

Universality of Short Range Correlations in Nuclei

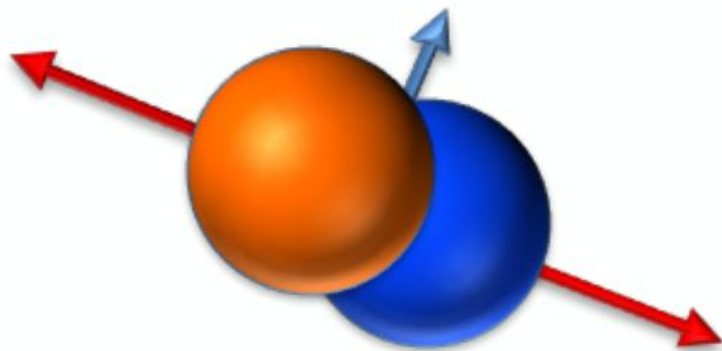
Justin Estee (MIT)

Short range, short lived,
highly correlated pairs

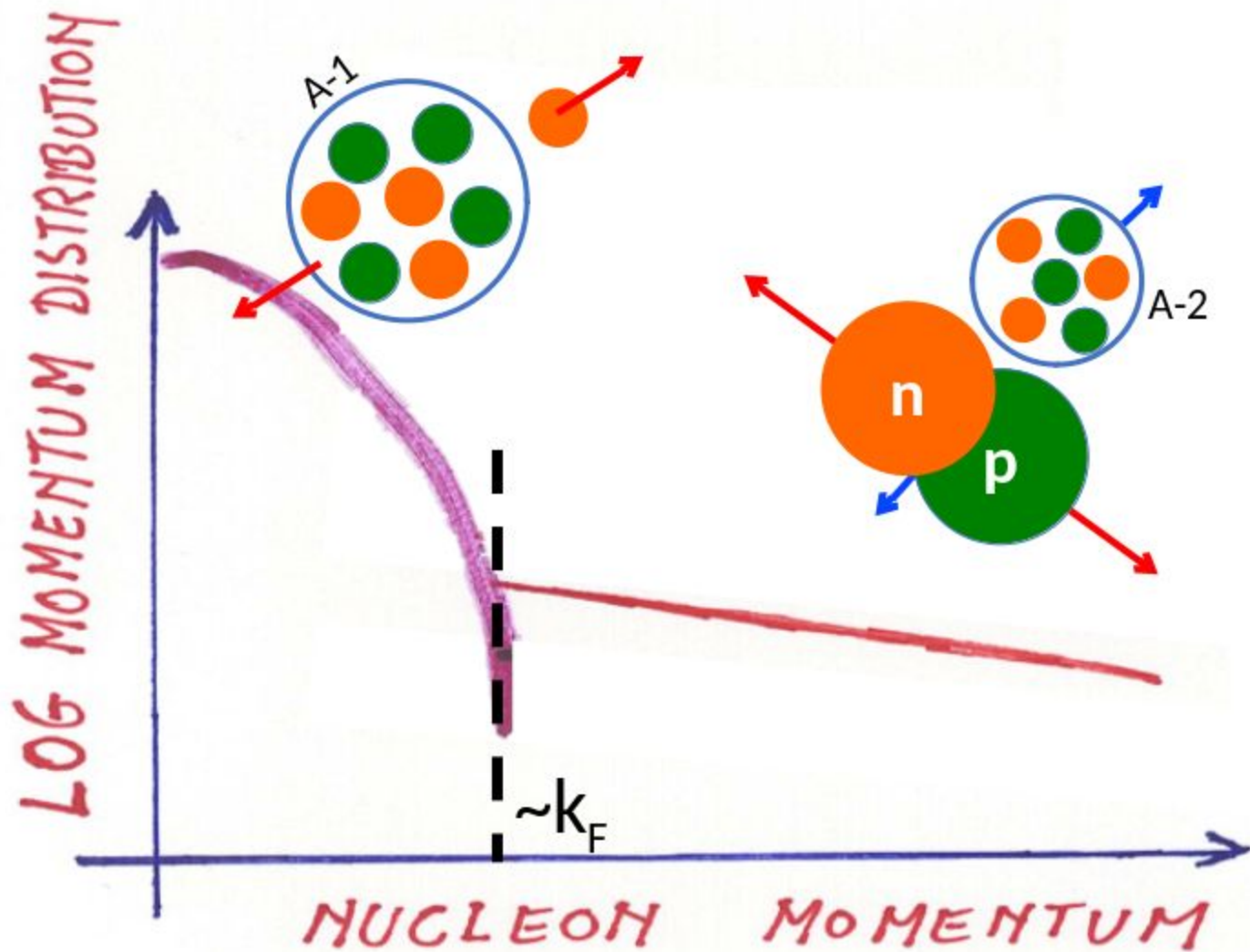


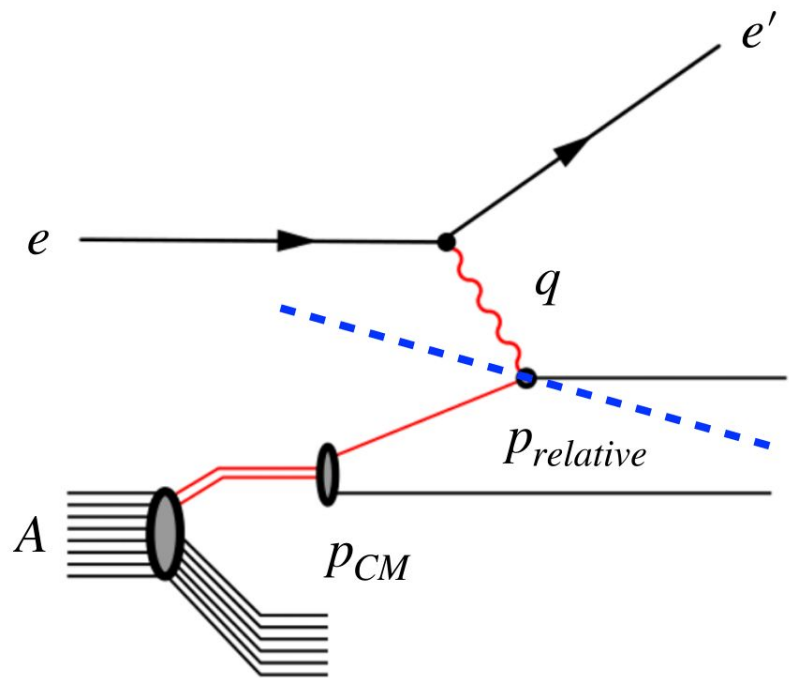
r-space

High **relative** momentum
Low **center of mass** momentum



k-space





$$\sigma = \sigma_{e,N}(q) \times S(p_i, p_{rec})$$

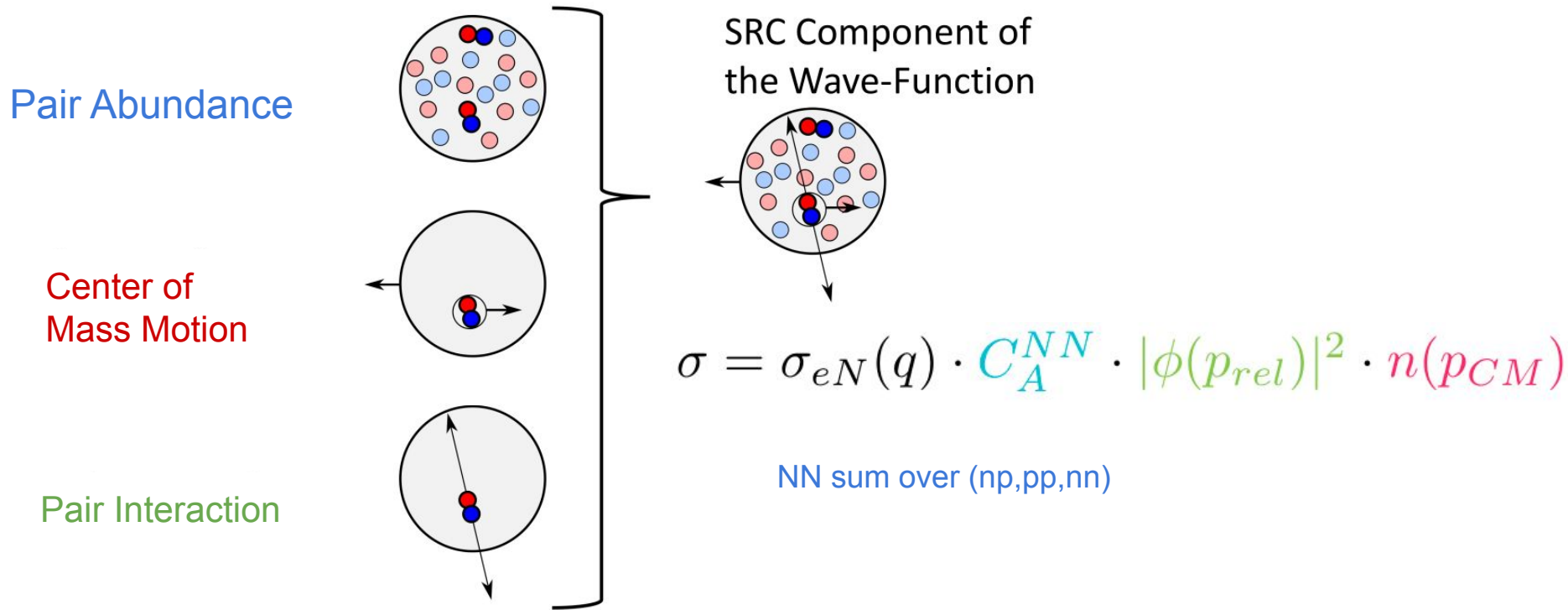
Reaction

- High-energy
- 1-body operator
- Kinematics- and probe- dependent

Ground-State

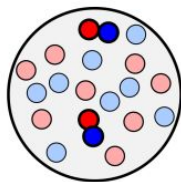
- Low-energy
- 2-body dynamics
- Universal

Generalized Contact Formalism (GCF)

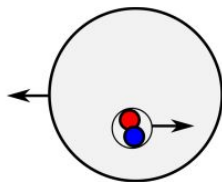


What we know...

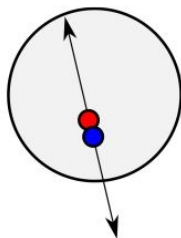
Pair Abundance



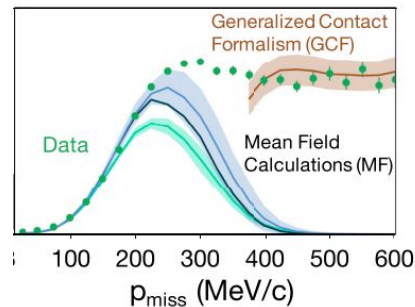
Center of Mass Motion



Pair Interaction

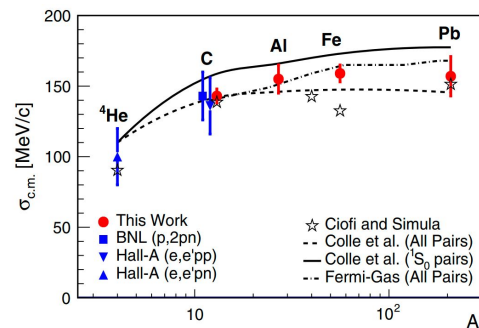


SRC dominate for $p > 350 \text{ MeV}/c$



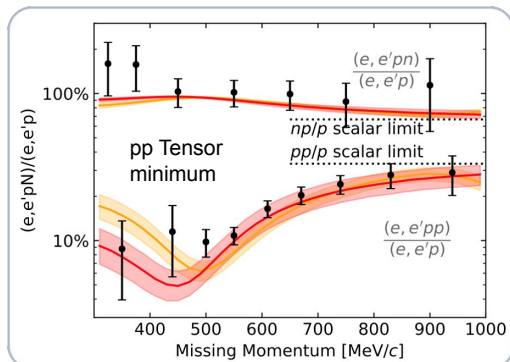
I. Korover, et al. PLB 820 (2021)

Measured P_{CM} motion



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

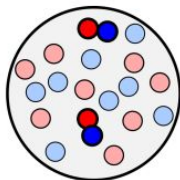
tensor to scalar transition
neutron-proton pairs dominate



Korover et al. PLB (2021)

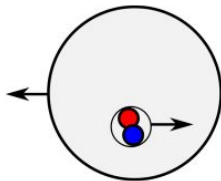
next generation questions...

Pair Abundance



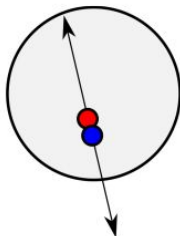
Where are pairs formed?
Which nucleons pair?
Do 3N SRC exist?

Center of
Mass Motion



Precision CM measurements

Pair Interaction

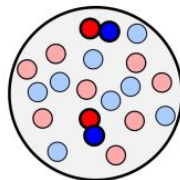


Precision NN interaction at short distances

Are SRC observables universal in scale and probe?

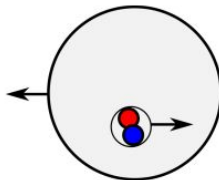
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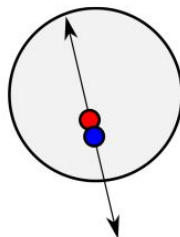
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Precision CM measurements

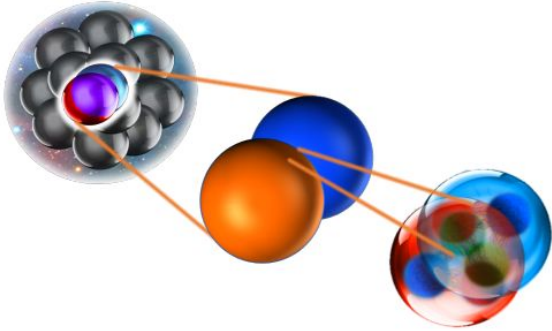
Pair Interaction



Precision NN interaction at short distances

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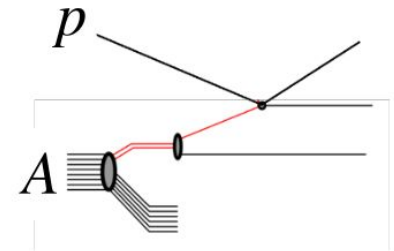
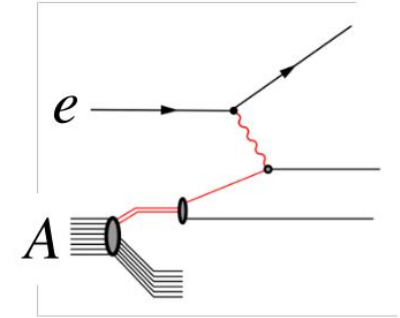
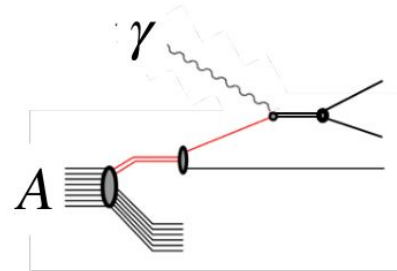
Scale



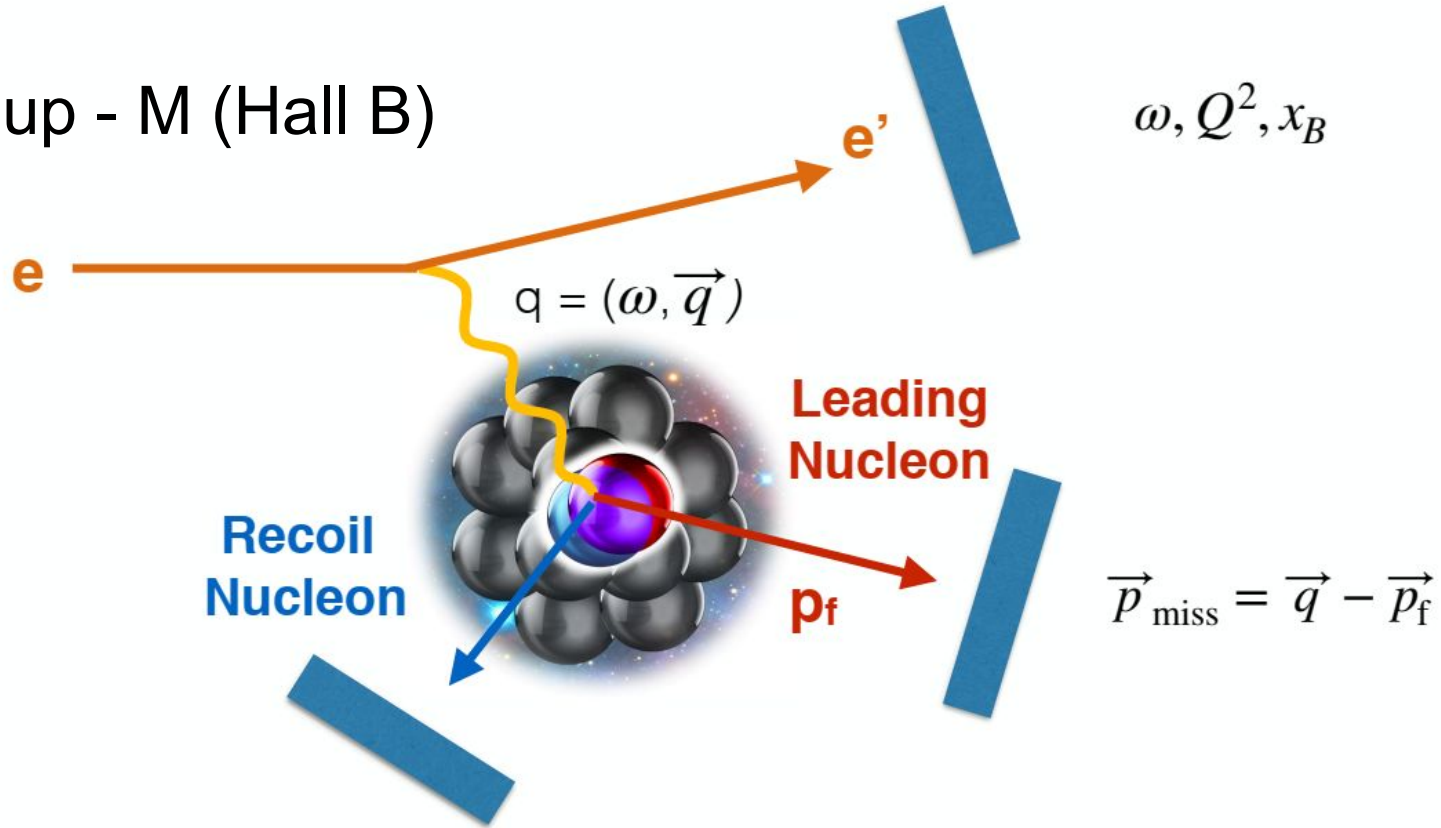
Change the resolution **scale**
of the reaction by looking at
dependence on momentum
transfer Q^2 , $|t|$

Probe

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



Run Group - M (Hall B)



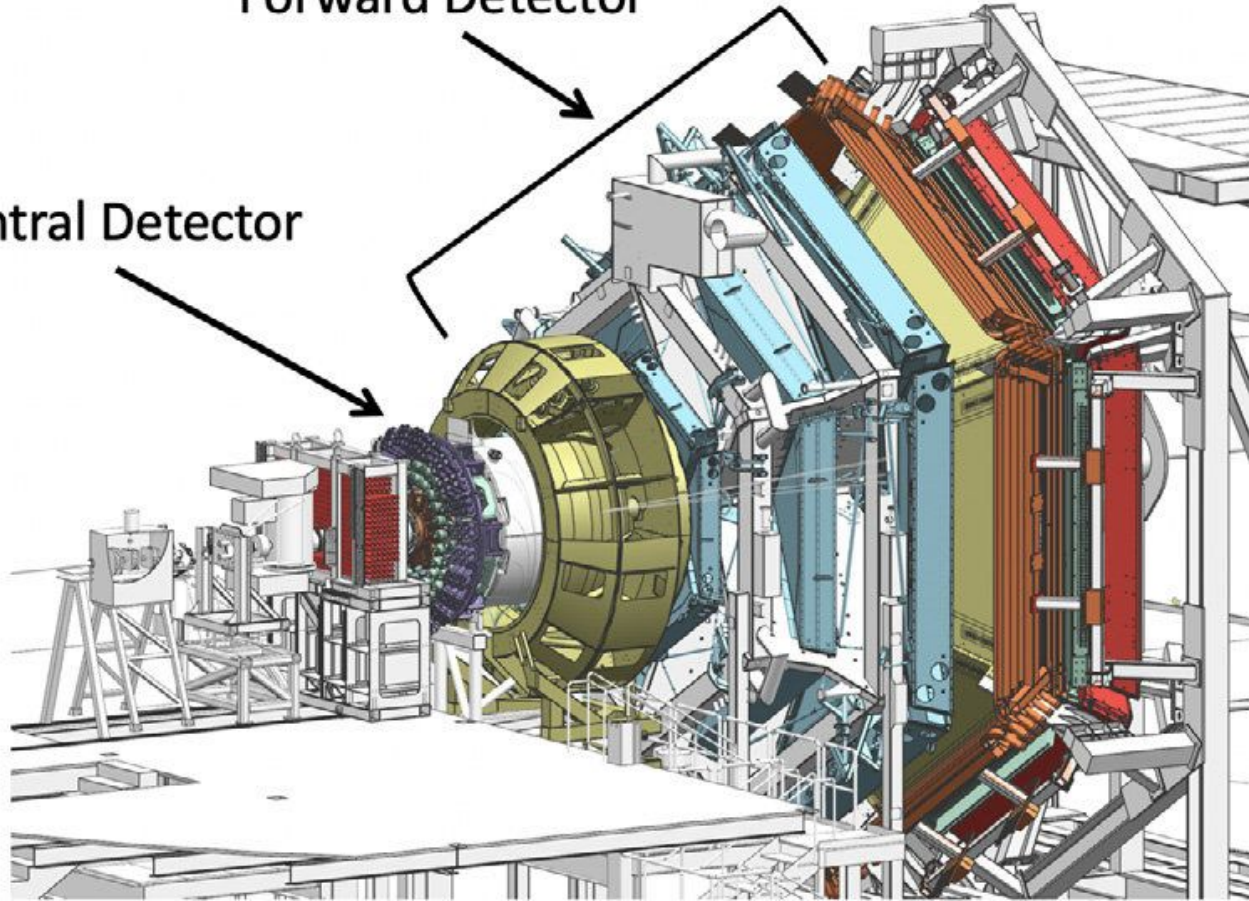
- (e, e') inclusive
- $(e, e'N)$
- $(e, e'NN)$

CLAS12 Detector (Hall B)

CEBAF Large Acceptance Spectrometer for operation at 12 GeV @ JLAB

Forward Detector

Central Detector



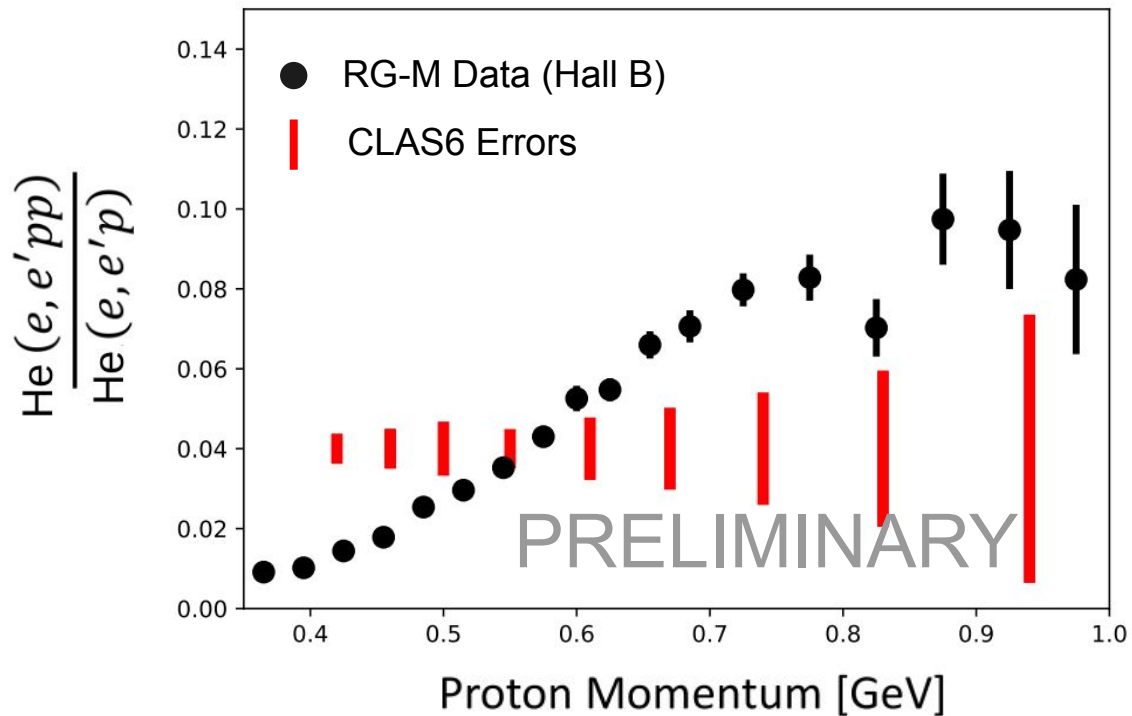
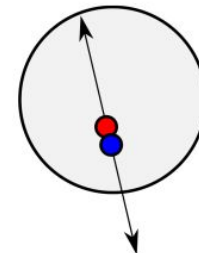
Run Group-M (RGM)

- Ran November 2021 - February 2022
- (H, D, ^4He , ^{40}Ar , ^{40}Ca , ^{48}Ca , ^{120}Sn)
- Fully calibrated
- ~55% data reconstruction (finishing within a ~month)



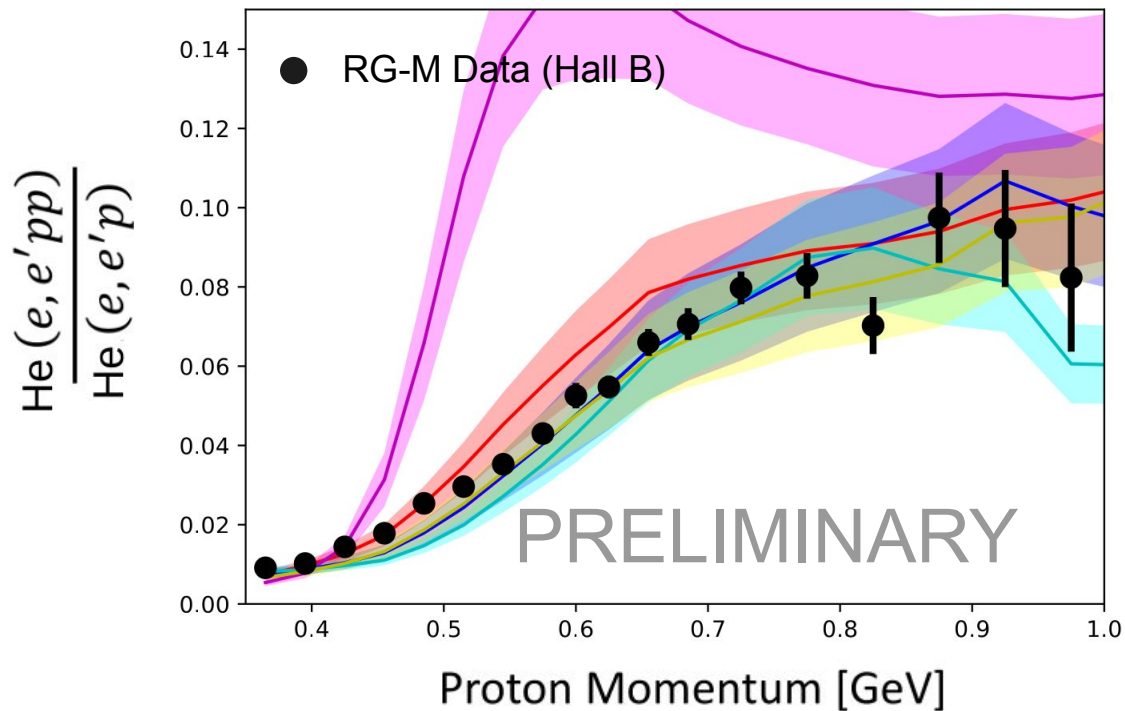
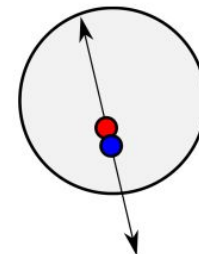
Precision NN interaction

Pair Interaction

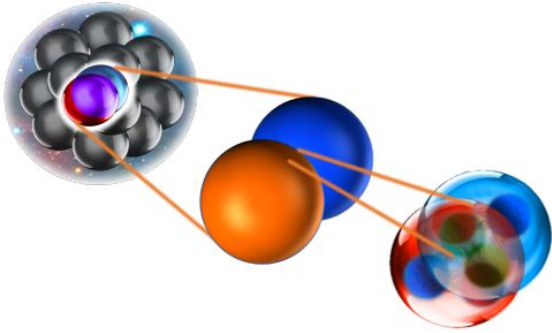


Precision NN interaction

Pair Interaction



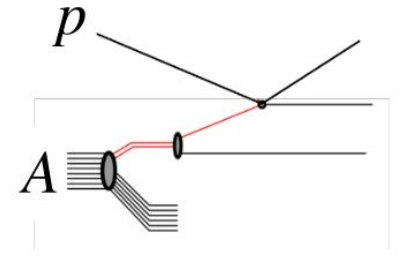
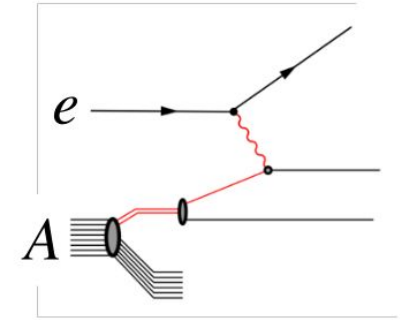
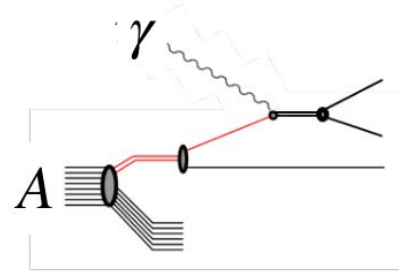
Scale



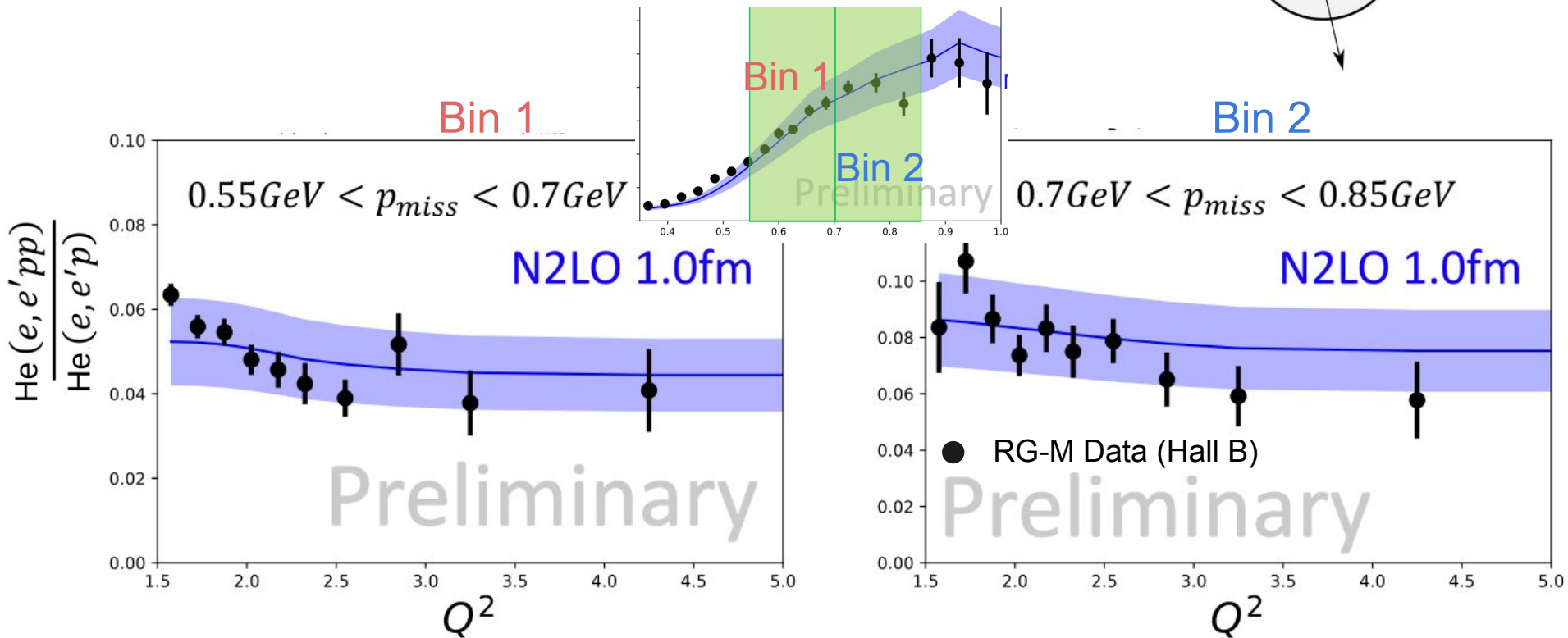
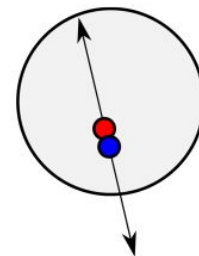
Change the resolution **scale**
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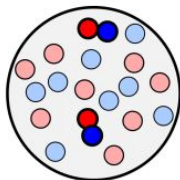


Scale independence of Pair Interaction



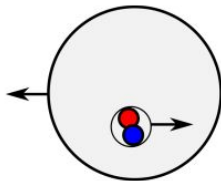
next generation questions...

Pair Abundance



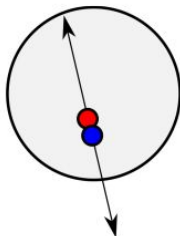
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Center of
Mass Motion



Precision COM measurements

Pair Interaction

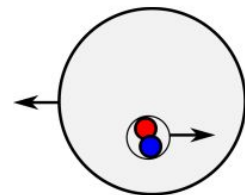


Precision NN interaction at short distances

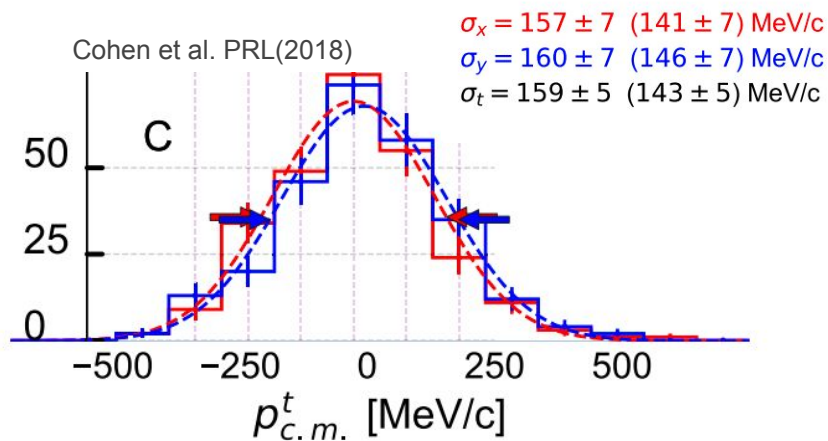
Scale (Q^2) independence of SRC observables

Precision C.M. motion

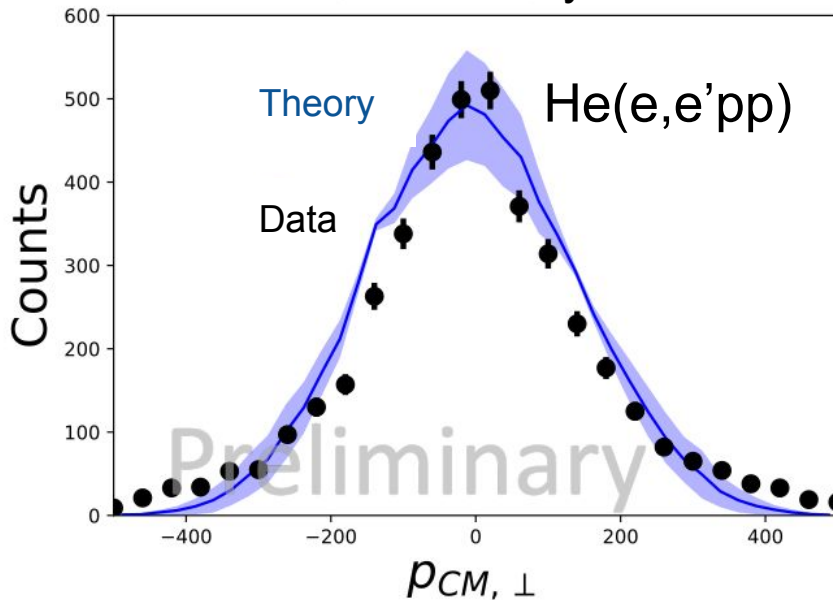
Center of
Mass Motion



CLAS6 Data

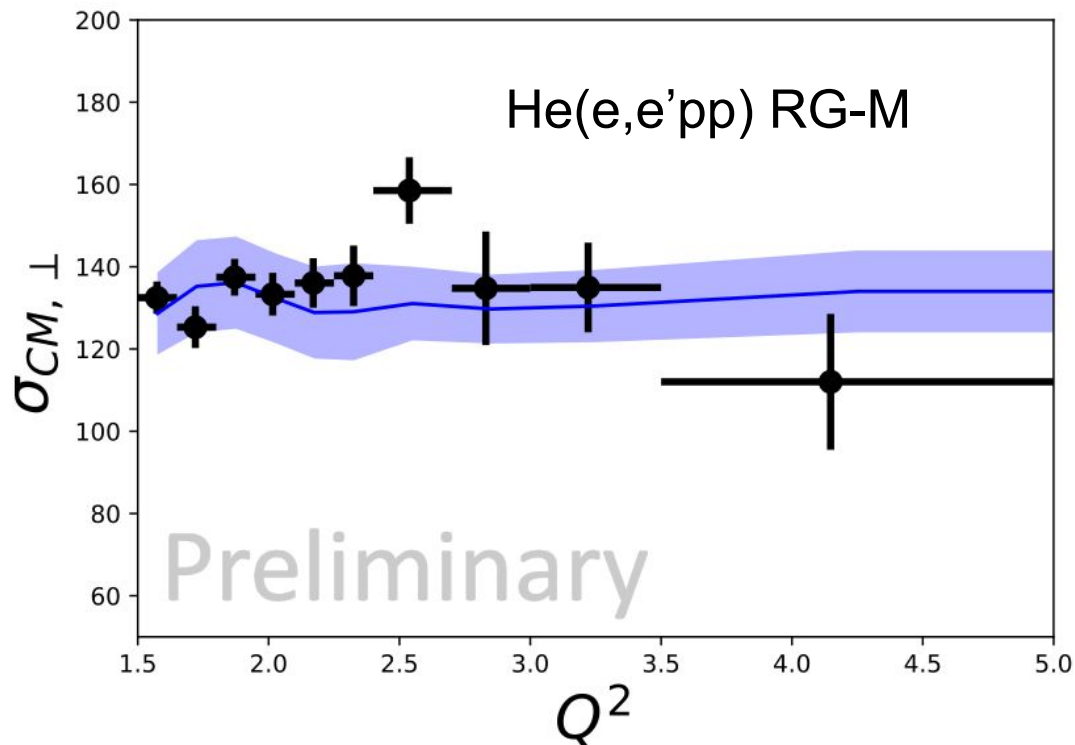
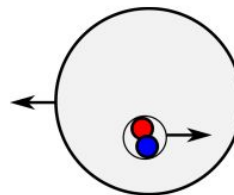


RG-M Preliminary Data

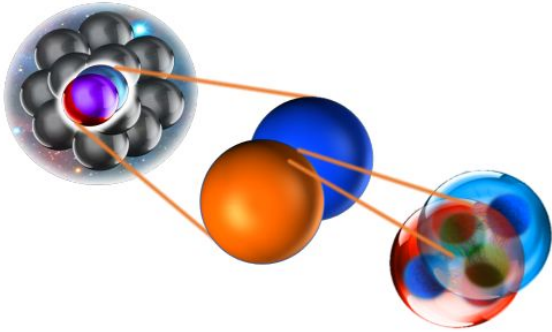


Scale independence

Center of
Mass Motion



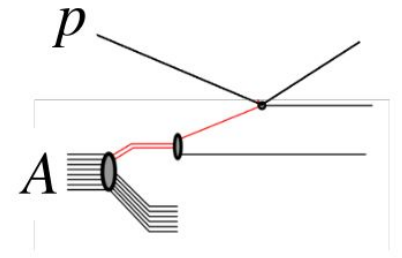
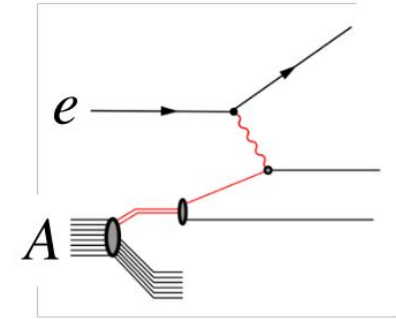
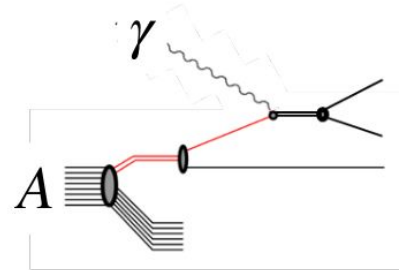
Scale

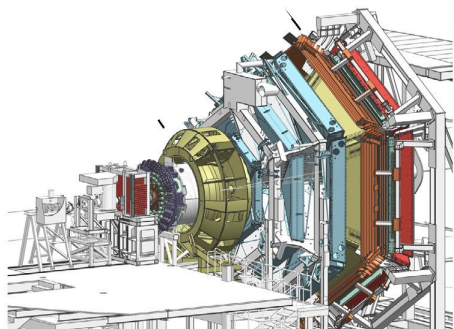
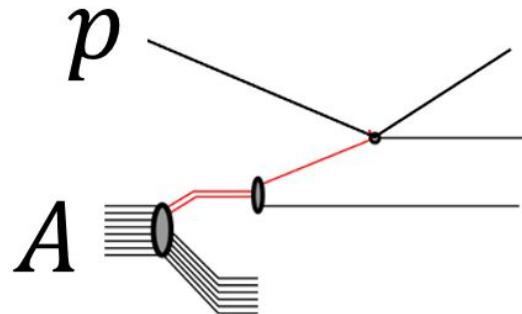
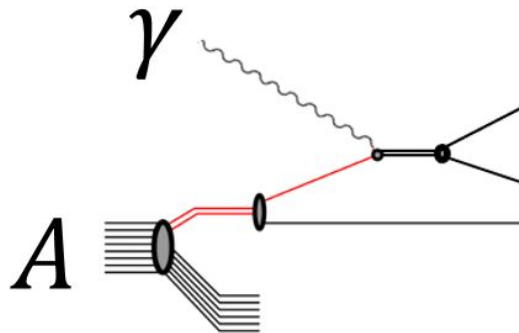
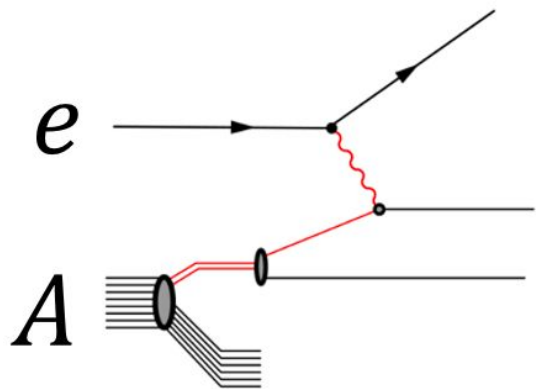


Change the resolution **scale**
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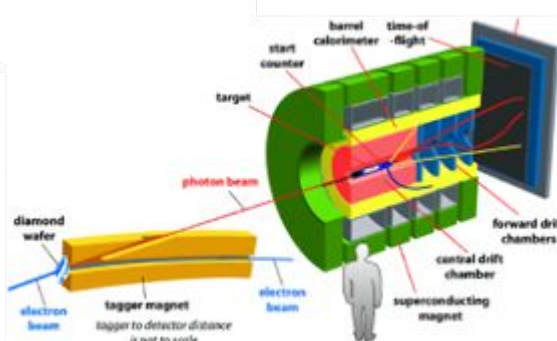
Probe

Compare different reactions
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Photoproduction

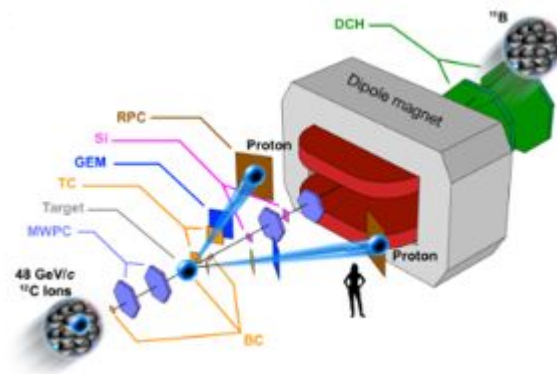




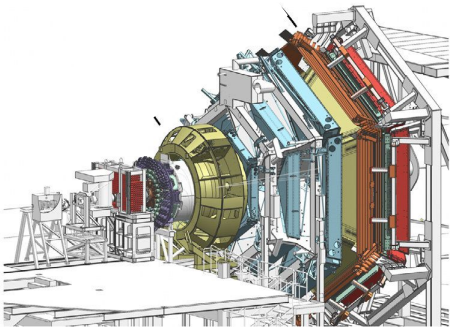
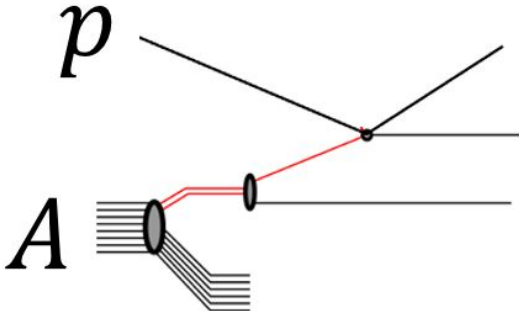
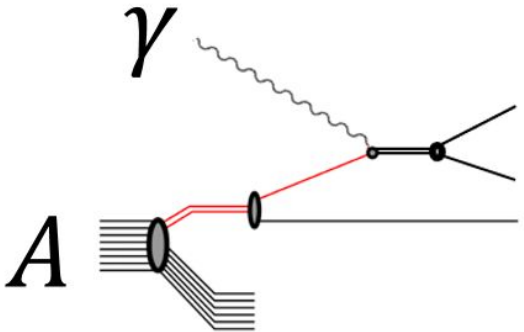
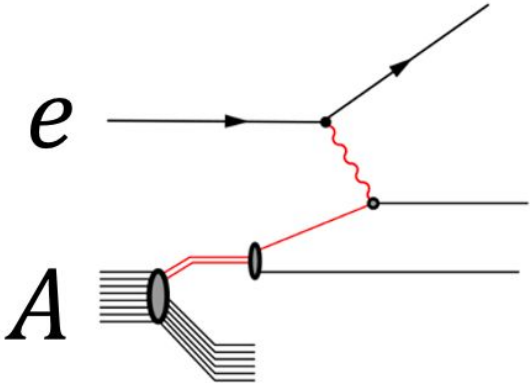
CLAS12/CLAS6



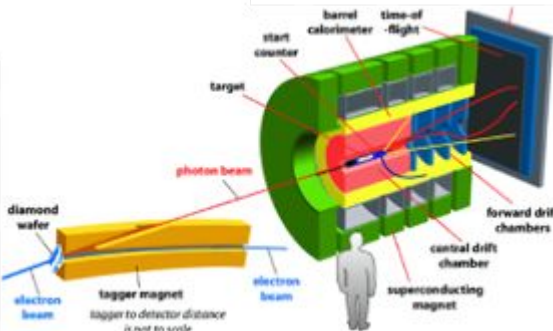
GLUEX (Hall-D)



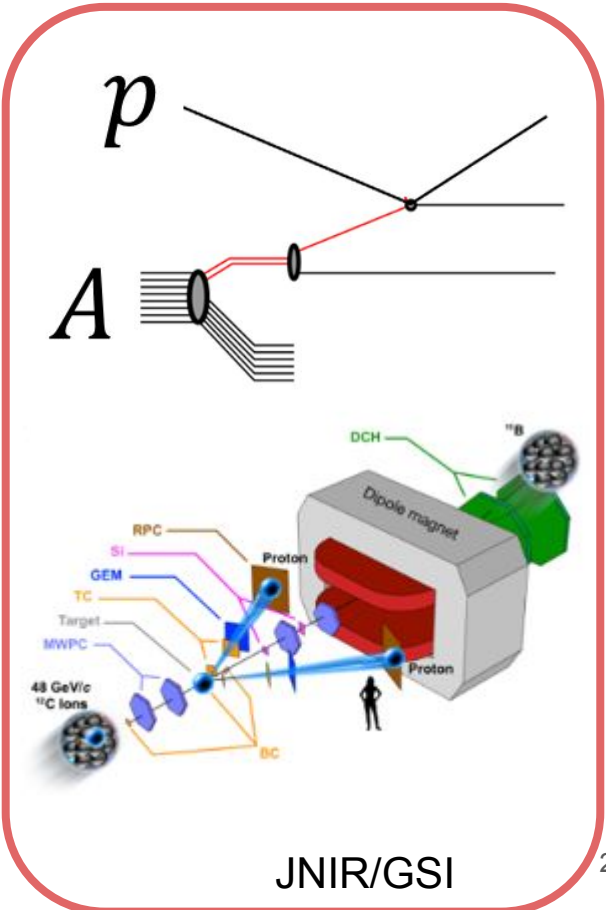
JNIR/GSI



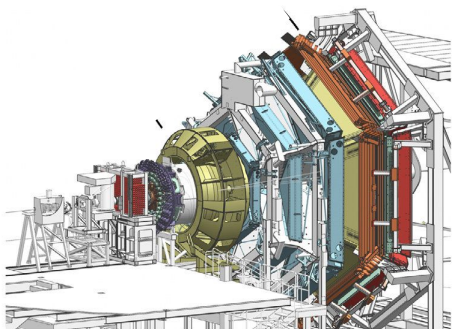
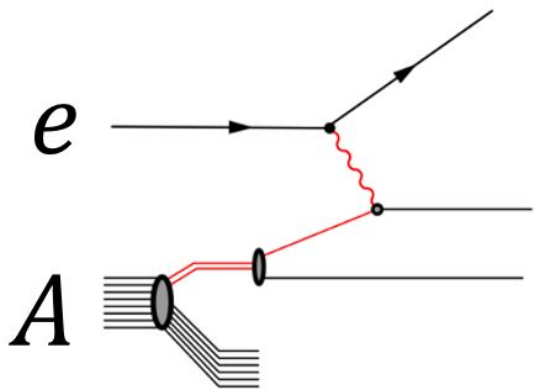
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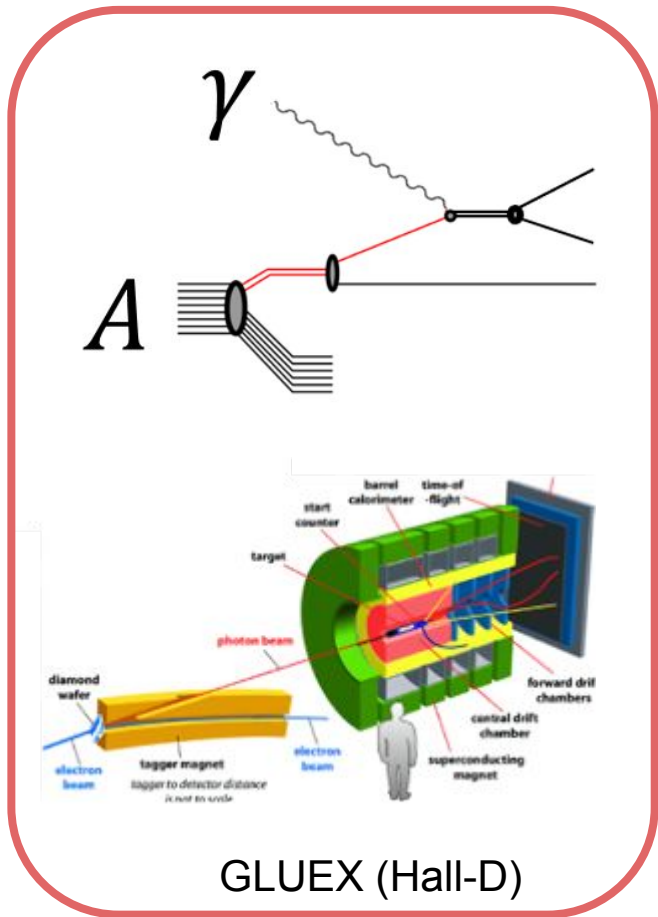
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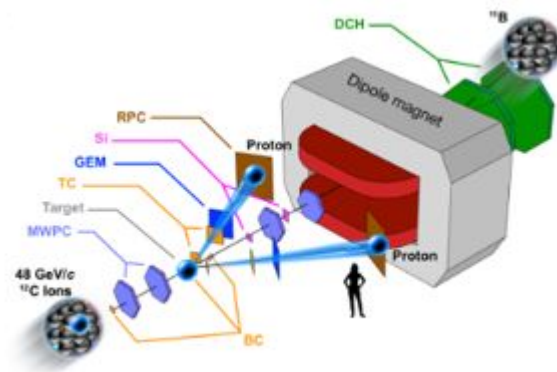
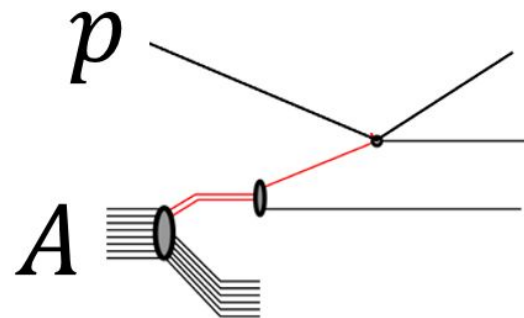
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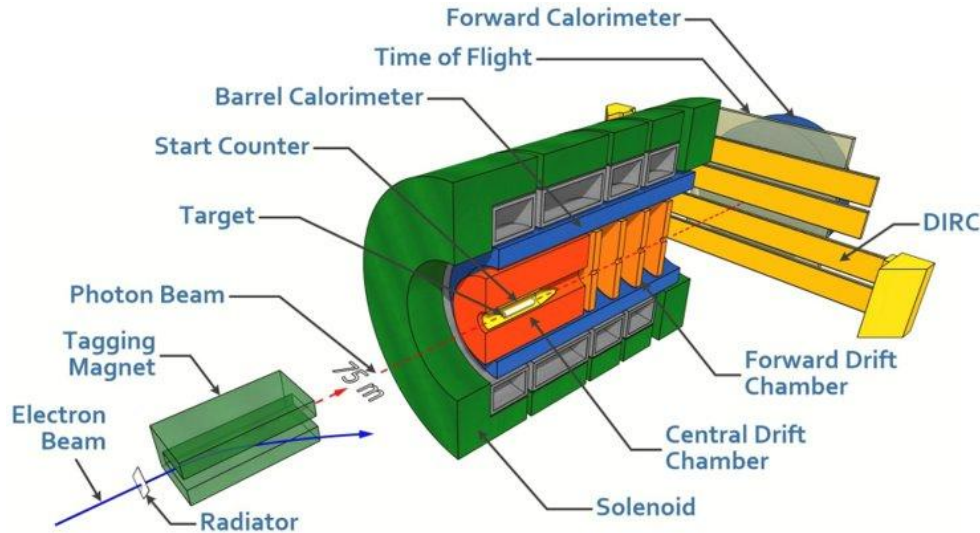


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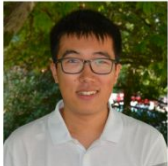


JNIR/GSI

SRC Photoproduction in Hall D

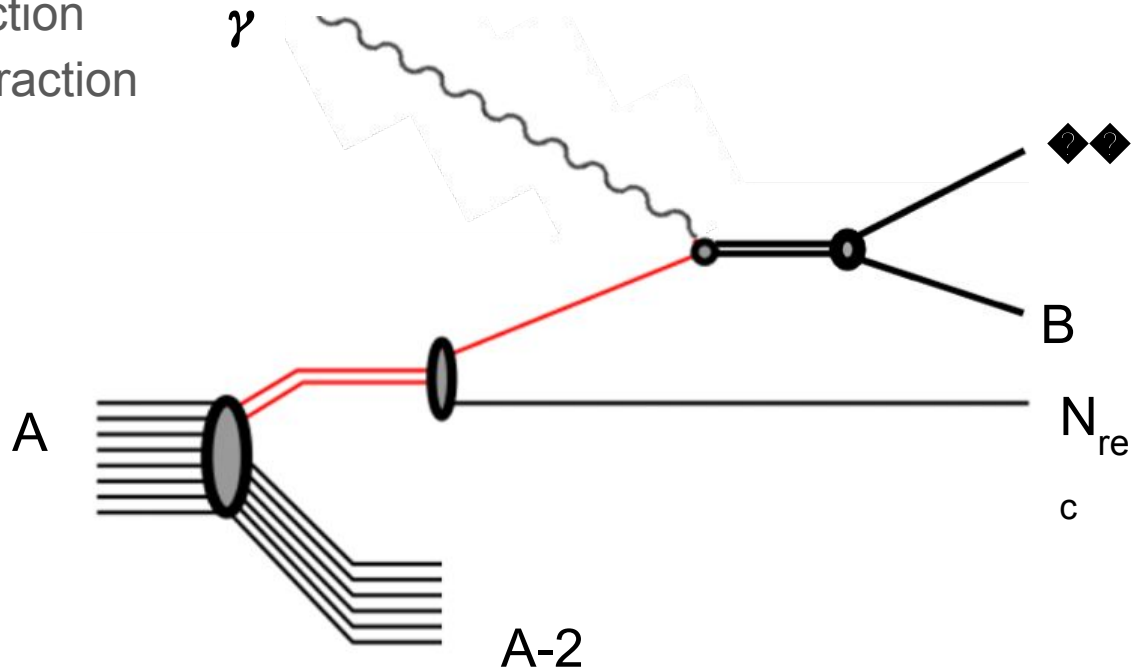


- Data taken in Fall 2021
- 10.8 GeV e- beam incident on diamond radiator
- Photon emitted via coherent bremsstrahlung
 - Scattered electron tagged
- D, He, C targets
- Particles detected in large acceptance GlueX spectrometer



SRC Photoproduction (Hall D)

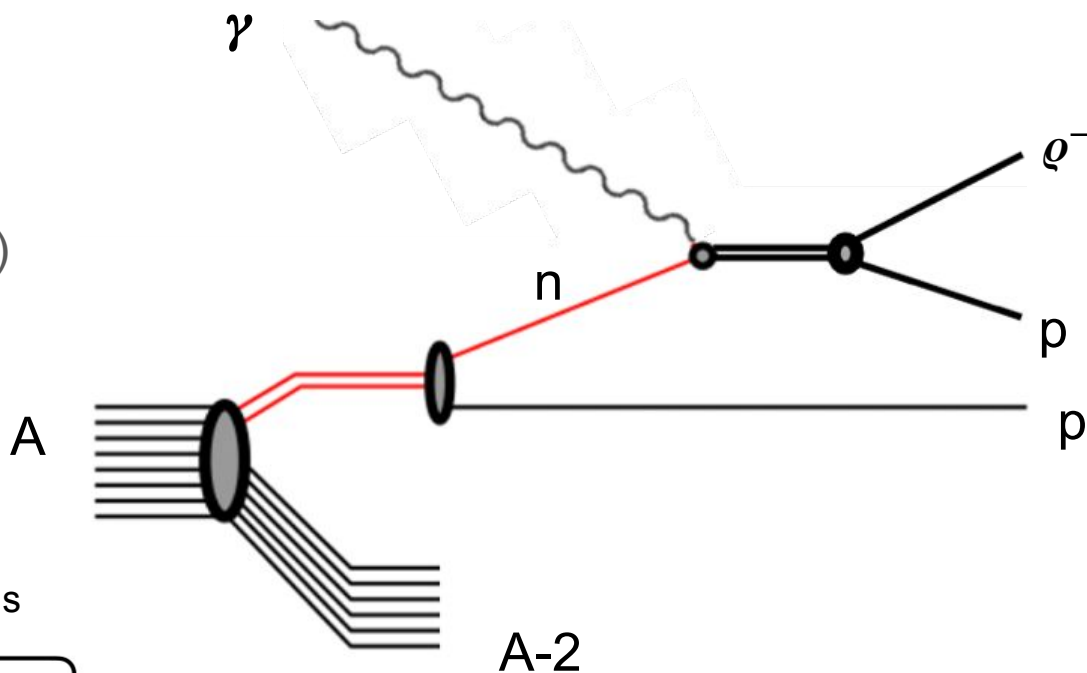
- Quasi-elastic photoproduction
- hard photon-nucleon interaction
- Many meson+baryon final-states are possible



SRC Photoproduction (Hall D)

- ρ^- photoproduction
- Initial state neutron
- $\rho^- \rightarrow \pi^- \pi^0$ decay

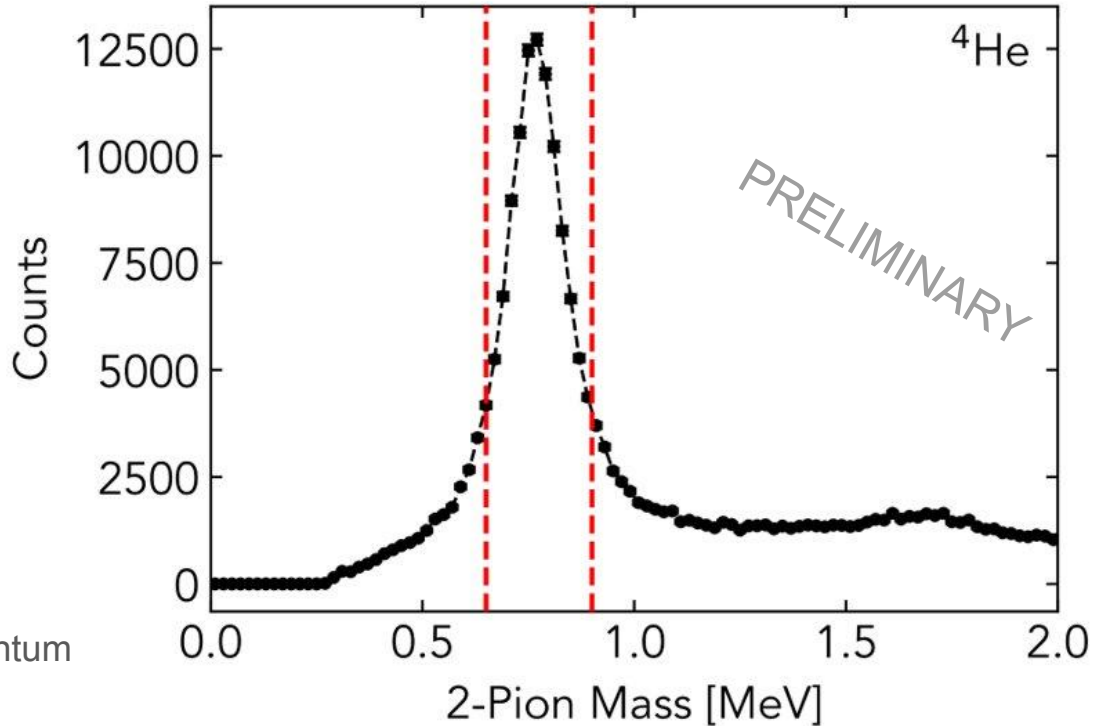
Exclusive detection of $(\gamma, \rho^- pp)$



Compare to PWIA + GCF calculations

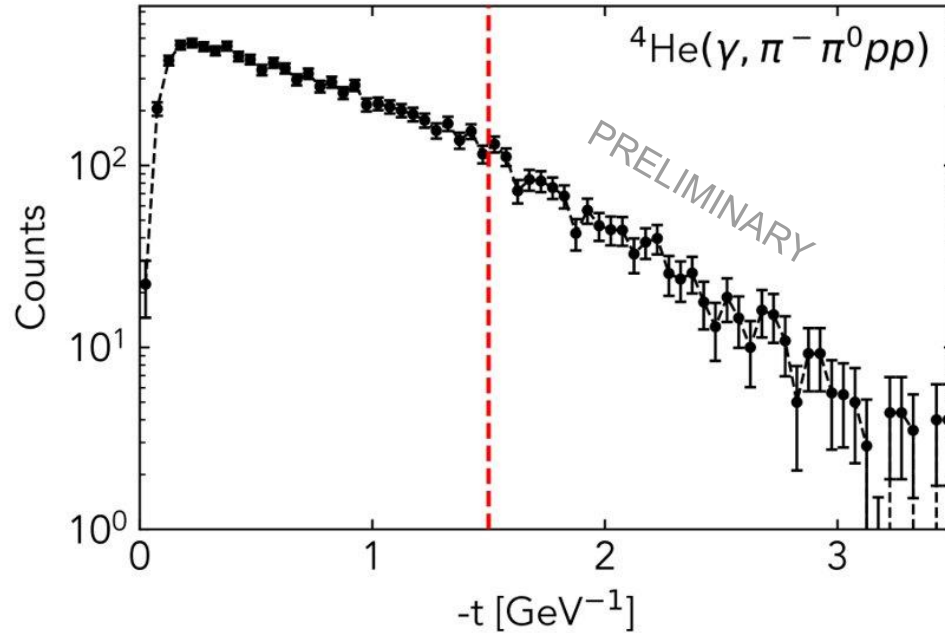
$$\sigma = \sigma(\gamma n \rightarrow \rho^- p) \times S(p_i, p_{rec})$$

SRC Event Selection



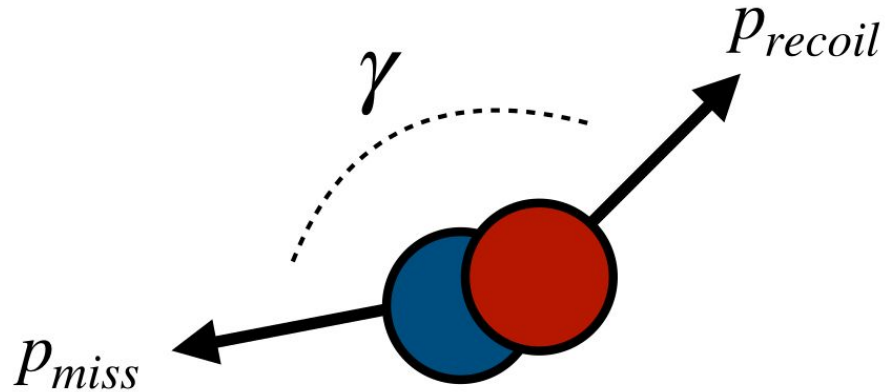
- High relative momentum
- ρ^- meson mass
- Background (diffractive) cuts

SRC Event Selection

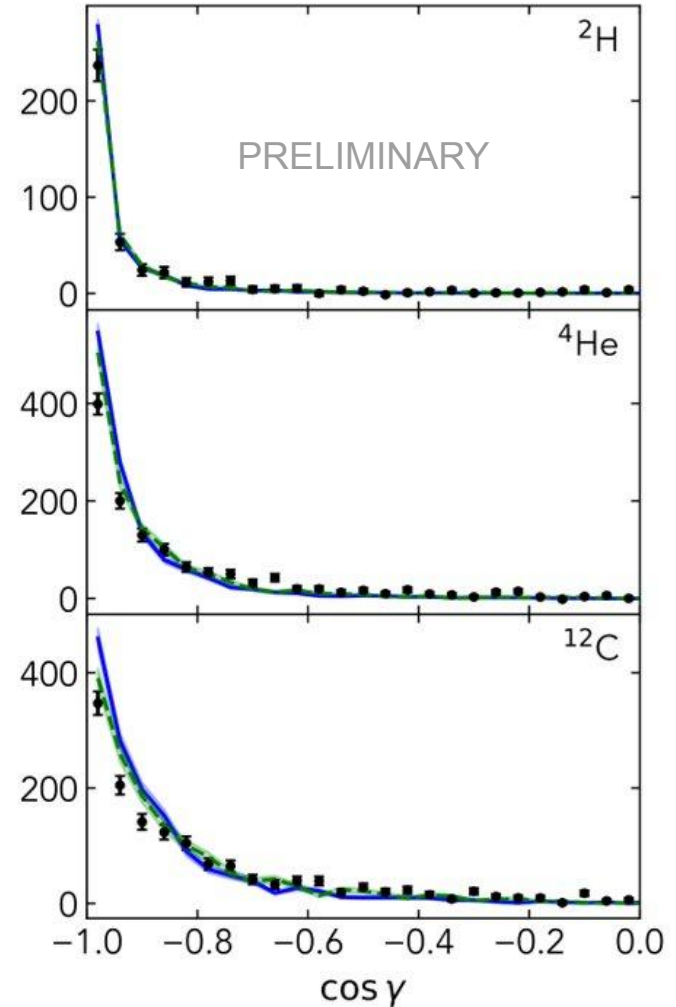


- High momentum-transfer $|t|, |u| > 1.5 \text{ GeV}^2$

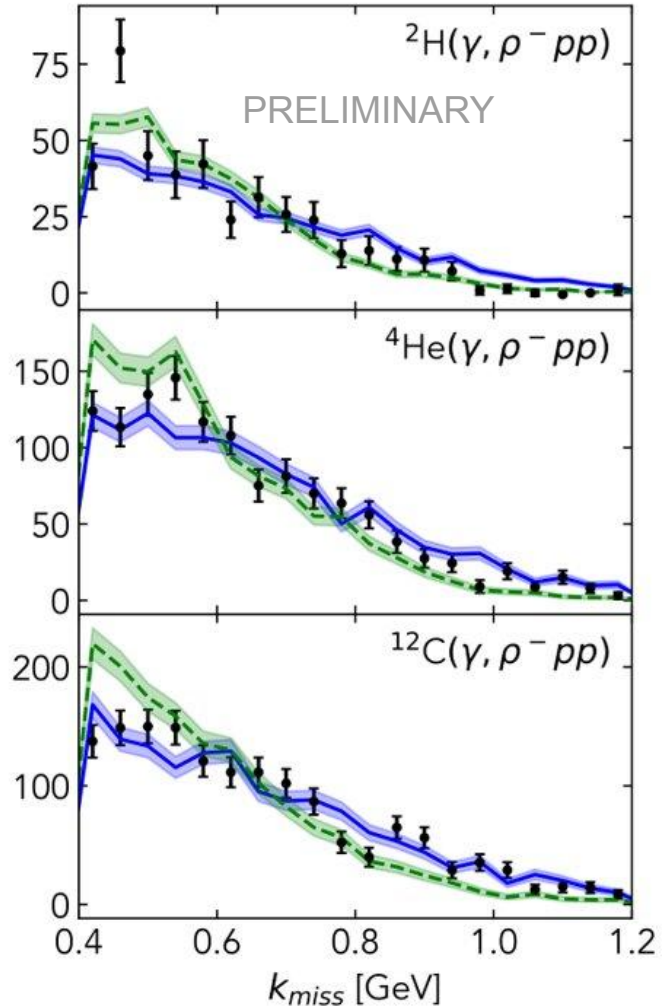
SRC Pair Opening Angle



- Reconstruct angle between initial-state neutron and spectator proton
- All nuclei show clear back-to-back correlation

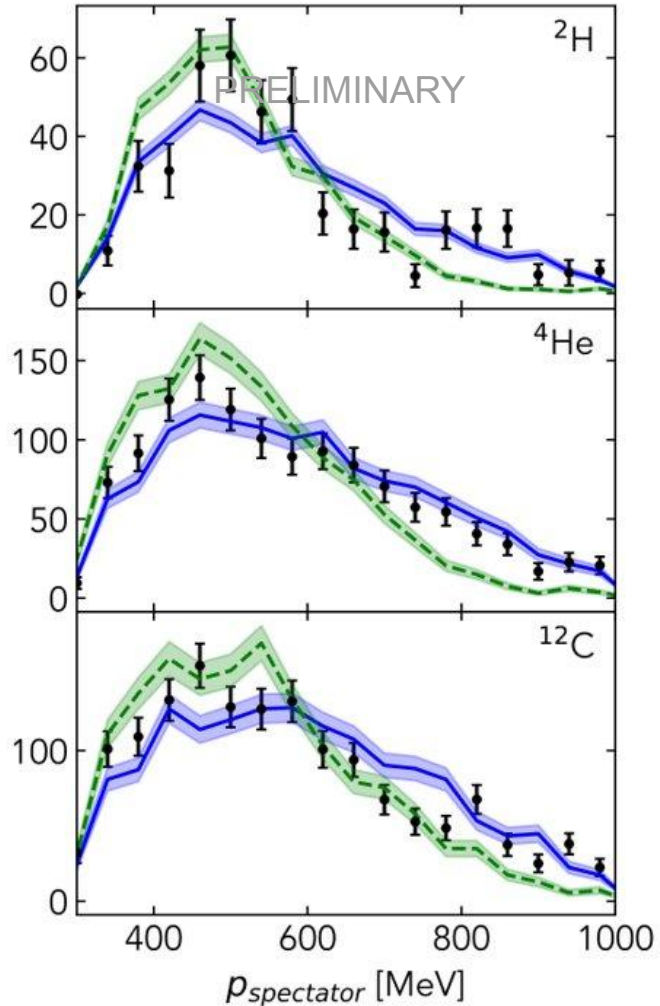


Initial Neutron Momentum



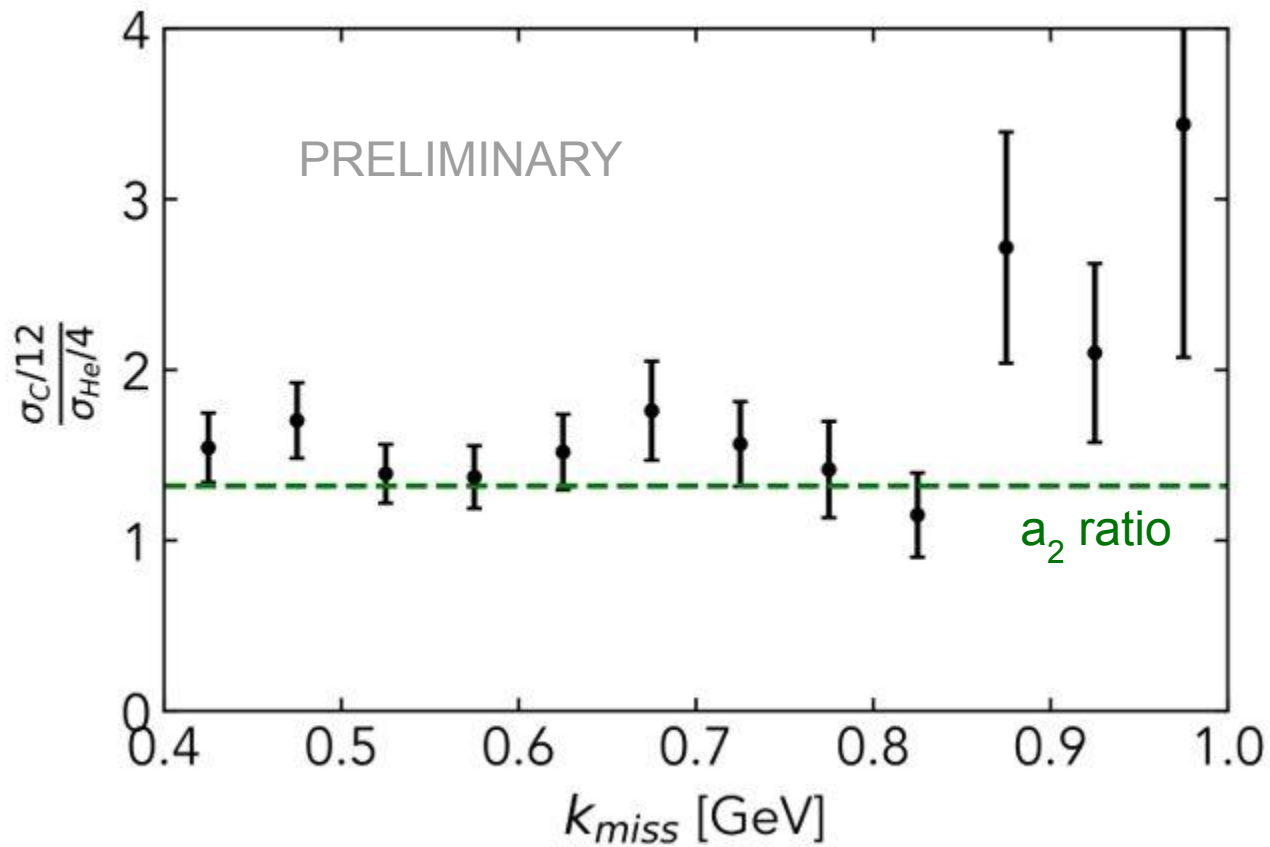
- Initial neutron momentum sensitive to short distance NN interaction
- Momentum distribution well described
- Agreement with AV18 predictions similar to that for electron-scattering data

Initial Proton Momentum

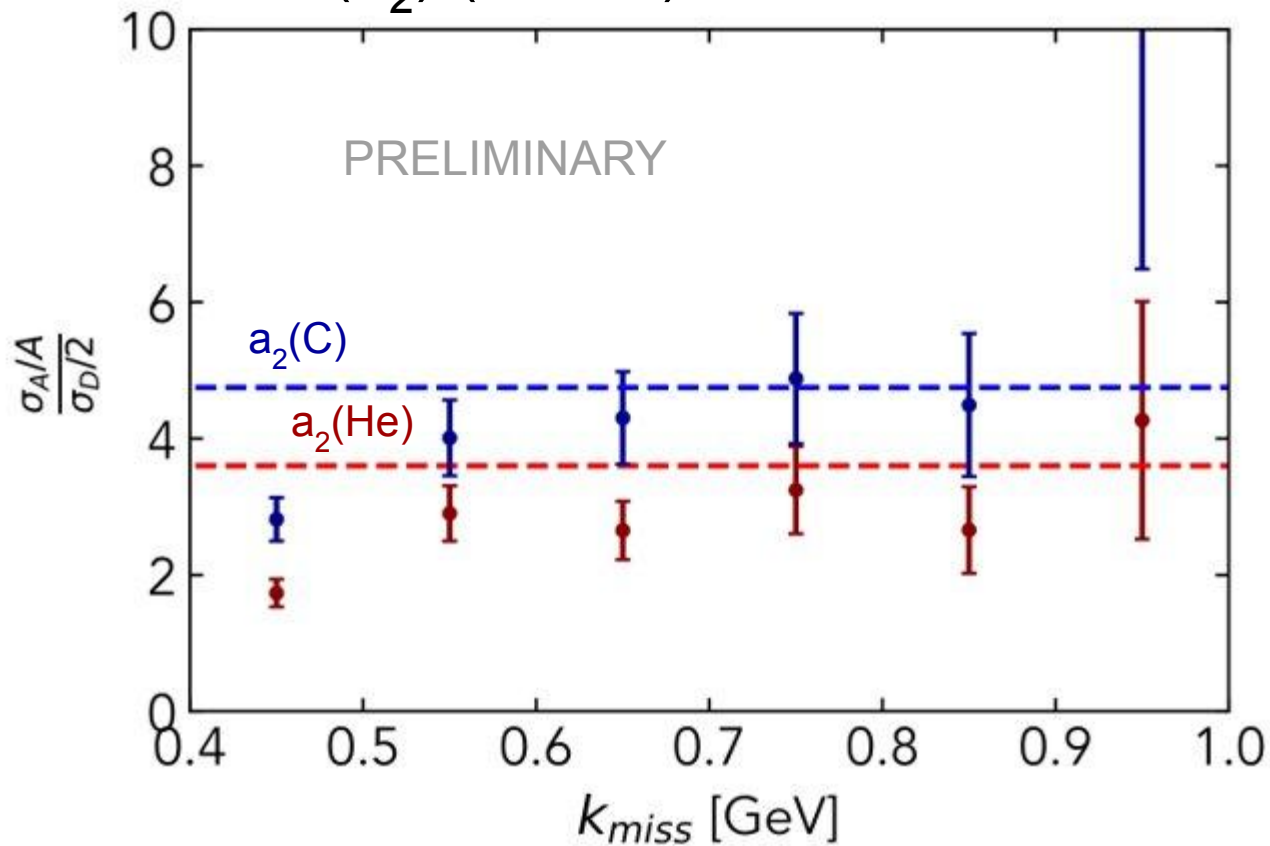


- Spectator momentum also well reconstructed but may be subject to rescattering
- Calculation of FSI using cascade models can help identify regions of large FSI

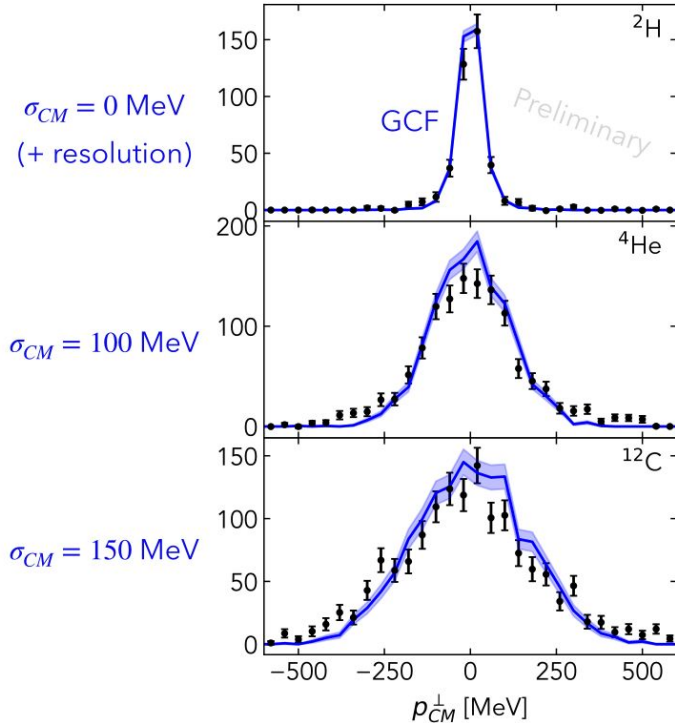
SRC Abundances (a_2 ratio) (Hall-D)



SRC Abundances (a_2) (Hall D)

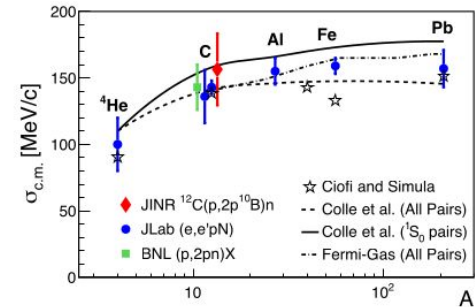


Center of Mass Motion



- Transverse C.M. component minimized
- FSI and other effects
- General trends agree with A but more detailed analysis need to be done

GCF Input

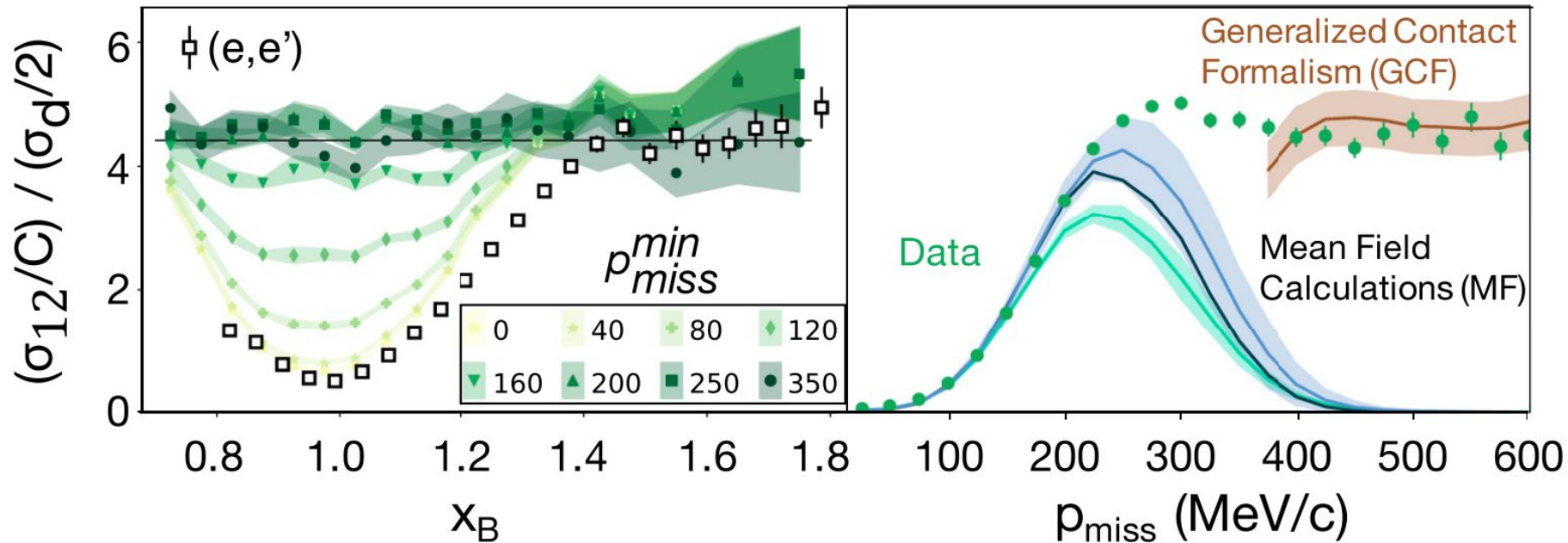


Conclusions

- Preliminary results indicate SRC observables exhibit scale and probe universality
- Further analysis precision SRC studies (inclusive, semi-inclusive, exclusive)
- Looking forward to possibly exclusive measurements of 3N SRCs
- Lots of data to analyze and work to be done

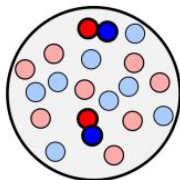
Thank you!

Backup Slides



next generation questions...

Pair Abundance

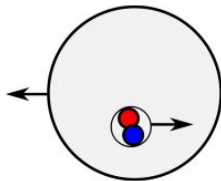


Where are pairs formed?

Which nucleons pair?

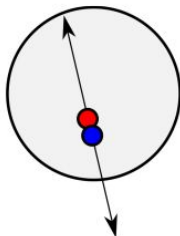
Do 3N SRC exist?

Center of
Mass Motion



Precision COM measurements

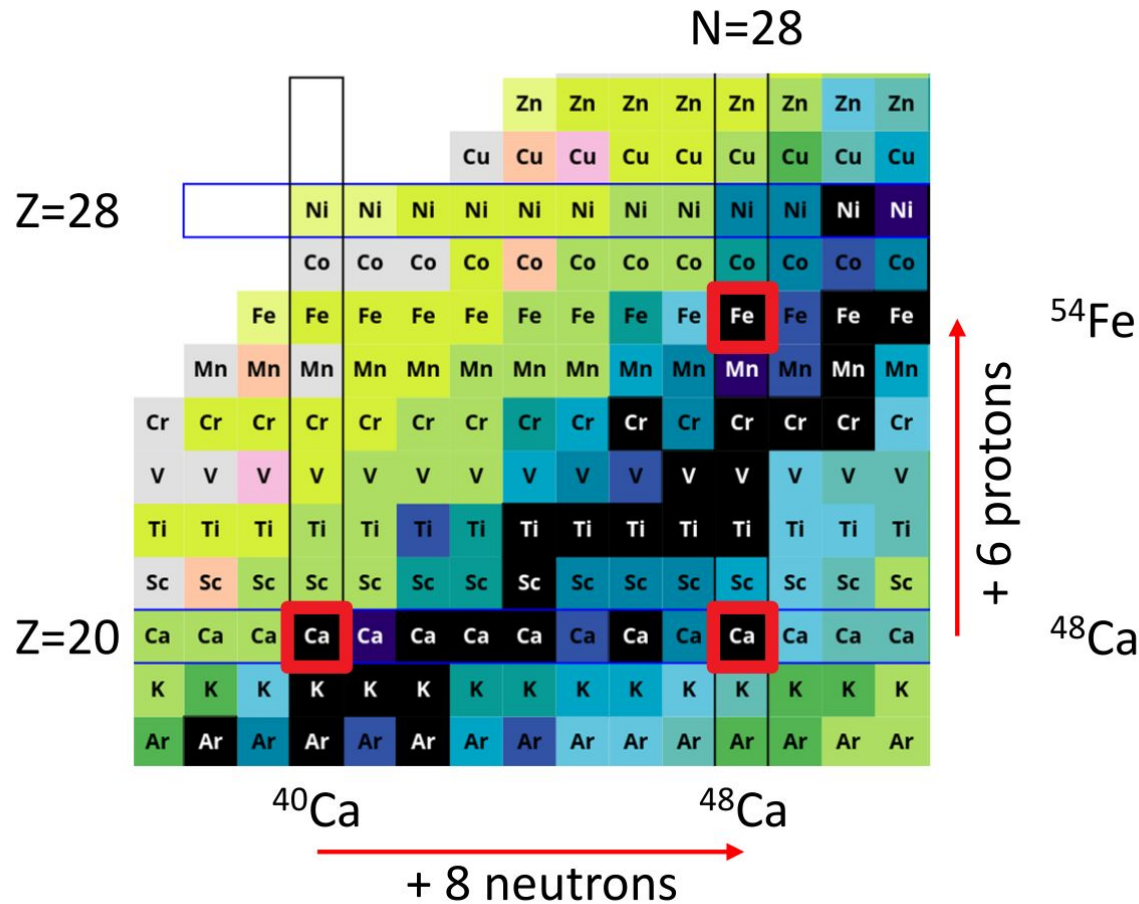
Pair Interaction

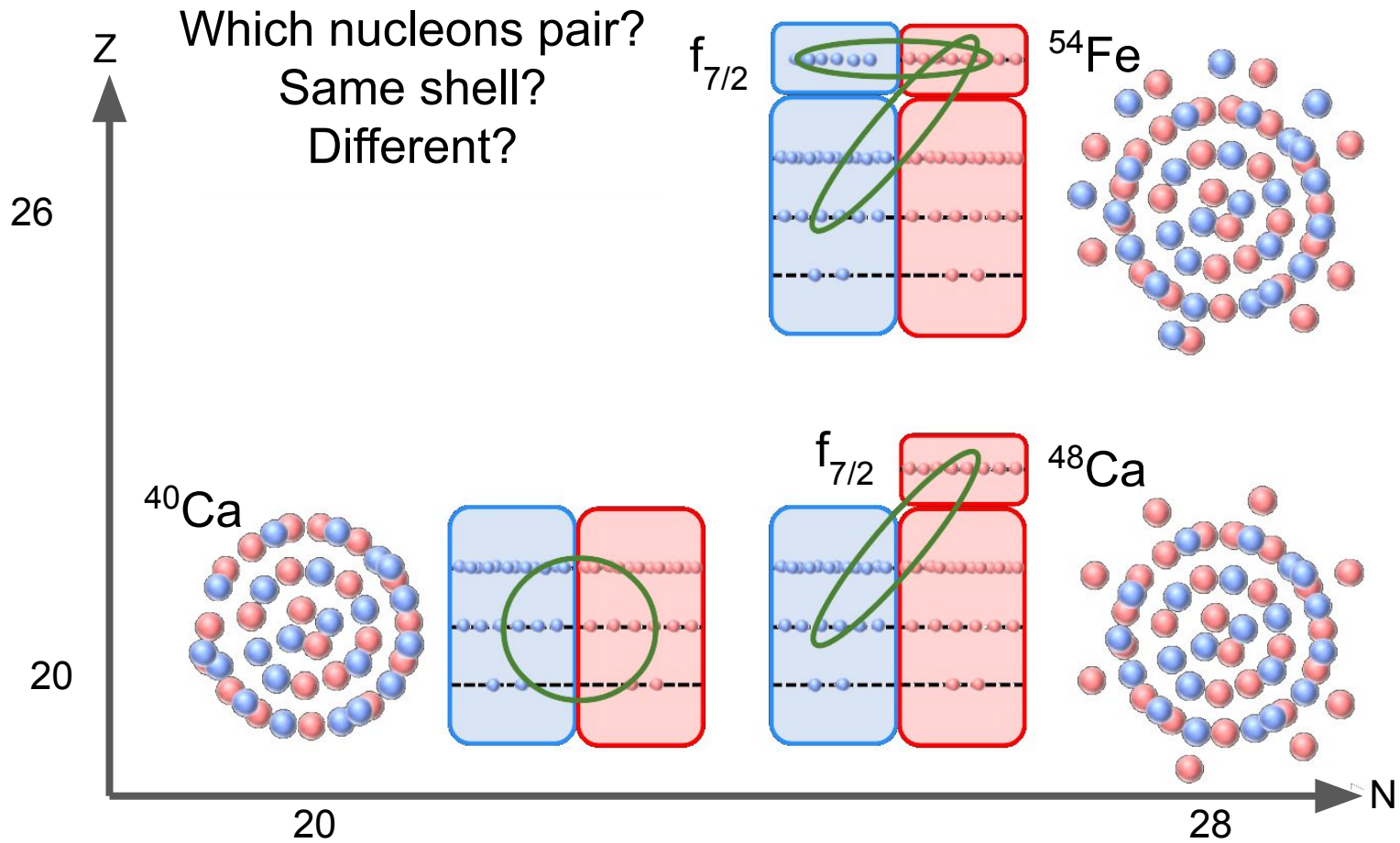


Precision NN interaction at short distances

Scale (Q^2) independence of SRC observables

SRC in Asymmetric Nuclei CaFe Exp. (Hall C)

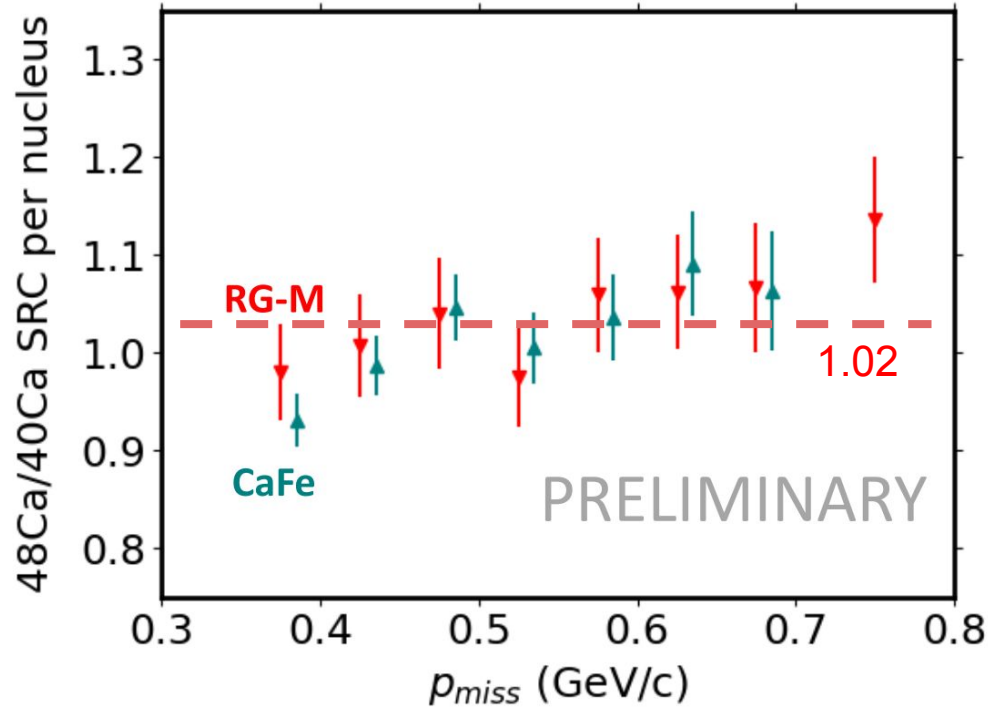




CaFe and RG-M

- CaFe (Hall C)
 - 11 GeV: ^9Be , ^{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 (Hall B)
 - 6 GeV : C, ^{40}Ca , ^{48}Ca , ^{120}Sn
 - CLAS12
 - (e,e'p), (e,e'pN)

RG-M and CaFe Agreement

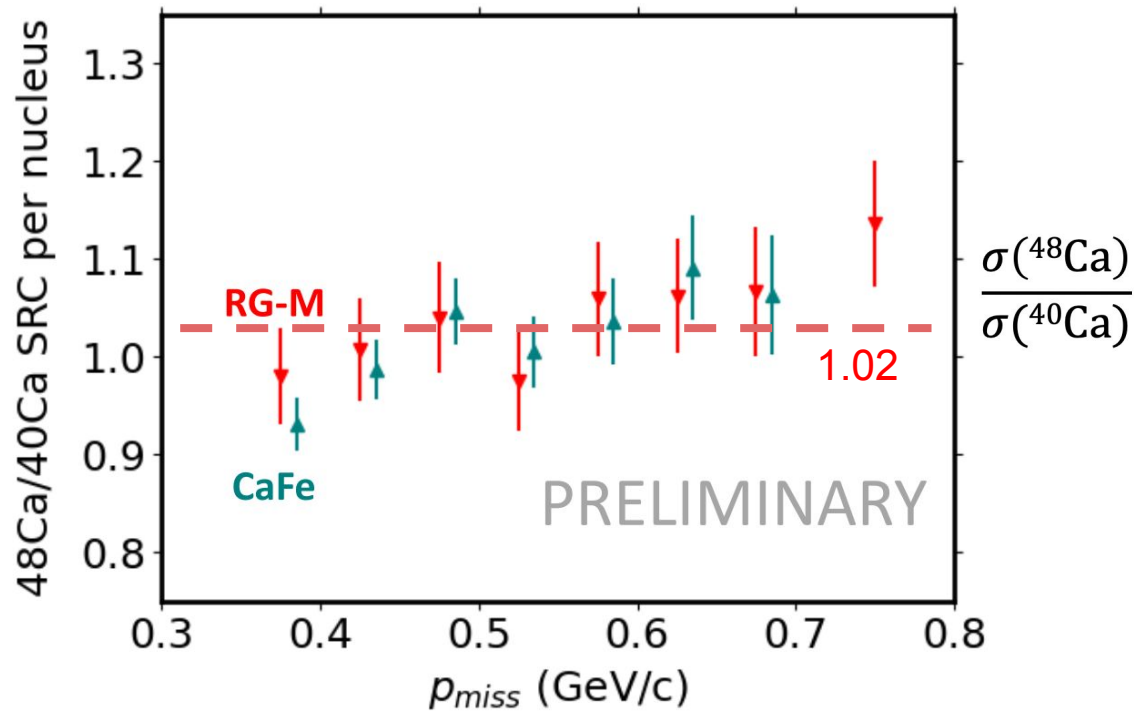


PRELIMINARY No systematic errors.	Integrated Ratios $^{48}\text{Ca}/^{40}\text{Ca}$ SRC per proton
RG-M (Hall B)	1.03 (2)
CaFe (Hall C)	1.02 (1)

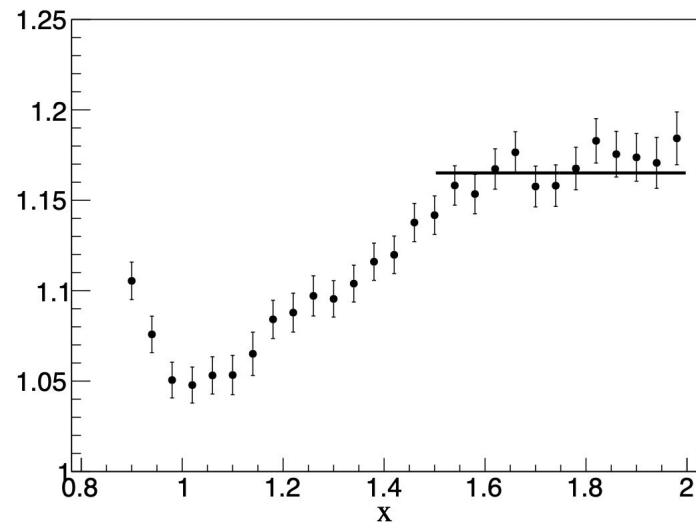
CaFe:
Carlos Yero (ODU)
Dien Nguyen (JLAB)

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

(e,e') and (e,e'p) disagreement?

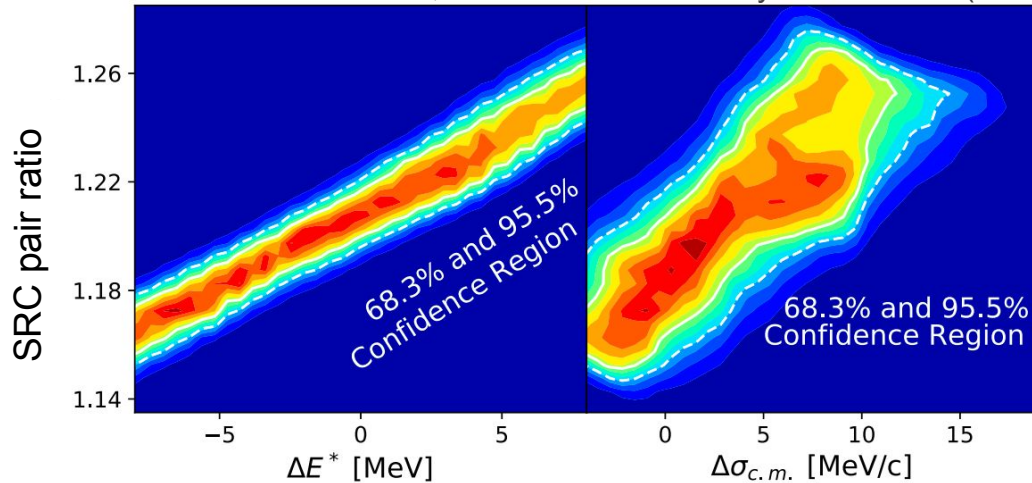


D. Nguyen et al. Phys Rev. C 102 (2020)

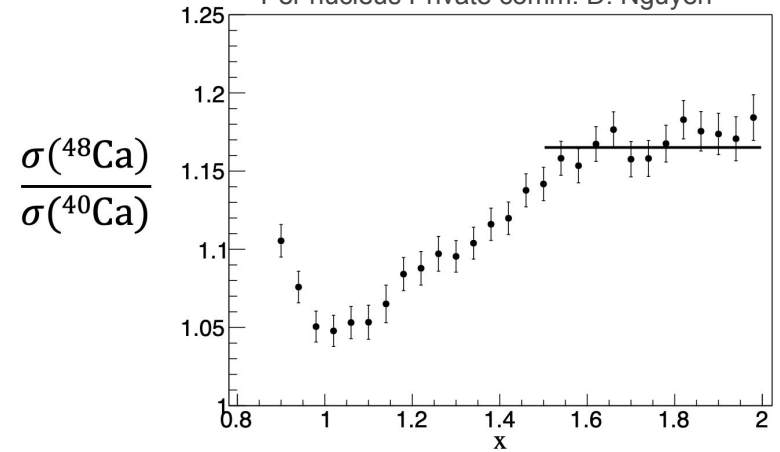


(e,e') cross section ratio is NOT the SRC pair ratio!

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



D. Nguyen et al. Phys Rev. C 102 (2020)
Per nucleus Private comm. D. Nguyen



Varying model parameters changes SRC pair ratio by 10%
(e,e') measures (np, pp, nn) pairs