Jefferson Lab
Thomas Jefferson National Accelerator Facility

Meson Photoproduction as a Measure of SRC Universality

Jackson Pybus

APS Topical Group on Hadronic Physics

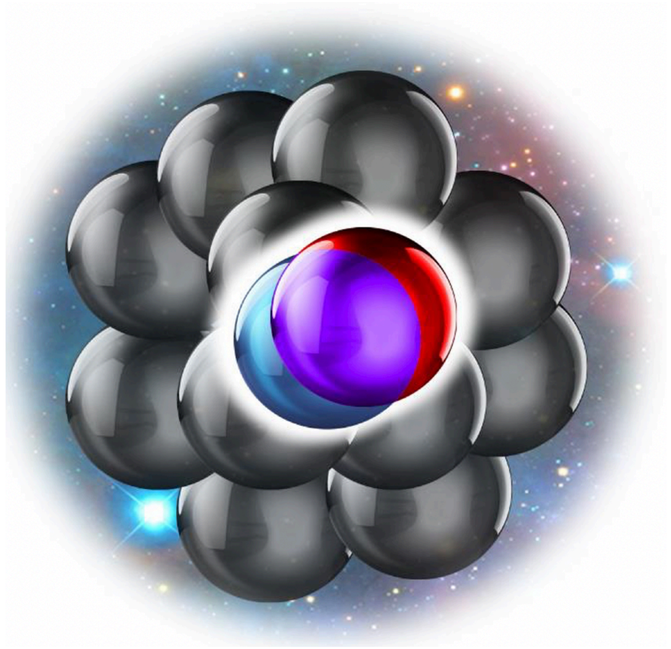
March 14, 2025

LNS
Laboratory for Nuclear Science

Los Alamos
NATIONAL LABORATORY

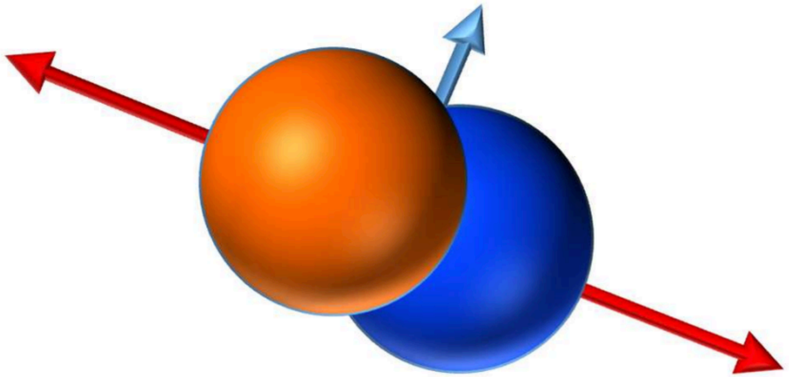
What do we know about SRCs?

Short-ranged, short-lived, highly correlated pairs of nucleons



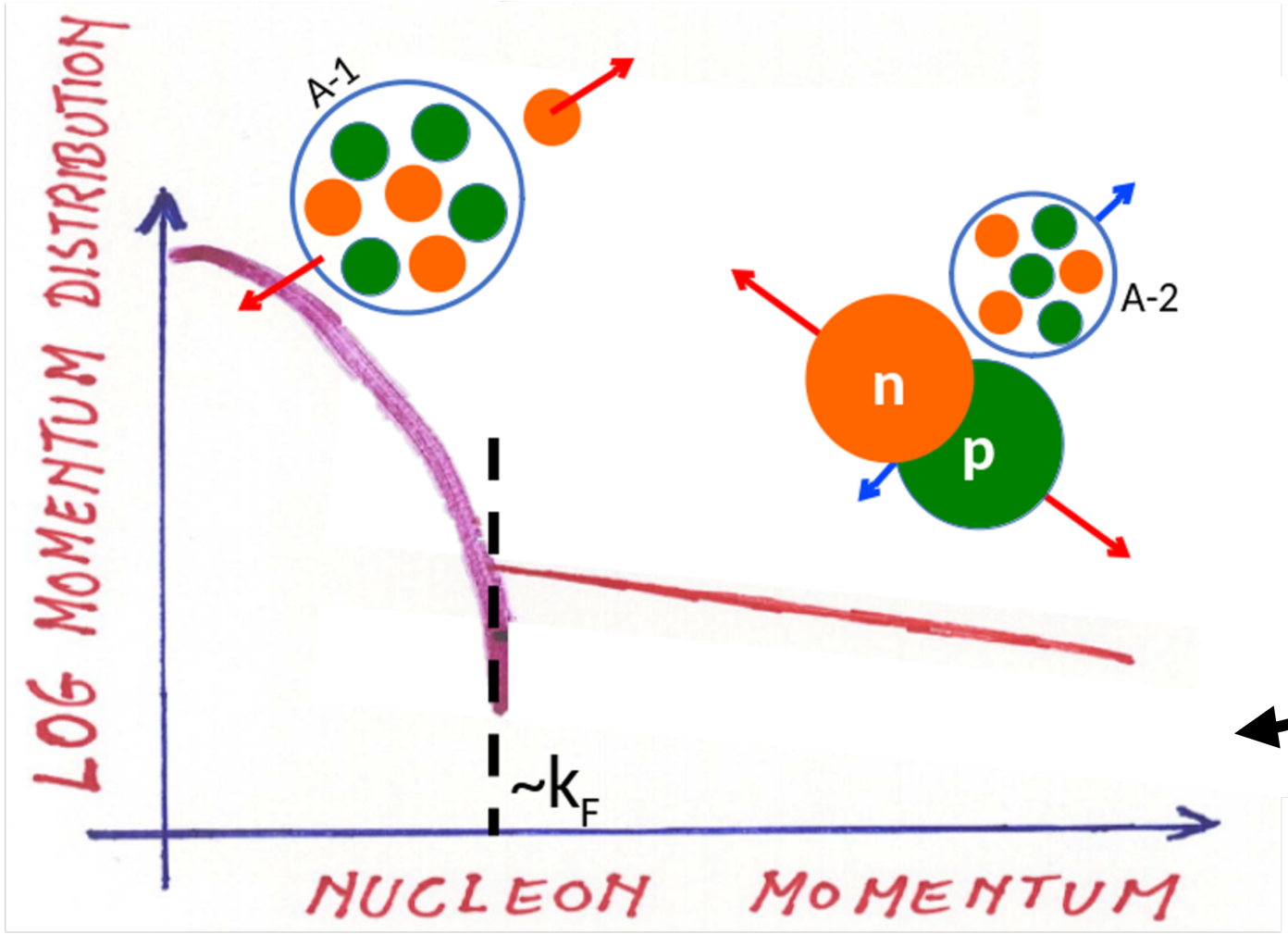
Position-space

High relative and lower center-of-mass momentum



Momentum-space

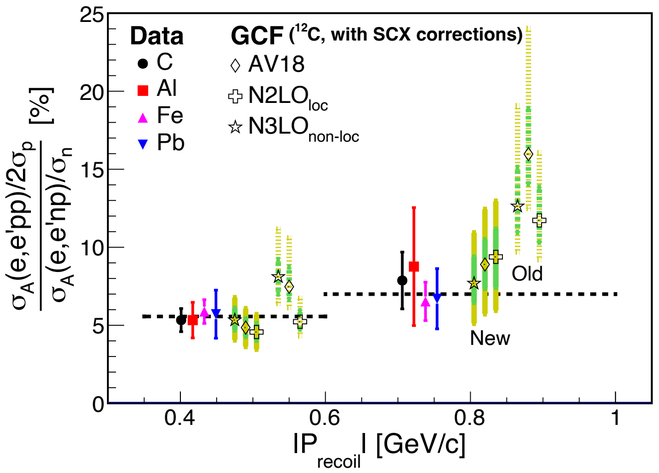
What do we know about SRCs?



Universal high-momentum "tail" – about 10-20% of nucleons

Many recent results in quantitative study of SRCs

PRL 122, 172502 (2019)



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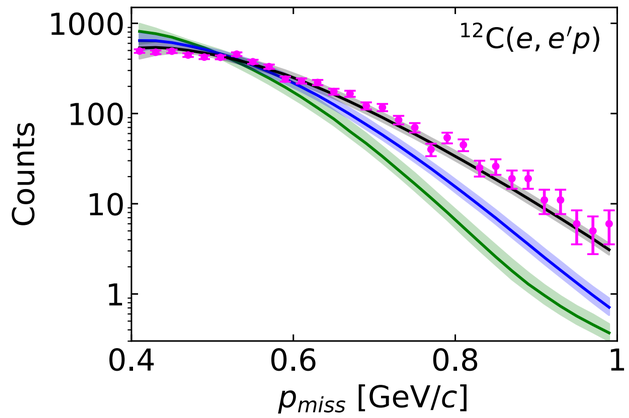

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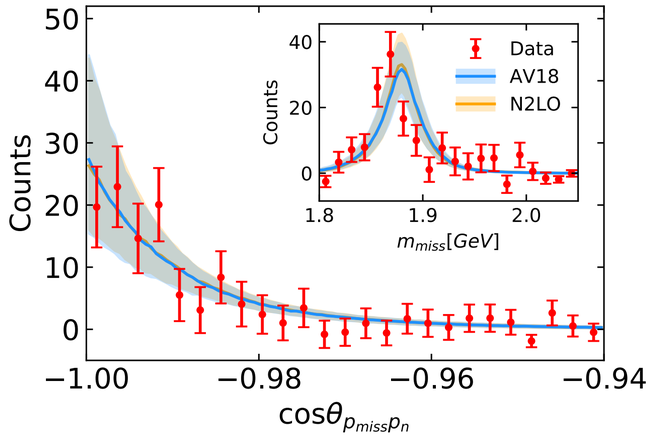
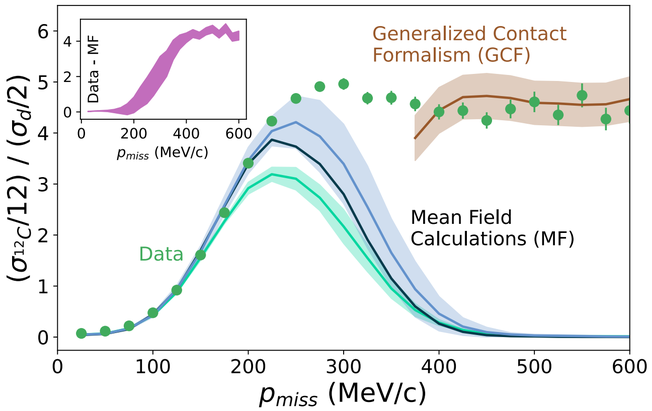


PRC 107, L061301 (2023)



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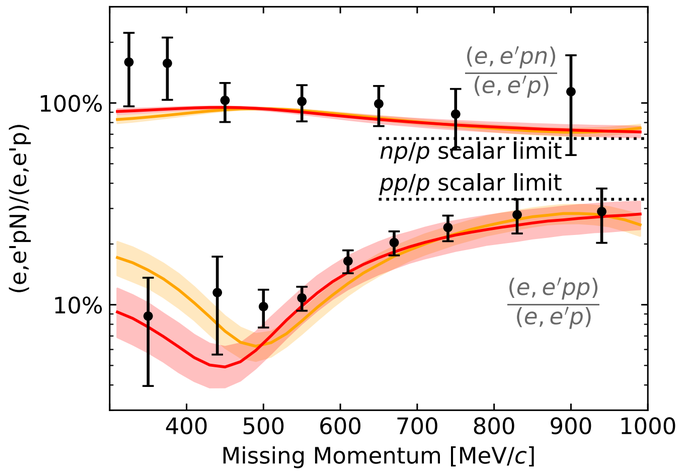

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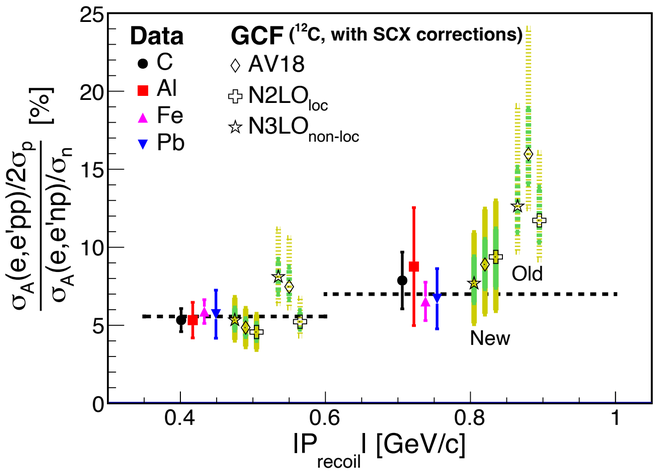

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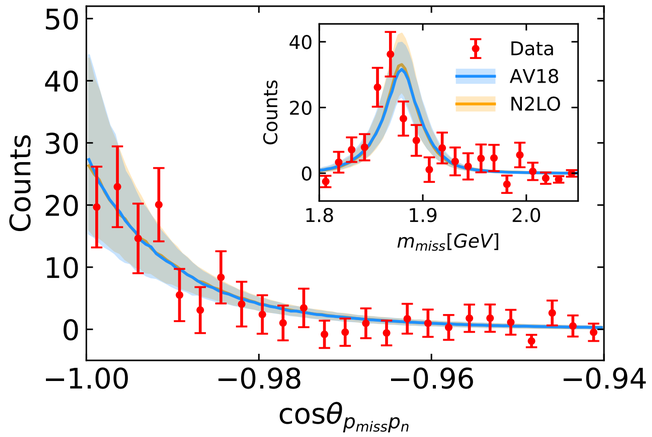
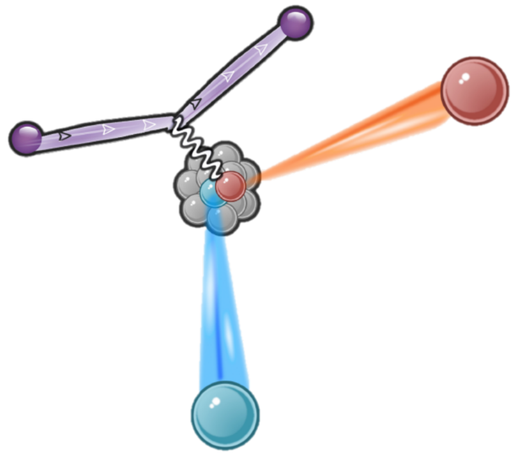
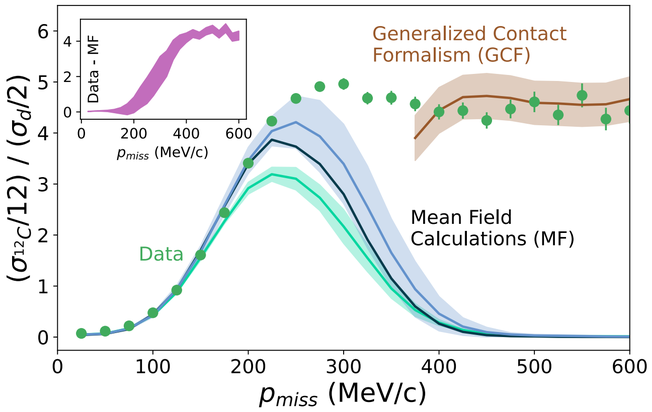




Electron Scattering Measurements

PRC 107, L061301 (2023)



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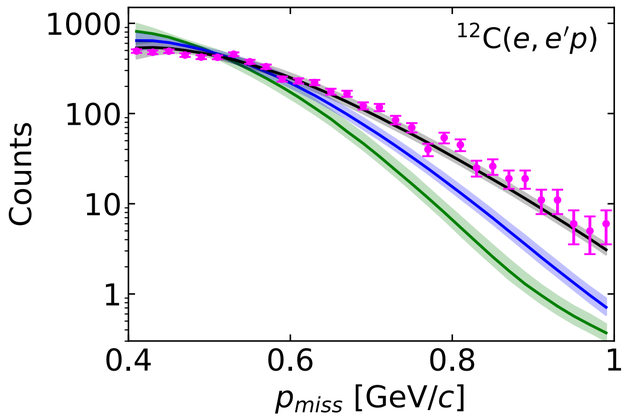

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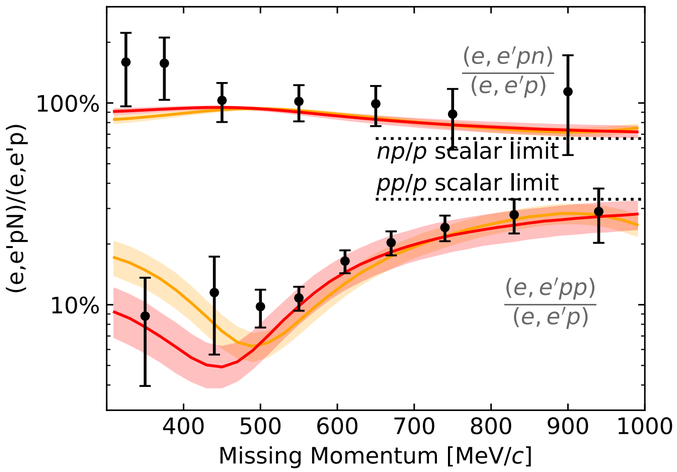
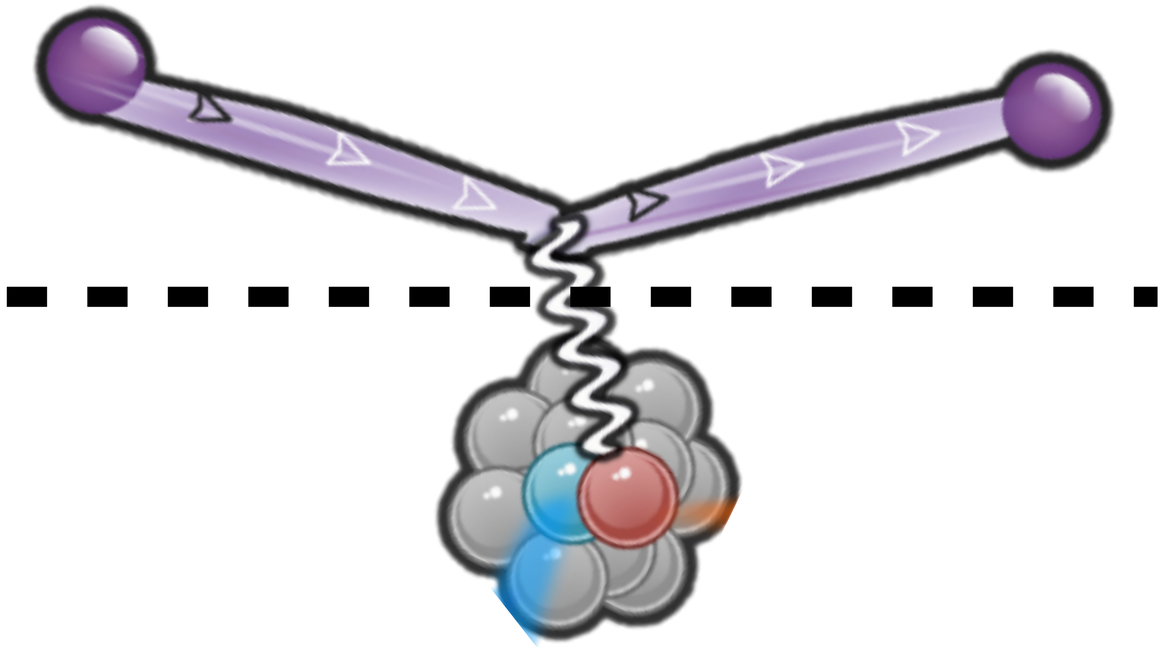


Ground-state interpretation requires establishing plane-wave factorization!



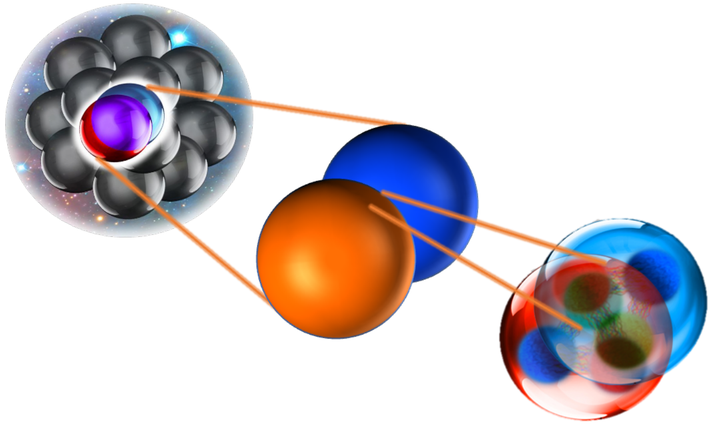
High-energy **Reaction**

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

Low-energy **Ground-State**

Two ways to examine reaction-dependence:

Scale



Q^2, $|t|$ change the resolution **scale**

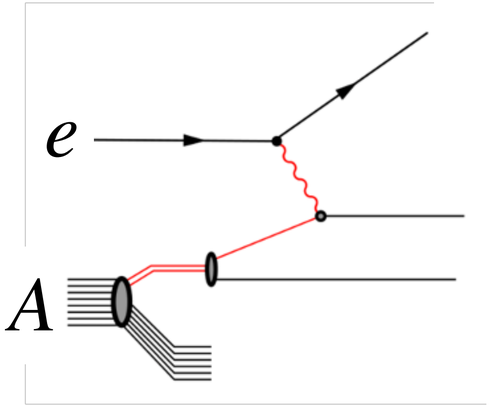
Probe

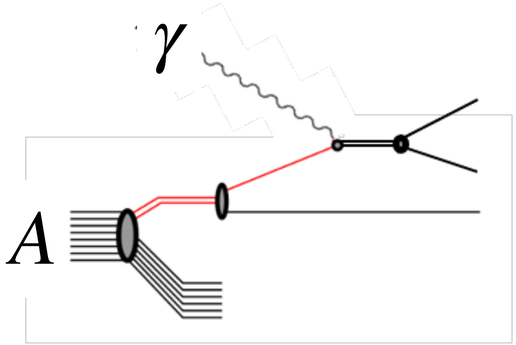
Different **probes**:

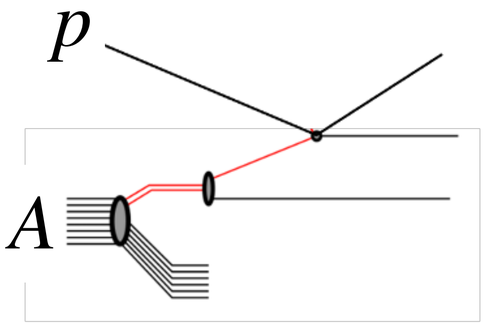
Electromagnetic (e^-),

Hadronic (p, A),

Photonuclear (γ)







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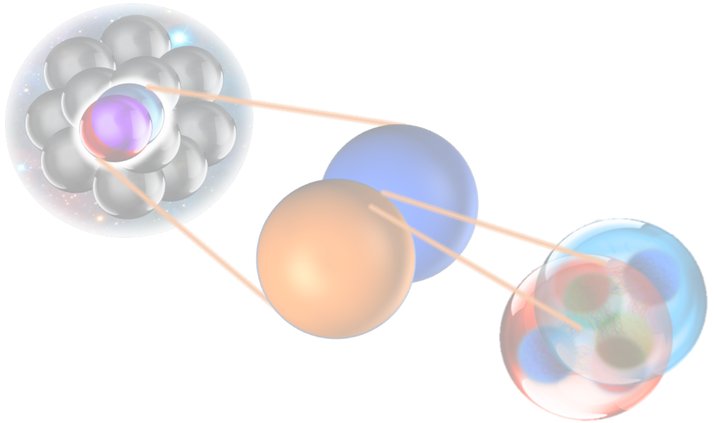

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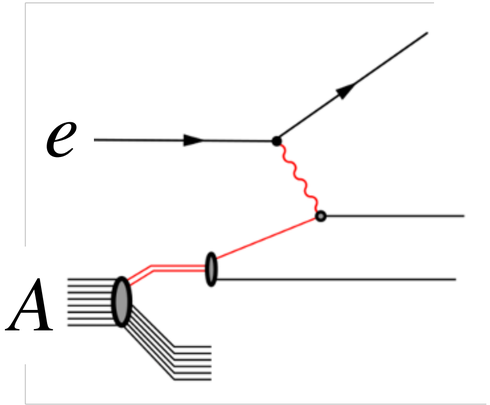
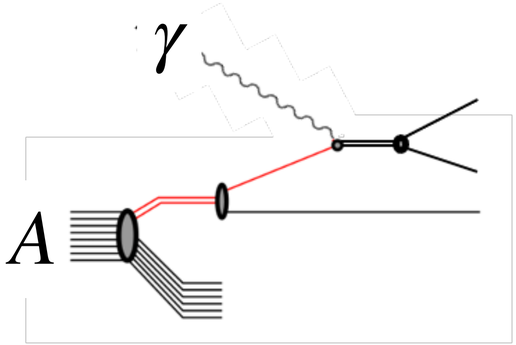
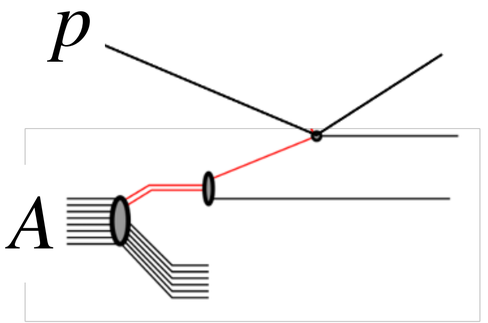
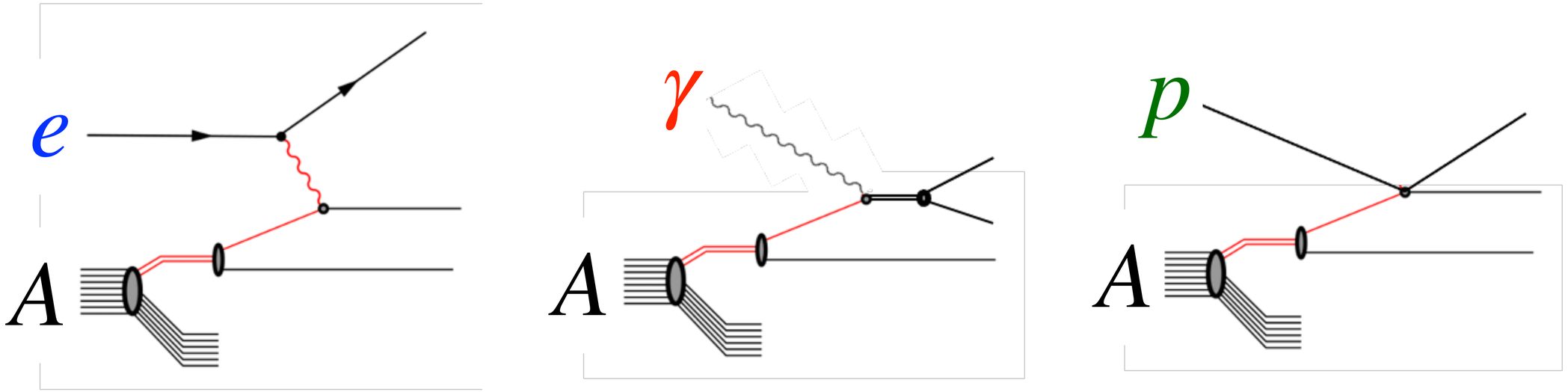






Probe Dependence of SRCs



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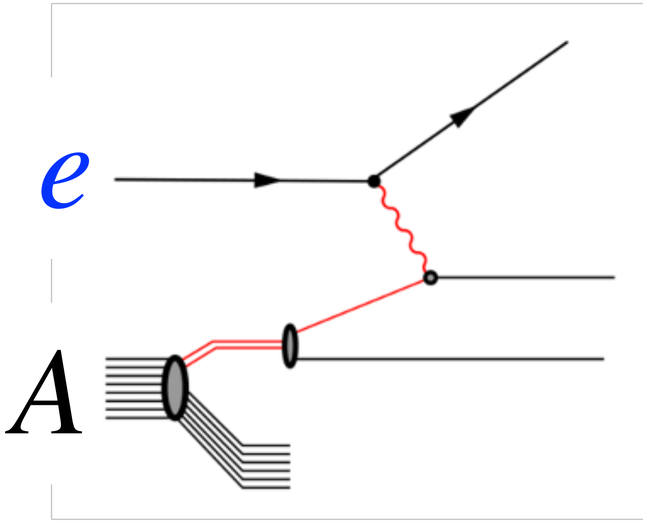
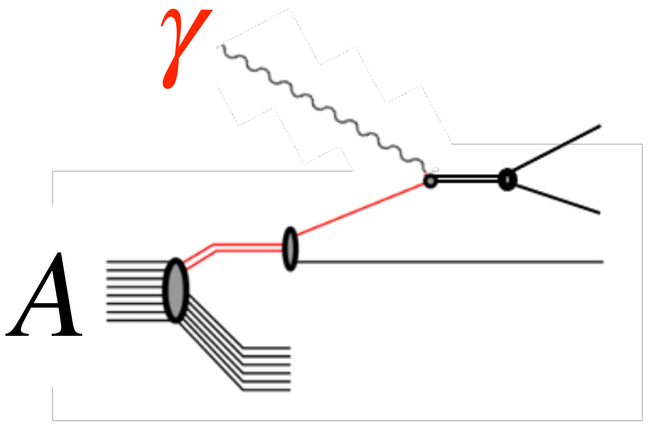
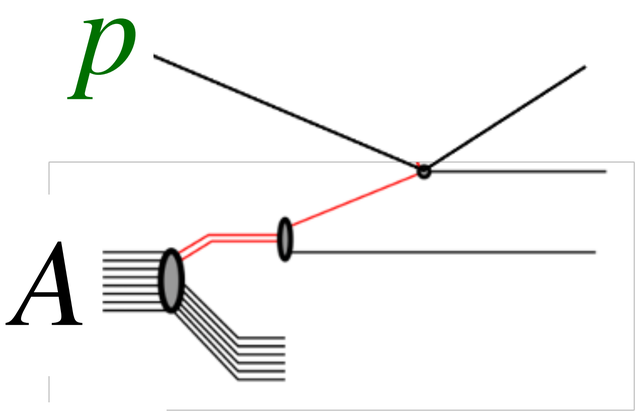
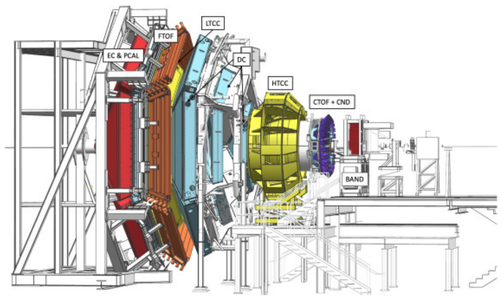
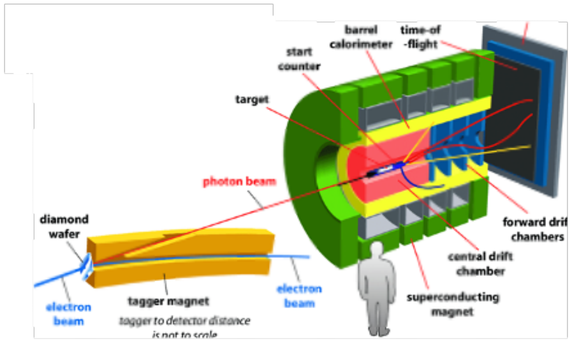




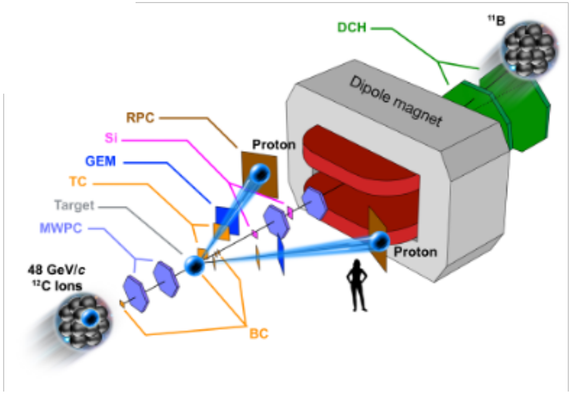




CLAS12

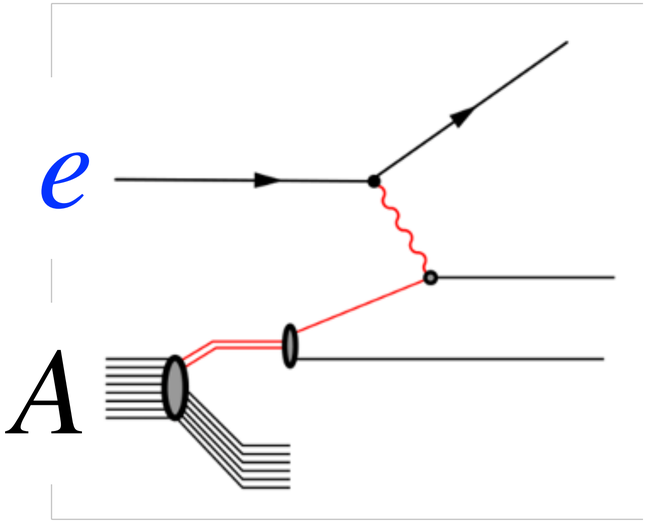


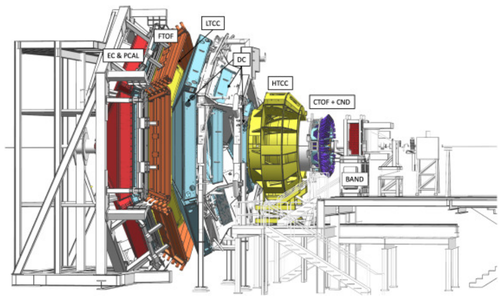
GlueX



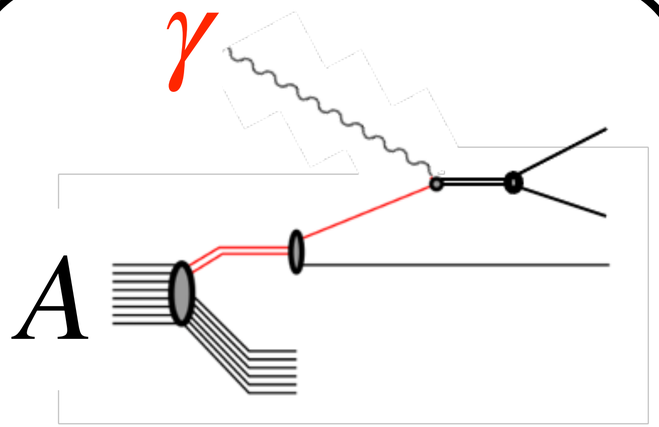
BM@N / R3B

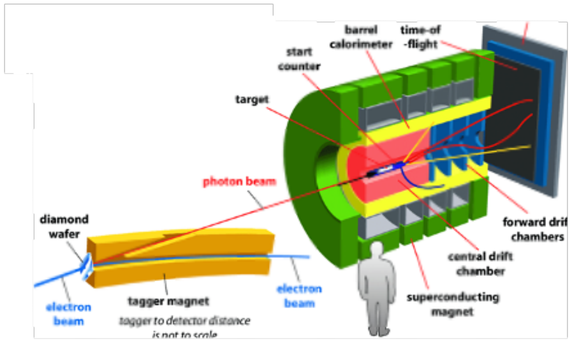
Probe Dependence of SRCs





CLAS12





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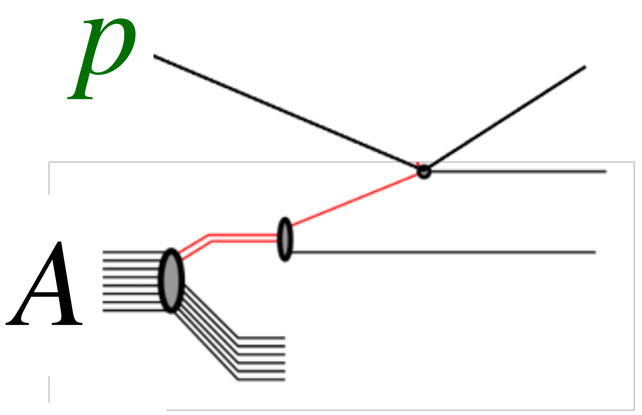
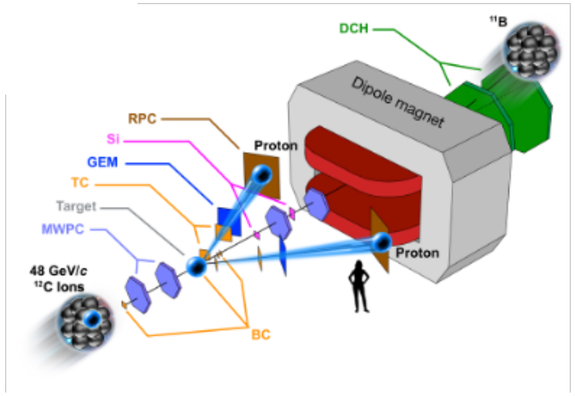
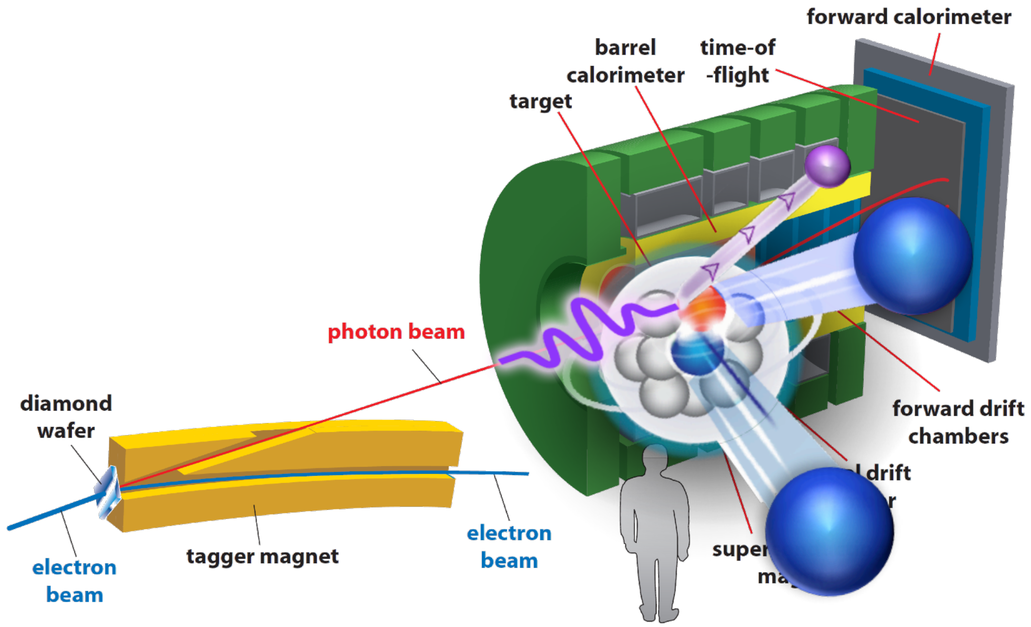


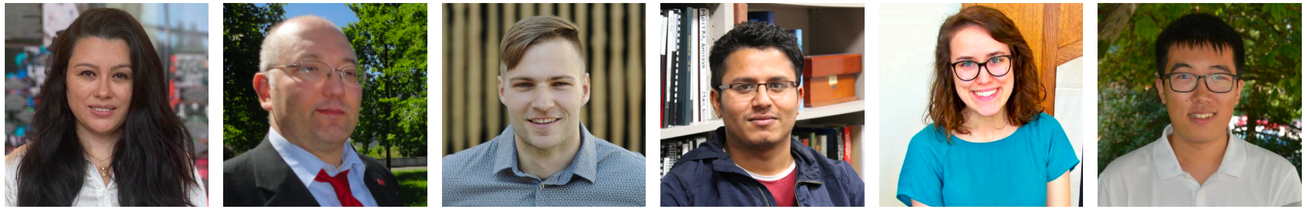


BM@N / R3B

Hall D SRC-CT Experiment



- Dedicated high-energy photonuclear measurement in Jefferson Lab Hall D
- 10.8-GeV electron beam – energy-tagged coherent bremsstrahlung
- ~40-day measurement of targets ^{2}H, ^{4}He, ^{12}C
- Final-state particles detected in large-acceptance GlueX spectrometer



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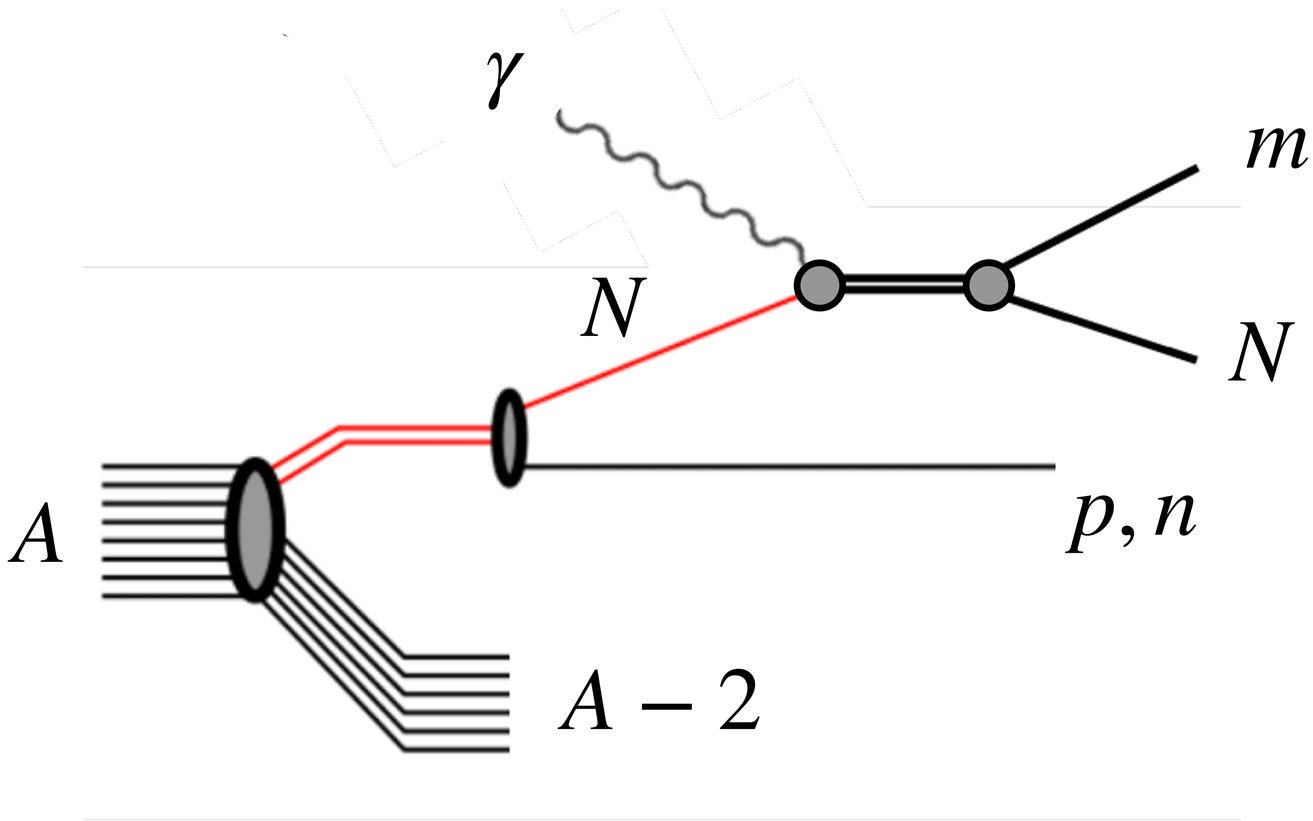
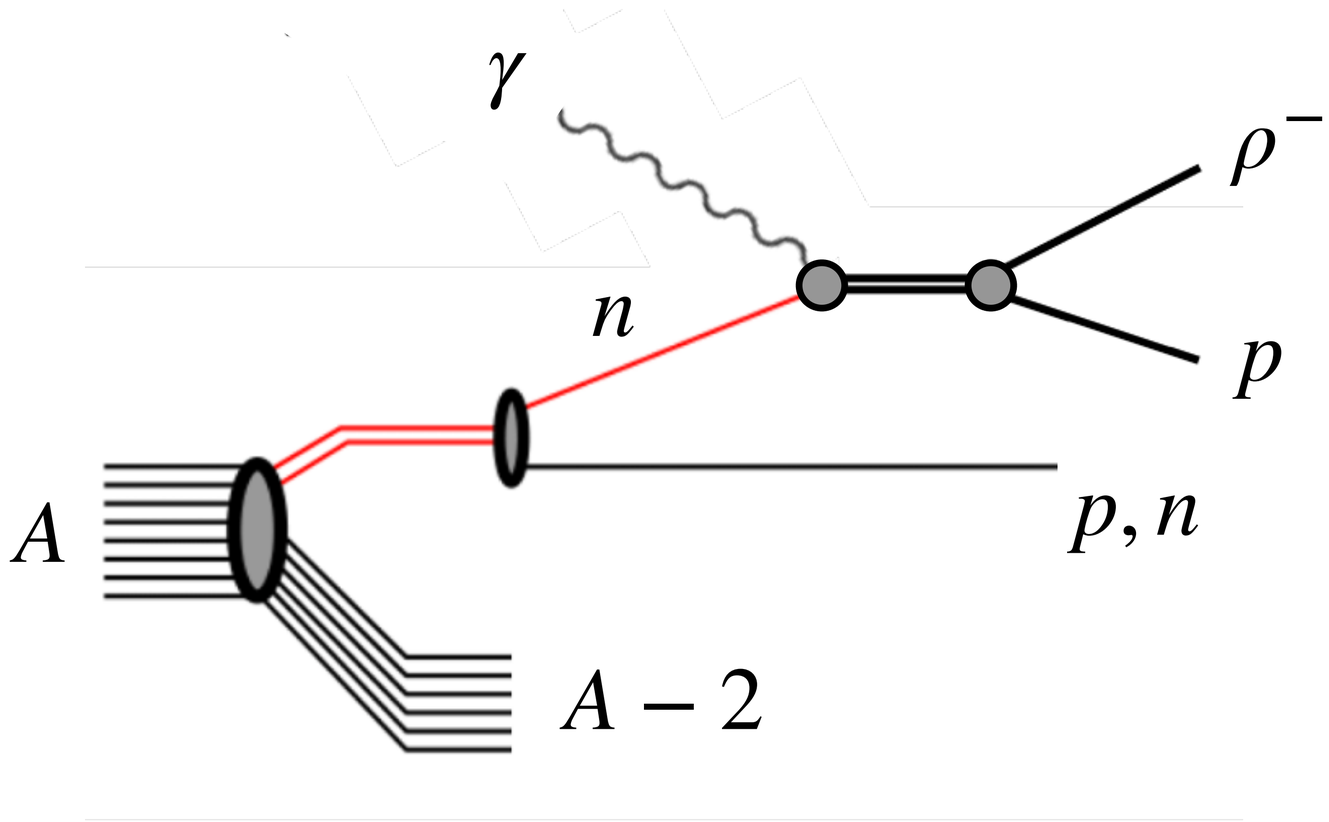
SRC Photoproduction in Hall D

- Quasi-elastic photoproduction: hard photon-nucleon interaction



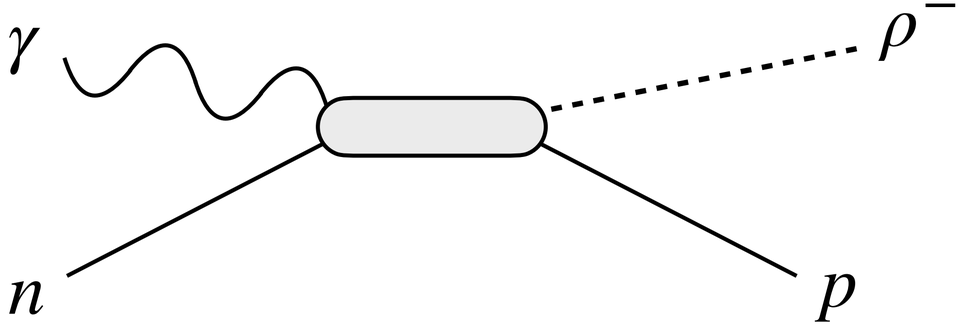
SRC Photoproduction in Hall D

- Quasi-elastic photoproduction: hard photon-nucleon interaction
- ρ^- photoproduction:
  - Initial-state neutron
  - Distinctive $\rho^- \rightarrow \pi^-\pi^0$ decay
- Measurements of $(\gamma, \rho^- p)$ and $(\gamma, \rho^- pp)$



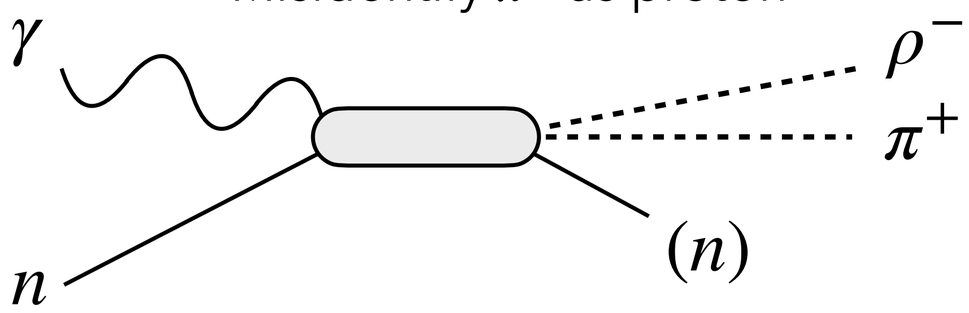
SRC Event Selection

Signal Process: $\gamma n \rightarrow \rho^- p$



Background: $\gamma n \rightarrow \rho^- \pi^+ n$

Misidentify π^+ as proton



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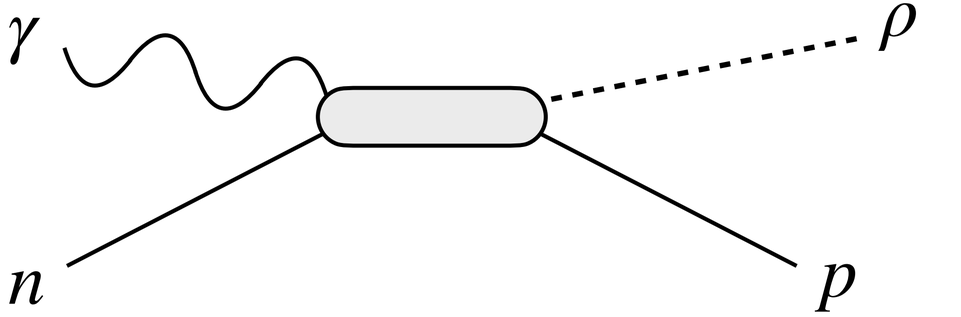

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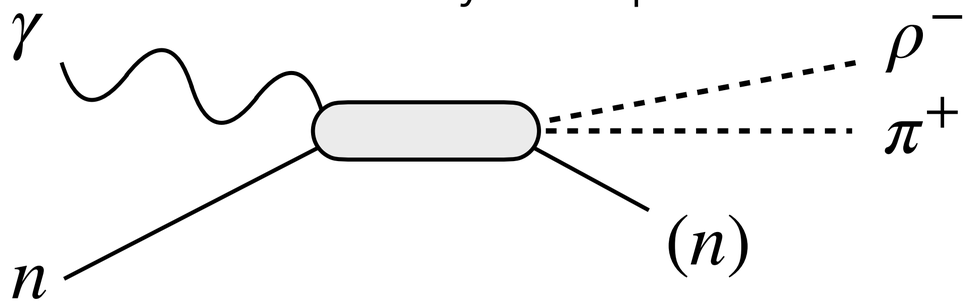
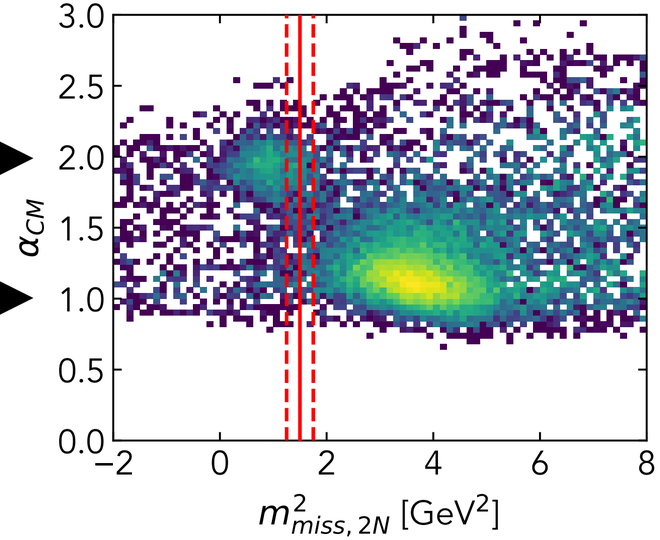


Two-nucleon knockout →

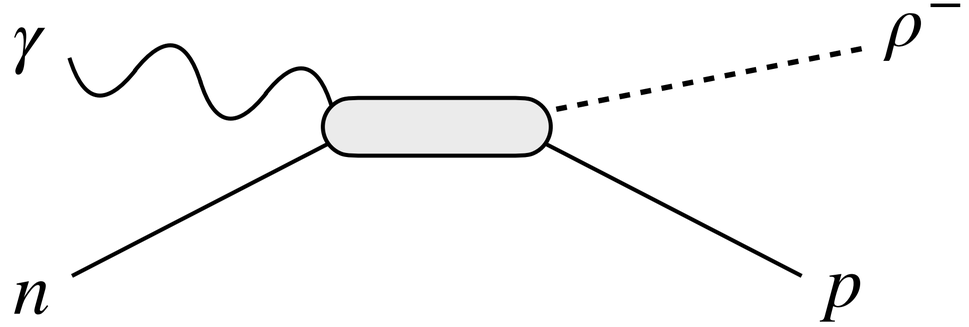
One-nucleon knockout →



Second nucleon detection can help identify signal vs. background kinematics

SRC Event Selection

Signal Process: $\gamma n \rightarrow \rho^- p$



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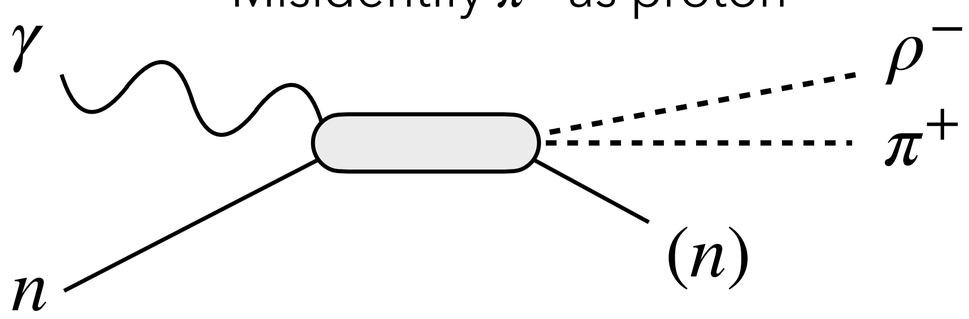
Misidentify π^+ as proton

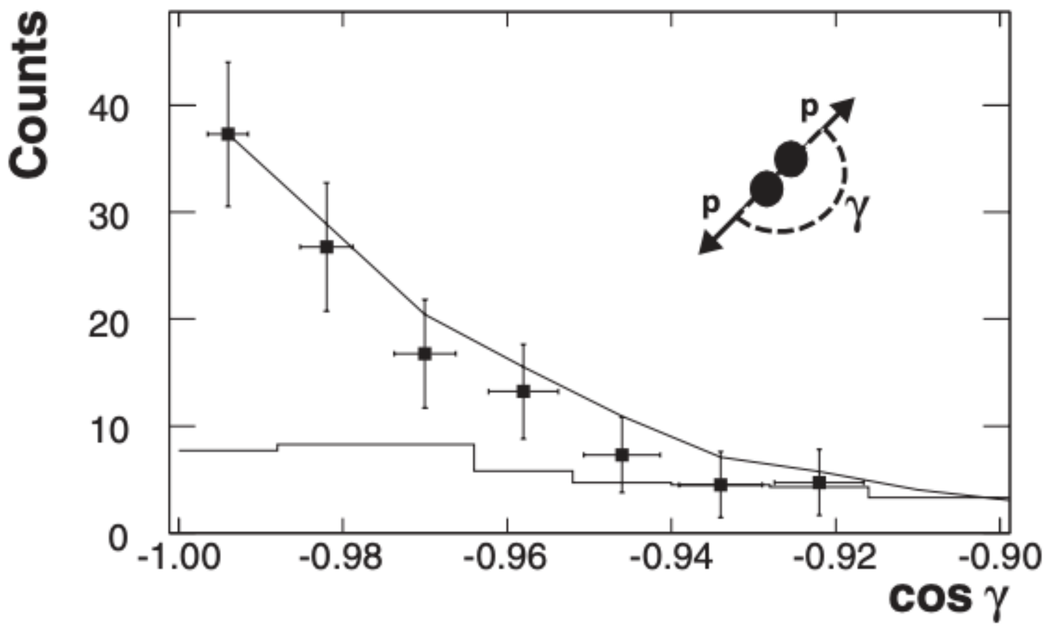


Inclusive variables:

- Momentum-transfer: $t_M = (p_\gamma - p_M)^2$
- Invariant mass: $W_M^2 = (p_\gamma + p_N - p_M)^2 \sim m_N^2$
- Scaling variable: $\zeta_M \equiv \dfrac{-t_M}{2m_N(E_\gamma - E_M)} \sim 1$

Novel photoproduction variables balance **PID**, **resolution**, and **kinematic** considerations to identify SRC signal

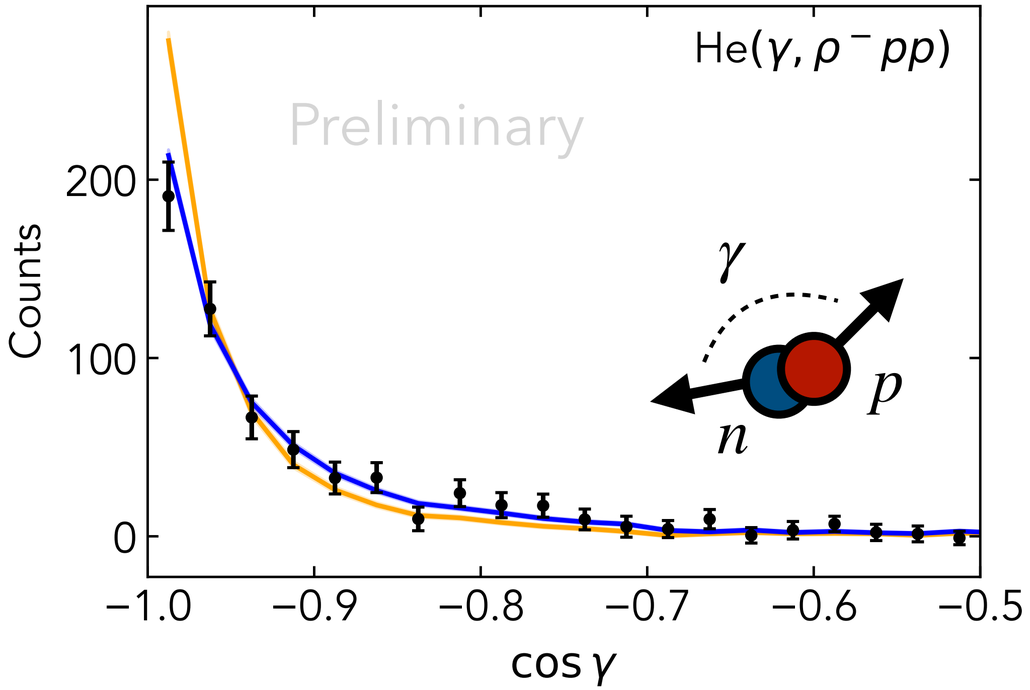
First observation of SRCs in photoproduction

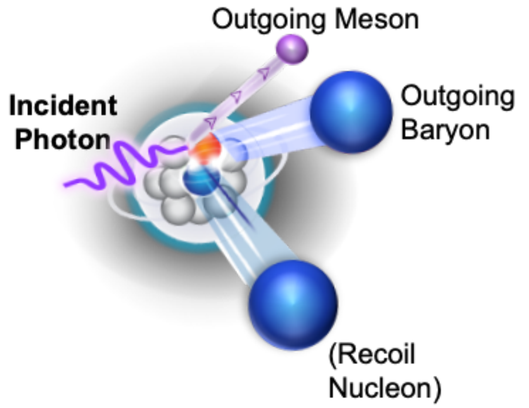


PRL 2007

Back-to-back correlation in

$(e, e'pp)$ @ Hall A





$\gamma np \rightarrow \rho^- pp$

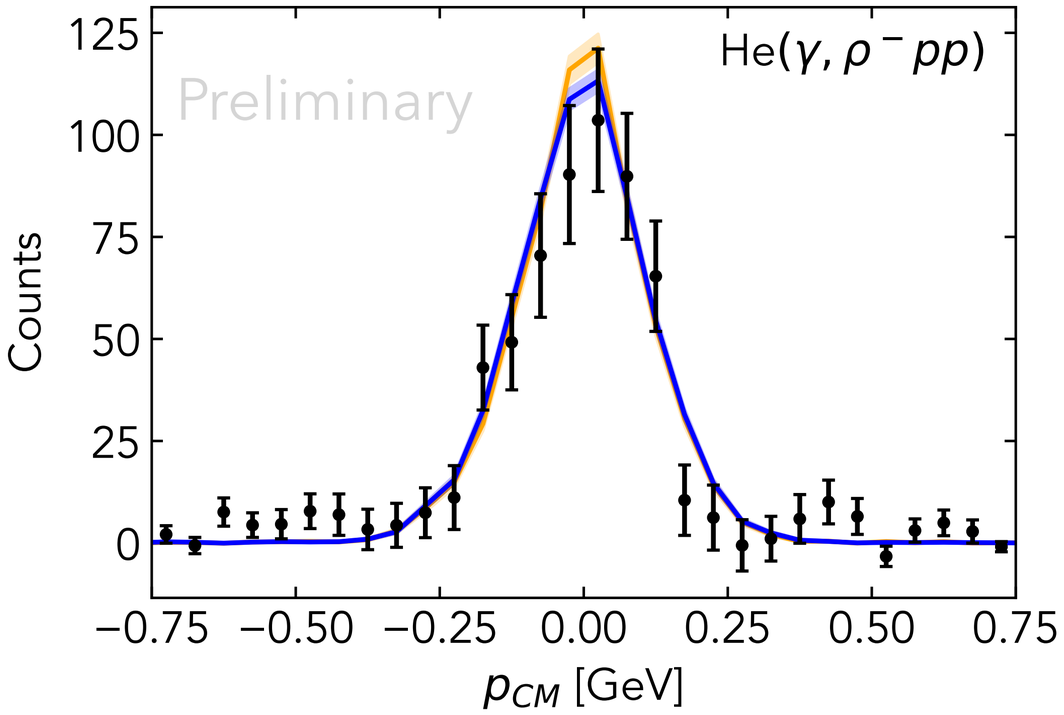
@ Hall D

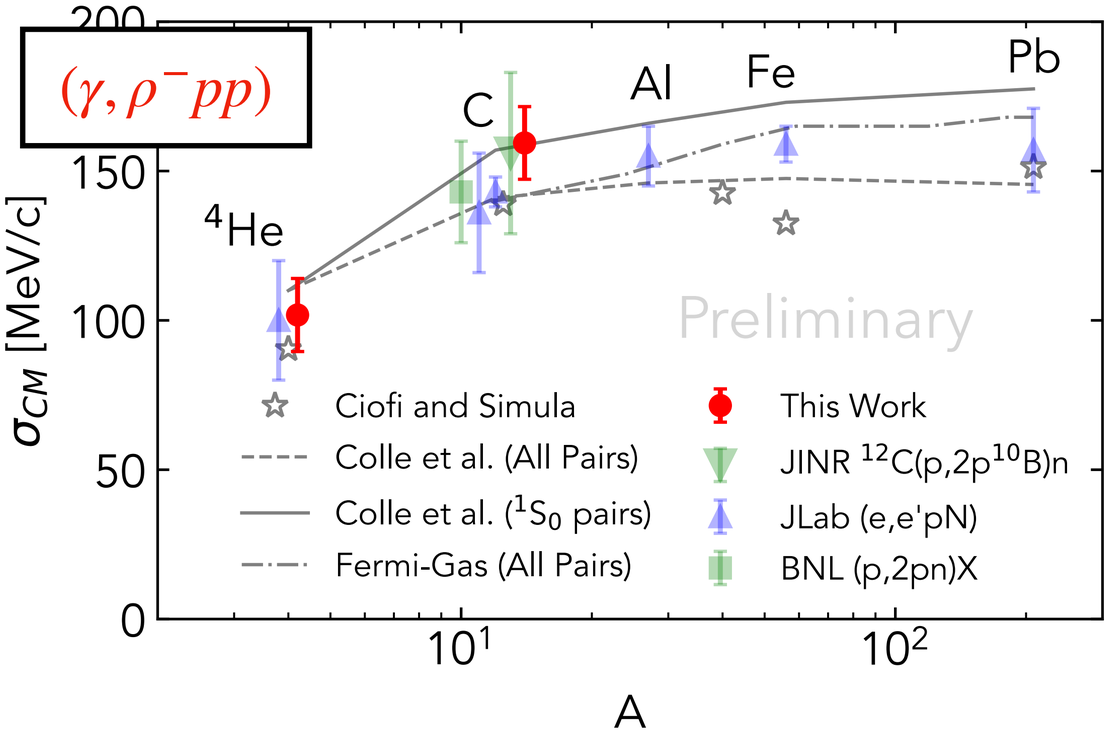
SRC Center-of-Mass Motion

e^-: **PRL (2018)**

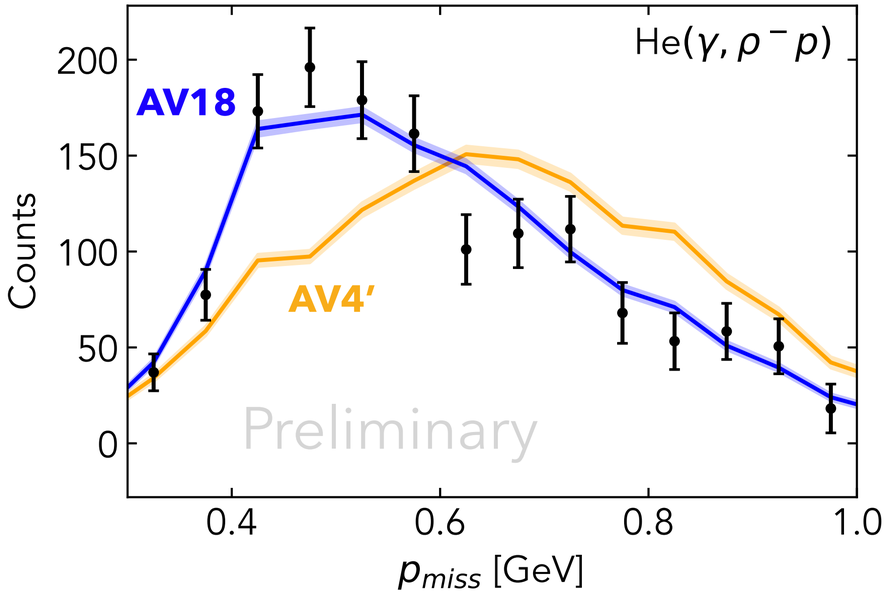
p: **Nature Physics (2021)**

γ: **SRC-CT (2024)**





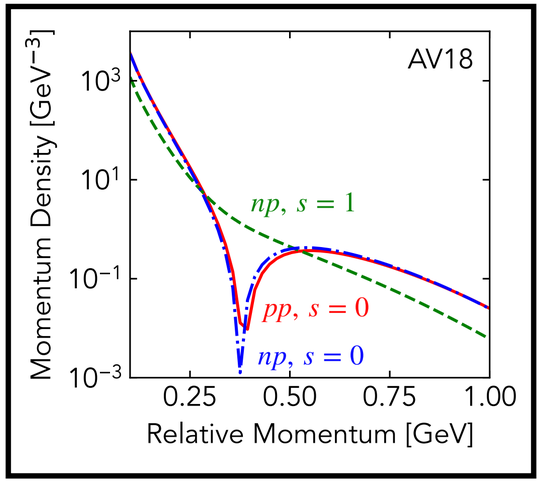
Data connect to ab-initio theory at high momentum; Distinguish realistic and unrealistic models

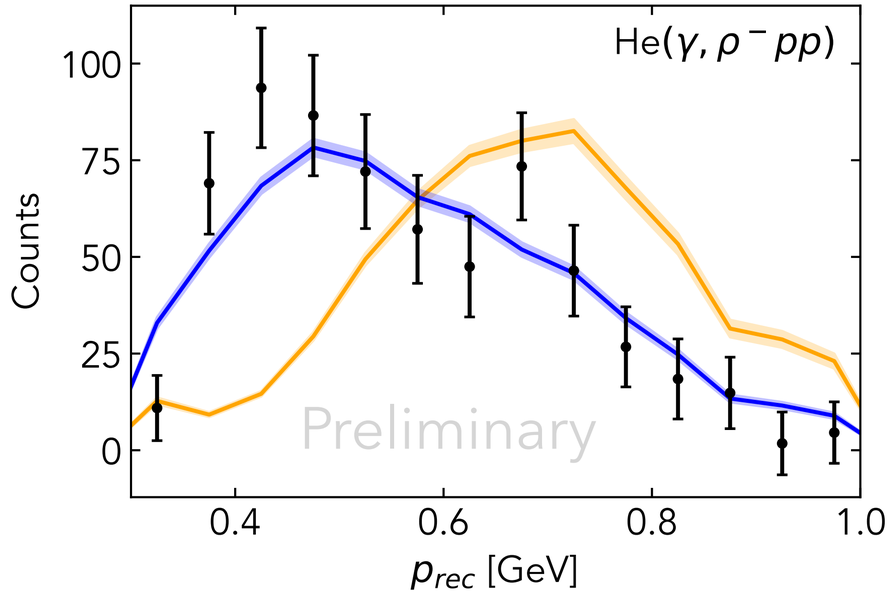


Initial neutron momentum

Inferred from momentum conservation

NN Interaction

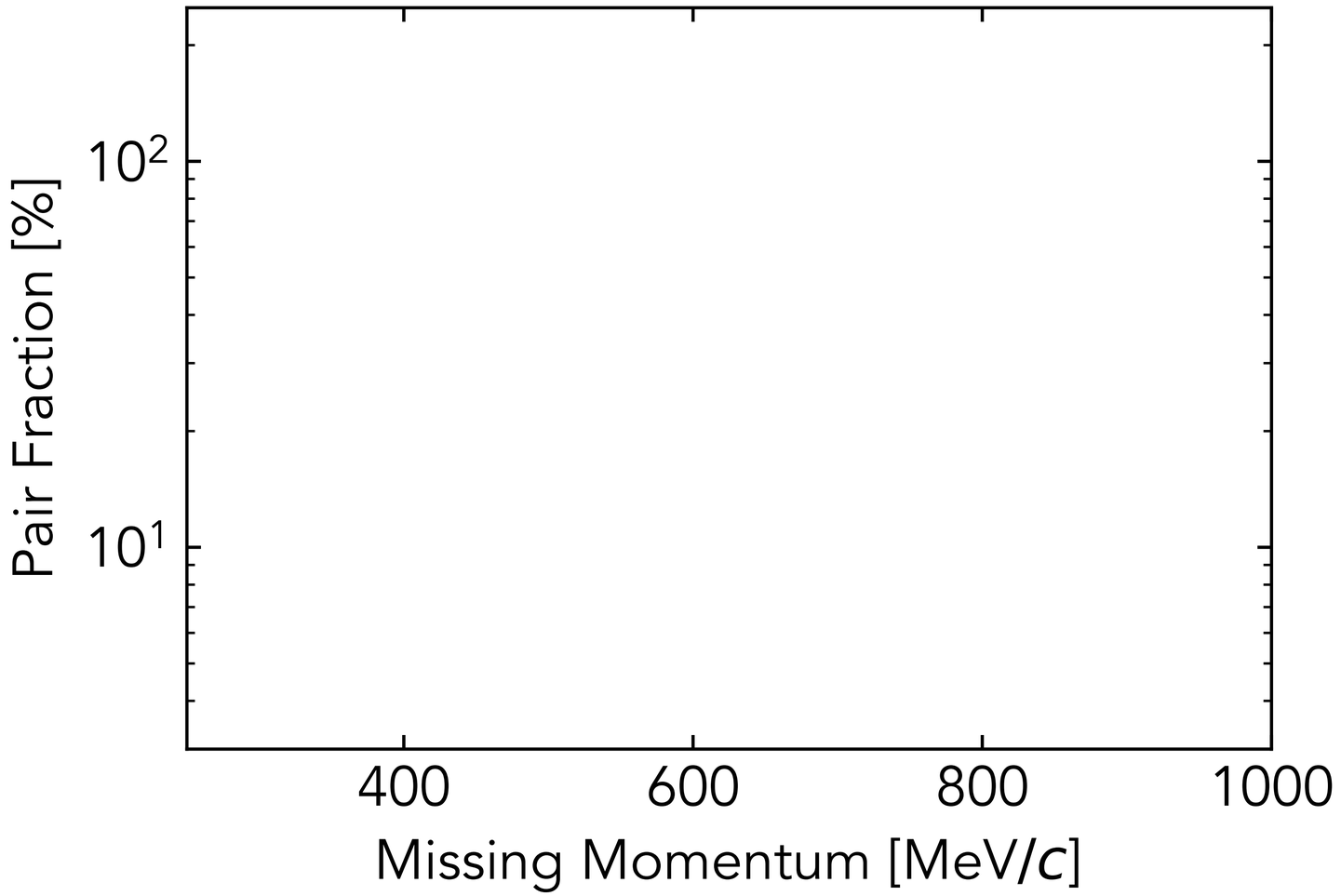




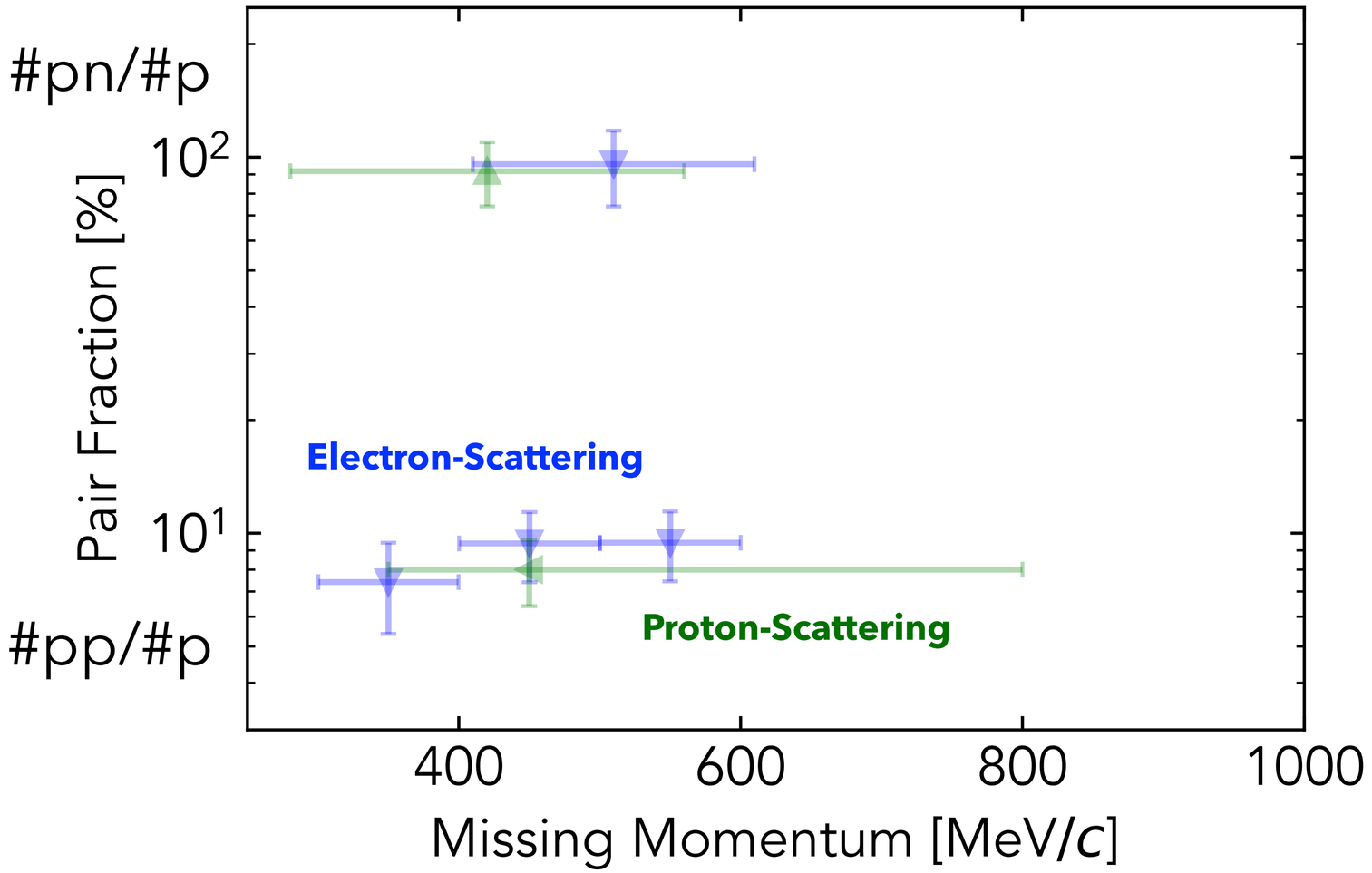
Initial recoil proton momentum

Directly measured

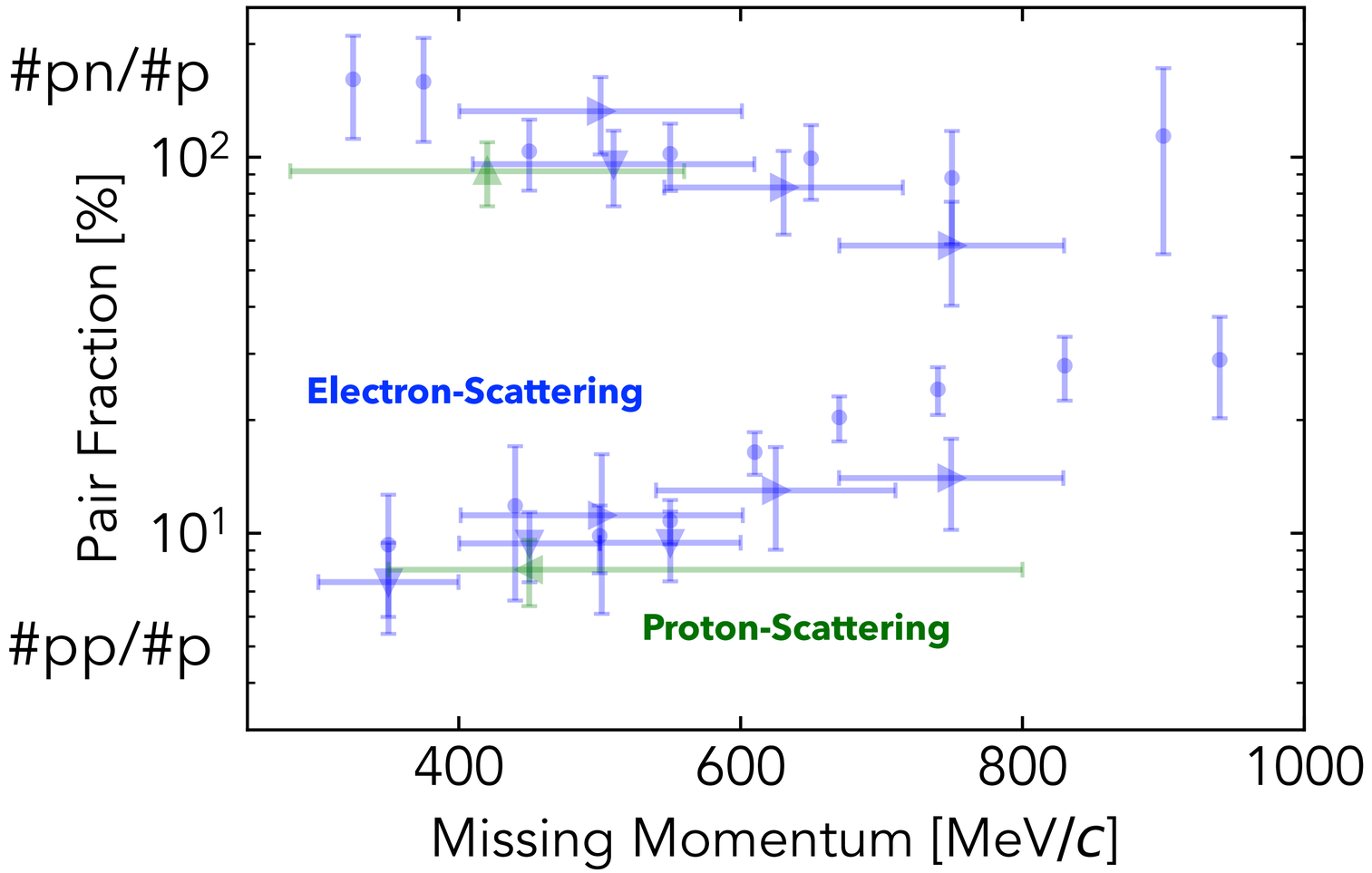
SRC Isospin Structure



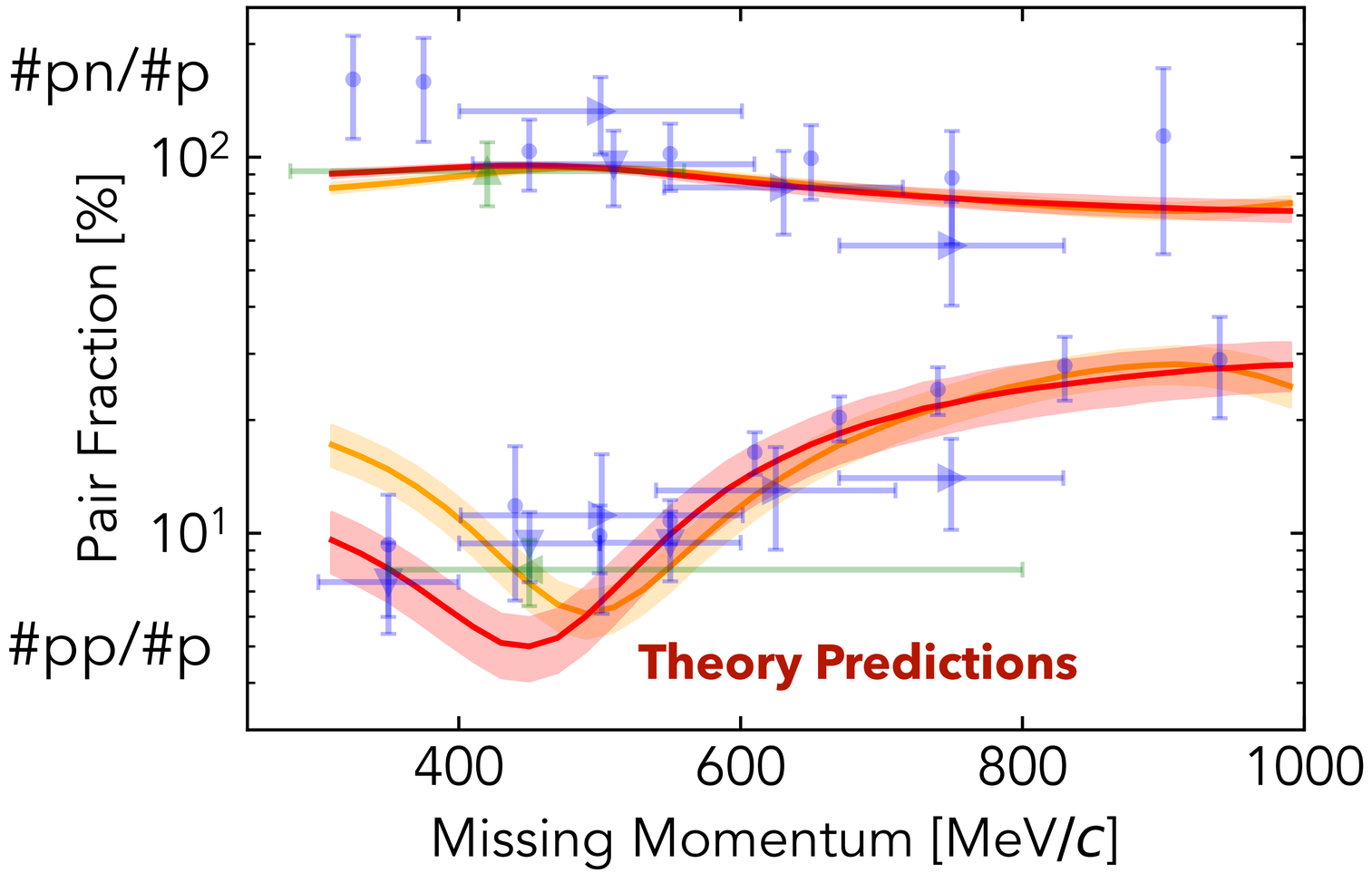
SRC Isospin Structure



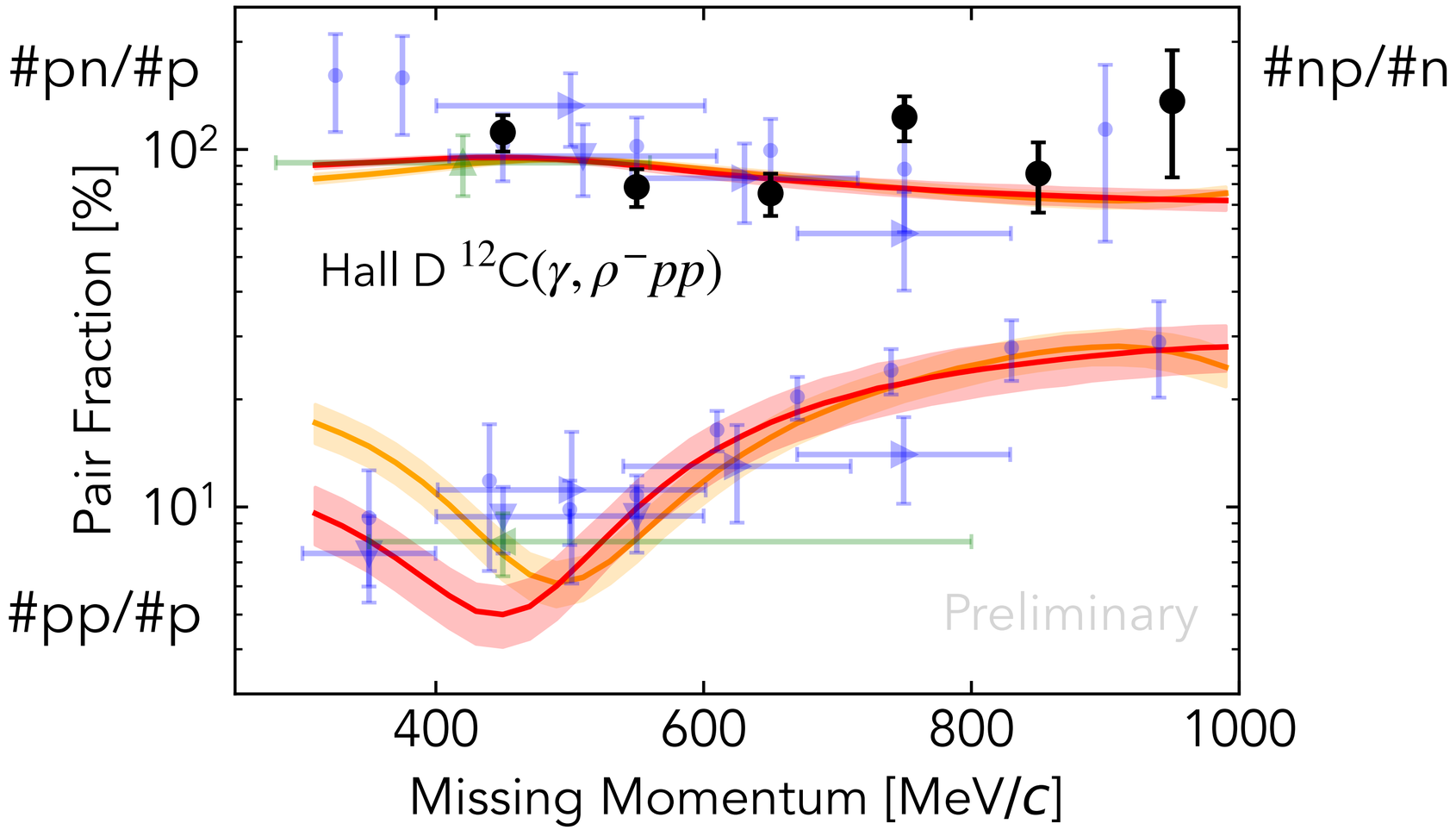
SRC Isospin Structure



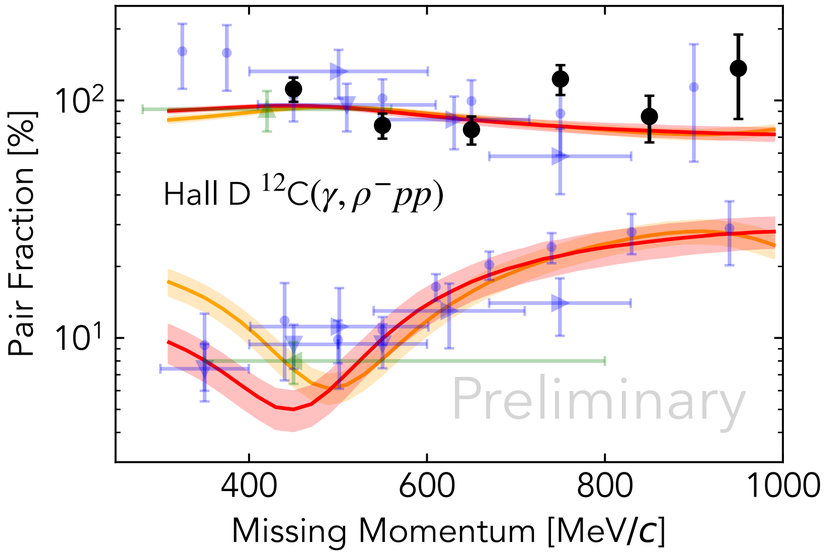
SRC Isospin Structure



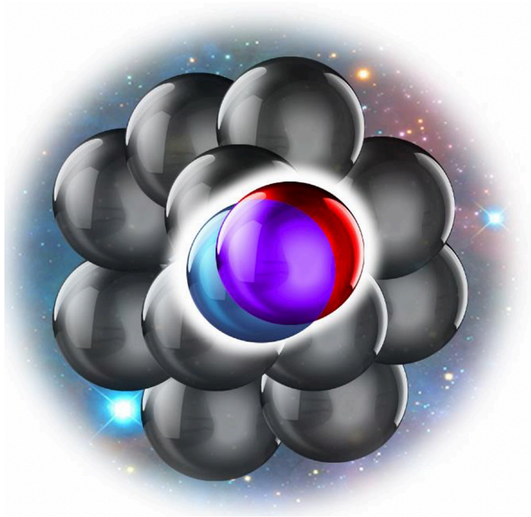
SRC Isospin Structure



Consistency with theory points to universal picture of the nuclear ground-state!

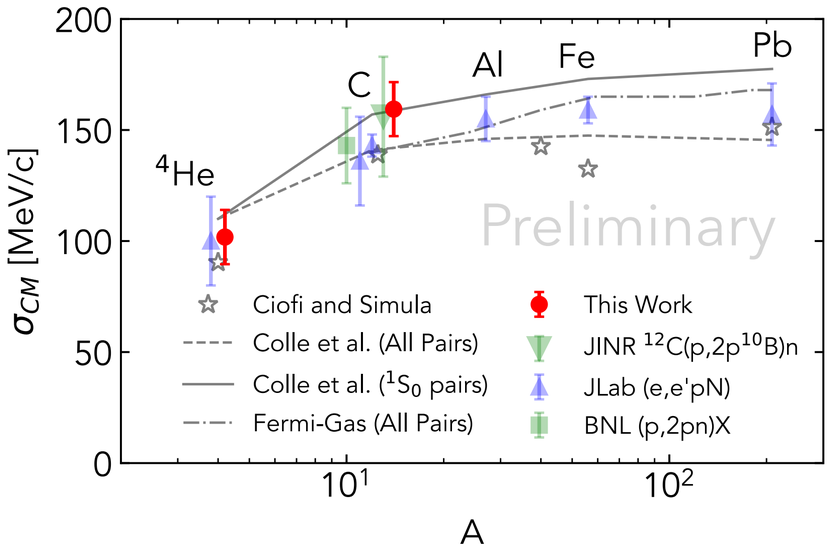


Photons



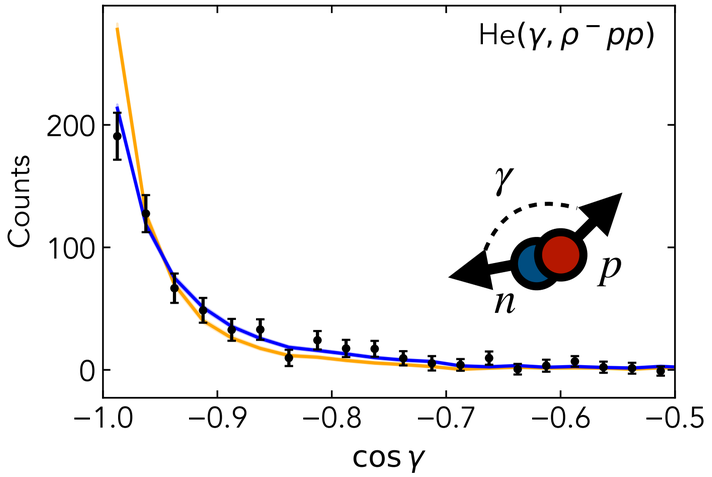
Electrons

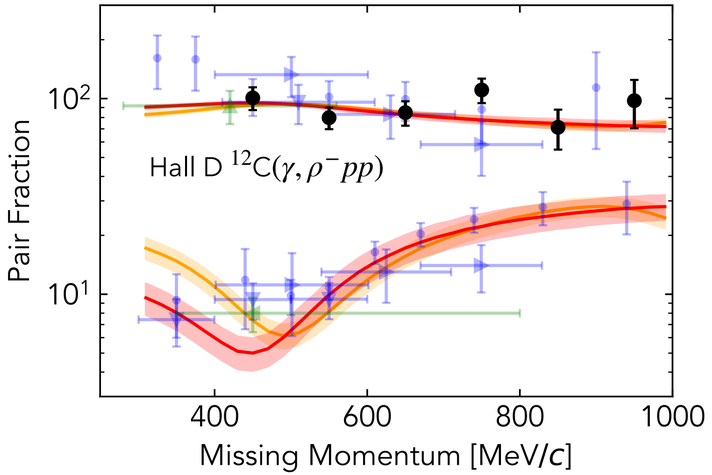
Protons



Conclusions

- First observation of SRCs using photoproduction reactions
- Extracted data show sensitivity to ground-state nuclear properties
- Data point to universal description of the ground-state of Short-Range Correlations across probes

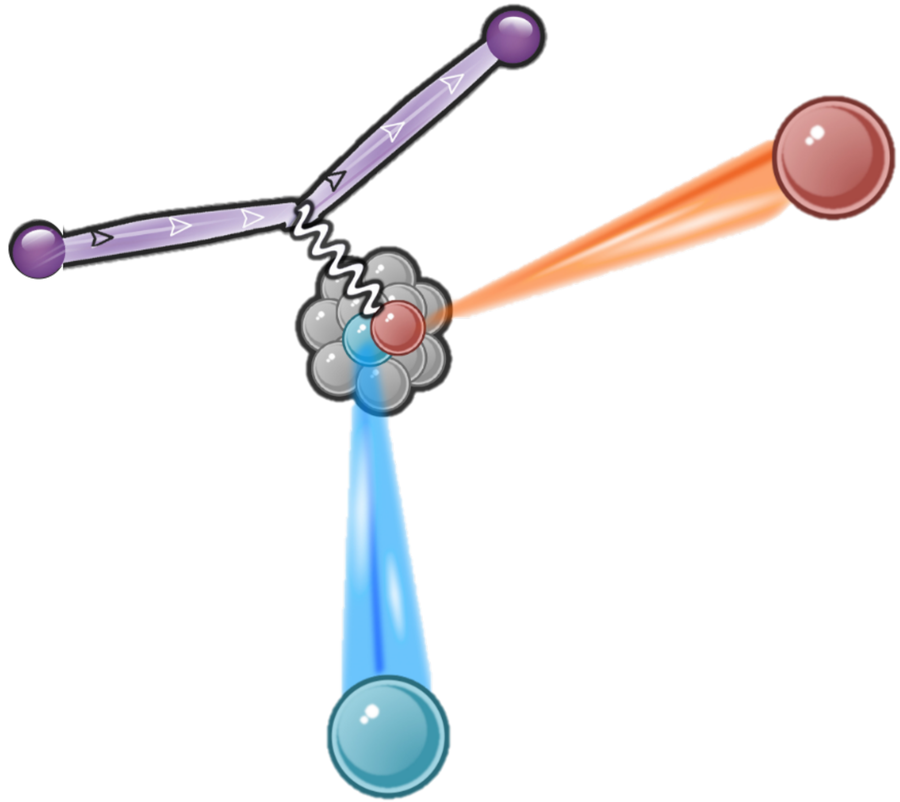




Backup Slides

Interpreting SRC results requires two things:

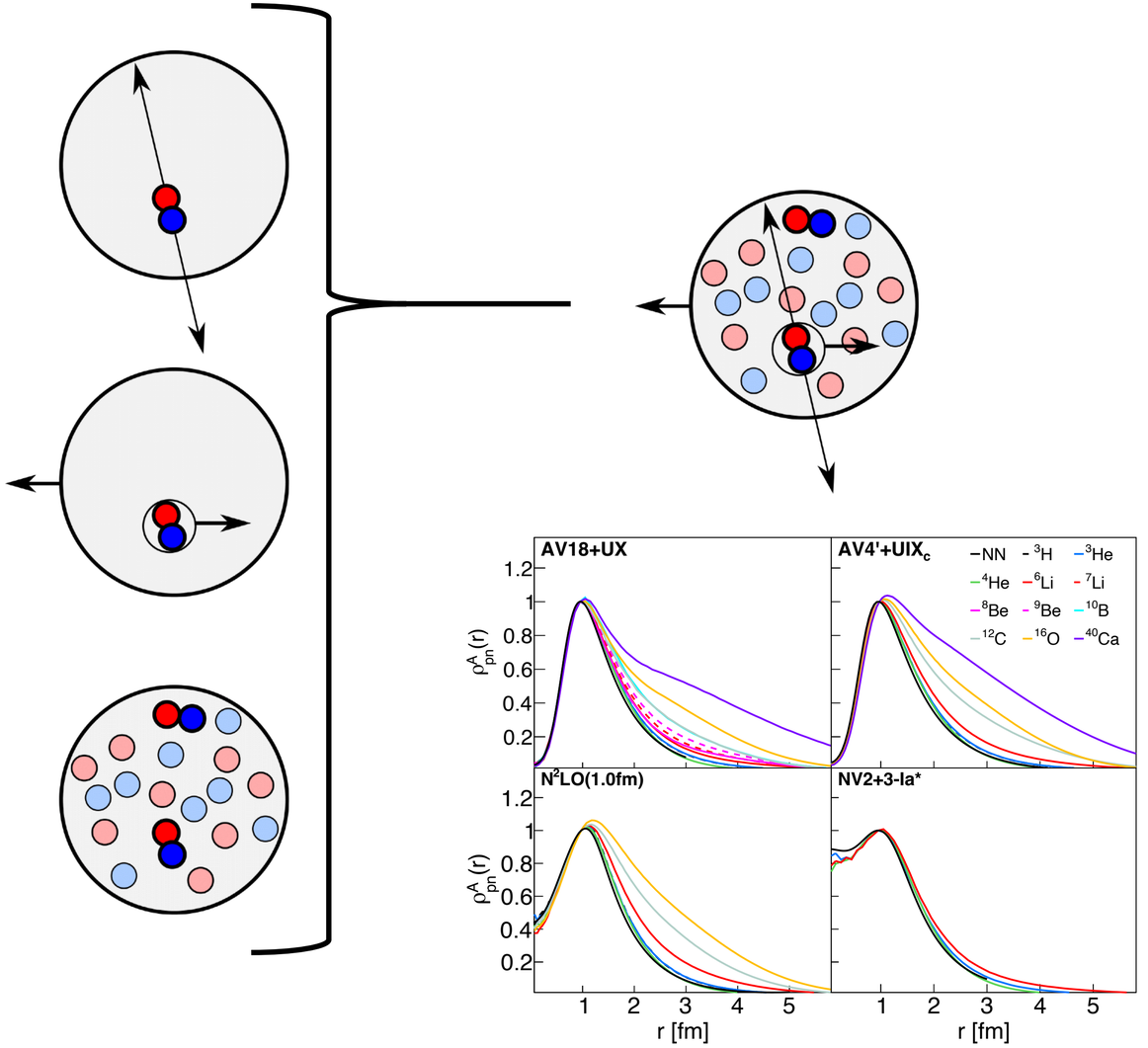
1. Clean measurements of SRC breakup using two-nucleon knockout



Interpreting SRC results requires two things:

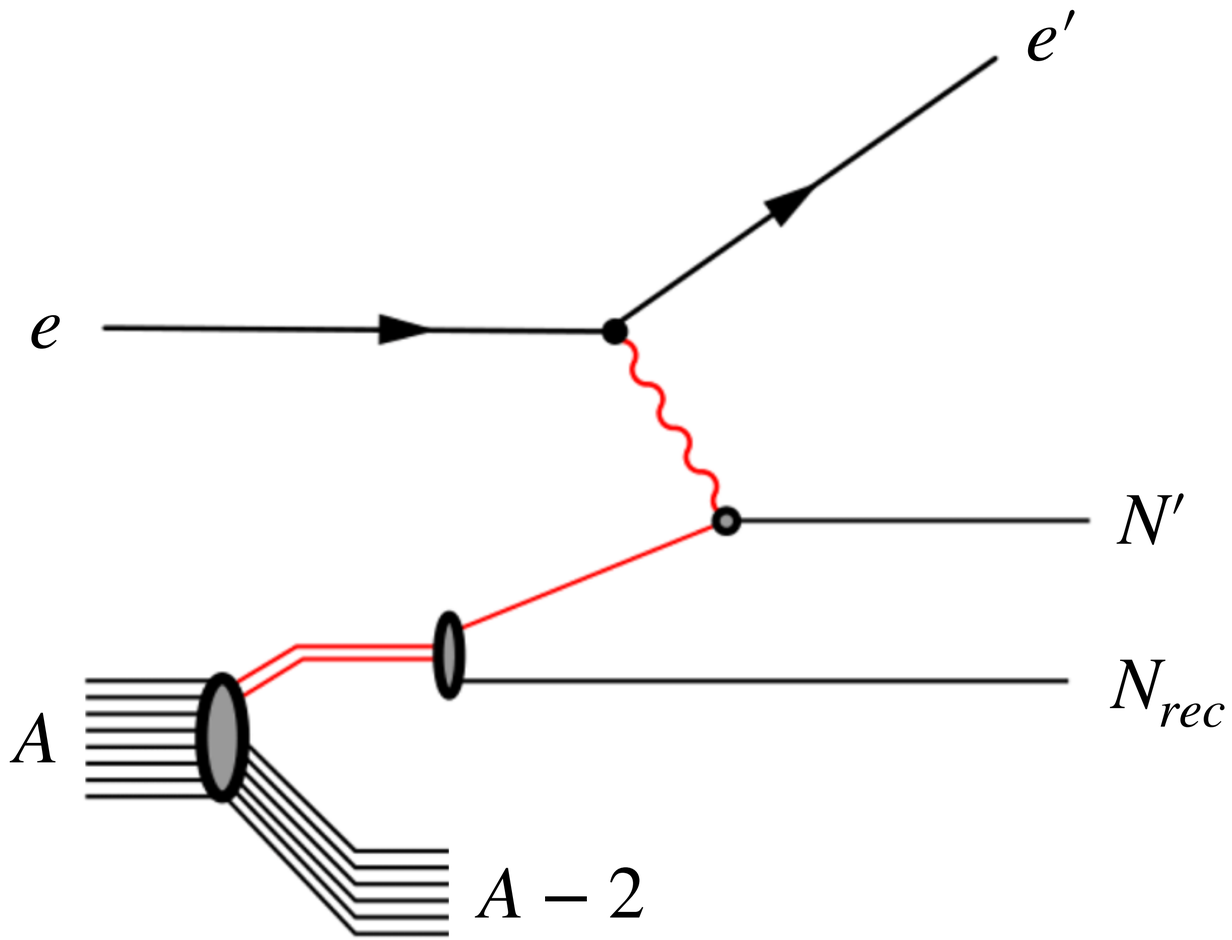
1. Clean measurements of SRC breakup using two-nucleon knockout

2. Model of the SRC component of the nuclear ground-state



Cruz-Torres et al., Nature Physics (2021)
Weiss et al., Phys. Lett. B 780 (2018)
Weiss, Bazak, Barnea, Phys. Rev. C 92 (2015)
Tropiano et al., Phys. Rev. C 104, 034311 (2021)
Lynn et al., JPG 47, 045109 (2020)
Chen, Detmold, Lynn, Schwenk, PRL 119 (2017)
Ryckebusch et al., Phys. Lett. B 792, 21 (2019)
Ciofi and Simula, Phys. Rev. C 53, 1689 (1996)

Ground-state model can be combined with **“Plane-Wave Impulse Approximation”**



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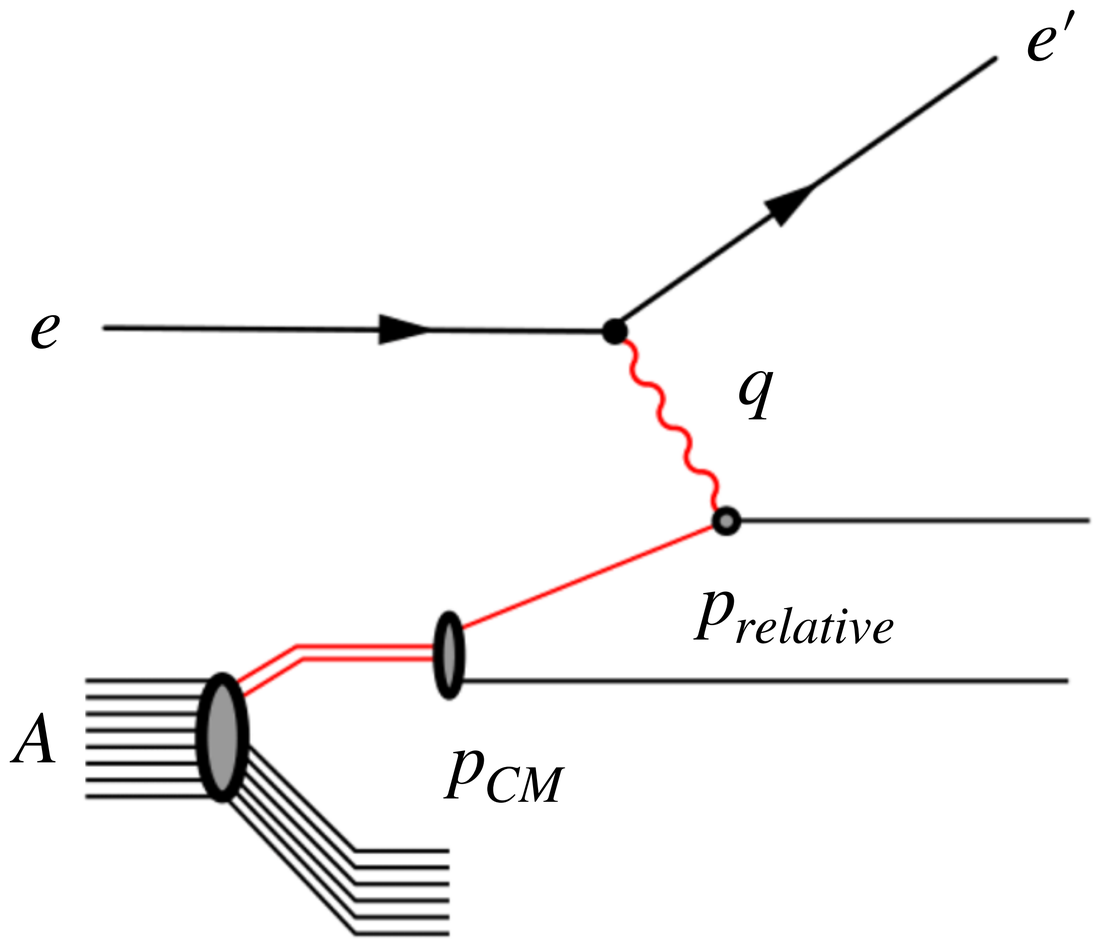

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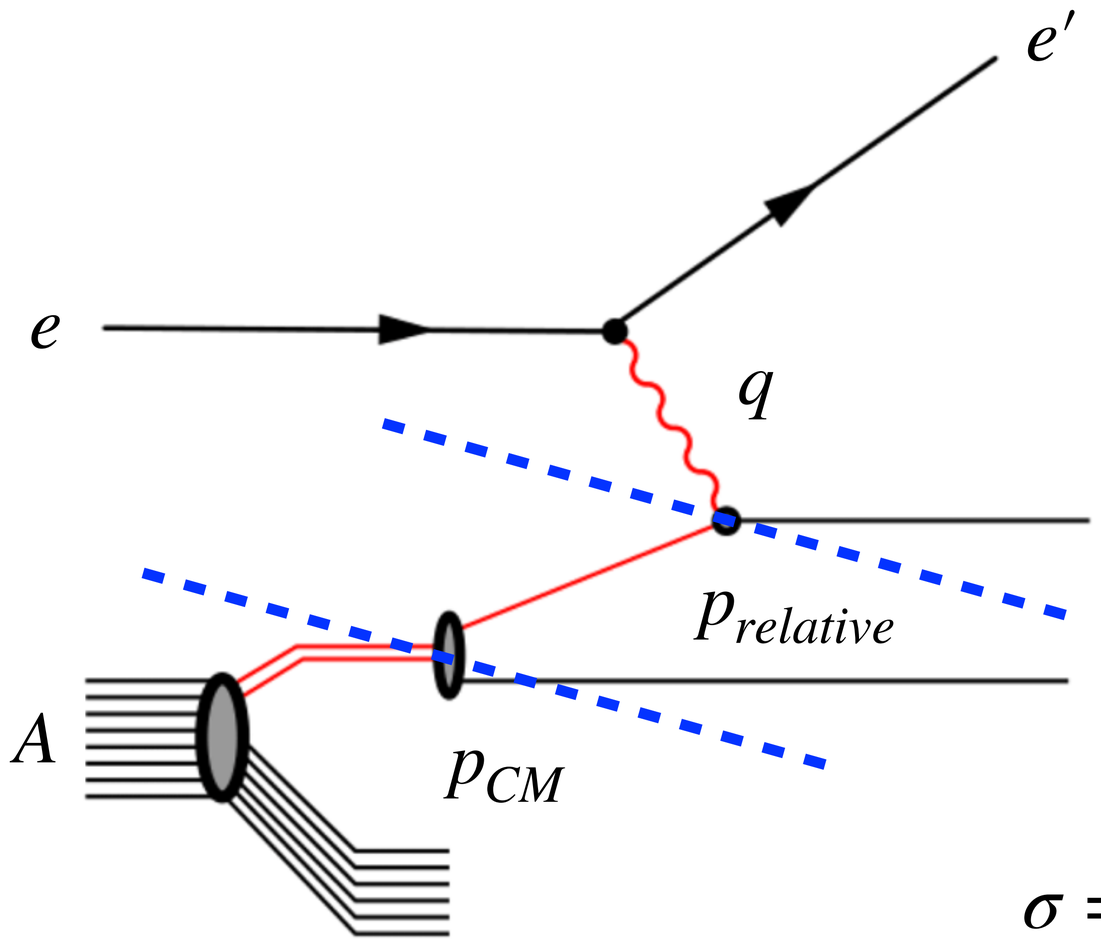
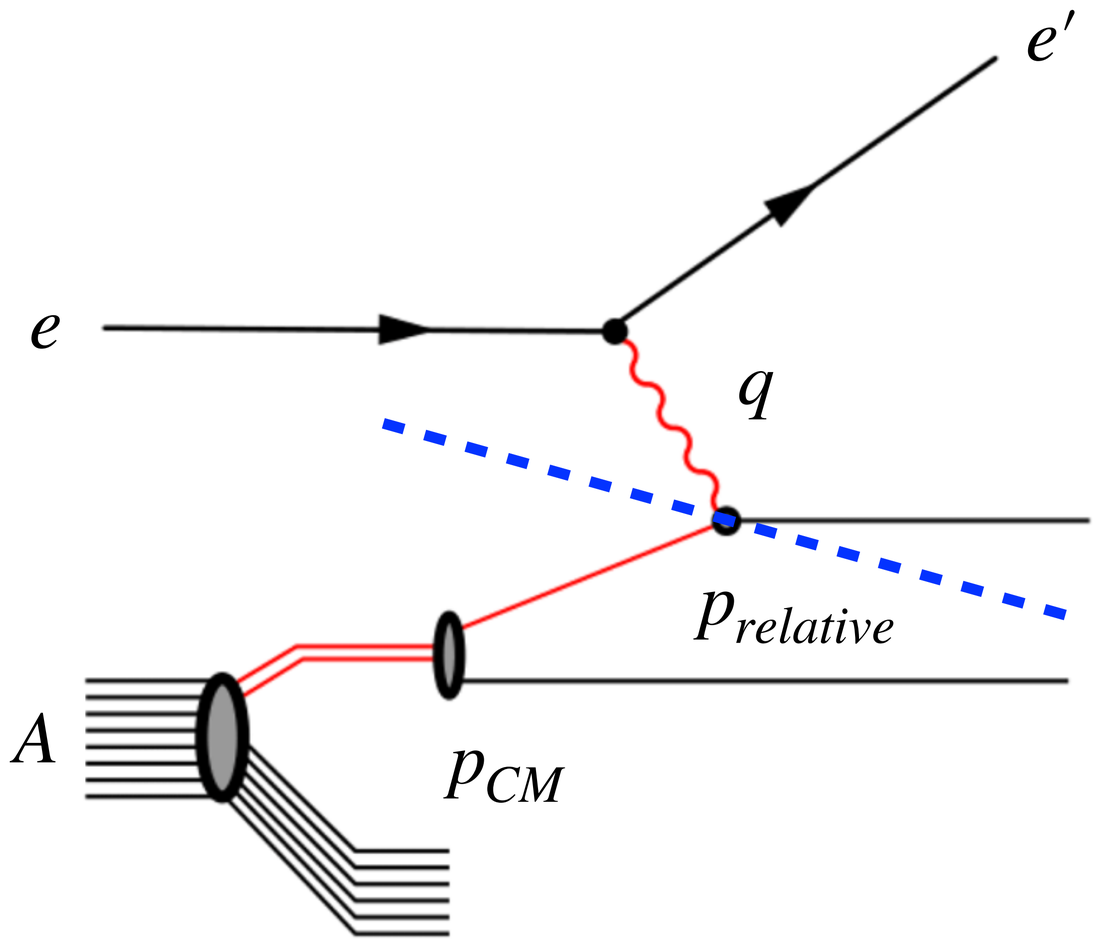


$$q > p_{relative} > p_{CM}$$

$$\sigma = \sigma_{e,N}(q) \sum_{\alpha} C^{\alpha} \, | \, \phi(p_{relative}) \, |^2 \, n(p_{CM})$$

PWIA relies on factorization between reaction and ground-state



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

Reaction

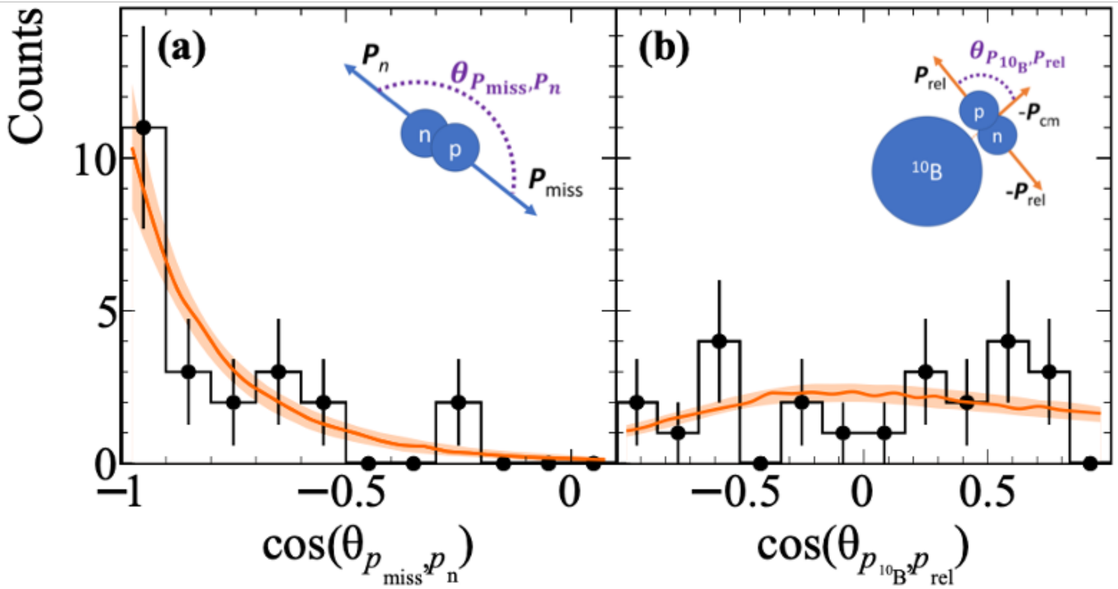
- High-energy
- 1-body operator
- Kinematics- and probe- dependent

Ground-State

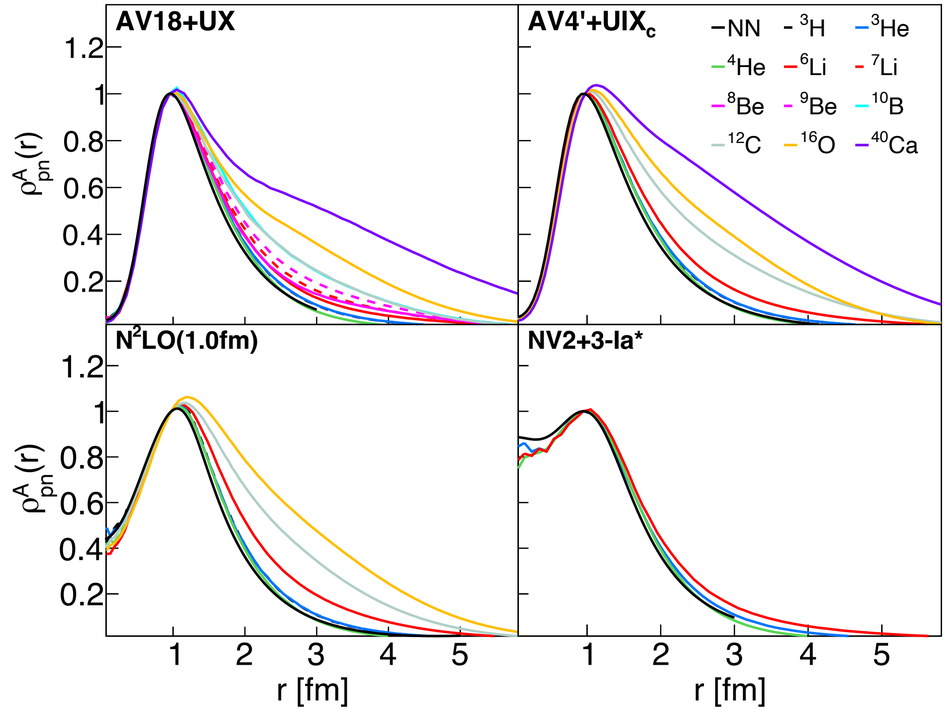
- Low-energy
- 2-body dynamics
- Universal

Internal scale separation of SRCs on good footing:

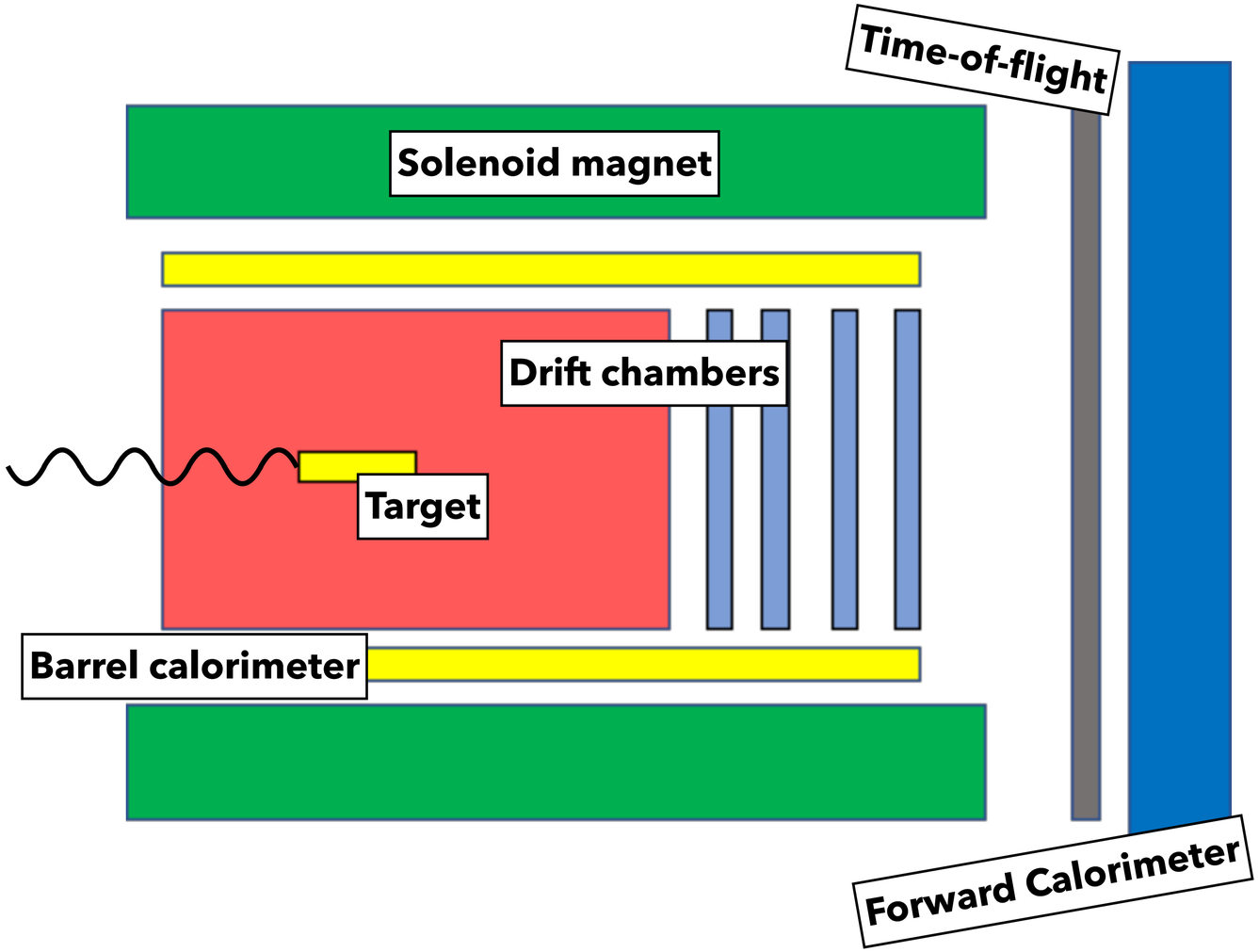
Nature Physics 17, 667 (2021)



Nature Physics 17, 306 (2021)

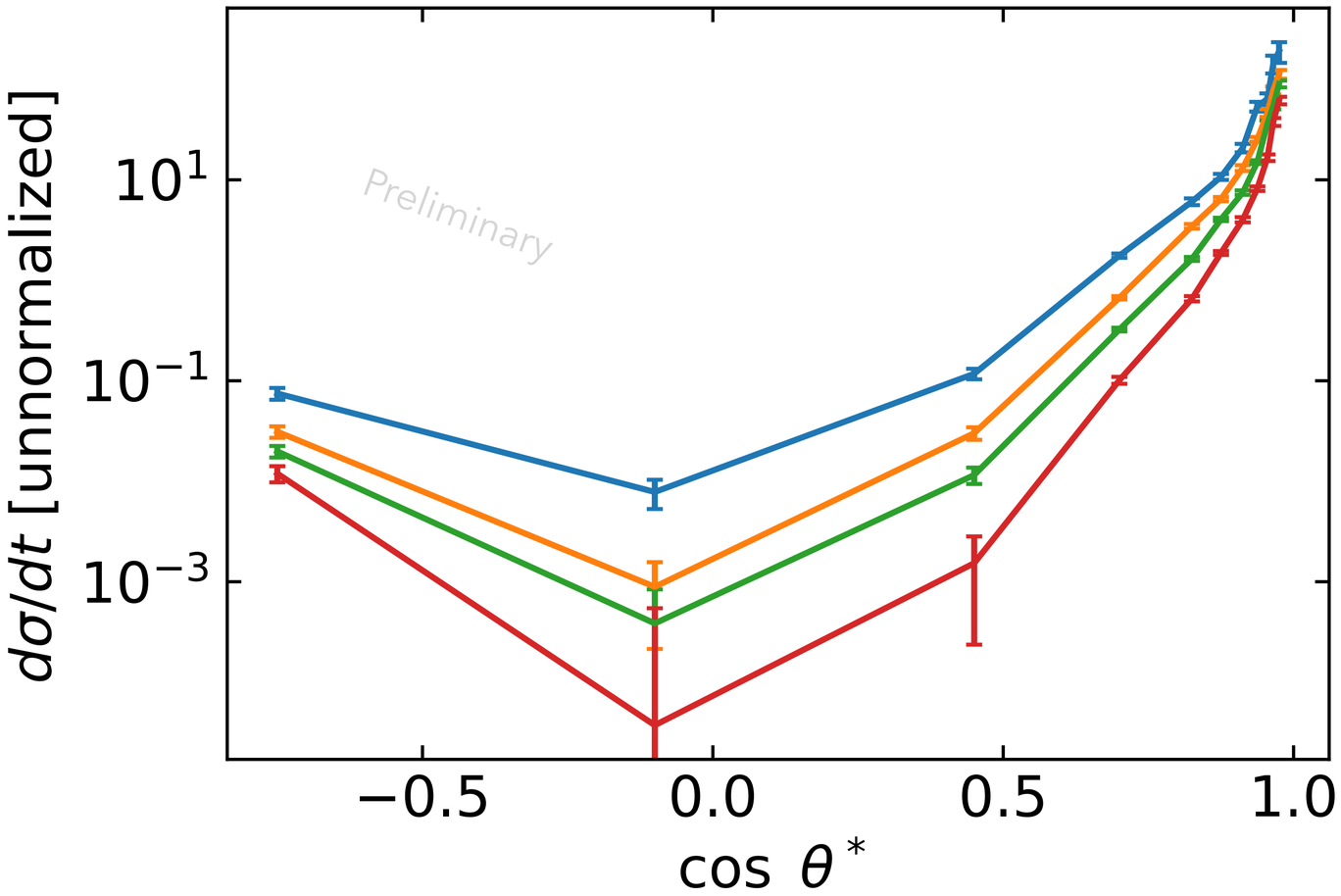


GlueX Spectrometer



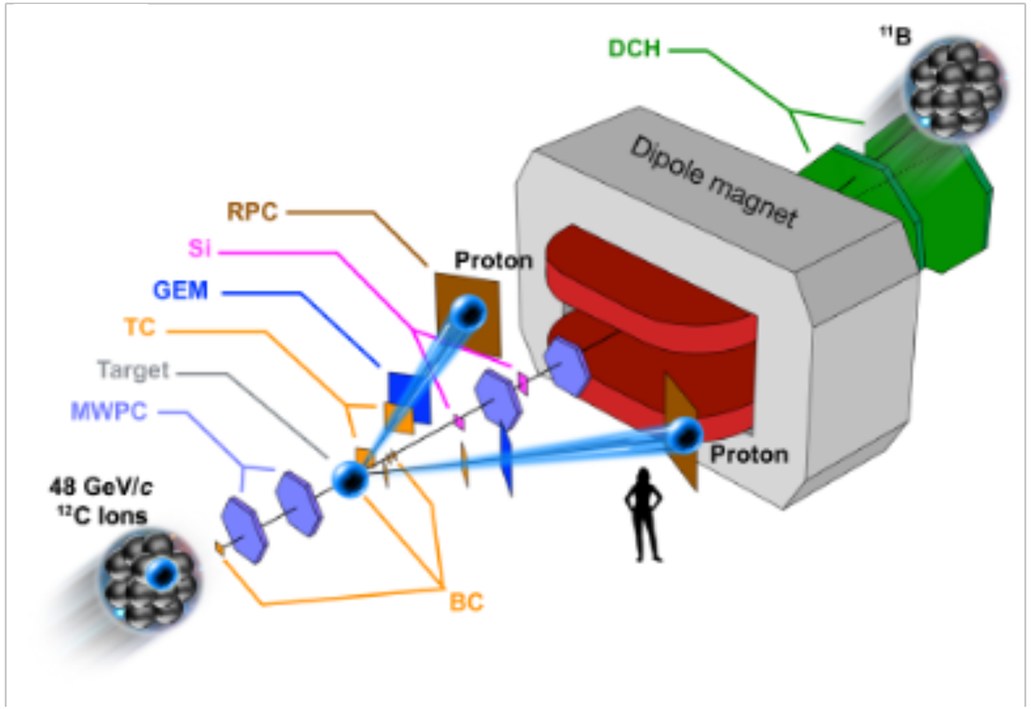
- Large-acceptance detector
- Solenoidal magnet:
  - Good p_T resolution
  - Poor p_z resolution
- Time-of-flight allows particle identification for forward-going charged particles
- Calorimeters allows good acceptance and reconstruction of final-state photons

Cross section extraction for $\gamma n \to \rho^- p$

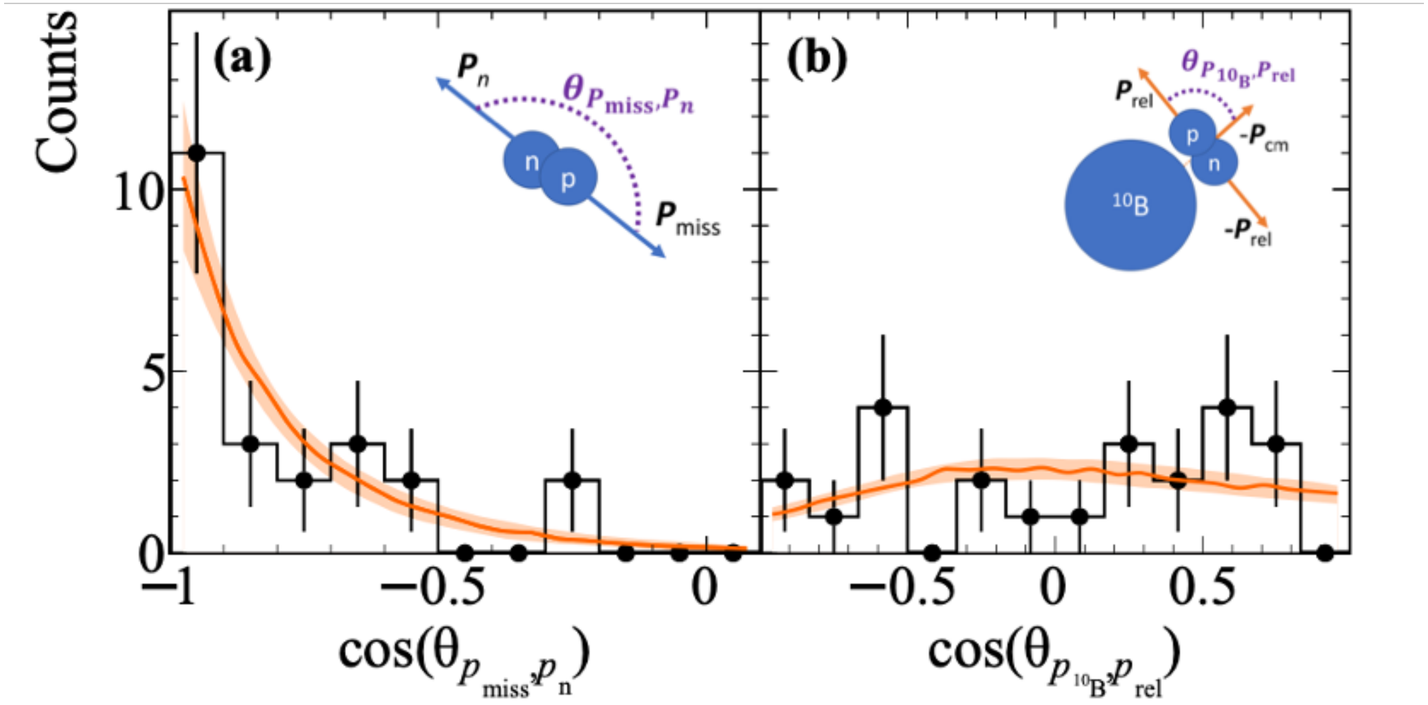


Hadron-scattering measurements of SRCs

- Inverse-kinematics measurement at Joint Institute for Nuclear Research in Dubna
- ^{12}C ions incident on hydrogen target
- Spectrometer measured final-state protons, nuclear fragments
- Allows reconstruction of nuclear final-state in SRC breakup scattering



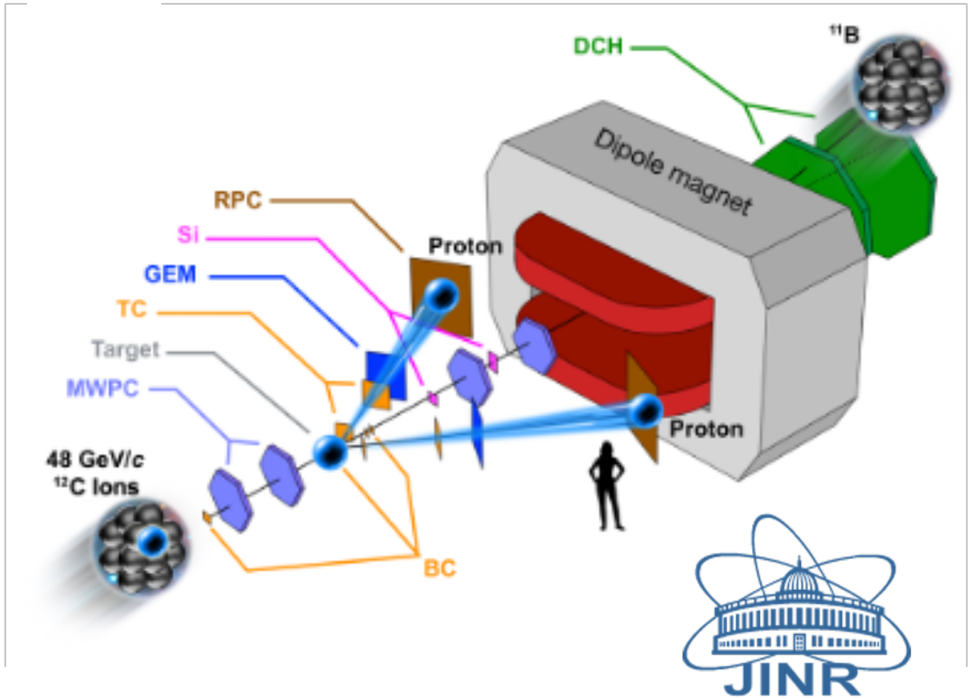
Experimental evidence for SRC scale-separation



M. Patsyuk et al, Nature Physics (2021)

Next generation of ion-beam SRC studies underway

JINR, Dubna



GSI, Frankfurt