The CaFe Experiment:

Isospin Dependence of Short Range Correlations in Nuclei

Hall C Proposal PR12-17-005

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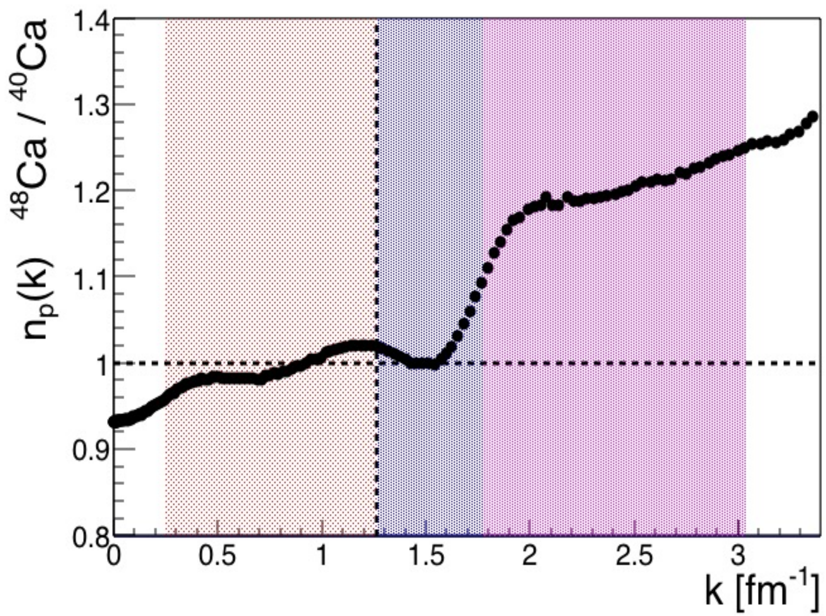
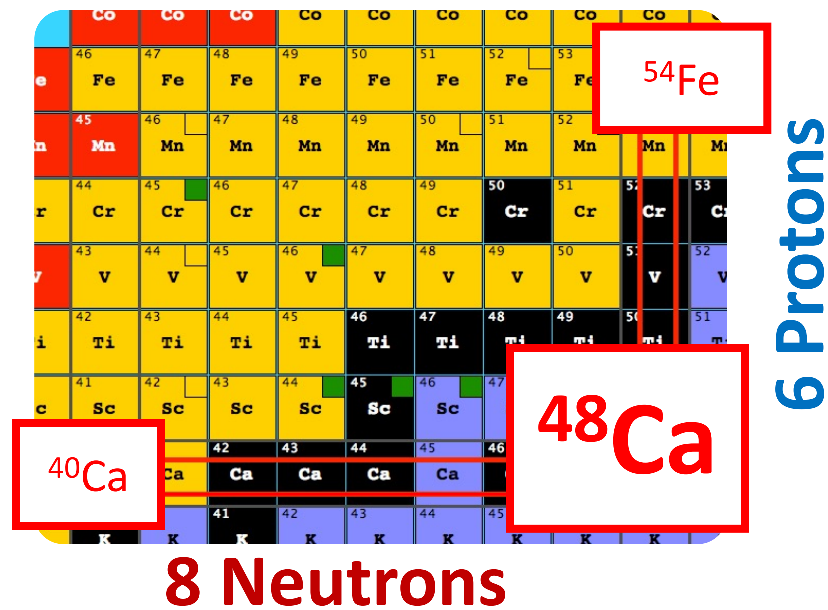
(On the behalf of the CaFe collaboration)

Hall C Collaboration Meeting, 02/18/2022

CaFe: Executive Summary

- ❑ Measure Mean-field and correlation nucleon using the (e,e'p) reaction
- ❑ 4 PAC-day in Hall C using standard HMS and SHMS, $^{40/48}$Ca, ^{54}Fe, ^{12}C, …



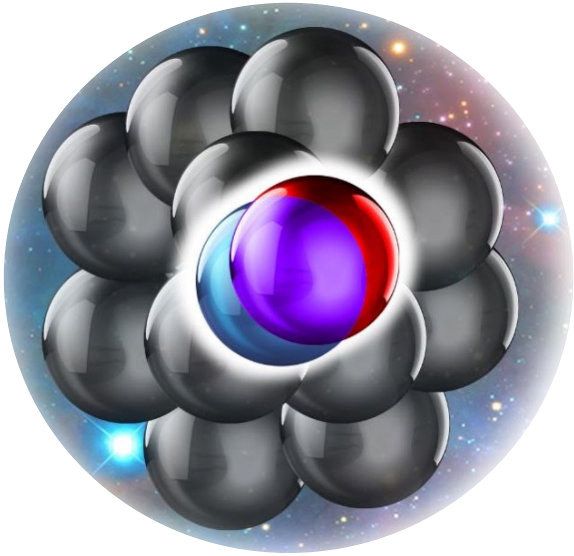


Used to extract:

- ❑ Absolute and reduce cross section => Distorted Spectral function
- ❑ SRC/mean-field protons ratios => Proton pairing probabilities
- ❑ Double ratios asym/sym nuclei => Pairing mechanism

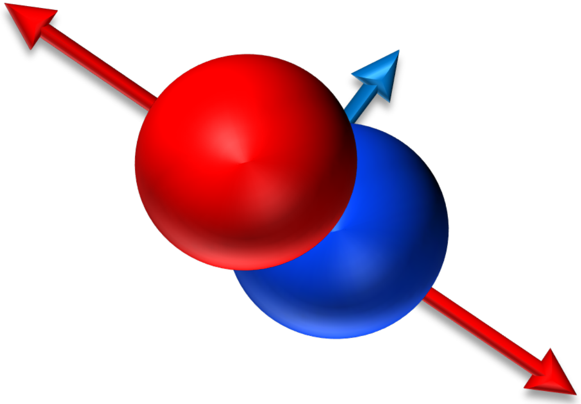
What are Short Range Correlations (SRCs) ?

r-space



Nucleon pairs that are close together in the nucleus

k-space

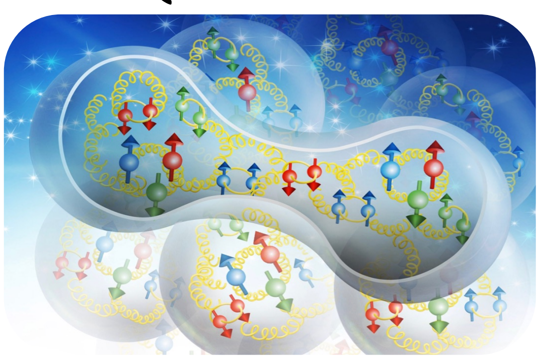


high ***relative*** and lower ***c.m.*** momentum compared to k_F

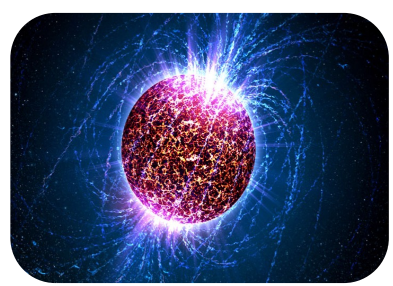
Why SRC?

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

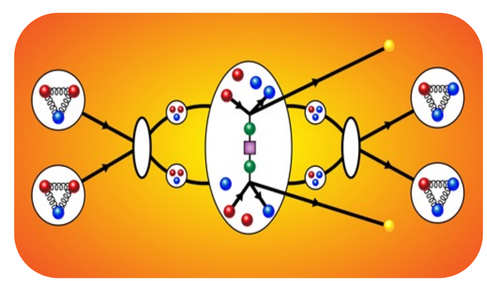
NN interaction from QCD & QCD in nuclei



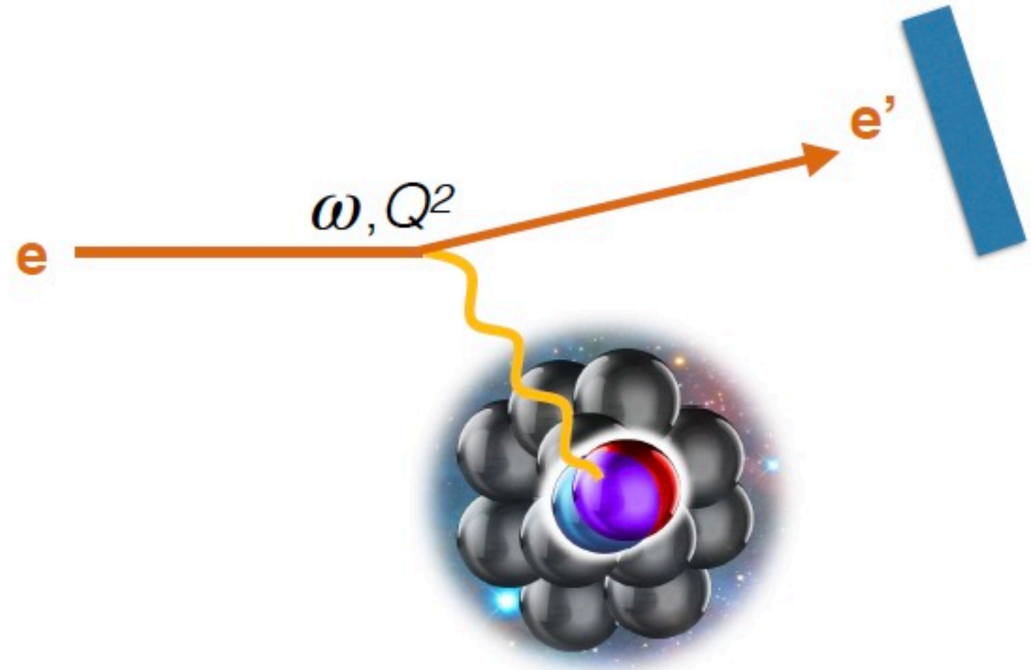
High-density systems



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



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



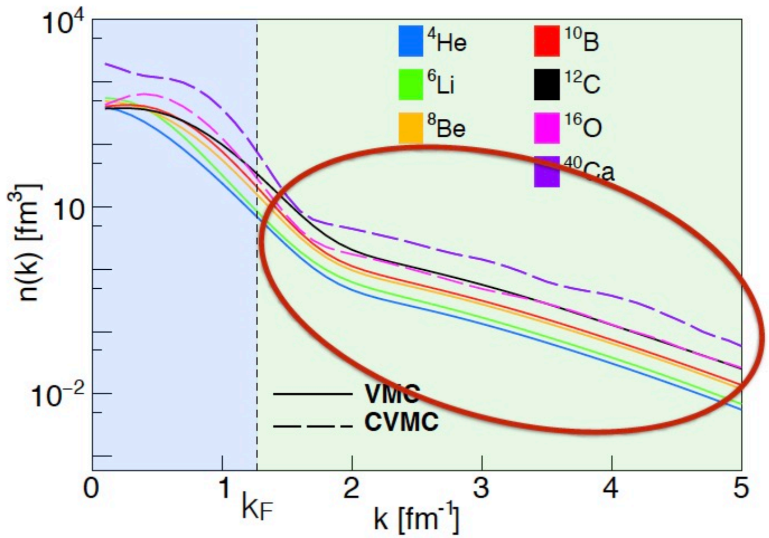
Kinematical variables:

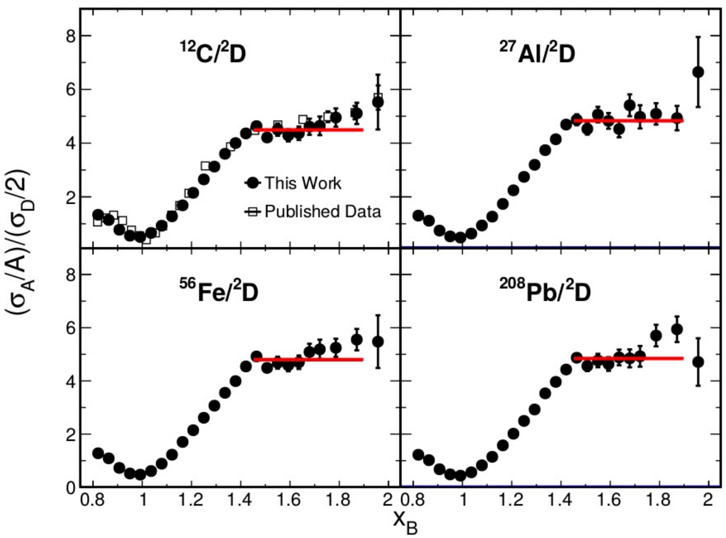
$Q^2 = -(p_e - p_e')^2$ Resolution scale

$x_B = Q^2/2m(E - E')$ Dynamic scale

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

Schmookler Nature (2019), Fomin PRL (2008) , Egiyan PRL (2006), Egiyan PRC (2003)





What we have learned:

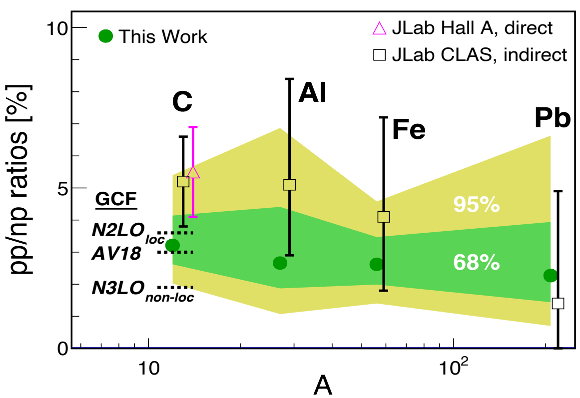
- ❑ High momentum tail is universal
- ❑ a_2 = A/D scaling factor ~ 4-5

Next questions:

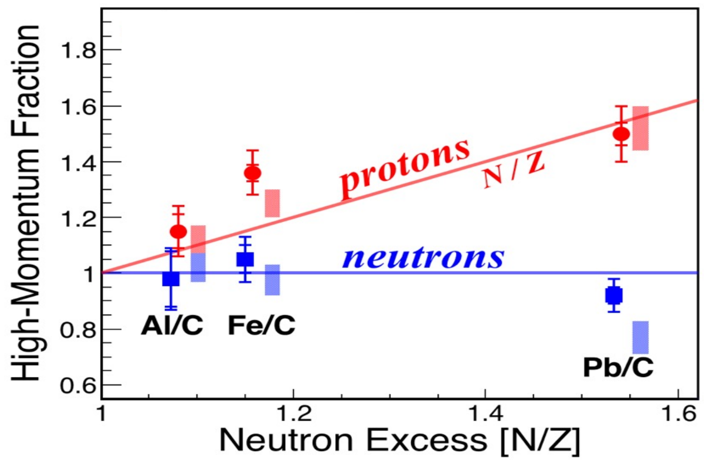
- ❑ **Do all high-momentum nucleon come in pair?**
- ❑ **What about *c.m.* momentum?**
- ❑ **What type of pairs?**

SRCs studies from two-knock out nucleon

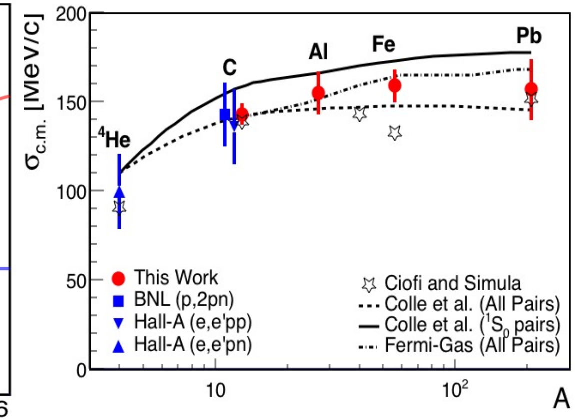
M. Duer et al., PRL (2019)



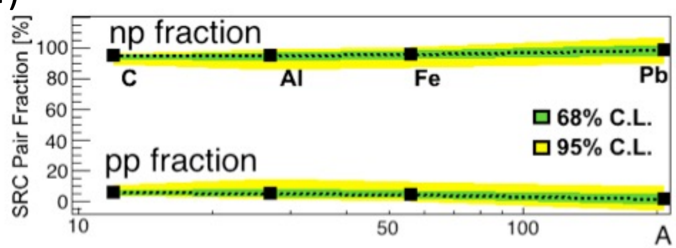
M. Duer, Nature (2018)



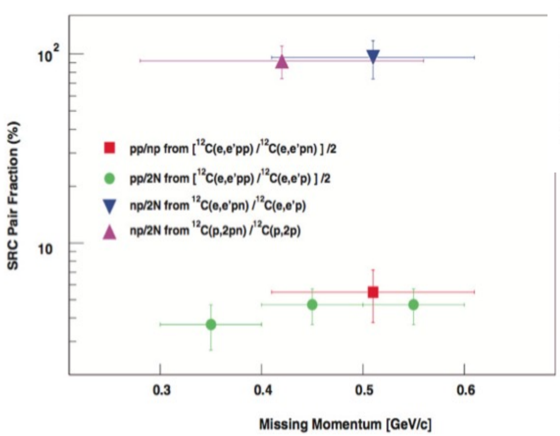
Cohen et al., PRL (2018)



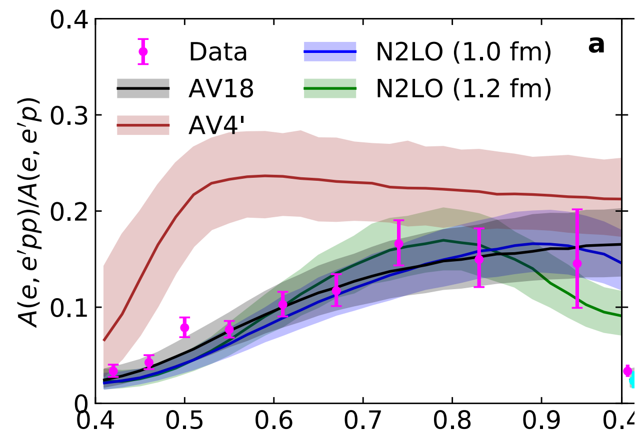
O. Hen, Science (2014)

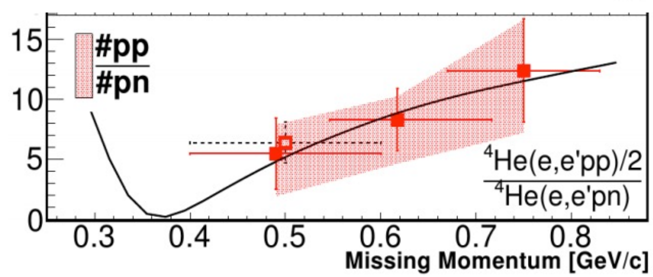


R.Subedi, Science (2008)



A. Schmidt Nature (2020)

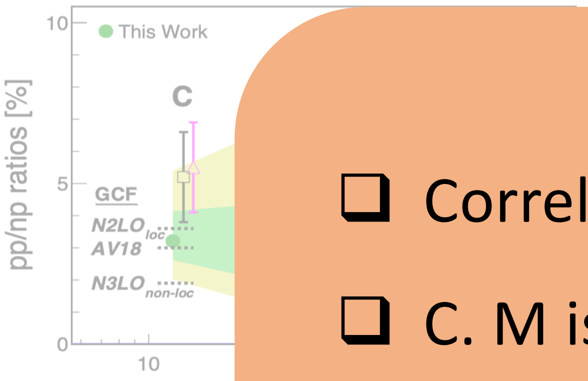


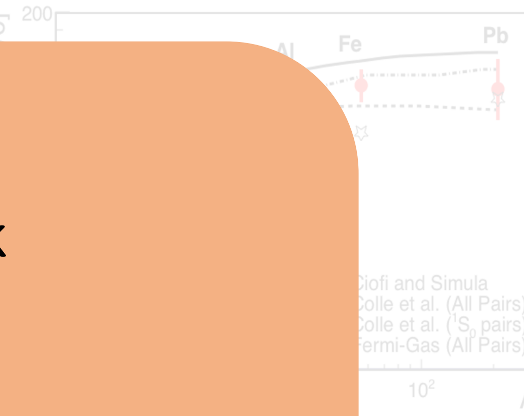


A. Tang, PRL (2003); E. Piasetzky, PRL (2006)

Korover, PRL (2014)

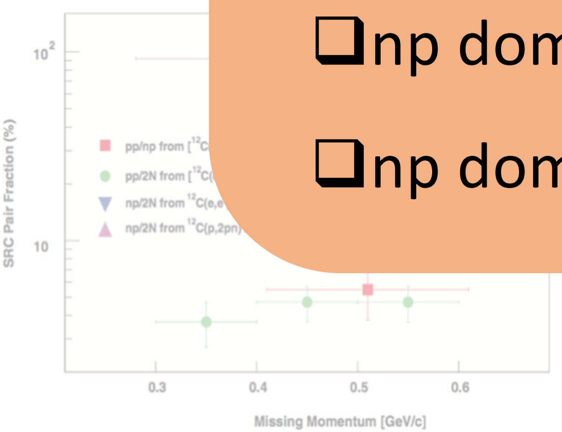
SRC study using two-knock out nucleon

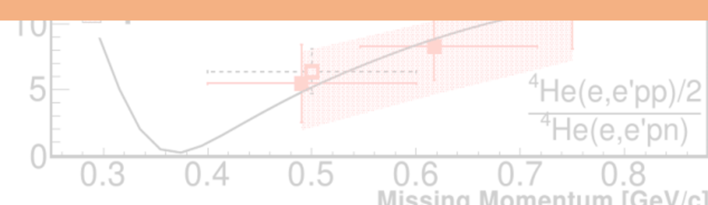




Bottom Line

- ❑ Correlated pairs are back-to-back
- ❑ C. M is lower than k_F
- ❑ SRCs is np dominance by factor ~ 20
- ❑ np dominance is observed from 4He – Pb
- ❑ np dominance due to tensor force





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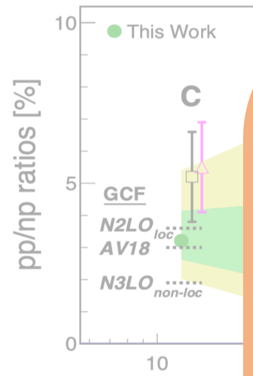

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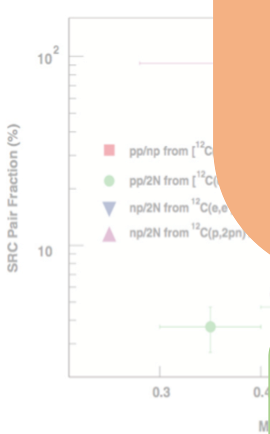


What happens to SRCs in neutron-rich nuclei?

Going to Neutron rich nuclei:

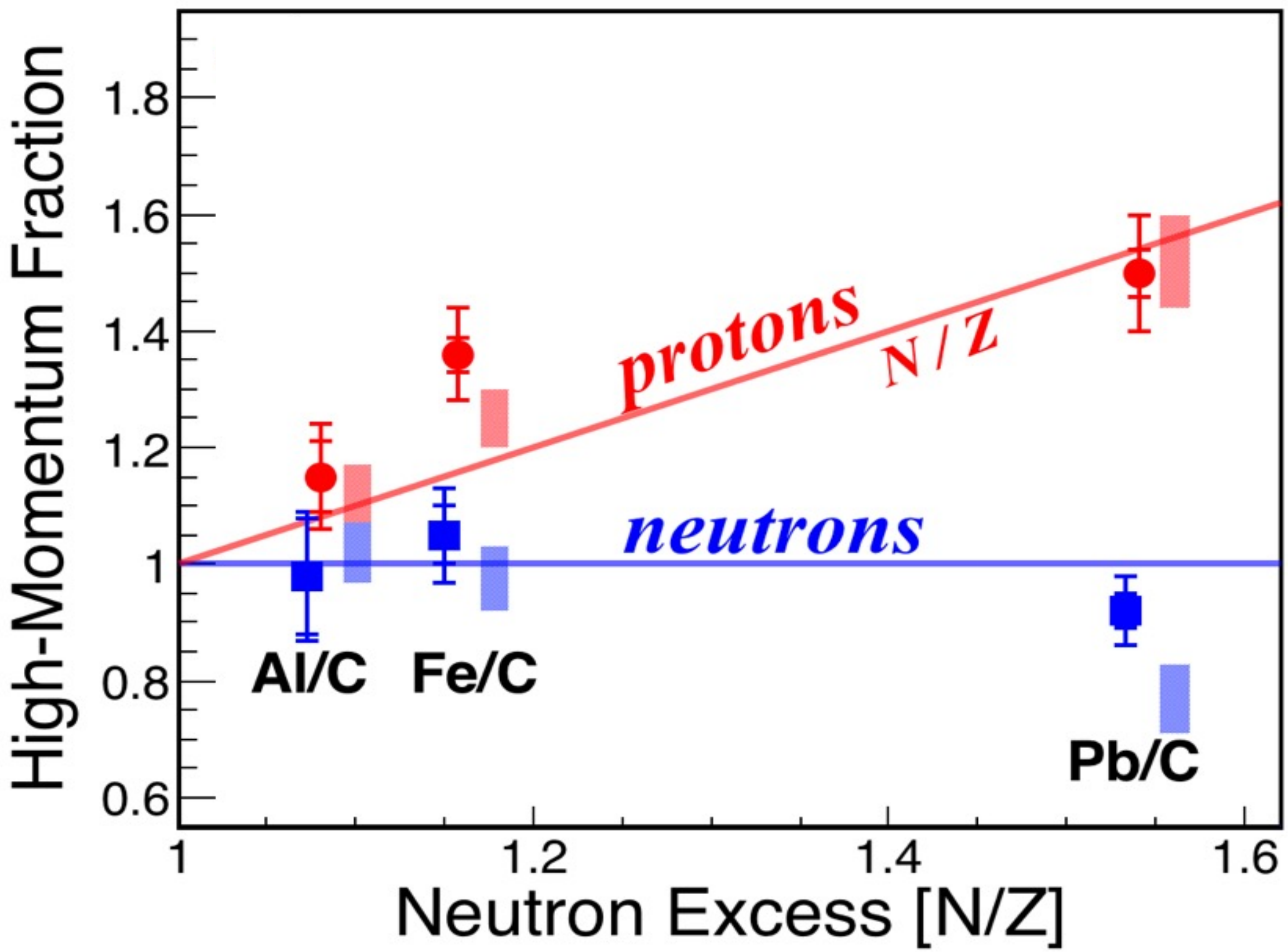
What do excess neutrons do?

don't correlate?

correlate with each other?

correlate with core protons?

Proton “speed up” in neutron-rich nuclei

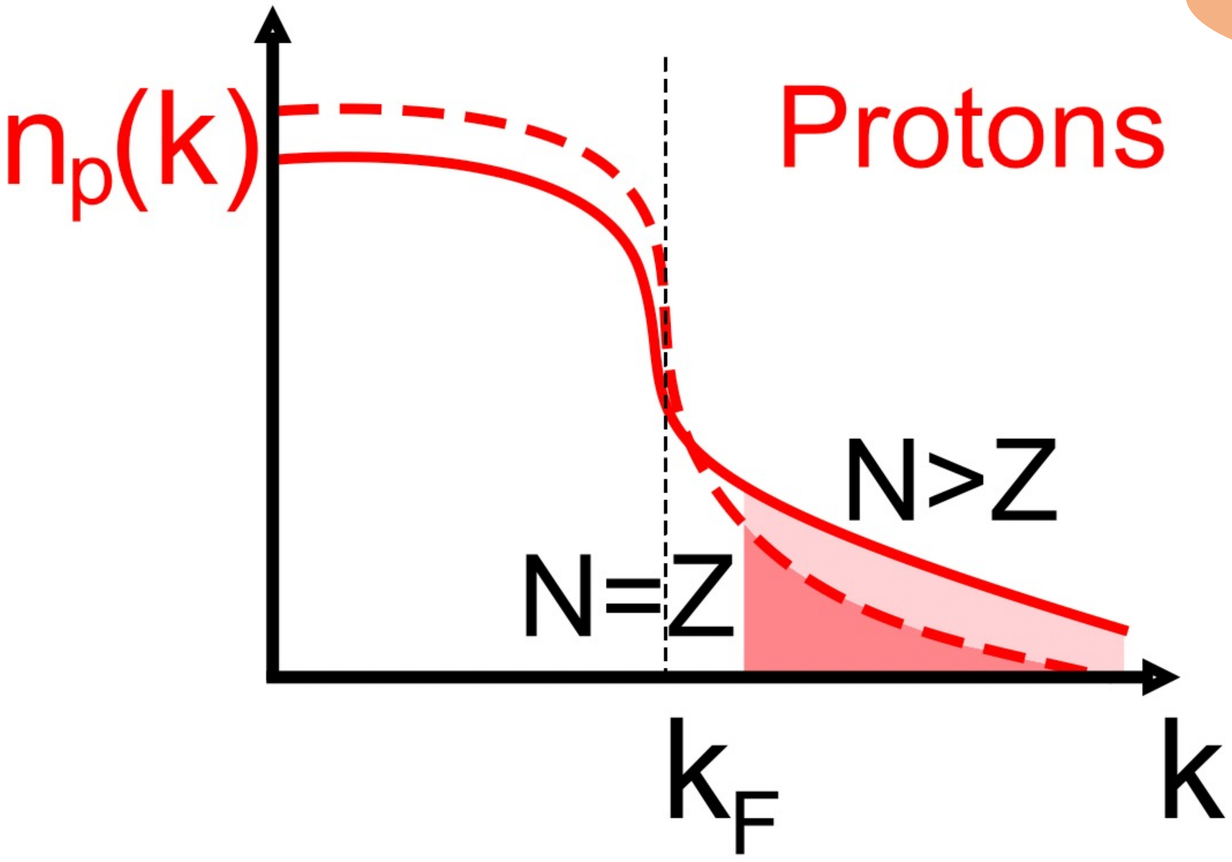


- ❑Minority nucleon moves faster than majority

M. Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

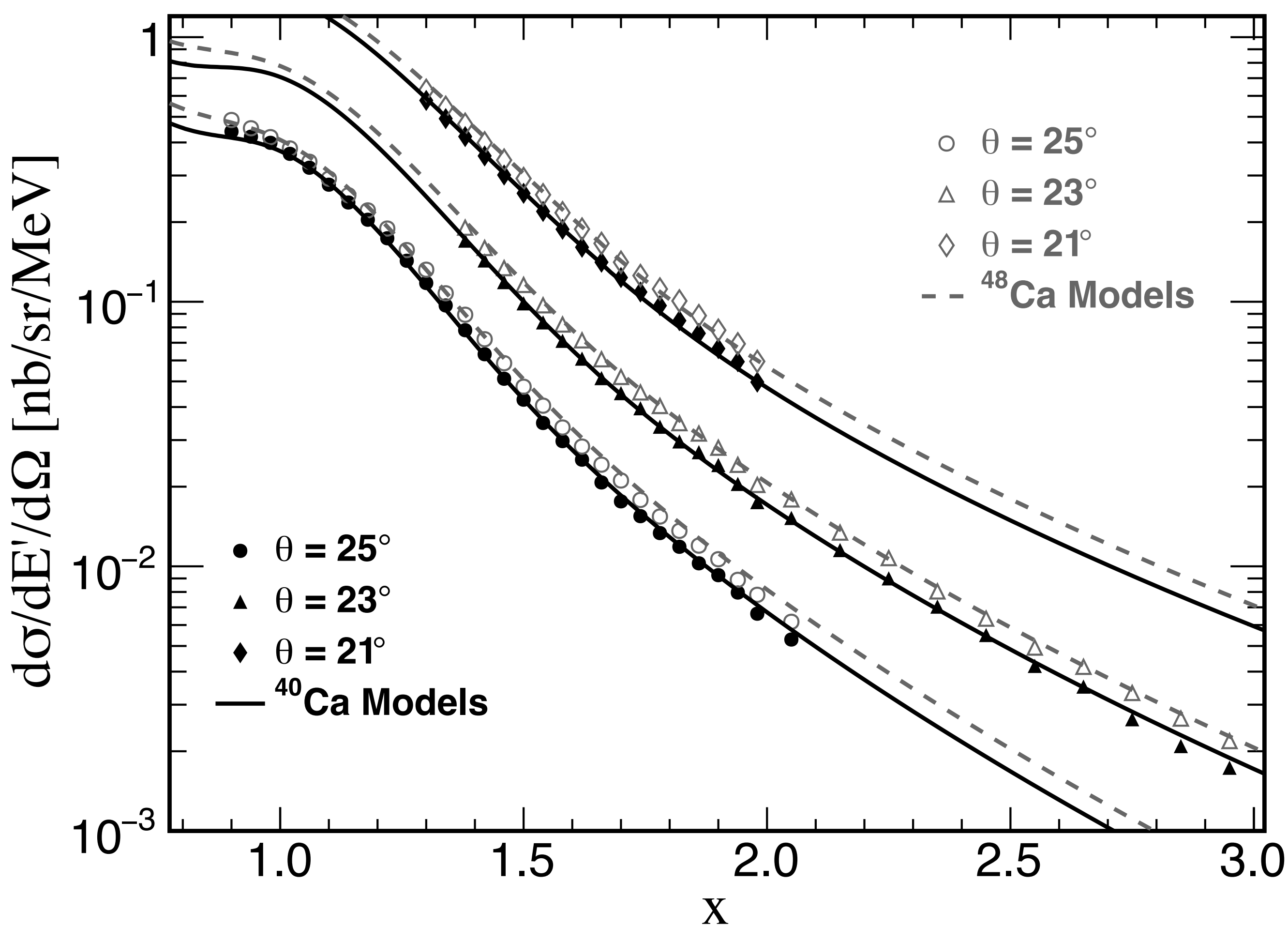
More neutron more correlated proton

correlate with
core protons



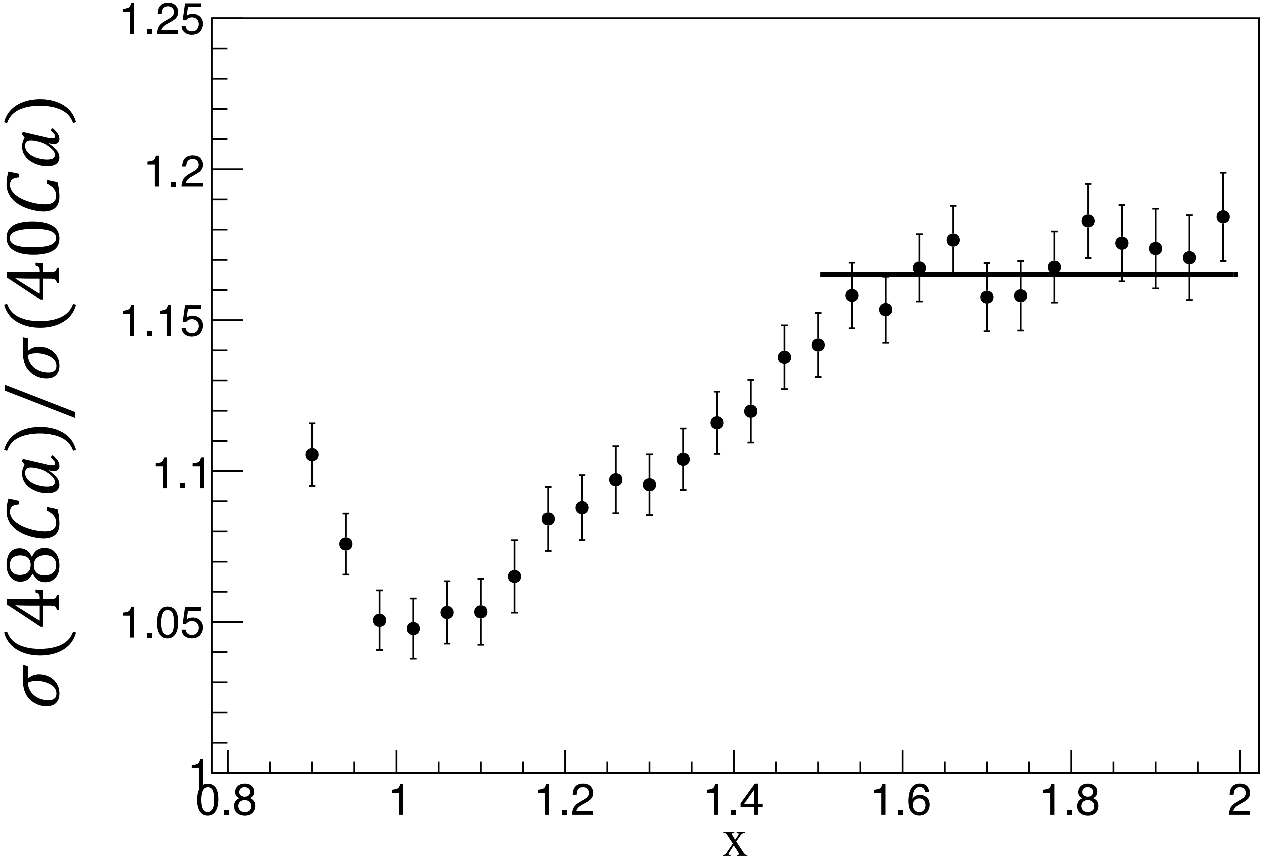
M. Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

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

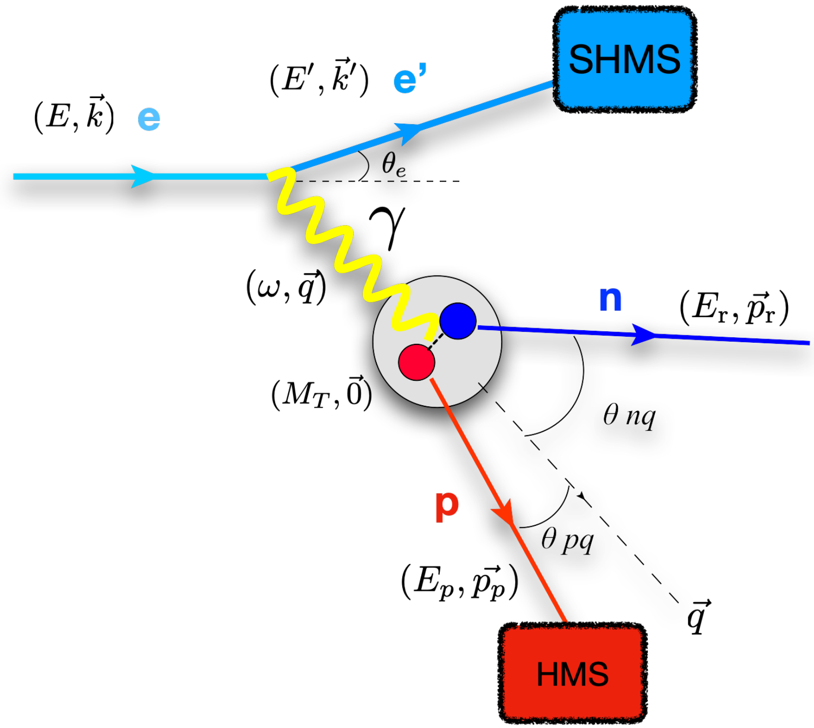
Kinematic variables:

$$Q^2 = -(p_e - p_e')^2$$

$$x_B = Q^2/2m(E - E')$$

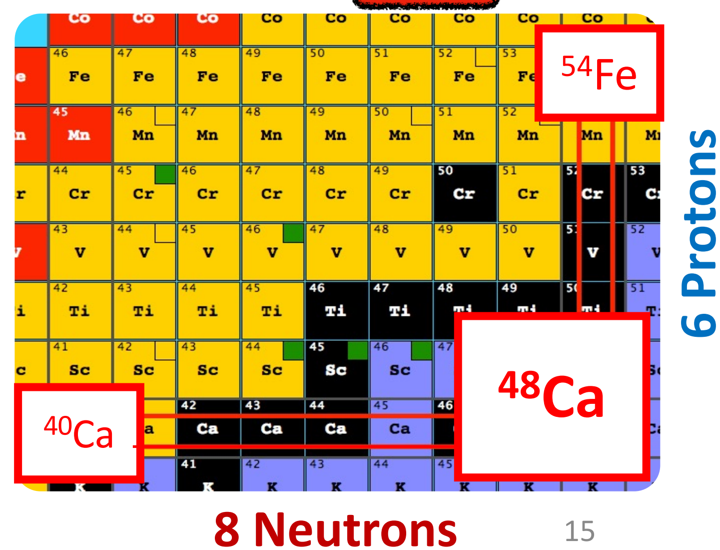
$$E_{\text{miss}} = \omega - T_p - T_{A-1}$$

$$\vec{p}_{miss} = \vec{q} - \vec{p}\,' = -\vec{p}_{init}$$



<u>We can answer questions:</u>

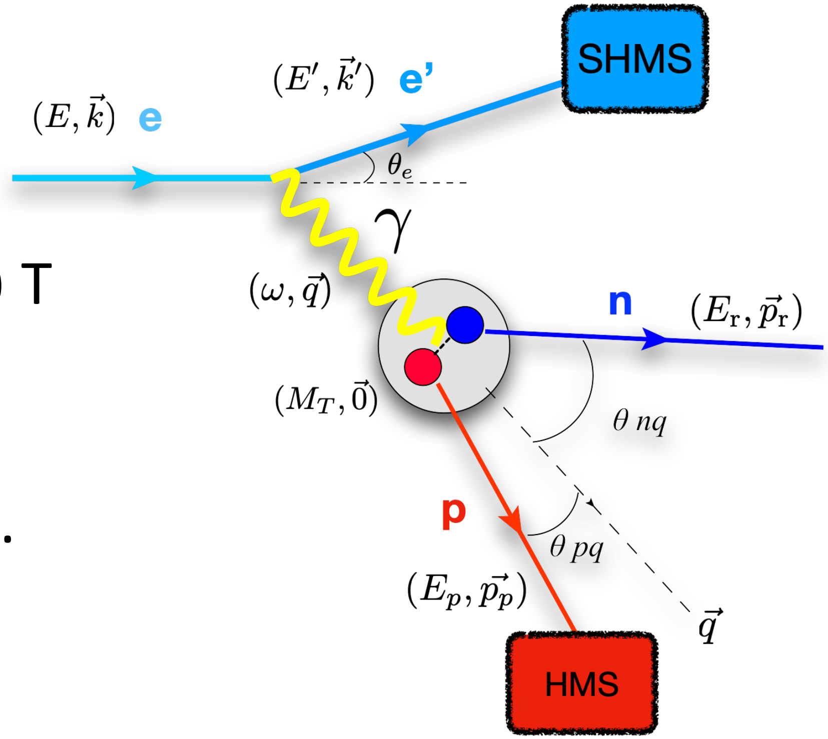
- ❑ Does ^{48}Ca has more Proton in SRCs?
- ❑ What is Proton high-momentum fraction?



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

Cross-section:

$$\sigma_{(e,e'p)} = k \;\; \sigma_{ep} \;\; S_p(E_{miss}, P_{miss}) \; \mathrm{T}$$



<u>Complications:</u>

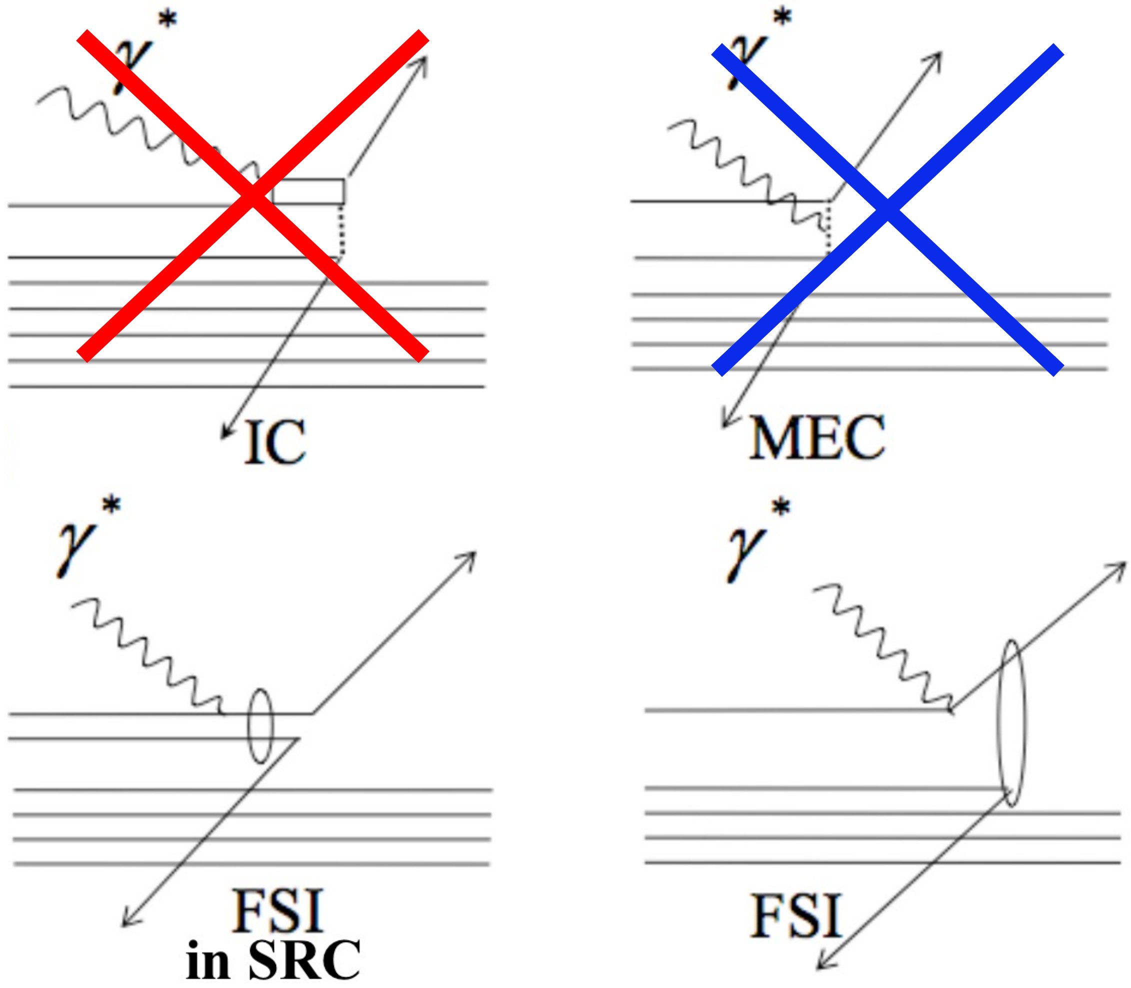
- ❑ Meson Exchange Currents (MEC).
- ❑ Delta production (i.e. IC).
- ❑ Final state interaction

<u>Solution:</u>

- ❑ Choosing the 'right' kinematics,
- ❑ Integrate over a wide P_{miss} range,
- ❑ Extract cross-section ratios.

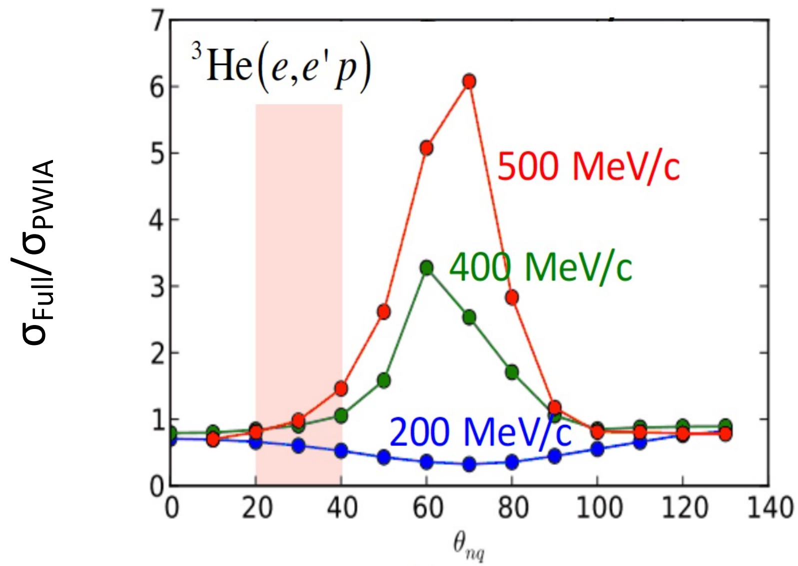
Choosing Kinematic: Minimizing non-QE mechanisms

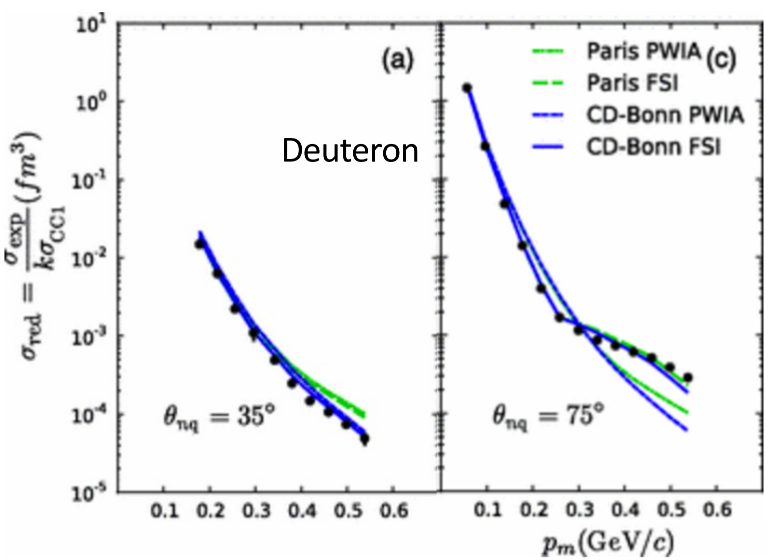
$X_B > 1$ $Q^2 > 2\ \mathrm{GeV}^2$

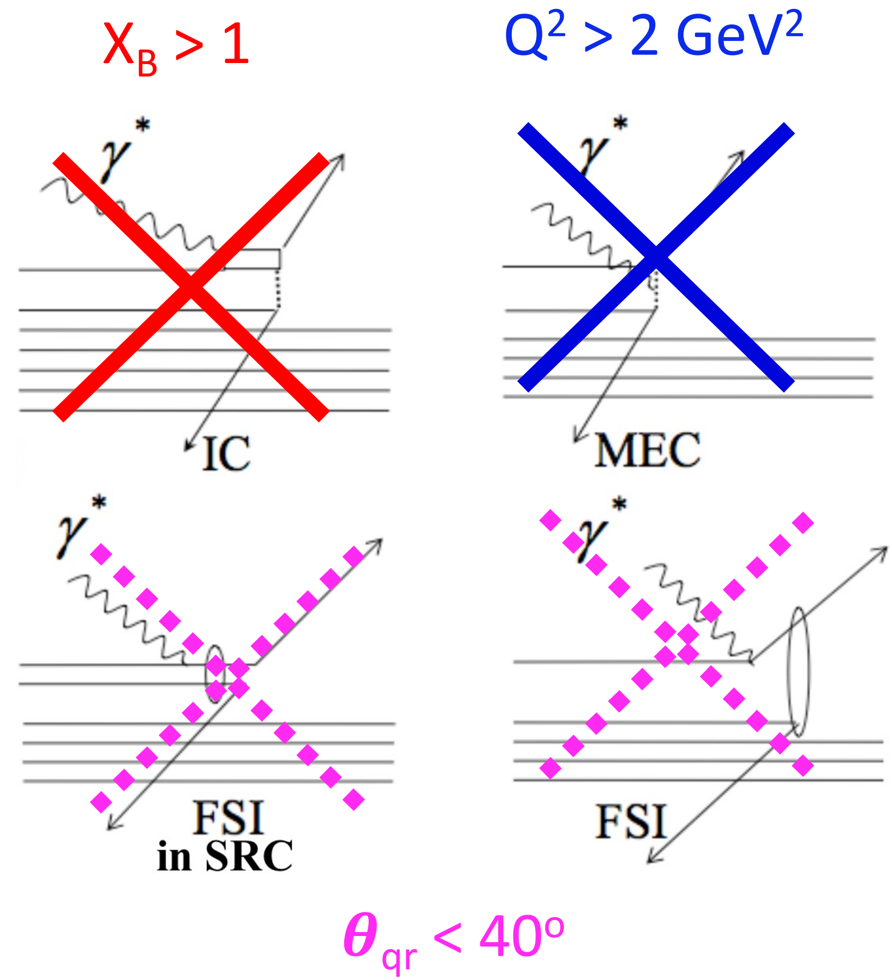


M. M. Sargsian, Int. J. Mod. Phys. E10, 405 (2001)
M. M. Sargsian et al., J. Phys. G29, R1 (2003)

Choosing Kinematic: Minimizing non-QE mechanisms





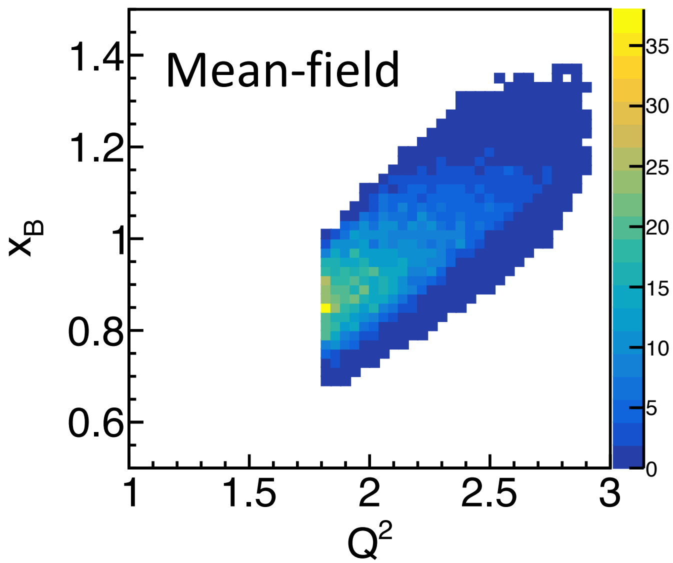


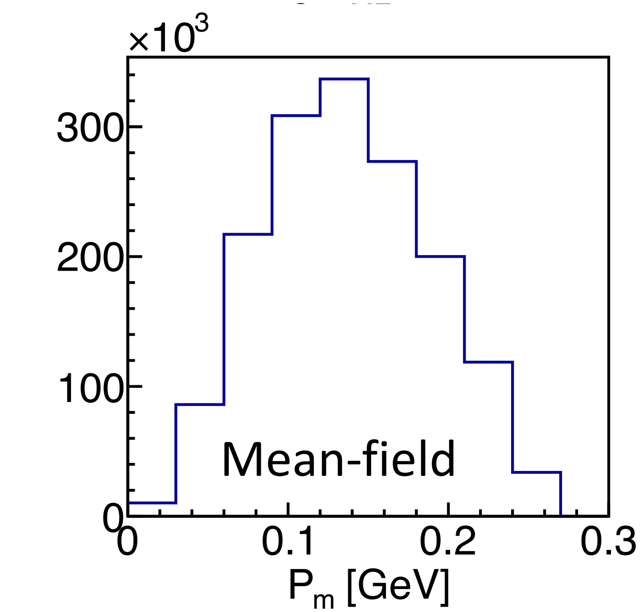
Boeglin et al., PRL 107 (2011) 262501

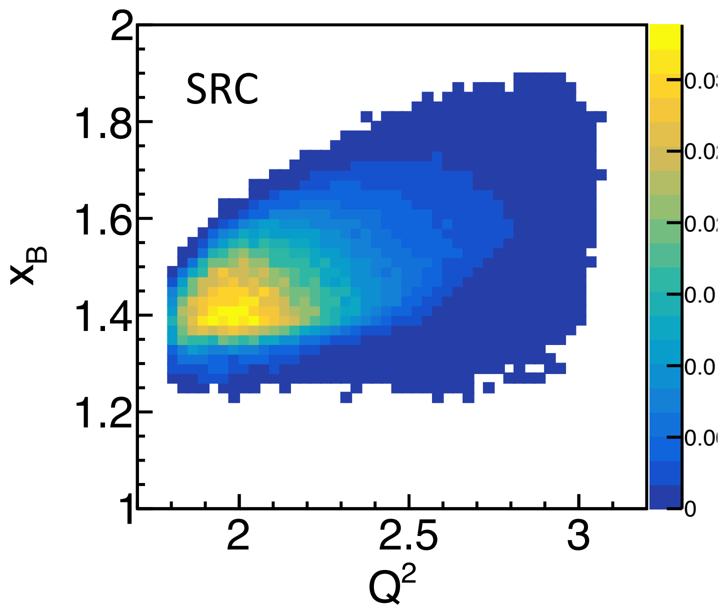
CaFe Kinematic and Acceptance

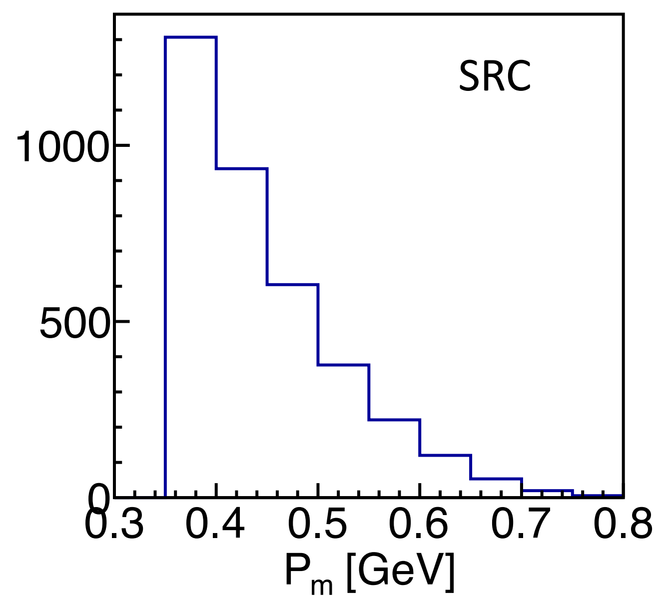
Ebeam (GeV)	E' (GeV)	θ_e Degree	$\|P_p\|$ GeV	θ_p Degree	P_m GeV	Q^2_cen	$\langle Q^2 \rangle$ GeV^2
10.6	8.85	8.3	1.325	66.4	0.4	2.1	
10.6	8.85	8.3	1.820	48.3	0.15	2.1	

CaFe Kinematic and Acceptance



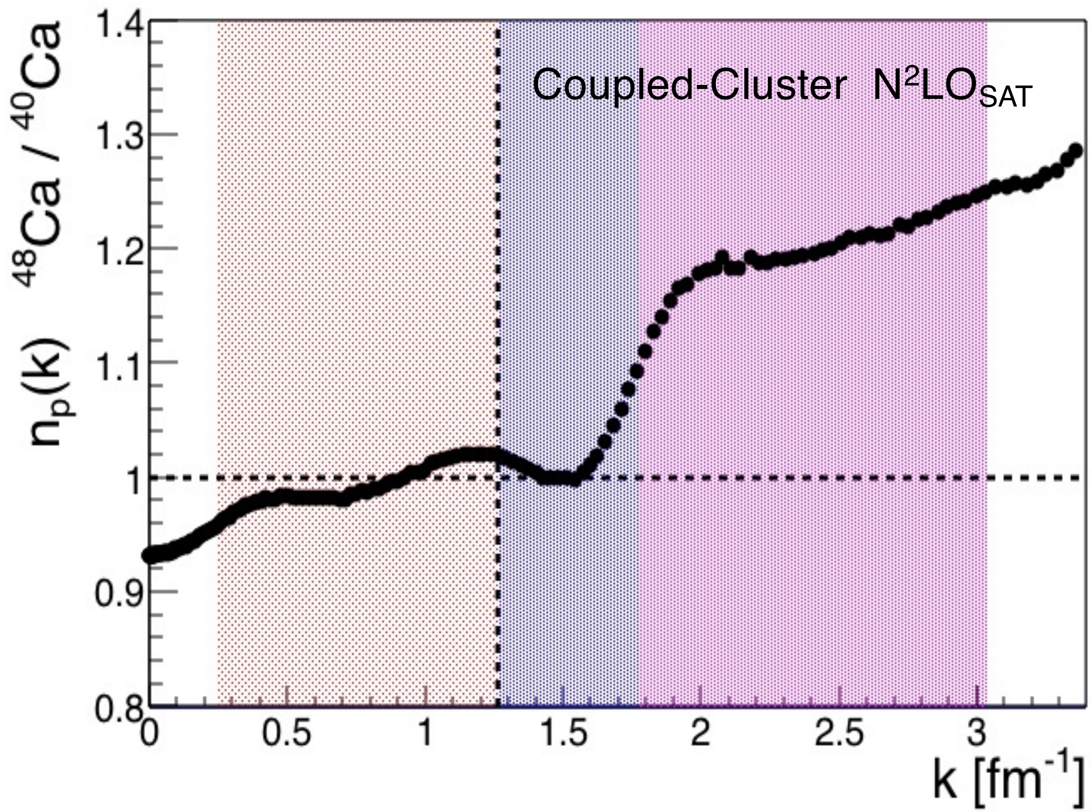






Q1: Does ^{48}Ca has more Proton in SRCs?

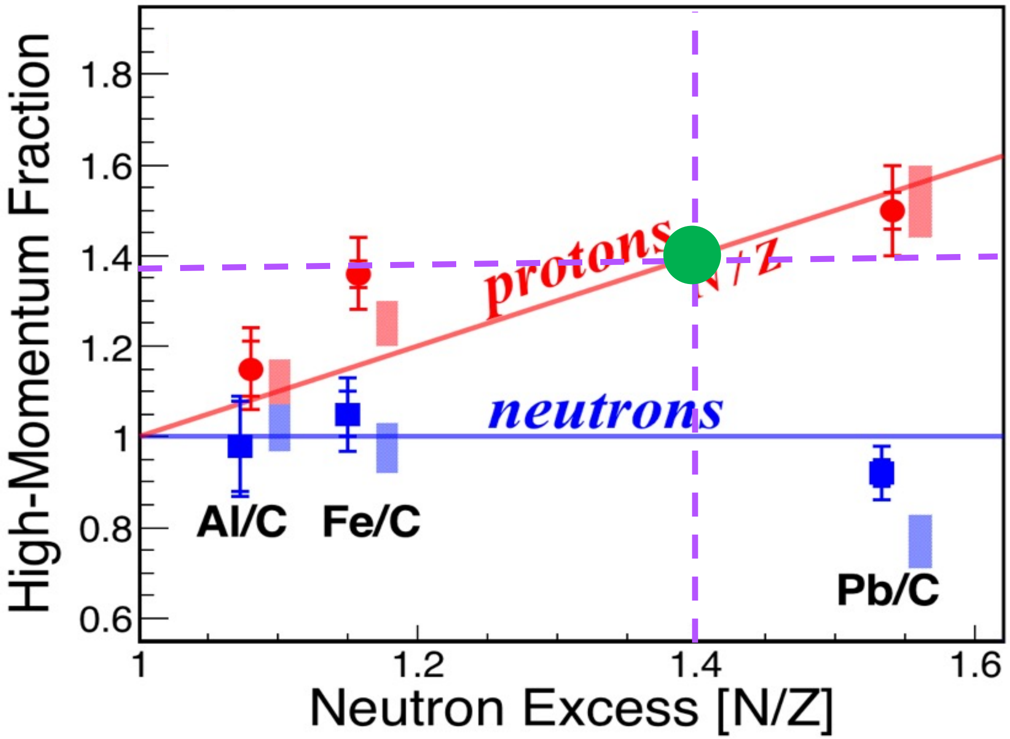
- ❑ Cross section ratio ^{48}Ca/^{40}Ca at high missing momentum



$$A1_{SRC}(e,e'p)/A2_{SRC}(e,e'p)$$

Q2: What is Proton High-momentum fraction?

- ❑ Double ratio of SRC/Mean-field Proton

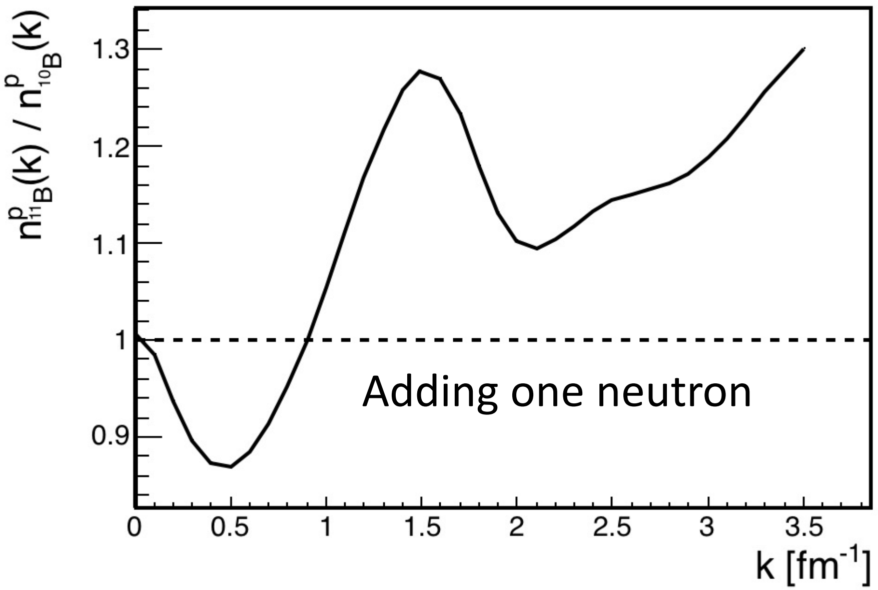


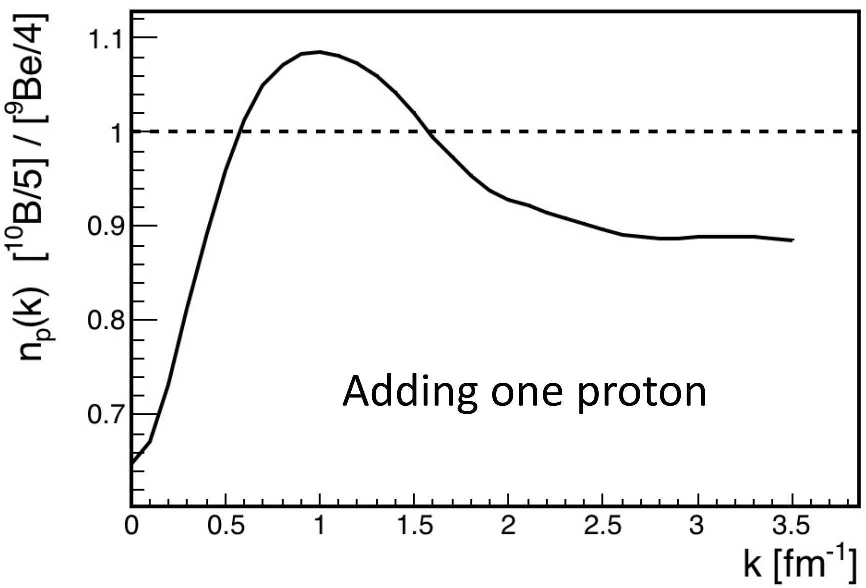
$$\frac{A_1(e,e'p)|_{SRC}}{A_1(e,e'p)|_{Mean-Field}} \Big/ \frac{A_2(e,e'p)|_{SRC}}{A_2(e,e'p)|_{Mean-Field}}$$

Other Potential observables

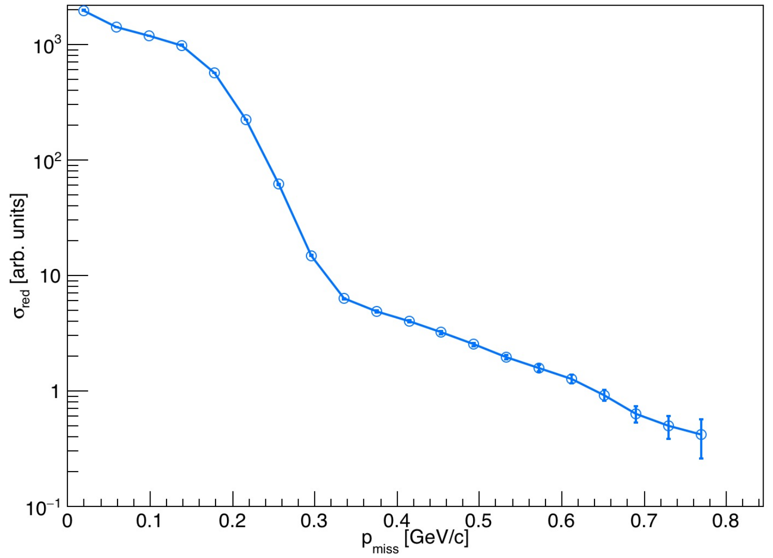
- Proton probability in SRC in light asymmetry nuclei

VMC AV18+UIX



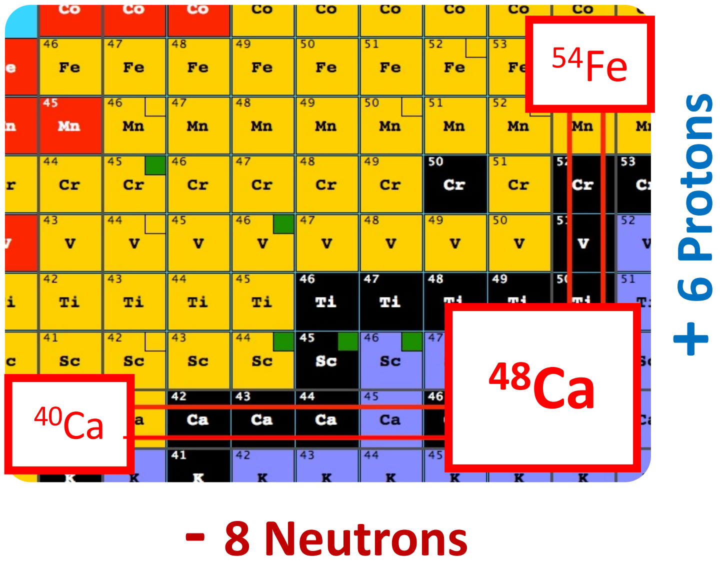


- Extracting absolute and reduced cross-section
  - Distorted spectral function
  - Compared to ab-initio effective theory calculation



Summary

- CaFe will do (e,e'p) measurements on different nuclear targets
- 4 PAC-day experiments using standard HMS and SHMS
- Data will be used to understand SRC pairing mechanism in asymmetry nuclei
- Observables are absolute cross-section, ratio and double ratio



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Jefferson Lab

ODU

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Back up slides