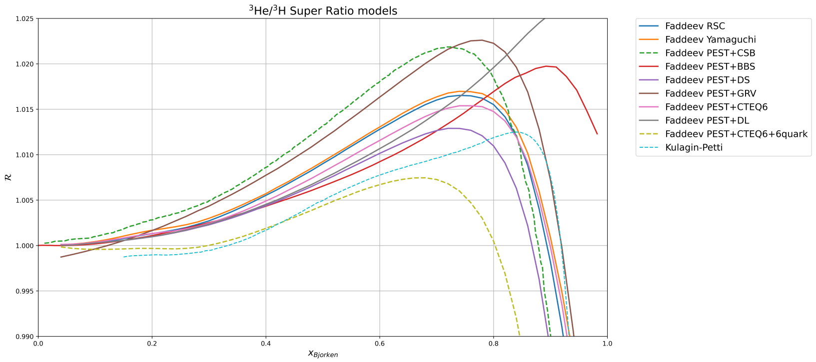


PRL in preparation

But wait, there’s more!

Assessing Model Uncertainties



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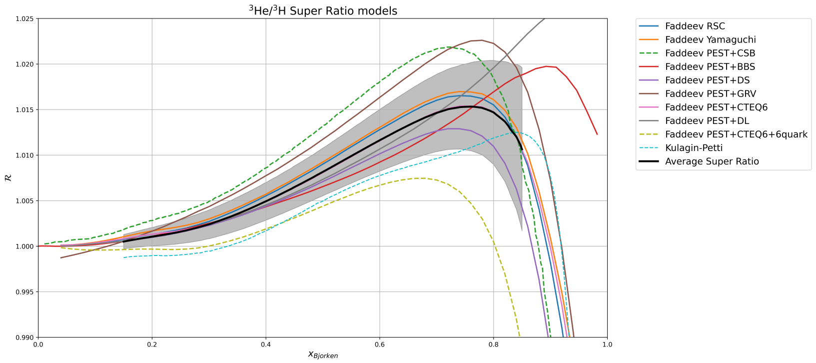

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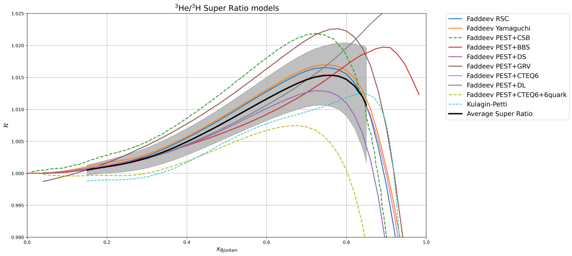

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This isn’t a bad thing, but it is worth noting when a result is model-dependent

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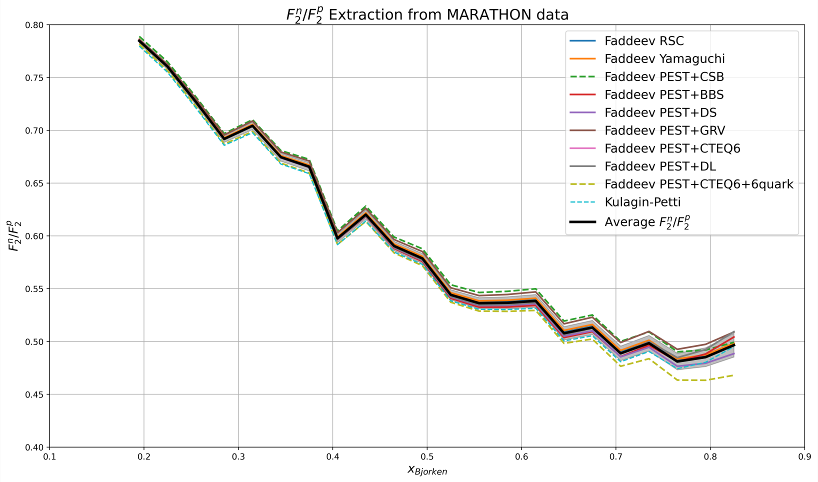
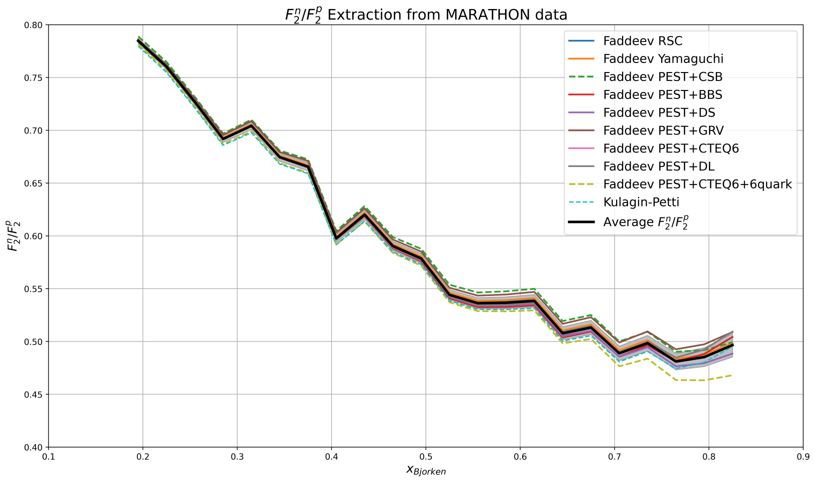
Average Super Ratio F_2^n/F_2^p Extraction



*Note that this does not include the $\sim 2.8\%$ normalization

Looking forward



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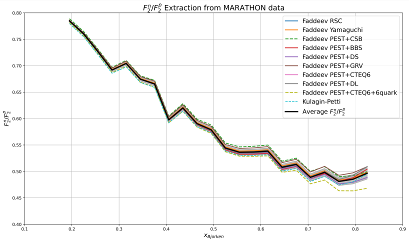

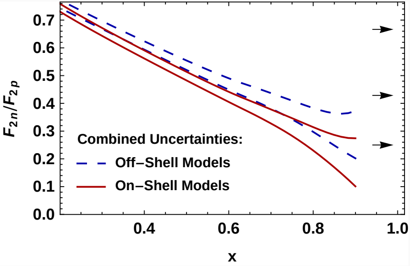

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The F_2^n/F_2^p extraction from $A = 3$ gives very different results from D/p

Potential implications for off-shell Deuteron structure and neutron structure

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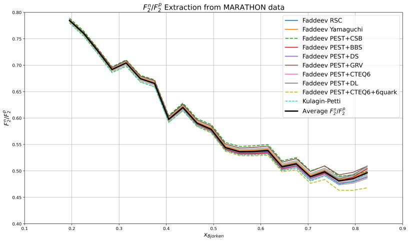

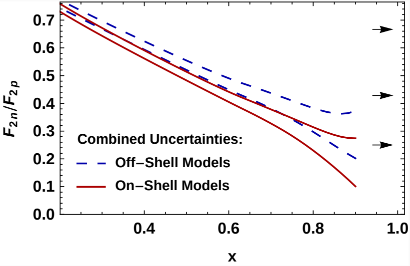

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Potential implications for off-shell Deuteron structure and neutron structure

Further EMC and SRC data will be recorded on a large group of nuclei very soon (the experiment begins at the end of the week)

Thank you!