# RG-M Analysis Update

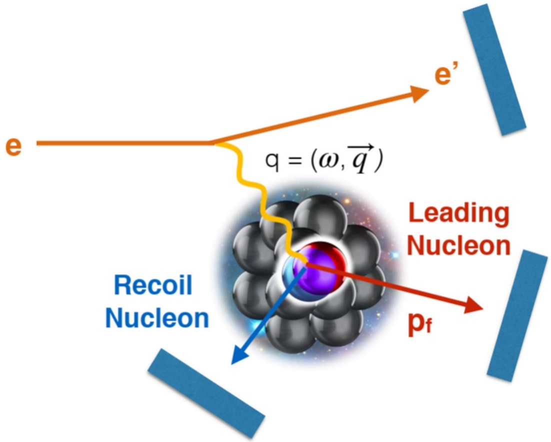
Andrew Denniston (MIT)

# Overview

- Run Group M Introduction
- Low Level Analysis
- Physics Analyses
  - Short Range Correlations (SRCs)
  - Electrons for Neutrinos (e4v)

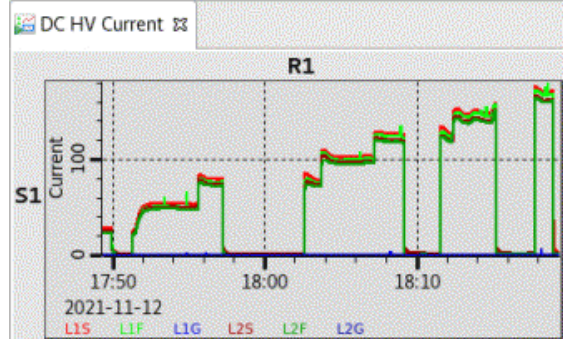
# RG-M Experiment at CLAS12

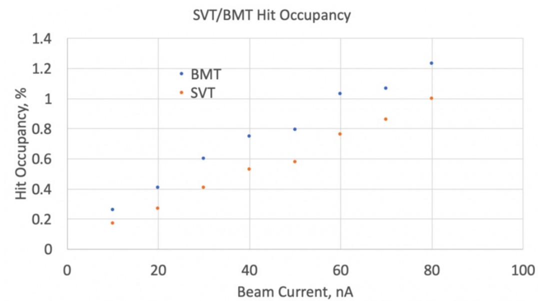
- November 2021 – February 2022
- Fully cooked production runs
- 2, 4, and 6 Gev Beam Energies
- H, D, He, C, 40Ca, 48Ca, Ar, and Sn

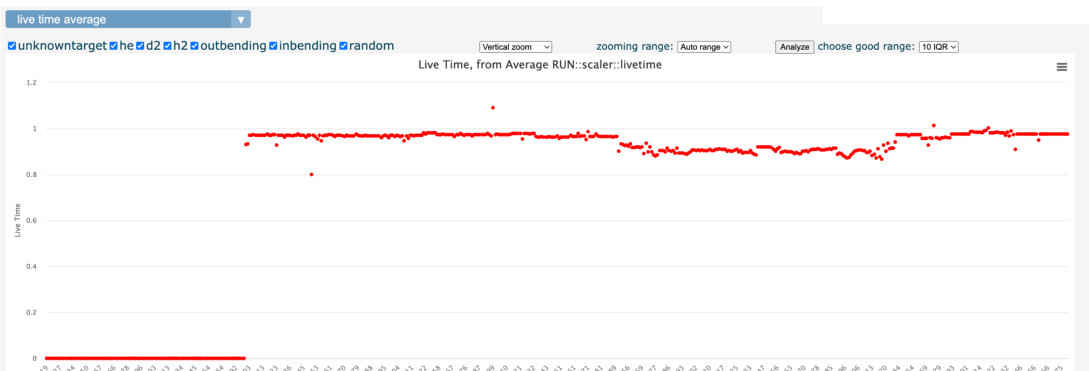
# RGM Tasks

- Cook luminosity scans and empty target runs.
- Recover collected charge for H, D, and He targets.



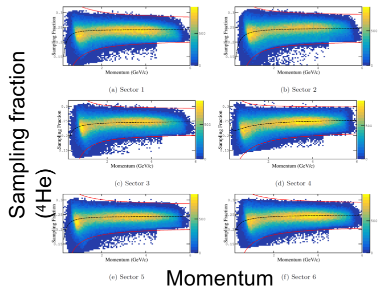

Live Time

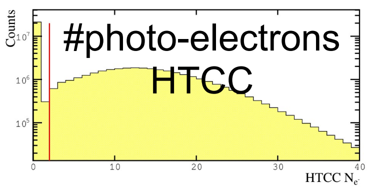



Run Number

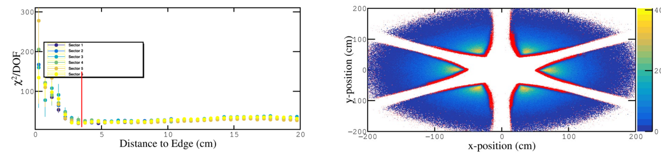
# Particle ID for Electrons in 6 GeV data

(charge, HTCC photo-electrons, ΔE(PCal), Sampling fraction)

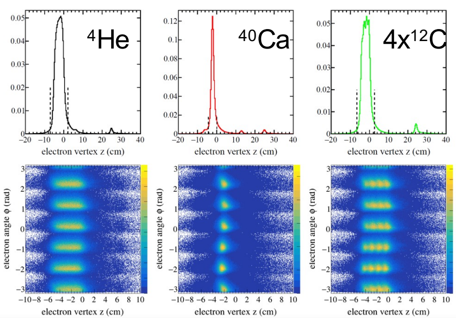



Fiducial Cuts

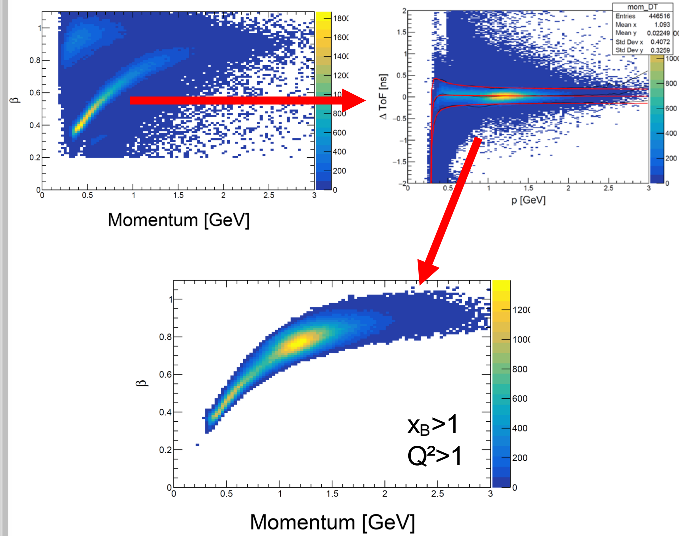



z Vertex

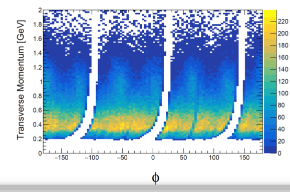


# Particle ID for Protons in 6 GeV data

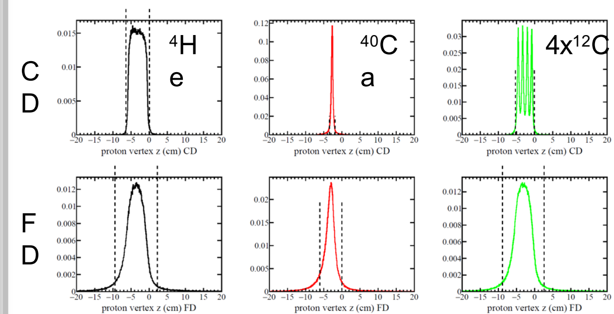
## Central detector ID in ΔToF (=measured - expected)




## Fiducial Cuts




## z Vertex



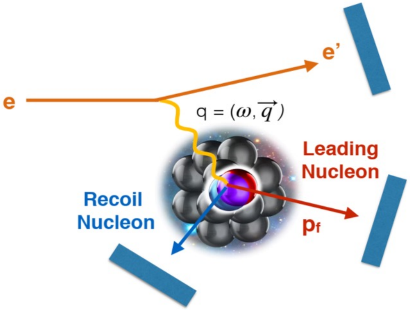
# Particle ID for 6 GeV data

RG-M Analysis Note: 6 GeV electron proton selection and Particle ID

Andrew Denniston[1], Justin Estee[1], Julian Kahlbow[1], and Erin Marshall Seroka[2]

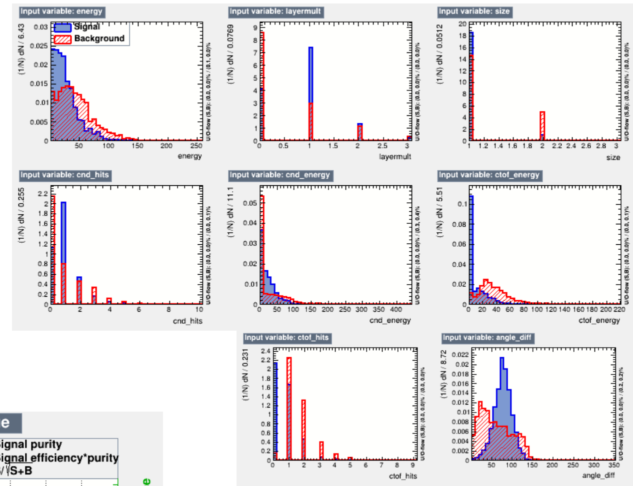
[1]Department of Physics, Massachusetts Institute of Technology
[2]Department of Physics, The George Washington University

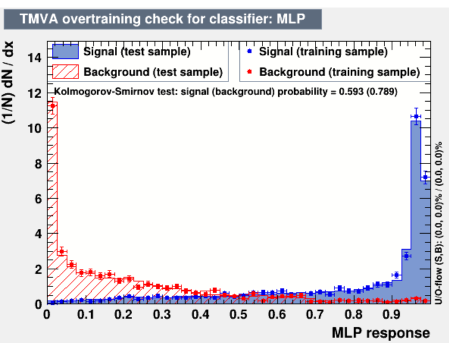
→ Working on second round of comments.

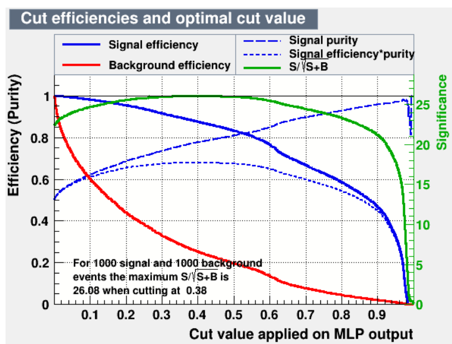


# Particle ID for Neutrons in 6 GeV data

- Received extensive comments on machine learning neutron algorithm in analysis note.
- We have new personnel addressing our neutron algorithm.

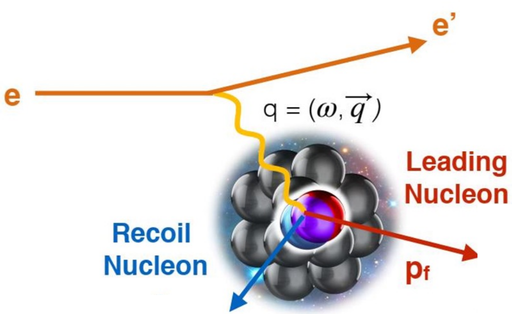


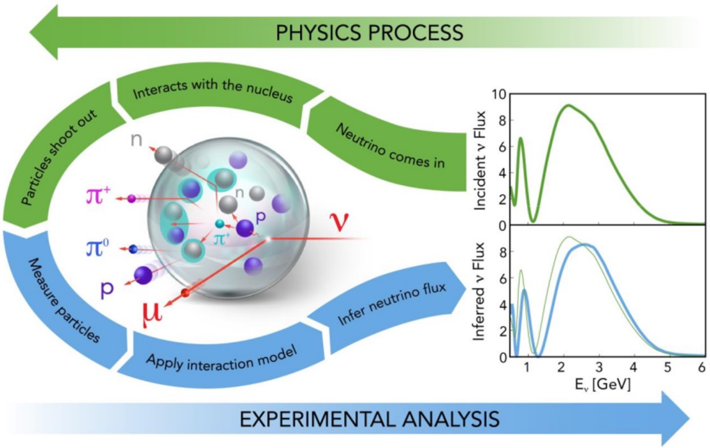
# Run Group-M Proposals

Short Range Correlations




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

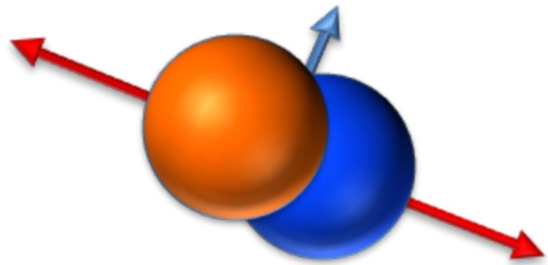
Electrons for Neutrinos (e4$\nu$)



Short range, short lived,
highly correlated pairs

r-space

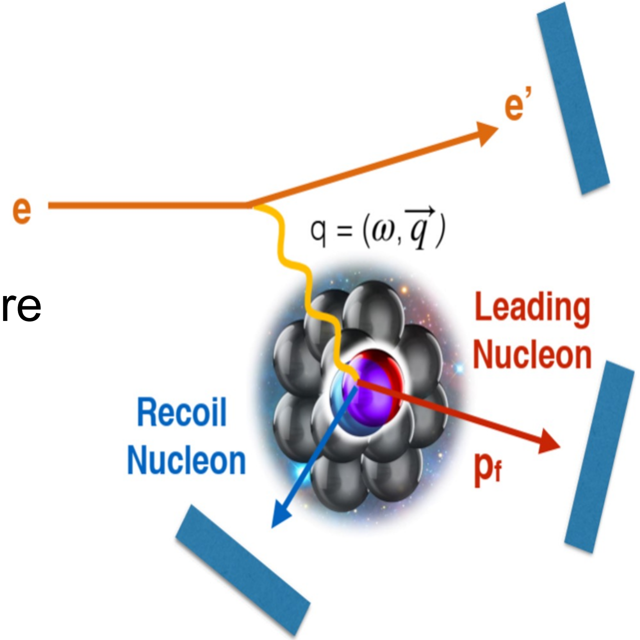
High relative momentum
Low center of mass momentum



k-space

# SRCs Goals with CLAS

- Compare old CLAS6 results with RGM results (30X the statistics).
- Verify that our observables are probe independent.
- Determine how SRCs are formed.

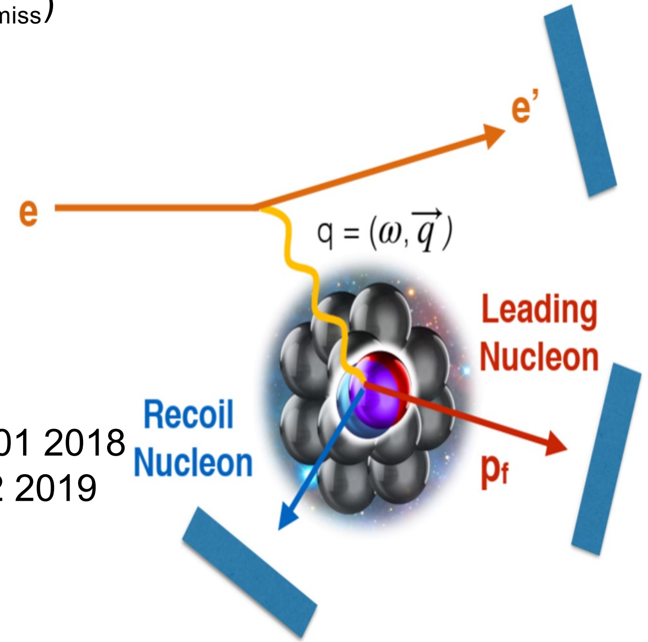


# SRC Cuts

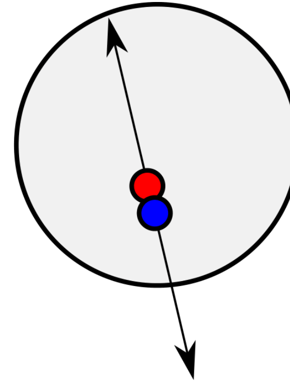
- $x_B > 1.3$
- $Q^2 > 1.5$
- $p_{lead} > 1$ GeV/c
- 0.8 GeV/c² $< M_{miss} <$ Cut($x_B$,$p_{miss}$)
- 0.4 GeV/c $< p_{miss} <$ 1.0 GeV/c
- $|p|/|q| < 0.96$

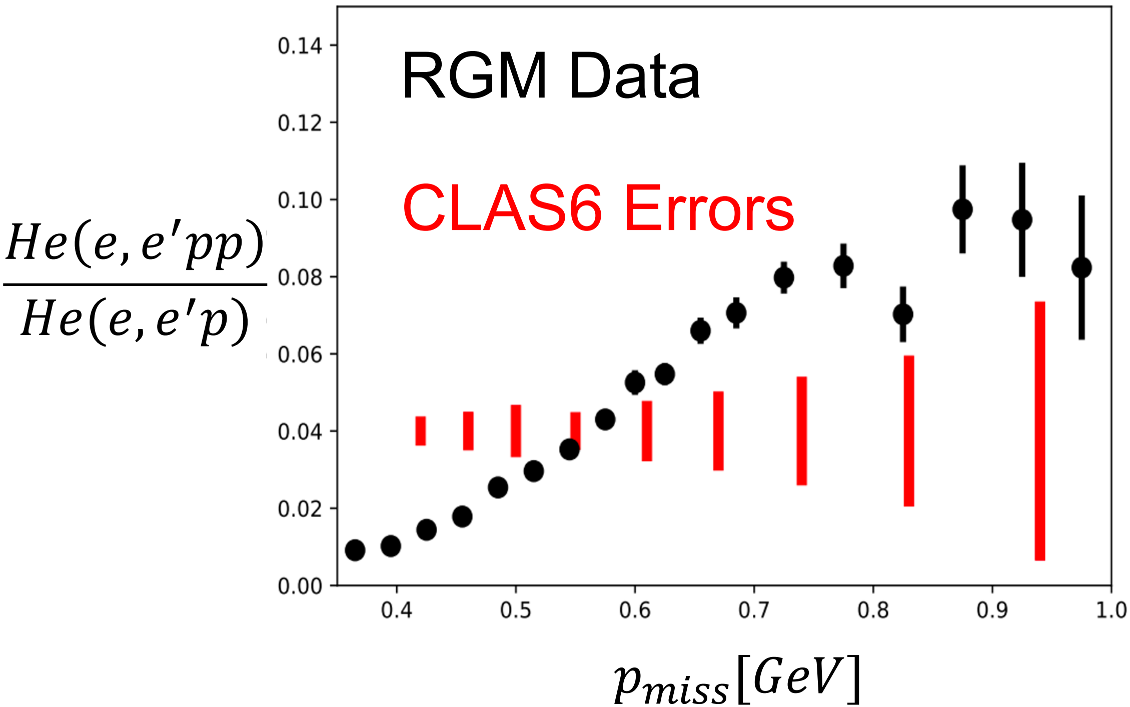
Derived From the CLAS6 Analysis Cuts:

- Physics Letters B 722 (2013) 63–68
- Science 346, 614 (2014)
- Nature 560, 617–621 (2018)
- Physics Letters B 797 (2019) 134792
- Cohen et al. Phys. Rev. Lett. 121, 092501 2018
- Duer et al. Phys. Rev. Lett. 122, 172502 2019

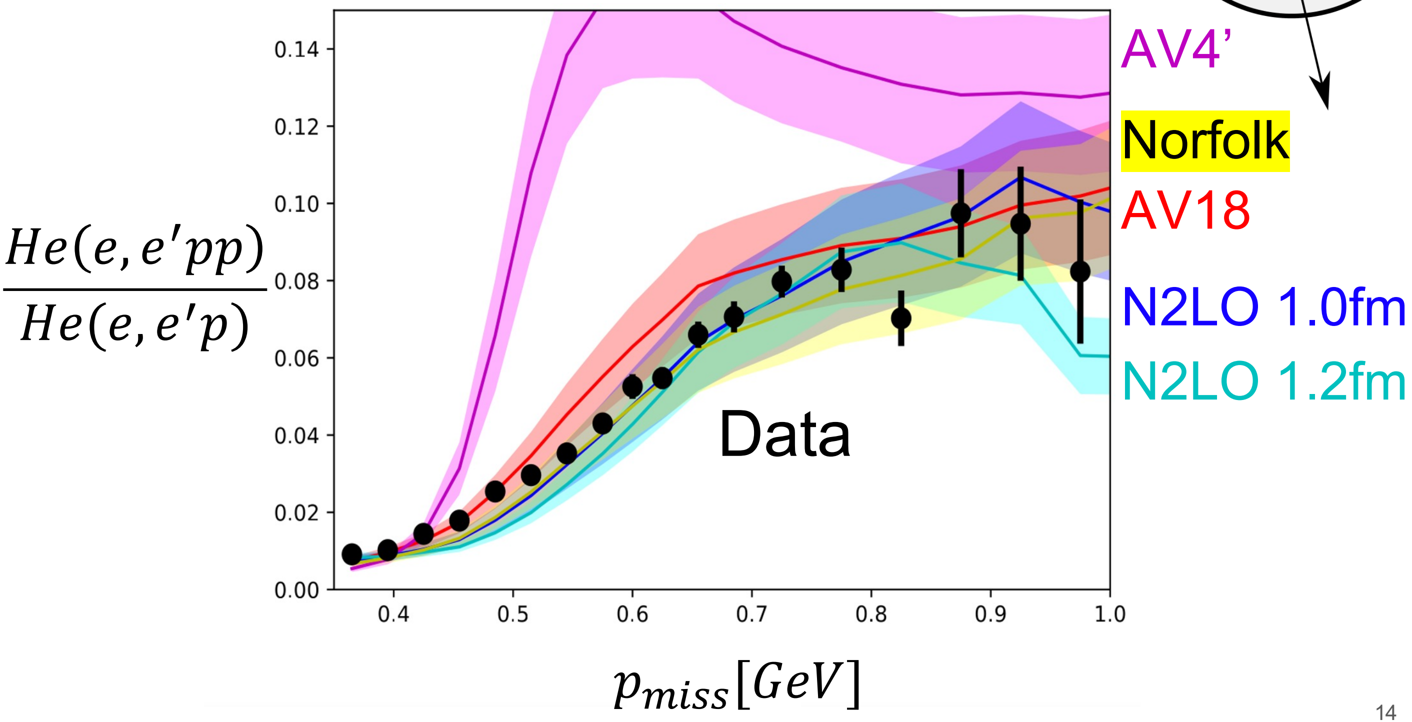


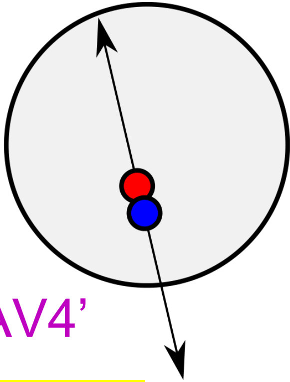
# Precision NN interaction



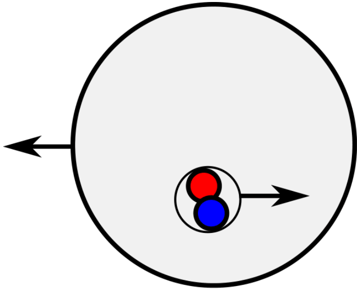


# Precision NN interaction

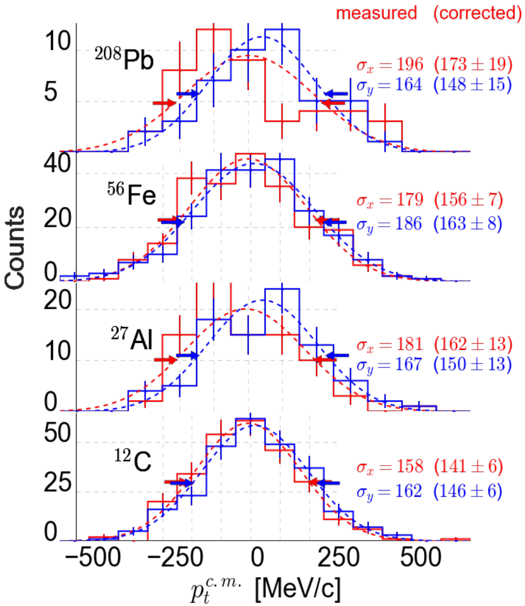


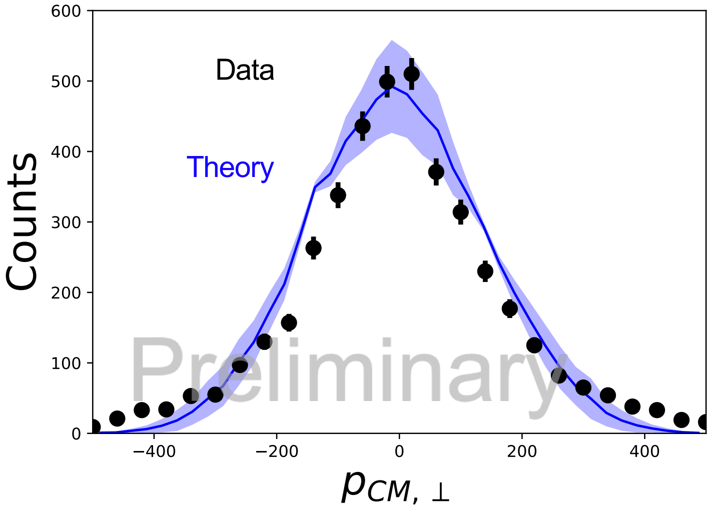
# Center of Mass Motion



## CLAS6 Data




## RGM Helium




- Cohen, PRL (2018)

# SRCs Goals with CLAS

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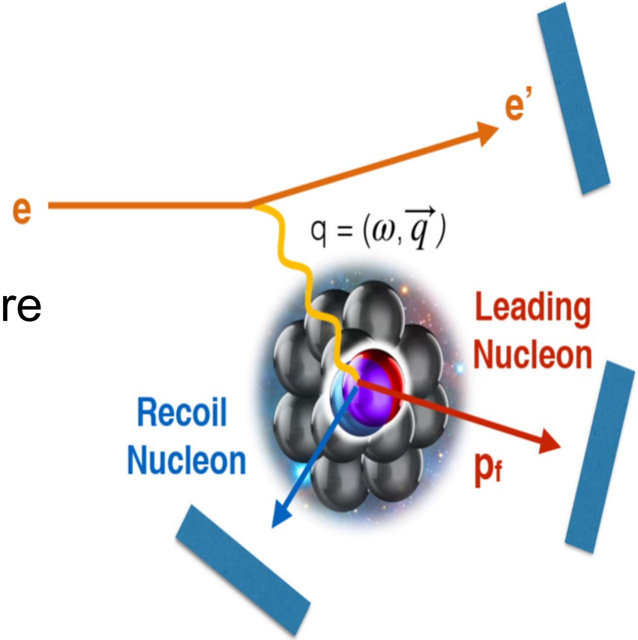
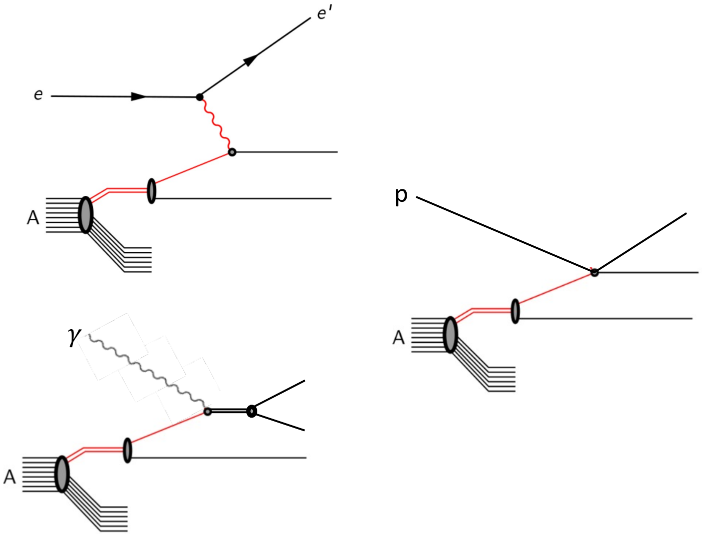
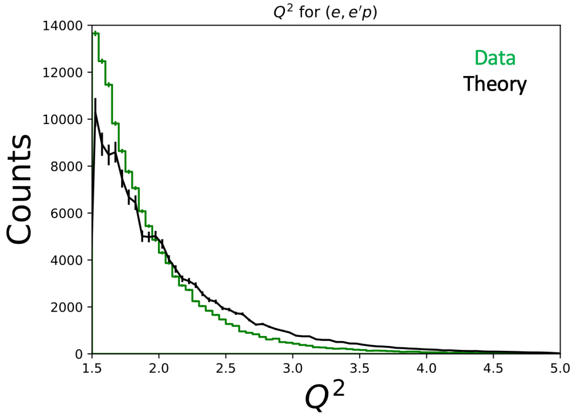


# Measuring SRC Probe (In)dependence

Change the Probe

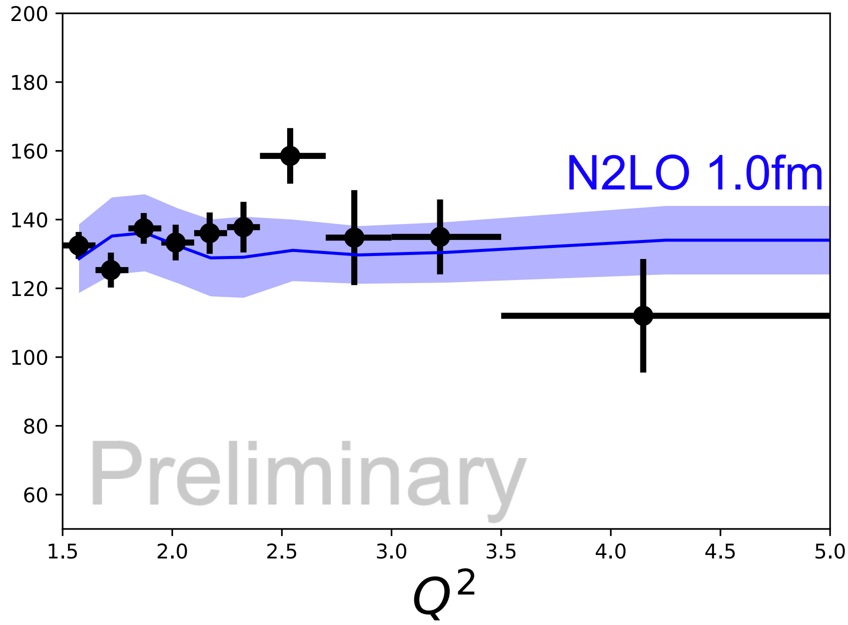



Change the Scale of the Probe



# Measuring SRC Probe (In)dependence

$\sigma_{CM}$ $[MeV]$
Center of Mass
Motion of SRC



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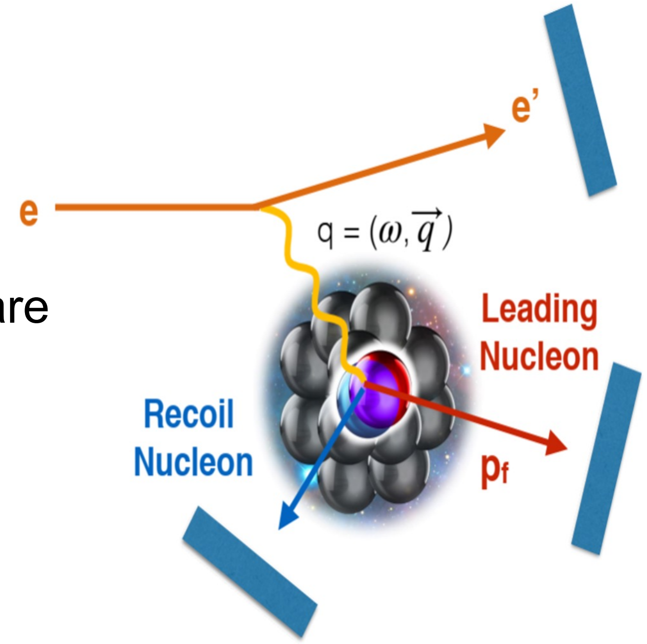
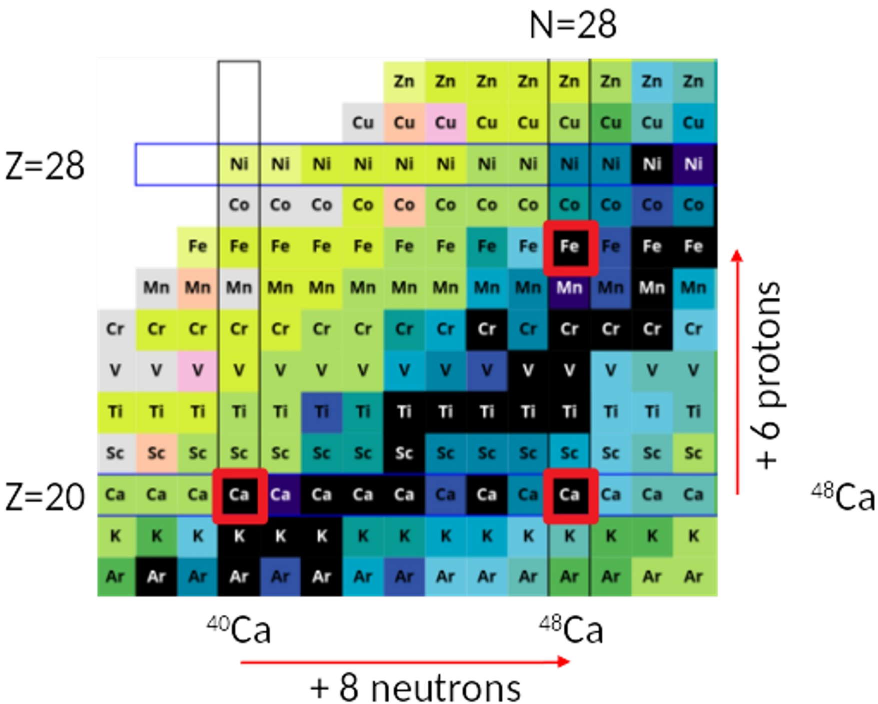
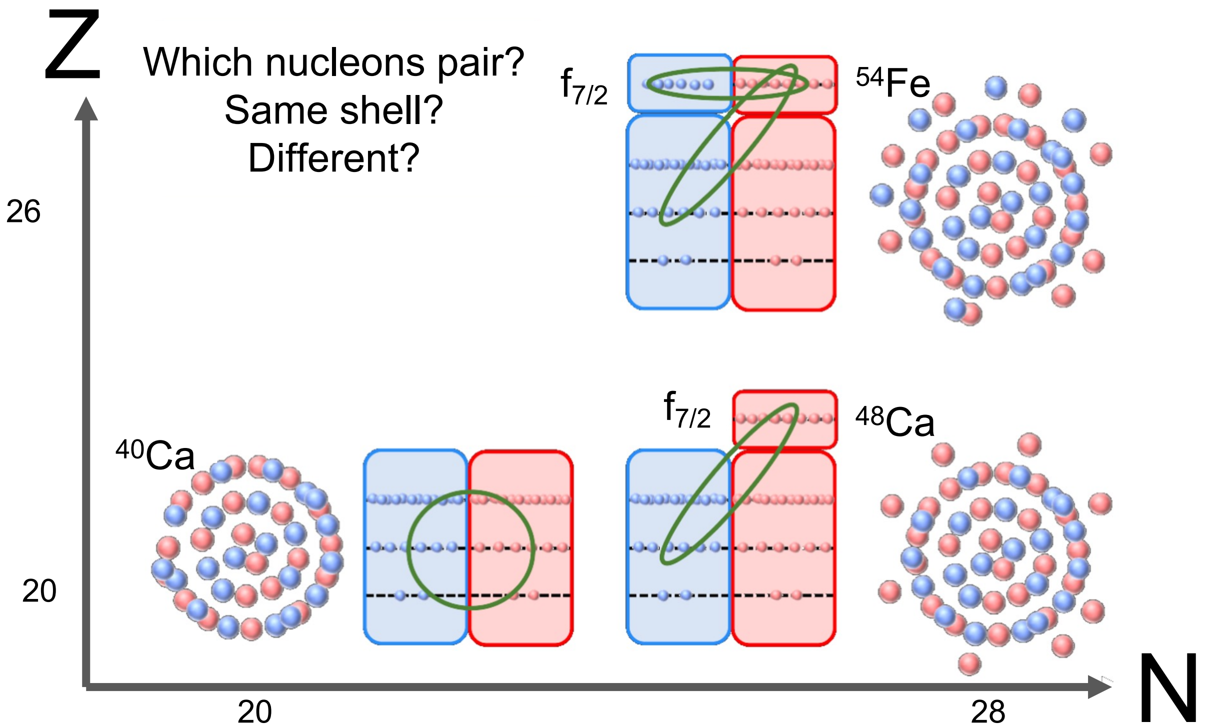


# SRCs in Asymmetric Nuclei



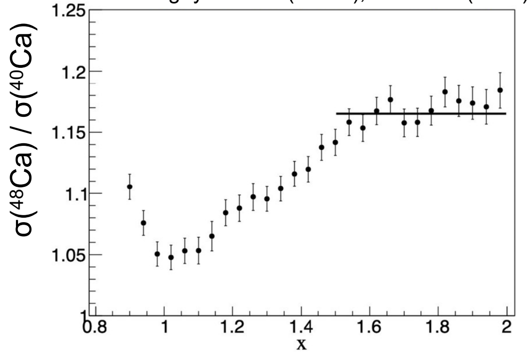
# SRCs in Asymmetric Nuclei



# SRCs in Asymmetric Nuclei

- (e,e’)
- (e,e’p)
- (e,e’n)
- (e,e’pp)
- (e,e’pn)

D. Nguyen et al. (Hall A), PRC 102 (2020).




Conclusion: *np* pair dominance

# SRCs in Asymmetric Nuclei

- (e,e')
- (e,e'p) → Hall C experiment 2022, under analysis: $^{40}Ca$, $^{48}Ca$, $^{54}Fe$, $^{197}Au$
- (e,e'n)
- (e,e'pp)
- (e,e'pn)

# SRCs in Asymmetric Nuclei

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

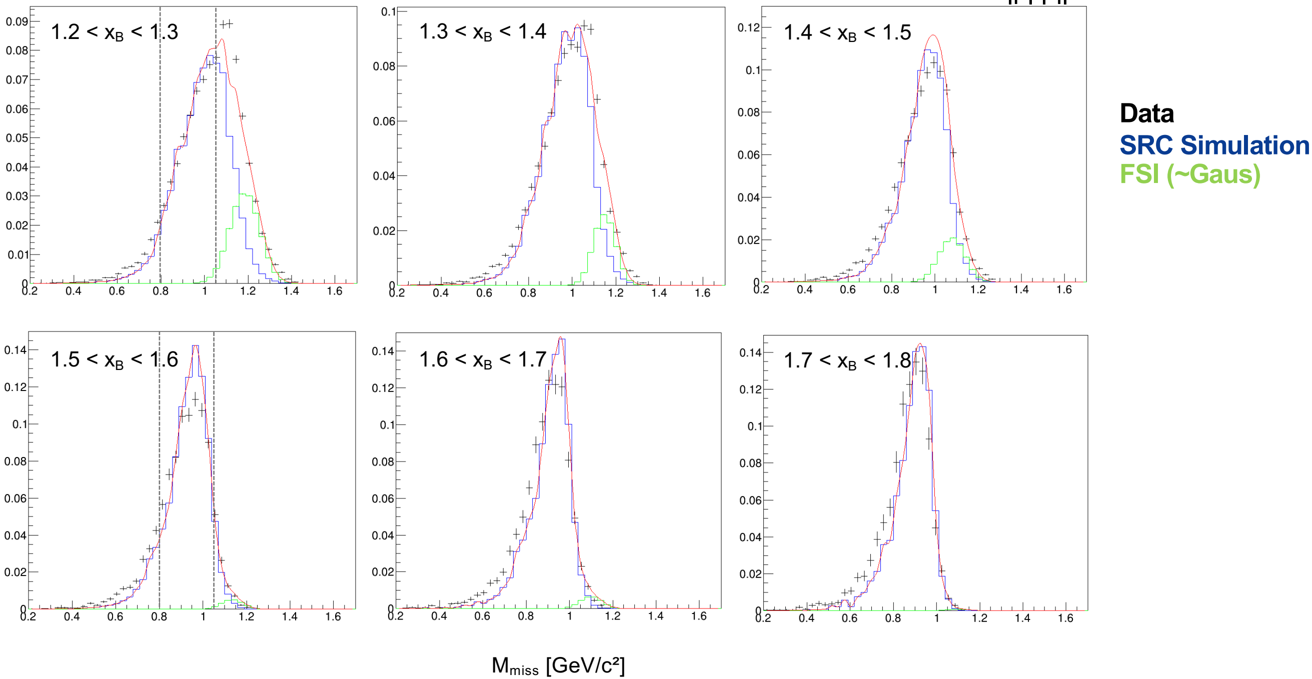
Hall C experiment 2022, under analysis: $^{40}$Ca, $^{48}$Ca, $^{54}$Fe, $^{197}$Au

Hall B RG-M experiment 2021/22, under analysis: $^{40}$Ca, $^{48}$Ca, $^{120}$Sn, …

# SRC selection: (e,e´p) in Ca
# Suppressing FSI

**SRC selection:**

- $x_B > 1.3$
- $Q^2 > 1.5$
- $p_{lead} > 1.1$ GeV/c
- $0.8 < M_{miss} < 1.05$ GeV/c²
- 0.4 GeV/c $< p_{miss} <$ 1.0 GeV/c
- $|p|/|q| < 0.96$



# SRC selection: (e,e´p) in Ca Data-Sim comparison

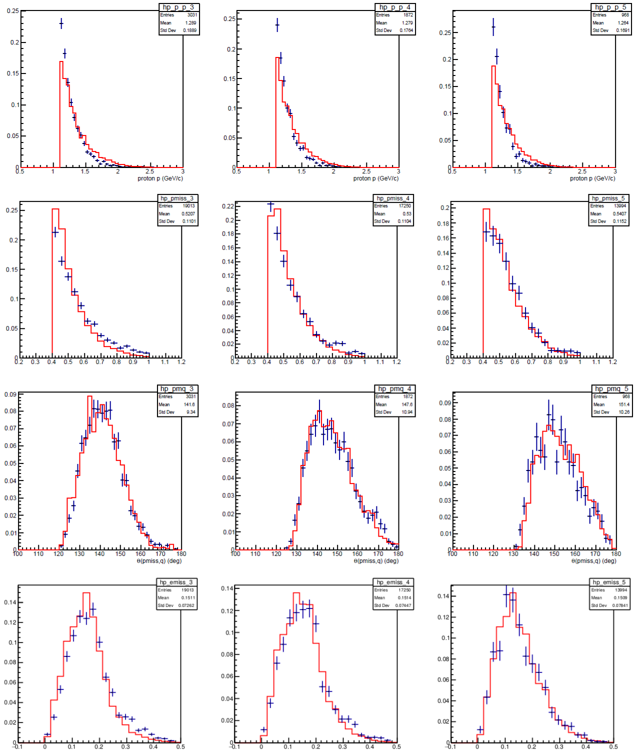
$1.3 < x_B < 1.4$ | $1.4 < x_B < 1.5$ | $1.5 < x_B < 1.6$

$p_{lead}$ (GeV/c)

$p_{miss}$ (GeV/c)

$\Theta(p_{miss},q)$ (deg)

$E_{miss}$ (GeV)



**Data**

**SRC Simulation (w/ bckgr merging)**

Very good Agreement with SRC Simulation

# SRCs in Asymmetric Nuclei

Advantages:
- informs on impact of nuclear structure
- many systematic effects cancel ($\epsilon$)

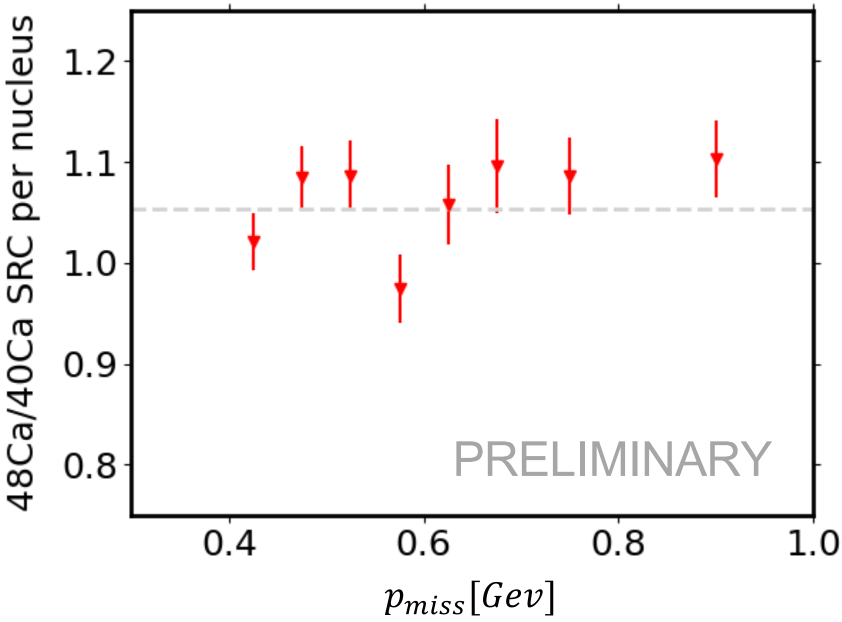
$$Ratio = \frac{yield_A/(N \cdot \rho_A)/T_A \cdot A \cdot \cancel{\epsilon}}{yield_{40Ca}/(N \cdot \rho_{40Ca})/T_{40Ca} \cdot A_{40Ca} \cdot \cancel{\epsilon}}$$

→ per nucleus yield ratio

*N* : norm (~ beam charge)
$\varrho$ : area density
→ luminosity normalization

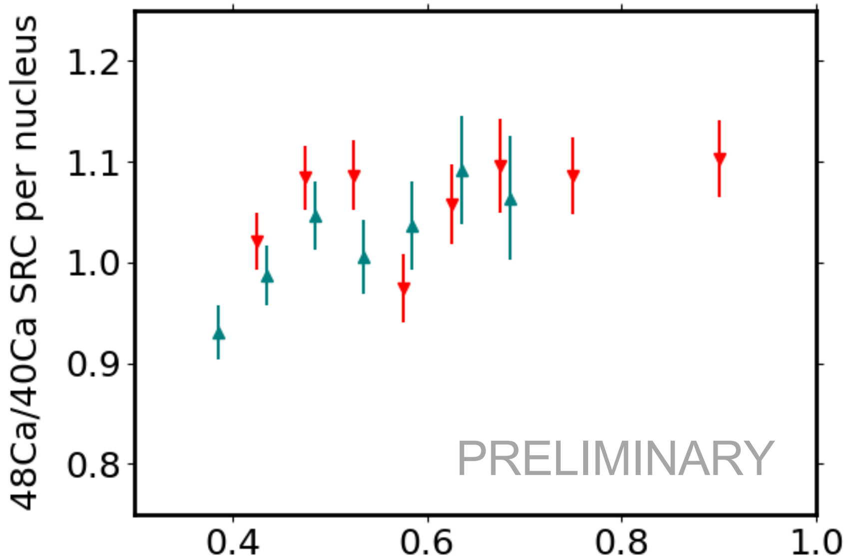
*T* : transparency
$\epsilon$: detector efficiency

# SRCs in Asymmetric Nuclei




≠ ~1.2

# SRCs in Asymmetric Nuclei

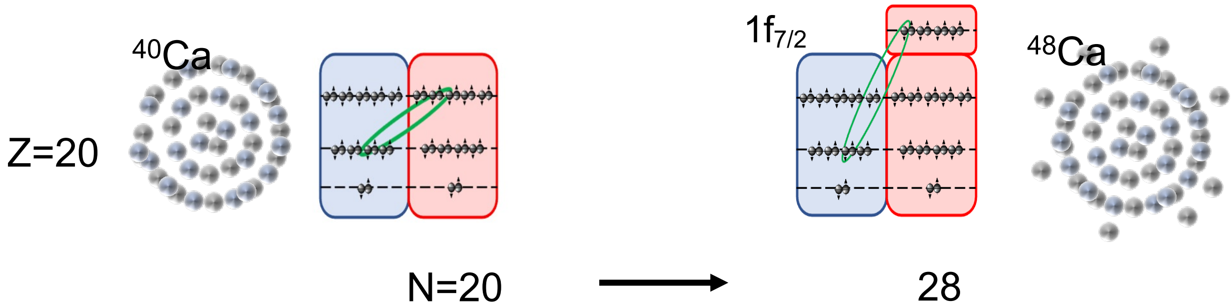



RG-M (Hall B) **1.05 (10)**

CaFe (Hall C) **1.02 (1)**

[Carlos Yero (ODU), Dien Nguyen (JLAB) et al.]

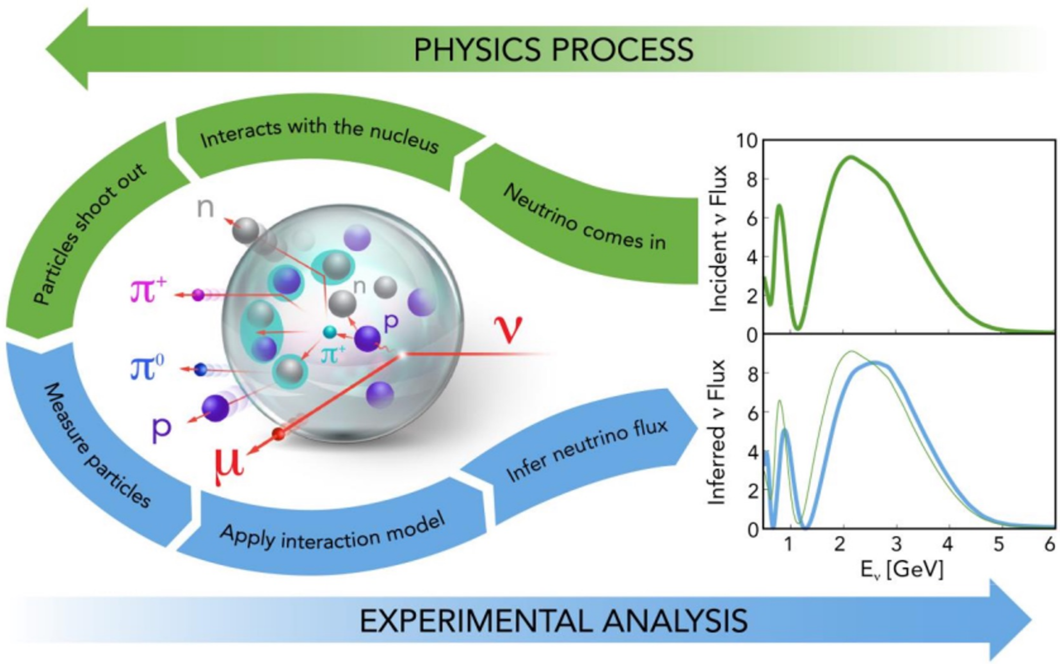
# SRCs in Asymmetric Nuclei



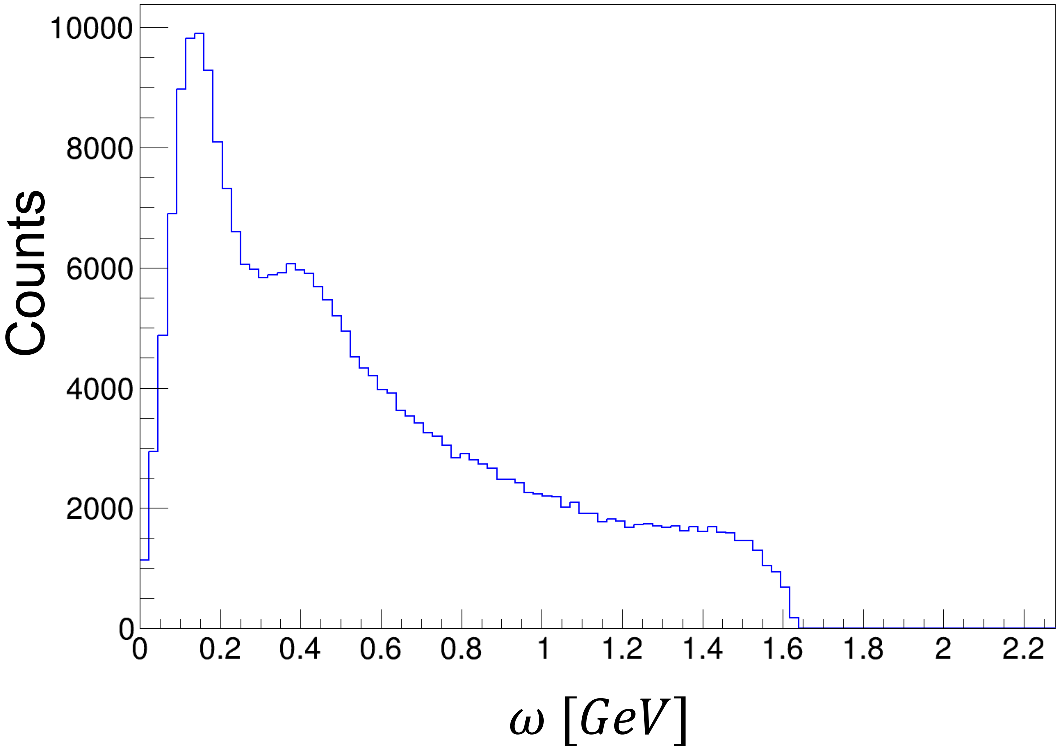

**48Ca/40Ca(e,e‘p) =**
**1.05**

**Reduction in**
**short-range pairing across shells!**
**Long-range nuclear structure**
**to impact SRC**

# Electrons for Neutrinos



# Electrons for Neutrinos (Argon inclusive)






Matan Goldenberg

# Normalization to Cross-Section:

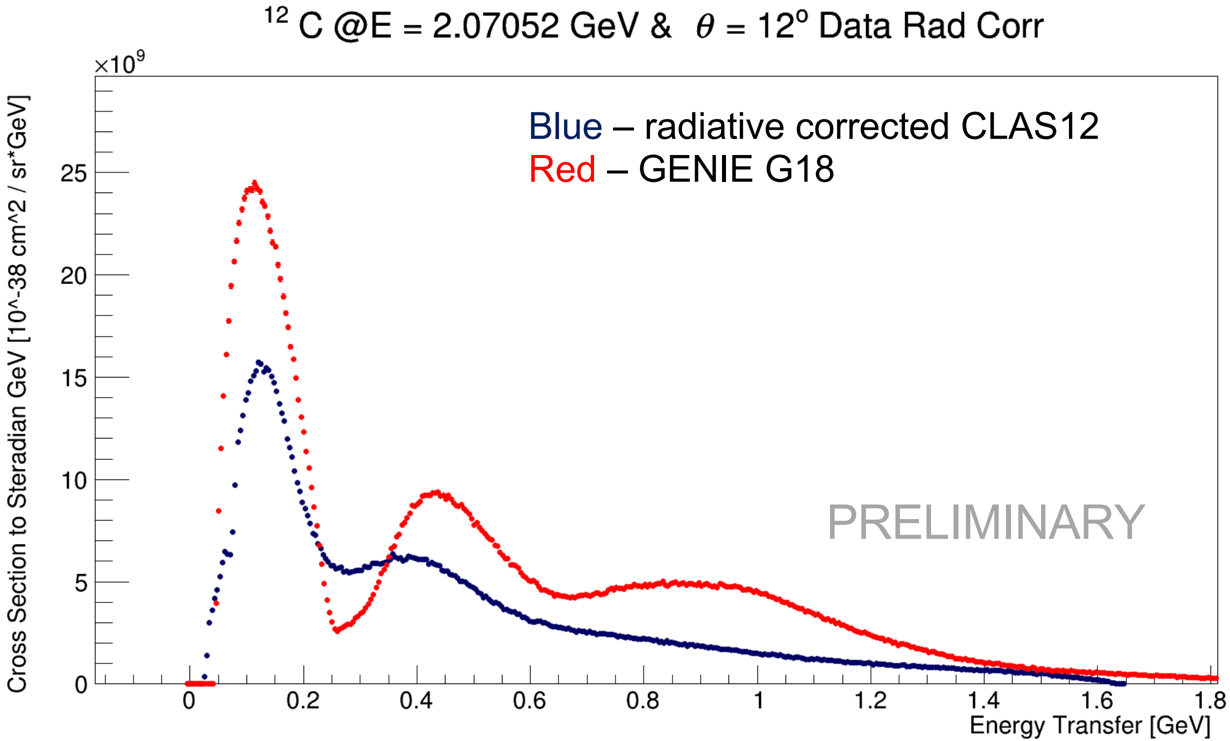
- What is in an Unnormalized bin?

$$\text{Bin Value} = \int_{Run-Time} \left\{ \int_{bin-width} \left[ \frac{d}{dv} \left( \int_{solid-angle-opening} \frac{d}{d\Omega} \left( \frac{dN_{events}}{dt} \right) d\Omega \right) \right] dv \right\} dt$$

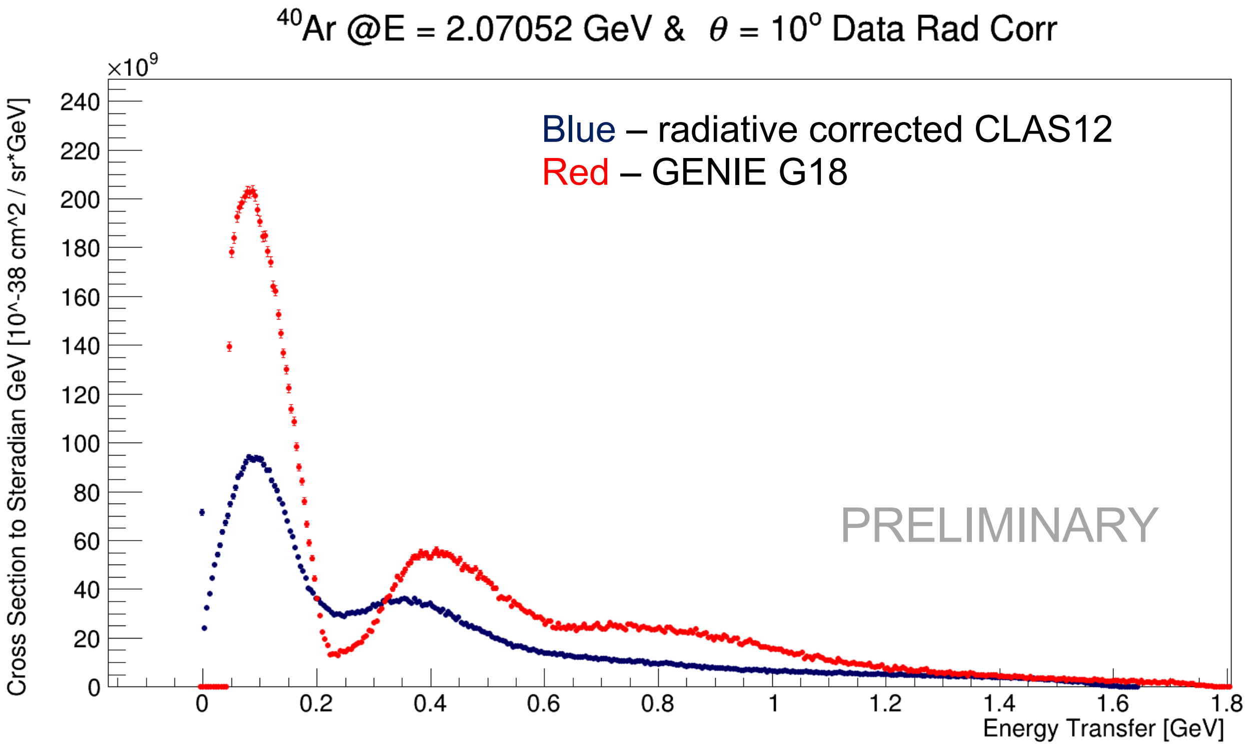
- Where $\frac{dN_{events}}{dt} = (\sigma_R * \Phi * n_t)$

- Normalization:
  Bin Normalization
  Angular Acceptance
  Integrated flux
  targets area density

# Cross Section Data vs. Theory



# Cross Section Data vs. Theory



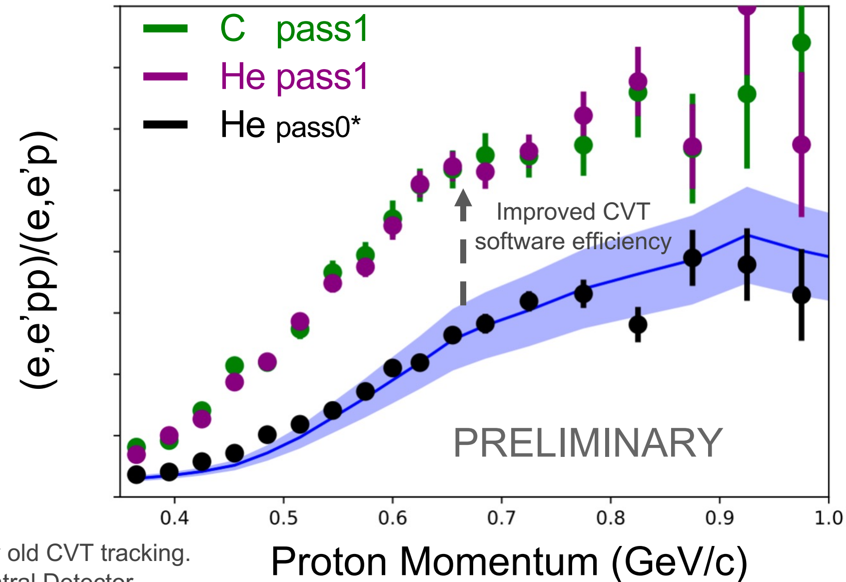
# Results with CLAS12 data - future

- Correct for systematics
- Use more statistics – There are much more available statistics!
- Create inclusive cross section for different beam energies and nuclei.

# Conclusion

- Low Level Analysis
  - Electron PID, Fiducial, and Vertex Cuts
  - Proton PID, Fiducial, and Vertex Cuts
  - Neutrons still have work
  - Working on second round of comments from analysis note.
- SRC Analysis
  - Q2 dependence of SRCs
  - SRCs in Asymmetric Nuclei
- e4v Analysis

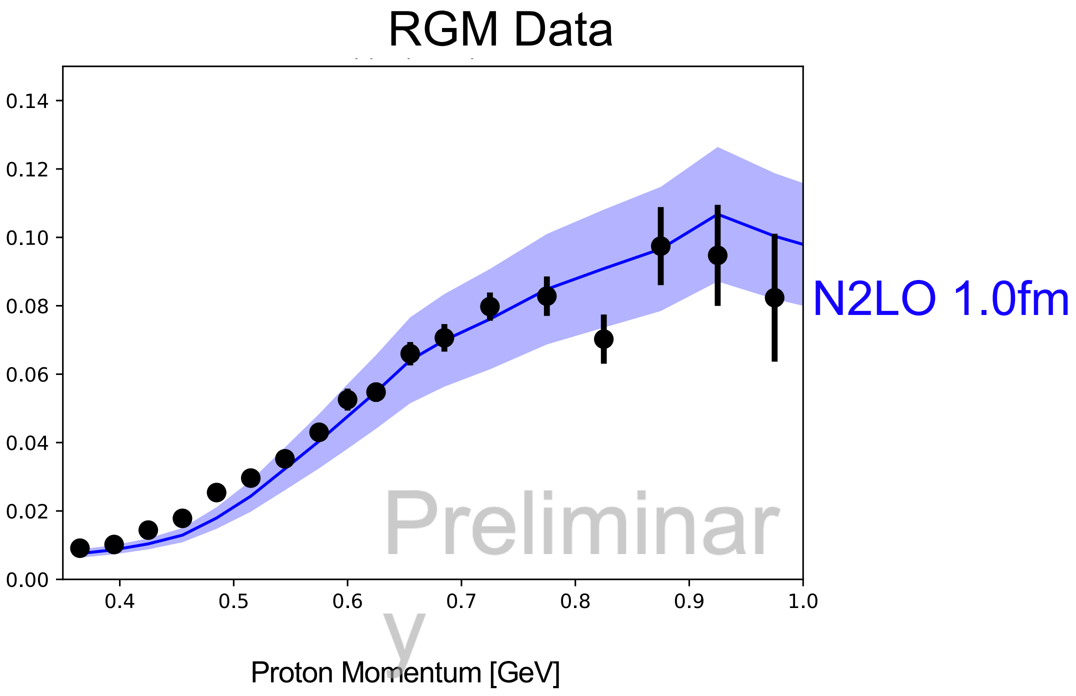
# Pass-1 Data preview



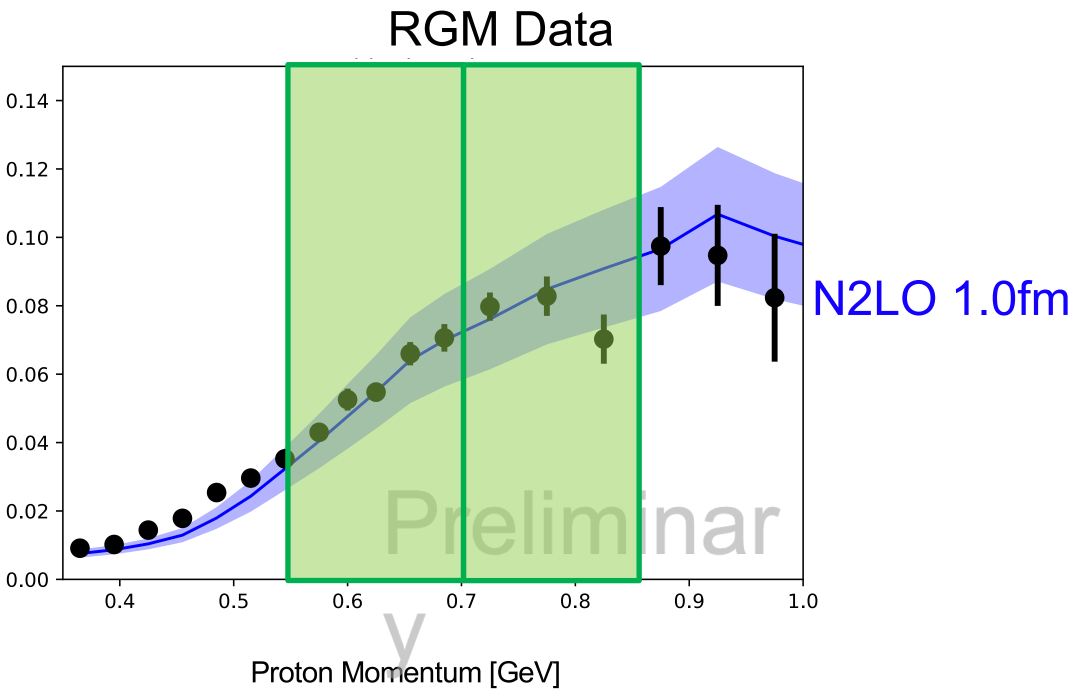

*old software notably old CVT tracking.
~90% protons in Central Detector

# Scale Dependence of SRC Measurements

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



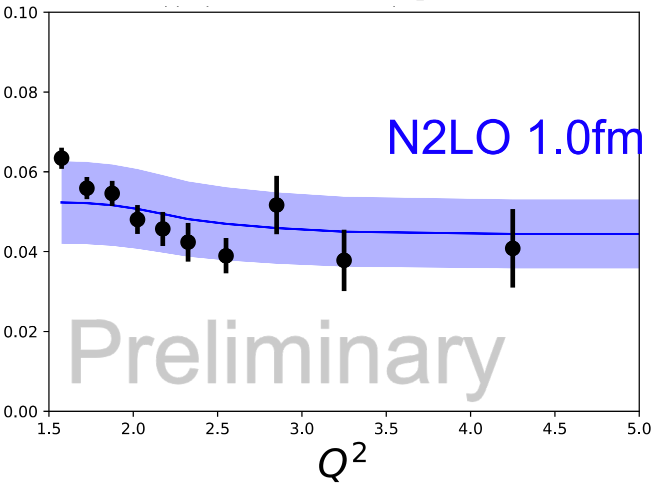
# Scale Dependence of SRC Measurements




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

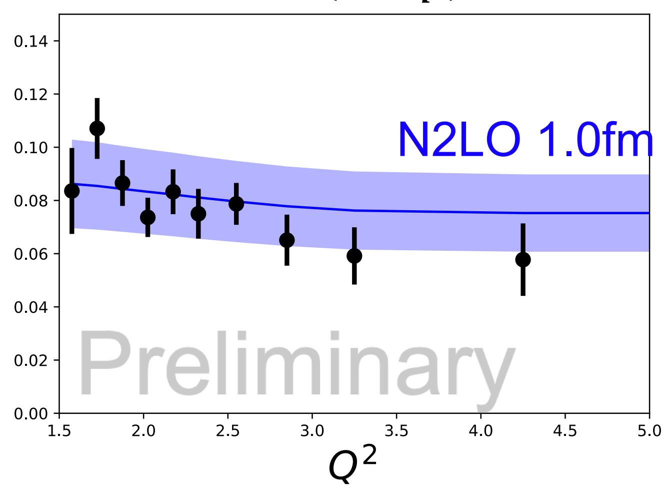
# Measuring SRC Probe (In)dependence

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




$0.55GeV < p_{miss} < 0.7GeV$

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




$0.7GeV < p_{miss} < 0.85GeV$