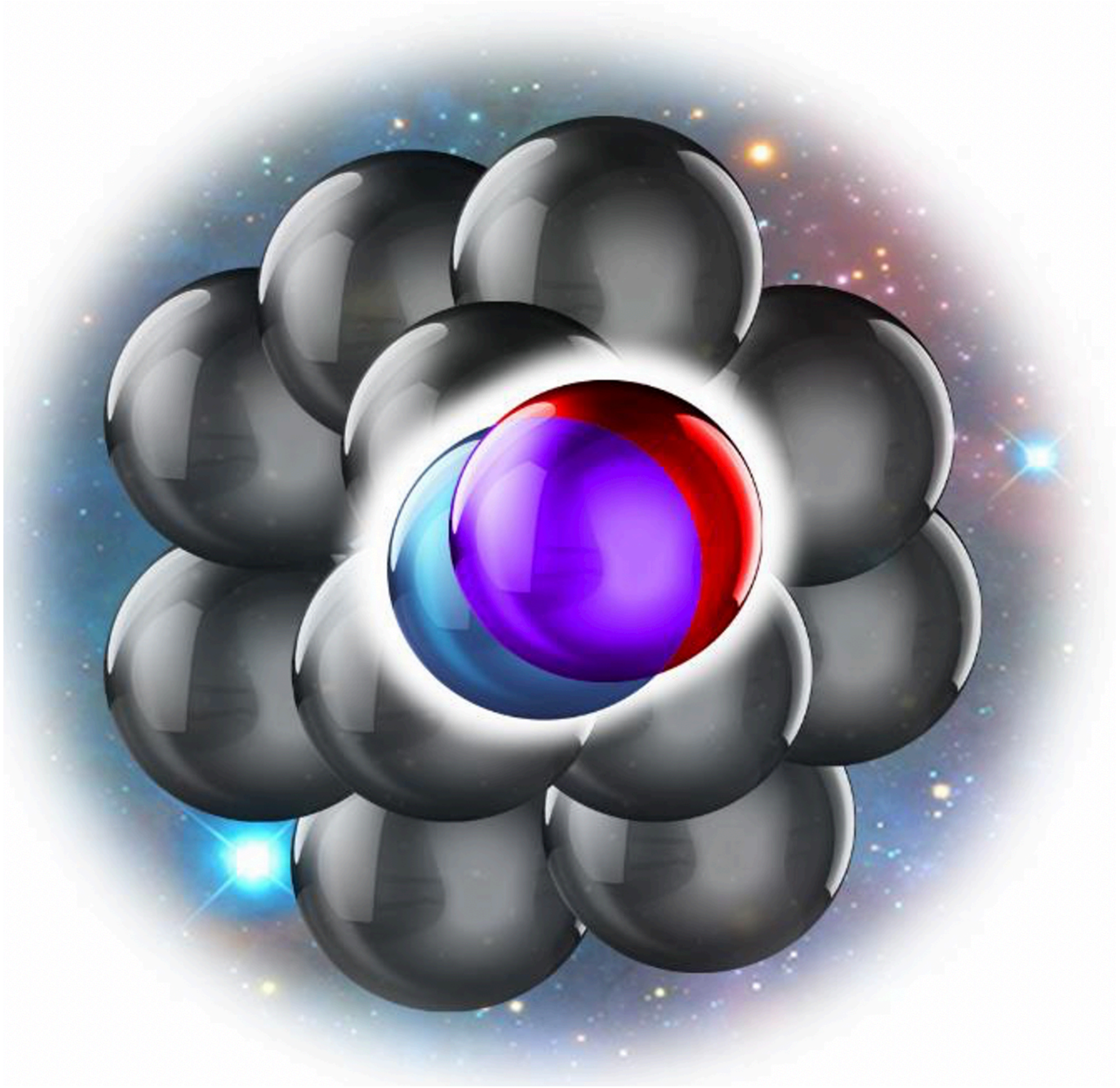
Testing the Universality of Nuclear Short-Range Correlations

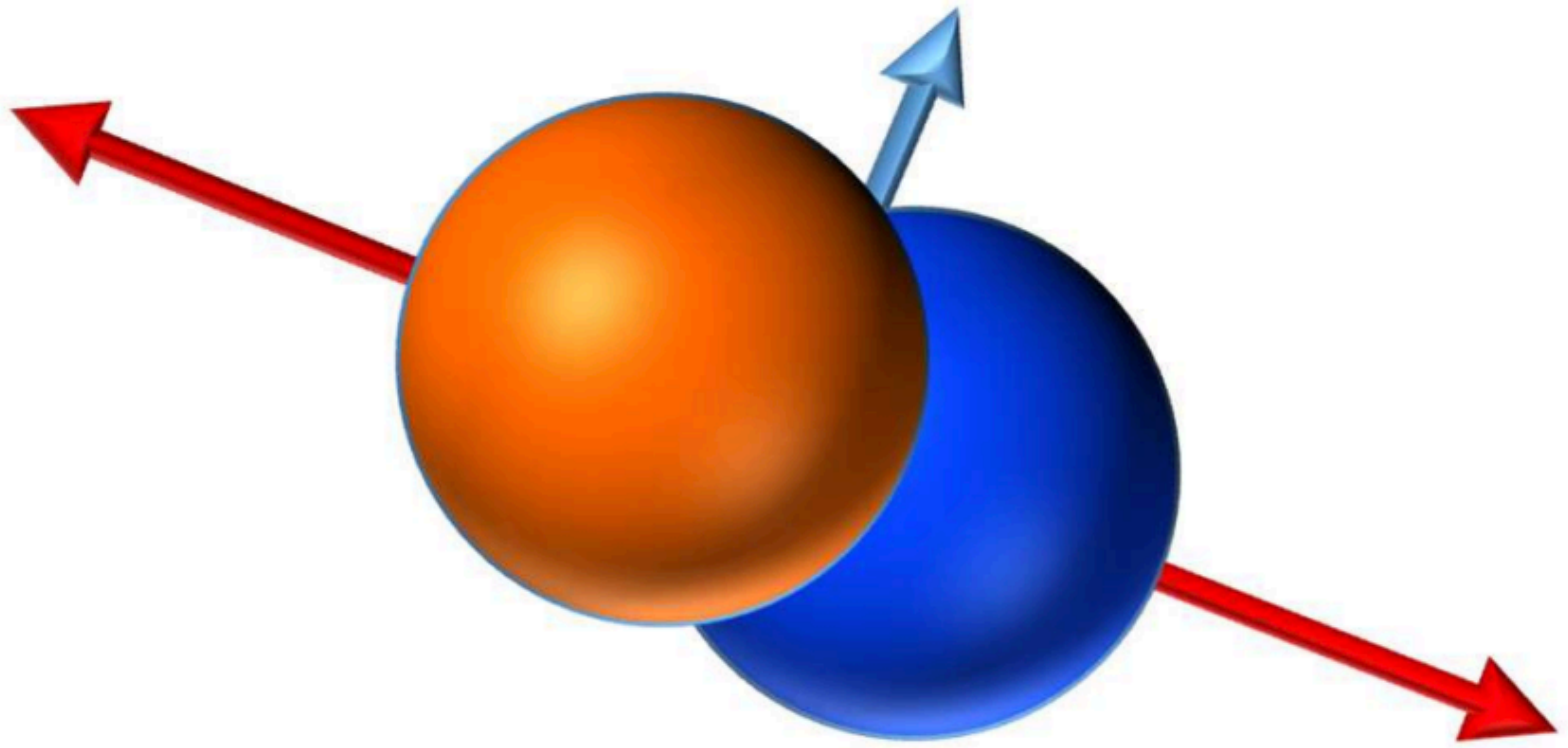
Jackson Pybus

What do we know about SRCs?

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

High relative and lower center-of-mass momentum

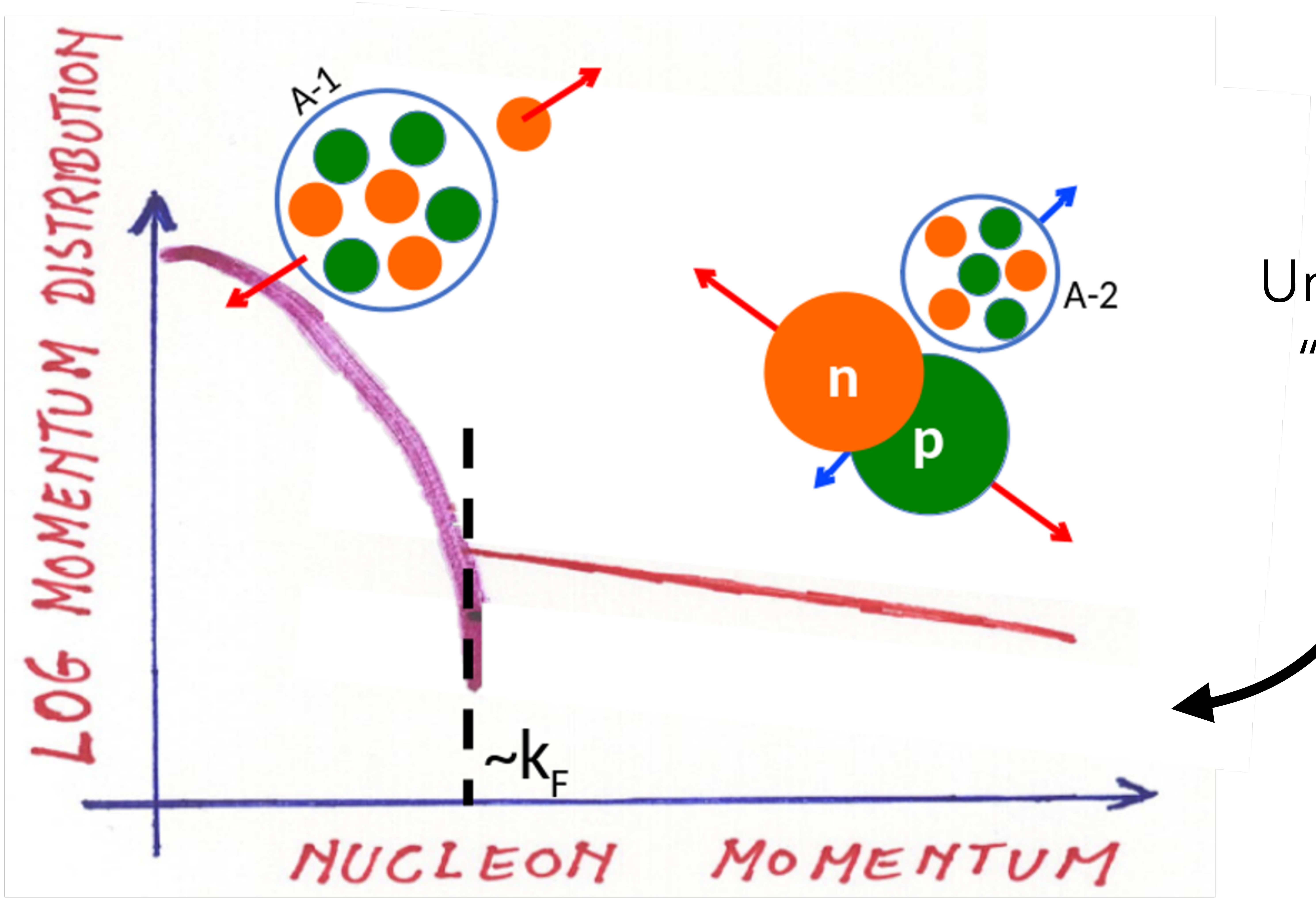




Position-space

Momentum-space

What do we know about SRCs?



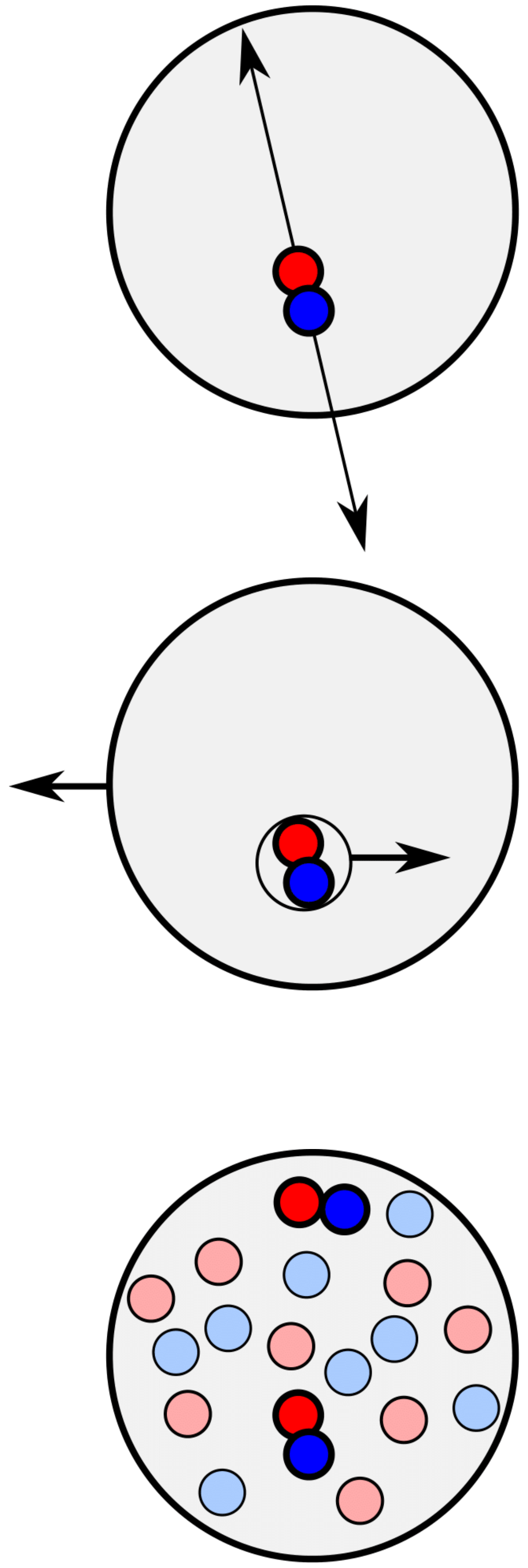
Universal high-momentum "tail" – about 10-20% of nucleons

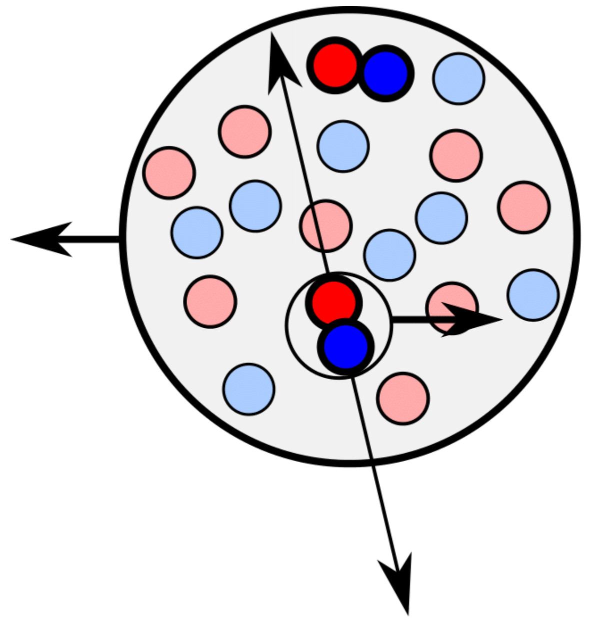
Factorized approach to SRC modeling

Pair interaction

Center-of-mass motion

Pair abundance





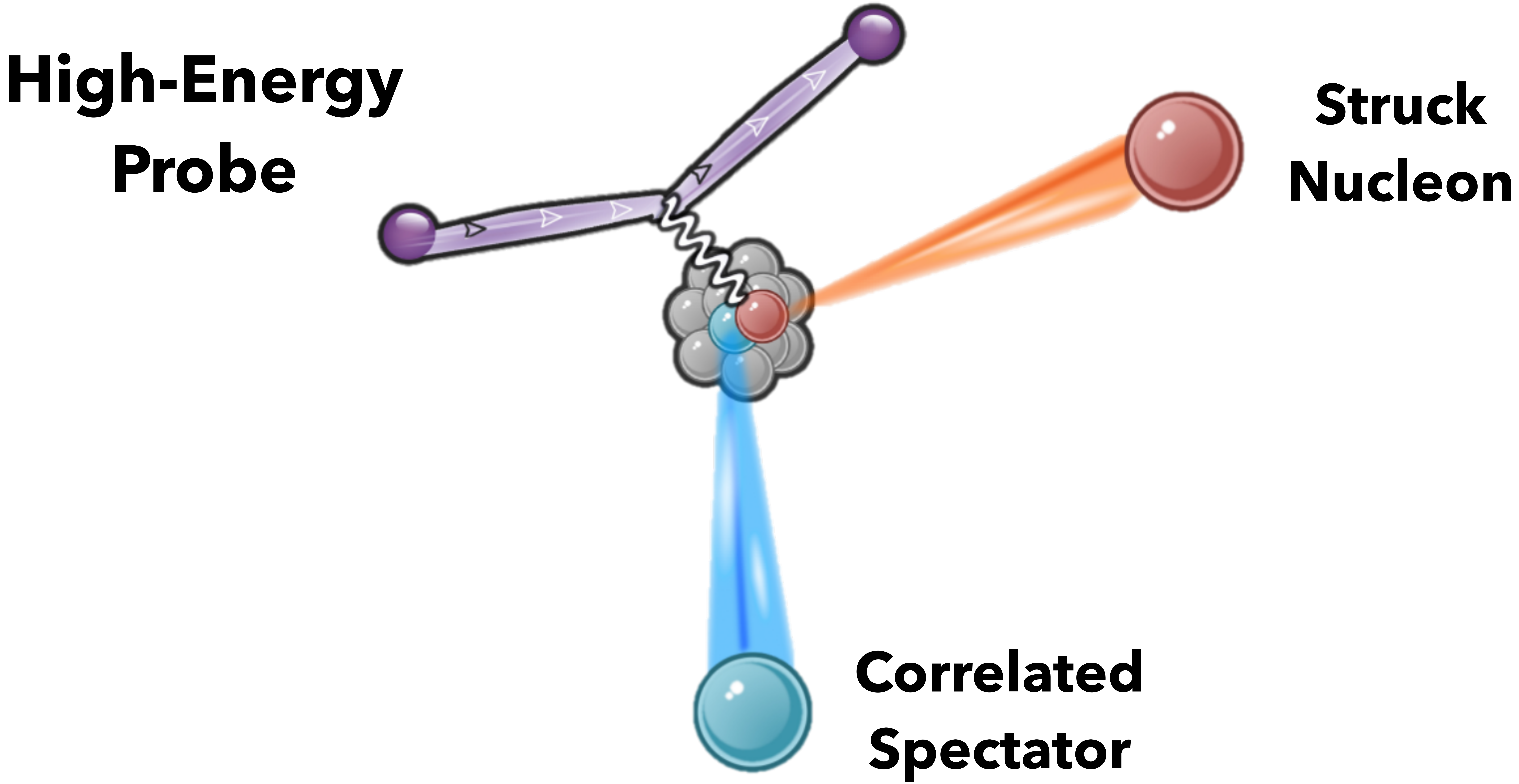
Factorized SRC spectral function:

$$S(p_i, E_i) \sim C_{NN} \cdot |\phi(k_{rel})|^2 \cdot n(p_{CM})$$

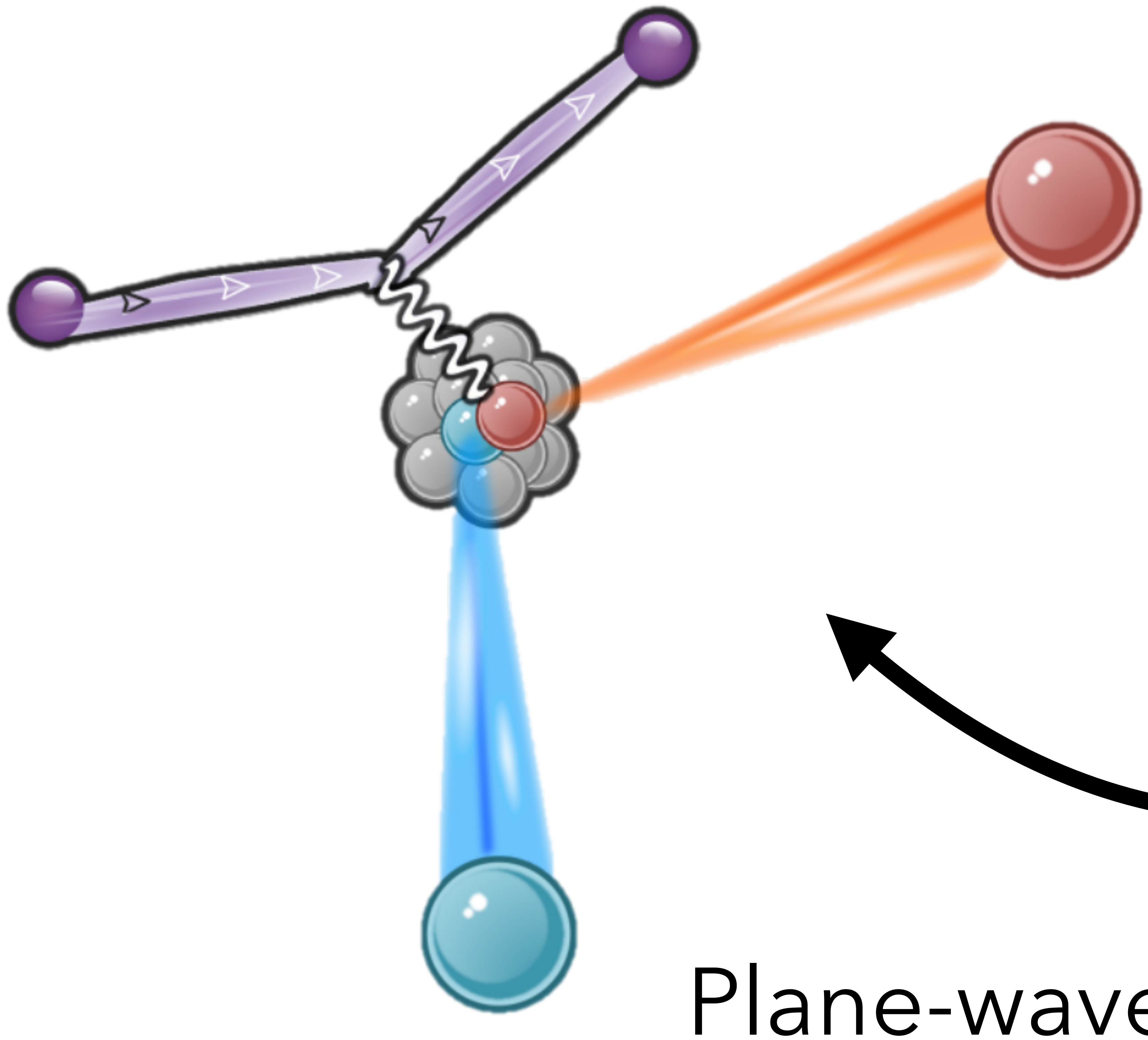
$$\boxed{k_{rel} \gg p_{cm}}$$

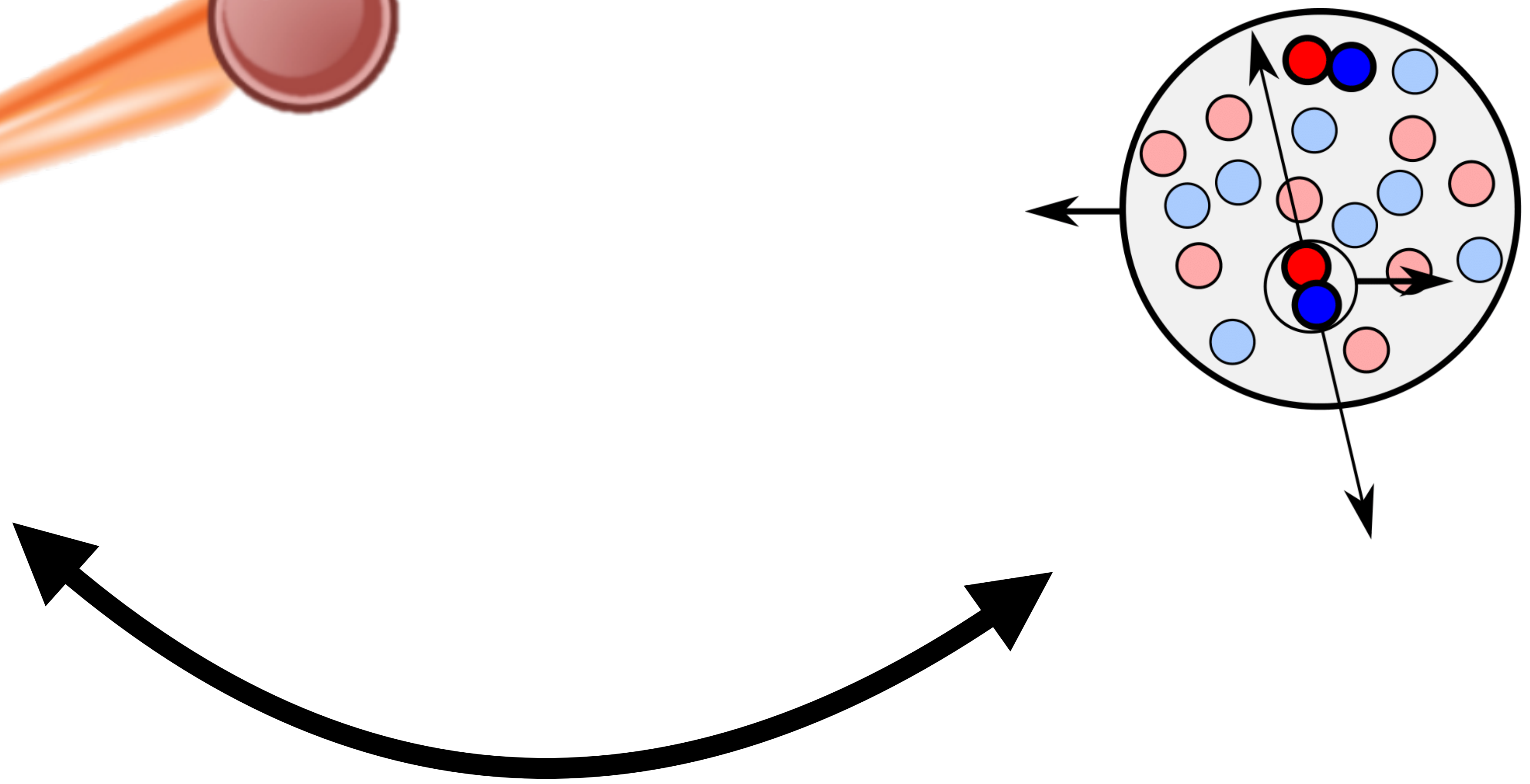
Nature Physics (2021), PLB (2018), PRC (2015), PRC (2021), JPG (2020), PRL (2017), PLB (2019), PRC (1996)…

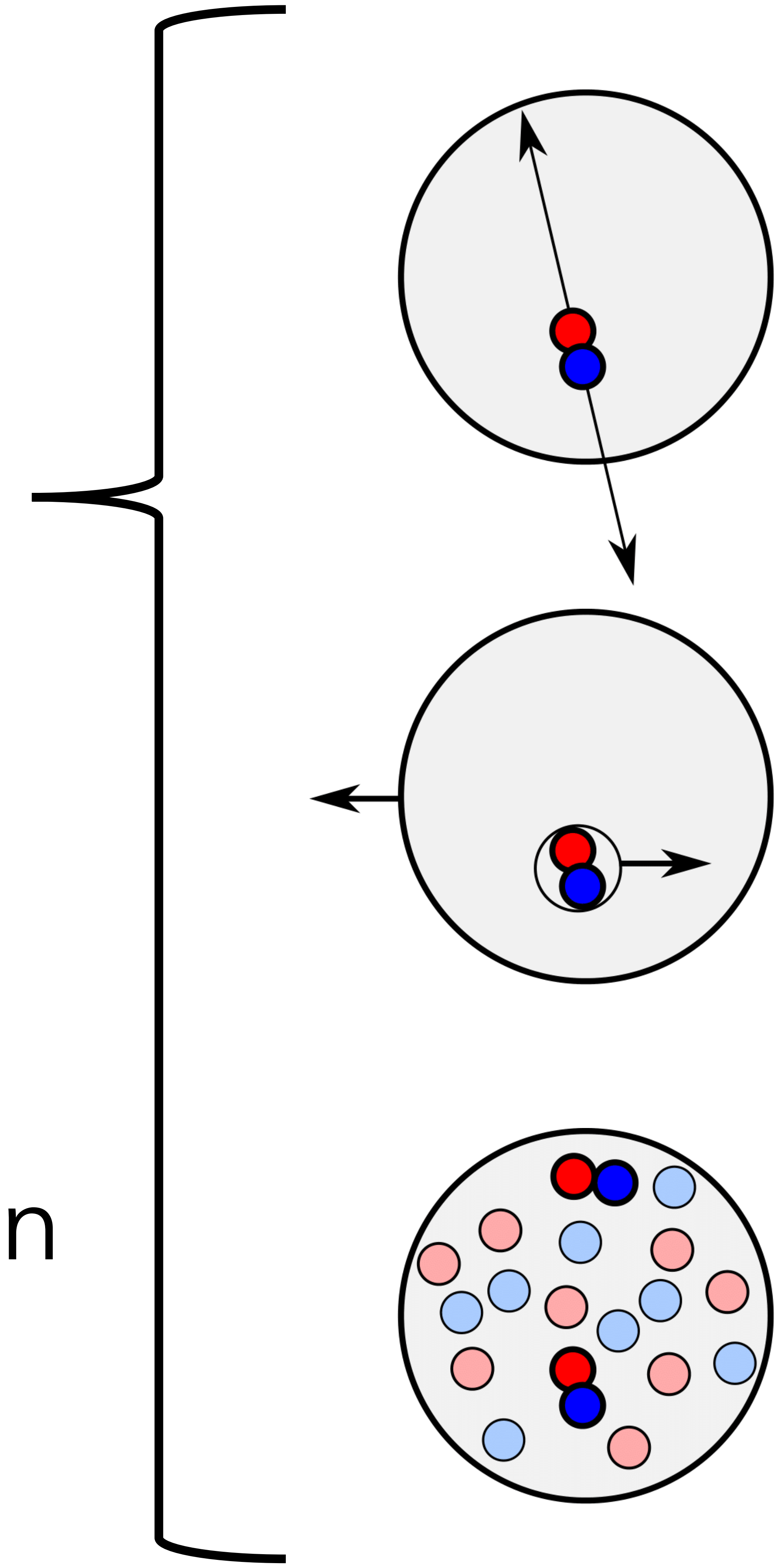
SRCs can be studied with hard breakup reactions



Scattering data can inform ab-initio theory



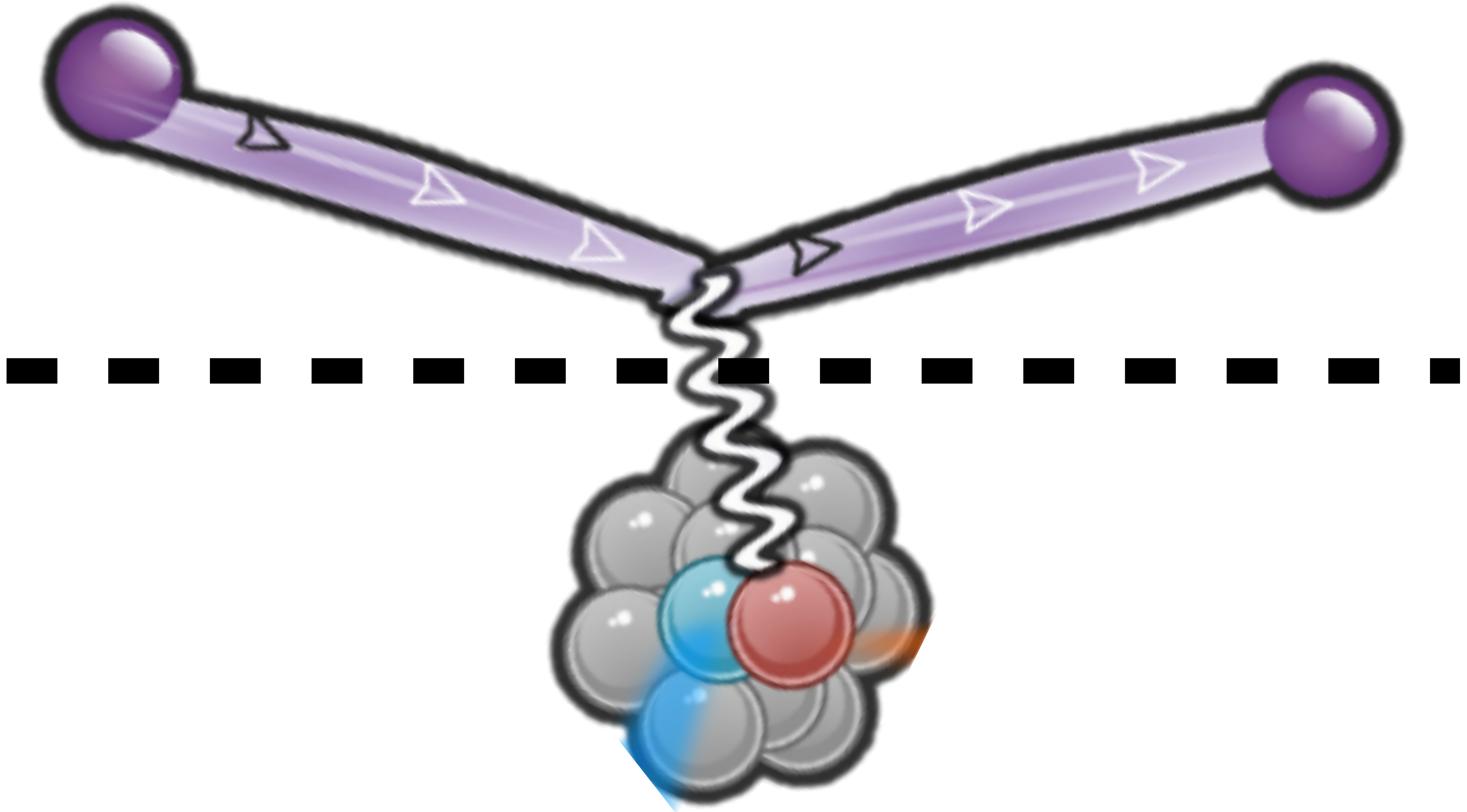




Plane-wave impulse approximation

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

Ground-state interpretation requires establishing plane-wave factorization!



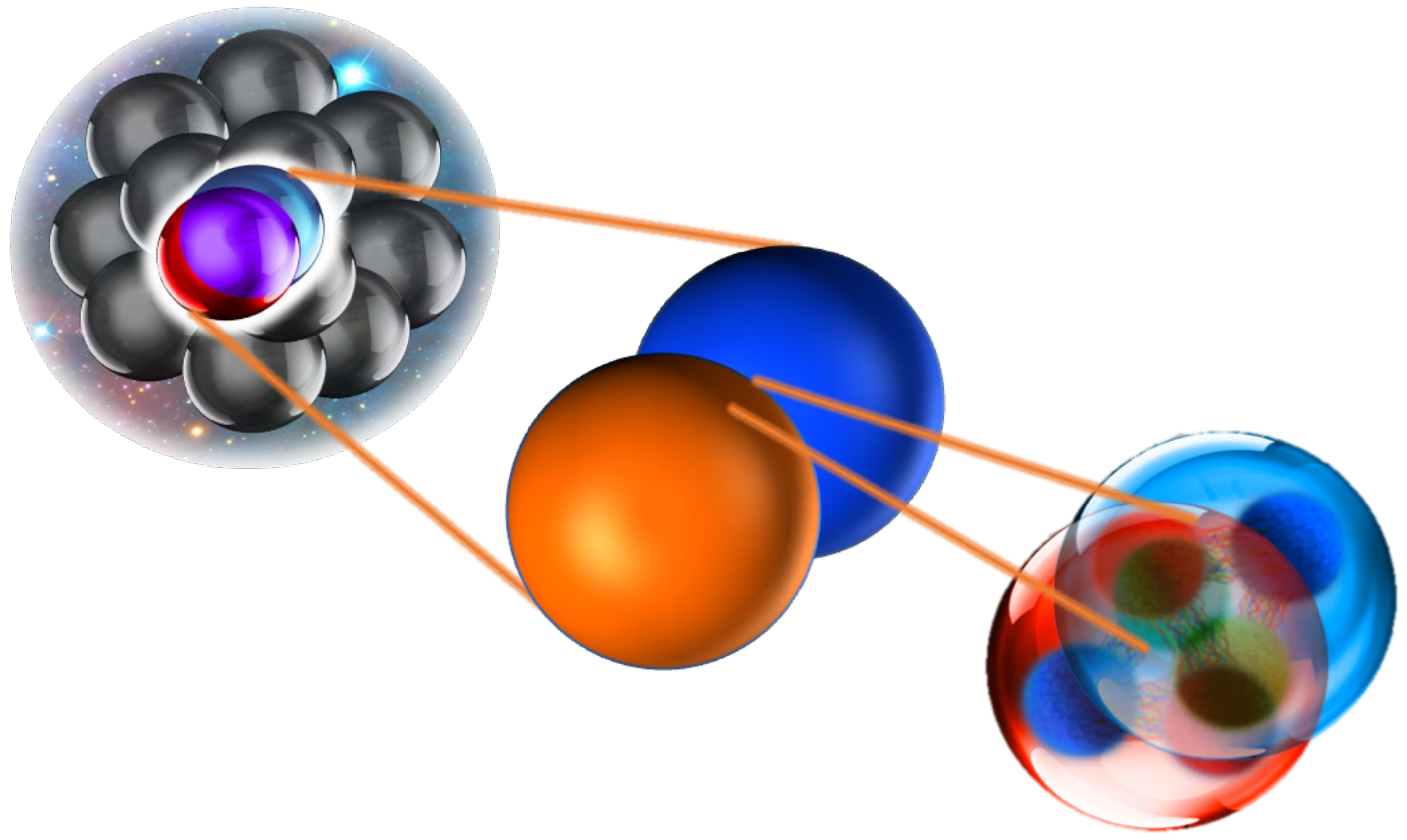
Reaction

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

Ground-State

Two ways to examine reaction-dependence:

Scale



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

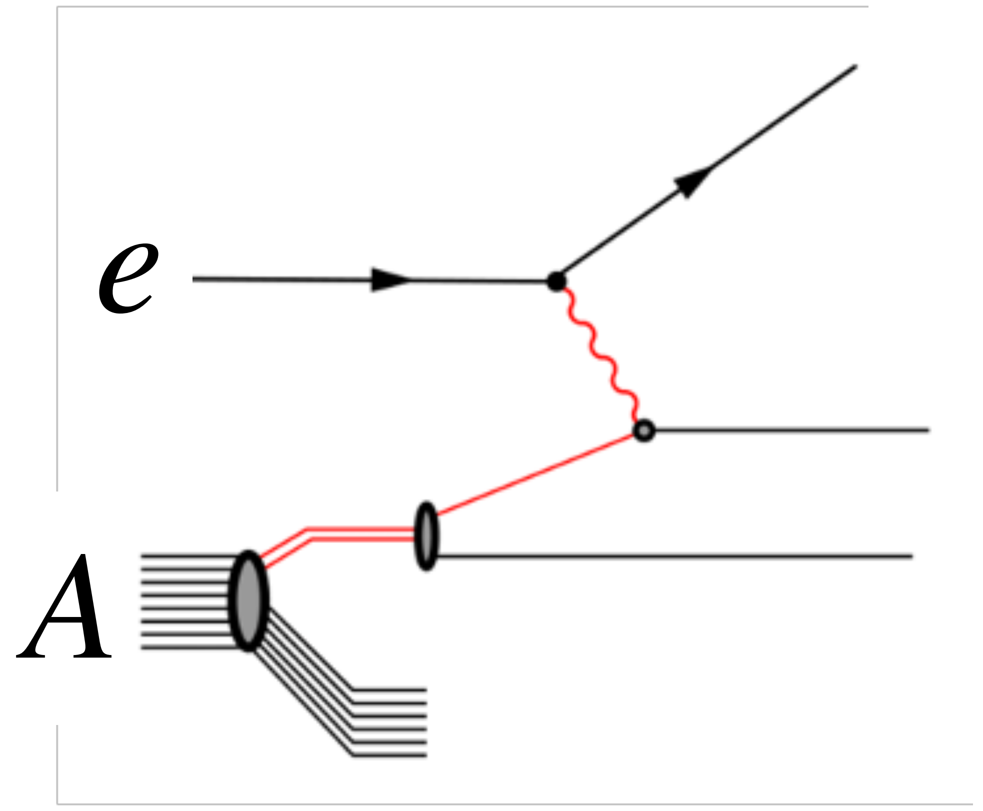
Probe

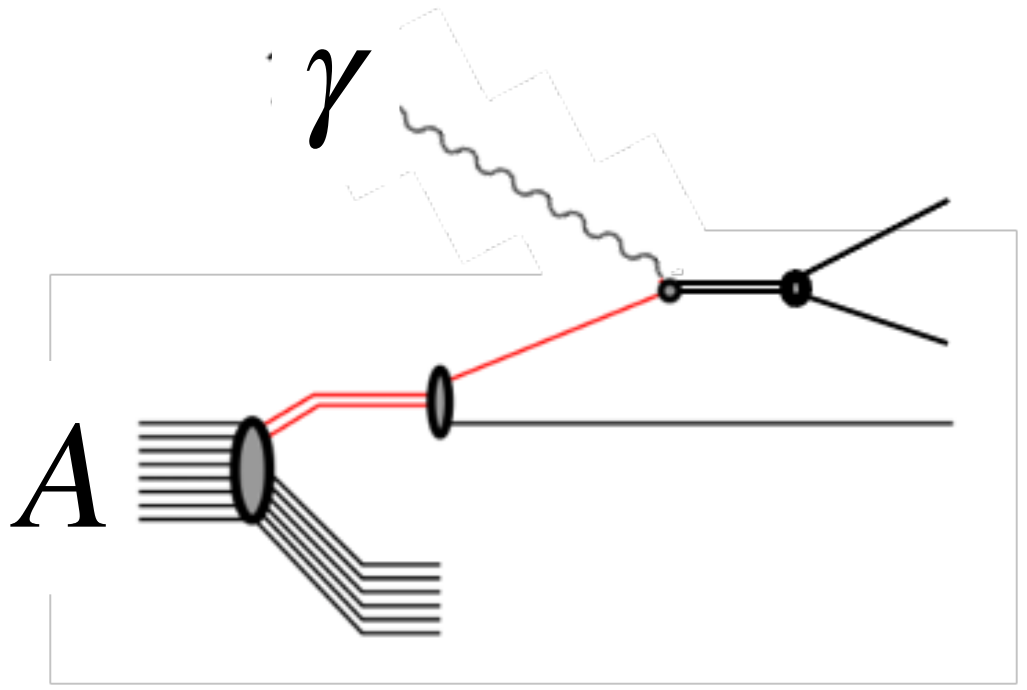
Different **probes**:

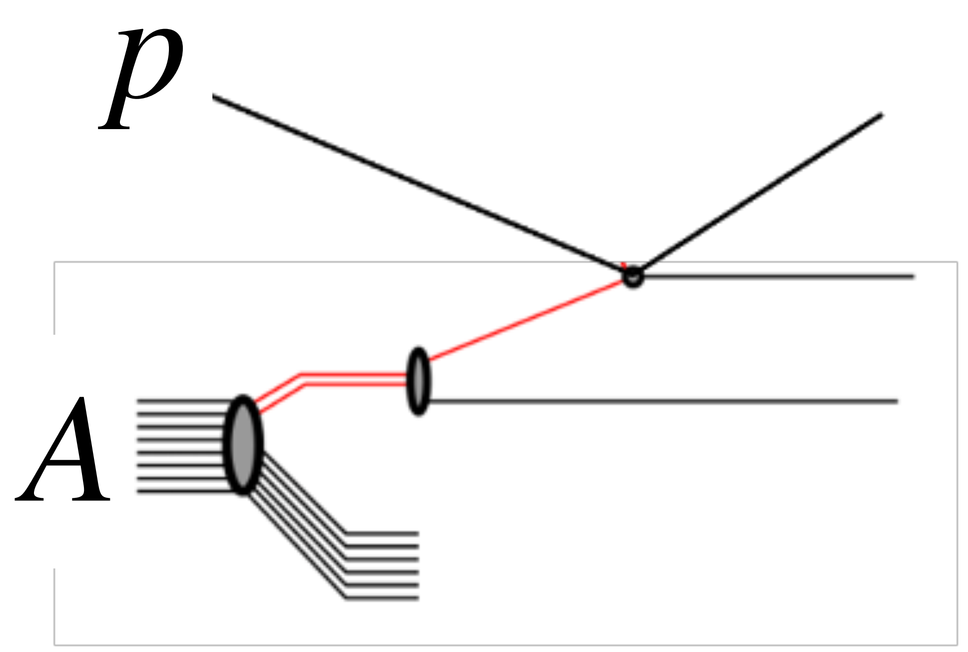
Electromagnetic (e^-),

Hadronic (p, A),

Photonuclear (γ)







Two ways to examine reaction-dependence:

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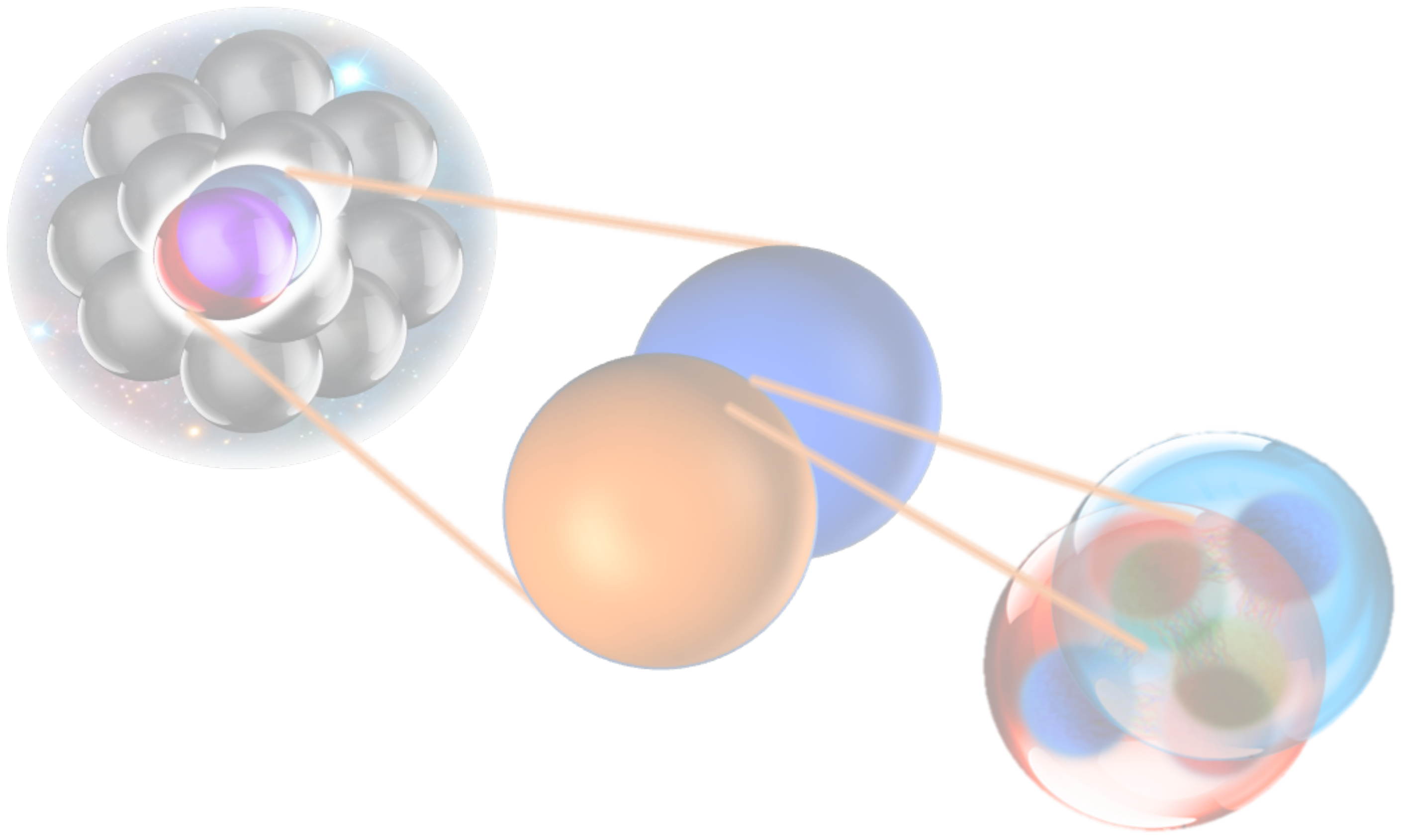

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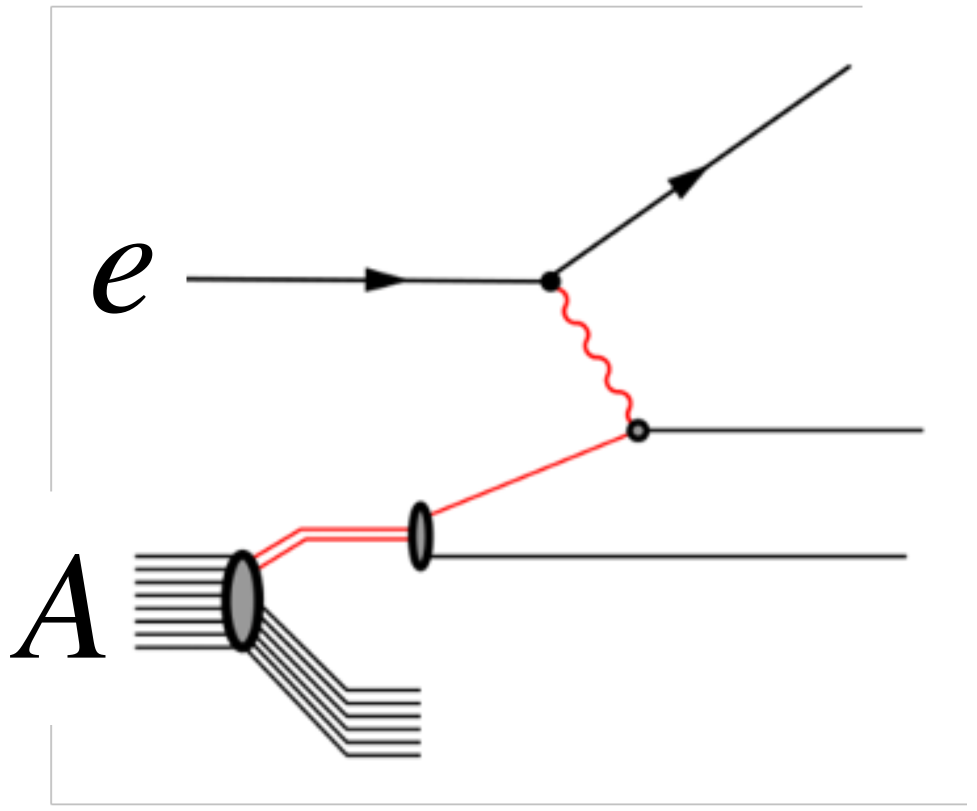
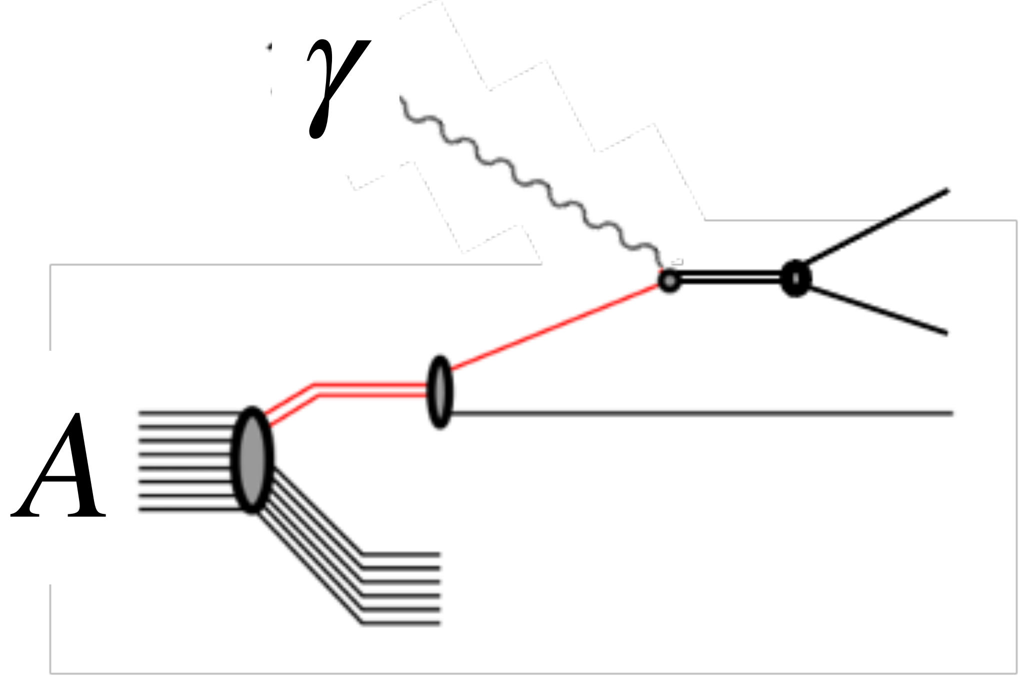
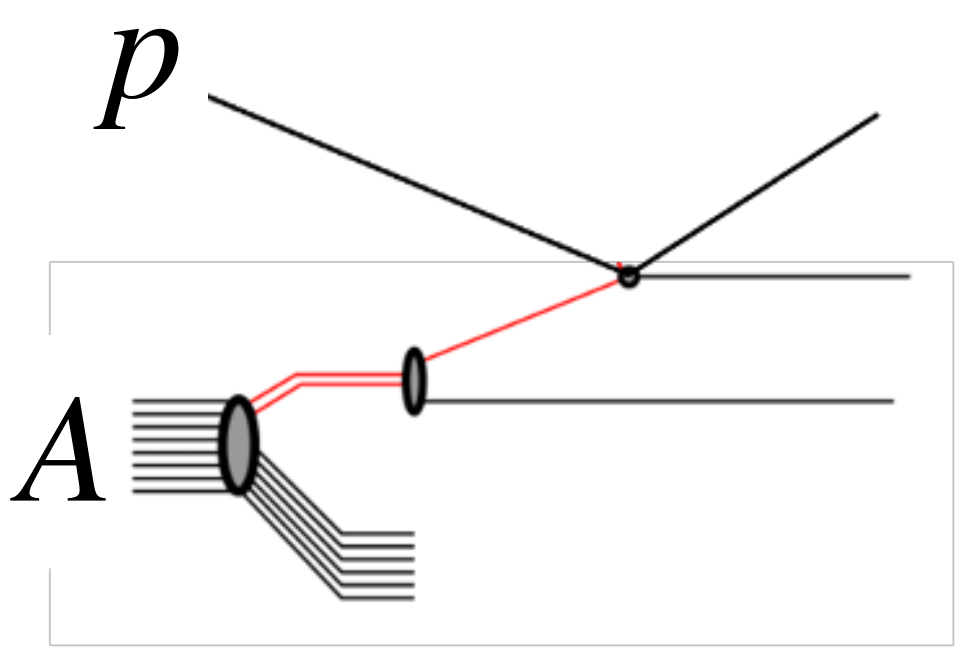
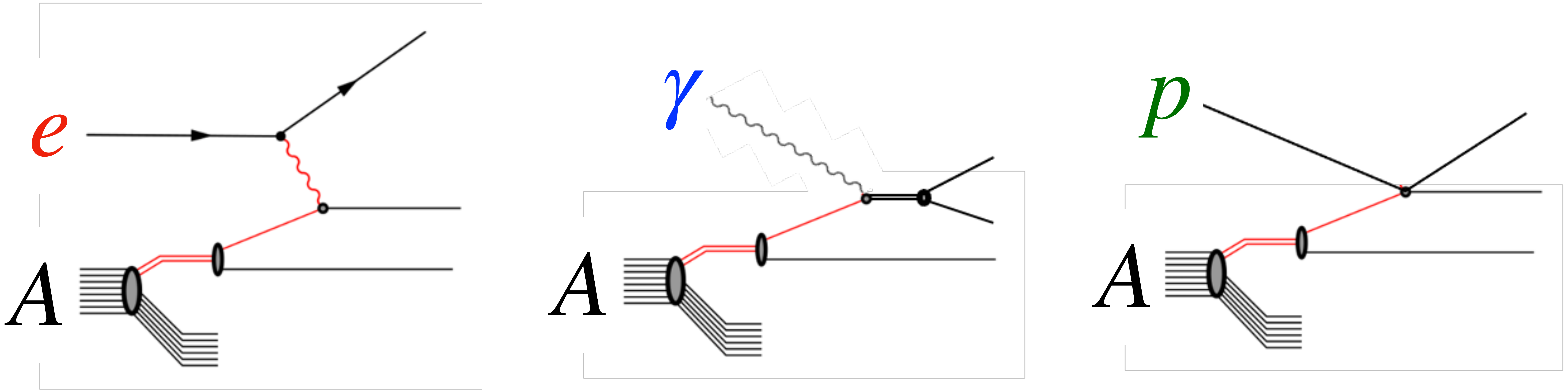


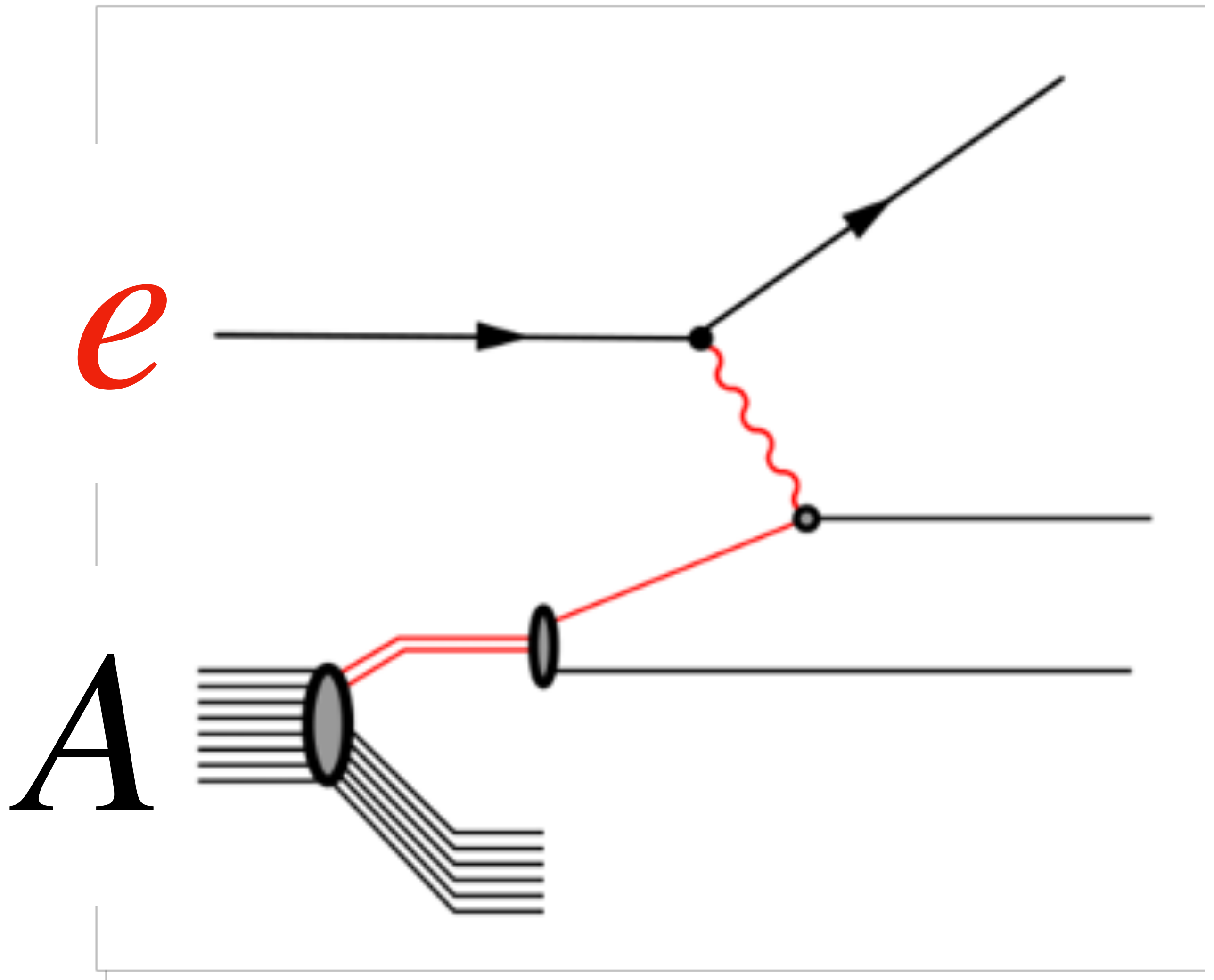


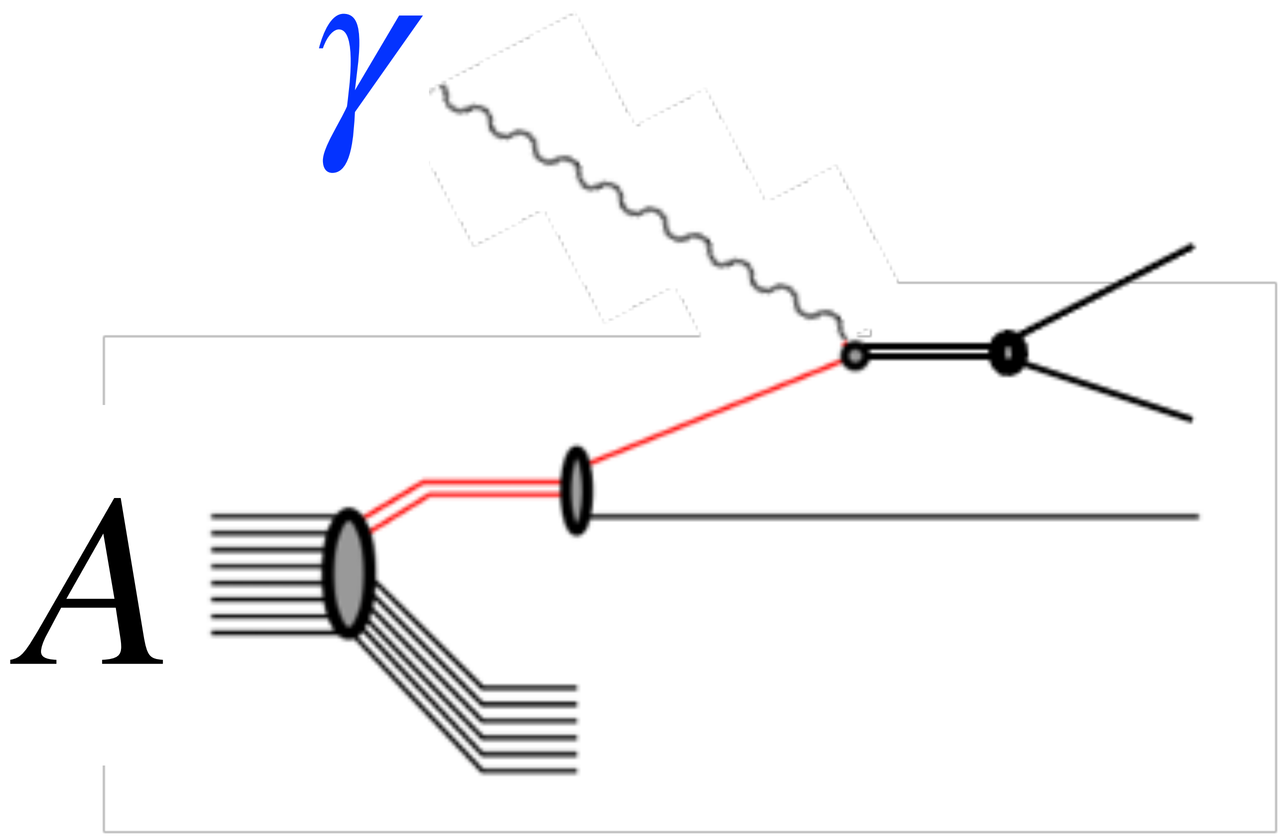


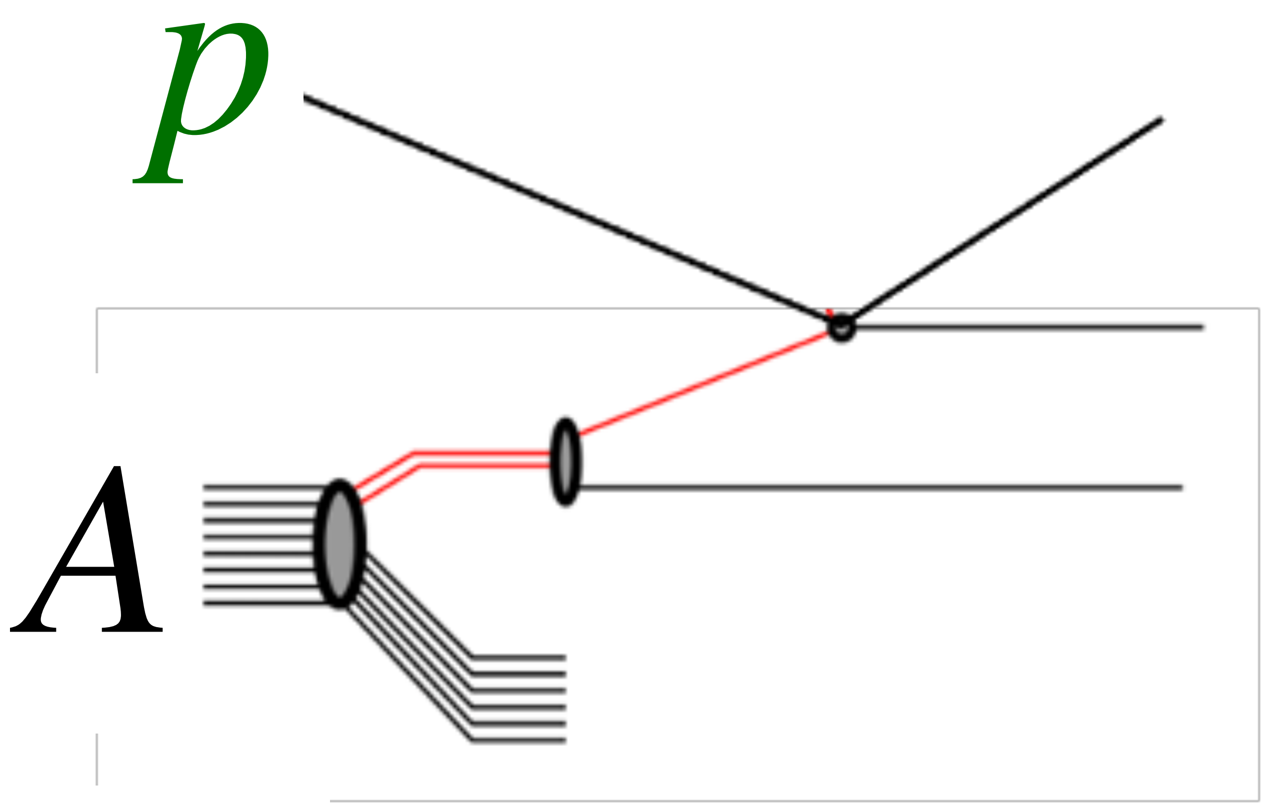
Probe Dependence of SRCs

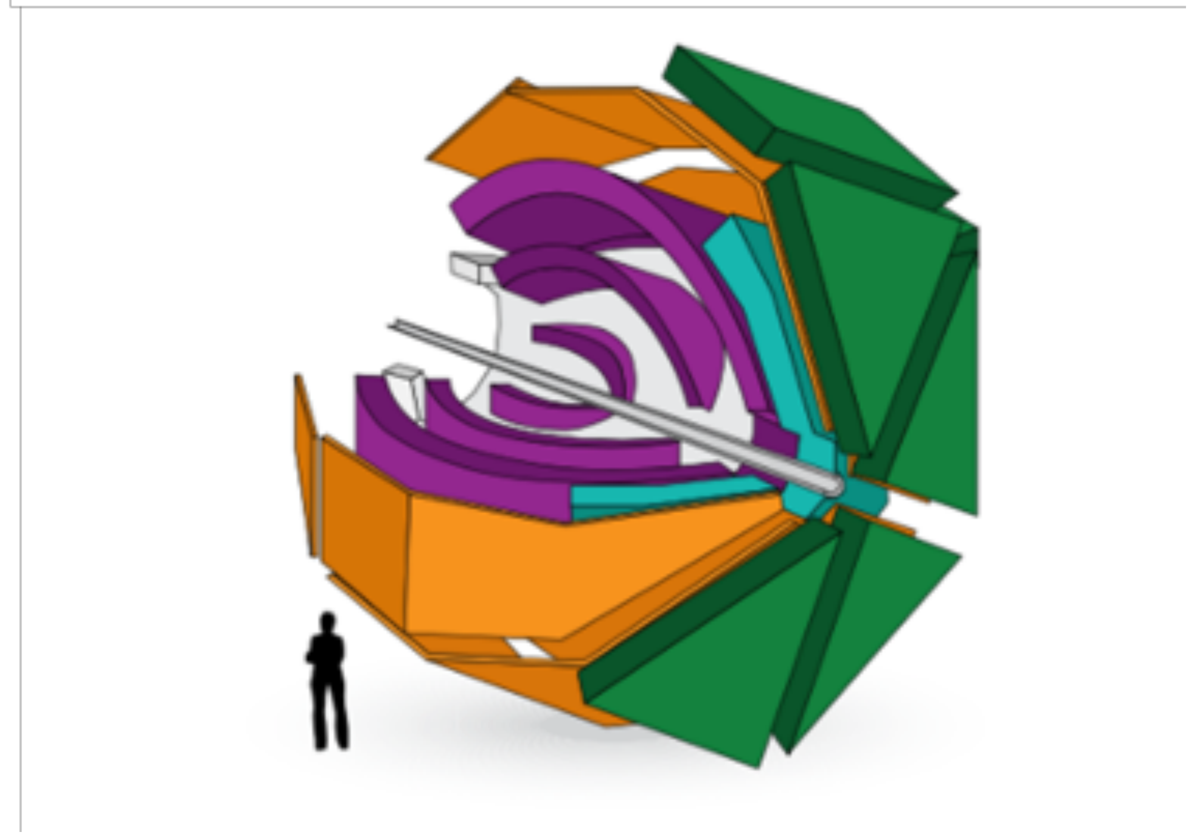


Probe Dependence of SRCs

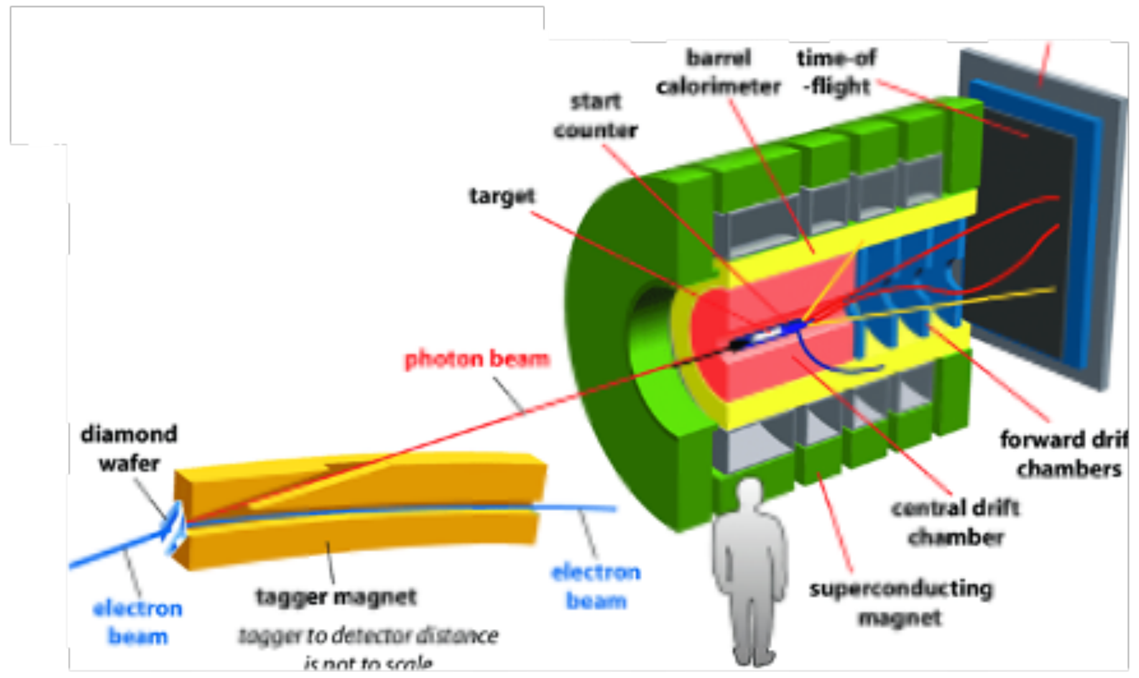




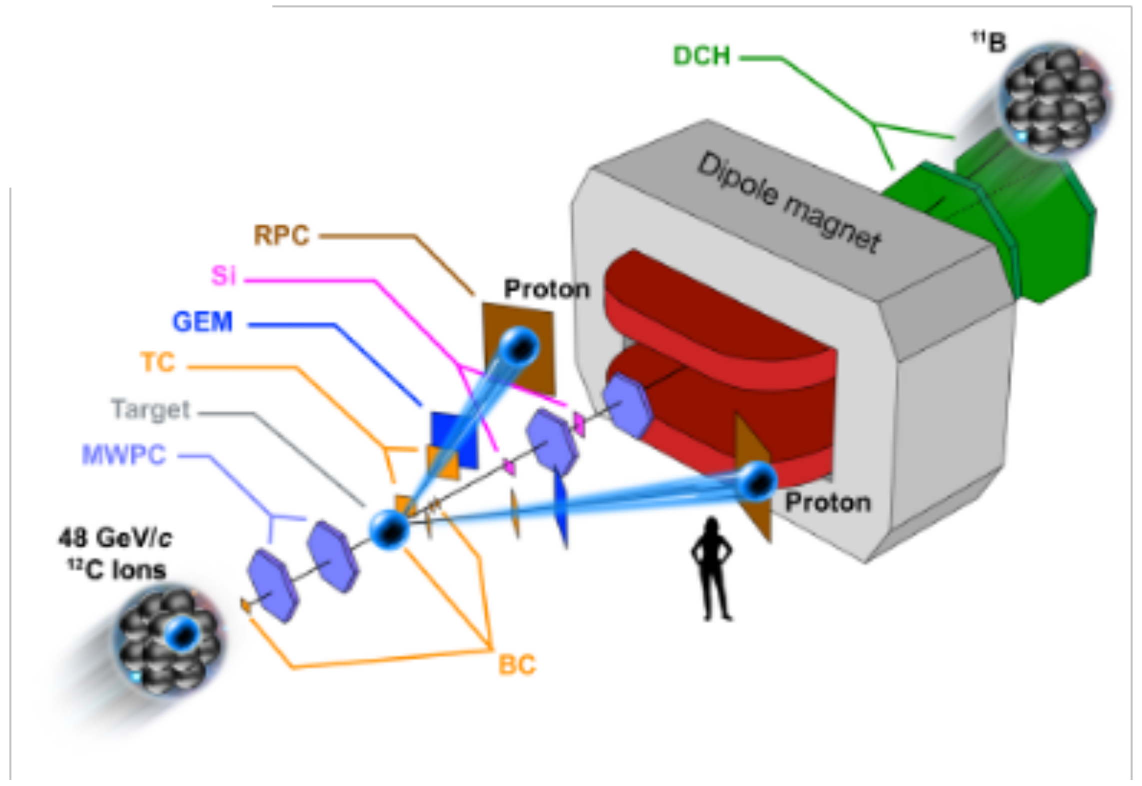




CLAS12

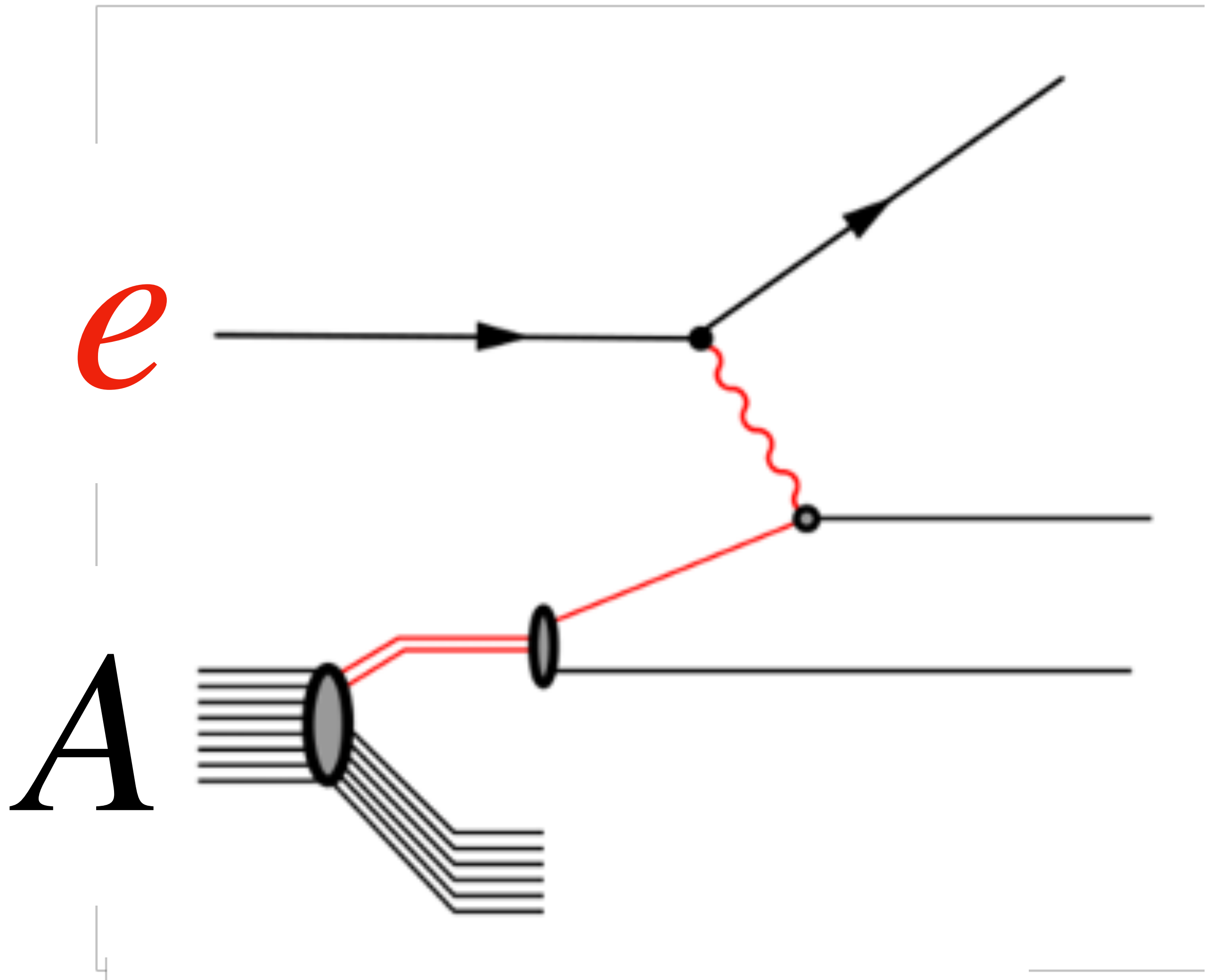


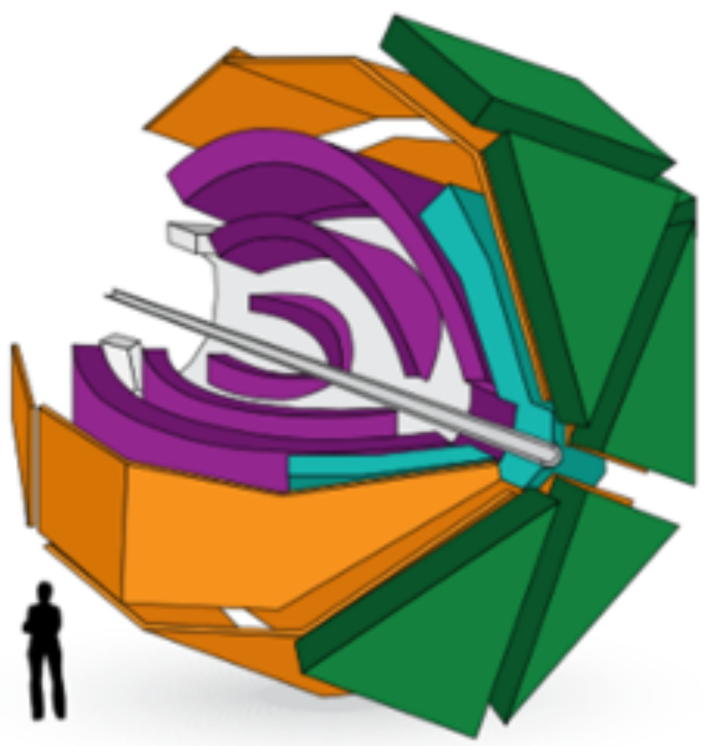
GlueX



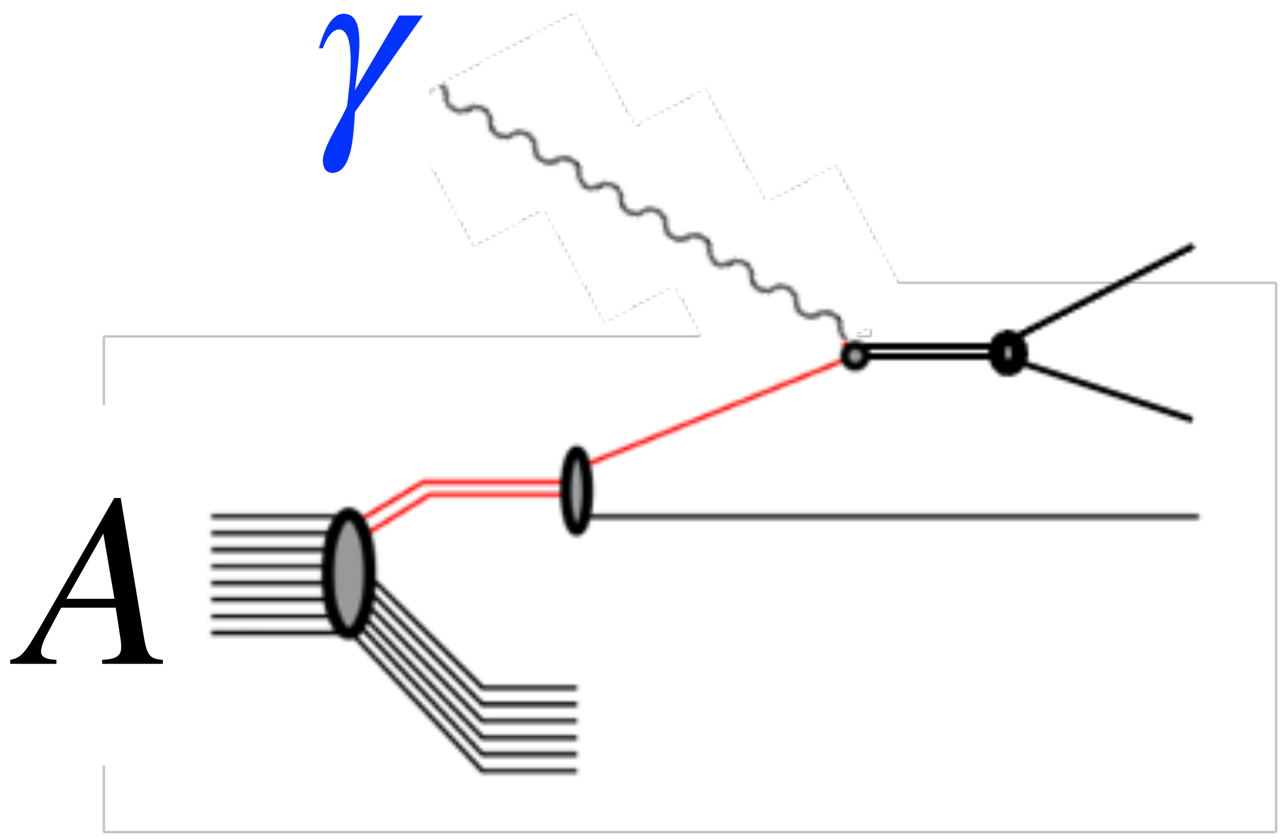
BM@N / R3B

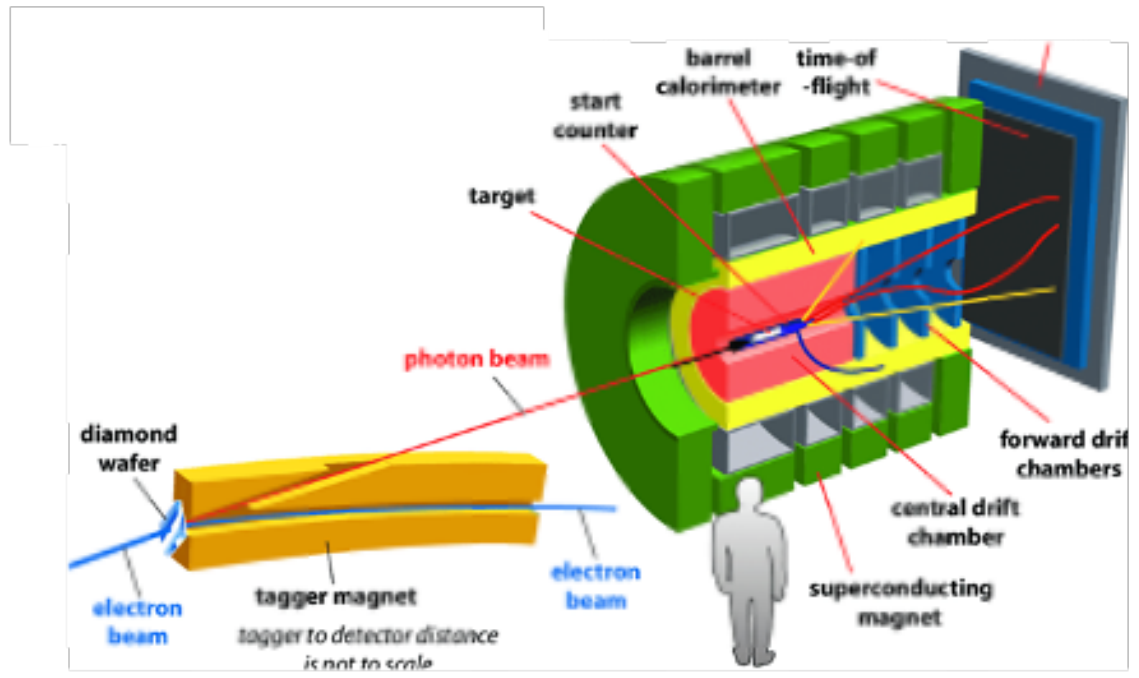
Probe Dependence of SRCs





CLAS12





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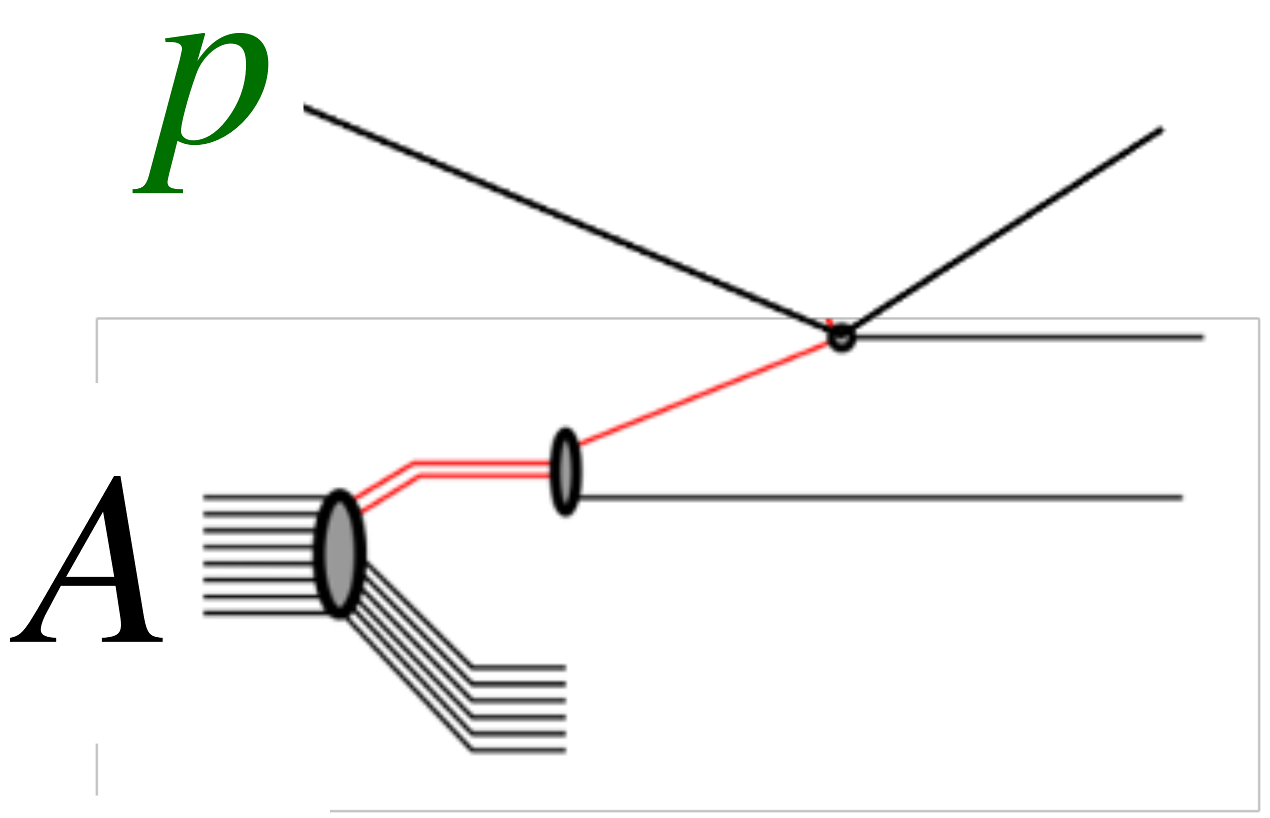
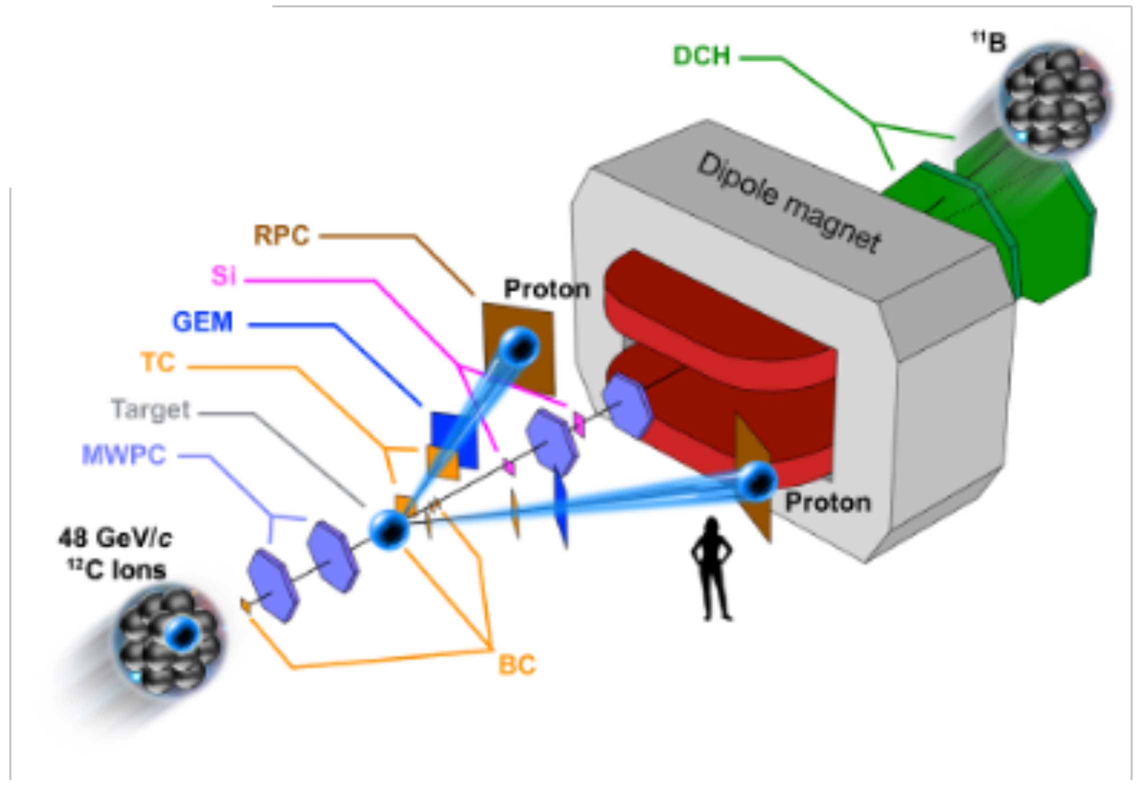
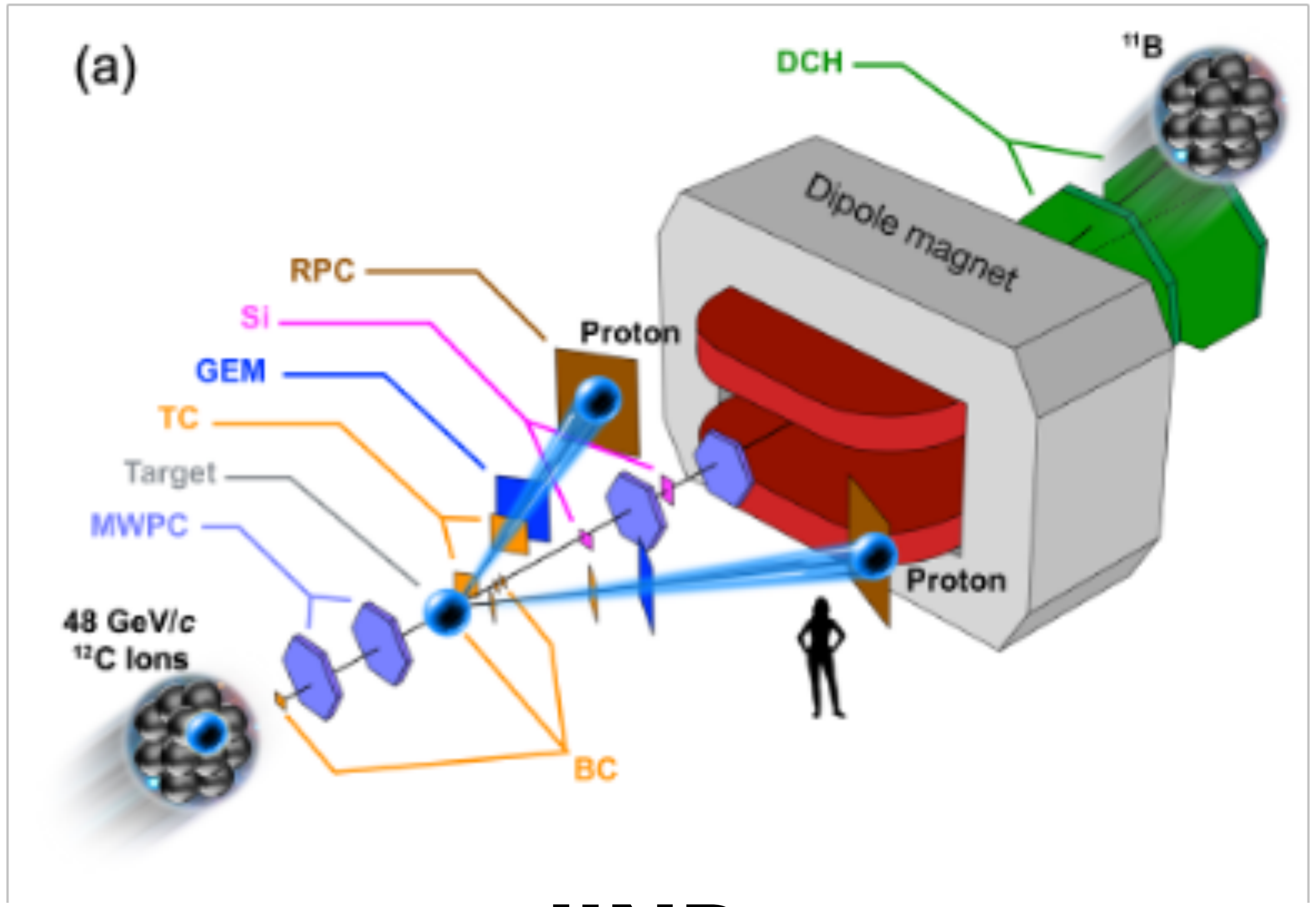




BM@N / R3B

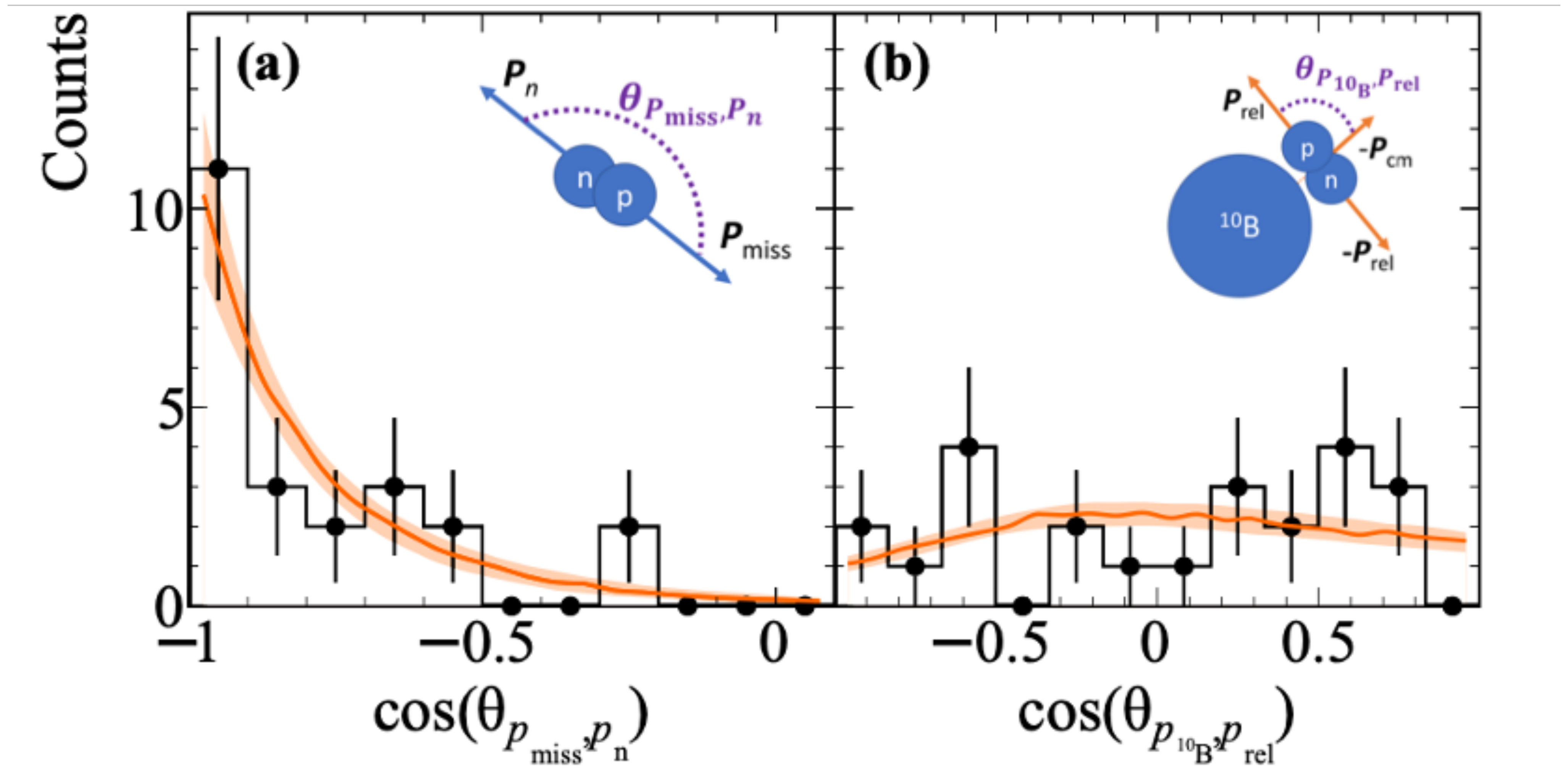
Hadron-scattering measurements of SRCs



JINR

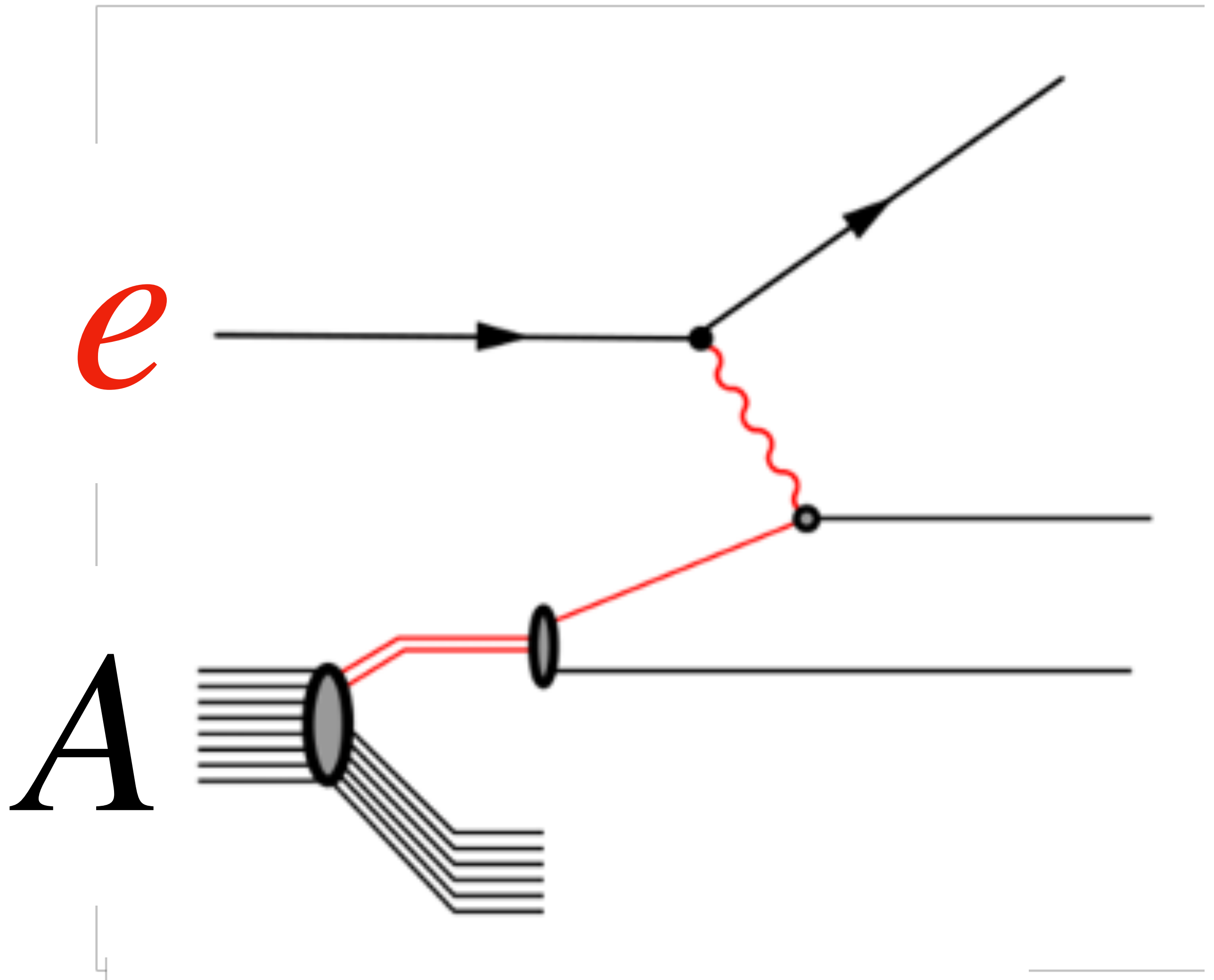
Inverse-kinematics → Fully-exclusive measurement of SRC breakup

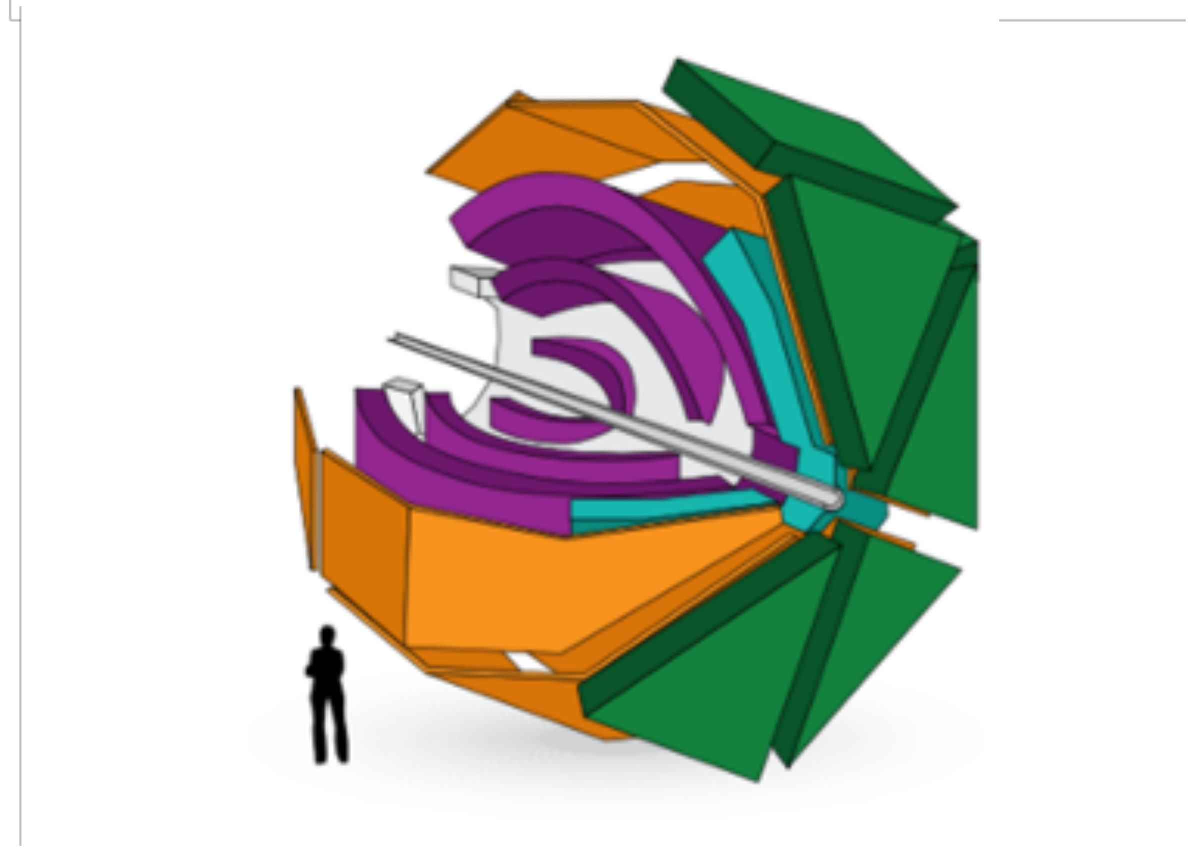
M. Patsyuk et al, Nature Physics (2021)



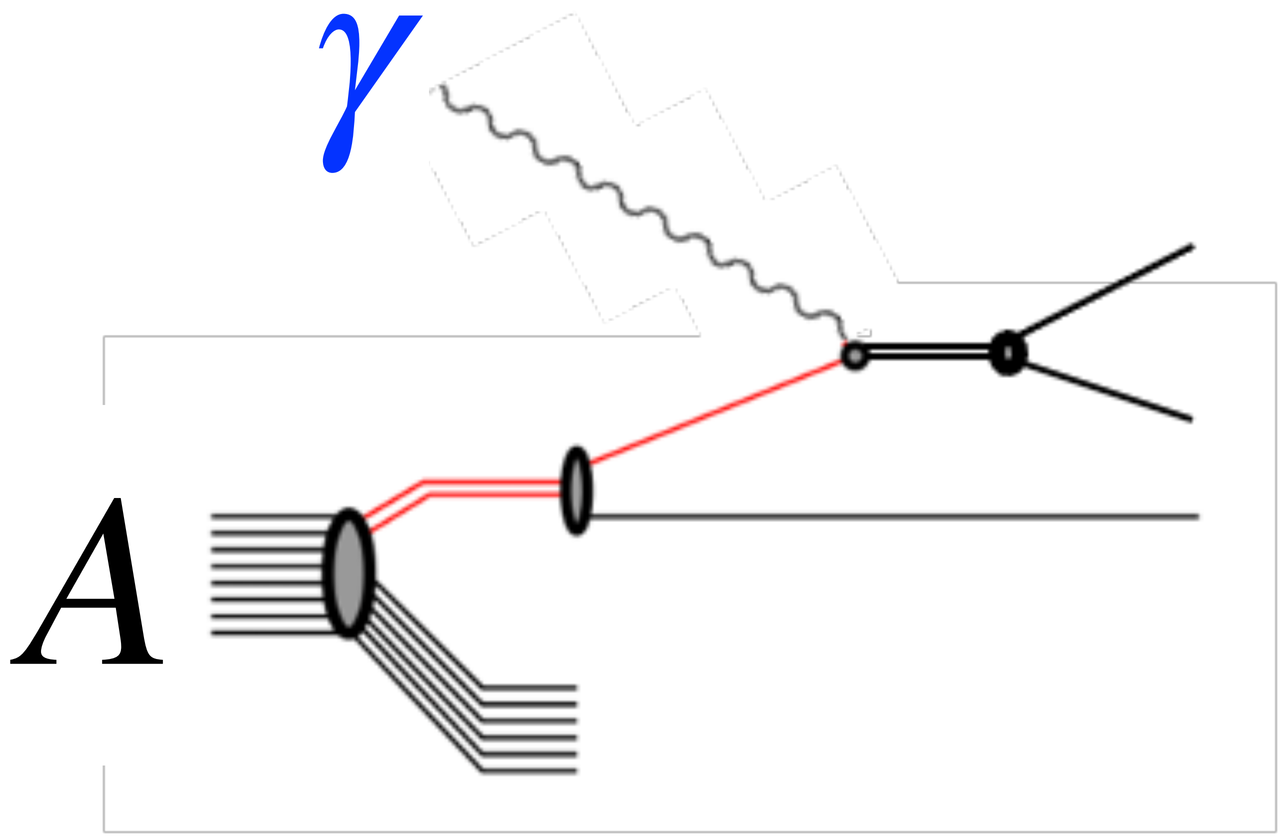
New data forthcoming from GSI

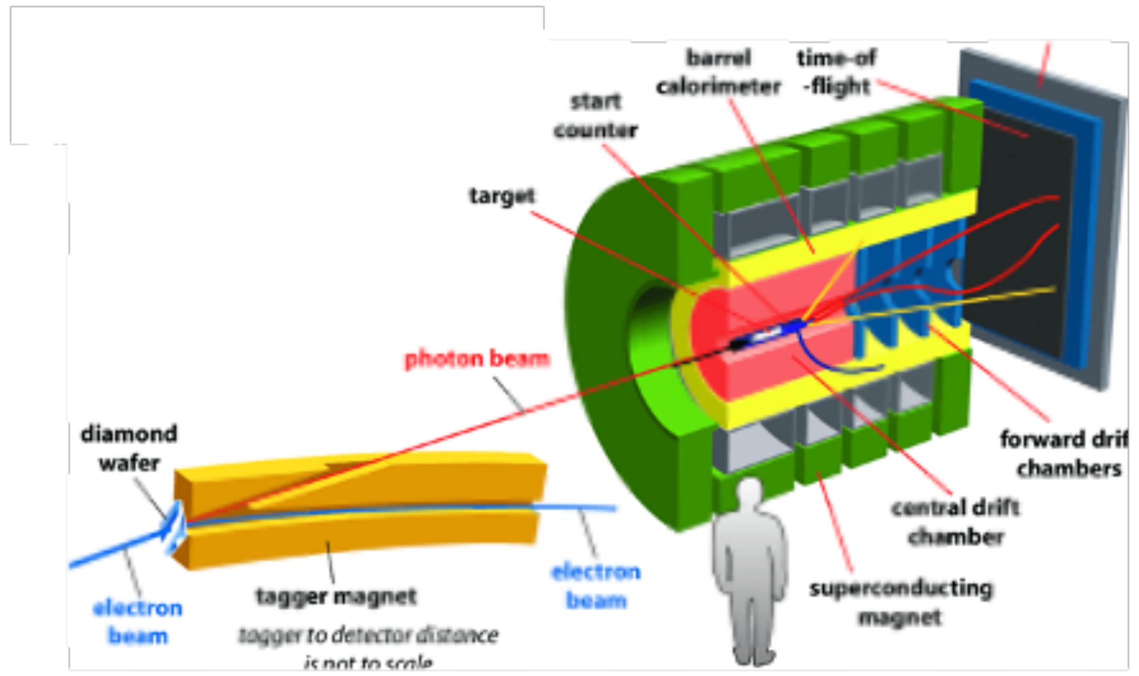
Probe Dependence of SRCs





CLAS12





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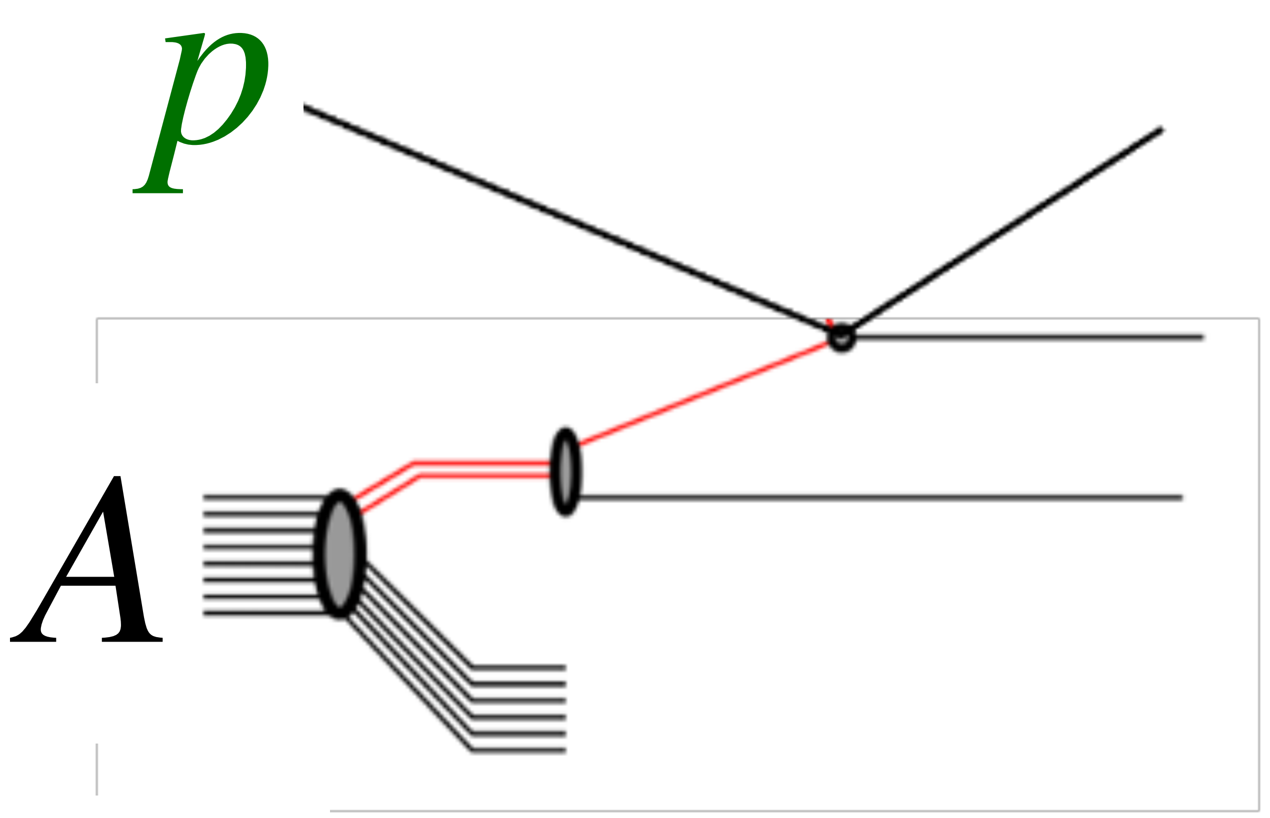
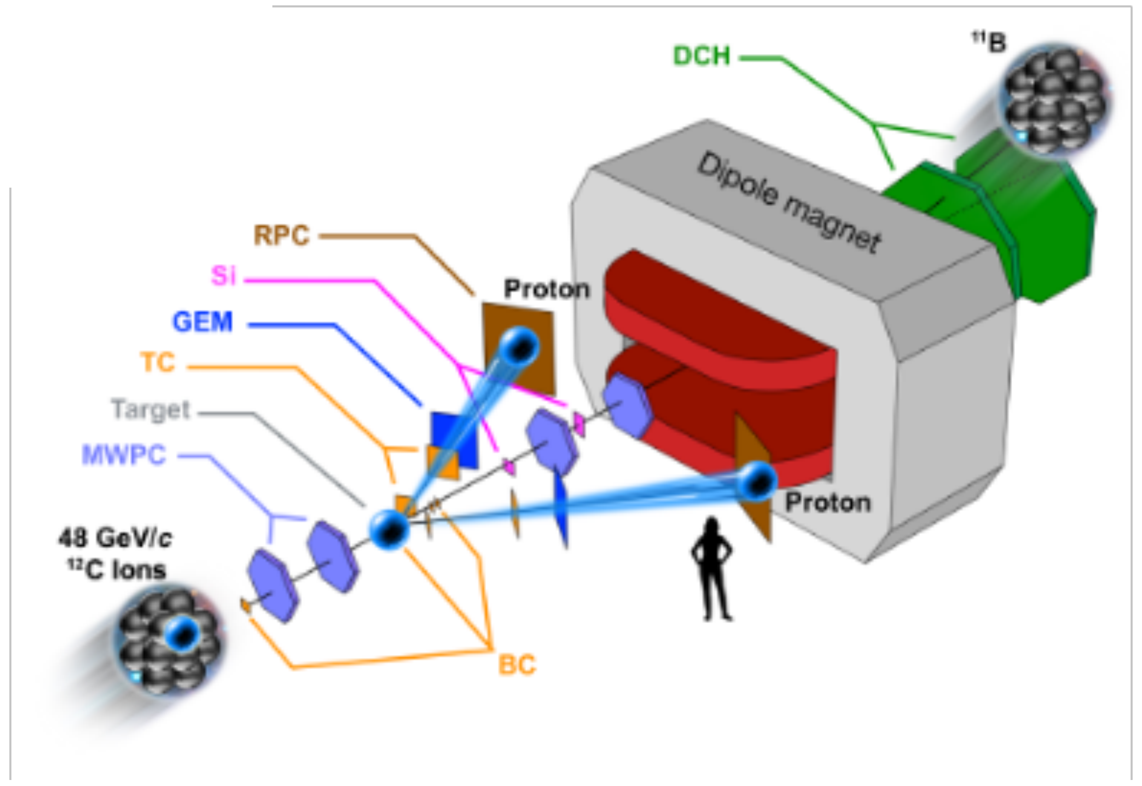
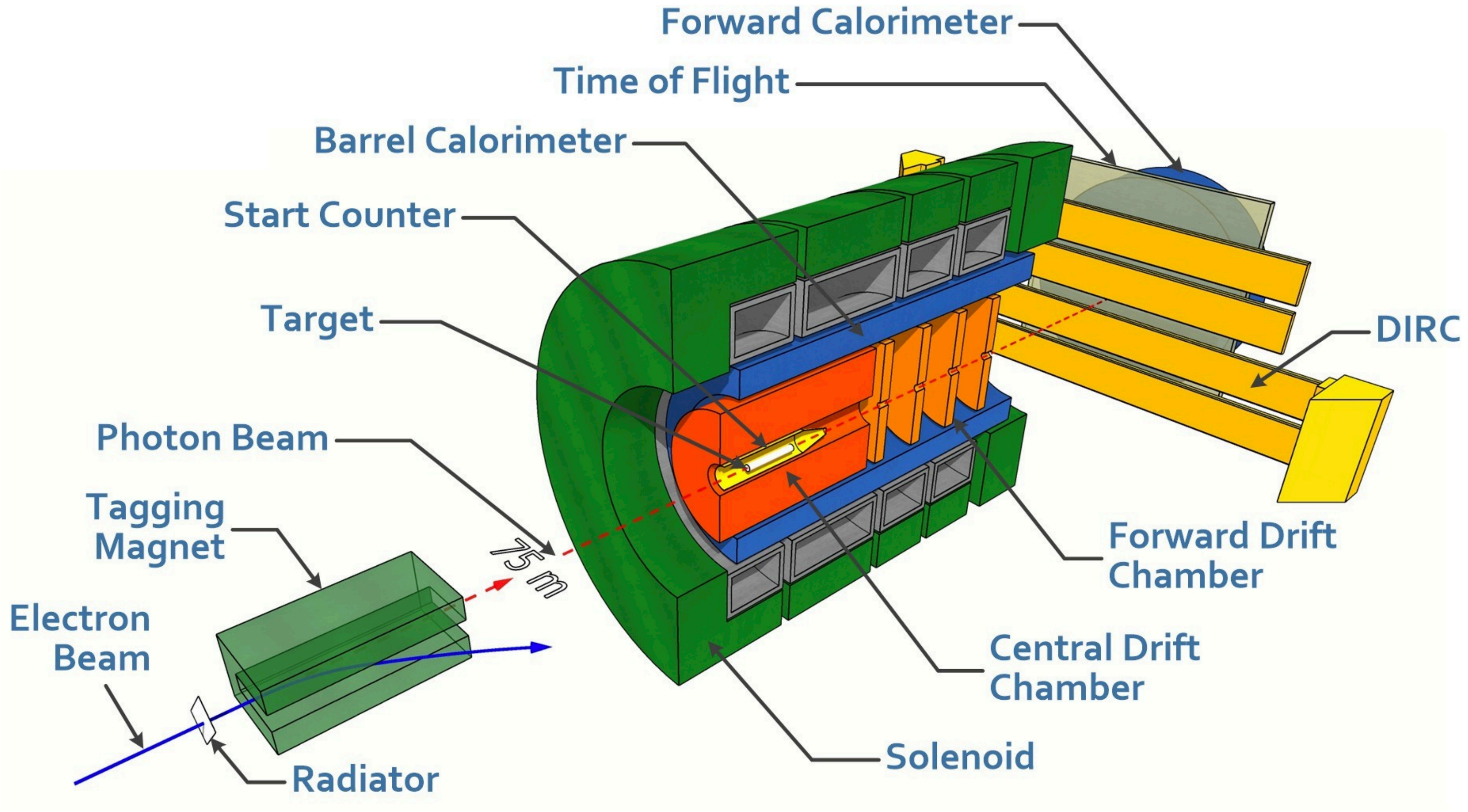


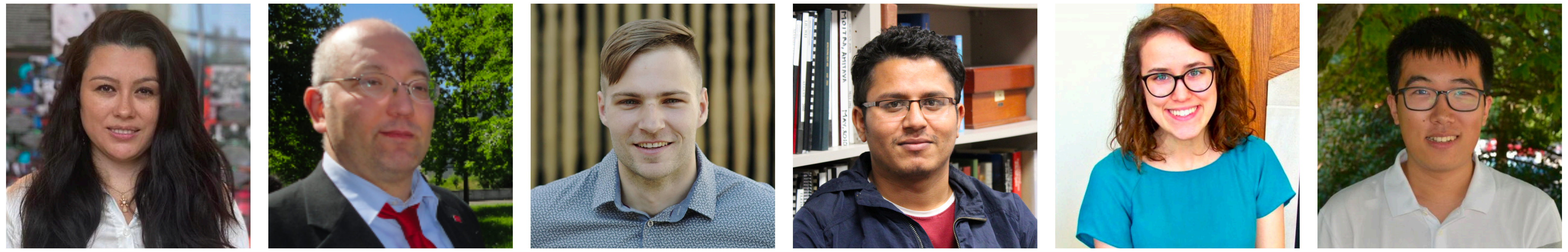


BM@N / R3B

SRC Photoproduction in Hall D



- At Jefferson Lab, Fall 2021
- 10.8 GeV e^- on diamond radiator
- E_γ from electron tagging
- GlueX spectrometer
- ^{2}H, ^{4}He, ^{12}C



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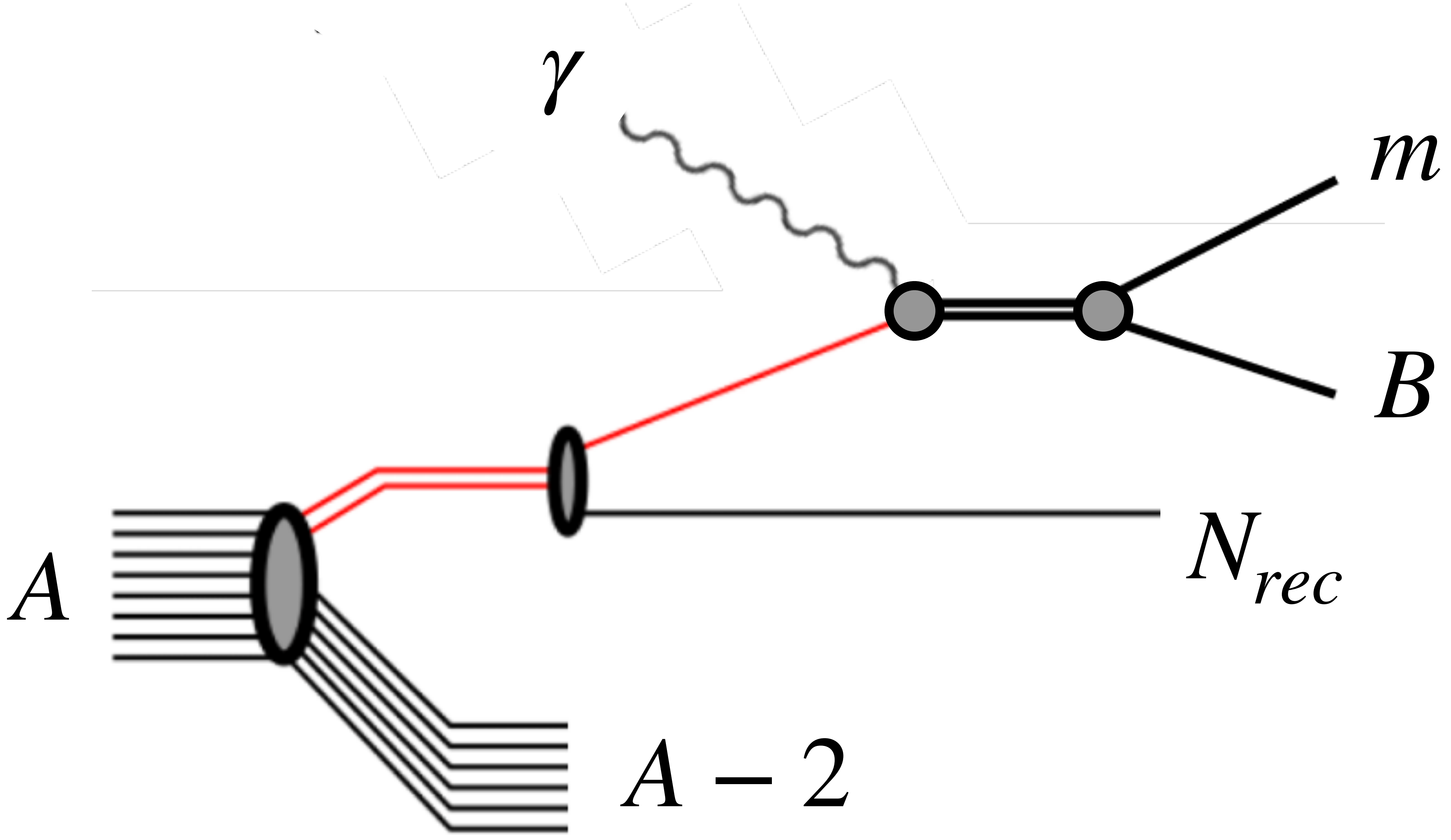
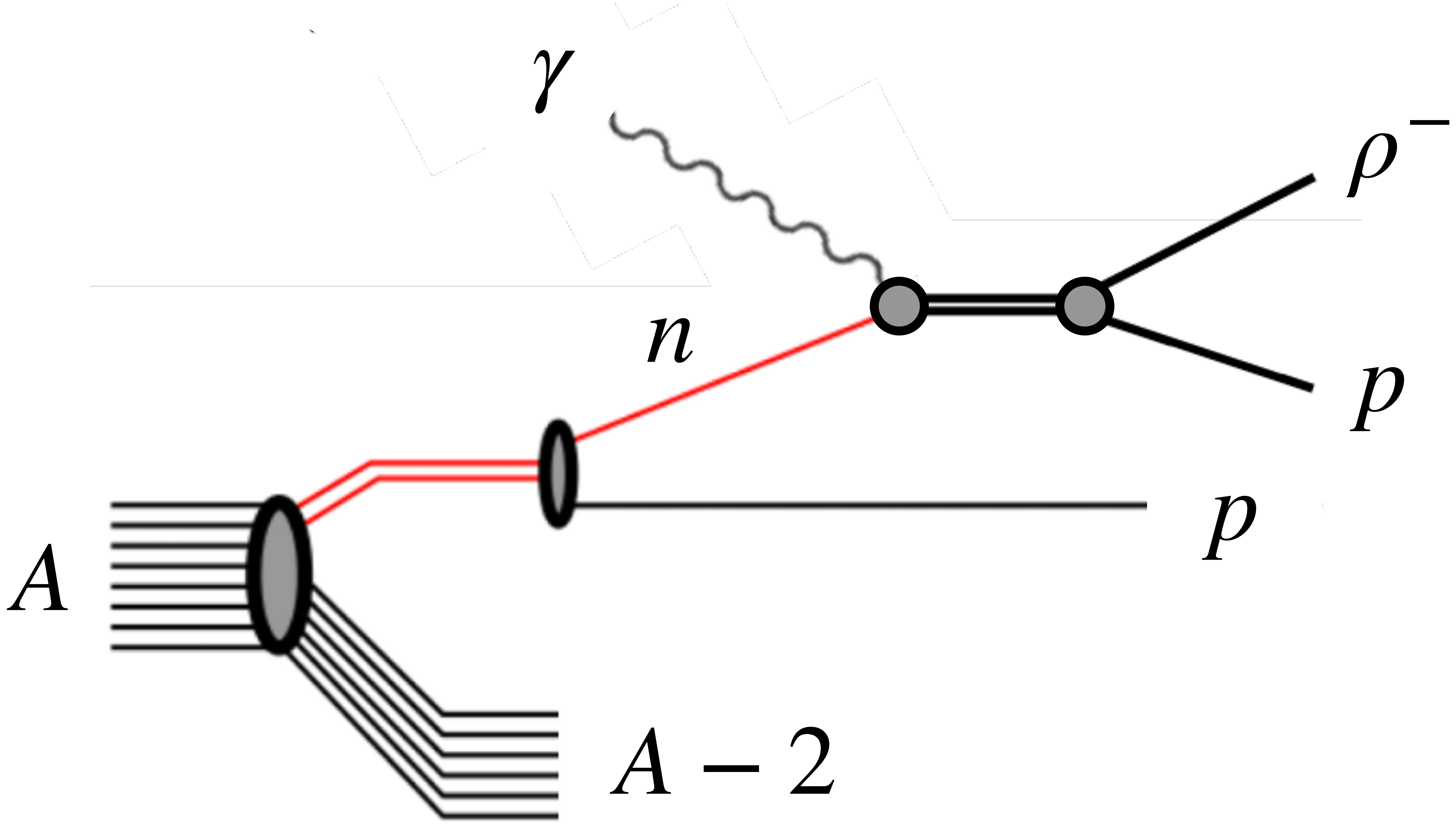
SRC Photoproduction in Hall D

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



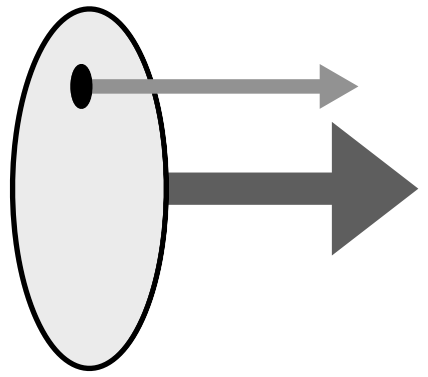
SRC Photoproduction in Hall D

- Quasi-elastic photoproduction: hard photon-nucleon interaction
- Many meson+baryon final-states are possible
- ρ^- photoproduction:
  - Initial-state neutron
  - Distinctive topology with $\rho^- \to \pi^-\pi^0$ decay
- Exclusive detection of $(\gamma, \rho^- pp)$



Analysis on the light-front

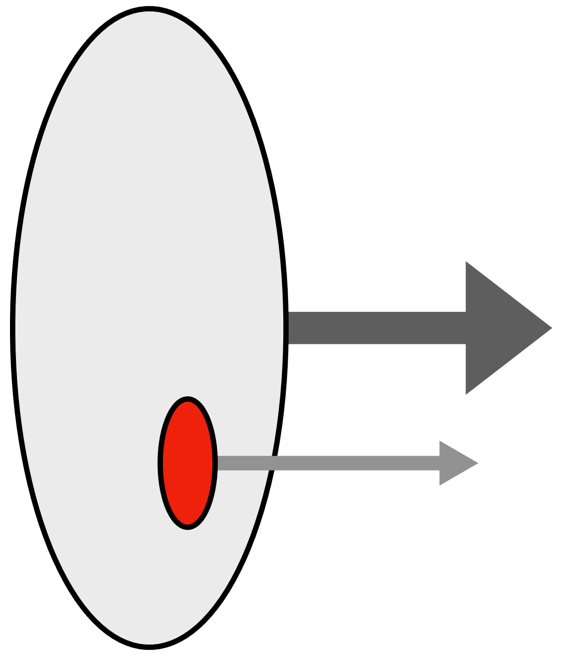
Parton in Hadron



Parton momentum fraction

$$x_B$$

Nucleon in Nucleus

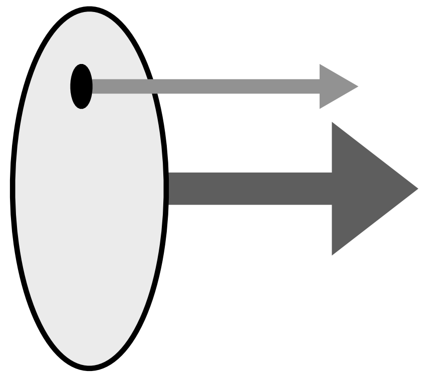


Nucleon momentum fraction

$$\alpha_N \equiv A \frac{E_N - p_N^z}{E_A - p_A^z}$$

Analysis on the light-front

Parton in Hadron

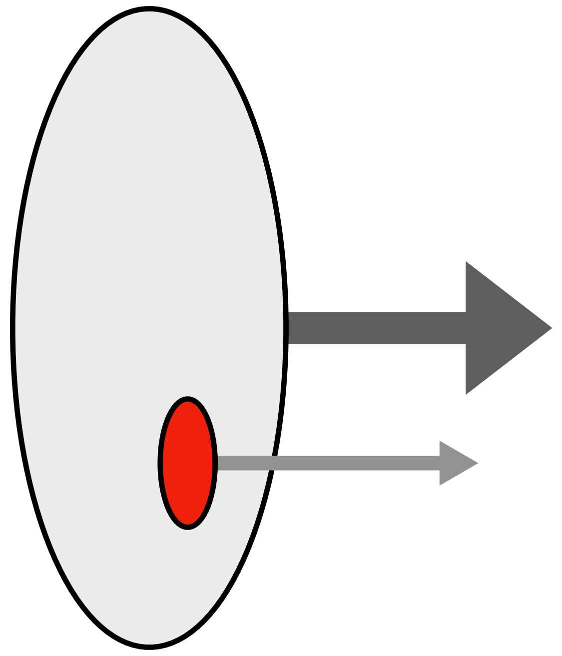


Parton momentum fraction

x_B

Light-front variables mitigate resolution effects

Nucleon in Nucleus



Nucleon momentum fraction

$$\alpha_N \equiv A \frac{E_N - p_N^z}{E_A - p_A^z}$$

Low-momentum nucleon

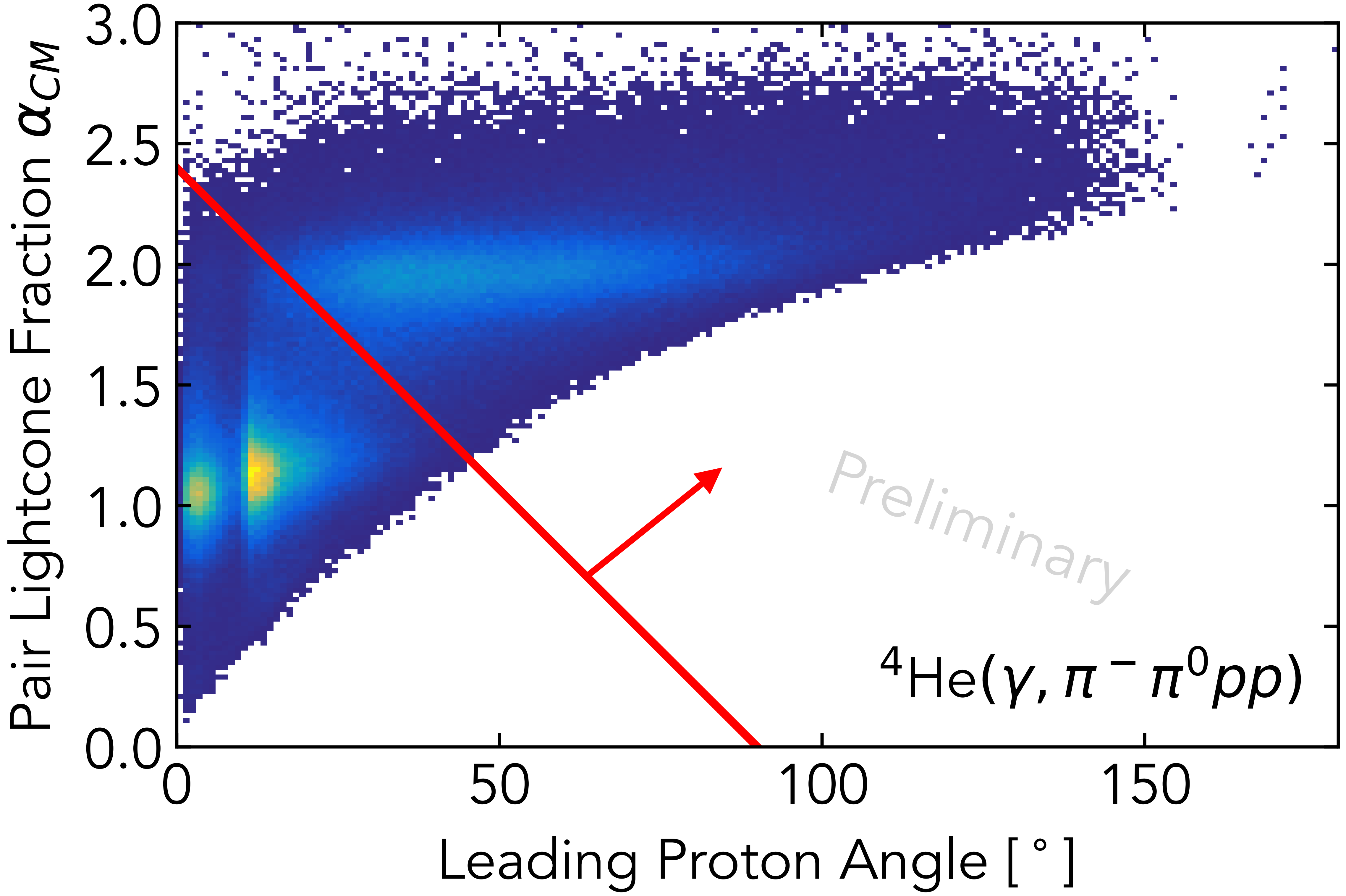
$\alpha_N \sim 1$

Standing nucleon pair

$\alpha_1 + \alpha_2 \equiv \alpha_{CM} \sim 2$

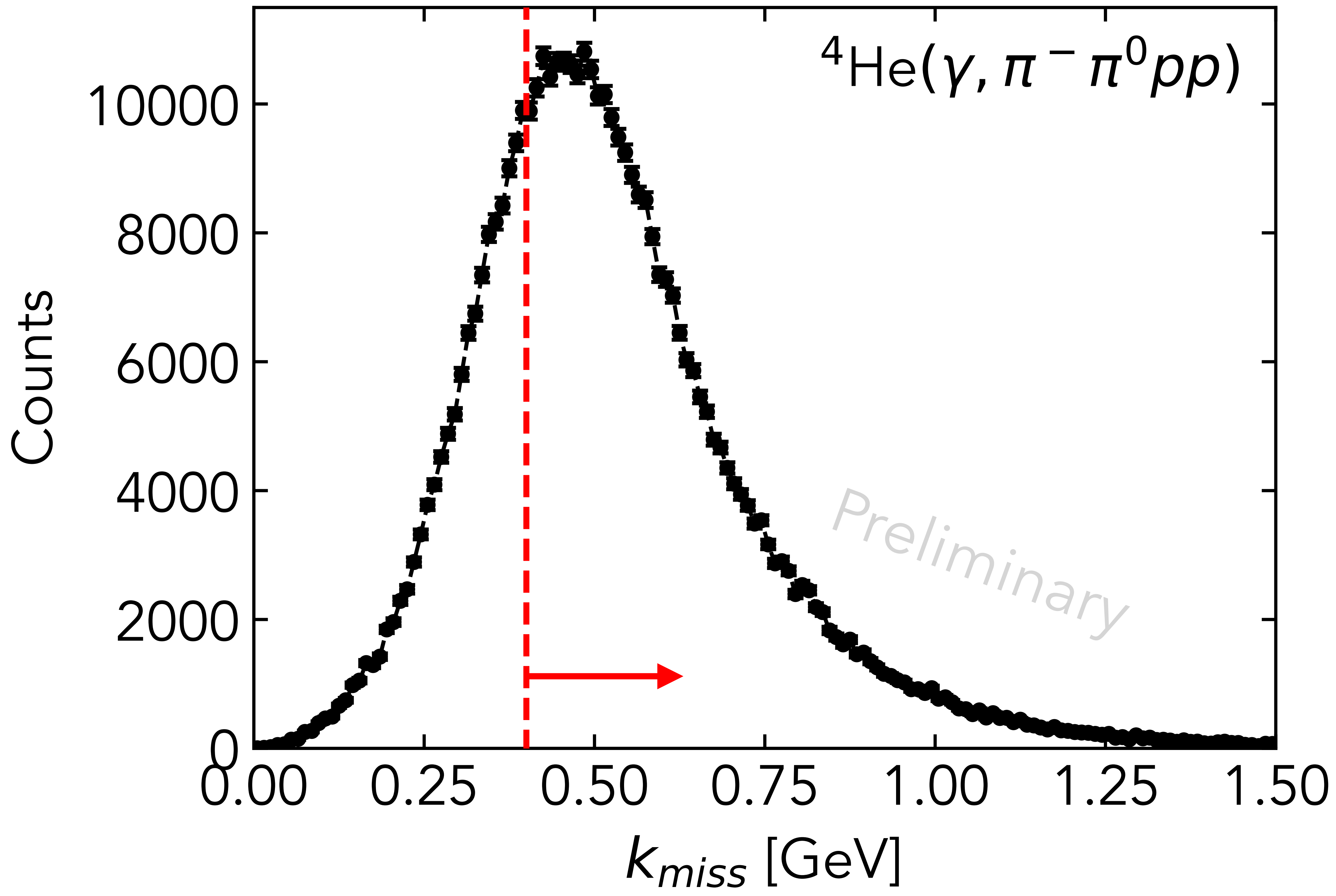
SRC Event Selection

- Diffractive background cut



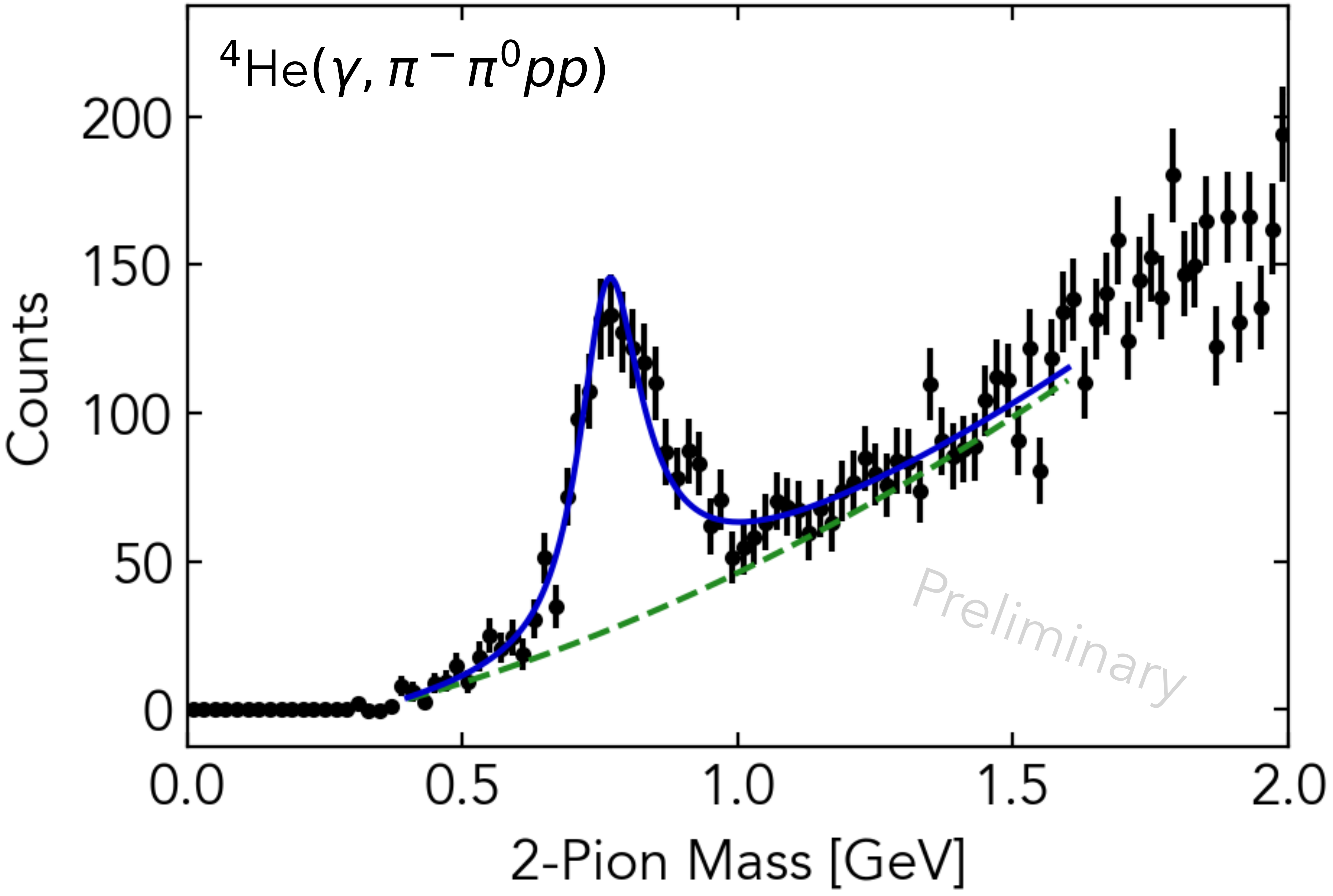
SRC Event Selection

- Diffractive background cut
- High relative momentum cut



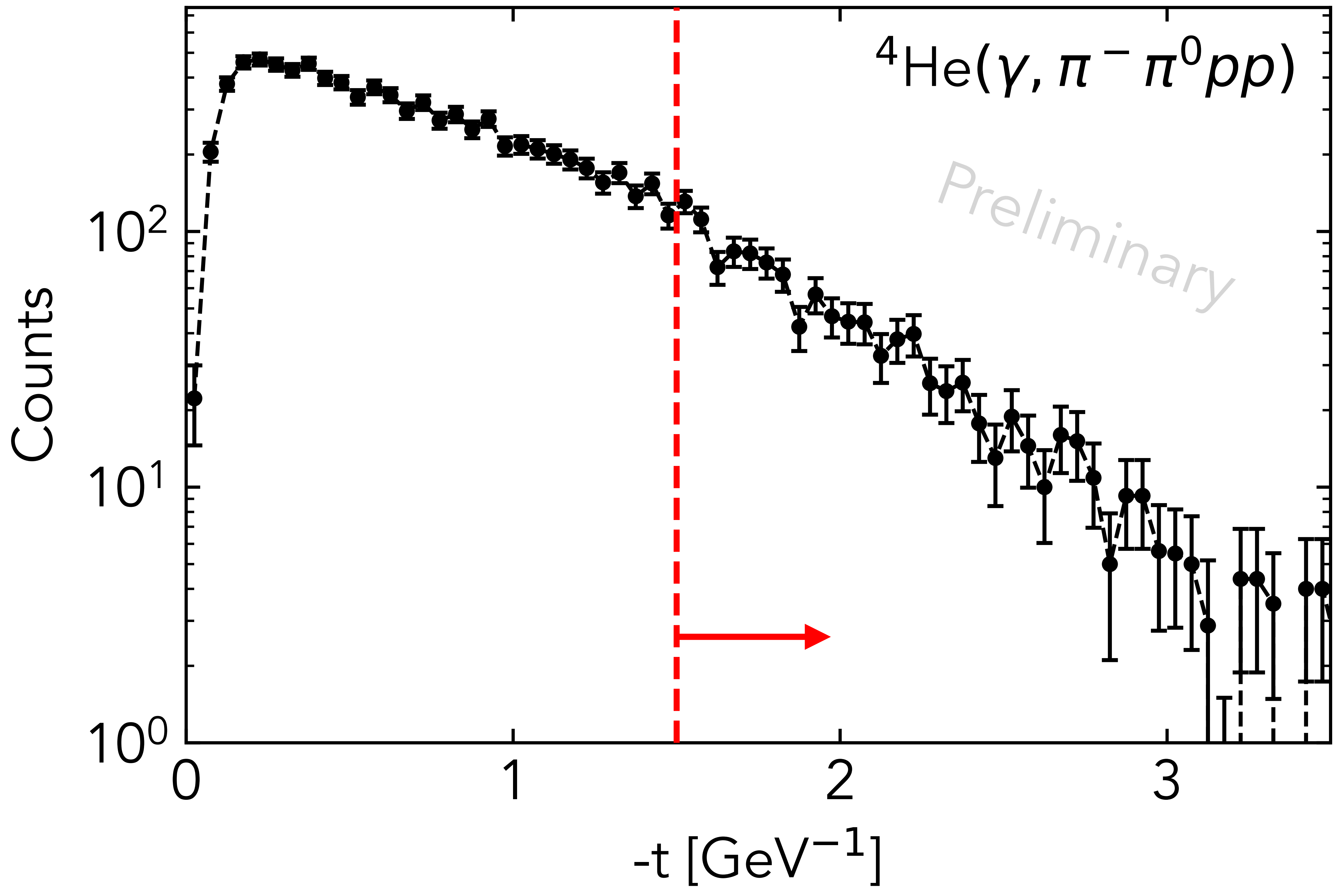
SRC Event Selection

- Diffractive background cut
- High relative momentum cut
- Cut on rho meson mass



SRC Event Selection

- Diffractive background cut
- High relative momentum cut
- Cut on rho meson mass
- $|t|, |u| > 1.5$ GeV^2



SRC Event Selection

- Diffractive background cut
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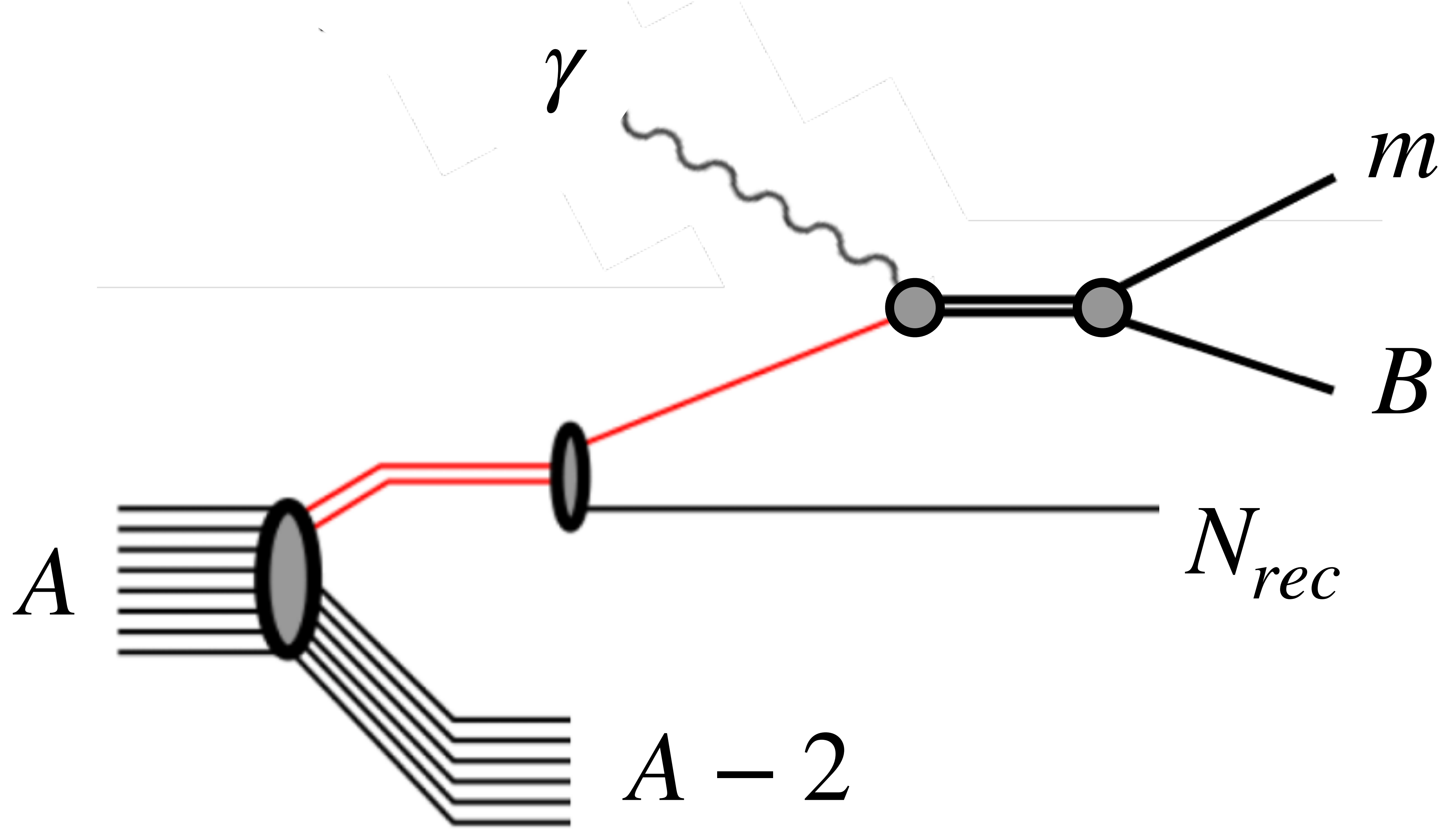
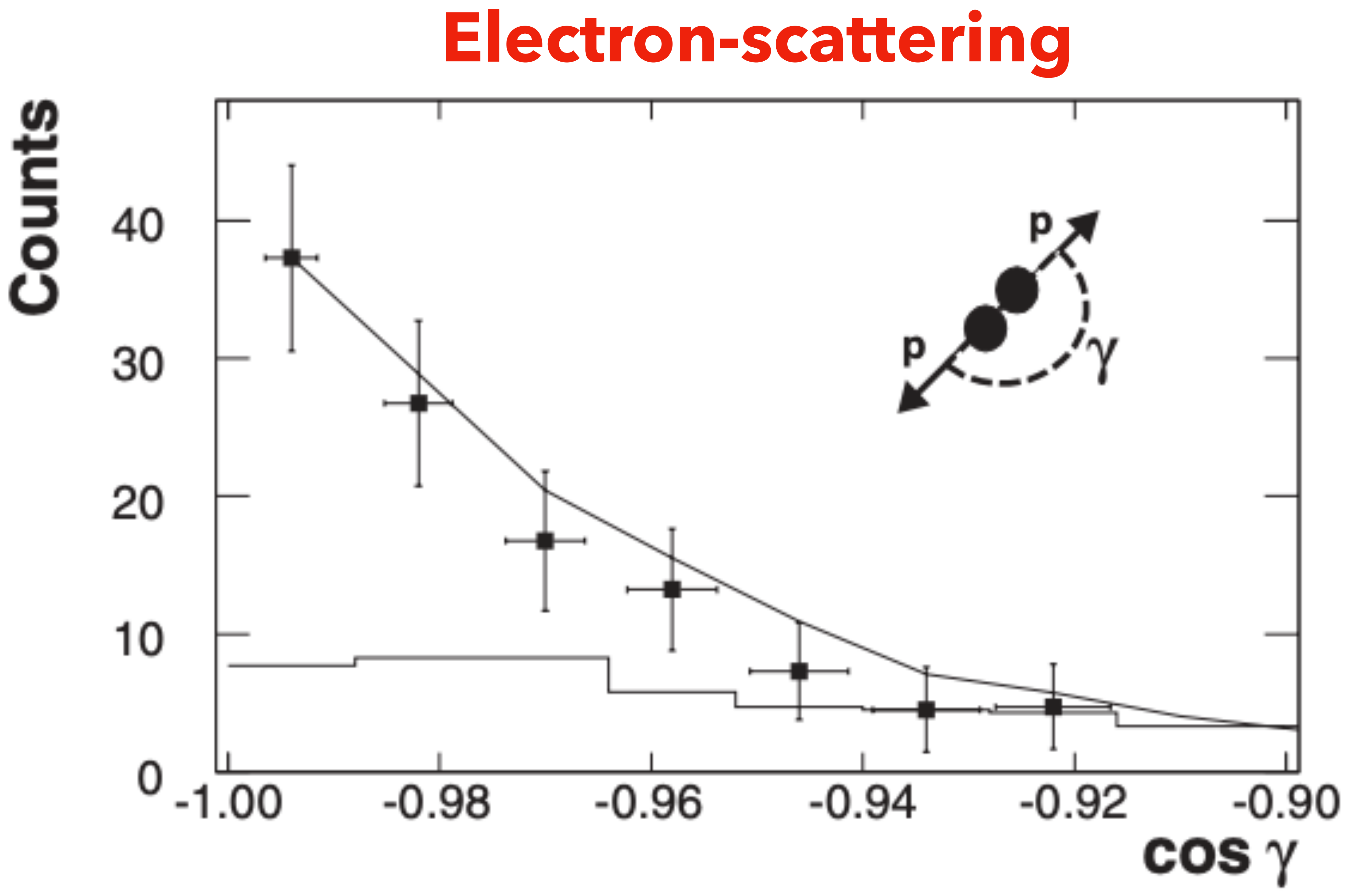
- Cut on rho meson mass
- $|t|, |u| > 1.5$ GeV^2
- **Compare with PWIA+GCF calculations**



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

A. Schmidt et al, Nature (2020)
J. R. Pybus et al, PLB (2020)
I. Korover et al, PLB (2021)

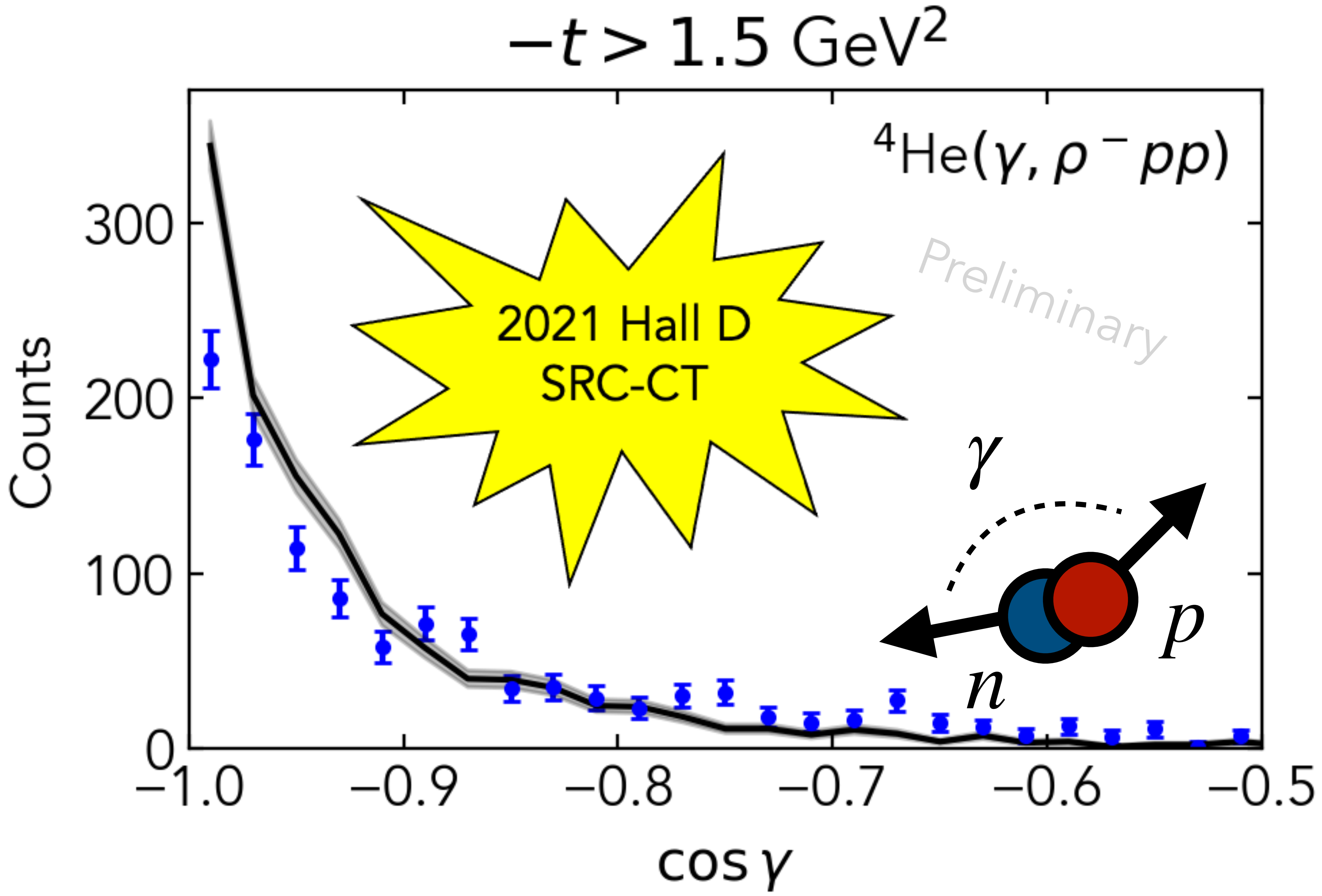
First observation of SRCs in photoproduction

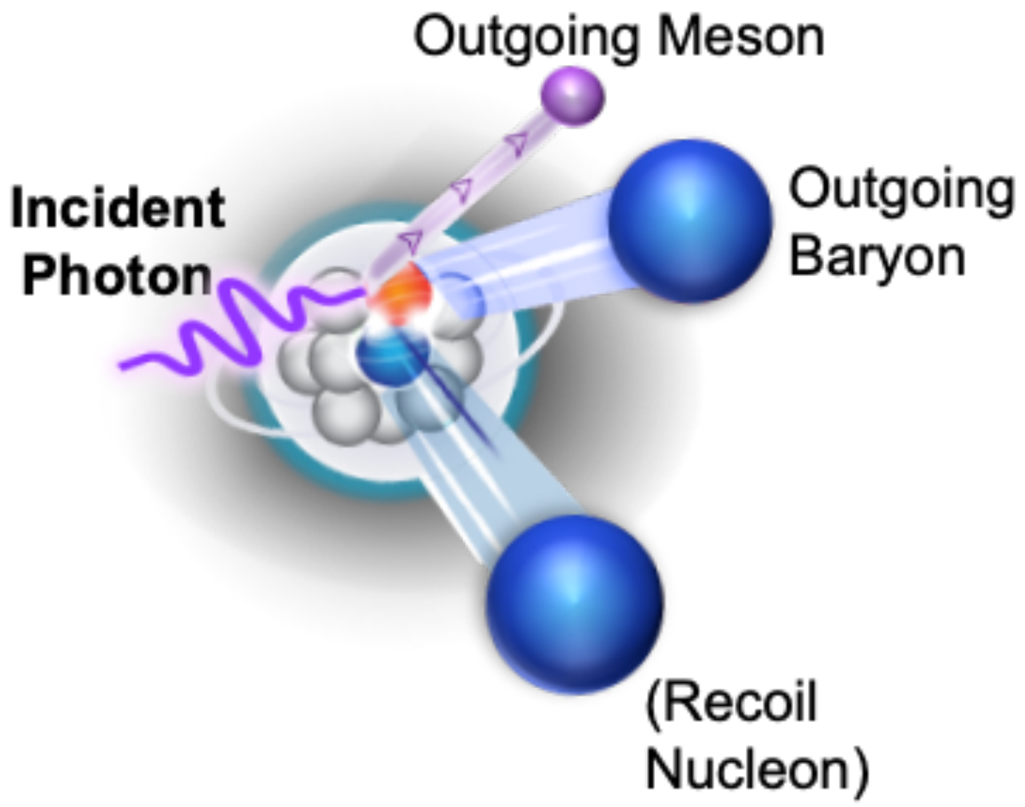


PRL 2007

Back-to-back correlation in

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

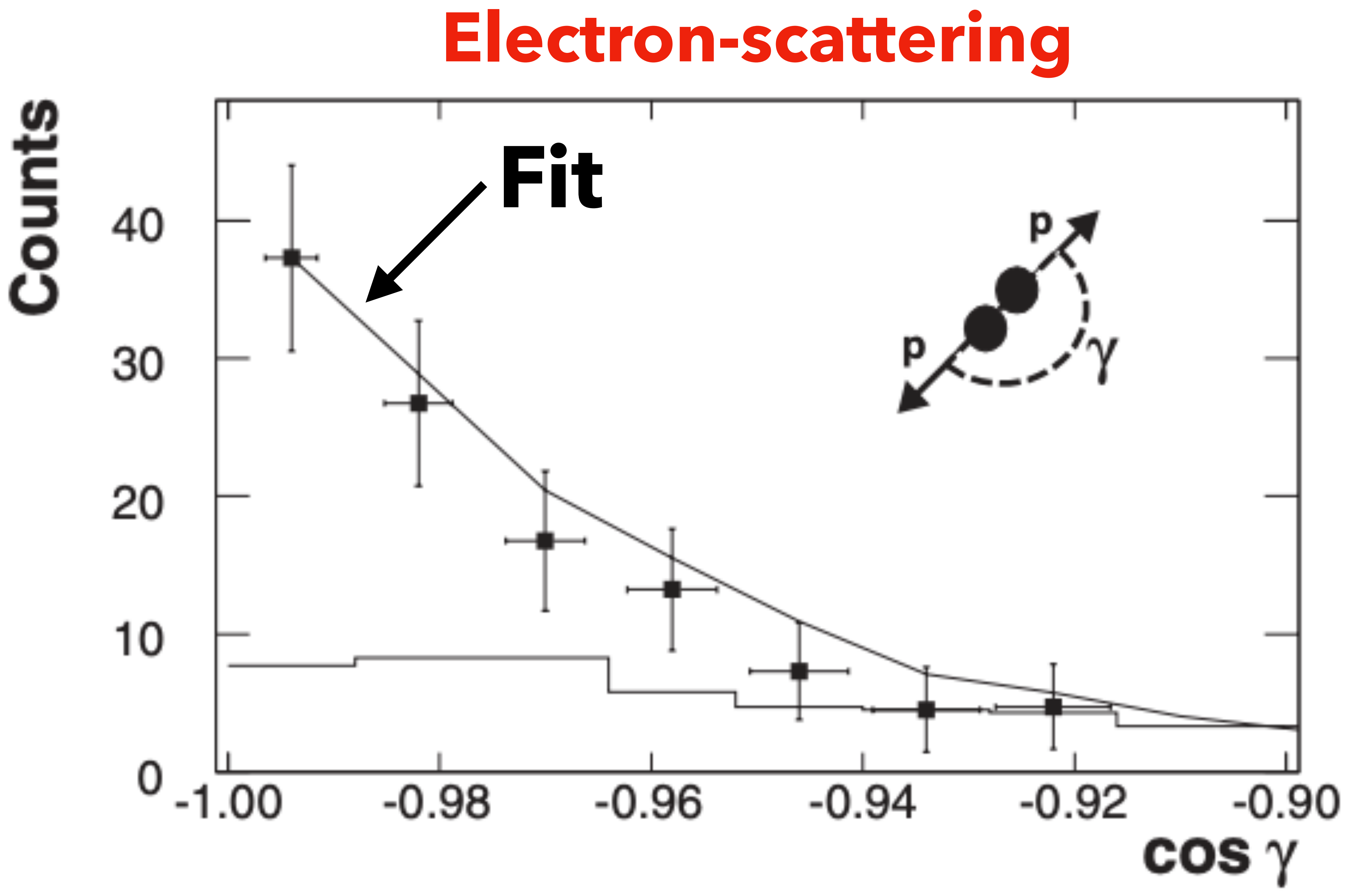




$\gamma np \to \rho^- pp$

@ Hall D

First observation of SRCs in photoproduction



PRL 2007

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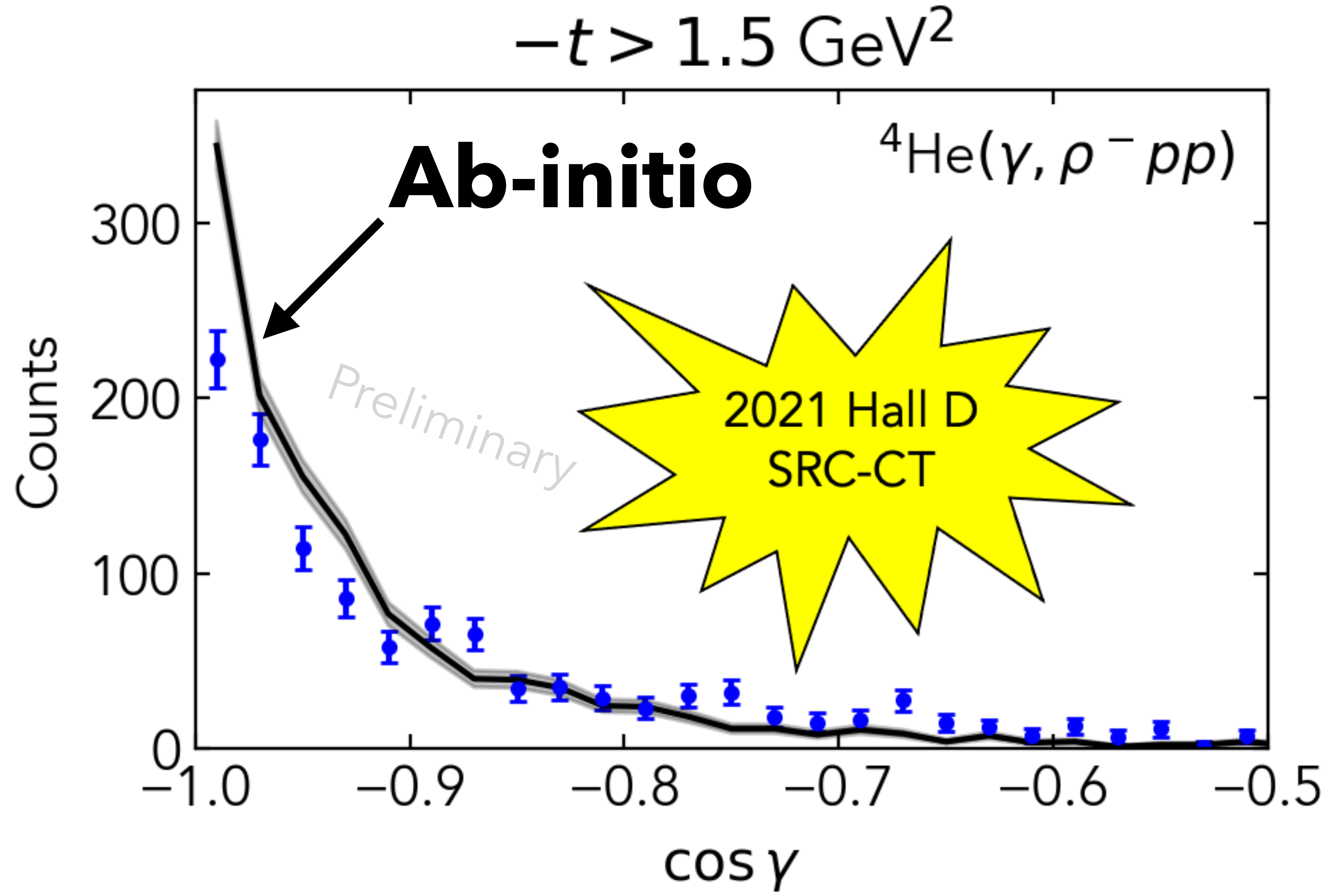
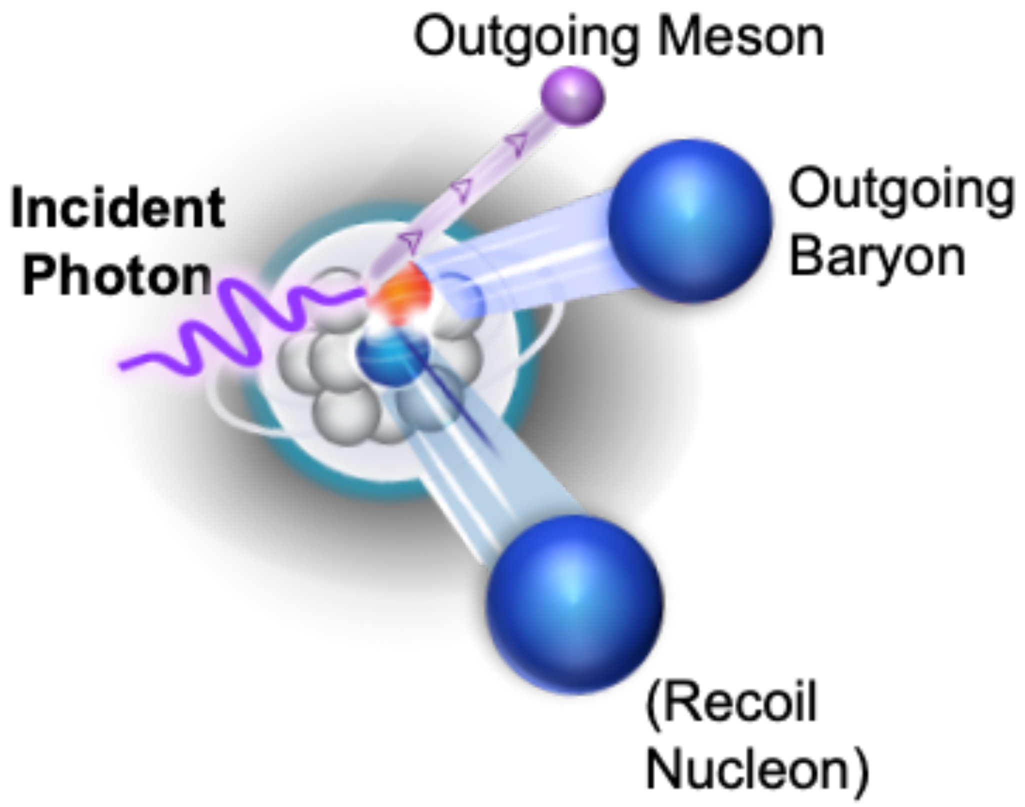


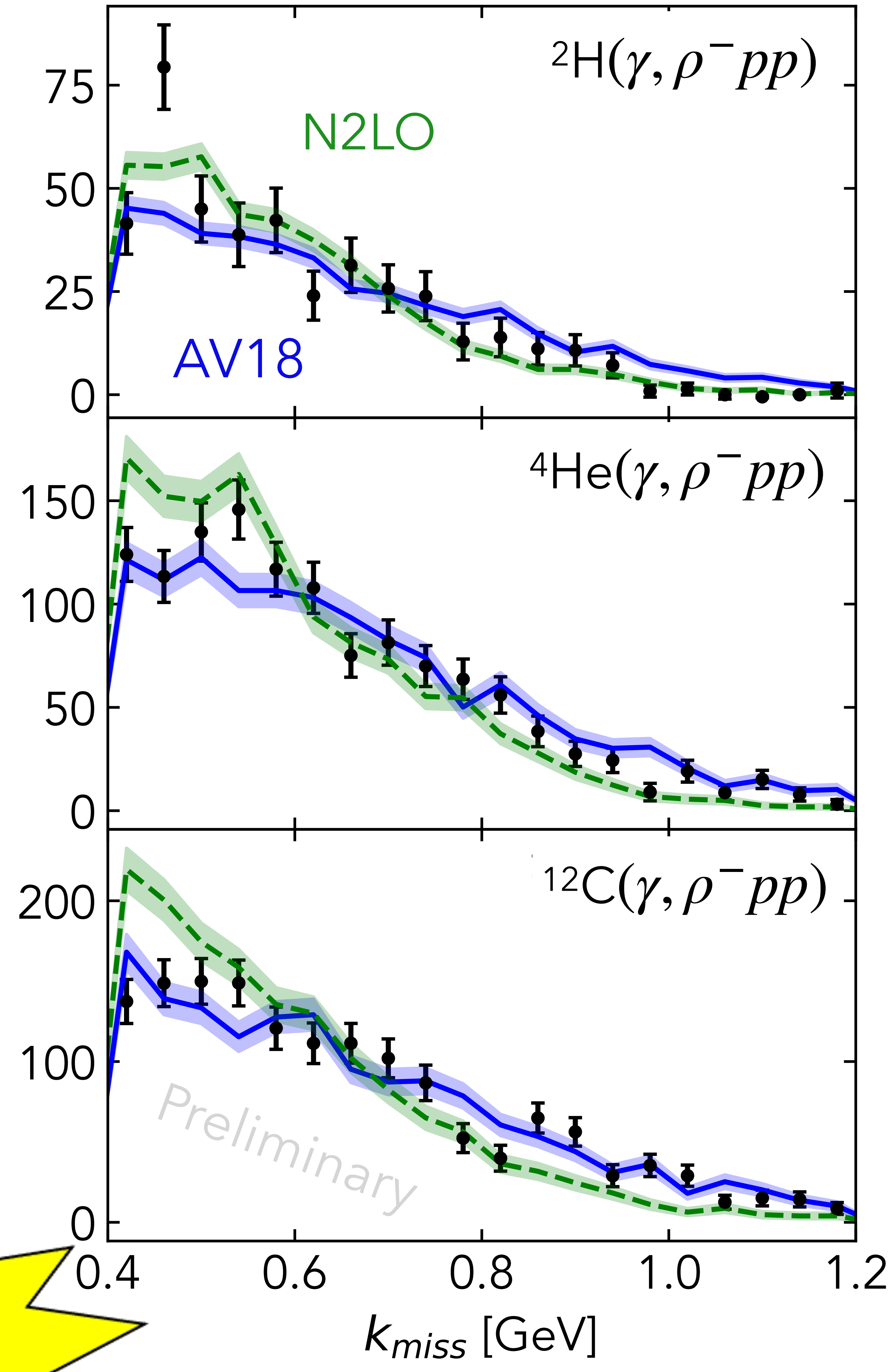


$\gamma np \rightarrow \rho^- pp$

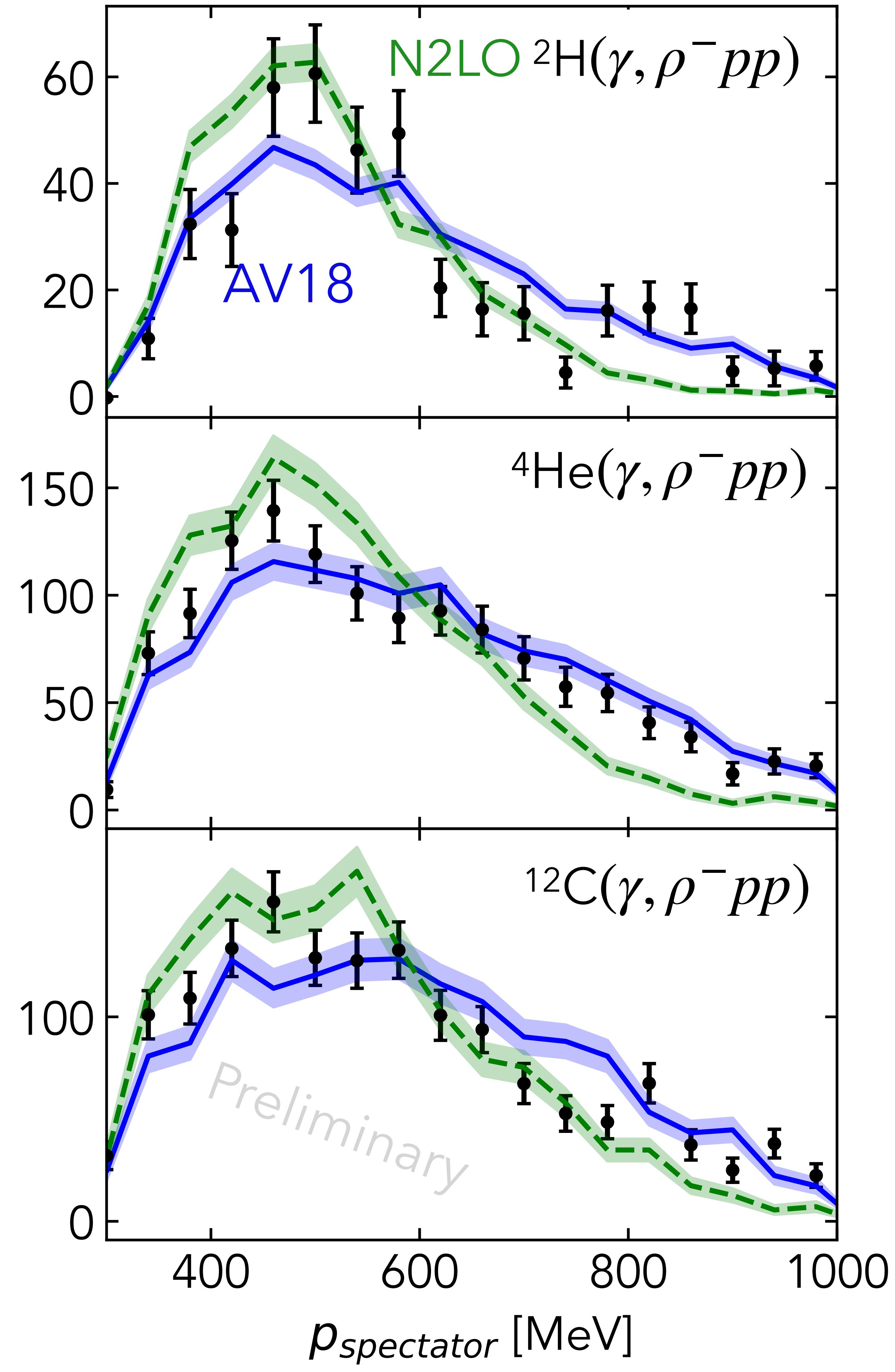
@ Hall D

Data can constrain ab-initio theory at high momentum

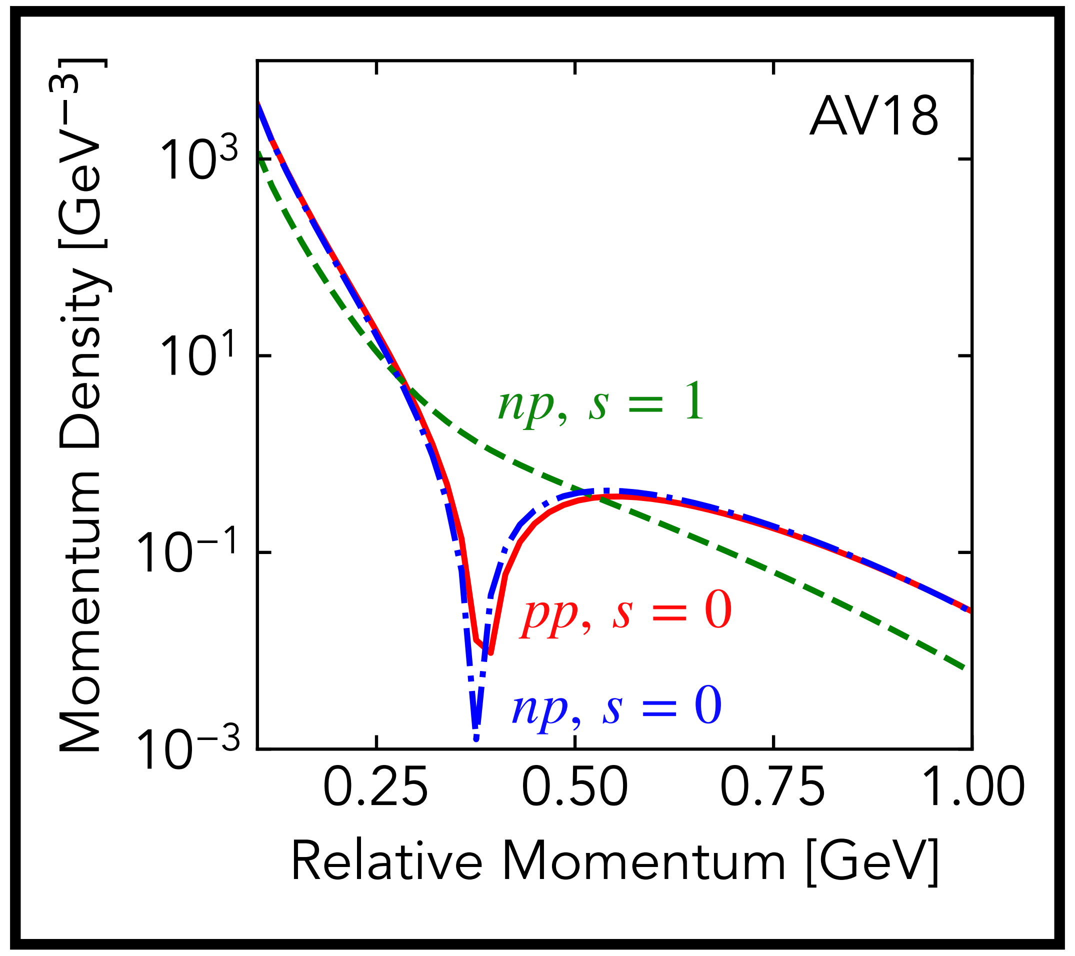
Initial Neutron Momentum



Recoil Proton Momentum

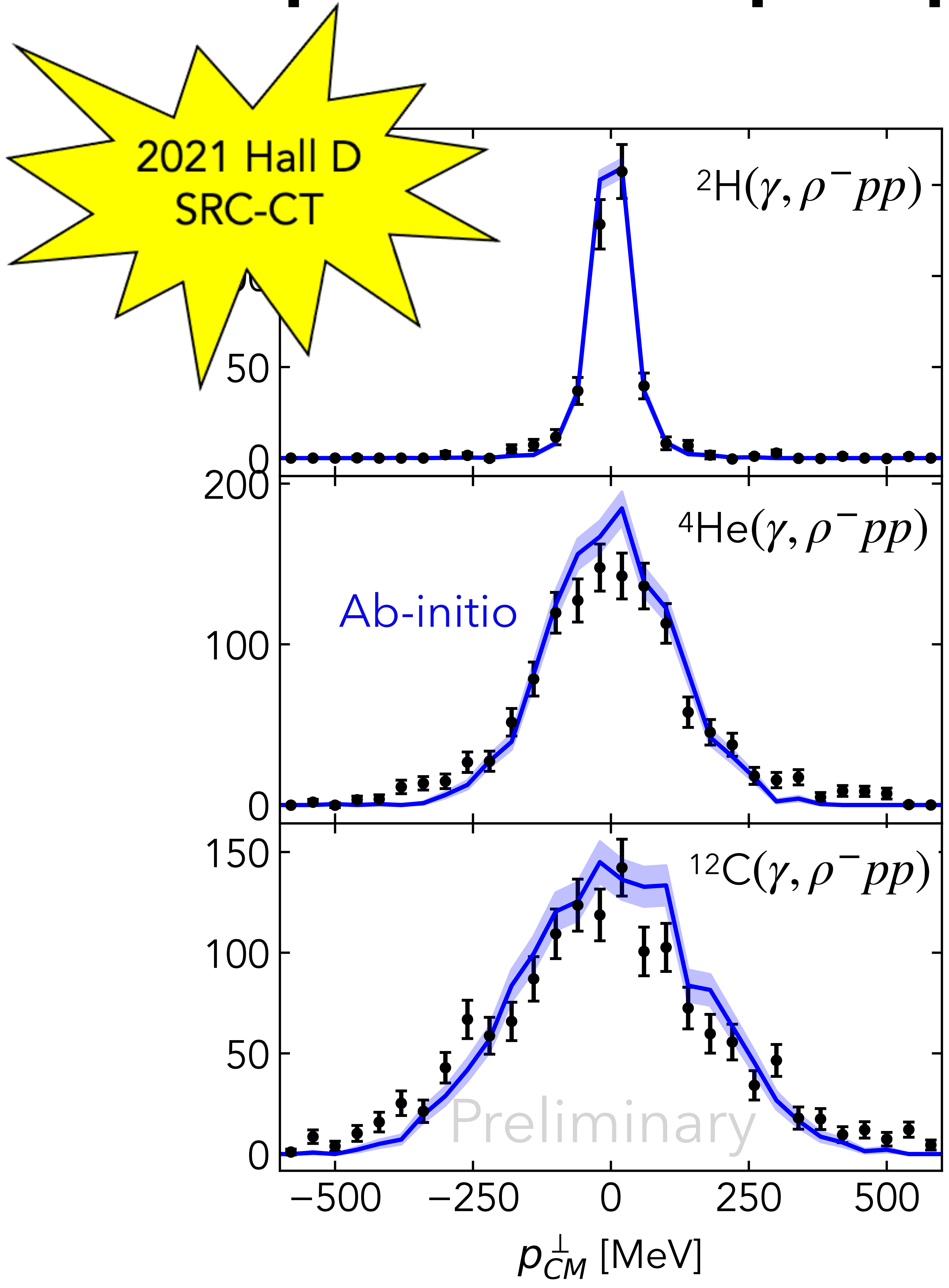


NN Interaction



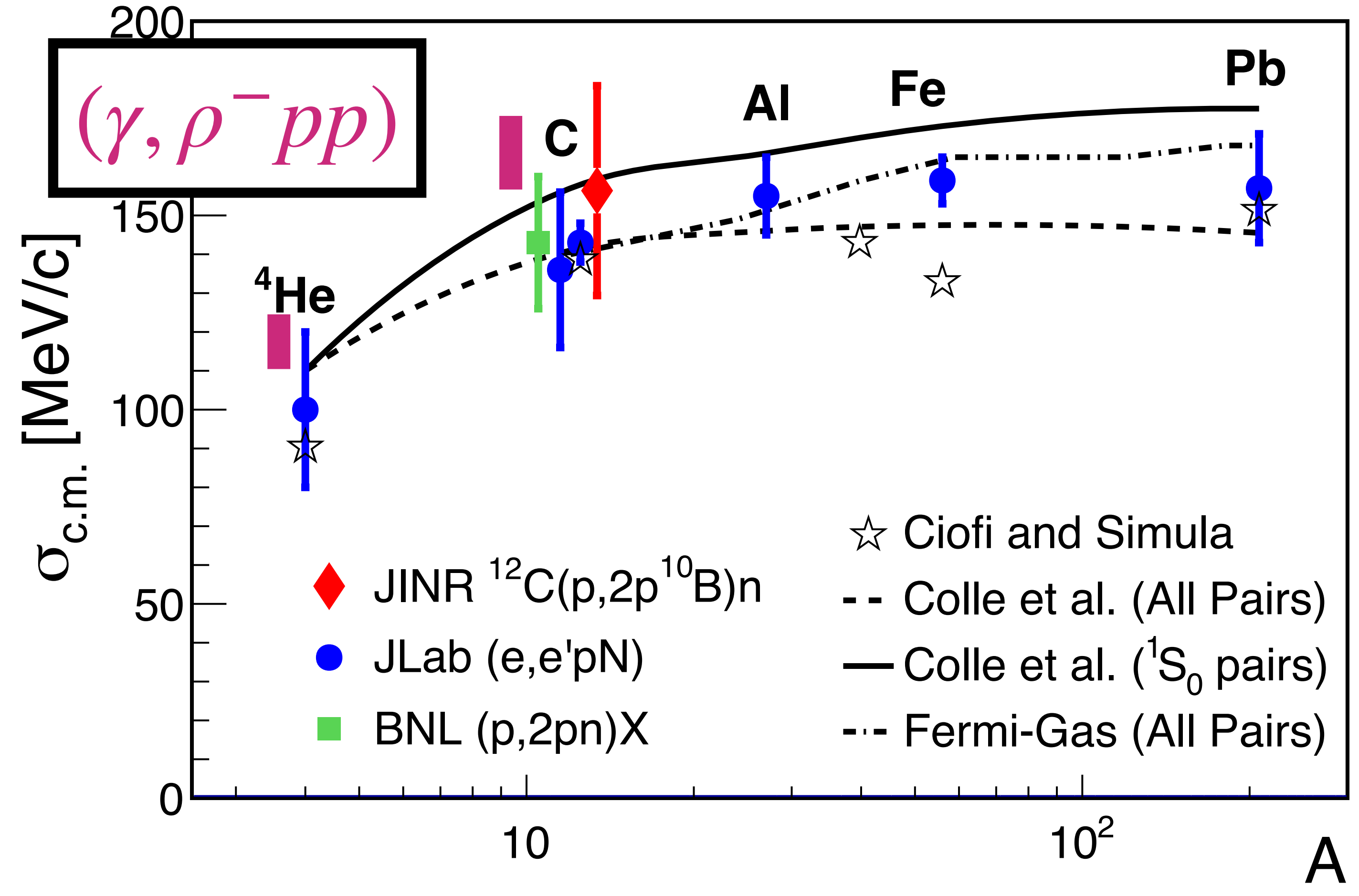
2021 Hall D
SRC-CT

A-dependent properties of SRCs also established

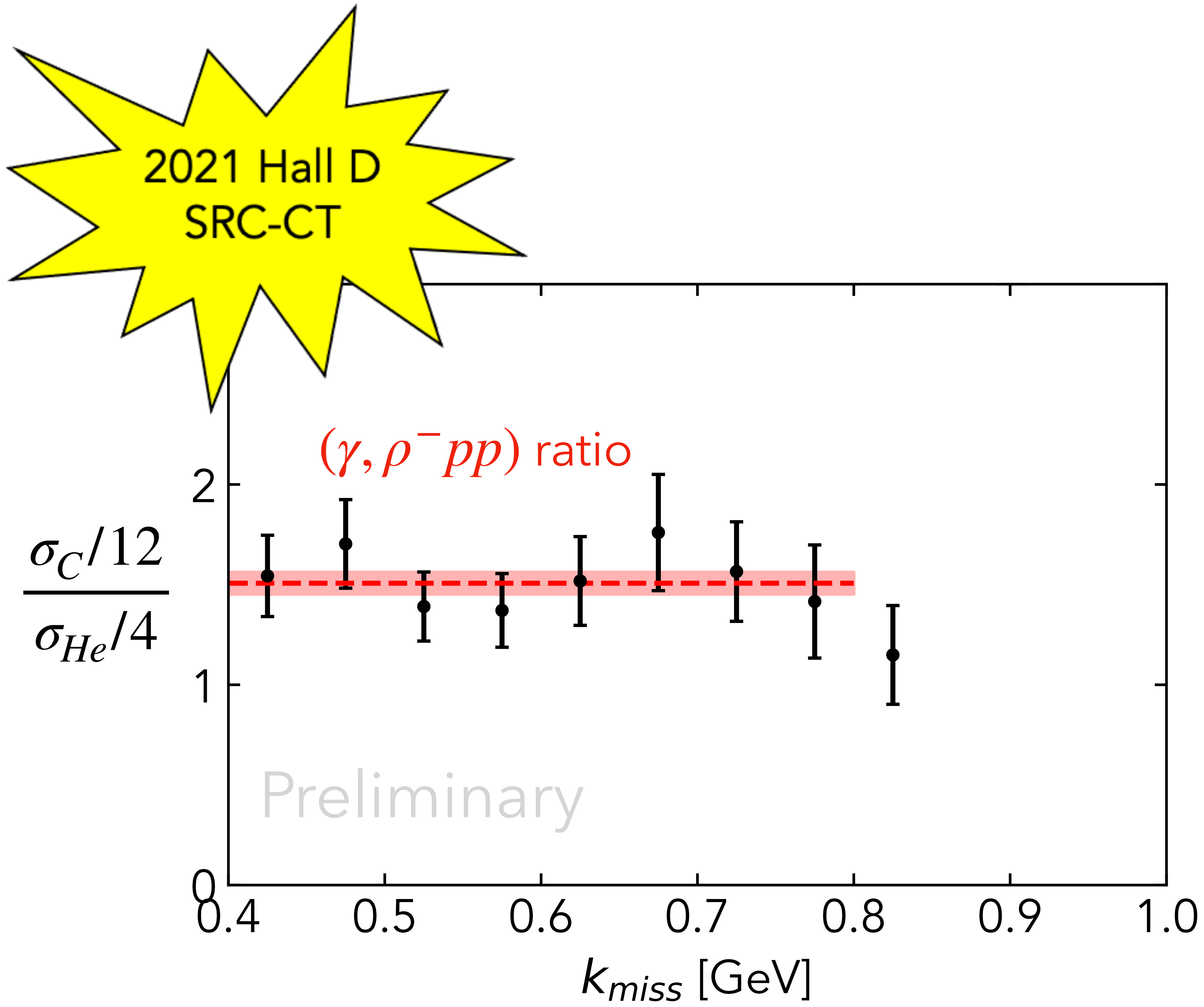


- Center-of-mass behavior of pairs

PRL (2018)
Nature Physics (2021)

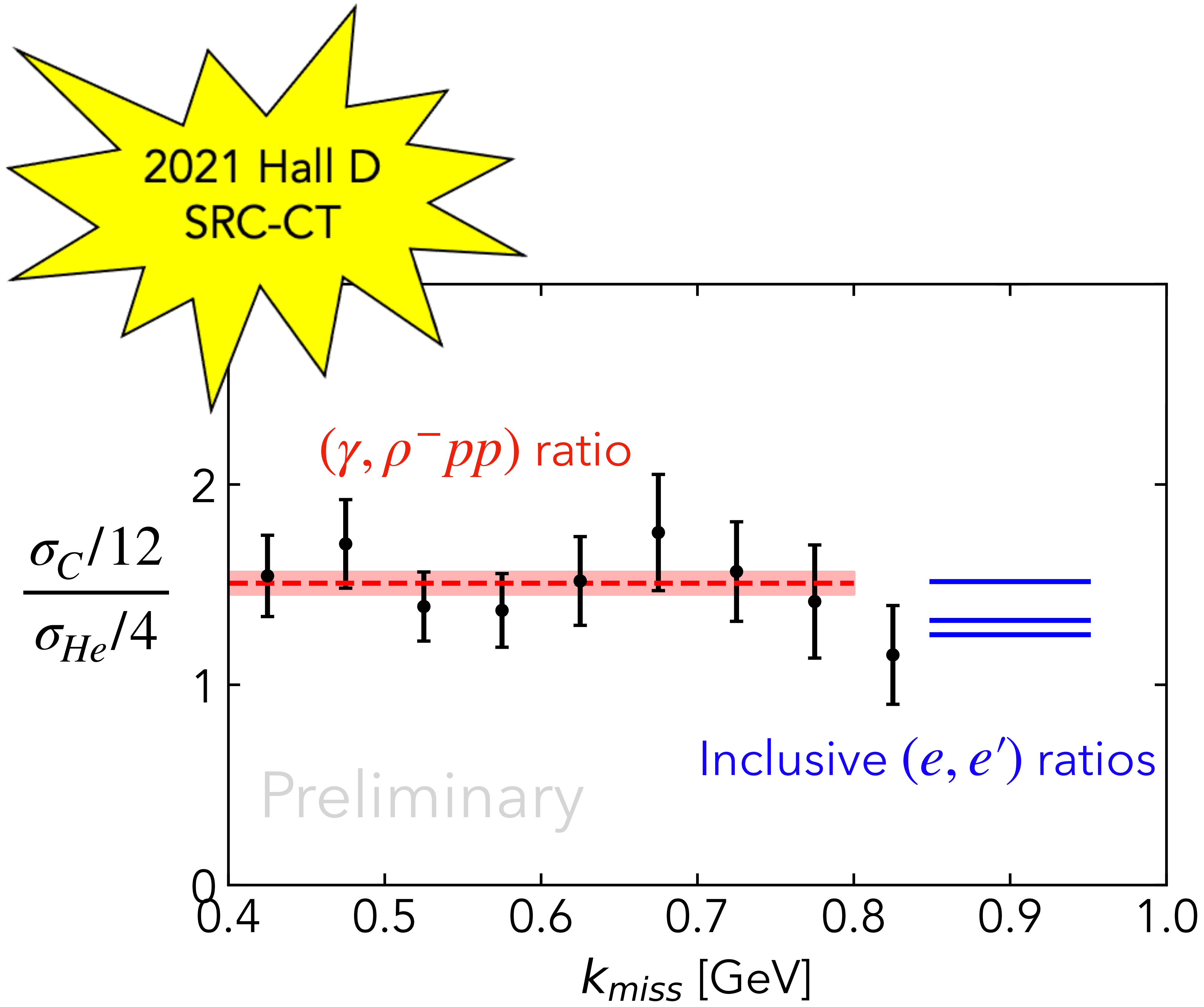


A-dependent properties of SRCs also established



- Center-of-mass behavior of pairs
- Cross-section scaling → universal high-momentum tail

A-dependent properties of SRCs also established

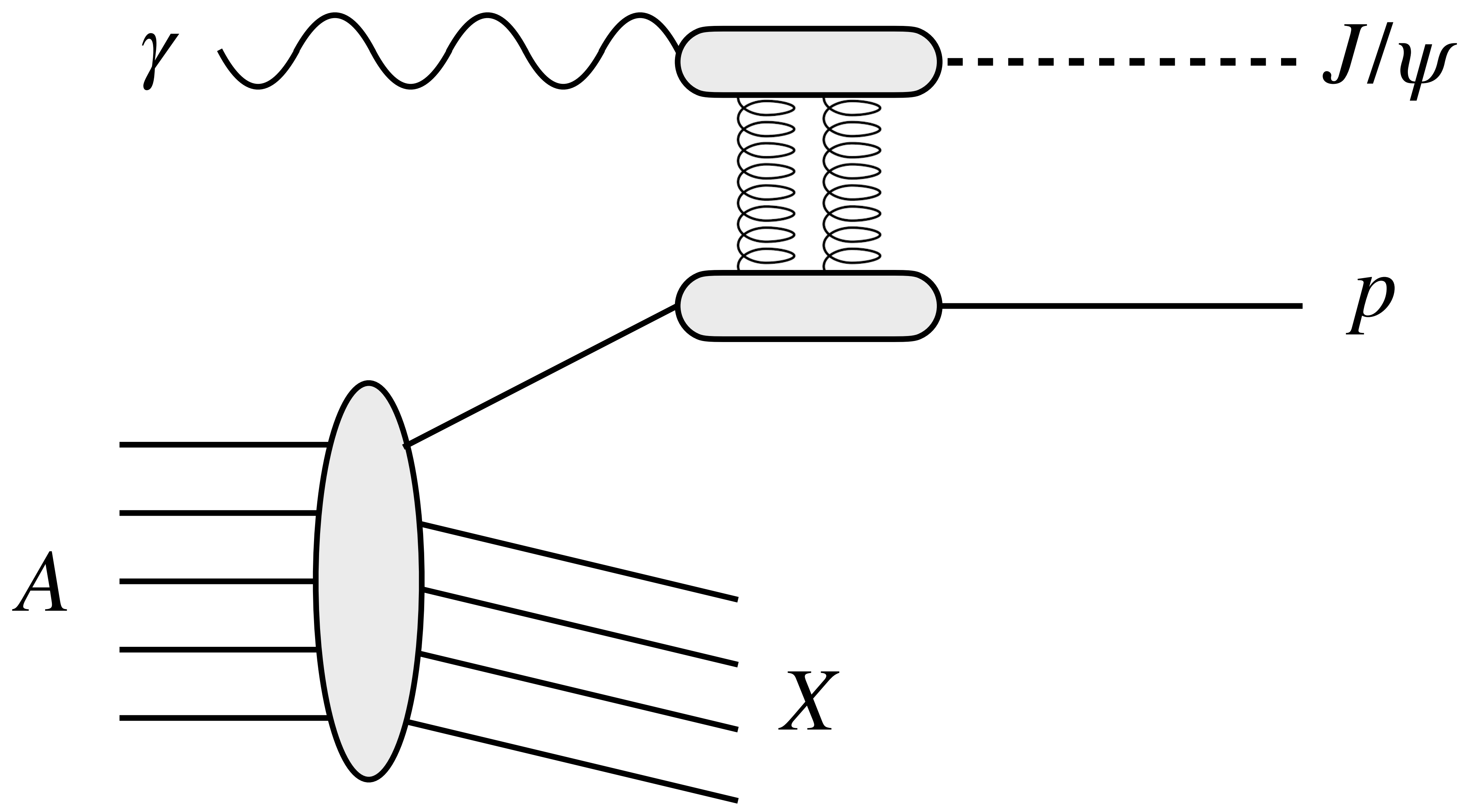


- Center-of-mass behavior of pairs
- Cross-section scaling → universal high-momentum tail
- SRC abundances match electron-scattering

Outlook for Hall D Nuclear Measurement

- Further study of systematics necessary to complete comparison to plane-wave predictions
  - Sensitivity to photoproduction cross section, understanding of FSI effects, impact of $|t|$ and $|u|$ cuts
- Complementary $(\rho^0 pp)$ channel allows access to pp pairs, enabling confirmation of isospin structure of SRCs
- Other ongoing projects: color transparency, neutron structure, medium modification

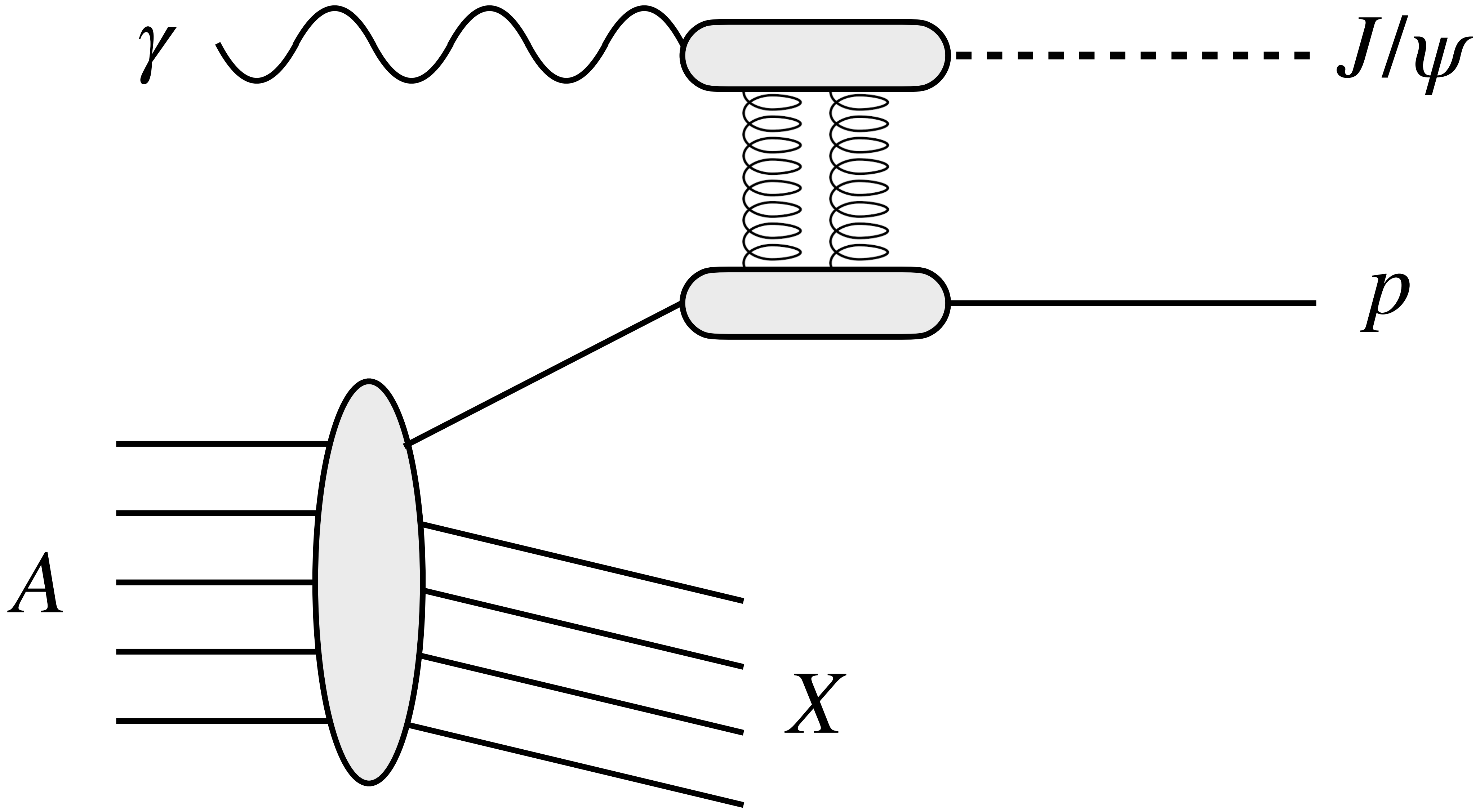
Nuclear Glue: J/ψ photoproduction from nuclei



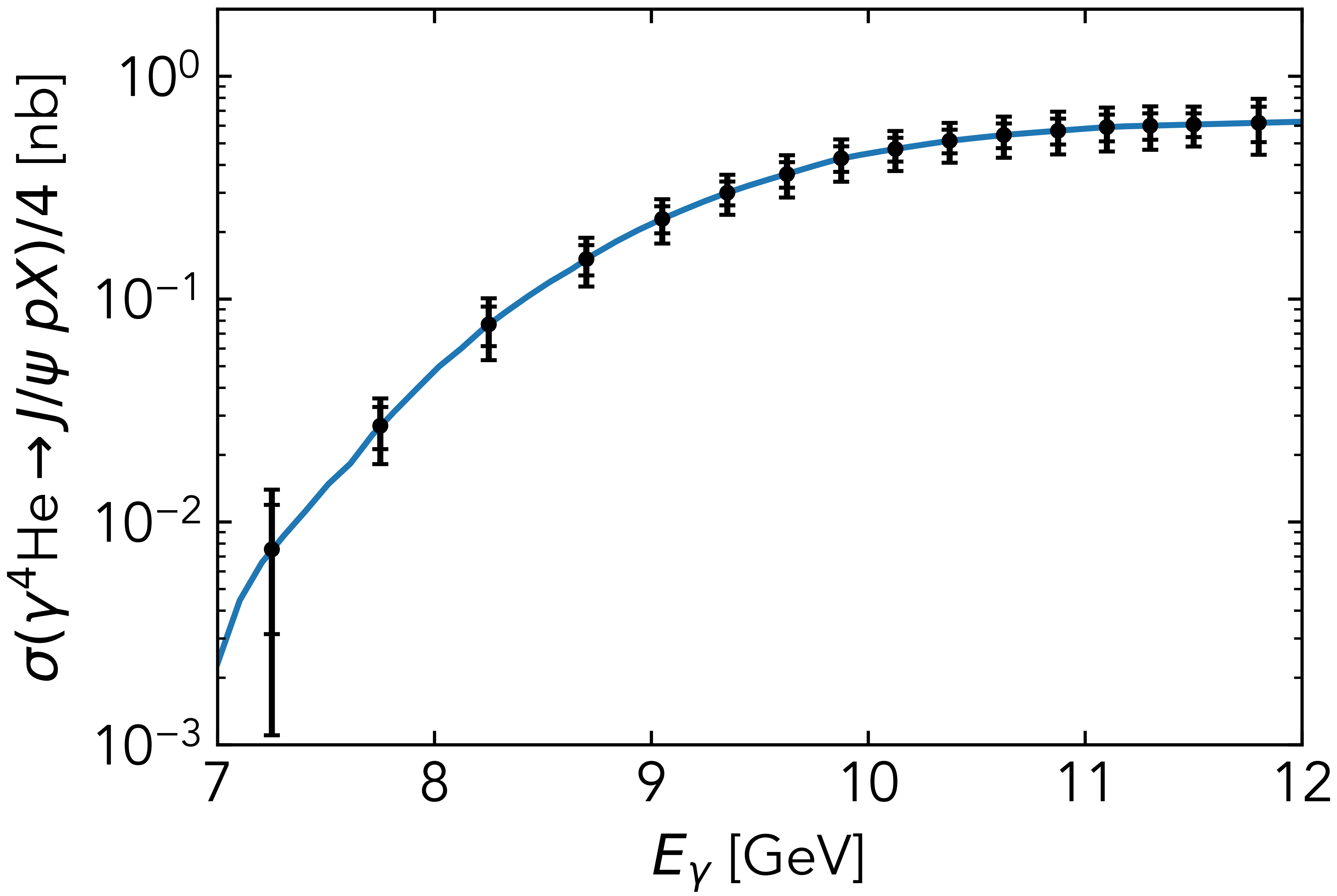
Access to high-x gluon content of nucleus and bound nucleon

Proposal **PR12-23-009** given C2 approval by JLab PAC

Nuclear Glue: J/ψ photoproduction from nuclei

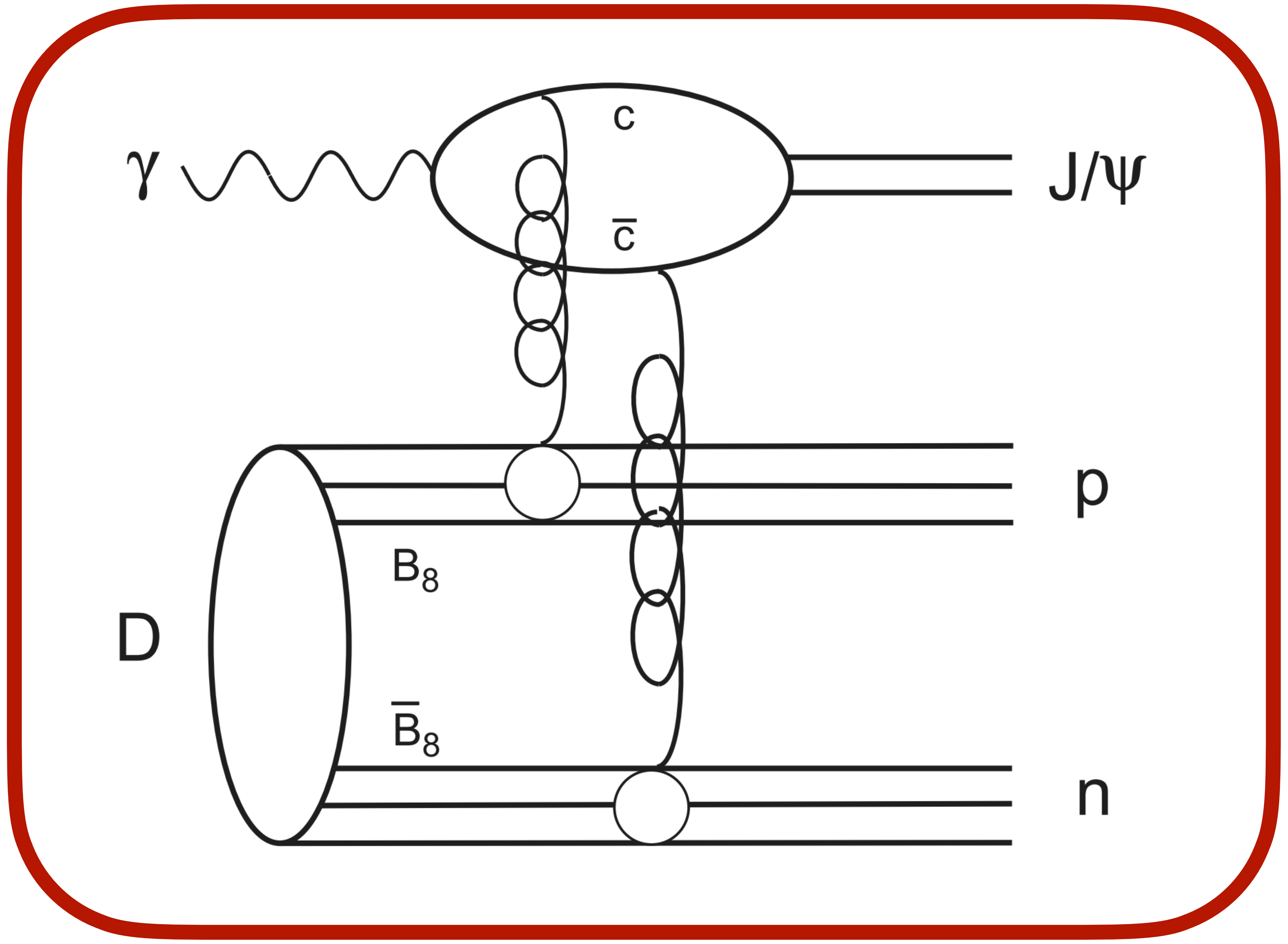


Proposal **PR12-23-009**

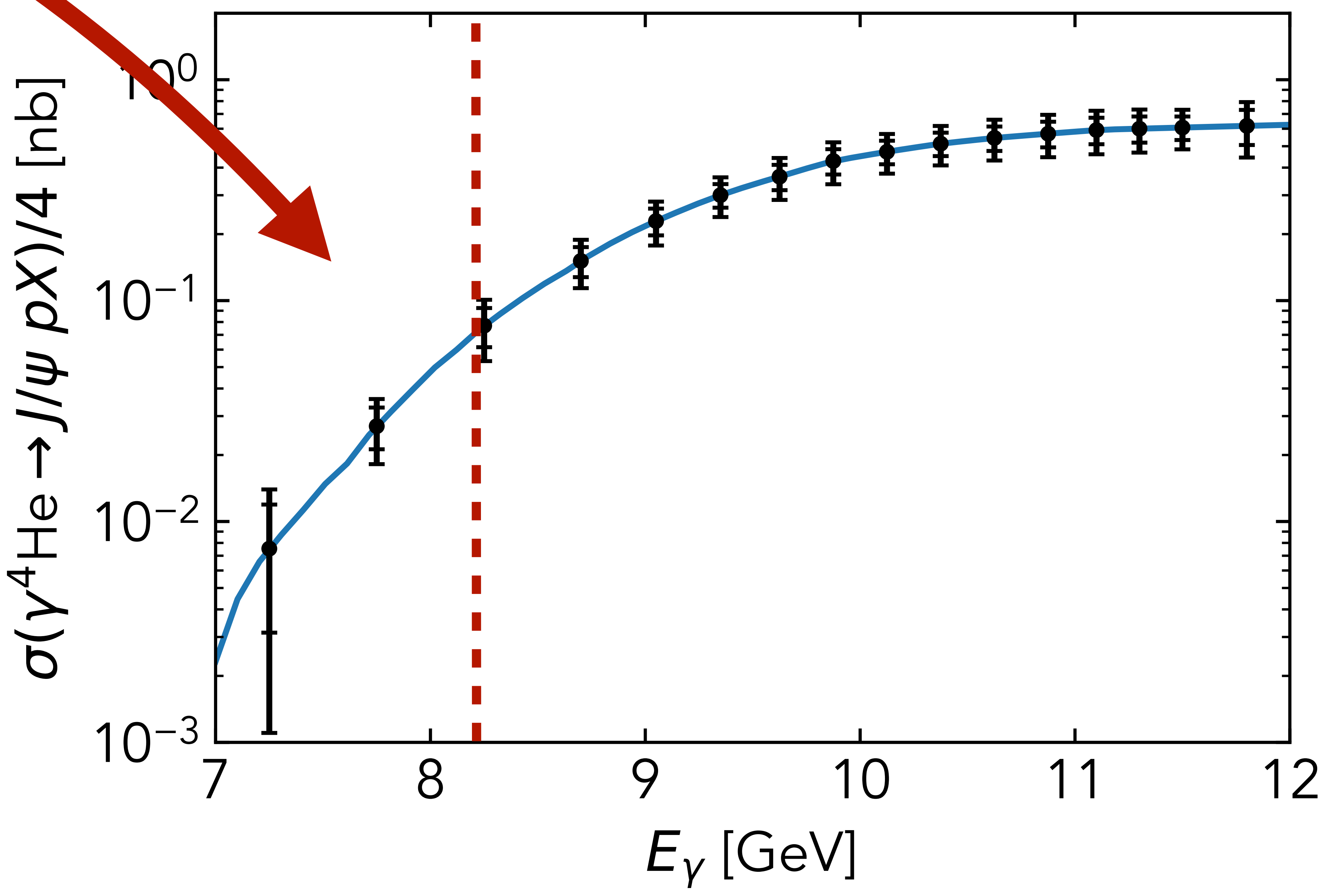


Nuclear Glue: J/ψ photoproduction from nuclei

Sub-threshold production:
Highly sensitive to exotic effects!



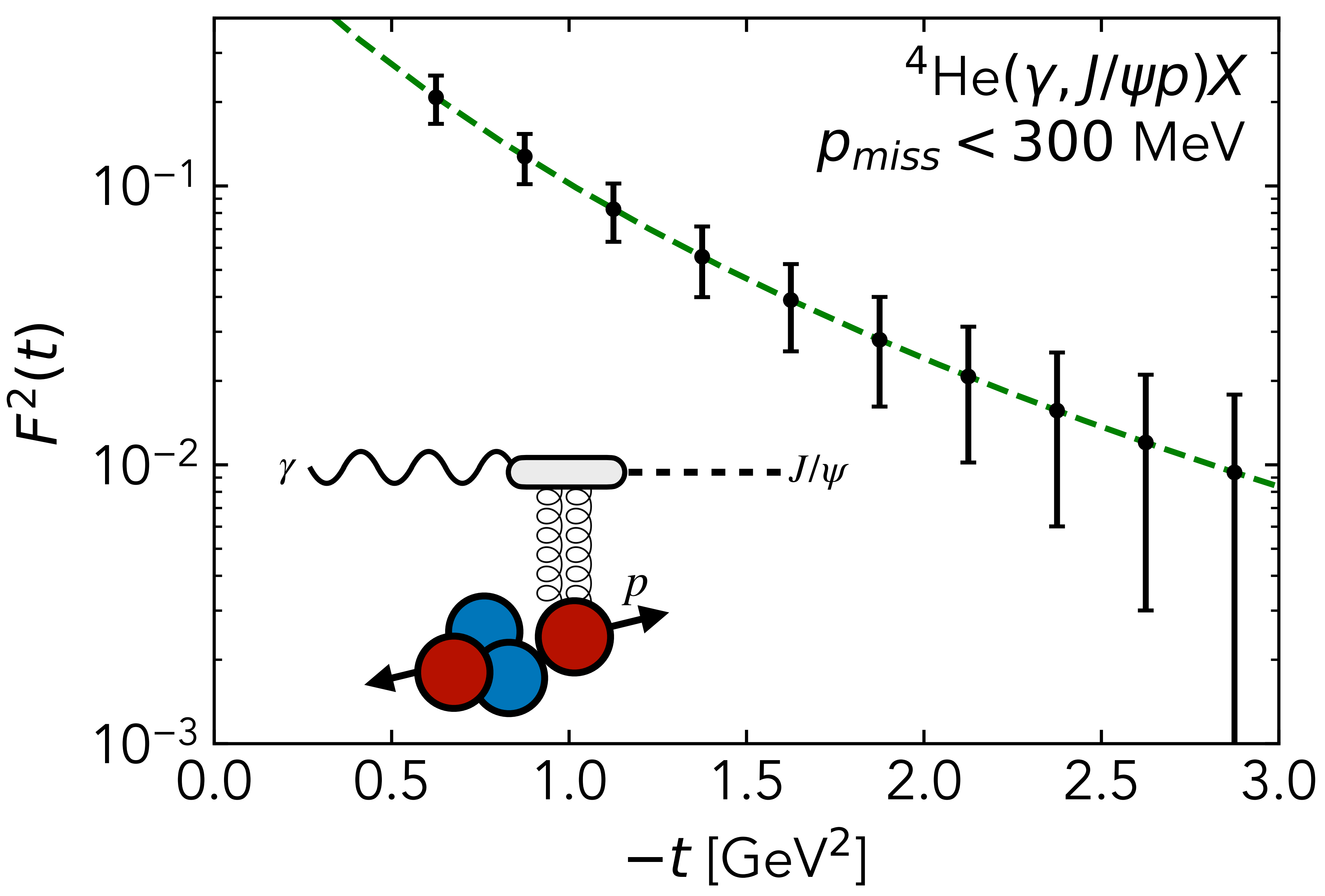
Proposal **PR12-23-009**



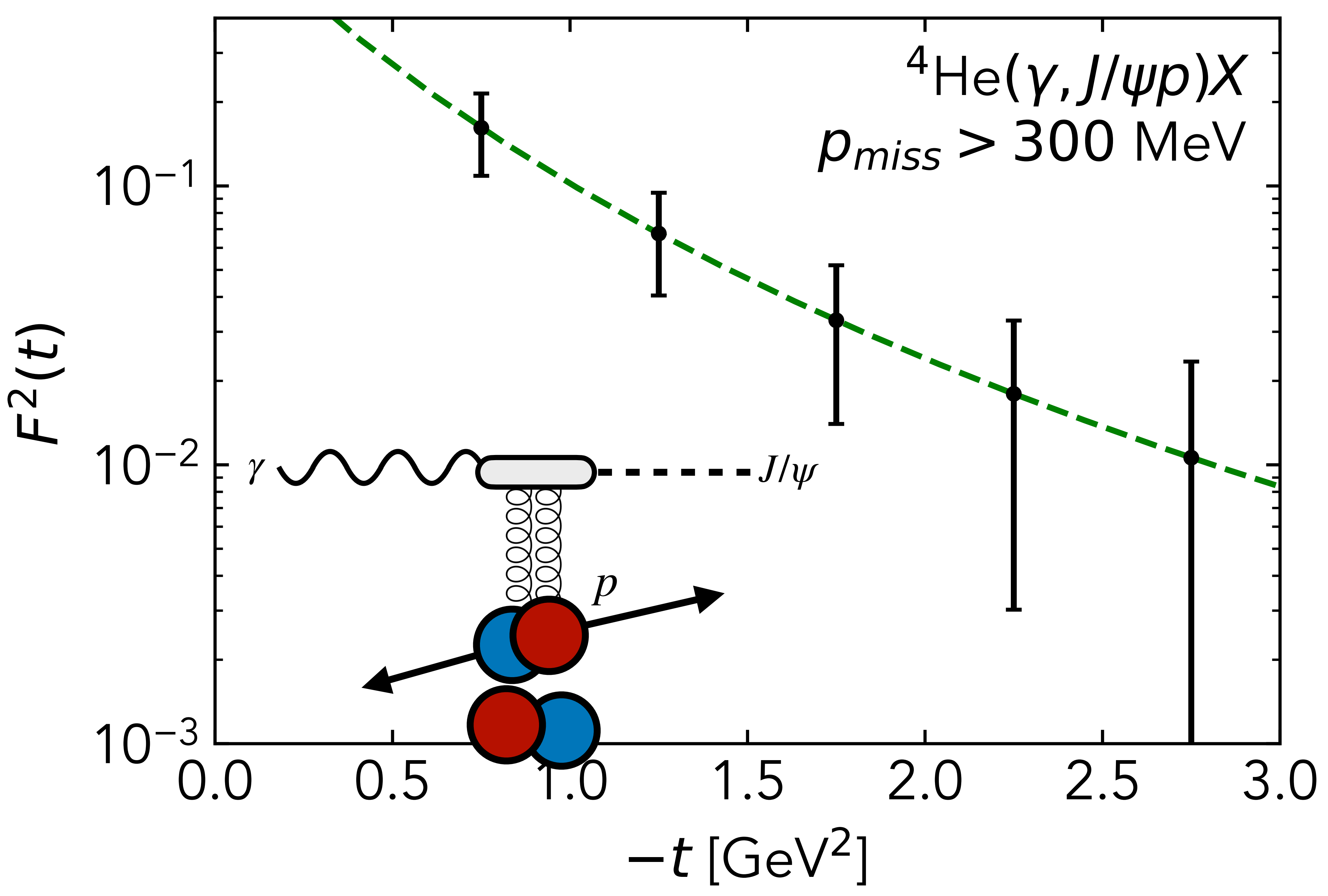
S.J. Brodsky et al, PLB (2001)

Proposed gluonic probe of correlated nucleons

~700 events

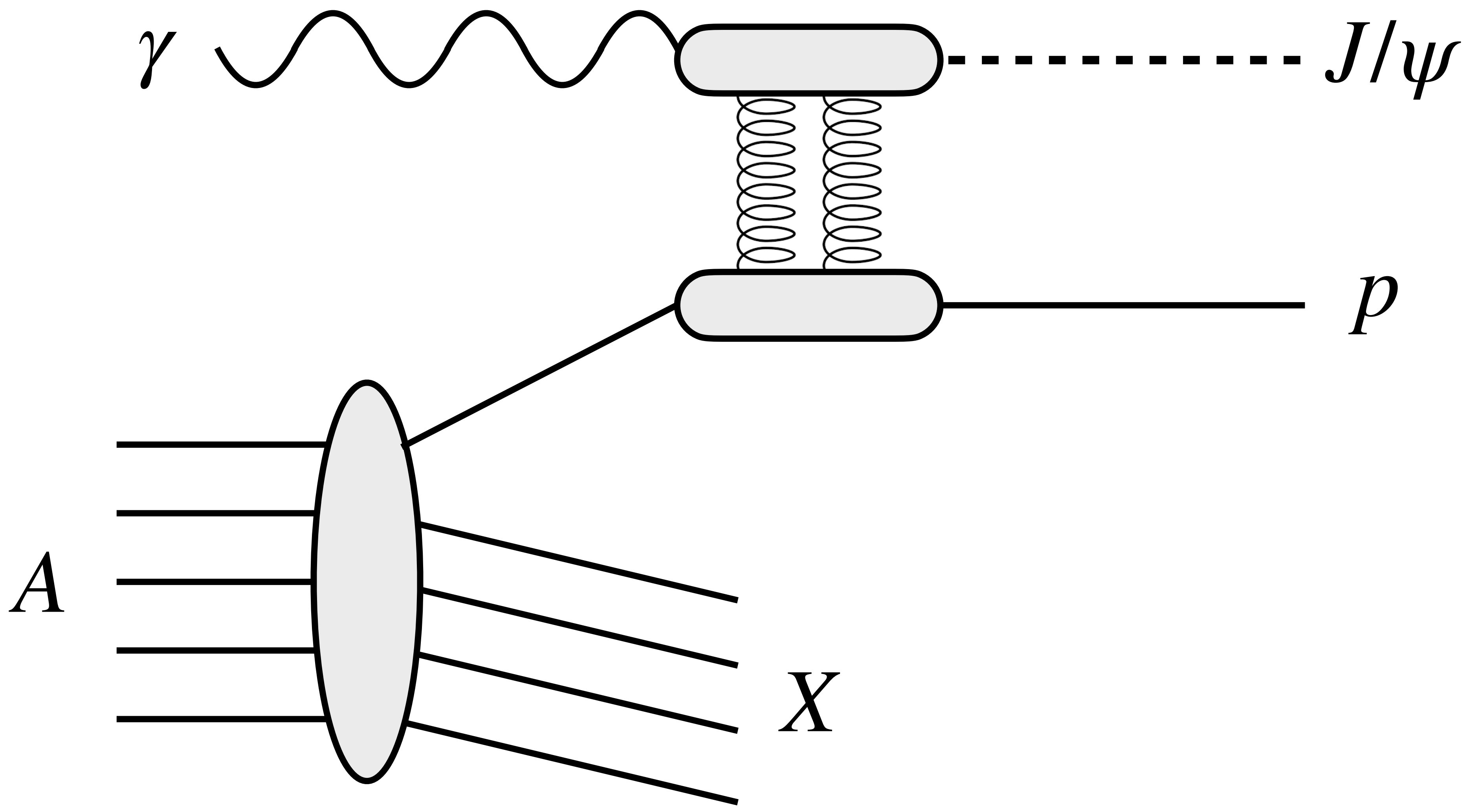


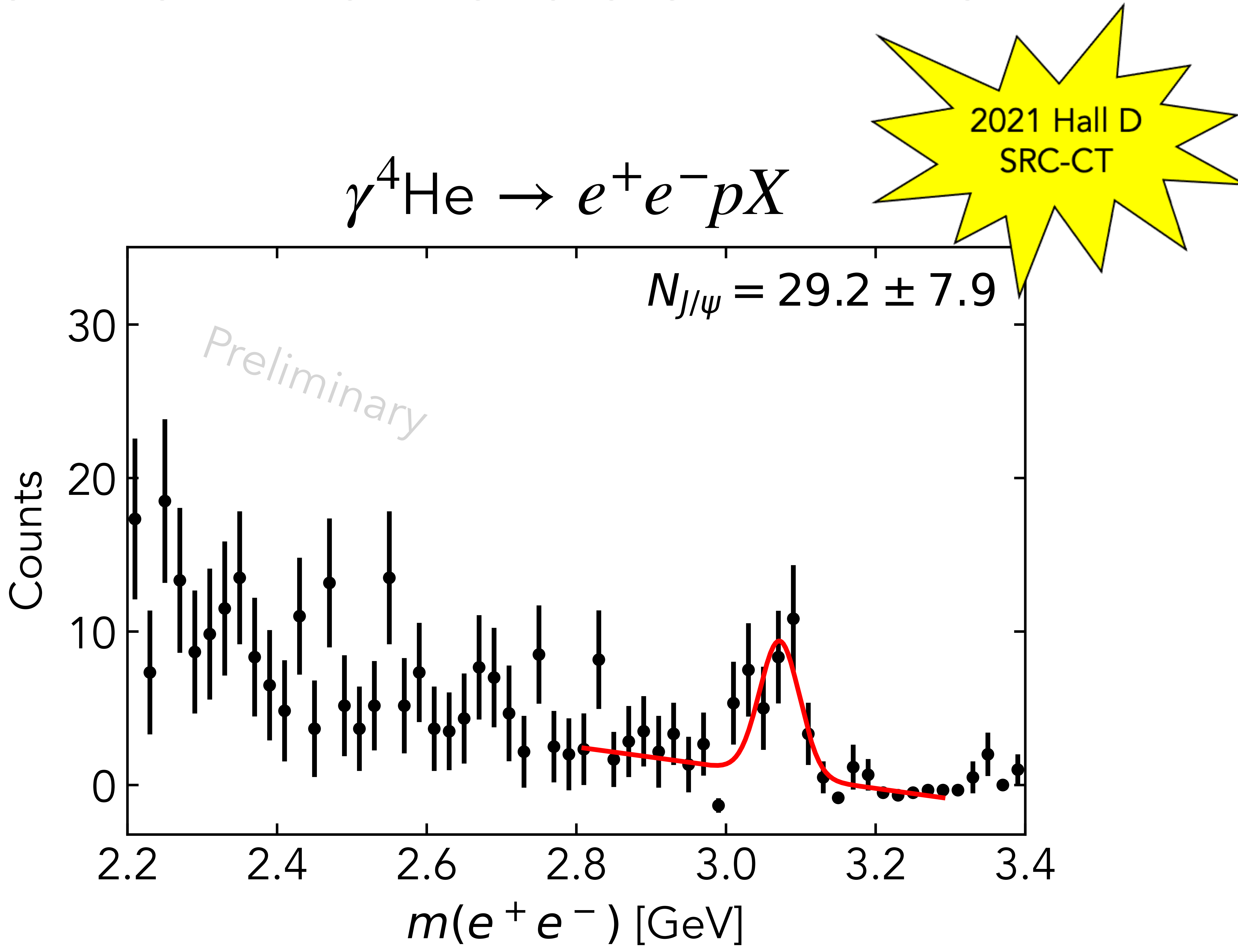
~100 events



Hall D Proposal **PR12-23-009**

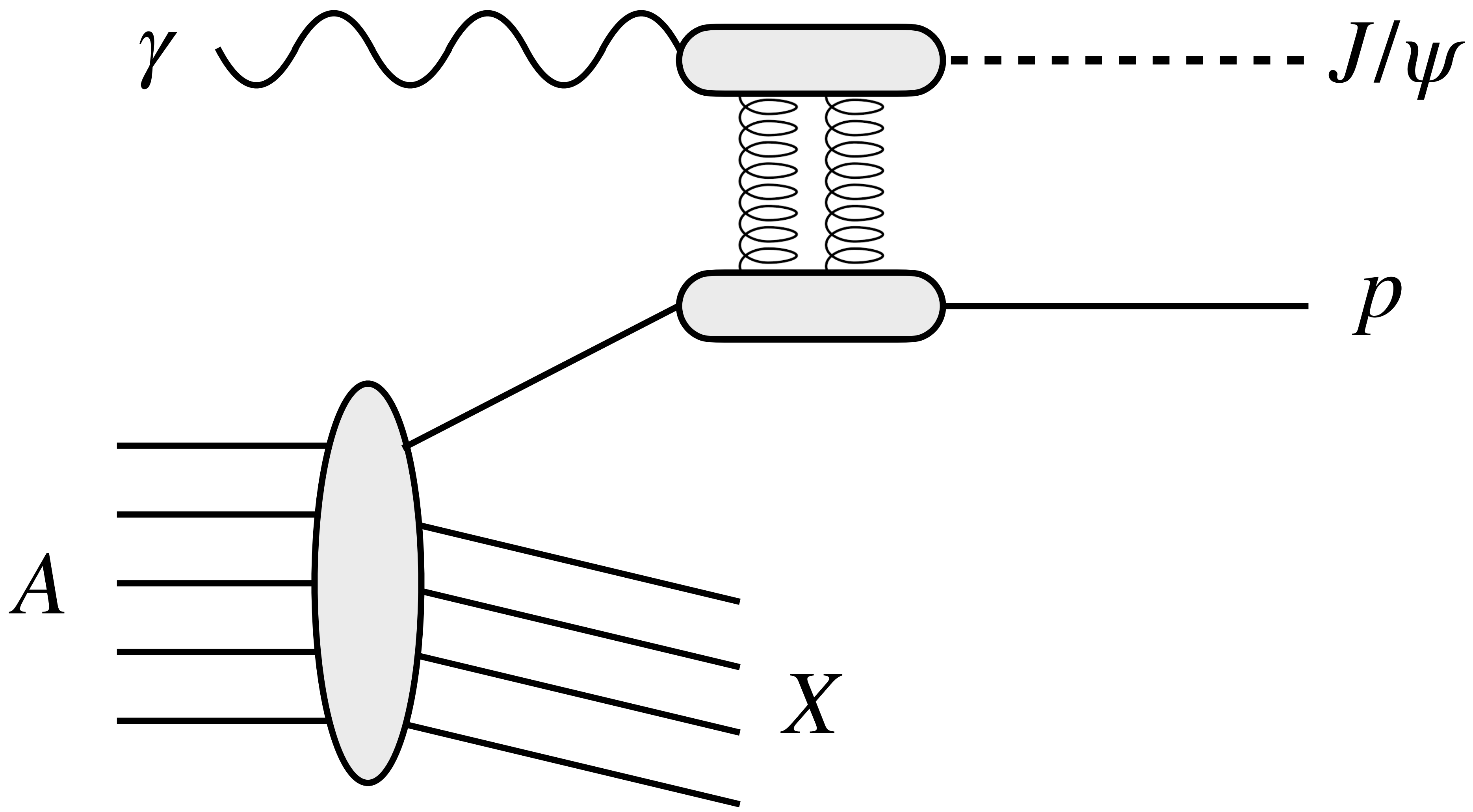
Current data allows first observation



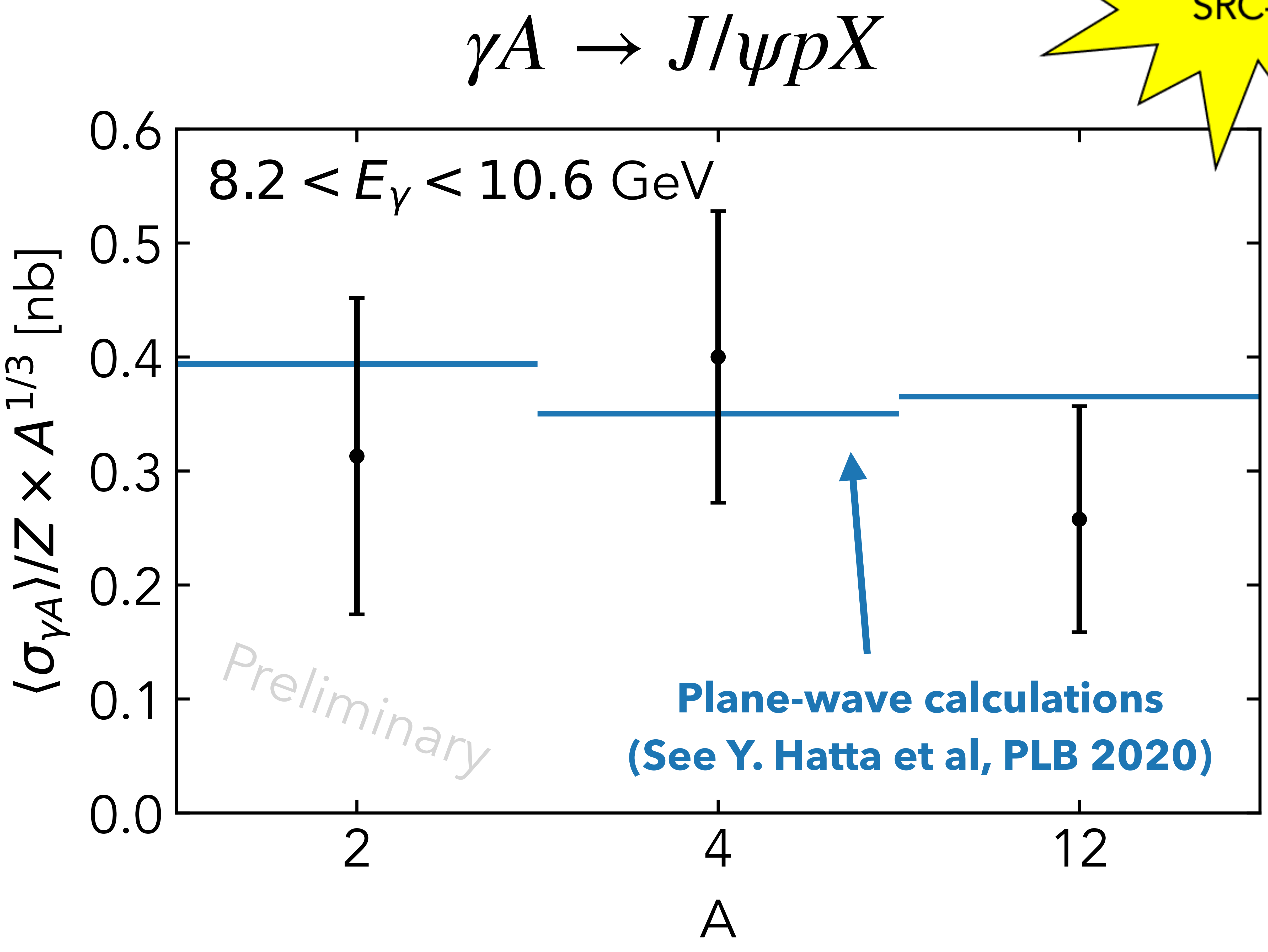


Current data allows first observation

NEW!



2021 Hall D SRC-CT

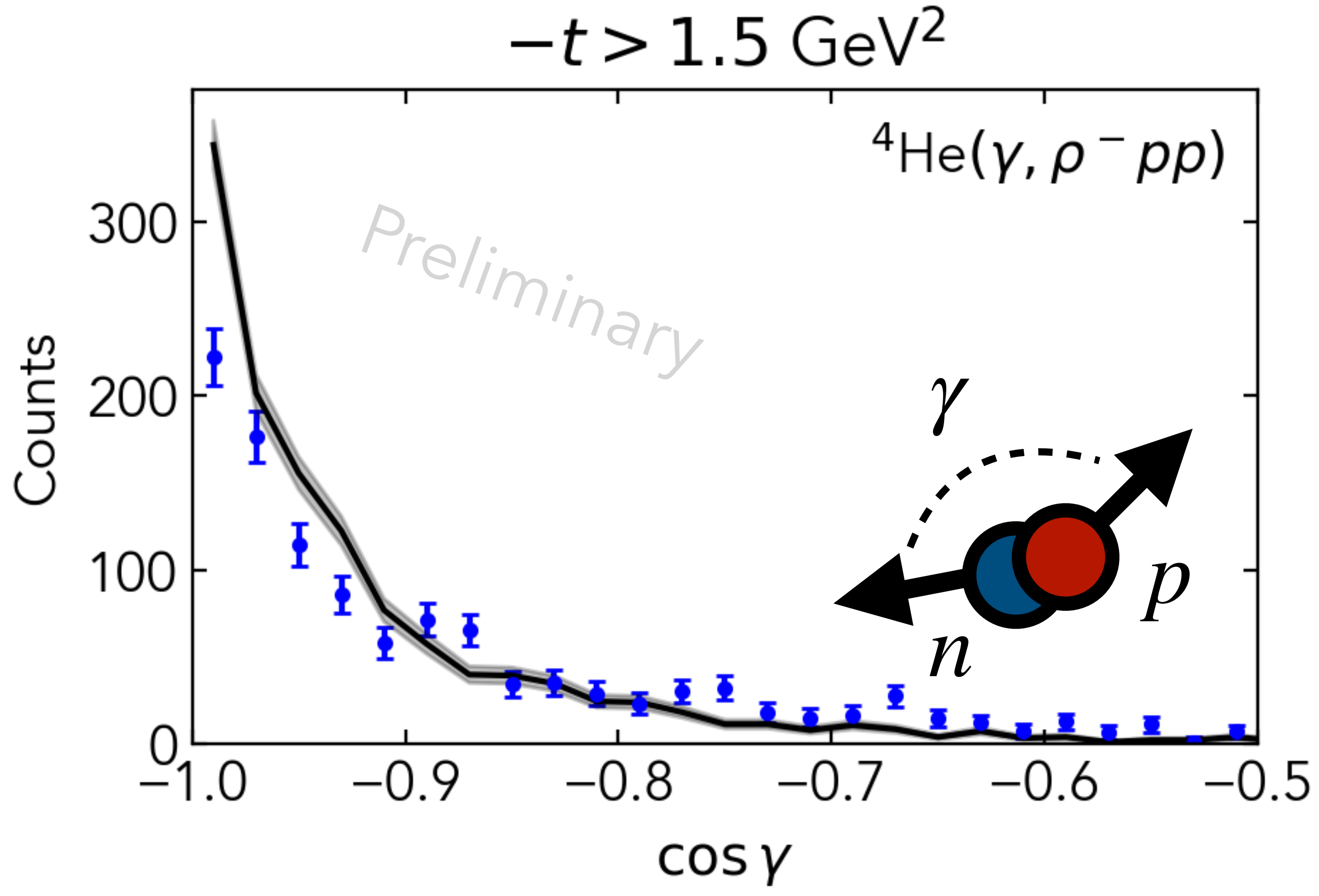


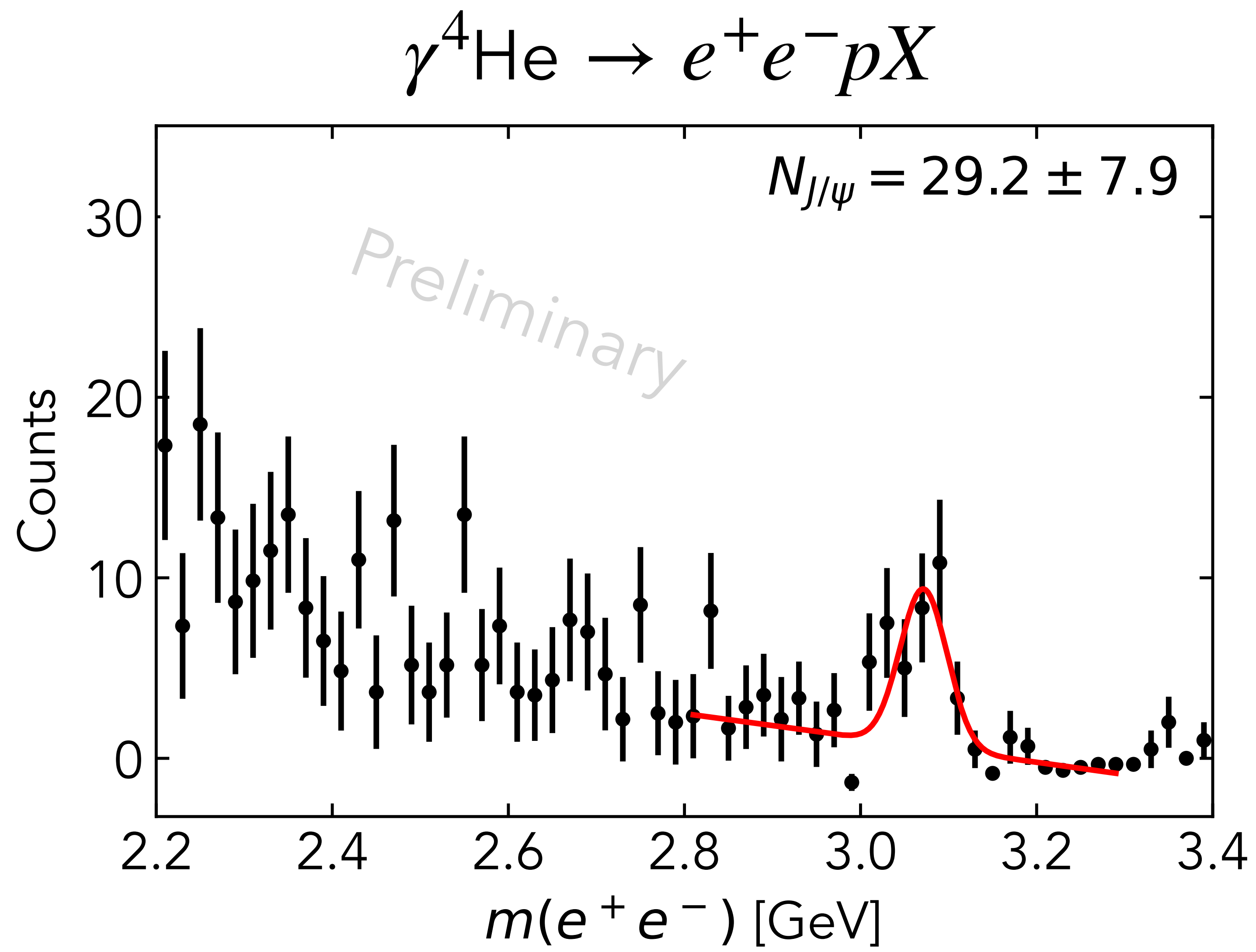
Conclusions

- Measurement of $(\gamma, \rho^- pp)$ shows first photonuclear probe of SRCs

- Initial results show consistency with ab-initio and electron-scattering expectations

- New measurement of threshold J/ψ from nuclei gives first insights to high-x nuclear gluons

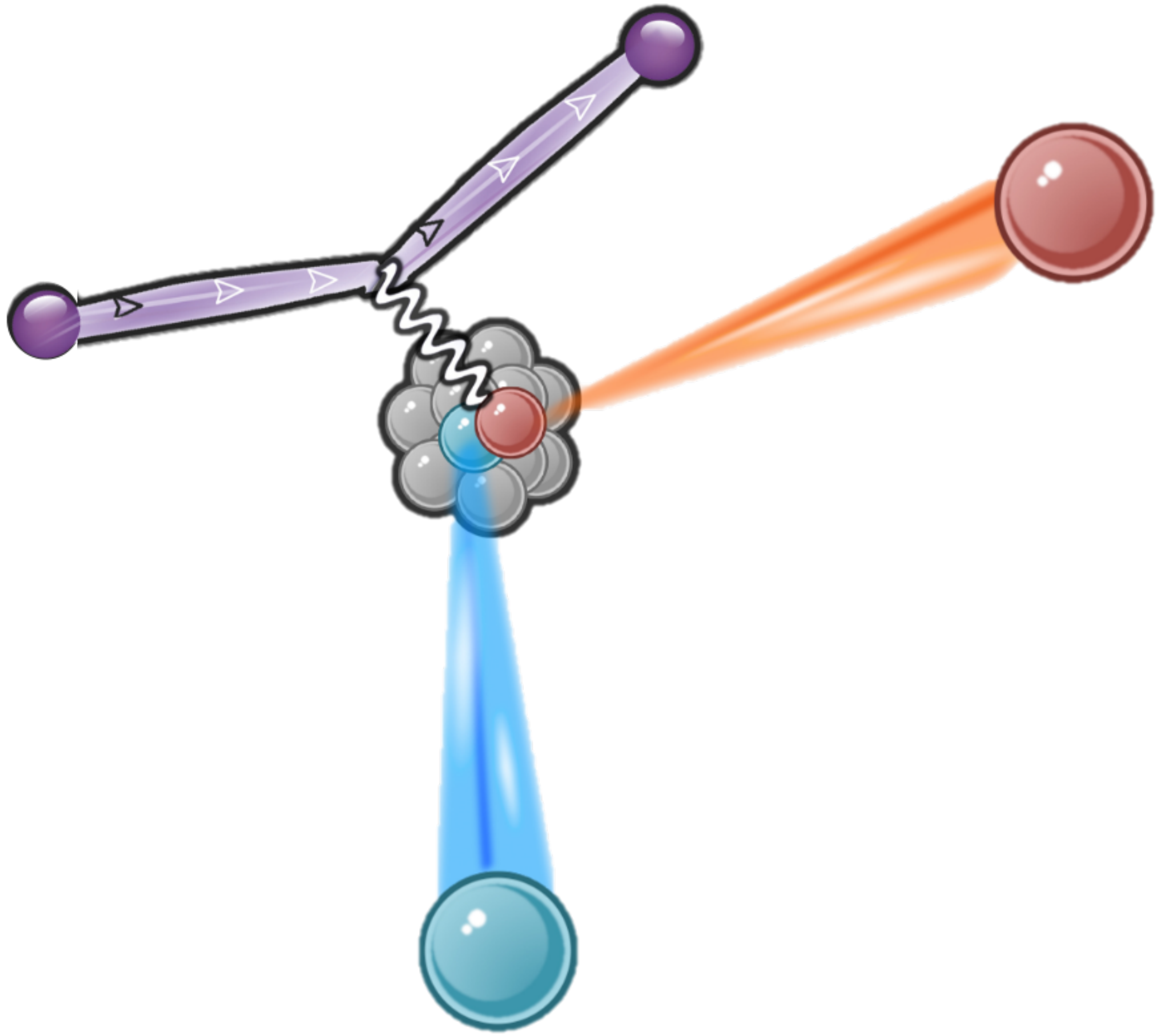




Backup Slides

Interpreting SRC results requires two things:

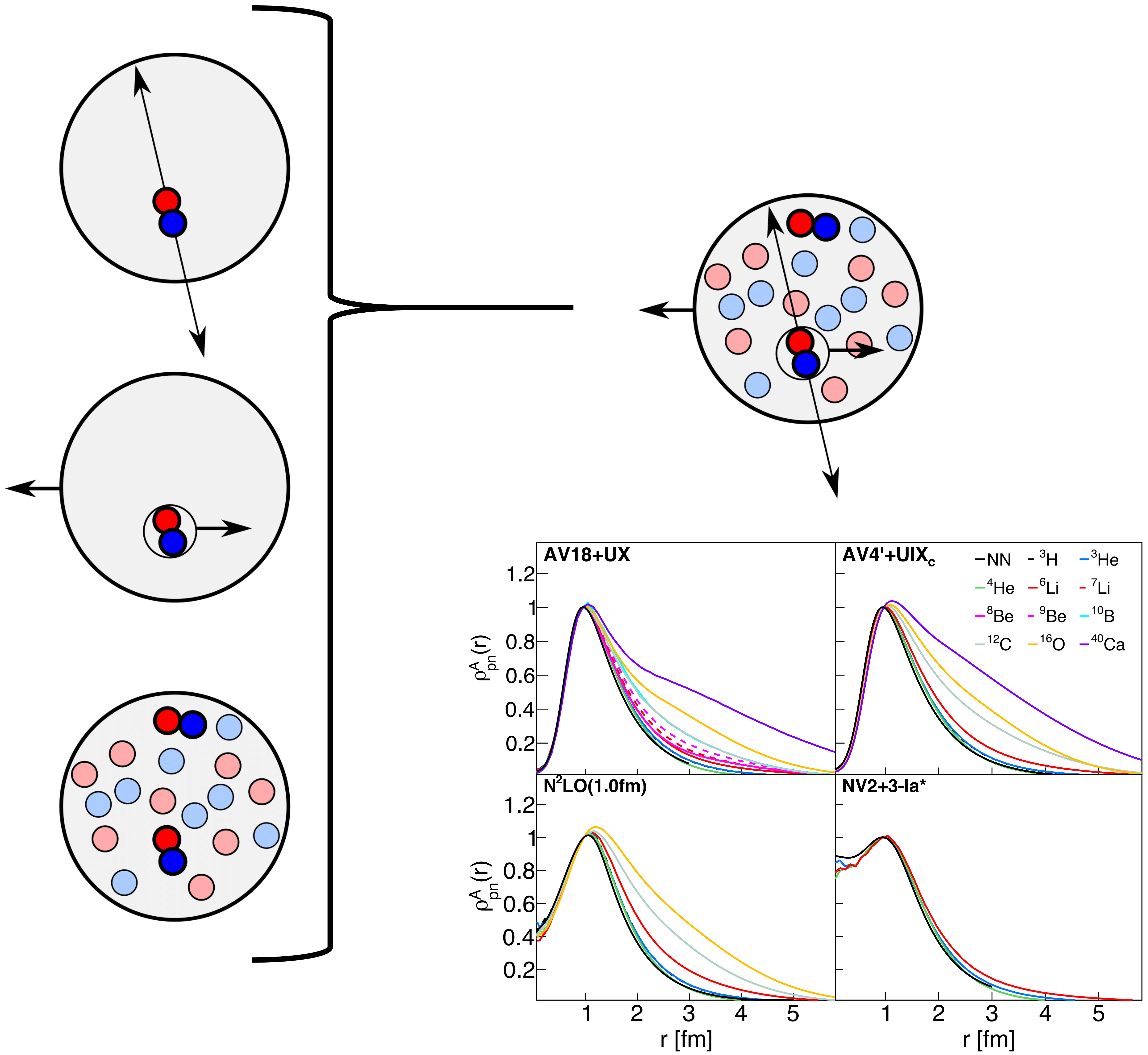
1. Clean measurements of SRC breakup using two-nucleon knockout



Interpreting SRC results requires two things:

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

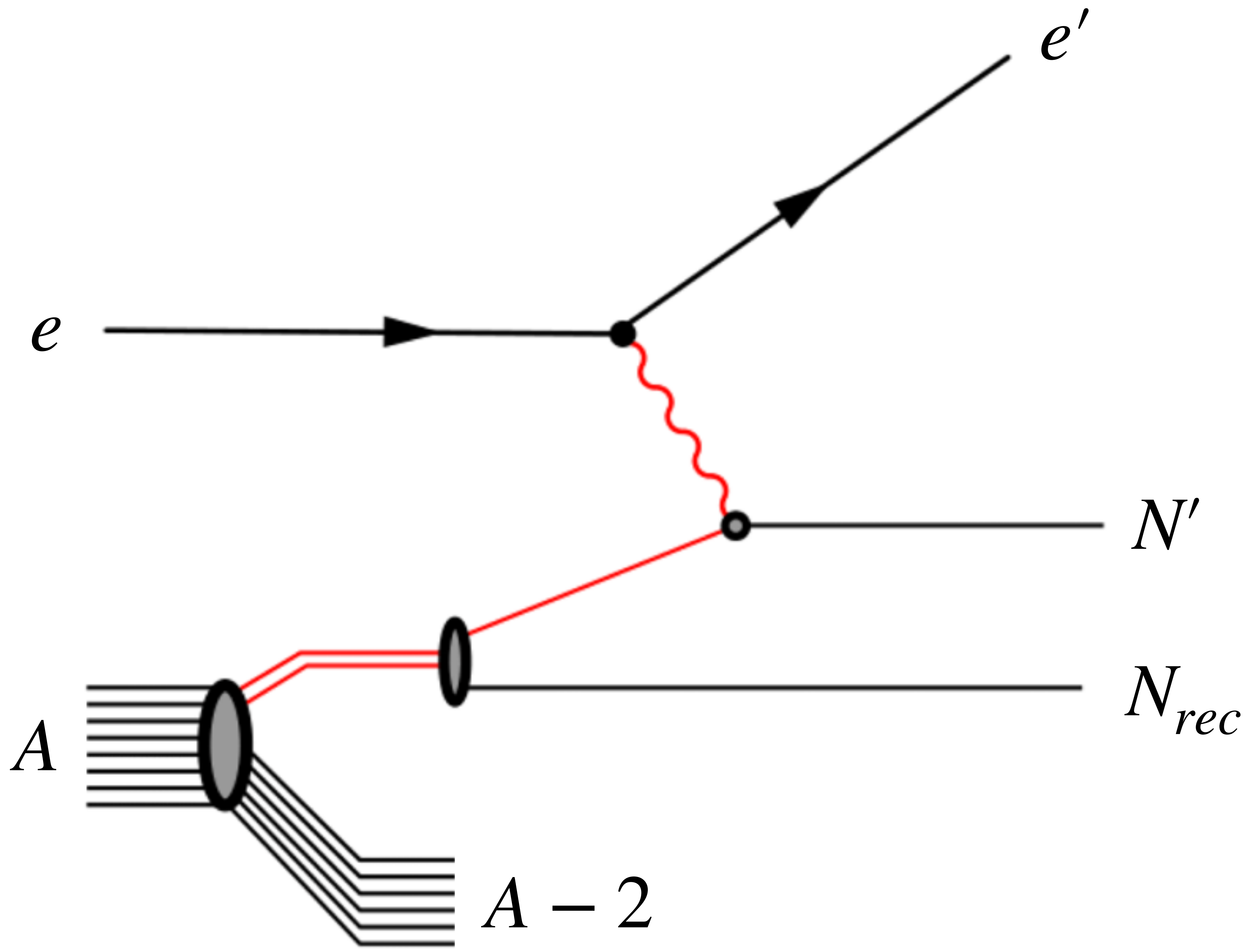
2. Model of the SRC component of the nuclear ground-state



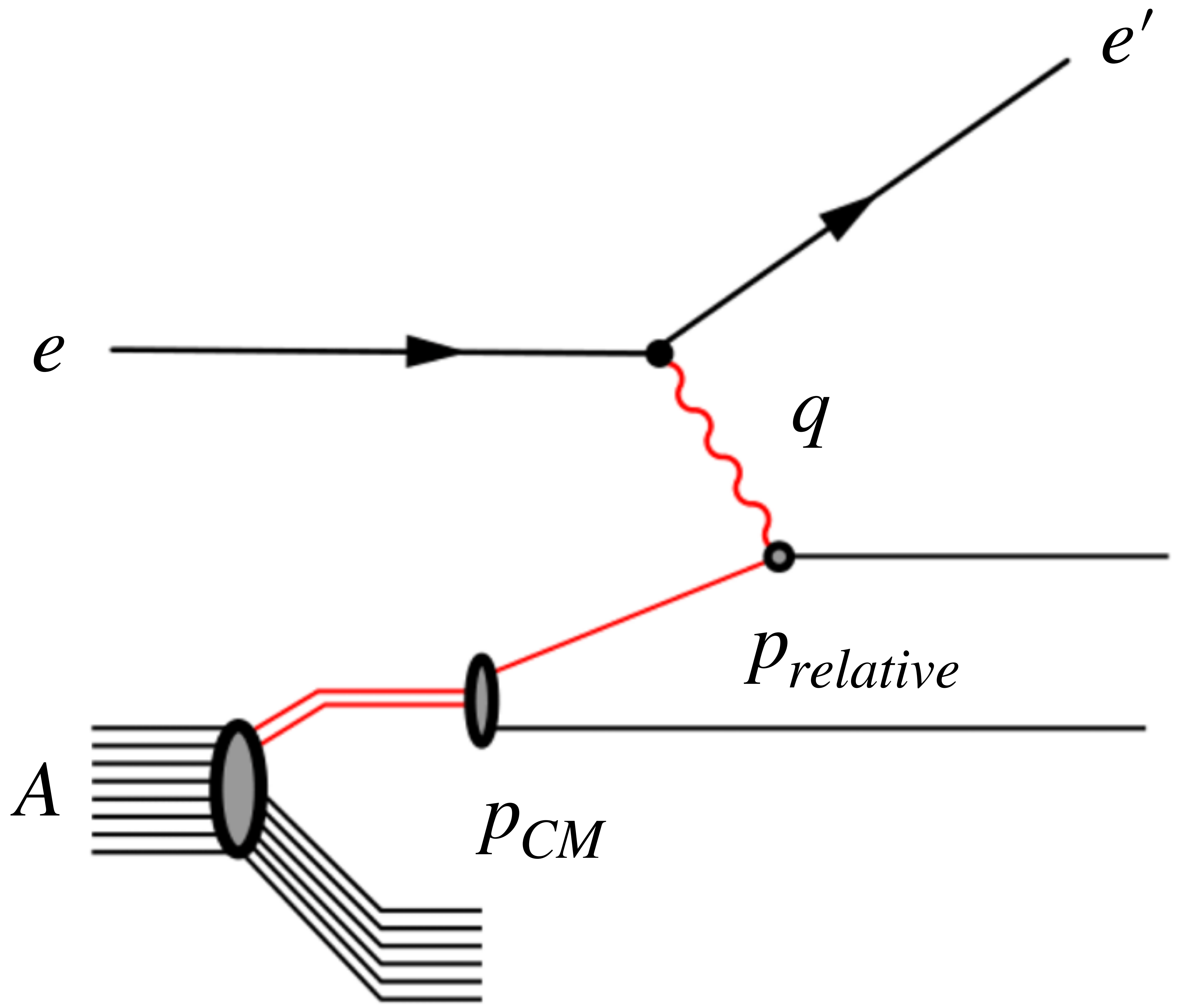
Cruz-Torres et al., Nature Physics (2021)

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)

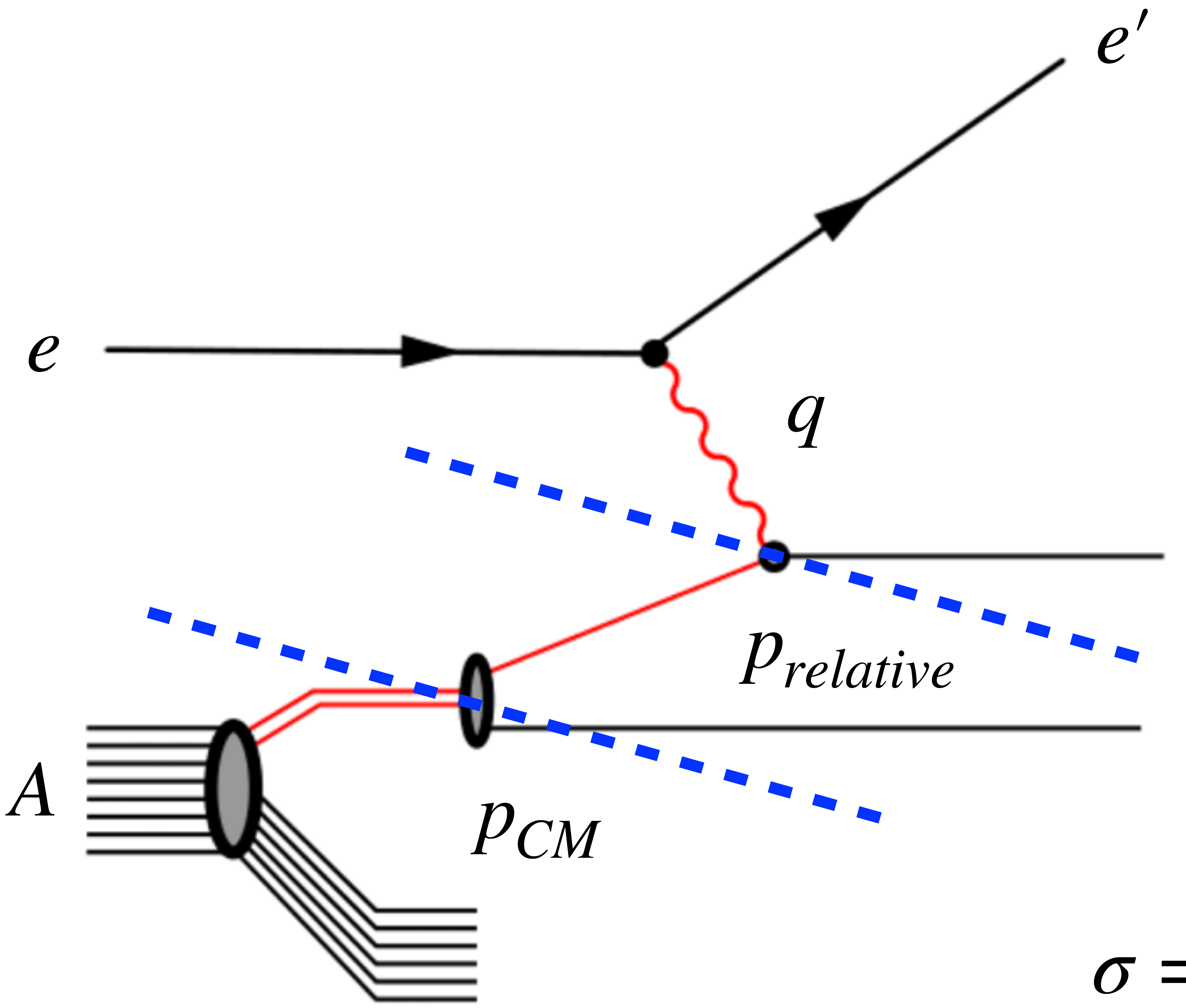
Ground-state model can be combined with **“Plane-Wave Impulse Approximation”**



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



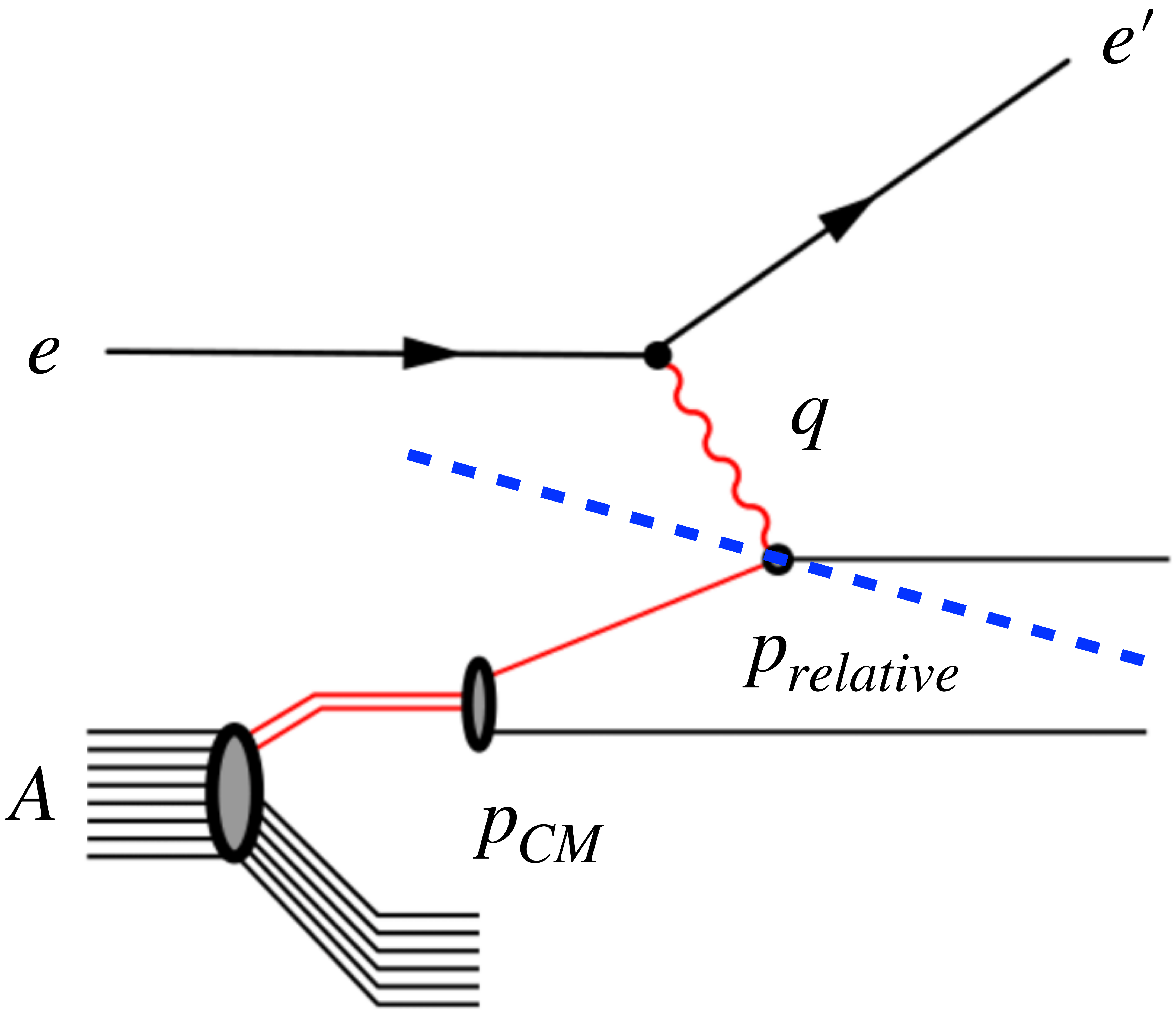
Ground-state model can be combined with **"Plane-Wave Impulse Approximation"**



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

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

PWIA relies on factorization between reaction and ground-state



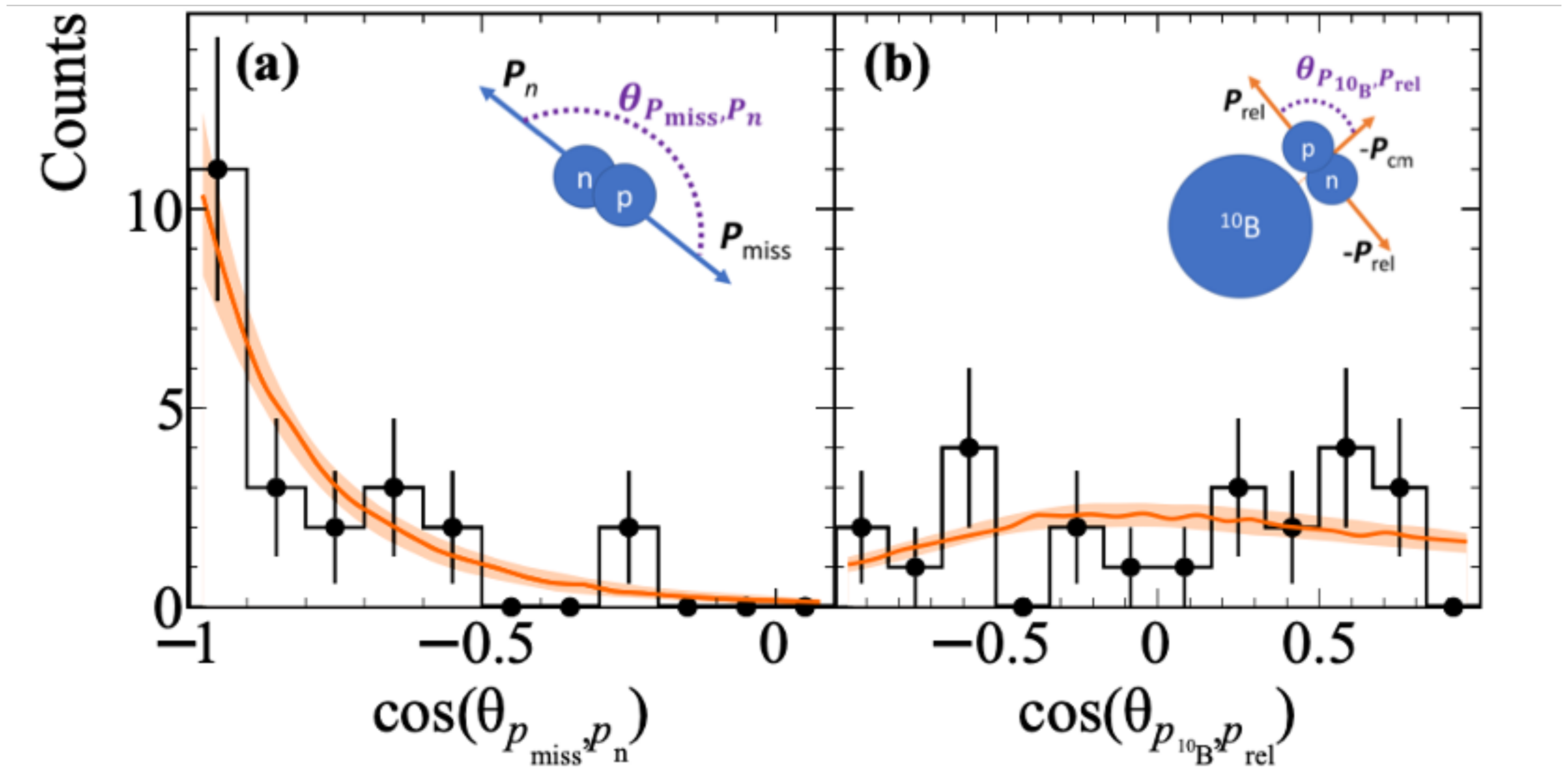
$$\sigma = \sigma_{e,N}(q) \times S(p_i, p_{rec})$$

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

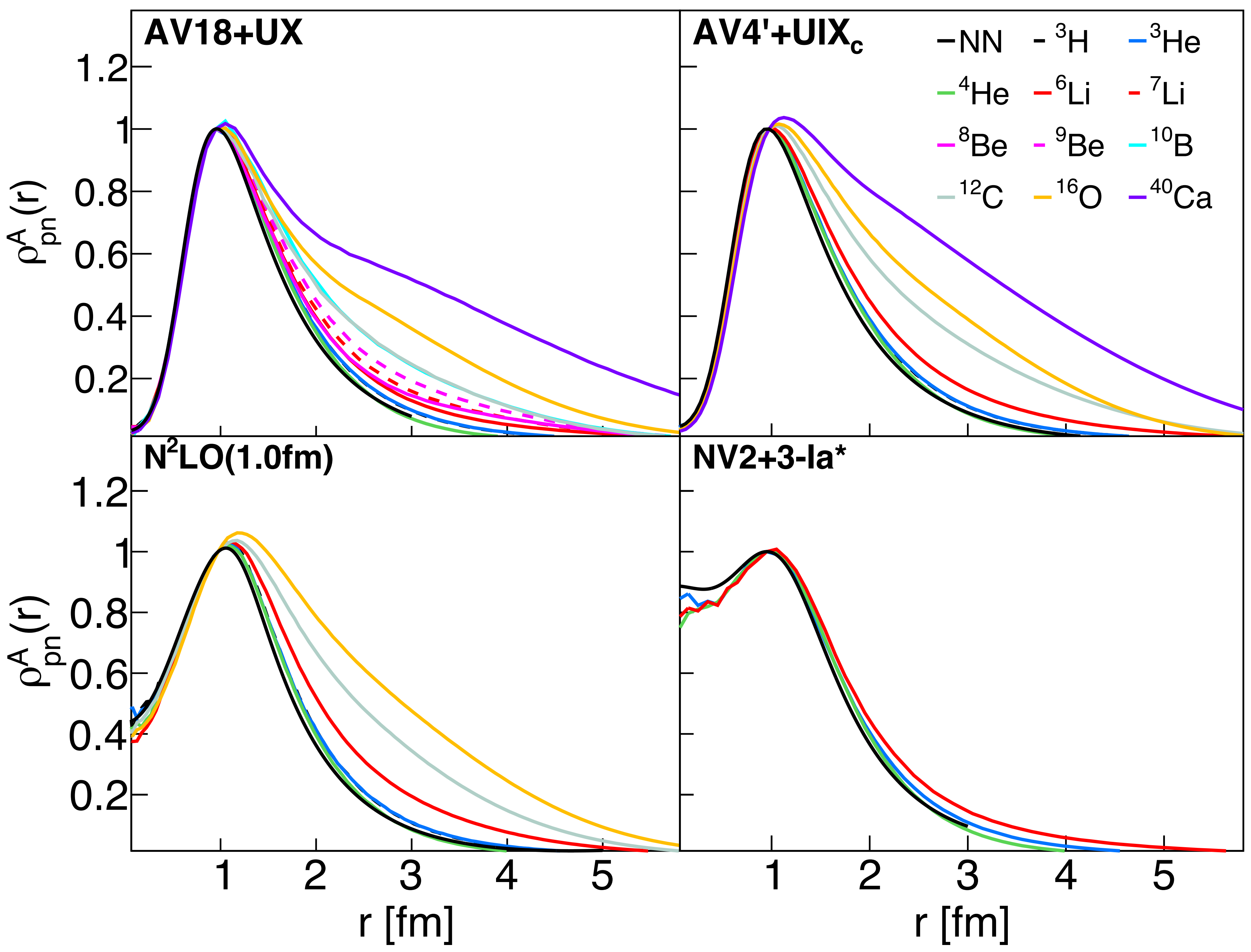
Ground-State
- Low-energy
- 2-body dynamics
- Universal

Internal scale separation of SRCs on good footing:

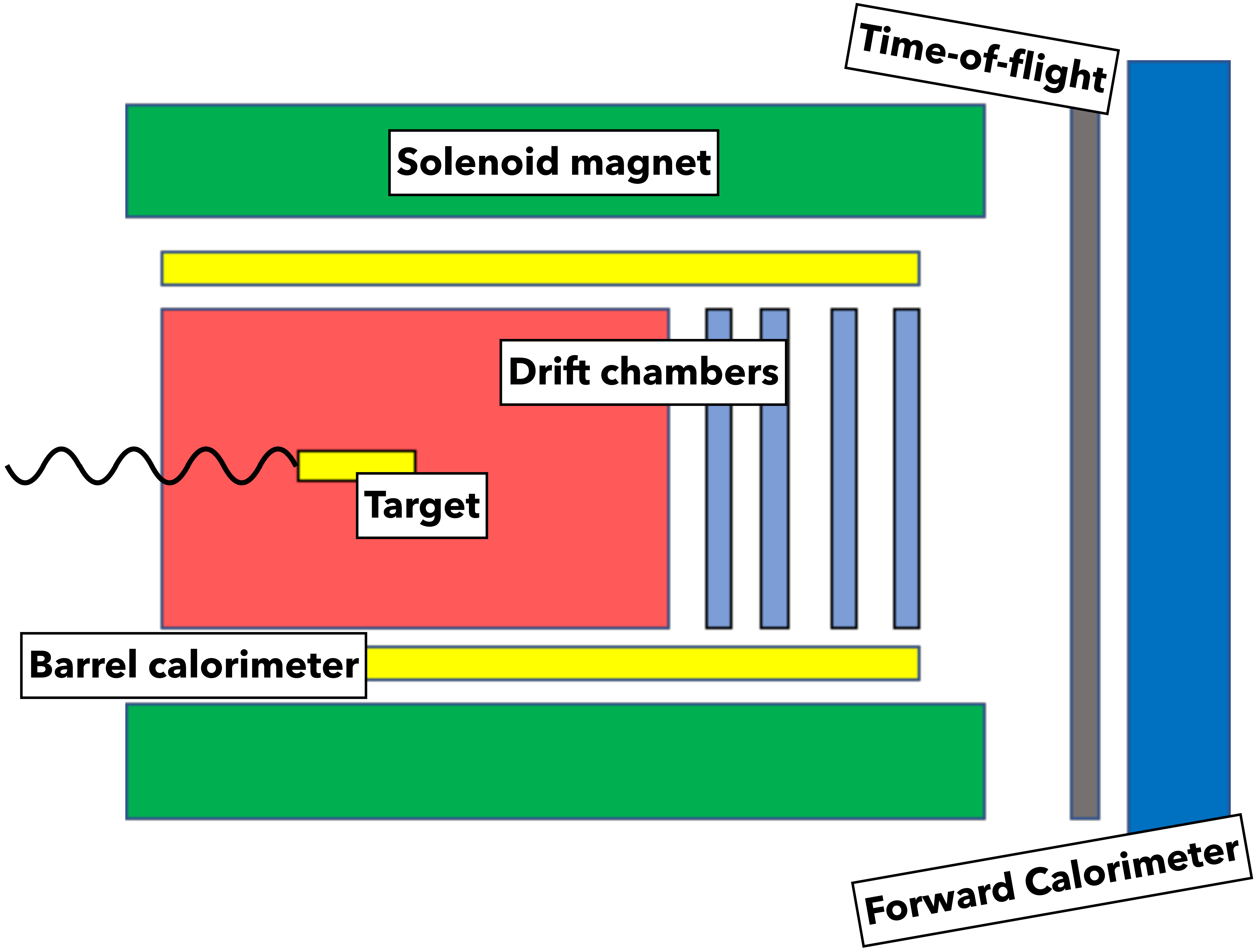
Nature Physics 17, 667 (2021)



Nature Physics 17, 306 (2021)

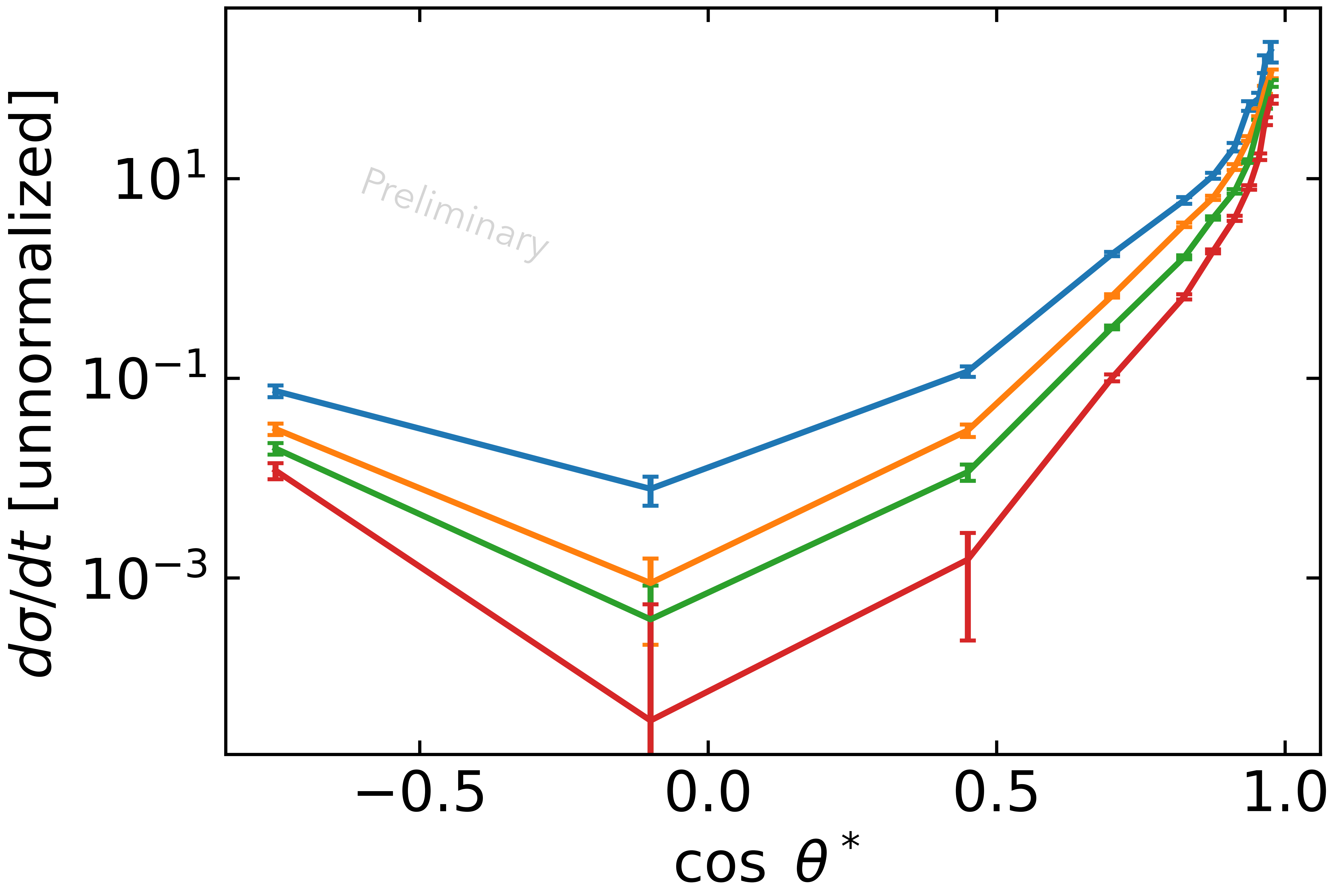


GlueX Spectrometer



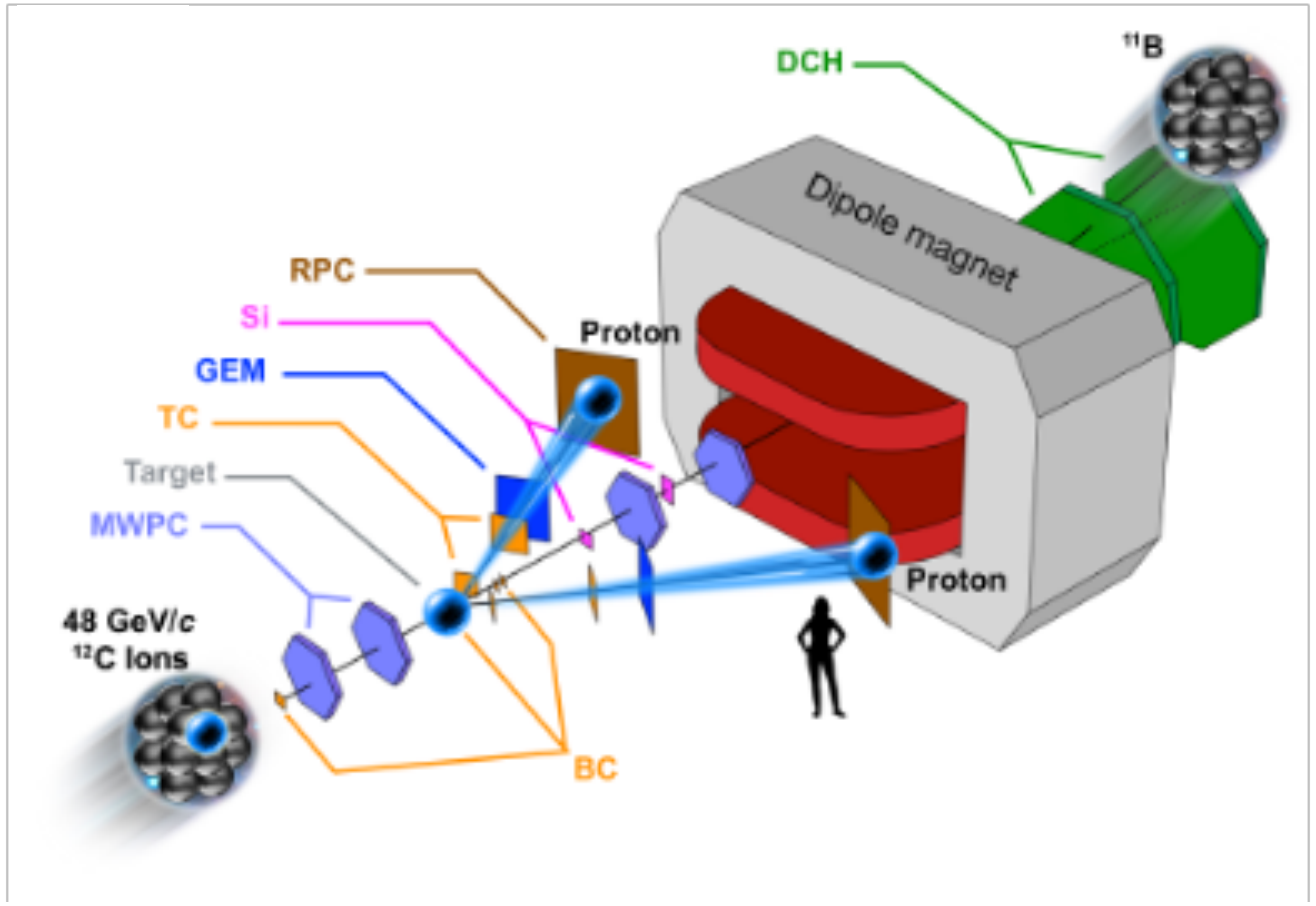
- Large-acceptance detector
- Solenoidal magnet:
  - Good p_T resolution
  - Poor p_z resolution
- Time-of-flight allows particle identification for forward-going charged particles
- Calorimeters allows good acceptance and reconstruction of final-state photons

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

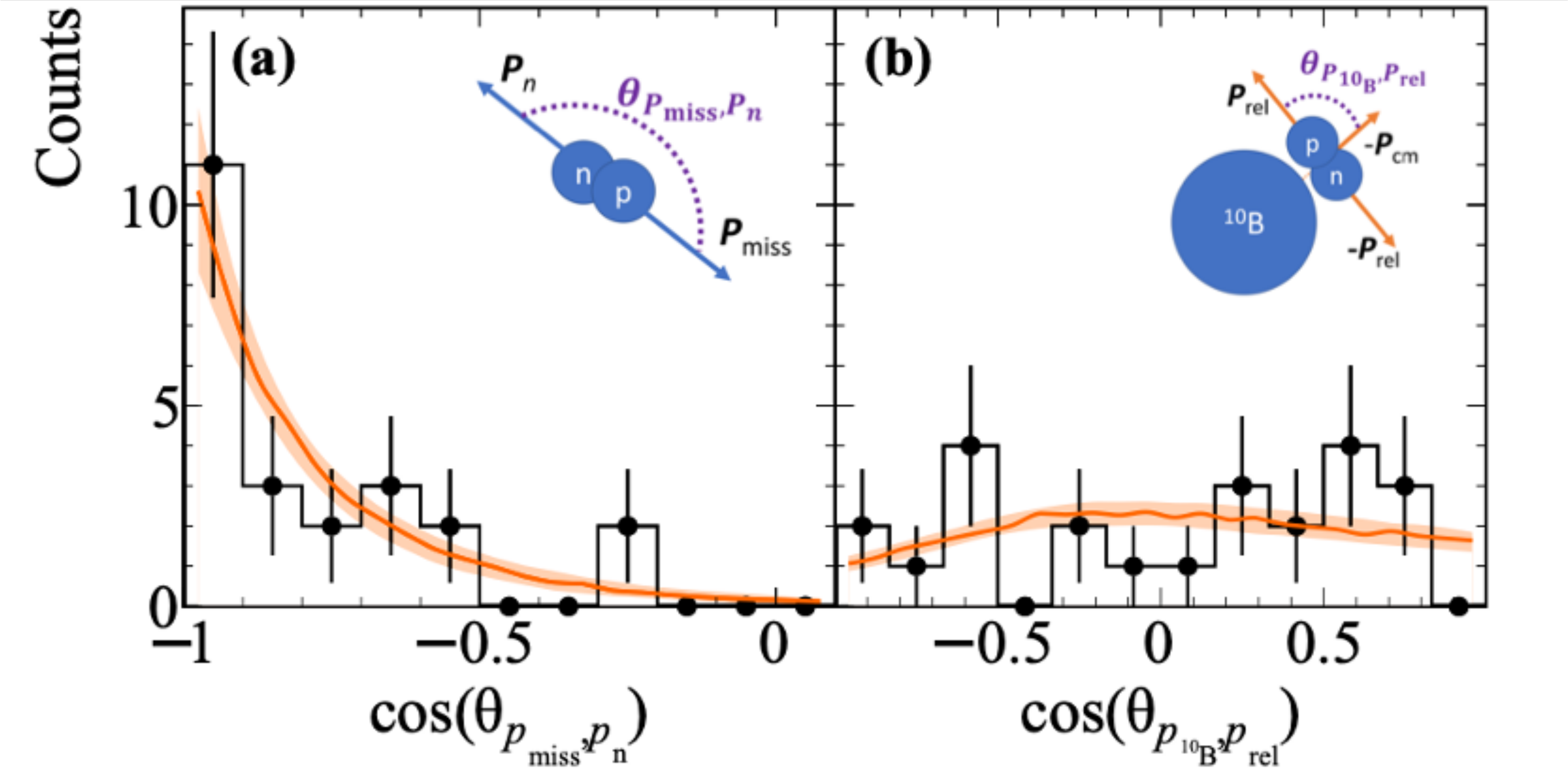


Hadron-scattering measurements of SRCs

- 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



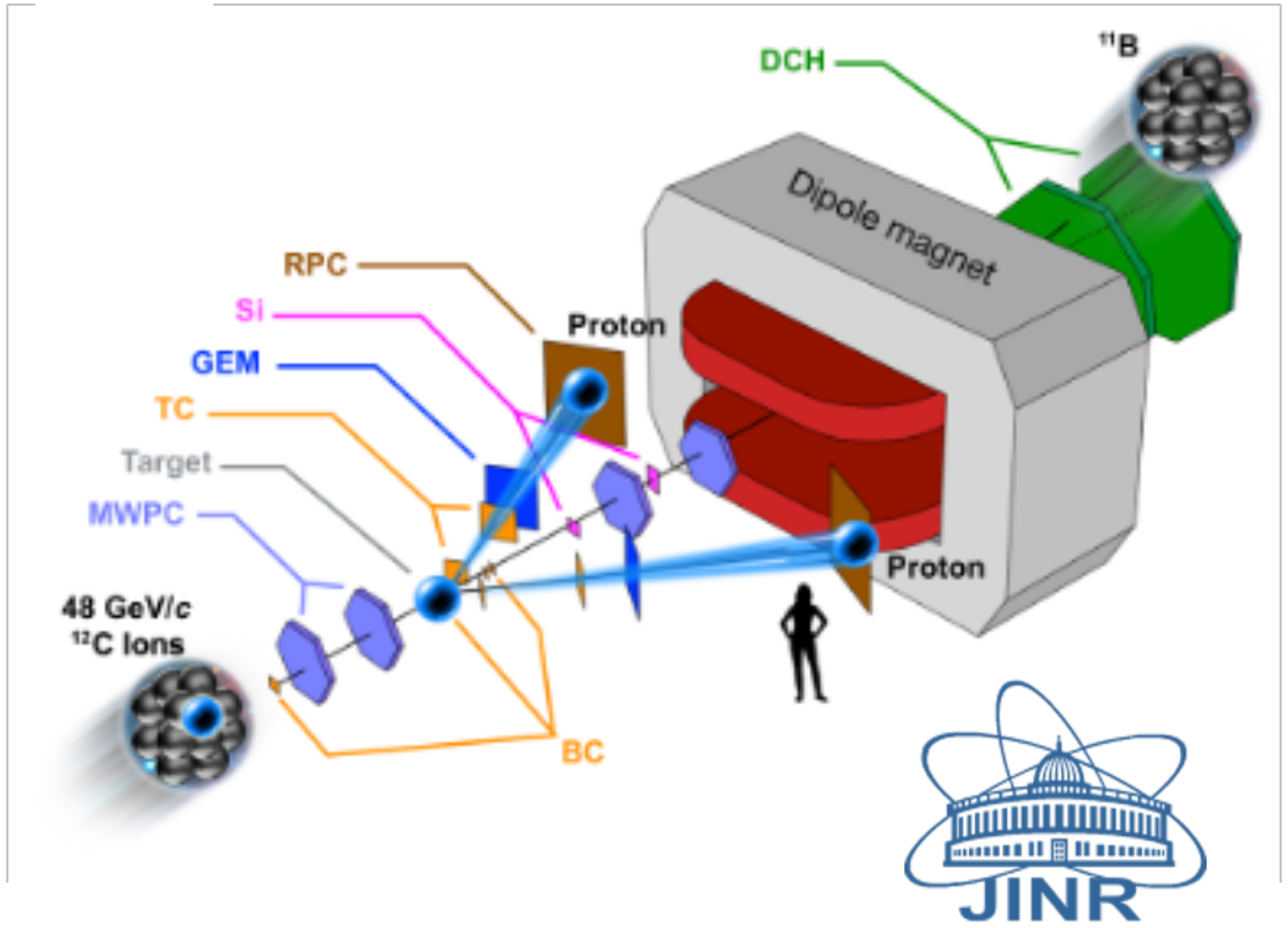
Experimental evidence for SRC scale-separation



M. Patsyuk et al, Nature Physics (2021)

Next generation of ion-beam SRC studies underway

JINR, Dubna



GSI, Frankfurt