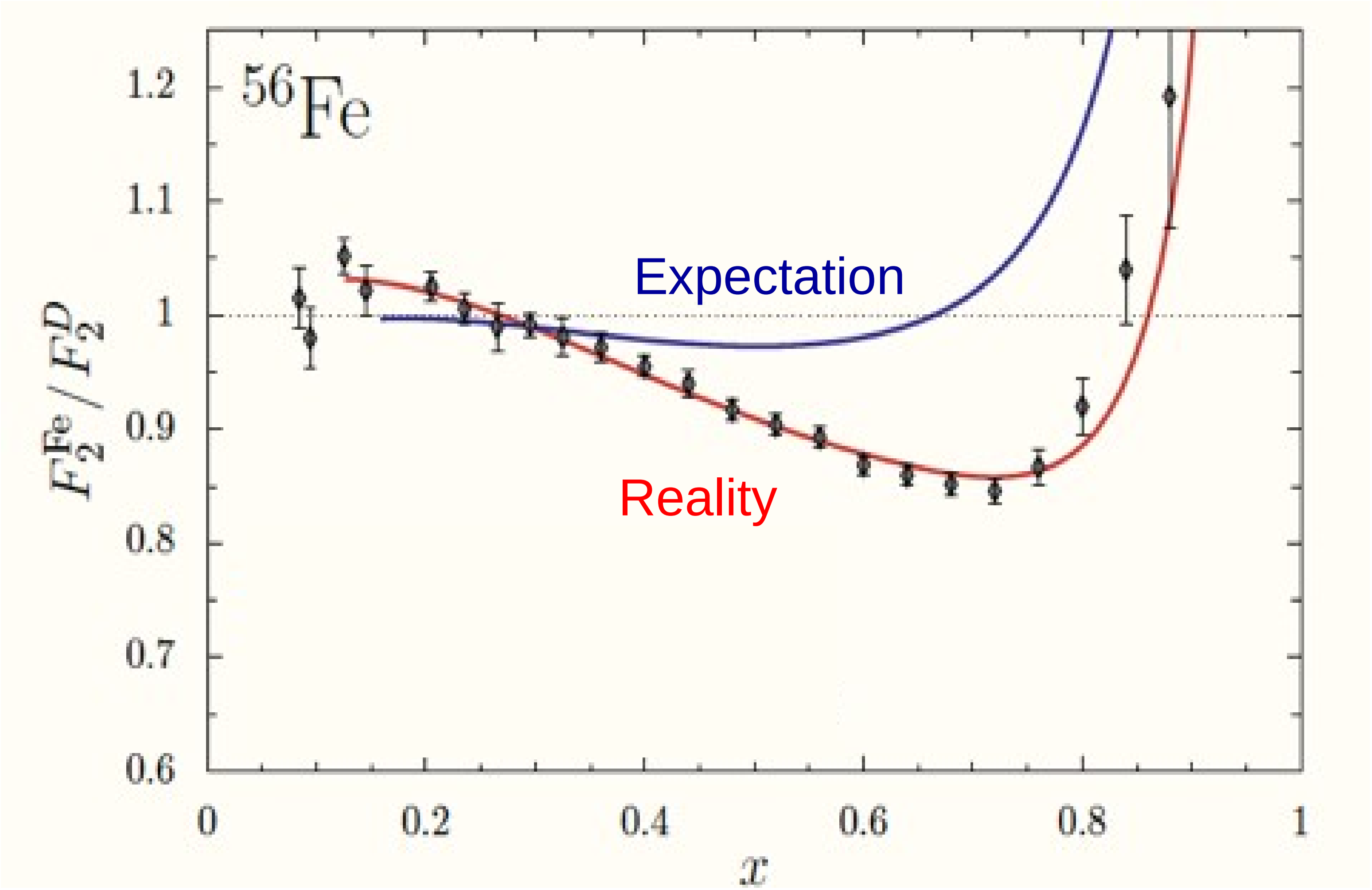
Massachusetts
Institute of
Technology

Isospin Dependence of the EMC Effect and Short-Range Correlations

Barak Schmookler

MIT

Deep Inelastic Scattering and the EMC Effect



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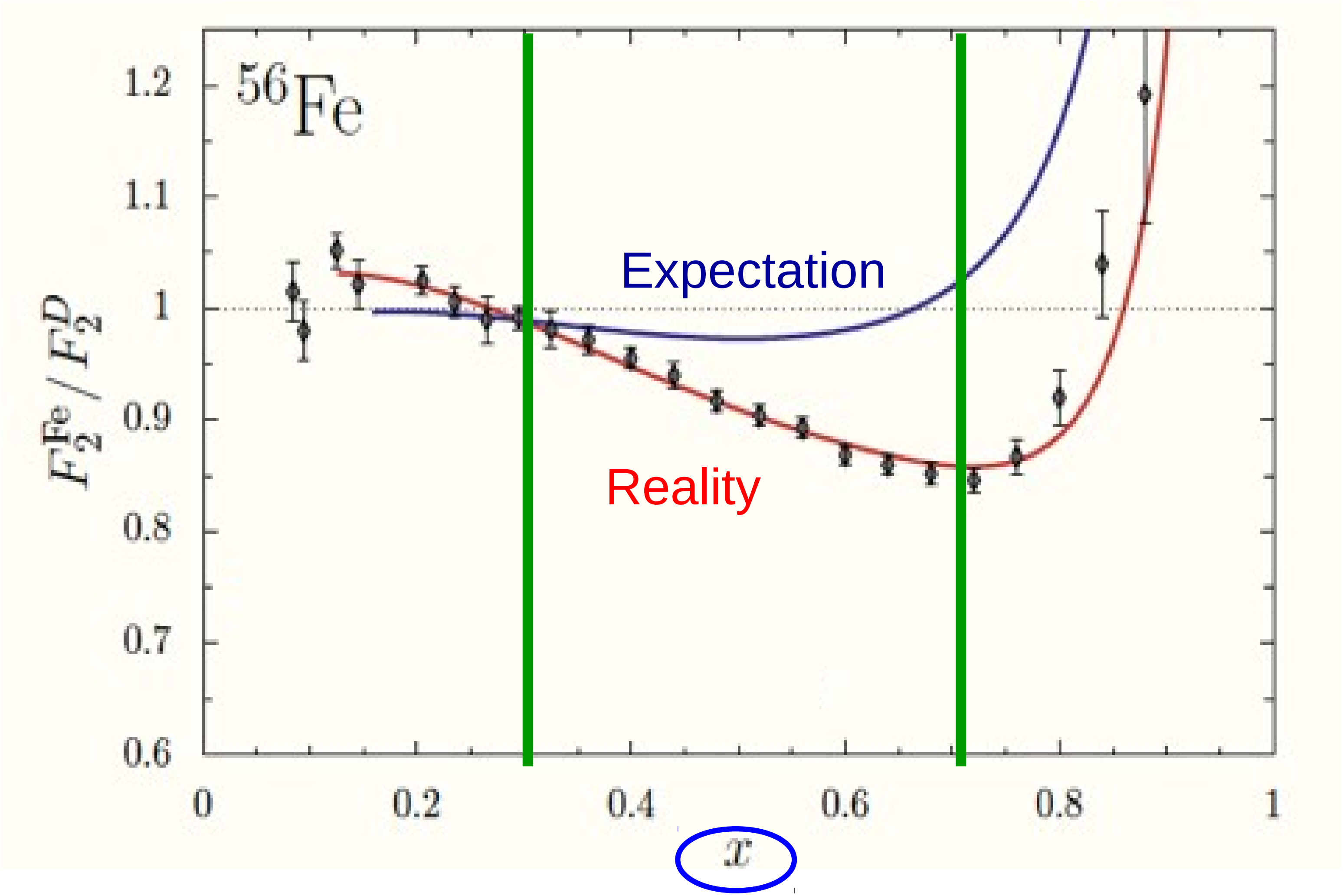
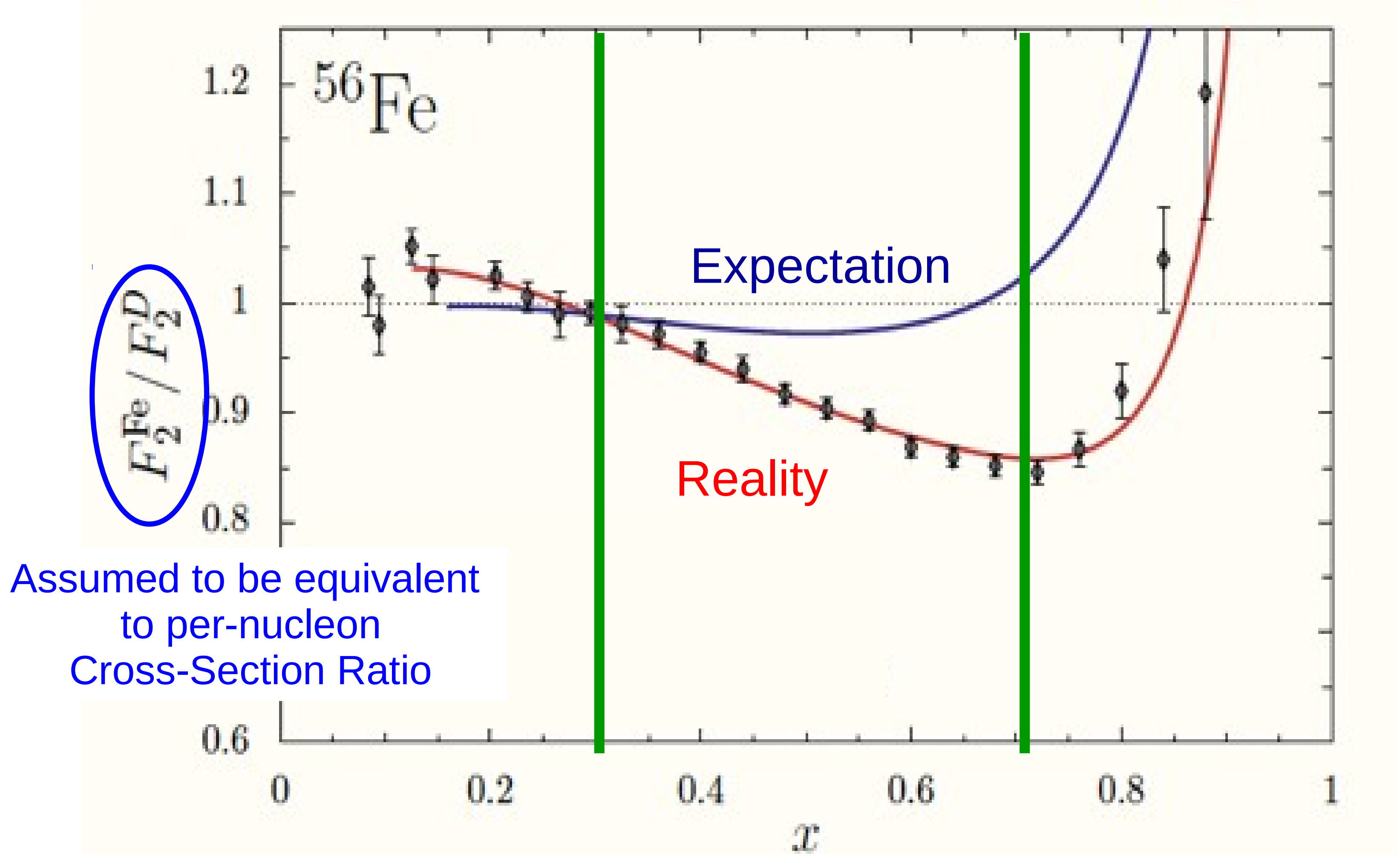
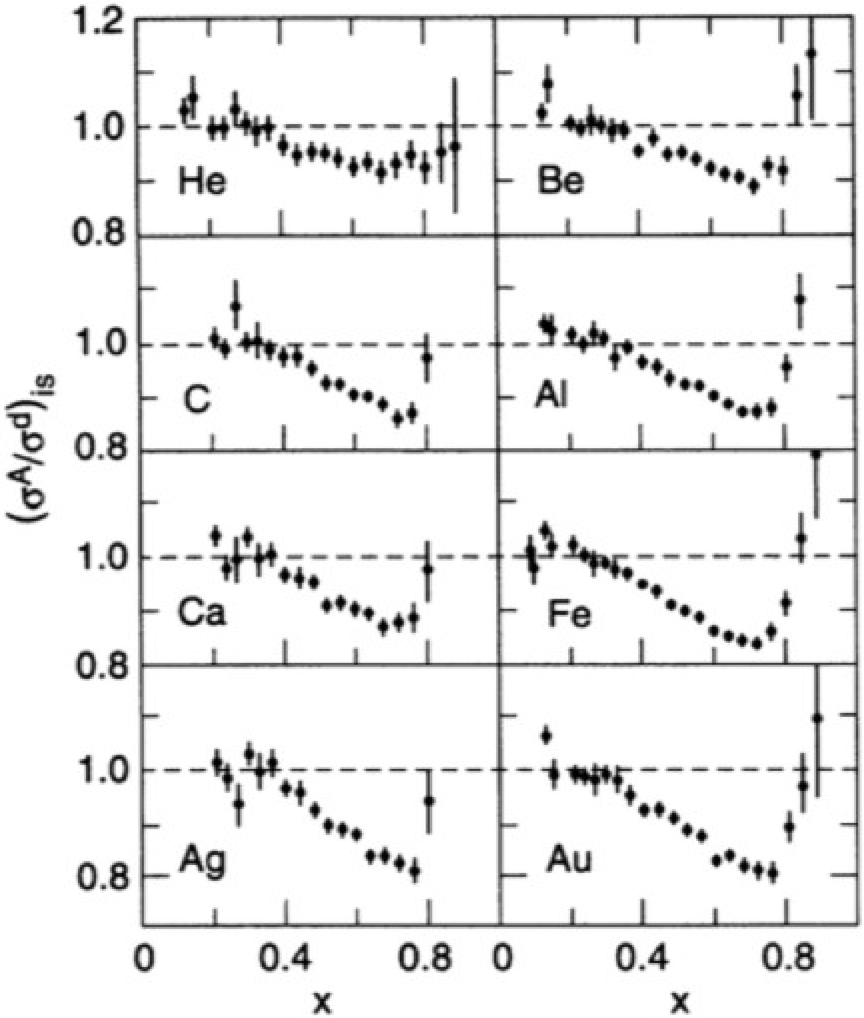


Momentum Fraction
of Struck Quark

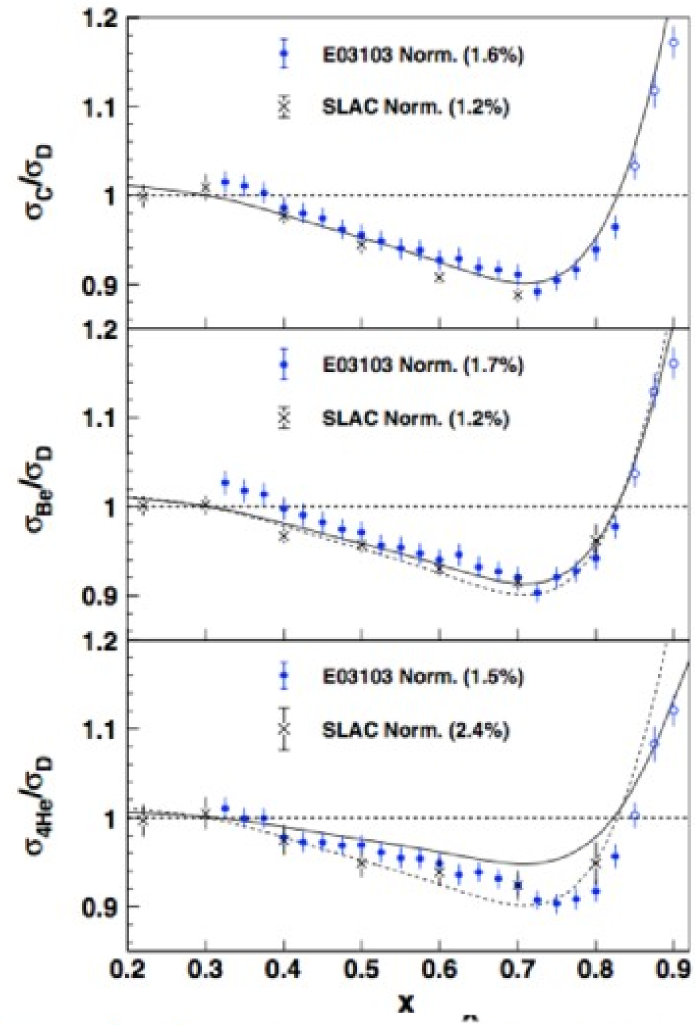
Deep Inelastic Scattering and the EMC Effect



The EMC Effect: Universal Nuclear Effect

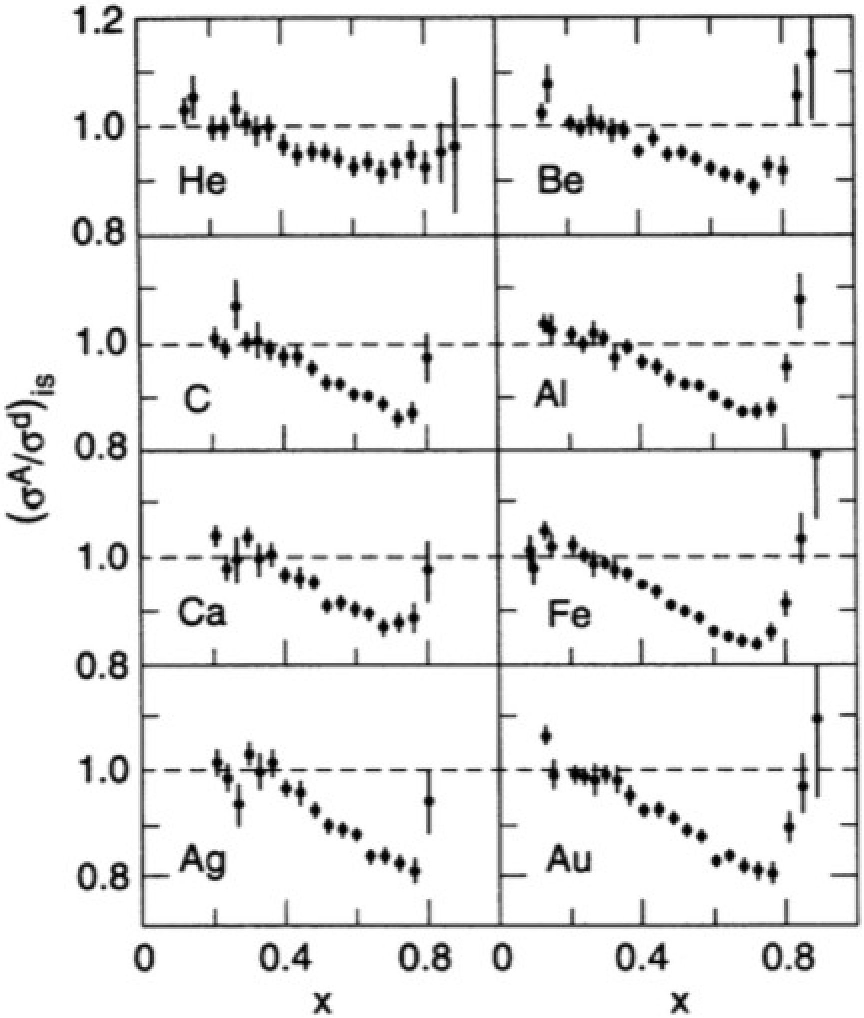


J. Gomez et al., Phys. Rev. D **49**, 4348 (1994).



J. Seely et al., Phys. Rev. Lett. **103**, 202301 (2009).

The EMC Effect: Universal Nuclear Effect



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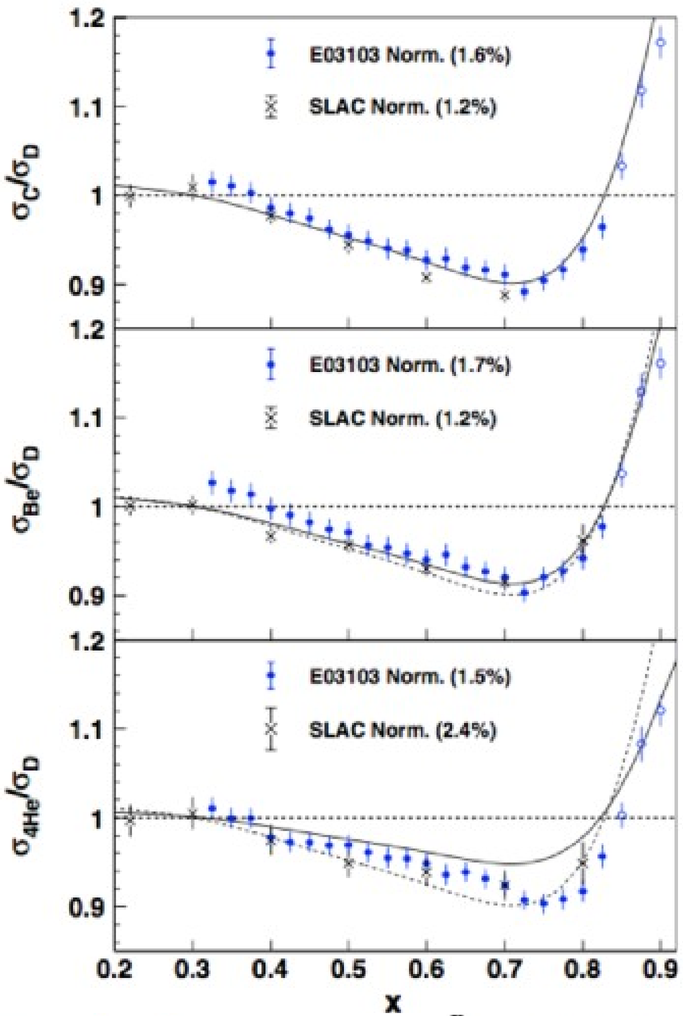

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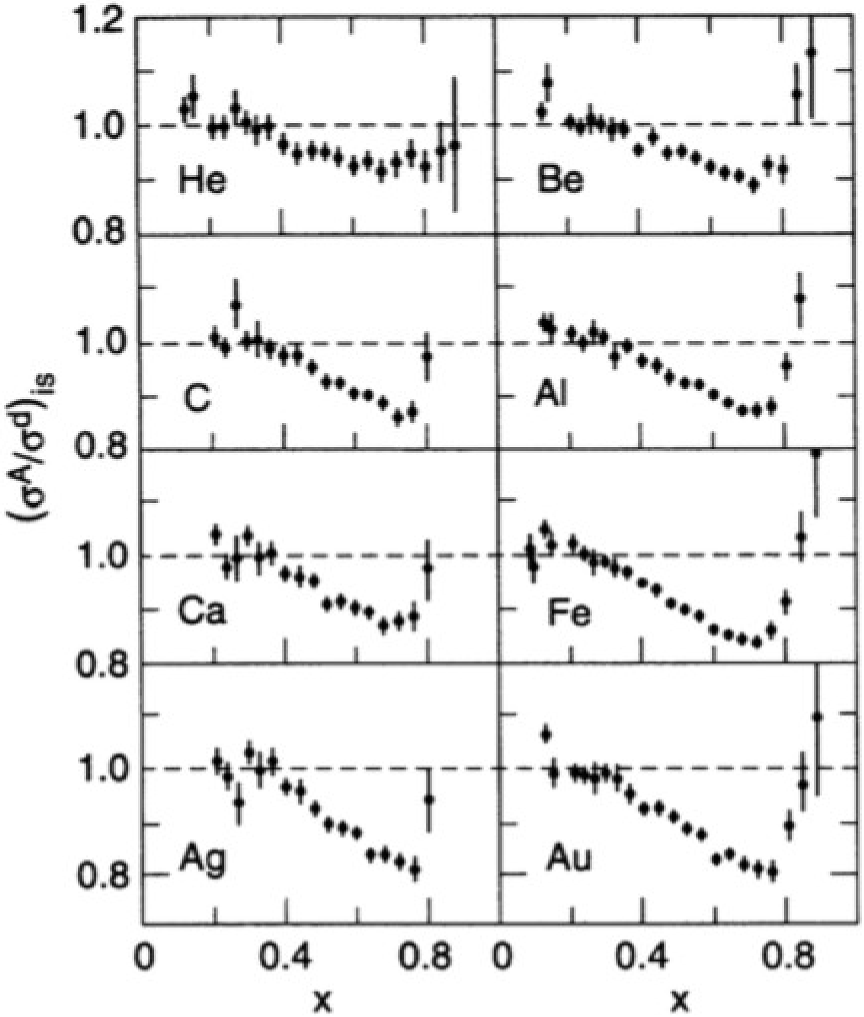

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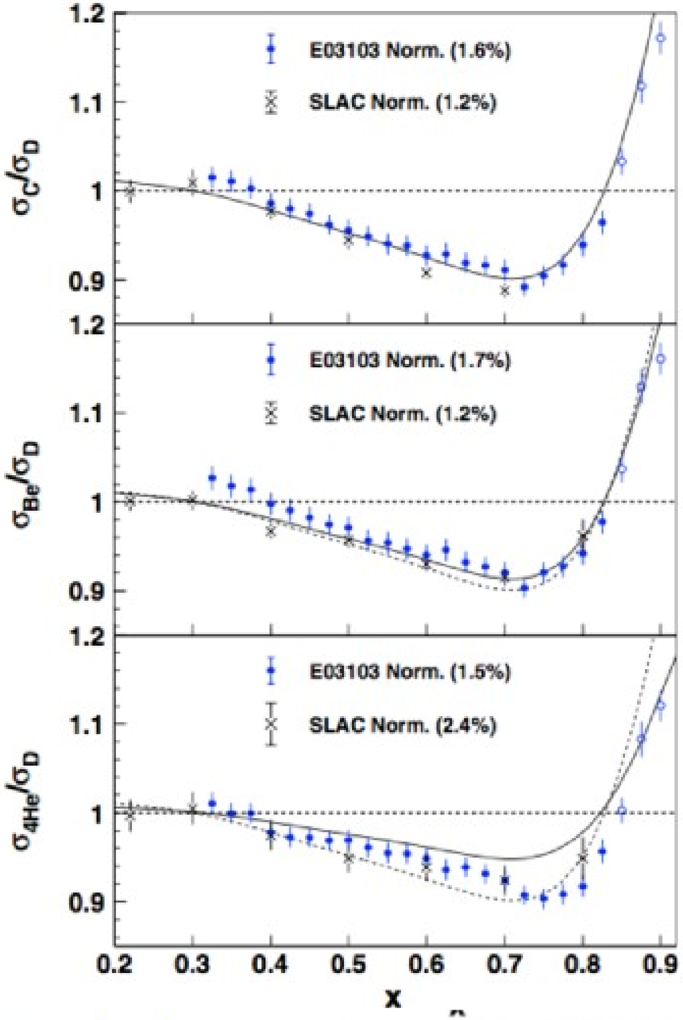


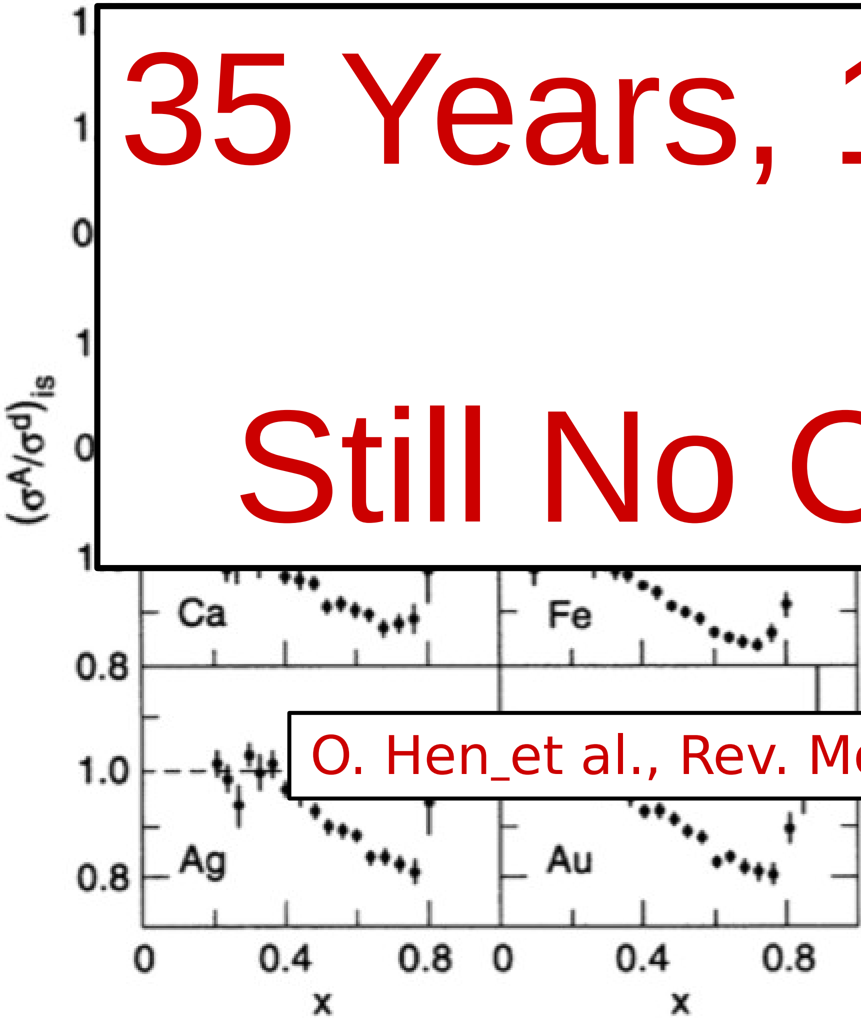
J. Seely et al., Phys. Rev. Lett. **103**, 202301 (2009).

The EMC Effect: Universal Nuclear Effect

35 Years, 1000+ Papers

Still No Consensus!!!

O. Hen_et al., Rev. Mod. Phys. 89, 045002 (2017)



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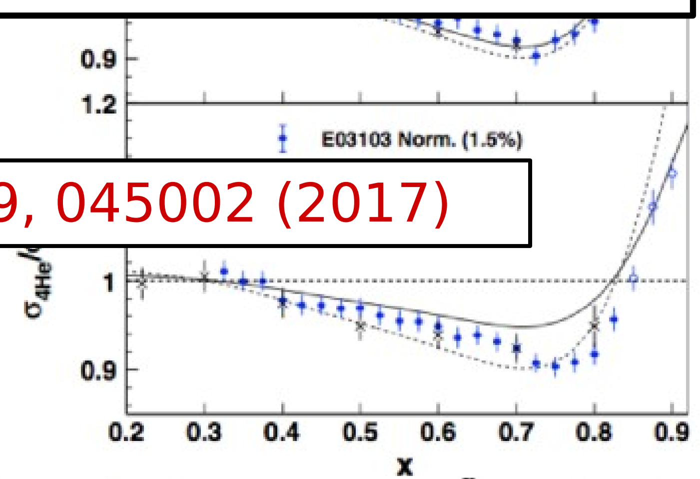

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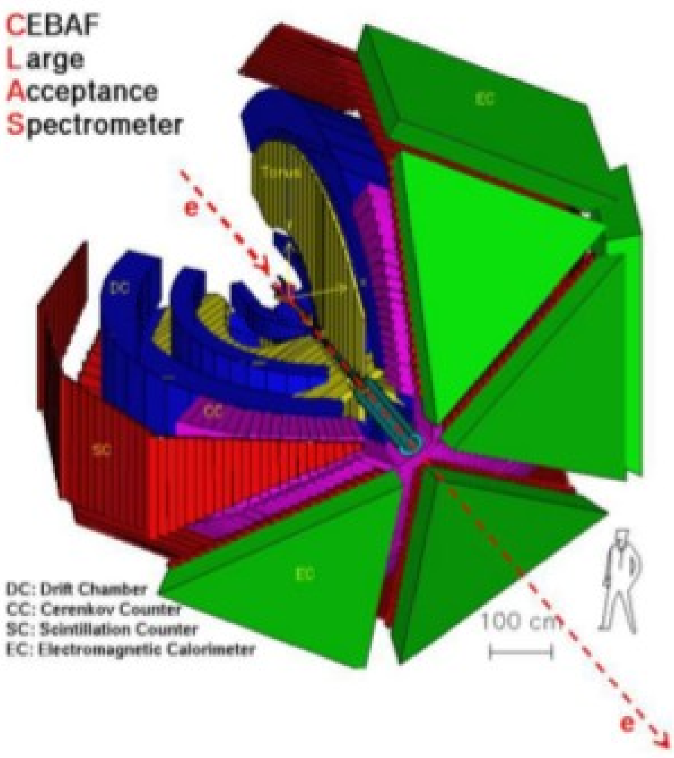
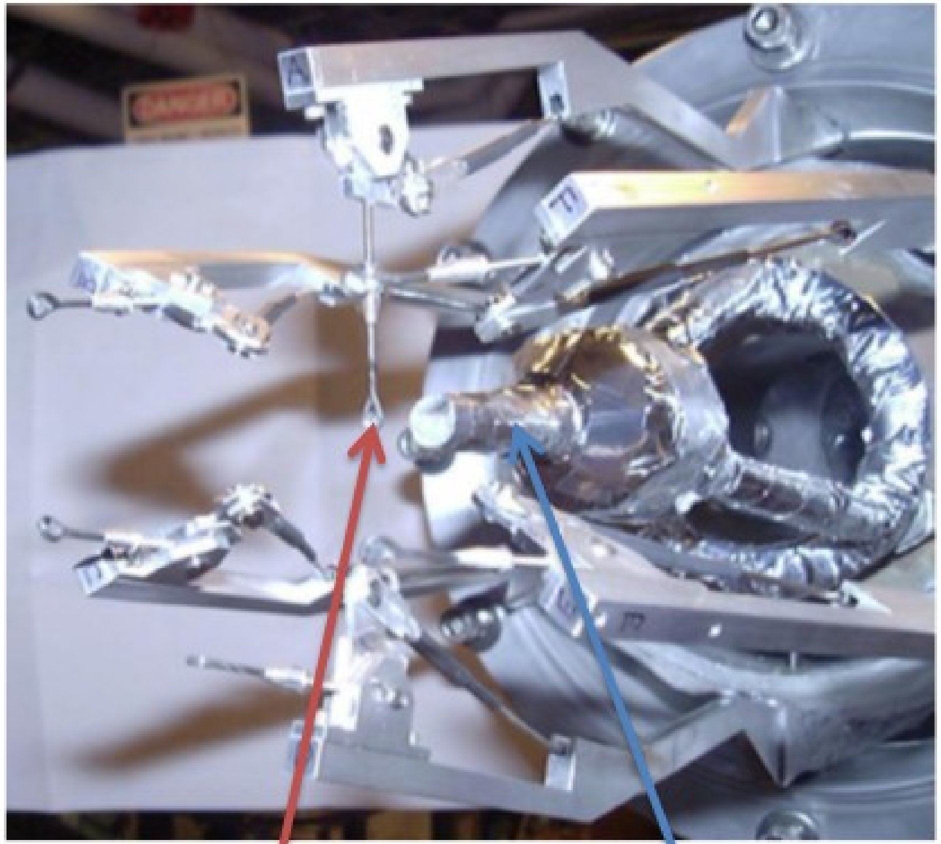
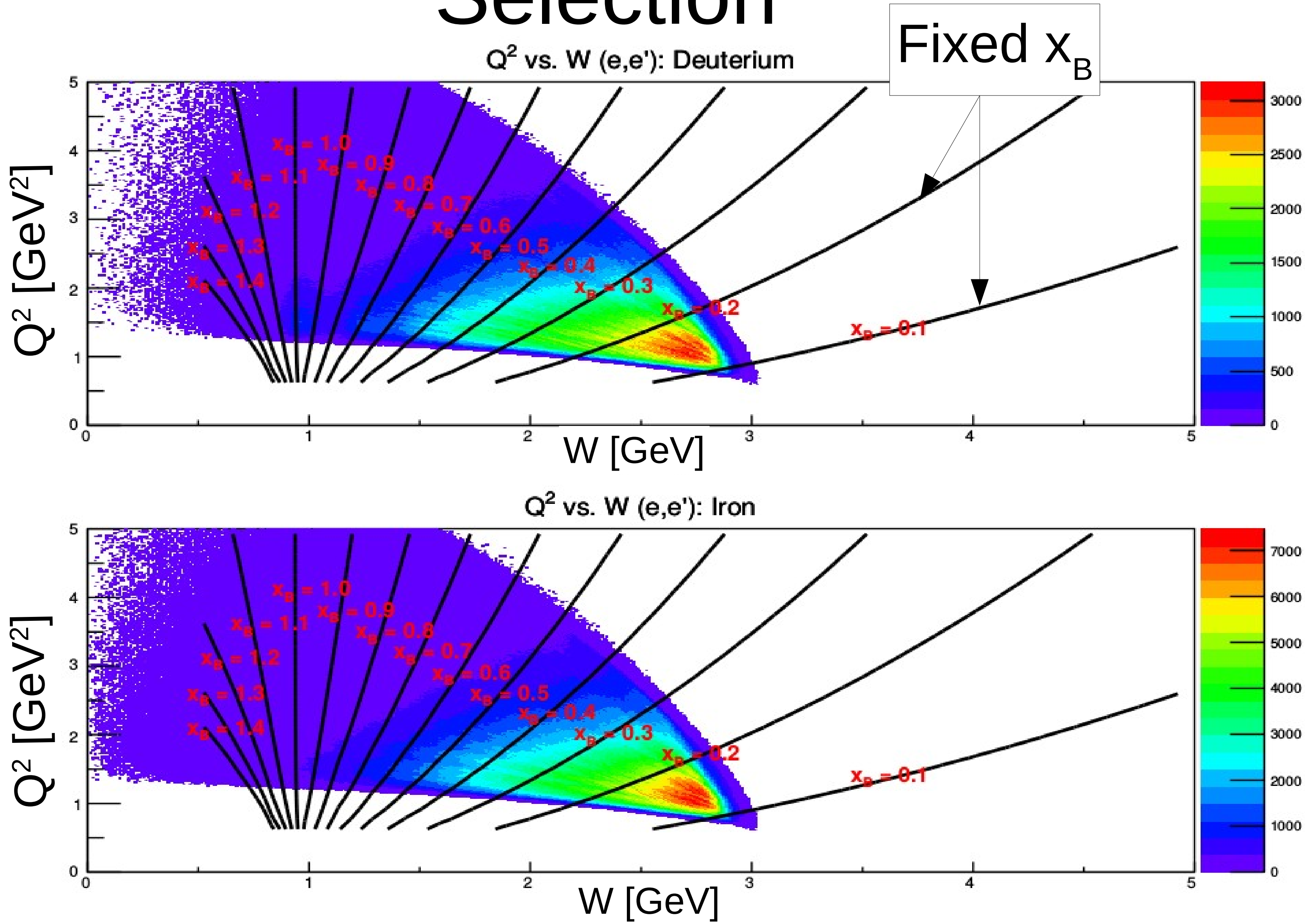
Study (e,e') Data using CLAS6 Detector



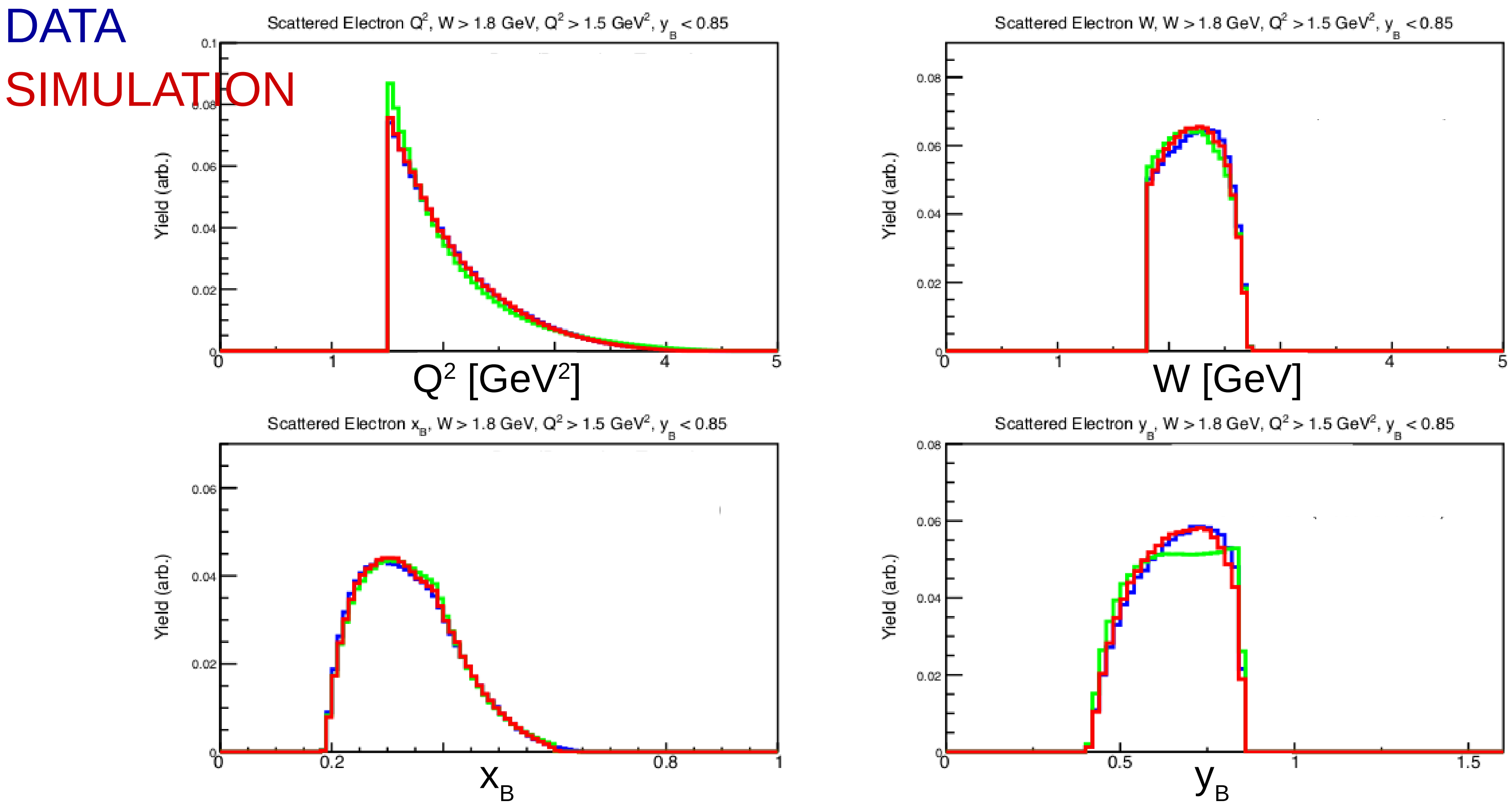
EG2C Dataset



Kinematic Coverage and Event Selection

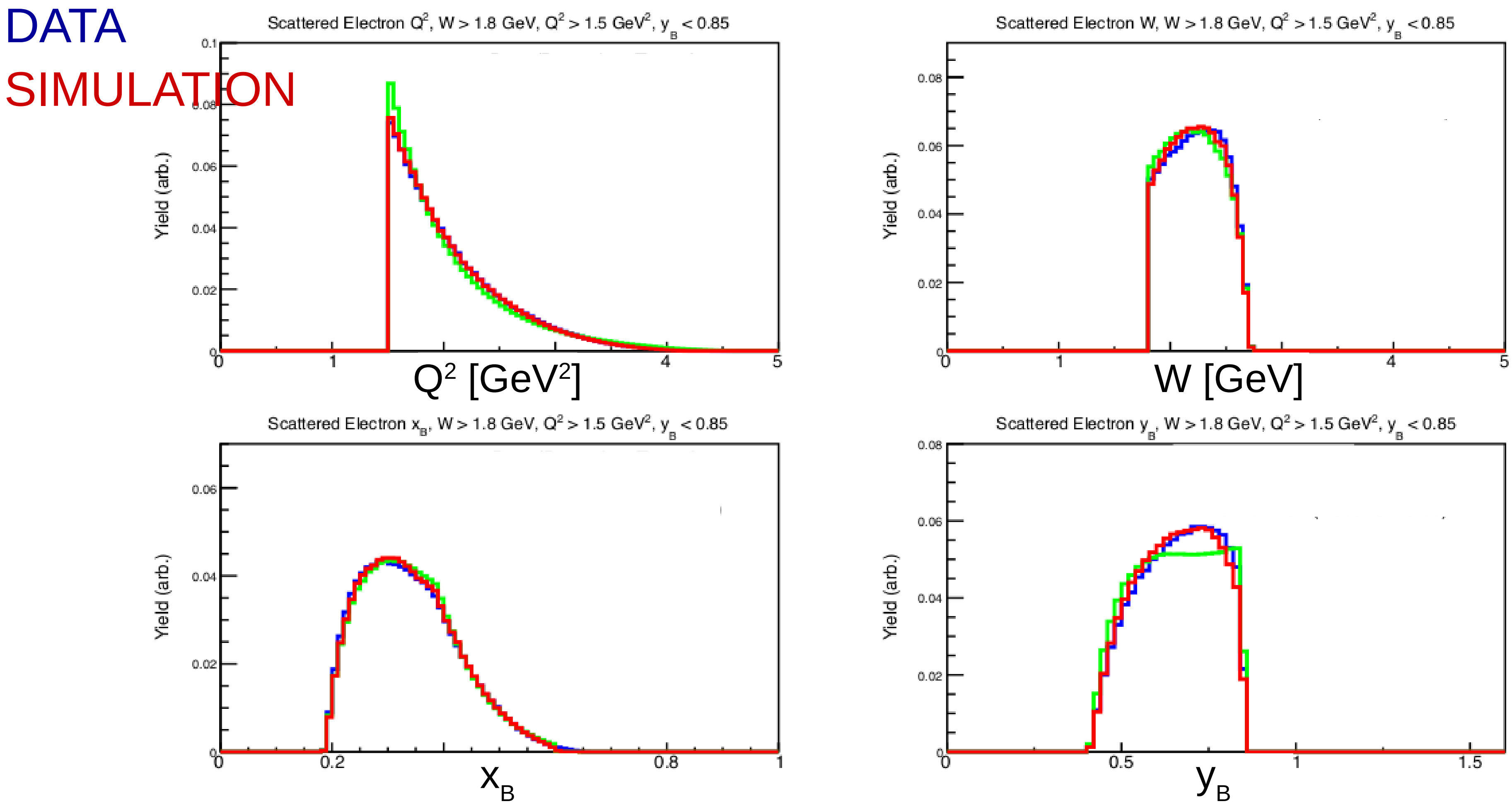


Cross-Section Ratio Extraction



Cross-Section Ratio Extraction

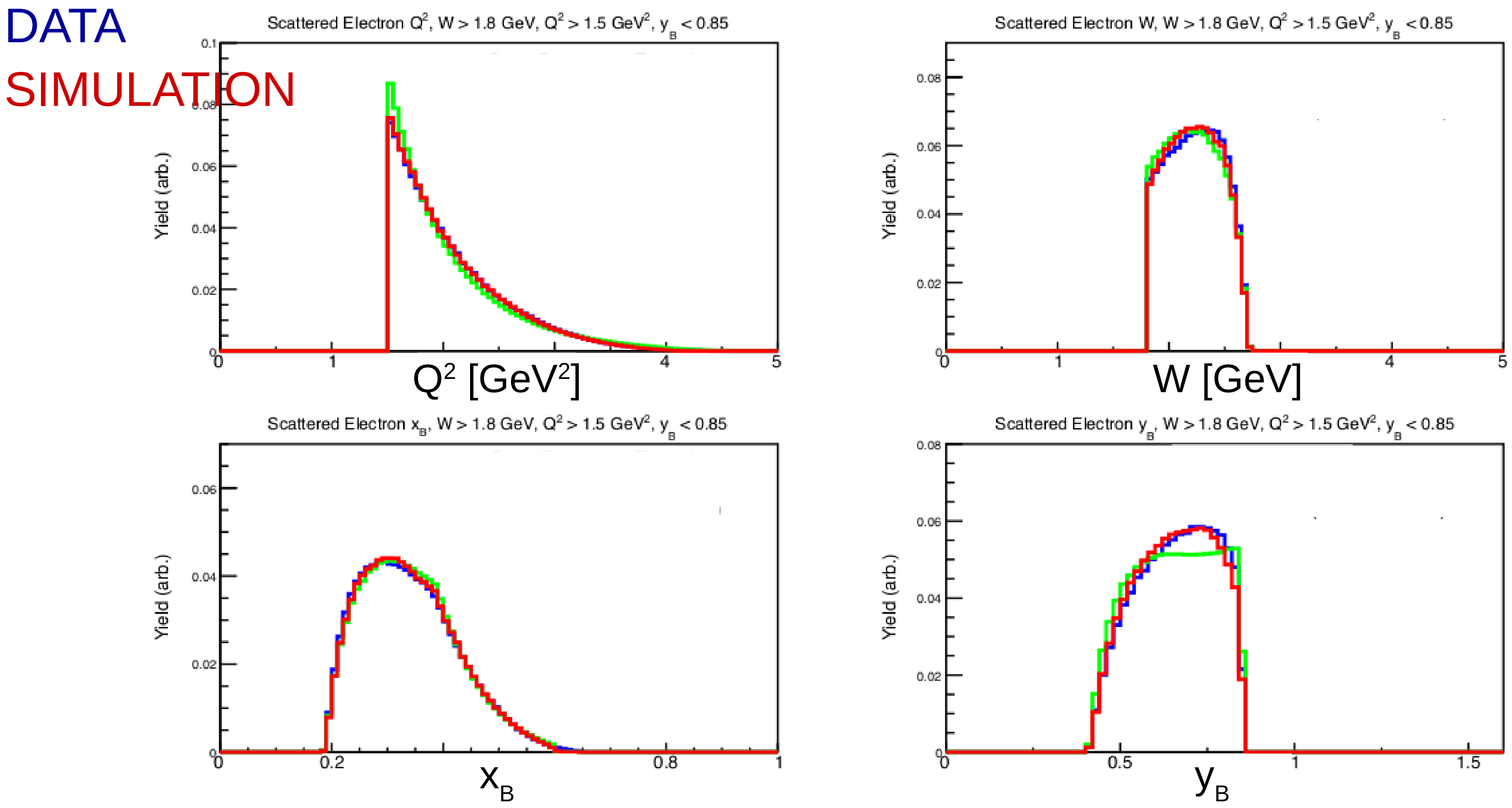
$$weight = \frac{RC \times CC}{NORM \times ACC} \times BC$$



Cross-Section Ratio Extraction

$$weight = \frac{RC \times CC}{NORM \times ACC} \times BC$$

Luminosity and Dead-Time Correction



Cross-Section Ratio Extraction

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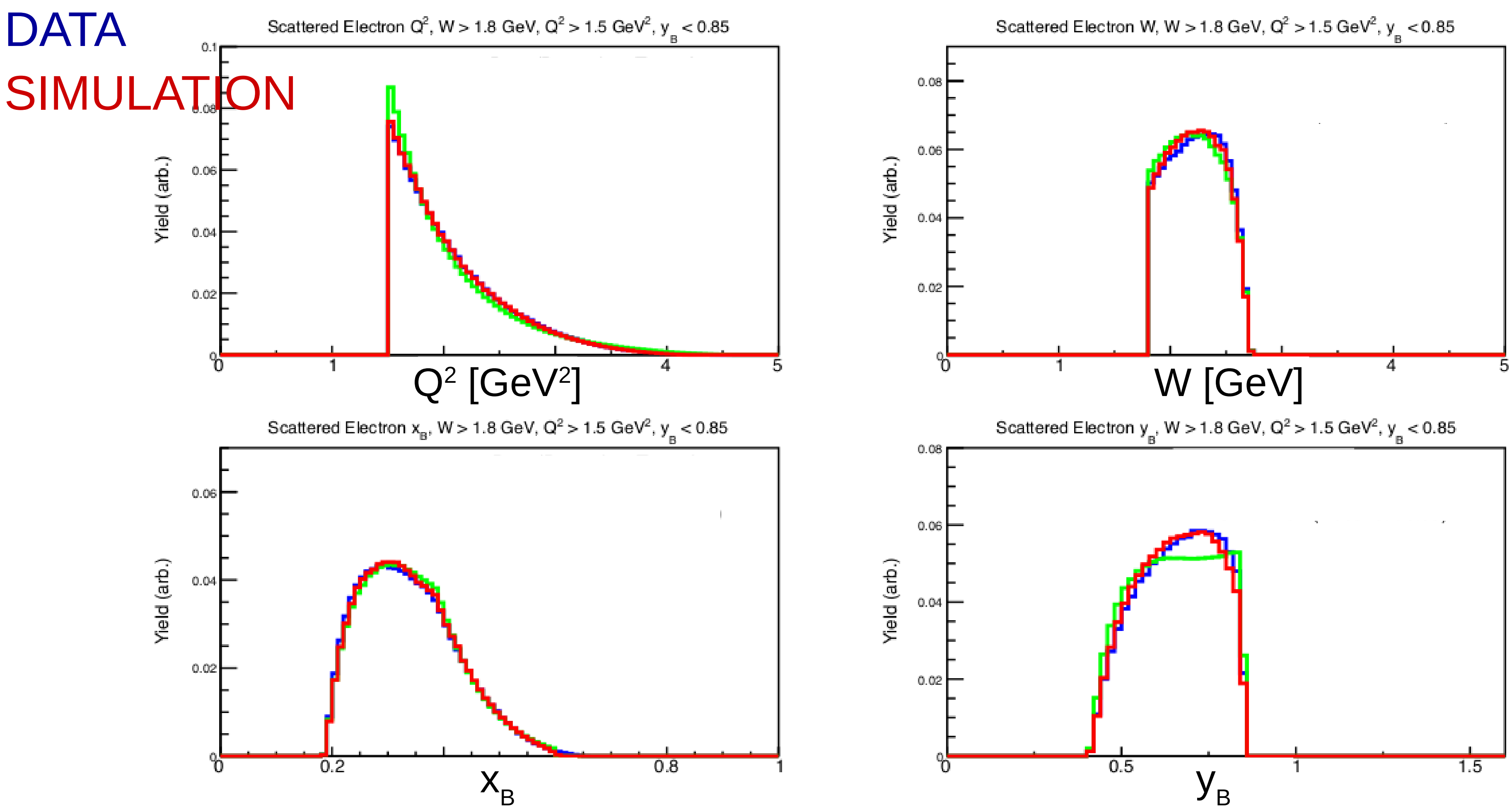
Acceptance and Bin-Centering Correction



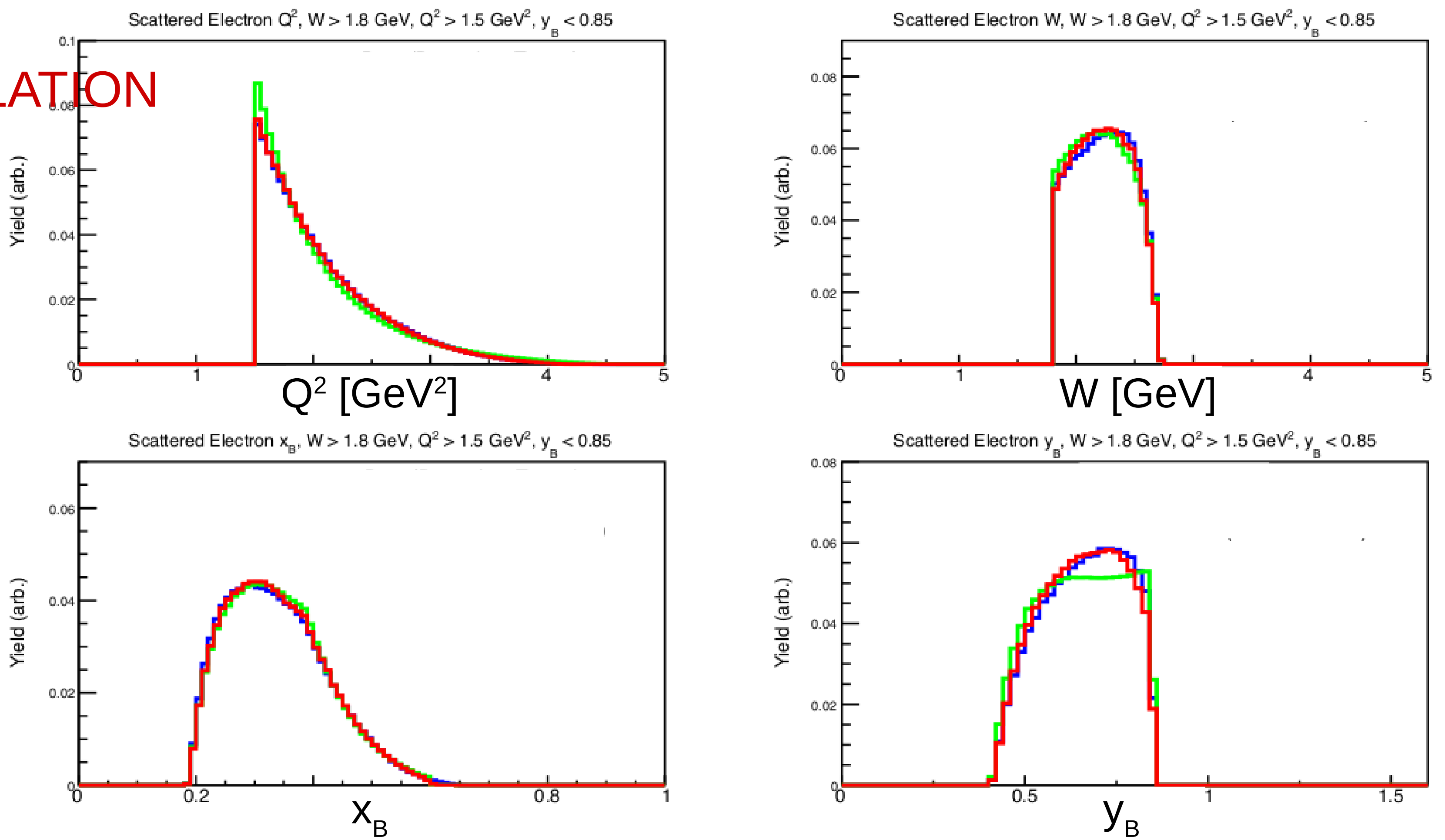
Cross-Section Ratio Extraction

$$weight = \frac{RC \times CC}{NORM \times ACC} \times BC$$

Radiative Correction

DATA

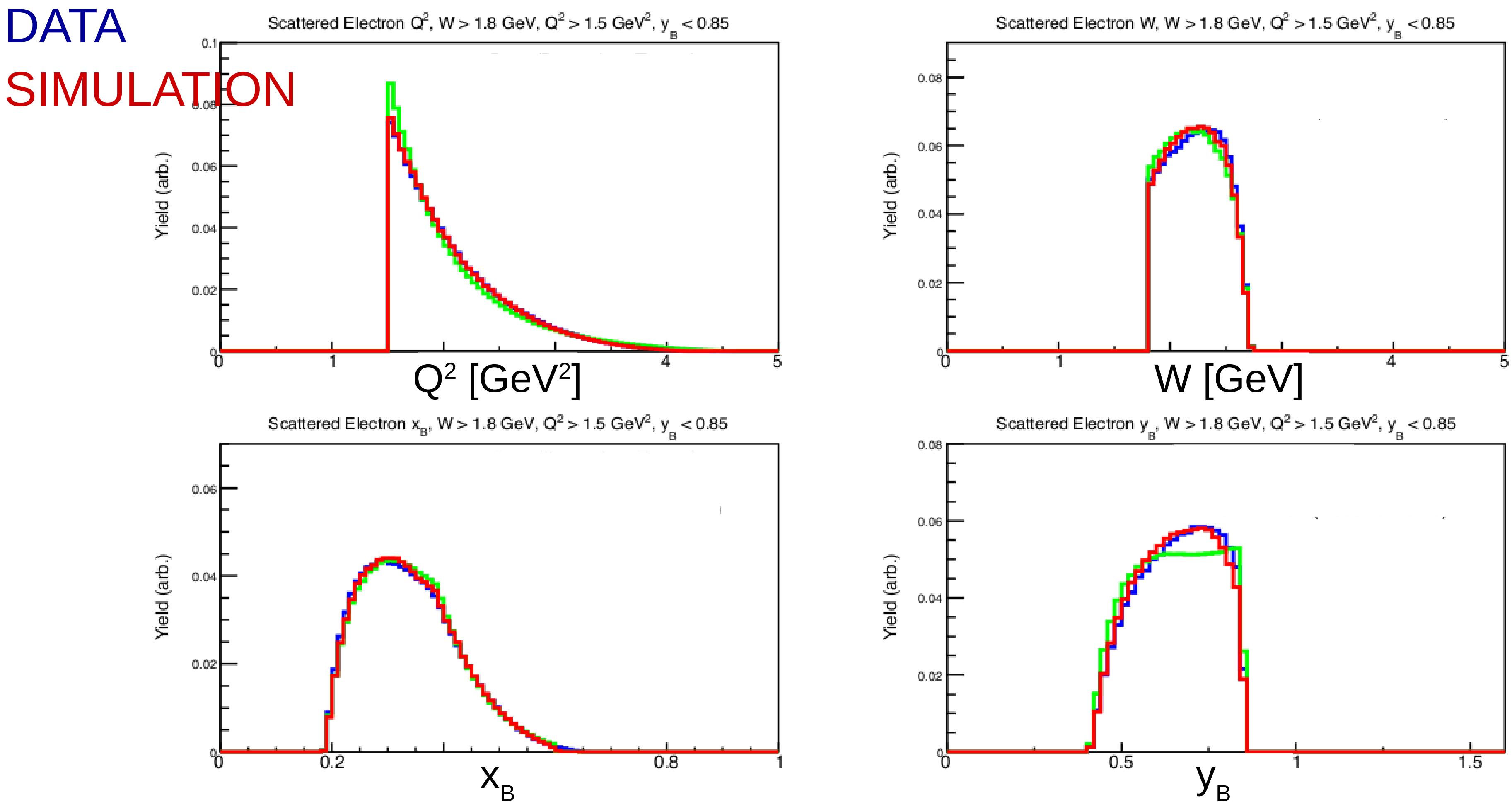
SIMULATION



Cross-Section Ratio Extraction

$$weight = \frac{RC \times CC}{NORM \times ACC} \times BC$$

Coulomb Correction



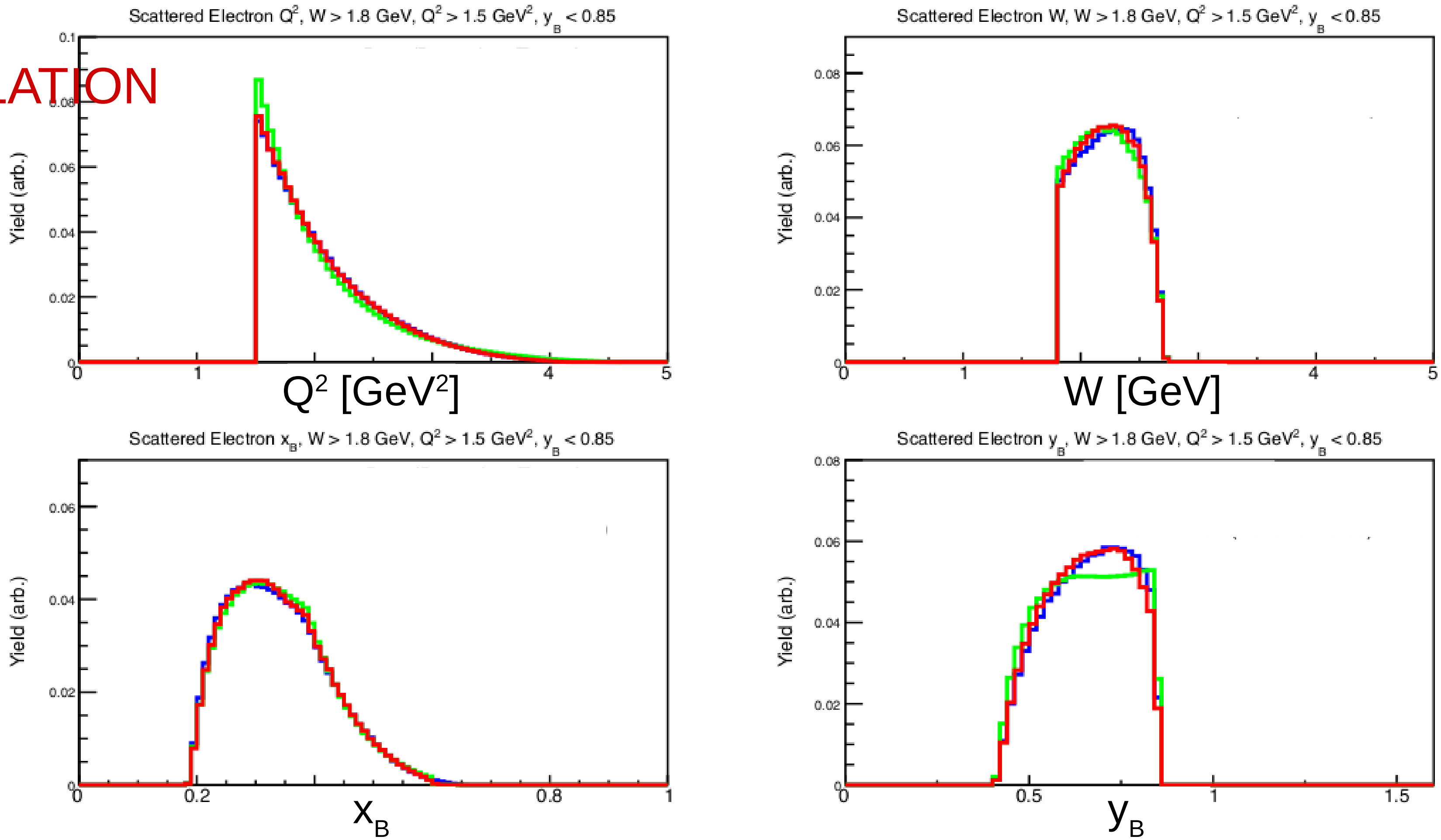
Cross-Section Ratio Extraction

$$weight = \frac{RC \times CC}{NORM \times ACC} \times BC$$

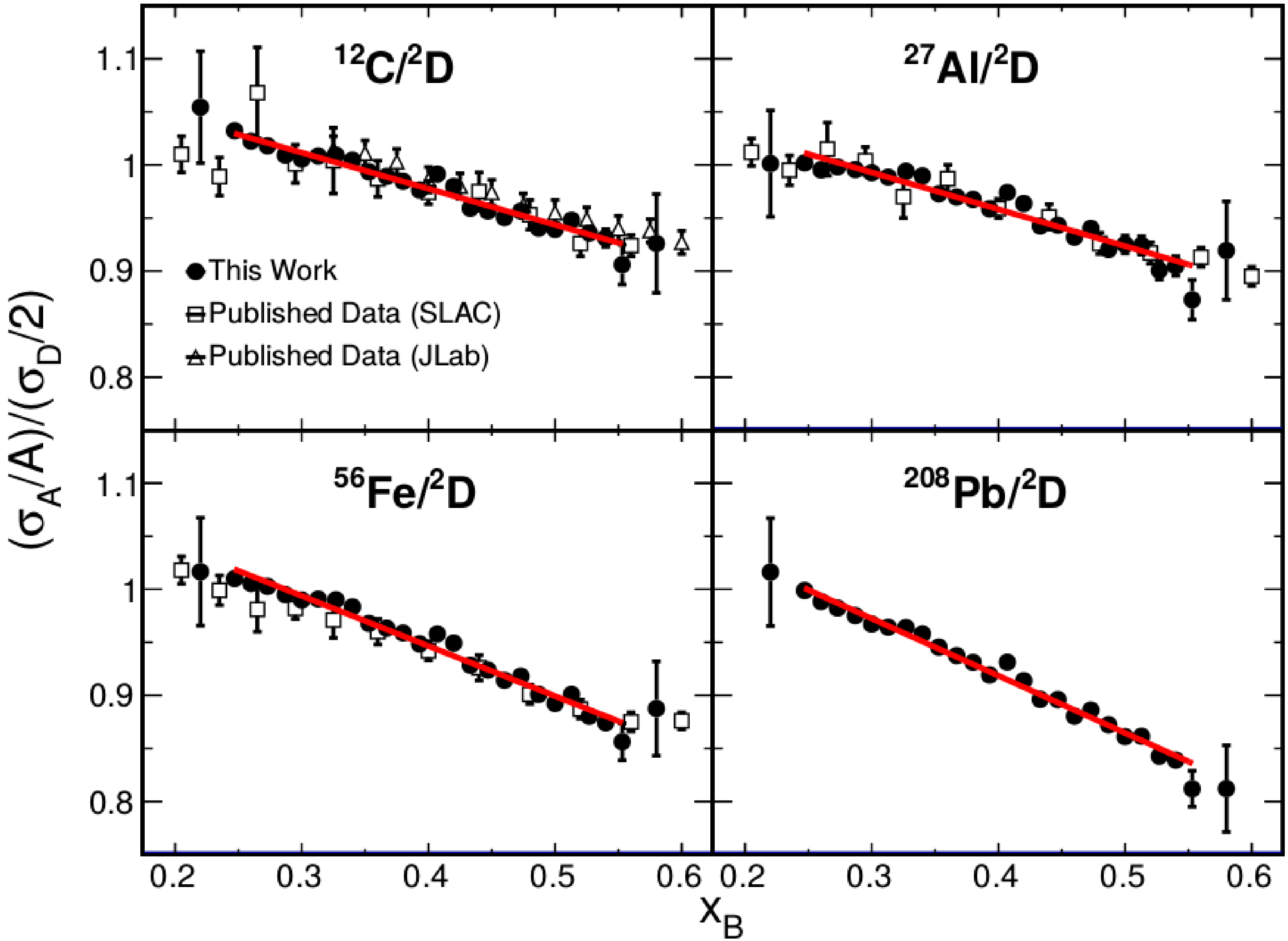
Bin-Centering Correction

DATA

SIMULATION



Our New EMC Effect Measurements



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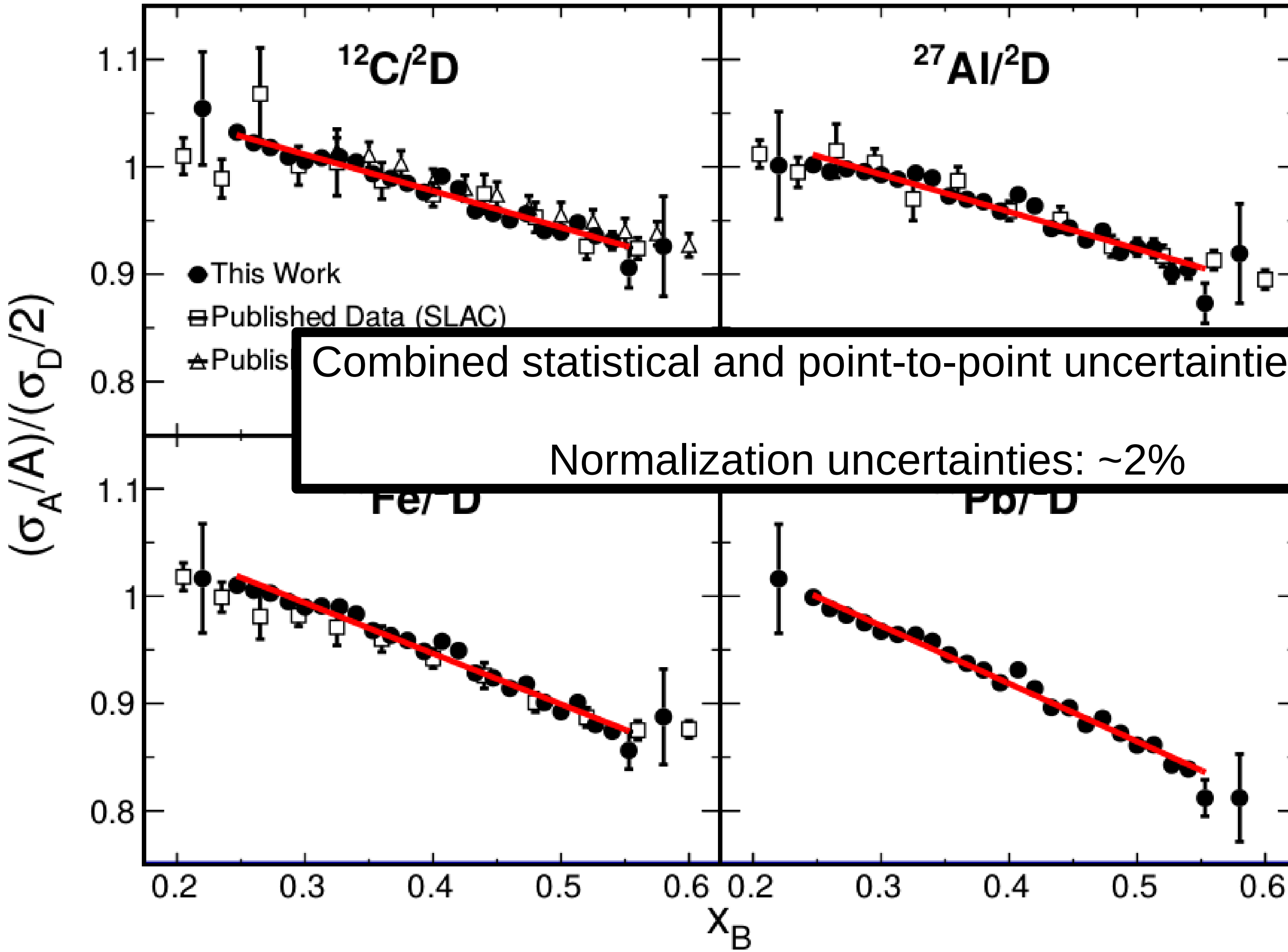
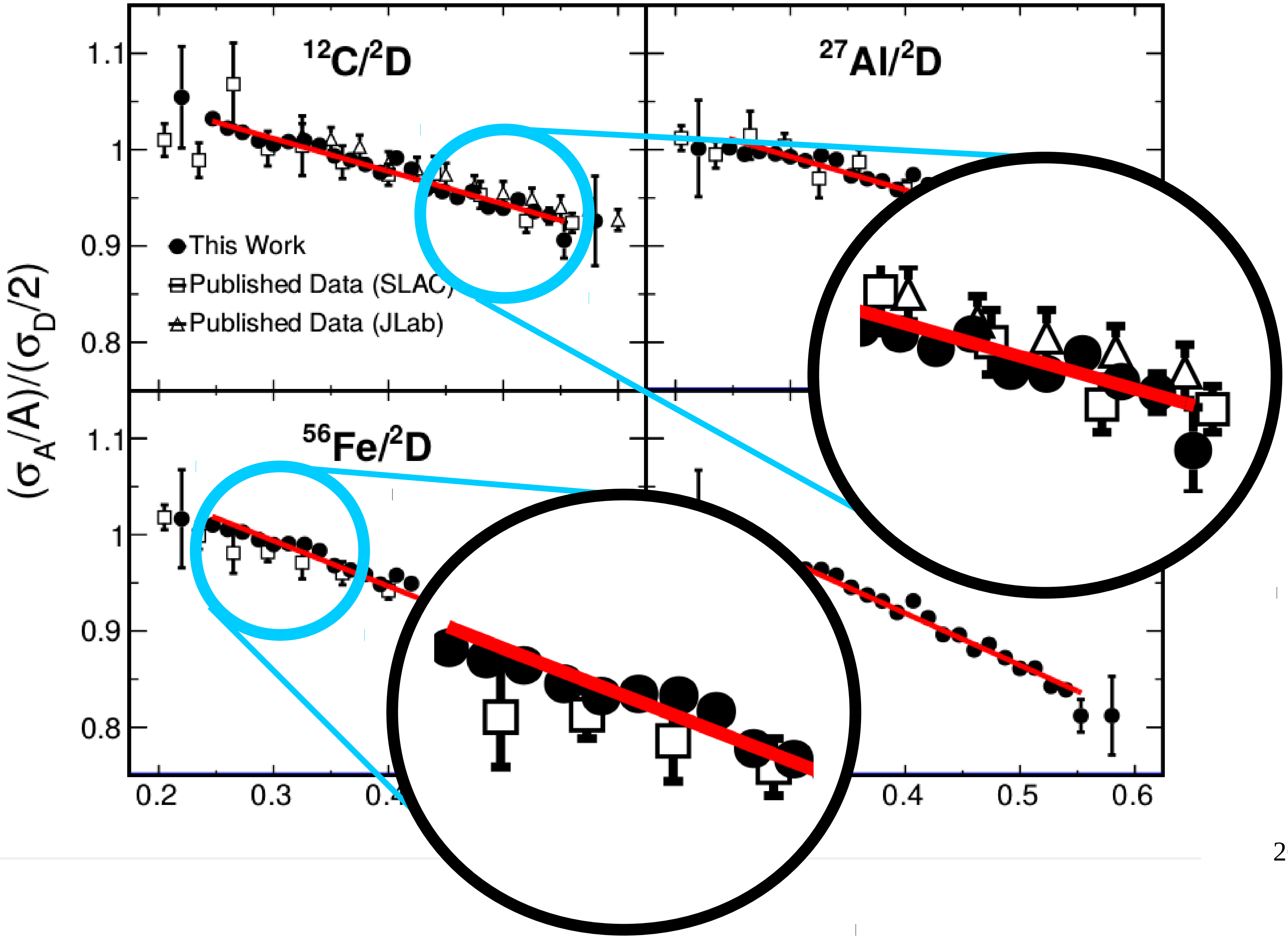


Combined statistical and point-to-point uncertainties: <1%

Normalization uncertainties: ~2%

Our New EMC Effect Measurements



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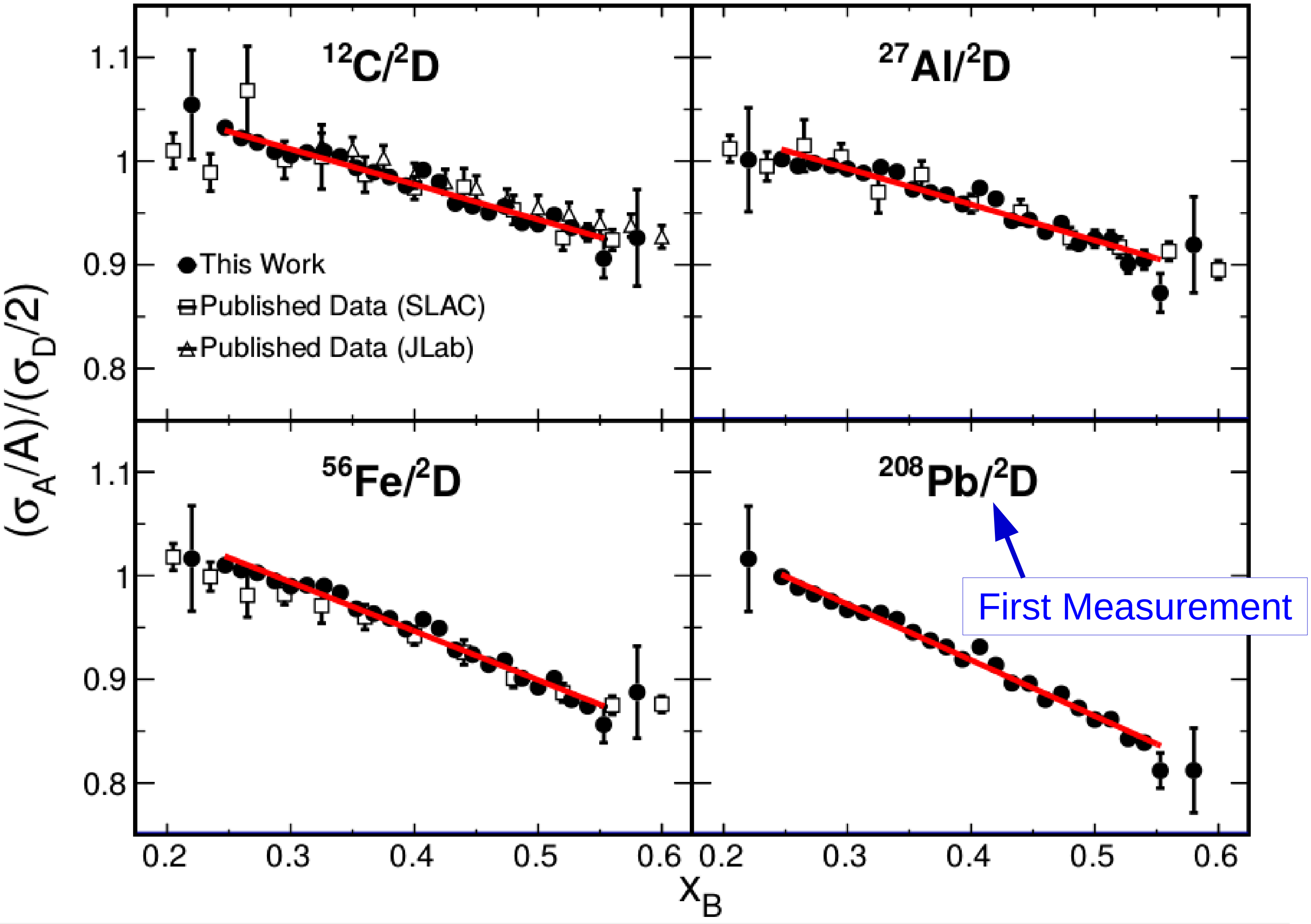

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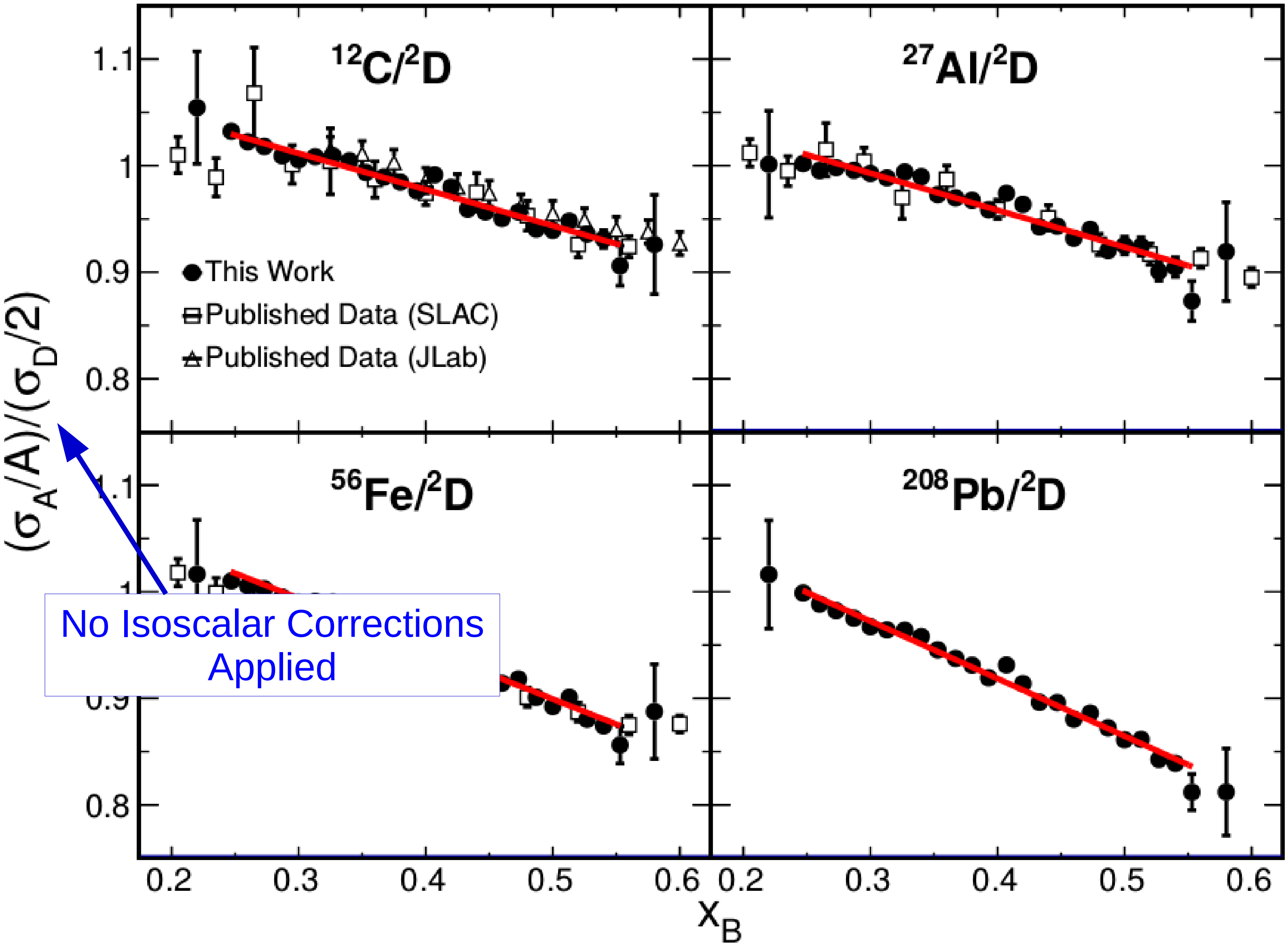

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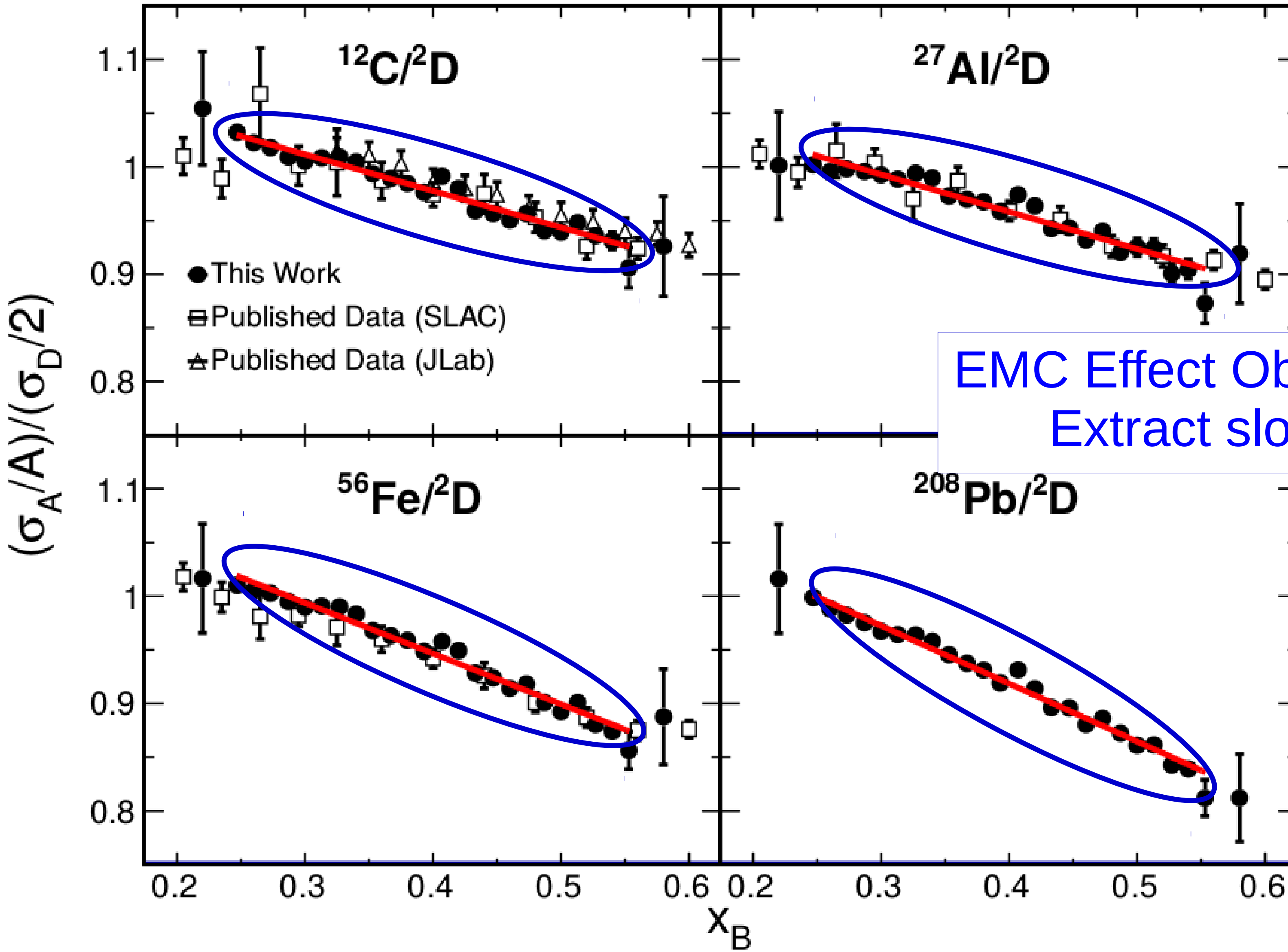
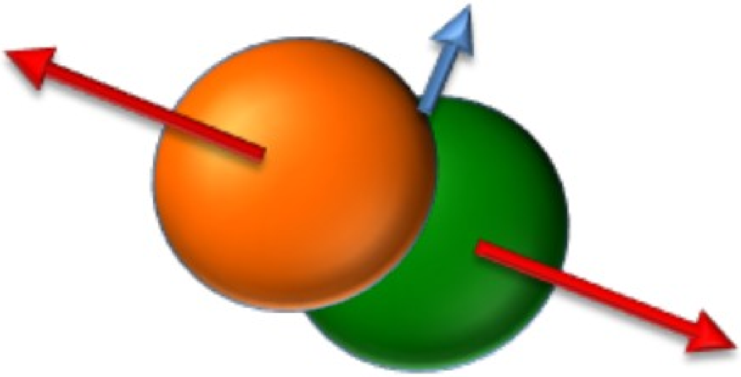


EMC Effect Observed!
Extract slopes

Short Range Correlations (SRC)

Nucleon pairs that are close together in the nucleus

Momentum space: *high relative* and *low c.m. momentum,* compared to the Fermi momentum (k_F)



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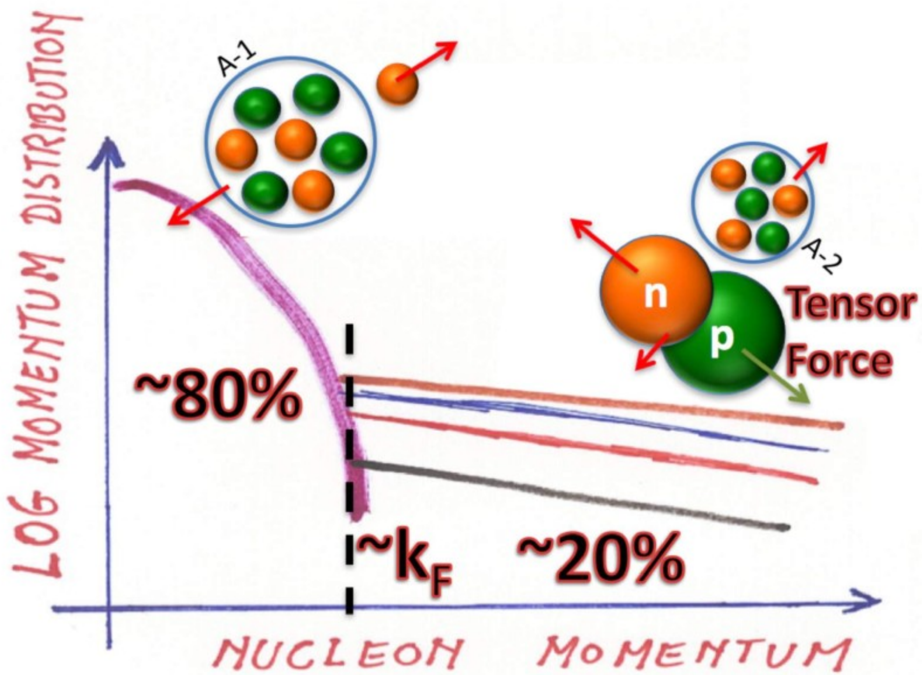

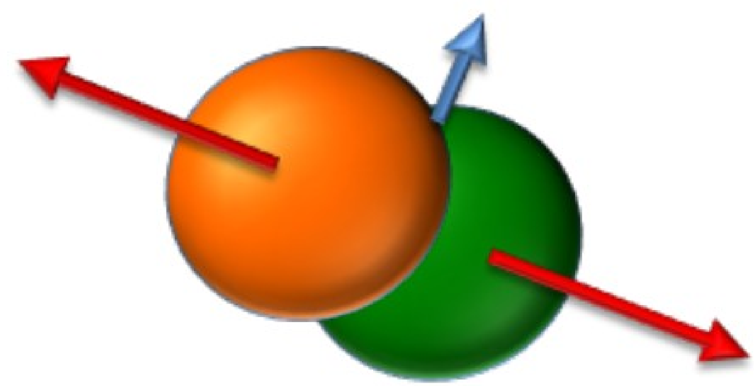

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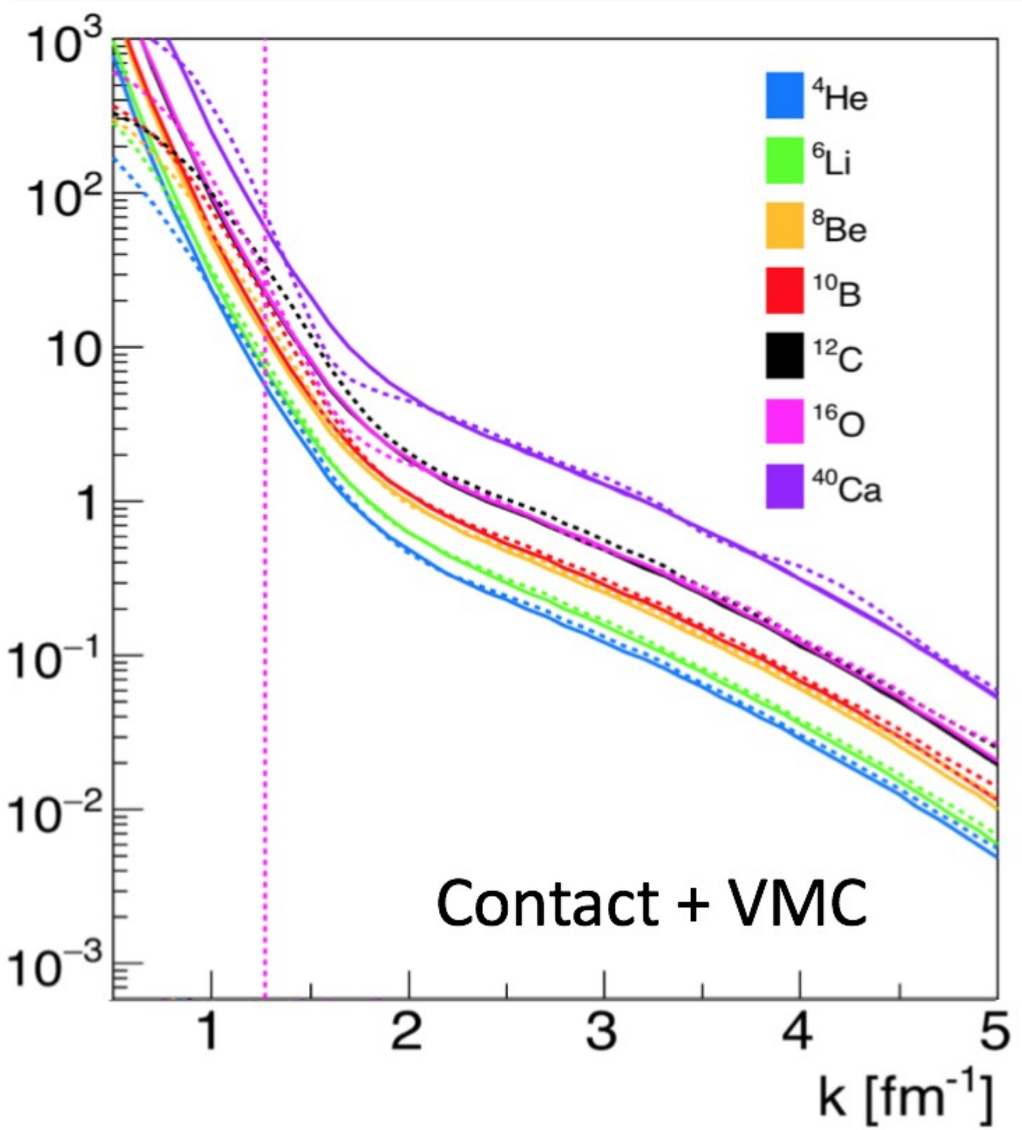
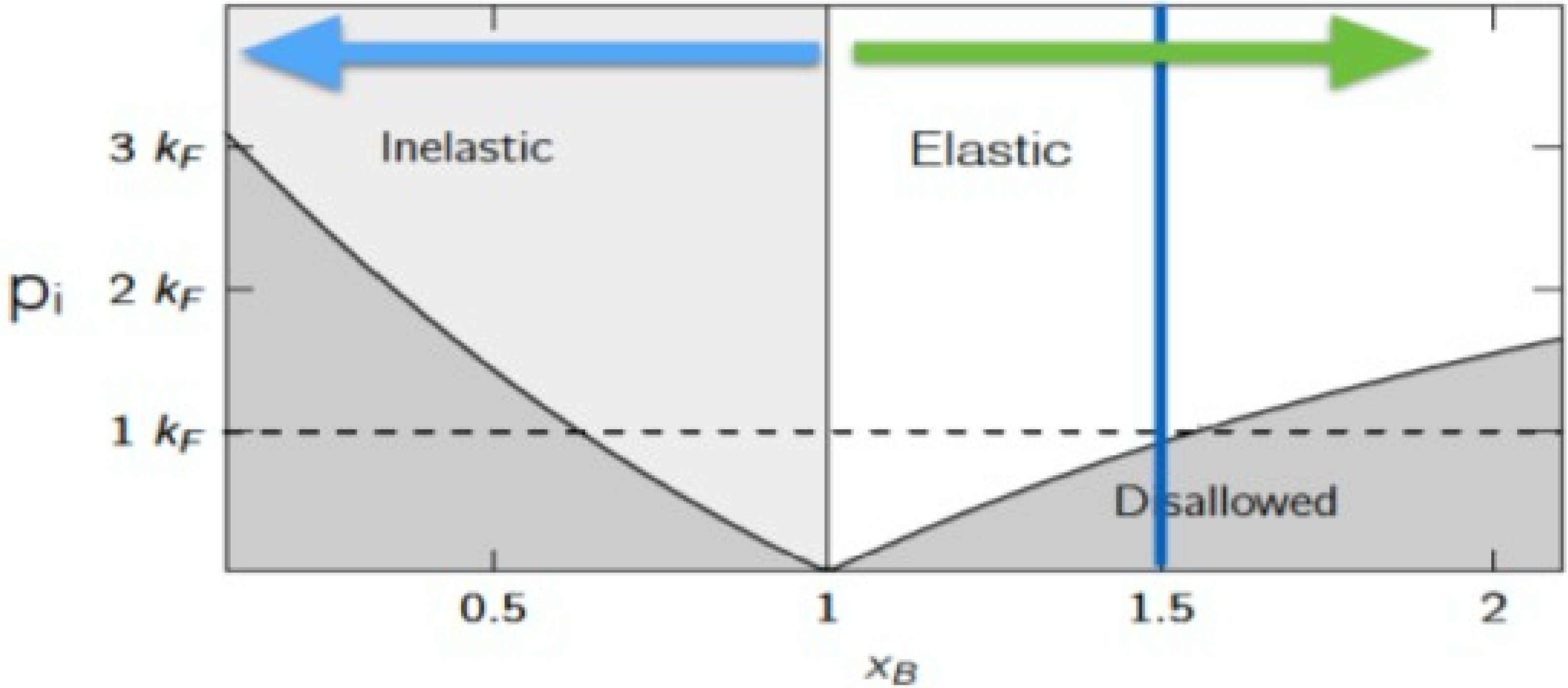


Scaling: High-momentum component of nuclear wave functions are deuteron-like.

a_2: Probability of finding a high momentum nucleon in nucleus A relative to deuterium

Weiss, Cruz-Torres, Barnea, Piasetzky and Hen, Phys. Lett. B 780, 211 (2018)

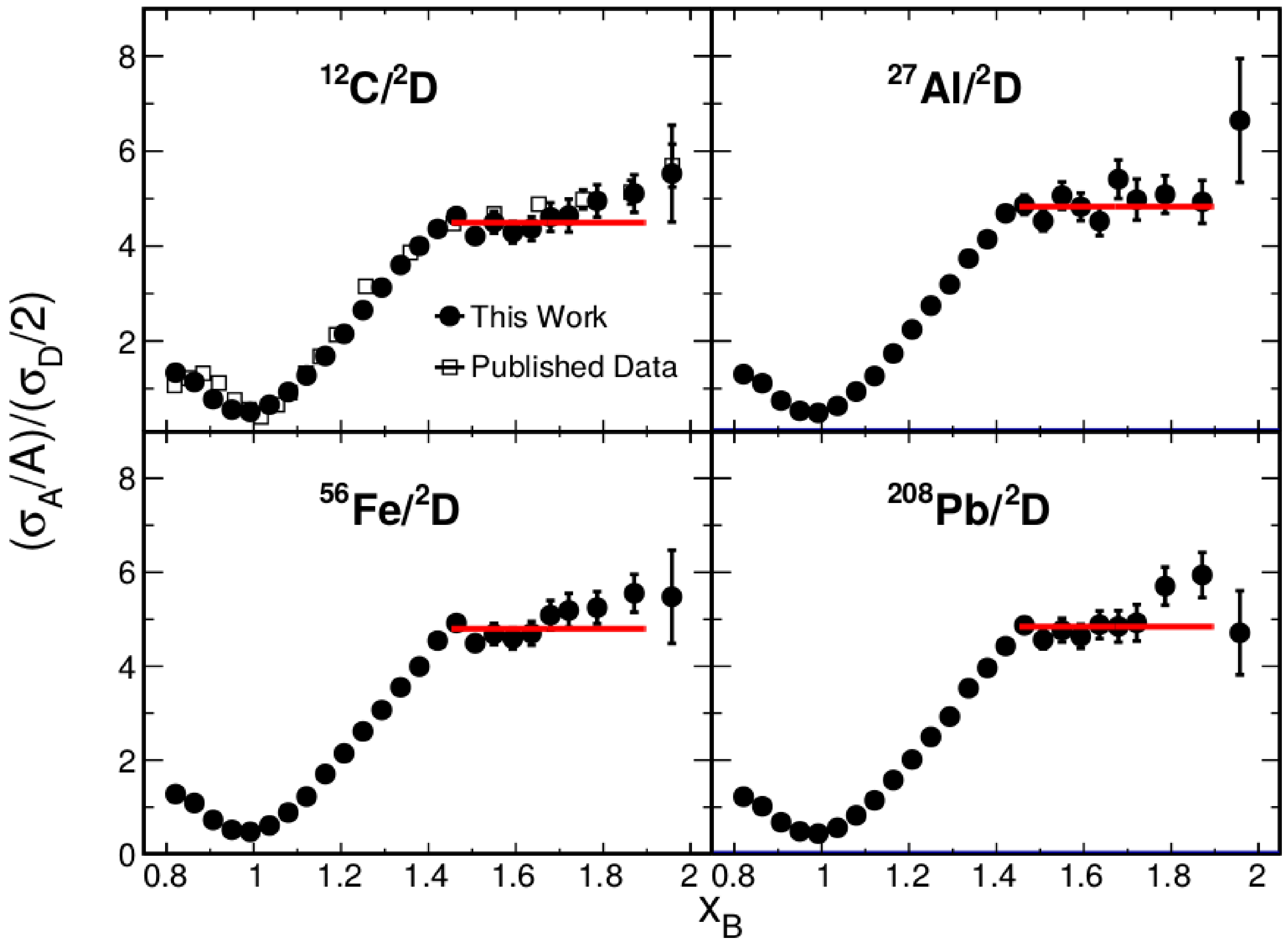
Short Range Correlations (SRC)



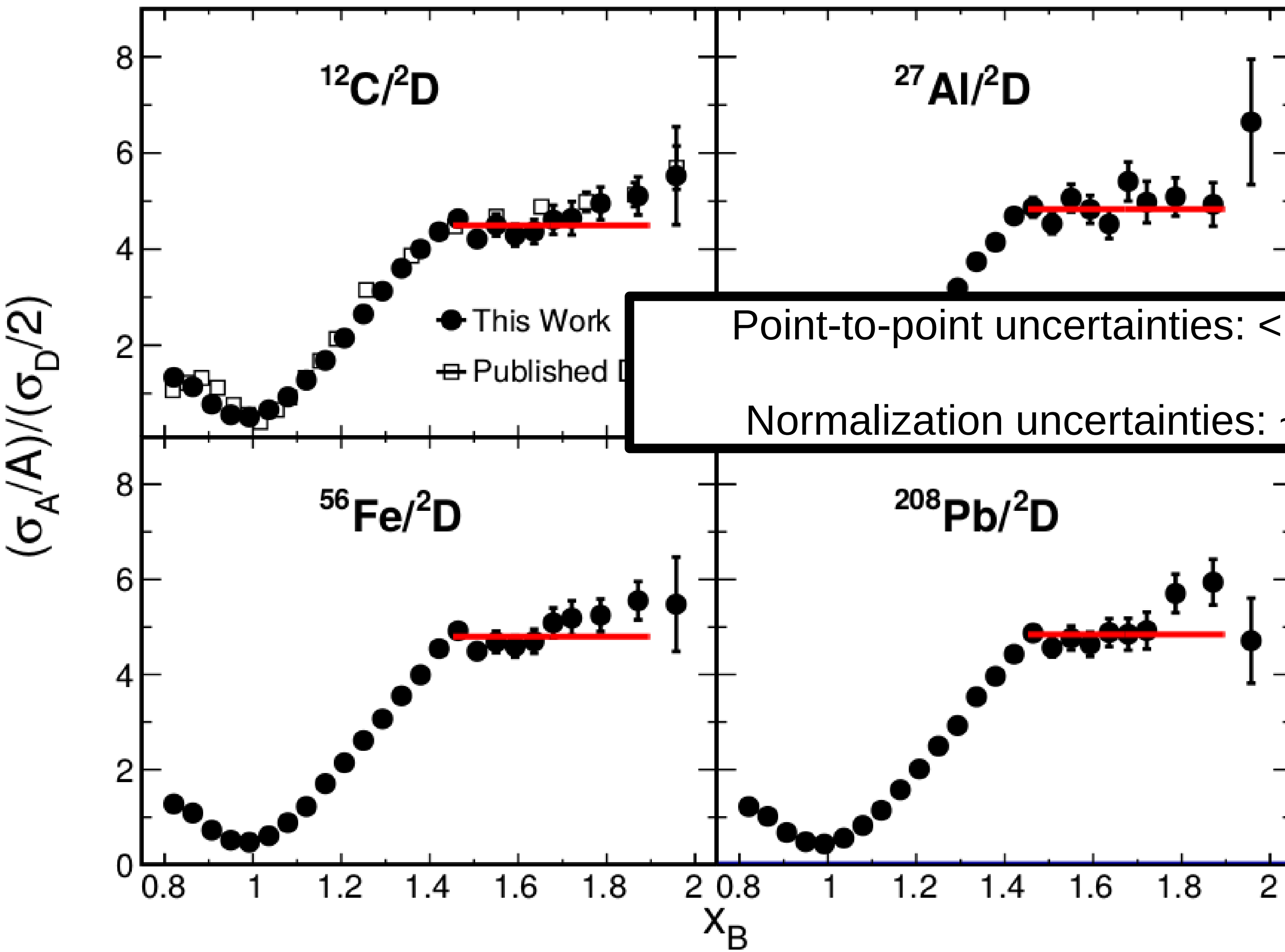
Inclusive quasi-elastic scattering →
minimum nucleon momentum depends on Q^2 and x_B

We access high-momentum part of the nuclear wave function at large Q^2 and x_B

Our New SRC a_2 Measurements



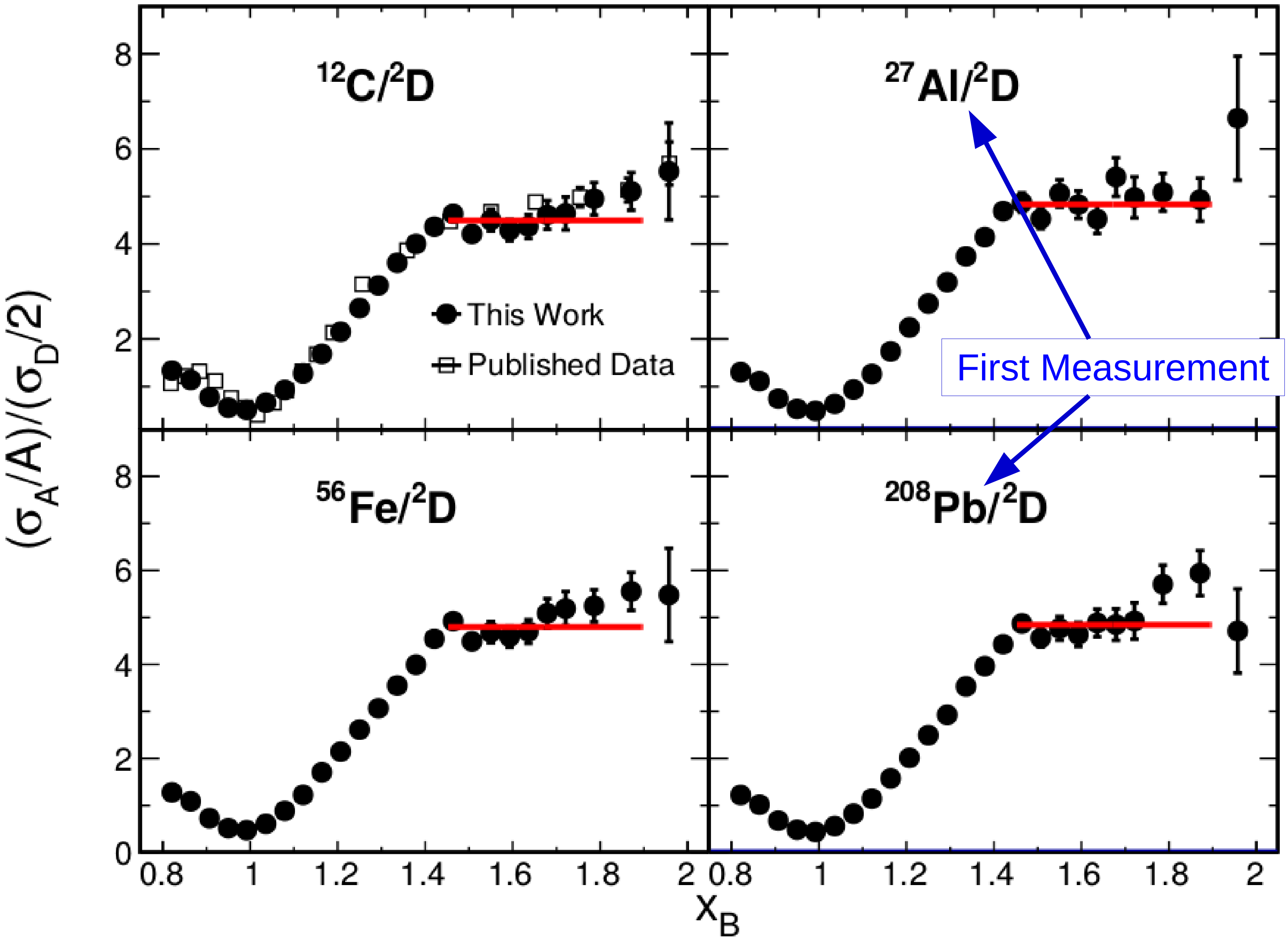
Our New SRC a_2 Measurements



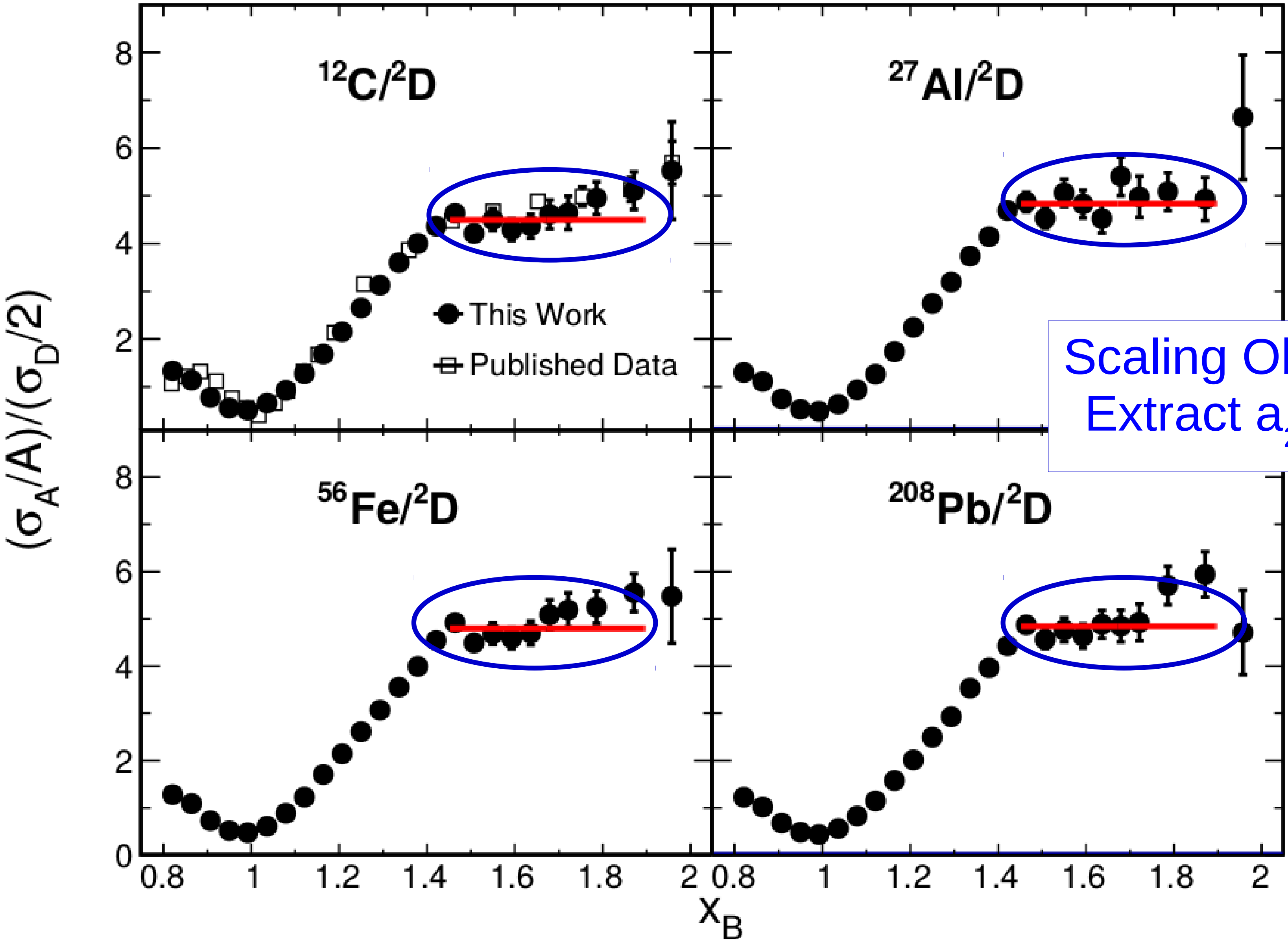
Point-to-point uncertainties: <1.5%

Normalization uncertainties: ~2%

Our New SRC a_2 Measurements



Our New SRC a_2 Measurements

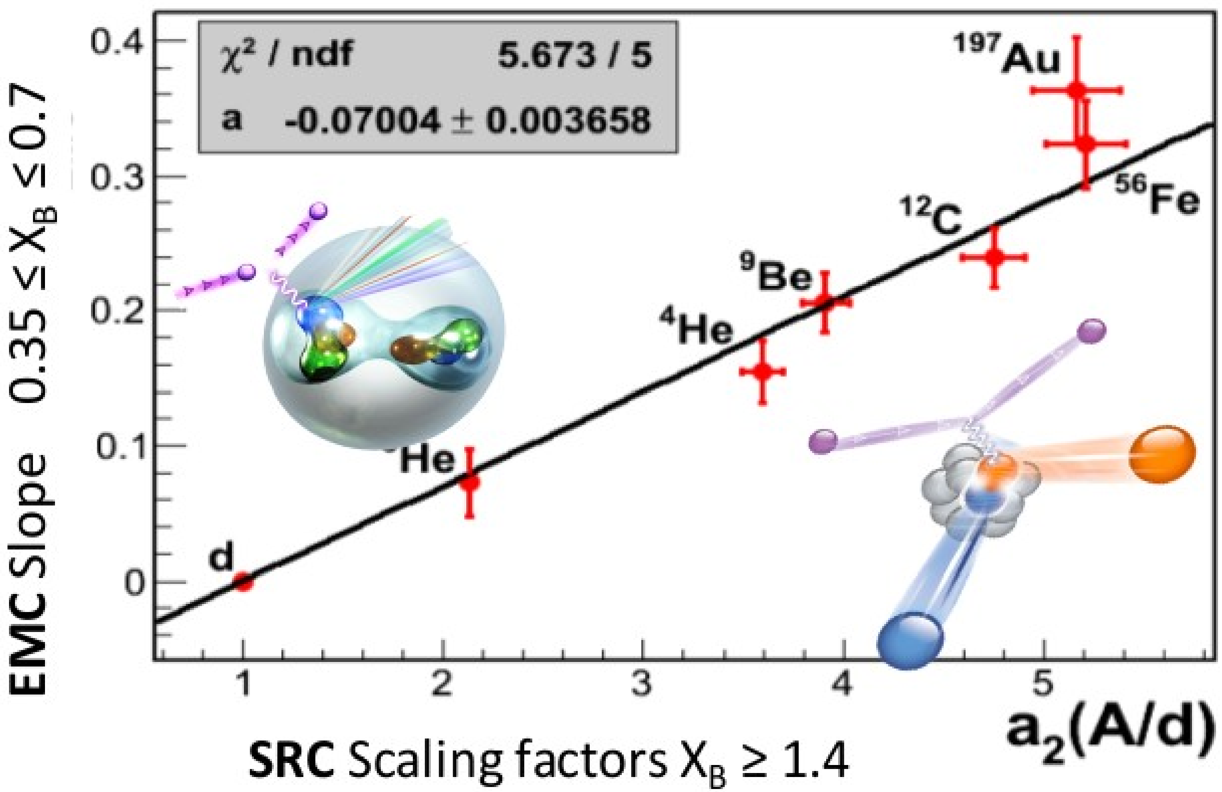


Scaling Observed!
Extract a_2 values

Back to the EMC Effect

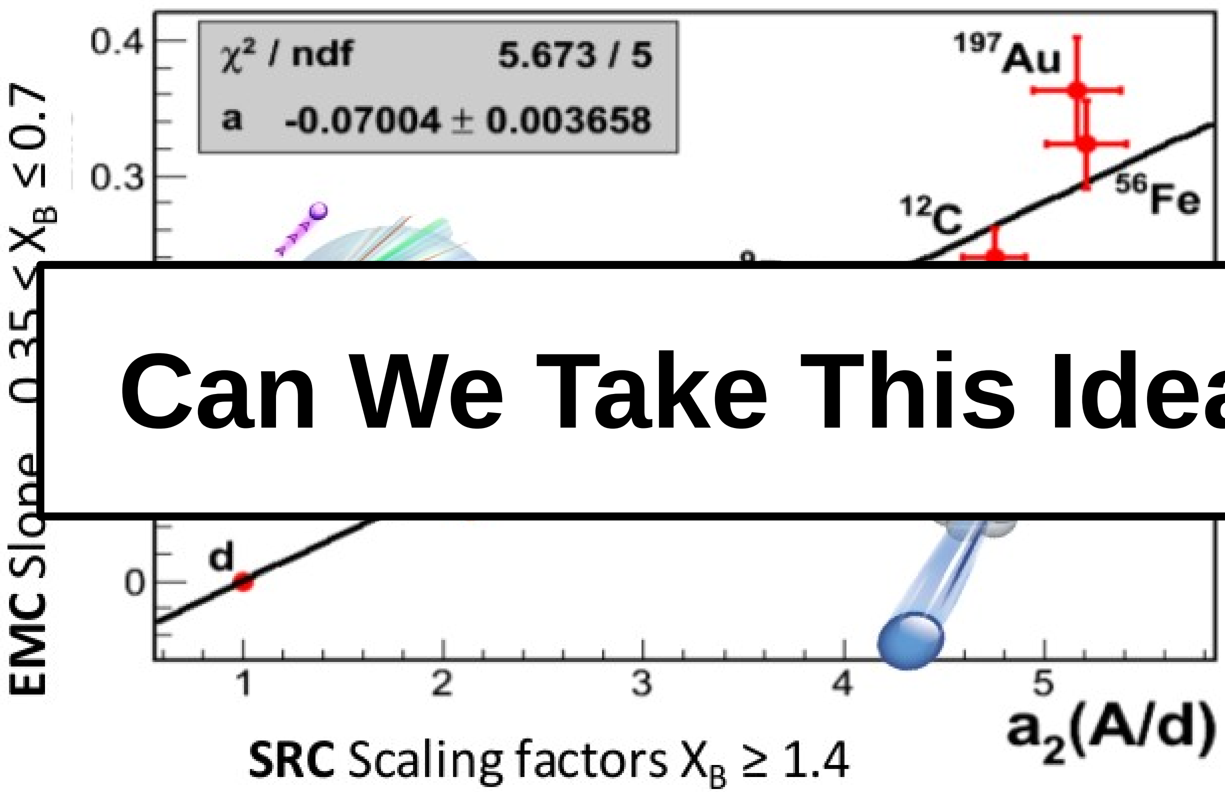
- Two leading approaches for describing the EMC effect:
  1) All nucleons are slightly modified when bound in nuclei
  2) Nucleons are unmodified most of the time, but are modified significantly when they fluctuate into SRC pairs

Observed EMC-SRC Correlation



L. Weinstein et. al., Phys. Rev. Lett. 106, 052301 (2011)
O. Hen et al. Phys. Rev. C 85 047301 (2012).
O. Hen et al., Rev. Mod. Phys. 89, 045002 (2017)

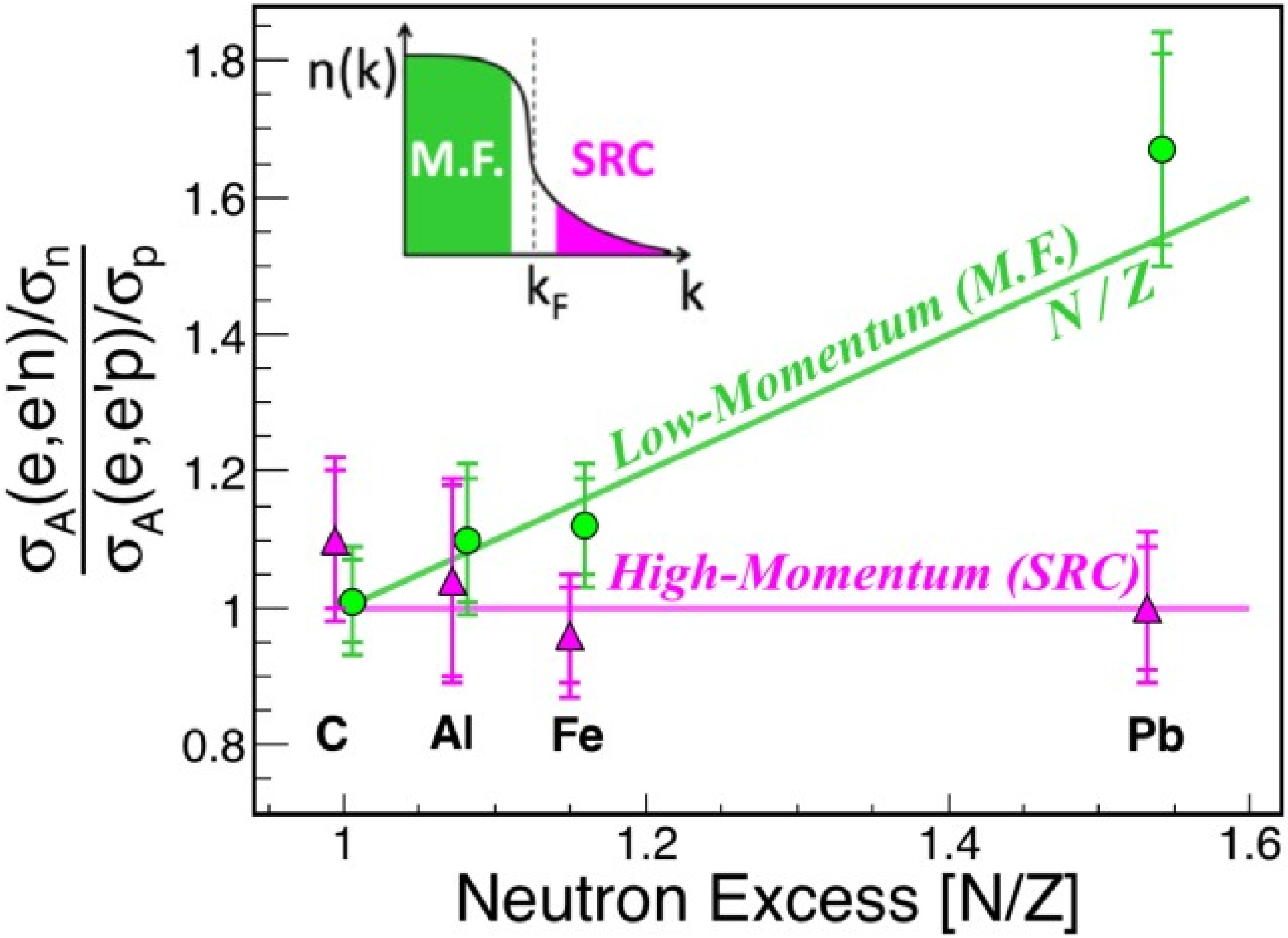
Observed EMC-SRC Correlation



Can We Take This Idea Further?

L. Weinstein et. al., Phys. Rev. Lett. 106, 052301 (2011)
O. Hen et al. Phys. Rev. C 85 047301 (2012).
O. Hen et al., Rev. Mod. Phys. 89, 045002 (2017)

Use the Isospin Dependence of SRC Pairs



M. Duer et al. (CLAS Collaboration), Nature, In-Print (2018)

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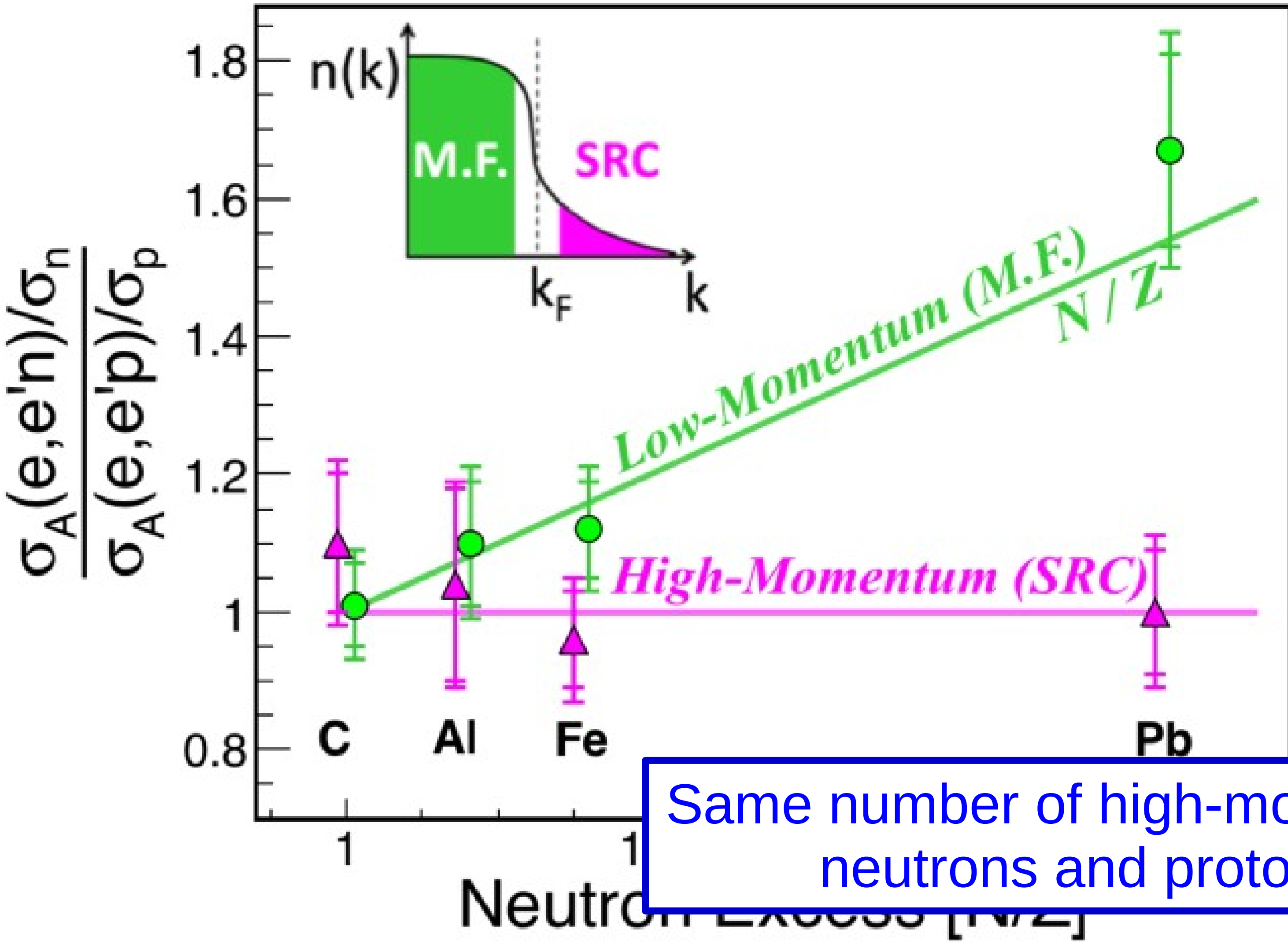
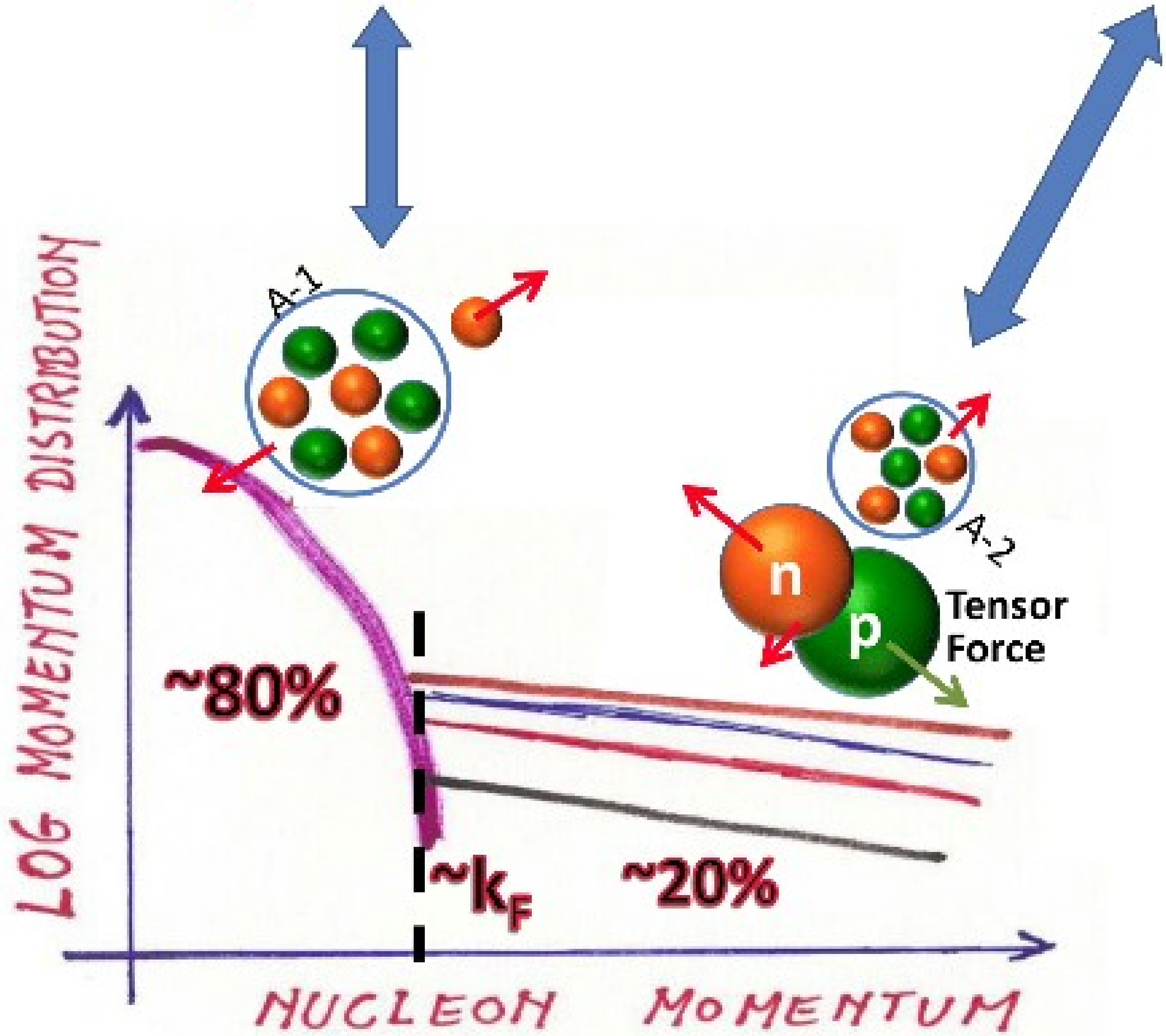


Same number of high-momentum neutrons and protons

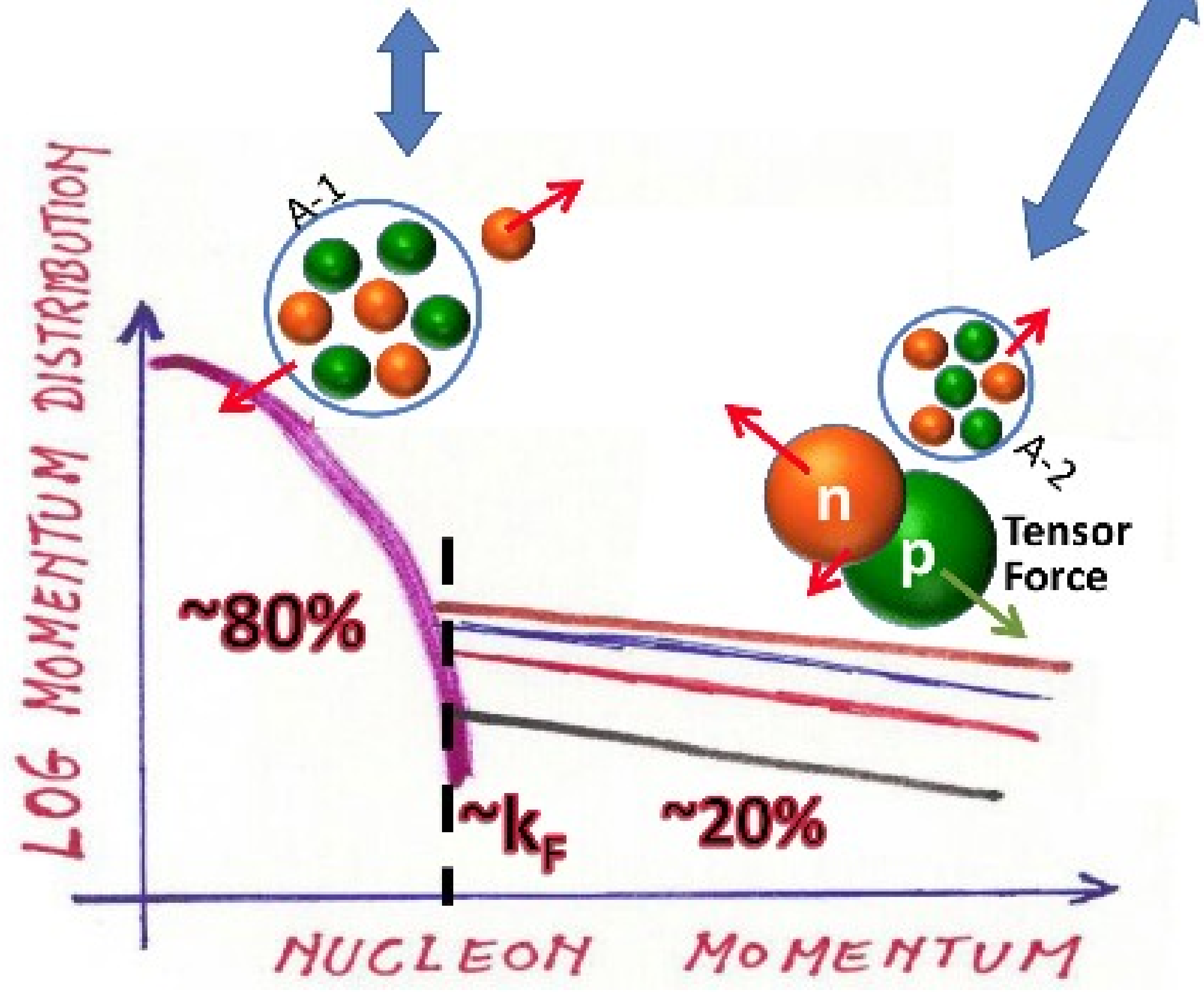
M. Duer et al. (CLAS Collaboration), Nature, In-Print (2018)

Bound = 'quasi Free' + Modified SRCs



Bound = 'quasi Free' + Modified SRCs

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



Bound = ‘quasi Free’ + Modified SRCs

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

$$\Delta F_2^N = F_2^{N*} - F_2^N$$

Bound = 'quasi Free' + Modified SRCs

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

$$\Delta F_2^N = F_2^{N*} - F_2^N$$

Not Well Constrained

$$\longrightarrow \quad F_2^d = F_2^p + F_2^n + n_d^{SRC}\left(\Delta F_2^p + \Delta F_2^n\right)$$

Can Solve for F_2^n

Bound = 'quasi Free' + Modified SRCs

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

$$\Delta F_2^N = F_2^{N*} - F_2^N$$

$$\longrightarrow \quad F_2^d = F_2^p + F_2^n + n_d^{SRC}\left(\Delta F_2^p + \Delta F_2^n\right)$$

$$\longrightarrow \quad a_2 \equiv \frac{2}{A} n_A^{SRC} / n_d^{SRC}$$

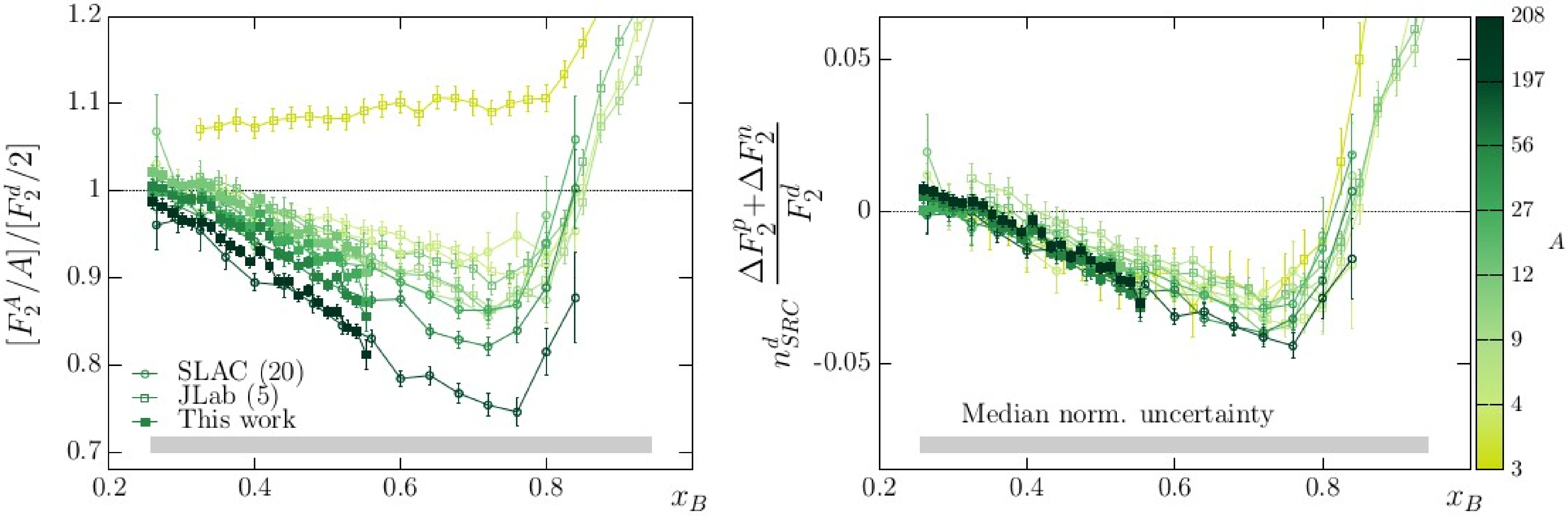
$$n_d^{SRC}\,\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} = \frac{\frac{F_2^A}{F_2^d} - (Z-N)\frac{F_2^p}{F_2^d} - N}{\frac{A}{2}a_2 - N}$$

Universal??? Nucleus-Dependent

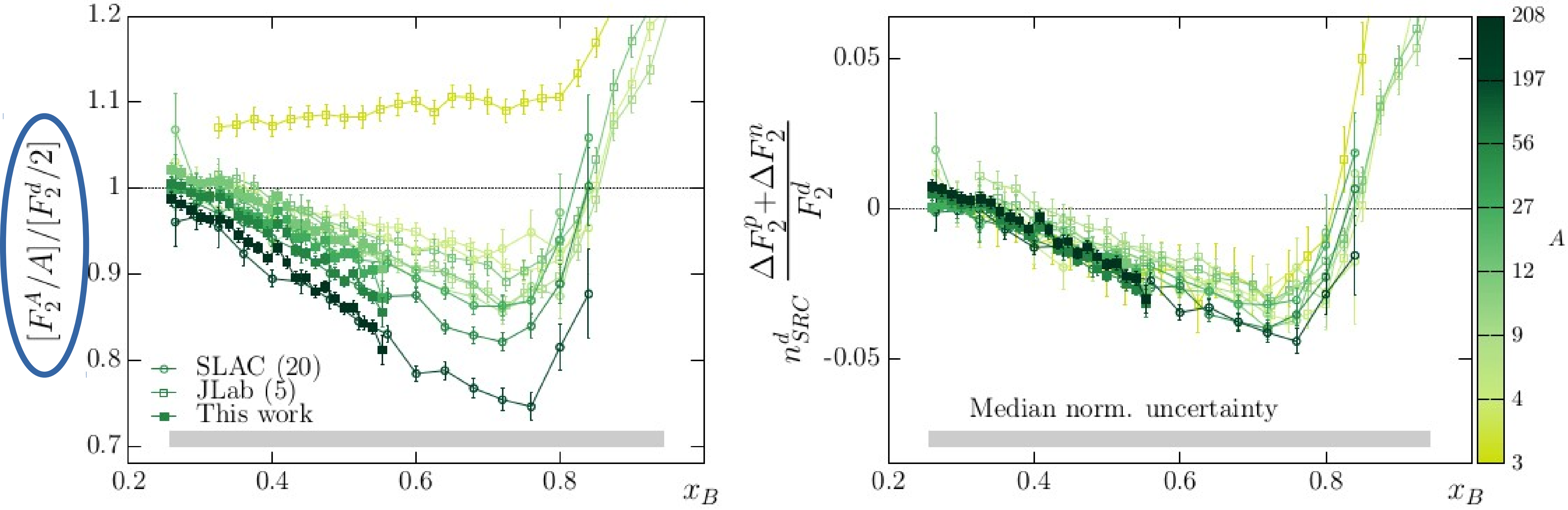
$$n_d^{SRC}\,\frac{\Delta F_2^p+\Delta F_2^n}{F_2^d}=\frac{\frac{F_2^A}{F_2^d}-(Z-N)\frac{F_2^p}{F_2^d}-N}{\frac{A}{2}a_2-N}$$

Everything is Known

Universal EMC Modification Function



Universal EMC Modification Function



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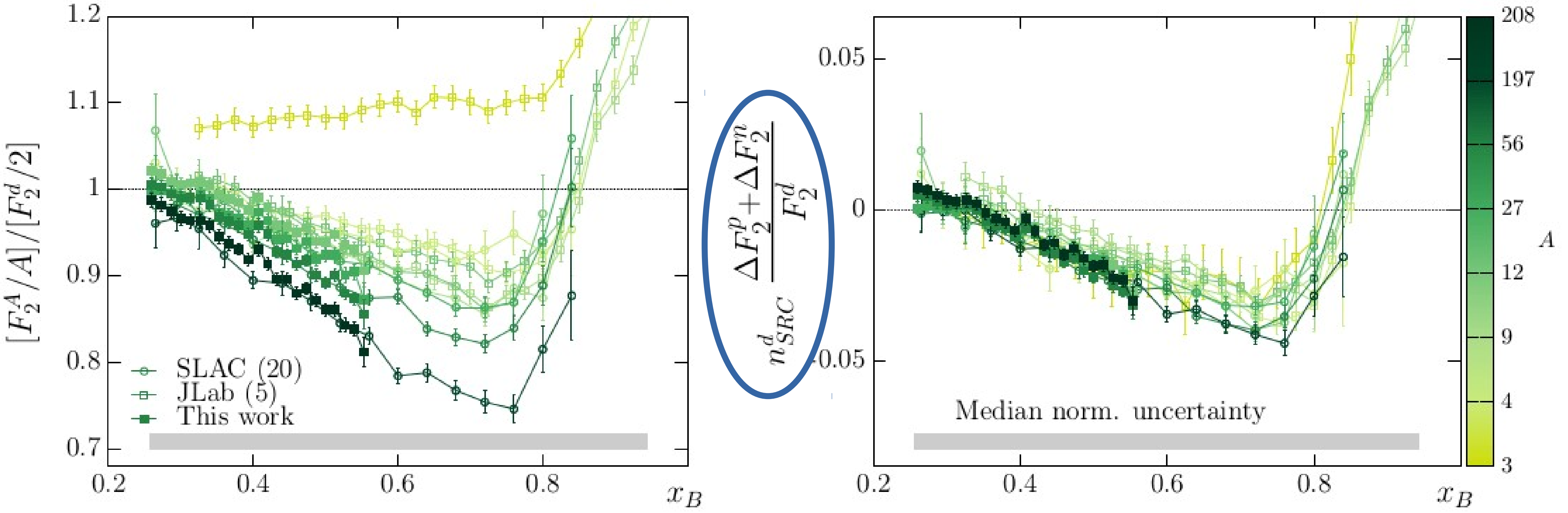
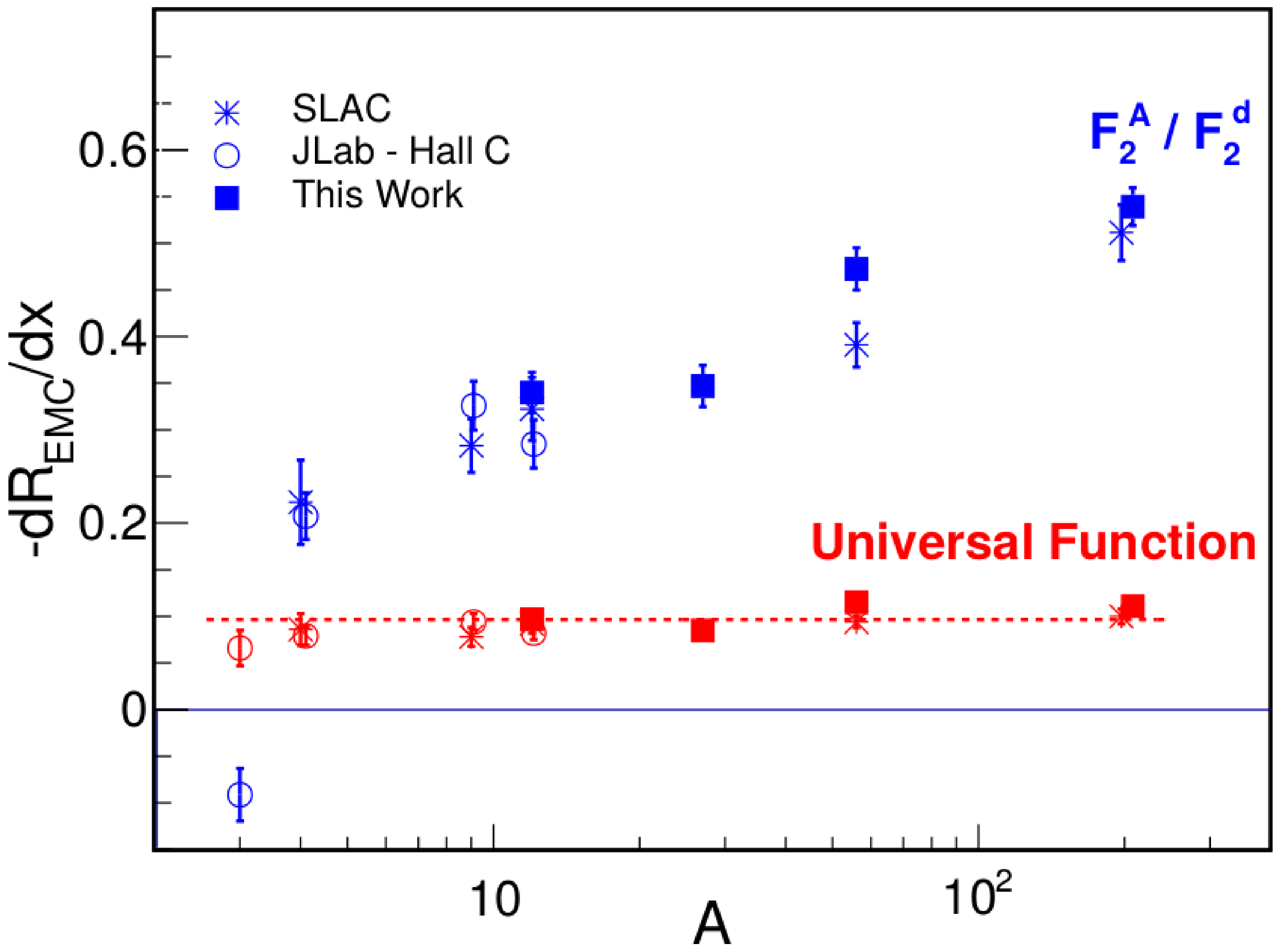


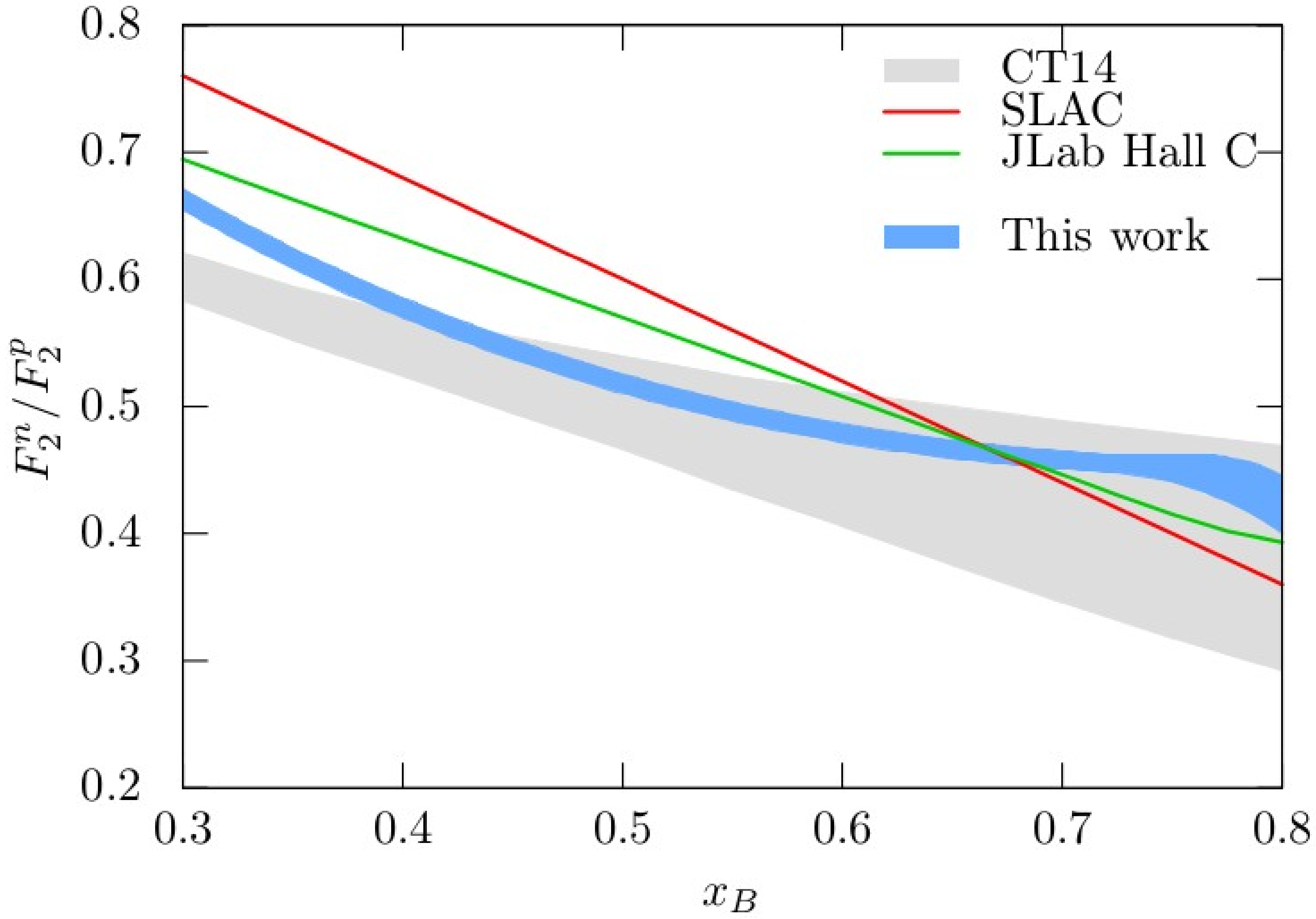
$$n_d^{SRC}\frac{\Delta F_2^p+\Delta F_2^n}{F_2^d}=\frac{\frac{F_2^A}{F_2^d}-(Z-N)\frac{F_2^p}{F_2^d}-N}{\frac{A}{2}a_2-N}$$

Universal!!!

Universal EMC Modification Function

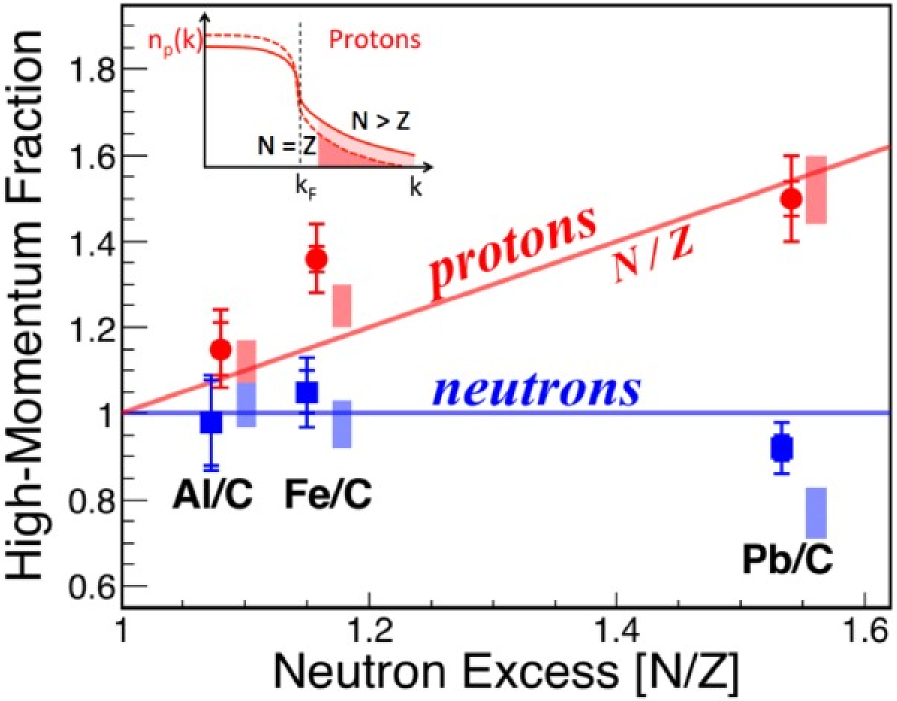


Interlude: Free Neutron Extraction



$$F_2^d = F_2^p + F_2^n + n_d^{SRC}\left(\Delta F_2^p + \Delta F_2^n\right)$$

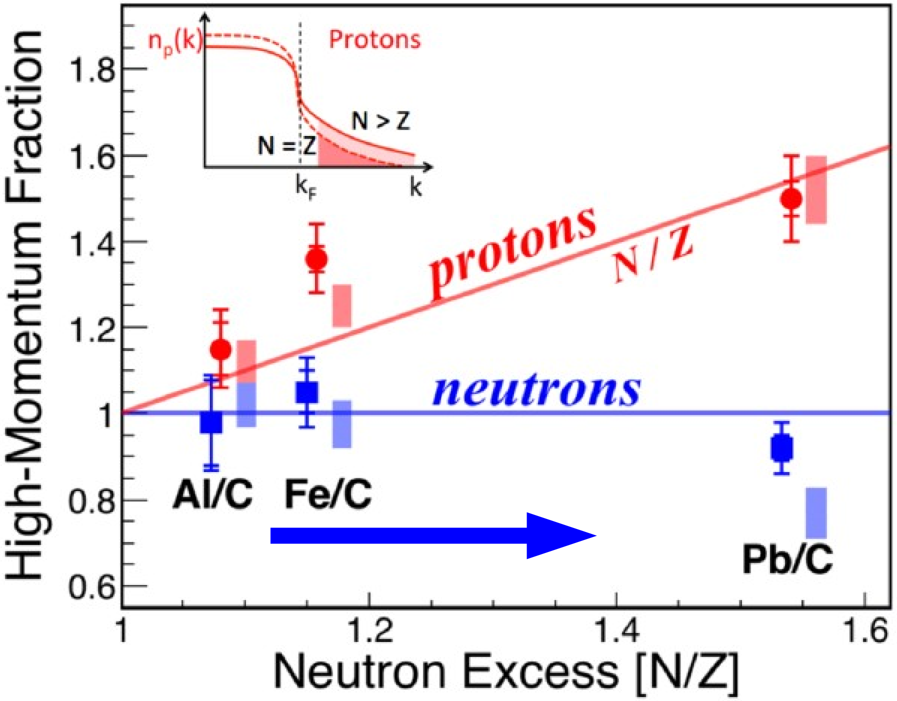
Focus on Neutron-Rich Nuclei



M. Duer et al. (CLAS Collaboration), Nature, In-Print (2018)

Focus on Neutron-Rich Nuclei

Prediction: EMC effect will show no growth for neutrons ...



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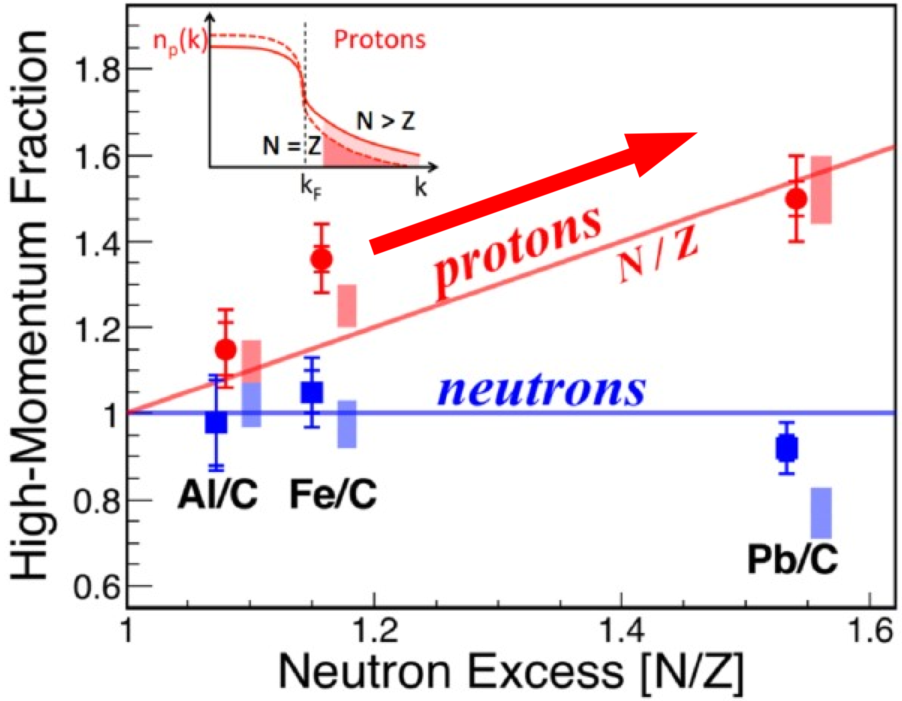
Focus on Neutron-Rich Nuclei

Prediction: EMC effect will show no growth for neutrons and grow for protons



M. Duer et al. (CLAS Collaboration), Nature, In-Print (2018)

Form New Per-Neutron (Proton) Quantities

Per-Neutron Quantities: $\boxed{\dfrac{\sigma_A/N}{\sigma_D/1}}$

Per-Proton Quantities: $\boxed{\dfrac{\sigma_A/Z}{\sigma_D/1}}$

Form New Per-Neutron (Proton) Quantities

Per-Neutron Quantities: $\boxed{\dfrac{\sigma_A/N}{\sigma_D/1}}$

$$dR^n_{EMC}/dx = \left(\frac{A}{2 \cdot N}\right) \times dR_{EMC}/dx \qquad a^n_2 = \left(\frac{A}{2 \cdot N}\right) \times a_2$$

Per-Proton Quantities: $\boxed{\dfrac{\sigma_A/Z}{\sigma_D/1}}$

$$dR^p_{EMC}/dx = \left(\frac{A}{2 \cdot Z}\right) \times dR_{EMC}/dx \qquad a^p_2 = \left(\frac{A}{2 \cdot Z}\right) \times a_2$$

Per-Neutron (Proton) Ratios: What Does Our Model Predict?

$$\frac{F_2^A/N}{F_2^d/1} = \left(a_2^n - 1\right)\cdot\left[n_{SRC}^d \frac{\Delta F_2^p + \Delta F_2^n}{F_2^d}\right] + \left(\frac{Z}{N} - 1\right)\frac{F_2^p}{F_2^d} + 1$$

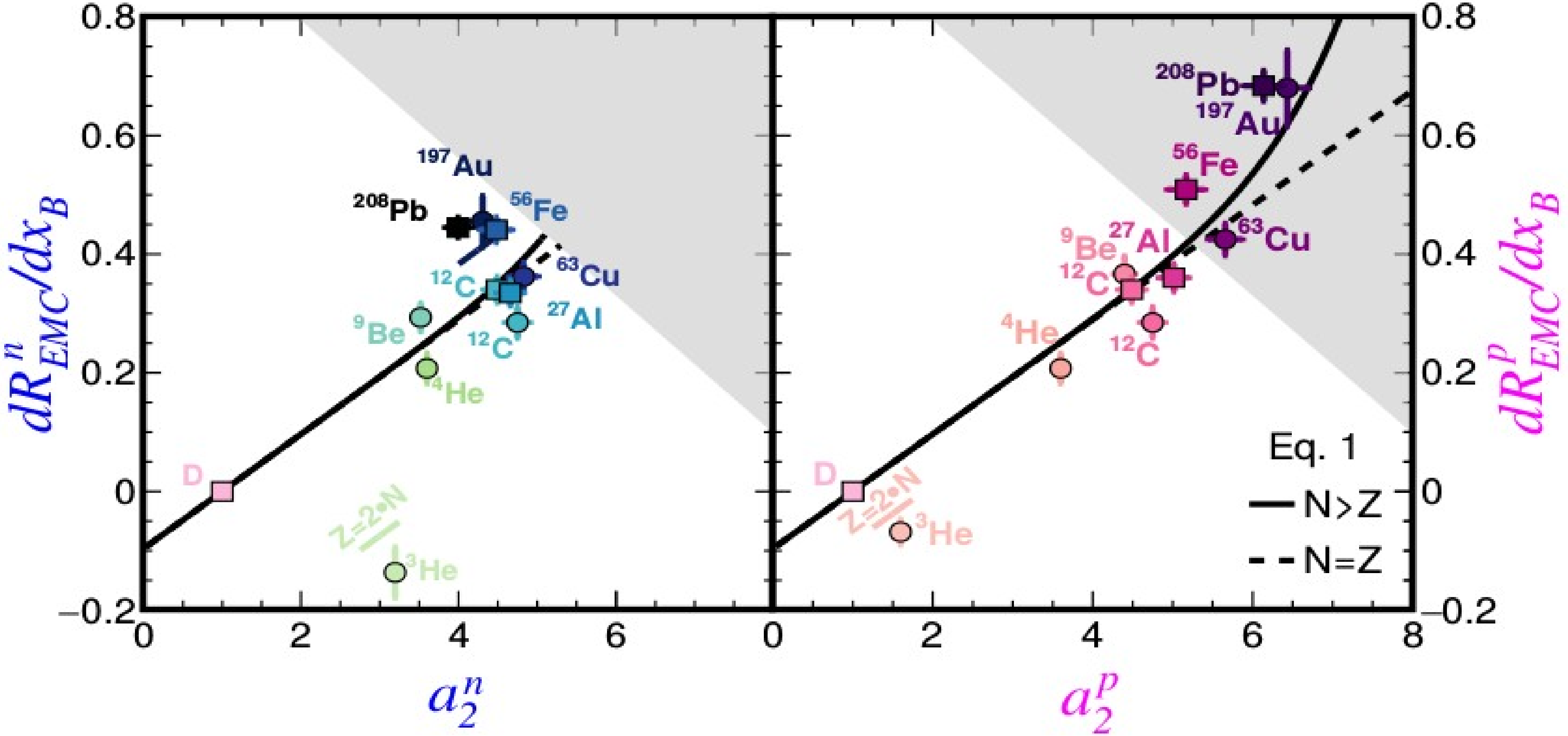
$$a_2^n = \frac{n_{SRC}^A/N}{n_{SRC}^d/1}$$

Per-Neutron (Proton) Ratios: What Does Our Model Predict?

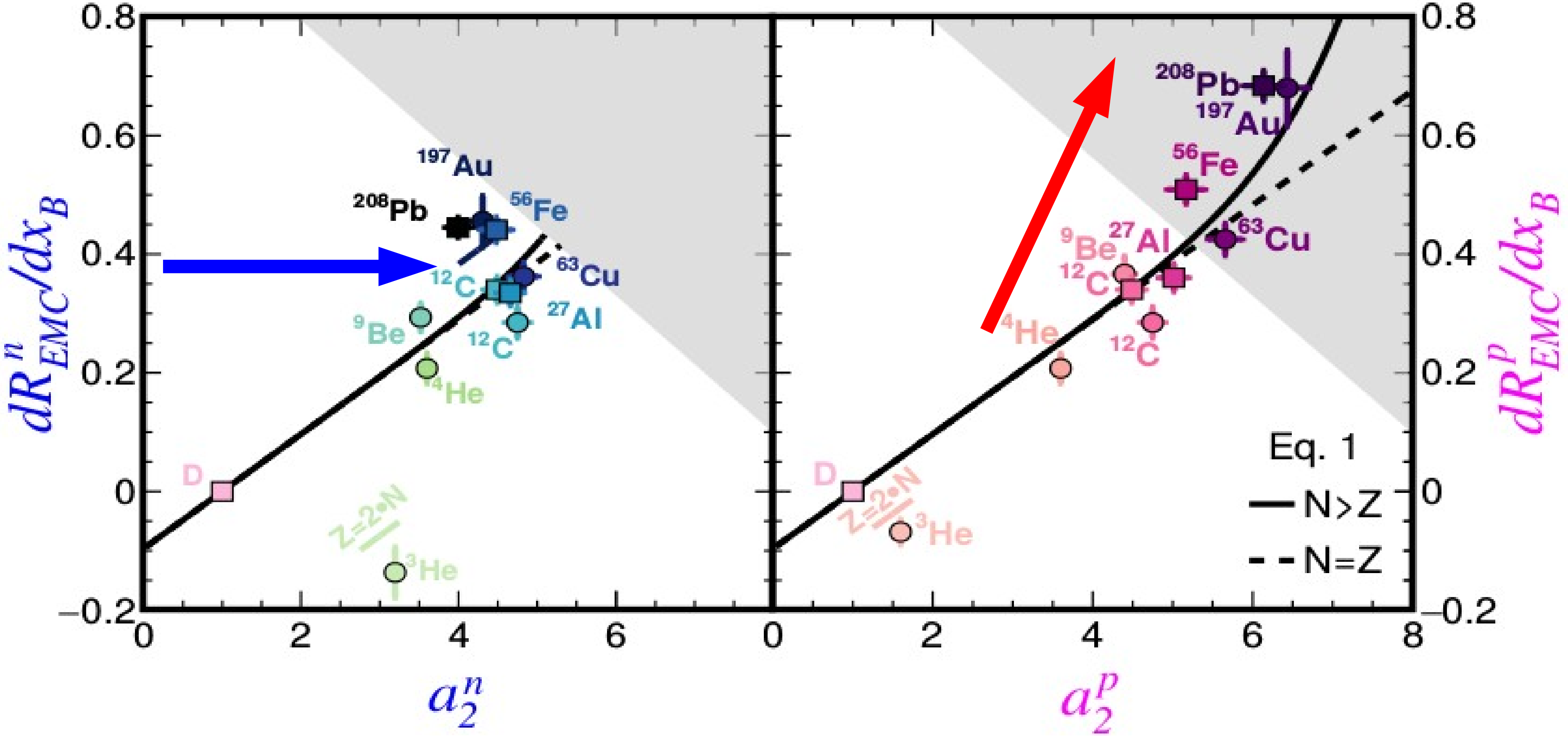
$$\frac{F_2^A/N}{F_2^d/1} = \left(a_2^n - 1\right) \cdot \left[n_{SRC}^d \frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} \right] + \left(\frac{Z}{N} - 1 \right) \frac{F_2^p}{F_2^d} + 1$$

Extract Per-Neutron (Proton) Slope

New EMC-SRC Correlation



New EMC-SRC Correlation



Thank You !!!

Additional Slides

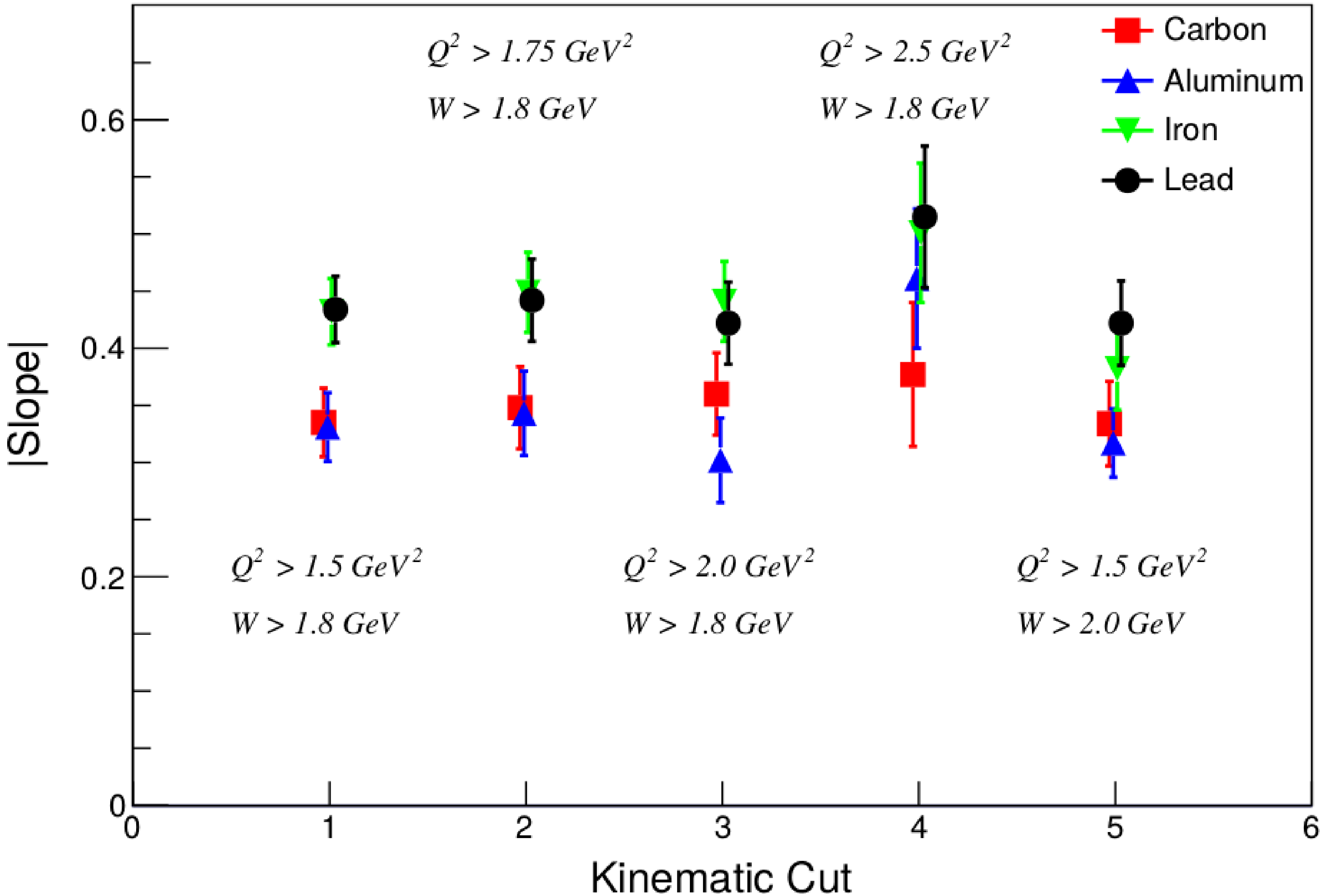
Uncertainties on DIS Cross-Section Ratios

Source	Point-to-point (%)	Normalization (%)
Time-Dependent Instabilities	—	1.0
Target Thickness and Cuts	—	1.42–1.58
Acceptance Corrections	0.6 (2,5)	—
Radiative Corrections	—	0.5
Coulomb Corrections	—	0.1
Bin-Centering Corrections	0.5	—
Total	0.78	1.81–1.94

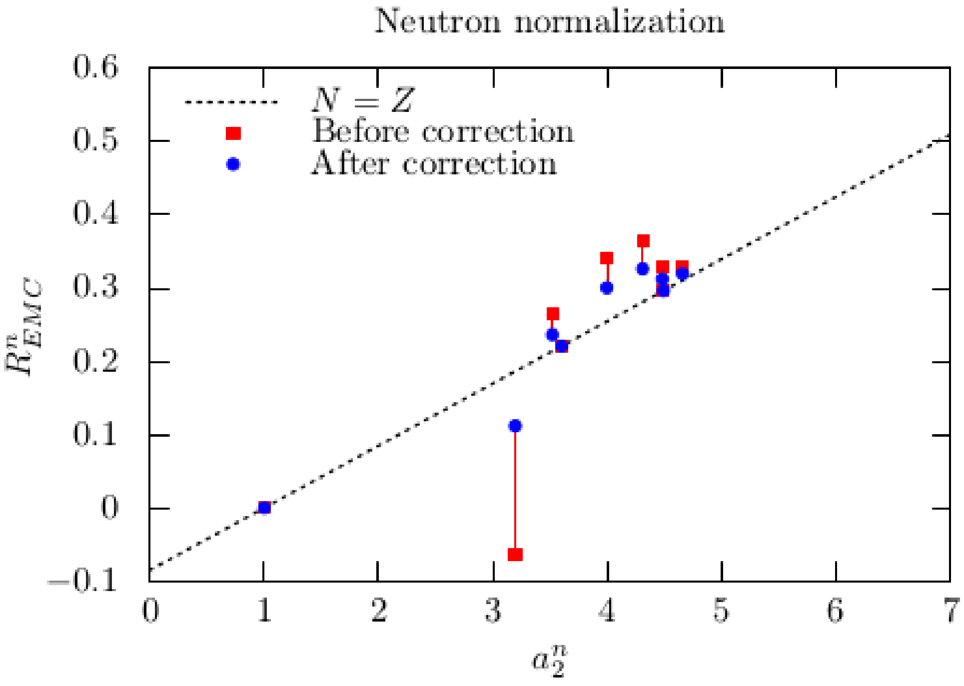
Uncertainties on QE Cross-Section Ratios

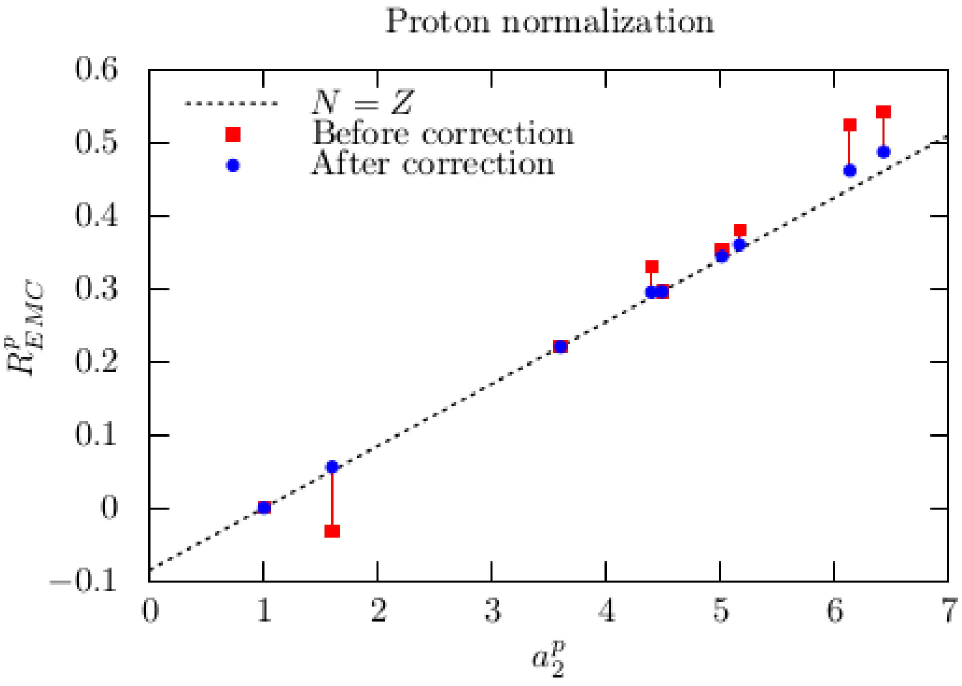
Source	Point-to-point (%)	Normalization (%)
Time-Dependent Instabilities	—	1.0
Target Thickness and Cuts	—	1.42–1.58
Acceptance Corrections	1.2 (2.5,10)	—
Radiative Corrections	—	0.5
Coulomb Corrections	—	0.2–1.0
Bin-Centering Corrections	0.5	—
Kinematical Corrections	0.3	—
Total	1.33	1.82–2.18

EMC Slopes are Stable to Kinematic Cut



Effect of our Isoscalar Corrections





EMC-SRC Correlations with Isoscalar Corrections