

# $\frac{F_2^n}{F_2^p}$ and EMC Ratios from MARATHON

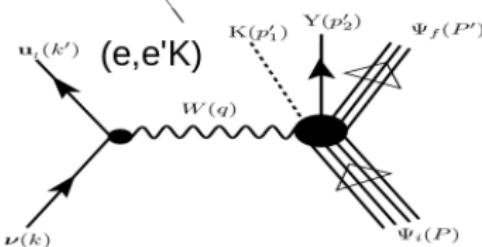
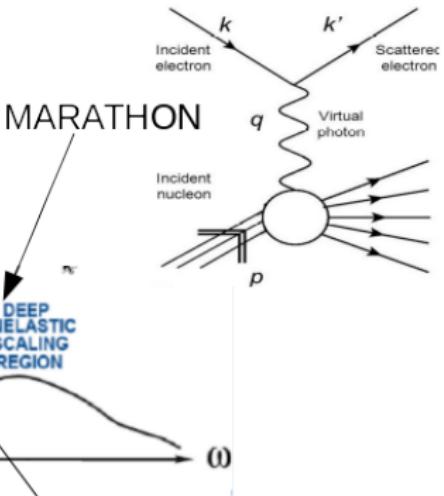
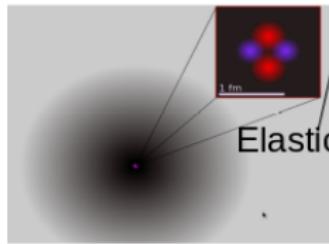
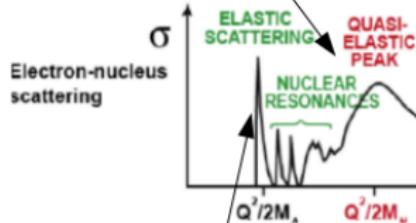
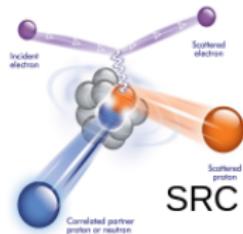
Jason Bane

University of Tennessee

*jbane1@vols.utk.edu*

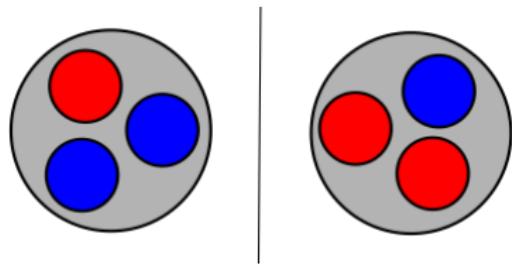
2 September 2019

# Tritium Experiments



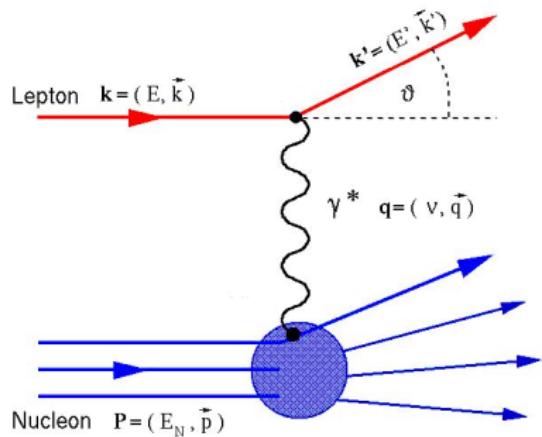
# MARATHON

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.



- Lightest and simplest mirror system
  - ▶ Number of protons in  ${}^3H$  = neutrons in  ${}^3He$
- Differences in the nuclear effects are small
- Improve the current measurement and understanding of  $F_2^n/F_2^p$  ratio
- Restrict the assumptions and parameters made in the model calculations of the down to up quark distribution ratio

# Deep Inelastic Scattering (DIS)



- $Q^2 \equiv 4EE' \sin^2 \frac{\theta}{2}$
- $X_{Bj} = \frac{Q^2}{2\nu M}$
- $\sigma_{eN} = \frac{\alpha^2}{eE^2 \sin^4(\frac{\theta}{2})} \left[ \frac{F_2}{\nu} \cos^2 \frac{\theta}{2} + \frac{2F_1}{M} \sin^2 \frac{\theta}{2} \right]$
- $W^2 = 2M\nu + M^2 - Q^2$
- $W^2 > 4 \rightarrow \text{DIS}$

## SLAC/CERN Data Interpretation in QPM

- Nachtmann inequality satisfied:  $1/4 \leq F_2^n / F_2^p \leq 4$

- For  $x \rightarrow 0$ :  $F_2^n / F_2^p \rightarrow 1$ : Sea quarks dominate with:

$$u + \bar{u} = d + \bar{d} = s + \bar{s}$$

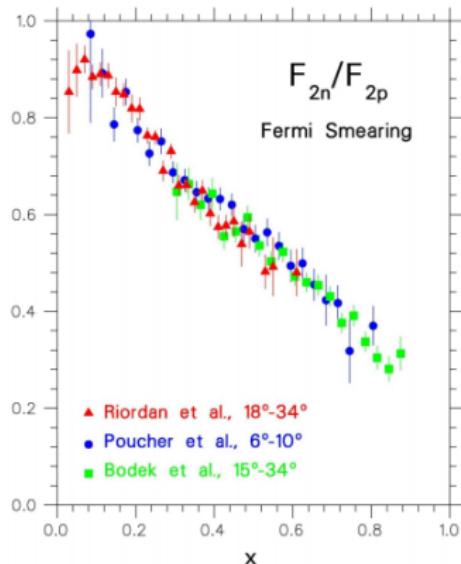
- For  $x \rightarrow 1$ :  $F_2^n / F_2^p \rightarrow 1/4$ : High momentum partons in proton (neutron) are up (down) quarks, and:

$$s + \bar{s} = 0$$

- For medium and high  $x$ , safe to assume that (with  $d$  and  $u$  denoting now quark plus antiquark distributions):

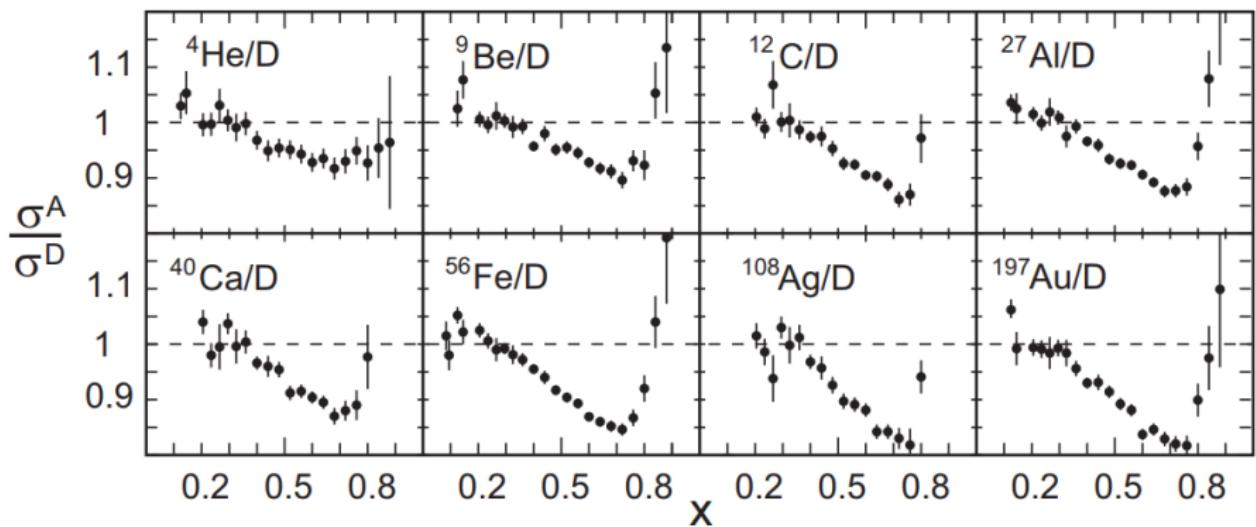
$$\frac{F_2^n}{F_2^p} = \frac{[1 + 4(d/u)]}{[4 + (d/u)]}$$

Makis Petratos



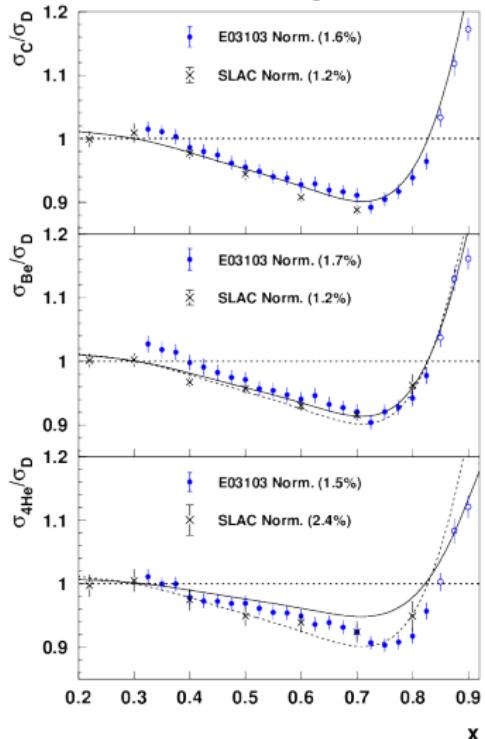
# EMC Effect

SLAC experiment E139 [J. Gomez et al., 1994] .

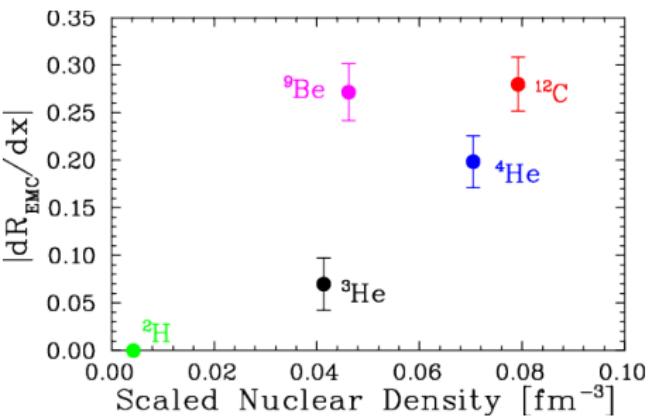


# EMC Effect

JLab experiment E03103  
 [J.Seely, A. Daniel et al]



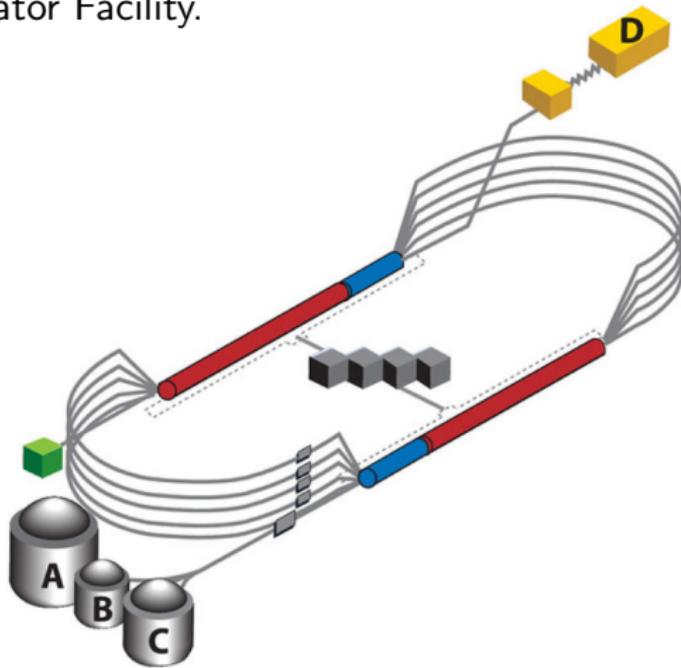
EMC as a function of Nuclear Density.  
 [J.Seely, A. Daniel et al]



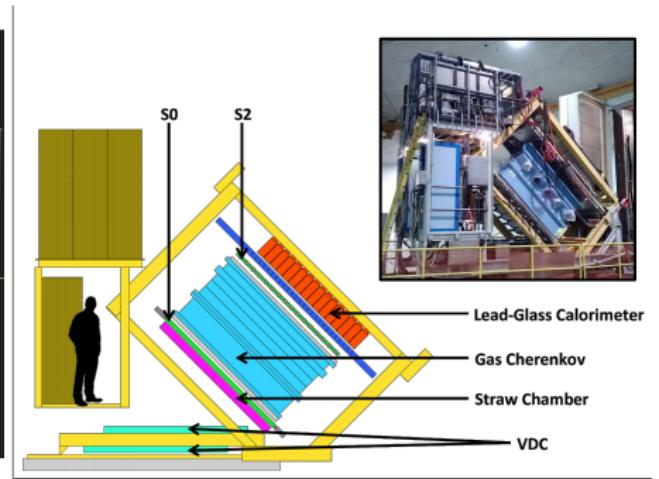
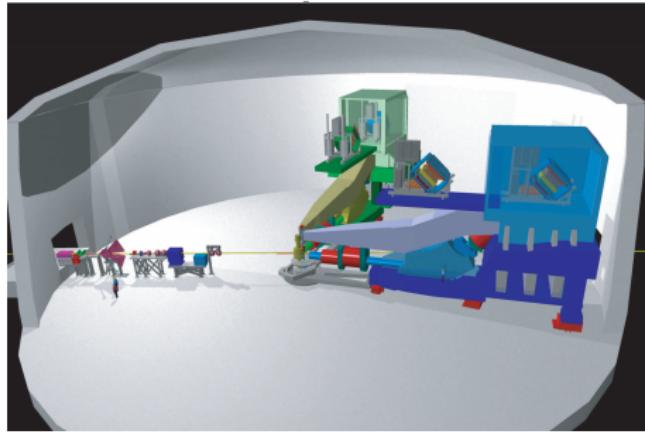
Scaled by  $\frac{(A-1)}{A}$

# CEBAF

The Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson Accelerator Facility.



# Hall A & The HRSs



# Systematics: $^3H$ Decay

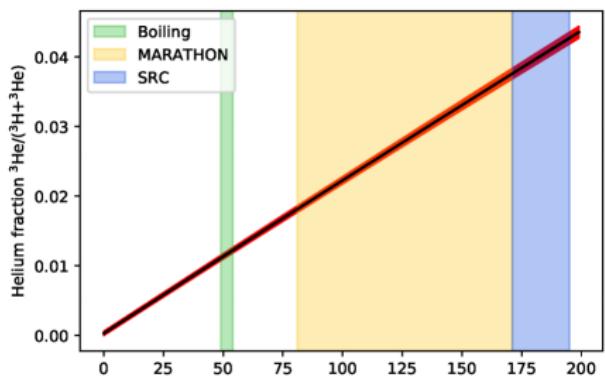


$$\tau(^3H) = 4500 \pm 8 \text{ days}$$

$$c = \frac{\eta_{^3He}}{\eta_{tot}}$$

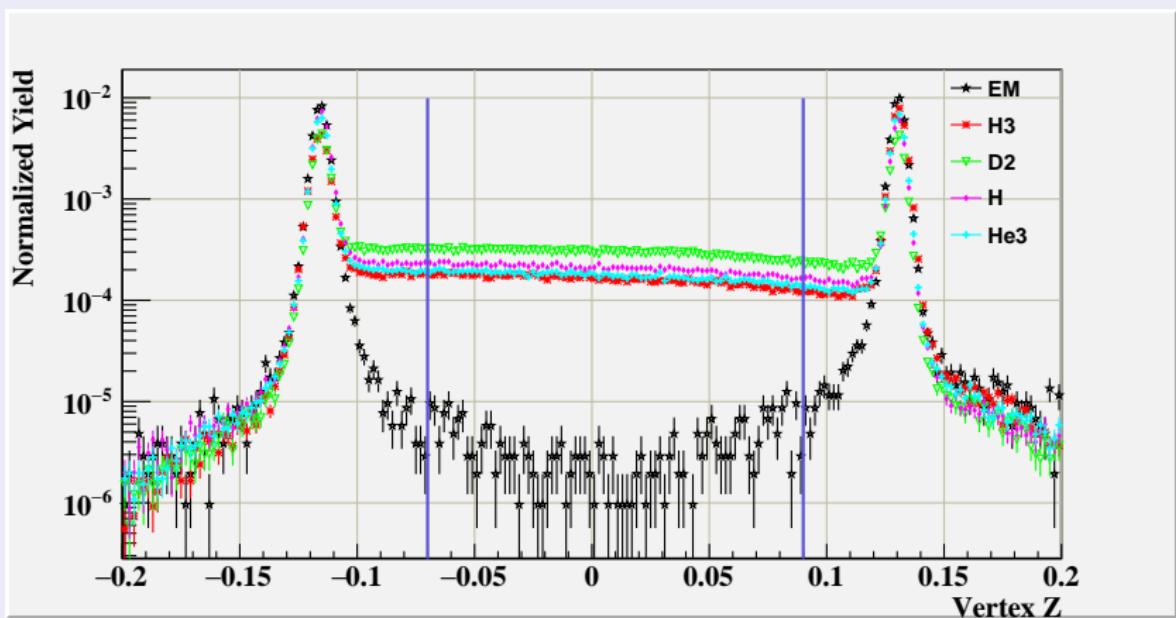
$$\sigma_{^3H} = \left( \frac{\sigma_{tot}}{\sigma_{^3He}} \right) \left( \frac{1}{1 - c} \right) - \left( \frac{1}{1 - c} \right)$$

Beta Decay Helium Fraction



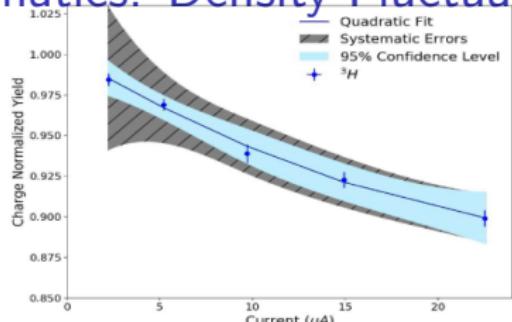
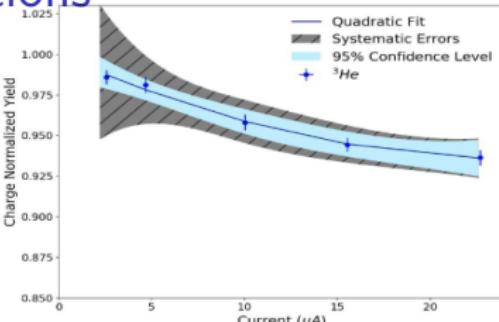
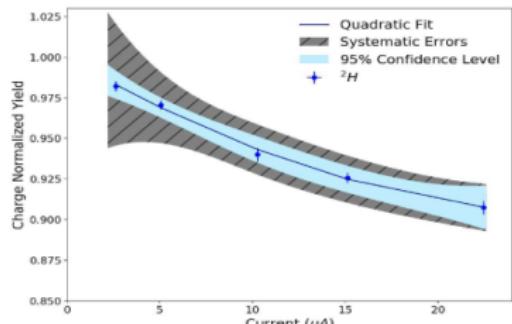
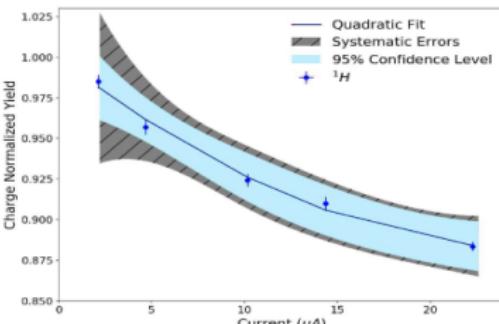
Tyler Kutz

# Systematics: Endcaps



- Extract ratio of the normalized yield from the gas cell to that of the empty cell

# Systematics: Density Fluctuations

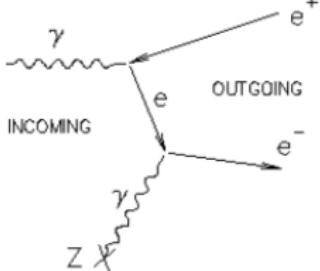
(a)  ${}^3\text{H}$  Density Analysis.(b)  ${}^3\text{He}$  Density Analysis.(c)  ${}^2\text{H}$  Density Analysis.(d)  ${}^1\text{H}$  Density Analysis.

[S.N.Santiestebana et. al]

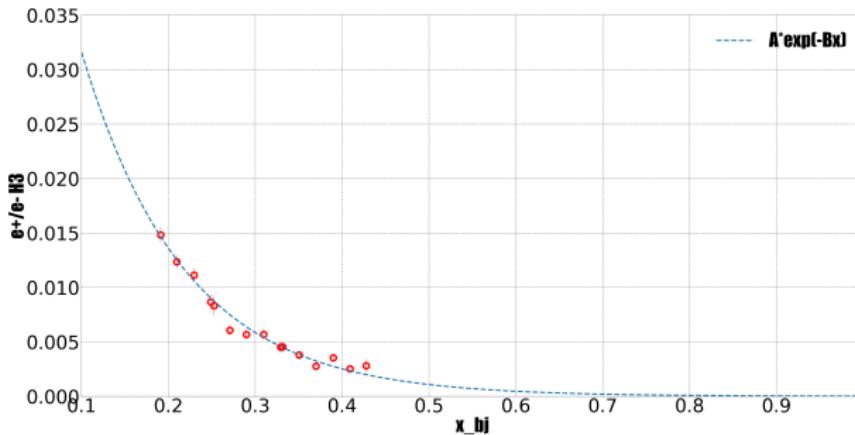
# Charge Symmetric back ground

- $\gamma$  decay into an  $e^+e^-$  pairs
- Pair produced  $\sim$  by detecting  $e^+$
- Extraction based on fit to Exponential function

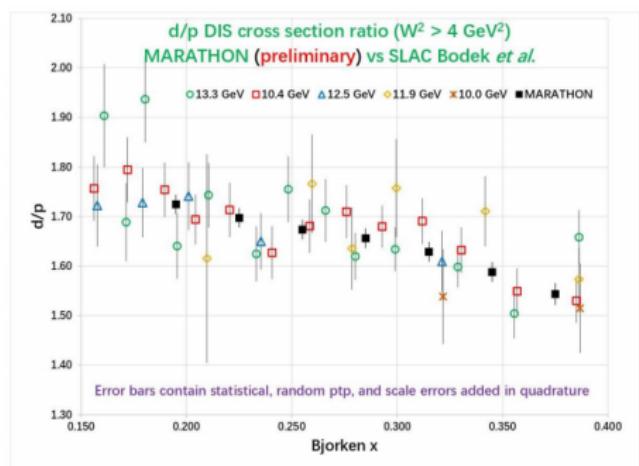
## Pair Production



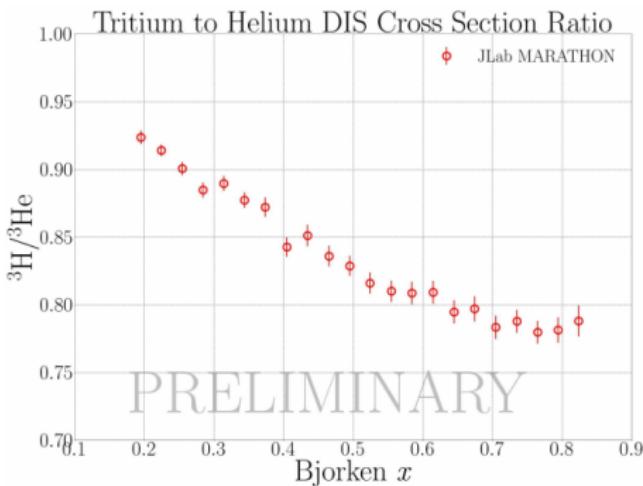
Tritium positron contamination. Credit: Tong Su



# d/p and $^3H/^3He$

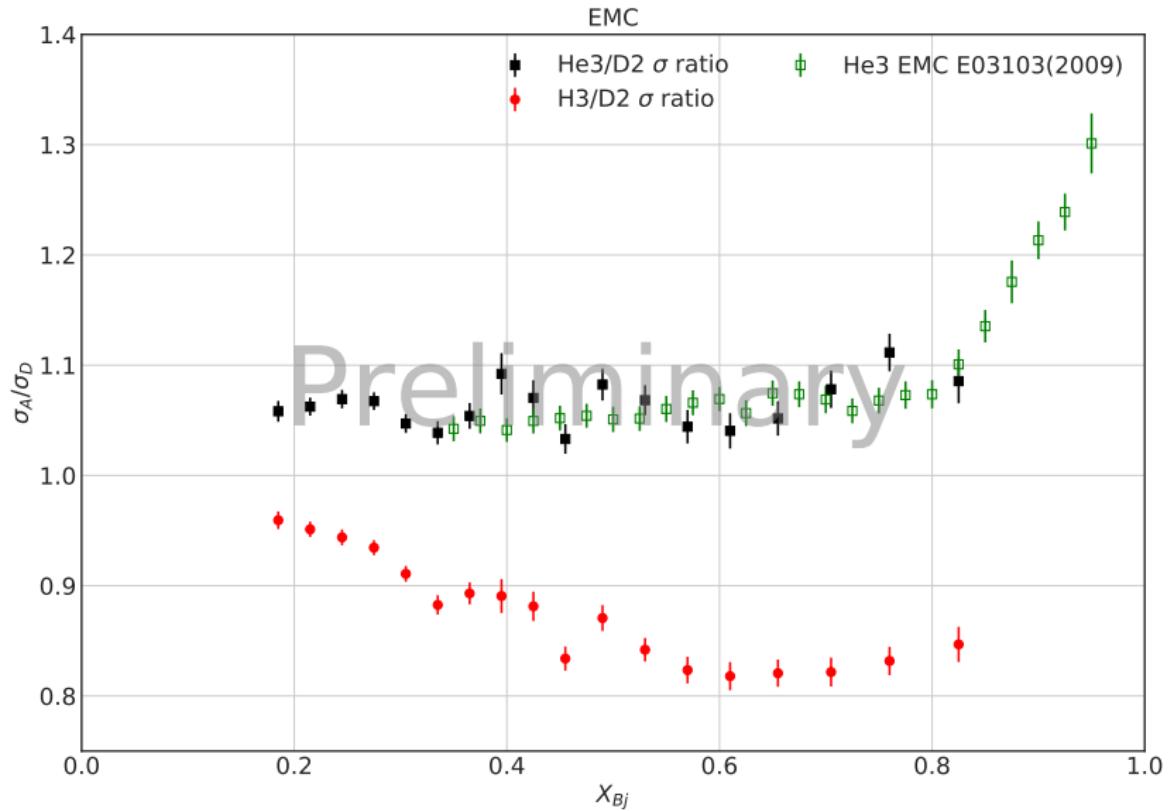


plot credit: Makis Petratos



plot credit: Tong Su

# EMC Effect



# Extracting F2 ratio

- Form the “SuperRatio” of EMC-type ratios for  $A=3$  mirror nuclei:

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

- Solve above equations for the  $A=3$  structure function ratio:

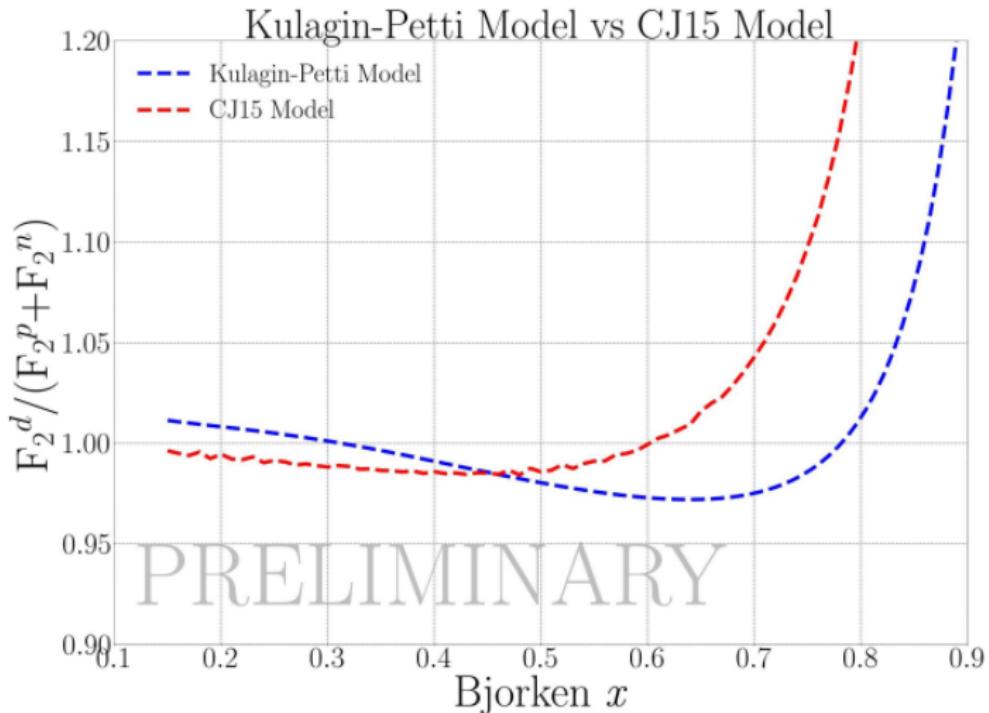
$$\frac{\sigma^{^3He}}{\sigma^{^3H}} = \frac{F_2^{^3He}}{F_2^{^3H}} = R^* \frac{2F_2^p + F_2^n}{F_2^p + 2F_2^n}$$

- Solve for the nucleon  $F_2$  ratio and calculate it, using  $R^*$  from a reliable theoretical model (value of  $R^*$  is very close to unity with small uncertainty), and the measured  $A=3$  DIS cross section ratio:

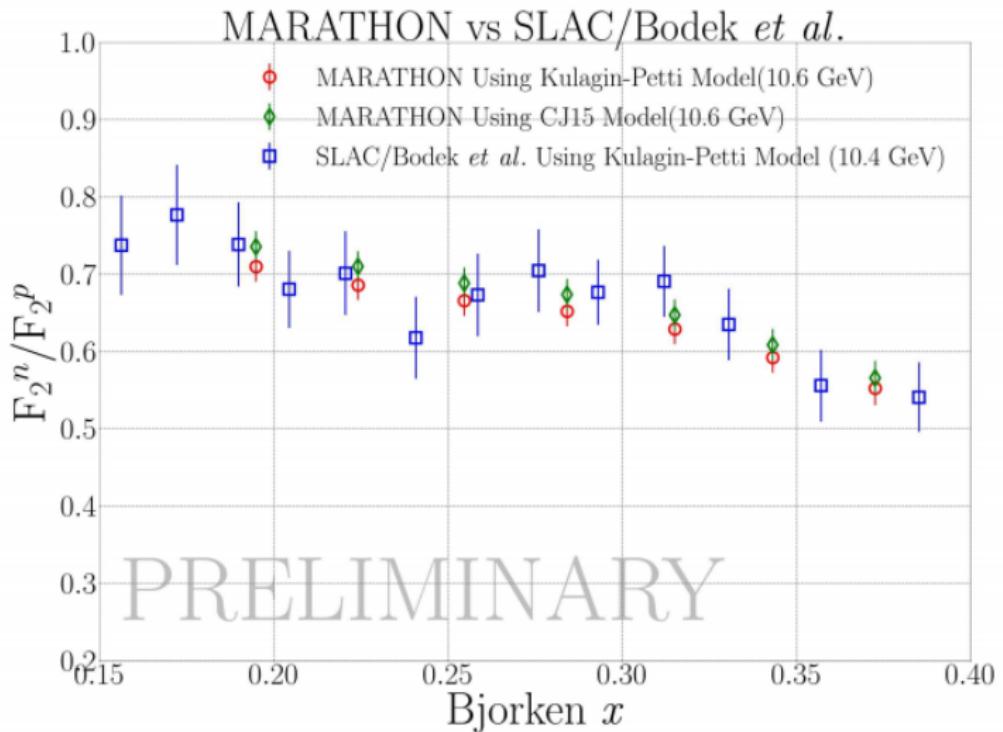
$$\frac{F_2^n}{F_2^p} = \frac{2R^* - \sigma^{^3He}/\sigma^{^3H}}{2\sigma^{^3He}/\sigma^{^3H} - R^*}$$

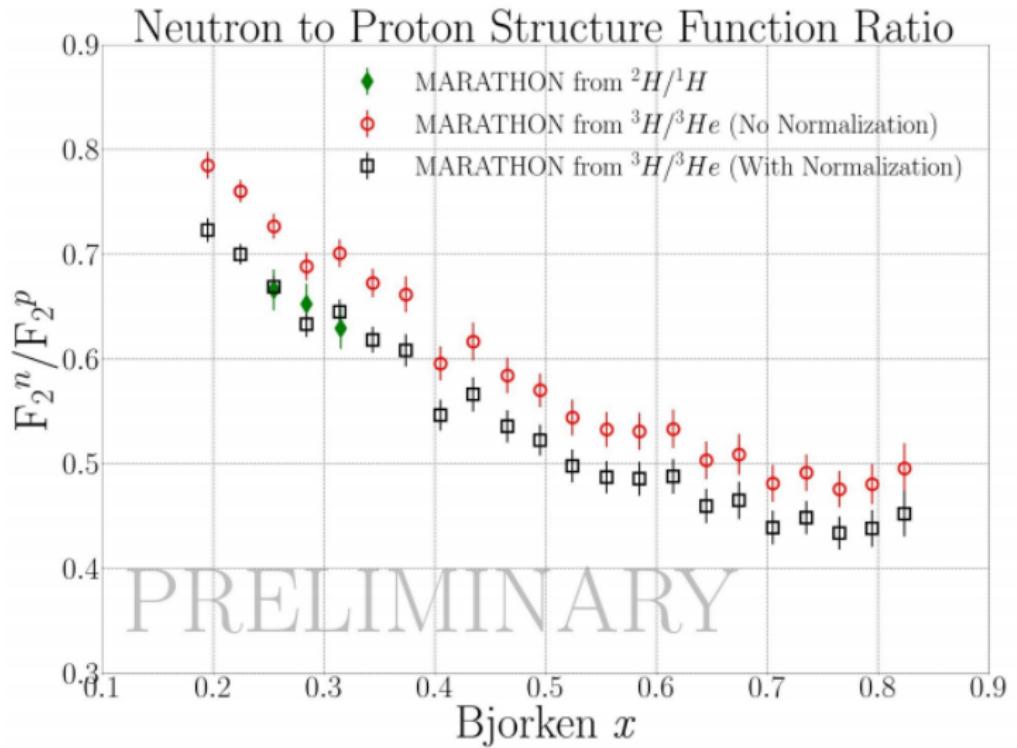
- Iterate the process until it converges to a stable  $F_2^n/F_2^p$  ratio.

# Extracting F2 ratio

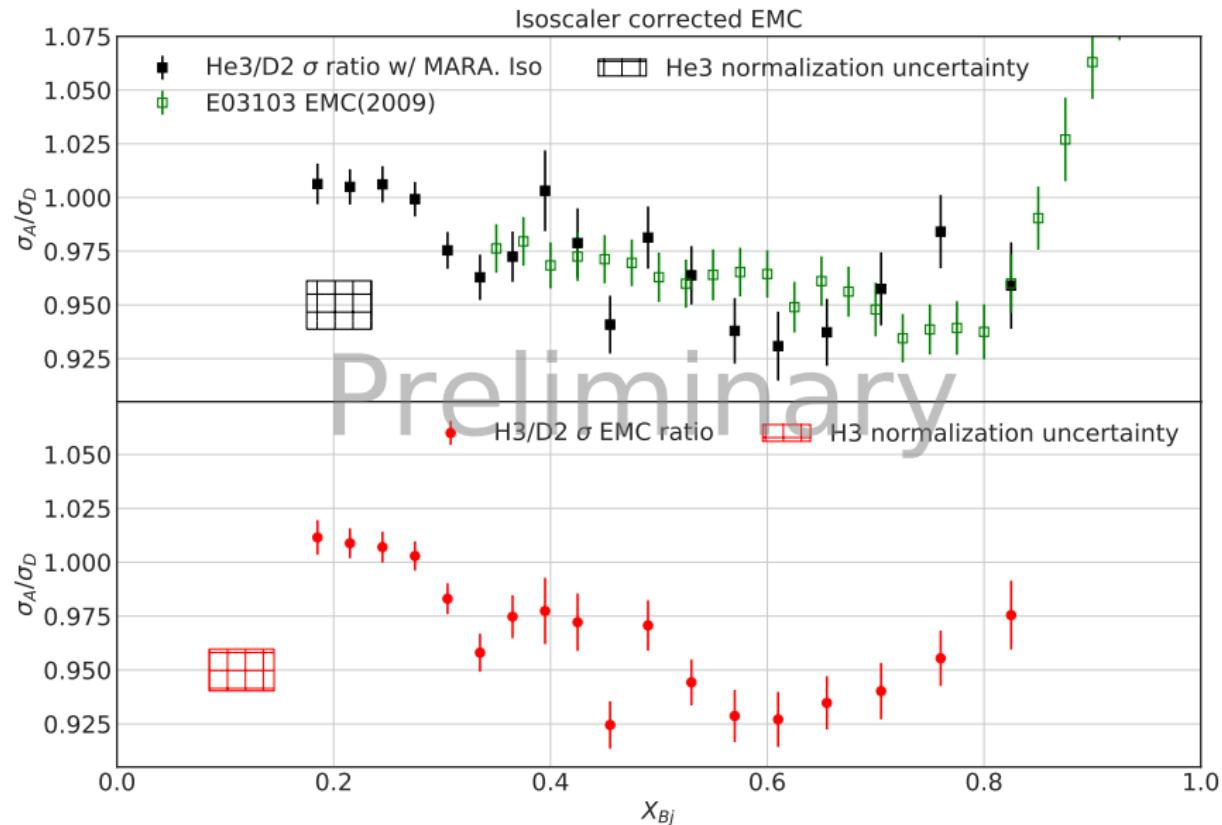


*plot credit: Tong Su*

$F_2^n / F_2^p$  for D/p

*plot credit: Tong Su*

$F_2^n / F_2^p$ *plot credit: Tong Su*

# EMC Effect



Thank you!!

- MARATHON students
- Tritium collaboration
- Hall A Collaboration
- Nadia Fomin and Doug Higinbotham
- DOE and JSA

# 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. Mihovilović, V. Nelyubin, **D. Nguyen**, N. Nuruzzaman, **M. Nyicz\***, 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. Pisetsky, 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.



## References I

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Basic instrumentation for Hall A at Jefferson Lab. NIM A 522(2004) 294-346
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*Phys. Rev D* 49 (1994) 4348
-  S.N.Santiestebana et. al (2019)  
*Nucl. Instrum. Meth. A* 940 (2019) 351-358
-  J.Seely, A. Daniel et al (2013)  
New Measurements of the EMC Effect in Very Light Nuclei. *nucl-ex/0904.4448*.