The EMC Effect of Tritium and Helium-3 from the JLab MARATHON Experiment

Michael Nycz

On behalf of the MARATHON Collaboration

University of Virginia

JLUO Annual Meeting, Jefferson Lab

June 25, 2026

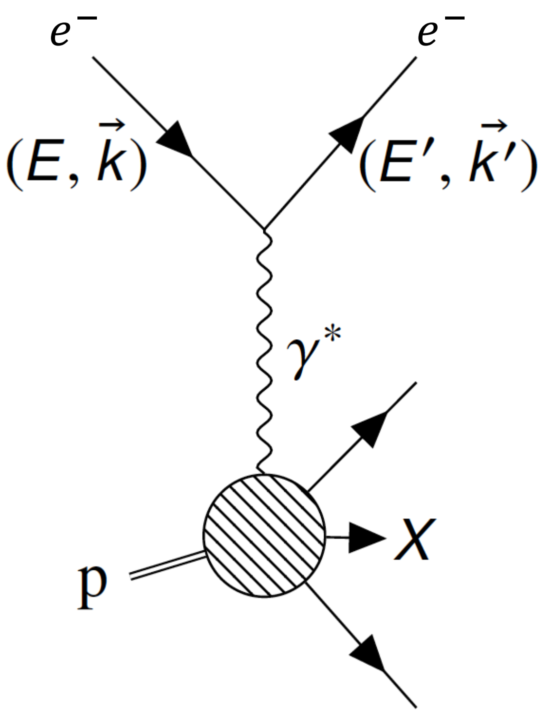
Outline

- Deep Inelastic Scattering and the EMC effect
- MARATHON Experiment and A=3 mirror nuclei
- MARATHON EMC Results
- Summary and Outlook

More details found in

D. Abrams et al., Phys. Rev. Lett. 135 (2025)

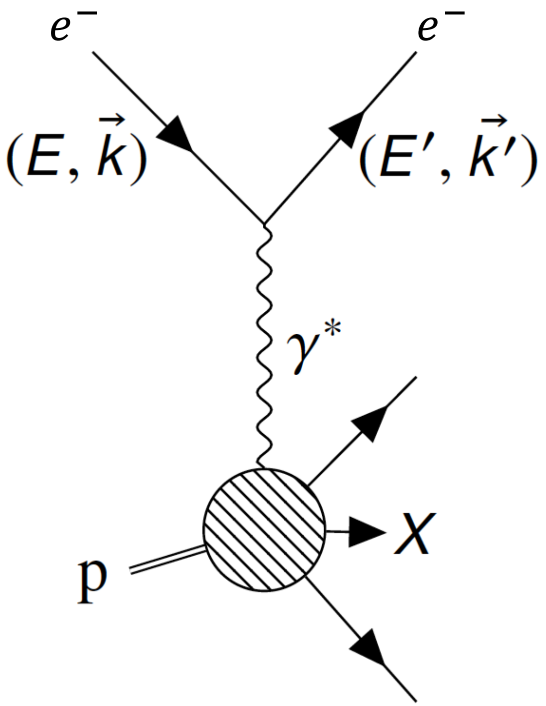
Deep Inelastic Scattering



$$\frac{d^2\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'}{Q^4}\left[\frac{2F_1(x)}{M}\sin^2\left(\frac{\theta}{2}\right) + \frac{F_2(x)}{\nu}\cos^2\left(\frac{\theta}{2}\right)\right]$$

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

Deep Inelastic Scattering



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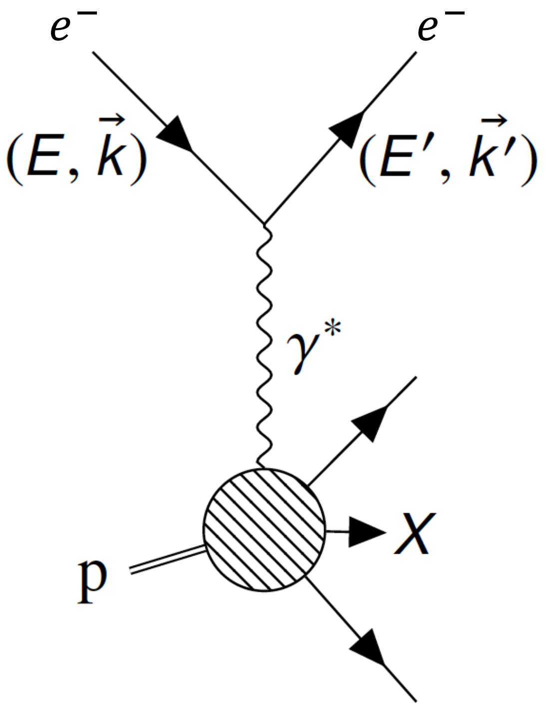
$$F_1 = \frac{1}{2}\sum_i e_i^2 q_i(x) \qquad F_2 = x\sum_i e_i^2 q_i(x)$$

Absorption cross section of **longitudinal** or **transverse** photons

$$R = \frac{\sigma_l}{\sigma_t} \qquad F_1 = \frac{MF_2(\nu^2 + Q^2)}{Q^2\nu(1 + R)}$$

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

Deep Inelastic Scattering



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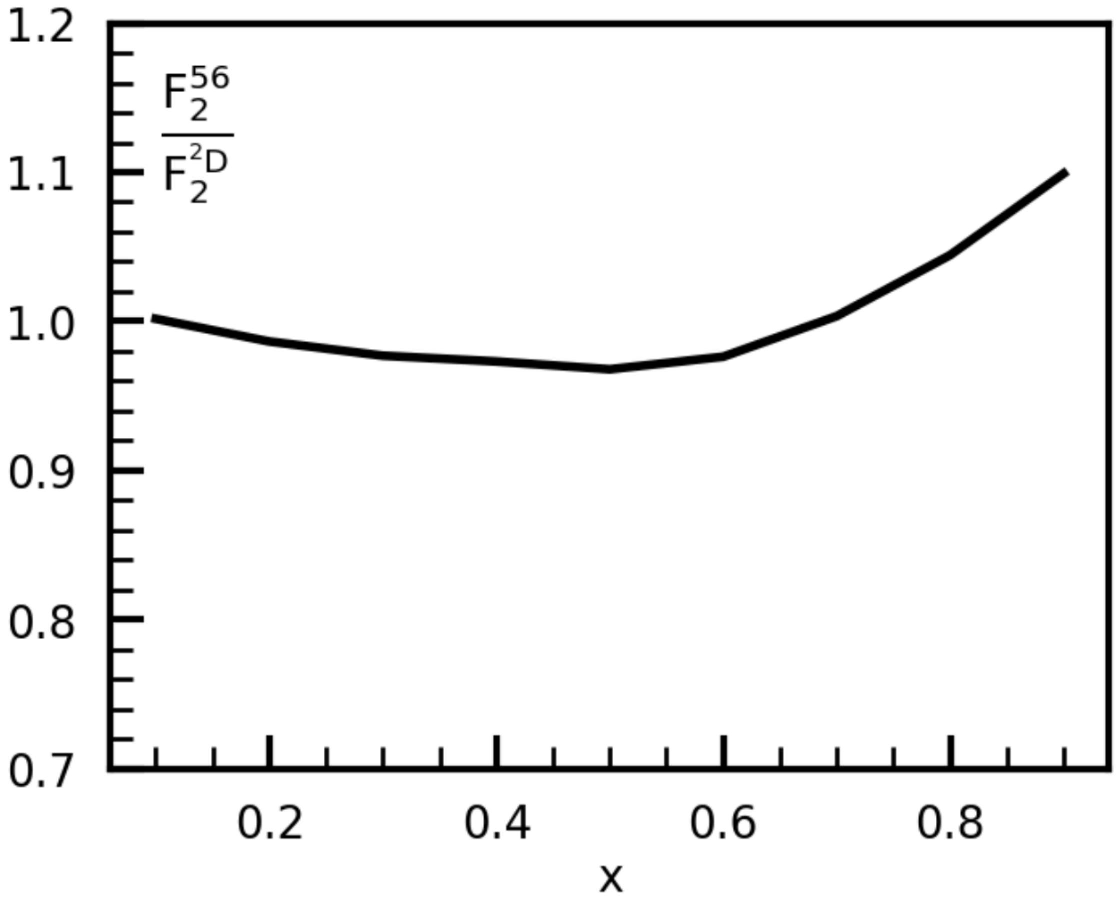
Ratio of structure functions

$$\frac{\sigma_{A1}}{\sigma_{A2}} = \frac{F_2^{A1}}{F_2^{A2}}$$

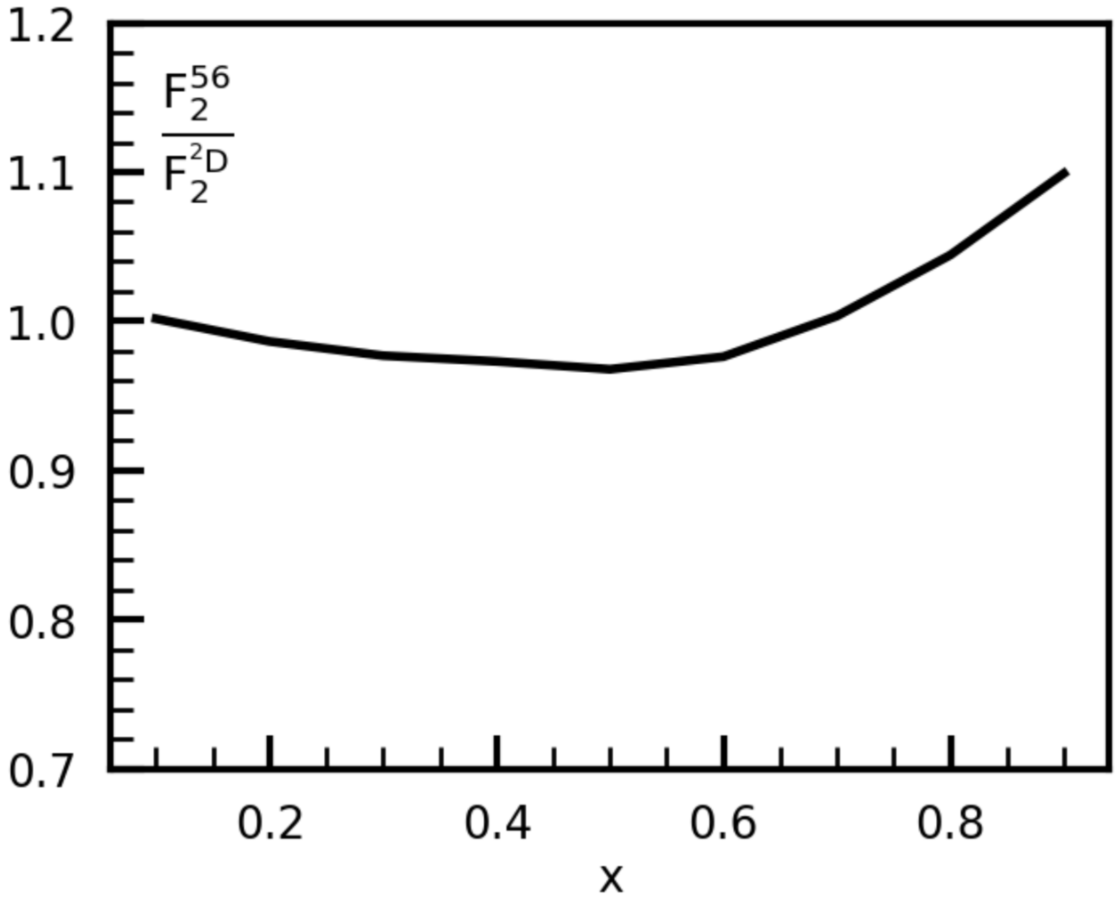
Expectation from Scaling and Nucleon Fermi Motion

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

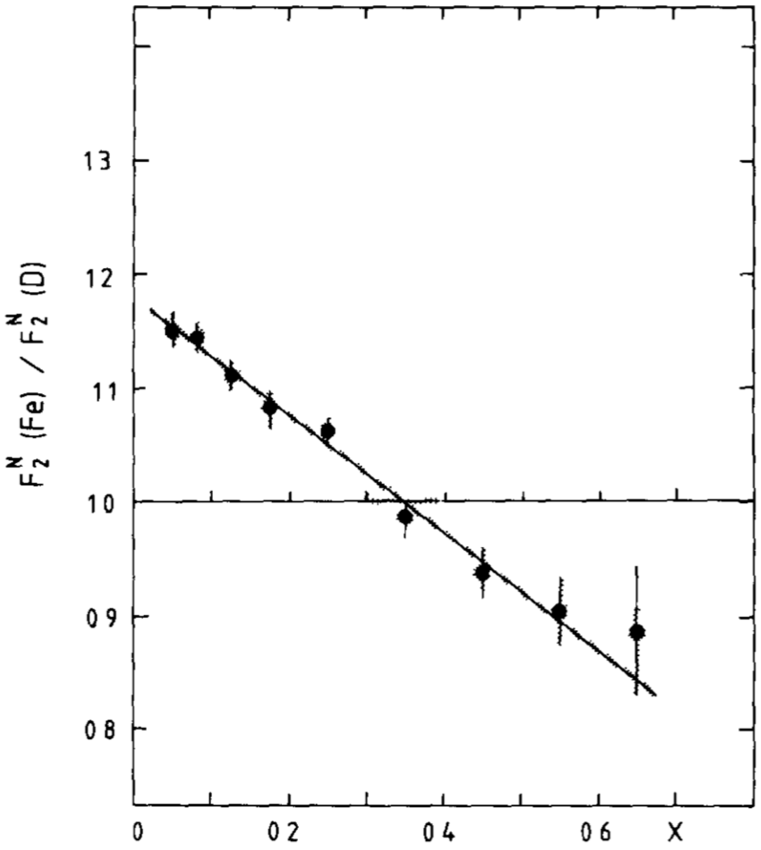


EMC Effect

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

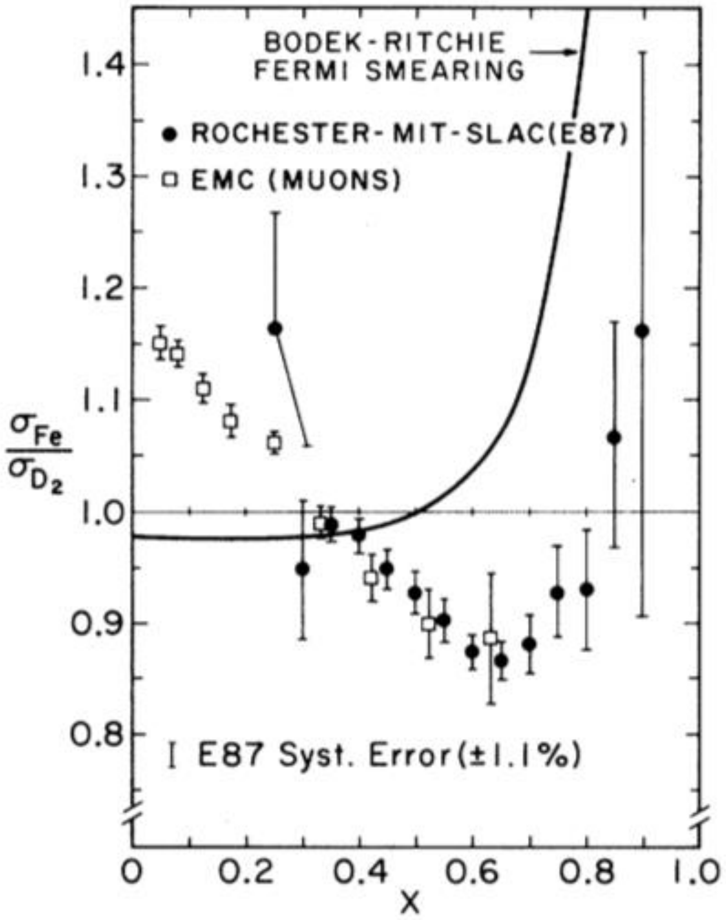


quark momentum distributions in nuclei are not simply the sum of free proton and neutron distributions



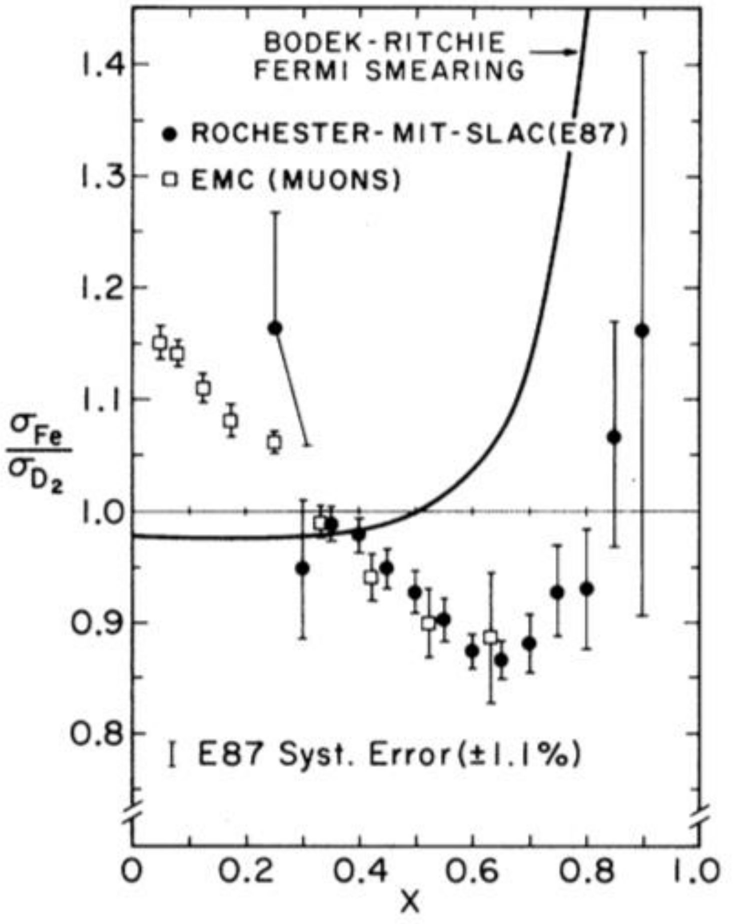
J. J. Aubert et al., Phys. Lett. B 123, 275 (1983)

EMC Effect: Confirmation



A. Bodek et al., Phys. Rev. Lett. 50, 1431 (1983

EMC Effect



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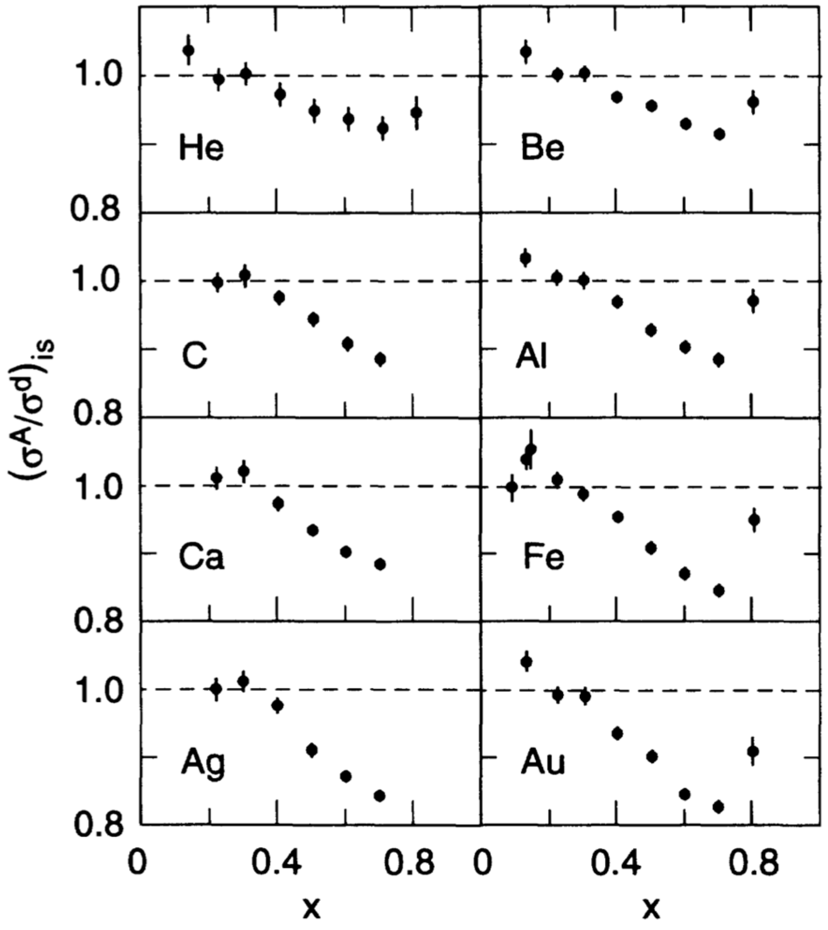
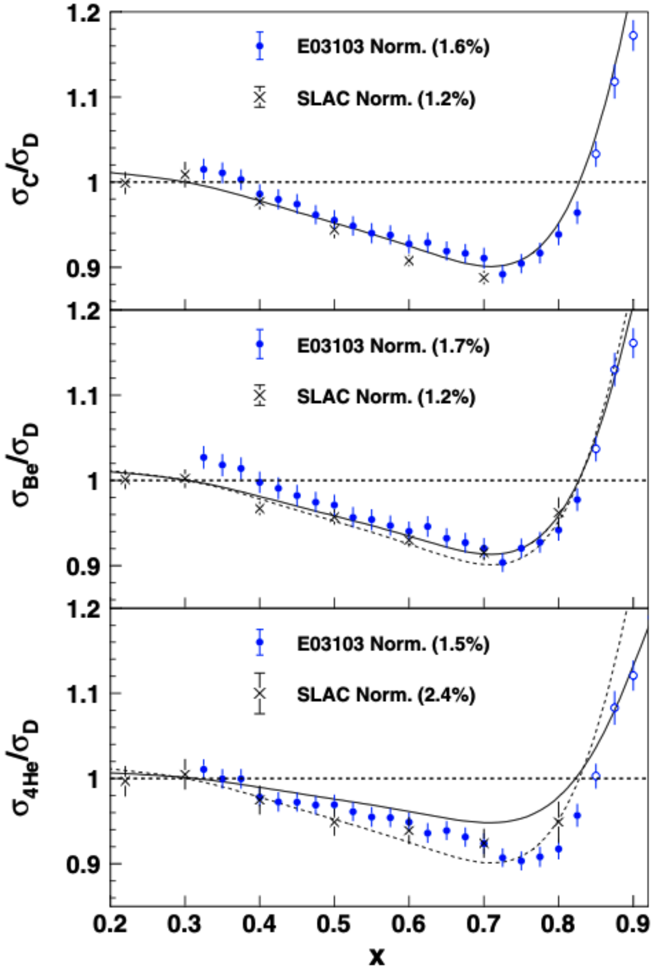
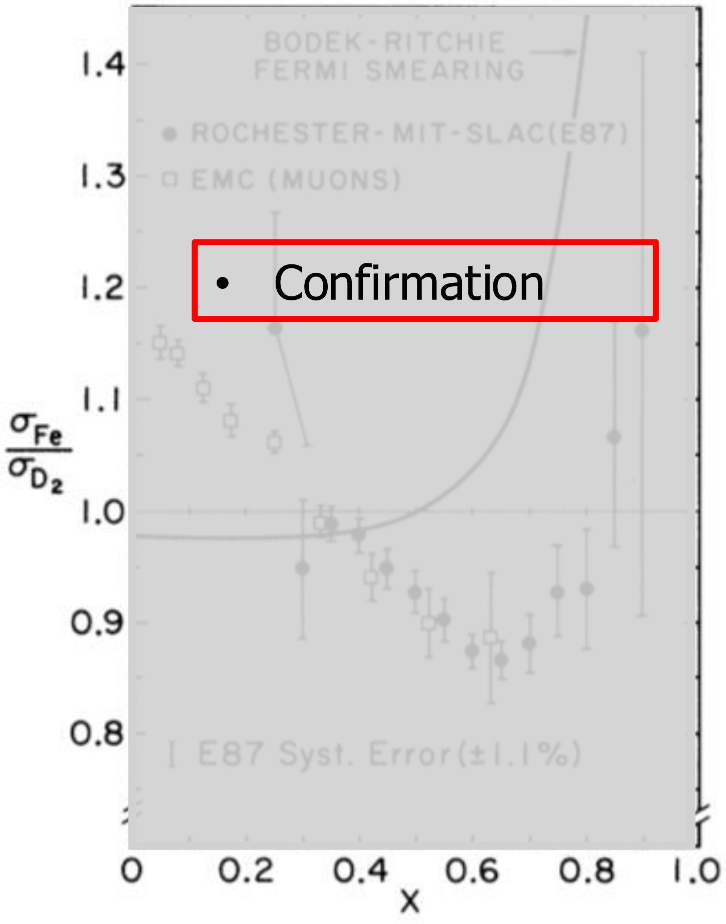


J. Gomez et al., Phys. Rev. D49 (1994)



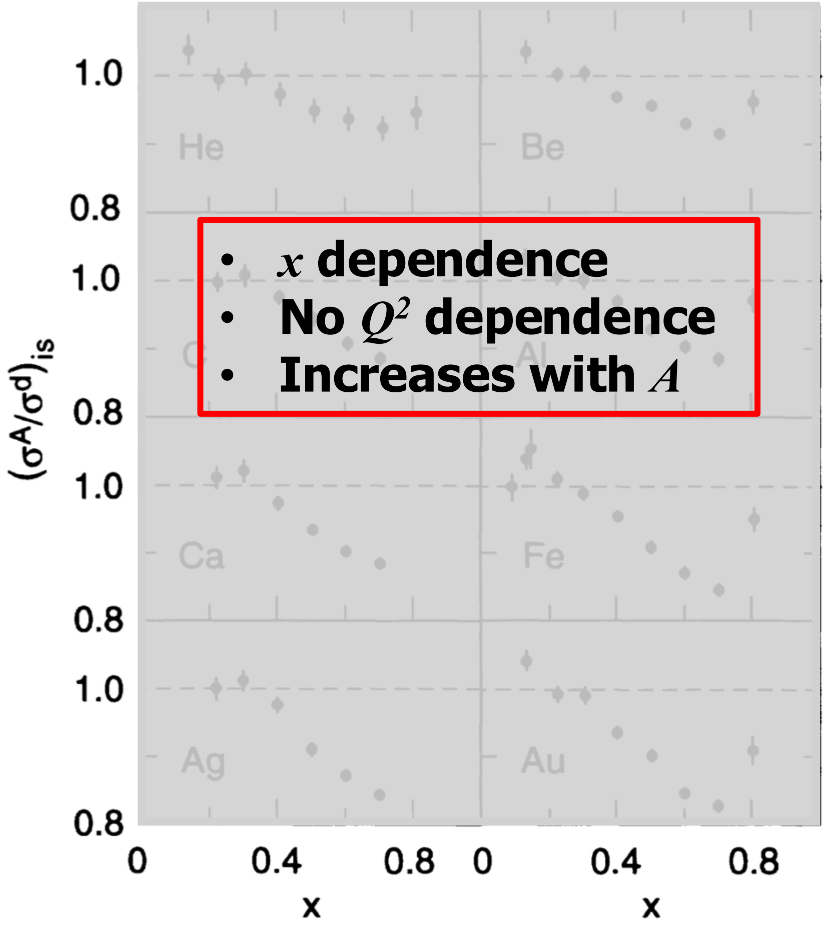
J. Seely et al., Phys. Rev. Lett. 103, (2009

EMC Effect



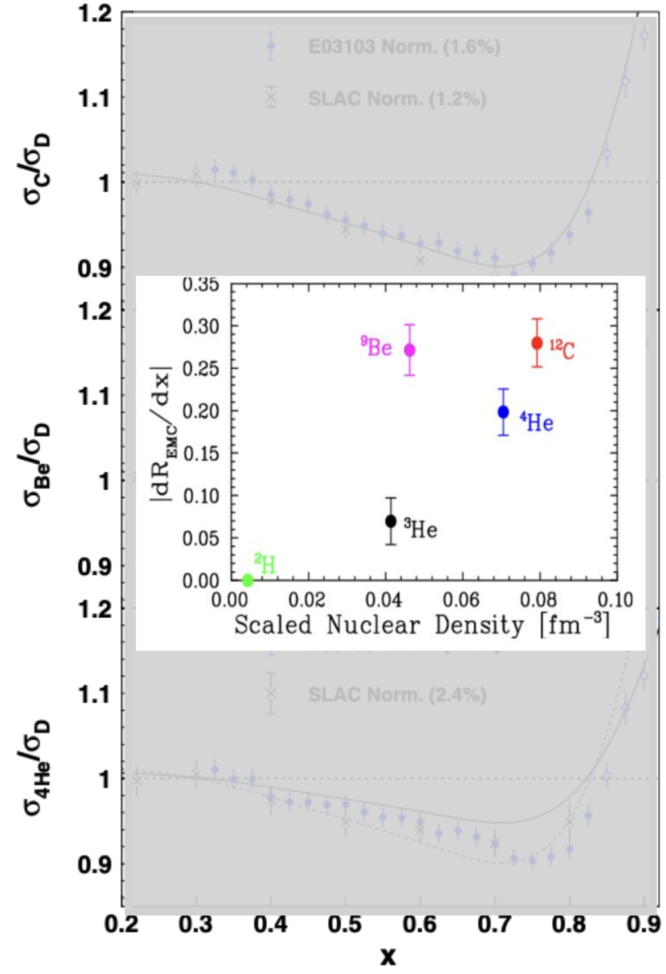
- Confirmation

[A. Bodek et al., Phys. Rev. Lett. 50, 1431 (1983](#)



- x **dependence**
- **No** Q^2 **dependence**
- **Increases with** A

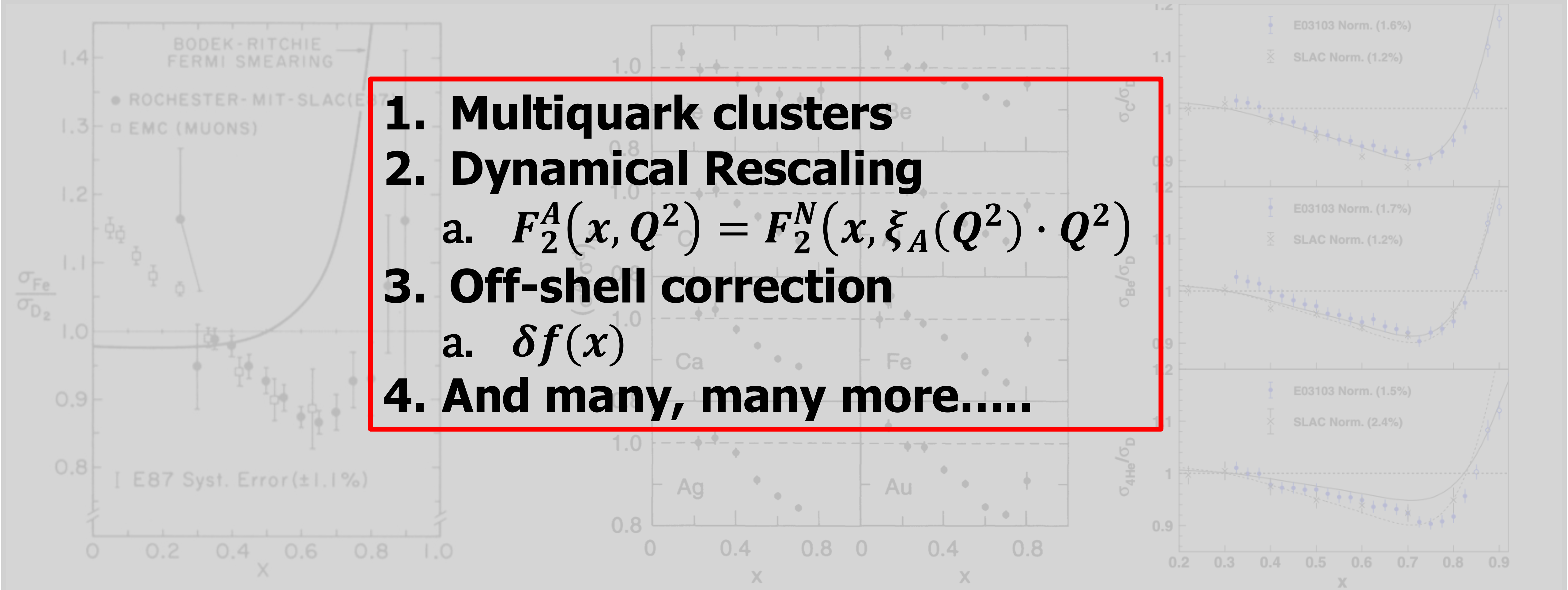
[J. Gomez et al., Phys. Rev. D49 (1994)](#)



[J. Seely et al., Phys. Rev. Lett. 103, (2009](#)

EMC Effect: Models and Predictions

1. **Multiquark clusters**
2. **Dynamical Rescaling**
   a. $F_2^A(x, Q^2) = F_2^N(x, \xi_A(Q^2) \cdot Q^2)$
3. **Off-shell correction**
   a. $\delta f(x)$
4. **And many, many more.....**

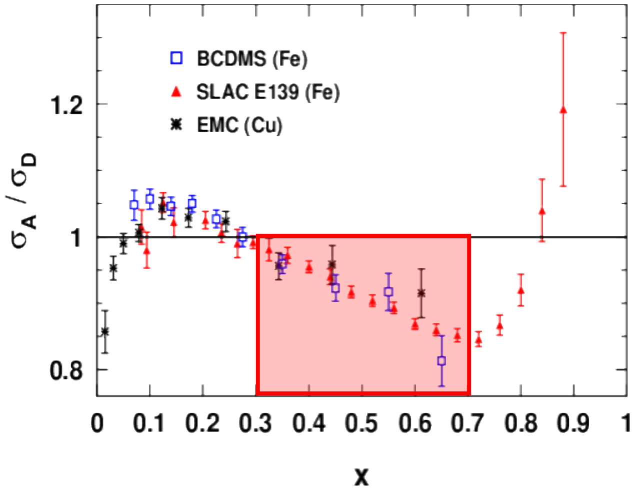


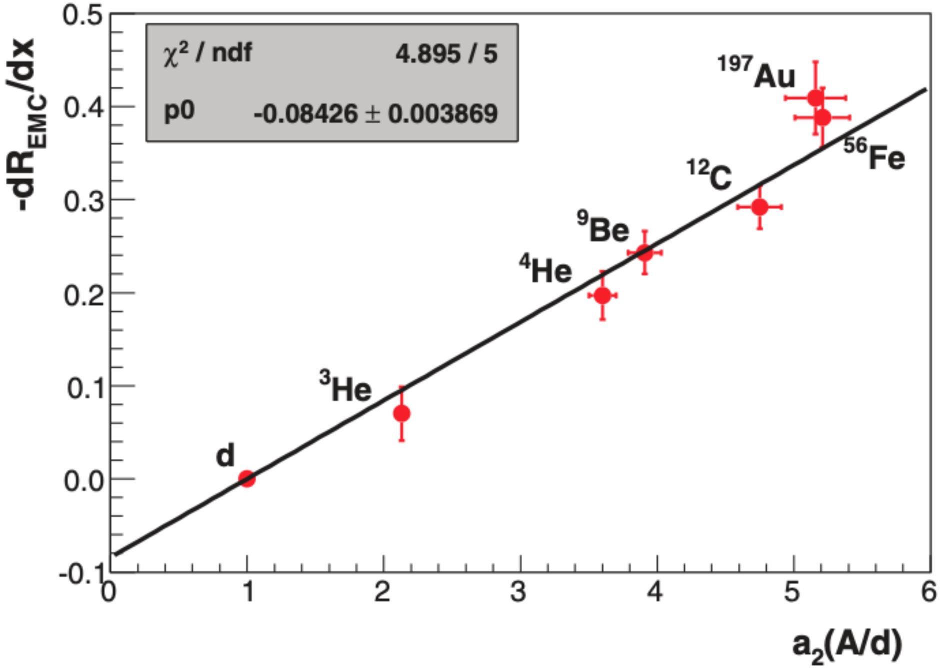
A. Bodek et al., Phys. Rev. Lett. 50, 1431 (1983

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

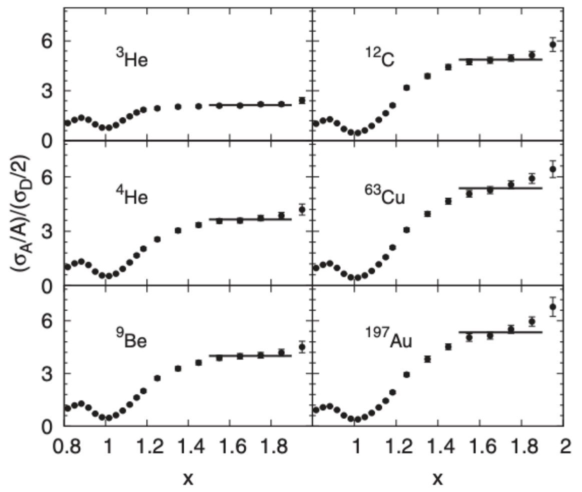
J. Seely et al., Phys. Rev. Lett. 103, (2009

EMC-SRC Correlation



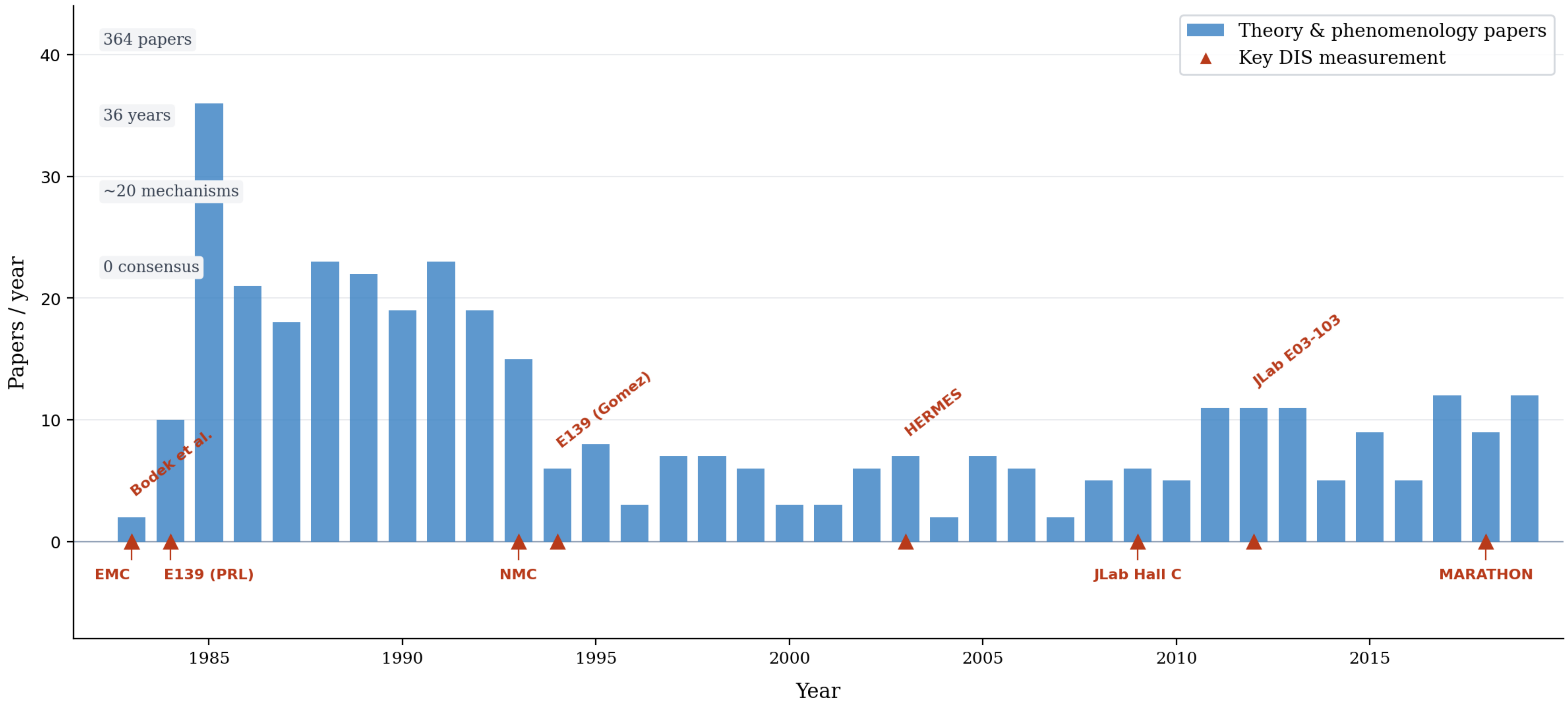


O. Hen et al., Phys. Rev. C 85 (2012) 047301



N Fomin, et al. Phys. Rev. Lett (2012)

40+ Years: No Consensus

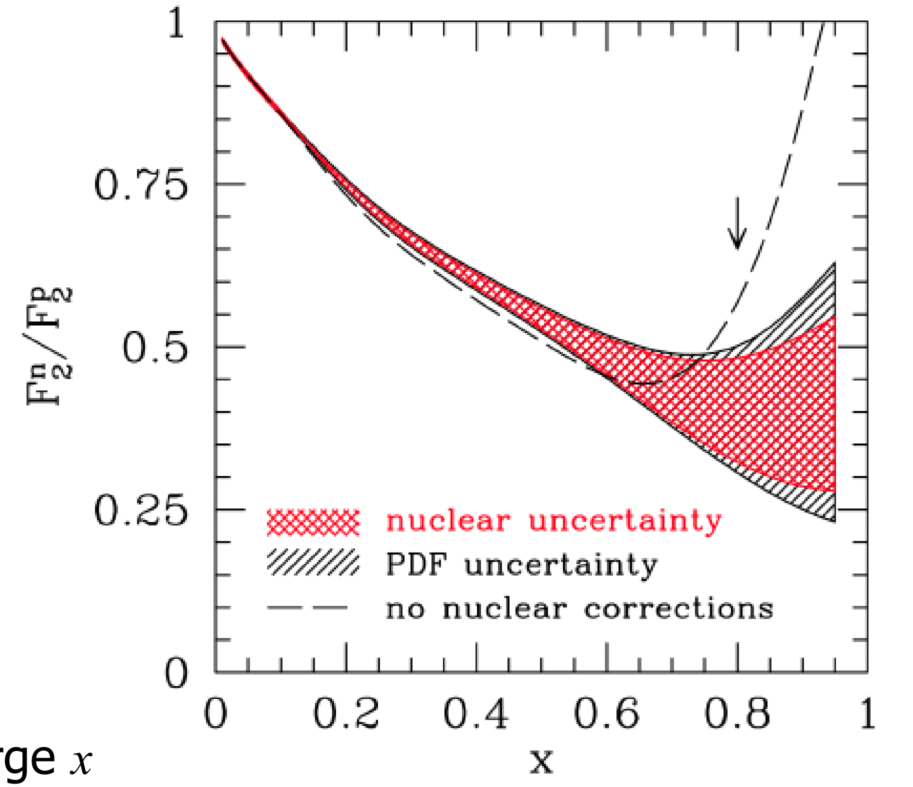


MARATHON

Me**A**surement 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.

Jefferson Lab PAC37 Proposal, December 2010

The JLab **MARATHON** Collaboration

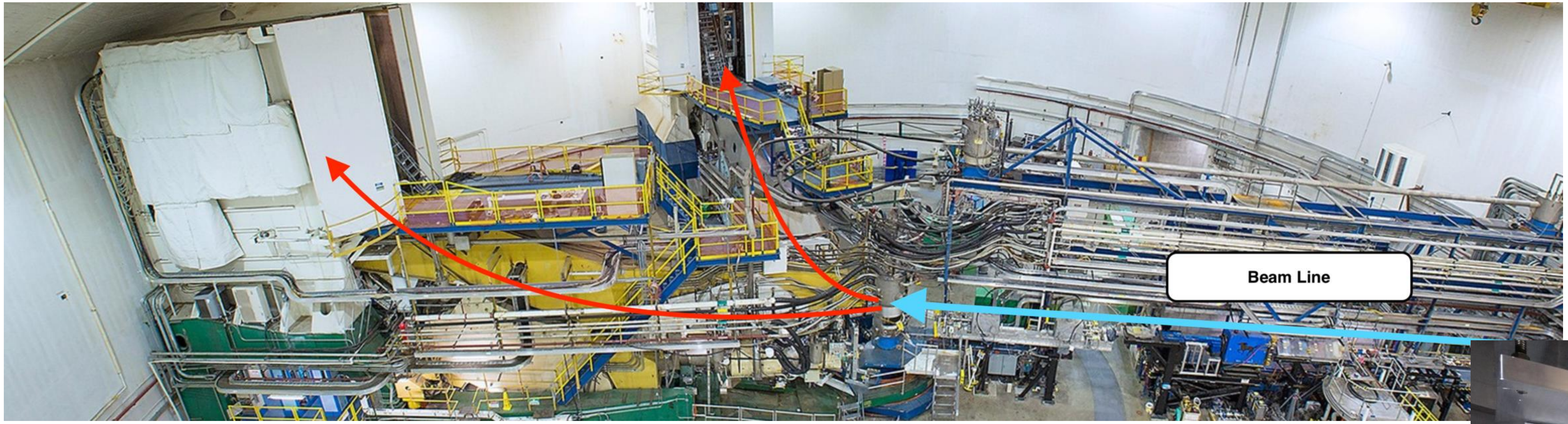


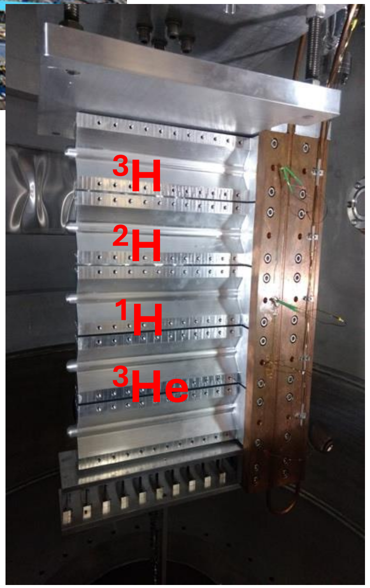
A. Accardi et al. Phys. Rev. D 84 (2011)

1. Ratio of mirror nuclei provides a novel method of the F_2^n/F_2^p ratio at large x
2. Measurement of EMC of light nuclei (A=3)

The MARATHON Experiment

Hall A



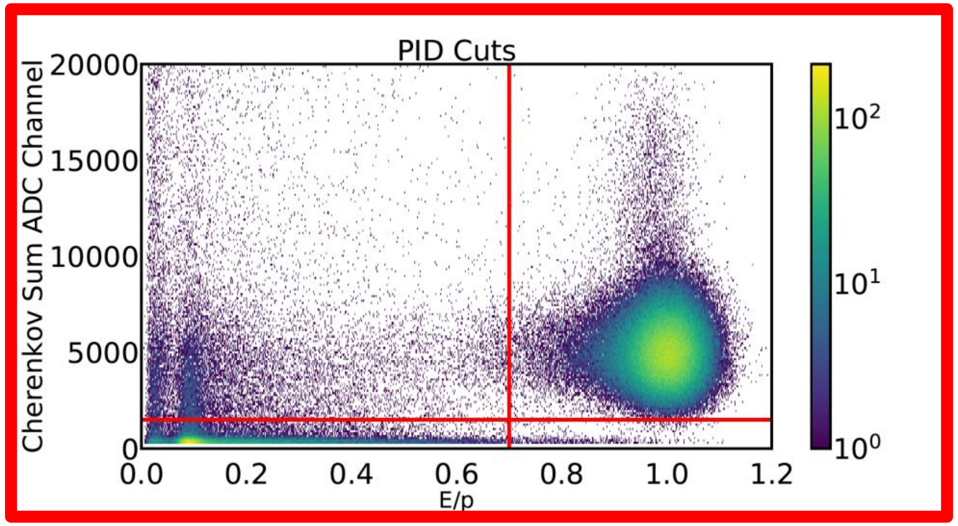


Data collection: Jan. - April 2018
- LHRS and RHRS independently to detect e^-
- Standard detector configurations

- Sealed target cells
  - Cooled to 40 K
- ^{3}H filled at Savannah River National Lab

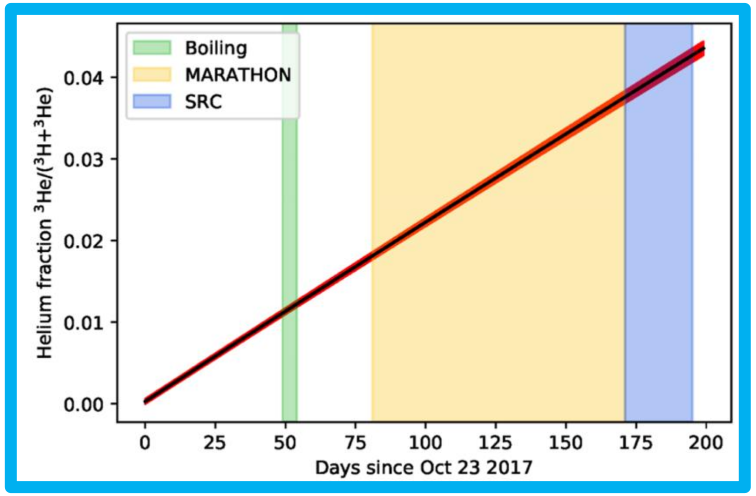
Kin	E (GeV)	E' (GeV)	Q^2 [(GeV/c)^2]	θ (deg)	x
0	10.59	3.1	2.79	16.90	0.19
1	10.59	3.1	3.06	17.58	0.22
2	10.59	3.1	3.61	19.12	0.26
3	10.59	3.1	4.19	20.58	0.29
4	10.59	3.1	4.76	21.93	0.34
5	10.59	3.1	5.31	23.21	0.38
7	10.59	3.1	6.47	25.59	0.46
9	10.59	3.1	7.56	27.77	0.54
11	10.59	3.1	8.71	29.92	0.62
13	10.59	3.1	9.84	31.73	0.70
15	10.59	3.1	10.96	33.56	0.78
16	10.59	2.9	11.83	36.12	0.82

MARATHON Analysis



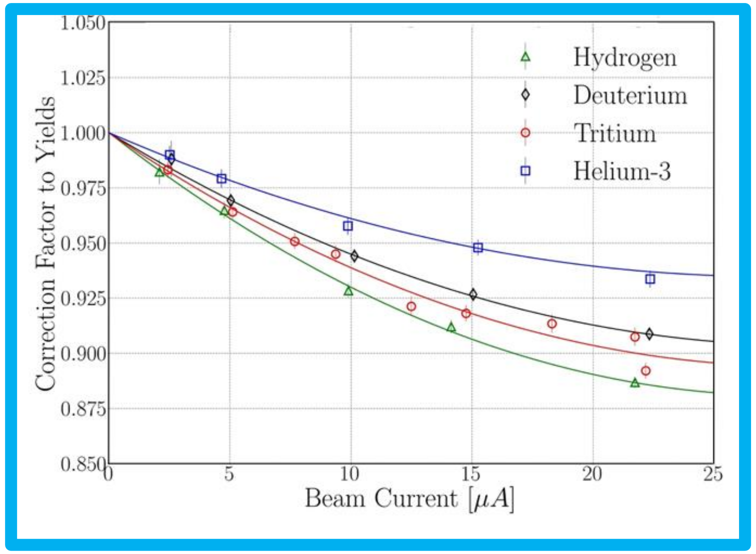
^{3}H Decay: $\tau = 4500 \pm 8$ days

$$^{3}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + e^{-} + \bar{\nu}_{e}$$



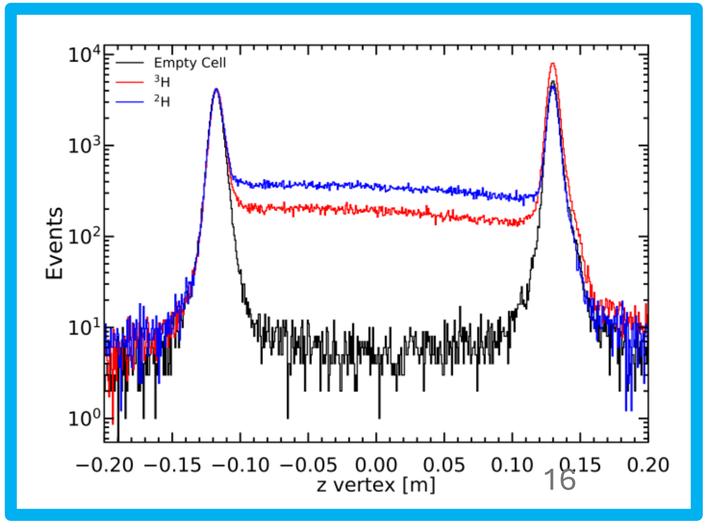
Charge Normalized Yield

$$Y = \frac{N_e C}{LTQ\rho L}$$



Corrections

- ^{3}H Decay
- *Density*
- *Radiative*
- *Charge symmetric*
- *Endcap*
- *Bin centering*



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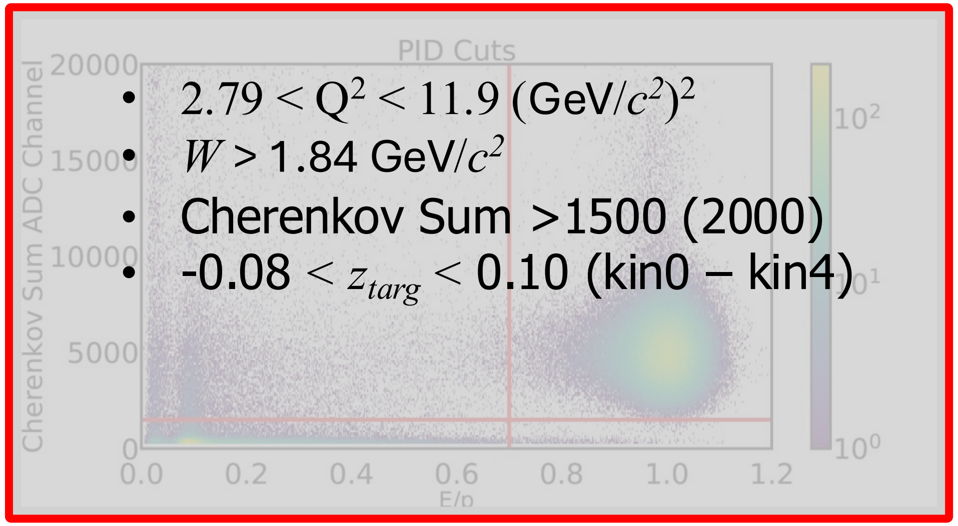
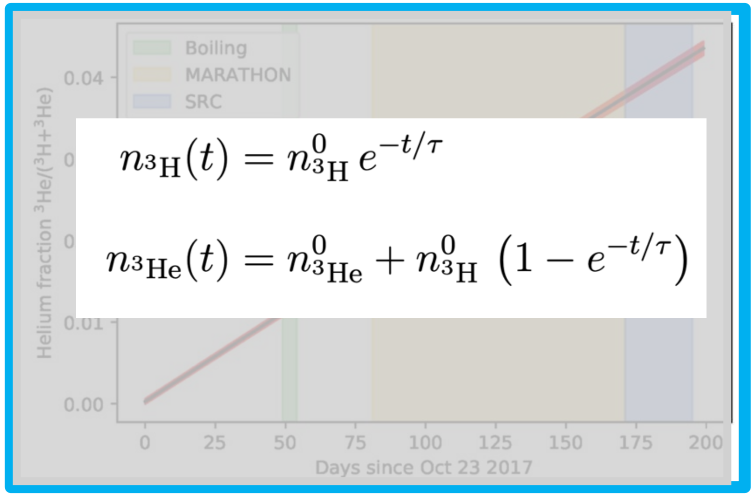


- $2.79 < Q^2 < 11.9$ $(\text{GeV}/c^2)^2$
- $W > 1.84$ GeV/c^2
- Cherenkov Sum >1500 (2000)
- -0.08 $< z_{targ} <$ 0.10 (kin0 – kin4)

^{3}H Decay: $\tau = 4500 \pm 8$ days

$${}^3\text{H} \rightarrow {}^3\text{He} + e^- + \bar{\nu}_e$$

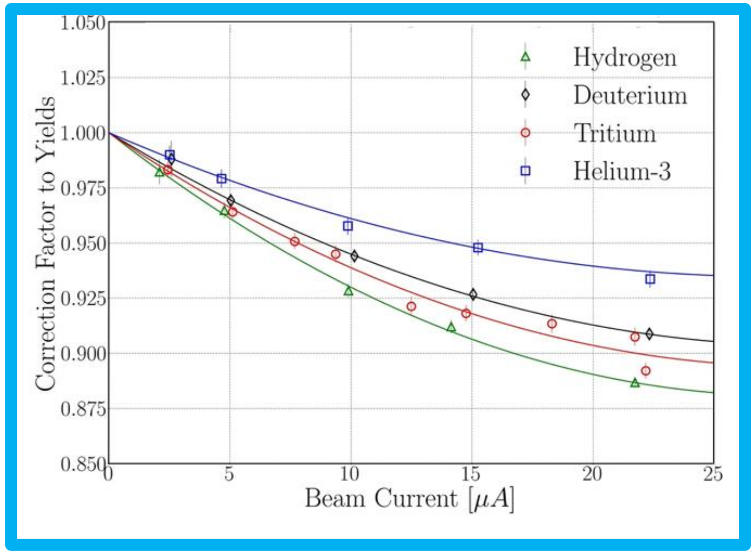


$$n_{^3\text{H}}(t) = n^0_{^3\text{H}}\, e^{-t/\tau}$$

$$n_{^3\text{He}}(t) = n^0_{^3\text{He}} + n^0_{^3\text{H}}\,\left(1 - e^{-t/\tau}\right)$$

Charge Normalized Yield

$$Y = \frac{N_e C}{LTQ\rho L}$$



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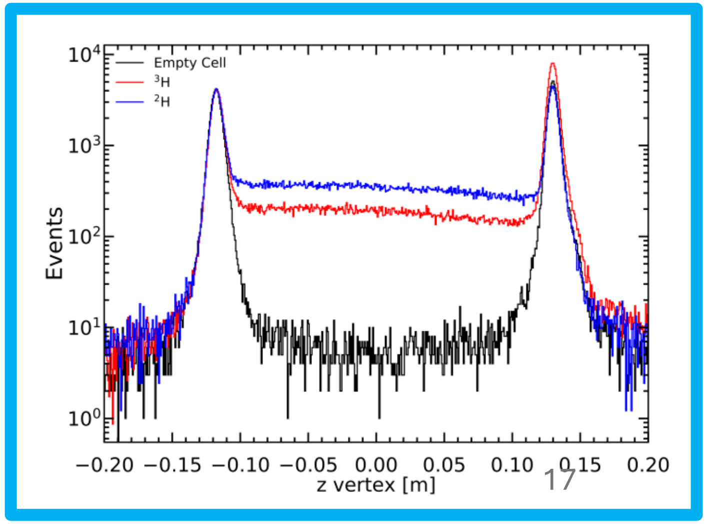


EMC Effect of ^{3}H and ^{3}He

Normalization

- F_2^n/F_2^p can be extracted from the ratios: σ_h/σ_d , σ_t/σ_d and σ_d/σ_p
- Around $x \approx 0.31$ nuclear corrections expected to be minimal
  - F_2^n/F_2^p should be mutually consistent

$$F_2^n/F_2^p = \frac{2\mathrm{R}_{hd}(\sigma_d/\sigma_h) - 1}{1 - \mathrm{R}_{hd}(\sigma_d/\sigma_h)} = \frac{2\mathrm{R}_{td}(\sigma_d/\sigma_t) - 1}{1 - \mathrm{R}_{td}(\sigma_d/\sigma_t)}$$

1. Data
2. Model Input

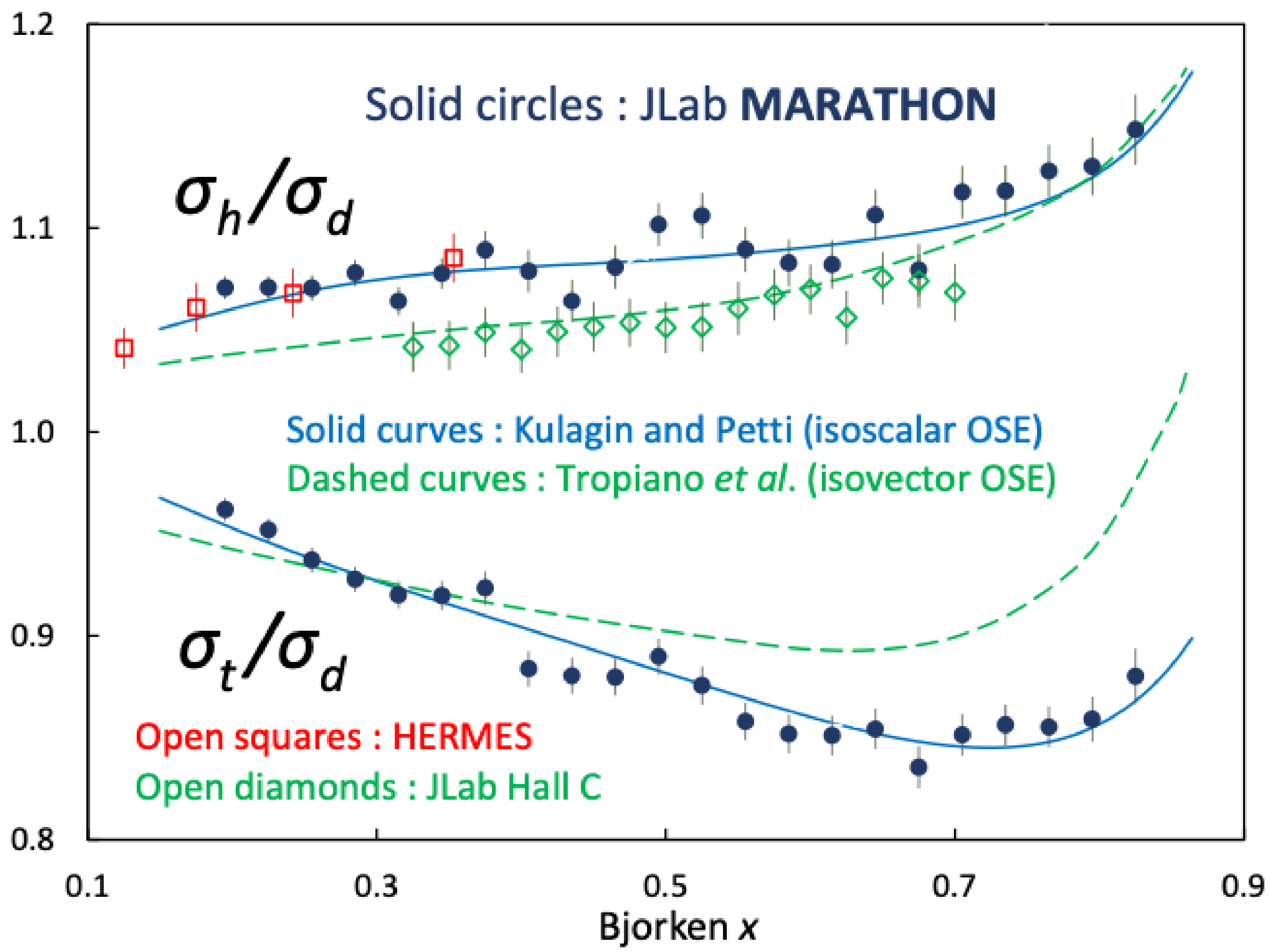
K-P Model
- Data-driven
- Describes very well all available DIS nucleon and nuclear world data

A comparison among these extractions found:

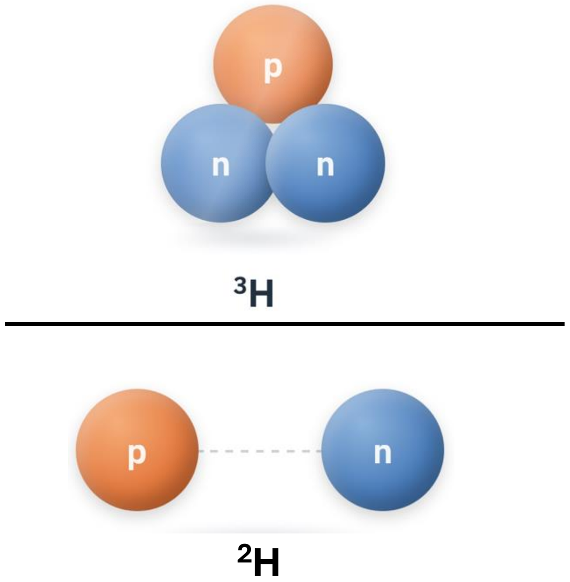
^{3}H & ^{3}He EMC ratios needed to be normalized to be consistent with σ_d/σ_p extraction

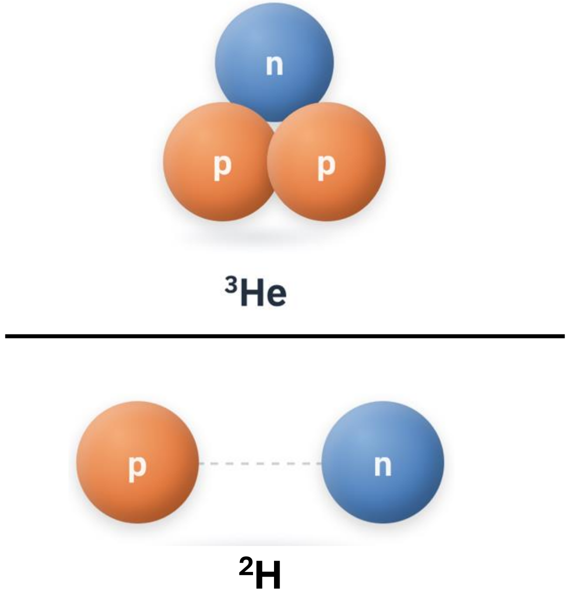
σ_t/σ_d	σ_h/σ_d
Normalization factor: 0.996 ± 0.005	Normalization factor: 1.021 ± 0.005

Normalized A=3 EMC Ratios



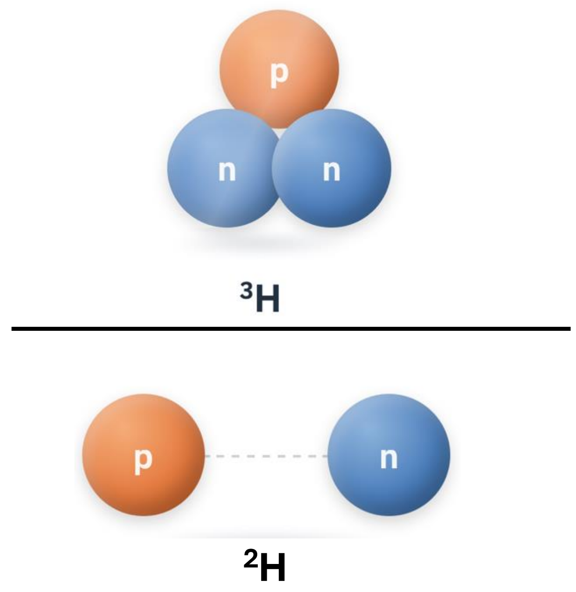
Isoscalar Correction: Neutron & Proton Excess

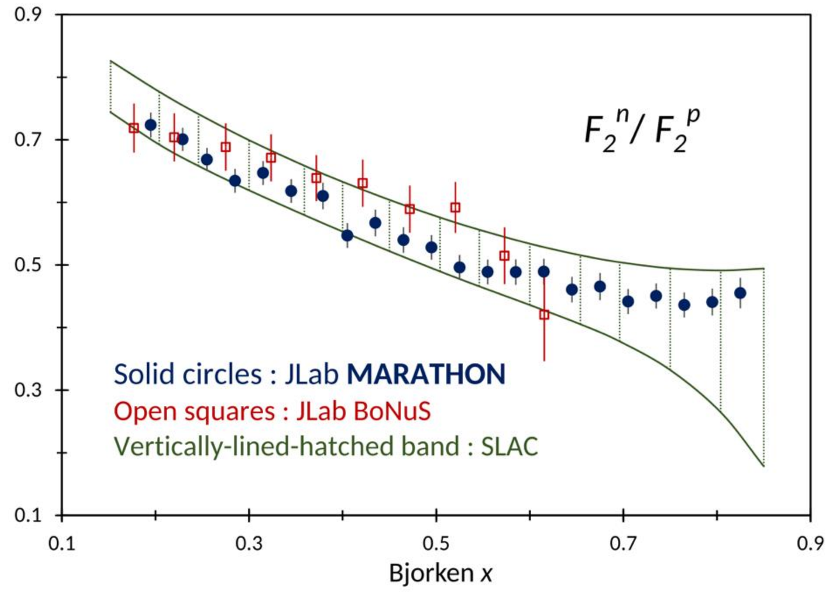


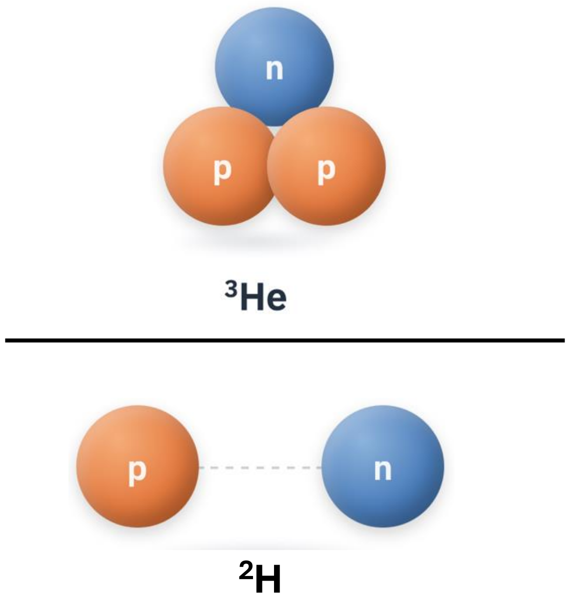


Isoscalar Correction: Neutron & Proton Excess

$$F_{iso} = \frac{A\left(1 + \sigma_n/\sigma_p\right)}{2\left[Z + (A - Z)\sigma_n/\sigma_p\right]}$$



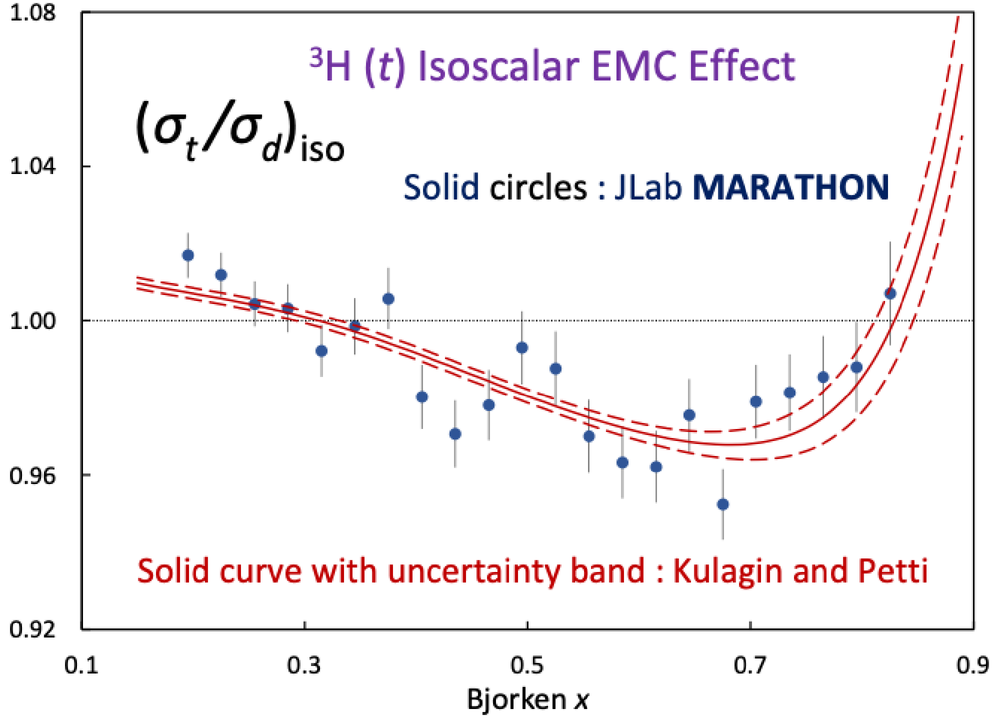


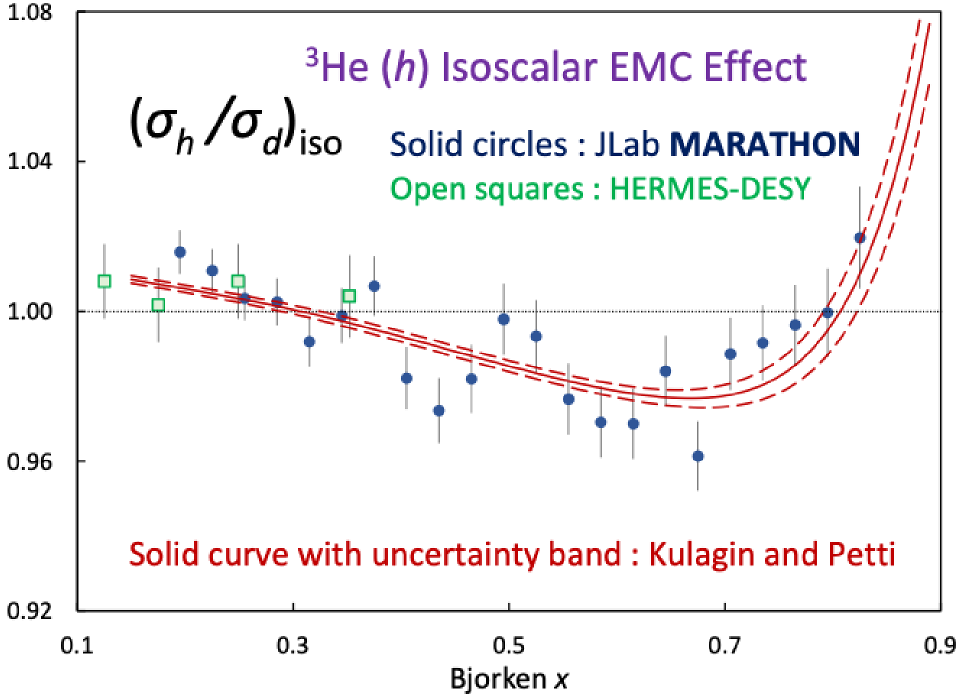


D. Abrams et al., Phys. Rev. Lett. 128 (2022)

Normalized A=3 EMC Ratios

First measurement

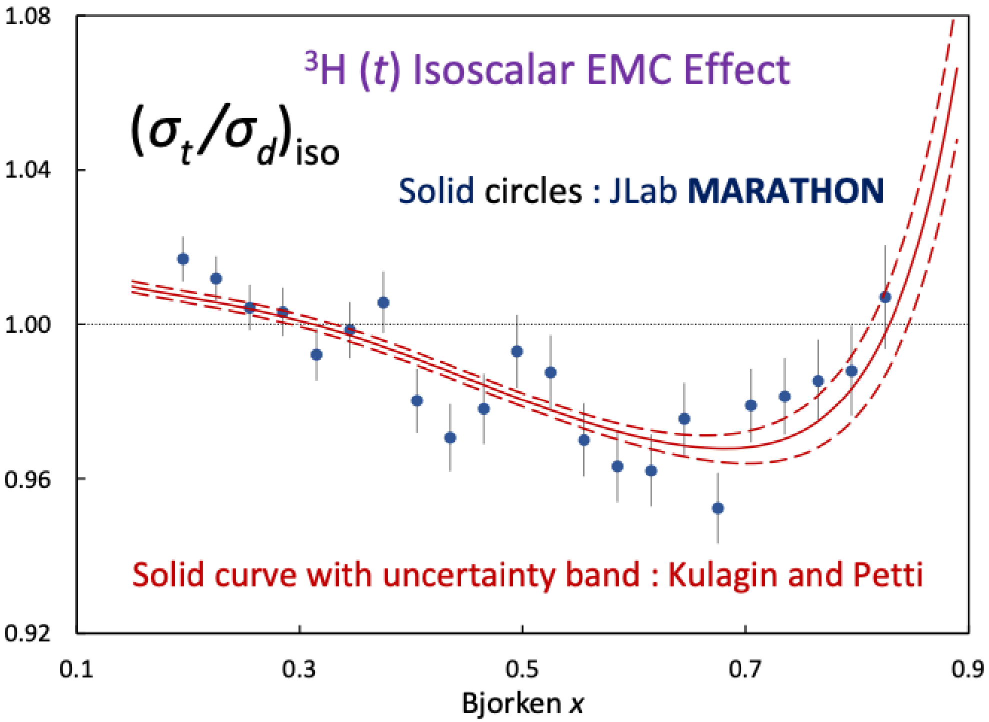




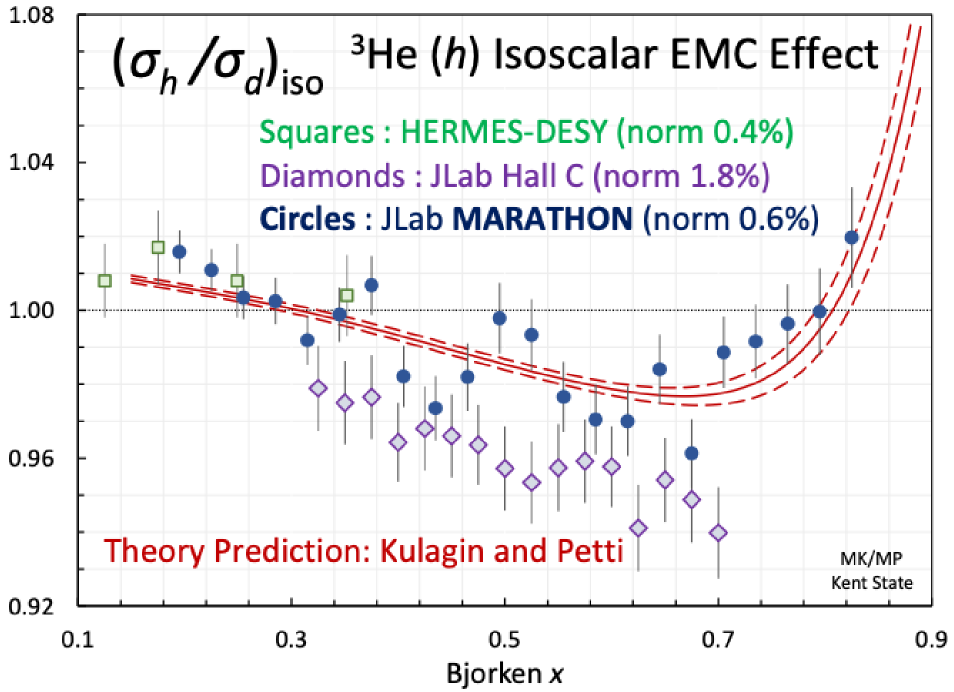
Systematic Uncertainties for EMC Ratios

- Target density due beam-heating: (0.1-0.5)%
- Radiative corrections: (0.25-0.45)%
- Acceptance: 0.2%

Normalized A=3 EMC Ratios



Comparison of world ^{3}He EMC data



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Summary and Outlook

PHYSICAL REVIEW LETTERS **135,** 062502 (2025)

Editors' Suggestion

EMC Effect of Tritium and Helium-3 from the JLab MARATHON Experiment

- The MARATHON reported the measurement of the EMC effect of the A=3 mirror nuclei
  - D. Abrams et al., Phys. Rev. Lett. 135 (2025)
  - First measurement of the EMC effect of ^{3}H
- A=3 data will provide
  - Unique input for QCD studies of the nucleons
  - Partonic structure of the few-body nuclear systems in the valence quark region
- The Hall A tritium program has proven to be a great success
  - More than 10 PhDs
  - PRL and Nature publications
  - A lot of interesting physics!
- Renewed interest in tritium
  - E12-20-05: Approved tritium experiment in Hall B