

# $\frac{F_2^n}{F_2^P}$ Ratios from MARATHON

Jason Bane

University of Tennessee

*jbane1@vols.utk.edu*

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# Agenda for the Workshop on Experiments with Tritium at JLab

Sept. 20-21, 1999 at JLab

9/20/99 Monday afternoon [Chair - Ron Ransome (Rutgers)]  
Location: Auditorium, CEBAF Center

13:00 Measurement of the Tritium Elastic Form Factors at Saclay  
Jacques Martino (Saclay)

13:30 Unpolarized Measurements: Elastic Form Factors, R\_L-R\_T Separation, and the Coulomb Sum Rule  
Cathleen Jones (Caltech)

13:50 Polarization Observables in Quasielastic Scattering  
Steffan Strauch (Rutgers)

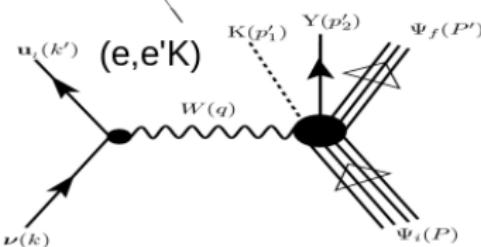
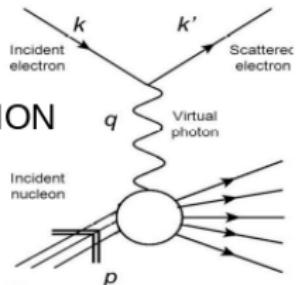
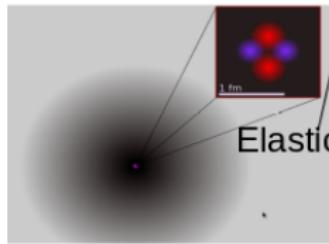
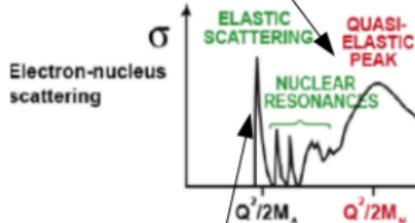
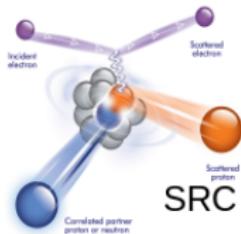
14:30 break

14:50 Kaon Electroproduction on Tritium  
Joerg Reinhold (FIU)

15:30 Measurement of the Ratio ( $\sigma_{en}/\sigma_{ep}$ ) at High x using a Tritium Target at JLab  
Makis Petratos (Kent State) [with J. Gomez, M. Katramatou, and W. Melnitchouk]

16:10 Measurements of the GDH Sum Rule on the 3-body Nuclei at JLab  
J.-P. Chen (TJNAF)

# 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.

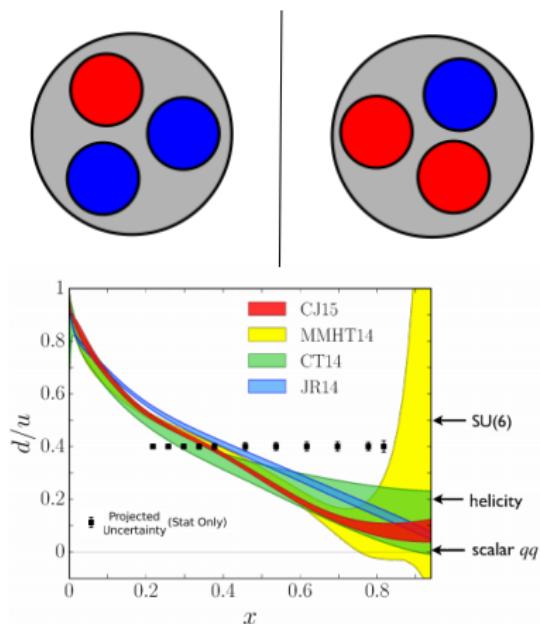
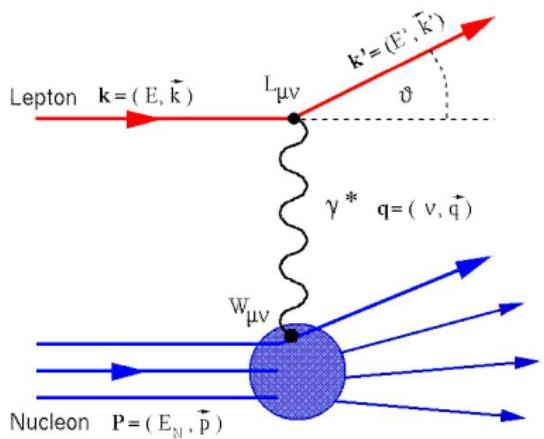


Figure:  $d/u$  quark distribution ratios

# Deep Inelastic Scattering (DIS)



- Momentum Transfer  

$$Q^2 \equiv 4EE' \sin^2 \frac{\theta}{2}$$
- Bjorken X ( $X_{bj}/x$ ) =  $\frac{Q^2}{2\nu M}$
- $\sigma_{eN} \equiv \frac{\alpha^2}{eE^2 \sin^4(\frac{\theta}{2})} \left[ \frac{F_2}{\nu} \cos^2 \frac{\theta}{2} + \frac{2F_1}{M} \sin^2 \frac{\theta}{2} \right]$
- Invariant Mass  

$$W^2 = 2M\nu + M^2 - Q^2$$
- $W^2 > 4 \rightarrow \text{DIS}$



# $\frac{F_2^n}{F_2^p}$ in the Quark Parton Model

- Assume isospin symmetry:

$$u^p(x) \equiv d^n(x) \equiv u(x) \quad \bar{u}^p(x) \equiv \bar{d}^n(x) \equiv \bar{u}(x)$$

$$d^p(x) \equiv u^n(x) \equiv d(x) \quad \bar{d}^p(x) \equiv \bar{u}^n(x) \equiv \bar{d}(x)$$

$$s^p(x) \equiv s^n(x) \equiv s(x) \quad \bar{s}^p(x) \equiv \bar{s}^n(x) \equiv \bar{s}(x)$$

- Proton and neutron structure functions:

$$F_2^p = x \left[ \frac{4}{9}(u + \bar{u}) + \frac{1}{9}(d + \bar{d}) + \frac{1}{9}(s + \bar{s}) \right]$$

$$F_2^n = x \left[ \frac{4}{9}(d + \bar{d}) + \frac{1}{9}(u + \bar{u}) + \frac{1}{9}(s + \bar{s}) \right]$$

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

## 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:

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

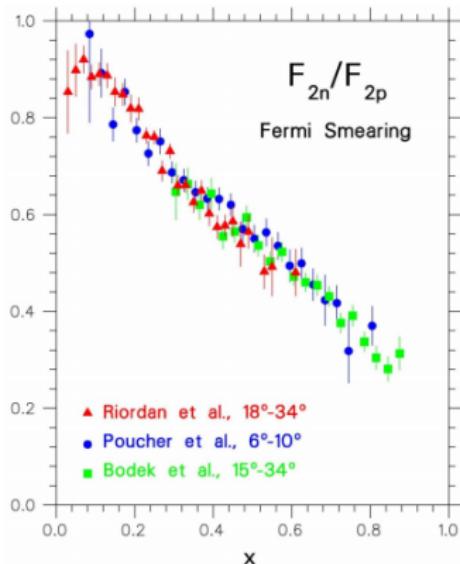
- For  $x \rightarrow 1$ :  $F_2^n / F_2^p \rightarrow 1/4$ : High momentum partons in proton (neutron) are up (down) quarks, and:

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

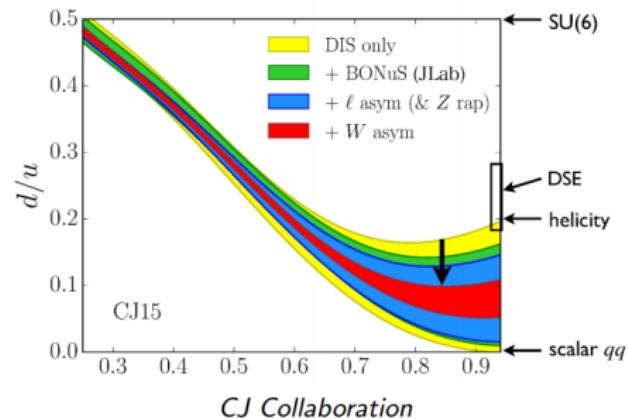
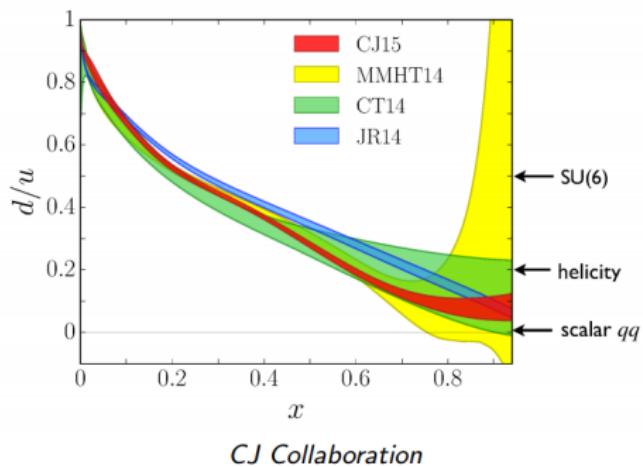
- For medium and high  $x$ , safe to assume that (with  $d$  and  $u$  denoting now quark plus antiquark distributions):

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

Makis Petratos

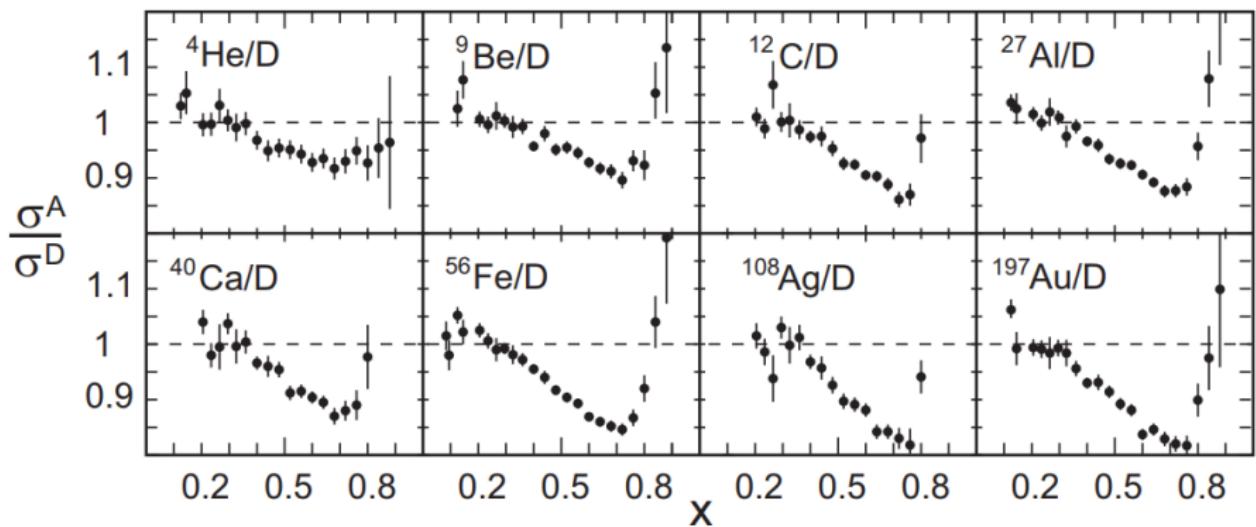


# d/u quark ratios



# EMC Effect

Figure: SLAC experiment E139 .



# EMC Effect

Figure: JLab experiment "EMC in light Nuclei". J.Seely, A. Daniel et al

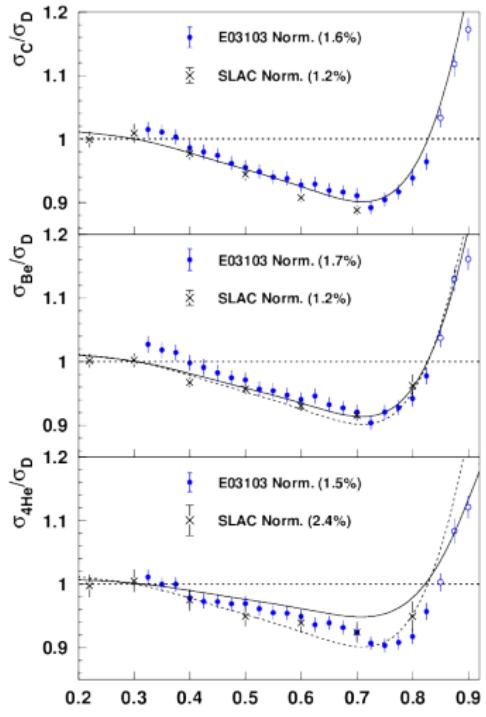
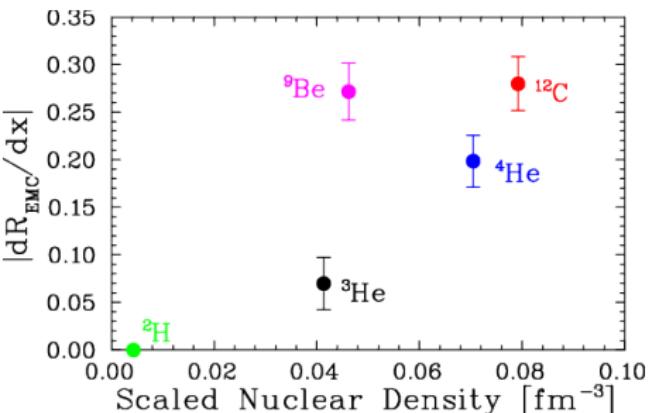


Figure: EMC as a function of Nuclear Density. J.Seely, A. Daniel et al



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



# 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. 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. 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



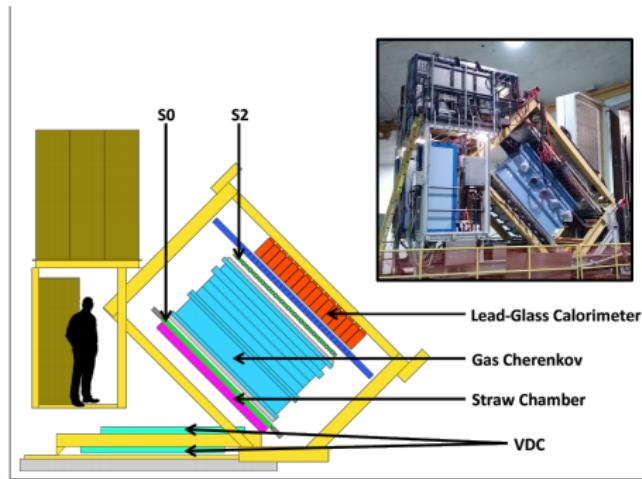
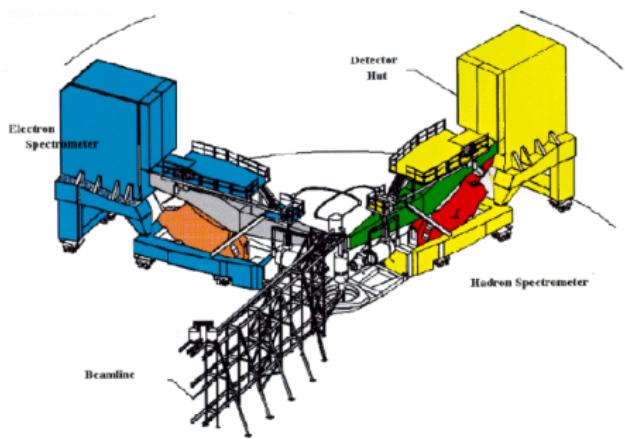
# The JLab MARATHON Tritium Collaboration

**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.

# Hall A & The HRSs

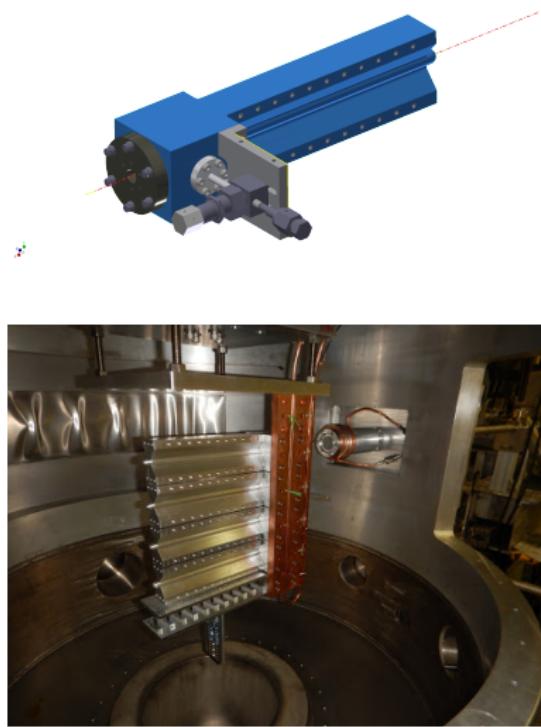
Use CEBAF(Continues Electron Beam Facility) to provide 10.6 GeV beam for electron scattering.



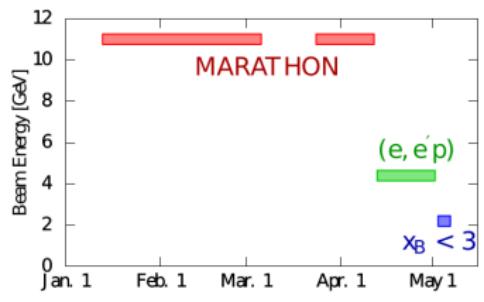
# Tritium Target Cell

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

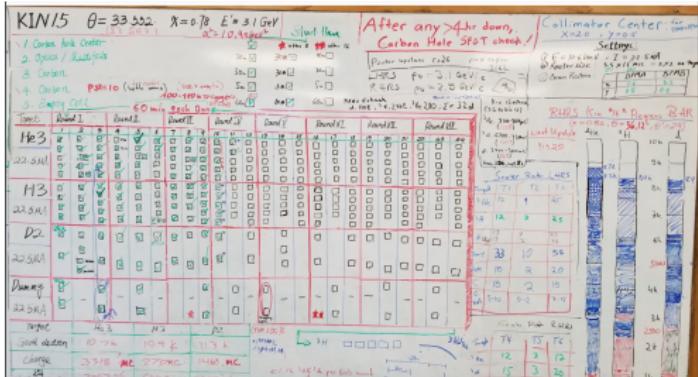


## The Run Period



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



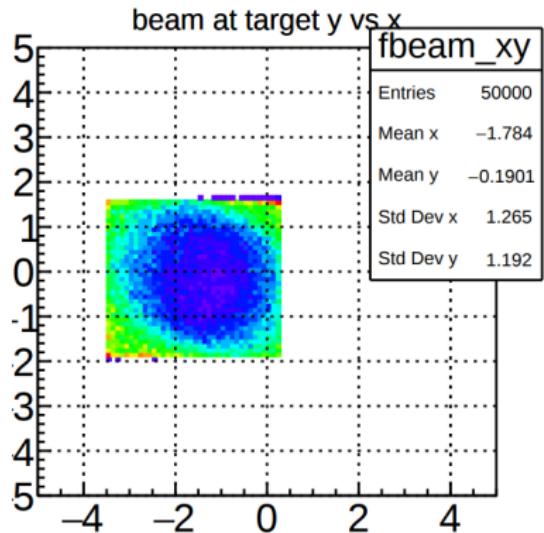
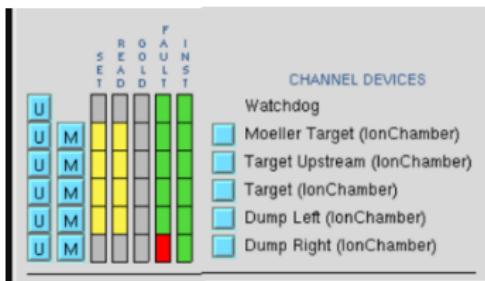
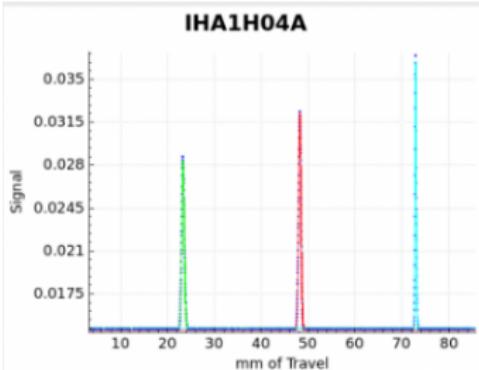


# Major Miscues

- Right Arm Dipole failed on January 11th
  - ▶ Return the dipole to functionality the following day
  - ▶ 01/13 - Dipole failed again, causing a chain reaction with the Left arm
  - ▶ Solution could not be found quickly
  - ▶ Change of Kinematic plan to use single HRS.
  - ▶ Recovered RHRSS on 01/16 - Set to take data at theta of 36.12°, x of 0.82
- A Transformer Failed on March 5th
  - ▶ Recovered on March 23rd
  - ▶ Spring run Period extended by 18 days
  - ▶ MARATHON took opportunistic data during recovery period

## Tritium Safety Requirements

- Harp and BPM Check!
- Ion Chamber functionality test
- Beam Center
- Raster Size calibration.



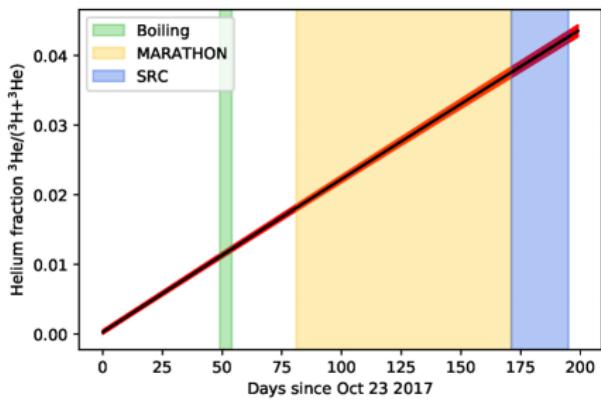
# Systematics: $^3H$ Decay



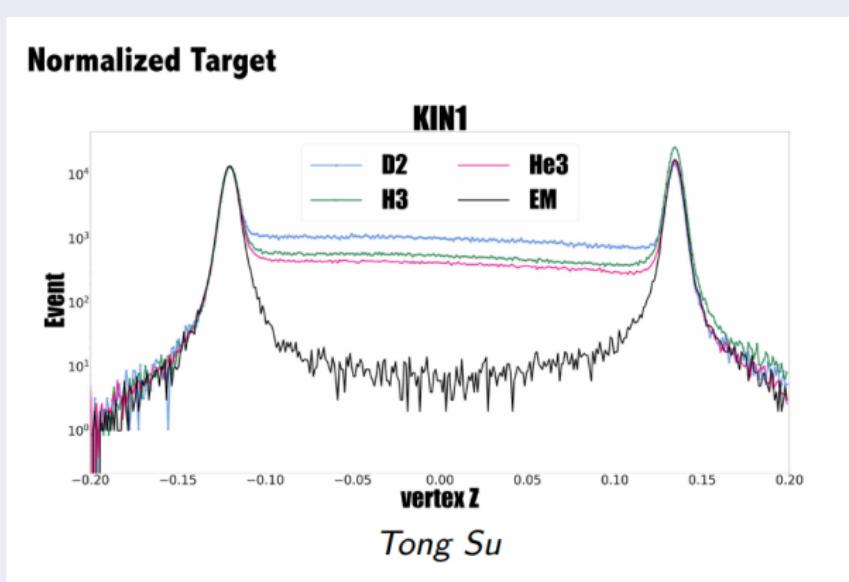
$$\tau^3He = 4500 \pm 8\text{ days}$$

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

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

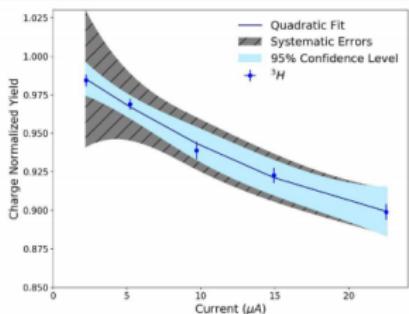
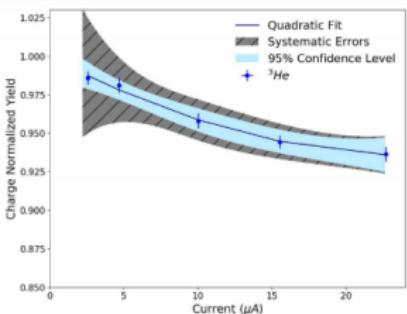
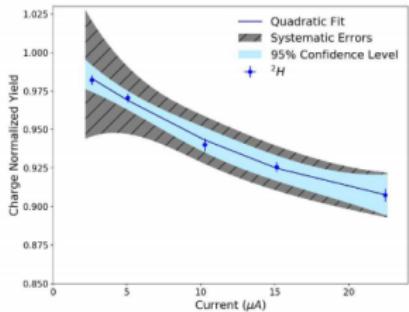
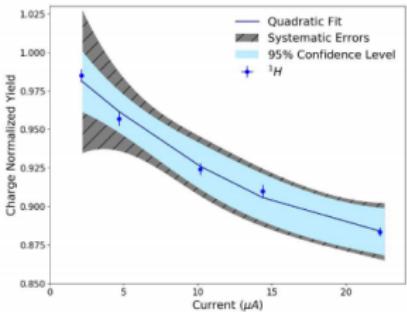


# Systematics: Endcaps



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

# Systematics: Density Fluctuations

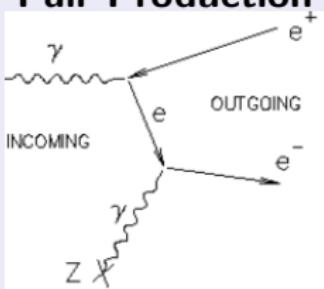
(a)  ${}^3\text{H}$  Density Analysis.(b)  ${}^3\text{He}$  Density Analysis.(c)  ${}^2\text{H}$  Density Analysis.(d)  ${}^1\text{H}$  Density Analysis.

Santiesteban et al

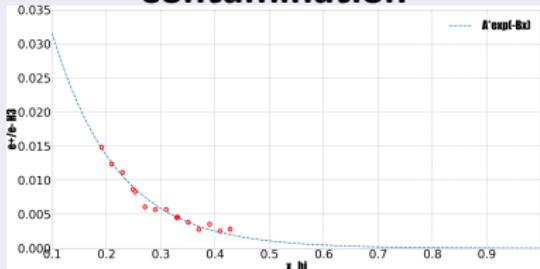
# Charge Symmetric back ground

- High energy photons decay into an  $e^+e^-$  pairs
- Account for the pair produced  $e^-$  by detecting the pair produced  $e^+$
- HRS positive polarity - kinematics 1,2 and 3
- Fit results with an exponential function to determine the contamination factor at high  $x_{Bj}$  kinematics.

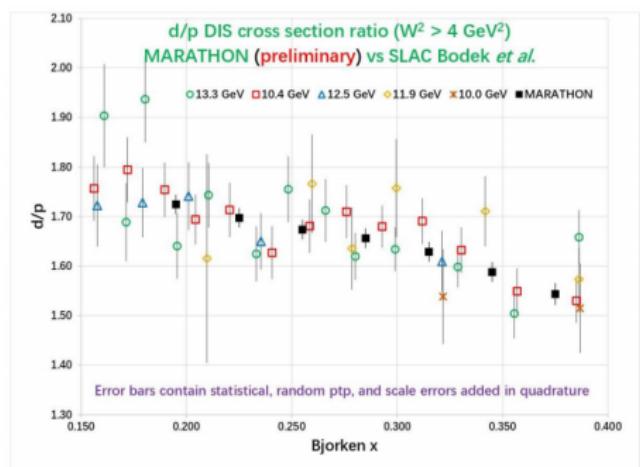
## Pair Production



## Tritium positron contamination



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



plot credit: Makis Petratos



plot credit: Tong Su



# Extracting F2

- 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:

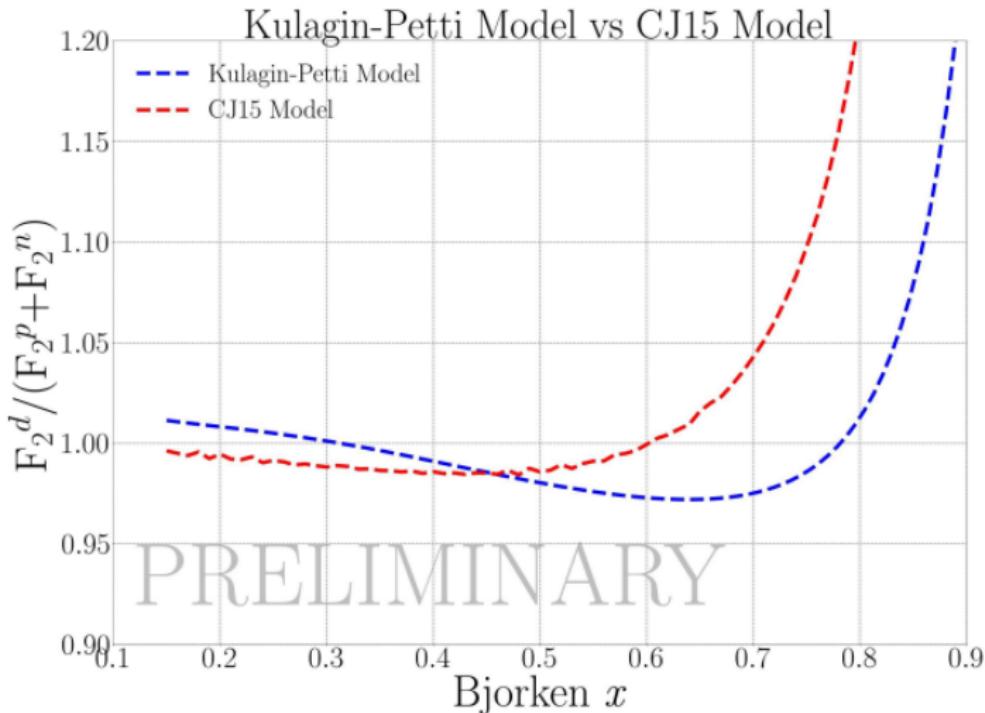
$$\frac{\sigma^{^3He}}{\sigma^{^3H}} = \frac{F_2^{^3He}}{F_2^{^3H}} = R^* \frac{2F_2^p + F_2^n}{F_2^p + 2F_2^n}$$

- 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:

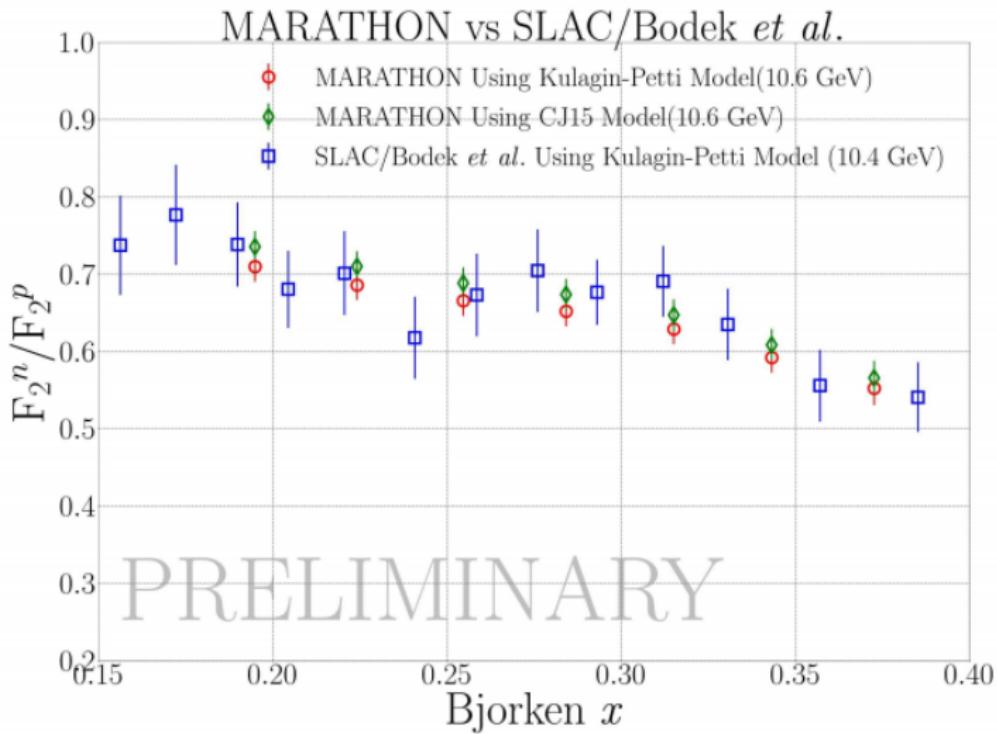
$$\frac{F_2^n}{F_2^p} = \frac{2R^* - \sigma^{^3He}/\sigma^{^3H}}{2\sigma^{^3He}/\sigma^{^3H} - R^*}$$

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

# Extracting F2

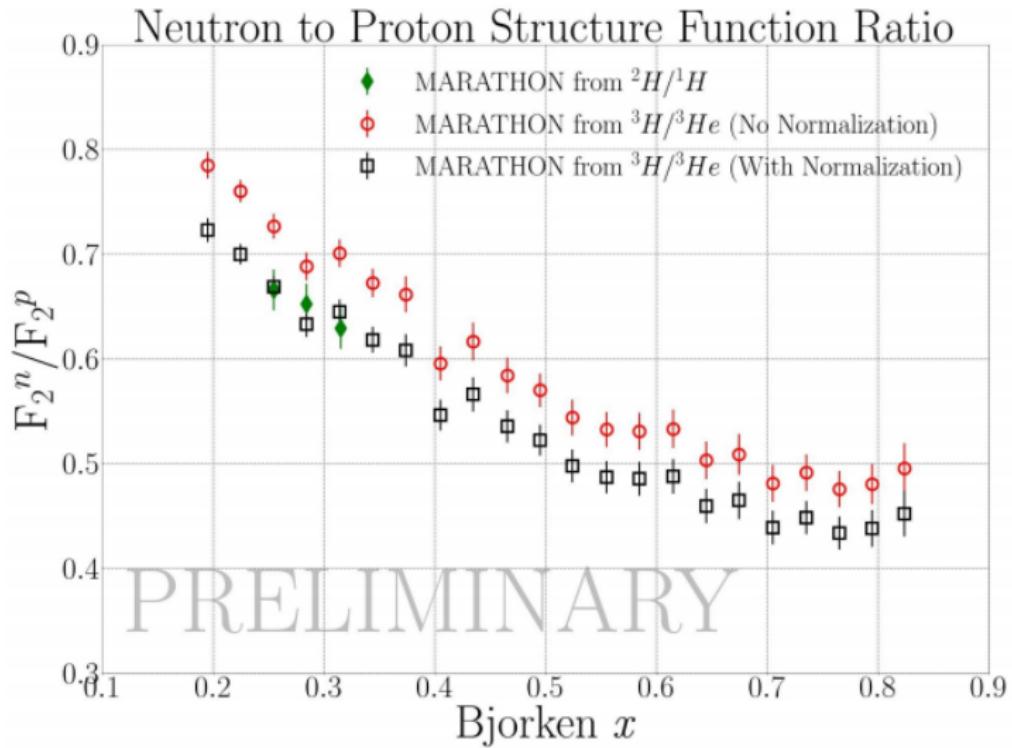


*plot credit: Tong Su*

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


plot credit: Tong Su

$$\frac{F_2^n}{F_2^p}$$

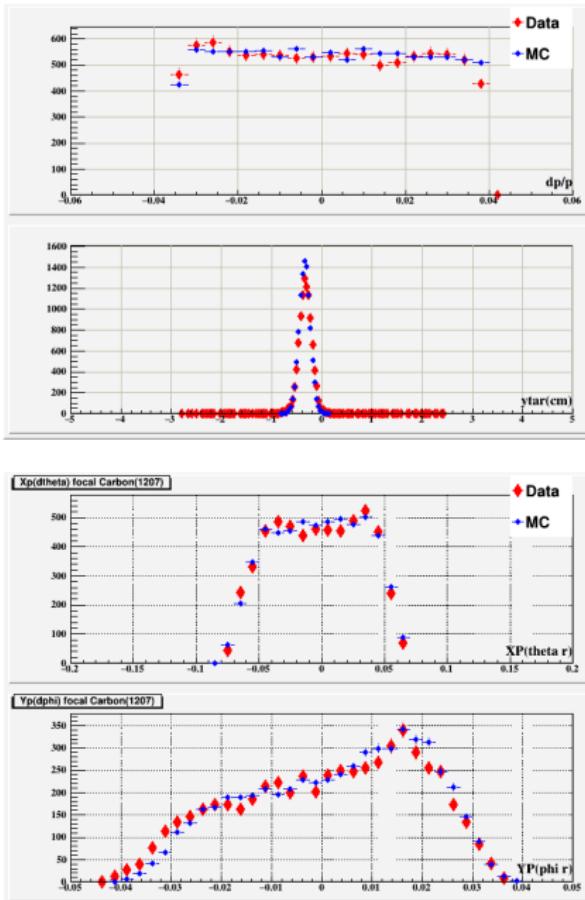


PRELIMINARY

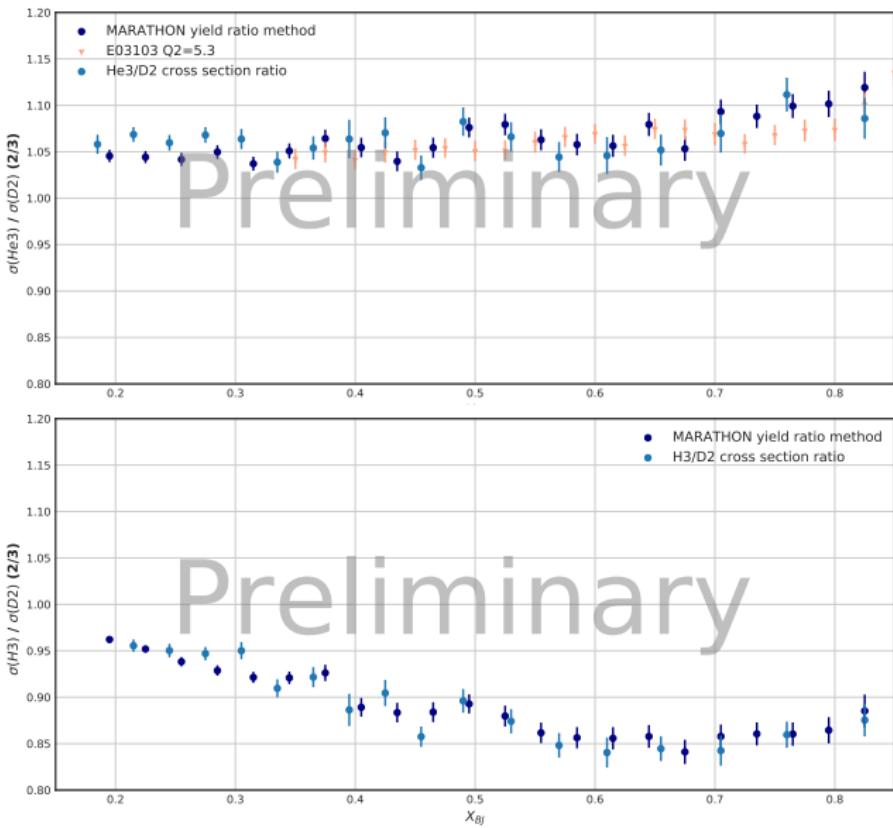
plot credit: Tong Su

## Monte Carlo

- Generate events in target space
- Pass through detector aperture
- Use optics matrix to project back to target from focal plane.
- Tune Simulation to match detector response
- Adjust initial parameters
- Use model to weight events
  - ▶ Deep Inelastic and resonance region from Bodek Fit
  - ▶ Quasi elastic model of F1F2QE09



## EMC Effect



Thank you!!

- MARATHON students
- Tritium collaboration
- Hall A Collaboration
- Hall C Collaborators that took shifts during MARATHON
- Nadia Fomin and Doug Higinbotham