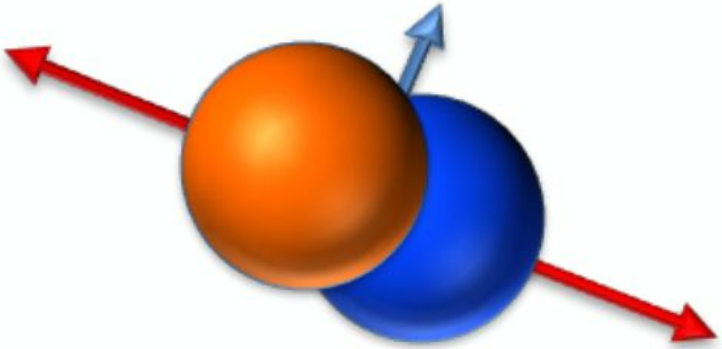
Precision Short Range Correlation studies in Nuclei

Justin Estee

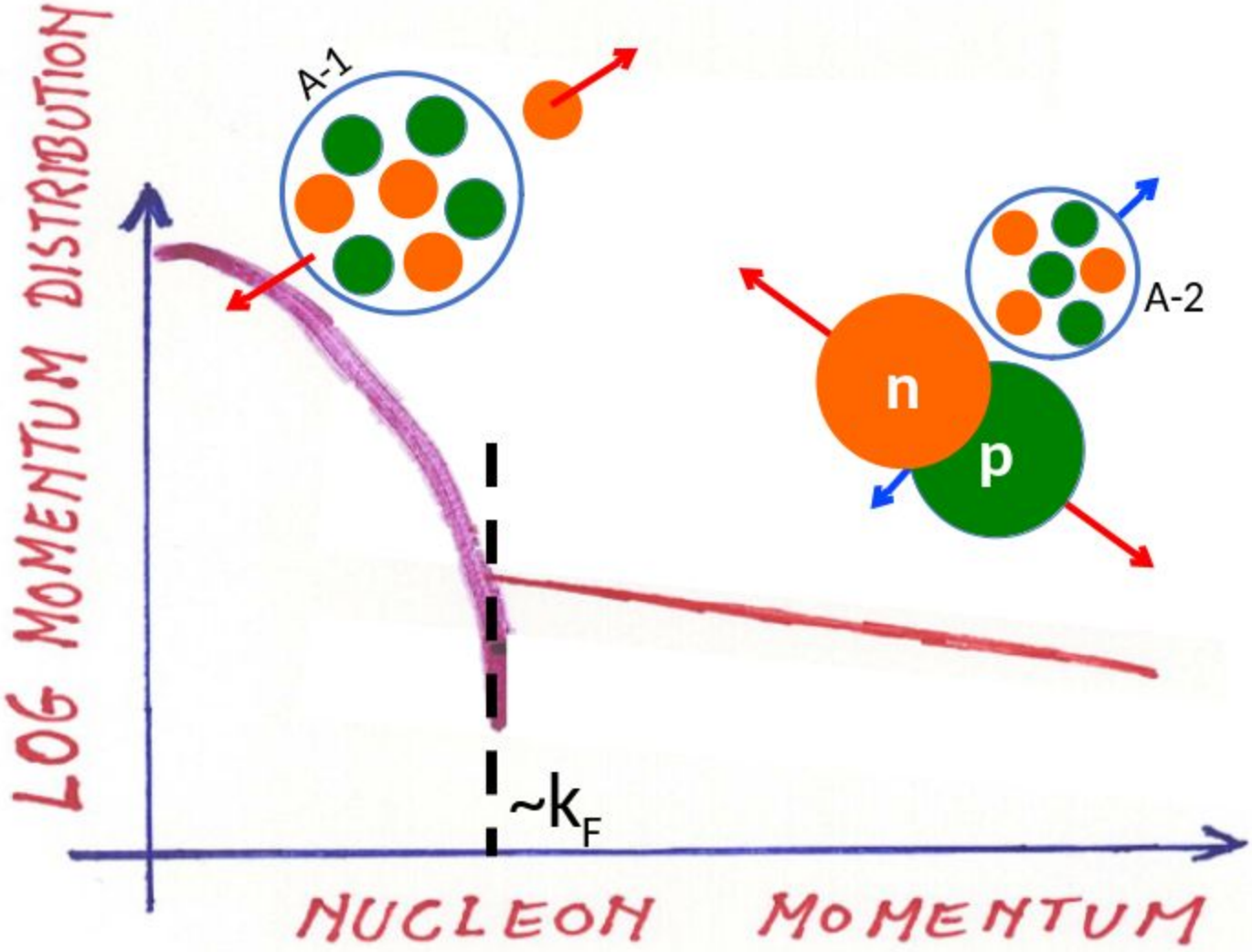
Short range, short lived,
highly correlated pairs

r-space

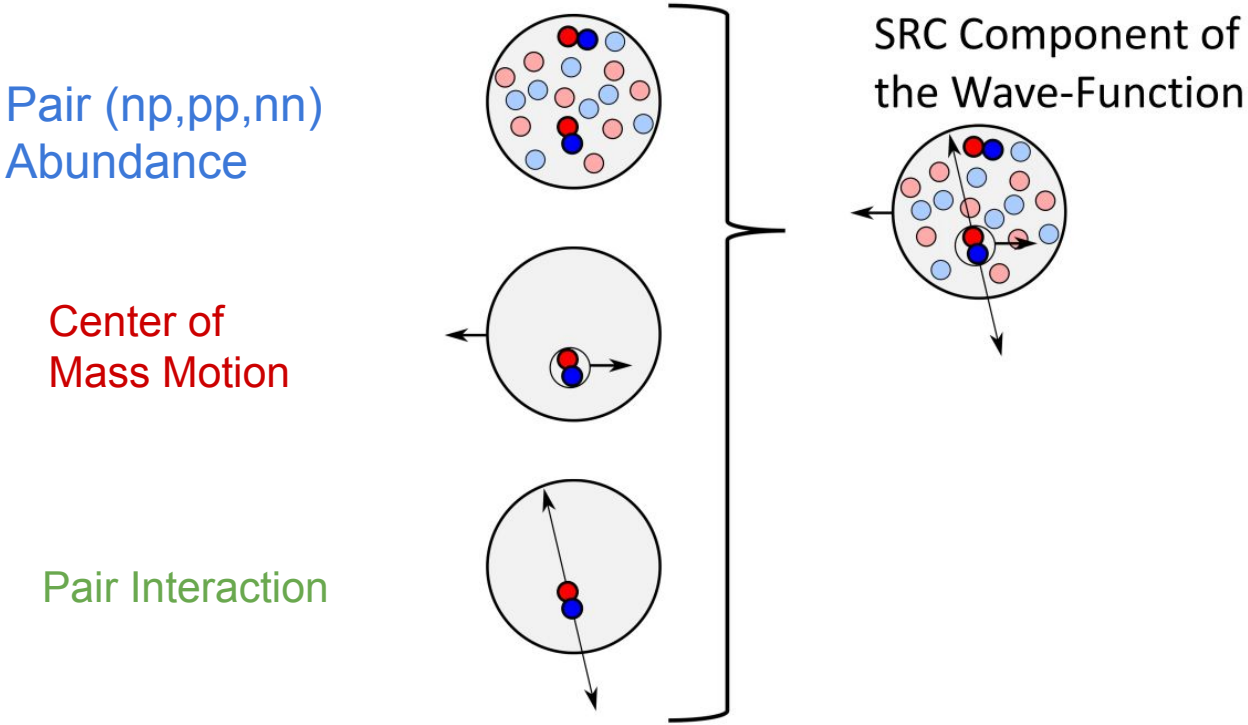
High relative momentum
Low center of mass momentum



k-space

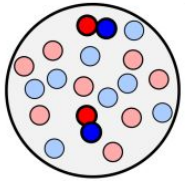

LOG MOMENTUM DISTRIBUTION
A-1
A-2
n
p
~k_F
NUCLEON MOMENTUM

n_SRC(p_rel, p_cm) = sum_pairs contact_pair phi^2(p_rel) n(p_cm)
Sigma(e,e'p) = integral K sigma_ep n_SRC



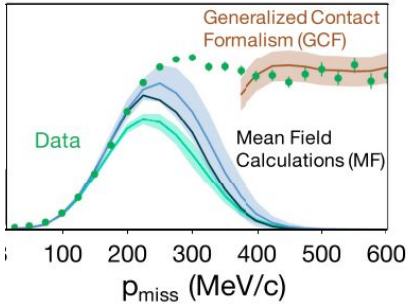
Questions Answered

Pair Abundance

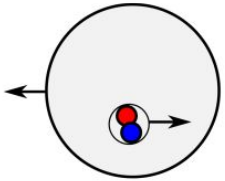


SRC dominate for p > 350 MeV/c

I. Korover, et al. PLB 820 (2021) 136523.



Center of Mass Motion

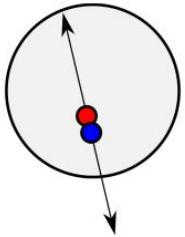


Pcm consistent with 2 mean field nucleons

E.O. Cohen, et al., PRL 121, 092501 (2018).

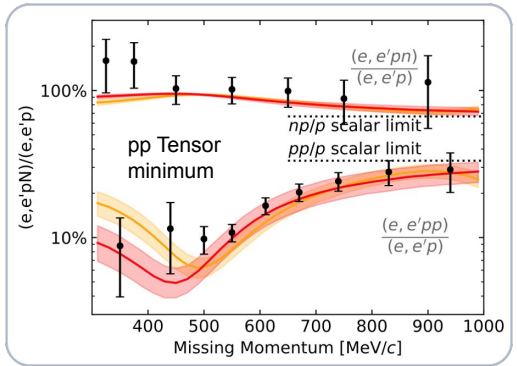
ADD A DEPENDENCE sigma cm

Pair Interaction



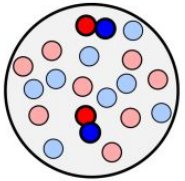
tensor to scalar transition neutron-proton pairs dominate

Schmidt and Pybus et al., Nature (2020)
Pybus et al., PLB (2020)
Korover and Pybus et al. PLB (2021)



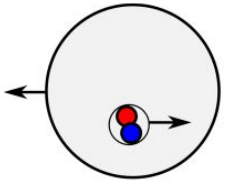
Questions next generation

Pair Abundance



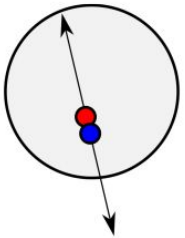
Where are pairs formed?
Which nucleons pair?
Do 3N SRC exist?

Center of
Mass Motion



SRC pairs move in the nucleus
Precision COM measurements

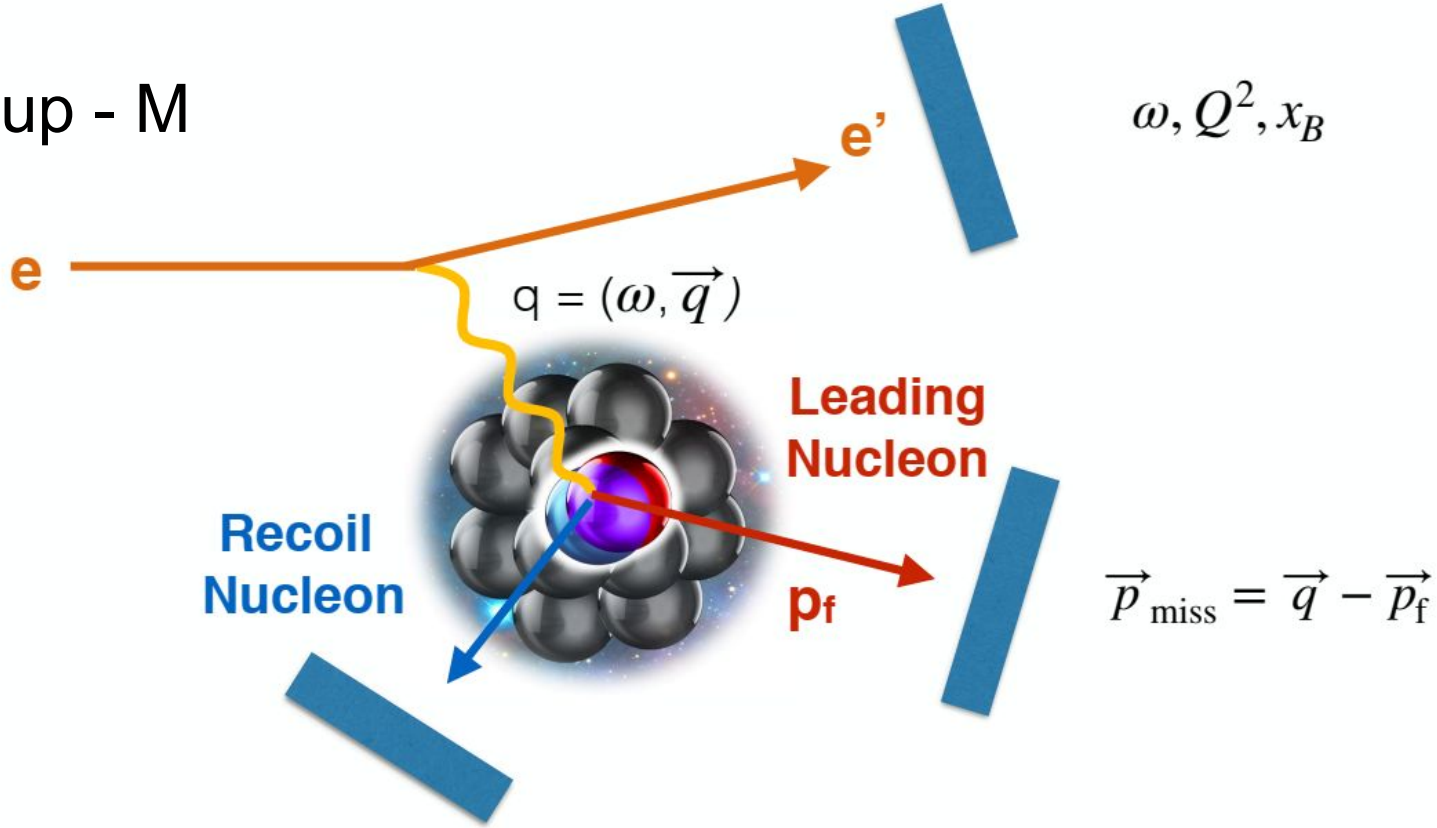
Pair Interaction



tensor to scalar transition
neutron-proton pairs dominate
Precision NN interaction at short distances

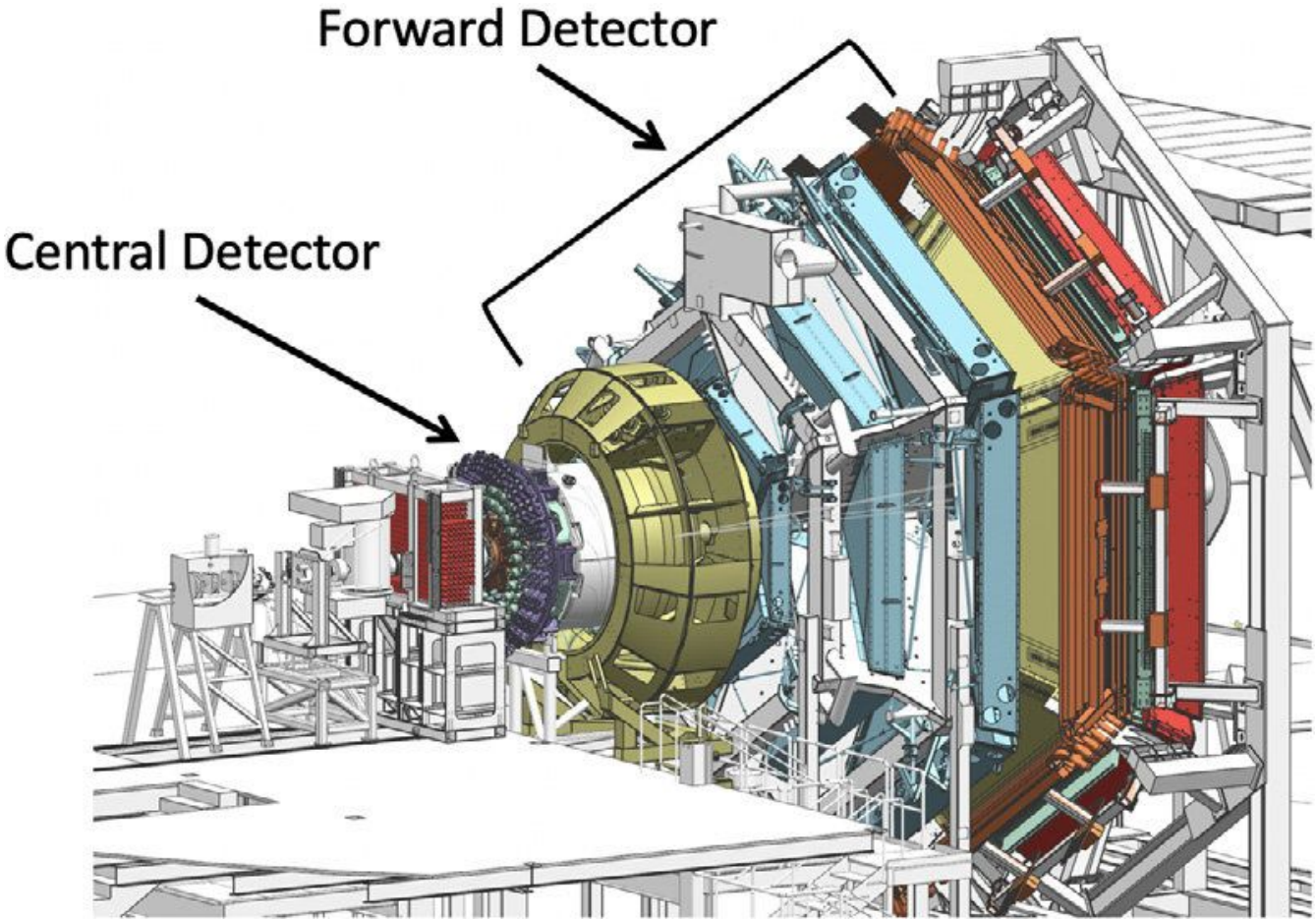
Scale (Q2) independence of SRC observables

Run Group - M



- (e,e') inclusive
- (e,e'N)
- (e,e'NN)

CLAS12 Detector (Hall B)
CEBAF Large Acceptance Spectrometer for operation at 12 GeV @ JLAB

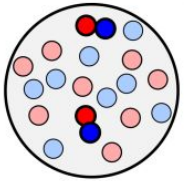


Run Group-M (RGM)

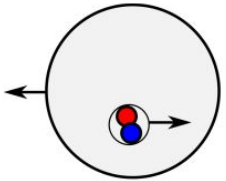
- Ran November 2021 - February 2022
- (120Sn,48Ca,40Ca,40Ar, C, 4He, D, H)
- Fully calibrated, currently reconstructing data

Questions RGM answers

Pair Abundance

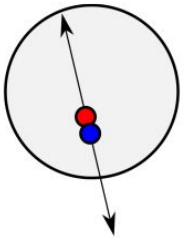


Center of
Mass Motion



SRC pairs move in the nucleus

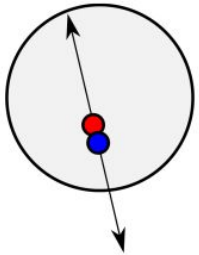
Pair Interaction

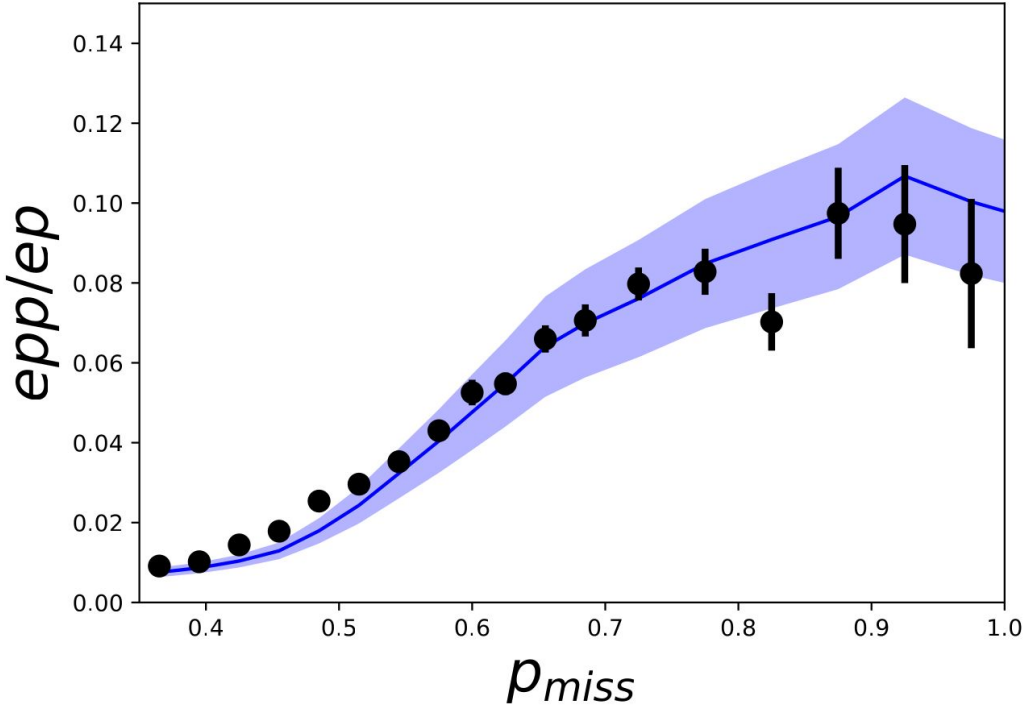


tensor to scalar transition
neutron-proton pairs dominate
Precision NN interaction at short distances

Precision NN interaction

Pair Interaction

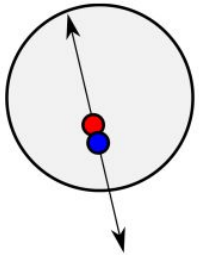


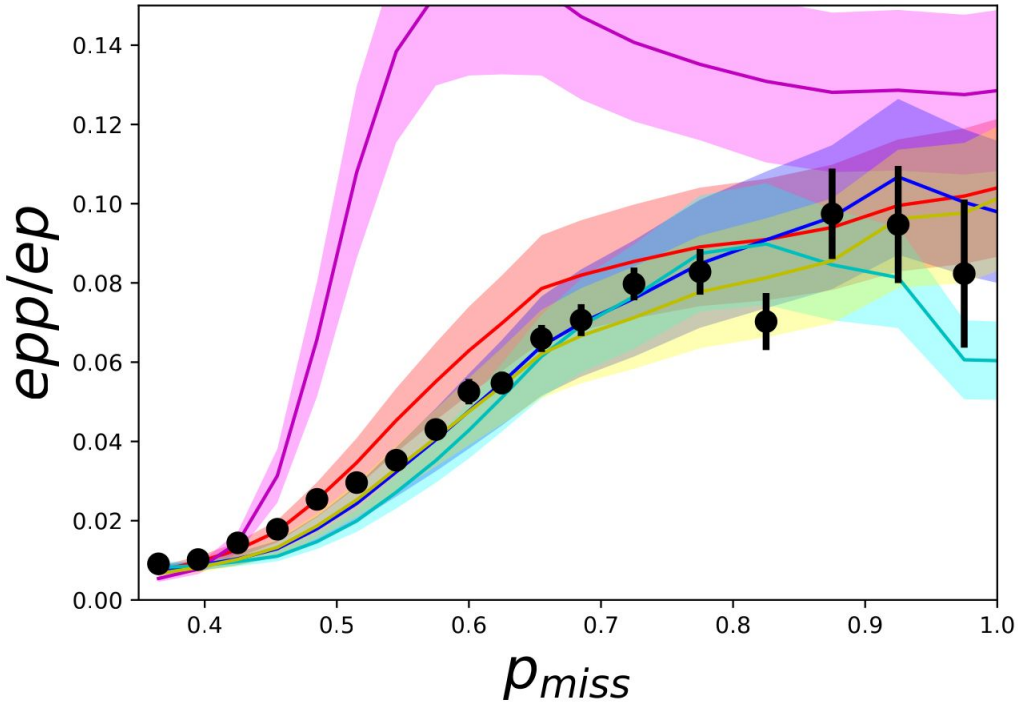


Andrew Deniston (MIT)

Precision NN interaction

Pair Interaction





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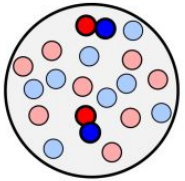
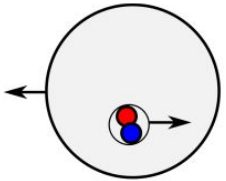
Questions RGM answers

Pair Abundance



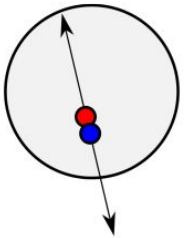
np dominance

Center of
Mass Motion



SRC pairs move in the nucleus

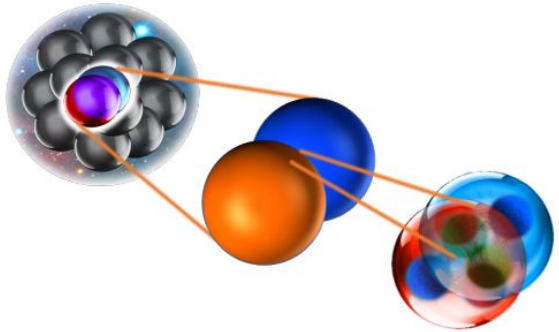
Pair Interaction



Tensor->Scalar transition (CLAS6)
Precision NN interaction at short distances

Scale independence of SRC observables

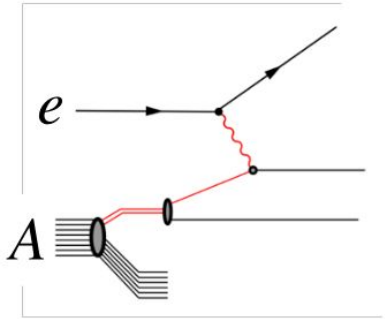
Scale

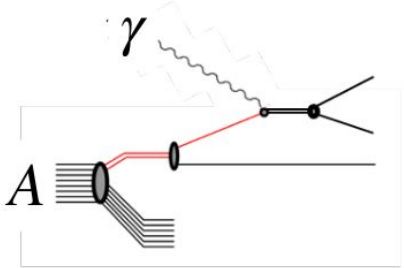


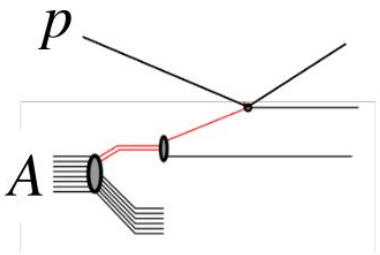
Change the resolution **scale** of the reaction by looking at dependence on momentum transfer Q^2, $|t|$

Probe

Compare different reactions using different **probes**:
Electron-scattering,
Proton-scattering,
Photoproduction



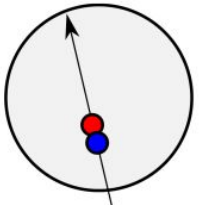




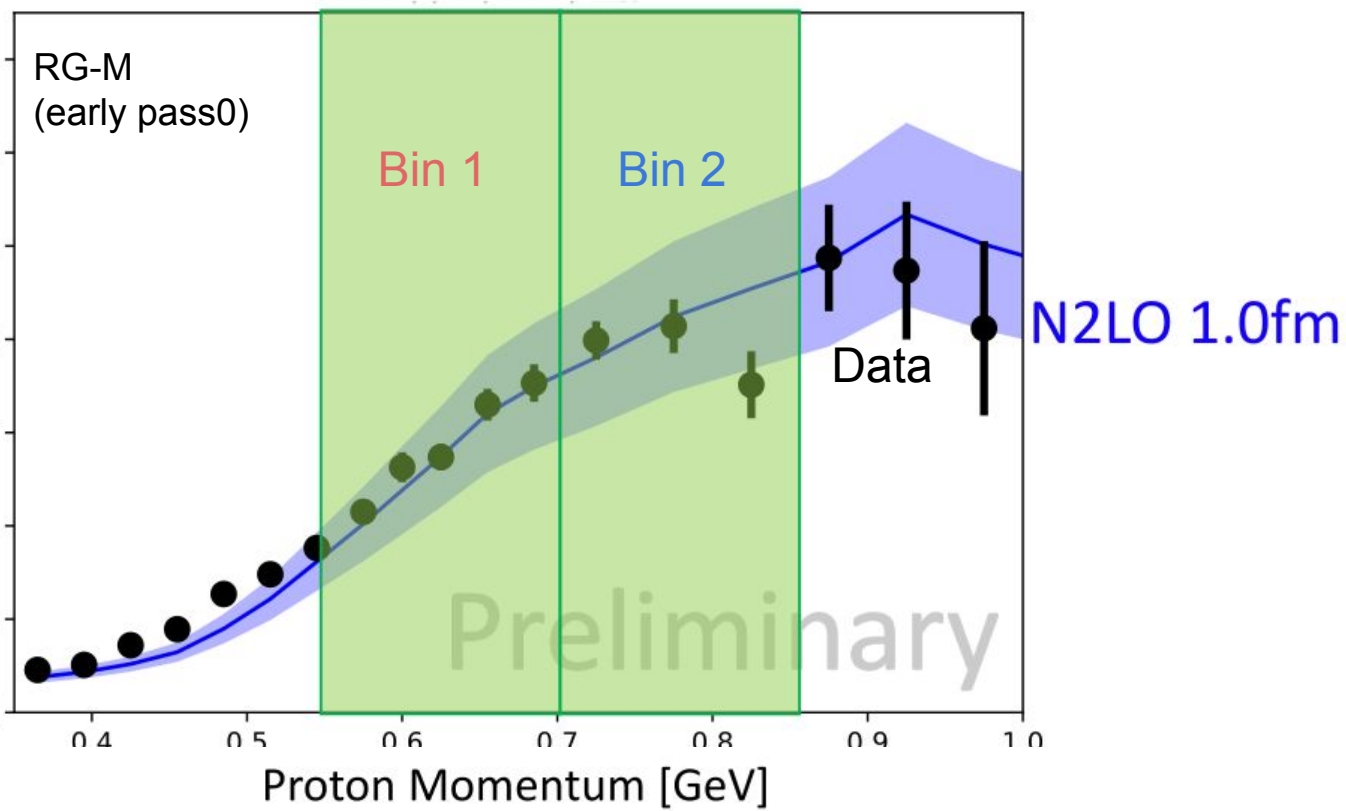
See Jackson Pybus's talk after this

Scale independence

Pair Interaction



$$\frac{\mathrm{He}\,(e,e'pp)}{\mathrm{He}\,(e,e'p)}$$



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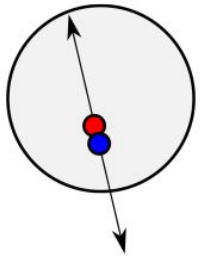
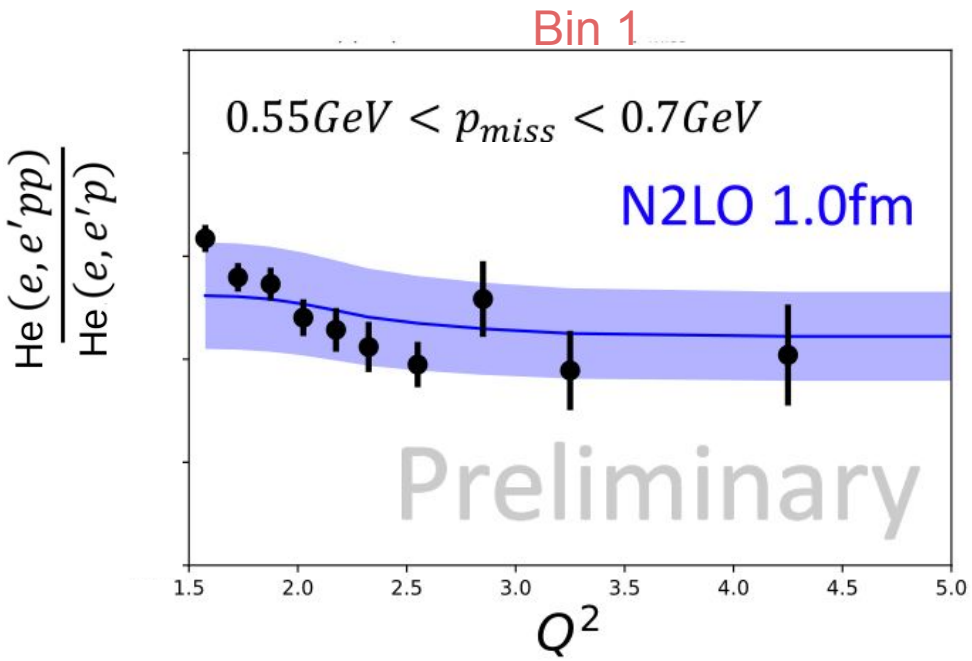
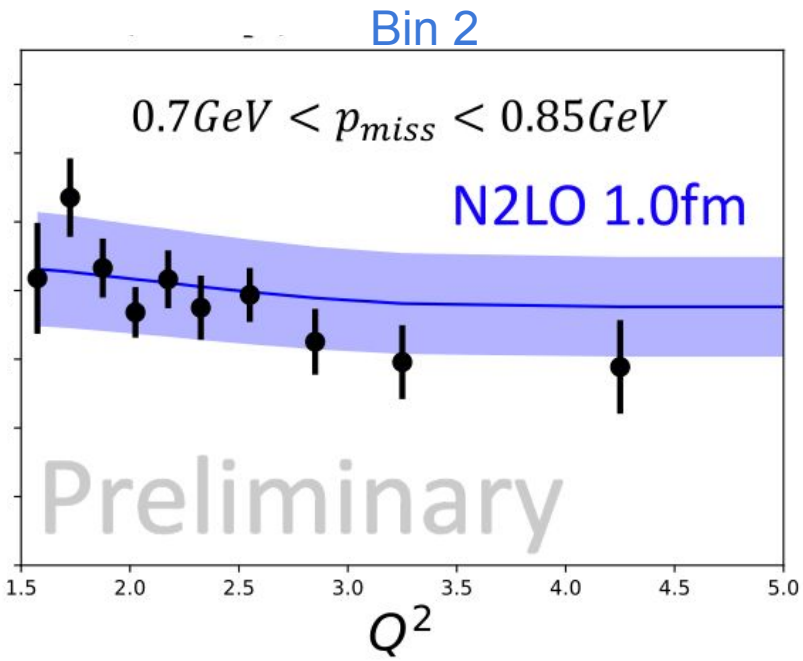
Scale independence of Pair Interaction







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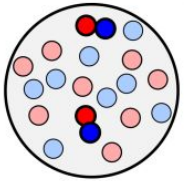
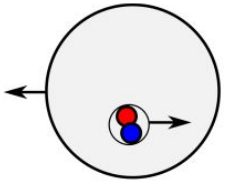
Questions RGM answers

Pair Abundance

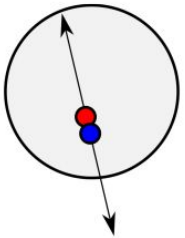


Center of
Mass Motion



SRC pairs move in the nucleus
Precision CM measurements

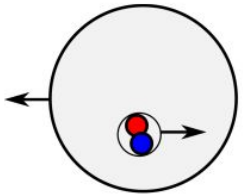
Pair Interaction



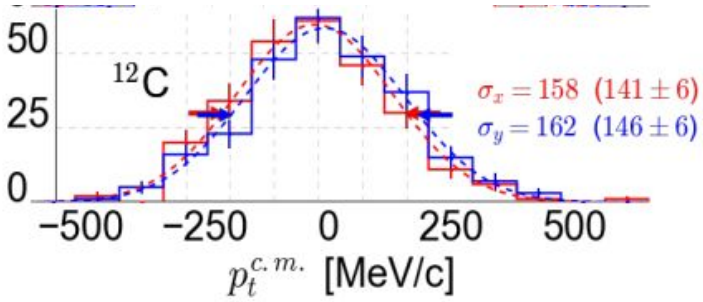
Tensor->Scalar transition (CLAS6)
Precision NN interaction at short distances

Scale (Q2) independence of SRC observables

Center of
Mass Motion

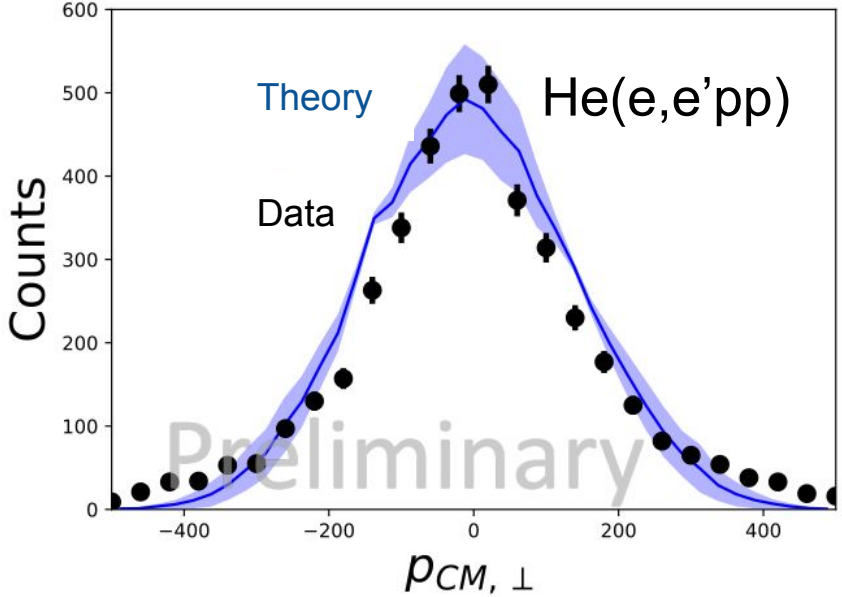


CLAS6 Data



Cohen et al. PRL(2018)

RG-M Data



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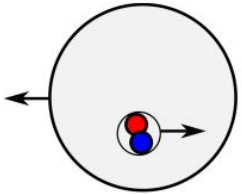
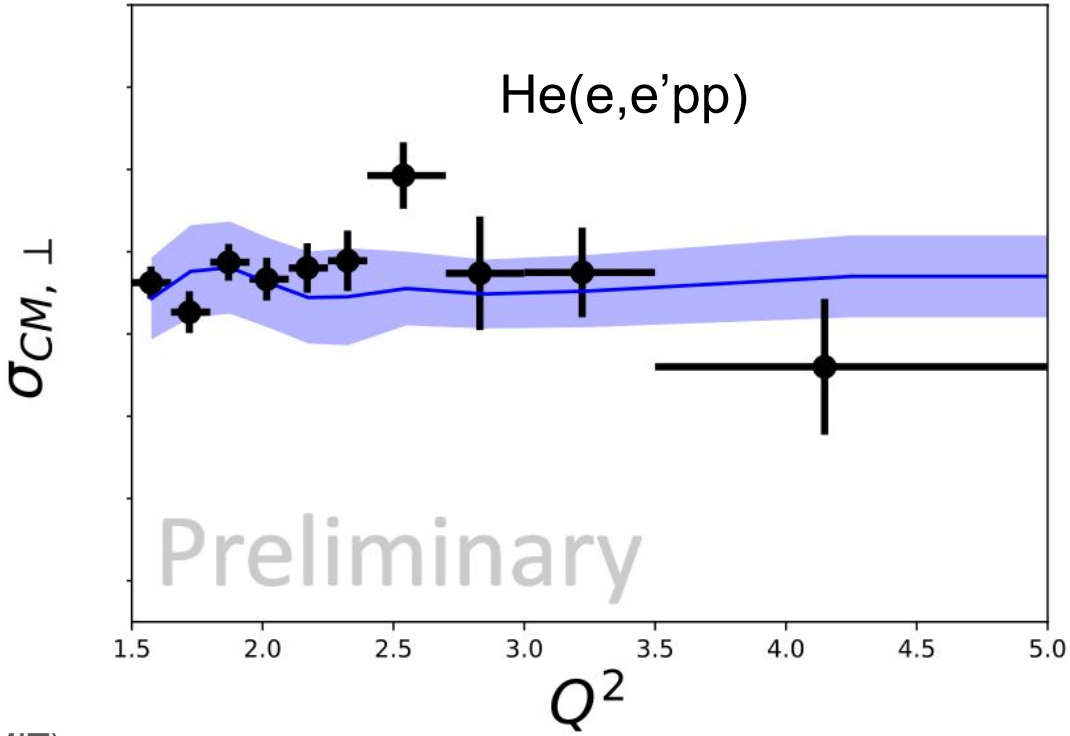
Scale independence

Center of
Mass Motion





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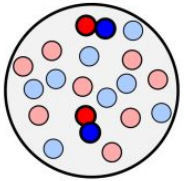
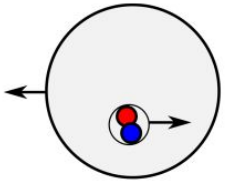
Questions RGM and CaFe answer

Pair Abundance



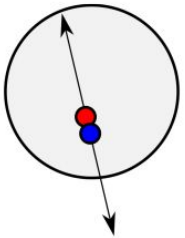
Where are pairs formed?
Which nucleons pair?

Center of Mass Motion



SRC pairs move, caracterize A dependence
Precision COM measurements

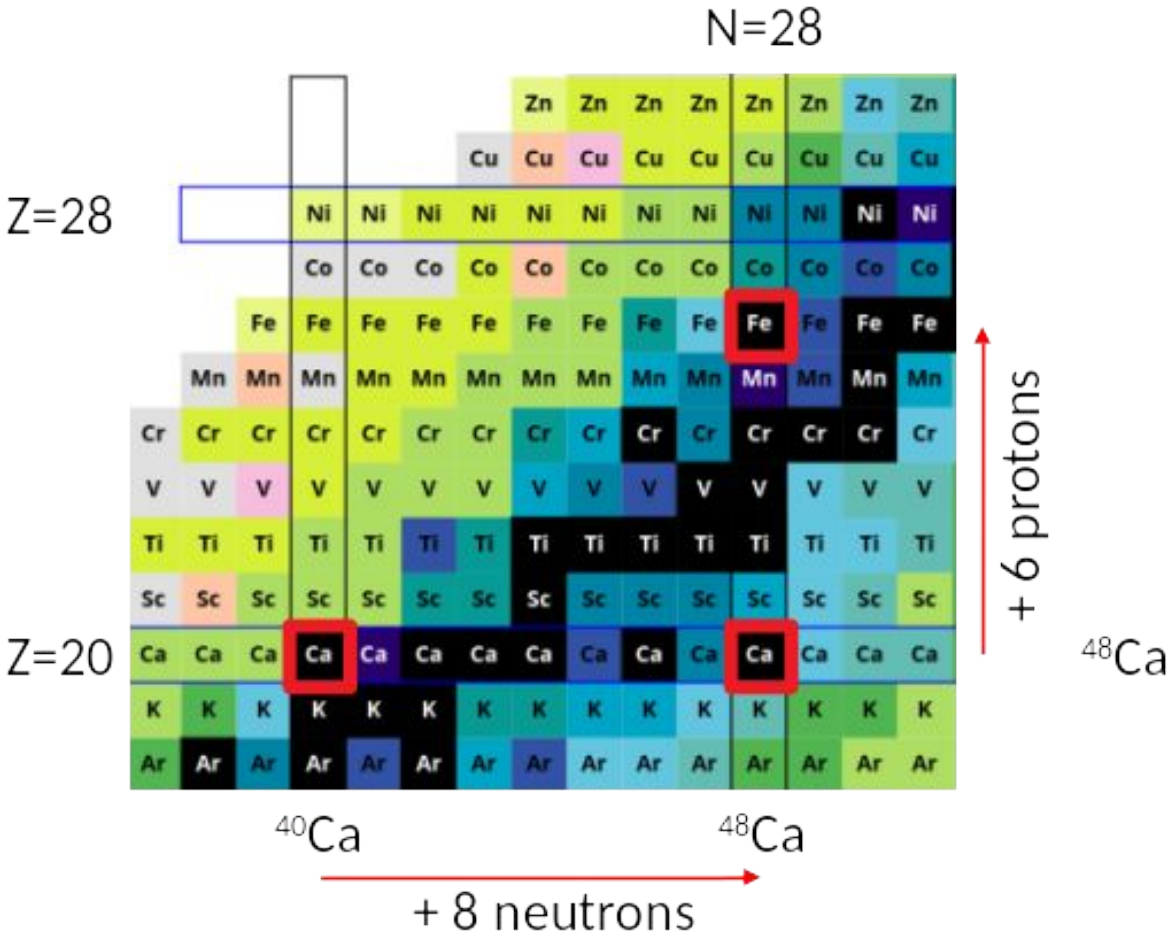
Pair Interaction

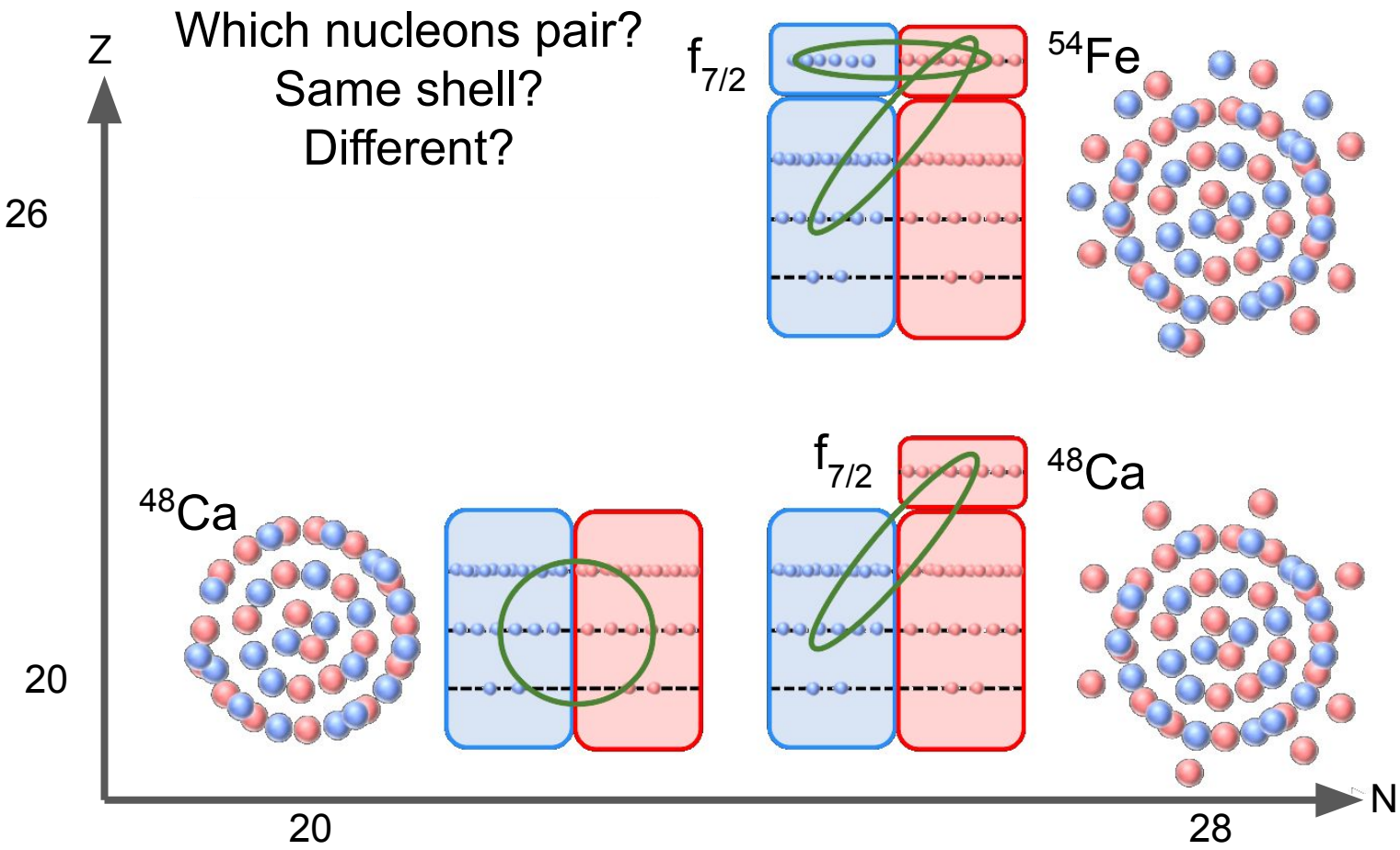


Tensor->Scalar transition (CLAS6)
Precision NN interaction at short distances

Scale independence of SRC observables

SRC in Asymmetric Nuclei CaFe Exp. (Hall C)

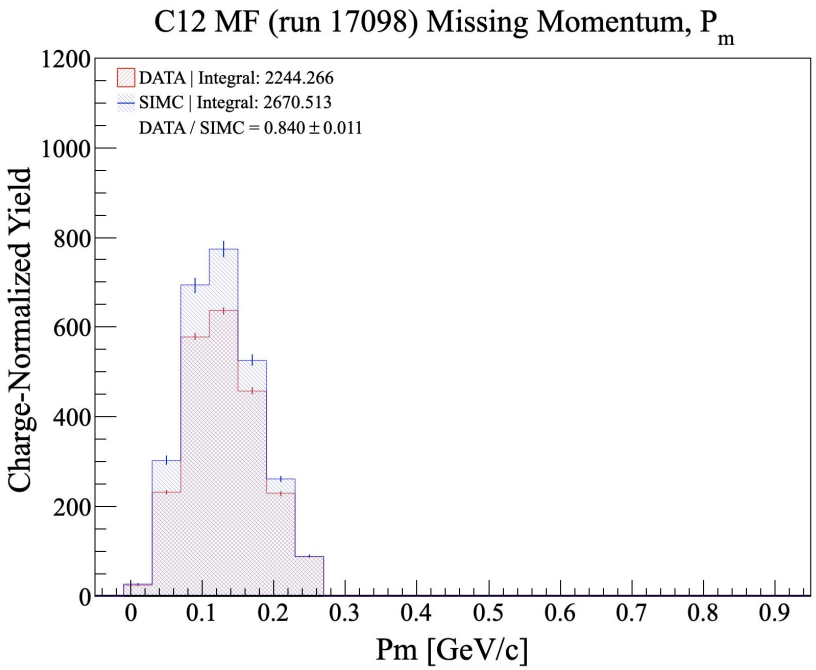


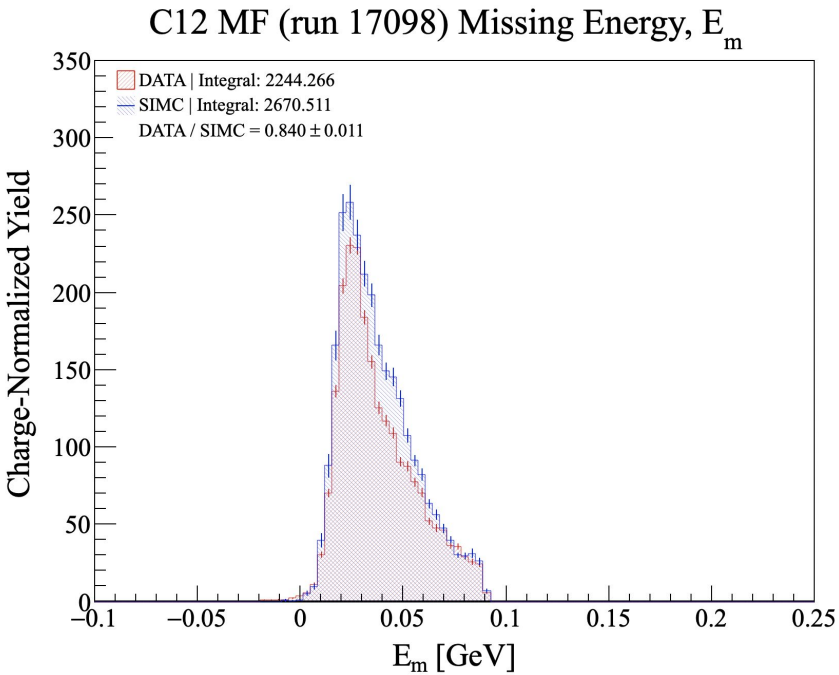

Which nucleons pair?
Same shell?
Different?
Z
26
20
20
28
N
$f_{7/2}$
^{54}Fe
^{48}Ca
$f_{7/2}$
^{48}Ca

CaFe and RG-M

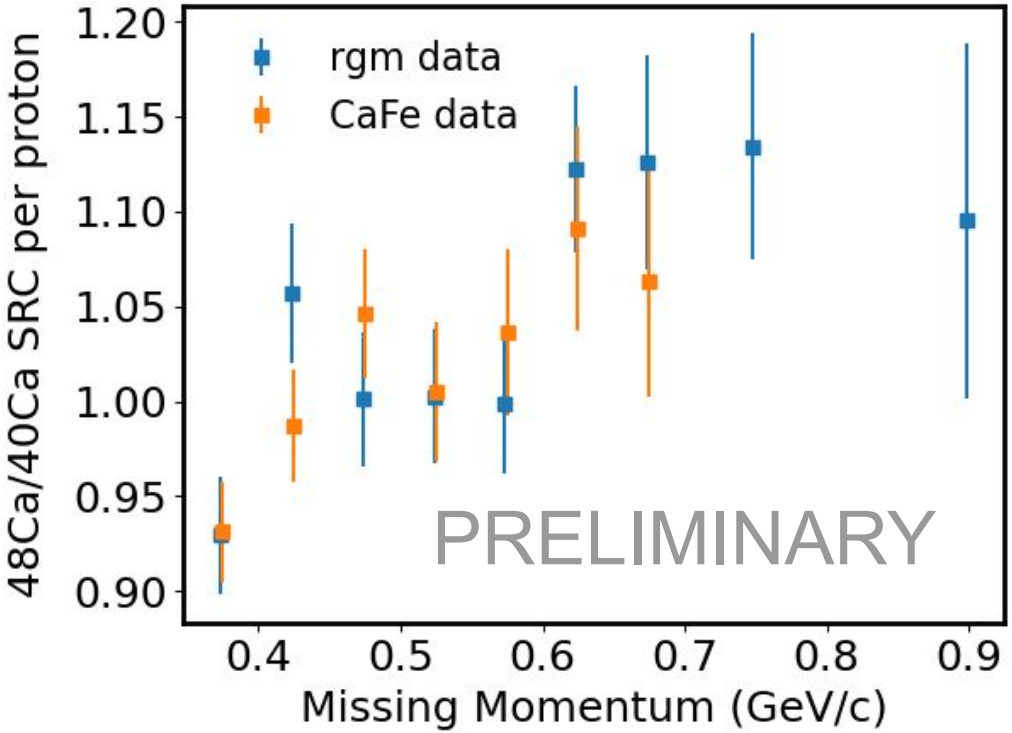
- CaFe
  - 11 GeV: ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{40}Ca, ^{48}Ca, ^{54}Fe
  - Small aperture spectrometers
  - Separate Mean field and SRC kinematic settings
  - (e,e’p) only
- RG-M
  - 6 GeV : C, ^{40}Ca, ^{48}Ca, ^{120}Sn
  - CLAS12
  - (e,e’p), (e,e’pN)

Data / MC comparison





Good agreement with mean field nucleons between data and simulation (SIMC)



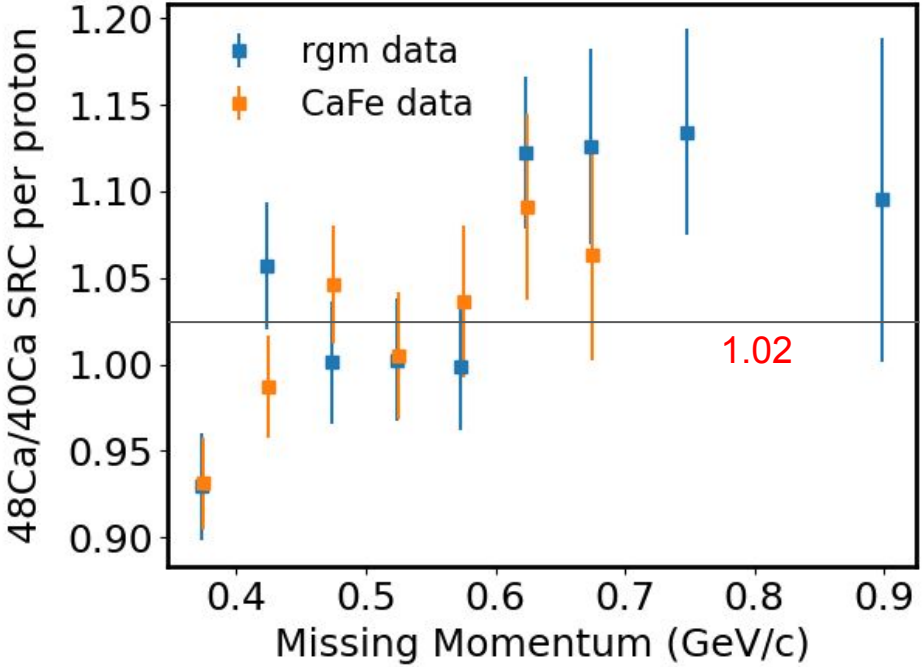
PRELIMINARY No systematic errors.	Integrated Ratios $^{48}Ca/^{40}Ca$ SRC per proton
RG-M (Hall B)	1.03 (2)
CaFe (Hall C)	1.02 (1)

RGM very preliminary
Confirms CaFe results

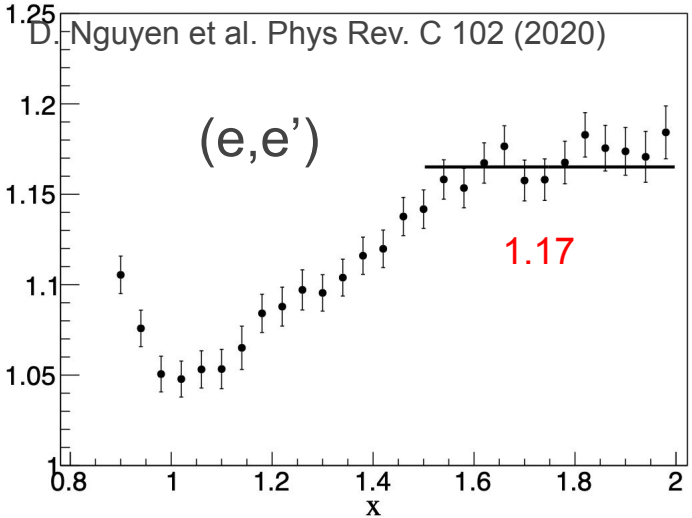
CaFe:
Carlos Yero (ODU)
Dien Nguyen (JLAB)

RG-M (CaFe)
Julian Kahlbow (MIT)
Ron Wagner (Tel Aviv U.)

(e,e’) and (e,e’p) disagreement?



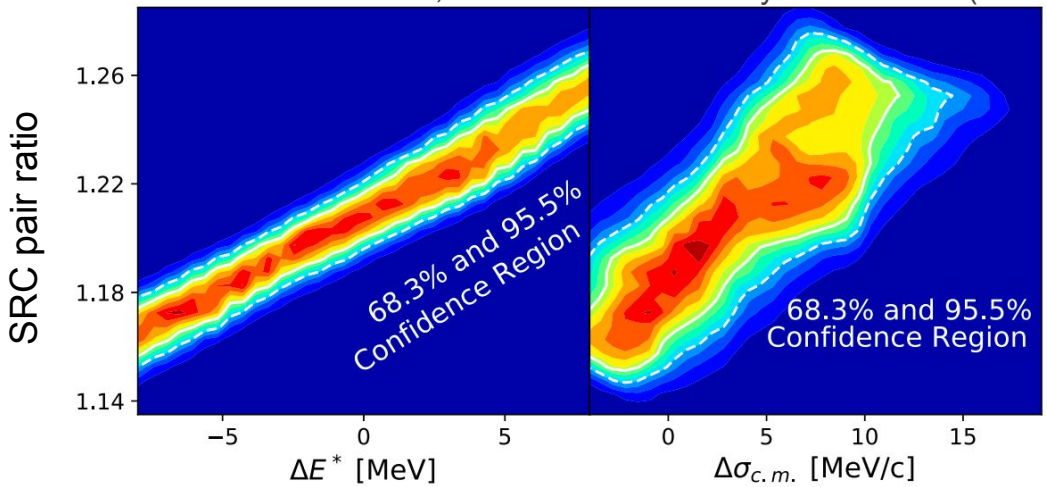
$$\frac{\sigma(^{48}\mathrm{Ca})}{\sigma(^{40}\mathrm{Ca})}$$



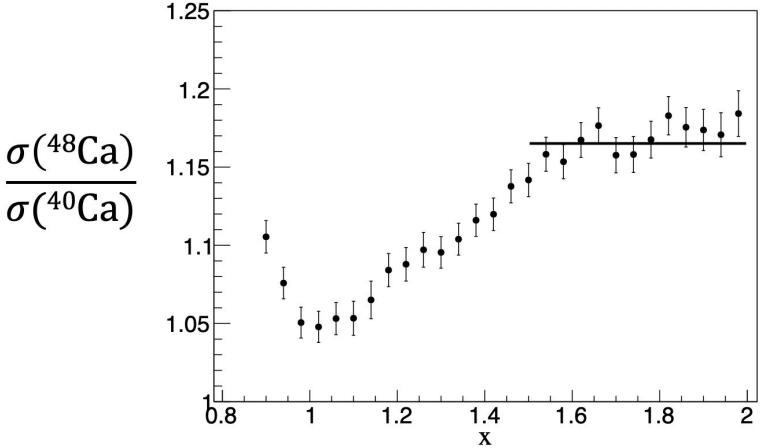
Contradiction????

(e,e') cross section ratio is NOT the SRC pair ratio!

R. Weiss, A. Denniston et al. Phys Rev. C 103 (2021)



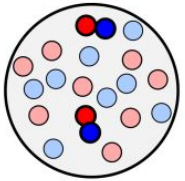
D. Nguyen et al. Phys Rev. C 102 (2020)



Varying model parameters changes SRC pair ratio by 10%

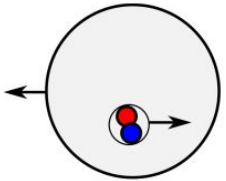
Questions RGM answers

Pair Abundance



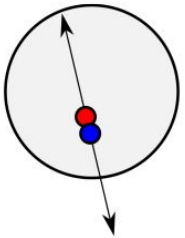
np dominance
Where are pairs formed?
Which nucleons pair?
Observe 3N SRC

Center of
Mass Motion



SRC pairs move, caracterize A dependence
Precision COM measurements

Pair Interaction

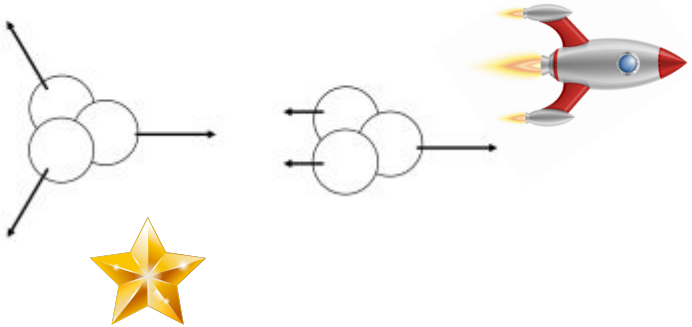


Tensor->Scalar transition (CLAS6)
Precision NN interaction at short distances

Scale independence of SRC observables

Pathway to 3N SRC Discovery…

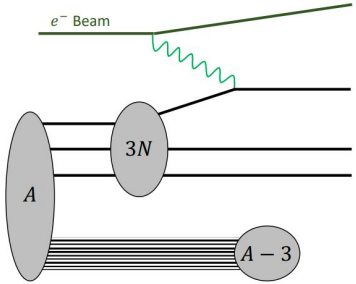
Characterize 3N SRC kinematics…

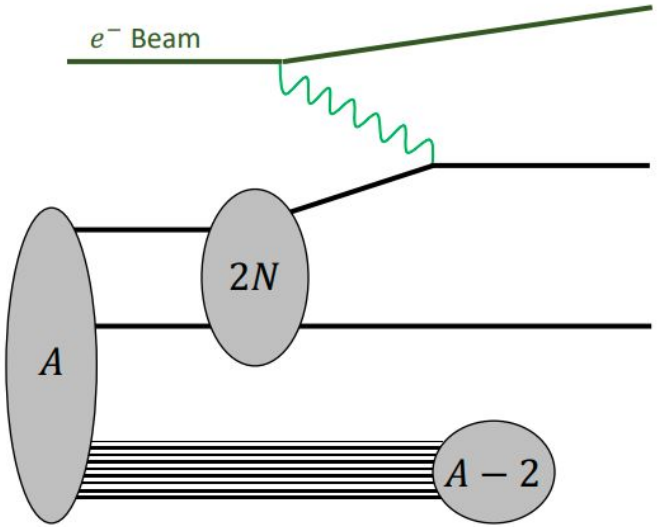


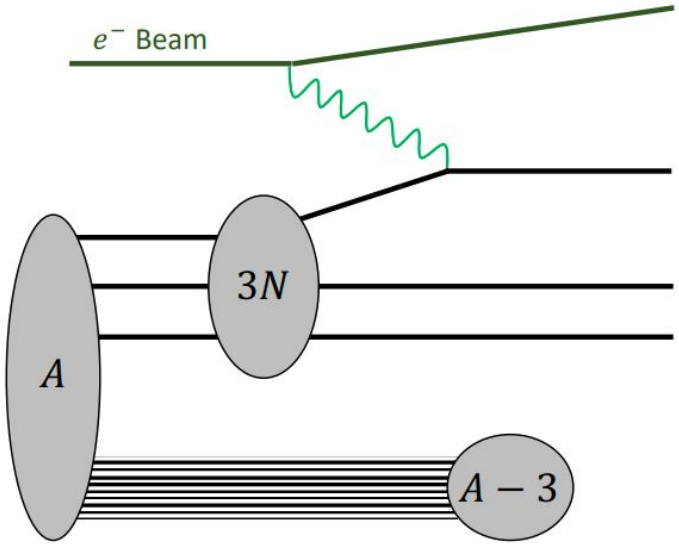
Variables to suppress FSI…

Q2, Xb, p/q ???
New ones

3N SRC cross-section…







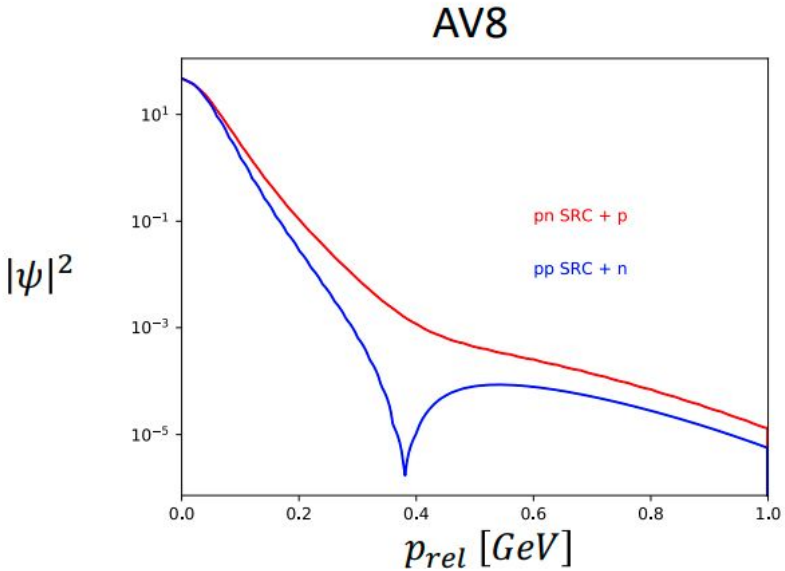
$$\frac{d^8\sigma}{d^8X^\mu} = \mathcal{J}\sigma_{eN} * |\phi_\alpha(p_{rel})|^2 * n(p_{cm})$$

$$\frac{d^{11}\sigma}{d^{11}X^\mu} = \mathcal{J}\sigma_{eN} * |\phi_\alpha(\vec{p}_1, \vec{p}_2, \vec{p}_3)|^2 * n(p_{cm})$$

Describing 3-NN interaction

2N-SRC (6 parameters)
3 - center of mass
2 - Euler angles
1 - NN interaction variable (p_{rel})

3N-SRC (9 parameters)
3 - center of mass
3 - Euler angles
3 - NN interaction variables



?

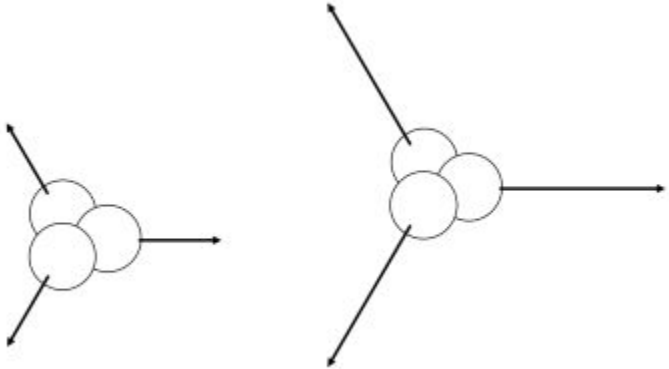
^{3}He wavefunction (ppn)
No 3-body interactions

3NN interaction variables

3 particles -> 9 variables

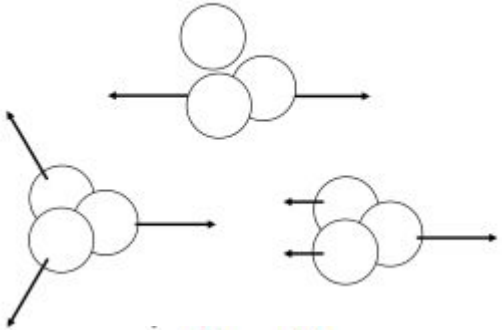
3 - center of mass
3 - euler angles
3 - NN interaction parameters

Size parameter



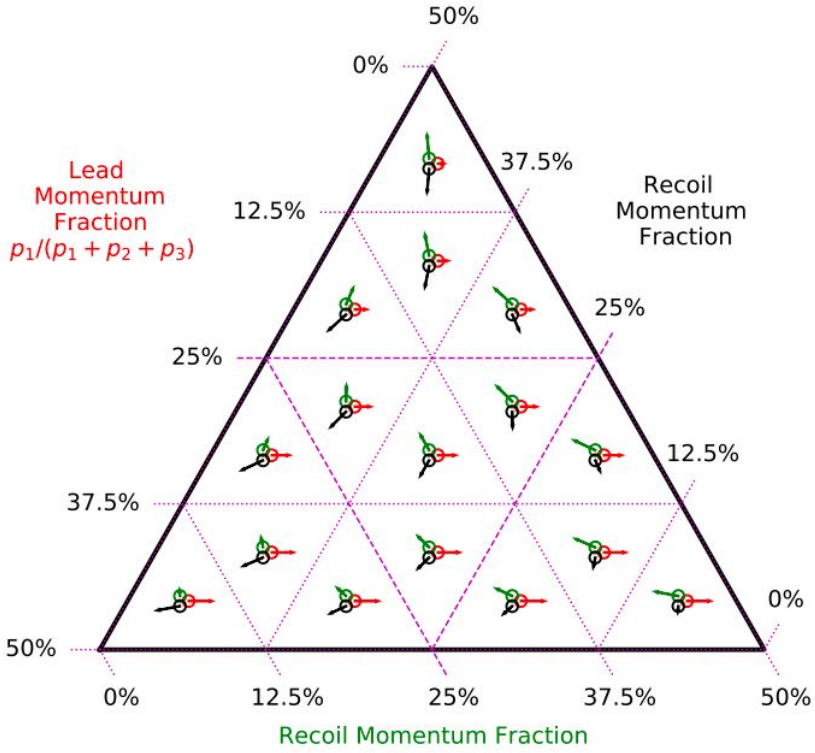
$$p_{tot} = p_1 + p_2 + p_3$$

Shape parameter



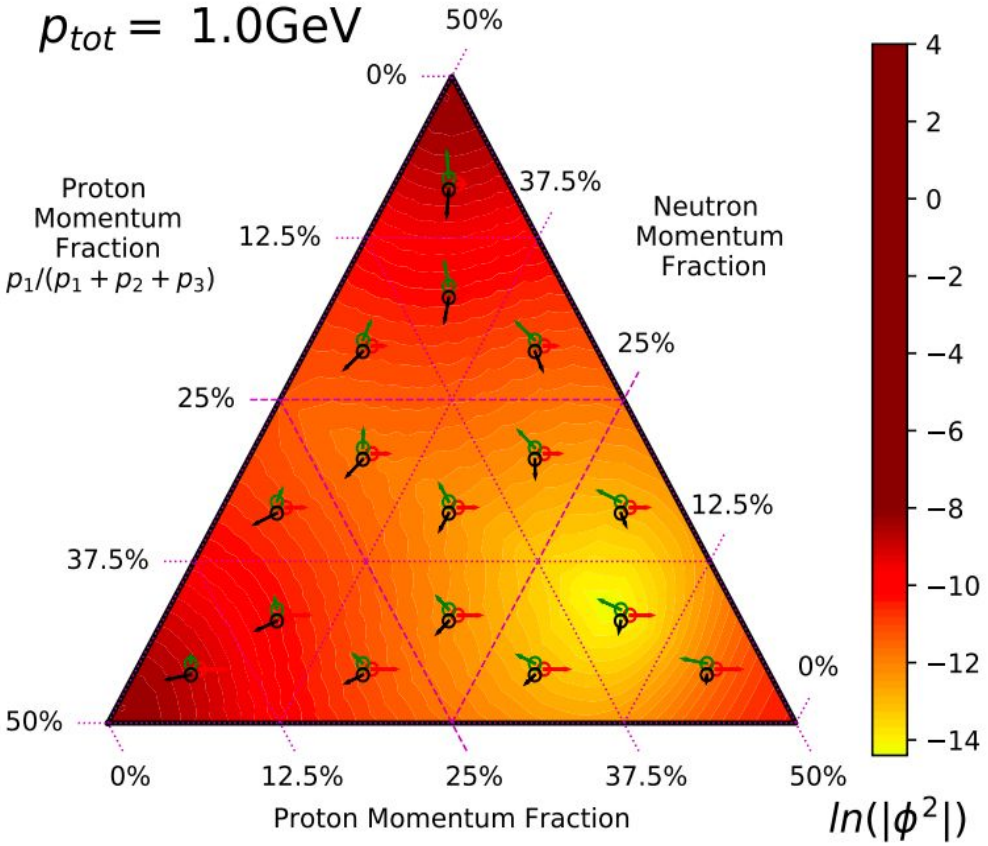
$$\frac{p_1}{p_{tot}}, \frac{p_2}{p_{tot}}$$

3N SRC modified-Dalitz plot (Denniston plot)

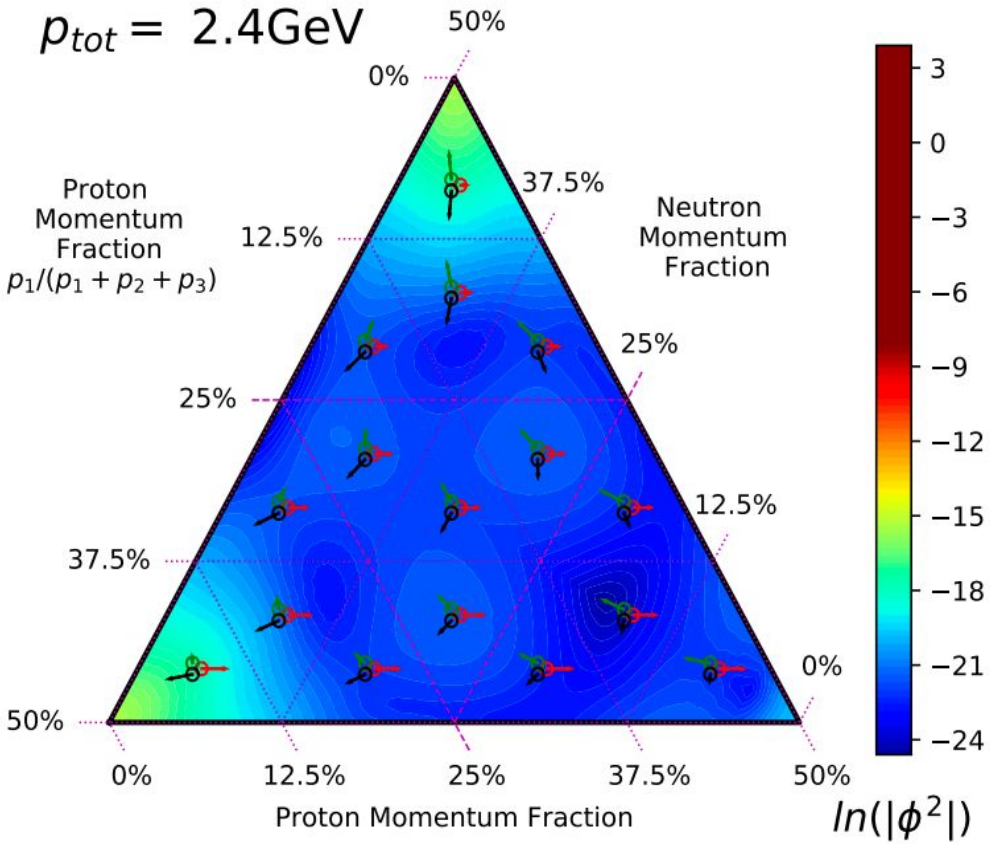


Andrew Denniston (MIT)

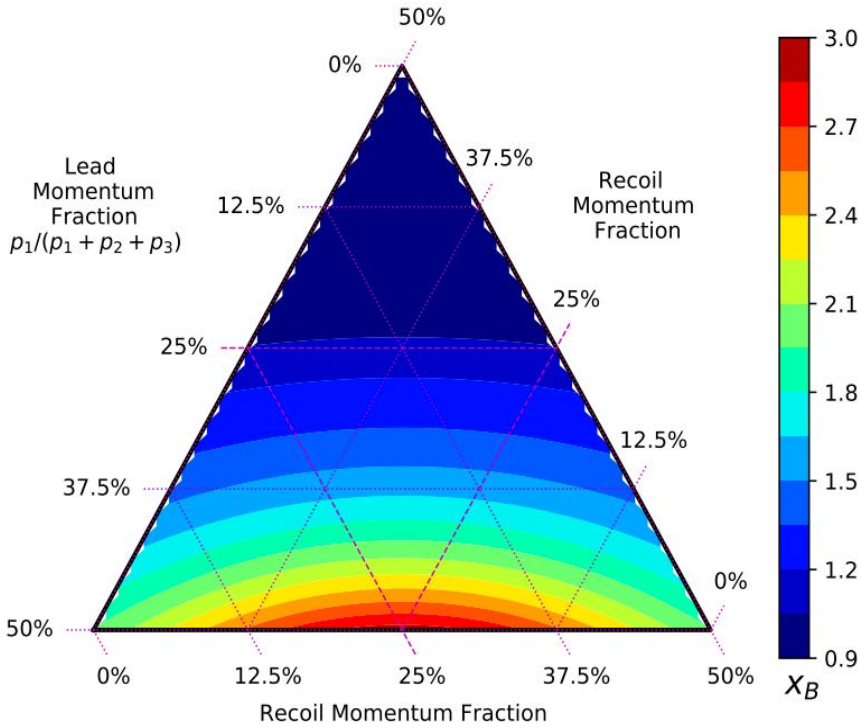
3-NN wavefunction slice



3-NN wavefunction slice



Acceptance


50%
0%
37.5%
12.5%
25%
25%
12.5%
37.5%
0%
50%
Lead
Momentum
Fraction
$p_1/(p_1+p_2+p_3)$
Recoil
Momentum
Fraction
0%
12.5%
25%
37.5%
50%
Recoil Momentum Fraction
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
x_B