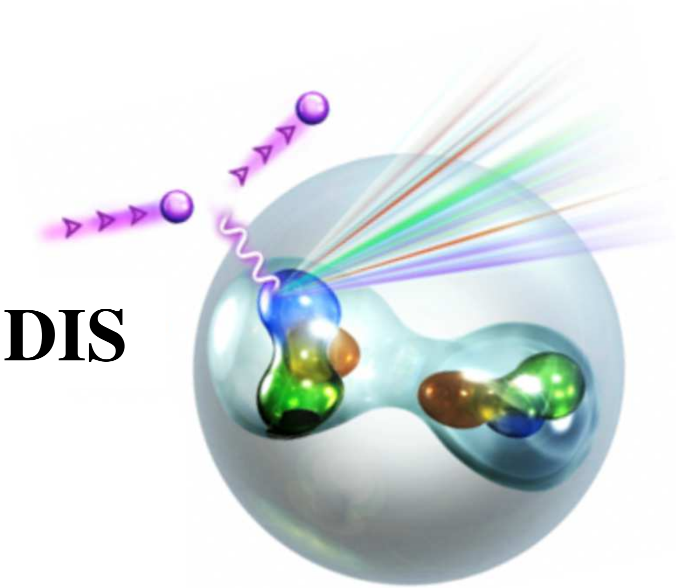
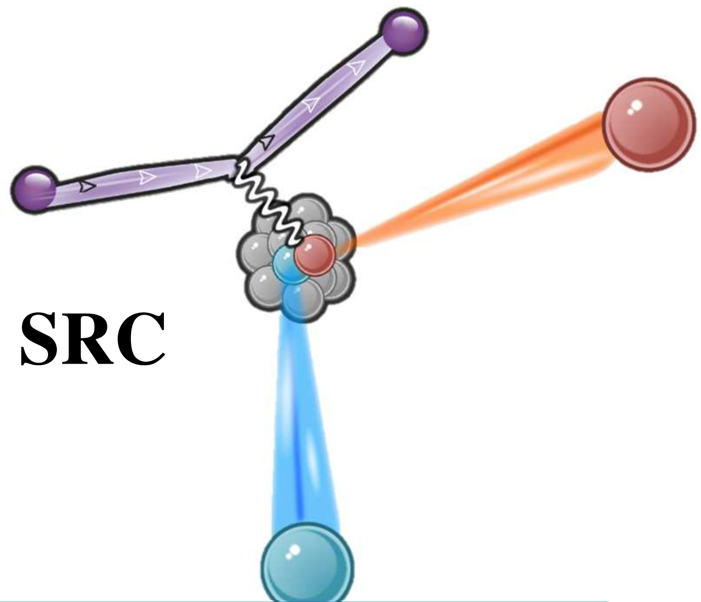
Nucleon-nucleon correlations, and the quarks within

DIS



SRC



4th International Workshop on Quantitative Challenges in Short-Range Correlations and the EMC Effect Research

January 30, 2023 to February 3, 2023
CEA Paris-Saclay

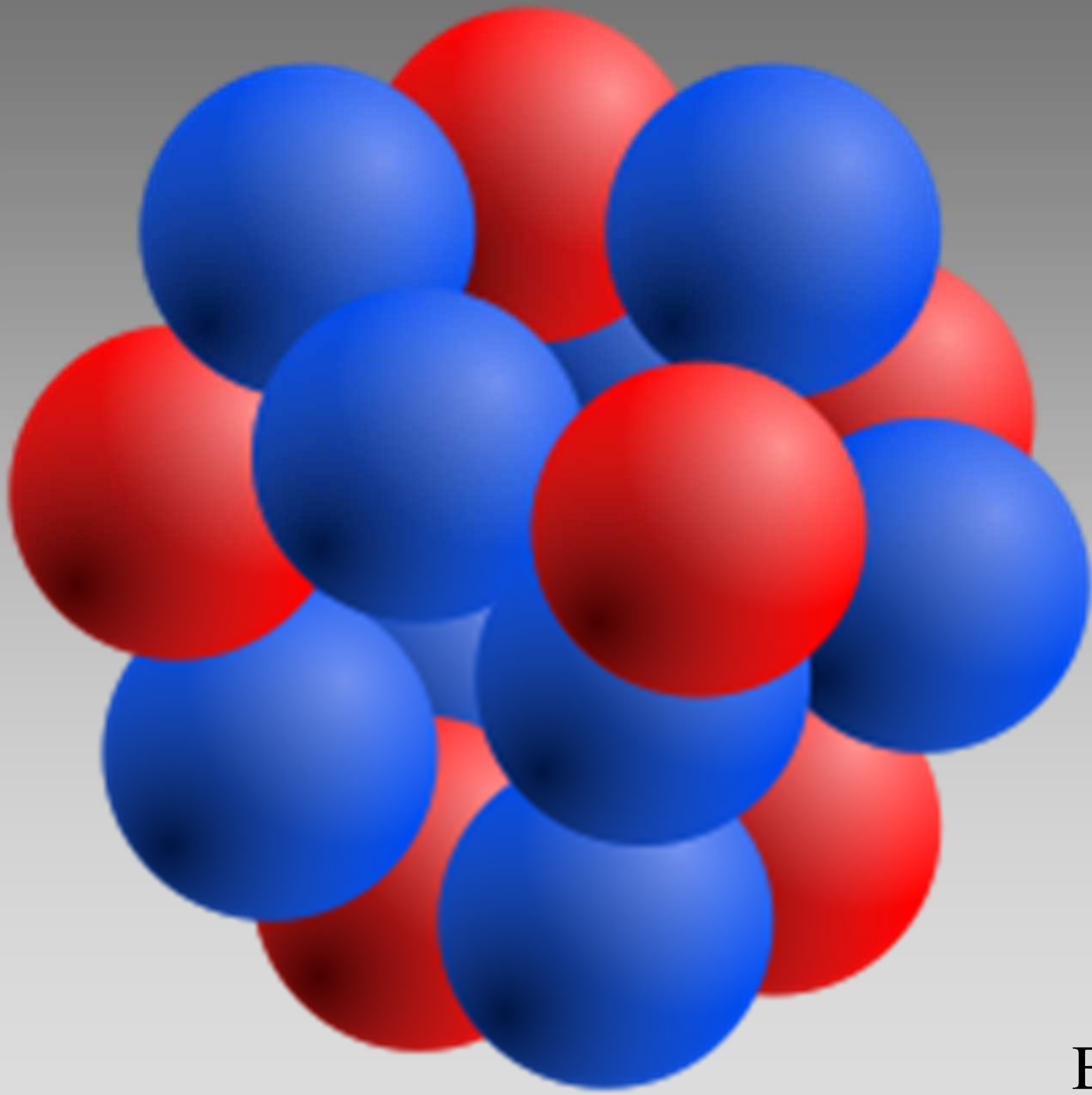
Enter your search term

Lab seminar

Eli Piasetzky Tel Aviv University

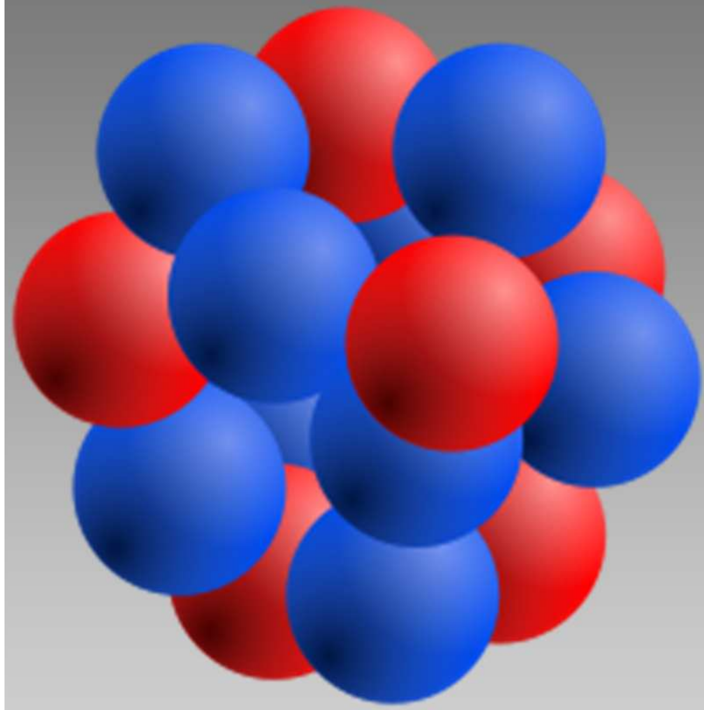

#3229817


A drop of seawater X25
David Liittschwager



B.E ~10 Mev

Confinement ~1 Gev/c



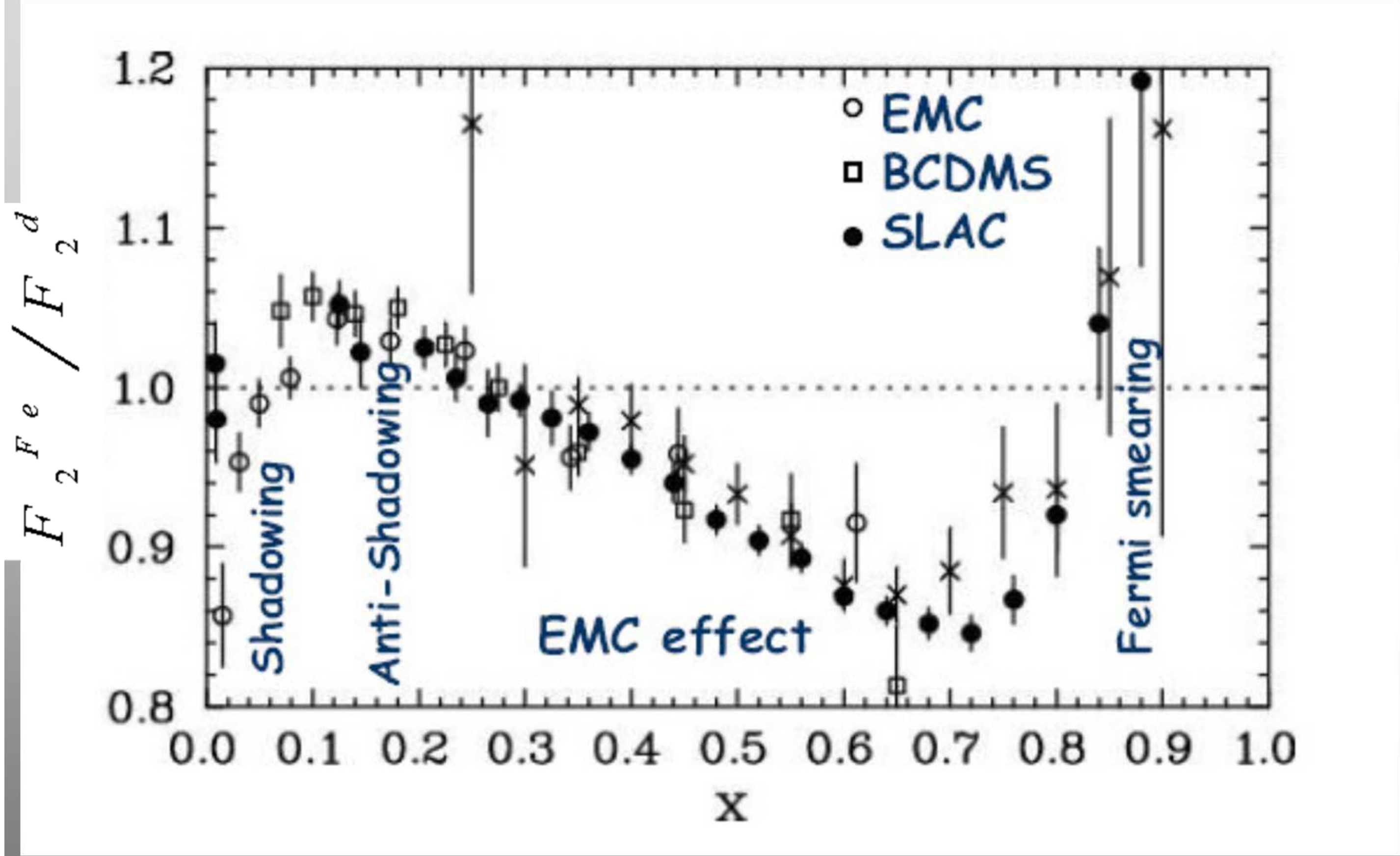
B.E ~1% M_N

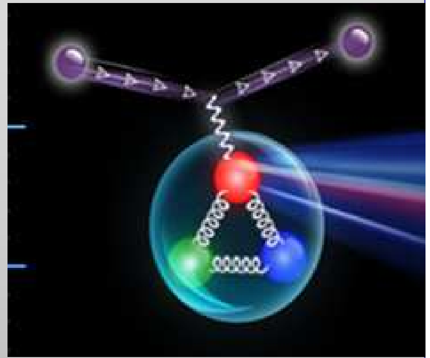
Low energy nuclear physics

Confinement ~1 Gev/c

high energy particle physics

The European Muon Collaboration (EMC) effect

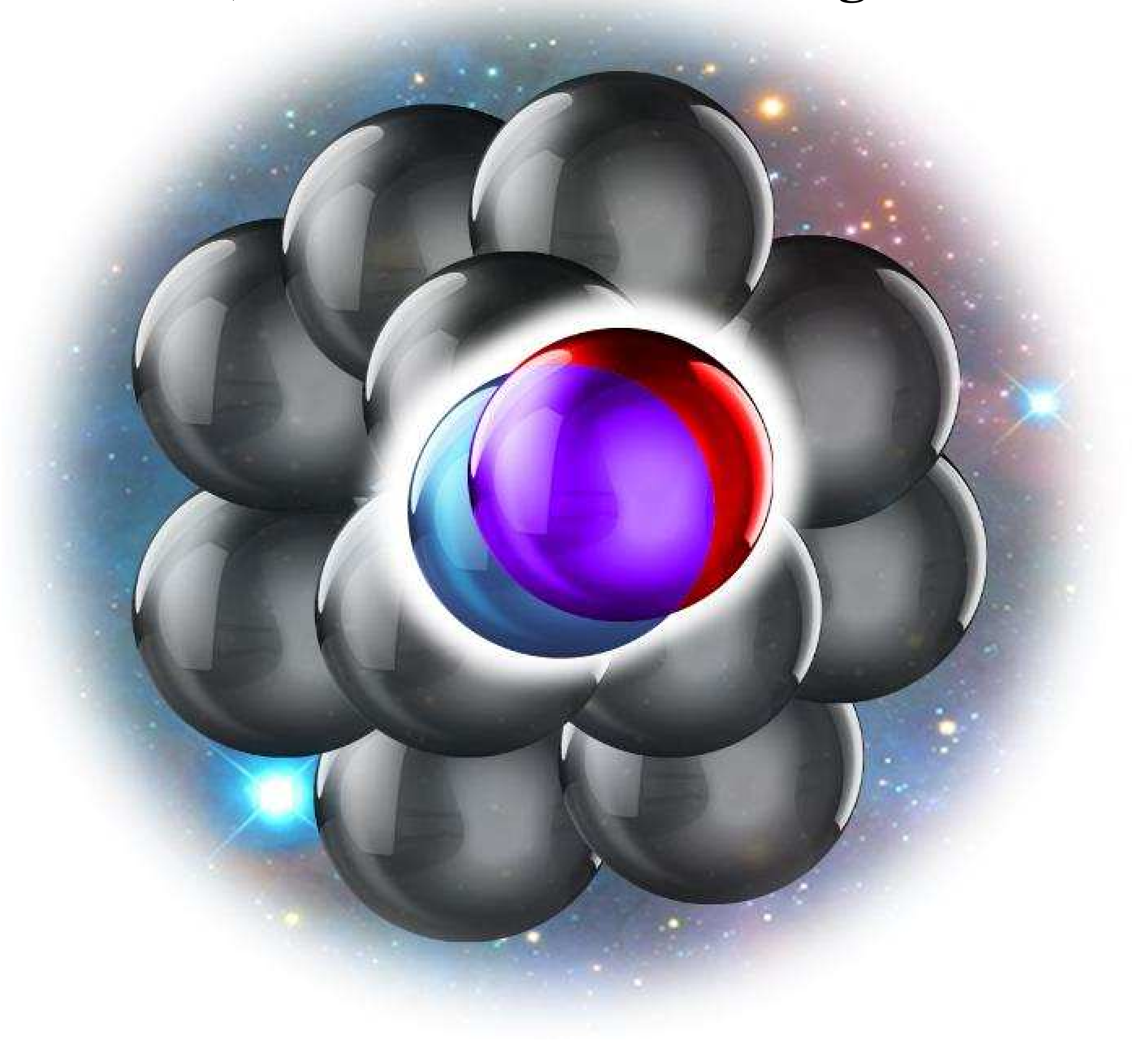




Aubert et al., PLB (1983); Ashman et al., PLB (1988); Arneodo et al., PLB (1988); Allasia et al., PLB (1990); Gomez et al., PRD (1994); Seely et al., PRL (2009); Schmookler et al., Submitted (2018)

$$F_2^A \neq Z \cdot F_2^p + N \cdot F_2^n$$

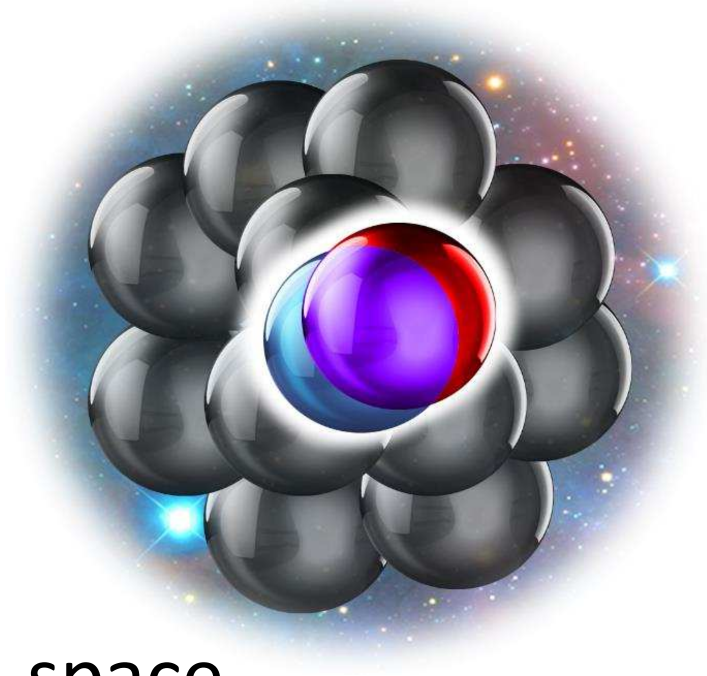
2N – SRC (two nucleons Short range Correlation)



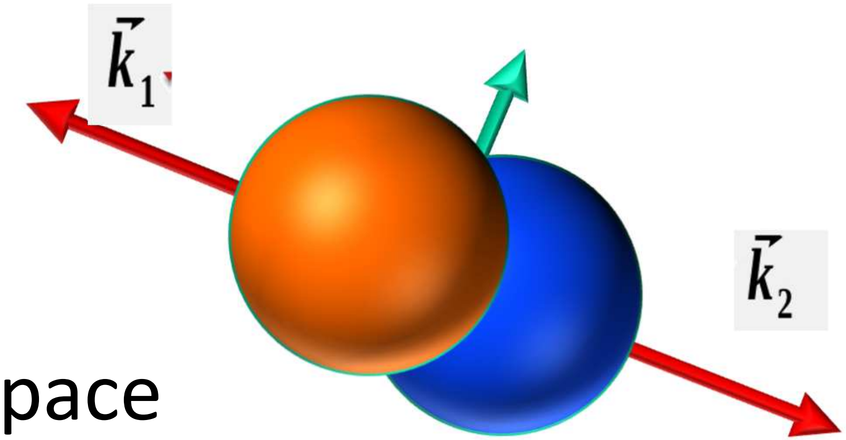
Short-Range Nucleon Correlations (SRC)

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)



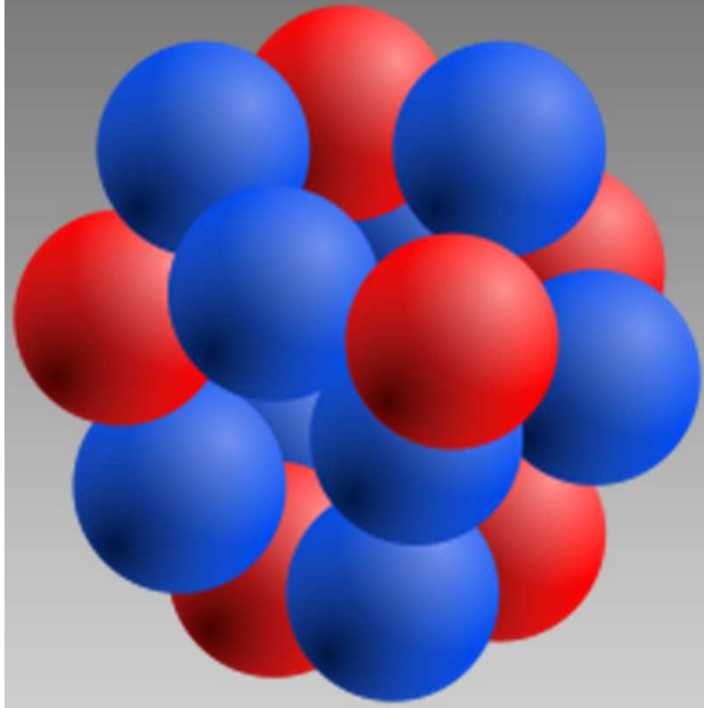
r-space

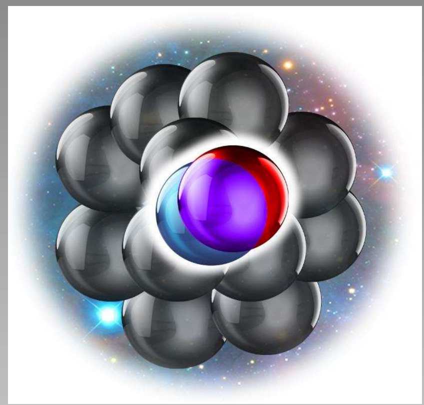


k-space

$$k_1 > k_F \quad k_2 > k_F \quad k_1 \simeq k_2$$

$$k_F \approx 250 \text{ MeV/c}$$



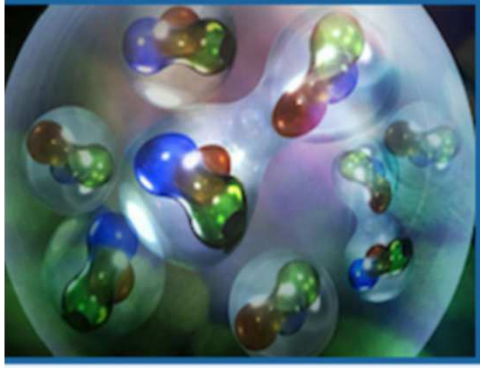


Confinement ~1 Gev/c

B.E ~10 Mev

Low energy nuclear physics

high energy particle physics



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CEA Paris-Saclay

Enter your search term

DE LA RECHERCHE À L'INDUSTRIE
cea
ESNT
Espace de Structure Nucléaire Théorique
DSM - DAM

This workshop is supported by

the Espace de Structure Nucléaire Théorique (ESNT)

of the CEA/DRF and CEA/DAM

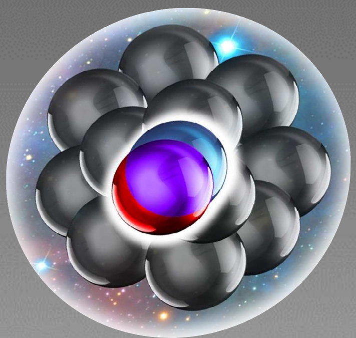
(https://esnt.cea.fr/)

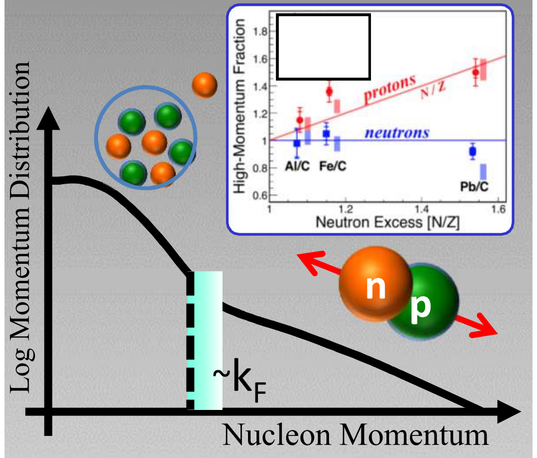
Local organizer: Anna Corsi
Andrea Lagni,
Valérie Lapoux
Aldric Revel

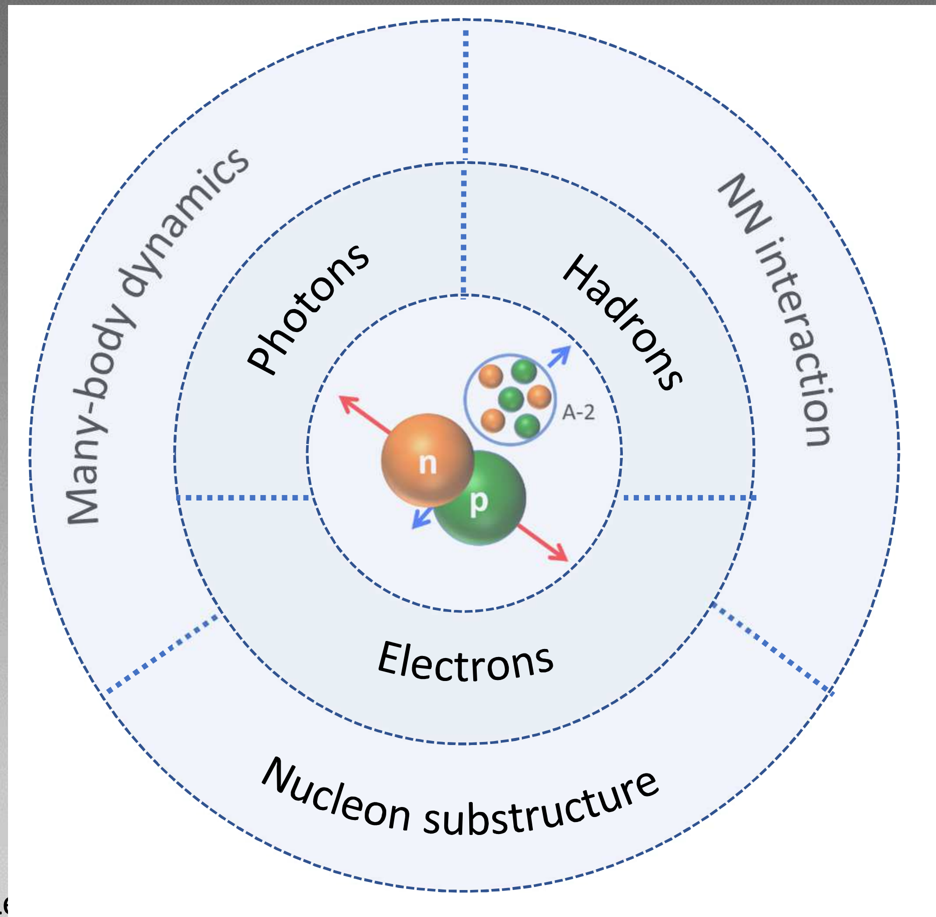
Organizing Committee:
- Tom Aumann (TUDa & GSI)
- Anna Corsi (CEA)
- Or Hen (MIT)
- Julian Kahlbow (MIT & TAU)
- Eli Piasetzky (TAU)
- Stefan Typel (TUDa & GSI)
- Erez Cohen (NRCN)

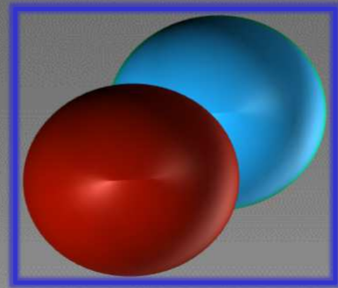
55 participants on site 70 on ZOOM

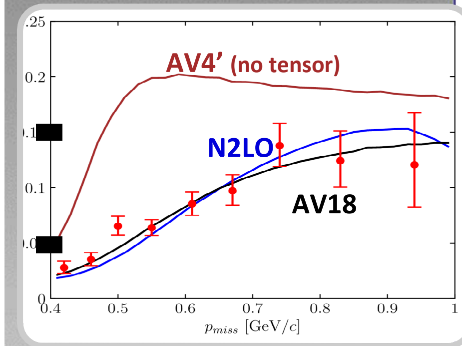
SRC Universe with multimessenger studies







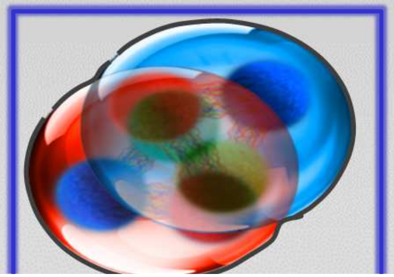


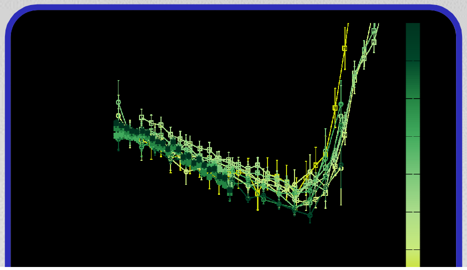


Nature '20
Phys. Rev. Lett. '20
Phys. Lett. B '20
Phys. Lett. B '21

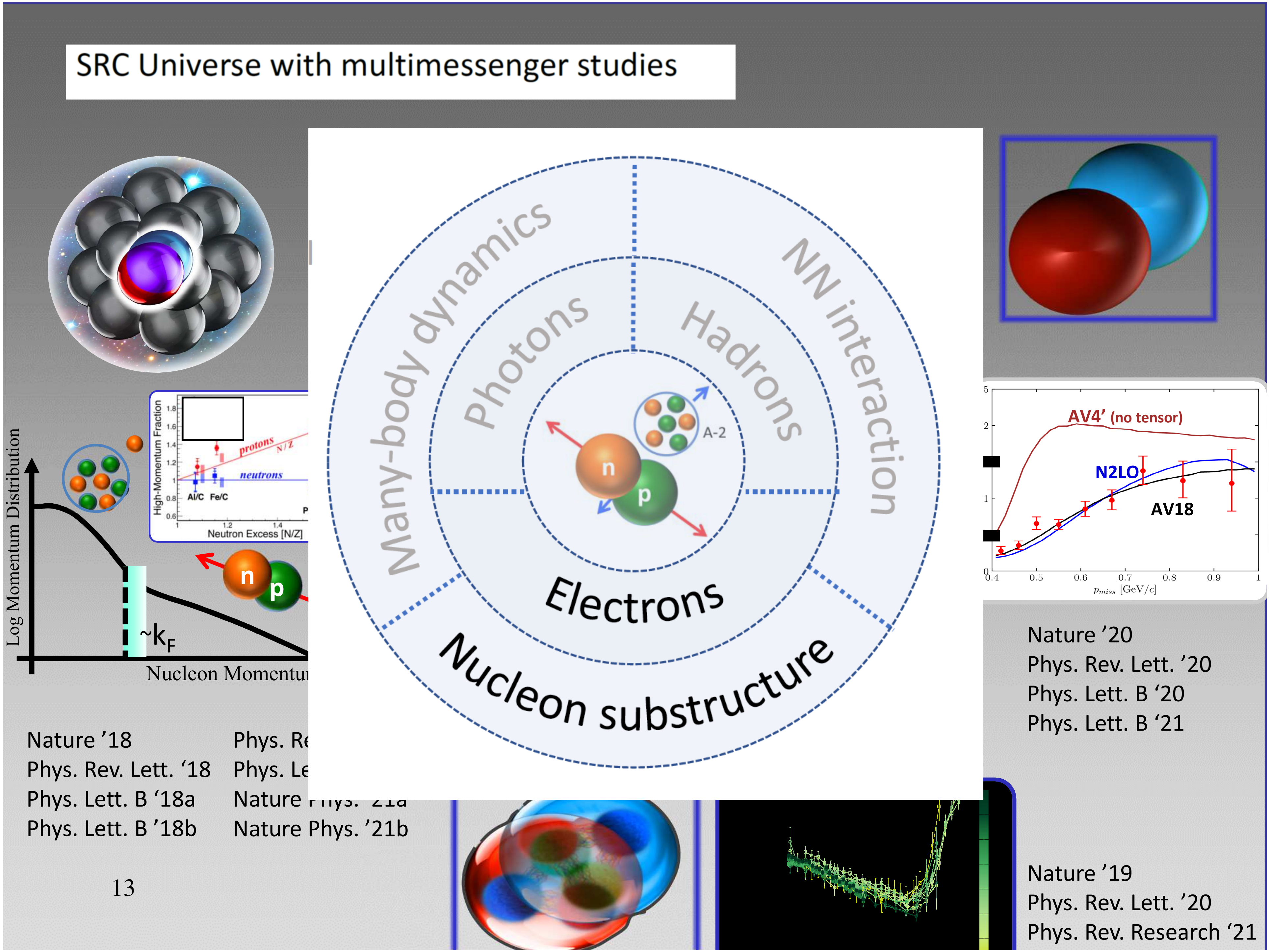
Nature '18
Phys. Rev. Lett. '18
Phys. Lett. B '18a
Phys. Lett. B '18b

Phys. Rev. Le
Phys. Lett. B '19
Nature Phys. '21a
Nature Phys. '21b





Nature '19
Phys. Rev. Lett. '20
Phys. Rev. Research '21


SRC Universe with multimessenger studies
Many-body dynamics
NN interaction
Photons
Hadrons
Electrons
Nucleon substructure
n
p
A-2
Log Momentum Distribution
Nucleon Momentu
~k_F
High-Momentum Fraction
protons
neutrons
N/Z
Al/C
Fe/C
Neutron Excess [N/Z]
AV4' (no tensor)
N2LO
AV18
p_miss [GeV/c]
Nature '18
Phys. Rev. Lett. '18
Phys. Lett. B '18a
Phys. Lett. B '18b
Phys. Re
Phys. Le
Nature Phys. '21a
Nature Phys. '21b
Nature '20
Phys. Rev. Lett. '20
Phys. Lett. B '20
Phys. Lett. B '21
Nature '19
Phys. Rev. Lett. '20
Phys. Rev. Research '21
13

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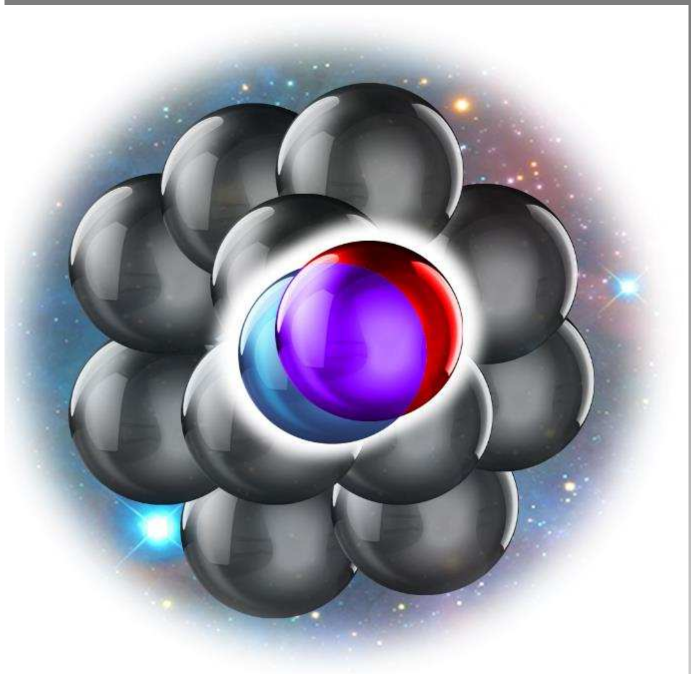


The EMC effect

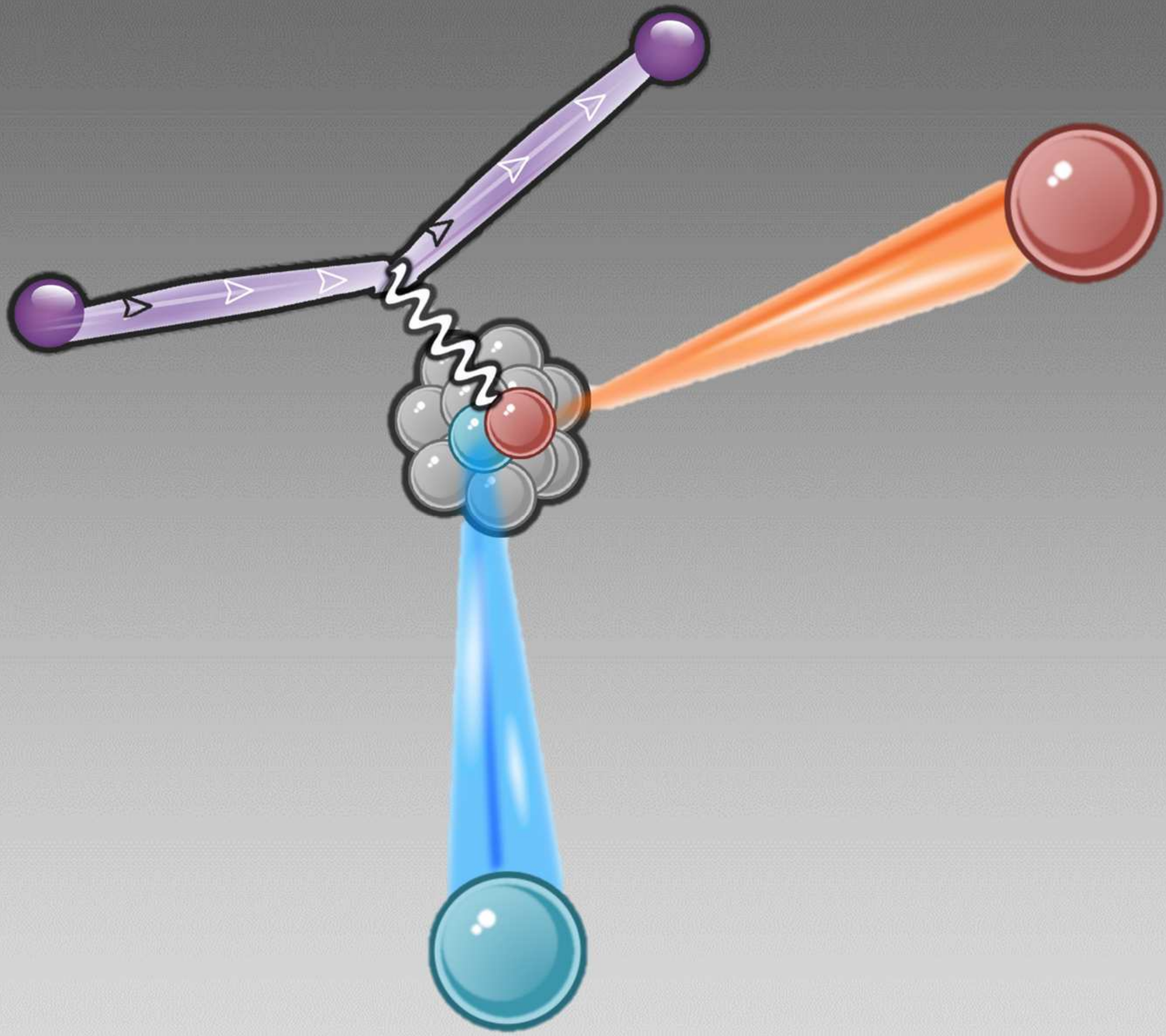
2N SRC

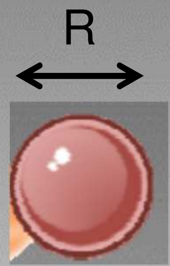
Confinement ~1 Gev/c

nuclear physics

high energy particle physics

Exclusive hard scattering





$$\lambda < R$$

$$q \cdot R < 1$$

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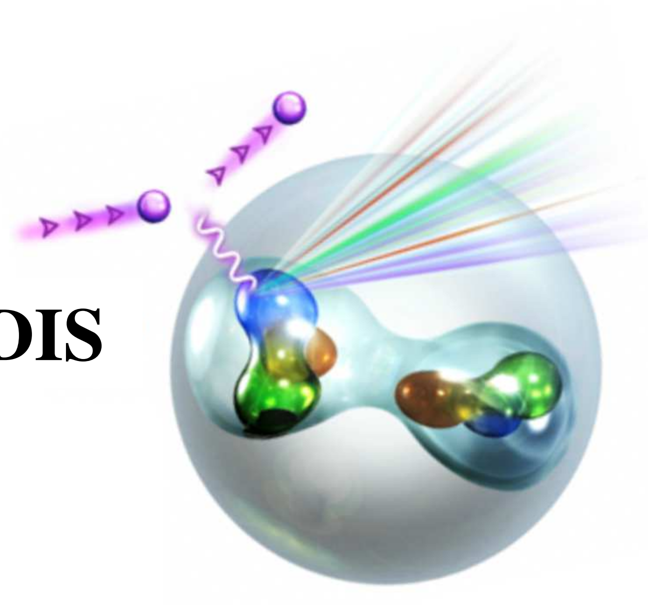
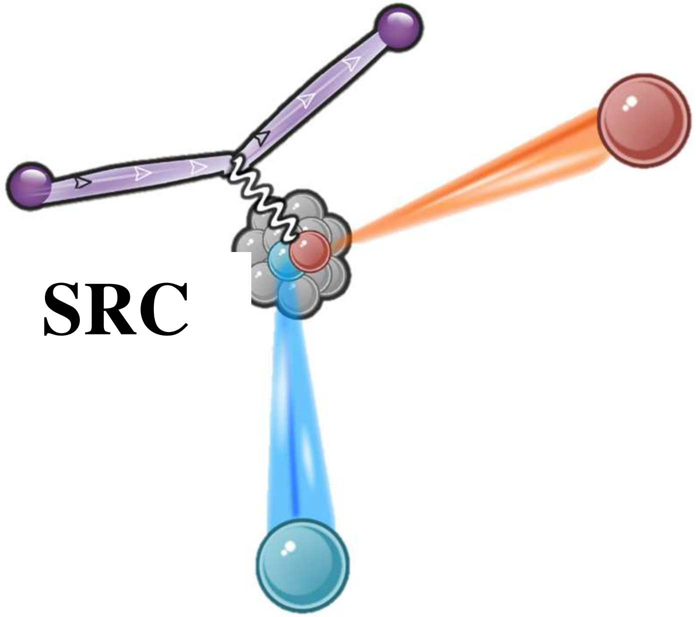
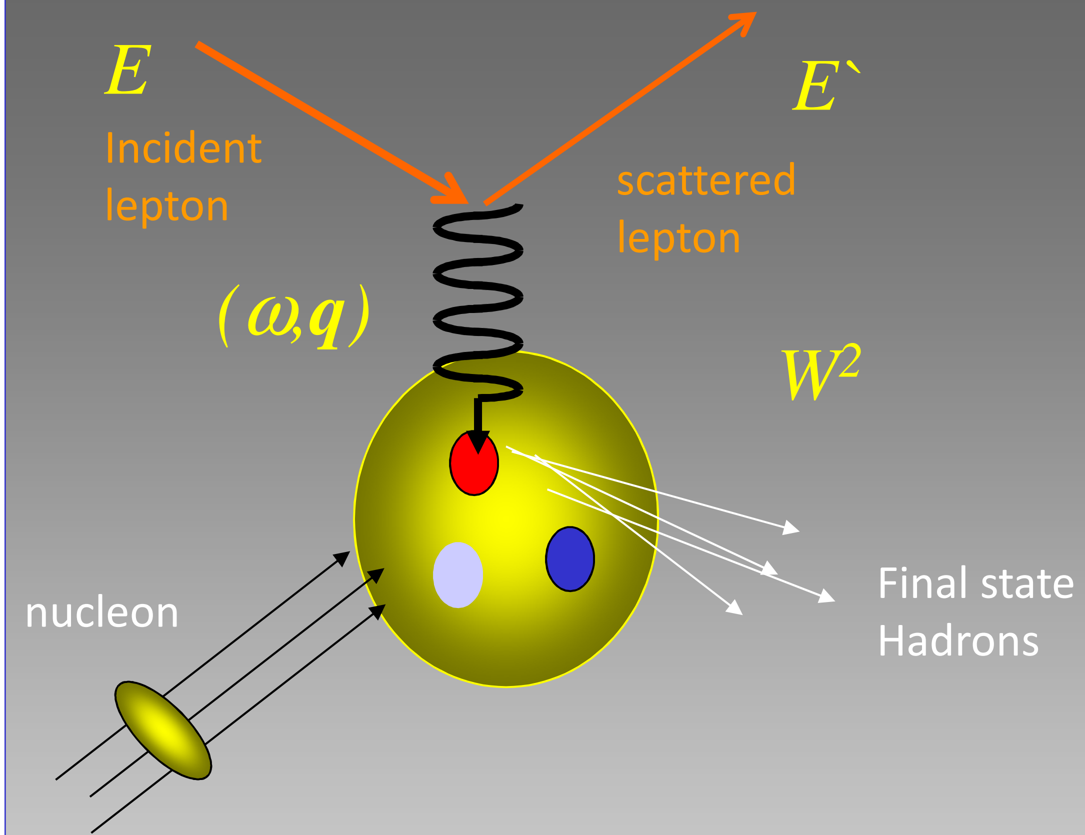
DIS



SRC



Deep Inelastic Scattering (DIS)



$$Q^2 = -q_\mu q^\mu = q^2 - \omega^2$$

$$\omega = E' - E$$

$$x_B = \frac{Q^2}{2m\omega} \qquad (= \frac{Q^2}{2(q \cdot p_T)})$$

$$0 \le x_B \le 1$$

Electrons, muons, neutrinos

SLAC, CERN, HERA, FNAL, JLAB

E, E’ 5-500 GeV

Q^2 5-50 GeV^2

w^2 >4 GeV^2

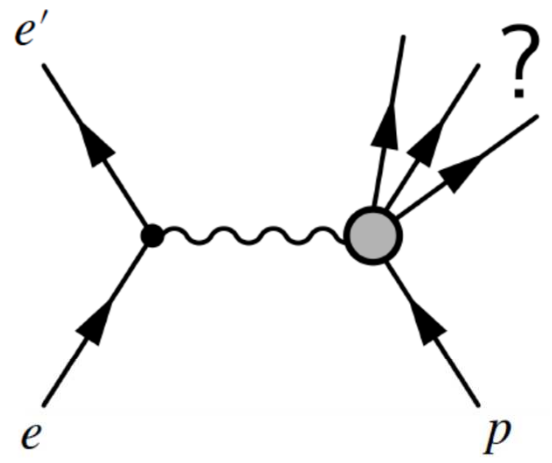
$0 \le X_B \le 1$

X_B gives the fraction of nucleon momentum carried by the struck parton

Information about nucleon vertex is contained in $F_1(x,Q^2)$ and $F_2(x,Q^2)$, the unpolarized structure functions

Deep Inelastic Scattering (DIS)

TEL AVIV UNIVERSITY



$$\frac{d\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{Q^4}\left[\left(1 - y - \frac{m_p^2 y^2}{Q^2}\right)\frac{F_2(x,Q^2)}{x} + y^2 F_1(x,Q^2)\right]$$

$$Q^2 = -q_\mu q^\mu = q^2 - \omega^2$$

$$\omega = E' - E$$

$$x_B = \frac{Q^2}{2m\omega} \quad \left(= \frac{Q^2}{2(q\cdot p_T)}\right)$$

$$0 \le x_B \le 1$$

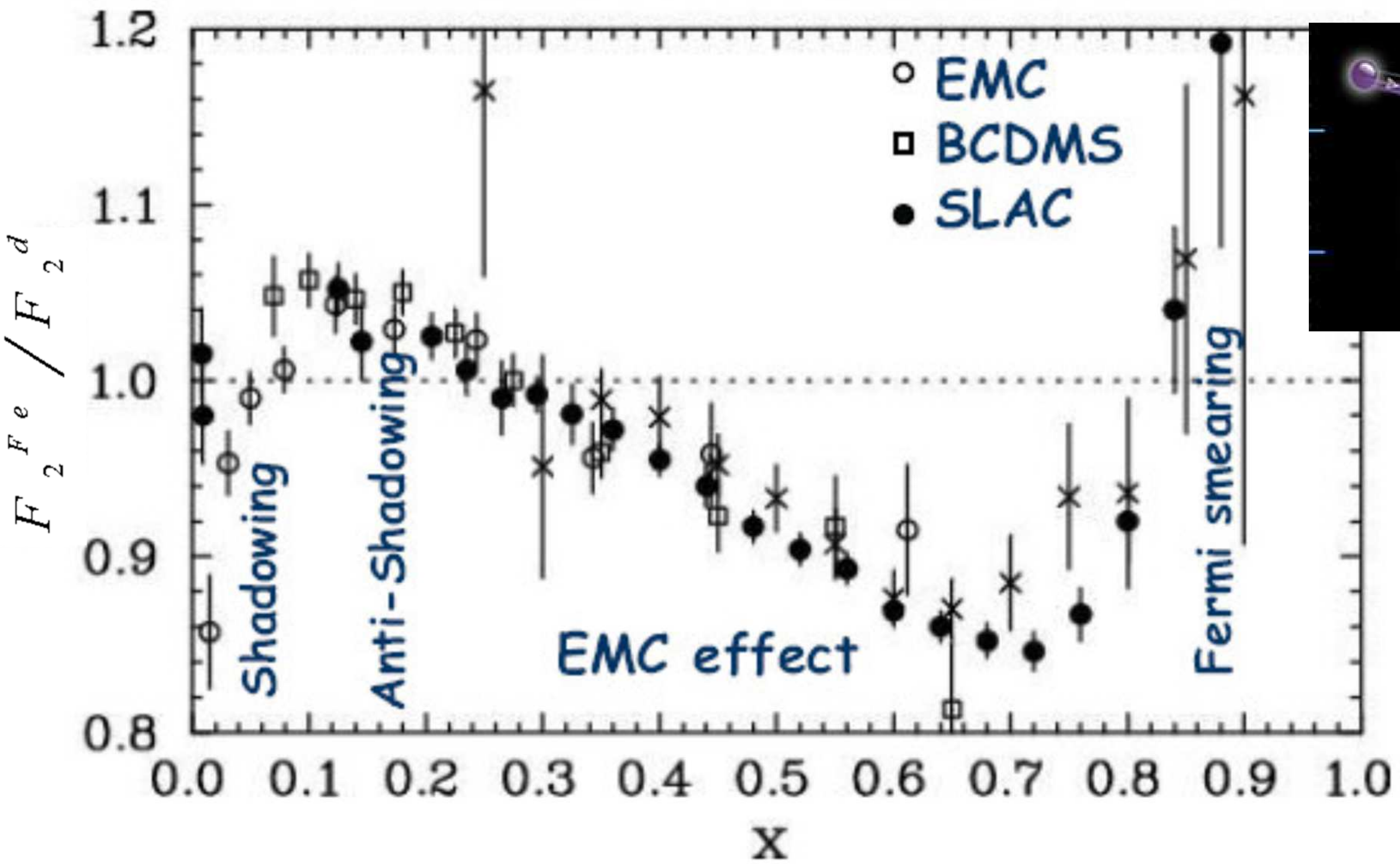
The fraction of nucleon momentum carried by the struck parton.

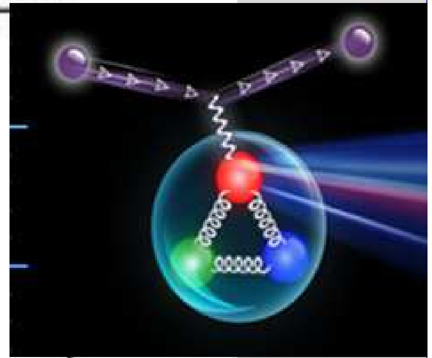
Information about the nucleon is contained in $F_1(x,Q^2)$ and $F_2(x,Q^2)$, the unpolarized structure functions.

$$\left.\frac{d\sigma}{dxdQ^2}\right\} F_2^p(x,Q^2)$$

$$\left.\frac{d\sigma^A}{dxdQ^2}\right\} F_2^A(x,Q^2)$$

The European Muon Collaboration (EMC) effect





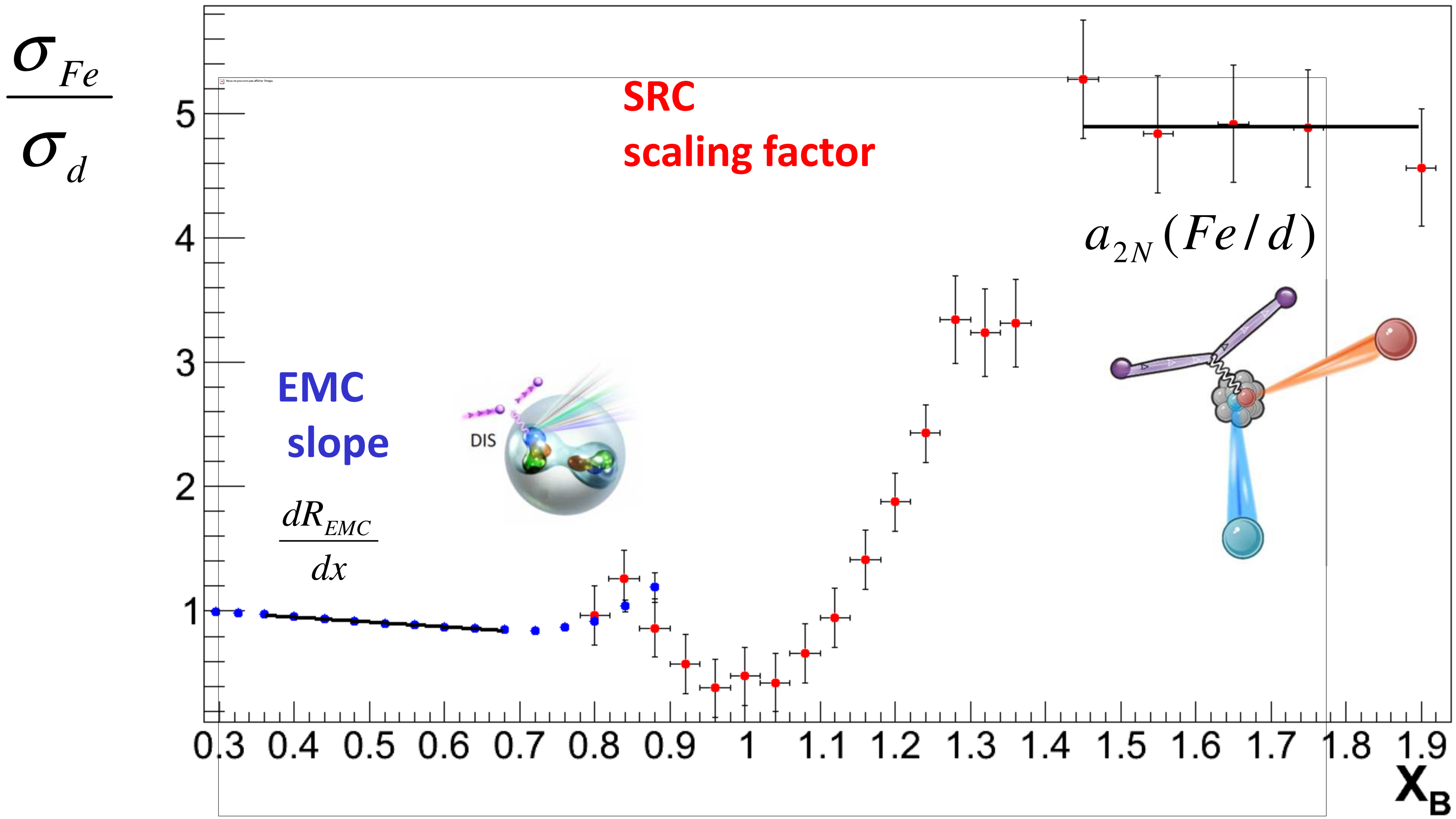
Aubert et al., PLB (1983 … neodo et al., PLB (1988); Allasia et al., PLB (1990); Gomez et a … (2009); Schmookler et al., Submitted (2018)

$$F_2^A \neq Z \cdot F_2^p + N \cdot F_2^n$$

After 40 years no consensus on cause … ct

Close nucleons

Comparing magnitude of EMC effect and SRC scaling factors



SLAC data:

Gomez et al., Phys. Rev. D49, 4348 (1983).

Frankfurt, Strikman, Day, Sargsyan, Phys. Rev. C48 (1993) 2451.

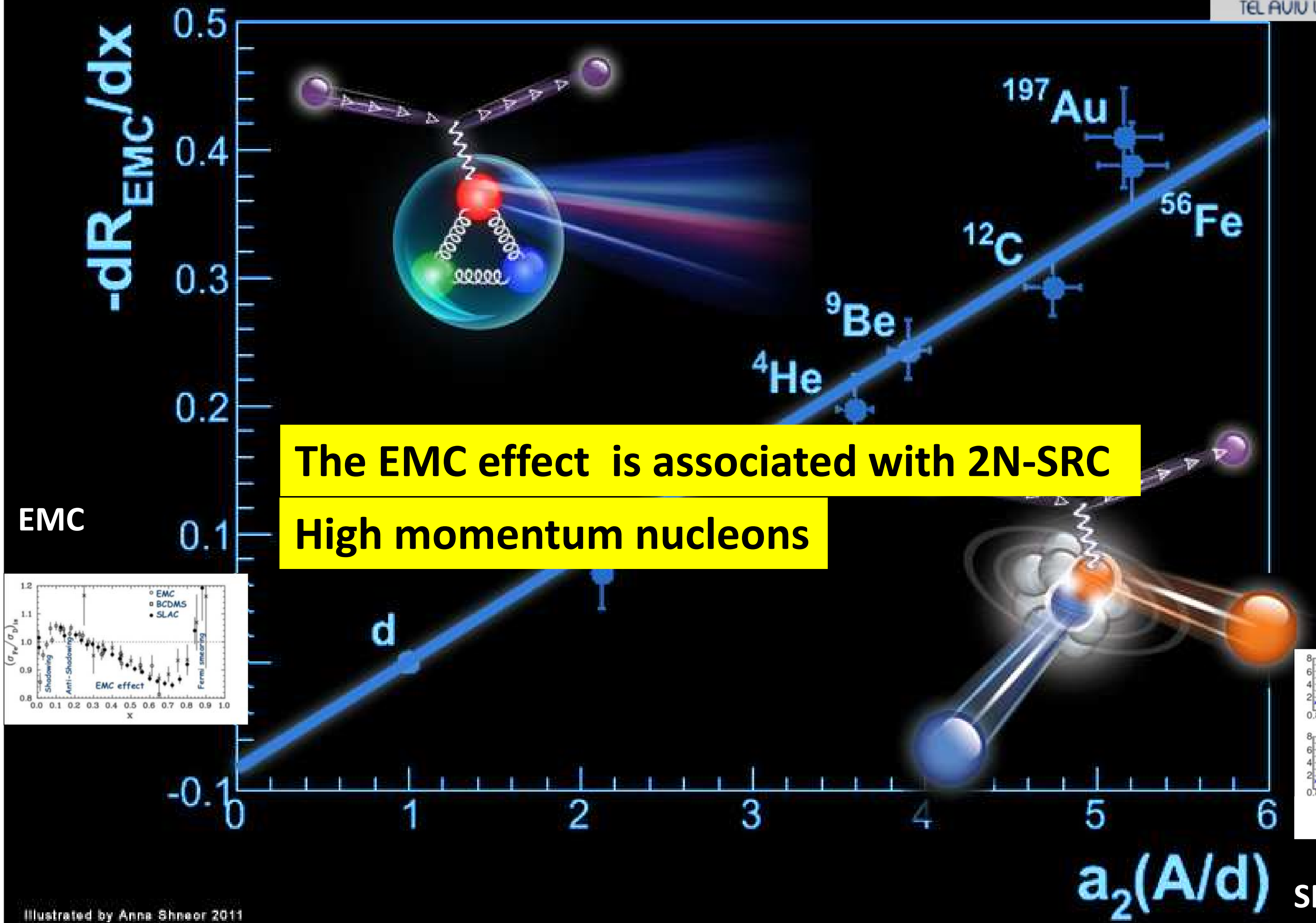
Q^2=2, 5, 10, 15 GeV/c^2 (averaged)

Q^2=2.3 GeV/c^2

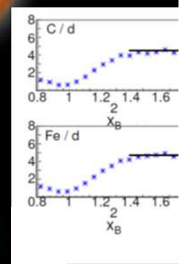
The EMC effect is associated with 2N-SRC

High momentum nucleons

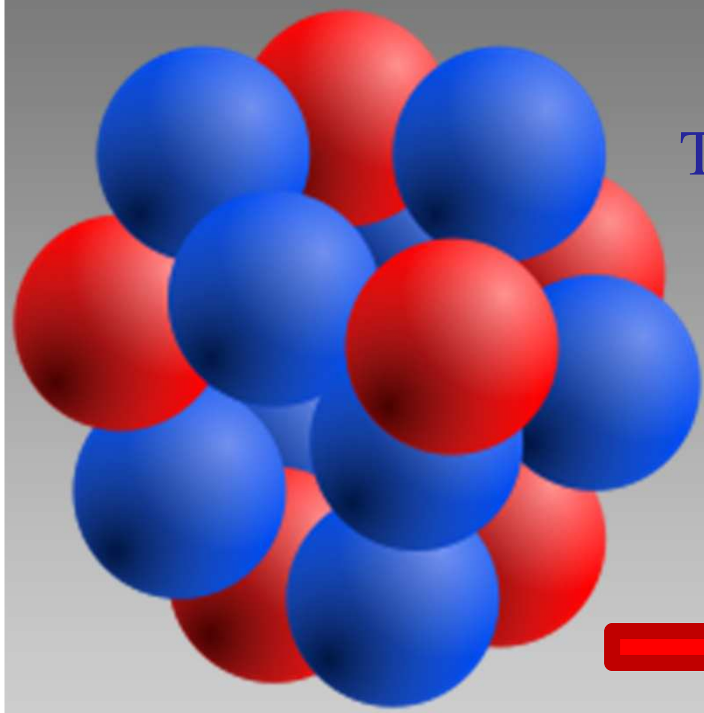
EMC



SRC



PRL 106, 052301 (2011), PRC 85 047301 (2012), RMP 89, 04500 (2017)



The EMC effect

2N SRC

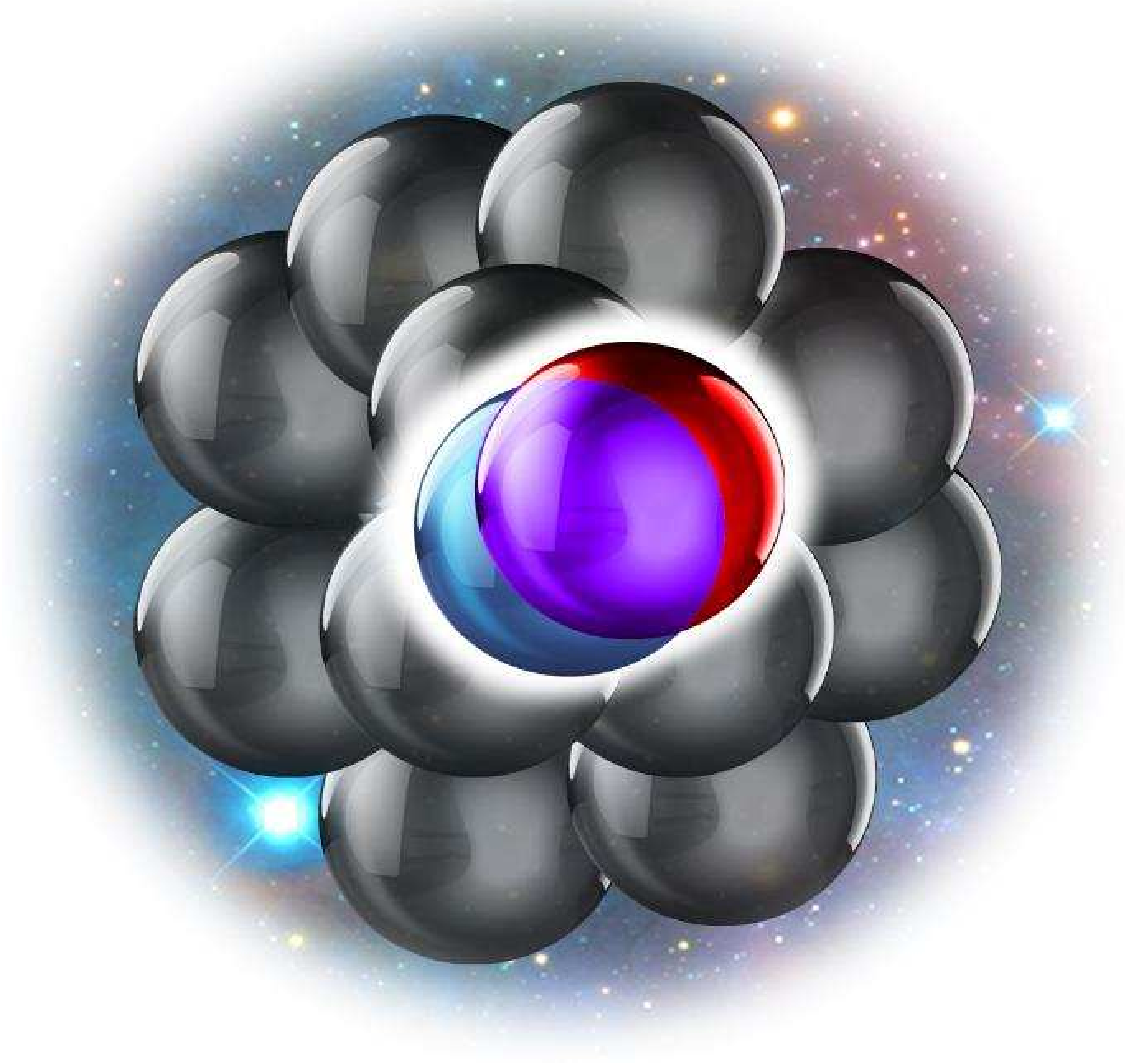
Confinement ~1 Gev/c

B.E ~10 Mev

Low energy nuclear physics

high energy particle physics

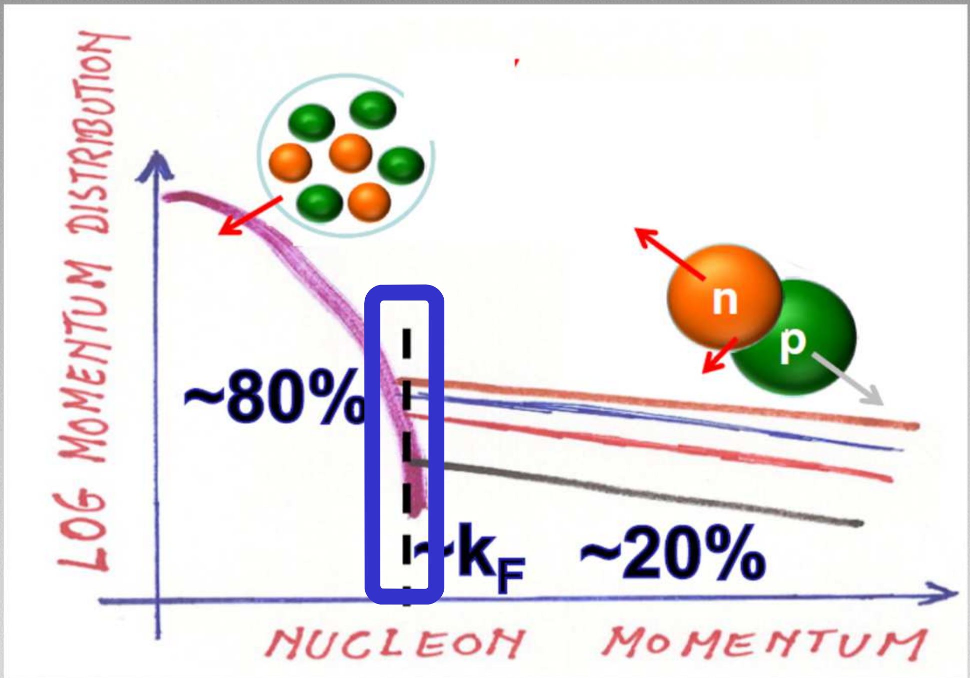
Short-Range Correlations (SRC)



Summary of SRC results

In nuclei the momentum distribution of nucleons can be divided into two distinct regions

$k<\sim 0.8k_F$	$k>1.5\ k_F$
Mean field region	Correlated / high momentum region
Single nucleons	SRC pairs



SRC domain

np-SRC dominance (tensor force)

Universality

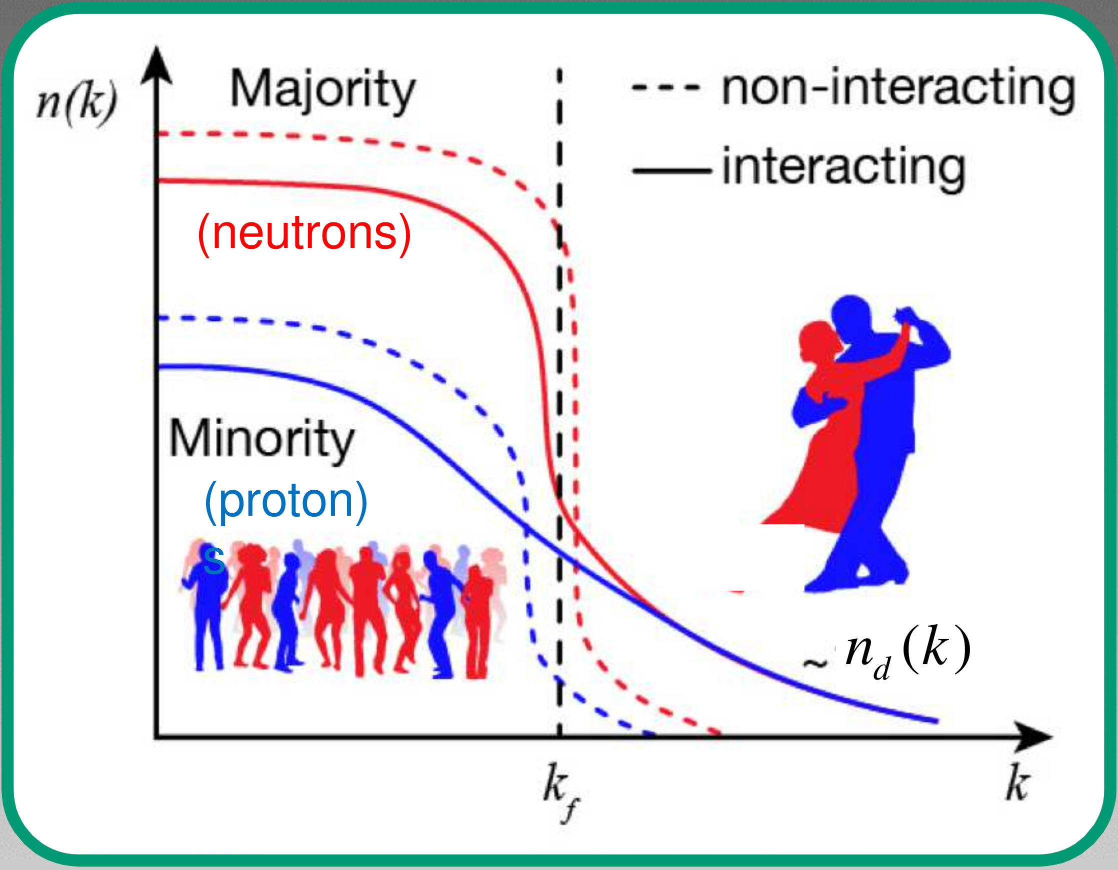
E. Piasetzky et al., PRL. 97 (2006) 162504.

R. Subedi et al., Science 320, 1476 (2008).

A. Schmidt et al., Nature (in print)

np-dominance in asymmetric nuclei

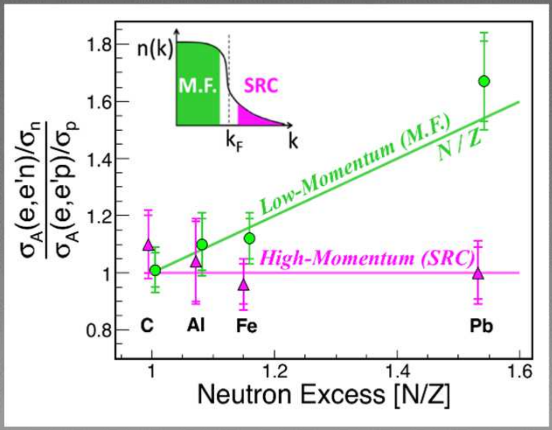
N>Z

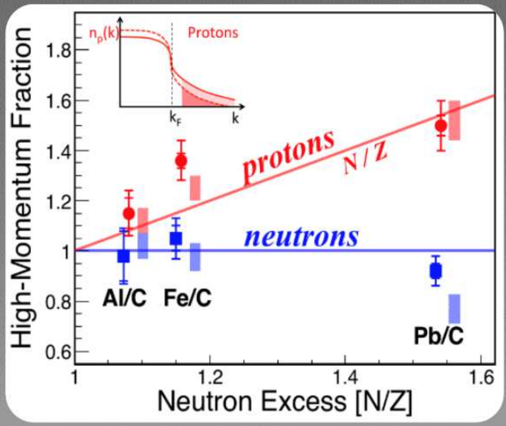


Boys have a greater probability than Girls to be above the Fermi sea.

The fraction of correlated girls/boys is grow/constant , as a function of the girls excess.

Summary of SRC results





Nature, 560 (2018) 617-621.

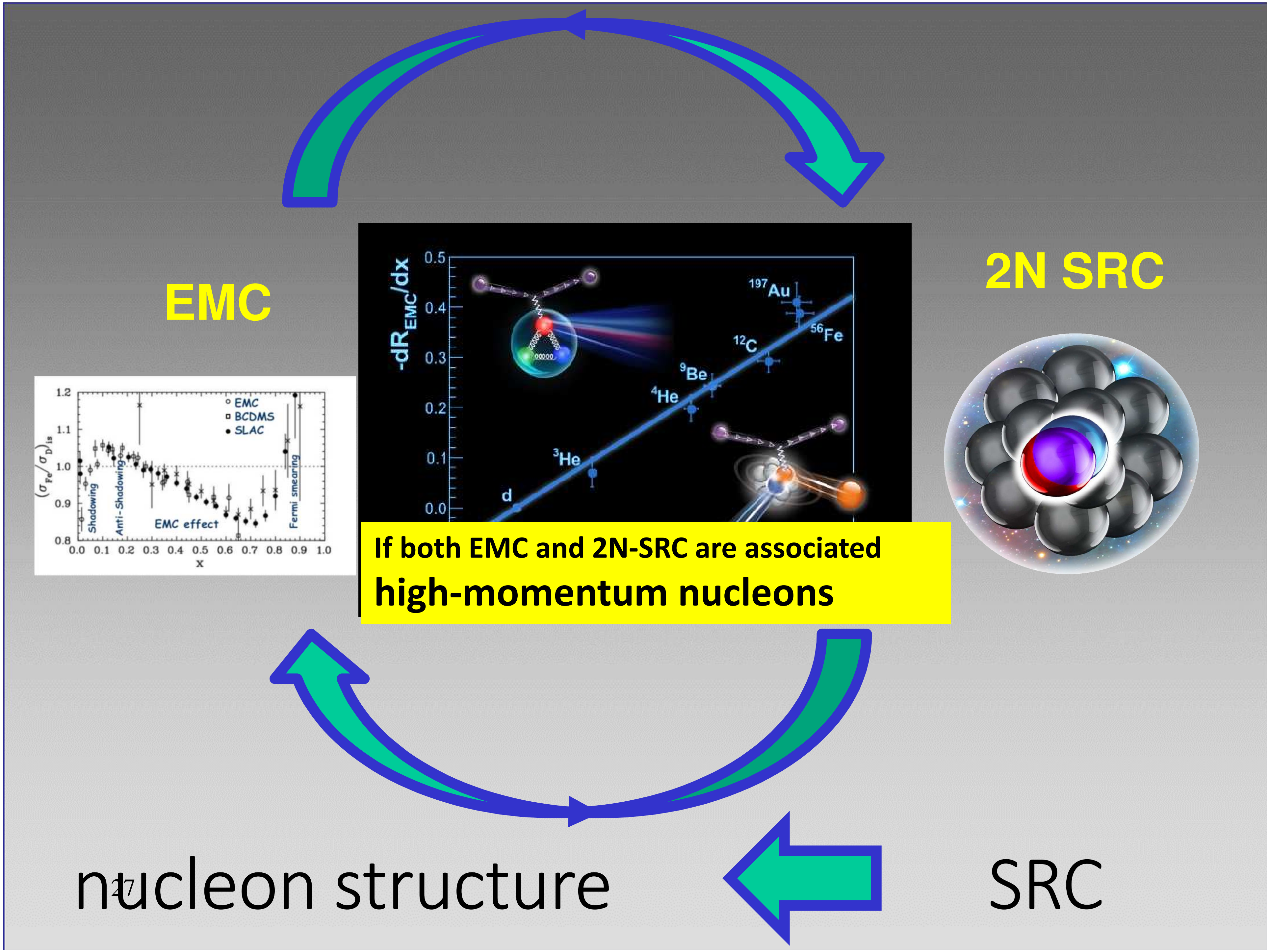
For nuclei with N>Z

In the high momentum tail, #protons = #neutrons, irrespectively of the neutron excess.

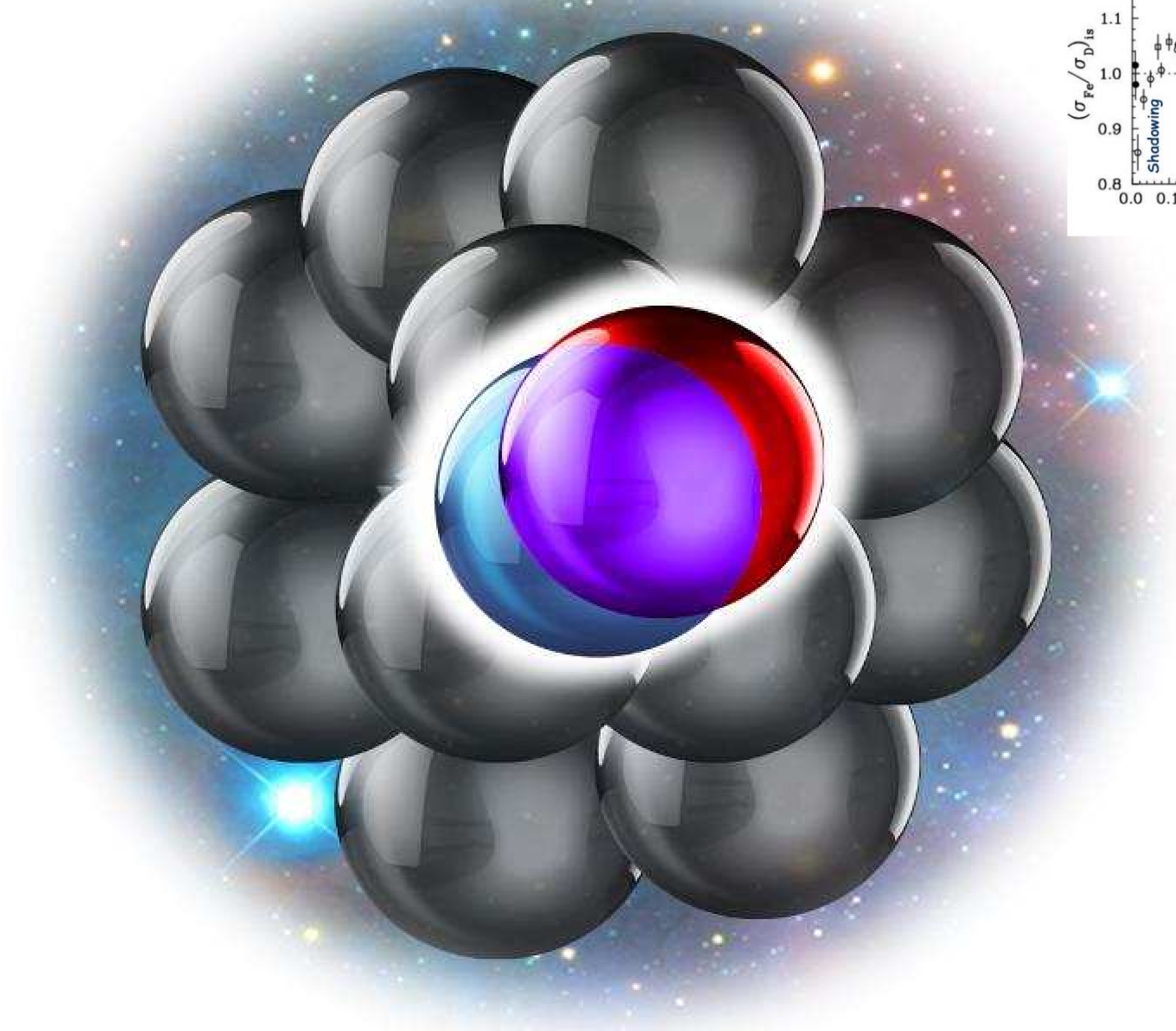
Protons have a greater probability than neutrons to be above the Fermi sea.

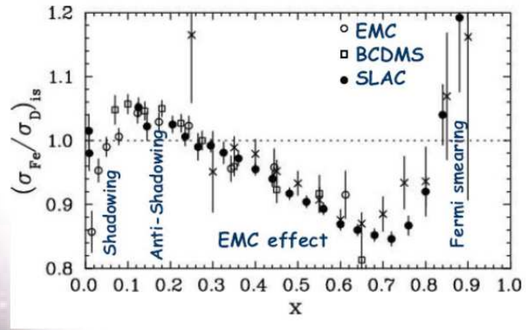
The fraction of correlated protons /neutrons is grow/constant , as a function of neutron excess.

Generalized Nuclear Contact Formalism Phys. Lett. B780 (2018) 211.


EMC
2N SRC
EMC
BCDMS
SLAC
Shadowing
Anti-Shadowing
EMC effect
Fermi smearing
$(\sigma_{Fe}/\sigma_D)_{is}$
x
$-dR_{EMC}/dx$
d
^{3}He
^{4}He
^{9}Be
^{12}C
^{56}Fe
^{197}Au
If both EMC and 2N-SRC are associated
high-momentum nucleons
nucleon structure
SRC

Prediction for the EMC effect





EMC: small number of strongly modified nucleons.

Prediction for the EMC effect

SRC universality →

Universal modification of the bound nucleon structure function (same for all nuclei).

Universal function (data from all nuclei) can be used to extract F_2^n

SRC np-dominance →

For nuclei with N>Z

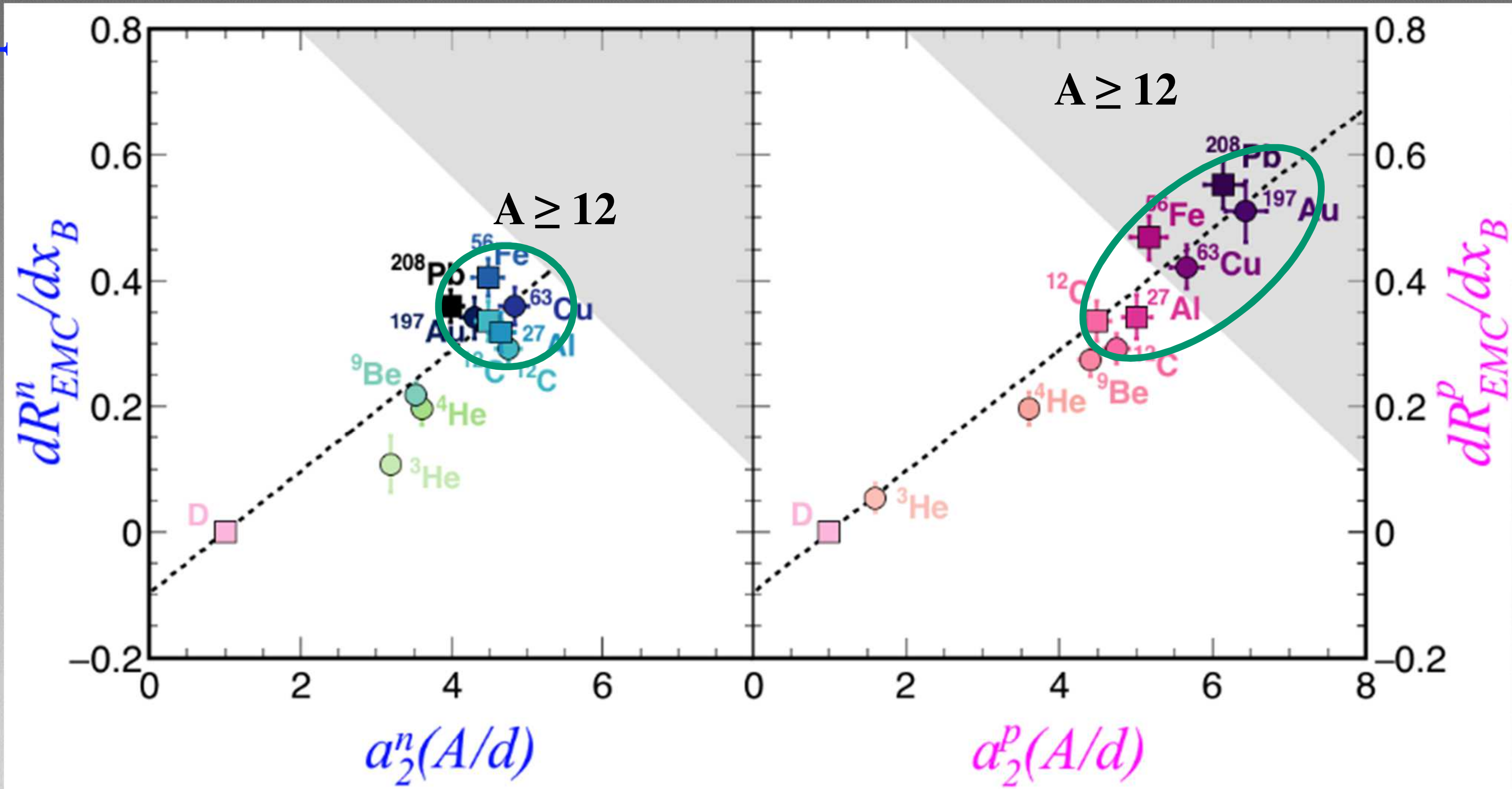
More protons larger EMC effect.

More Neutrons Saturation.

Neutrons Saturate, Protons Grow

DIS slop/N

DIS slop/Z



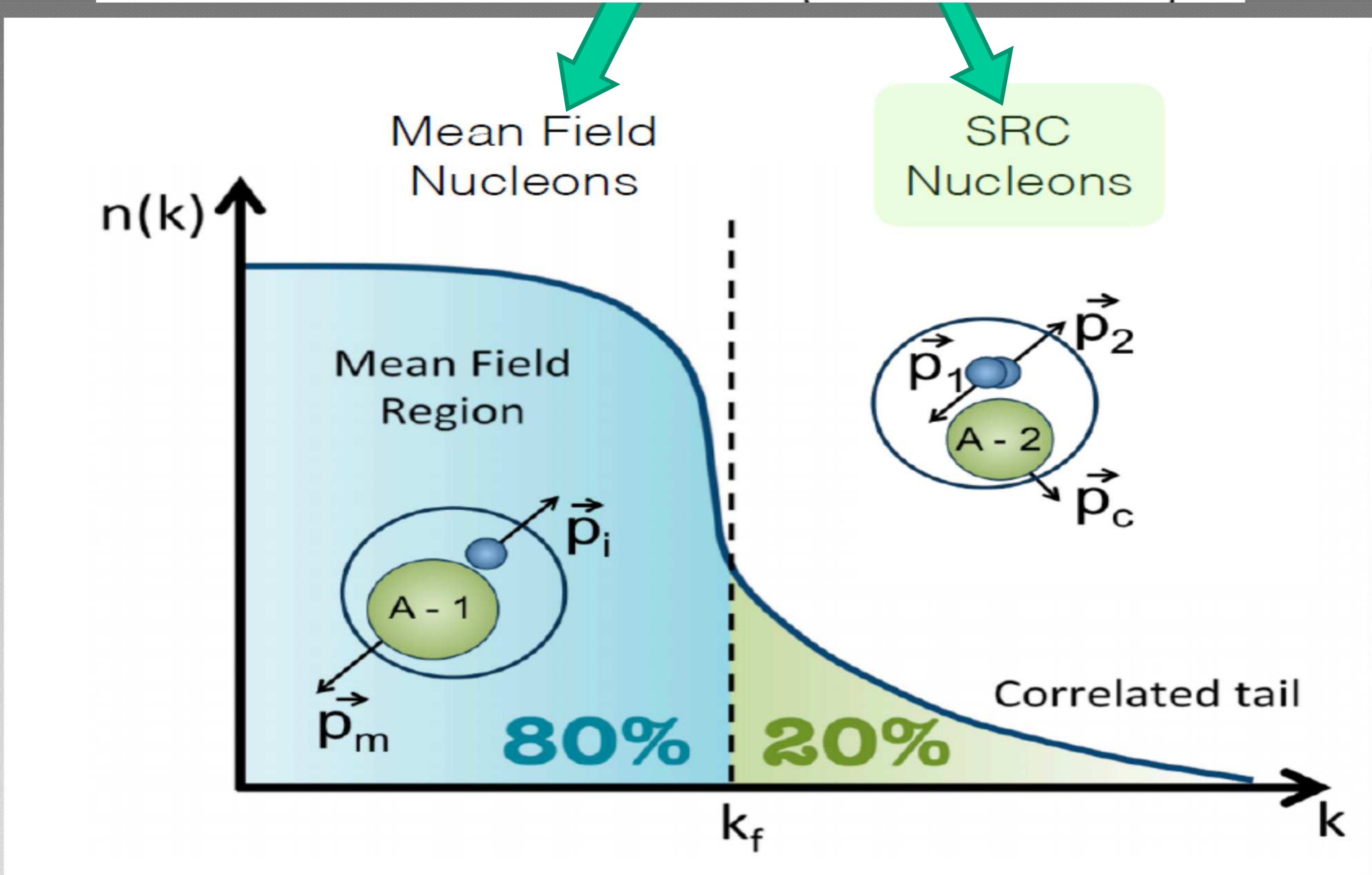
$$a_2^n = \frac{(\sigma_A / N)}{\sigma_d}$$

$$a_2^p = \frac{(\sigma_A / Z)}{\sigma_d}$$

Schmookler, Duer, and Schmidt et al., Nature 566 (2018) 354-358

Nucleus -independent

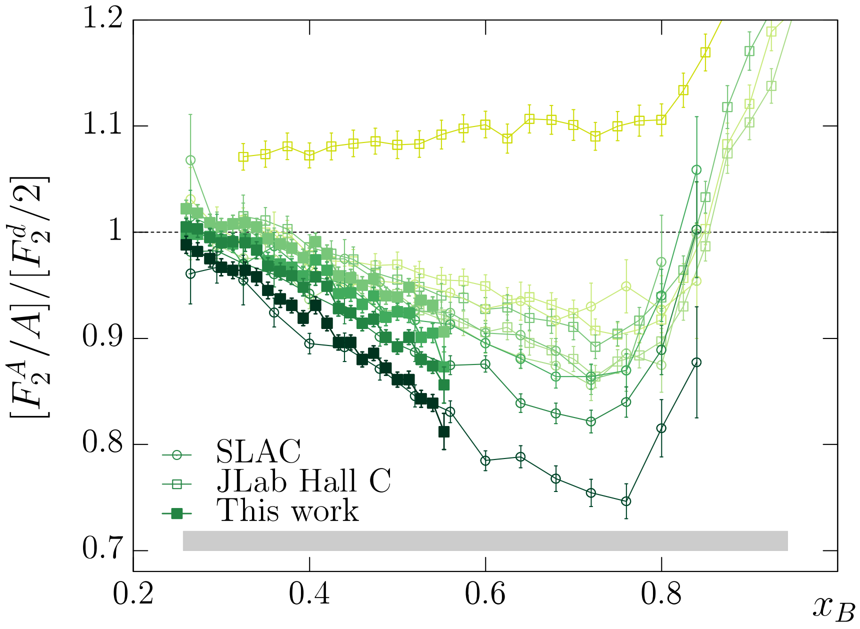
$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A \left(\Delta F_2^p + \Delta F_2^n \right)$$

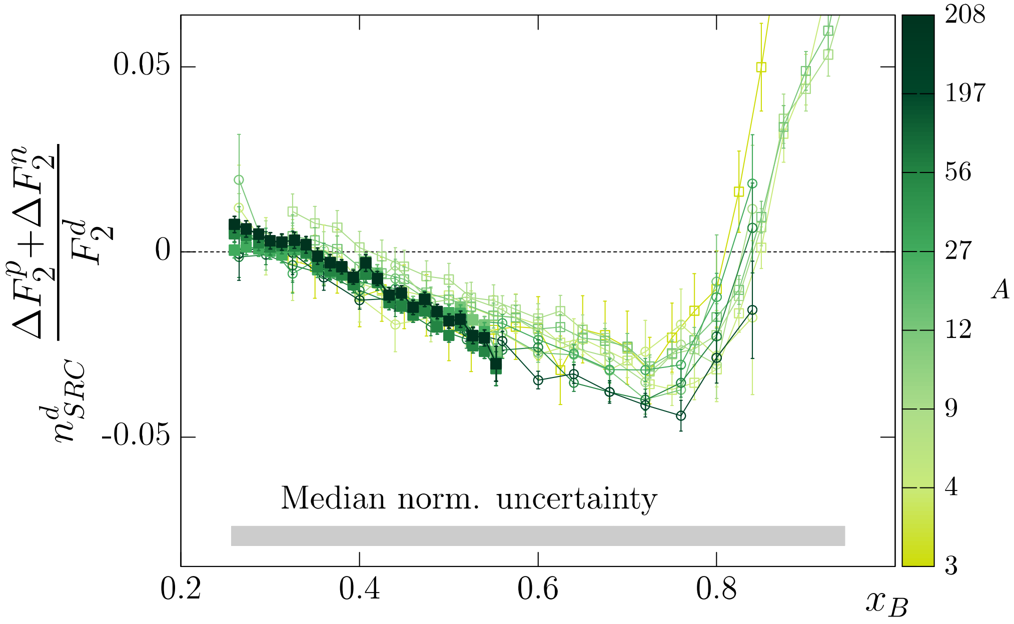


$$\frac{F_2^A}{F_2^d} = \left(n_{SRC}^A - N n_{SRC}^d\right)\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} + (Z - N)\frac{F_2^p}{F_2^d} + N$$

A Dependent **Universal!** **A Dependent**

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





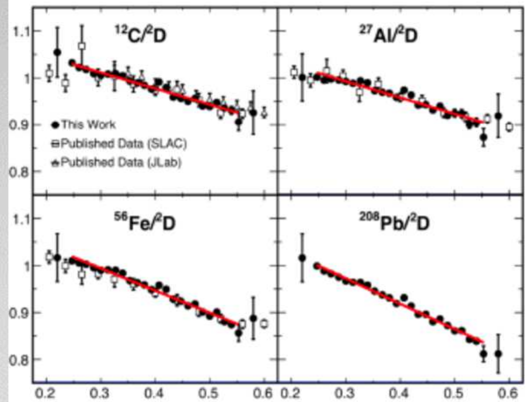
Schmookler, Duer, and Schmidt et al., Nature 566 (2018) 354-358

Extract universal modification using Bayesian inference via Hamiltonian Markov Chain Monte Carlo

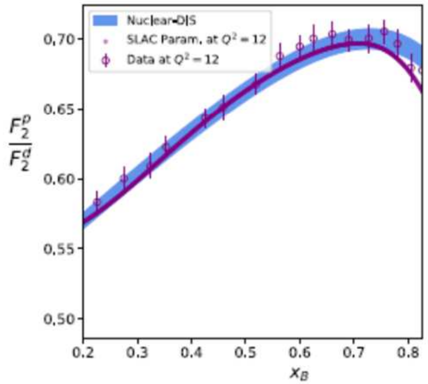
$$\frac{F_2^A}{F_2^d} = (Z-N)\frac{F_2^p}{F_2^d} + N + \left(\frac{n_{SRC}^A}{n_{SRC}^d} - N\right)\frac{n_{SRC}^d}{F_2^d}\left(\Delta F_2^p + \Delta F_2^n\right)$$

Universal modification function

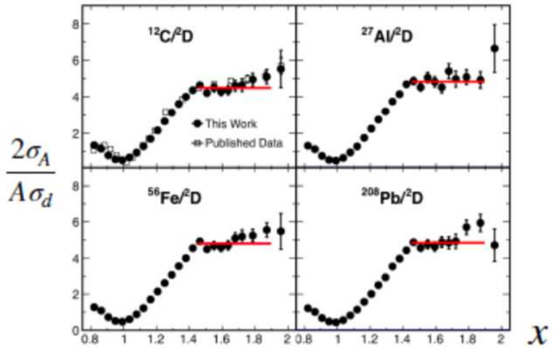
EMC-DIS Data



F_2^p/F_2^d Data



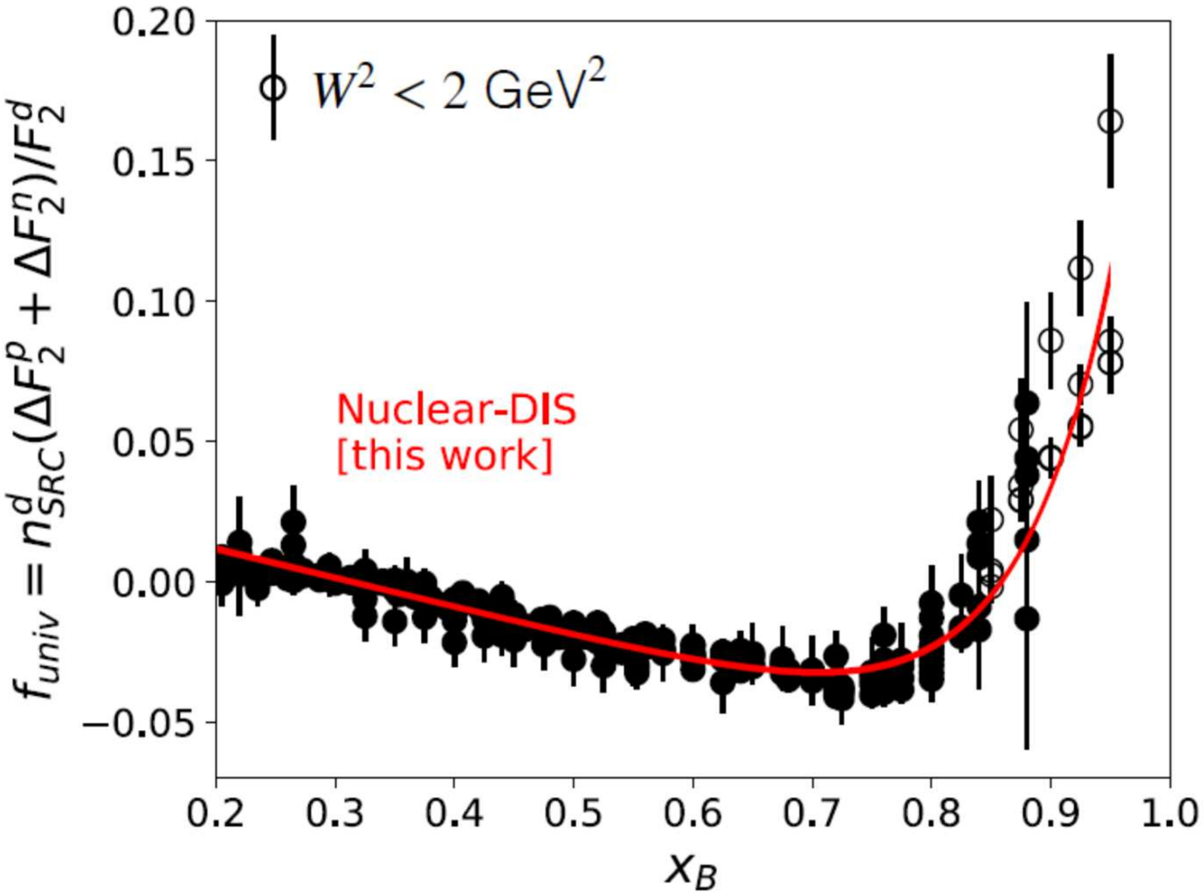
a_2 Pair Abundances



Nature 566 (2018) 354-358

Nature 566 (2018) 354-358

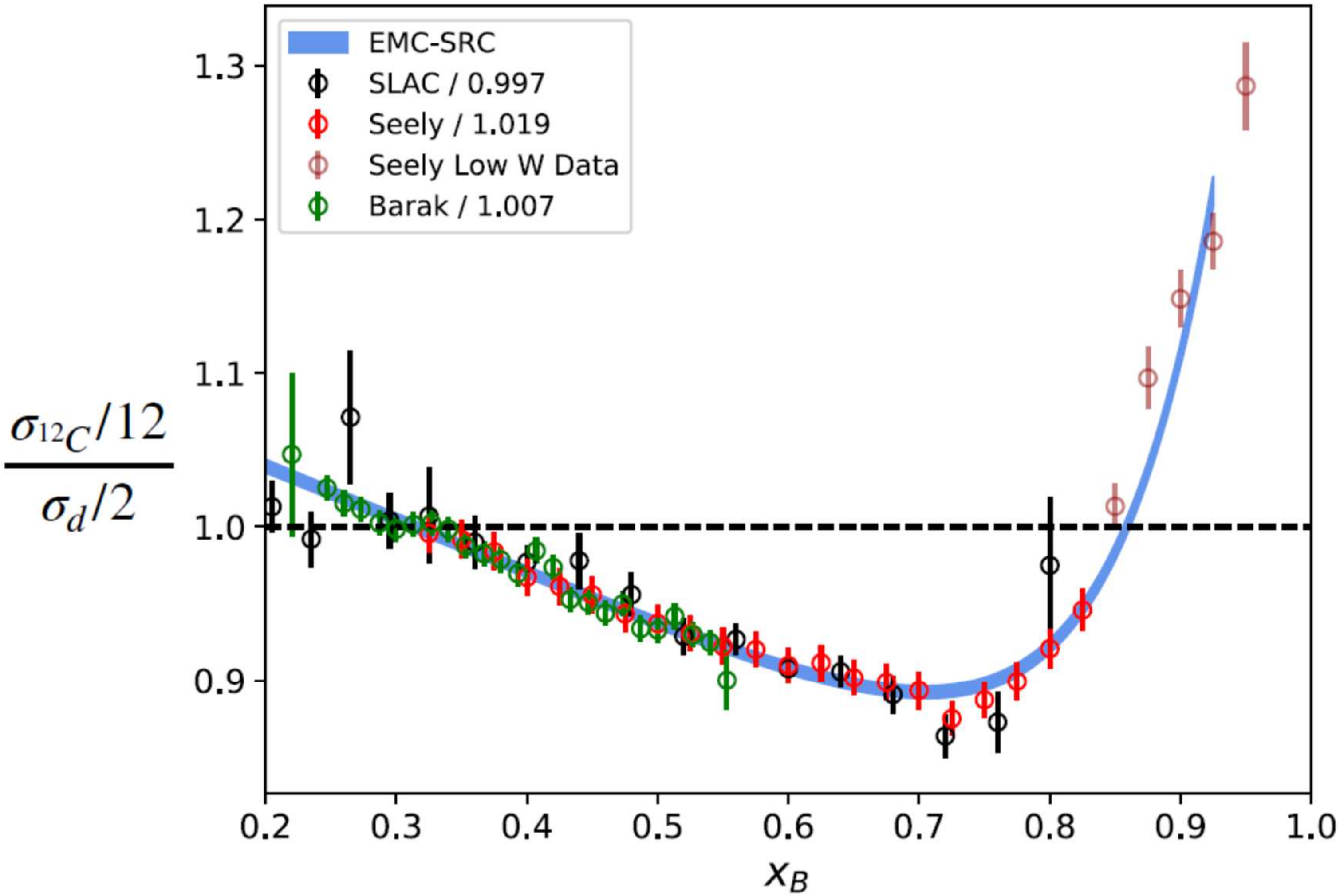
Universal modification function of nuclei



(All 31 model parameters simultaneously extracted from joint posterior)

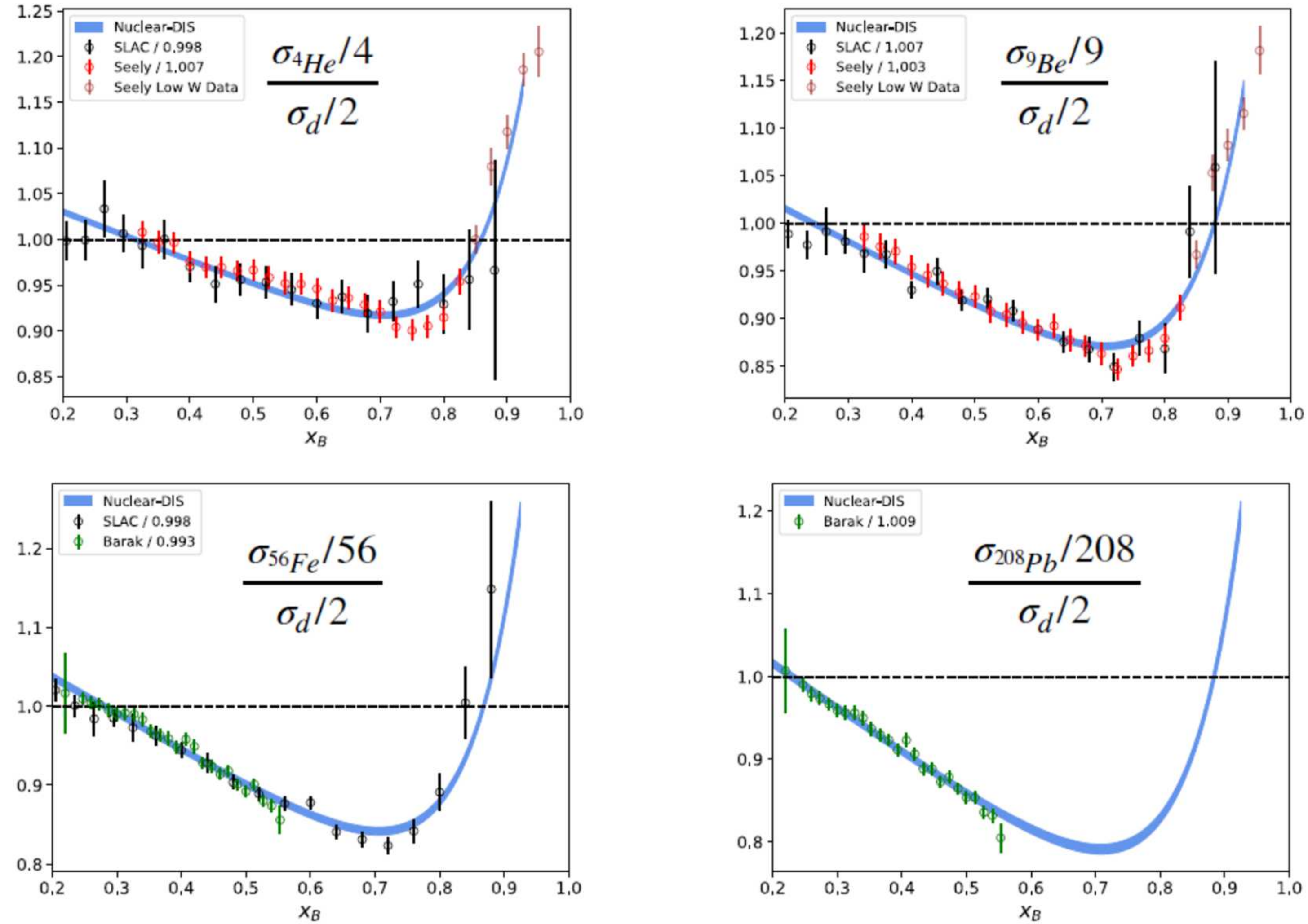
Segarra et al., Phys. Rev. Lett. (2020);
Segarra and Pybus et al., Phys. Rev. Research (2021)

Reproduce the data remarkably well



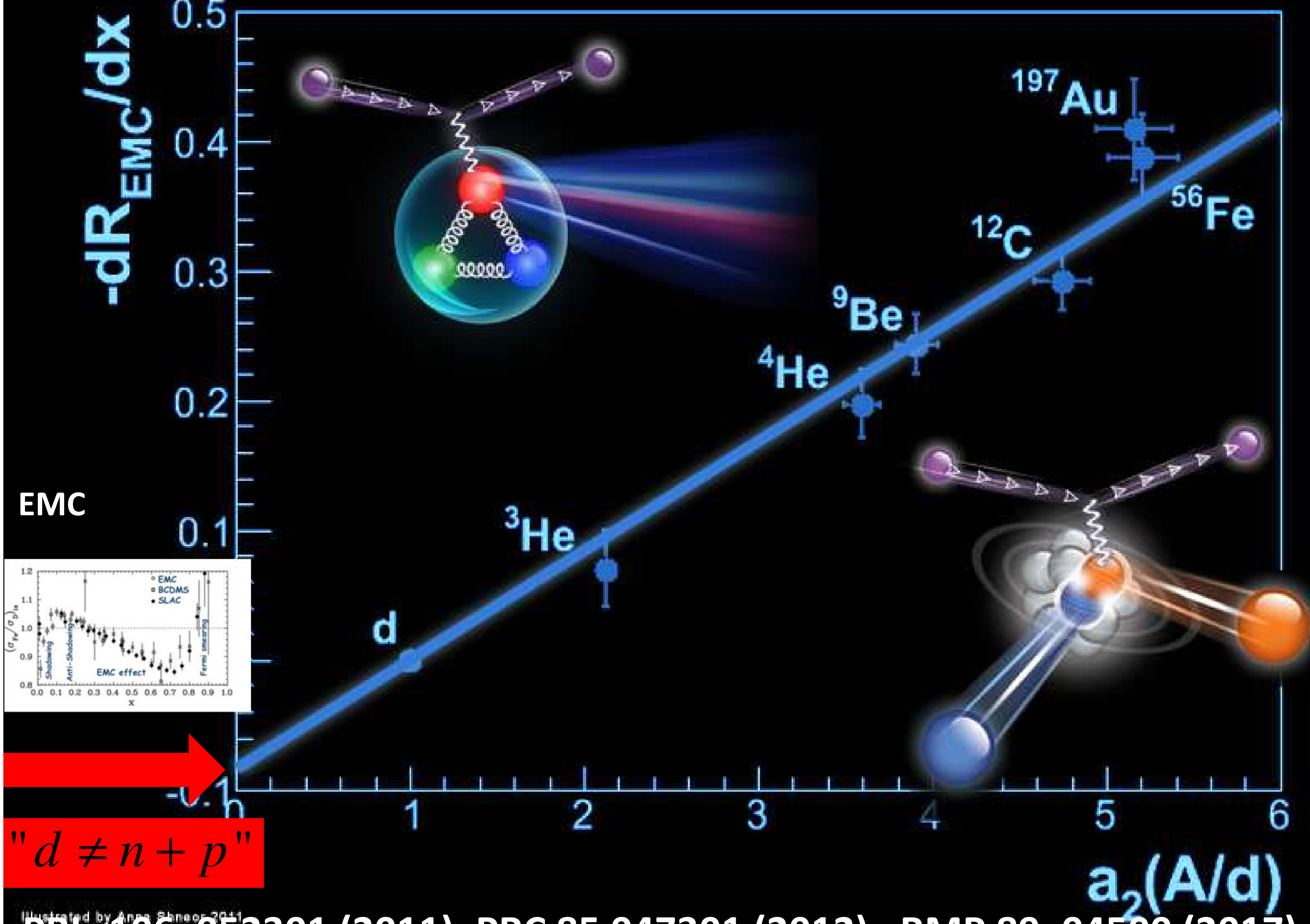
Segarra et al., Phys. Rev. Lett. (2020);
Segarra and Pybus et al., Phys. Rev. Research (2021)

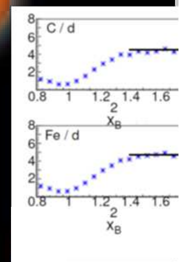
Reproduce the data remarkably well



Segarra et al., Phys. Rev. Lett. (2020);
Segarra and Pybus et al., Phys. Rev. Research (2021)

EMC





$"d \neq n + p"$

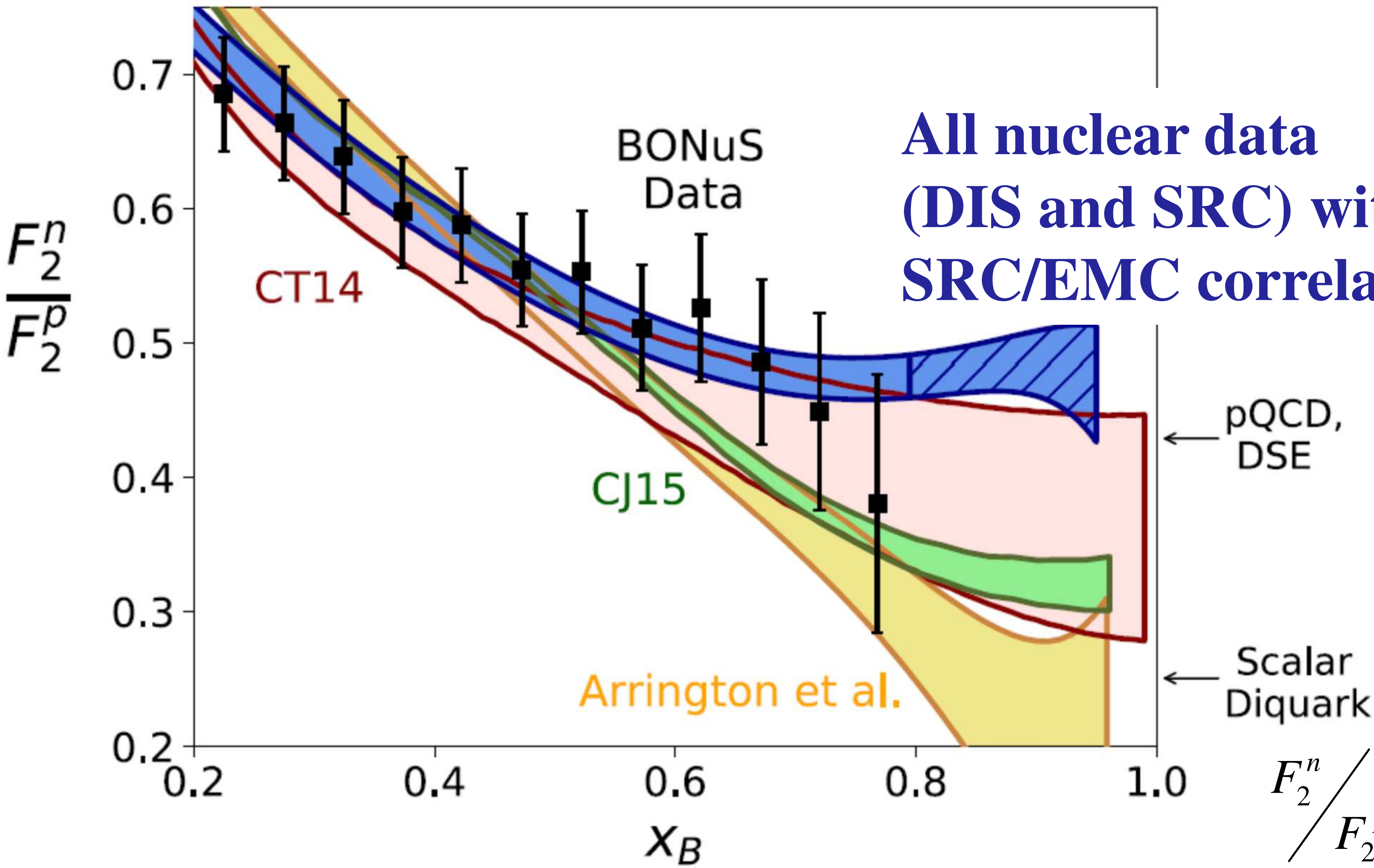
SRC

Illustrated by Anna Shneor 2011

PRL 106, 052301 (2011), PRC 85 047301 (2012), RMP 89, 04500 (2017)

ATON
diction

$$\frac{F_2^n}{F_2^p} = \frac{1 - f_{univ}}{F_2^p / F_2^d} - 1$$

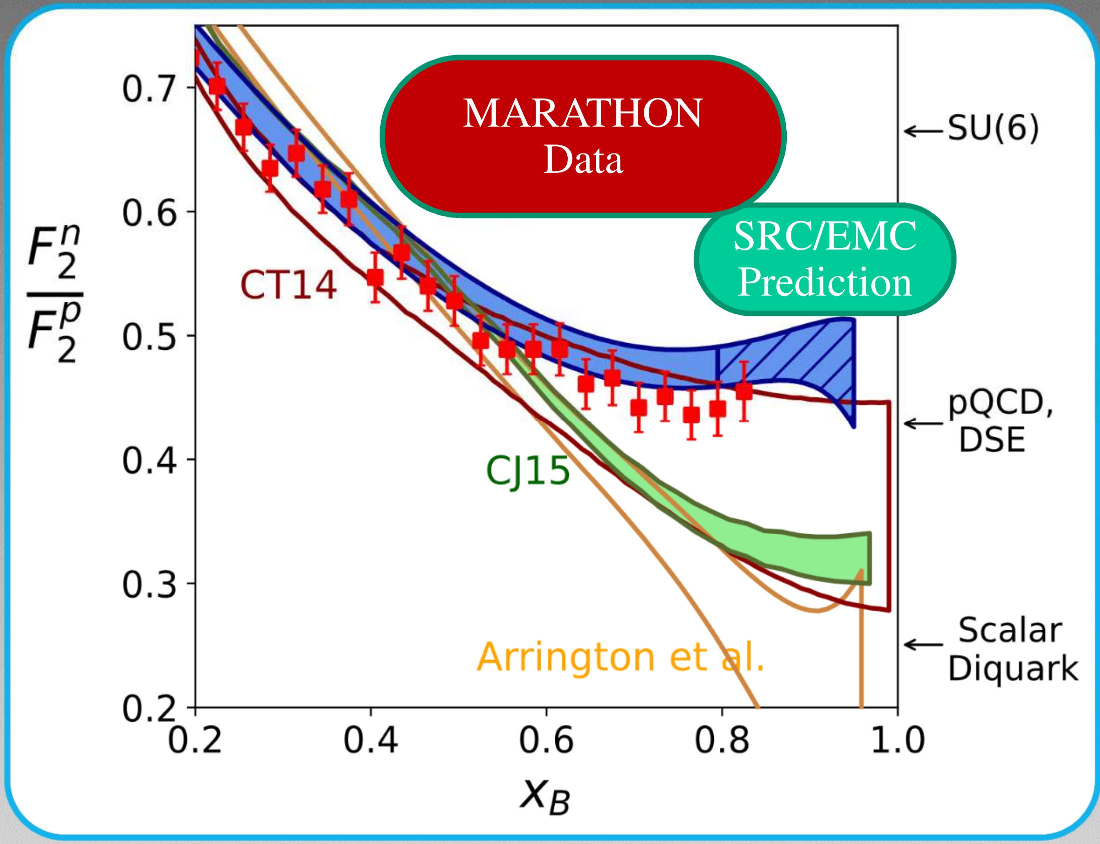


All nuclear data (DIS and SRC) with SRC/EMC correlations

$F_2^n / F_2^p = 1/4$

Segarra et al., Phys. Rev. Lett. (2020)

Verified Predictions!

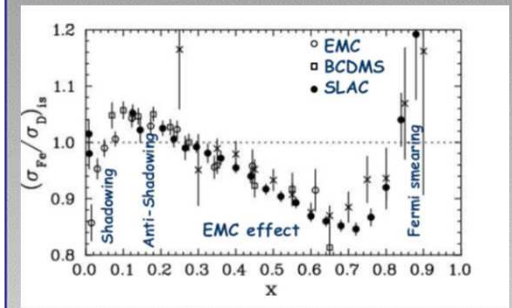


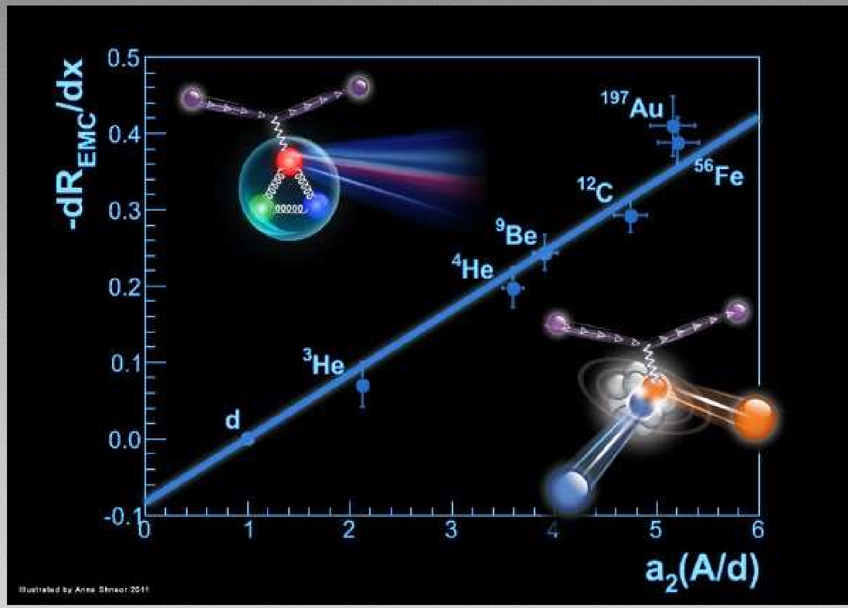
MARATHON Data: Abrams et al., Phys. Rev. Lett. (2022)

SRC/EMC Prediction: Segarra et al., Phys. Rev. Lett. (2020)

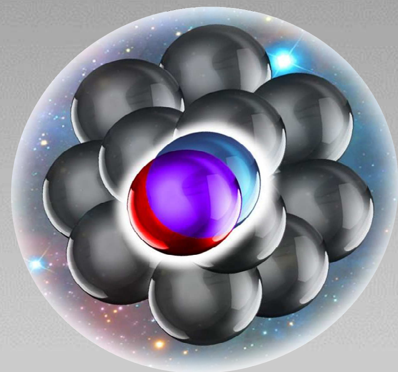
nucleon structure (nPDF) SRC

EMC





2N SRC



Extracting nPDFs

$$F_2^A \neq Z \cdot F_2^p + N \cdot F_2^n$$

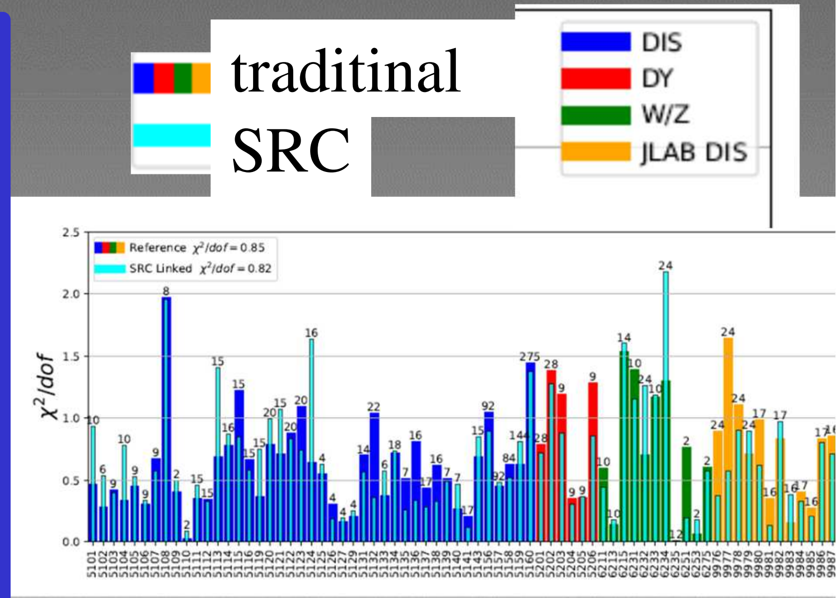
Data

DIS
DY
W Z production

Traditional nCTEQ

All nucleons modified

nucleus (A) dependent parameters



Equal quality global fits

SRC inspire nCTEQ

Only pairs are universally modified

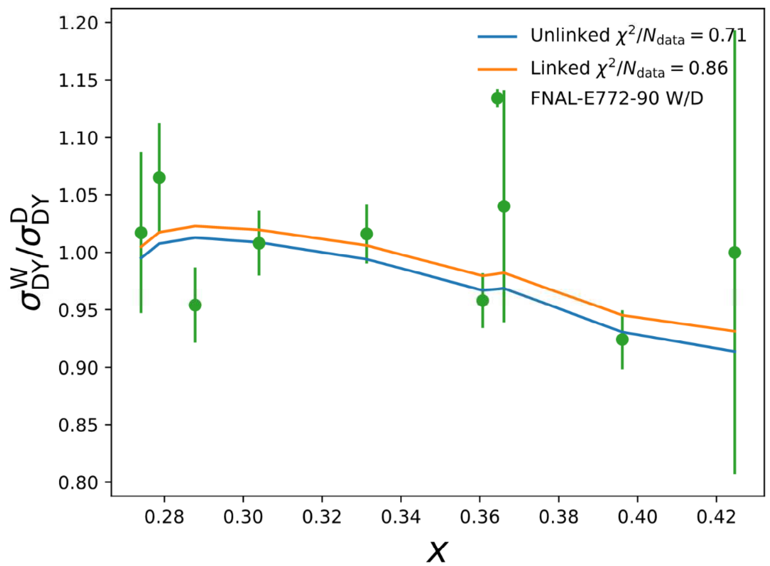
Fit well non DIS data

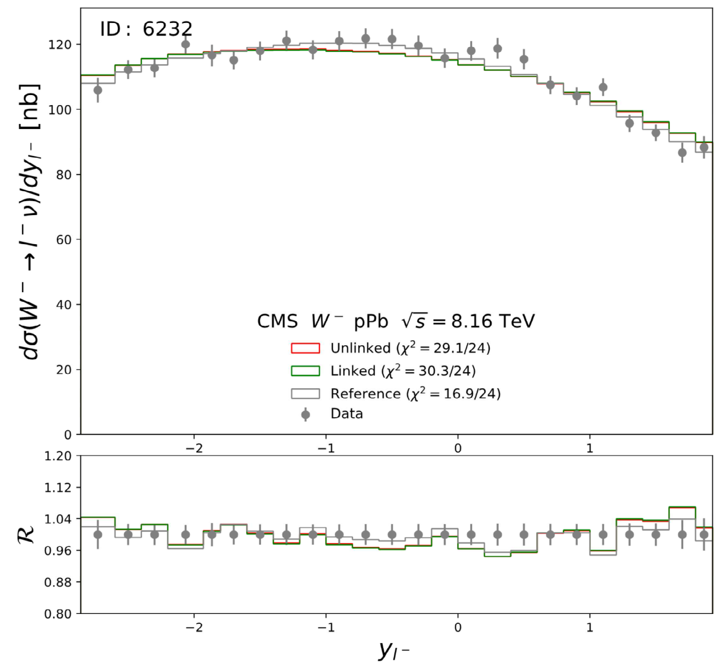
Fit well large and low XB beyond the EMC range

A. Kusina talk, DIS202

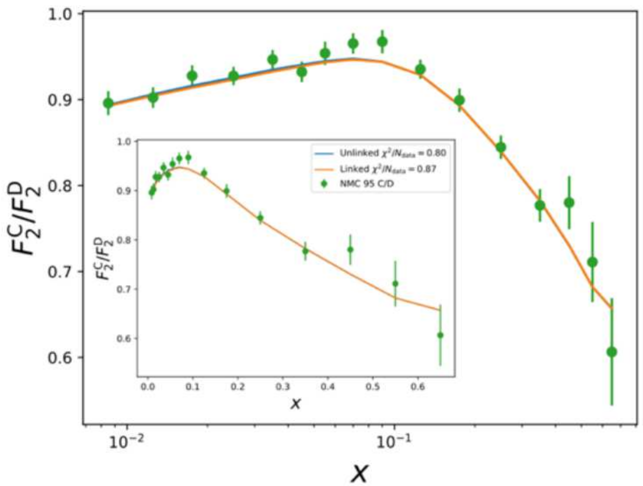
Can go beyond EMC data?

Nuclear Drell-Yan Data





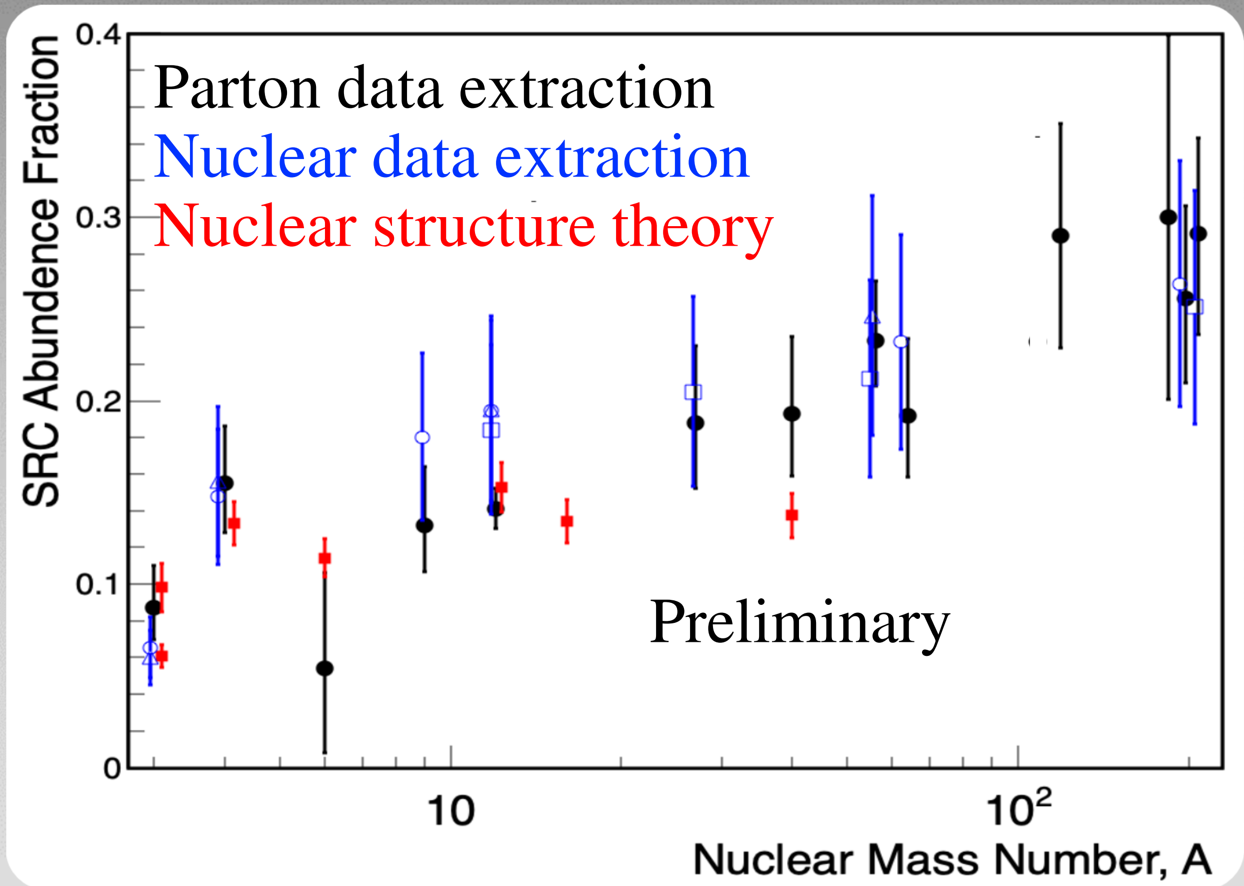
LHC p+Pb W production



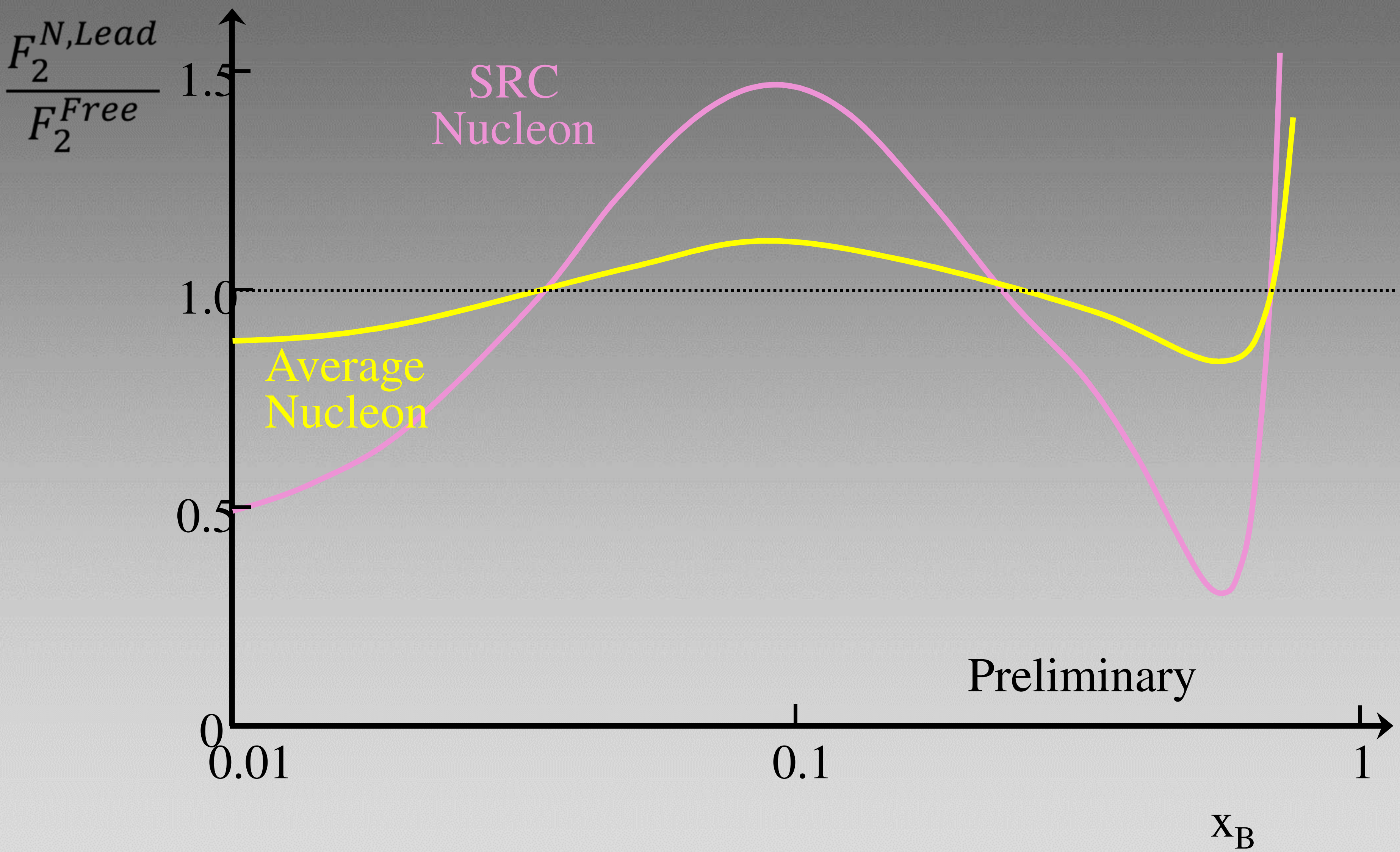
Nuclear DIS
(EMC + Shadowing)

Predict: np dominance and SRC Abundances

 # modified p = # modified n



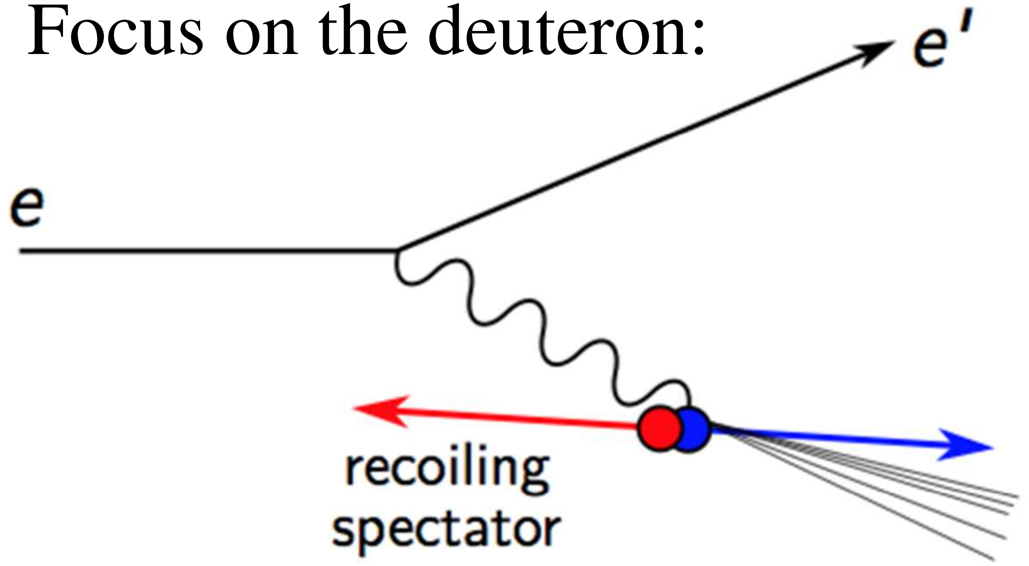
Predict large modification in SRC pairs



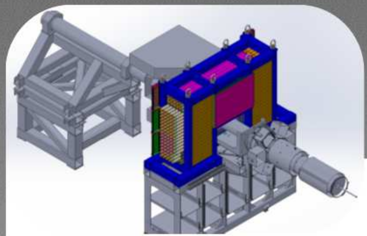
Is the EMC effect associated with large momentum nucleons ?

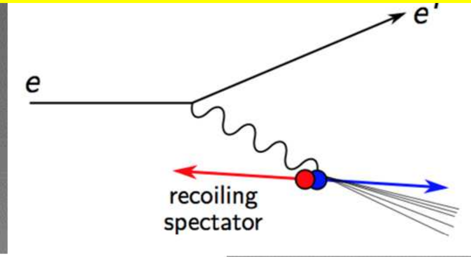
Hypothesis can be verified by measuring DIS off Deuteron tagged with high momentum recoil nucleon

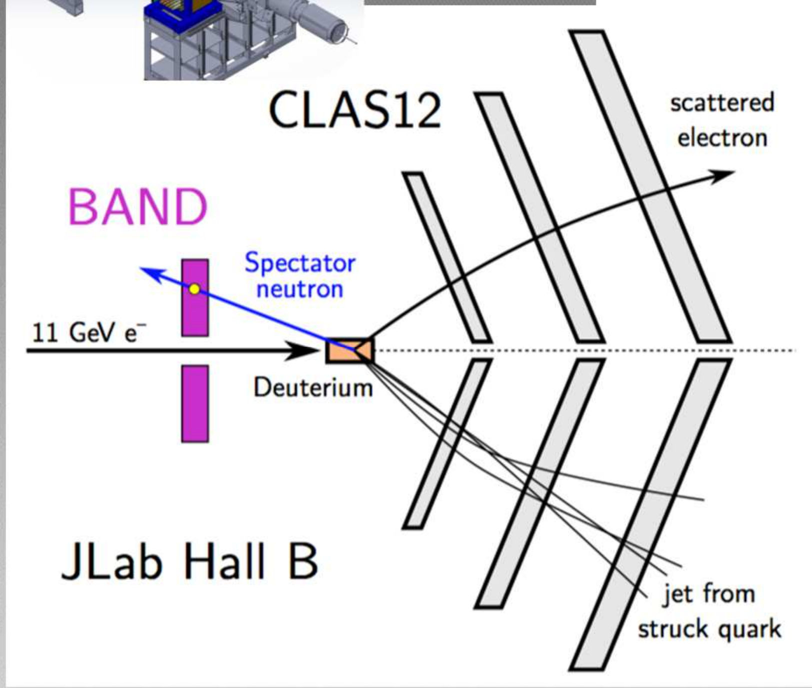
Focus on the deuteron:

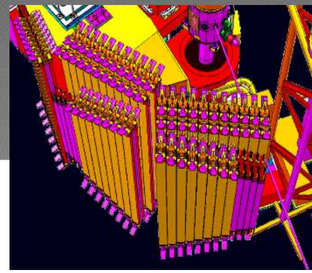


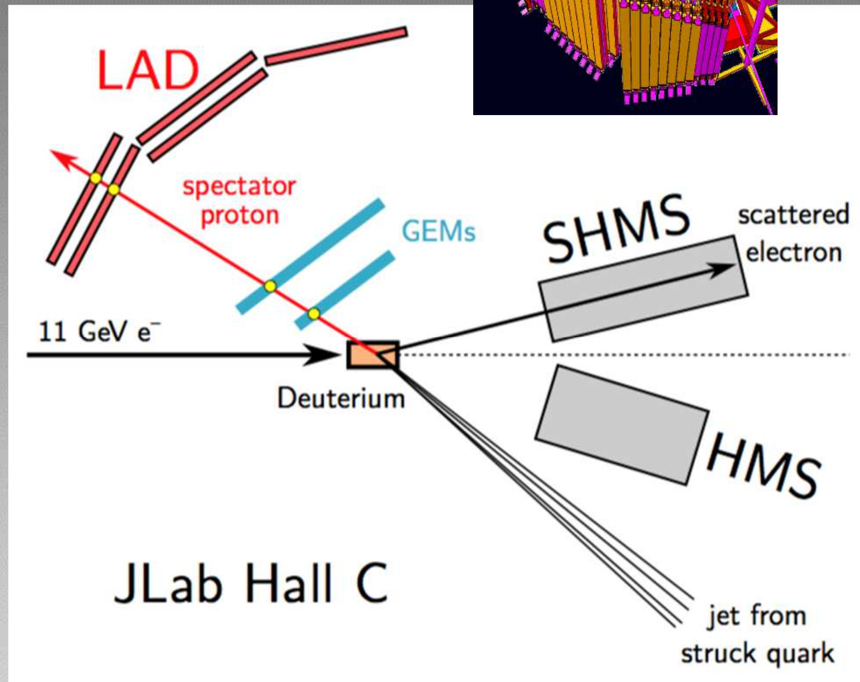
Is the EMC effect associated with large momentum nucleons ?



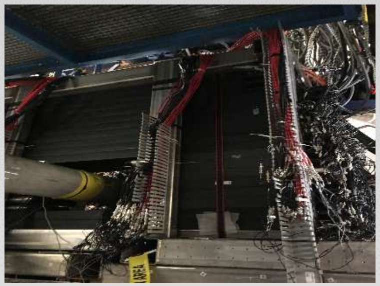








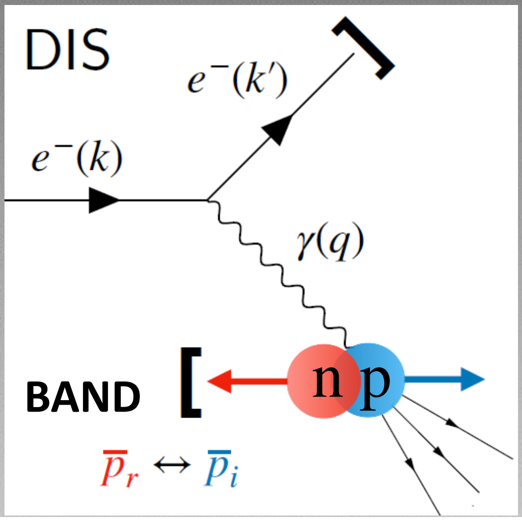
12 GeV JLab/ Hall B took data in 2019 **E 12-11-107**



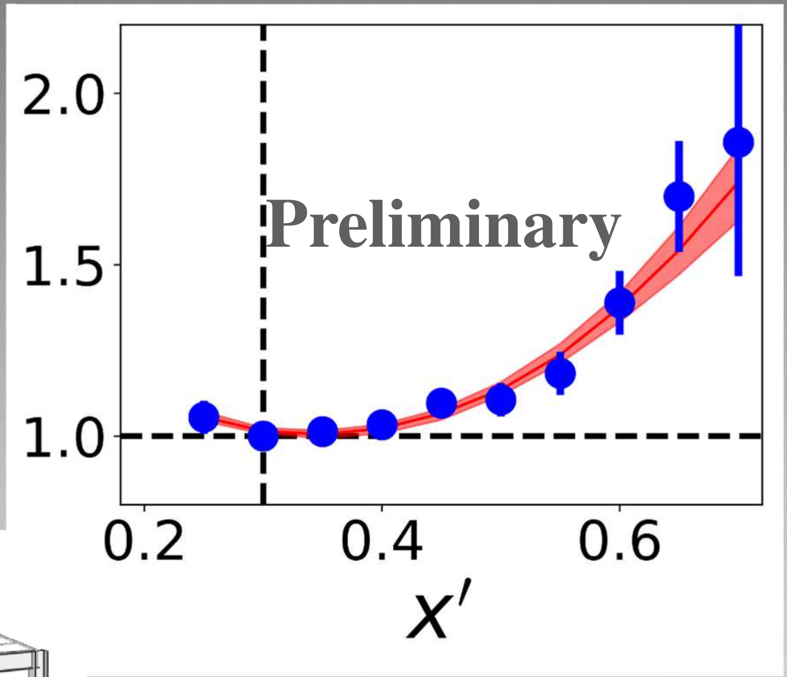
12 GeV JLab/ Hall C approved experiment **E12-11-003a**

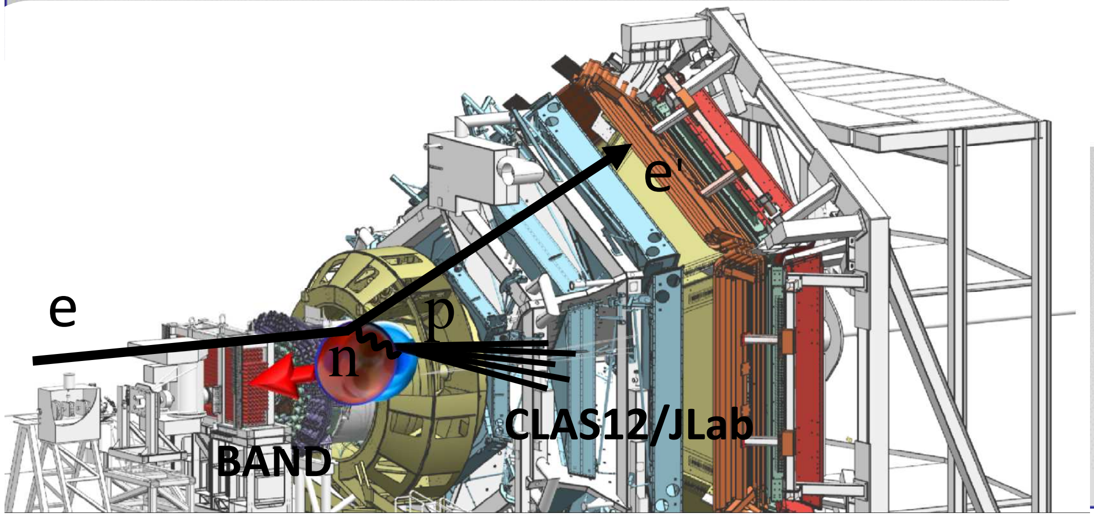
Neutron tagged DIS on ^2H

BAND experiment at CLAS12/JLab:



$1.3 < \alpha_s < 1.4$
(~ large missing momentum)





large modification of deeply bound proton

Summary

In nuclei the momentum distribution of nucleons can be divided into two distinct regions

$k<k_F$

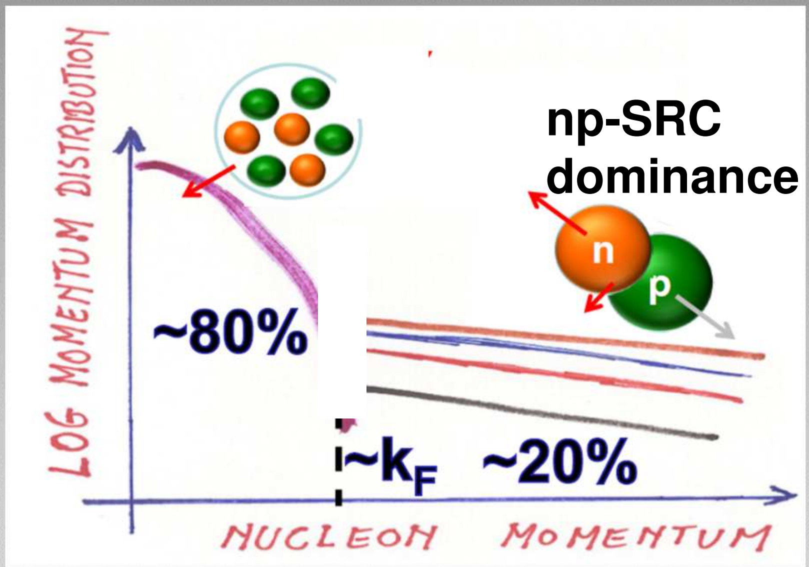
Mean field region

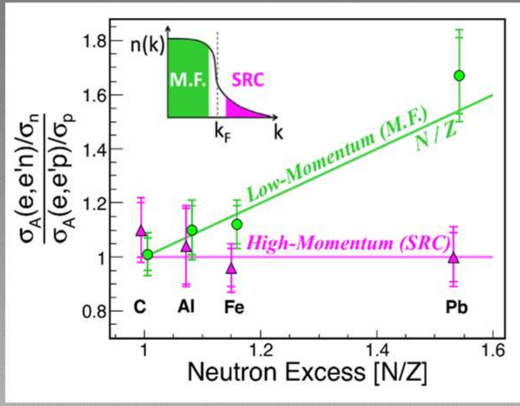
Single nucleons

$k>k_F$

Correlated / high momentum region

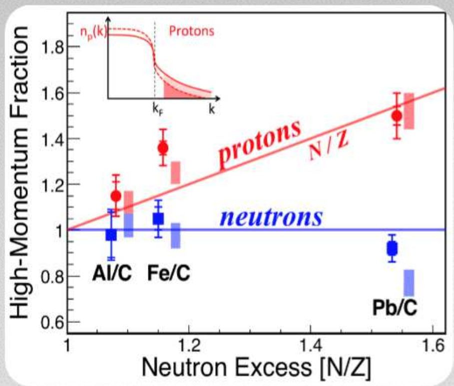
SRC pairs





#protons = #neutrons, irrespectively of the neutron excess.

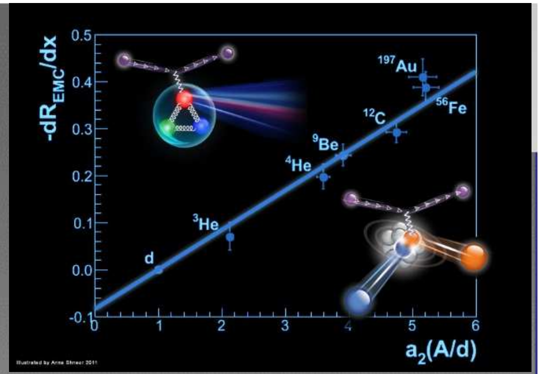
The fraction of correlated protons /neutrons is grow/constant , as a function of neutron excess.



Generalized Nuclear Contact Formalism

Summary

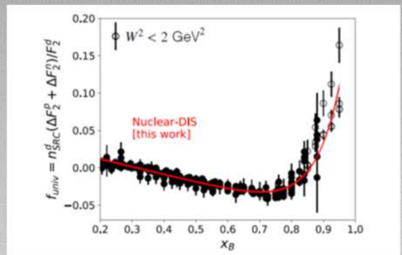
EMC is associate with 2N SRC:

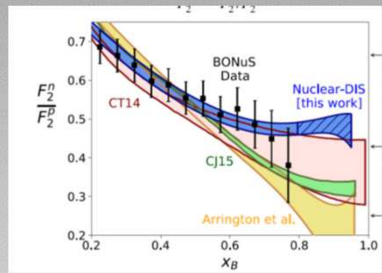


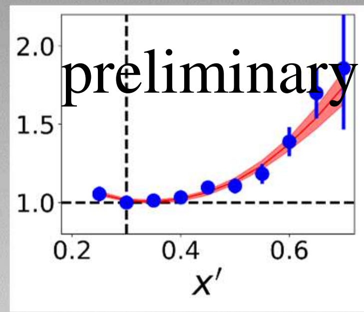
*** Nucleon is normally normal except when close to another nucleon.**

*** Small number of universal strongly modified nucleons.**

***Protons are more medium modified than neutron**

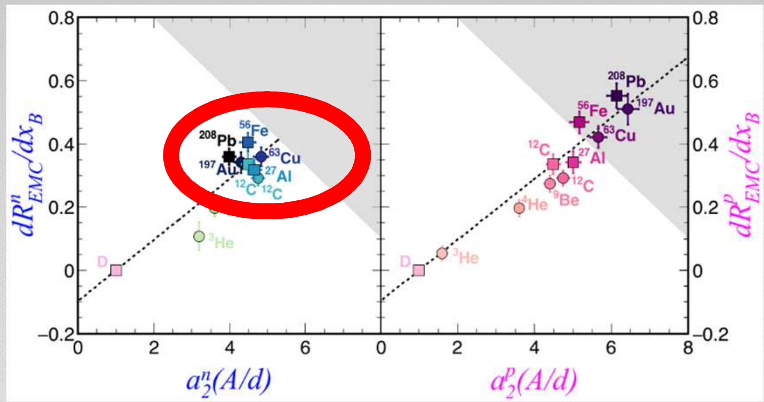


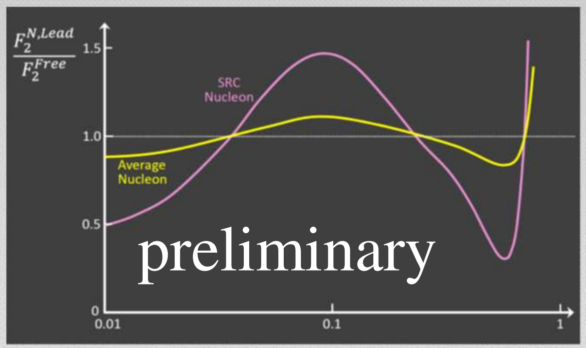




Universality

Strong modification

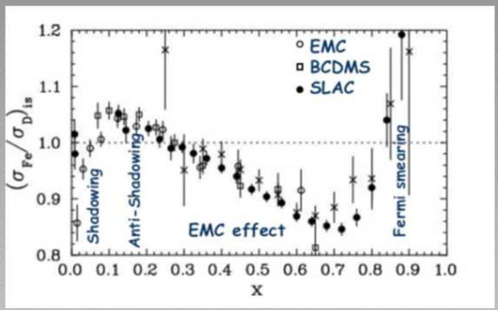


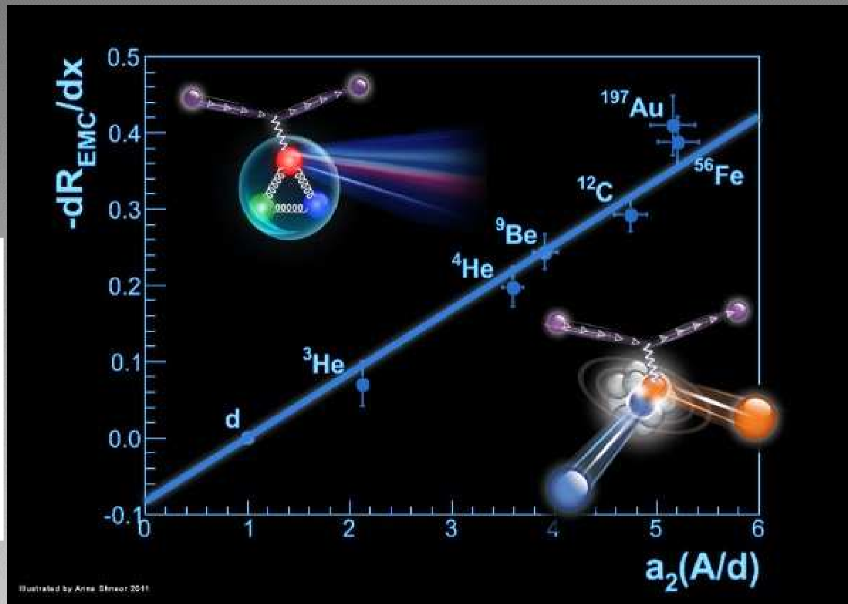


EMC effect is isospin dependent

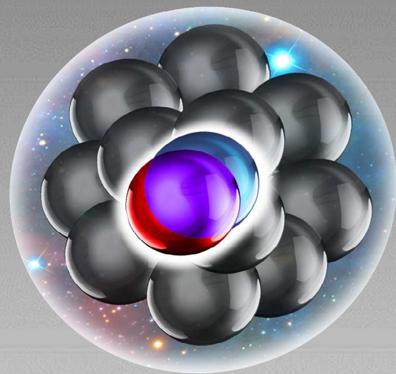

4th International Workshop on Quantitative Challenges in Short-Range Correlations and the EMC Effect Research
January 30, 2023 to February 3, 2023
CEA Paris-Saclay
Acknowledgment
TEL AVIV UNIVERSITY
Collaborators
Larry Weinstien
Shalev Gilad
Axel Schmidt
Meytal Duer
Barak Schmookler
Efrain Segarra
F. Hauenstein
Or Hen
Wim Cosyn
Jan Ryckebush
Tyler Kutz
Justin Estee
Ronen Weiss
Nir Barnea
Jerry Miller
Leonid Frankfurt
Mark Strikman
Misak Sargsian
Data-Mining collaboration
CLAS collaboration
Jefferson Lab

EMC

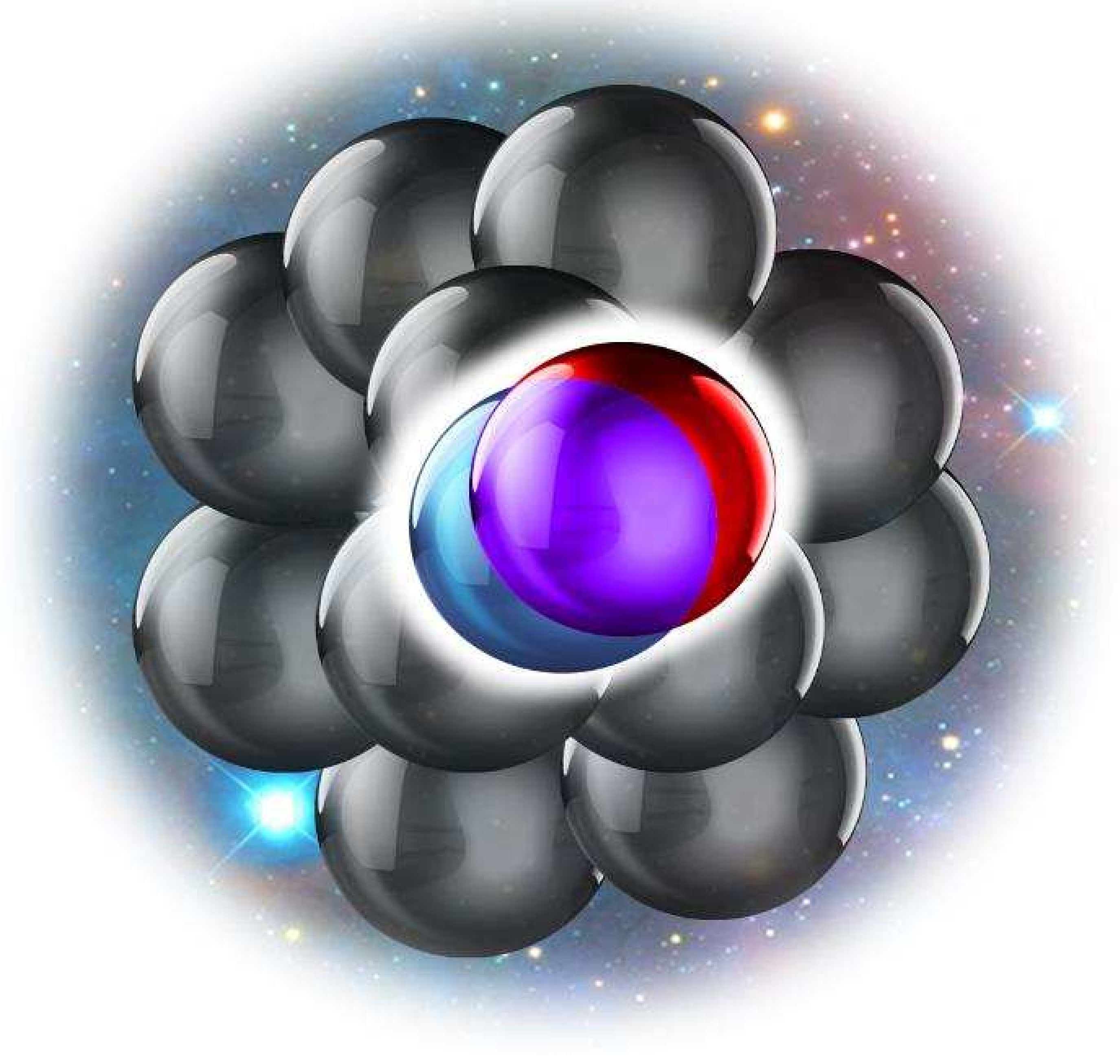

EMC
BCDMS
SLAC
Shadowing
Anti-Shadowing
EMC effect
Fermi smearing
$(\sigma_{Fe}/\sigma_D)_{is}$
x
1.2
1.1
1.0
0.9
0.8
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0


$-dR_{EMC}/dx$
$a_2(A/d)$
d
^{3}He
^{4}He
^{9}Be
^{12}C
^{56}Fe
^{197}Au
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0 1 2 3 4 5 6

2N SRC

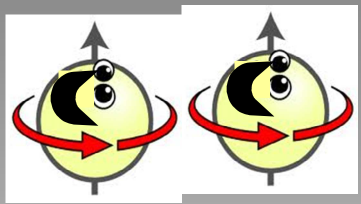


Short-Range Correlations (SRC)

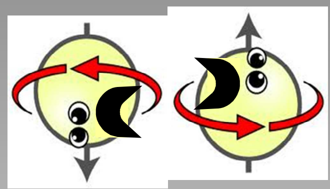


Nucleons has Isophobia (np – dominance)

The reason: tensor force

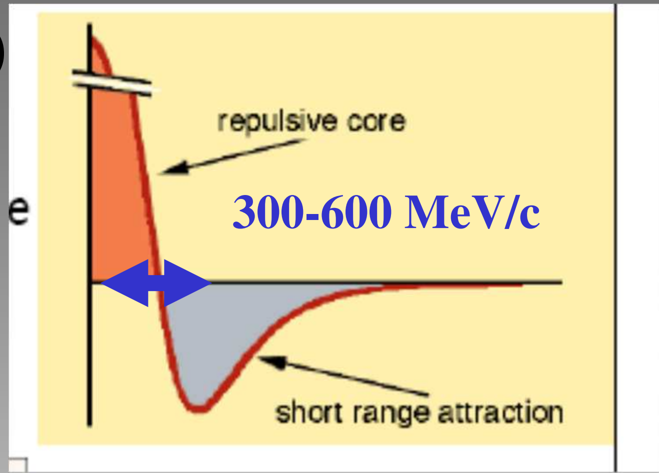


only np-SRC



pp- nn- np- SRC

$V_c(r)$



$$V_{NN}(r) = V_c(r) + V_T(r) S_{12}$$

$$S_{12} = 3(\sigma_1 \cdot \hat{r})(\sigma_2 \cdot \hat{r}) - \sigma_1 \sigma_2$$

The consequences:

Protons have a greater probability than neutrons to be above the Fermi sea.

For nuclei with N>Z

More Neutrons => More Correlated Protons

Piasetzky et al., PRL. 97 (2006) 162504.

R. Subedi et al., Science 320, 1476 (2008).

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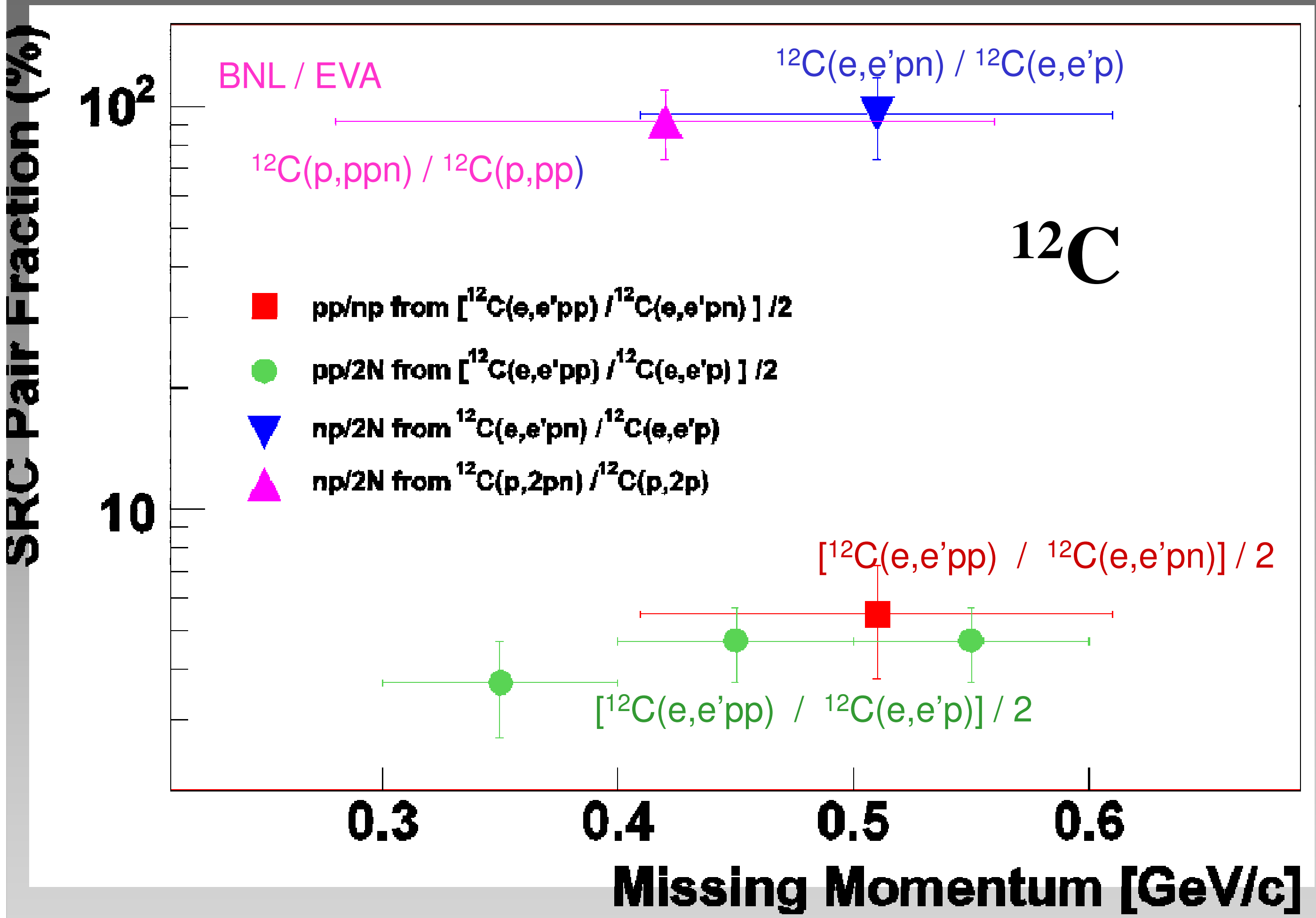
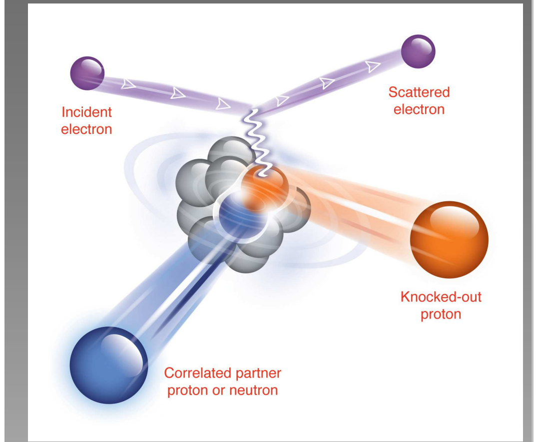


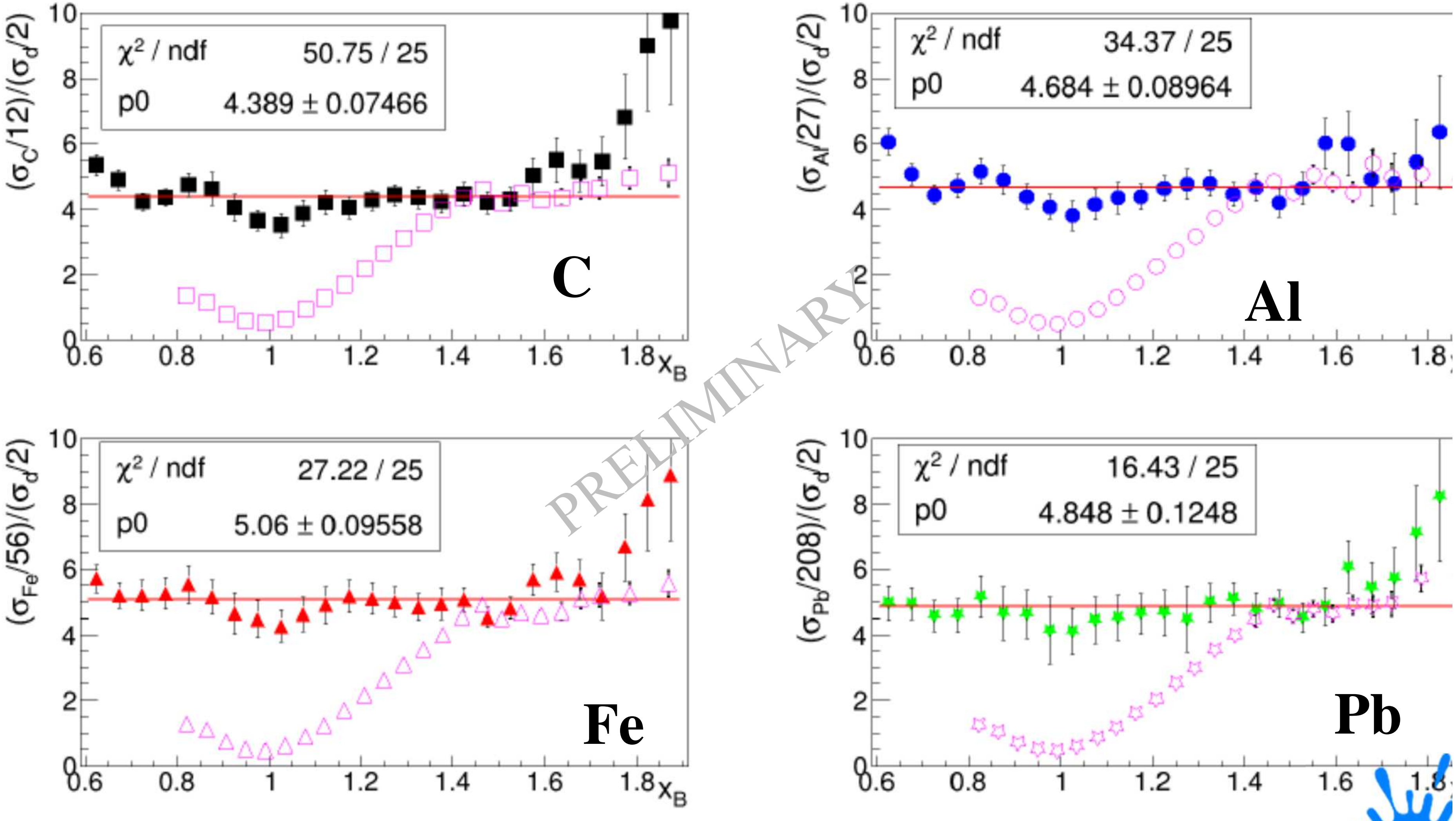


The high momentum tail in nuclei is dominated by SRC pairs

Most of the SRC pairs (90%) are np only 5% pp and 5% nn

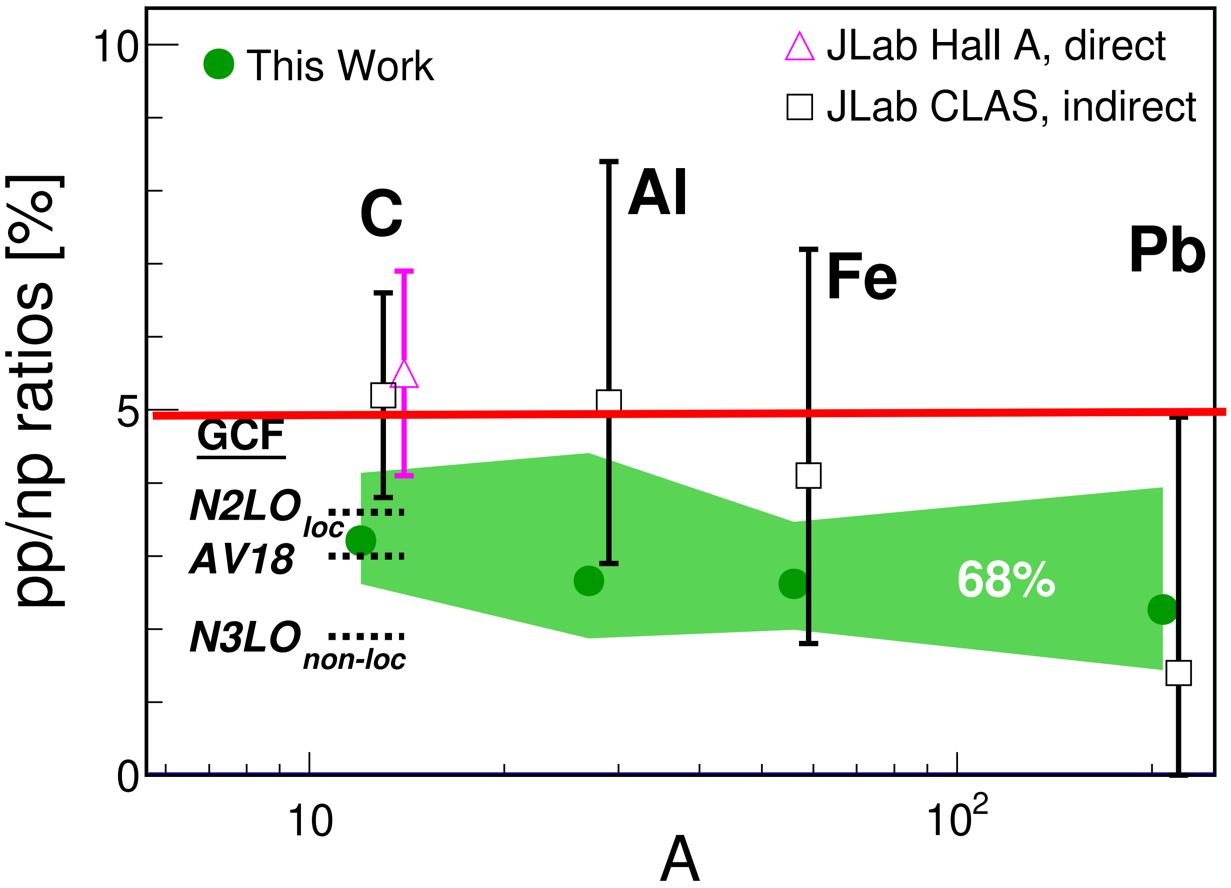
A(e, e' p)

$P_{miss}>k_F$ and MM cuts replace the $X_B>1$ cut



Korover et al. See talk by Andrew Denniston

SRCs Dominated by np pairs

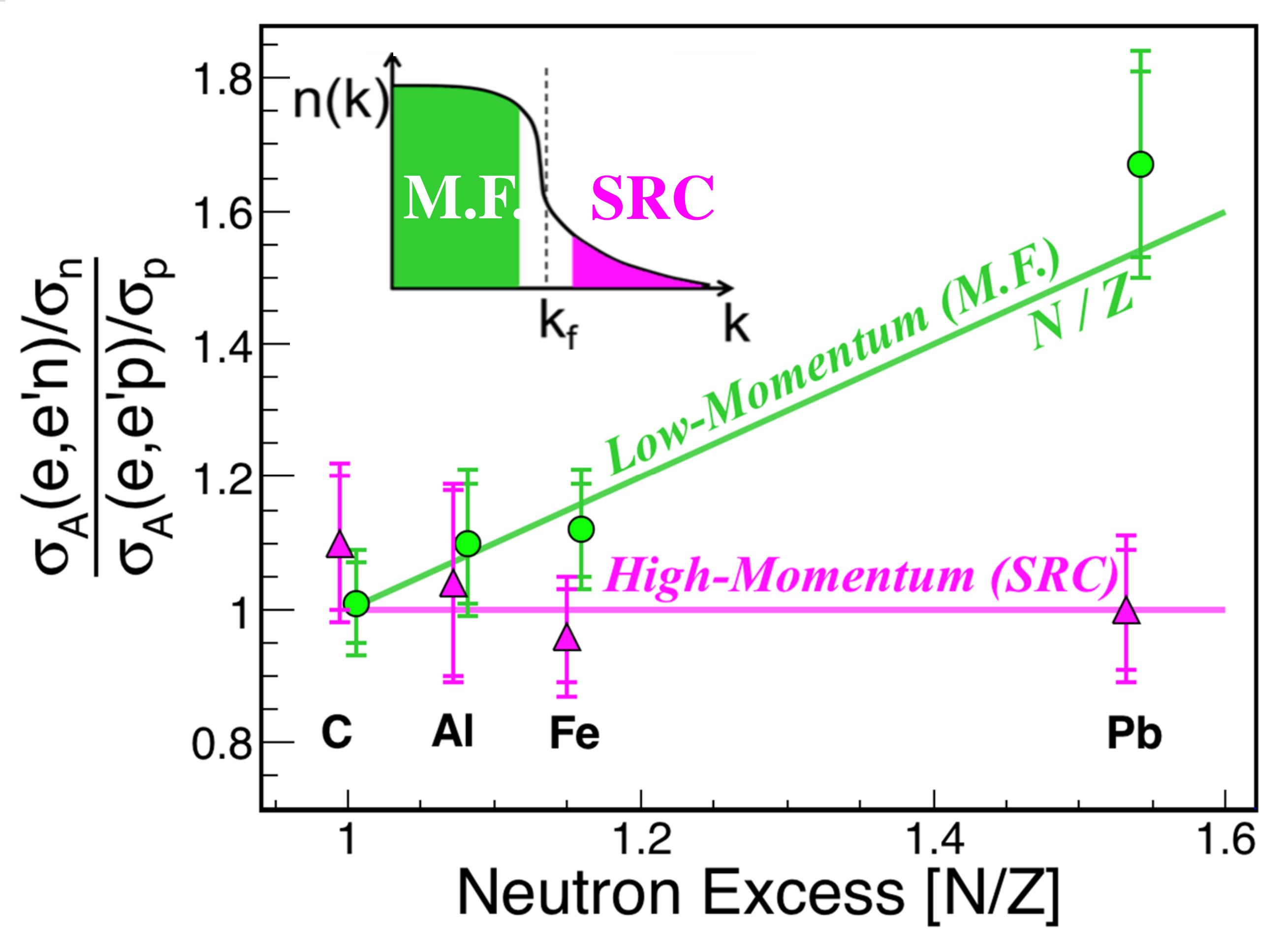


5%

Duer, PRL (2019); Duer, Nature (2018); Hen, Science (2014); Korover, PRL (2014); Subedi, Science (2008); Shneor, PRL (2007); Piasetzky, PRL (2006); Tang, PRL (2003); Review: Hen RMP (2017);

Asymmetric nuclei

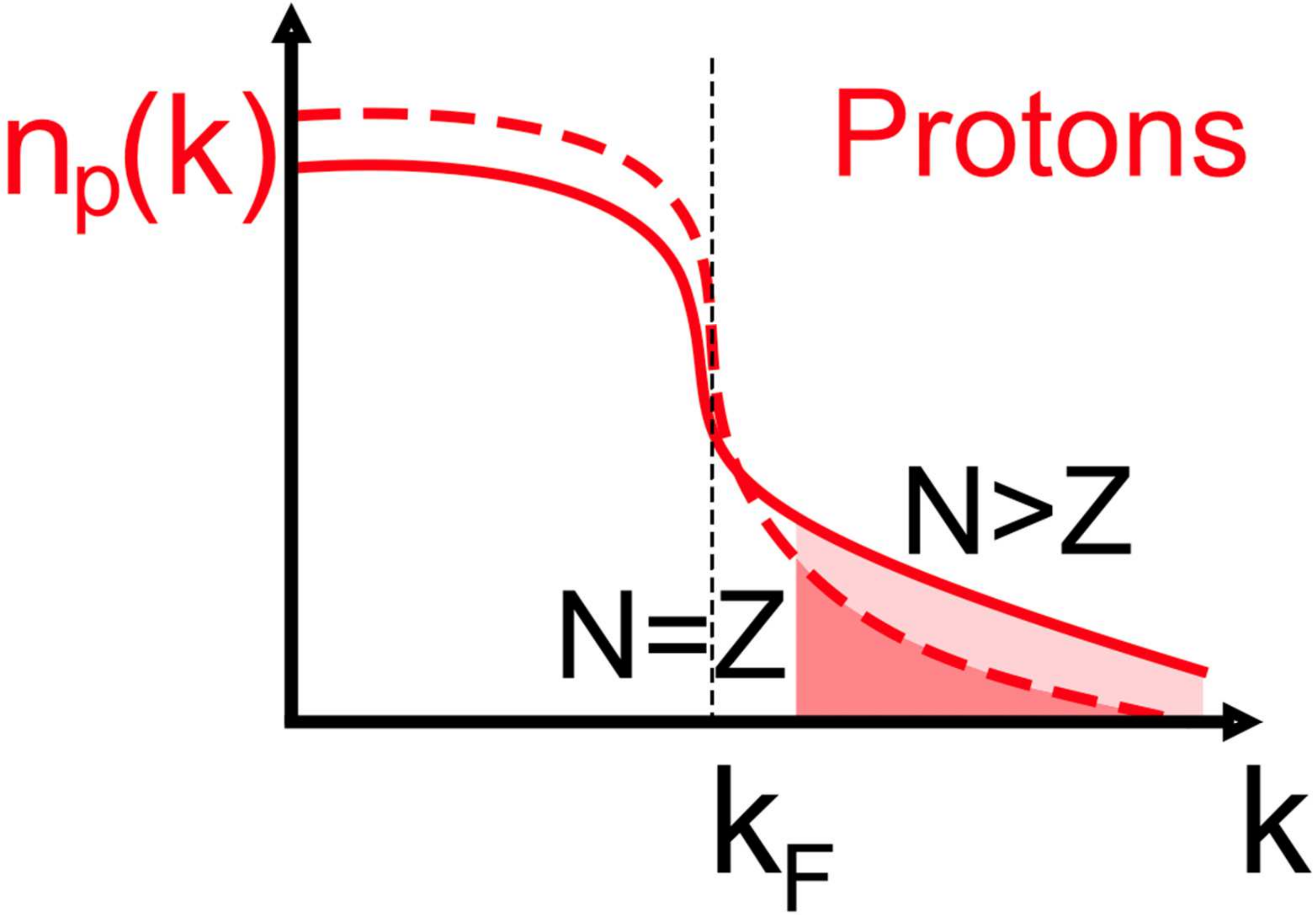
$A(e,e'p)$ $A(e,e'n)$



➔ **Same # of high-momentum protons and neutrons**

M. Duer et al. (CLAS Collaboration), Nature, 560 (2018) 617-621

Fraction of Neutrons and Protons in the high momentum tail



$$\frac{A(e,e'N)_{high}/A(e,e'N)_{low}}{^{12}C(e,e'N)_{high}/^{12}C(e,e'N)_{low}}$$

M. Duer et al. (CLAS Collaboration), Nature, 560 (2018) 617-621.

More Neutrons => More Correlated Protons

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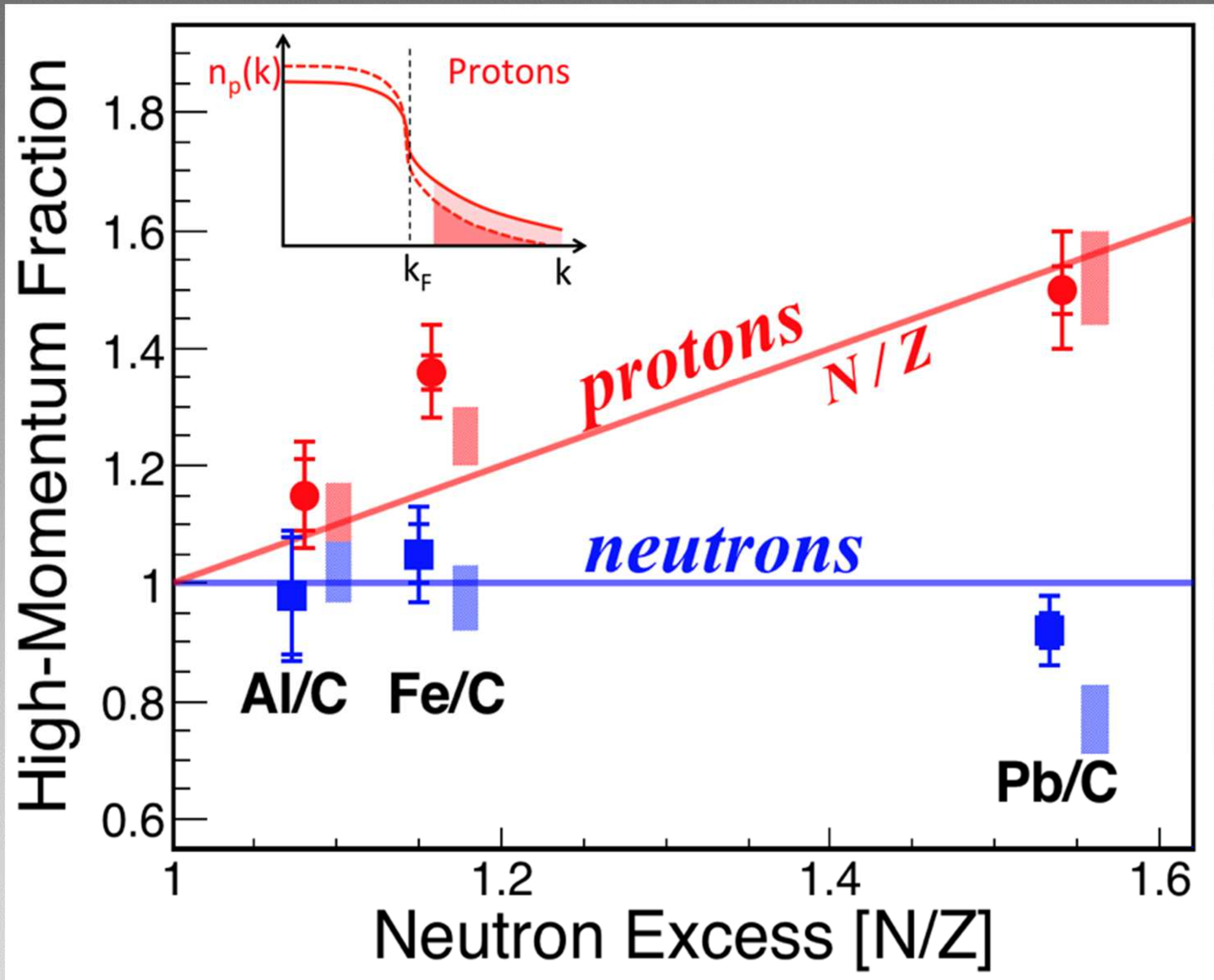
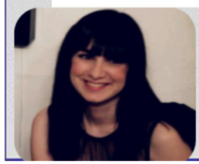
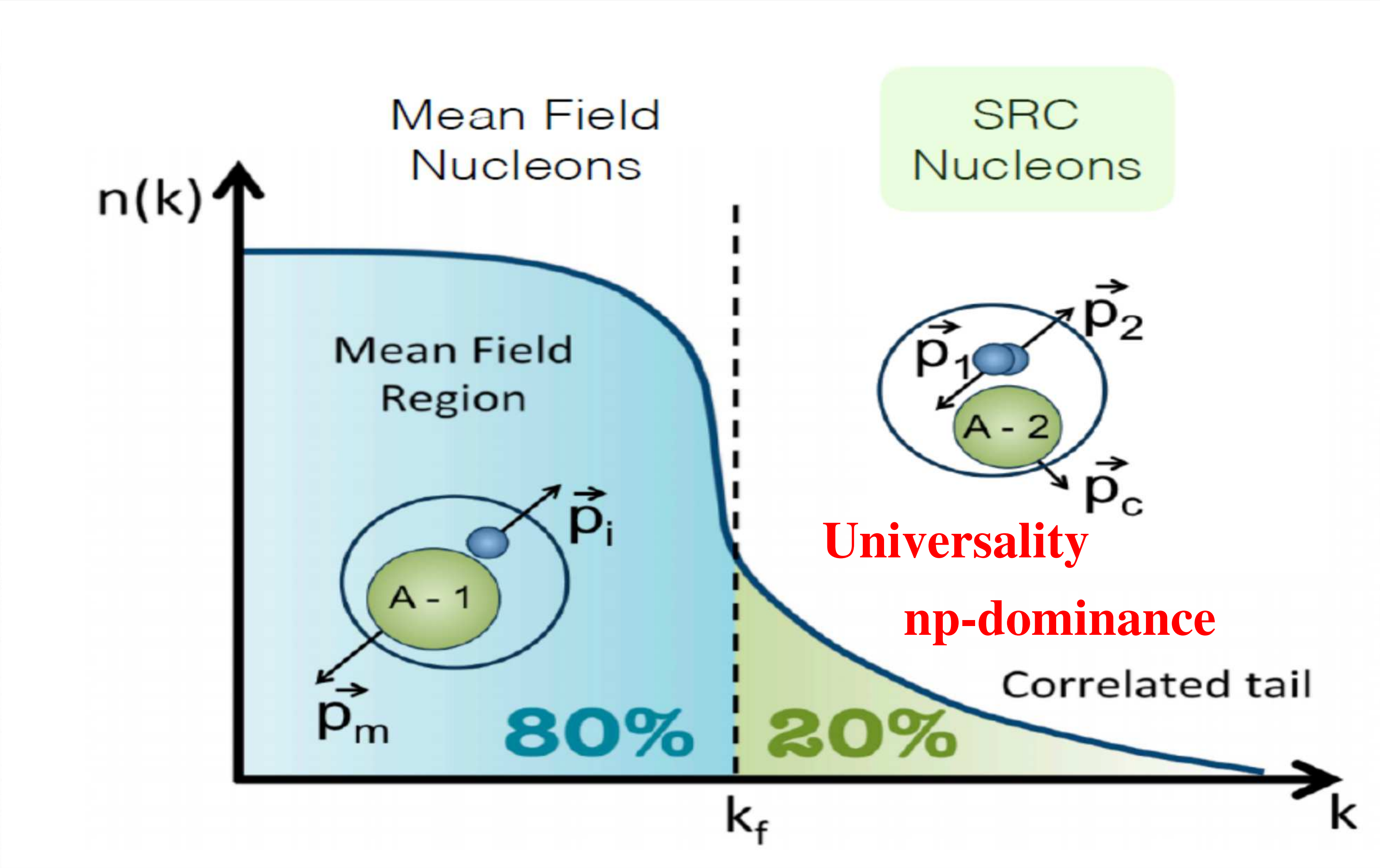


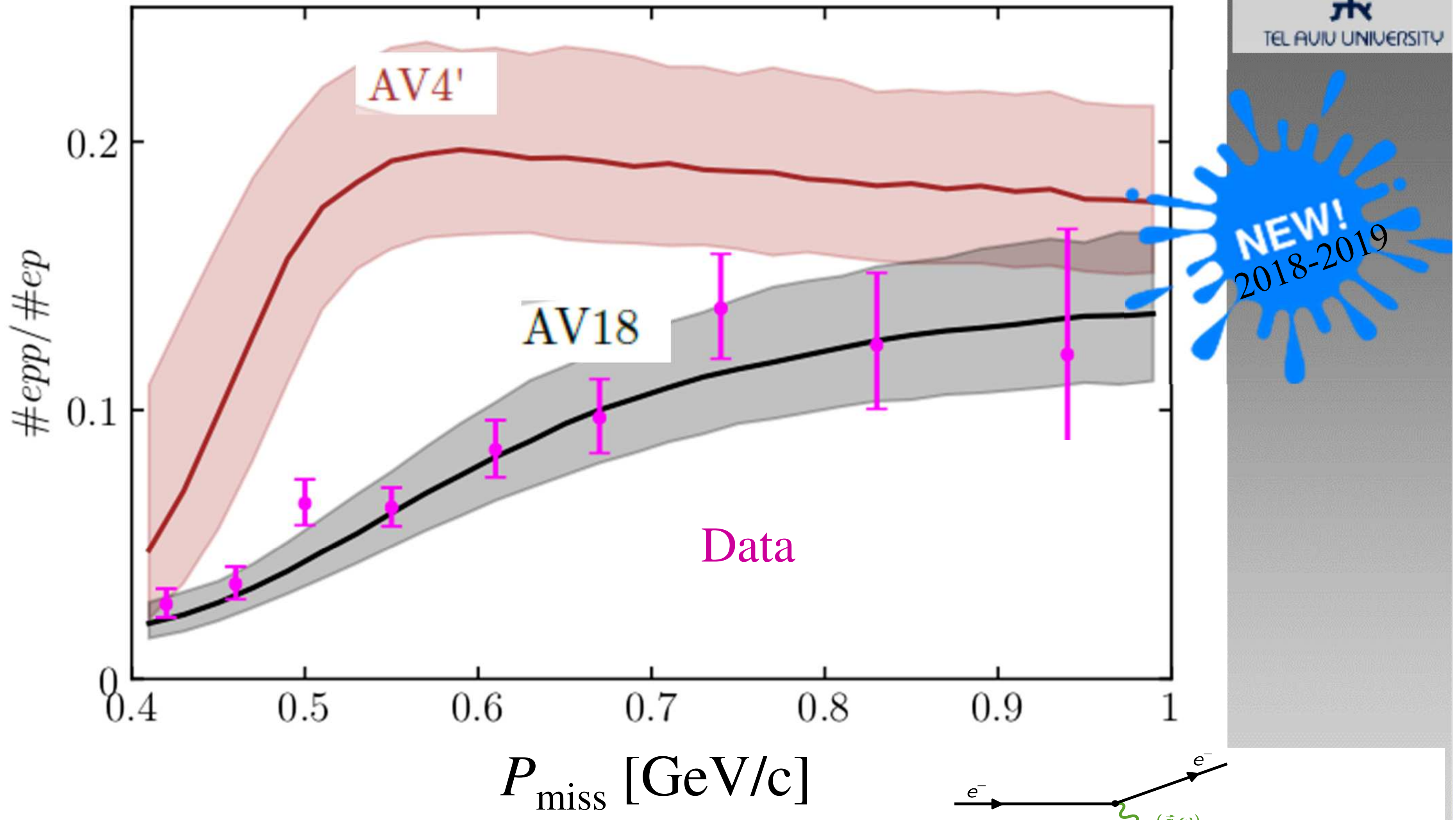
$$\frac{A(e,e'N)_{high}/A(e,e'N)_{low}}{^{12}C(e,e'N)_{high}/^{12}C(e,e'N)_{low}}$$

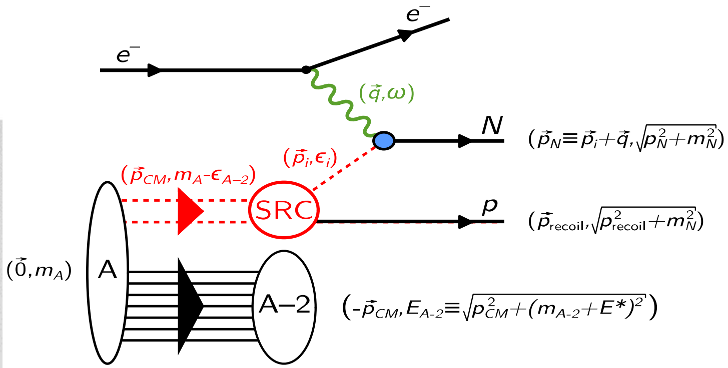


M. Duer et al. (CLAS Collaboration), Nature, 560 (2018) 617-621.

Short-Range Nucleon Correlations (SRC)

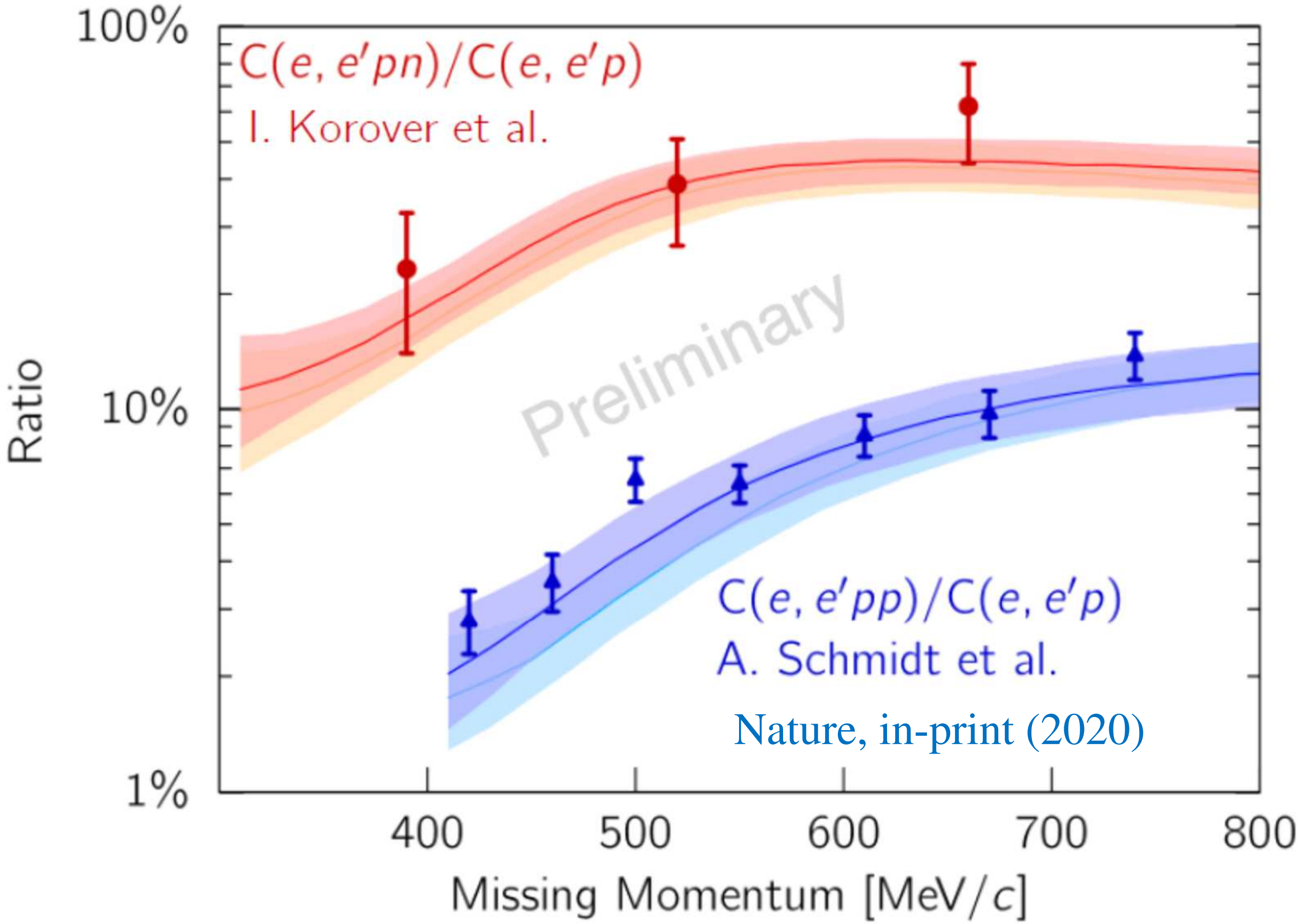






Probing the core of the strong nuclear interaction

A. Schmidt et al. (CLAS Collaboration) Nature (in print)



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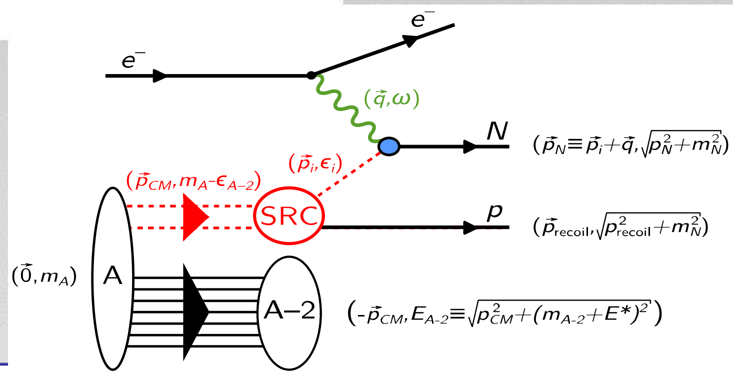
NEW! 2020

Probing the core of the strong nuclear interaction

A. Schmidt et al. (CLAS Collaboration) Nature (in print)



Universality (factorization)

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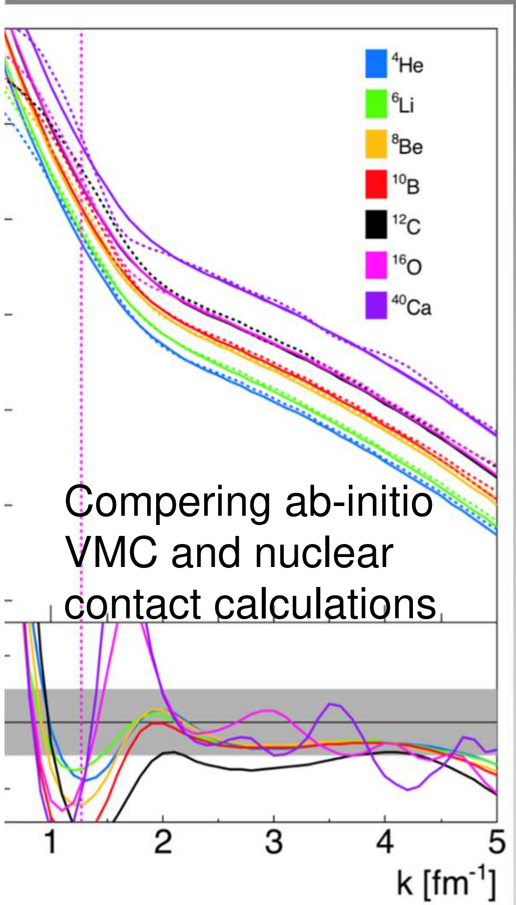
Iomentum Distribution



Compering ab-initio VMC and nuclear contact calculations

a factorized ansatz

$$\Psi \xrightarrow{r_{ij}\to 0} \sum_{\alpha} \varphi_{\alpha}(\boldsymbol{r}_{ij}) A_{ij}^{\alpha}(\boldsymbol{R}_{ij}, \{\boldsymbol{r}\}_{k\neq ij})$$

- Universal function: the zero energy solution to the 2 body problem

GCF: Generalized Contact Formalism

Phys. Lett. B780 (2018) 211.

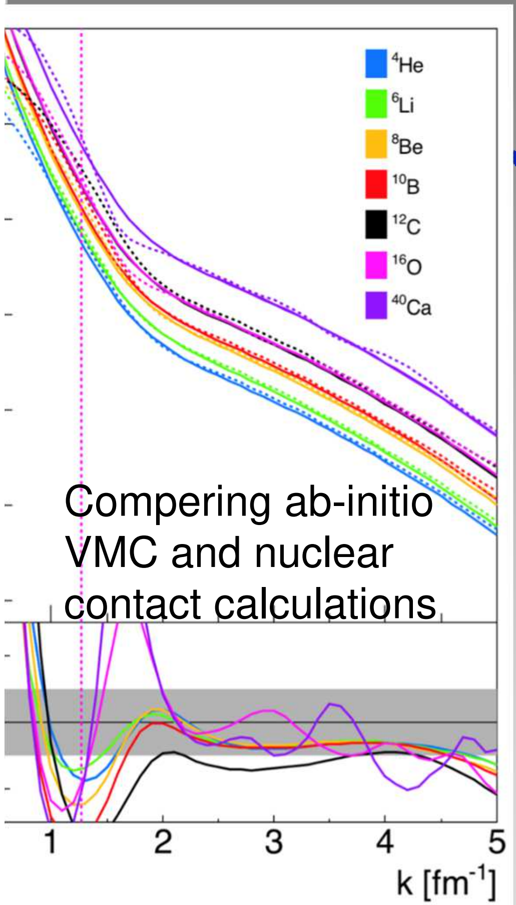
GCF: Generalized Contact Formalism

a factorized ansatz

$$\Psi \xrightarrow{r_{ij}\to 0} \sum_\alpha \varphi_\alpha(\boldsymbol{r}_{ij}) A^\alpha_{ij}(\boldsymbol{R}_{ij}, \{\boldsymbol{r}\}_{k\neq ij})$$

- Universal function: the zero energy solution to the 2 body problem
- Nucleus (A-2) specific function

Momentum Distribution



Residual

The nuclear contacts and short range correlations in nuclei

R. Weiss,[1] R. Cruz-Torres,[2] N. Barnea,[1] E. Piasetzky,[3] and O. Hen[2]

Phys. Lett. B780 (2018) 211.

A universal description of SRC:

$$n_p(k) \xrightarrow[k\to\infty]{} C^d_{pn}\left|\varphi^d_{pn}(k)\right|^2 + C^0_{pn}\left|\varphi^0_{pn}(k)\right|^2 + 2C^0_{pp}\left|\varphi^0_{pp}(k)\right|^2$$

$l = 0, 2\ s = 1\ j = 1$

np pairs

$l = s = j = 0$

pp, nn, np pairs

Exclusive Hard scattering in selected kinematics

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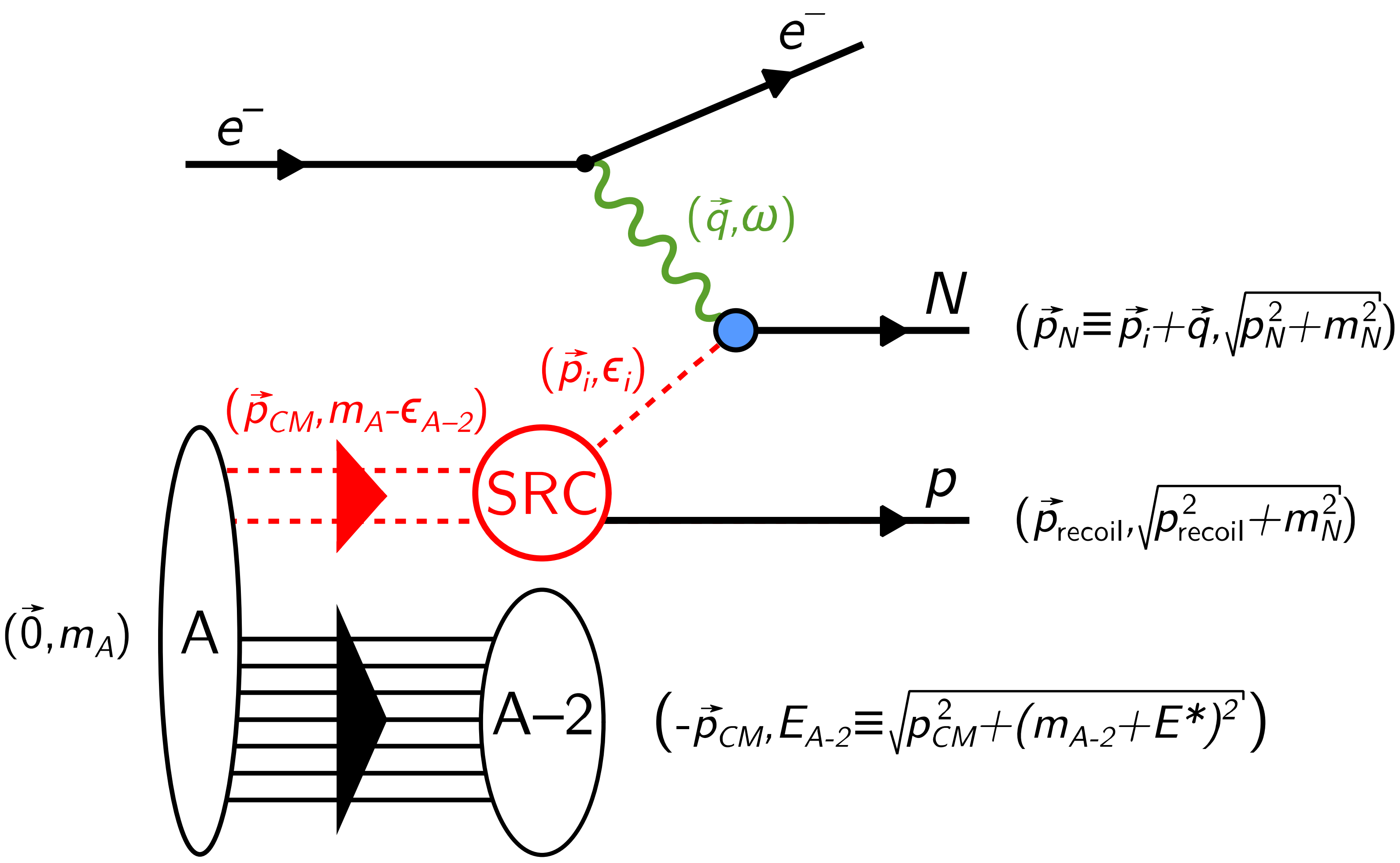
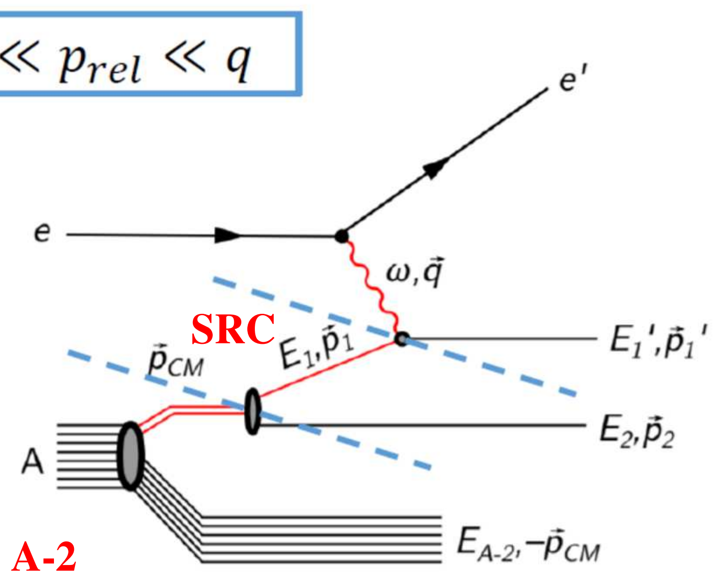


$$\sigma = K \cdot \sigma_{eN} \cdot \underbrace{D(p_i, p_{recoil}, E_{recoil})} \cdot T_{FSI}$$

GCF $\rightarrow n(\vec{p}_{CM}) \cdot \sum_{\alpha} C_{\alpha} \cdot \varphi_{2N}(\vec{p}_{relative})$

selected kinematics
→ scale separation, factorization



Sensitivity to NN interaction

Universality

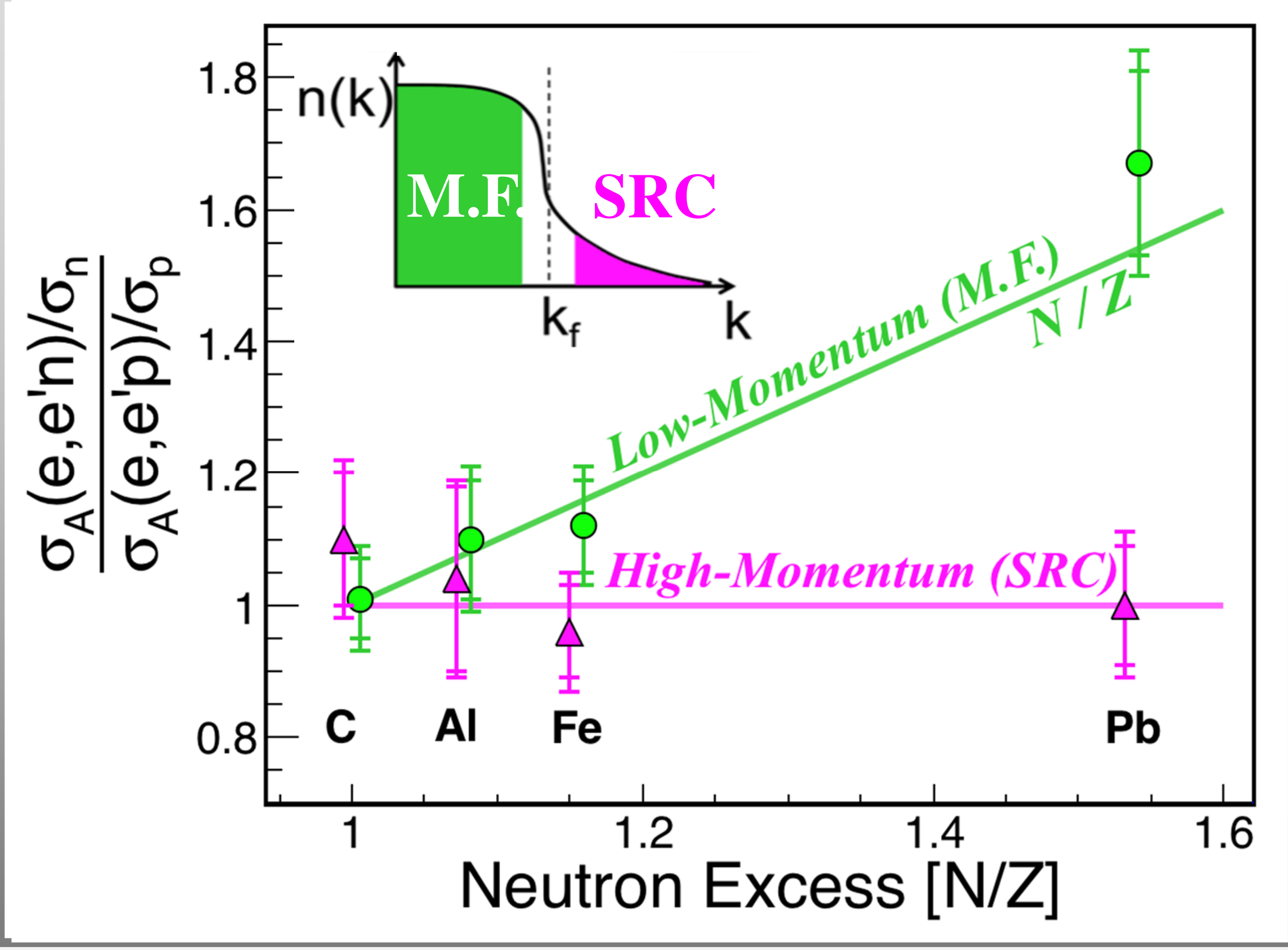
$$\sigma = K \cdot \sigma_{eN} \cdot \underbrace{D(p_i, p_{recoil}, E_{recoil})}_{\text{GCF}} \cdot T_{FSI}$$

$$\hookrightarrow n(\vec{p}_{CM}) \cdot \sum_{\alpha} C_{\alpha} \varphi_{2N}(\vec{p}_{relative})$$

A. Schmidtet al. (CLAS Collaboration), Nature, in print (2020)

Asymmetric nuclei

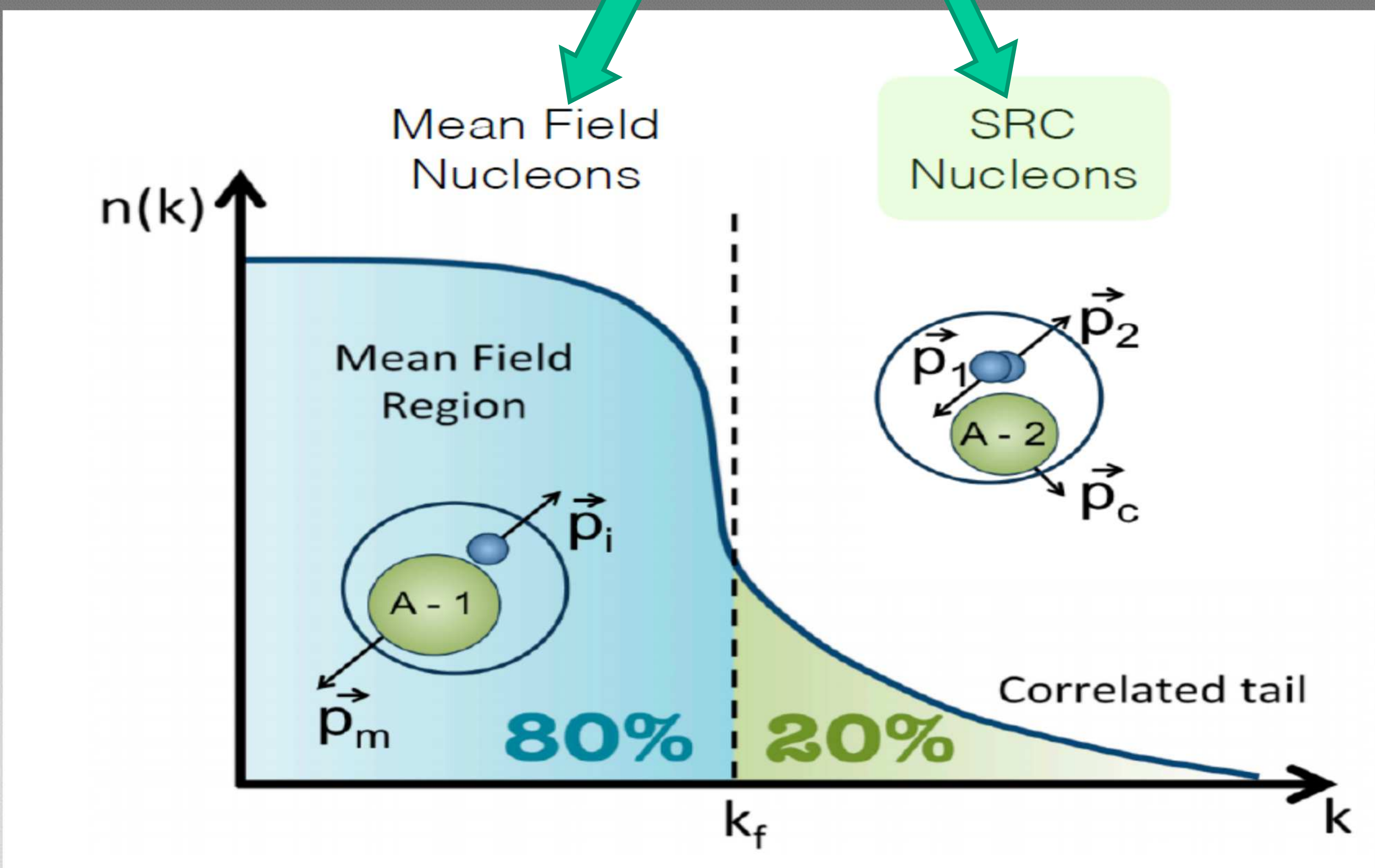
$A(e,e'p)\ A(e,e'n)$



➔ Same # of high-momentum protons and neutrons

M. Duer et al. (CLAS Collaboration), Nature, 560 (2018) 617-621

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

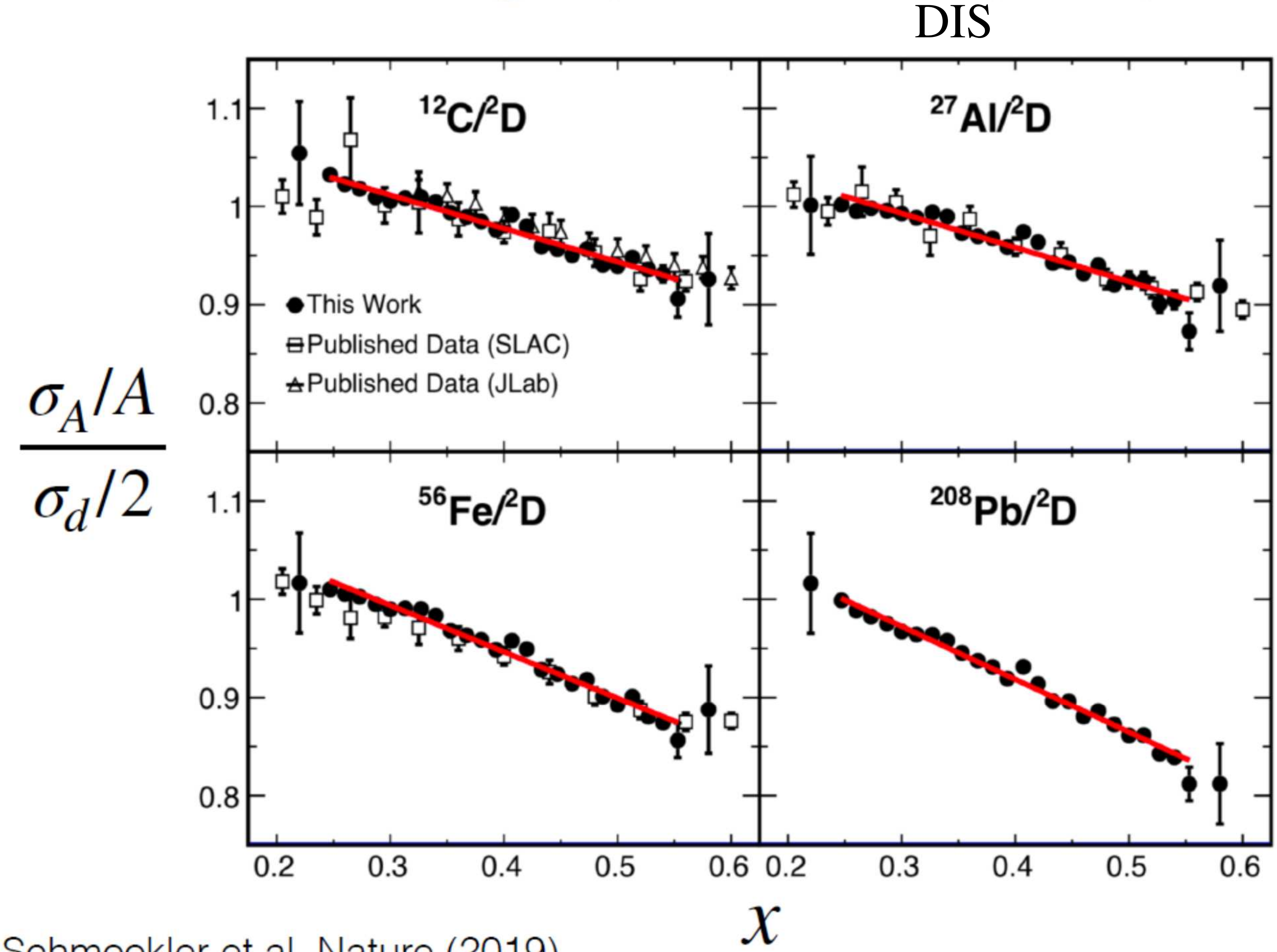


Is there any connection between correlation in partonic and in hadronic interactions ?

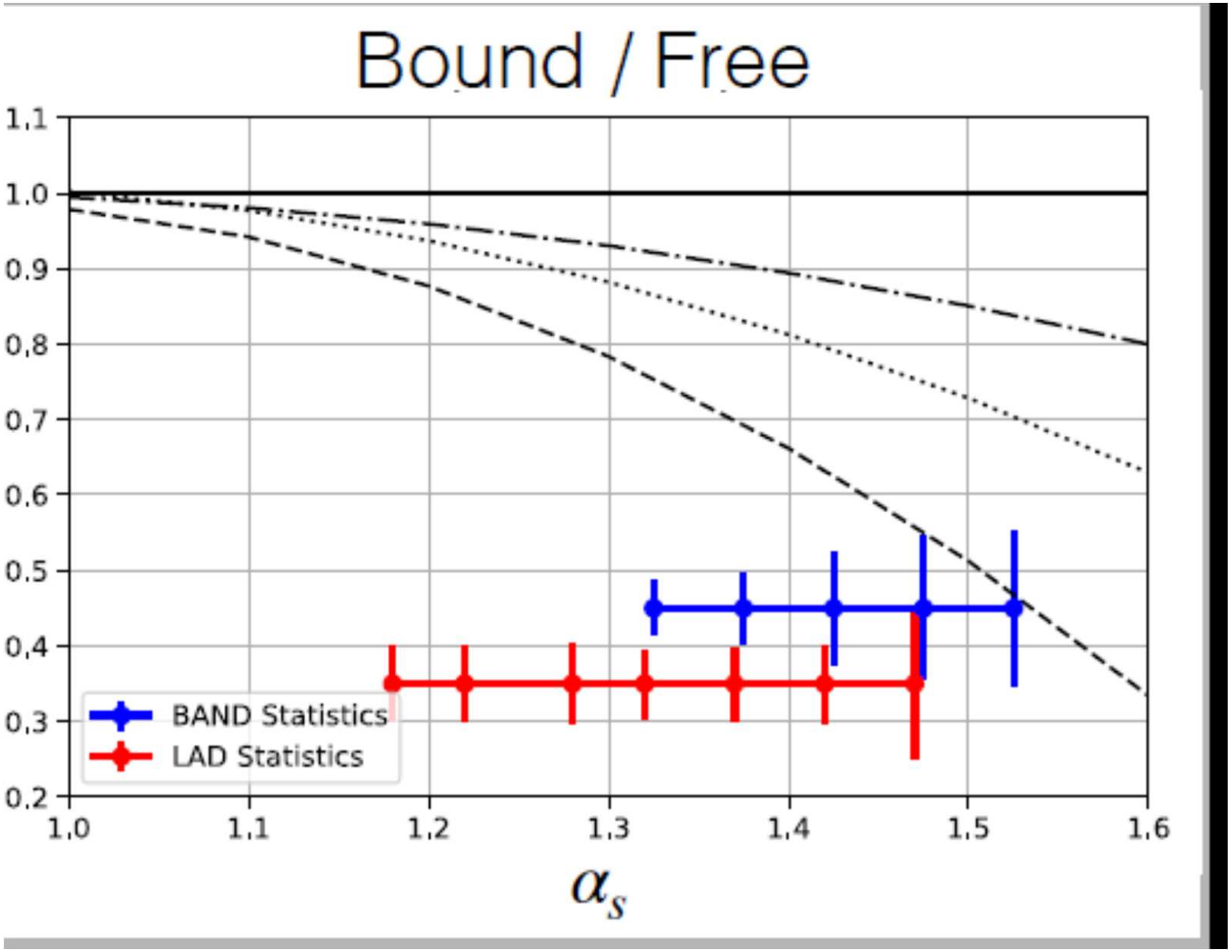
Dominance of scalar –diquark @ $x_B=1$

➔ $F_2^n / F_2^p = 1/4$

Recent high precision (e,e') data



Schmookler et al. Nature (2019)



Bound / Free
1,1
1.0
0.9
0,8
0,7
0.6
0.5
0,4
0,3
0,2
1,0
1.1
1,2
1.3
1,4
1,5
1,6
α_s
BAND Statistics
LAD Statistics

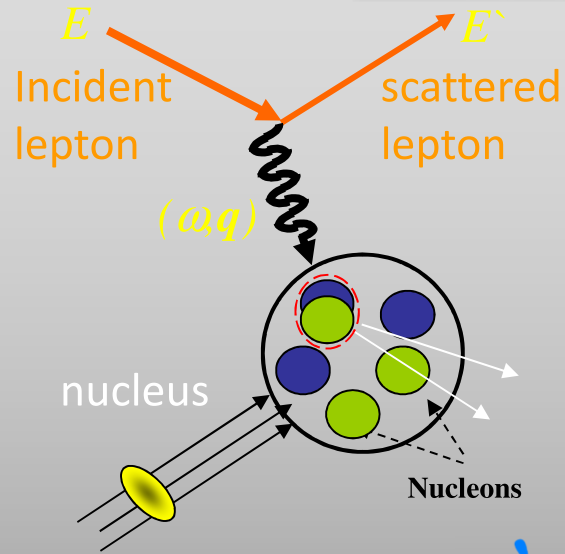
Inclusive electron scattering A(e,e')

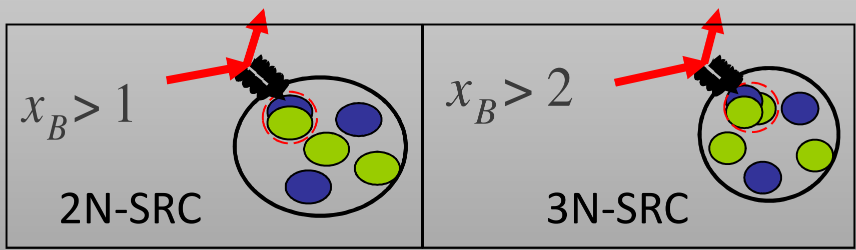
$$Q^2 = -q_\mu q^\mu = q^2 - \omega^2$$

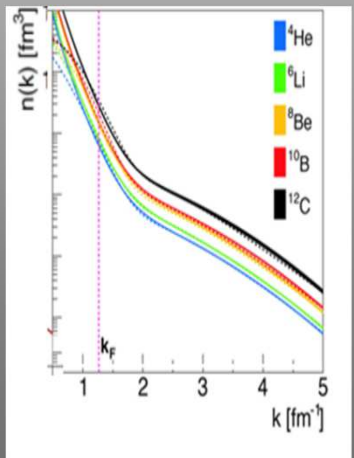
$$\omega = E' - E$$

$$x_B = \frac{Q^2}{2m\omega} \qquad \left(x_B' = \frac{Q^2}{2(q \cdot p_T)}\right)$$

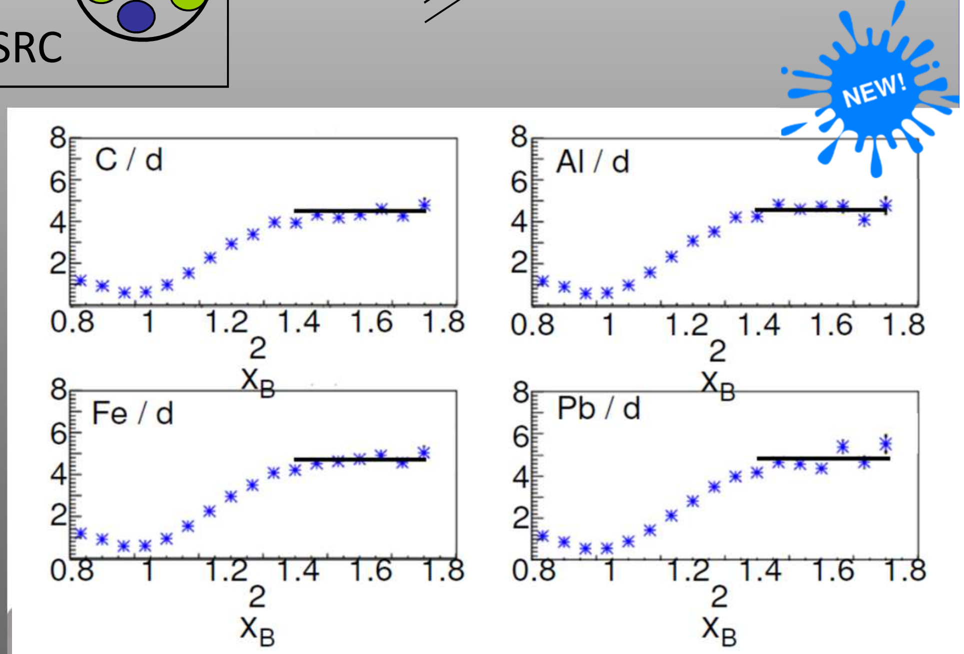
$$0 \le x_B \le A$$







Momentum scaling →



Schmookler Duer et al., Nature 566 (2019) 354-358

--> **Counts the number of SRC clusters in nuclei** $a_{2N}(A/d)$

Data mining (EG2c)

Comparing magnitude of EMC effect and SRC scaling factors

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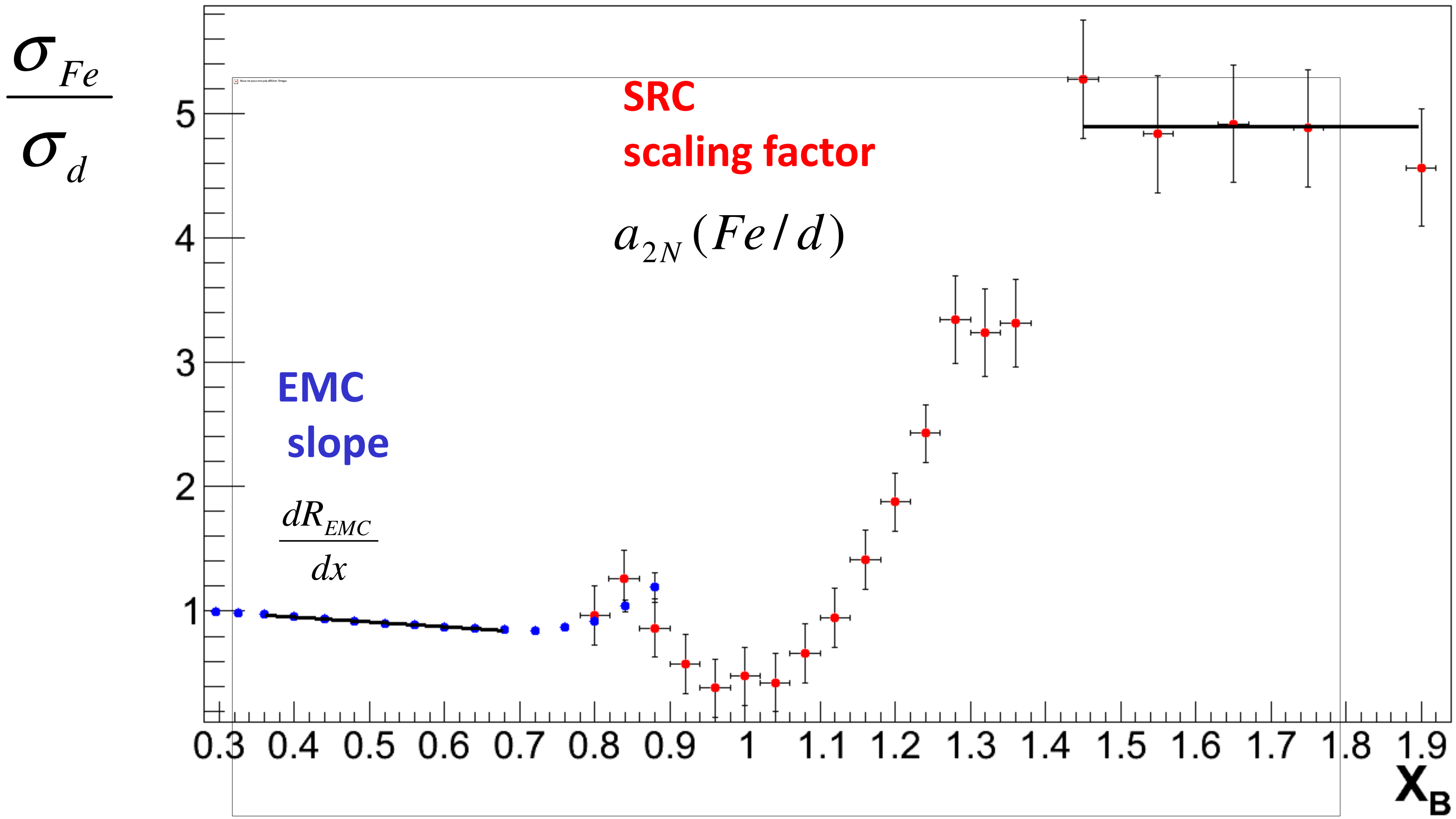

SLAC data:

Gomez et al., Phys. Rev. D49, 4348 (1983).

Frankfurt, Strikman, Day, Sargsyan, Phys. Rev. C48 (1993) 2451.

Q^2=2, 5, 10, 15 GeV/c^2 (averaged)

Q^2=2.3 GeV/c^2

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Is the distribution of partons in bound nucleons same as in free nucleons ?

What is the connection between the quark / gluon structure of bound nucleons and nuclear structure ?

How to extract the distribution of partons in a free neutron ?

Close nucleons

Baryons 2022

7-11 November, Sevilla

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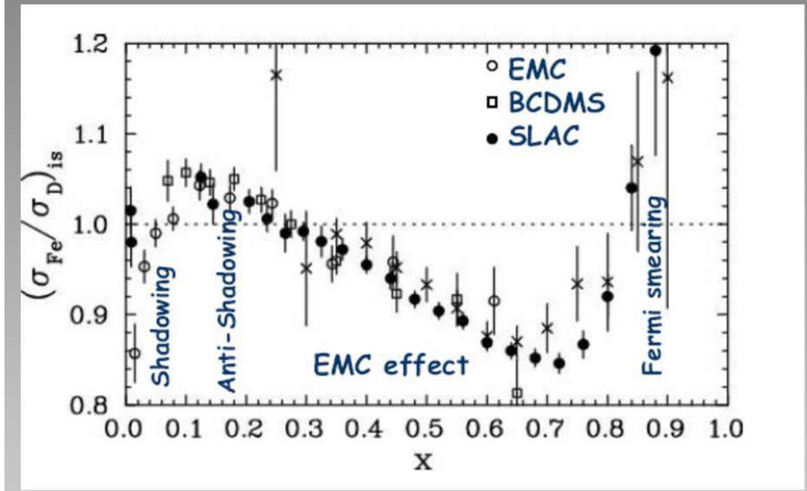
Free ≠ bound nucleon

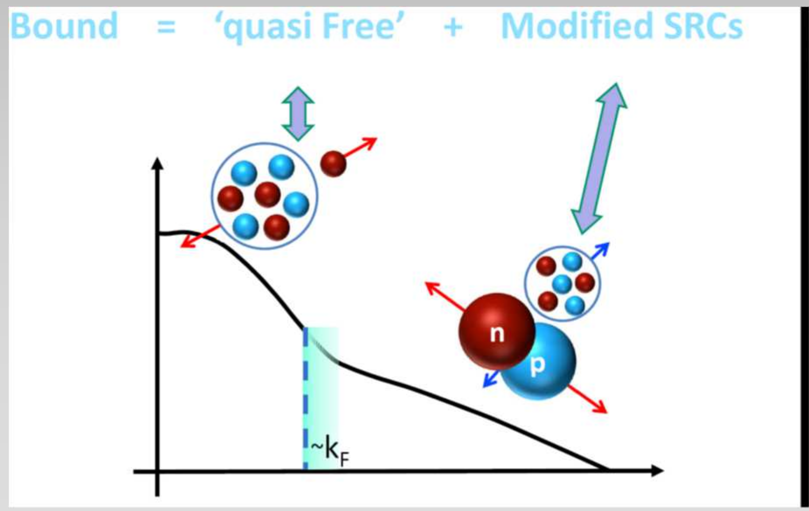


Suppression of quark momenta in nuclei (EMC Effect)

$$F_2^A \neq Z \cdot F_2^p + N \cdot F_2^n$$

$$F_2 \approx \cdot F_2^{free}$$

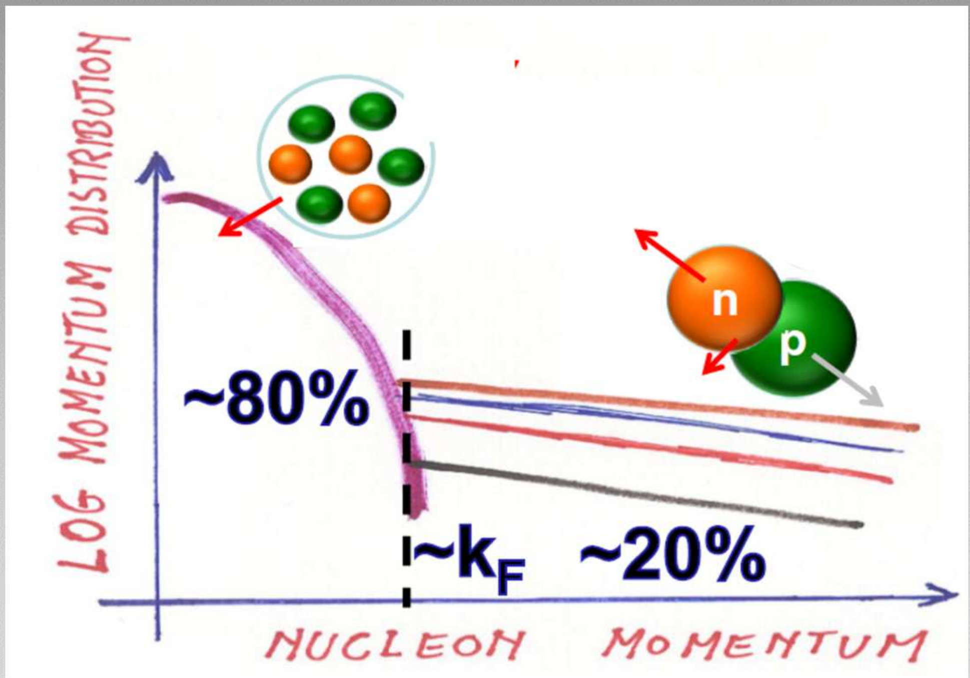
$$F_2 \neq \cdot F_2^{free}$$



Summary of SRC results

In nuclei the momentum distribution of nucleons can be divided into two distinct regions

$k<k_F$	$k>k_F$
Mean field region	Correlated / high momentum region
Single nucleons	SRC pairs



Universality

np-SRC dominance (tensor force)

E. Piasetzky et al., PRL. 97 (2006) 162504.
R. Subedi et al., Science 320, 1476 (2008).
A. Schmidt et al., Nature (in print)

Summary of SRC results

SRC domain

3 regions in nuclei

k<~0.8k$_F$

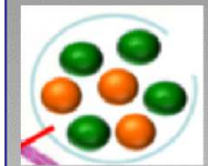
MF domain

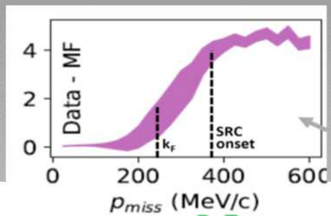
Single nucleons

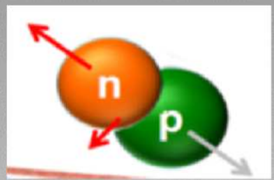
k>~1.5k$_F$

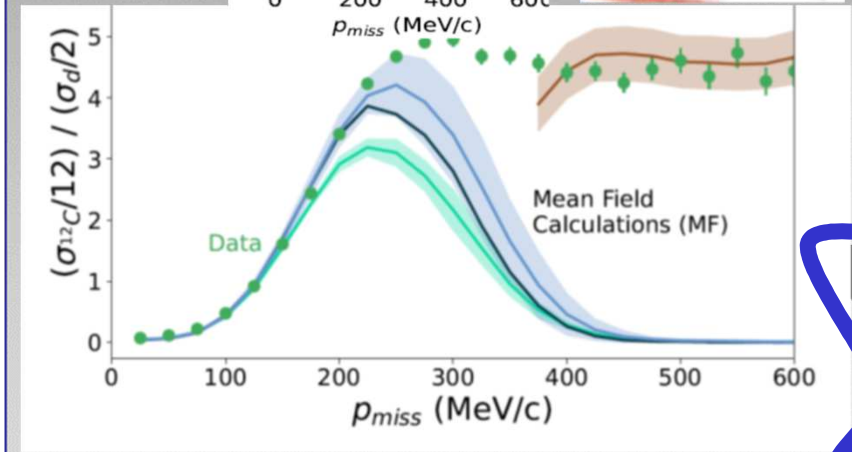
SRC domain

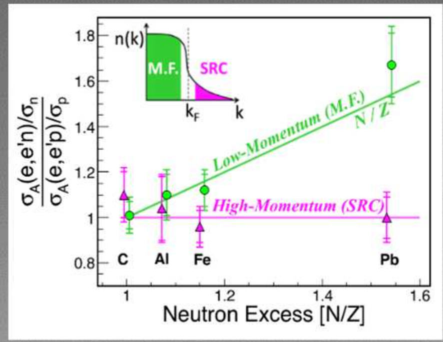
SRC pairs

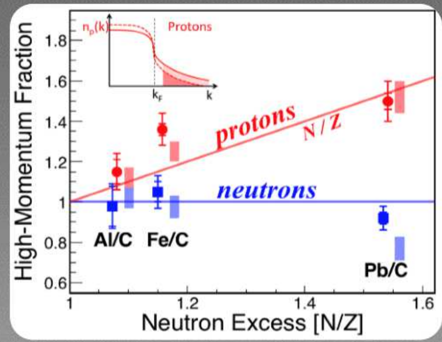












np-SRC dominance

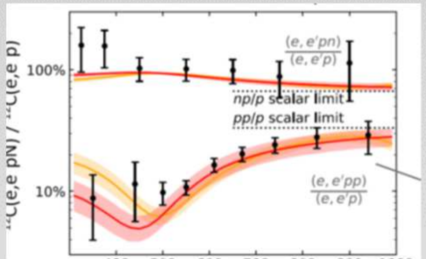
SRC Paring

Energy sharing

Universality/ scale separation

Generalized Contact Formalism (G

Sensitivity to NN interaction



Refine transition from Mean- field to SRC domain

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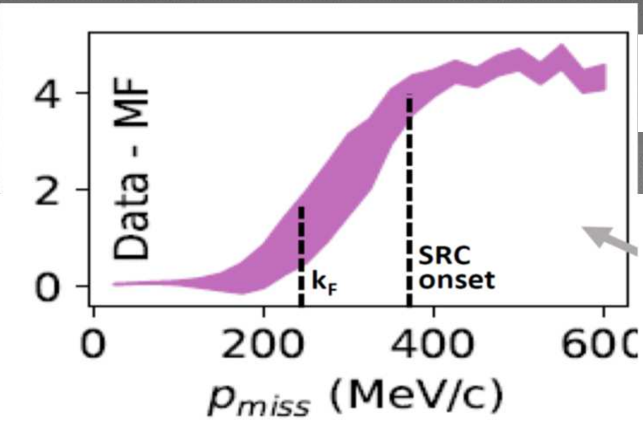
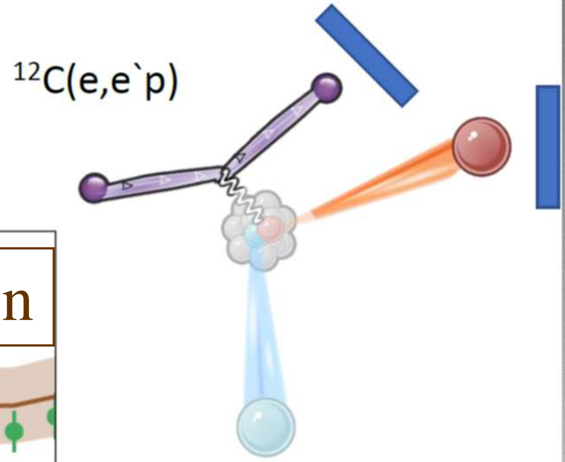
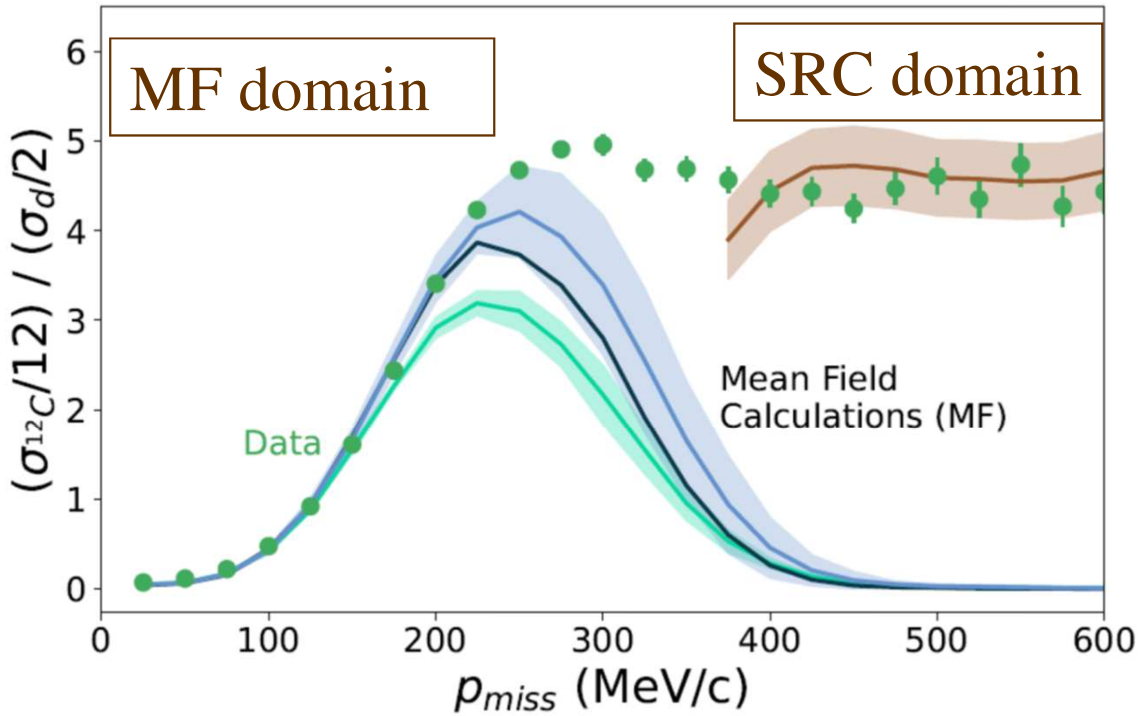


MF+LRC+SRC



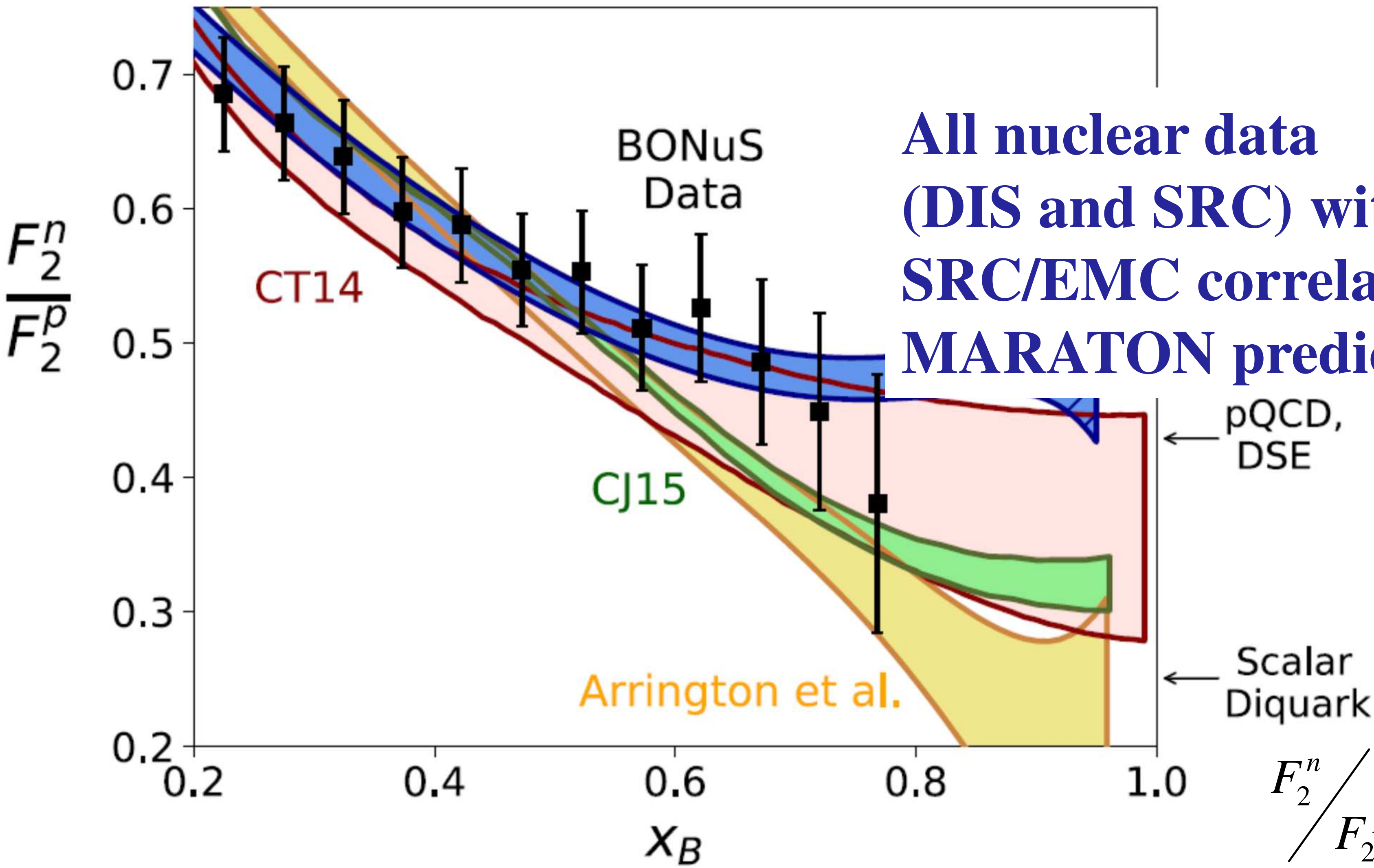


$0.7 < x_B < 1.8$

QMC (teal),
IPSM (black),
Skryme (azure)

I. Korover et al., arXiv:2209.01492 [nucl-ex] (Sep 2022).

$$\frac{F_2^n}{F_2^p} = \frac{1 - f_{univ}}{F_2^p / F_2^d} - 1$$



All nuclear data (DIS and SRC) with SRC/EMC correlations MARATON prediction

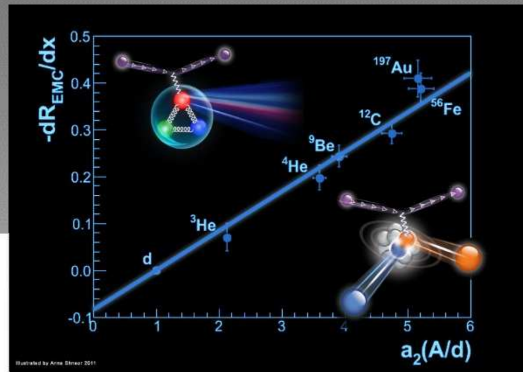
$$F_2^n / F_2^p = 1/4$$

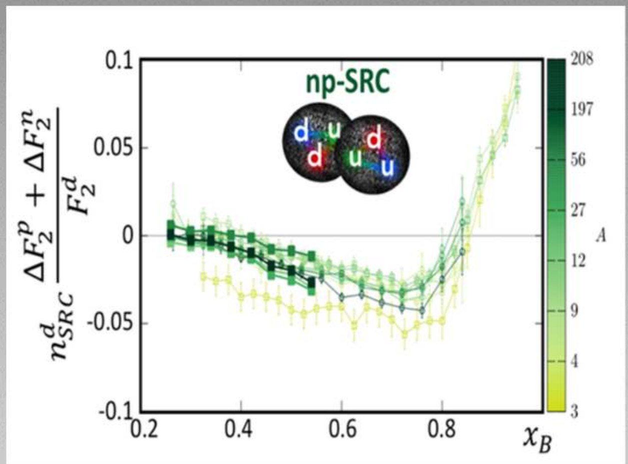
E.P. Segarra et al., arXiv: 1908.02223 (2019)

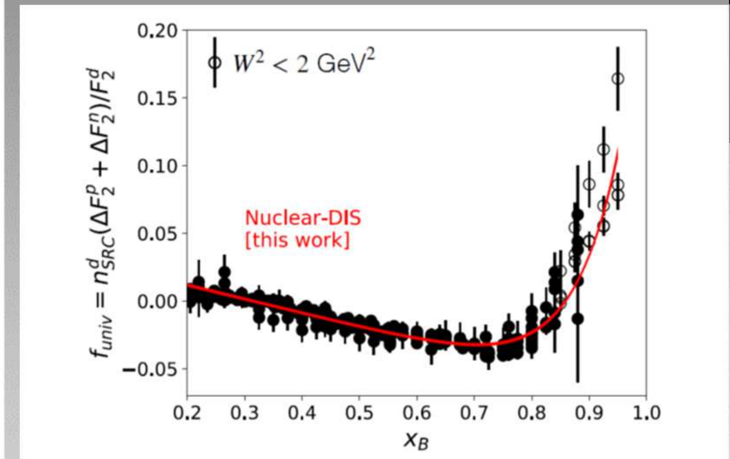
Summary

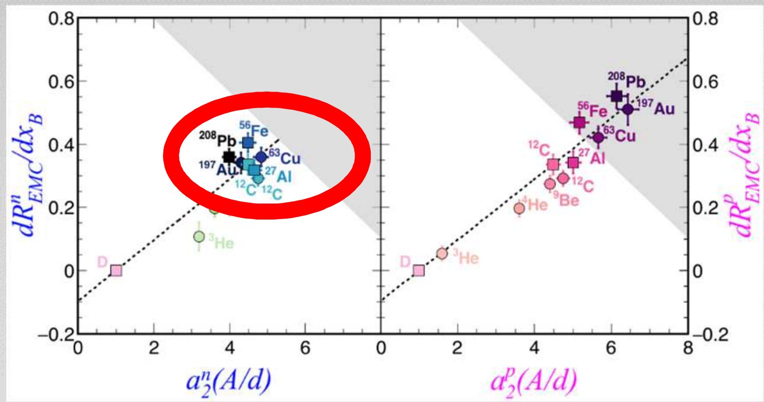
EMC is associate with 2N SRC

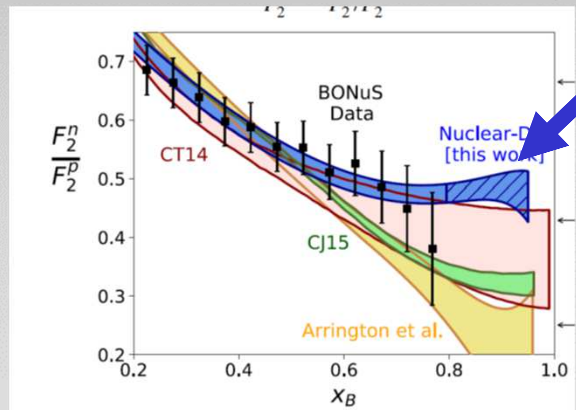
EMC: Nucleons are normally normal except when close to others.









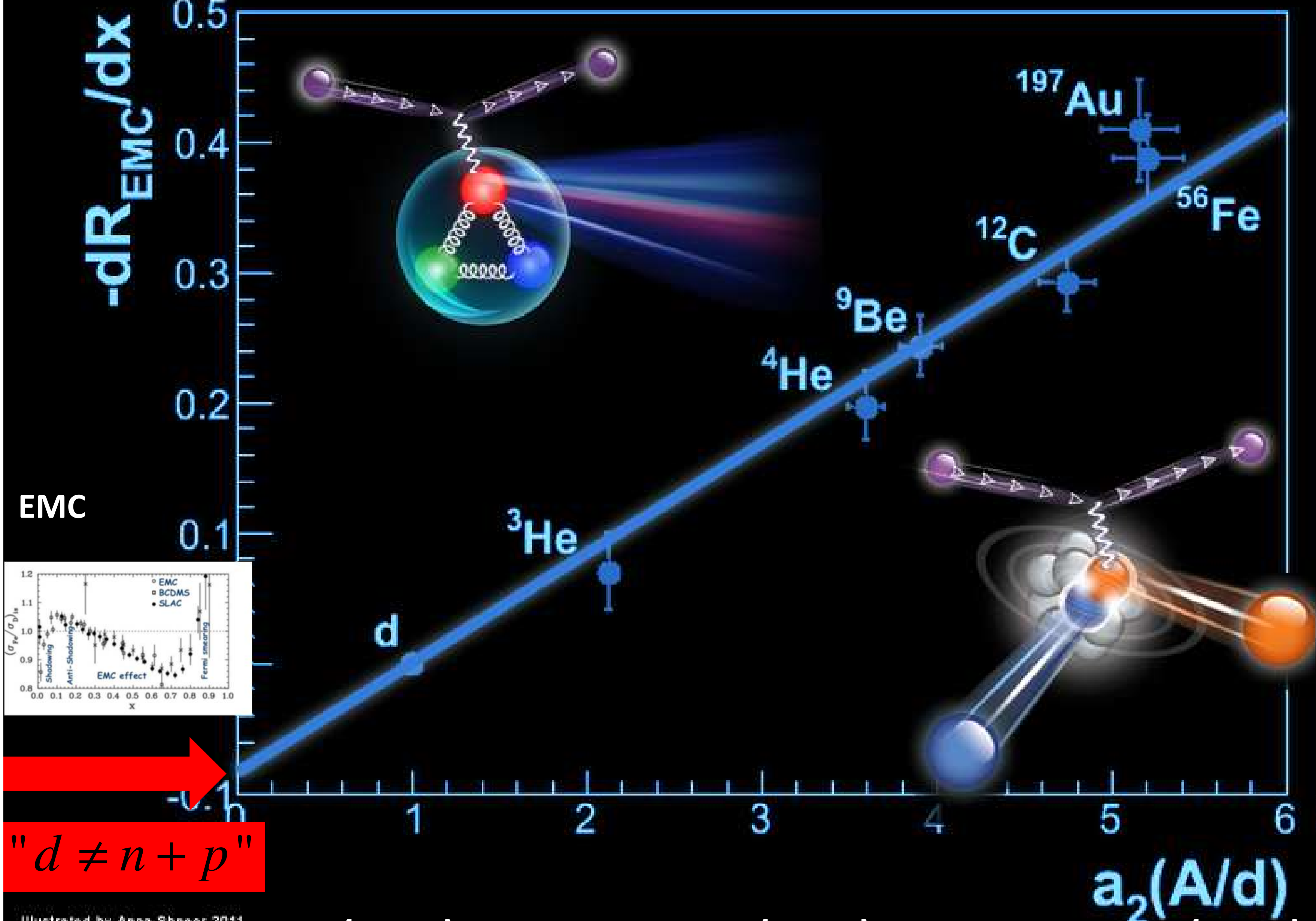


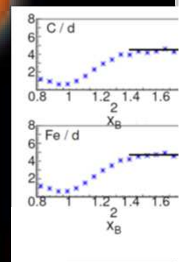
<u>Predictions:</u>

MARATHON results

EMC effect is isospin dependent

EMC





SRC

"$d \neq n + p$"

PRL 106, 052301 (2011), PRC 85 047301 (2012), RMP 89, 04500 (2017)

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EMC-SRC hypothesis proposes universal modification

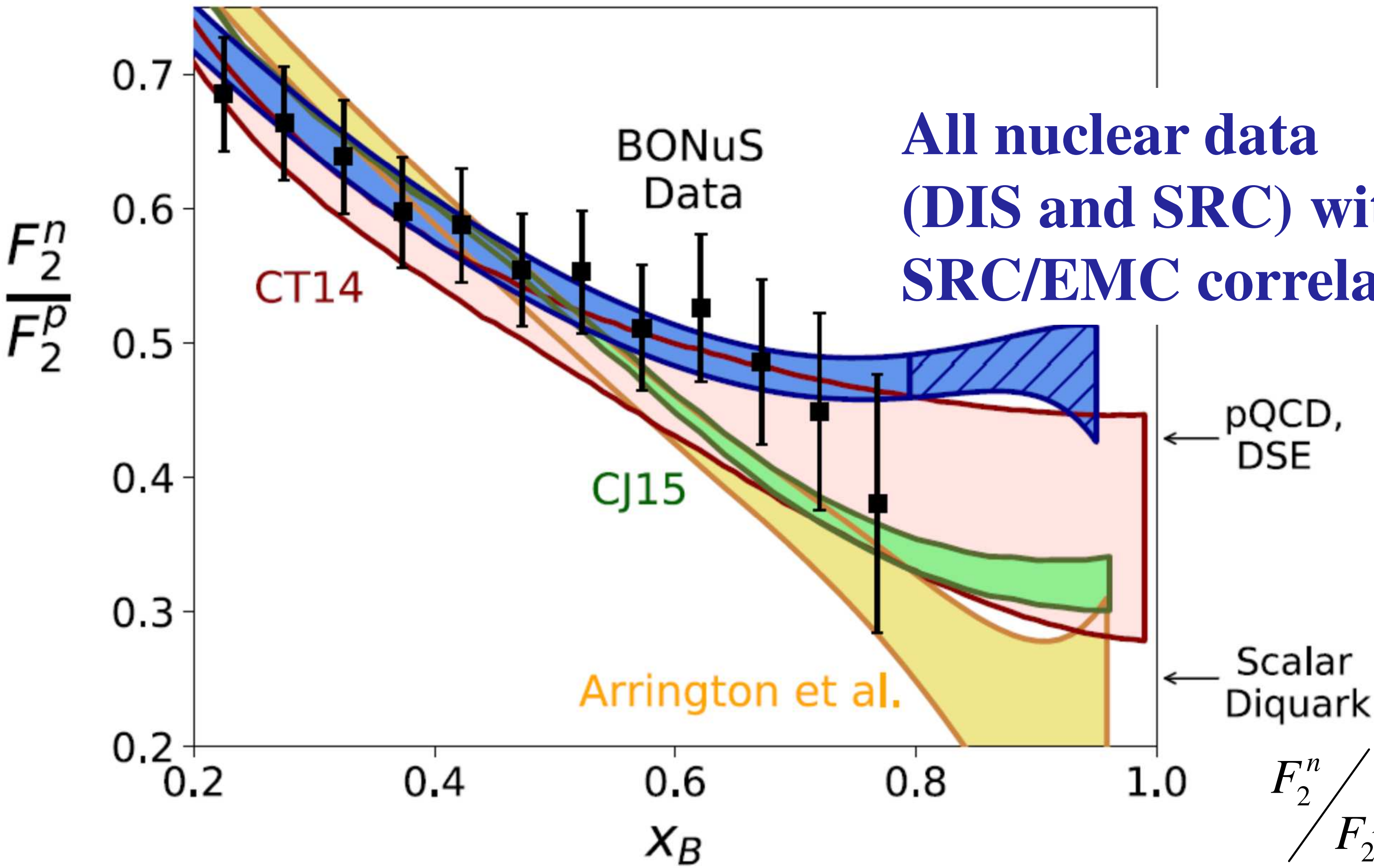
$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A\left(\Delta F_2^p + \Delta F_2^n\right)$$

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

$$F_2^A = (Z - N)\,F_2^p + NF_2^d + \left(n_{SRC}^A - Nn_{SRC}^d\right)\left(\Delta F_2^p + \Delta F_2^n\right)$$

Treat **all** bound nucleon structure **consistently** with **all** nuclear DIS and QE data

$$\frac{F_2^n}{F_2^p} = \frac{1 - f_{univ}}{F_2^p / F_2^d} - 1$$



All nuclear data (DIS and SRC) with SRC/EMC correlations

$F_2^n / F_2^p = 1/4$

E.P. Segarra et al., arXiv: 1908.02223 (2019)

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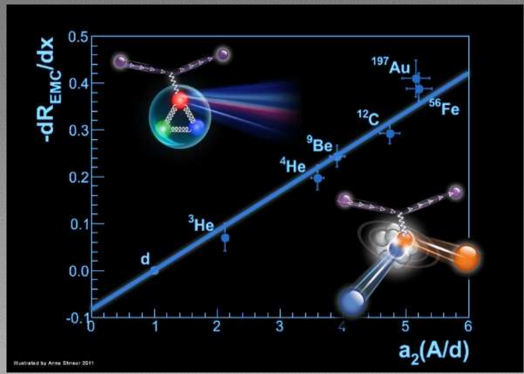
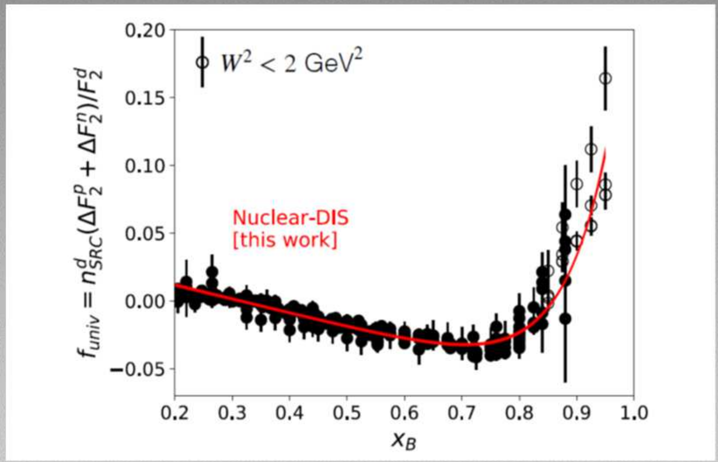
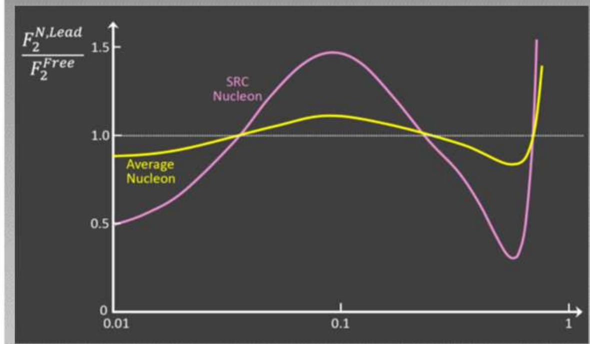
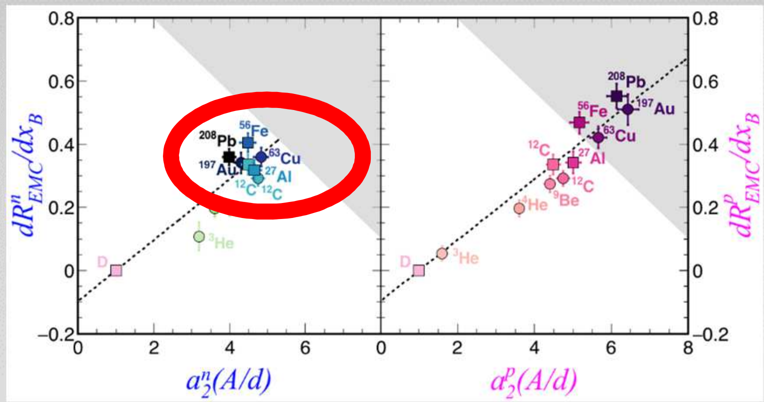


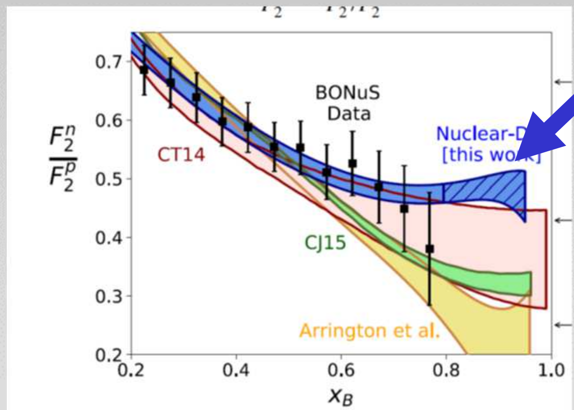




Predictions:

MARATHON results





EMC effect is isospin dependent

Summary

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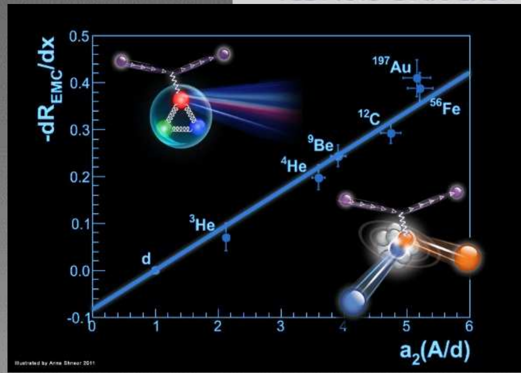
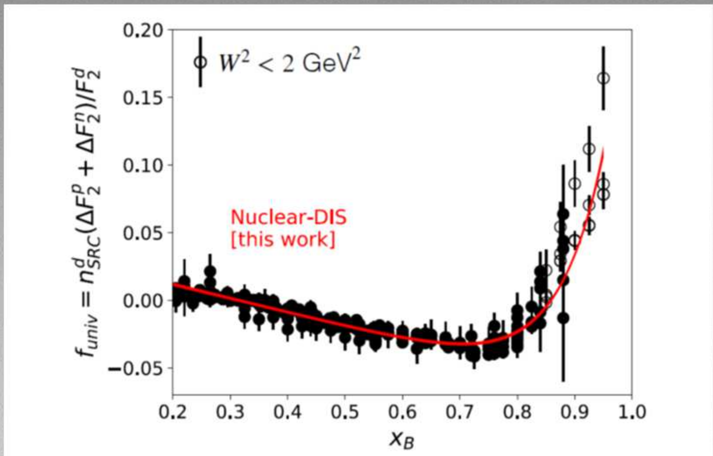
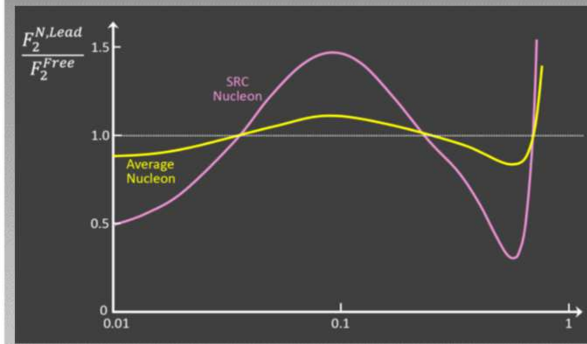
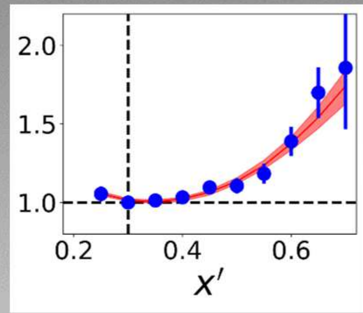
EMC is associate with 2N SRC

EMC: Nucleons are normally normal except when close to others.



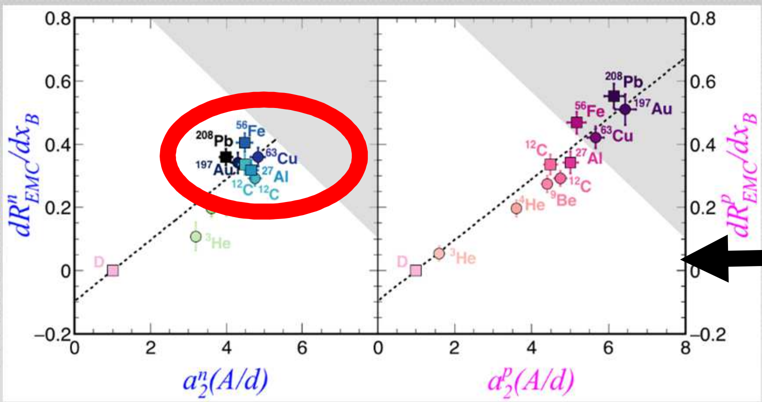


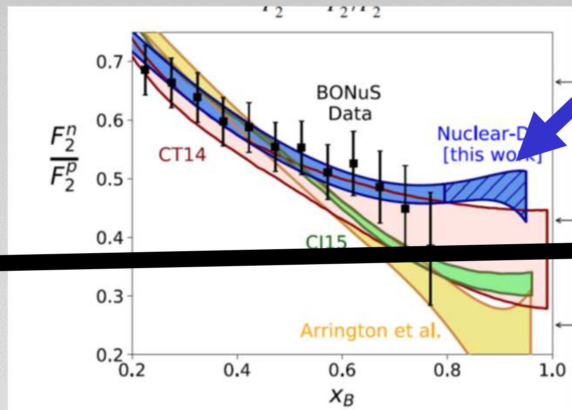




Predictions:

u/d≠0 $X_B \rightarrow 1$



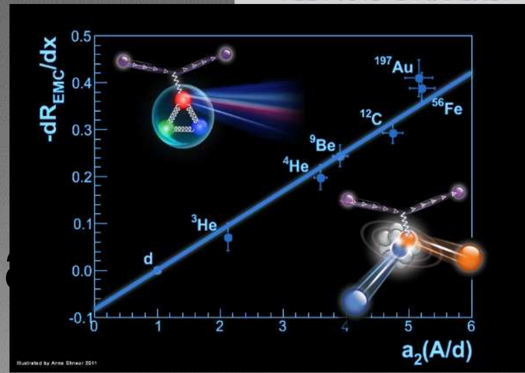


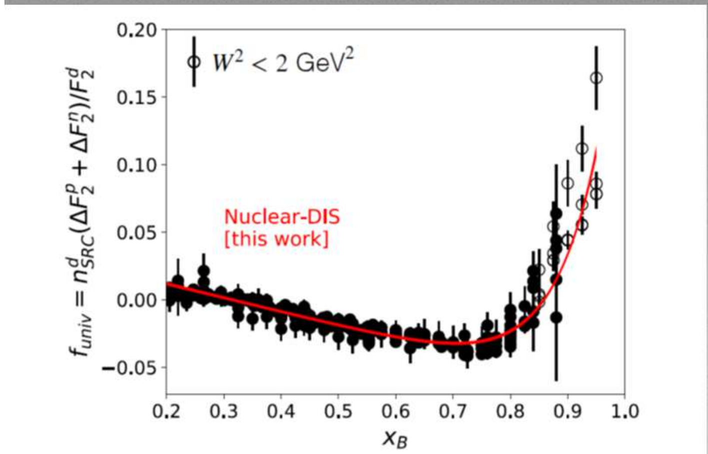
EMC effect is isospin dependent

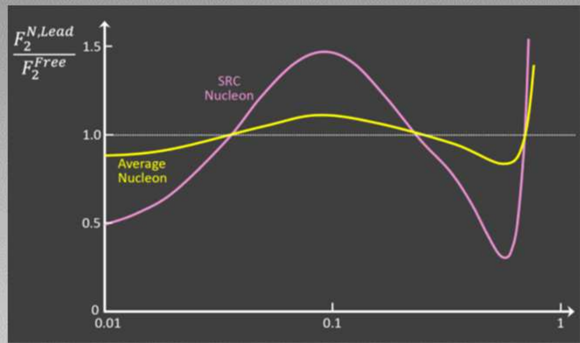
Summary

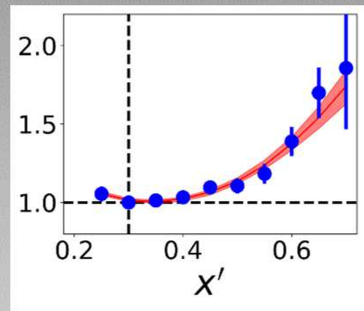
EMC is associate with 2N SRC

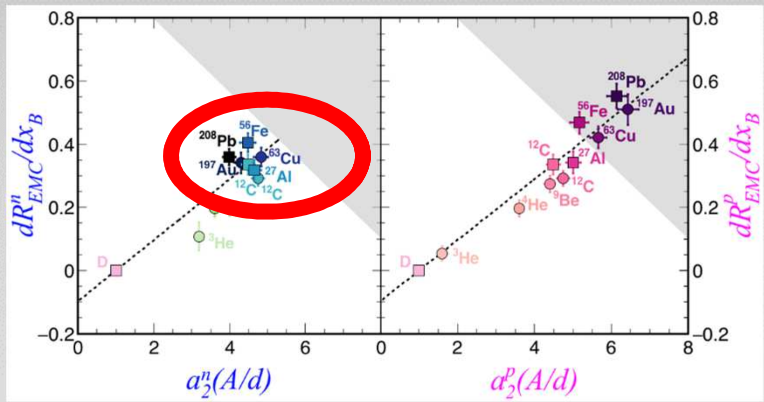
EMC: Nucleons are normally normal except when close to others. Protons a more medium modified than neutron











Predictions:

EMC effect is isospin dependent

EMC-SRC hypothesis universal modification

$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A \underbrace{\left(\Delta F_2^p + \Delta F_2^n\right)}_{\text{Nucleus-independent}}$$

Nucleus-independent

Baryons 2022

7-11 November, Sevilla

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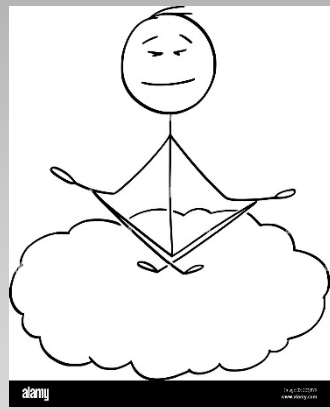
Free ≠ bound nucleon

neutron

free

I have only 15 min

Bound



I am here for ever

Adapted from Rolf

Valance quarks

sea quarks

anti quarks

gluons

Structure functions

PDF

GPDF

TMD

All these particles you cannot see. That's what drove me to drink. But now I can see them.

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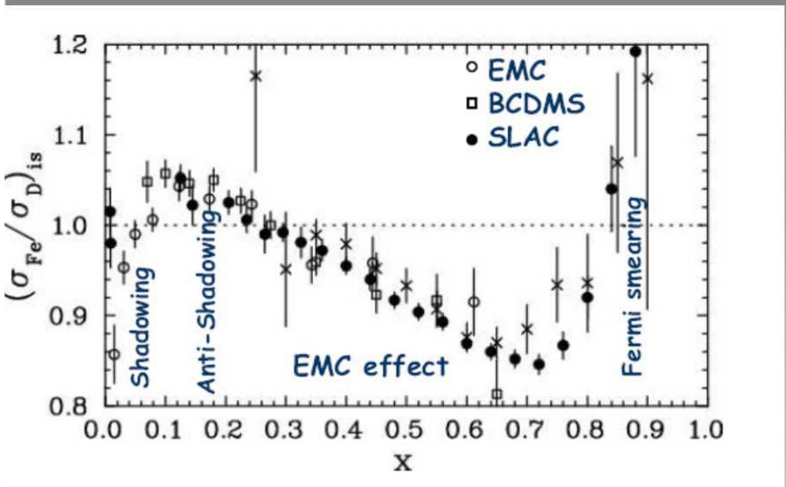
Free ≠ bound nucleon

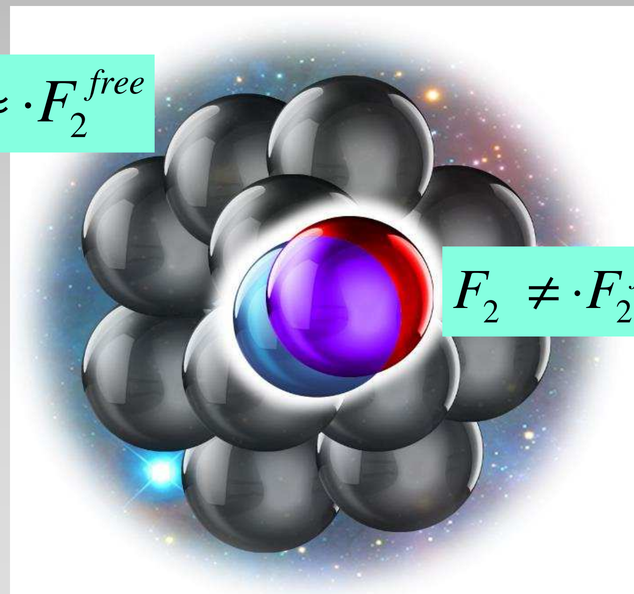


Suppression of quark momenta in nuclei (EMC Effect)

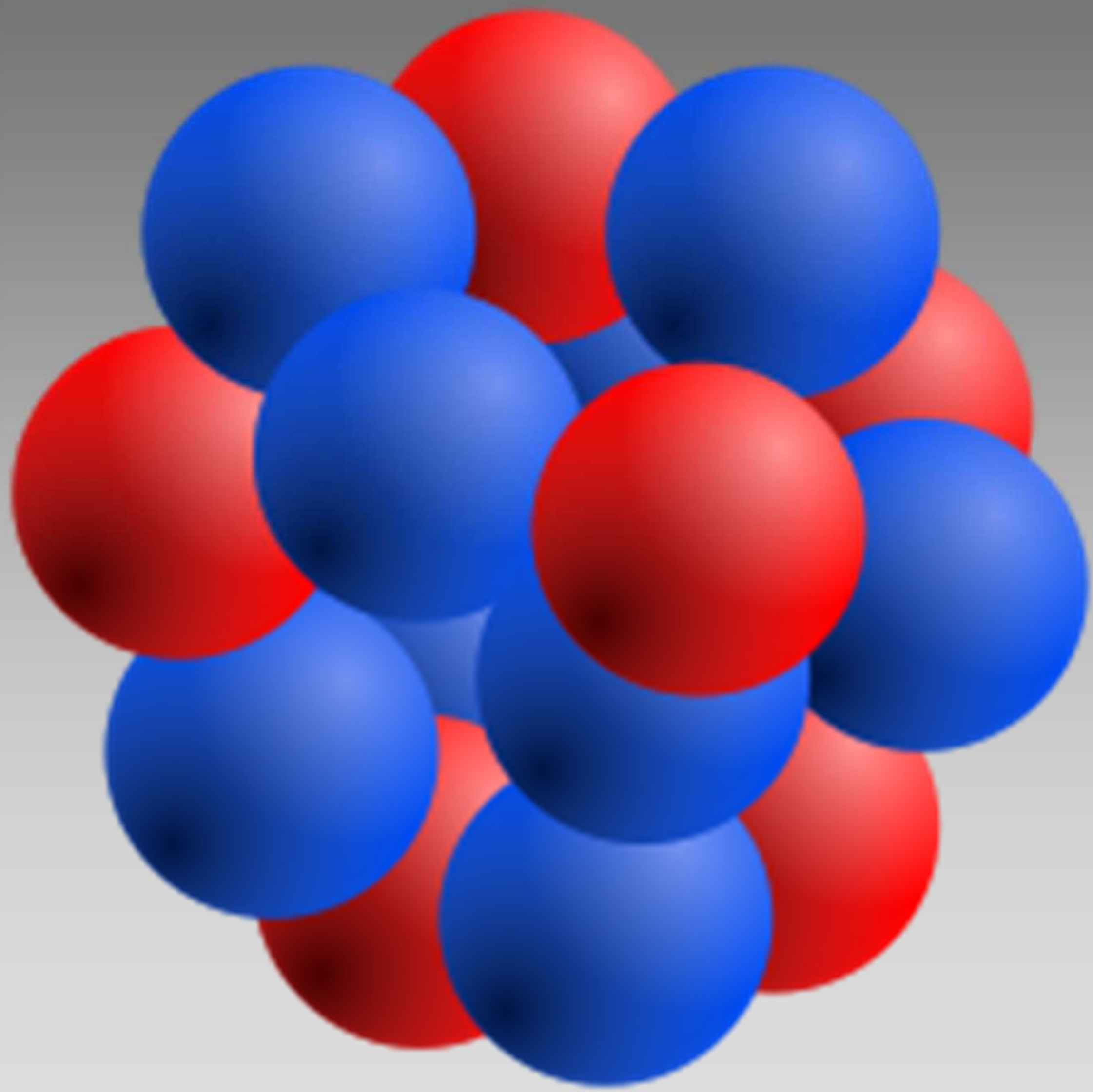
EMC Effect

$$F_2^A \neq Z \cdot F_2^p + N \cdot F_2^n$$

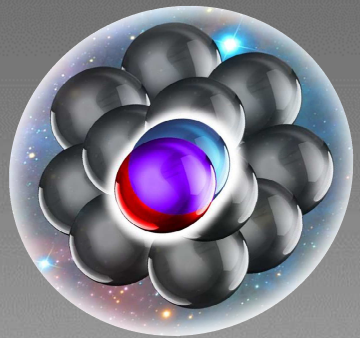
$$F_2 \approx \cdot F_2^{free}$$

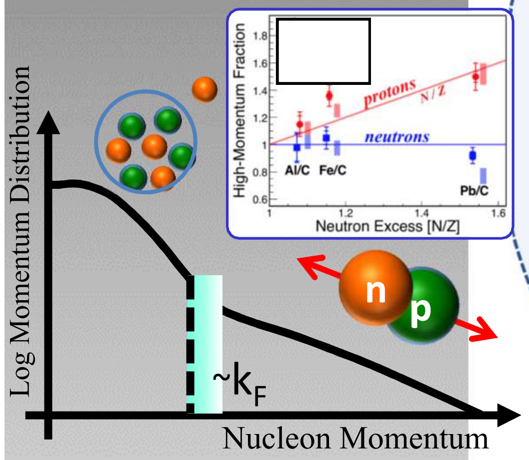


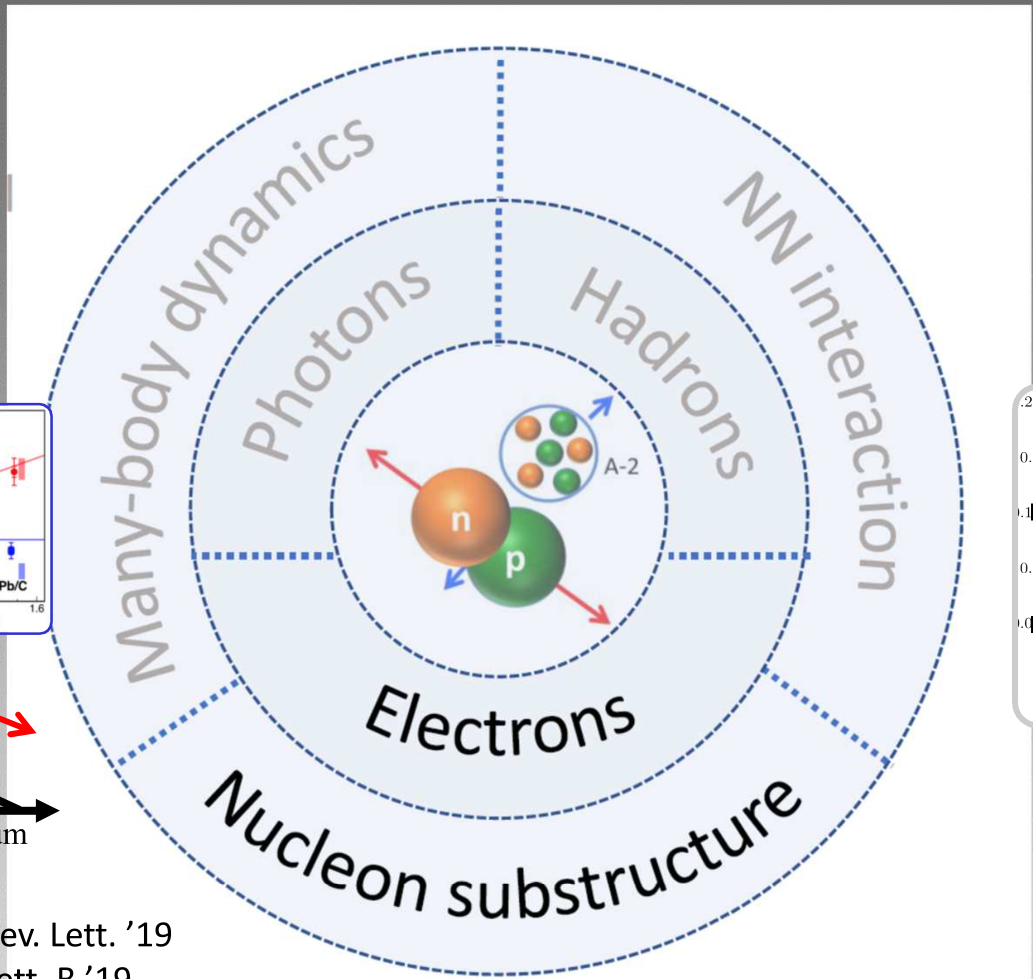
$$F_2 \neq \cdot F_2^{free}$$



SRC Universe with multimessenger studies

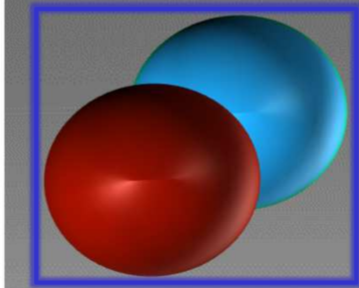


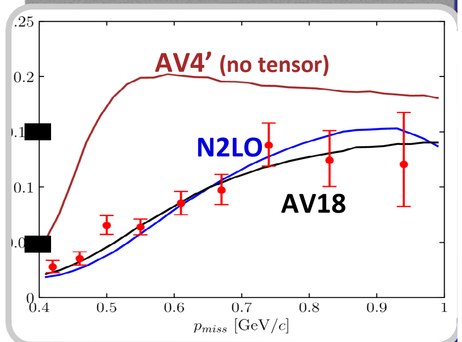




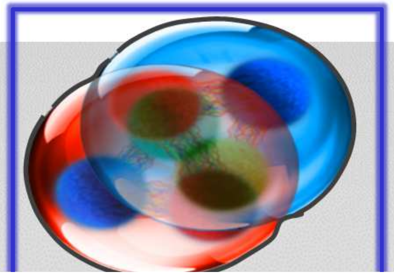
Nature '18
Phys. Rev. Lett. '18
Phys. Lett. B '18a
Phys. Lett. B '18b

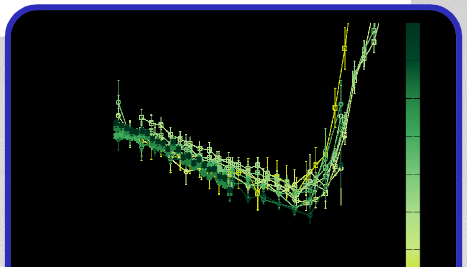
Phys. Rev. Lett. '19
Phys. Lett. B '19
Nature Phys. '21a
Nature Phys. '21b





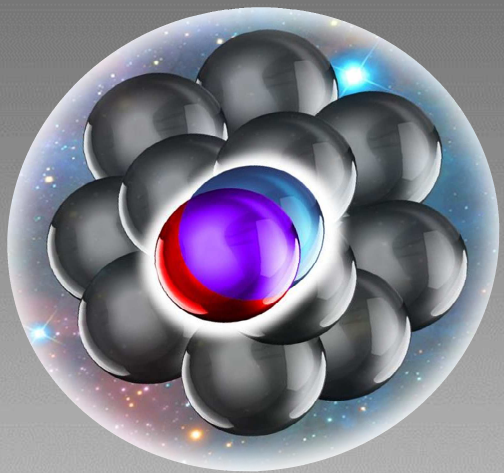
Nature '20
Phys. Rev. Lett. '20
Phys. Lett. B '20
Phys. Lett. B '21

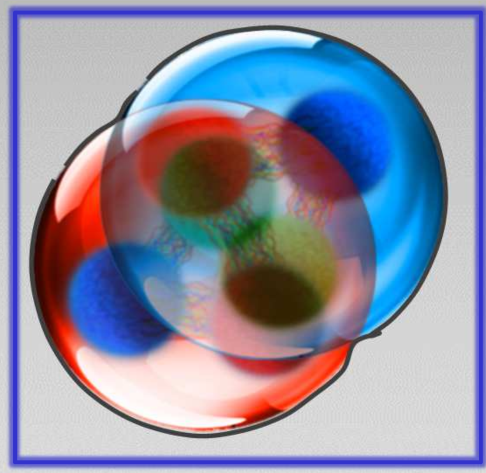




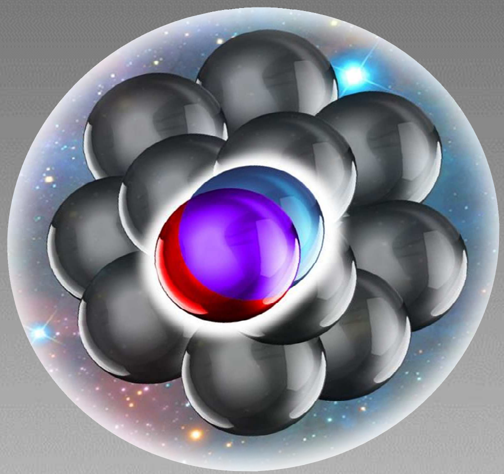
Nature '19
Phys. Rev. Lett. '20
Phys. Rev. Research '21

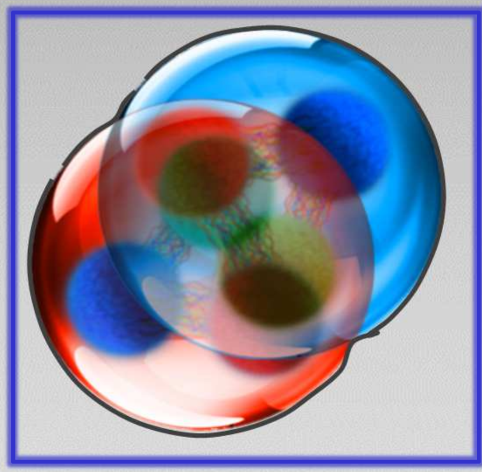
SRC ⇒ nucleon structure





nPDF → SRC





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Valance quarks

sea quarks

anti quarks

gluons

Structure functions

PDF

GPDF

TMD

All these particles you cannot see. That's what drove me to drink. But now I can see them.

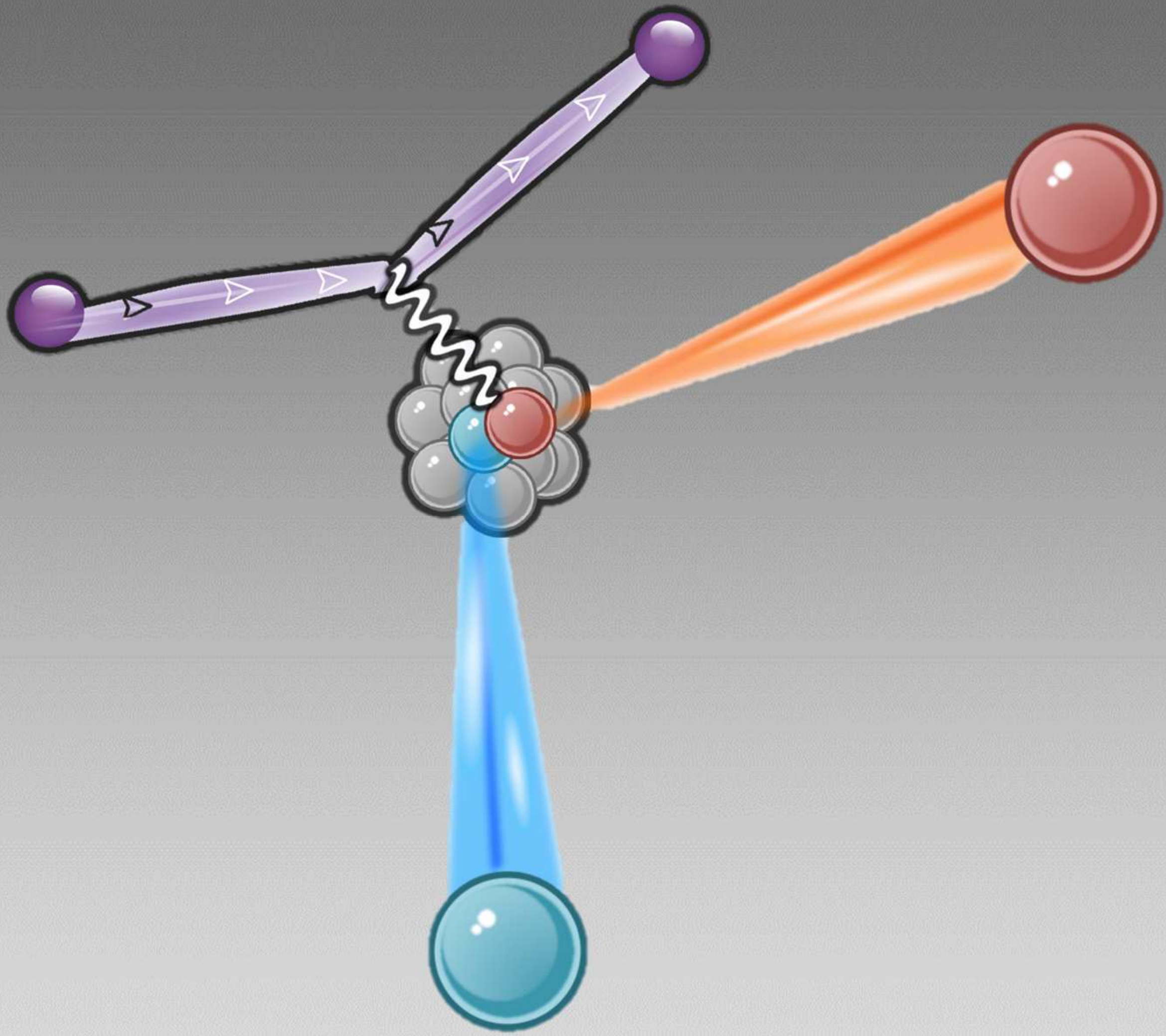
Is the distribution of partons in bound nucleons same as in free nucleons ?

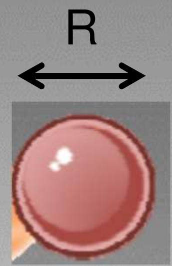
$$F_2^A(x,Q^2) = Z \cdot F_2^p(x,Q^2) + N \cdot F_2^n(x,Q^2)$$

$$F_2^d(x,Q^2) = F_2^p(x,Q^2) + F_2^n(x,Q^2)$$

free neutron?

How do we study SRC?



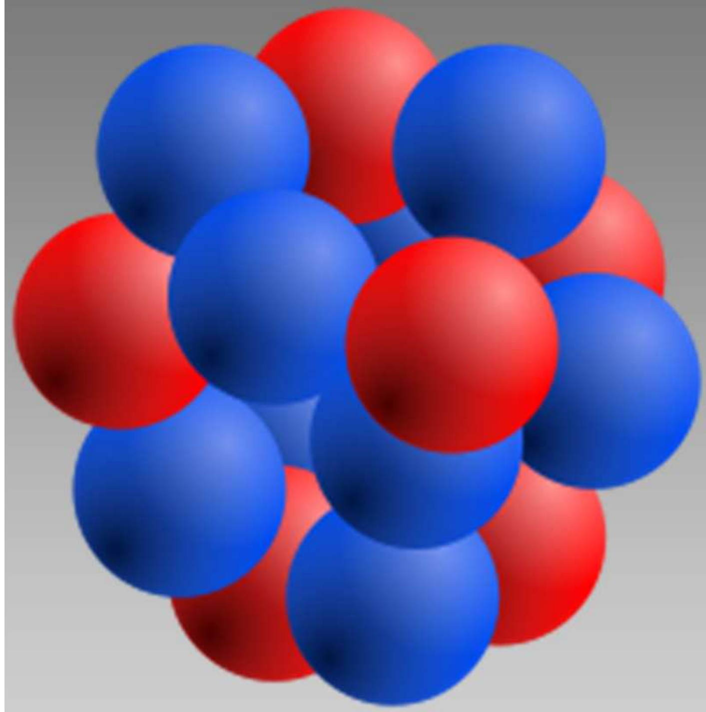


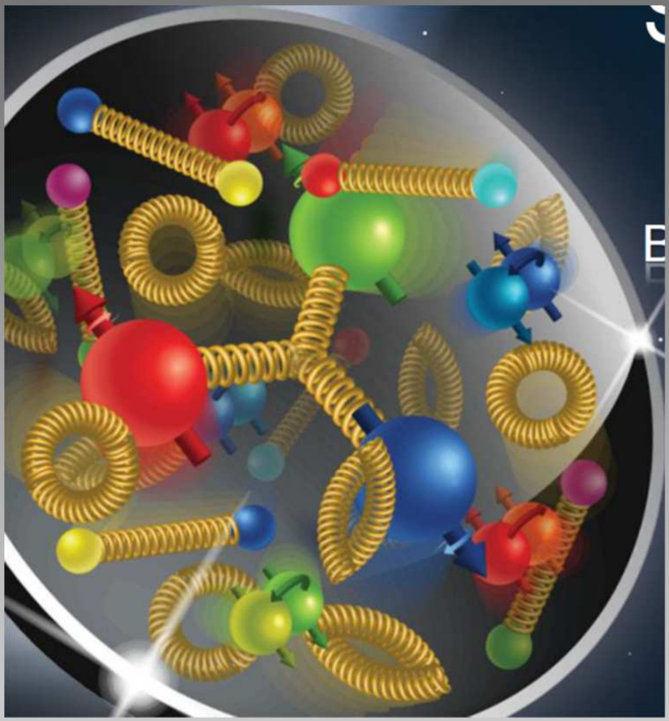
$\lambda < R$

$q \cdot R < 1$

$X_B > 1$

Exclusive hard scattering in selected kinematics (electron, photon, hadron, and nuclei scattering)





B.E ~10 Mev

Confinement ~1 Gev/c

Low energy nuclear physics

high energy particle physics

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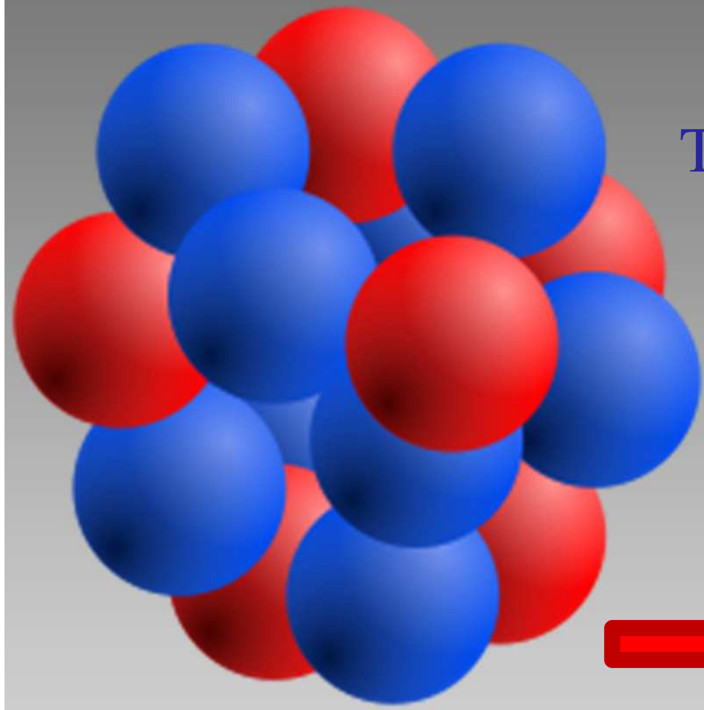

The EMC effect

2N SRC

B.E ~10 Mev

Confinement ~1 Gev/c

Low energy nuclear physics

high energy particle physics