Semi-Inclusive Reactions: N, Z, Nucleon momenta, and Pairing

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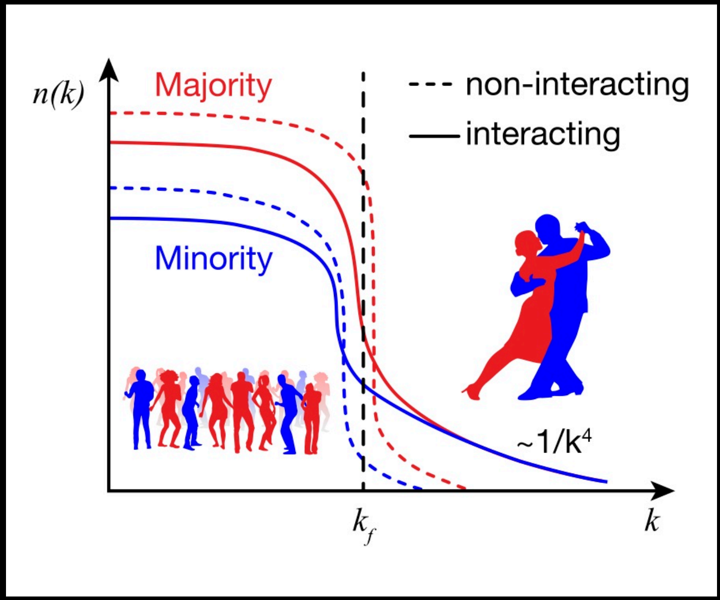
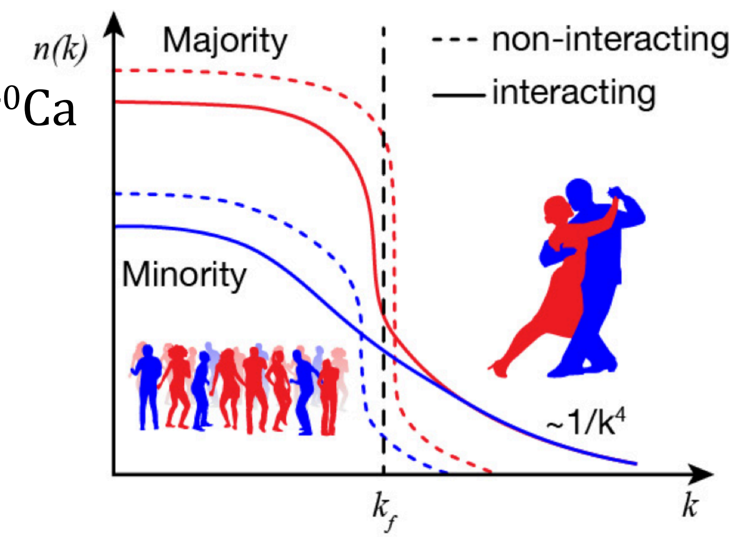


N, Z and high momentum nucleons:
"54-40 or Fight" aka "The CaFe Experiment"

- Goal: understand pairing mechanisms in symmetric and asymmetric nuclei
  - Neutron skins
  - Connection to EMC effect
- Method: Measure A(e,e'p) at low and hi missing momentum at kinematics sensitive to $n(k)$
- Targets: D, ^{12}C, ^{40}Ca, ^{48}Ca, ^{54}Fe
  - Add p, n symmetrically from D to ^{12}C to ^{40}Ca
  - Add 8 neutrons from ^{40}Ca to ^{48}Ca
  - Add 6 protons from ^{48}Ca to ^{54}Fe



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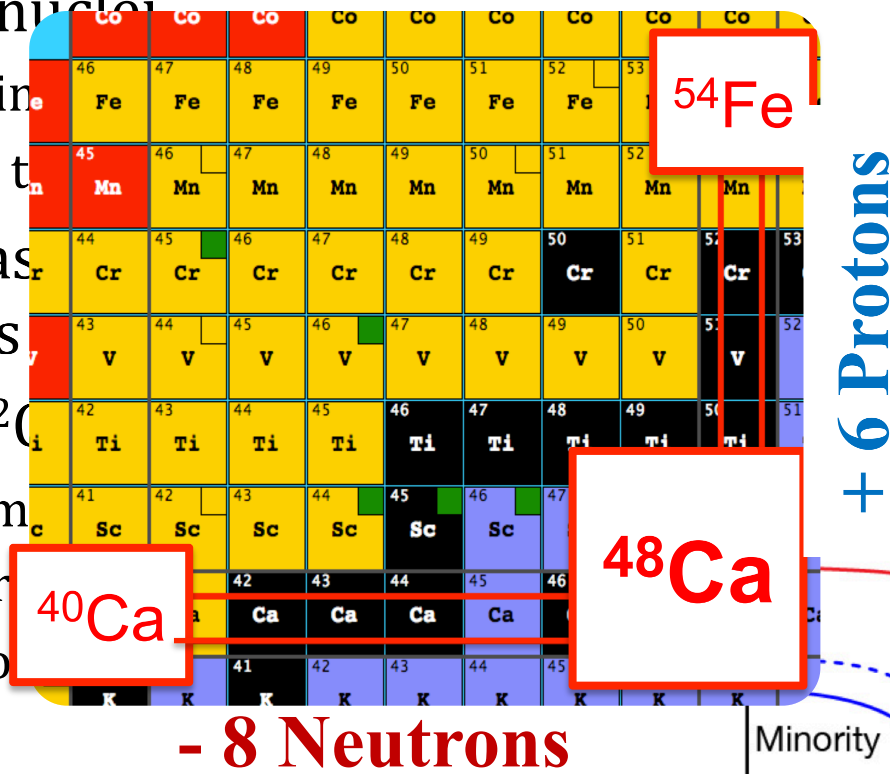
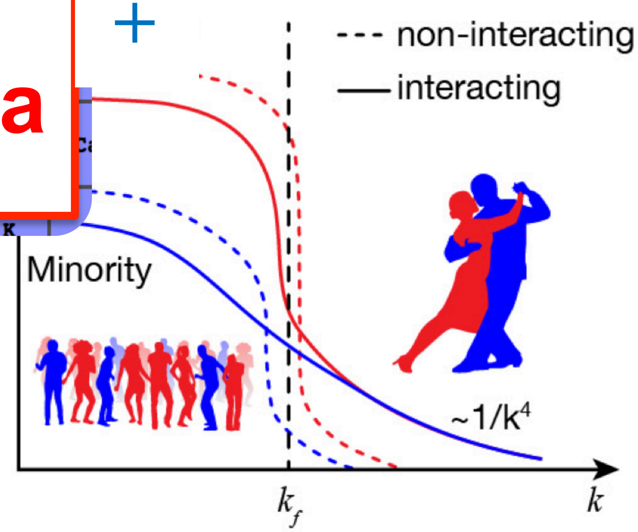
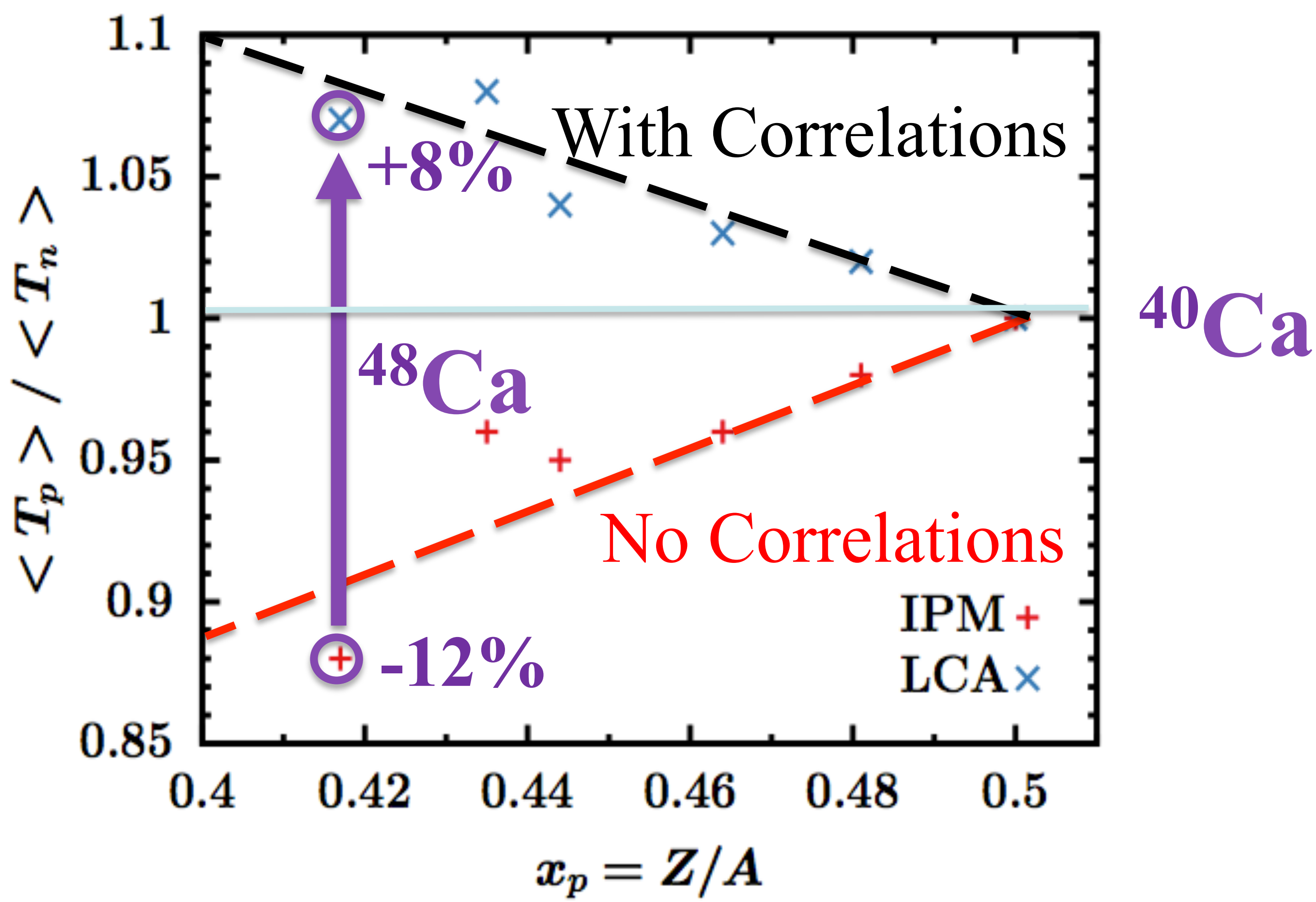




Adding neutrons to 40Ca

Two models:

- More neutrons, similar volume ➔ larger p_n
- **More neutrons, more *np* pairs ➔ larger p_p**



M. Vanhalst, et al., J. Phys. G **42**, 055104 (2015)

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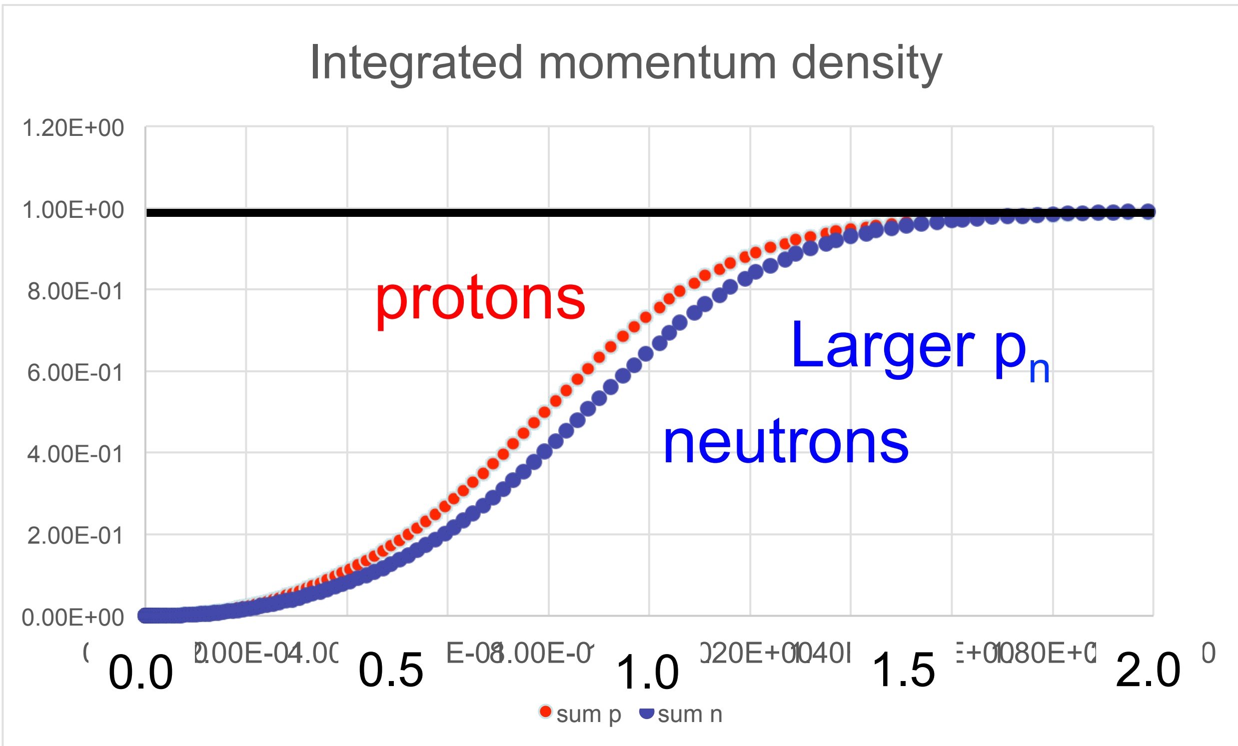
N2LO saturation

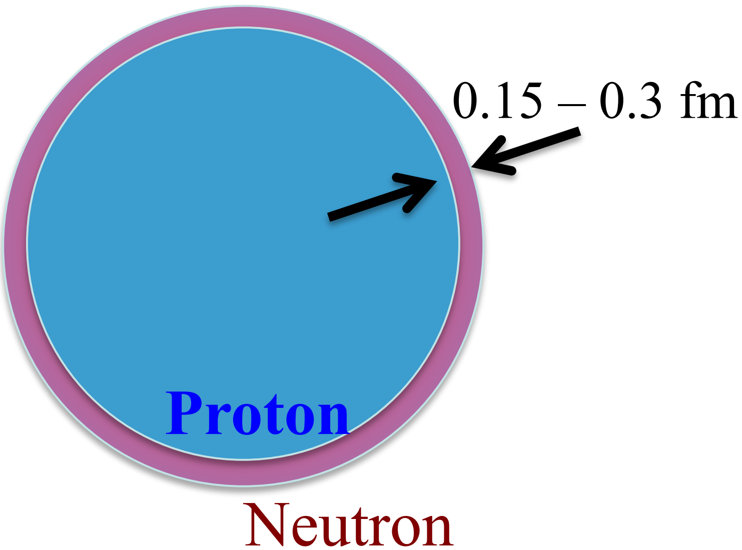


Hagen et al, Nature Phys **12**, p186 (2015)

Focusing on ^{48}Ca

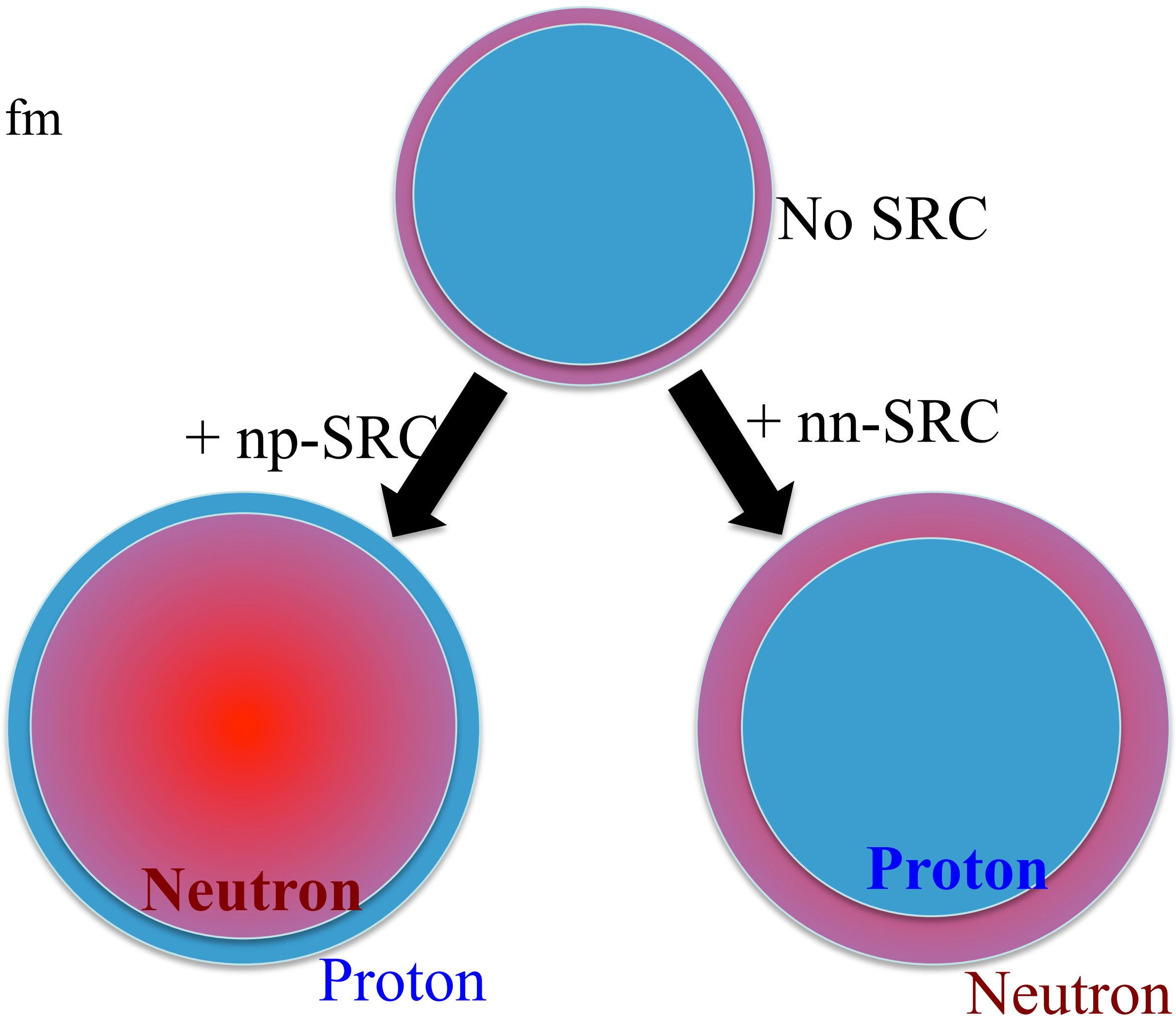
Coordinate space:

[CREX]



Momentum space:

[CaFe]



Adding correlations:

- Reduce the radius.
- Inverts the momentum skin?

M. Vanhalst, et al., J. Phys. G **42**, 055104 (2015)

Focusing on ^{48}Ca

<u>Coordinate space:</u>

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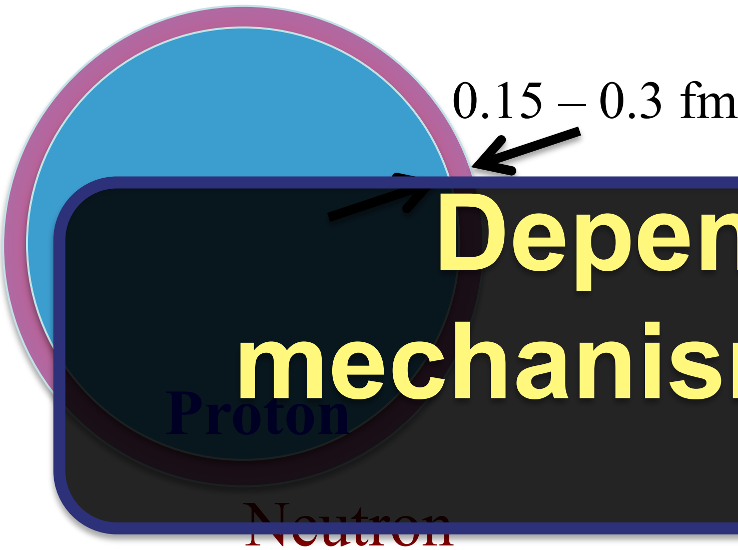
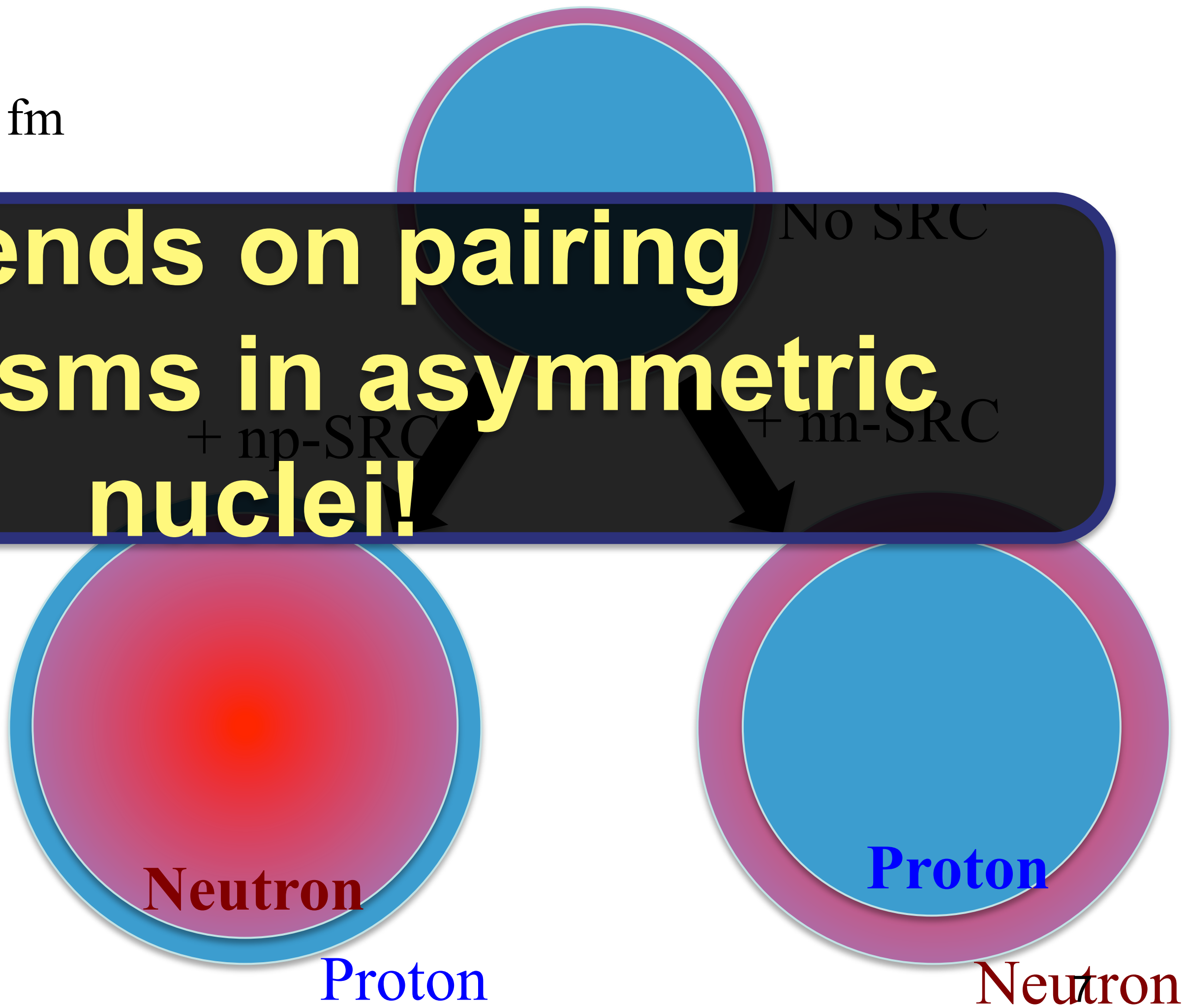


<u>Momentum space:</u>

[CaFe]



Depends on pairing mechanisms in asymmetric nuclei!

<u>Adding correlations:</u>

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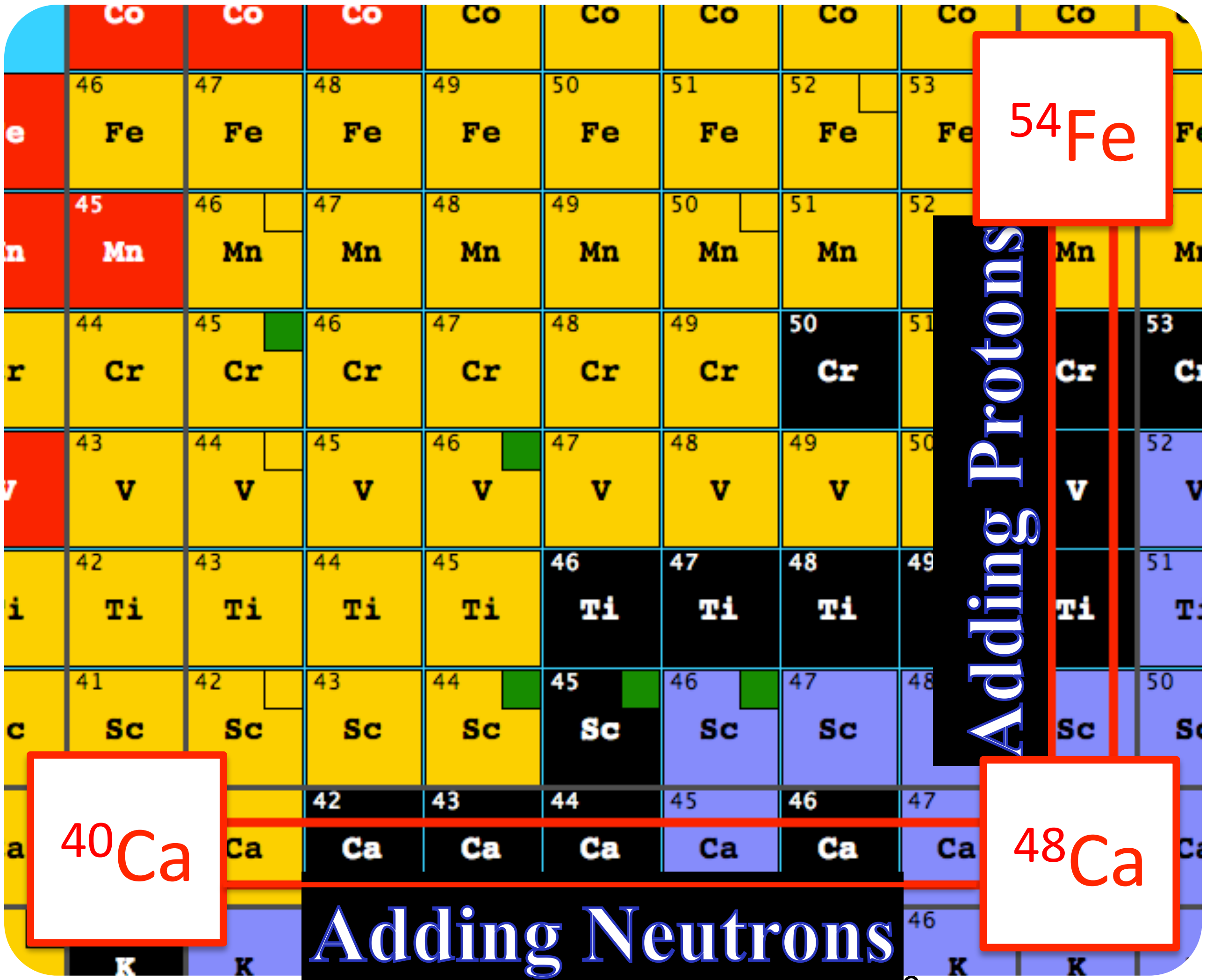
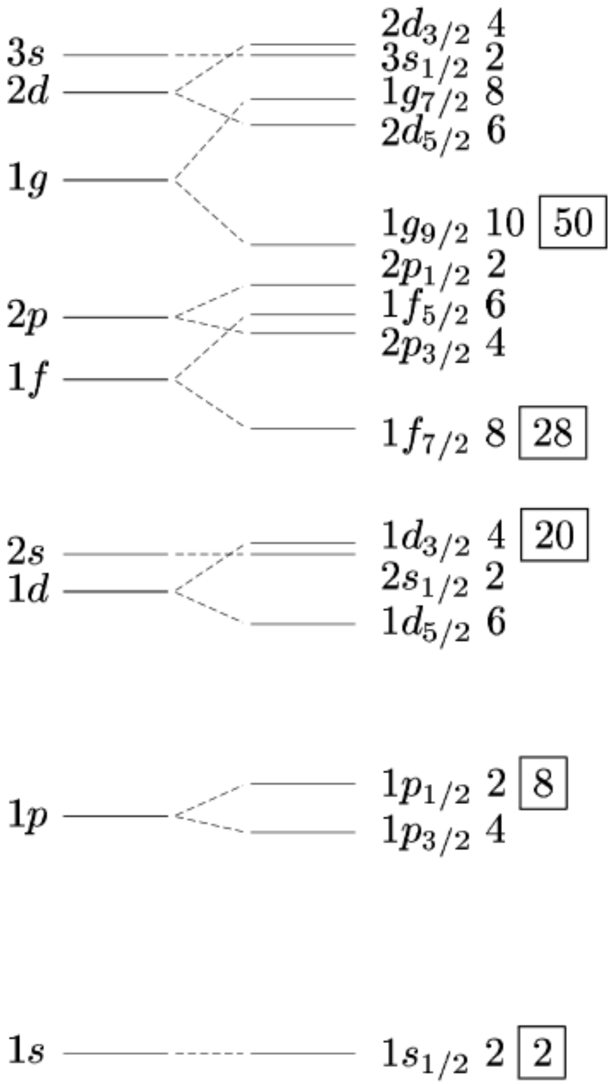
M. Vanhalst, et al., J. Phys. G **42**, 055104 (2015)

The CaFe Triplet: A Lab for Asymmetric Nuclei



^{48}Ca has a 40% neutron excess!!

The CaFe Triplet:
A Lab for Asymmetric Nuclei

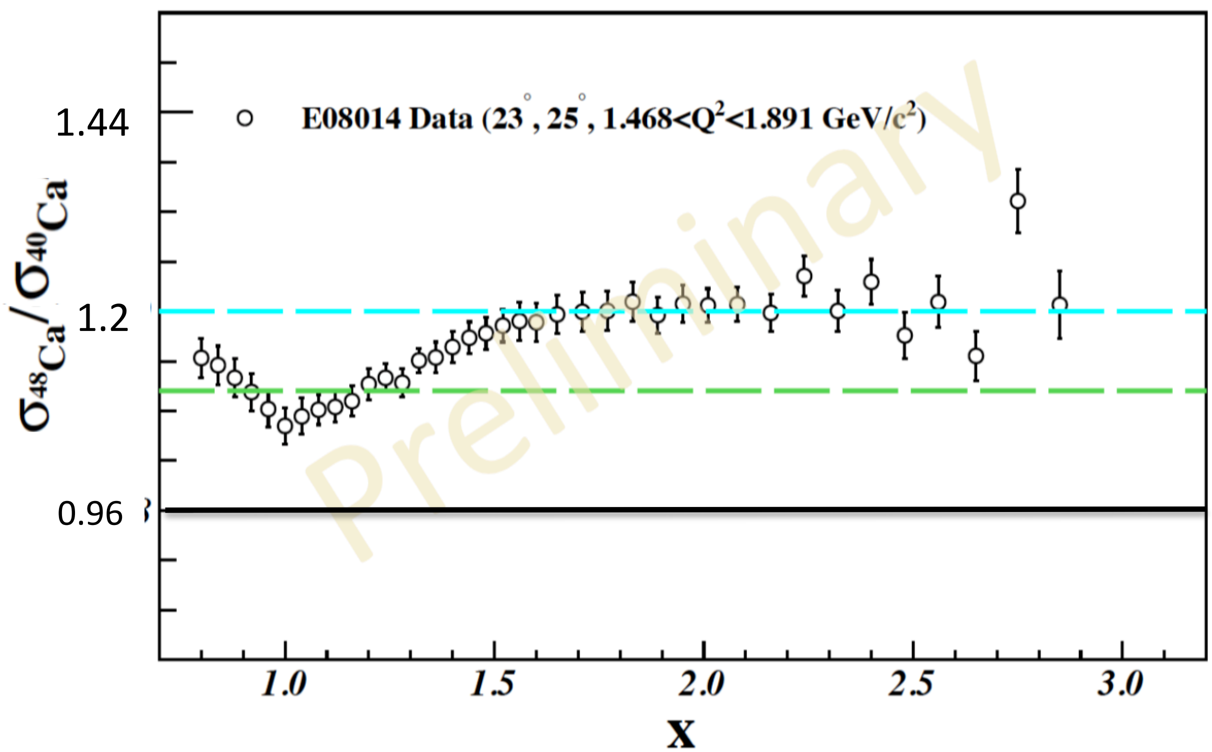


Nucleus	Z	N	
^{40}Ca	20	20	Symmetric double magic
^{48}Ca	20	28	+ Full neutron shell ($1f_{7/2}$)
^{54}Fe	26	28	Almost symmetric double magic

How do the neutrons from the outer $1f_{7/2}$ shell correlate with the ^{40}Ca core?

What do we already know?

(e,e') cross-section ratios at $x_B>1$ are sensitive to the TOTAL NUMBER OF SRC PAIRS:



~5% norm uncertainty not shown

=> ^{48}Ca: + 20% nucleons, +20% SRC pairs!

Z. Ye Ph.D. Thesis, UVA. arXiv: 1408.5861

Z. Ye, JLab Users Group Meeting Talk (2016)

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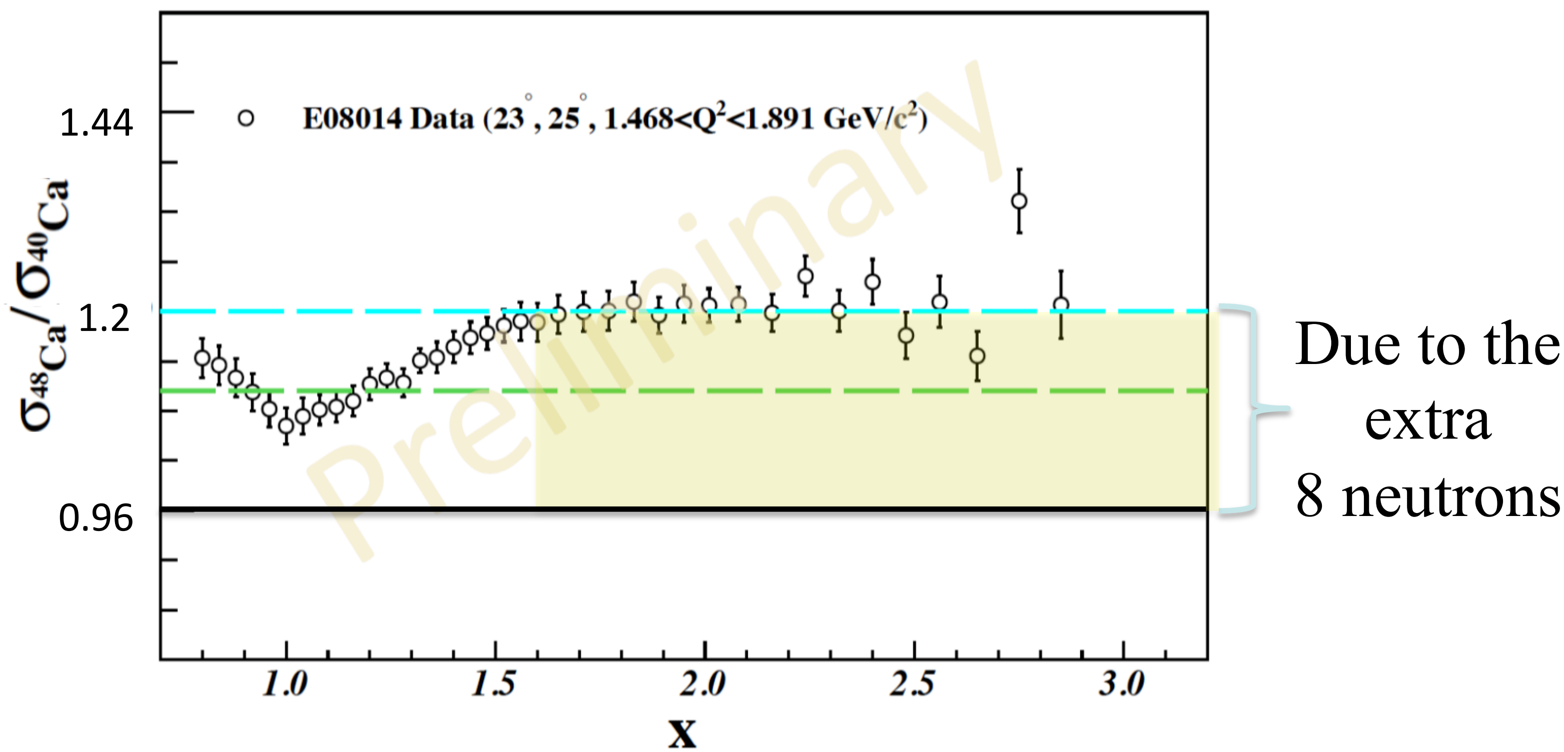
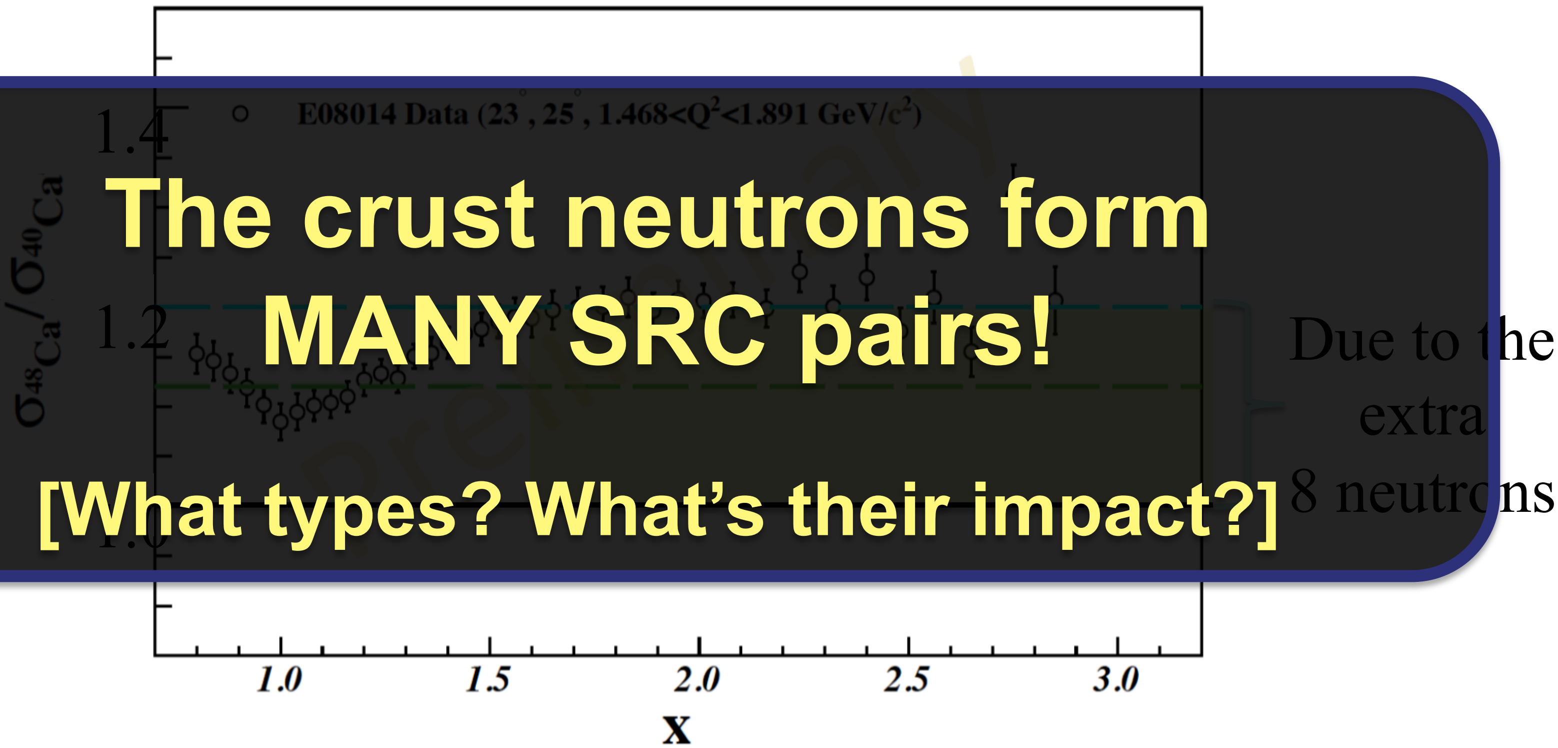


The neutrons in the outer $1f_{7/2}$ shell (i.e. in the skin) are *equally correlated* as the nucleons in the ^{40}Ca core![11]

What do we already know?

(e,e') cross-section ratios at $x_B > 1$ are sensitive to the TOTAL NUMBER OF SRC PAIRS:



The crust neutrons form MANY SRC pairs!

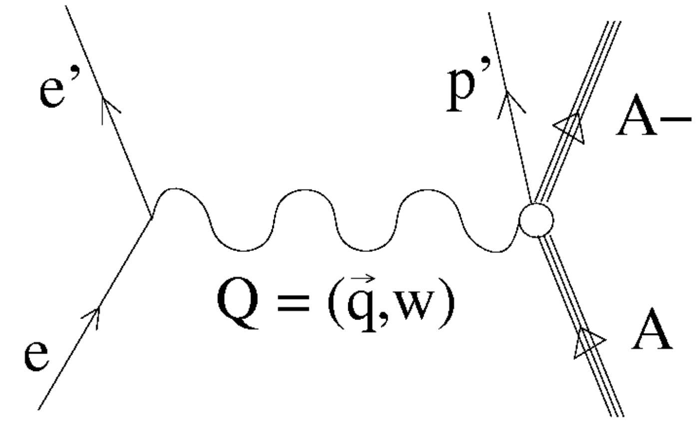
[What types? What's their impact?]

The neutrons in the outer $1f_{7/2}$ shell (i.e. in the skin) are *equally correlated* as the nucleons in the ^{40}Ca core!

detect the proton (e,e'p)

Cross section factorizes (in PWIA):

$$\frac{d\sigma}{dE_e d\Omega_e dT_p d\Omega_p} = K S(\vec{p}_{miss}, E_{miss}) \frac{d\sigma^{free}}{d\Omega}$$



$$E_{miss} = \nu - T_p - T_{A-1}$$

$$\vec{p}_{miss} = \vec{q} - \vec{p}_p = -\vec{p}_{initial}$$

Complications:

- Rescattering of the outgoing proton.
- Off-shell proton cross-section.
- Meson Exchange Currents (MEC).
- Delta production (i.e. IC).

=> **Spectral function is not an observable!**

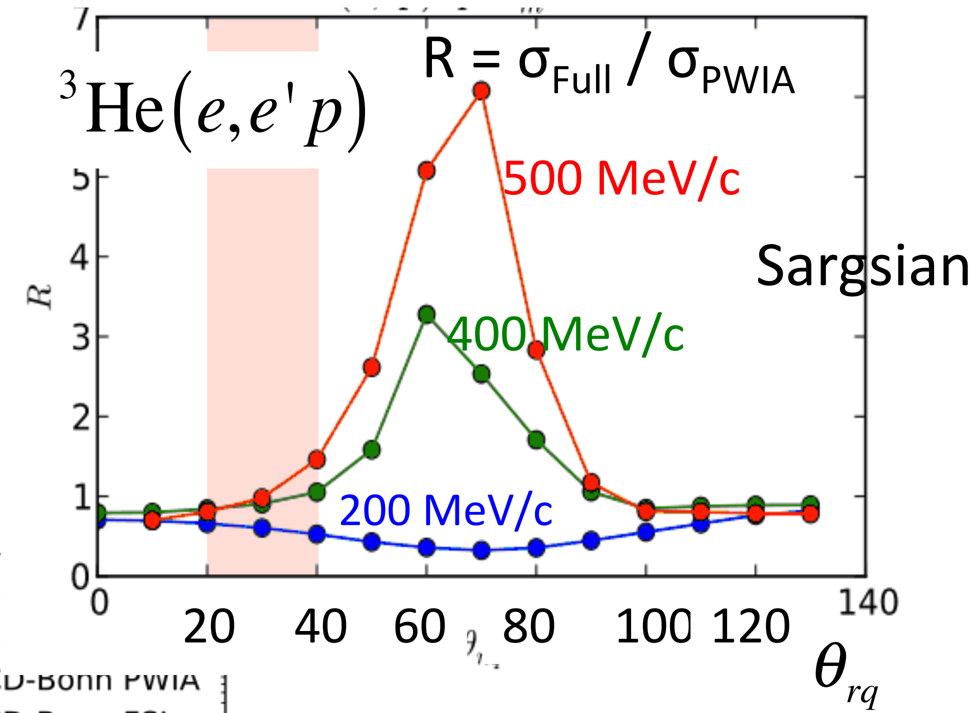
$$S^D(\vec{p}_{miss}, E_{miss}) = \frac{d\sigma}{dE_e d\Omega_e dT_p d\Omega_p} / K \frac{d\sigma^{free}}{d\Omega}$$

Compare cross sections for high (SRC) and low (MF) missing momentum protons in various nuclei

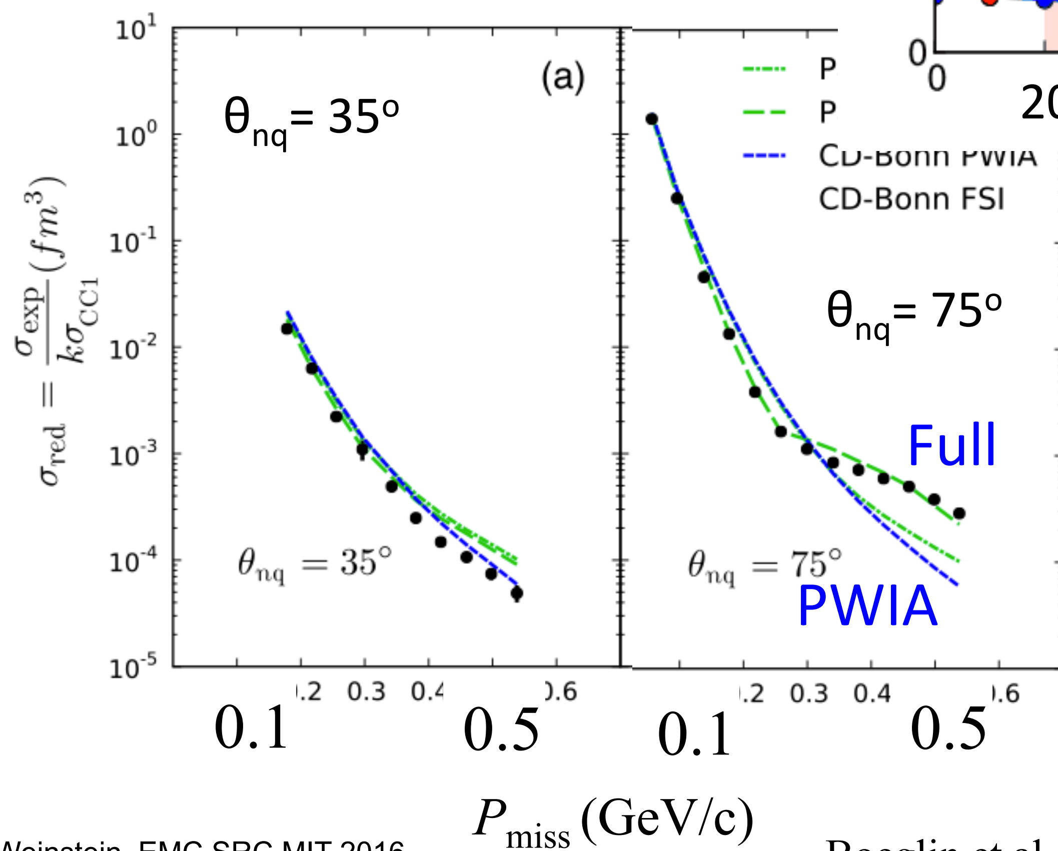
Minimizing FSI

Full = PWIA + FSI

Θ_{rq} = angle between q and recoil



d(e,e'p)



Avoid rescattering peak at $\theta_{rq} \approx 70°$

Boeglin et al., PRL **107** (2011) 262501

Optimizing (e,e'p) kinematics

- E_{beam} = 11 GeV @ 40 uA to maximize rates.
- ^{1}H, ^{2}H, ^{12}C, ^{40}Ca, ^{48}Ca, and ^{54}Fe targets.
- $Q^2 \approx 3.5$ GeV^2
  – Reduces non-nucleonic currents (MEC, IC).
  – Proton energies high enough for Glauber FSI calculations.
- $x_B = Q^2/2m\omega > 1.2$ to minimize non-nucleonic currents.
- $\theta_{rq} < 50^o$ to minimize FSI.
- Two Kinematics:
  – $350 < p_{miss} < 600$ MeV/c ("SRC")
  – $p_{miss} < 250$ MeV/c ("Mean-Field")

"Observables"

- Distorted spectral functions (*i.e.*, reduced σ)
  - Need theory support to interpret
- Double ratios of $$\frac{\sigma(SRC)/\sigma(MF)_{A1}}{\sigma(SRC)/\sigma(MF)_{A2}}$$
  - ➔ extra SRC *p* from A_1 to A_2
    - *e.g.:* from 40 to 48Ca ➔ *np* pairs created by 8 more *n*
  - Reduced transparency (FSI) corrections
  - Compare symmetric and asymmetric nuclei
    - 40 and 48Ca; 6 and 7Li
    - d, C, Ca, Fe