

# Meson Photoproduction as a Measure of SRC Universality

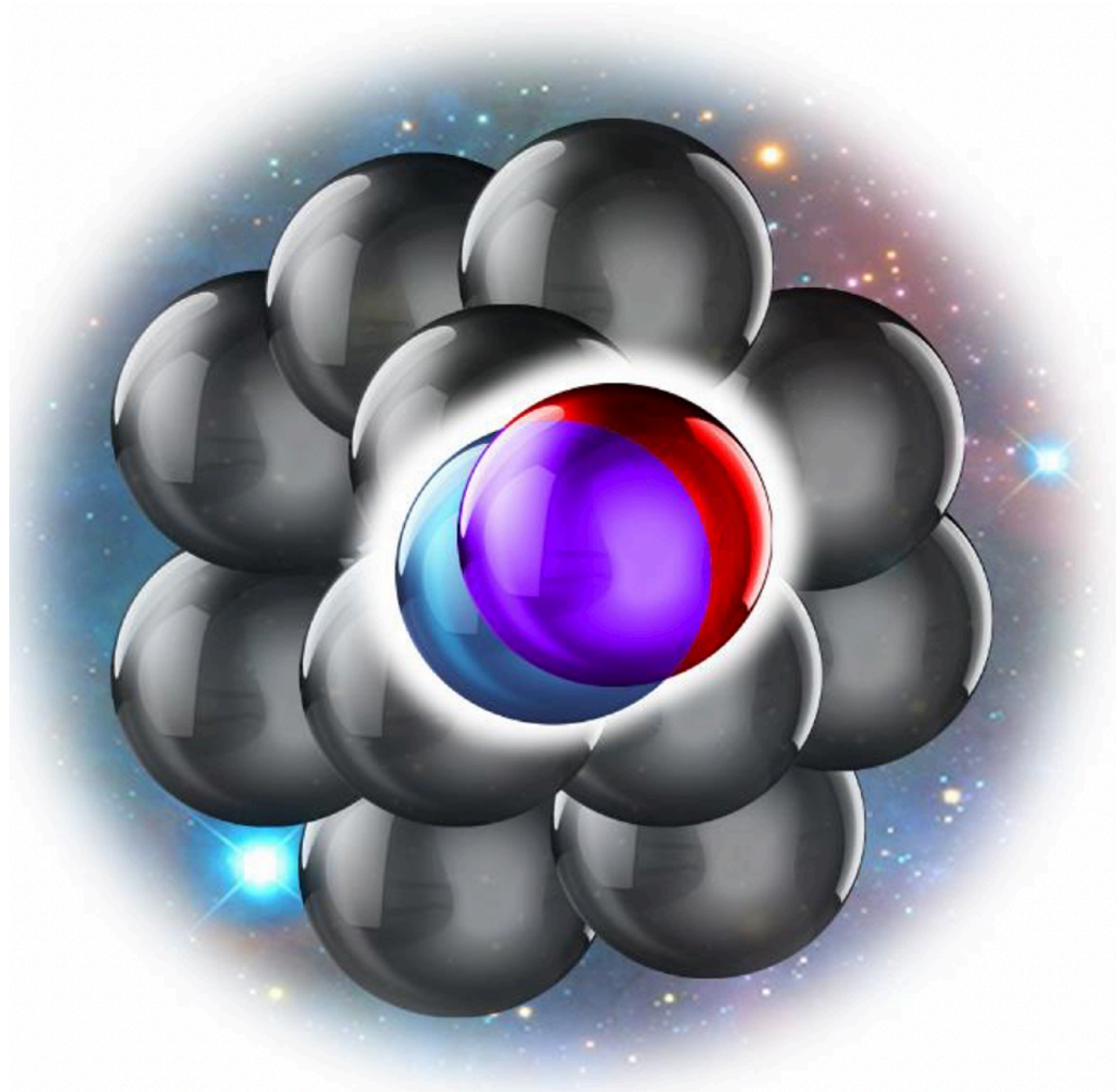
Cheng-Wei (Oscar) Lin and Jackson Pybus

5th International SRC Workshop

June 09, 2026

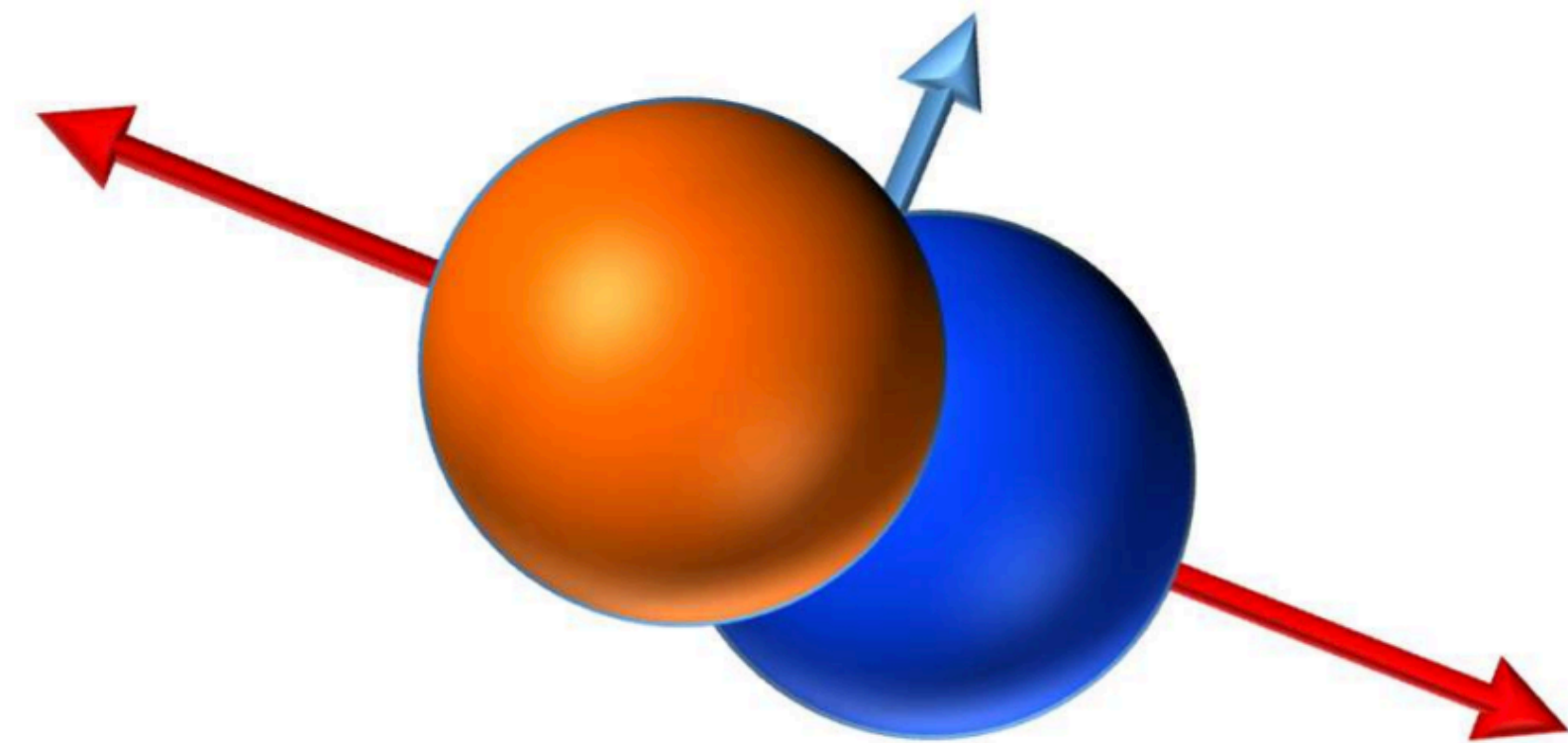
# What do we know about SRCs?

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



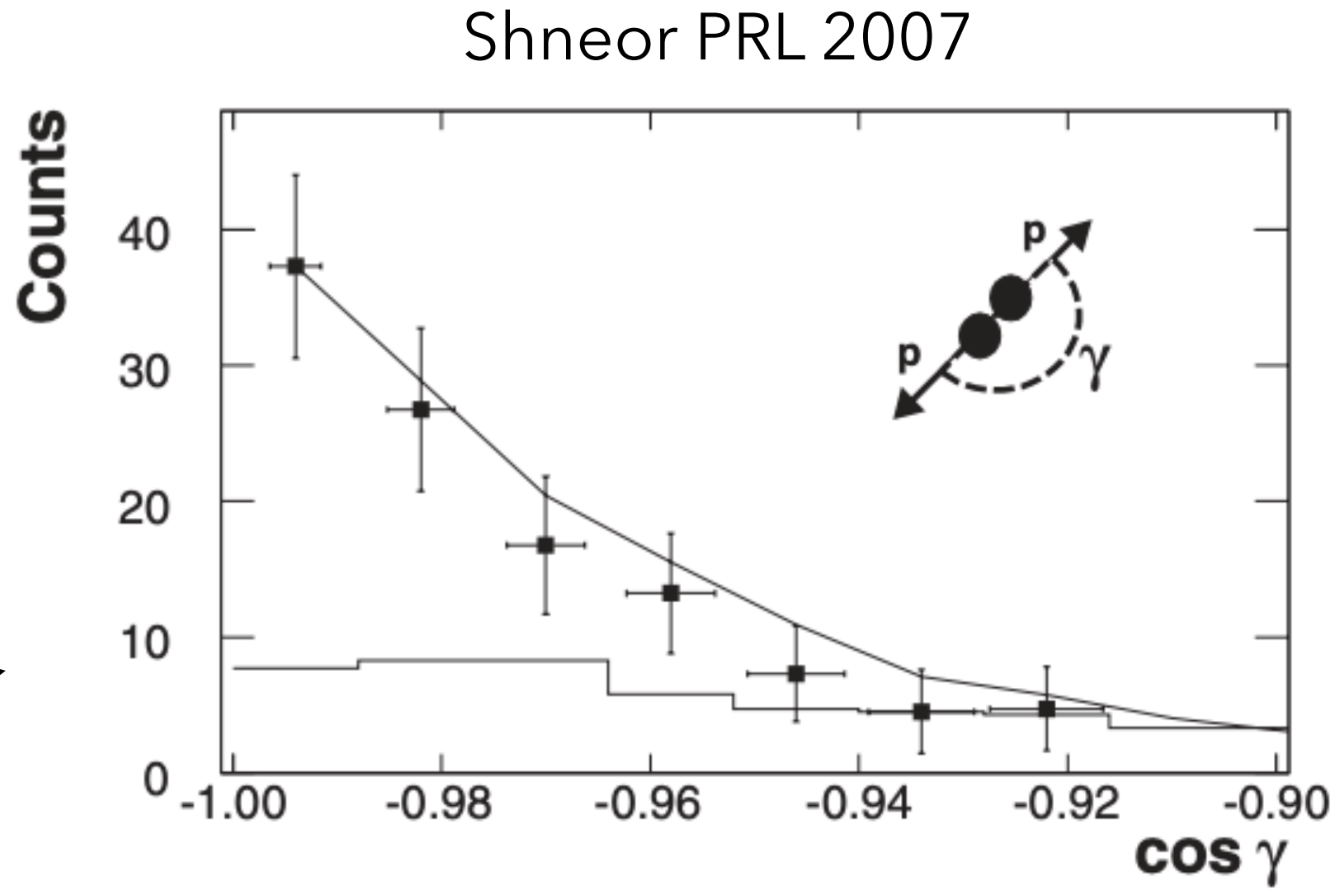
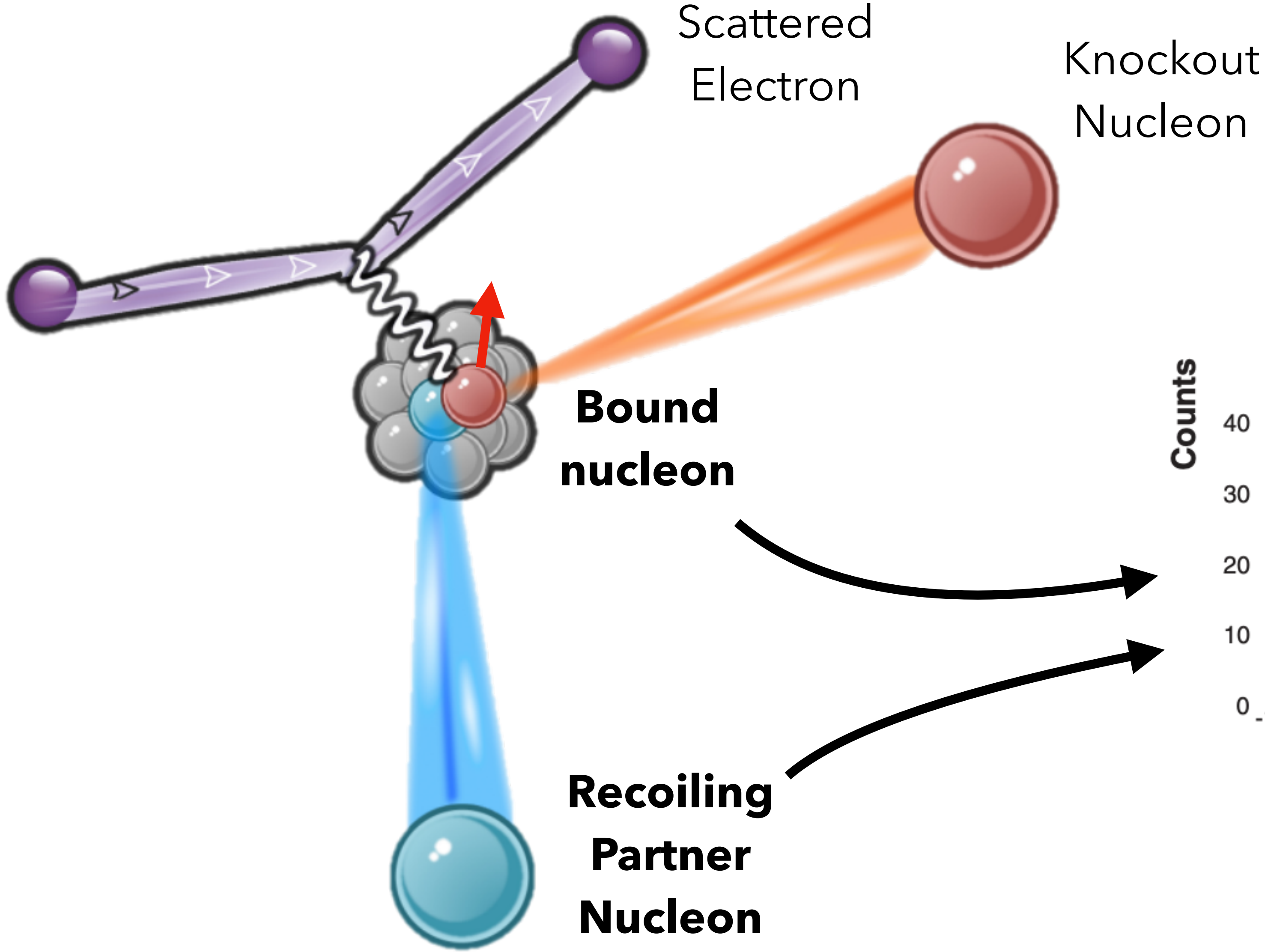
**Position-space**

High **relative** and lower **center-of-mass** momentum



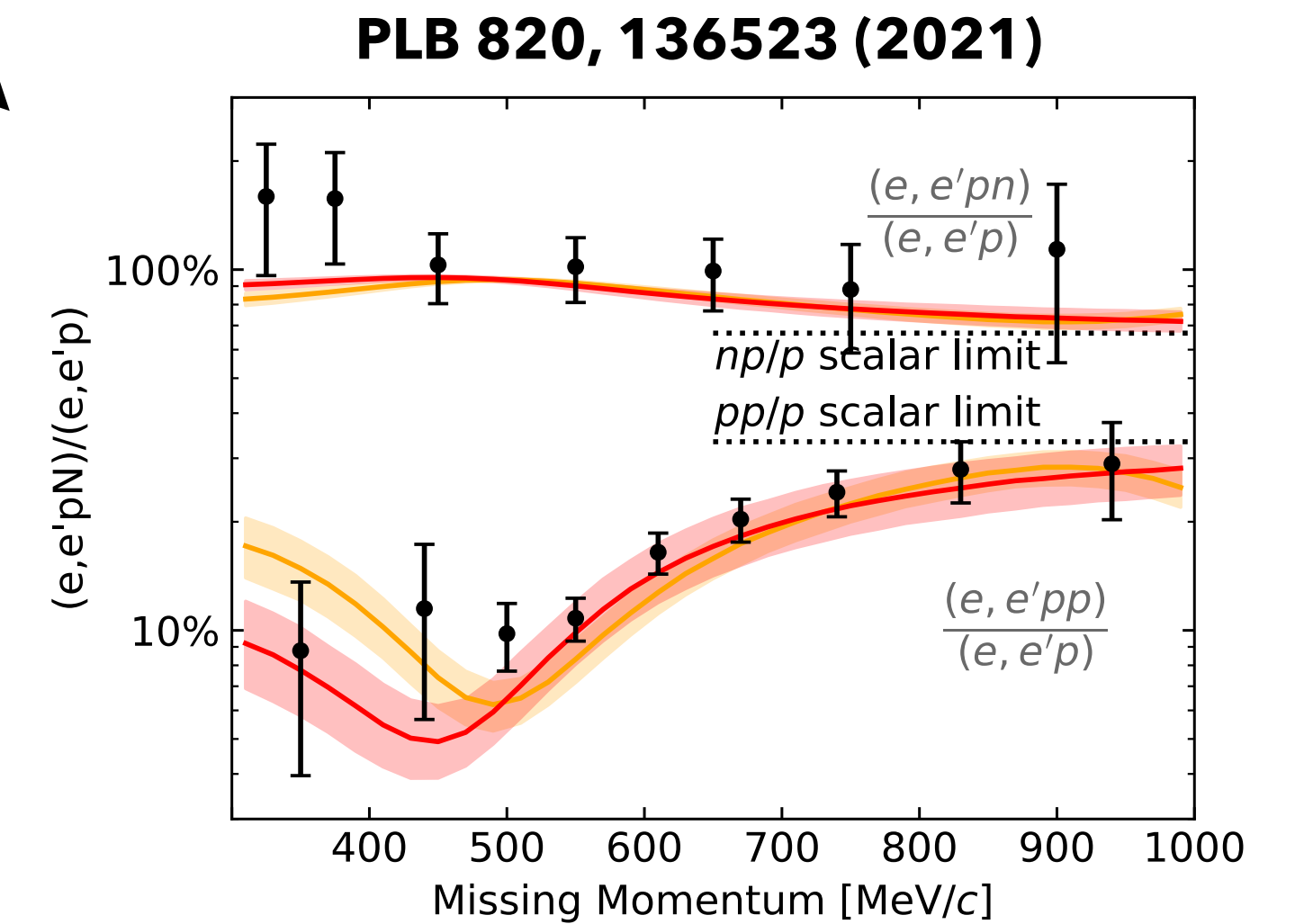
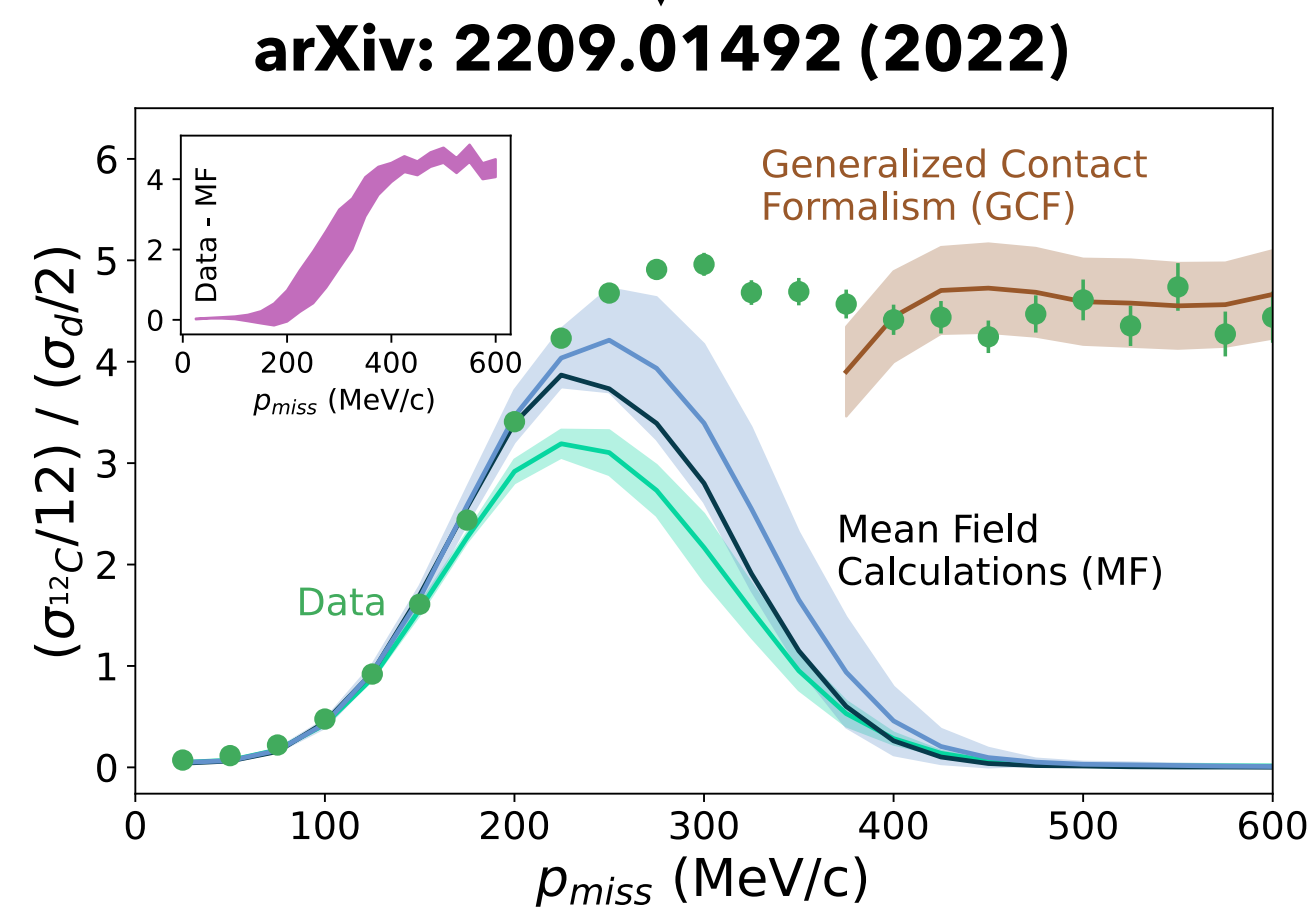
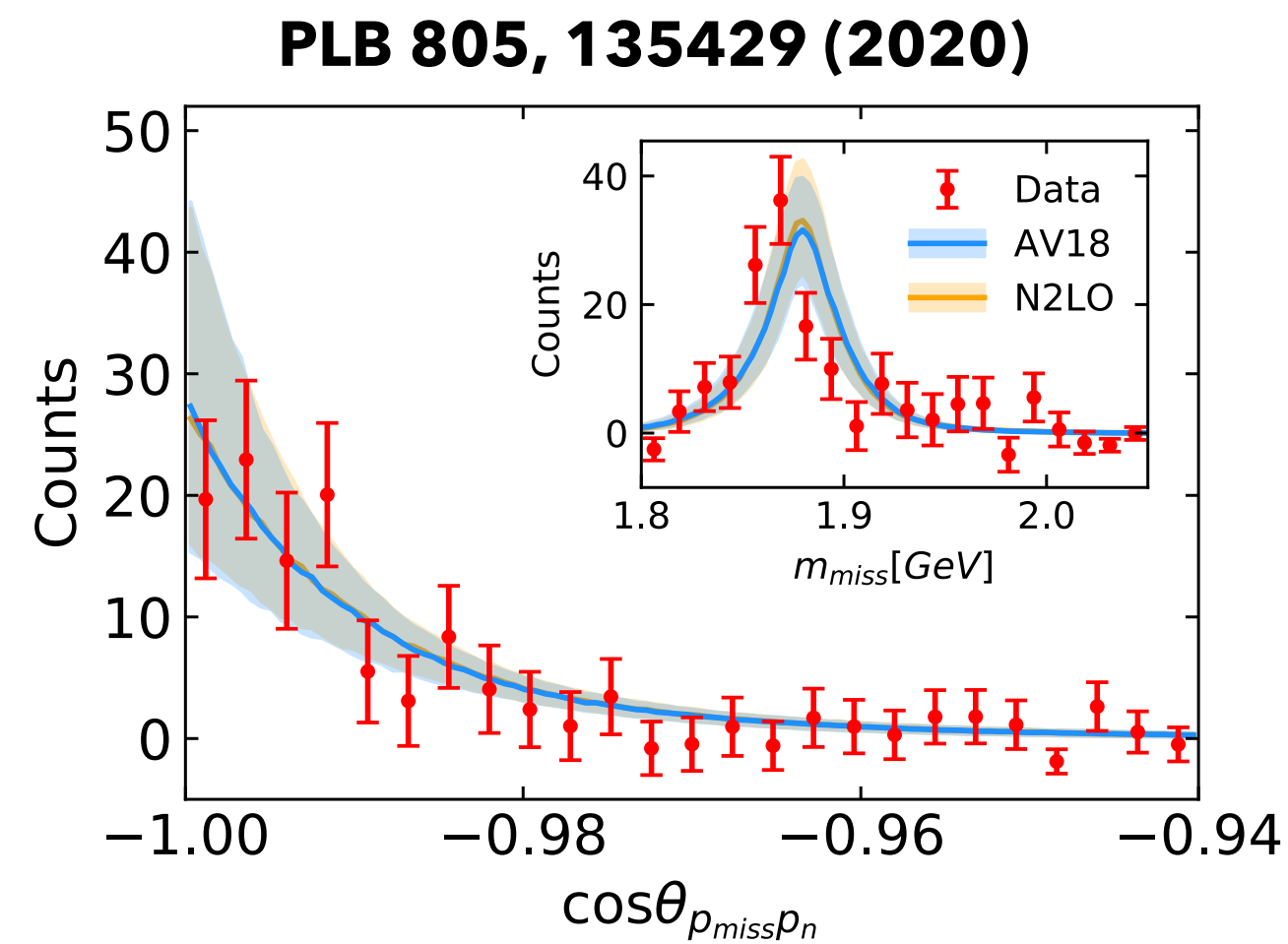
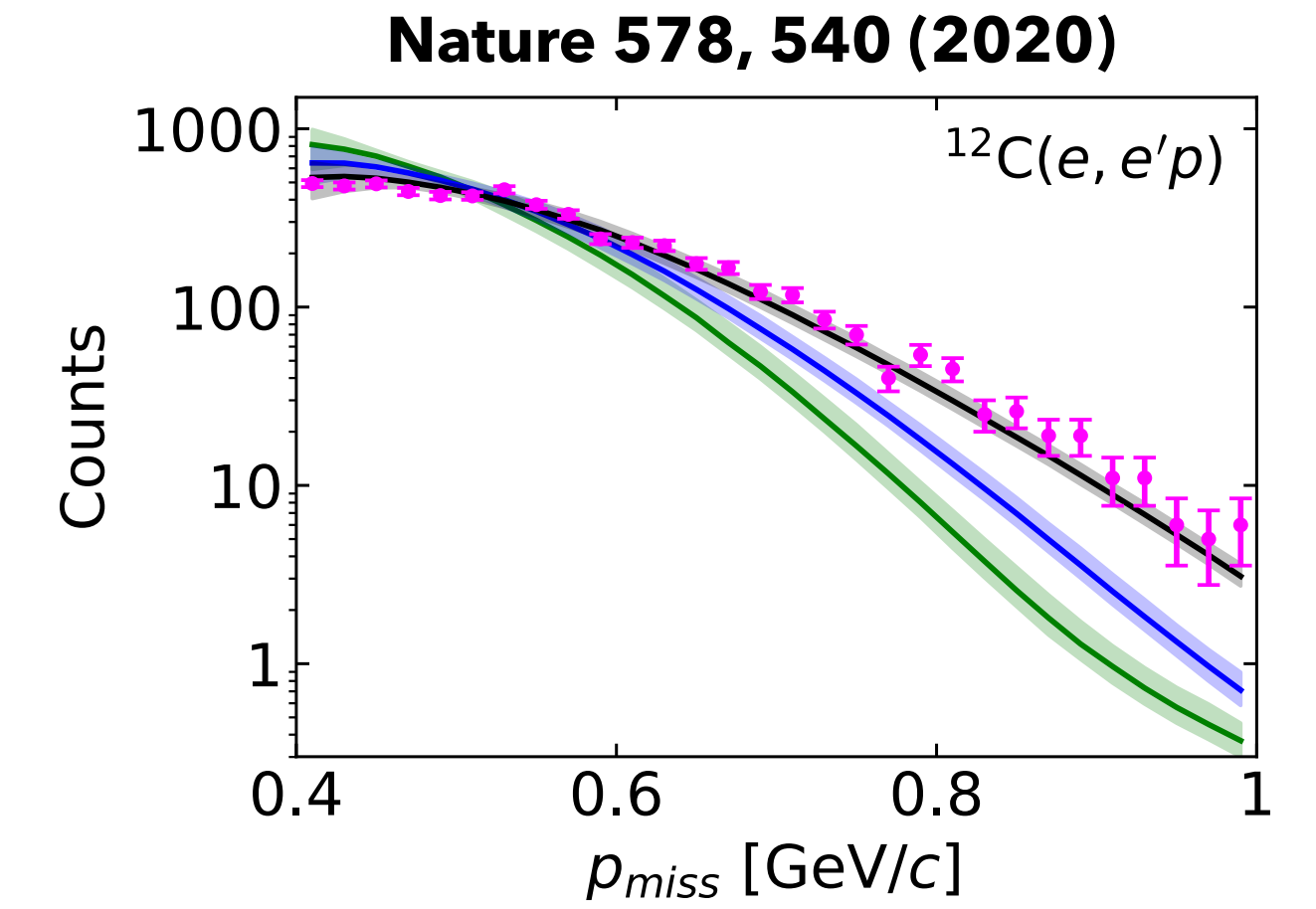
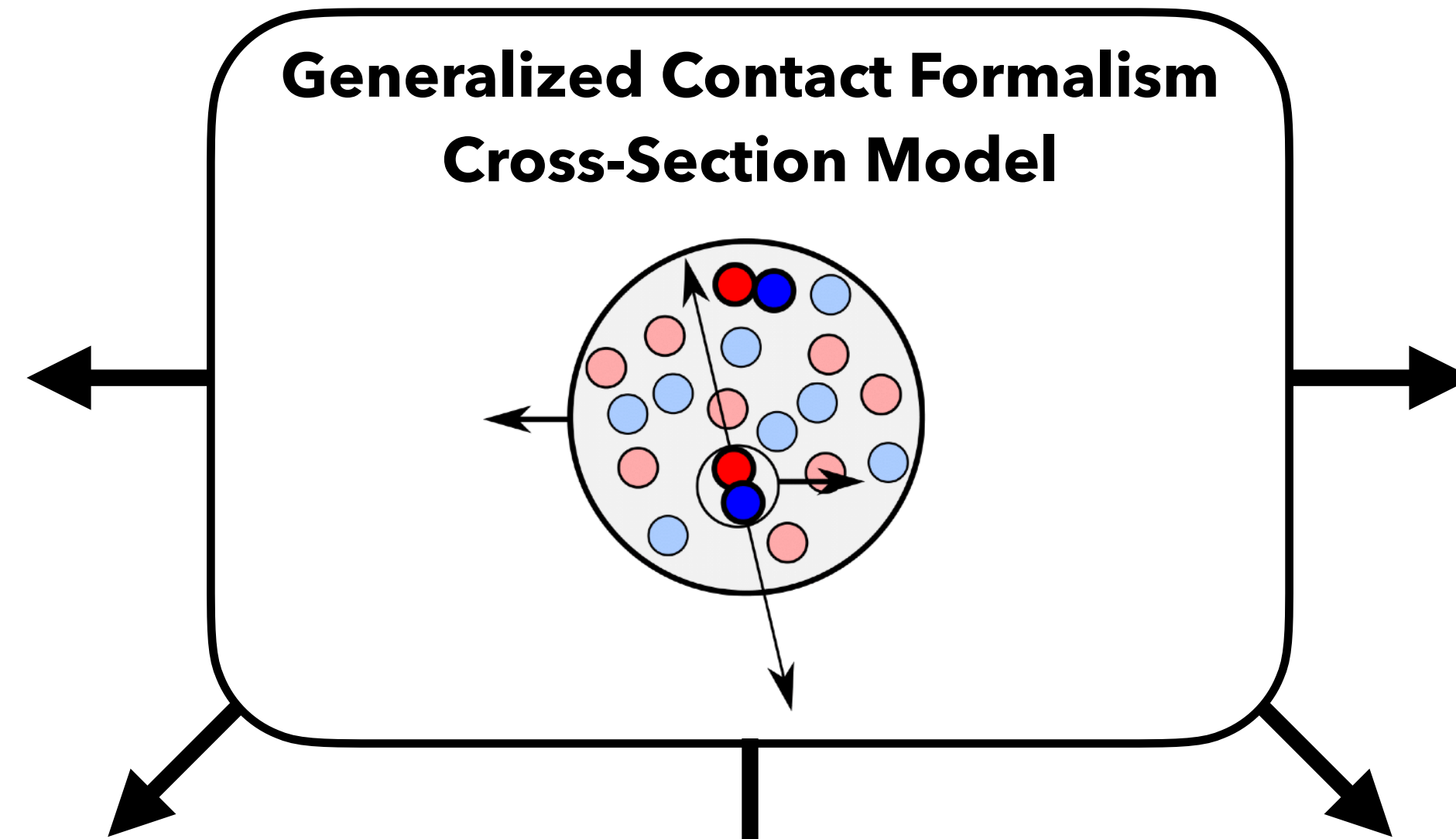
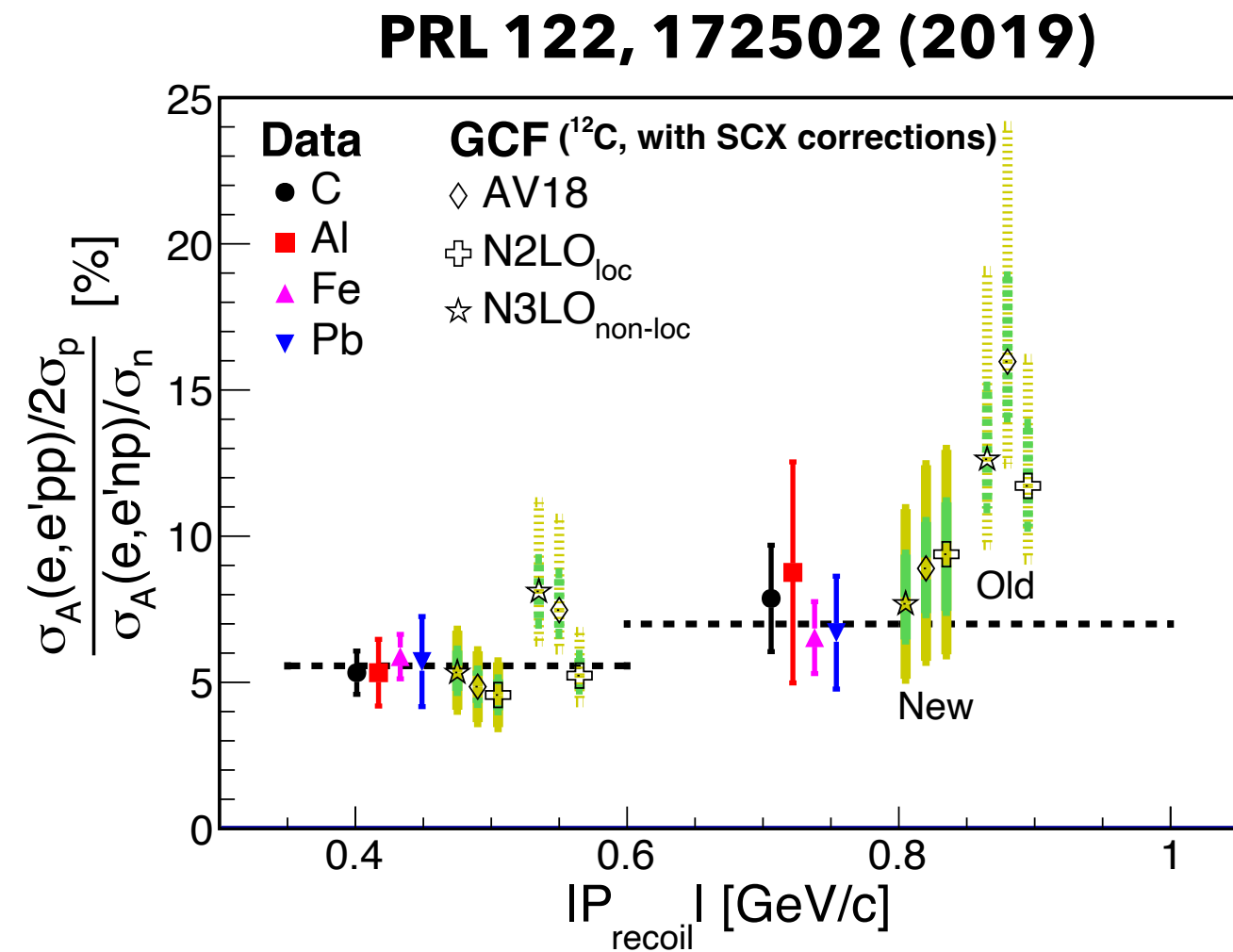
**Momentum-space**

# Nuclei probed using knockout reactions

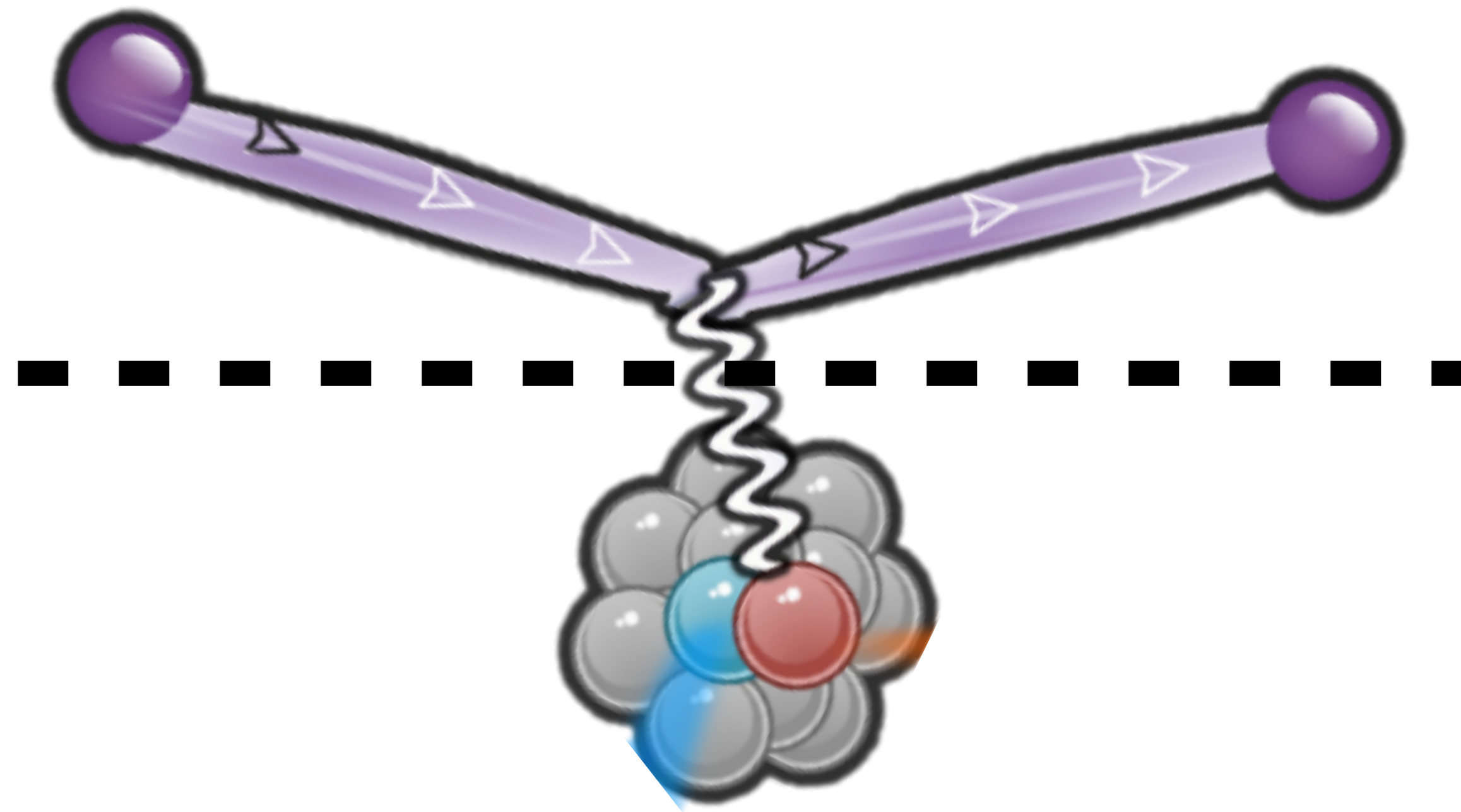


**High-momentum, back-to-back pairs**

# Many recent results in quantitative study of SRCs



# Ground-state interpretation requires establishing plane-wave factorization!

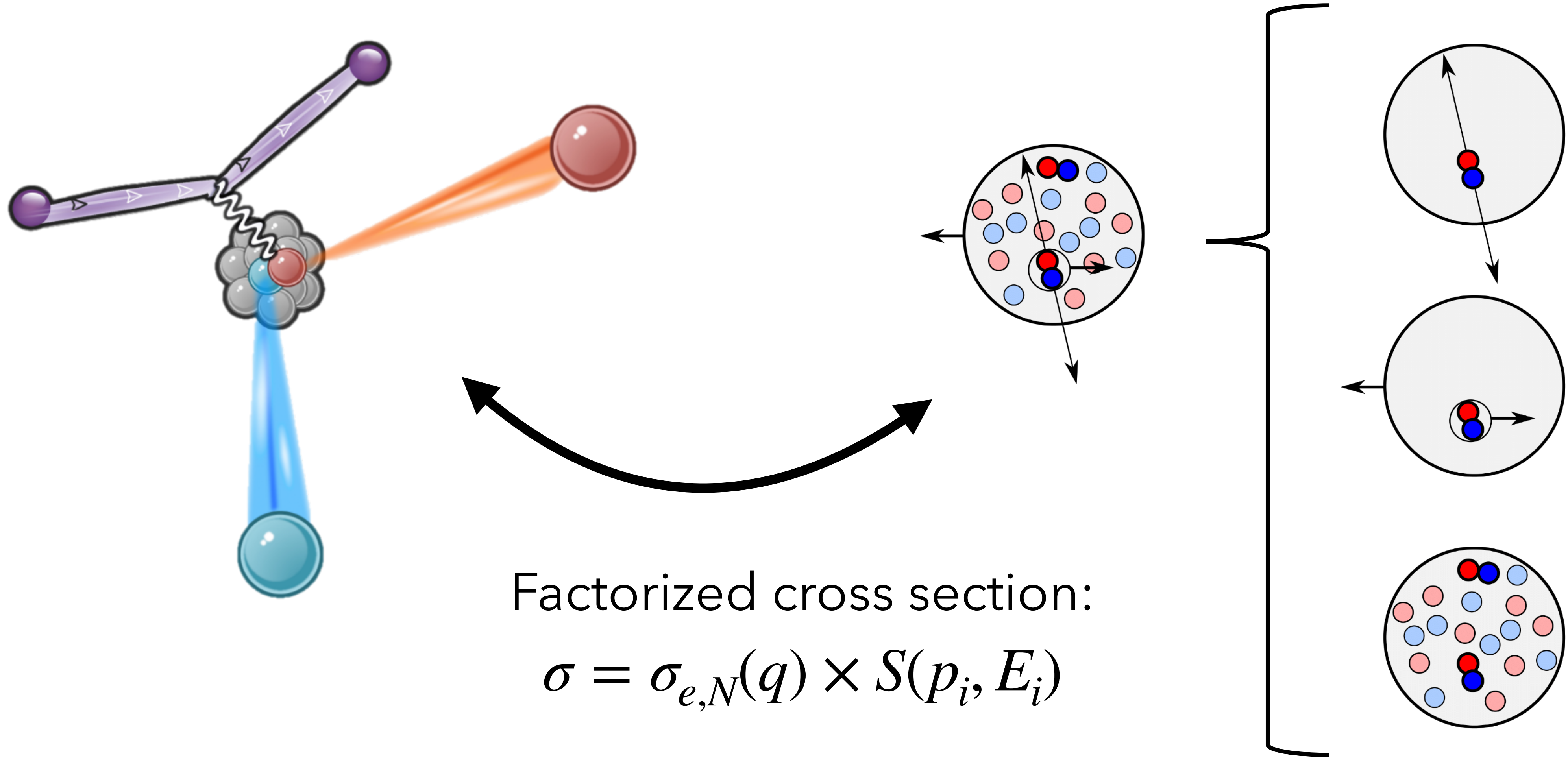


High-energy **Reaction**

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

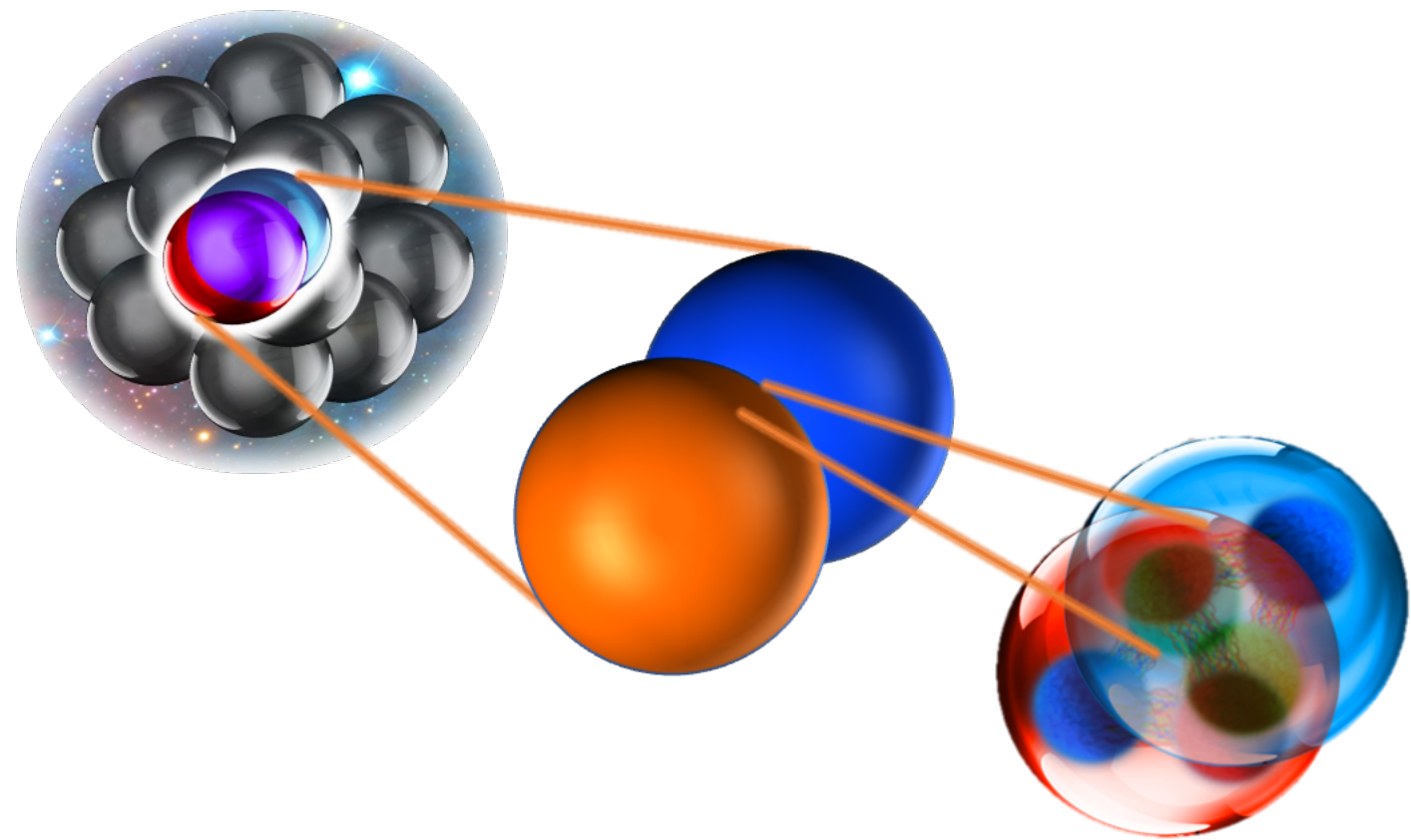
Low-energy **Ground-State**

# Relies on connection between electron scattering data and nuclear ground-state



# Two ways to examine reaction-dependence:

## Scale

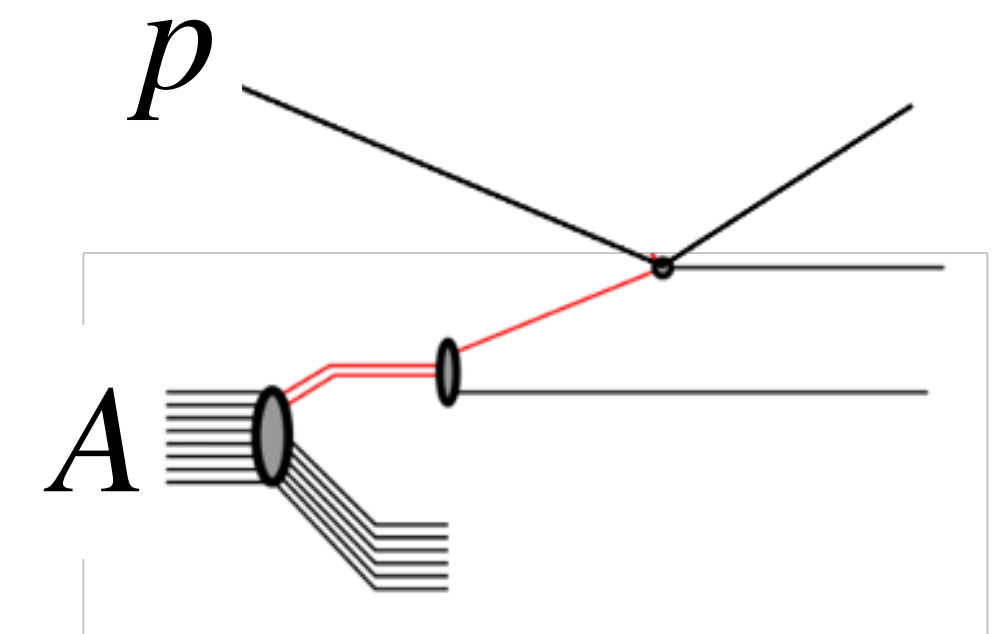
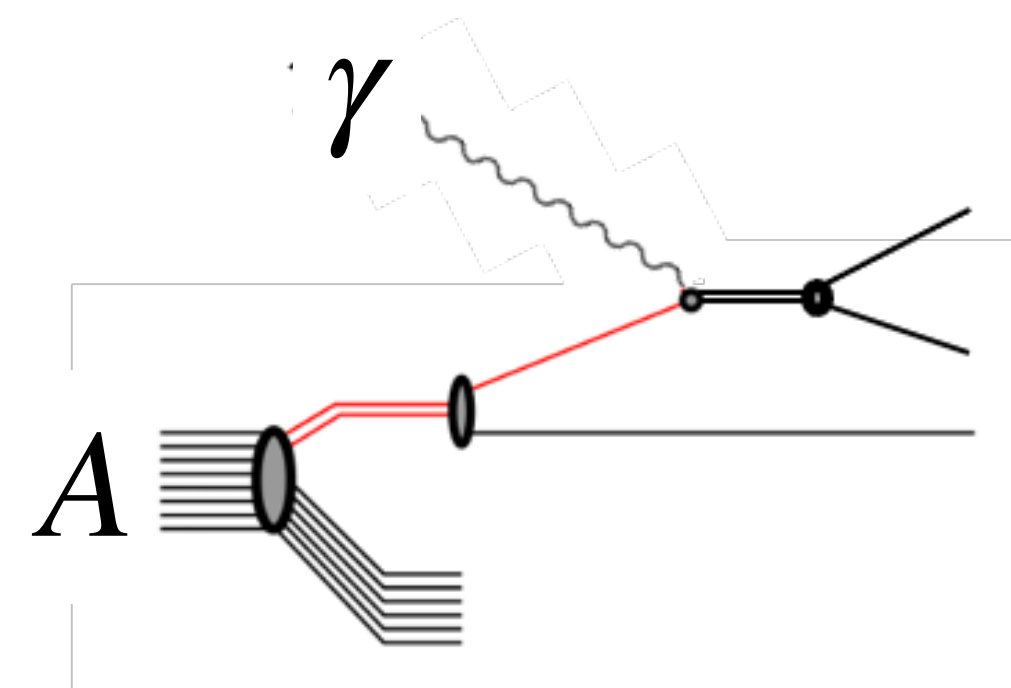
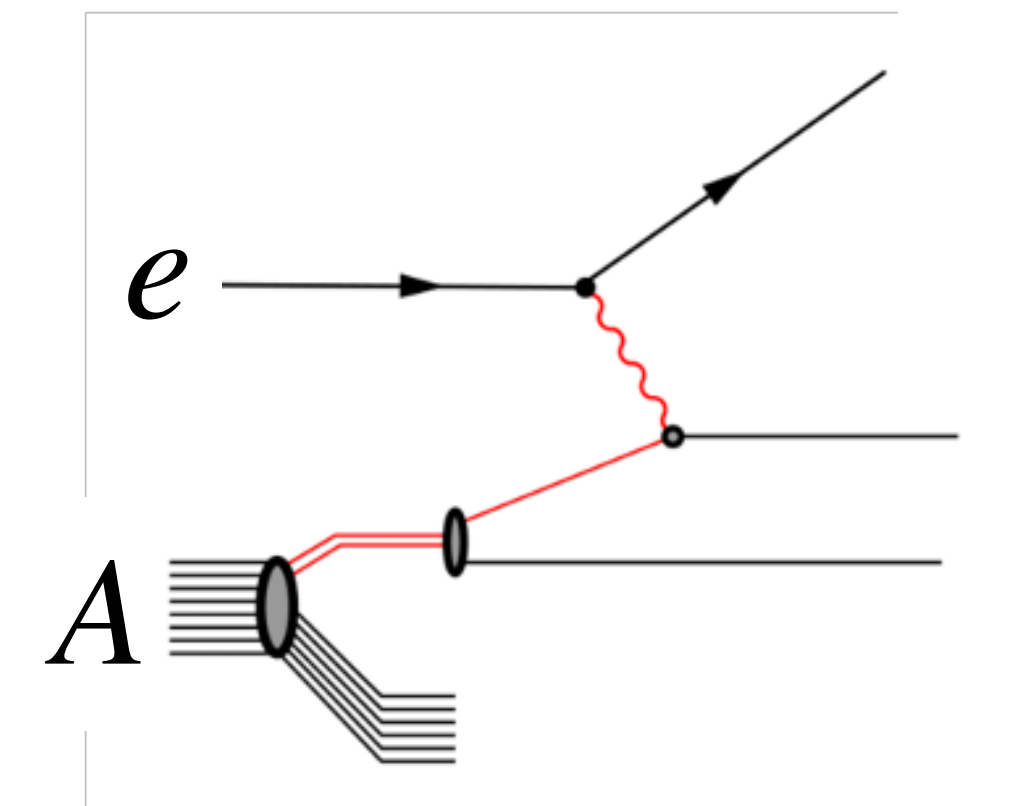


$Q^2, |t|$  change the resolution **scale**

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

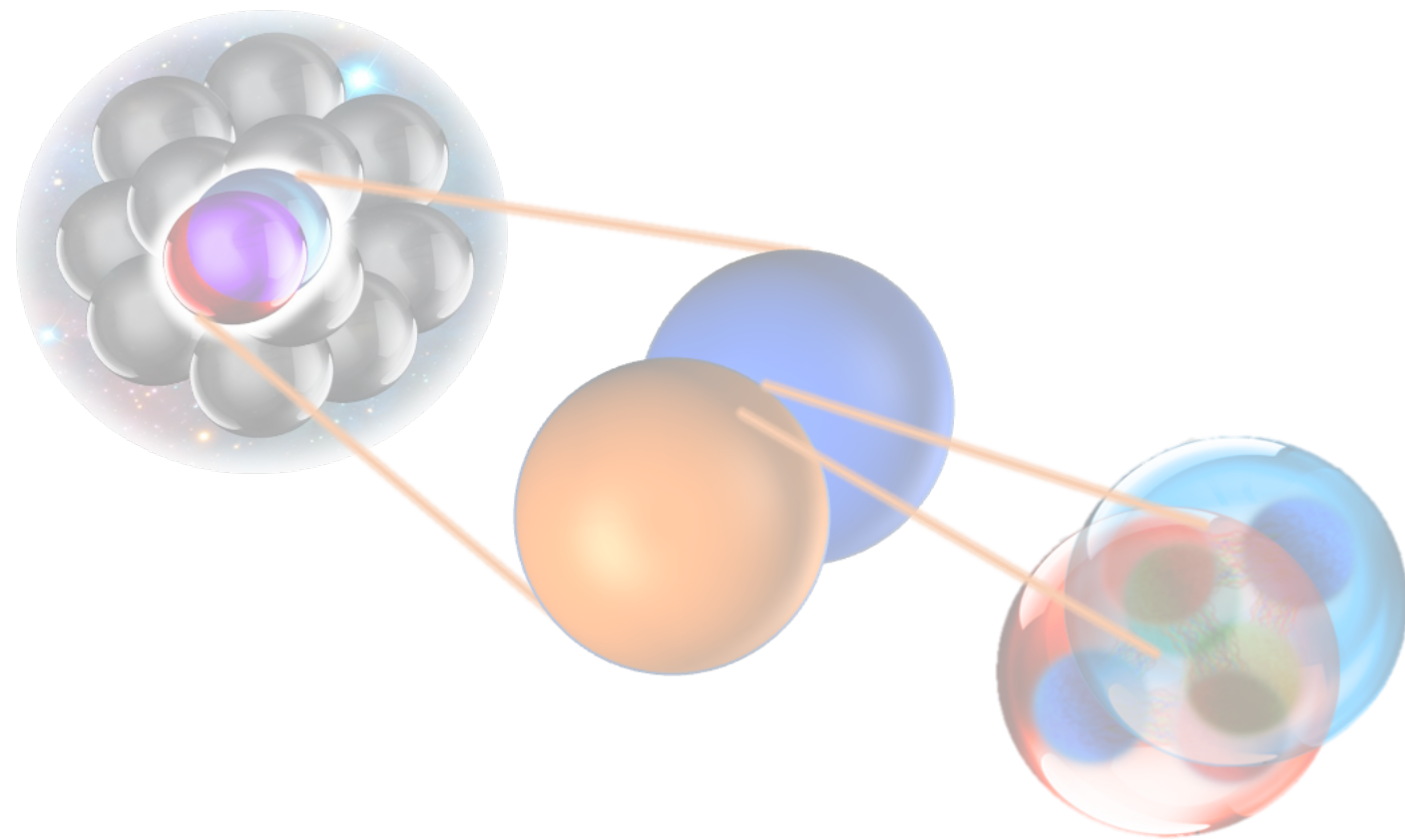
## Probe

Different **probes**:  
Electromagnetic ( $e^-$ ),  
Hadronic ( $p, A$ ),  
Photonuclear ( $\gamma$ )



# Two ways to examine reaction-dependence:

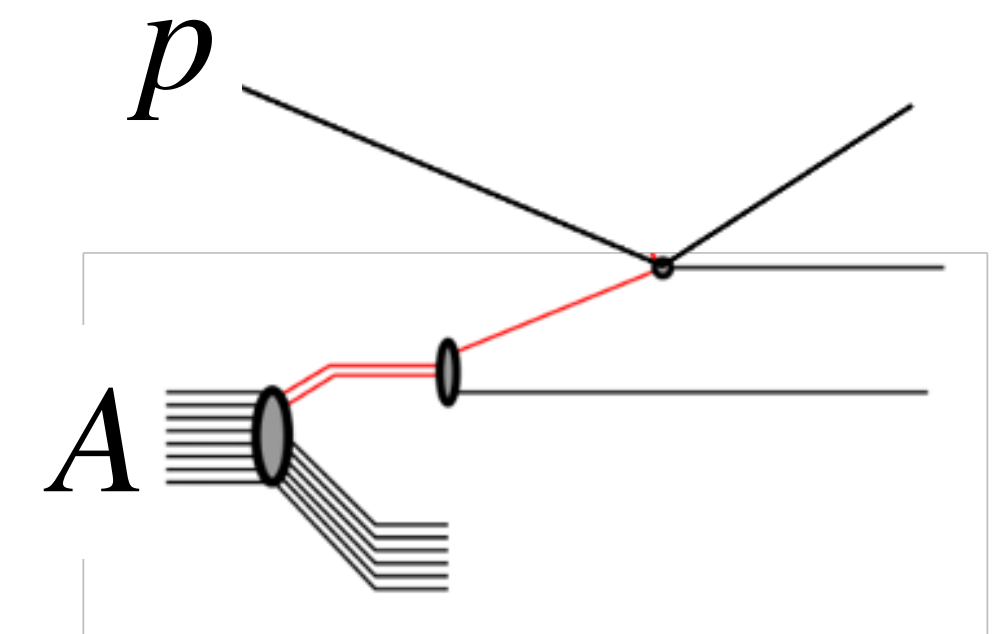
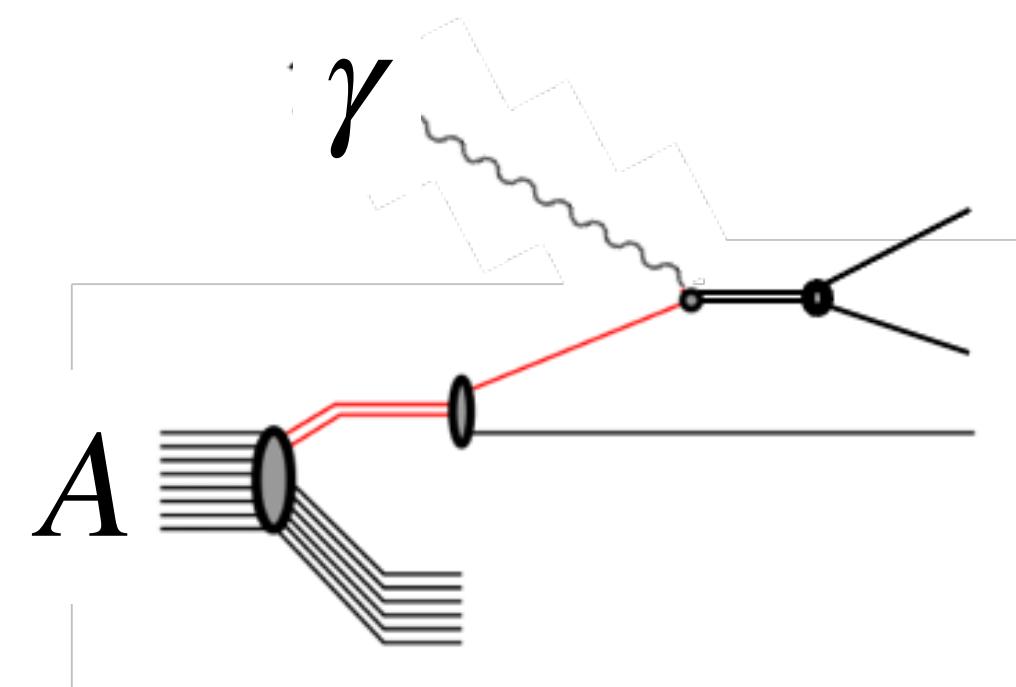
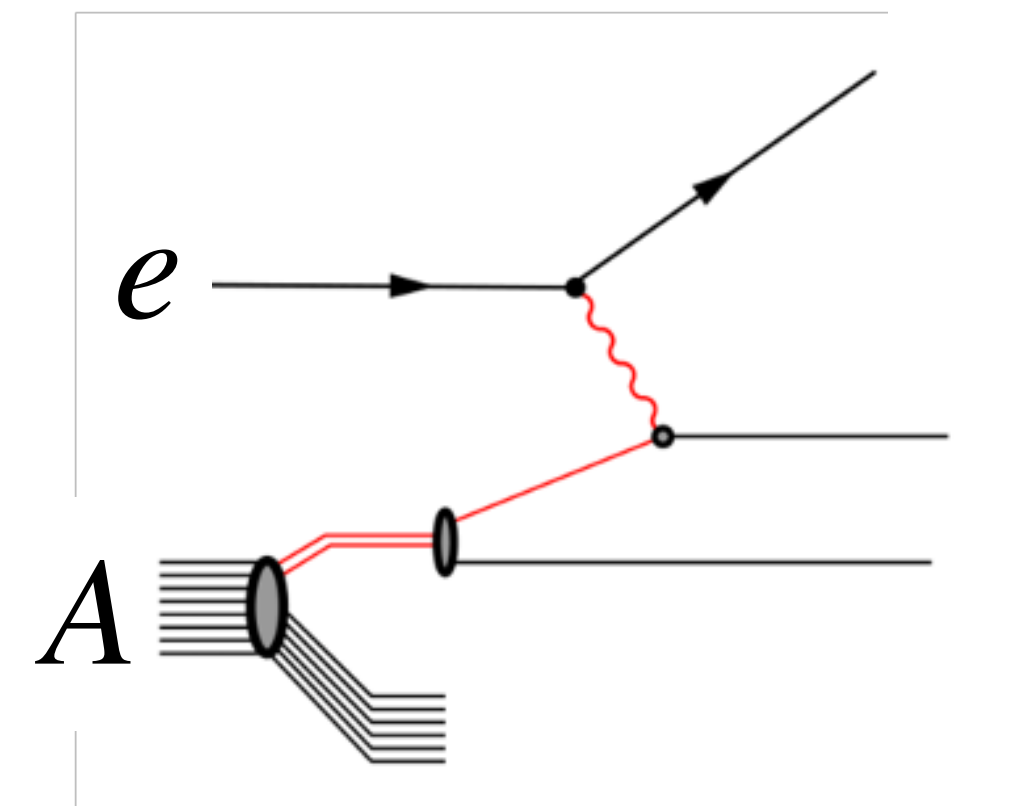
## Scale



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

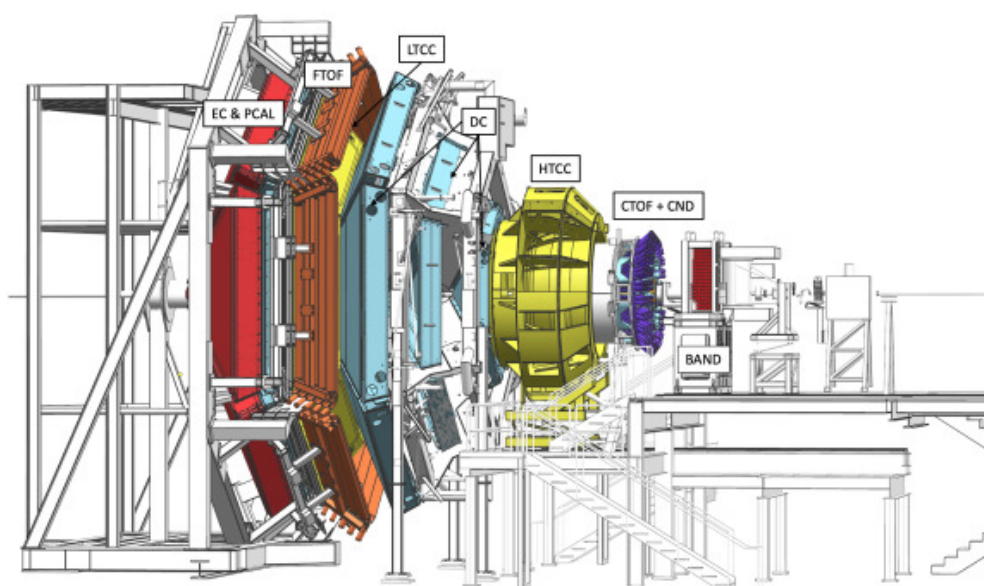
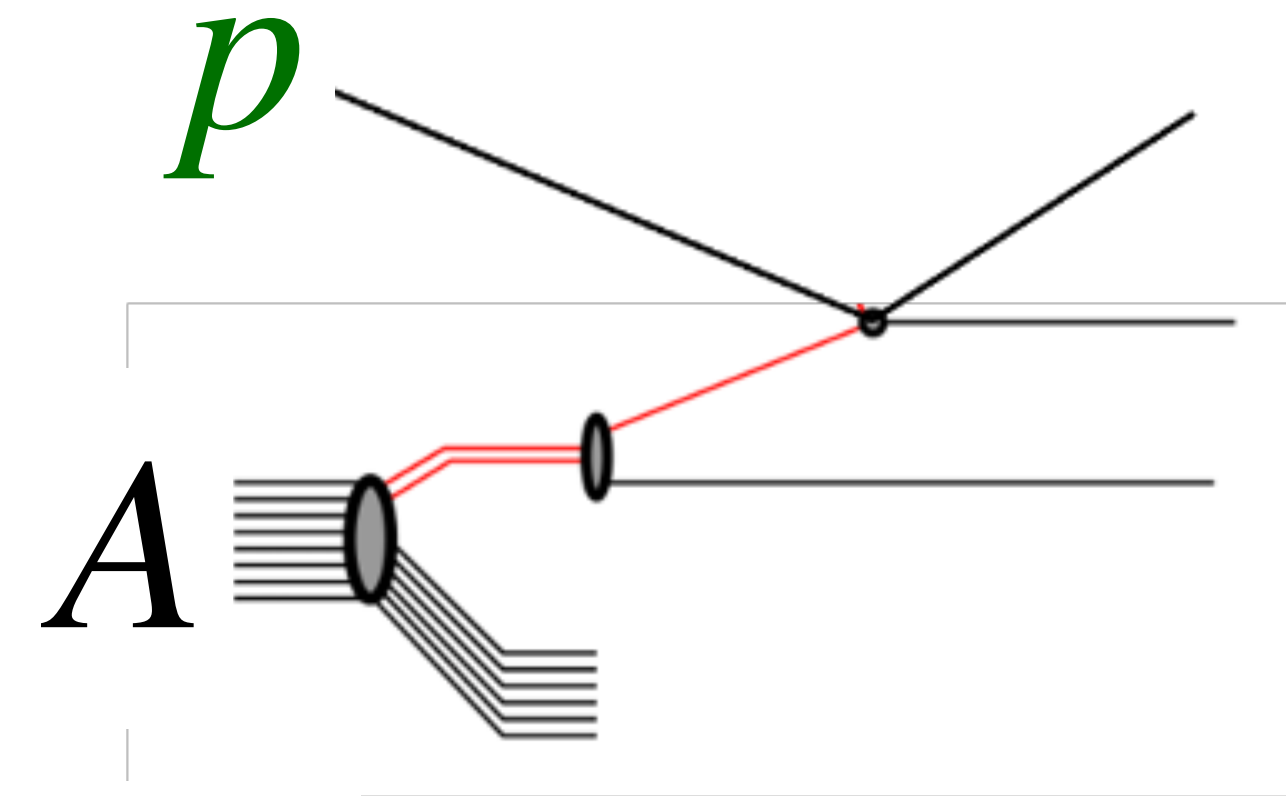
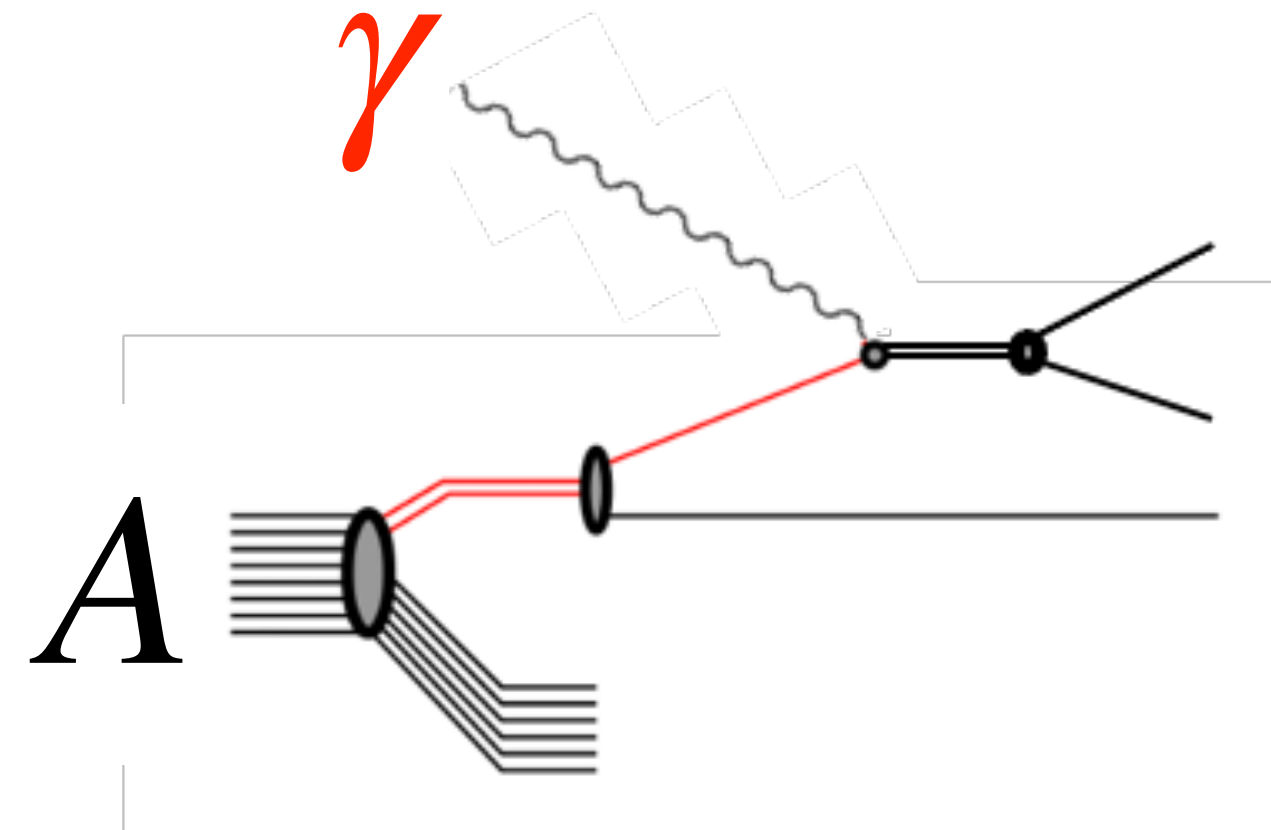
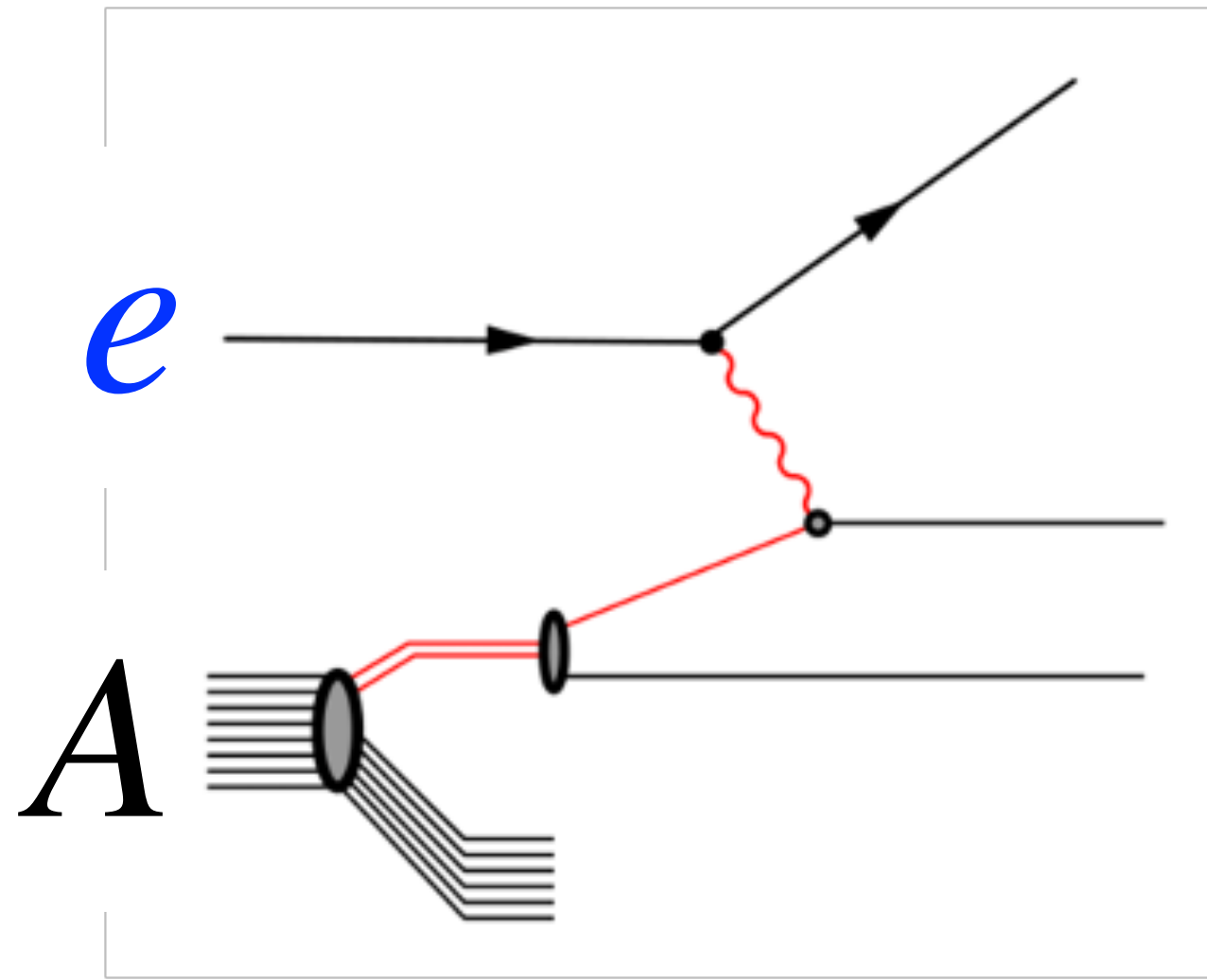
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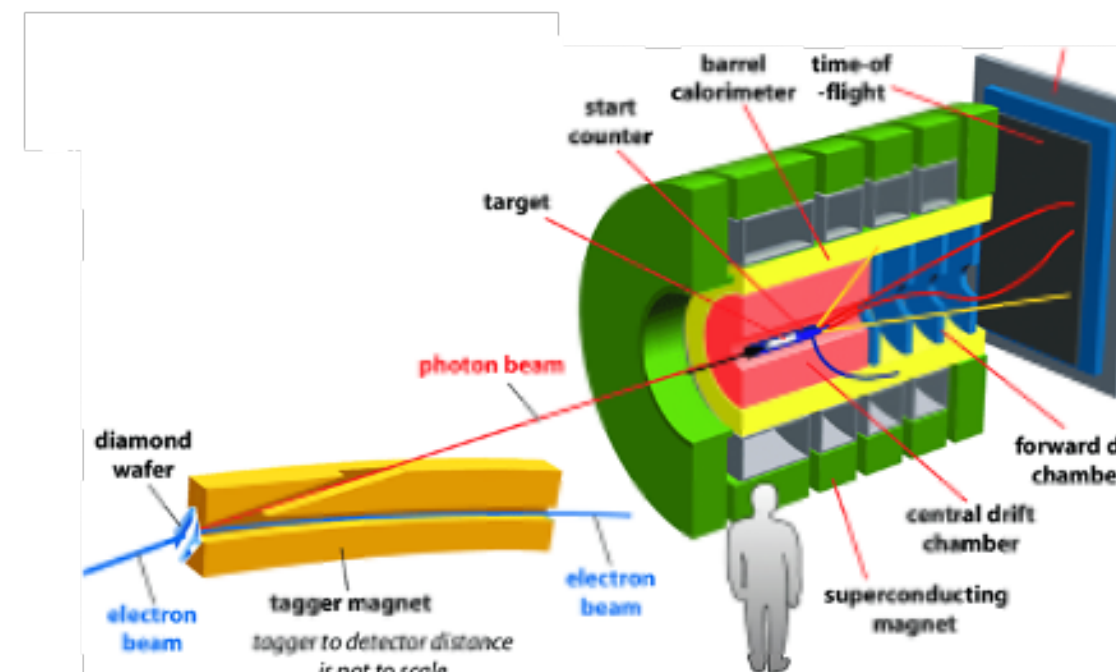


$$\sigma = \sigma_{\gamma, N}(q) \times S(p_i, E_i)$$

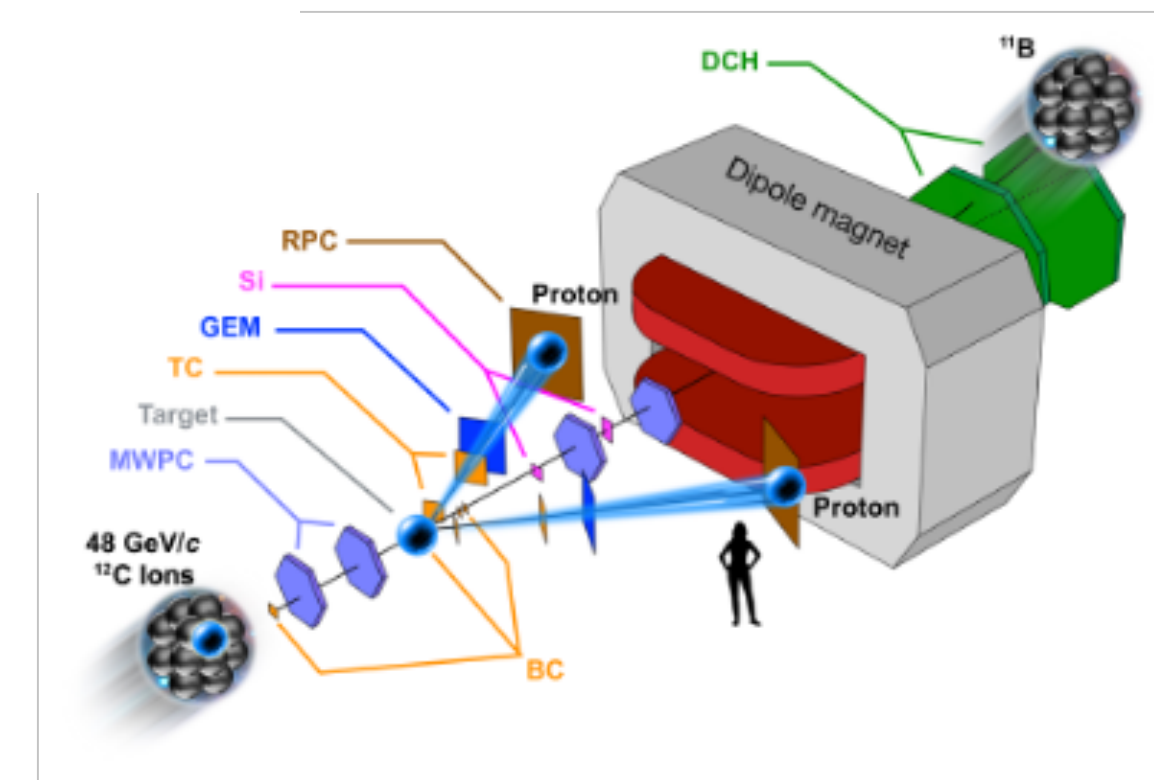
# Probe Dependence of SRCs



**CLAS12**

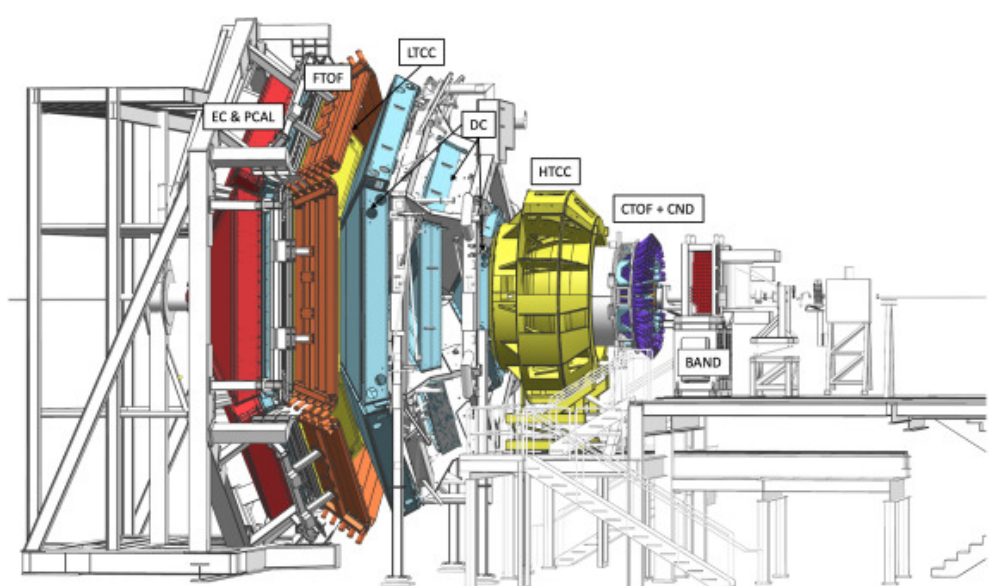
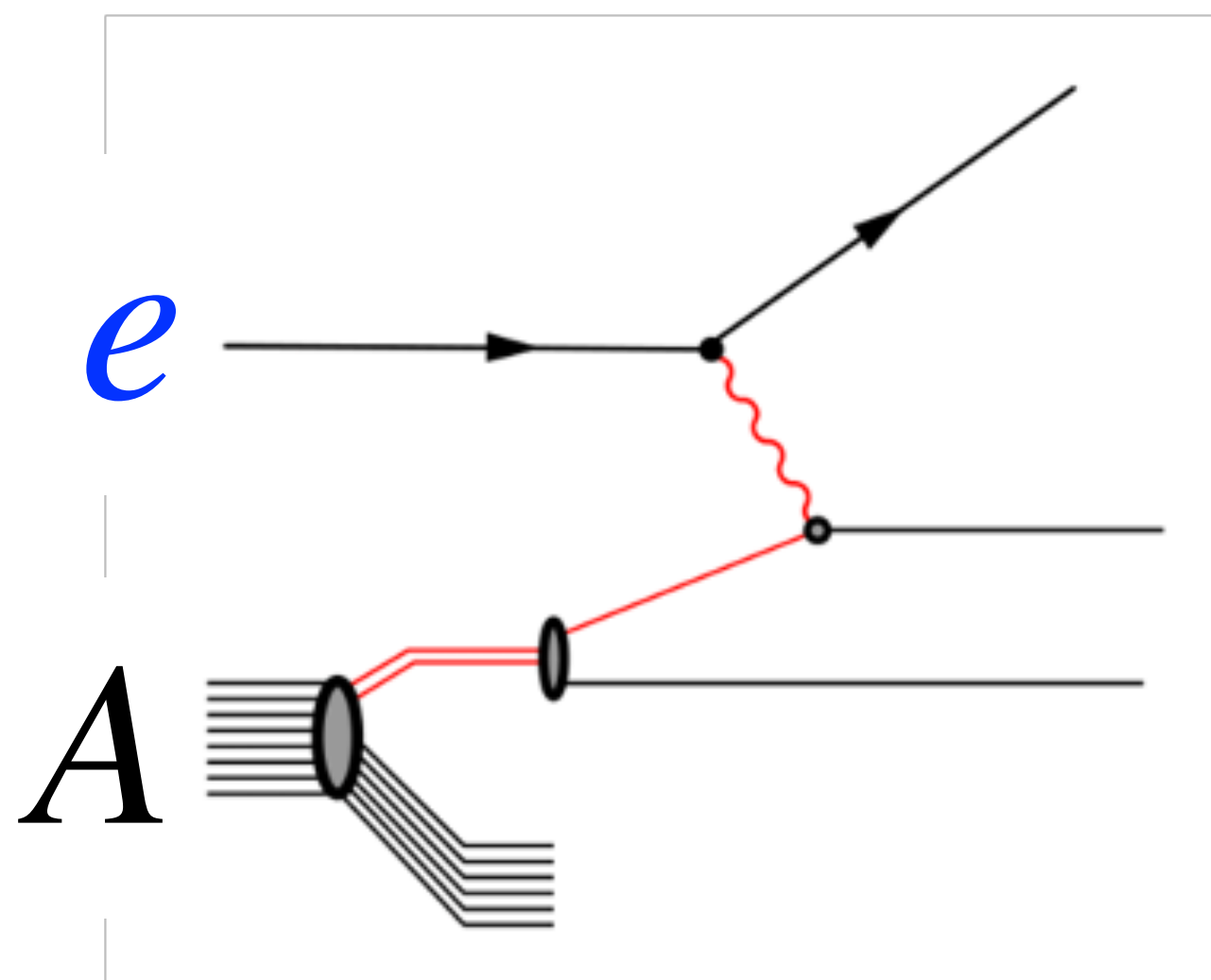


**GlueX**

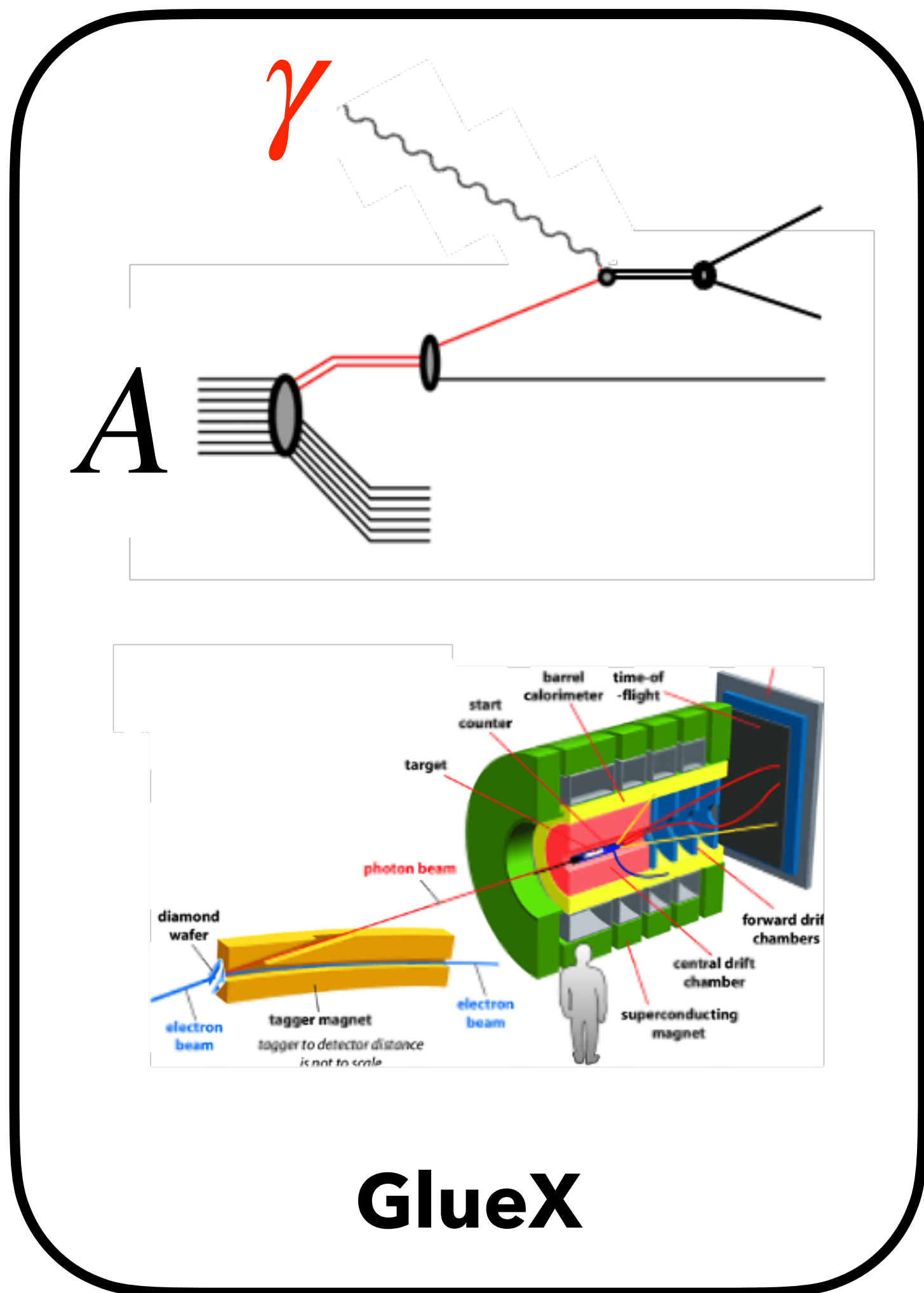


**BM@N / R3B**

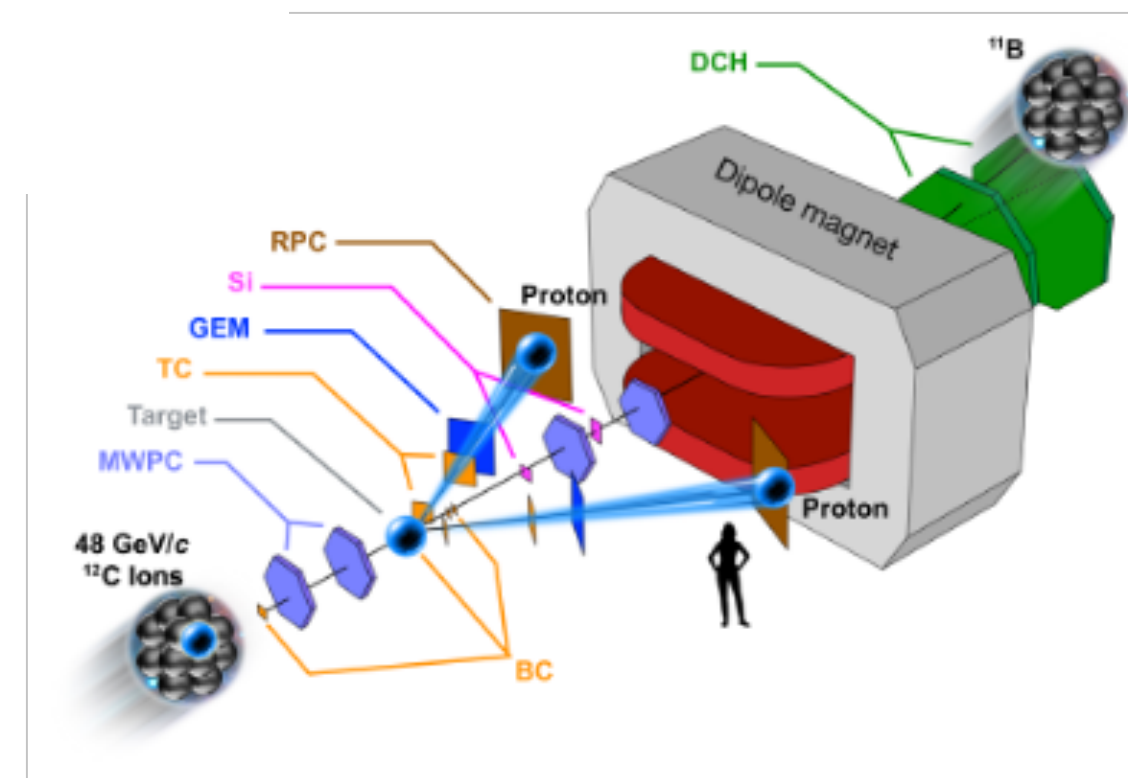
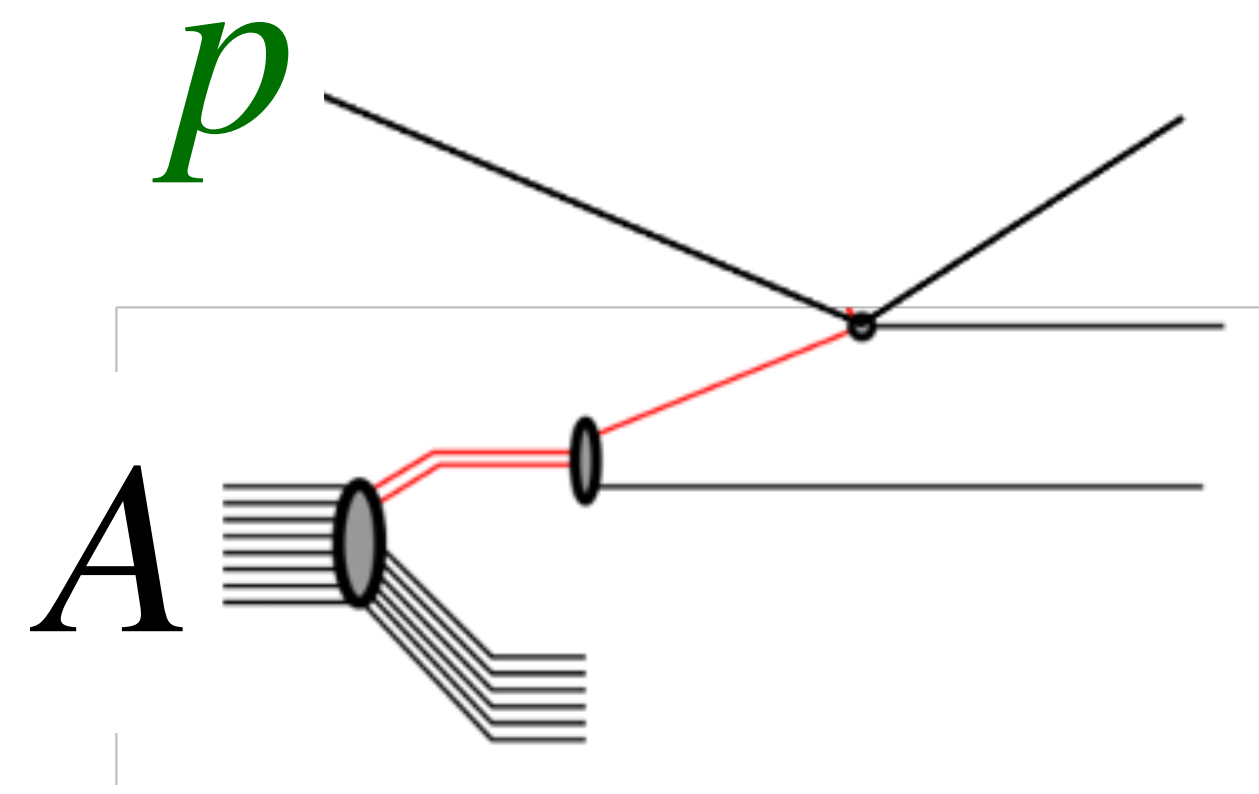
# Probe Dependence of SRCs



**CLAS12**



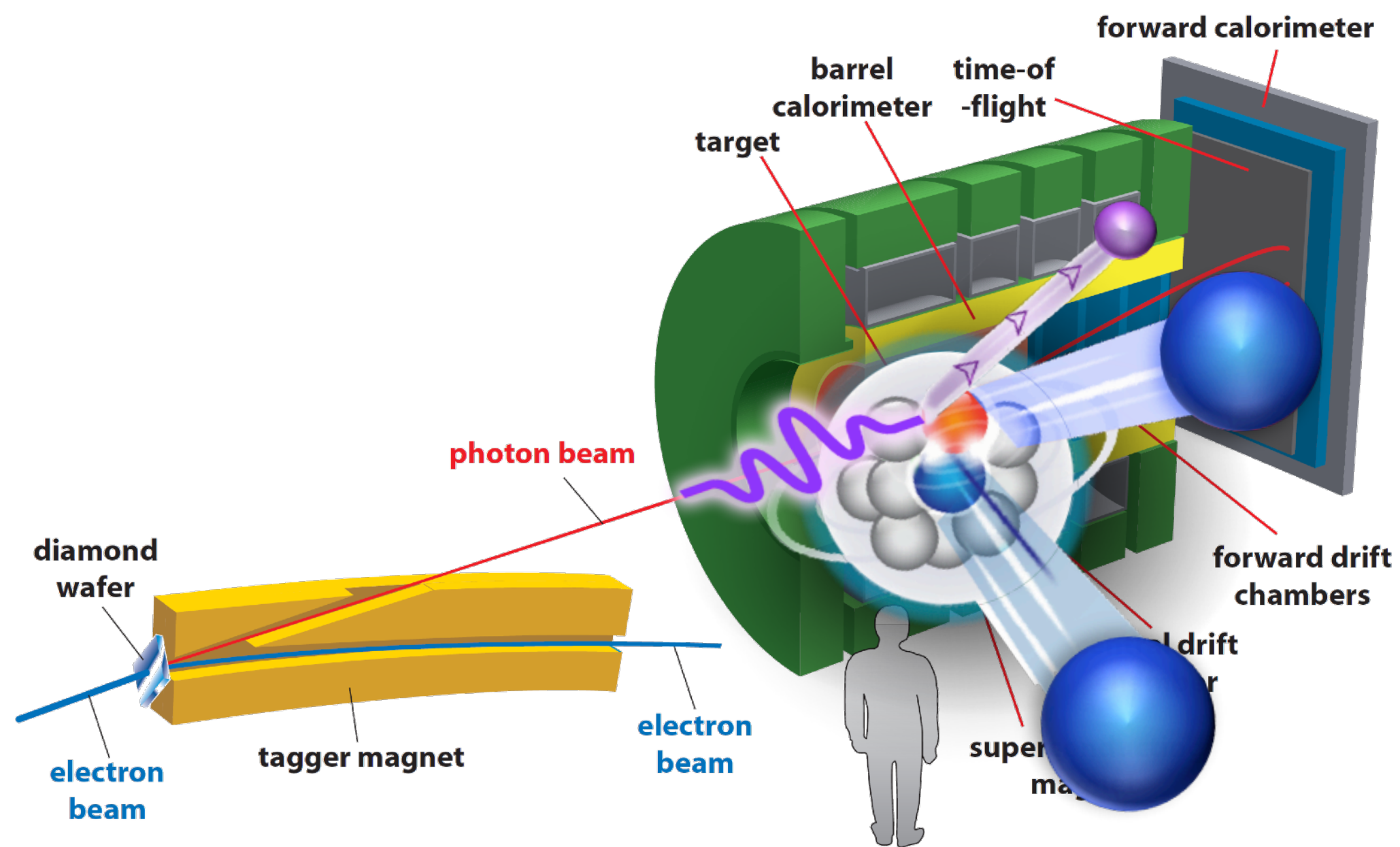
**GlueX**



**BM@N / R3B**

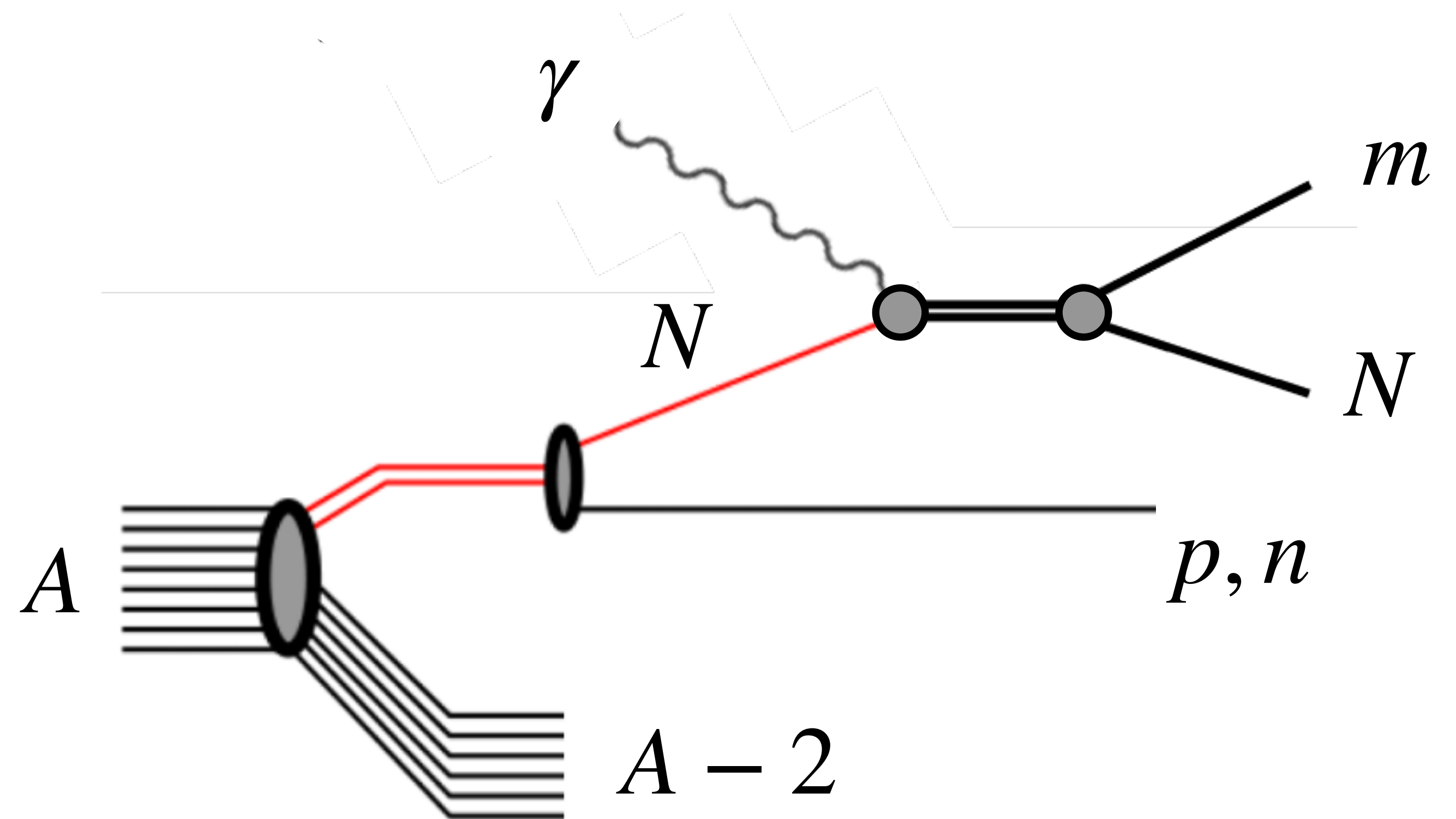
# Hall D SRC-CT Experiment

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



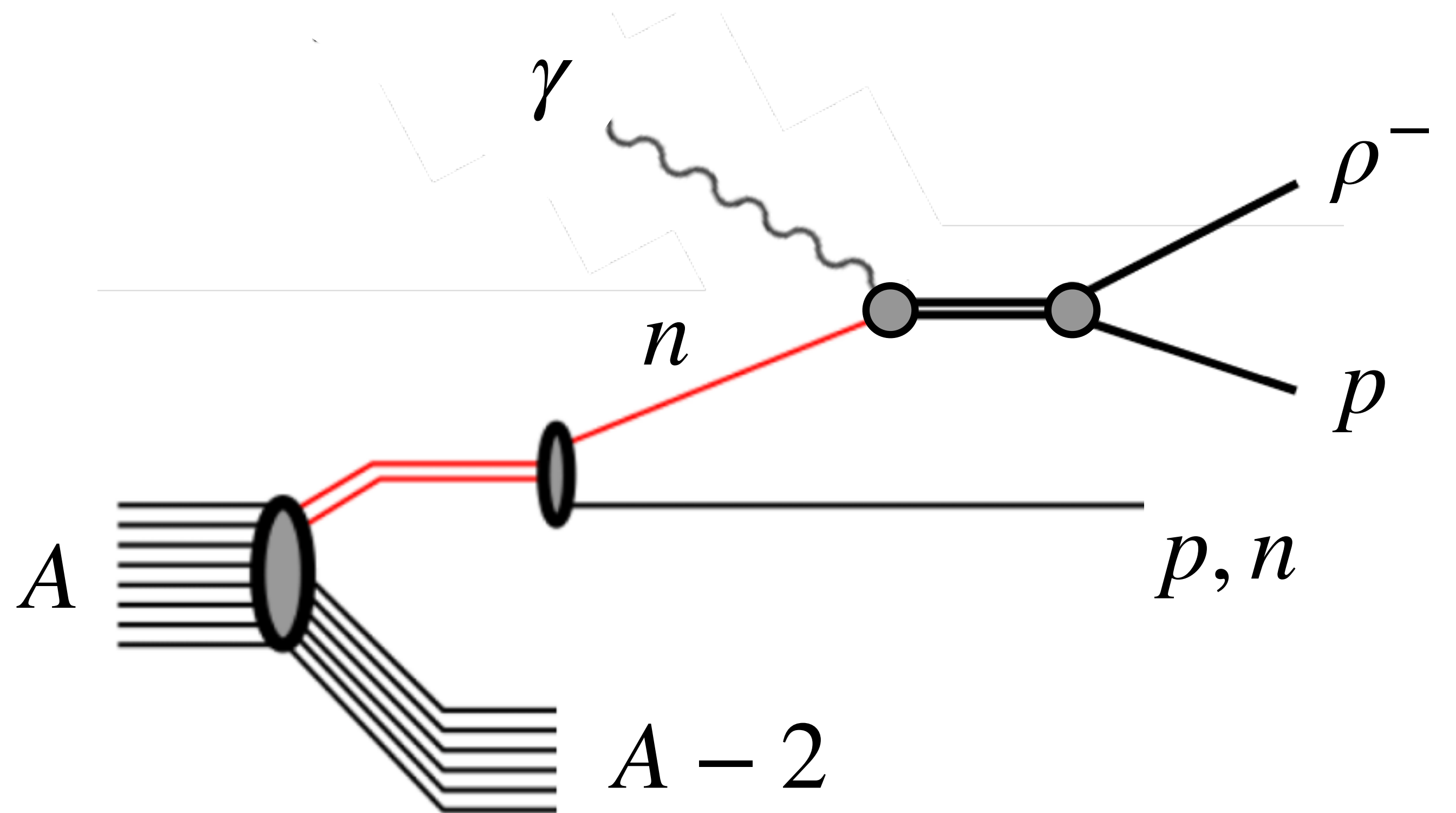
# SRC Photoproduction in Hall D

- Quasi-elastic photoproduction: hard photon-nucleon interaction



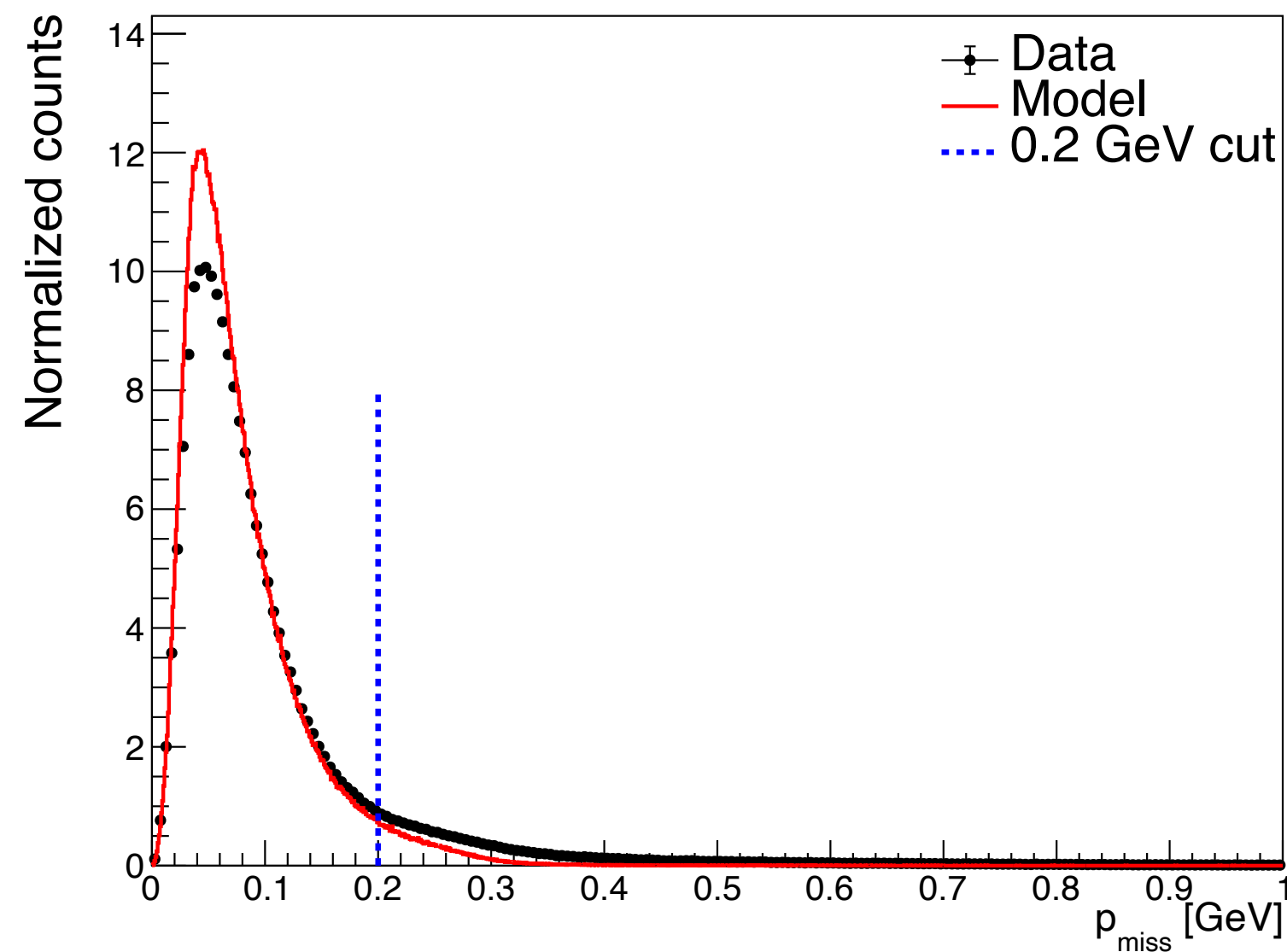
# SRC Photoproduction in Hall D

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

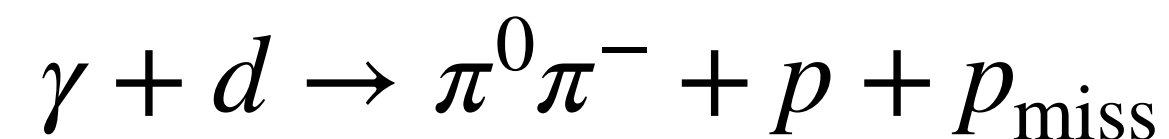


# $\rho^-$ Photoproduction Cross Section

$$\sigma = \sigma_{\gamma n}(t) \times S(p_i, E_i)$$

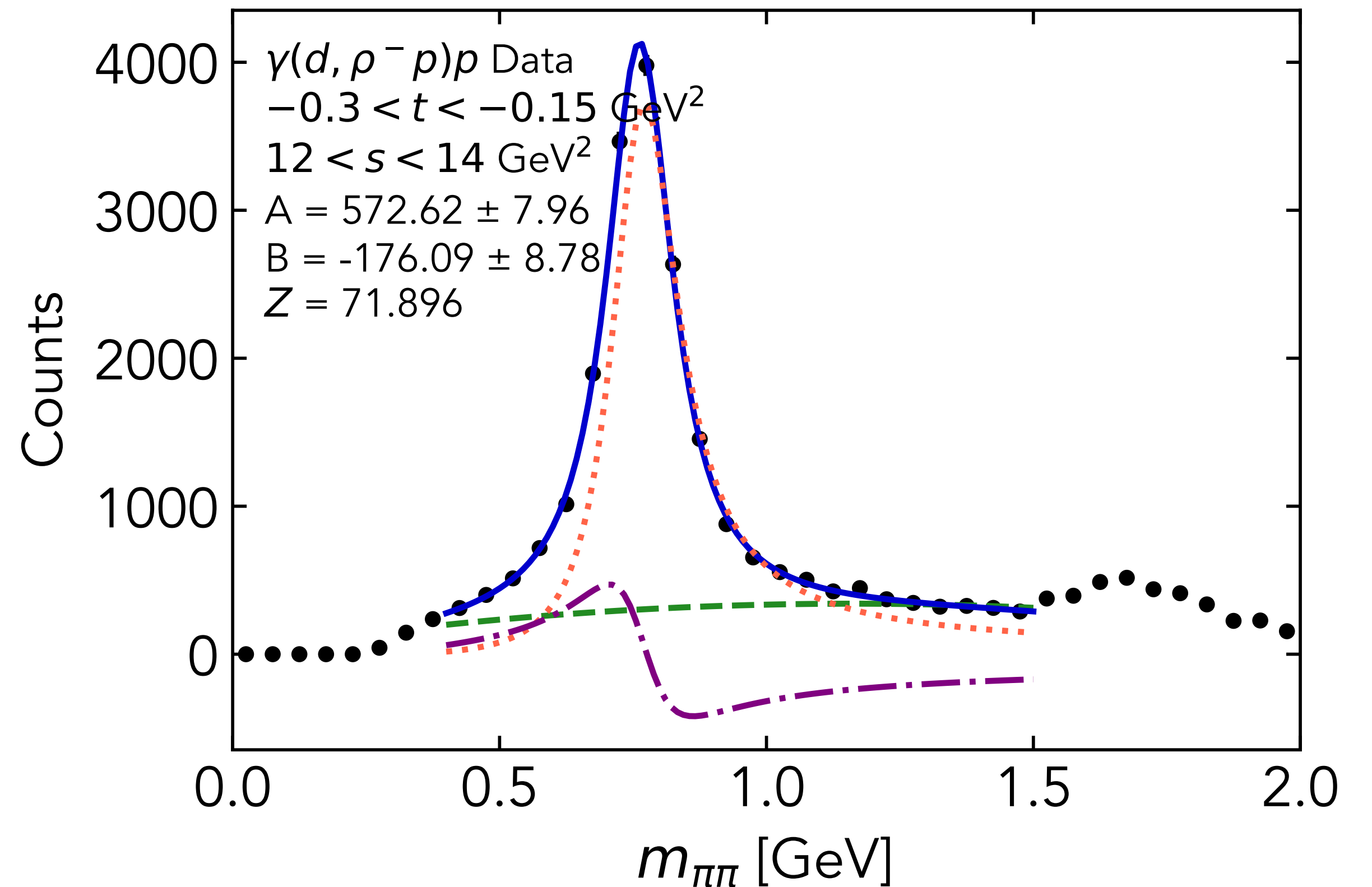


Quasi-free reaction in deuteron



$$|p_{\text{miss}}| < 0.2 \text{ GeV}/c$$

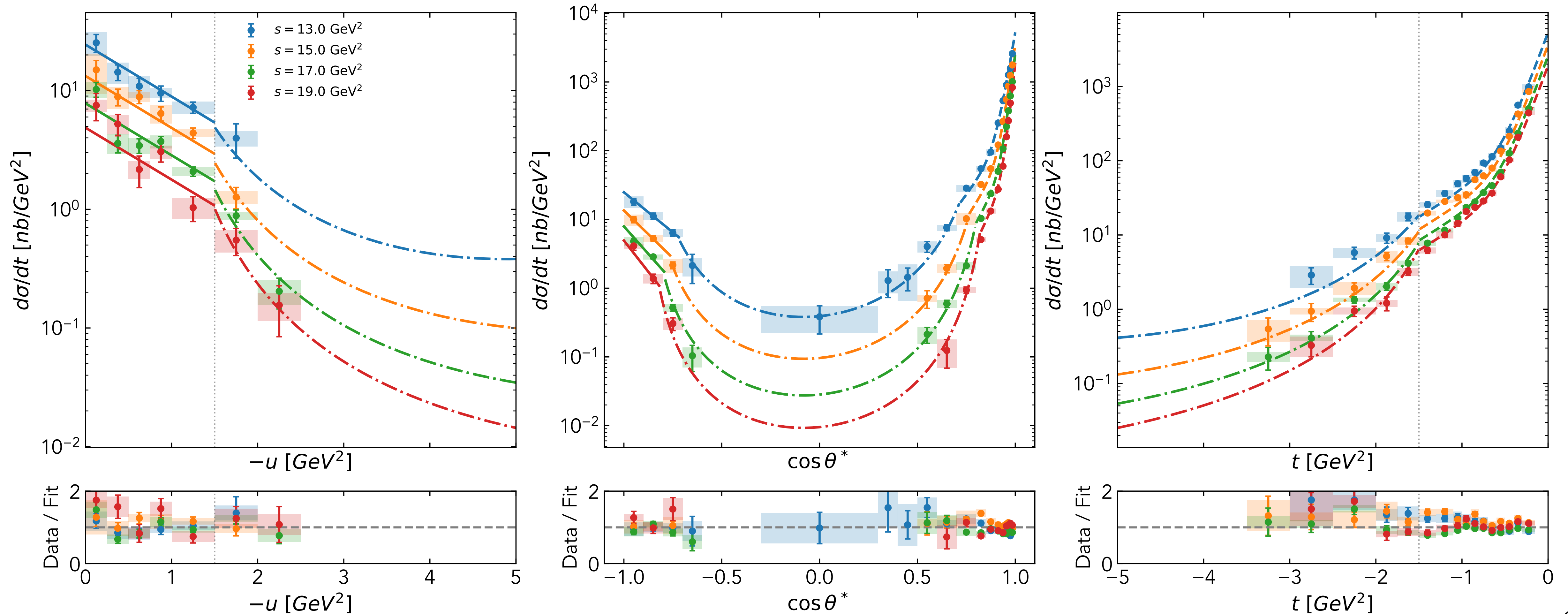
$$p_{\text{miss}}^- < 0.975 \text{ GeV}/c$$



Non-resonant interference

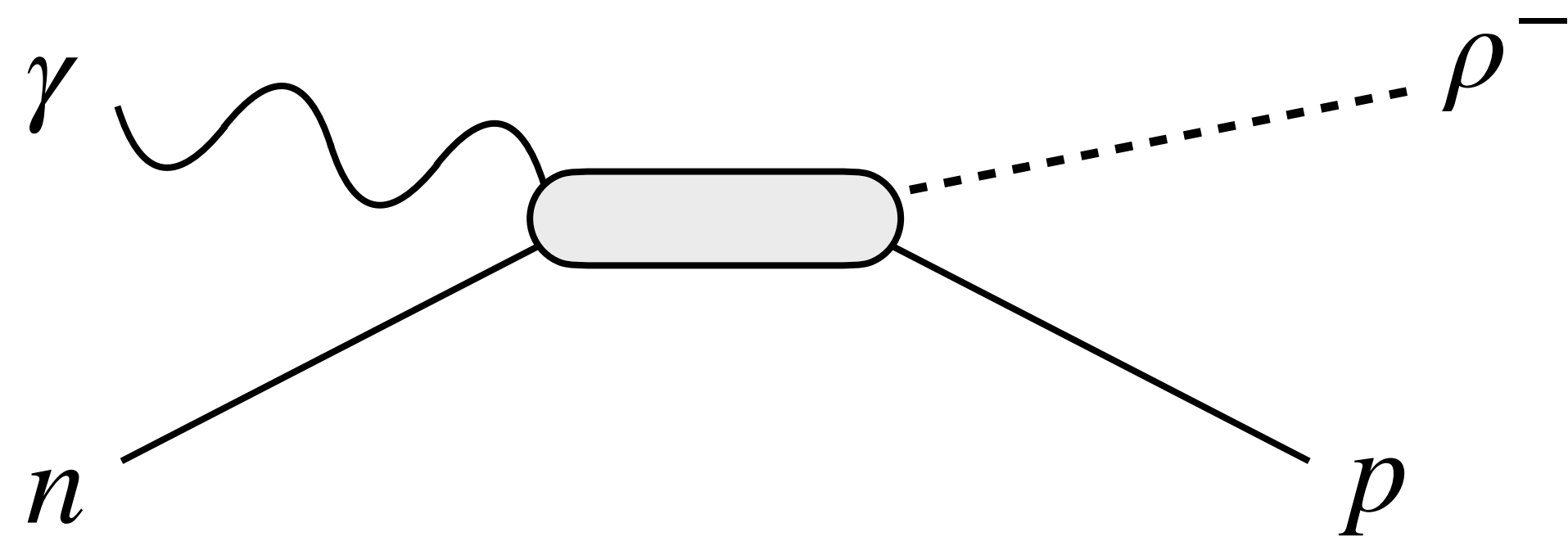
# $\rho^-$ Photoproduction Cross Section

$$\sigma = \sigma_{\gamma n}(t) \times S(p_i, E_i)$$



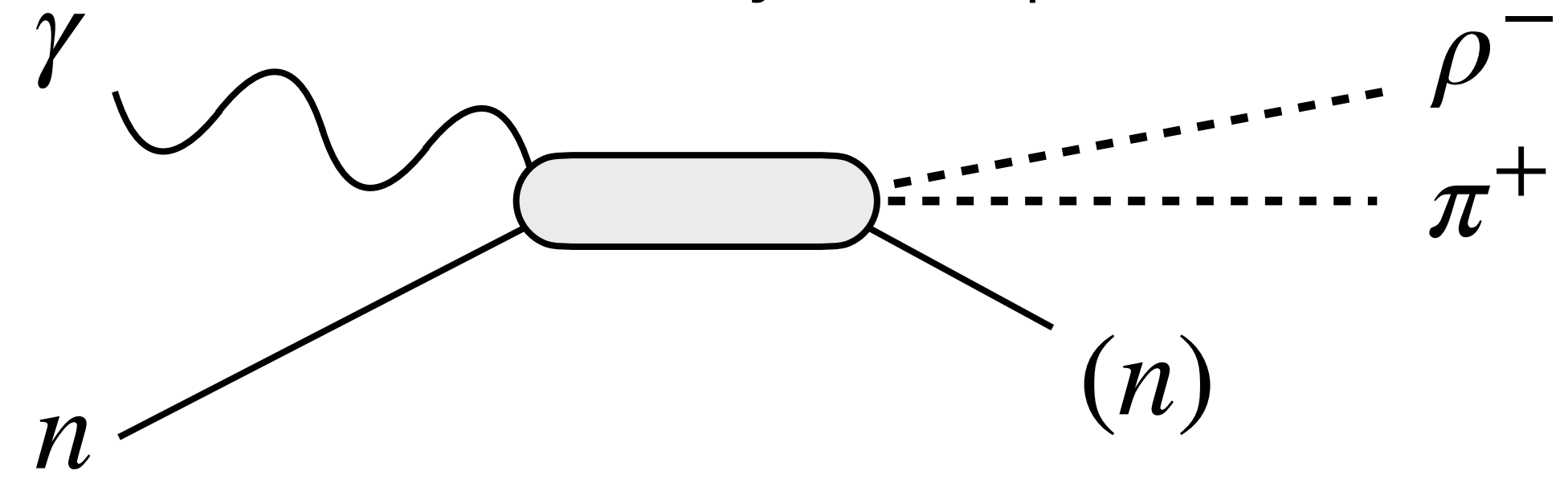
# SRC Event Selection

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



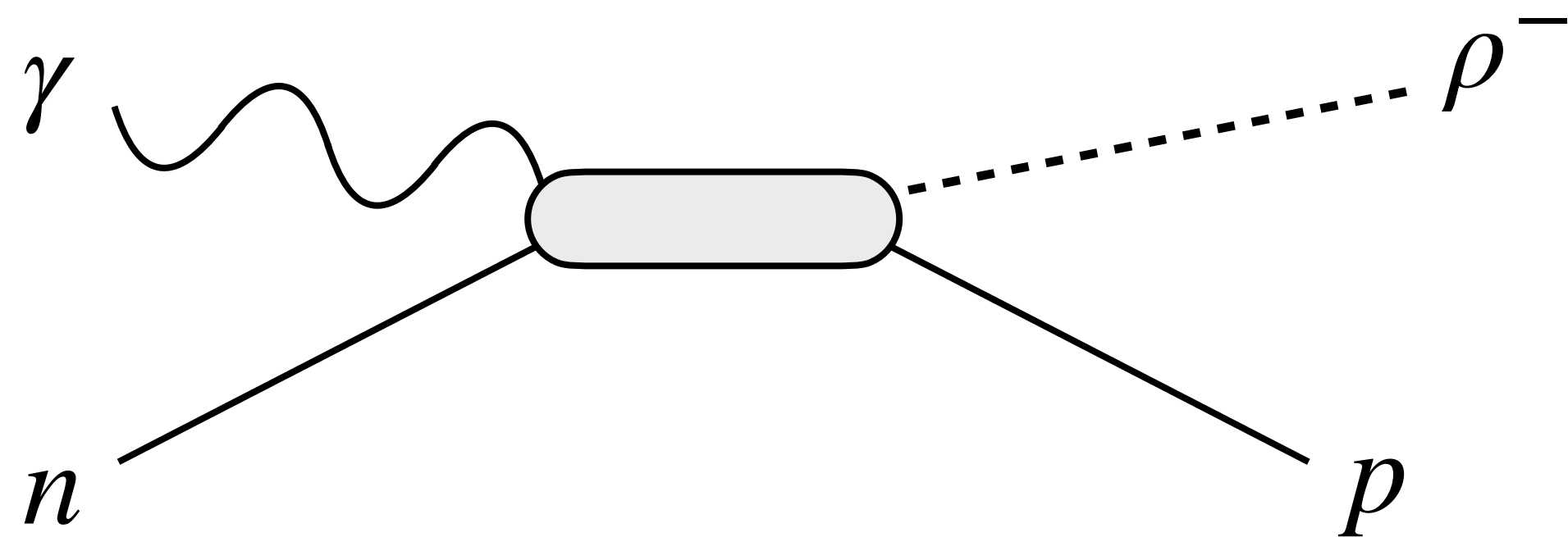
Background:  $\gamma n \rightarrow \rho^- \pi^+ n$

Misidentify  $\pi^+$  as proton



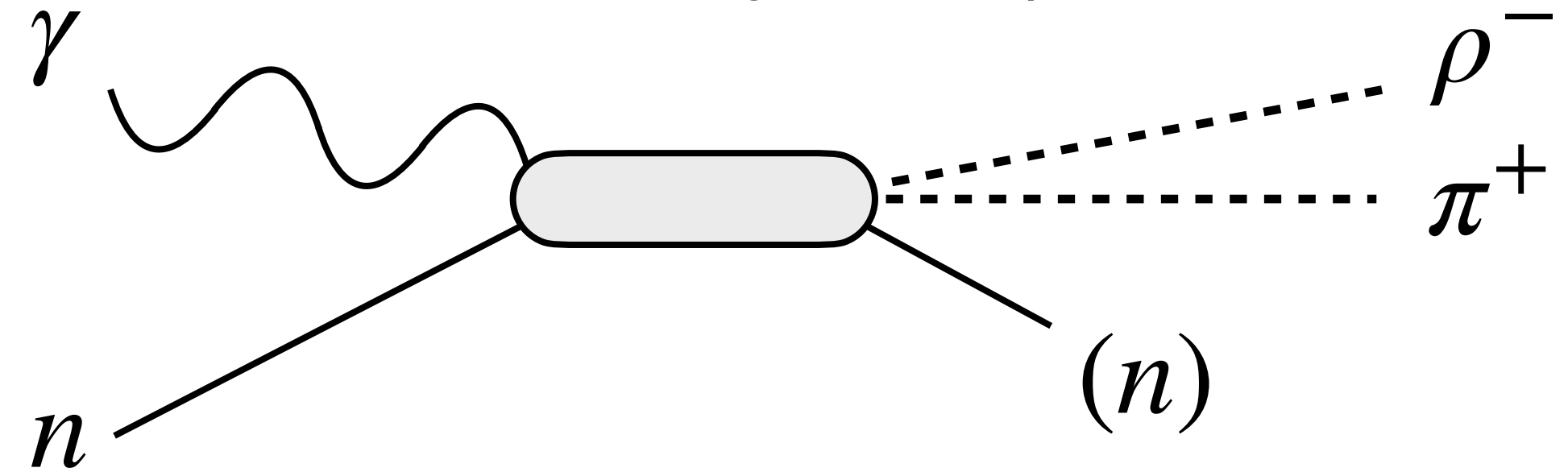
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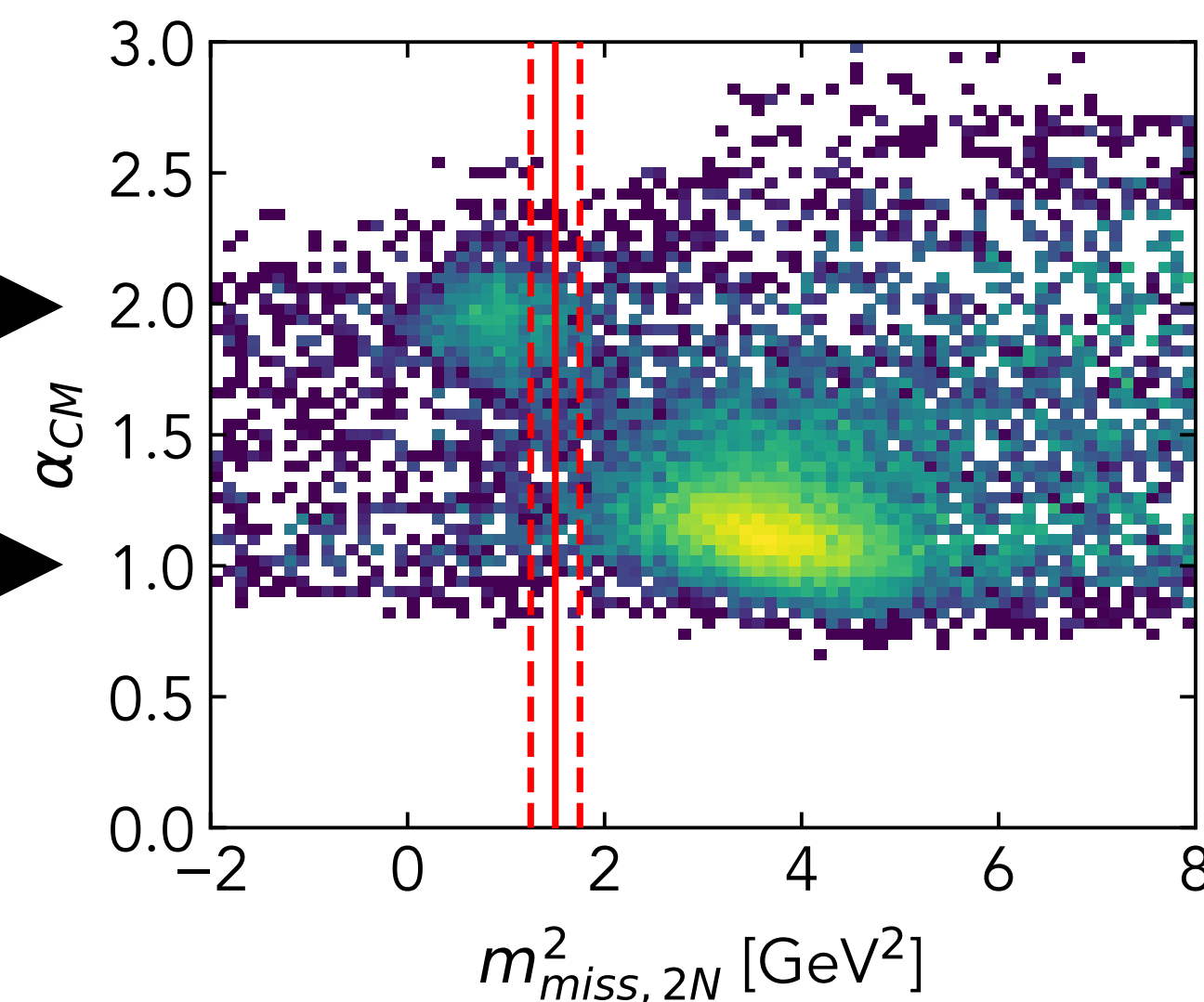
Misidentify  $\pi^+$  as proton



Two-nucleon knockout



One-nucleon knockout

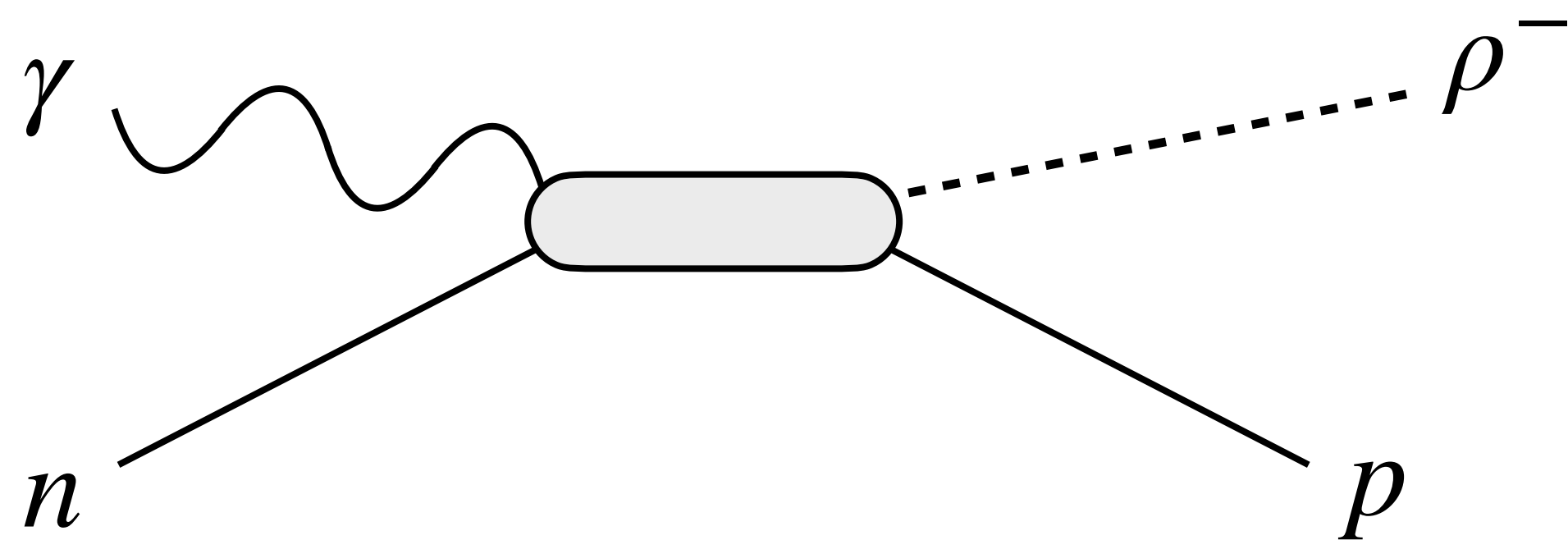


**Second nucleon detection  
can help identify signal vs.  
background kinematics**

$$m^2_{miss,2N} \equiv (p_\gamma + 2p_N - p_M - p_{lead})$$

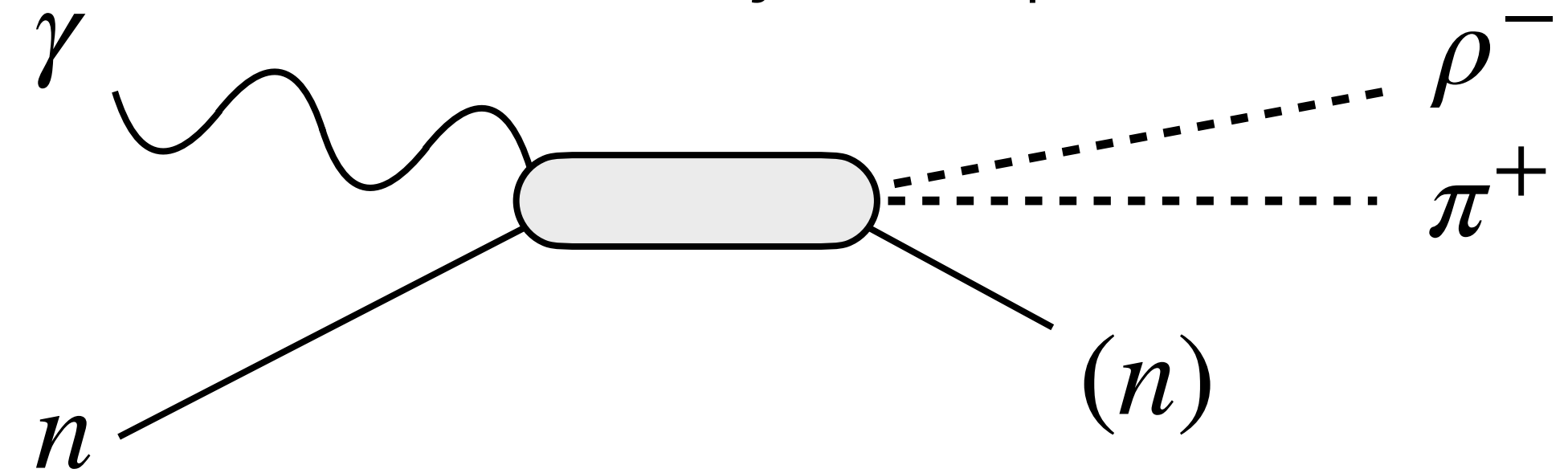
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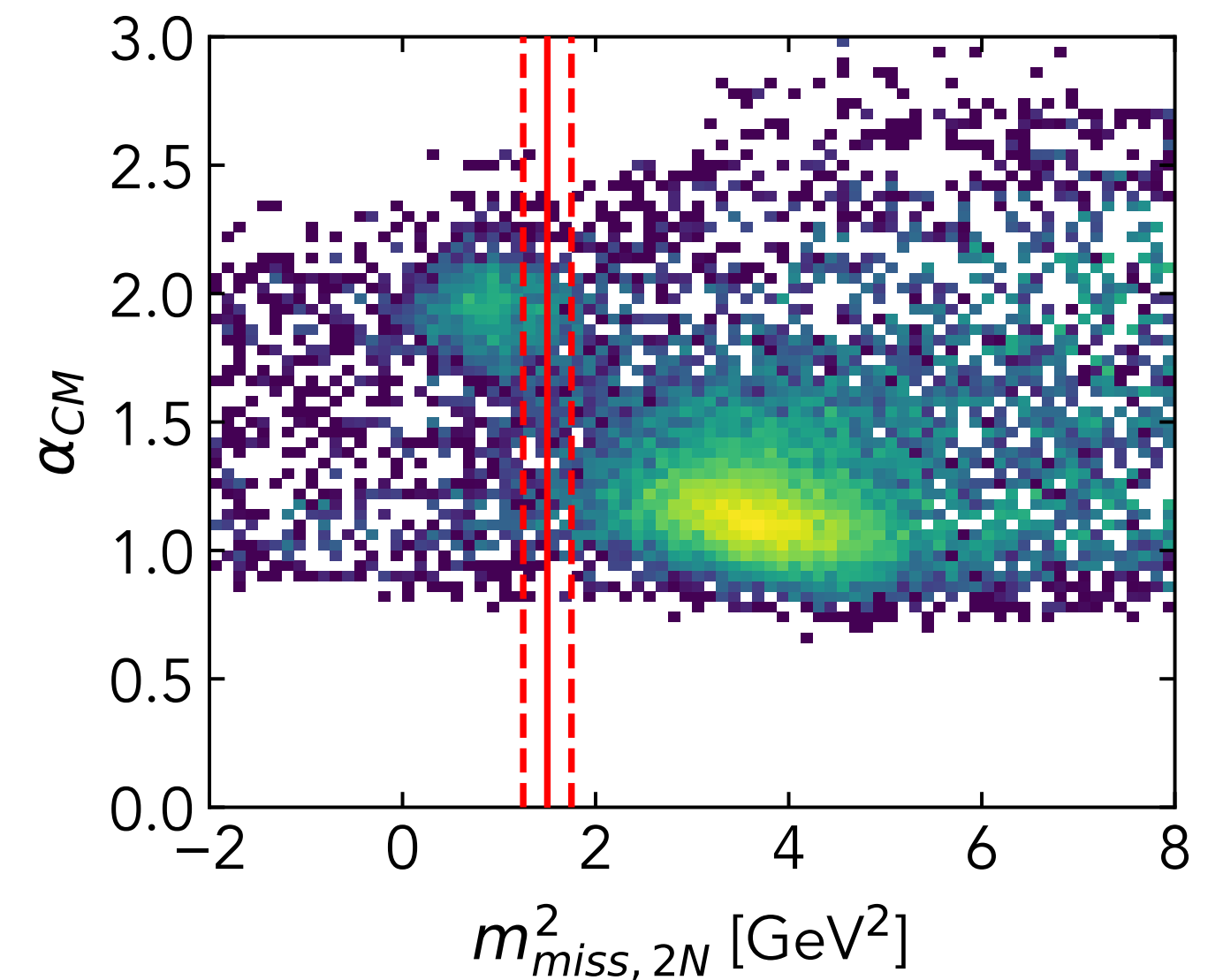
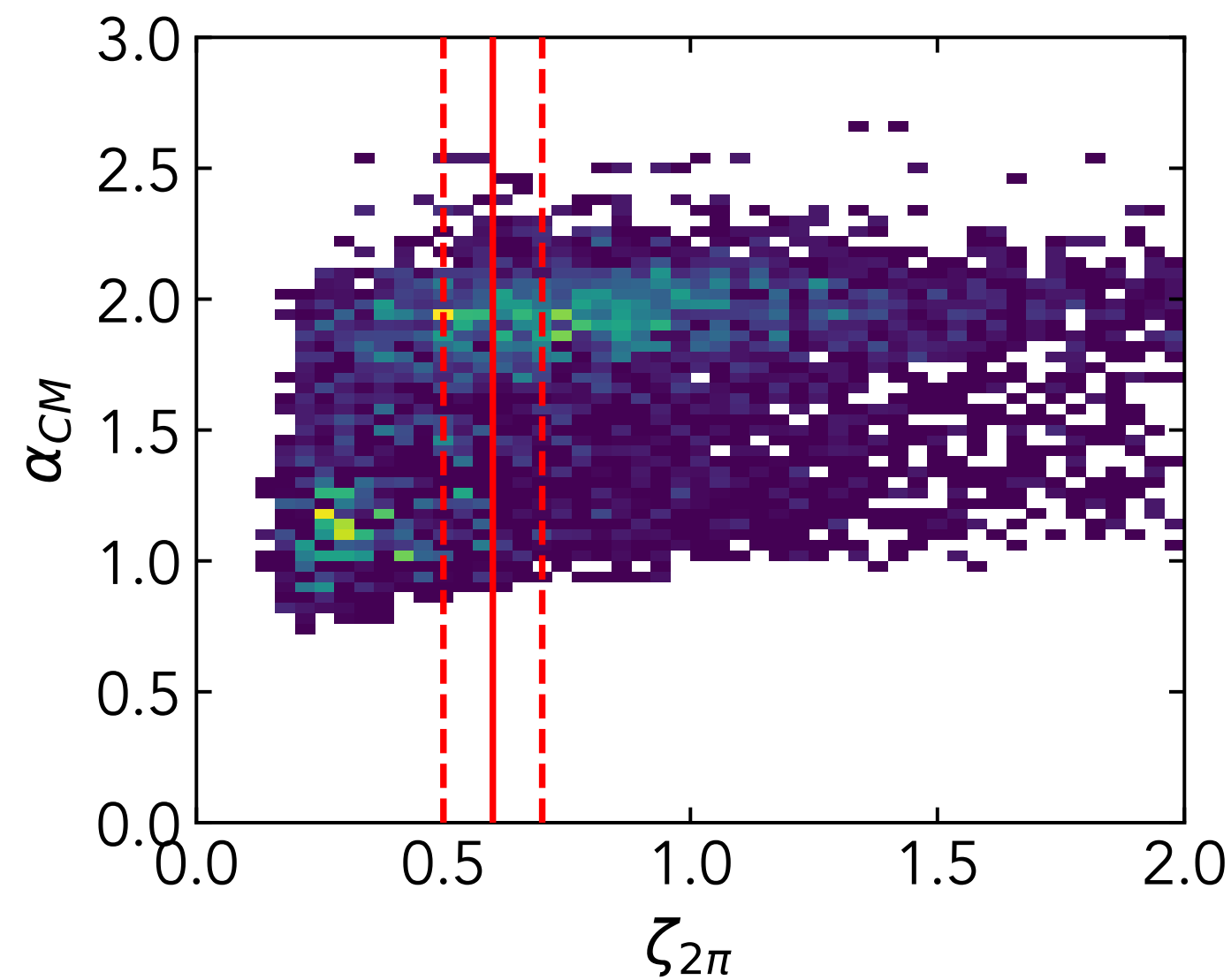
Inclusive variables:

- 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:  $\zeta_M \equiv \frac{-t_M}{2m_N(E_\gamma - E_M)} \sim 1$

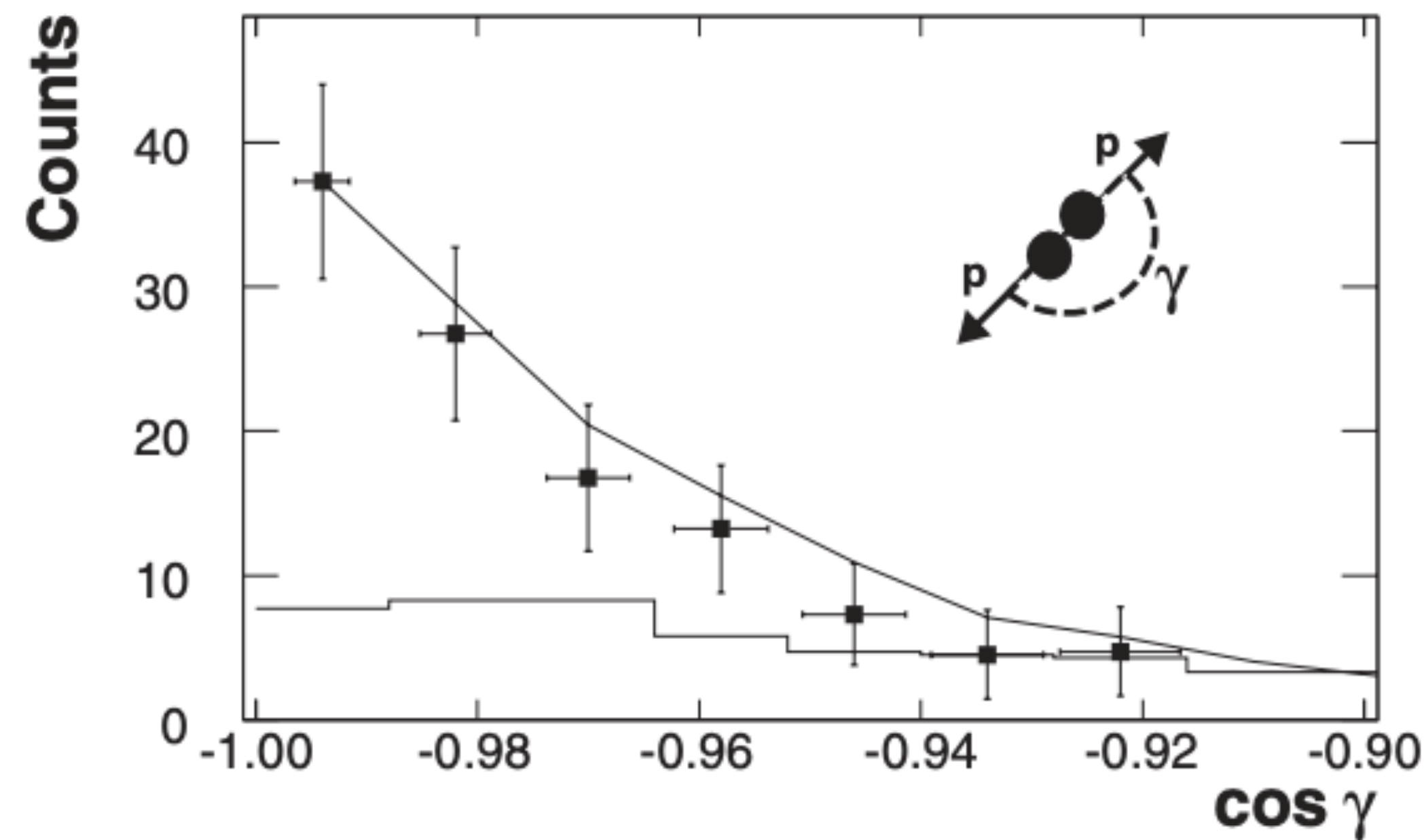
Novel photoproduction variables balance **PID**, **resolution**, and **kinematic** considerations to identify SRC signal

# SRC Event Selection

- $p_{\text{lead}} > 1.2 \text{ GeV}/c$
- $|t|, |u| > 1.5 \text{ GeV}^2$
- $0.4 < k_{\text{miss}} < 1.2 \text{ GeV}/c$
- $\zeta_{2\pi} > 0.6$
- $m_{\text{miss},2N}^2 < 1.5 \text{ GeV}^2$
- $0.3 < p_{\text{rec}} < 1 \text{ GeV}/c$

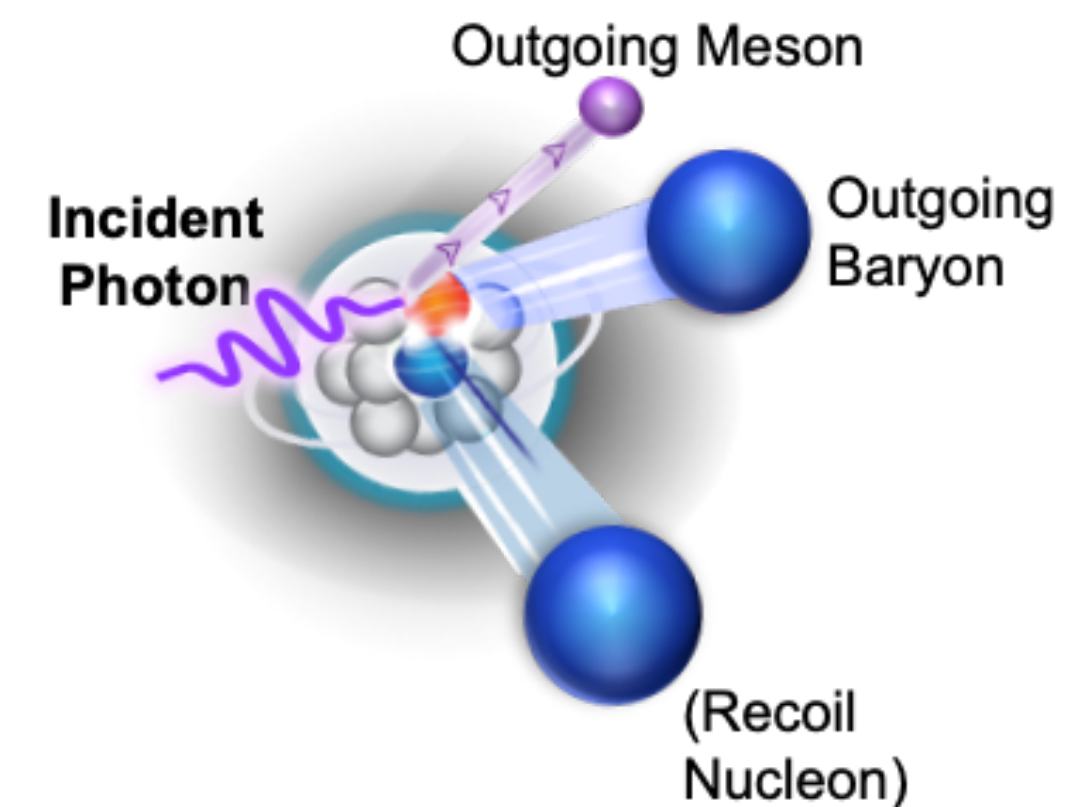
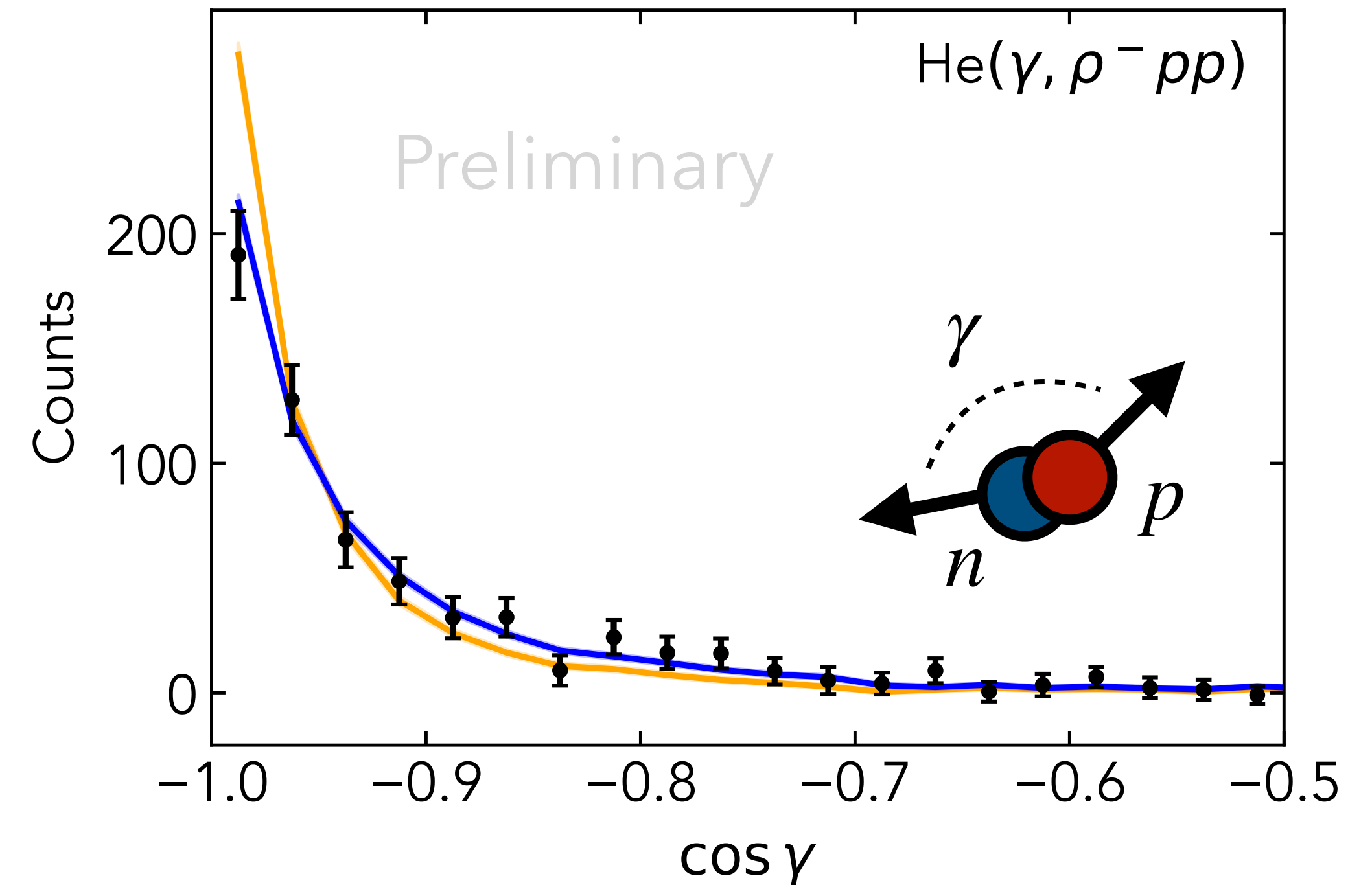


# First observation of SRCs in photoproduction



**PRL 2007**

Back-to-back correlation in  
 $(e, e'pp)$  @ Hall A



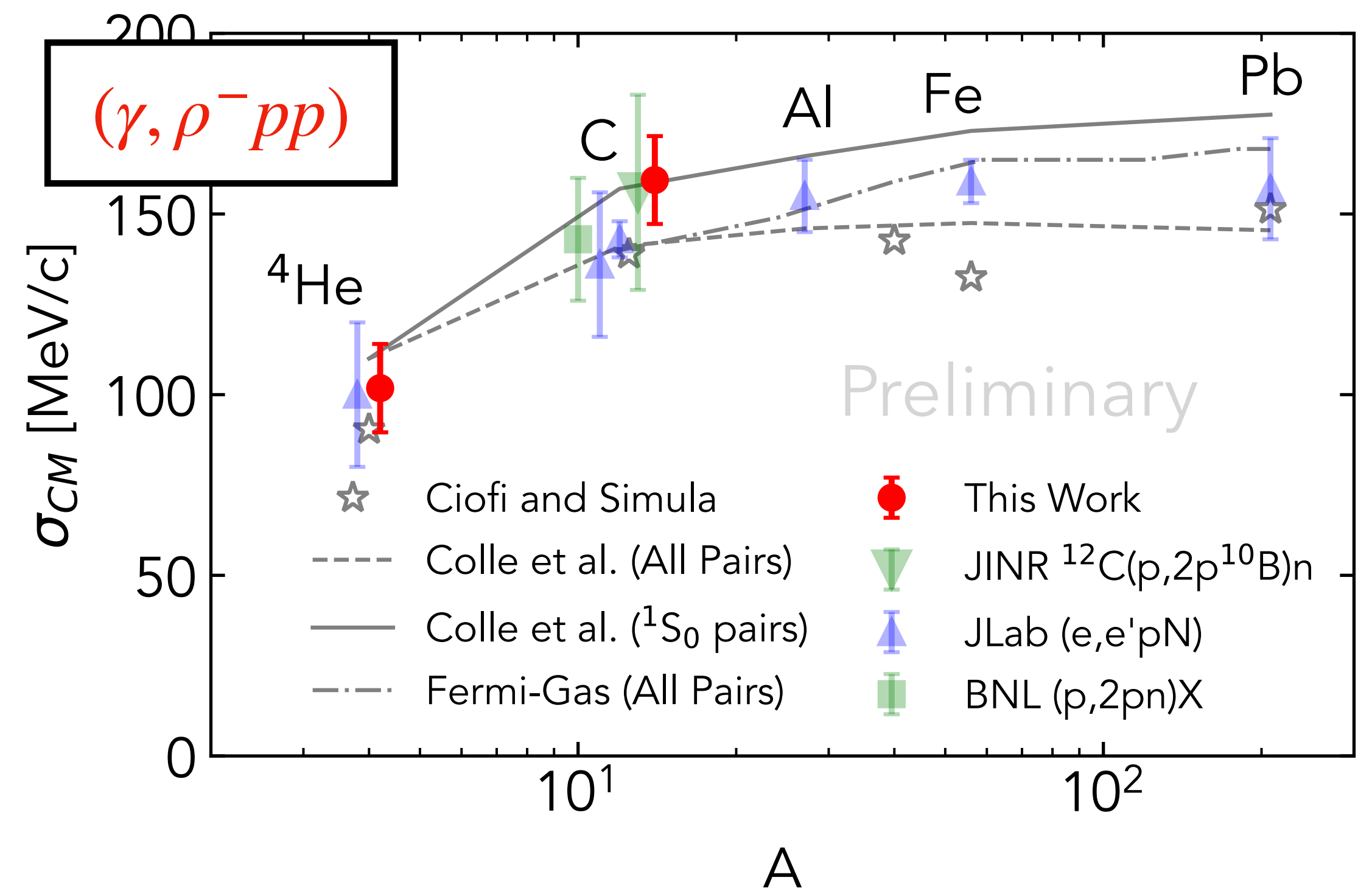
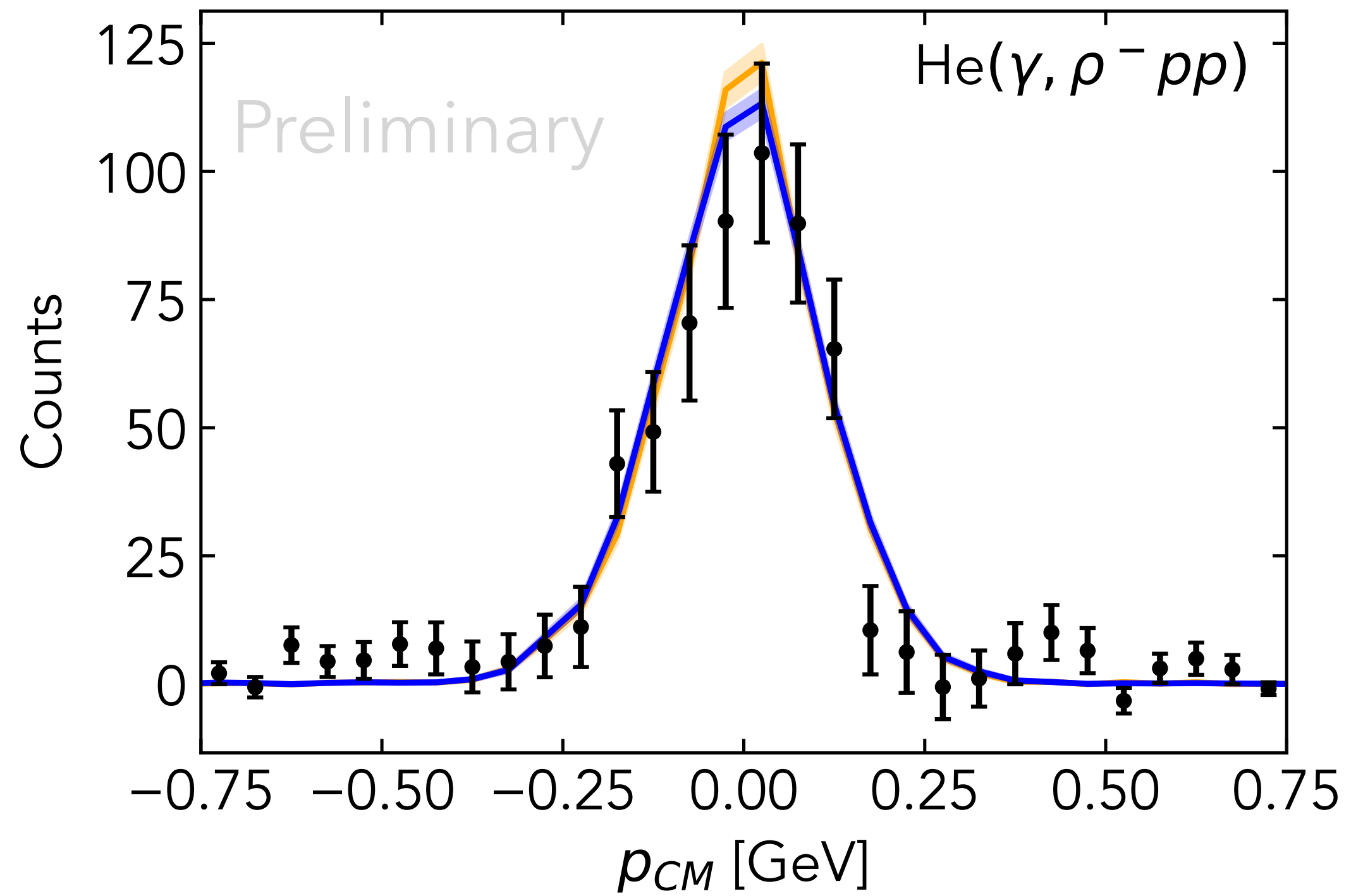
$\gamma np \rightarrow \rho^- pp$   
 @ Hall D

# SRC Center-of-Mass Motion

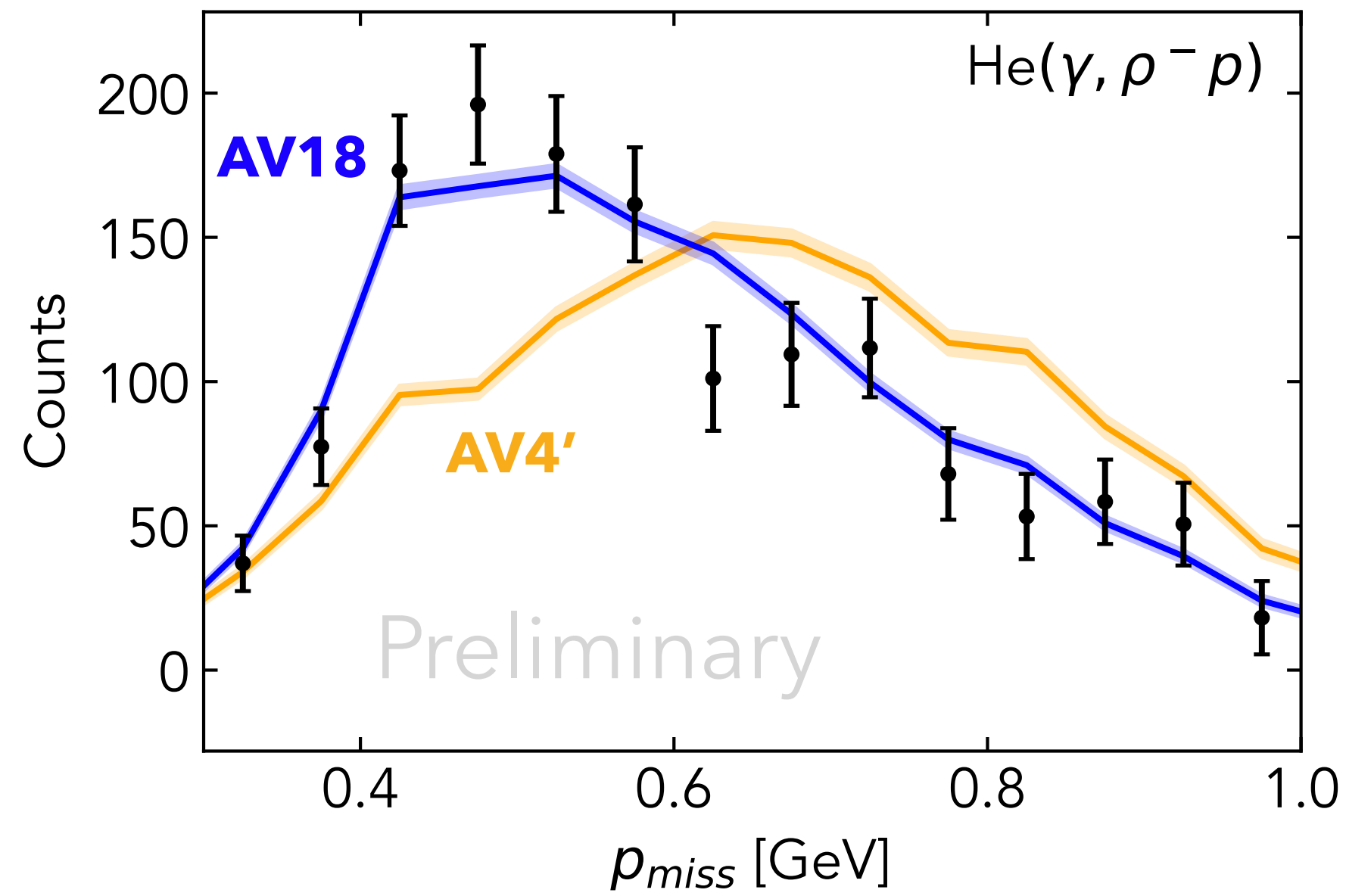
$e^-$ : PRL (2018)

$p$ : Nature Physics (2021)

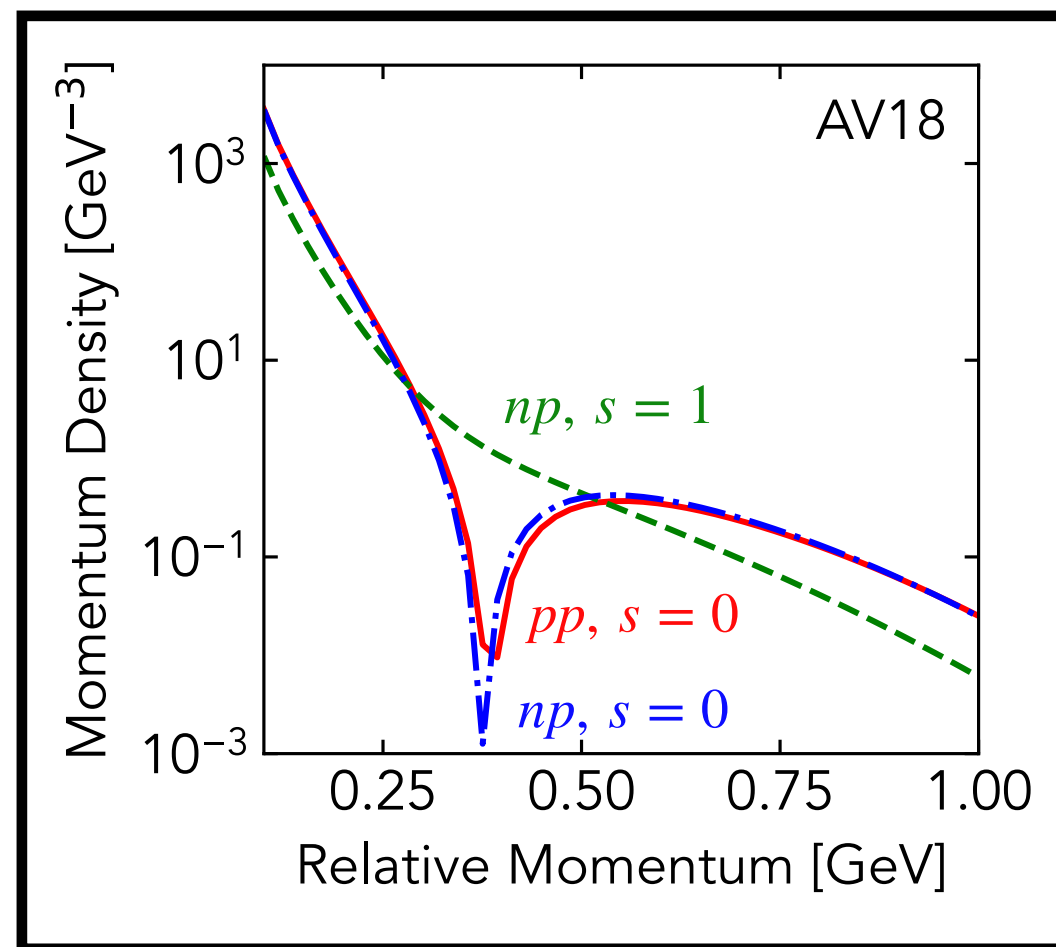
$\gamma$ : SRC-CT (2024)



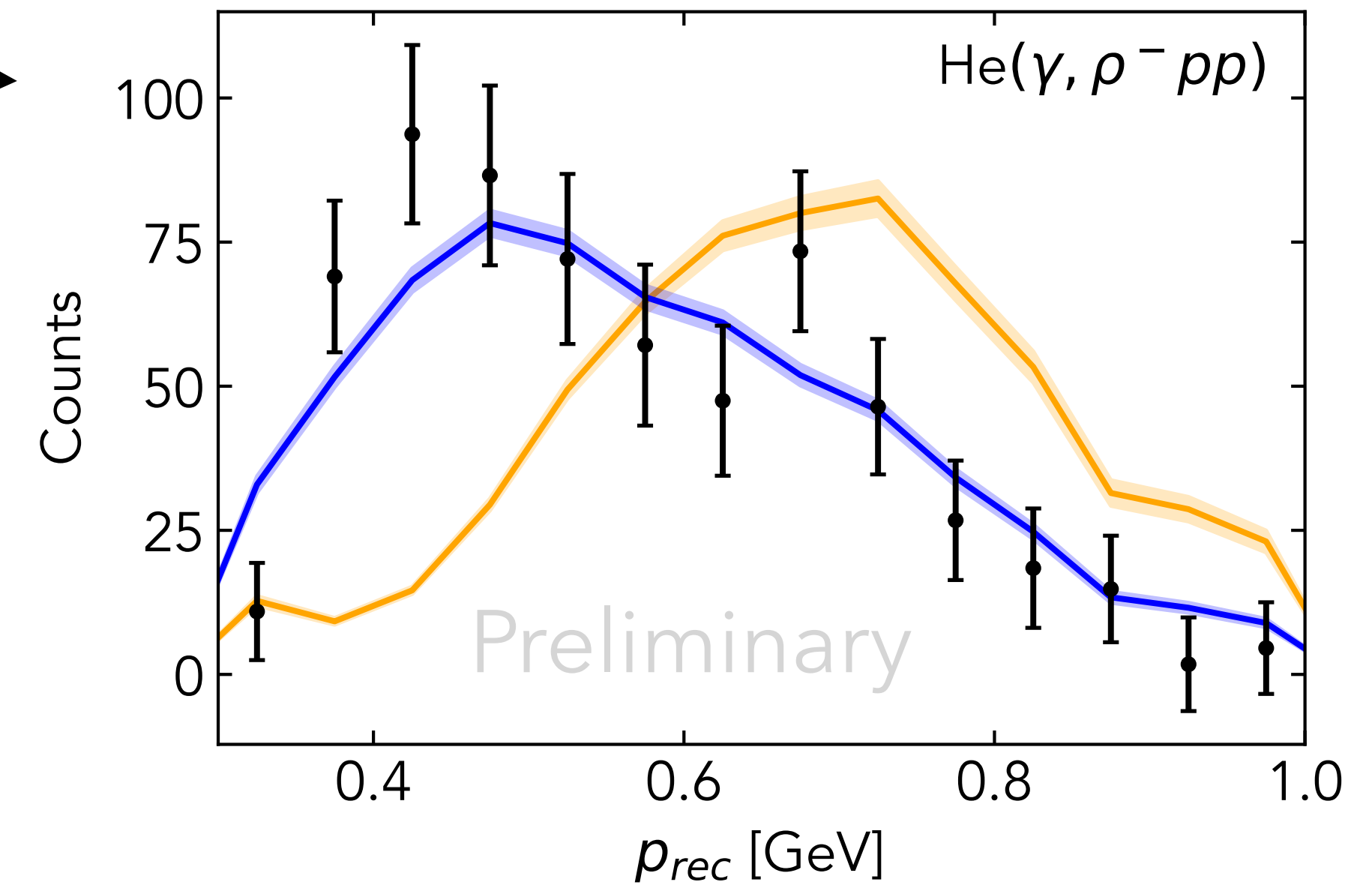
# Data connect to ab-initio theory at high momentum; Distinguish realistic and unrealistic models



**Initial neutron momentum**  
Inferred from momentum  
conservation

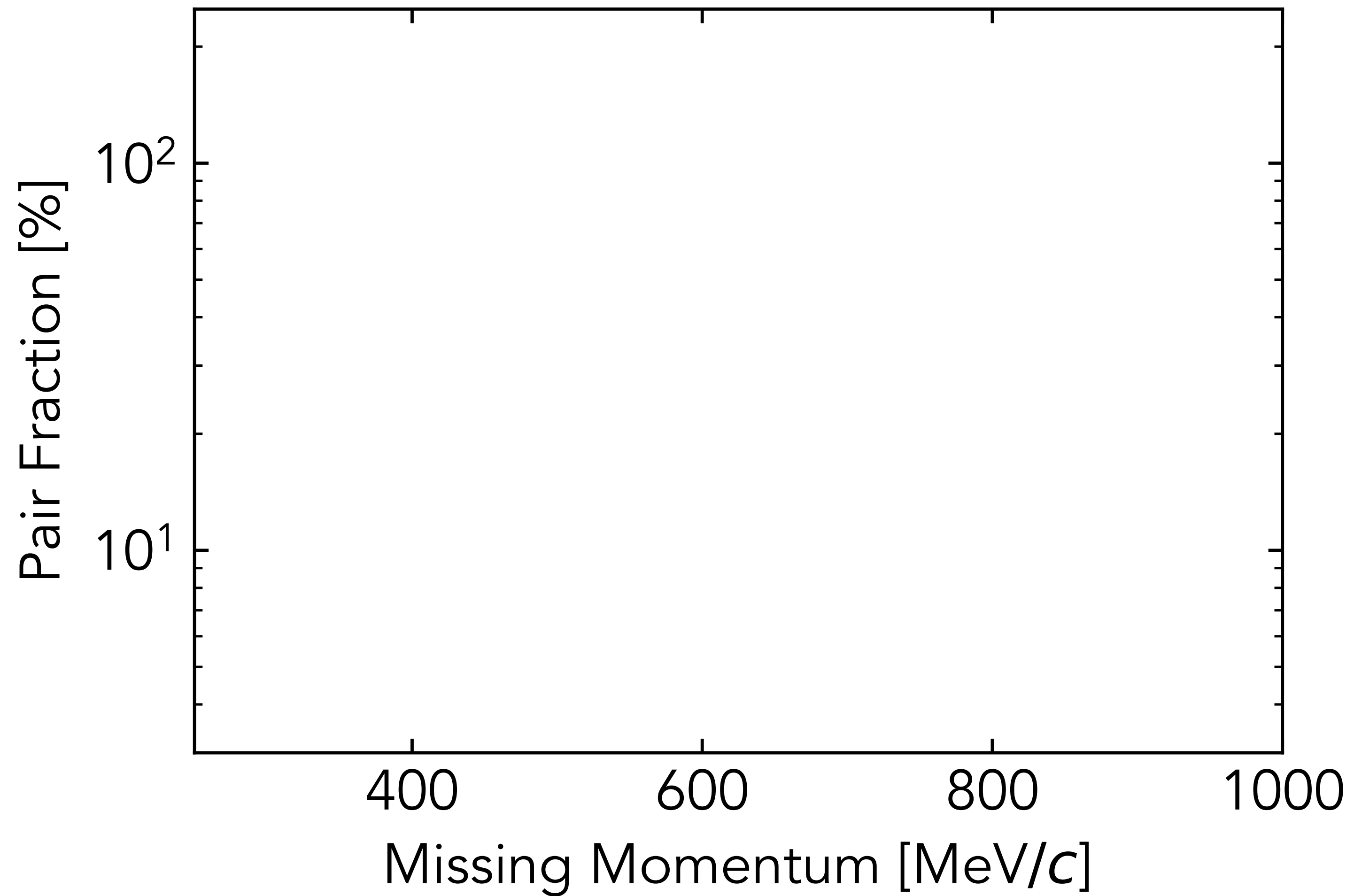


**NN Interaction**

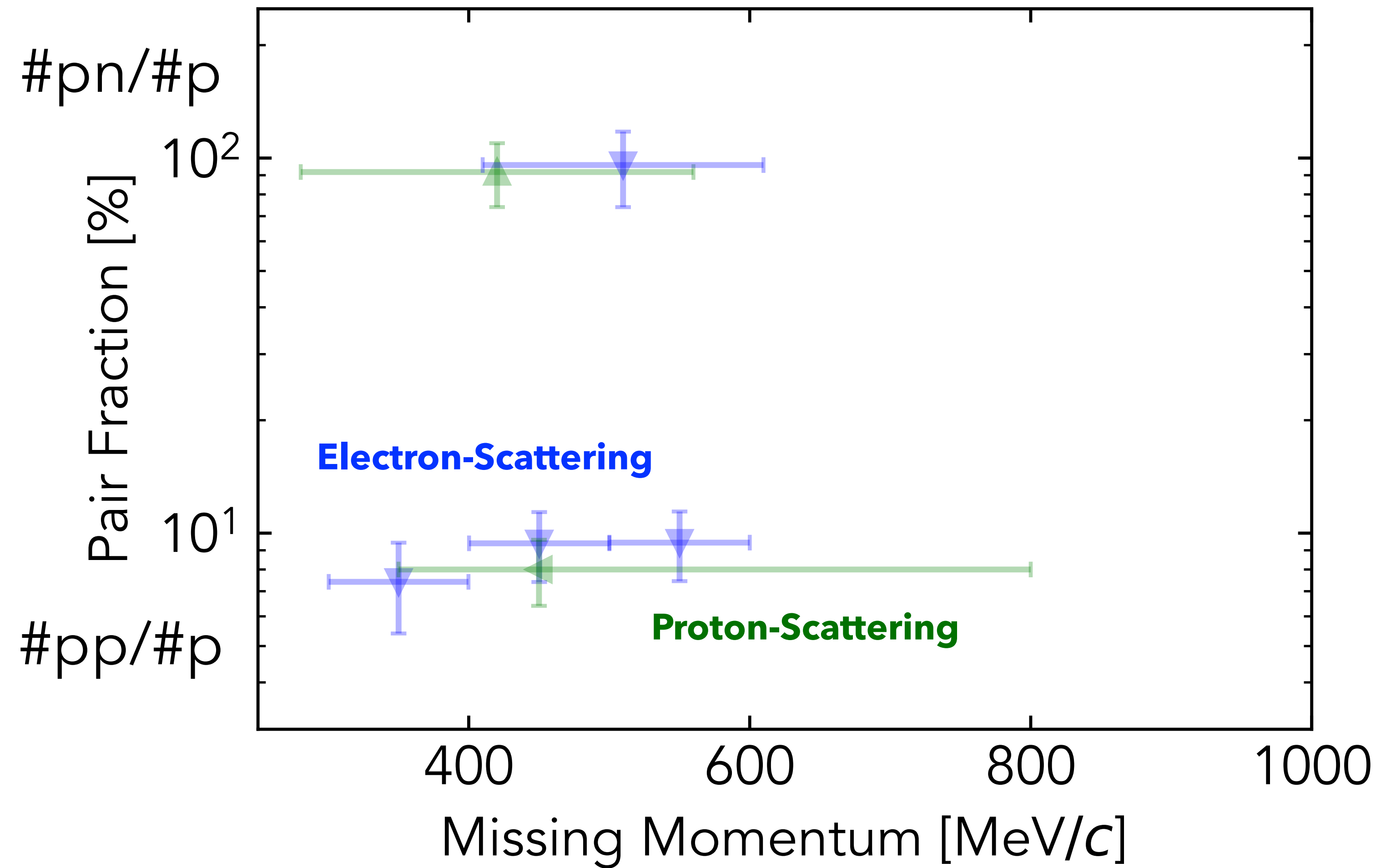


**Initial recoil proton momentum**  
Directly measured

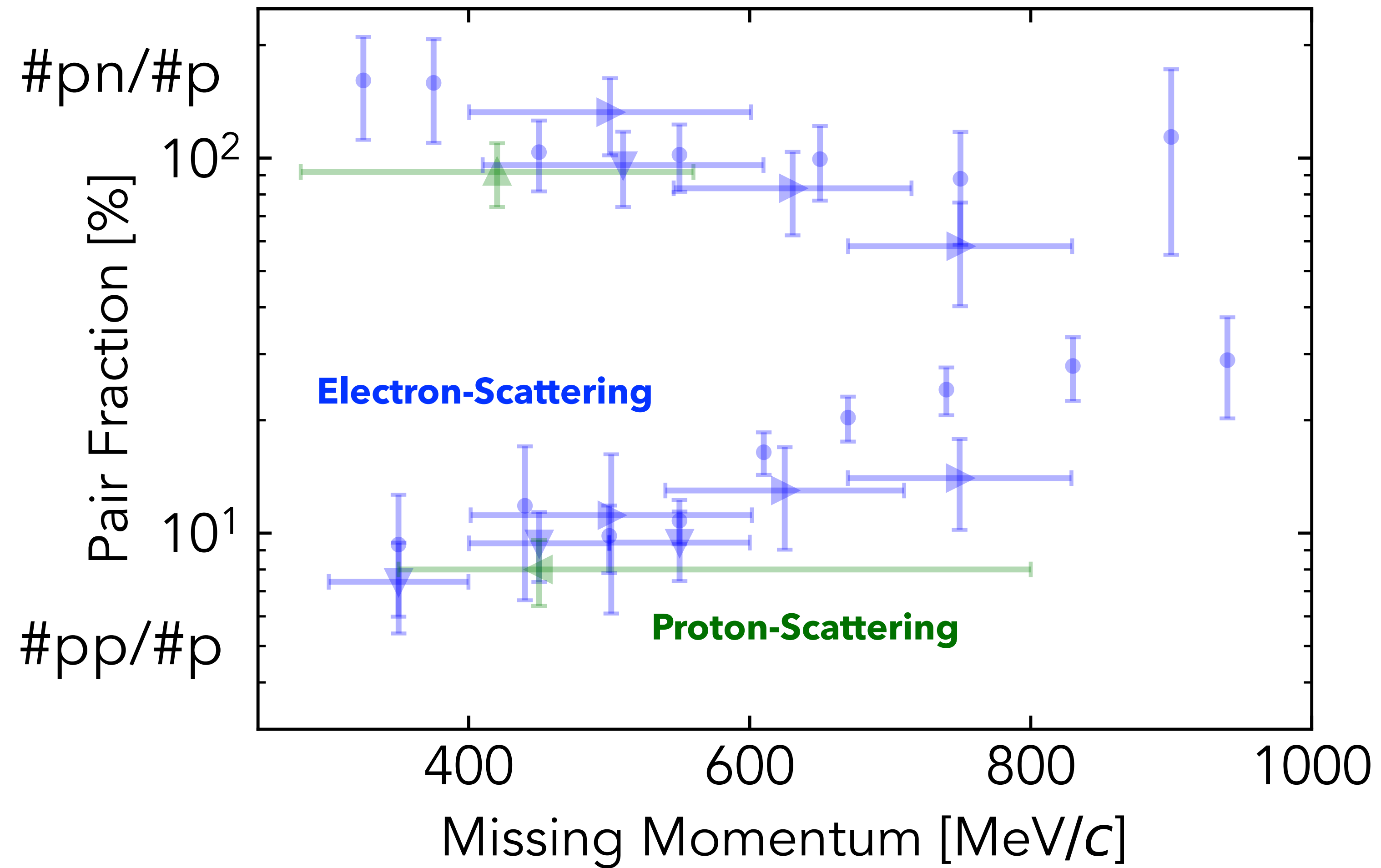
# SRC Isospin Structure



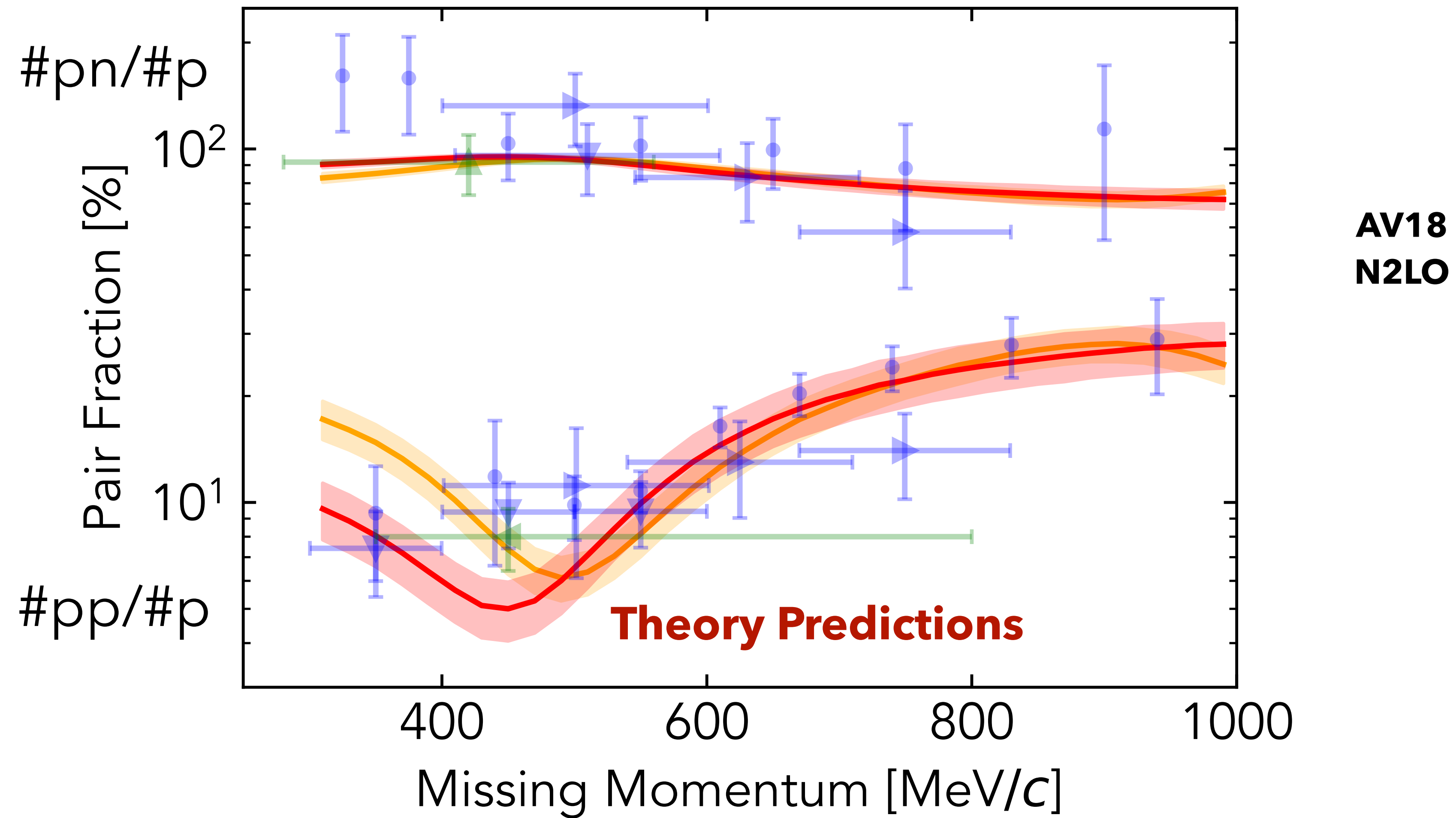
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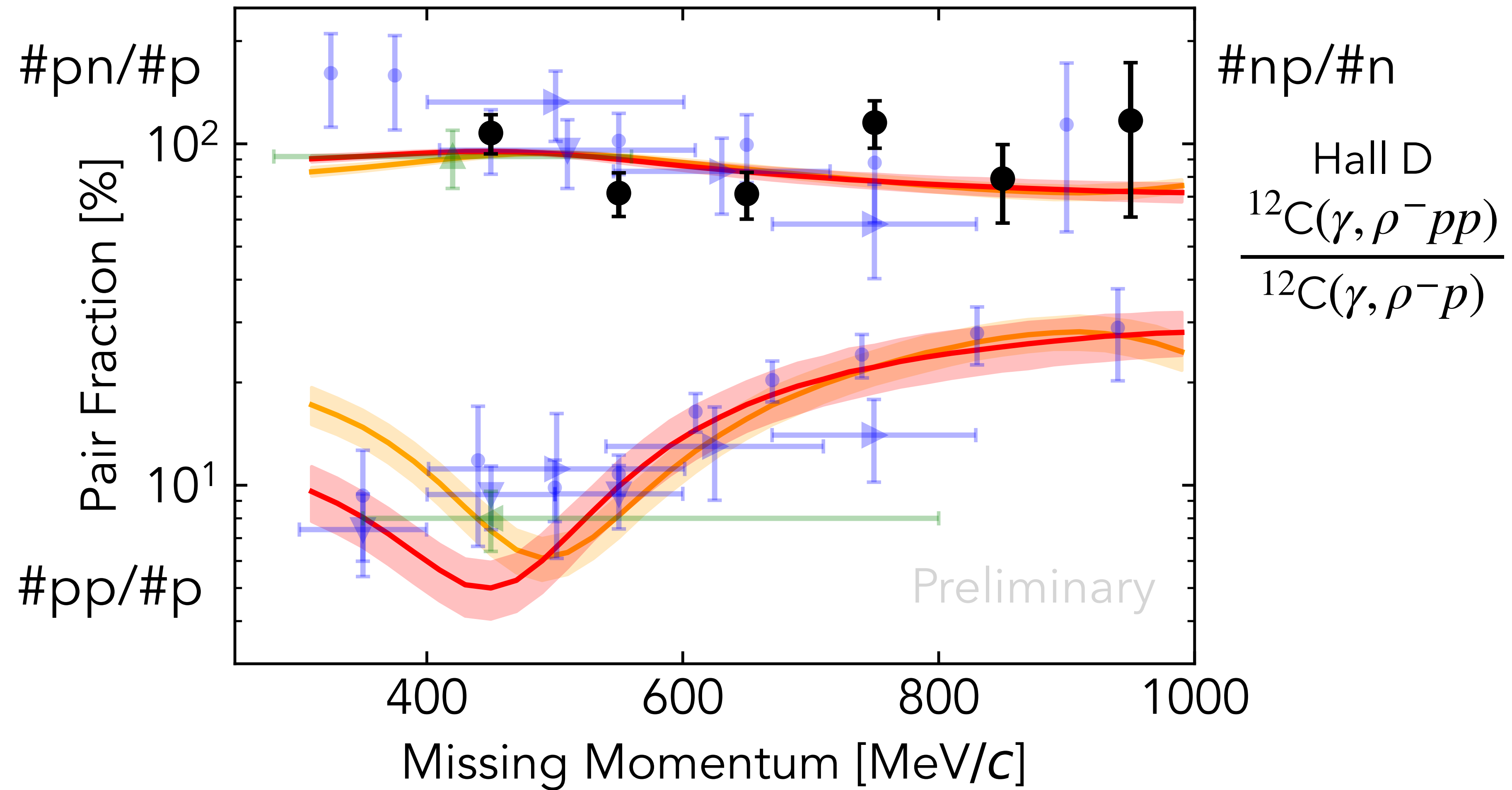
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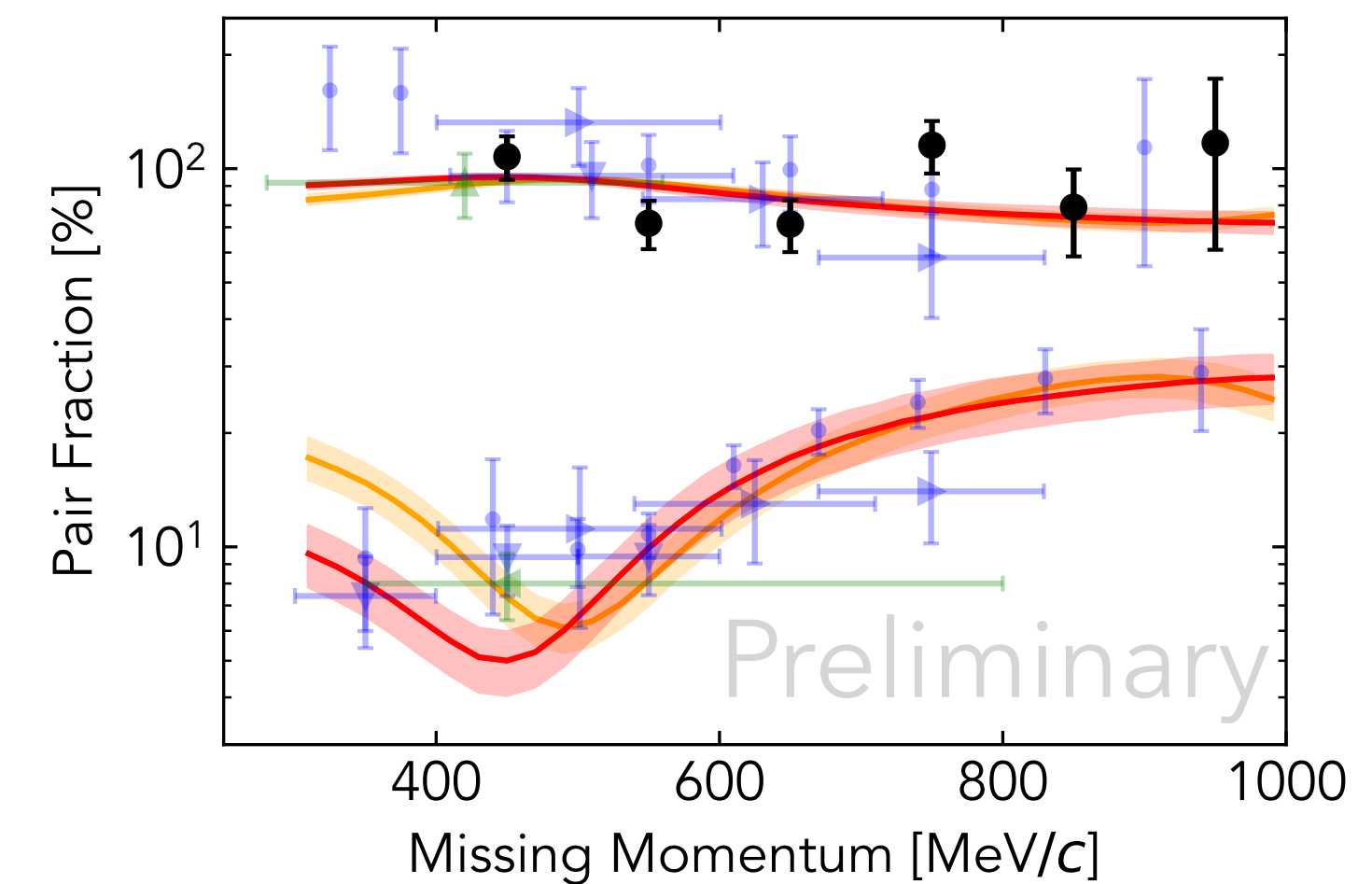
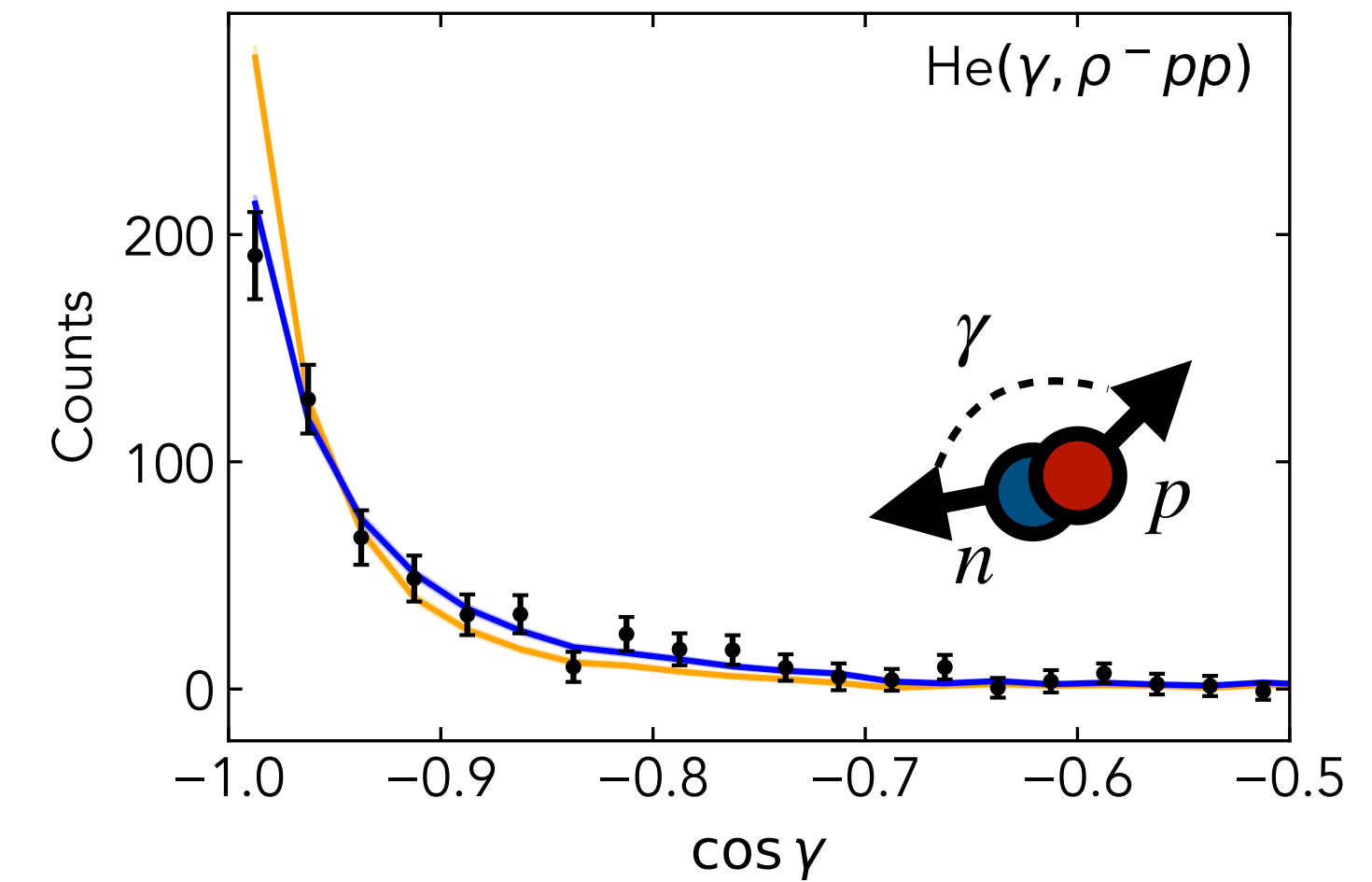


# SRC Isospin Structure



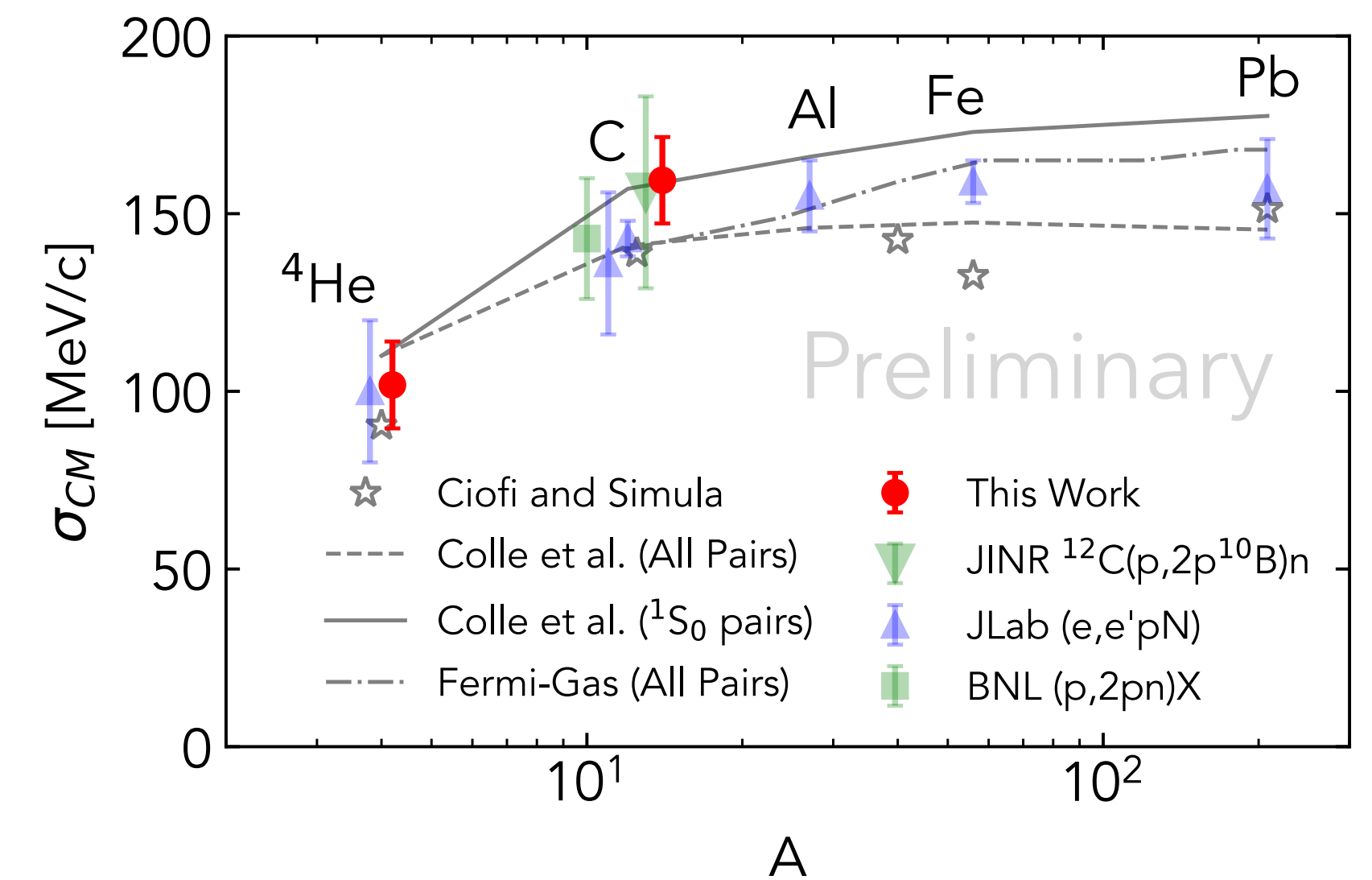
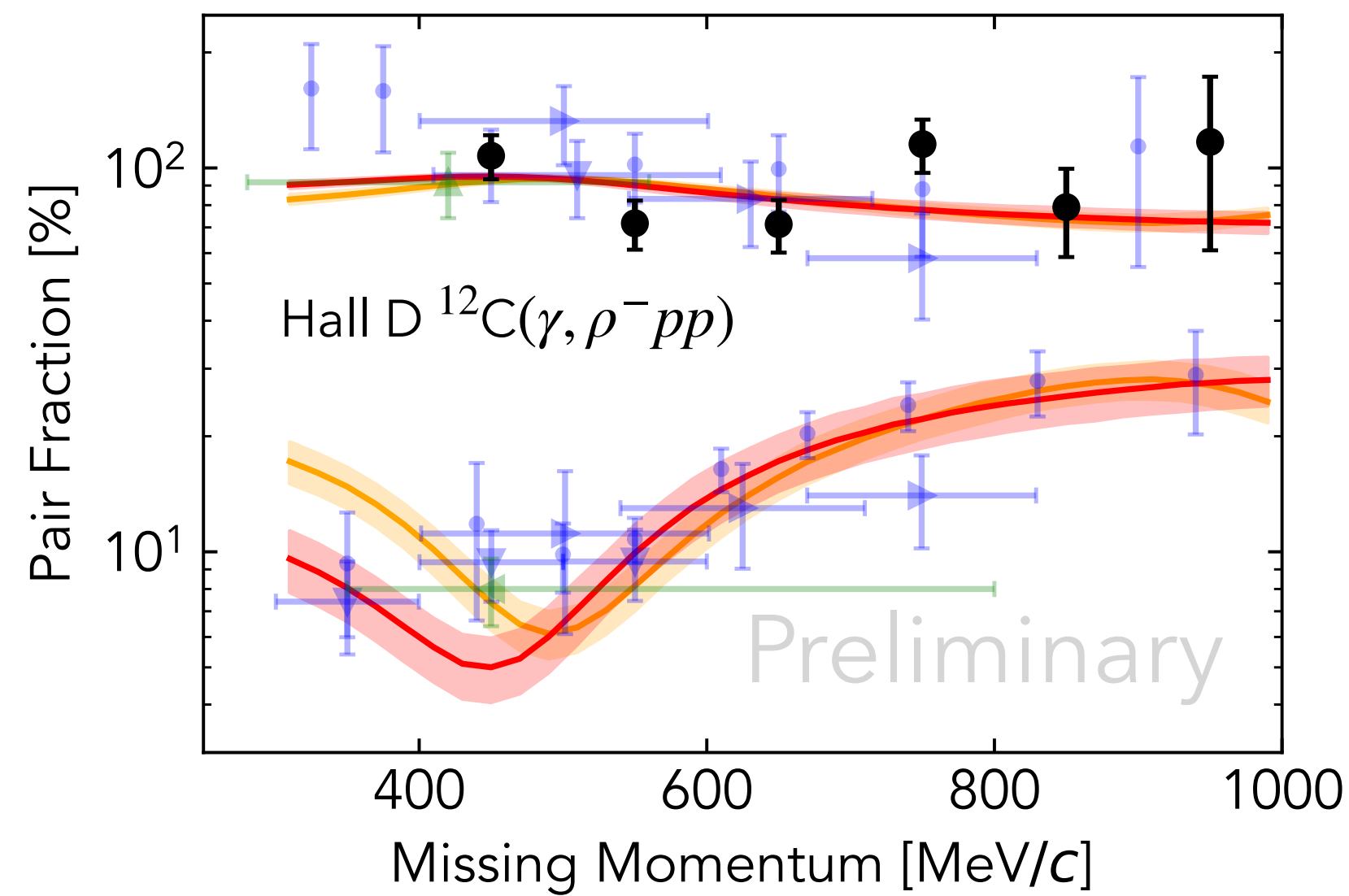
# Conclusions

- 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

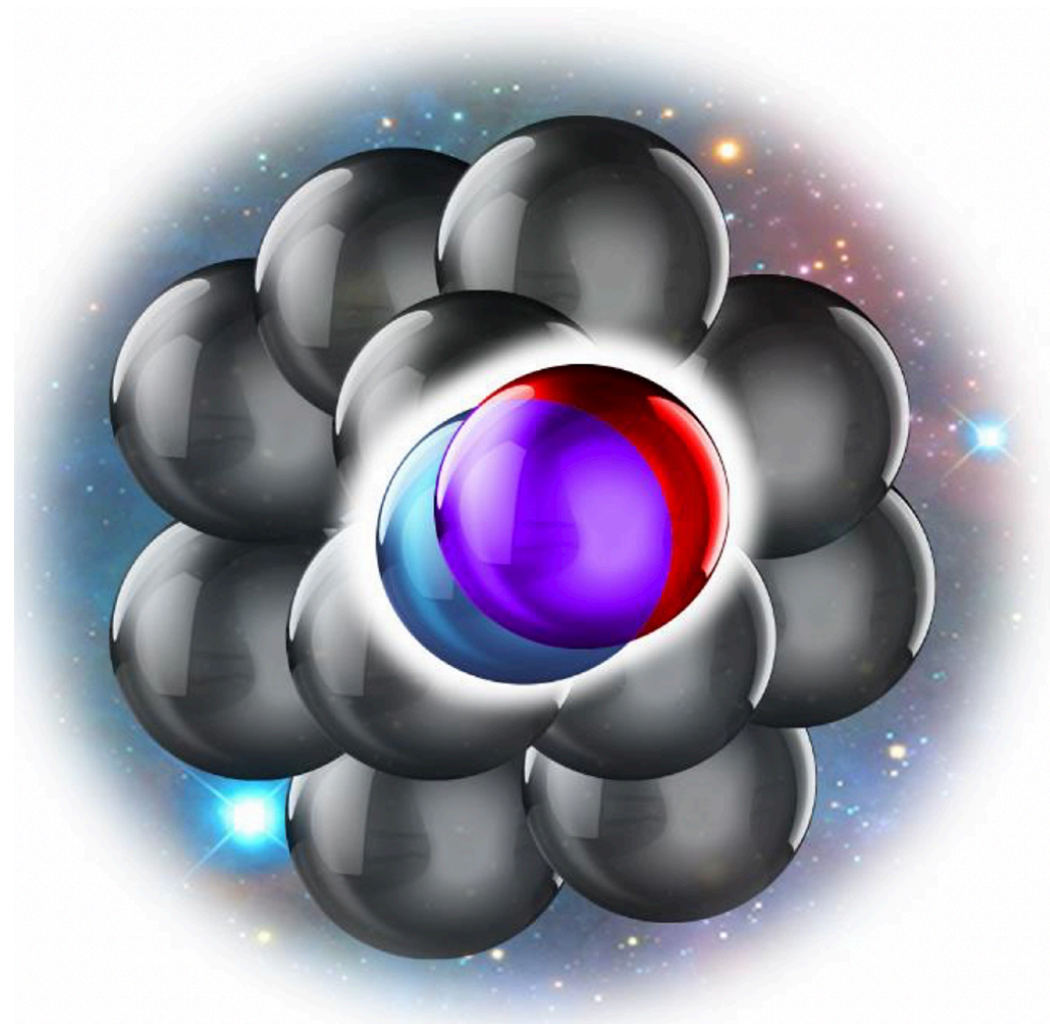


# Backup Slides

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



**Electrons**



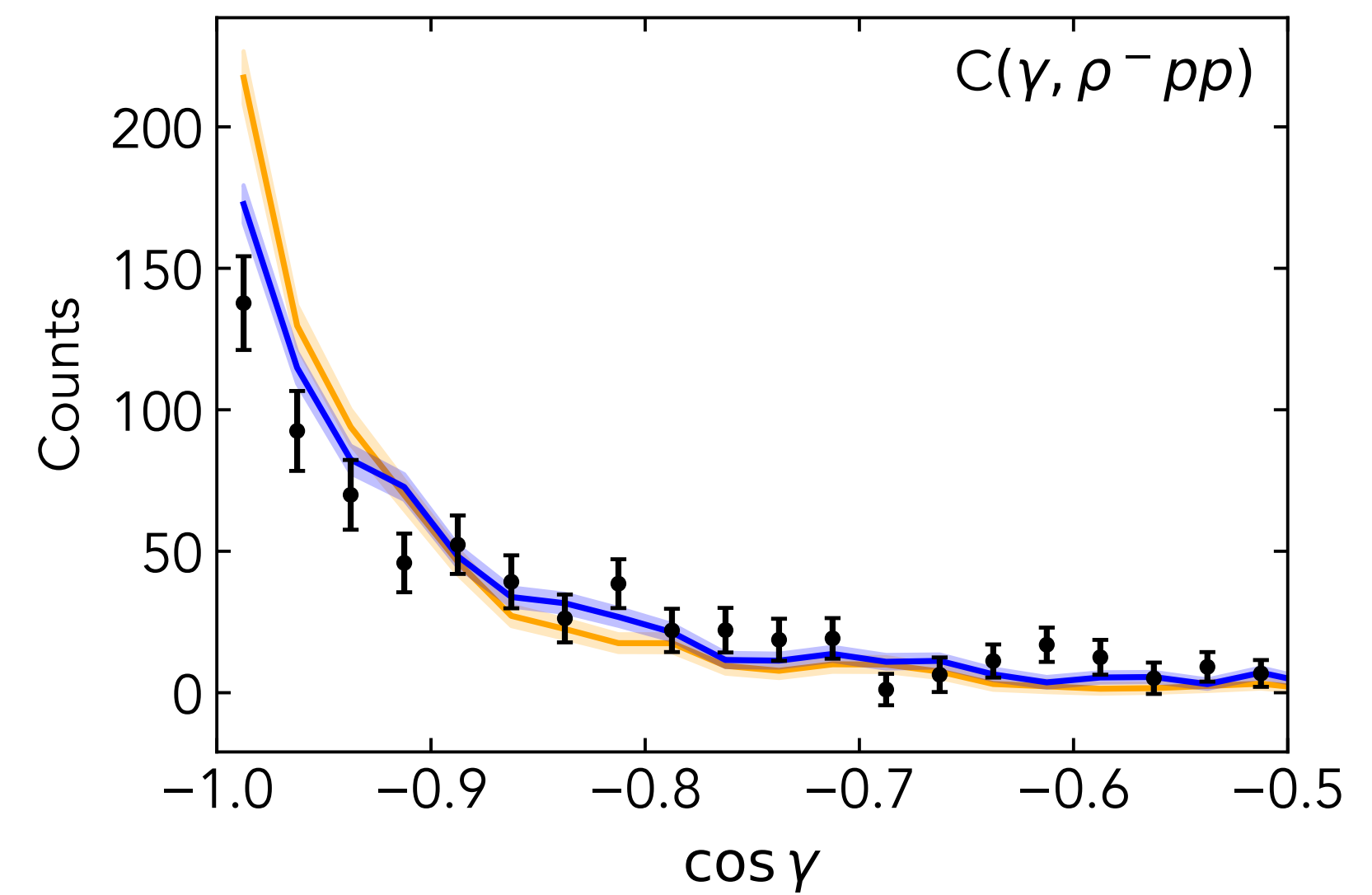
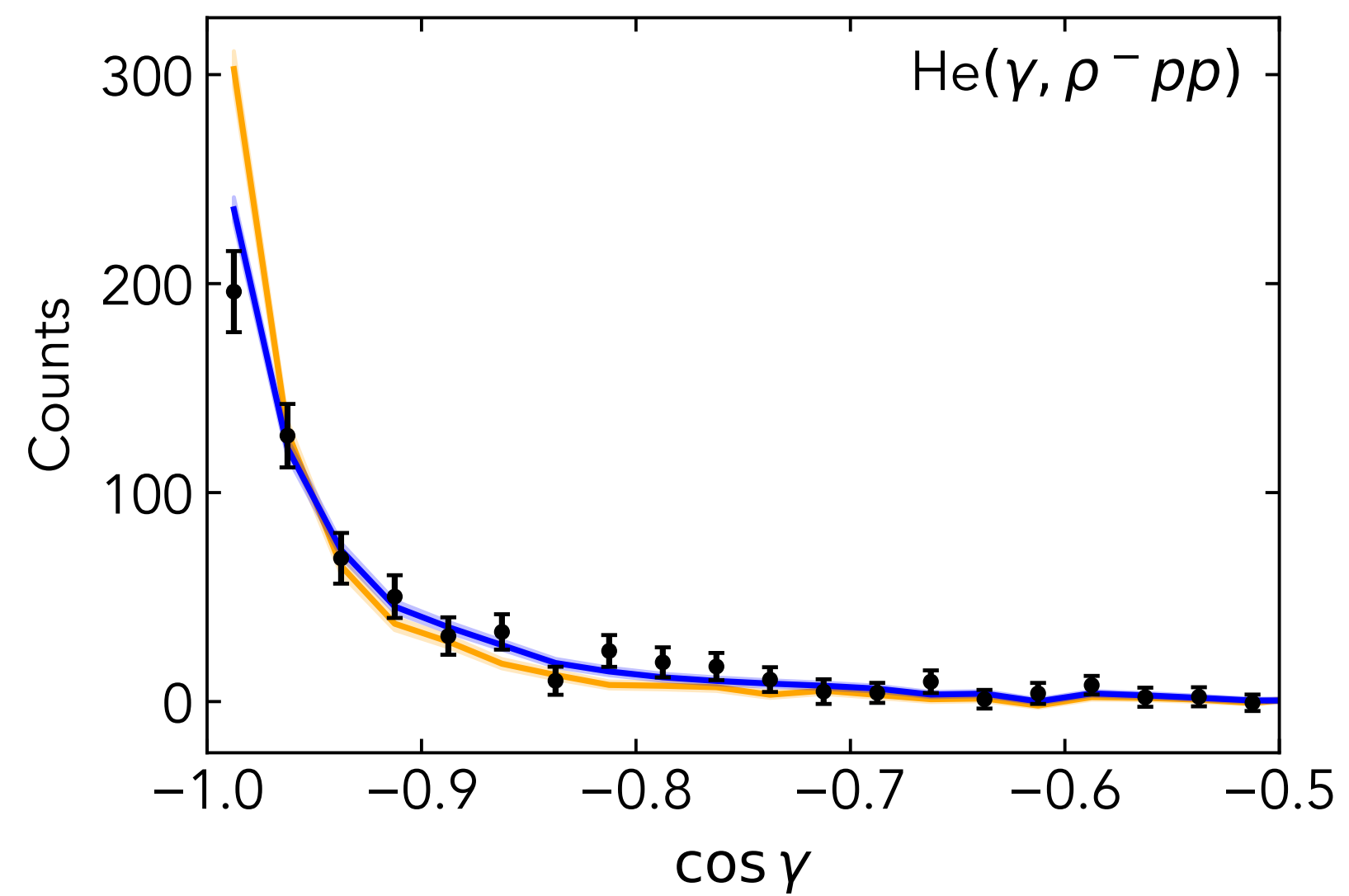
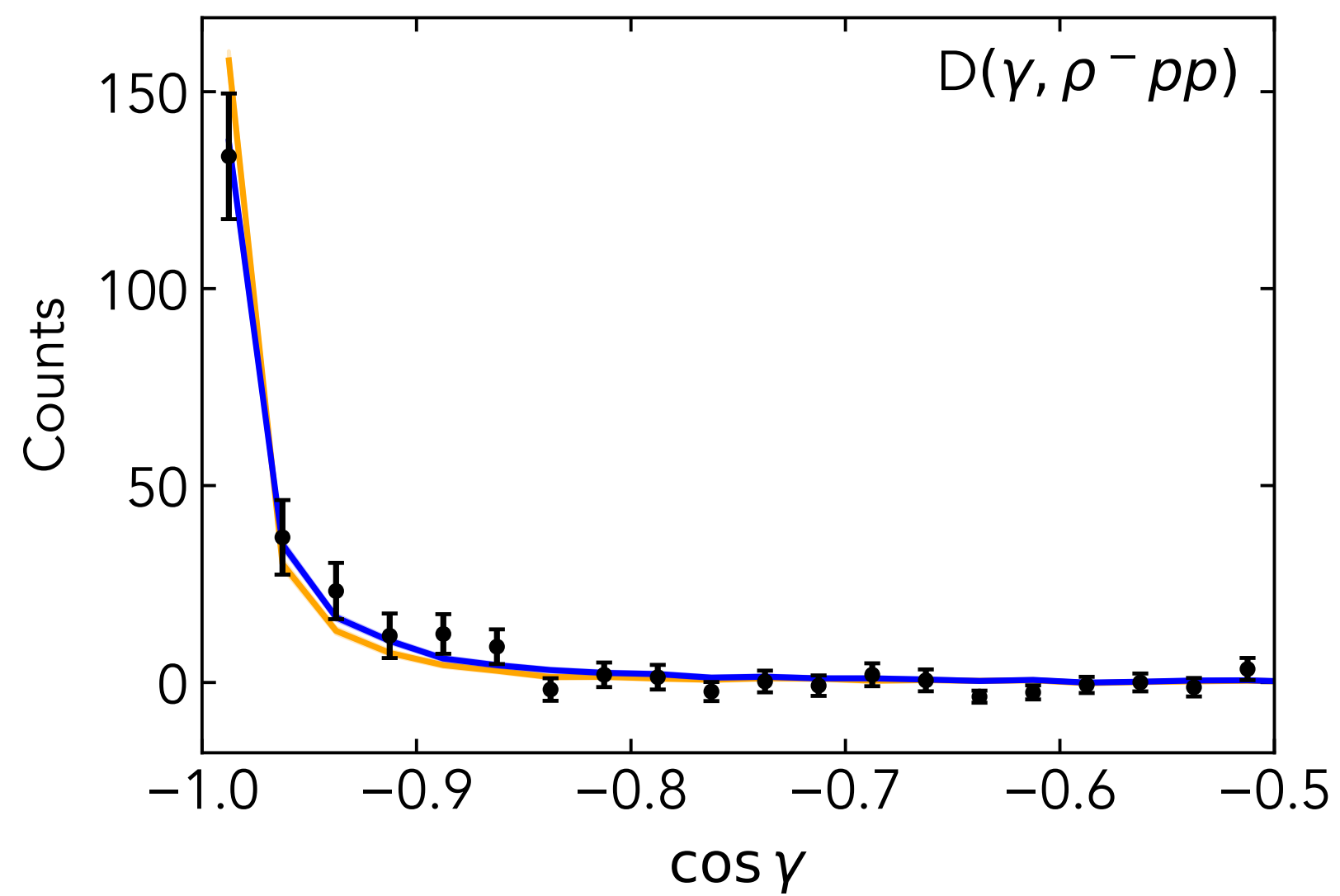
**Photons**



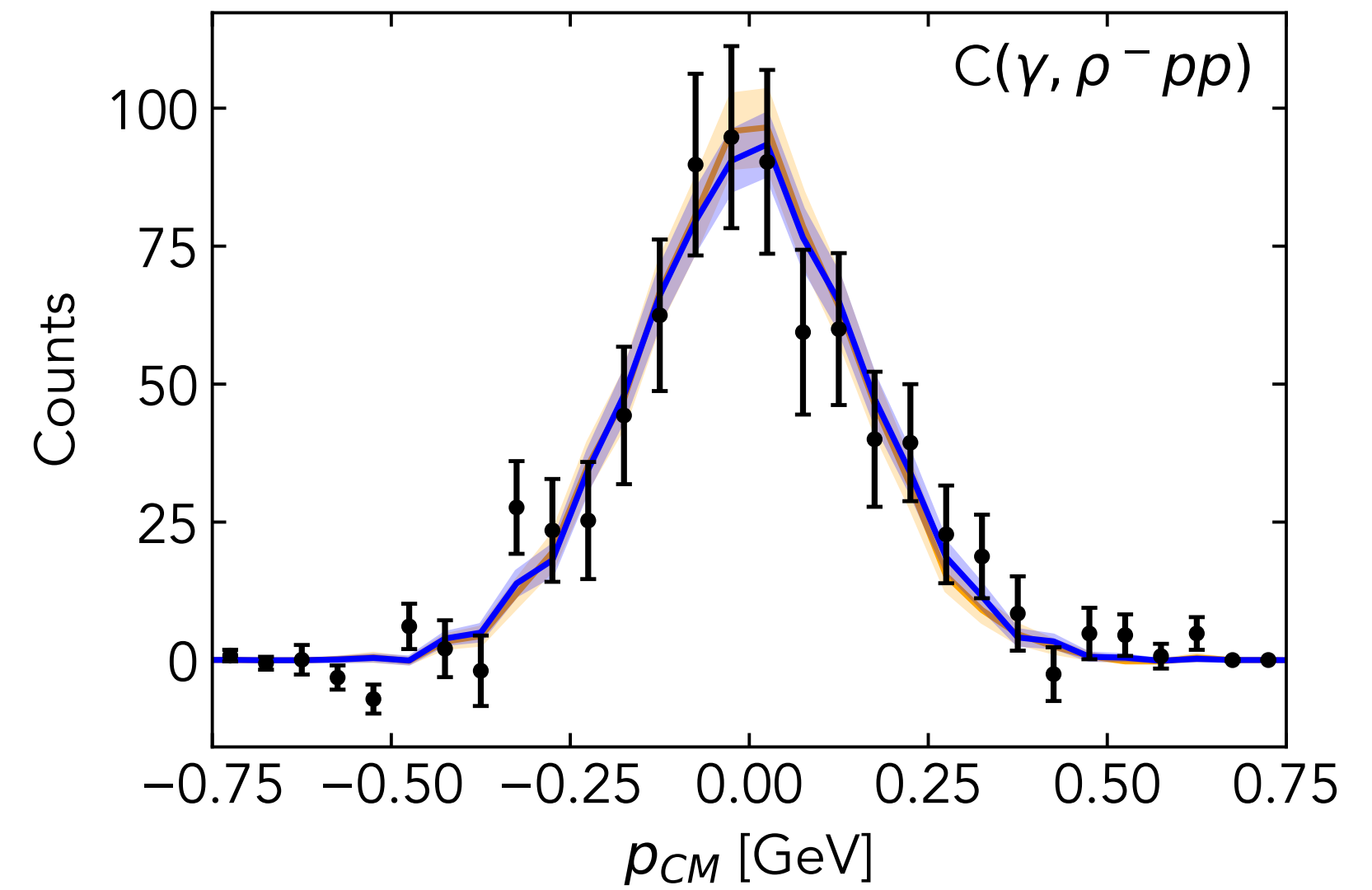
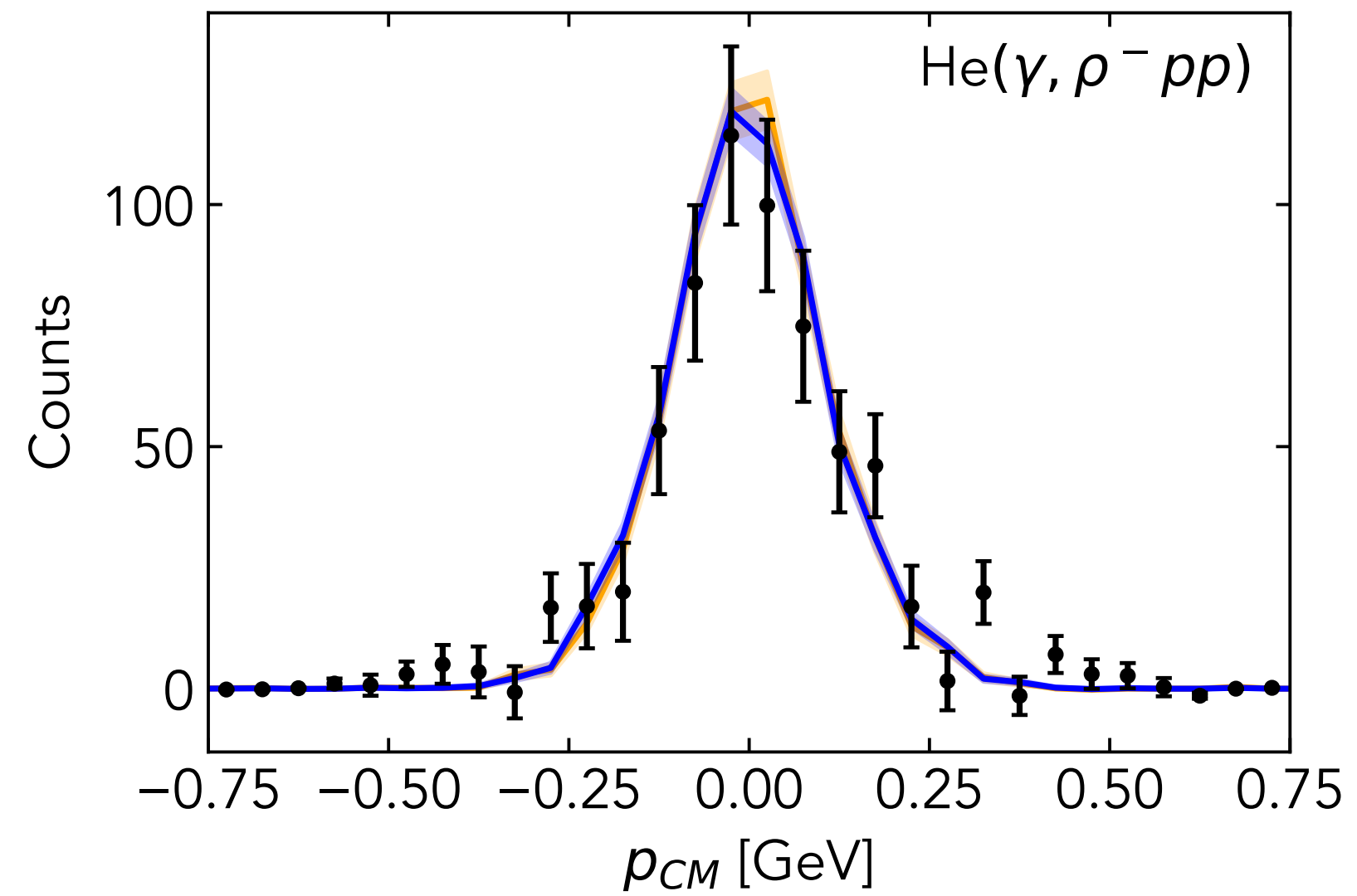
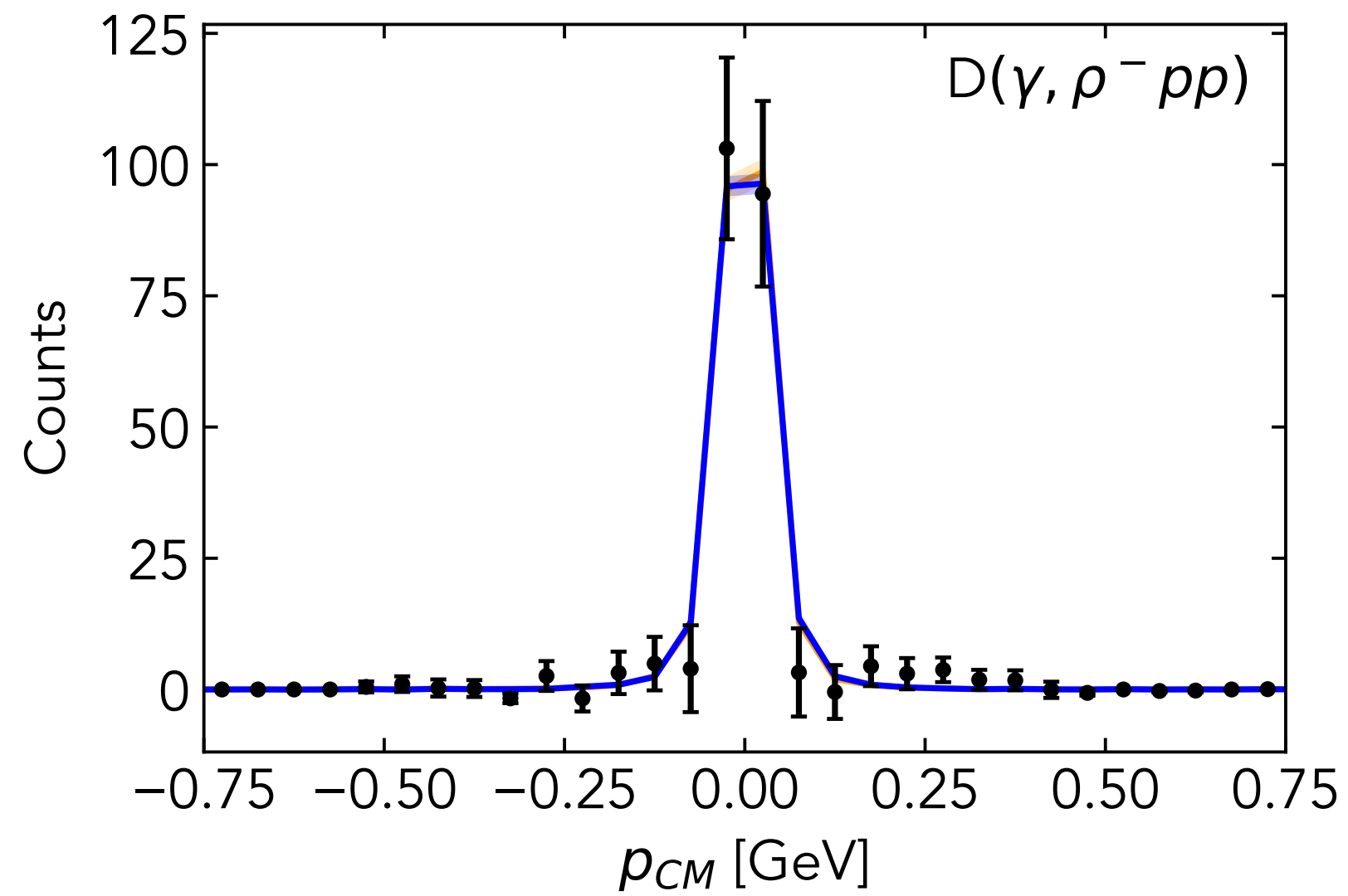
**Protons**



# Back-to-back Correlation

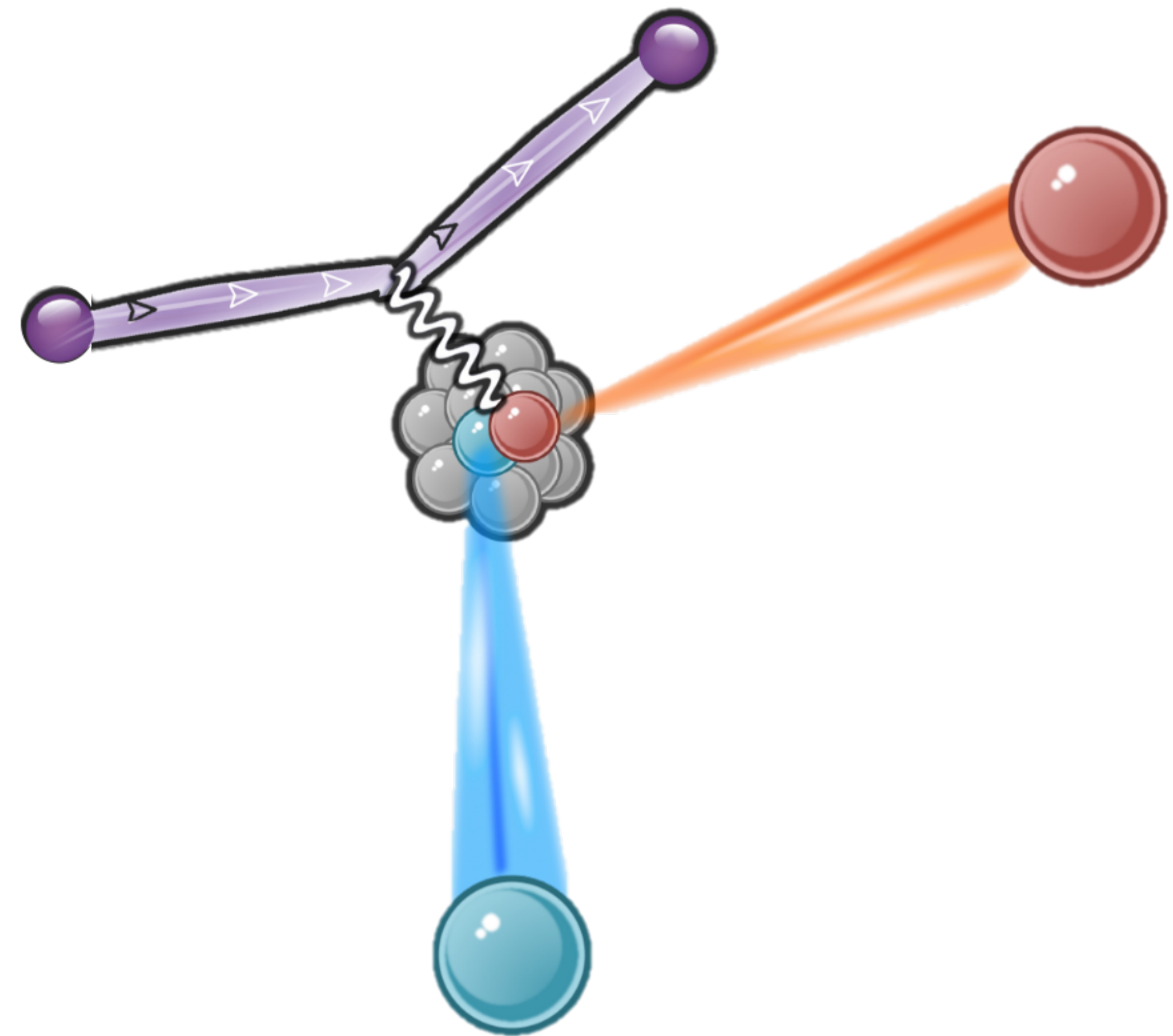


# Center-of-mass Motion



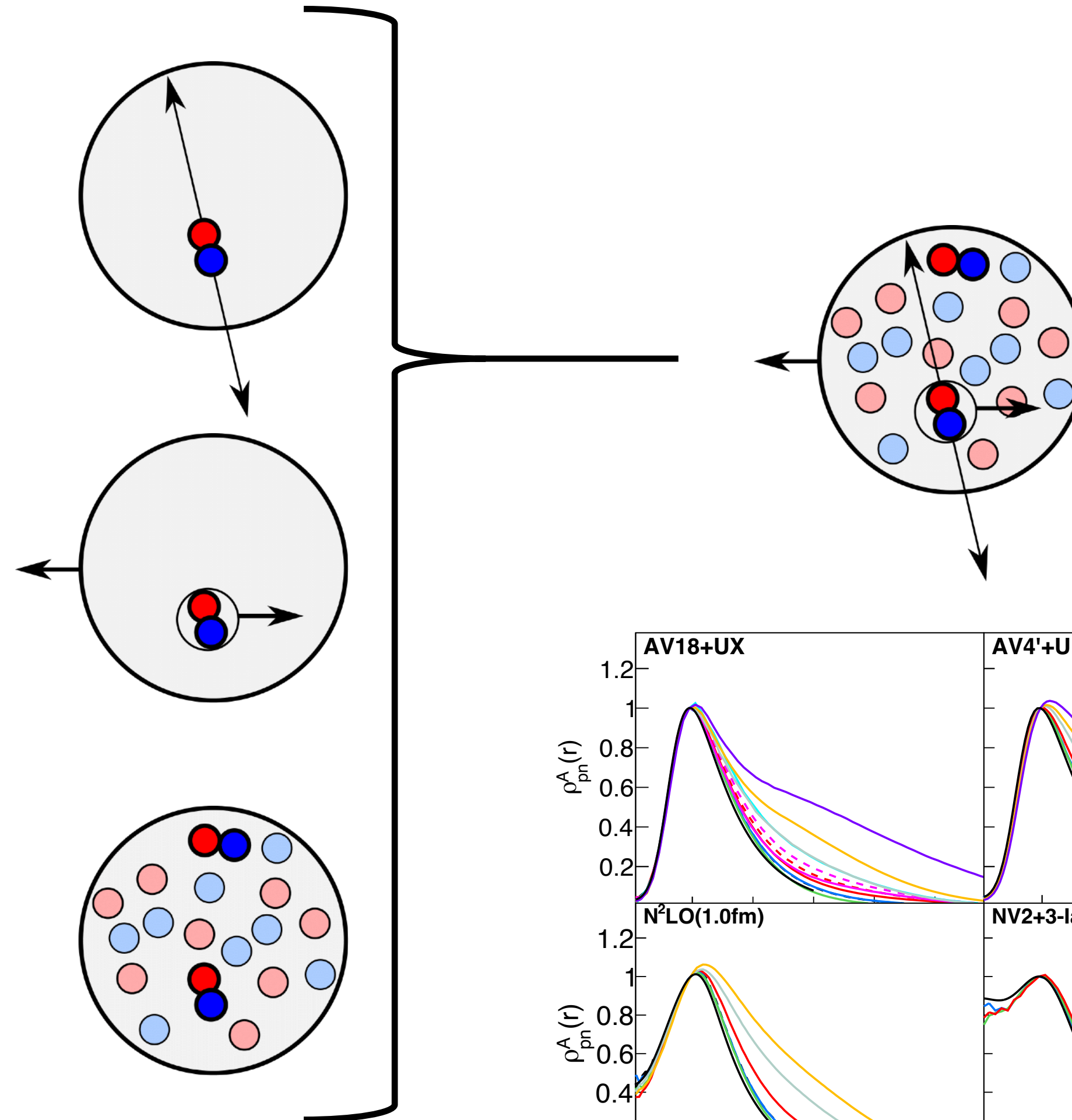
# Interpreting SRC results requires two things:

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)

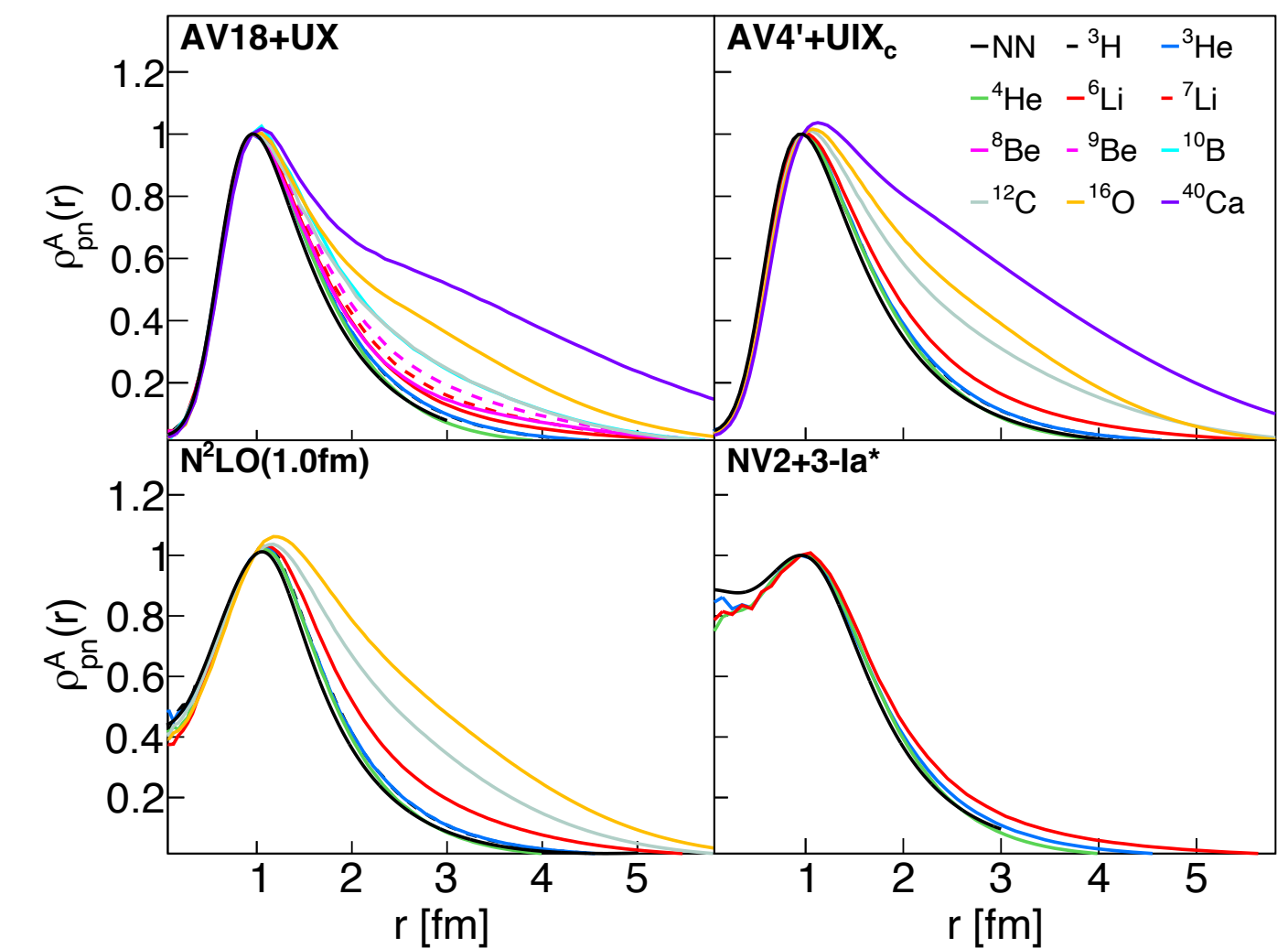
Tropiano et al., Phys. Rev. C 104, 034311 (2021)

Lynn et al., JPG 47, 045109 (2020)

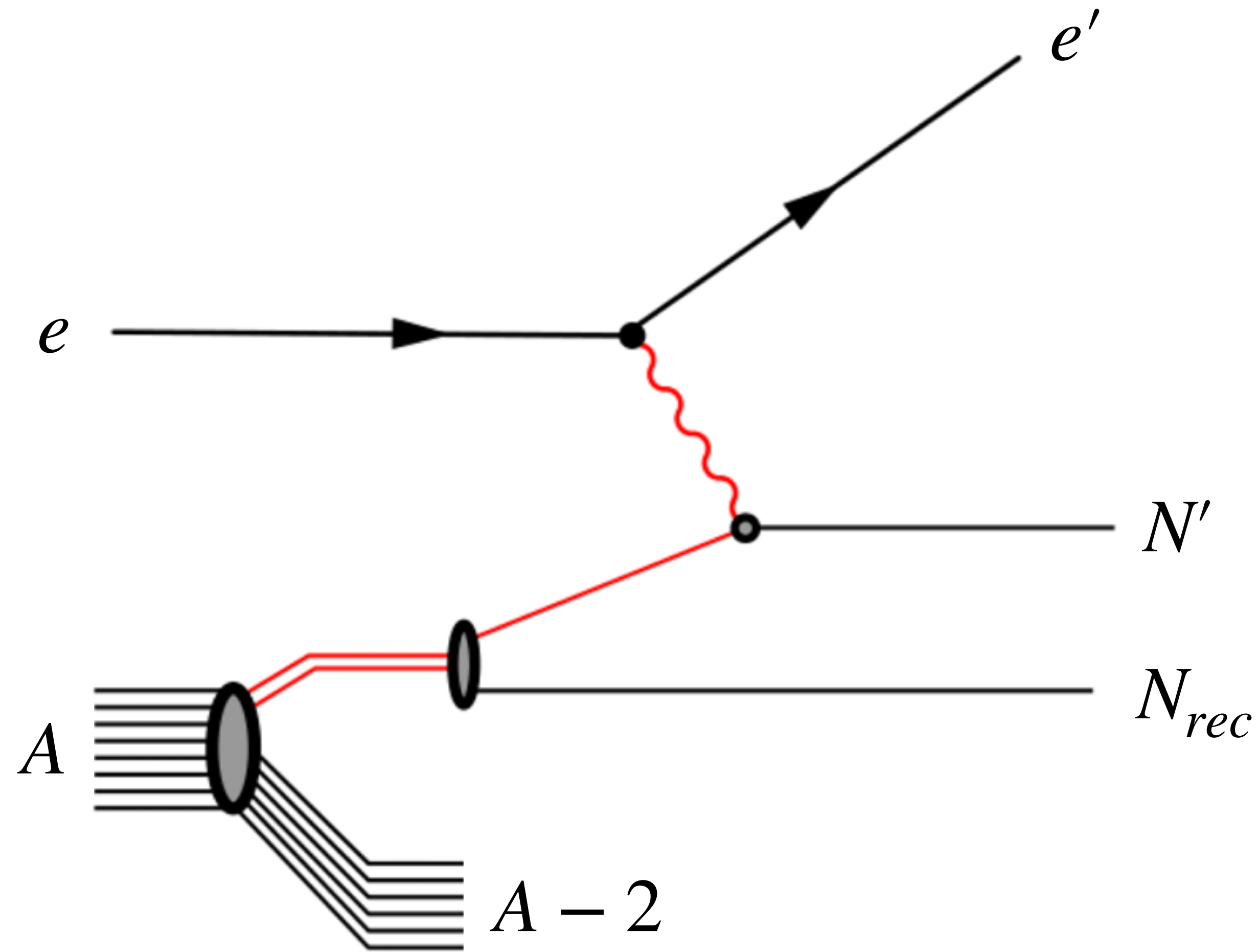
Chen, Detmold, Lynn, Schwenk, PRL 119 (2017)

Ryckebusch et al., Phys. Lett. B 792, 21 (2019)

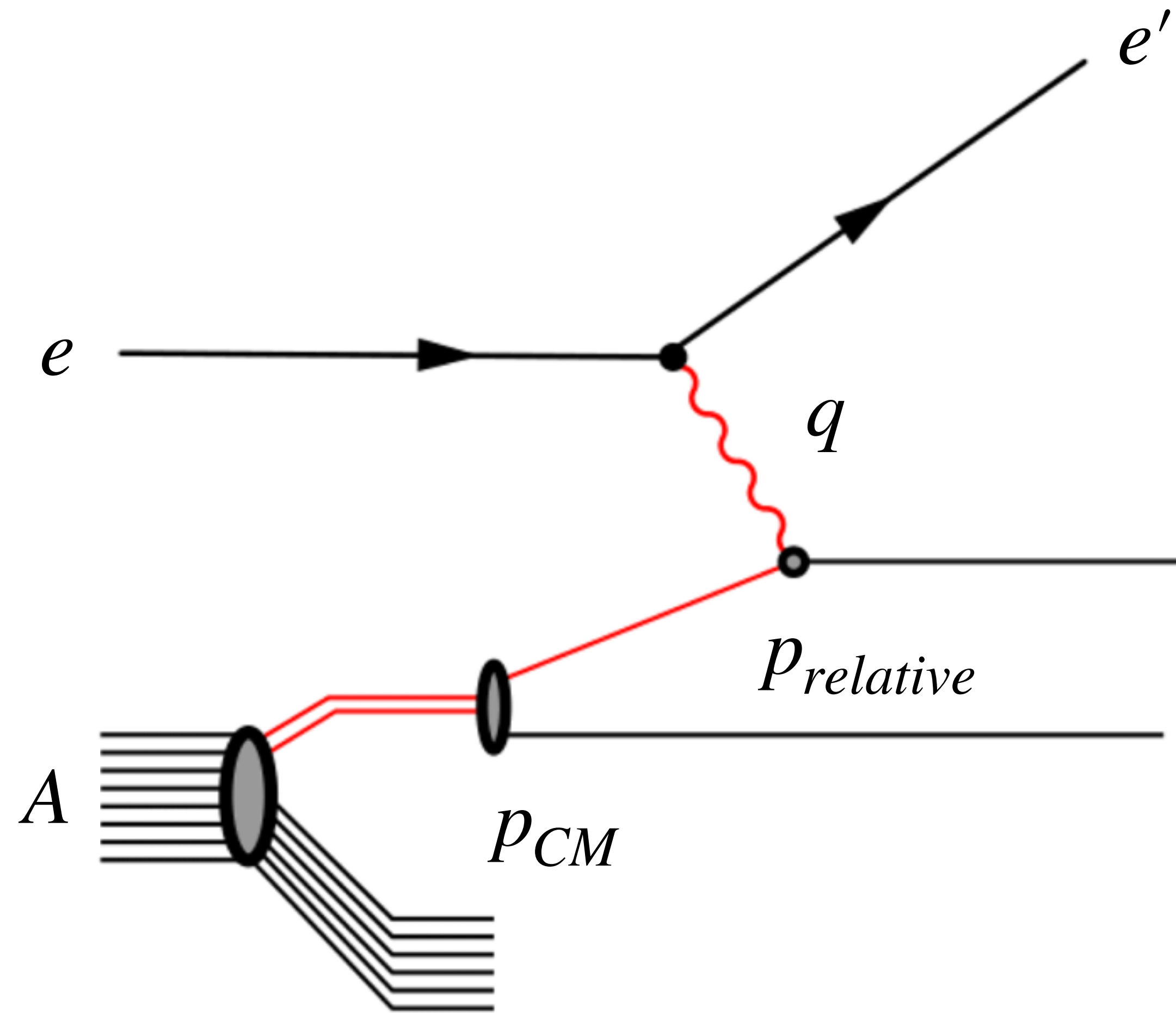
Ciofi and Simula, Phys. Rev. C 53, 1689 (1996)



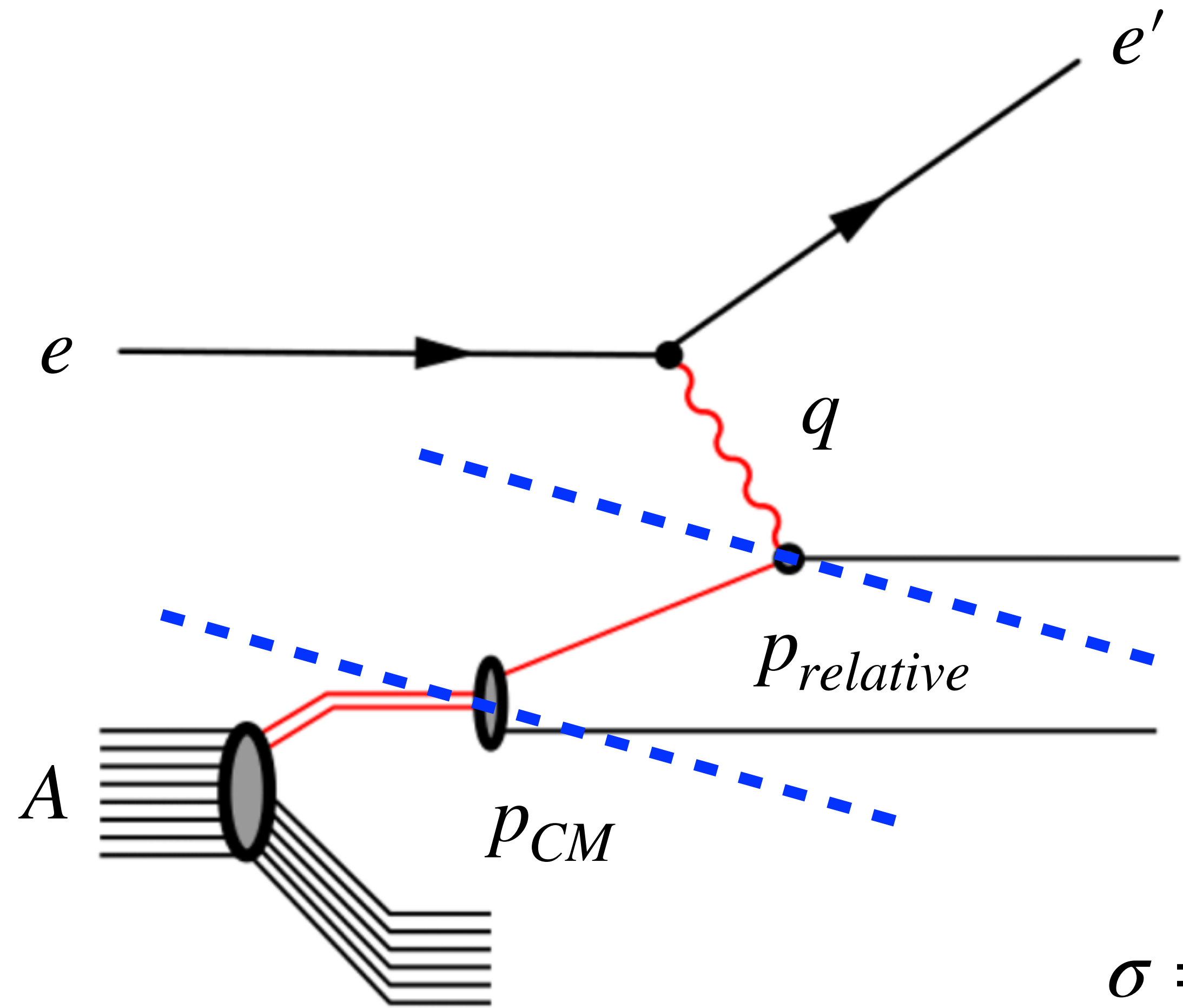
# Ground-state model can be combined with "Plane-Wave Impulse Approximation"



# Ground-state model can be combined with "Plane-Wave Impulse Approximation"



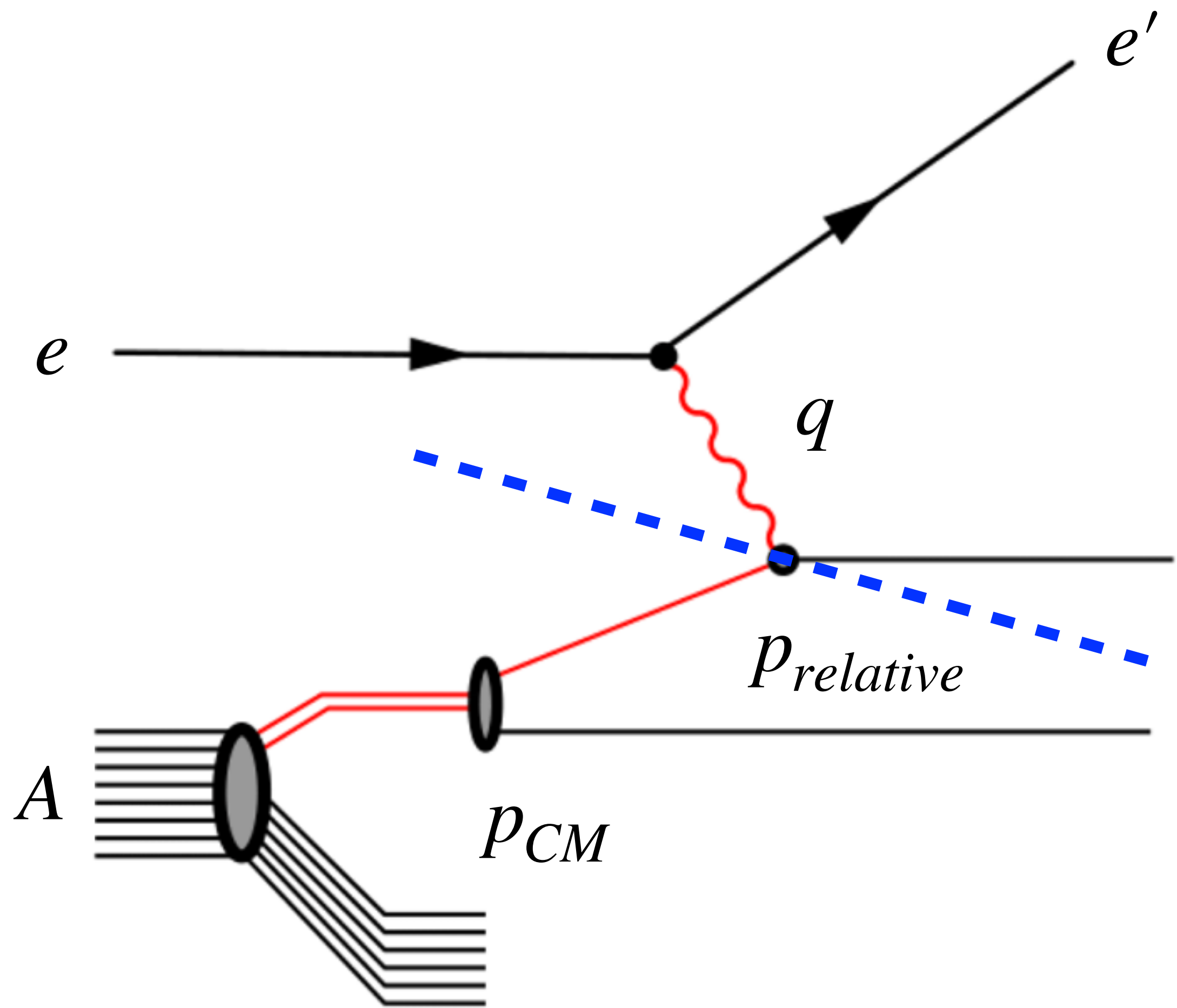
# Ground-state model can be combined with "Plane-Wave Impulse Approximation"



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

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

# PWIA relies on factorization between reaction and ground-state



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

**Reaction**

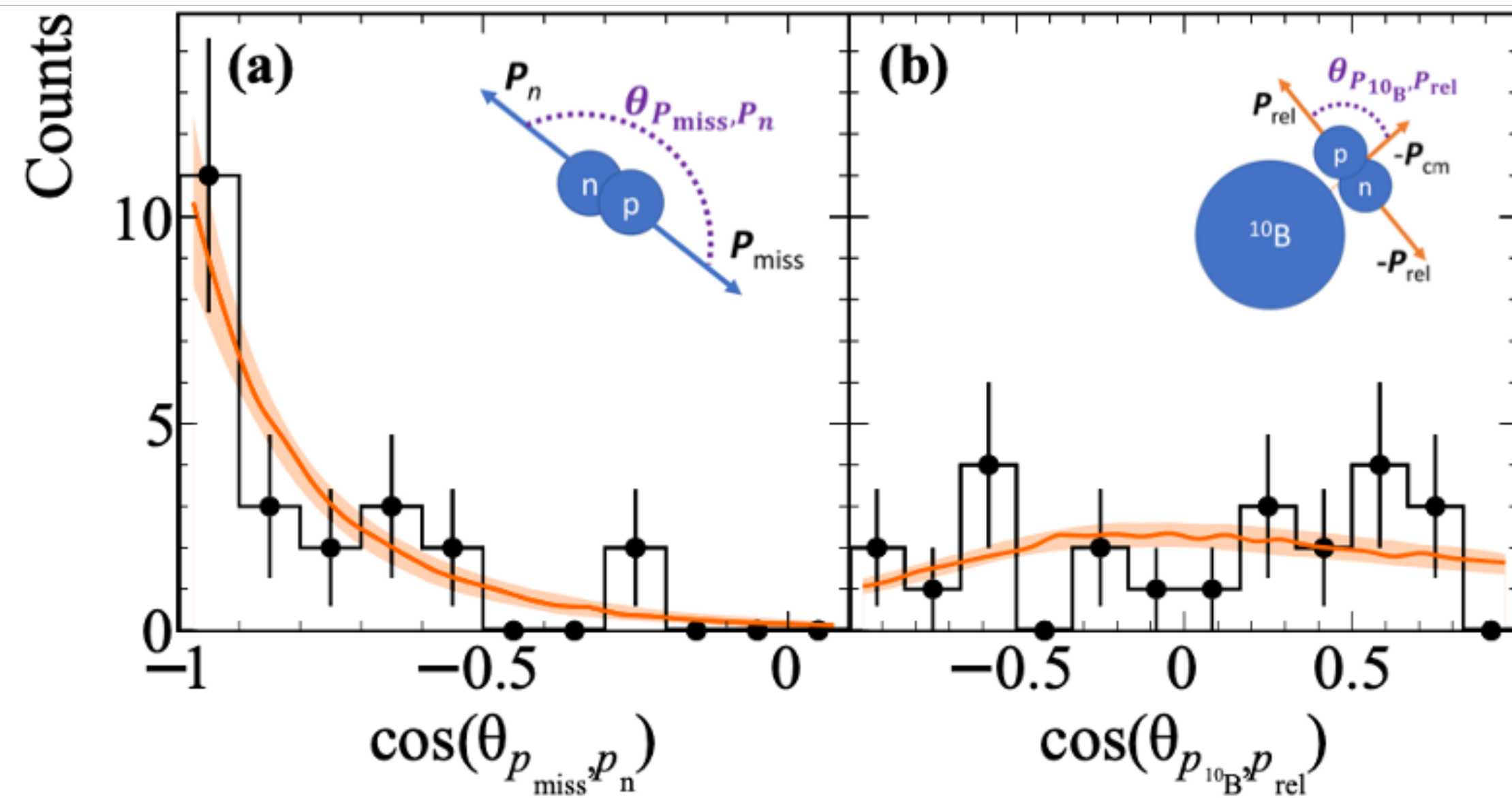
- High-energy
- 1-body operator
- Kinematics- and probe- dependent

**Ground-State**

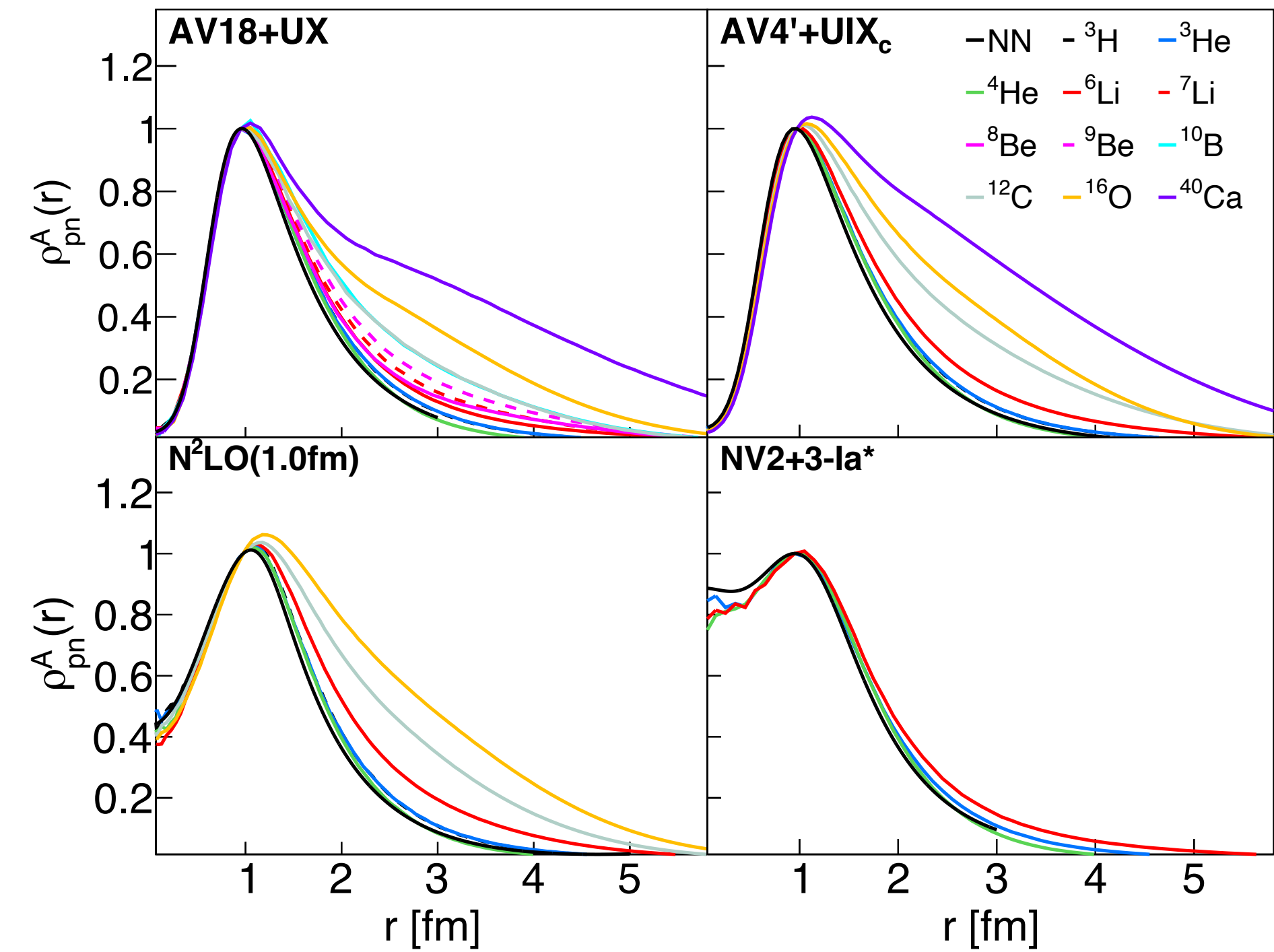
- Low-energy
- 2-body dynamics
- Universal

# Internal scale separation of SRCs on good footing:

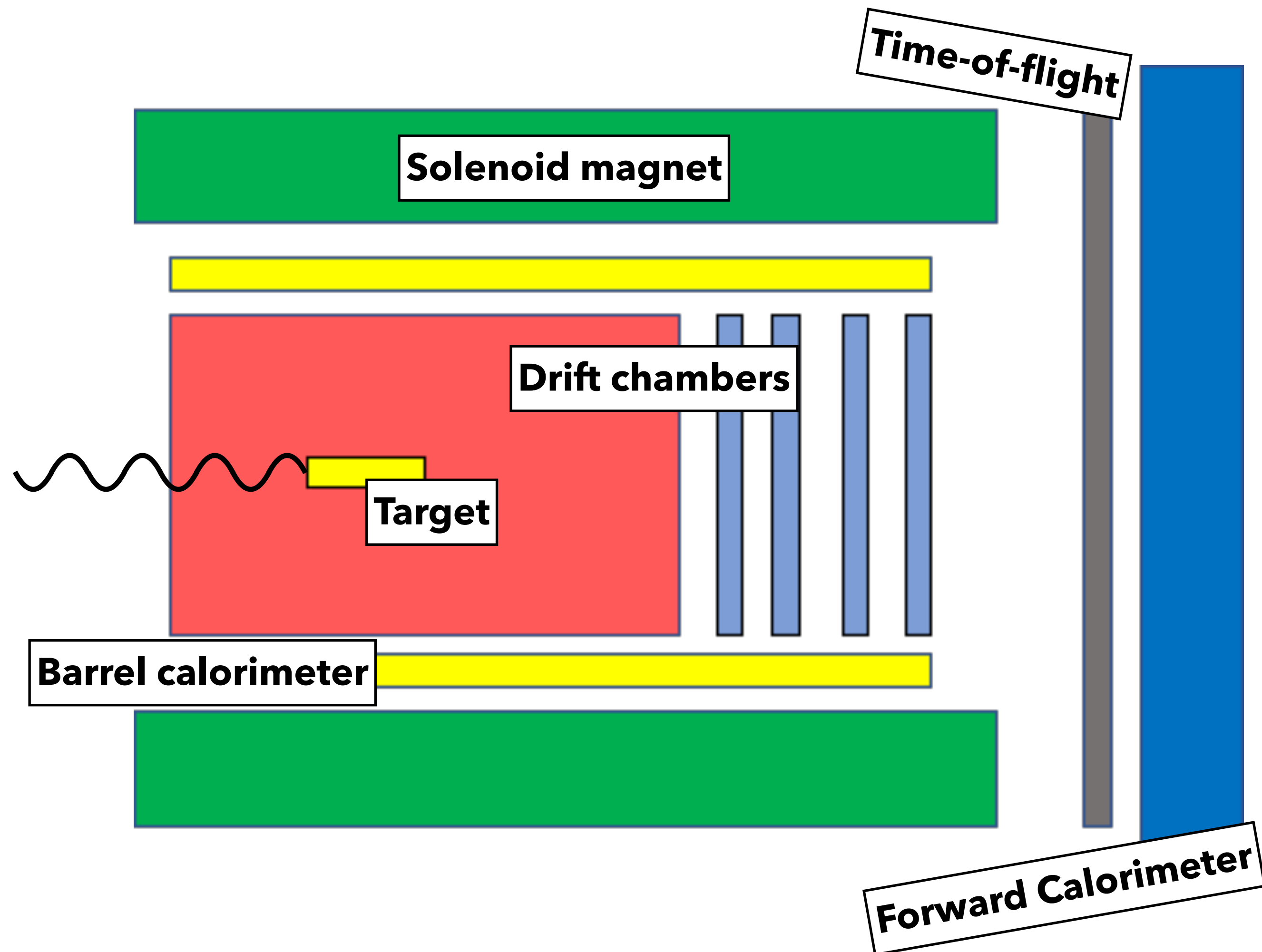
Nature Physics 17, 667 (2021)



Nature Physics 17, 306 (2021)



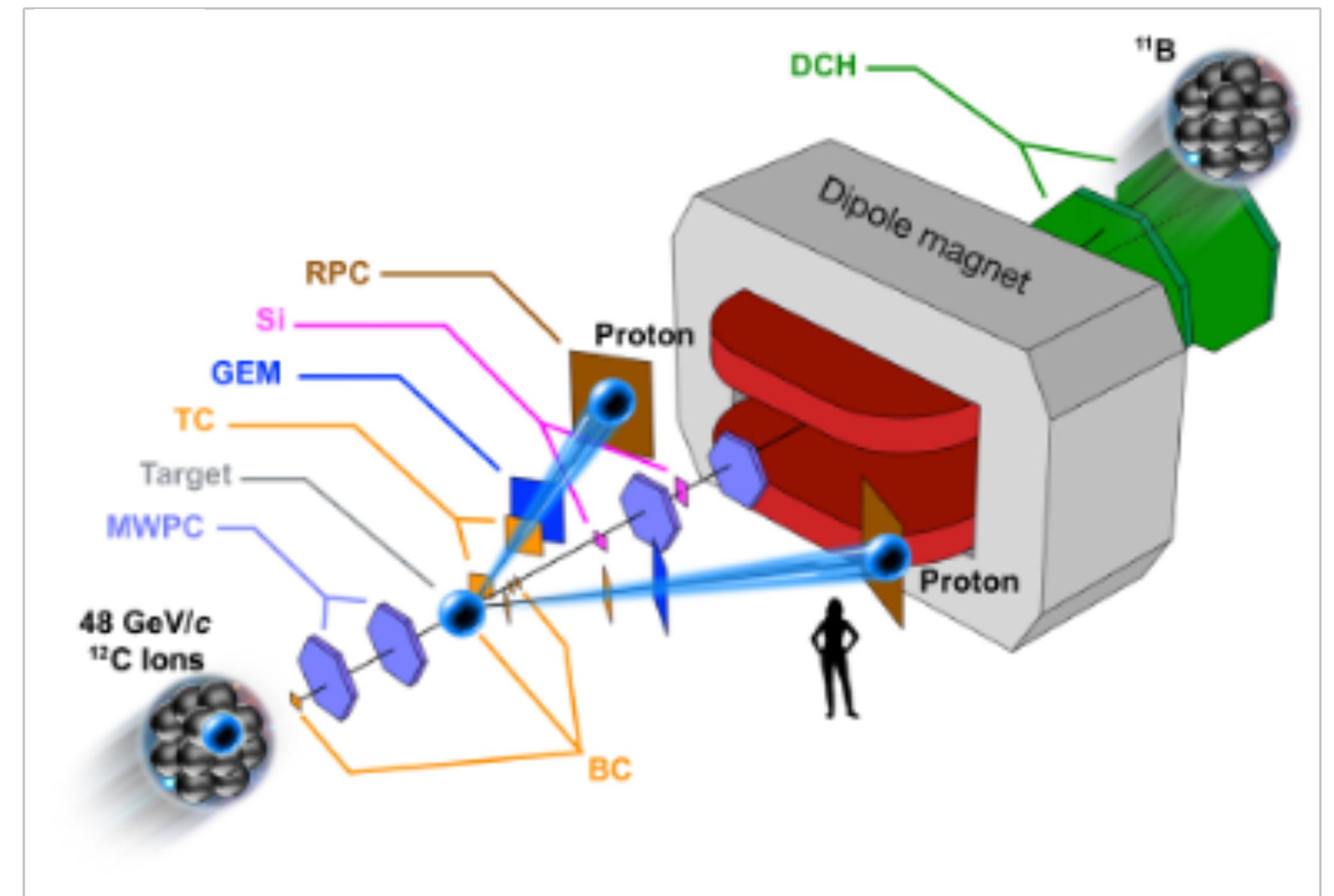
# GlueX Spectrometer



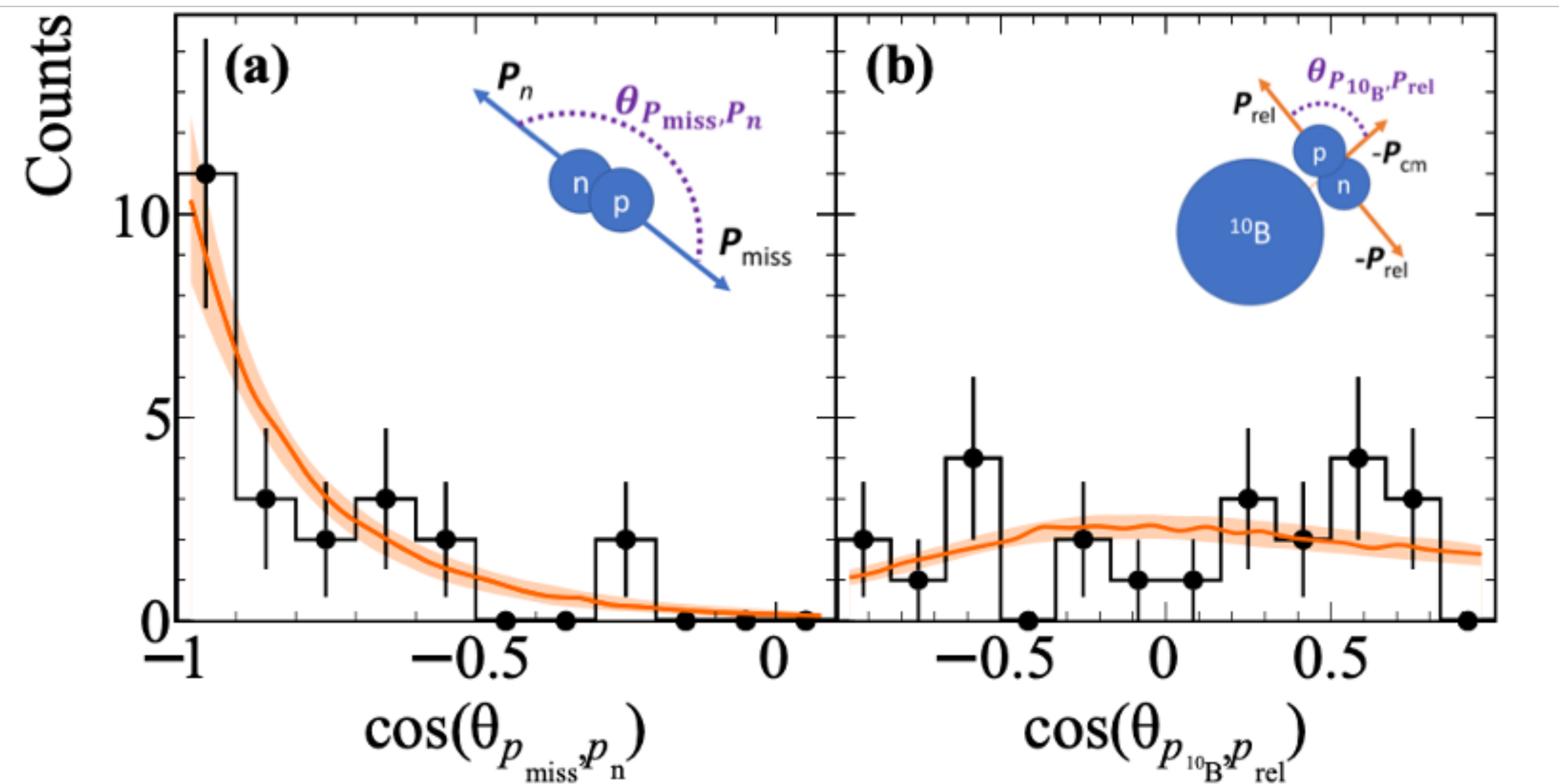
- Large-acceptance detector
- Solenoidal magnet:
  - Good  $p_T$  resolution
  - Poor  $p_z$  resolution
- Time-of-flight allows particle identification for forward-going charged particles
- Calorimeters allows good acceptance and reconstruction of final-state photons

# Hadron-scattering measurements of SRCs

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



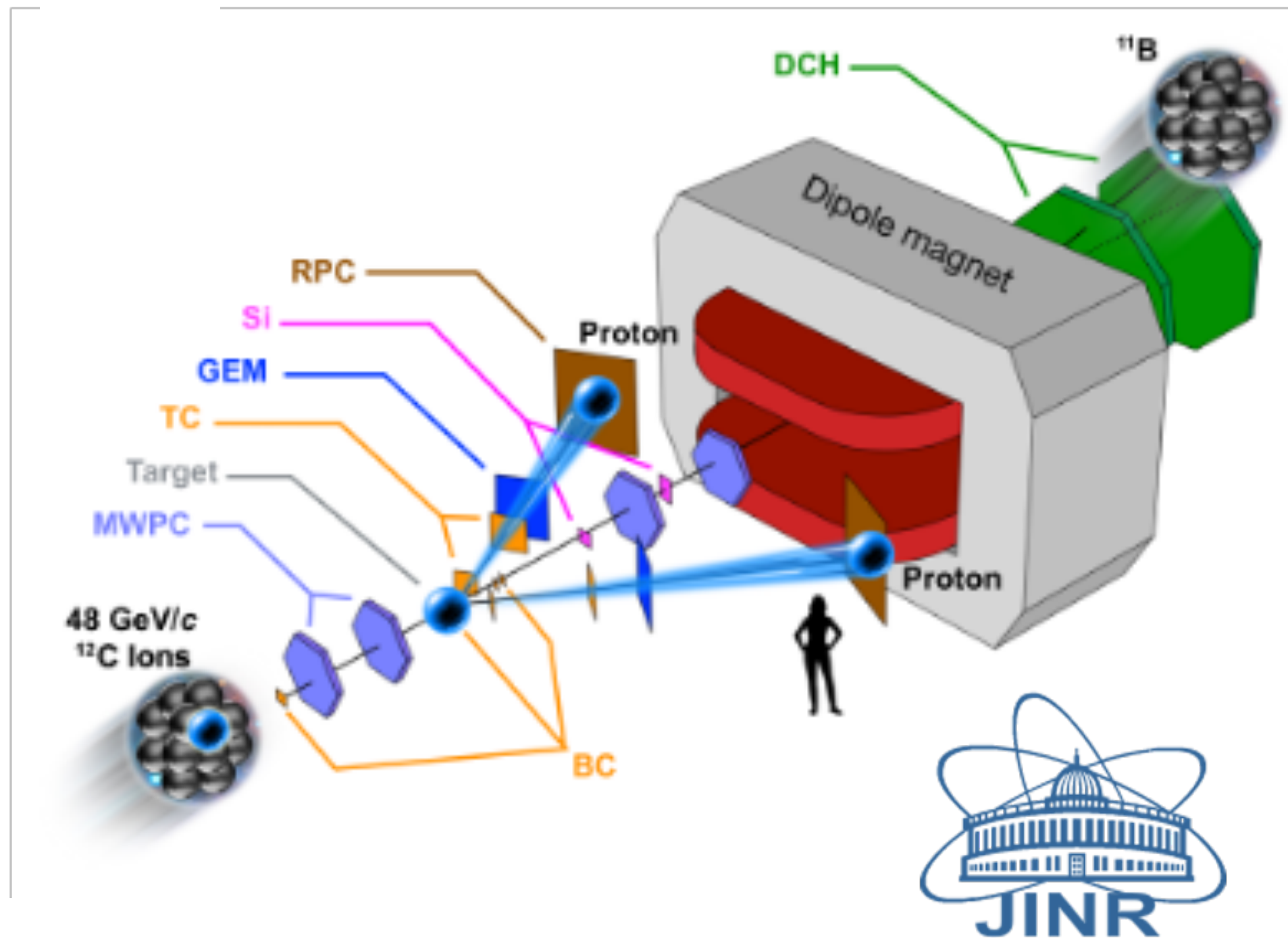
# Experimental evidence for SRC scale-separation



M. Patsyuk et al, Nature Physics (2021)

# Next generation of ion-beam SRC studies underway

## JINR, Dubna



## GSI, Frankfurt

