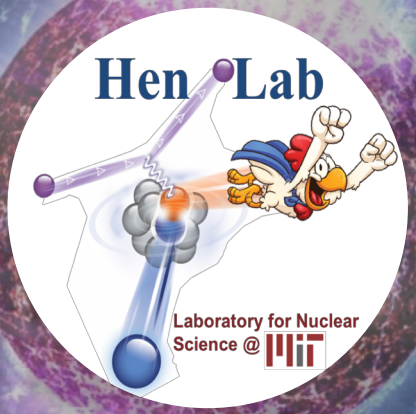
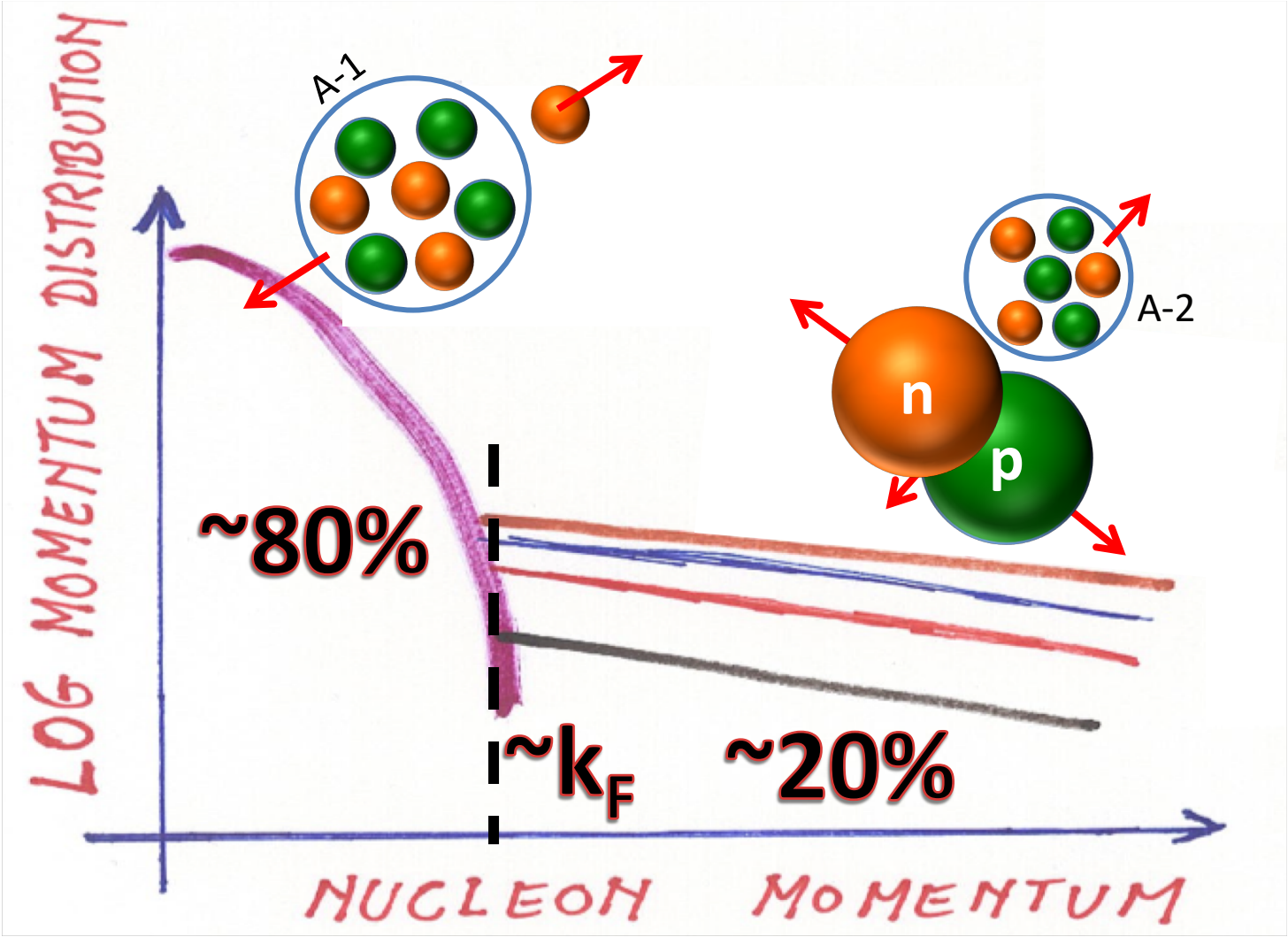
(e,e'N) and (e,e'Np) in heavy nuclei

Or Hen for

<u>Meytal Duer (TUD)</u>

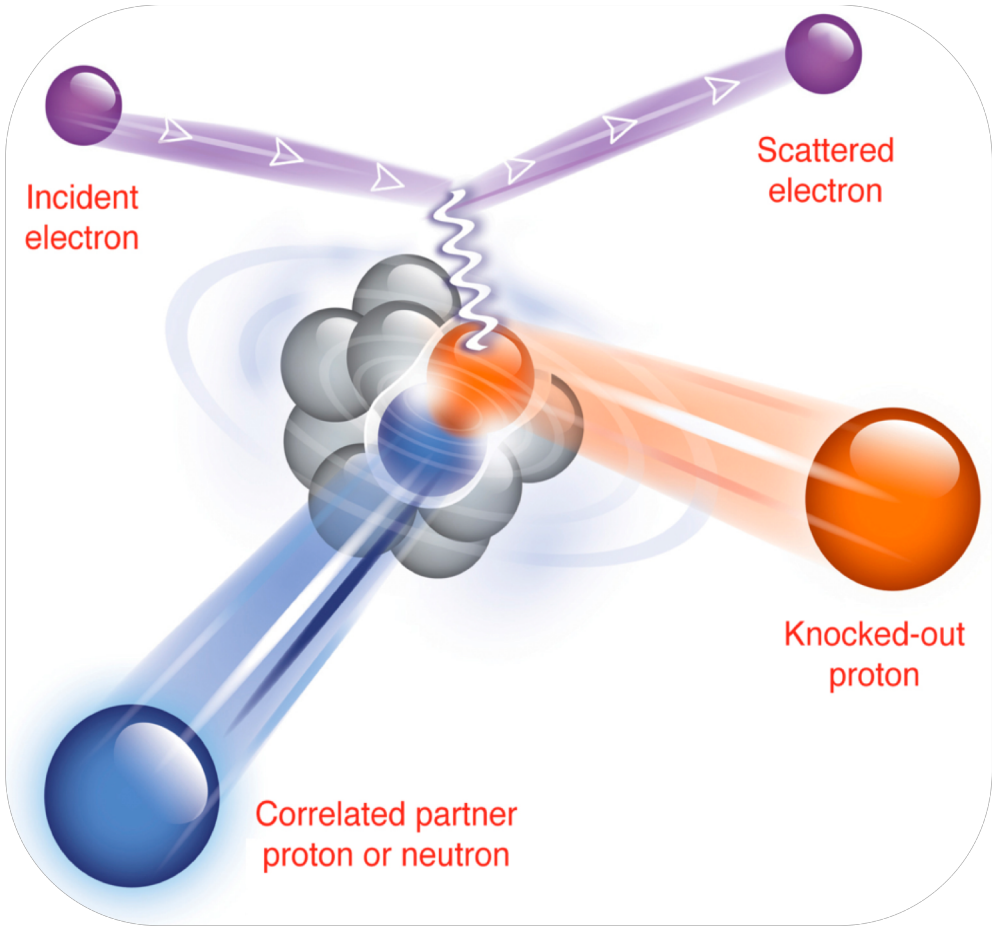



LOG MOMENTUM DISTRIBUTION
A-1
A-2
n
p
~80%
~k_F
~20%
NUCLEON MOMENTUM

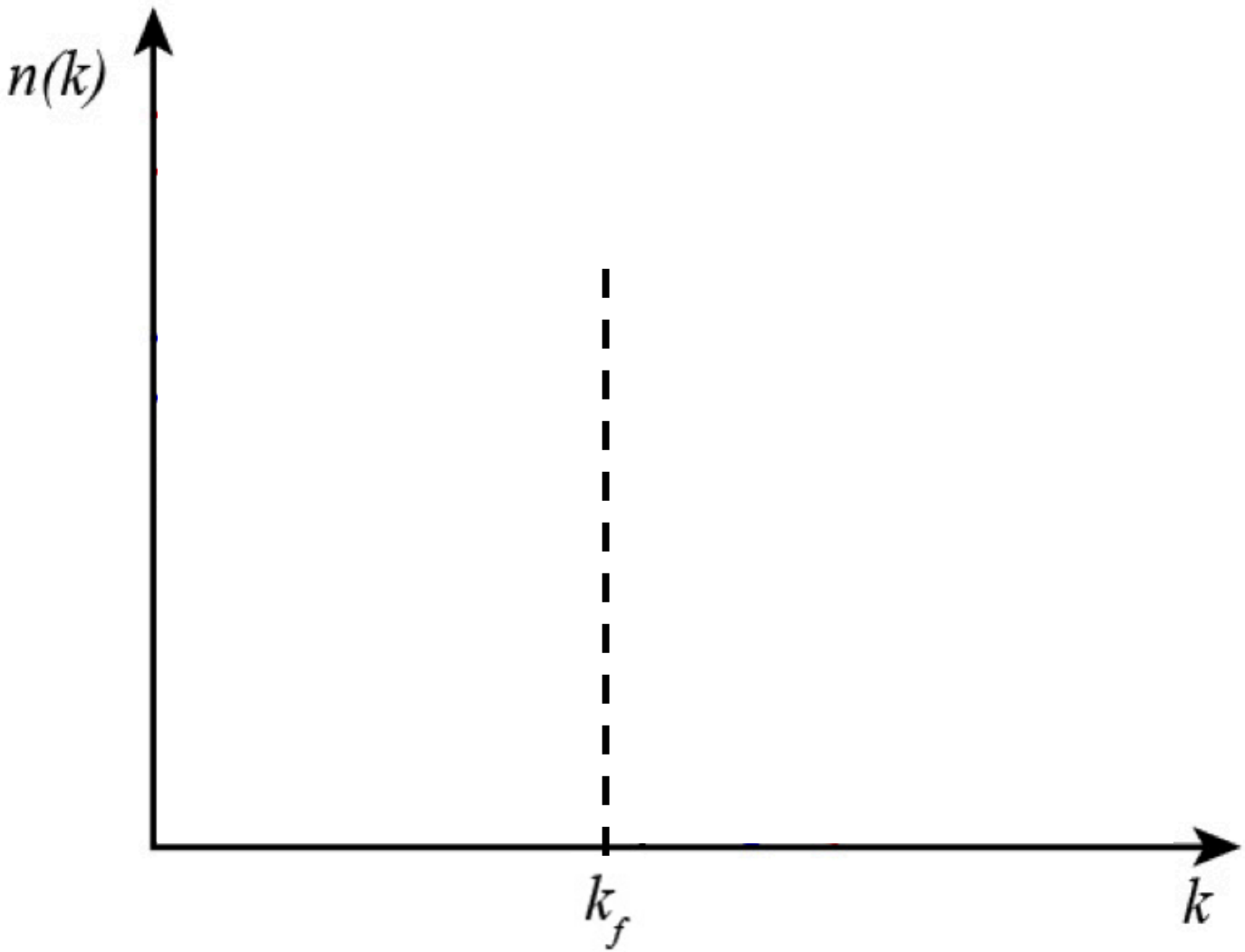
Breakup the pair =>

Detect ***both*** nucleons =>

Reconstruct 'initial' state

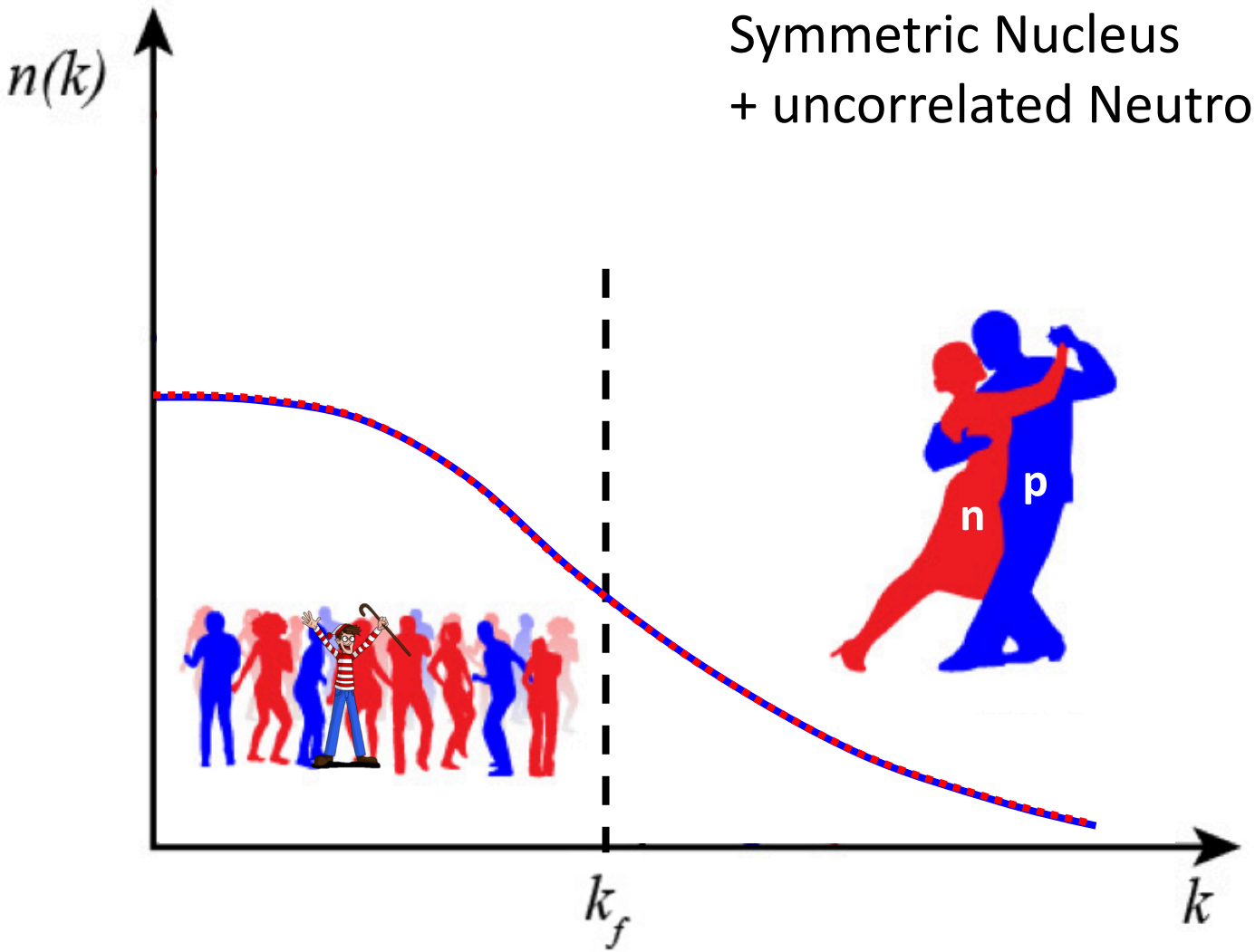


Going Neutron Rich

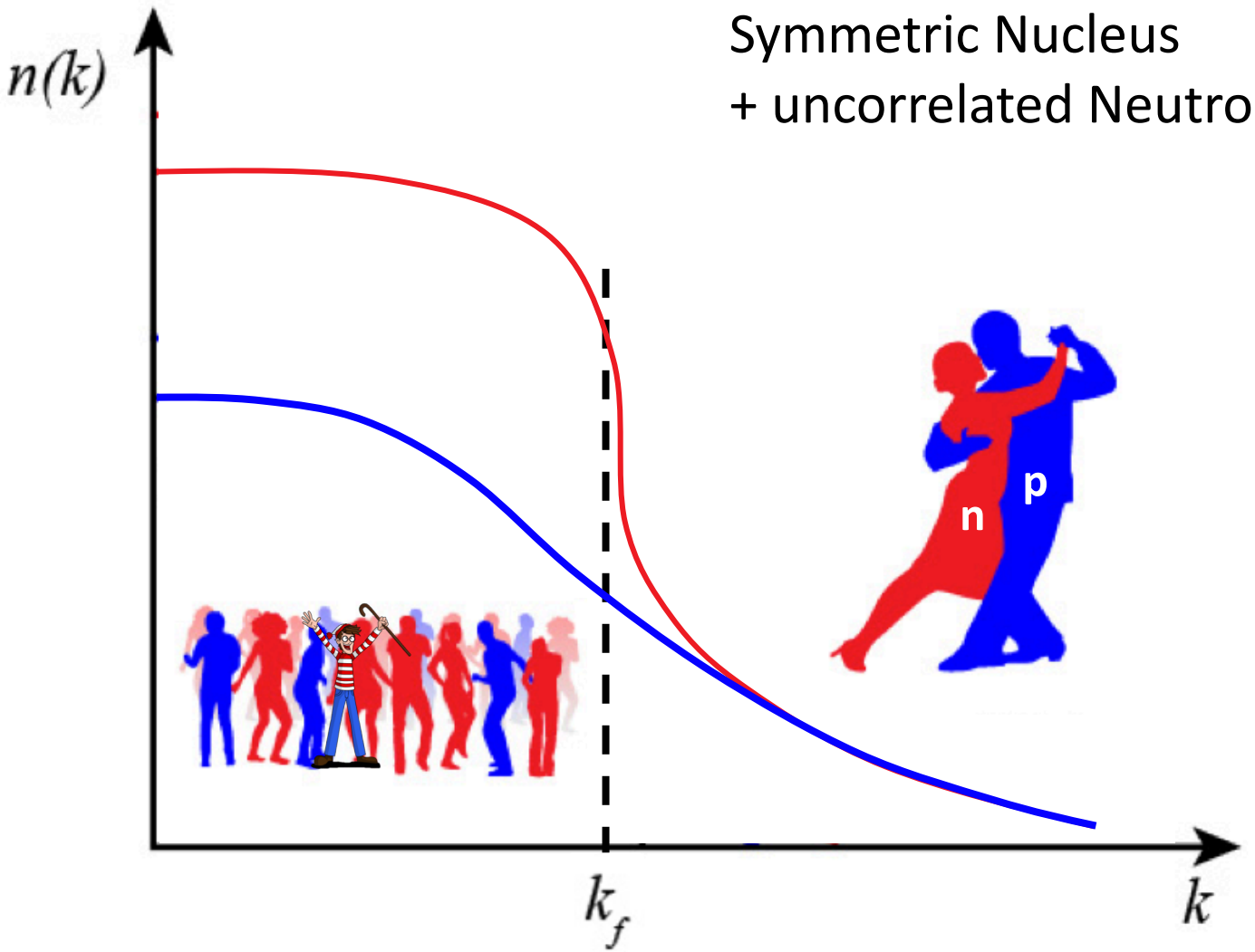


Going Neutron Rich

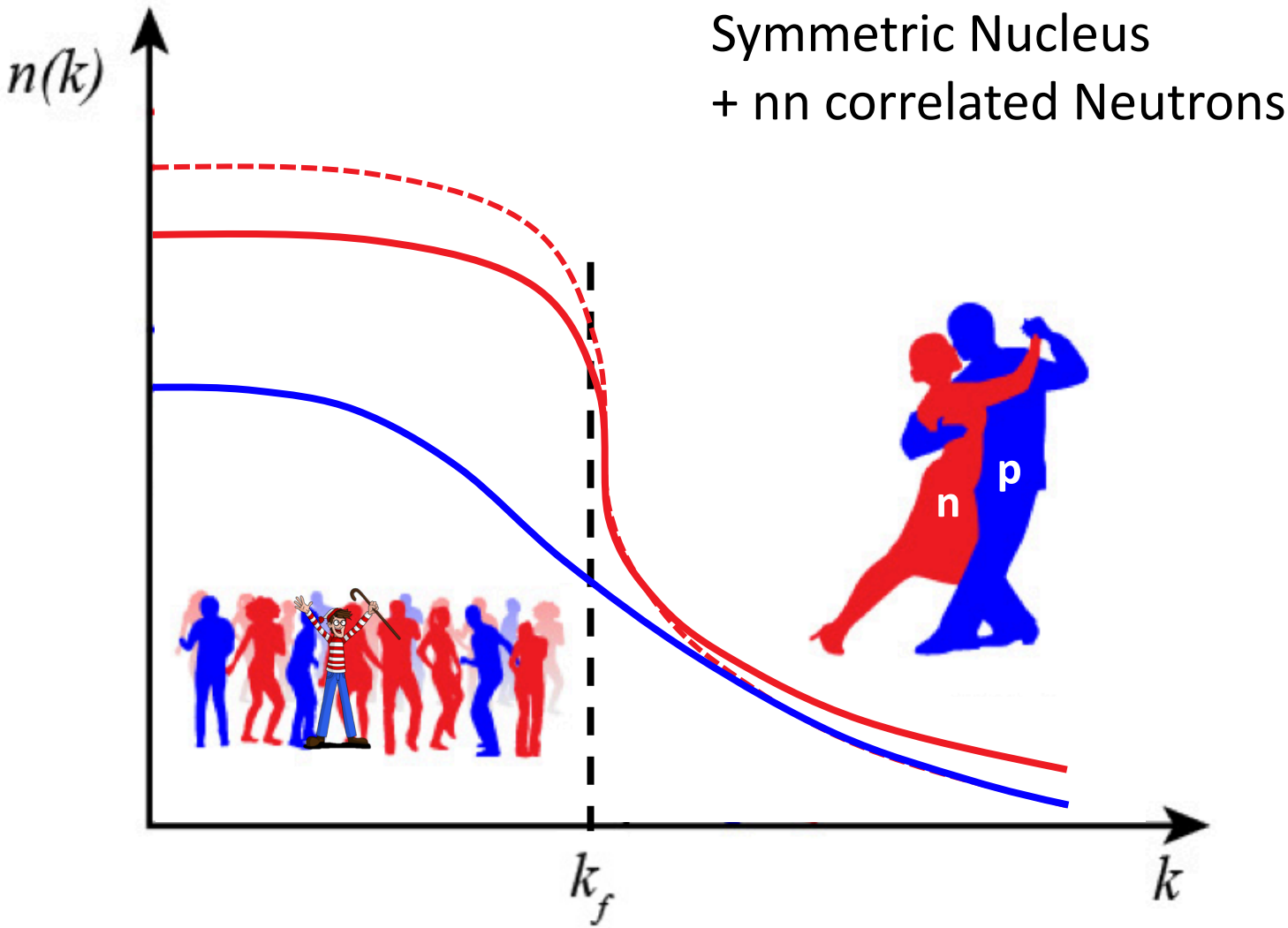
Symmetric Nucleus
+ uncorrelated Neutrons



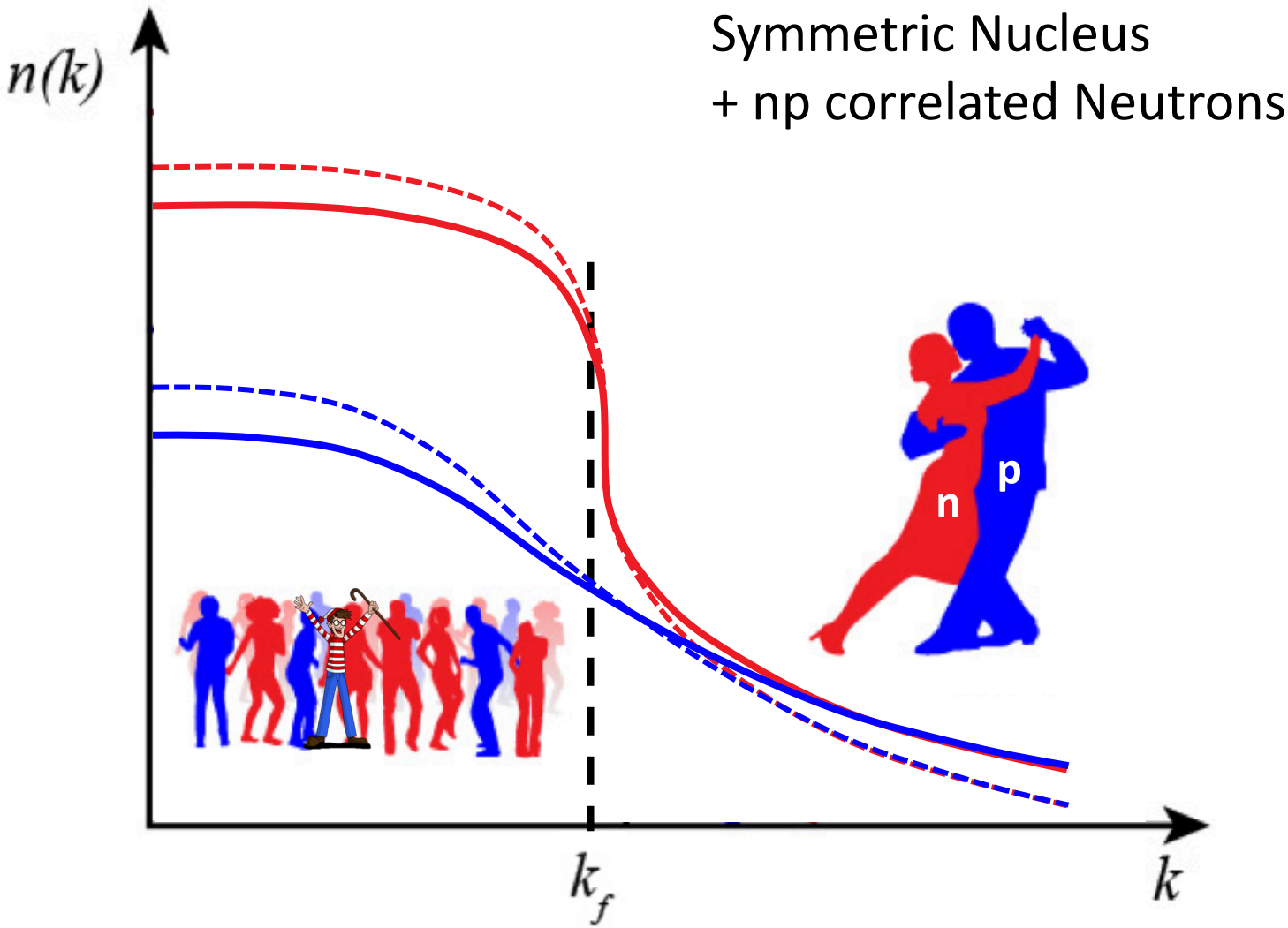
Going Neutron Rich



Going Neutron Rich



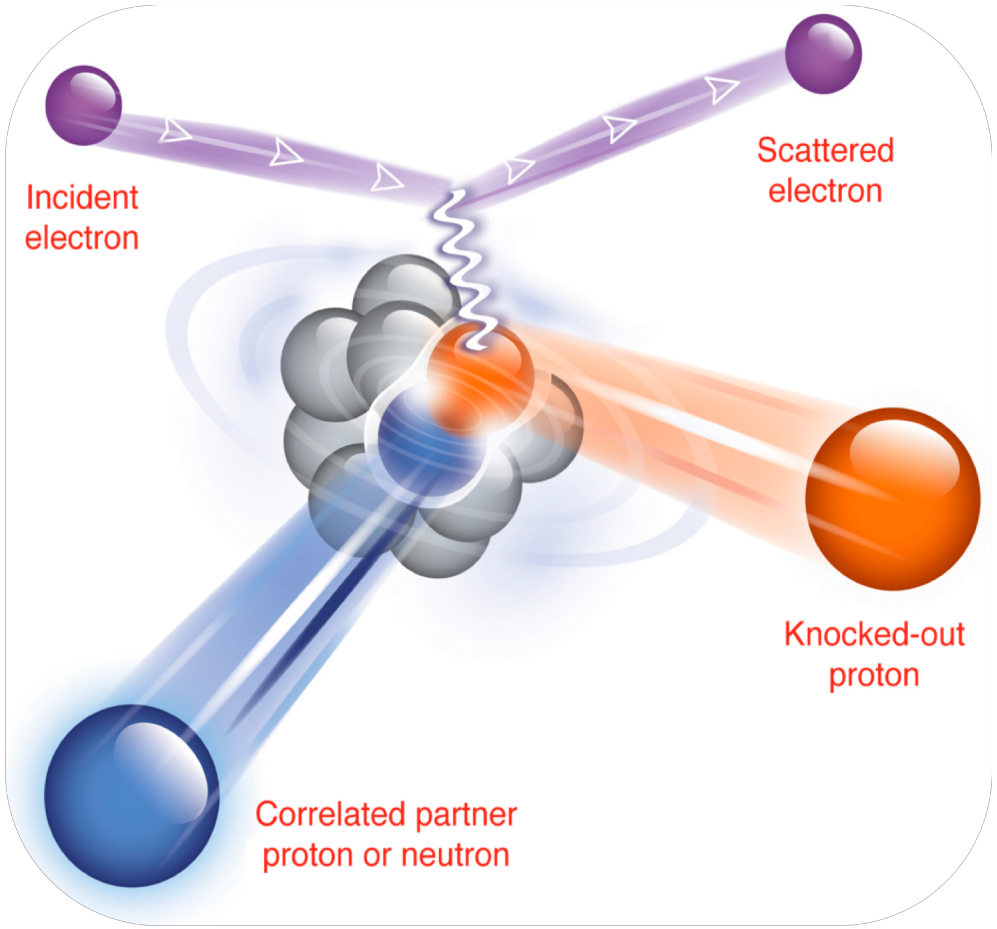
Going Neutron Rich



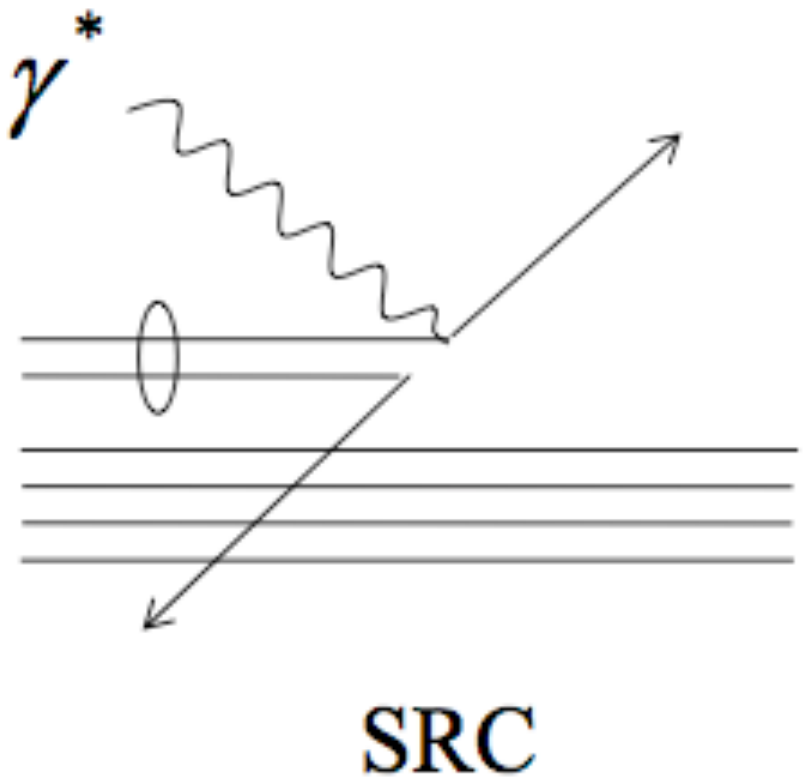
Breakup the pair =>

Detect ***both*** nucleons =>

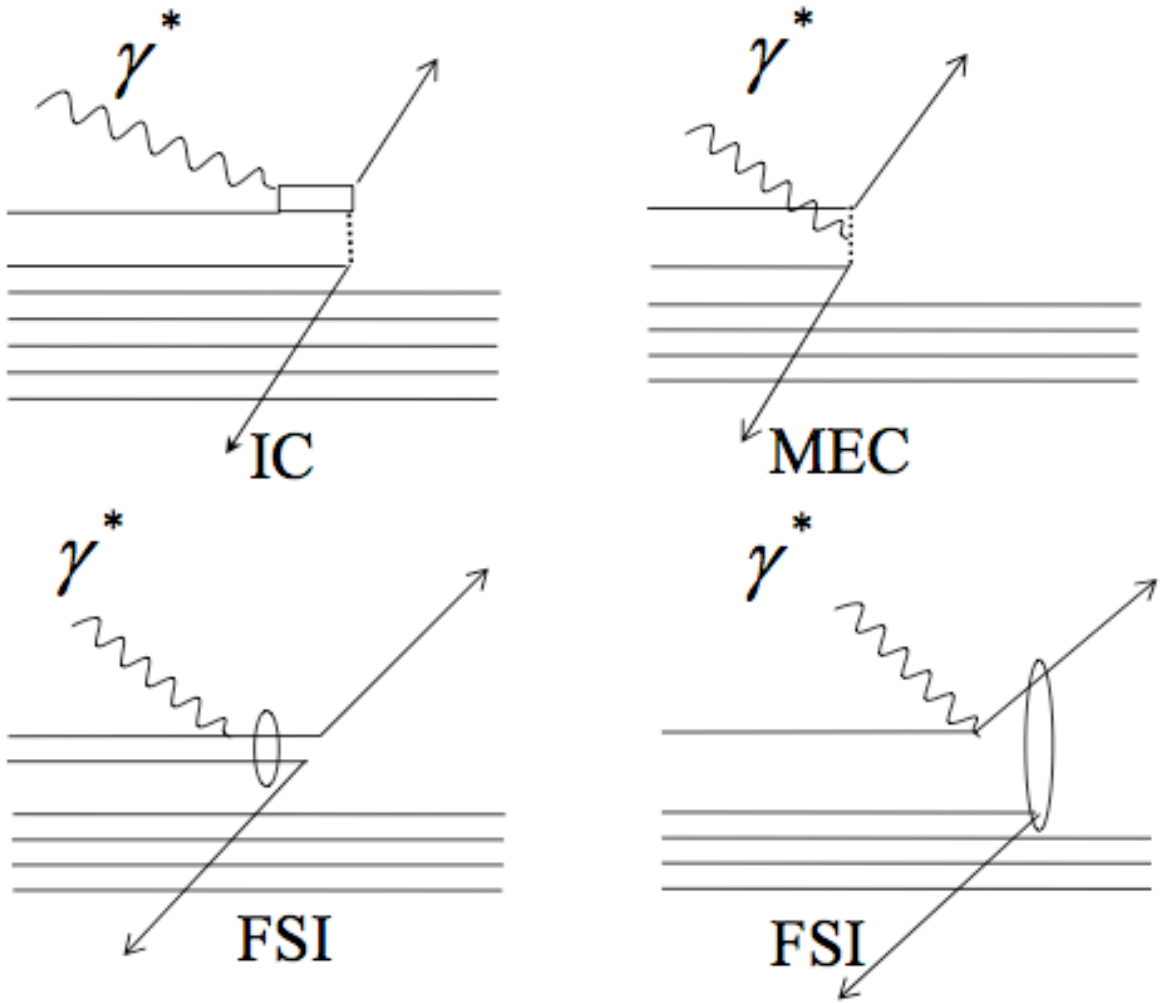
Reconstruct 'initial' state



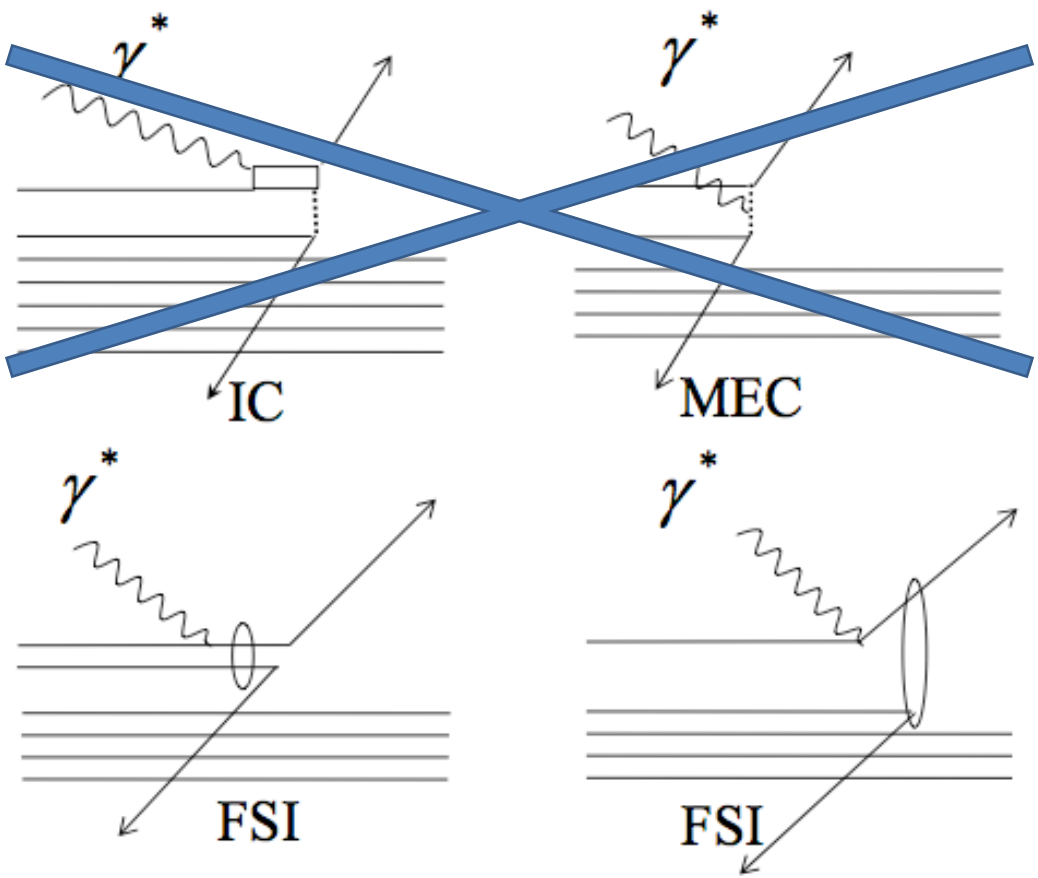
Two-Nucleon Knockout



Two-Nucleon Knockout



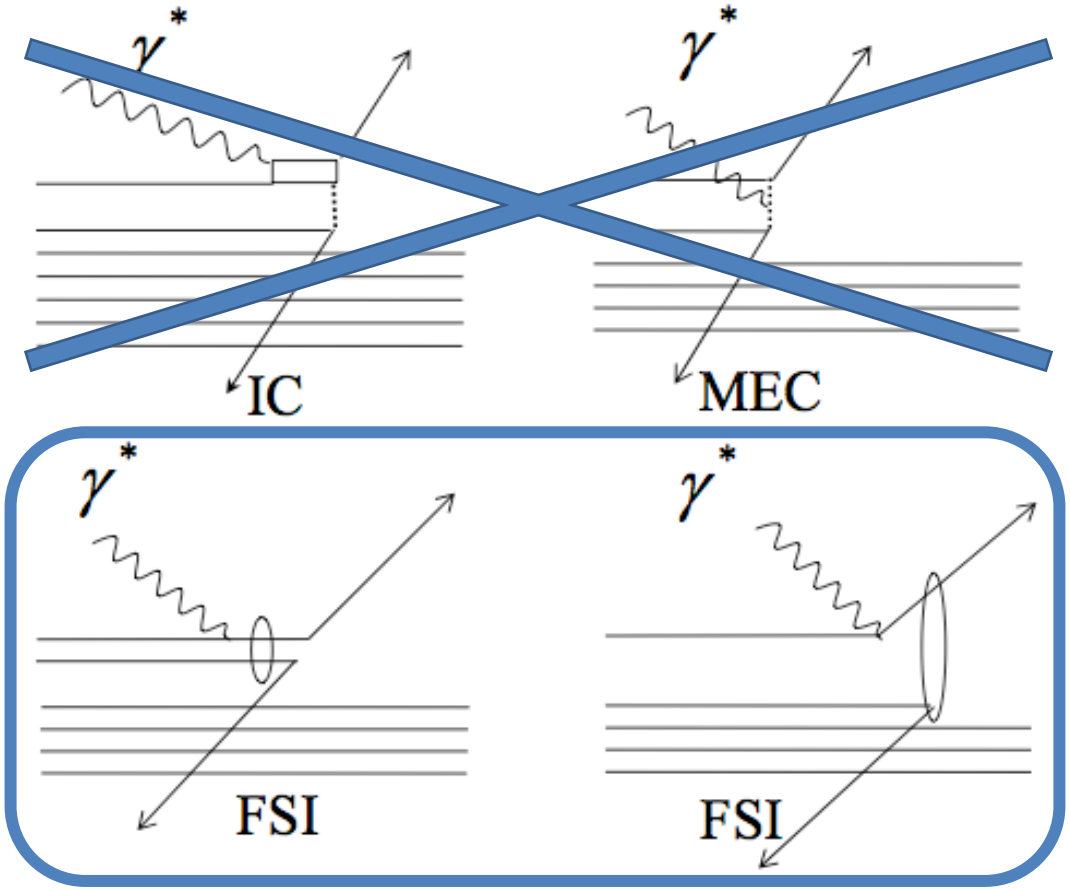
Two-Nucleon Knockout



MEC suppressed @ **high-Q^2**,
IC suppressed at **$x_B > 1$.**

Frankfurt, Sargsian, and Strikman PRC **56**, 1124 (1997).
Colle, Cosyn, and Ryckebusch, PRC **93**, 034608 (2016).

Two-Nucleon Knockout



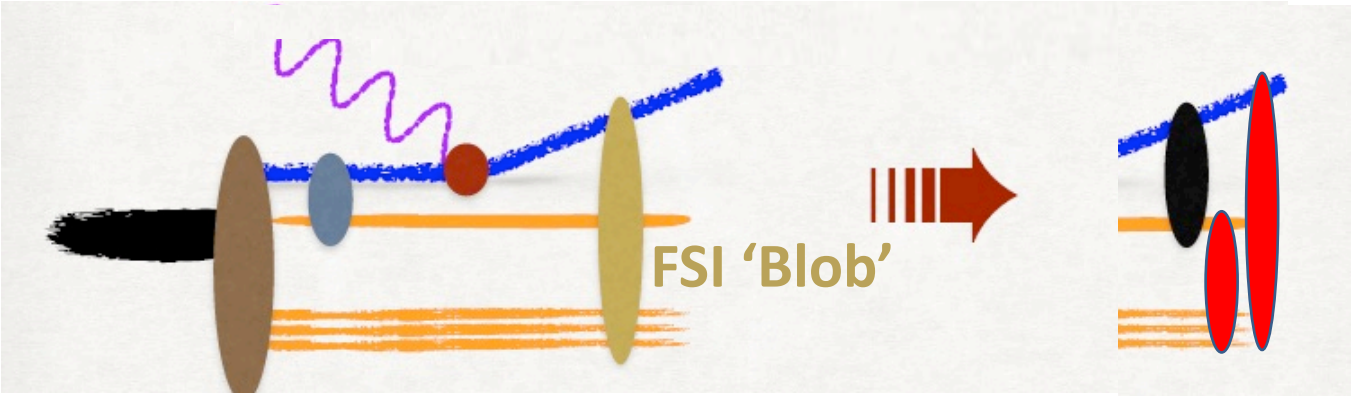
MEC suppressed @ **high-Q^2**, IC suppressed at **$x_B > 1$.**

FSI suppressed in **anti-parallel** kinematics. Treated using **Glauber** approximation.

Frankfurt, Sargsian, and Strikman PRC **56**, 1124 (1997).
Colle, Cosyn, and Ryckebusch, PRC **93**, 034608 (2016).

FSI: Theory Guidance

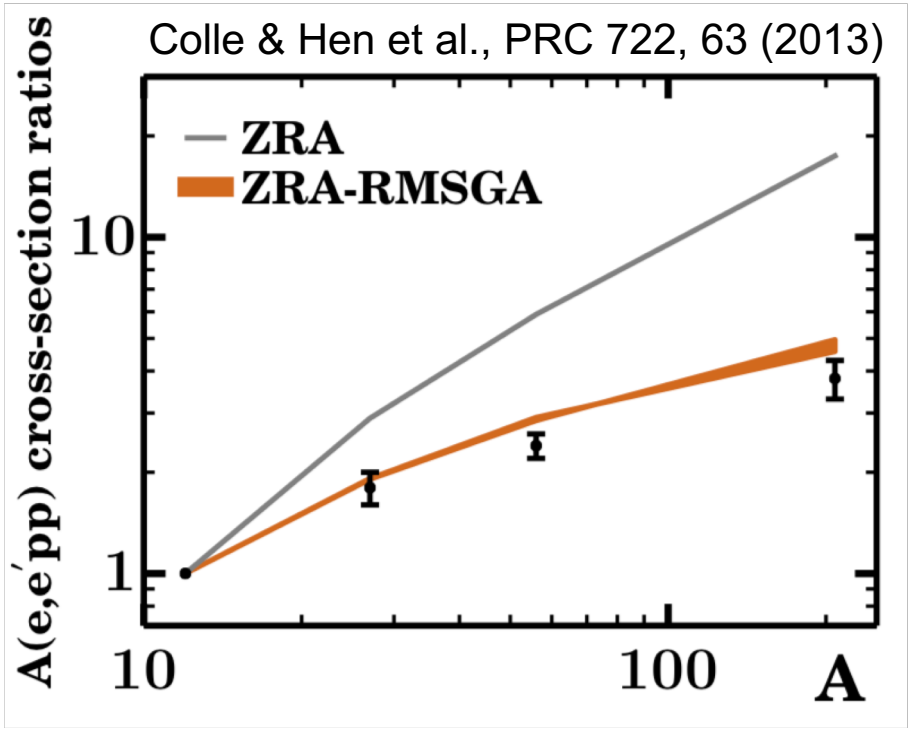
For large Q^2, x>1

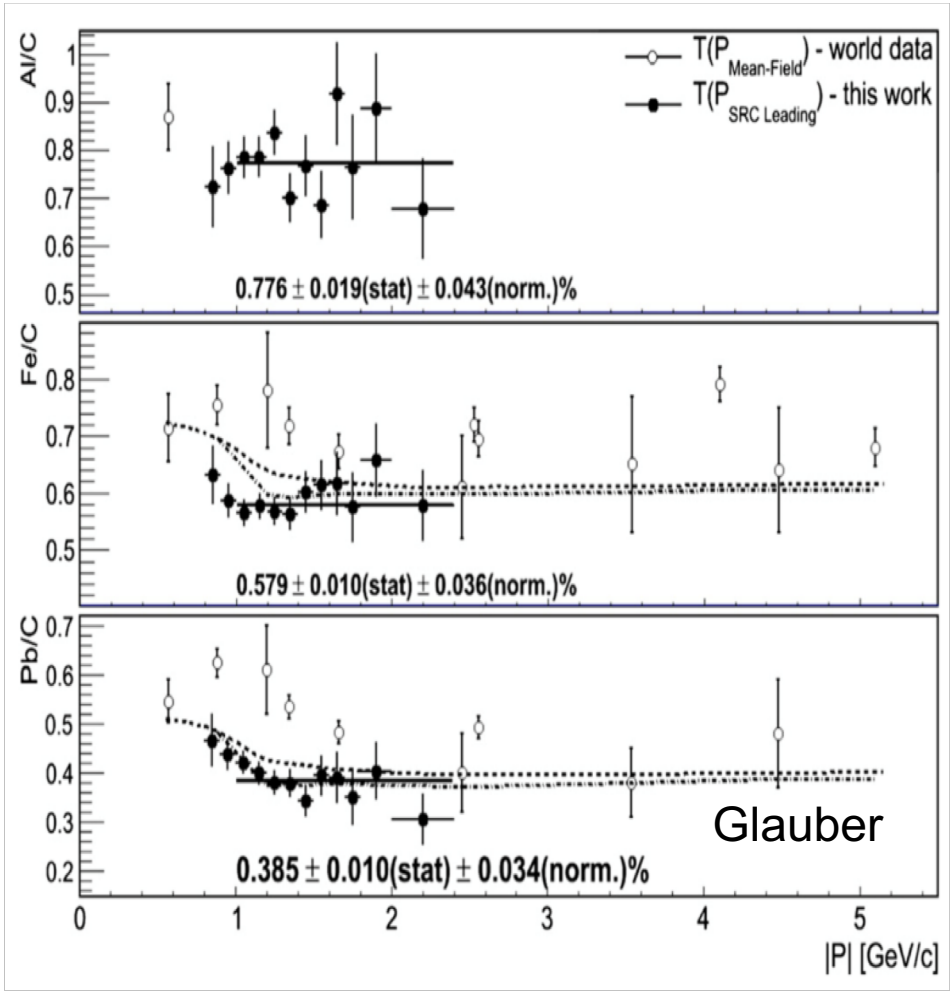


Pair rescattering:
Minimize by choosing correct kinematics

Attenuation:
Calculate using Glauber.

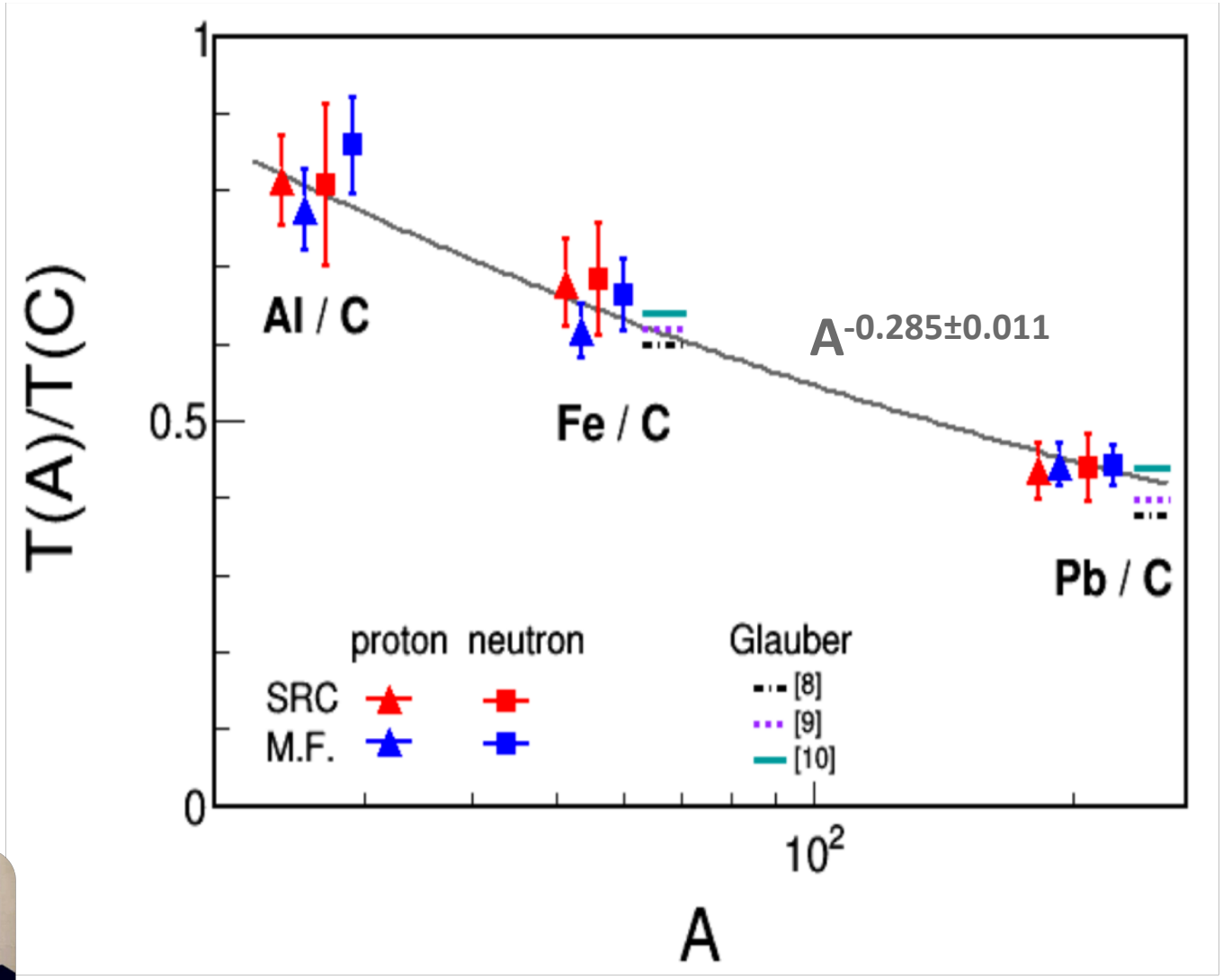
Attenuation: Glauber





Hen et al., Phys. Lett. B 722, 63 (2013)

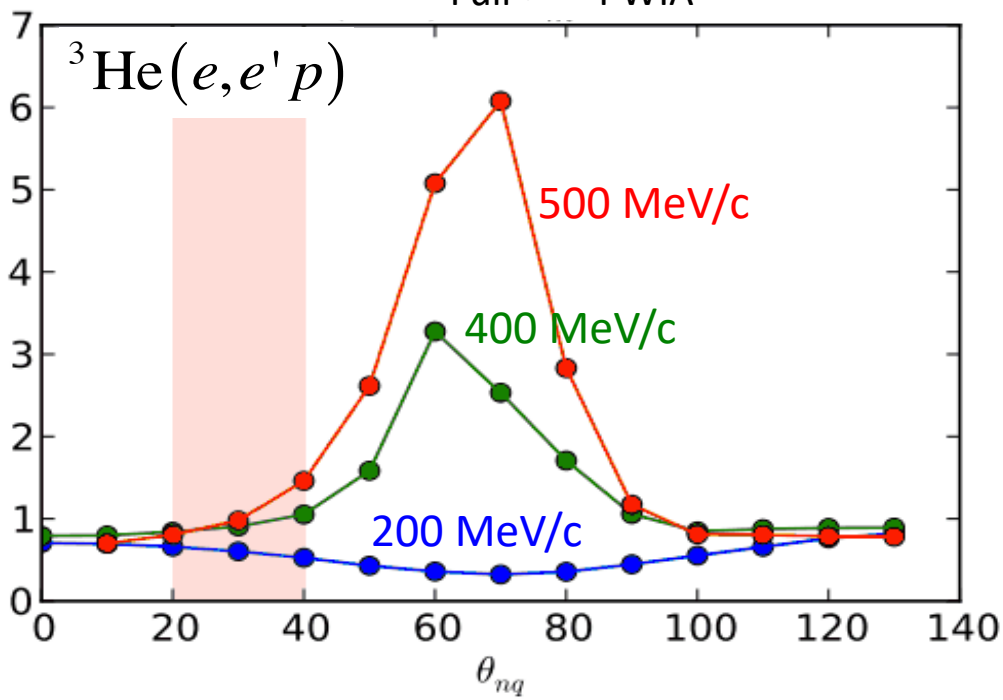
Attenuation: Glauber

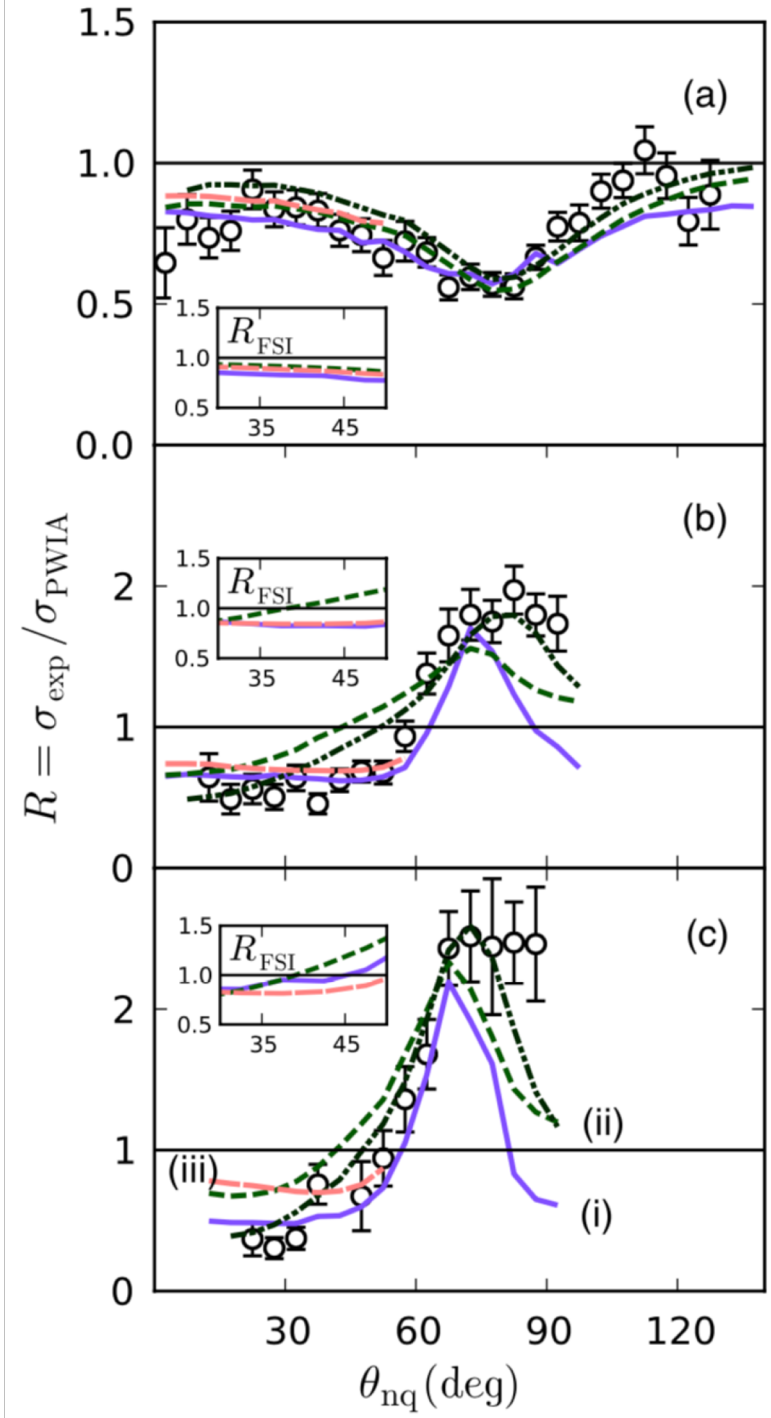


M. Duer et al., submitted (2018)

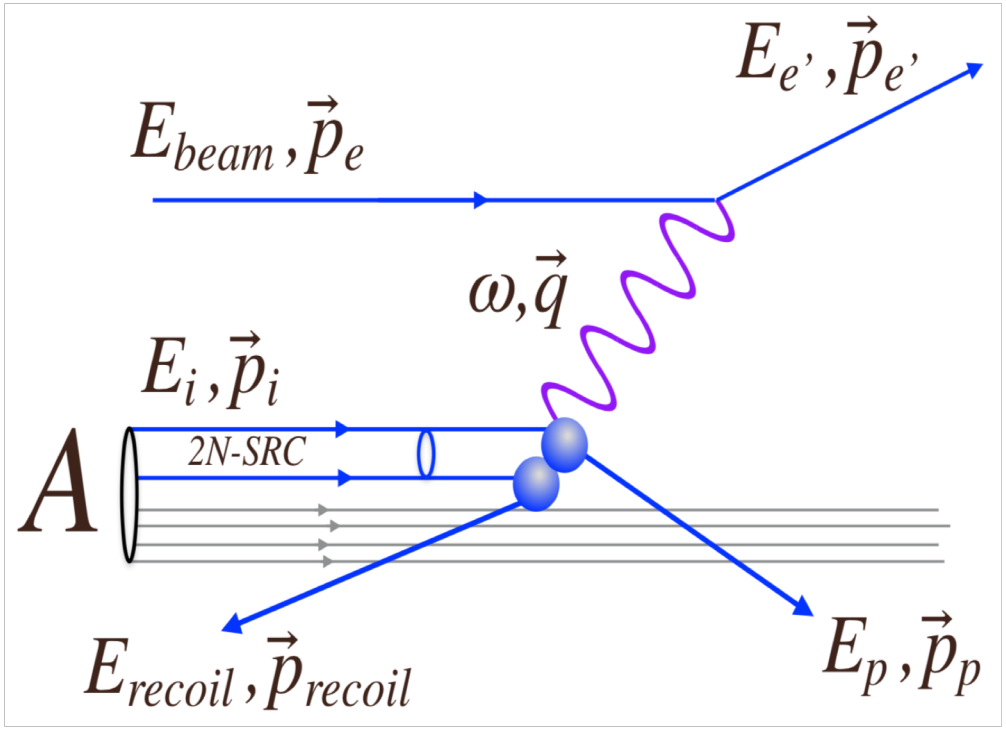
Pair Rescattering

$R = \sigma_{Full} / \sigma_{PWIA}$





M. Sargsian; Boeglin PRL (2011).



$$\vec{P}_{c.m.} = \left(\vec{P}_p - \vec{q}\right) + \vec{P}_{recoil}$$

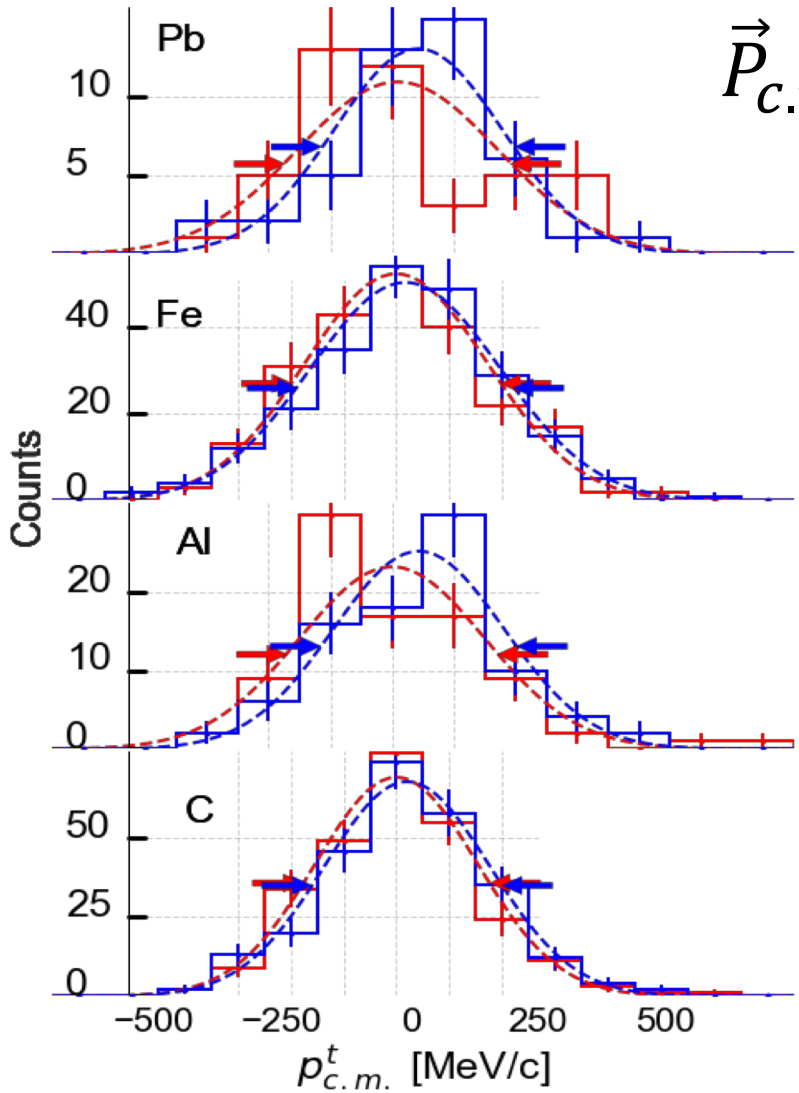
FSI Between nucleons in the pair:

$$\vec{P}_p \rightarrow \vec{P}_p + \vec{\Delta}$$
$$\vec{P}_{recoil} \rightarrow \vec{P}_{recoil} - \vec{\Delta}$$

$$\Rightarrow \vec{\boldsymbol{P}}_{c.m.} \ \boldsymbol{Invarient}$$

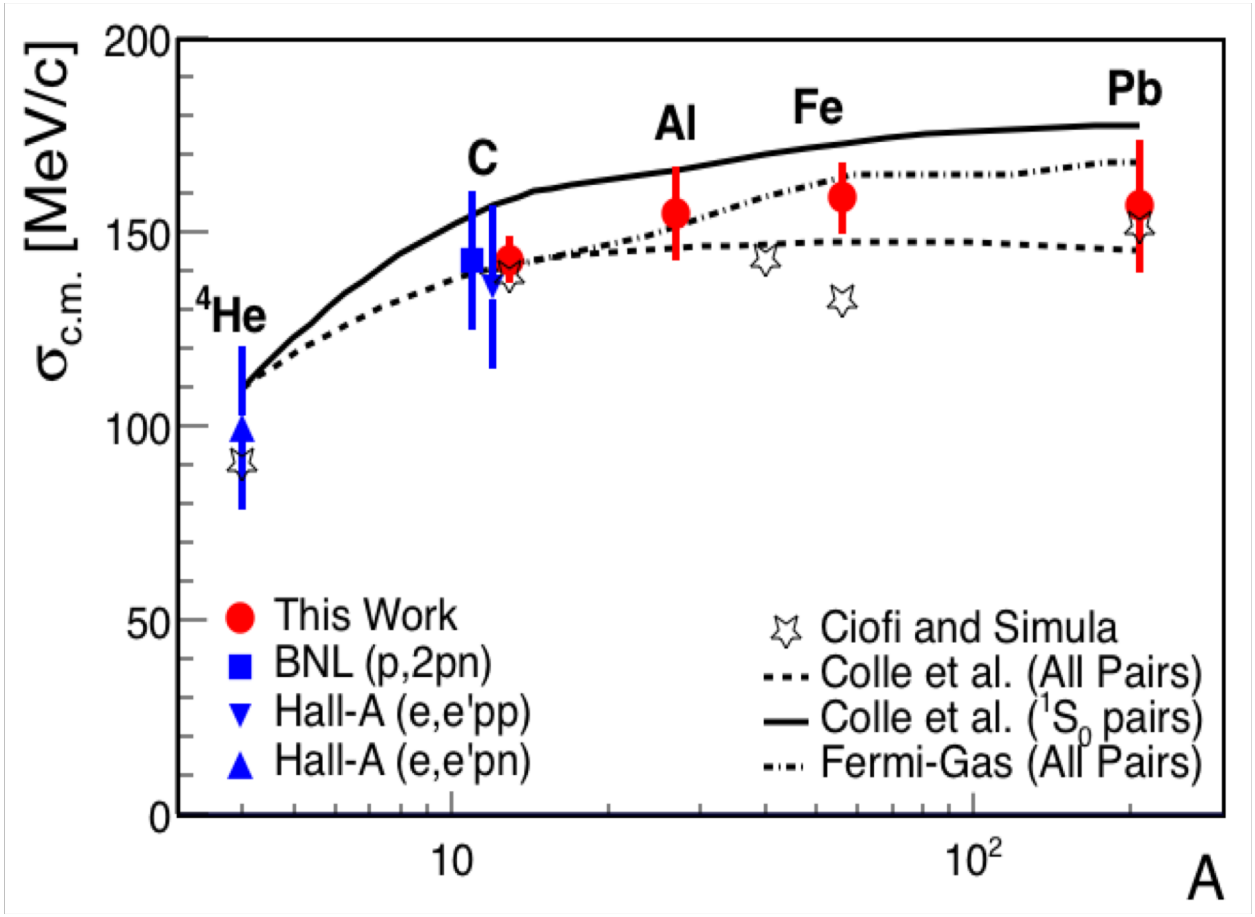
Low Pair C.M. Motion

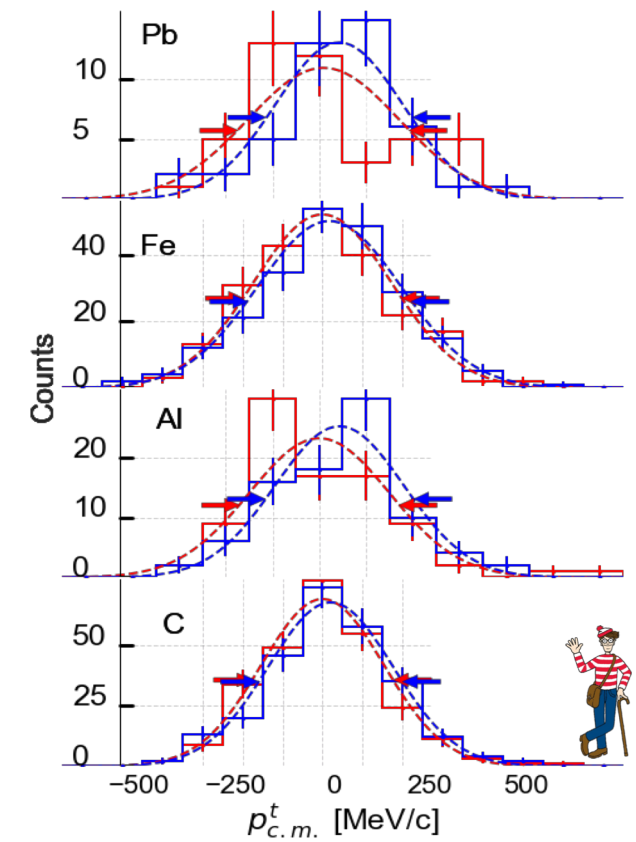
$$\vec{P}_{c.m.} = \vec{P}_{N1} + \vec{P}_{N2}$$



Cohen, PRL (2018).

Low Pair C.M. Motion

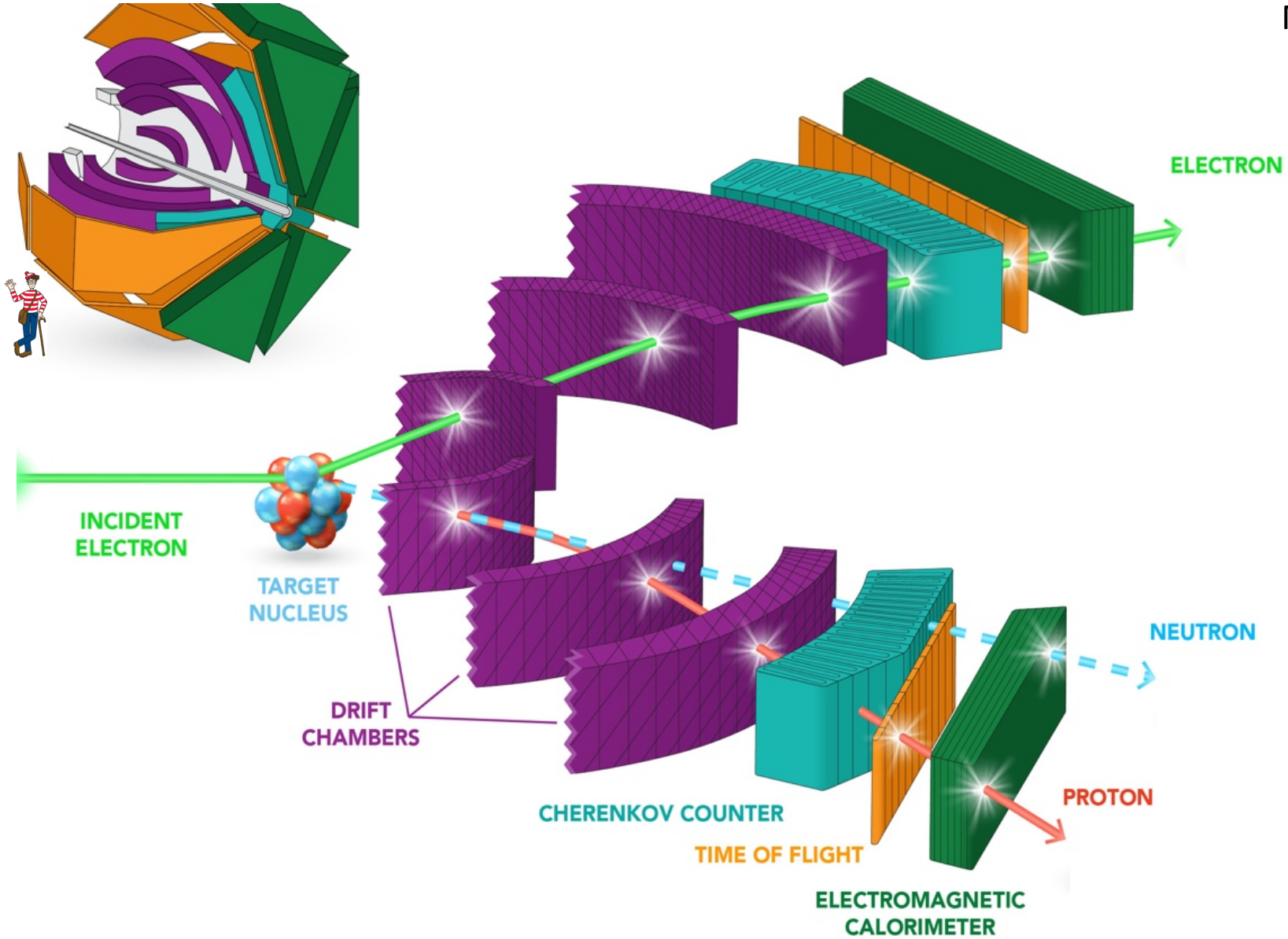




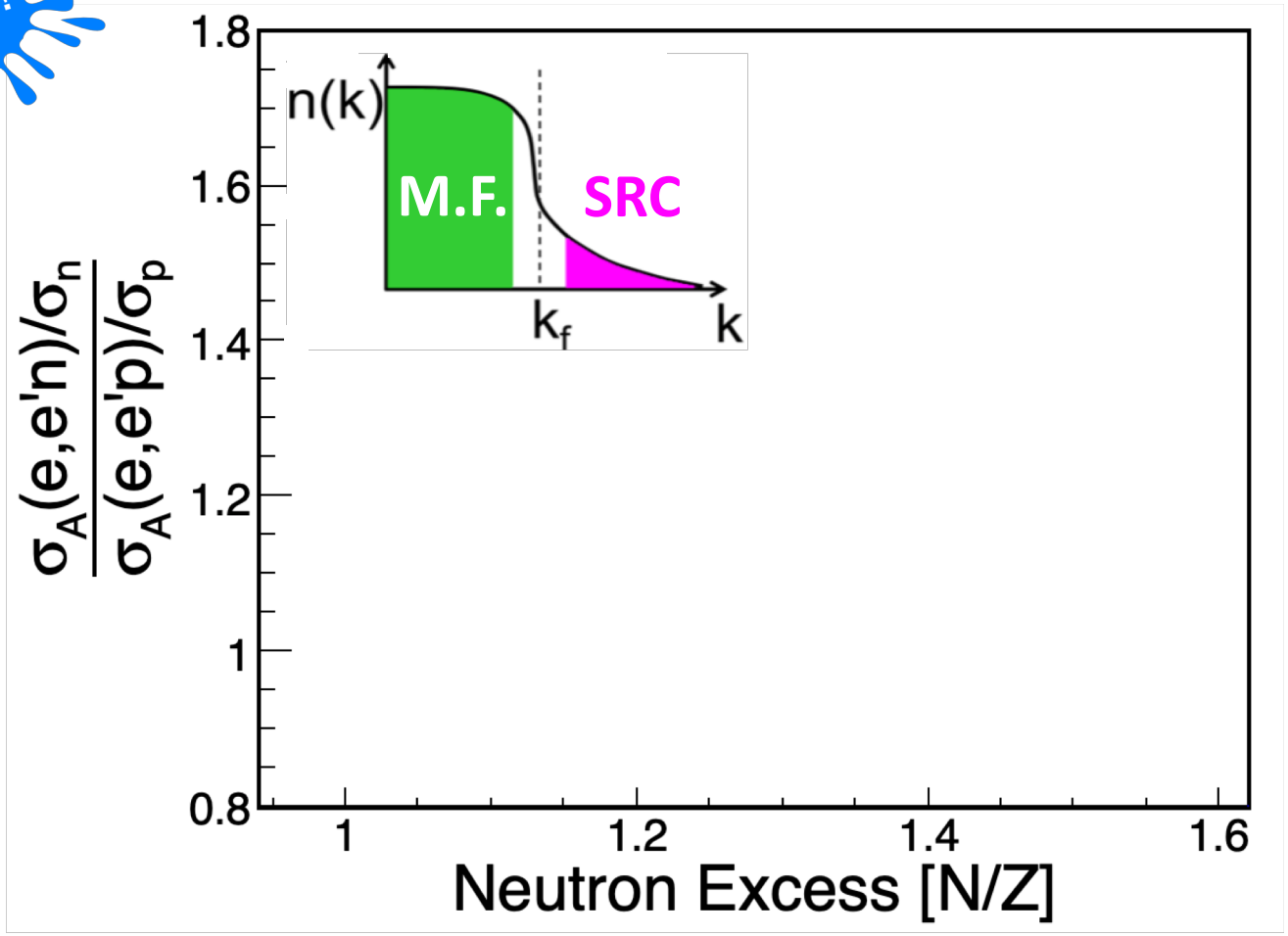
Cohen, PRL (2018).

Proton vs. Neutron Knockout

M. Duer

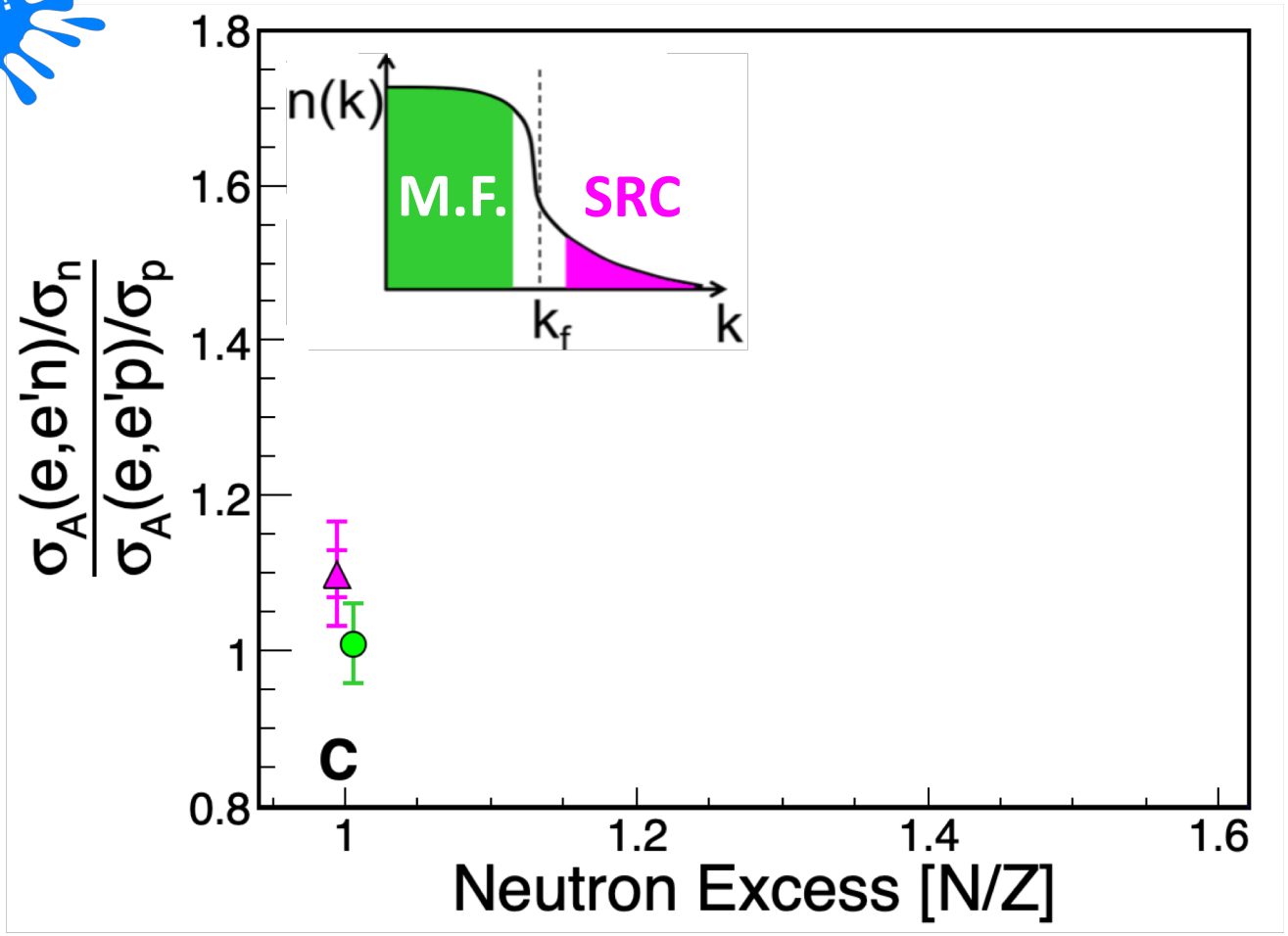


Proton / Neutron Populations



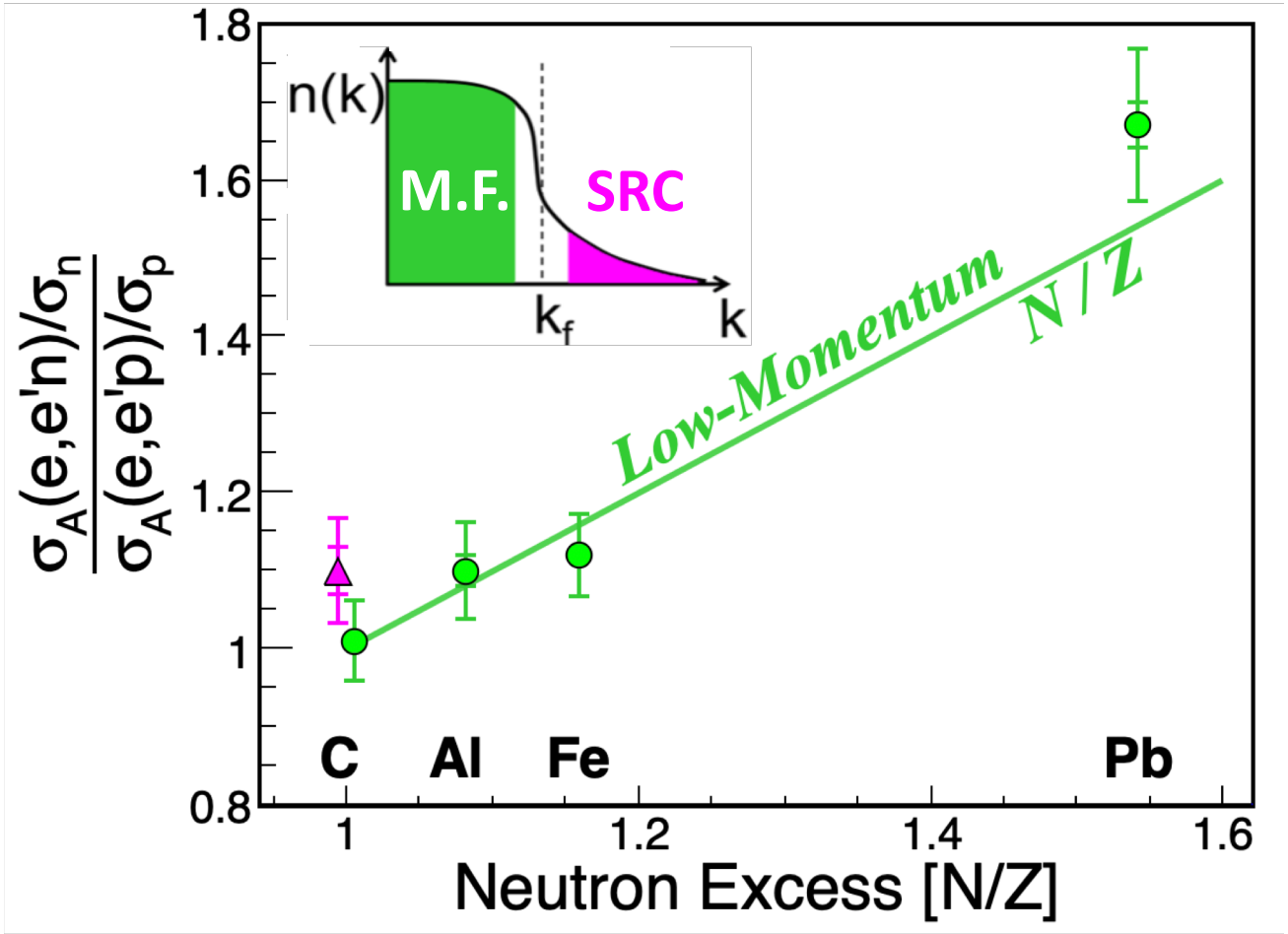
Duer et al.,
Nature (2018)

Symmetric: n/p = 1



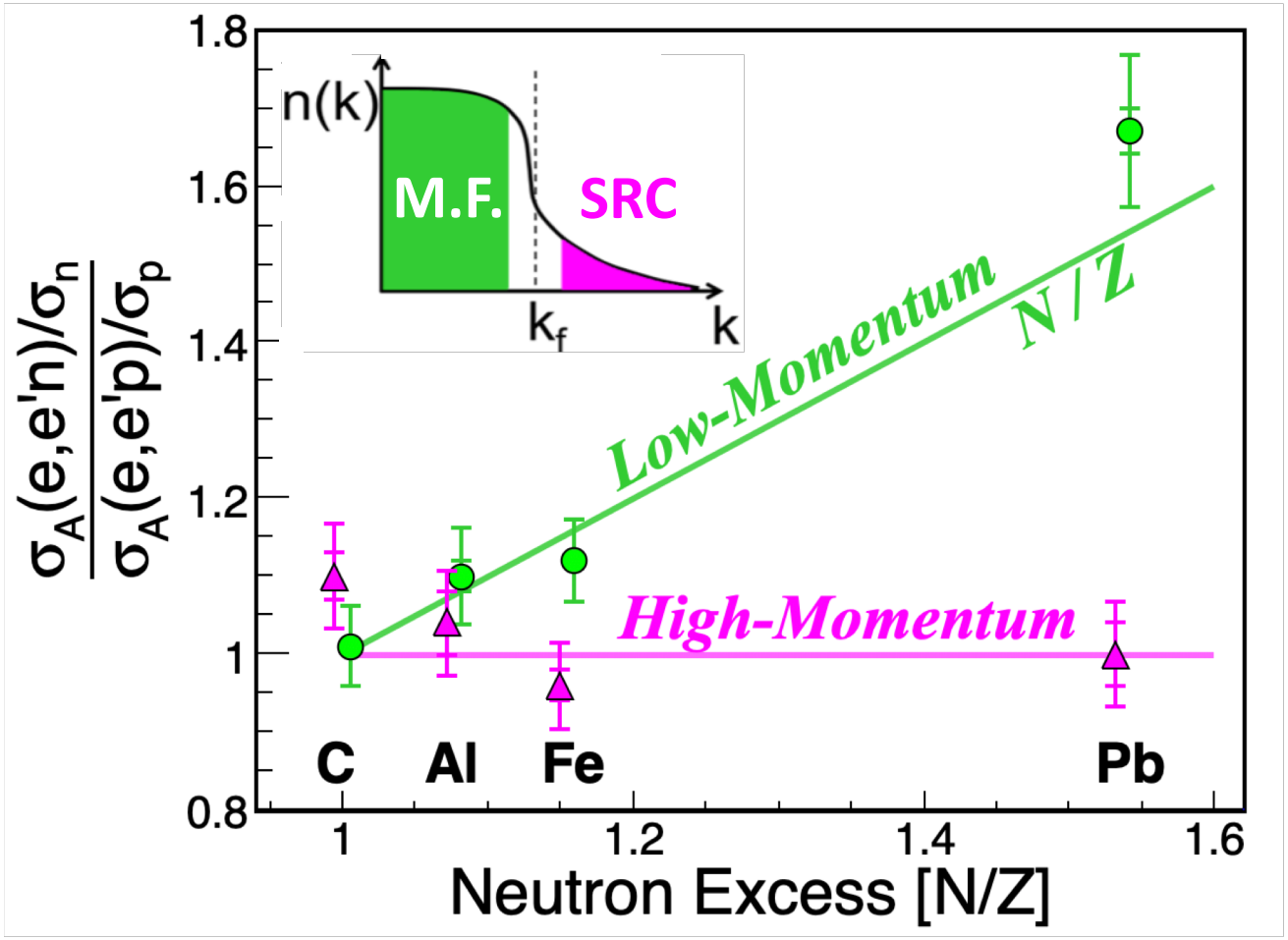
Duer et al.,
Nature (2018)

Mean-Field: n/p = N/Z



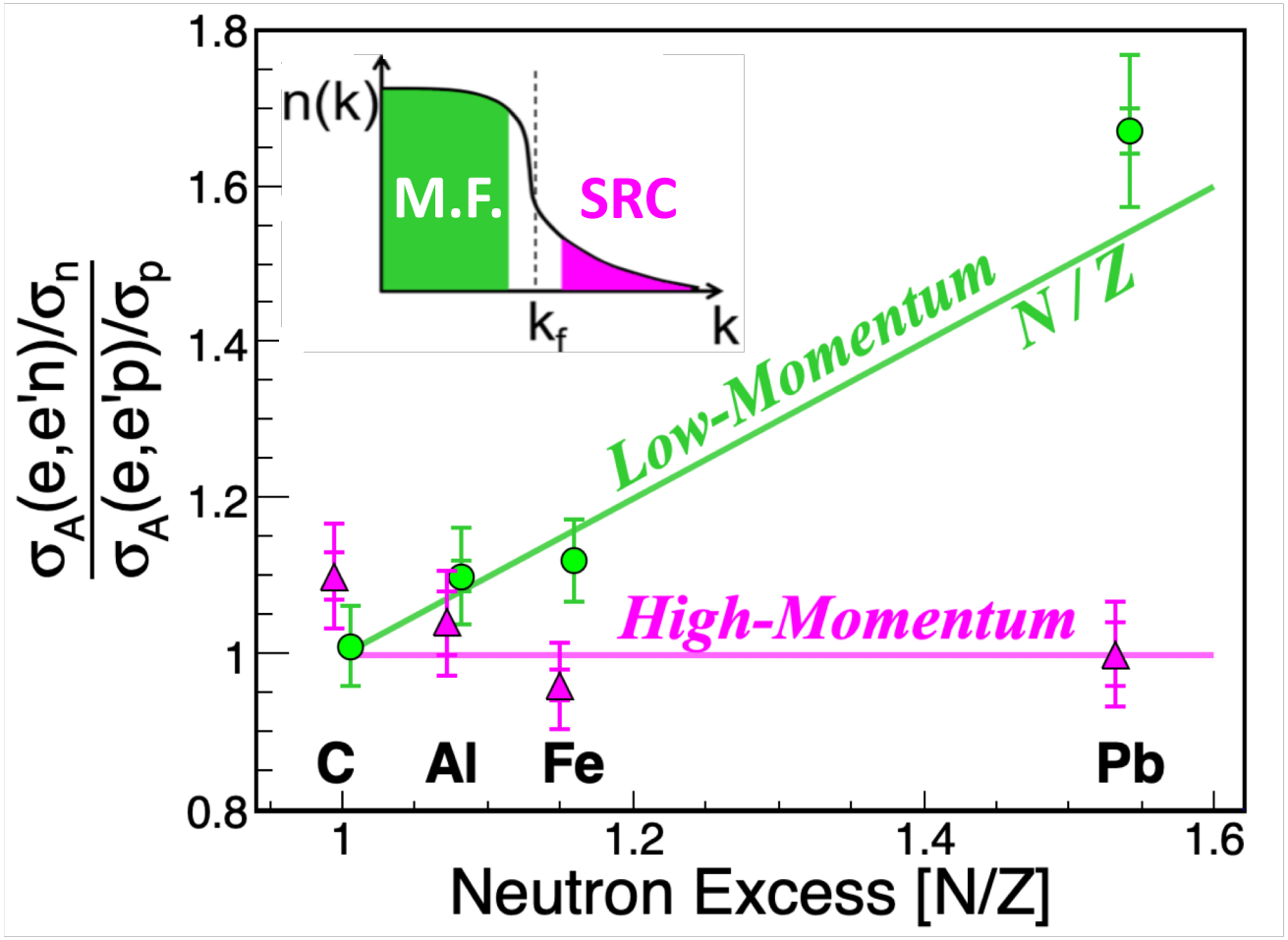
Duer et al.,
Nature (2018)

SRC: n/p = 1



Duer et al.,
Nature (2018)

➔ Same # of high-momentum protons and neutrons



Duer et al.,
Nature (2018)

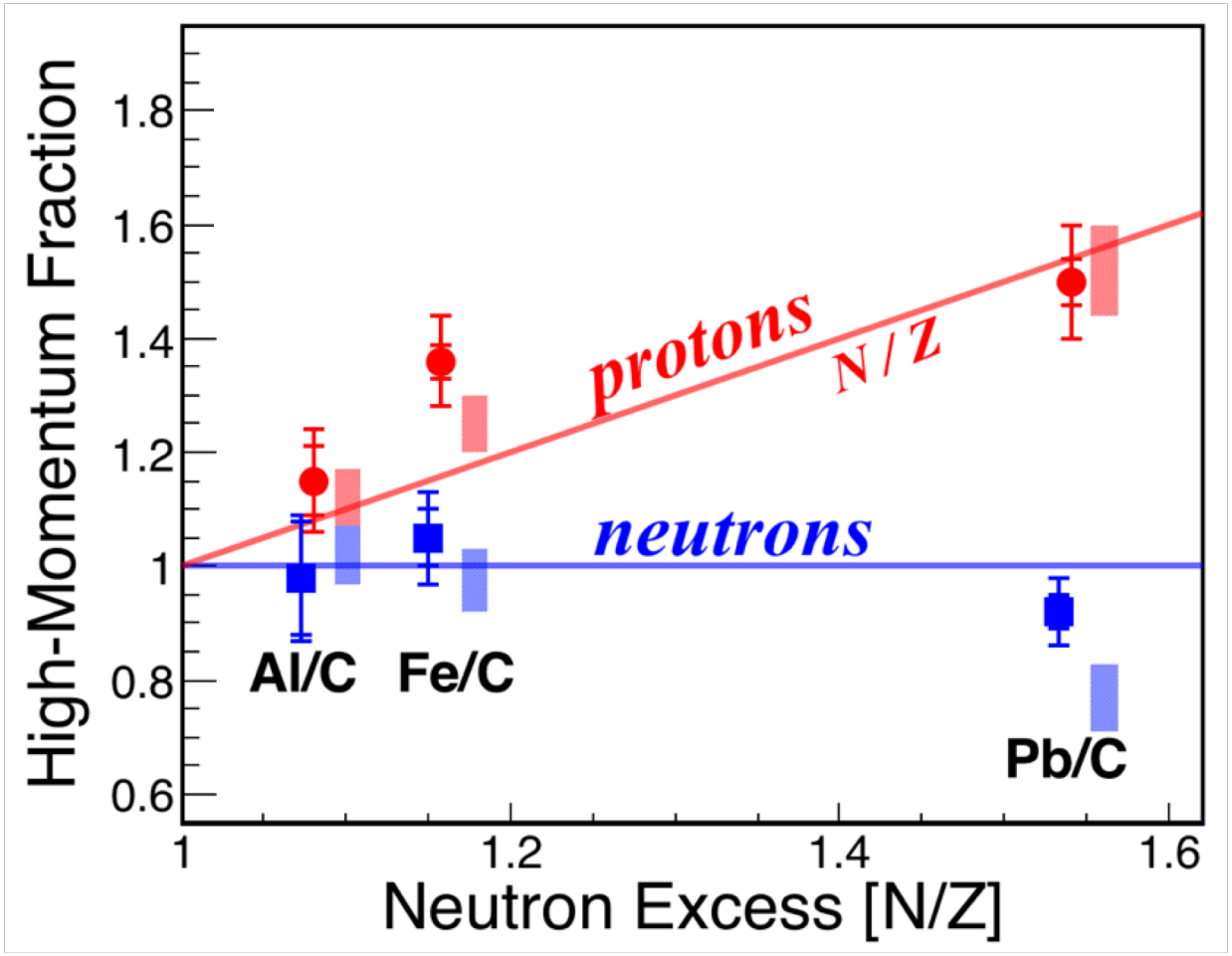
What do the outer neutrons do?

don’t correlate?

correlate with core protons?

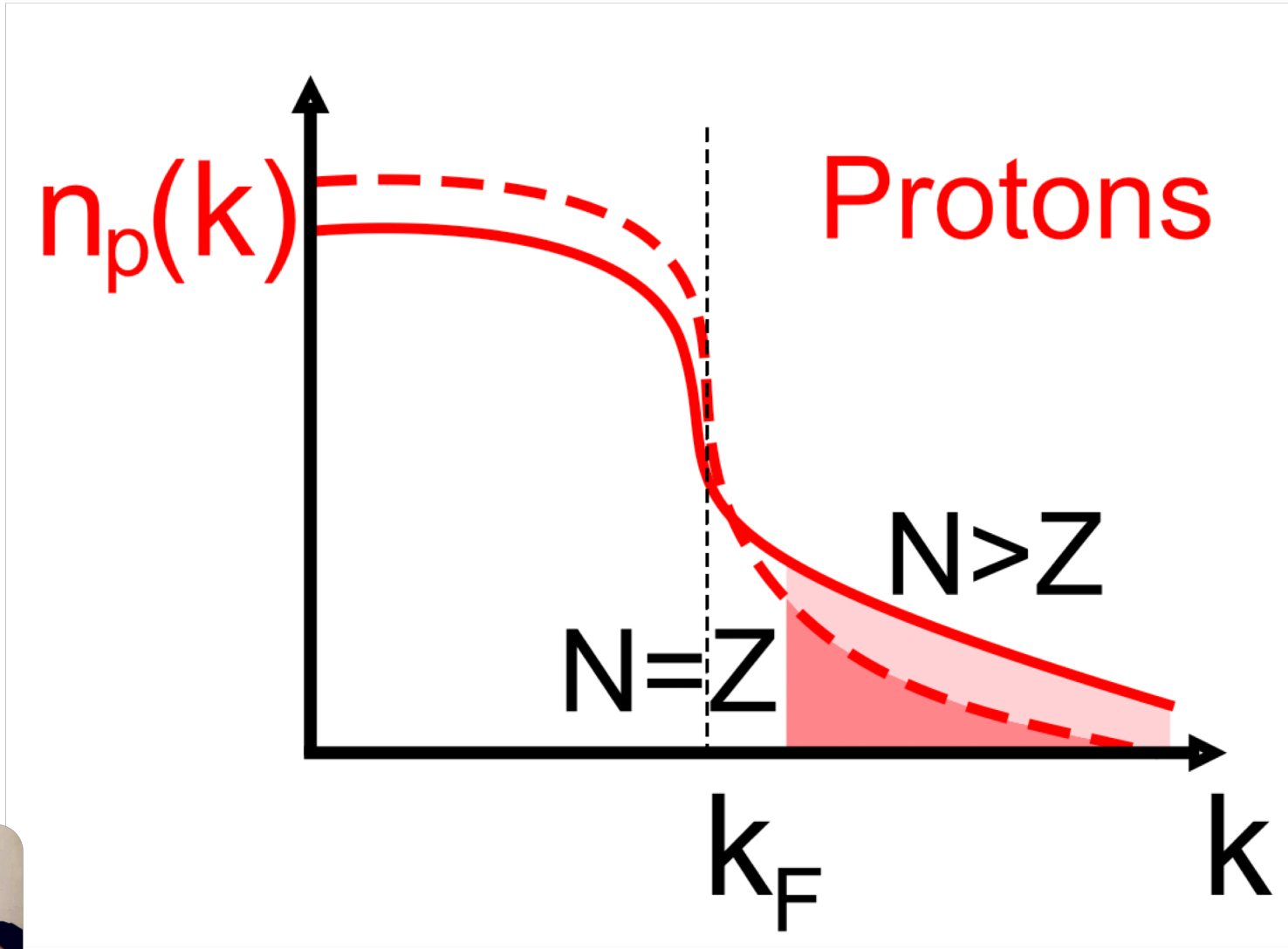
Duer et al., Nature (2018)

Correlation Probability:
Neutrons saturate Protons grow



Duer et al., Nature (2018)

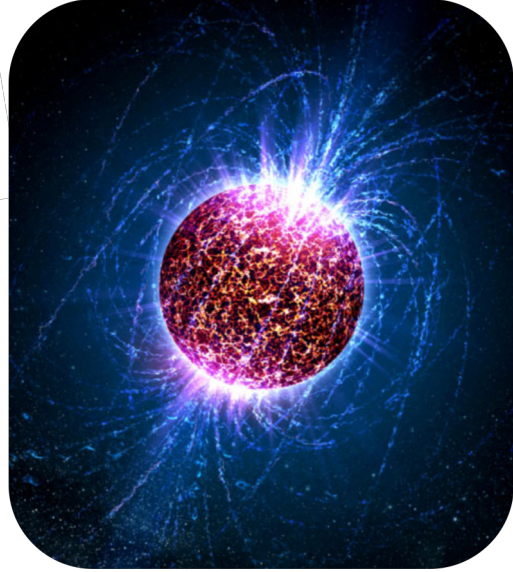
Protons ‘Speed-Up’ In Neutron-Rich Nuclei



Duer et al., Nature (2018)

Daily Press

Jefferson Lab breaks new ground, from nucleons to neutron stars

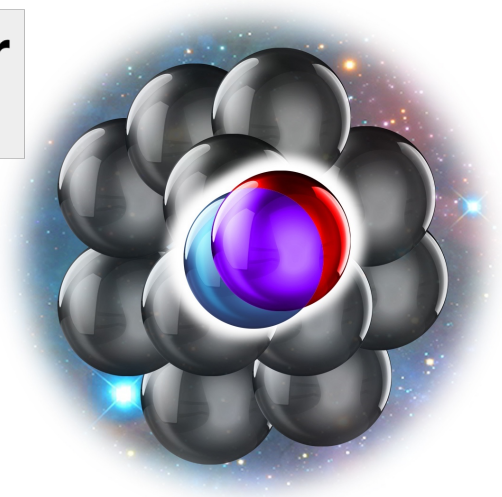


PHYS.ORG

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

Daily Press

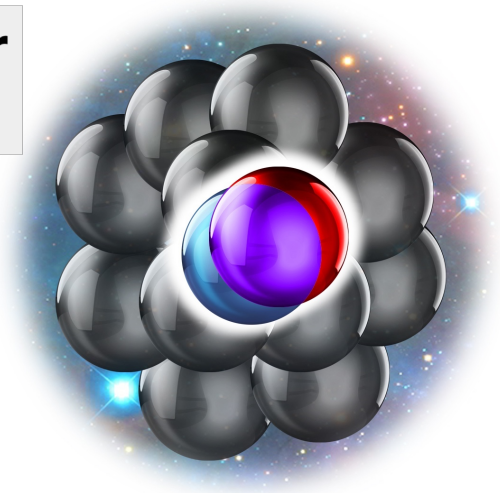
Jefferson Lab breaks new ground, from nucleons to neutron stars

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

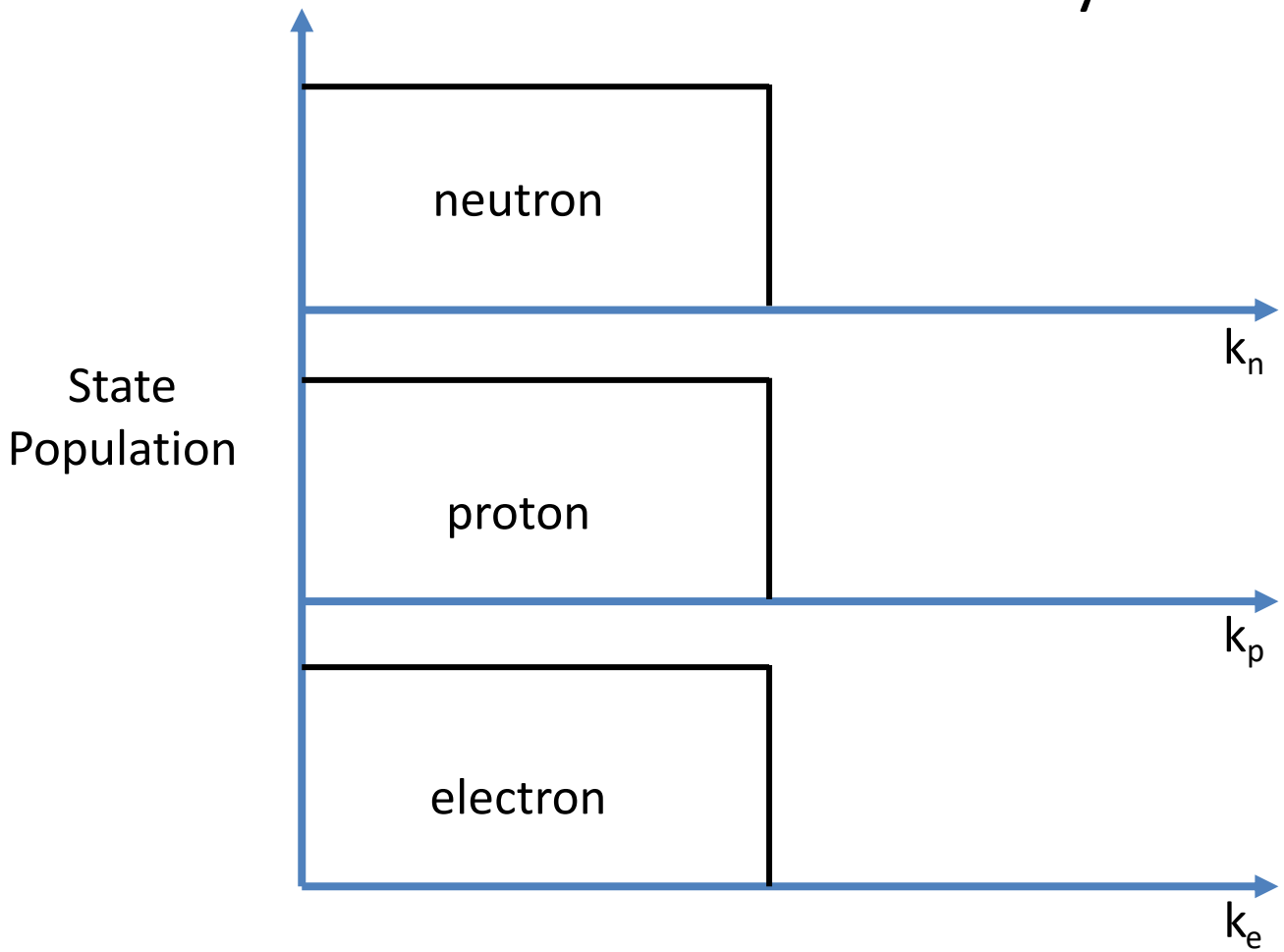
Surprising Accelerator Finding Could Change the Way We Think About Neutron Stars

Example: URCA cooling of neutron stars

$$\mathrm{n} \rightarrow \mathrm{p} + e^{-} + \bar{\nu} \quad ; \quad \mathrm{p} + e^{-} \rightarrow \mathrm{n} + \nu$$

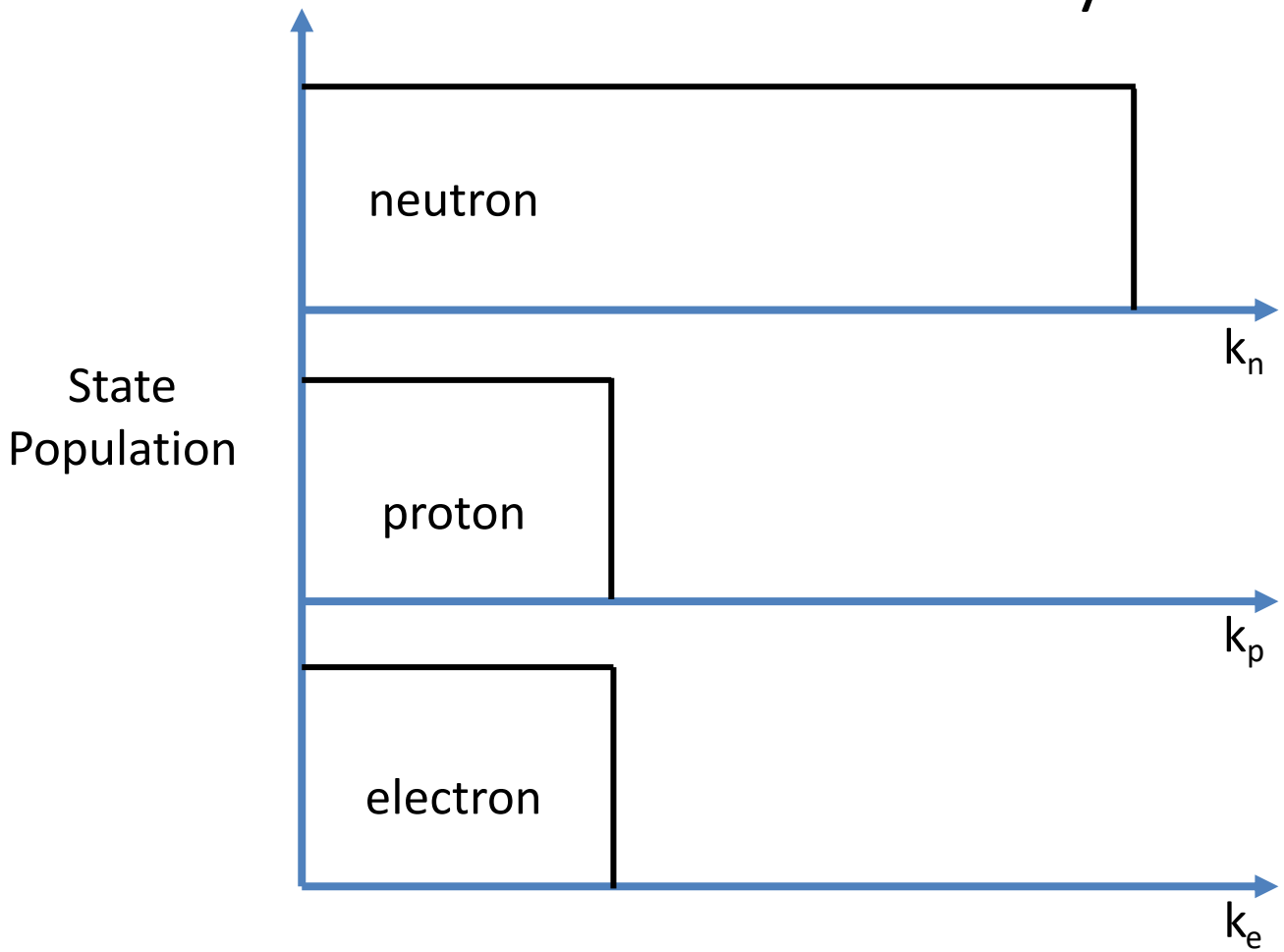
$$\mathrm{n} \rightarrow \mathrm{p} + e^{-} + \bar{\nu} \quad ; \quad \mathrm{p} + e^{-} \rightarrow \mathrm{n} + \nu$$

Symmetric Fermi-Gas



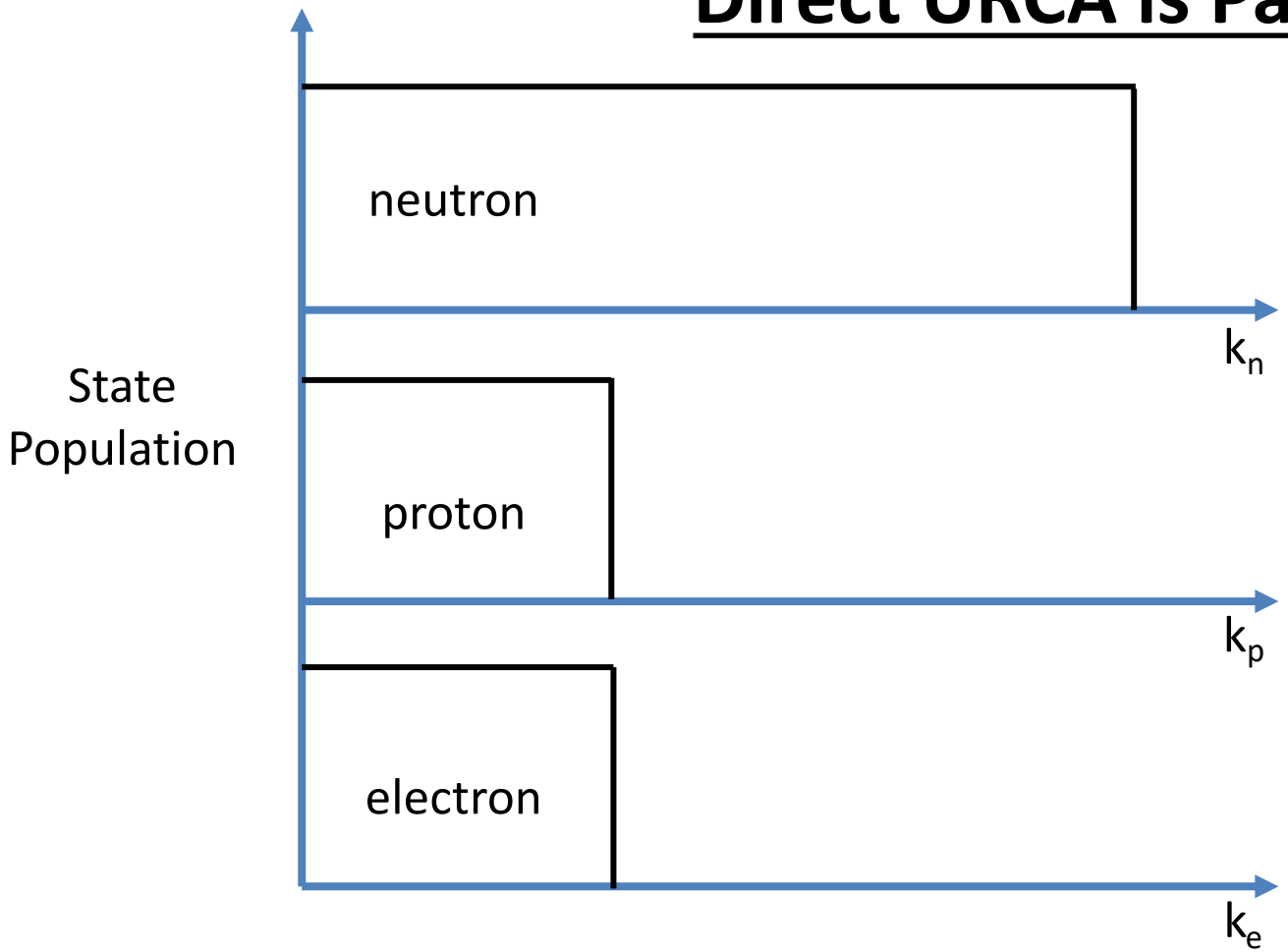
$$\mathrm{n} \rightarrow \mathrm{p} + e^{-} + \bar{\nu} \;\; ; \;\; \mathrm{p} + e^{-} \rightarrow \mathrm{n} + \nu$$

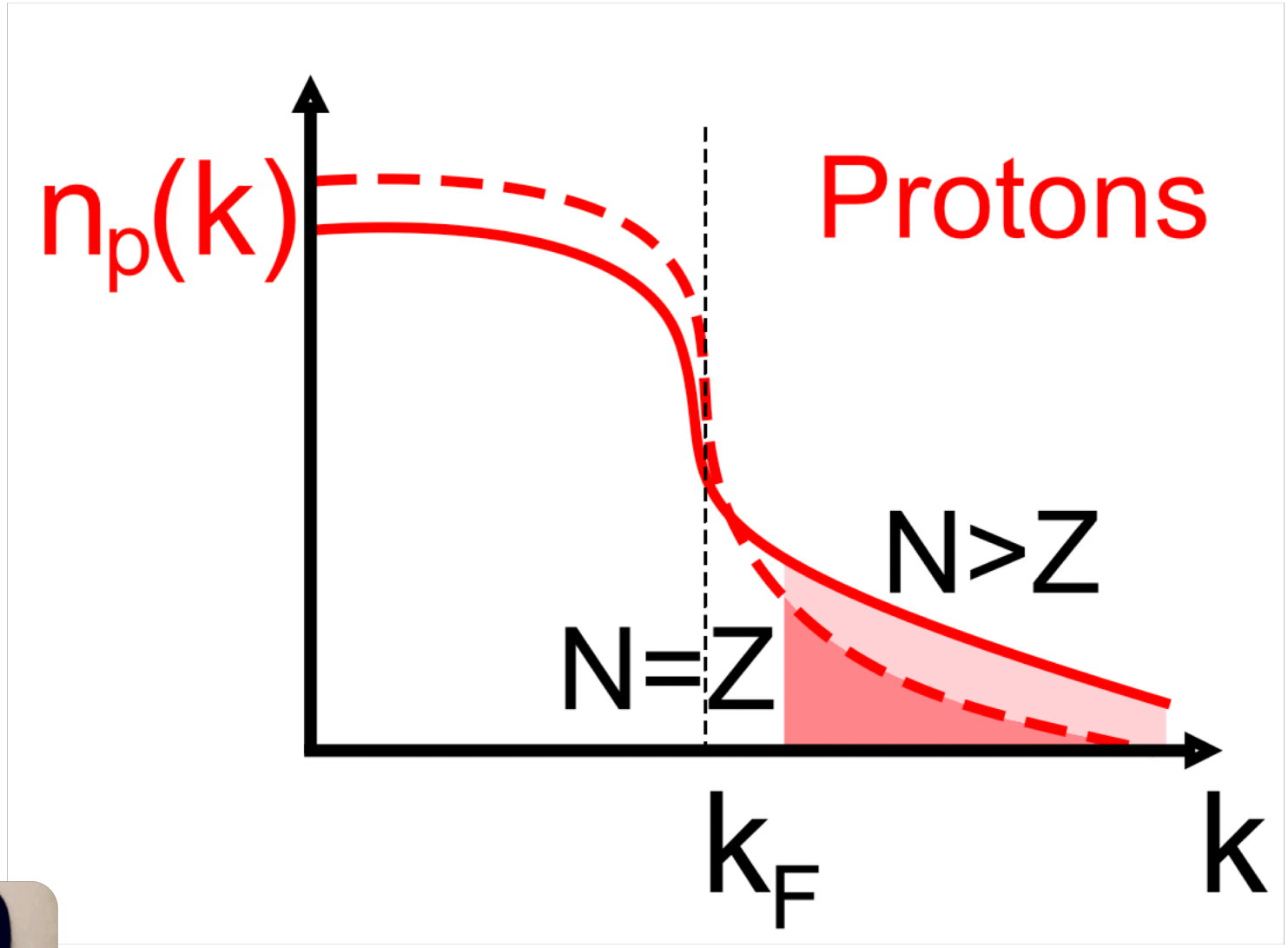
Asymmetric Fermi-Gas



$$\mathrm{n} \rightarrow \mathrm{p} + e^{-} + \bar{\nu} \;\; ; \;\; \mathrm{p} + e^{-} \rightarrow \mathrm{n} + \nu$$

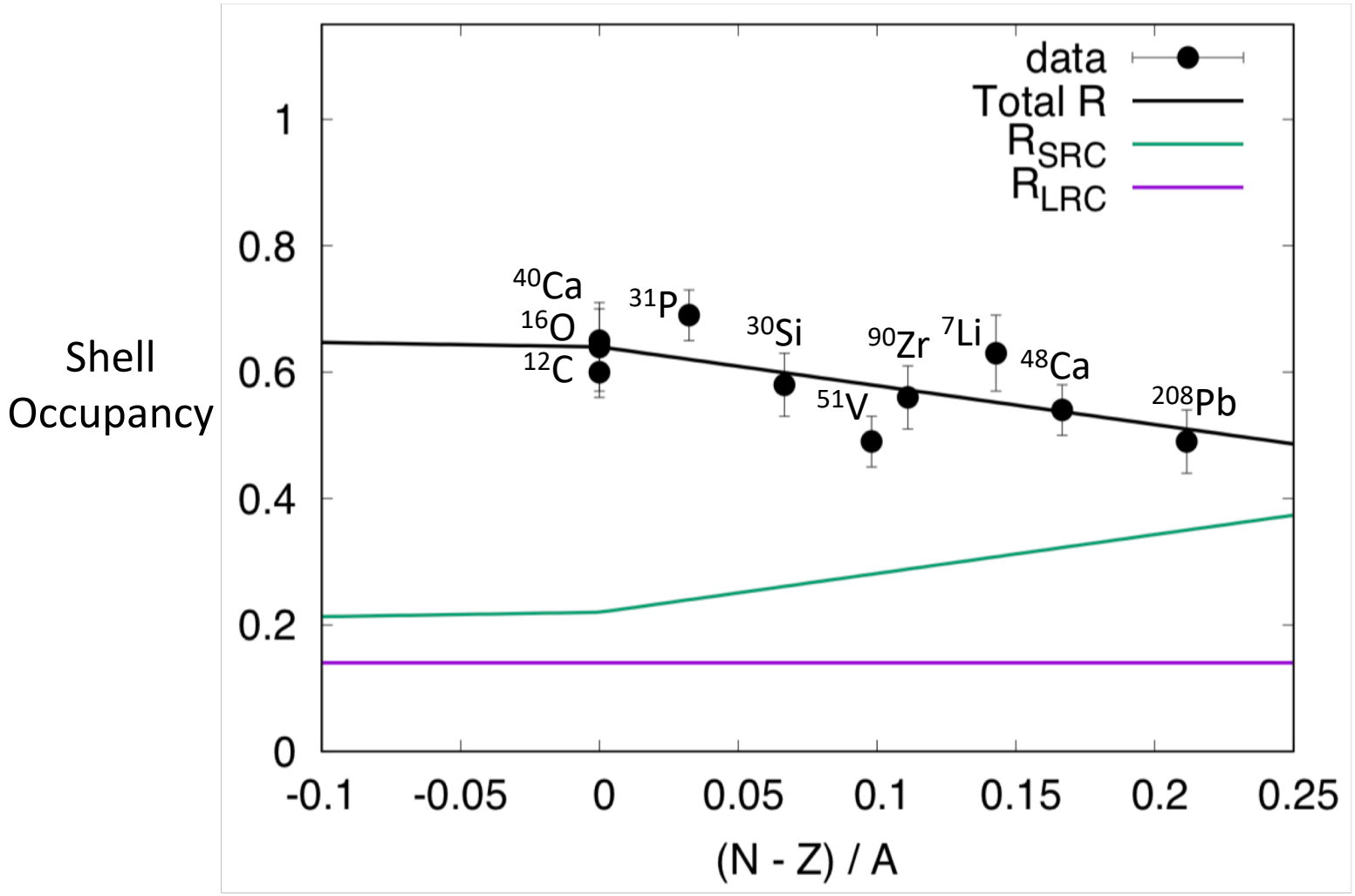
Direct URCA is Pauli blocked!





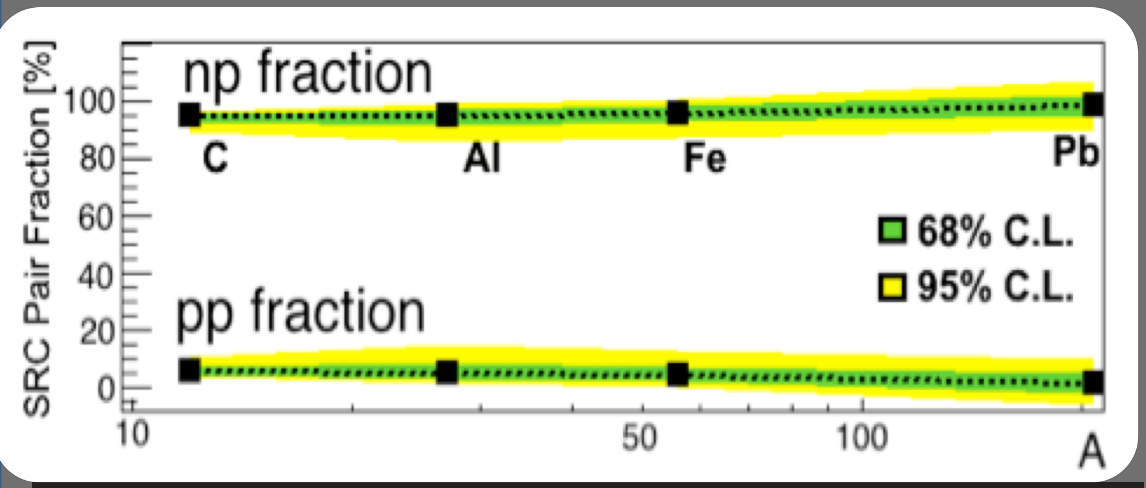
Duer et al., Nature (2018)

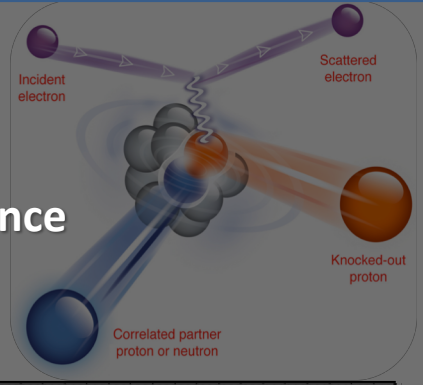
Proton decrees visible also @ low-momentum!



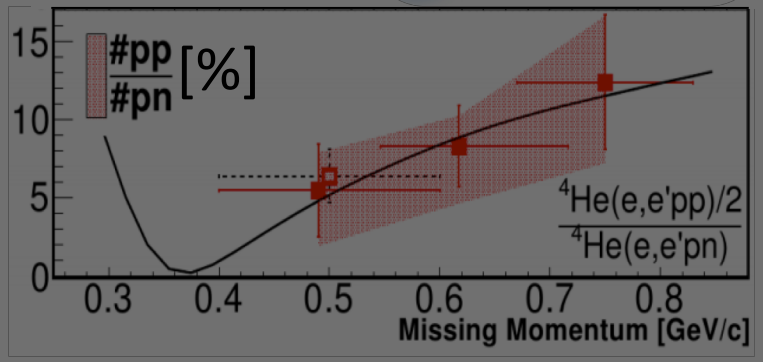
Paschalis, Petri, Macchiavelli, Hen, and Piasetzky, arXiv 1812.08051 (2018)

np dominance results





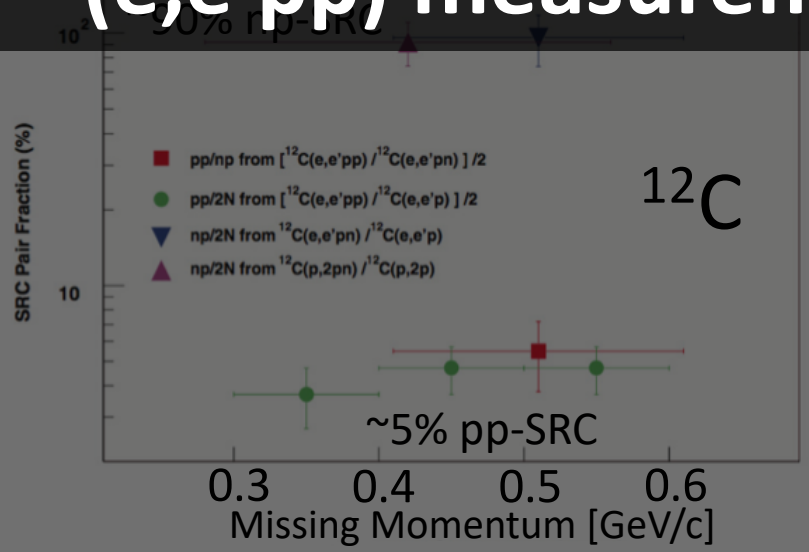
O. Hen et al., Science 364 (2014) 614

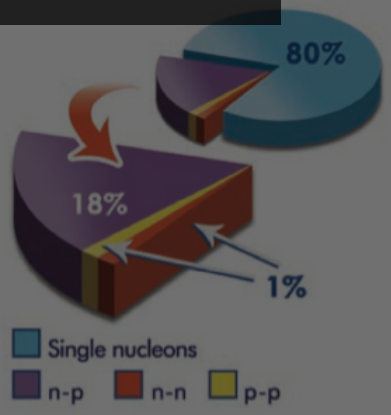


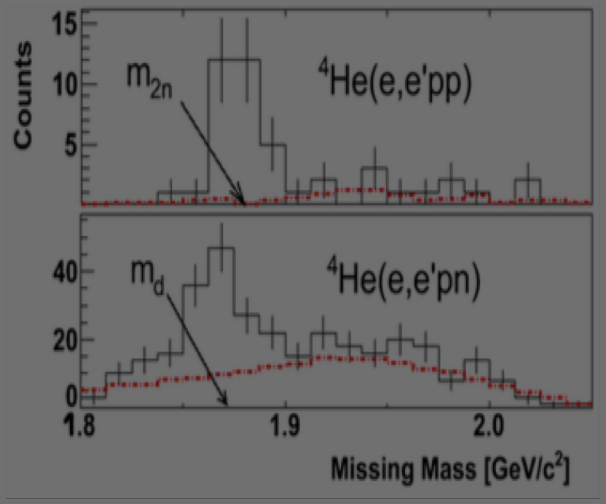
I. Korover et al., PRL 113 (2014) 022501

^^ Inferred from (e,e'p) & (e,e'pp) measurements

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





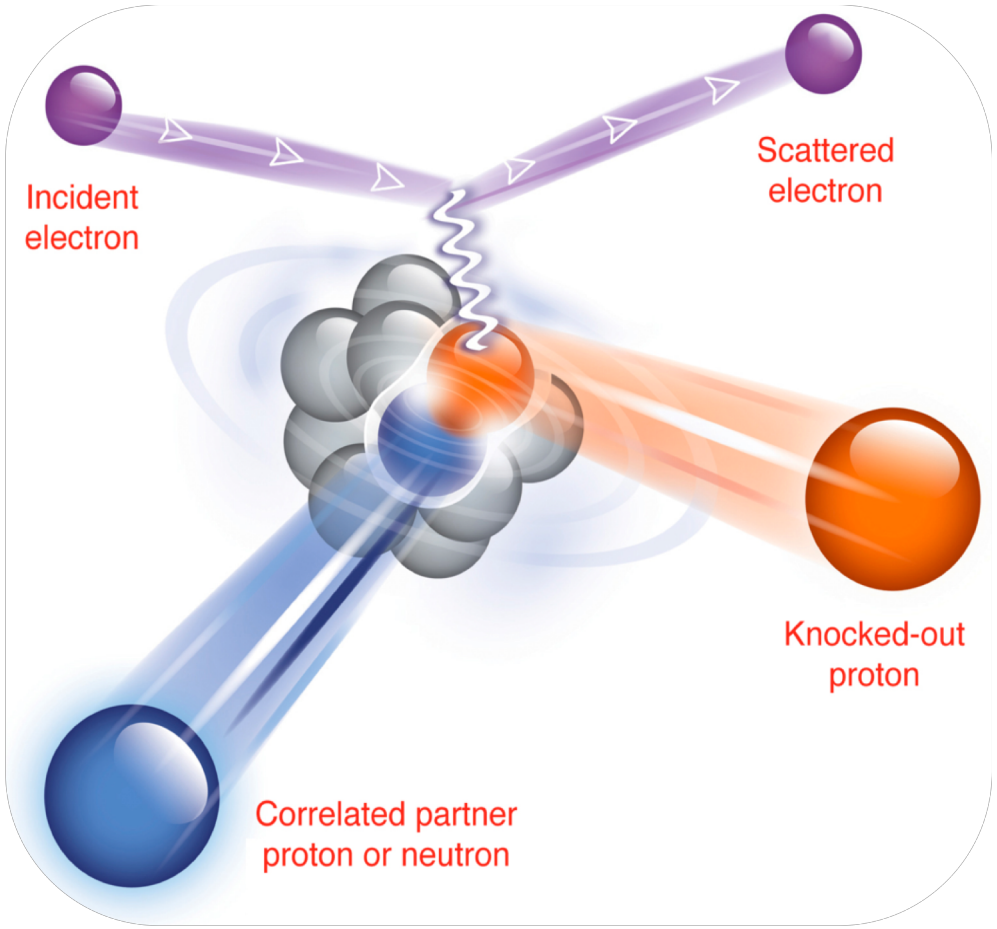


A. Tang et al., PRL (2003); E. Piasetzky et al., PRL (2006); R. Shneor et al., PRL (2007)

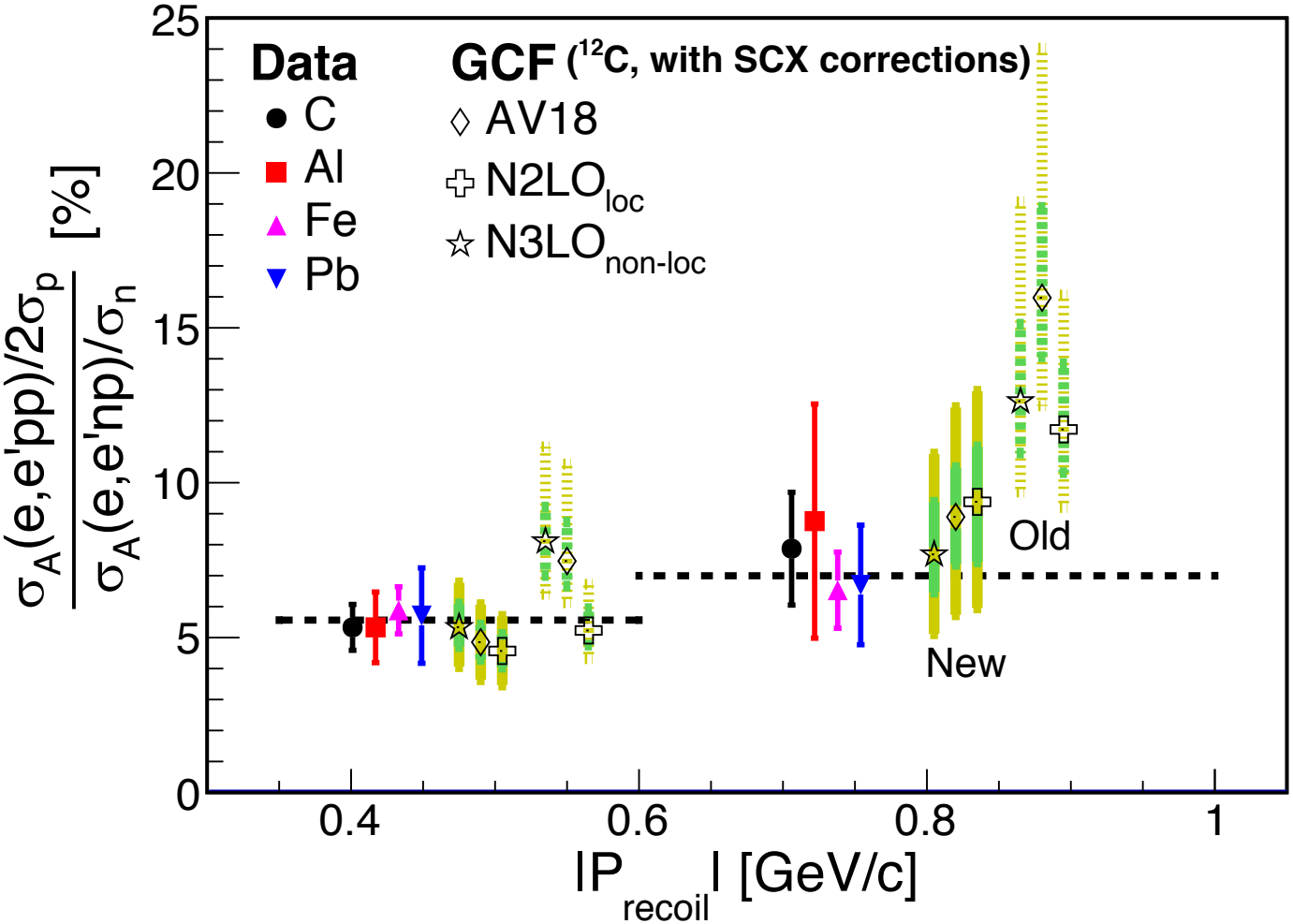
Breakup the pair =>

Detect ***both*** nucleons =>

Reconstruct 'initial' state

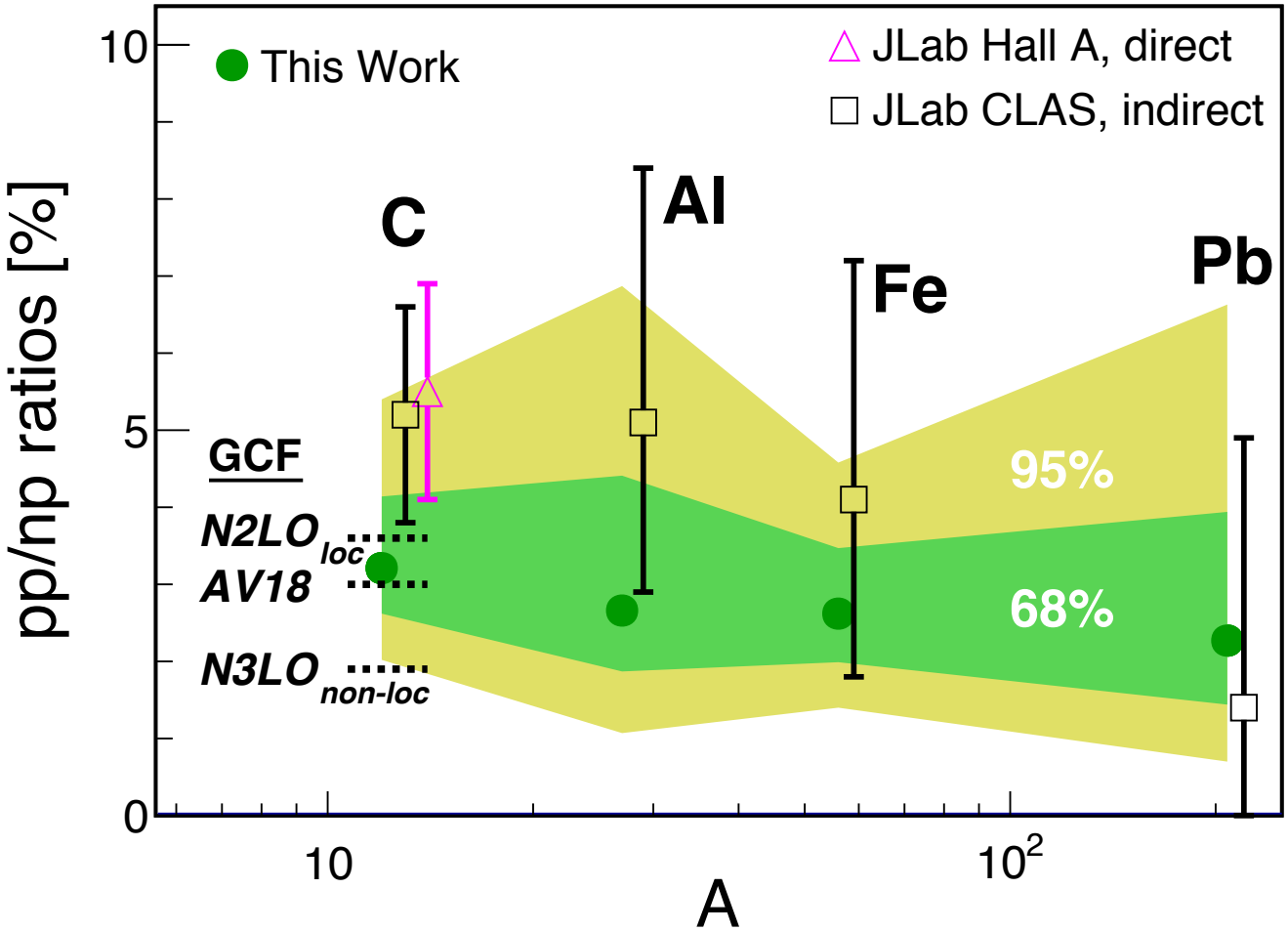


Starting to describe cross-sections!



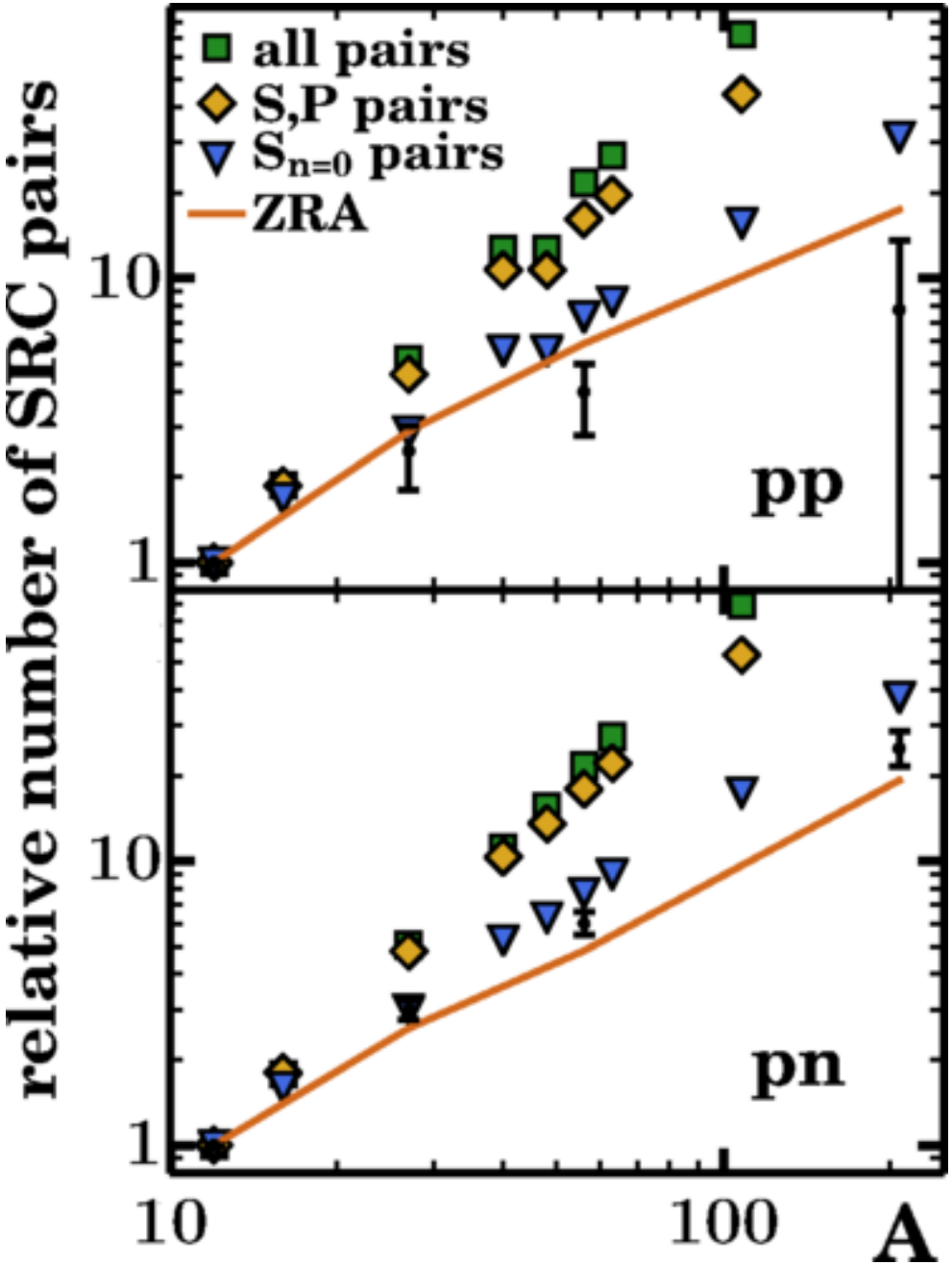
Duer, submitted (2018); Duer, Nature (2018); Hen, Science (2014); Korover, PRL (2014); Subedi, Science (2008); Shneor, PRL (2007); Piasetzky, PRL (2006); Tang, PRL (2003); Review: Hen RMP (2017);

np dominate in all interactions!

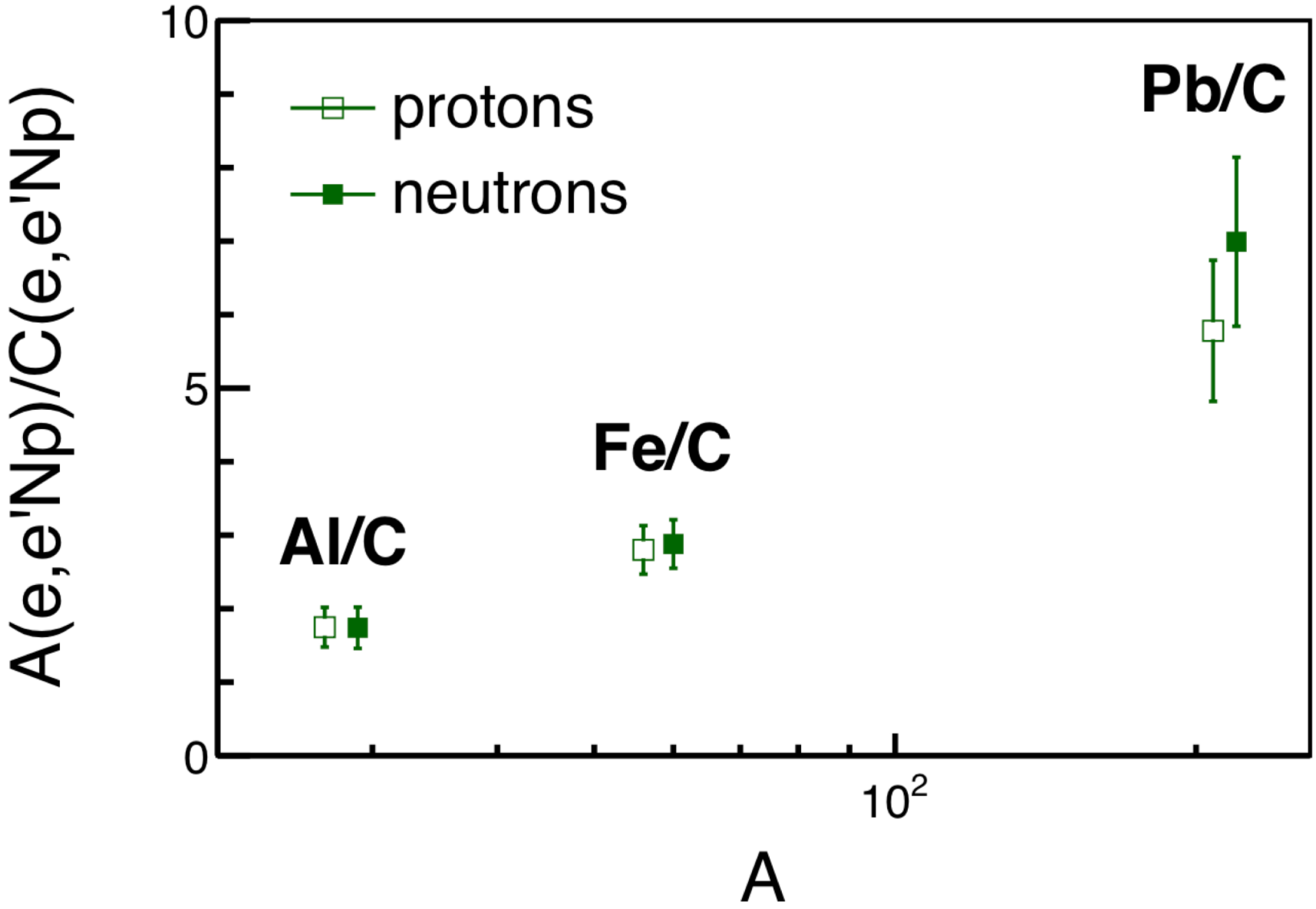


Duer, submitted (2018); Duer, Nature (2018); Hen, Science (2014); Korover, PRL (2014); Subedi, Science (2008); Shneor, PRL (2007); Piasetzky, PRL (2006); Tang, PRL (2003); Review: Hen RMP (2017);

Other pair properties: A – Dependence



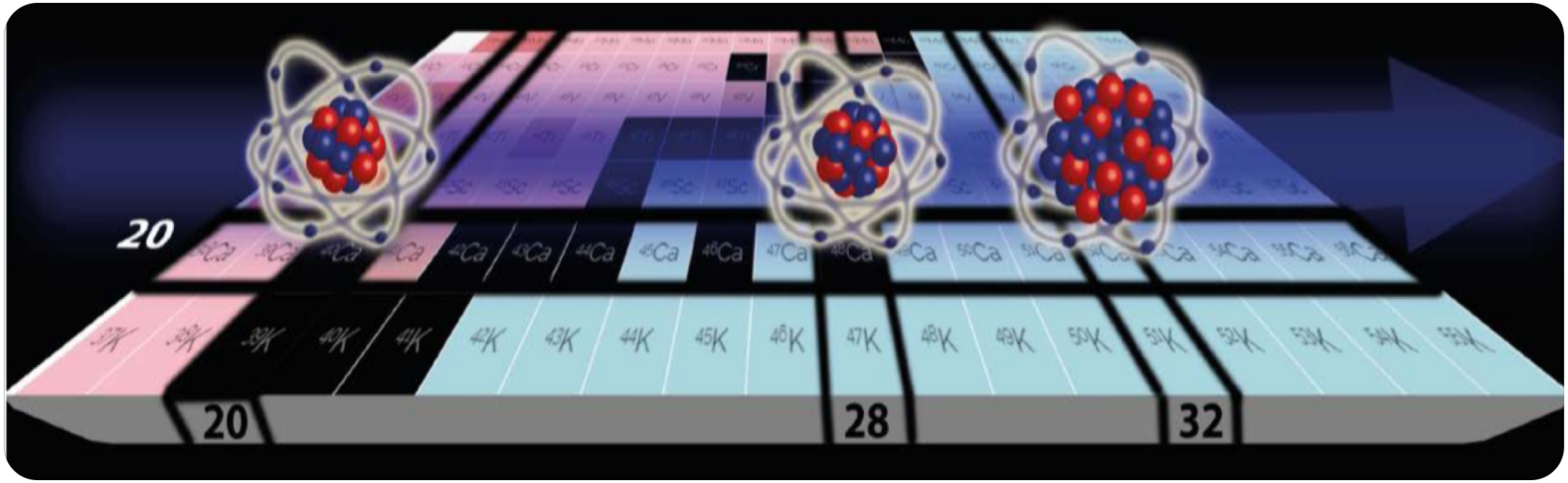
C. Colle et al., PRC 92, 024604 (2015).


10
5
0
protons
neutrons
Pb/C
Fe/C
Al/C
10^2
A
A(e,e'Np)/C(e,e'Np)

Proton Charge Radii of neutron rich nuclei

Add *neutrons* => Measure impact on *protons*
=> Learn about proton-neutron pairing

#Protons



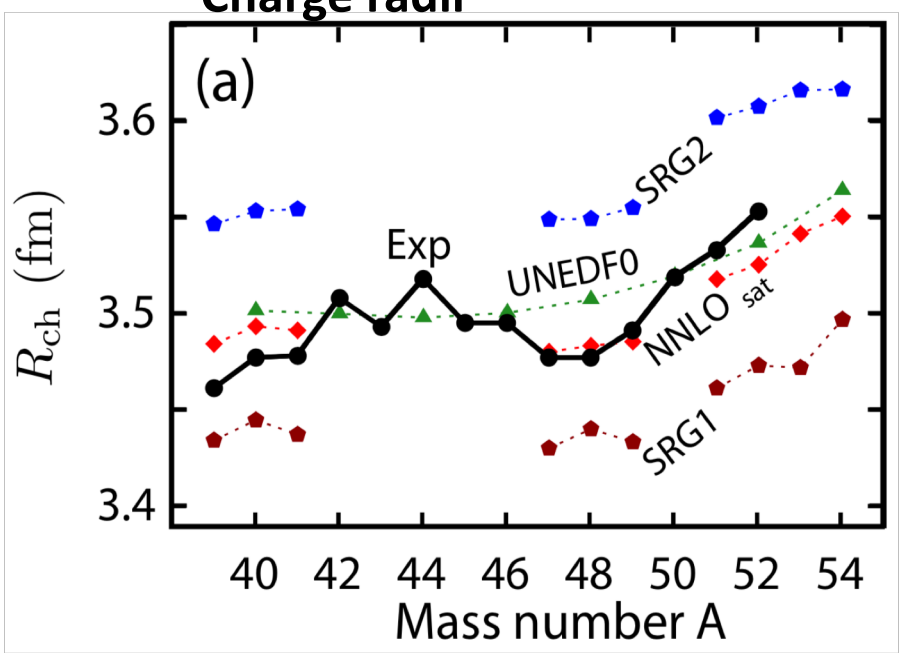
#Neutrons

Ab-Initio Under Predict….

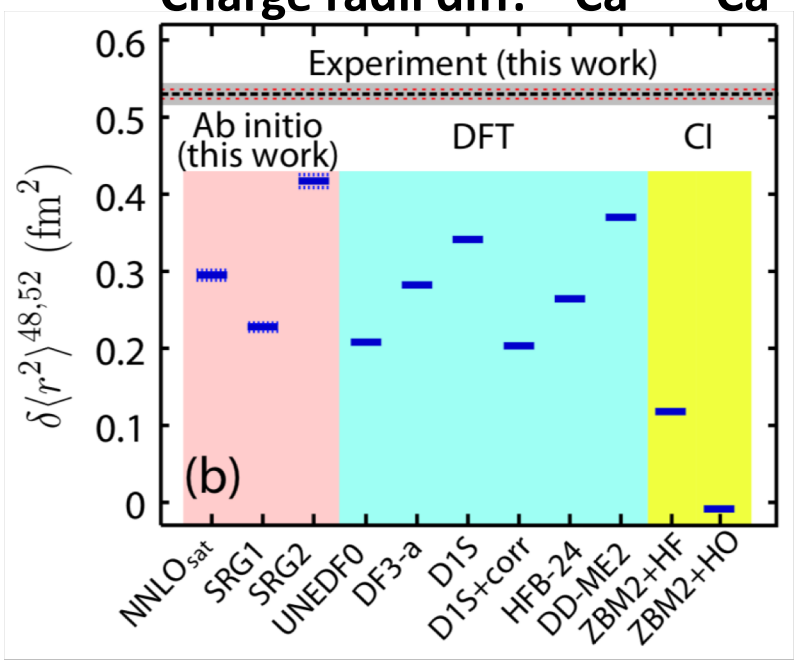
Specifically under predict the measured charge radius increase from ^{48}Ca to ^{52}Ca

These calculations truncate SRCs by evolving the wave function but not the radius operator

Charge radii



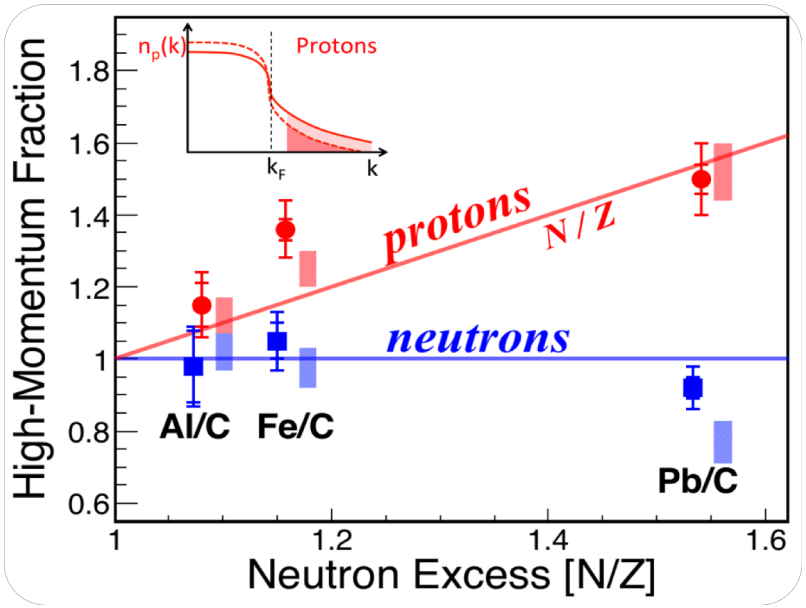
Charge radii diff: ^{52}Ca – ^{48}Ca



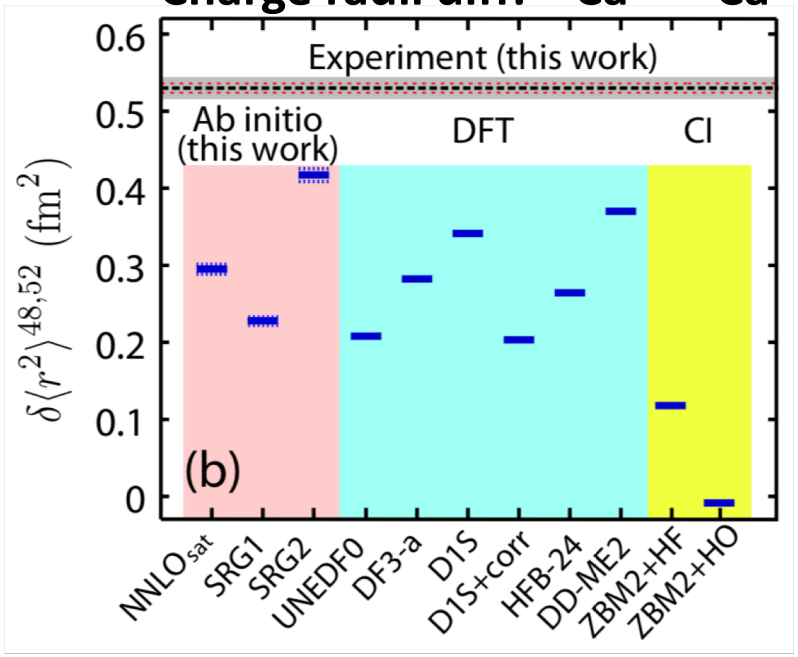
R.F. Garcia Ruiz et al., Nature Physics **12**, 594 (2016)

SRCs not Included in the Calculations

np-SRCs of core protons & outer neutrons:
pull out protons, increasing their radius?



Charge radii diff: ^{52}Ca – ^{48}Ca

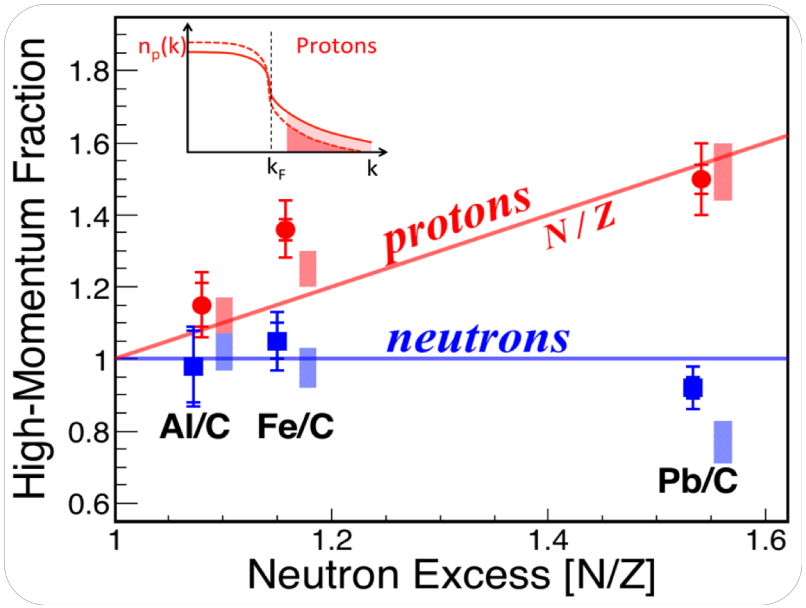


Miller, Beck, May-Tal Beck, Piasetzky, Weinstein and Hen, arXiv: 1805.12099 (2018)

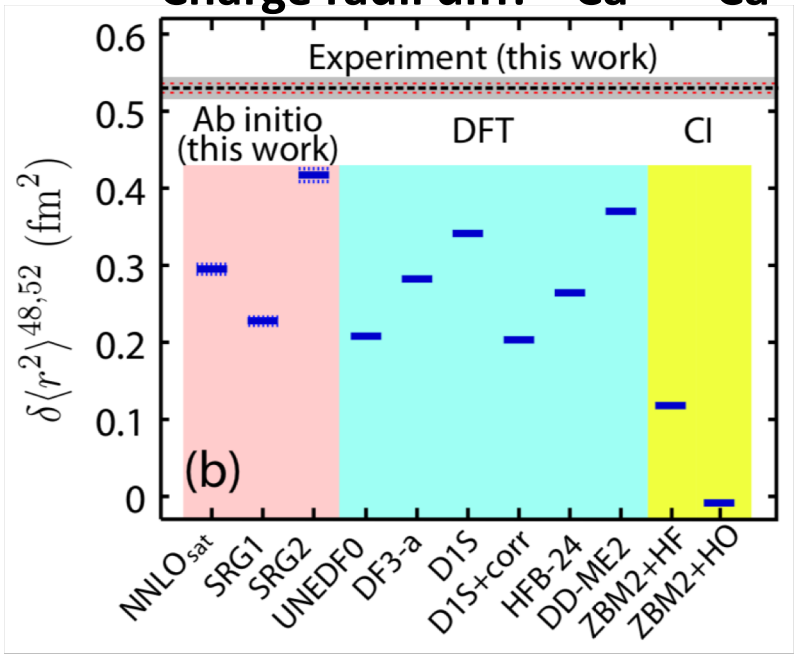
SRCs Can Account for the Difference!

Our estimation for the impact of np-SRCs:

^{49}Ca - ^{48}Ca: $\delta_{SRC}\langle r^2 \rangle = 0.15$ fm^2

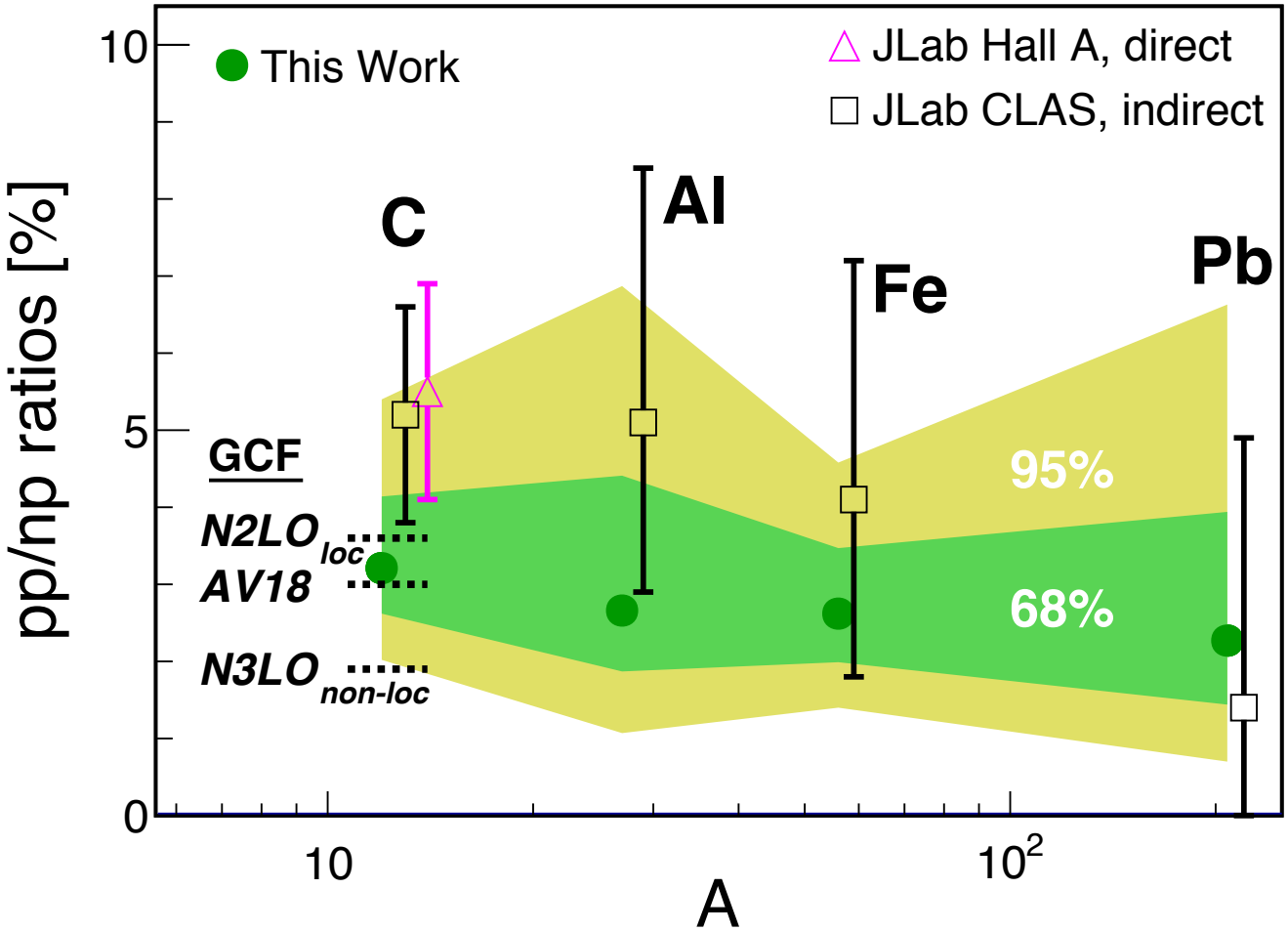


Charge radii diff: ^{52}Ca – ^{48}Ca



Miller, Beck, May-Tal Beck, Piasetzky, Weinstein and Hen, arXiv: 1805.12099 (2018)

np dominate in all interactions!



Duer, submitted (2018); 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);