MARATHON EMC Effect

Hall A Collaboration

Michael Nycz[1]

On behalf of the MARATHON Collaboration

[1] University of Virginia

January 26, 2023

Outline

MARATHON

MeAsurement of the F_2^n/F_2^p,d/u **RA**tios and A=3 EMC Effect in Deep Inelastic Electron Scattering Off the **T**ritium and **H**elium Mirr(**O**)r **N**uclei

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Neutron Structure Function and $A = 3$ Mirror Nuclei

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[2] *Special Research Centre for the Subatomic Structure of Matter, and Department of Physics and Mathematical Physics, Adelaide University, Adelaide 5005, Australia*
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Abstract

We investigate deep inelastic scattering from ^{3}He and ^{3}H within a conventional convolution treatment of binding and Fermi motion effects. Using realistic Faddeev wave functions together with a nucleon spectral function, we demonstrate that the free neutron structure function can be extracted in deep-inelastic scattering from $A = 3$ mirror nuclei, with nuclear effects canceling to within 2% for $x \lesssim 0.85$.

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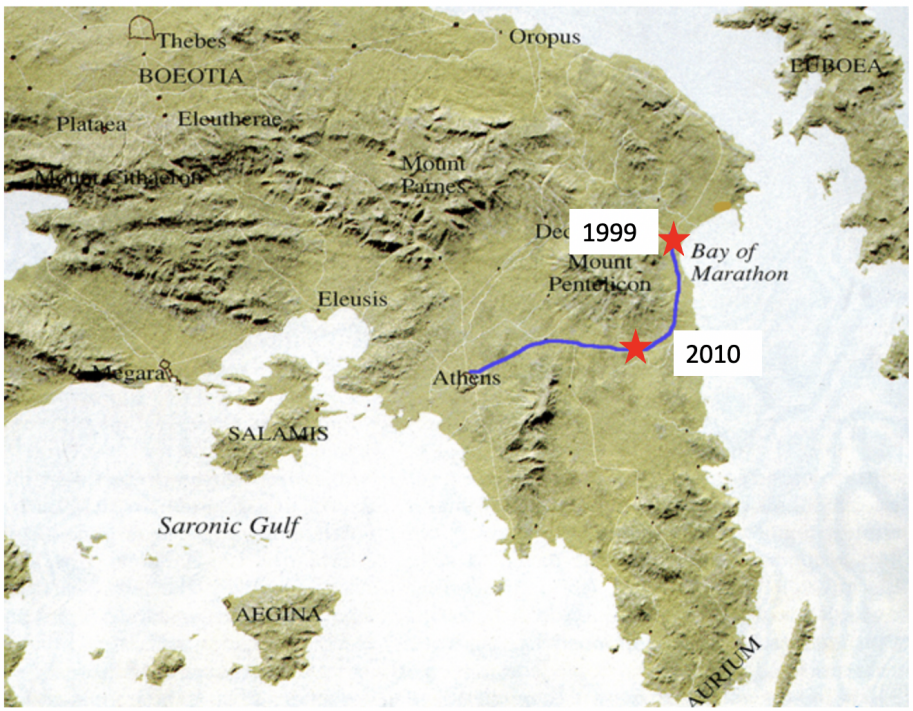


Title: Measurement of the F^n_2/F^p_2, d/u Ratios and A=3 EMC Effect in Deep Inelastic Electron Scattering Off the Tritium and Helium Mirror nuclei

Spokespersons: J. Gomez, R.J. Holt, G. G. Petratos (Contact), R. Ransome

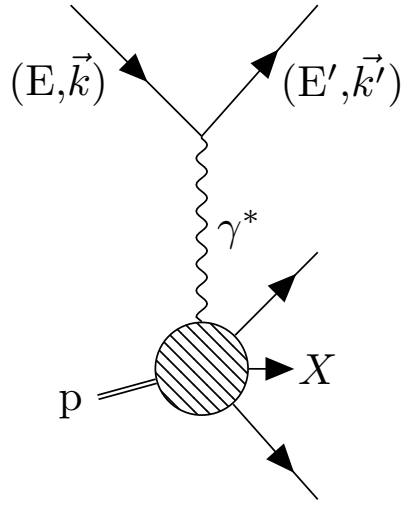
Motivation:
The collaboration proposes to carry out a precise measurement of the ratio of F^n_2/F^p_2 at deep inelastic kinematics ($x = 0.2$ to 0.83) using tritium and helium mirror nuclei to reduce uncertainties due to nuclear effects. The ratio of d/u at medium and large x values will be extracted from the data to test various model predictions of this ratio at large x. Furthermore, the A=3 EMC effect will be studied with measurements off helium and tritium at the same kinematics to allow for more stringent tests of various theoretical calculations of the EMC effect. This is one of the flagship experiments driving the original scientific case for the 12-GeV energy upgrade of CEBAF.

Motivation

$$\frac{d\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4} cos^2\frac{\theta}{2} F_2(x) \left[\frac{1}{\nu} + \frac{1+\frac{Q^2}{\nu^2}}{xM(1+R)tan^2\frac{\theta}{2}}\right]$$

Quark Parton Model

$$F_1 = \frac{1}{2}\sum_i e_i^2 q_i(x) \quad F_2 = x\sum_i e_i^2 q_i(x)$$



Isospin Symmetry

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

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

Motivation

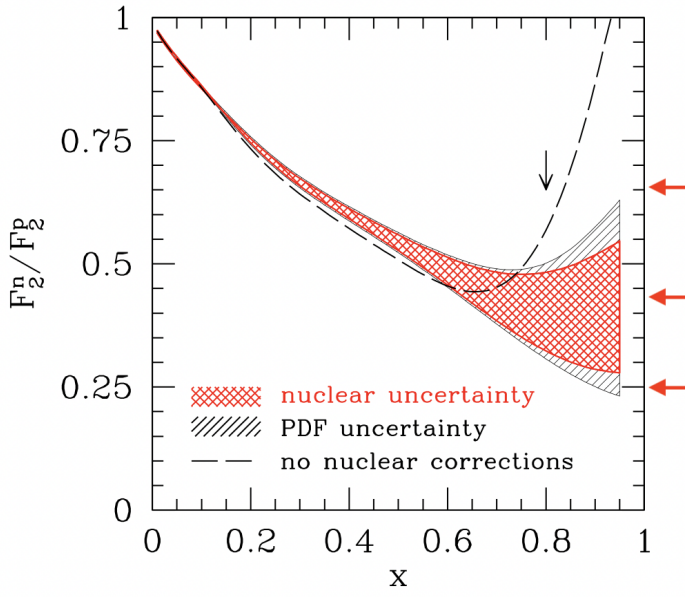
$$\frac{d\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4} cos^2\frac{\theta}{2} F_2(x) \left[\frac{1}{\nu} + \frac{1+\frac{Q^2}{\nu^2}}{xM(1+R)tan^2\frac{\theta}{2}}\right]$$

Quark Parton Model

$$F_1 = \frac{1}{2}\sum_i e_i^2 q_i(x) \quad F_2 = x\sum_i e_i^2 q_i(x)$$

Natchman Inequlaity

$$1/4 \leq \frac{F_2^n}{F_2^p} \leq 4$$



- SU6, pQCD,etc...

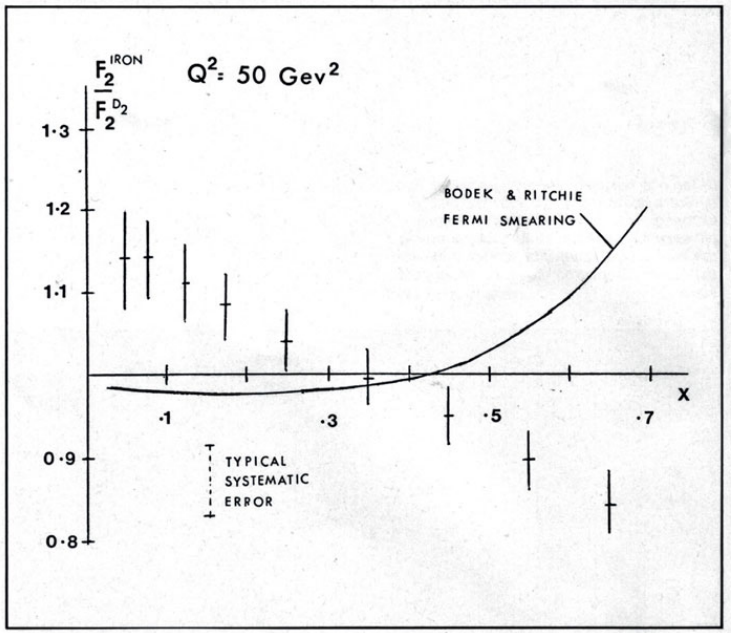
EMC Effect

Assumption

Structure functions should scale

$$AF_2^A = ZF_2^p + (A - Z)F_2^n$$

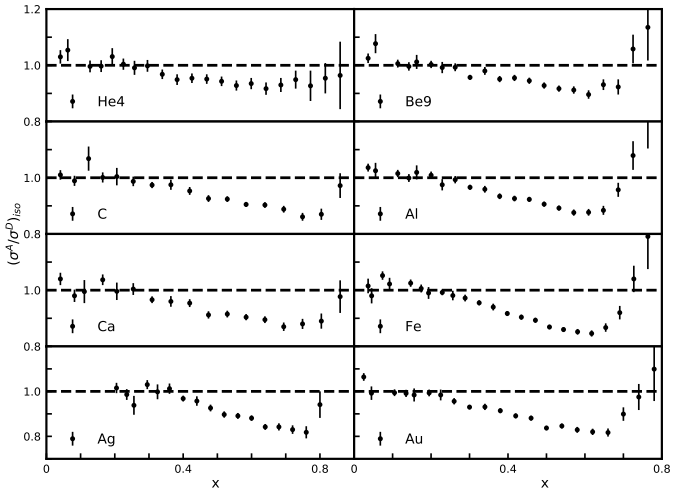
Reduction in cross section ratio:
$F_2^{Fe}/F_2^{D_2}$



EMC Effect

SLAC E139

- Systematic study light and heavy nuclei
  - A dependence
  - Q^2 dependence
  - Density dependence

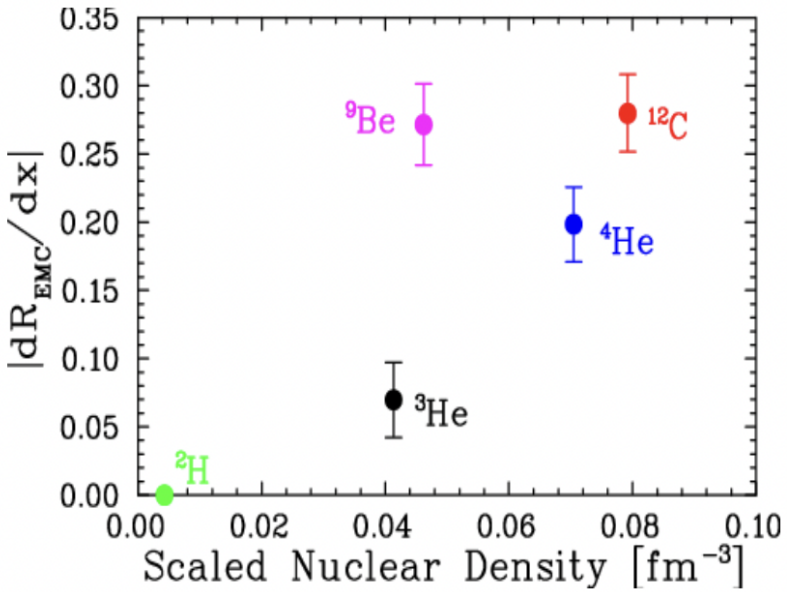


J. Gomez *et al.*, Phys. Rev. D49 (1994)

EMC Effect

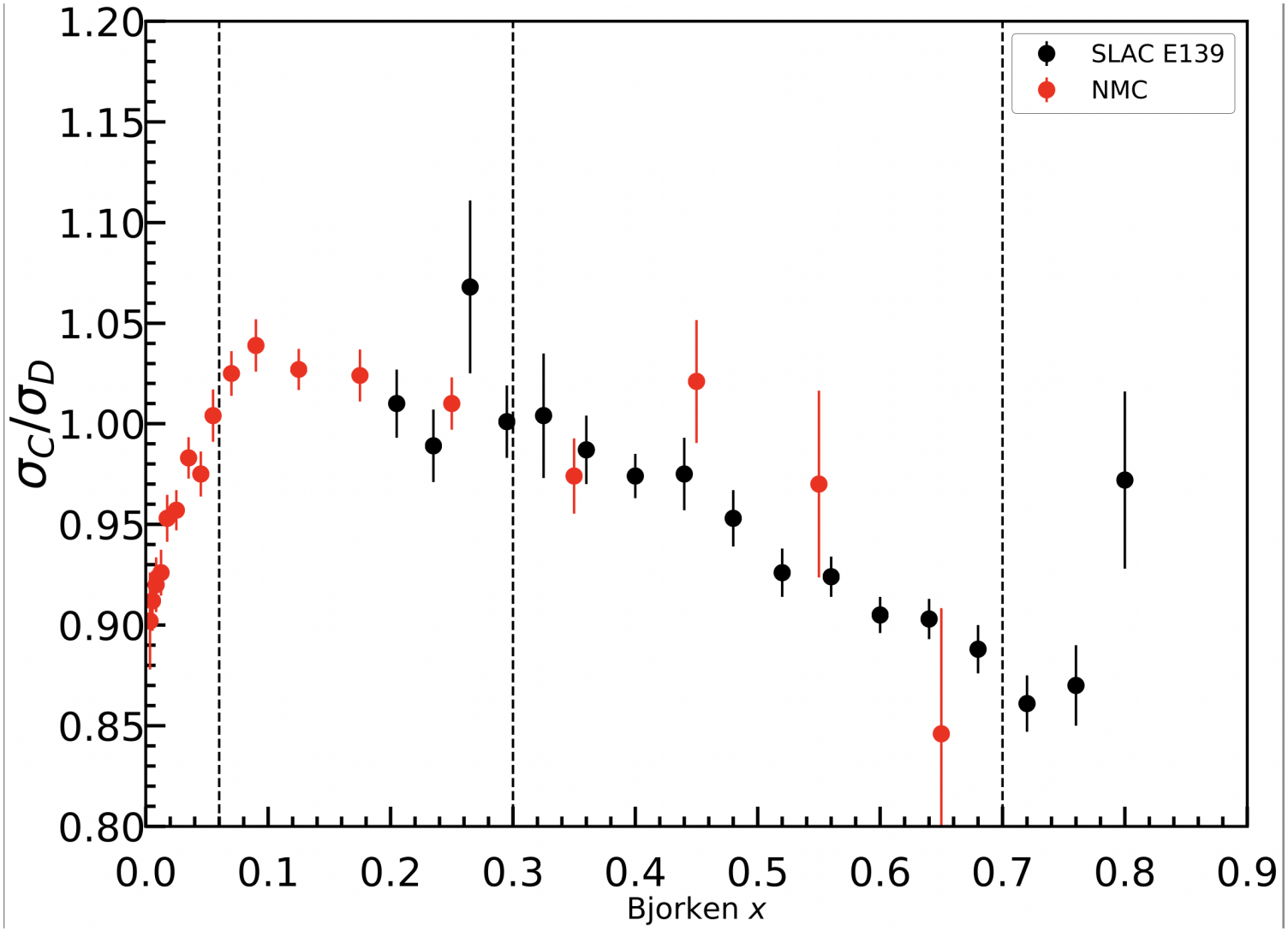
JLab: E03-103

- Precision measurement of light nuclei
- ^{9}Be does not follow the scaled nuclear density trend
- Local density rather than average density effect?

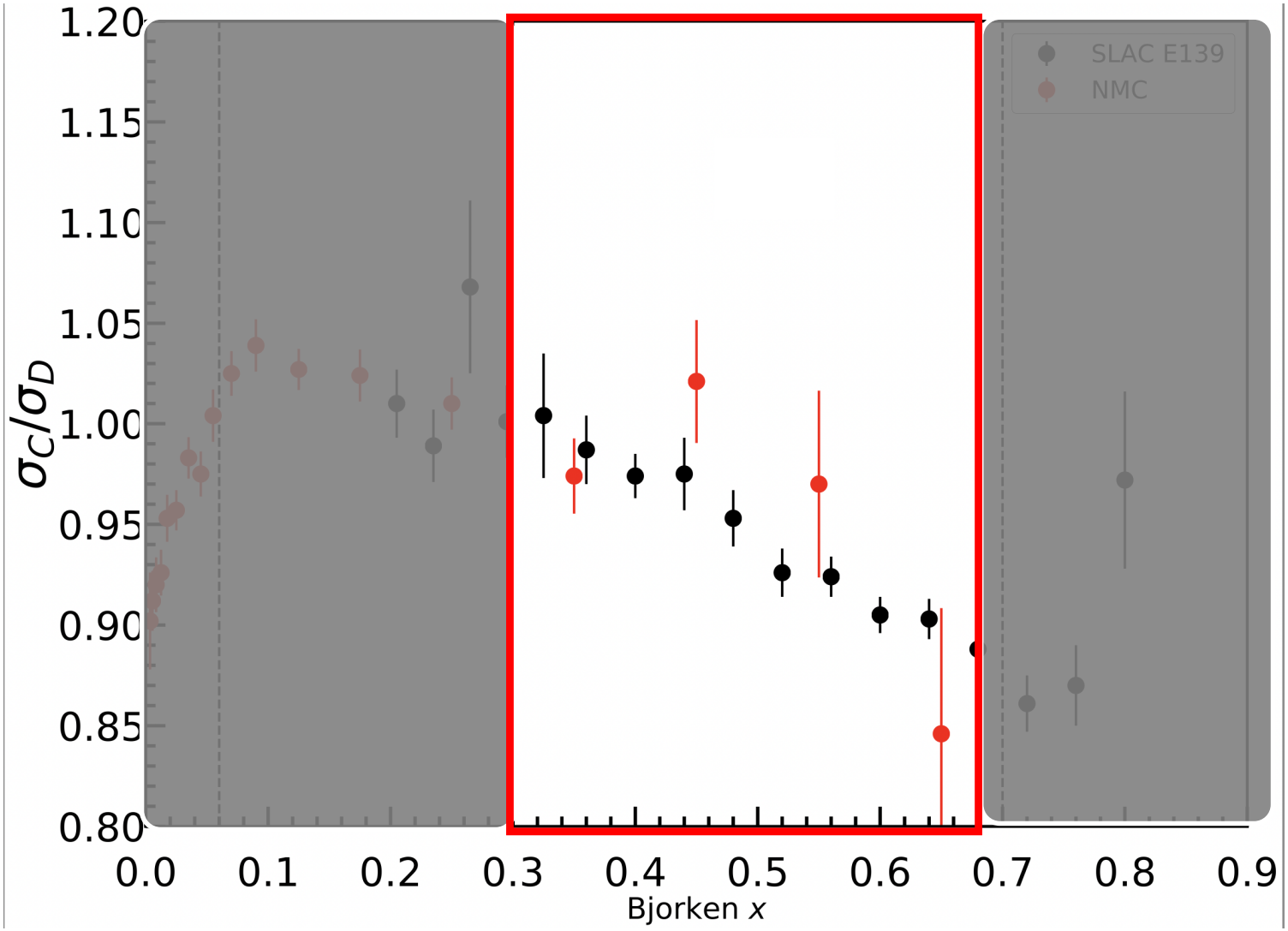


J. Seely *et al.*, Phys. Rev. Lett. 103, (2009)

EMC Effect


SLAC E139
NMC
σ_C/σ_D
Bjorken x
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

EMC Effect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0.5
0.6
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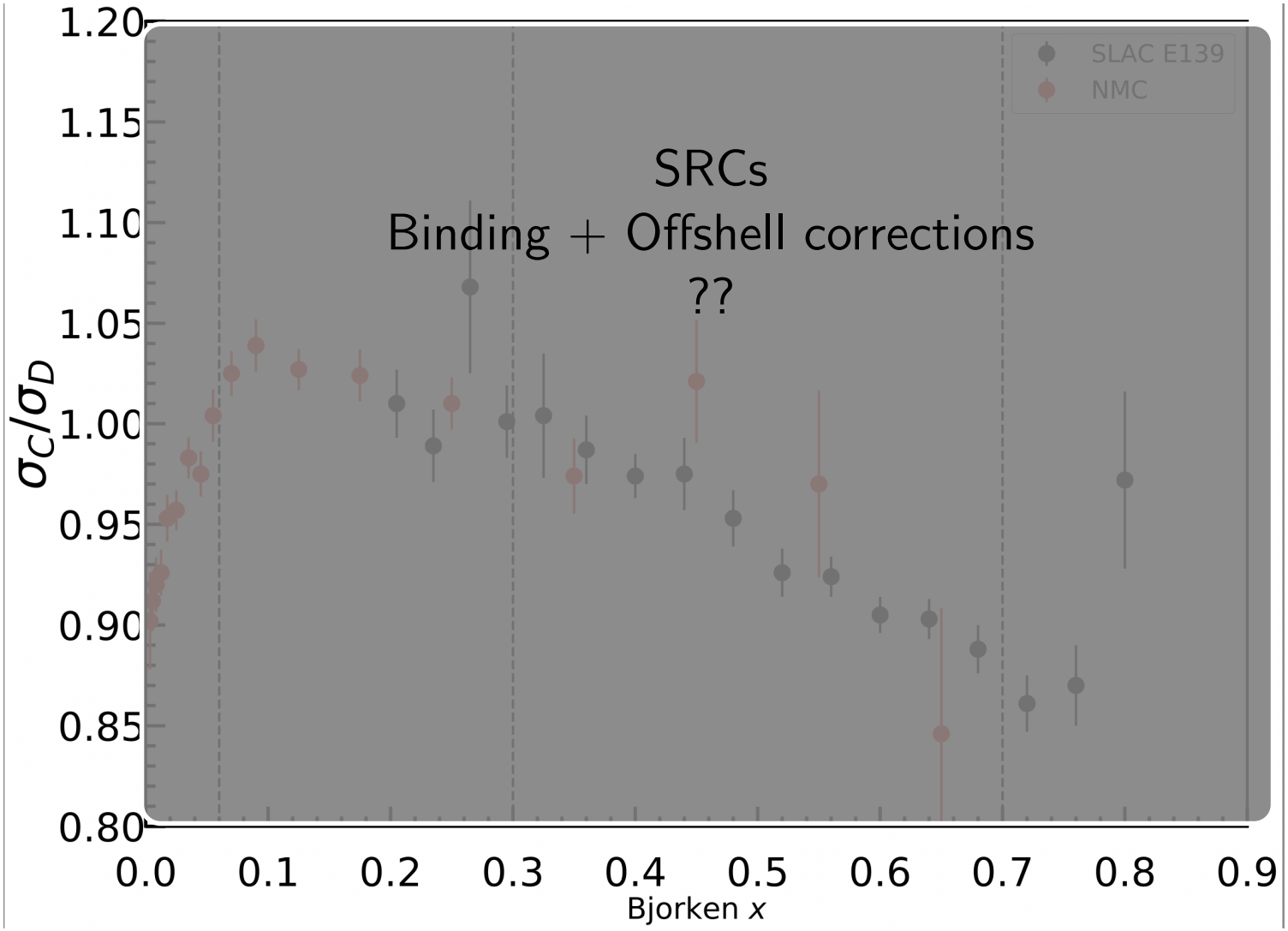
Bjorken x

EMC Effect


SLAC E139
NMC
SRCs
Binding + Offshell corrections
??
σ_C/σ_D
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.0
0.1
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0.5
0.6
0.7
0.8
0.9
Bjorken x

Marathon

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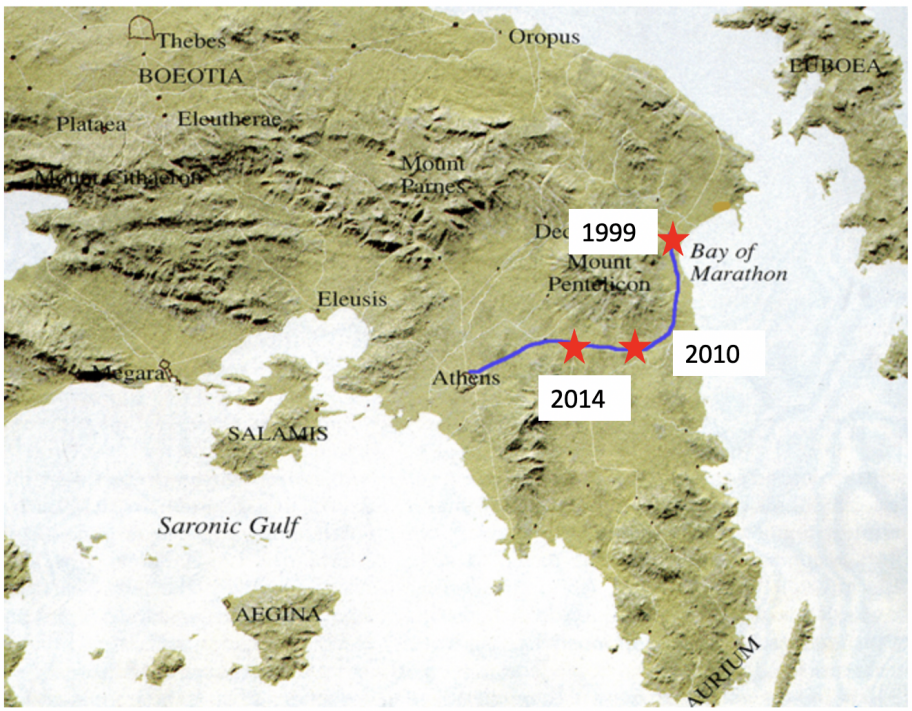

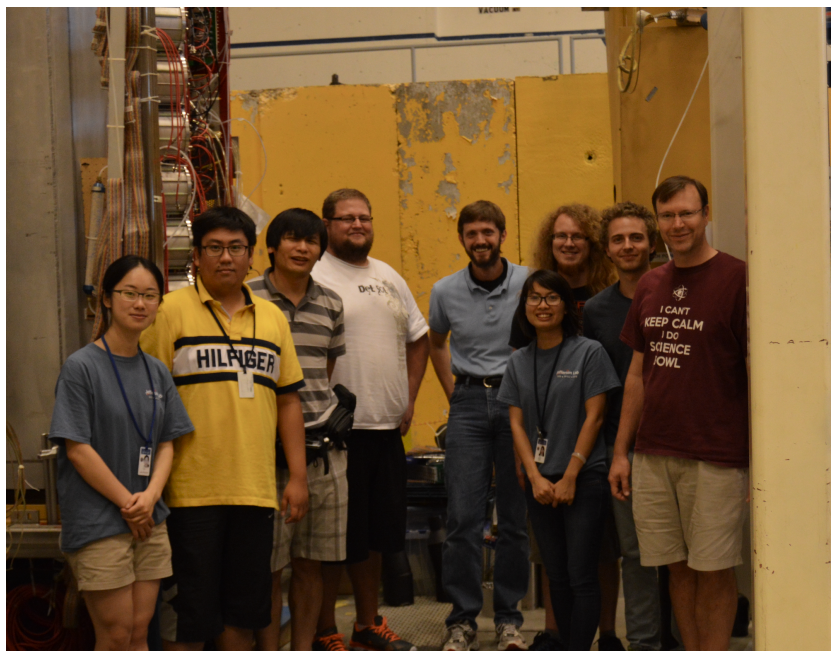

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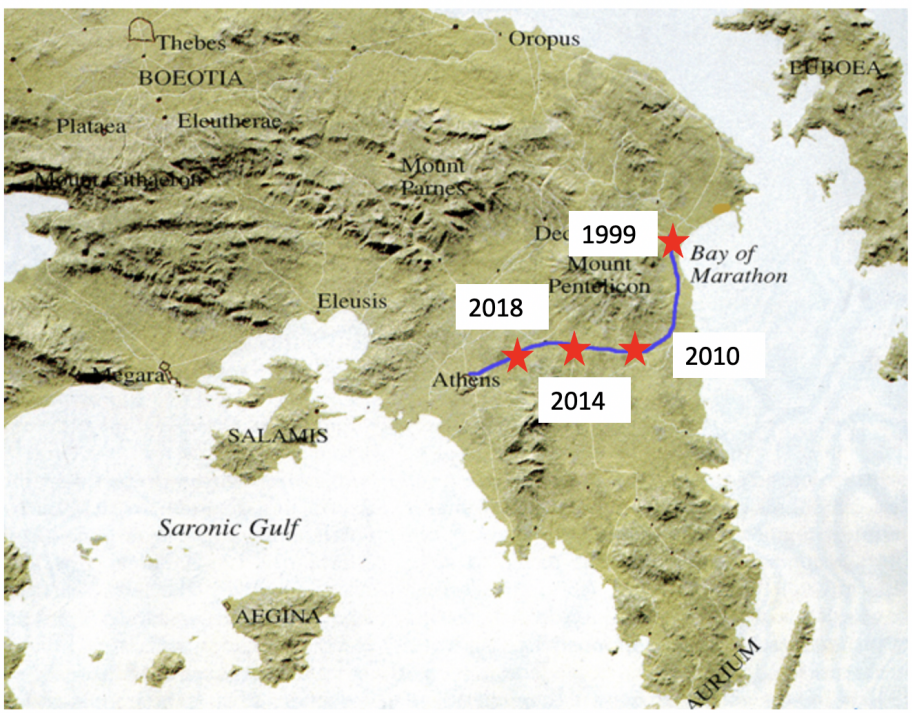


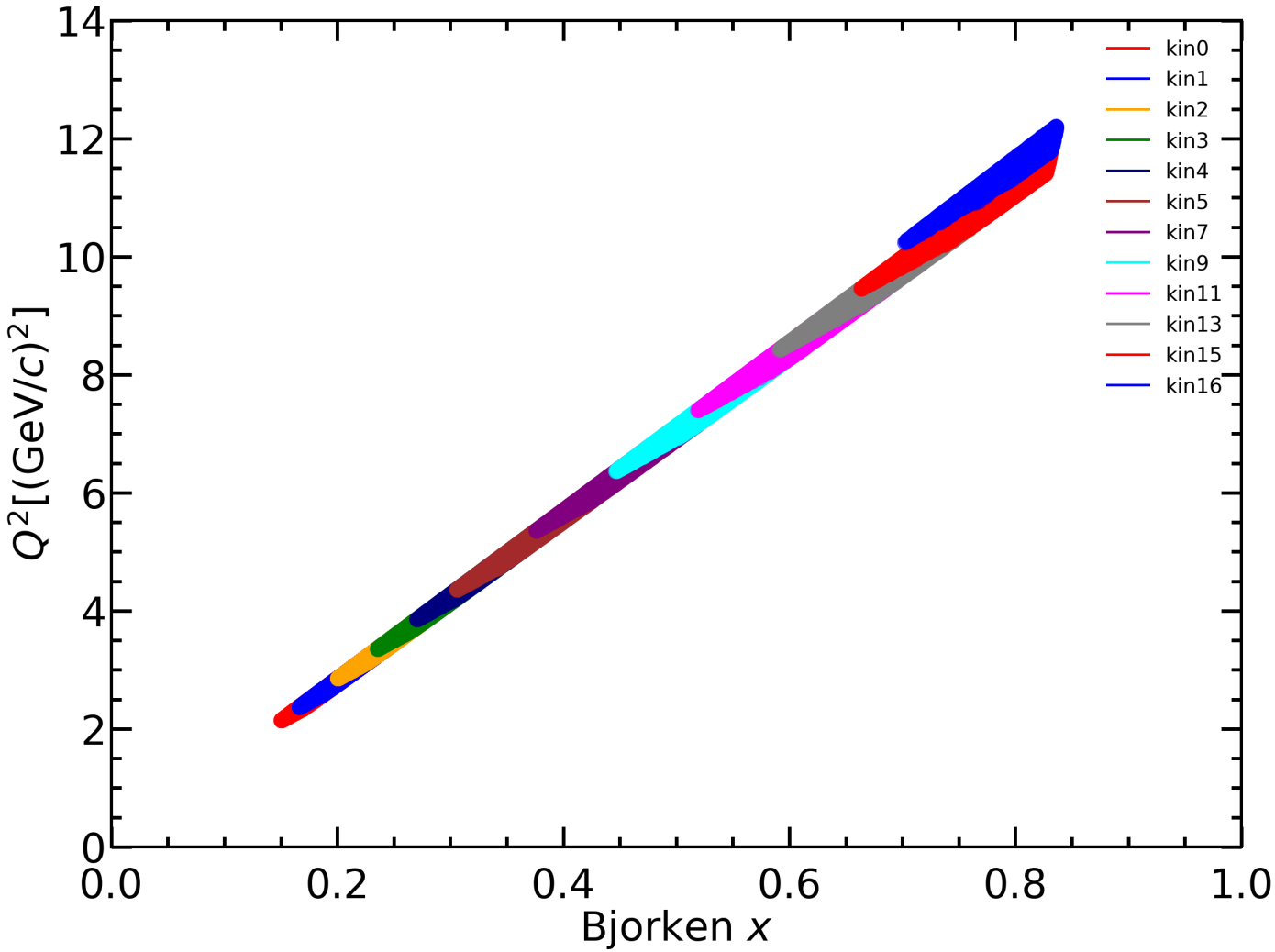
First Tritium target in 30 years

MARATHON Experiment

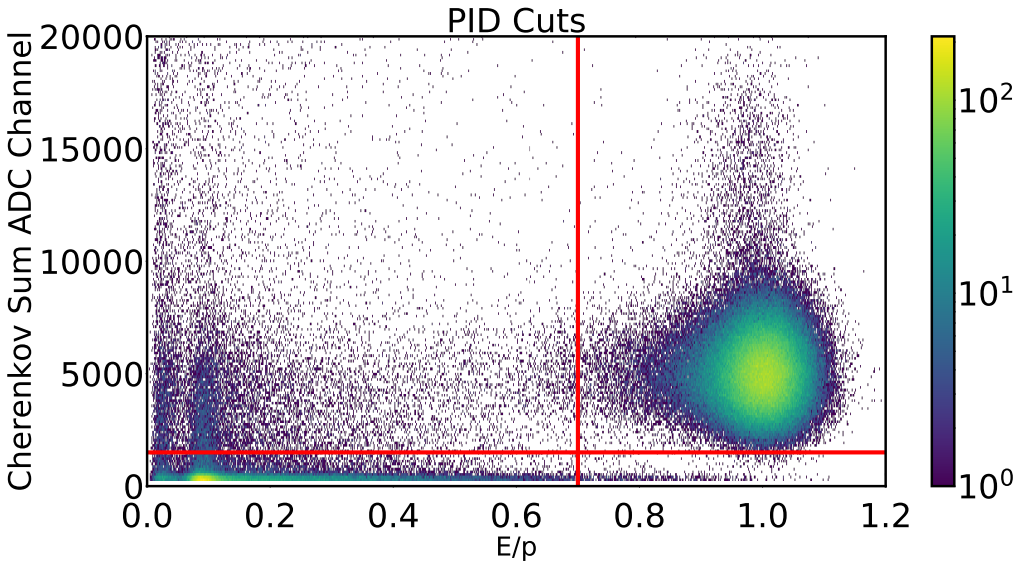
Data collection: Jan. - April 2018

1. ^{3}He, ^{3}**H**, ^{2}H, ^{1}H targets
2. LHRS and RHRS used to detect scattered electrons
3. Beam energy: 10.59 GeV
4. Beam Current: 25 μA

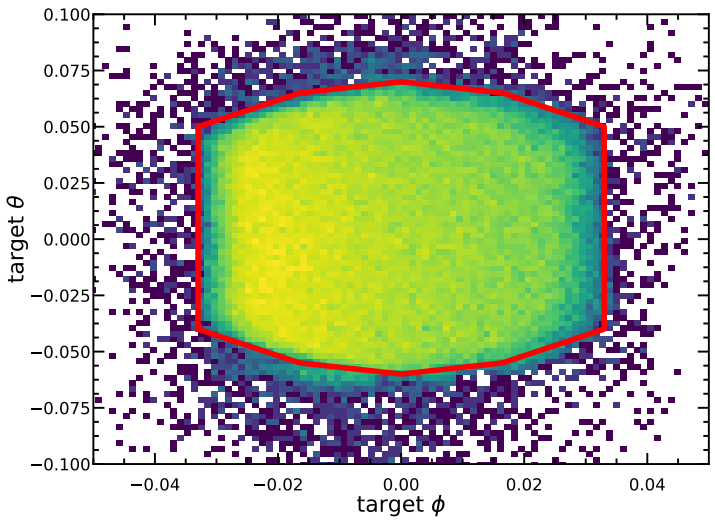
MARATHON Kinematic Coverage



Electron Identification



Particle ID

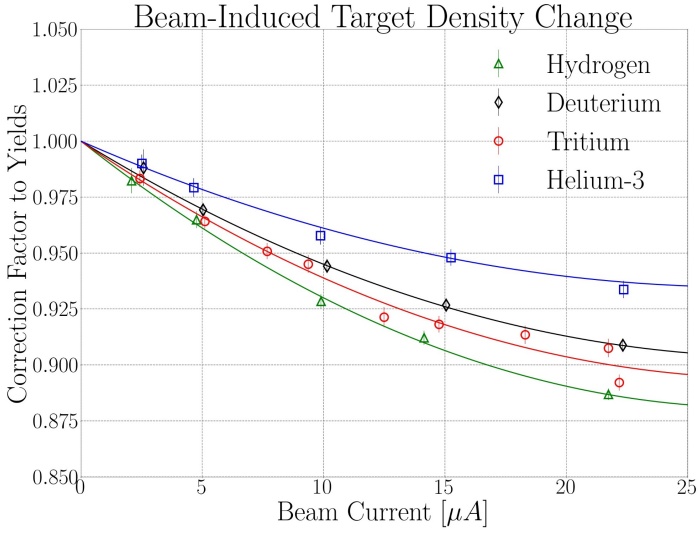


LHRS Acceptance

- W $\geq$1.8 GeV
- $Q^2 \geq 2.73\ (\mathrm{GeV}/c)^2$

Systematic Corrections

- Target density
- ^{3}H decay: Half life 4500 $\pm$ 8 days
  - $^3\mathrm{H} \rightarrow {}^3\mathrm{He} + \mathrm{e}^- + \bar{\nu}$
- Charge symmetric background
- Radiative Correction
- Coulomb Correction
- Target endcaps



Caption

Systematic Corrections

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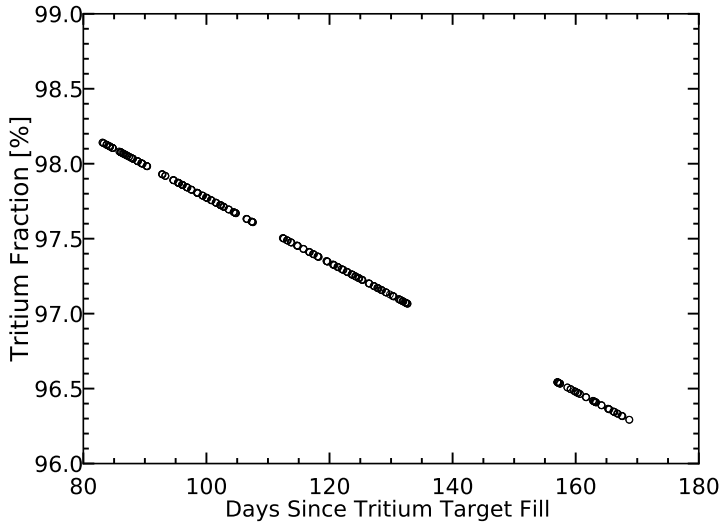

Caption

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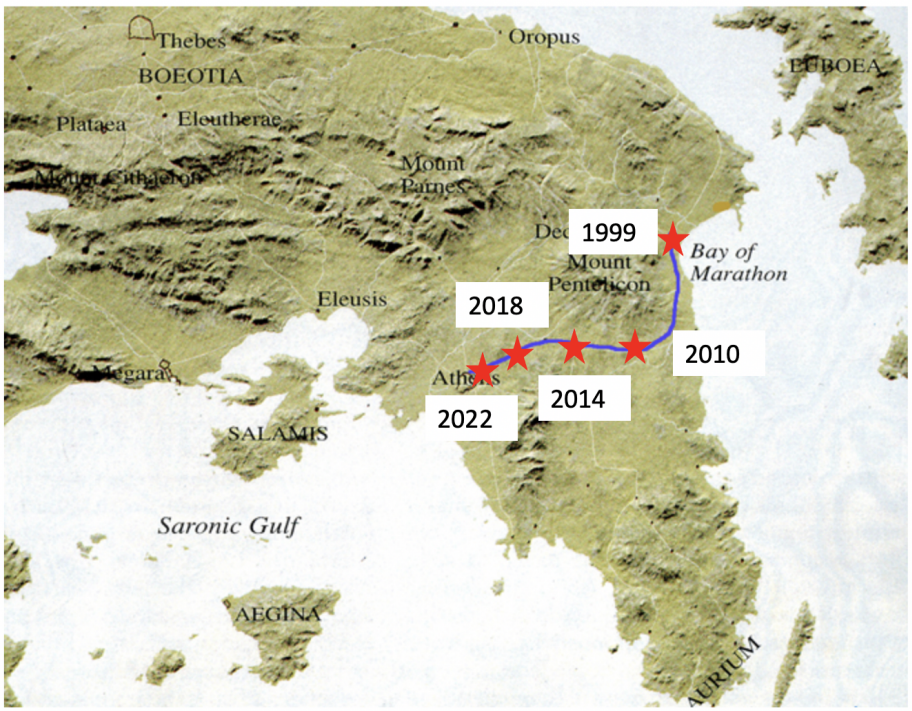


PHYSICAL REVIEW LETTERS **128,** 132003 (2022)

Measurement of the Nucleon F_2^n/F_2^p Structure Function Ratio by the Jefferson Lab MARATHON Tritium/Helium-3 Deep Inelastic Scattering Experiment

D. Abrams,[1] H. Albataineh,[2] B. S. Aljawrneh,[3] S. Alsalmi,[4,5] D. Androic,[6] K. Aniol,[7] W. Armstrong,[8] J. Arrington,[8,9] H. Atac,[10] T. Averett,[11] C. Ayerbe Gayoso,[11] X. Bai,[1] J. Bane,[12] S. Barcus,[11] A. Beck,[13] V. Bellini,[14] H. Bhatt,[15] D. Bhetuwal,[15] D. Biswas,[16] D. Blyth,[8] W. Boeglin,[17] D. Bulumulla,[18] J. Butler,[19] A. Camsonne,[19] M. Carmignotto,[19] J. Castellanos,[17] J.-P. Chen,[19] E. O. Cohen,[20] S. Covrig,[19] K. Craycraft,[11] R. Cruz-Torres,[13] B. Dongwi,[14] B. Duran,[10] D. Dutta,[15] E. Fuchey,[21] C. Gal,[1] T. N. Gautam,[16] S. Gilad,[13] K. Gnanvo,[1] T. Gogami,[22] J. Gomez,[19] C. Gu,[1] A. Habarakada,[16] T. Hague,[4] J.-O. Hansen,[19] M. Hattawy,[8] F. Hauenstein,[18] D. W. Higinbotham,[19] R. J. Holt,[8,*] E. W. Hughes,[23] C. Hyde,[18] H. Ibrahim,[24] S. Jian,[1] S. Joosten,[10] A. Karki,[15] B. Karki,[25] A. T. Katramatou,[4] C. Keith,[19] C. Keppel,[19] M. Khachatryan,[18] V. Khachatryan,[26] A. Khanal,[17] A. Kievsky,[27] D. King,[28] P. M. King,[25] I. Korover,[29] S. A. Kulagin,[30] K. S. Kumar,[26] T. Kutz,[26] N. Lashley-Colthirst,[16] S. Li,[31] W. Li,[32] H. Liu,[23] S. Liuti,[1] N. Liyanage,[1] P. Markowitz,[17] R. E. McClellan,[19] D. Meekins,[19] S. Mey-Tal Beck,[13] Z.-E. Meziani,[10] R. Michaels,[19] M. Mihovilovic,[33,34,35] V. Nelyubin,[1] D. Nguyen,[1] Nuruzzaman,[36] M. Nycz,[4] R. Obrecht,[21] M. Olson,[37] V. F. Owen,[11] E. Pace,[38] B. Pandey,[16] V. Pandey,[39] M. Paolone,[10] A. Papadopoulou,[13] S. Park,[26] S. Paul,[11] G. G. Petratos,[4] R. Petti,[40] E. Piasetzky,[20] R. Pomatsalyuk,[41] S. Premathilake,[1] A. J. R. Puckett,[21] V. Punjabi,[42] R. D. Ransome,[36] M. N. H. Rashad,[18] P. E. Reimer,[8] S. Riordan,[8] J. Roche,[25] G. Salmè,[43] N. Santiesteban,[31] B. Sawatzky,[19] S. Scopetta,[44] A. Schmidt,[13] B. Schmookler,[13] J. Segal,[19] E. P. Segarra,[13] A. Shahinyan,[45] S. Širca,[33,34] N. Sparveris,[10] T. Su,[4,46] R. Suleiman,[19] H. Szumila-Vance,[19] A. S. Tadepalli,[36] L. Tang,[16,19] W. Tireman,[47] F. Tortorici,[14] G. M. Urciuoli,[43] B. Wojtsekhowski,[19] S. Wood,[19] Z. H. Ye,[8,†] Z. Y. Ye,[48] and J. Zhang[26]

(Jefferson Lab Hall A Tritium Collaboration)

F_n^2/F_p^2 Extraction

EMC-type ratios

$$R(^3\mathrm{He}) = \frac{F_{^3\mathrm{He}}^2}{2F_p^2 + F_n^2} \qquad R(^3\mathrm{H}) = \frac{F_{^3\mathrm{H}}^2}{F_p^2 + 2F_n^2}$$

$$R^* = \frac{R(^3\mathrm{He})}{R(^3\mathrm{H})}$$

From the ratio of experimental cross sections

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

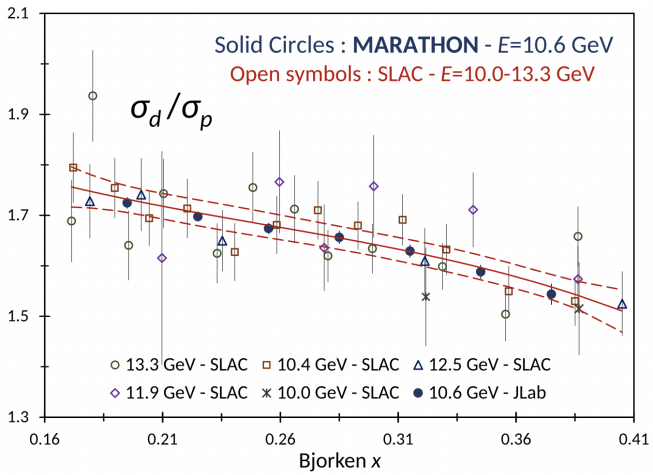
where $2R^*$ is from a reliable theoretical model $\Rightarrow$ Kulagin and Petti

F_2^n/F_n^p Results

- σ_d/σ_p data at low x

F_2^n/F_n^p Results

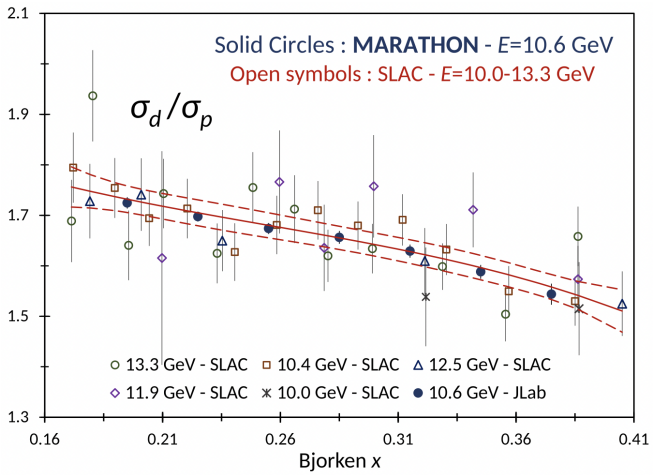
- σ_d/σ_p data at low x



D. Abrams *et al.* Phys. Rev. Lett. 128 (2022)

F_2^n/F_n^p Results

- σ_d/σ_p data at low x
- F_2^n/F_2^p
  - Extracted from Marathon data
  - σ_d/σ_p and σ_h/σ_t
- F_2^n/F_2^p at x=0.31
  - Used for normalization
  - Nuclear corrections expected to contribute negligibly
  - $\sigma_h/\ \sigma_t$ normalized by 1.025



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F_2^n/F_n^p Results

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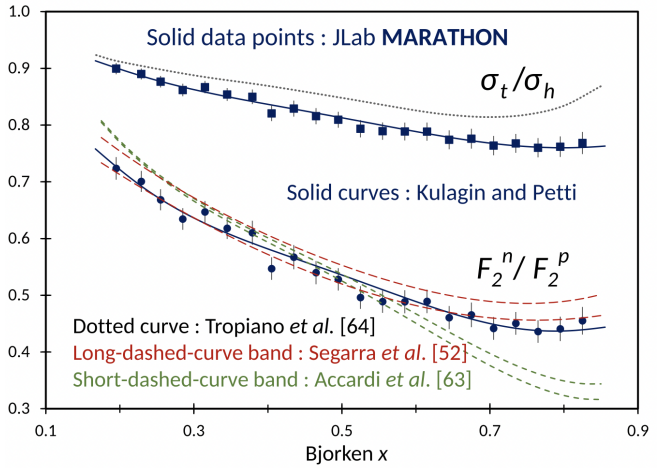

D. Abrams *et al.* Phys. Rev. Lett. 128 (2022)

EMC Effect Results

- $^3He/^2H$ ratio normalized by 1.021
- $^3H/^2H$ ratio normalized by 0.996
- Isoscalar Correction
  - $Z \neq A$
  - Correction depends on F_2^n/F_2^p

$$f_{iso} = \frac{\frac{1}{2}(1 + \frac{F_2^n}{F_2^p})}{\frac{1}{A}(Z + (A - Z)\frac{F_2^n}{F_2^p})}$$

EMC Effect Results

- $^3He/^2H$ ratio normalized by 1.021
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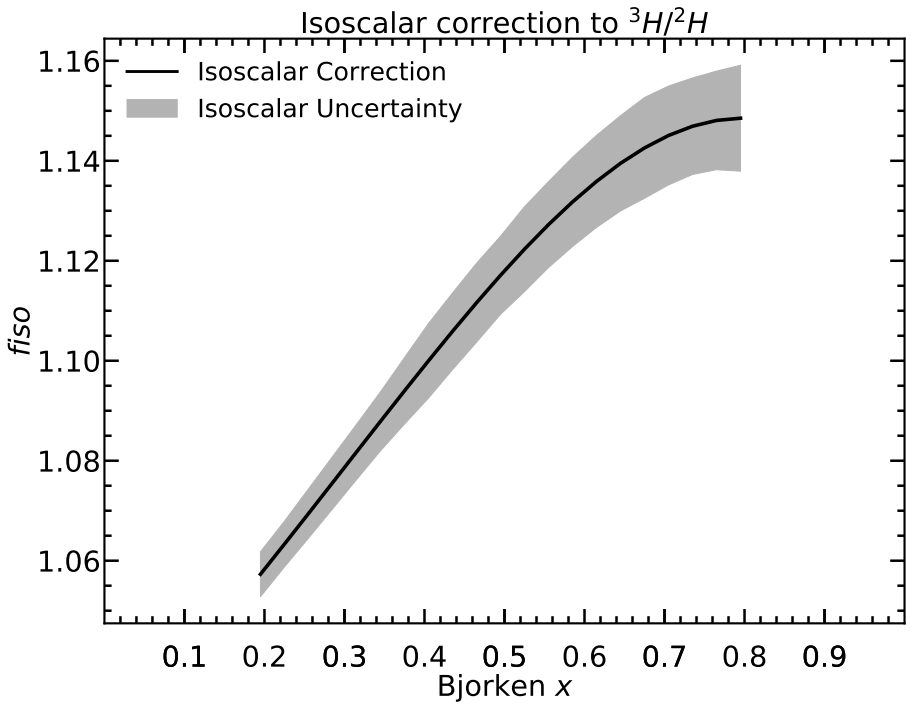
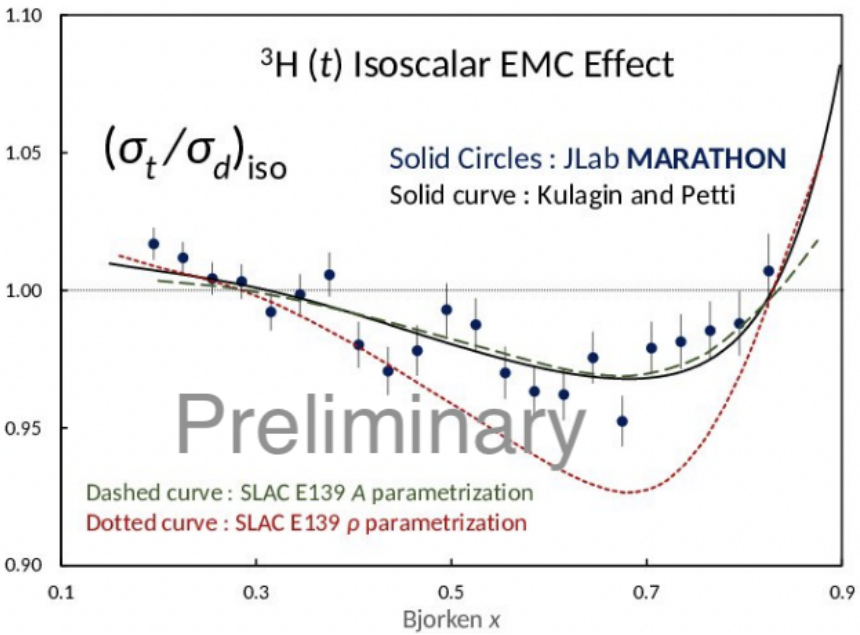
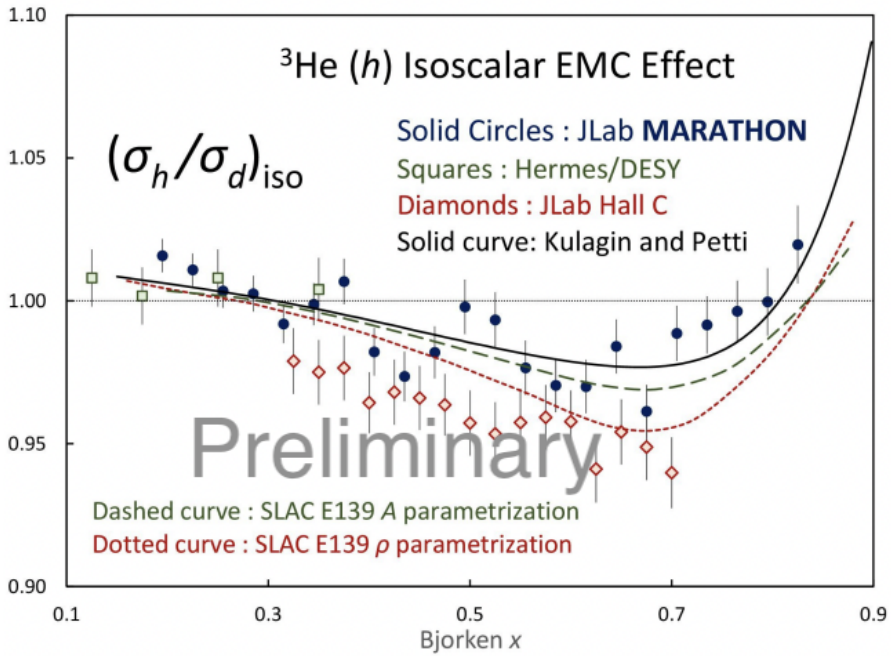


Tritium isoscalar correction

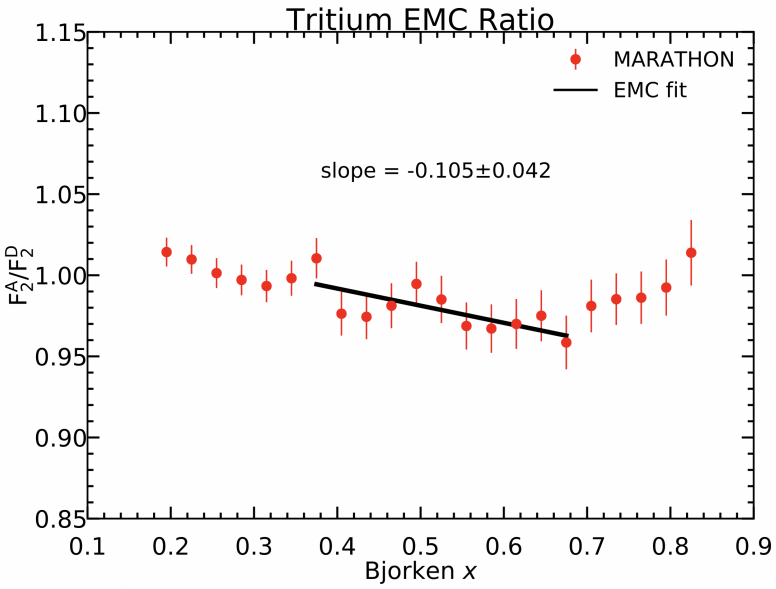
EMC Effect

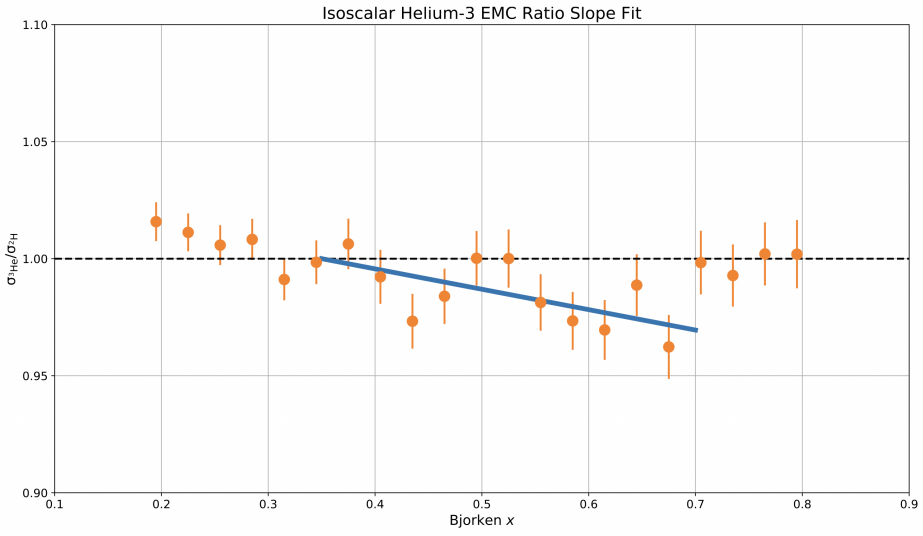




- Marathon ^{3}He EMC effect normalized by a factor of 1.021
- Draft publication being prepared

EMC Effect: Slope





Normalization will not effect on the magnitude of EMC slopes

Summary and Outlook

- Marathon publication on F_2^n/F_2^p
  - D. Abrams et al. Phys. Rev. Lett. 128 (2022)
- Draft of ^{3}H and ^{3}He EMC results currently being circulated
  - Anticipate submitting for publication soon (months timescale)
- Thank you to the Hall A staff, technicians, and users for supporting the experiment