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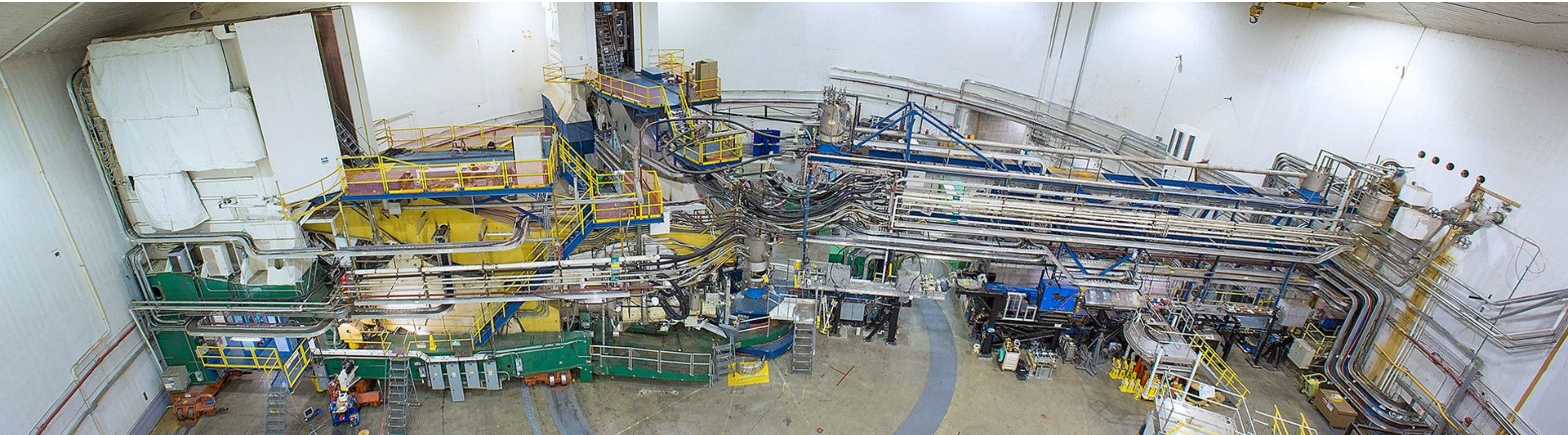
MARATHON: Nucleon structure, the EMC Effect, and Impact

Tyler Hague

Berkeley Lab



Physics and History

The EMC Effect

All is not well in the nucleus

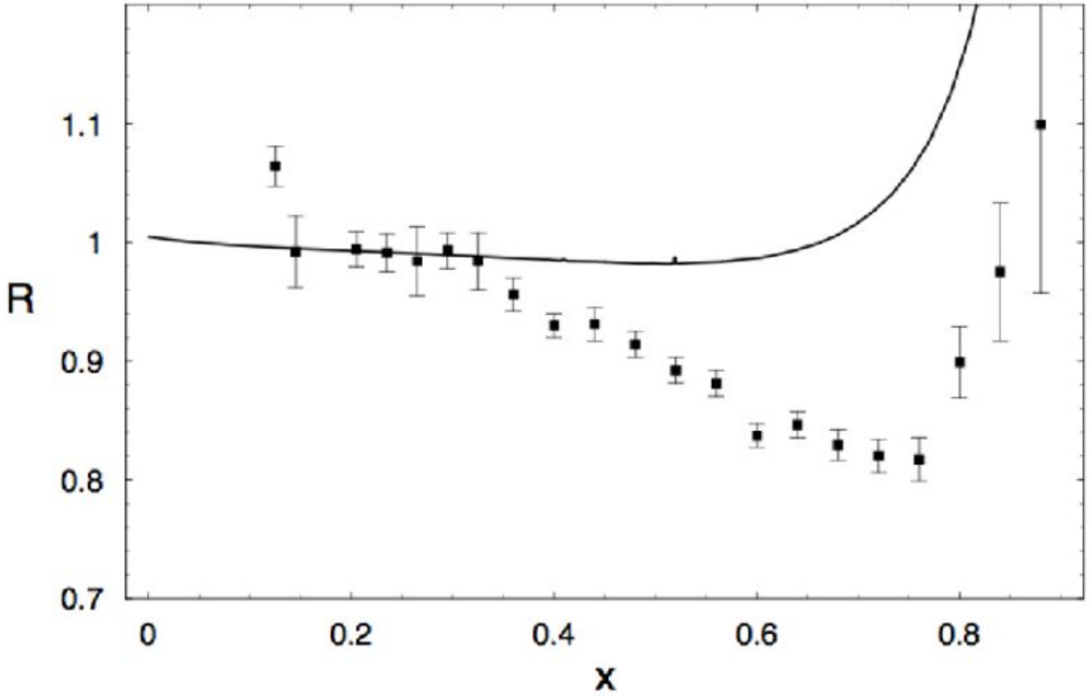
- The European Muon Collaboration sought to measure nuclear structure in lepton deep inelastic scattering
- The experiment used a lead target as their assumption was that nuclear structure functions were the sum of their nucleon constituents

$$\frac{\sigma_A/A}{\sigma_D/2} \approx \frac{F_2^A/A}{F_2^D/2} \approx 1$$

- As a check on their luminosity, the experiment compared the ratio of lead to deuterium assuming that

$$F_2^A = ZF_2^p + (A-Z)\,F_2^n$$

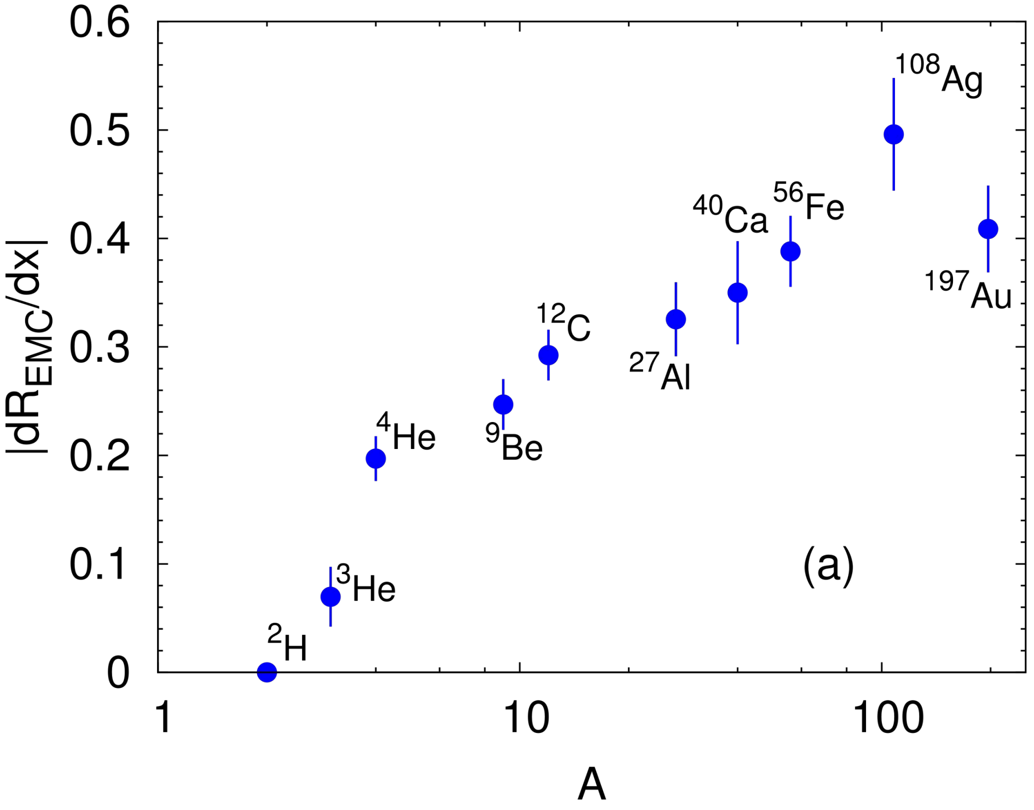
J. J. Aubert, et al., PLB 123, 275 (1983)



The EMC Effect

What we know and what we don't

- It scales approximately with mass number *A*
  - But this doesn't have sufficient predictive power
- The density extrapolation model is not correct
  - See JLab E03-103 results (particularly He4 and Be9)
- It is highly correlated with the number of SRC pairs in a nucleus
  - The nature of this correlation is an area of continued research (e.g. JLab XEM2 experiments)
- Knowledge of neutron structure is a limiting factor in our understanding
  - See this talk



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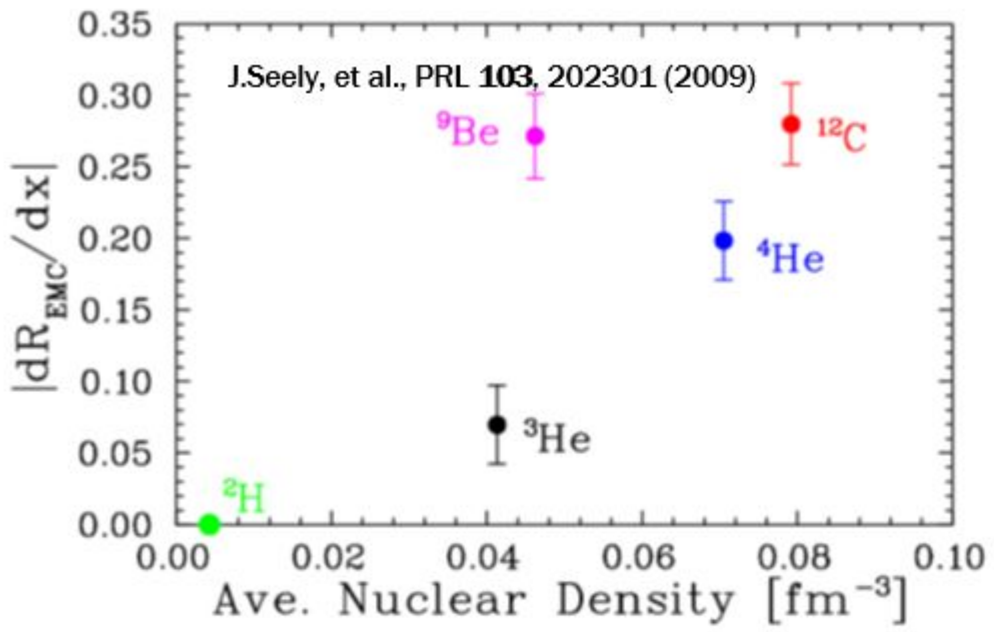

[J. Seely, *et al* PRL 103 (2009)]

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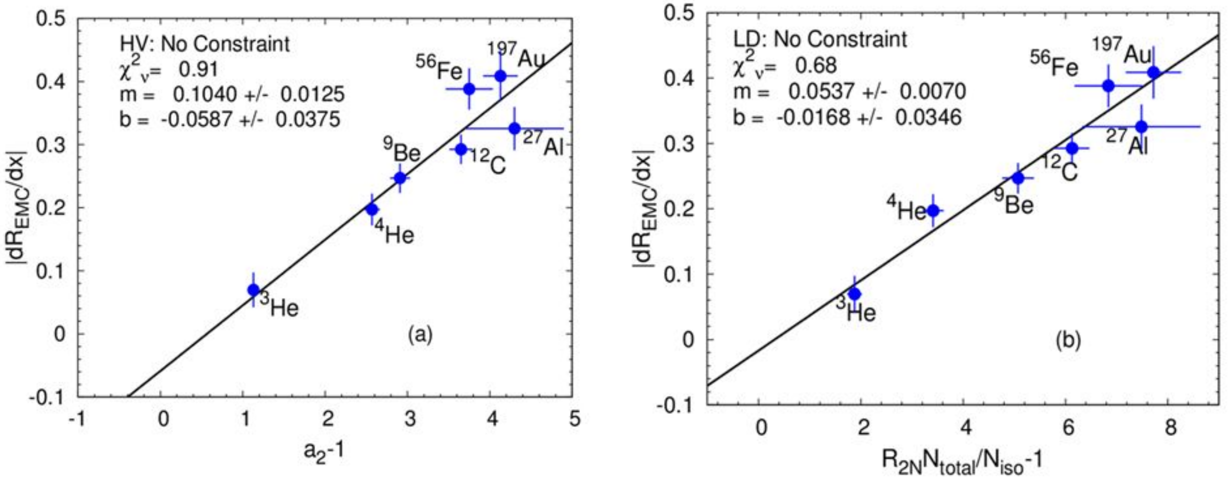

JLab experiments E12-06-105 and E12-10-008

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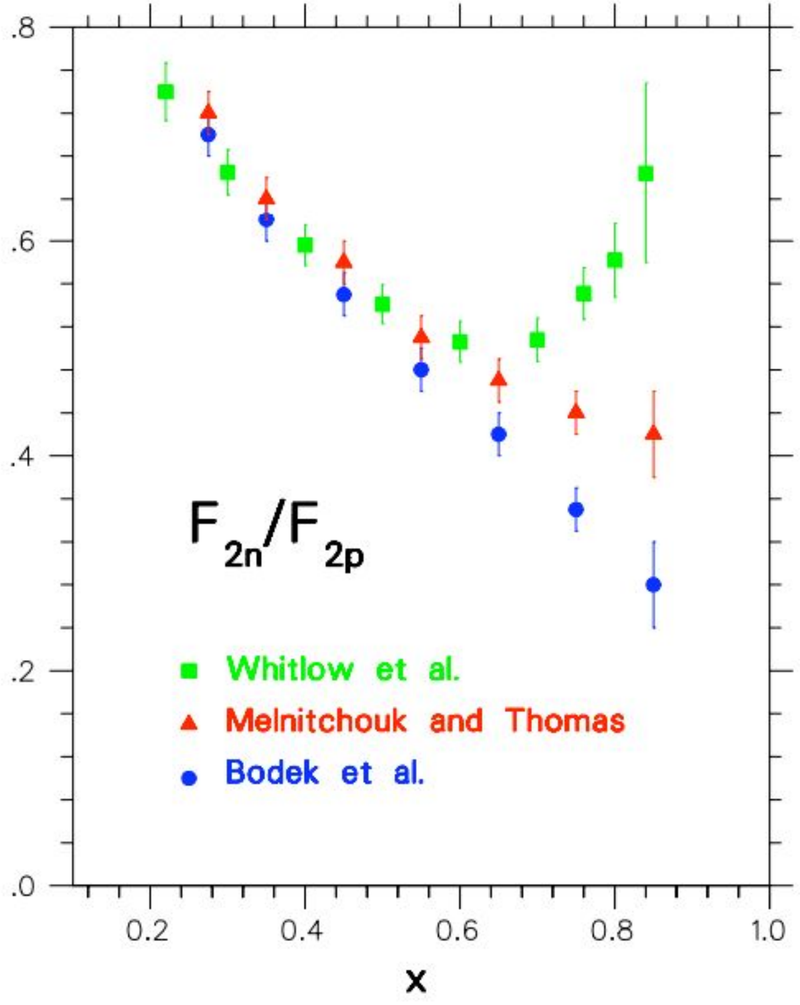
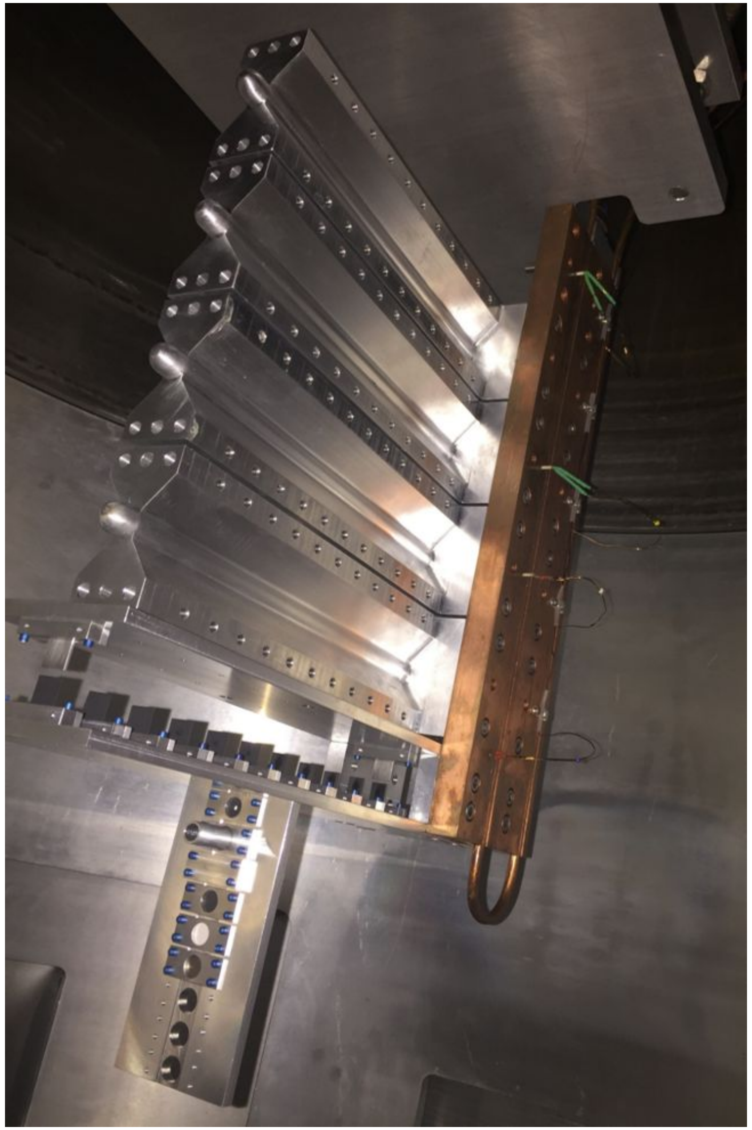


MARATHON

A new way of studying nucleon structure

- Nucleons bound in a nucleus have modified structure
- While the proton is well understood, the neutron is not
  - There is no free neutron target (half life of ~15 minutes)
  - How do we know how modified it is if we don't know the unmodified structure?
- Extracting free neutron structure requires knowledge of nuclear effects
  - What if we could (mostly) cancel these?



F_2^n/F_2^p

(a.k.a. neutrons are tricky)

- Neutron structure is extracted as a ratio to a known quantity (proton structure) to constrain uncertainties
- This is also used in so-called “isoscalar correction” in which a nucleus with neutron or proton excess is “converted” to an isoscalar nucleus
- This is typically extracted from Deuteron-to-proton ratios
  - Relies on our knowledge of deuteron nuclear effects (not good as *x* grows)
- MARATHON measured this with the A=3 mirror nuclei
  - Similar nuclei → similar nuclear effects that largely cancel in the ratio

$$R_h = \frac{F_2^h}{2F_2^p + F_2^n} \qquad R_t = \frac{F_2^t}{F_2^p + 2F_2^n}$$

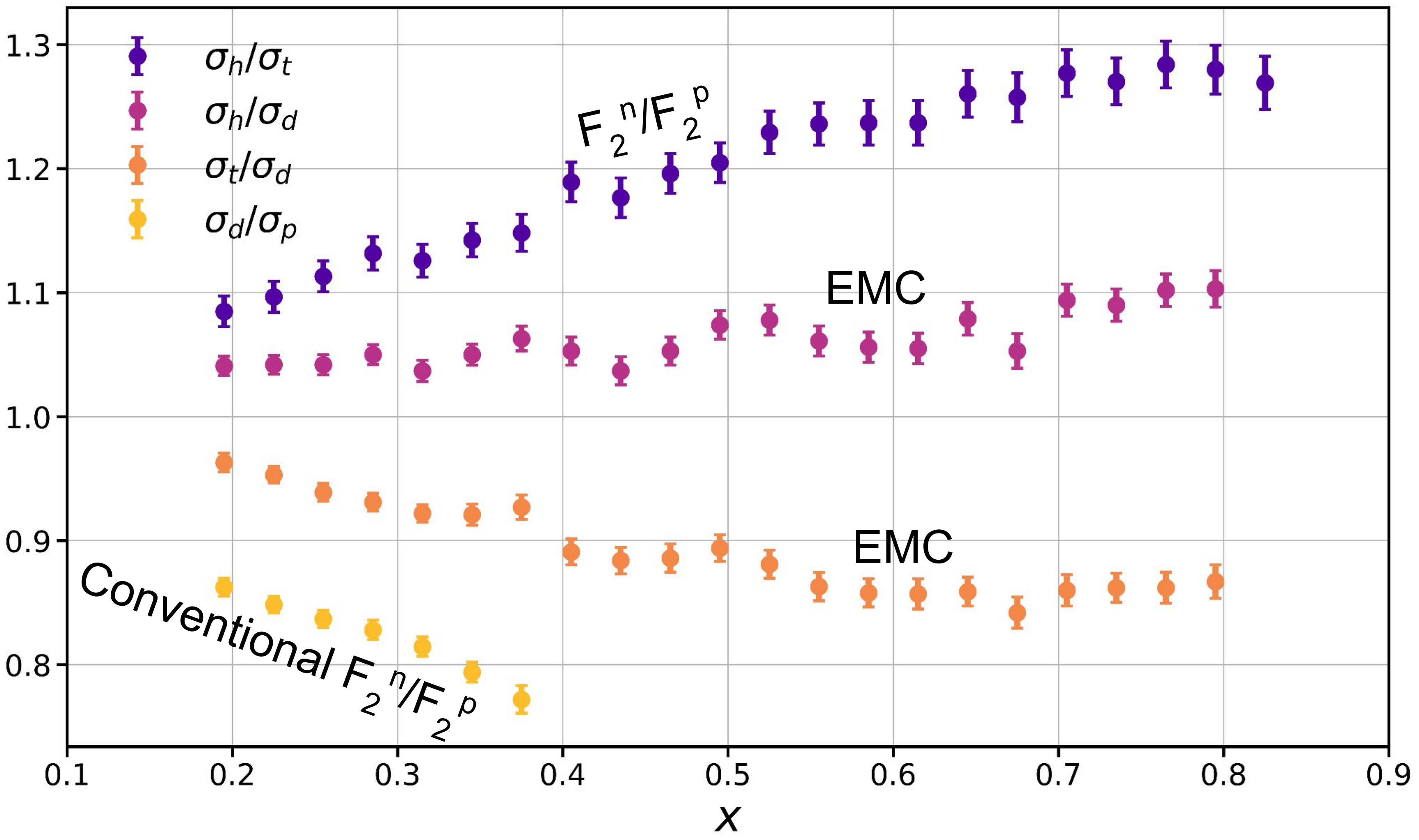
$$\mathcal{R}_{ht} = \frac{R_h}{R_t}$$

$$\frac{F_2^n}{F_2^p} = \frac{F_2^h/F_2^t - 2\mathcal{R}_{ht}}{\mathcal{R}_{ht} - F_2^h/F_2^t}$$

$$F_{2,\mathrm{iso}}^A = F_2^A \cdot \frac{A\left(1 + F_2^n/F_2^p\right)}{2\left(Z + N F_2^n/F_2^p\right)}$$

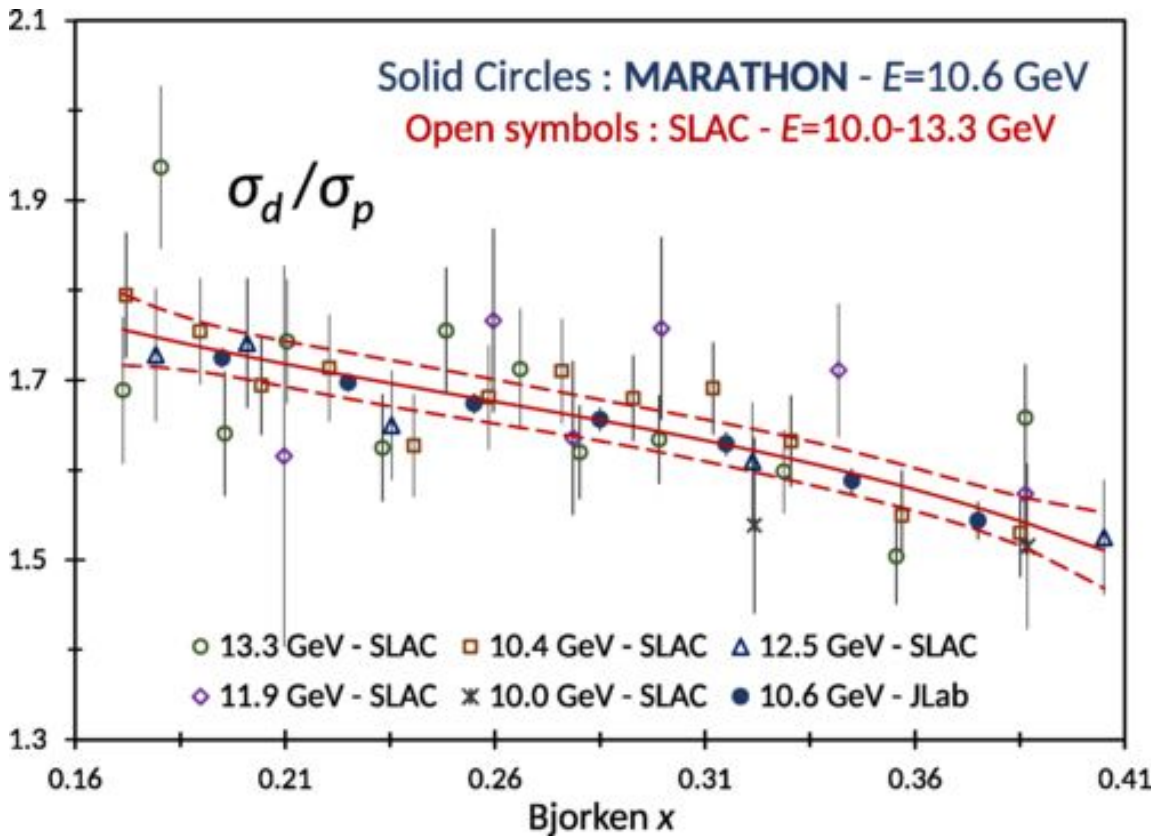
Results

Yield ratios!



D/p and Extraction Consistency Checks

- The Deuterium/Proton ratio was measured as a systematic check
  - This data is shown to agree well with SLAC data



[Jefferson Lab Hall A Tritium Collaboration, *et al* PRL 128 (2022)]

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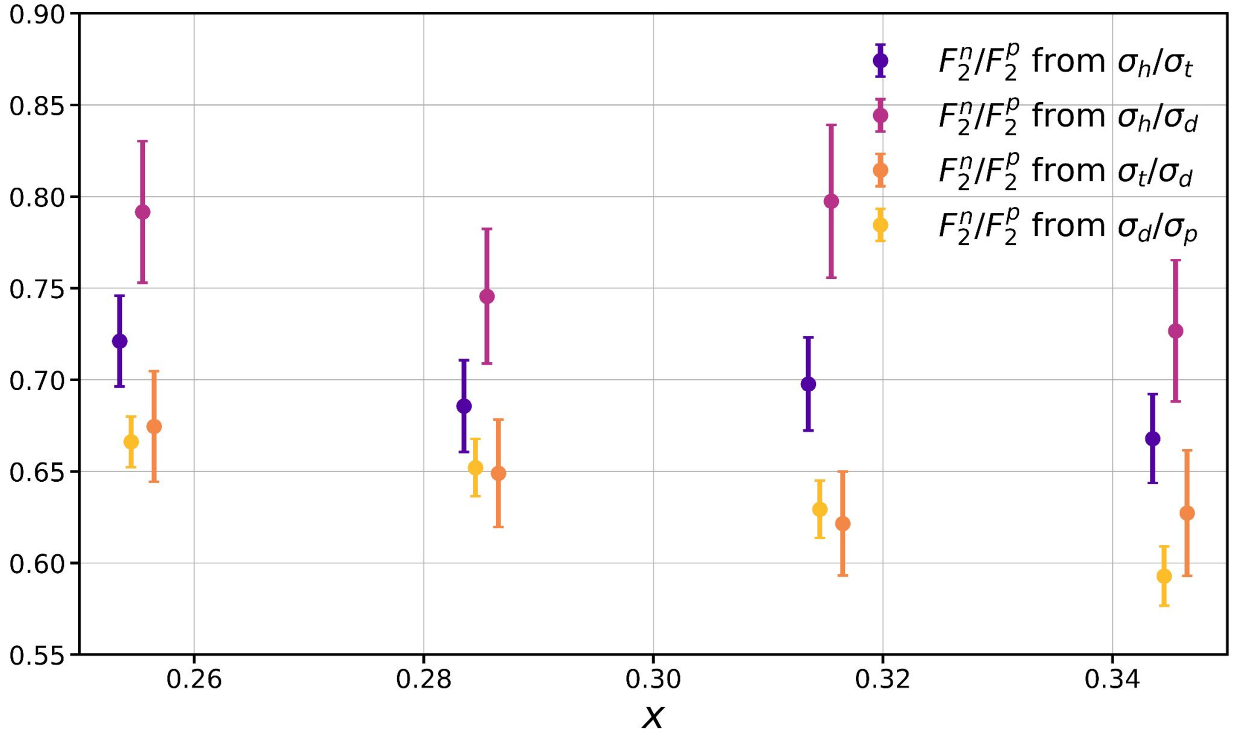
  - This is then a logical kinematic region to check the consistency of F_2^n/F_2^p extractions from each ratio



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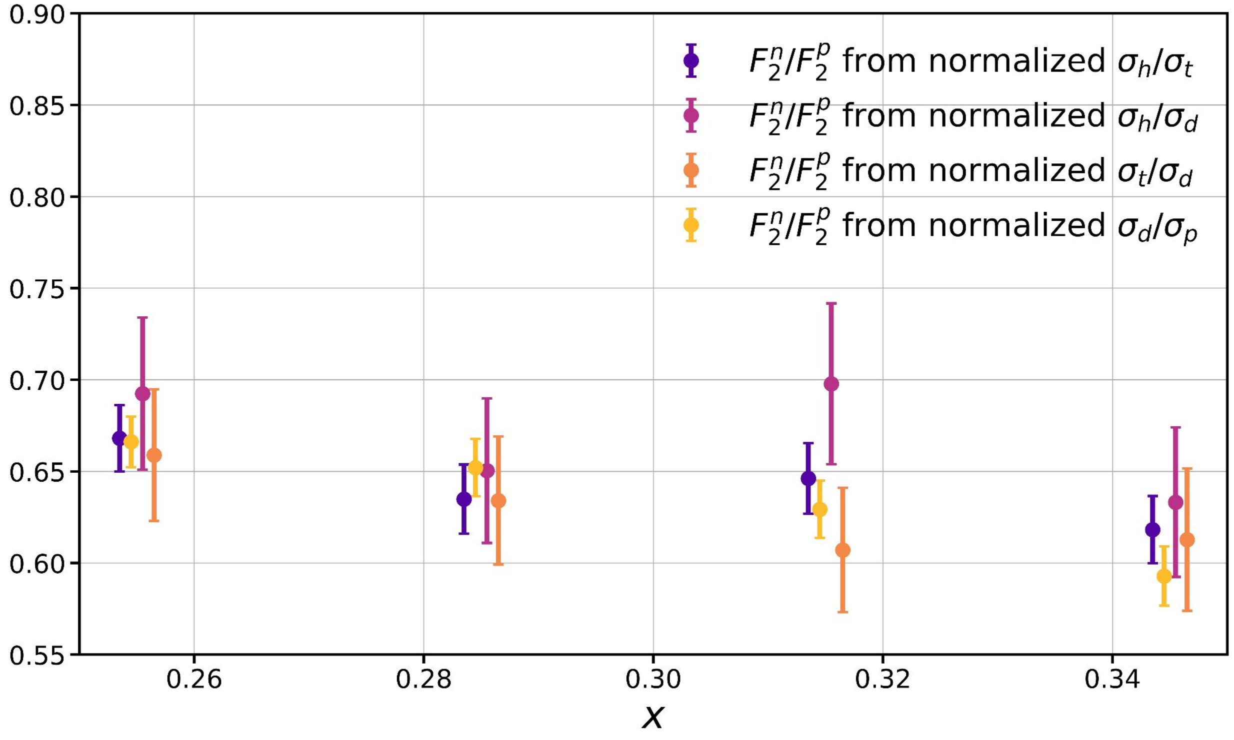
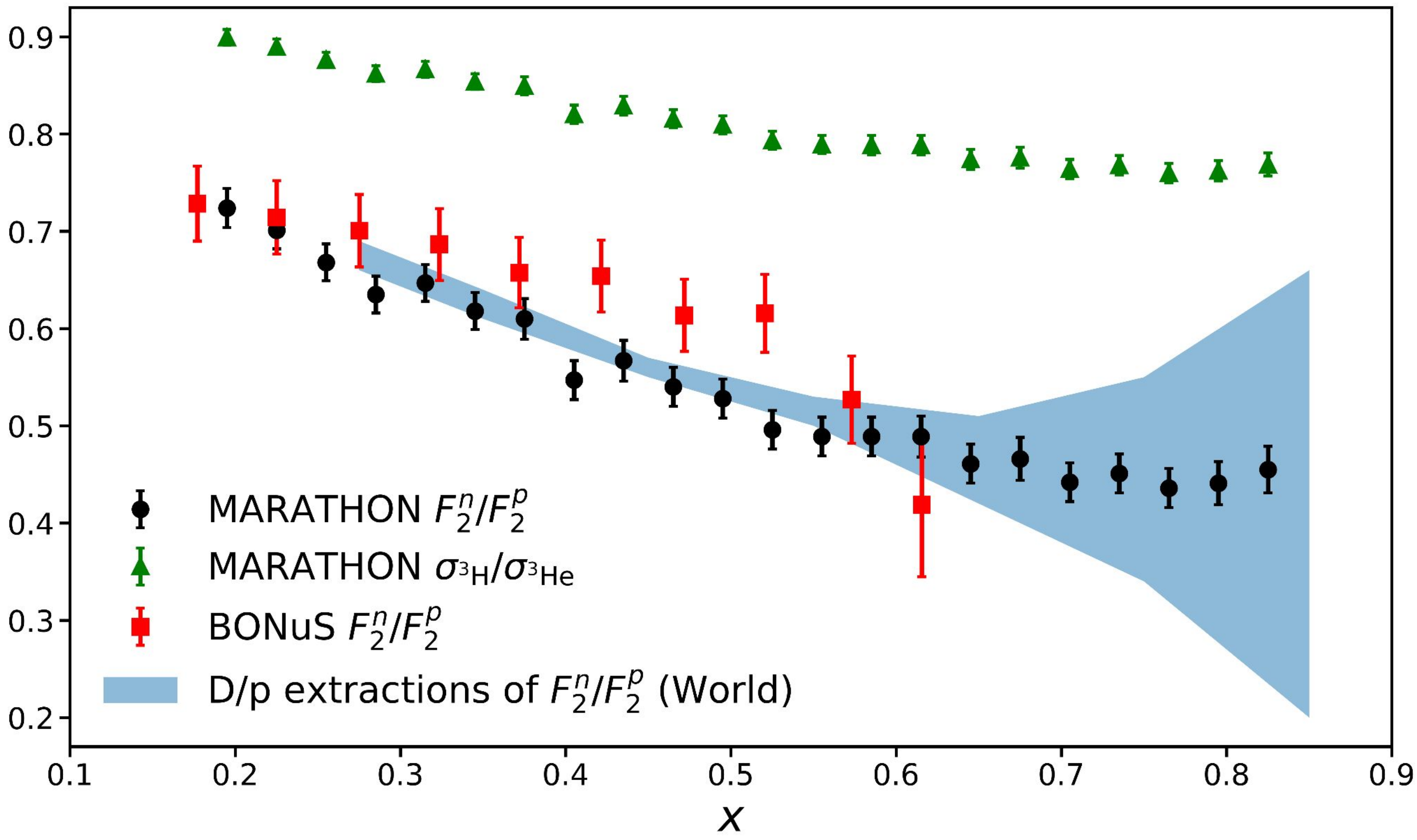
  - This is then a logical kinematic region to check the consistency of F_2^n/F_2^p extractions from each ratio
- It is assumed that the target densities are the cause of this discrepancy and a normalization is applied to the A=3 targets to bring them into agreement*
  - He3 is normalized up by 2.1%
  - H3 is normalized down by 0.4%



*Values determined by χ^2 minimization for agreement with D/p extraction

F_2^n/F_2^p Results!

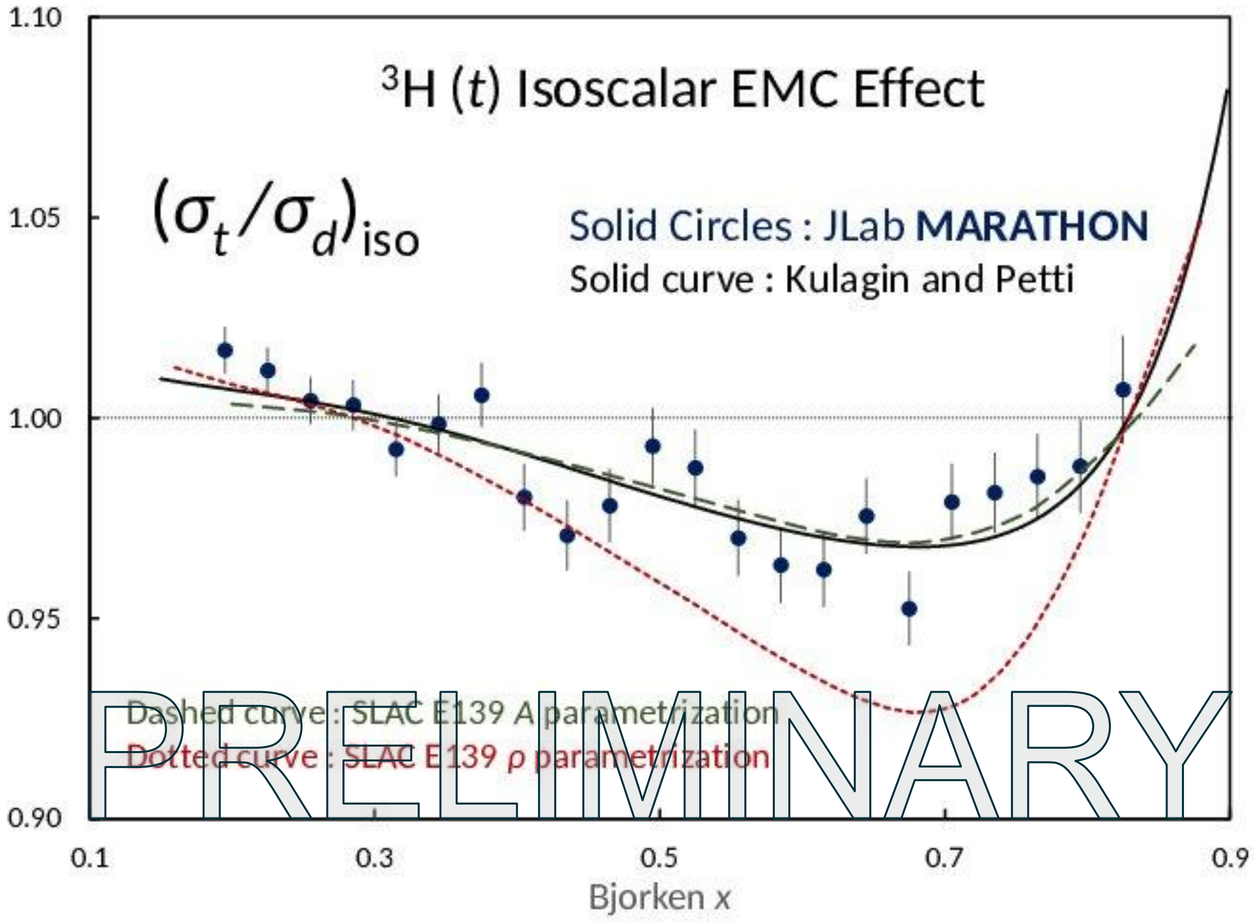
AS SEEN ON PRL



Jefferson Lab Hall A Tritium Collaboration, *et al* PRL 128 (2022)

EMC Results

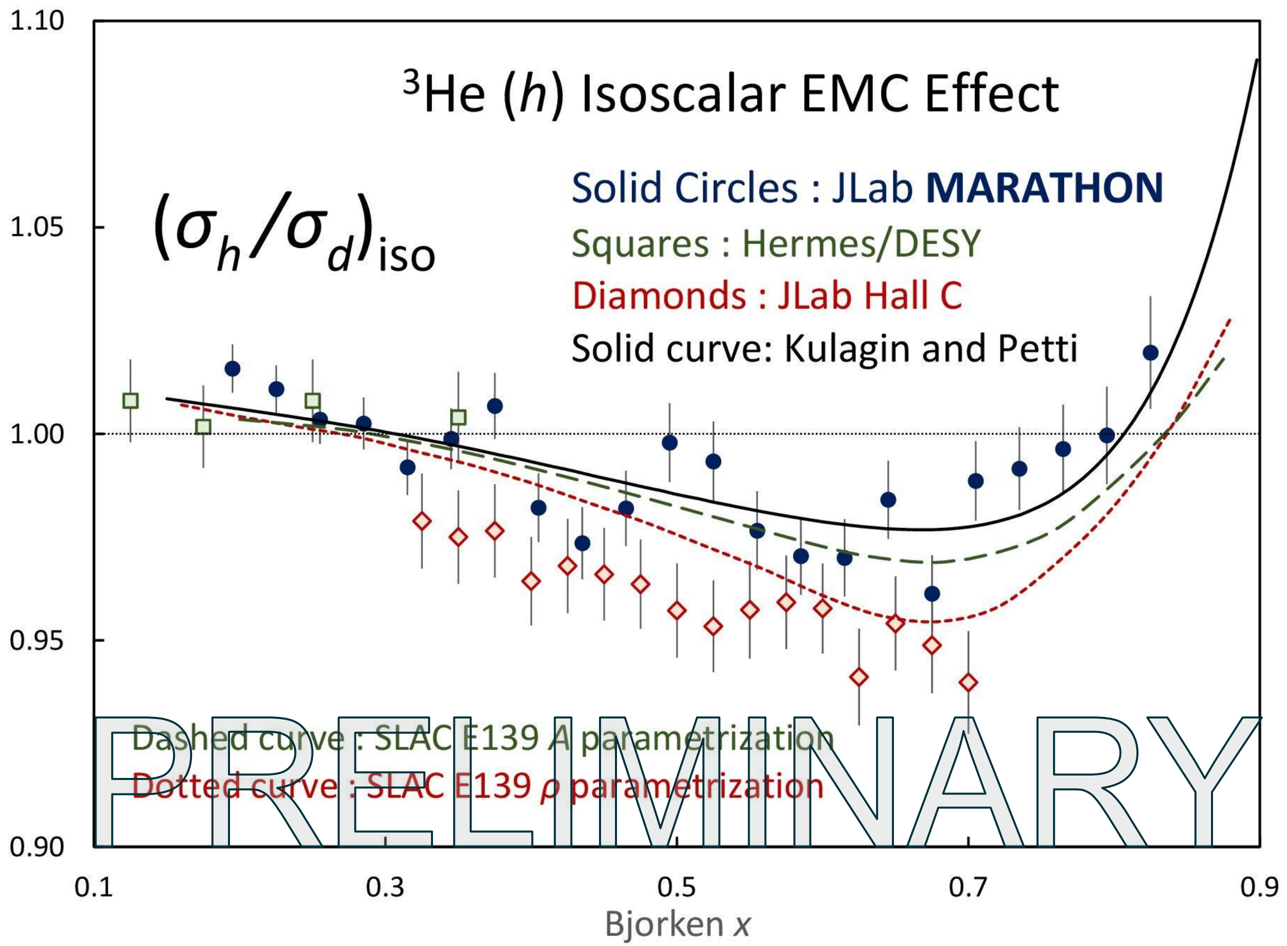
The first EMC measurement on Tritium!



Paper in preparation

EMC Results

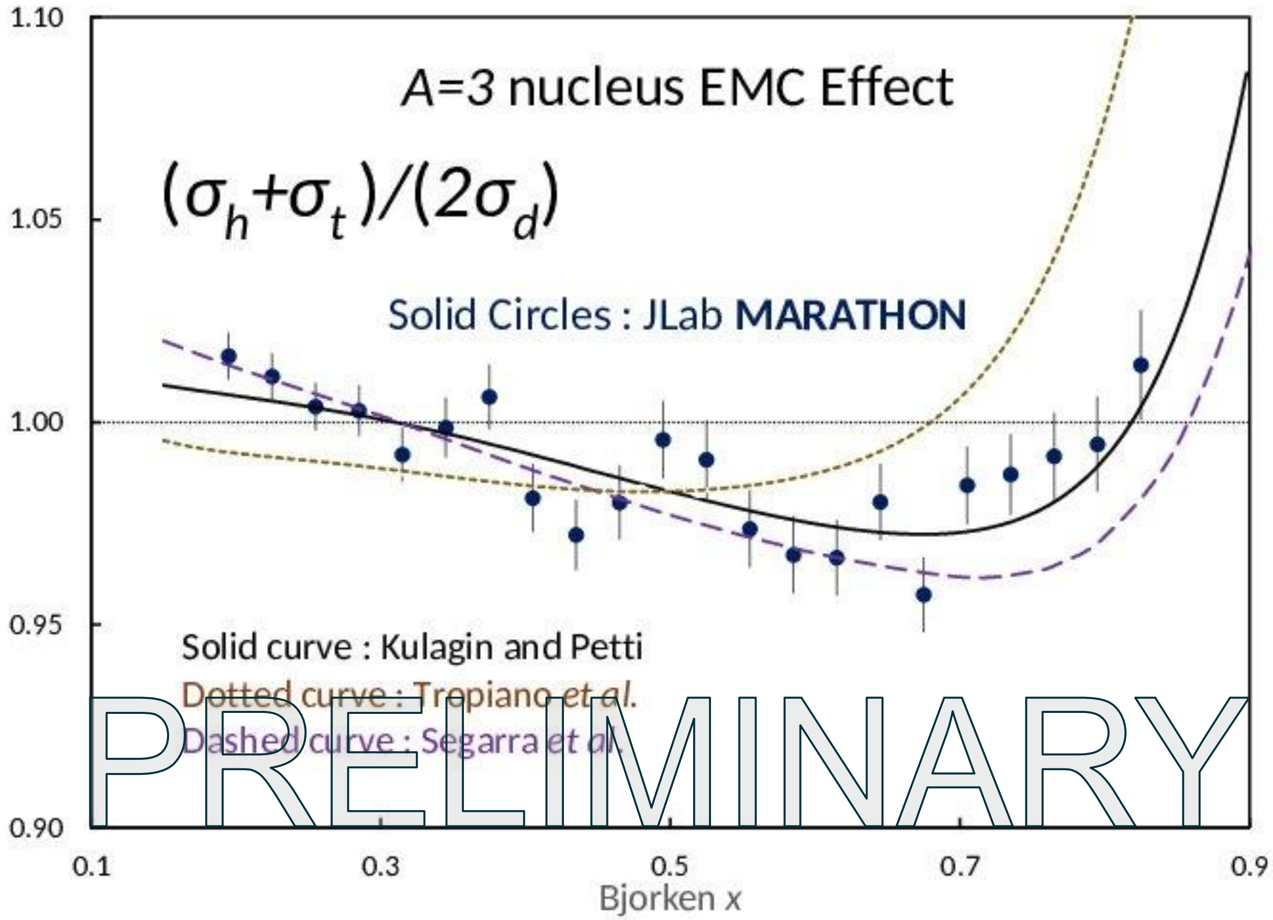
Helium-3!



Paper in preparation

EMC Results

Isoscalar Average



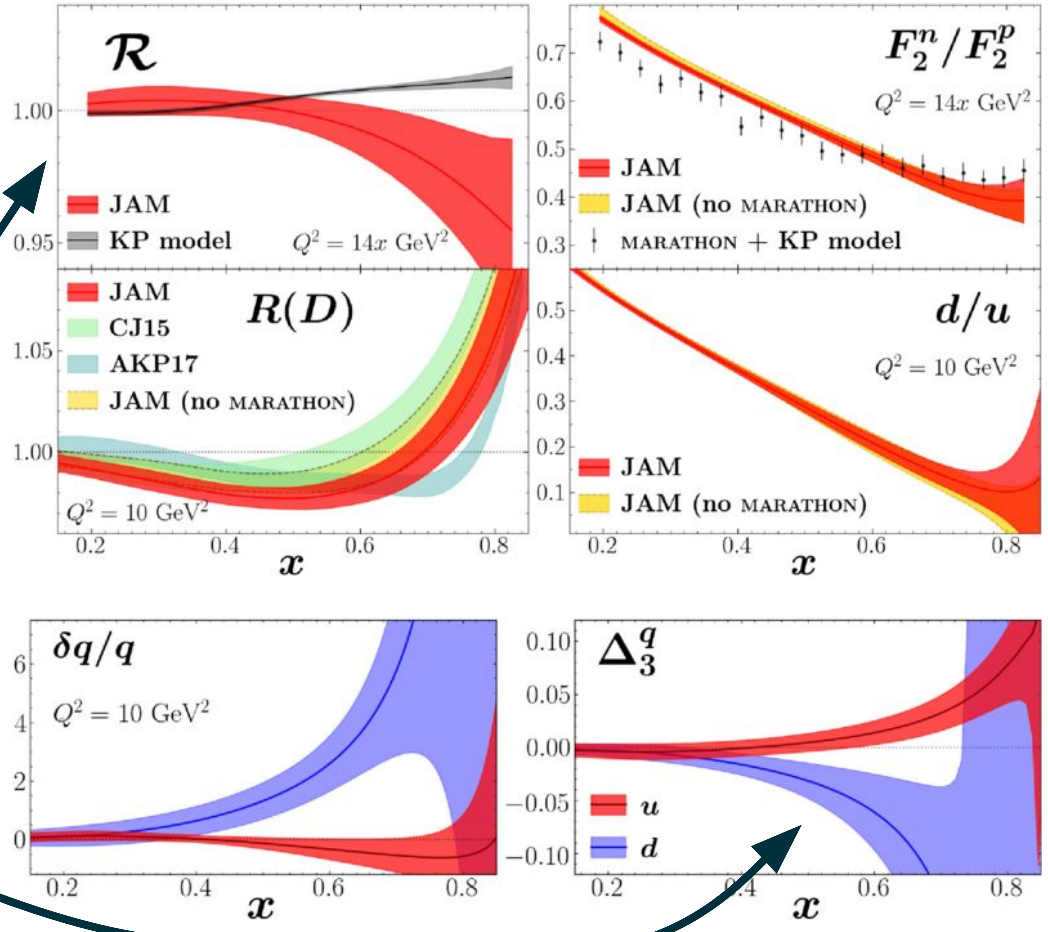
Paper in preparation

Impact and further studies

DISCLAIMER: This section consists of studies that are not official MARATHON results. Rather, the following slides describe studies using the published MARATHON data.

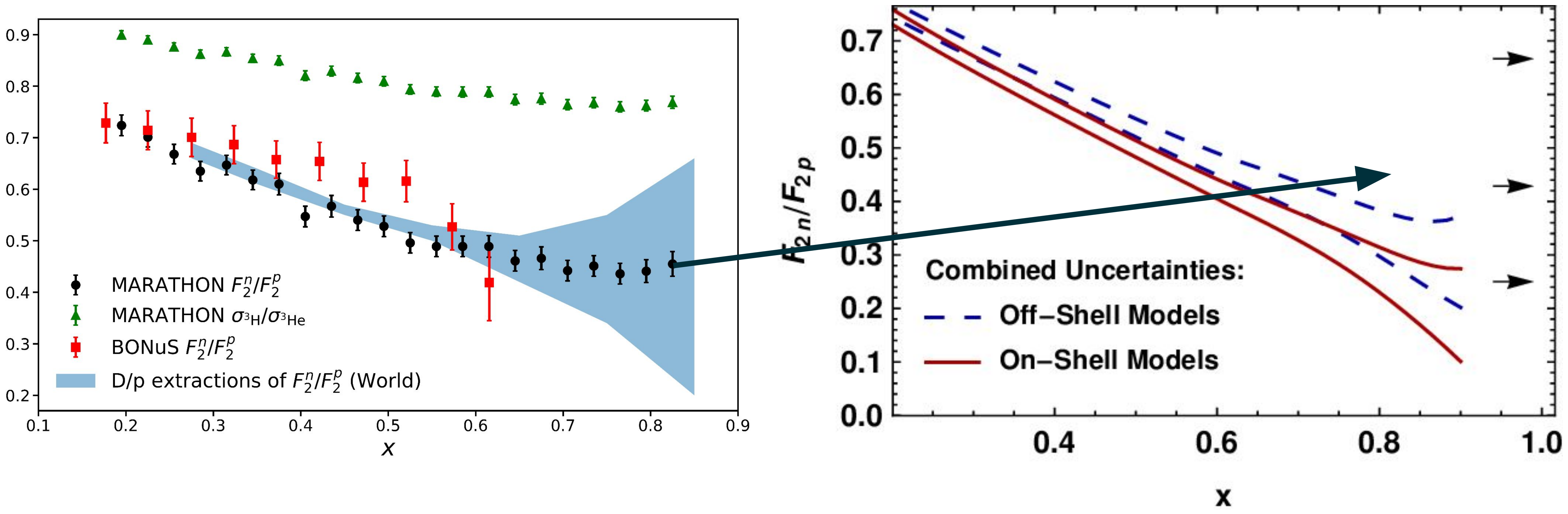
JAM Analysis

- The JAM collaboration performed a global QCD analysis of the MARATHON F_2^n/F_2^p results while floating the quark offshell corrections
- While this analysis found the results to have limited impact on F_2^n/F_2^p uncertainties, other interesting takeaways were found
- This analysis calculated, from the data, a strikingly different super ratio than what was used to extract F_2^n/F_2^p
- Data requires very large quark off-shell effects
- Data shows hints of an isovector EMC effect!



Jefferson Lab Angular Momentum (JAM) Collaboration, *et al* PRL 127 (2021)

Evidence of large Deuteron Off-shell Effects



How sensitive is this result to the model input?

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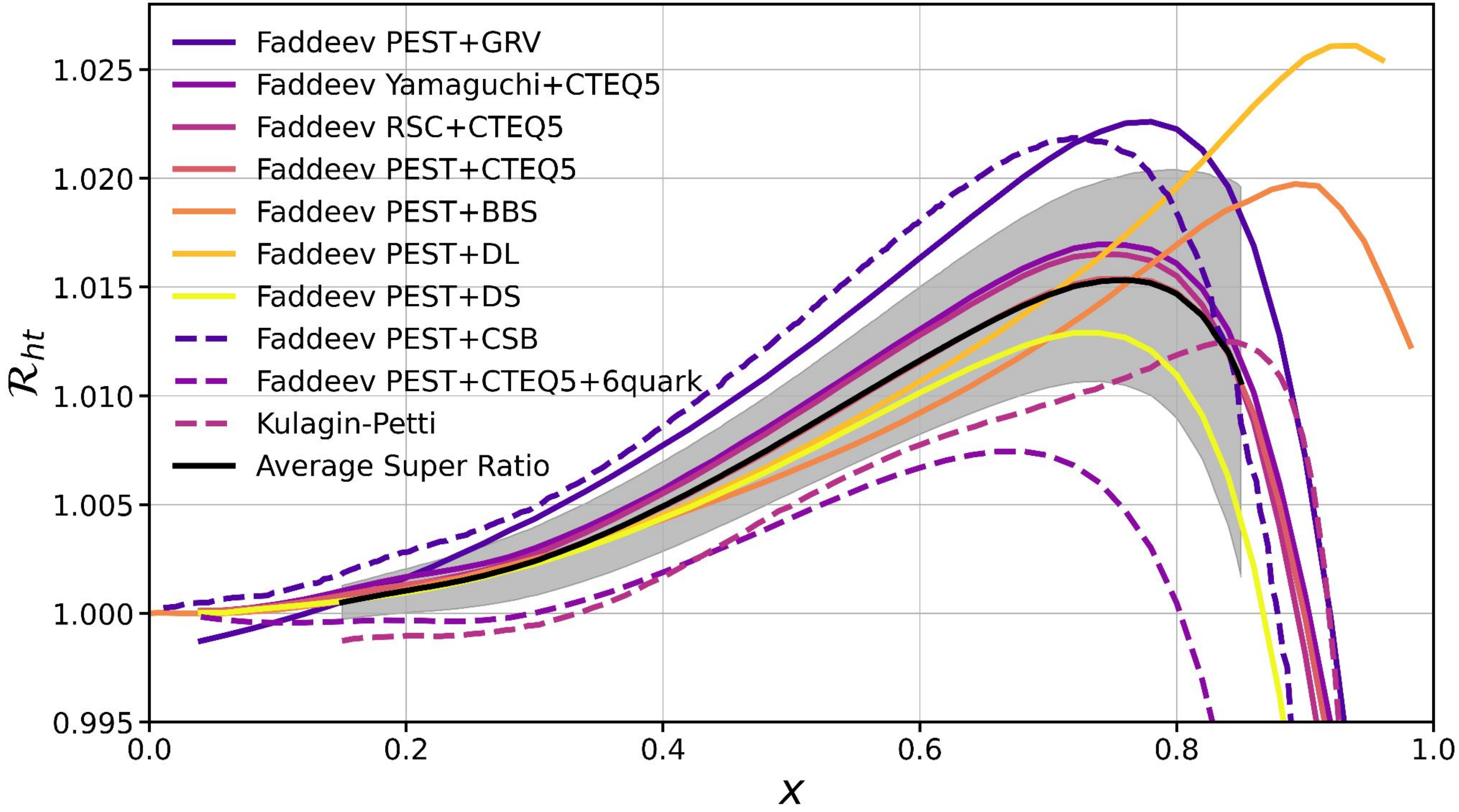
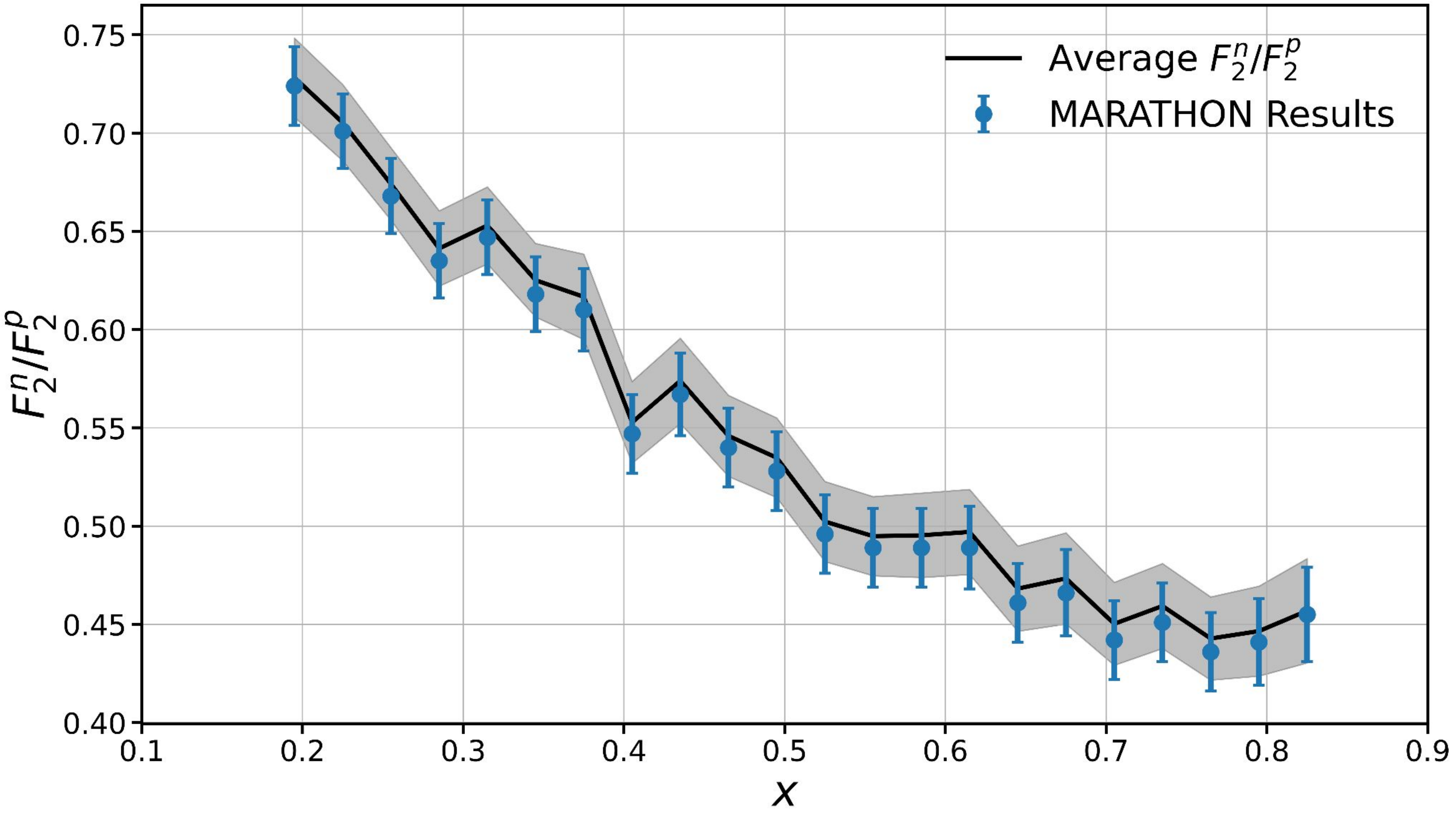
There are many super ratios to choose from, what if we used the “average super ratio”?



Selection from [I. R. Afnan, *et al* PRC 68 (2003)](), Not wholly representative of modern calculations

Answer: Not very

Takeaways from the results are driven by the data, model uncertainty plays a very small role!



Thank you!