Short-Range Correlations: Current Status and the path forward

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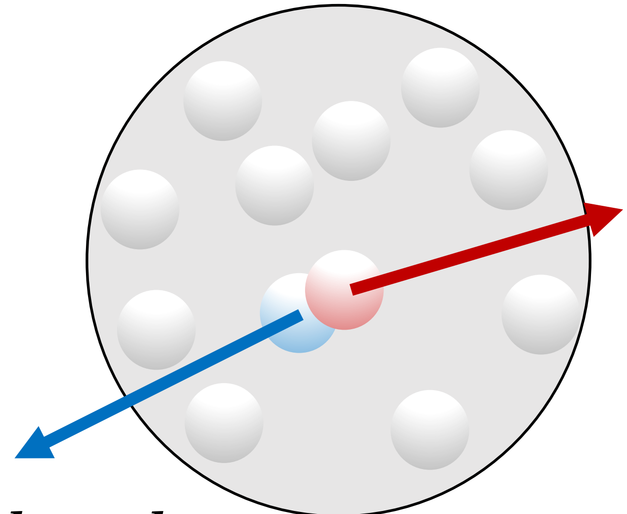
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Short-range correlations (SRCs) are a universal feature of nuclei.

- All nuclei have them
- Nucleon pair close together
- High-momentum nucleons
- Back-to-back momenta
- ≈10–20% of nucleons



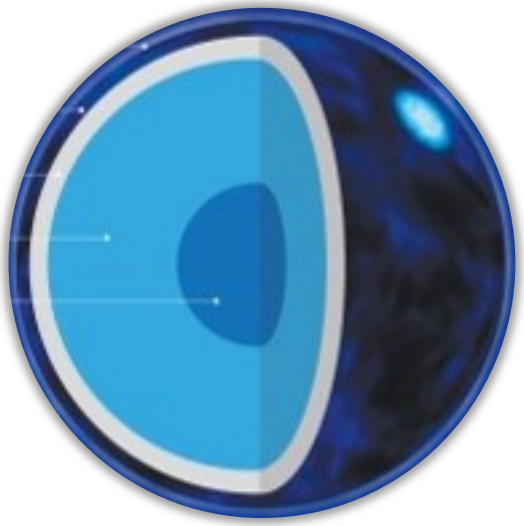
SRCs play a role in many open questions of nuclear, hadronic physics.

1. Nuclear structure
   - How do correlations form?
   - What type of pairs?
   - SRCs influence nuclear properties.

SRCs play a role in many open questions of nuclear, hadronic physics.

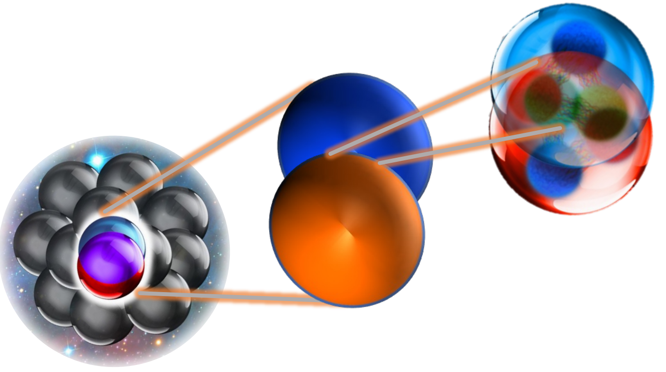
1. Nuclear structure

2. Nuclear matter at high density
   - High-density laboratory
   - Effective NN forces at short-distances
   - Connection to neutron star matter



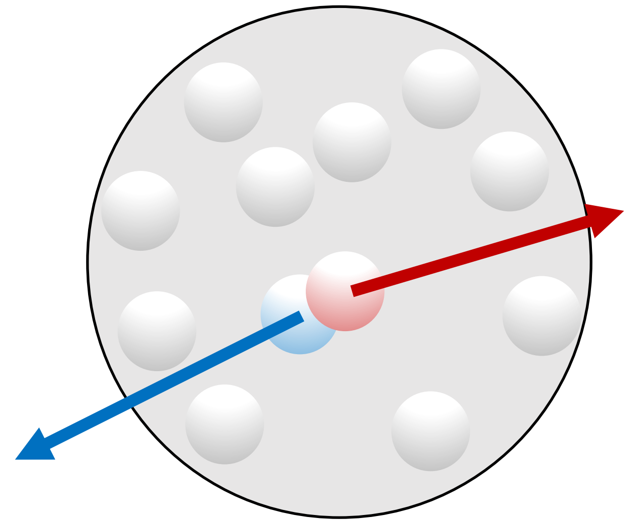
SRCs play a role in many open questions of nuclear, hadronic physics.

1. Nuclear structure
2. Nuclear matter at high density
3. Hadronic-Partonic bridge
   - EMC Effect
   - Emergence of quark d.o.f.s

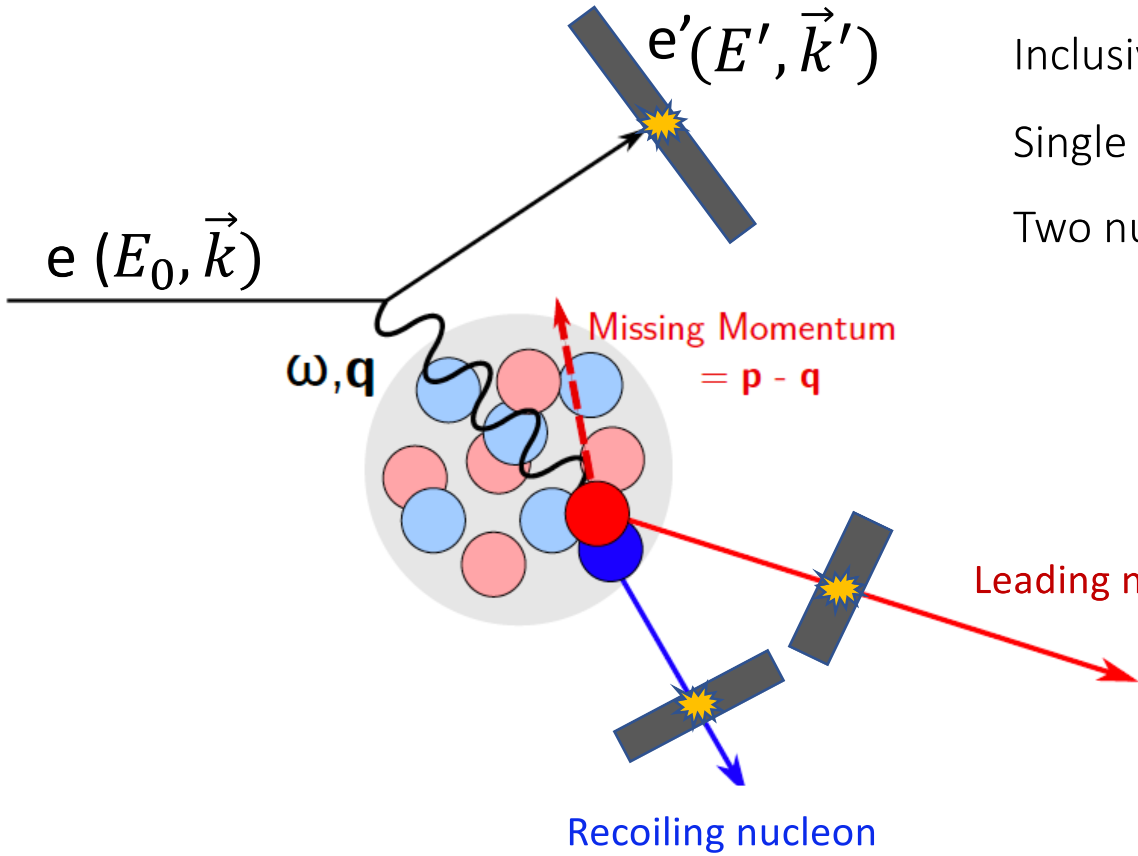


In this talk:

- **How do we probe SRCs?**
  - Using electron scattering
- **What have we learned about SRC?**
  - Recent results from SRC studies
- **The path forward**
  - New data coming
  - Different probes
  - Open questions



Probing SRC using electron Quasi-elastic scattering



Inclusive: (e,e’)

Single nucleon Knockout: A(e,e’N)

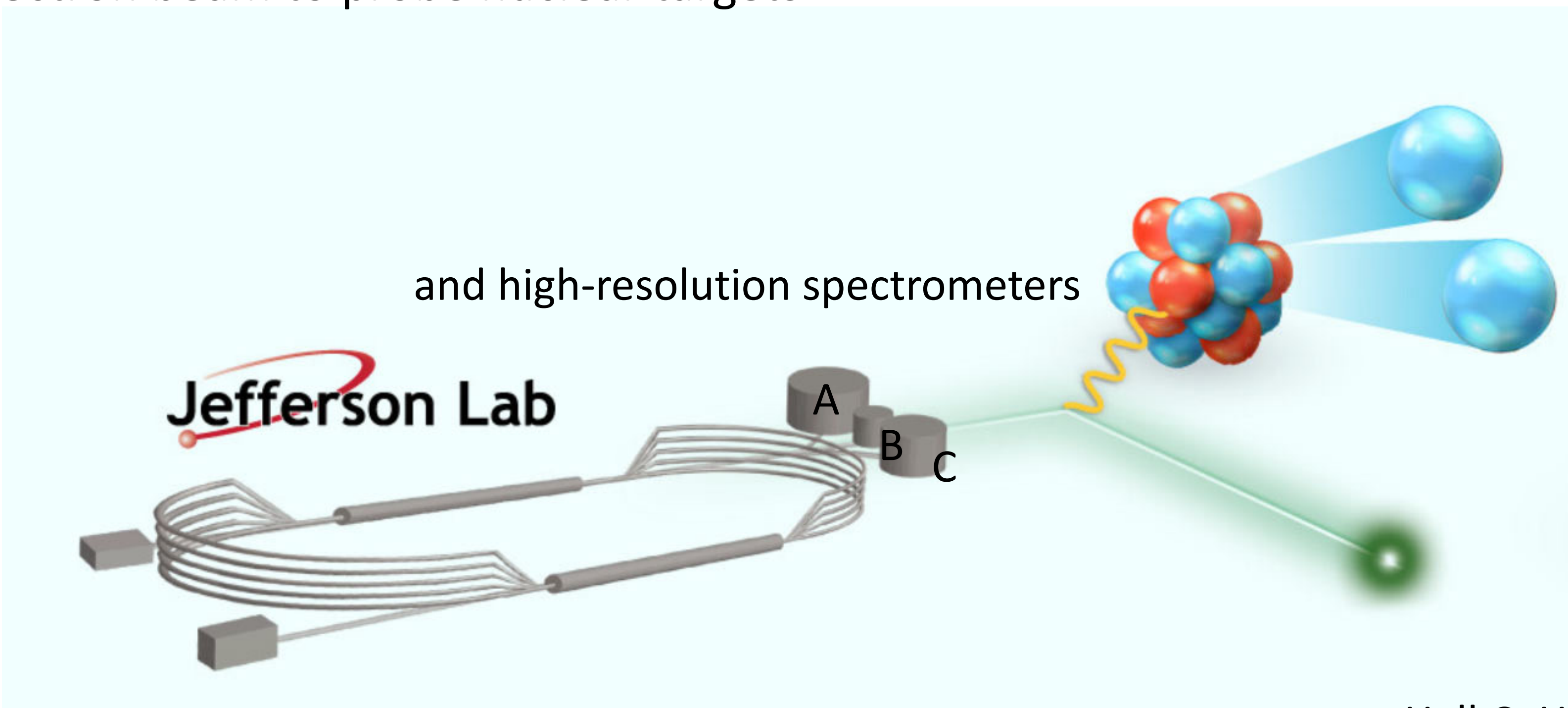
Two nucleon knock out: A(e,e’NN)

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

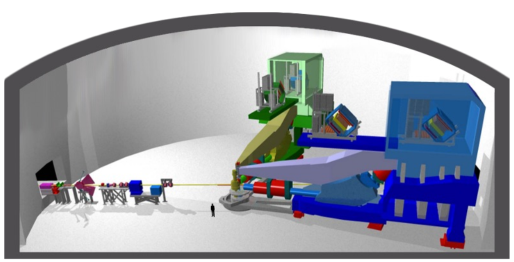
Quasi-elastic: electron scatters elastically off an almost free nucleon.

SRC studies with electron scattering at JLab

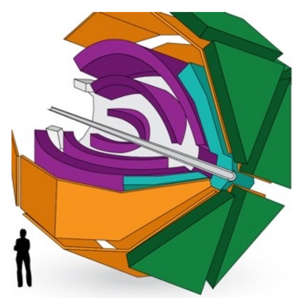
Electron beam to probe nuclear targets



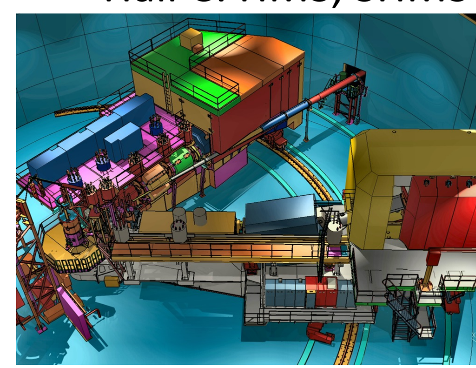
Hall A: HRS



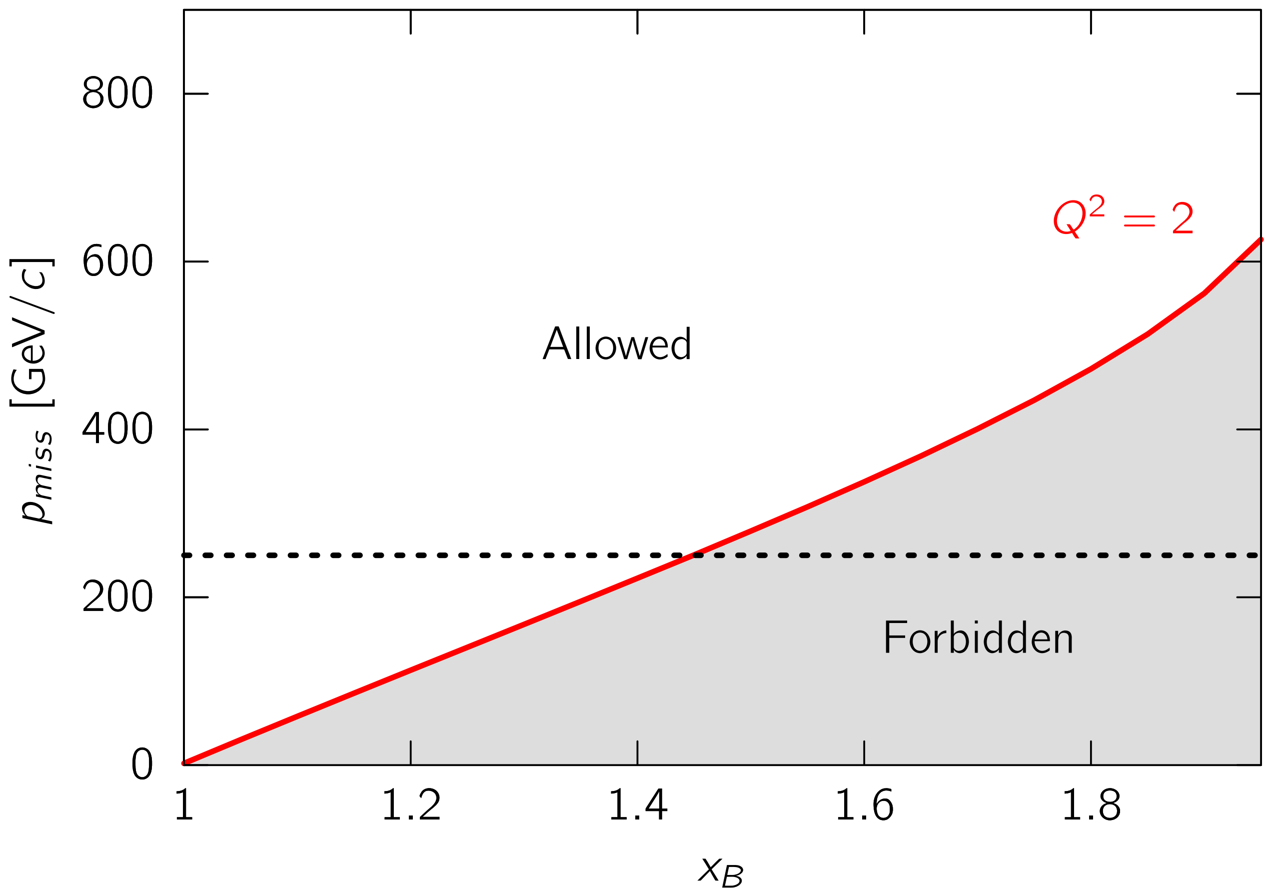
Hall B: CLAS, CLAS12



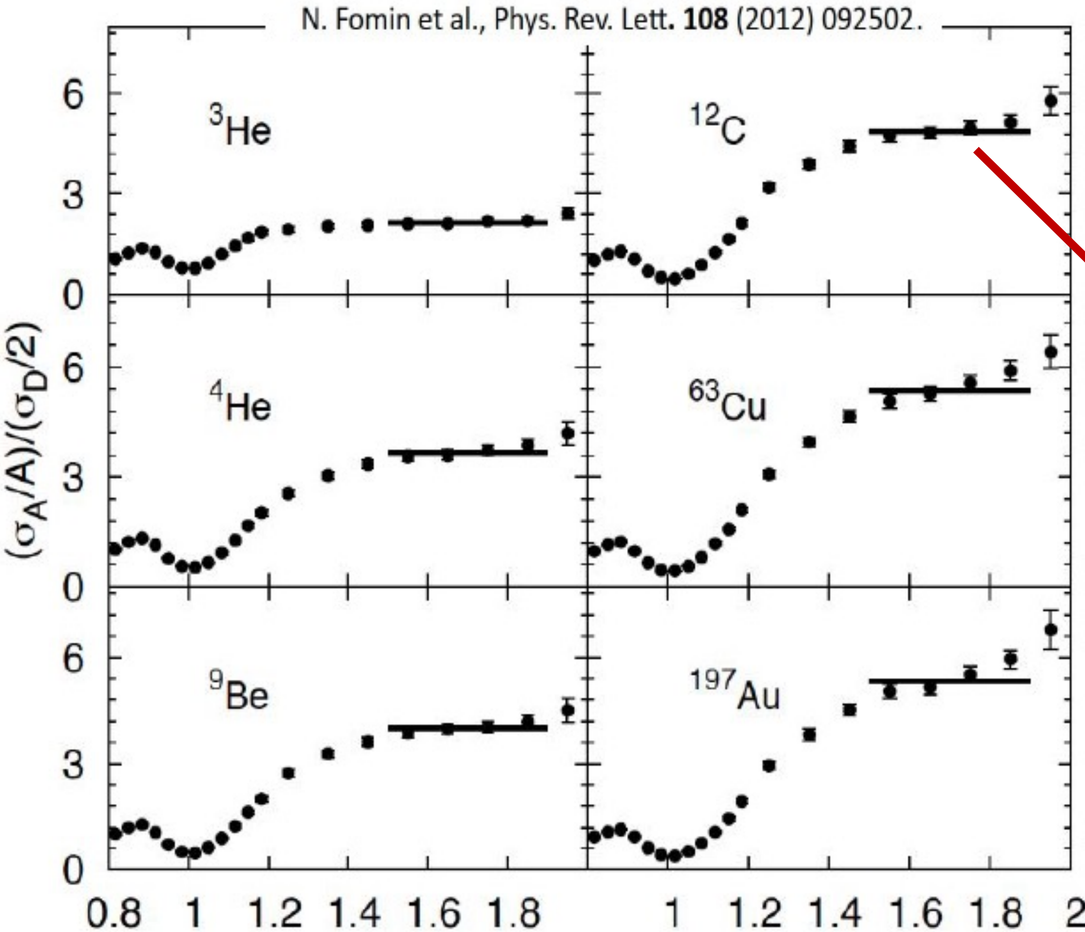
Hall C: HMS, SHMS



Inclusive scattering: SRC is dominant at high x_B and Q^2

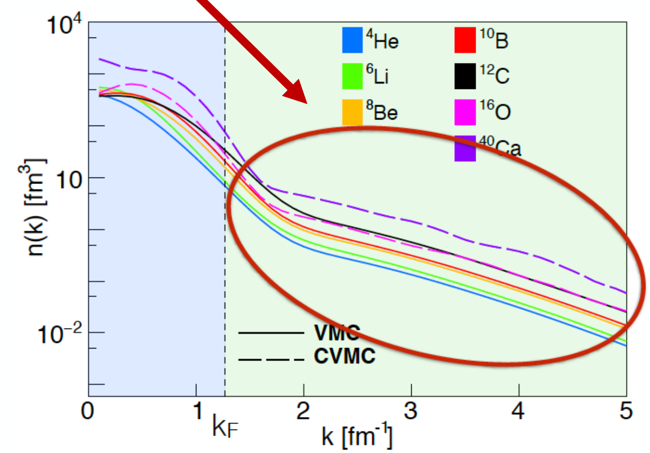


Scaling and pair abundance in inclusive scattering



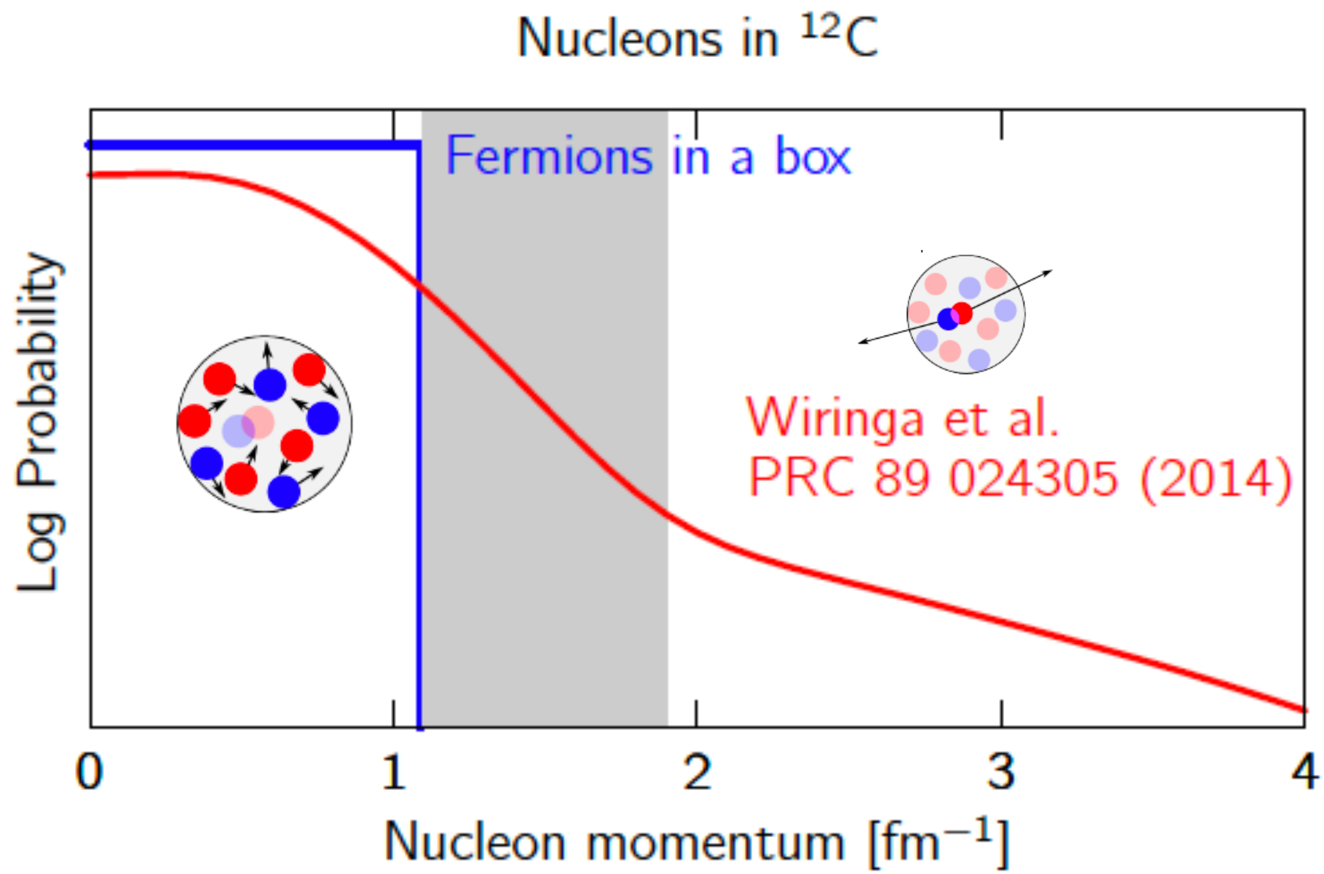
Scaling constant: a_2

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



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

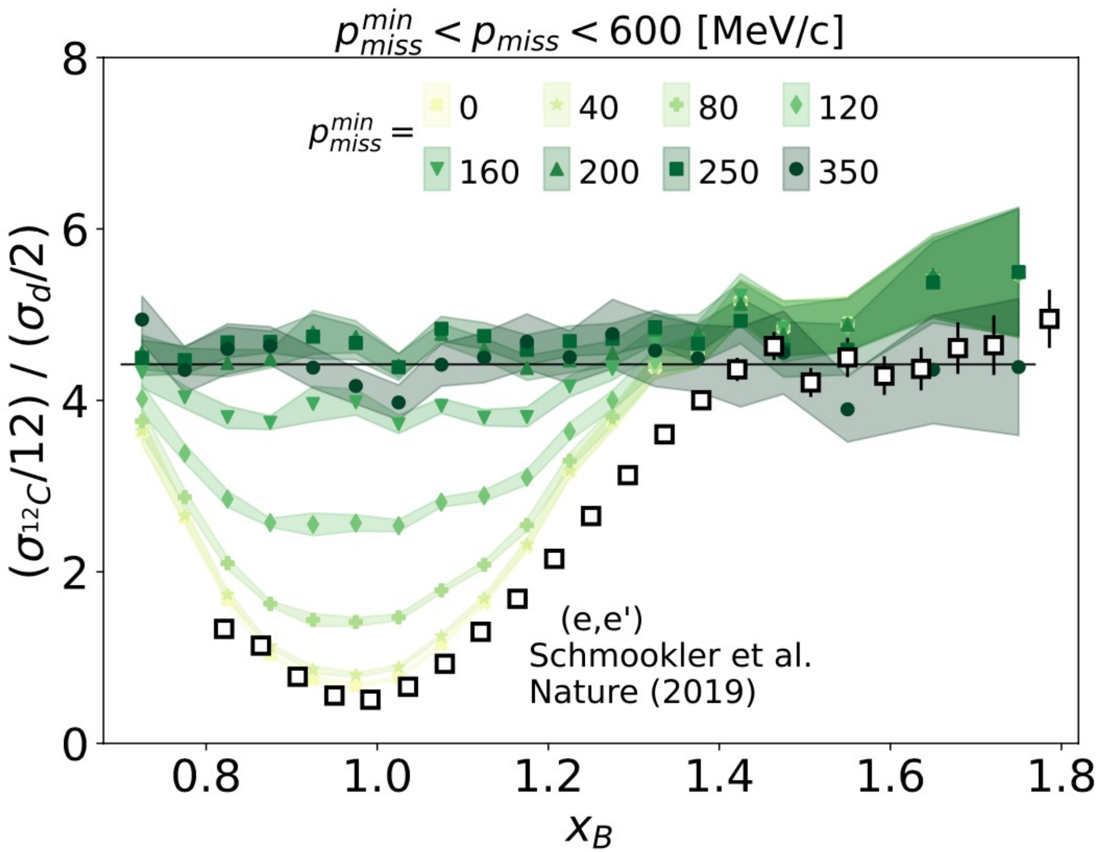
SRC: Universal High-momentum tail



L. Frankfurt et al. ,PRC (1993), K. Egiyan et al., PRC (2003), K. Egiyan et al PRL (2006).
N. Fomin et al., PRL (2012), O. Hen et al., PRC (2012),

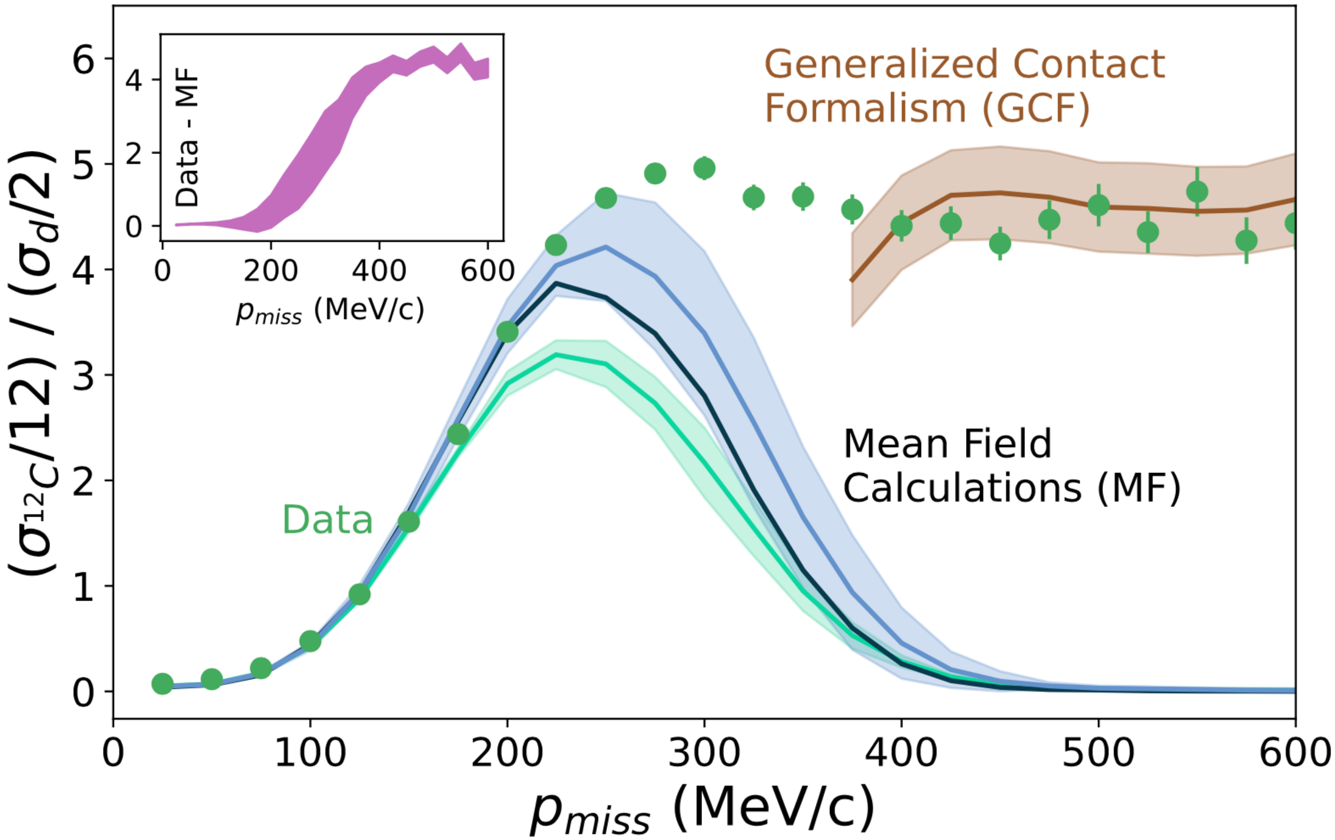
Scaling persist down to $x_B = 1$, P_{miss} > 350 MeV

$(e, e'p)$ data from CLAS



I. Korover, A. Denniston et al. (CLAS), PRC (2023)

Transition from mean-field (MF) to SRC.

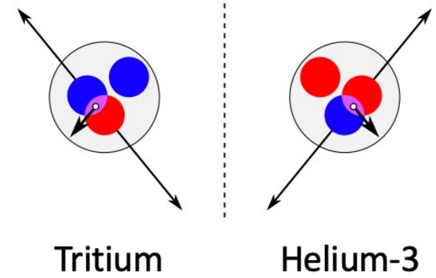


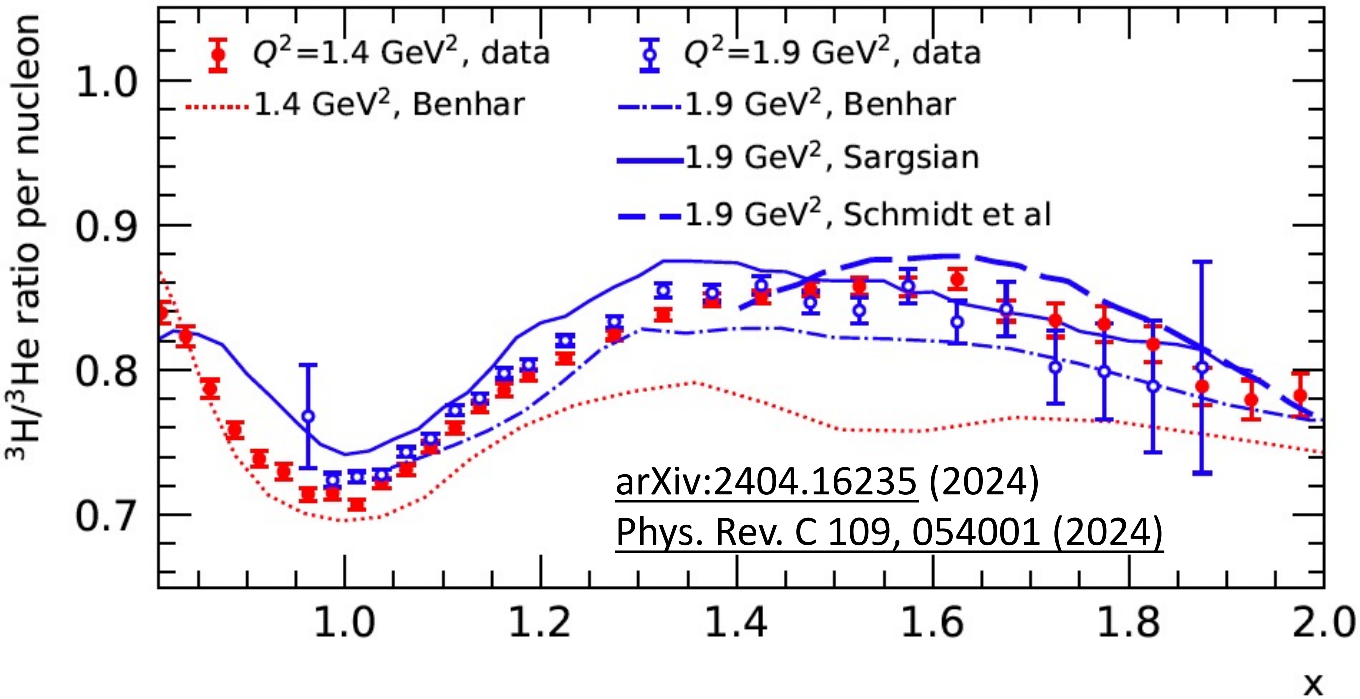
- Narrow transition from MF to SRC (250 MeV – 350 MeV)

I. Korover, A. Denniston et al. (CLAS), PRC (2023)

A=3 nuclei: Ideal systems to test theory calculations

(e.e') data from Hall A JLab



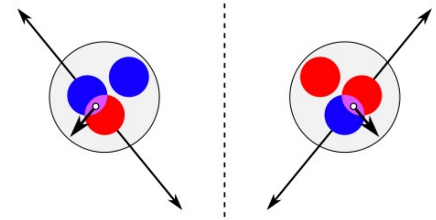


arXiv:2404.16235 (2024)
Phys. Rev. C 109, 054001 (2024)

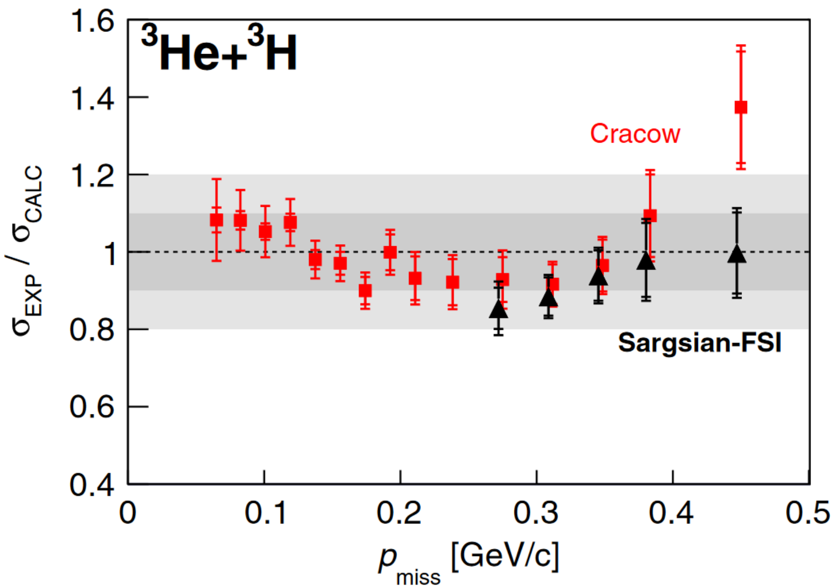
- Theory calculations agree well up to high x_B and Q^2

See Ronen's talk

A=3 nuclei: Ideal systems to test theory calculations



(e.e'p) data from Hall A JLab

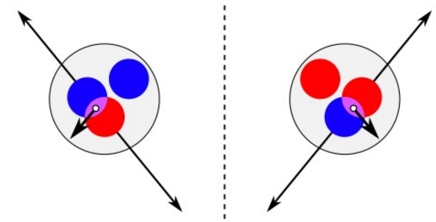


- Data and theoretical calculations agree within 10% up to 500 MeV/c

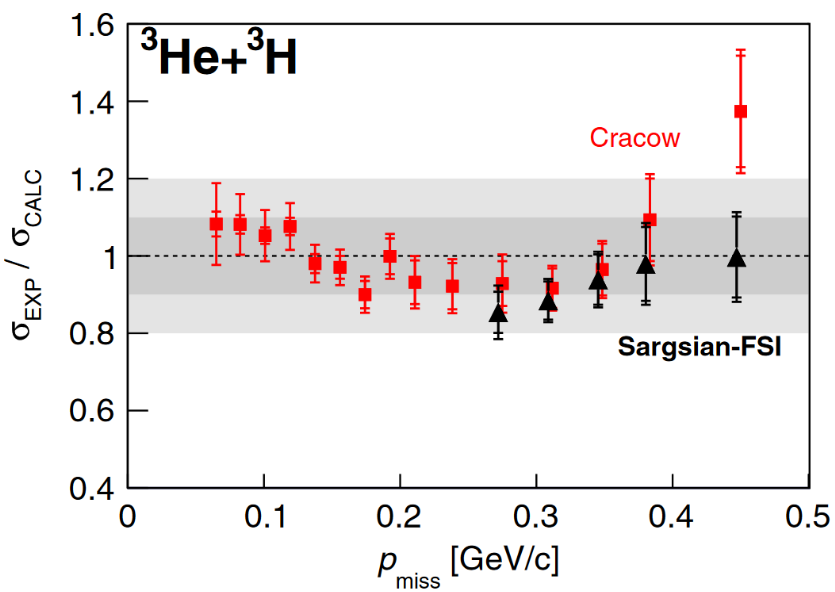
R. Cruz-Torres, D. Nguyen, PRL(2020).
R. Cruz-Torres PLB (2019).

See Ronen's talk

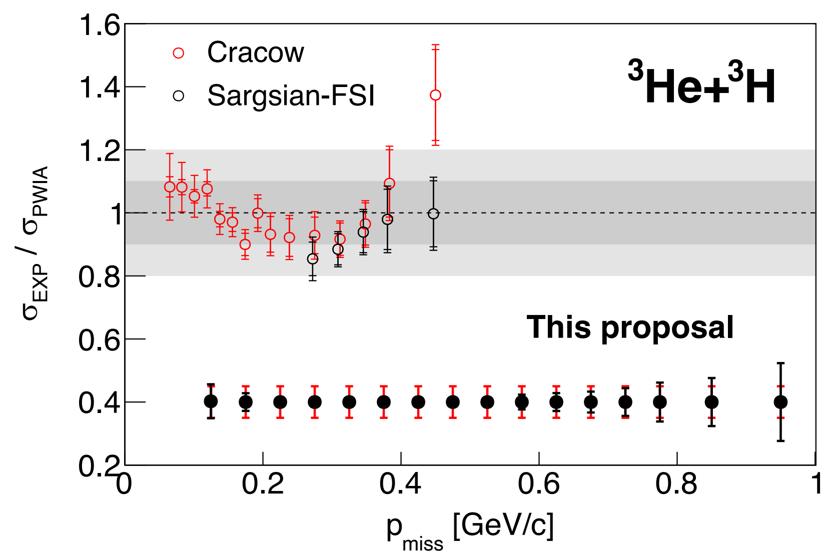
A=3 nuclei: Ideal systems to test theory calculations



(e.e'p) data from Hall A JLab



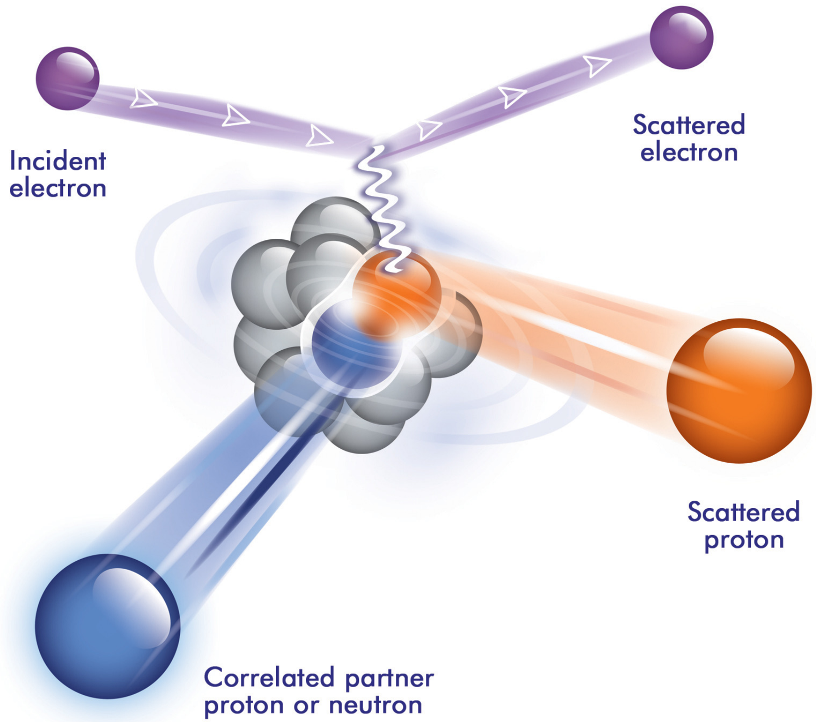
Future measurement with CLAS12



R. Cruz-Torres, D. Nguyen, PRL(2020).
R. Cruz-Torres PLB (2019).

See Ronen's talk

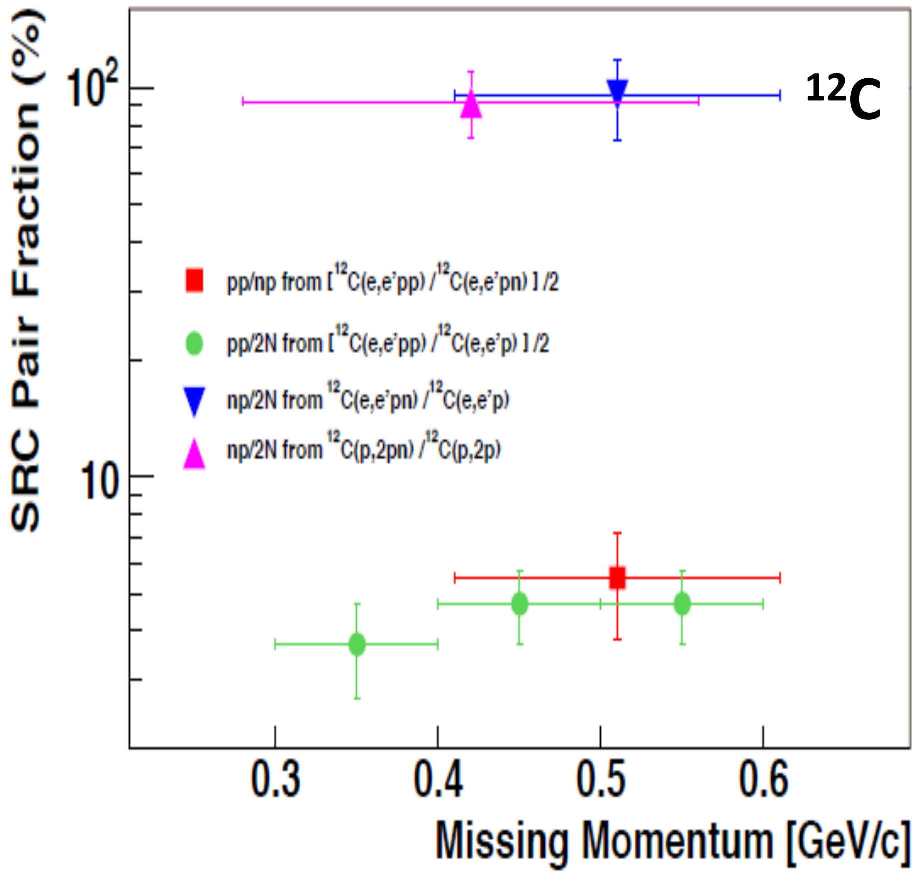
Two-nucleon knockout studies

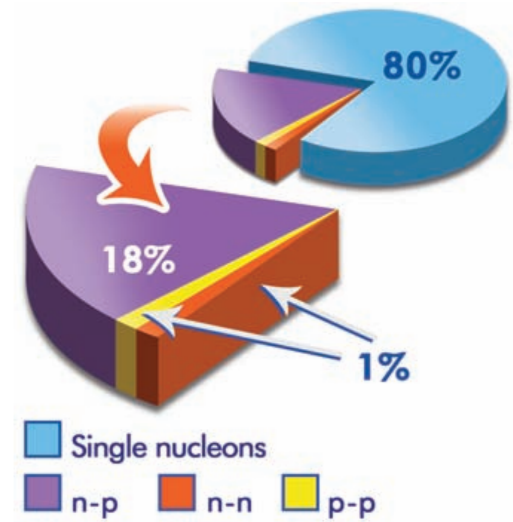


Looking for High missing-momentum nucleon ($k > k_F$) and recoil partner

SRCs are predominantly in neutron-proton pairs

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



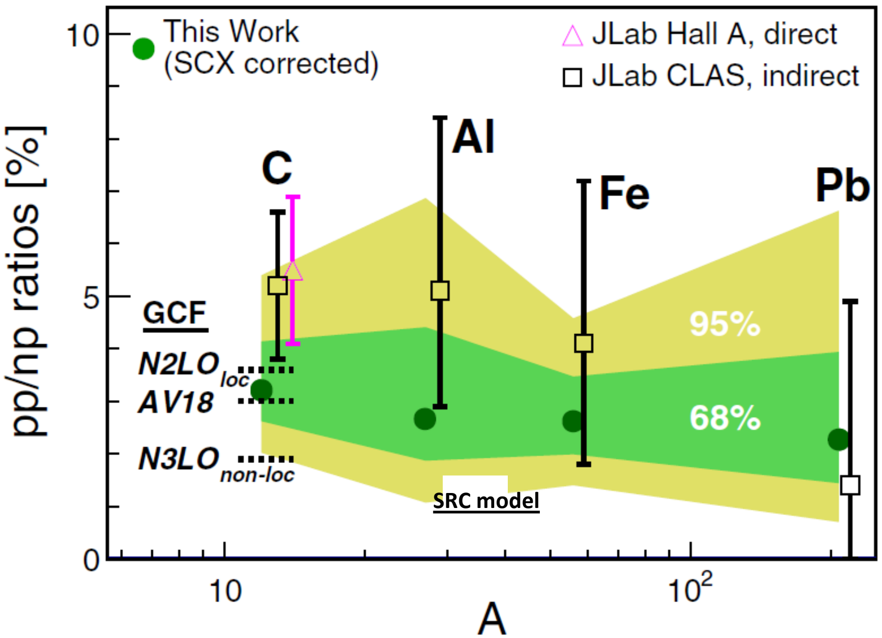


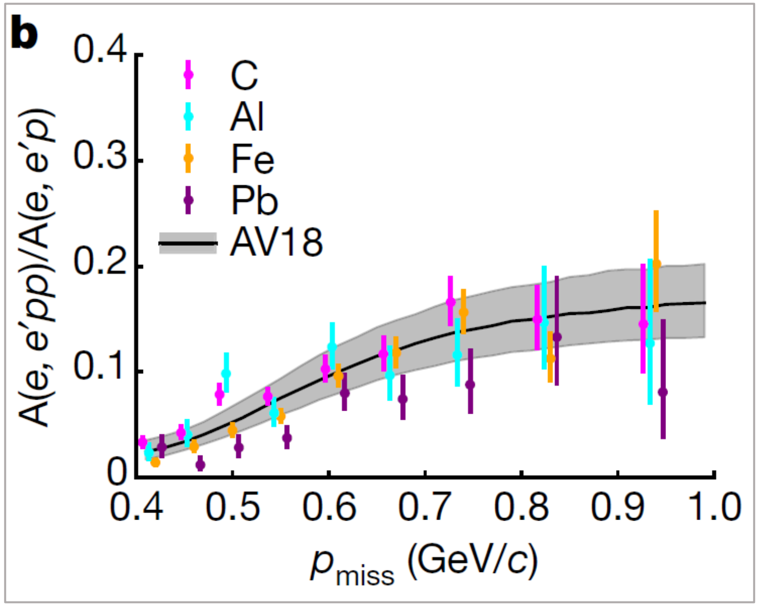
SRCs ~ 20% of nucleons

- 90% np pairs
- 10% nn and pp pairs

All knocked out high momentum protons ($k > k_F$) have recoiled partner nucleon with high momentum in the opposite direction

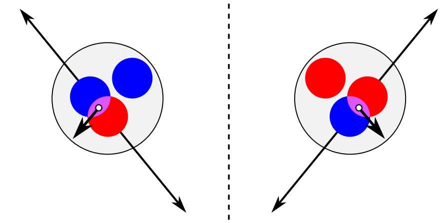
SRCs are predominantly in neutron-proton pairs





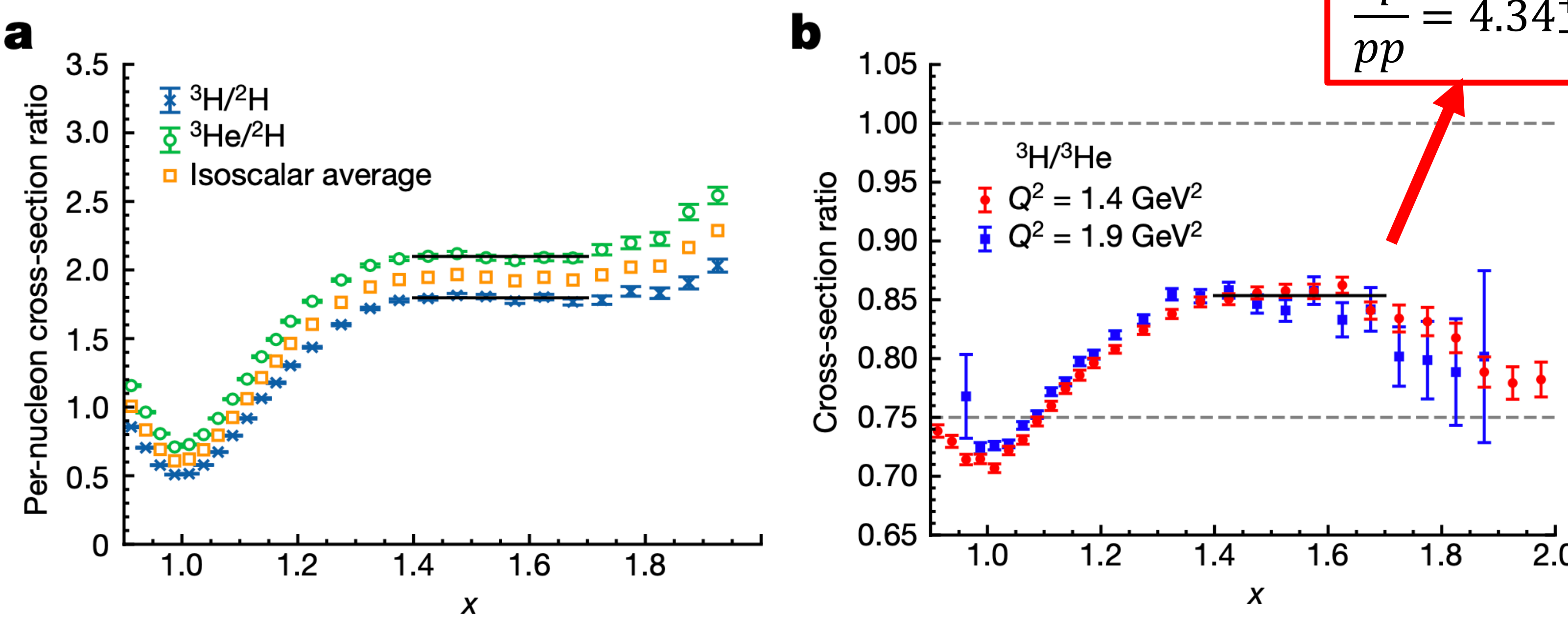
M. Duer et al., Phys. Rev. Lett. 122 (2019).
A. Schmidt et al. (CLAS), Nature 578 (2020).
O. Hen et al., Science 346 (2014).
R. Subedi et al., Science 320 (2008).

Preference for np pairs is less strong in the A=3 system.



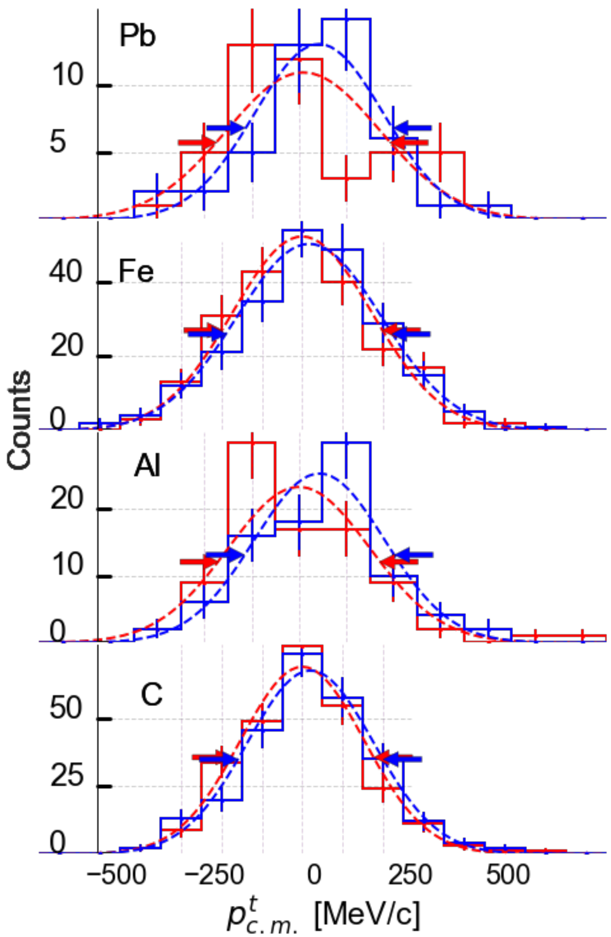
S. Li et al. (Hall A), Nature 609 p. 41 (2022)

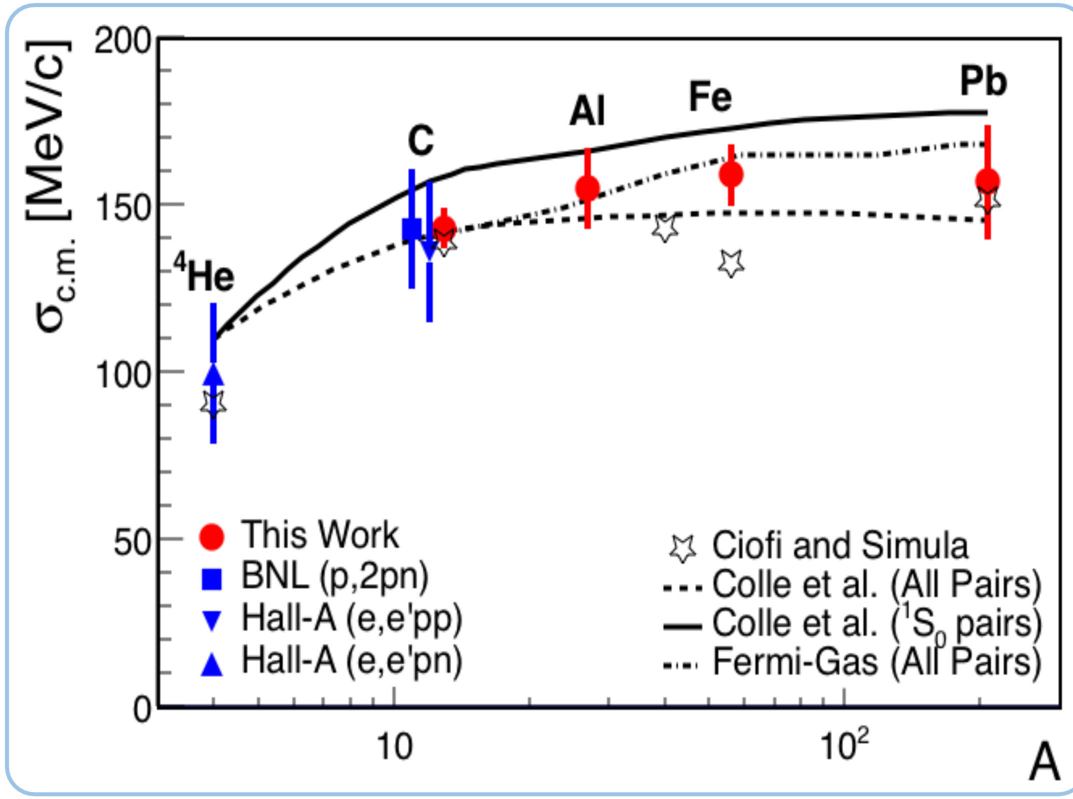
$$\frac{np}{pp} = 4.34^{+0.49}_{-0.40}$$



See John Arrington's talk

SRC pair center of mass momentum





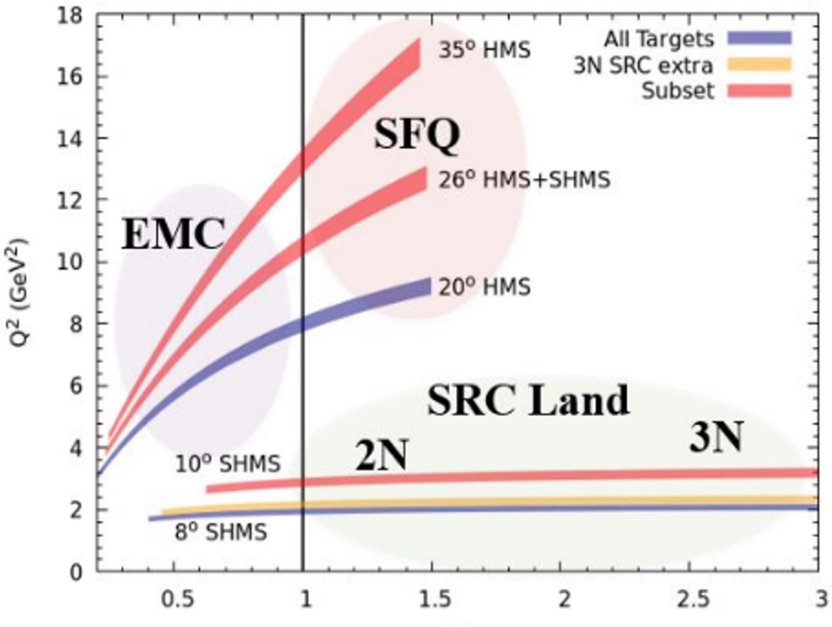
Cohen, PRL (2018)

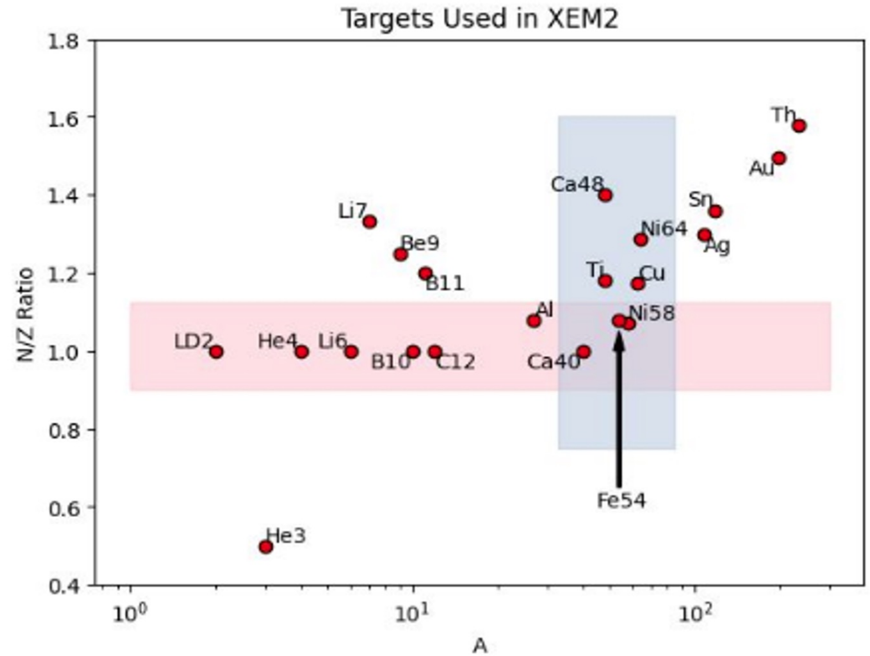
New SRC data on nuclear targets are under analysis!

- Hall C
  - XEM2: Inclusive x>1 experiment on nuclear targets
  - CaFe $(e,e'p)$ experiment: 40Ca, 48Ca, 54Fe

- CLAS-12
  - Nuclear targets experiment
  - 40Ca, 48Ca targets

XEM2: Inclusive x> 1 experiment

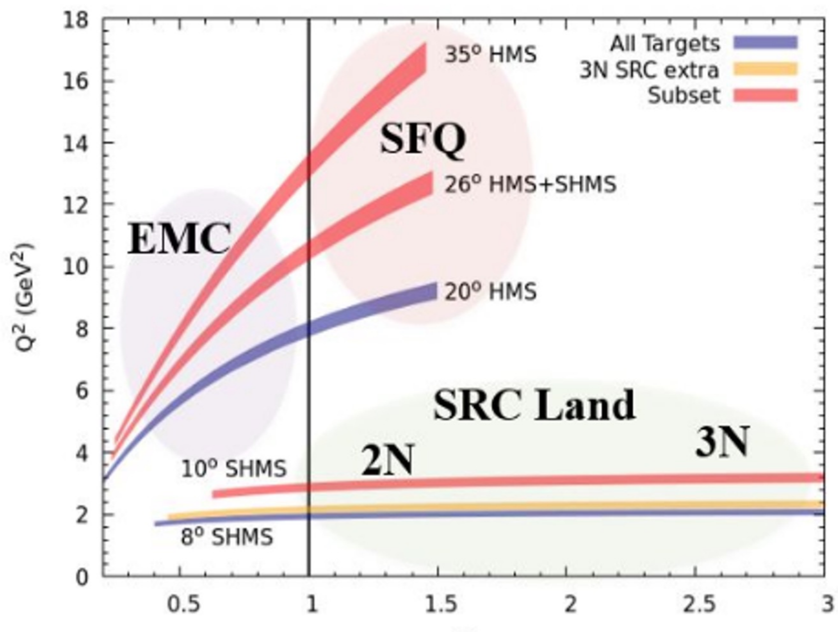


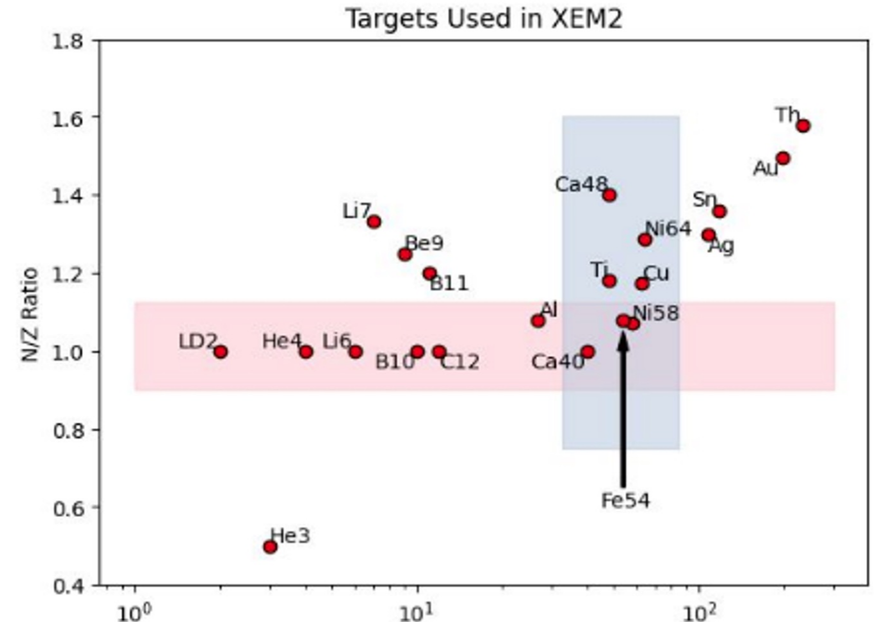


What we can learn about SRC:

- Understanding A and N/Z dependence of a2

XEM2: Inclusive x> 1 experiment

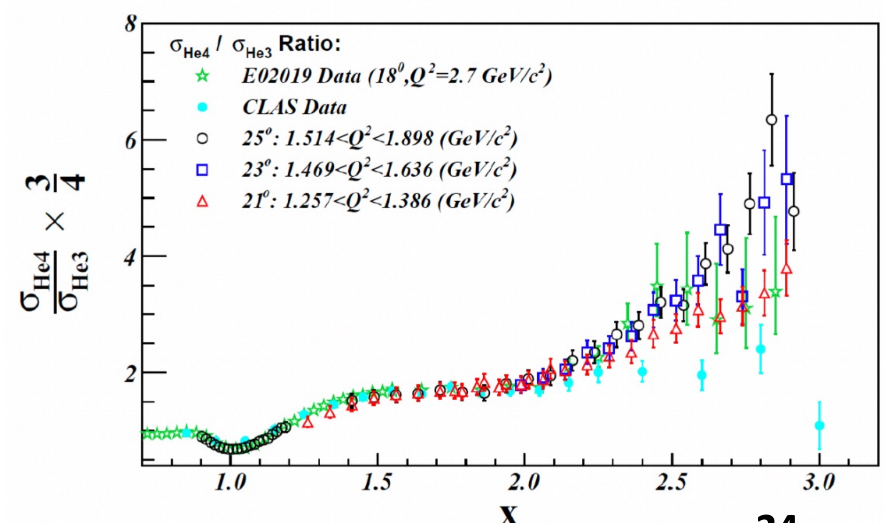




See Burcu's Talk

What we can learn about SRC:

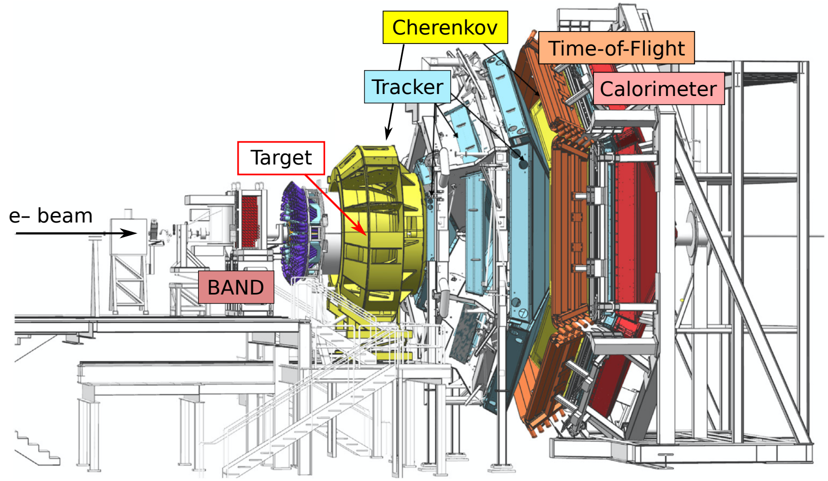
- Understanding A and N/Z dependence of a2
- Looking for signal of 3N-SRC
  - Second scaling regime?



CLAS12 SRC Experiment (Run Group M)

JLab E12-17-006A

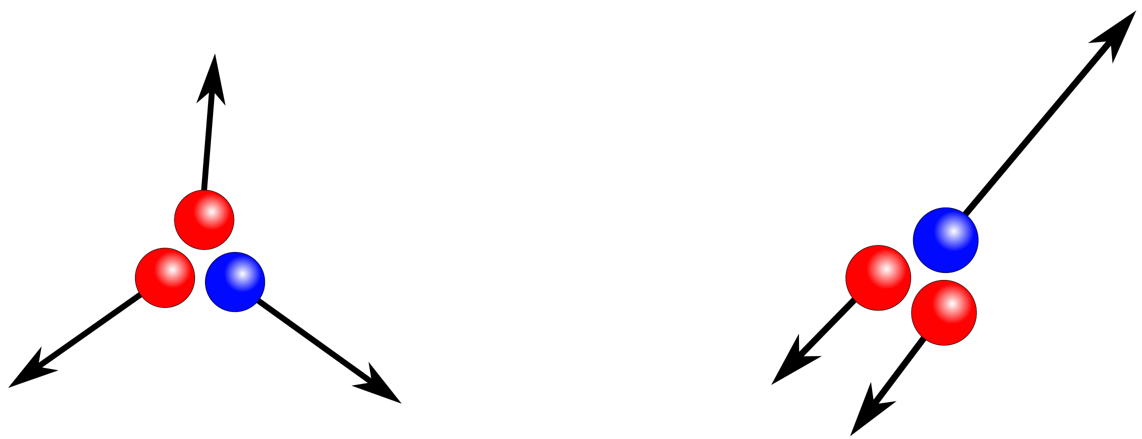
- Nov 10, 2021 – Feb 7, 2022
- > 300 fb^{-1}
  - >10x improvement over CLAS6
- Targets: H, d, ^{4}He, ^{12}C, ^{40,48}Ca, ^{120}Sn
- 2, 4, and 6 GeV beam
- CLAS12 Spectrometer



(e,e'p), (e,e'pp), (e,e'pn)

Goal: Direct detection of 3N SRCs

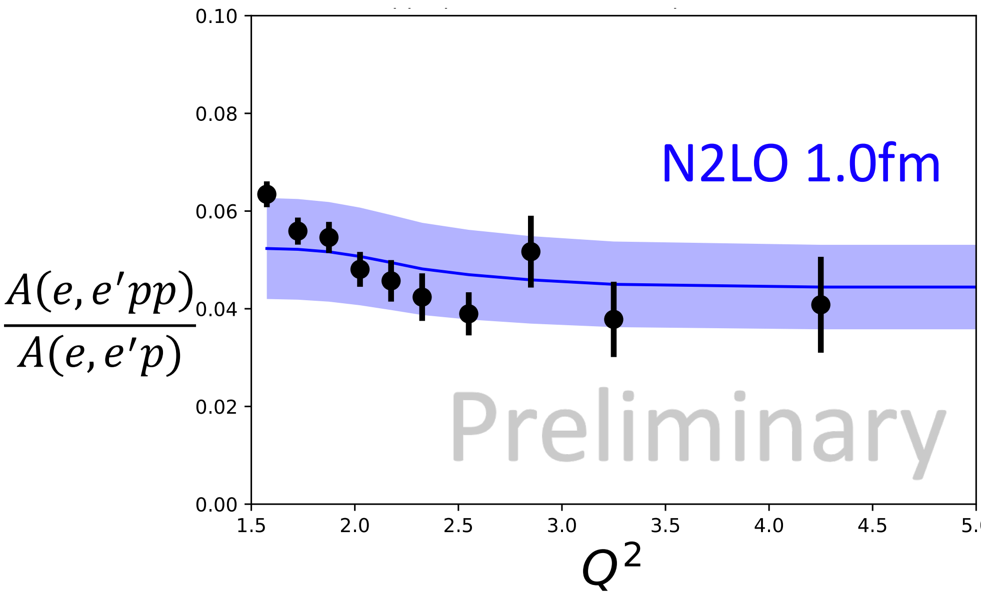
Formation mechanism will lead to different structures:



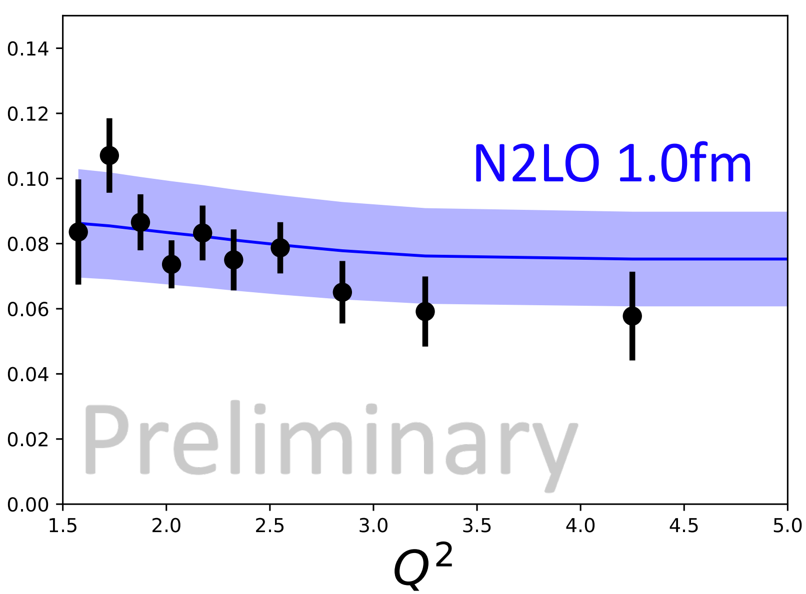
Fomin, Higinbotham, Sargsian, Solvignon, Ann.Rev.Nucl.Part.Sci. 67 129 (2017)
Day, Frankfurt, Sargsian, Strikman, arXiv:1803.07629 (2018)

SRC properties are consistent across Q^2.

Proton-proton pairing probability



p_{miss}: 550 – 700 MeV/c



p_{miss}: 700 – 850 MeV/c

Figure credit: Andrew Denniston

SRC properties are consistent across Q^2.

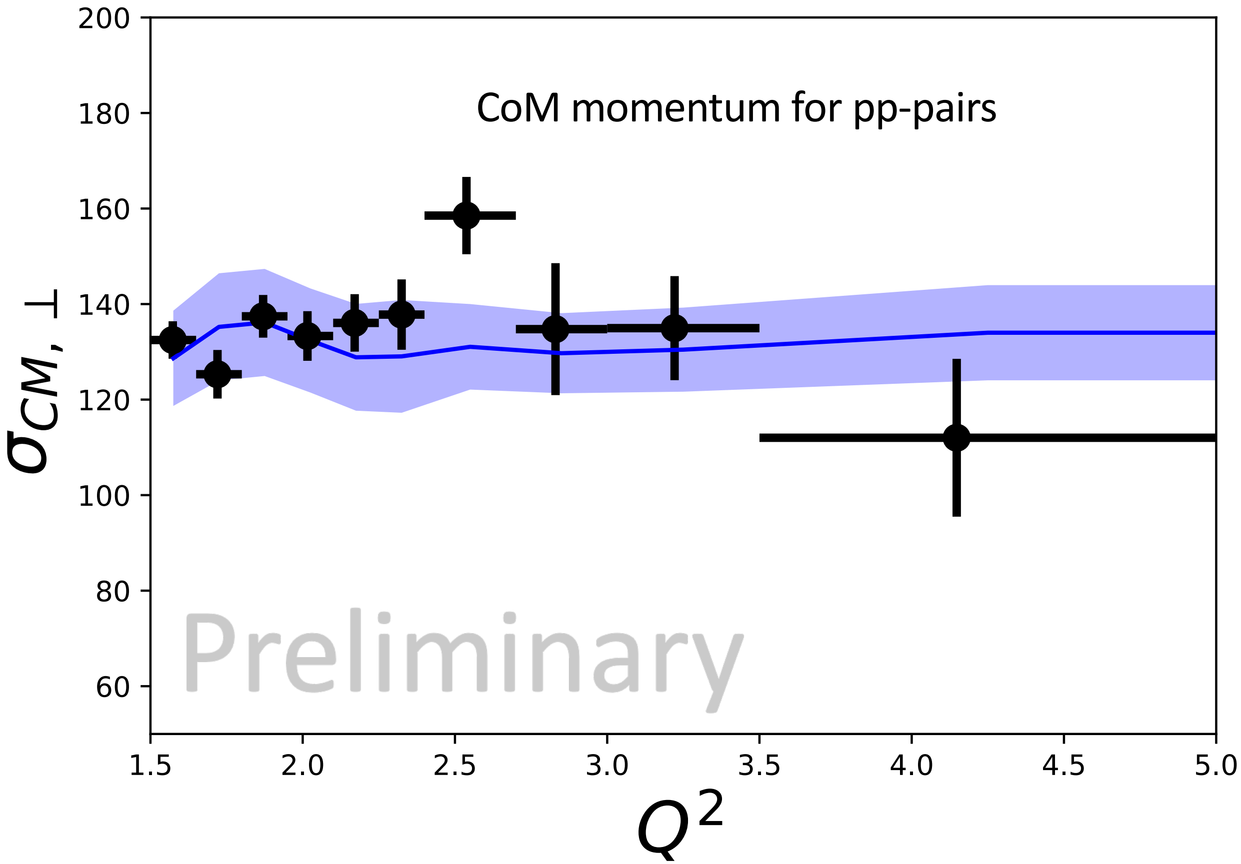
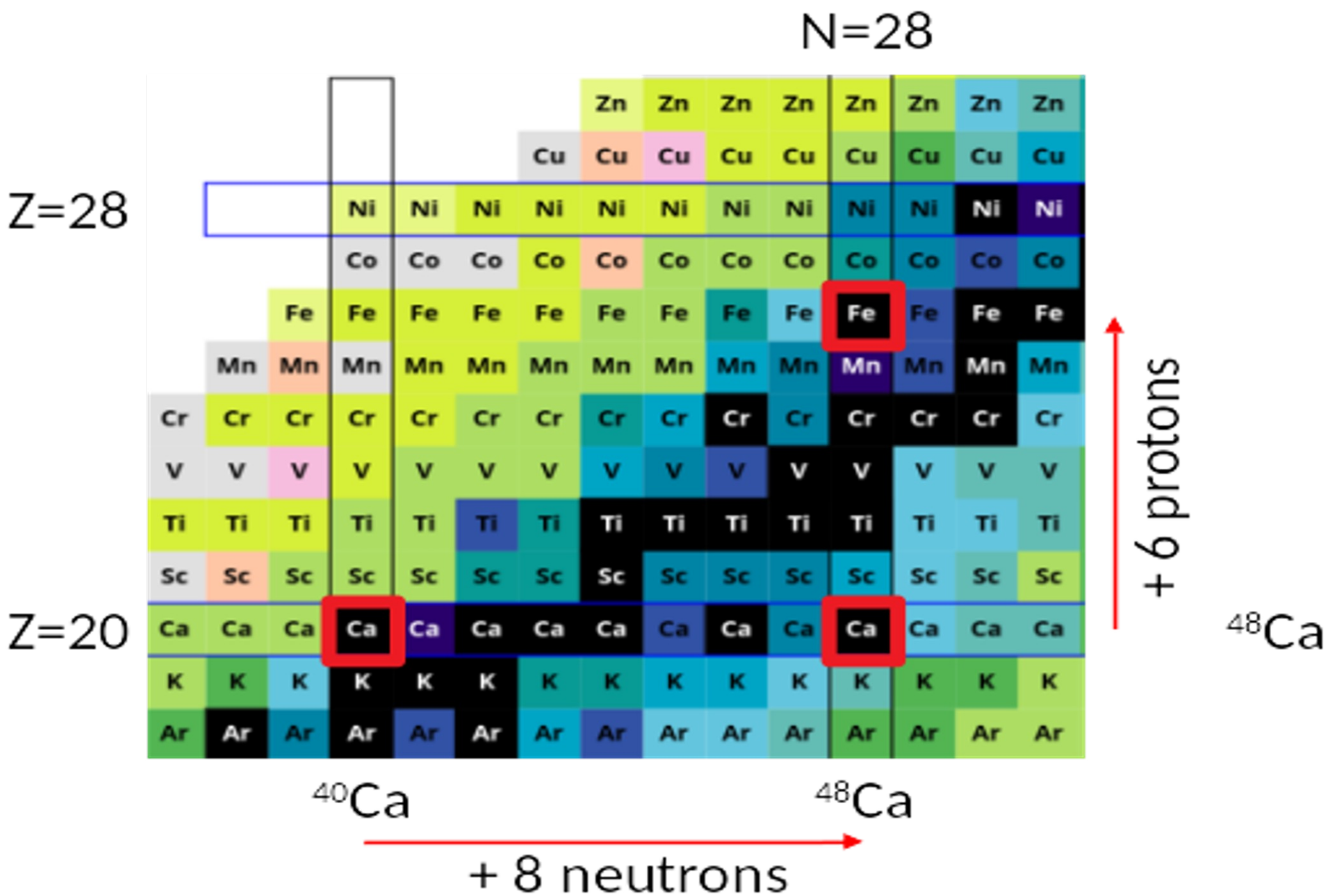
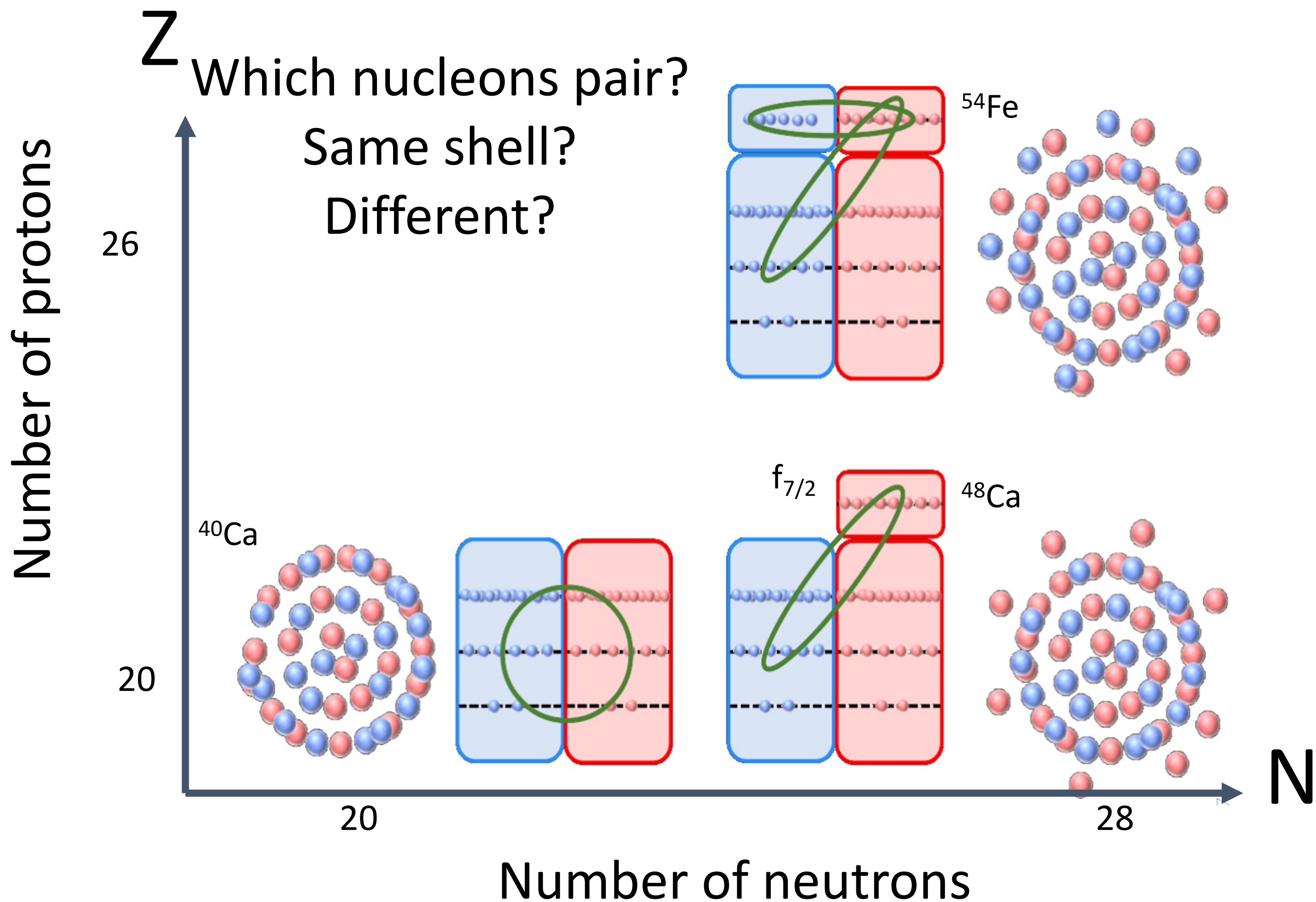


Figure credit: Andrew Denniston

SRC pairing mechanism



The 40Ca, 48Ca, 54Fe system can teach us about pairing mechanisms.



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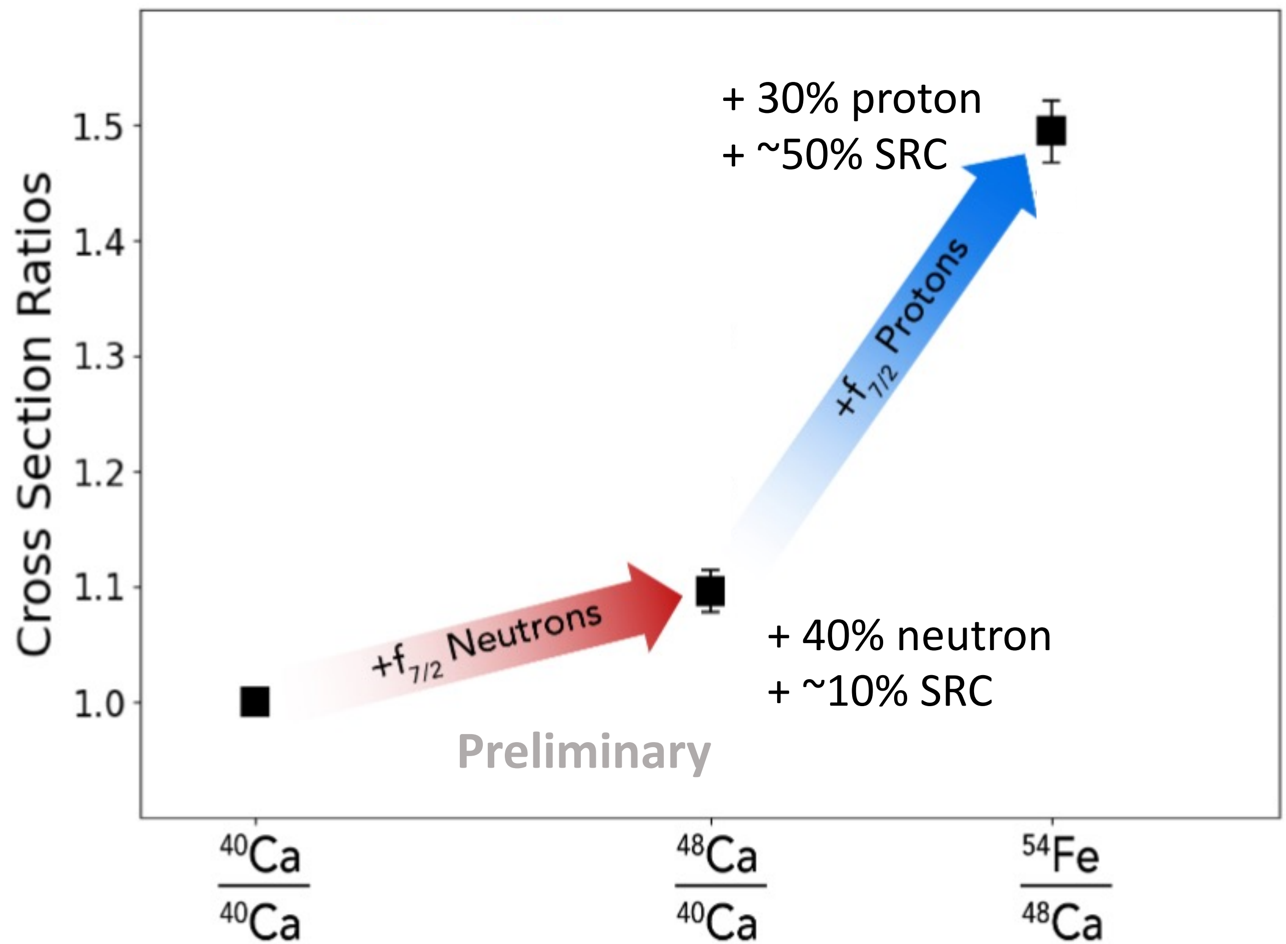
New Hall C data : CaFe (e,e'p)



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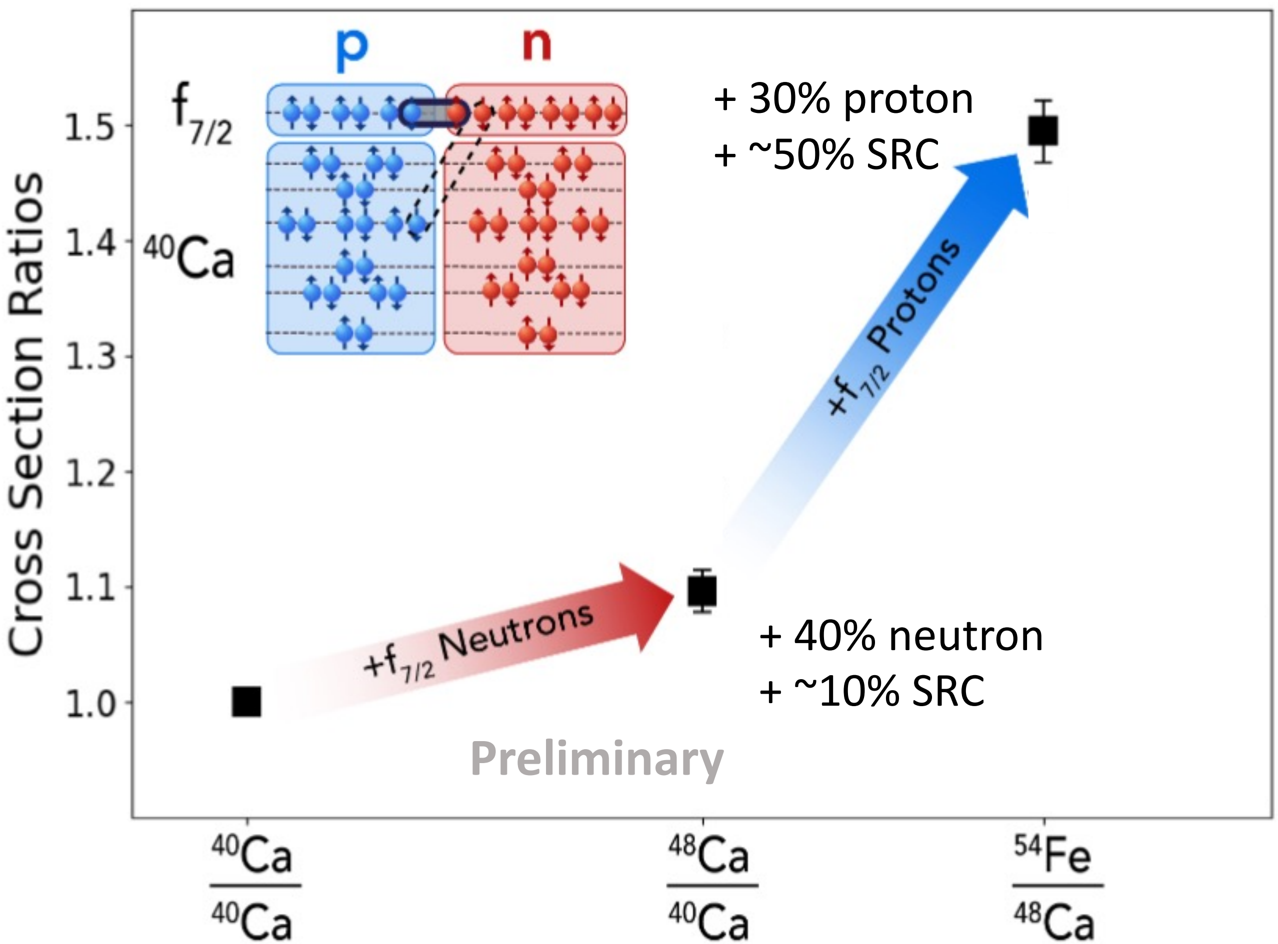
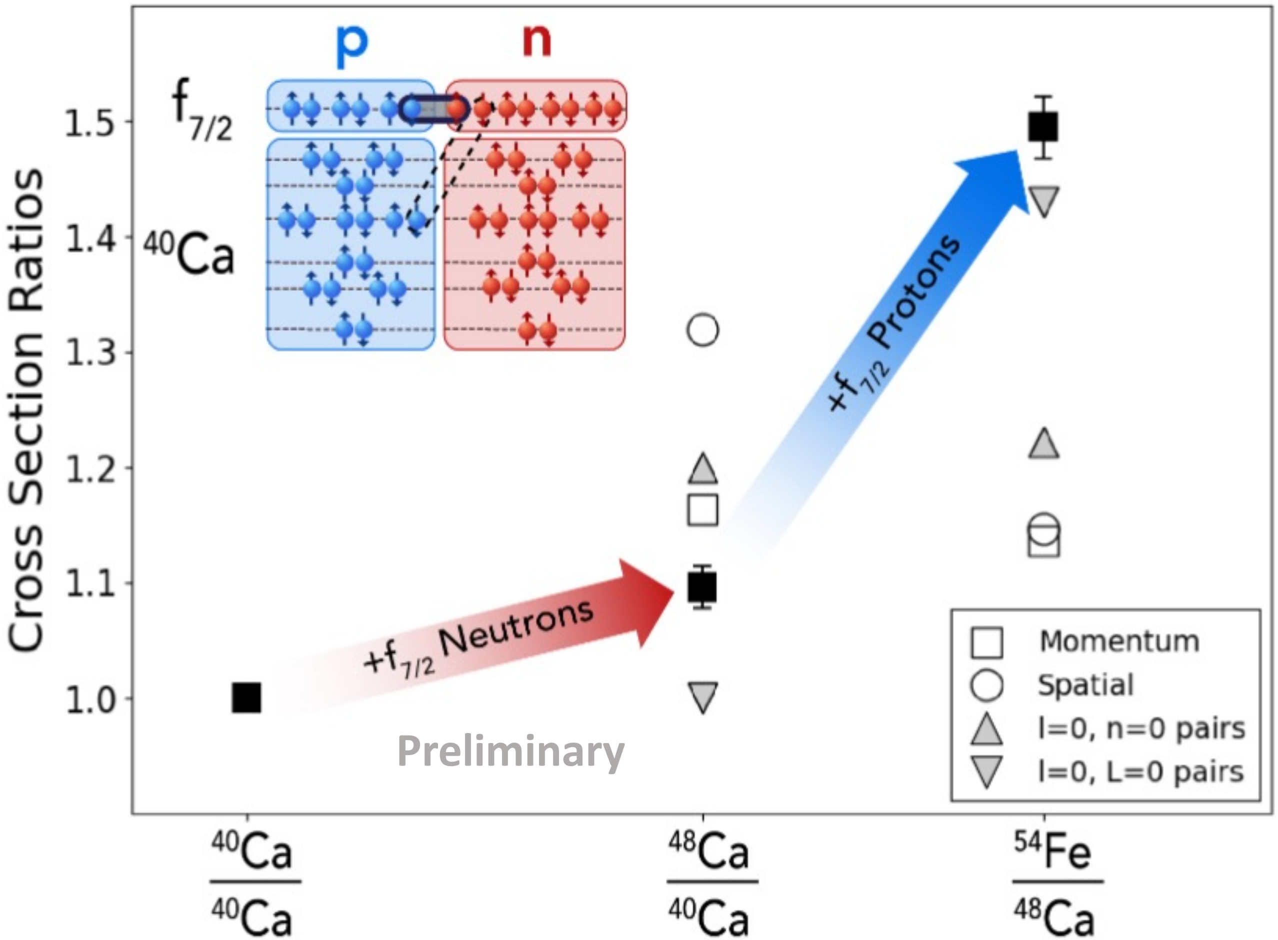


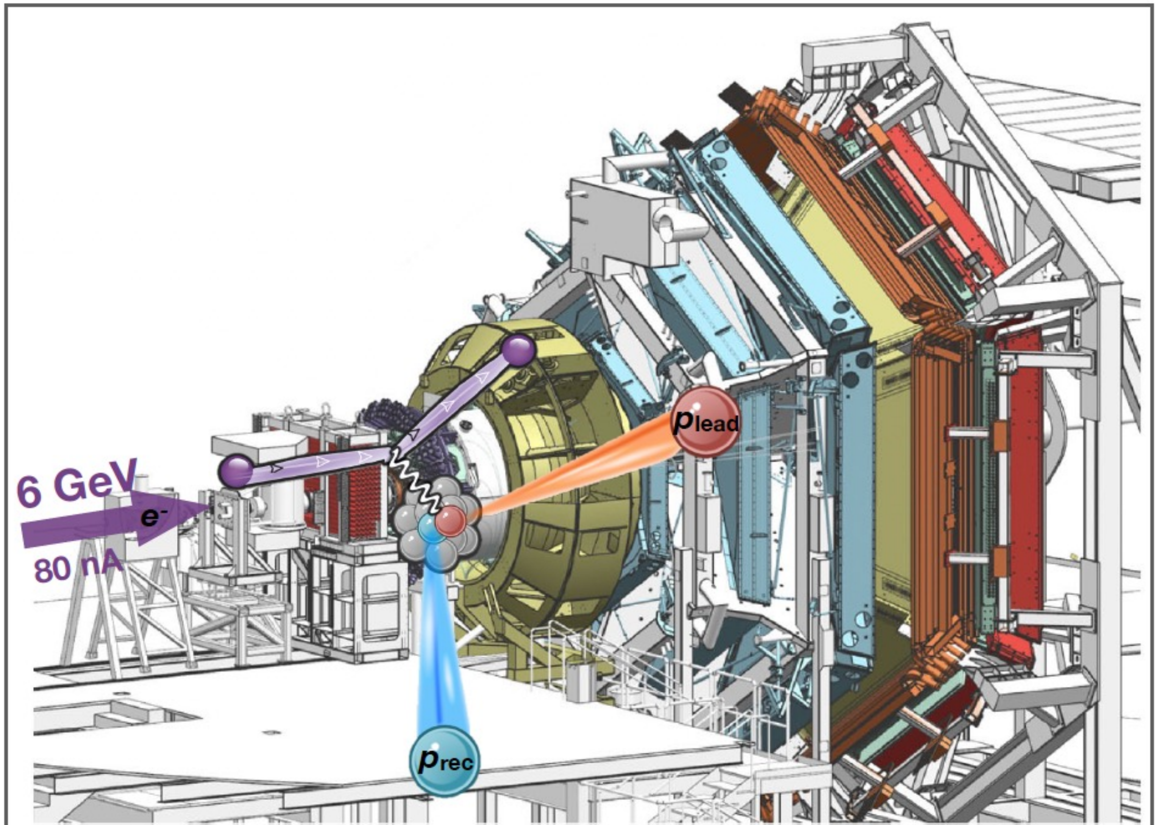
SRC pairing within the same shell

New Hall C data : CaFe (e,e'p)



The 40Ca, 48Ca, 54Fe system can teach us about pairing mechanisms.

New data from RGM: (e,e’pp), (e,e’pn)



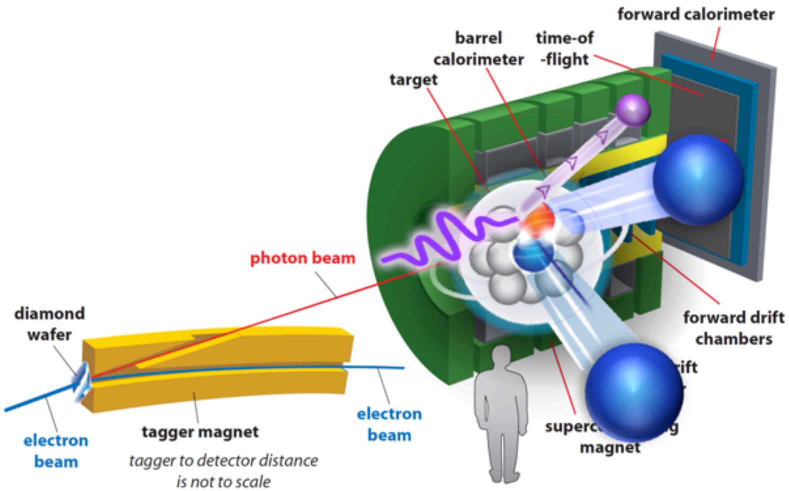
See Julian’s talk

SRC properties: probing universal

Photo-production

JLab Hall D

(GlueX spectrometer)



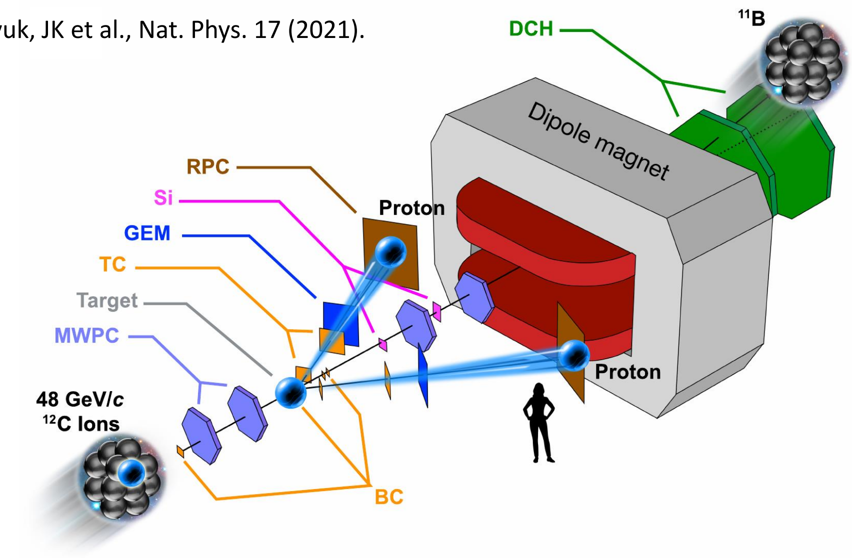
Proton-Nucleus Scattering

JINR/GSI

(in inverse kinematics)

$^{12}C(p,2p)X$

M. Patsyuk, JK et al., Nat. Phys. 17 (2021).



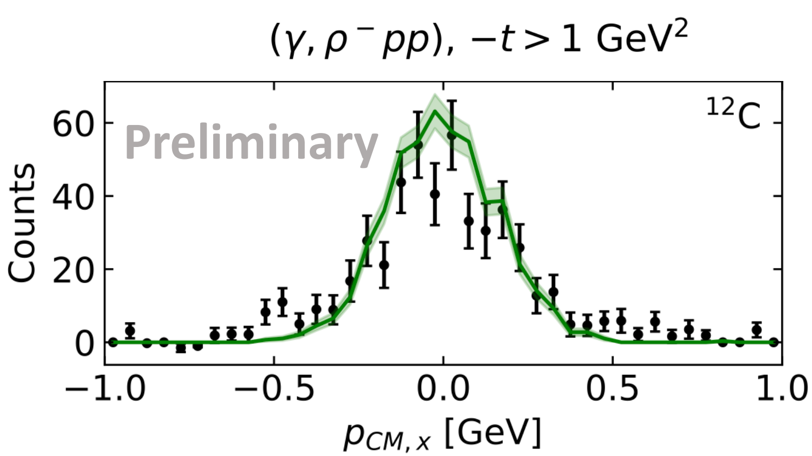
SRC properties: probing universal

Photo-production

JLab Hall D

(GlueX spectrometer)

J.R. Pybus et al.

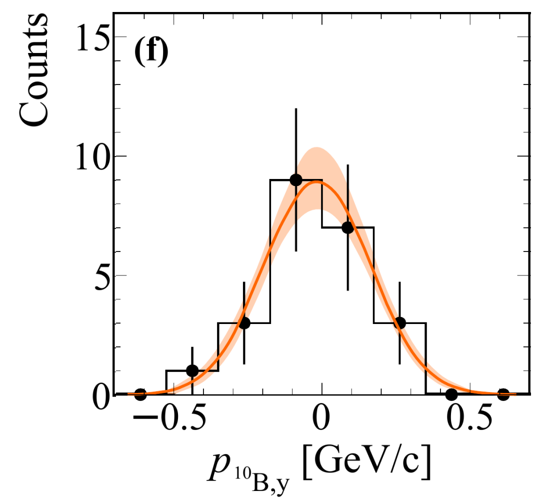


Proton-Nucleus Scattering

JINR/GSI

(in inverse kinematics)

$^{12}C(p,2p)^{10}B$



Different probes for same observable and underlying physics:

^{12}C σ(c.m.) ~ 150 MeV/c in agreement with SRC model

Summary:

- High momentum nucleon $k > k_f$, predominantly belong to SRC pair.
- SRC properties are universal cross nuclei, with high p_{rel} and lower p_{cm}
- Narrow transition from MF to SRC
- SRC are predominantly np pairs, due to tensor force
- Transition from tensor to scalar
- Light nuclei measurement validates the model up to high momentum

(key) Open questions

<u>2N SRC</u>

- Scale dependence (Q^2)
  - All observables
- Probe independence (e,p,γ)
  - Confirm factorization
- Pairing mechanisms
- Precision of interpretation in terms of ground state properties (theory)
- Neutron rich systems

<u>3N SRC</u>

- (e,e') high Q^2 x>2
- 3N KO (e,e'ppN)

<u>Theory guidance:</u>

- Kinematics
- Ground state
- Factorization
- Phenomenology

SRC white paper: Current contributors