

The EMC Effect for Tritium and Helium-3 from MARATHON

Jason Bane

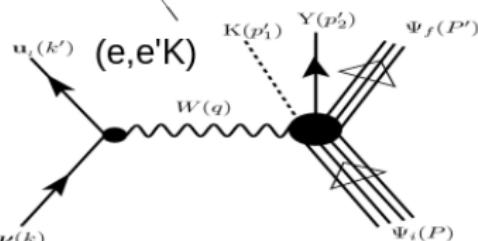
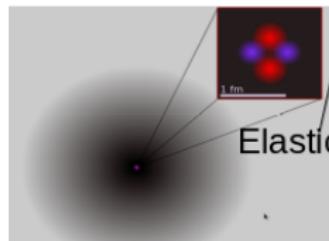
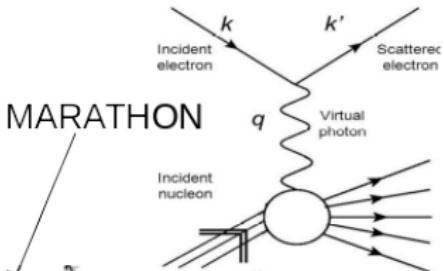
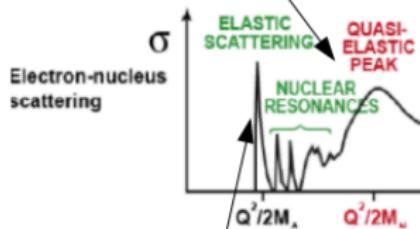
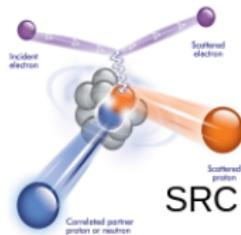
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Outline

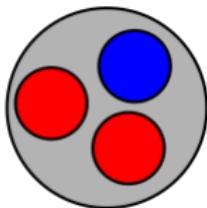
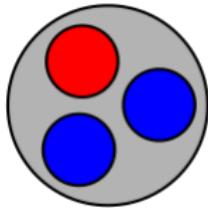
Tritium Experiments





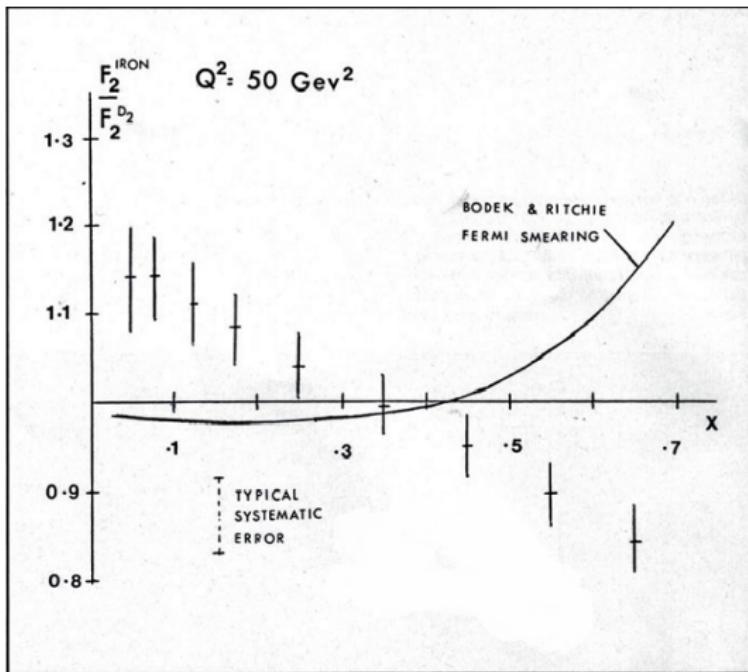
MARATHON

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 MirOr Nuclei.



- Lightest and simplest mirror system
 - ▶ Number of protons in 3H = neutrons in 3He
- Differences in the nuclear effects are small

The EMC Effect

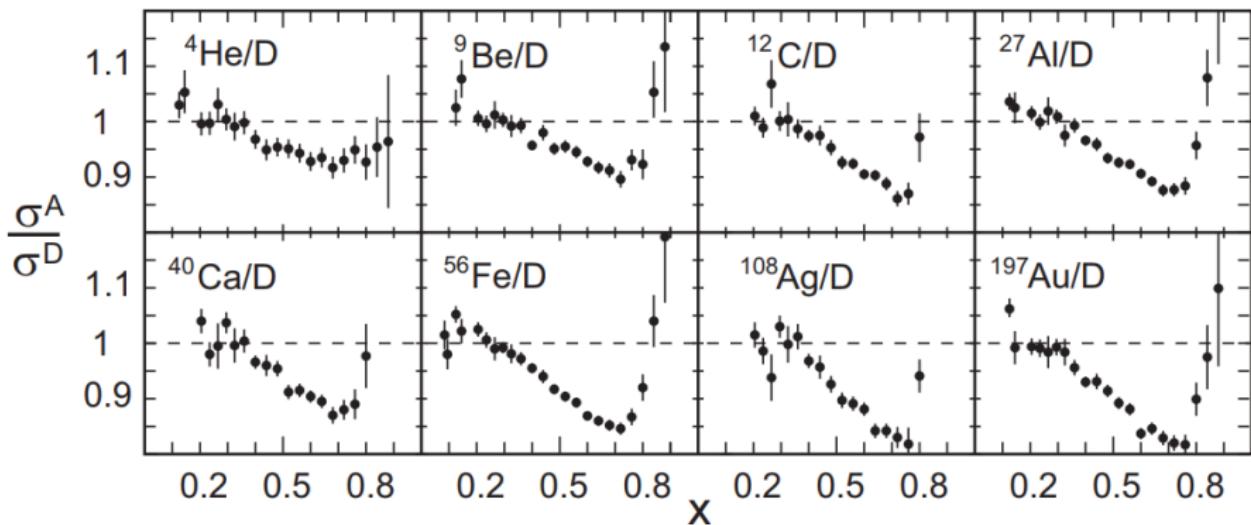


European Muon Collaboration

- Expected Unity → Binding < interaction
- $F^A = Z \cdot F^p + (A - Z) \cdot F^n$
- Unexpected Relative Decrease
- EMC Effect \equiv magnitude of the decrease

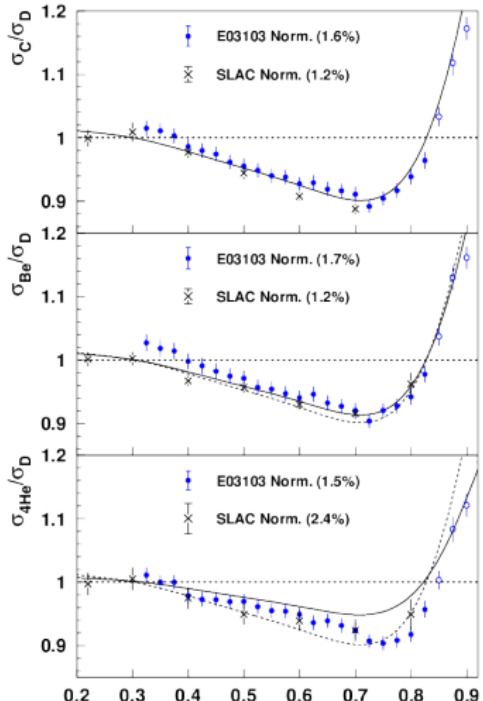
EMC Effect

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

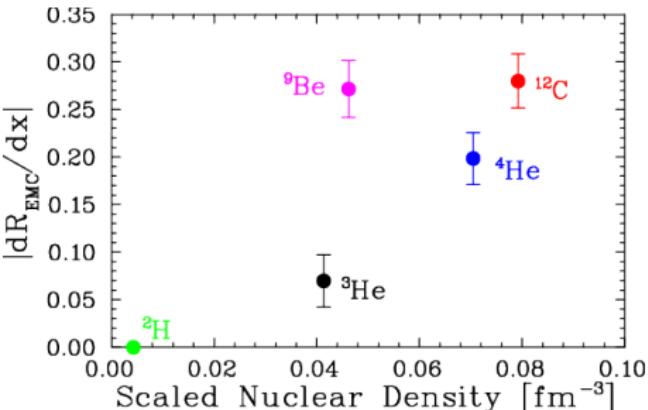


EMC Effect

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

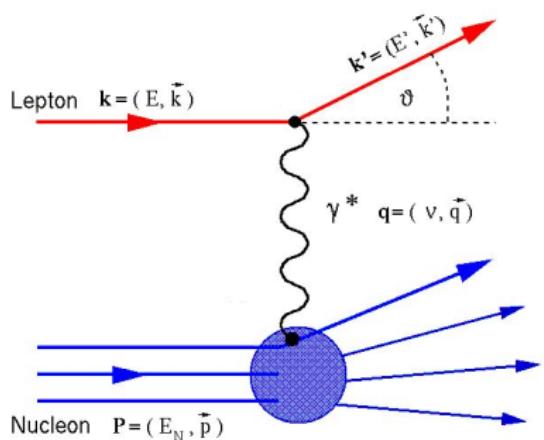


EMC as a function of Nuclear Density.
[J.Seely, A. Daniel et al]



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

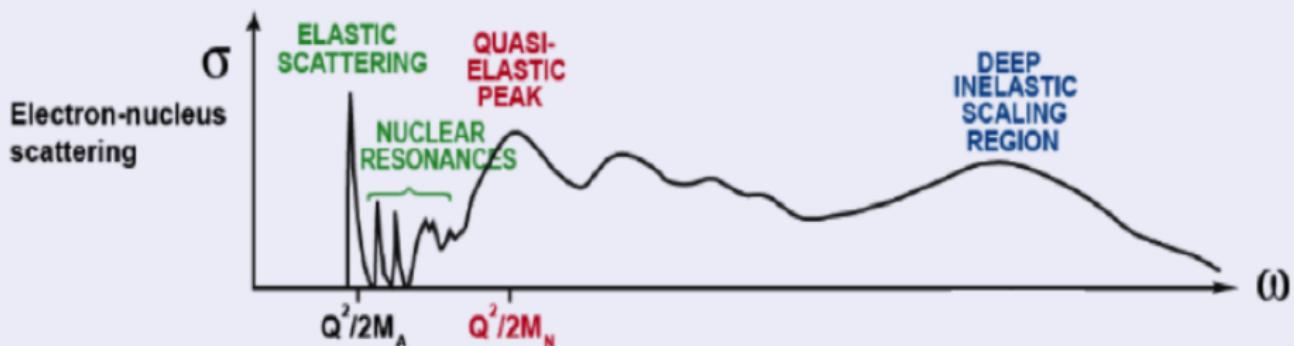
Deep Inelastic Scattering (DIS)



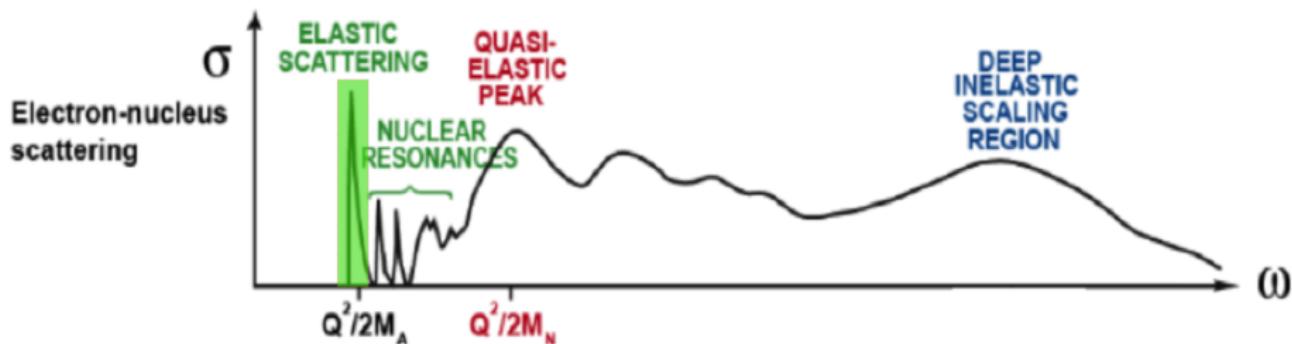
- $Q^2 \equiv 4EE' \sin^2 \frac{\theta}{2}$
- $X_{Bj} = \frac{Q^2}{2\nu M}$
- $W^2 = 2M\nu + M^2 - Q^2$
- $W^2 > 1$ Inelastic Scattering

$$\sigma_{eN} = \frac{\alpha^2}{4E^2 \sin^4(\frac{\theta}{2})} \left[\frac{F_2(Q^2, \nu)}{\nu} \cos^2\left(\frac{\theta}{2}\right) + \frac{2F_1(Q^2, \nu)}{M} \sin^2\left(\frac{\theta}{2}\right) \right]$$

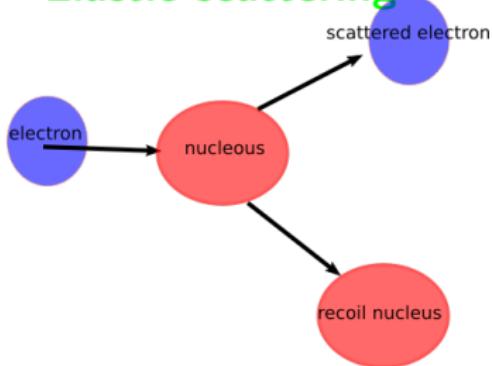
DIS ??????

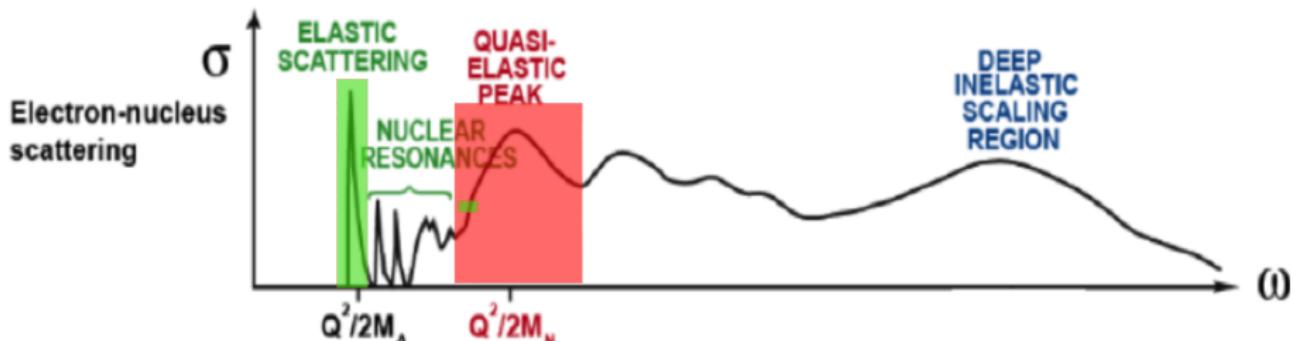


[?].

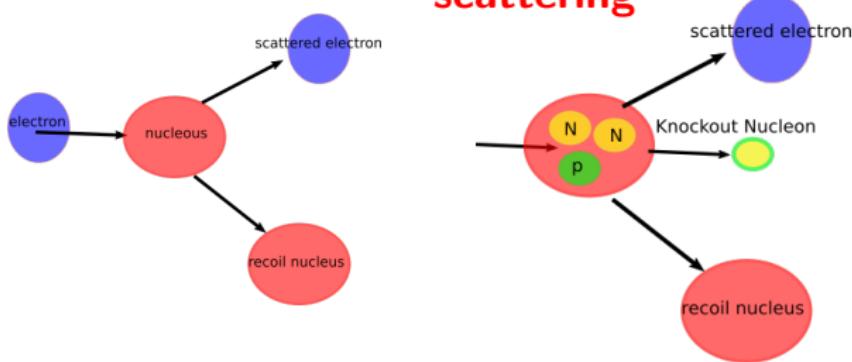


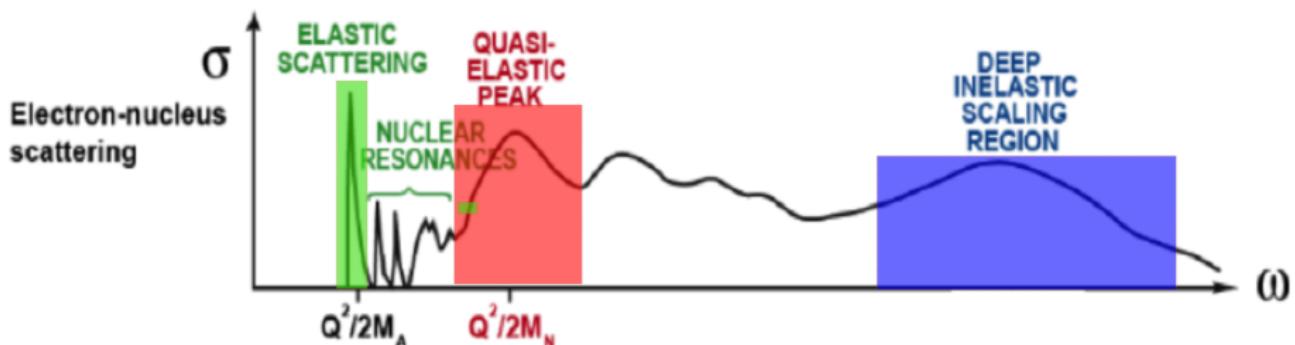
- Elastic scattering





- Elastic scattering
- Quasielastic scattering

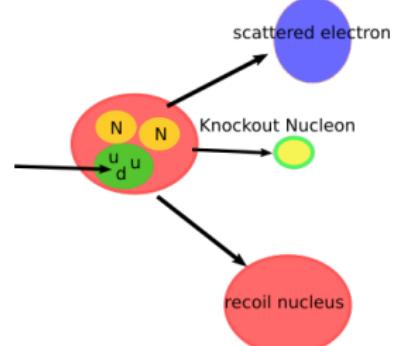
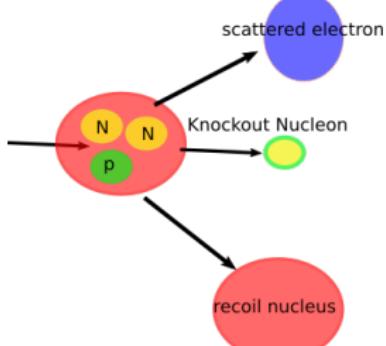
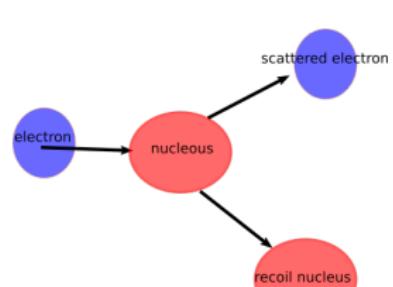




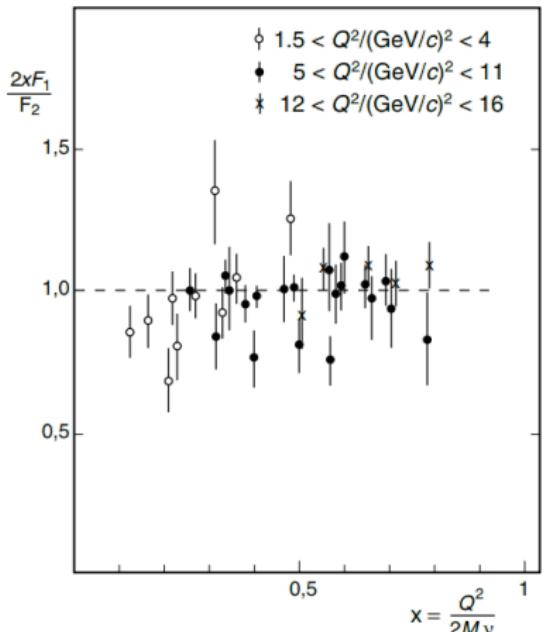
- Elastic scattering

- Quasielastic scattering

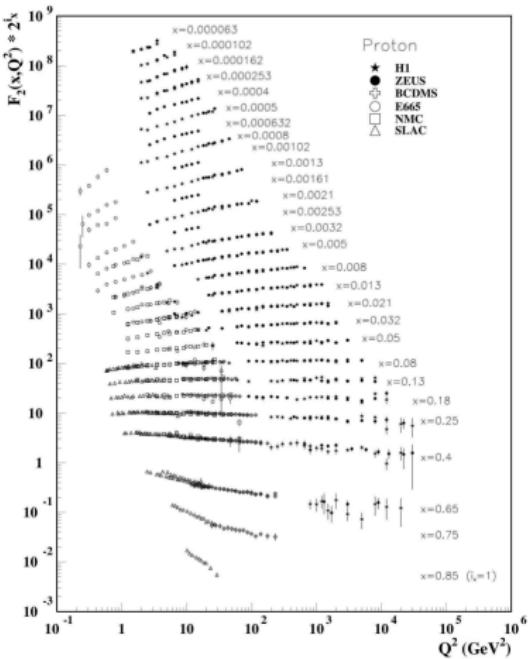
- DIS



Why DIS?

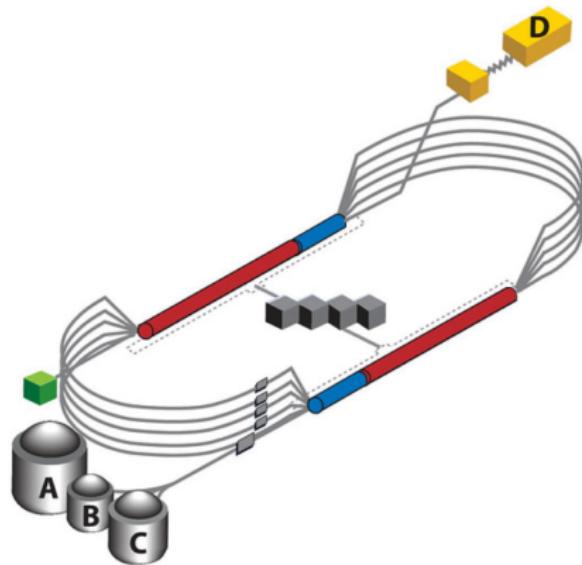


Ratio of $2x \cdot F_1(x)$ and $F_2(x)$ vs. x [?, ?].



Measurements of the proton structure function $F_2(x, Q^2)$ for different x settings[?].

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



- ≈ 2.2 GeV per revolution
- 12 GeV for Hall D
- Superconducting RF cavities
- RF separators split the beam to each Hall

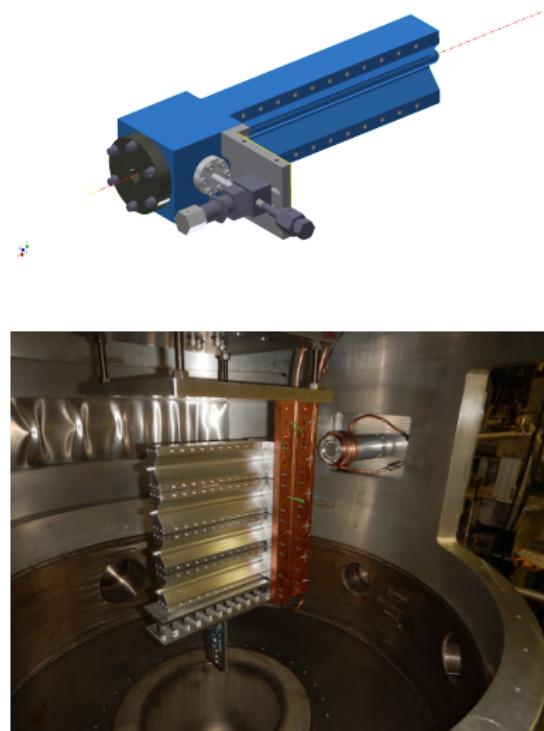
MARATHON purposed to use:

- 11 GeV Beam
- $22.5 \mu\text{A}$ current
- Hall A's spectrometers and Big Bite Spectrometer

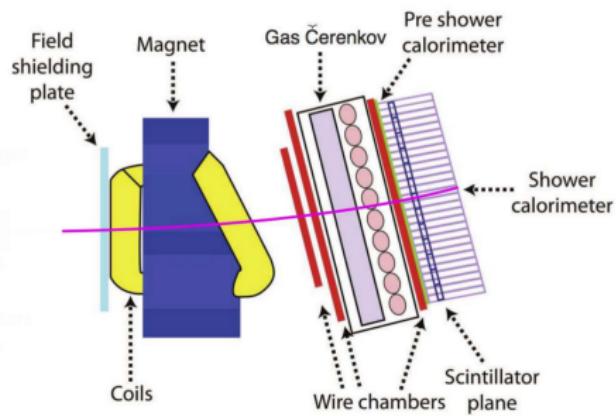
Tritium Target Cell

First tritium target at JLab

- Thin Al entrance and exit windows 0.01 inches
- 1090Ci of Tritium (0.1 g)
- 25 cm long
- Tritium Cell was filled in Savannah River
- 40 kelvin Helium is used to cool an attached heat sink



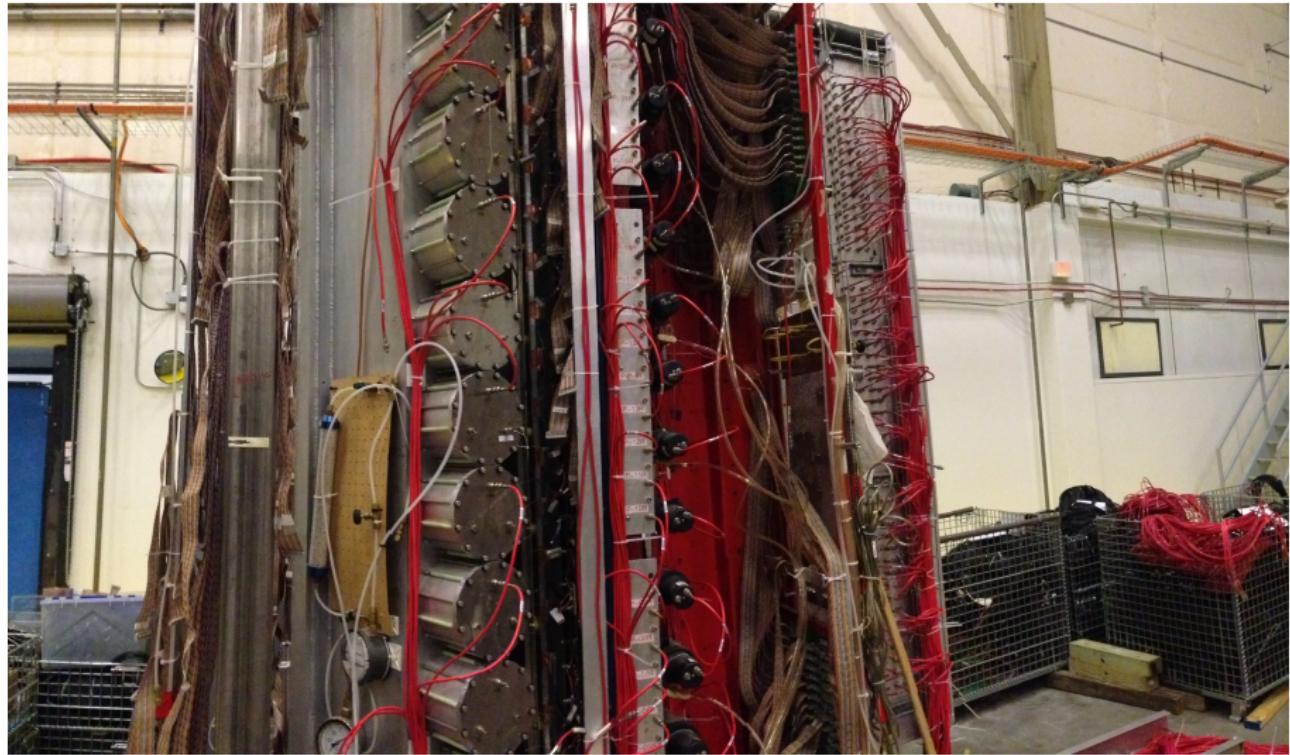
The Big Bite Spectrometer



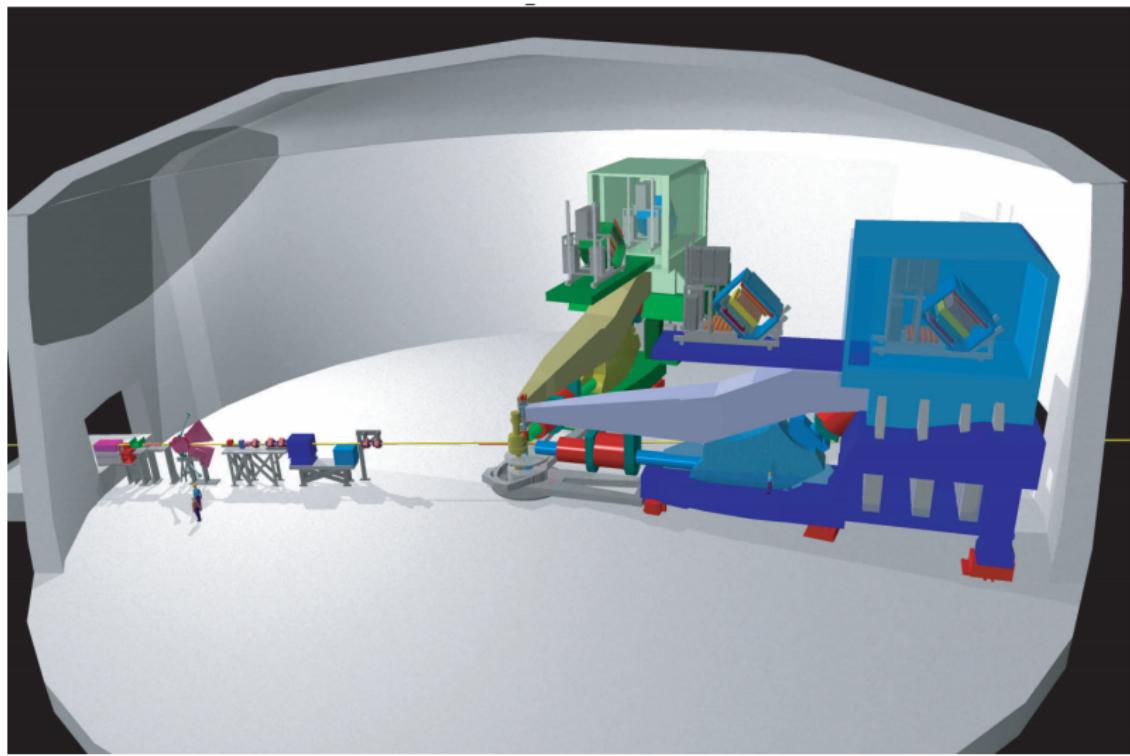
Preparing Big Bite

- Refurbishing signal electronics and cables
- Testing then repairing or replacing PMTs
- Building front end electronics and coincidence trigger logic
- Testing High voltage power sources and providing power to the detectors

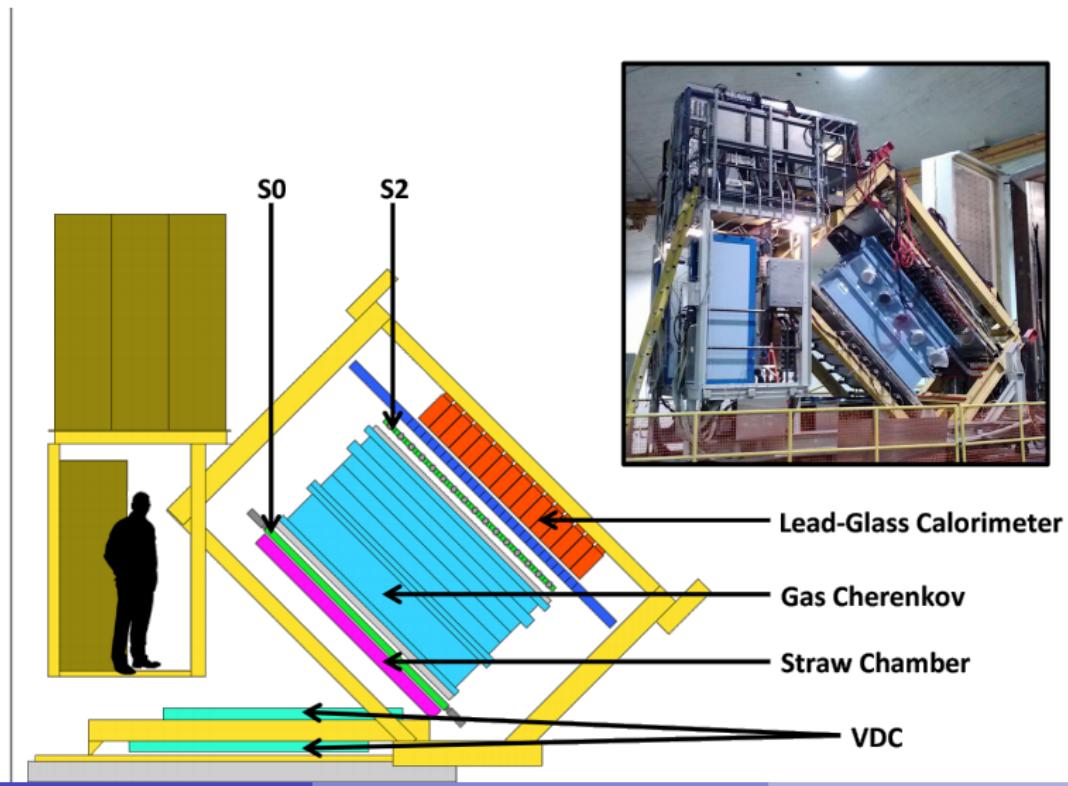
The Big Bite Spectrometer



Hall A

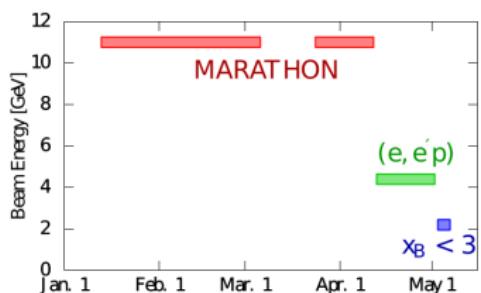


High Resolution Spectrometers (HRSs)



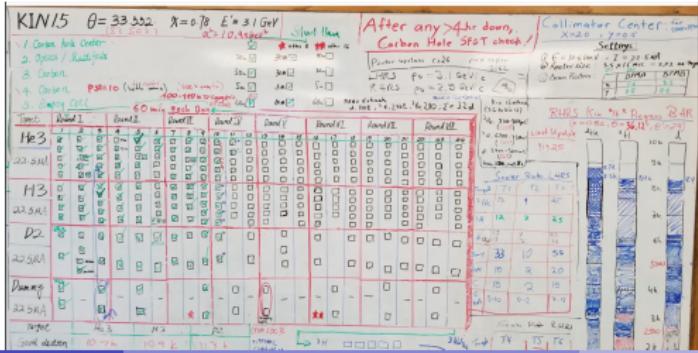


The Run Period



Rey Torres

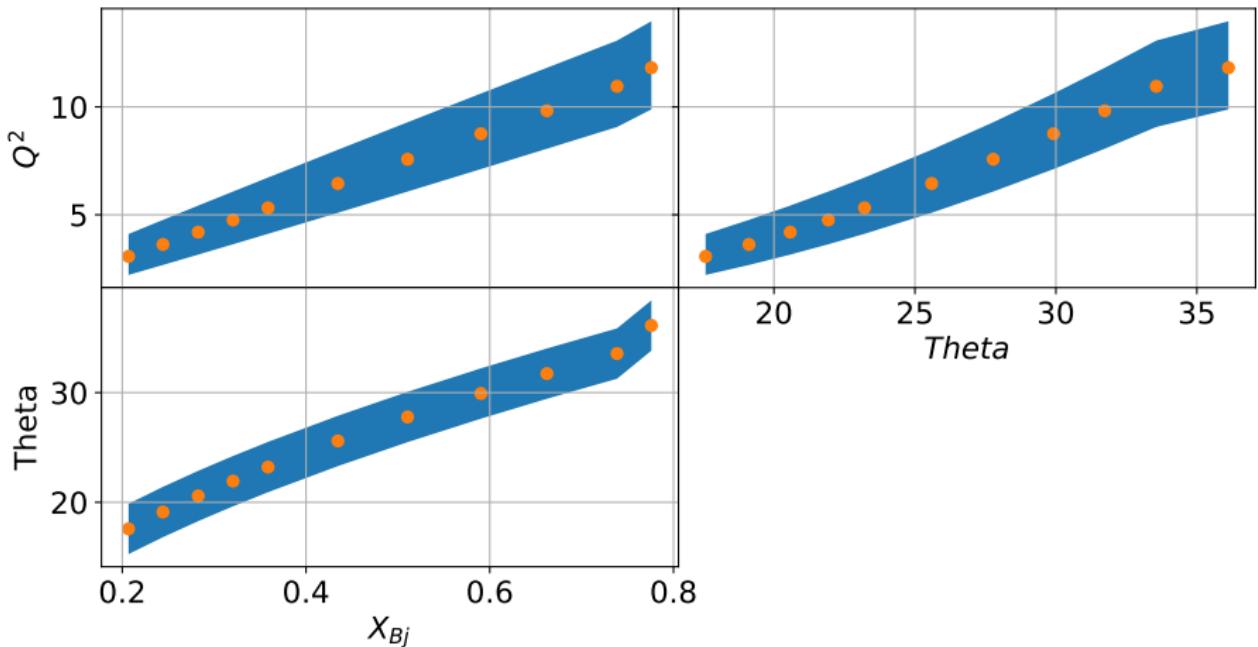
- Ran from January 11th to April 12th of 2018.
- Gaseous Tritium, Deuterium, Helium-3, and Hydrogen
- Single Carbon Foil, Carbon foil with hole, and multi-foil
- Rotated through targets to achieve equal statics and reduce the impact of unforeseen circumstances



Jason Bane (UTK)

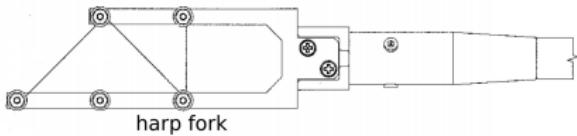
EMC A=3

Kinematic Coverage

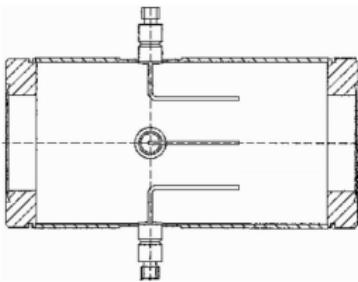


Kinematic coverage between Q^2 , x , and Θ . The band around the points represents the approximate spectrometer acceptance in the y axis.

Beam Position Monitor(BPM) Calibration



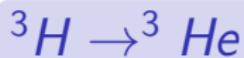
Intrusive absolute position measurement



Relative position measurement

$$\begin{pmatrix} X_{position} \\ Y_{position} \end{pmatrix} = \begin{pmatrix} C(0,0) & C(0,1) \\ C(0,0) & C(0,1) \end{pmatrix} * \begin{pmatrix} X_{BPM} \\ Y_{BPM} \end{pmatrix} + \begin{pmatrix} X_{offset} \\ Y_{offset} \end{pmatrix}$$

Systematics: 3H Decay

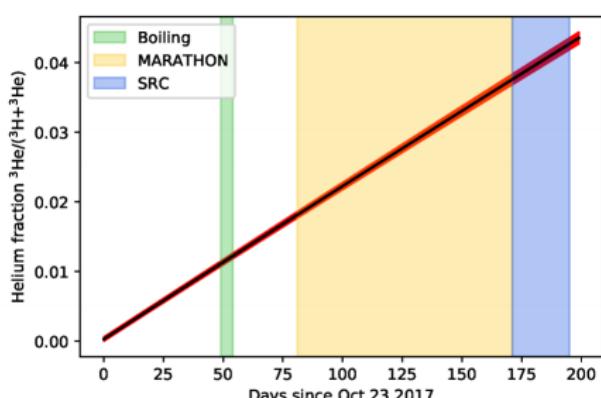


$$\tau(^3H) = 4500 \pm 8 \text{ days}$$

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

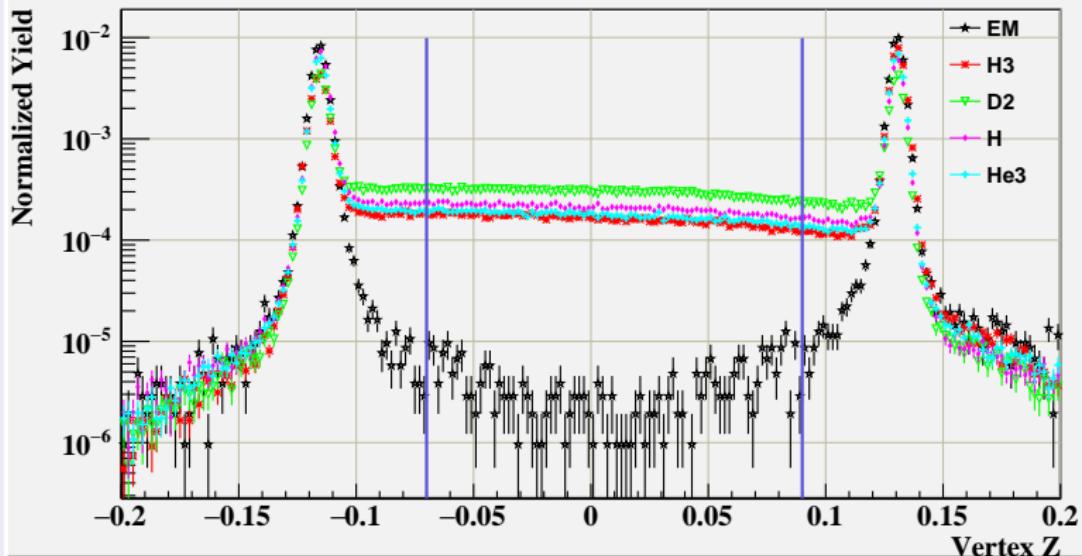
$$\sigma_{^3H} = \left(\frac{\sigma_{tot}}{\sigma_{^3He}} \right) \left(\frac{1}{1 - c} \right) - \left(\frac{1}{1 - c} \right)$$

Beta Decay Helium Fraction



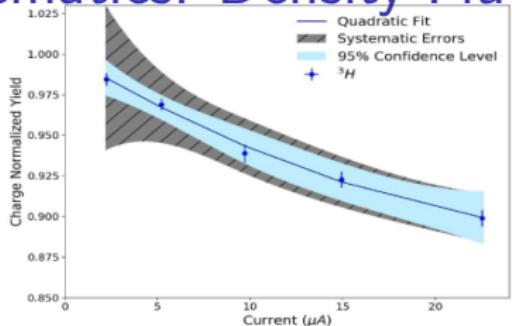
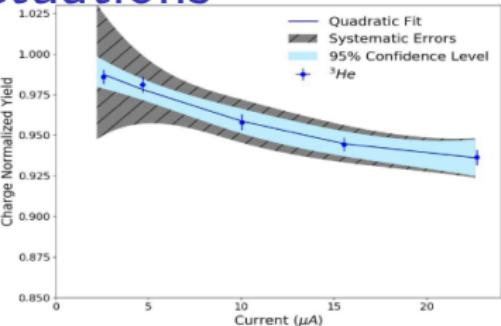
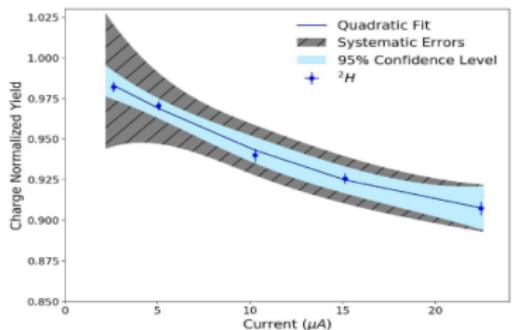
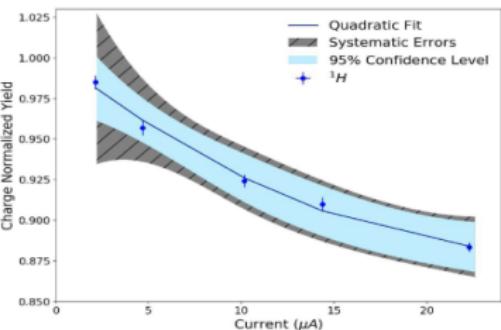
Tyler Kutz

Systematics: Endcaps



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

Systematics: Density Fluctuations

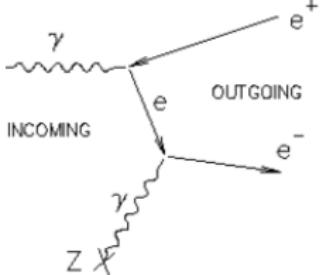
(a) ${}^3\text{H}$ Density Analysis.(b) ${}^3\text{He}$ Density Analysis.(c) ${}^2\text{H}$ Density Analysis.(d) ${}^1\text{H}$ Density Analysis.

[S.N.Santiestebana et. al]

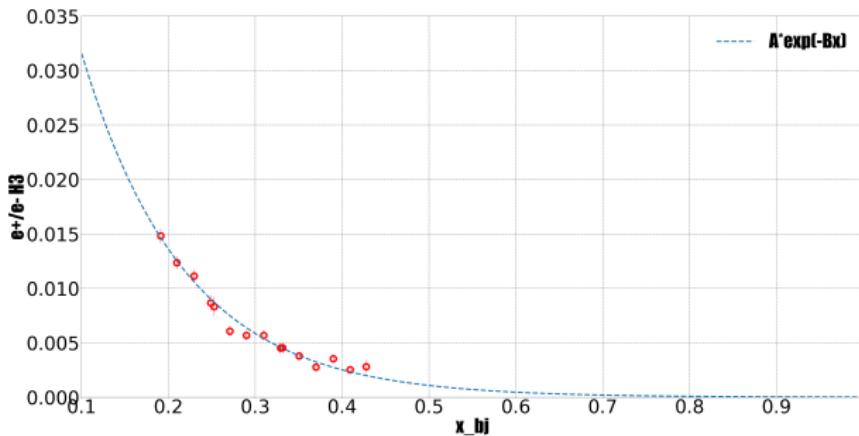
Charge Symmetric back ground

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

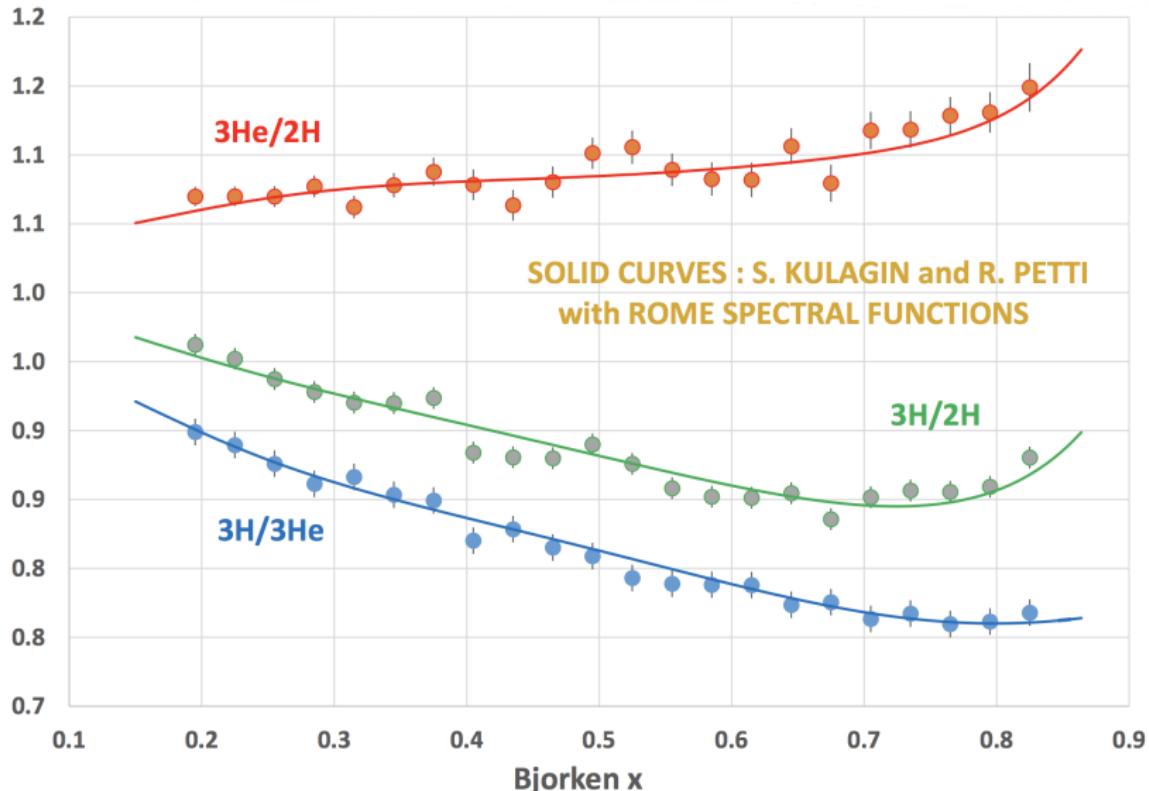
Pair Production



Tritium positron contamination. Credit: Tong Su



Ratio of Yields





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:

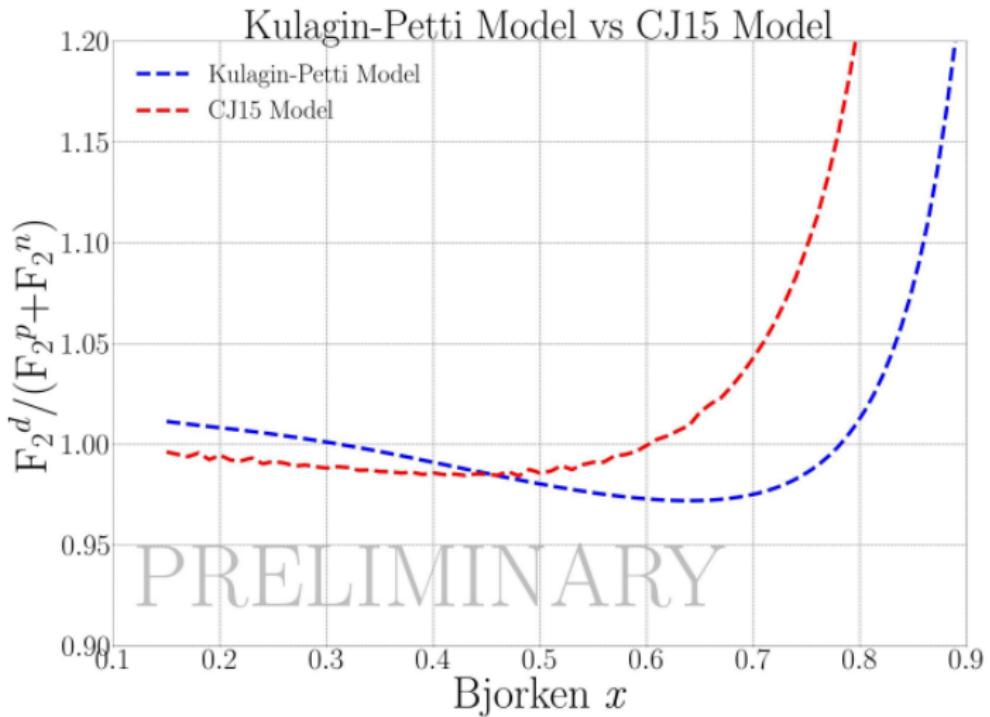
$$\frac{\sigma^{^3He}}{\sigma^{^3H}} = \frac{F_2^{^3He}}{F_2^{^3H}} = R^* \frac{2F_2^p + F_2^n}{F_2^p + 2F_2^n}$$

- 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:

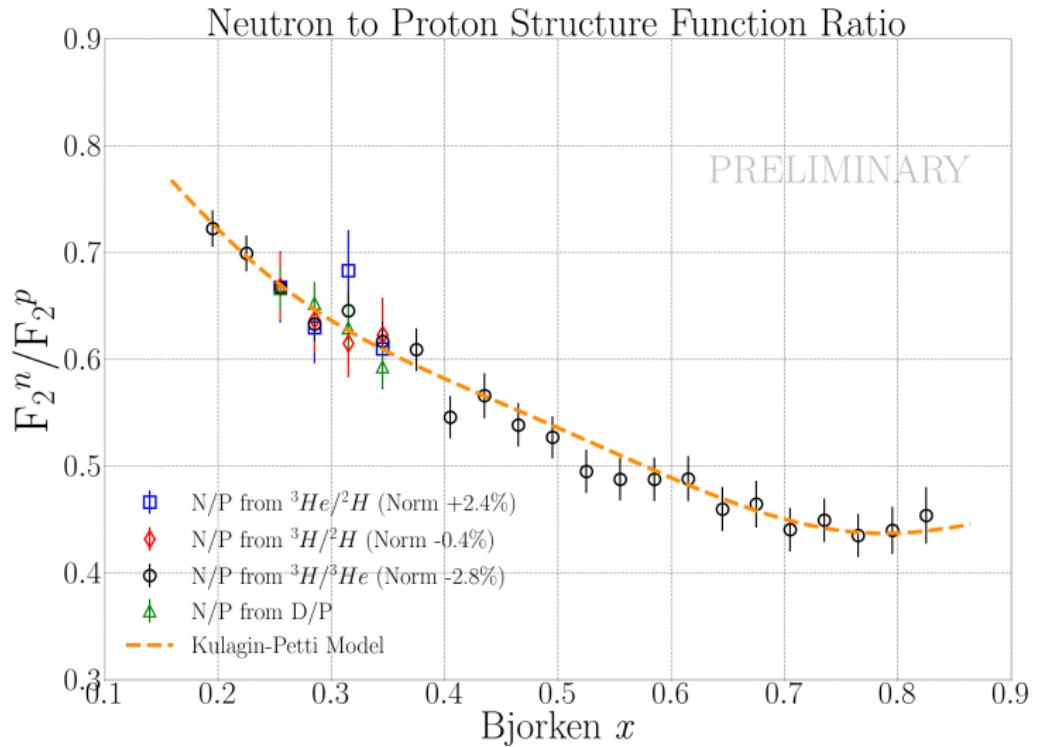
$$\frac{F_2^n}{F_2^p} = \frac{2R^* - \sigma^{^3He}/\sigma^{^3H}}{2\sigma^{^3He}/\sigma^{^3H} - R^*}$$

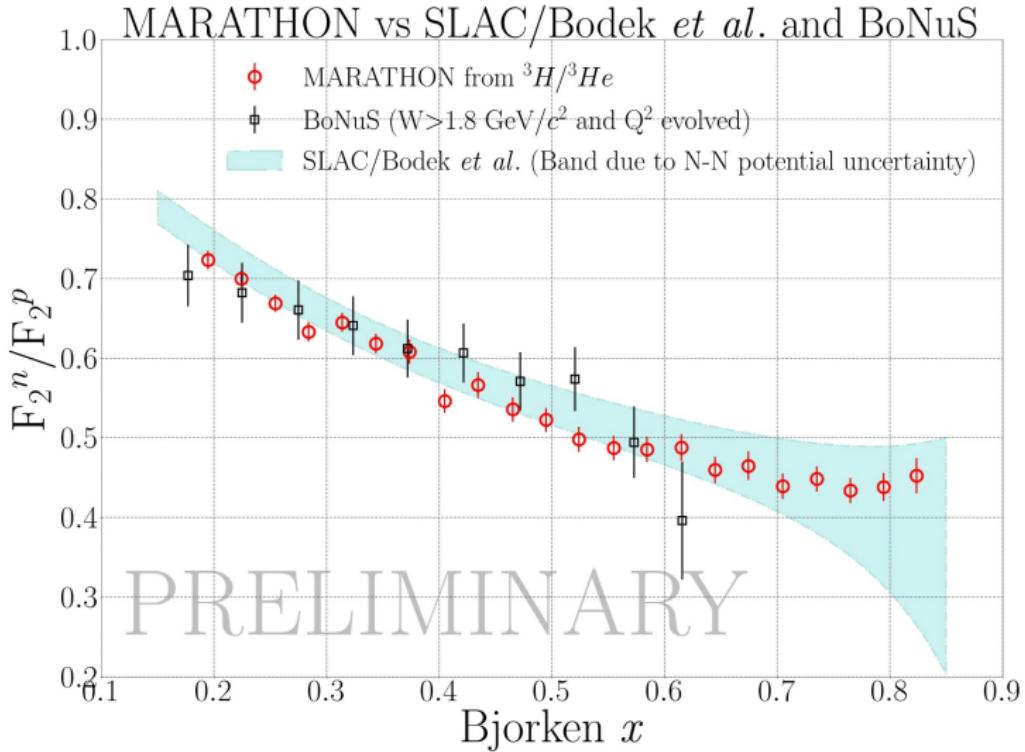
- Iterate the process until it converges to a stable F_2^n/F_2^p ratio.

Extracting F2 ratio

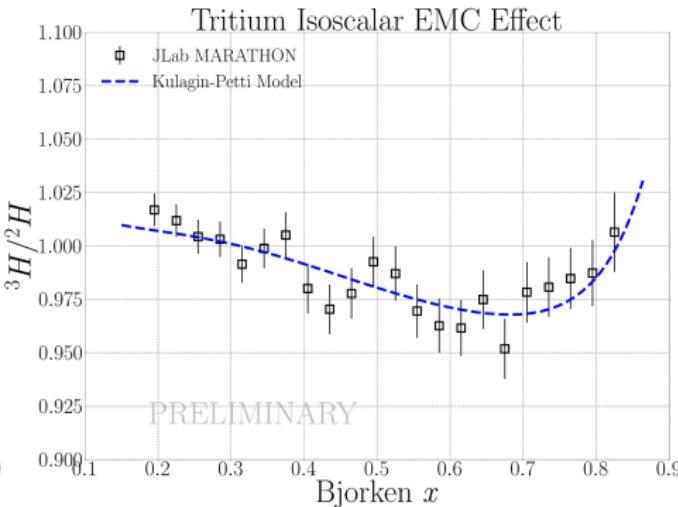
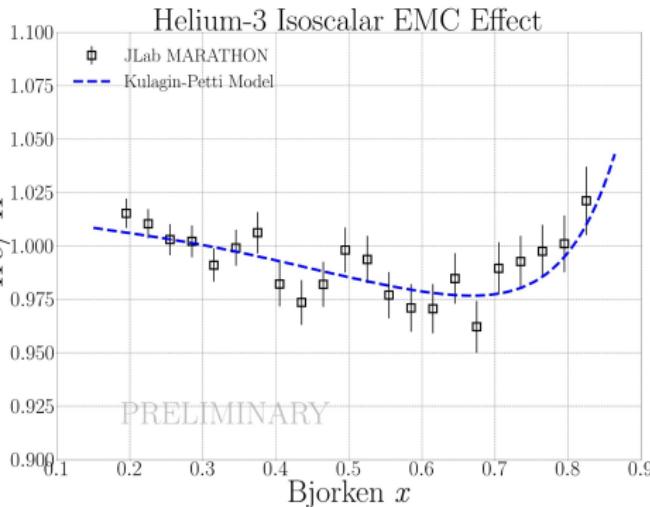


plot credit: Tong Su

F_2^n / F_2^p for D/p and $^3\text{H}/^3\text{He}$ 

F_2^n / F_2^p 

EMC Effect



- ${}^3\text{H}$ normalized by -0.4%
- ${}^3\text{He}$ normalized by 2.4%
- Isoscalar corrections from MARATHON $F_n(\text{n/p})$

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. 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. Pettit, 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. Sirca, 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. Wojtsekowski, 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.



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Basic instrumentation for Hall A at Jefferson Lab. NIM A 522(2004) 294-346
-  J. Gomez et al. (SLAC-E139)
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nucl-ex/0904.4448.