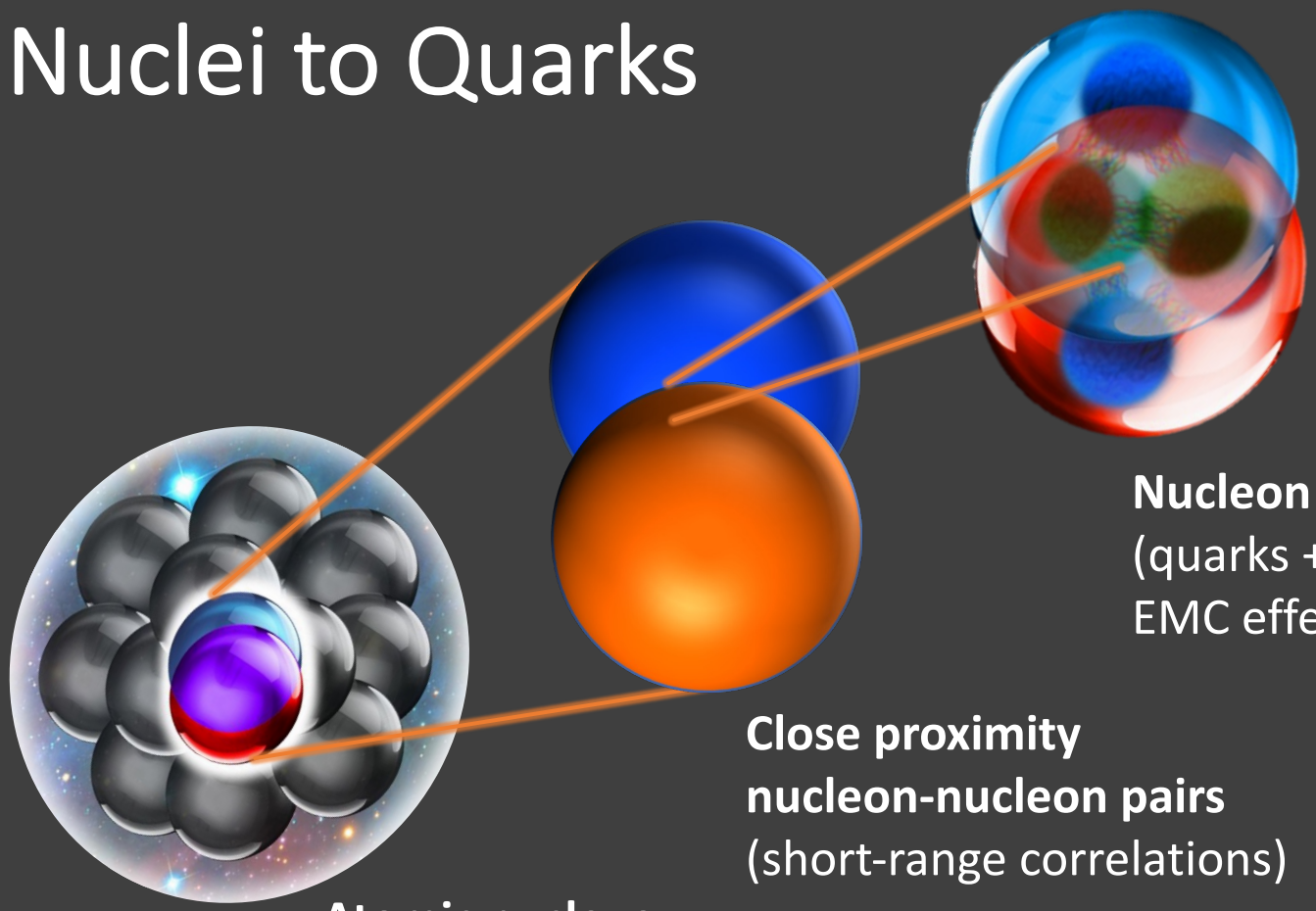
Short-Range Correlations in Nuclei

Or Hen
(MIT)

Hen Lab
Laboratory for Nuclear Science @ MIT

9th International Conference on Quarks and Nuclear Physics (QNP22), September 6th (2022)

From Quarks to Nuclei / From Nuclei to Quarks

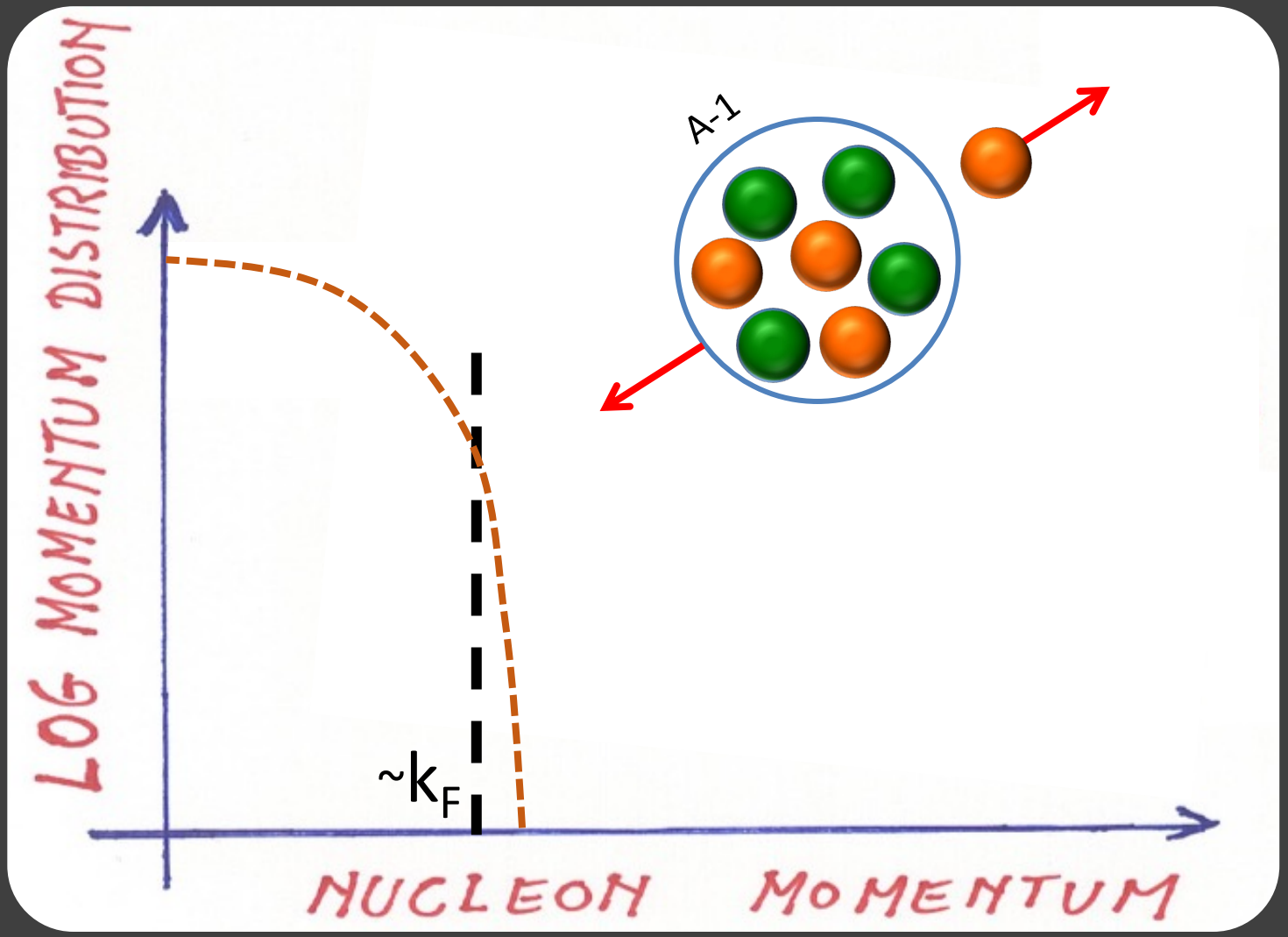


Nucleon structure
(quarks + gluons, EMC effect)

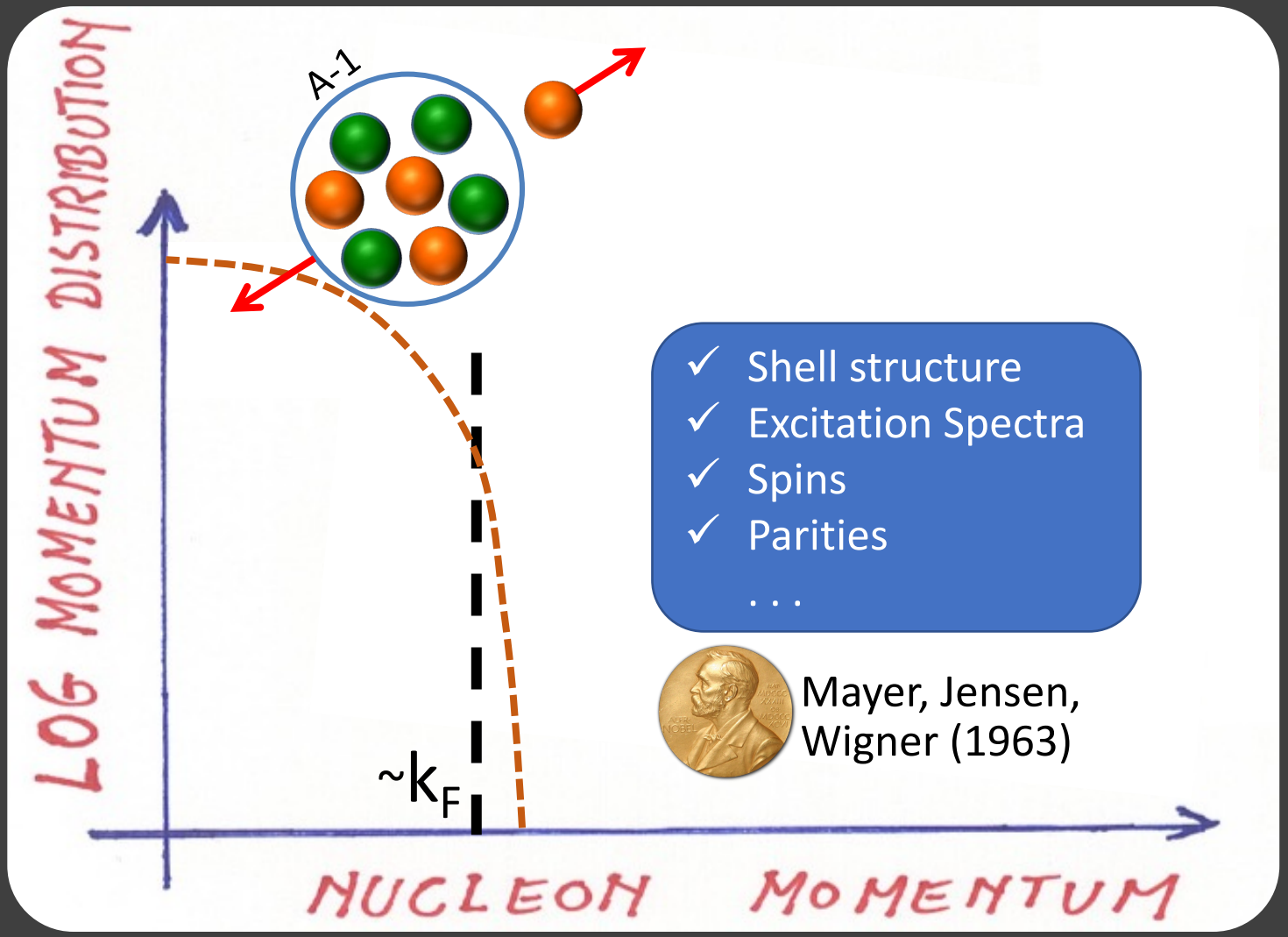
Close proximity nucleon-nucleon pairs
(short-range correlations)

Atomic nucleus
(mean-field nucleons, clusters)

Single-nucleon picture of nuclei



Single-nucleon picture of nuclei

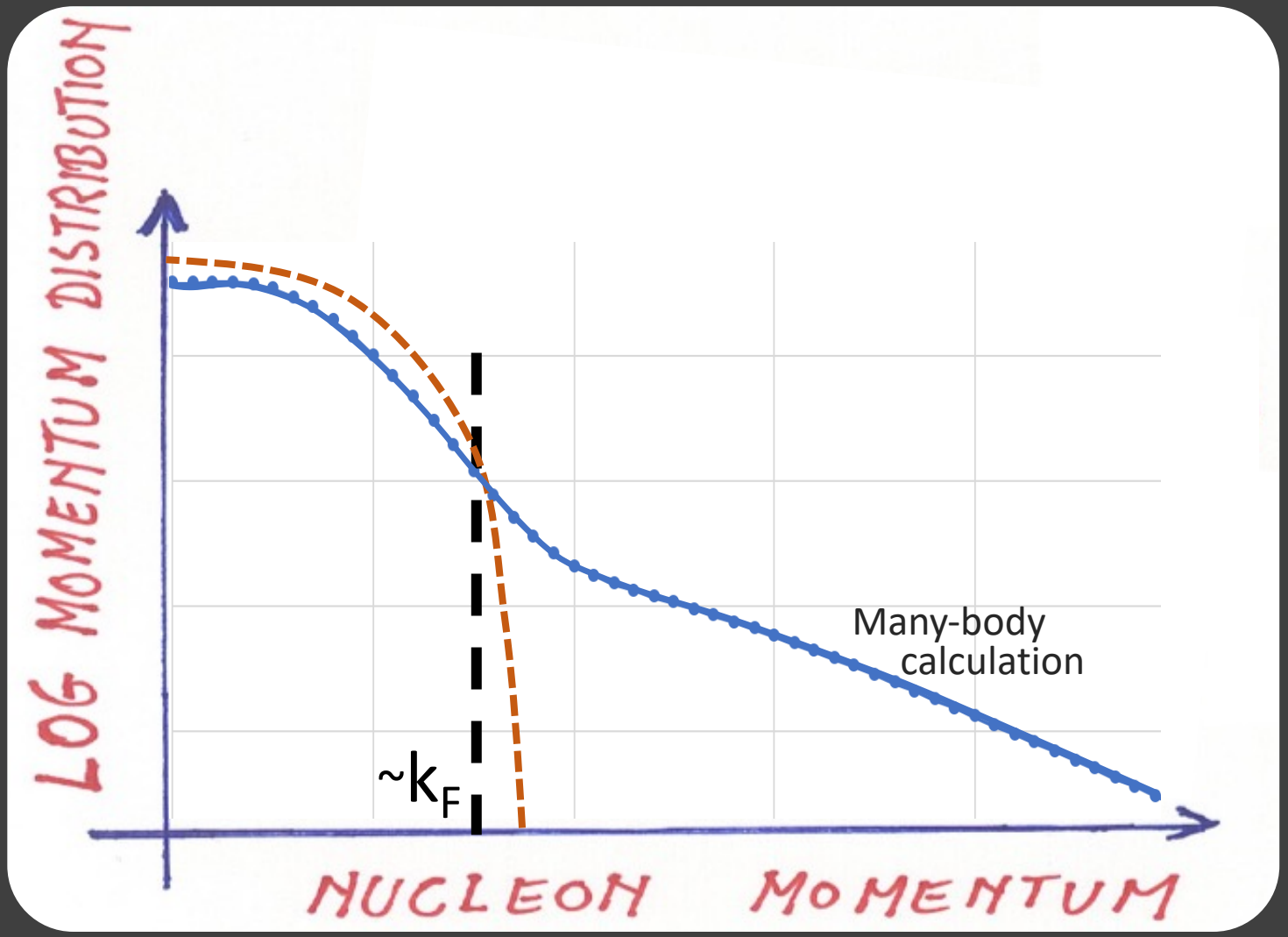


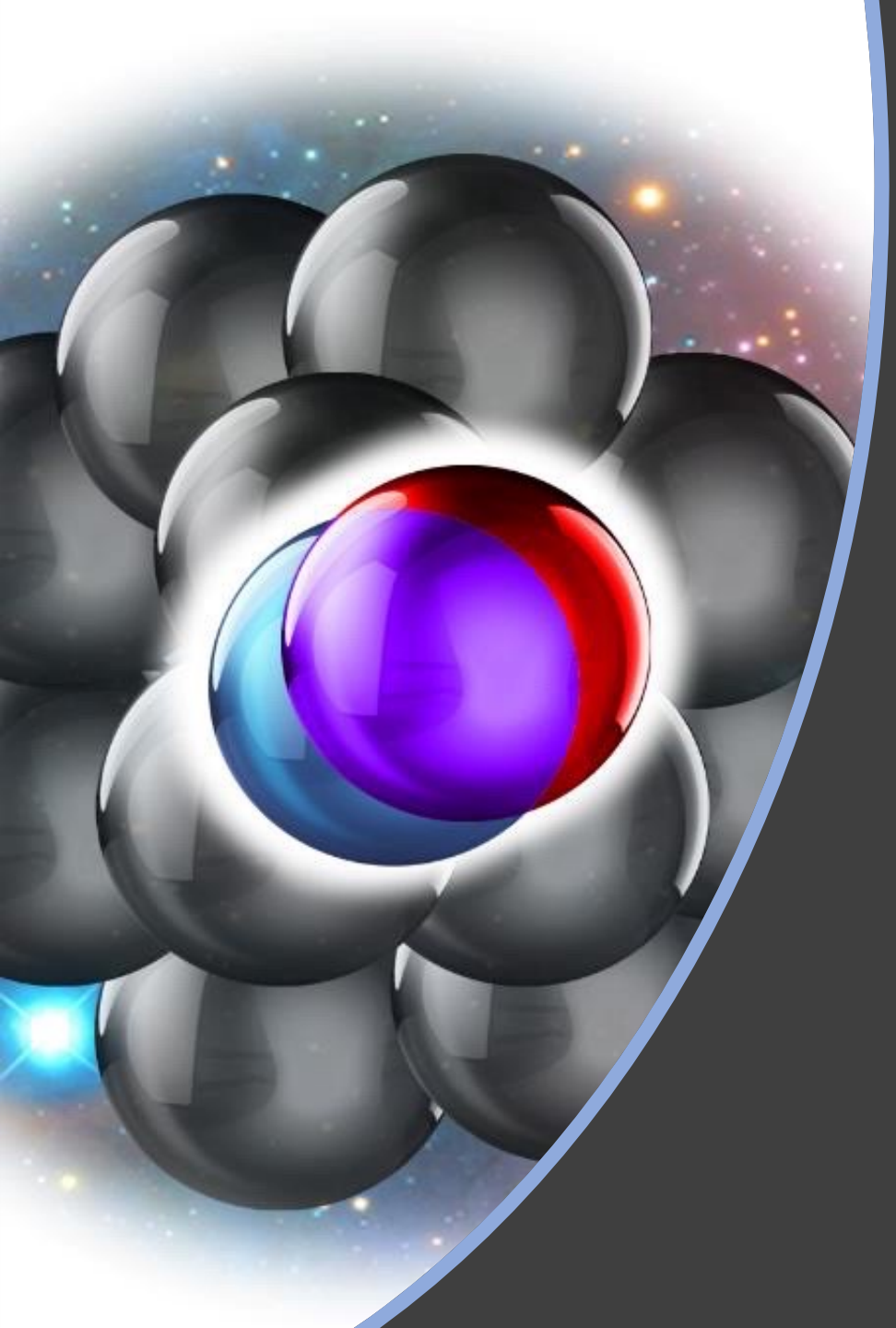
- ✓ Shell structure
- ✓ Excitation Spectra
- ✓ Spins
- ✓ Parities

. . .

Mayer, Jensen, Wigner (1963)

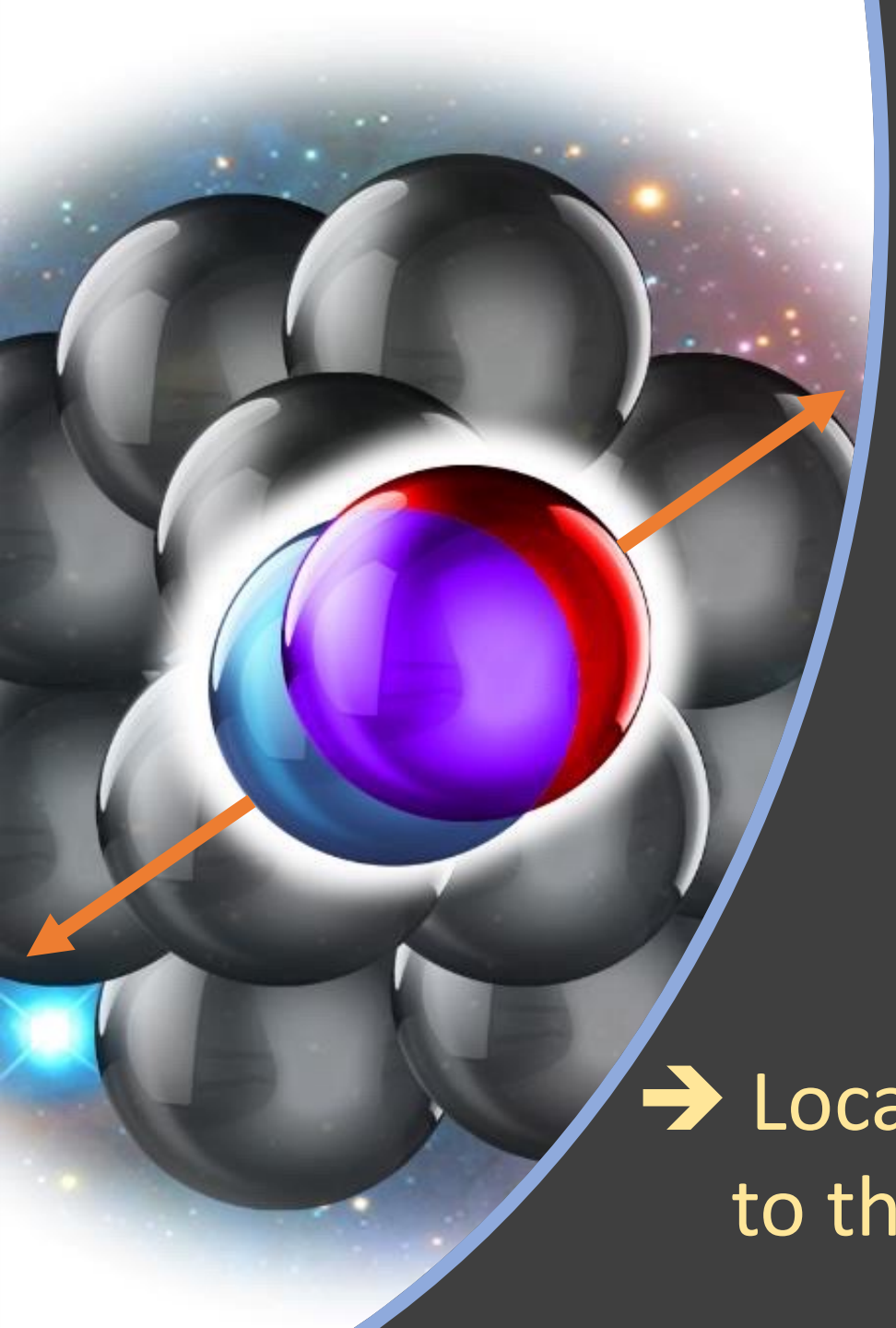
~~Single-nucleon picture of nuclei~~ incomplete





Short-Range Correlations (SRC)

Fluctuations of close-proximity nucleon pairs

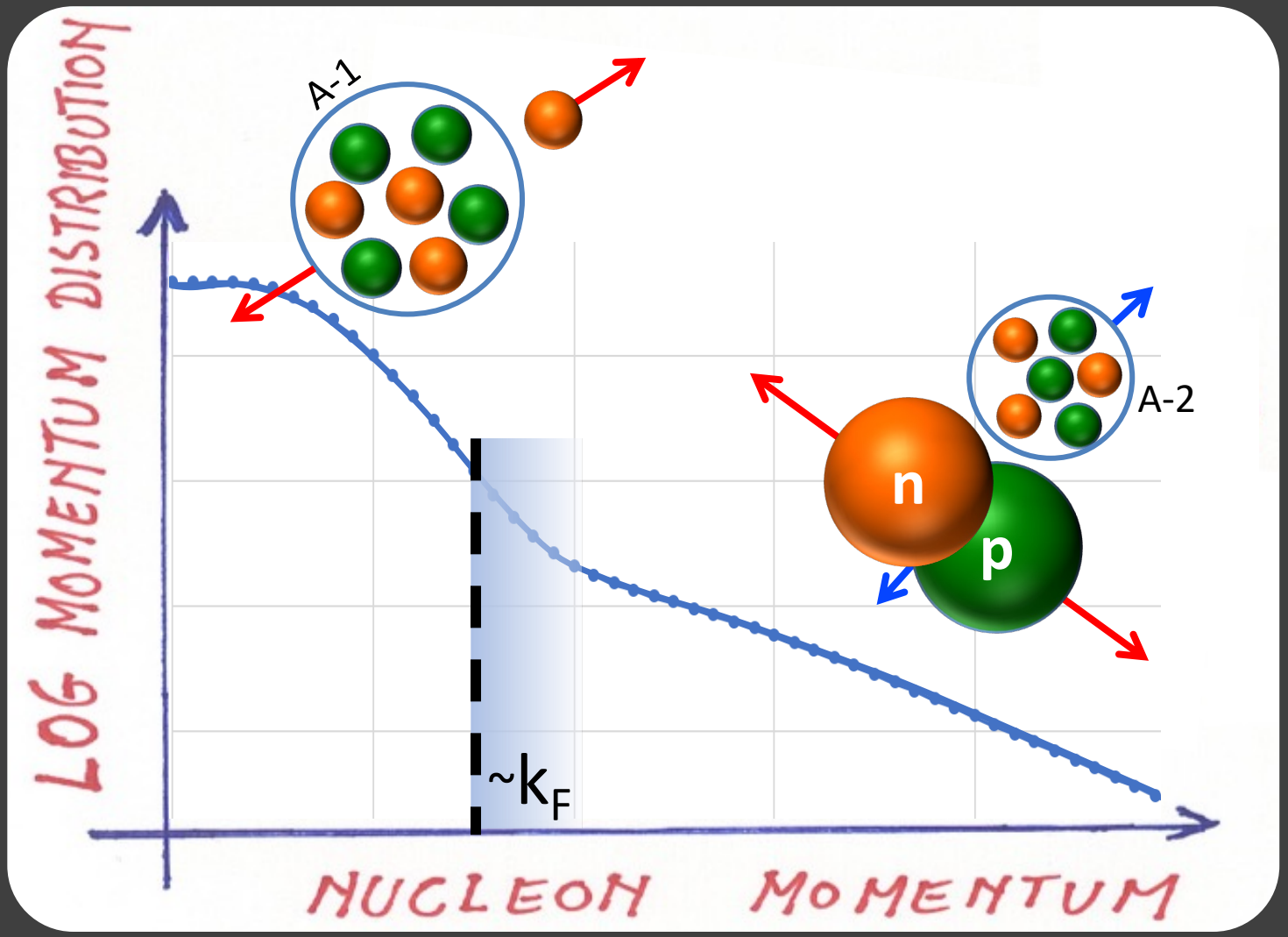


Short-Range Correlations (SRC)

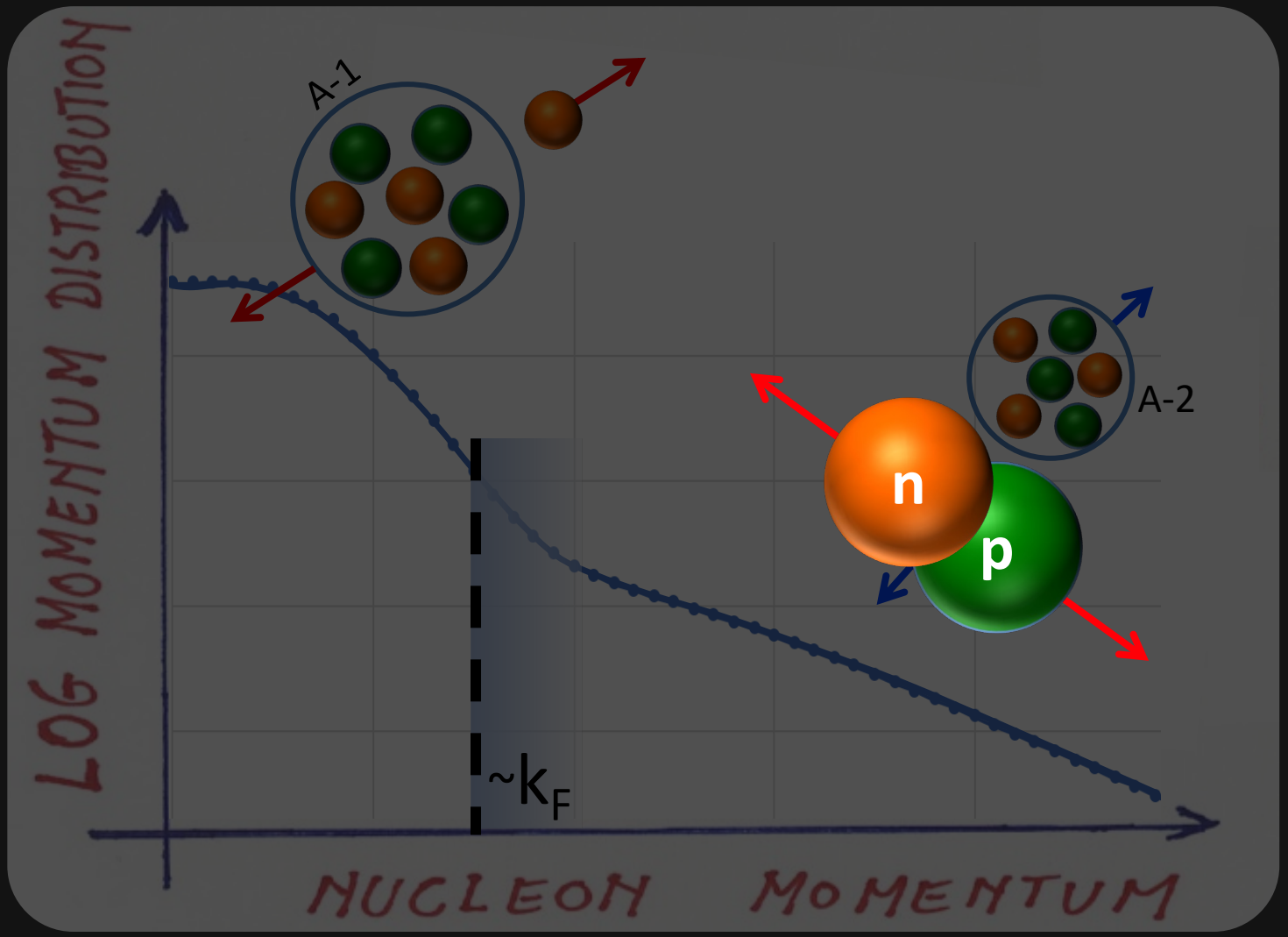
Fluctuations of close-proximity nucleon pairs

➔ Local density comparable to that of neutron stars

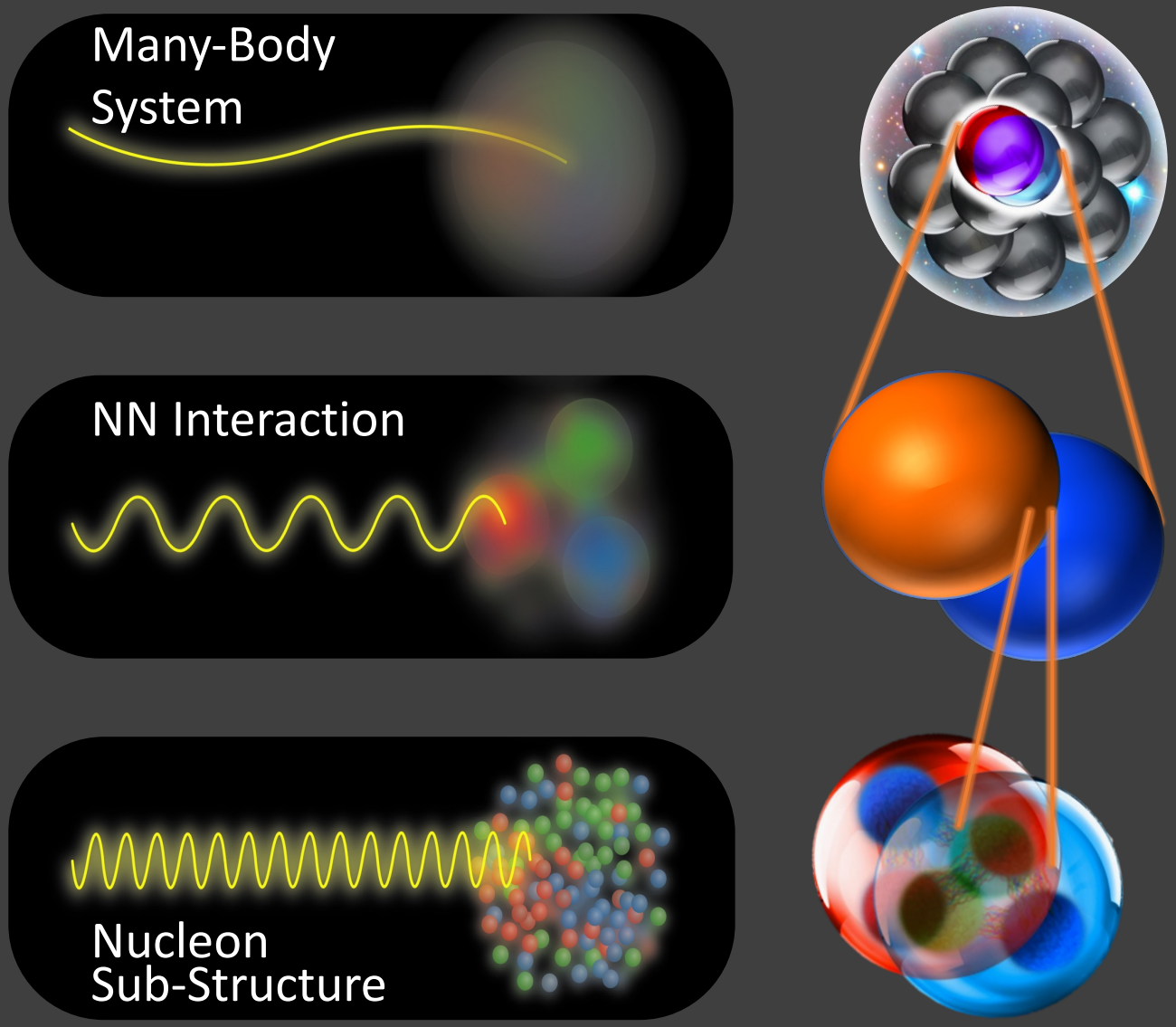
Step 1: One + Two-body picture of nuclei



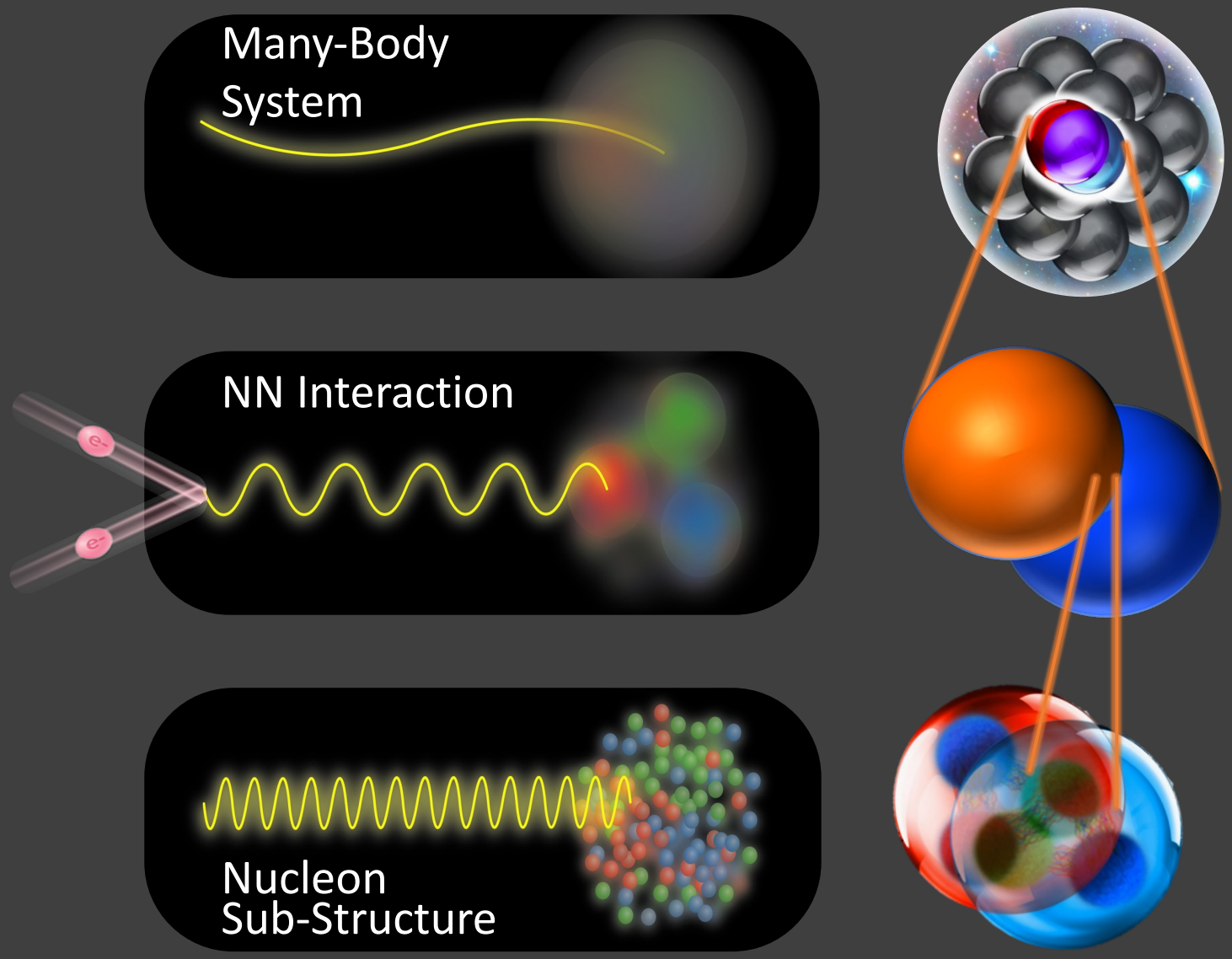
Step 1: One + Two-body picture of nuclei

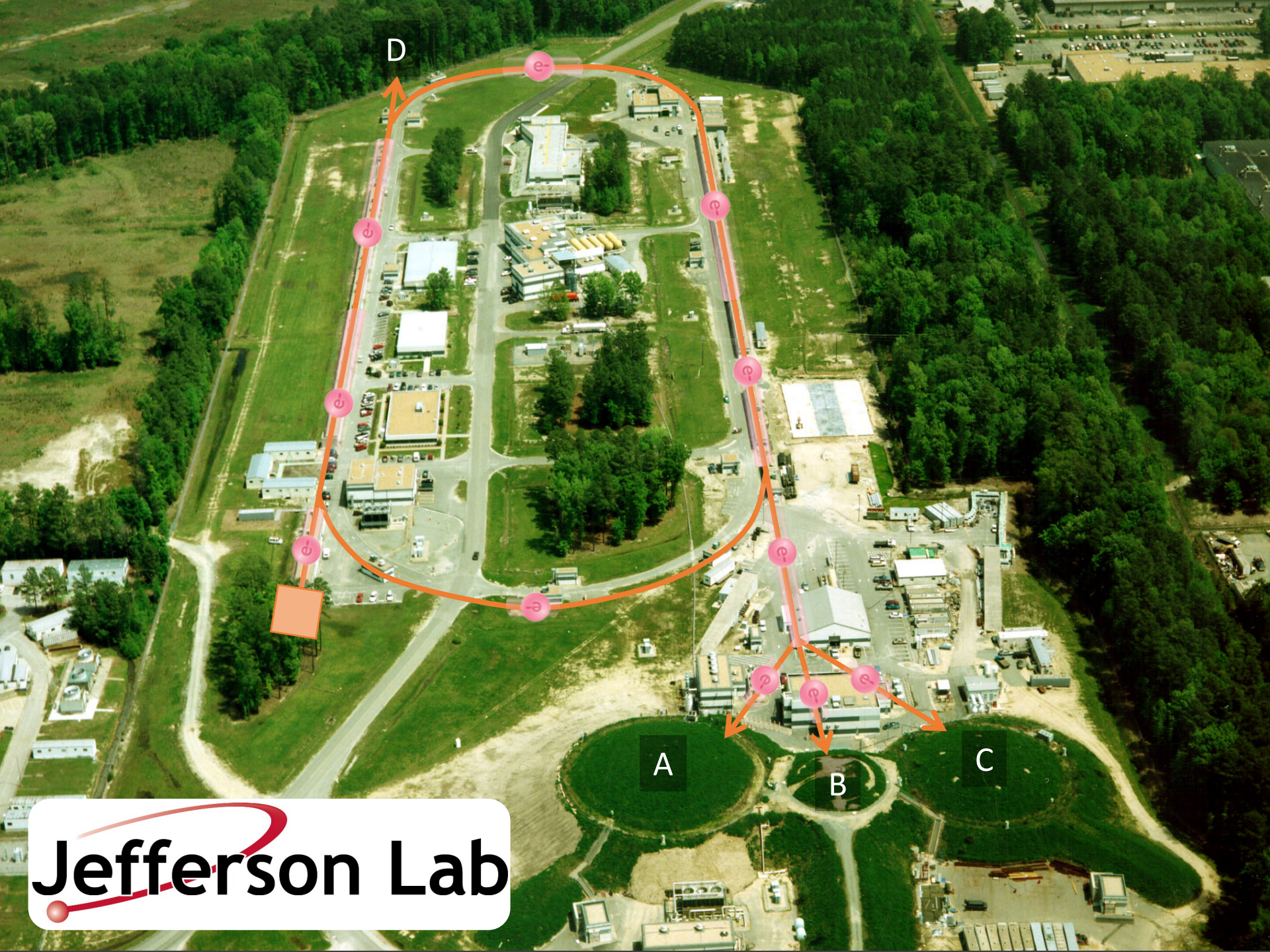


Step 2: SRCs Across Nuclear Scales

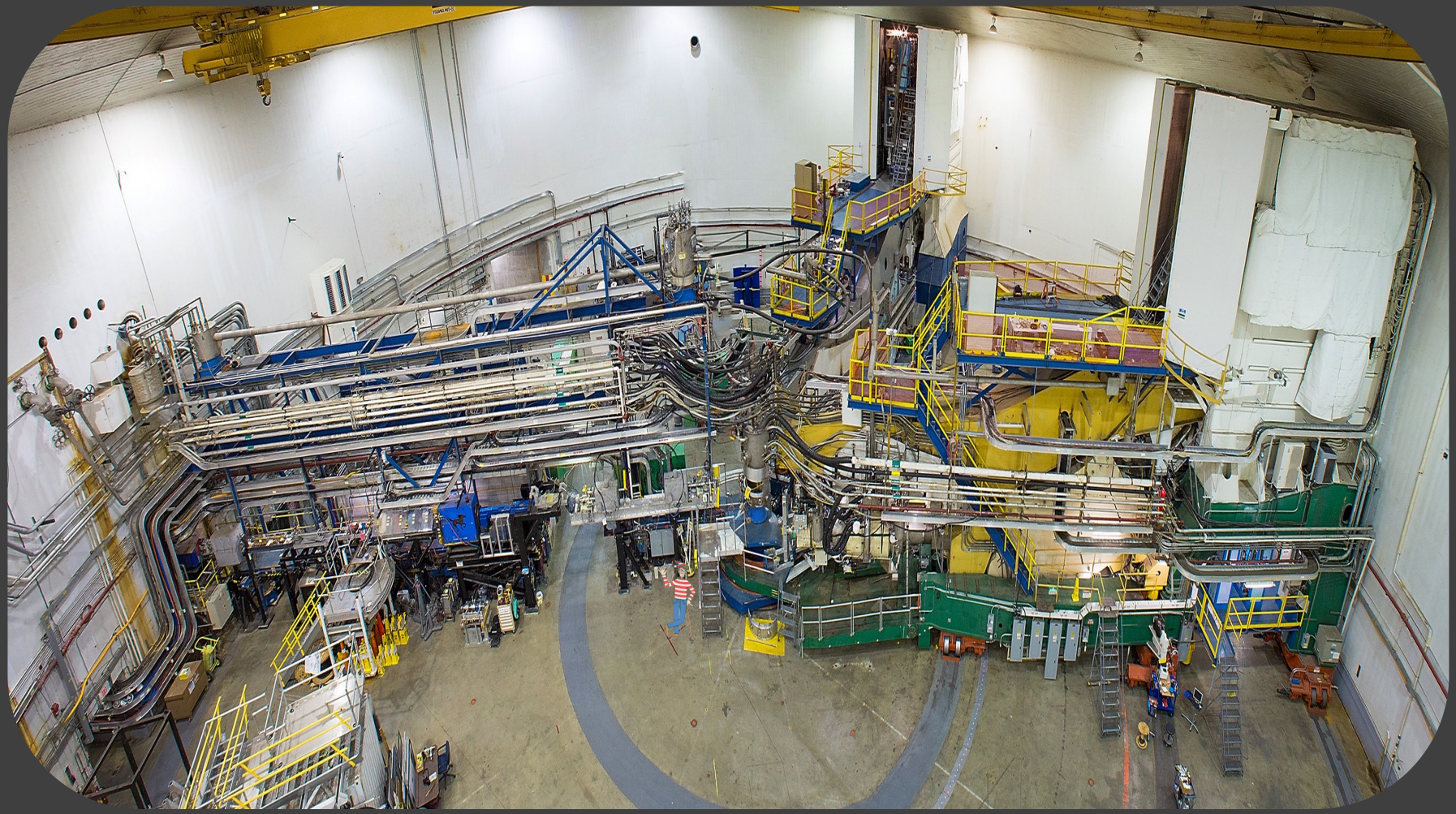


Step 2: SRCs Across Nuclear Scales



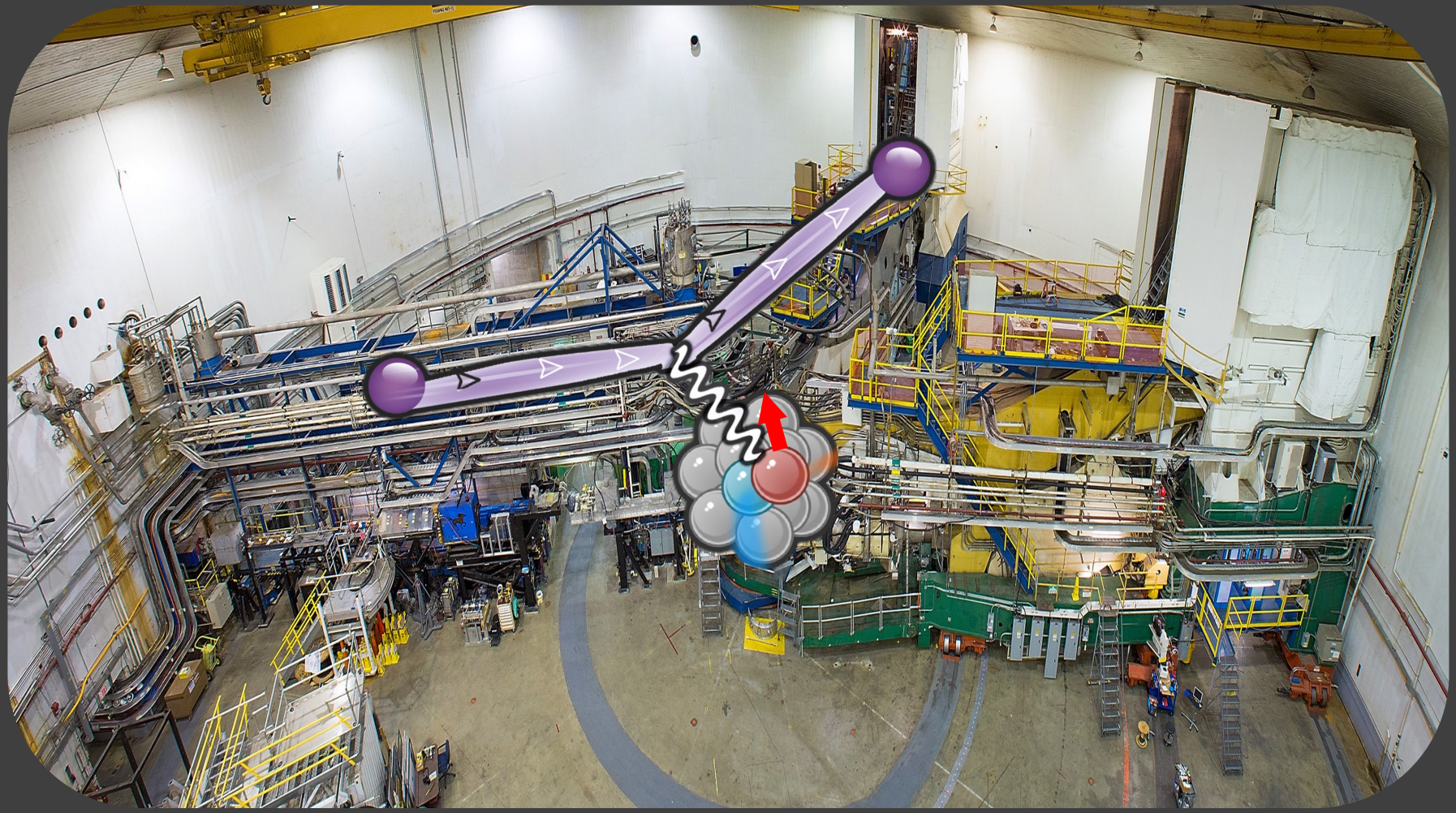

D
A
B
C
Jefferson Lab

Hall A

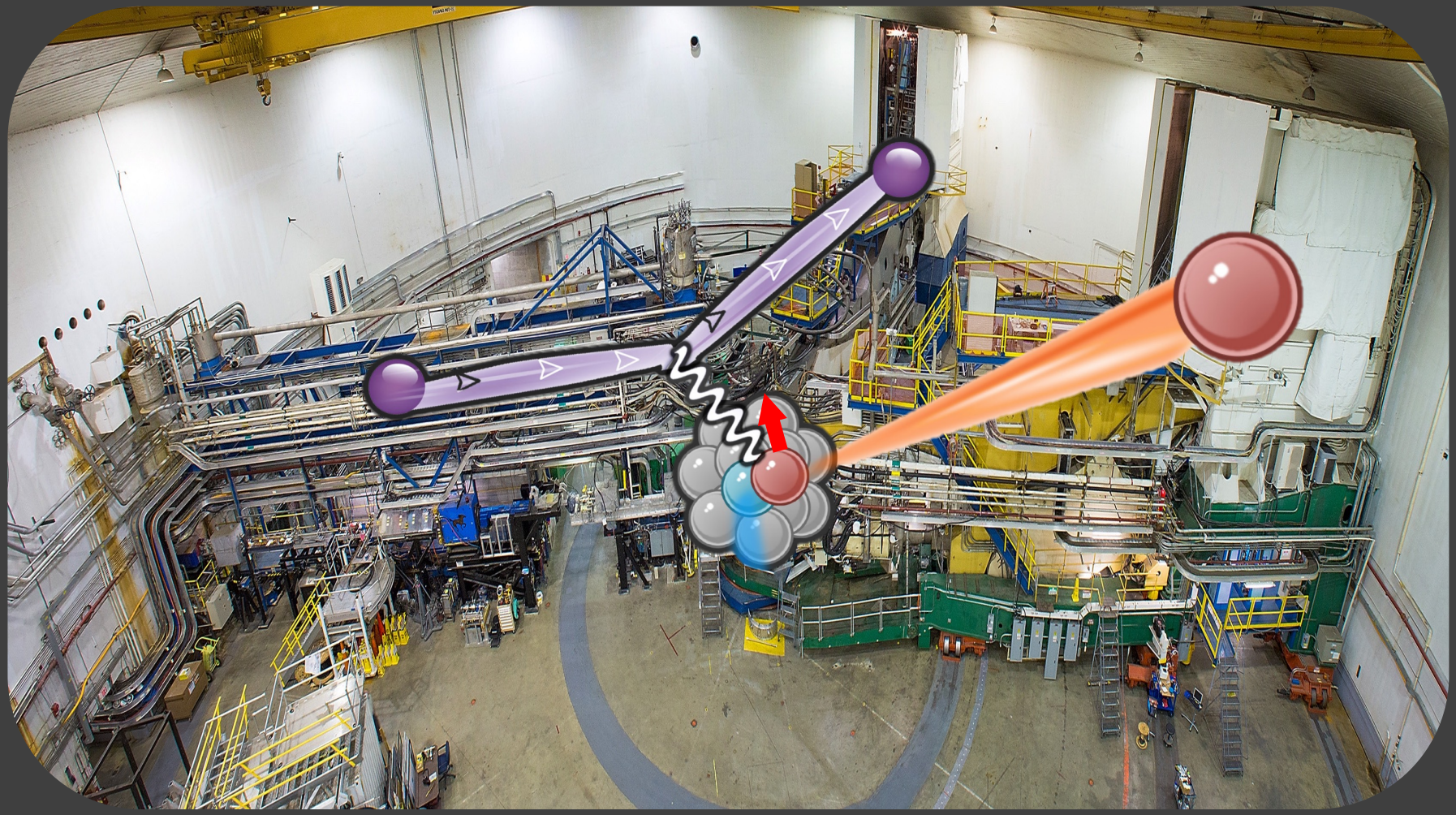


Hall A

Hall A



Hall A



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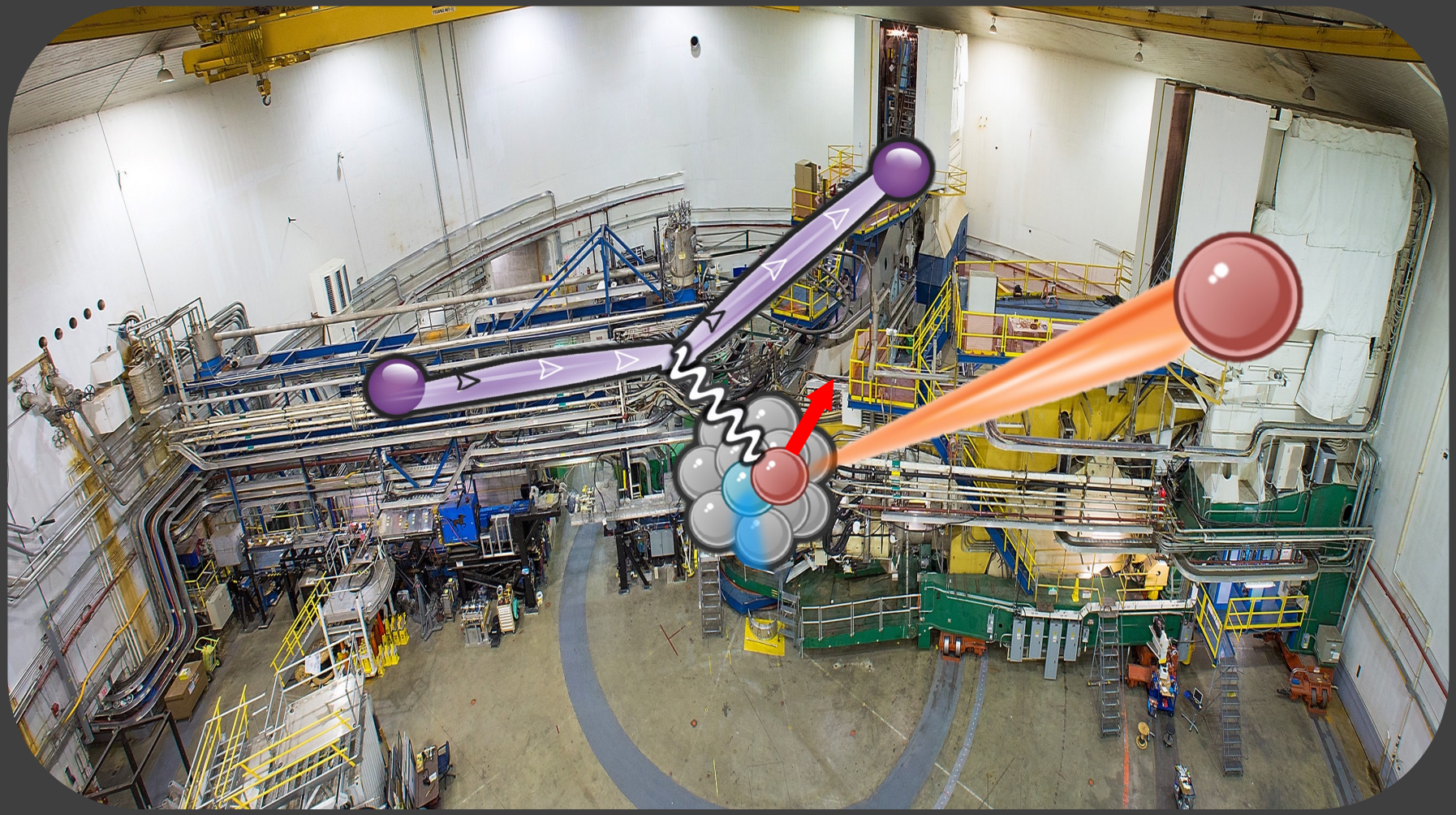

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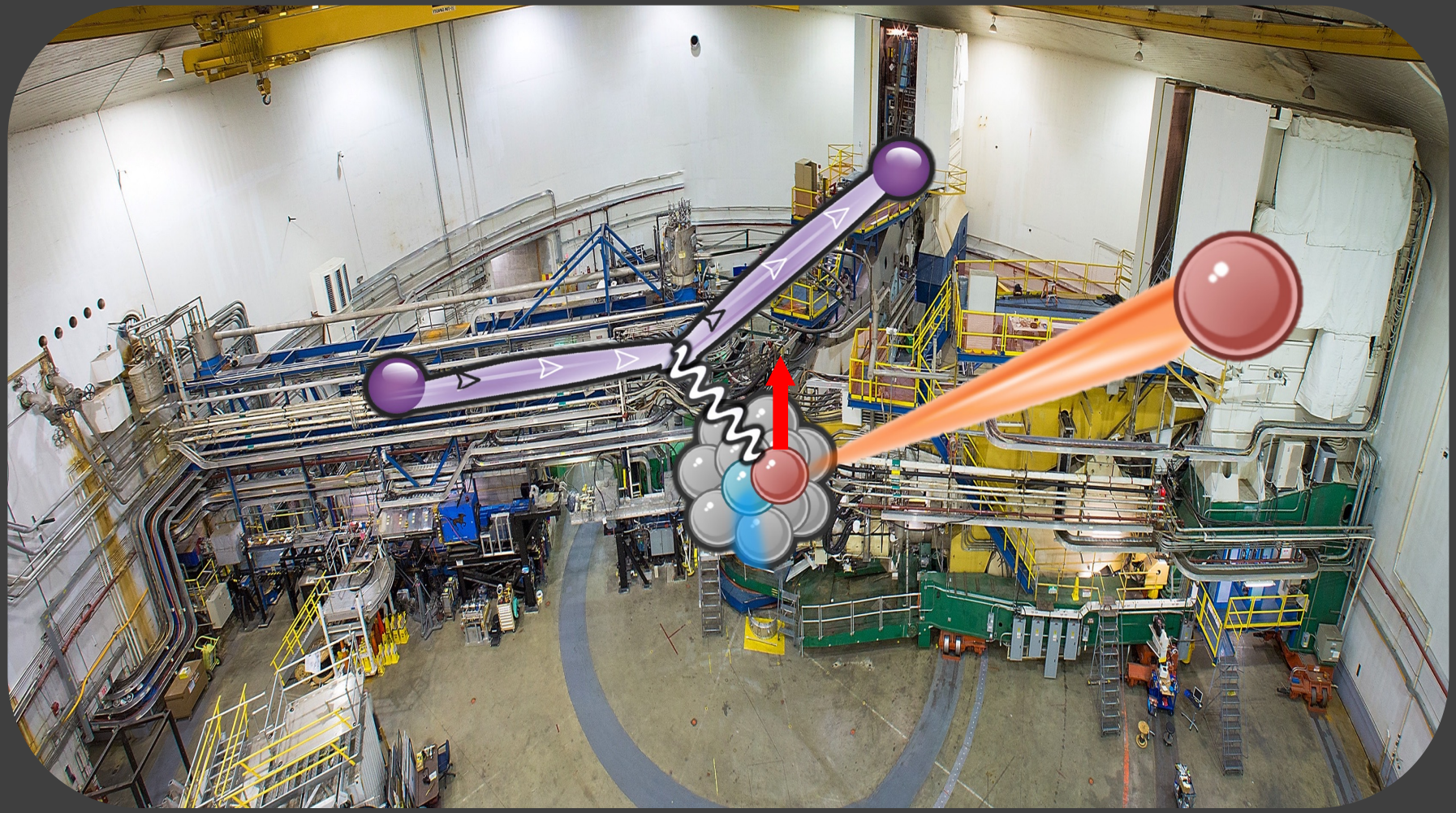

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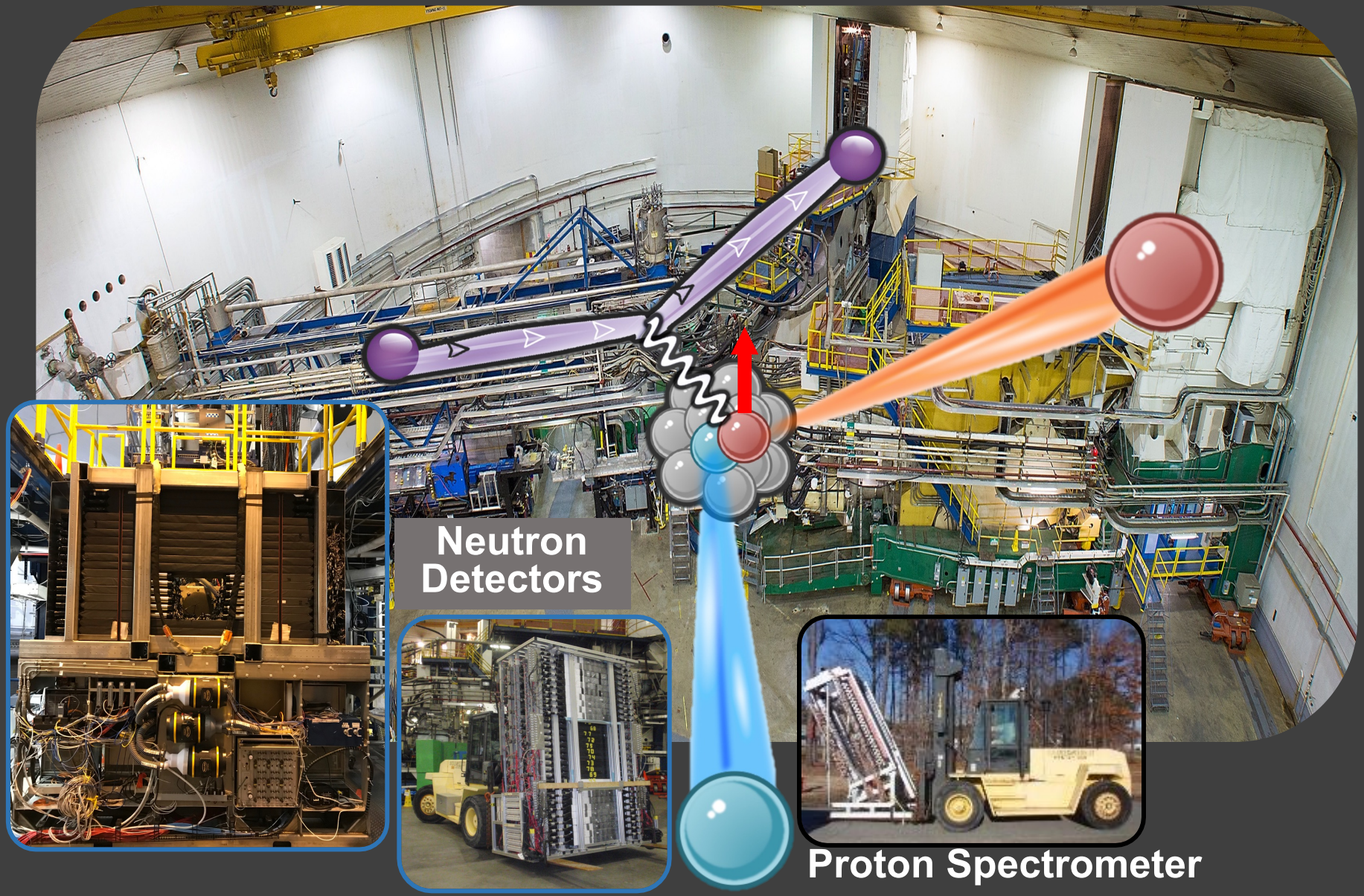
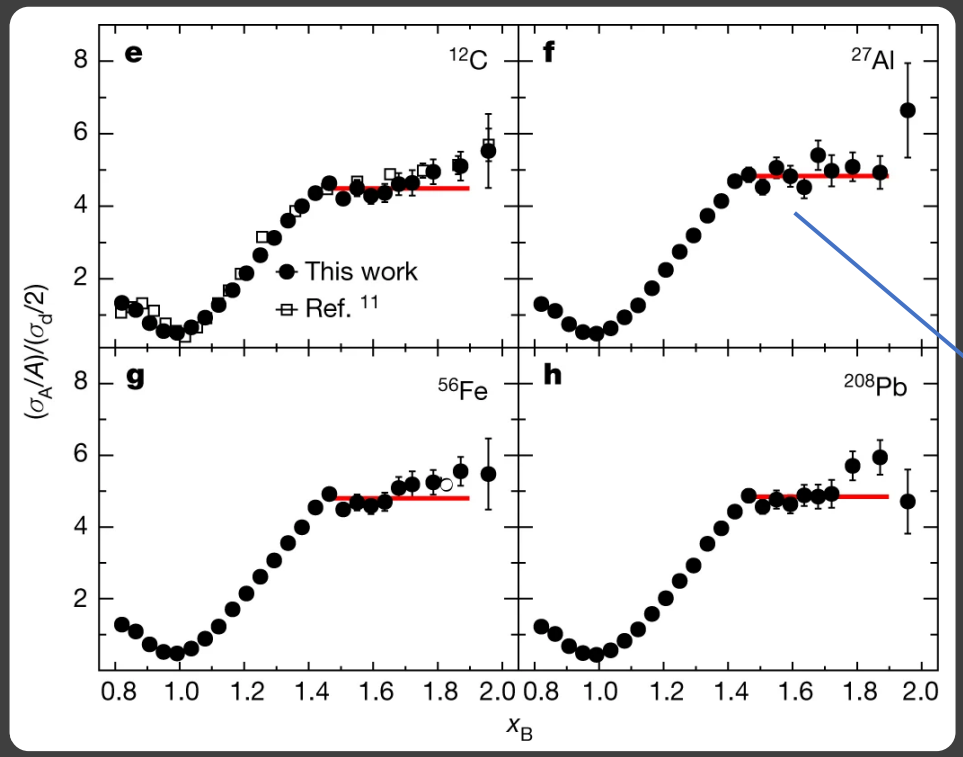
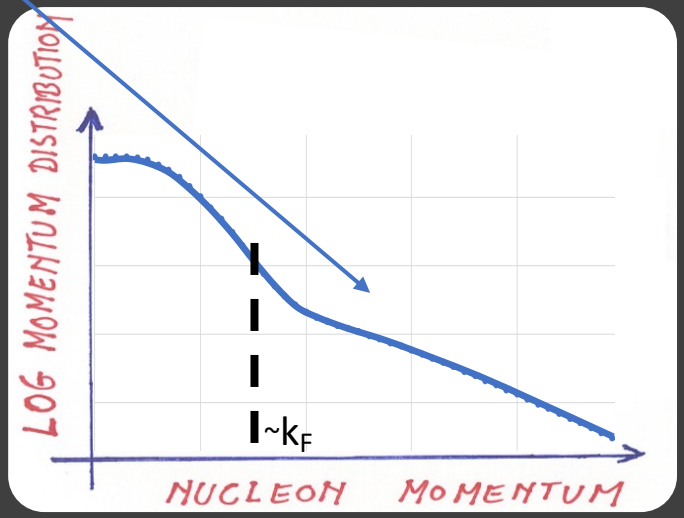


‘Quasi-Deuterons’ in Nuclei?

(e,e`) cross-section ratio scaling @ high-x_B

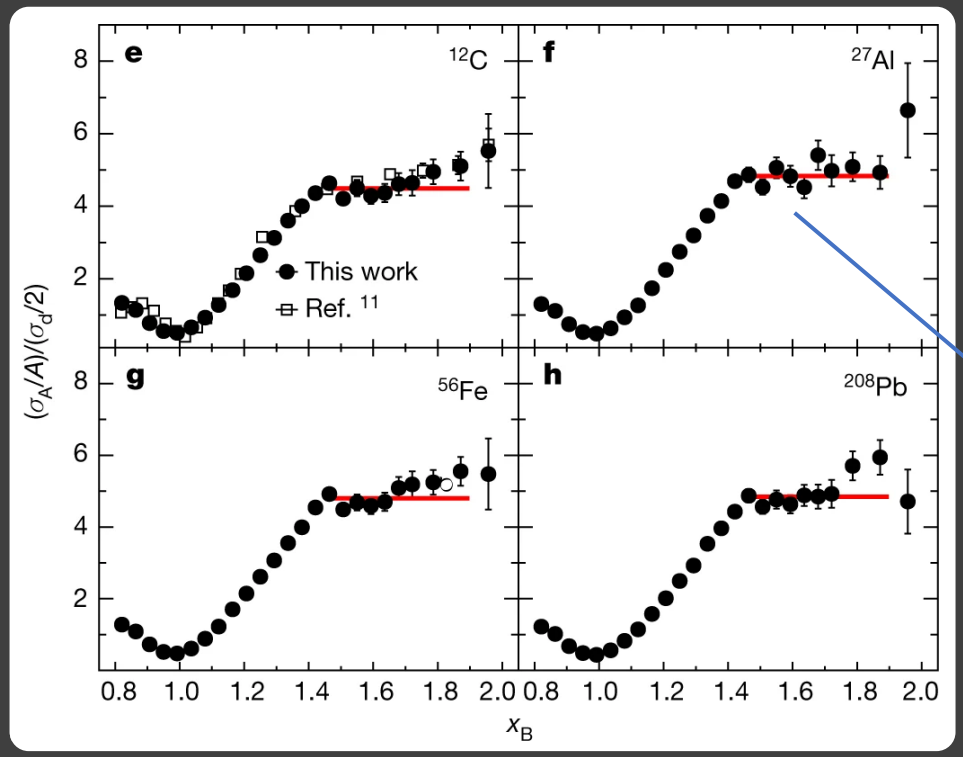


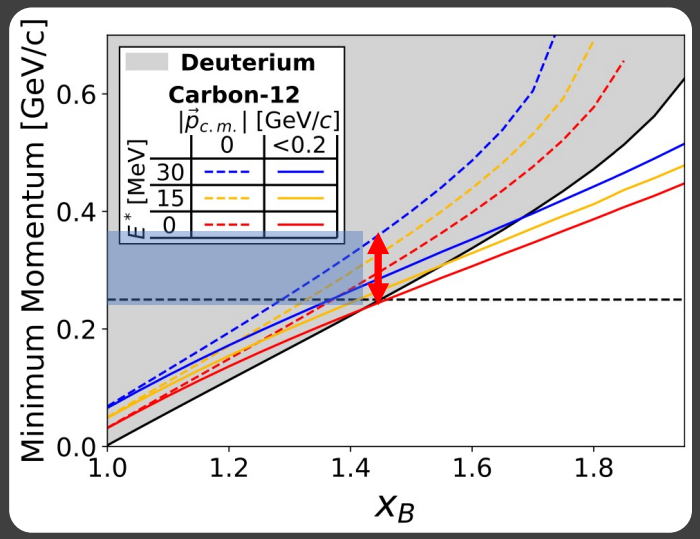


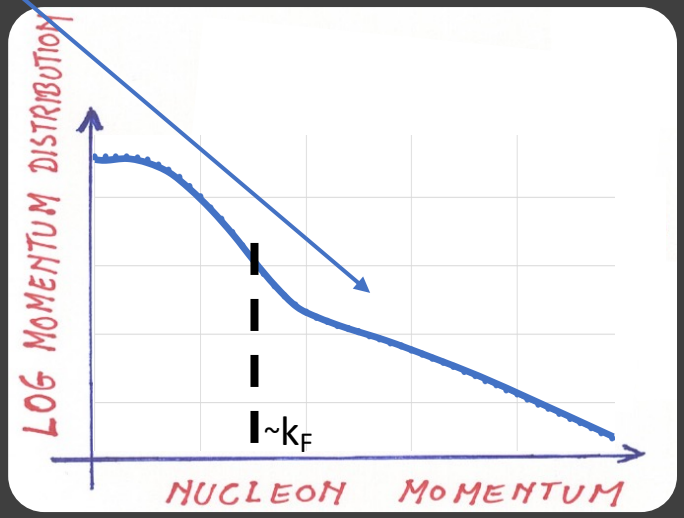
K.Sh. Egiyan et al. (CLAS), Phys. Rev. C 68 (2003).
B. Schmookler et al. (CLAS), Nature 566 (2019).
D. Nguyen et al. (JLab Hall A), Phys. Rev. C 102 (2020).
S. Li et al., Nature 609 (2022).

Onset of SRC Regime?

(e,e`) cross-section ratio scaling @ high-x_B







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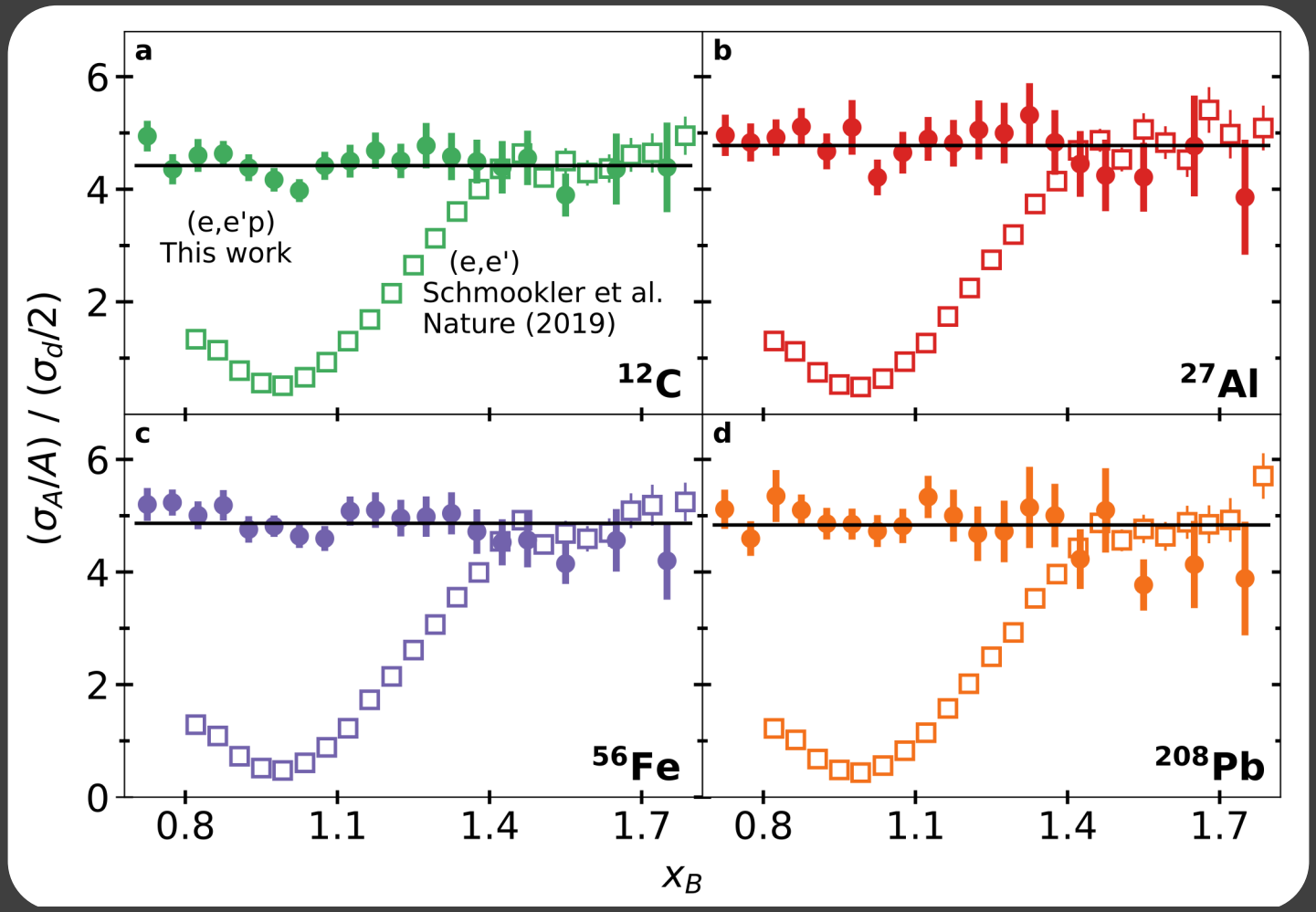
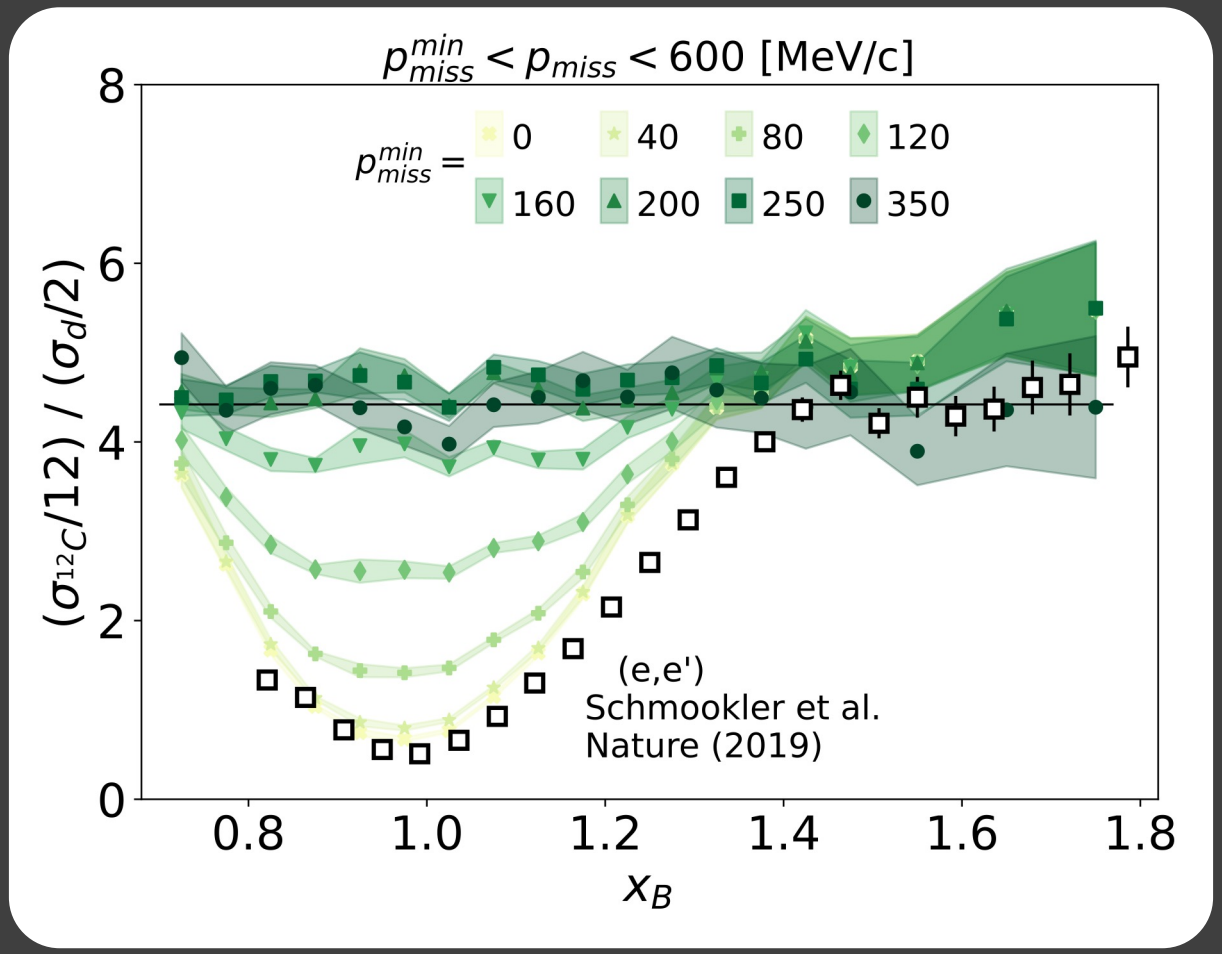
New scaling via (e,e'p) ratios




Korover and Denniston et al., Submitted (2022)

Onset of SRC Regime?

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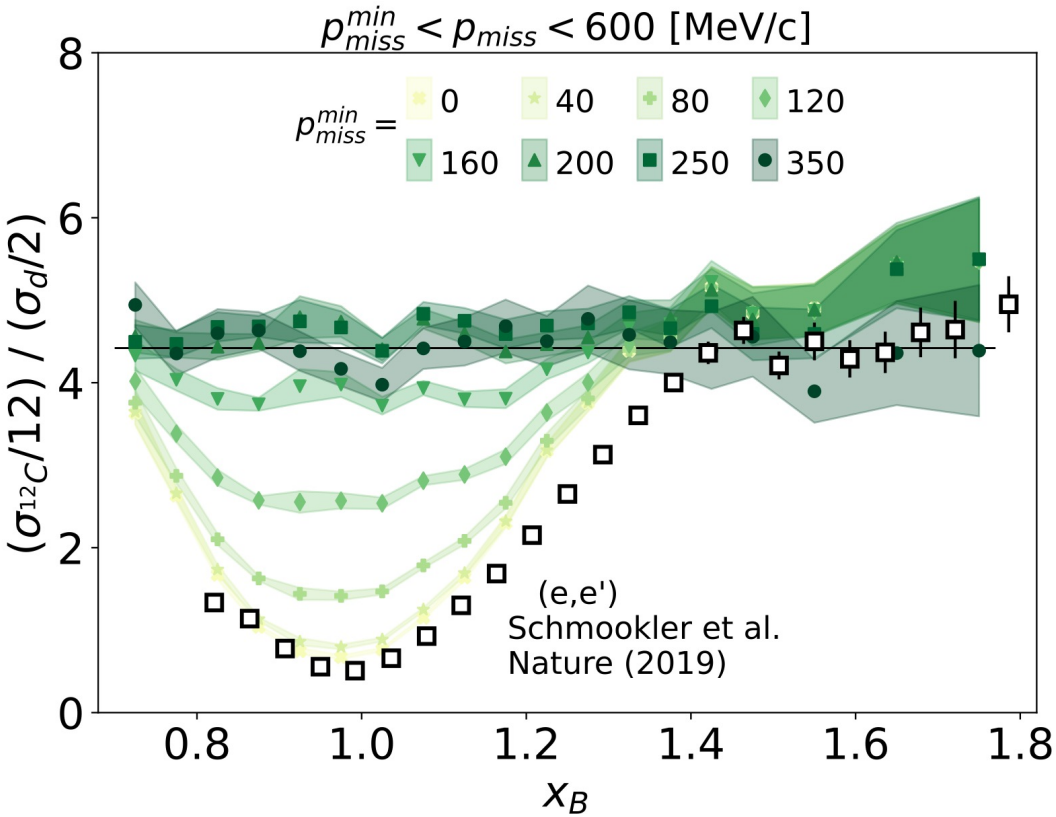

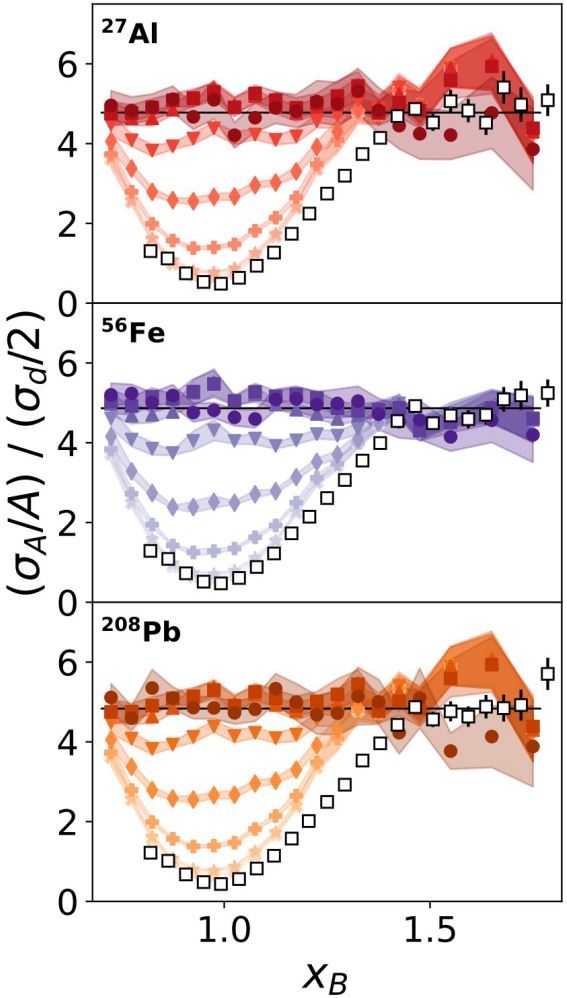


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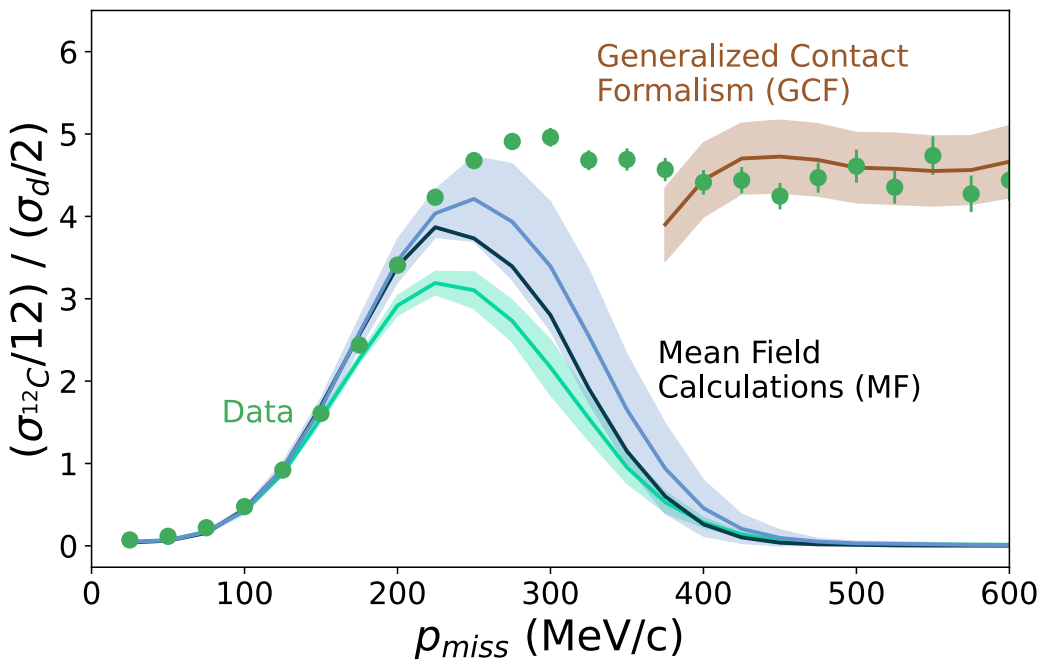

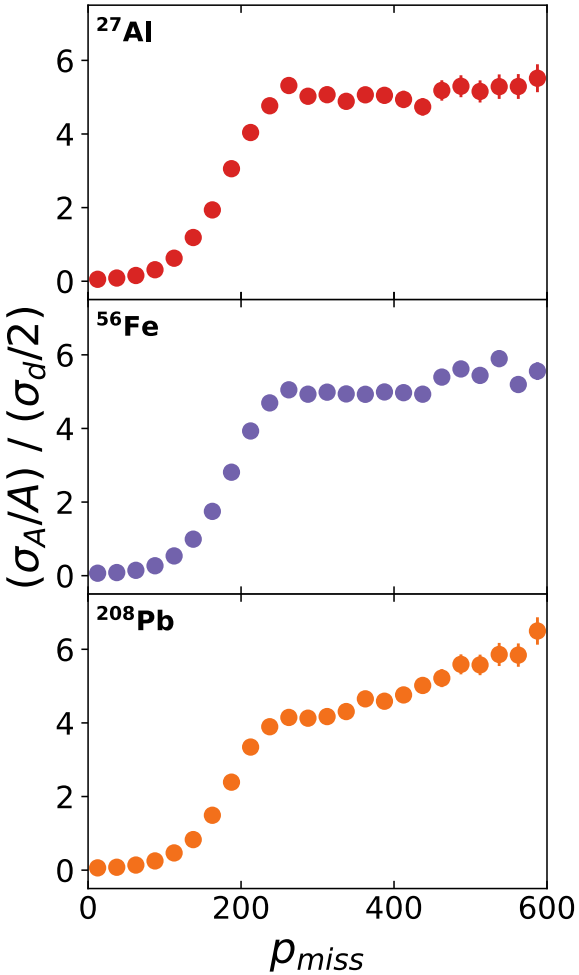


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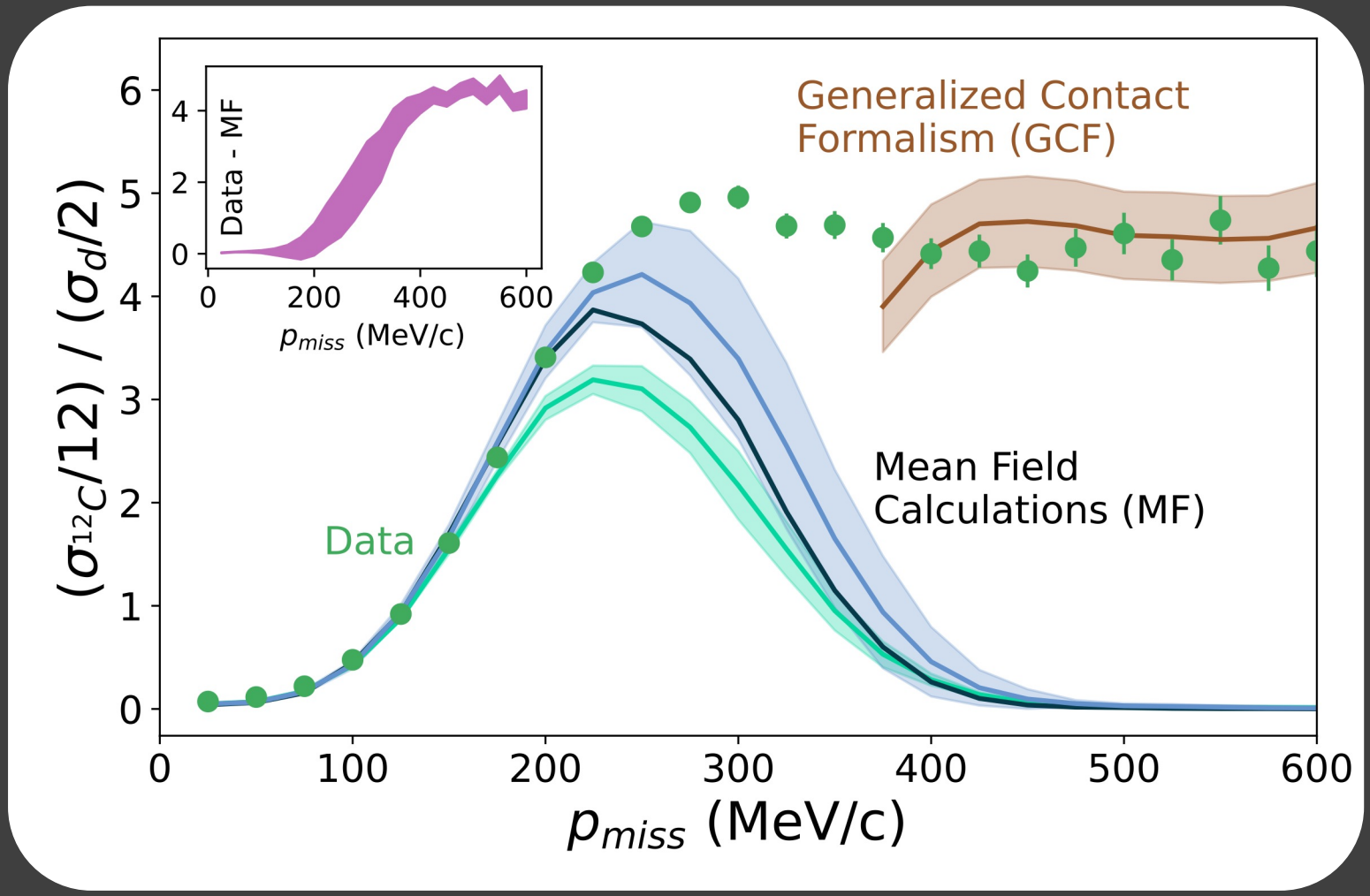


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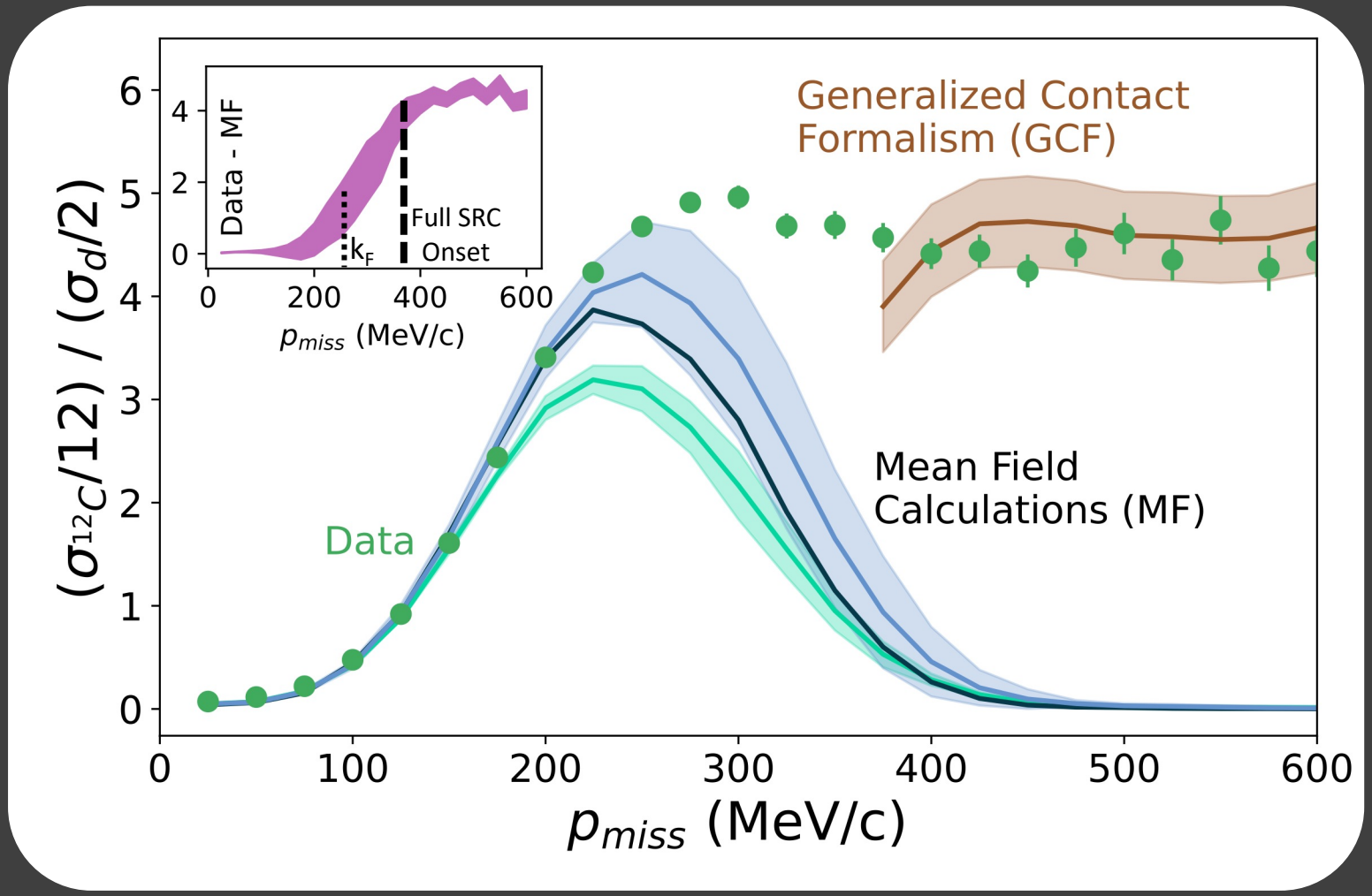
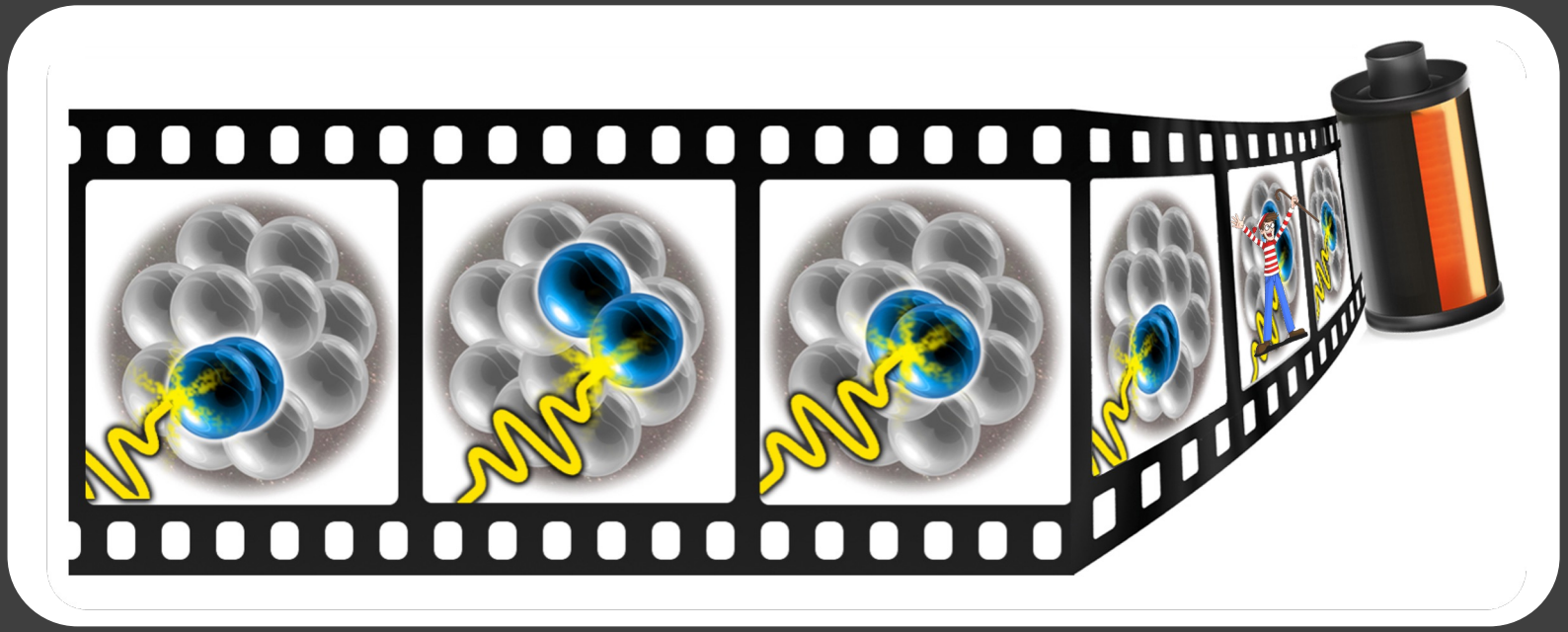
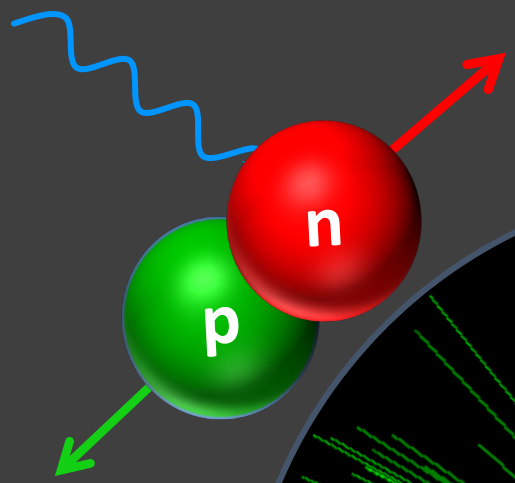


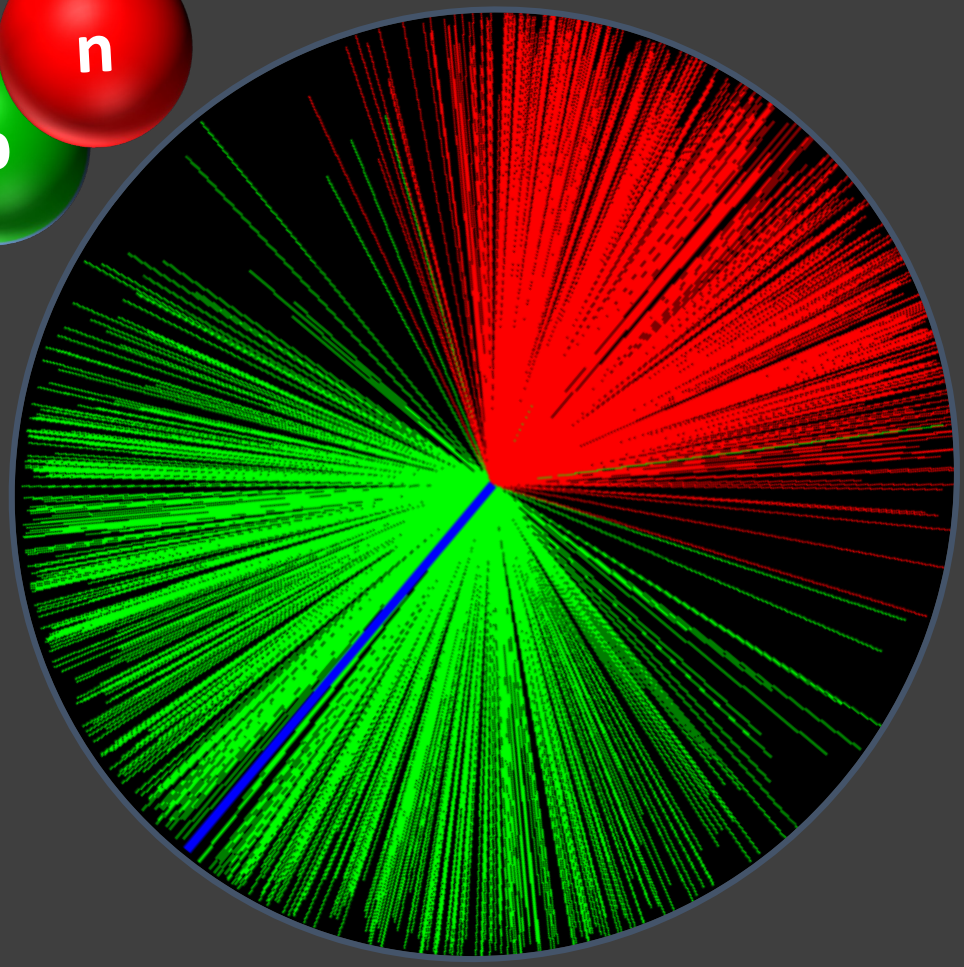

Korover and Denniston et al., Submitted (2022)

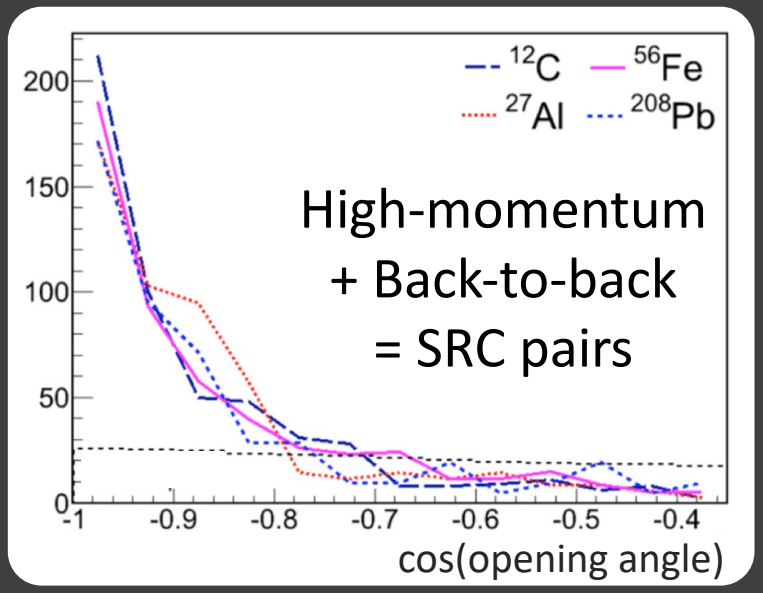
SRC Breakup Reactions



‘Measuring’ SRCs

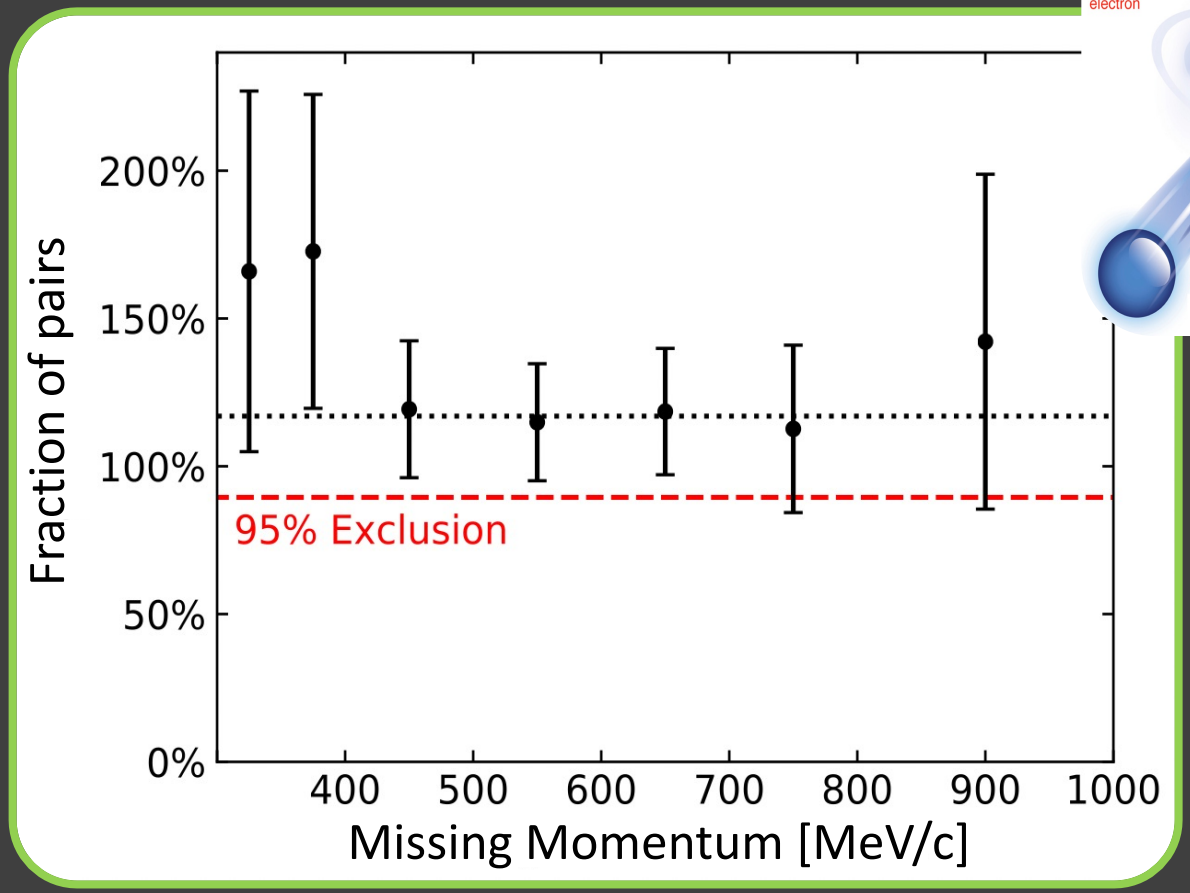


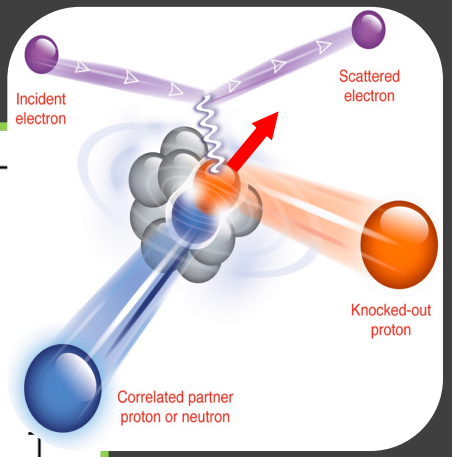




Hen et al., Science 2014

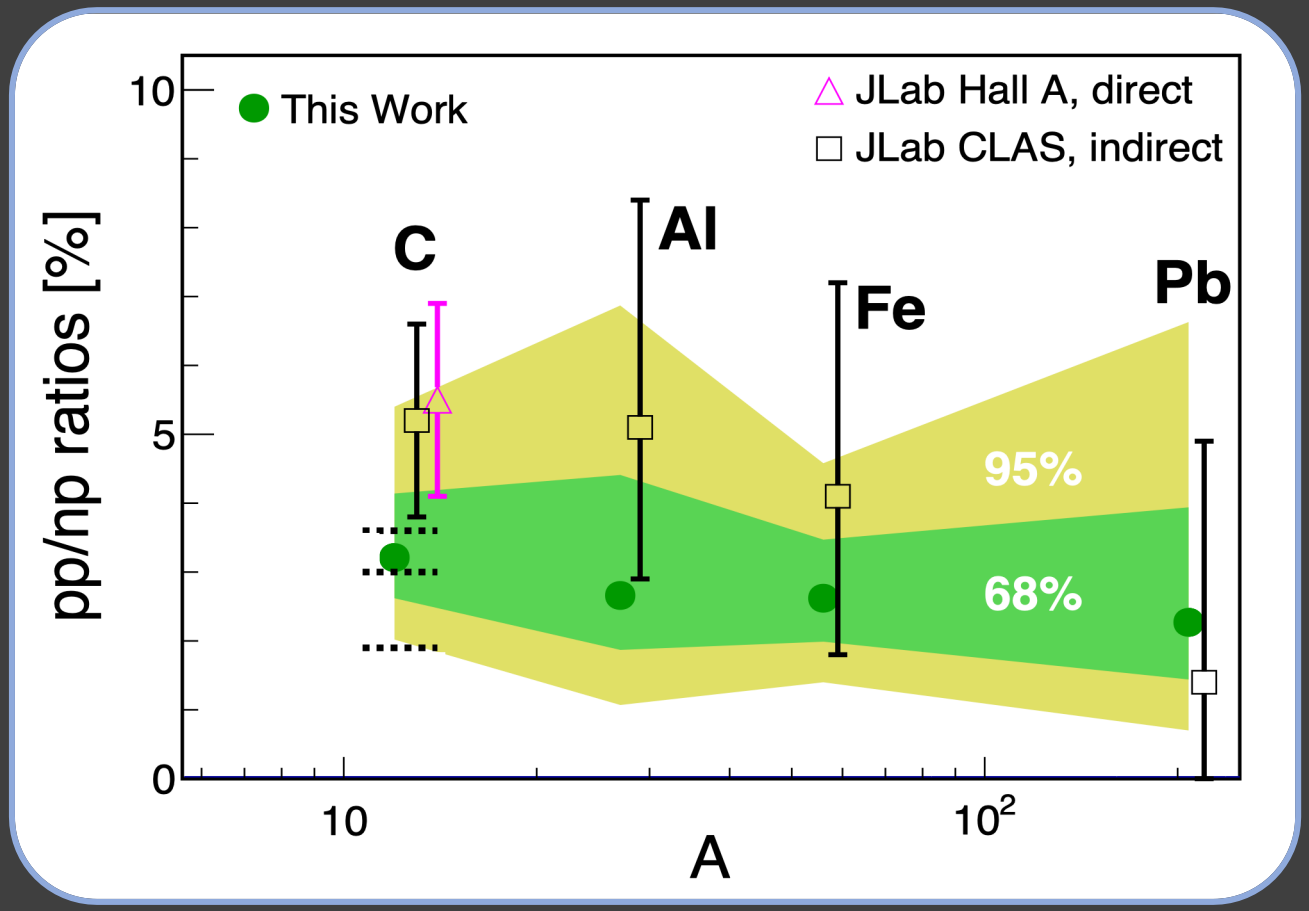
Do High-Momentum Nucleons Come in Pairs? Yes!





Korover et al., PLB (2021)

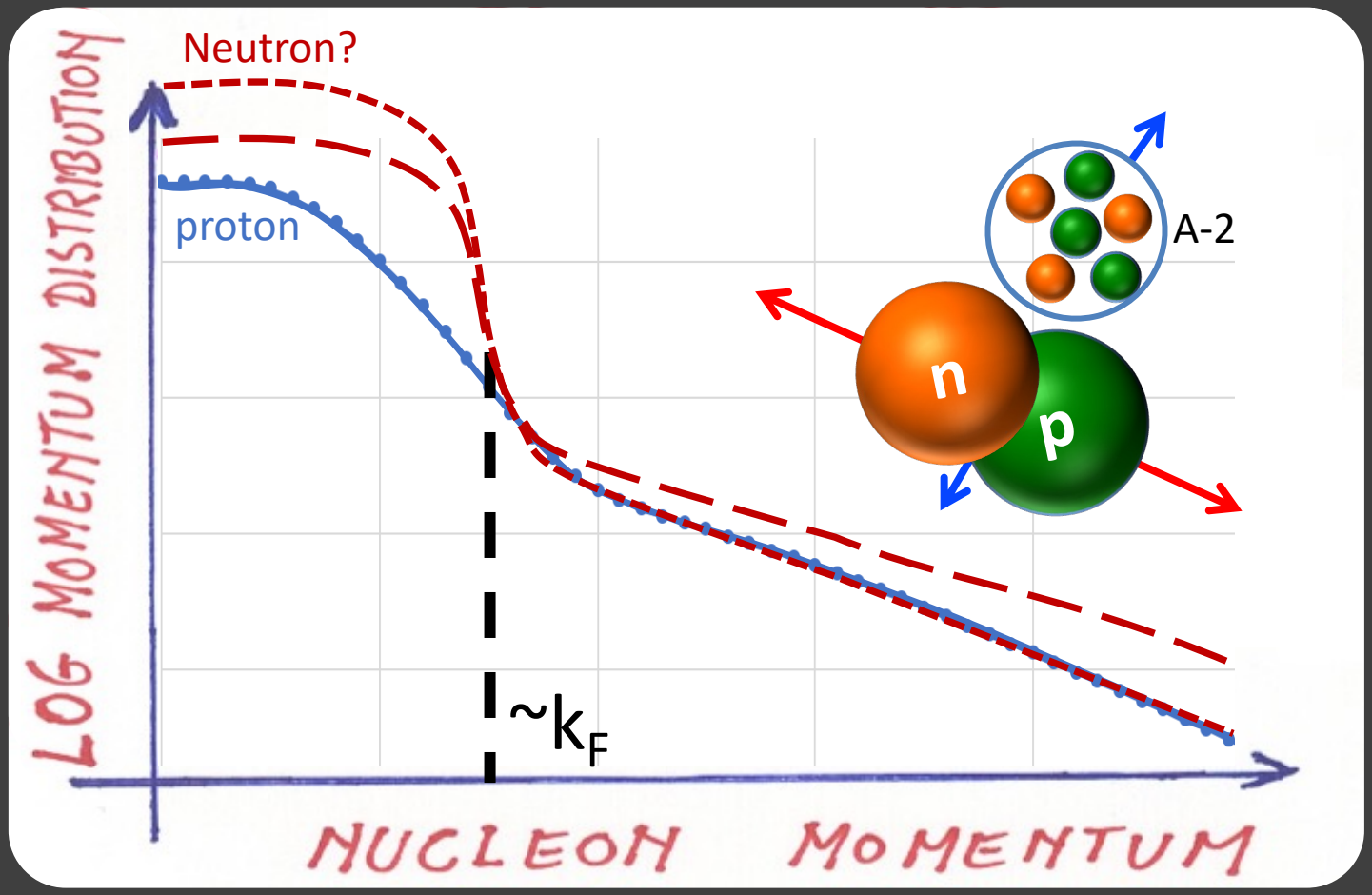
What kind? Predominantly neutron-proton (np) Pairs



2-4% pp pairs

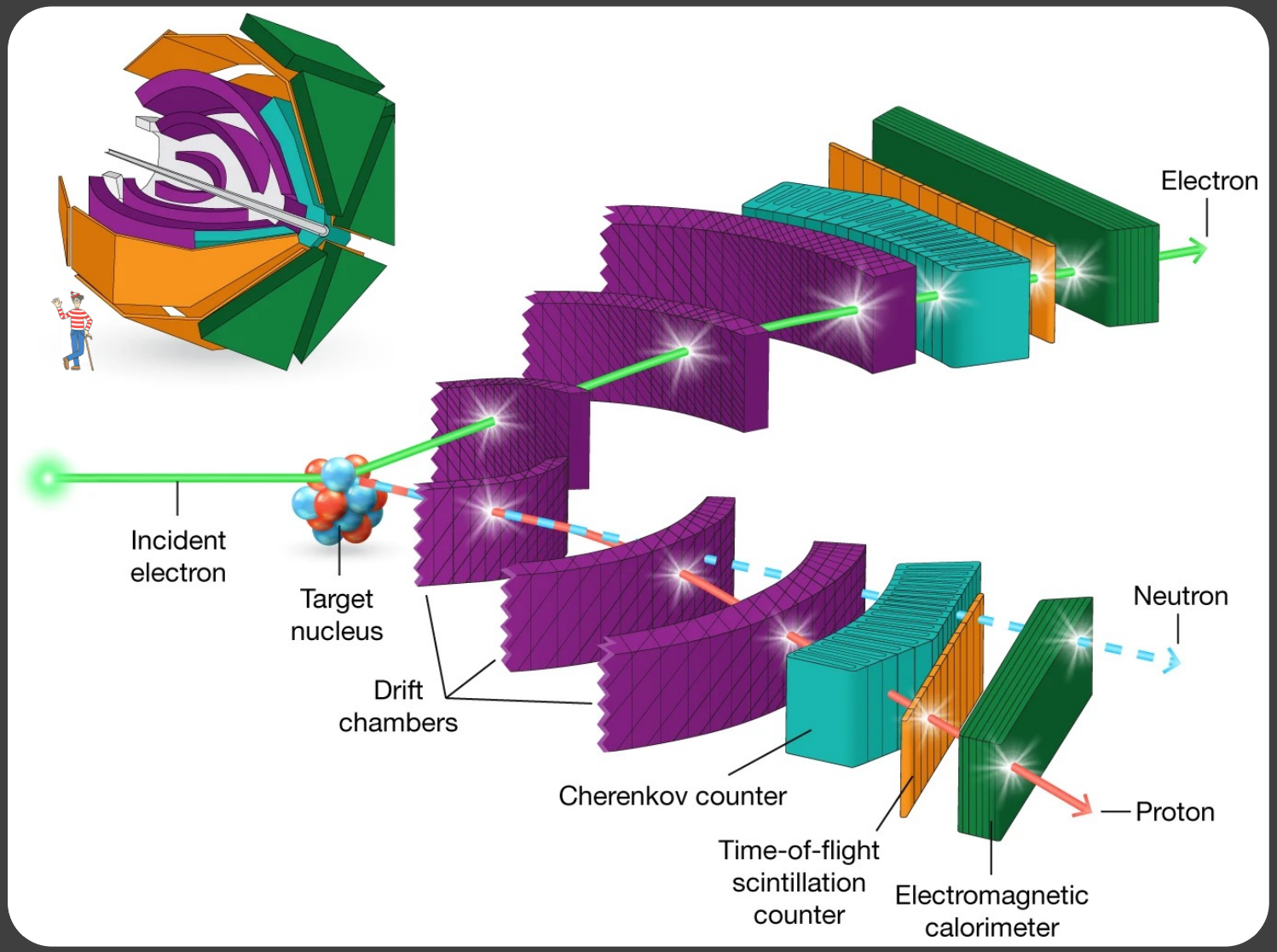
Duer PRL '19; Duer Nature '18; Hen Science '14; Korover PRL '14; Subedi Science '08; Shneor PRL '07; Piasetzky PRL '06; Tang PRL '03; Review: Hen RMP '17;

What do excess neutrons do?

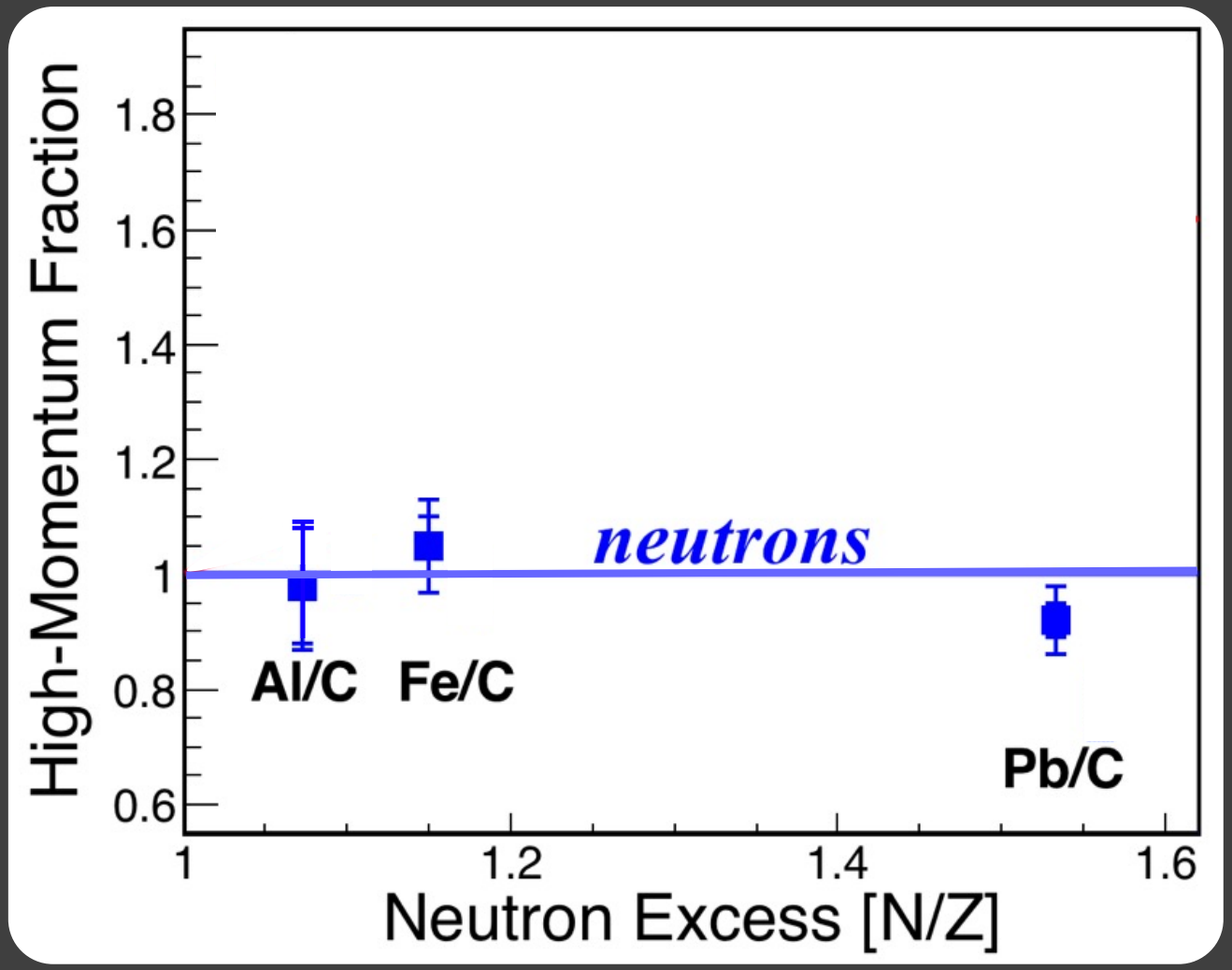


Wiringa, PRC (2014); Carlson, RMP (2015); …

Comparing Proton & Neutron Dynamics

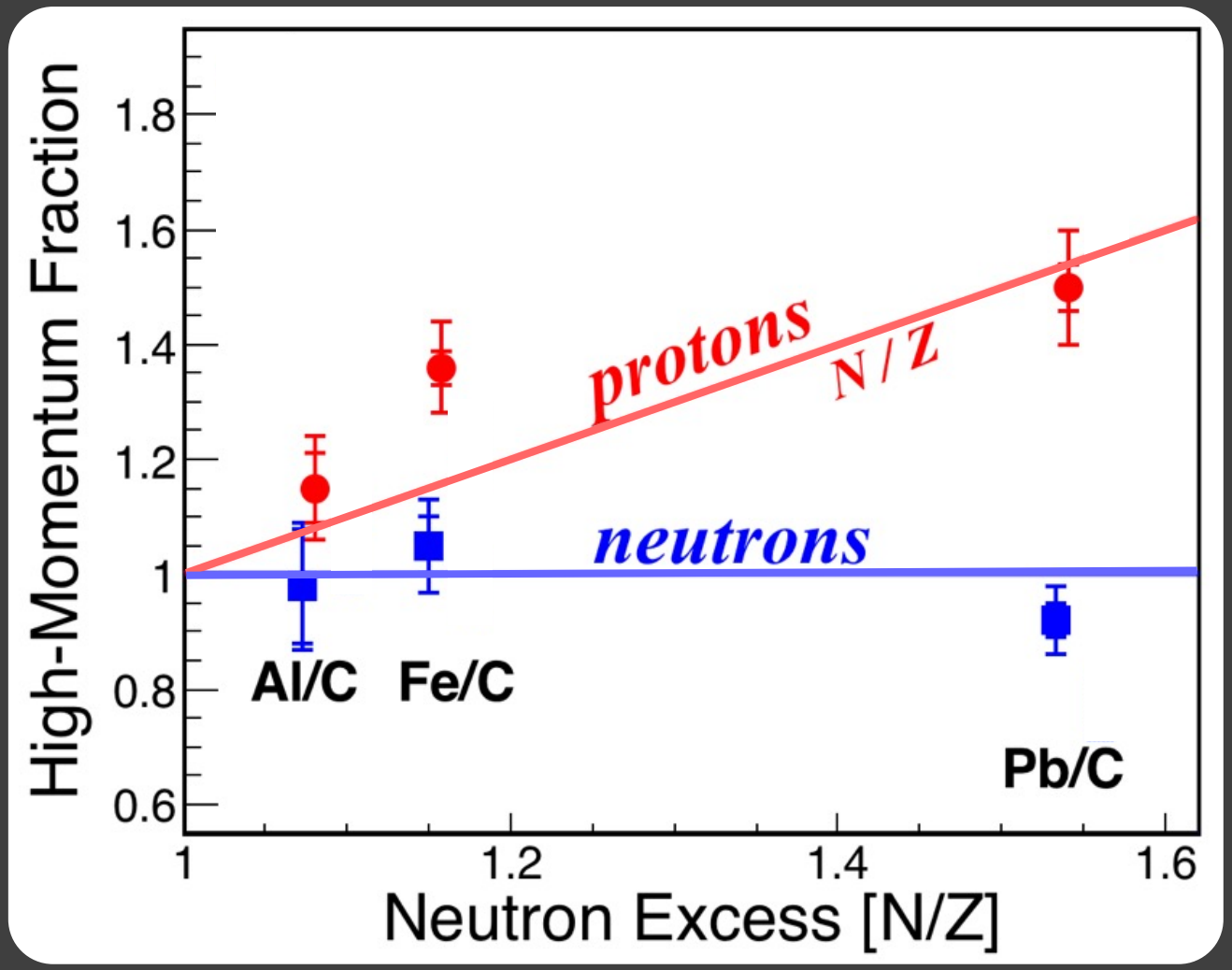


Correlation Probability:
Neutrons saturate



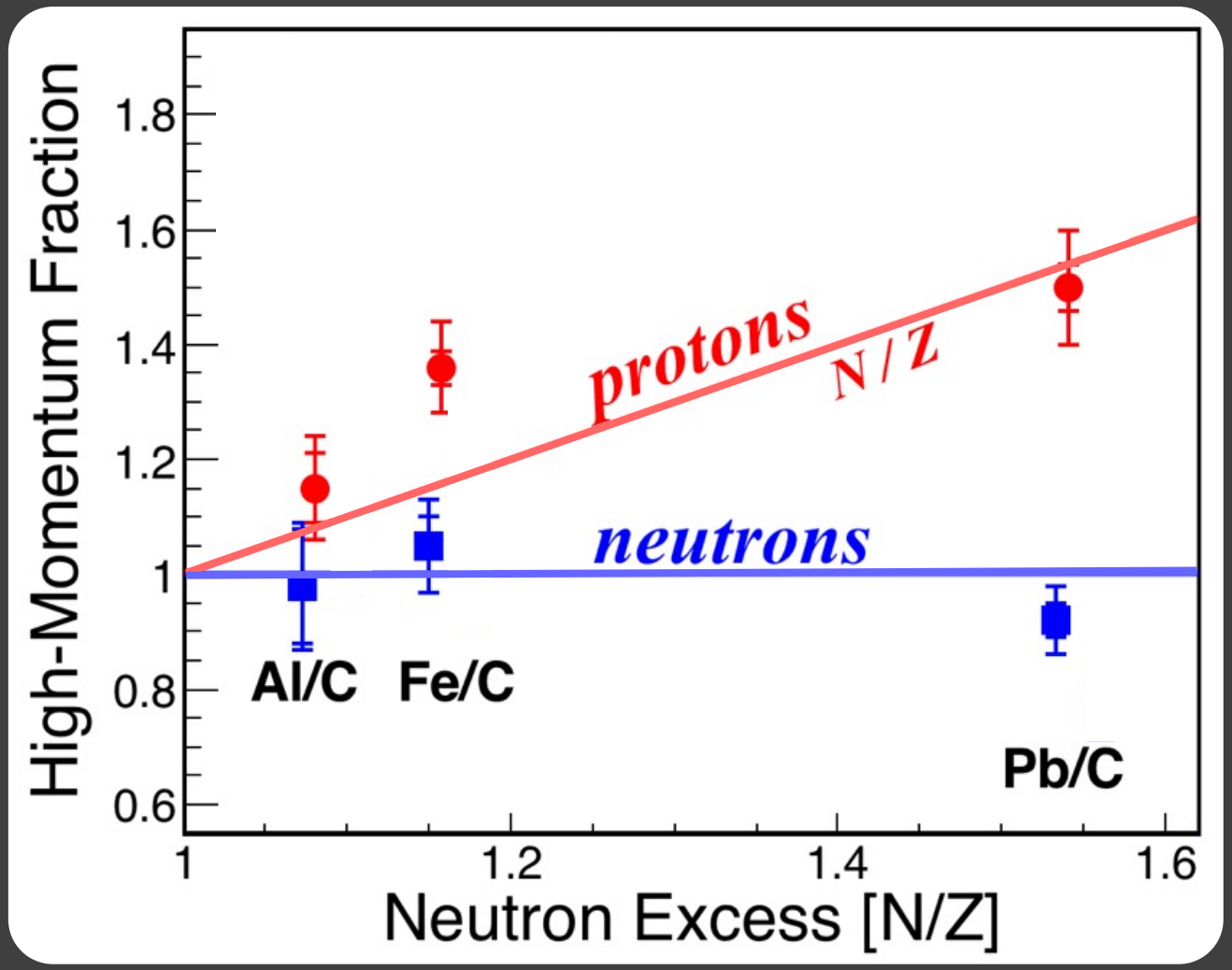
Duer Nature (2018)

Correlation Probability:
Neutrons saturate Protons grow



Duer Nature (2018)

Protons 'Speed-Up' In Neutron-Rich Nuclei



Duer Nature (2018)

Daily Press

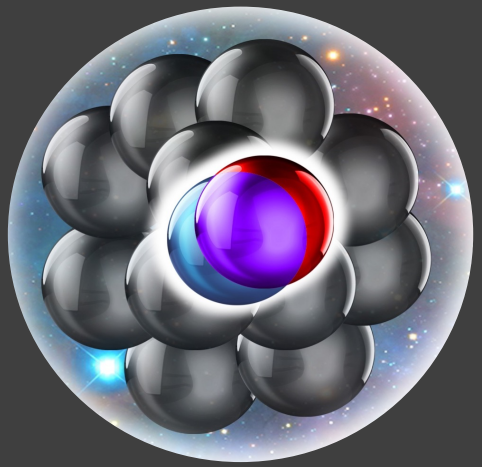
Jefferson Lab breaks new ground, from nucleons to neutron stars

PHYS.ORG

Protons may have an outsize influence on the properties of neutron stars and other neutron-rich objects

Space ANSWERS

Protons strongly influence the behaviour of neutron stars



Astronomy Now

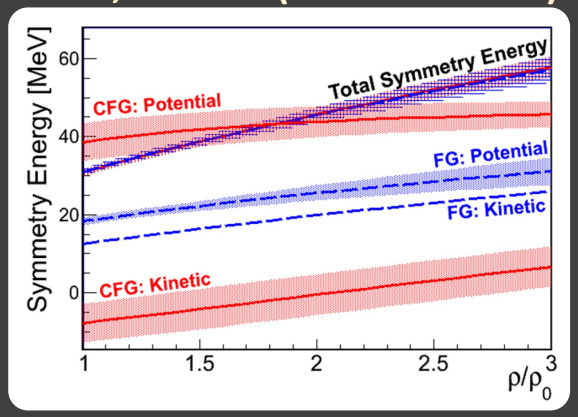
physicsworld

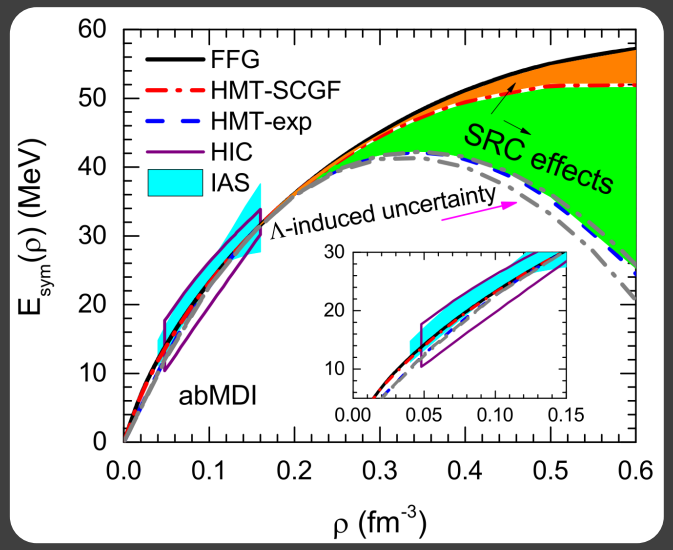
GIZMODO

Surprising Accelerator Finding Could Change the Way We Think About Neutron Stars

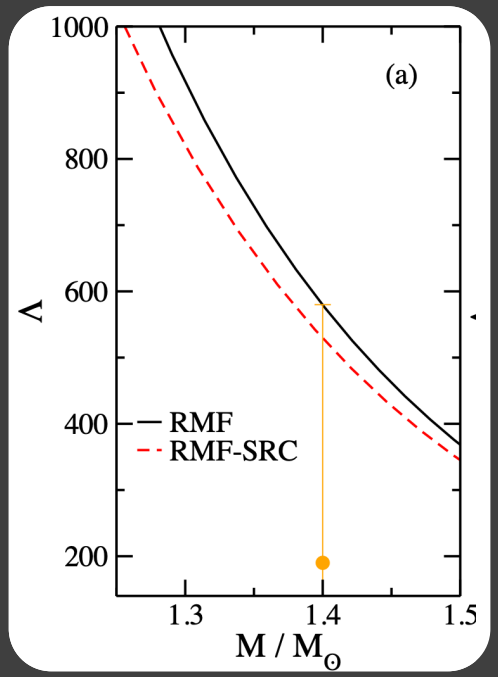
Affects neutron star calculations

Hen+, PRC '15 (>100 citations)

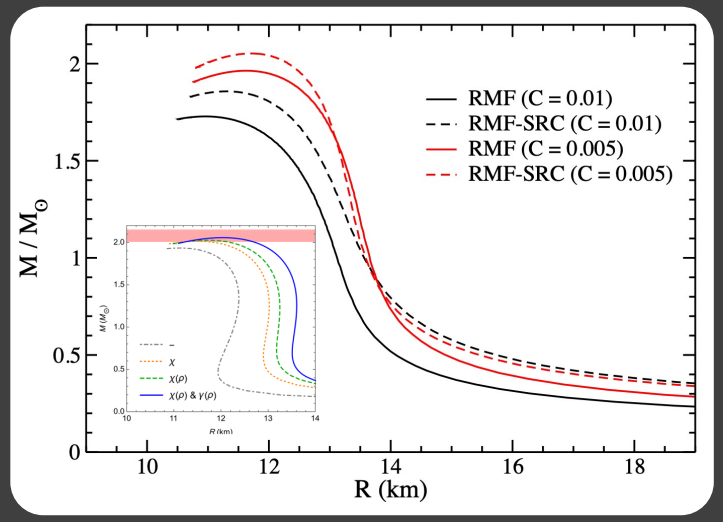


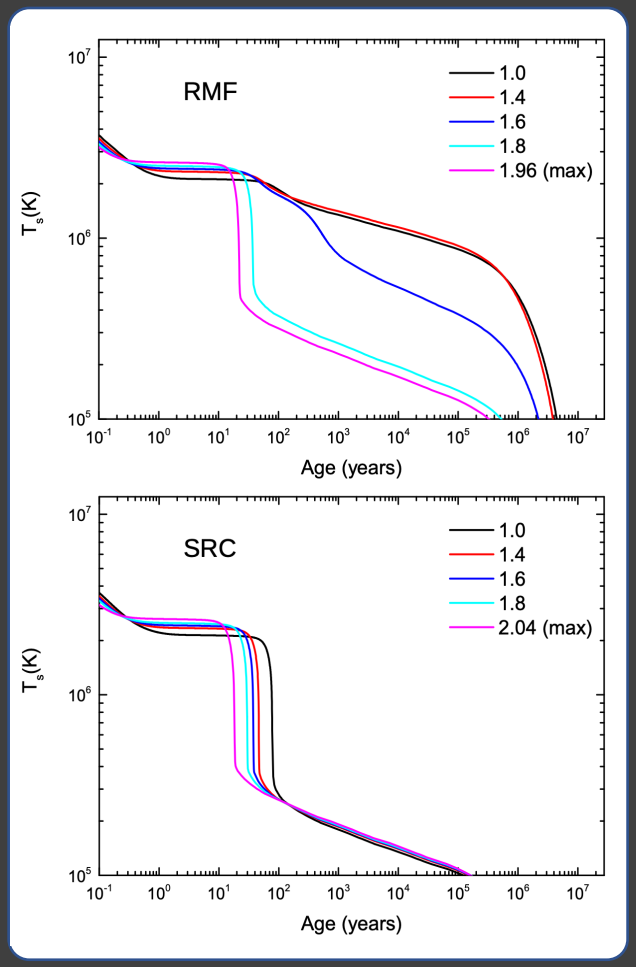


Prog. Part. Nucl. Phys. 99, 29 (2018)
Eur. Phys. J. A 55, 117 (2015)



PRC 101, 065202 (2020)
NPA 990, 118 (2019)





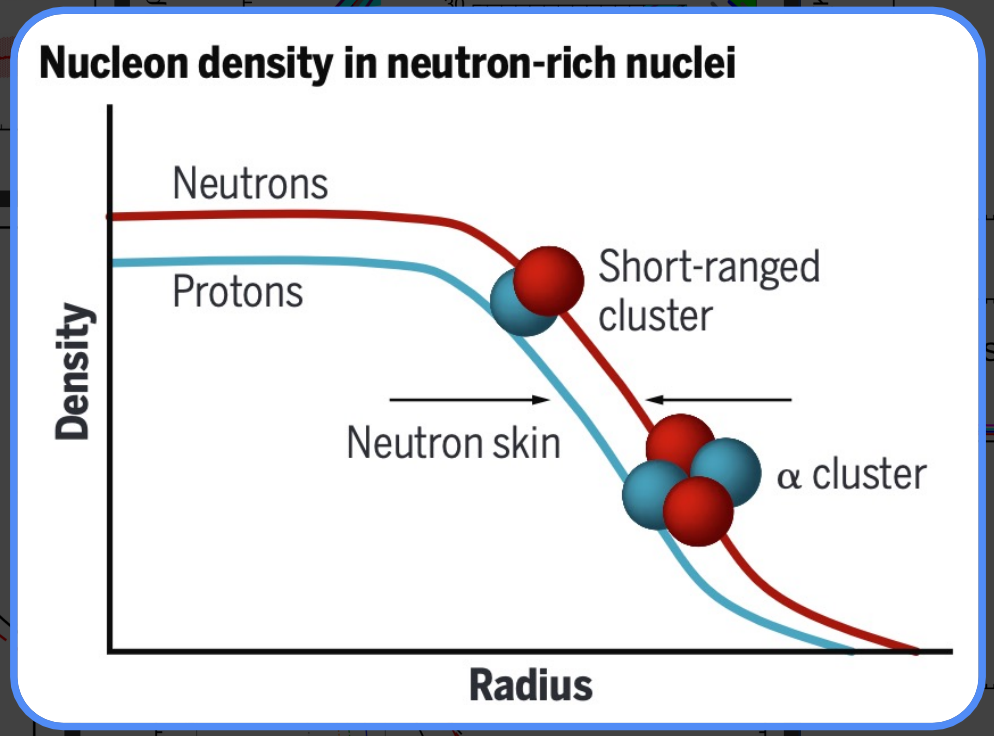
arXiv 2004.10309

INSIGHTS | PERSPECTIVES

Science AAAS

NUCLEAR PHYSICS

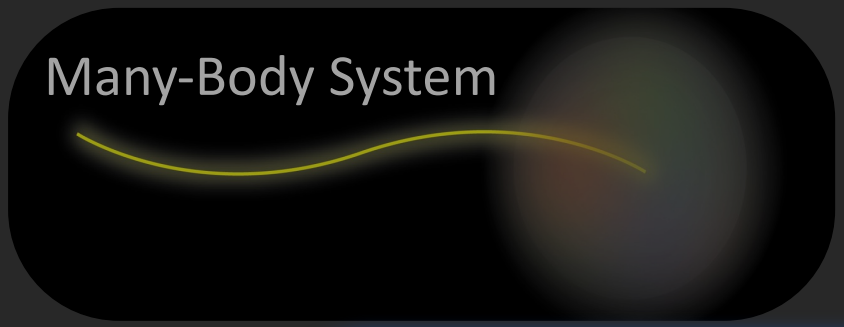
From nuclear clusters to neutron stars



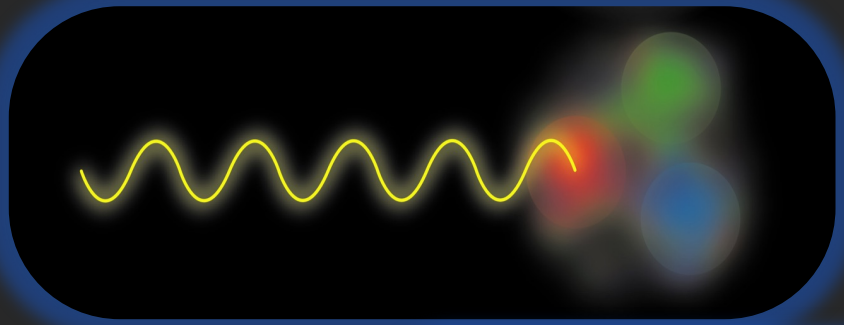
Hen, Science 371, 232 (2021)
Tanaka et al., Science 371, 260 (2021)
Miller et al., Phys. Lett. B 793, 360 (2019)

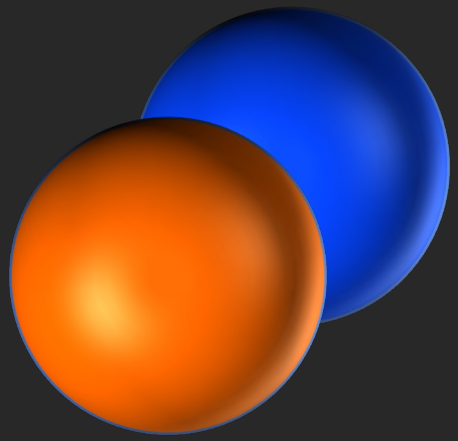
arXiv 2004.10309

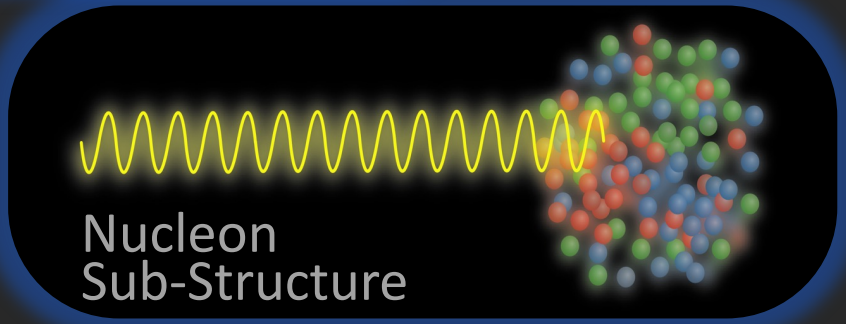
“SRC Lab”



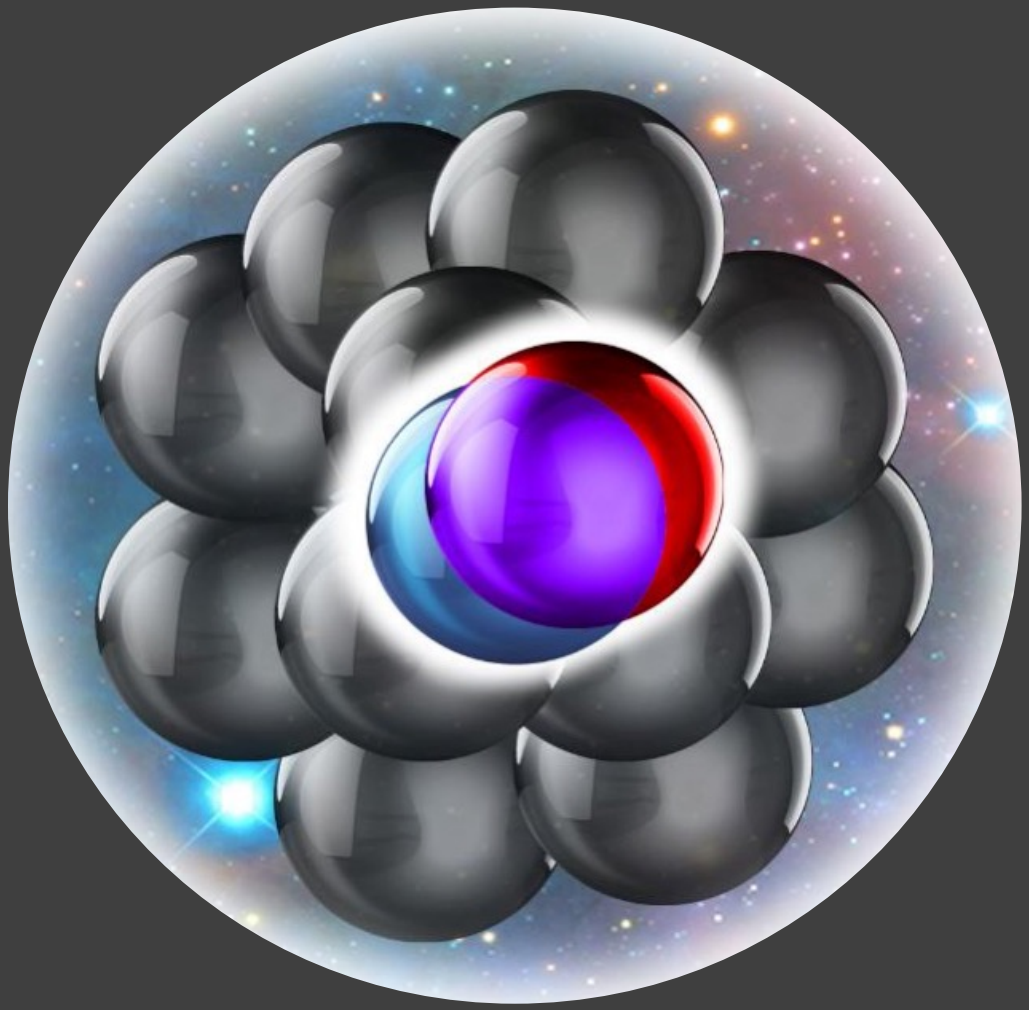
Short-Ranged Interaction

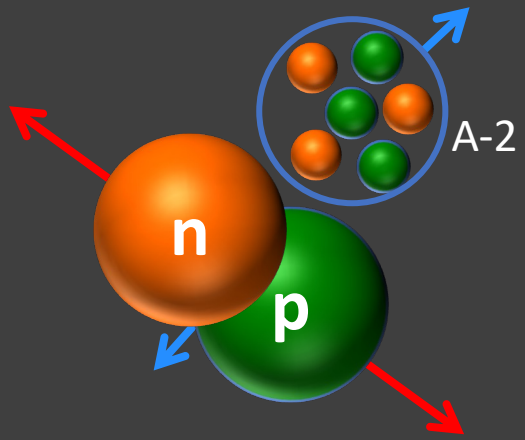






Pairs ⇔ Scale Separation?



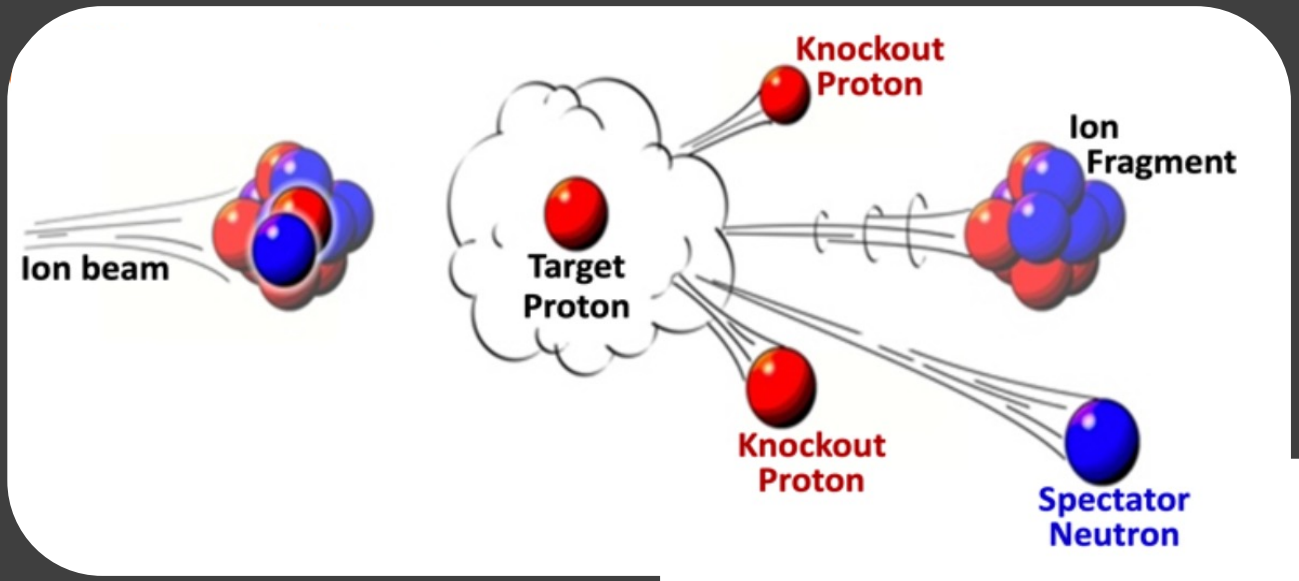


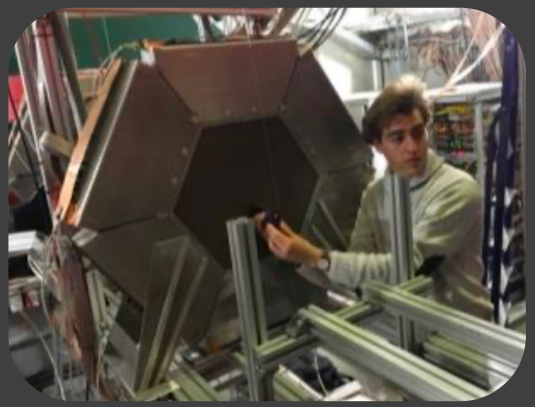
R. Cruz-Torres et al., Nature Physics (2021)
R. Weiss et al., Phys. Lett. B 780 (2018)
J.-W. Chen, W. Detmold, J. E. Lynn, A. Schwenk, PRL 119 (2017)
R. Weiss, B. Bazak, N. Barnea, Phys. Rev. C 92 (2015)

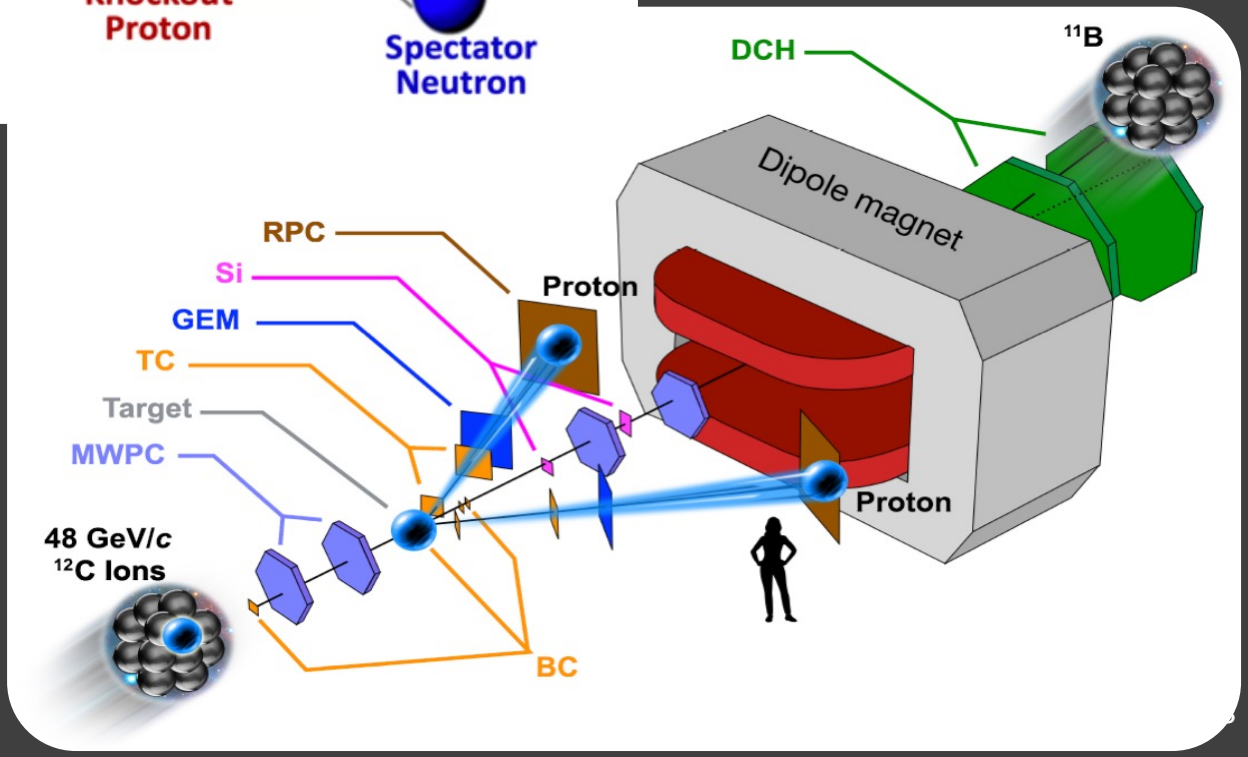
Experimental Signature: no correlation between relative & c.m. motions

C. Ciofi degli Atti, Phys. Rep. (2015)

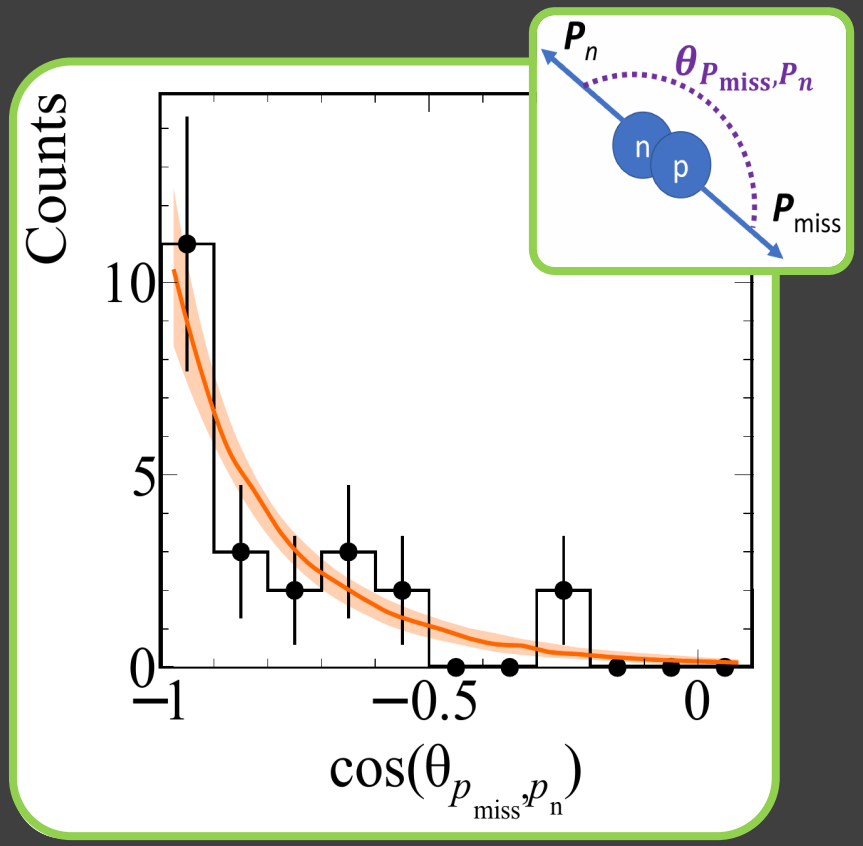
Inverse Kinematics Measurement



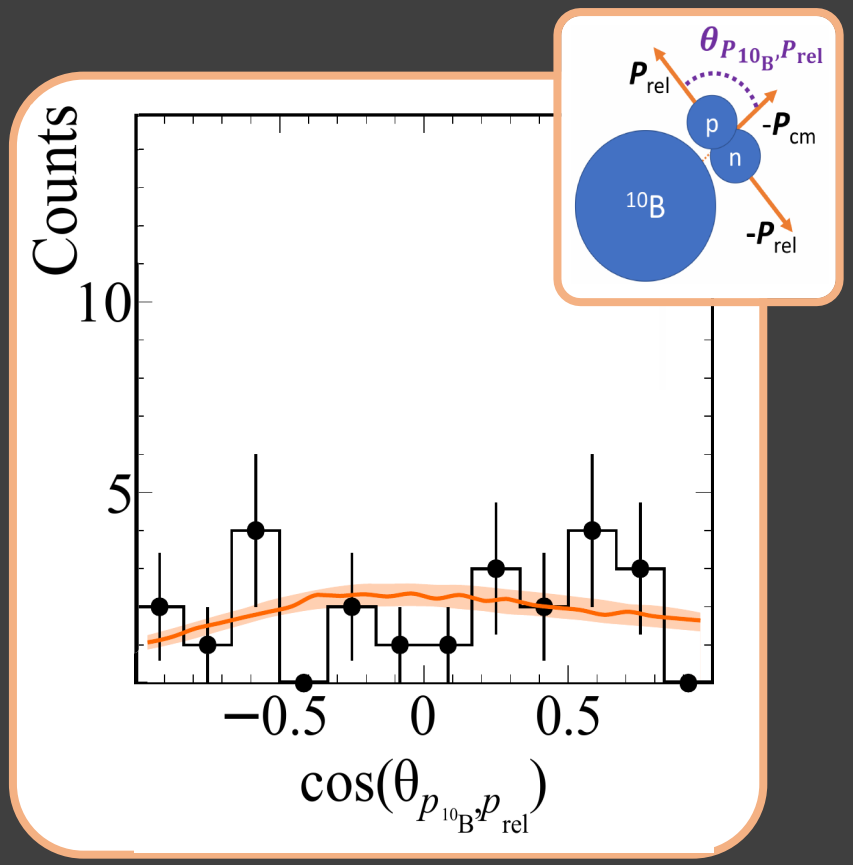




Correlated pairs

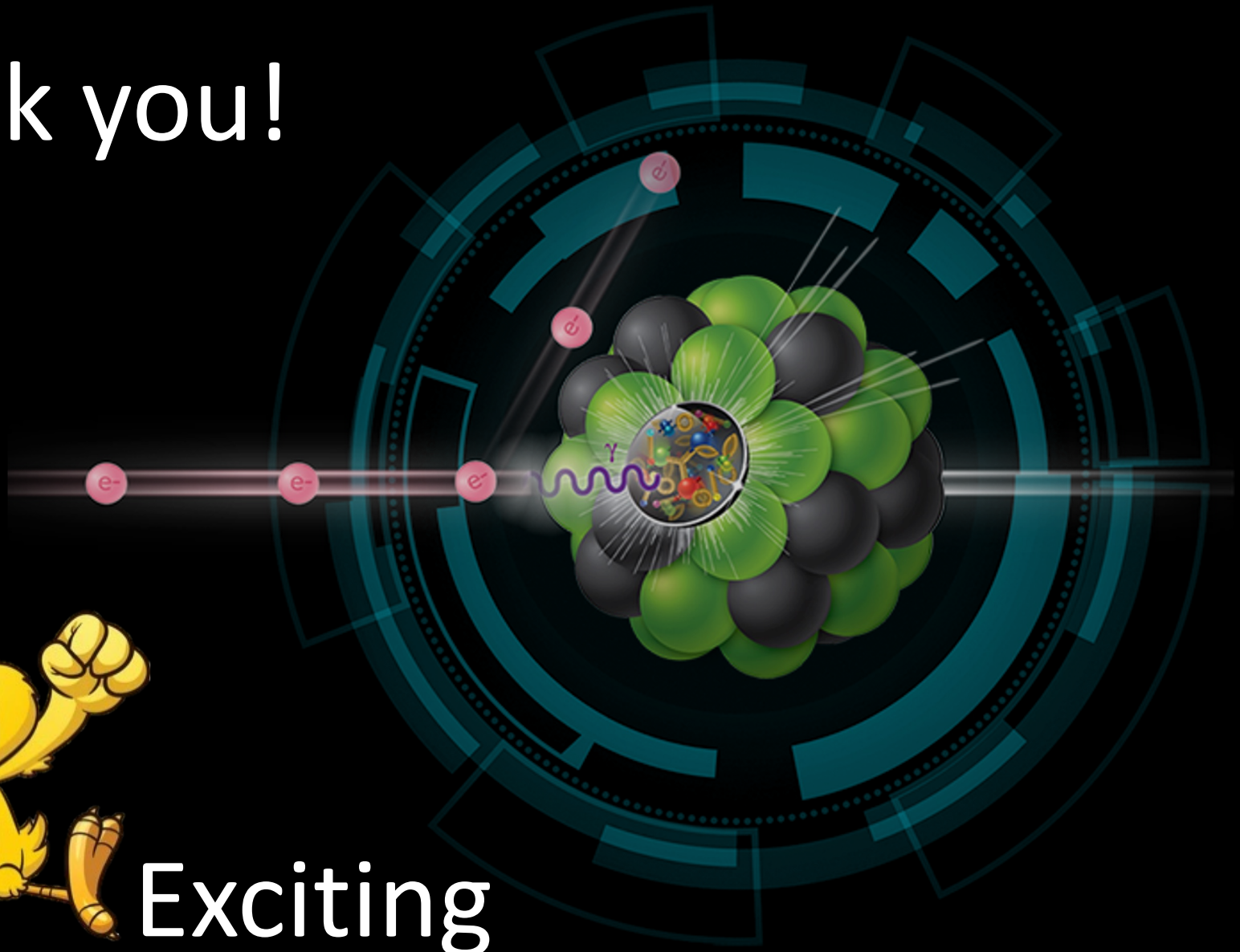


A-2 Factorization



Patsyuk and Kahlbow et al.,
Nature Physics 17, 693 (2021)

Thank you!



Exciting
Times Ahead!