Measurement of the EMC effect of the ^{3}He nucleus from the JLab MARATHON experiment

TYLER HAGUE

KENT STATE UNIVERSITY

This work is supported by NSF Grants PHY-1405814 and PHY-1714809 (Kent State University), and DOE Contract DE-AC05-06OR23177 (JLab).

The JLab MARATHON Tritium Collaboration

D. Abrams, H. Albataineh, **S. Alsalmi**, D. Androic, K. Aniol, W. Armstrong, J. Arrington, H. Atac, T. Averett, C. Ayerbe Gayoso, X. Bai, **J. Bane***, **S. Barcus**, A. Beck, V. Bellini, H. Bhatt, D. Bhetuwal, D. Biswas, D. Blyth, W. Boeglin, D. Bulumulla, A. Camsonne, **M. Carmignotto**, **J. Castellanos**, J-P. Chen, C. Ciofi degli Atti, E. O. Cohen, S. Covrig, K. Craycraft, **R. Cruz-Torres**, B. Dongwi, M. Duer, B. Duran, D. Dutta, N. Fomin, E. Fuchey, C. Gal, T. N. Gautam, S. Gilad, K. Gnanvo, T. Gogami, J. Gomez, C. Gu, A. Habarakada, **T. Hague***, O. Hansen, M. Hattawy, **F. Hauenstein**, O. Hen, D. W. Higinbotham, R. Holt, E. Hughes, C. Hyde, H. Ibrahim, S. Jian, S. Joosten, A. Karki, B. Karki, A. T. Katramatou, C. Keppel, M. Khachatryan, V. Khachatryan, A. Khanal, D. King, P. King, I. Korover, S. A. Kulagin, **T. Kutz***, N. Lashley-Colthirst, G. Laskaris, **S. Li**, W. Li, **H. Liu***, S. Liuti, N. Liyanage, D. Lonardoni, R. Machleidt, L.E. Marcucci, P. Markowitz, **E. McClellan**, D. Meekins, W. Melnitchouk, S. Mey-Tal Beck, Z-E. Meziani, R. Michaels, M. Mihovilovič, V. Nelyubin, **D. Nguyen**, N. Nuruzzaman, **M. Nycz***, R. Obrecht, M. Olson, L. Ou, V. Owen, E. Pace, **B. Pandey**, V. Pandey, A. Papadopoulou, M. Paolone, S. Park, M. Patsyuk, S. Paul, G. G. Petratos, R. Petti, E. Piasetzky, R. Pomatsalyuk, S. Premathilake, A. J. R. Puckett, V. Punjabi, R. Ransome, M. N. H. Rashad, P. E. Reimer, S. Riordan, J. Roche, F. Sammarruca, G. Salmè, **N. Santiesteban**, B. Sawatzky, J. Segal, E. P. Segarra, B. Schmookler, A. Schmidt, S. Scopetta, A. Shahinyan, S. Širca, N. Sparveris, **T. Su***, R. Suleiman, H. Szumila-Vance, A. S. Tadepalli, L. Tang, W. Tireman, F. Tortorici, G. Urciuoli, M. Viviani, L. B. Weinstein, B. Wojtsekhowski, S. Wood, **Z. H. Ye**, Z. Y. Ye, and J. Zhang.

More than 140 Collaborators

Red-Boldfaced Names: Tritium Program grad students; **starred**: MARATHON Ph.D. students

Blue-Boldfaced Names: Tritium Program postdoctoral associates

The JLab MARATHON Tritium Collaboration

Forty Five Institutions (in no particular order): University of Virginia; Texas A & M University; Kent State University; University of Zagreb; California State University, Los Angeles; Argonne National Laboratory; Temple University; The College of William and Mary; University of Tennessee; Massachusetts Institute of Technology; INFN Sezione di Catania; INFN Sezione di Roma, INFN Sezione di Pisa; Mississippi State University; Hampton University; Florida International University; Old Dominion University; Jefferson Lab; University of Perugia; Tel Aviv University; University of Connecticut; Tohoku University; Columbia University; Cairo University; Ohio University; Stony Brook, State University of New York; Syracuse University; Nuclear Research Center-Negev, Beer-Sheva; Institute for Nuclear Research of the Russian Academy of Sciences; University of New Hampshire; University of Regina; Columbia University; Facility for Rare Isotope Beams, Michigan State University; Los Alamos National Laboratory; University of Idaho; University of Pisa; Jožef Stefan Institute, University of Ljubljana; Johannes Gutenberg-Universität Mainz; Saint Norbert College; Center for Neutrino Physics, Virginia Tech; University of South Carolina; Kharkov Institute of Physics and Technology; Norfolk State University; Rutgers University; Artem Alikhanian National Laboratory; Tel Aviv University; Northern Michigan University; University of Illinois, Chicago.

Twelve Countries: Armenia, Canada, Croatia, Egypt, Germany, Israel, Italy, Japan, Russia, Slovenia, Ukraine, United States.

Deep Inelastic Scattering

Cross Section – Nucleon structure functions F_1 and F_2:

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

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

$$\nu = E - E'$$

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

Quark-Parton Model (QPM) interpretation in terms of quark probability distributions qi(x) (large Q2 and ν):

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

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

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

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

EMC Effect

Nuclear F_2 structure function per nucleon is different than that of deuterium: large dependence on Bjorken x and mass A.

Quark distribution functions modified in the nuclear medium.

Possible explanations include:

- Binding and off-shell 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
- Local environment and density dependence

No universally accepted theory for the effect explanation.

A=3 data are expected to be valuable for the full understanding of the EMC effect. The EMC effect ratio of ^3H and ^3He is of particular importance!

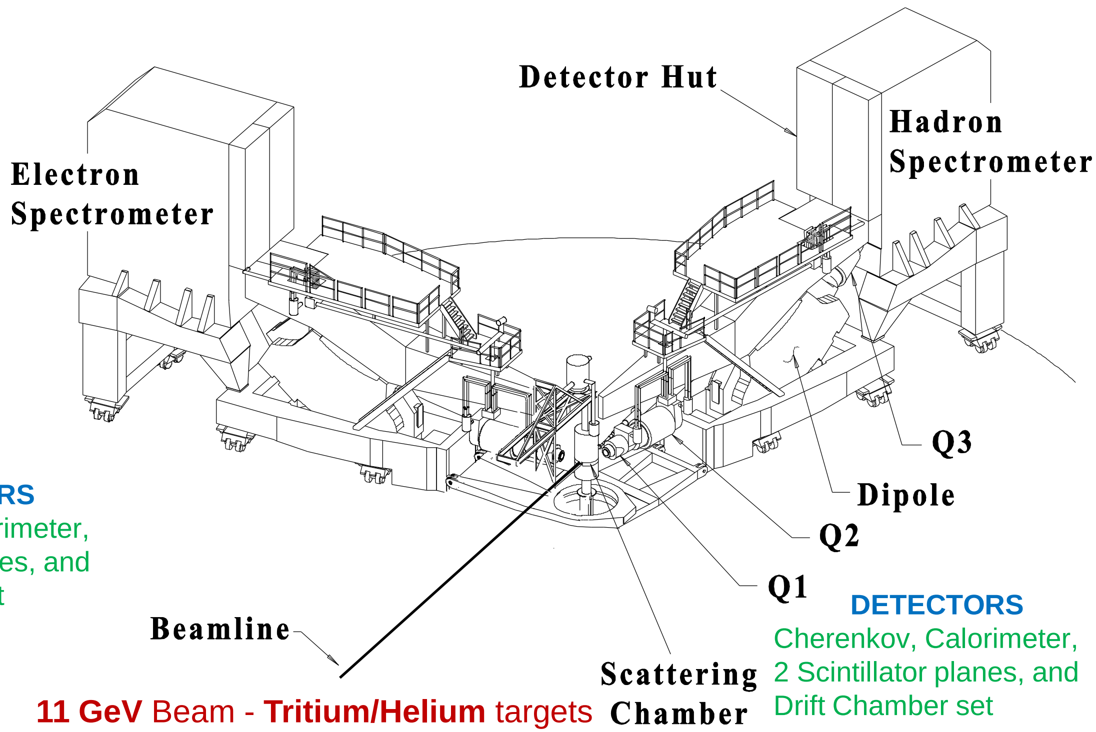
The Jlab CEBAF Accelerator

CEBAF is a racetrack accelerator that allows up to 5 passes (5.5 for Hall D) at 2.12 GeV per pass.

JLab is home to four halls (A, B, C, and D) that each house unique setups to extend our understanding of nuclear physics.

MARATHON took place in Hall A using the standard High Resolution Spectrometer setups during the Spring of 2018.

Experimental Setup – Hall A High Resolution Spectrometers



DETECTORS
Cherenkov, Calorimeter, 2 Scintillator planes, and Drift Chamber set

DETECTORS
Cherenkov, Calorimeter, 2 Scintillator planes, and Drift Chamber set

11 GeV Beam - **Tritium/Helium** targets

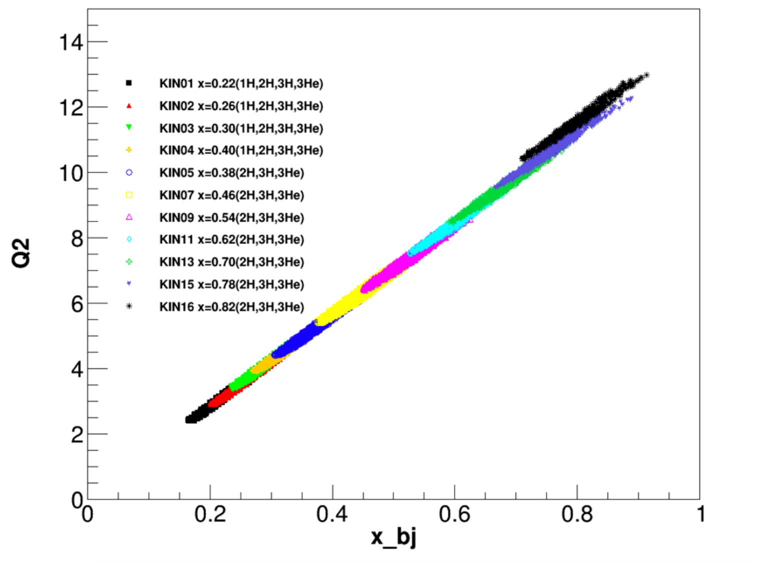
MARATHON Target Ladder

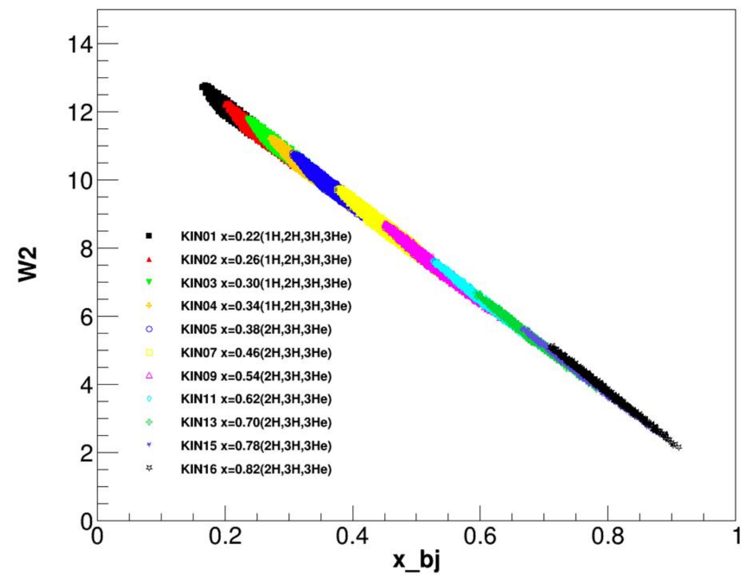
Specially designed High Pressure Gas Cells (in order from top to bottom):

- Tritium (^3H)
- Deuterium (^2H)
- Hydrogen (H)
- Helium-3 (^3He)

The Tritium cell was filled at the Tritium Handling Facility at Savannah River National Laboratory

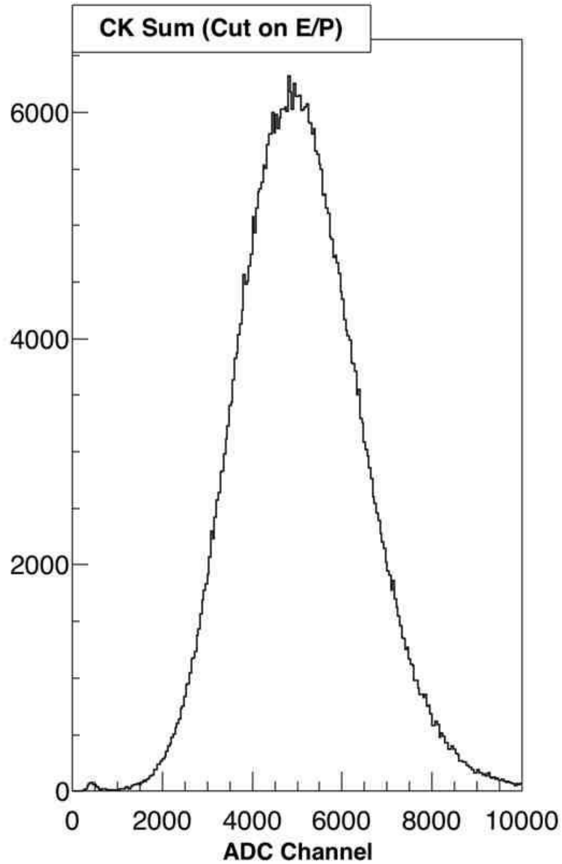
MARATHON Kinematics



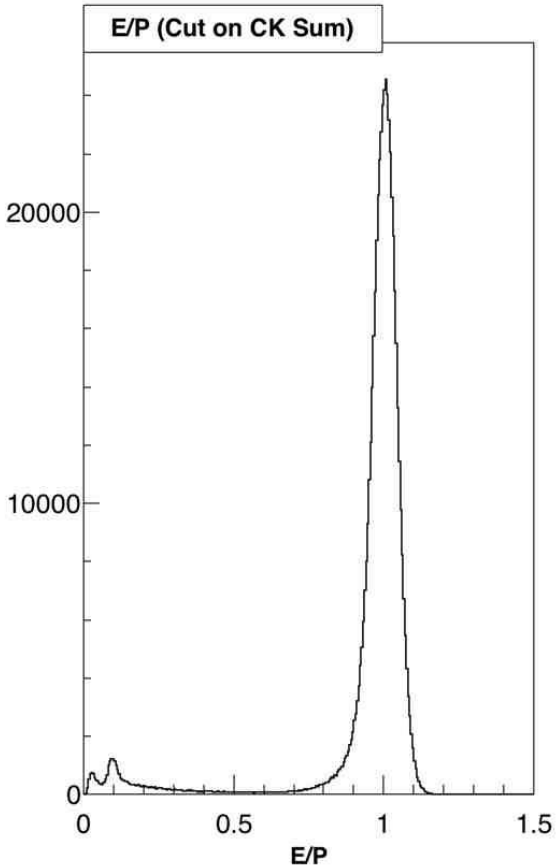


Plots Courtesy of Tong Su

Electron Identification



Cherenkov Detector - Cut: Channel > 1500



Lead Glass Calorimeter - Cut: E/P > 0.7

F_2^n/F_2^p Extraction

The nucleon structure function ratio can be extracted by defining a "Super-Ratio" as the ratio of "EMC-Type" ratios:

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

By assuming that the cross section ratio is equal to the structure function ratio, we can solve the above equations for the nucleon structure function ratio in terms of the ^{3}He and ^{2}H cross section ratio and R^*:

$$\frac{\sigma(3He)}{\sigma(2H)} = \frac{F_2^{^3He}}{F_2^{^2H}} \qquad \frac{F_2^n}{F_2^p} = \frac{F_2^{^3He}\big/F_2^{^2H} - 2R^*}{R^* - F_2^{^3He}\big/F_2^{^2H}}$$

Using the measured ^{3}He and ^{2}H data and a theoretical model for R the nucleon structure function ratio can be easily extracted.

Isoscalar Correction

To compare EMC effects is necessary to apply an isoscalar correction to approximate a nucleus with equal protons and neutrons:

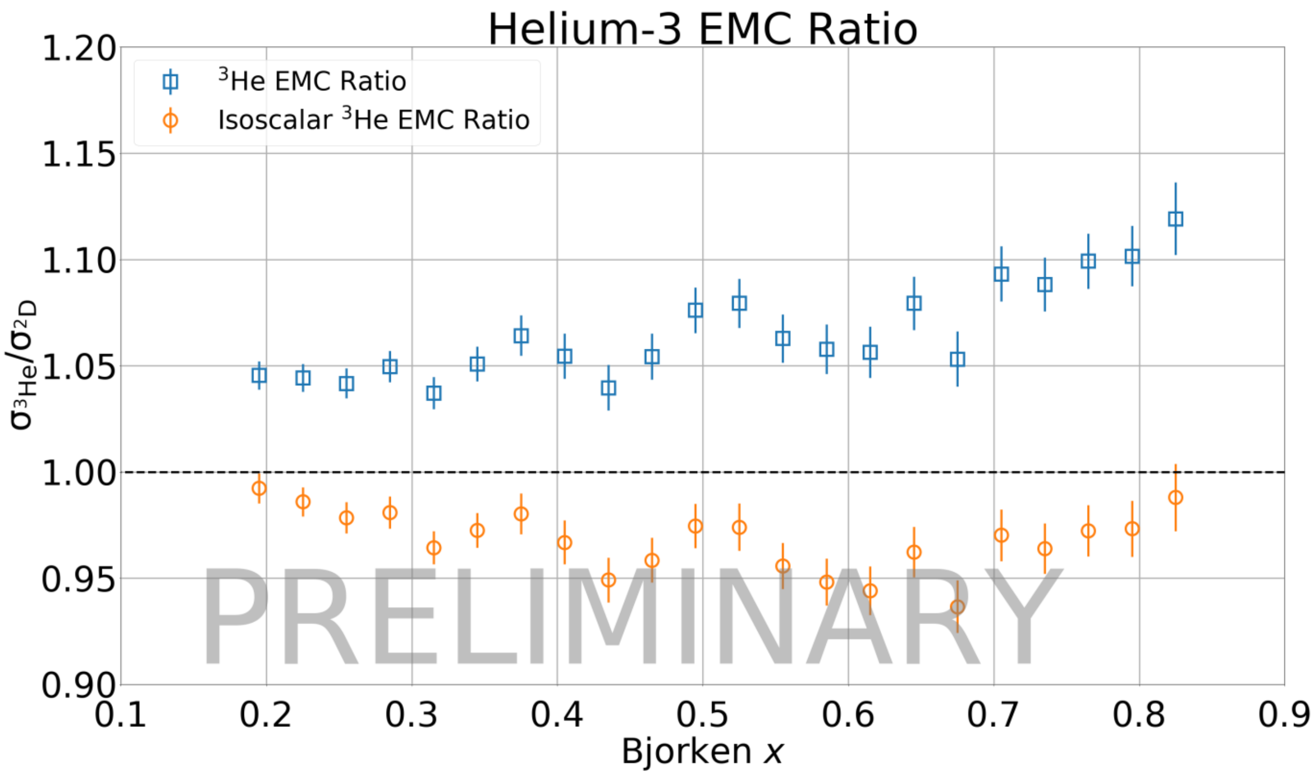
$$\text{Isoscalar Correction Factor} = \frac{{}^{1}\!/_{2}\left(1 + {}^{F_2^n}\!/_{F_2^p}\right)}{{}^{1}\!/_{A}\left(Z + (A-Z)\,{}^{F_2^n}\!/_{F_2^p}\right)}$$

A and *Z* are the mass and proton numbers of the target, respectively.

The input of ${}^{F_2^n}\!/_{F_2^p}$ is the ratio as extracted from the ${}^{{}^3H}\!/_{{}^3He}$ target ratio.

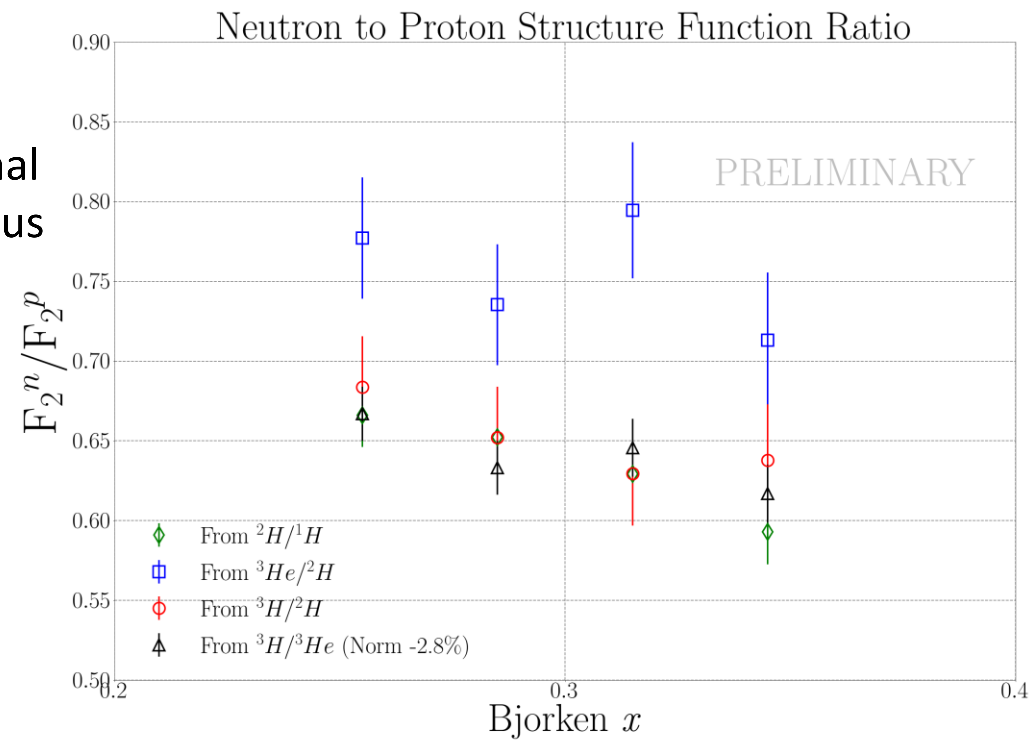
For more info on the MARATHON ${}^{F_2^n}\!/_{F_2^p}$ extraction, see Tong Su's talk *"JLab measurement of the ratio of the nucleon structure functions, ${}^{F_2^n}\!/_{F_2^p}$, from electron DIS off ^3H and ^3He at large Bjorken x"*

Helium-3 EMC Ratio - Raw



Nucleon Structure Function Ratio Extractions

Nuclear Effects should be minimal around *x=0.3*, thus the extractions should agree.

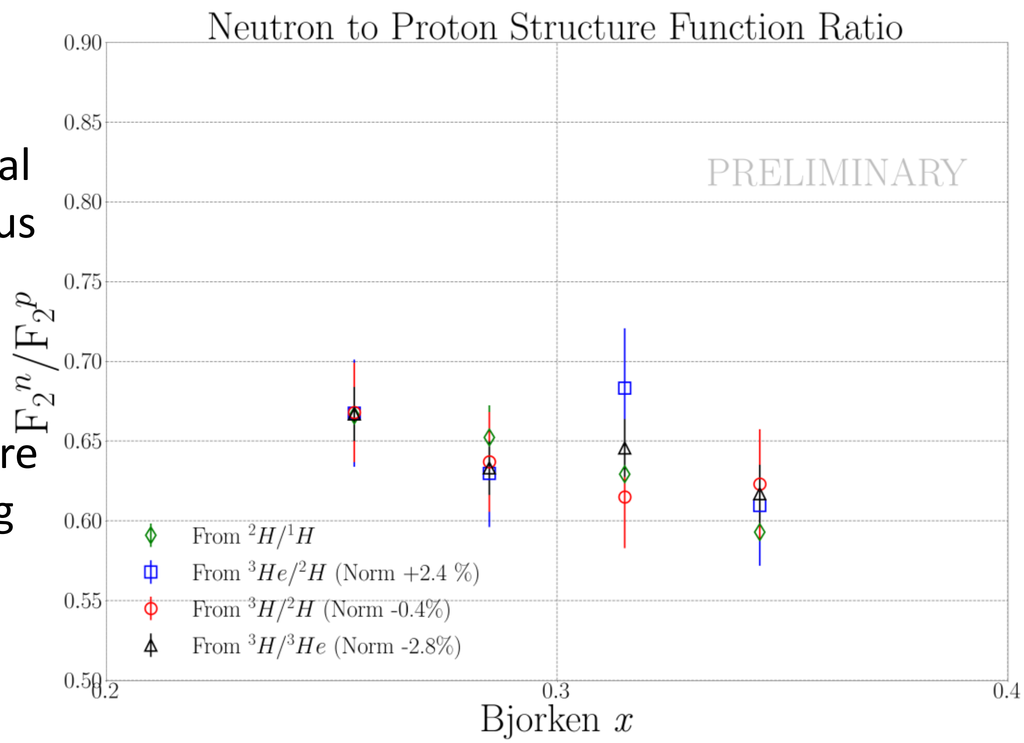


Plot Courtesy of Tong Su

Nucleon Structure Function Ratio Extractions - Normalized

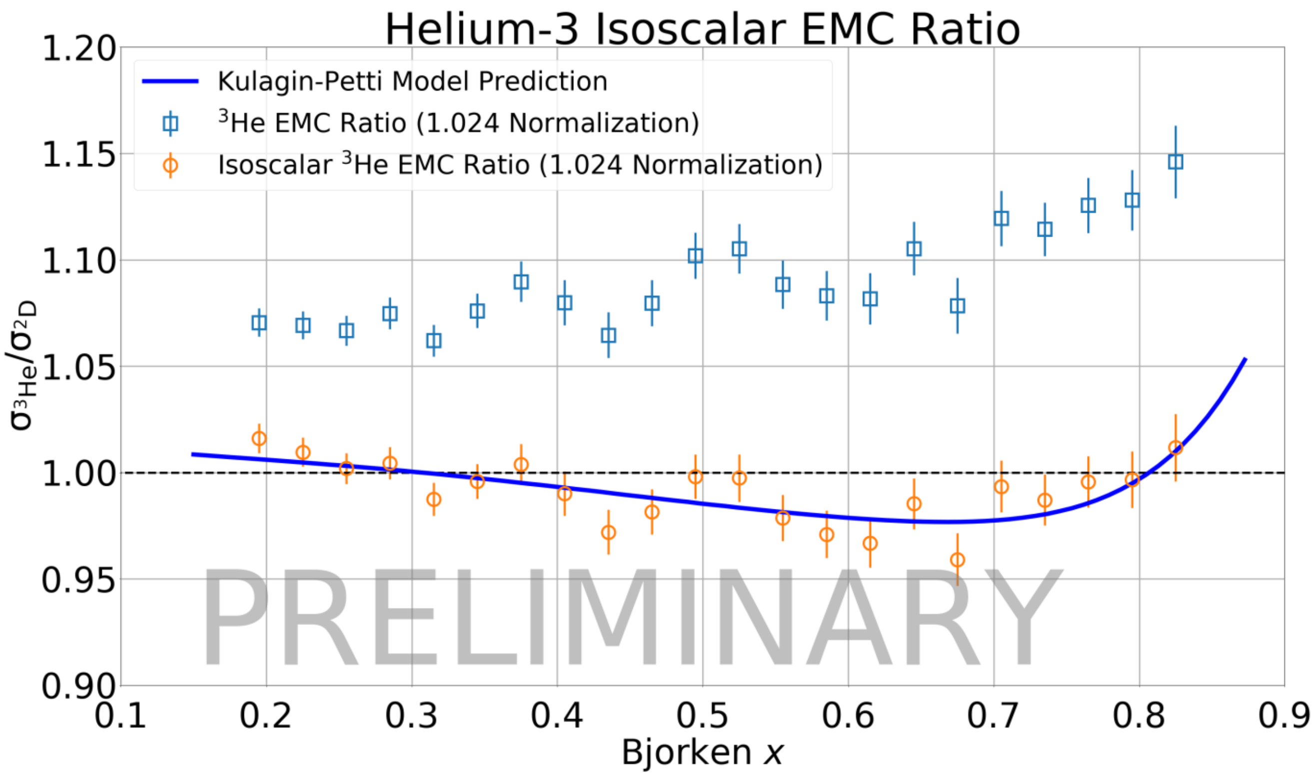
Nuclear Effects should be minimal around *x=0.3*, thus the extractions should agree.

Normalizations are determined using Chi-Squared Minimization



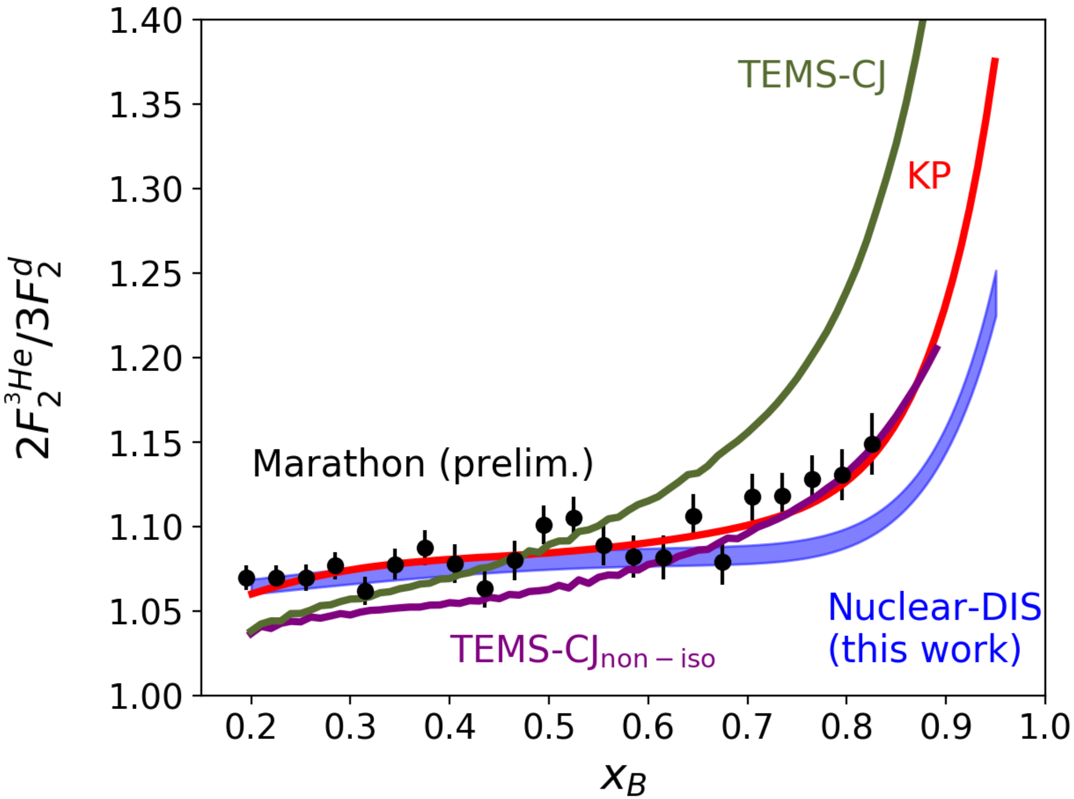
Plot Courtesy of Tong Su

Helium-3 EMC Ratio



Thank you!

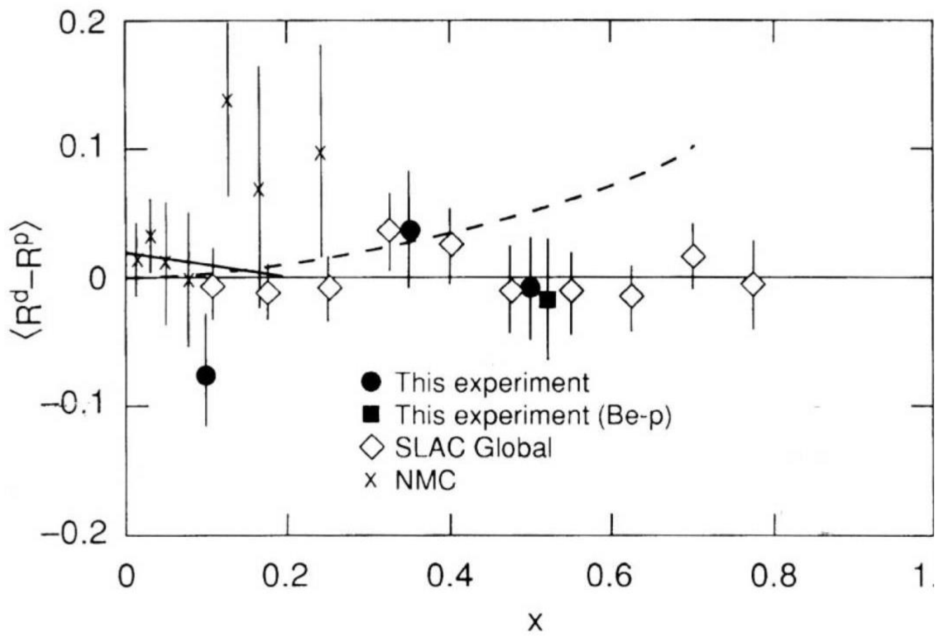
Model Comparison

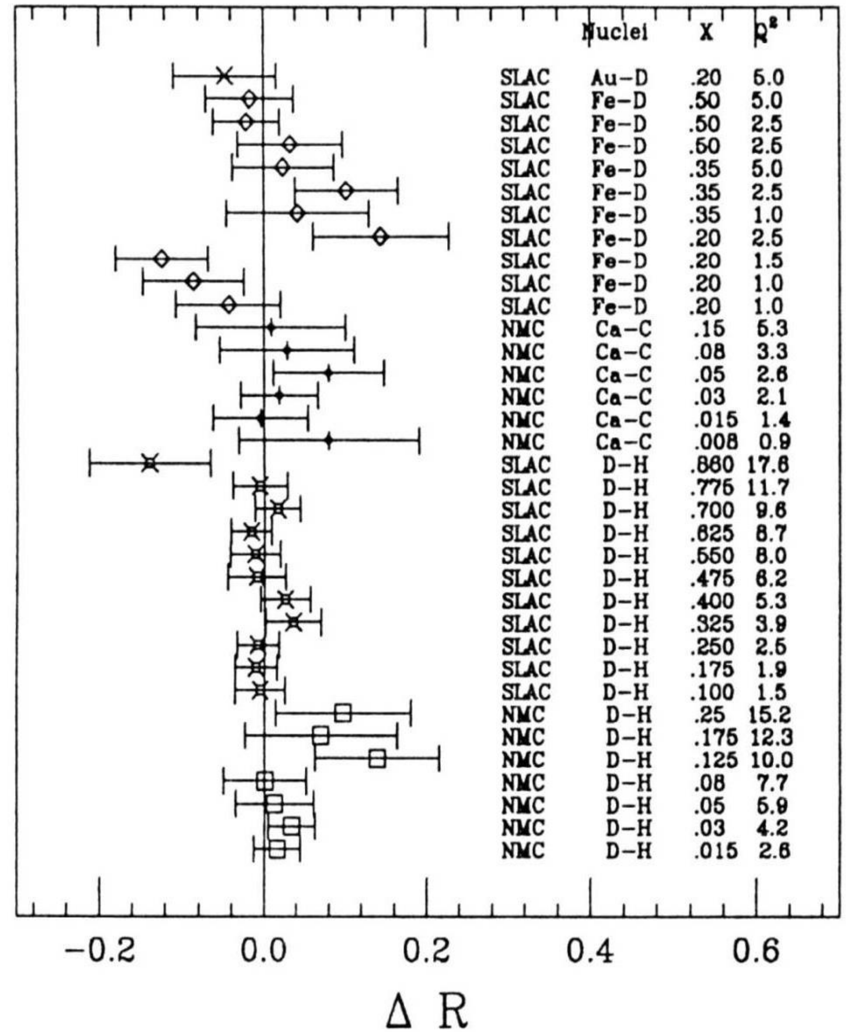


Plot Courtesy of Florian Hauenstein

Universality of $R=\sigma_L/\sigma_T$ – Existing Data

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





MARATHON assumes that $R=\sigma_L/\sigma_T$ is also the same for the 3H and 3He nuclei.
Therefore $\sigma(3H)/\sigma(3He) = F_2(3H)/F_2(3He)$