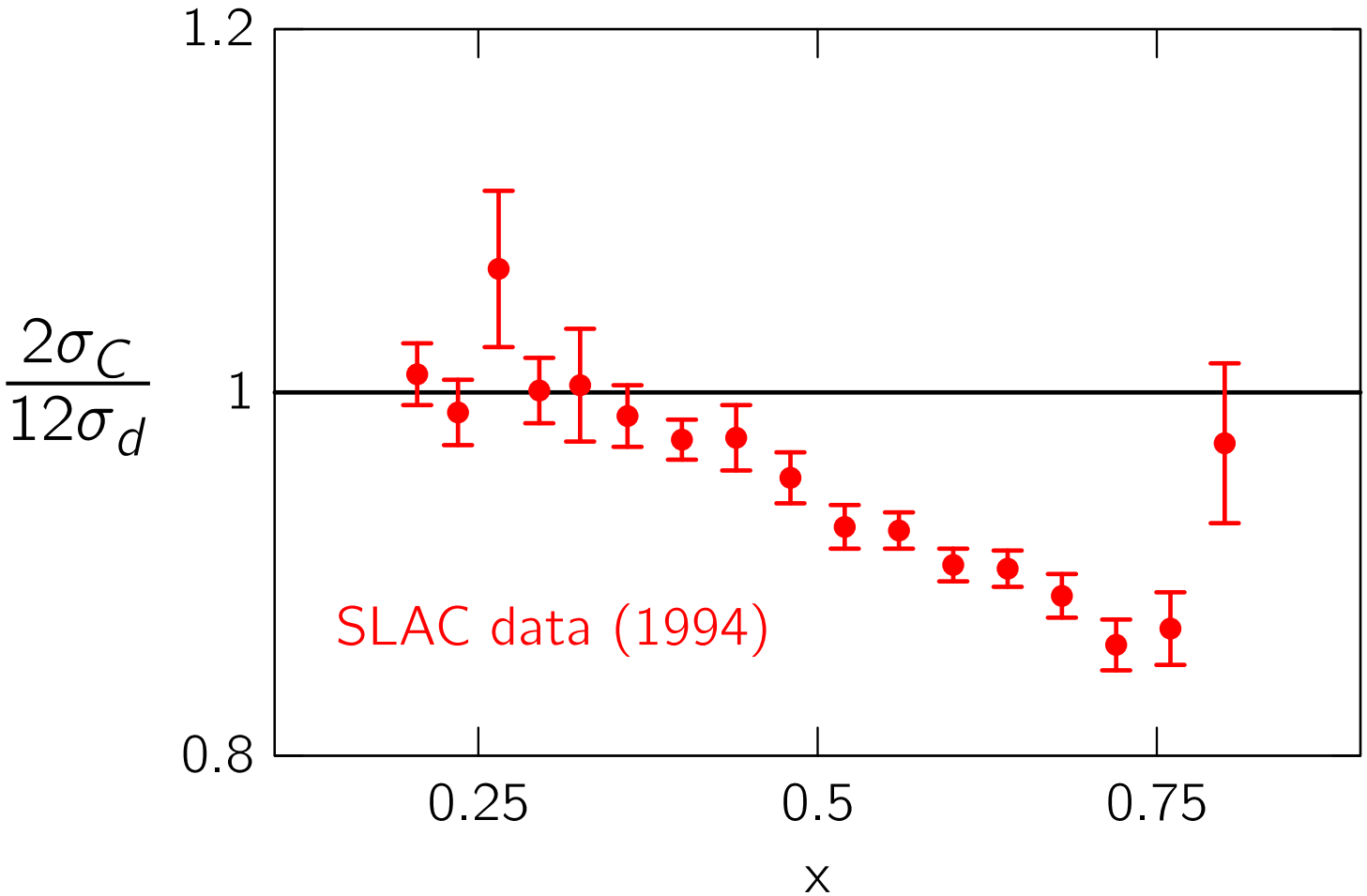
Modified structure of protons and neutrons in correlated pairs

Axel Schmidt

George Washington University

October 30, 2019
EINN Conference, Paphos Cyprus

The EMC Effect:
Nucleon structure changes in nuclei!



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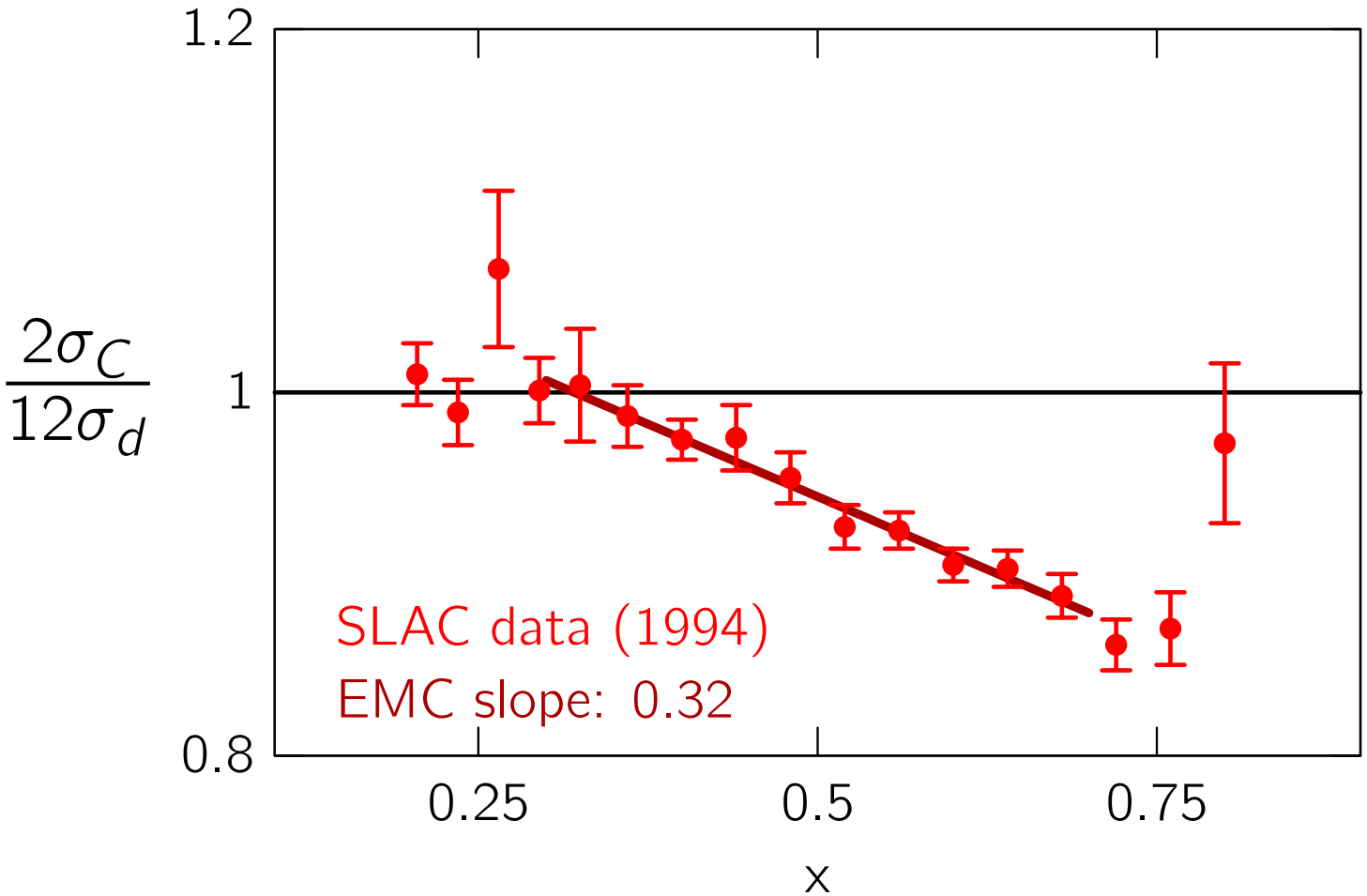

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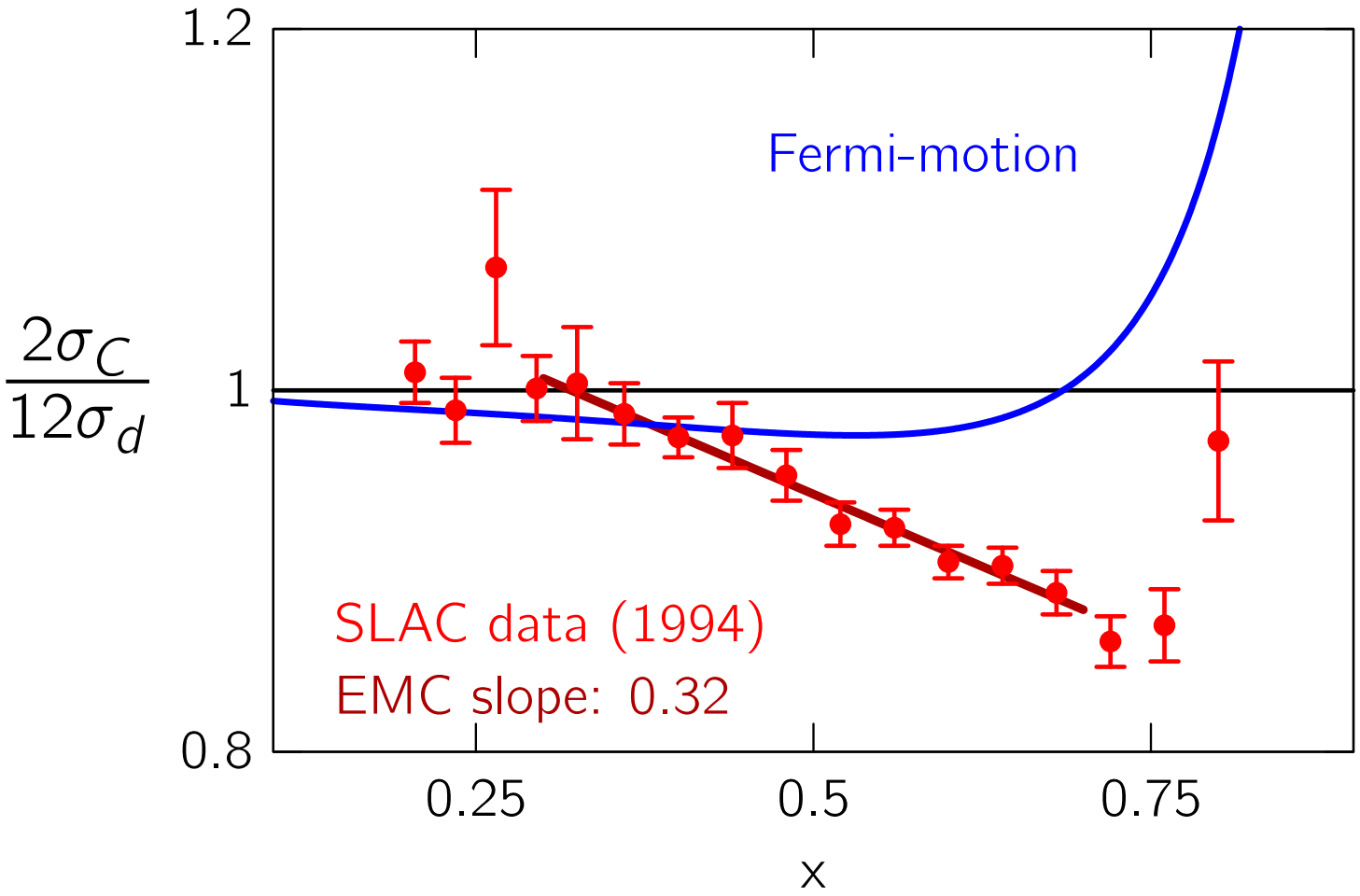
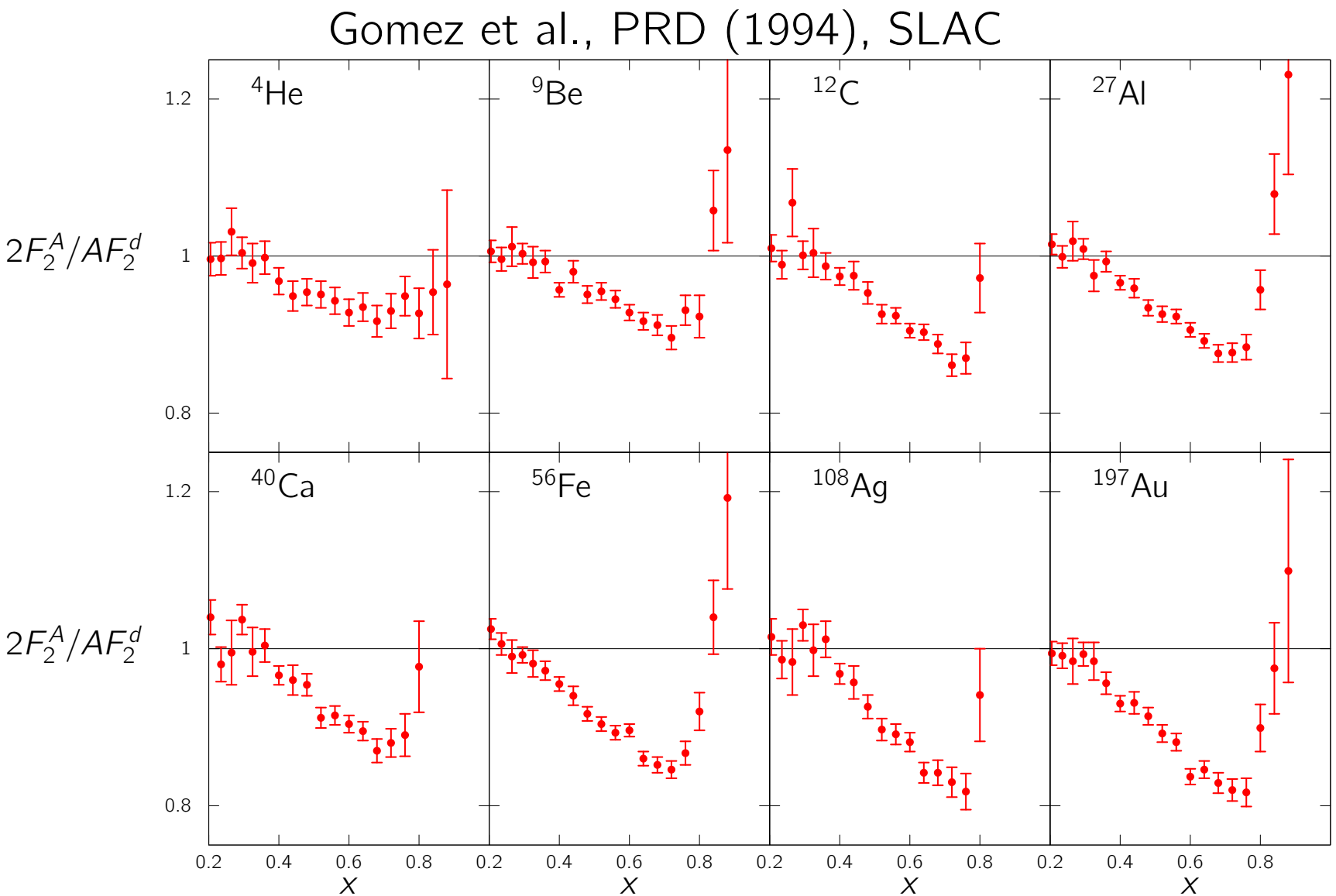
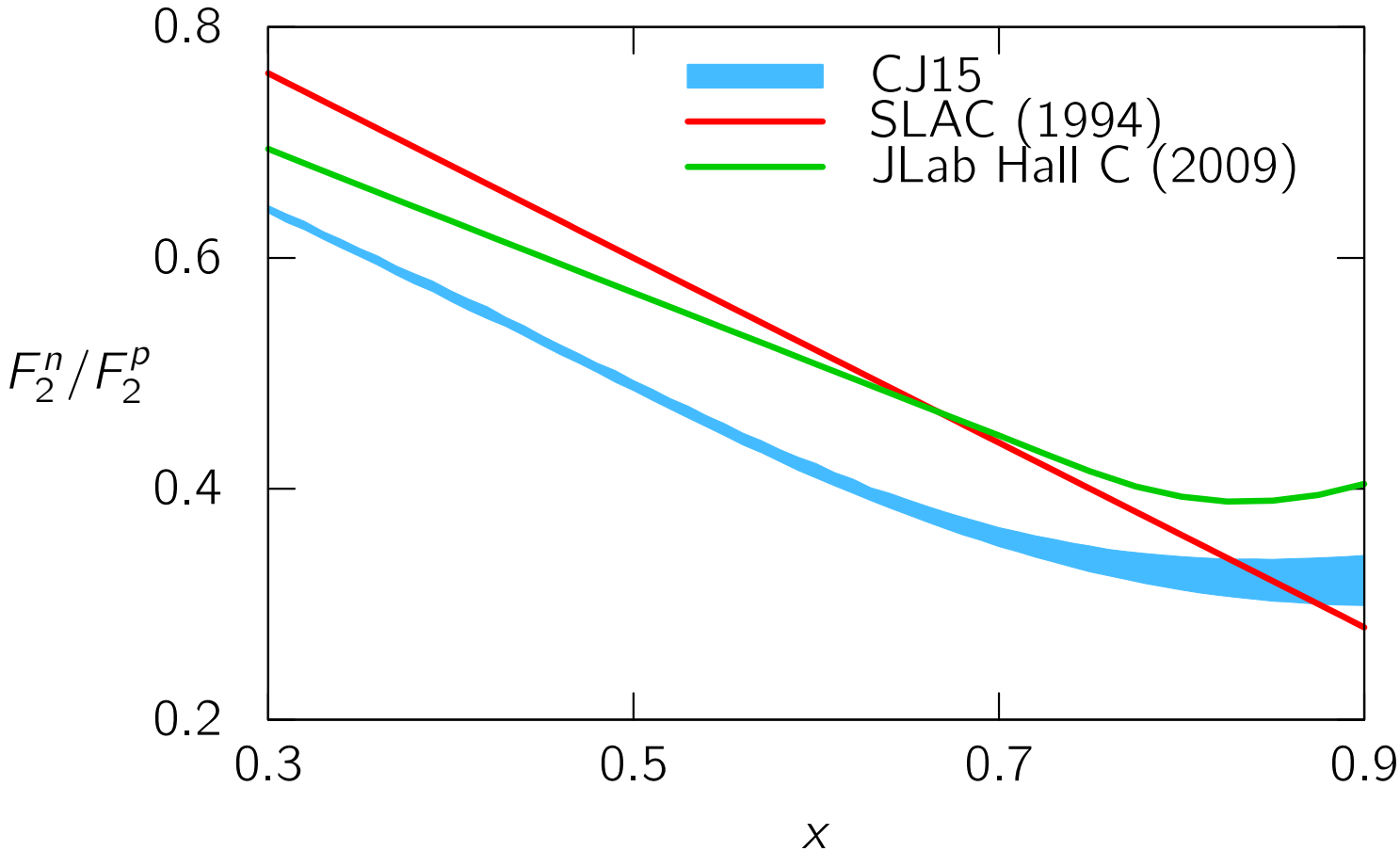


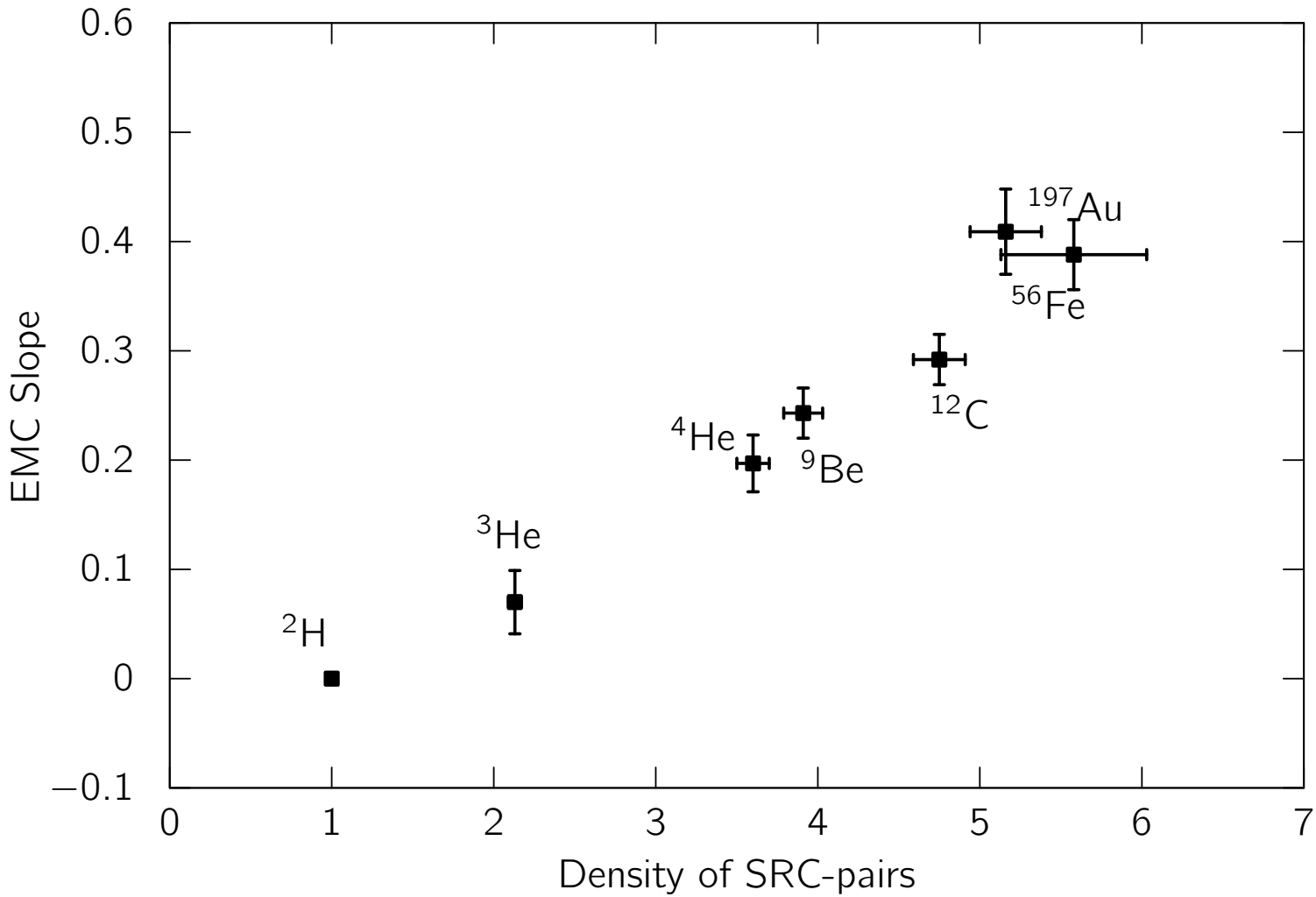
The EMC Effect grows with nuclear size.



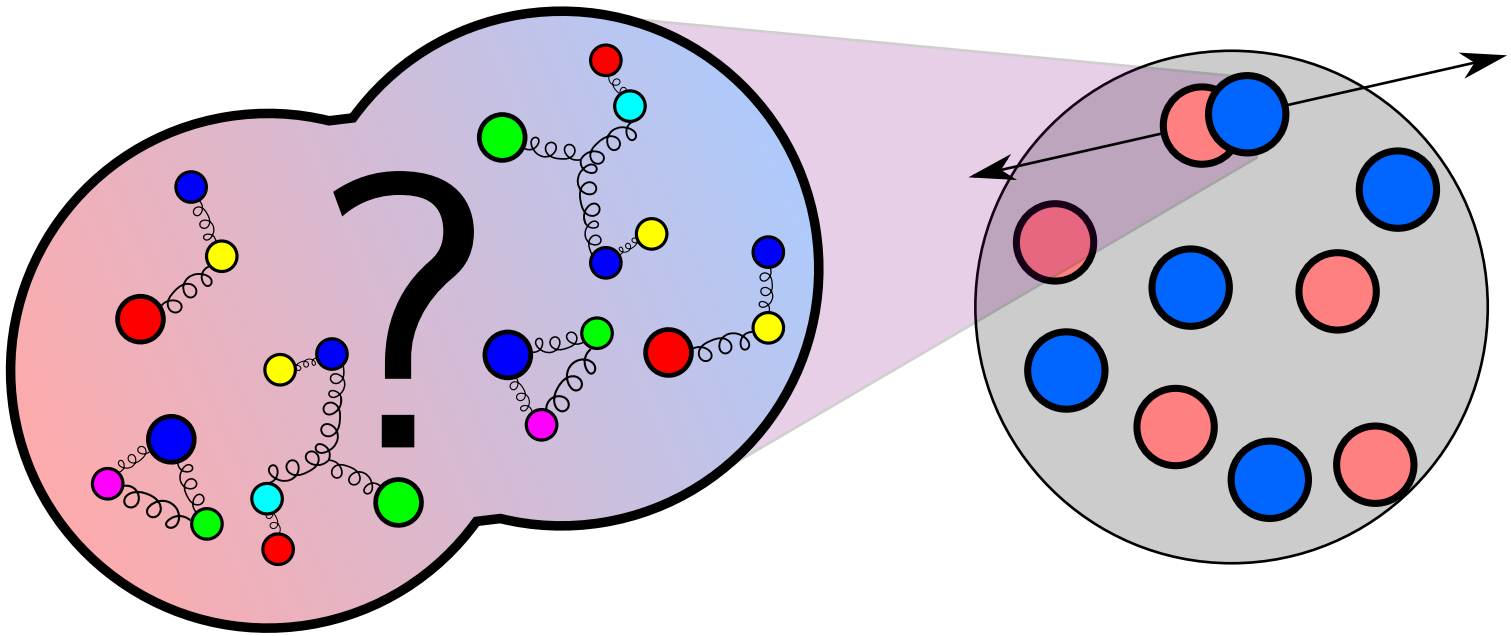
"Isoscalar corrections" are applied to neutron-rich nuclei.



The EMC Effect correlates with short-range correlated pairs.



What if only SRC nucleons have significant modification?



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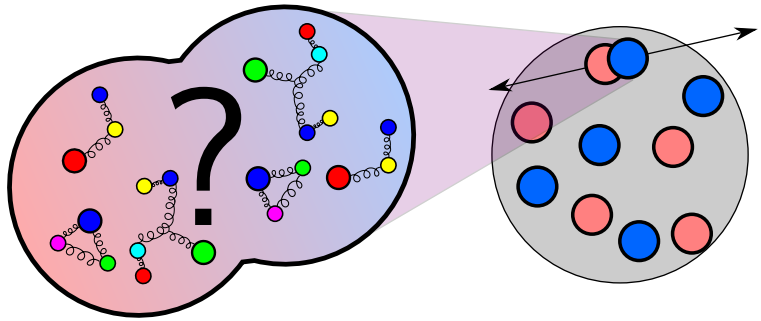

- The per-pair modification is universal.
  - B. Schmookler et al., Nature 566 p. 354 (2019)
- The SRC-EMC hypothesis makes predictions for MARATHON.
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- Direct tests with BAND and LAD experiments
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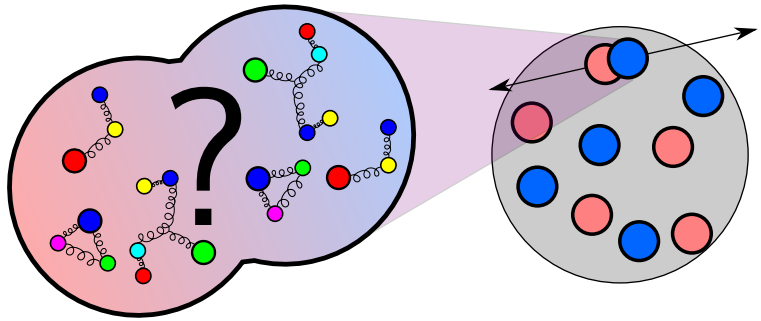

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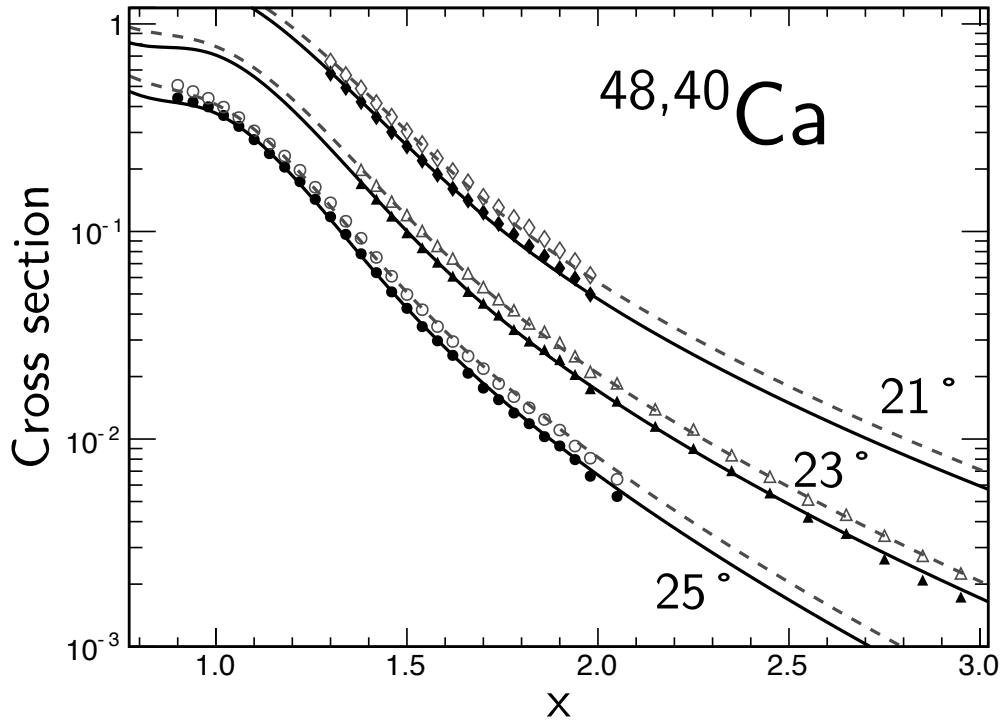
What are short-range correlated pairs?

Two nucleons in close proximity with high relative momentum.

- High-momentum tails



D. Nguyen et al., in preparation

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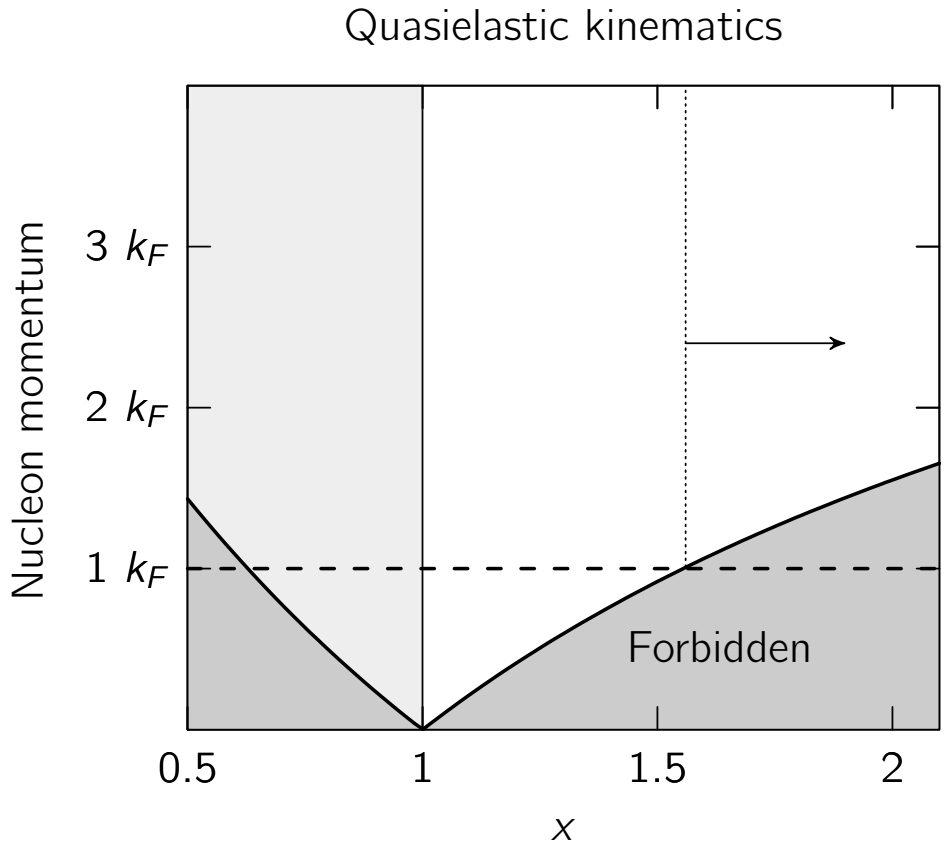

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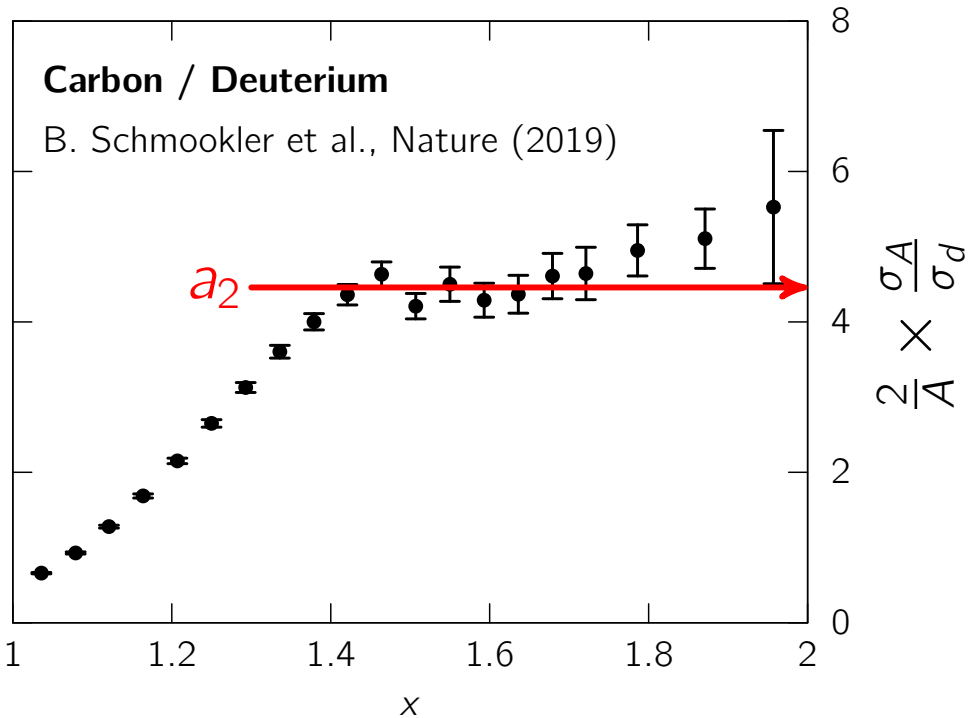

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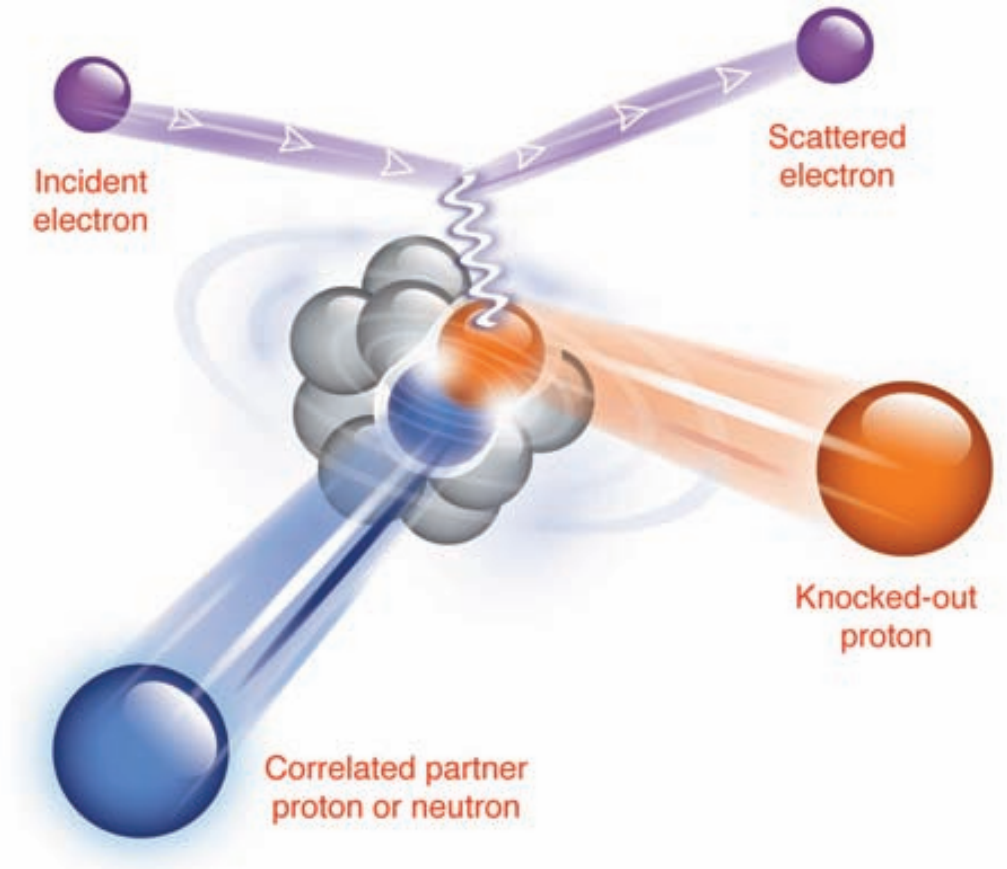

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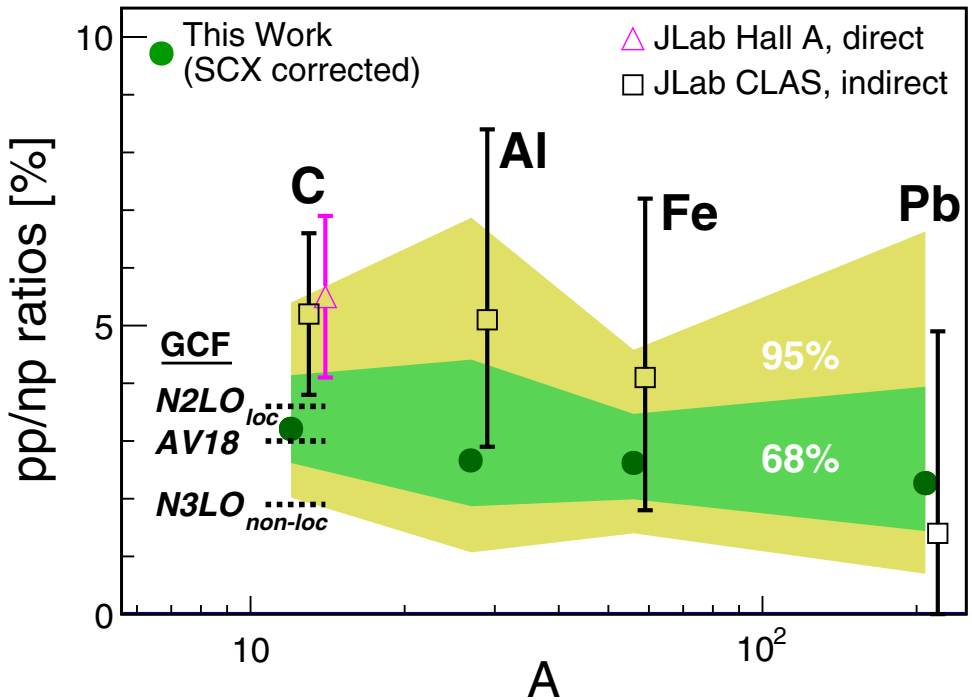
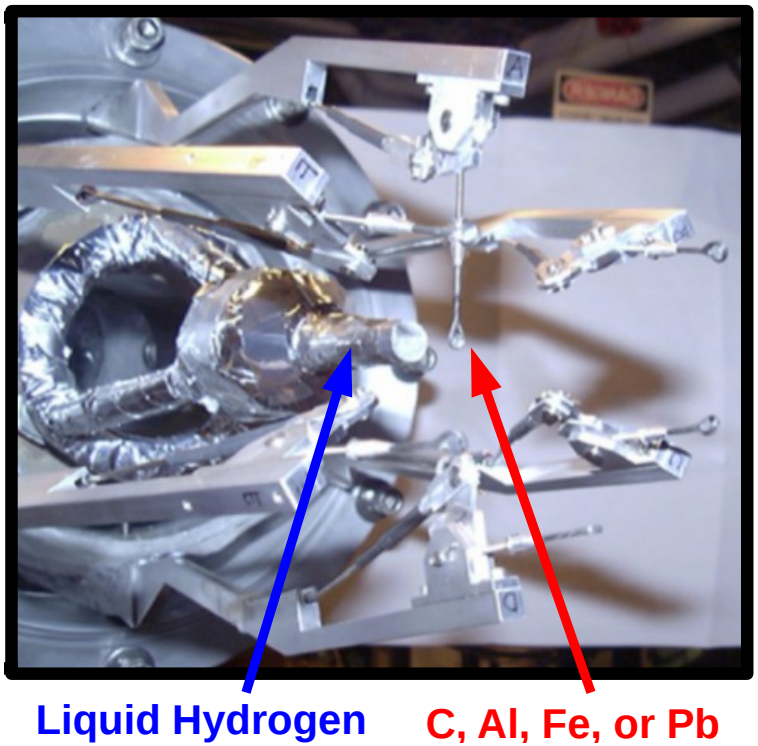
- *np*-pairs dominant



M. Duer, A. Schmidt, J. R. Pybus et al., PRL (2019)

CLAS EG2: simultaneous SRC-EMC measurement

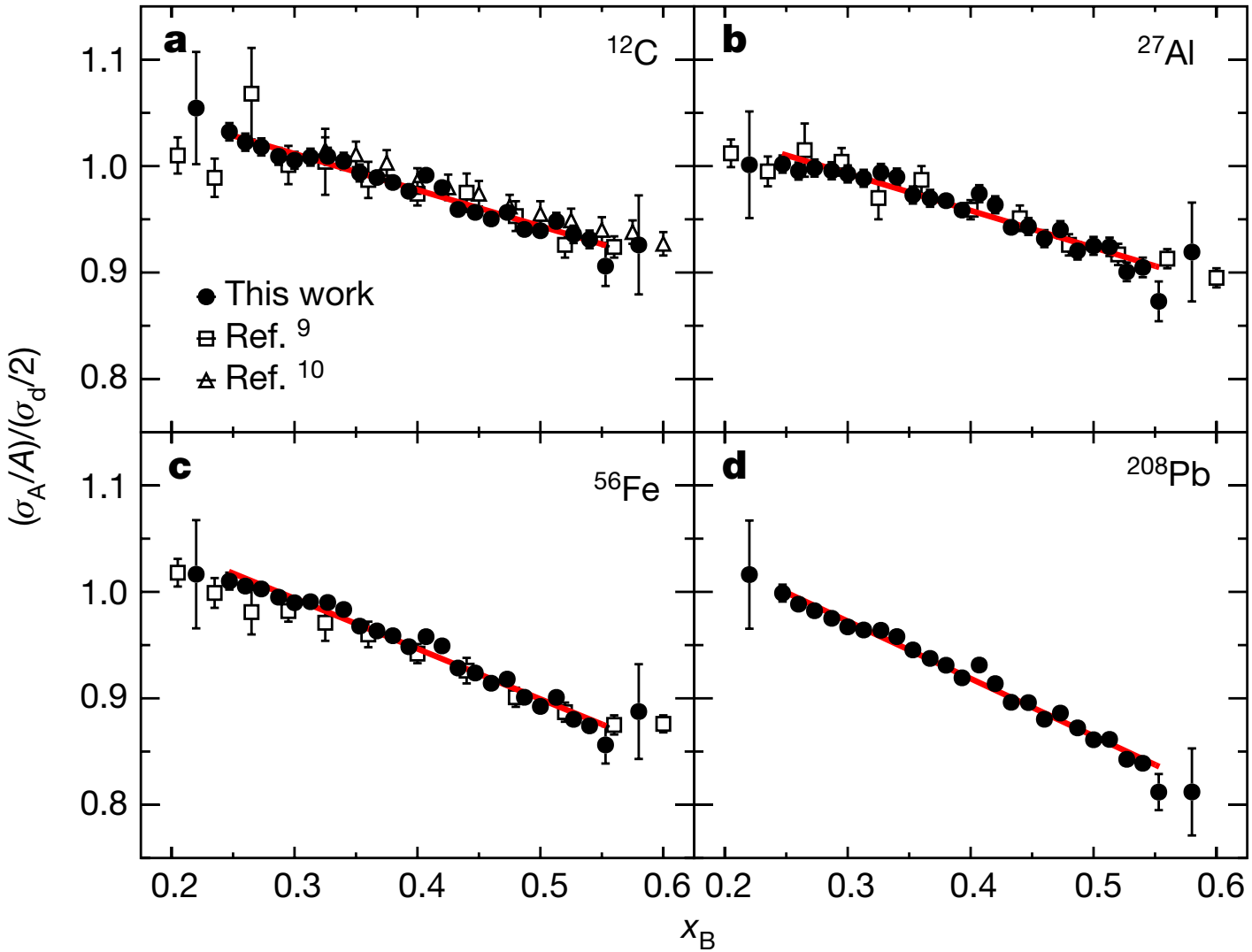
work by Barak Schmookler
MIT PhD 2018



CLAS EG2 Experiment (2004)

- 5 GeV e^- beam
- Deuterium target AND C, Al, Fe, Pb
- Measured quark distributions and SRC pair density

We measured the EMC Effect and pair densities.



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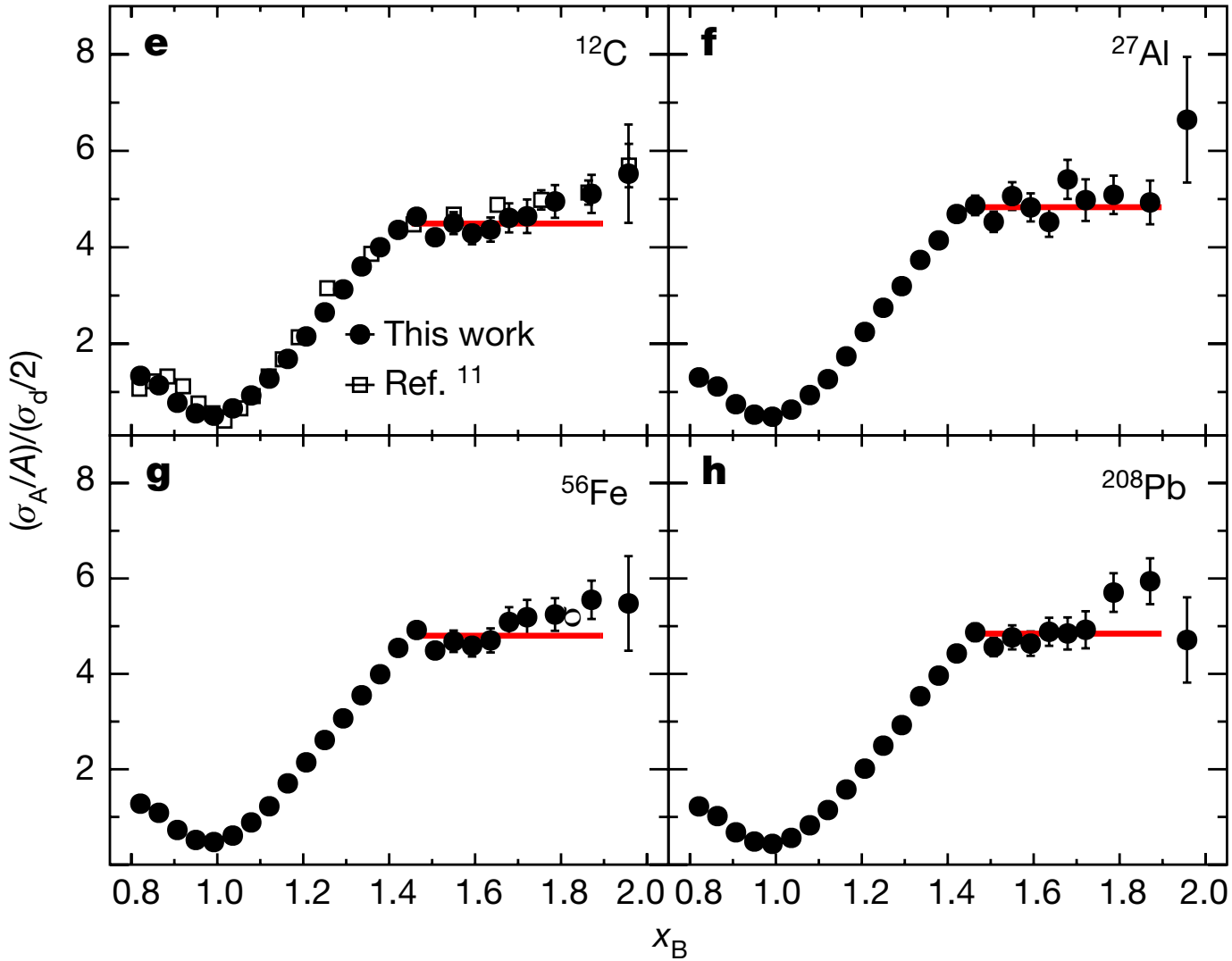

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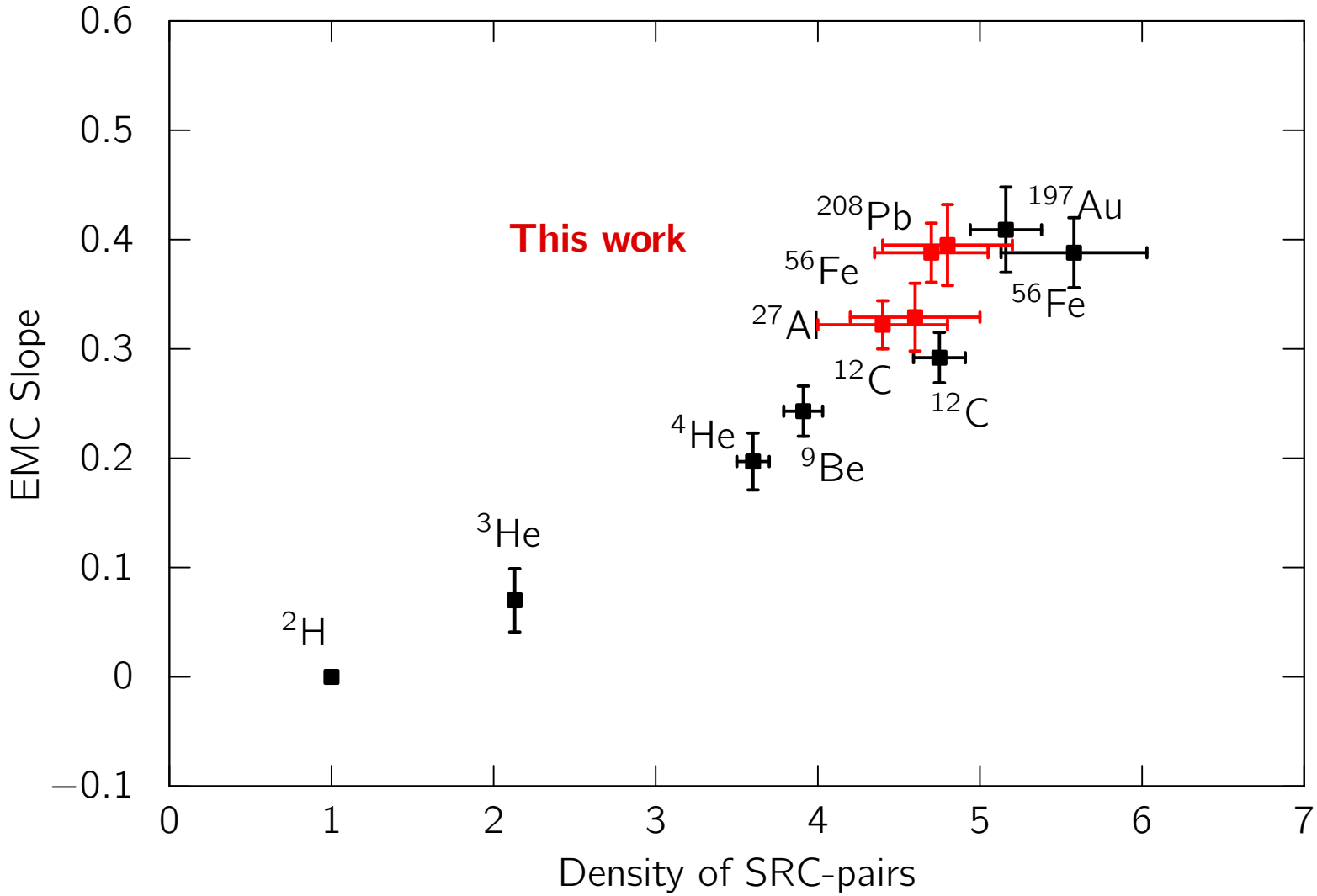
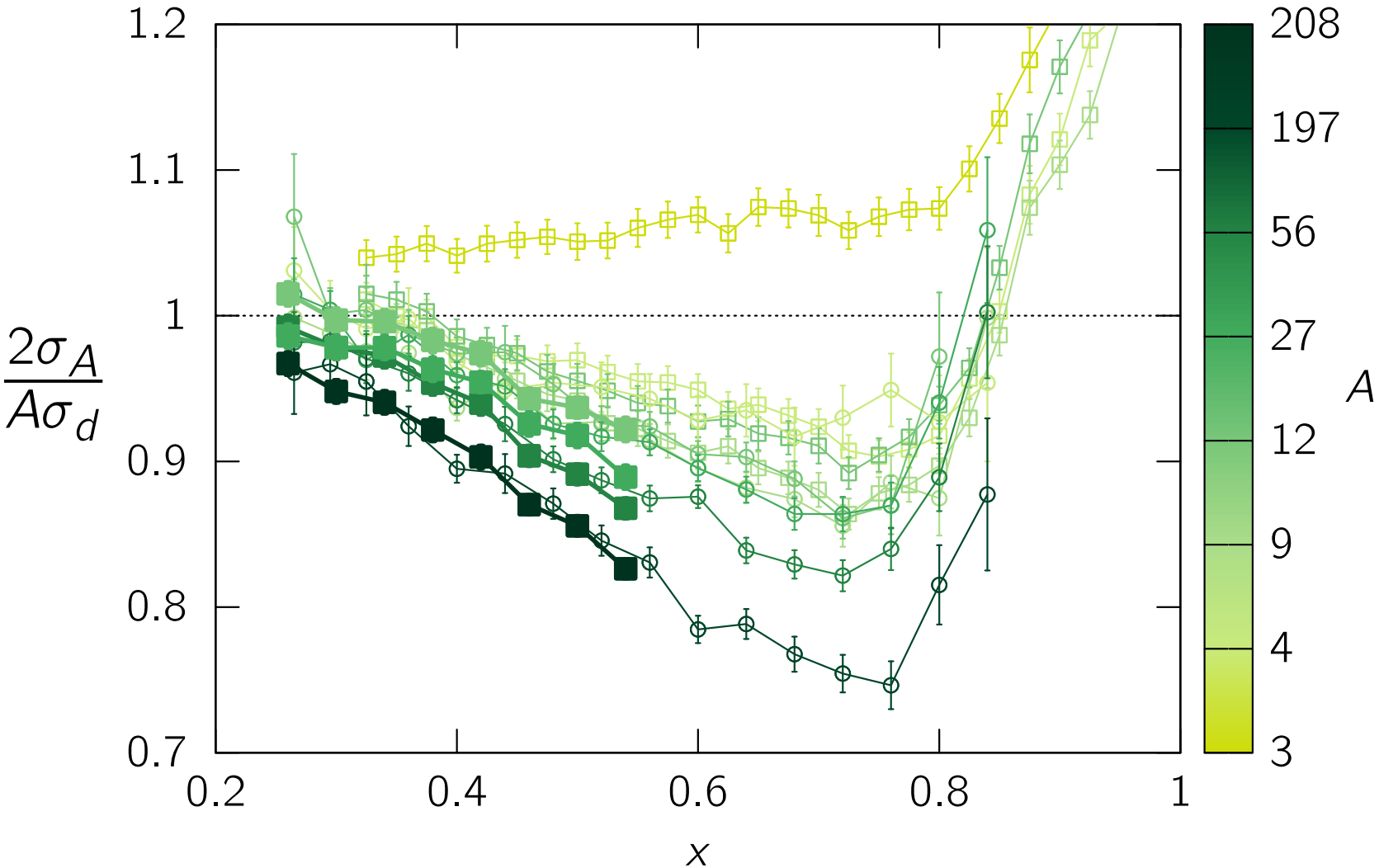
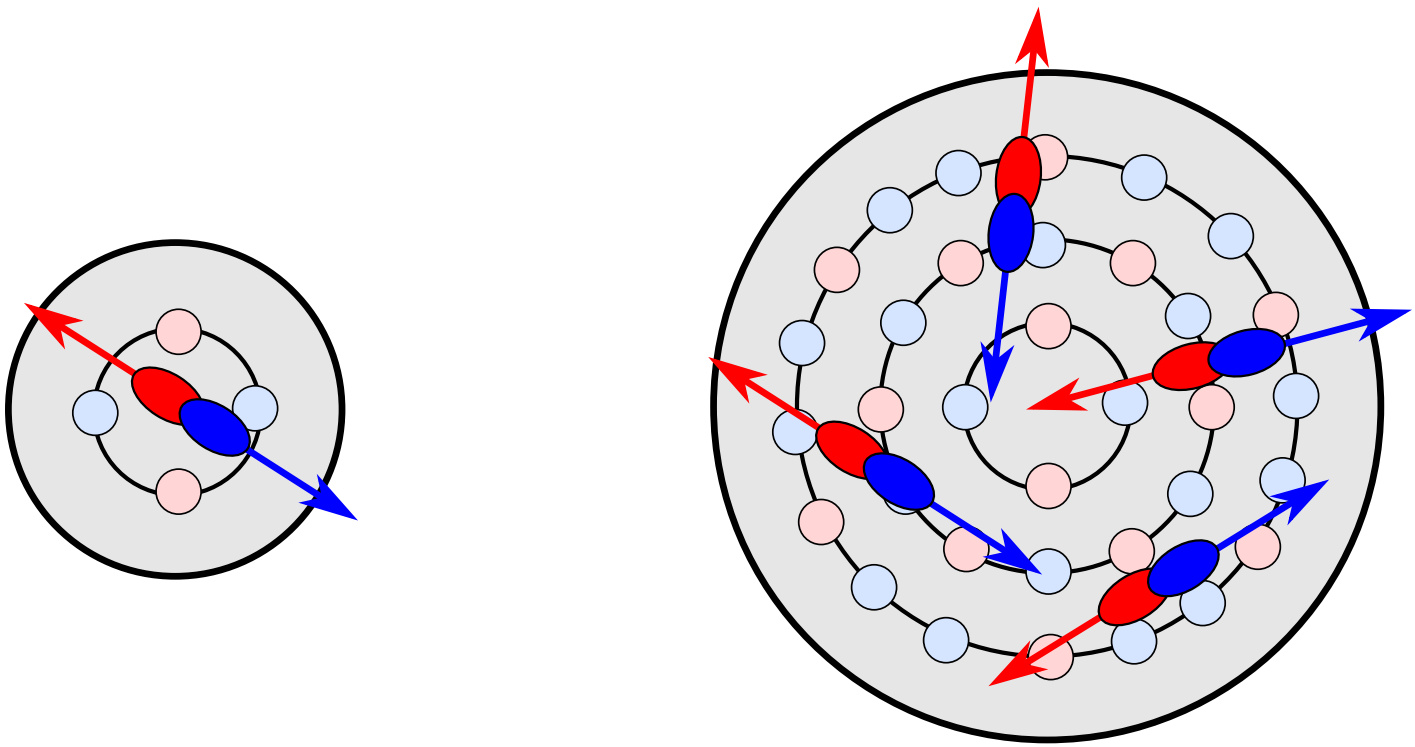


Barak's data show excellent agreement with previous EMC measurements.



The SRC-EMC hypothesis predicts "Universal Modification"



The modification of an SRC pair should be independent of nuclear structure.

Isolating the modification of an individual pair:

Assume *only np* pairs

$$F_2^A = (Z - n_{\mathrm{SRC}}^A)F_2^p + (N - n_{\mathrm{SRC}}^A)F_2^n + n_{\mathrm{SRC}}^A(F_2^{p*} + F_2^{n*})$$

Isolating the modification of an individual pair:

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$$F_2^A = ZF_2^p + NF_2^n + n_{\mathrm{SRC}}^A(\Delta F_2^p + \Delta F_2^n)$$

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$$F_2^A = ZF_2^p + NF_2^n + n_{\mathrm{SRC}}^A(\Delta F_2^p + \Delta F_2^n)$$

$$F_2^n = F_2^d - F_2^p - n_{\mathrm{SRC}}^d(\Delta F_2^p + \Delta F_2^n)$$

Isolating the modification of an individual pair:

$$\frac{n_{\mathrm{src}}^{d}(\Delta F_2^p + \Delta F_2^n)}{F_2^d} = \left[R_{\mathrm{EMC}} - \frac{2(Z-N)}{A}\frac{F_2^p}{F_2^d} - \frac{2N}{A} \right] / \left[a_2 - 2N/A \right]$$

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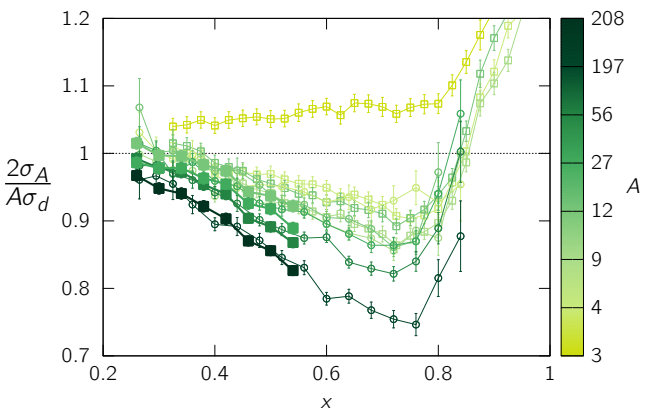

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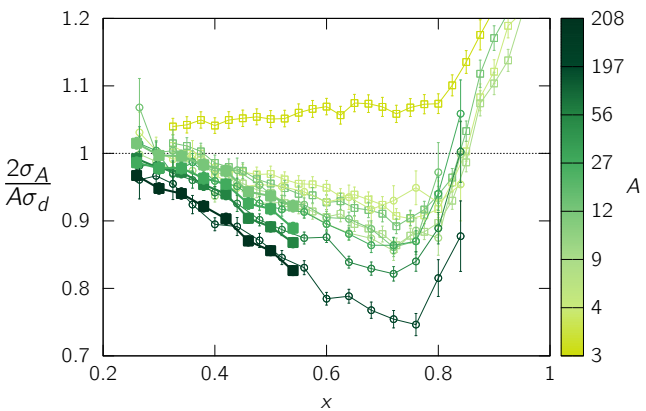

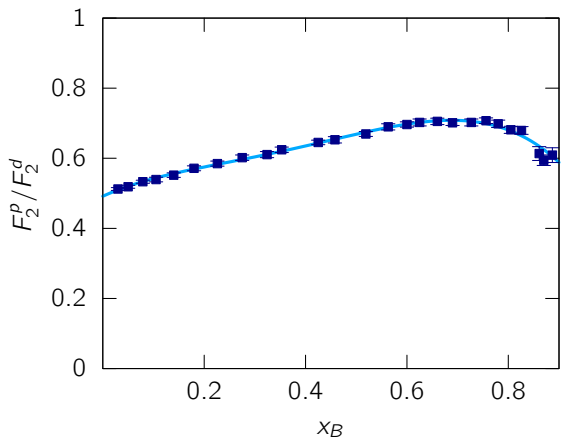

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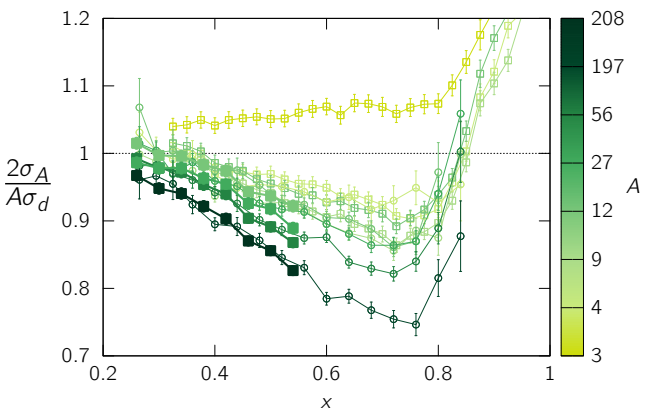
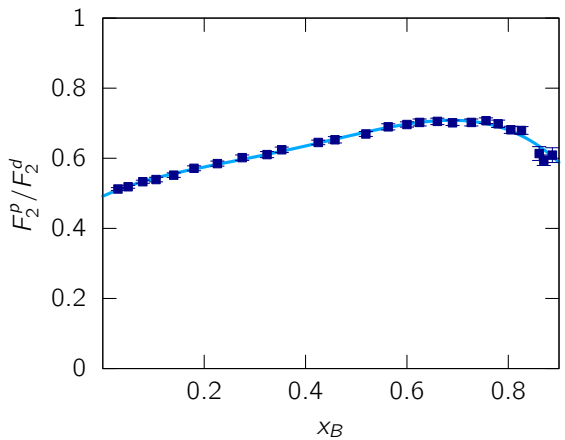
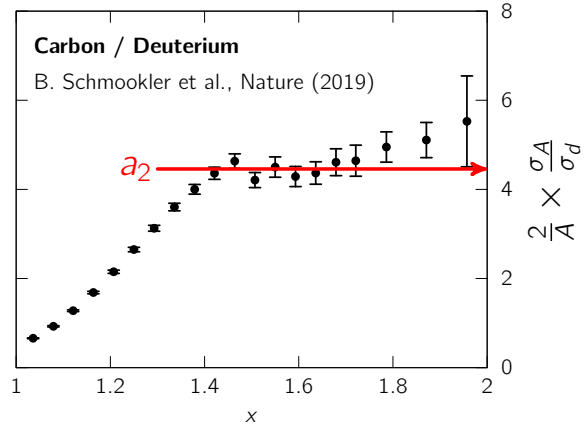
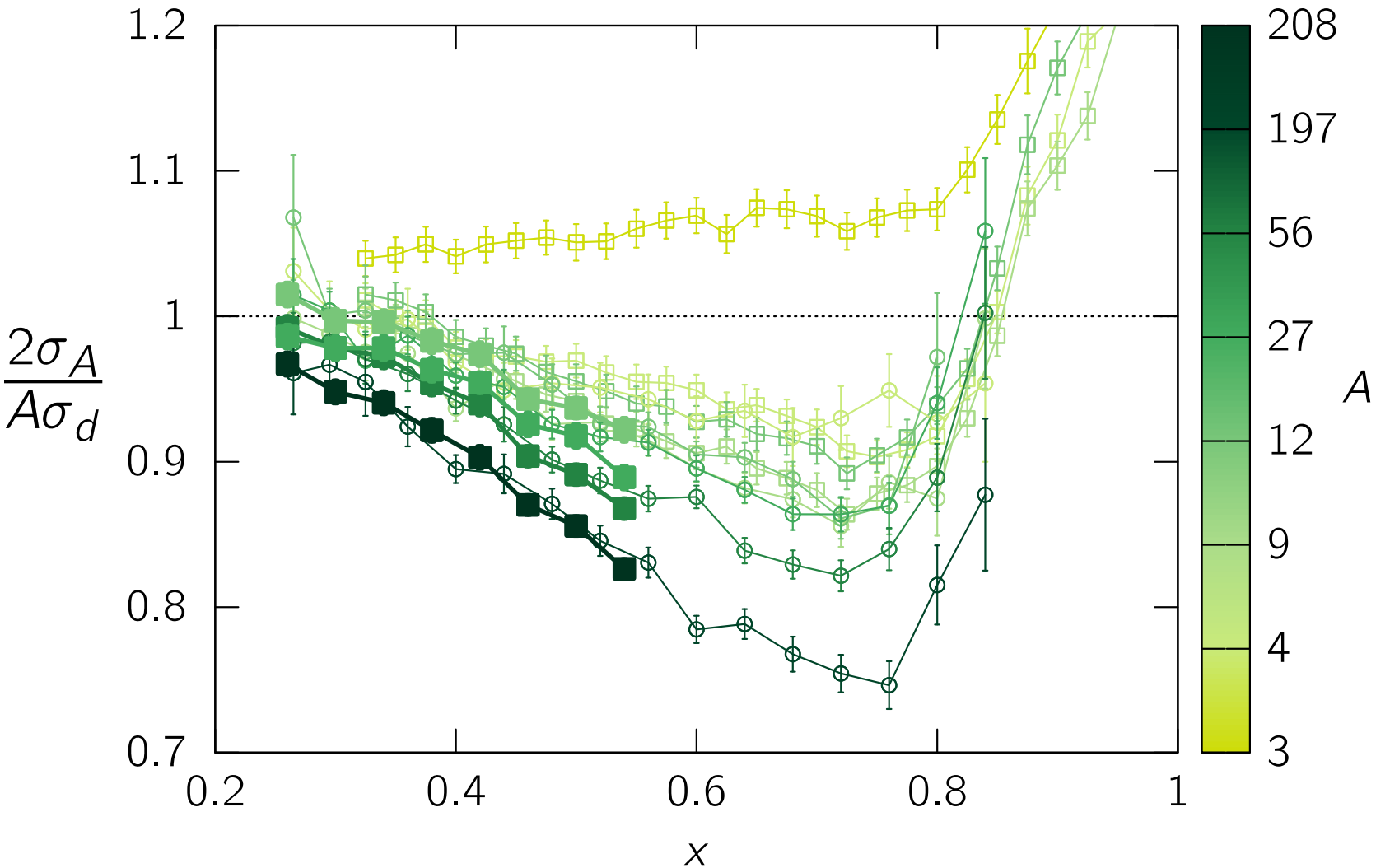


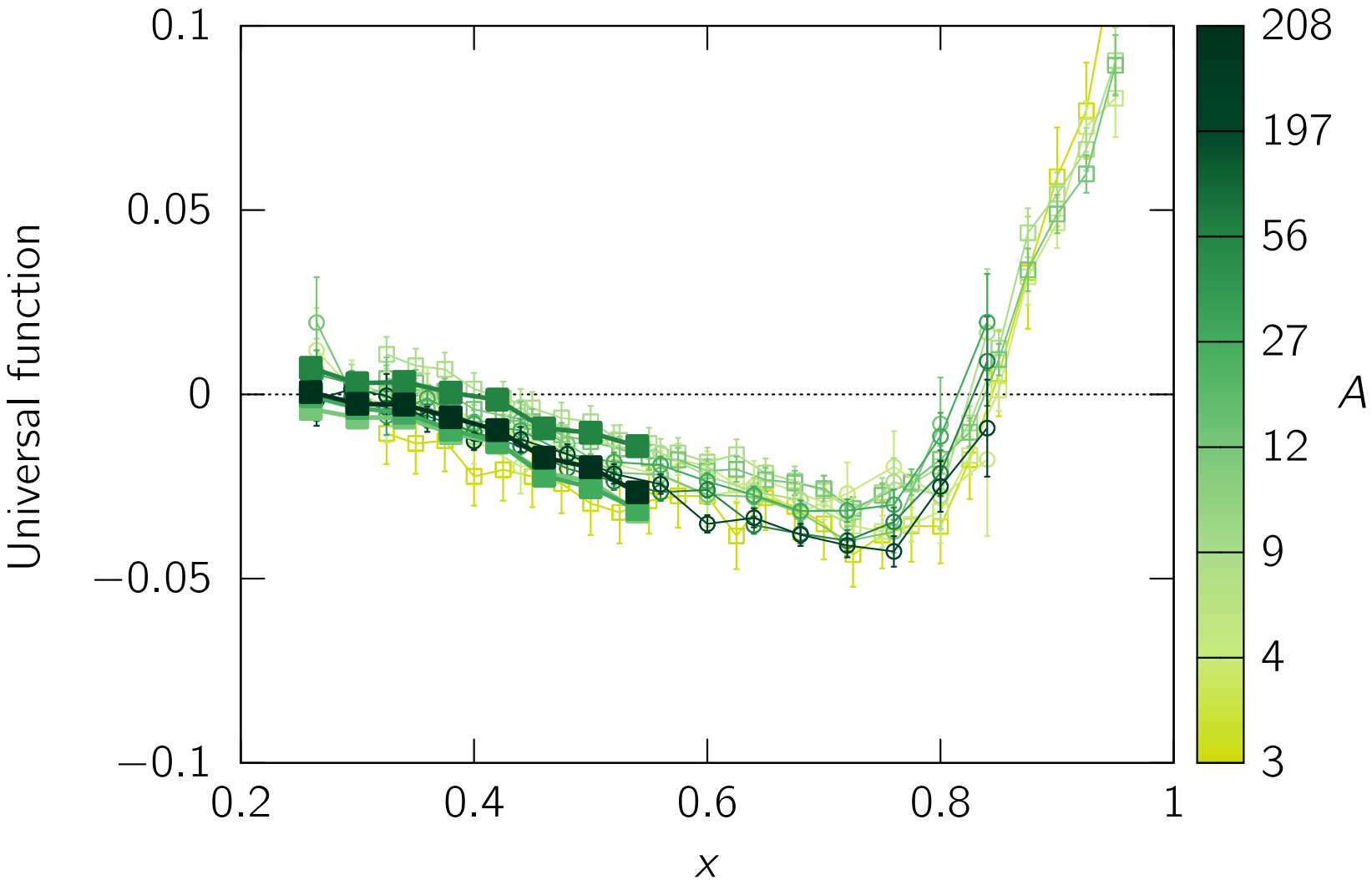




EMC Data vary significantly by nucleus.



The modification of SRC pairs is universal!



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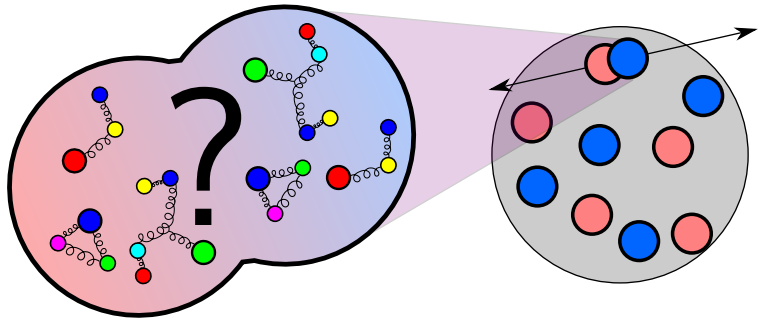

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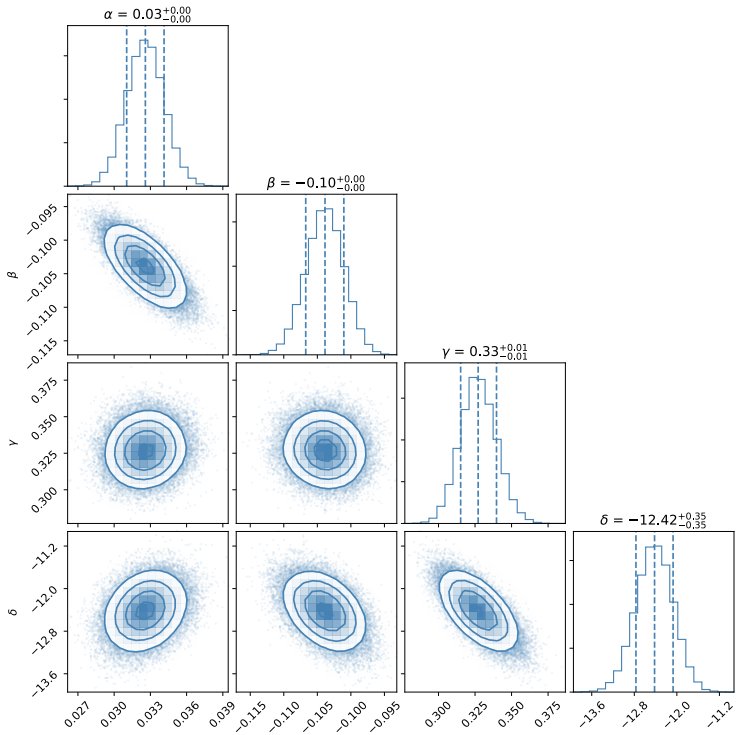
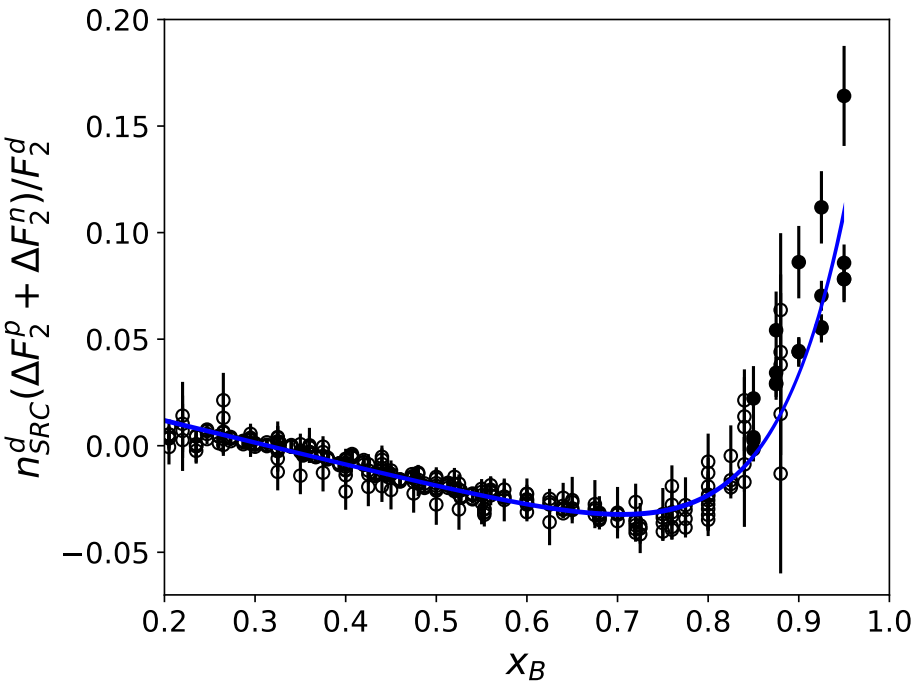
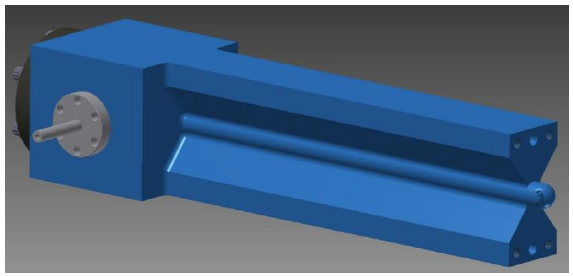
We extracted the universal modification from EMC and SRC data.

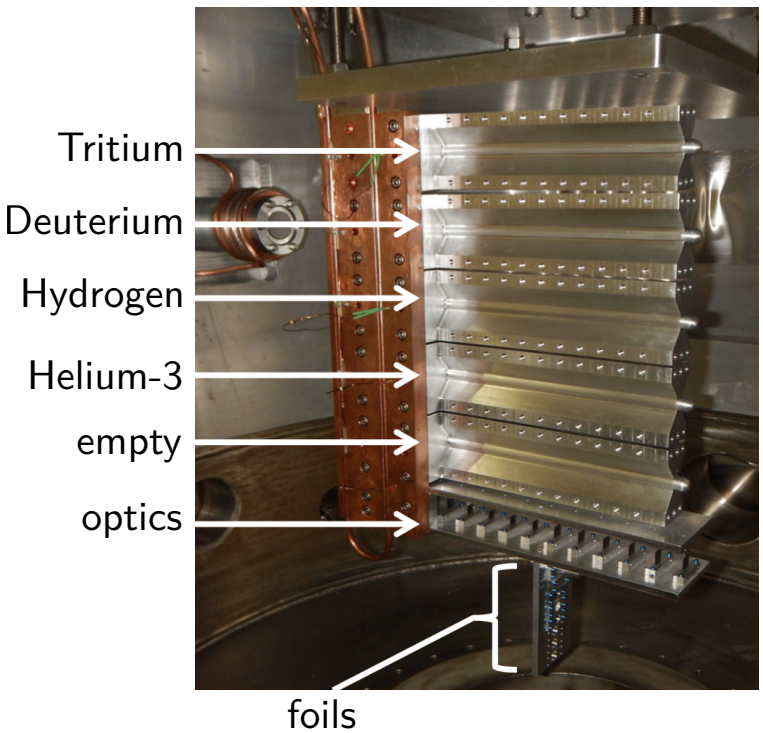
work by Efrain Segarra (MIT)
arXiv:1908.02223



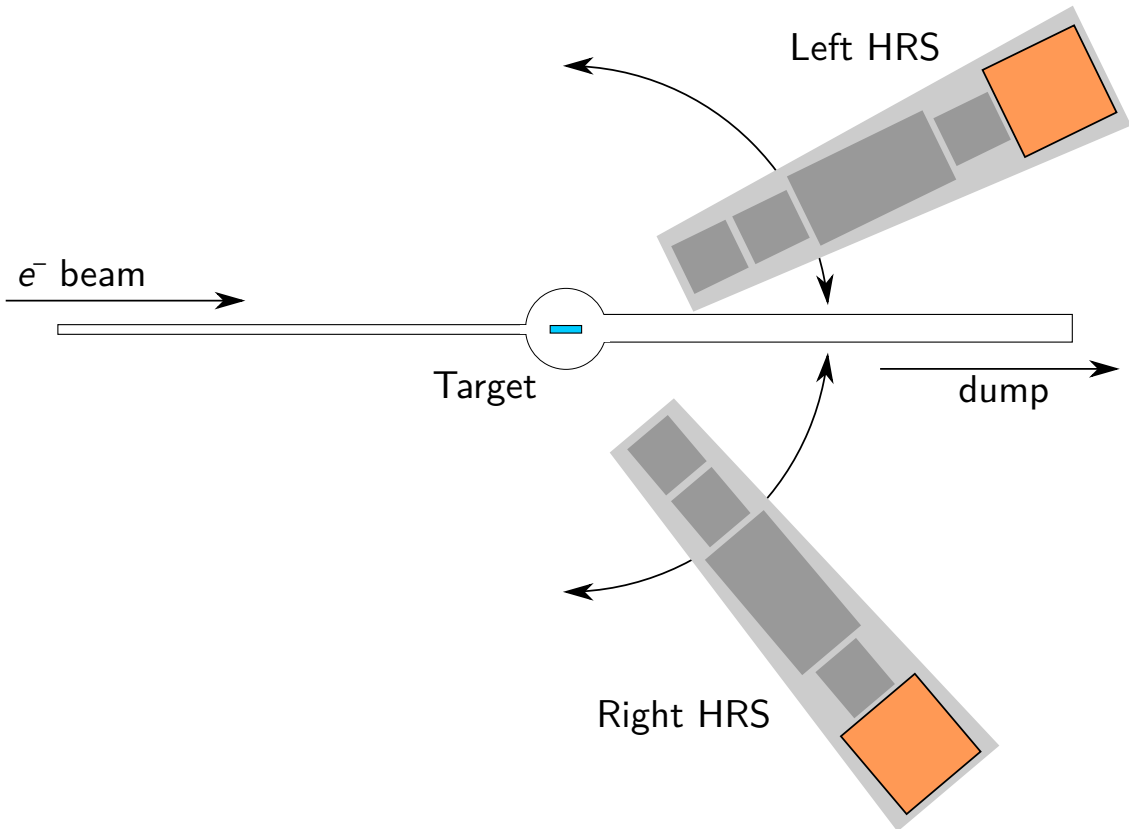


MARATHON made a once-in-a-generation DIS measurement on tritium.



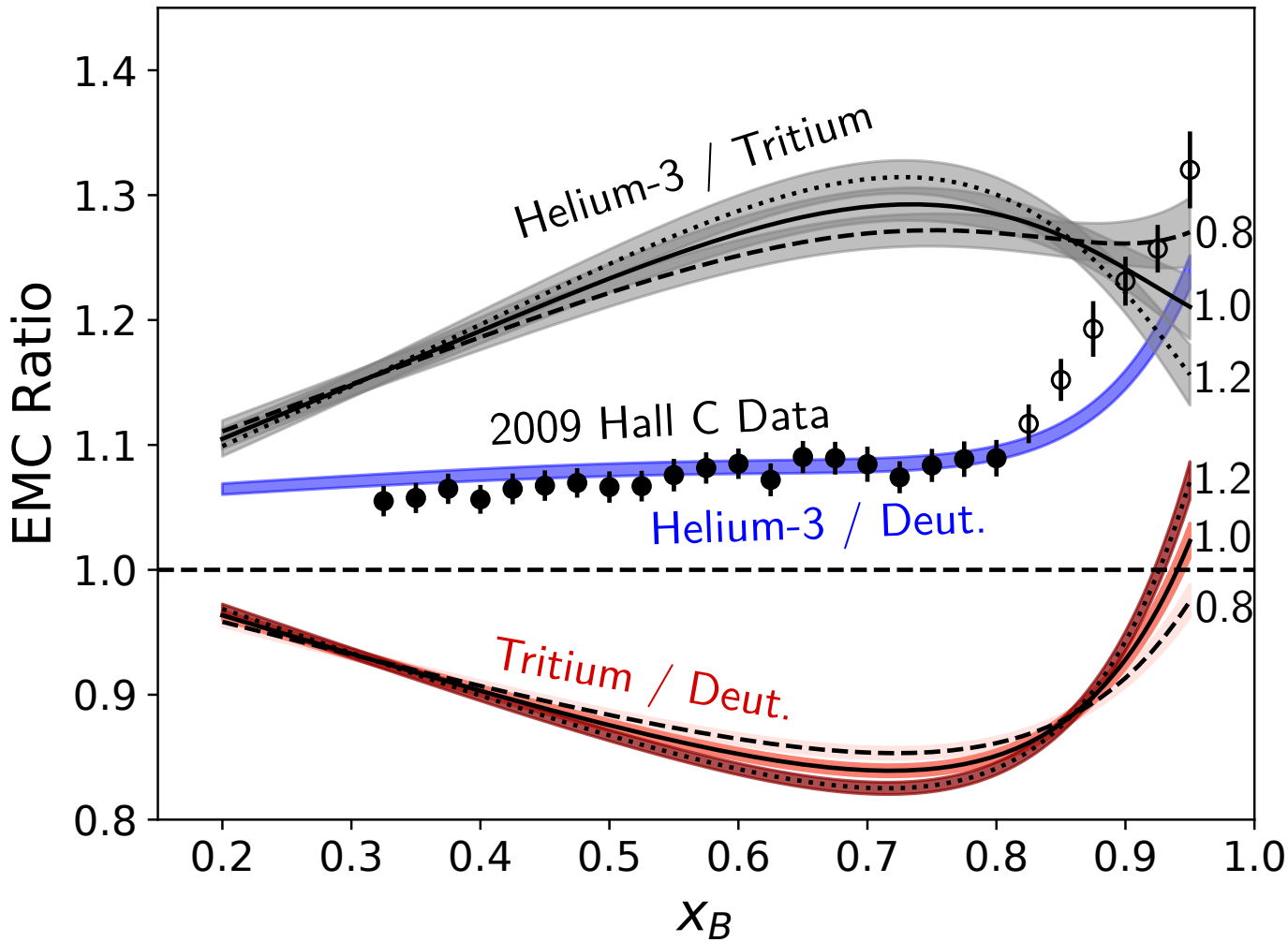


- Jefferson Lab Hall A
- 11 GeV beam, $0.20 < x < 0.84$

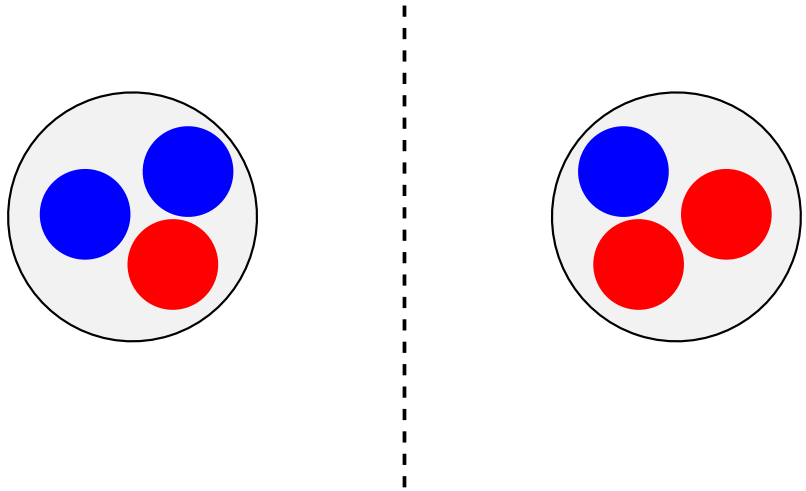


SRC-EMC model makes predictions for the $A = 3$ EMC Effect.

(predictions agree with MARATHON prelim. results.)



MARATHON aims to extract F_2^n/F_2^p at large x.



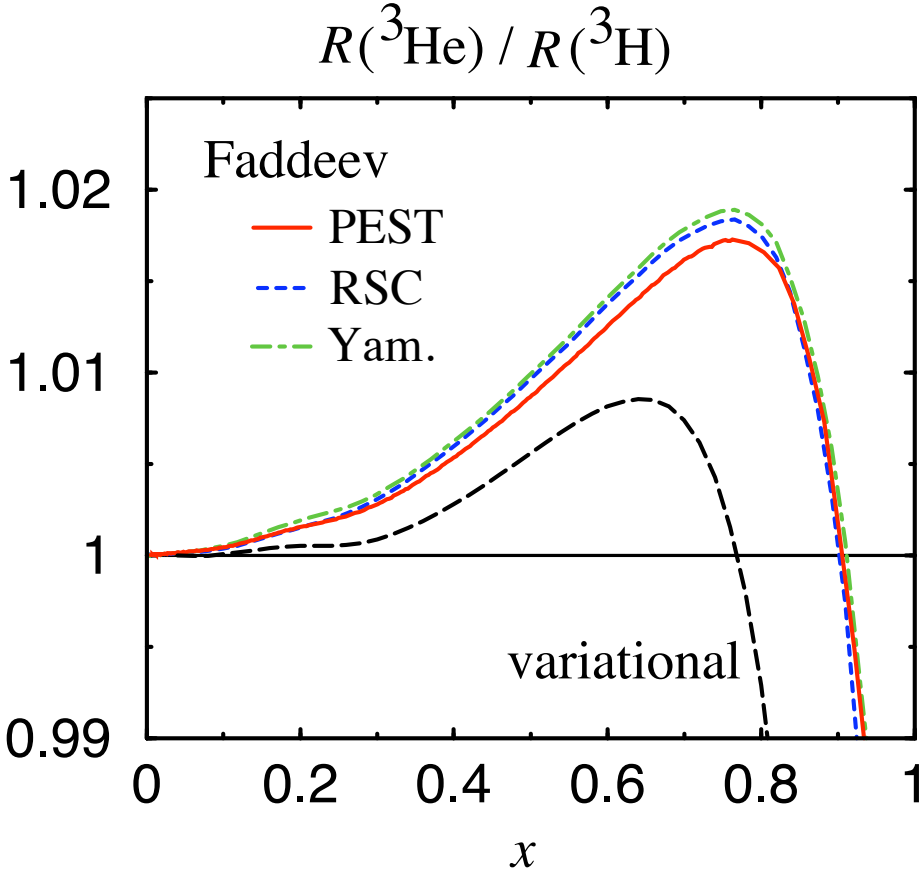
Using isospin symmetry:

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

Requires the ratio of EMC Effects:

$$\mathcal{R} \equiv \frac{F_2^{^3\mathrm{He}}}{2F_2^p + F_2^n} \Big/ \frac{F_2^{^3\mathrm{H}}}{F_2^p + 2F_2^n}$$

Hopefully model dependence of $\mathcal{R}$ is small.



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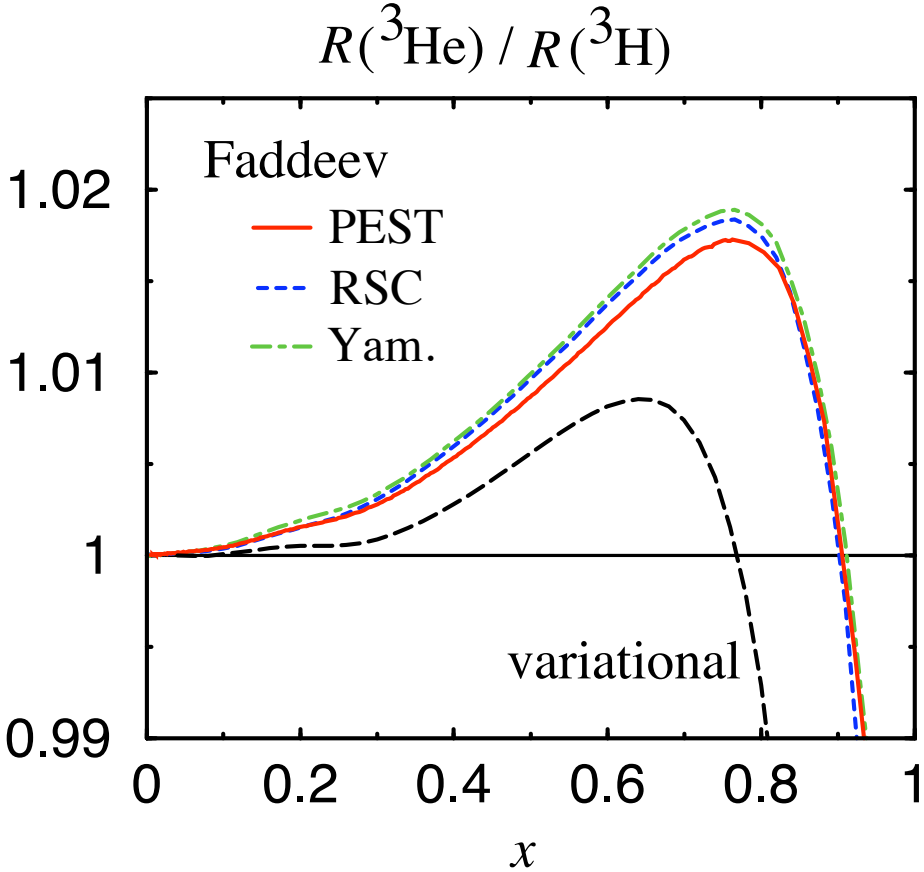

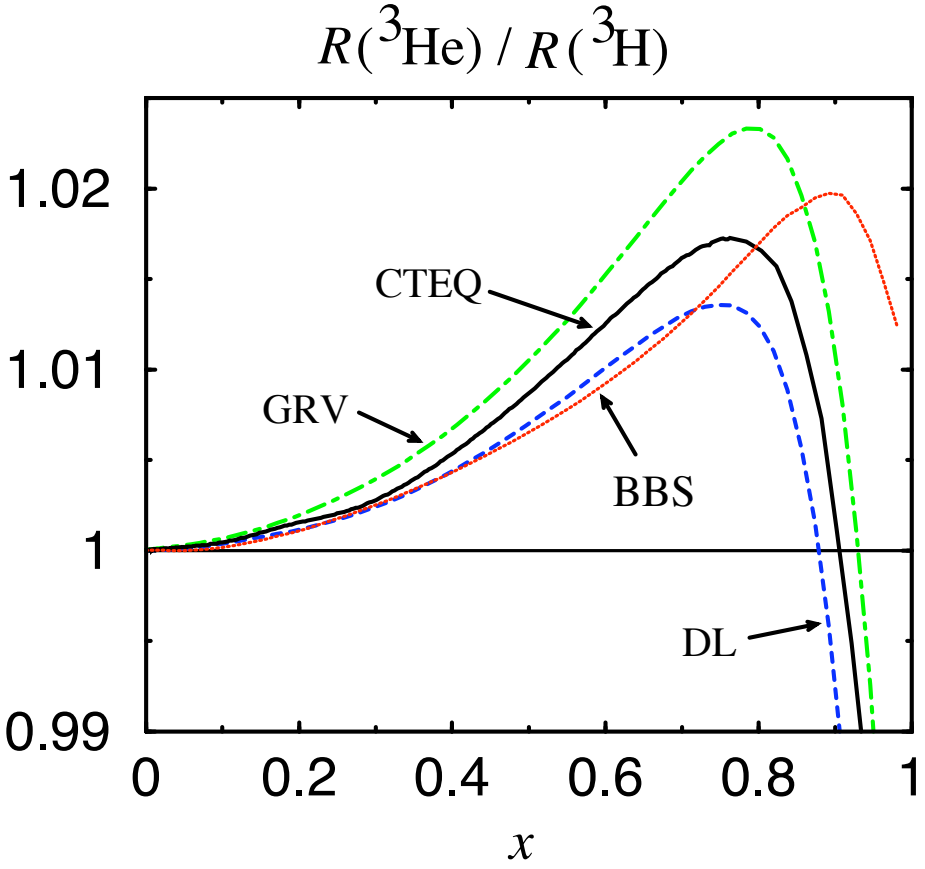

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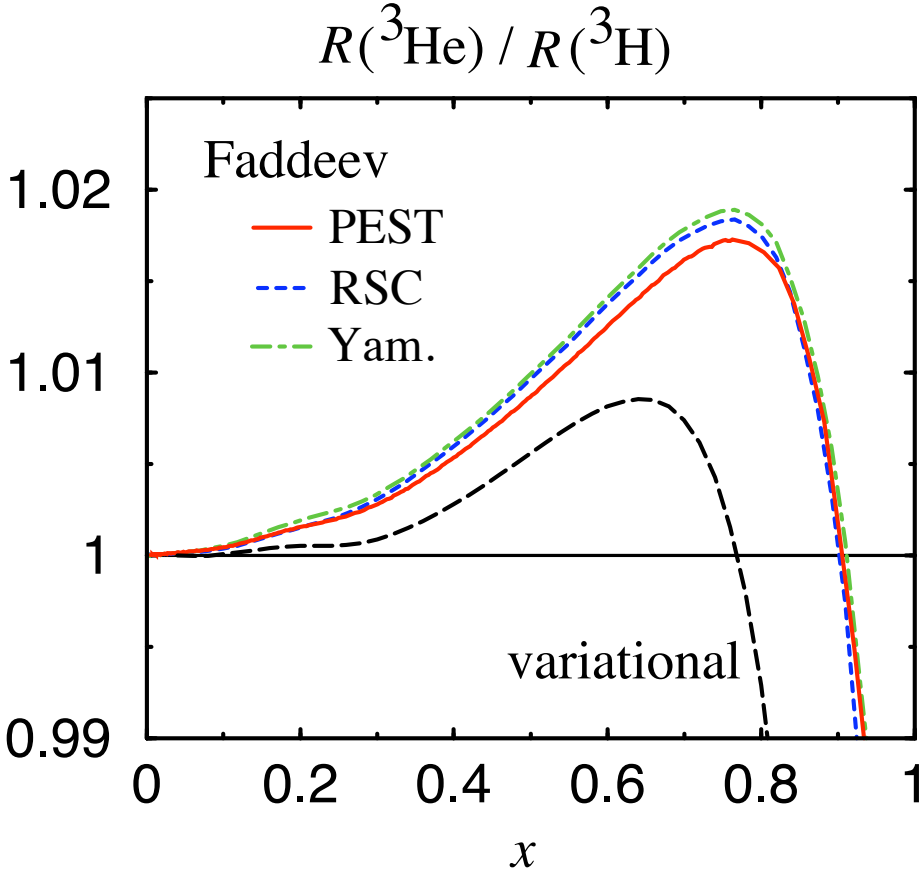
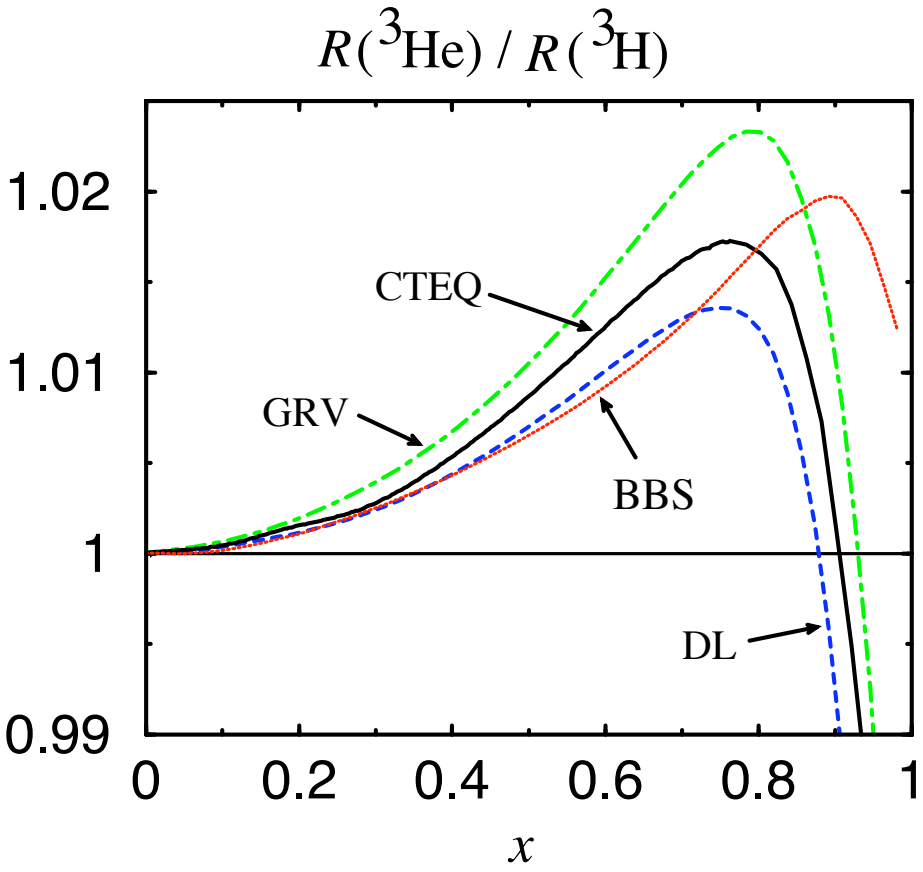
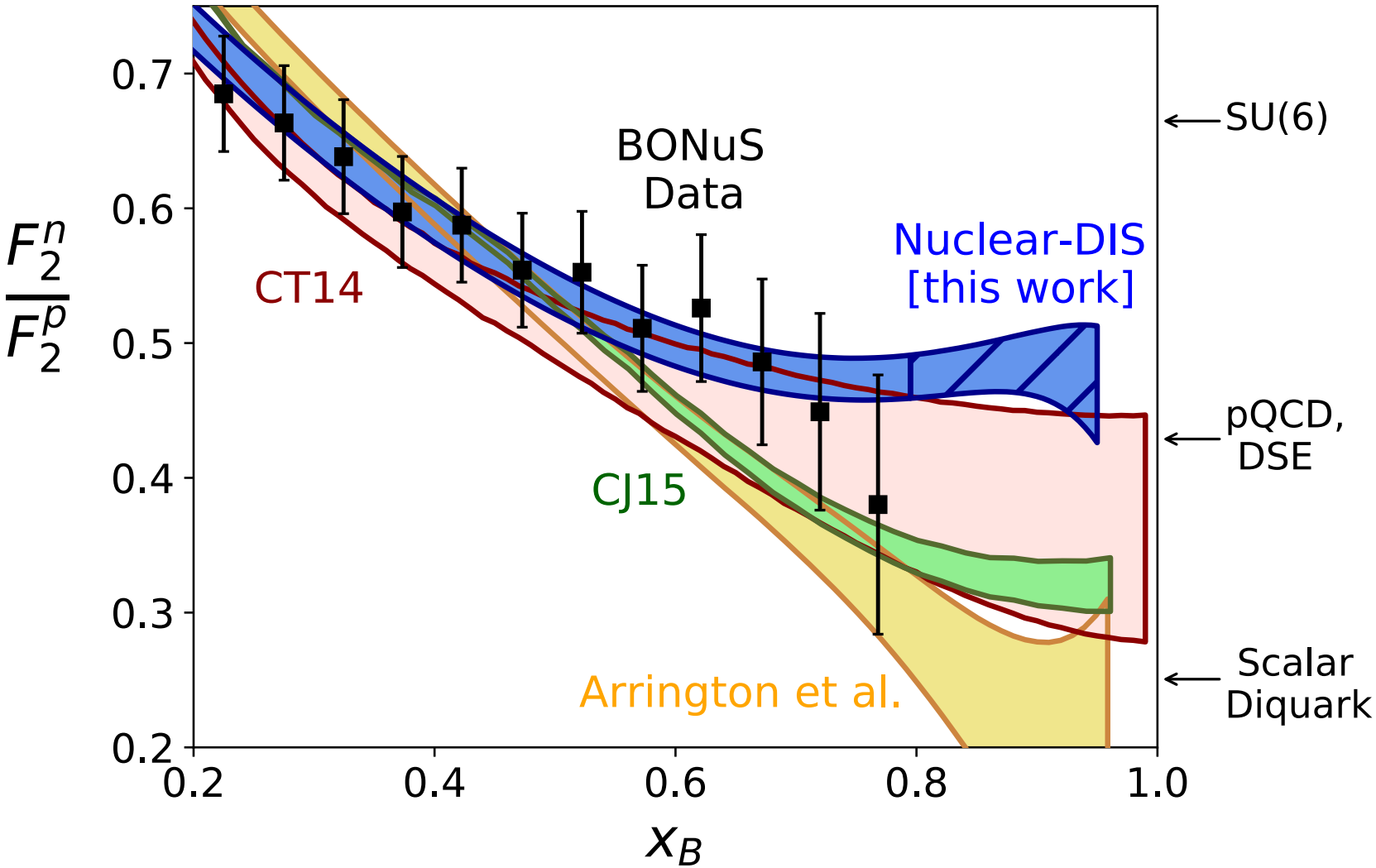


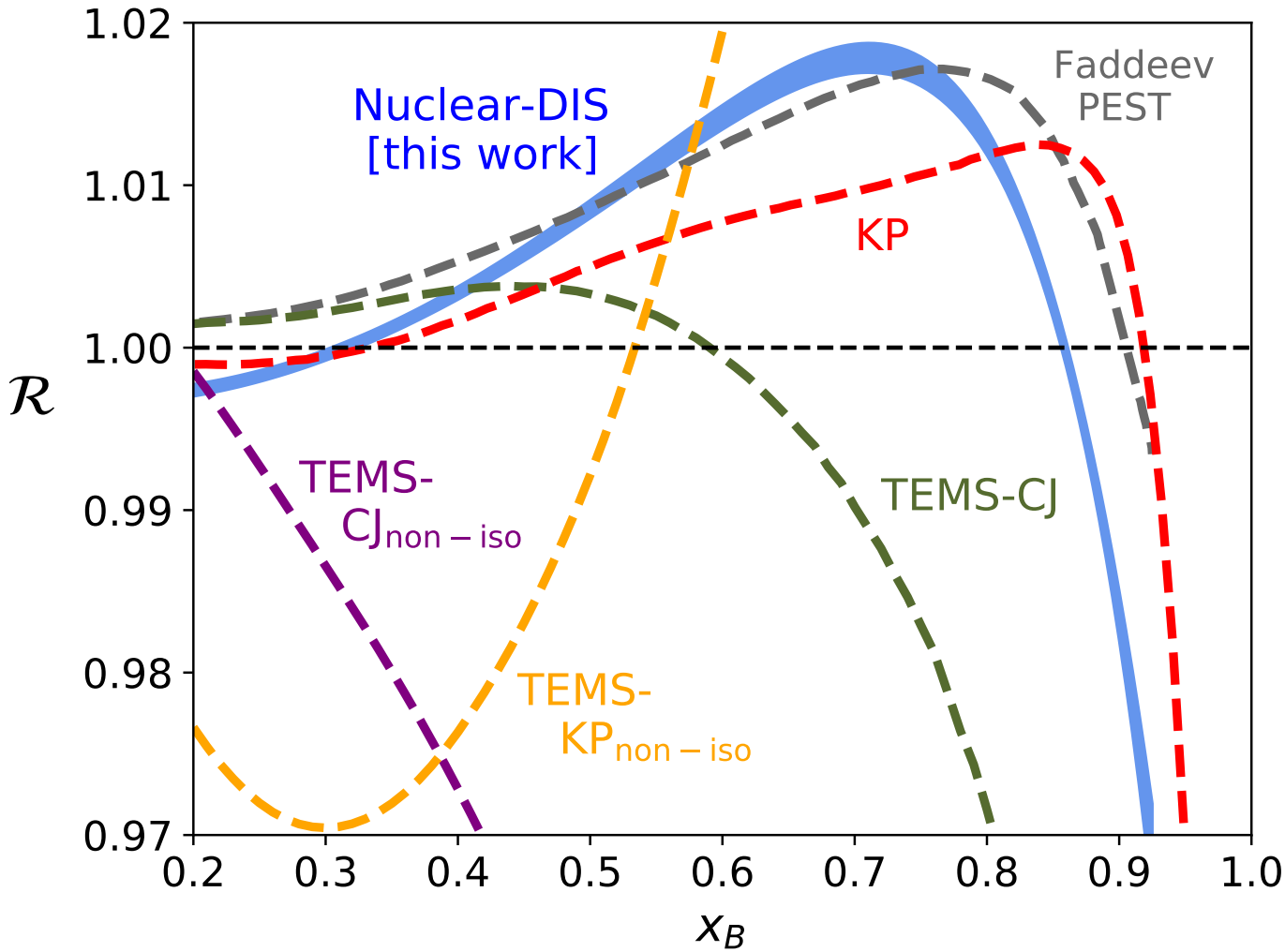


Iterative procedure: use measured F_2^n to recalculate $\mathcal{R}$

The EMC-SRC Model predicts leveling at $F_2^n/F_2^p \approx 0.47$.



Reasonable assumptions can lead to wide variation in $\mathcal{R}$.



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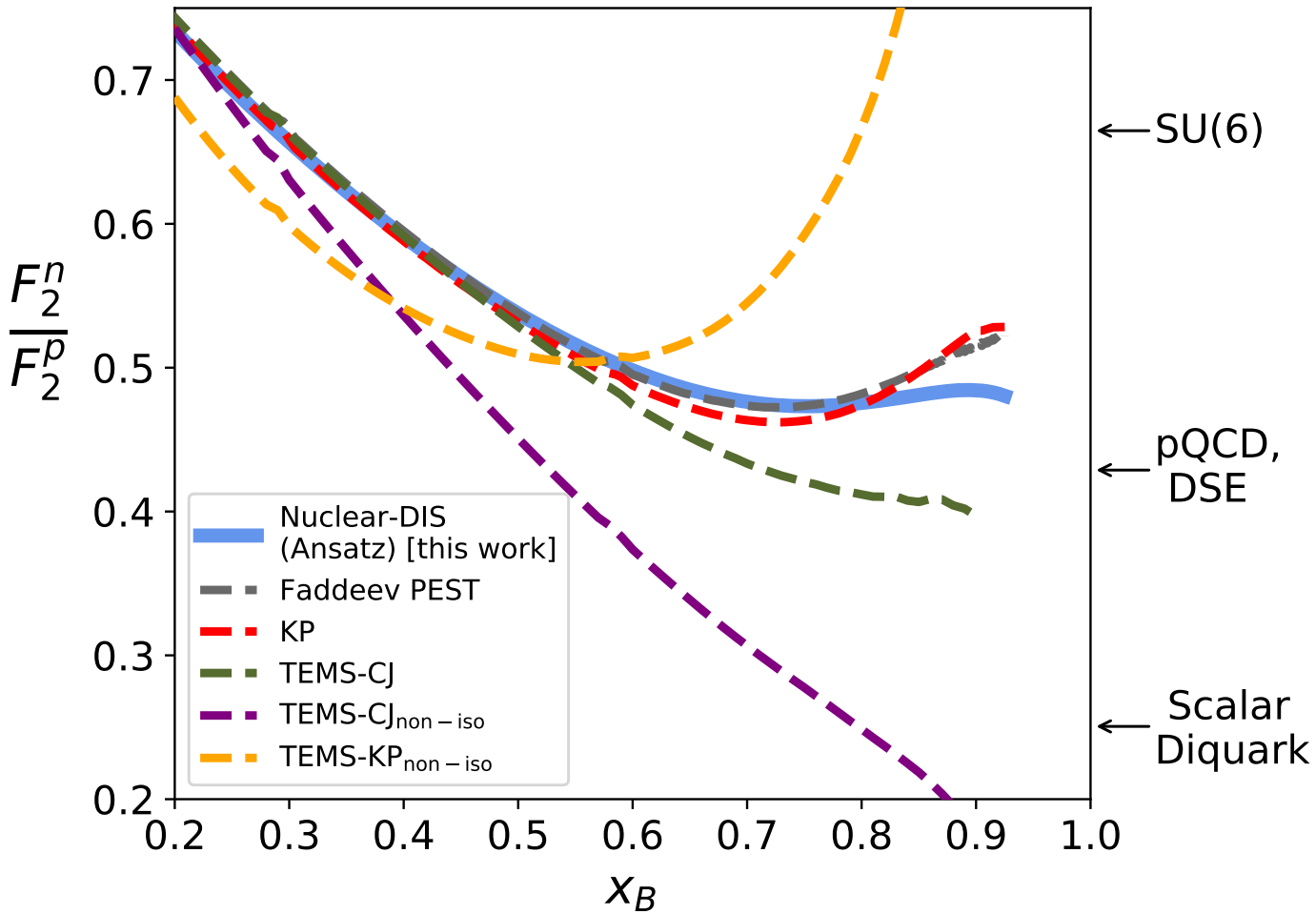

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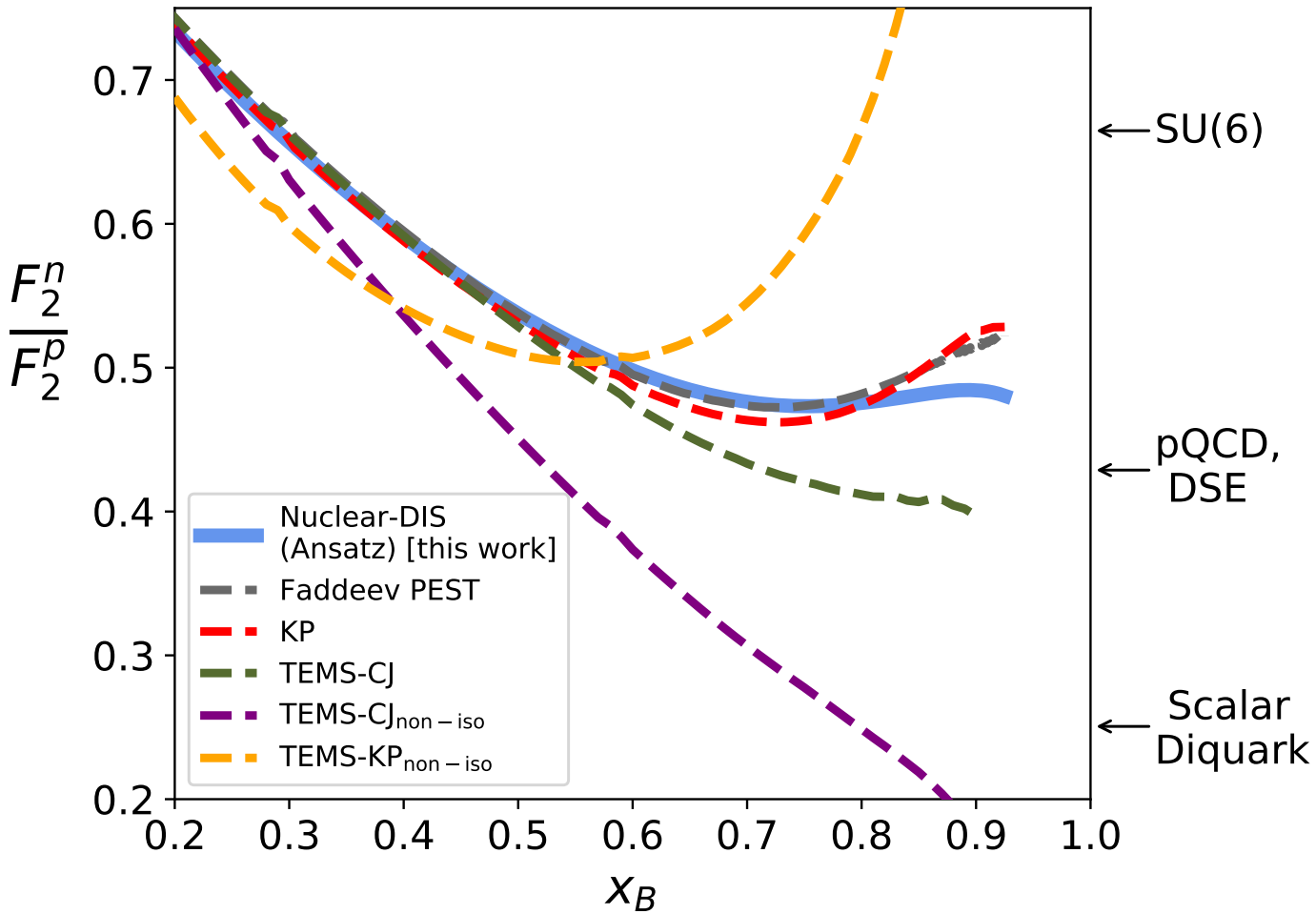
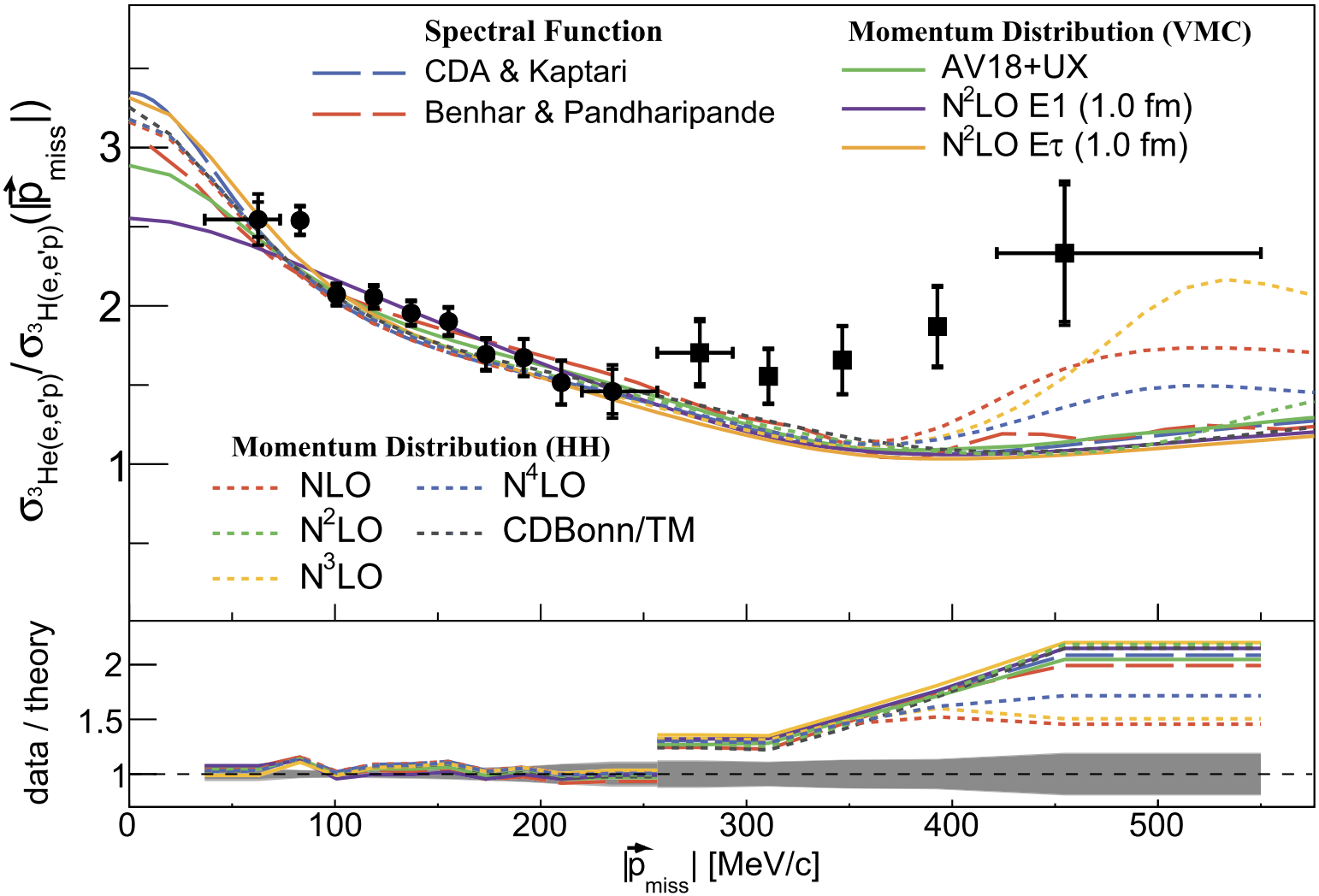


More robust: simultaneous analysis of H, d, tritium, helium-3 data!

Even $A = 3$ can be messy!

R. Cruz-Torres et al., Phys. Lett. B 797 134890 (2019)



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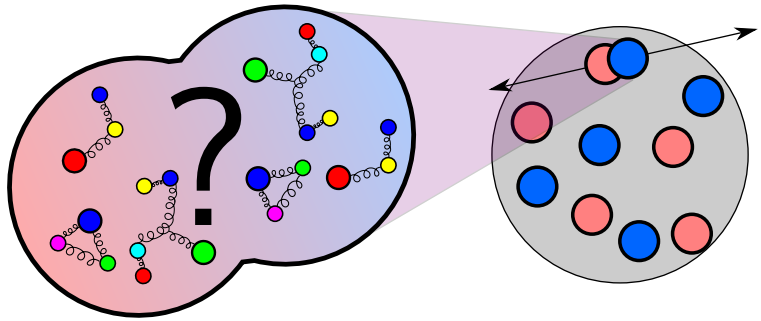
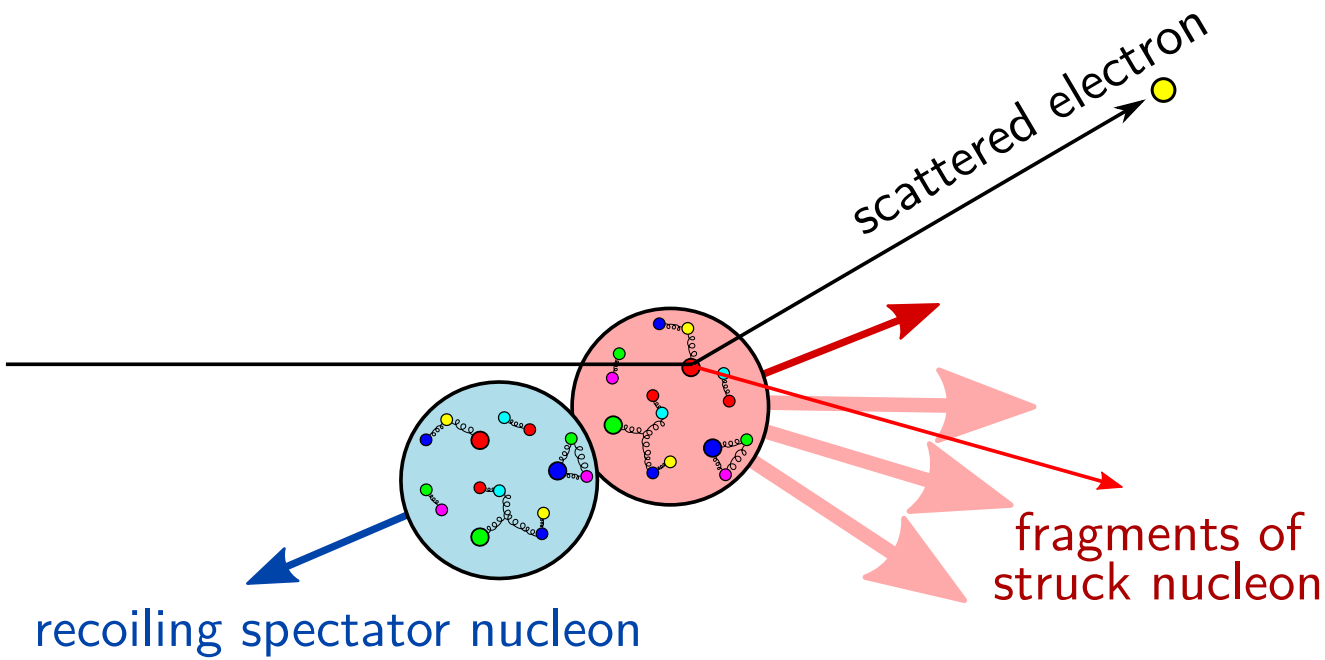


- The per-pair modification is universal.
  - B. Schmookler et al., Nature 566 p. 354 (2019)
- The SRC-EMC hypothesis makes predictions for MARATHON.
  - E. P. Segarra et al., arXiv:1908.02223 (2019)
- **Direct tests with BAND and LAD experiments**
  - **Recoil spectator tagging at Jefferson Lab**

We can isolate SRC nucleons by "tagging" a correlated partner.



1. Mom. of the scattered e^- $\longrightarrow$ determine quark momentum
2. Mom. of the spectator $\longrightarrow$ determine if SRC configuration

Need to measure 200–700 MeV/c spectators!

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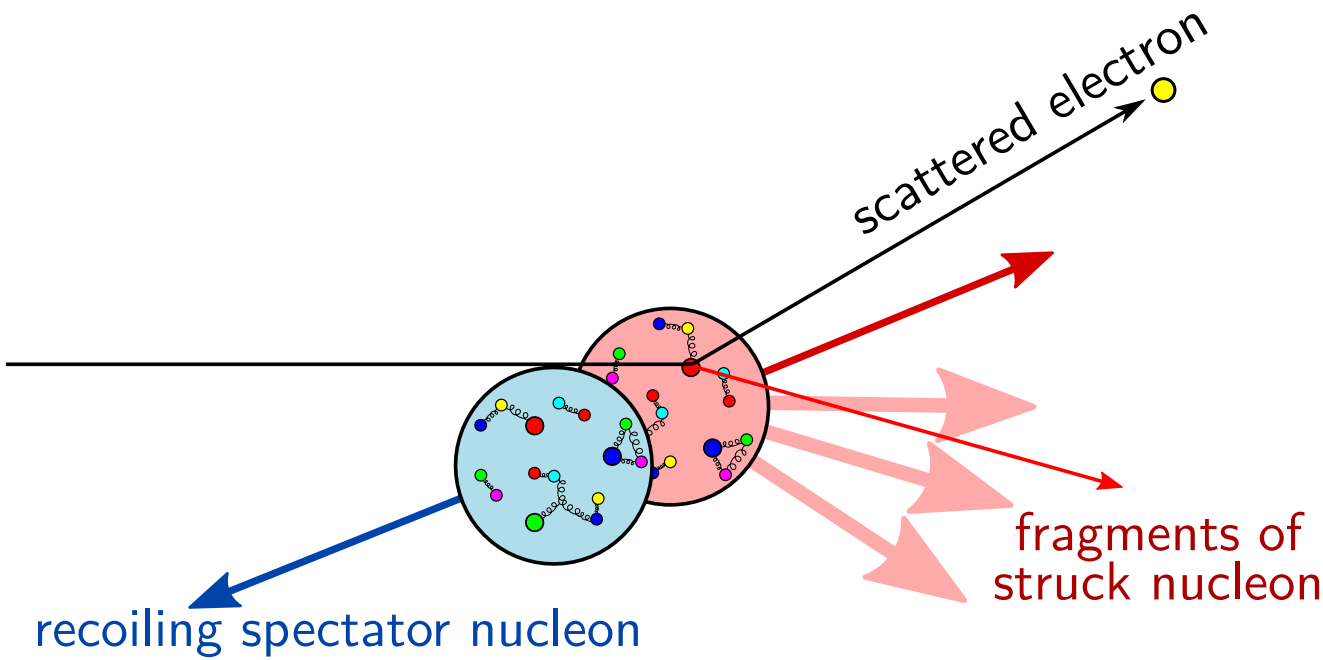

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2. Mom. of the spectator $\longrightarrow$ determine if SRC configuration

Need to measure 200–700 MeV/c spectators!

What we want to measure:

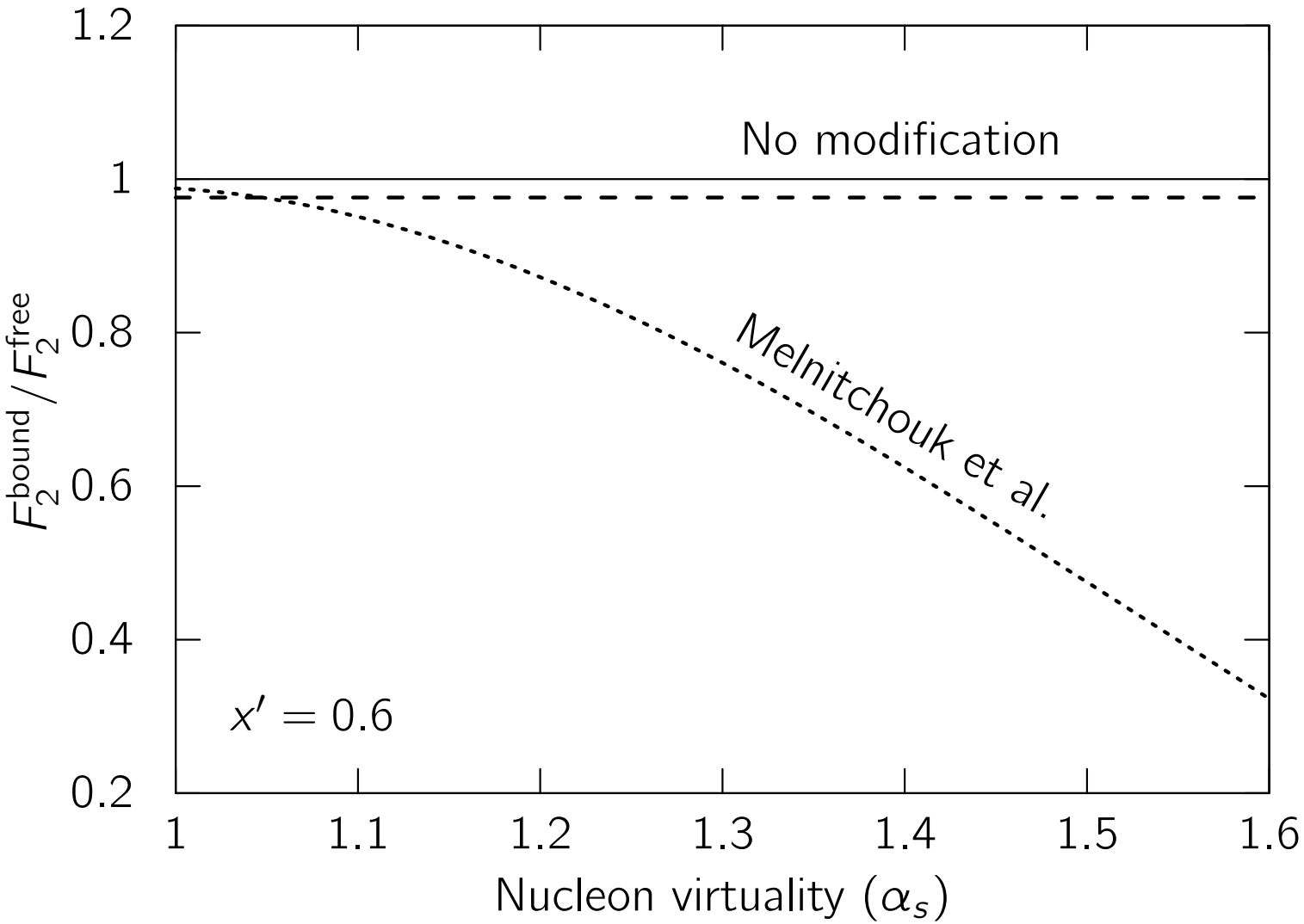
$$\frac{F_2(x', Q^2, \alpha_s)_{\text{bound}}}{F_2(x, Q^2)_{\text{free}}} \approx \frac{\sigma_{\text{DIS}}(x', Q^2, \alpha_s)_{\text{bound}}}{\sigma_{\text{DIS}}(\text{low } x', Q_0^2, \alpha_s)_{\text{bound}}} \times \frac{\sigma_{\text{DIS}}(\text{low } x, Q_0^2)_{\text{free}}}{\sigma_{\text{DIS}}(x, Q^2)_{\text{free}}} \times R_{\text{FSI}}$$

·	Tagged DIS measurement	Input	≈ 1

At low x, the EMC effect should be small:

$$\sigma_{\text{DIS}}(\text{low } x', Q_0^2, \alpha_s)_{\text{bound}} \approx \sigma_{\text{DIS}}(\text{low } x, Q_0^2)_{\text{free}}$$

The SRC hypothesis predicts more modification with larger spectator virtuality.



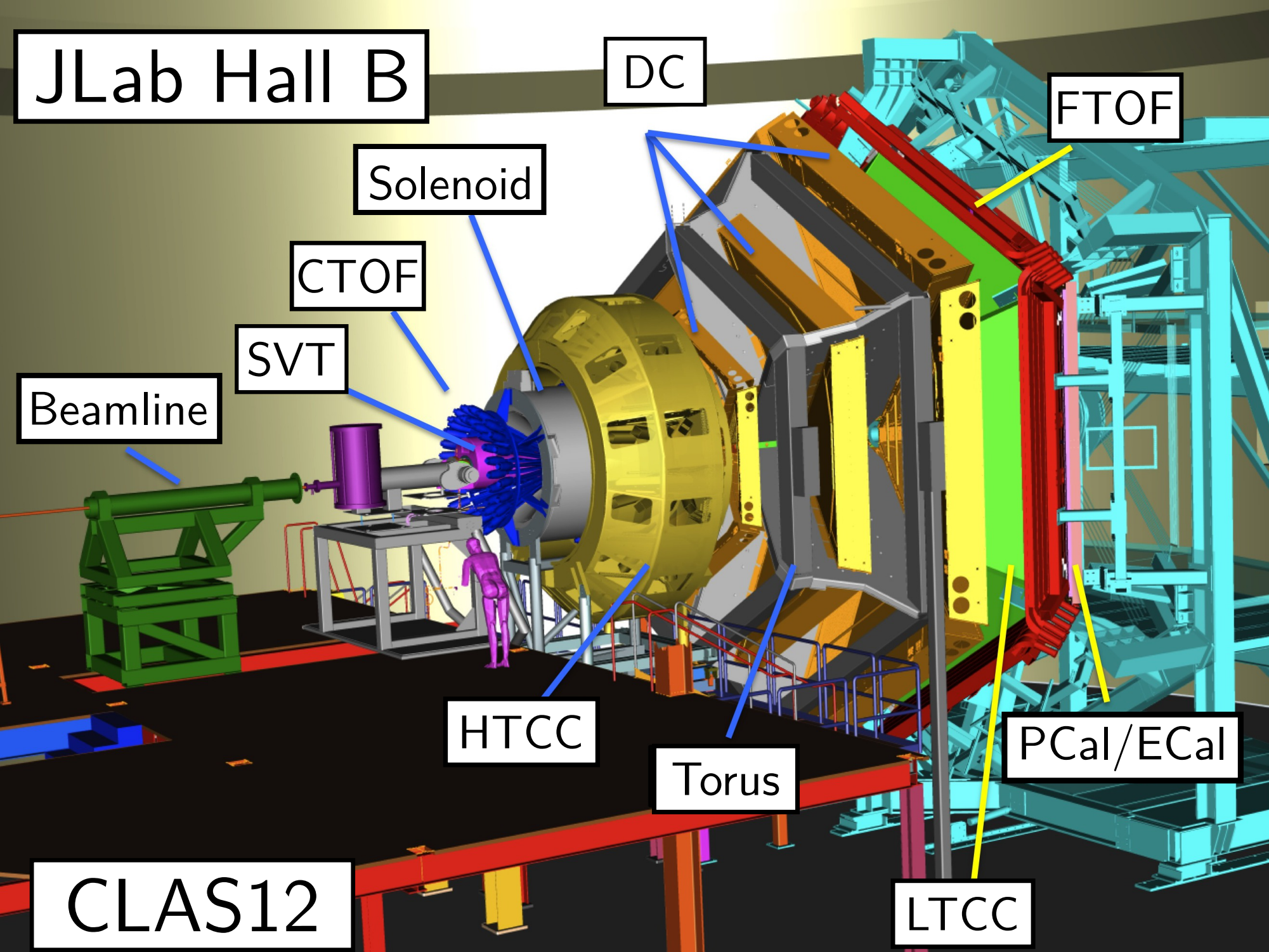
Two upcoming experiments at Jefferson Lab will complement each other.

BAND

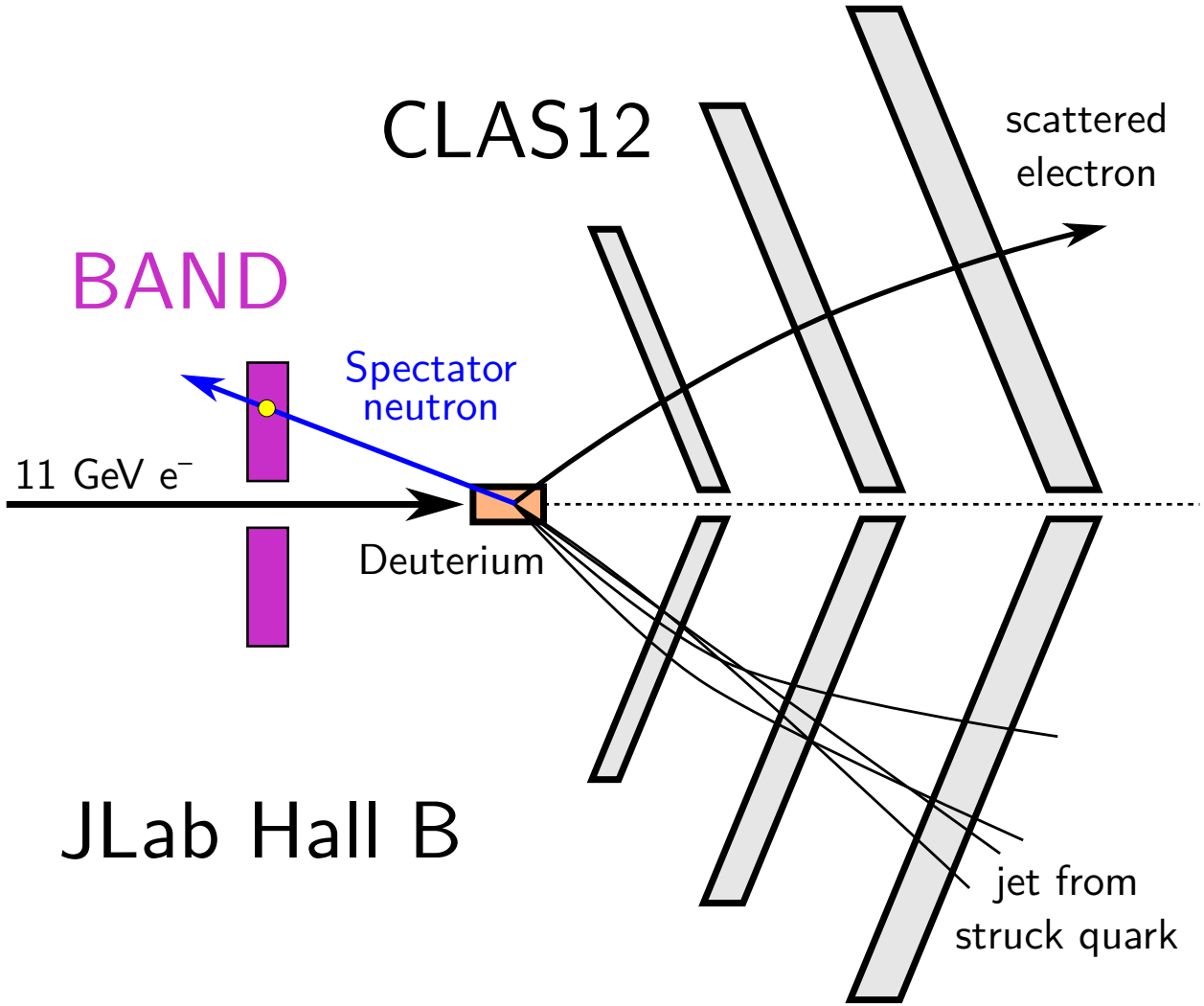
- quarks in protons
- detect recoil neutrons
- JLab Hall B
- Data taking started this spring!

LAD

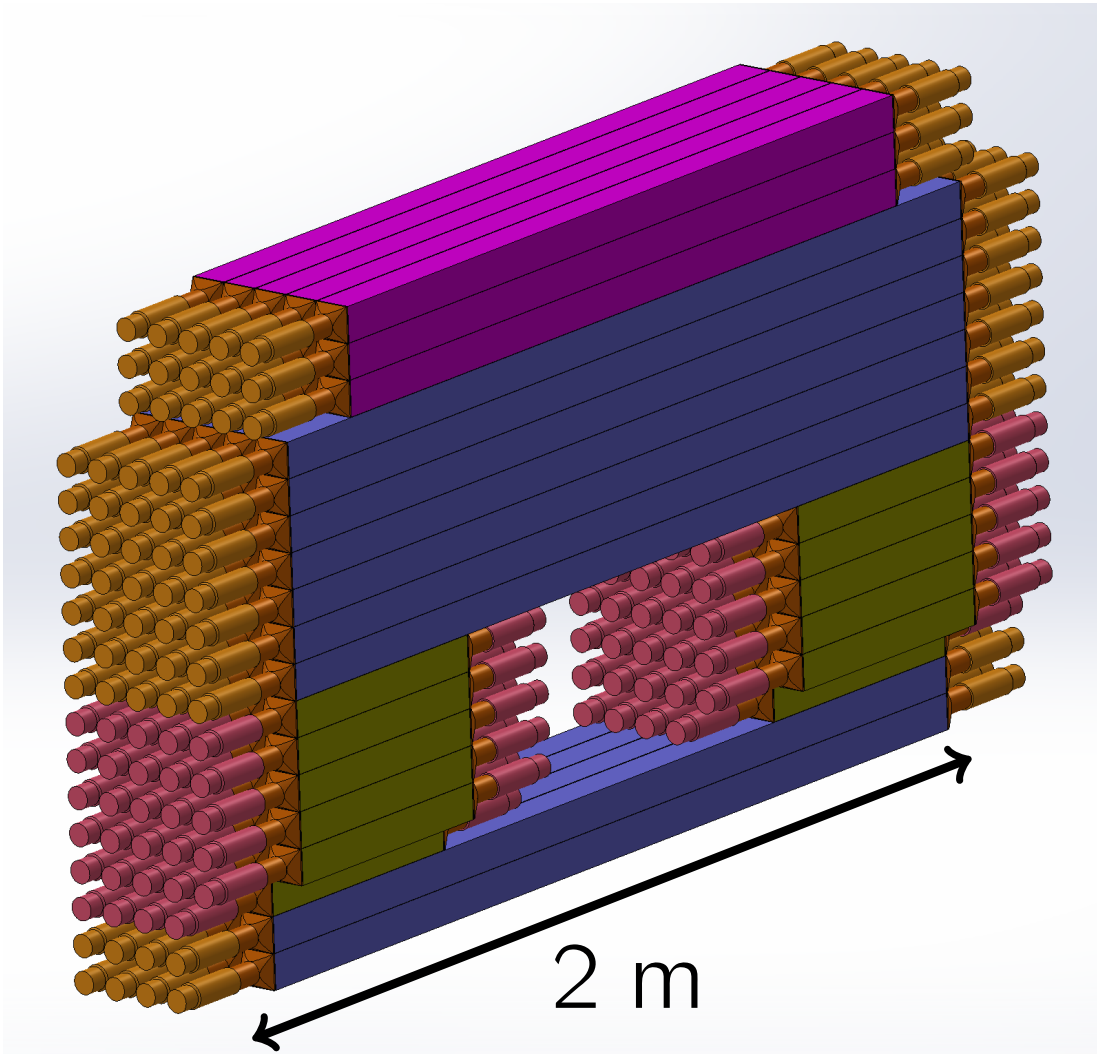
- quarks in neutrons
- detect recoil protons
- JLab Hall C
- to be scheduled. . .


JLab Hall B
DC
FTOF
Solenoid
CTOF
SVT
Beamline
HTCC
Torus
PCal/ECal
LTCC
CLAS12

“Backward Angle Neutron Detector” detects recoiling spectator neutrons



BAND is made up of modular bars made of scintillating plastic.



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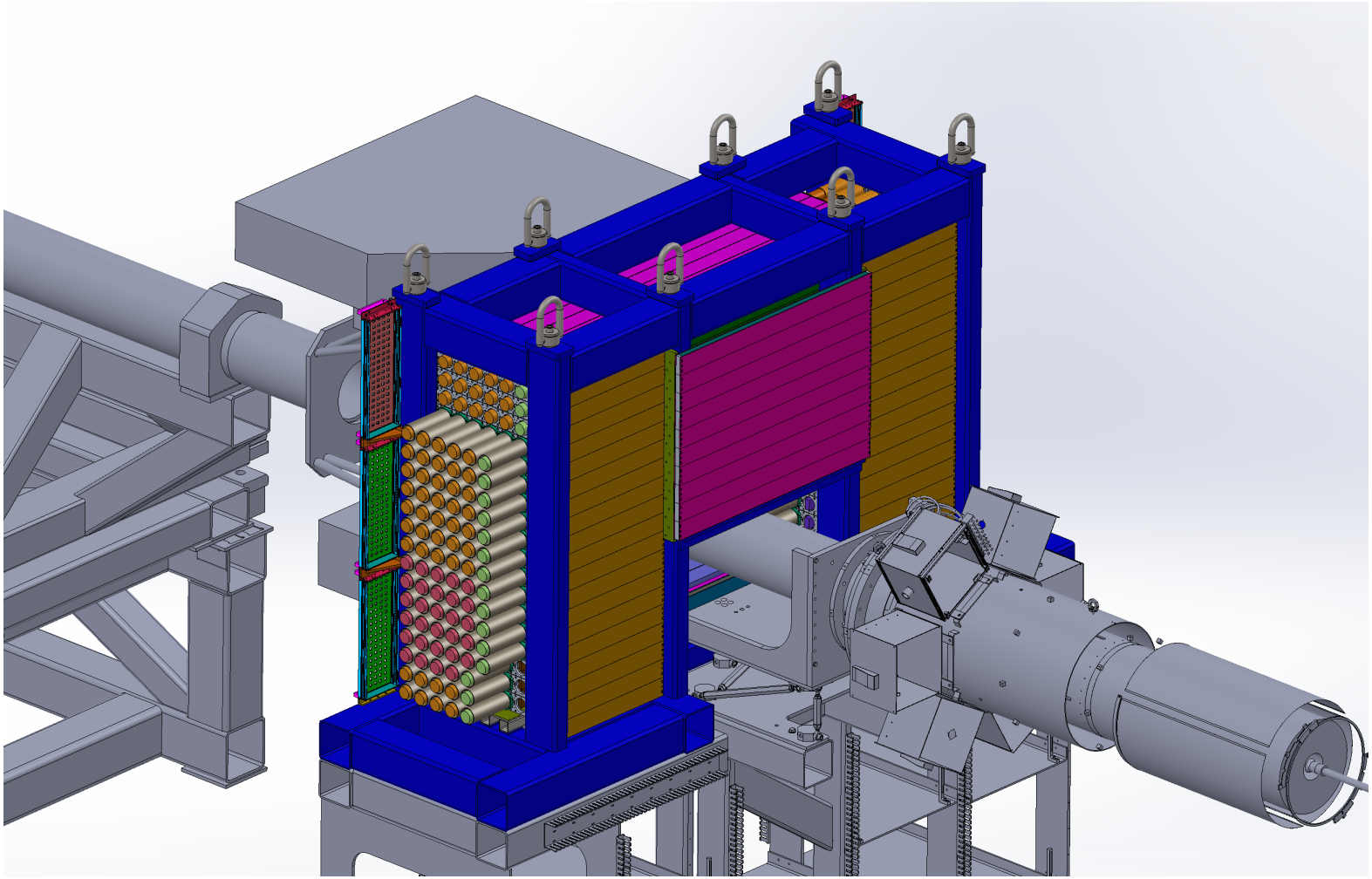
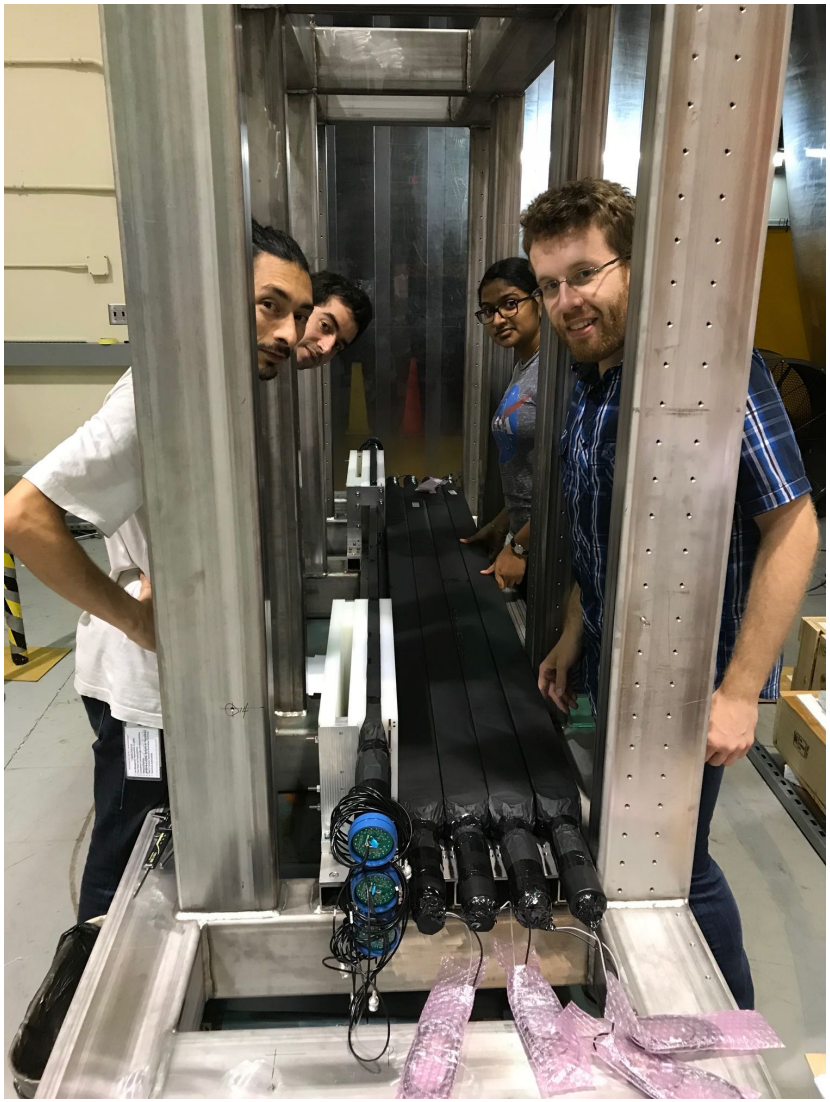


BAND assembly (2018)



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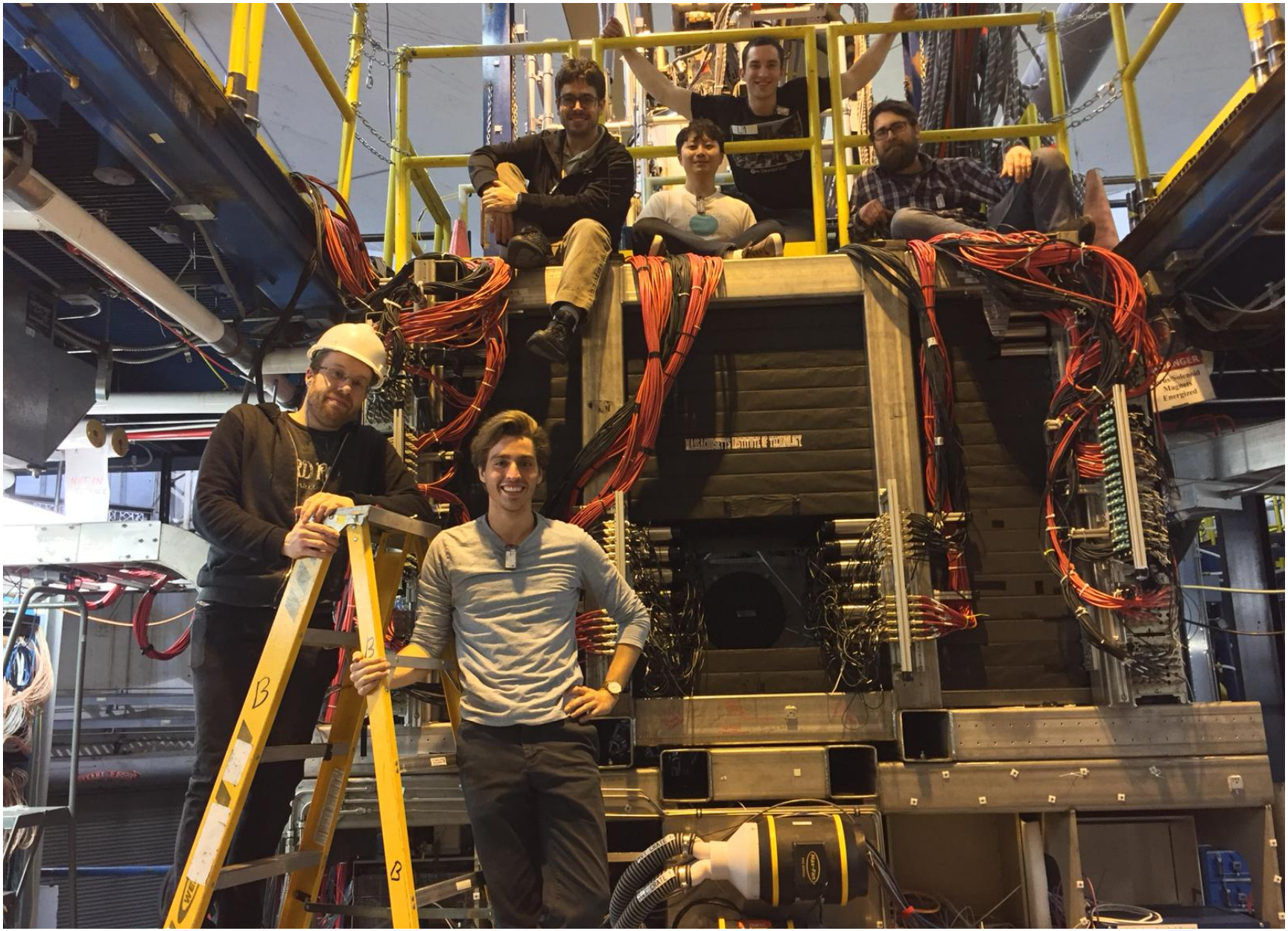
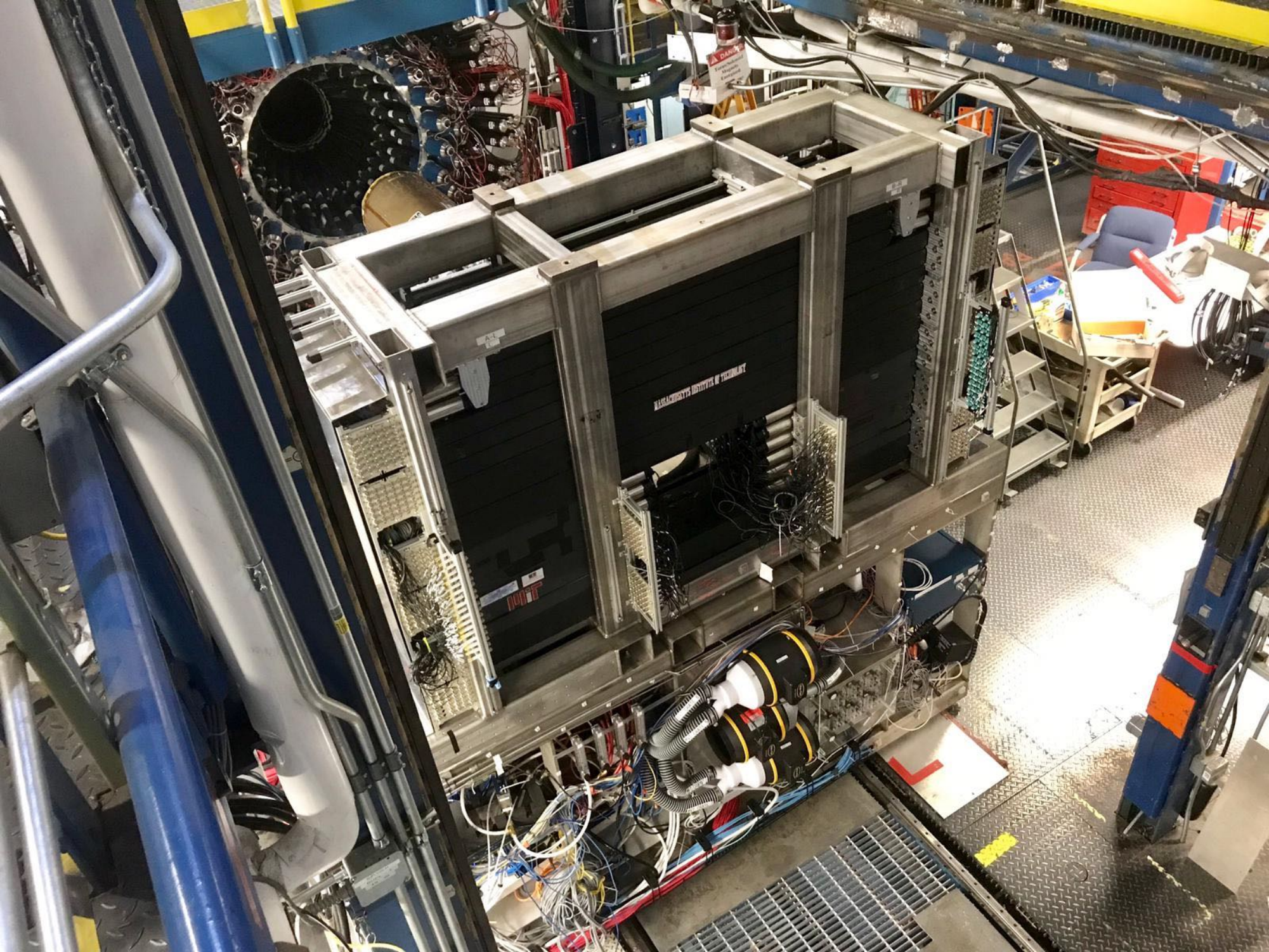
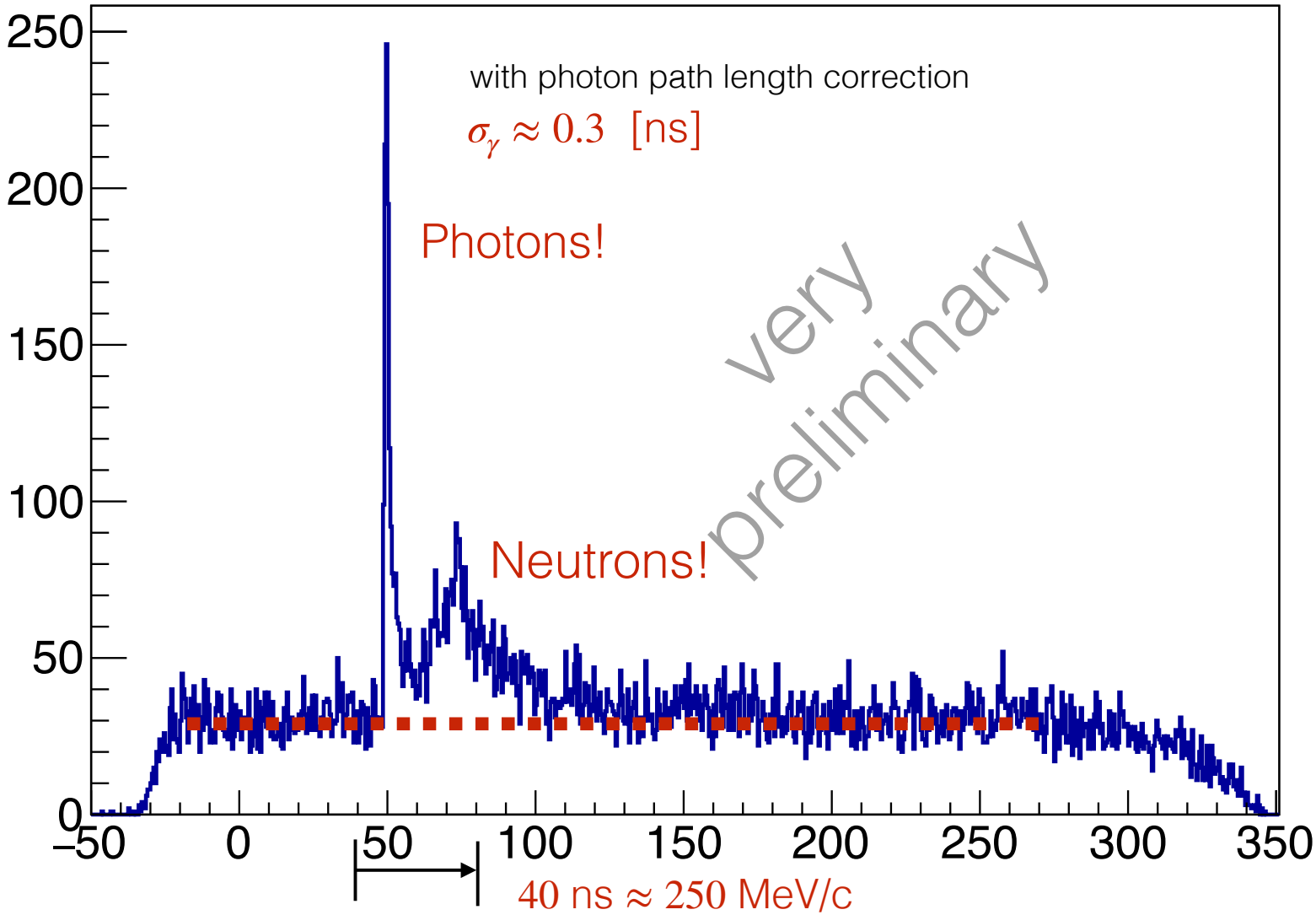
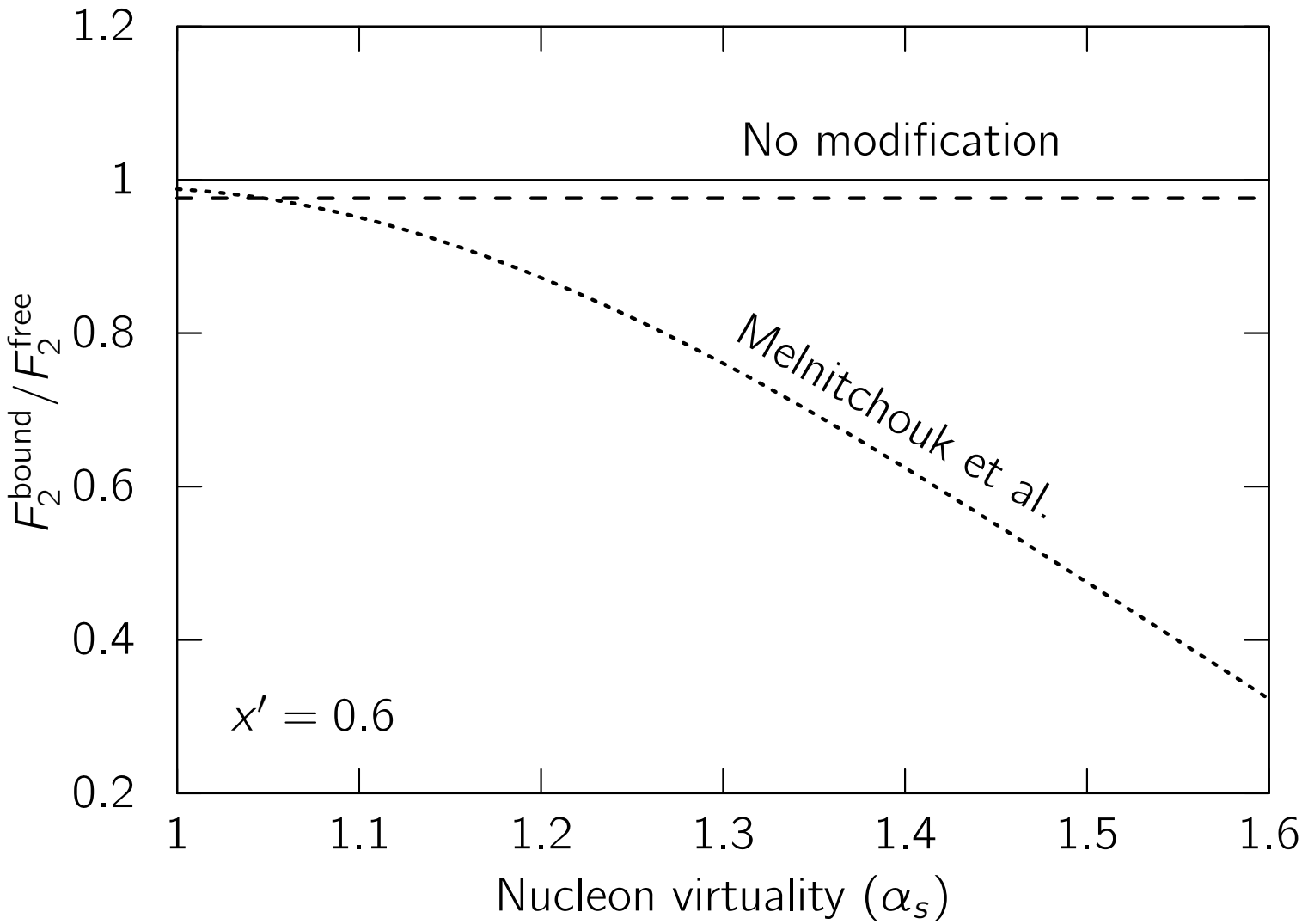




We already see a clear neutron signal.



The SRC hypothesis predicts more modification with larger spectator virtuality.



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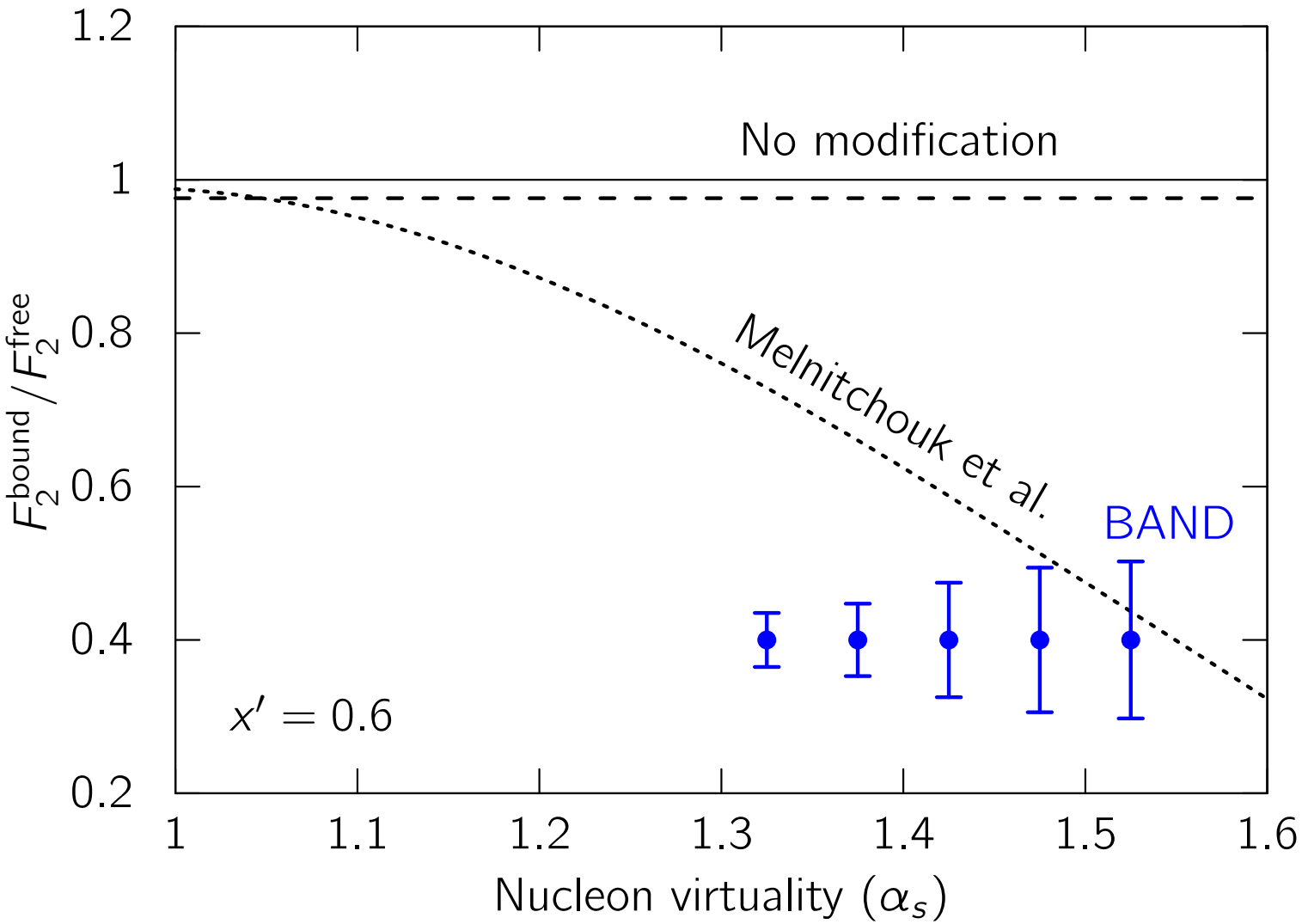
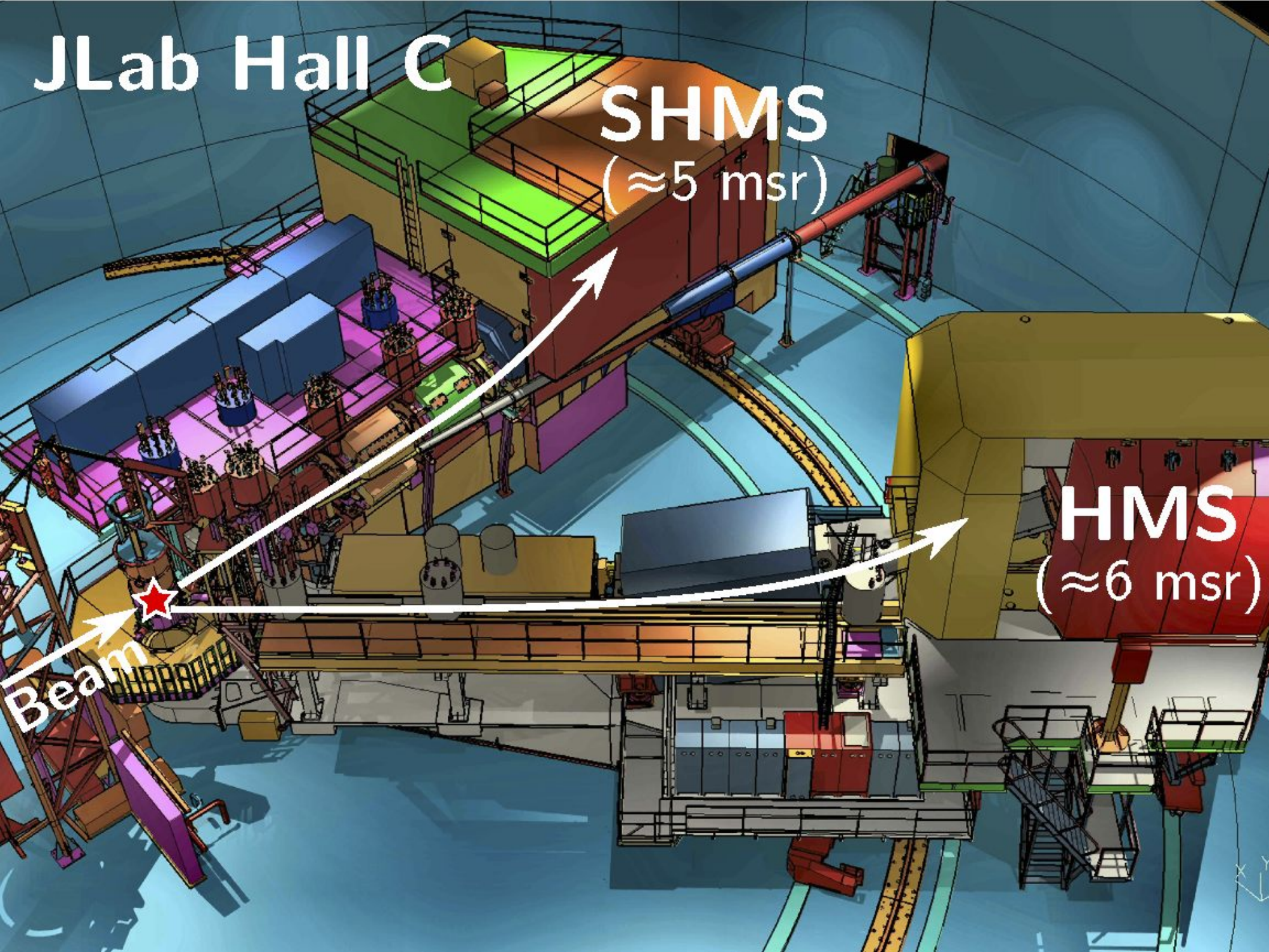
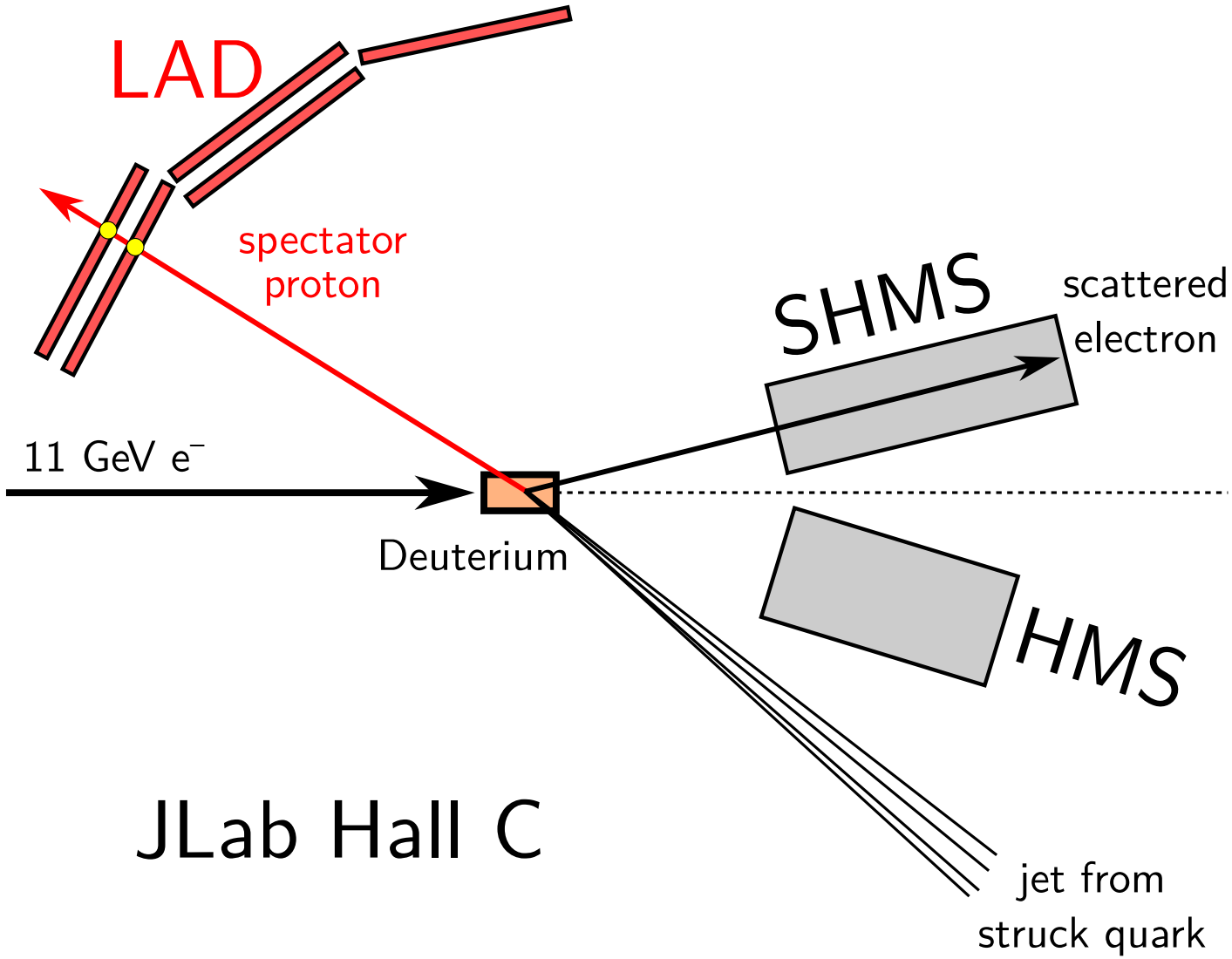


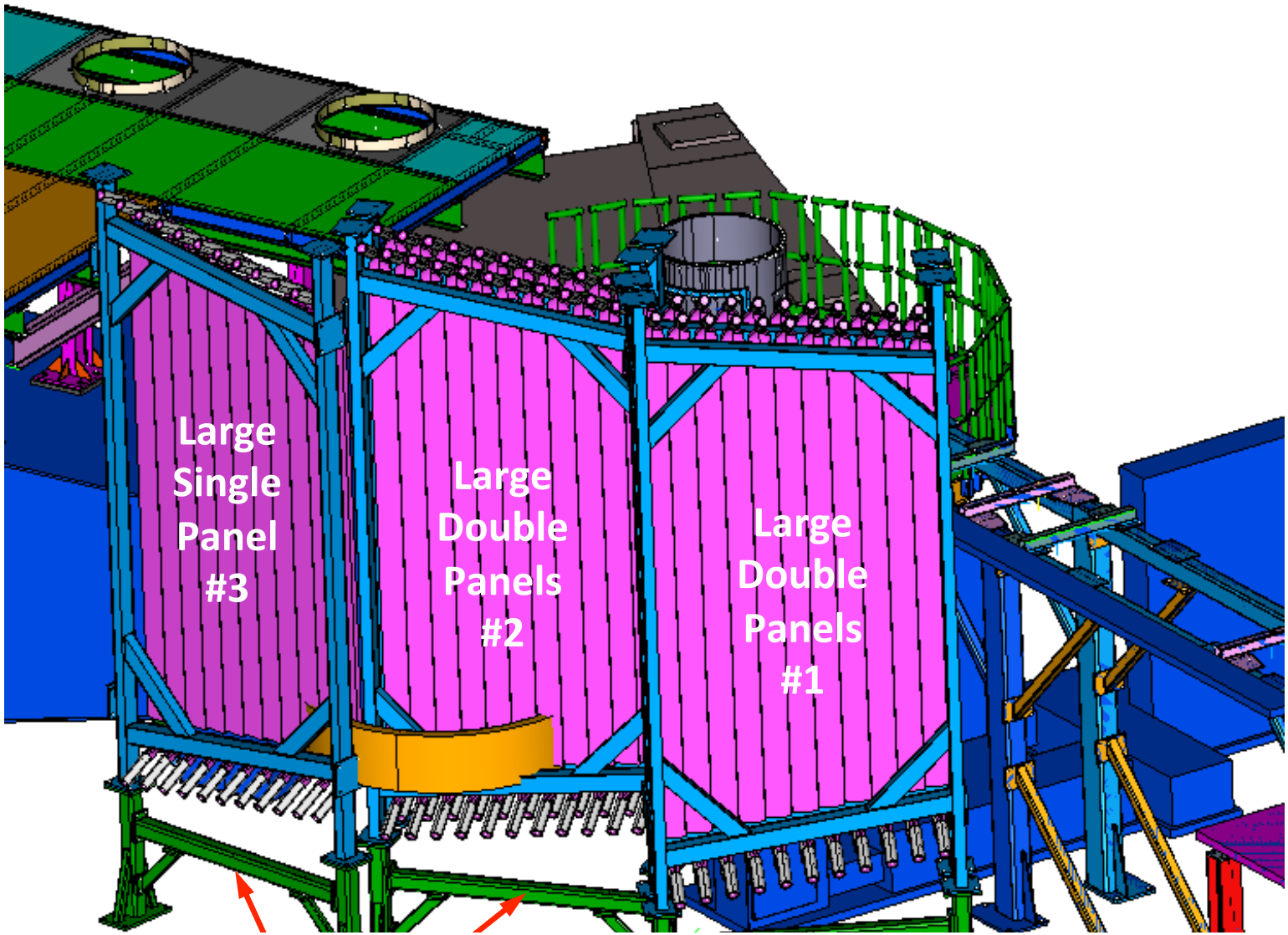

JLab Hall C
SHMS
(≈5 msr)
HMS
(≈6 msr)
Beam

"Large Acceptance Detector"
will detect recoiling spectator protons.

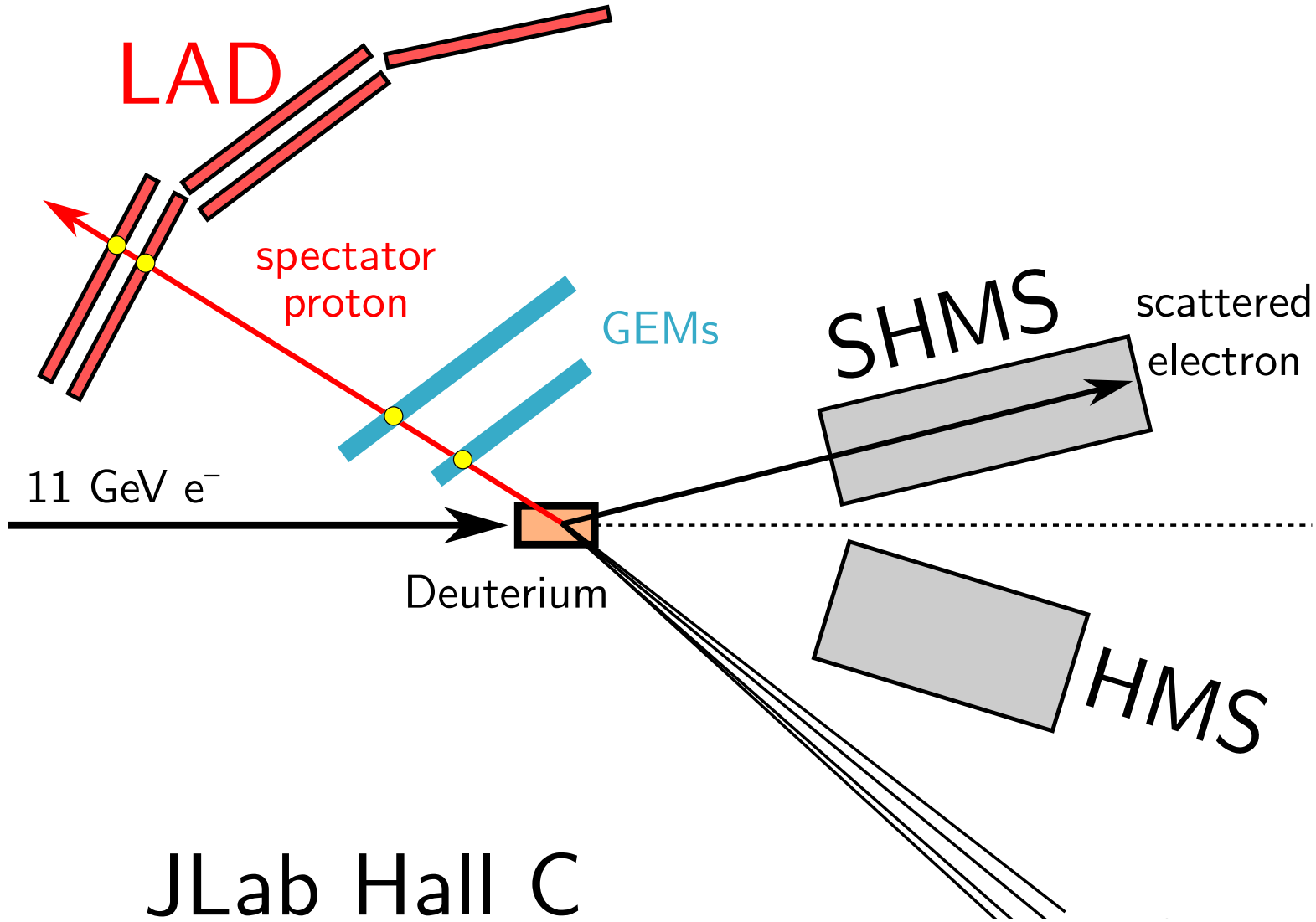


JLab Hall C

LAD is three panels of scintillator bars, reused from the original CLAS.

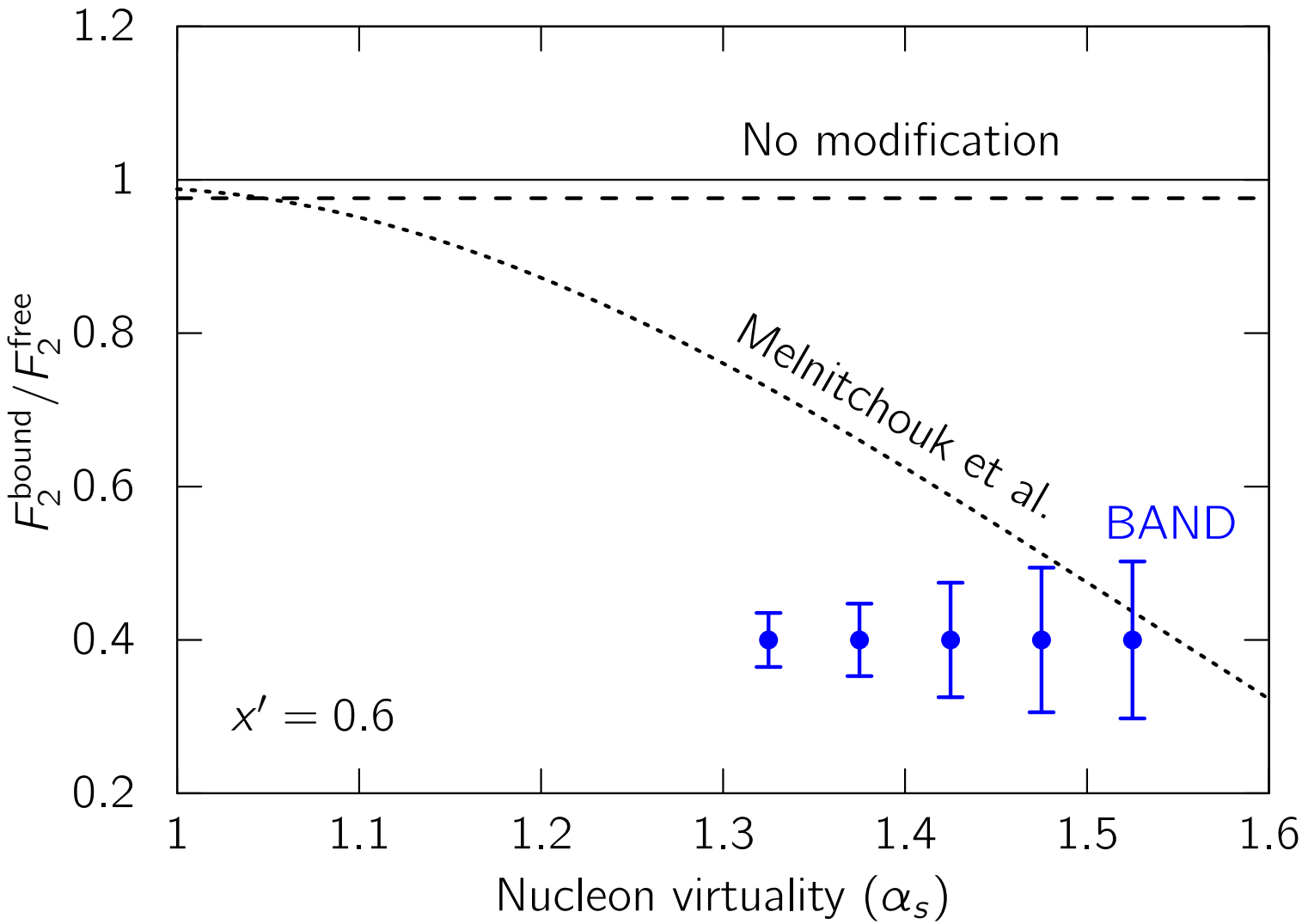


GEMs will be a huge help in background reduction.



JLab Hall C

The SRC hypothesis predicts increasing modification with nucleon momentum.



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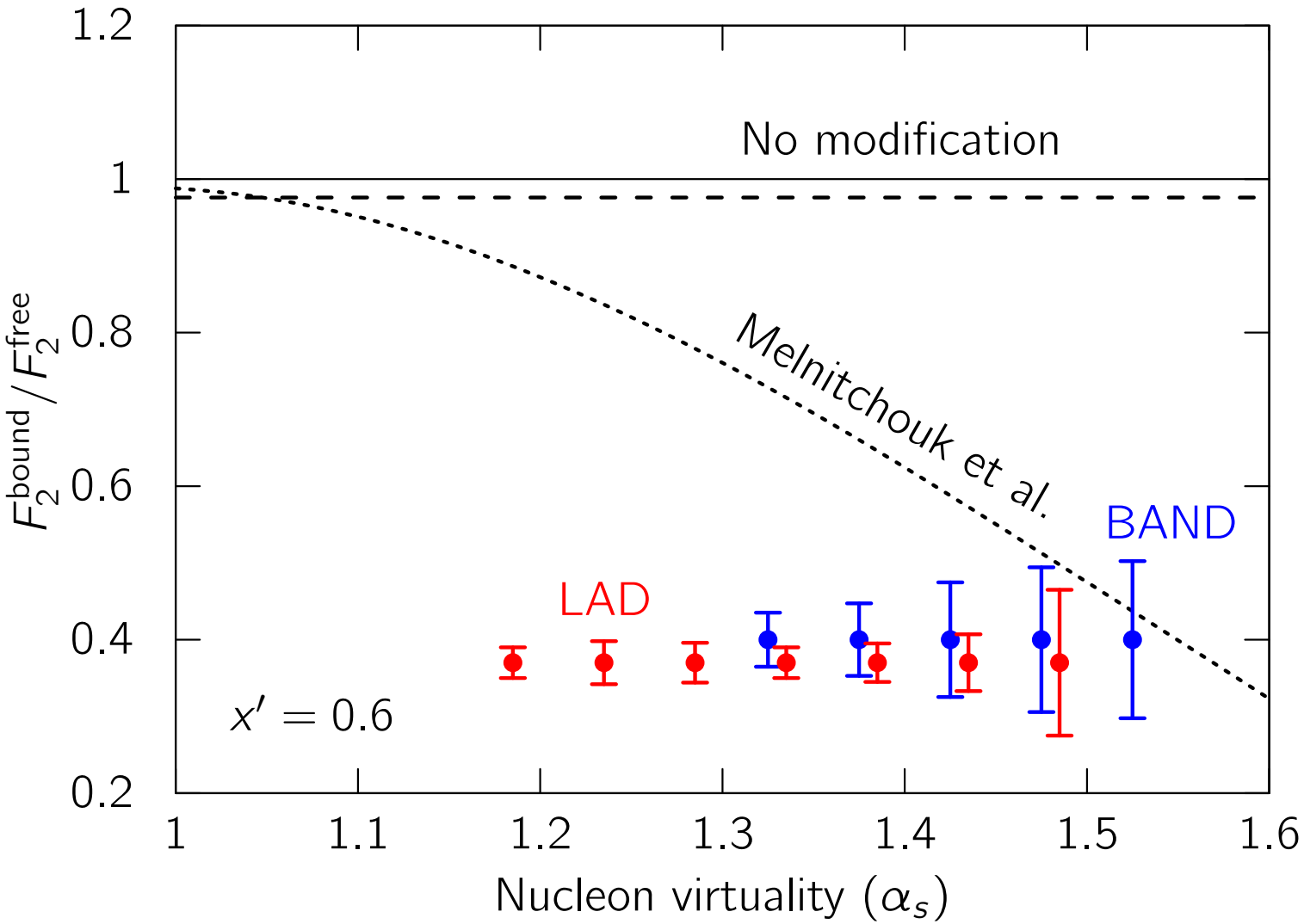
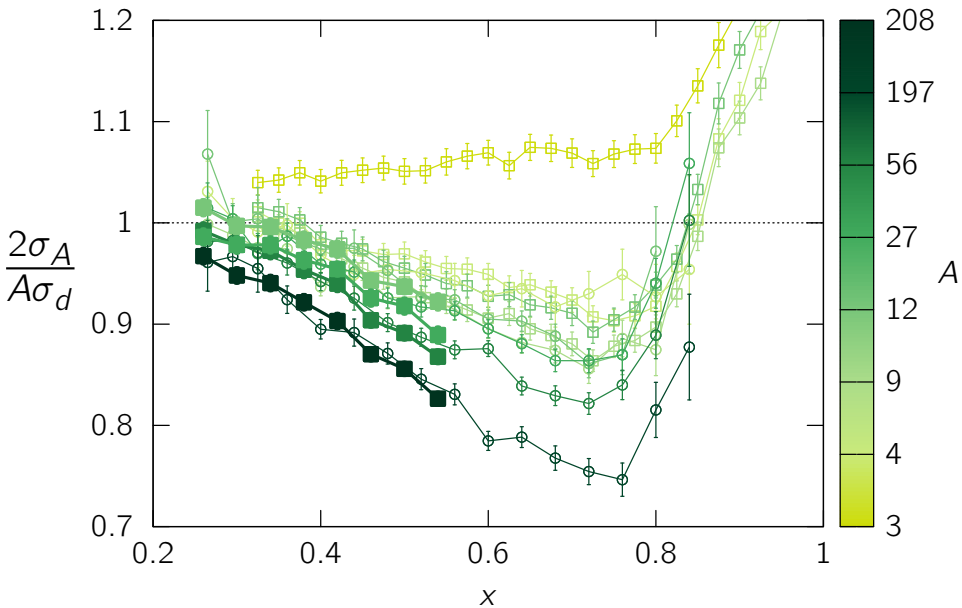


To recap:

- Universal Modification



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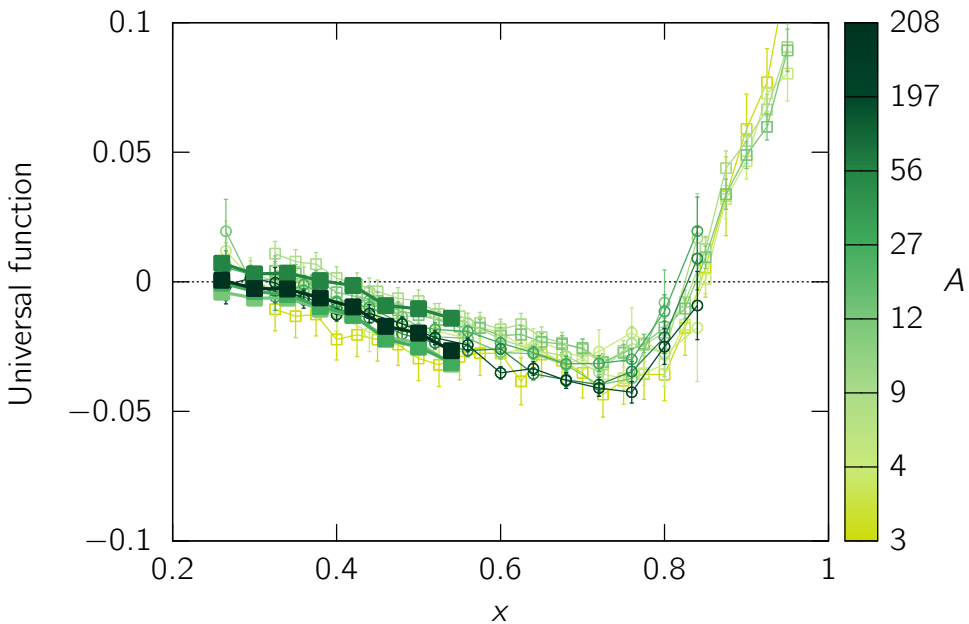
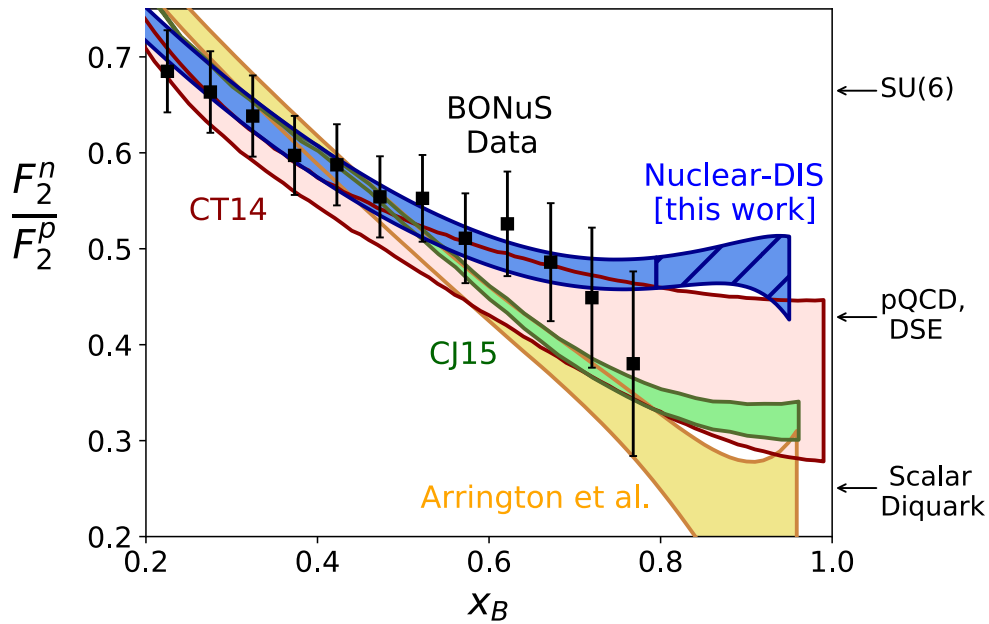


To recap:

- Universal Modification
- MARATHON Predictions



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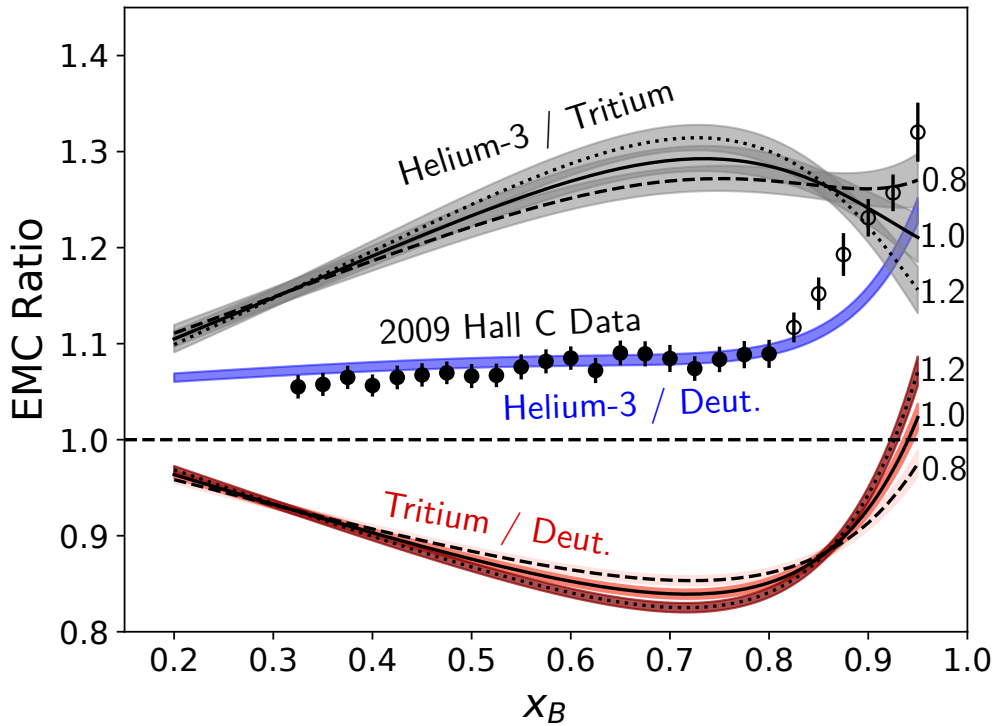

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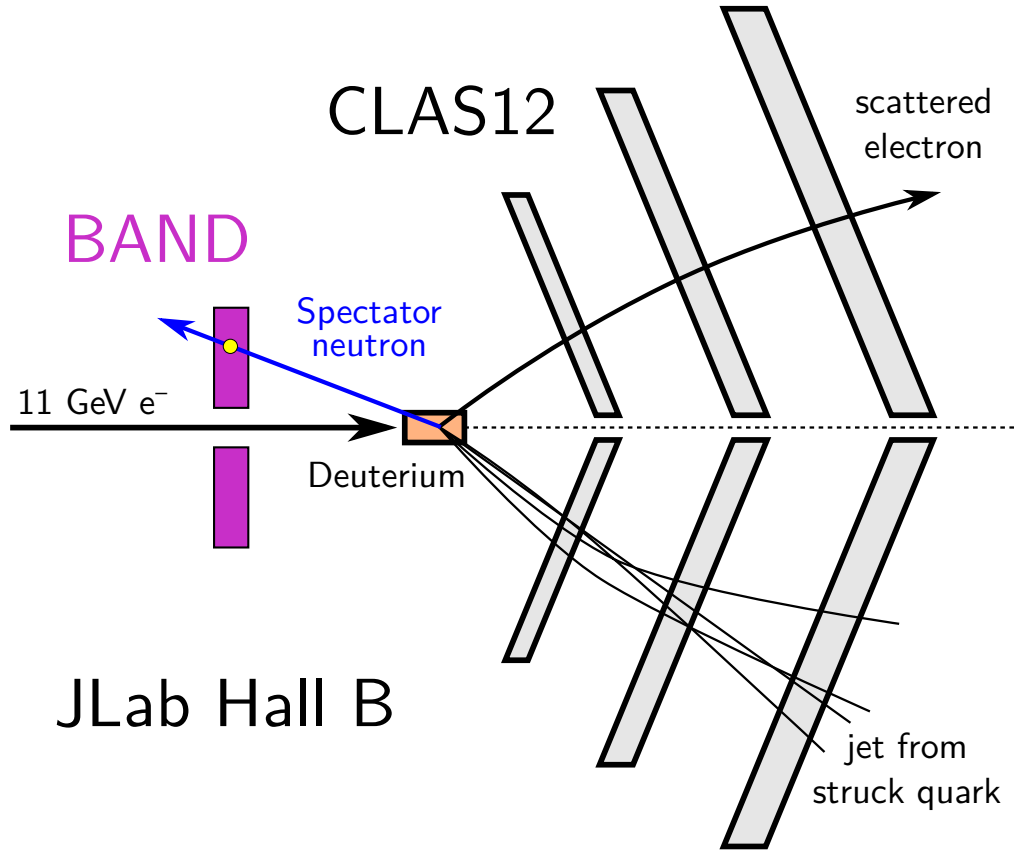
- BAND and LAD



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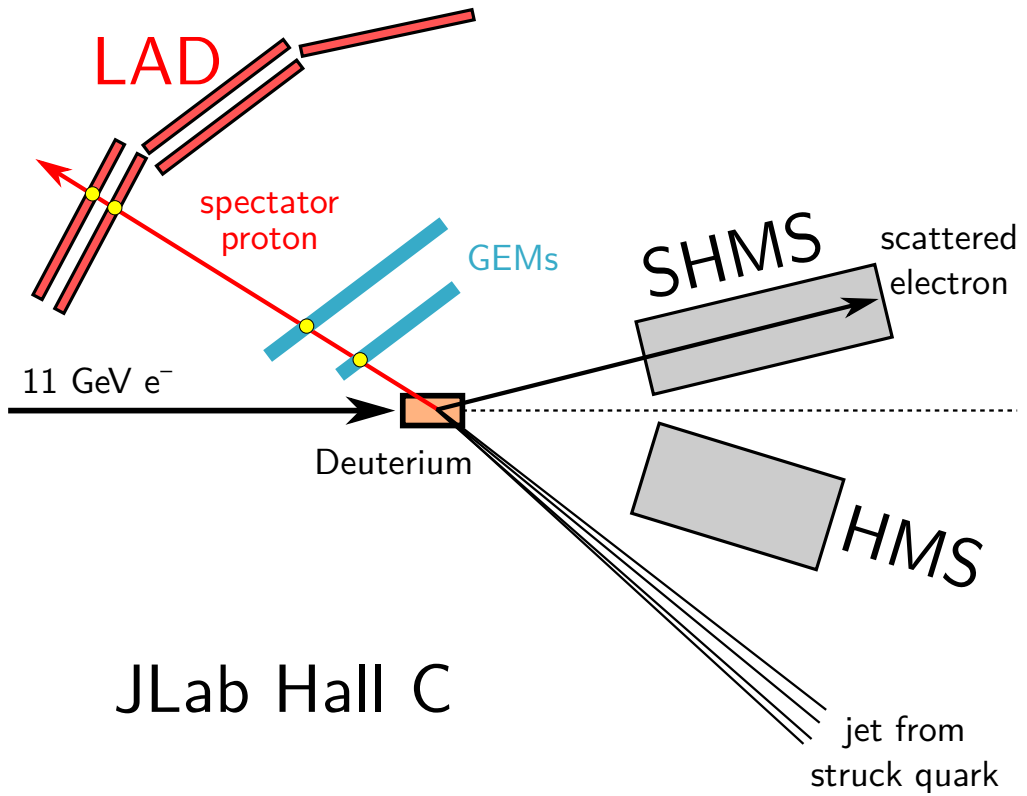

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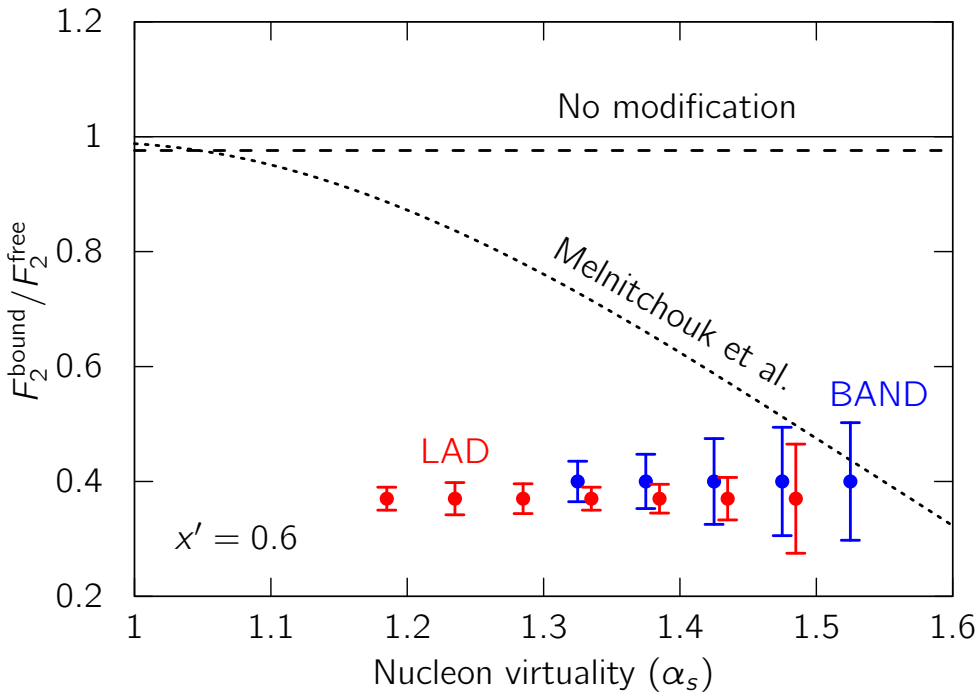

The SRC-EMC hypothesis will be directly confronted by data in the next few years!