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

Jason Bane

University of Tennessee

jbane1@vols.utk.edu

May 3, 2019

Agenda for the Workshop on Experiments with Tritium at JLab

Sept. 20-21, 1999 at JLab

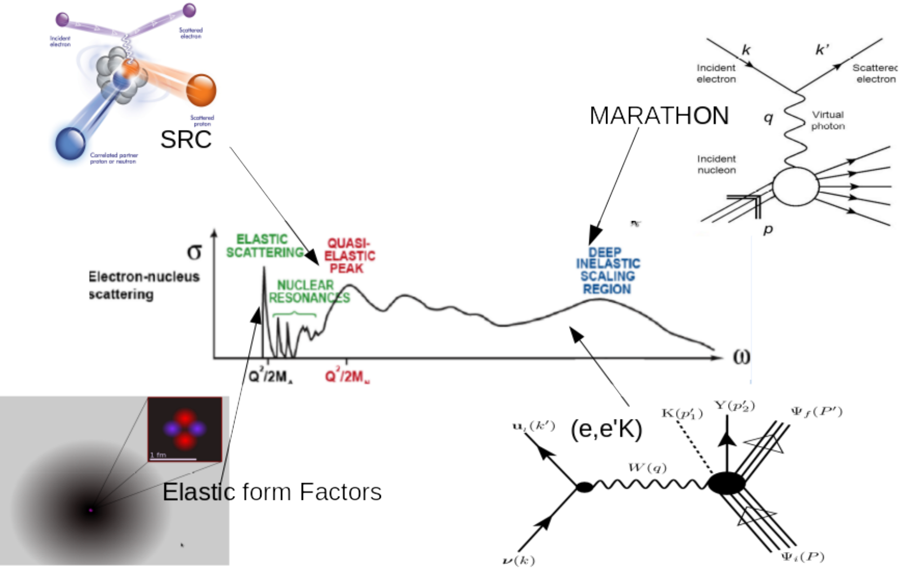
9/20/99 Monday afternoon [Chair - Ron Ransome (Rutgers)]
Location: Auditorium, CEBAF Center

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

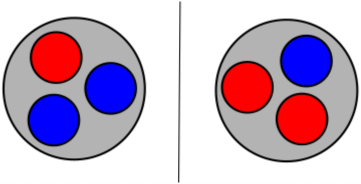
14:50 Kaon Electroproduction on Tritium
Joerg Reinhold (FIU)
15:30 Measurement of the Ratio (sigma_en/sigma_ep) at High x using a Tritium Target at JLab
Makis Petratos (Kent State) [with J. Gomez, M. Katramatou, and W. Melnitchouk]
16:10 Measurements of the GDH Sum Rule on the 3-body Nuclei at JLab
J.-P. 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.



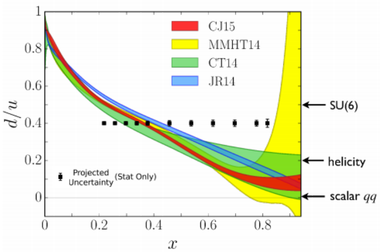
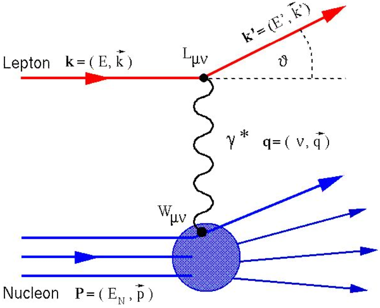


Figure: d/u quark distribution ratios

- 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)



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

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

- Assume isospin symmetry:

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

- 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: $1/4 \le F_2^n / F_2^p \le 4$

SLAC/CERN Data Interpretation in QPM

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

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

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

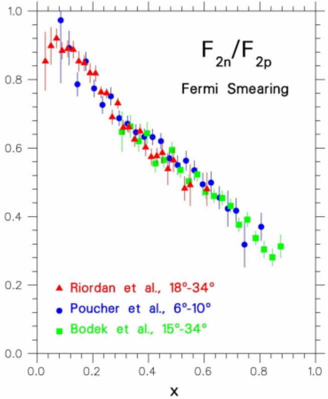
- For $x \to 1$: $F_2^n/F_2^p \to 1/4$: High momentum partons in proton (neutron) are up (down) quarks, and:

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

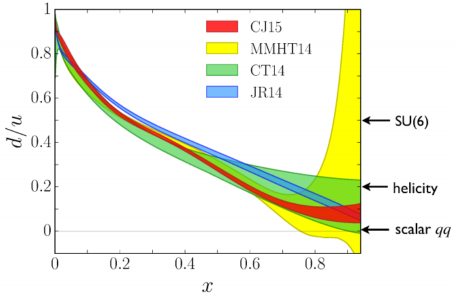
- For medium and high x, safe to assume that (with d and u denoting now quark plus antiquark distributions):

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

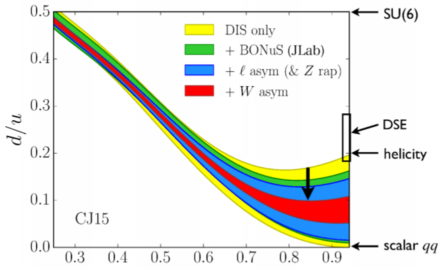
Makis Petratos



d/u quark ratios



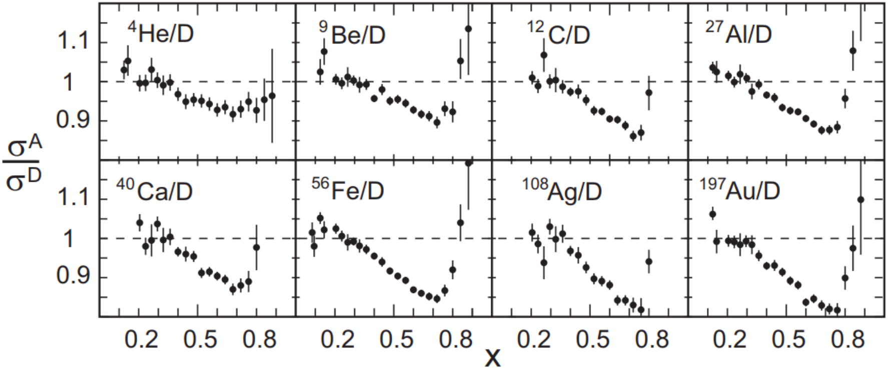
CJ Collaboration



CJ Collaboration

EMC Effect

Figure: SLAC experiment E139 .



EMC Effect

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

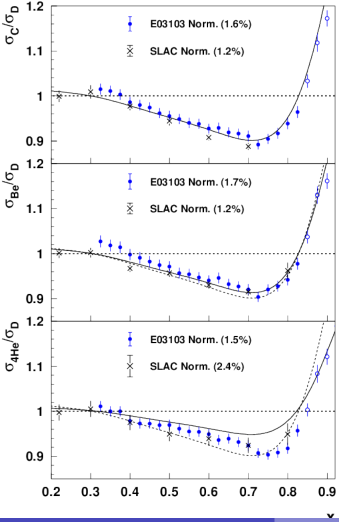
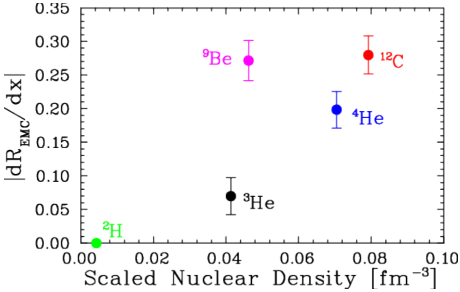


Figure: EMC as a function of Nuclear Density. J.Seely, A. Daniel et al



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. 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

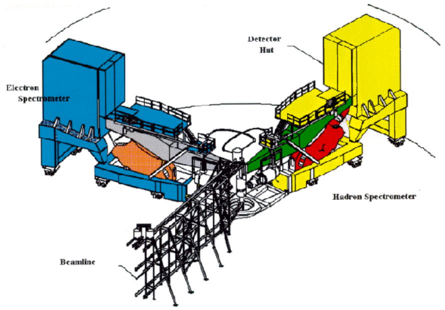
The JLab MARATHON Tritium Collaboration

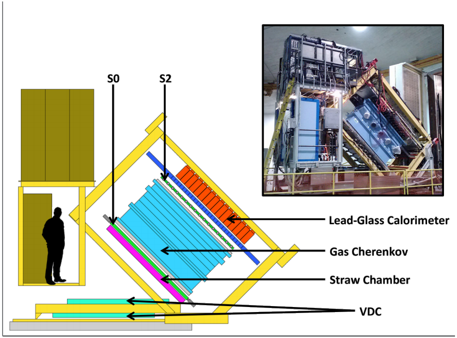
Forty Five Institutions (in no particular order): University of Virginia; Texas A & M University; Kent State University; University of Zagreb; California State University, Los Angeles; Argonne National Laboratory; Temple University; The College of William and Mary; University of Tennessee; Massachusetts 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.

Hall A & The HRSs

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

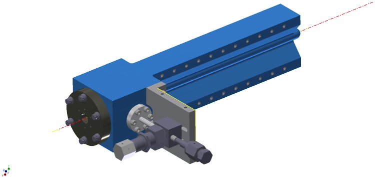


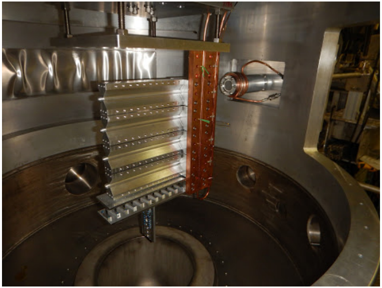


Tritium Target Cell

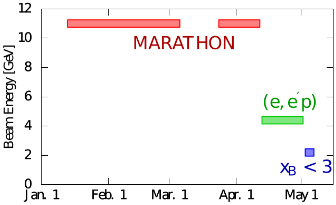
First tritium target at JLab

- 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



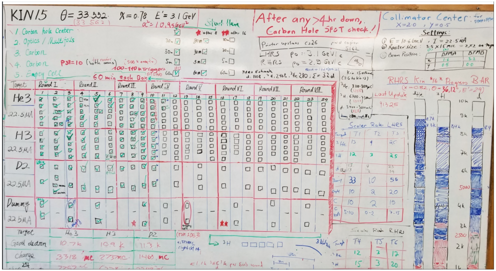


The Run Period



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

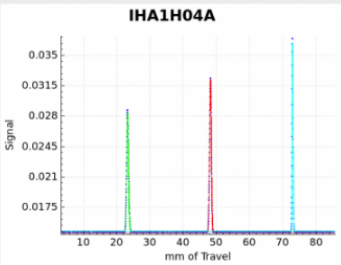


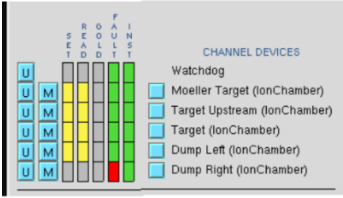
Major Miscues

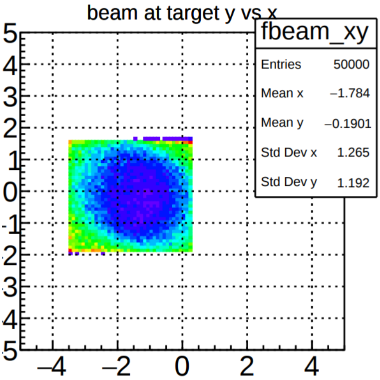
- Right Arm Dipole failed on January 11th
  - Return the dipole to functionally the following day
  - 01/13 - Dipole failed again, causing a chain reaction with the Left arm
  - Solution could not be found quickly
  - Change of Kinematic plan to use single HRS.
  - Recovered RHRS on 01/16 - Set to take 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.







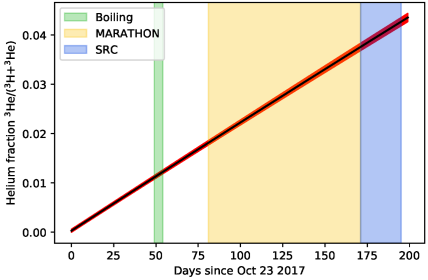
Systematics: ^3H Decay

$^3H \rightarrow ^3He$

$$\tau^3He = 4500 \pm 8 days$$

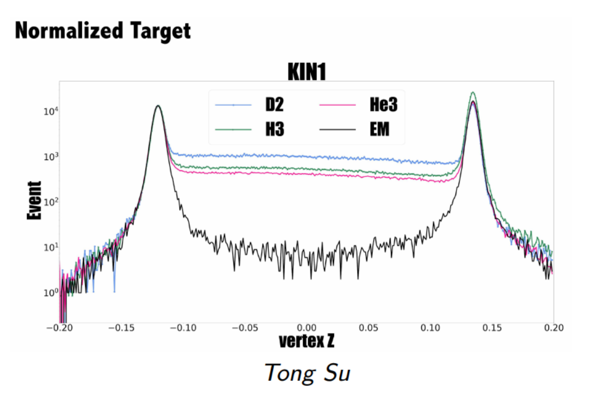
$$c = \frac{\eta_{^3He}}{\eta_{tot}}$$

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



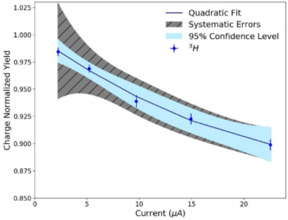
Tyler Kutz

Systematics: Endcaps

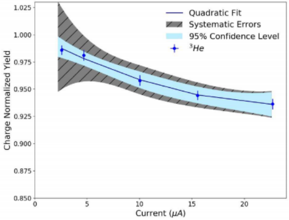


- Extract ratio of the normalized yield from the gas cell to that of the empty cell

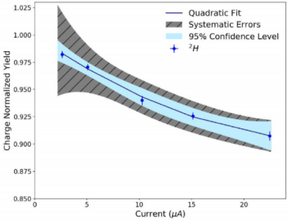
Systematics: Density Fluctuations



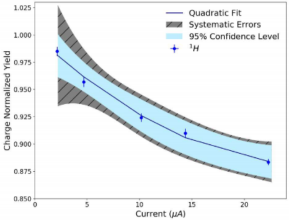
(a) ^{3}H Density Analysis.



(b) ^{3}He Density Analysis.



(c) ^{2}H Density Analysis.



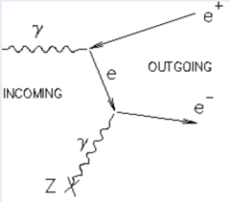
(d) ^{1}H Density Analysis.

Santiesteban et al

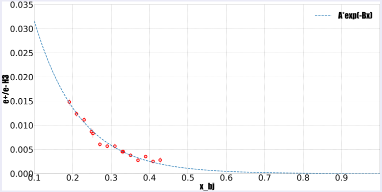
Charge Symmetric back ground

- 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.

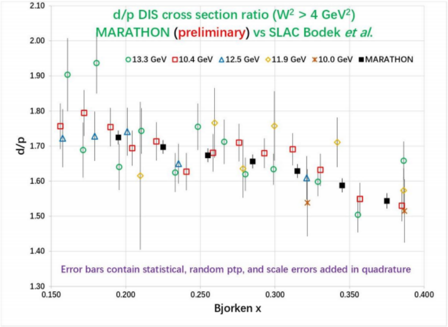
Pair Production



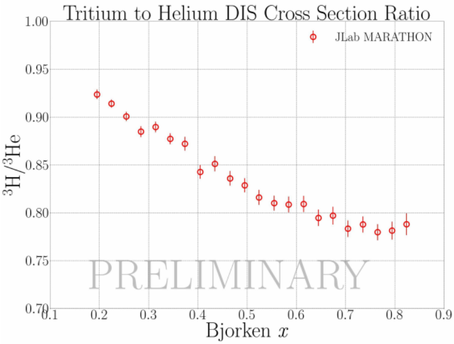
Tritium positron contamination



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:

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

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

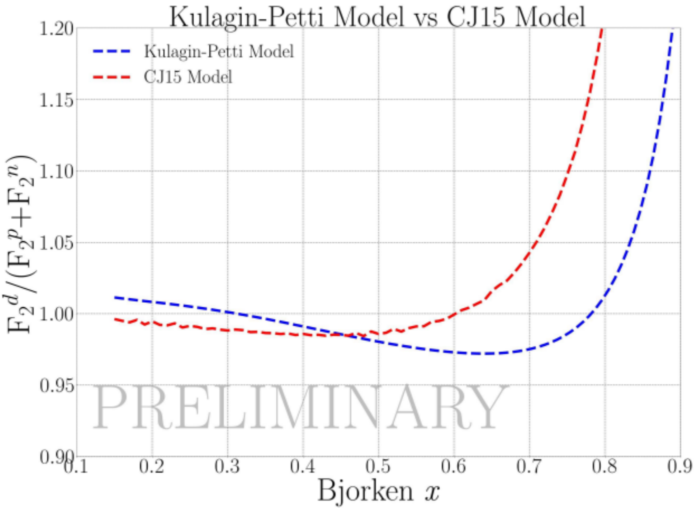
$$\frac{\sigma^{\,^3He}}{\sigma^{\,^3H}} = \frac{F_2^{\,^3He}}{F_2^{\,^3H}} = R^* \frac{2F_2^p + F_2^n}{F_2^p + 2F_2^n}$$

- 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:

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

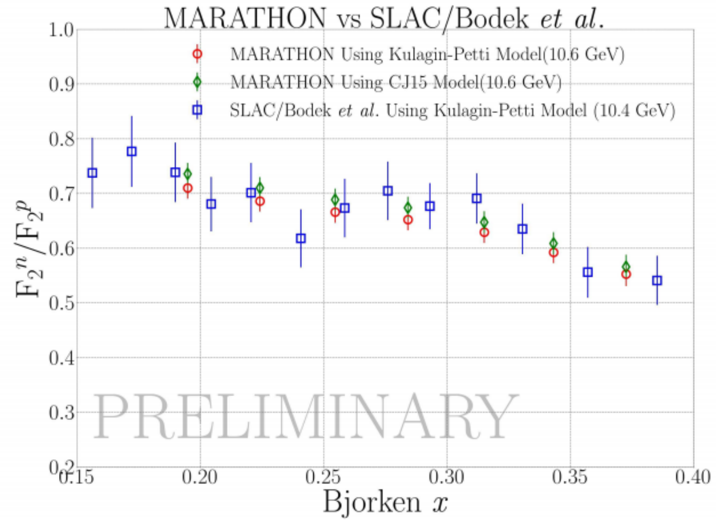
- Iterate the process until it converges to a stable F_2^n/F_2^p ratio.

Extracting F2



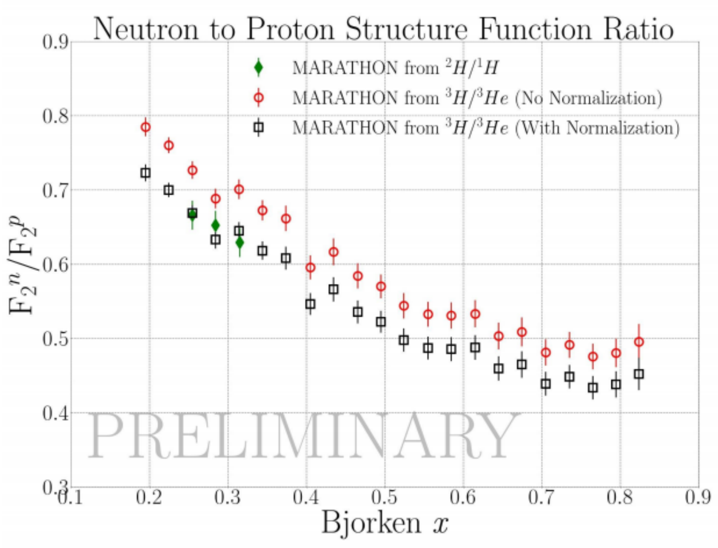
plot credit: Tong Su

$\frac{F_2^n}{F_2^p}$ for D/p



plot credit: Tong Su

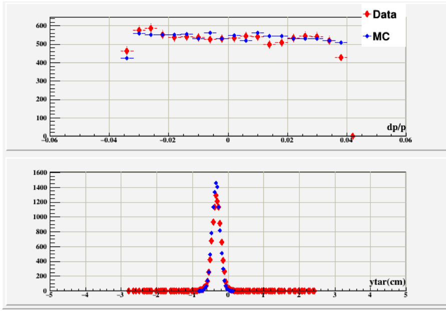
$\frac{F_2^n}{F_2^p}$

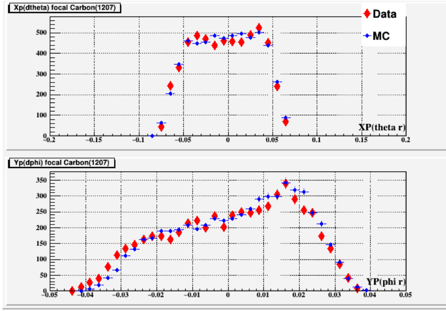


plot credit: Tong Su

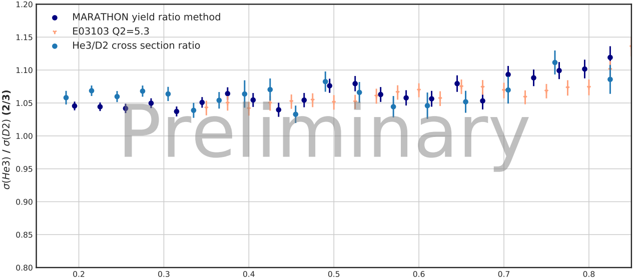
Monte Carlo

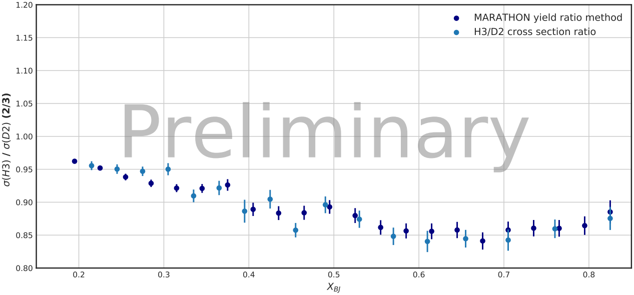
- Generate events in target space
- Pass through detector aperture
- Use optics matrix to project back to target from focal plane.
- Tune Simulation to match detector response
- Adjust initial parameters
- Use model to weight events
  - Deep Inelastic and resonance region from Bodek Fit
  - Quasi elastic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





EMC Effect


MARATHON yield ratio method
E03103 Q2=5.3
He3/D2 cross section ratio
Preliminary
σ(He3) / σ(D2) (2/3)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.2
0.3
0.4
0.5
0.6
0.7
0.8


MARATHON yield ratio method
H3/D2 cross section ratio
Preliminary
σ(H3) / σ(D2) (2/3)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.2
0.3
0.4
0.5
0.6
0.7
0.8
X_{BJ}

Thank you!!

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