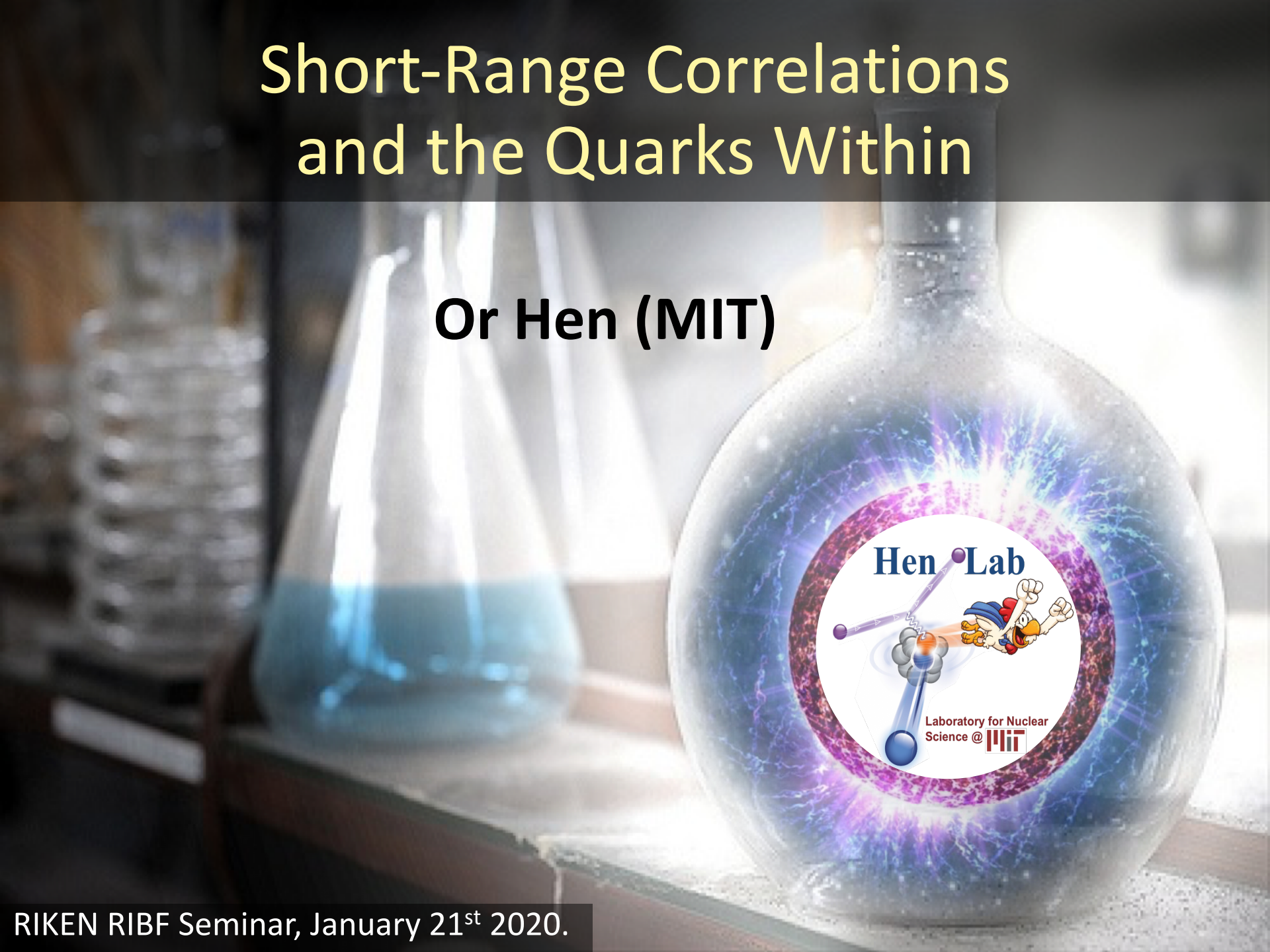
Short-Range Correlations and the Quarks Within

Or Hen (MIT)



RIKEN RIBF Seminar, January 21st 2020.

Starting from the end:

- Short-range part of the NN interaction
  still largely unknown.

- Role of quark degrees of freedom in nuclei
  still largely unknown.

- Role of relativity in nuclei
  still largely unknown.

➔ **Exclusive electron scattering data can address all of these issues, and more!**

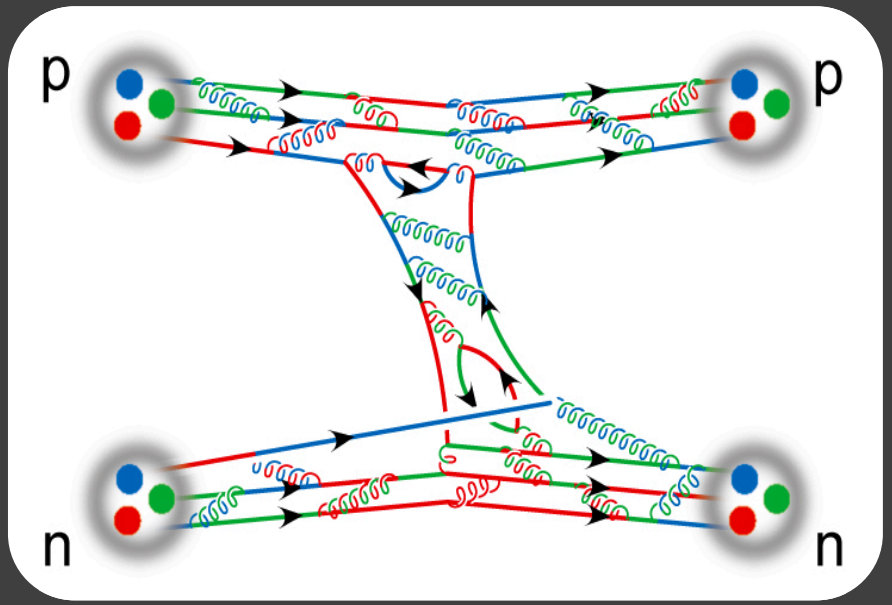
Now to the beginning….

The Nuclear Challenge

1. Many-body problem

$$\sum_i \left\{ -\frac{\hbar^2}{2m_i} \nabla_i^2 \Psi(\vec{r}_1, \ldots, \vec{r}_N, t) \right\} + U(\vec{r}_1, \ldots, \vec{r}_N) \Psi(\vec{r}_1, \ldots, \vec{r}_N, t) = i\hbar \frac{\partial}{\partial t} \Psi(\vec{r}_1, \ldots, \vec{r}_N, t)$$

2. Complex QCD interaction

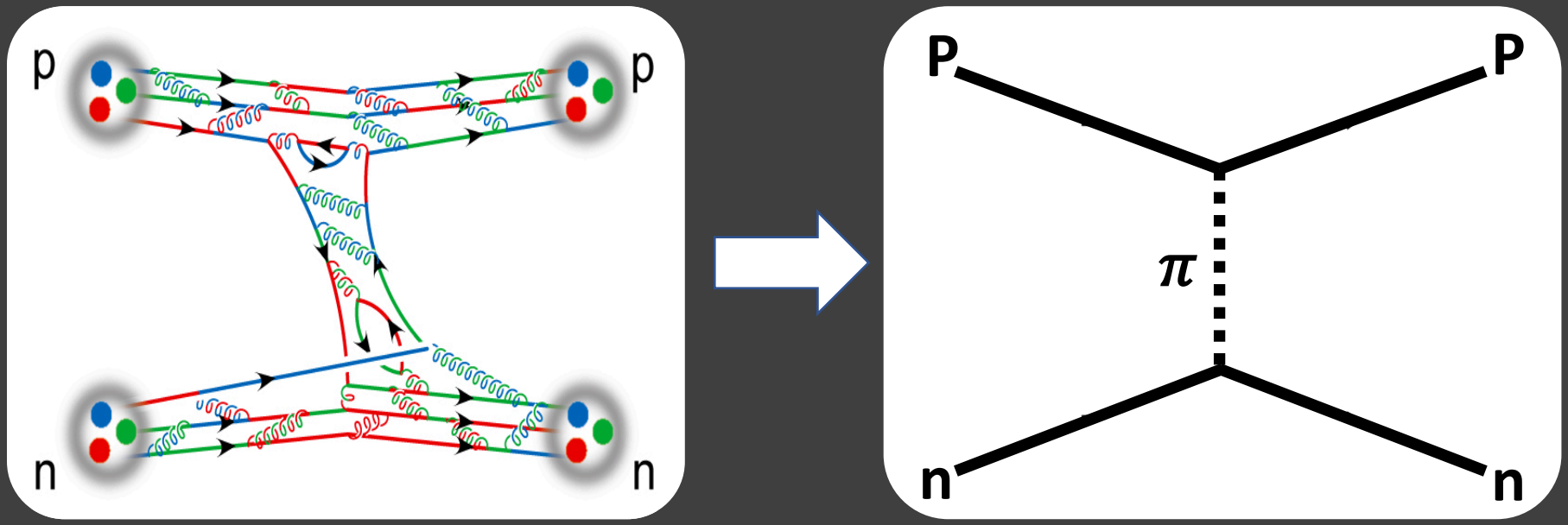


The Nuclear Challenge

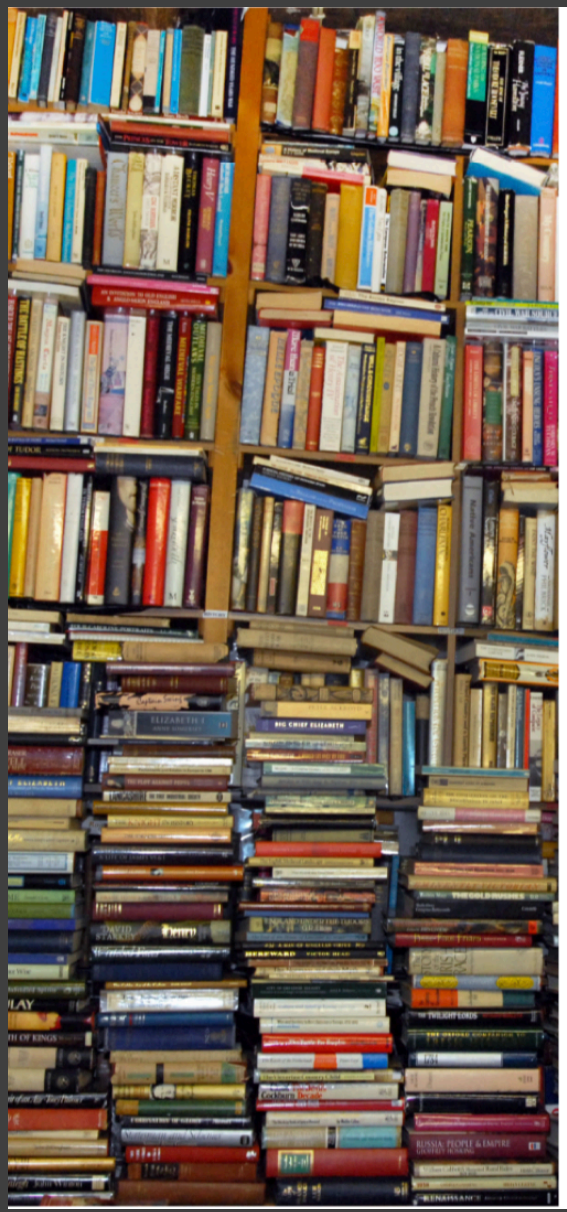
1. Many-body problem

   ➔ **Numerical techniques** (Quantum Monte Carlo, Lattice, SCGF, HH, Coupled Clusters, …)

2. Complex ~~QCD~~ **Effective interactions**



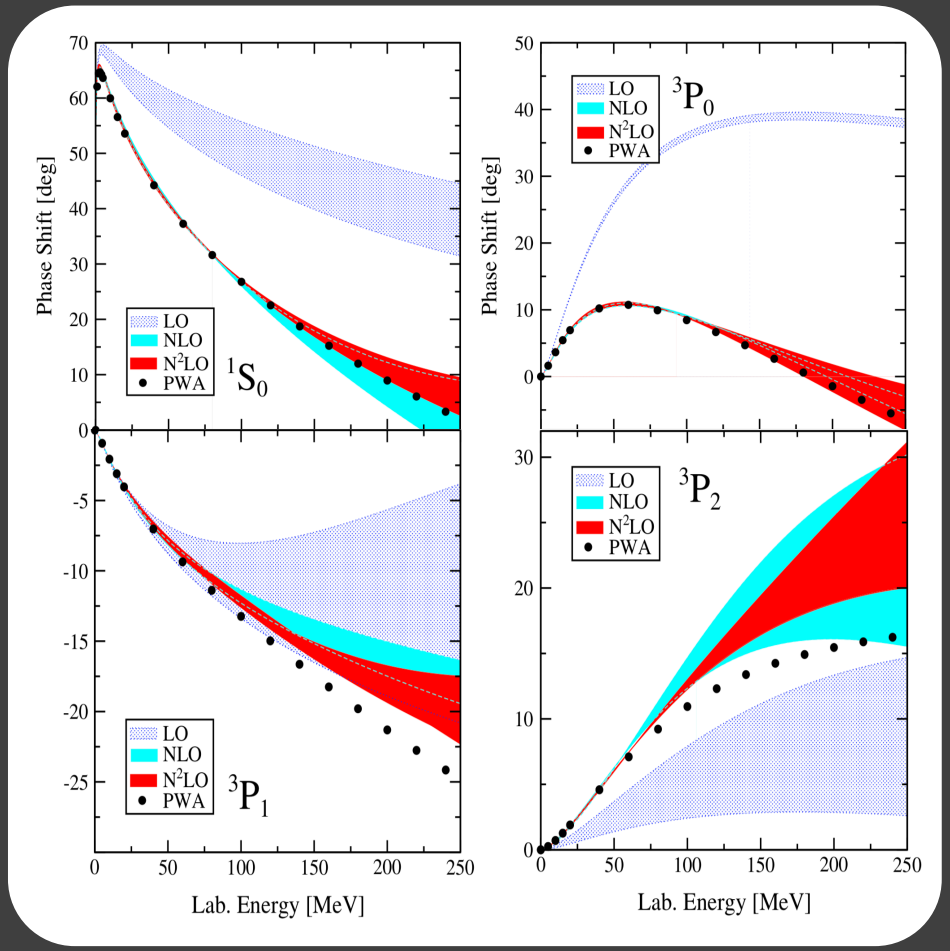
Many ways to derive effective interactions



- Hamada-Johnston Potential
- Yale-Group Potential
- Reid68 Potential
- Reid-Day Potential
- Partovi-Lomon Potential
- Paris-Group Potentials
- Stony-Brook Potential
- dTRS Super-Soft-Core Potentials
- Funabashi Potentials
- Urbana-Group Potentials
- Argonne-Group Potentials
  - Argonne V14
  - Argonne V28
  - Argonne V18
- Bonn-Group Potentials
  - Full-Bonn Potential
  - CD-Bonn Potential
- Padua-Group Potential
- Nijmegen-Group Potentials
  - Nijm78 Potential
  - Partial-Wave-Analysis
  - Nijm93
  - Nijml
  - NijmII
  - Reid93 Potential
  - Extended Soft-Core
  - Nijmegen Optical Potentials
- Hamburg-Group Potentials
- Moscow-Group Potentials
- Budapest(IS)-Group Potential
- MIK-Group Potential
- Imaginary Potentials
- QCD-Inspired Potentials
- The Oxford Potential
- The First CHPT NN Potentials
- Sao Paulo-Group CHPT Potentials
- Munich-Group CHPT Potentials
- Idaho-Group CHPT Potentials
- Bochum-Julich-Group CHPT Potentials
  - LO Potentials
  - NLO Potentials
  - NNLO Potentials
  - NNNLO Potentials
- **and more!**

Common features of all models

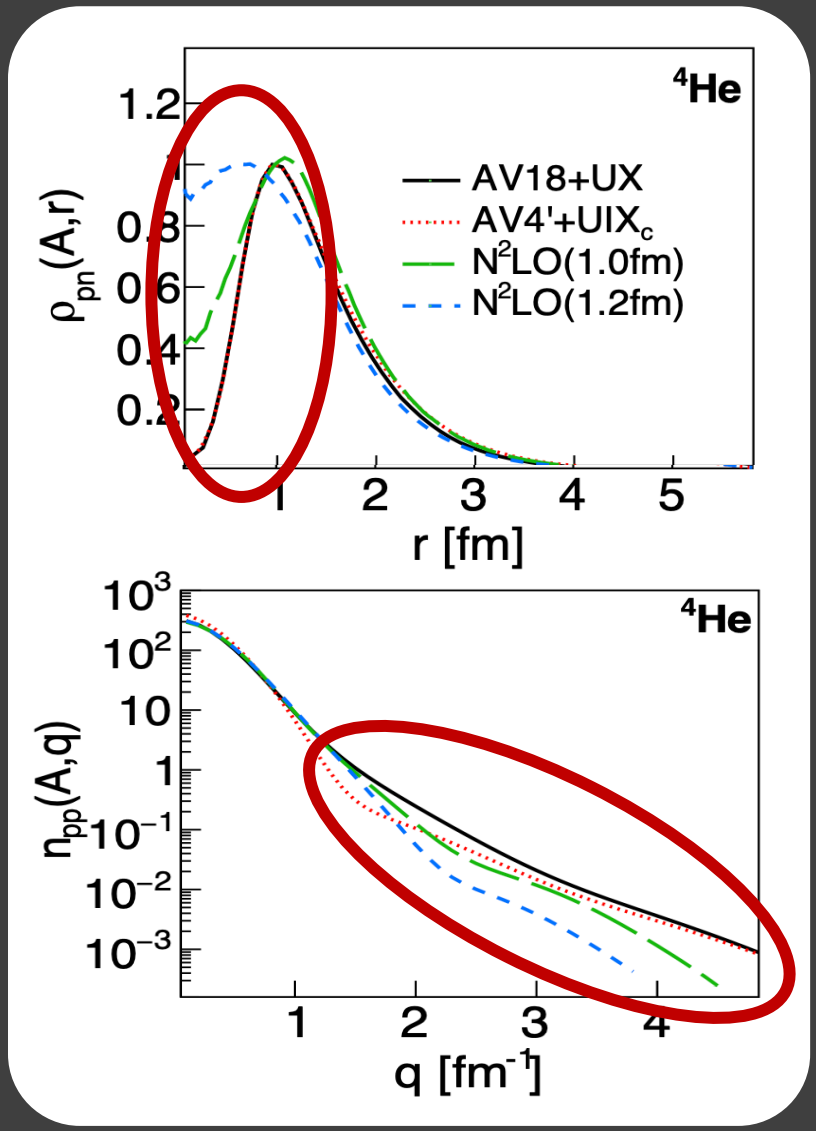
1. Contain experimentally determined parameters.



Common features of all models

1. Contain experimentally determined parameters.

2. Large model dependence at short-distance / high-momentum.

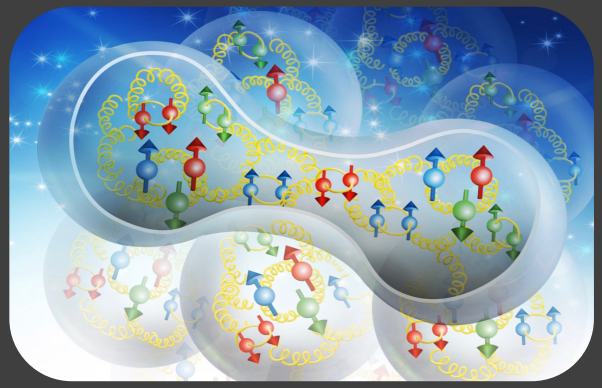


Short-distance interactions: still a challenge

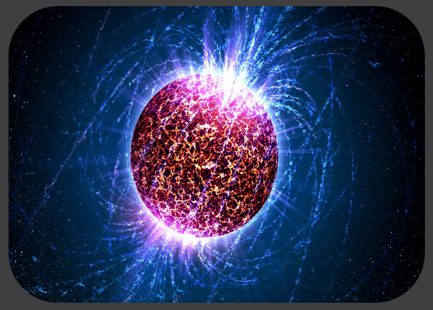
Short-distance interactions: still a challenge

Required for a high-resolution, first principle, description of nuclear systems & processes.

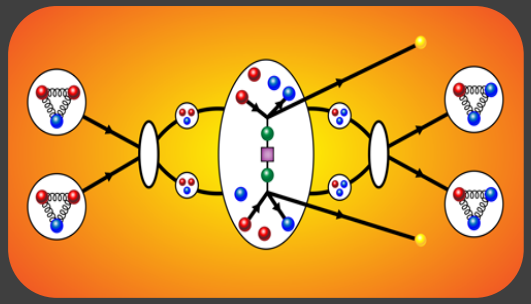
NN interaction from QCD & QCD in nuclei

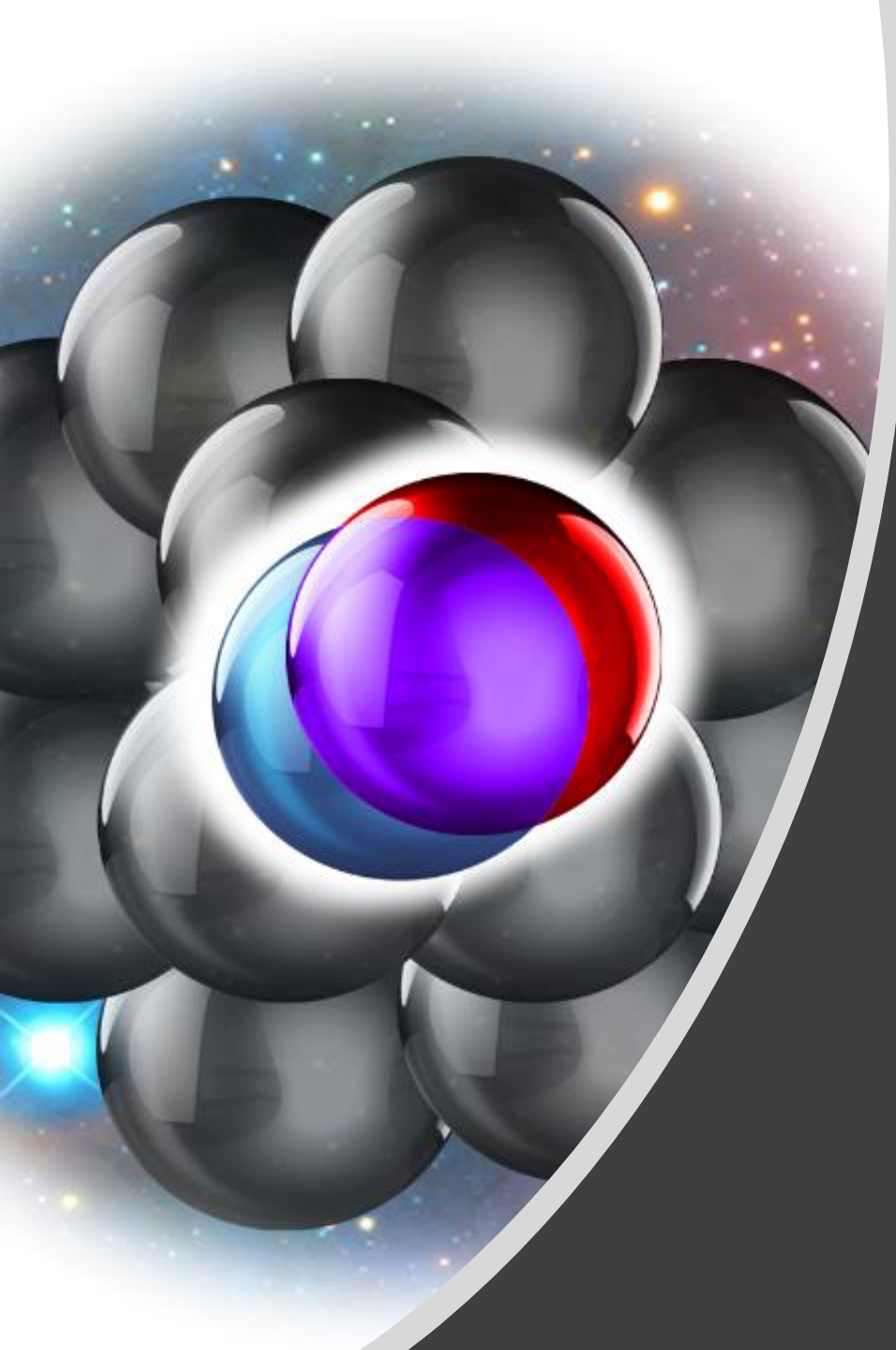


High-density systems



High-q processes
(e.g. $0\nu\beta\beta$ decay)

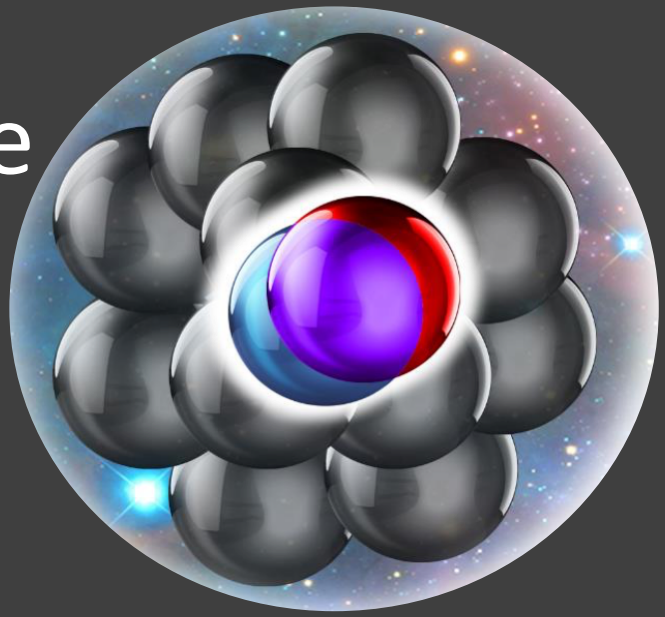




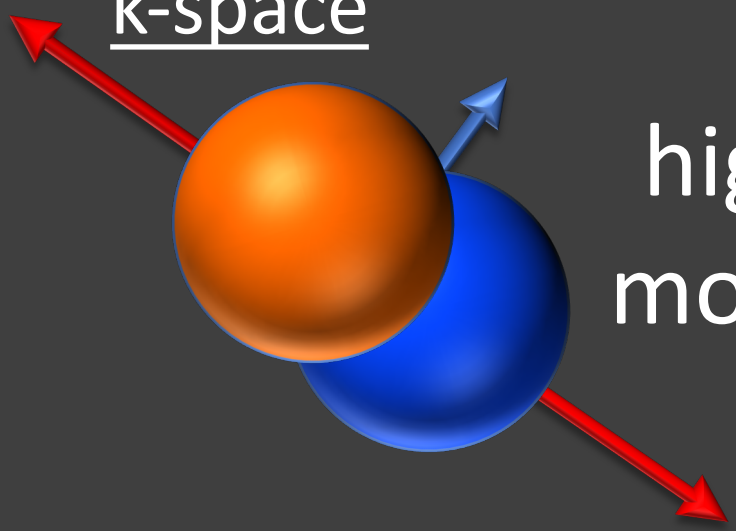
Short-Range Correlations (SRC)

Nucleon pairs that are close together in the nucleus

r-space

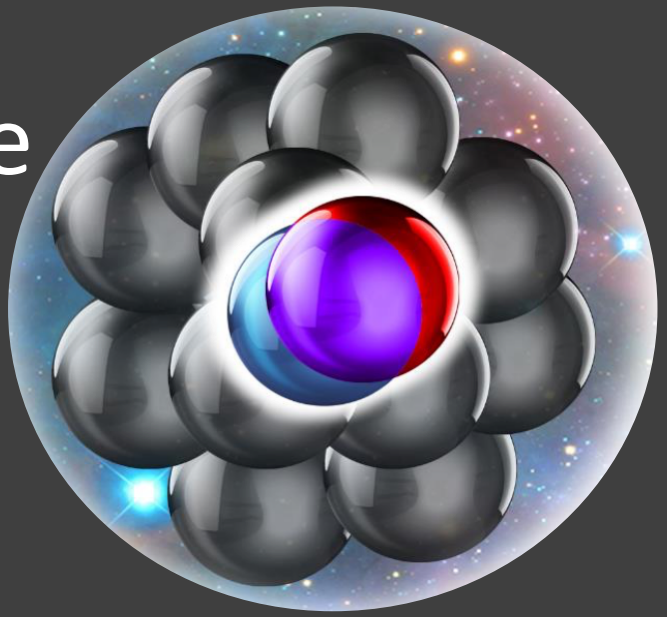


k-space



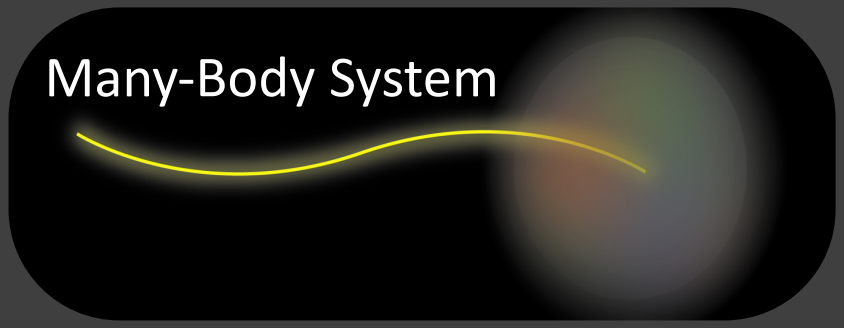
high ***relative*** and low ***c.m.*** momentum compared to k_F

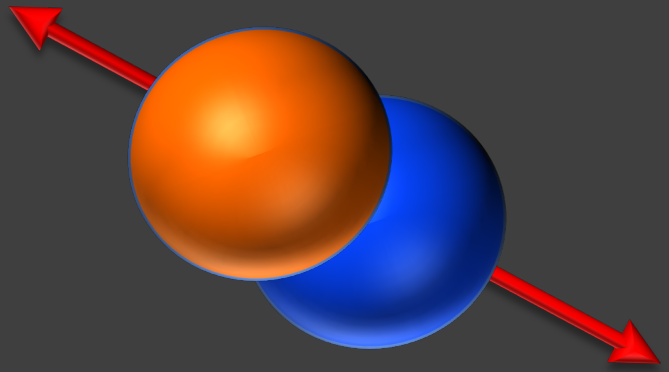
r-space

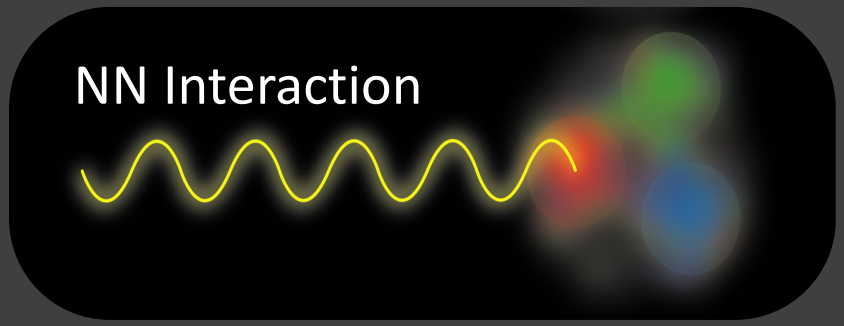


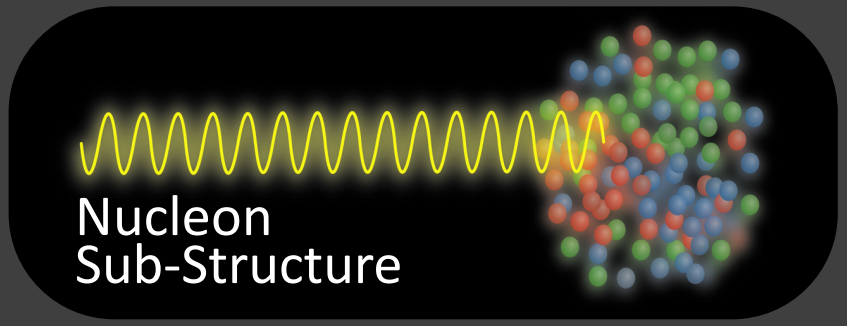
Nucleon pairs that are close together in the nucleus

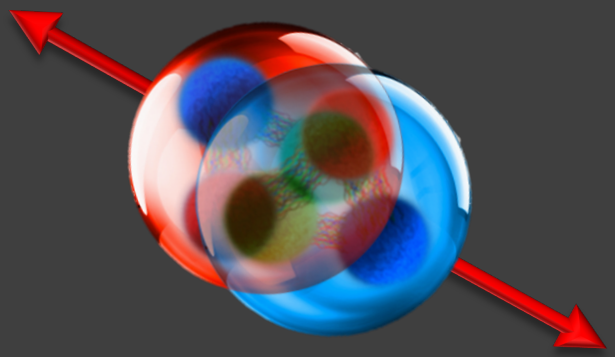
Today: SRCs Across Scales



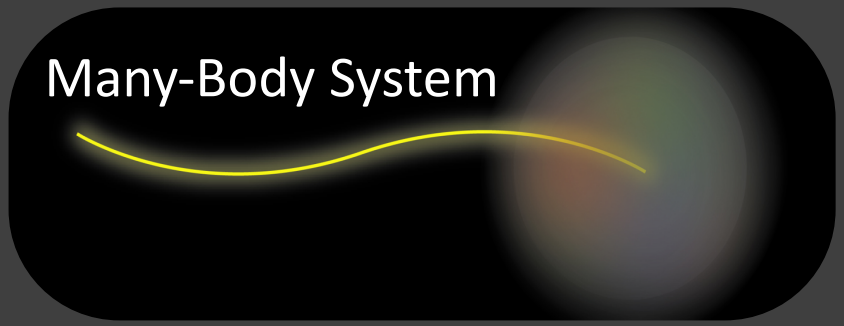


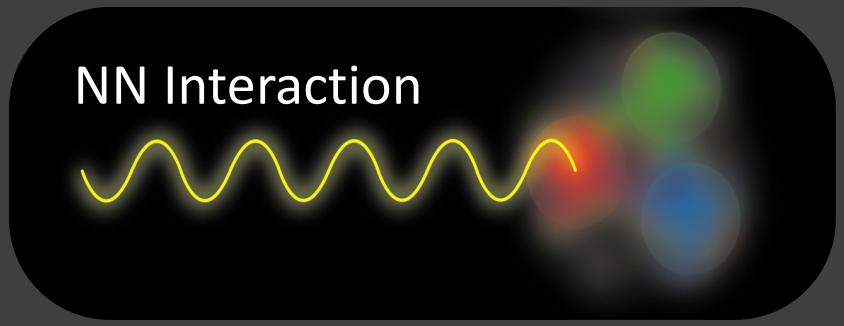


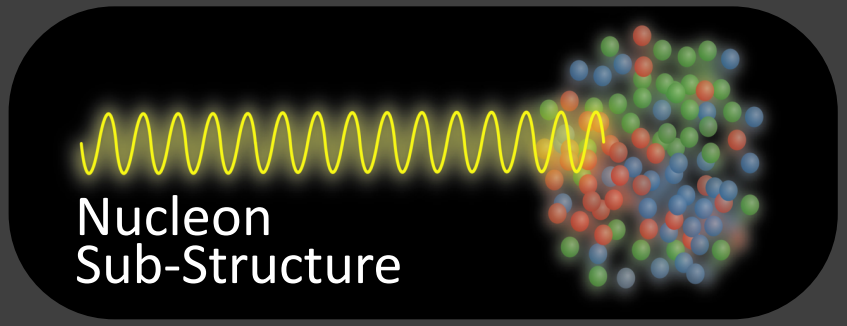




Today: SRCs Across Scales



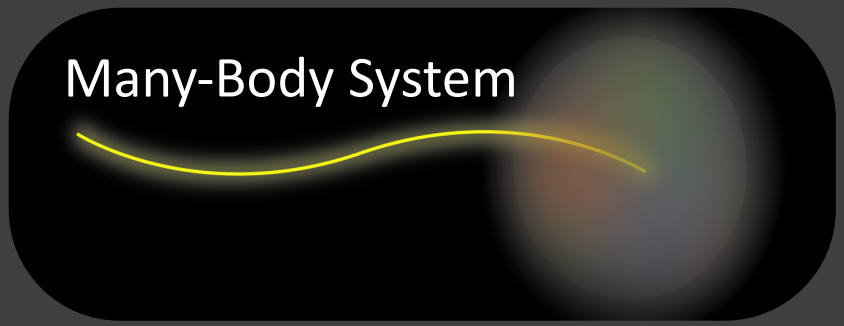


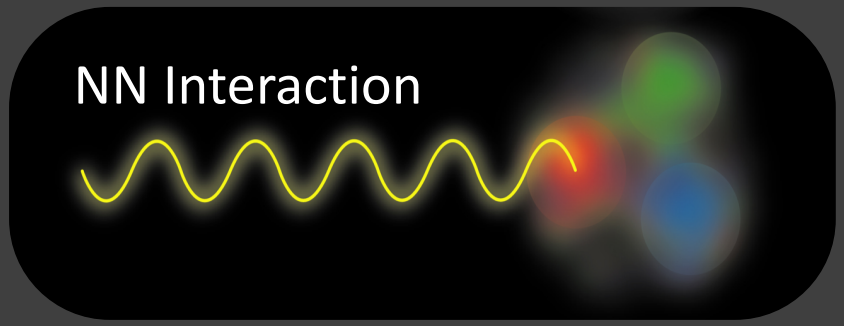


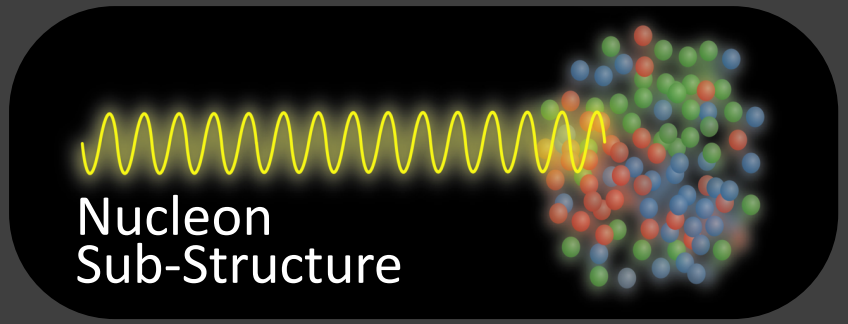
2018-20 SRC Publications:

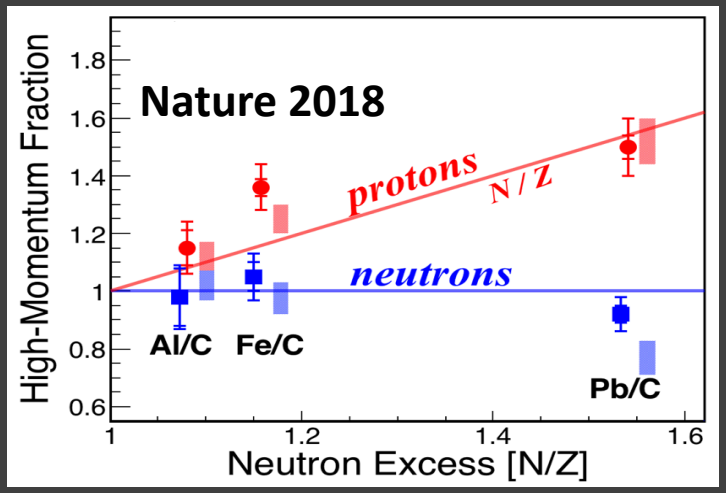
- Nature, In-Print (2020)
- Nature 566, 354 (2019)
- Nature 560, 617 (2018)
- PRL 122, 172502 (2019)
- PRL 121, 092501 (2018)
- Phys. Lett. B 800, 135110 (2019)
- Phys. Lett. B 797, 134890 (2019)
- Phys. Lett. B 797, 134792 (2019)
- Phys. Lett. B 791, 242 (2019)
- Phys. Lett. B 793, 360 (2019)
- Phys. Lett. B 785, 304 (2018)
- Phys. Lett. B 780, 211 (2018)
- Chin Phys. C 42, 064105 (2018)

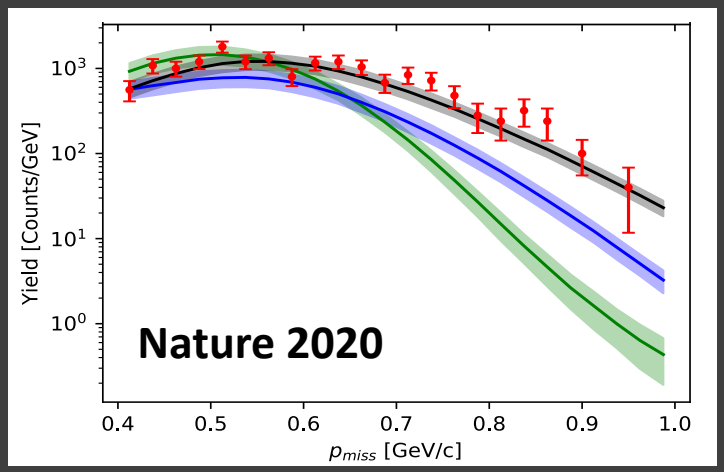
arXiv: 1908.02223; 1907.03658

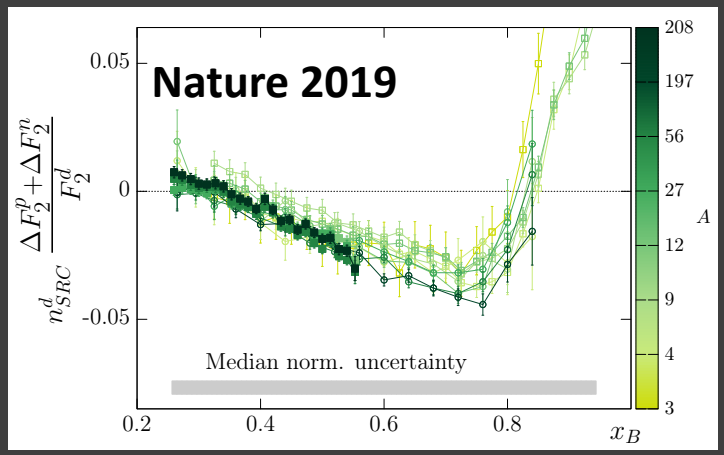

Many-Body System


NN Interaction

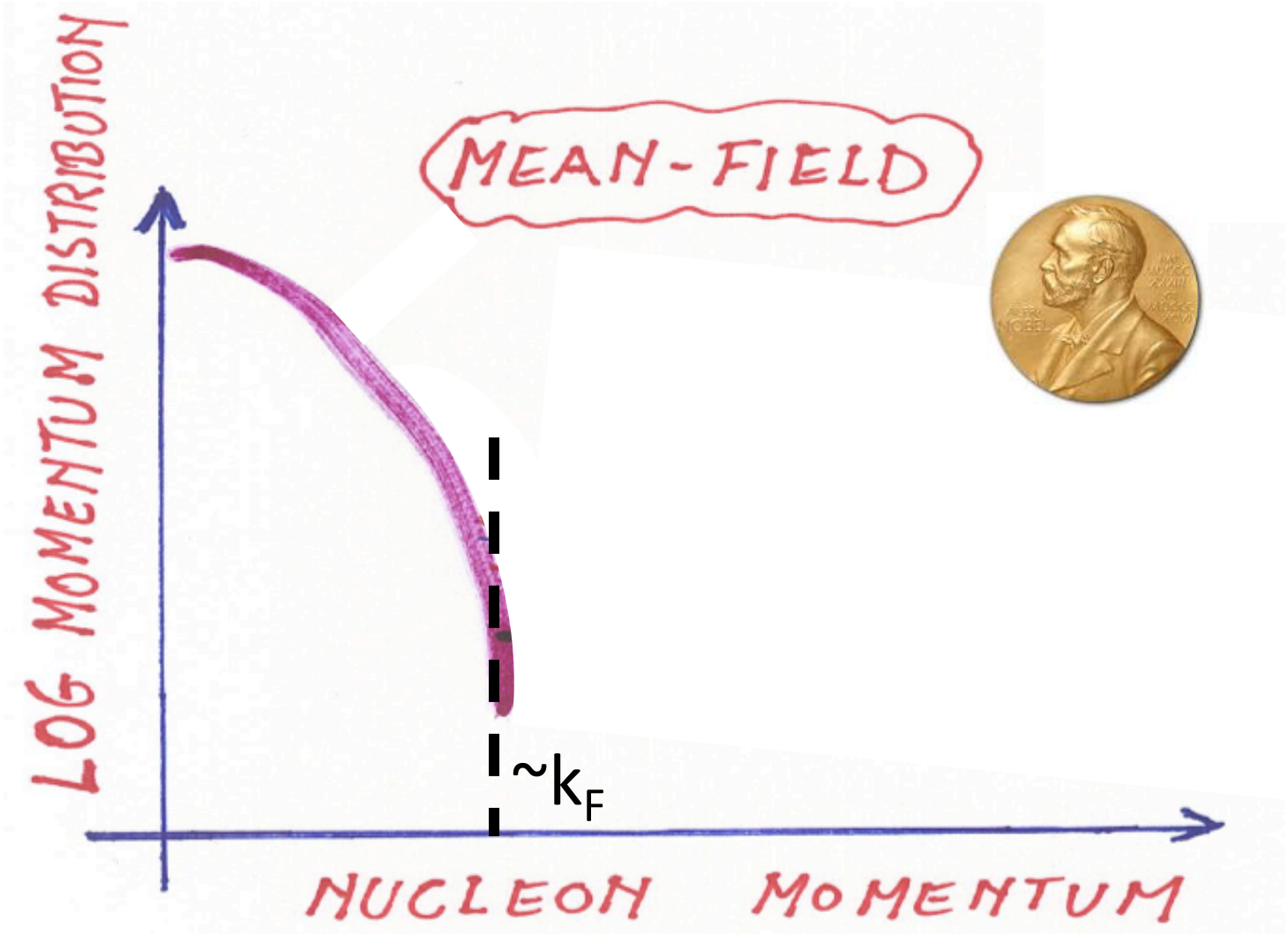

Nucleon
Sub-Structure

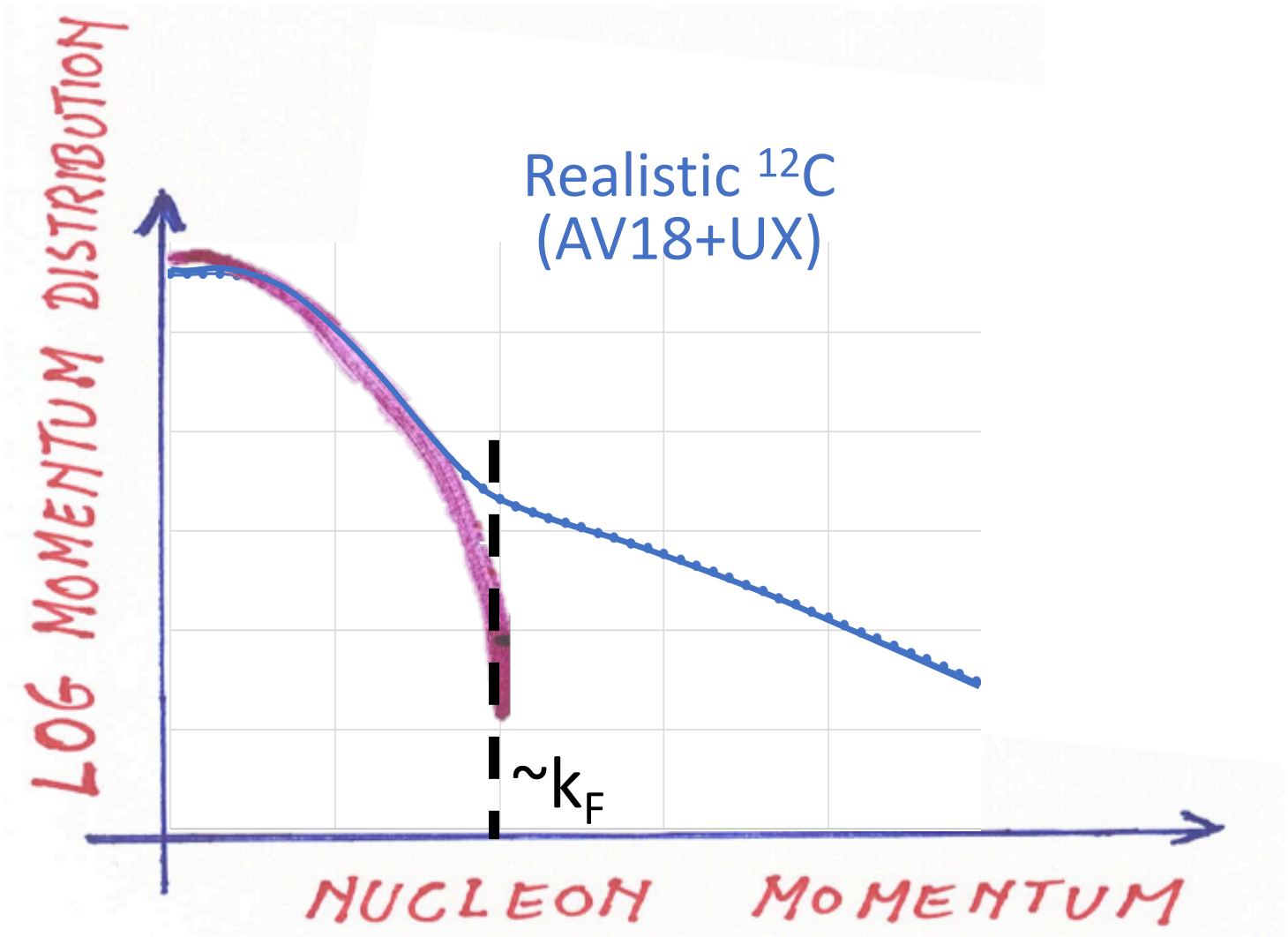

Nature 2018
High-Momentum Fraction
Neutron Excess [N/Z]
protons
N / Z
neutrons
Al/C
Fe/C
Pb/C
1.8
1.6
1.4
1.2
1
0.8
0.6
1
1.2
1.4
1.6


Nature 2020
Yield [Counts/GeV]
p_{miss} [GeV/c]
10^3
10^2
10^1
10^0
0.4
0.5
0.6
0.7
0.8
0.9
1.0

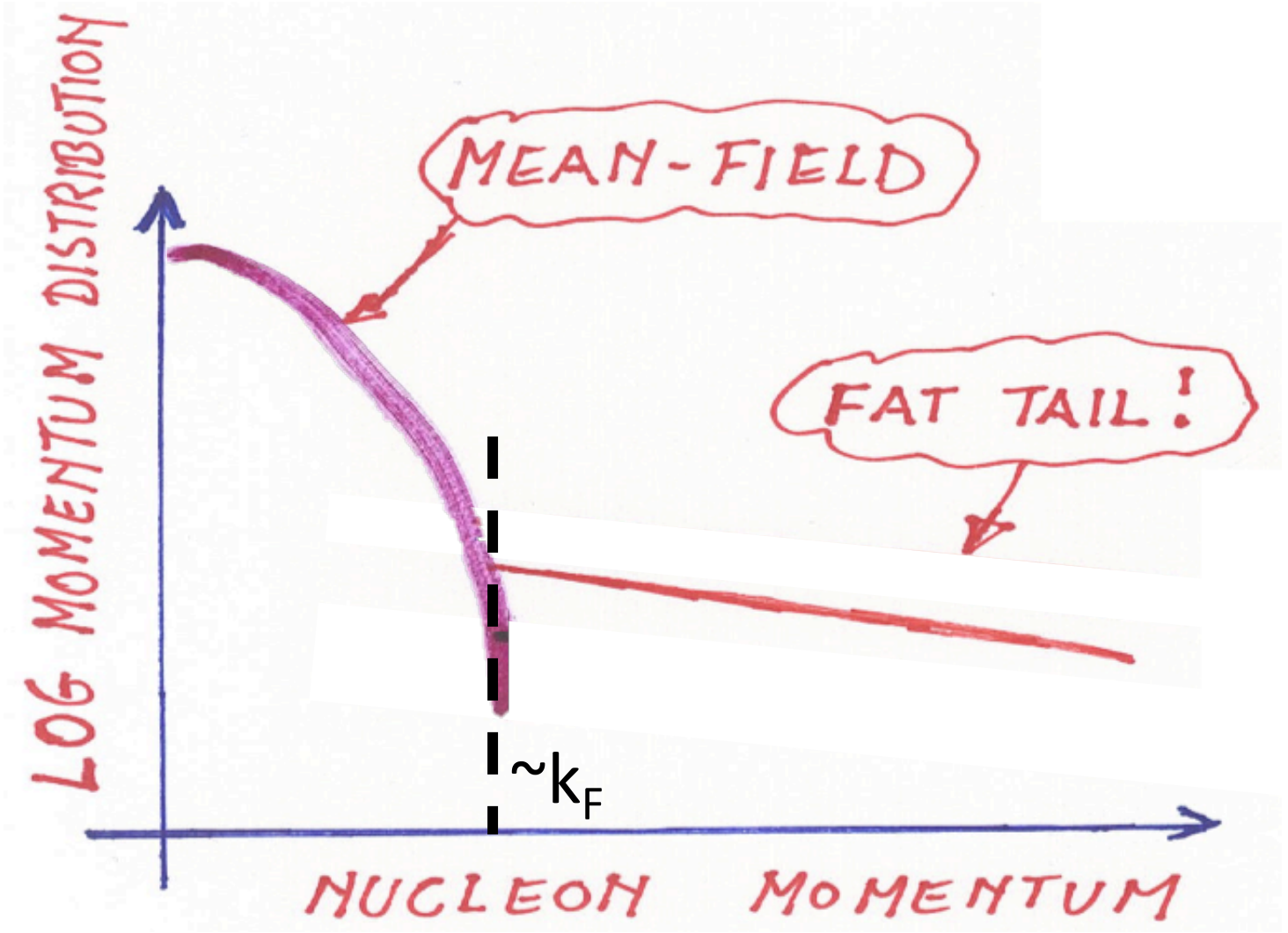

Nature 2019
$\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} \frac{1}{n_{SRC}^d}$
x_B
Median norm. uncertainty
0.05
0
-0.05
0.2
0.4
0.6
0.8
208
197
56
27
12
9
4
3
A

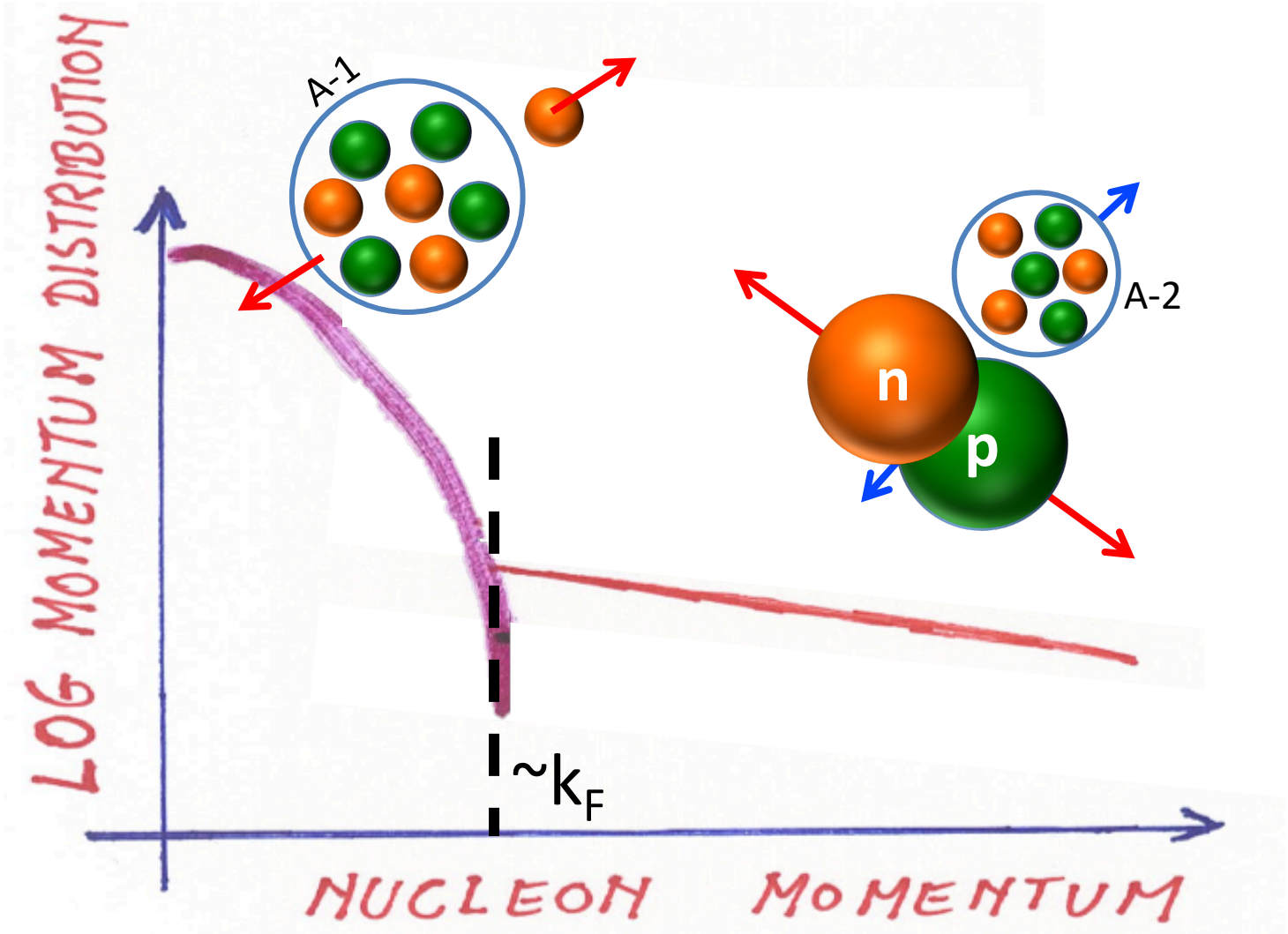
Looking For Correlations



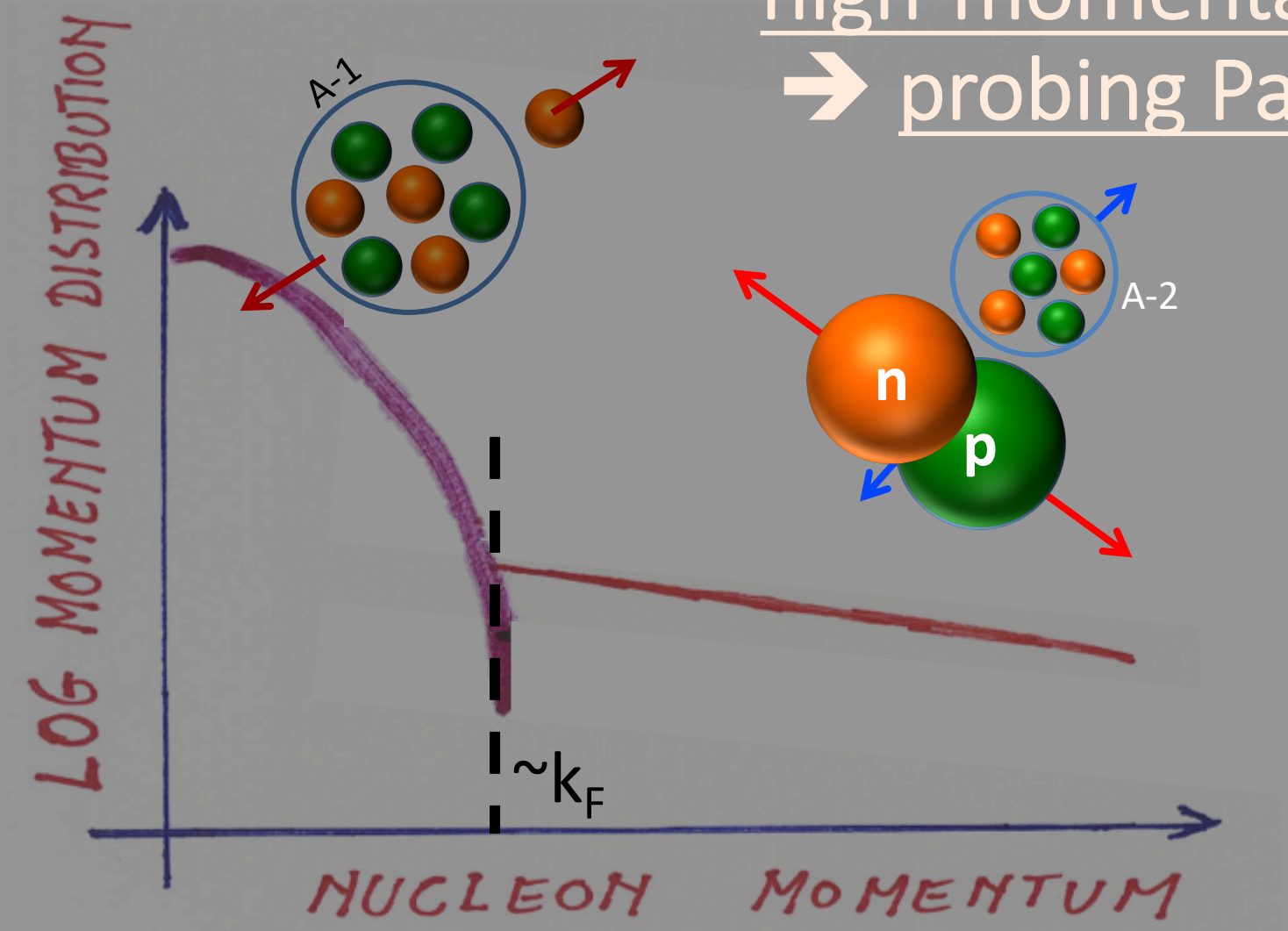


Wiringa, PRC (2014); Carlson, RMP (2015); …

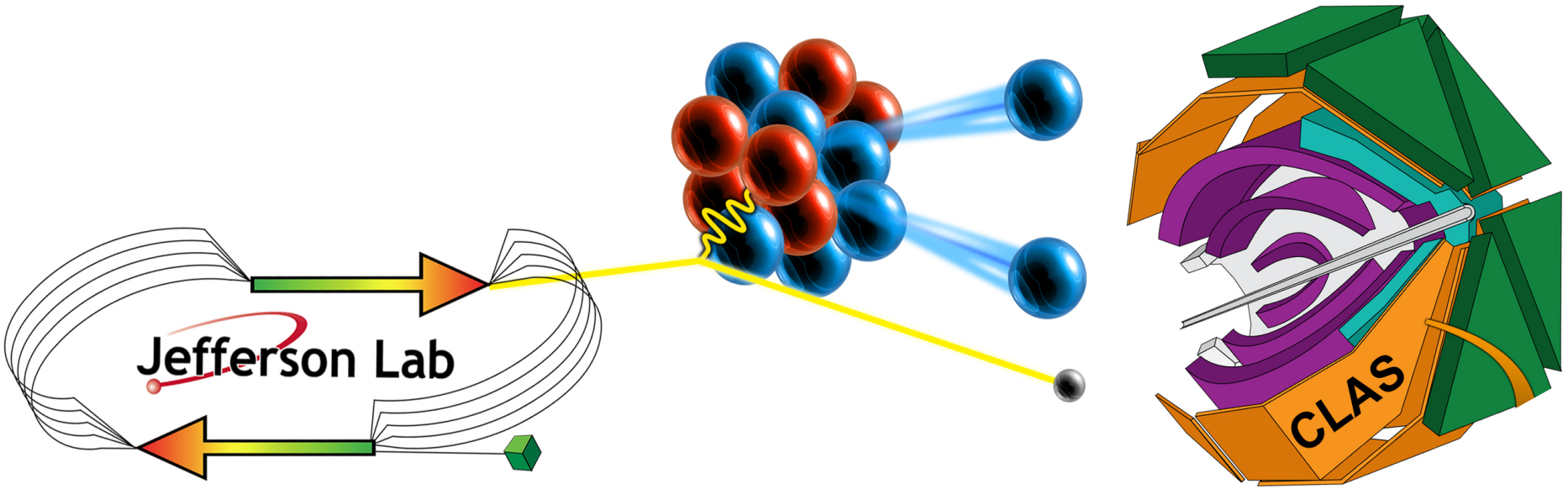

LOG MOMENTUM DISTRIBUTION
MEAN-FIELD
FAT TAIL!
~k_F
NUCLEON MOMENTUM


LOG MOMENTUM DISTRIBUTION
A-1
A-2
n
p
~k_F
NUCLEON MOMENTUM

high-momenta ➔ probing Pairs



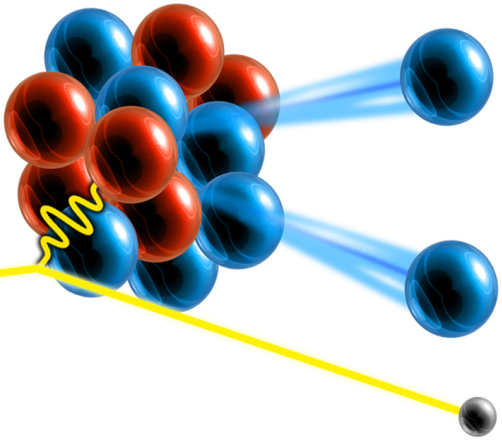
Breakup the pair =>
Detect ***both*** nucleons

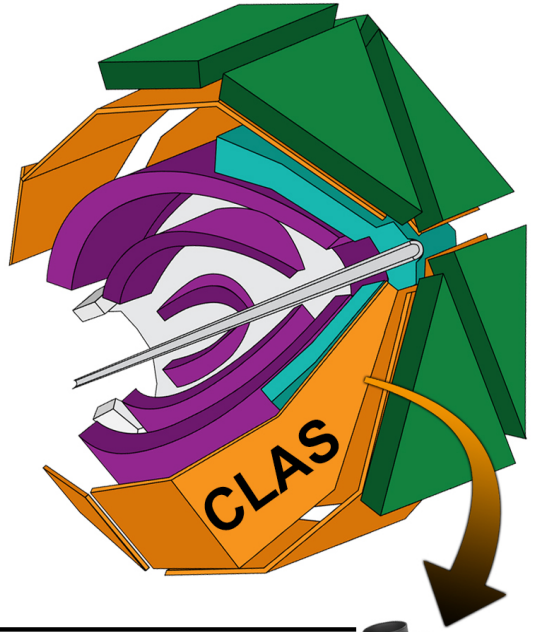


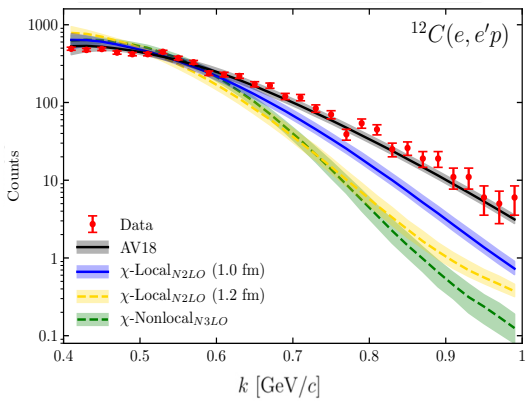
Breakup the pair =>

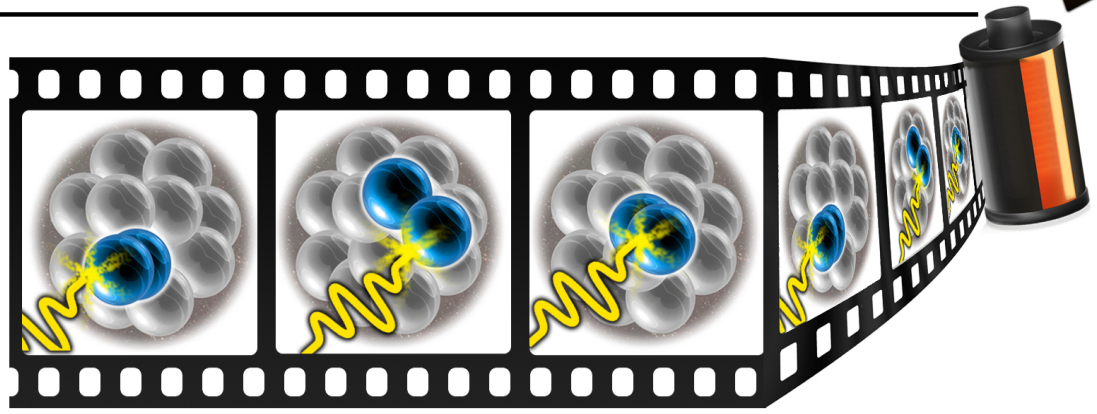
Detect ***both*** nucleons =>

Reconstruct ‘initial’ state



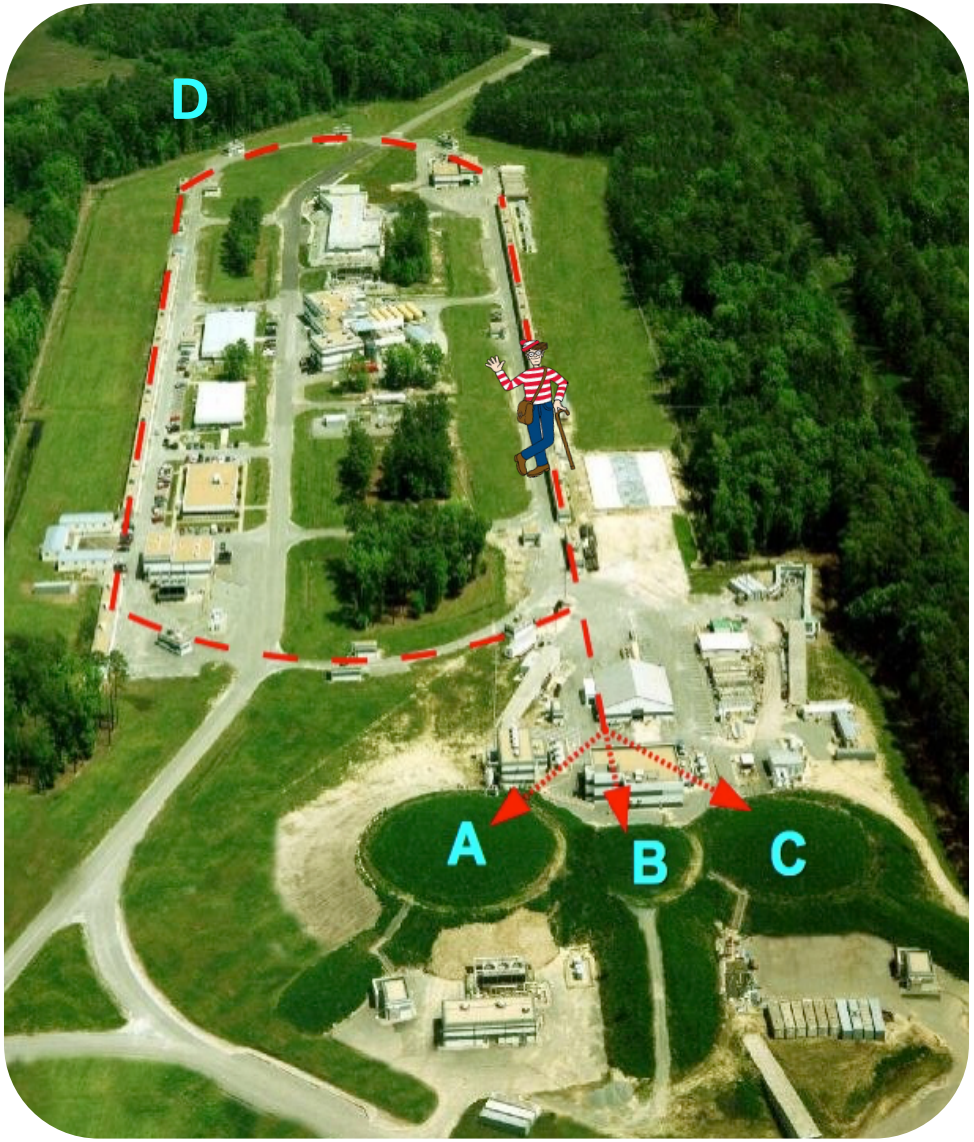




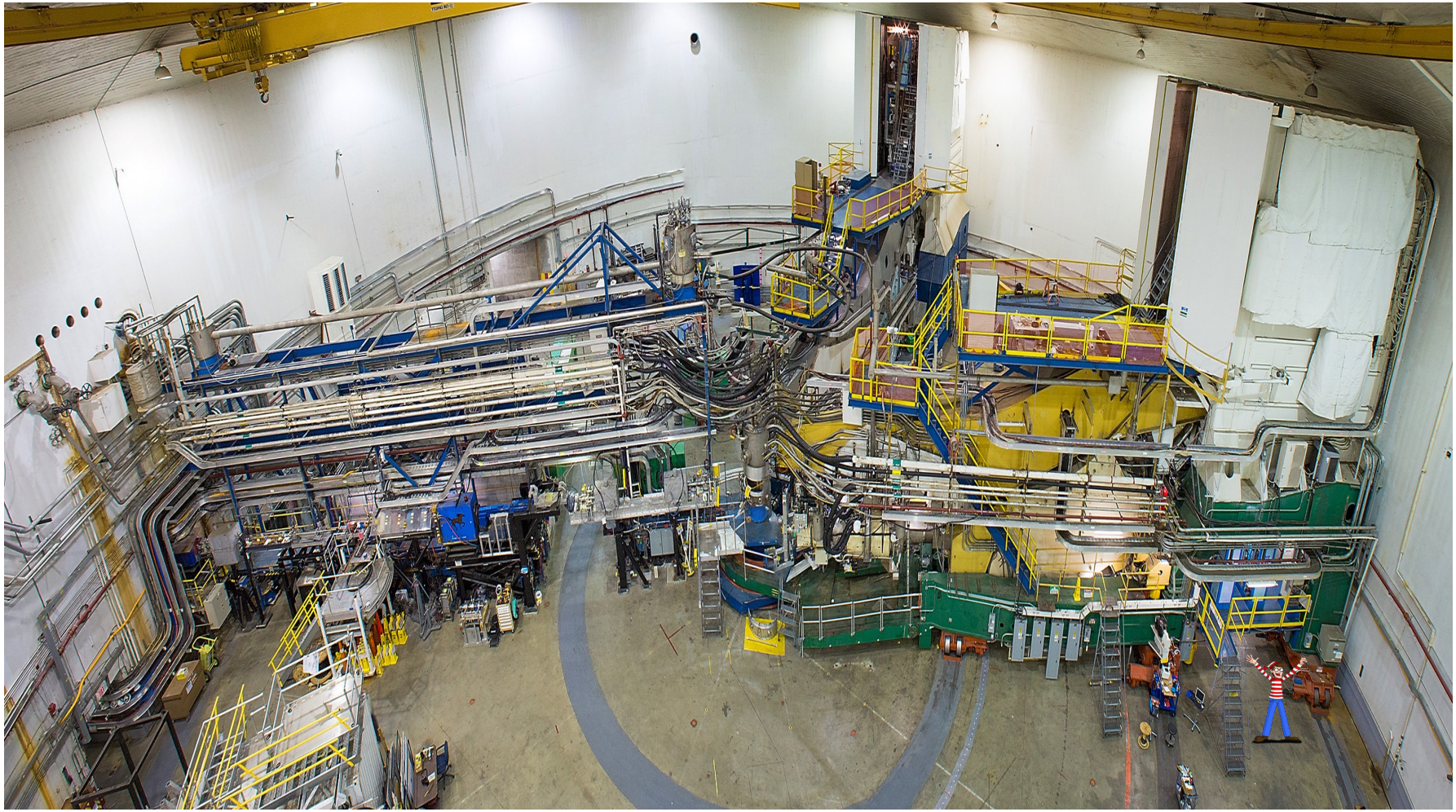


Jefferson-Lab National Accelerator Facility

- Virginia, USA.
- Electron beam.
  [12 GeV; ~80 uA; polarized]
- 4 experimental halls.
- Approved program for coming decade; Leading to EIC.

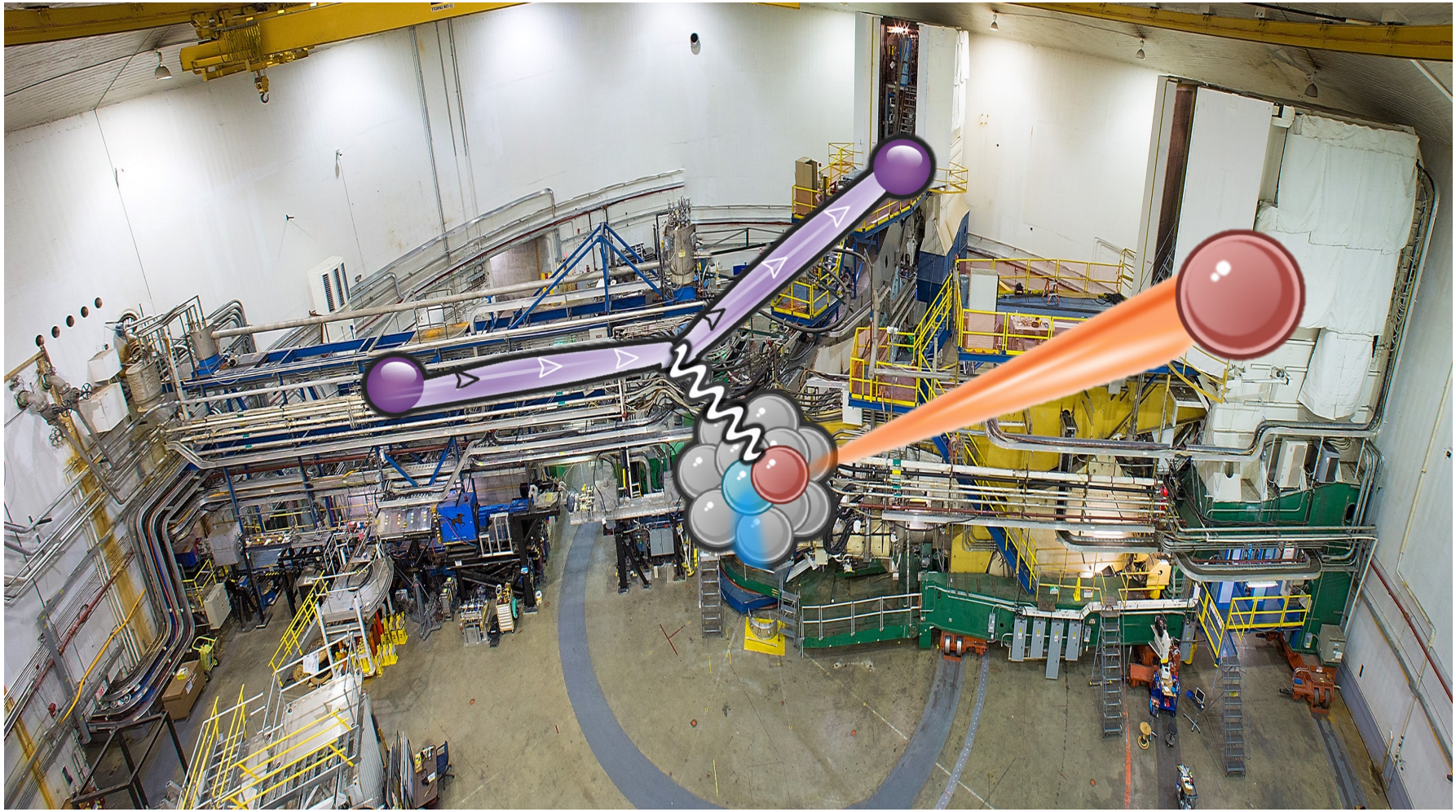


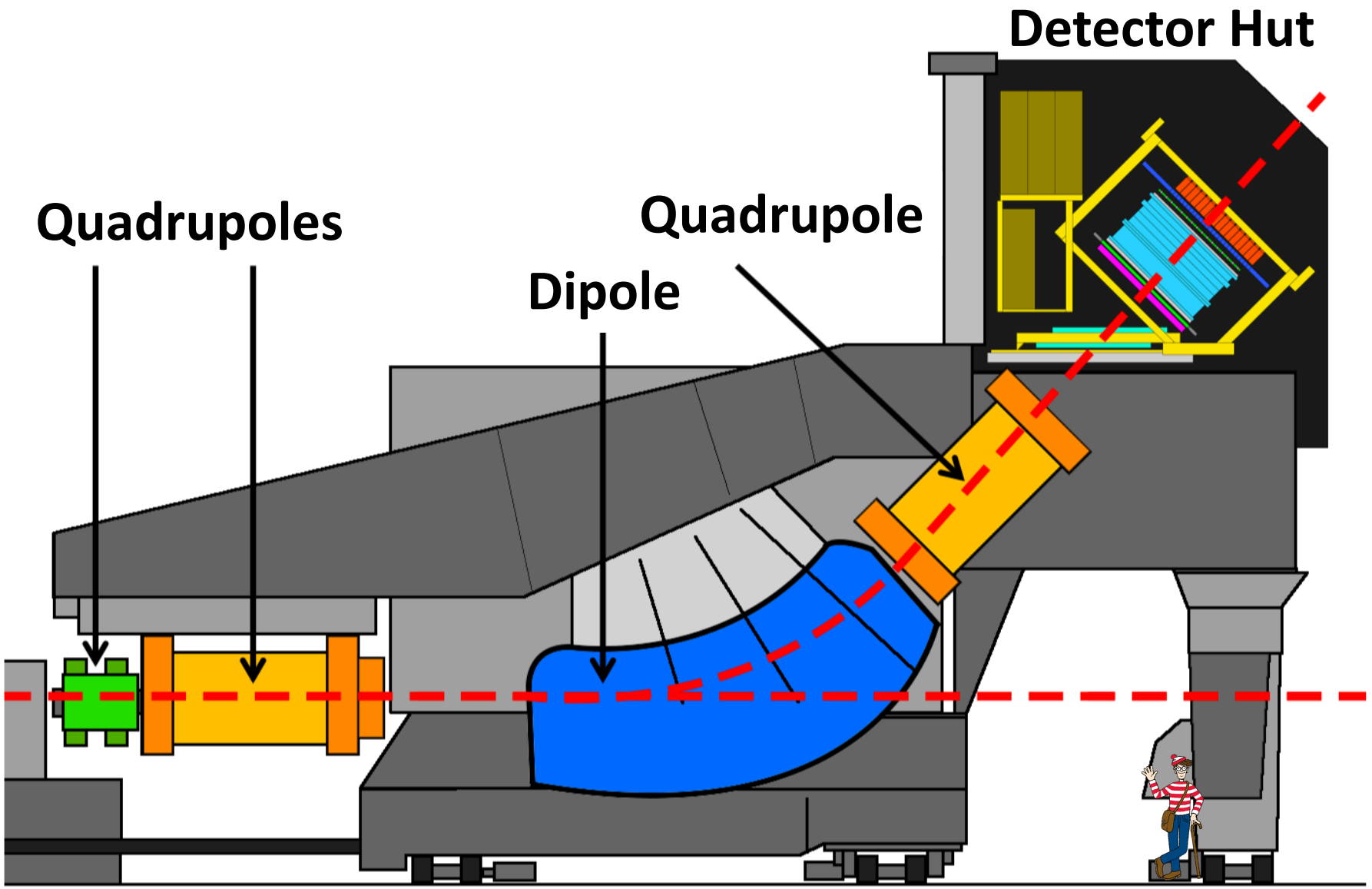
Hall-A: High-Resolution Spectrometers



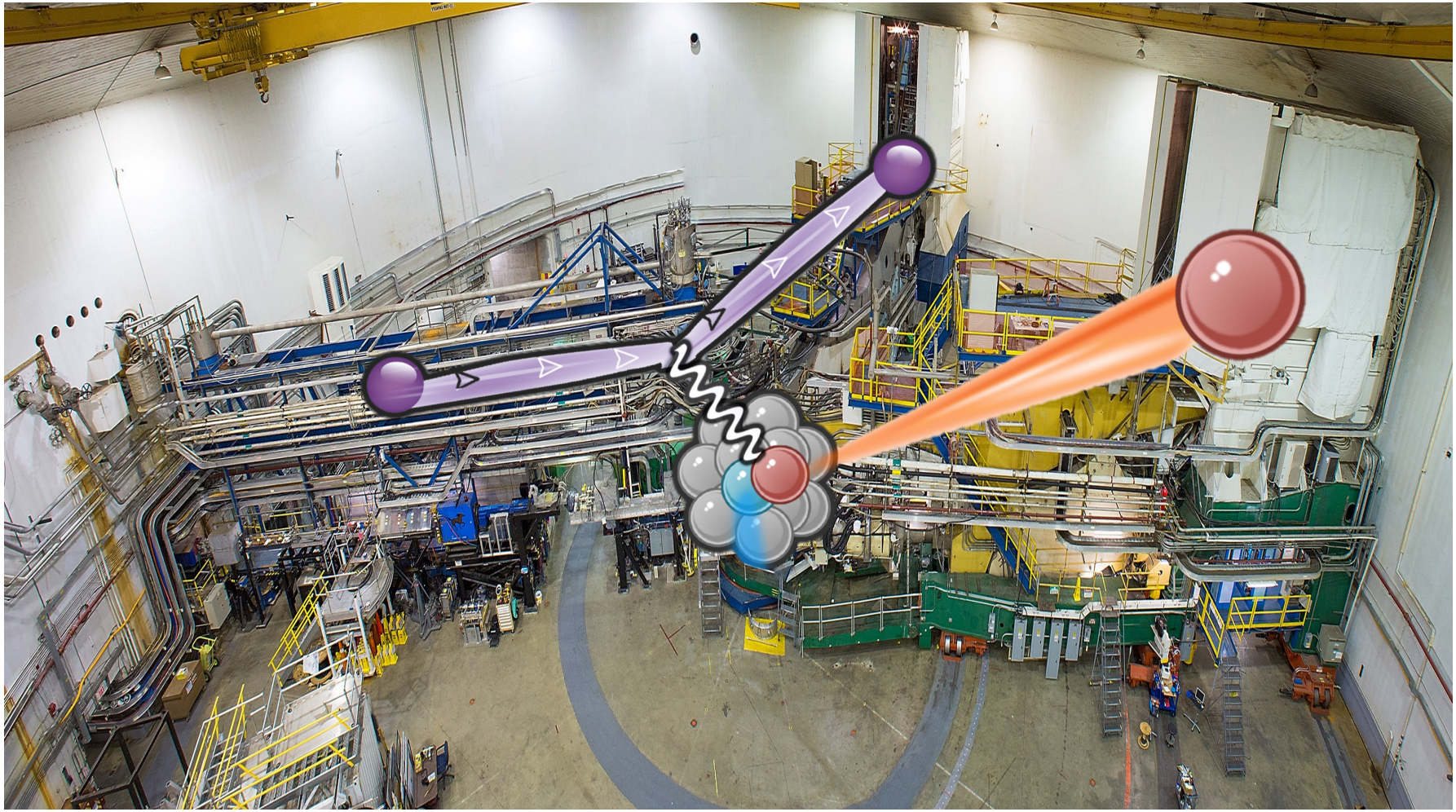
Hall-A: High-Resolution Spectrometers

Hall-A: High-Resolution Spectrometers

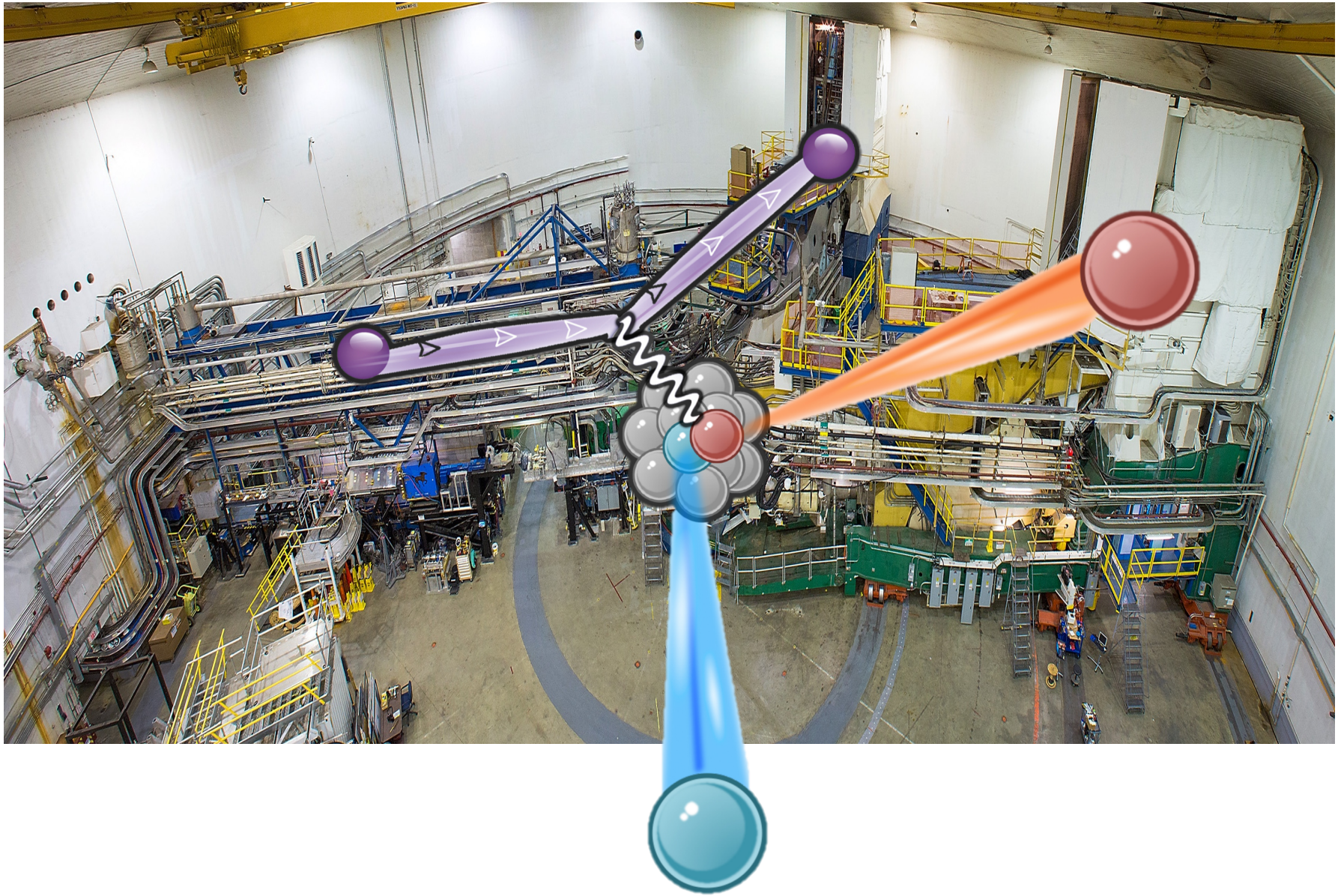



Detector Hut
Quadrupoles
Quadrupole
Dipole

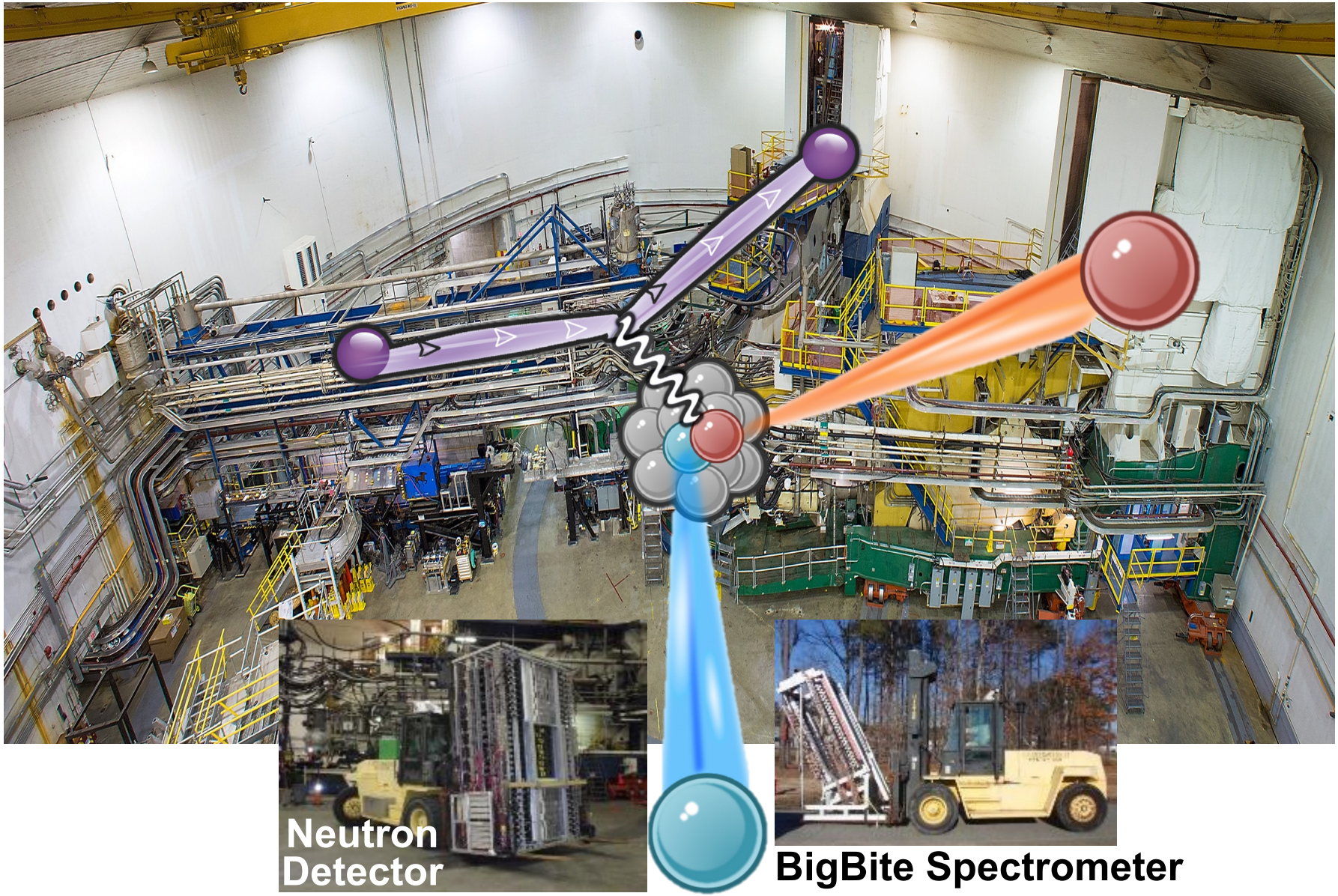
Hall-A: High-Resolution Spectrometers

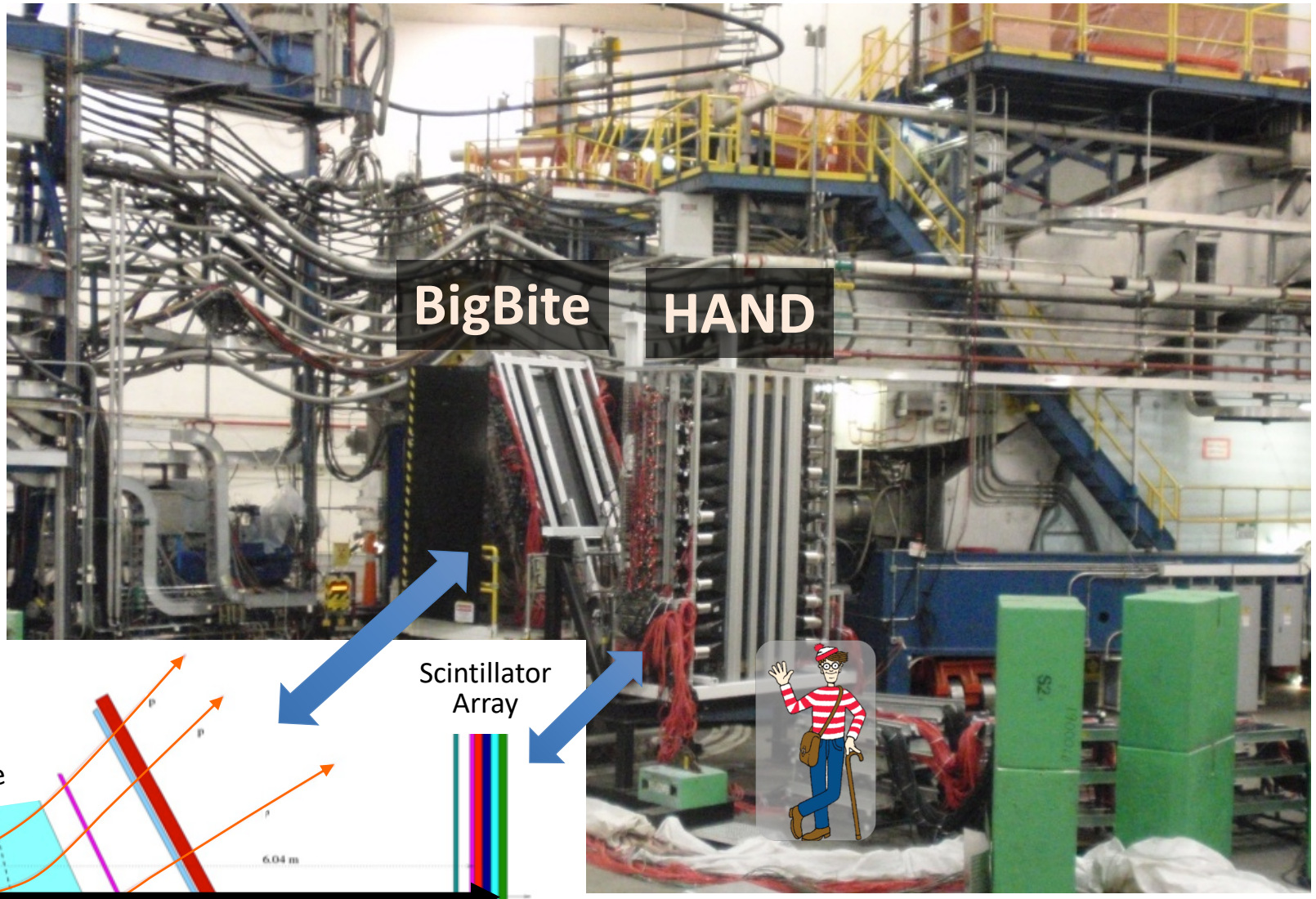


Hall-A: High-Resolution Spectrometers



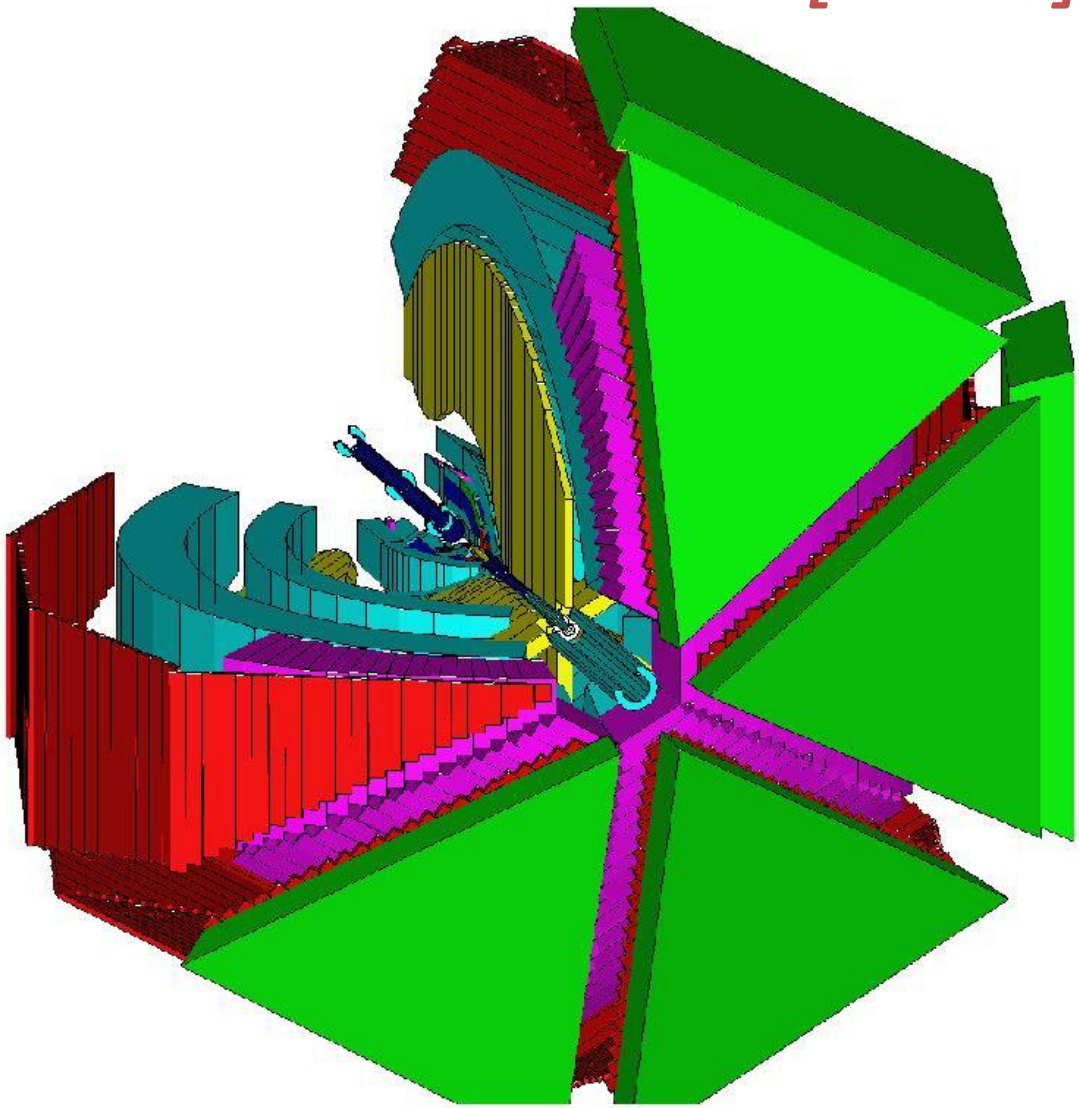
Hall-A: High-Resolution Spectrometers

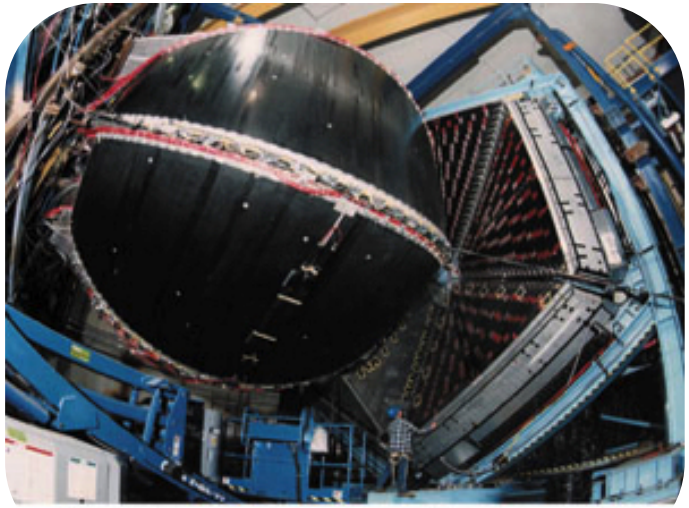




Recoil Proton / Neutron

CEBAF Large Acceptance Spectrometer *[CLAS]*





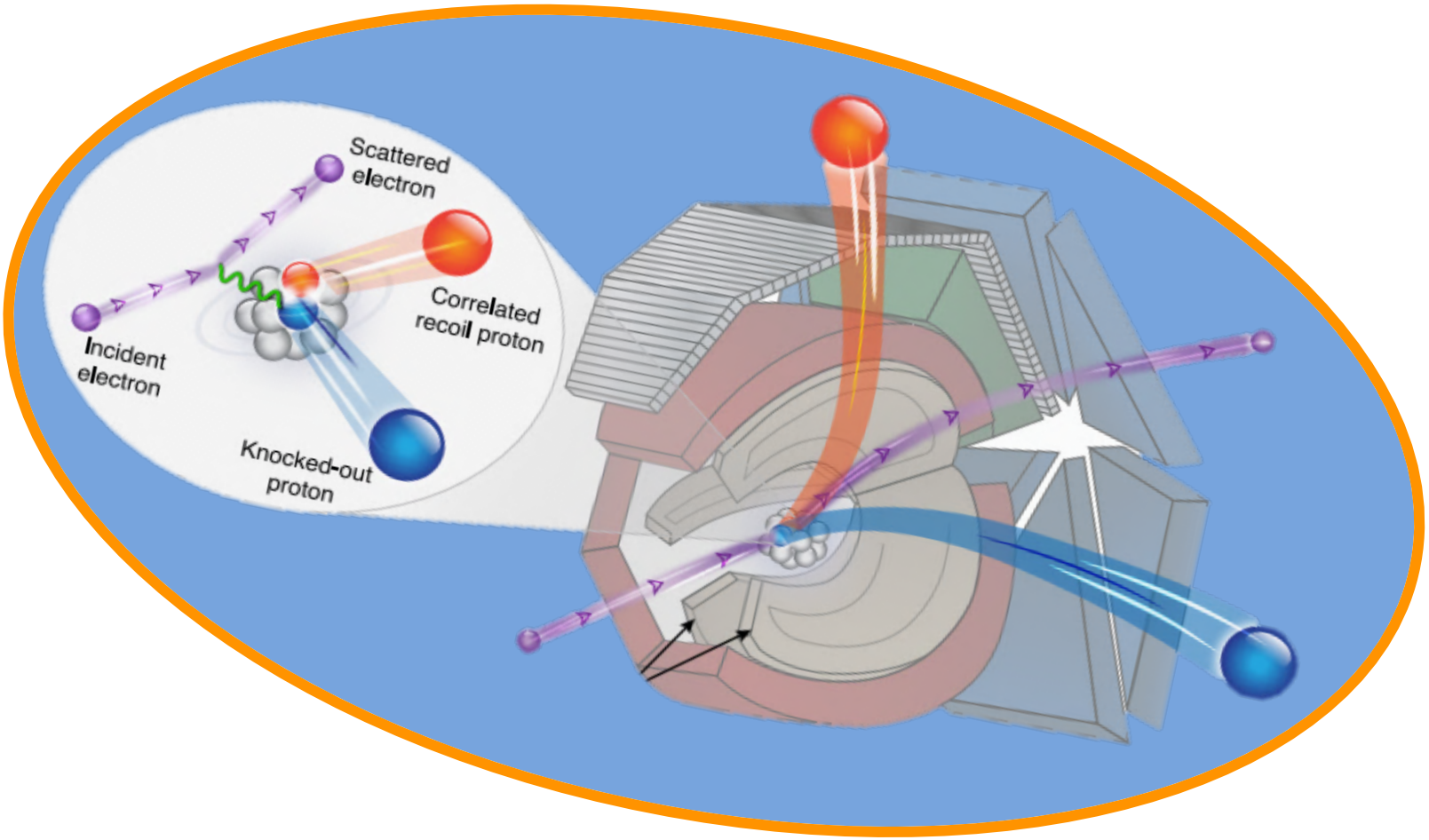
Hall B Large Acceptance Spectrometer

Open (e,e') trigger, Large-Acceptance, Low luminosity (~10^{34} cm^{-2} sec^{-1})

Breakup the pair =>

Detect ***both*** nucleons =>

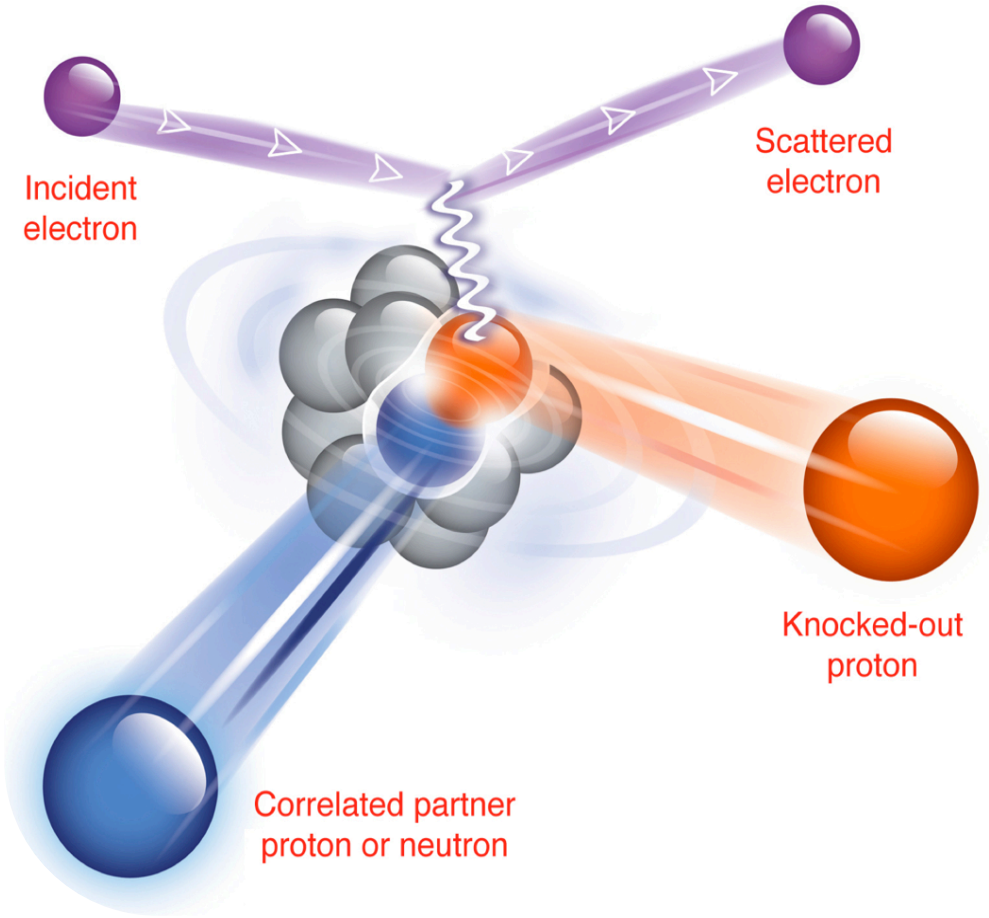
Reconstruct ‘initial’ state



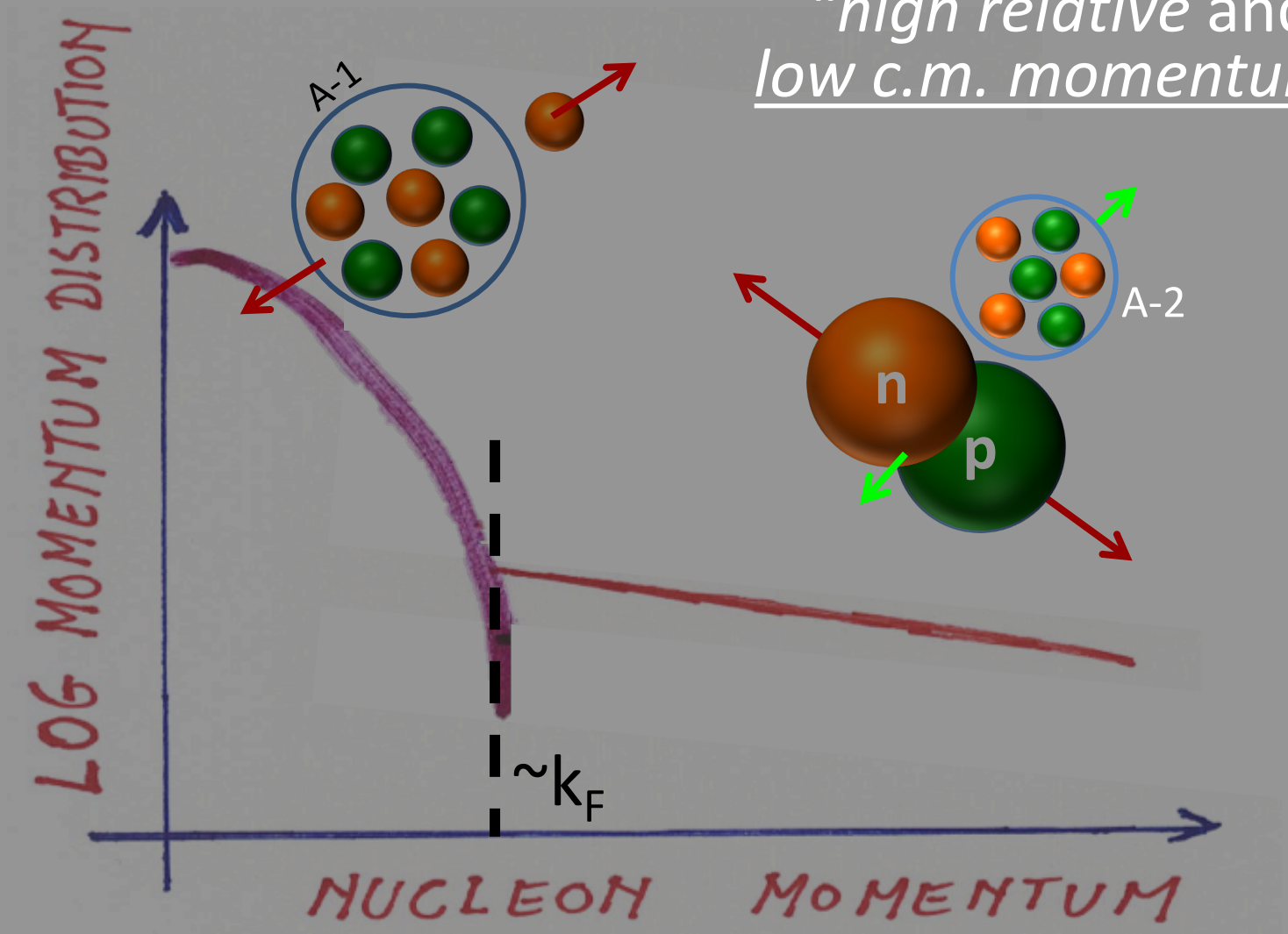
Breakup the pair =>

Detect ***both*** nucleons =>

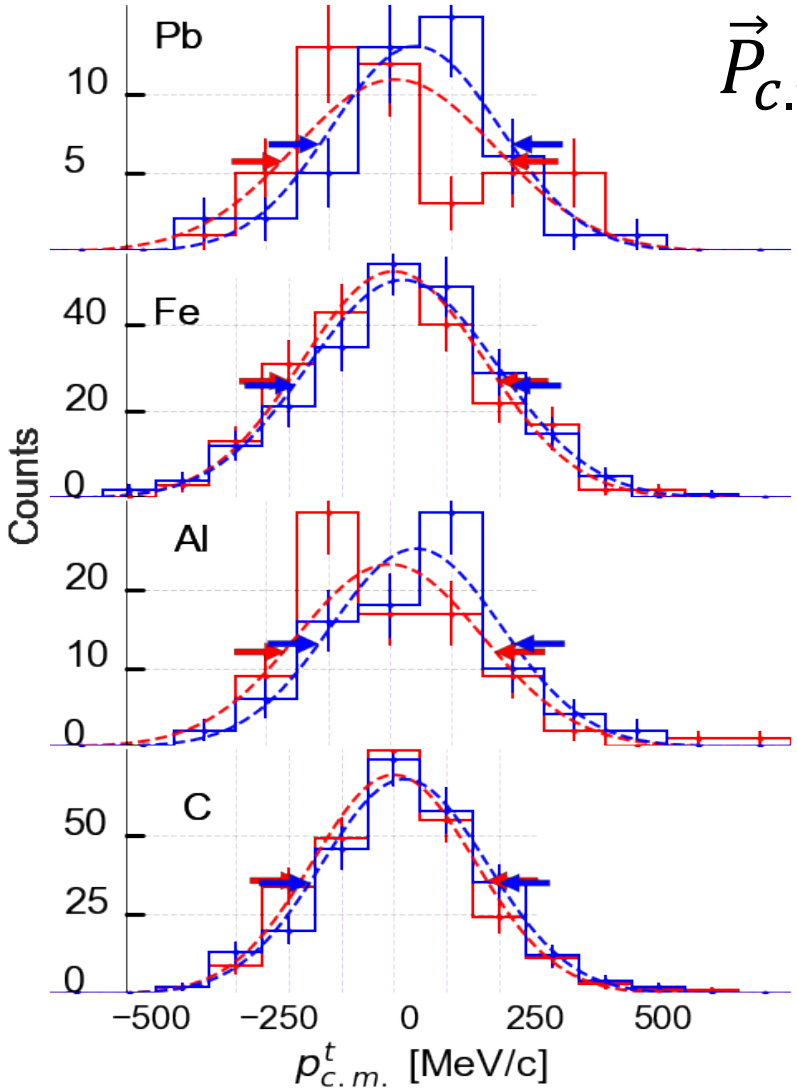
Reconstruct ‘initial’ state



"high relative and *low c.m. momentum"*



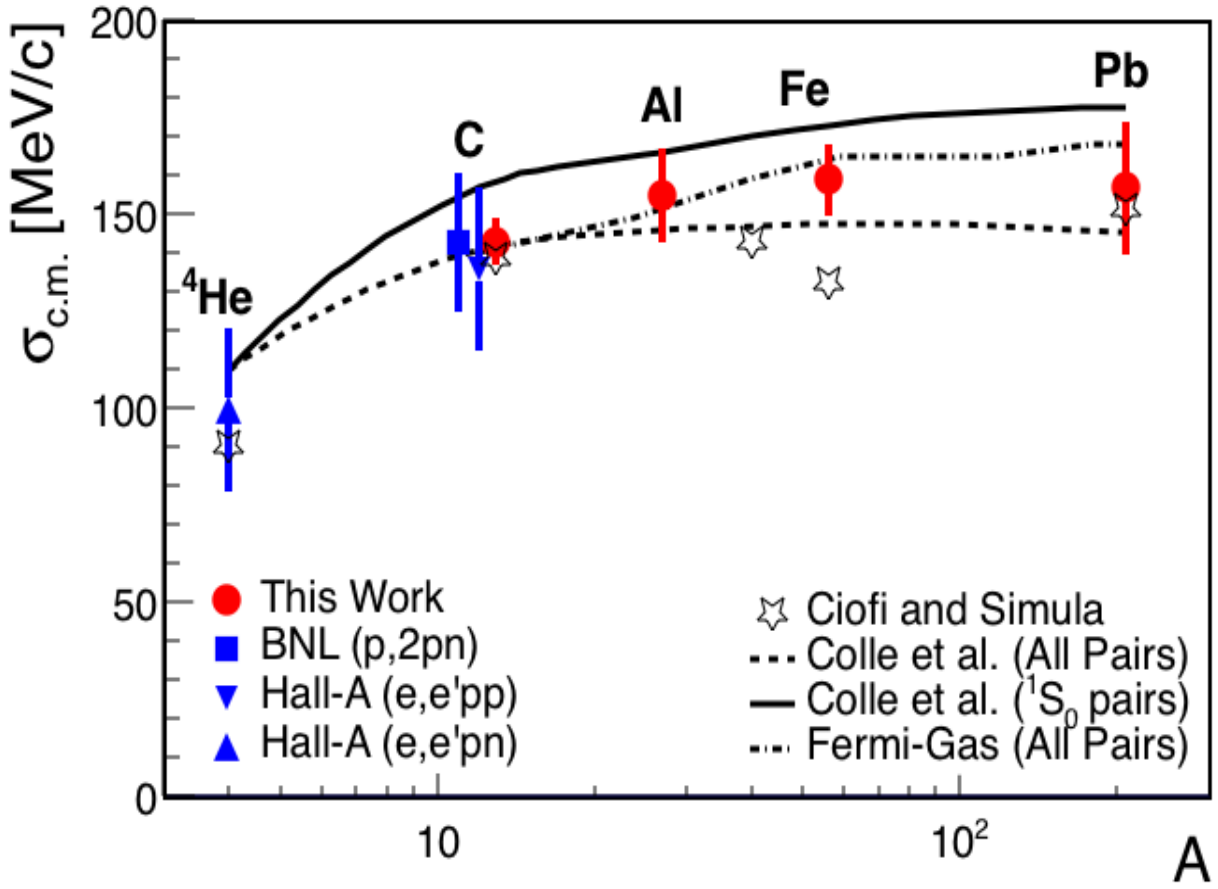
Low Pair C.M. Motion

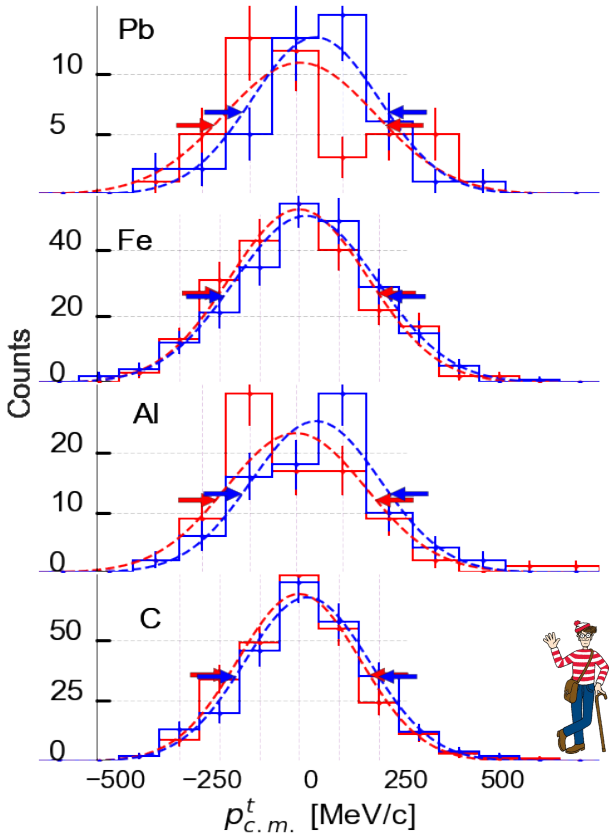


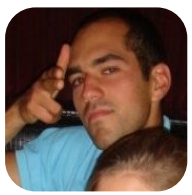
$$\vec{P}_{c.m.} = \vec{P}_{N1} + \vec{P}_{N2}$$

Cohen, PRL (2018).

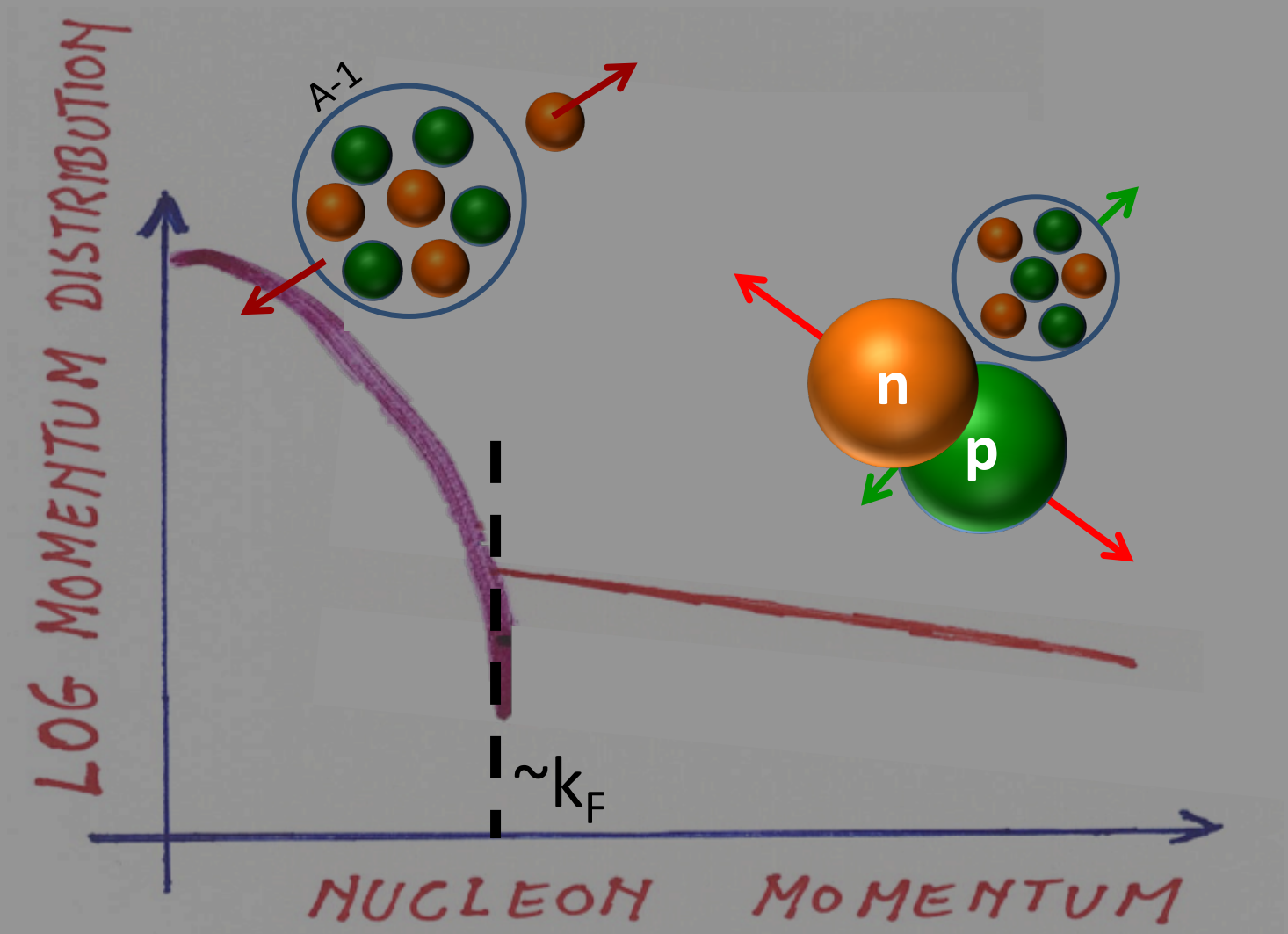
Consistent \w combining two mean-field nucleons



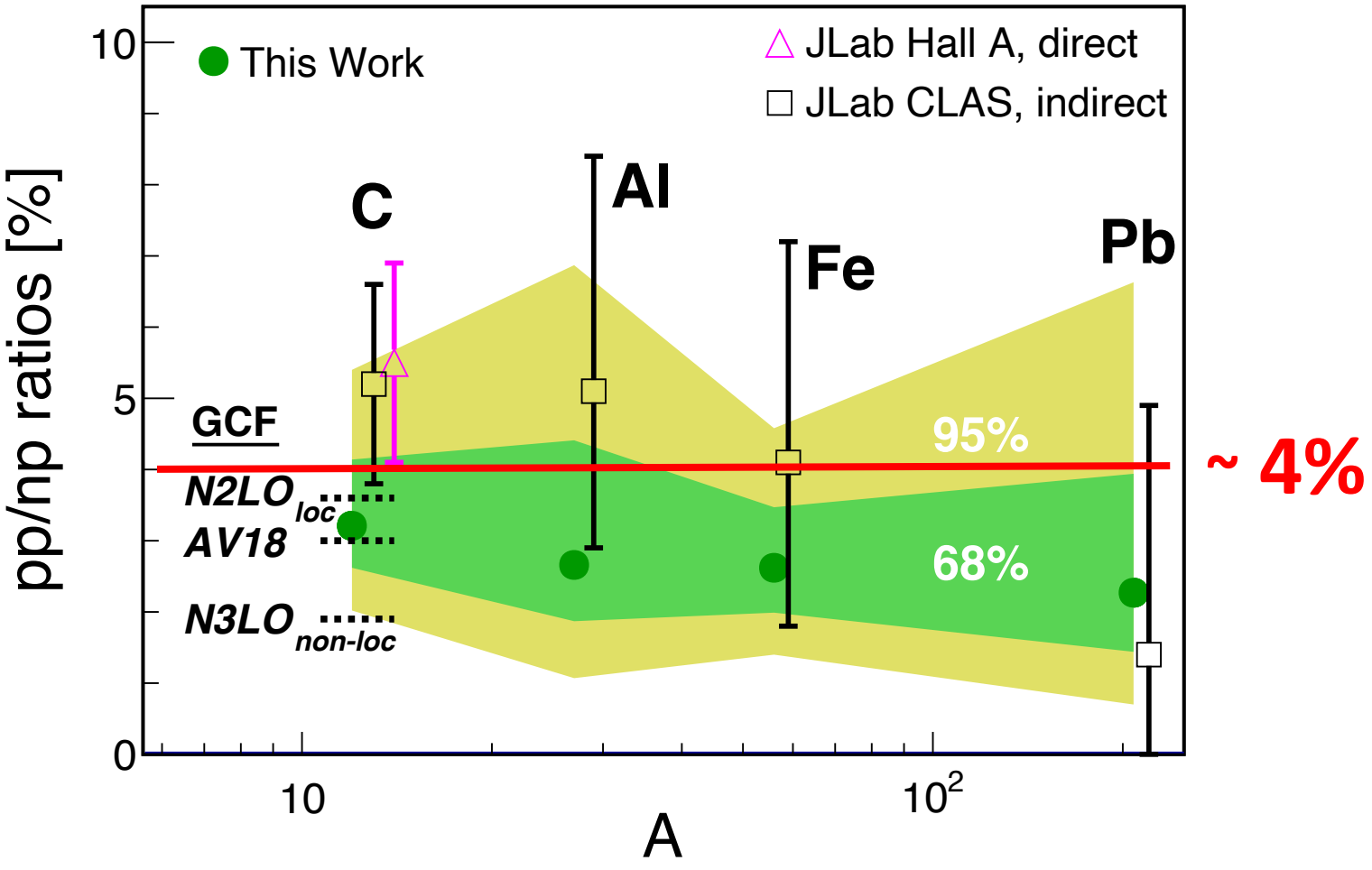




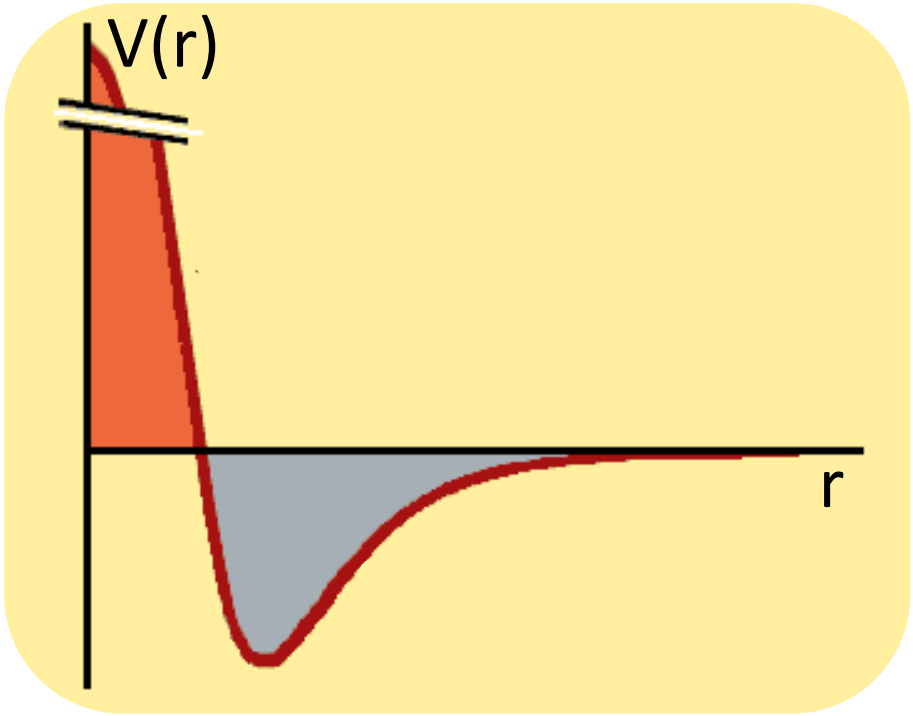
Cohen, PRL (2018),
Korover, PRL (2014),
Shneor, PRL (2007),
Tang, PRL (2003).

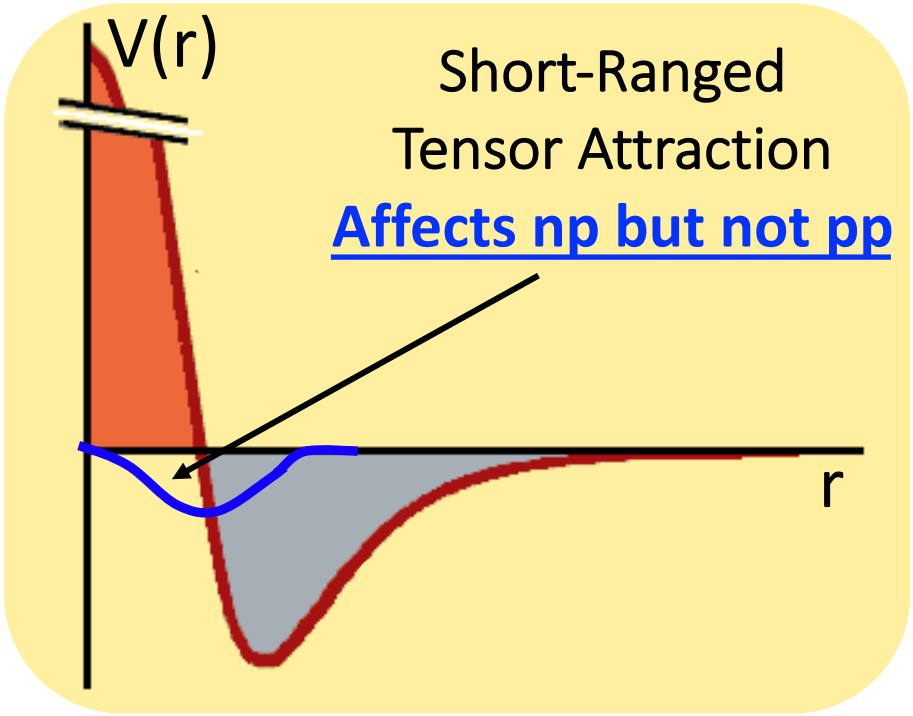

LOG MOMENTUM DISTRIBUTION
A-1
n
p
~k_F
NUCLEON MOMENTUM

np pairs predominate



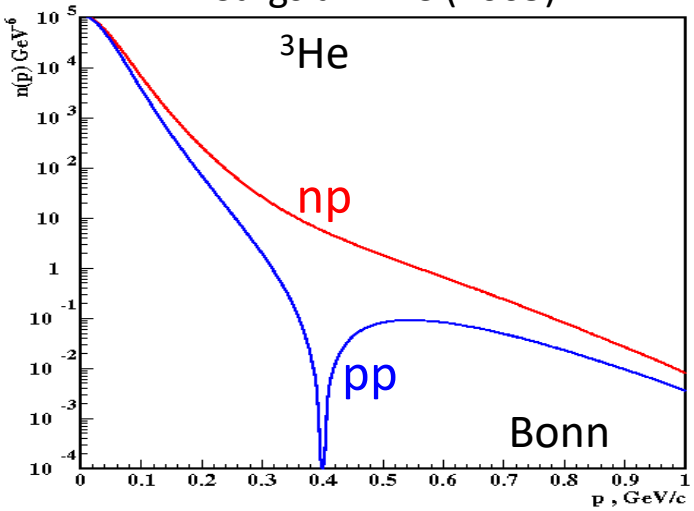
Duer, PRL (2019); Duer, Nature (2018); Hen, Science (2014); Korover, PRL (2014); Subedi, Science (2008); Shneor, PRL (2007); Piasetzky, PRL (2006); Tang, PRL (2003); Review: Hen RMP (2017);


V(r)
r

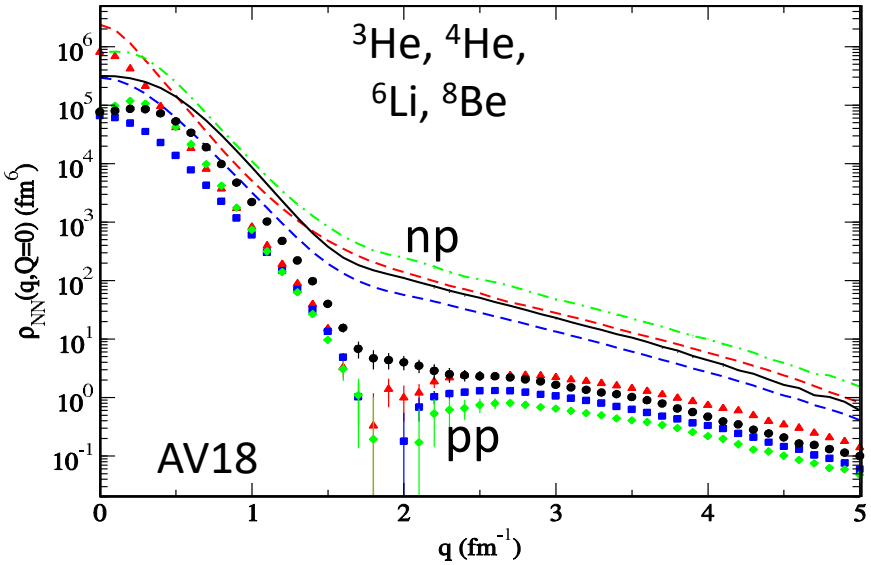

V(r)
Short-Ranged
Tensor Attraction
Affects np but not pp
r

Also seen in ab-initio pair distributions

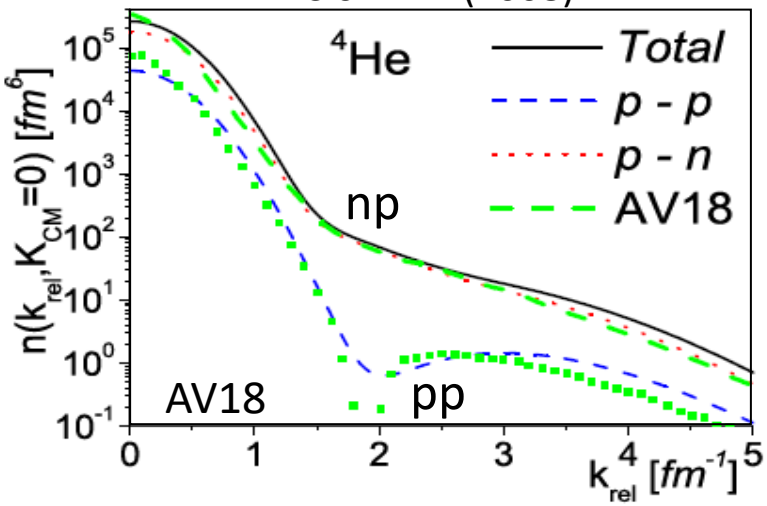
Sargsian PRC (2005)



Schiavilla PRL (2007)



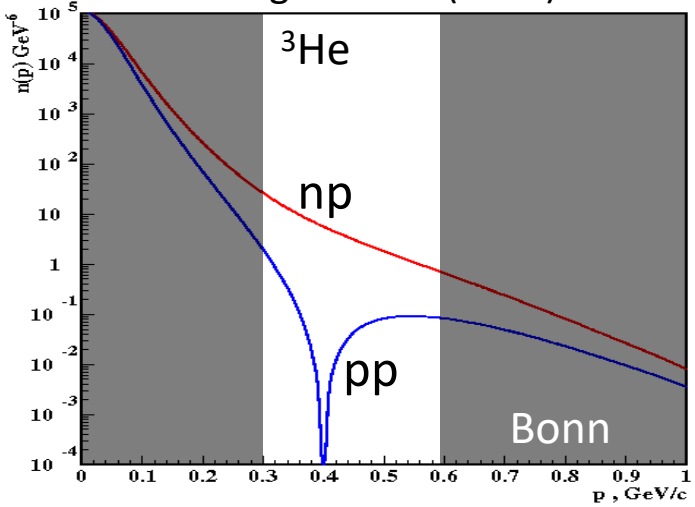
Ciofi PRL (2008)



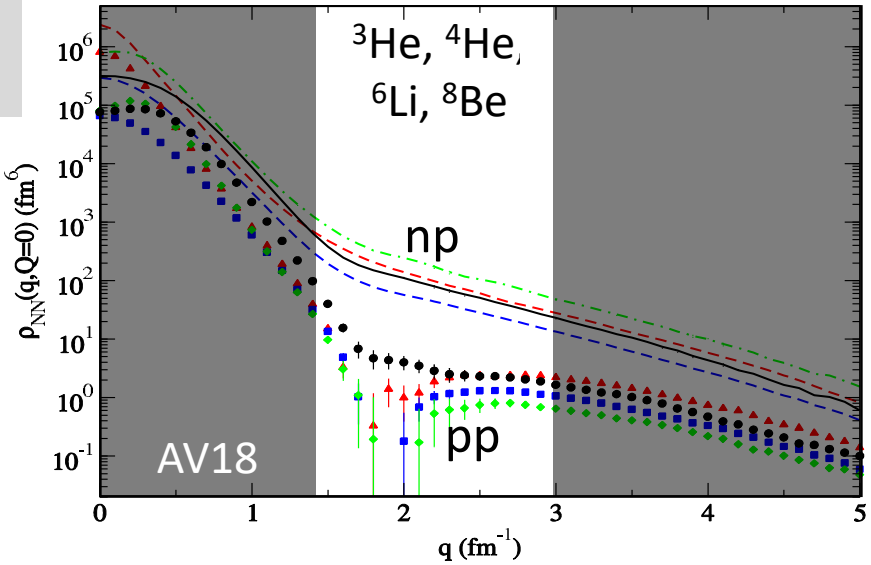
Also seen in ab-initio pair distributions

300 – 600 MeV/c Window

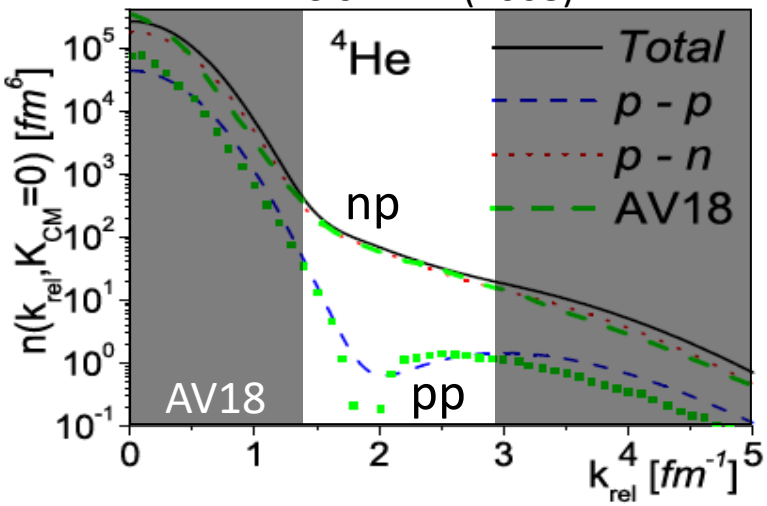
Sargsian PRC (2005)

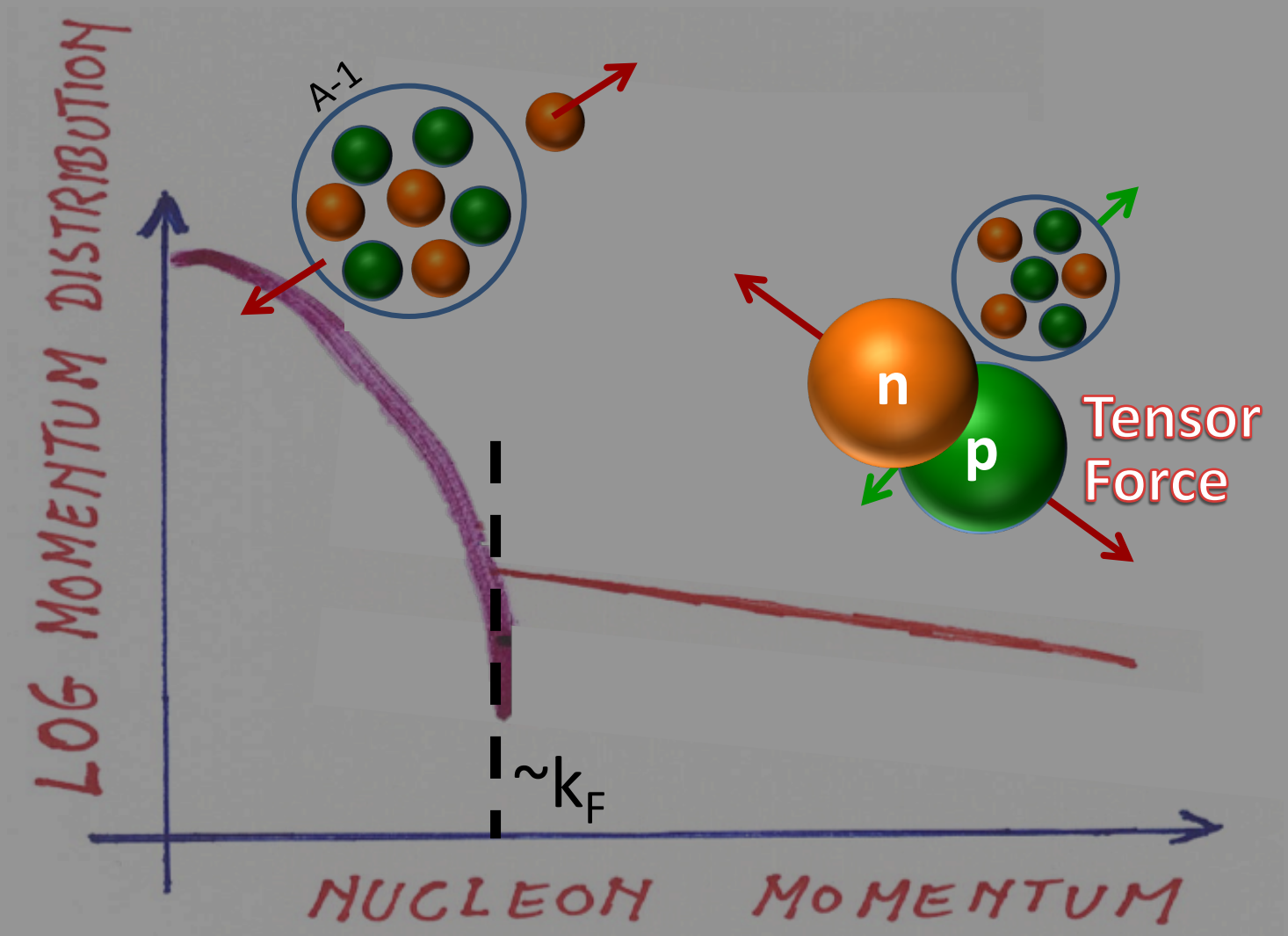


Schiavilla PRL (2007)



Ciofi PRL (2008)




LOG MOMENTUM DISTRIBUTION
A-1
n
p
Tensor
Force
~k_F
NUCLEON MOMENTUM

Going neutron rich:

What do excess neutrons do?

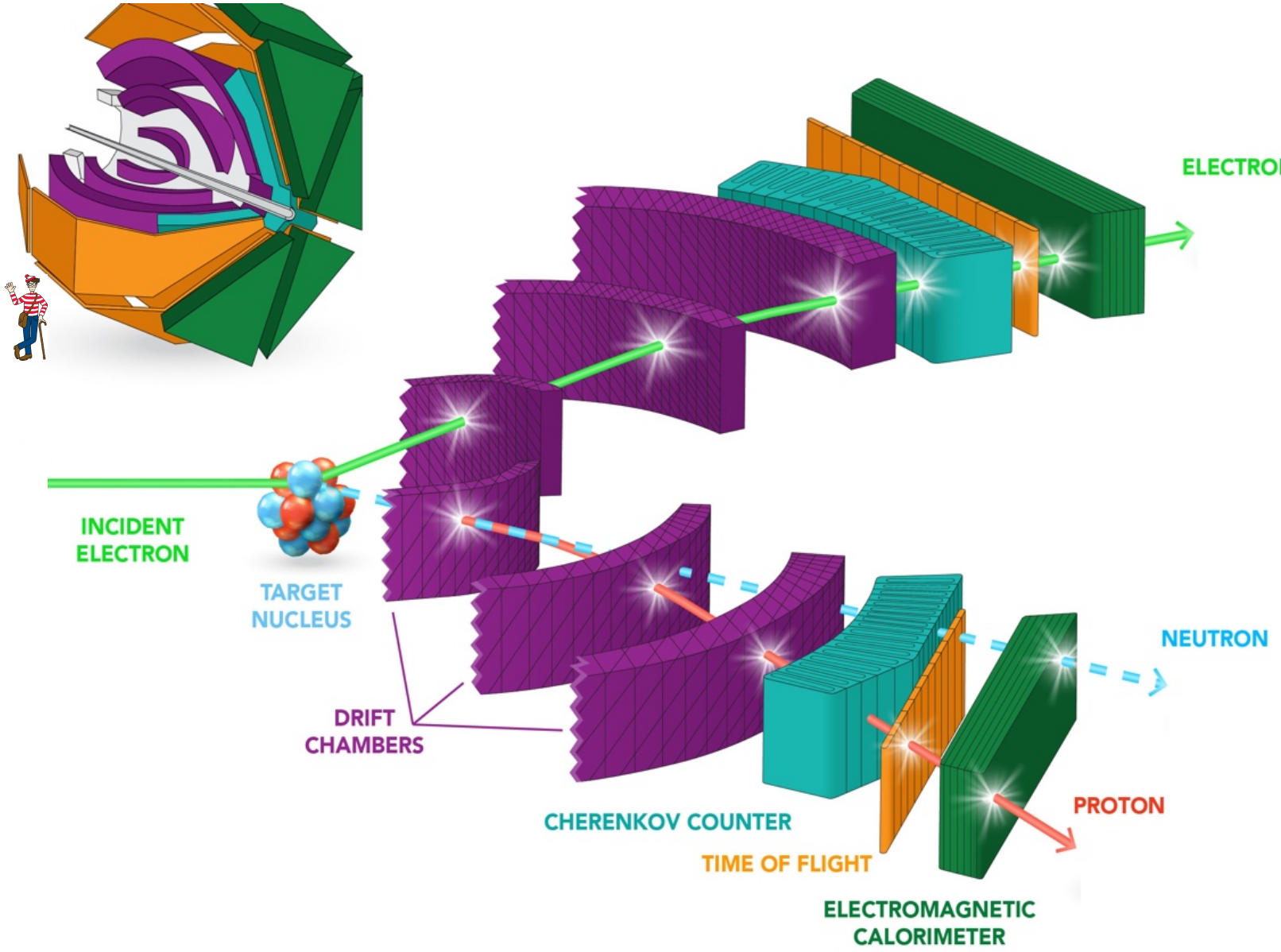
don't correlate?

correlate with each other?

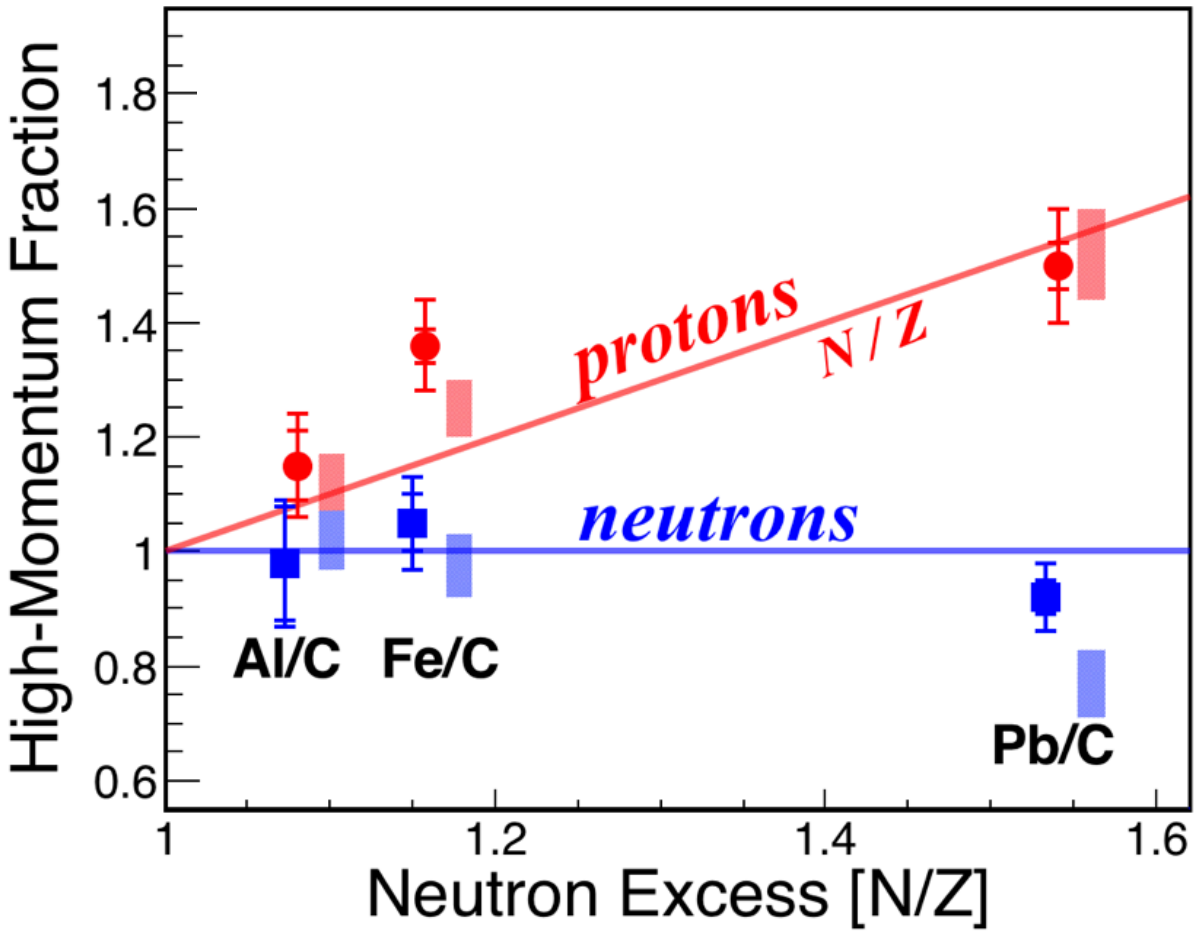
correlate with core protons?

Proton vs. Neutron Knockout

M. Duer

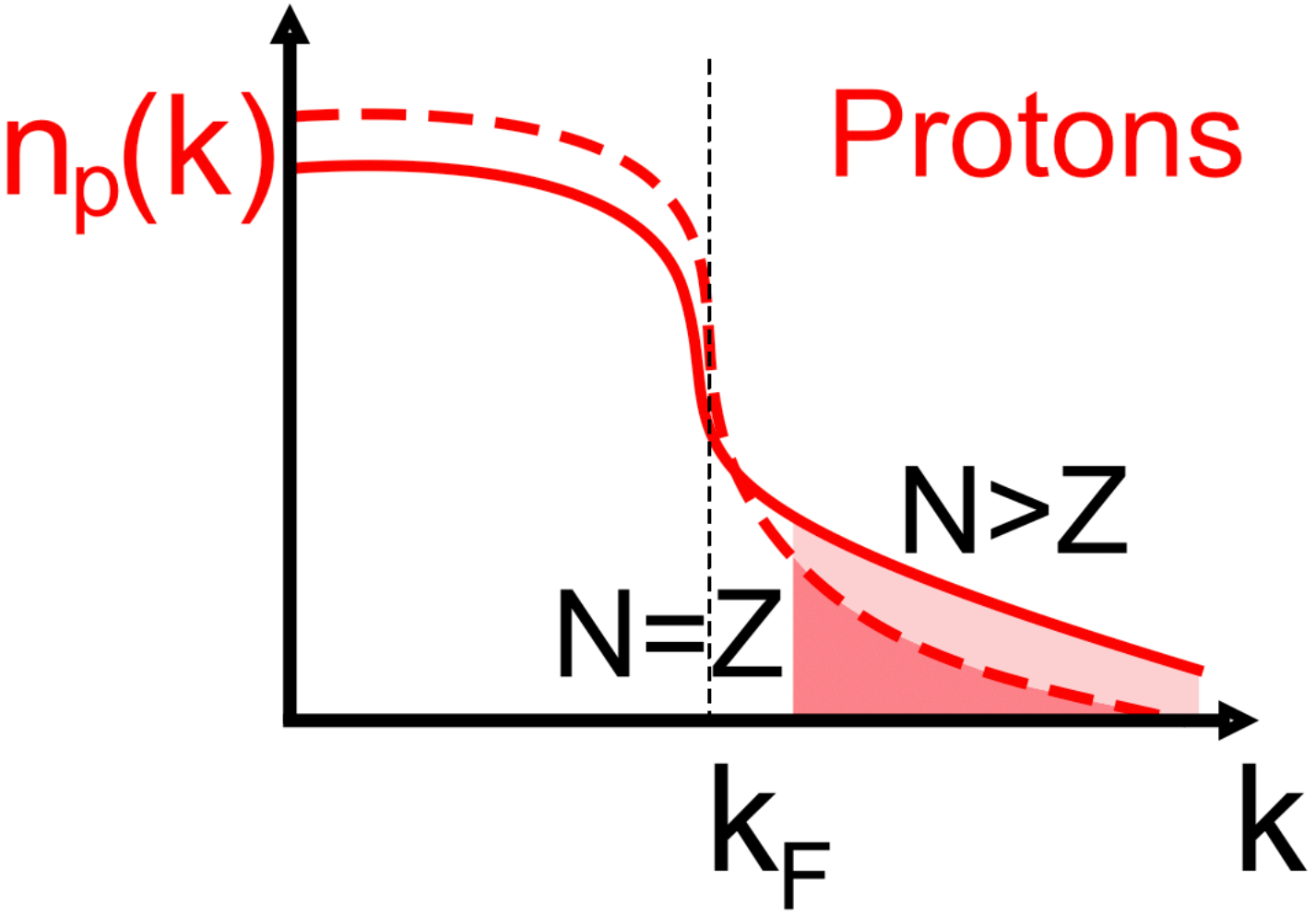


Correlation Probability:
Neutrons saturate Protons grow



Duer Nature (2018)

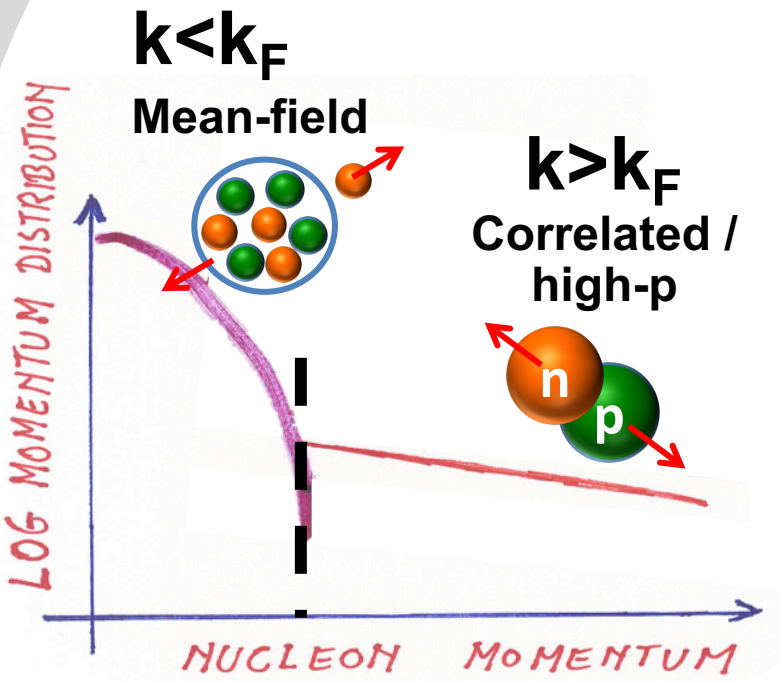
Protons ‘Speed-Up’ In Neutron-Rich Nuclei



Duer Nature (2018)

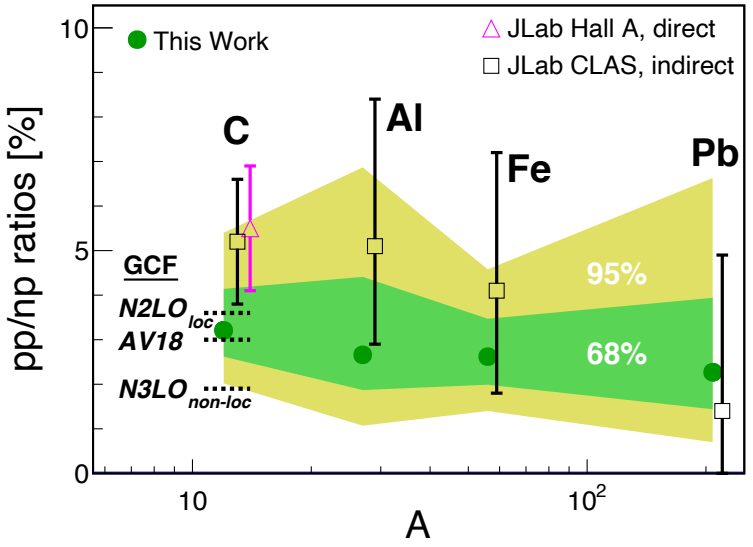
Interim Summary

- Nuclear momentum distribution has two distinct regions.



Interim Summary

- Nuclear momentum distribution has two distinct regions.
- #SRC-protons = #SRC-neutrons, independent of neutron excess.



Interim Summary

- Nuclear momentum distribution has two distinct regions.
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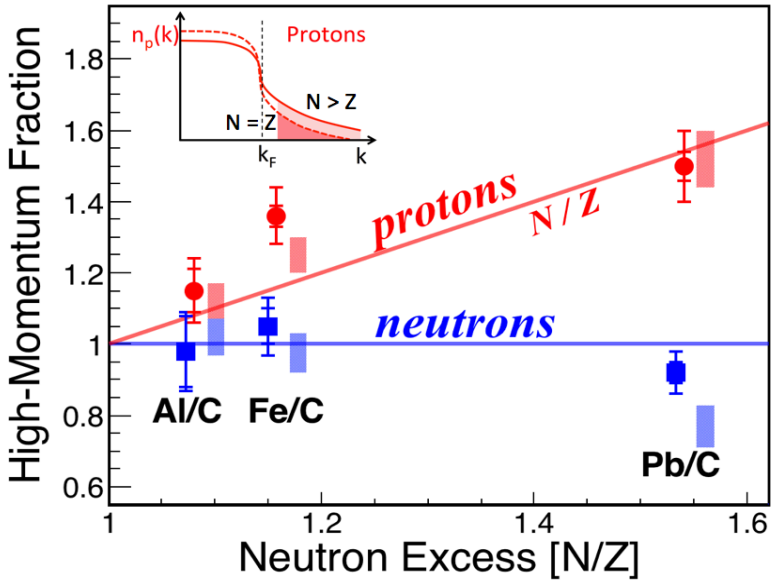
- The fraction of correlated protons / neutrons grow / saturate with neutron excess.



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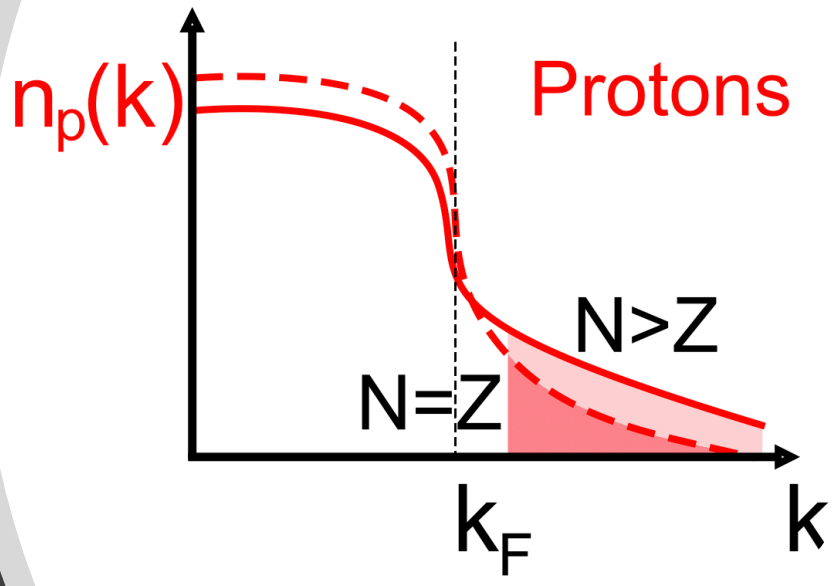
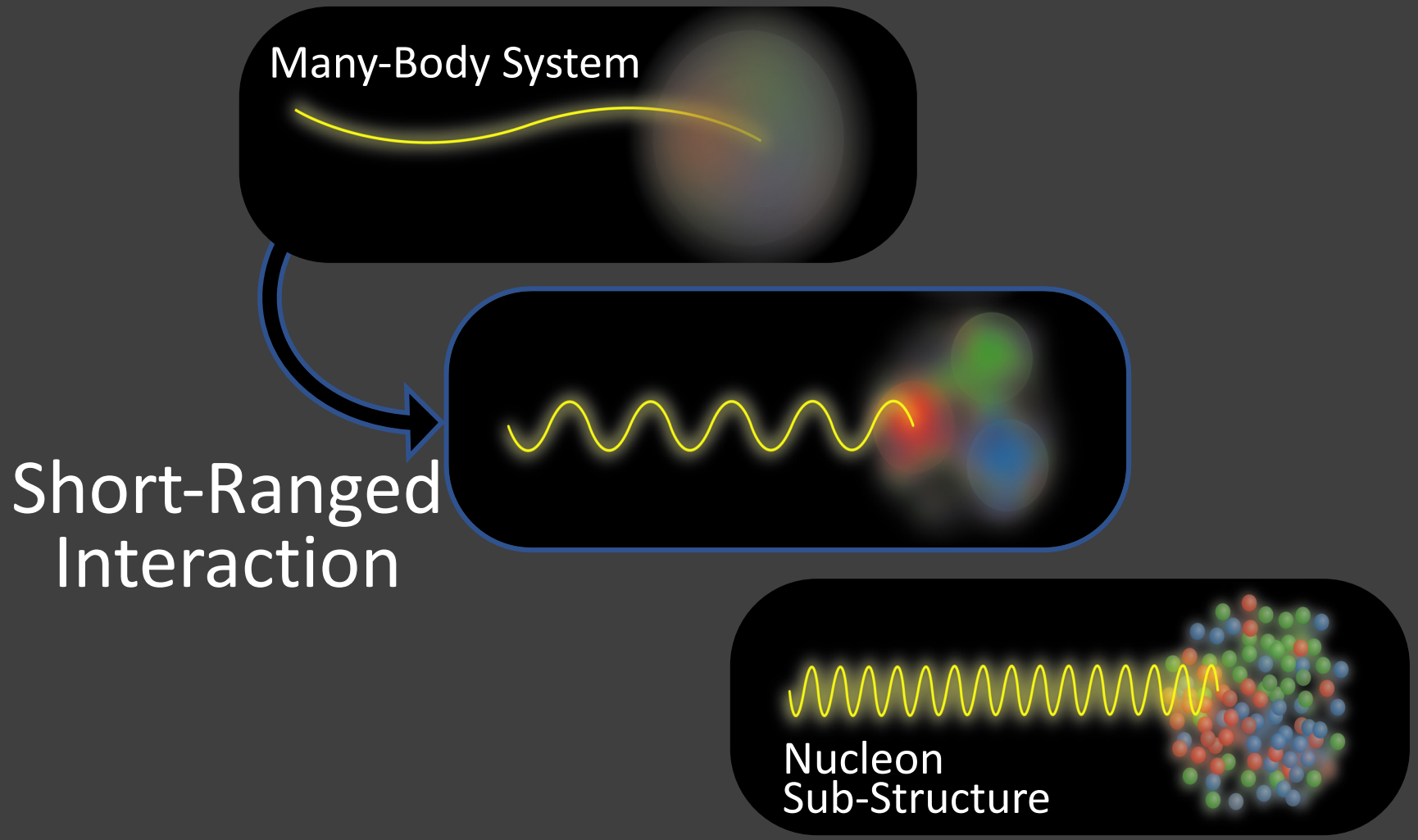



Many-Body System
Short-Ranged
Interaction
Nucleon
Sub-Structure

Probing the NN Interaction

- Measure one- and two-nucleon knockout cross-sections.
- Compare with calculations using different NN interactions.
- See which one works best

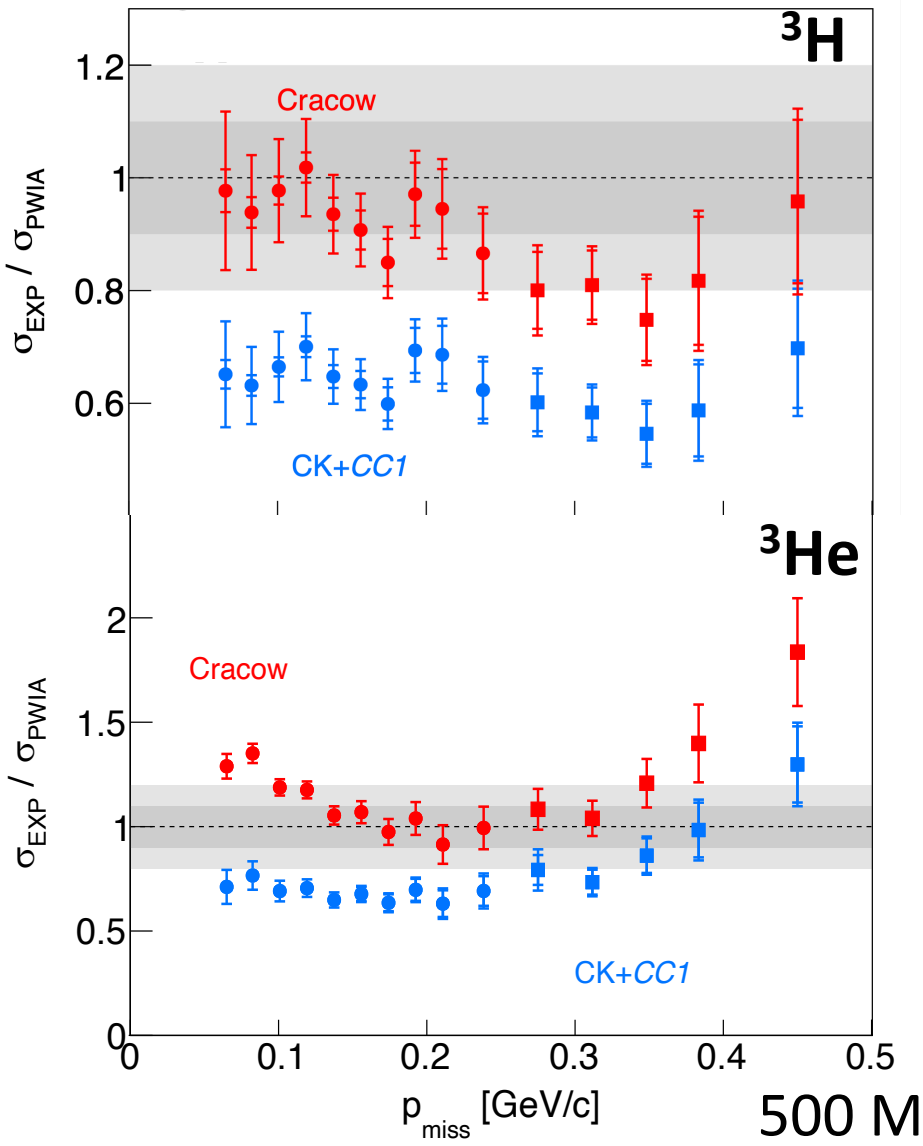
Probing the NN Interaction

What's needed?

- Data

- Ab-initio cross-section calculations

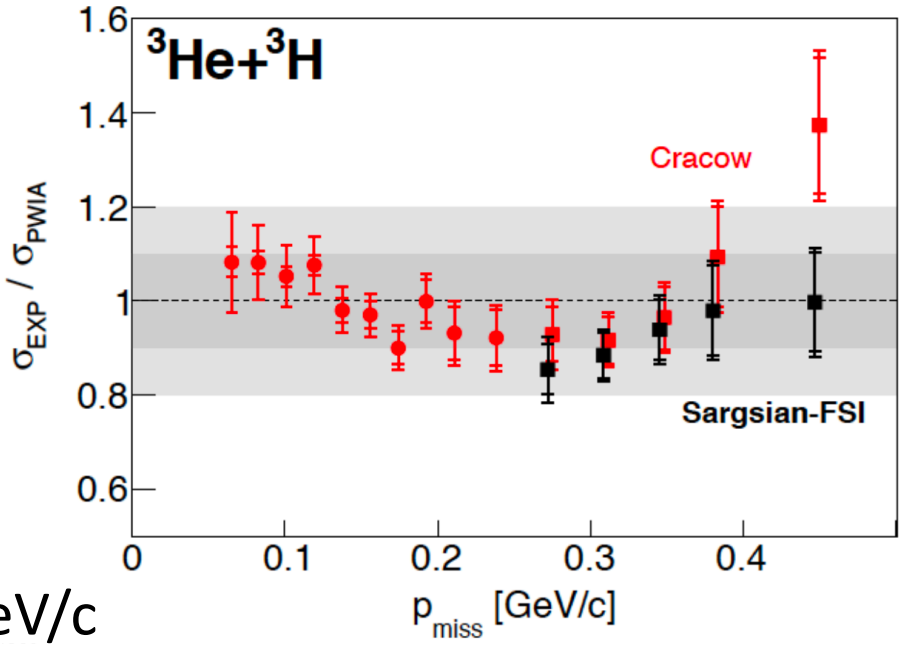
First high-Q^2 A=3 Studies



500 MeV/c

Great success for few-body physics!

But… Data statistically limited



Cruz Torres and Nguyen et al., submitted (2020)

What About Heavier Nuclei?

<u>What's needed?</u>

✓ Data (\w high stat)

- ~~Ab-initio cross-section calculations~~

What About Heavier Nuclei?

What's needed?

✓ Data

- ~~Ab-initio cross-section calculations~~

✓ Factorization \w spectral functions from NN interaction

$$\frac{d^4\sigma}{d\Omega_{k'}\,d\epsilon'_k\,d\Omega_{p'_1}\,d\epsilon'_1} = p'_1\epsilon'_1\sigma_{eN}S^N(\boldsymbol{p}_1,\epsilon_1)$$

What About Heavier Nuclei?

<u>What's needed?</u>

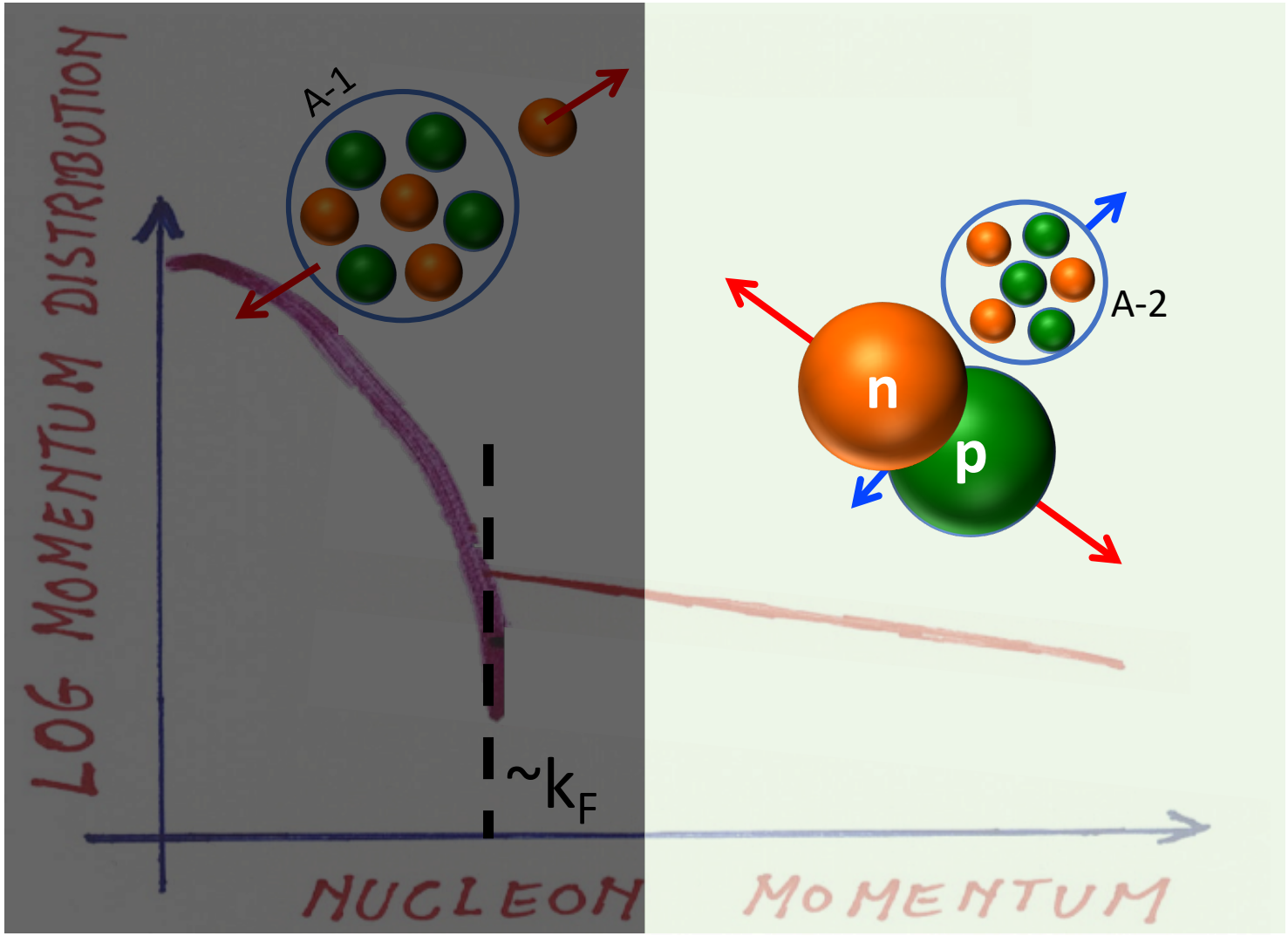
✓ Data

- ~~Ab-initio cross-section calculations~~

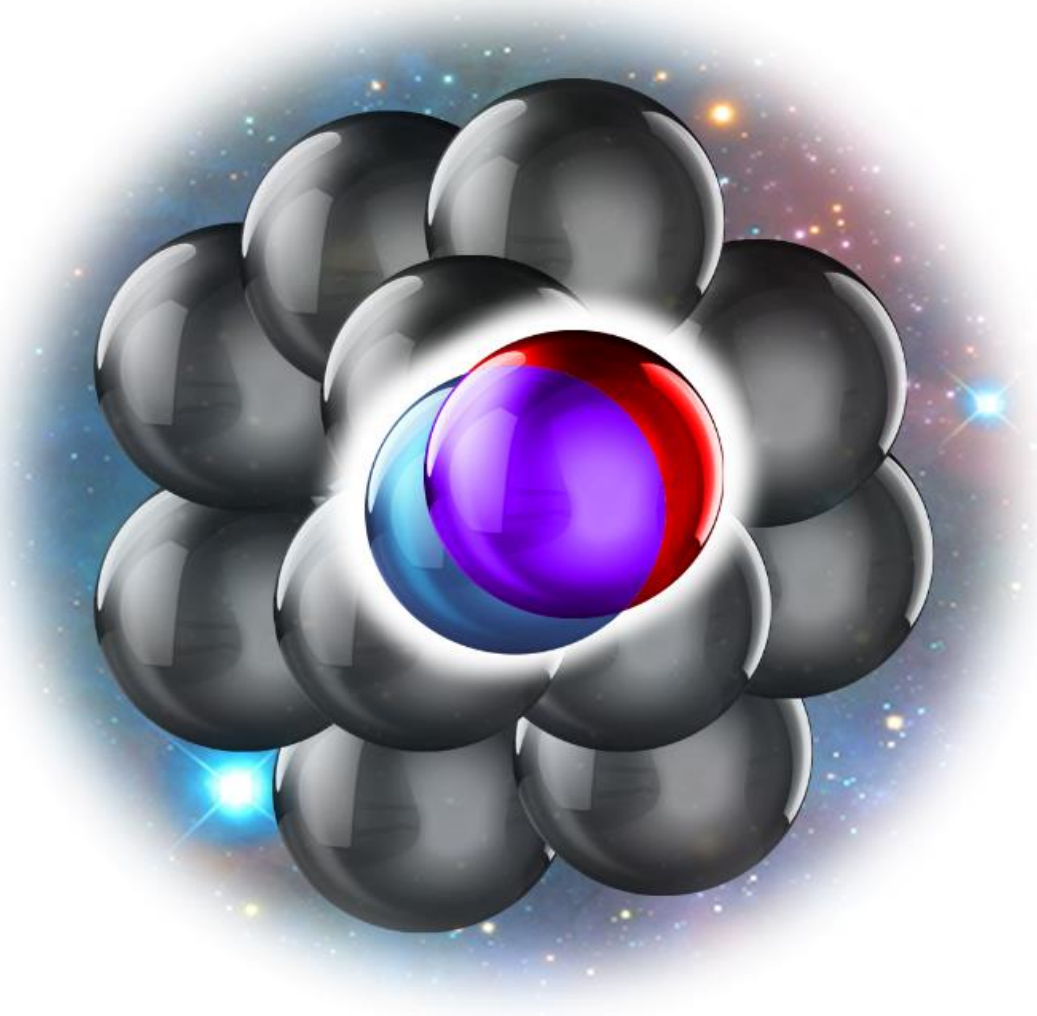
✓ Factorization \w spectral functions from NN interaction

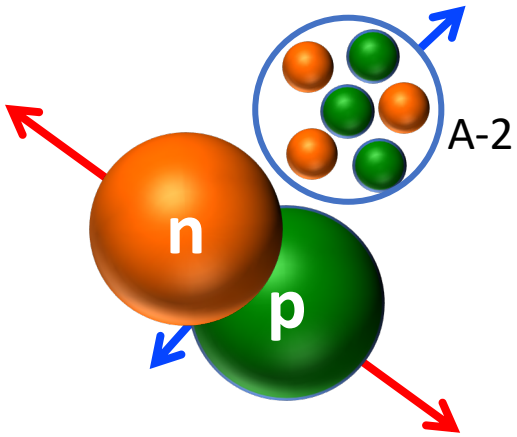
$$\frac{d^4\sigma}{d\Omega_{k'}\,d\epsilon'_k\,d\Omega_{p'_1}\,d\epsilon'_1} = p'_1\epsilon'_1\sigma_{eN}S^N(\boldsymbol{p}_1,\epsilon_1)$$

High-Momenta => Pairs Spectral Functions



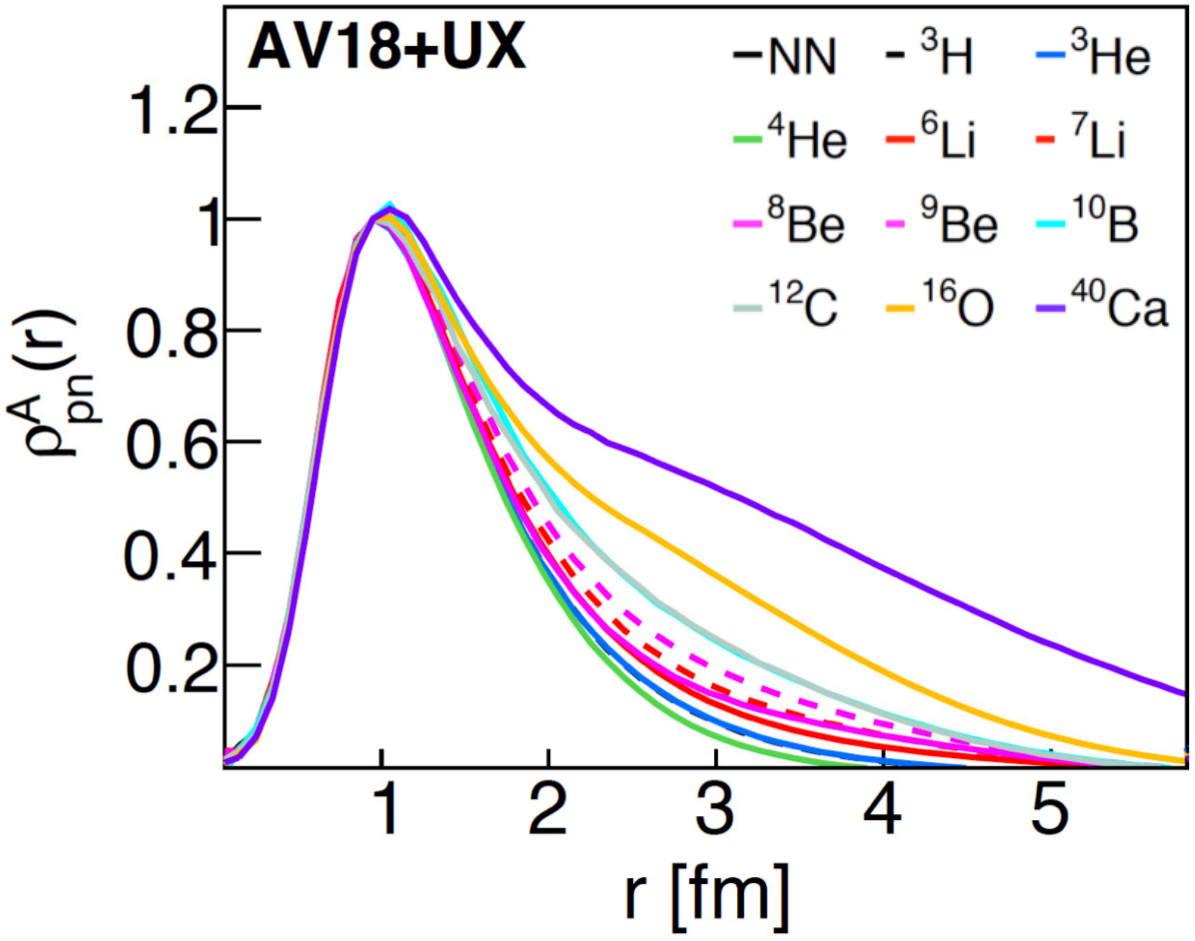
Pairs ⇔ Scale Separation





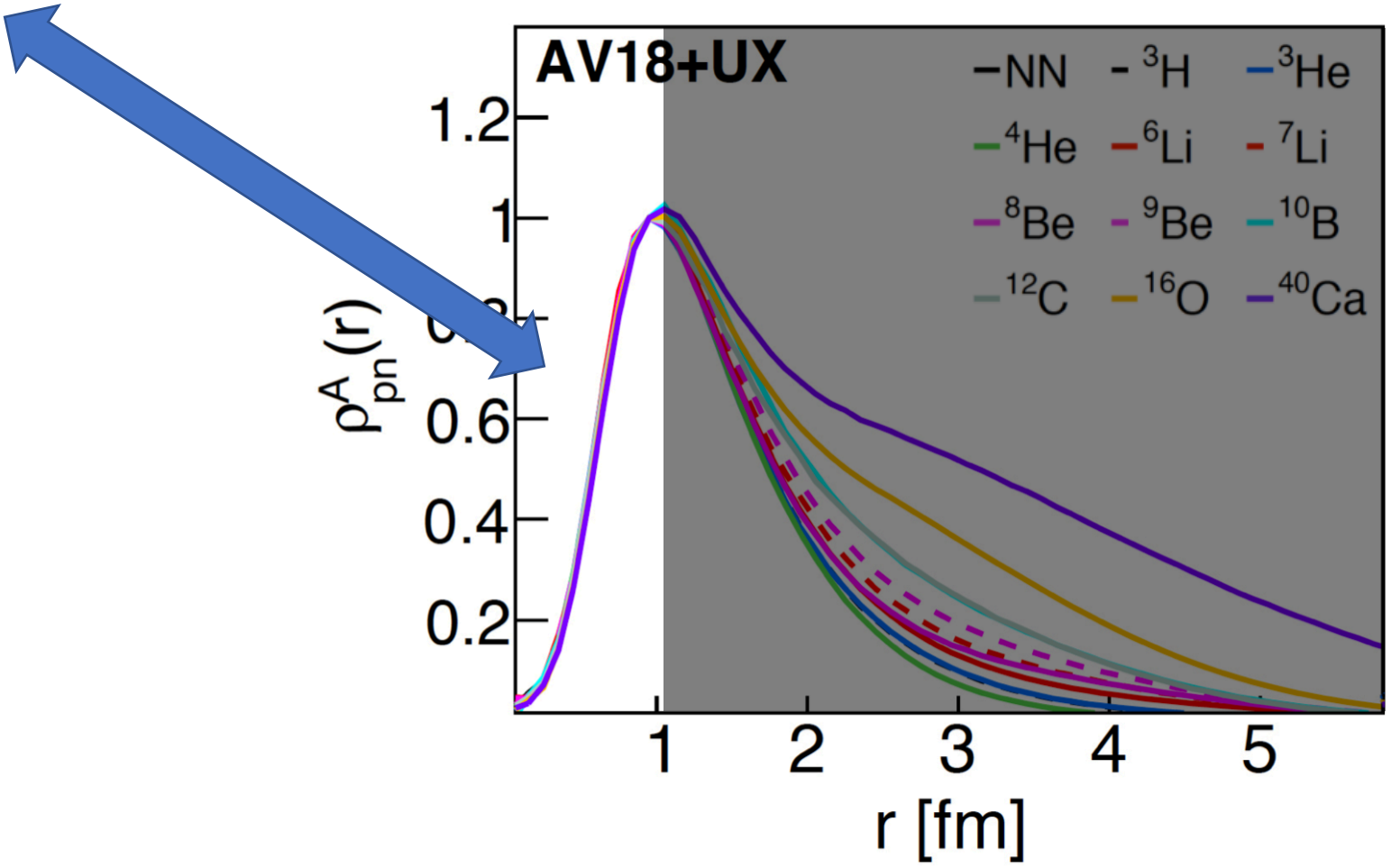
SRCs from Quantum Monte-Carlo (QMC):

Pair Distance Distributions



Cruz Torres and Lonardoni et al., arXiv: 1907.03658 (2019)

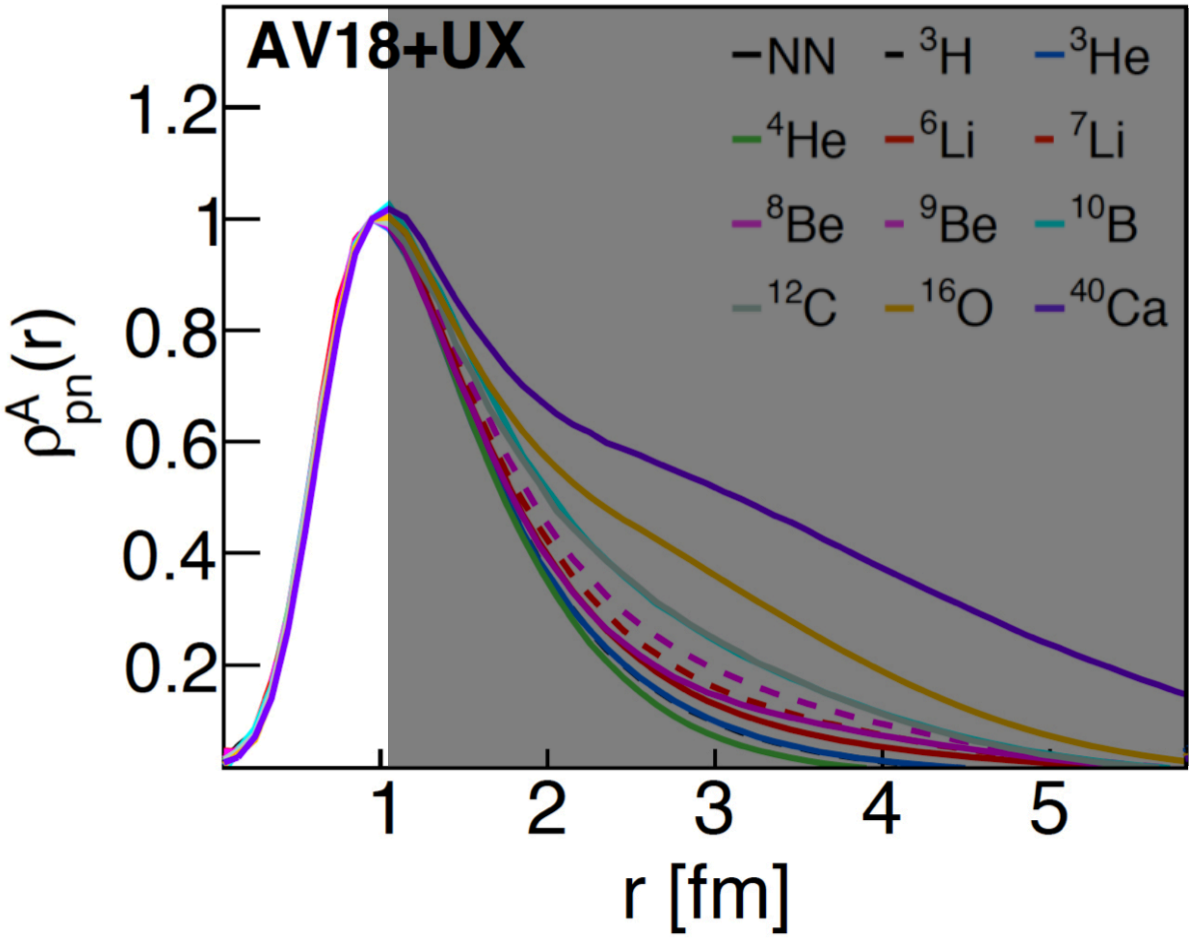
Many Body = Constant x Two-Body



Cruz Torres and Lonardoni et al., arXiv: 1907.03658 (2019)

$$\rho_A^{NN,\alpha}(r) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(r)|^2$$

Many Body = Constant x Two-Body



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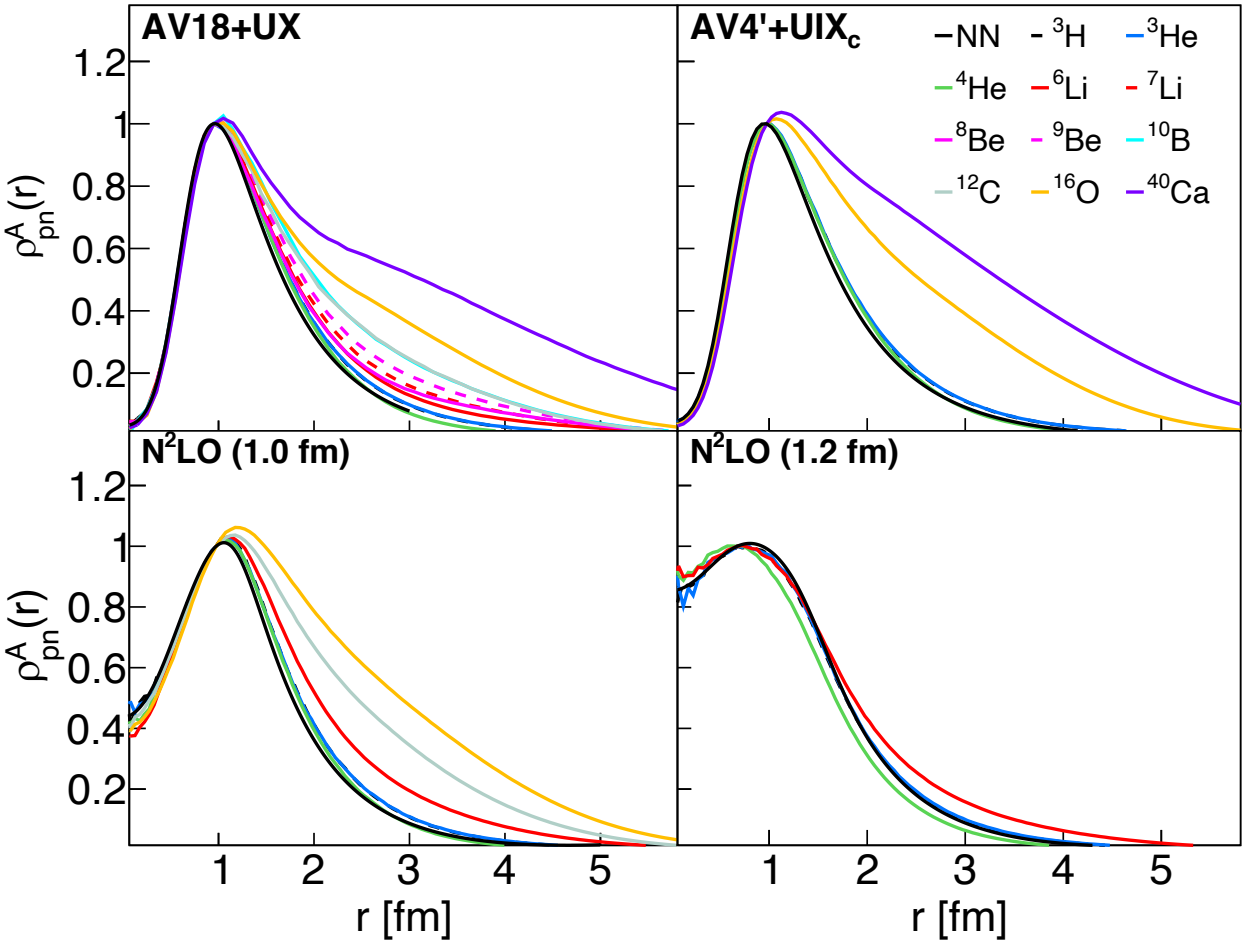
Factorization is Scheme Independent



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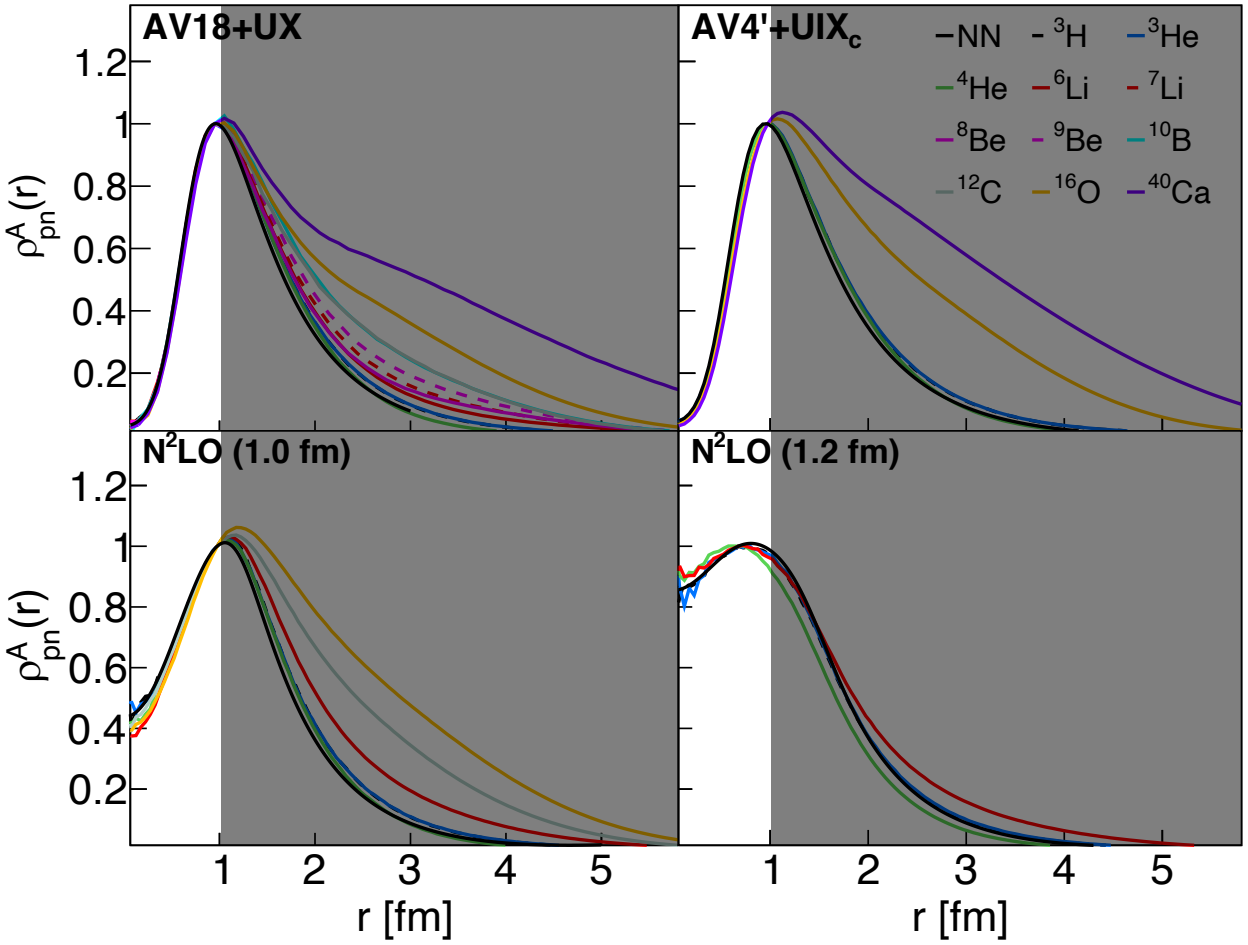
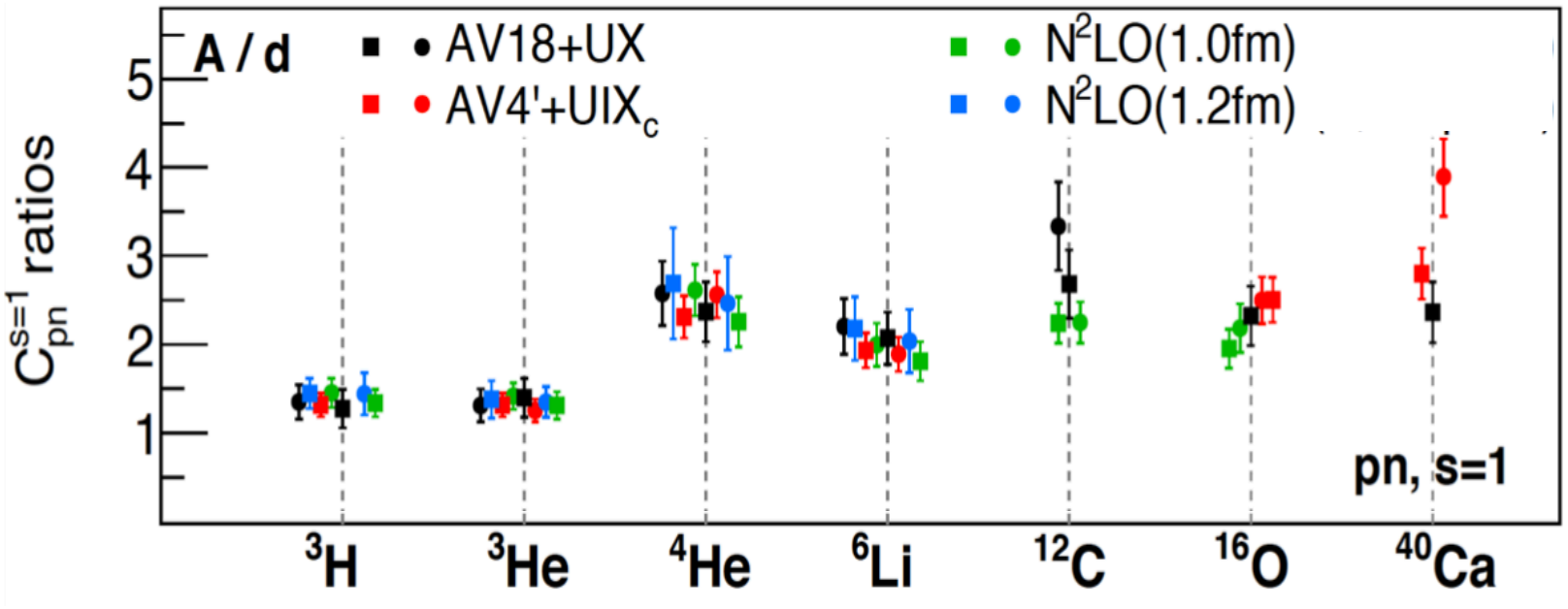


Cruz Torres and Lonardoni et al., arXiv: 1907.03658 (2019)

Scale & Scheme Independence
Momentum–Position Equivalence



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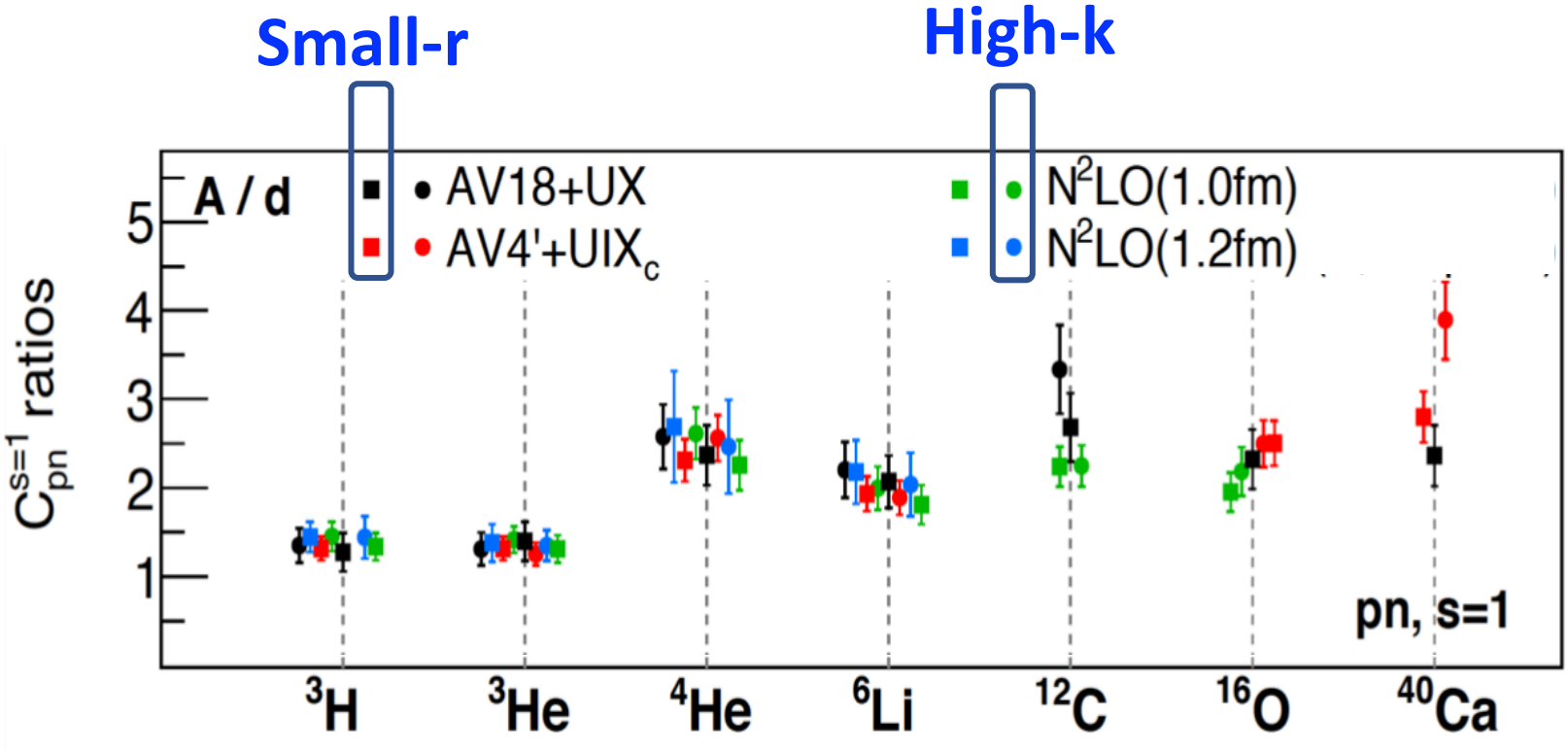

Cruz Torres and Lonardoni et al., arXiv: 1907.03658 (2019)

Scale Separation

$$\rho_A^{NN,\alpha}(r) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(r)|^2$$

Total Dist. = Constant (Low-Energy) x Two-body (High-Energy)

Generalized Contact Formalism (GCF):

Pairs Spectral Functions

$$
\begin{aligned}
S^{p}(p,\varepsilon) \quad = \quad & C_{A}^{pn,\,s=1} \cdot S_{pn}^{s=1}(p,\varepsilon) + \\
& C_{A}^{pn,\,s=0} \cdot S_{pn}^{s=0}(p,\varepsilon) + \\
& 2C_{A}^{pp,\,s=0} \cdot S_{pp}^{s=0}(p,\varepsilon)
\end{aligned}
$$

Weiss, Phys. Lett. B (2018); Cruz Torres, Phys. Lett B (2018); Weiss Phys. Lett B (2019).
+ many works by Claudio Ciofi; Jan Ryckebusch; Frankfurt Strikman; …

Generalized Contact Formalism (GCF):

Pairs Spectral Functions

$$S^p(p,\varepsilon) = C_A^{pn,\,s=1} \cdot S_{pn}^{s=1}(p,\varepsilon) + C_A^{pn,\,s=0} \cdot S_{pn}^{s=0}(p,\varepsilon) + 2C_A^{pp,\,s=0} \cdot S_{pp}^{s=0}(p,\varepsilon)$$

Low-Energy x High-Energy

Weiss, Phys. Lett. B (2018); Cruz Torres, Phys. Lett B (2018); Weiss Phys. Lett B (2019).
+ many works by Claudio Ciofi; Jan Ryckebusch; Frankfurt Strikman; …

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Each pair is convoluted with c.m. motion:

$$s_{ab}^{\alpha} = \frac{1}{4\pi}\int \frac{dp_2}{(2\pi)^3}\,\delta[f(p_2)]\;\left|\varphi_{ab}^{\alpha}(p_1-p_2)/2\right|^2\, n_{ab}^{\alpha}(p_1+p_2)$$

Weiss, Phys. Lett. B (2018); Cruz Torres, Phys. Lett B (2018); Weiss Phys. Lett B (2019).

Generalized Contact Formalism (GCF):

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Weiss, Phys. Lett. B (2018); Cruz Torres, Phys. Lett B (2018); Weiss Phys. Lett B (2019).

Generalized Contact Formalism (GCF):

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Weiss, Phys. Lett. B (2018); Cruz Torres, Phys. Lett B (2018); Weiss Phys. Lett B (2019).

Probing the NN Interaction

What's needed?

✓ Data

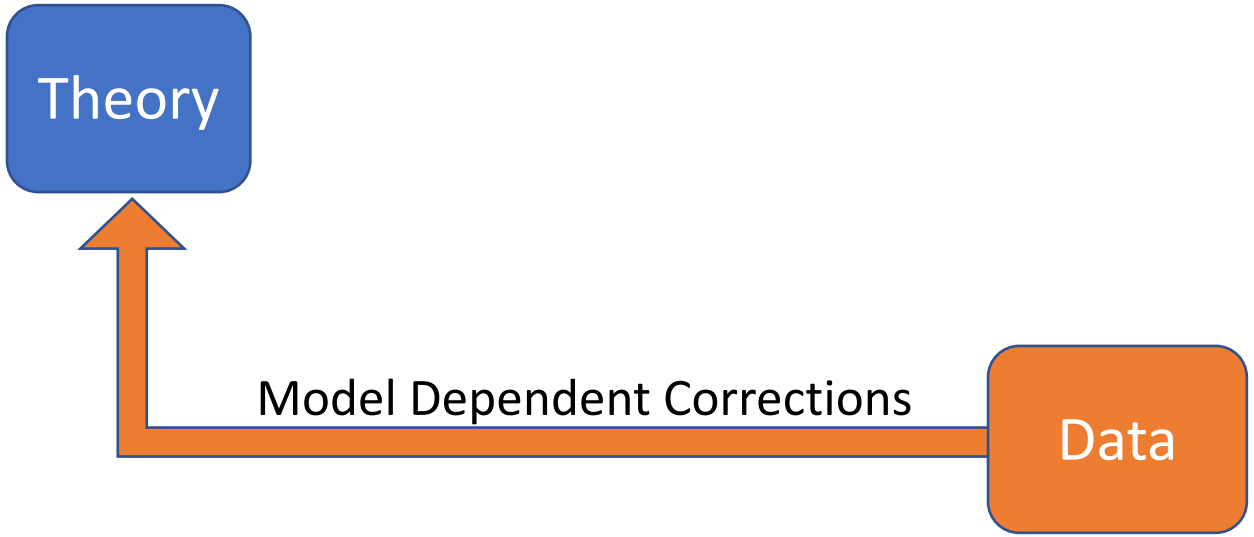
- ~~Ab-initio cross-section calculations~~

✓ Factorization \w spectral functions from NN interaction

$$\frac{d^4\sigma}{d\Omega_{k'}\,d\epsilon'_k\,d\Omega_{p'_1}\,d\epsilon'_1} = p'_1\epsilon'_1\sigma_{eN}S^N(\boldsymbol{p}_1,\epsilon_1)$$

Theory-Data Comparisons

Experiments usually correct data for detector acceptance and reaction mechanism effect before comparing with theory.



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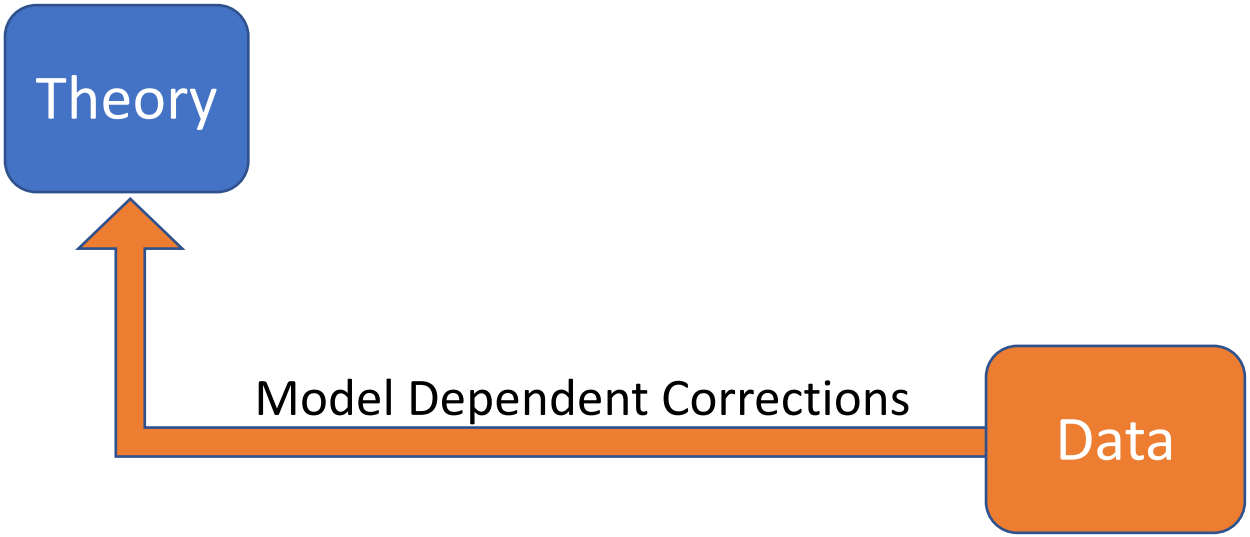

Theory-Data Comparisons

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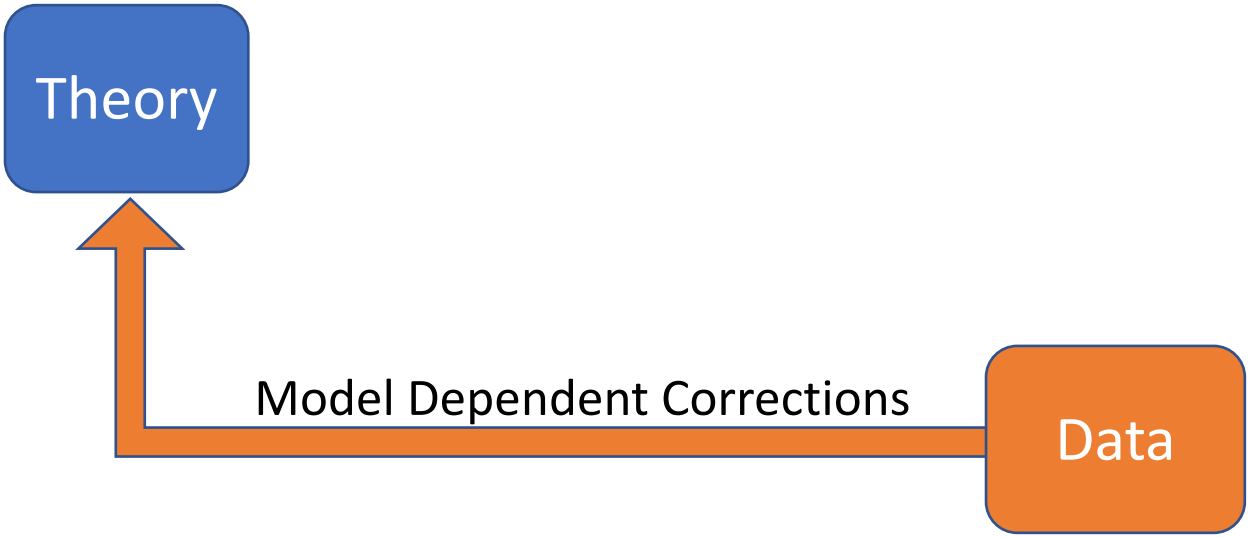
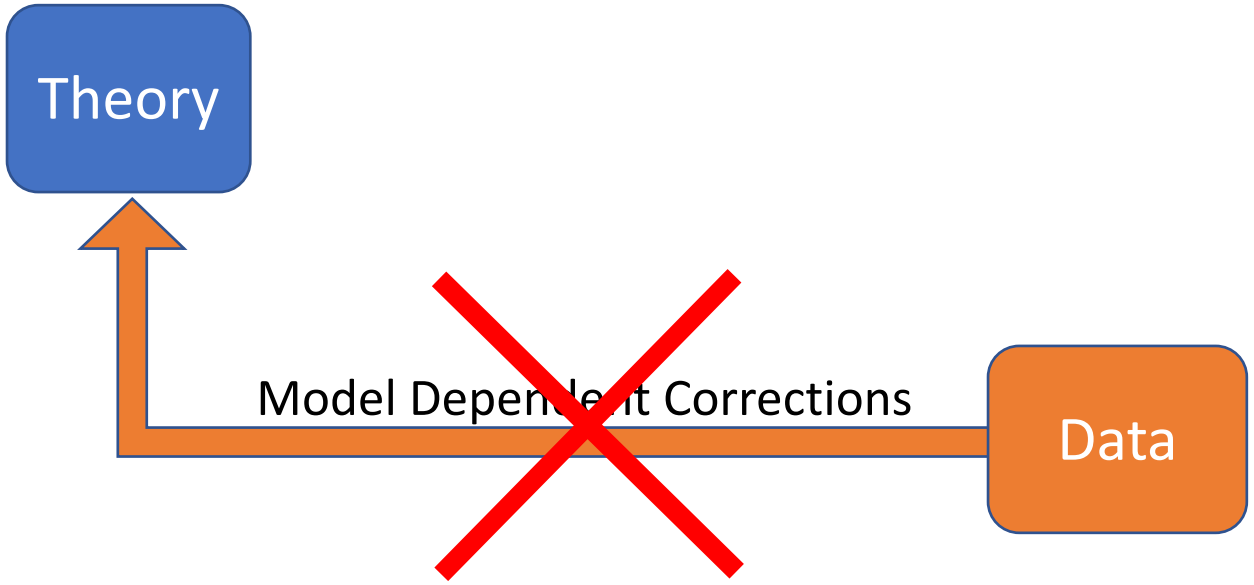


Theory-Data Comparisons

Experiments usually correct data for detector acceptance and reaction mechanism effect before comparing with theory.

This often leads to ‘model dependent data’ 😬



Theory-Data Comparisons

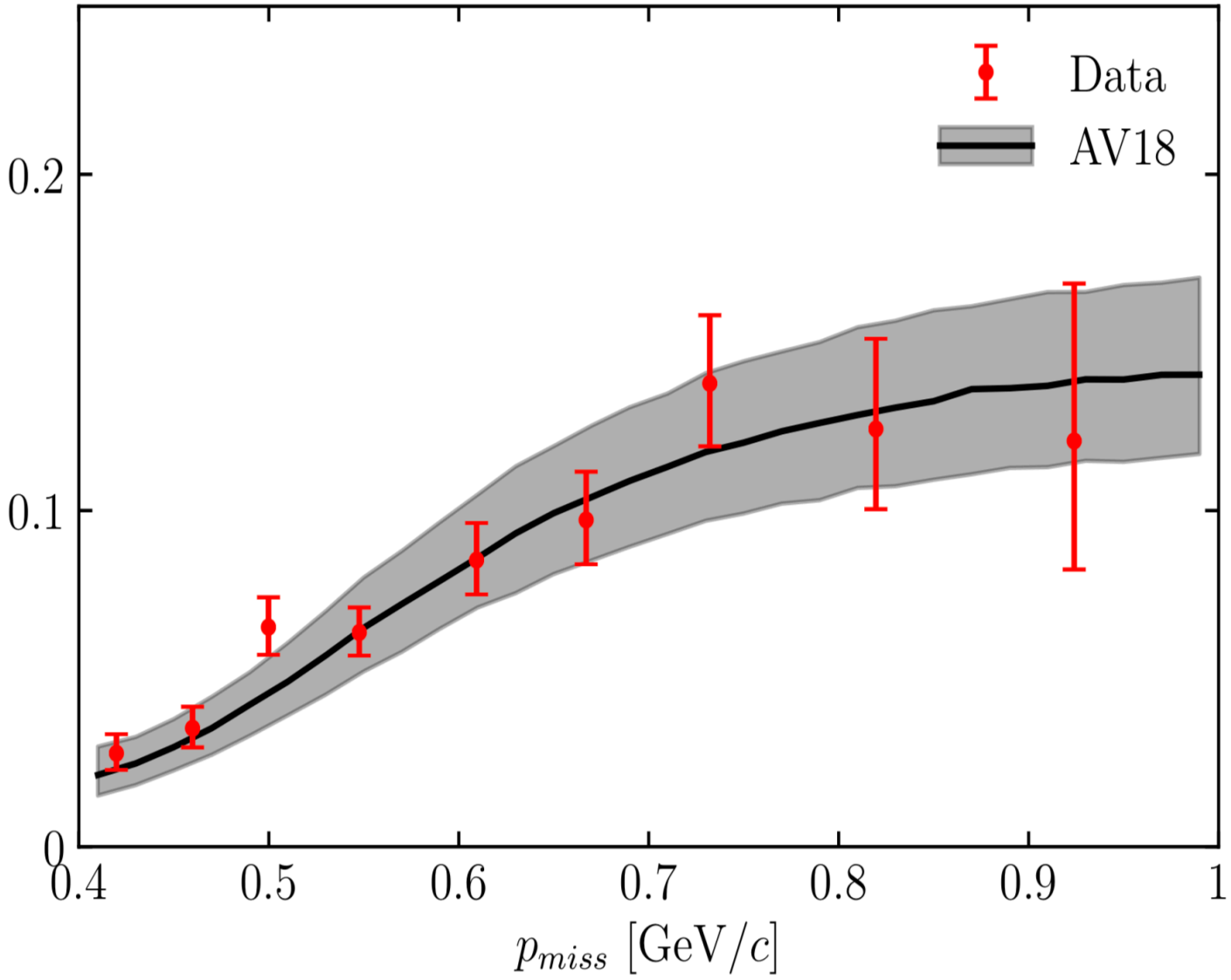
Experiments usually correct data for detector acceptance and reaction mechanism effect before comparing with theory.

Instead, we bring theory to data!

[theory based simulation forms 'pseudo-data' that is overlaid on exp-data]

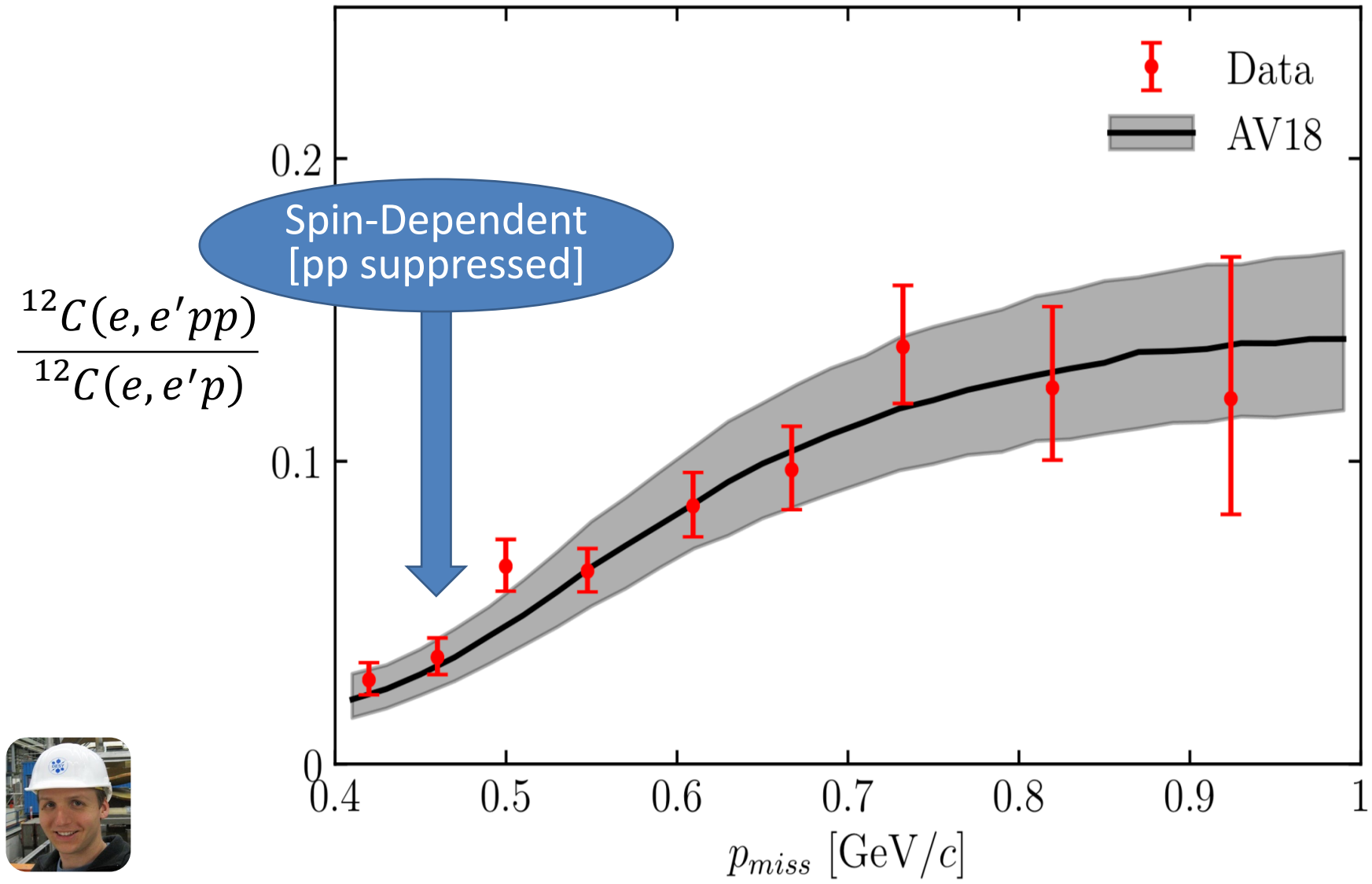
Reaching the Repulsive Core

$$\frac{^{12}C(e,e'pp)}{^{12}C(e,e'p)}$$



Schmidt et al., Nature (2020)

Reaching the Repulsive Core



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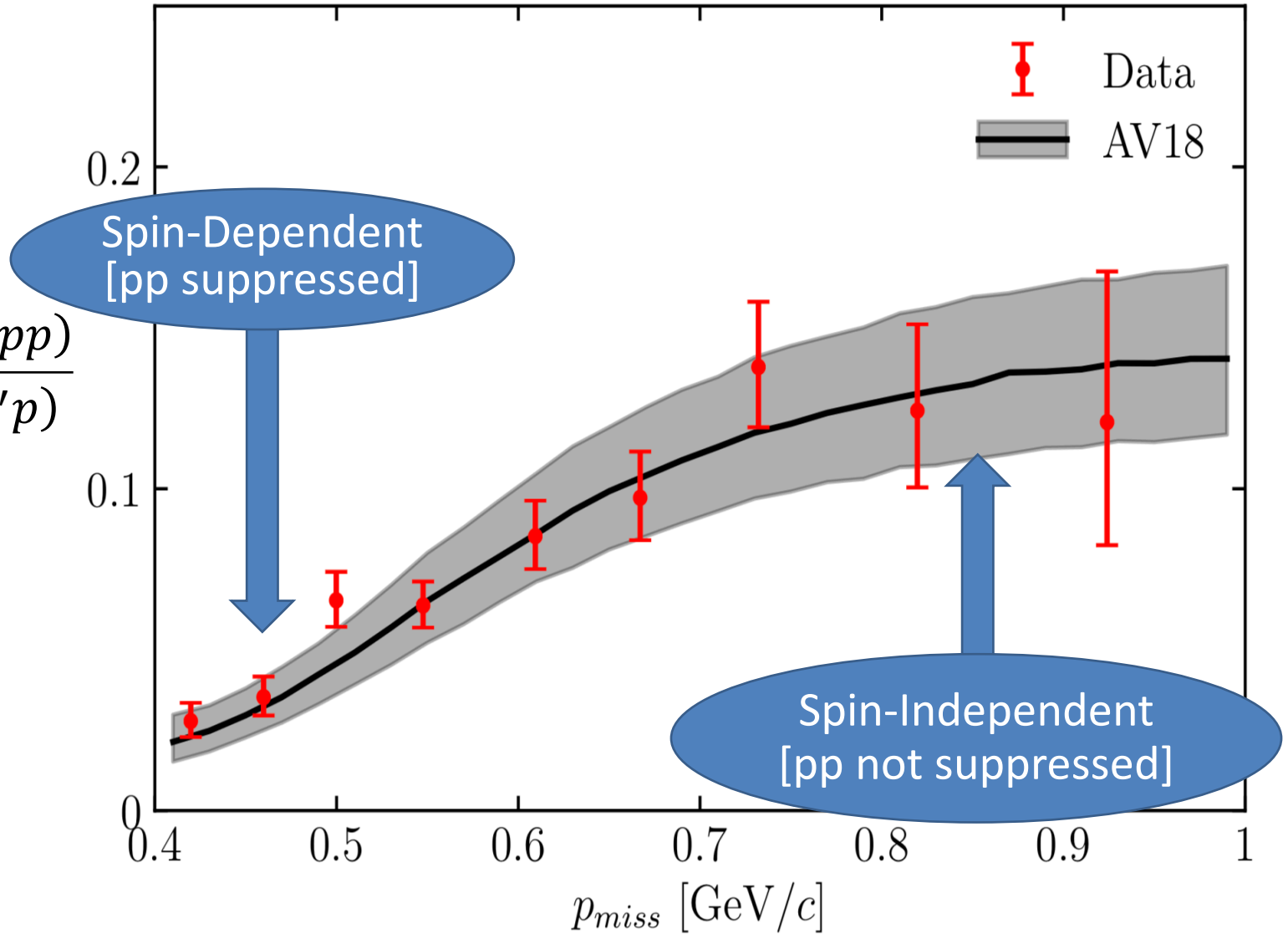

Schmidt et al., Nature (2020)

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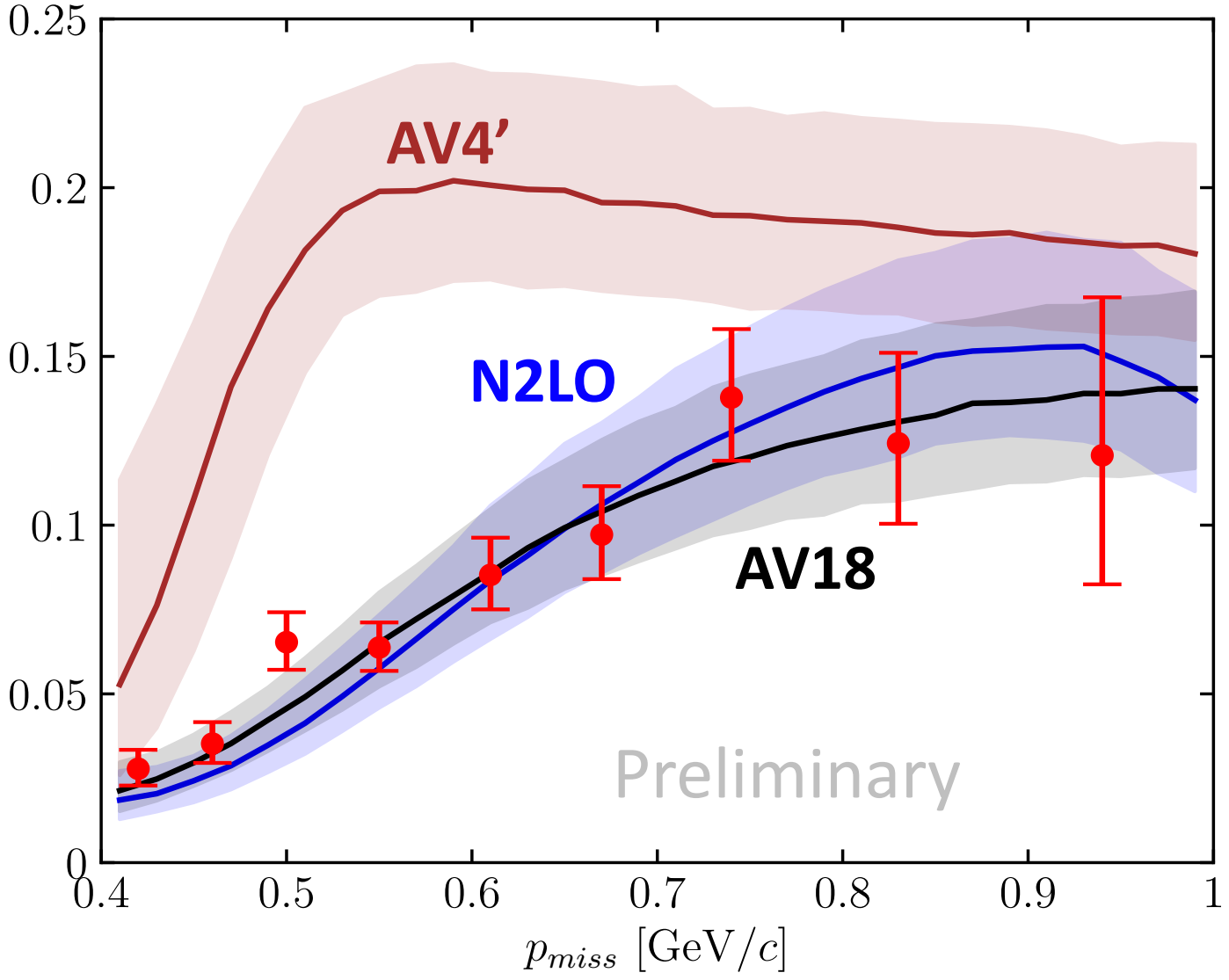
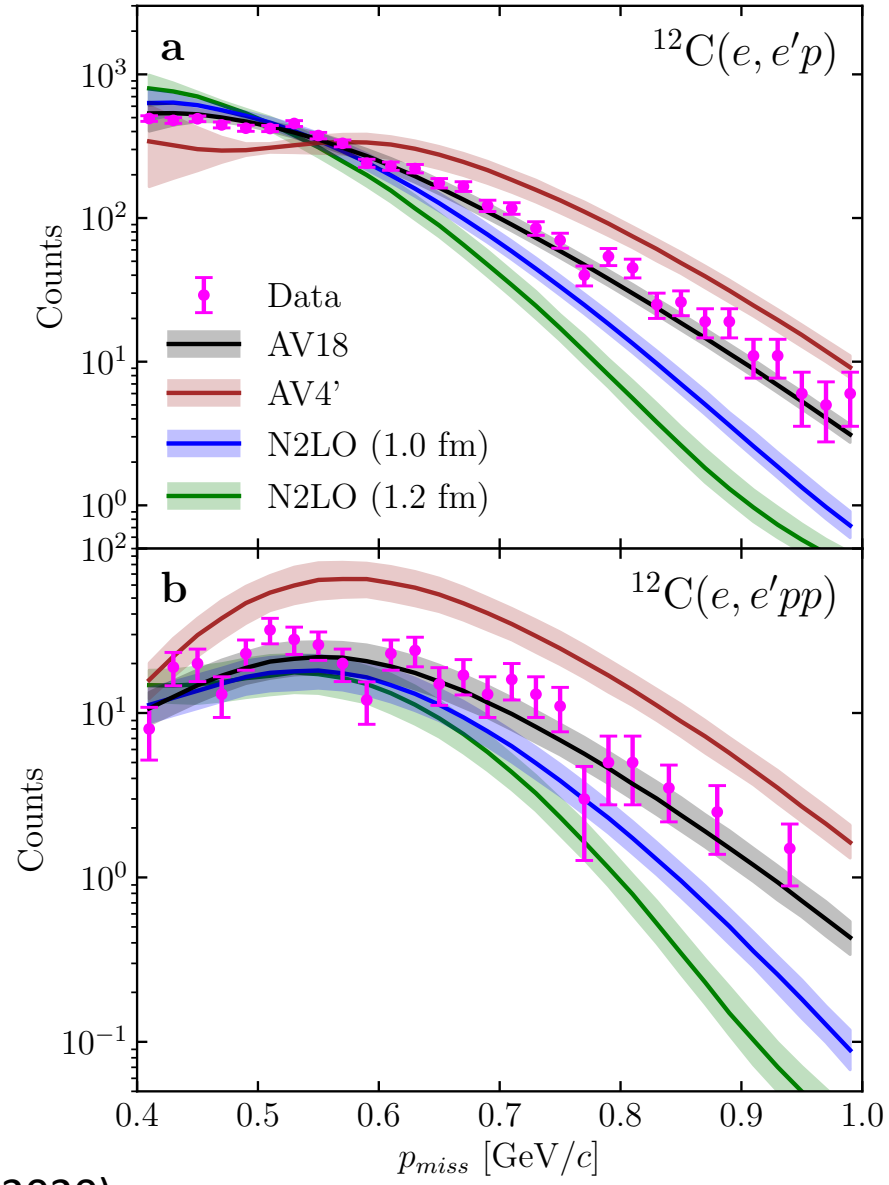


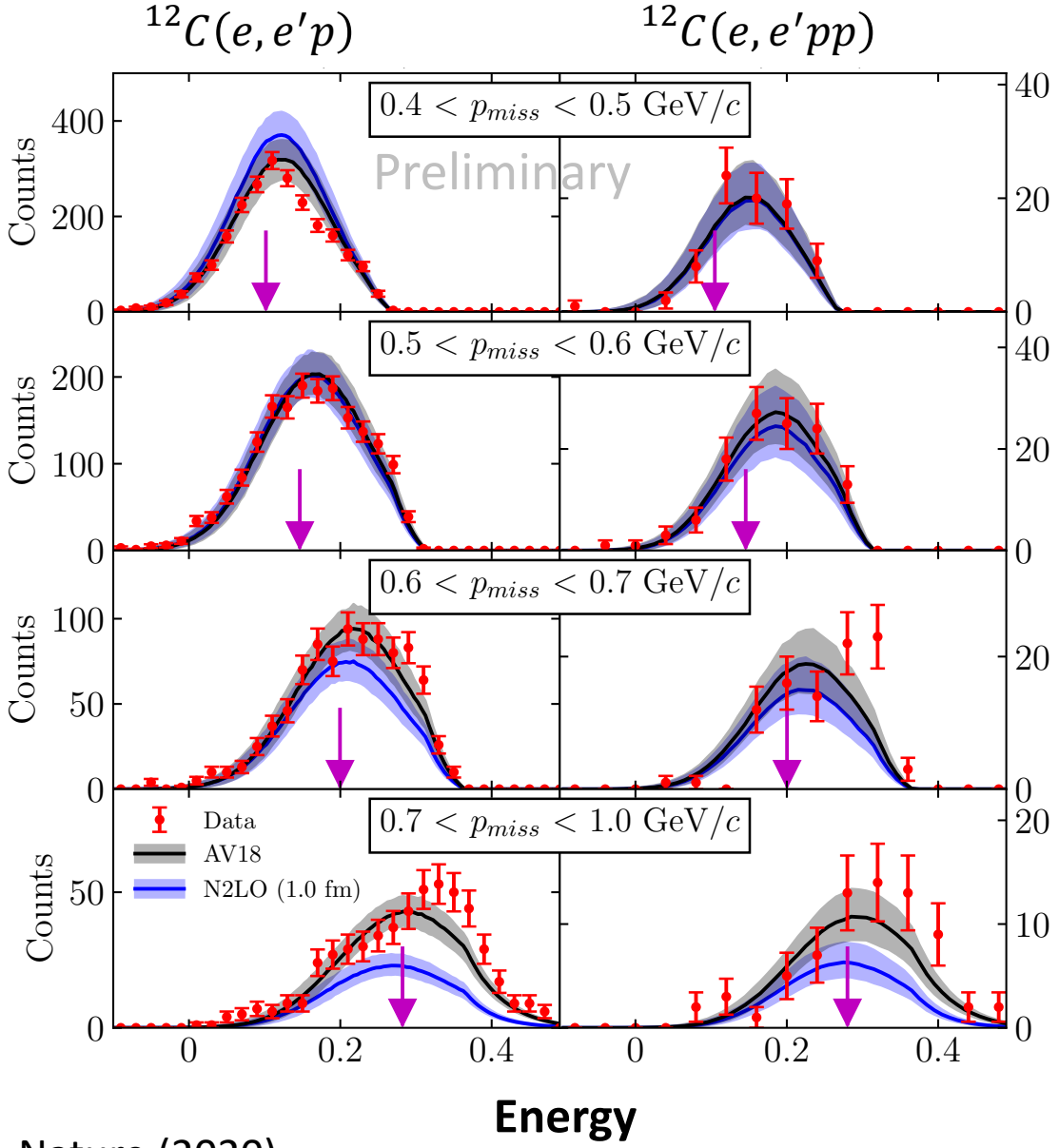
Schmidt et al., Nature (2020)

Nucleon Distributions Sensitivity



Schmidt et al., Nature (2020)

Spectral function Sensitivity



Momentum

400 – 500 MeV/c

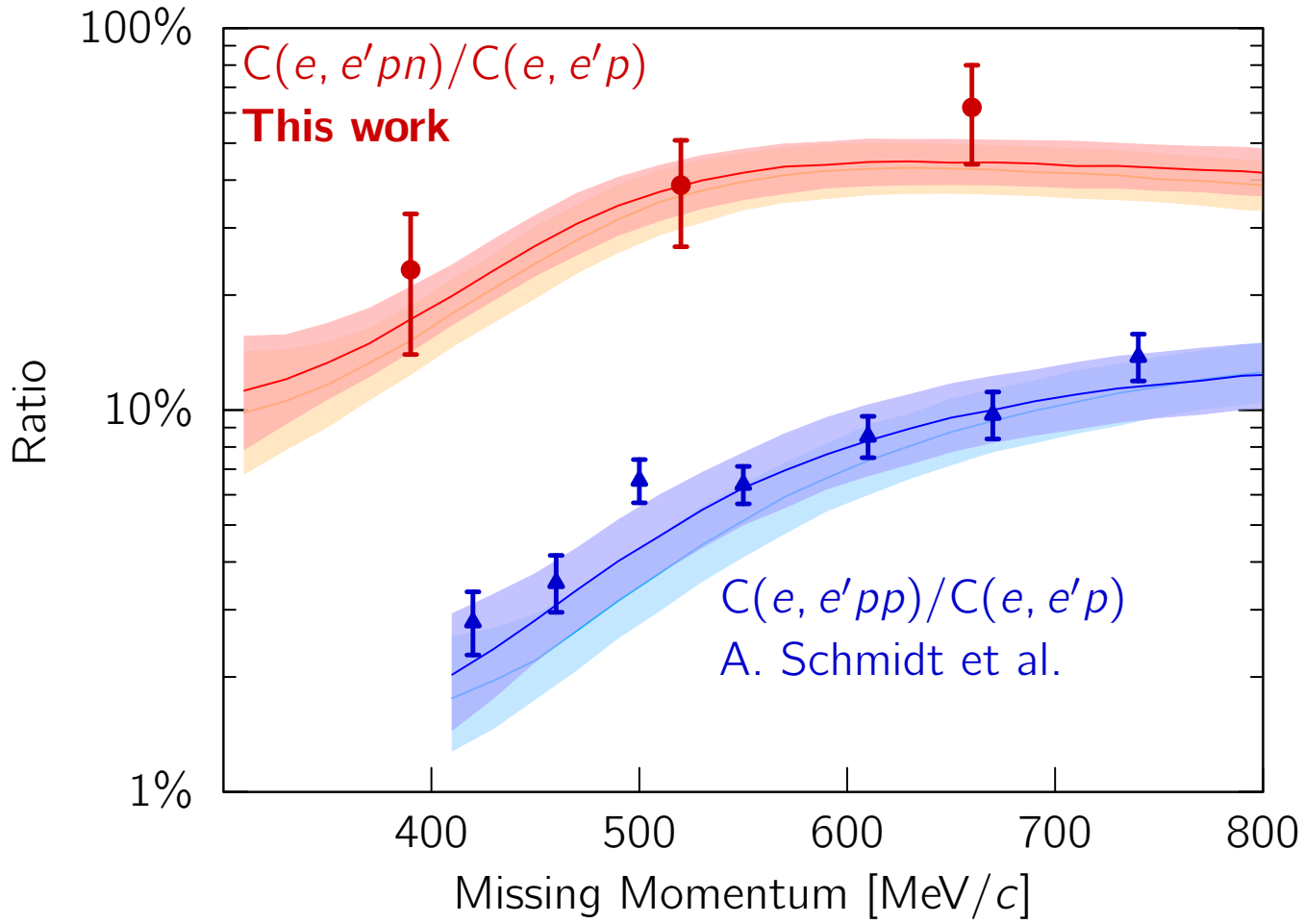
500 – 600 MeV/c

600 – 700 MeV/c

700 – 1000 MeV/c

Schmidt et al., Nature (2020)

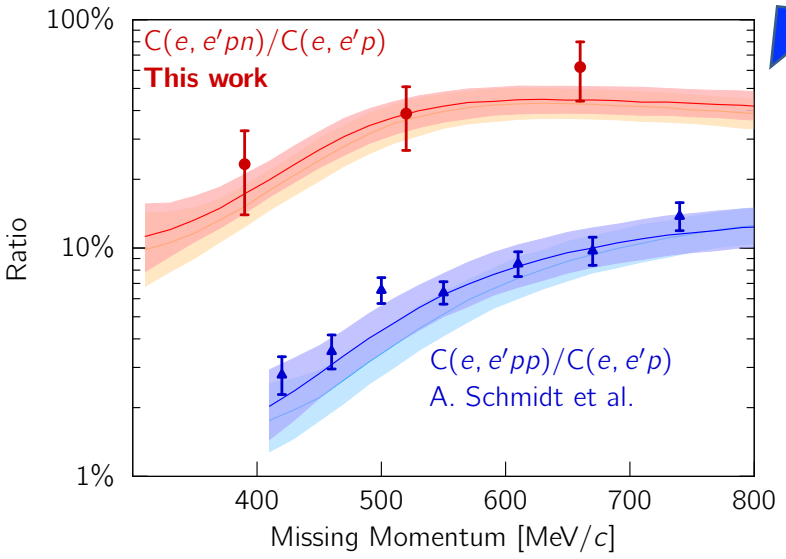
pn data completes the picture!



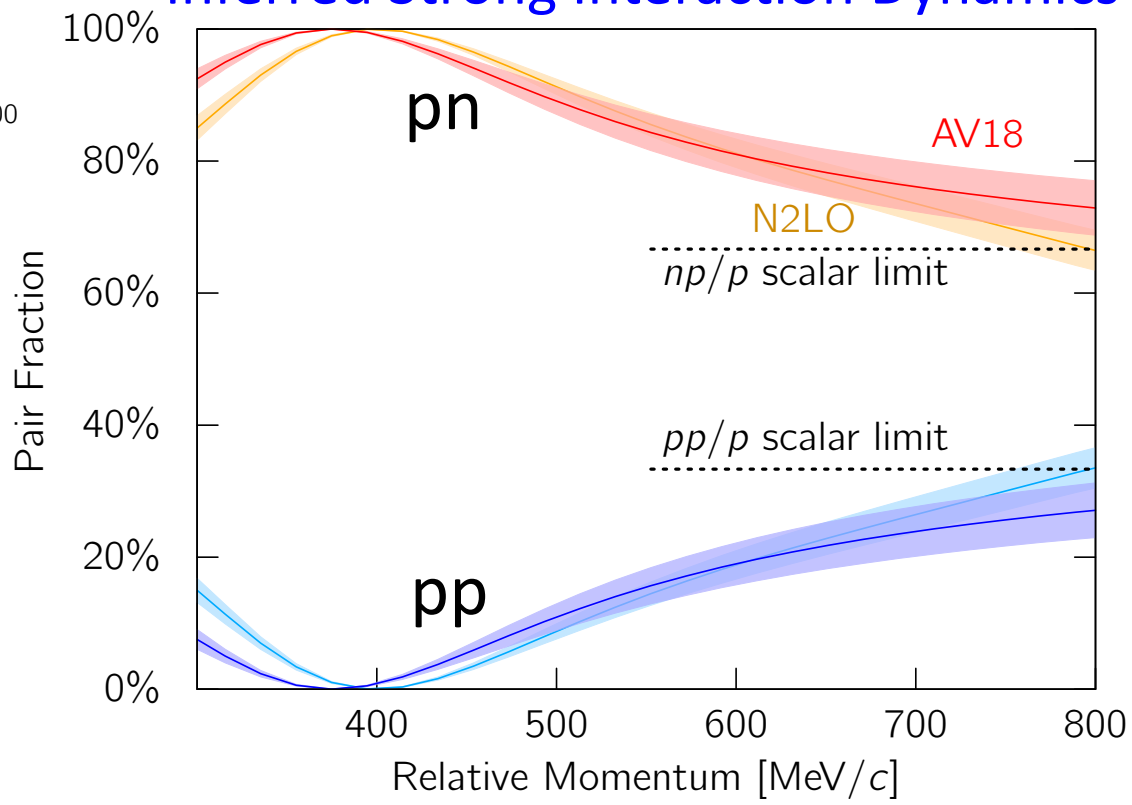
Korover et al. (2020)

pn data completes the picture!

Measured cross-sections



Inferred Strong Interaction Dynamics

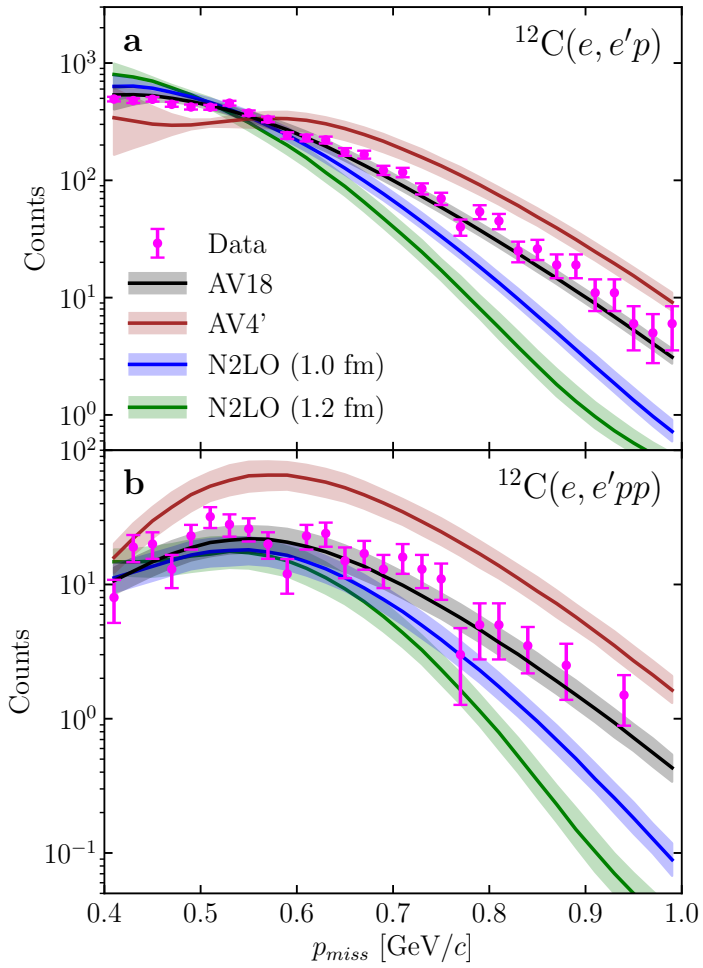


Korover et al. (2020)

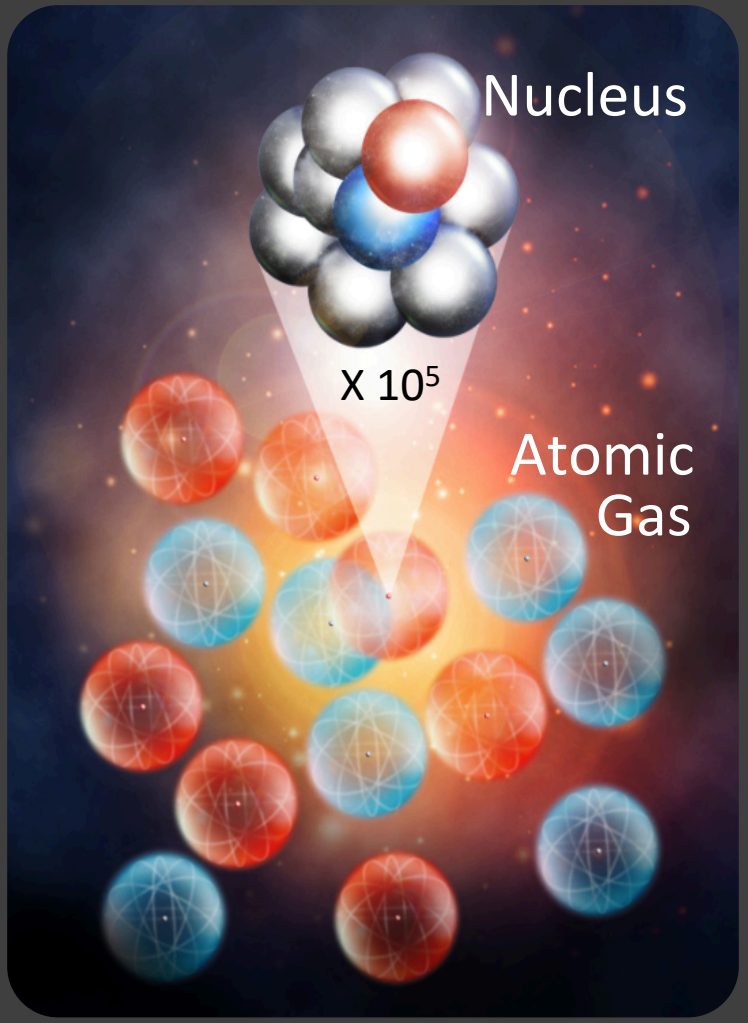
Interim Summary

- Nuclear momentum distribution has two distinct regions.
- #SRC-protons = #SRC-neutrons, independent of neutron excess.
- The fraction of correlated protons / neutrons grow / saturate with neutron excess.

+ Allow probing NN interaction up to 1 GeV/c.



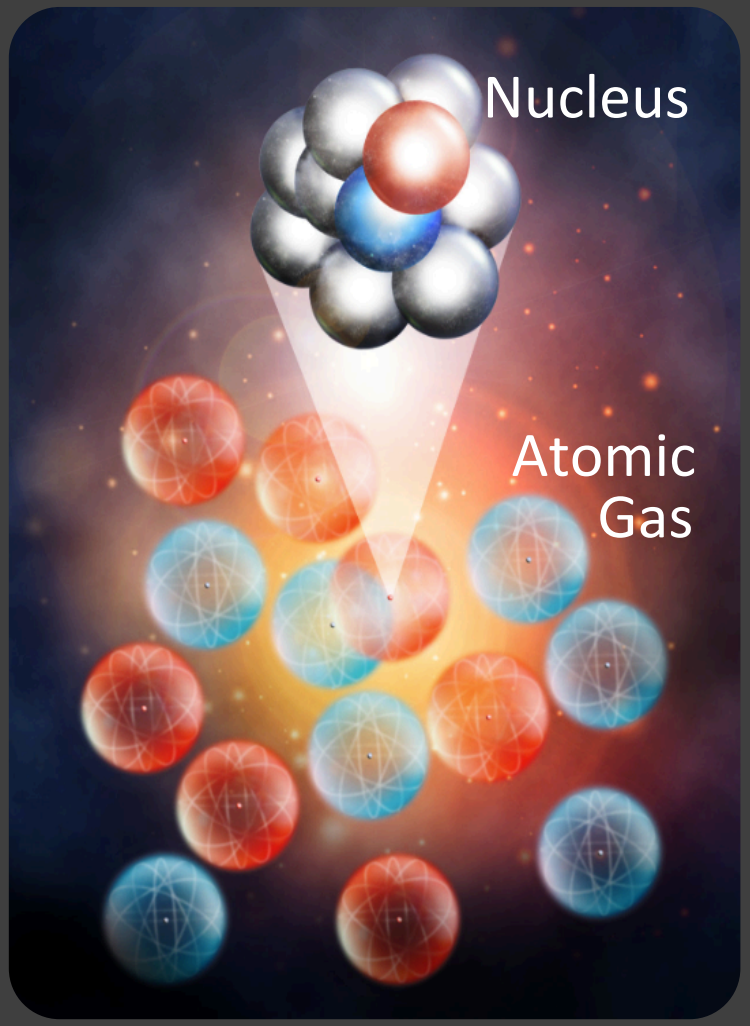
Generalization of the Atomic Contact Formalism



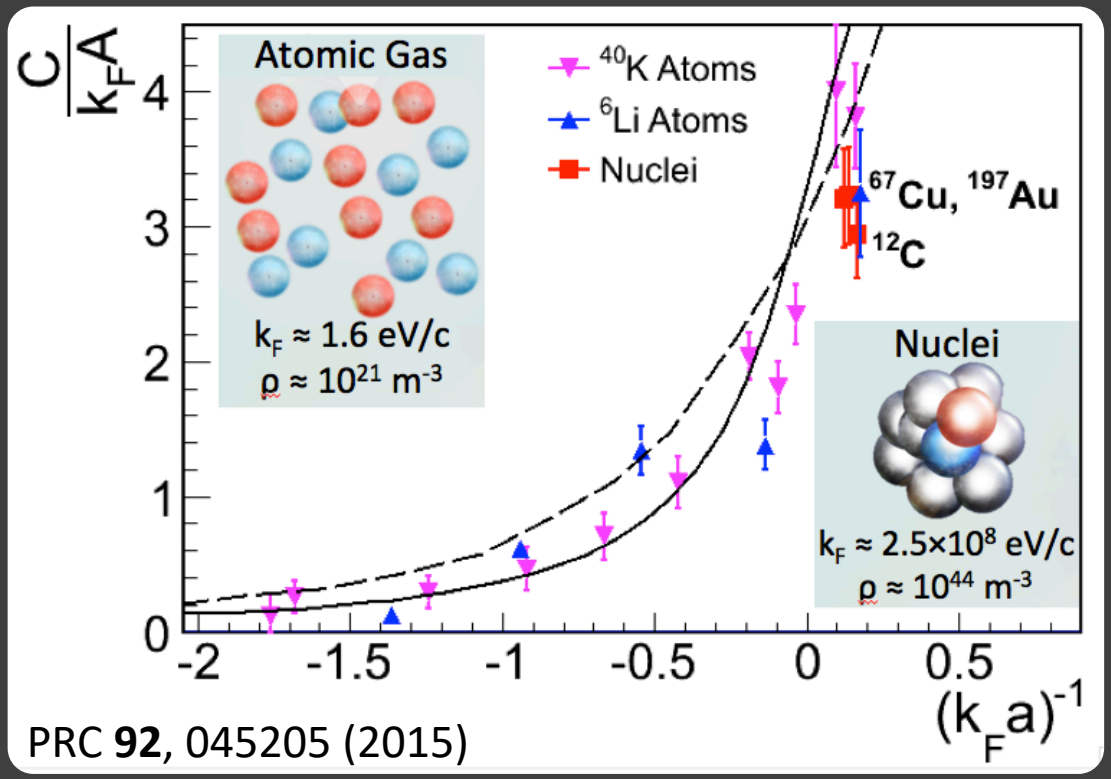
Generalization of the Atomic Contact Formalism

While two body interactions can differ….

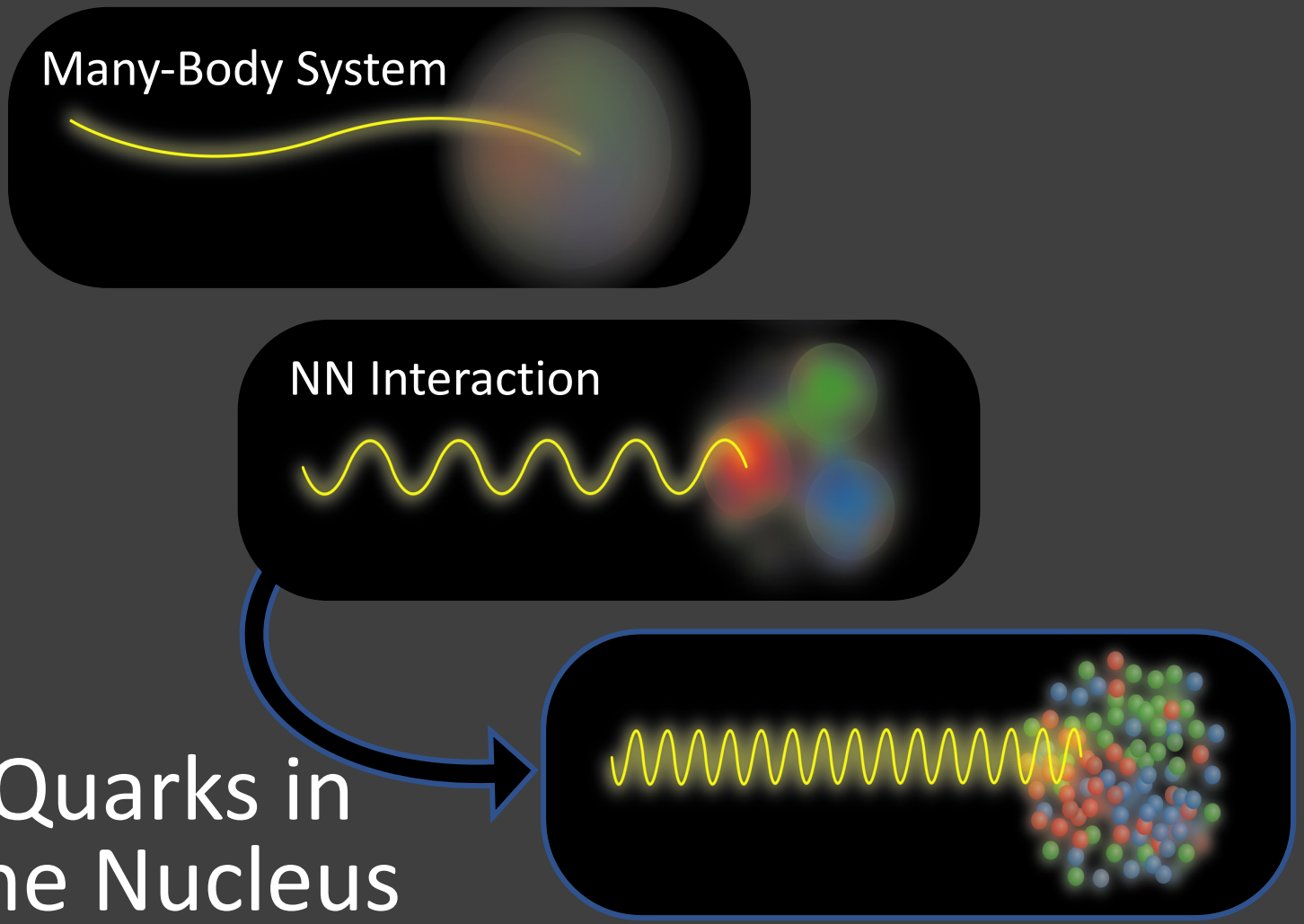
… Many tools can be shared



Generalization of the Atomic Contact Formalism

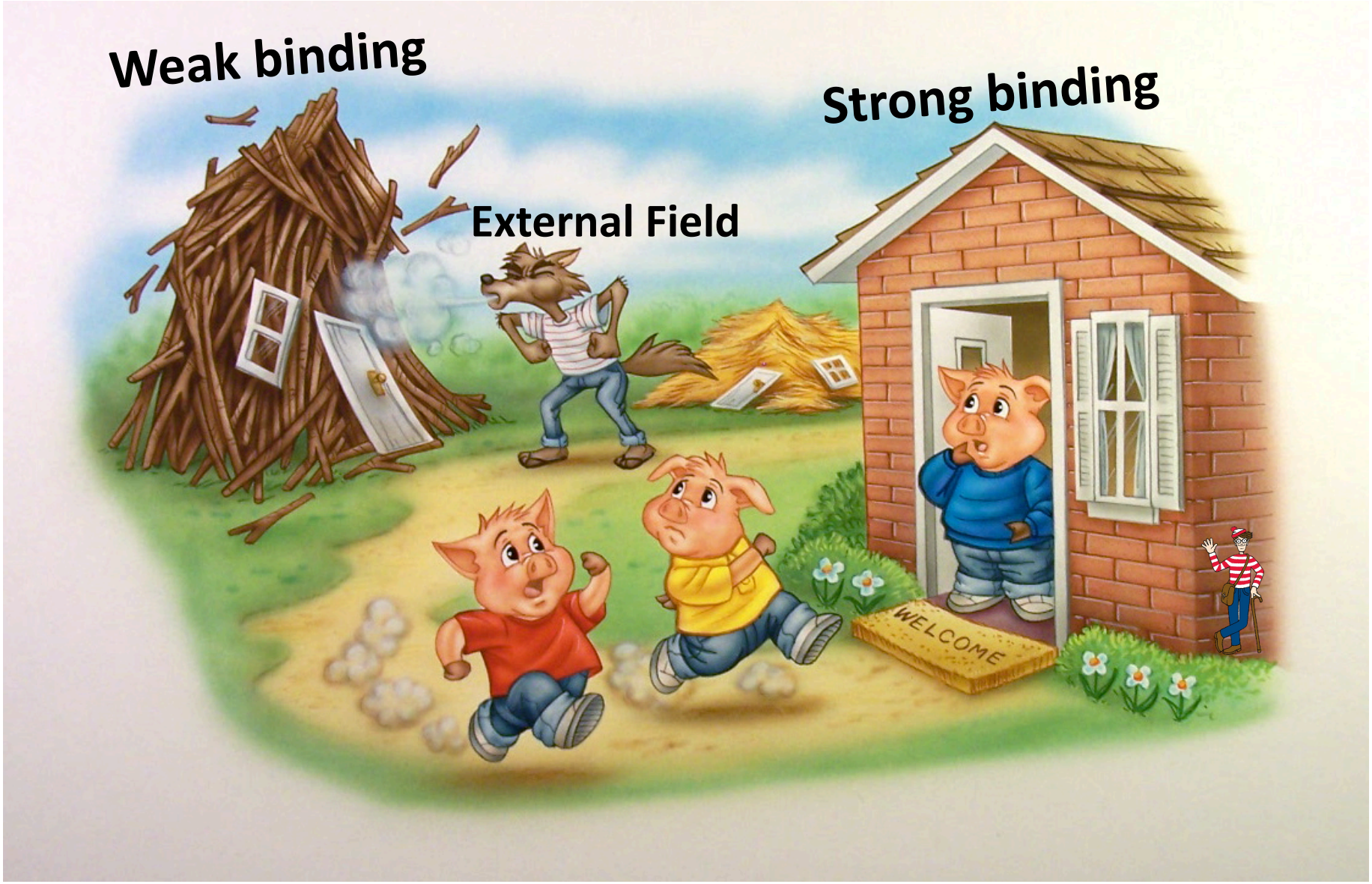


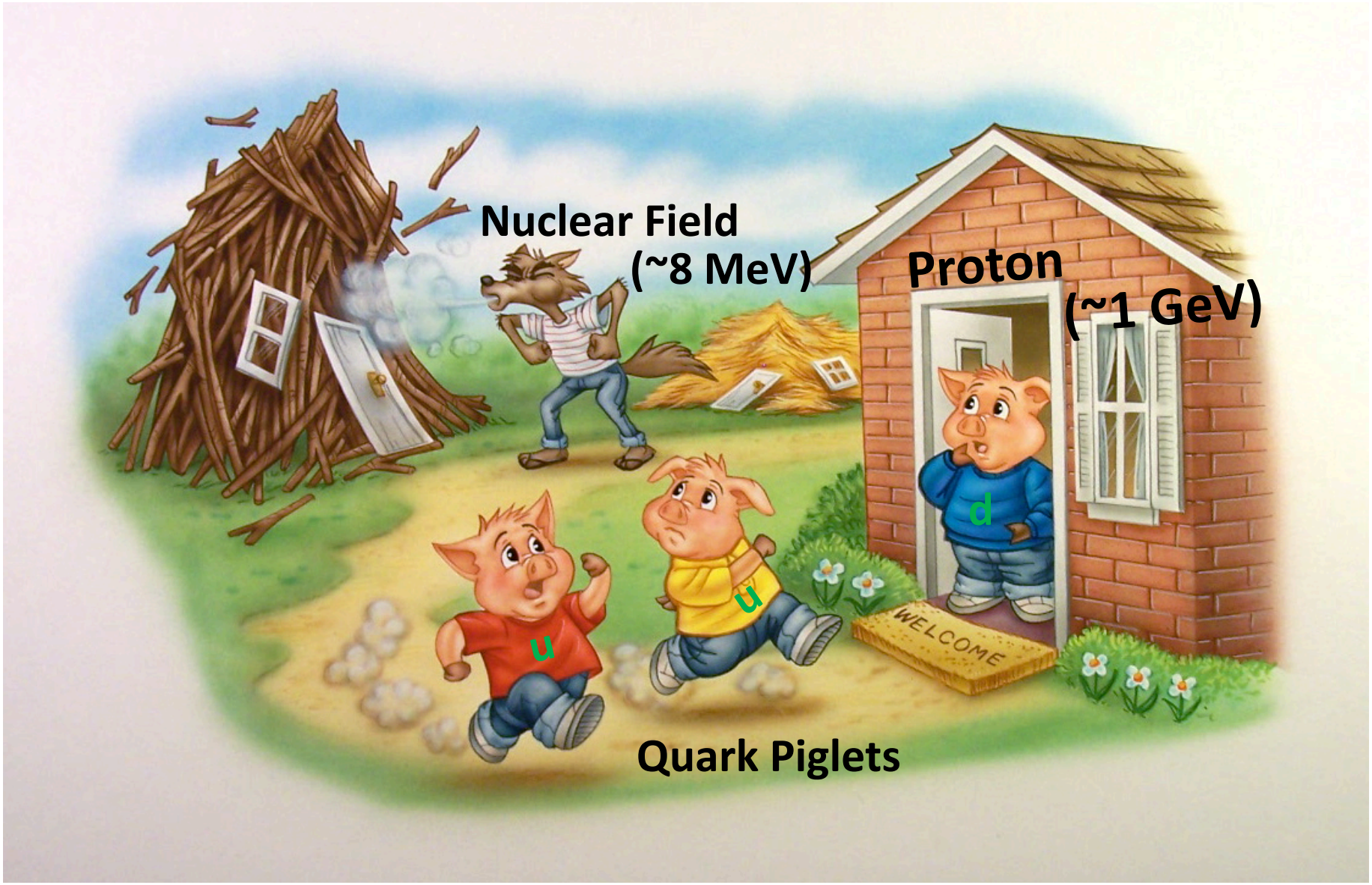
PRC **92**, 045205 (2015)


Many-Body System
NN Interaction
Quarks in
the Nucleus


WELCOME

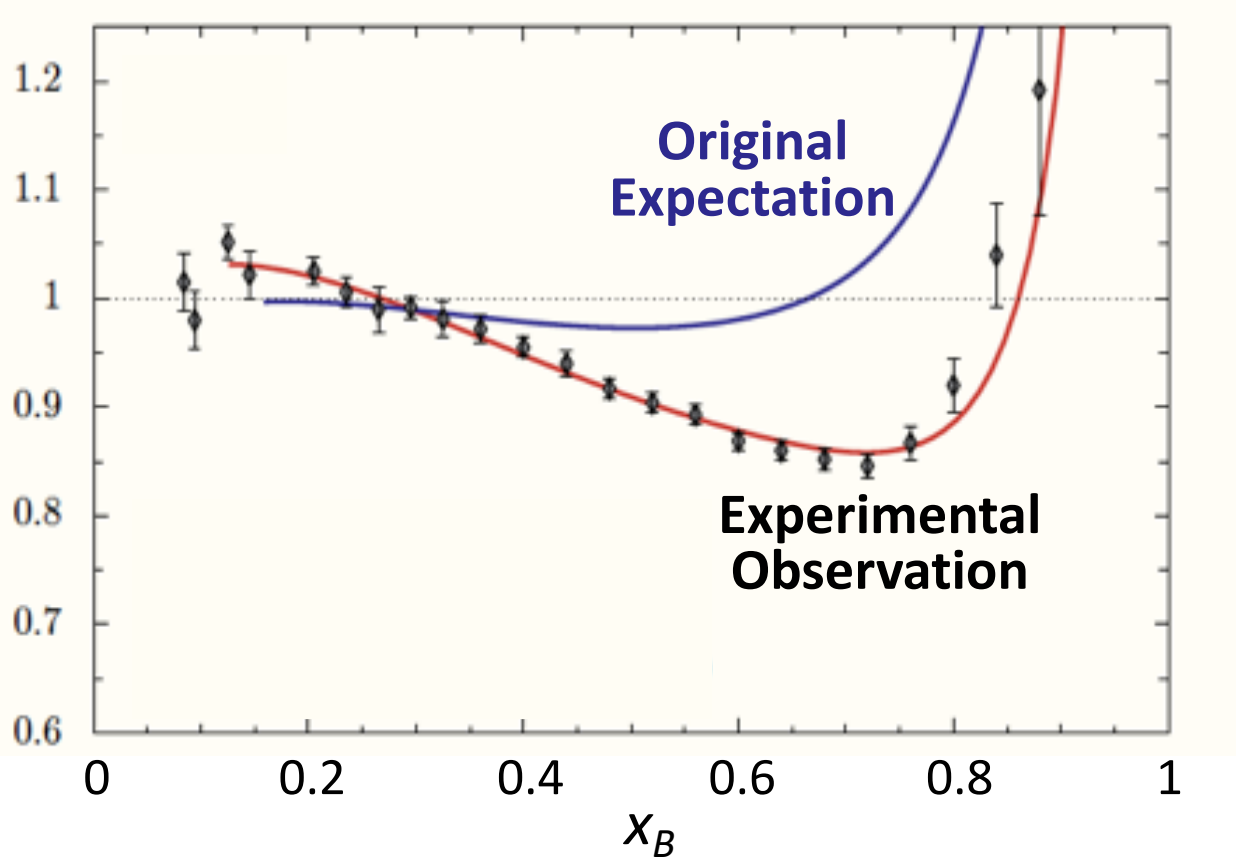
A Tale of *Scale Separation & Confinement*


Weak binding
Strong binding
External Field
WELCOME


Nuclear Field
(~8 MeV)
Proton
(~1 GeV)
u
u
d
WELCOME
Quark Piglets

EMC Effect:

Iron / Deuterium
Structure Function



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., Nature (**2019**)

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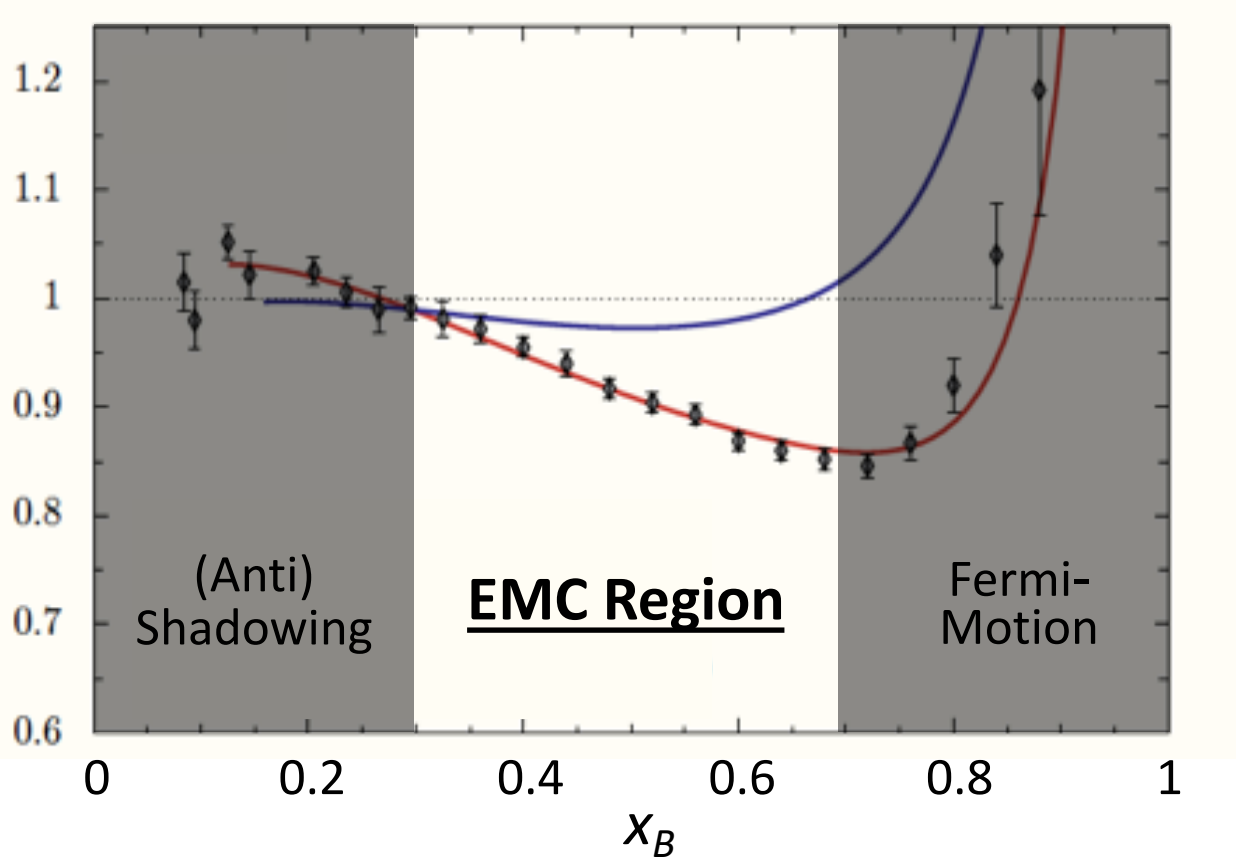

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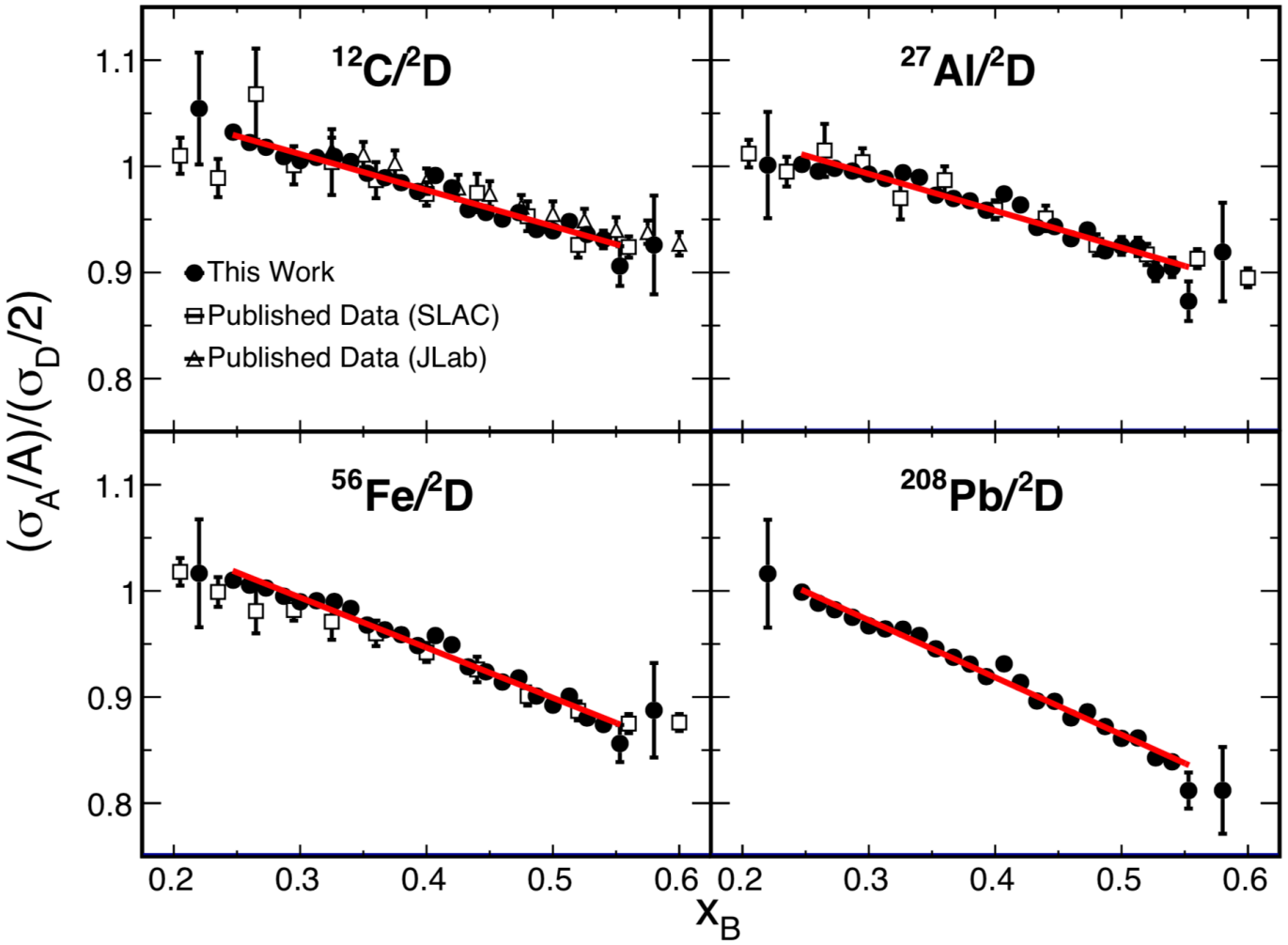
High Precision data!



JLab (2019)

Schmookler et al., Nature (2019)

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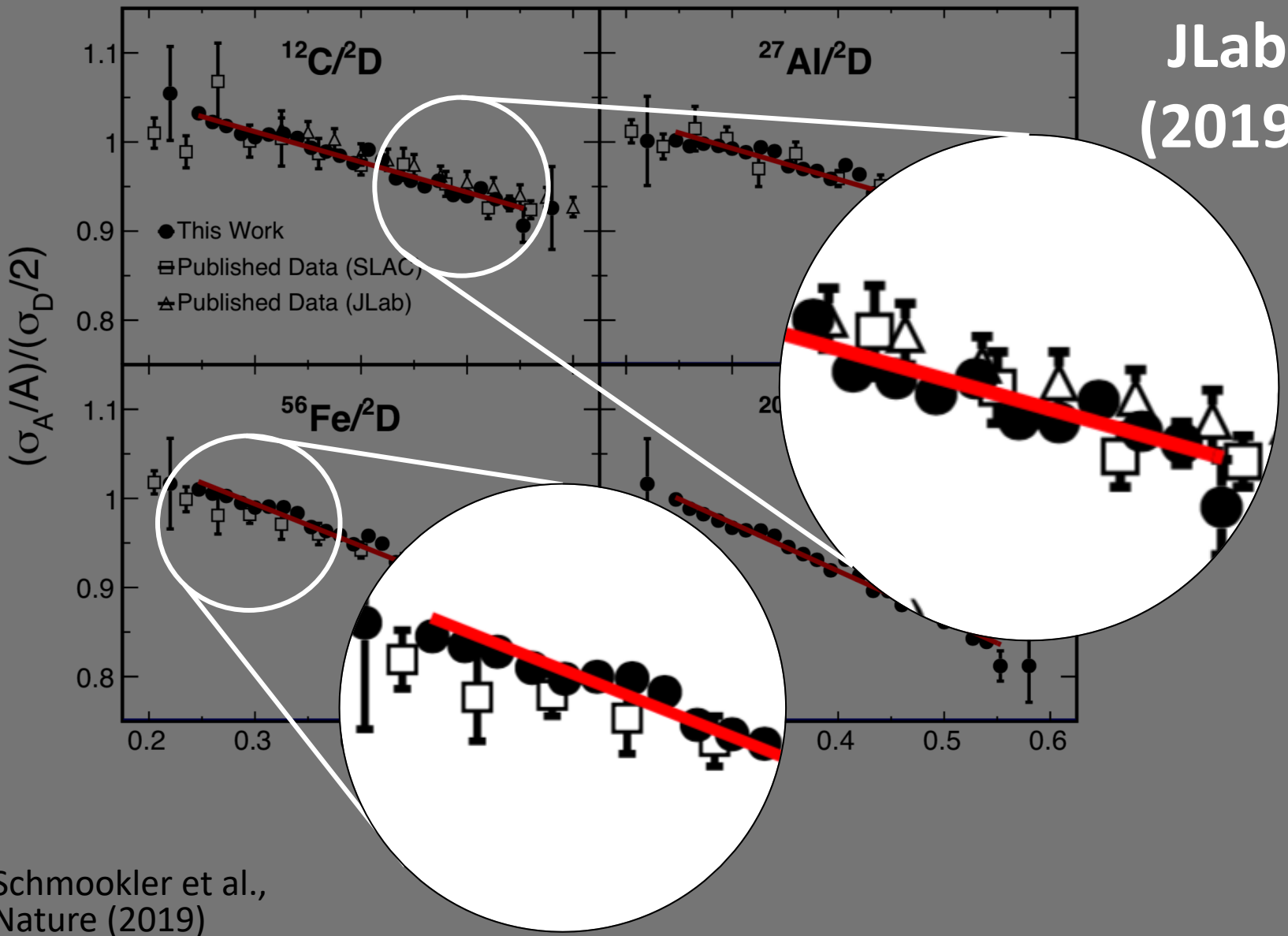
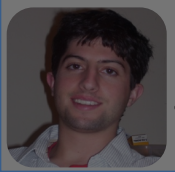
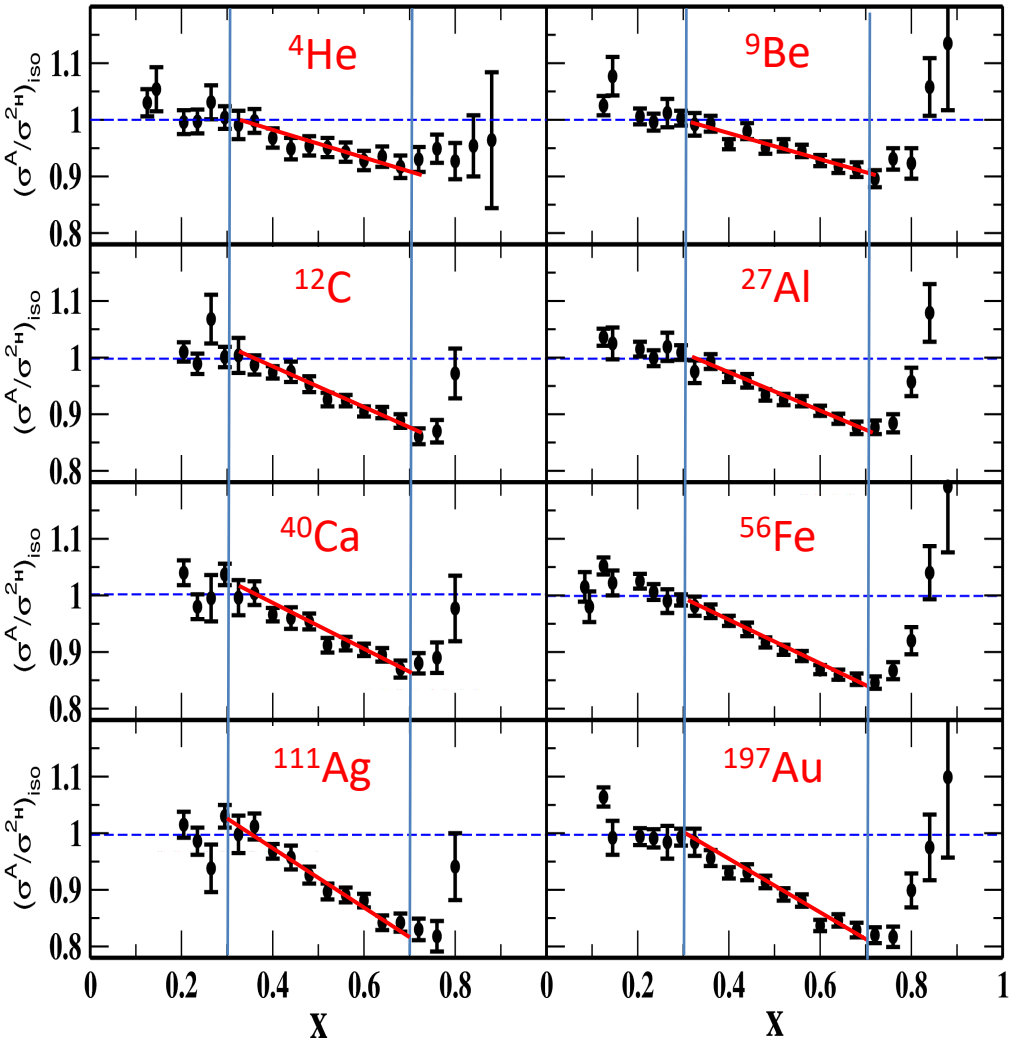


JLab (2019)



Schmookler et al., Nature (2019)

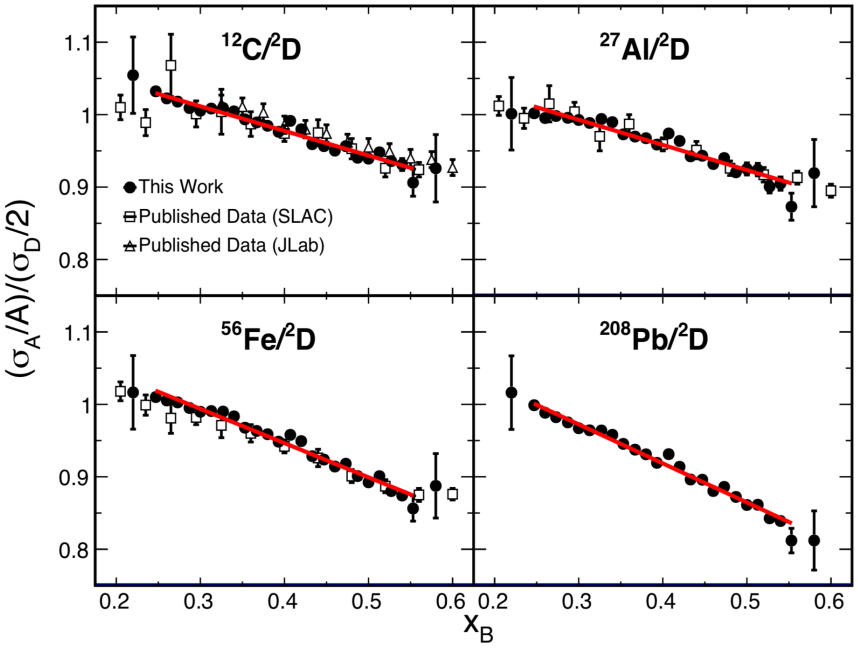
‘Global’ EMC Data



Gomez PRD (1994)

SLAC (1994)

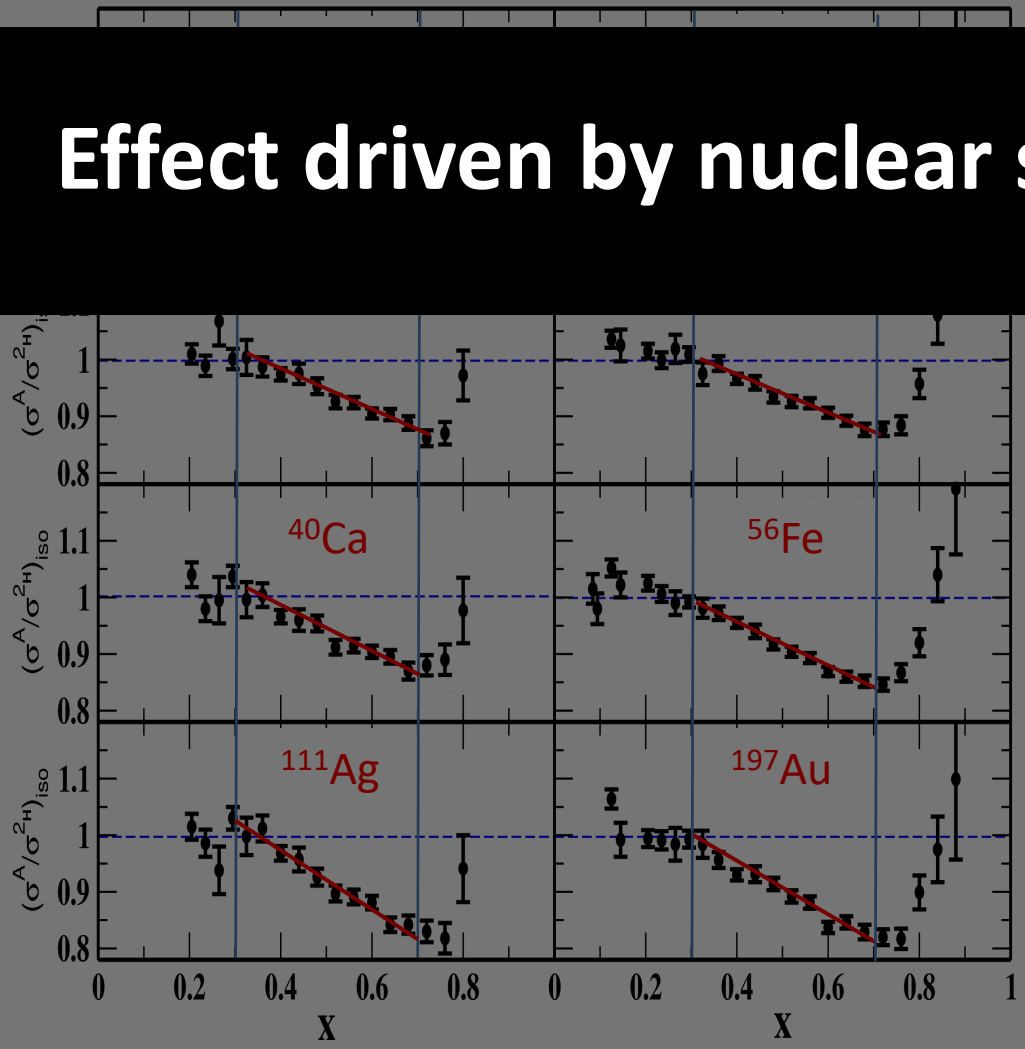
JLab (2019)



Schmookler, Nature (2019)

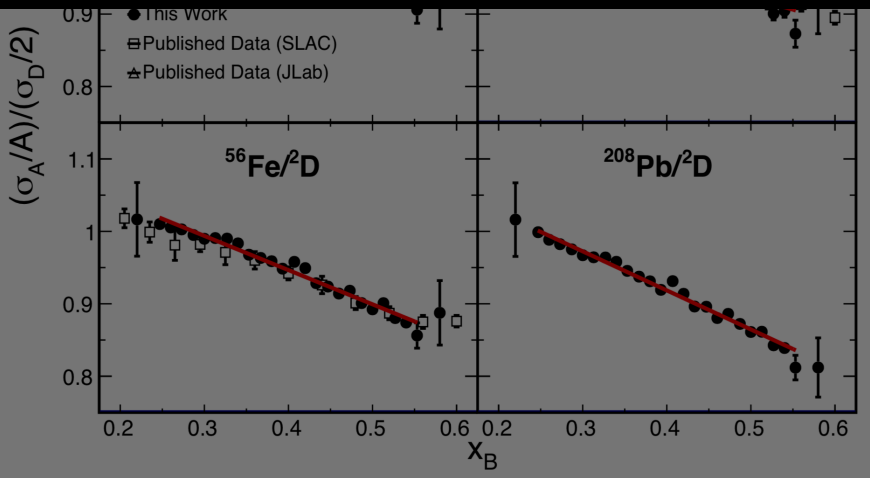
‘Global’ EMC Data

Effect driven by nuclear structure & dynamics



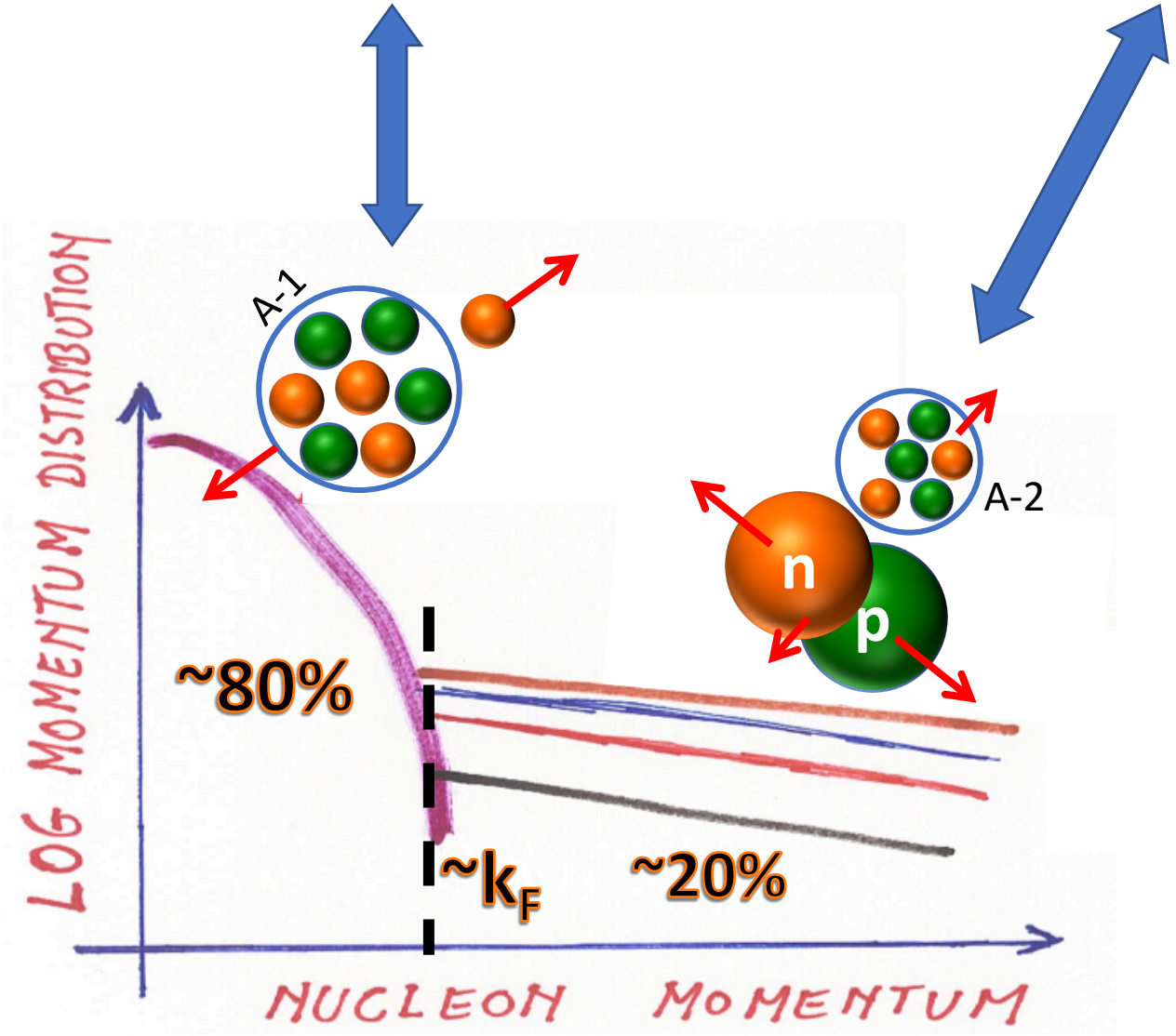
Gomez PRD (1994)

SLAC (1994)



Schmookler, Nature (2019)

Bound = 'quasi Free' + Modified SRCs



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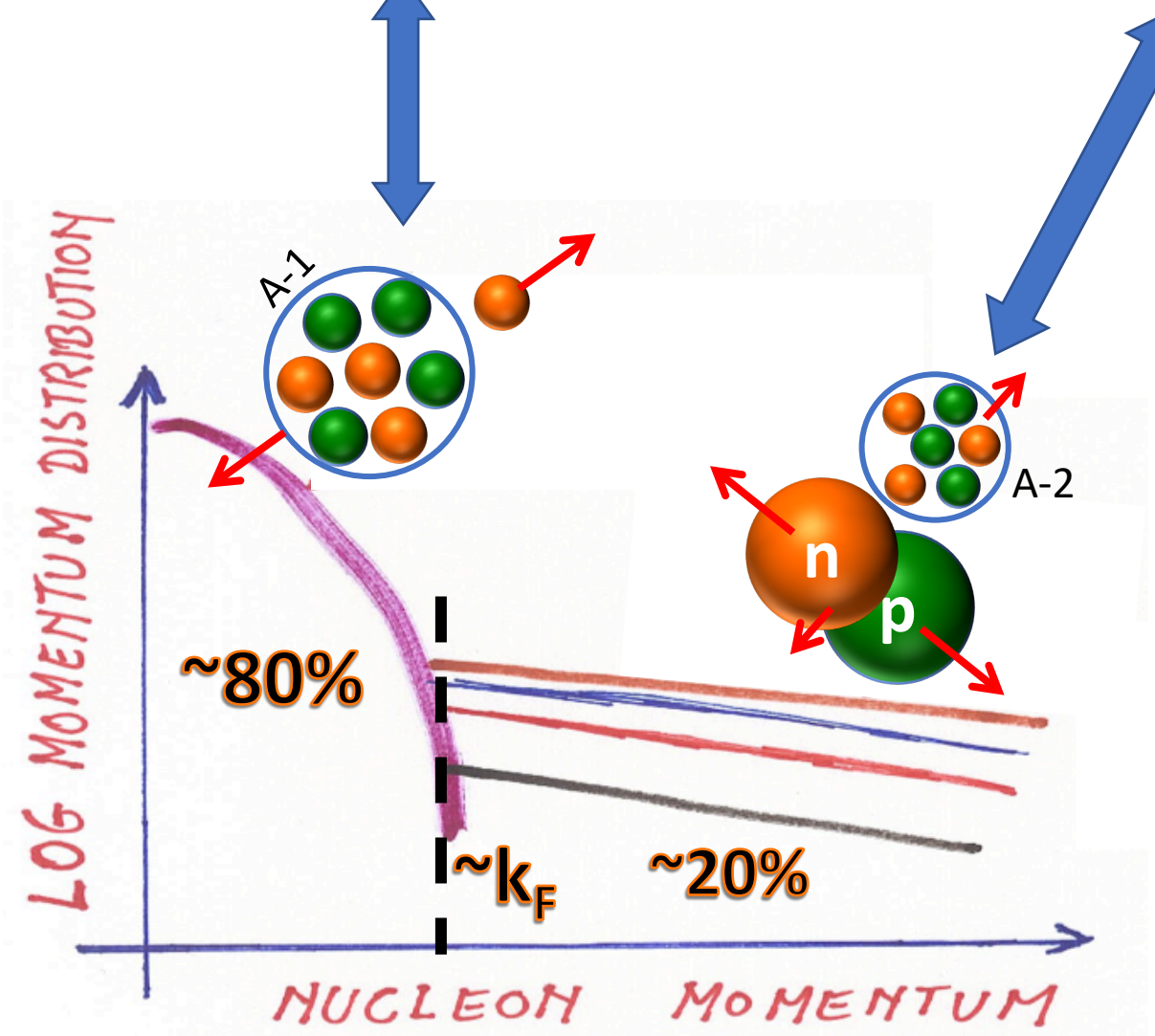

Schmookler, Nature (2019)

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Schmookler, Nature (2019)

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Schmookler, Nature (2019)

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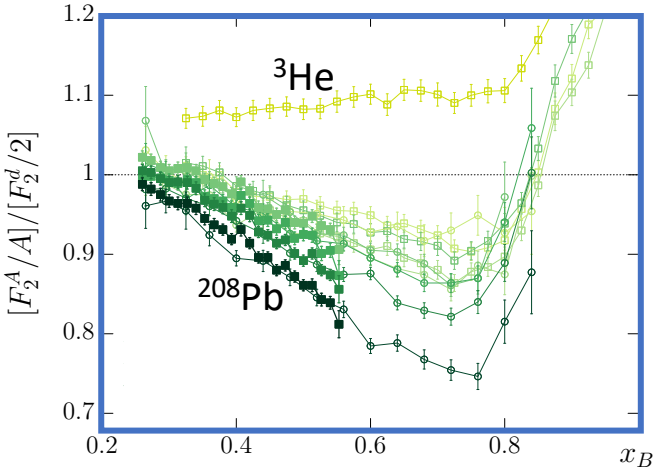
✓ **EMC**



Schmookler, Nature (2019)

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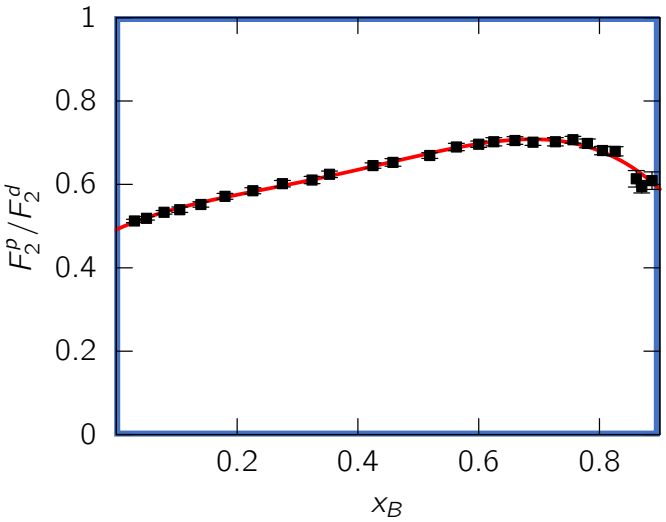
✓ EMC ✓ DIS



Schmookler, Nature (2019)

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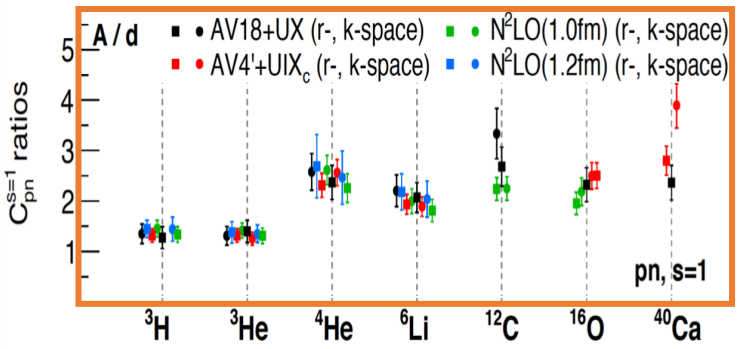
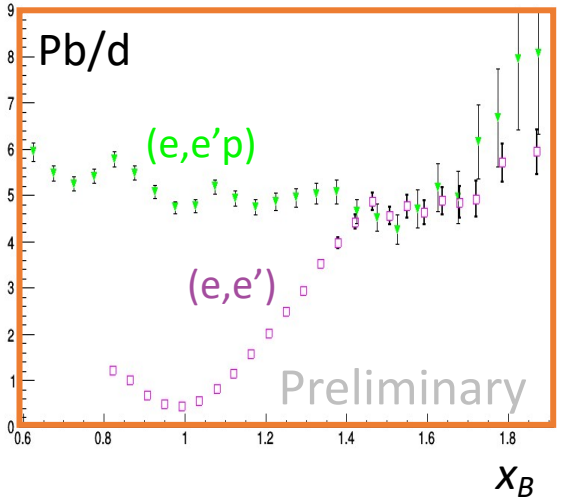
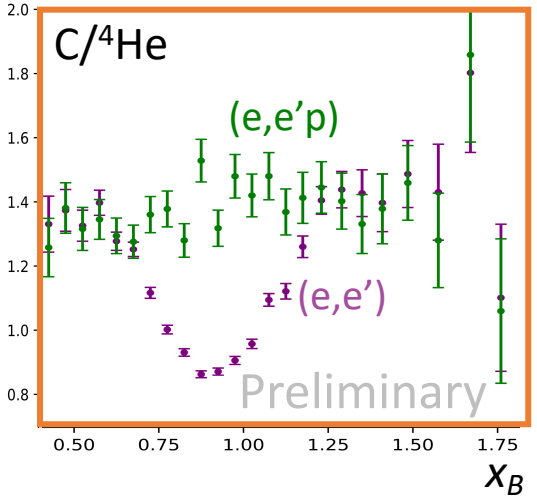
✓ EMC ✓ DIS ✓ QE / Ab-Initio







Schmookler, Nature (2019)

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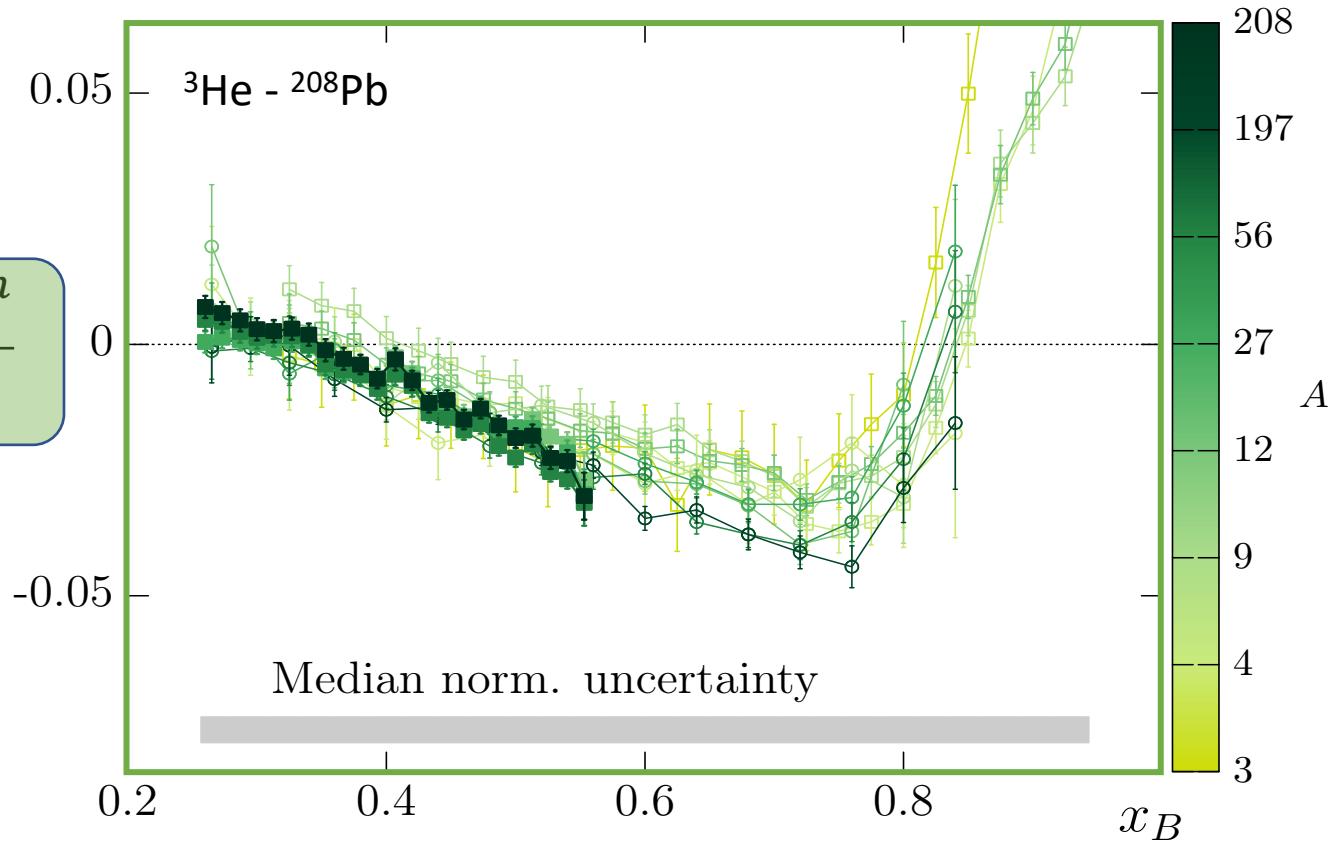
✓ EMC ✓ DIS ✓ QE / Ab-Initio **Universal?**

Schmookler, Nature (2019)

SRC Universality!

$$n_{SRC}^{d}\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d}$$



Schmookler, Nature (2019)

Many Implications; e.g. Global Analysis

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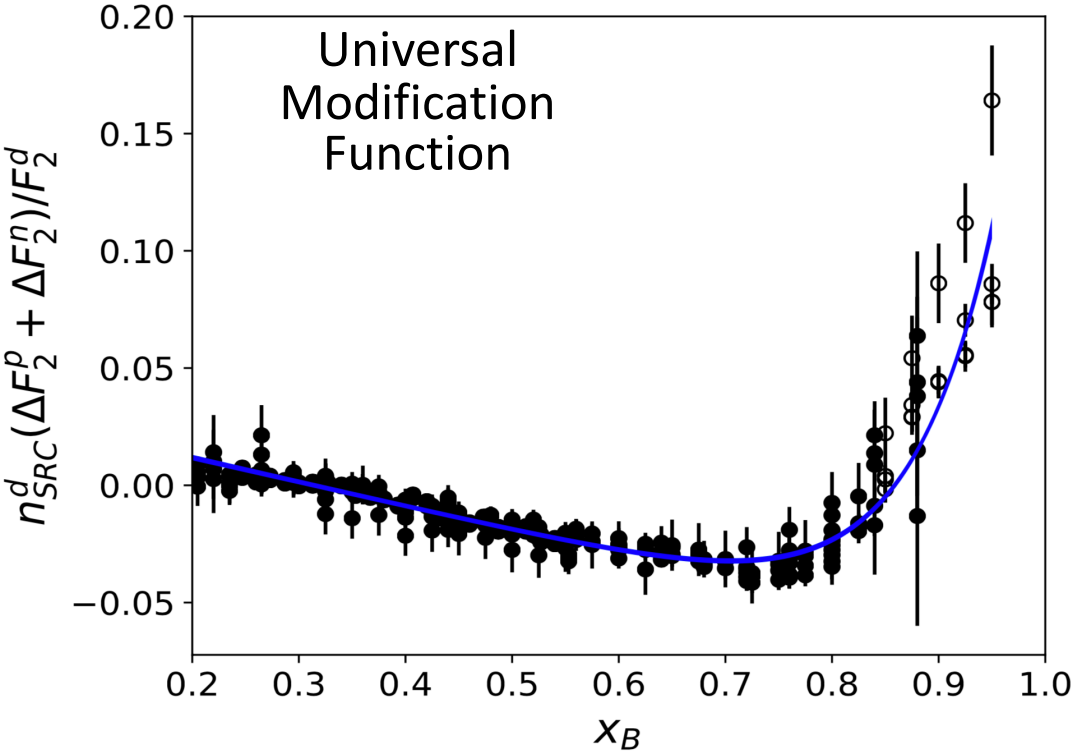
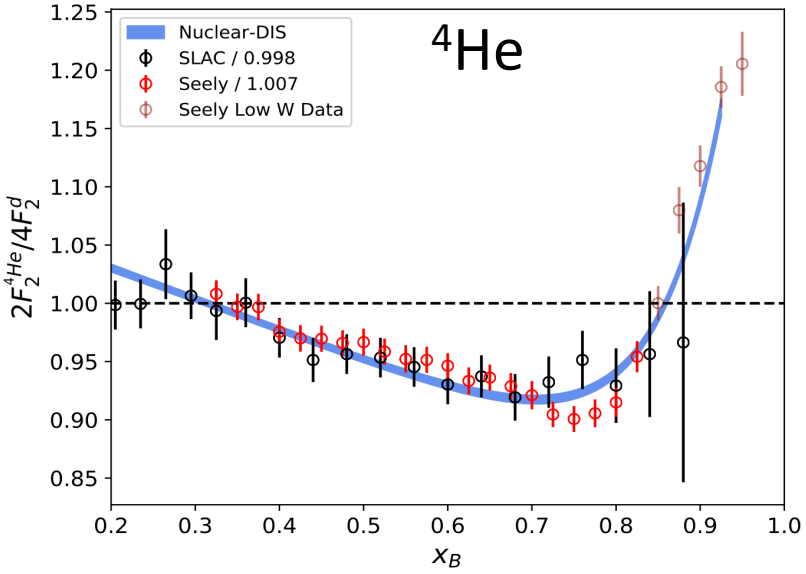
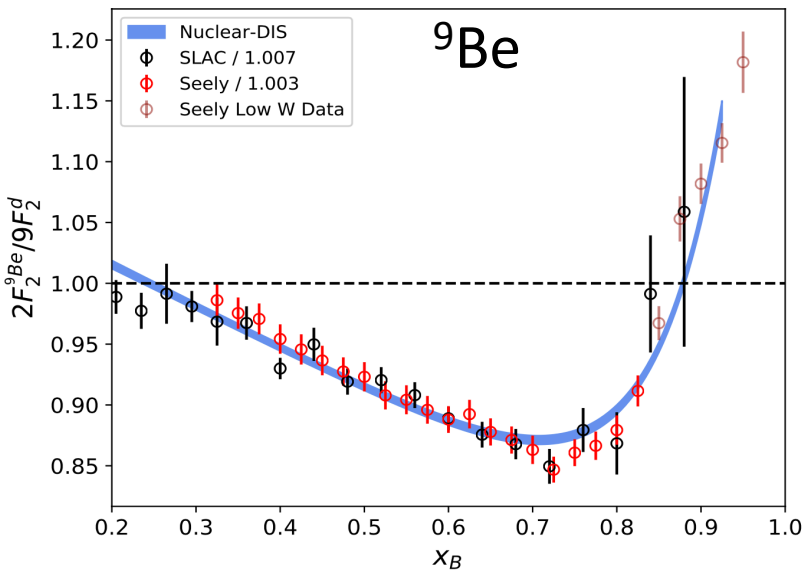
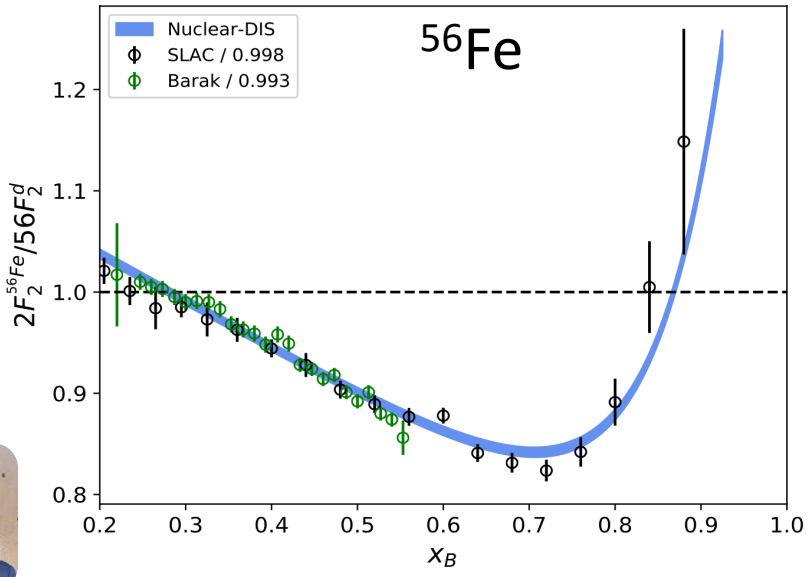


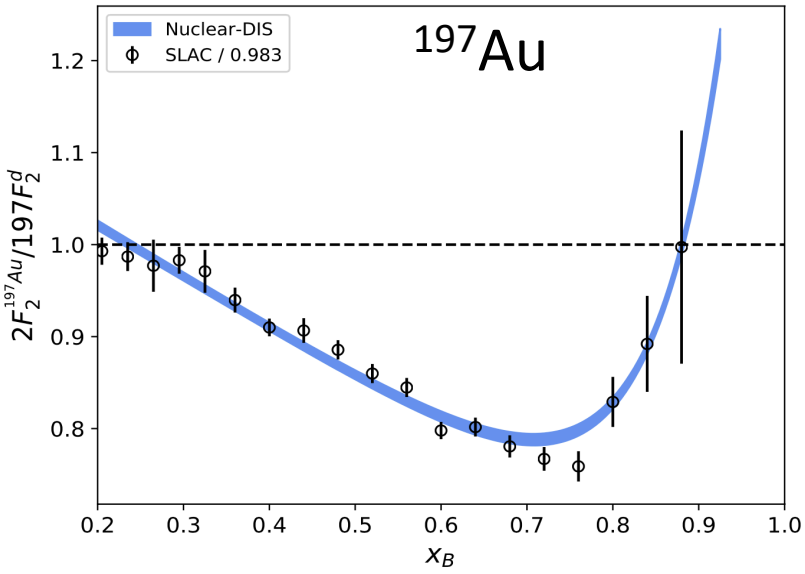
E.P. Segarra et al., arXiv: 1908.02223 (2019)

Many Implications; e.g. Global Analysis









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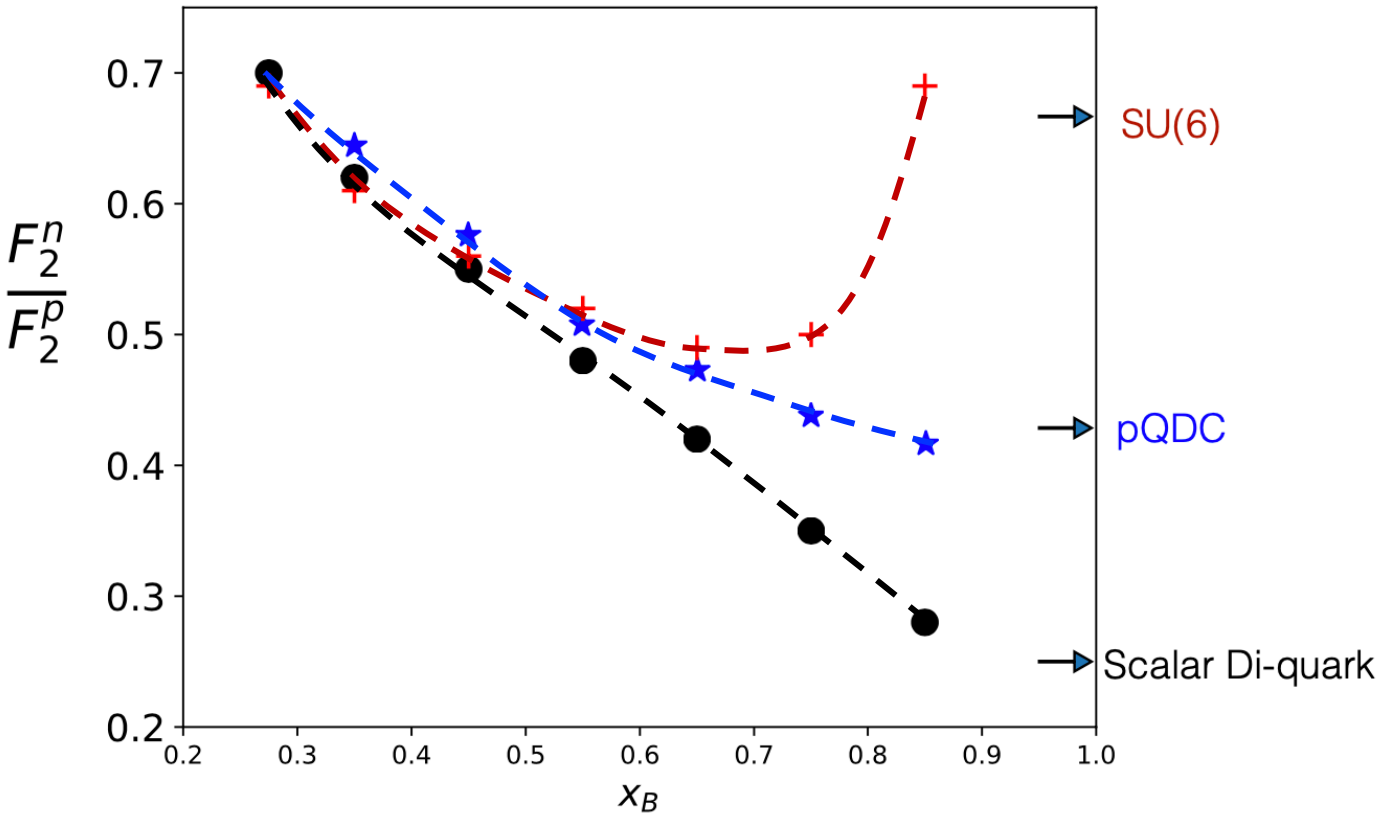
Many Implications; e.g. Global Analysis & F_2^n Extraction

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



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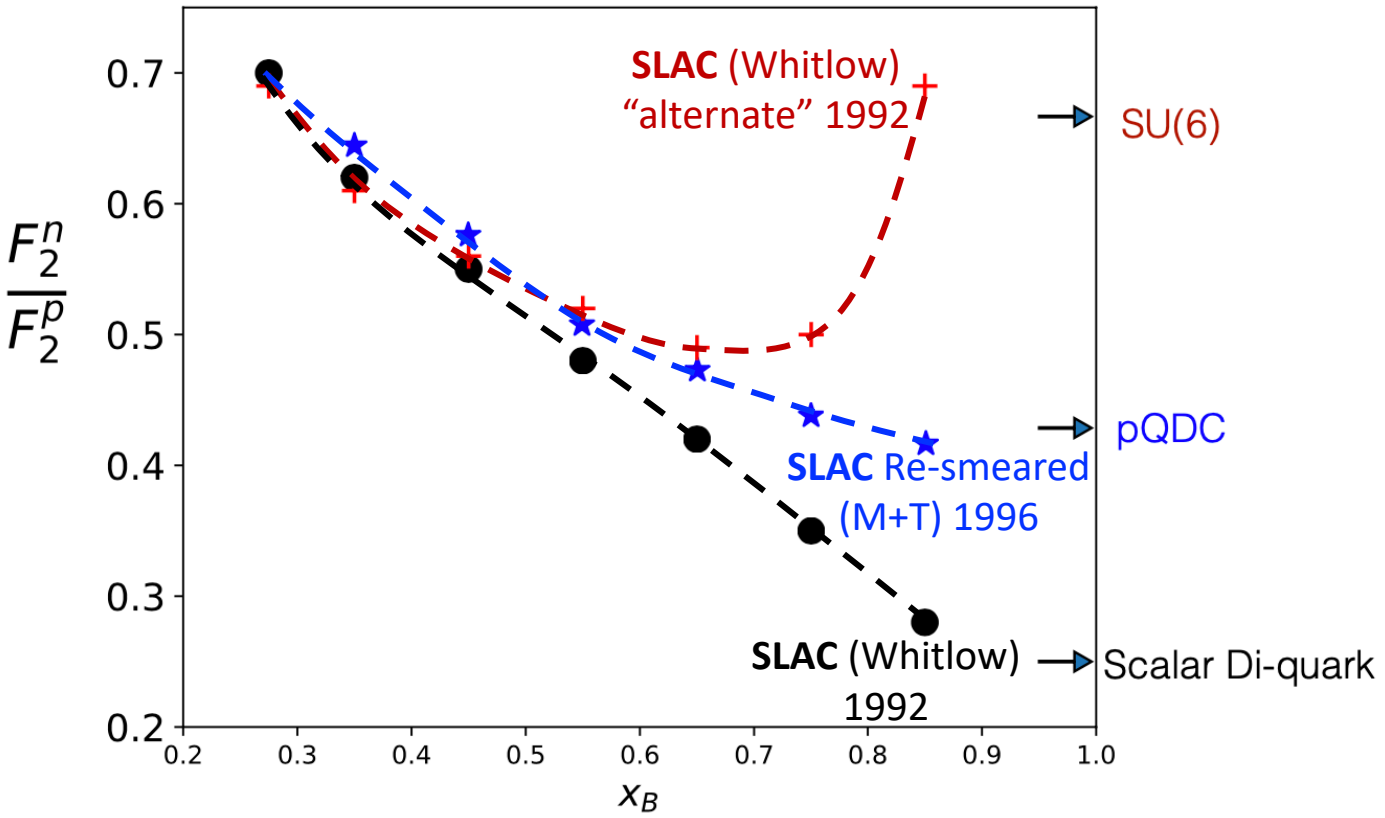
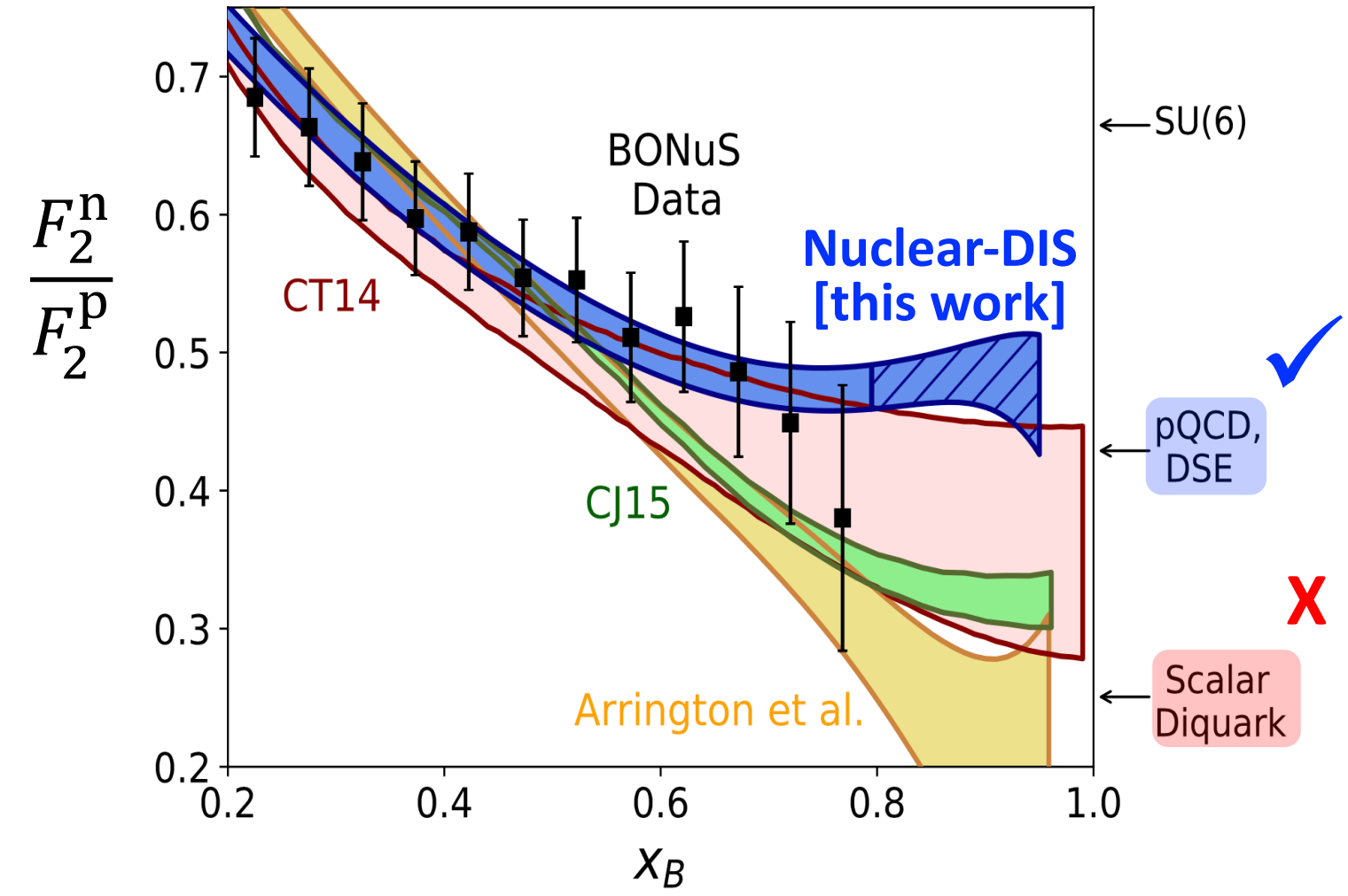
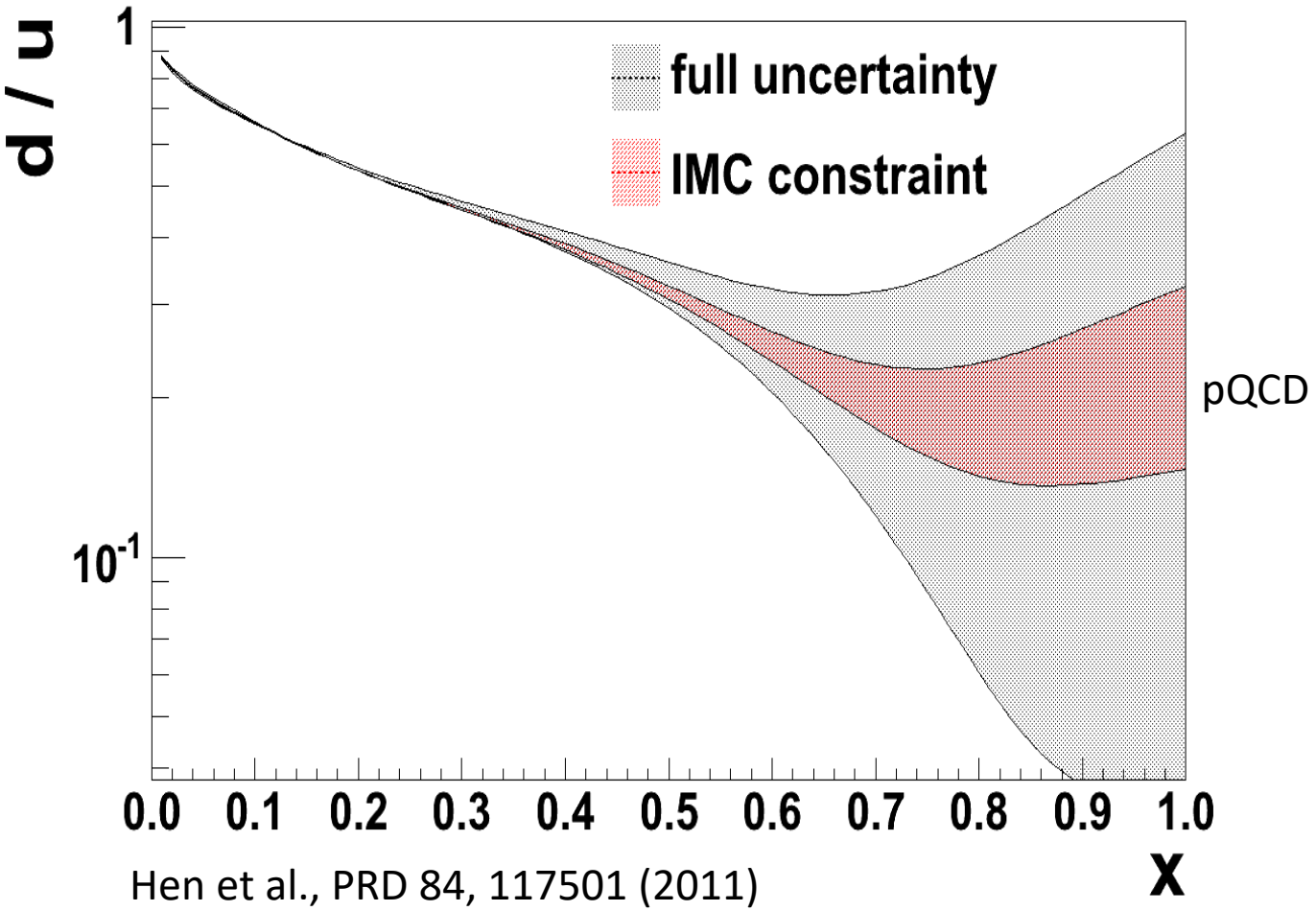


Many Implications; e.g. Global Analysis & F_2^n Extraction



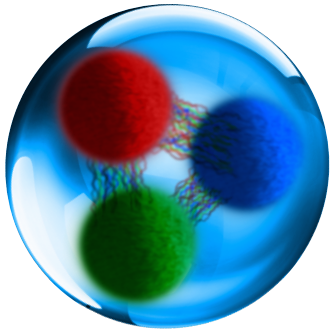
E.P. Segarra et al., arXiv: 1908.02223 (2019)

Many Implications; e.g. Global Analysis & F_2^n Extraction



Hen et al., PRD 84, 117501 (2011)

SRC quark-gluon structure



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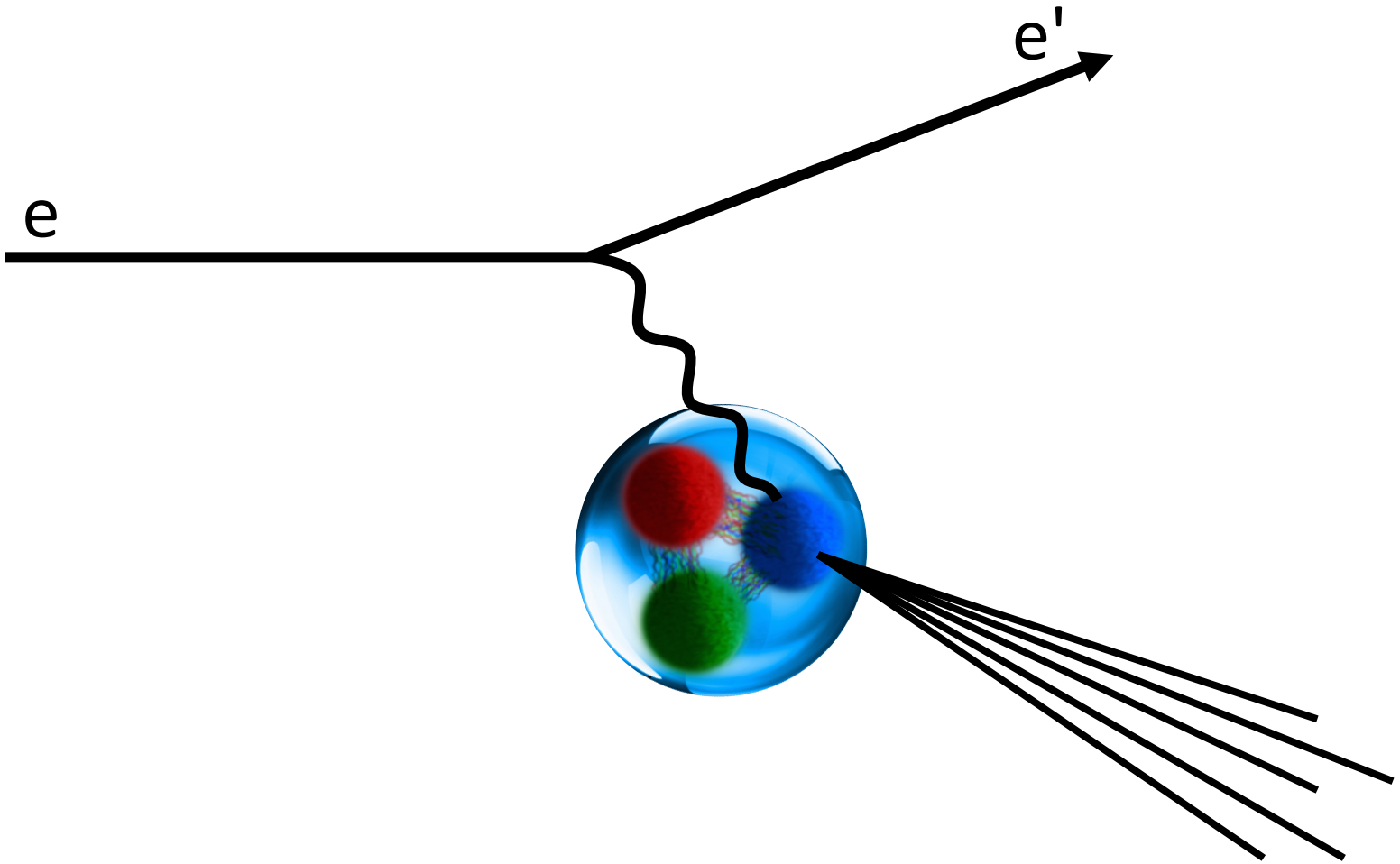

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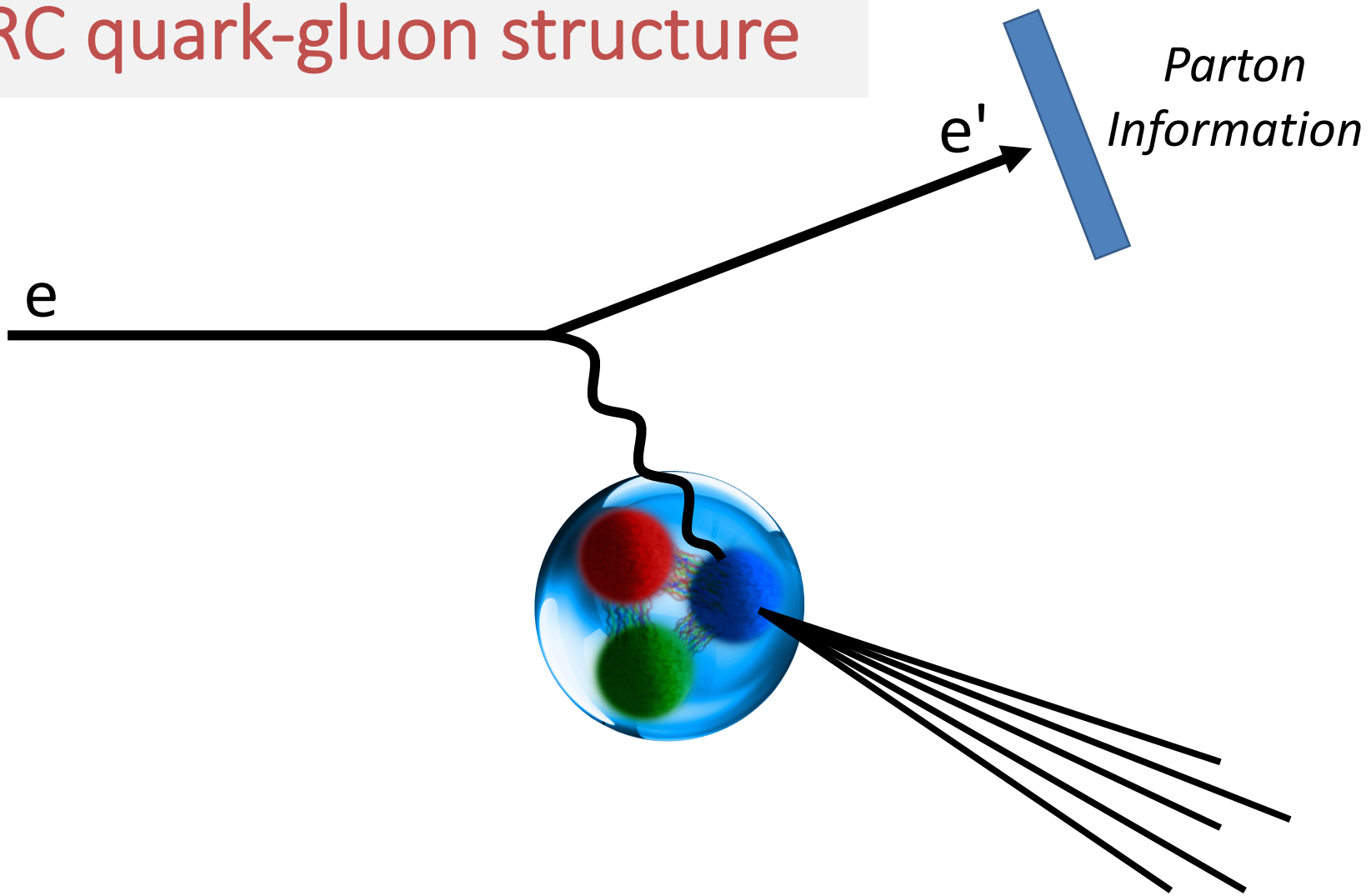

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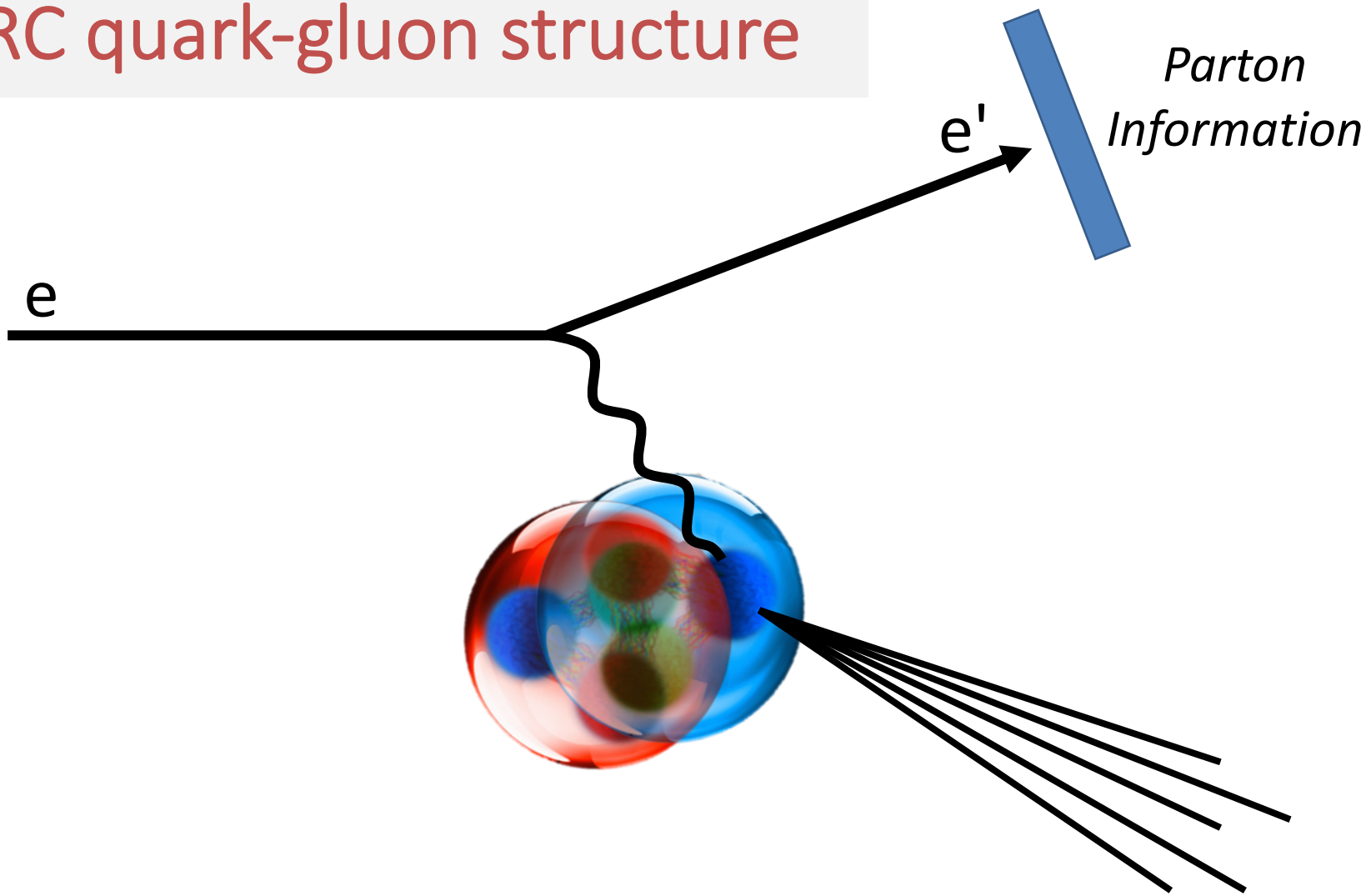

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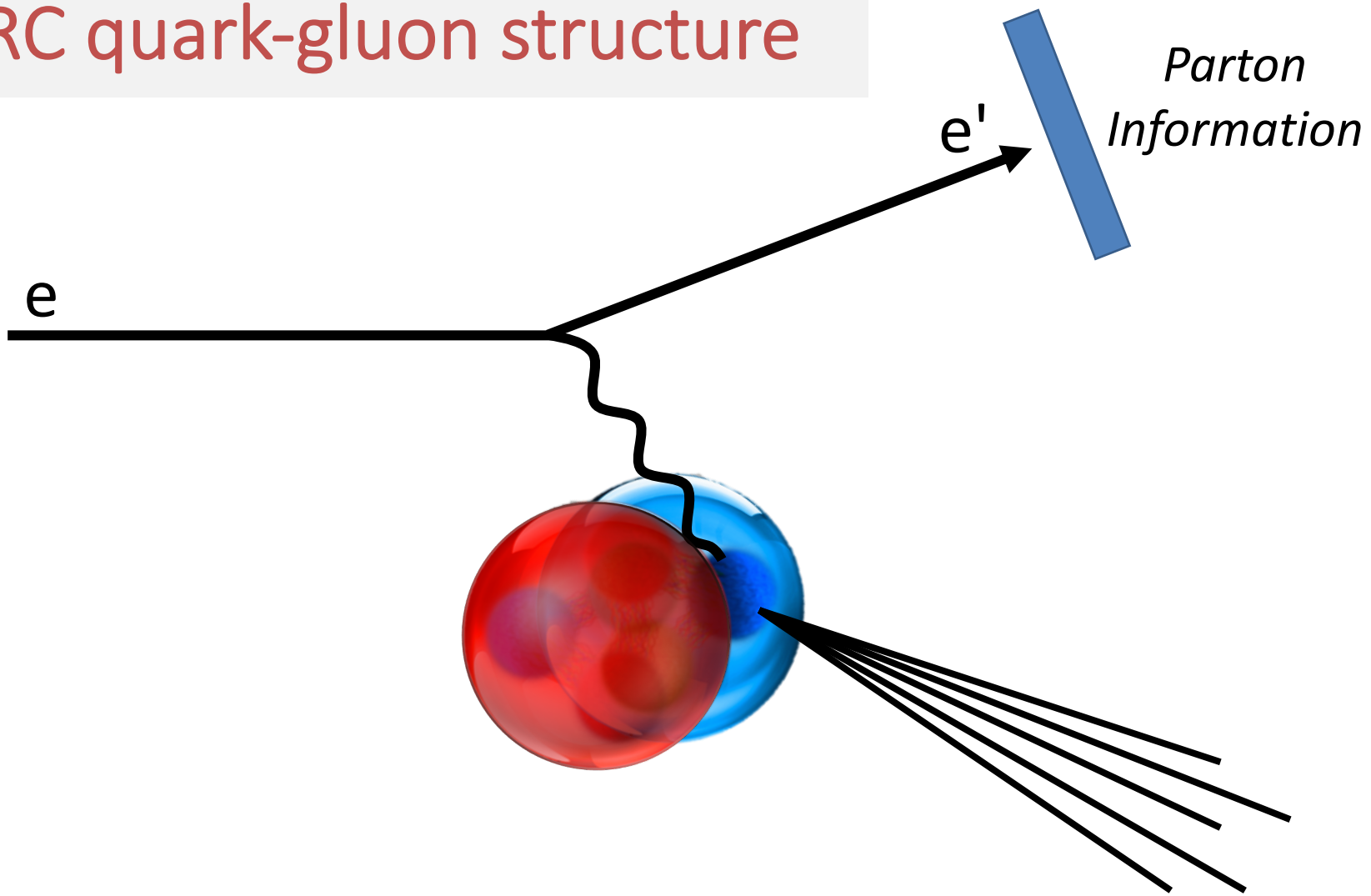

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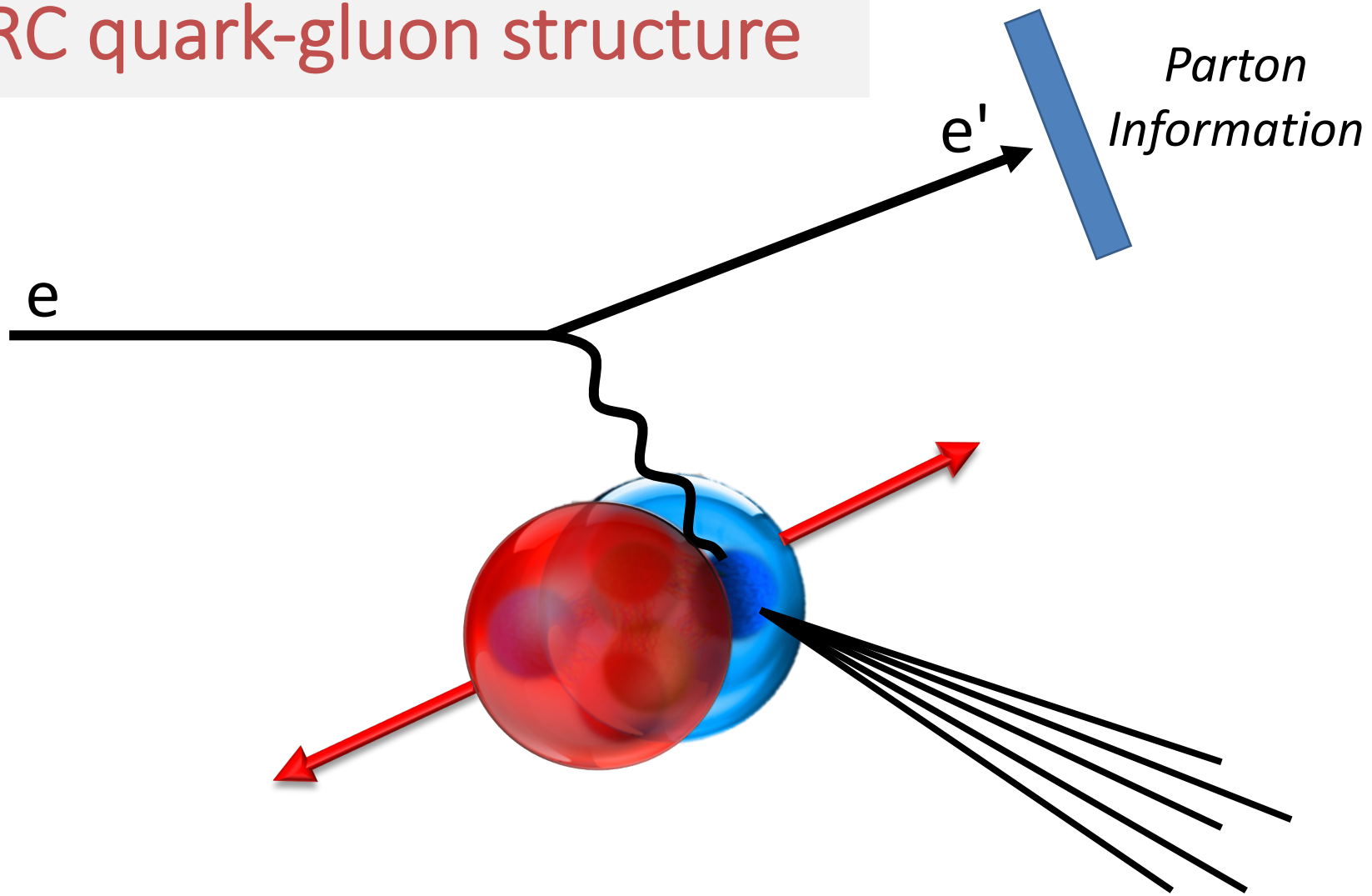

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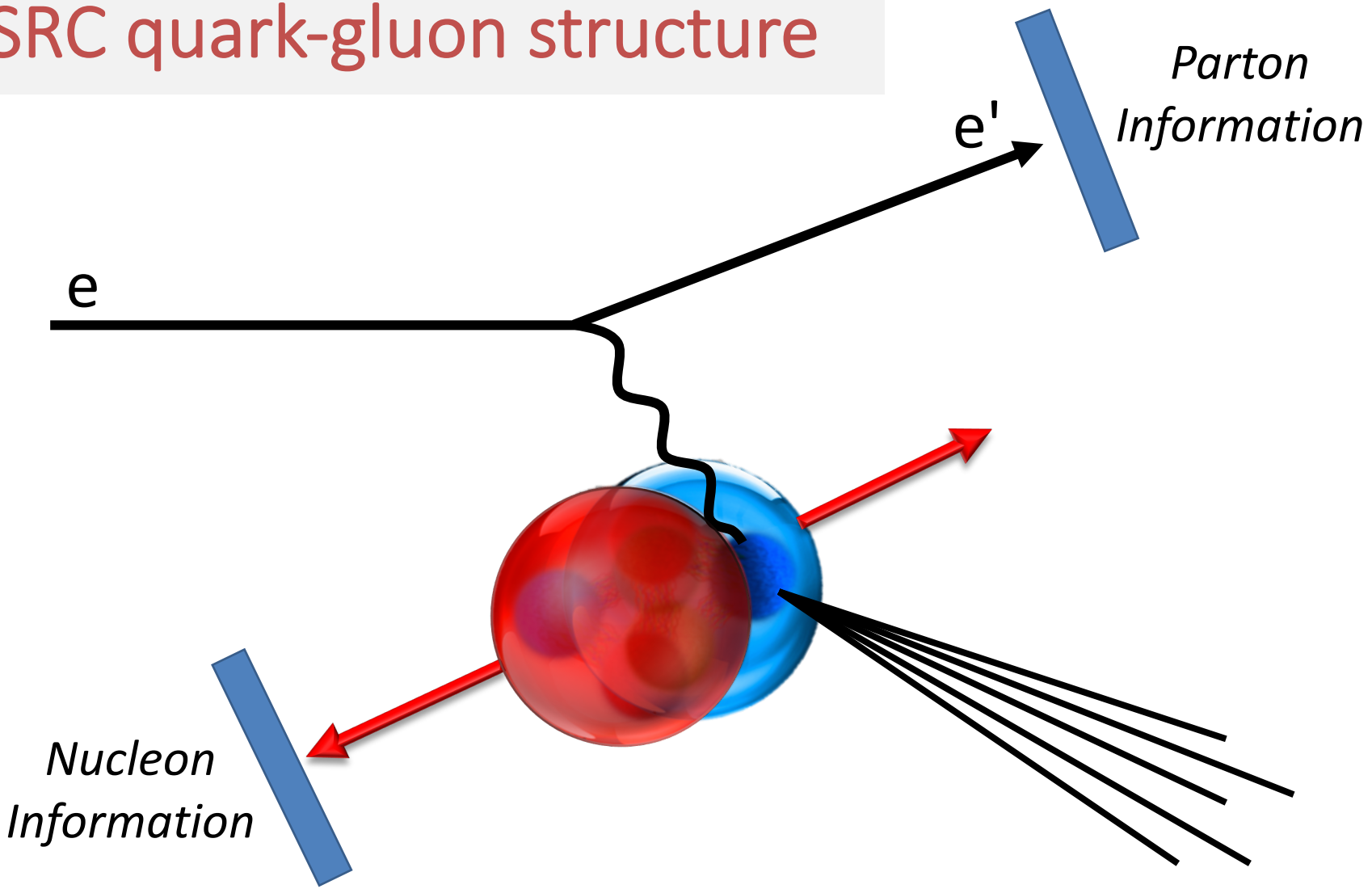
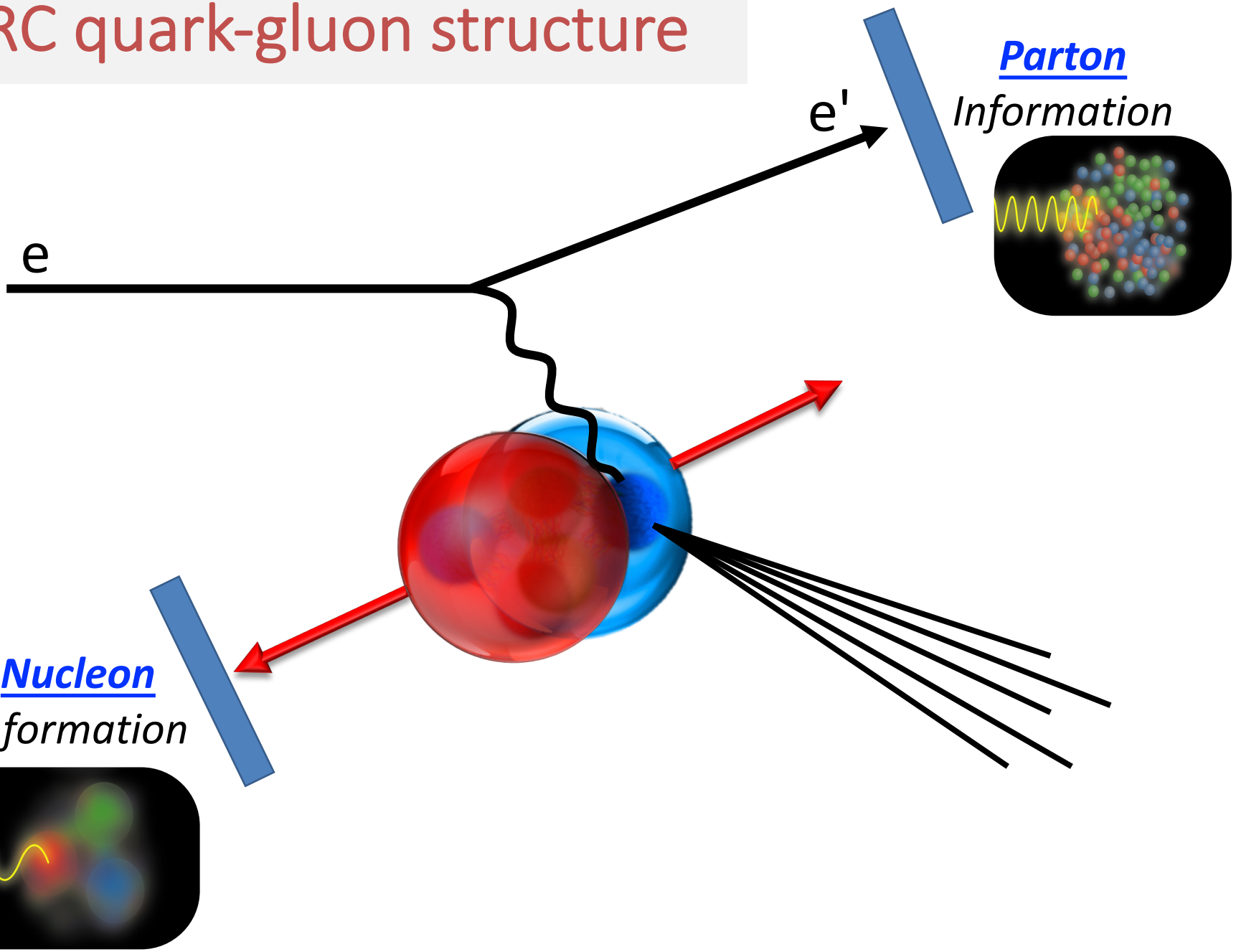
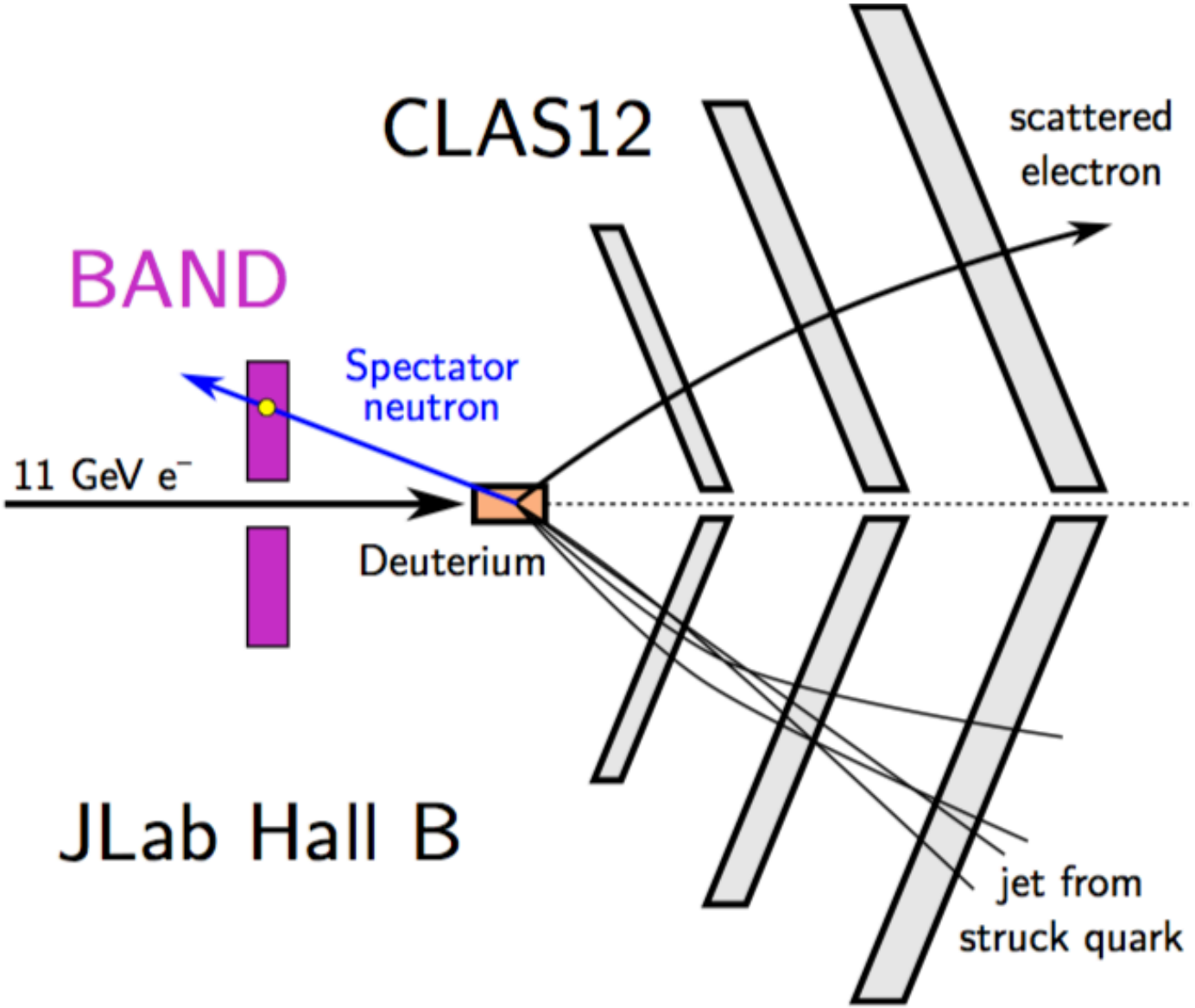
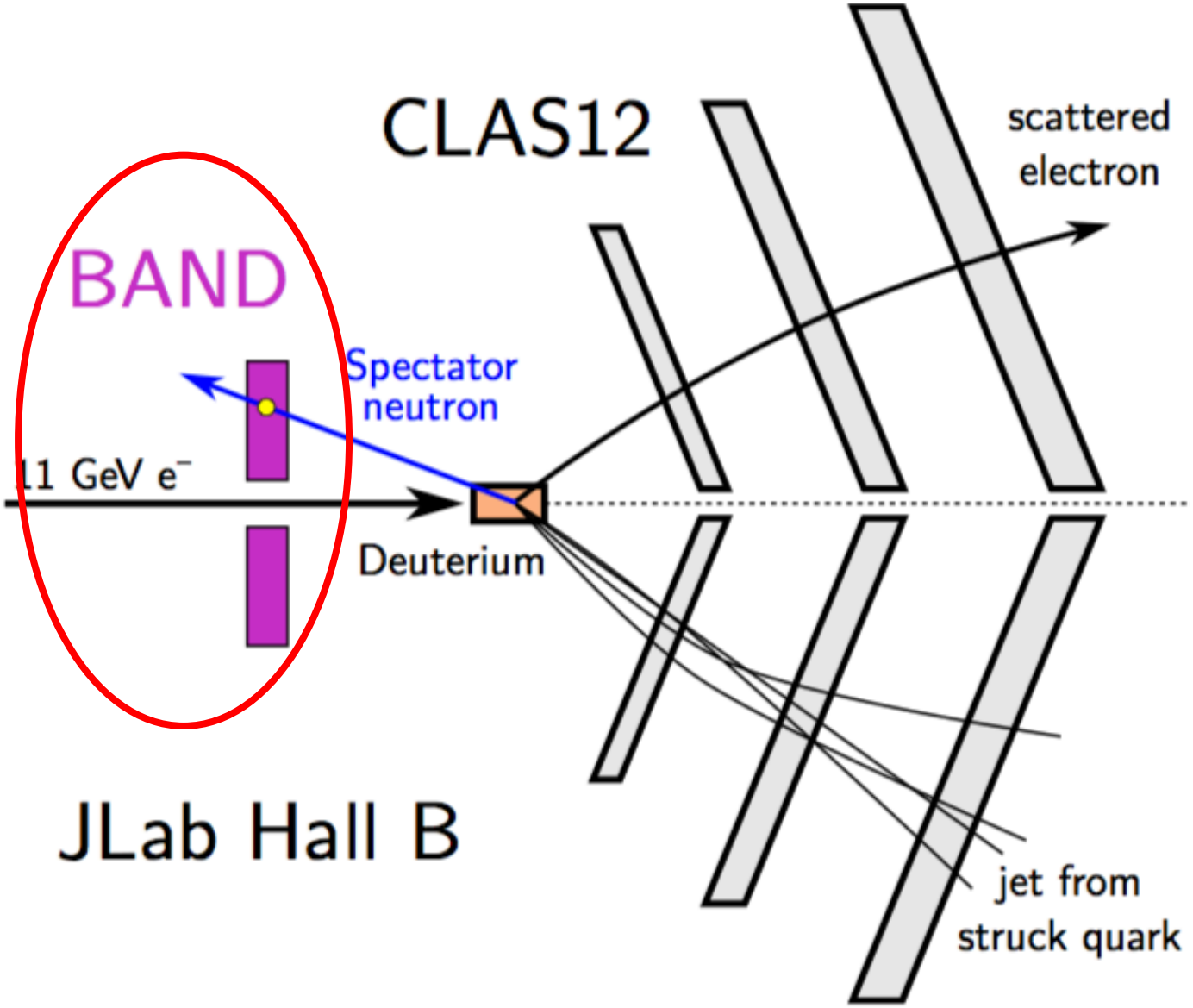


SRC quark-gluon structure




CLAS12
scattered
electron
BAND
Spectator
neutron
11 GeV e⁻
Deuterium
JLab Hall B
jet from
struck quark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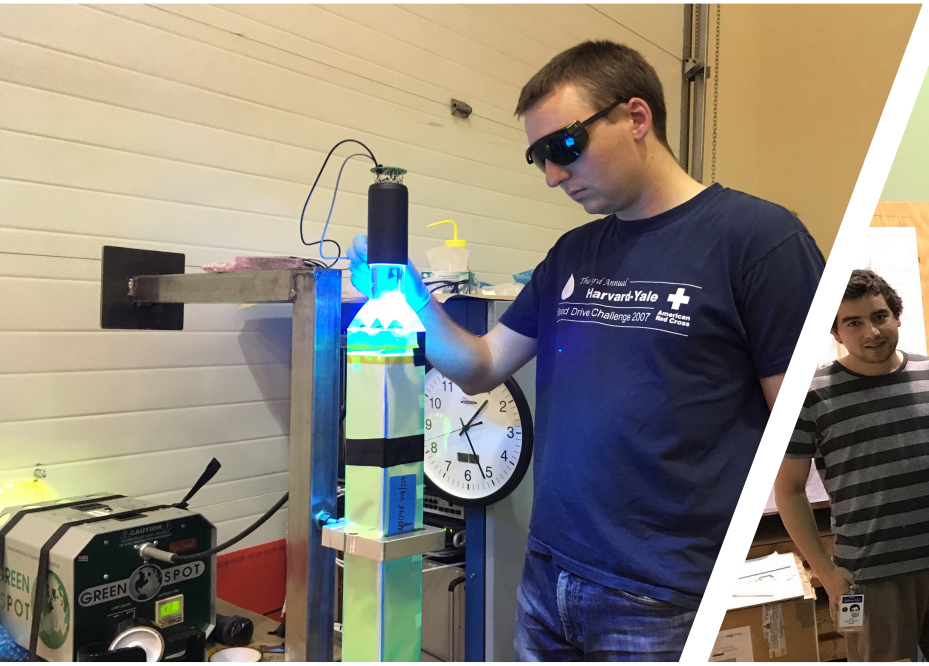
Massachusetts Institute of Technology

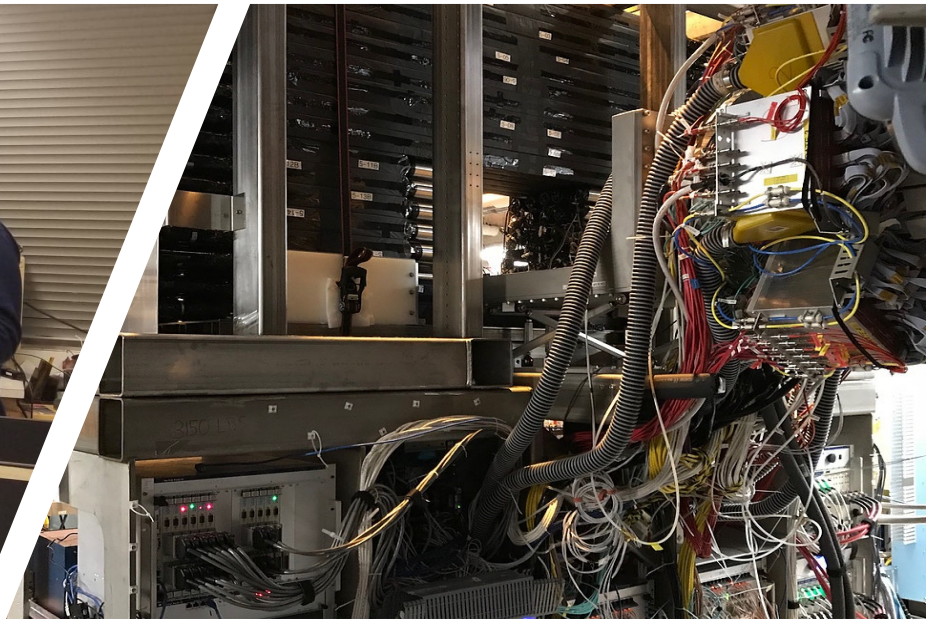
UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

OLD DOMINION UNIVERSITY

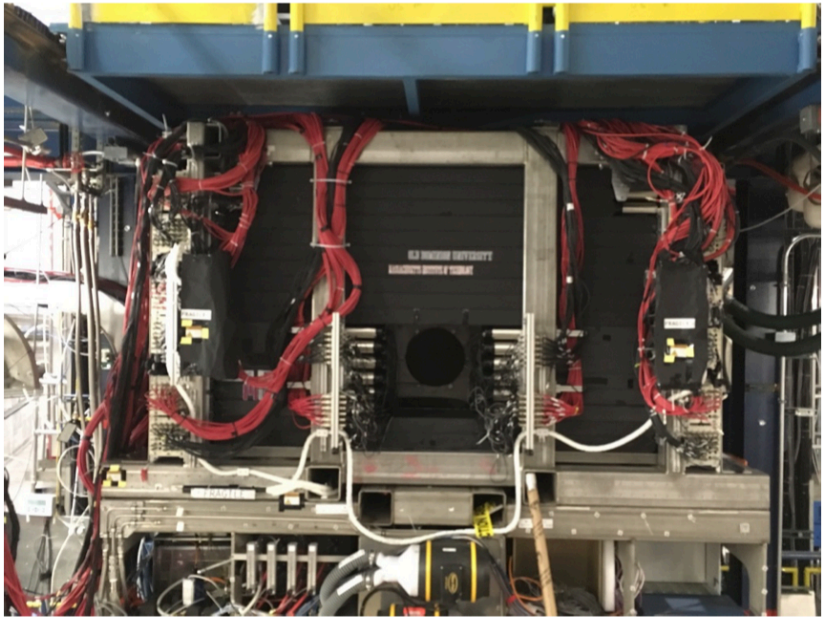
TEL AVIV UNIVERSITY

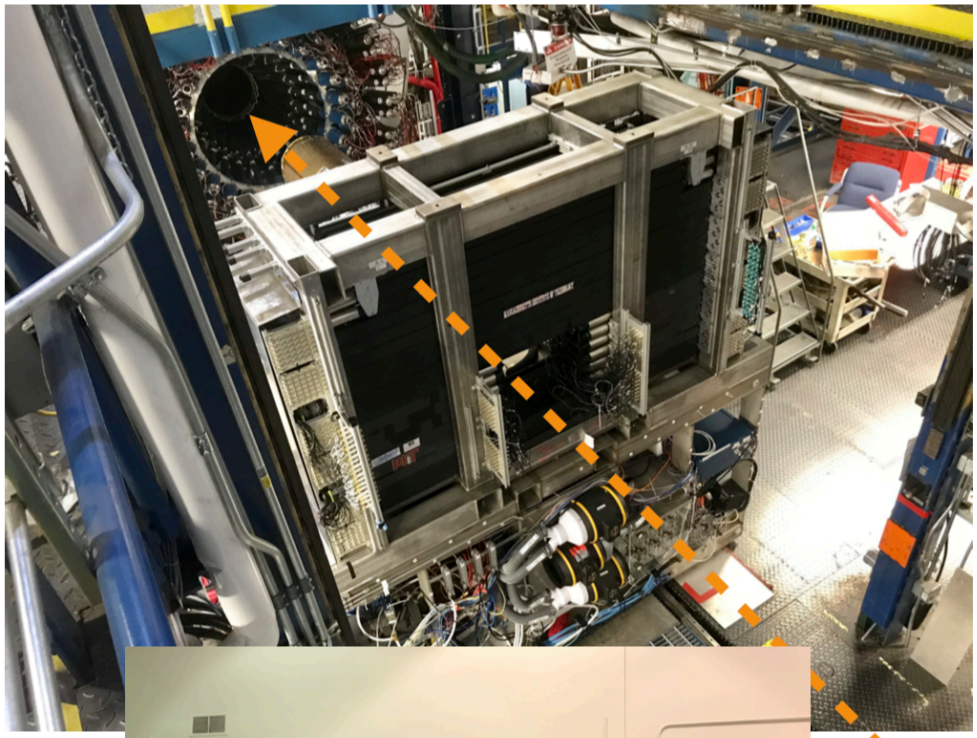
FLORIDA STATE UNIVERSITY 1851


Harvard-Yale
American Red Cross
GREEN SPOT

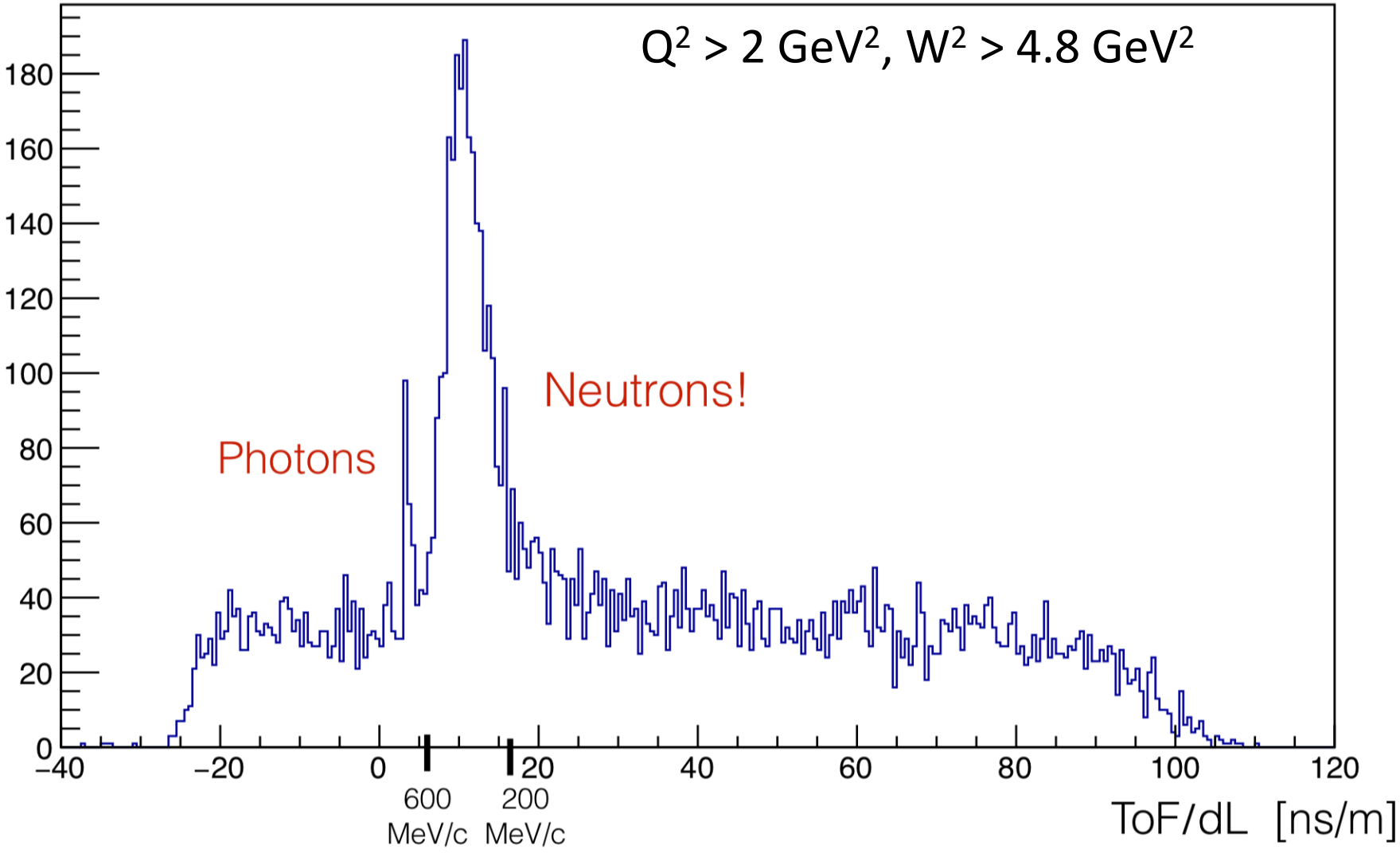


BAND @ JLab Hall B

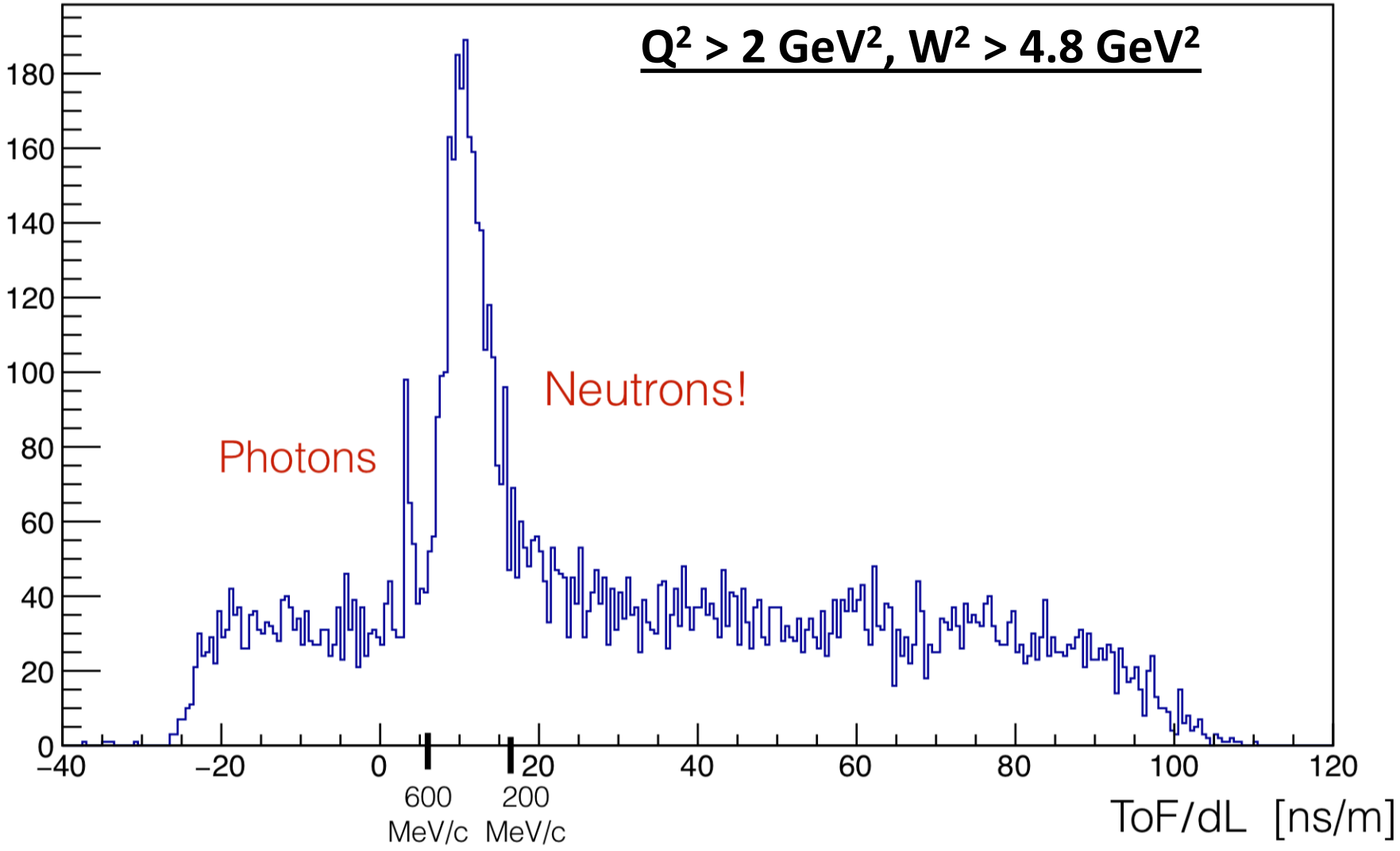




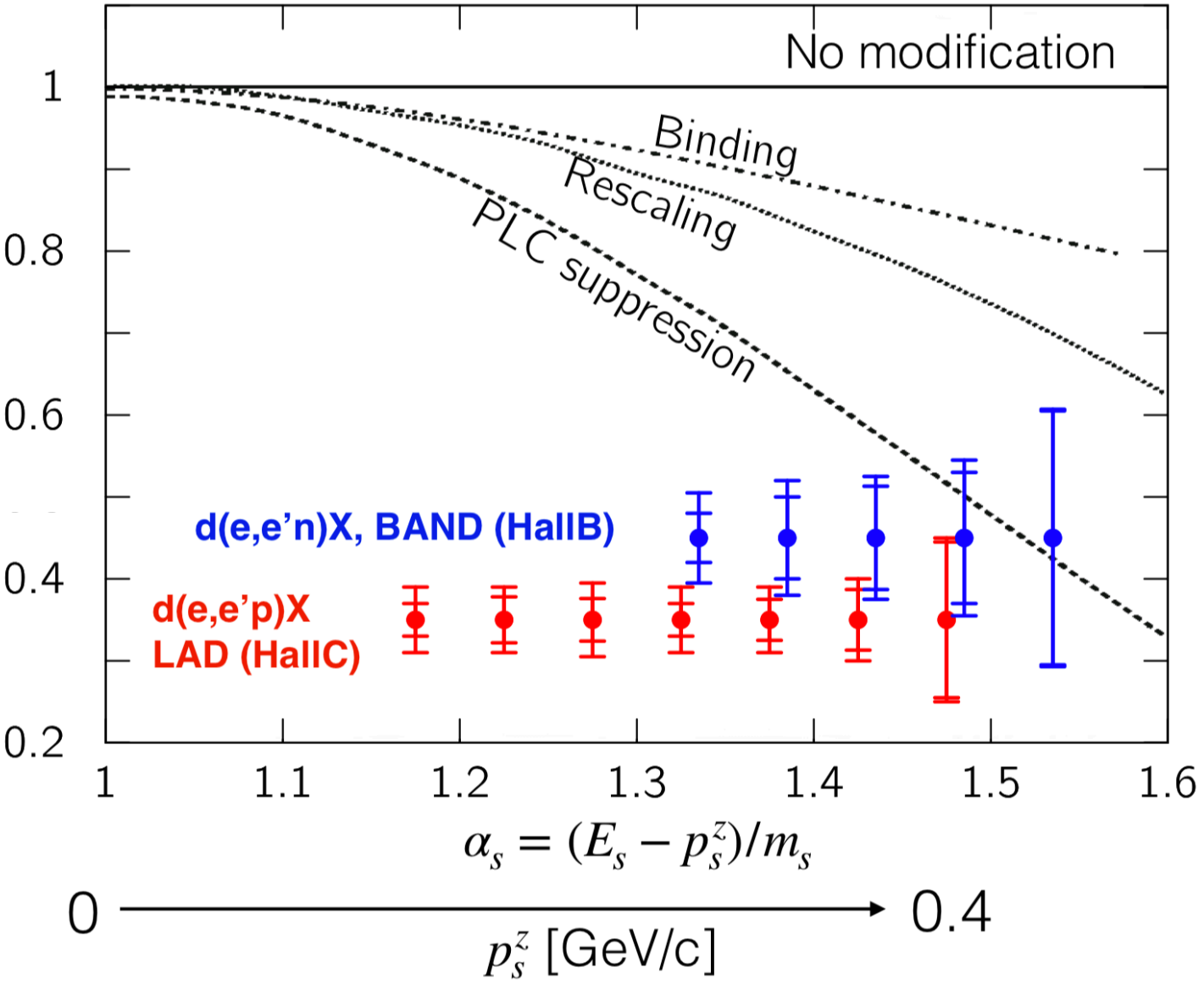
CLAS12+BAND: DIS \w Tagged Neutrons!!



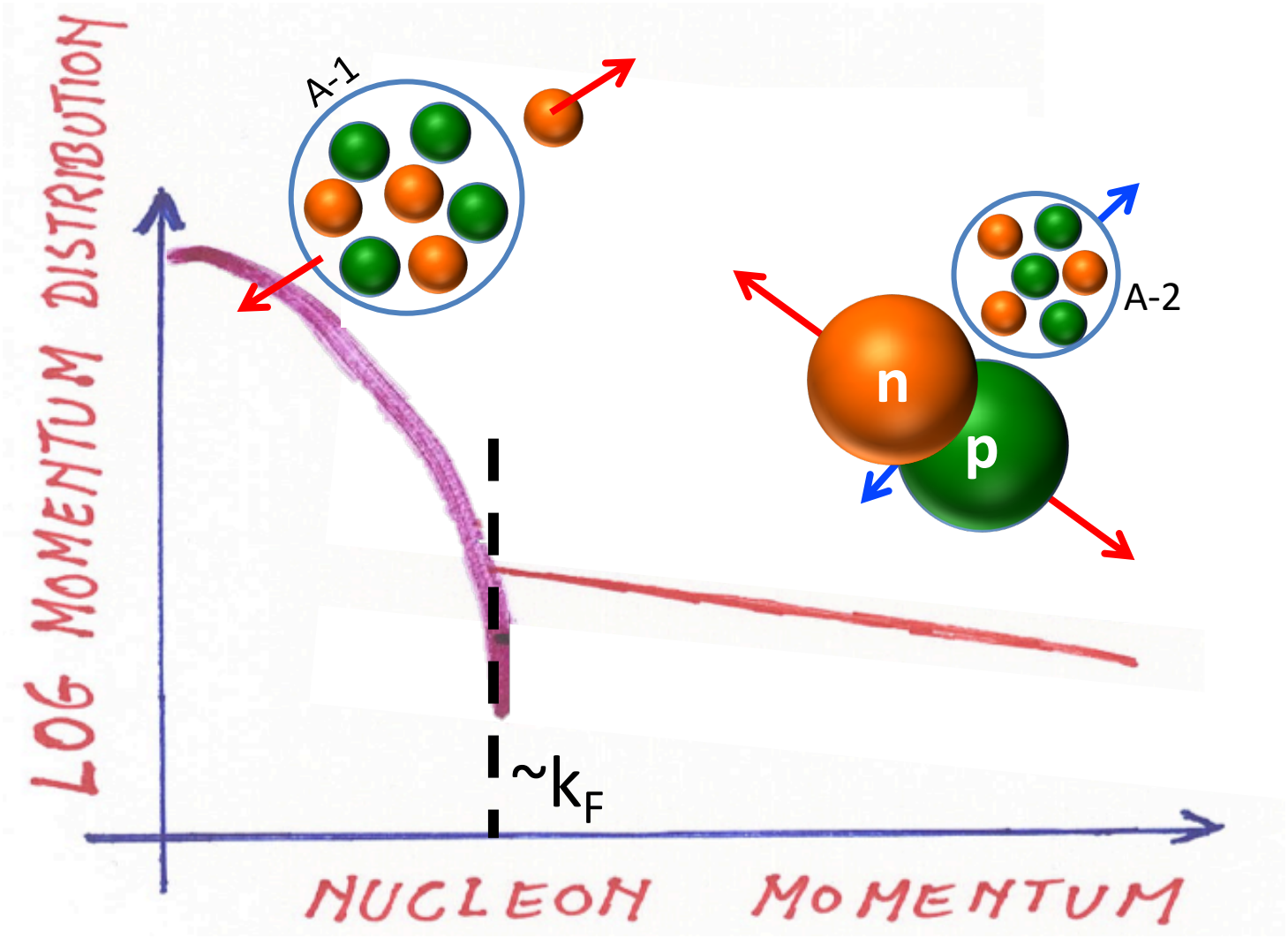
CLAS12+BAND: DIS \w Tagged Neutrons!!



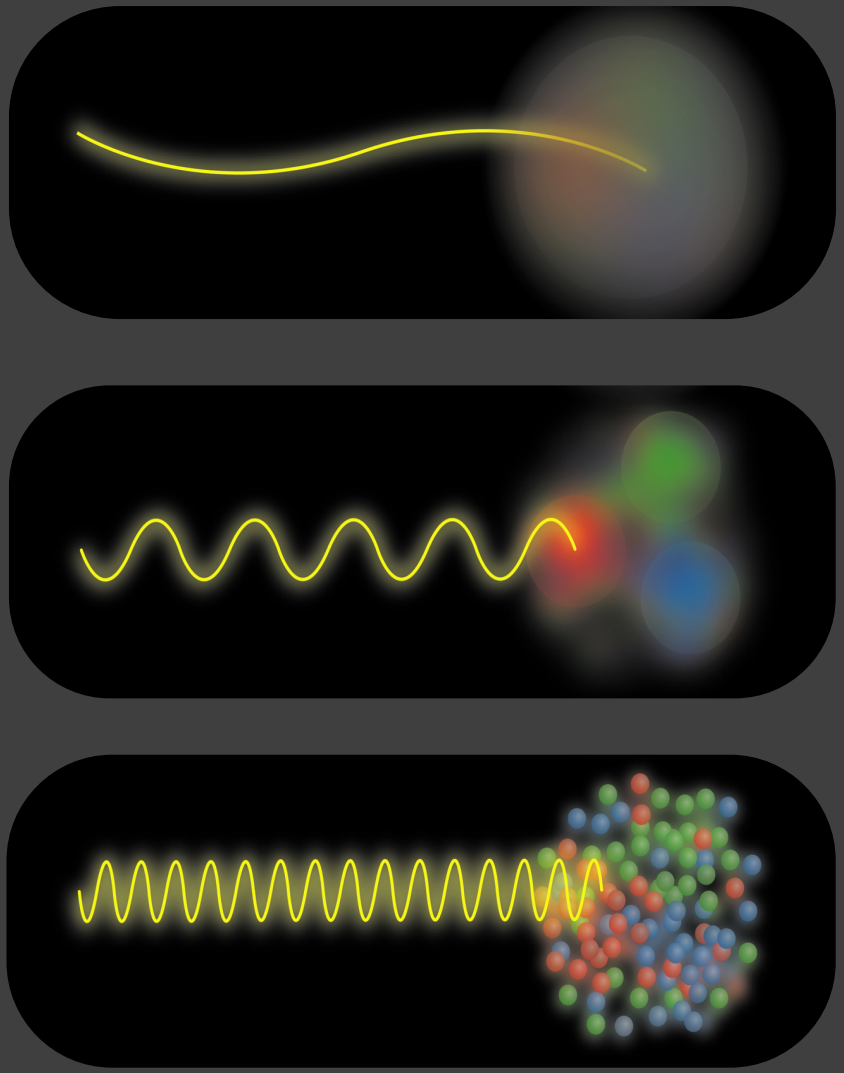
$$\frac{F_2^{Bound}}{F_2^{Free}}$$

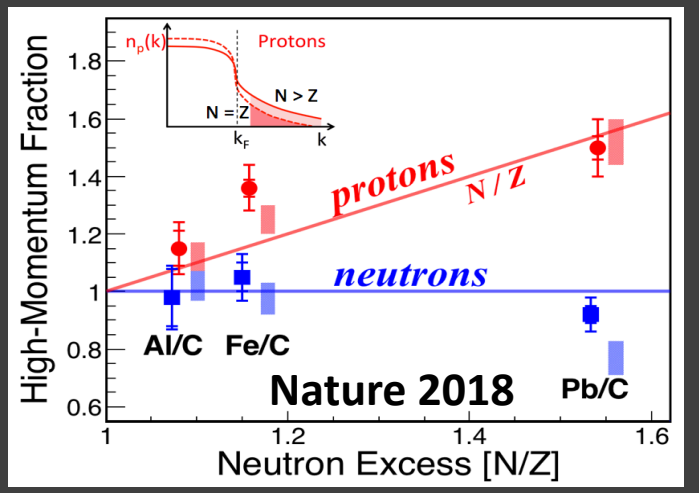


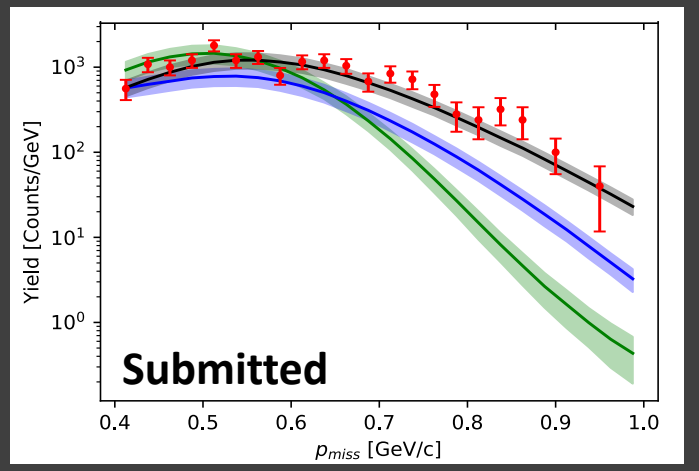
(1) Atomic nuclei have 2 ‘phases’

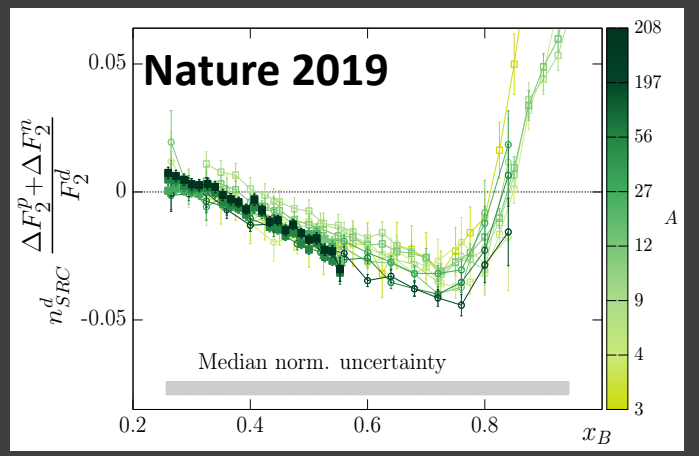


(2) Correlated phase significant across scales

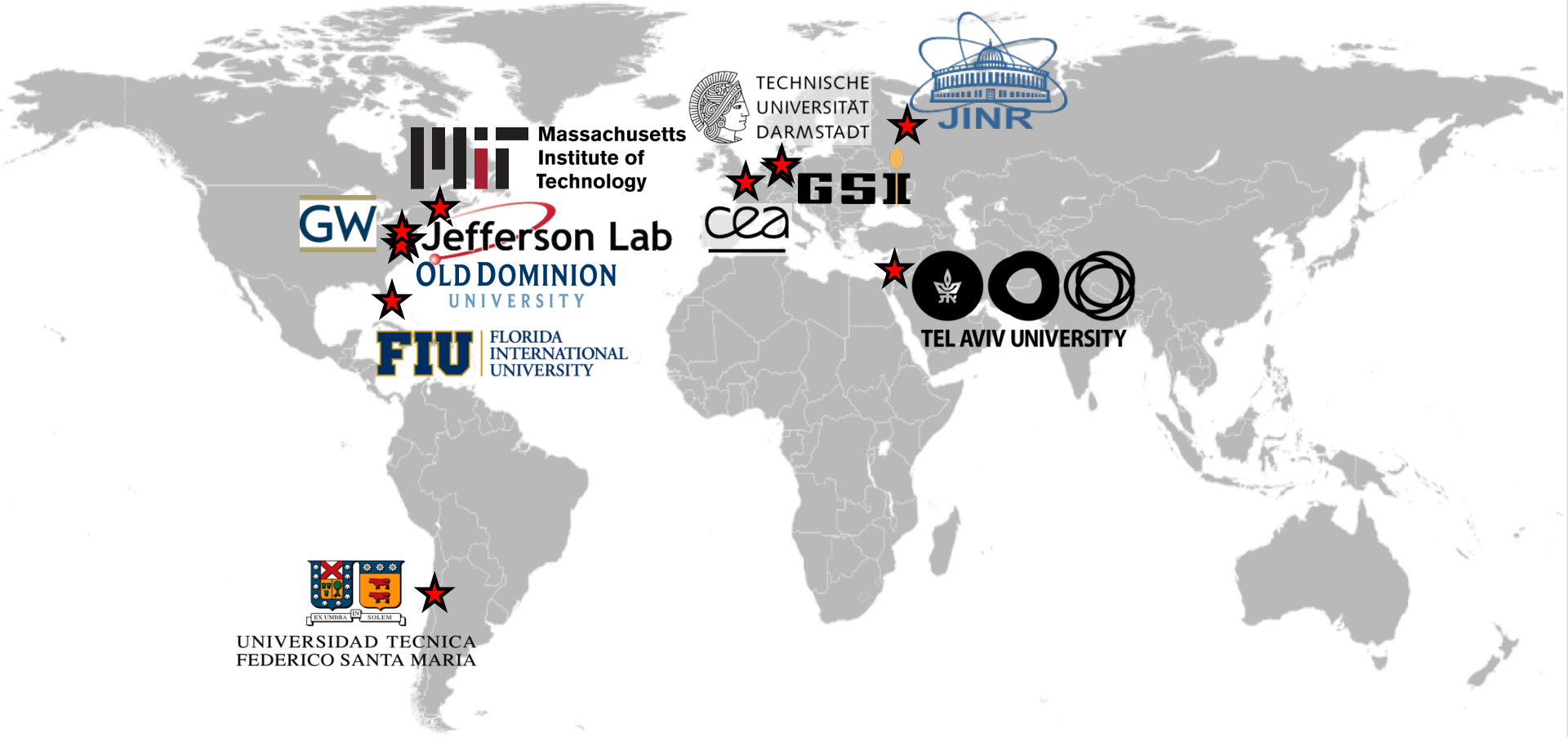




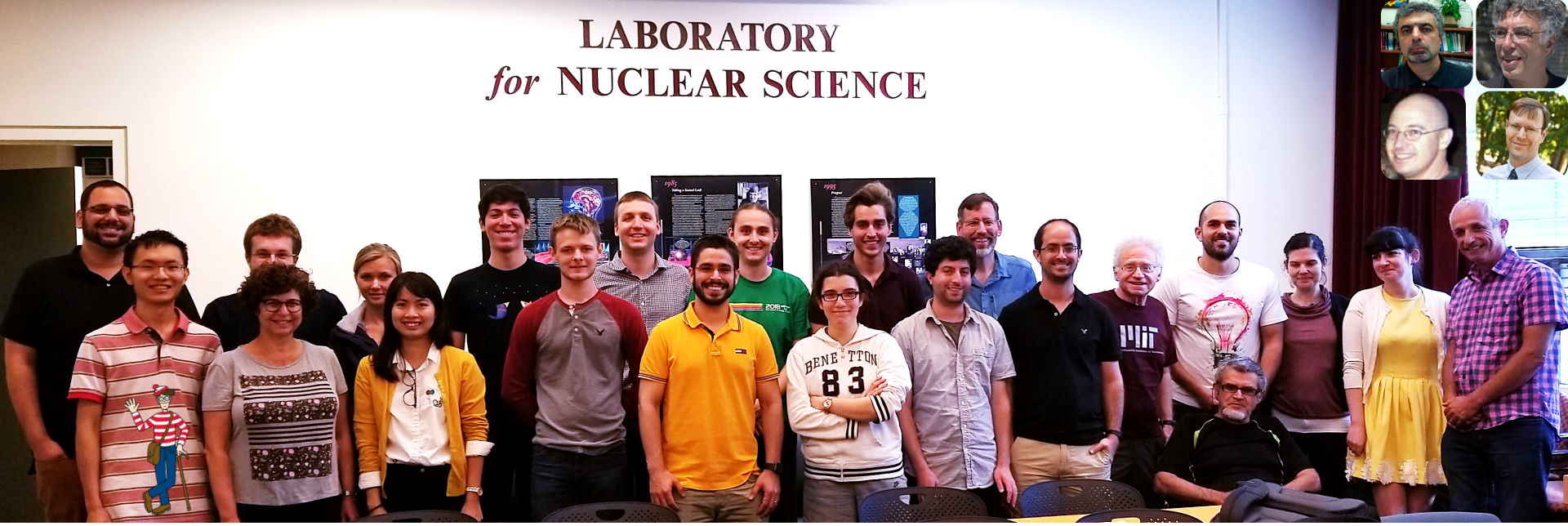




‘Our’ SRC World

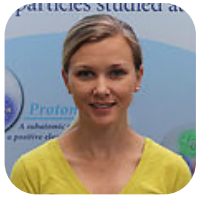


+ Many Theory Collaborators: UW, PSU, HUJI, LANL, ANL, Gent, FIU, Perugia, Pisa, …



Dr. Adi Ashkenazy

Dr. Dien Nguyen



Dr. Holly Vanse

Dr. Tyler Kutz

Dr. Florian Hauenstein

Dr. Julian Kahlbow

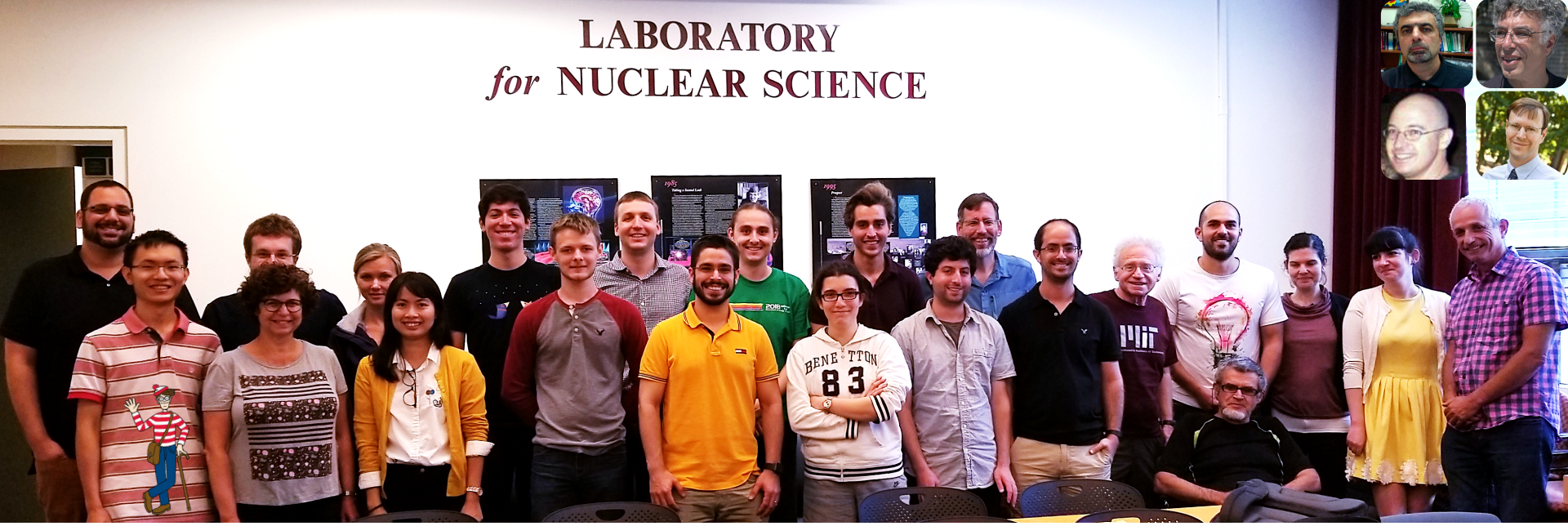
Efrain Segarra

Jackson Pybus

Afroditi Papadopoulou

Reynier Cruz-Torres

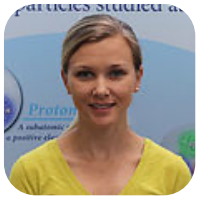
Andrew Denniston













2018-20 SRC Publications:

- Nature, In-Print (2020)
- Nature 566, 354 (2019)
- Nature 560, 617 (2018)
- Phys. Rev. Lett. 122, 172502 (2019)
- Phys. Rev. Lett. 121, 092501 (2018)
- Phys. Lett. B 800, 135110 (2019)
- Phys. Lett. B 797, 134890 (2019)
- Phys. Lett. B 797, 134792 (2019)
- Phys. Lett. B 791, 242 (2019)
- Phys. Lett. B 793, 360 (2019)
- Phys. Lett. B 785, 304 (2018)
- Phys. Lett. B 780, 211 (2018)

arXiv: 1908.02223; 1907.03658.