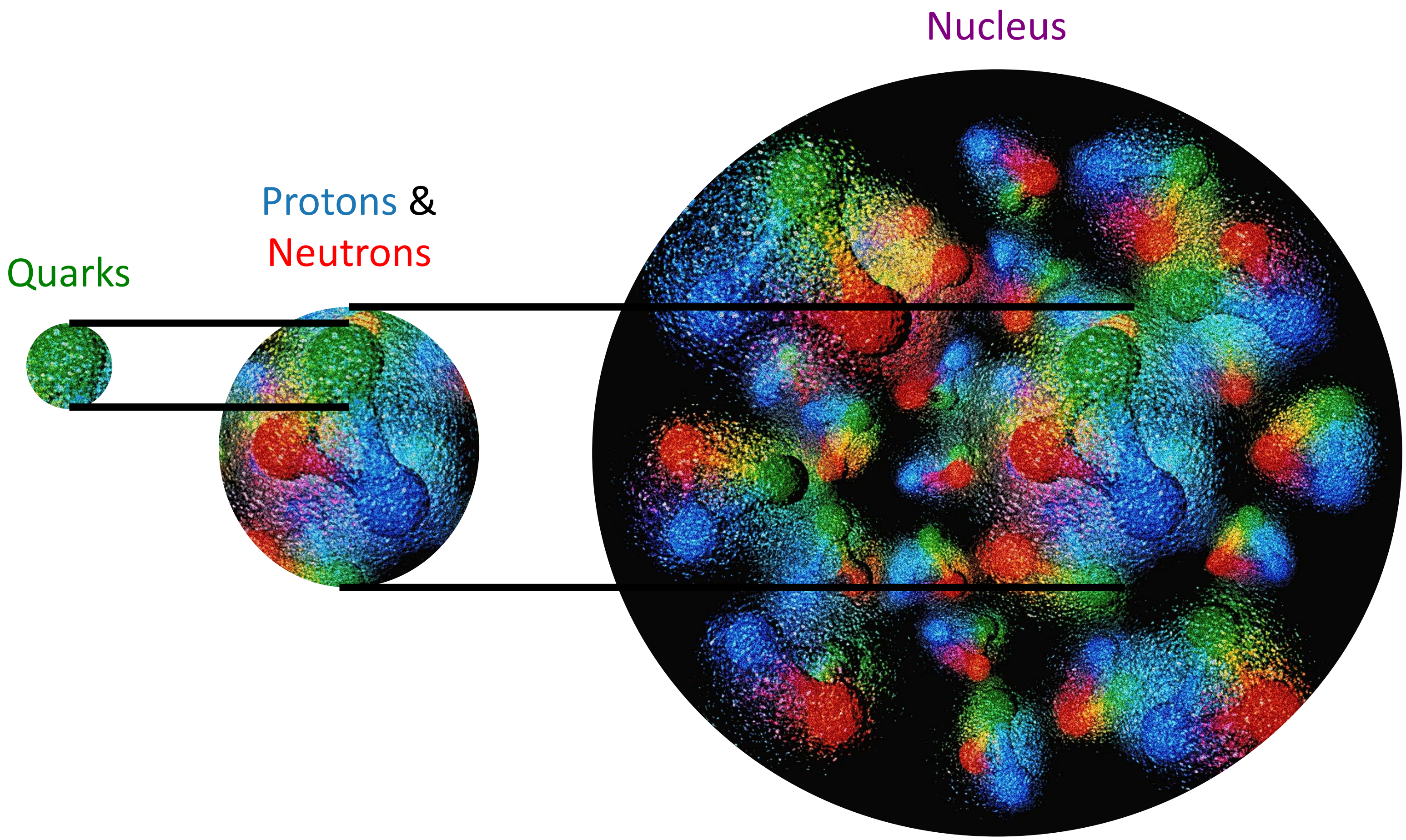
Modification of Quark-Gluon Distributions in Nuclei by Correlated Nucleons Pairs

Andrew Denniston (MIT)

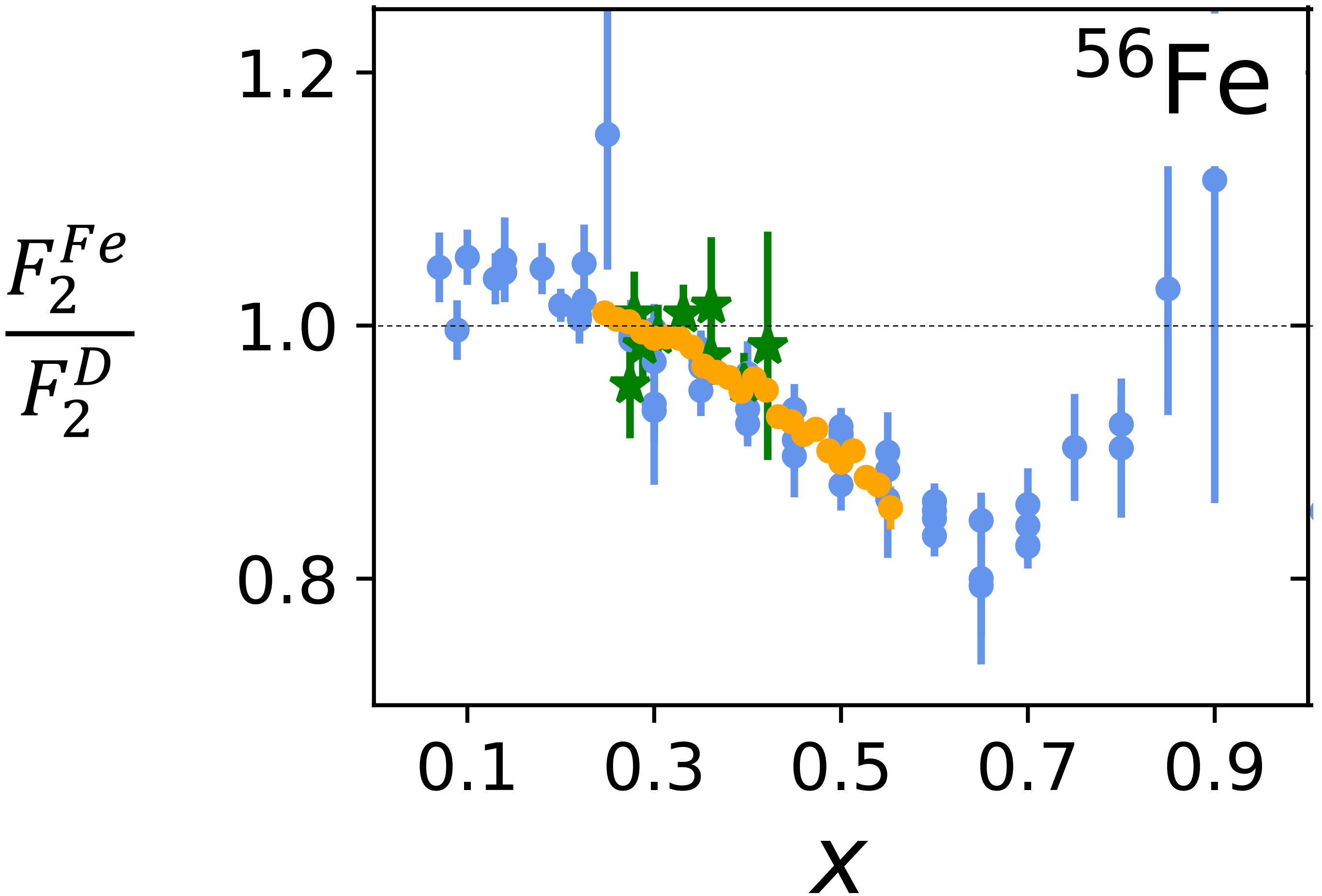
In Collaboration with: Tomas Jezo, Aleksander Kusina, Fred Olness, Or Hen and nCTEQ Collaboration

June 21st , 2023

Quarks in the Nucleus

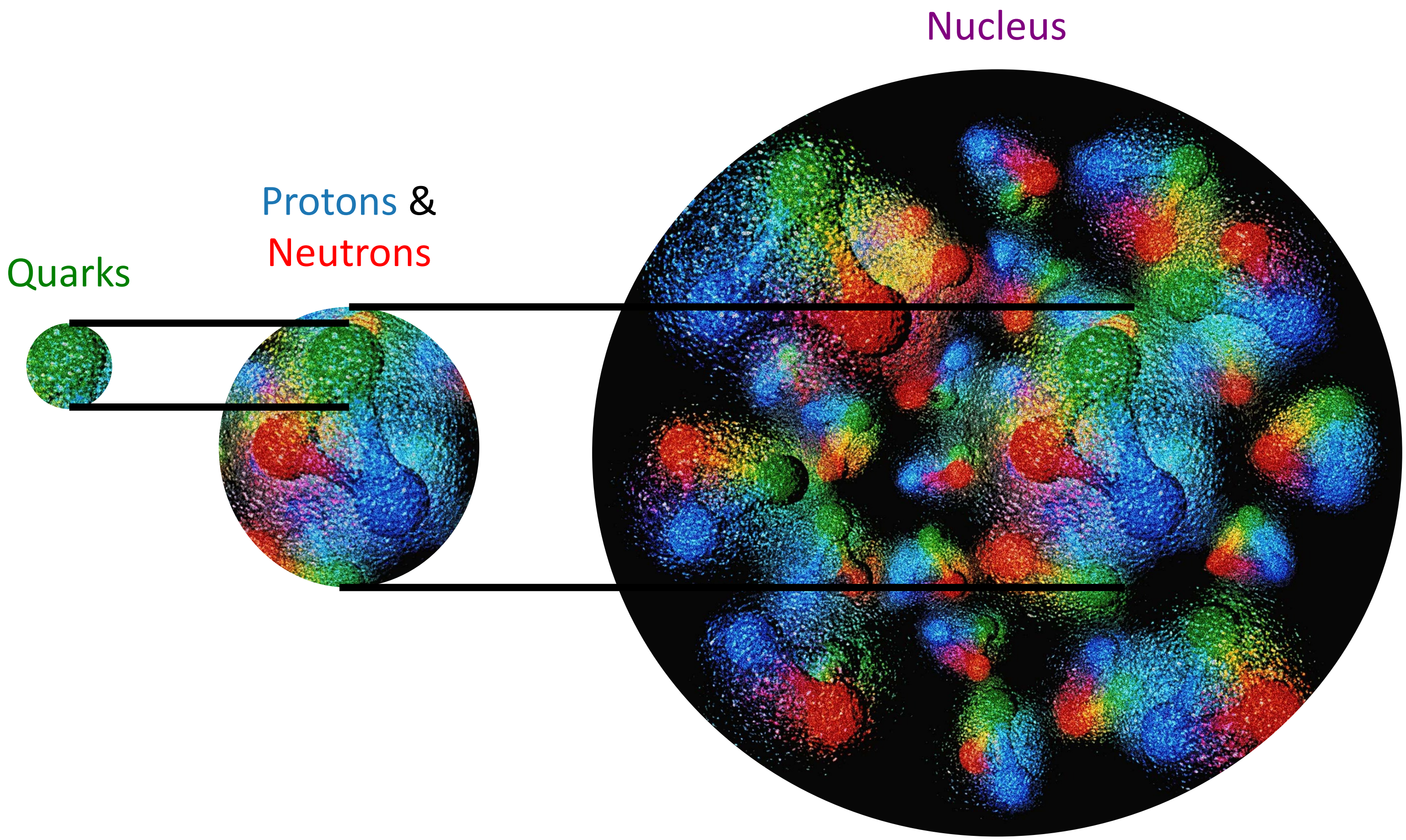


The EMC Effect



Segarra PRD (2021)

Quarks in the Nucleus



Cause of the EMC Effect?

Traditional Nuclear Effects

Medium Modification

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Drell-Yan Reactions

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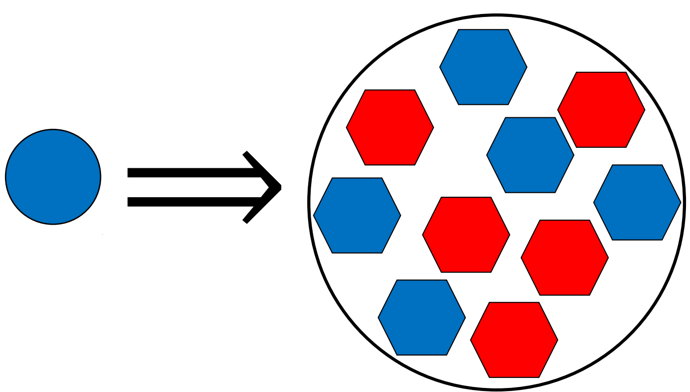
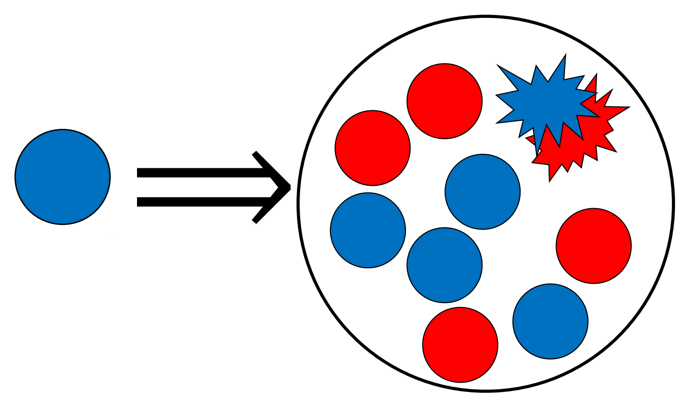


Few Nucleons Modified



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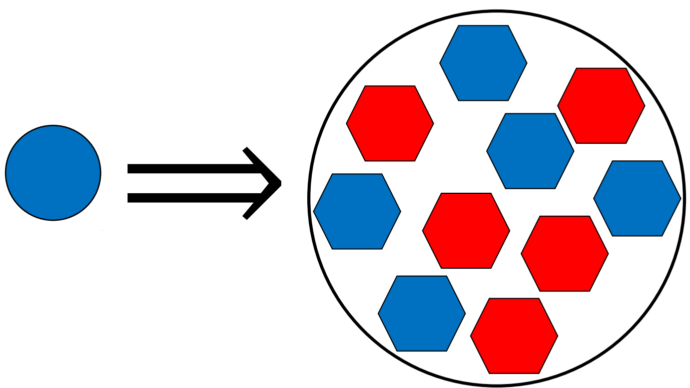
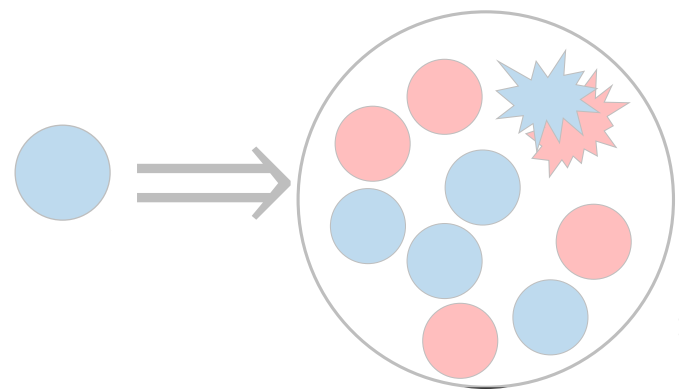
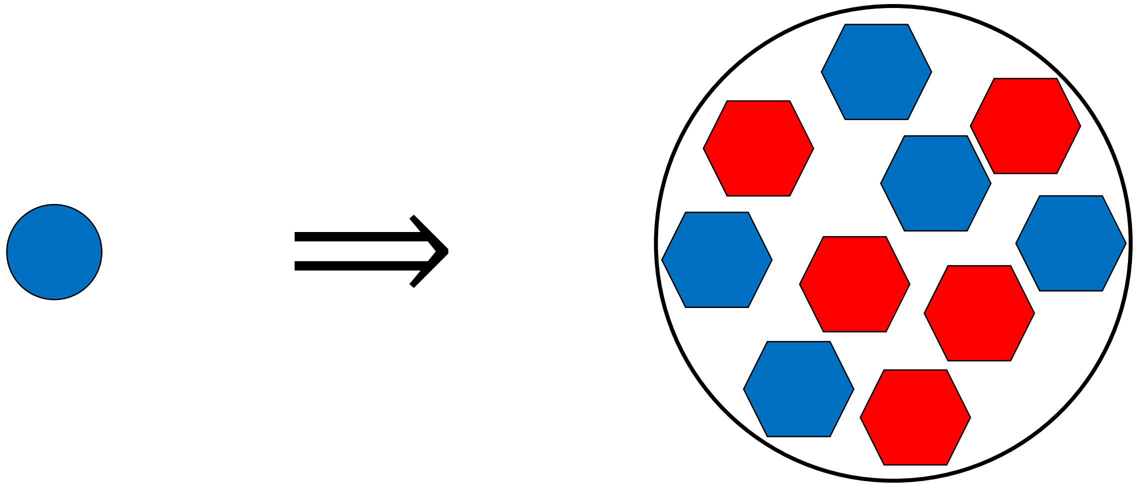




All Nucleons Modified Approach

$$f_i^A(x) = \frac{Z}{A} f_i^{p(A)}(x) + \frac{A-Z}{A} f_i^{n(A)}(x)$$



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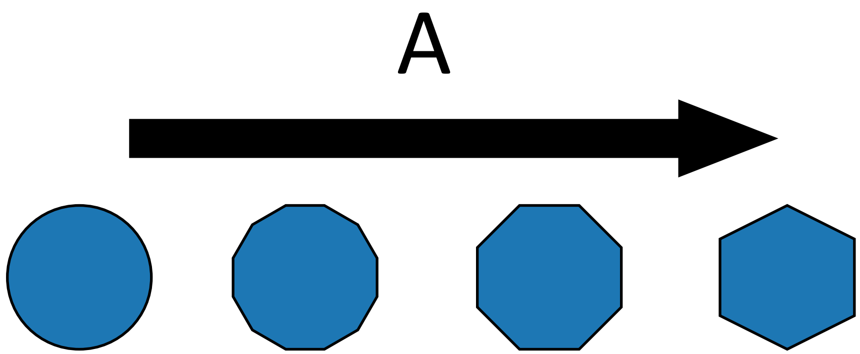

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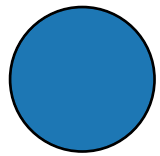
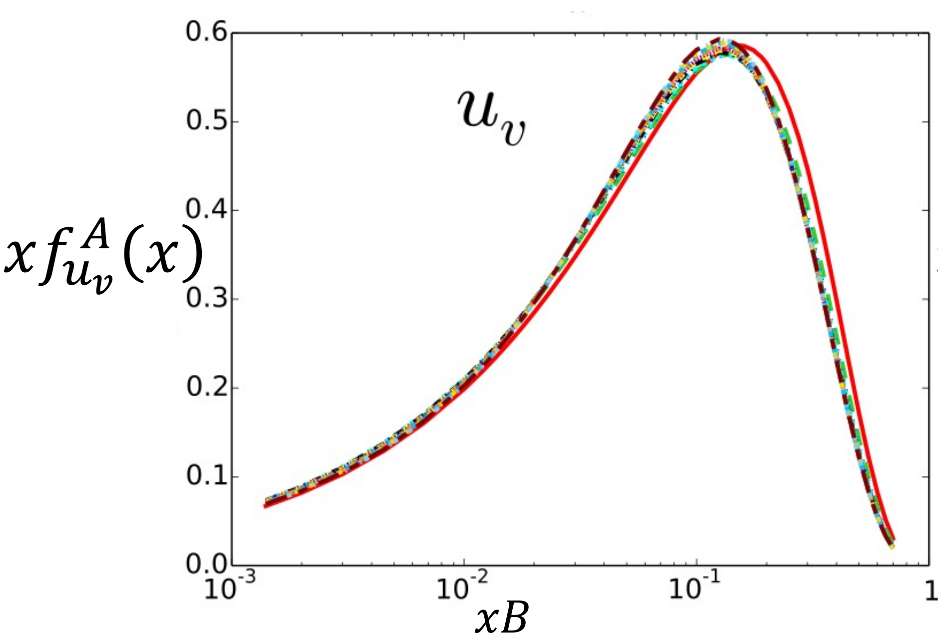


$$xf_i^{p(A)}(x\ ) = c_0 x^{c_1}(1-x)^{c_2} e^{c_3 x}(1+e^{c_4}x)^{c_5}$$



Kovarik PRD (2015)

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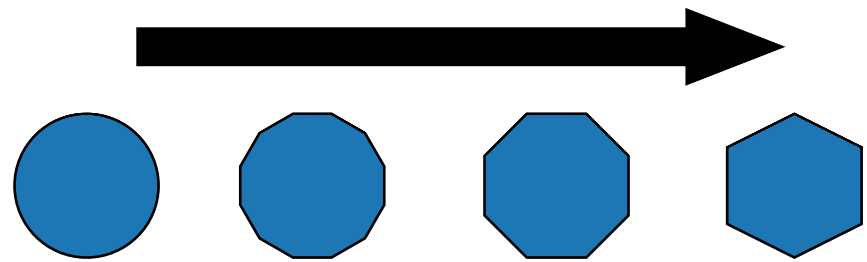
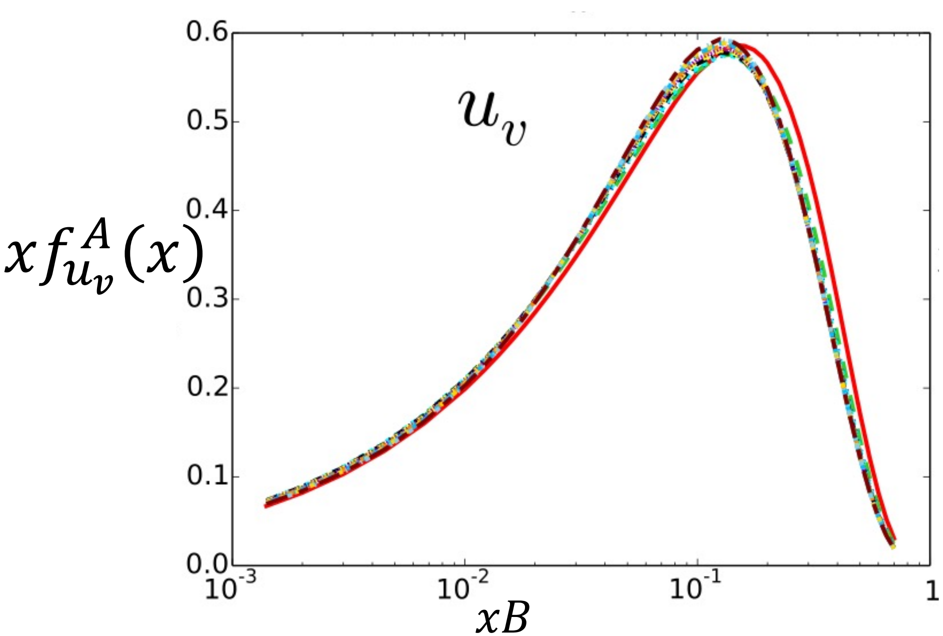
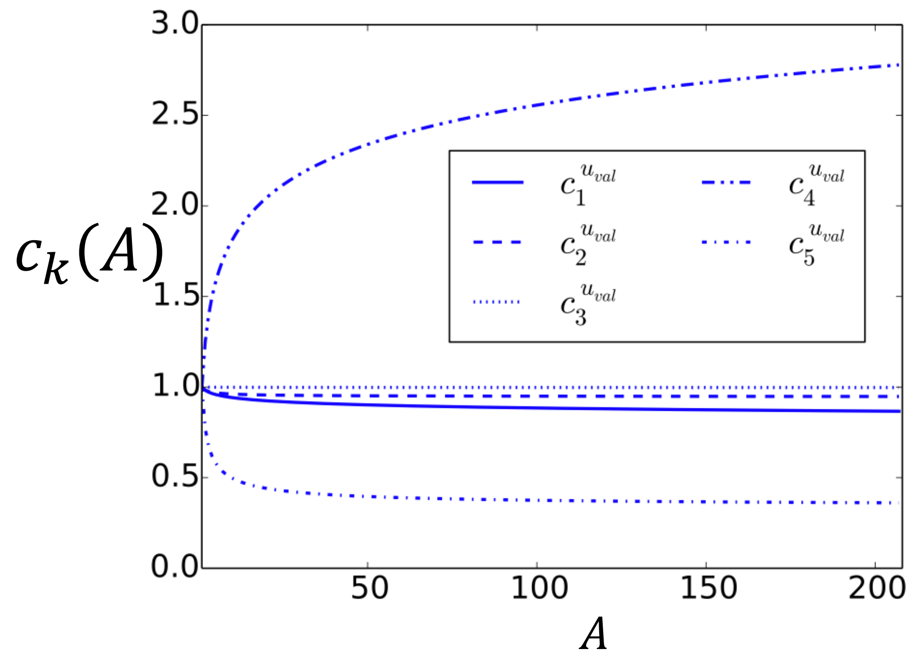


$$xf_i^{p(A)}(x) = c_0 x^{c_1}(1-x)^{c_2} e^{c_3 x}(1+e^{c_4}x)^{c_5} \qquad c_k(A) = c_{k,0} + c_{k,1}(1 - A^{-c_{k,2}})$$





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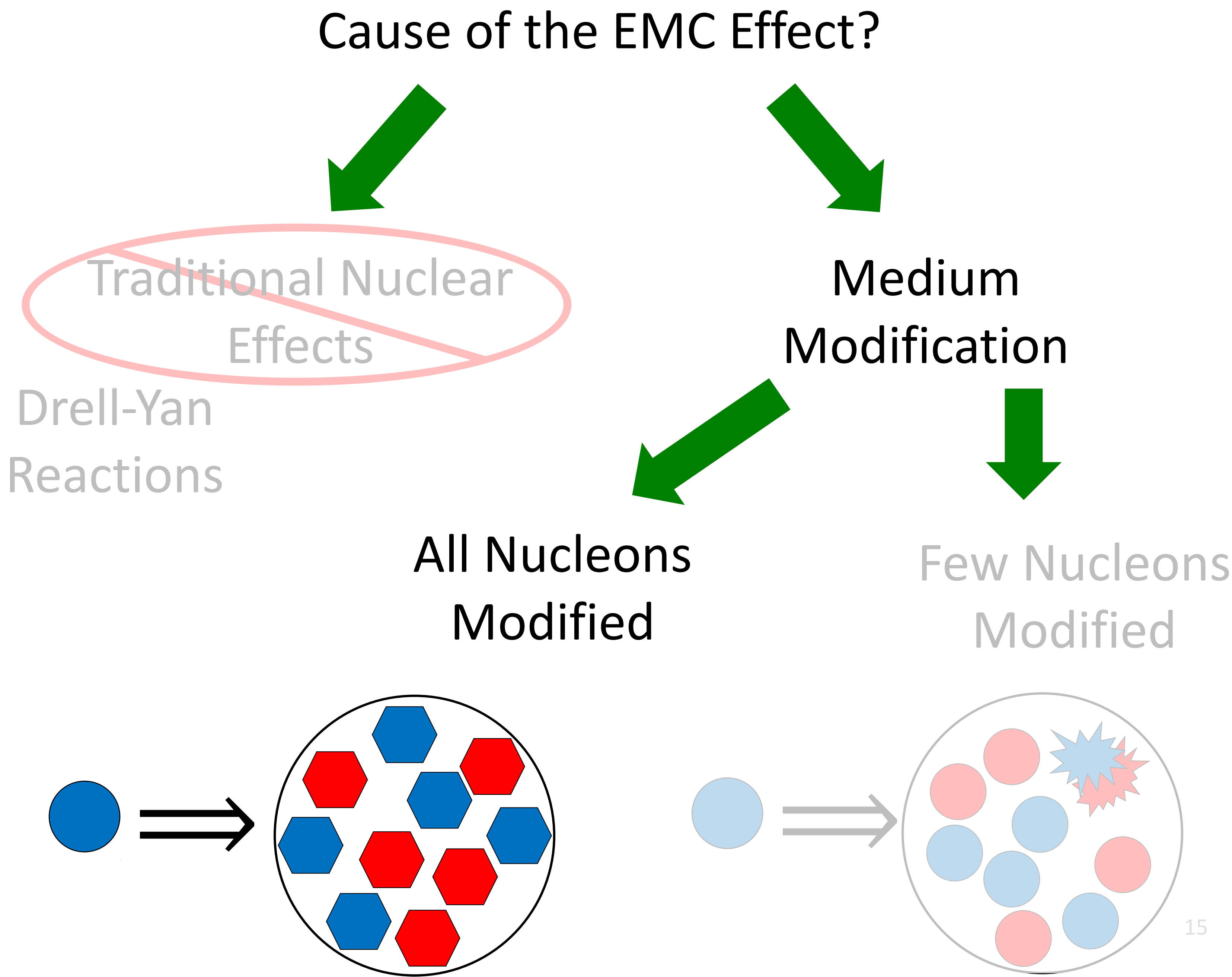
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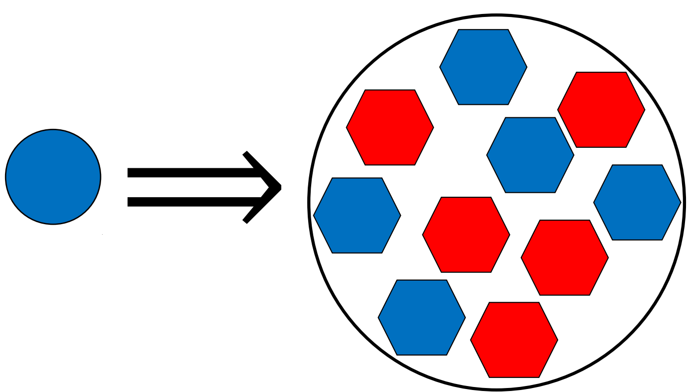

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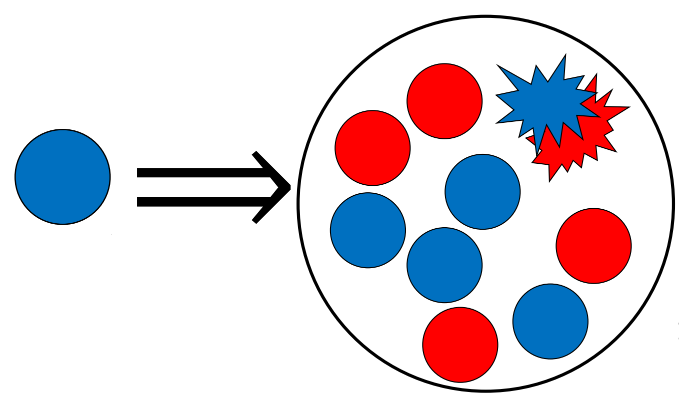

Nuclear Short-Range Correlations

- Pairs with small separation

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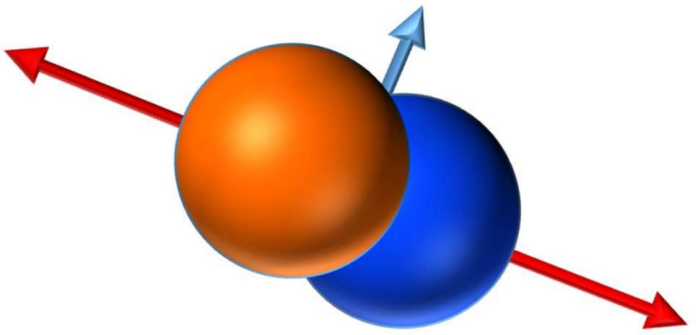
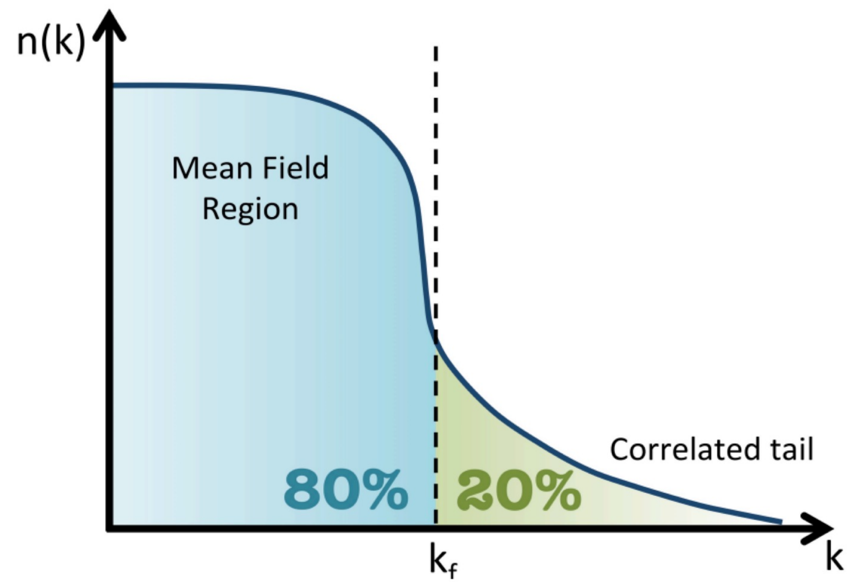
- High relative momentum compared to k_F



Nuclear Short-Range Correlations

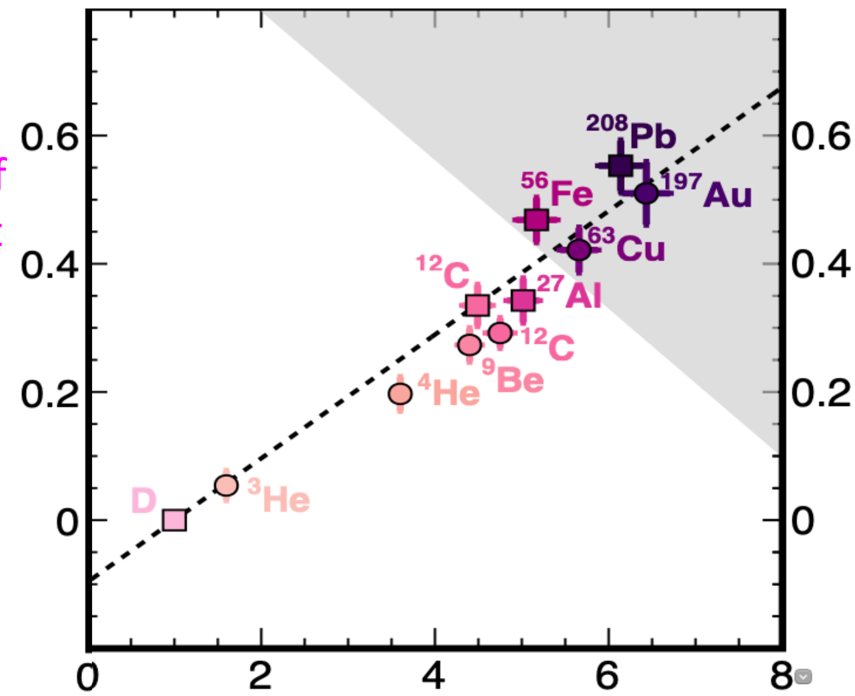
- Pairs with small separation
- High relative momentum compared to k_F
- Significant fraction of the nuclear spectral function



Nuclear Short-Range Correlations

- Pairs with small separation
- High relative momentum compared to k_F
- Significant fraction of the nuclear spectral function
- Correlated with the EMC Effect

Strength of EMC Effect

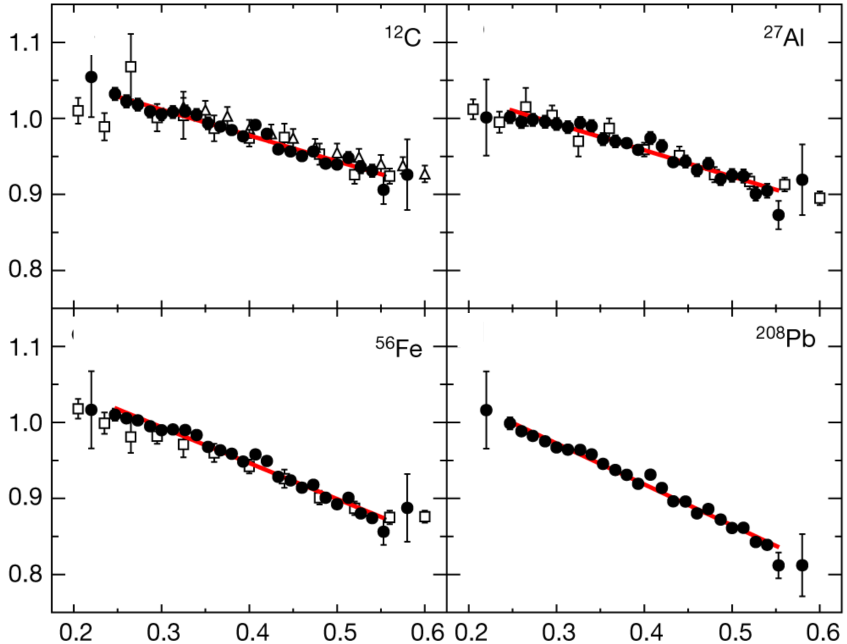


Abundance of SRCs

Schmookler Nature (2019)

Comparing SRCs with the EMC Effect

$$\frac{\sigma_A/A}{\sigma_d/2}$$



x_B

Deep Inelastic

Schmookler Nature (2019)

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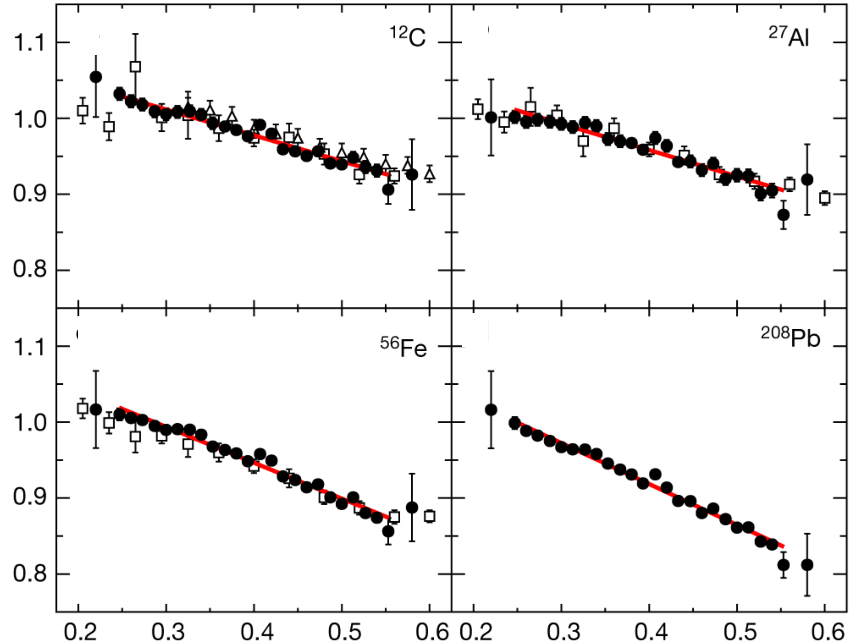

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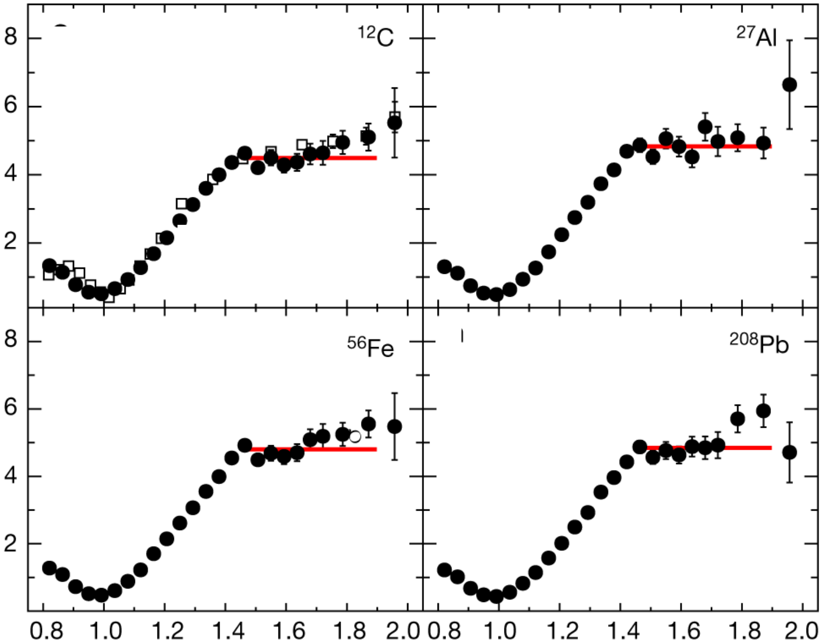
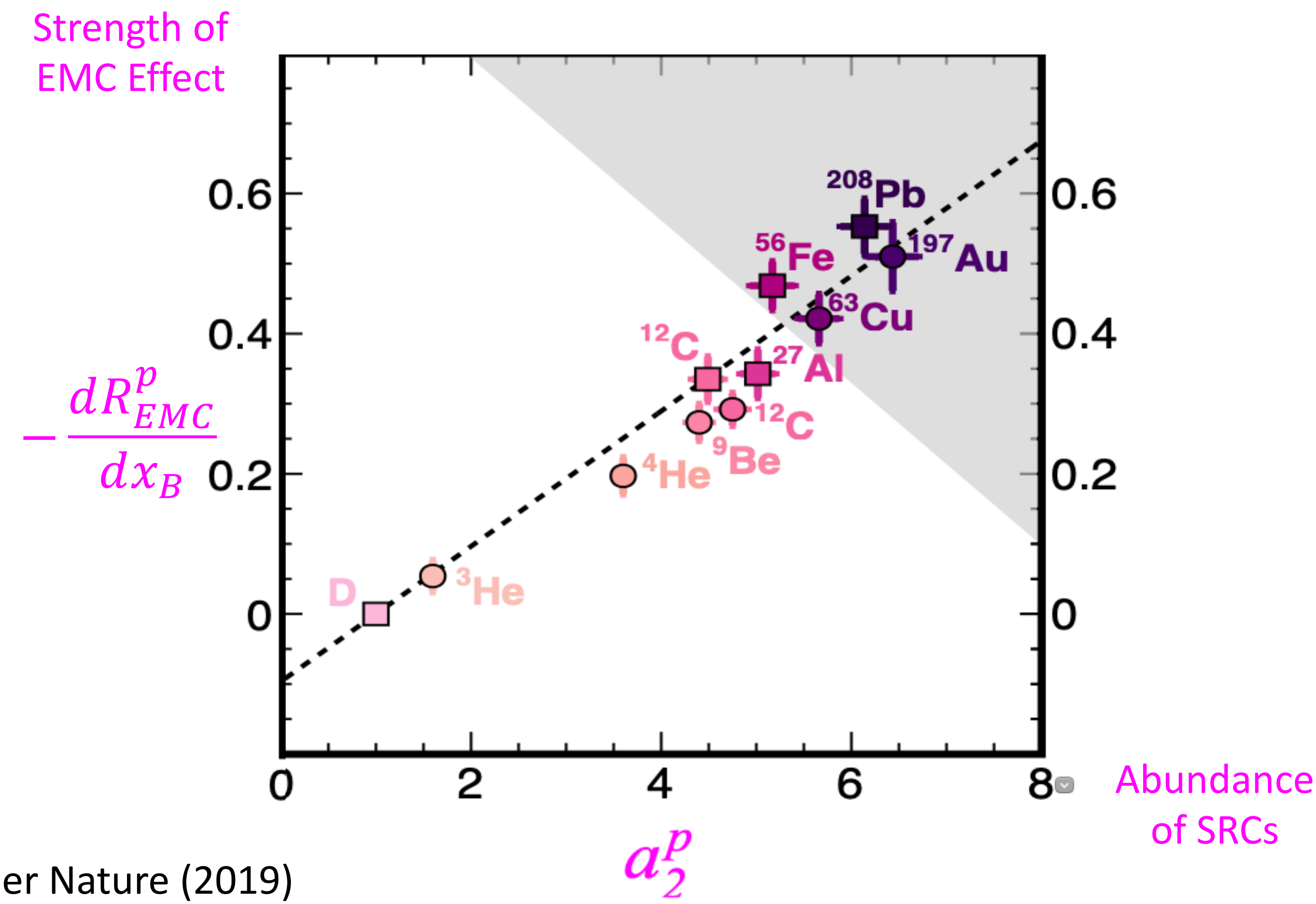


x_B

Quasi-Elastic

Schmookler Nature (2019)

Comparing SRCs with the EMC Effect



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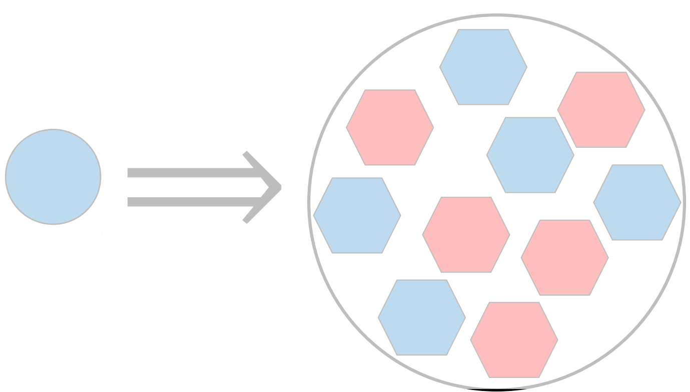
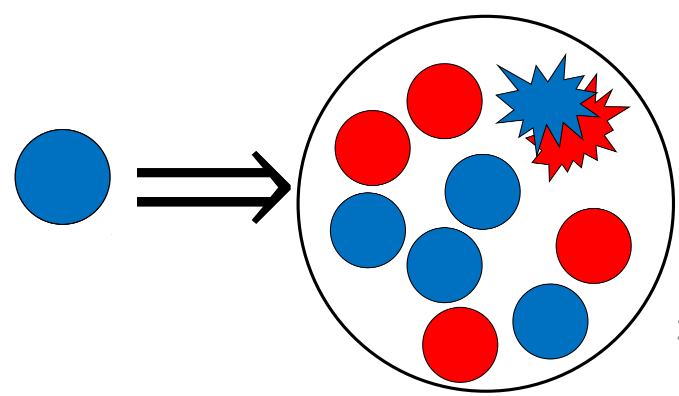
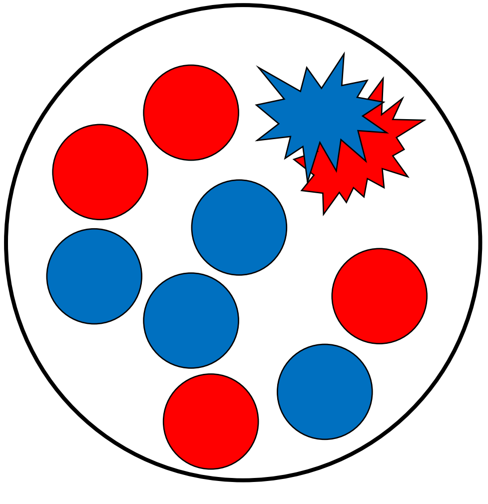




Incorporating SRCs

$$f_i^A(x) = \frac{Z}{A}\left[\left(1 - C_p^A\right)f_i^p(x) + C_p^A f_i^{SRC\,p}(x)\right] +$$

$$\frac{A-Z}{A}\left[(1 - C_n^A)f_i^n(x) + C_n^A f_i^{SRC\,n}(x)\right]$$



Incorporating SRCs

Free Nucleons SRC Nucleons

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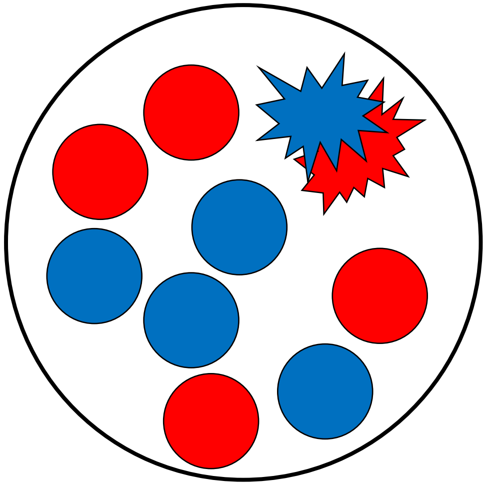

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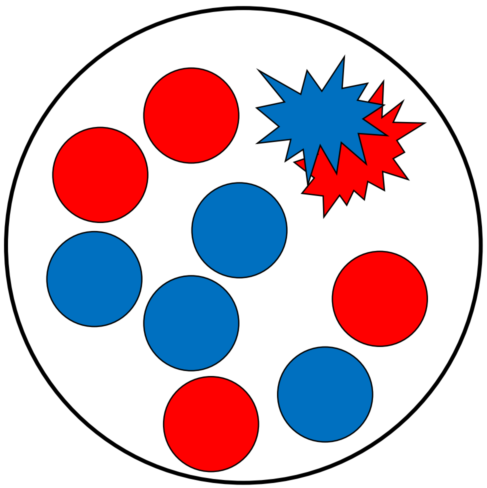
Independent of A

$f_i^p(x)$ $f_i^{SRC\,p}(x)$

$f_i^n(x)$ $f_i^{SRC\,p}(x)$



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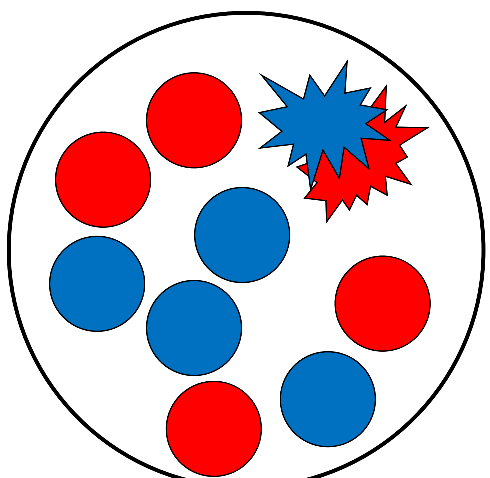

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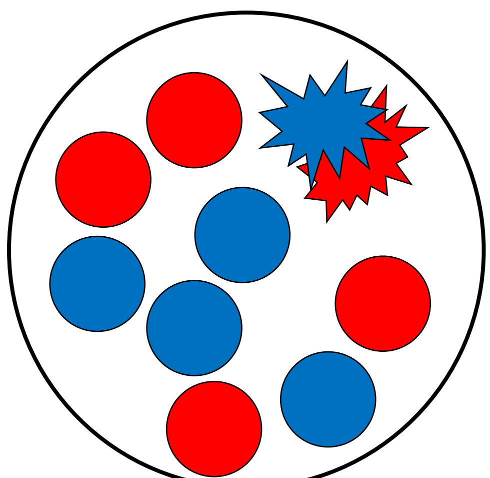

Depend on A

SRC Abundancies

C_p^A, C_n^A

Incorporating SRCs

Free Nucleons SRC Nucleons

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Inputs of SRC Fit

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C_p^A C_n^A: **Fitted** Dependent on A

Details of Fit:

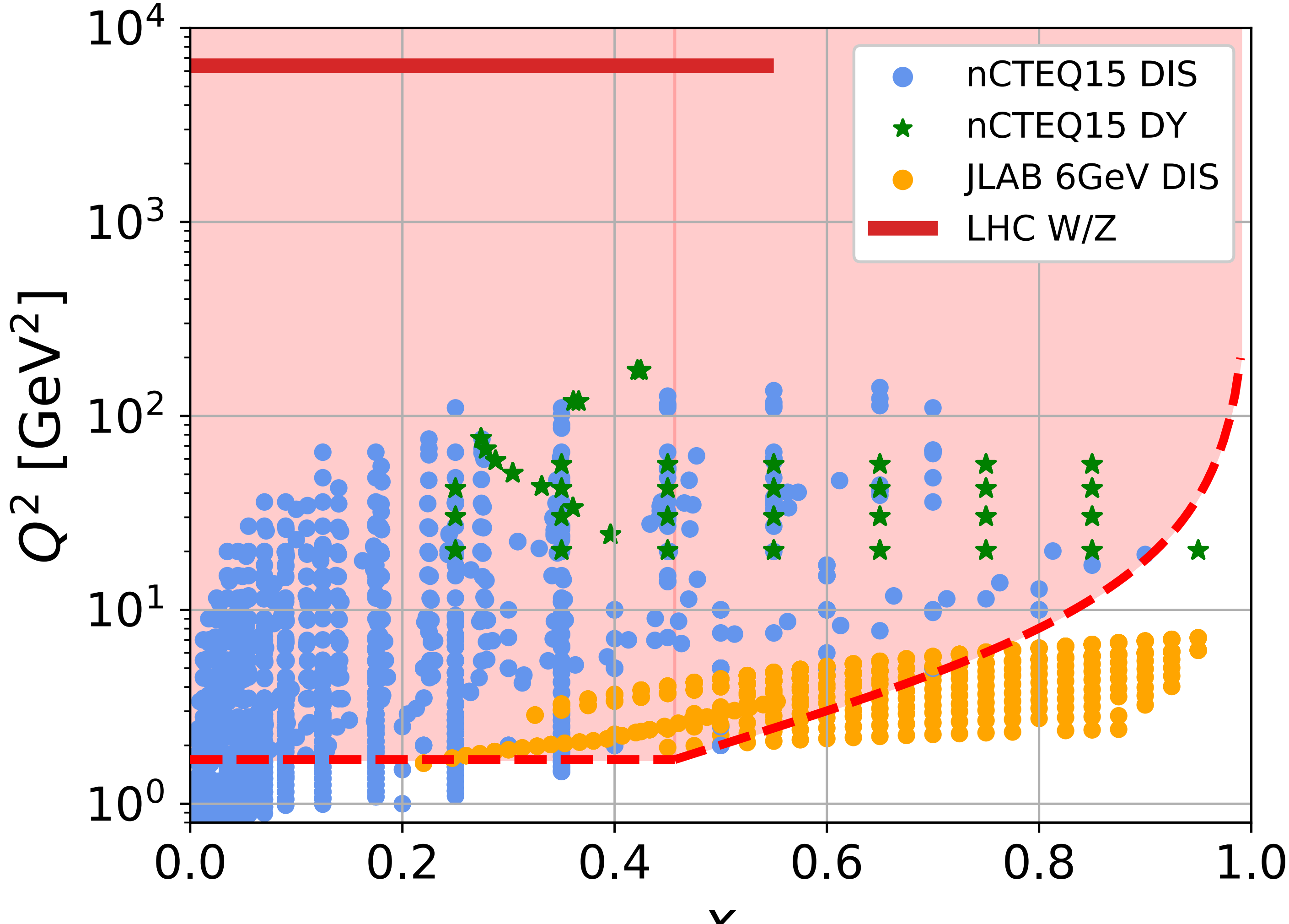
1. Minimize χ^2
2. Cut out non-DIS kinematics
3. Satisfy Sum Rules
4. Full Theoretical Calculations
5. DGLAP Evolve PDFs
6. All PDFs are defined for $x \in (0,1)$

$$\int_0^1 dx\, x f_i^A(x,Q) = 1 \qquad \int_0^1 dx\, f_{u_v}^A(x,Q) = \frac{A+Z}{A} \qquad \int_0^1 dx\, f_{d_v}^A(x,Q) = \frac{A+N}{A}$$

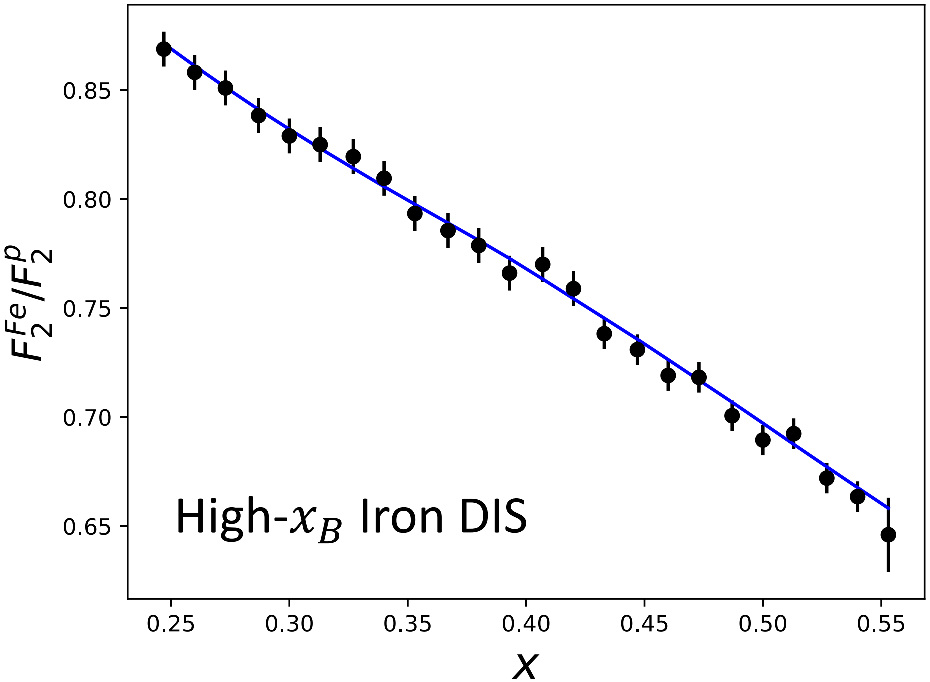
$$F_2^{A,Z}(x,Q) = \sum_i C_i\,(x,Q) \otimes f_{\mathrm{i}}^{A,Z}(x,Q)$$

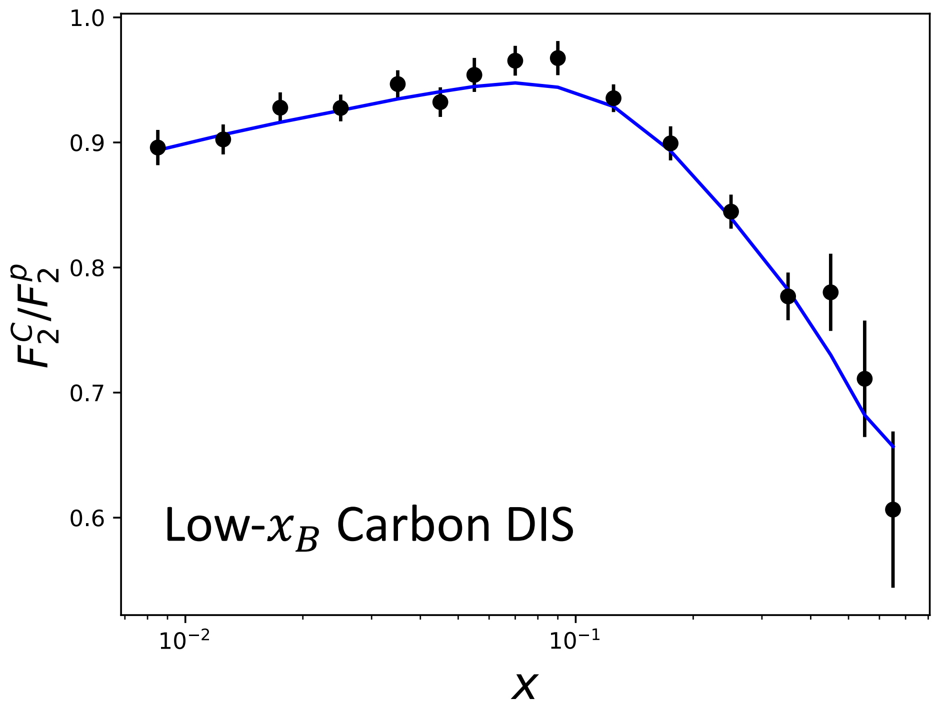
World Data to Fit:

$Q > 1.3\ GeV$
$W > 1.7\ GeV$

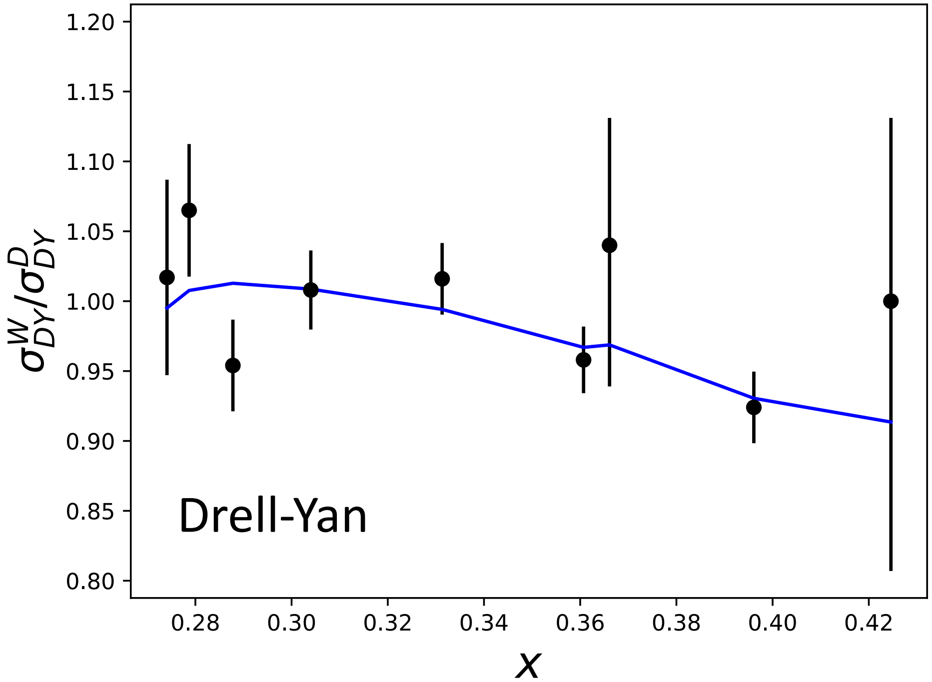


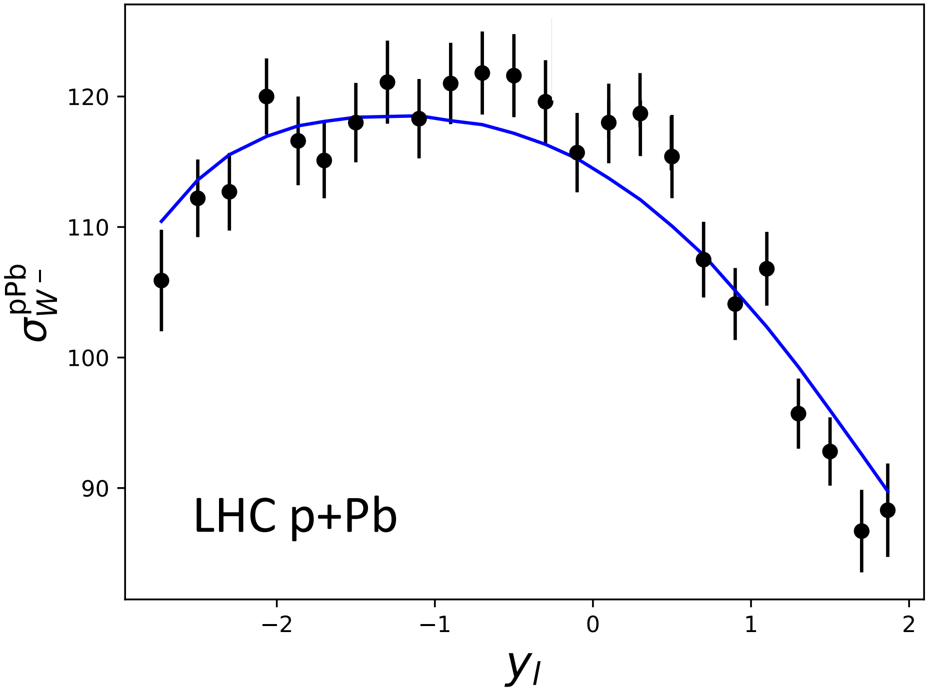
Fit Over Wide x_B Range





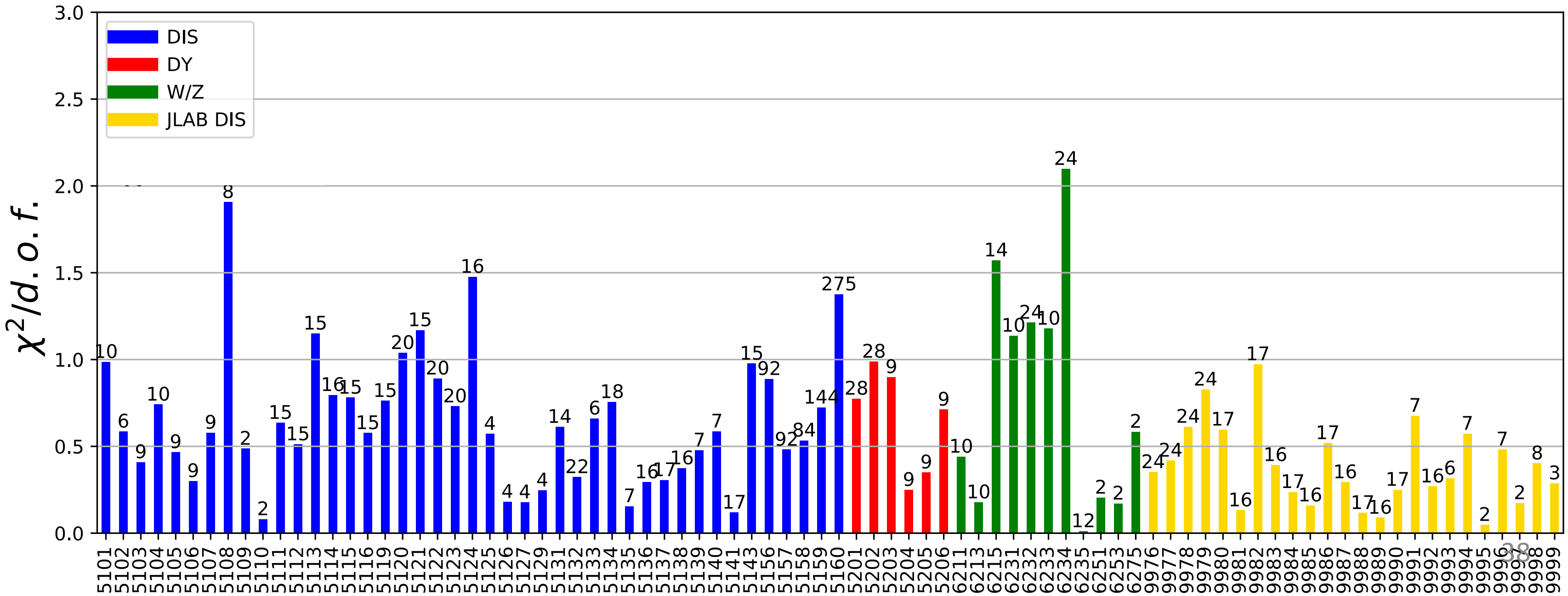
Drell-Yan and W Production are Well Described





Fit Result:

χ^2/N_{data}	$\frac{\chi^2_{\mathrm{tot}}}{N_{\mathrm{DOF}}}$
Traditional	0.85
SRC	0.80



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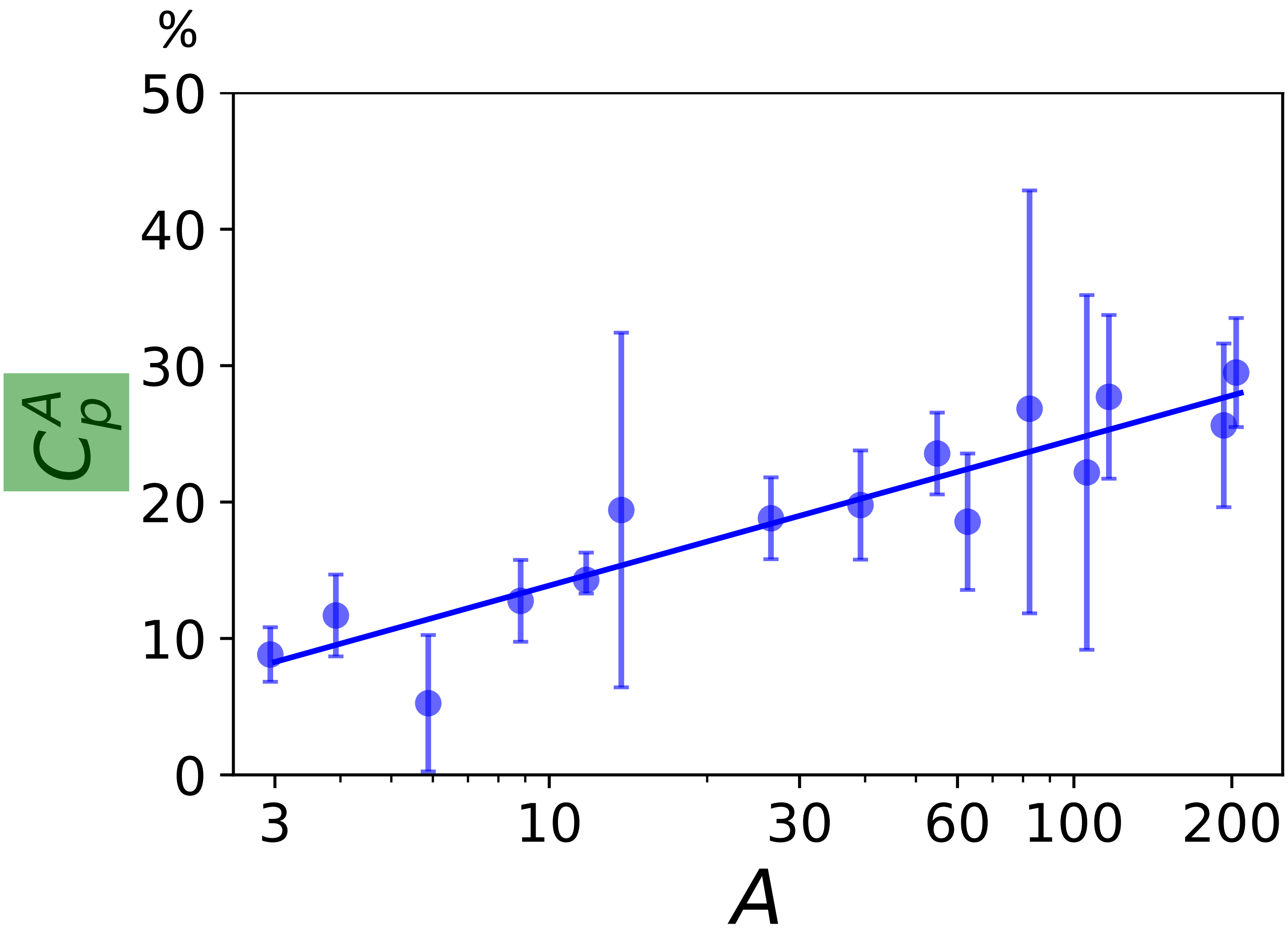
C_p^A C_n^A: **Fitted** Dependent on A

How Many SRCs do we expect?



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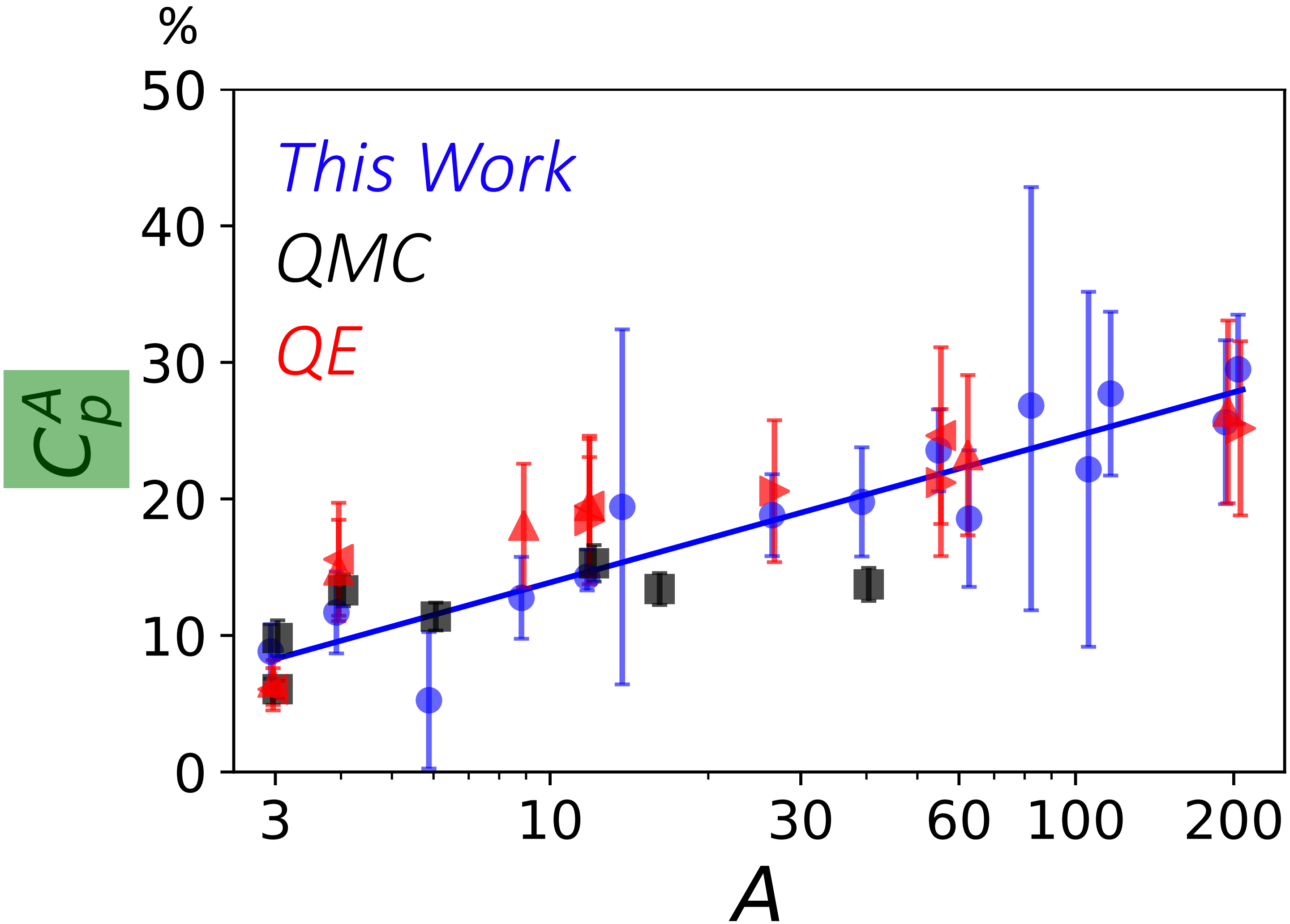
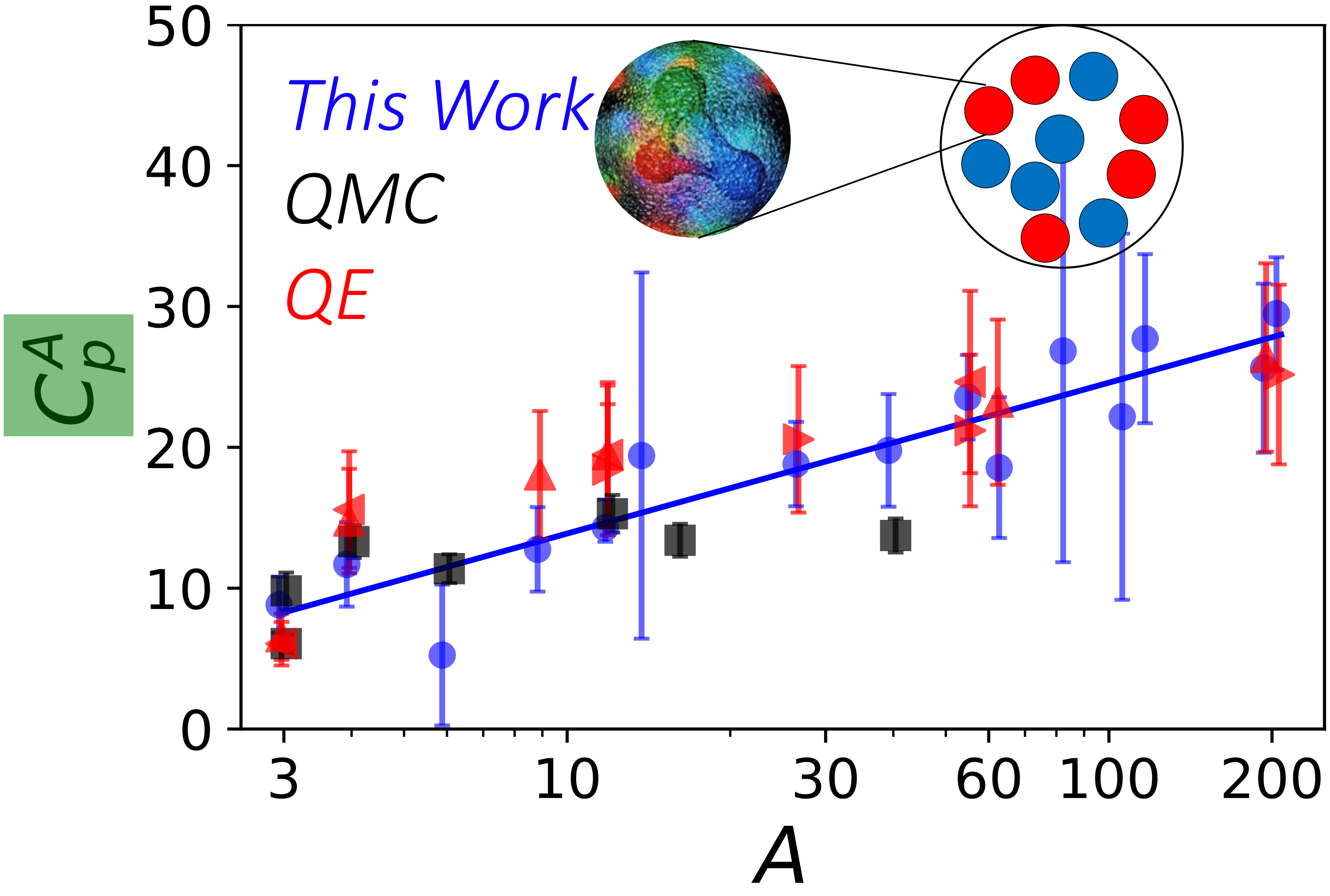
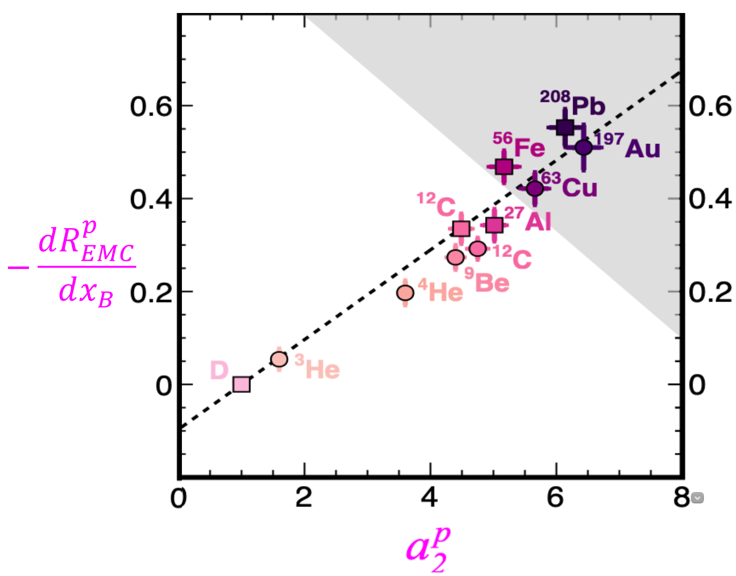


Nuclear Physics Extracted from Parton Measurements



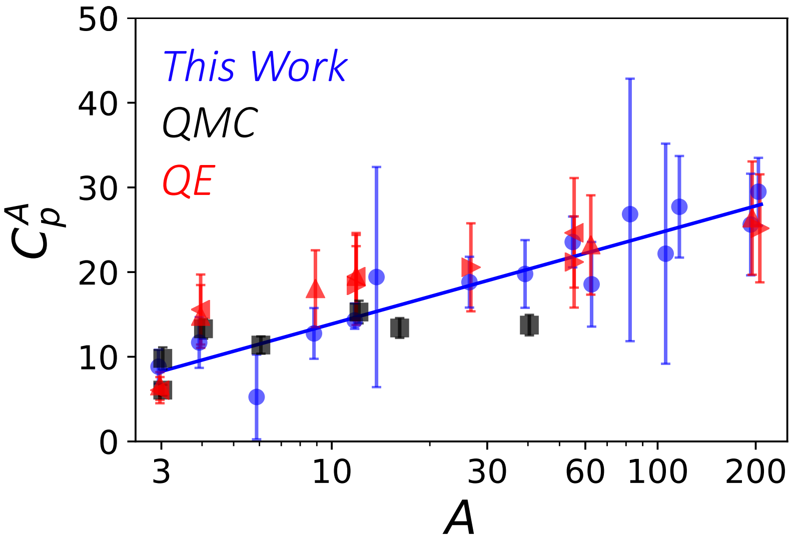
Beyond the SRC-EMC Relation

SRC $\Longleftrightarrow$ EMC



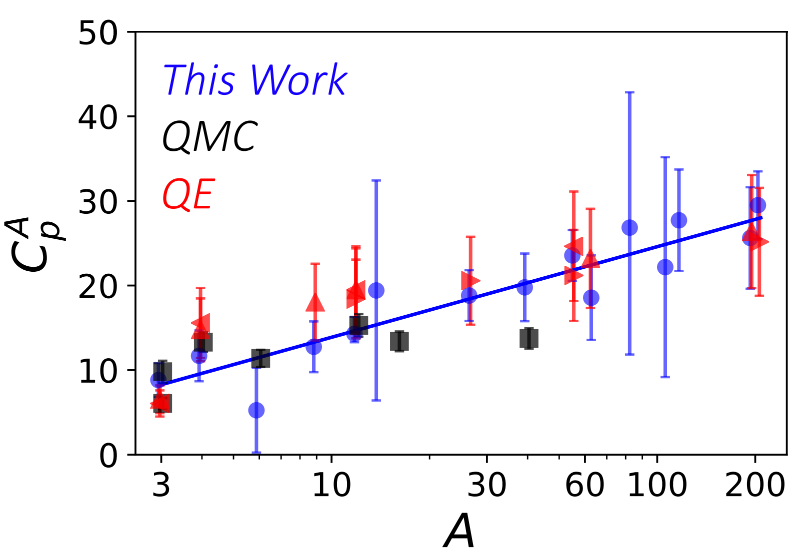
Beyond the SRC-EMC Relation

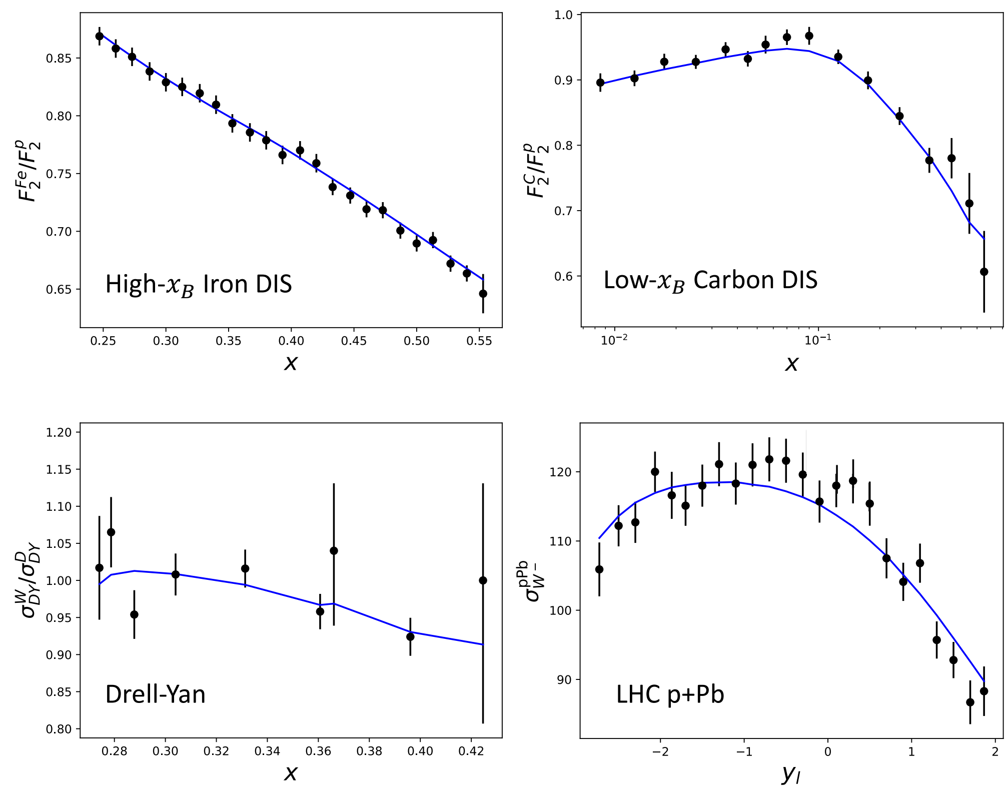
SRC ⟺ EMC



Beyond the SRC-EMC Relation

SRC $\Longleftrightarrow$
- EMC
- Shadowing
- Anti-shadowing
- Drell-Yan
- W/Z





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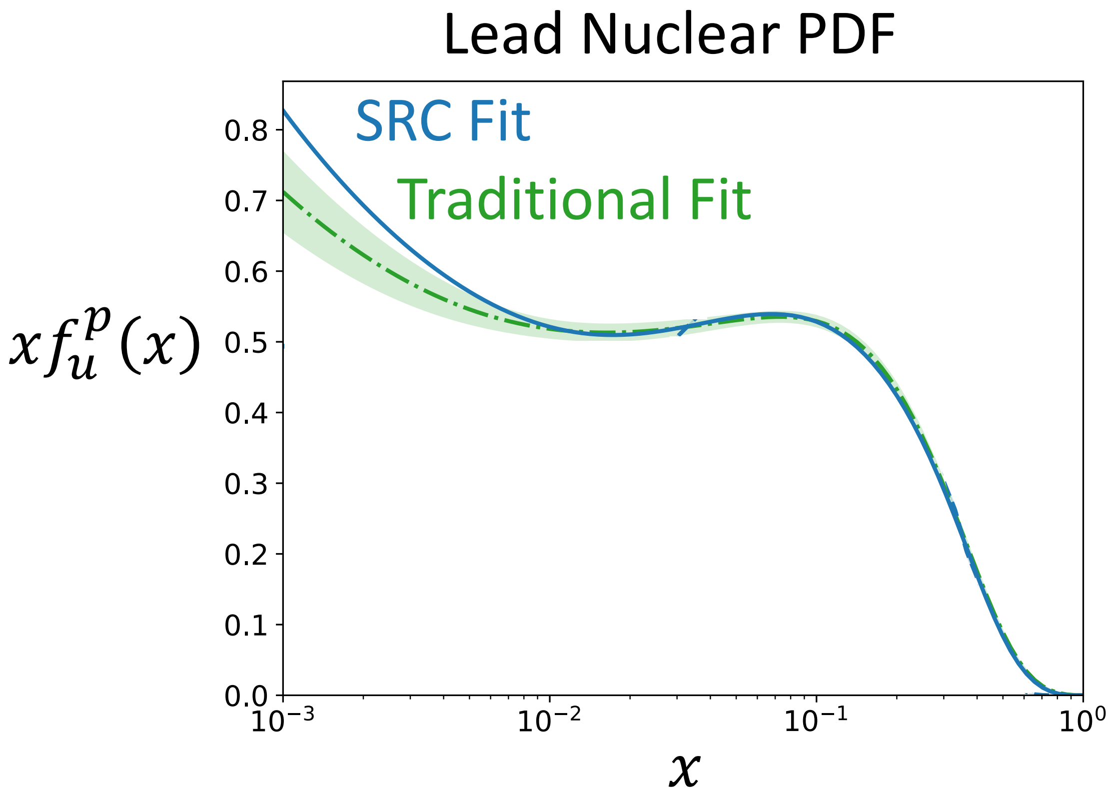
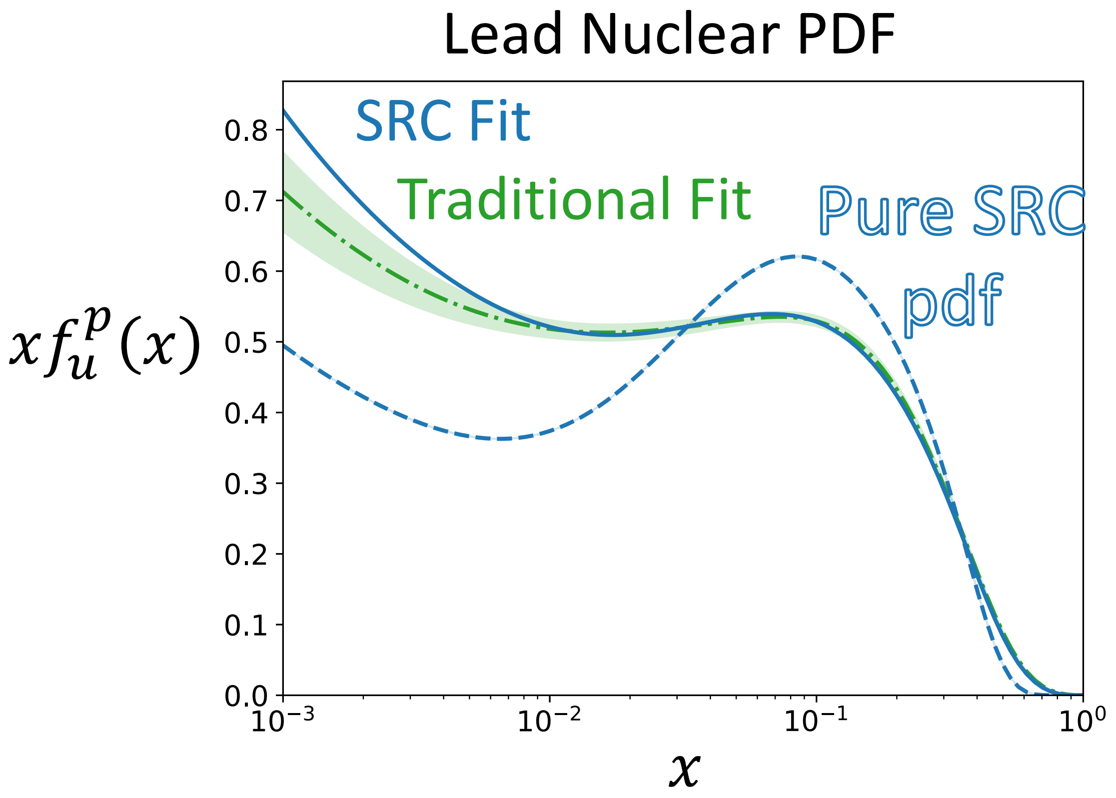
C_p^A C_n^A: **Fitted** Dependent on A

Nuclear PDF



$Q^2 = 10\ GeV^2$

Nuclear PDF and SRC PDF



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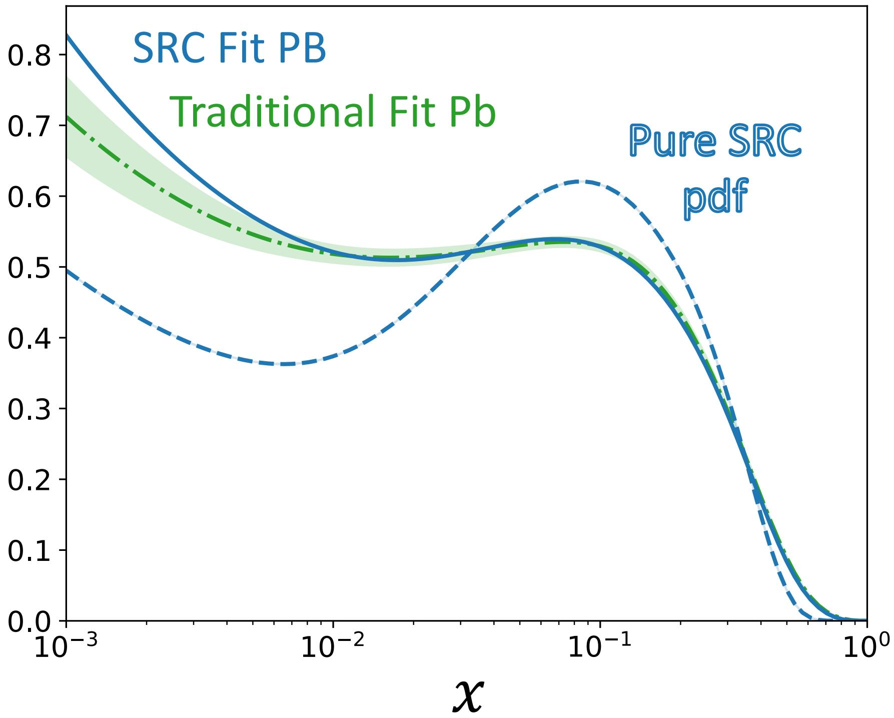

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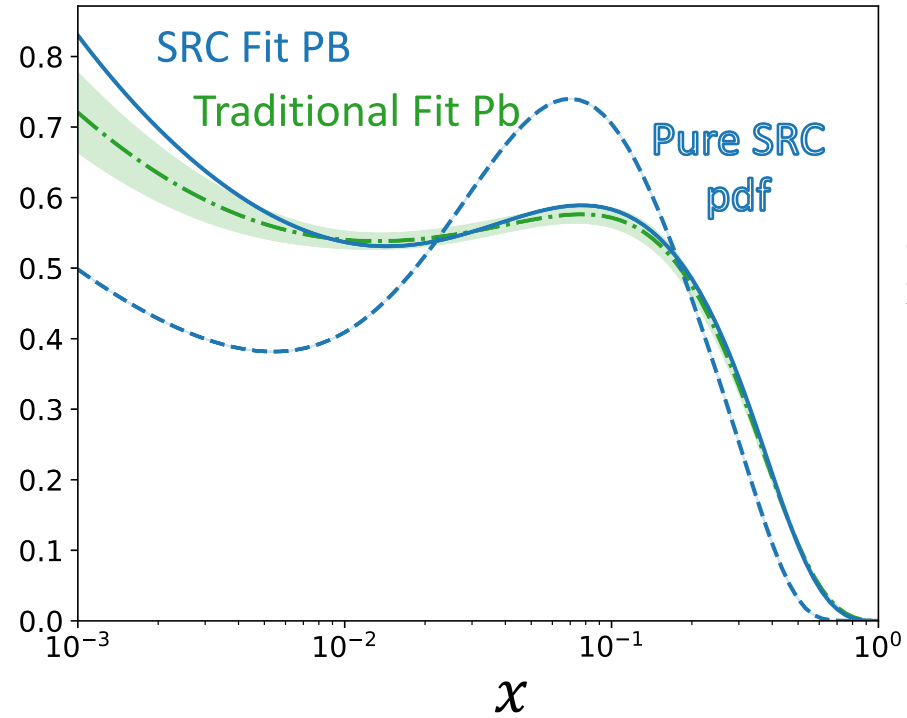
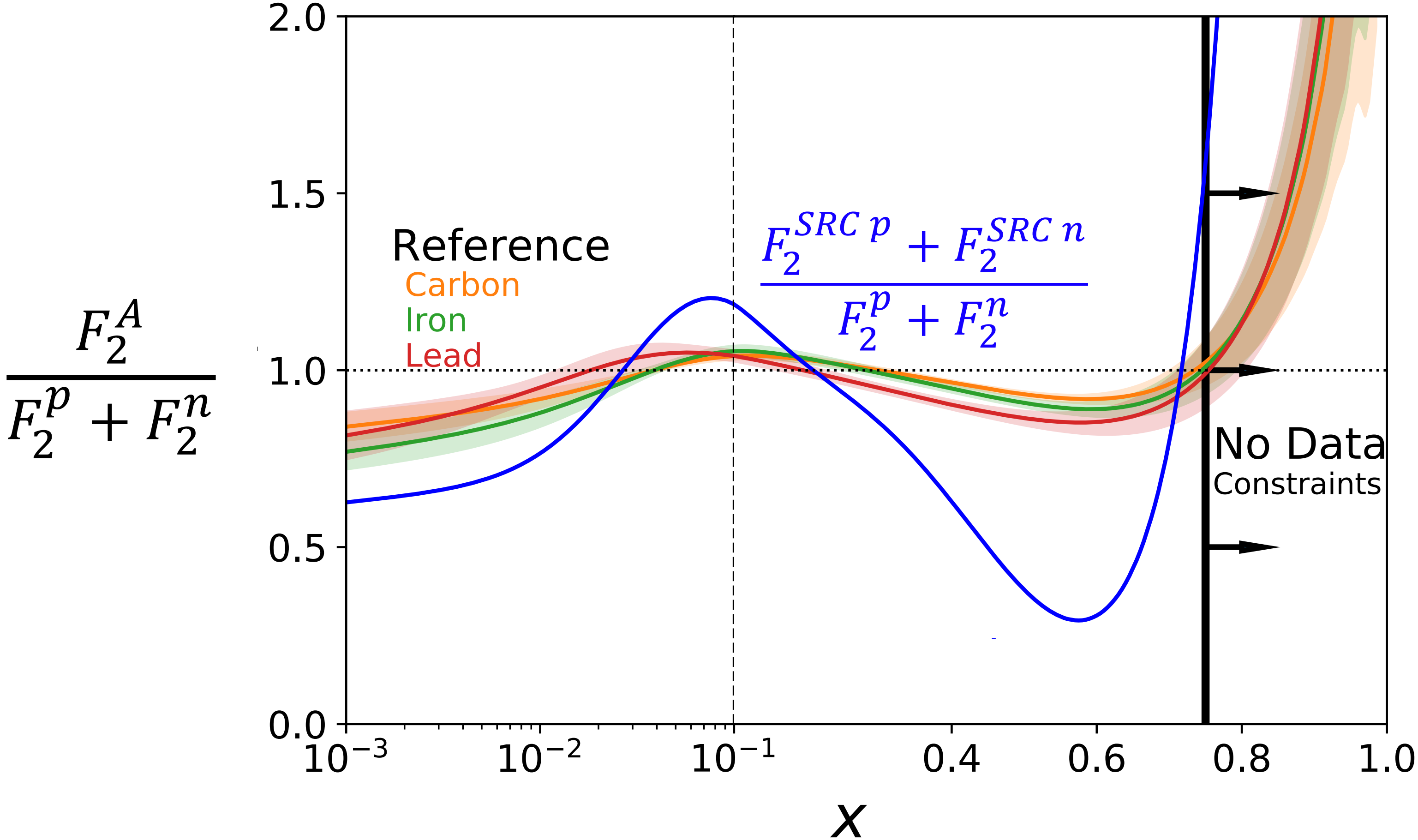


$Q^2 = 10\ GeV^2$

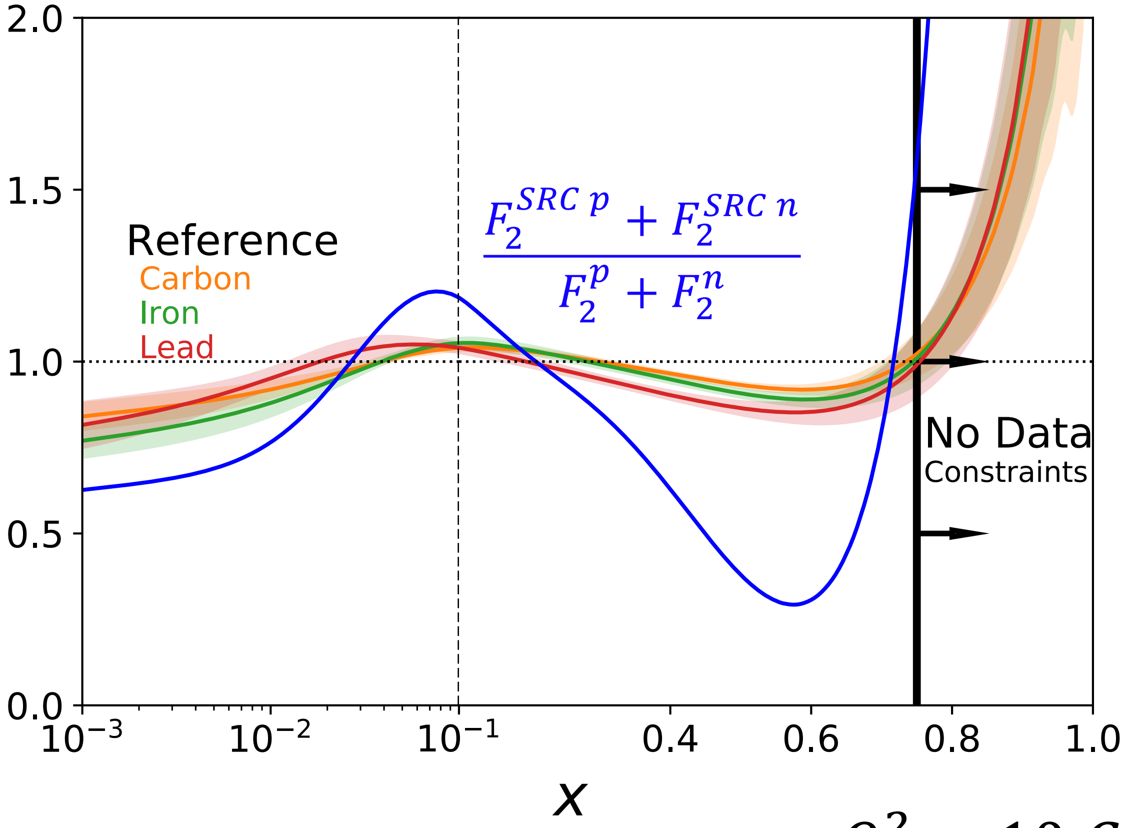
Structure of SRC Nucleons

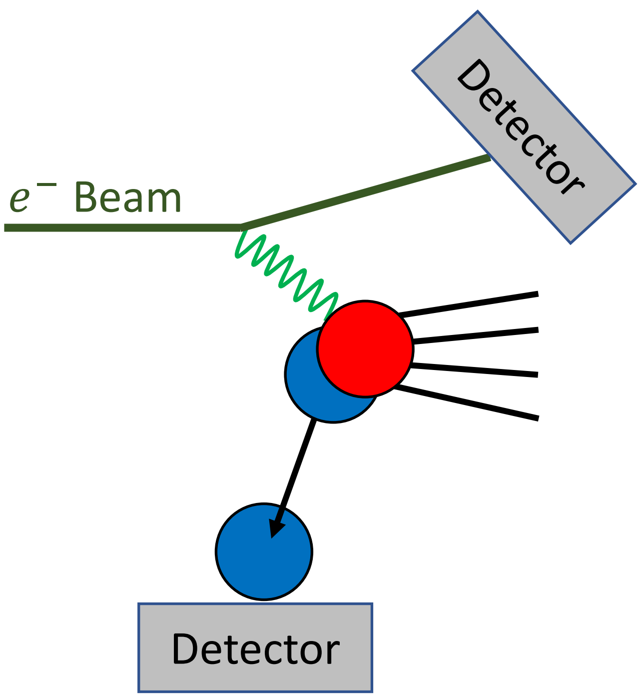


$Q^2 = 10\ GeV^2$

Tagged Experiments Might Measure this Observable

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





$Q^2 = 10\ GeV^2$

Eg. BAND, LAD

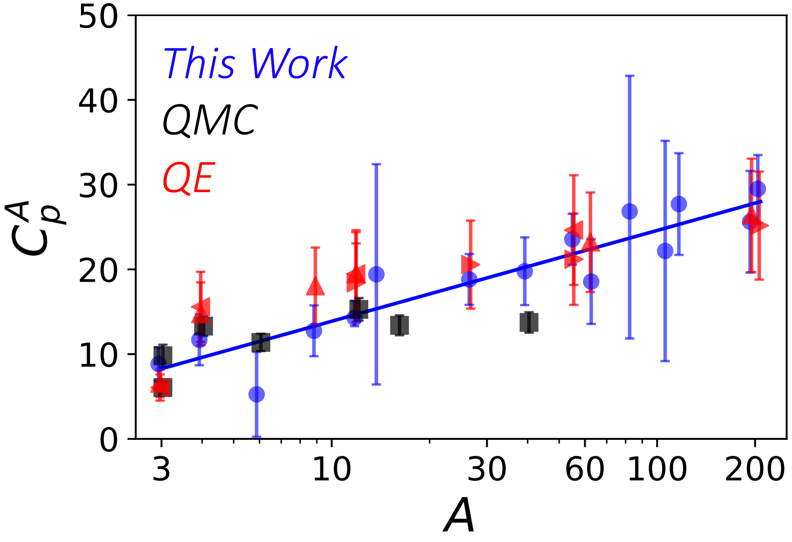
Summary

- SRC Parameterization produces a good fit.

$\chi^2/N_{\rm data}$	$\frac{\chi^2_{\rm tot}}{N_{\rm DOF}}$
Traditional	0.85
SRC	0.80

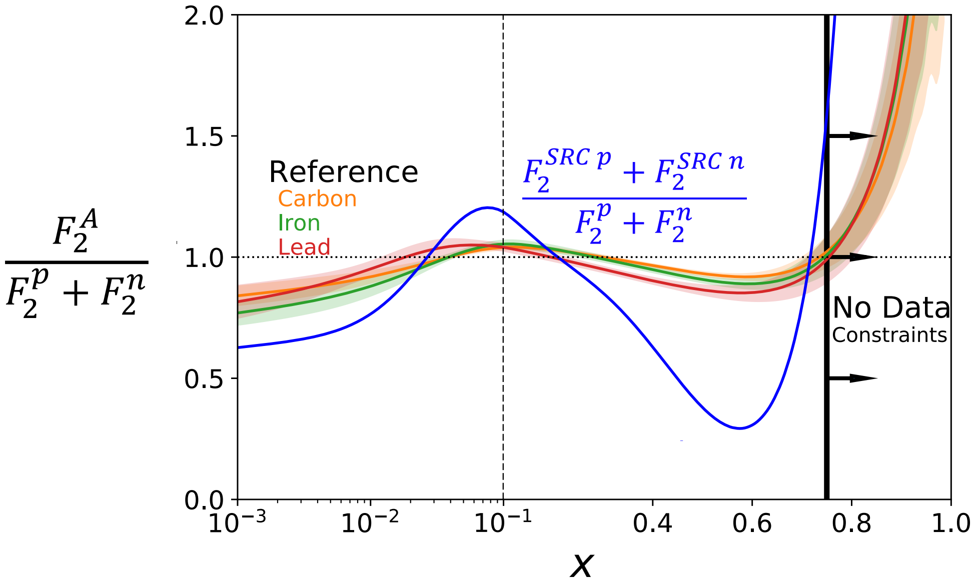
Summary

- SRC Parameterization produces a good fit.
- Nuclear physics extracted from parton measurements.



Summary

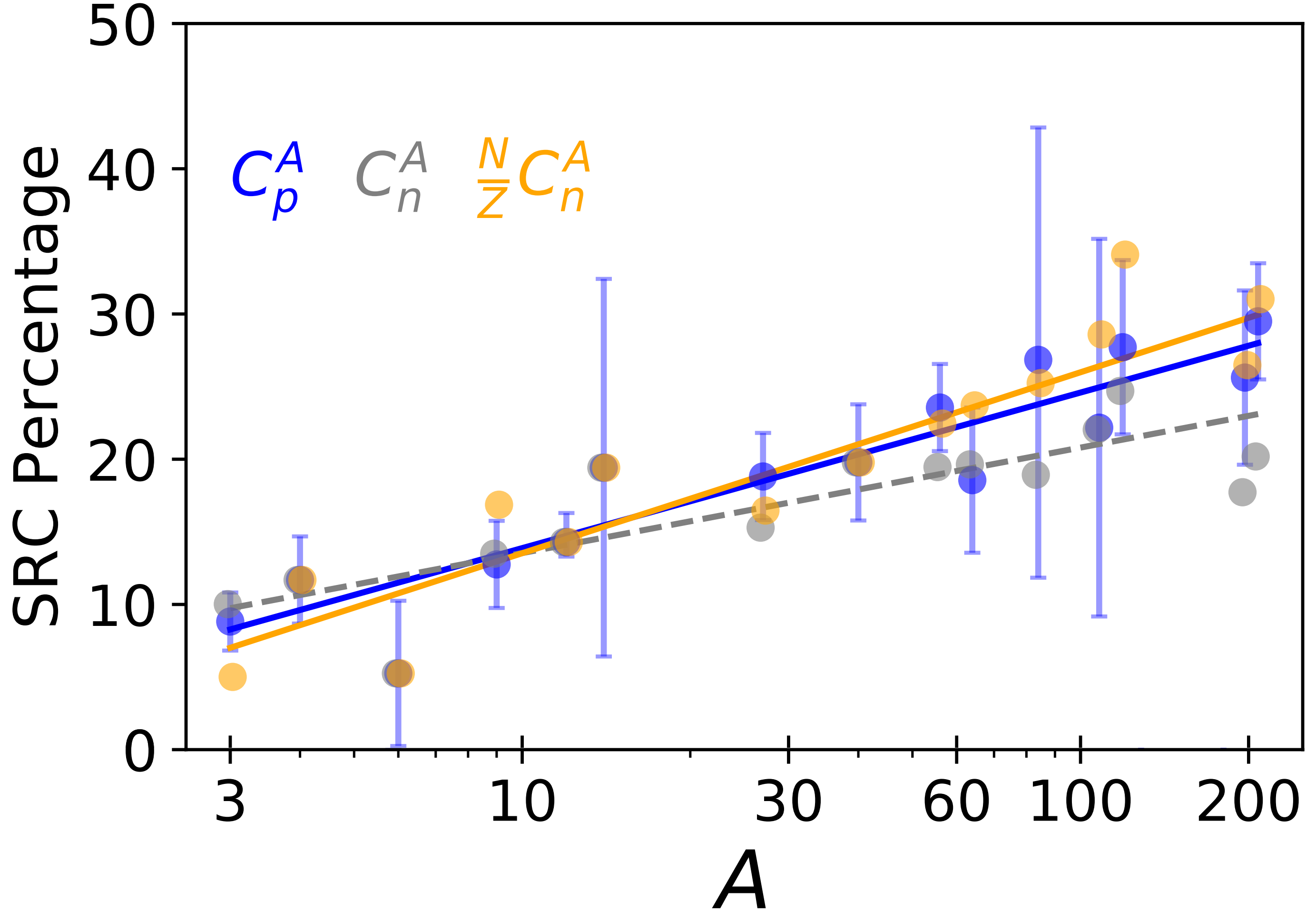
- SRC Parameterization produces a good fit.
- Nuclear physics extracted from parton measurements.
- The SRC Structure is heavily modified.



End

Extra

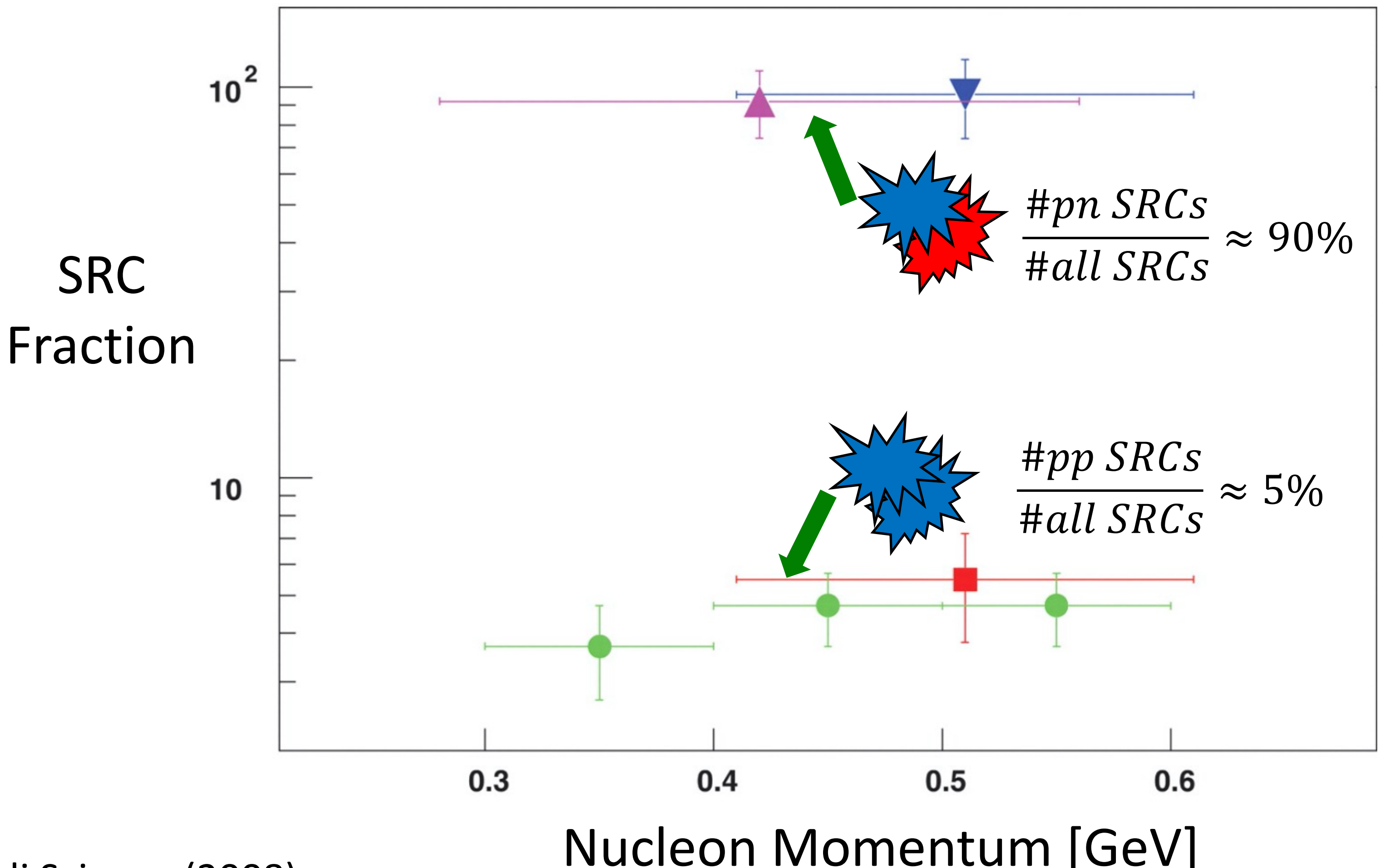
Neutron Abundance? C_n^A



$\#SRC\ Protons = \#SRC\ Neutrons$

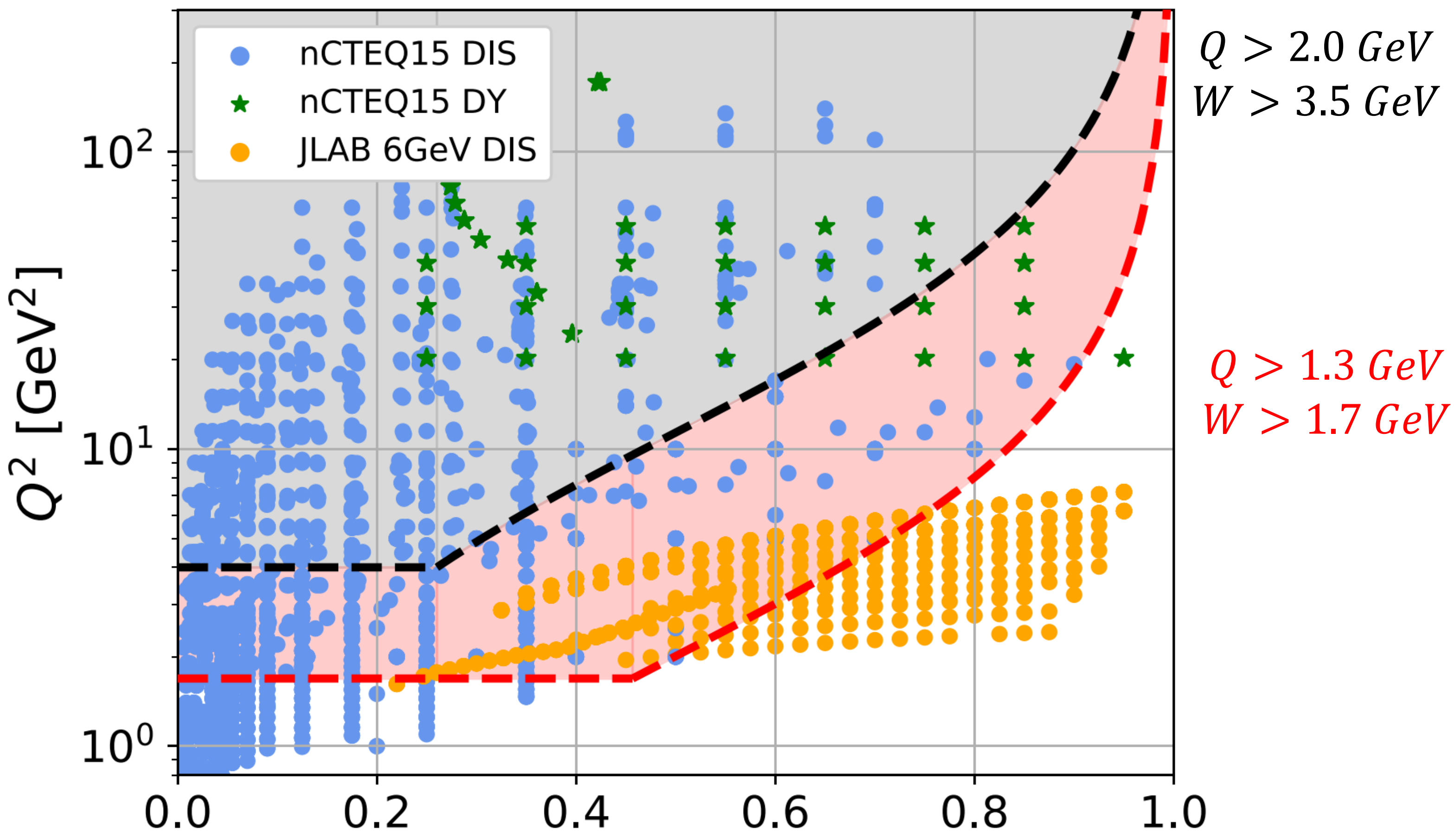
Proton-Neutron Pairs Dominate

Equal number of SRC protons and neutrons.



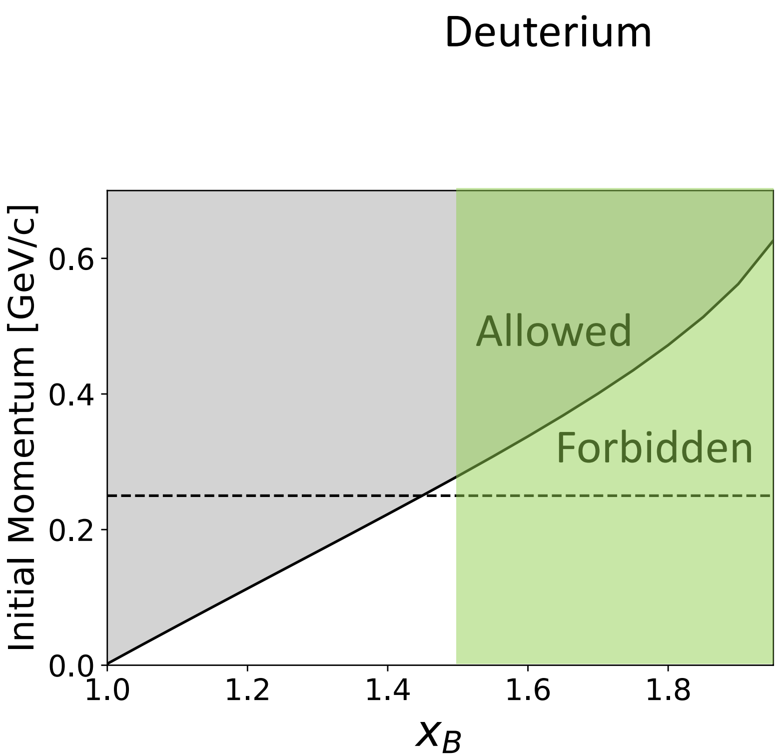
Subedi Science (2008)

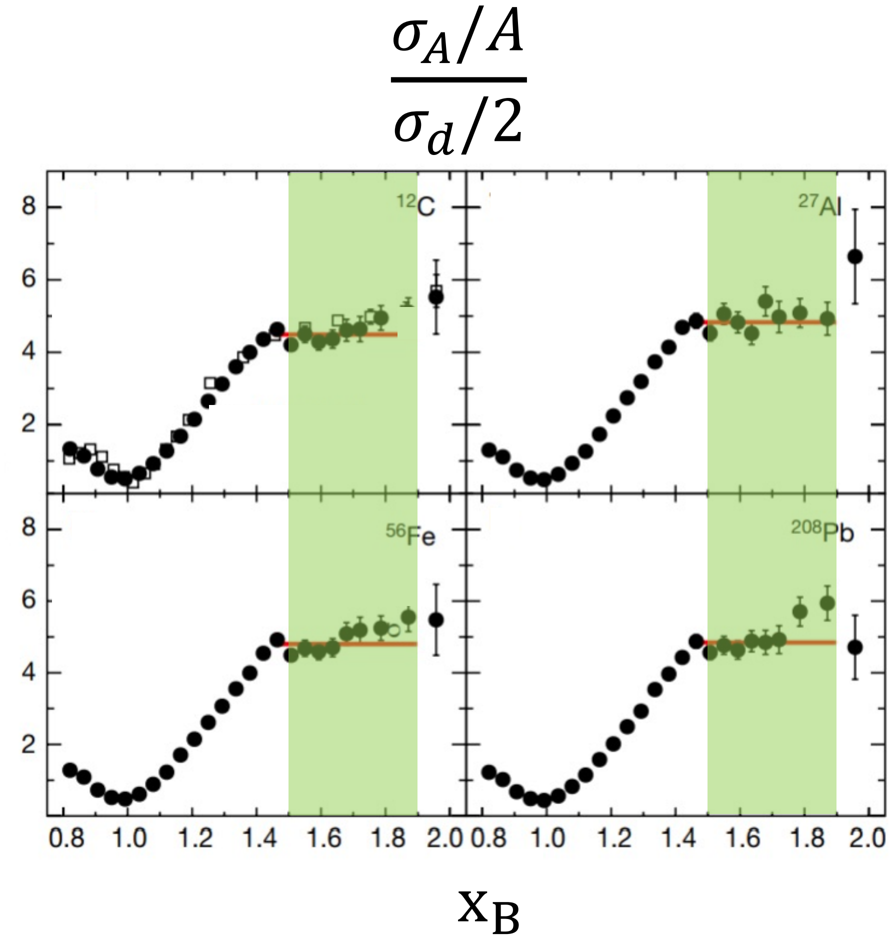
Cut out data with non-DIS Kinematics



Segarra PRD (2021)

SRC Measurements



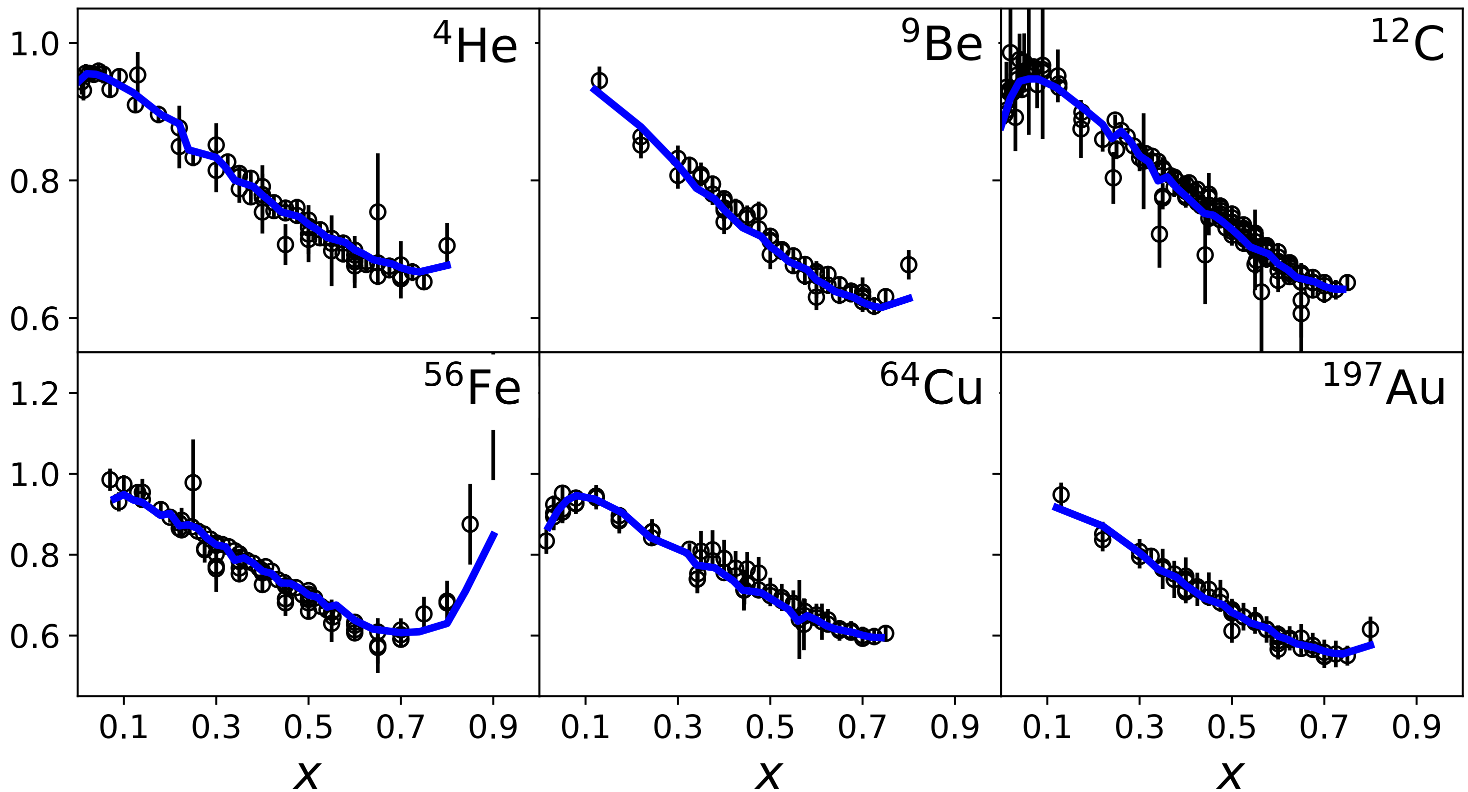


Schmookler Nature (2019)

Fitting to World Data

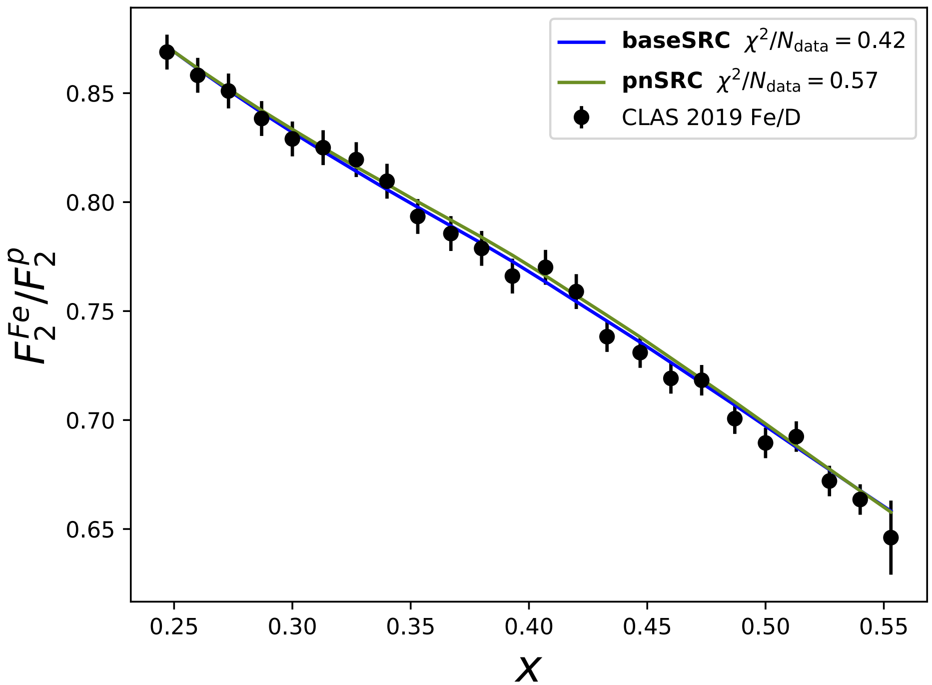
$$\frac{\chi^2_{Tot}}{DOF} = 0.85$$

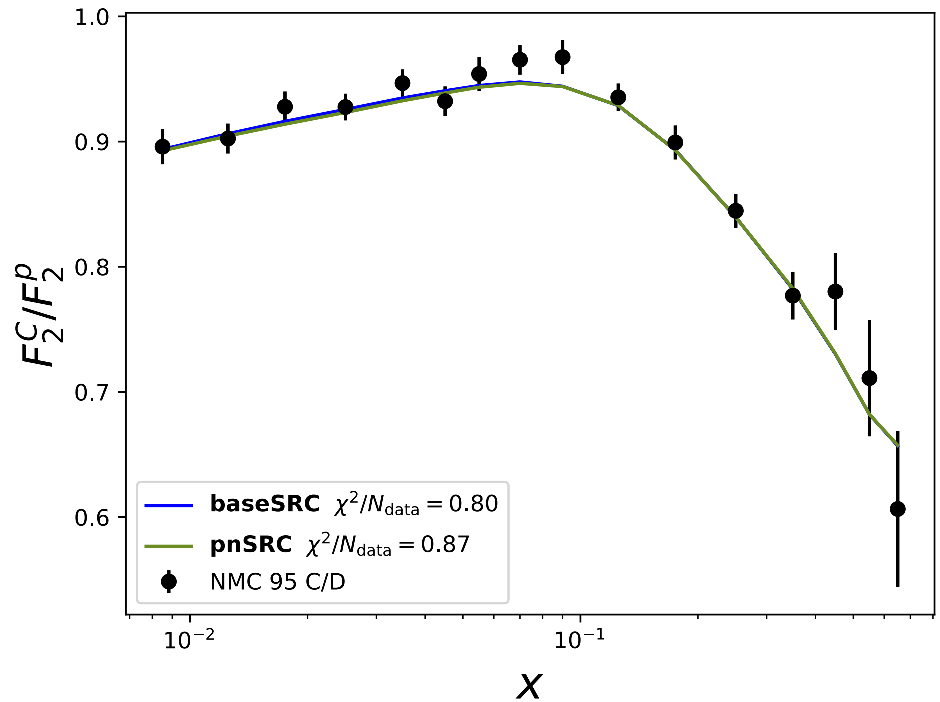
$$\frac{F_2^A}{F_2^D}\left(\frac{F_2^D}{F_2^p}\right)_{CJ}$$



Segarra PRD (2021)

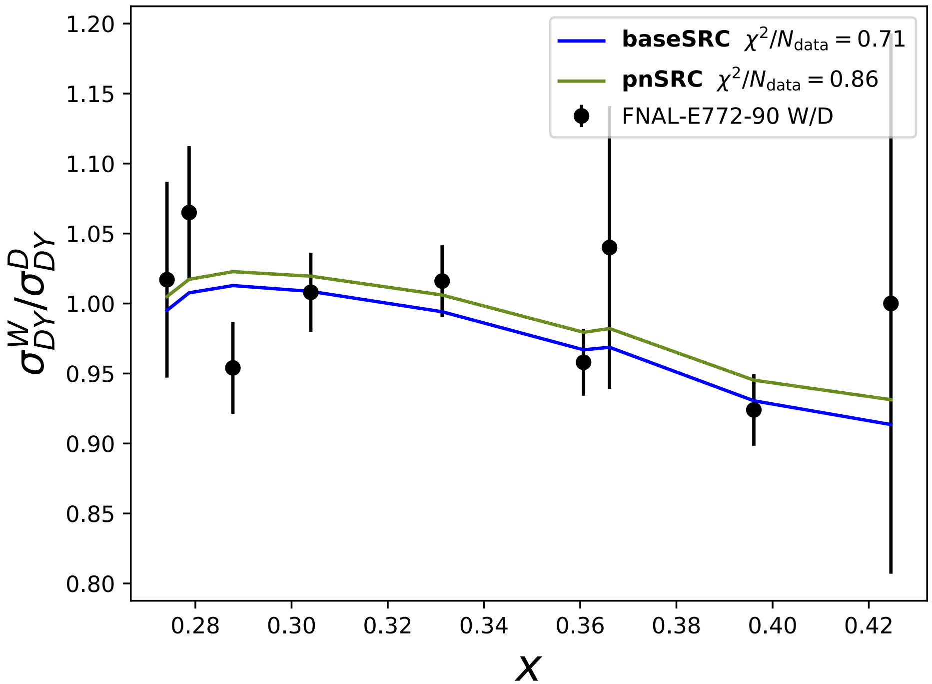
Enforcing pn-dominance does not affect the results of the fit.

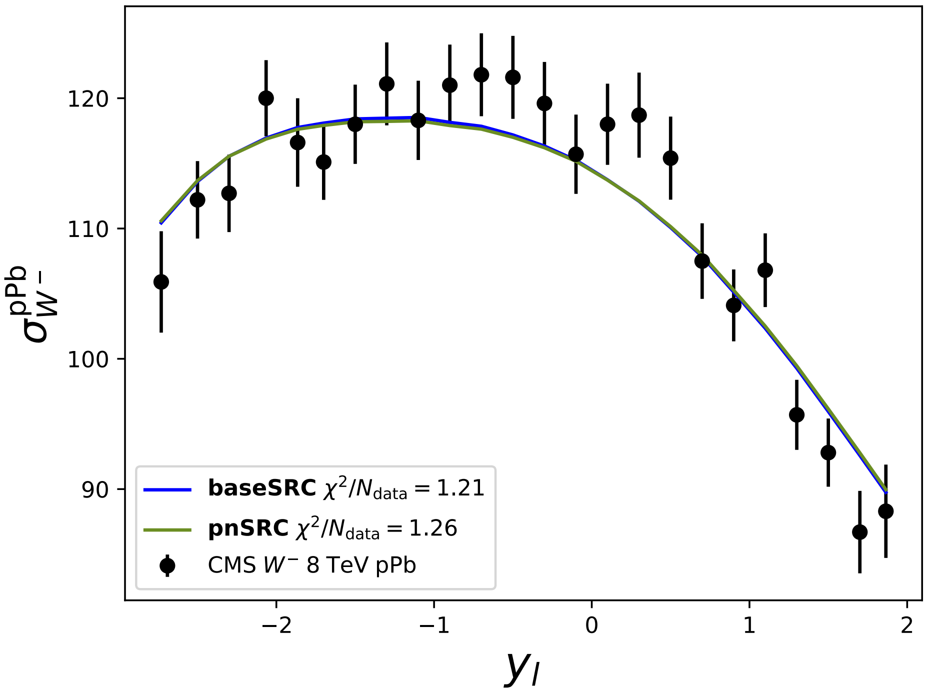


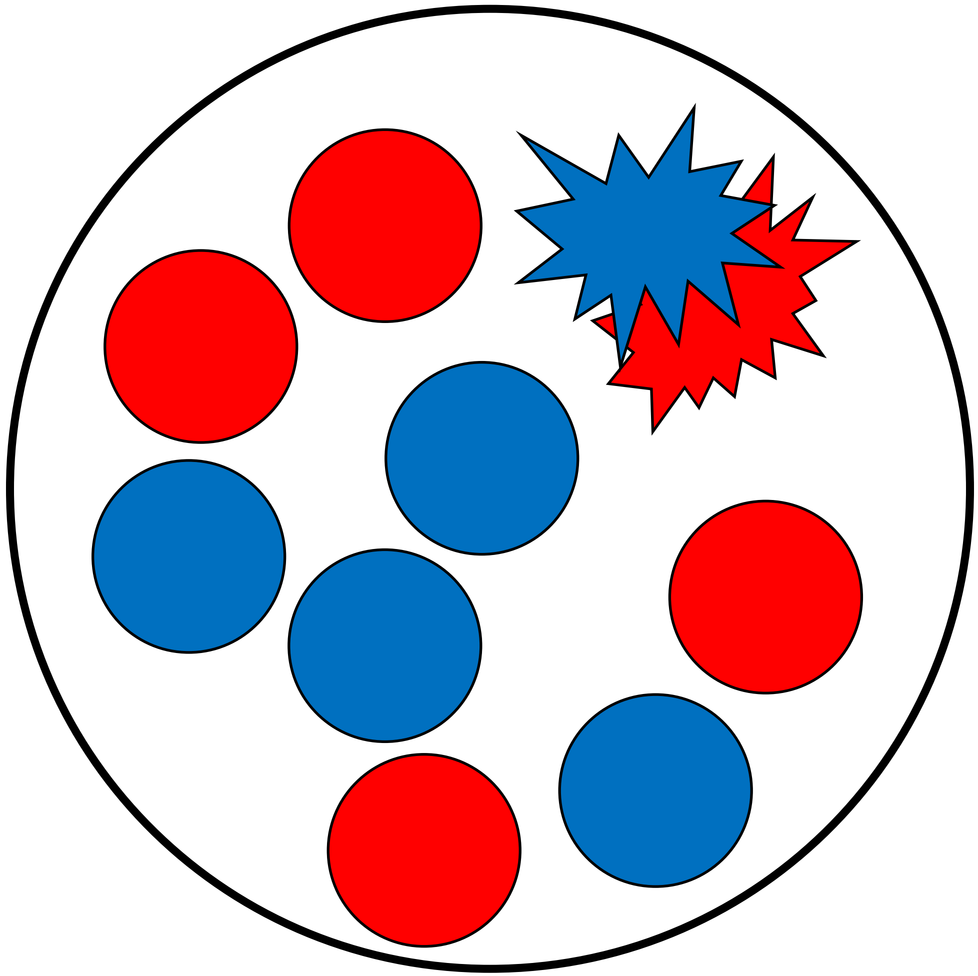


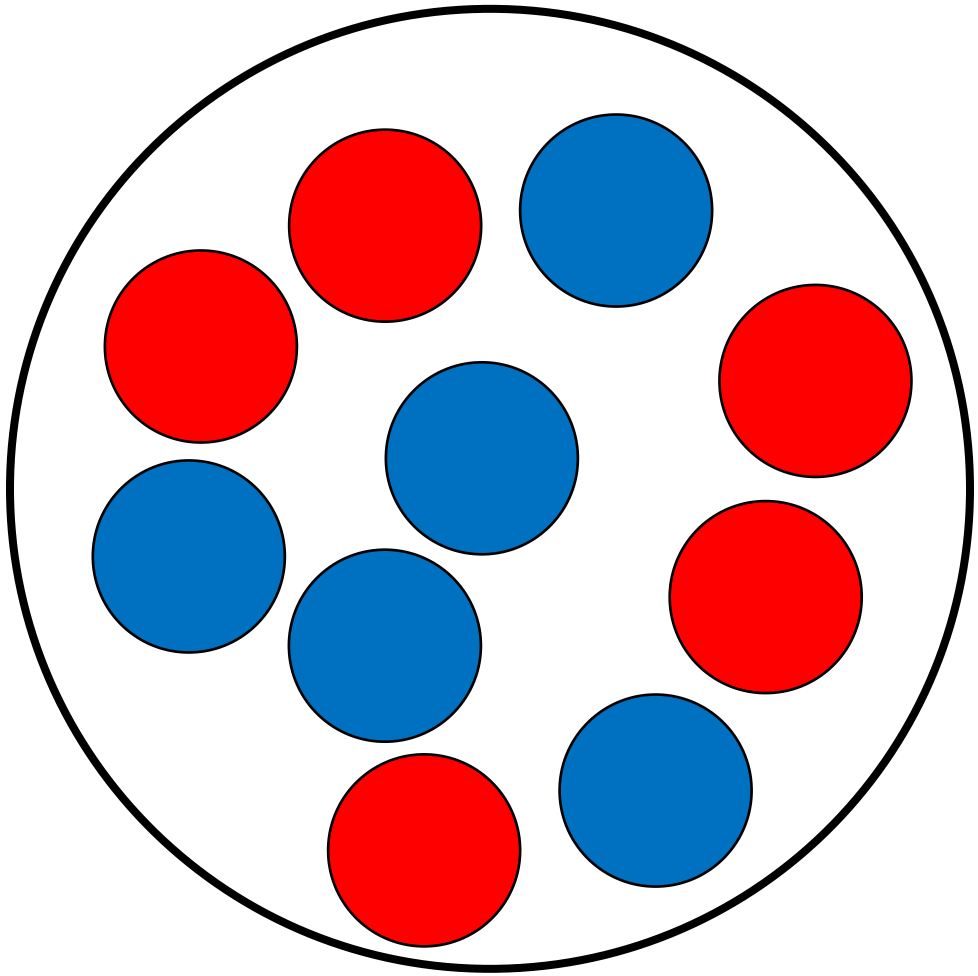
$\chi^2/N_{\rm data}$	$\frac{\chi^2_{\rm tot}}{N_{\rm DOF}}$
reference	0.85
baseSRC	0.80
pnSRC	0.82

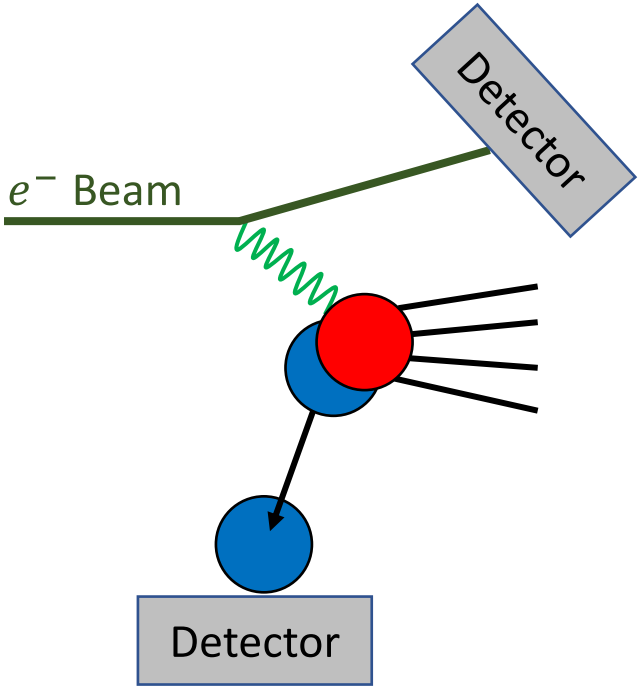
Enforcing pn-dominance does not affect the results of the fit.



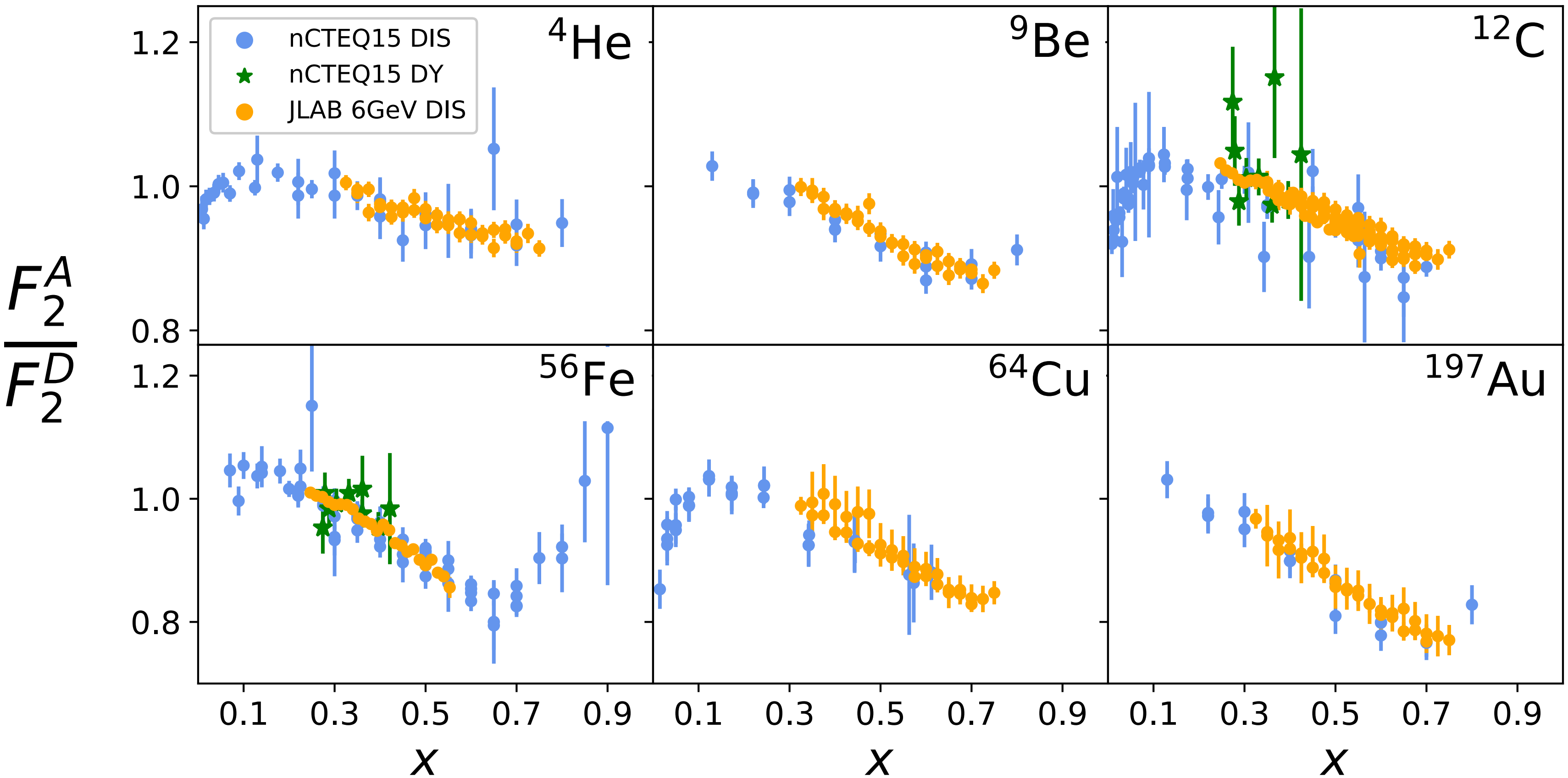







e^- Beam
Detector
Detector

Nuclear Dependance



Segarra PRD (2021)