Jefferson Lab
Thomas Jefferson National Accelerator Facility

JSA

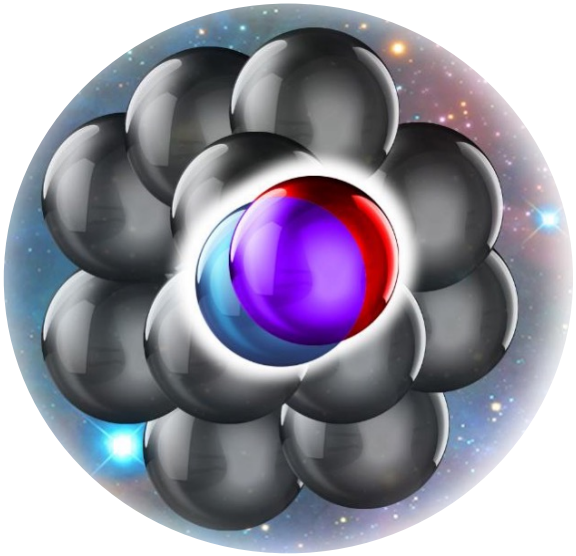
Short Range Correlations measurements in asymmetry nuclei

Dien Nguyen
Nathan Isgur Fellow

10th workshop of the APS Topical Group on Hadronic physics
April 12 , 2023

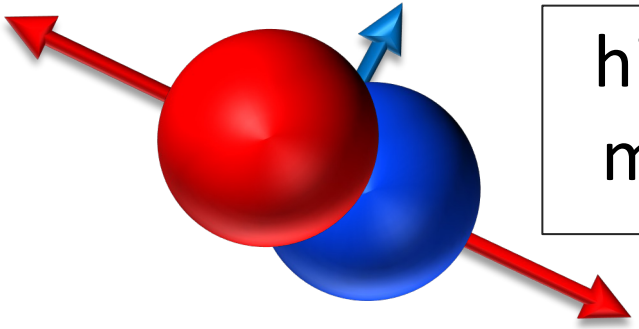
What are Short Range Correlations (SRCs) ?

r-space



Nucleon pairs that are close together in the nucleus

k-space



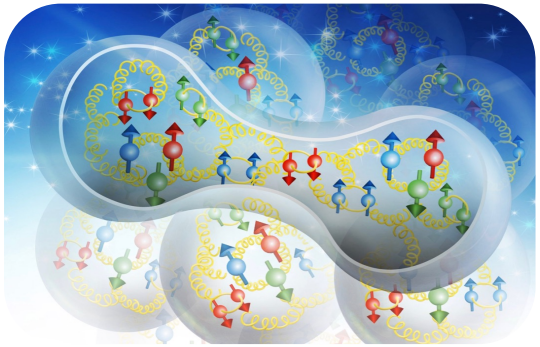
high ***relative*** and lower ***c.m.*** momentum compared to k_F

Why SRC?

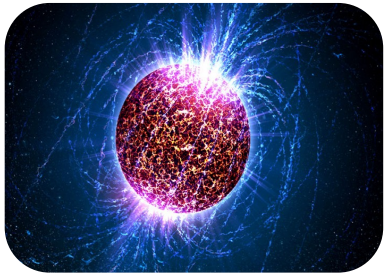
The bridge between Nucleon interaction and Partonic structure

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

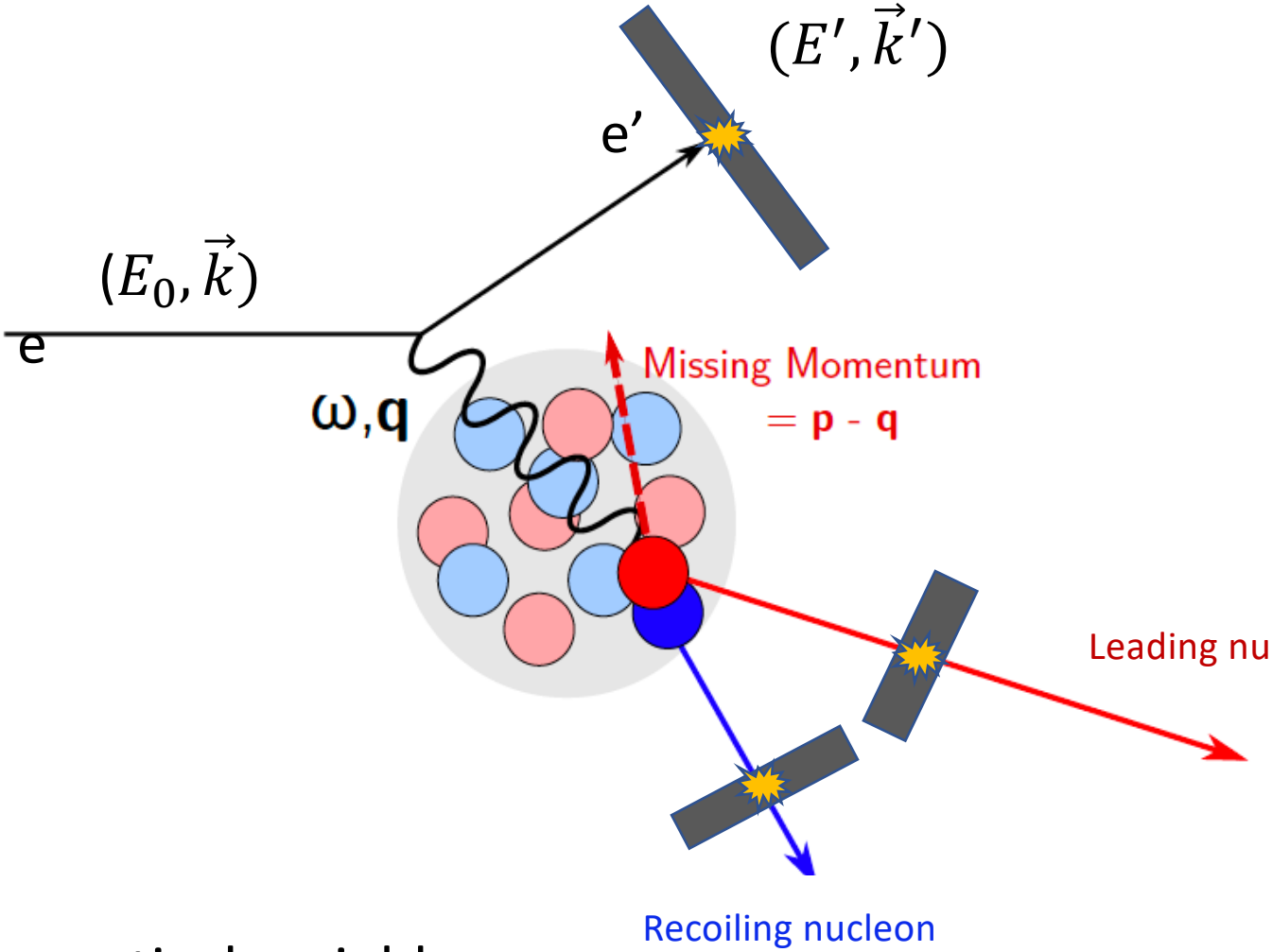
NN interaction from QCD & QCD in nuclei



High-density systems



SRC studies using electron scattering



A(e,e')

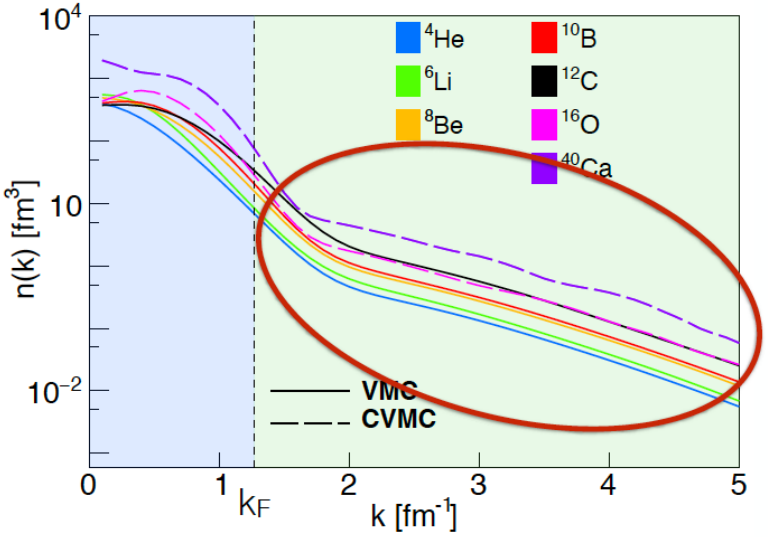
A(e,e'N)

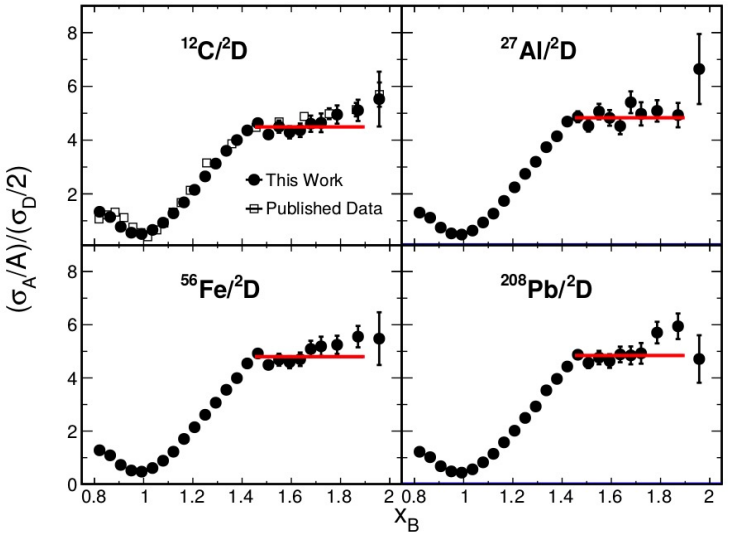
A(e,e'NN)

Kinematical variables:

$Q^2 = -(p_e - p'_e)^2$ $\quad x_B = Q^2/2m(E - E')$ $\quad \vec{p}_{\text{miss}} = \vec{p}_{\text{f}} - \vec{q}$

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





What we have learned:

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

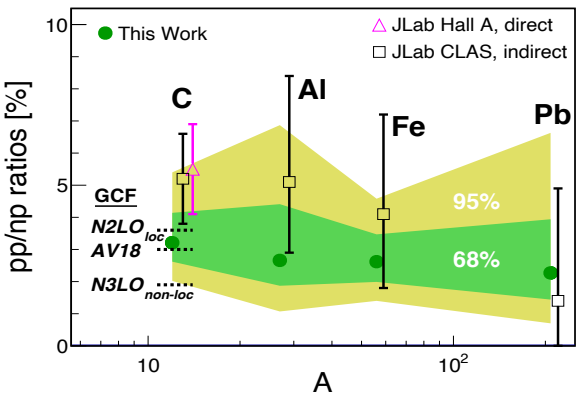
Next questions:

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

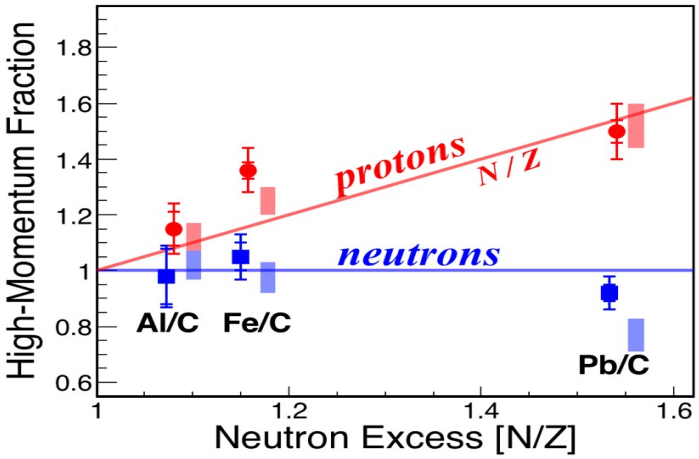
S. Li Nature (2022), Schmookler Nature (2019), Fomin PRL (2008), Egiyan PRL (2006), Egiyan PRC (2003),), L. L. Frankfurt, PRC (1993)

SRCs studies from two-knock-out nucleon (e,e'NN)

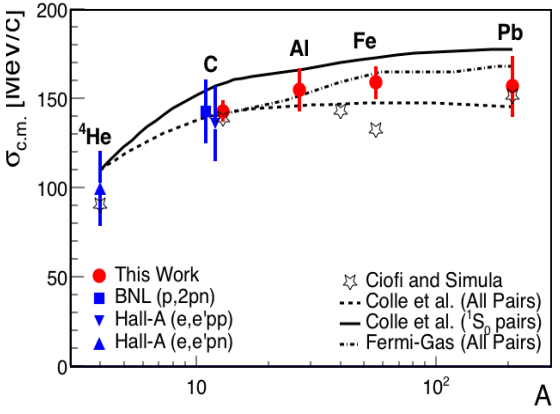
M. Duer et al., PRL (2019)



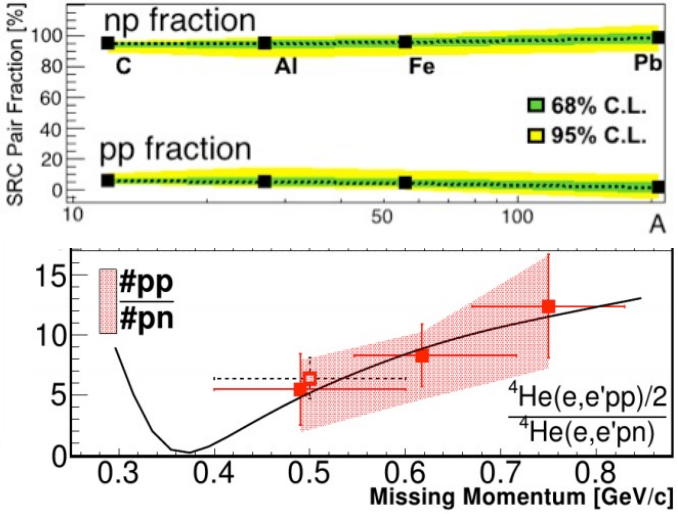
M. Duer, Nature (2018)



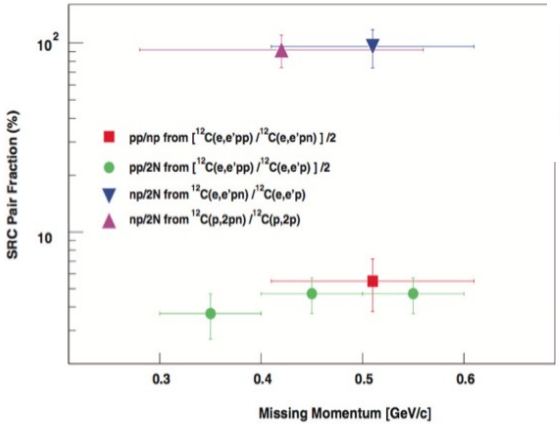
Cohen et al., PRL (2018)



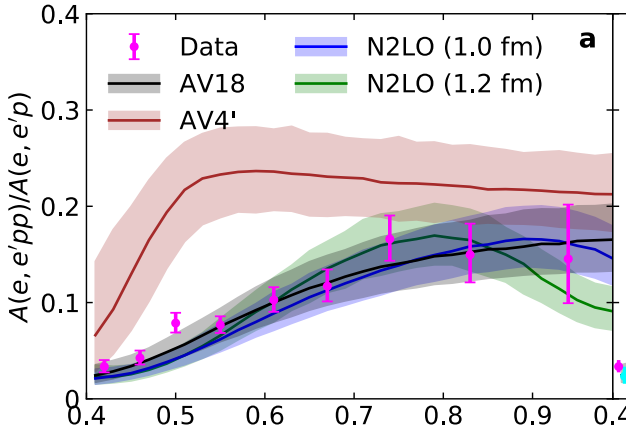
O. Hen, Science (2014)



R.Subedi, Science (2008)



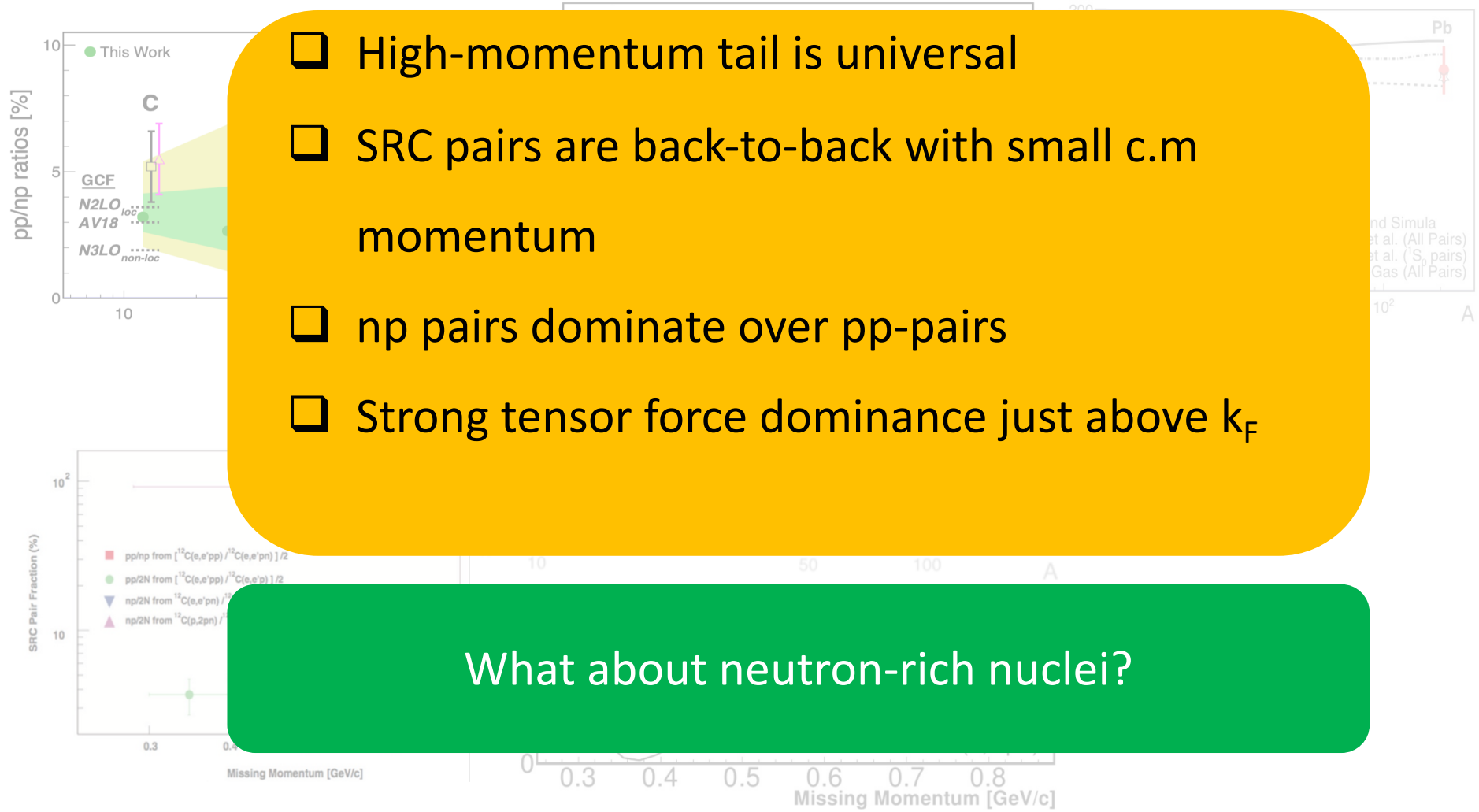
A. Schmidt Nature (2020)



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

Korover, PRL (2014)

What have we learned about SRCs?

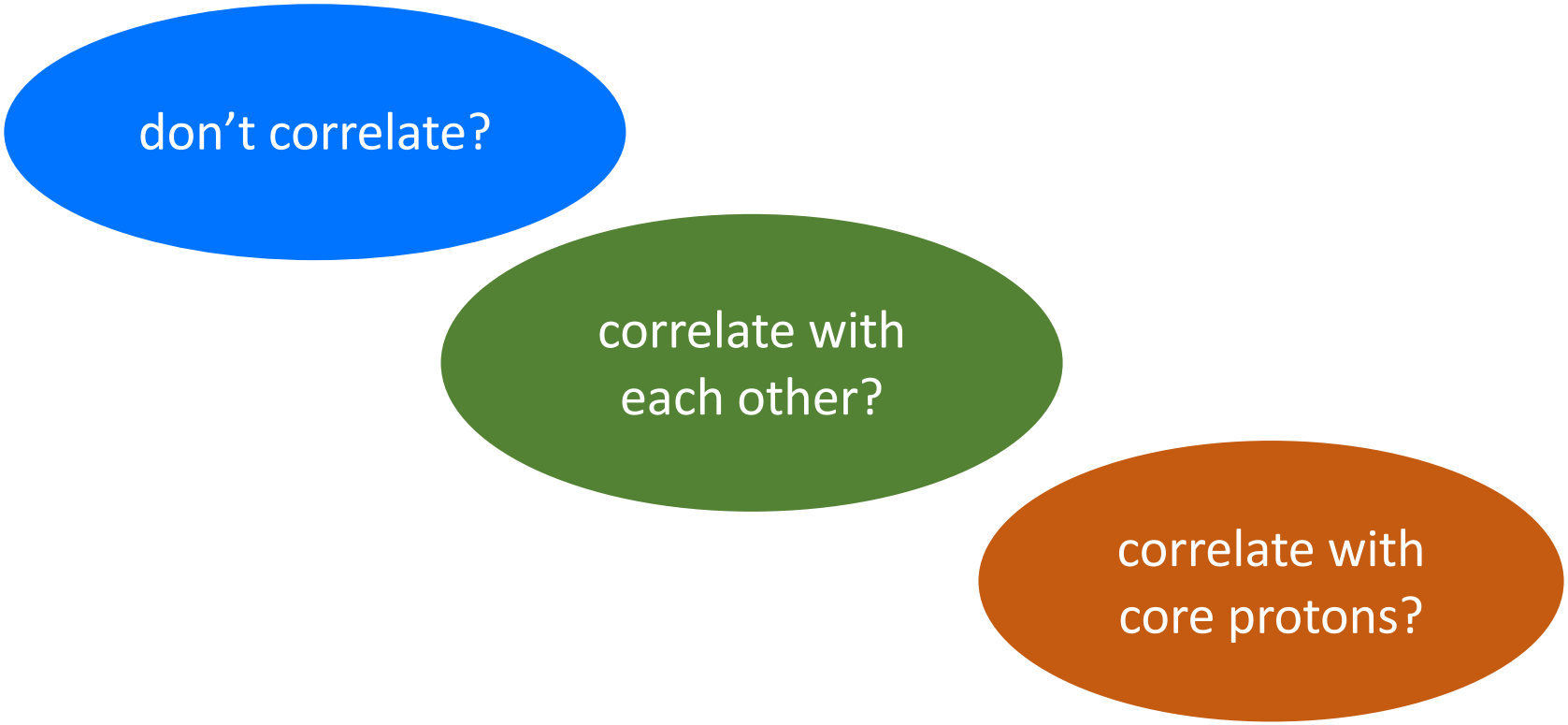


- High-momentum tail is universal
- SRC pairs are back-to-back with small c.m momentum
- np pairs dominate over pp-pairs
- Strong tensor force dominance just above k_F

What about neutron-rich nuclei?

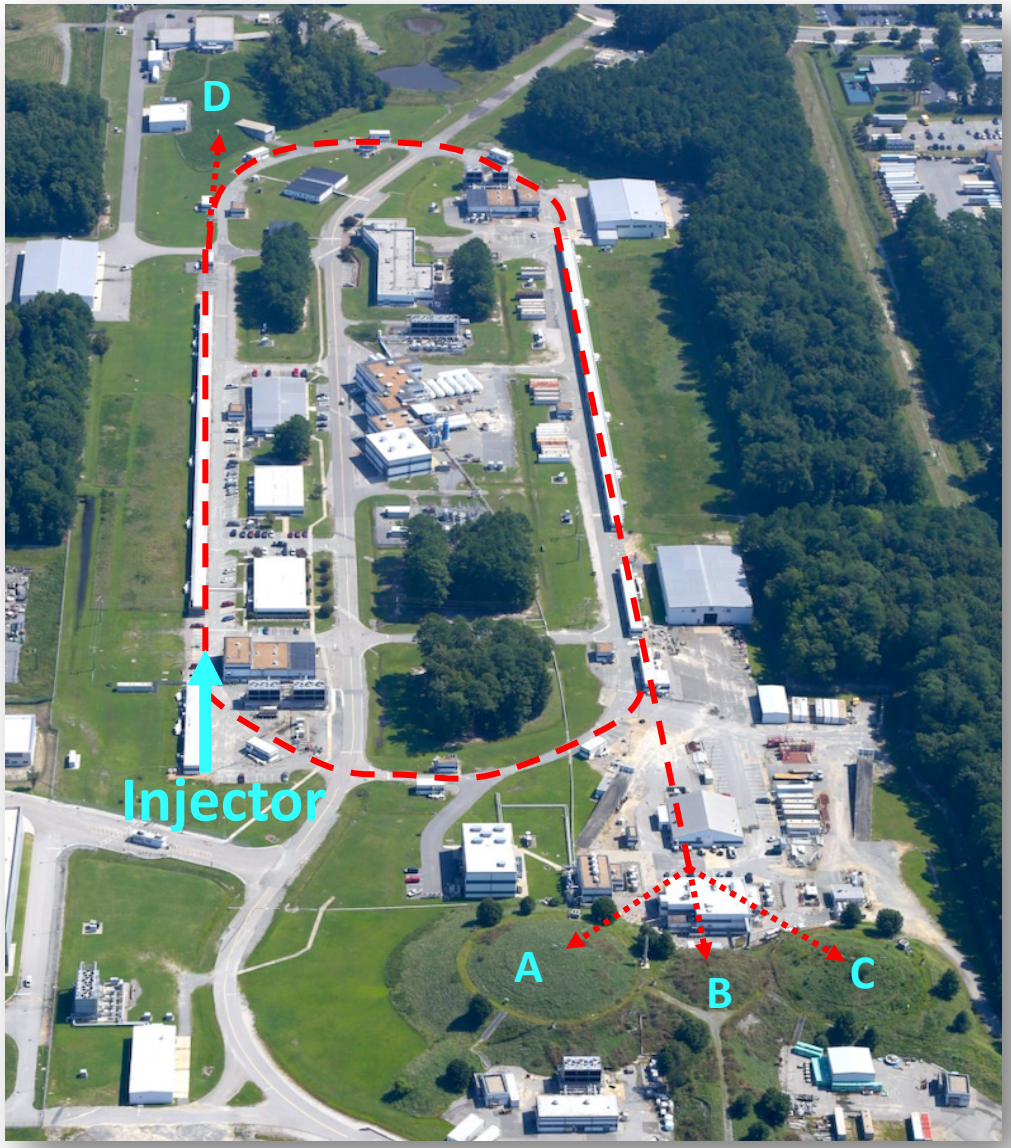
SRCs in Neutron rich nuclei:

What do excess neutrons do?



Jefferson Lab

- Virginia, USA
- 1- 11 GeV Electron beam
- 4 experimental halls
- Approved physics for the next 10+ years, moving toward EIC.

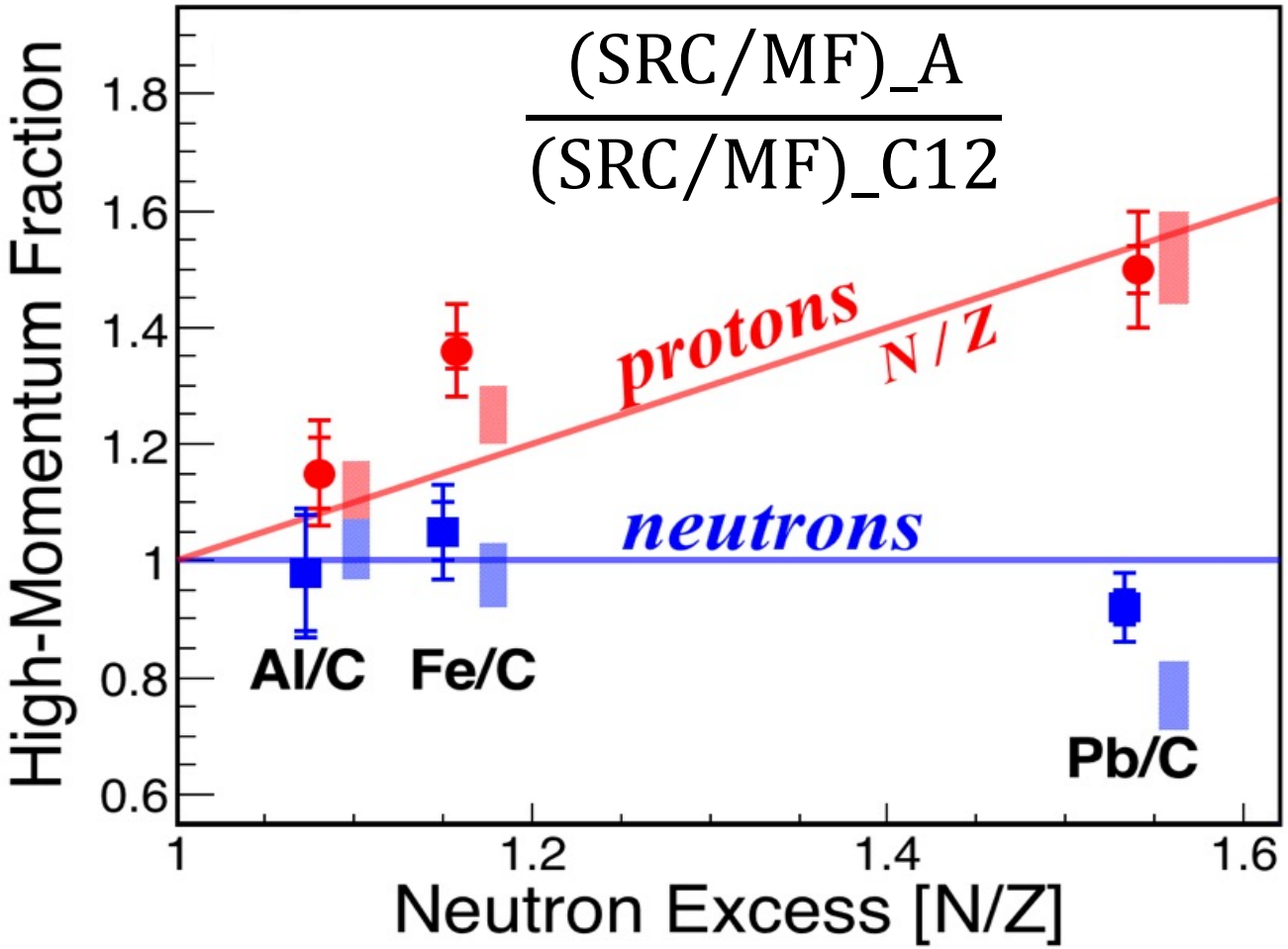


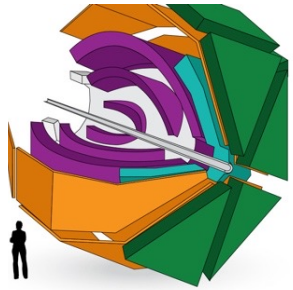
Experiments and results

- (e,e'NN) results from CLAS 6GeV, Hall B, JLab

- Results from ^{48}Ca and ^{40}Ca
  - (e,e') Hall A
  - (e,e'p) Hall C
  - (e,e'p) and (e,e'N) Hall B

Protons “speed up” in neutron-rich nuclei





Hall B CLAS

Is this A or N/Z dependence?

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

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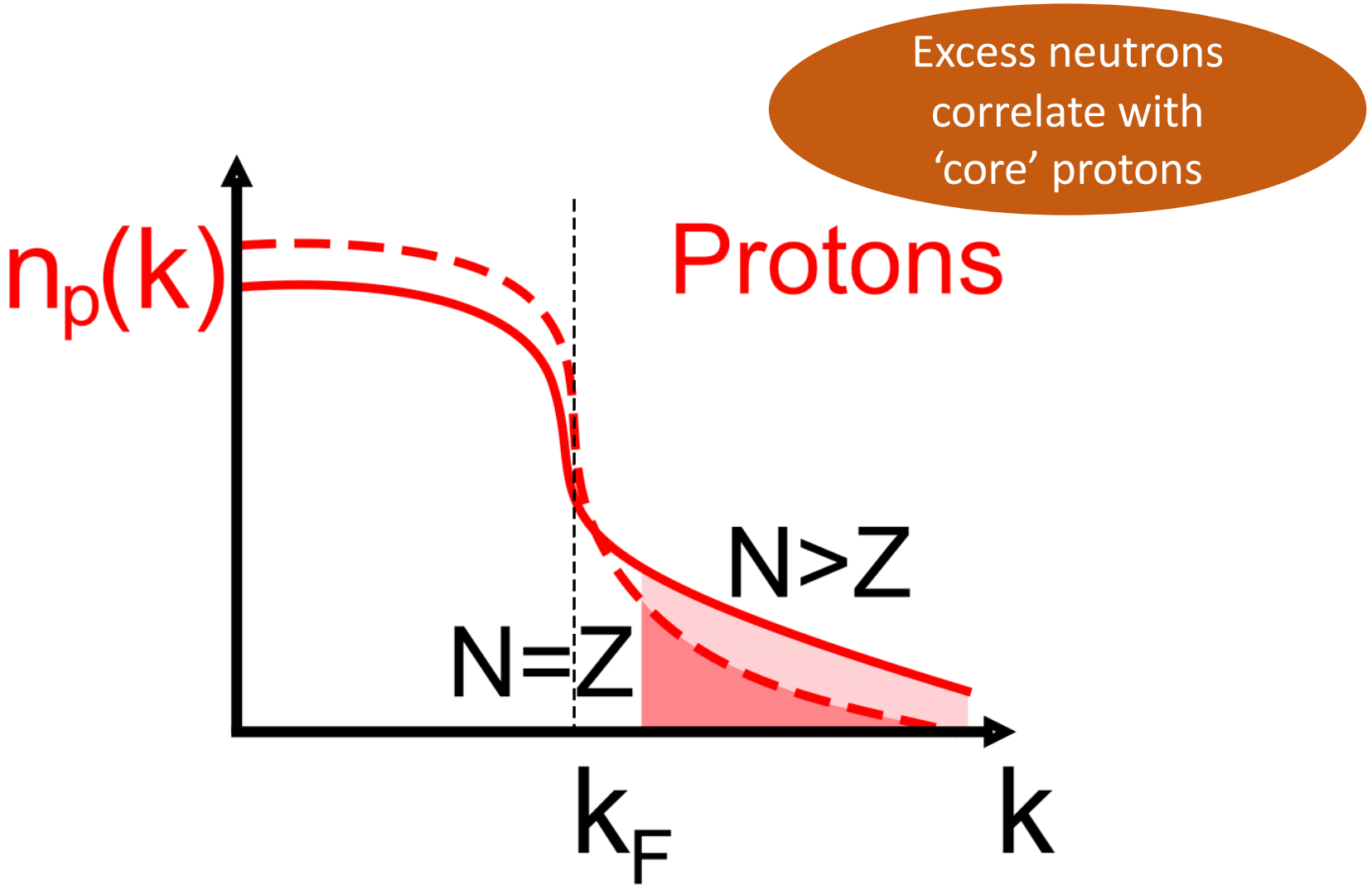

Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

Experiments and results

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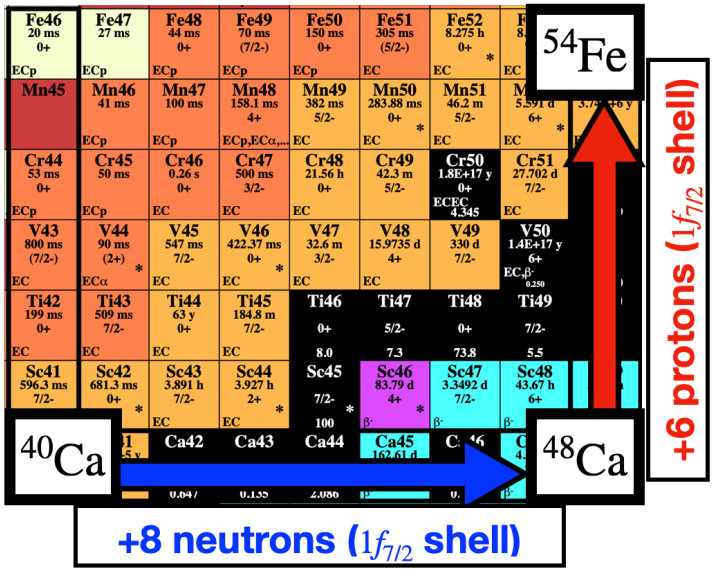
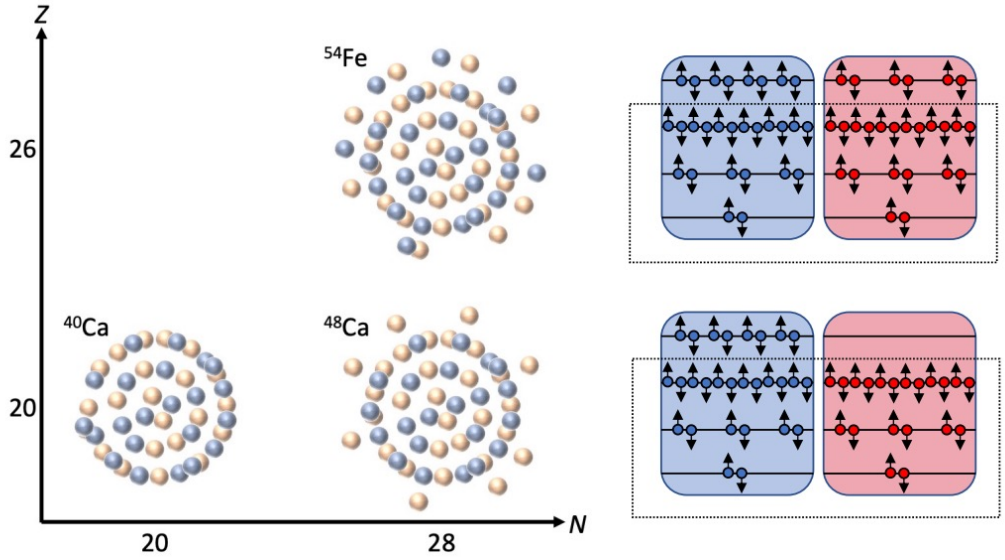
Ca Isotopes: Great nuclei to study

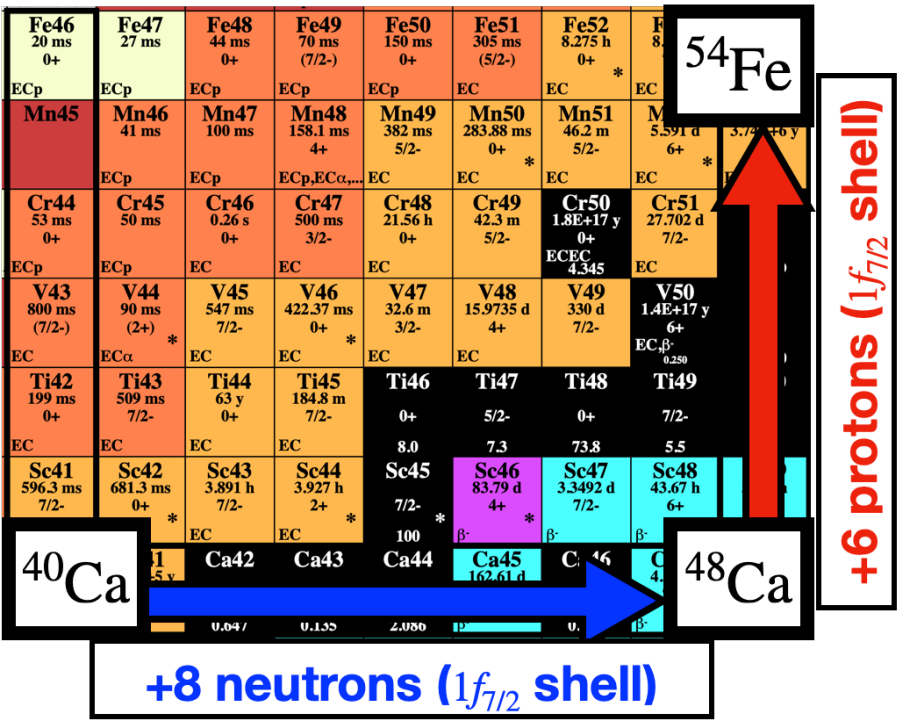


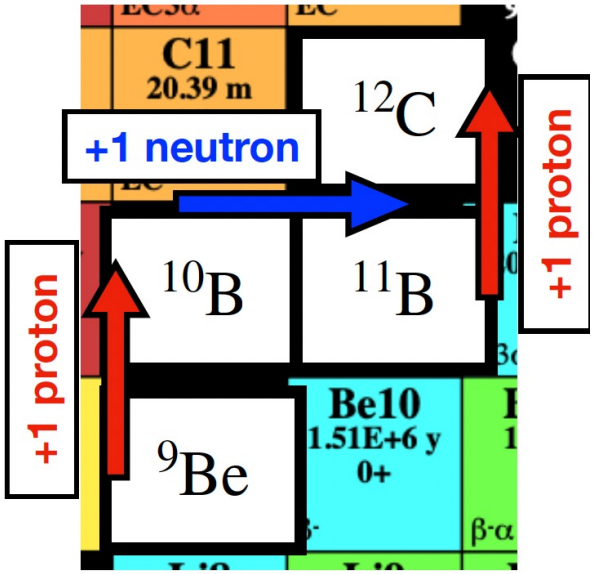


Questions:

- Does ^{48}Ca have more proton in SRC compared to ^{40}Ca
- Mass (A) and symmetry (N/Z) dependence
- How does +8 1f7/2 neutron correlate with core protons
- How does +6 1f7/2 proton correlate with core proton

Ca Isotopes: Great nuclei to study



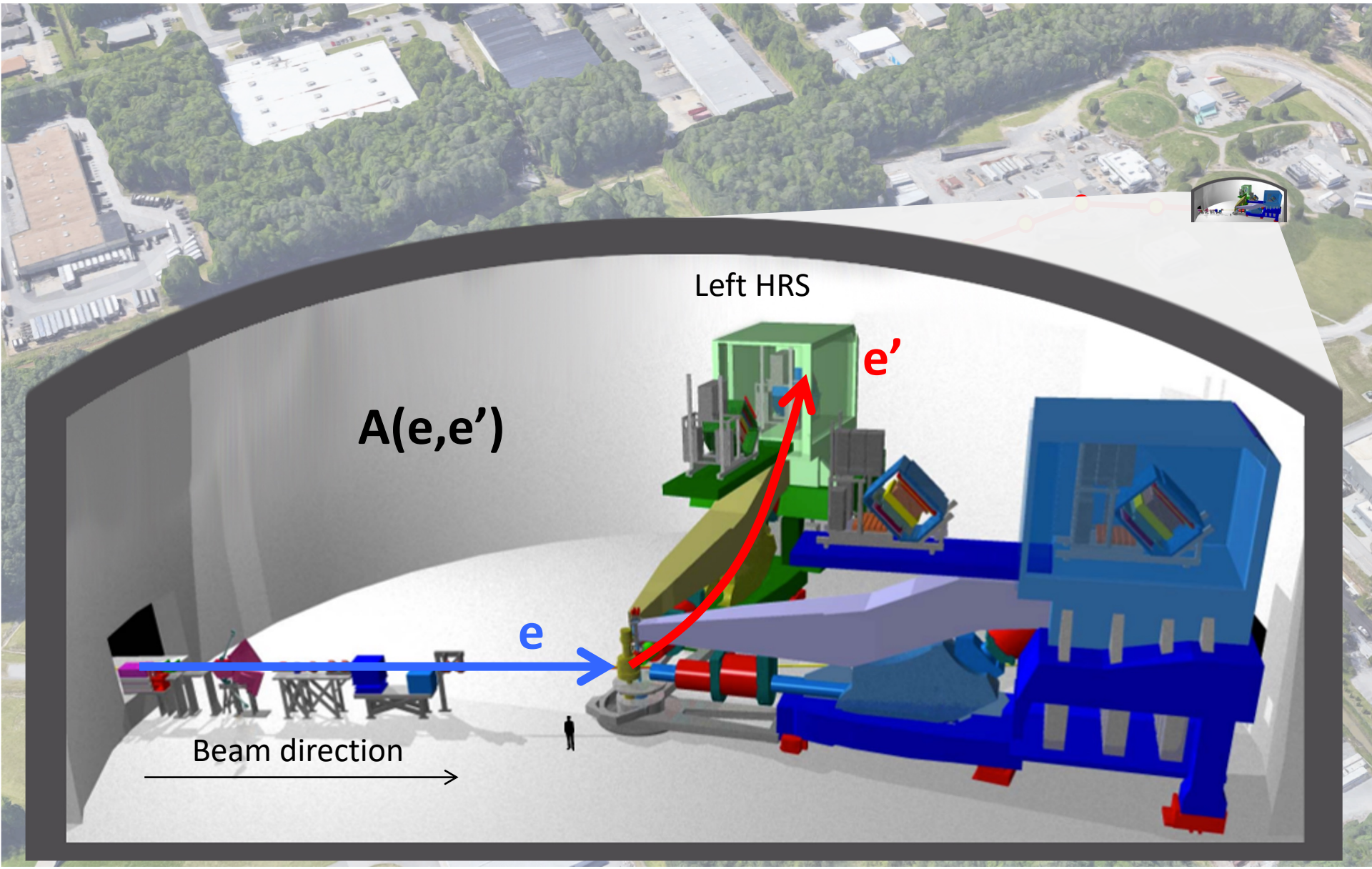


Questions:

- How about light nuclei?

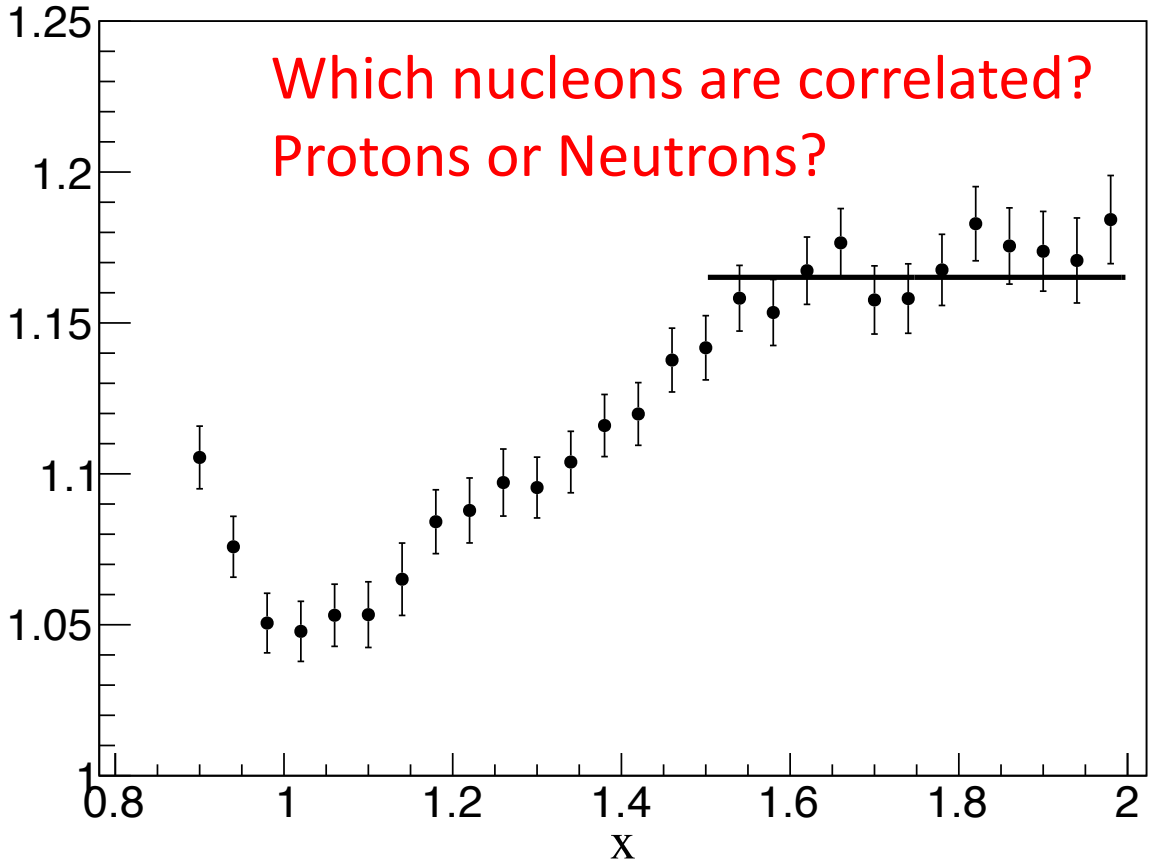
They are calculable, a great place to compare with theory calculation

Hall-A of Jefferson Lab



17% more pairs in ^{48}Ca!

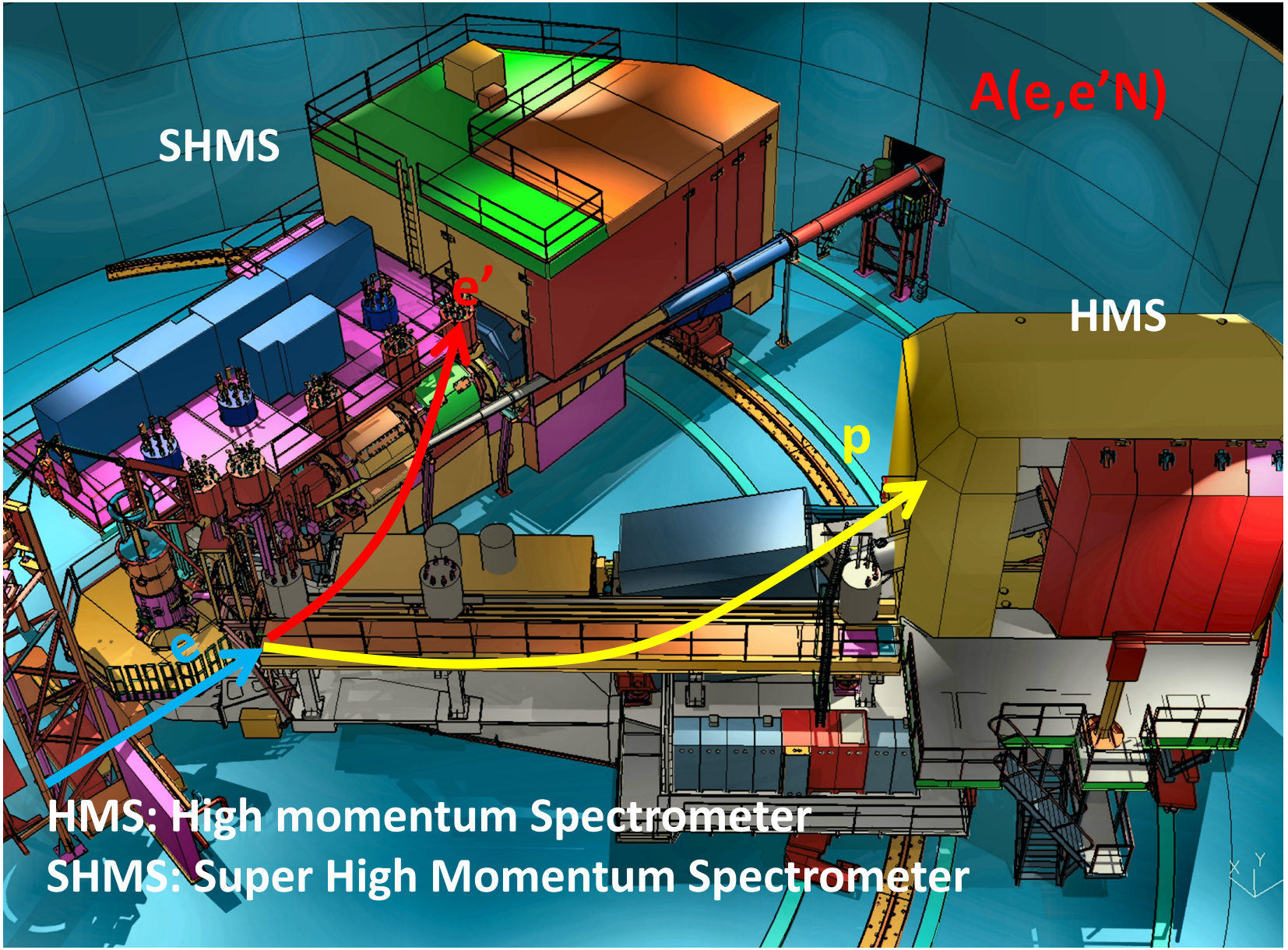
$$\frac{\sigma(^{48}\mathrm{Ca})}{\sigma(^{40}\mathrm{Ca})}$$



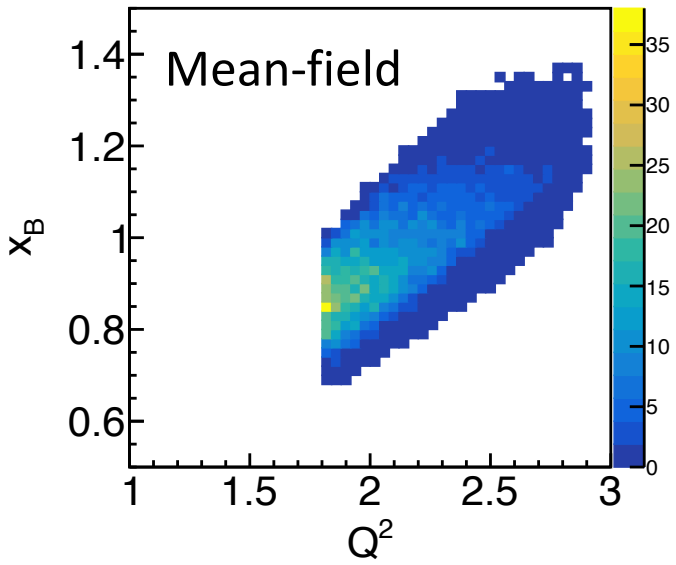
Adding neutrons increases number of SRCs!

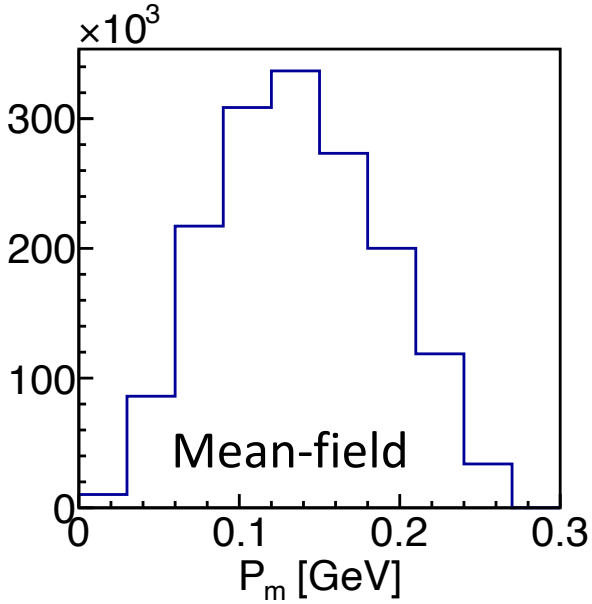
D. Nguyen et al., Hall A Collaboration PRC (2020).

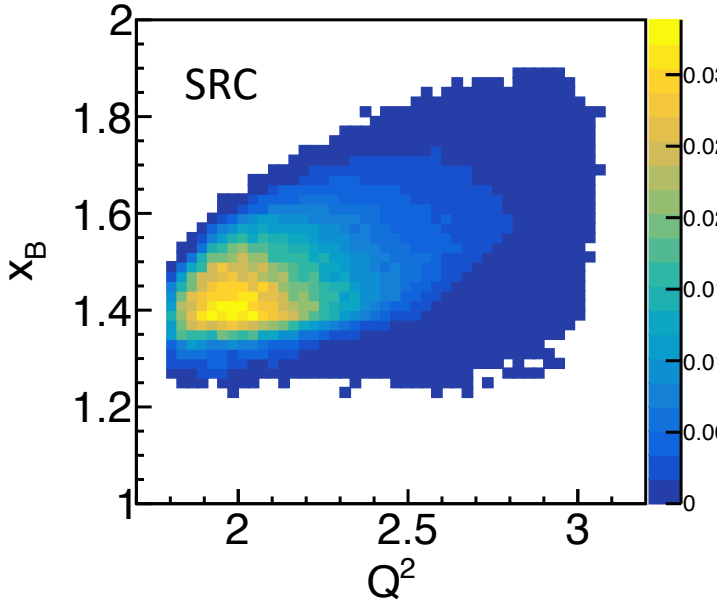
Hall-C of Jefferson Lab

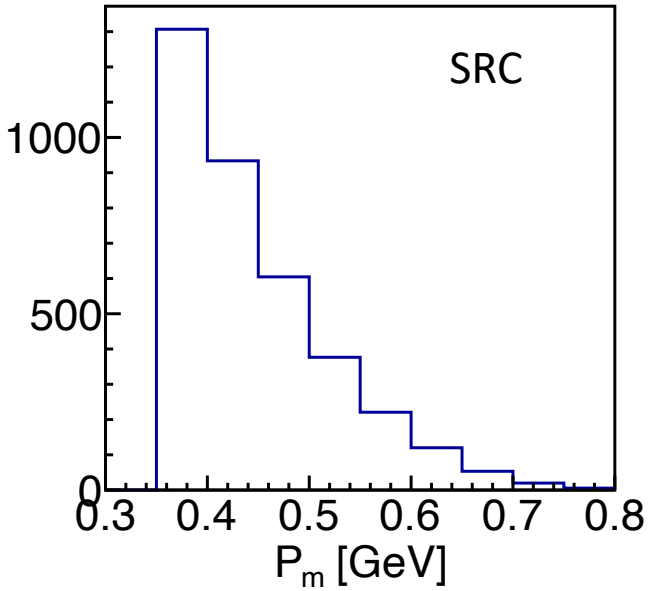


CaFe Kinematic coverage





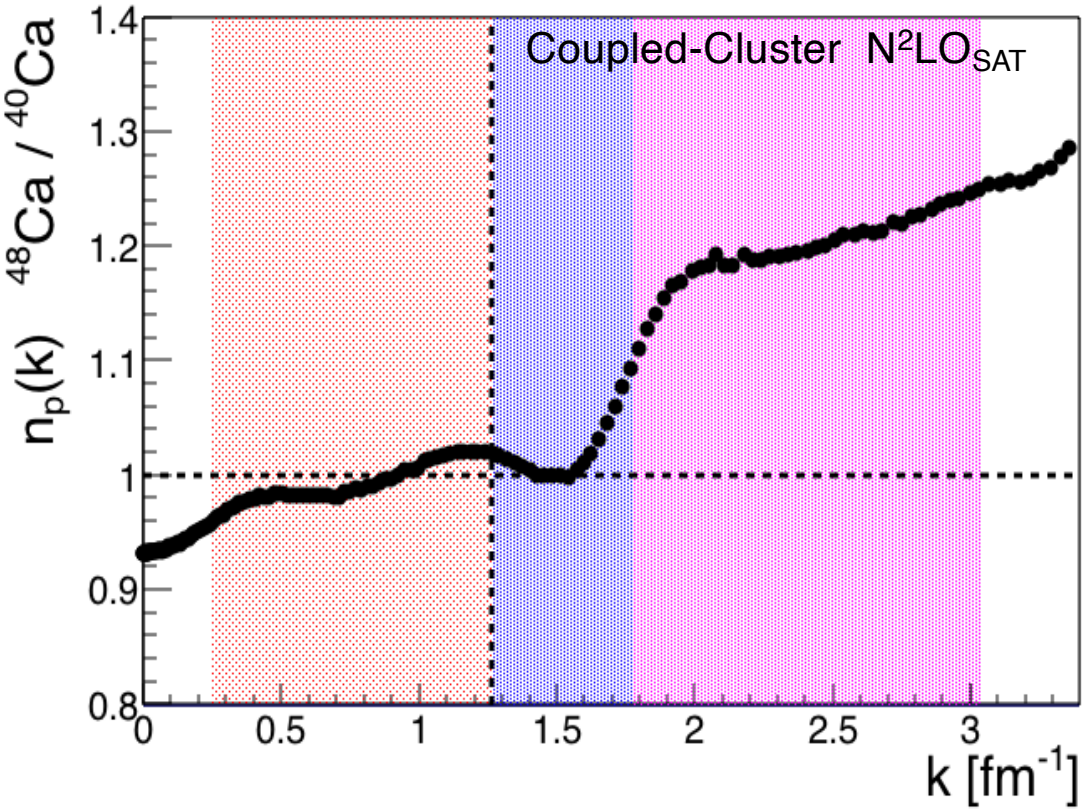




Q1: Does ^{48}Ca has more Proton in SRCs?

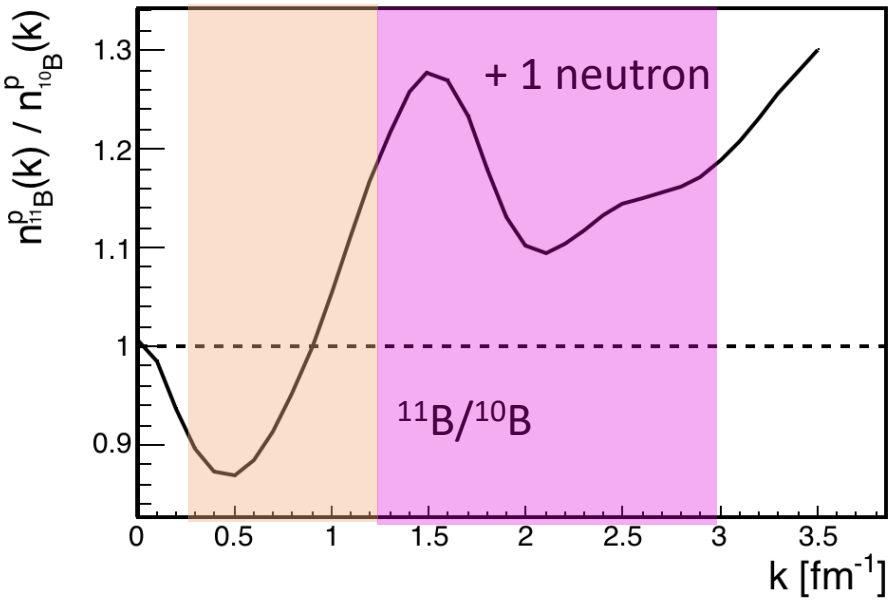
- Cross-section ratio ^{48}Ca/^{40}Ca at high missing momentum

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

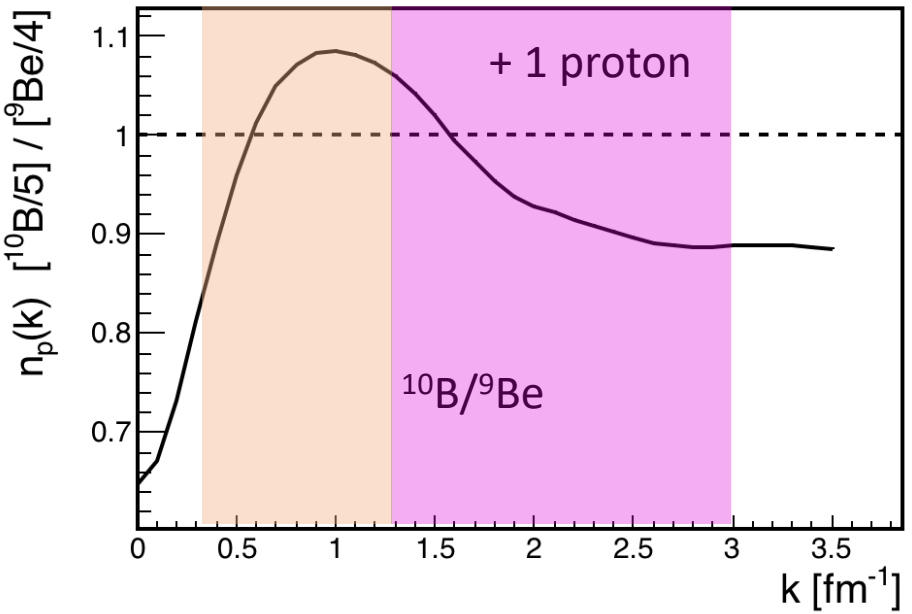


Light nuclei?

VMC AV18 + UIX potential



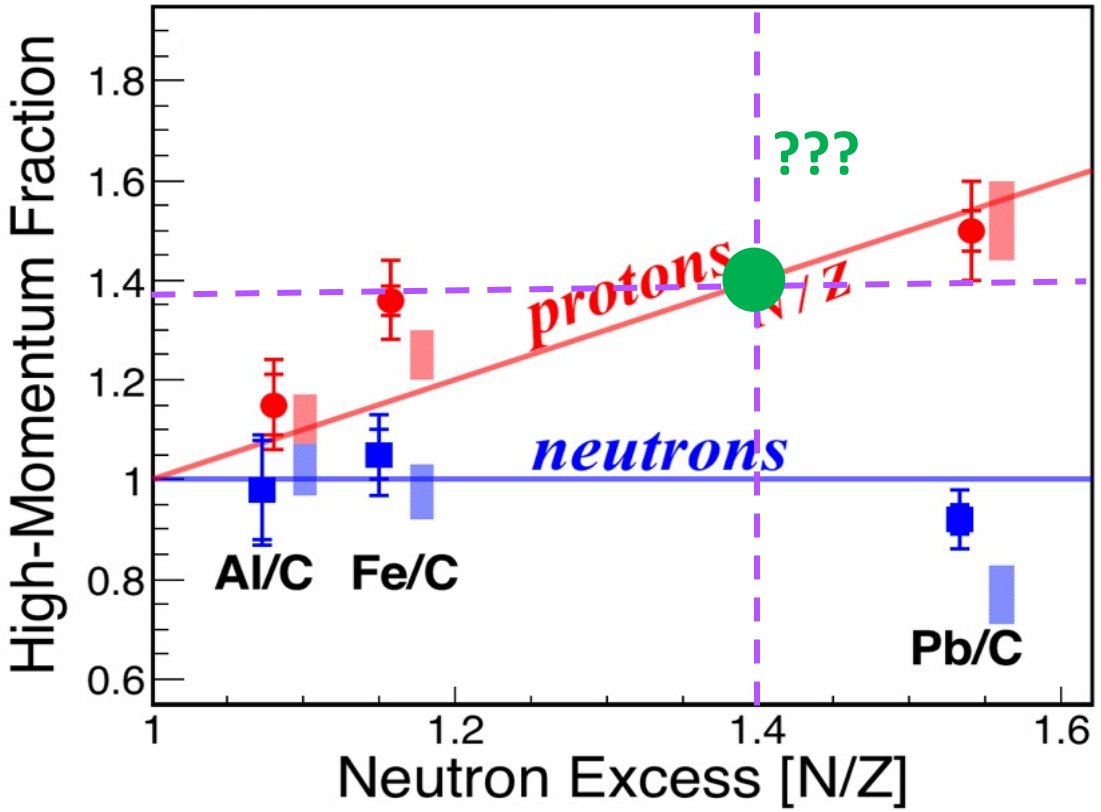
D. Lonardoni, (2017) 1705.04337



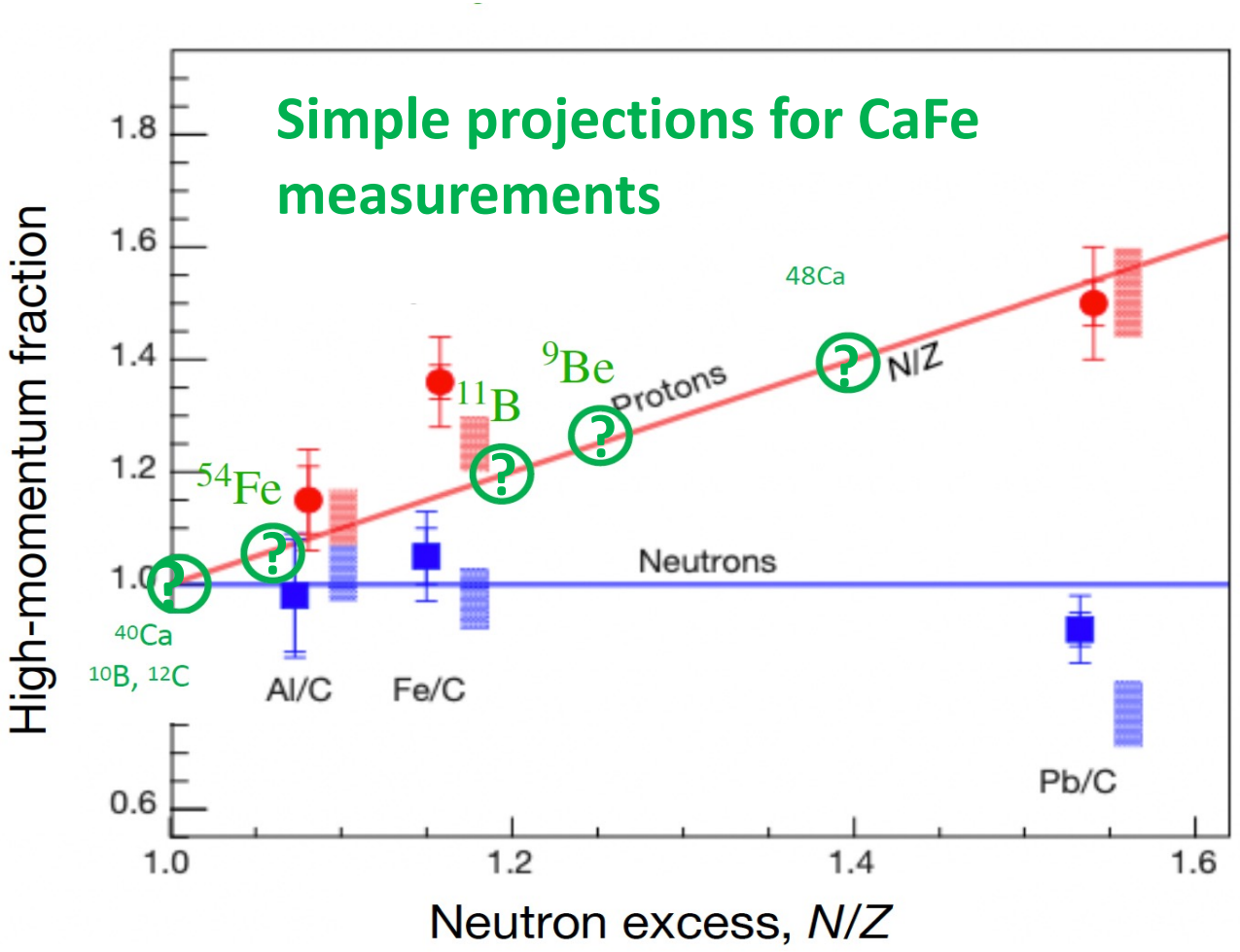
- What does additional proton/neutron do to SRC in light nuclei?

Q2: What is Proton High-momentum fraction in 48Ca?

- Double ratio of SRC/Mean-field Proton



How about light nuclei?



Data analysis status

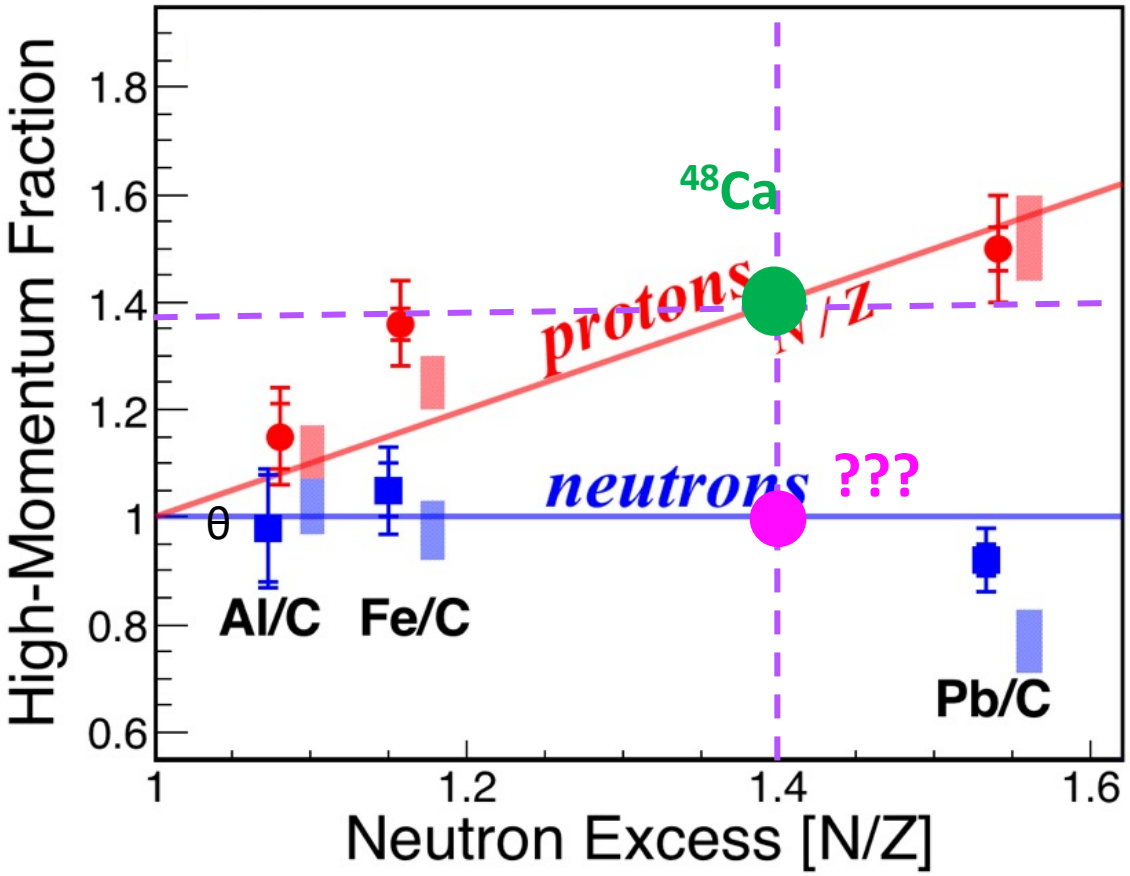
- Finished taking data on 02/2023
- Finished all calibration
- Working on different efficiency study
- Systematic studies
- Expecting final results this summer

Carlos Yero
(NSF Fellow)

Noah Swan
(PhD student)

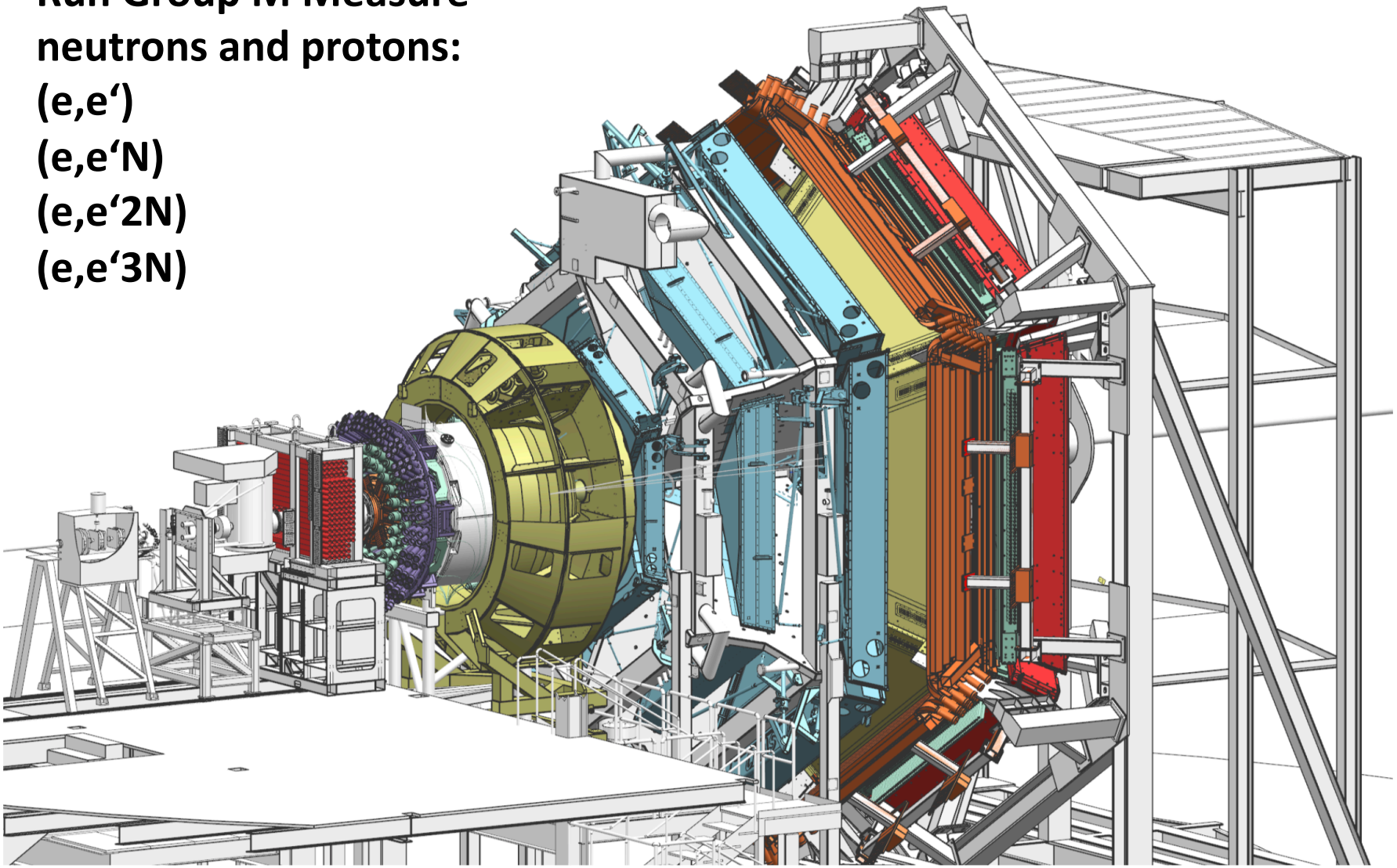
Holly Szumila-Vance
(Staff)

Q3:What is Neutron High-momentum fraction?

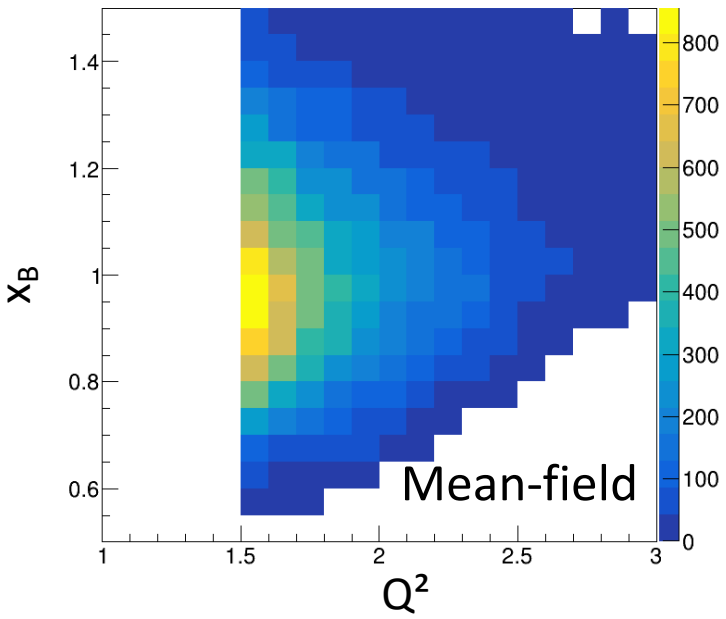


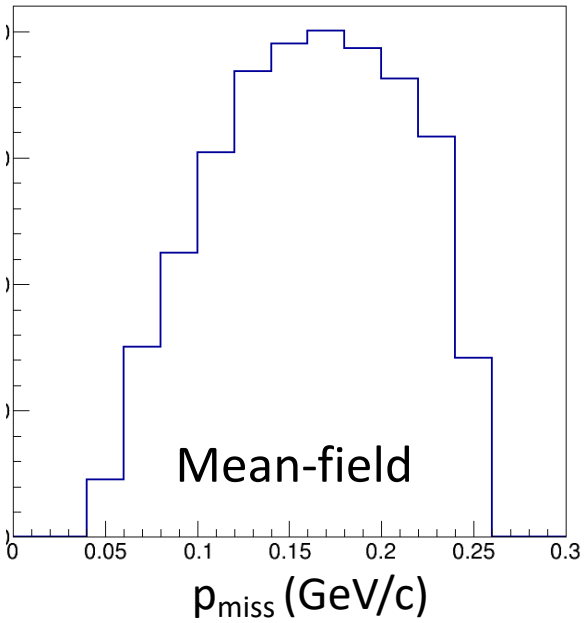
Complementary measurement at CLAS12, Hall B

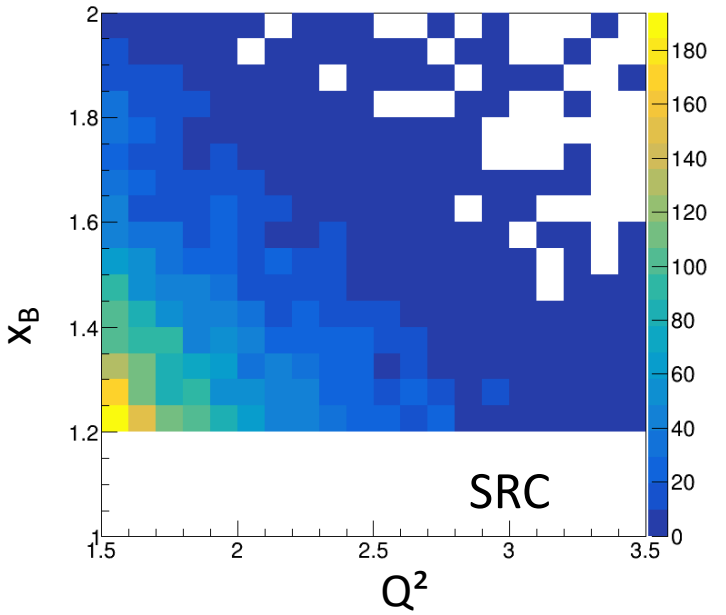
Run Group M Measure neutrons and protons:
(e,e‘)
(e,e‘N)
(e,e‘2N)
(e,e‘3N)

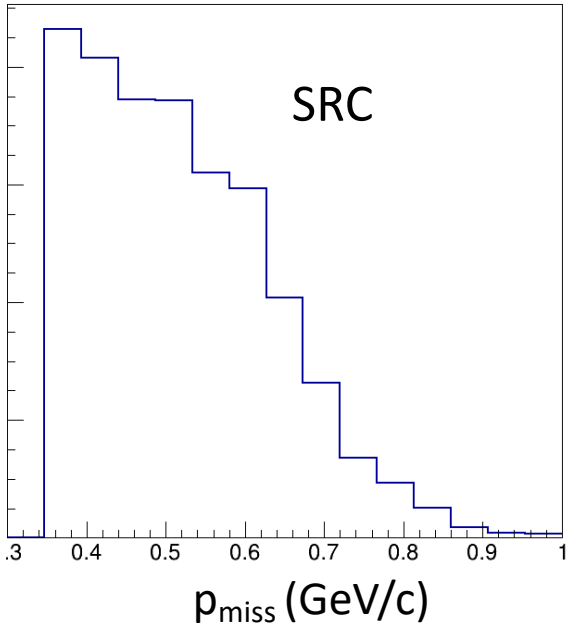


CLAS12 Kinematic coverage



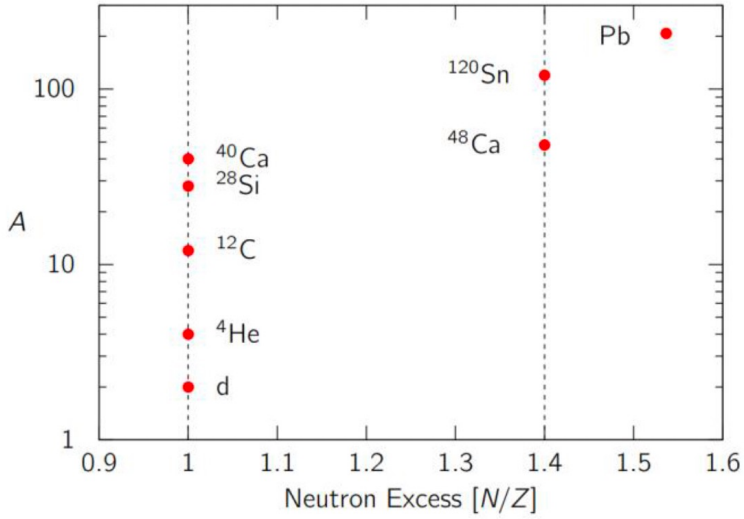






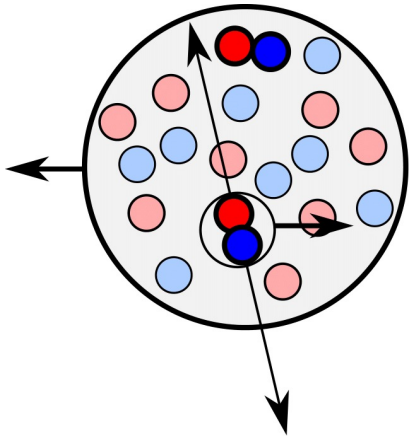
Run Group M at CLAS12 Hall B at JLab

- Measure both proton and neutron
- Missing momentum ~ 1000 MeV



Studies Questions:

- ❑ Short Range Correlations
  - ❑ NN interaction
  - ❑ SRC pair formation
  - ❑ EMC/SRC relation
  - ❑ SRC scale universality
- ❑ Search for 3N SRCs



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Julian Kahlbow
(MIT Postdoc)

Justin Estee
(MIT Postdoc)

Andrew Deniston
(MIT PhD student)

Summary

- SRC is an important part of nuclear structure
- SRC in neutron-rich nuclei is very interesting
  - Mass and symmetry dependence
  - Separate contribution of proton and neutron to SRC
  - Contribution of nucleon in different shells to SRC

Stay tuned, Many results will come out in the next couple of months

Thank you!

Nathan Isgur Fellowship and collaborators