SRC Analysis Update using RG-M Data

Julian Kahlbow for RG-M

CLAS Collaboration Meeting, Nov 08

Justin Estee

MIT

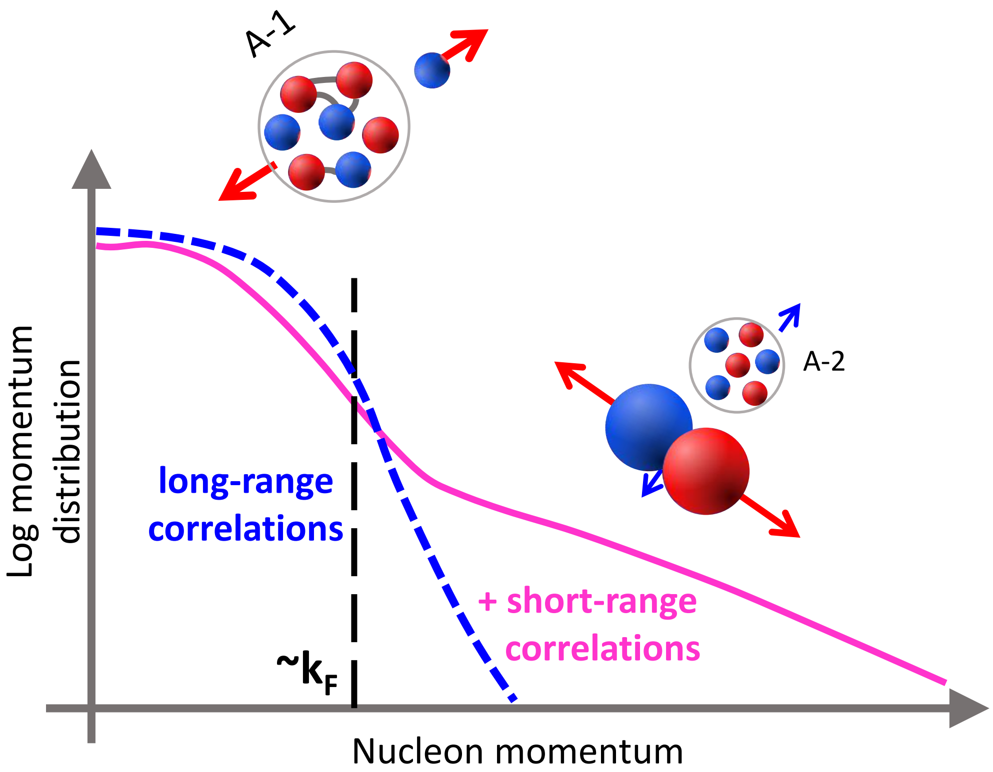
Andrew Denniston

MIT

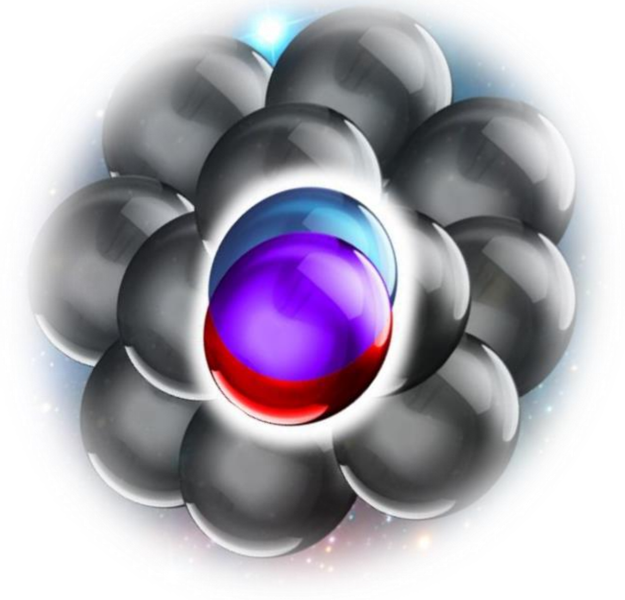
Erin Seroka

GWU

Nuclear structure determined by correlations

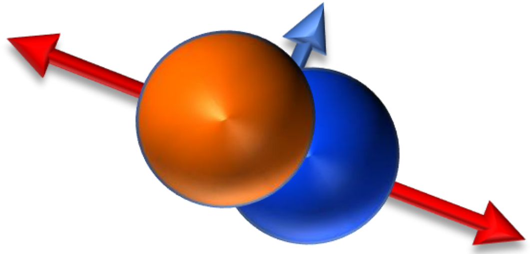


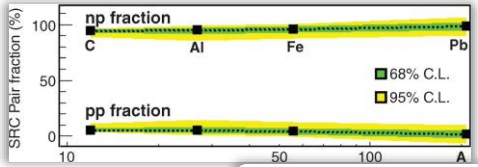
Short-range correlations
=
Close proximity nucleon-nucleon pairs

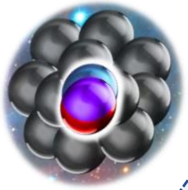


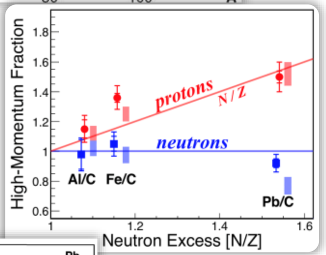
- *large* relative momentum
- *small* center-of-mass motion

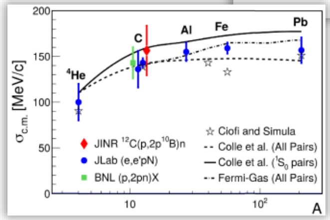
relative to k_F

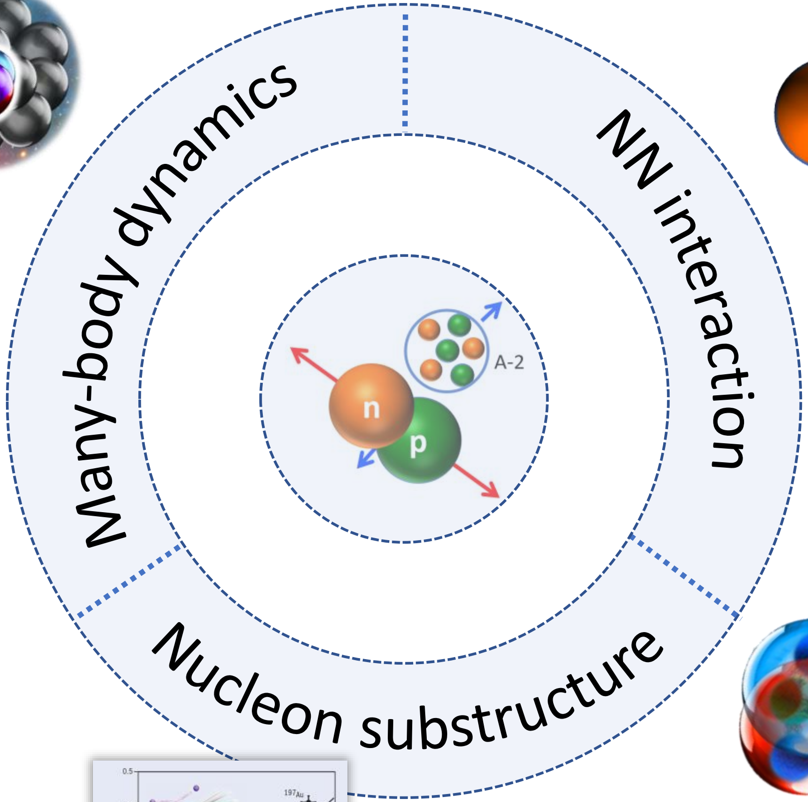


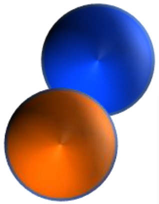


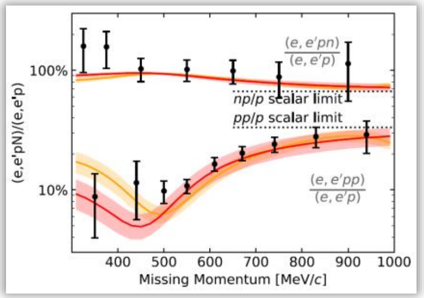


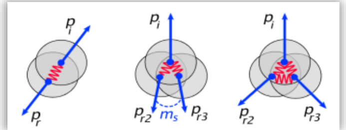


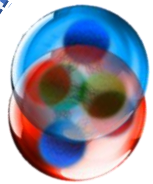


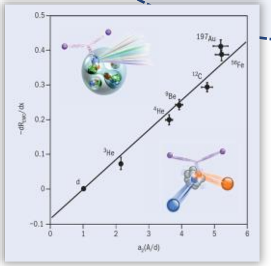


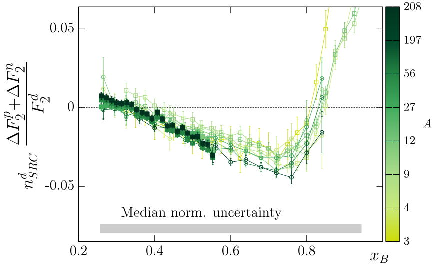






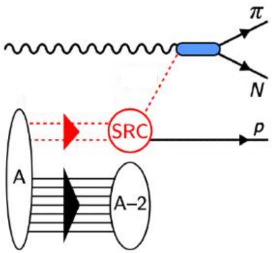






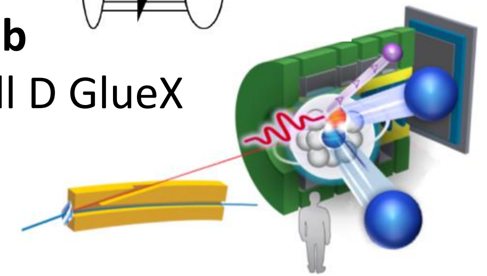
O. Hen et al. (CLAS), Science 346 (2014)
E. Cohen et al. (CLAS), Phys. Rev. Lett. 121 (2018)
M. Duer et al. (CLAS), Nature 560 (2018)
B. Schmookler et al. (CLAS), Nature 566 (2019)
M. Duer et al. (CLAS), Phys. Rev. Lett. 122 (2019)
A. Schmidt et al. (CLAS), Nature 578 (2020)
M. Patsyuk, JK et al. (BM@N), Nature Phys. 17 (2021)
R. Cruz-Torres et al., Nature Physics 17 (2021)
I. Korover et al. (CLAS), Phys. Lett. B 820 (2021)

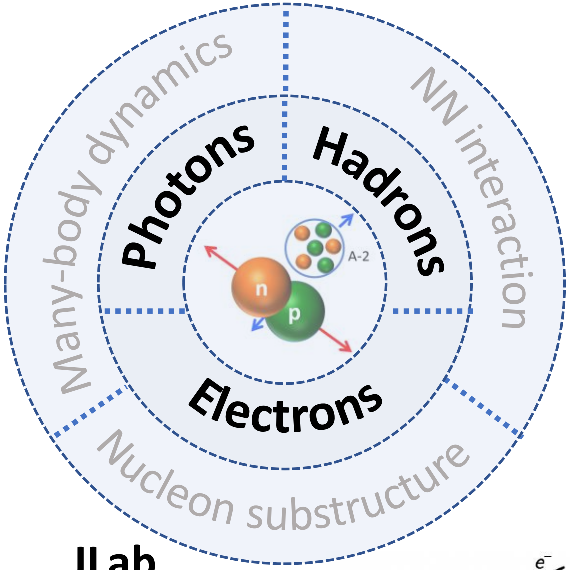
SRC Universe with multimessenger studies

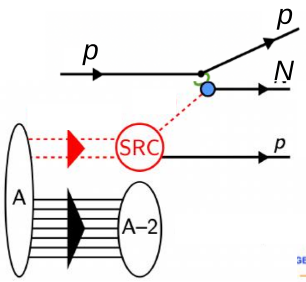


(γ,mN)

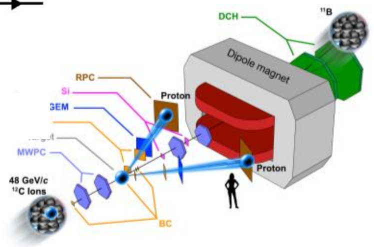
JLab
Hall D GlueX







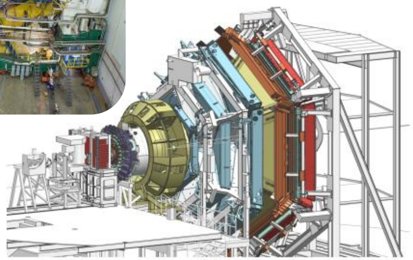
(p,2p), (p,2pN)

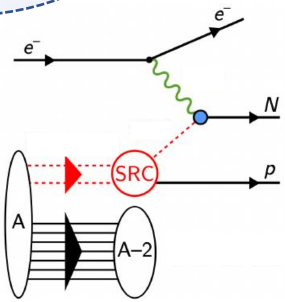


JINR

R³B at GSI

JLab
Halls A,B,C

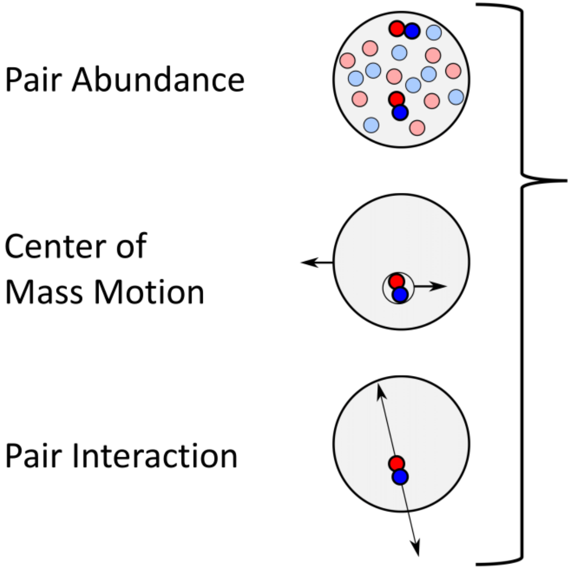




(e,e´), (e,e´p), (e,e´pN)

RG-M experiment at CLAS12

- intensity frontier
- variety of nuclear targets
- exclusive (e,e´NN) measurements
- e4ν: “electrons for neutrinos“



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

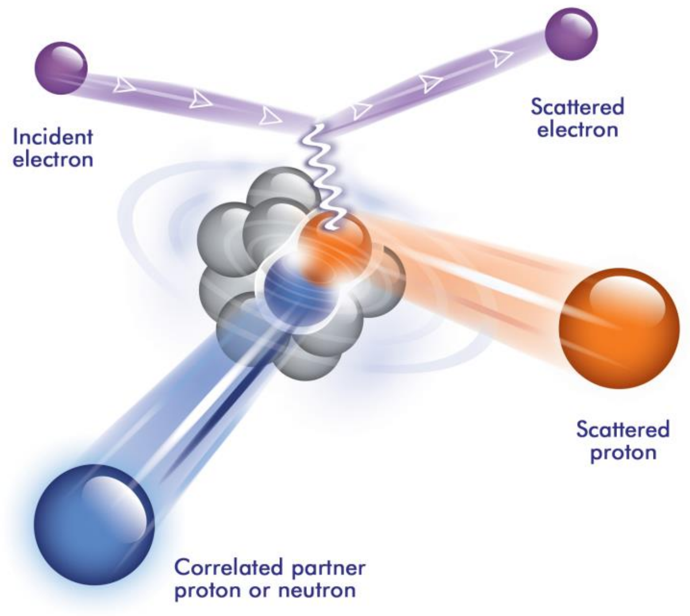
precision CM measurements

precision NN interaction

Scale (Q^2) independence of SRC observables

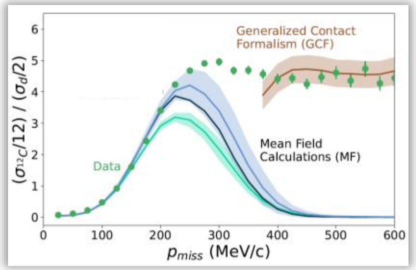
RG-M experiment at CLAS12

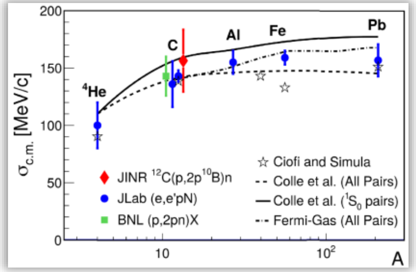
- ran November 2021 - February 2022
- fully calibrated (Pass1 approved)
- all 6 GeV target data reconstructed: H, D, ^{4}He, ^{40}Ar, ^{40}Ca, ^{48}Ca, ^{120}Sn

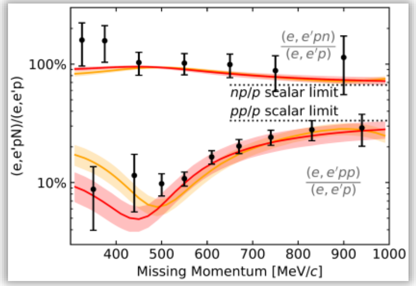


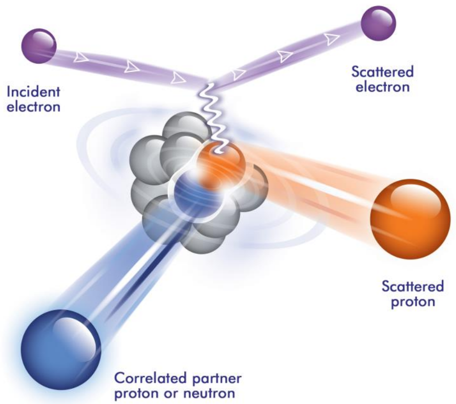
Reaction tools

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







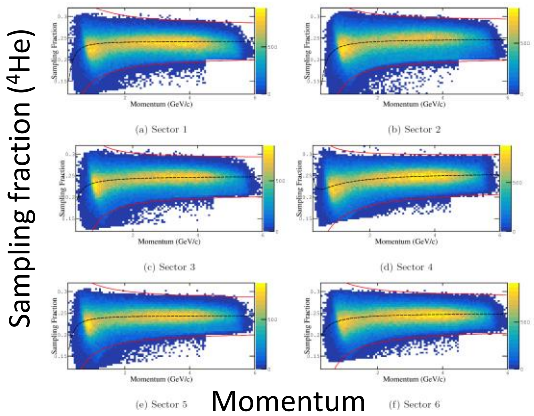


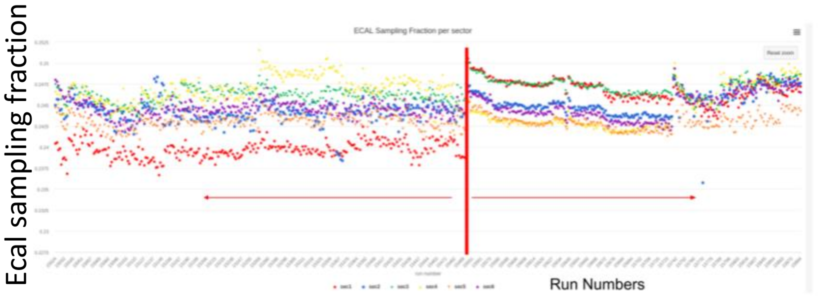
I. Korover et al. (CLAS), PRC Lett. 107 (2023)
E. Cohen et al. (CLAS), Phys. Rev. Lett. 121 (2018)
I. Korover et al. (CLAS), Phys. Lett. B 820 (2021)

Particle ID concluded for 6 GeV data (Pass1)

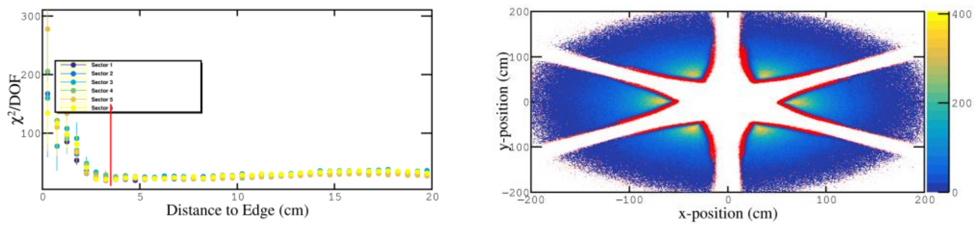
Electrons

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

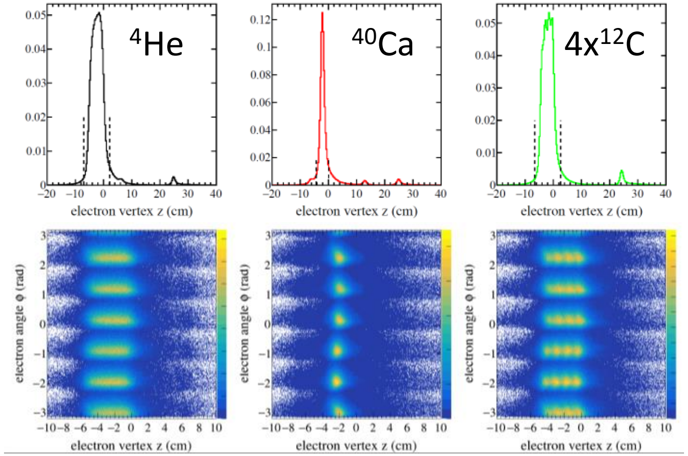




Fiducial Cuts



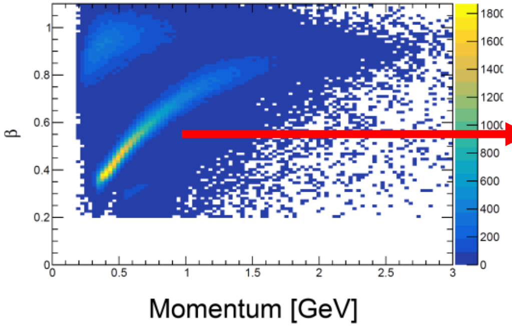
z Vertex

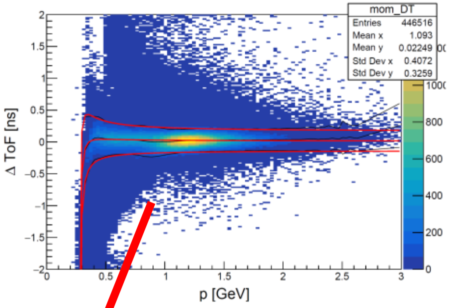


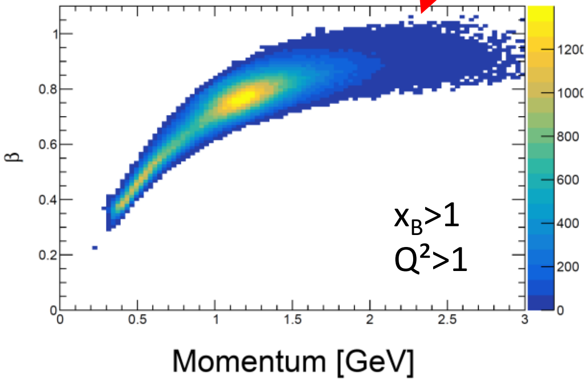
Particle ID concluded for 6 GeV data (Pass1)

Protons

Central detector ID in ΔToF (=measured - expected)







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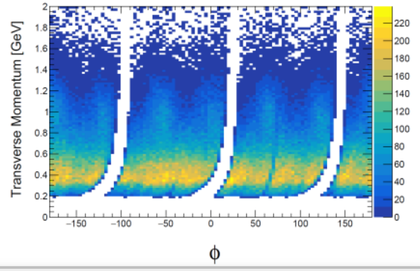

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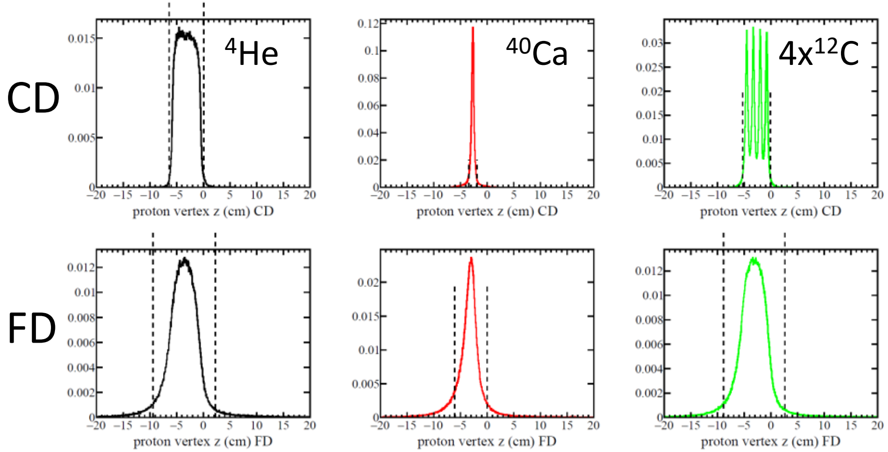
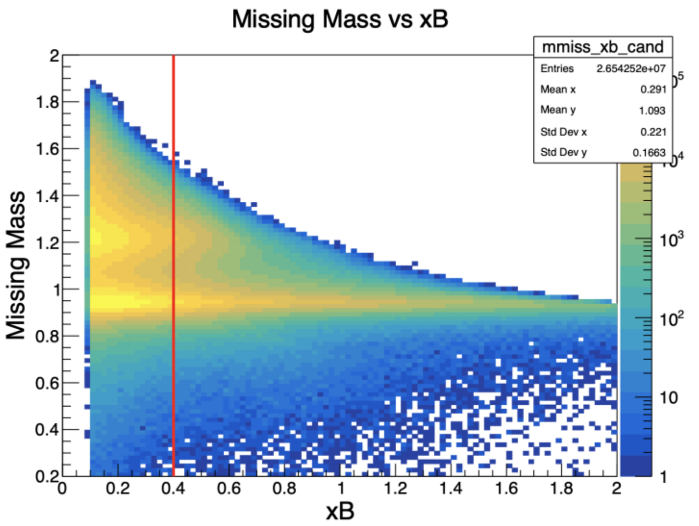


Particle ID concluded for 6 GeV (Pass1)

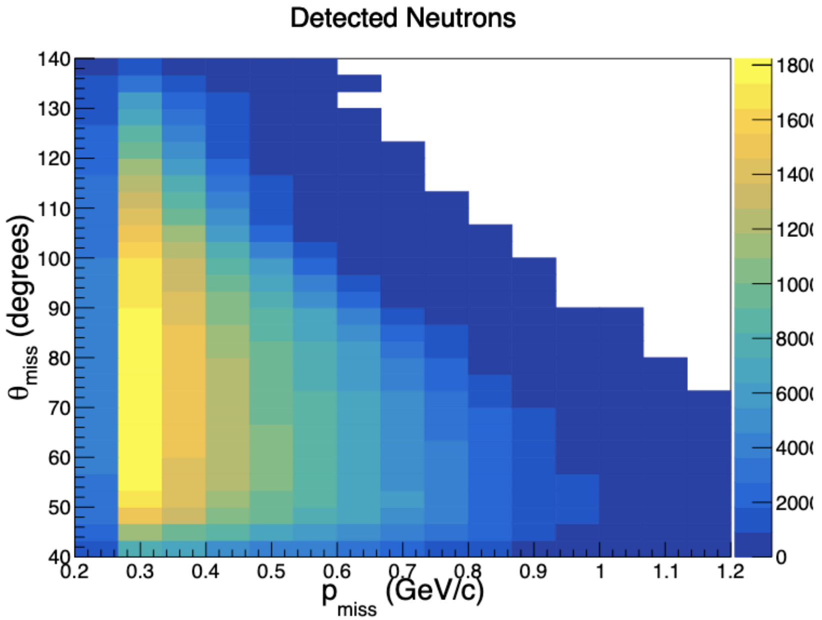
Neutrons

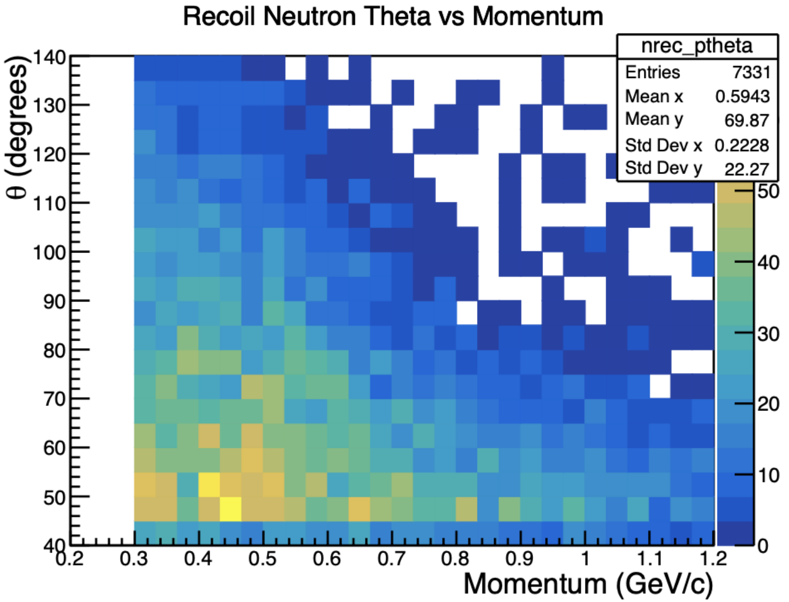
(e,e’pn): recoil n efficiency

- Quasielastic *d(e,e’pn)*
- Need analytical model to cover phase space of *(e,e’pn)* observable

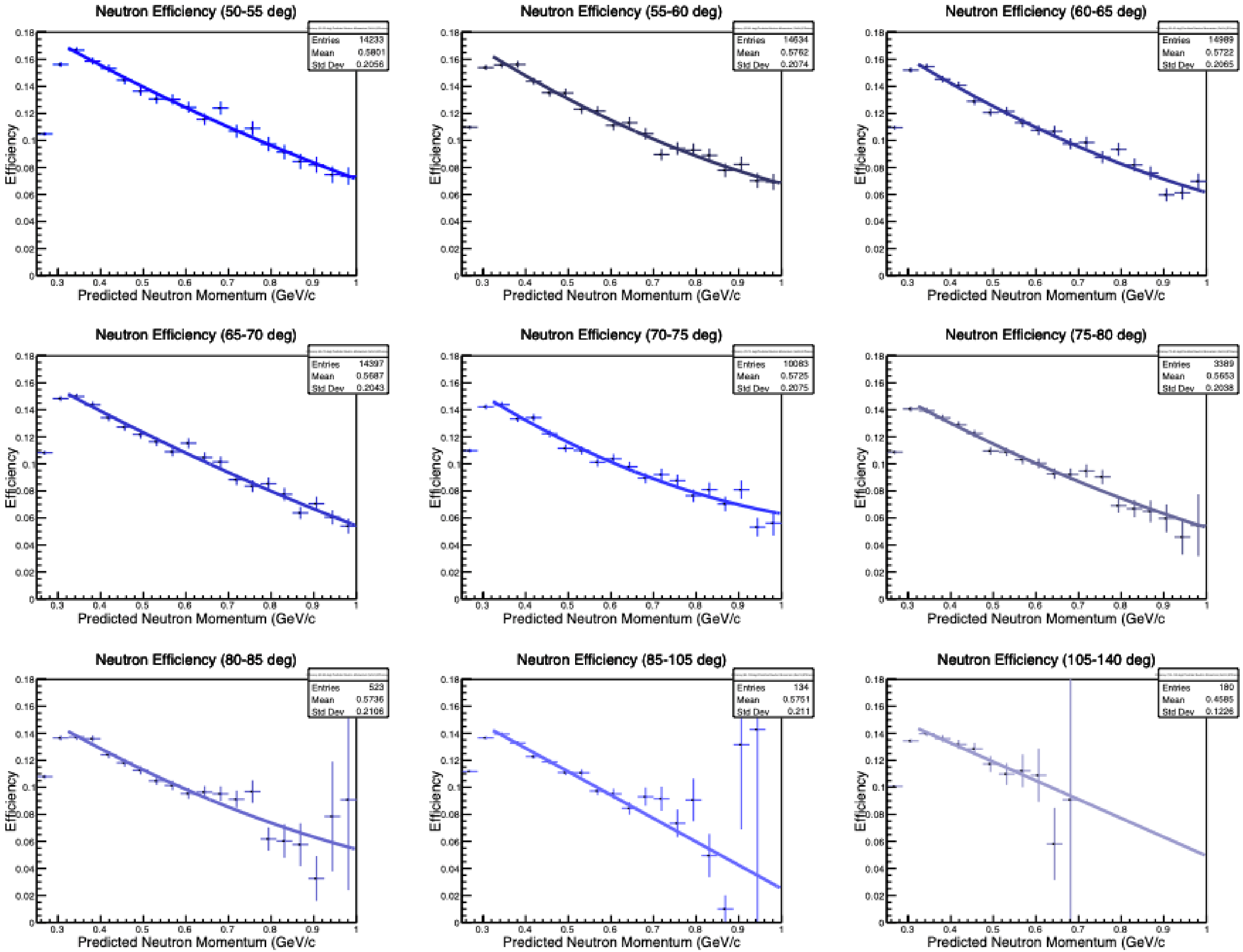


d*(e,e’pn)*





C*(e,e’pn)*

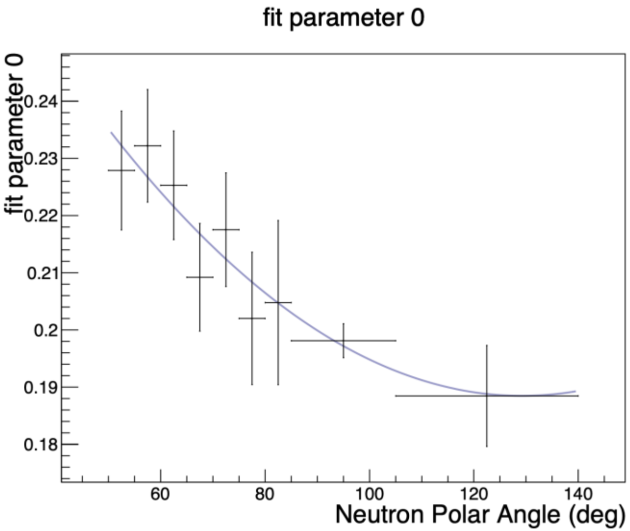


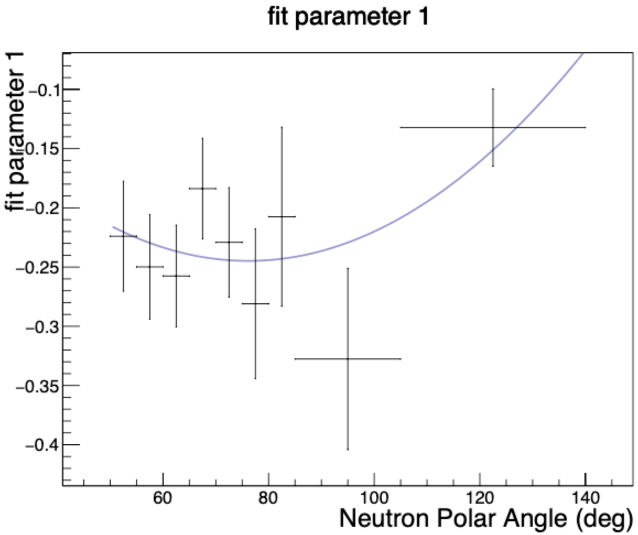
Neutron Efficiency (50-55 deg)
Entries 14233
Mean 0.5801
Std Dev 0.2056
Neutron Efficiency (55-60 deg)
Entries 14634
Mean 0.5762
Std Dev 0.2074
Neutron Efficiency (60-65 deg)
Entries 14989
Mean 0.5722
Std Dev 0.2065
Neutron Efficiency (65-70 deg)
Entries 14397
Mean 0.5687
Std Dev 0.2043
Neutron Efficiency (70-75 deg)
Entries 10083
Mean 0.5725
Std Dev 0.2075
Neutron Efficiency (75-80 deg)
Entries 3389
Mean 0.5653
Std Dev 0.2038
Neutron Efficiency (80-85 deg)
Entries 523
Mean 0.5736
Std Dev 0.2106
Neutron Efficiency (85-105 deg)
Entries 134
Mean 0.5751
Std Dev 0.211
Neutron Efficiency (105-140 deg)
Entries 180
Mean 0.4585
Std Dev 0.1226
Efficiency
Predicted Neutron Momentum (GeV/c

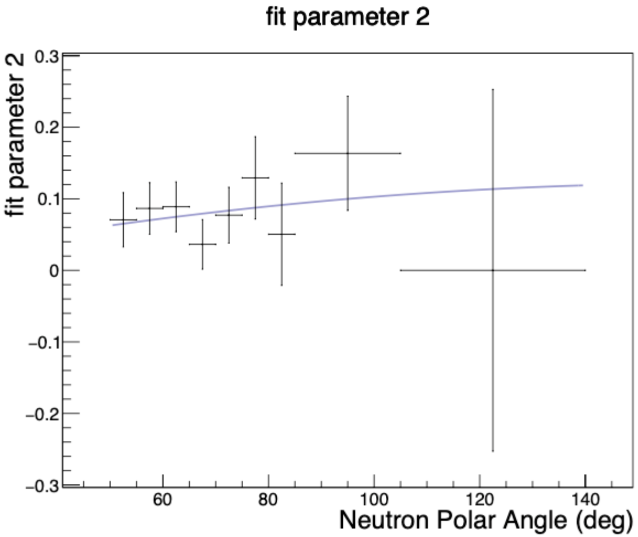
(e,e'pn): recoil n efficiency

- $n_{eff}(p,\theta) = a_0(\theta) + a_1(\theta)p + a_2(\theta)p^2$
- $a_0(\theta) = b_0 + b_1\theta + b_2\theta^2$
- $a_1(\theta) = b_3 + b_4\theta + b_5\theta^2$
- $a_2(\theta) = b_6 + b_7\theta + b_8\theta^2$

b0	0.31
b1	-1.92e-3
b2	7.44e-6
b3	1.16e-12
b4	-2.78e-3
b5	5.55e-18
b6	-0.11
b7	5.02e-3
b8	3.52e-5

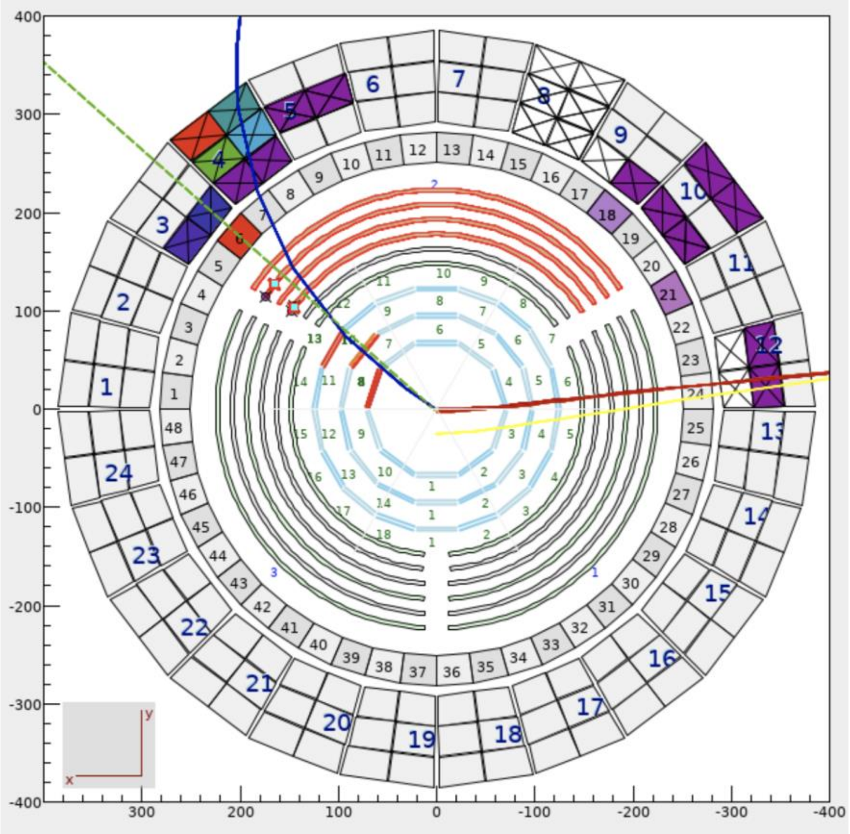






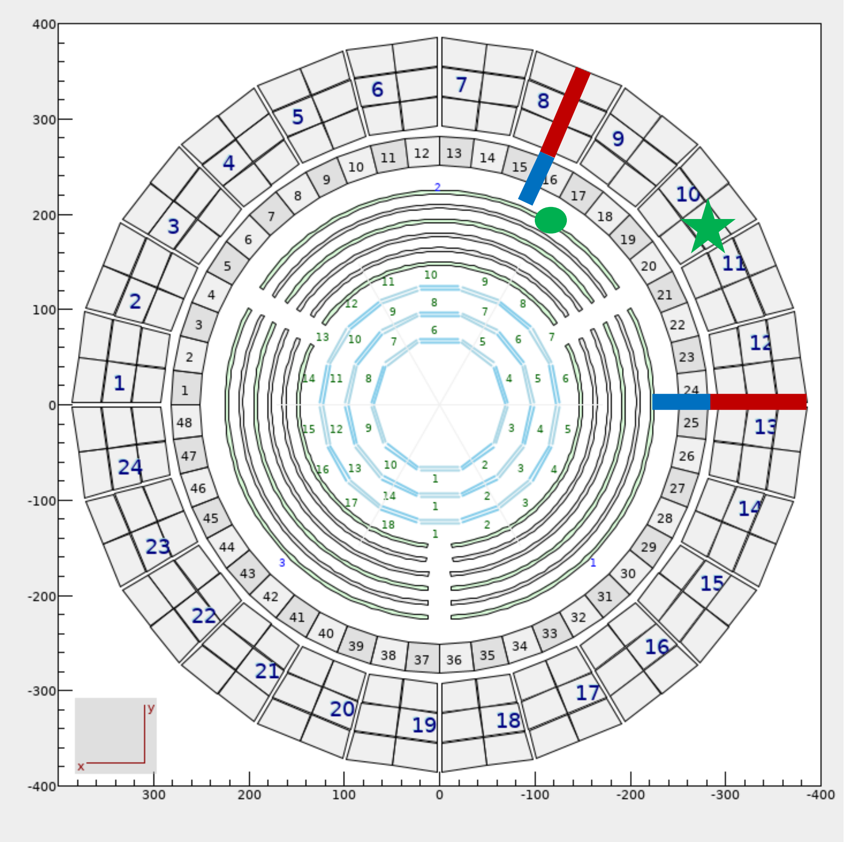
(e,e'pn): charged particle veto

- Using Machine Learning (MLP) to distinguish between real neutrons and protons mis-IDed as neutrons
  - Define signal and background
  - Split data into training and testing samples
  - Define "features" to train model on training sample
  - Evaluate performance using testing sample
- Train using simulated events and Deuterium events from RGM, apply to Carbon data from RGM



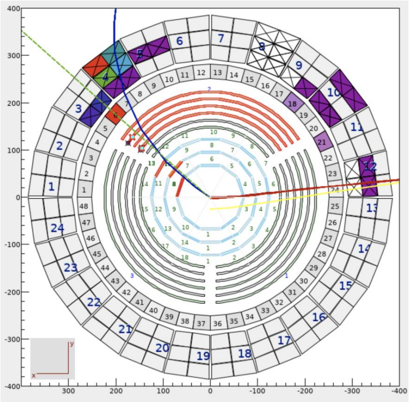
(e,e'pn): features

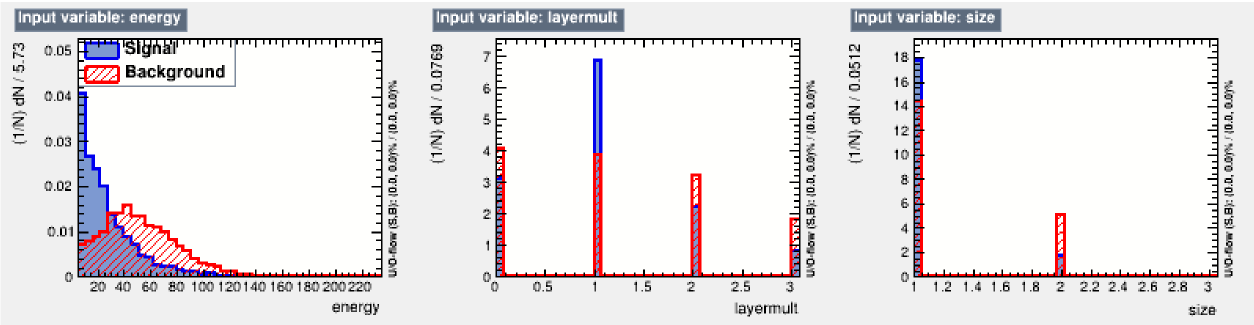
- Number of CND hits within 30 degrees of neutron
- CND energy deposition within 30 degrees of neutron
- Number of CTOF hits within 30 degrees of neutron
- CTOF energy deposition within 30 degrees of neutron
- Number of hits in CND cluster
- Neutron energy
- CND layer multiplicity (0 if CTOF only)
- Angular separation between hit in CVT layer 12 and neutron hit (180° if no track)

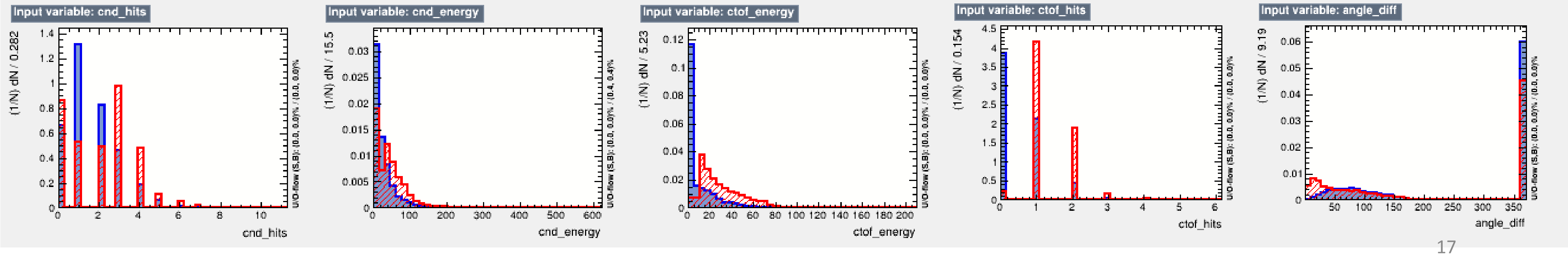


(e,e’pn): charged particle veto (simulation)

- *e’n* (signal) and *e’p* (background), with RGM background, passed through CLAS12 geant4 simulation and reconstruction







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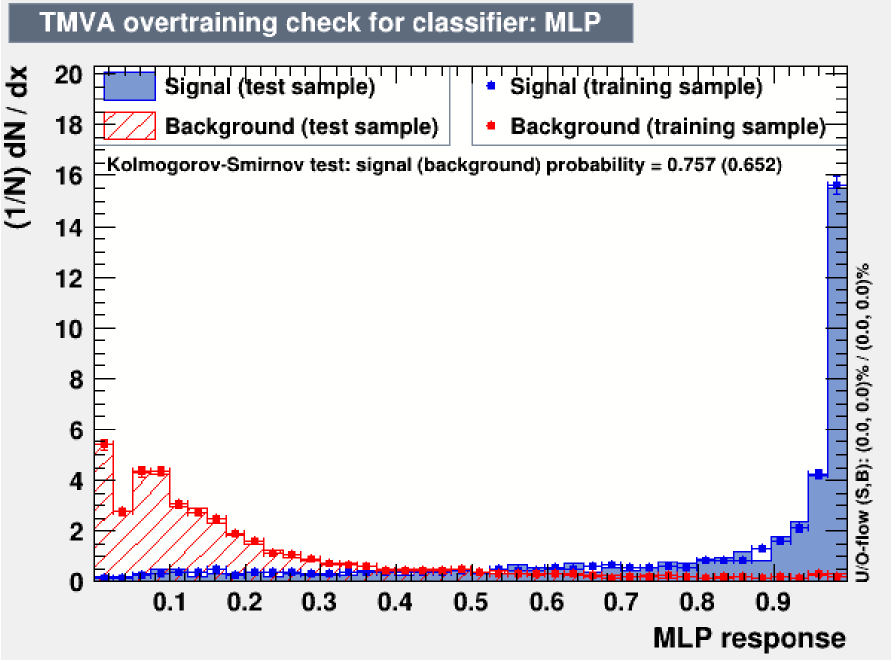
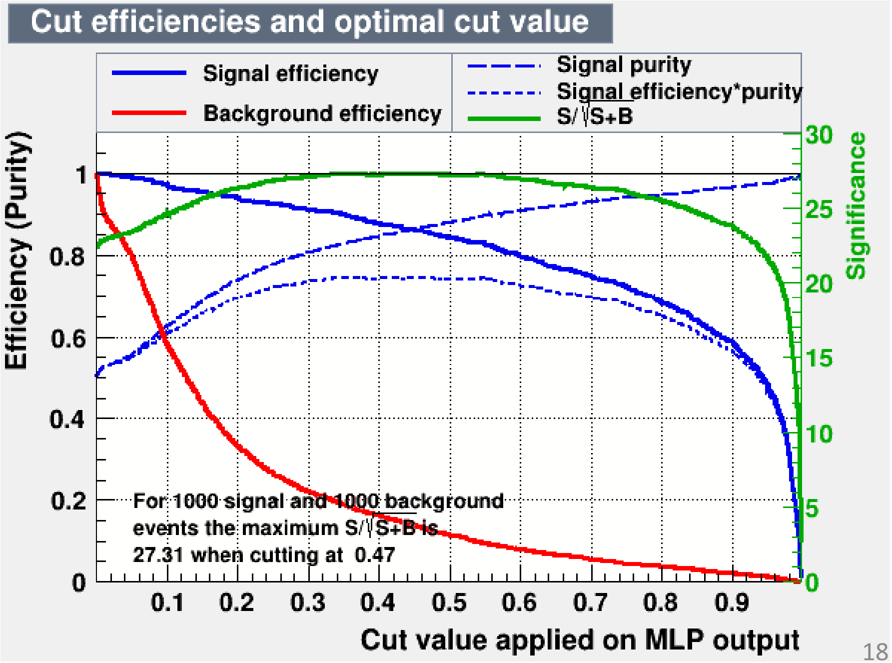
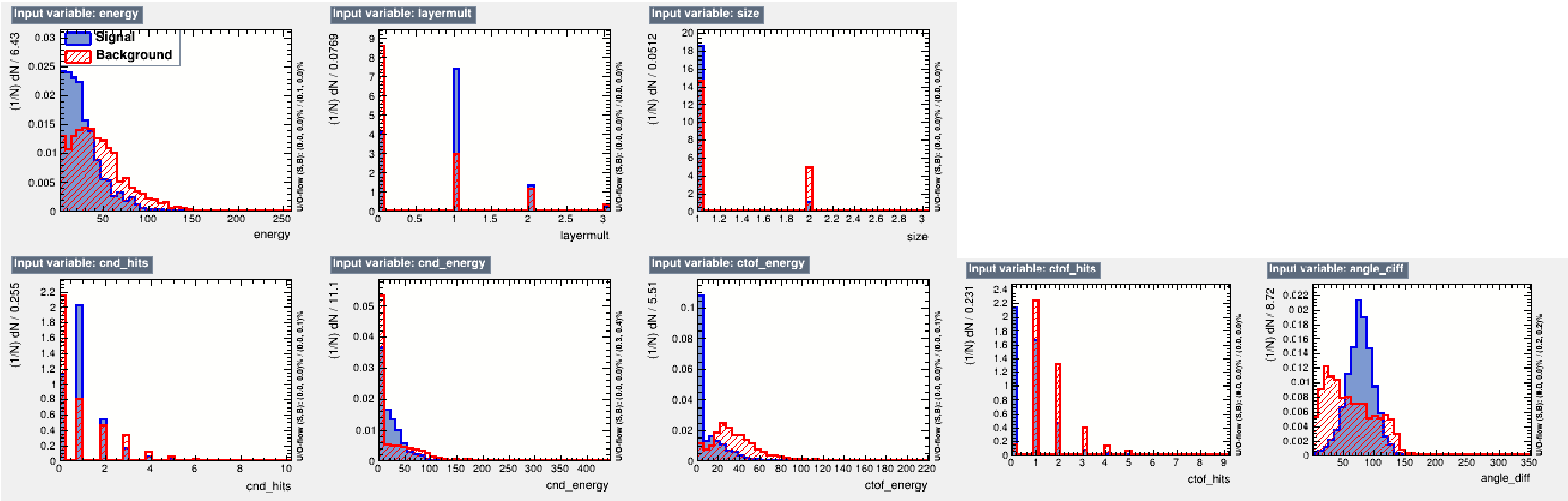




(e,e’pn): charged particle veto (deuterium)

- $d(e,e'pn)$ (signal) and $d(e,e'p\pi^- p)$ in which CLAS12 reconstruction misidentifies protons as neutrons (background)



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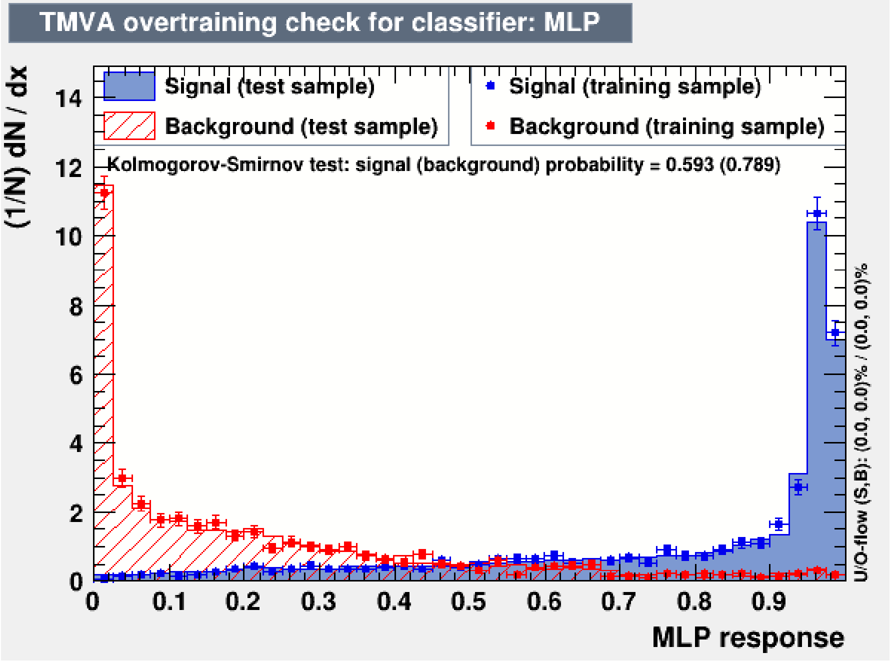

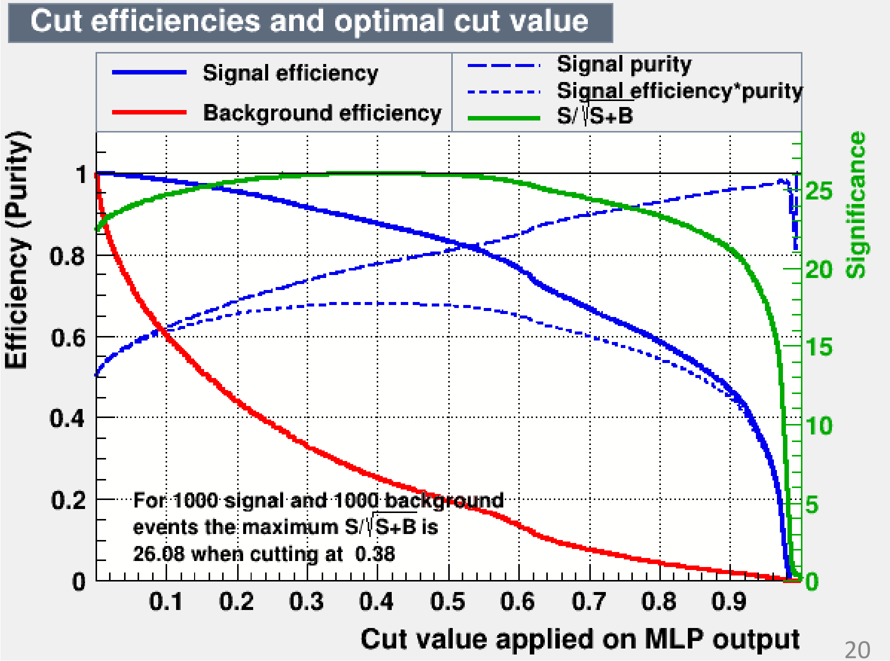

Particle ID concluded for 6 GeV (Pass1)

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

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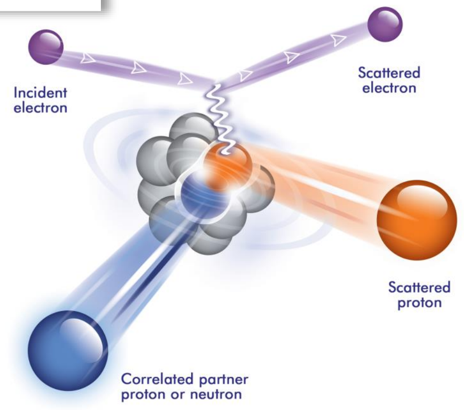
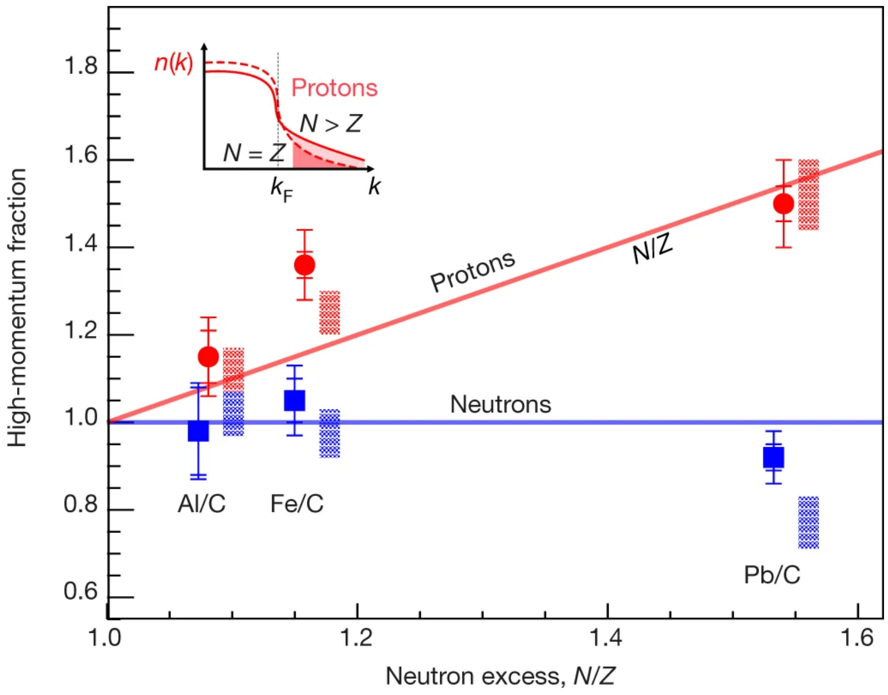
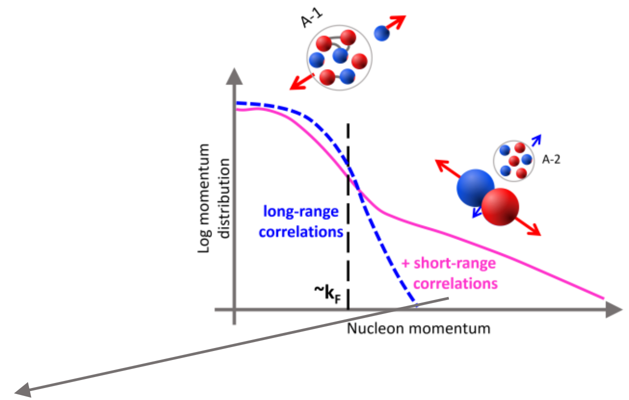
[1]Department of Physics, Massachusetts Institute of Technology
[2]Department of Physics, The George Washington University

→ Submitted “General“ Analysis Note



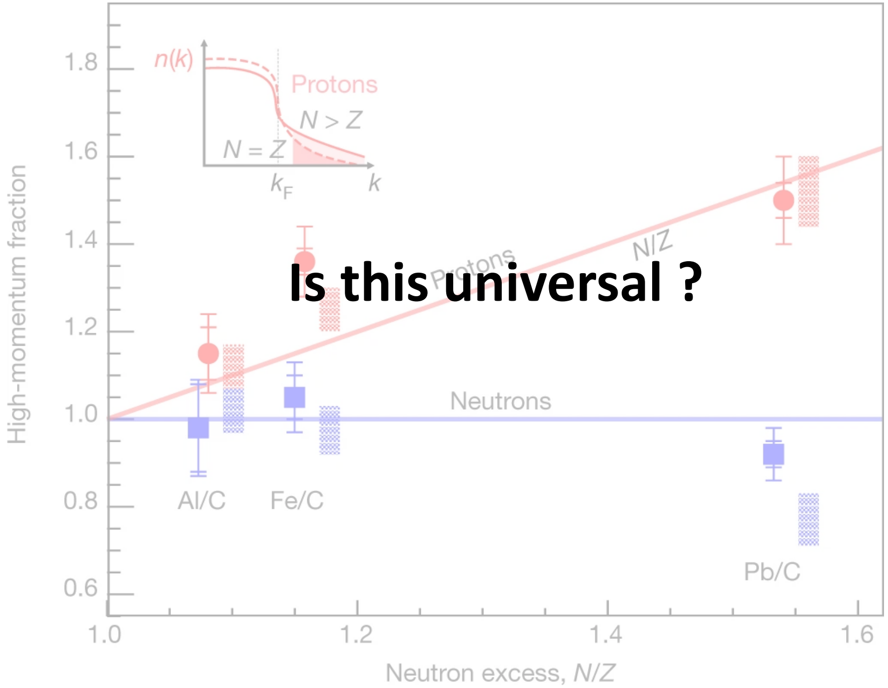
SRCs in neutron-rich nuclei



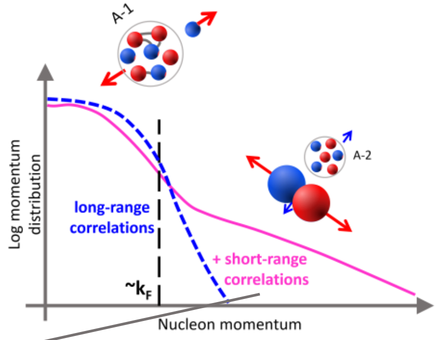


M. Duer et al. (CLAS), Nature 560 (2018).

SRCs in neutron-rich nuclei

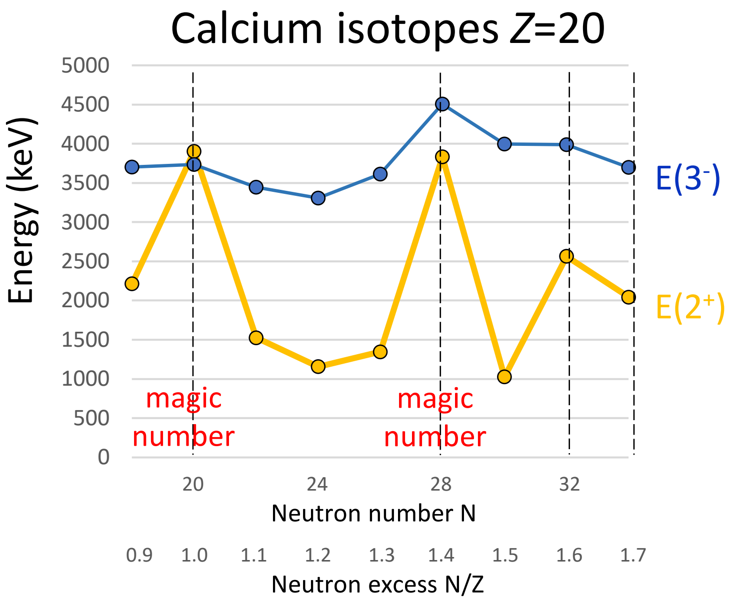


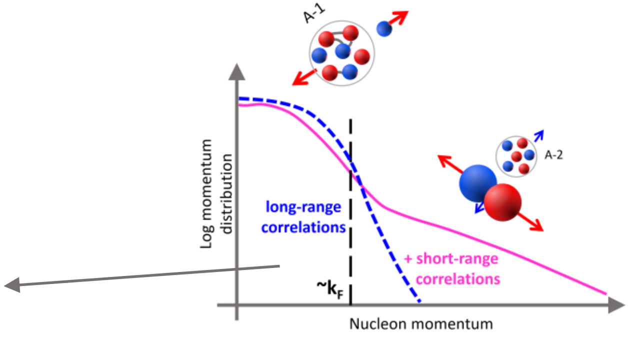
Is this universal ?



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

Understand role of excess neutrons directly and systematically in Ca chain





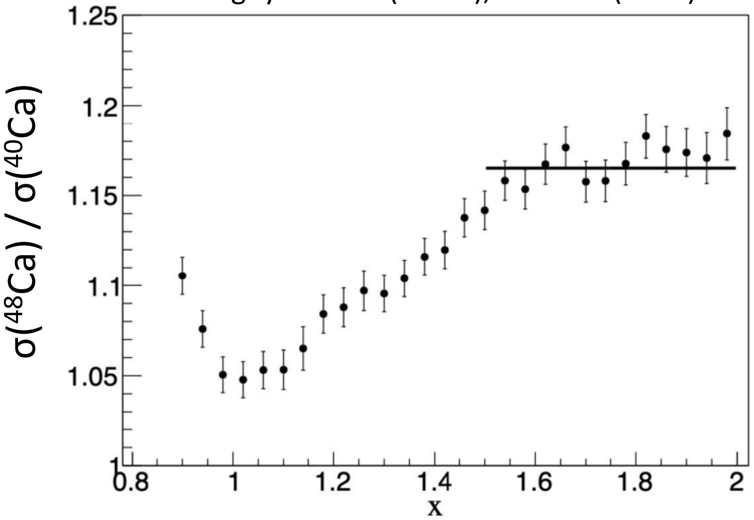
^{40}Ca → ^{48}Ca

+ 8 neutrons in f7/2 orbital

Reaction tools

- (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

Reaction tools

- (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)

Reaction tools

- (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, …

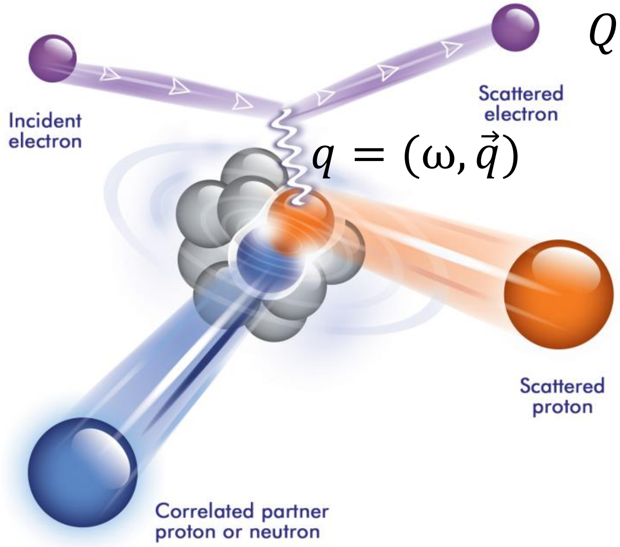
Hall B RG-M experiment 2021/22, under analysis: ^{40}Ca, ^{48}Ca, ^{120}Sn, …

mass & asymmetry
dependence
(N/Z=1.4)

Reaction tools

- (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)

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



Q^2, x_B

$q = (\omega, \vec{q})$

Leading proton:

$\vec{p}_{miss} = \vec{q} - \vec{p}_p$

(e,e'p) breakup reactions of SRC pairs

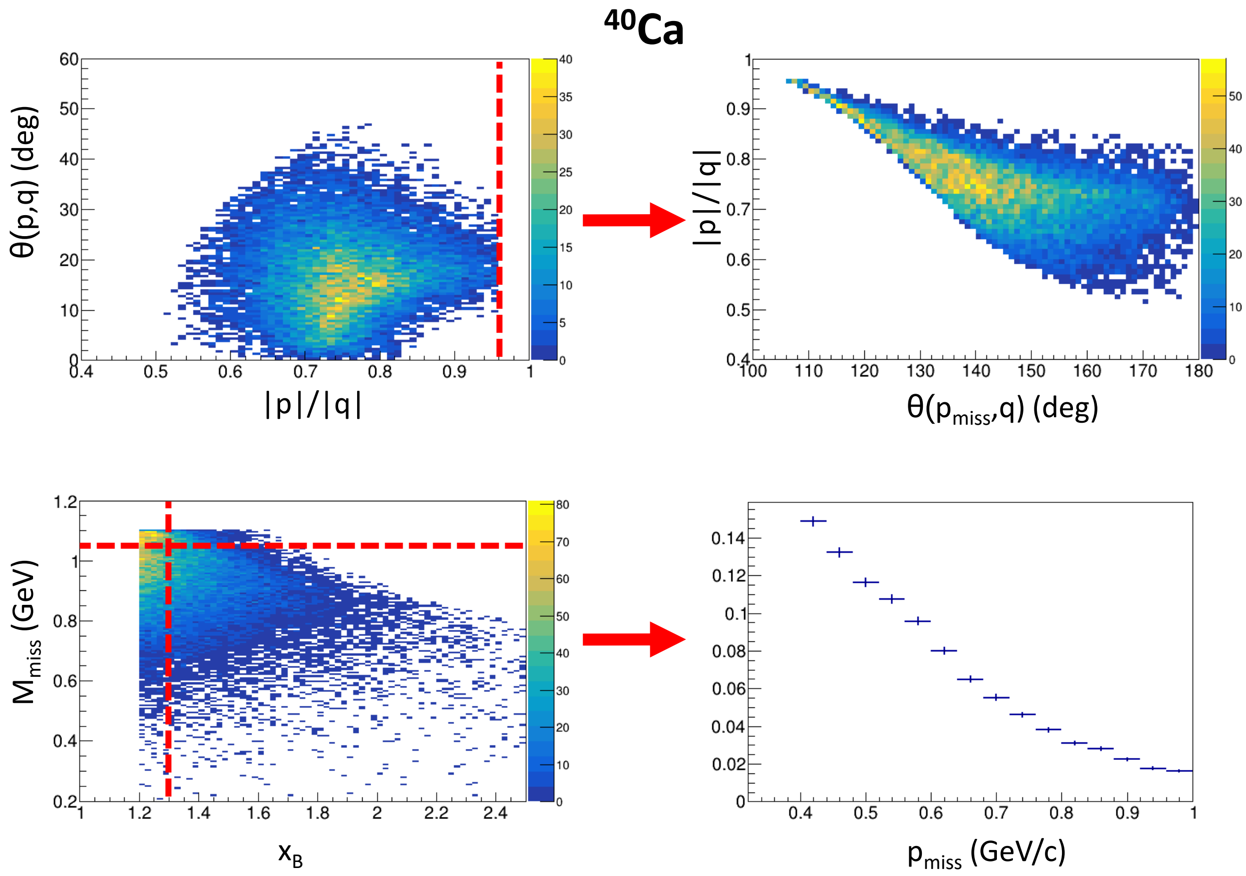
SRC selection:

Physics

- $x_B > 1.2$ → 1.3
- $Q^2 > 1.5$
- $p_{lead} > 1$ GeV/c
- $M_{miss} < 1.05$ GeV/c²
- 0.4 GeV/c < p_{miss} < 1.0 GeV/c

Detector

- electron in FD
- leading proton in CD:
  - 0.62 < p/q < 0.96 → < 0.96
  - ~~$\theta_{pq} < 25°$~~



O. Hen et al. (CLAS), Science 346 (2014).
M. Duer et al. (CLAS), Nature 560 (2018).
M. Duer et al. (CLAS), PRL 122 (2019).
A. Schmidt et al. (CLAS), Nature 578 (2020).
I. Korover et al. (CLAS), PLB 820 (2021).

Observable: (e,e´p) yield ratios (per nucleus)

Advantages:
- informs on impact of nuclear structure
- many systematic effects cancel (ϵ)

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

→ per nucleus yield ratio

N: norm (~ beam charge)
ϱ: area density
→ luminosity normalization

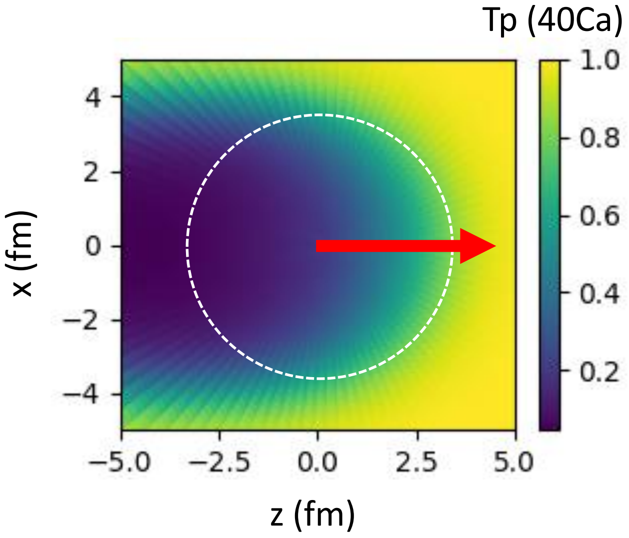
T: transparency
ϵ: detector efficiency

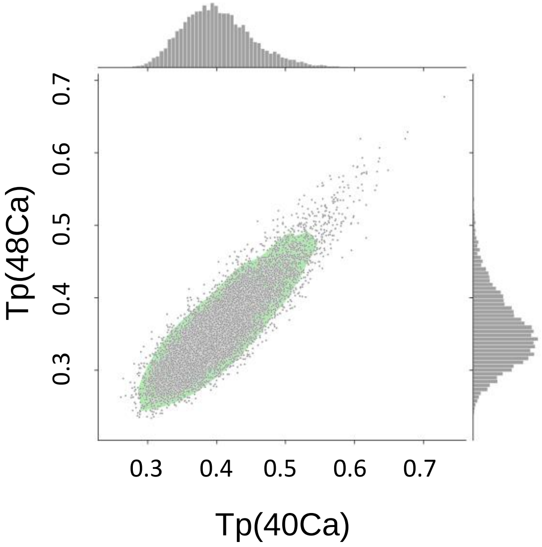
Single proton transparency in Glauber Model

$$T_p = \frac{1}{A}\int \rho(r) \times \exp\left\{-\sigma_{eff}^{lead}\int_C \rho(r)\hat{z}d\vec{l}\right\} d^3r$$

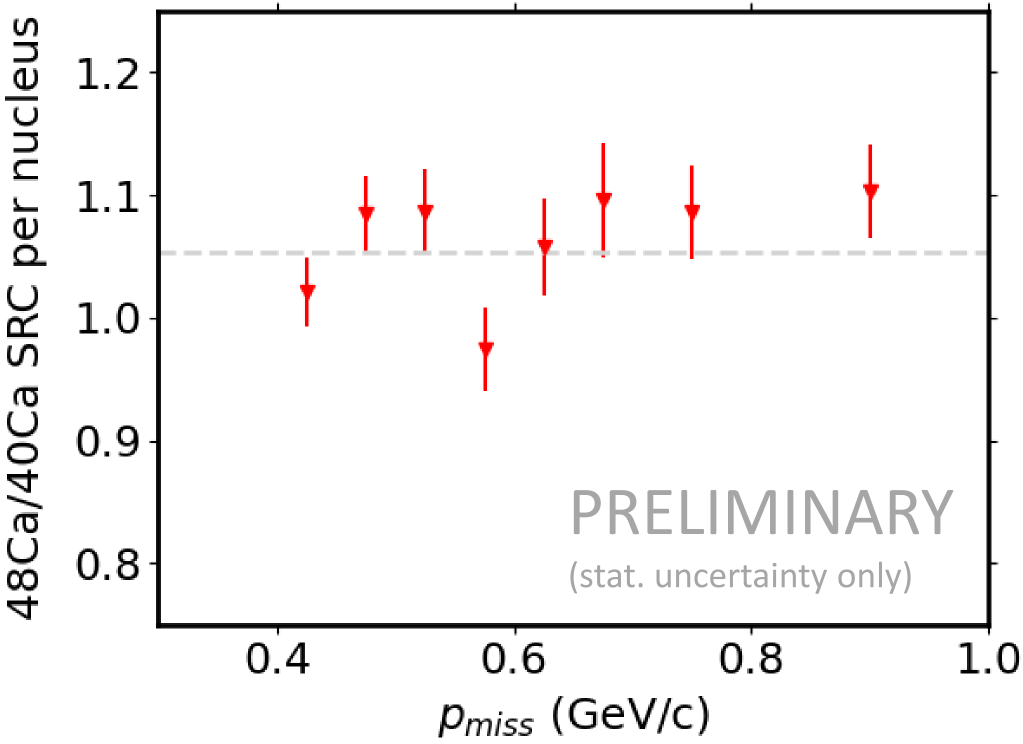
Input:

- 3 par. Fermi density distribution
- σ = 37±7 mb



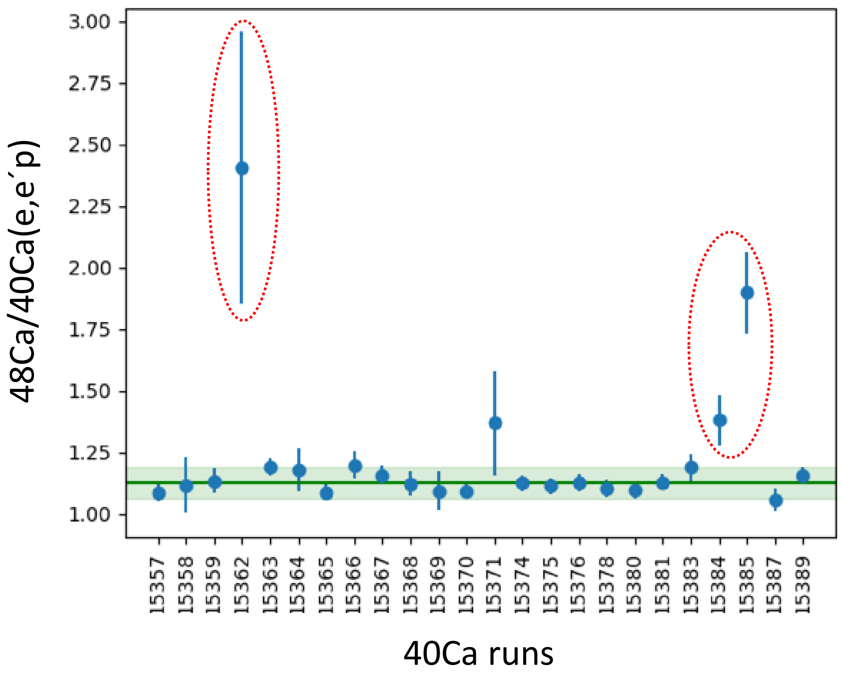


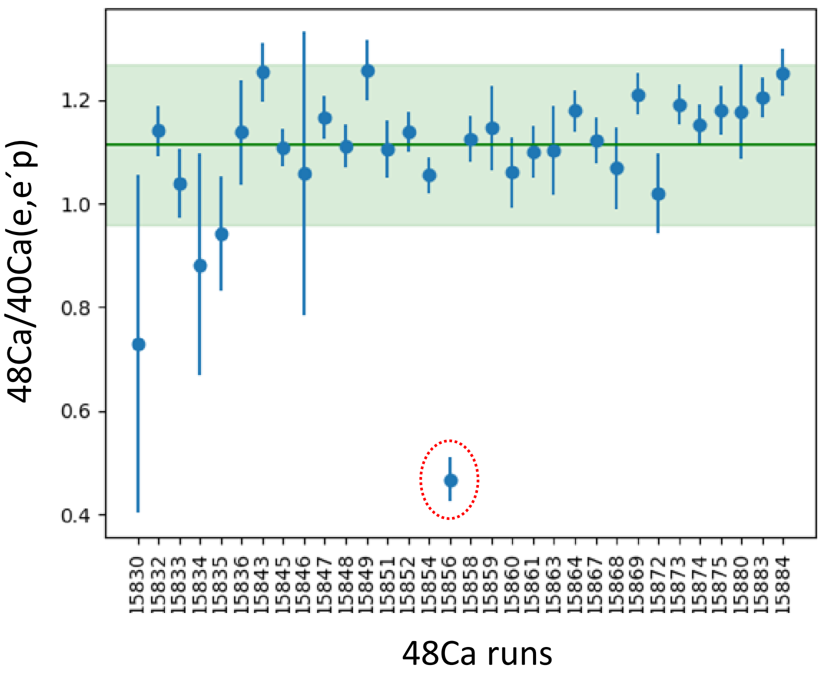
$^{48}Ca/^{40}Ca$ (e,e´p) yield ratio close to unity



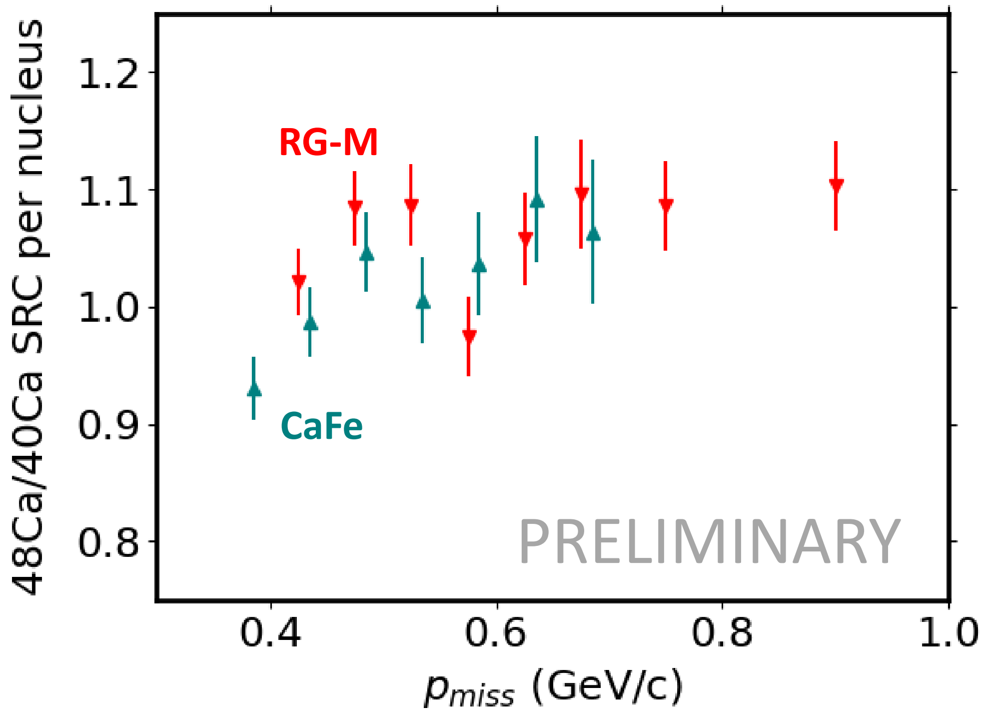
≠ ~1.2

Run dependence





RG-M consistent with Hall C results

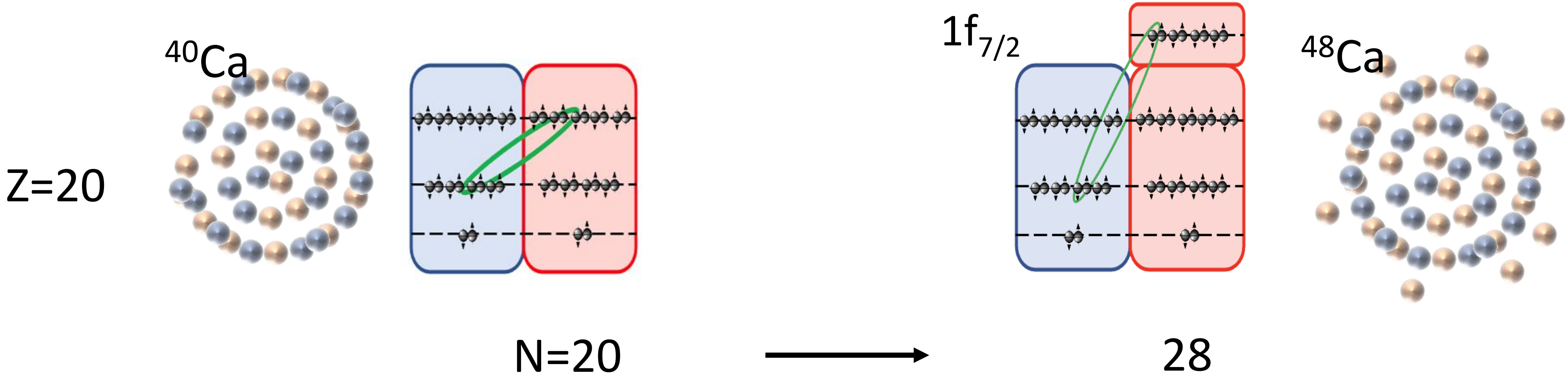


PRELIMINARY

	Integrated $^{48}Ca/^{40}Ca$ SRC ratio per nucleus	
RG-M (Hall B)	**1.05 (10)**	stat. + Tp + norm uncertainty
CaFe (Hall C)	**1.02 (1)**	

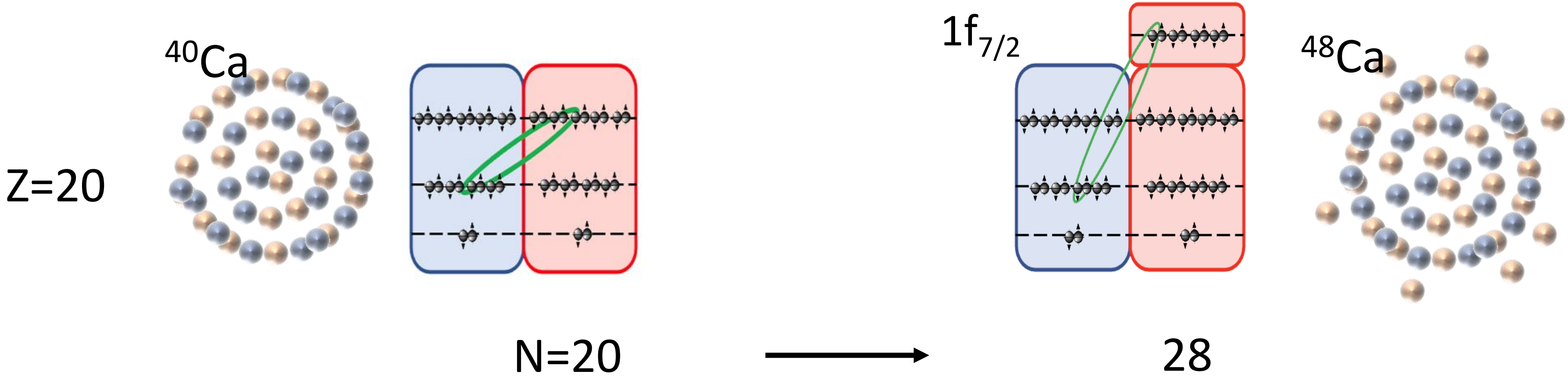
[Carlos Yero (ODU), Dien Nguyen (JLAB) et al.]

Preliminary interpretation: MF to impact SRC



48Ca/40Ca(e,e‘p) = 1.05

Preliminary interpretation: MF to impact SRC



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

Thank you.