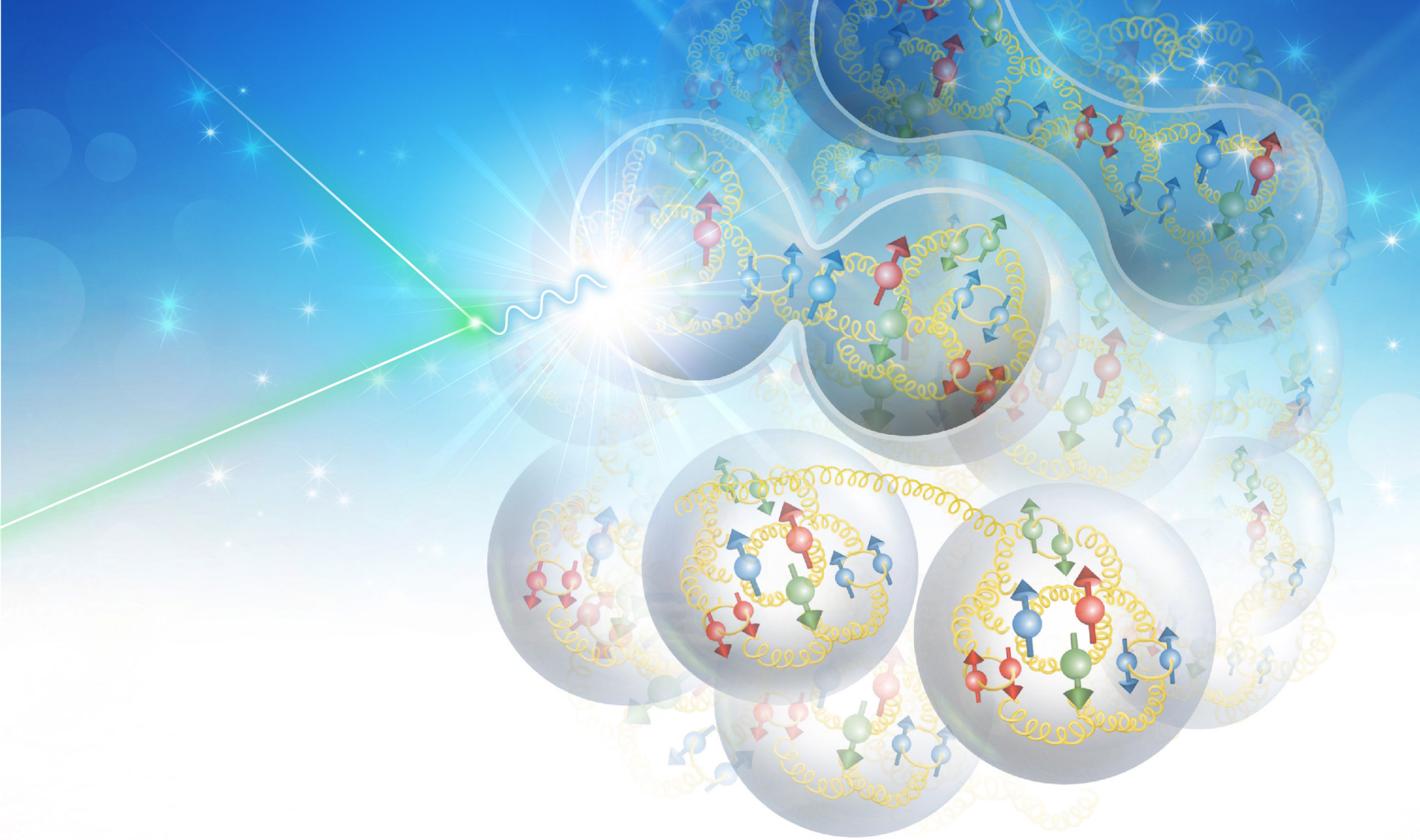


Hampton University Graduate School (HUGs)

June 2022, JLab, Newport News, VA.

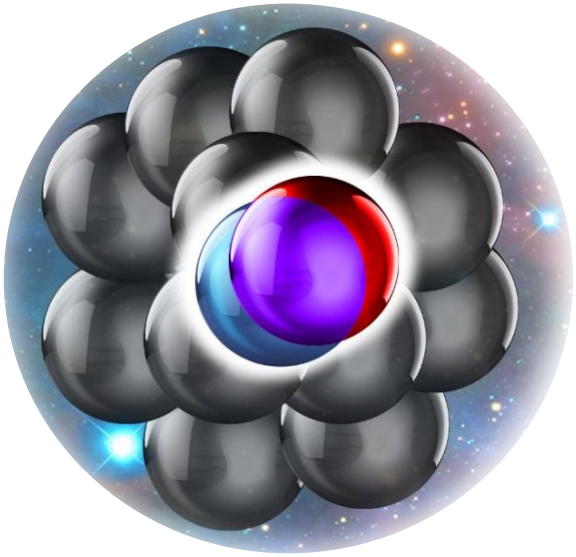
Lecture3:

- Introduction to Short Range Correlations
- Short-range Correlation Studies
  - (e,e') measurements
  - (e,e'NN) measurement
  - Neutron-rich nuclei

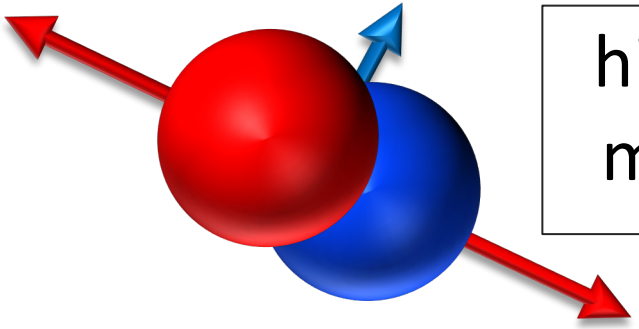
What are Short Range Correlations (SRCs) ?

r-space

Nucleon pairs that are close together in the nucleus



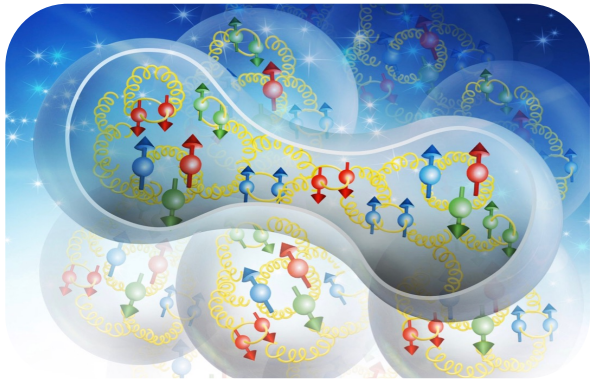
k-space

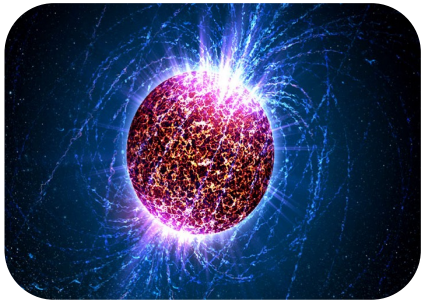


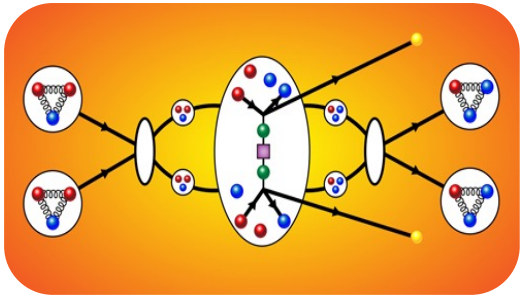
high ***relative*** and lower ***c.m.*** momentum compared to k_F

Why SRC?

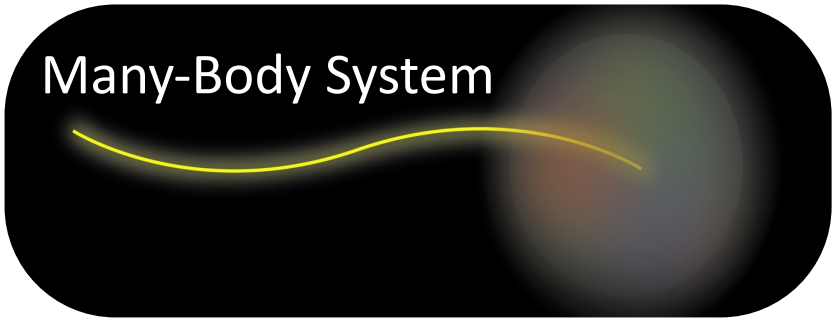
Required for a high-resolution, first principle, description of nuclear systems & processes.

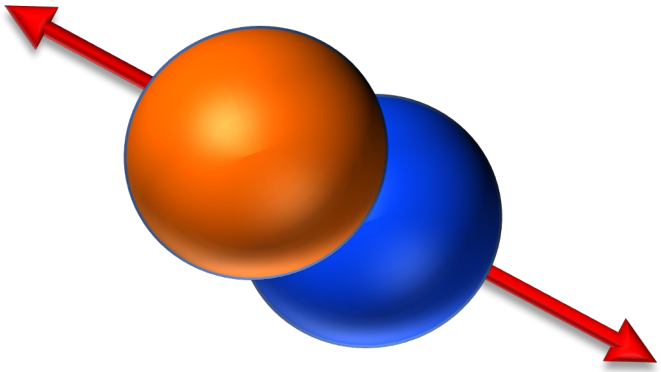


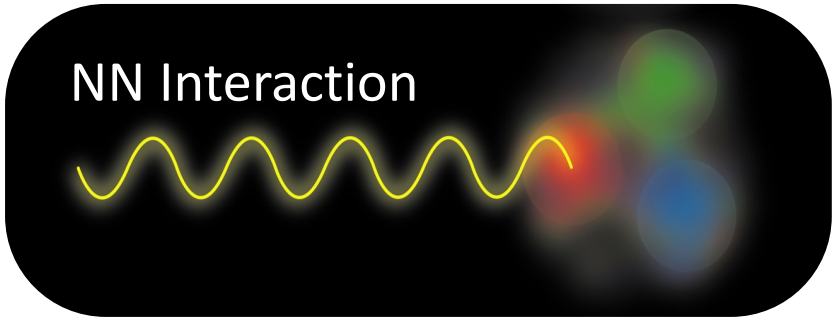


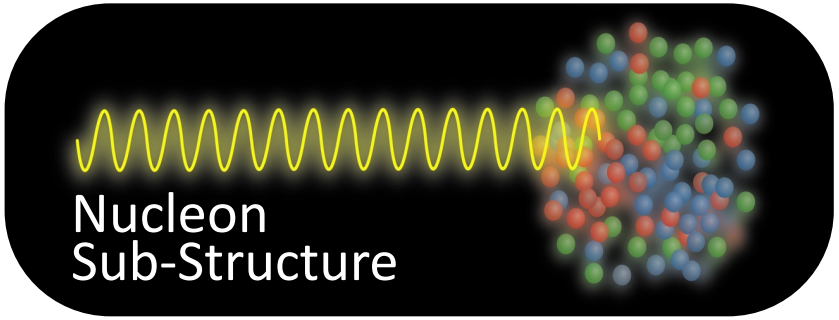


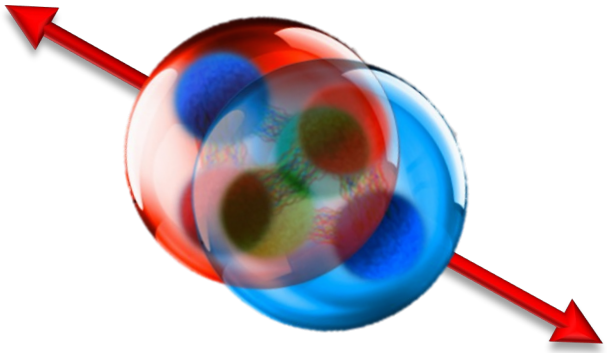
SRCs cross scales



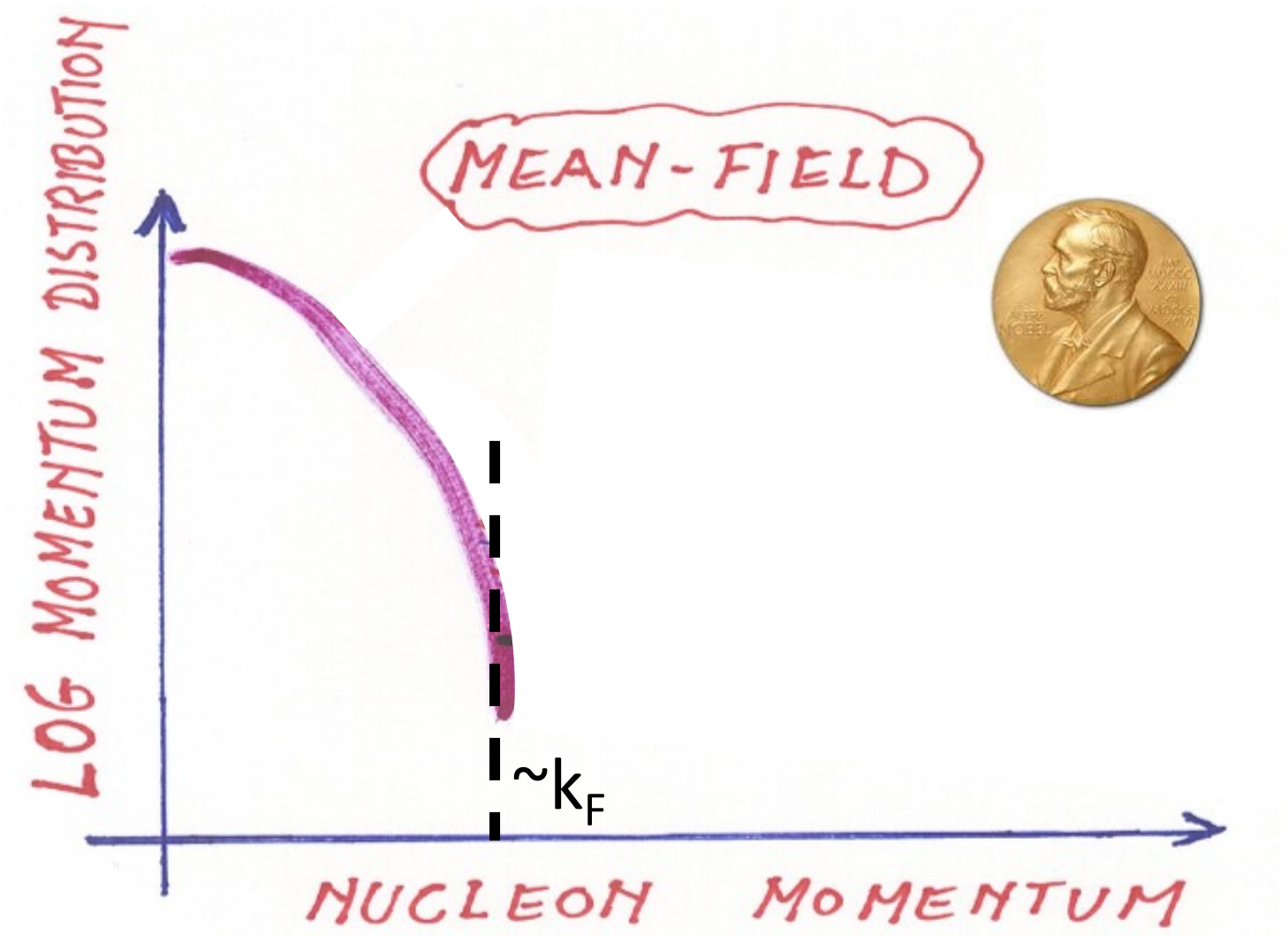


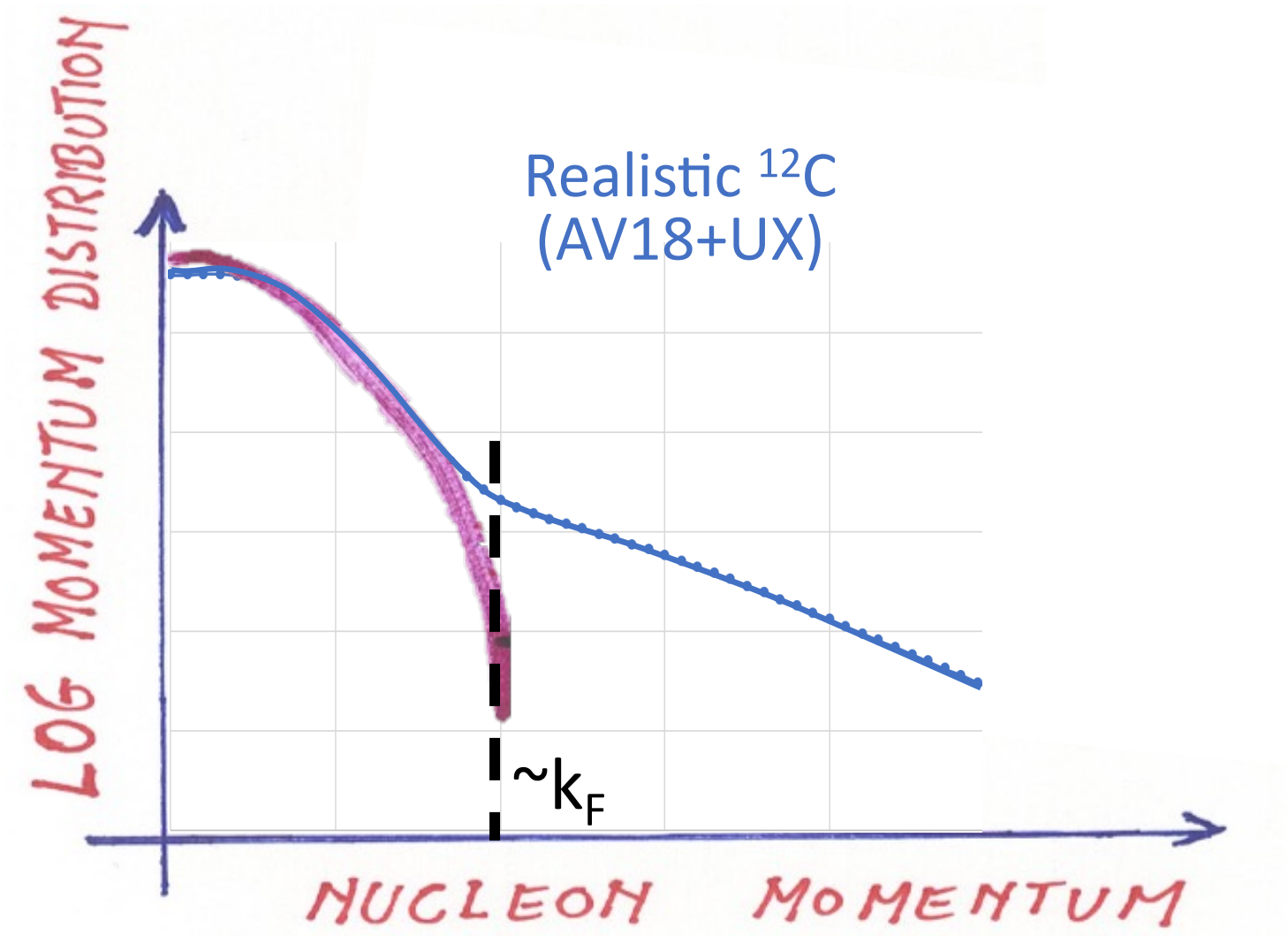




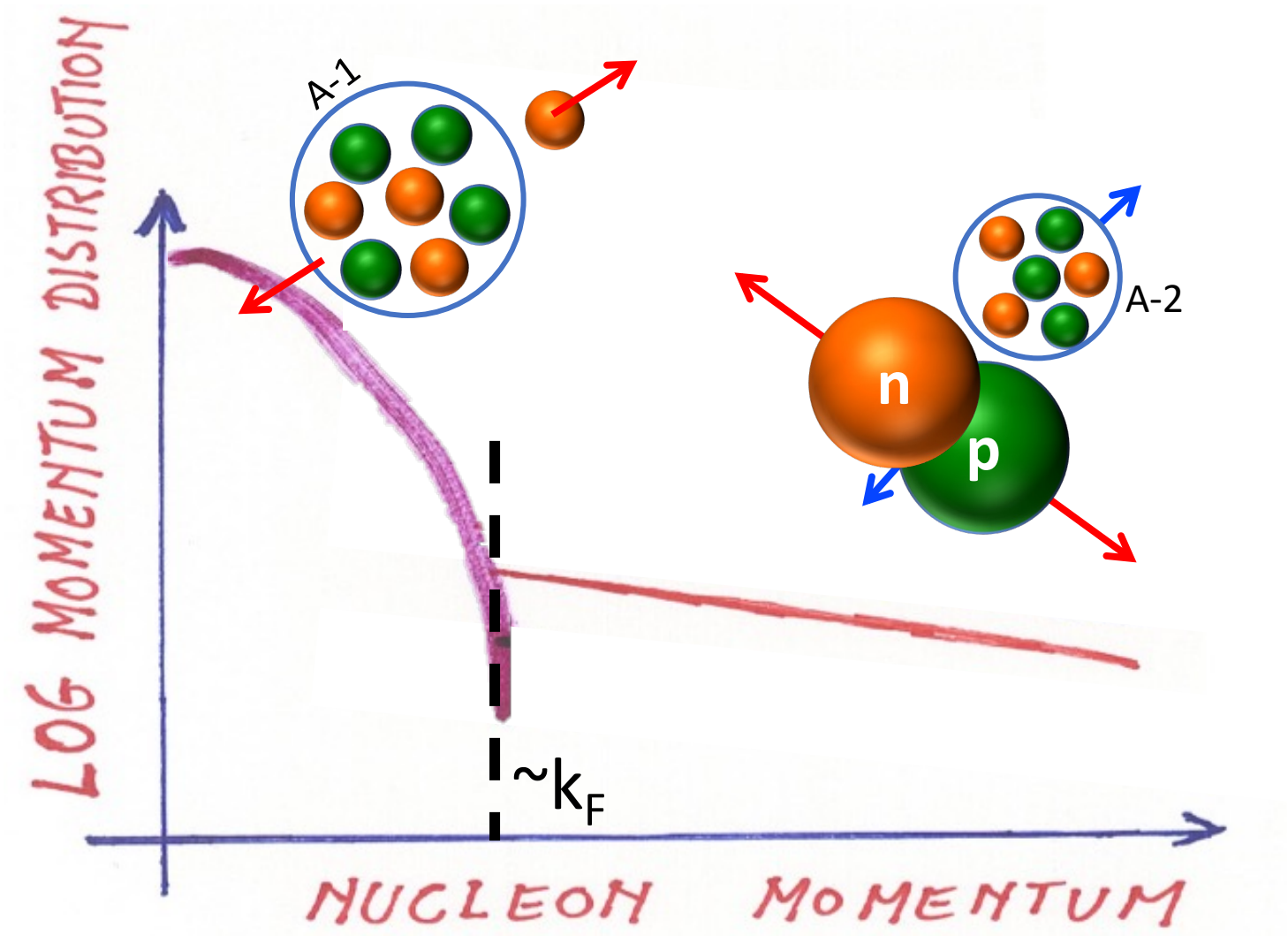


Looking For Correlations

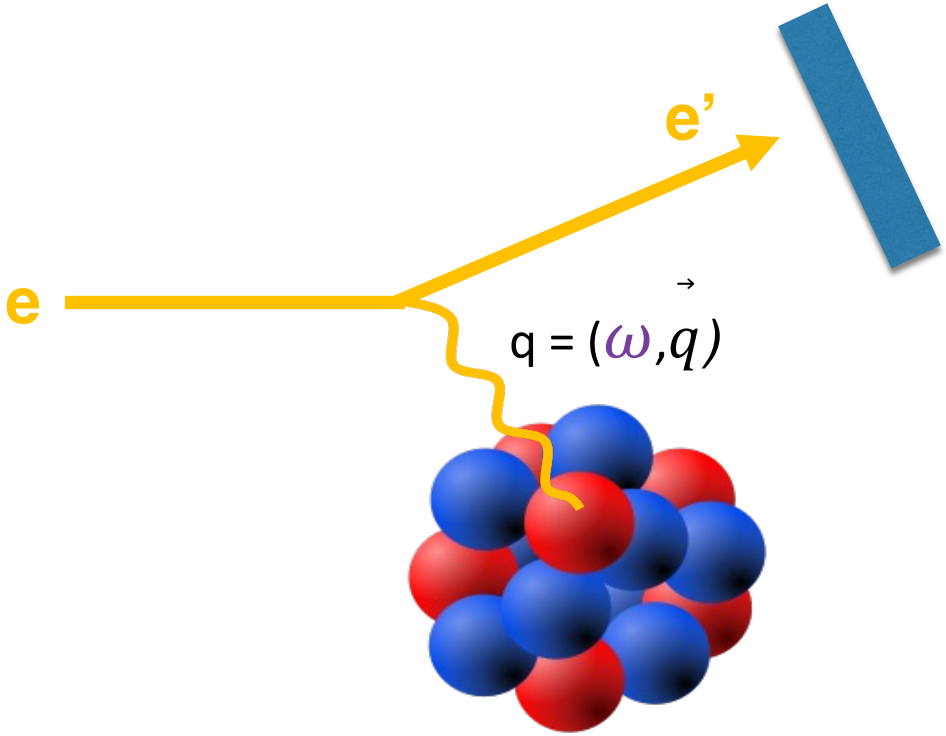




Wiringa, PRC (2014); Carlson, RMP (2015); …


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

SRCs study using QE inclusive scattering (e,e')



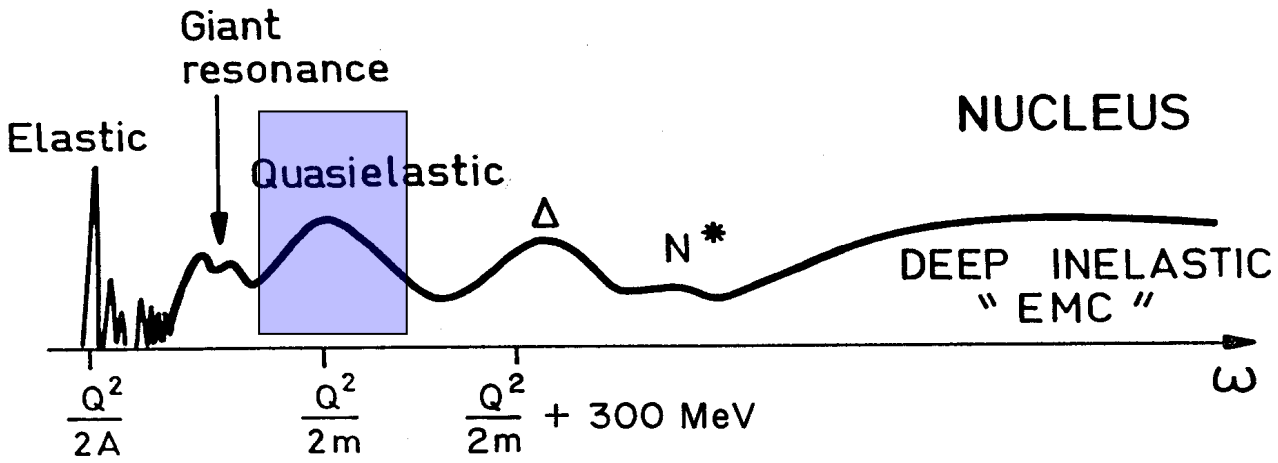
Resolution

4-momentum square

$Q^2 = -q^\mu q_\mu = |\vec{q}|^2 - \omega^2$

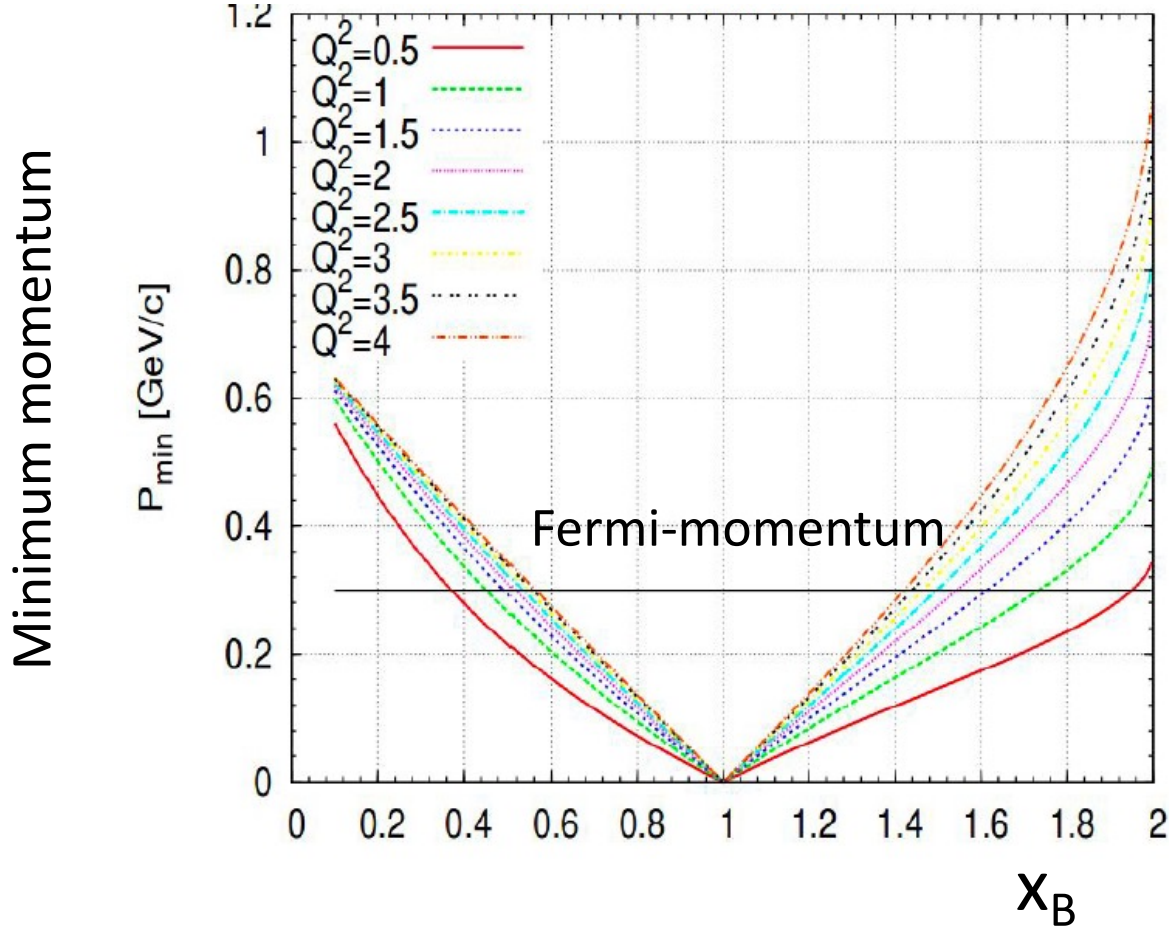
Dynamic: Bjorken-x

$x_b = Q^2/2m_p\omega$



How can we study SRCs?

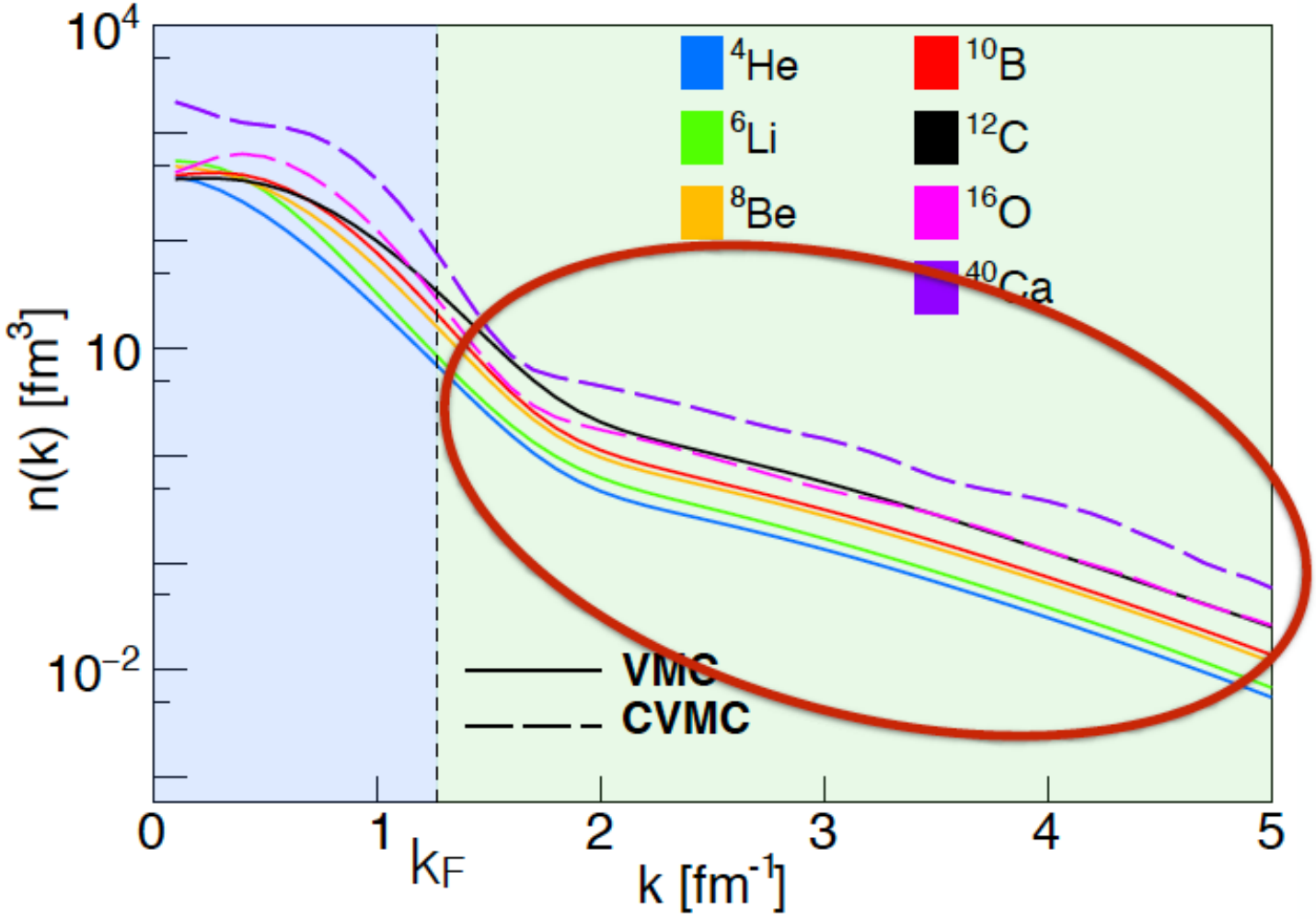
$$(q + p_A - p_{A-1})^2 = p_f^2 = m_N^2$$



SRCs dominate
@ high-x_B & high-Q^2

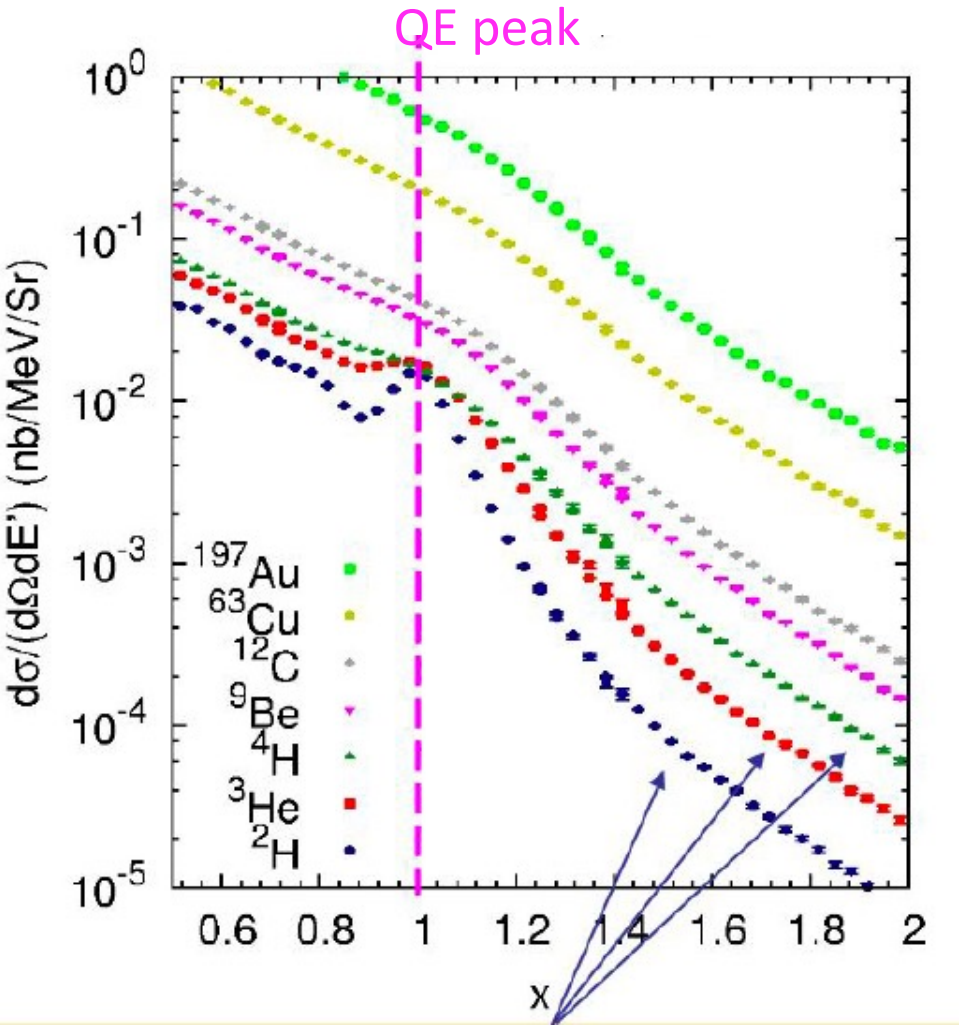
What is the expectation?

Universal High-Momentum Tail



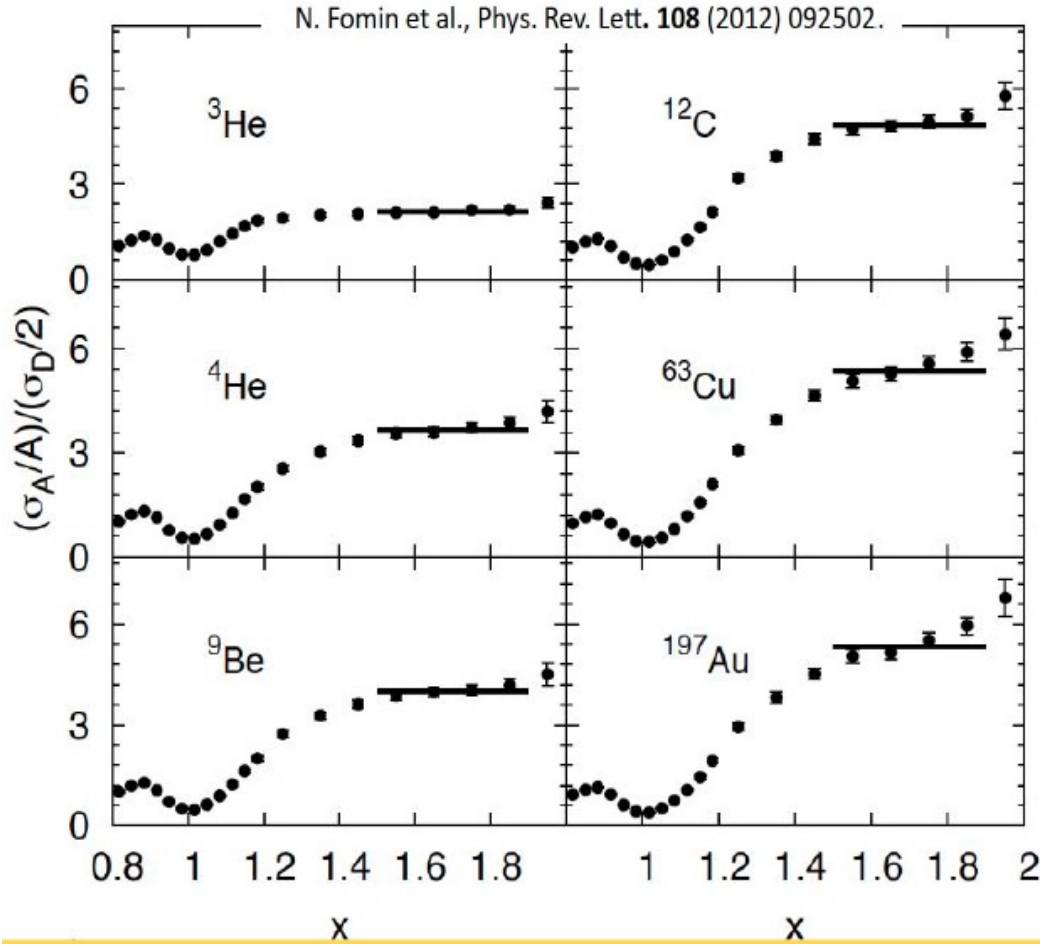
High momentum tail has the same shape, only different by a scaling factor

Inclusive cross section



High momentum tail will yield constant ratio in region where SRCs dominant

High-momentum scaling factors



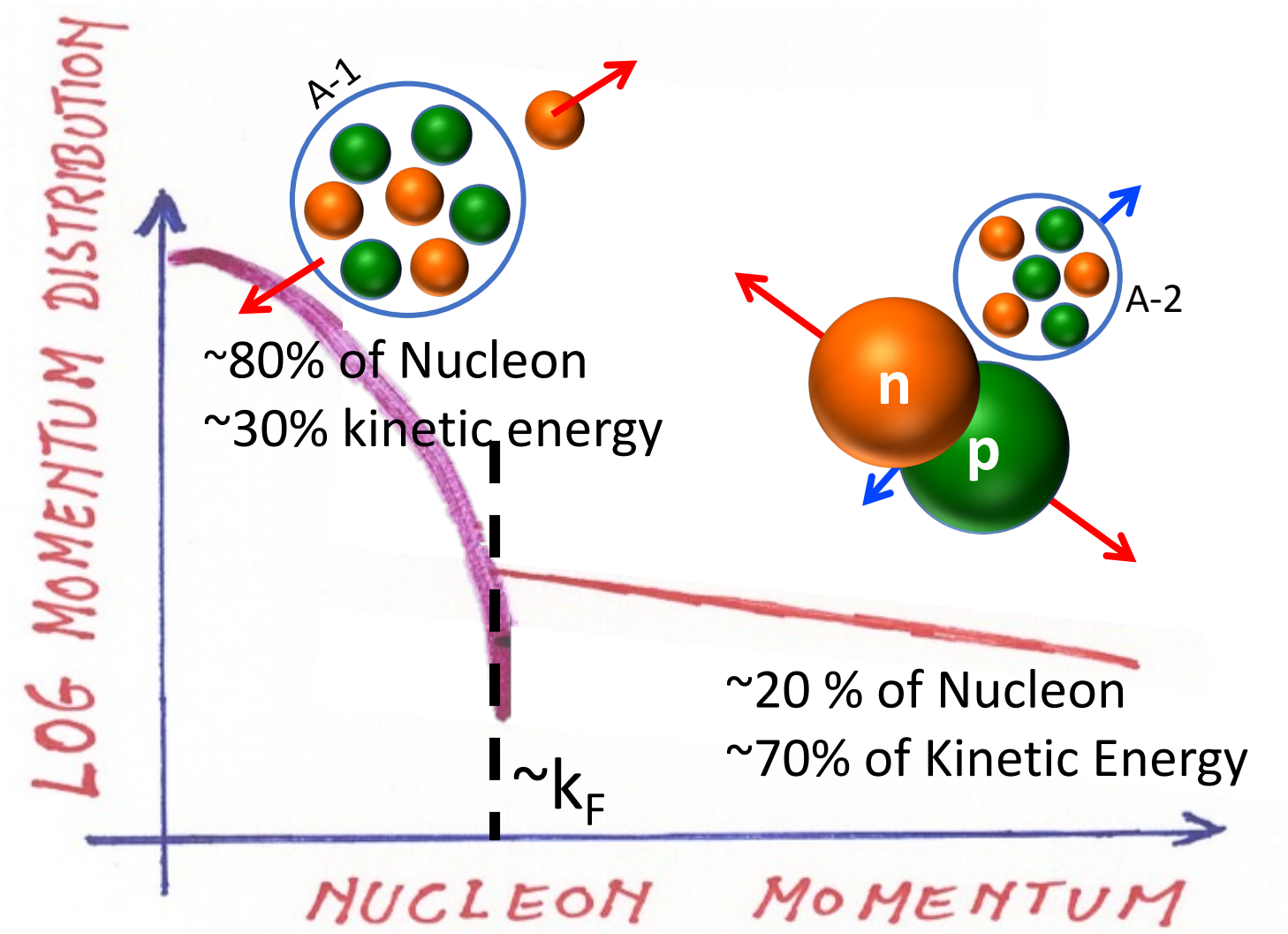
Scaling constant: a_2

$$\sigma_A = a_2 \times \frac{A}{2}\,\sigma_D$$

Relative probability of finding SRC pairs in different nuclei compared to the Deuterium

Schmookler Nature (2019), Fomin PRL (2008) , Egiyan PRL (2006), Egiyan PRC (2003), L. L. Frabkfurt, PRC (1993)

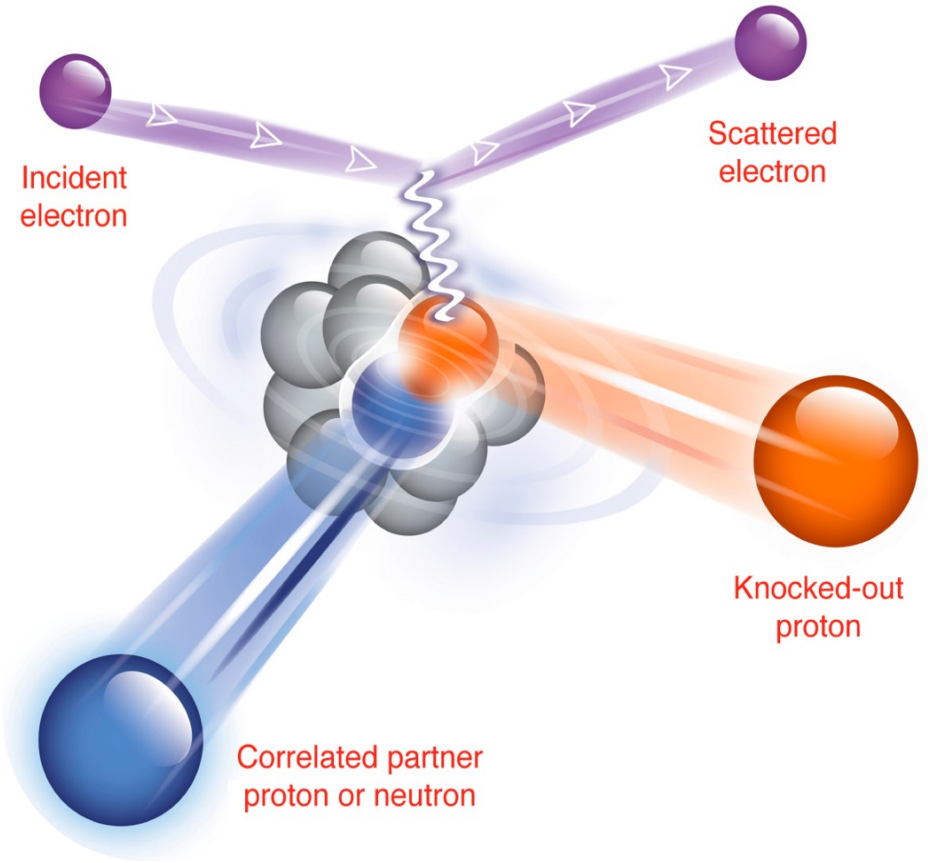
SRCs is responsible for high-momentum tail



What are the next questions?

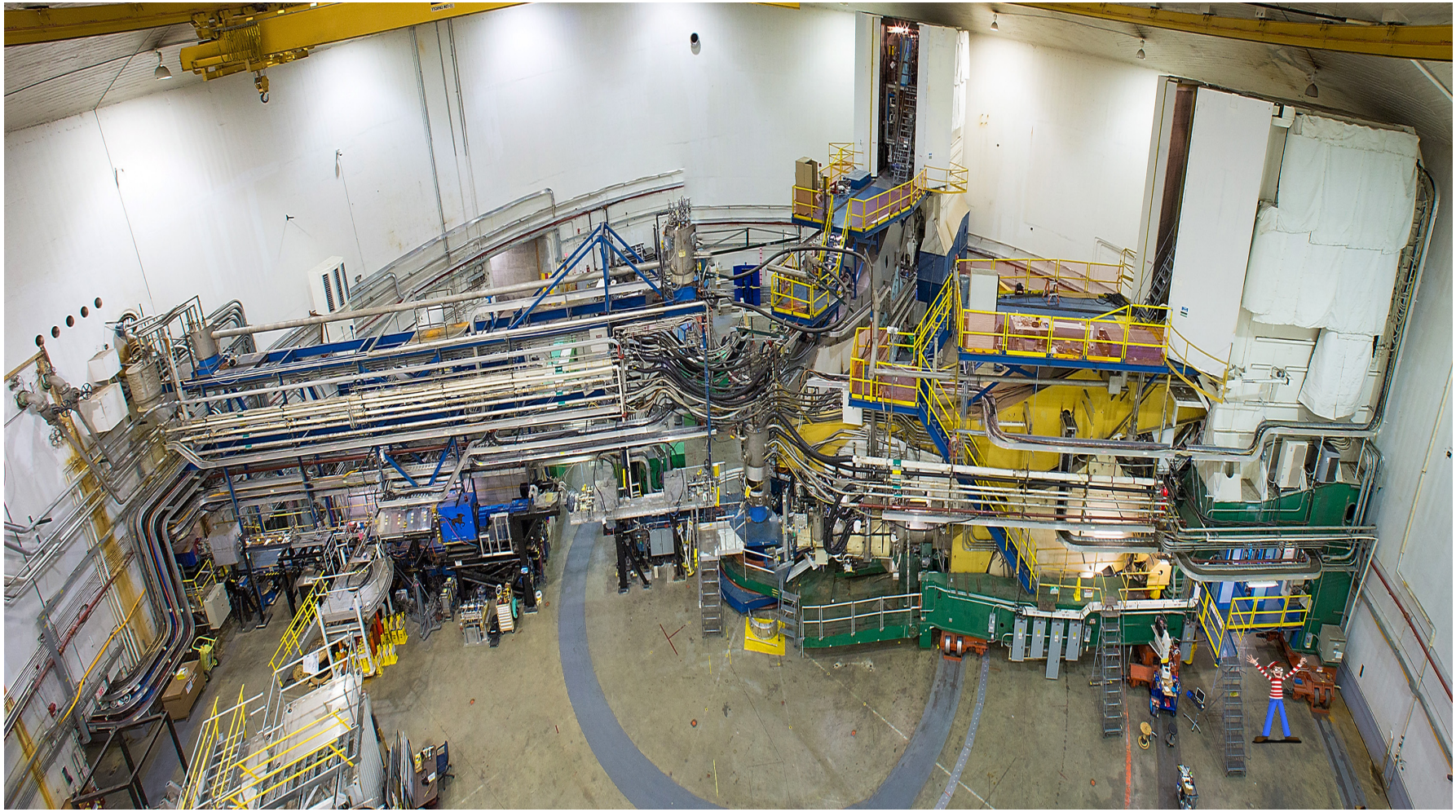
- **What are the properties of SRC?**
- **What about *c.m.* momentum?**
- **What type of pairs?**

Exclusive Two-nucleon knockout studies

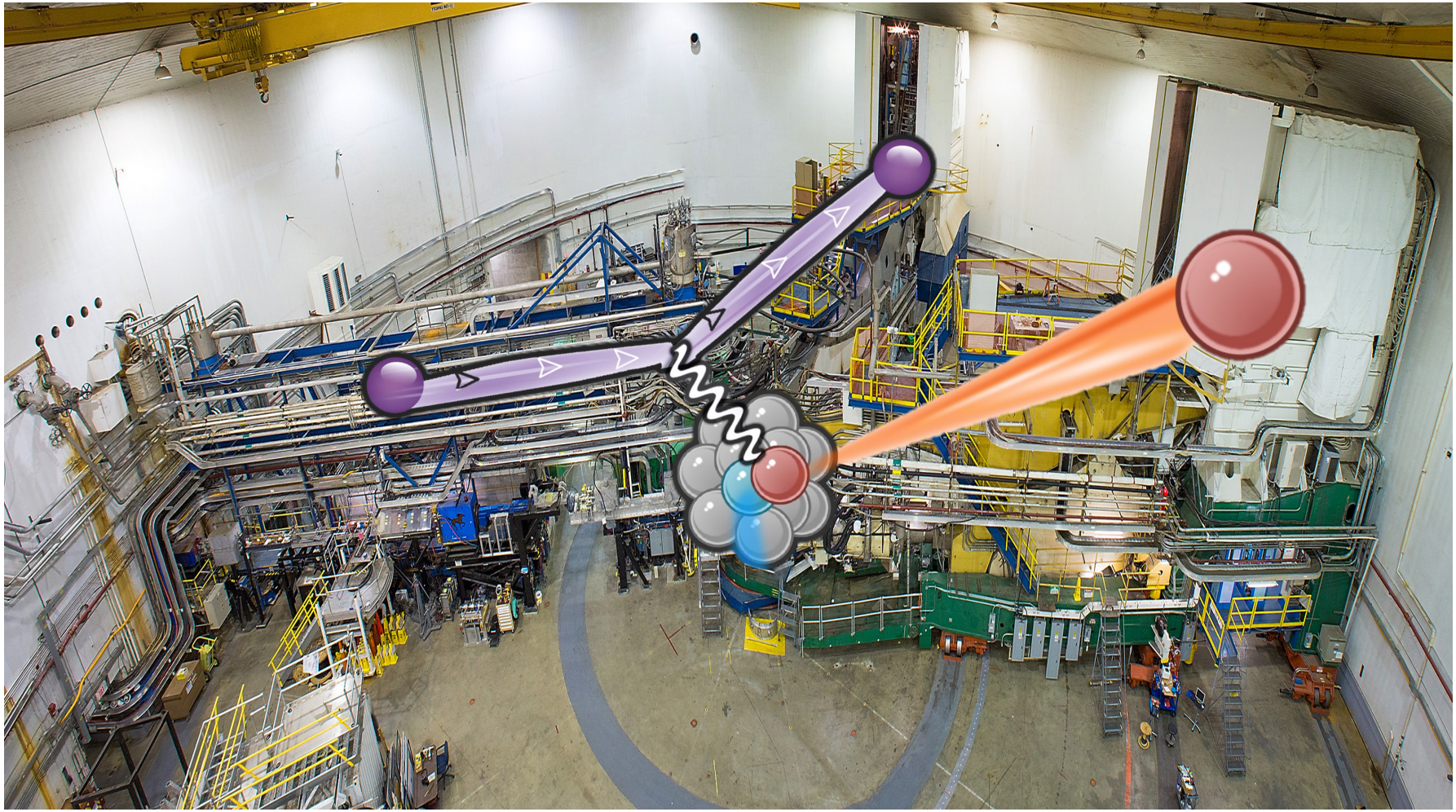


- Breakup the pair and detect both nucleon
  - Looking for High missing-momentum nucleon ($k > k_F$) and recoil partner

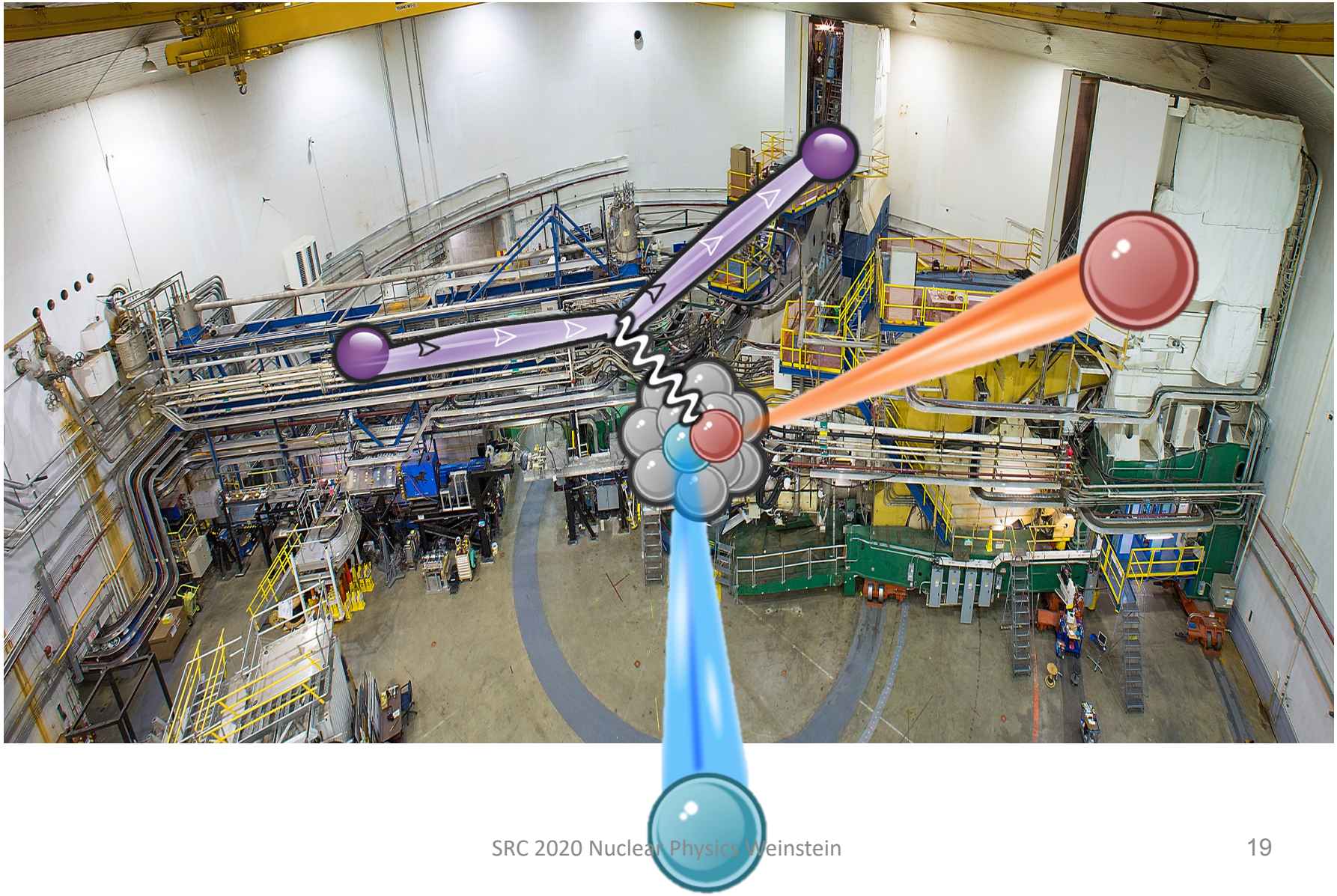
Hall-A: High-Resolution Spectrometers



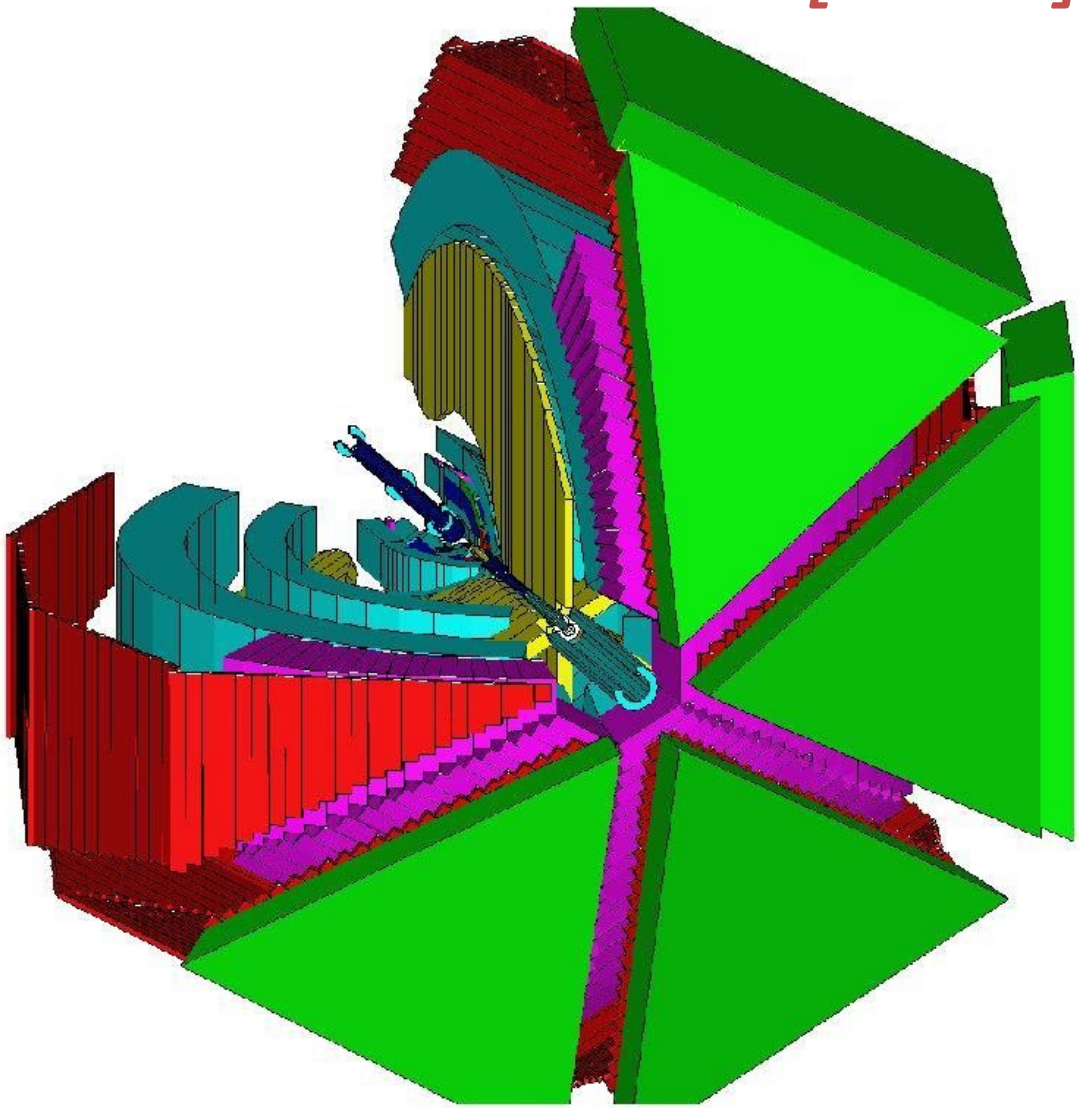
Hall-A: A(e,**e'p**N)

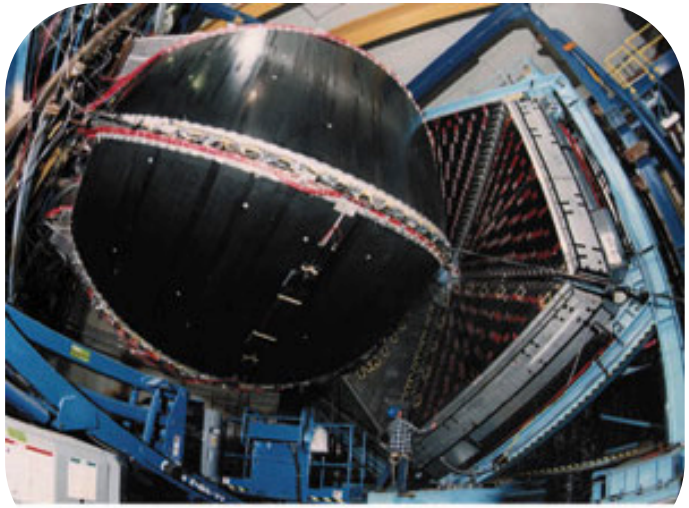


Hall-A: A(e,**e'pN**)



CEBAF Large Acceptance Spectrometer *[CLAS]*

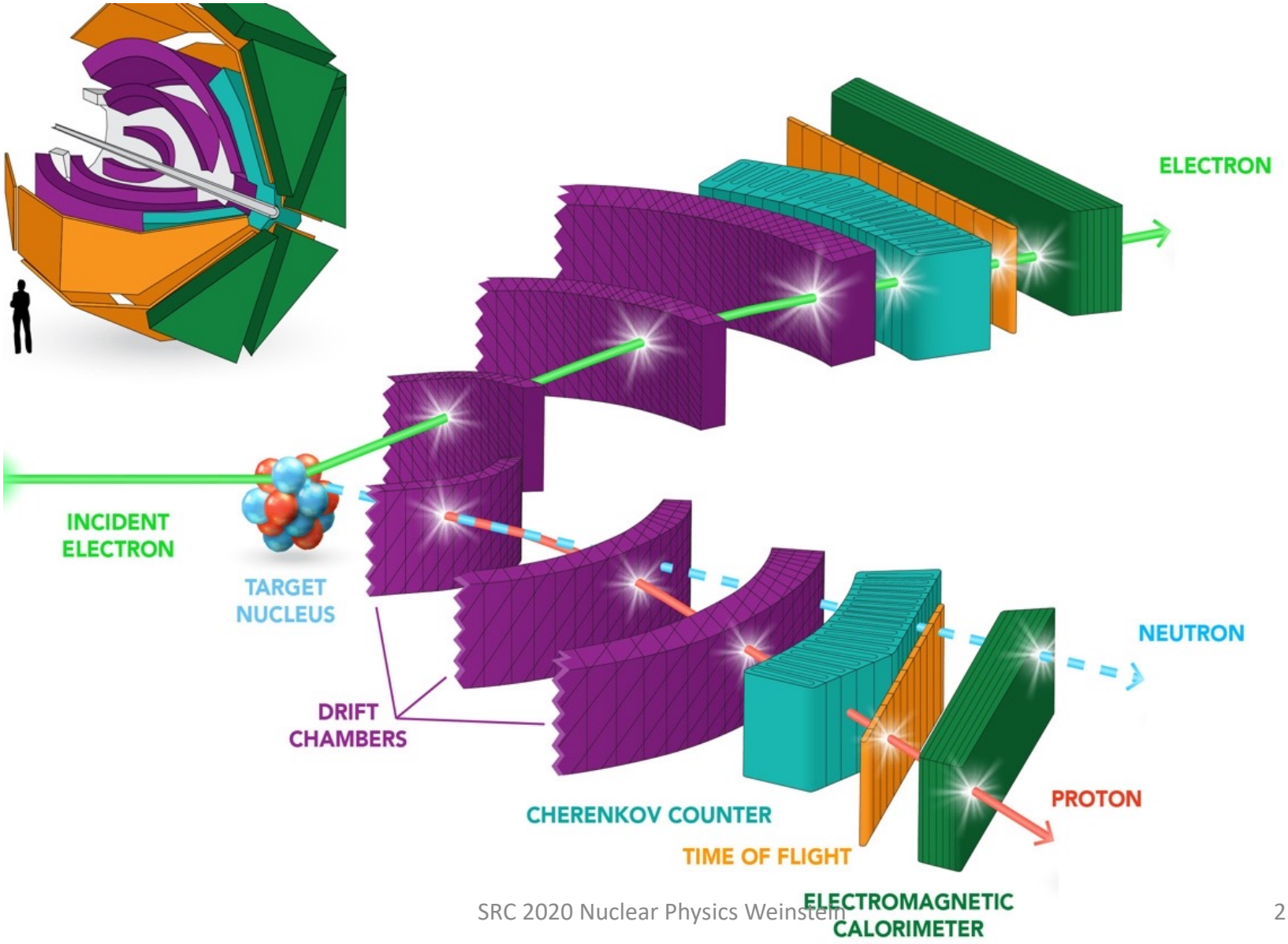




Hall B Large Acceptance Spectrometer

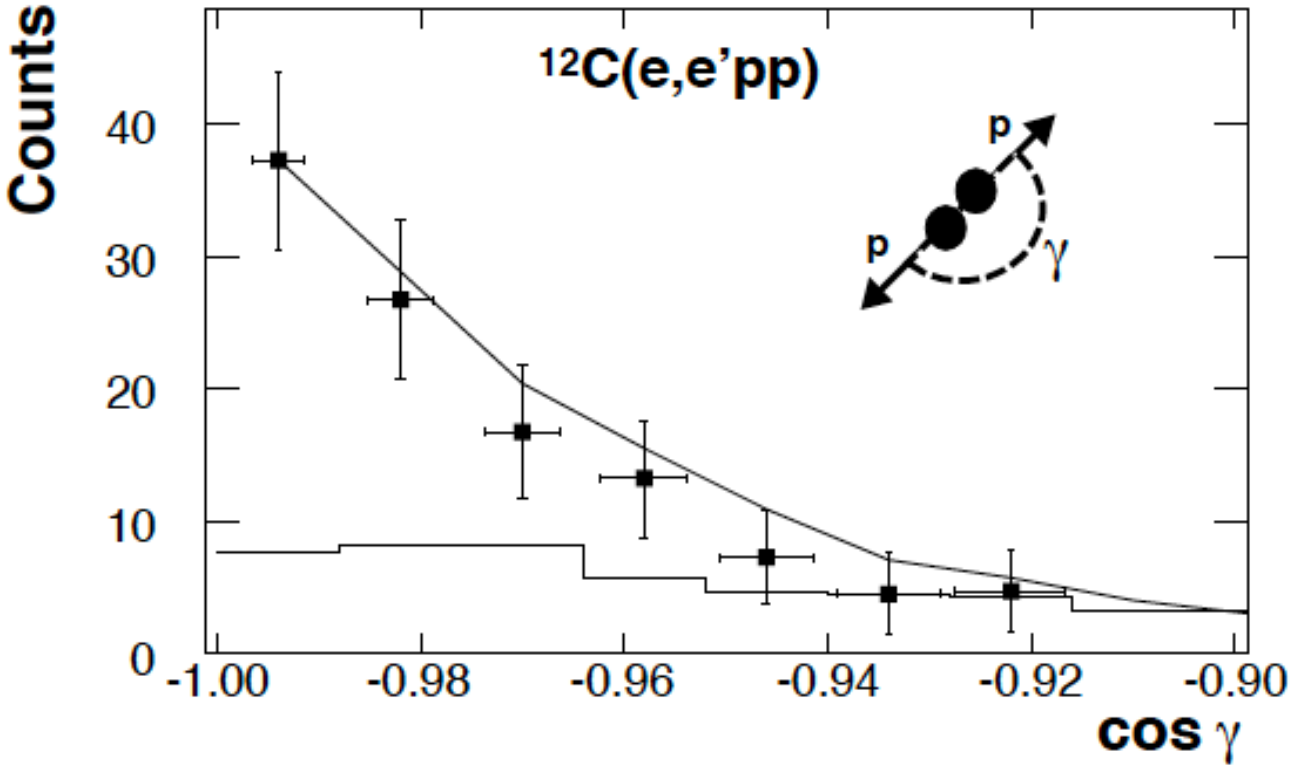
Open (e,e') trigger, Large-Acceptance, Low luminosity (~10^{34} cm^{-2} sec^{-1})

Proton vs. Neutron Knockout



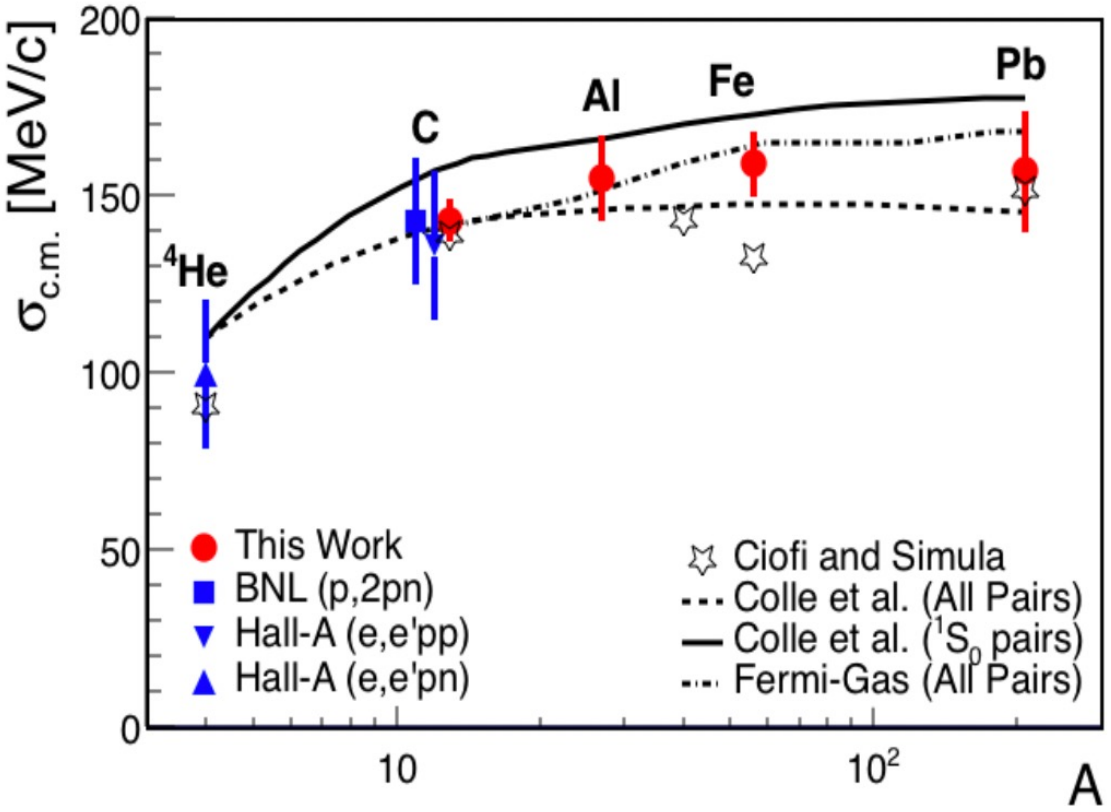
SRCs in 2-nucleon knockout

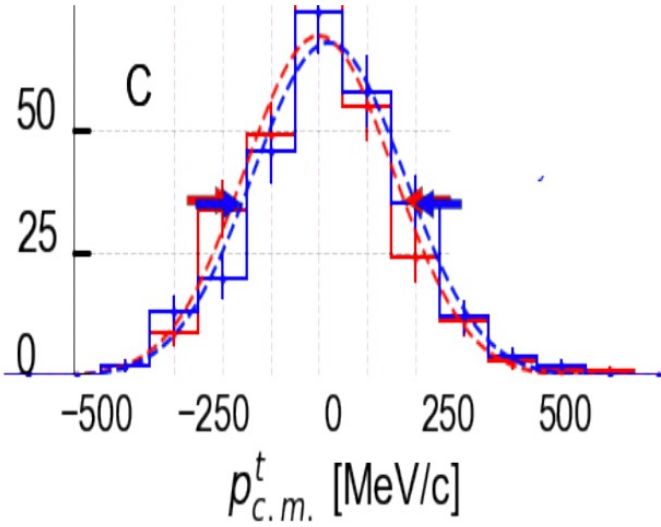
R. Shneor et al., PRL (2007)



Almost all proton with $k > k_F$ in C(e,e'p) have a paired proton or neutron with similar momentum in opposite direction.

The CM momentum distribution of SRCs pairs





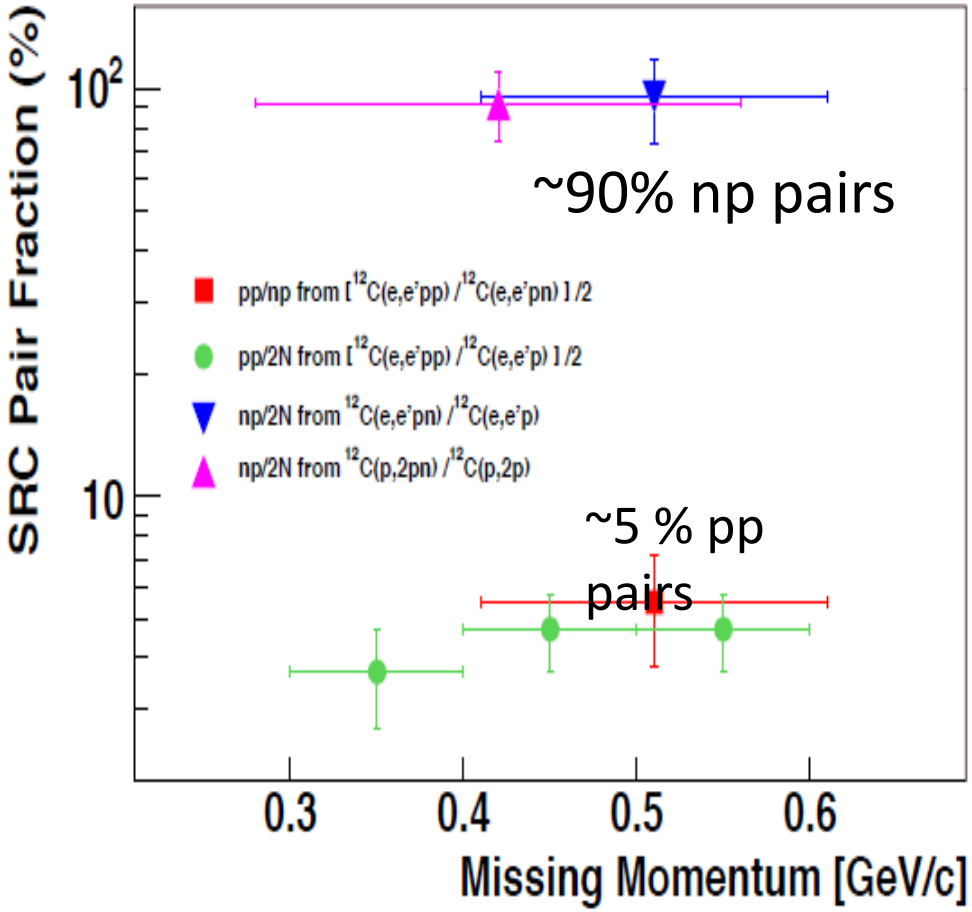
Cohen et al., PRL (2018)

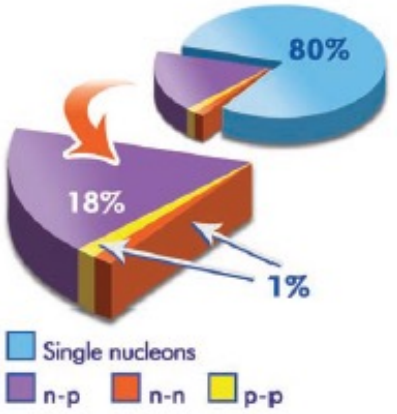
SRCs is Isospin dependence

Simple SRCs model: SRCs are assumed to be isospin independent

Experiment E01-015

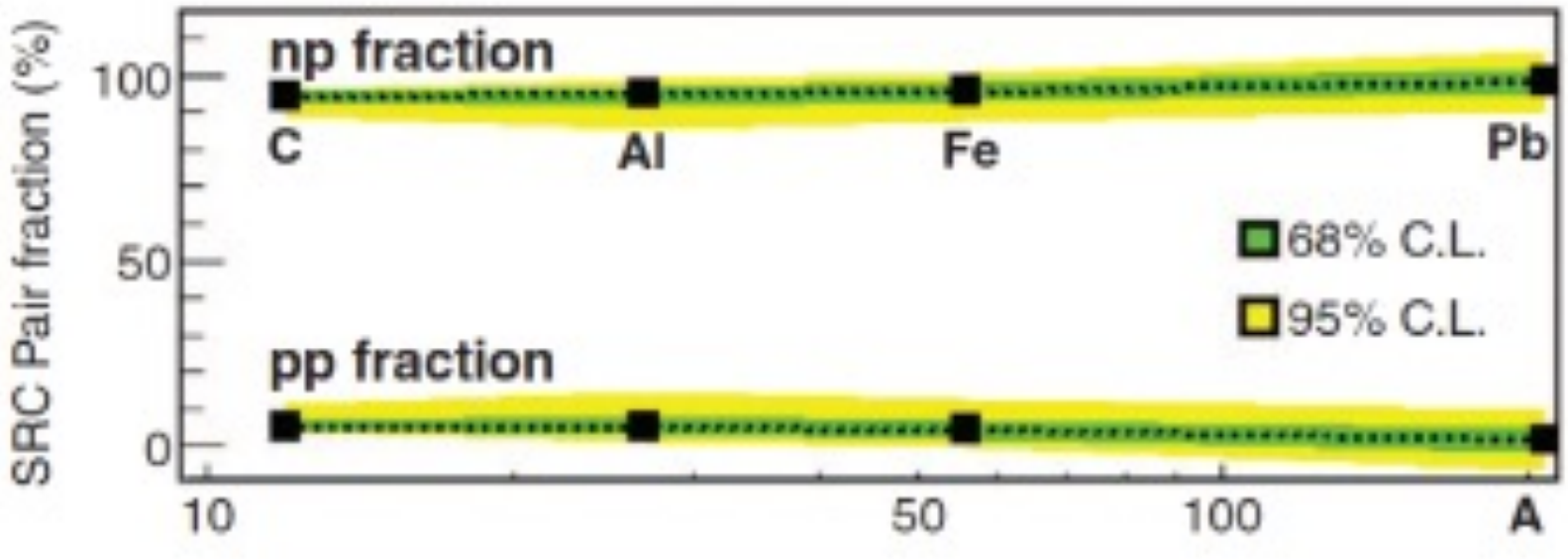
R. Subedi et al, Sc 320, 1476(2008)





SRCs: np pair dominate pp pairs by a factor of ~ 20 times

SRCs: np dominance established for a wide range of nuclei

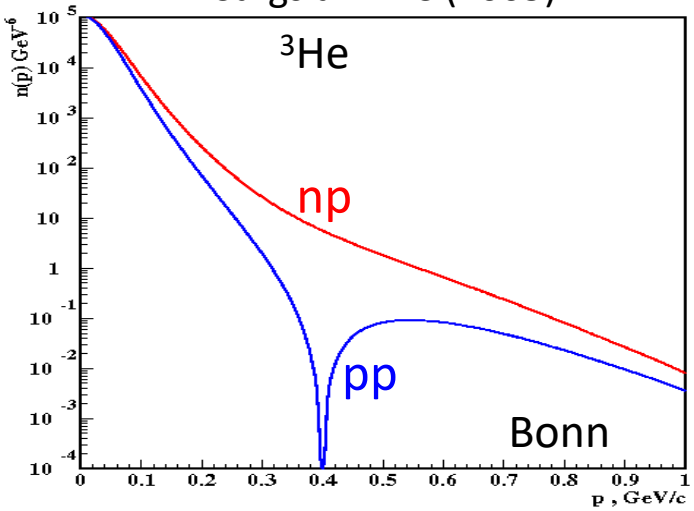


O. Hen, Science (2014)

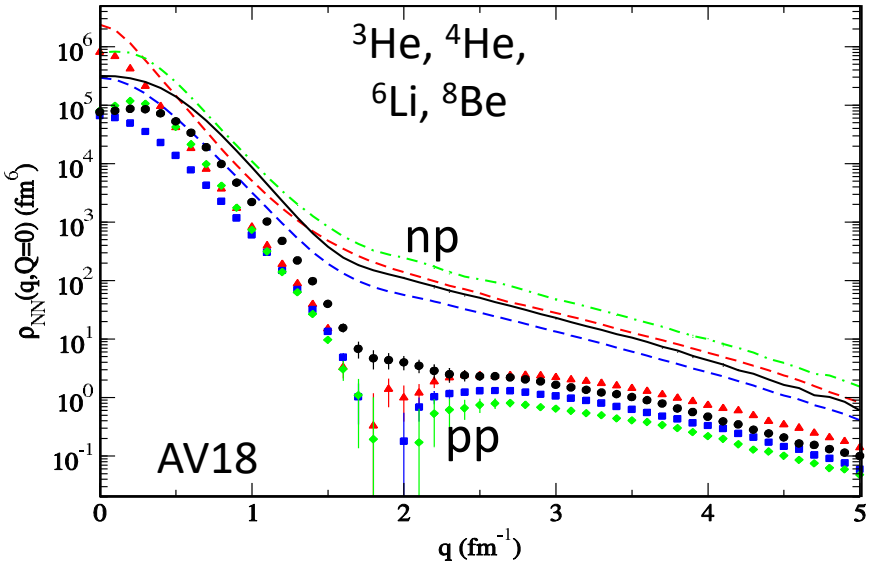
M. Duer et al., PRL (2019)

Also seen in ab-initio pair distributions

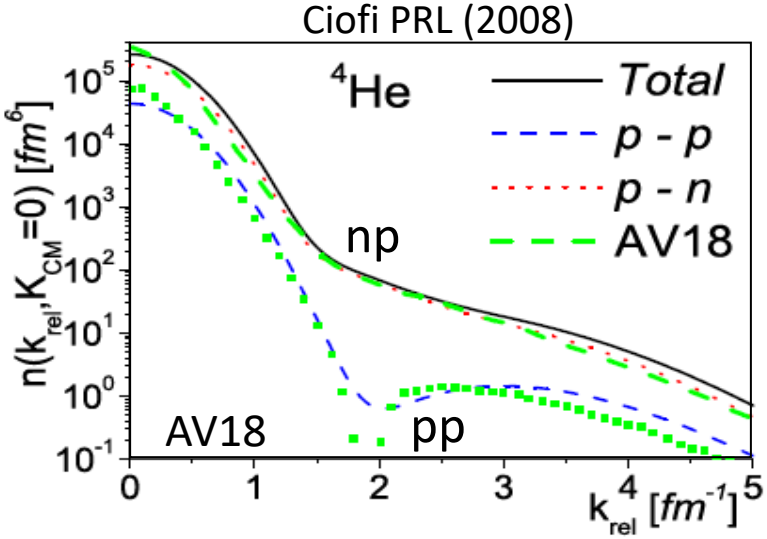
Sargsian PRC (2005)



Schiavilla PRL (2007)



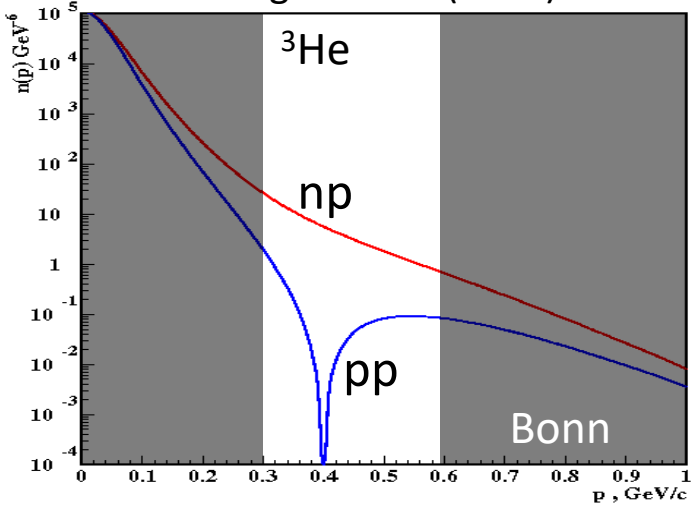
Ciofi PRL (2008)



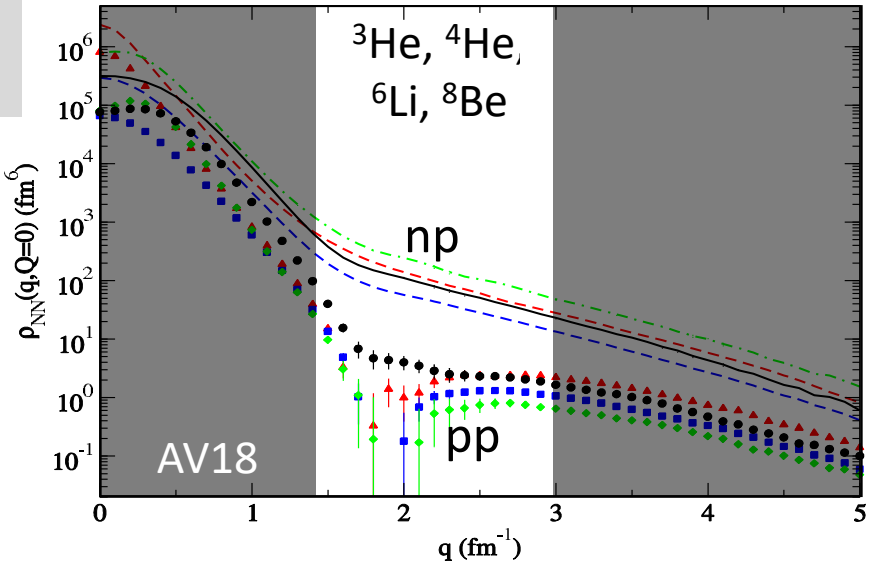
Also seen in ab-initio pair distributions

300 – 600 MeV/c Window

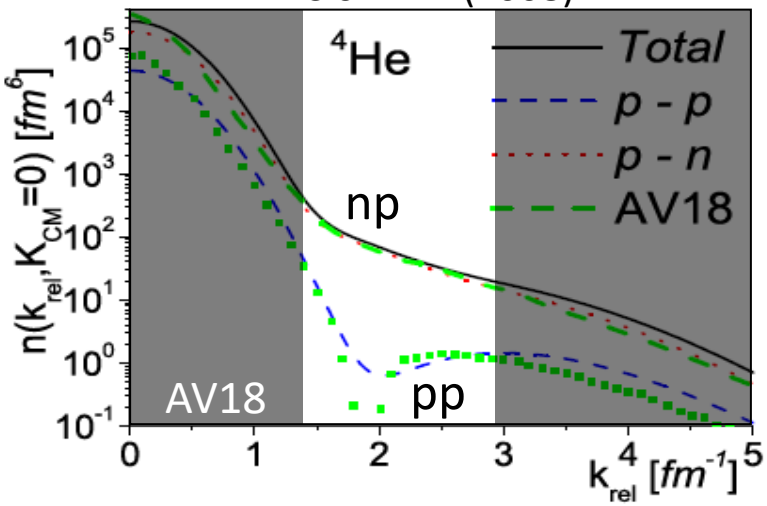
Sargsian PRC (2005)



Schiavilla PRL (2007)



Ciofi PRL (2008)



What we have learned about SRCs?

- ❑ SRCs is responsible for high-momentum tail
- ❑ SRCs accounts for ~20% of nucleon
- ❑ SRC pairs are back-to-back with small C.M.
- ❑ np pairs dominate over pp-pairs by ~ x20

  in nuclei from ^{4}He – Pb

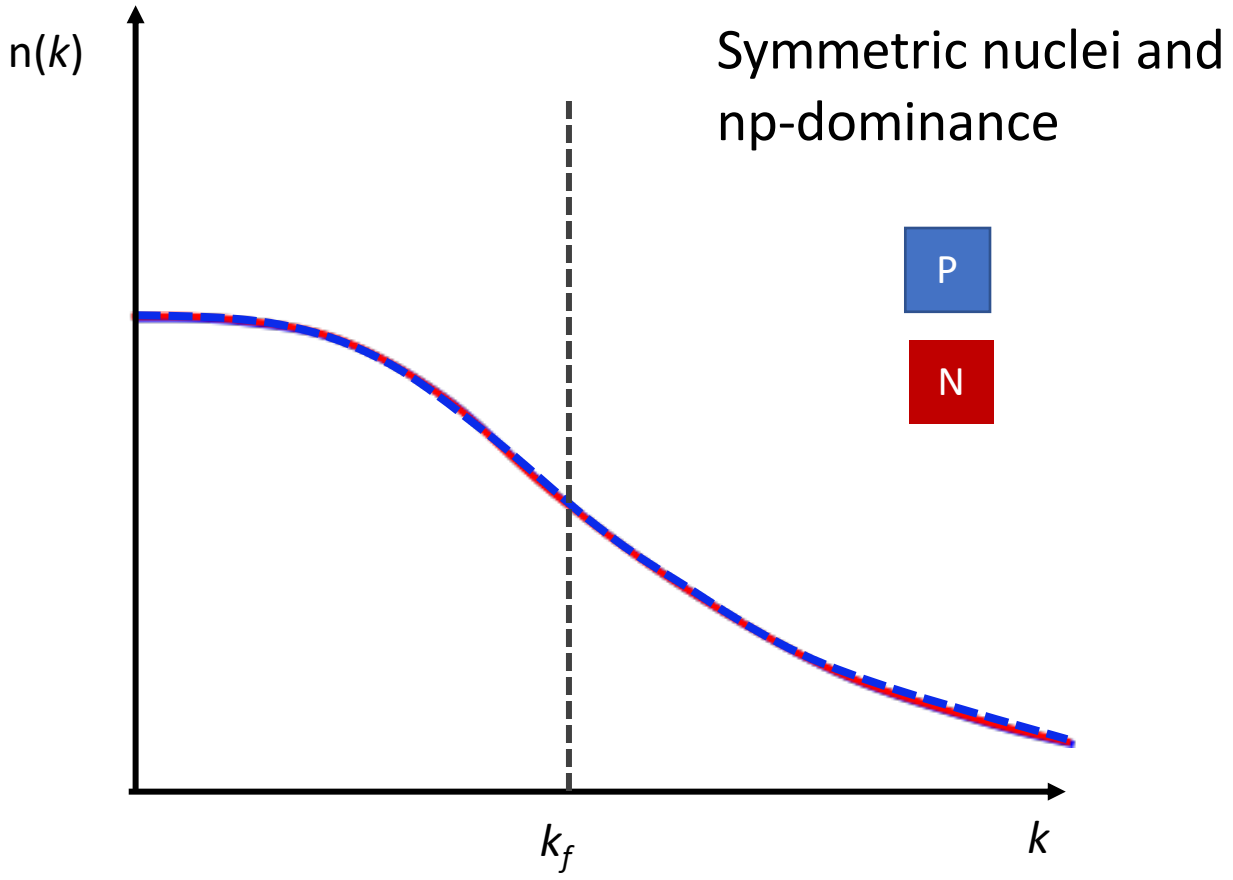
What about neutron-rich nuclei?

Going to Neutron rich nuclei:

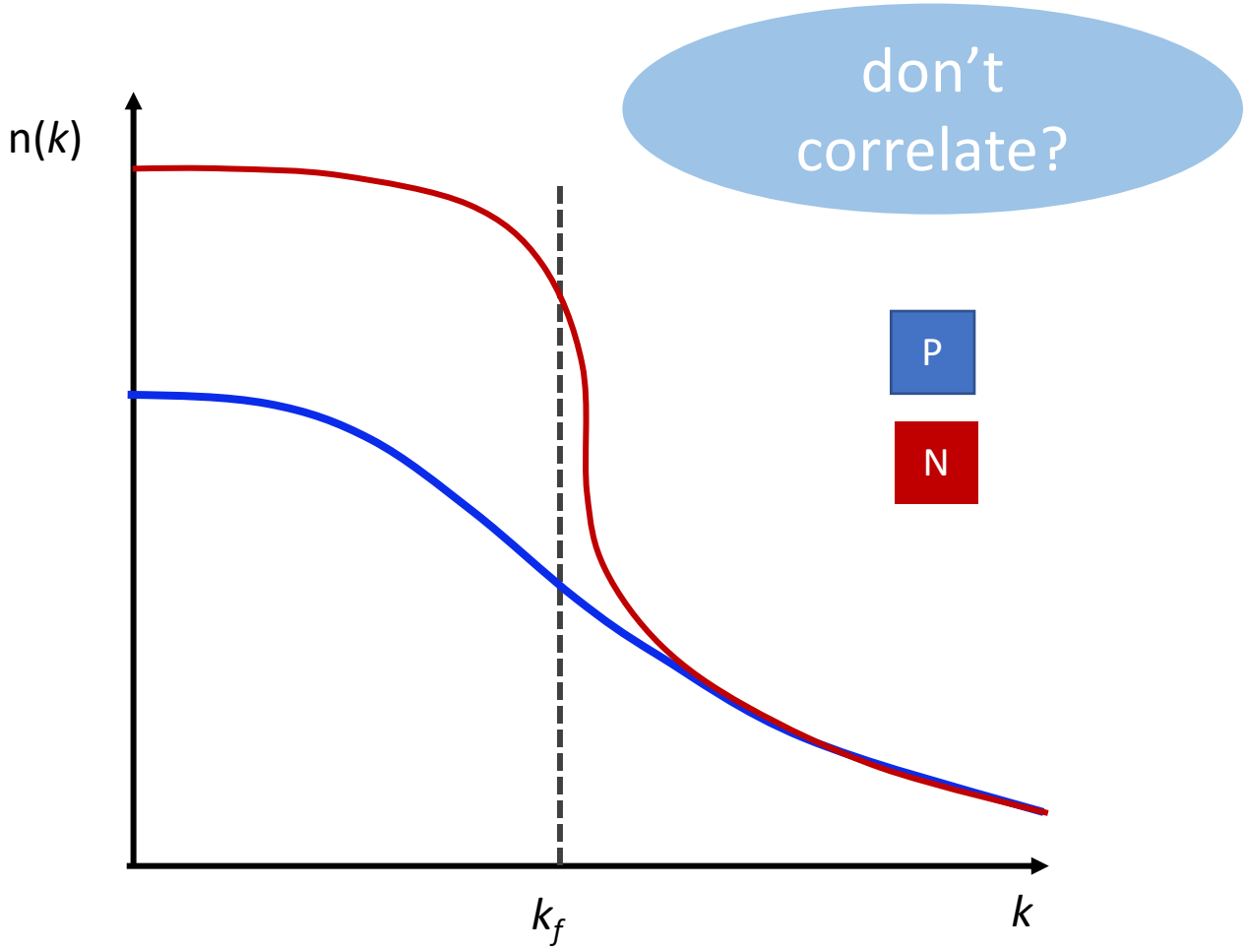
<u>What can we learn?</u>

- Nuclear asymmetry-dependence
- Separated contribution of proton and neutron

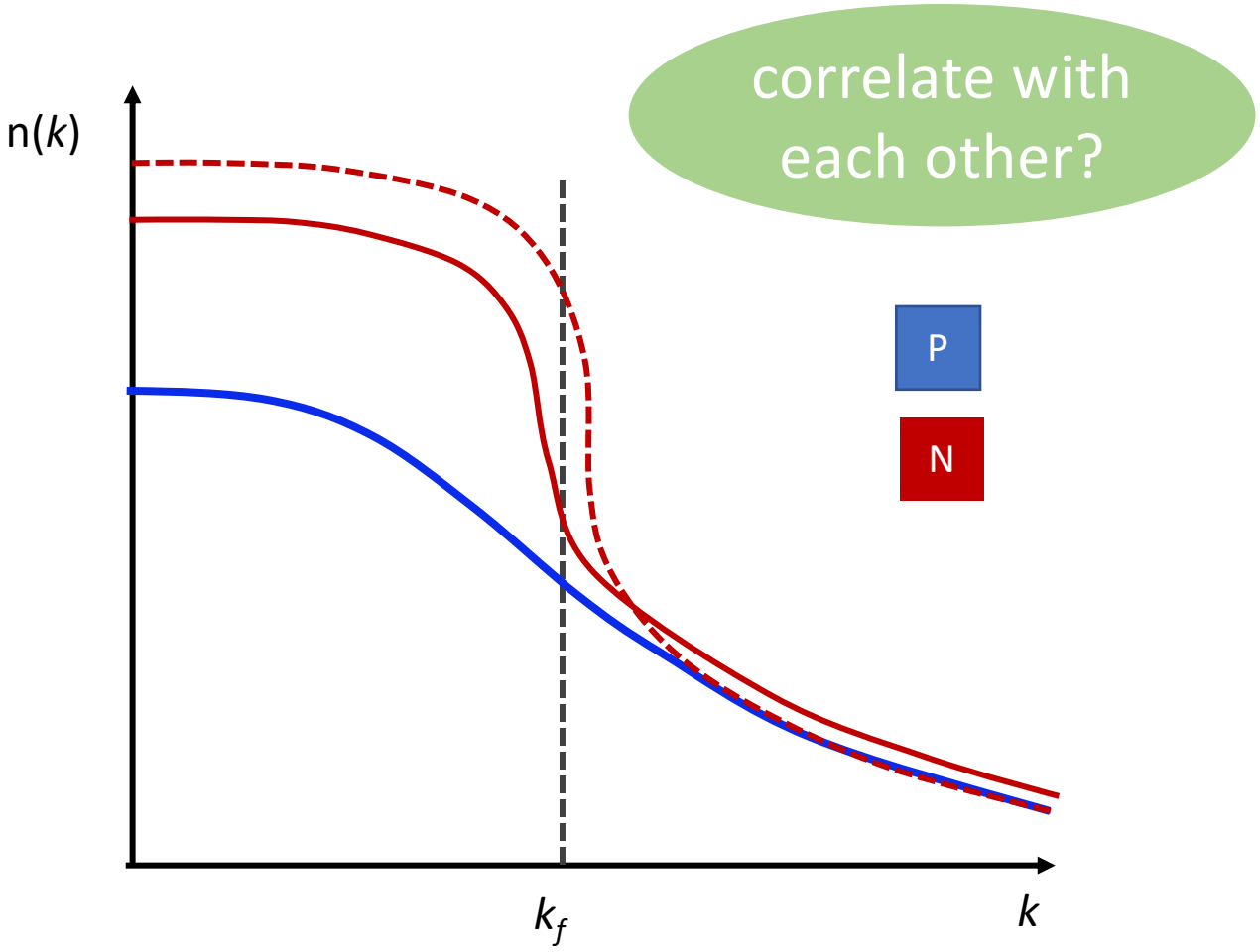
What happens to SRCs in Neutron-rich nuclei?



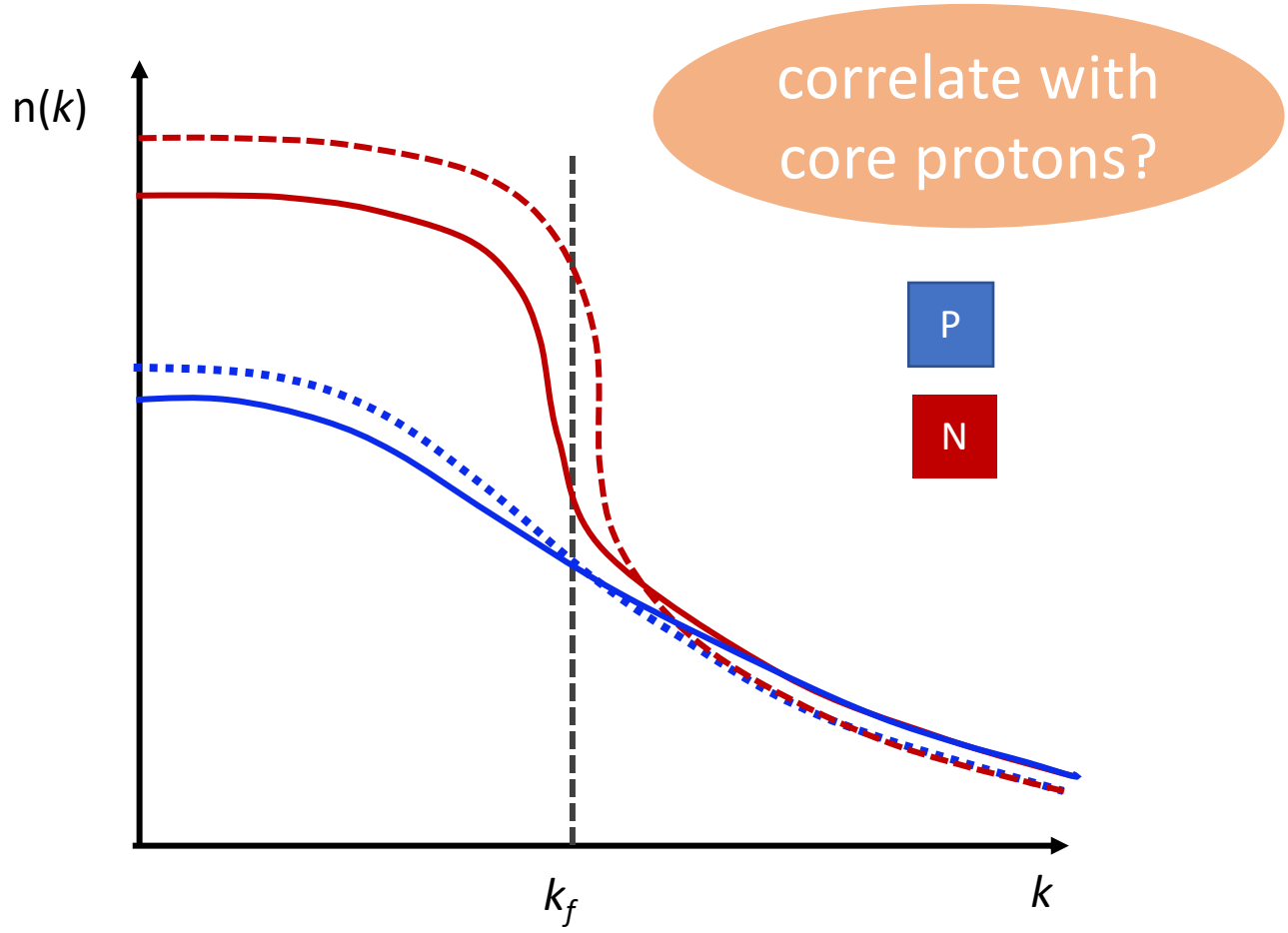
What happen to SRCs in Neutron-rich nuclei?



What happen to SRCs in Neutron-rich nuclei?



What happen to SRCs in Neutron-rich nuclei?



Going to Neutron rich nuclei:

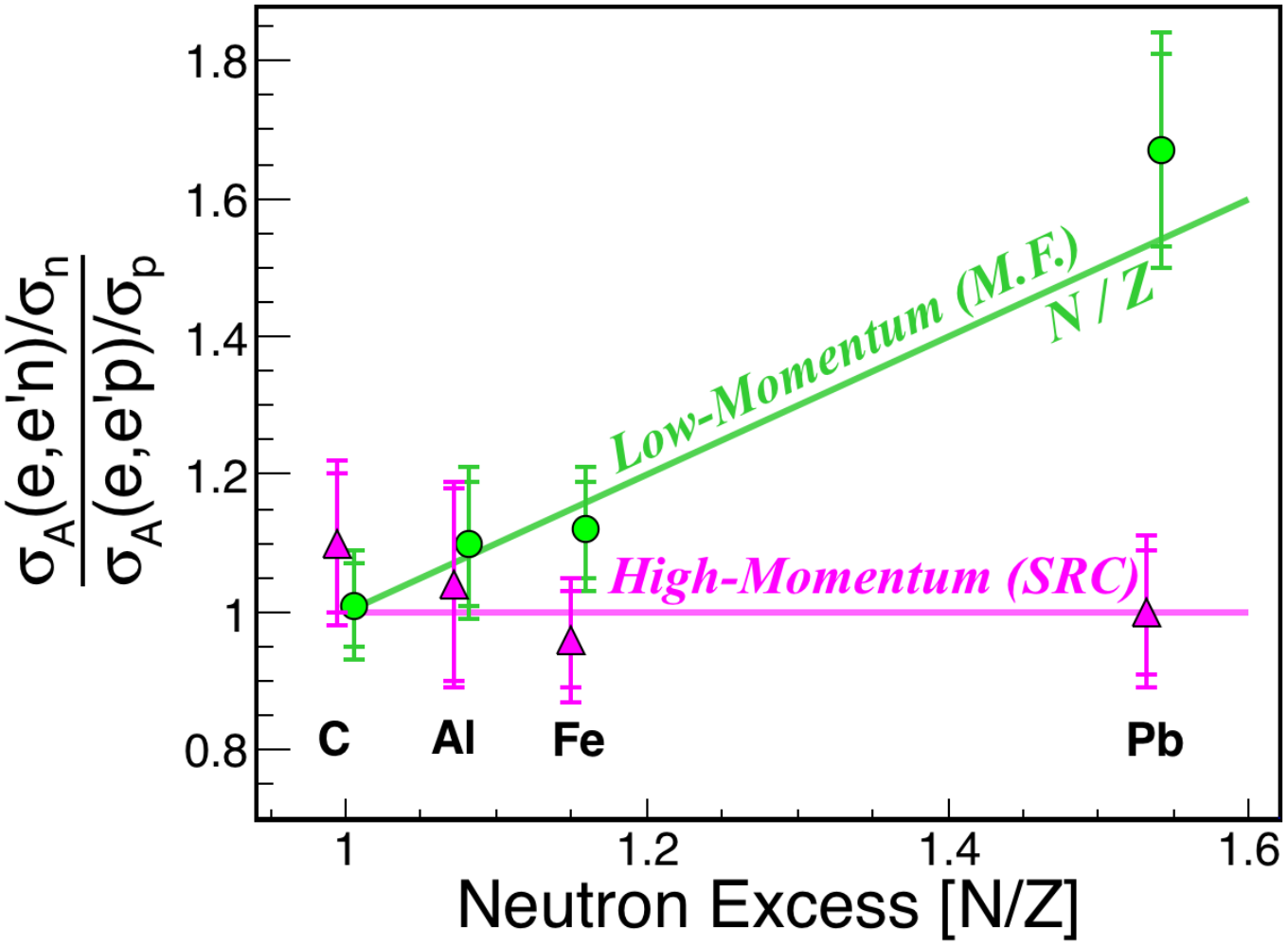
What do excess neutrons do?

don't correlate?

correlate with each other?

correlate with core protons?

n/p ratio for high-momentum nucleon is a constant with asymmetry



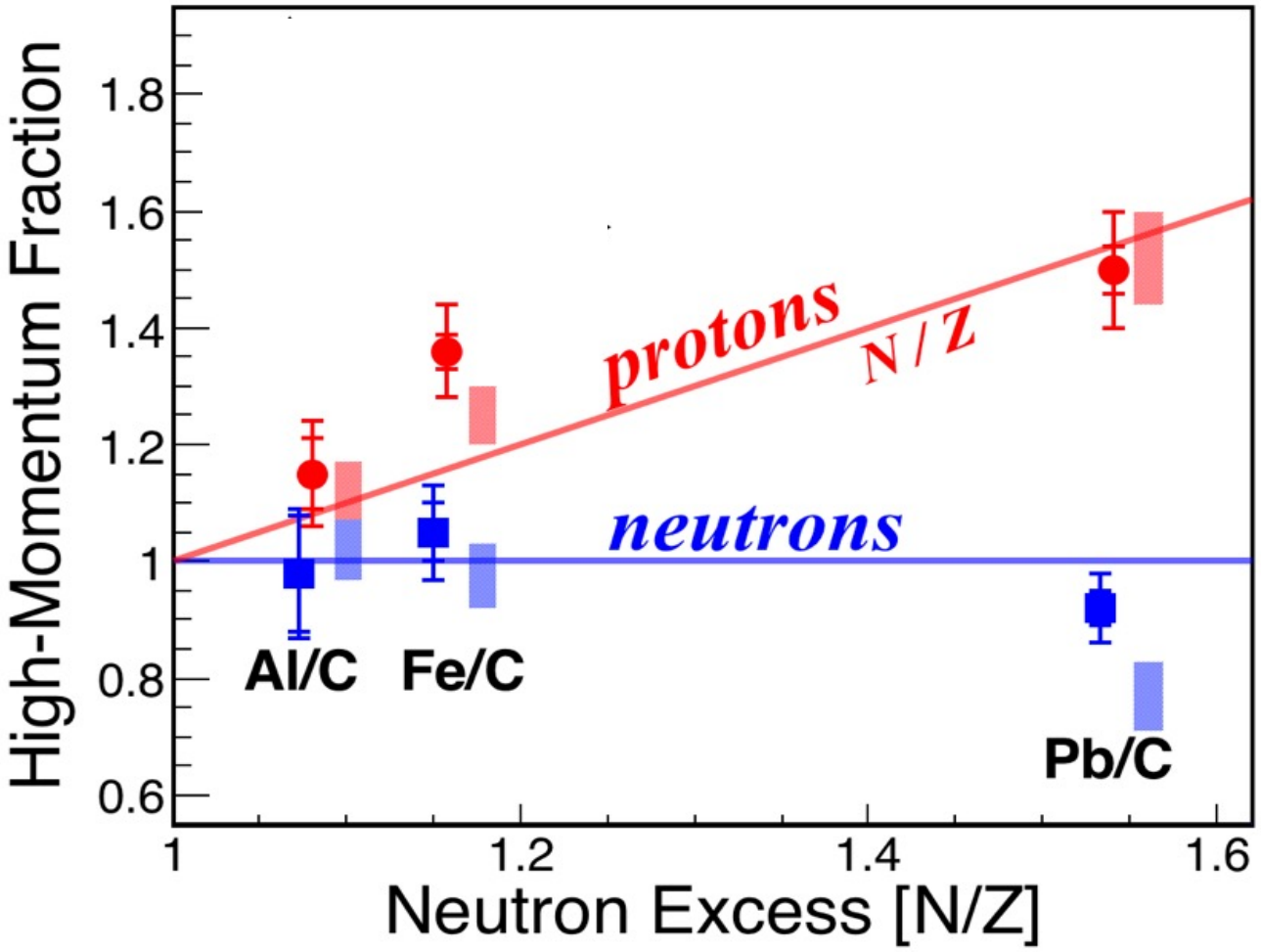
N_{MF}/P_{MF}

N_{SRC}/P_{SRC}

Duer et al., Nature (2018)

Proton “speed up” in neutron-rich nuclei

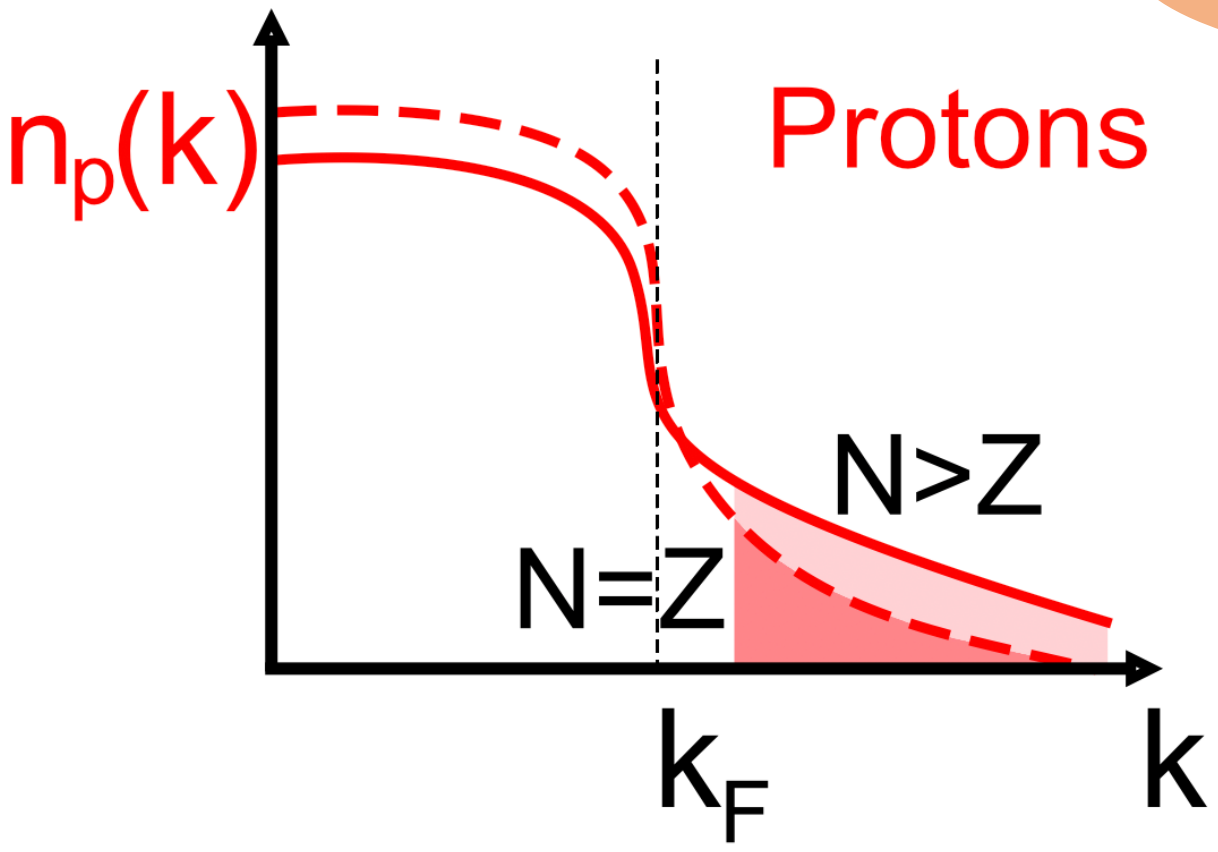
$$\frac{\sigma^{A}_{SRC}(e,e'N)}{\sigma^{A}_{MF}(e,e'N)} \Big/ \frac{\sigma^{C}_{SRC}(e,e'N)}{\sigma^{C}_{MF}(e,e'N)}$$



Duer et al., Nature (2018)

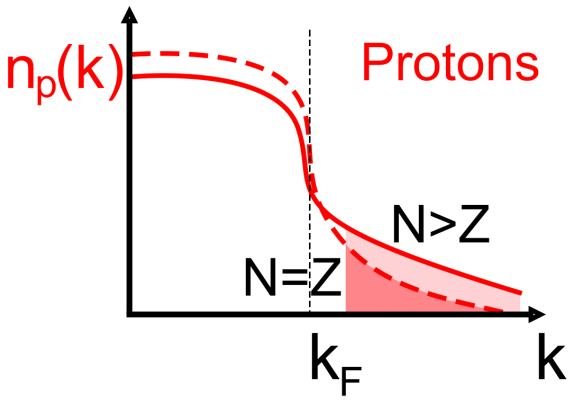
Protons are more correlated in neutron-rich nuclei

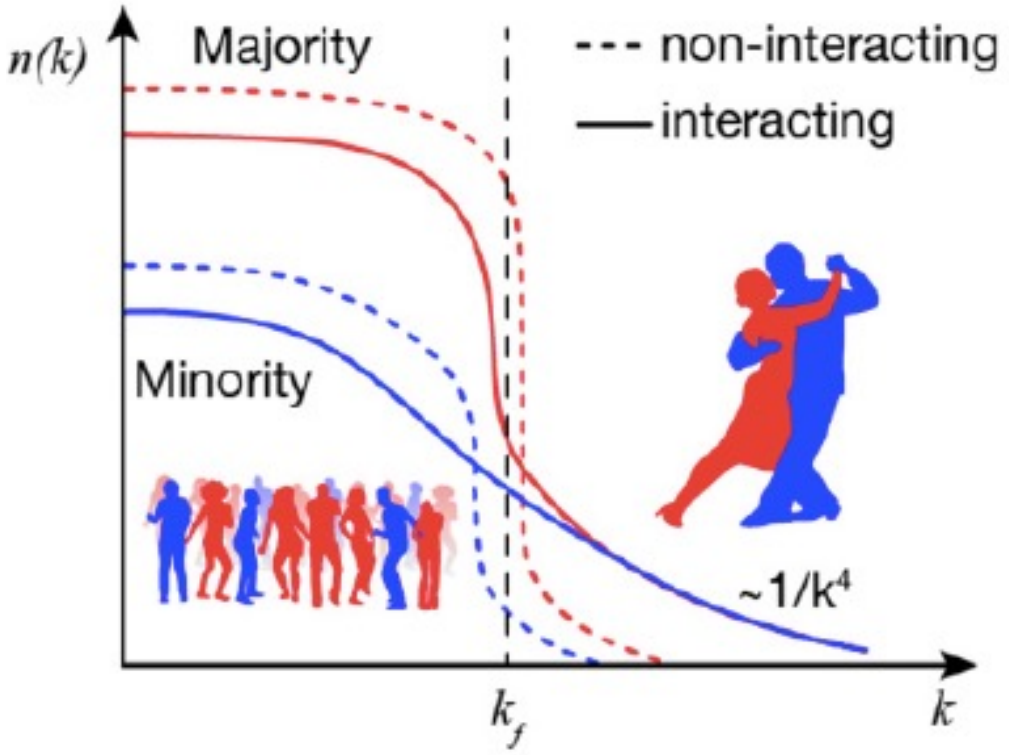
correlate with core protons



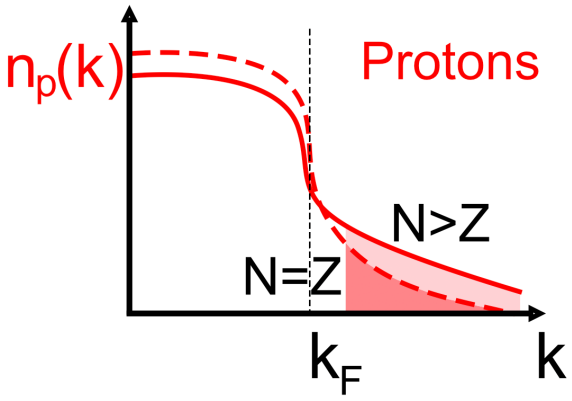
Pb/C

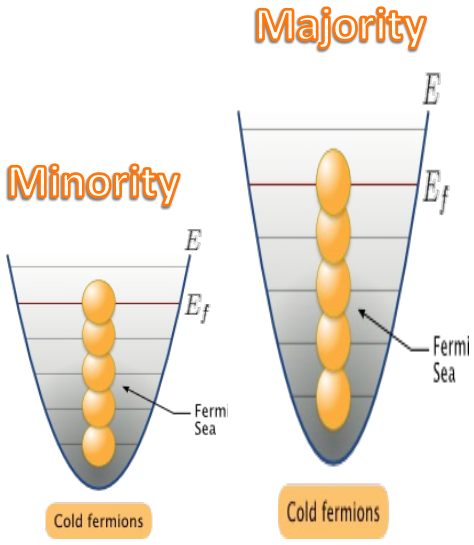
Proton ”speed up” in neutron-rich nuclei

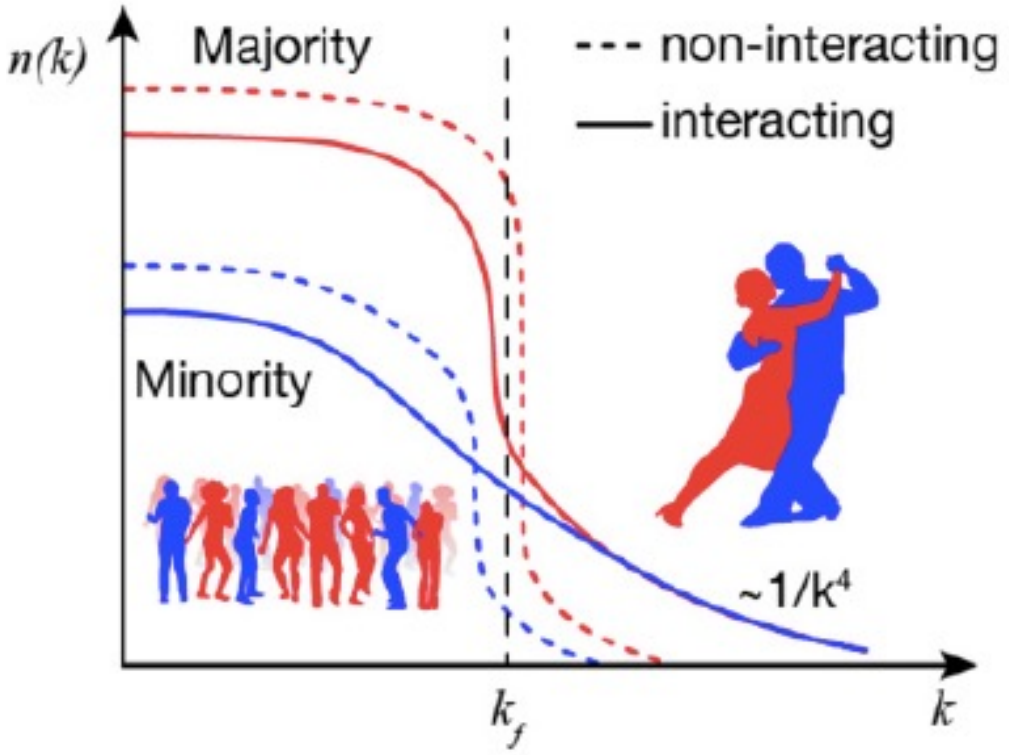




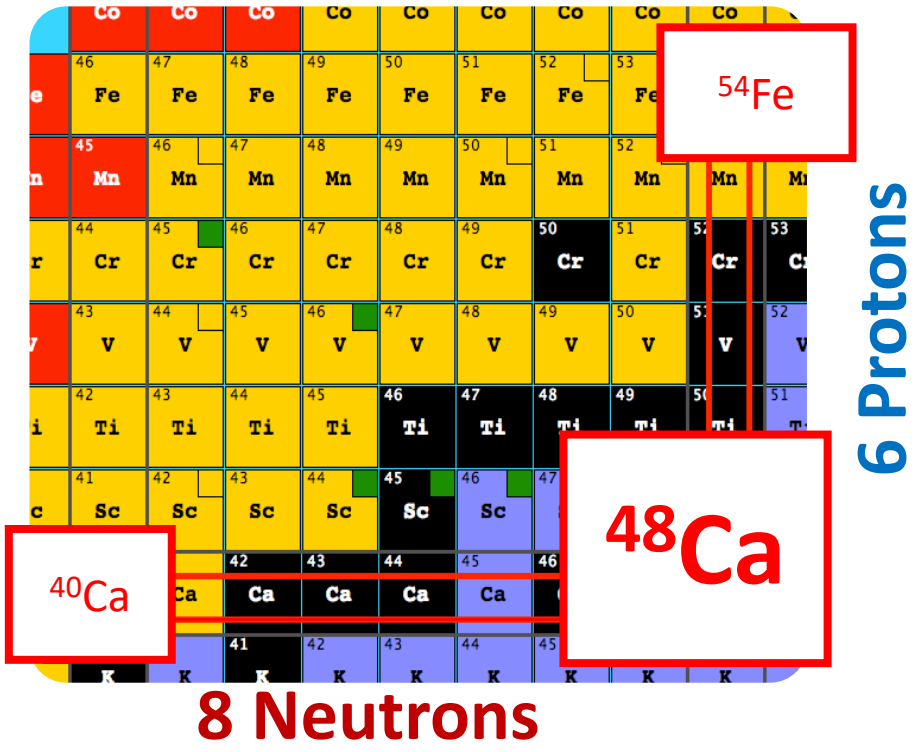
Proton ”speed up” in neutron-rich nuclei







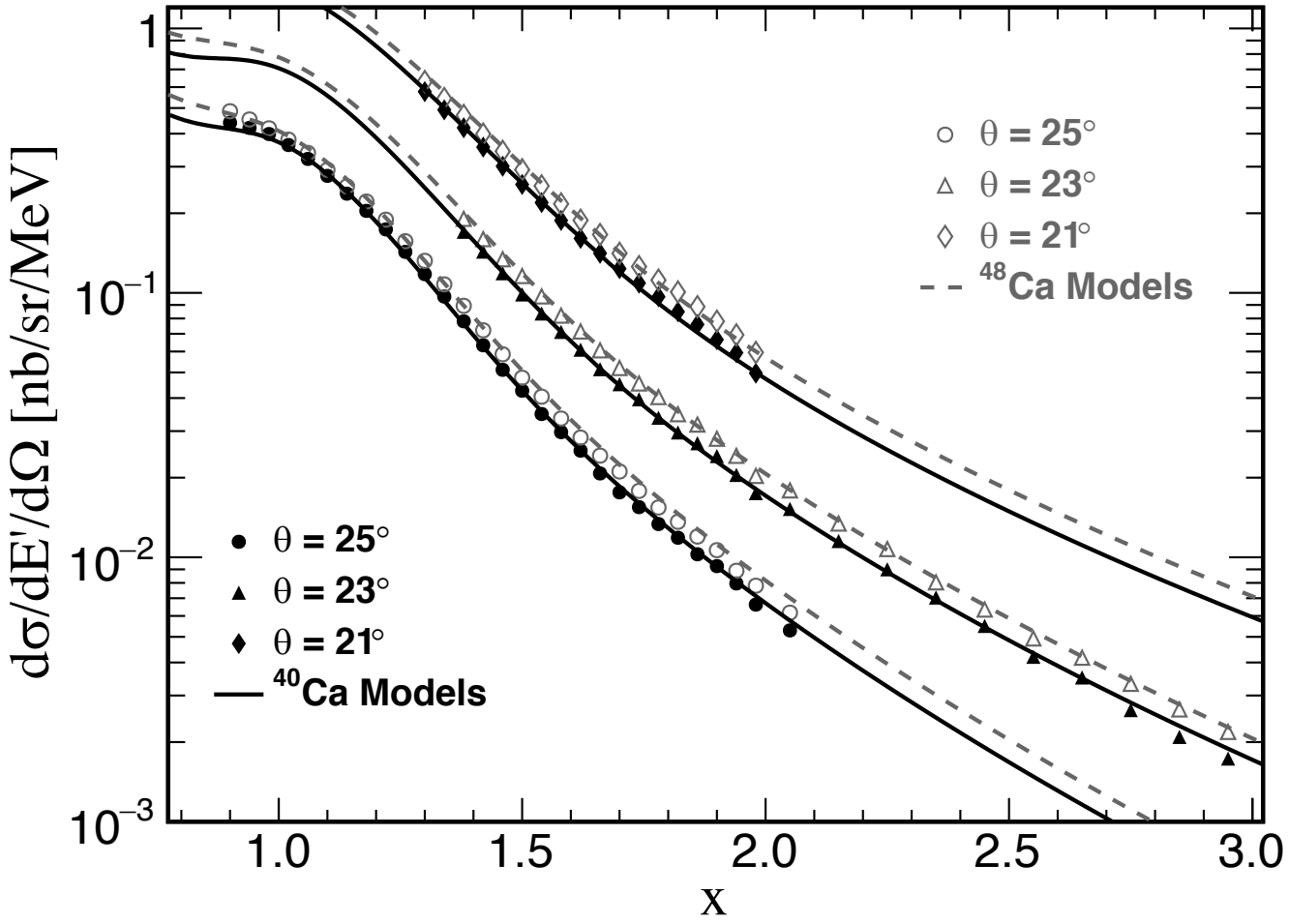
More studies from Ca isotopes



Open Questions:

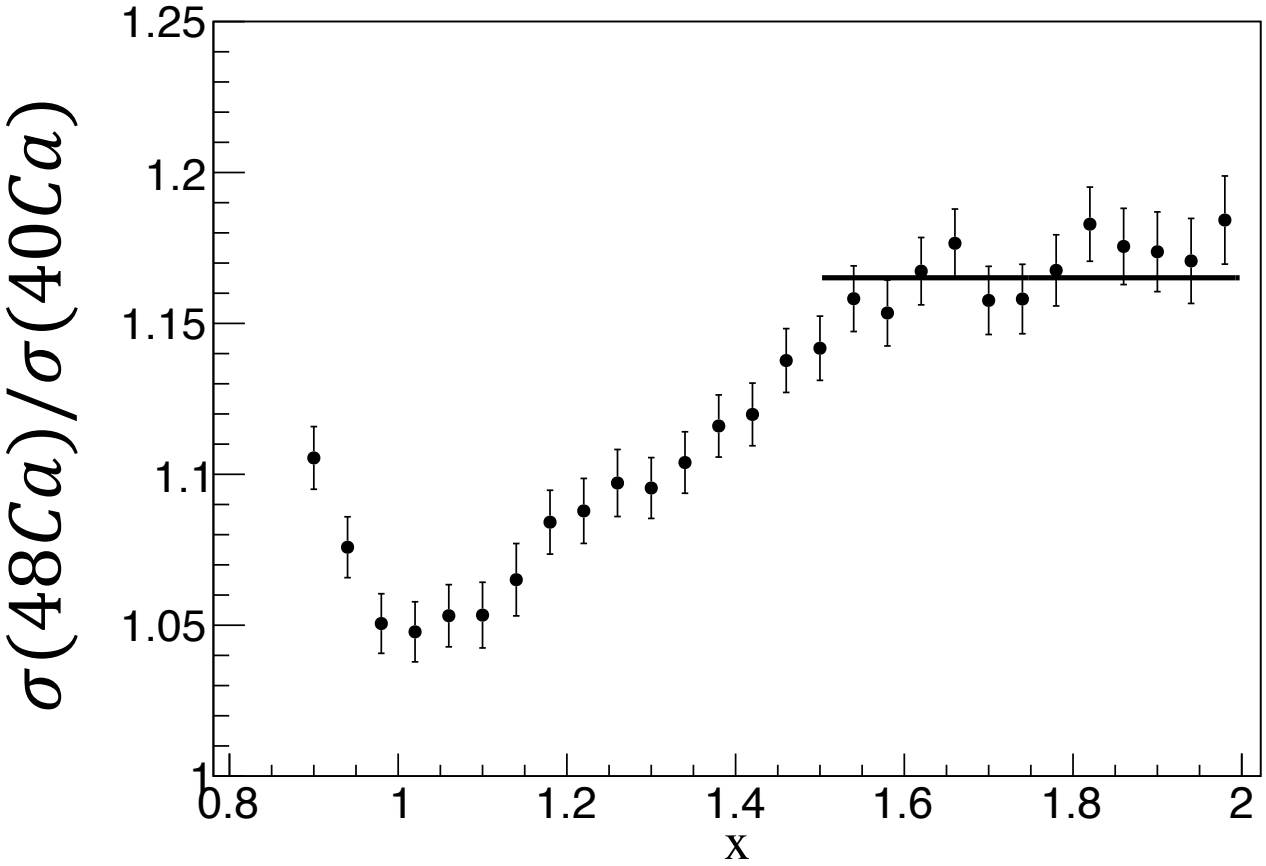
- ❑ What correlations do the outer $f_{7/2}$ neutrons form in ^{48}Ca?
- ❑ Does ^{48}Ca have more Protons in SRCs?
- ❑ If so, with what fraction?

Absolute (e,e’) cross-section measurement



D. Nguyen et al. PRC (2020)

More pairs in ^{48}Ca!

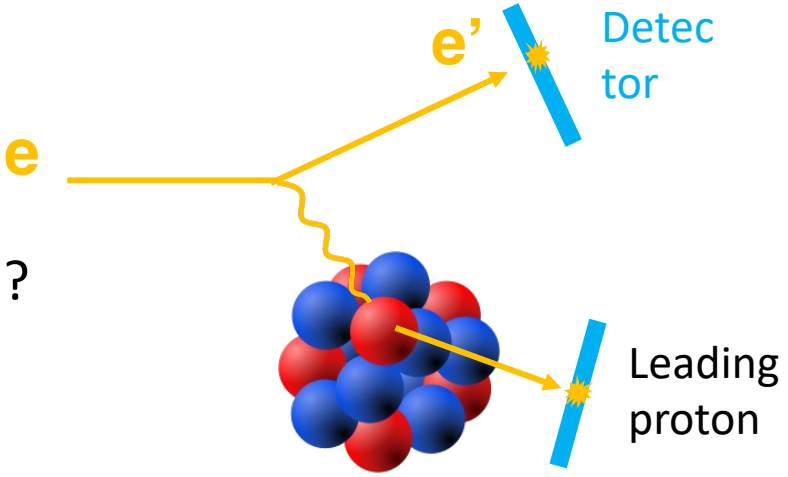


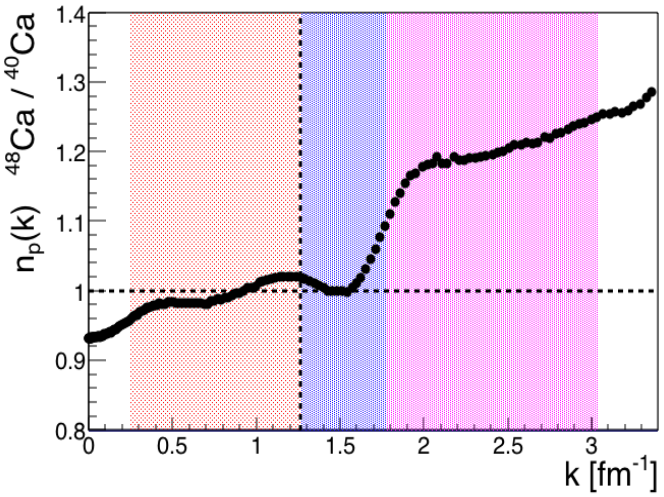
D. Nguyen et al., PRC(2020).

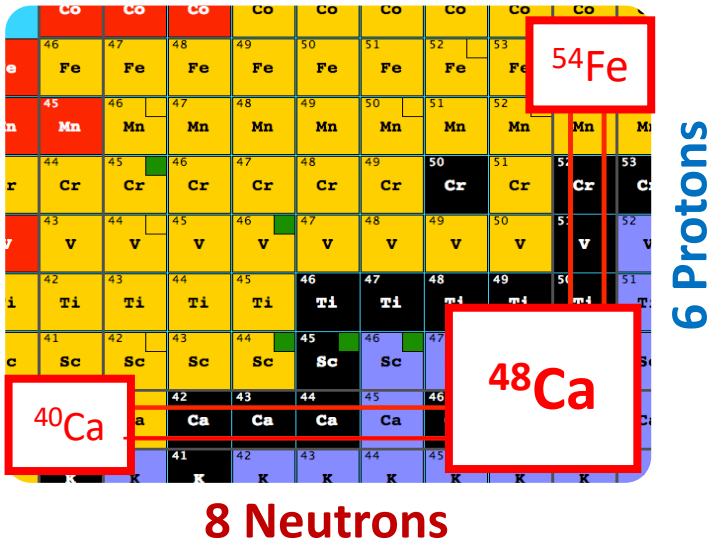
CaFe (e,e'p): Understand pairing probability

We can answer questions:

- ❑ Does ^{48}Ca has more Proton in SRCs?
- ❑ What is Proton high-momentum fraction?

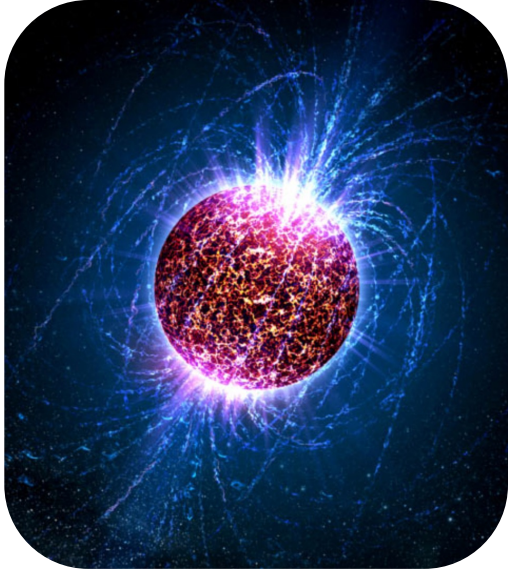






Daily Press

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

physicsworld.com Volume 29 No 7 July 2016

GIZMODO

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