Neutron-Proton Pair Dominance of SRC pairs with a Real Photon Beam

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Frontiers and Careers 2022

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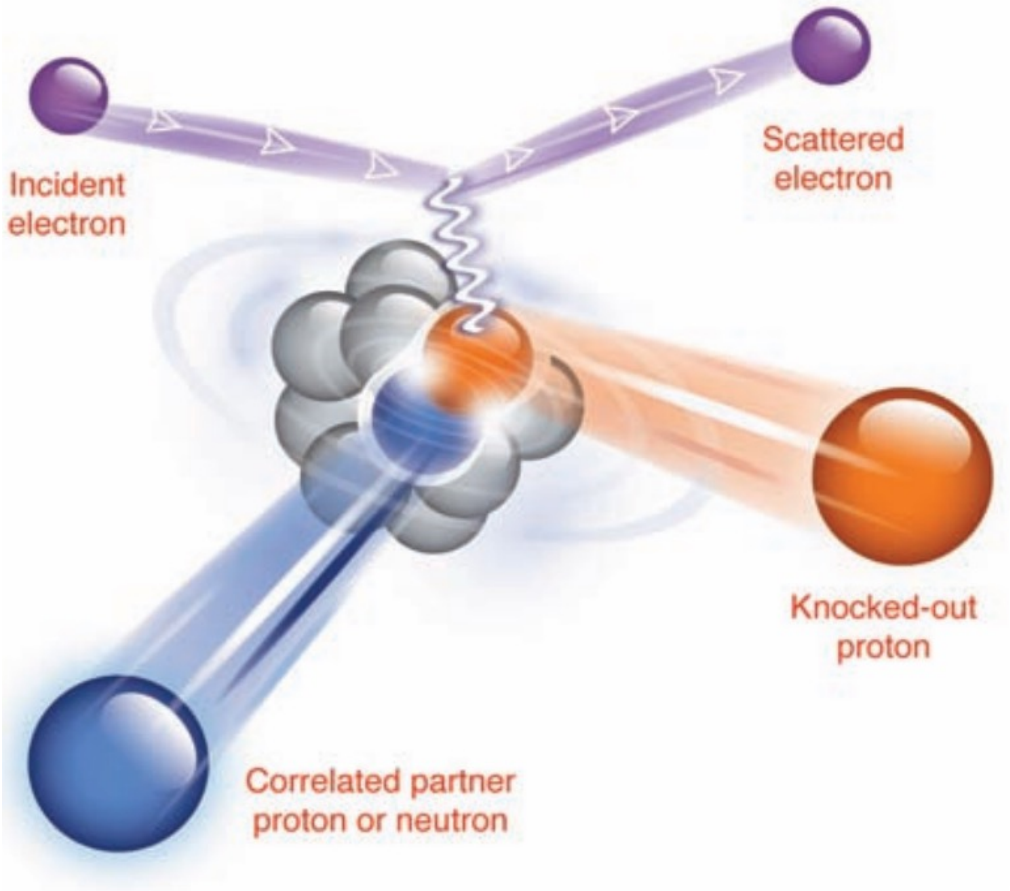
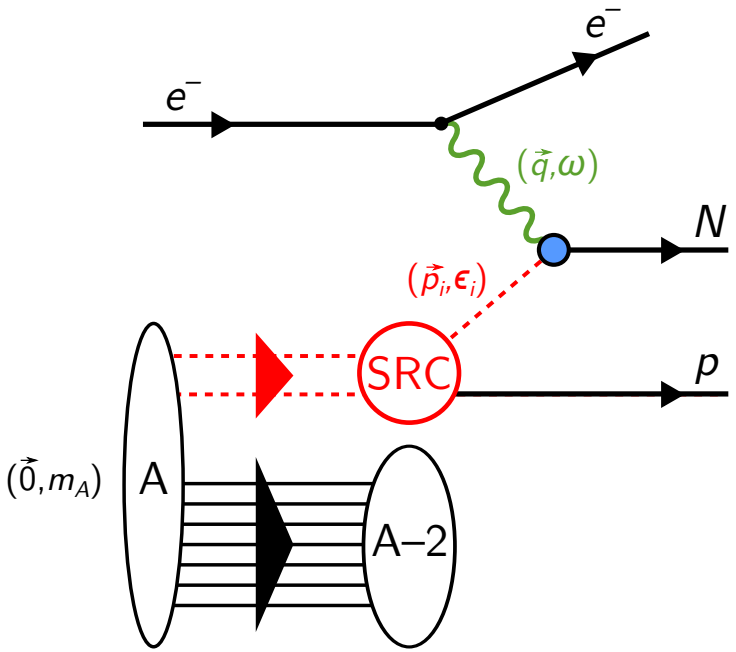
Previous Short Range Correlation(SRC) Experiments we taught us:

- SRCs are found in all nuclei
- 10-20% of nucleons are in SRC pairs
- SRCs have high relative momentum (compared to Fermi momentum)
- 90% of SRC pairs are neutron-proton (np) pairs
  - Np-dominance

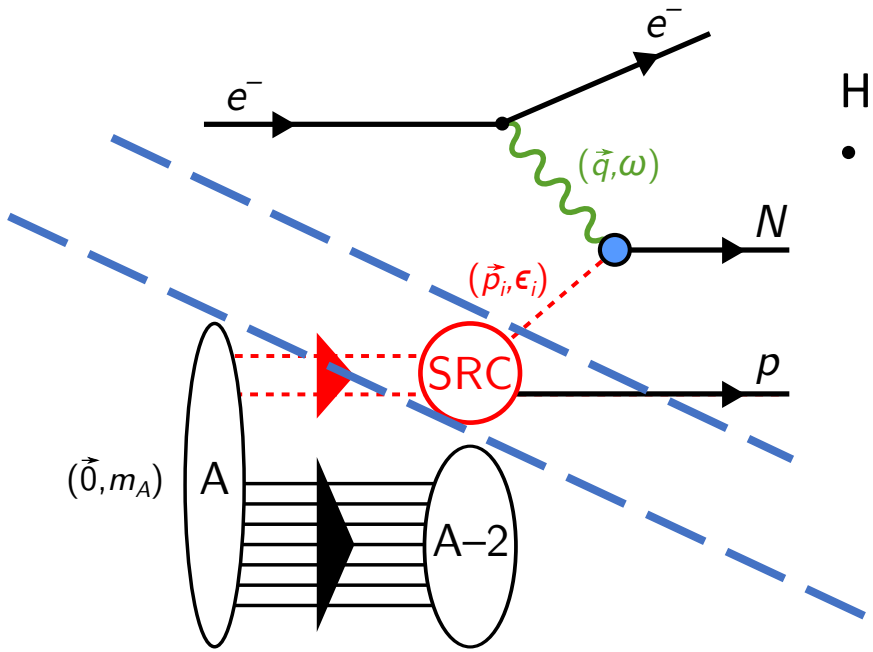


A primary goal of the ESCAPE experiment: Validate Scale Separation Observed in e^- scattering

A primary goal of the ESCAPE experiment: Validate Scale Separation Observed in e⁻ scattering



This reaction can be broken up into 3 scales.

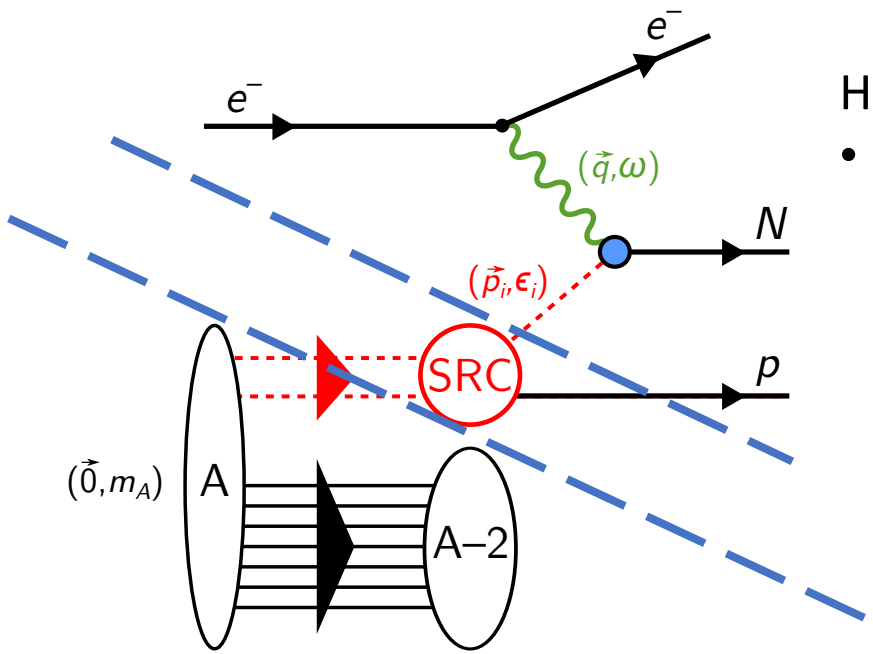


High Momentum
- Probe

Medium Momentum
- Relative Motion

Low Momentum
- CM Motion

We can describe these three scales with Generalized Contact Formalism (GCF).



High Momentum
- Probe

Medium Momentum
- Relative Motion

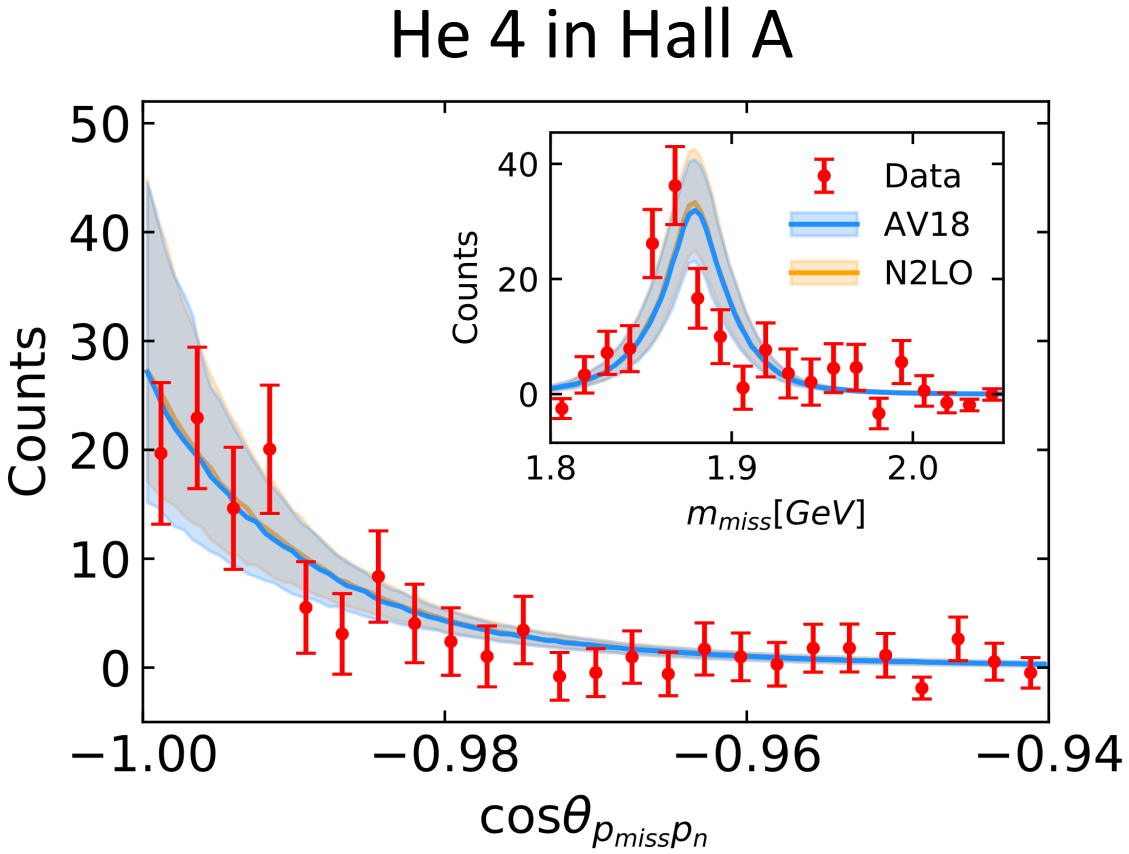
Low Momentum
- CM Motion

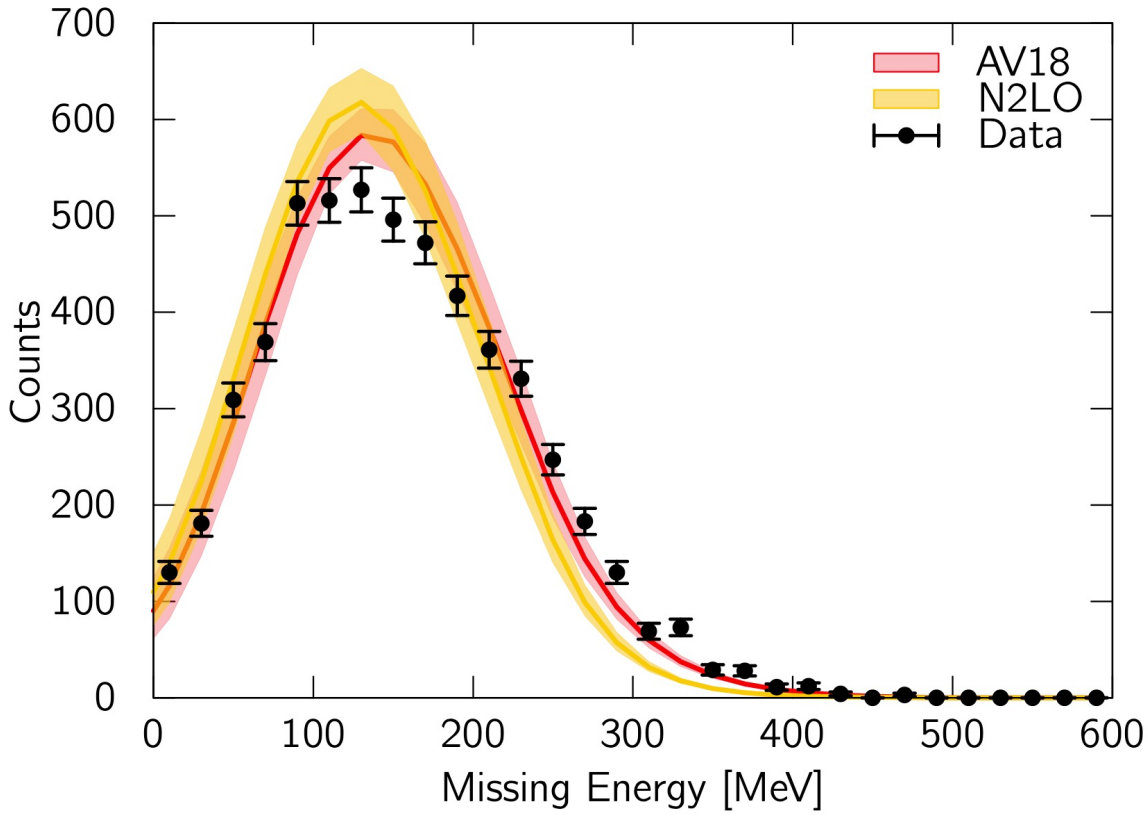
$$d\,\sigma \sim \sigma_{eN} \cdot \Sigma_\alpha\, C_\alpha \cdot P_\alpha(k_{cm}) \cdot \left|\tilde{\phi}(k_{rel})\right|^2$$

- σ_{eN}: single nucleon cross section
- C_α: Pair abundances (contacts)
- $P_\alpha(k_{cm})$: CM motion (Gaussian)
- $\left|\tilde{\phi}(k_{rel})\right|$: Rel. Motion (2-body)

Leads to Factorized Approximation!

GCF and previous e⁻ scattering experiments

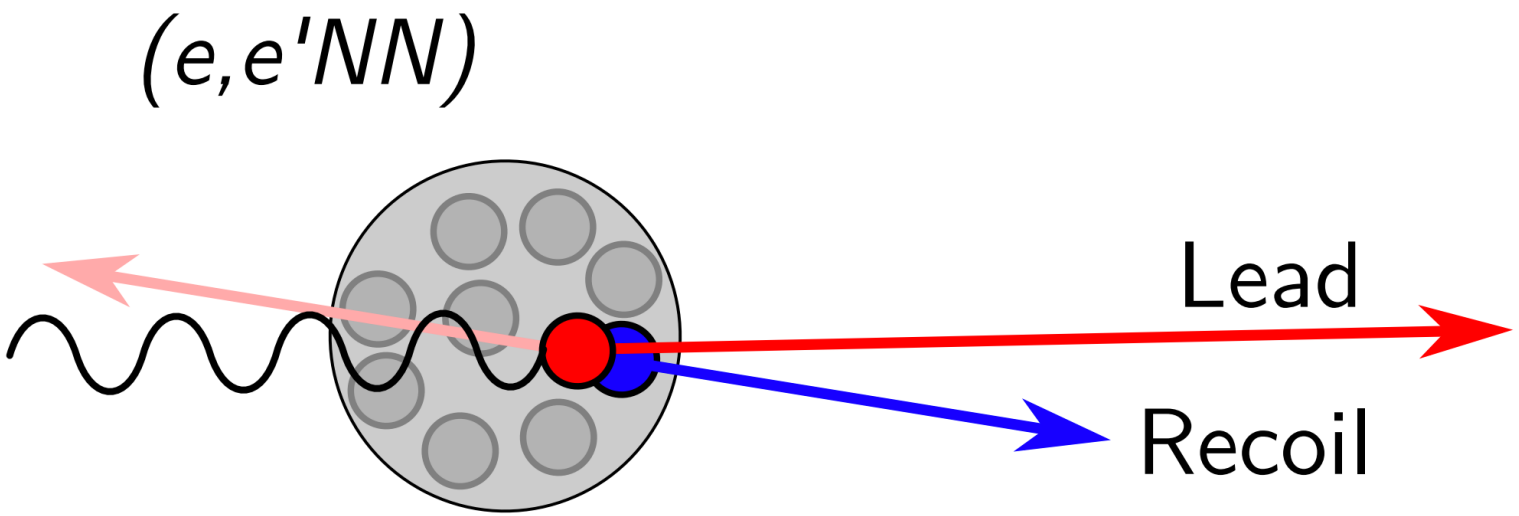




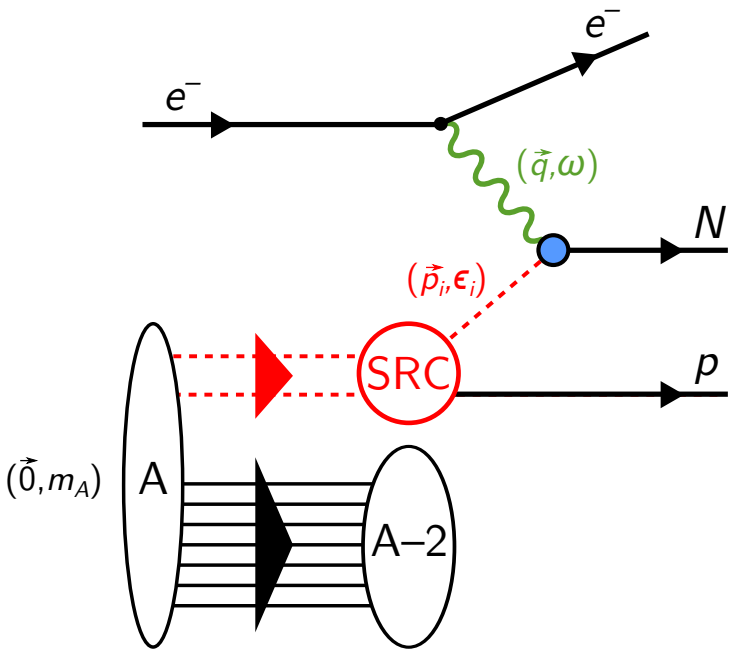
Pybus, J. R., et. al, (2020). Generalized contact formalism analysis of the 4 He (e , e pN) reaction. *Physics Letters B*, *805*, 135429.

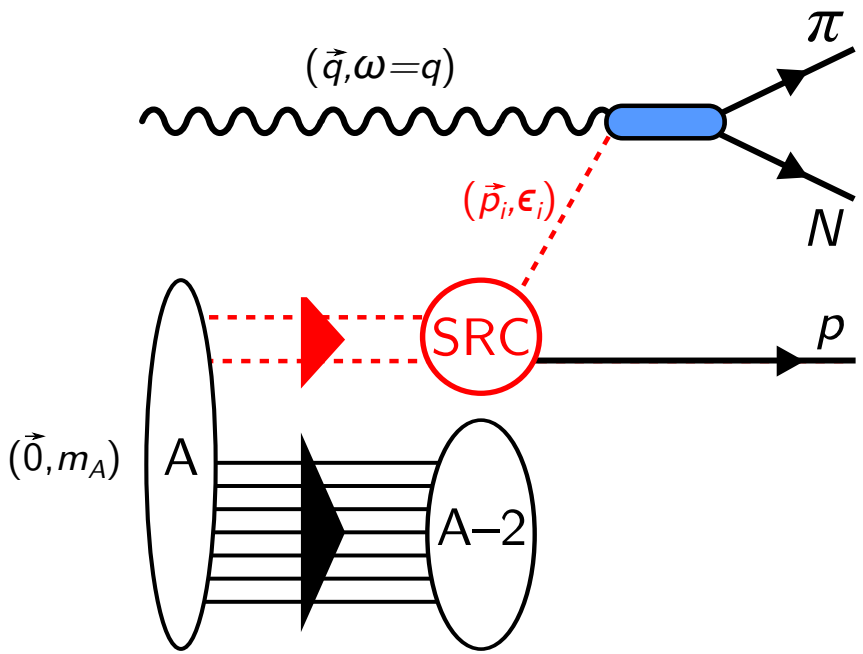
Schmidt, A., et.al. *Probing the core of the strong nuclear interaction*. Nature *578*(February 2020).

Caveat: These results work in a narrow wedge of anti-parallel kinematics.



Scale separation: hard reaction factorizes





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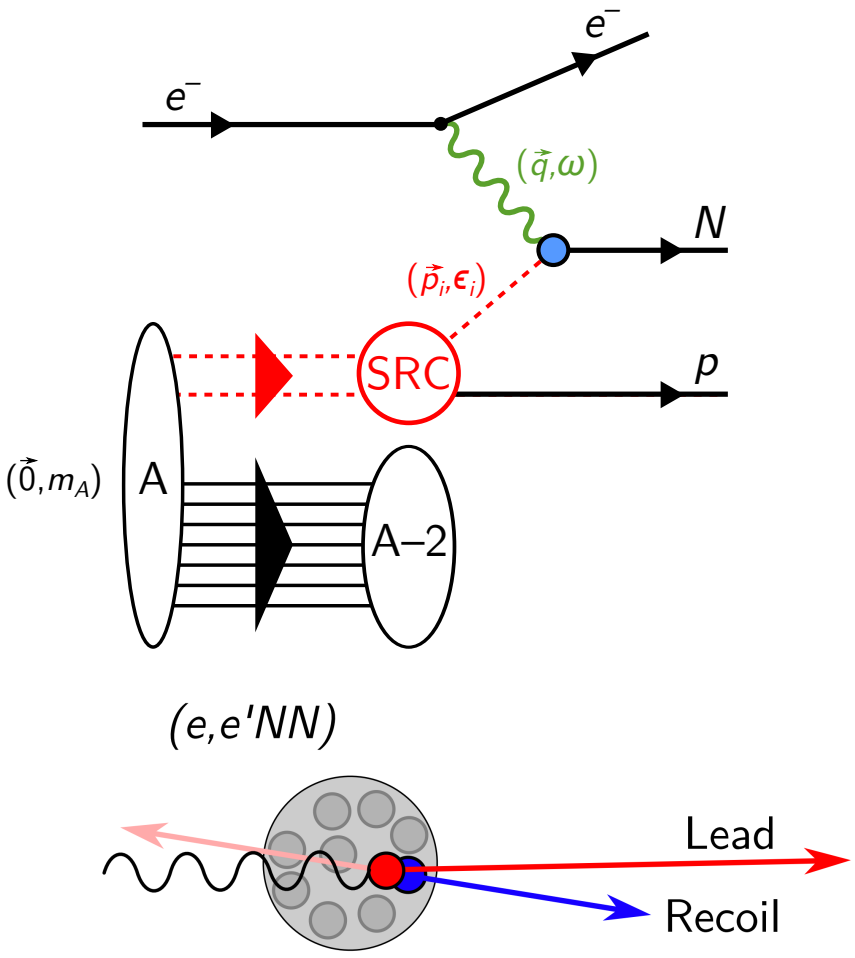
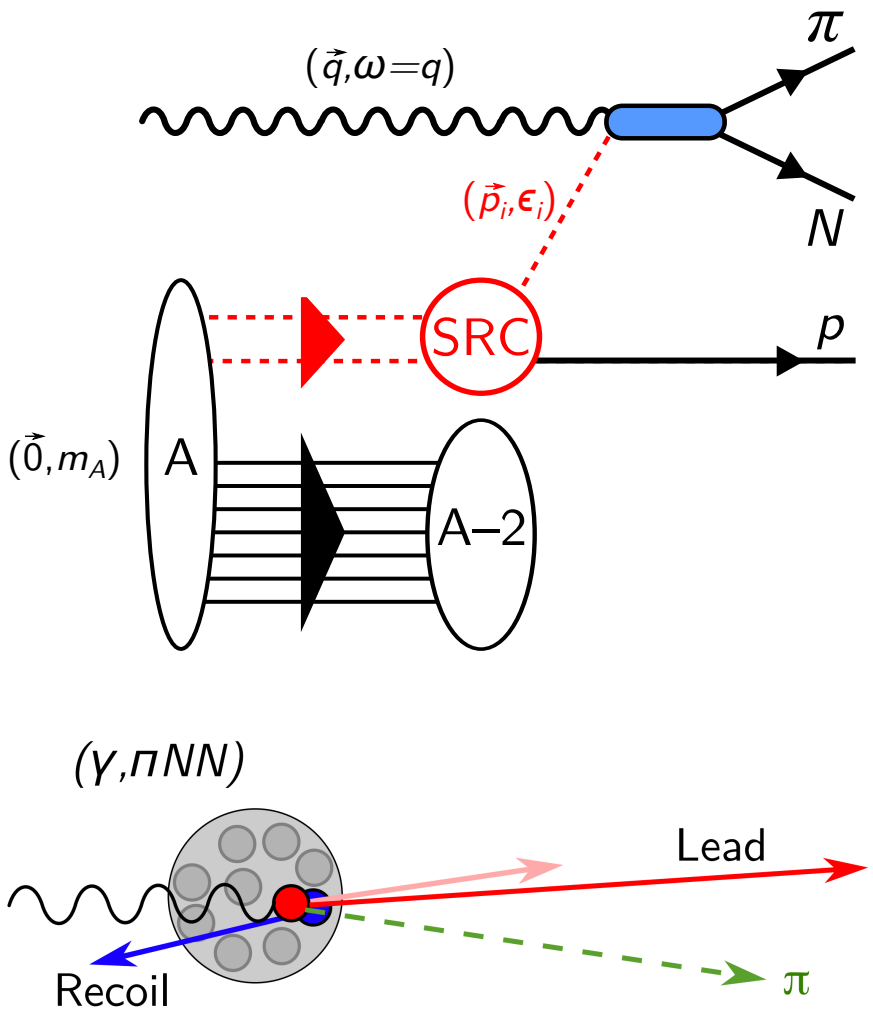
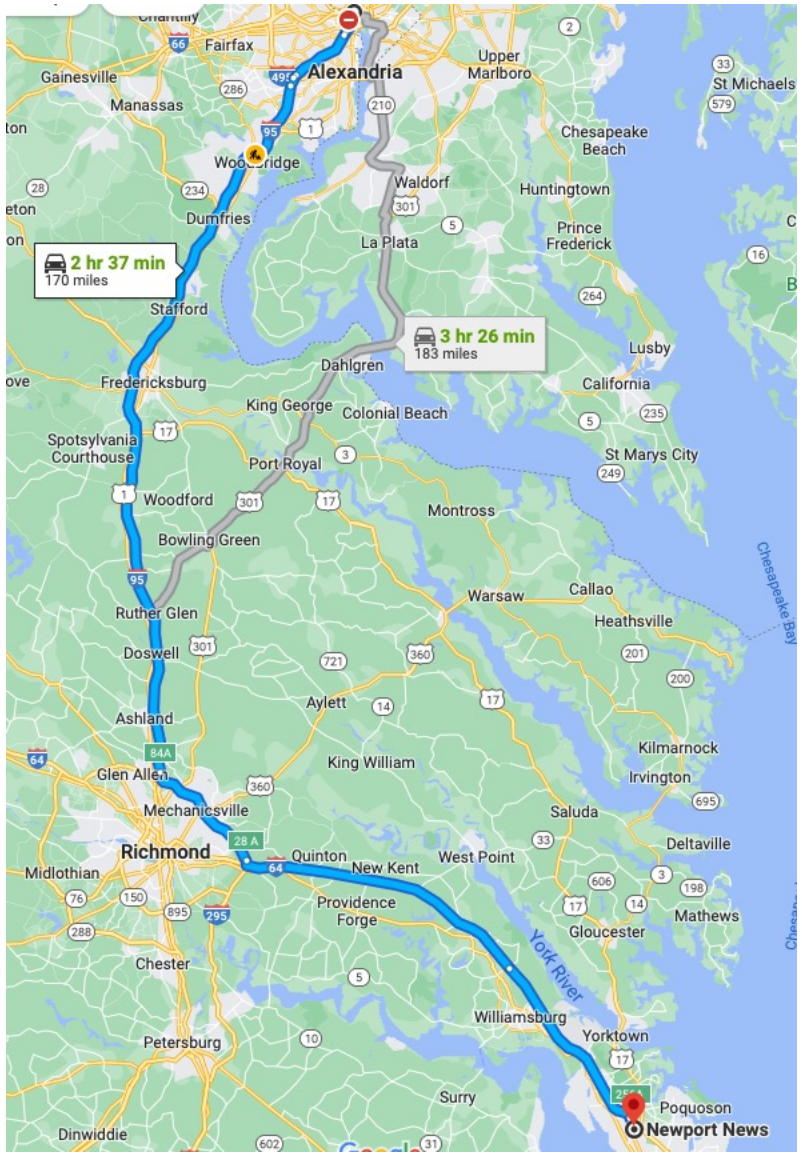


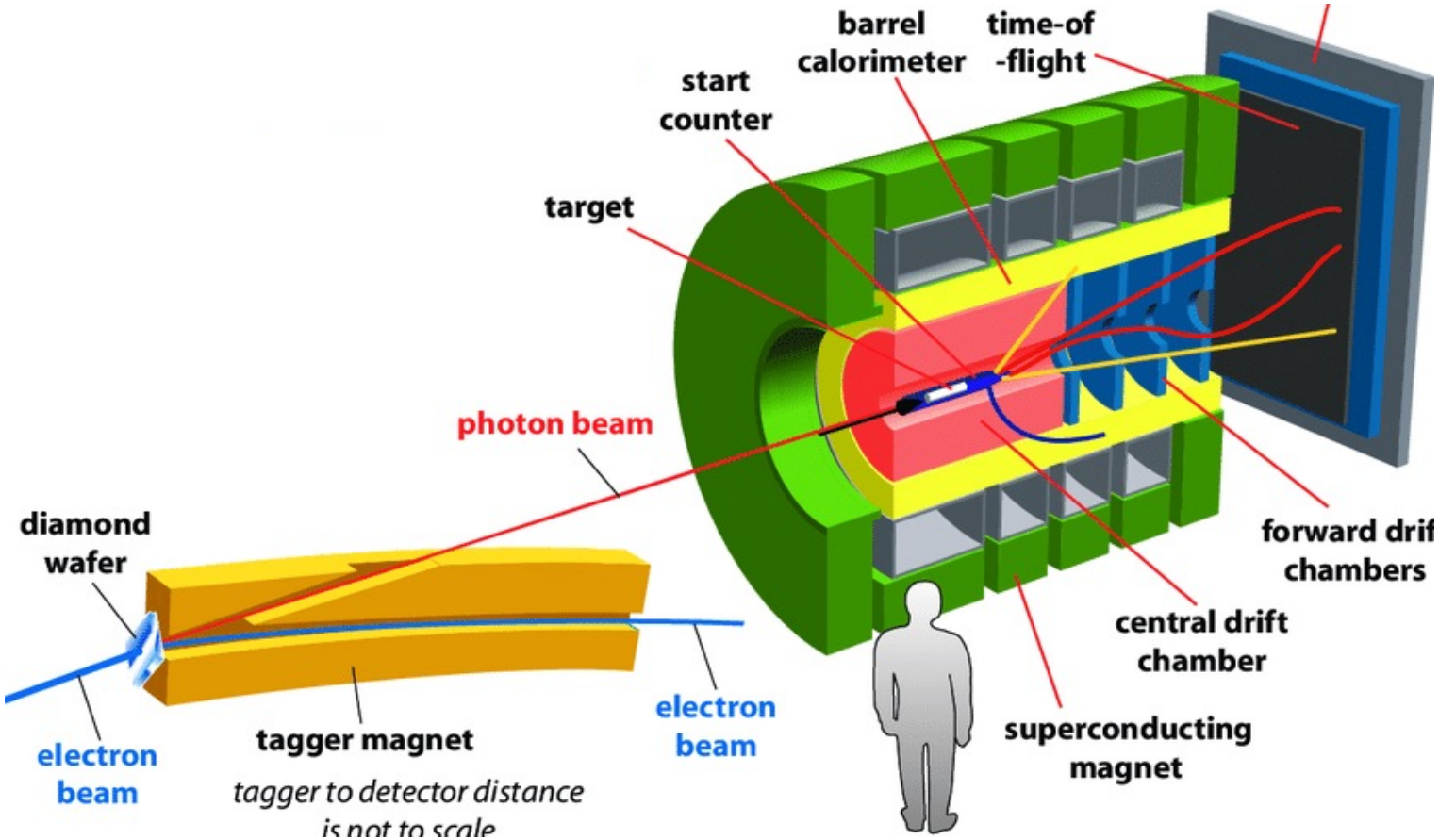


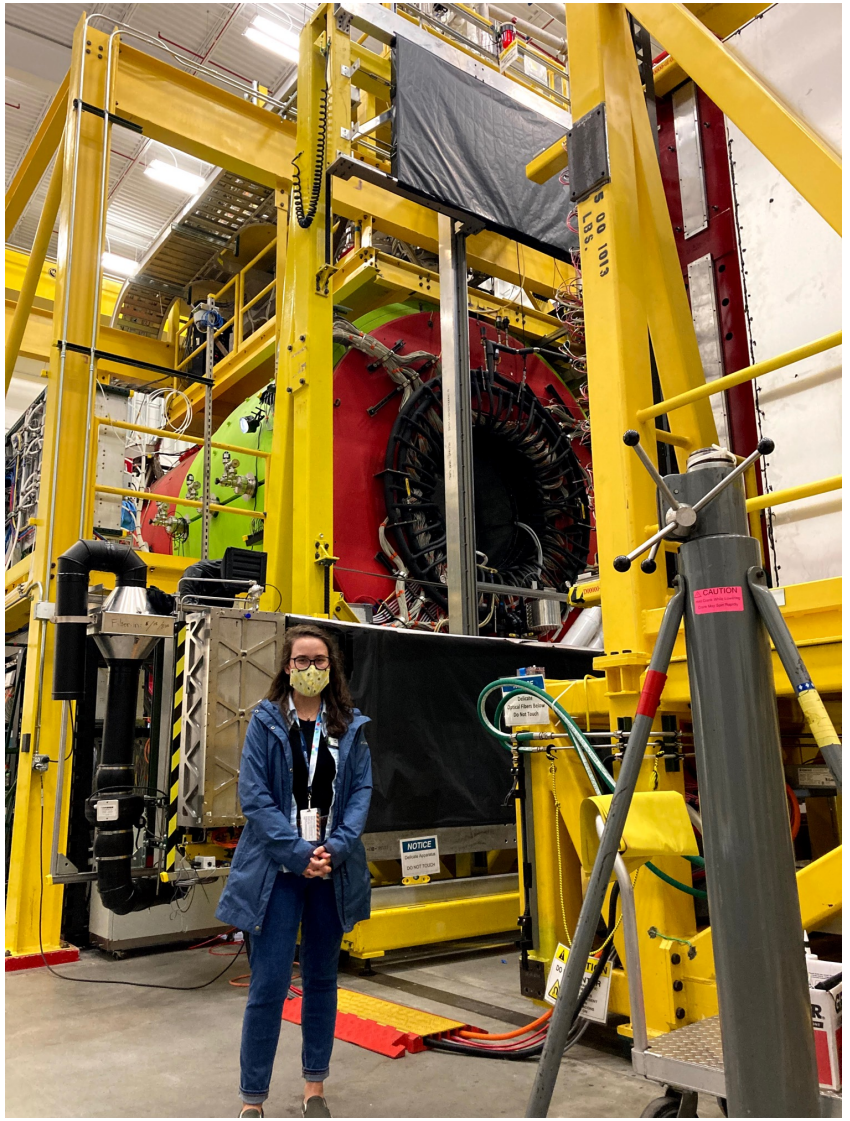
Jefferson Lab



https://phys.org/news/2015-12-jefferson-lab-gev-electrons.html

GlueX: Glossy Schematic





GlueX Collaboration, et al. *First Results from The GlueX Experiment*. Dec. 2015. *ResearchGate*, doi:10.1063/1.4949369.

ESCAPE: Experimental Details

- November - December 2021
- 43 days
- Collaboration at GW, MIT, Duke, MSU, Tel Aviv, ODU, and JLab

Target	Days on Beam
Liquid Helium 4	10
Liquid Deuterium	4
Carbon Multi-Foil	14

This experiment looked at a number of reaction channels.

p reactions	n reactions
$\gamma p \to \pi^0 p$	$\gamma n \to \pi^- p$
$\gamma p \to \pi^- \Delta^{++}$	$\gamma n \to \pi^- \Delta^+$
$\gamma p \to \rho^0 p$	$\gamma n \to \rho^- p$
$\gamma p \to K^+ \Lambda$	$\gamma n \to K^0 \Lambda$
$\gamma p \to K^+ \Sigma^0$	$\gamma n \to K^0 \Sigma^0$
$\gamma p \to \omega p$	$\gamma n \to K^+ \Sigma^-$
$\gamma p \to \phi p$	$\gamma n \to K^- \Sigma^+$
$\vdots$	$\vdots$

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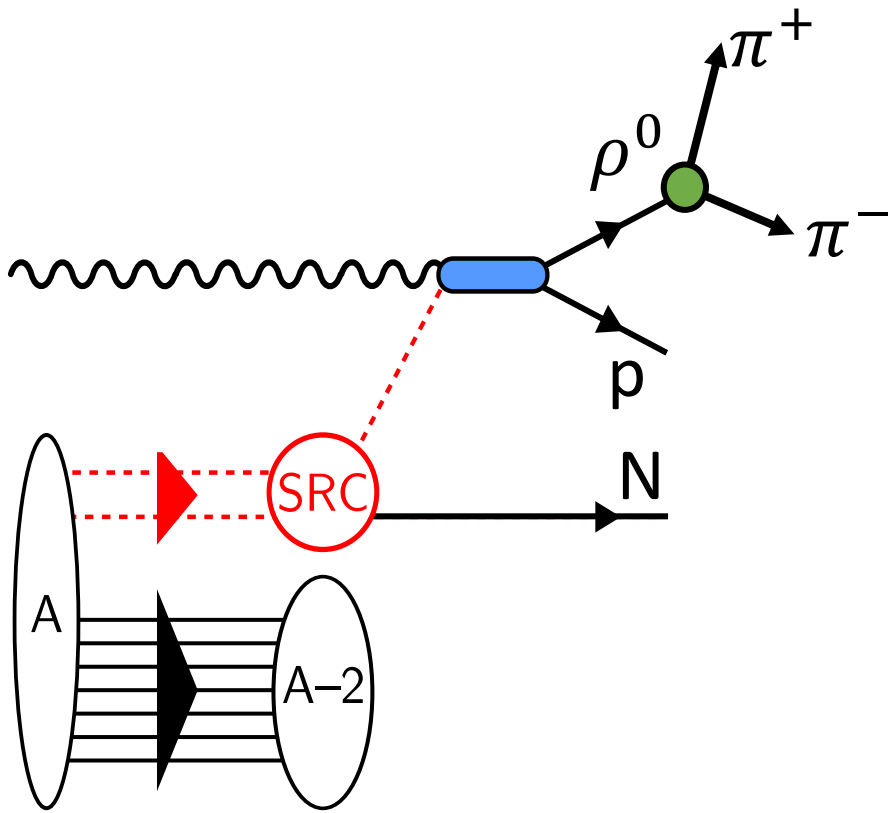
$$\gamma + p \rightarrow \rho^0 + p \rightarrow \pi^+ + \pi^- + p$$



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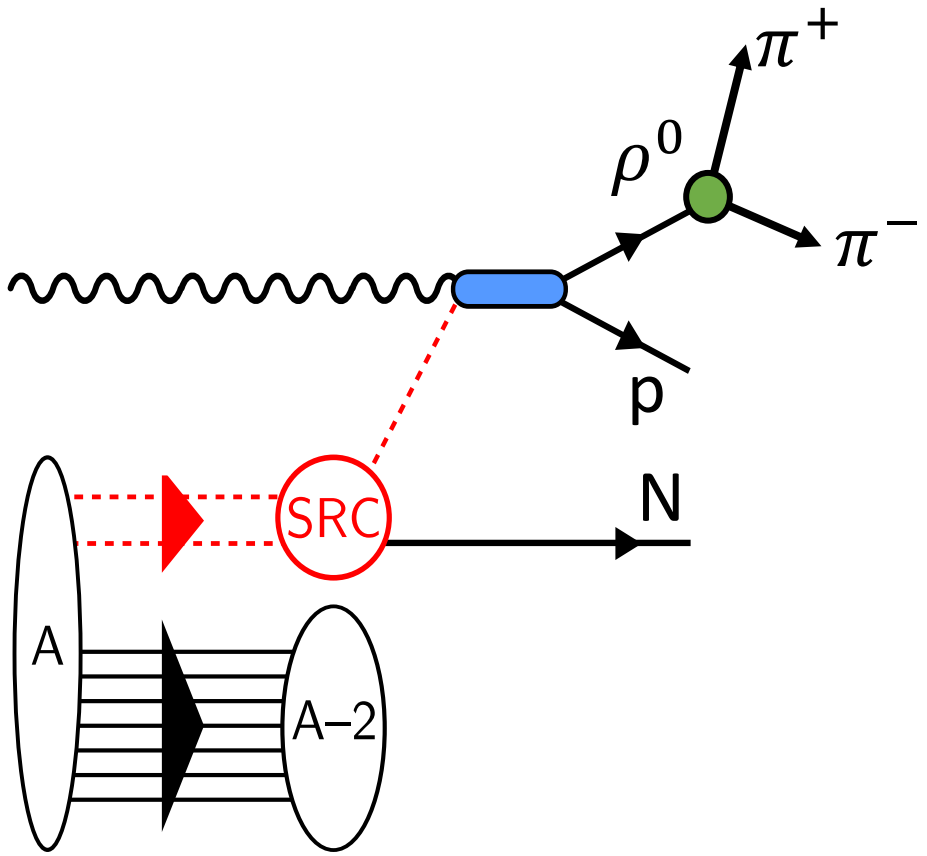
⋮	⋮

Tagged SRC pair from ρ^0



$$d\,\sigma \sim \sigma_{eN} \cdot \Sigma_\alpha\, C_\alpha \cdot P_\alpha(k_{cm}) \cdot \left|\tilde{\phi}(k_{rel})\right|^2$$

- σ_{eN}: single nucleon cross section
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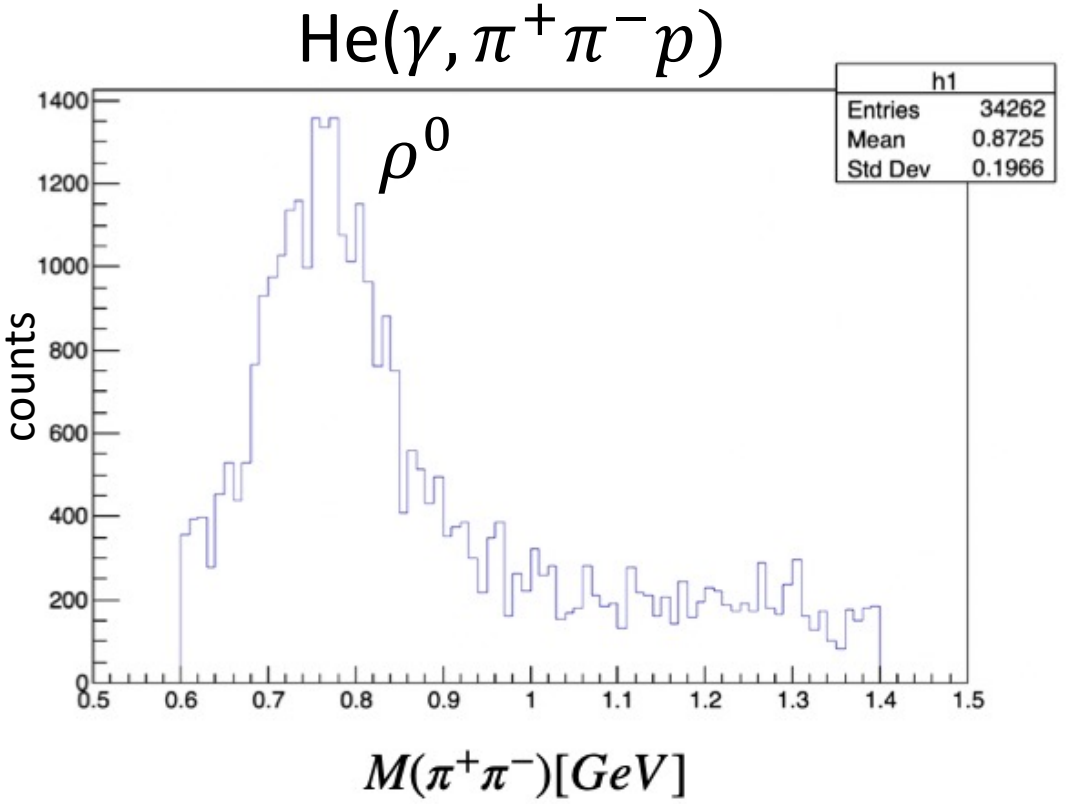
$$d\,\sigma \sim \boldsymbol{\sigma_{\rho^0}} \cdot \Sigma_\alpha\, C_\alpha \cdot P_\alpha(k_{cm}) \cdot \left|\tilde{\phi}(k_{rel})\right|^2$$

The ρ^0 meson is a great for identifying SRC pair breakup.

- High Cross Section
  - Vector Meson Dominance
  - $J^{\pi C}_{\rho^0} = 1^{--}$



Plot Credit: N. Santiesteban. Fall 2021

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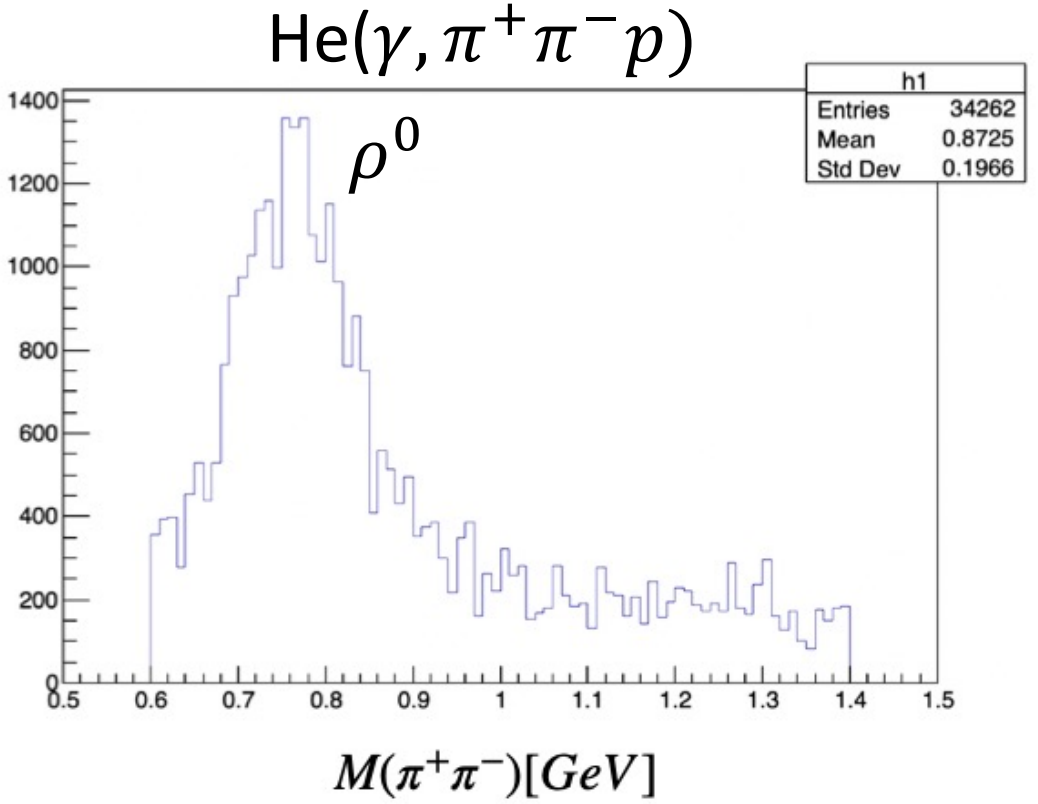
  - ρ^0 lifetime: ~4.5×10^{-24} s



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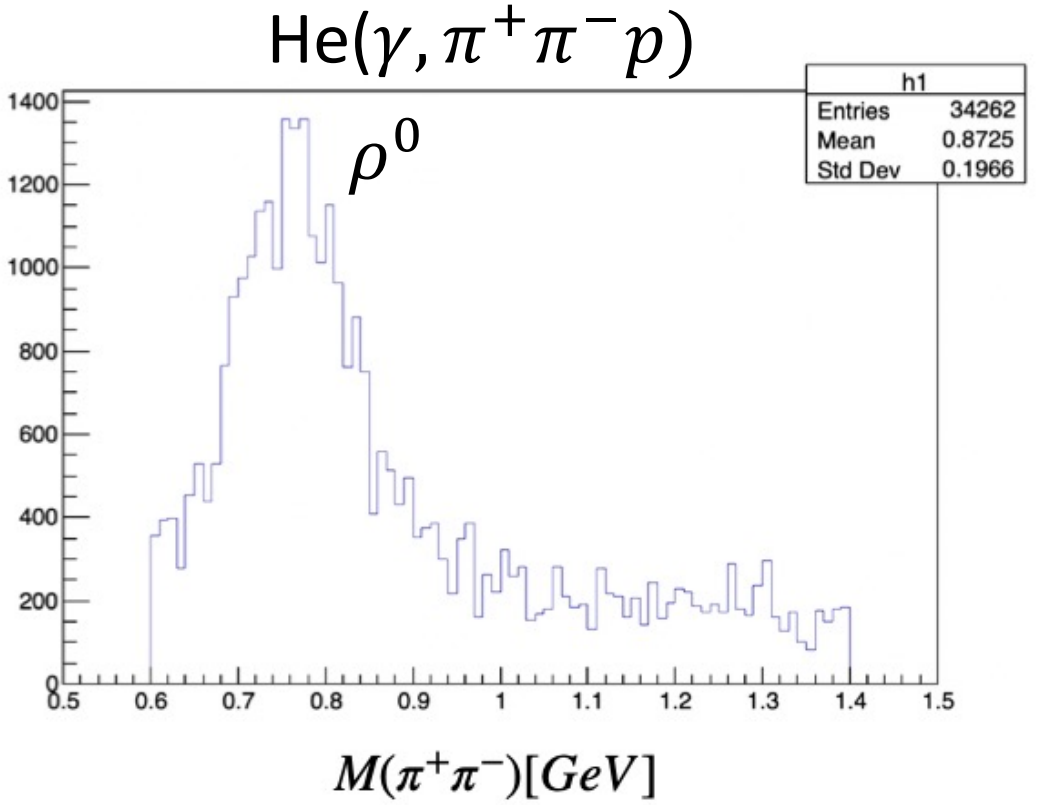
- Always decays into π^+ and π^-
  - ρ^0 lifetime: ~4.5×10^{-24} s
- Identified by invariant mass
  - ρ^0 mass: 0.775 GeV/c^2



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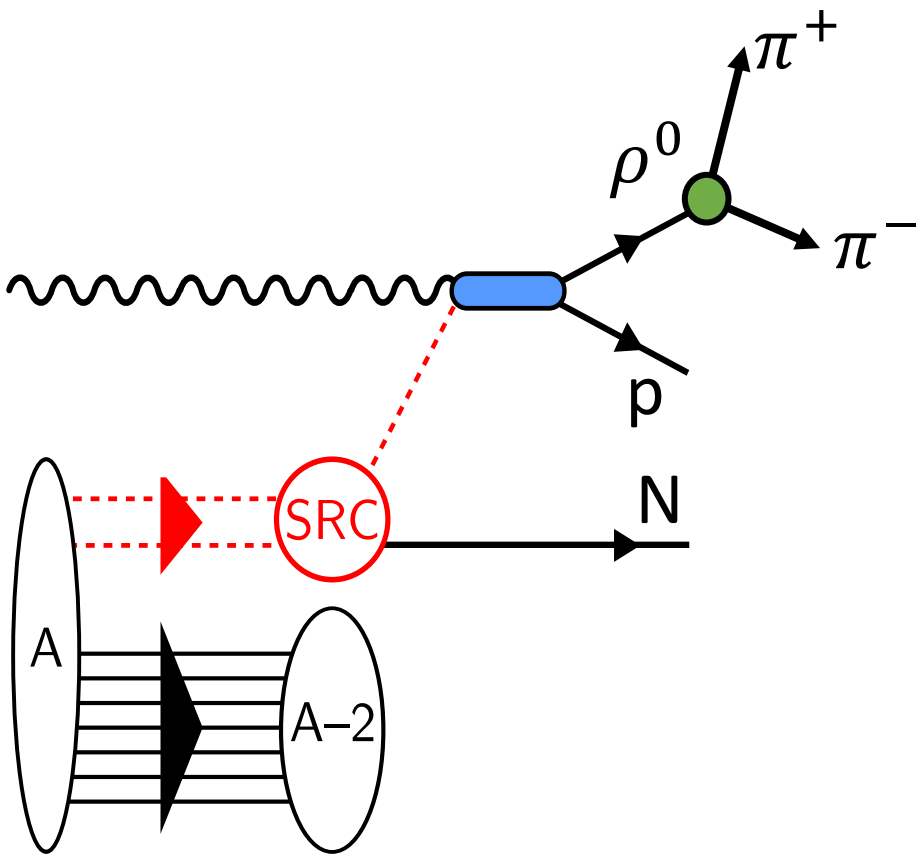
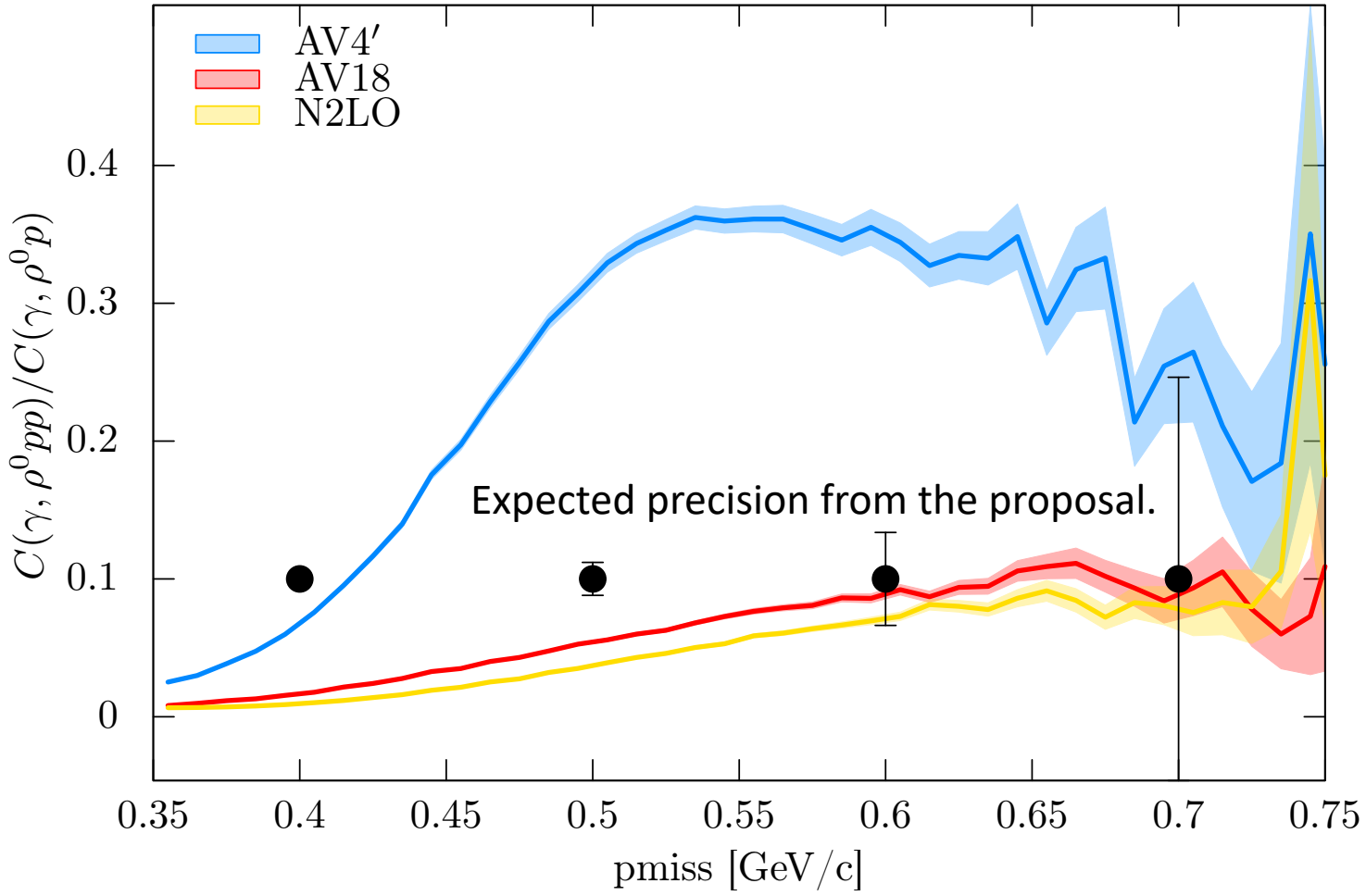
Using the ρ^0 reaction channel, I want to answer these question:

$$\gamma + p \rightarrow \rho^0 + p \rightarrow \pi^+ + \pi^- + p$$

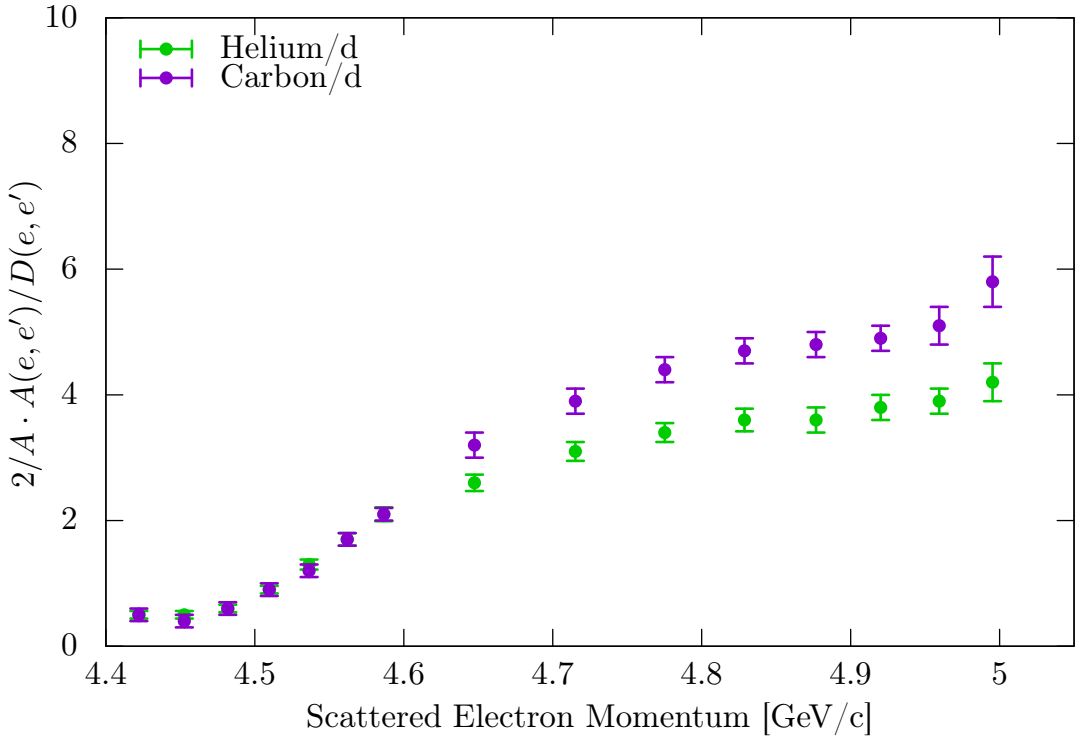


1. Can np-dominance be verified with photon scattering?
2. Can photoproduction confirm the abundances of SRC pairs?

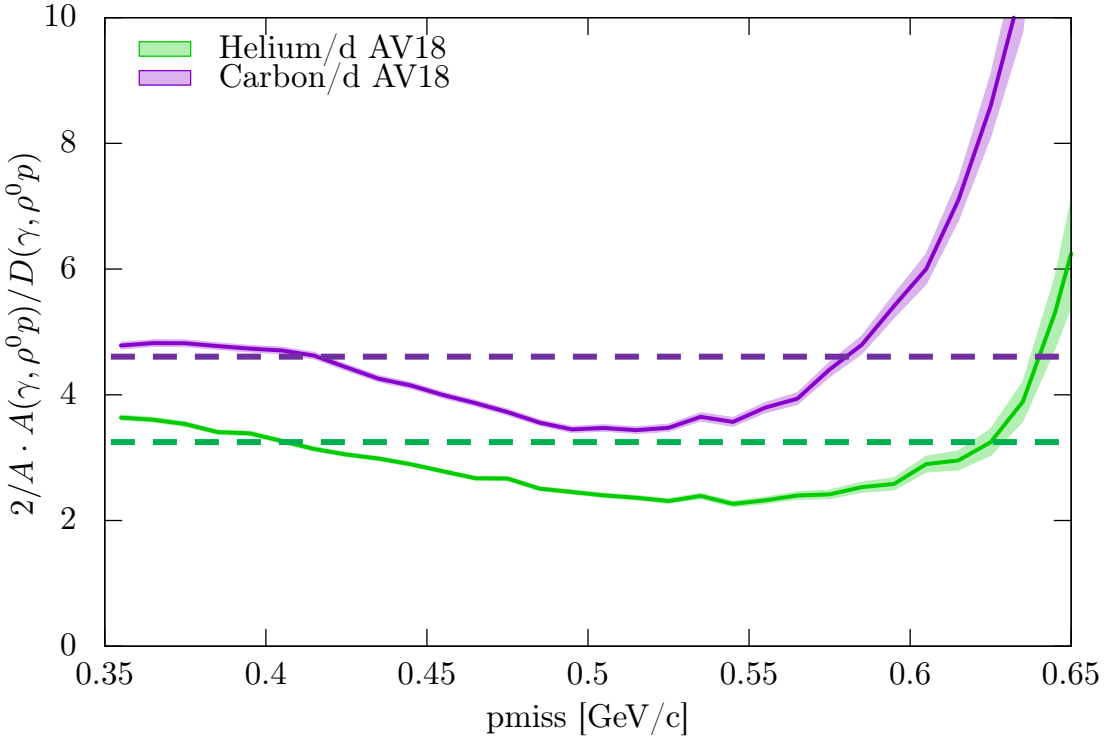
GCF Predictions of np-pair dominance using ρ^0 photoproduction.



GCF Predictions of pair abundances using ρ^0 photoproduction.



Previous electron scattering data



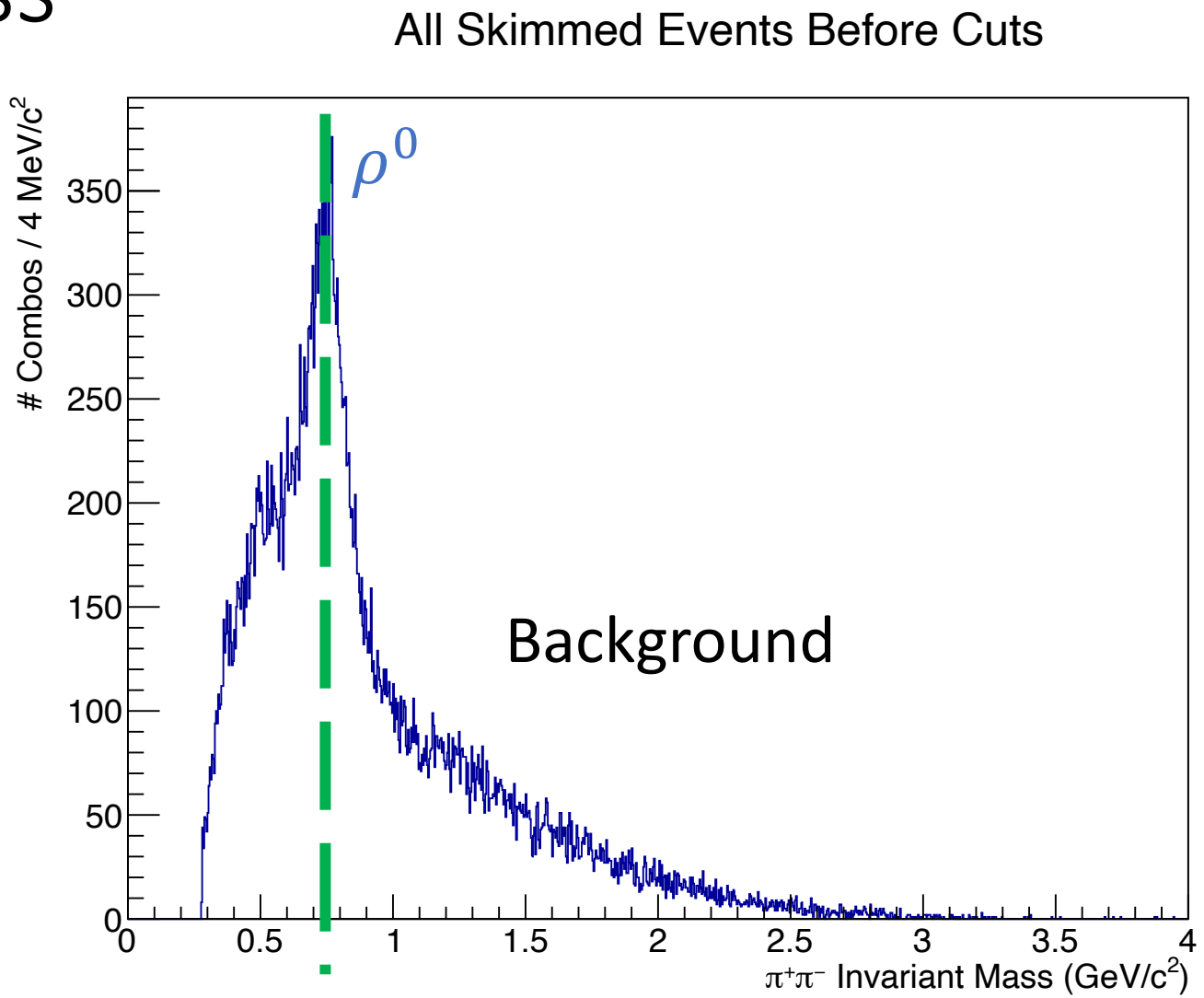
Photoproduction prediction

N. Fomin, J. Arrington, R. Asaturyan, F. Benmokhtar, W. Boeglin, P. Bosted et al., *New measurements of high-momentum nucleons and short-range structures in nuclei*, *Phys. Rev. Lett.* **108** (2012) 092502.

Data: Invariant Mass

$\gamma\, d \rightarrow \pi^+\, \pi^-\, p$ (n)

- Cuts Applied
  - KFCL > 0.01
  - PIDCL> 0.1
  - 6 < Ebeam < 10

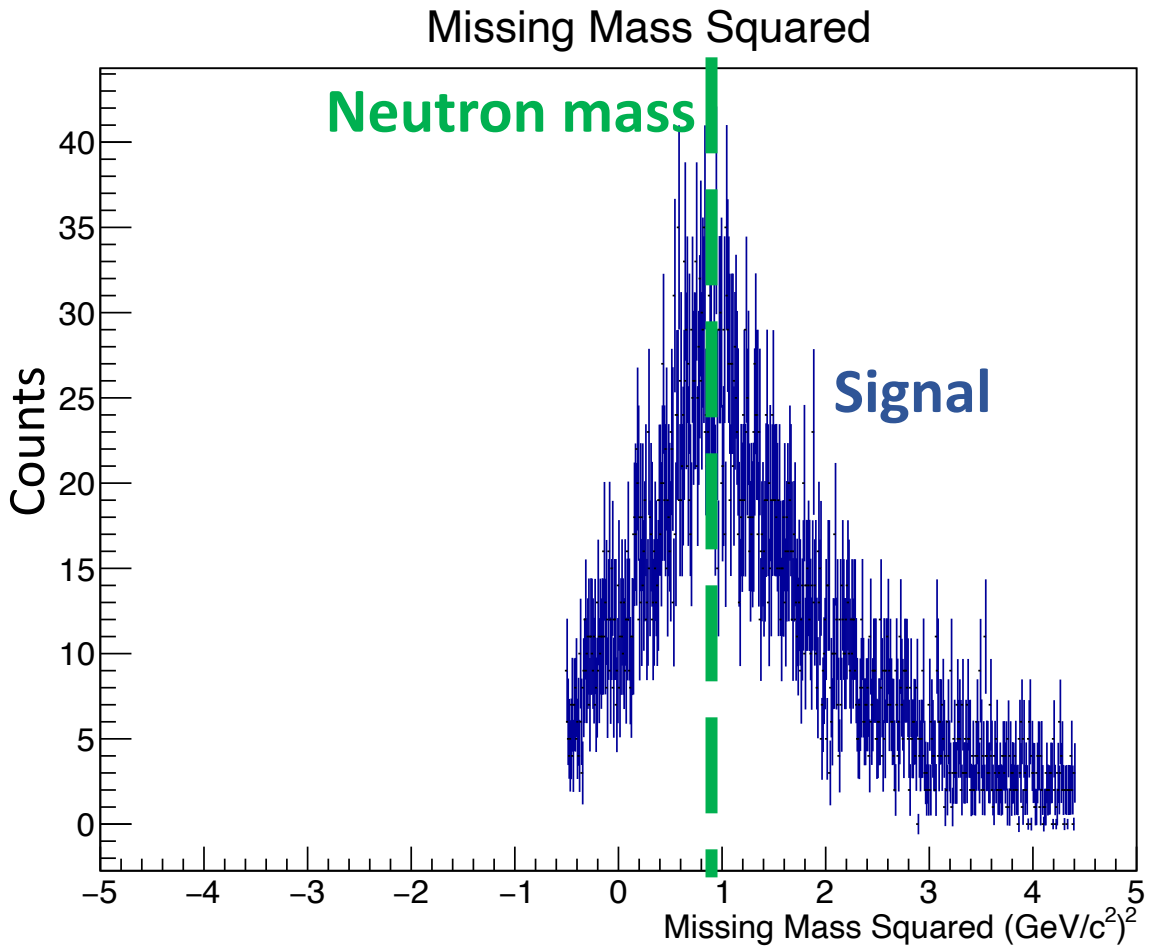


From < 1% of available data

Data: Missing Mass Squared

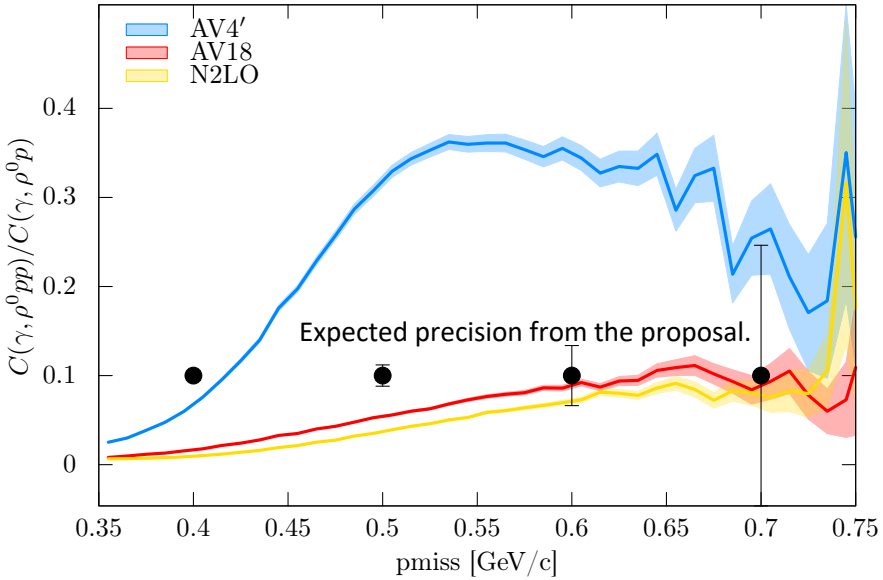
$\gamma\, d \rightarrow \pi^+\, \pi^-\, p$ (n)

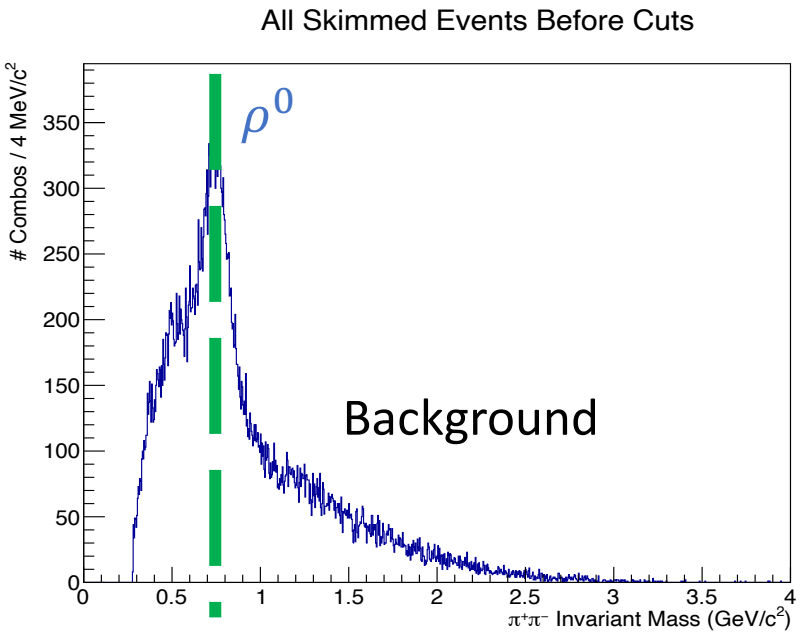
- Cuts Applied
  - KFCL > 0.01
  - PIDCL> 0.1
  - 6 < Ebeam < 10
  - OffTime Subtraction
  - Vertex Cuts

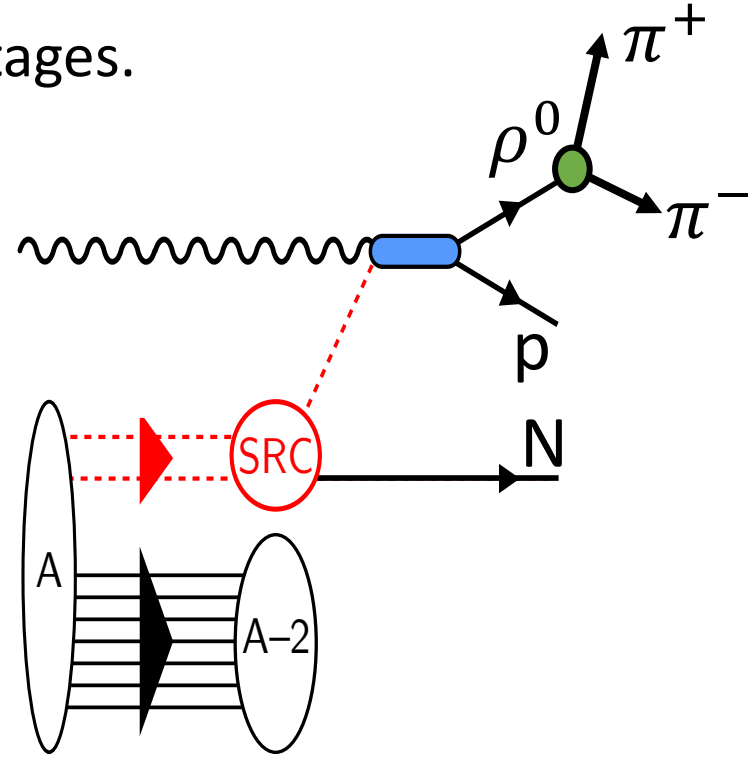


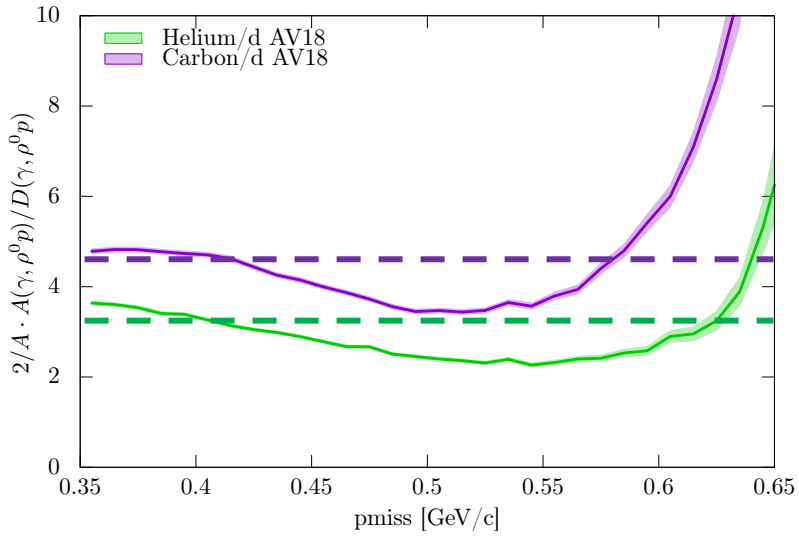
Conclusion

- The Hall D SRC/CT experiment will validate scale separation.
- Photoproduced ρ^0 mesons will be used to tag SRC pairs.
- Analysis is in preliminary stages.



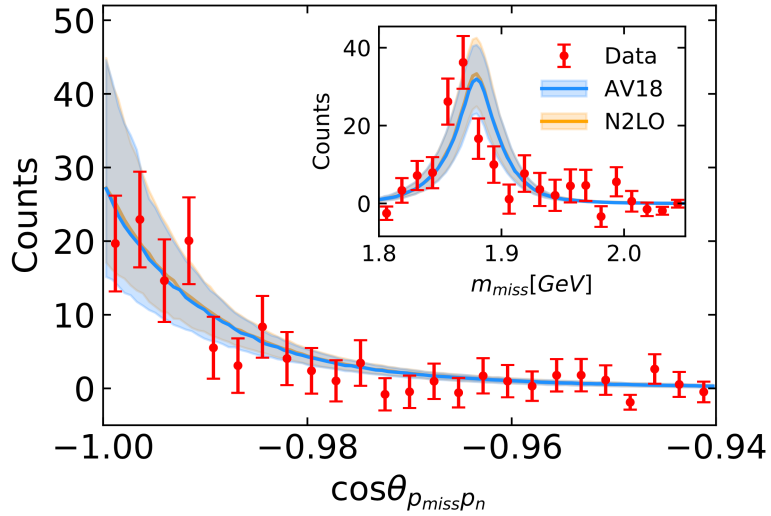


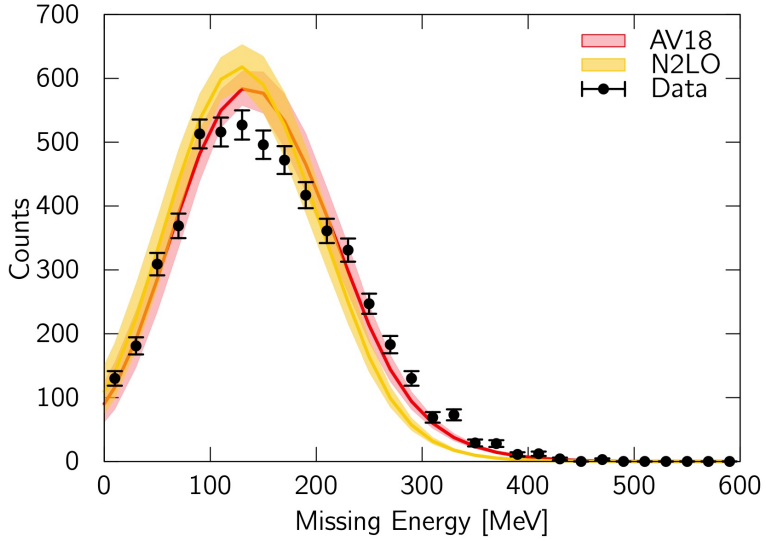




BACK UP

GCF in Electron Scattering SRC Papers





List of papers:

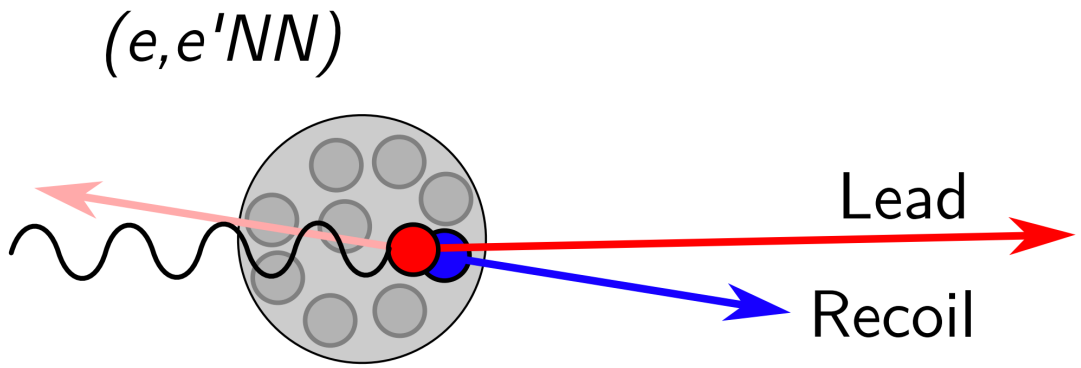
- Duer PRL 2019
- Schmidt Nature 2020
- Pybus PLB 2020
- Korover PLB 2021
- Weiss PRC 2021
- *Under Review:*
  - *Wright 2021, with PLB*
  - *Korover 2021, with Science*

Pybus, J. R., et. al, (2020). Generalized contact formalism analysis of the 4 He (e , e pN) reaction. *Physics Letters B*, *805*, 135429.

Schmidt, A., et.al. *Probing the core of the strong nuclear interaction*. Nature *578*(February 2020).

Caveat: These results work in a narrow wedge of anti-parallel kinematics.

- Typical Event Selection Criteria:
  - $x_B > 1.2$
  - $Q^2 > 1$
  - $\theta_{p_{miss},q} > 120^\circ$
  - $0.62 < \frac{|p|}{|q|} < 0.96$
  - $\theta_{p,q} < 25^\circ$



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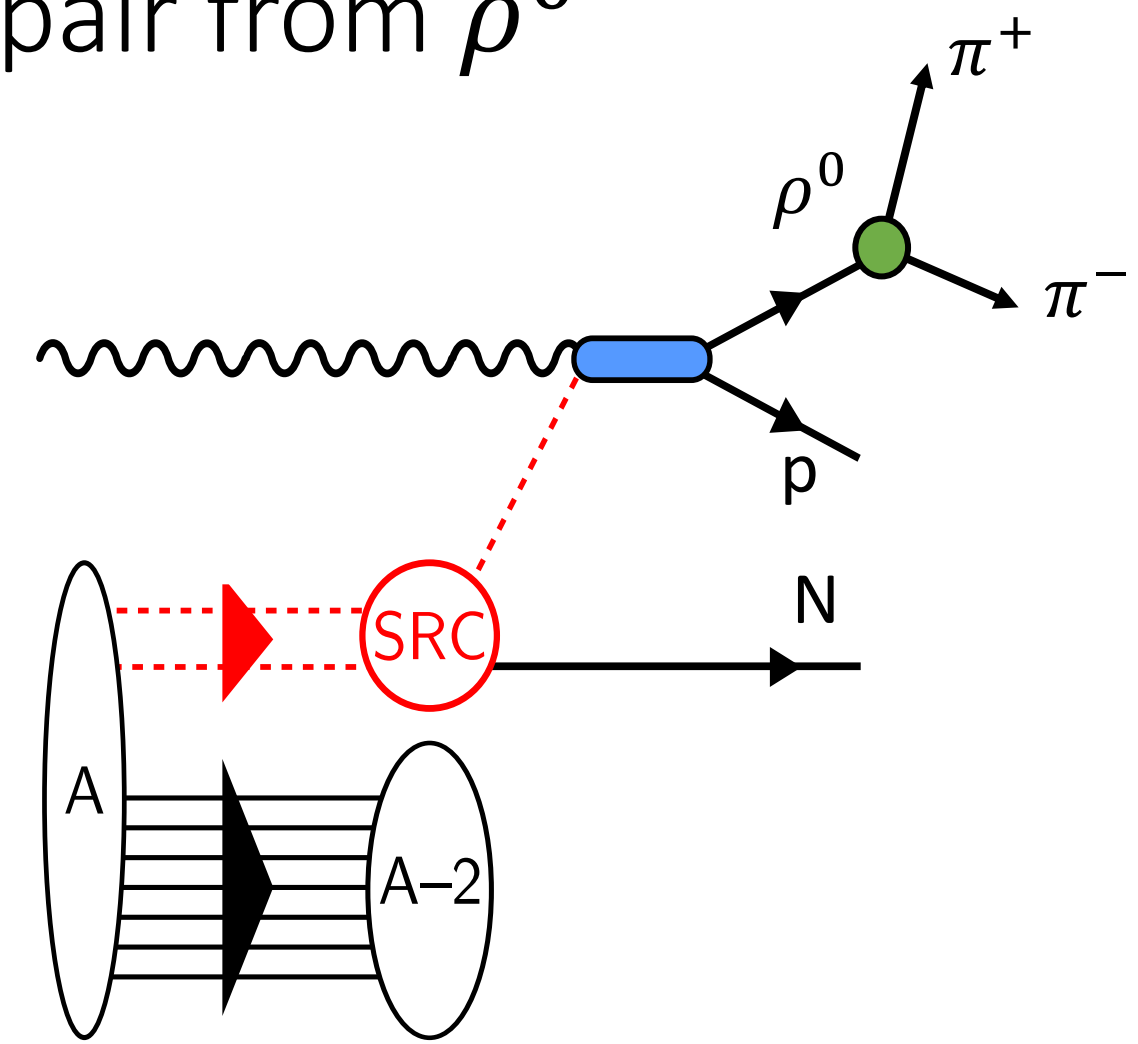
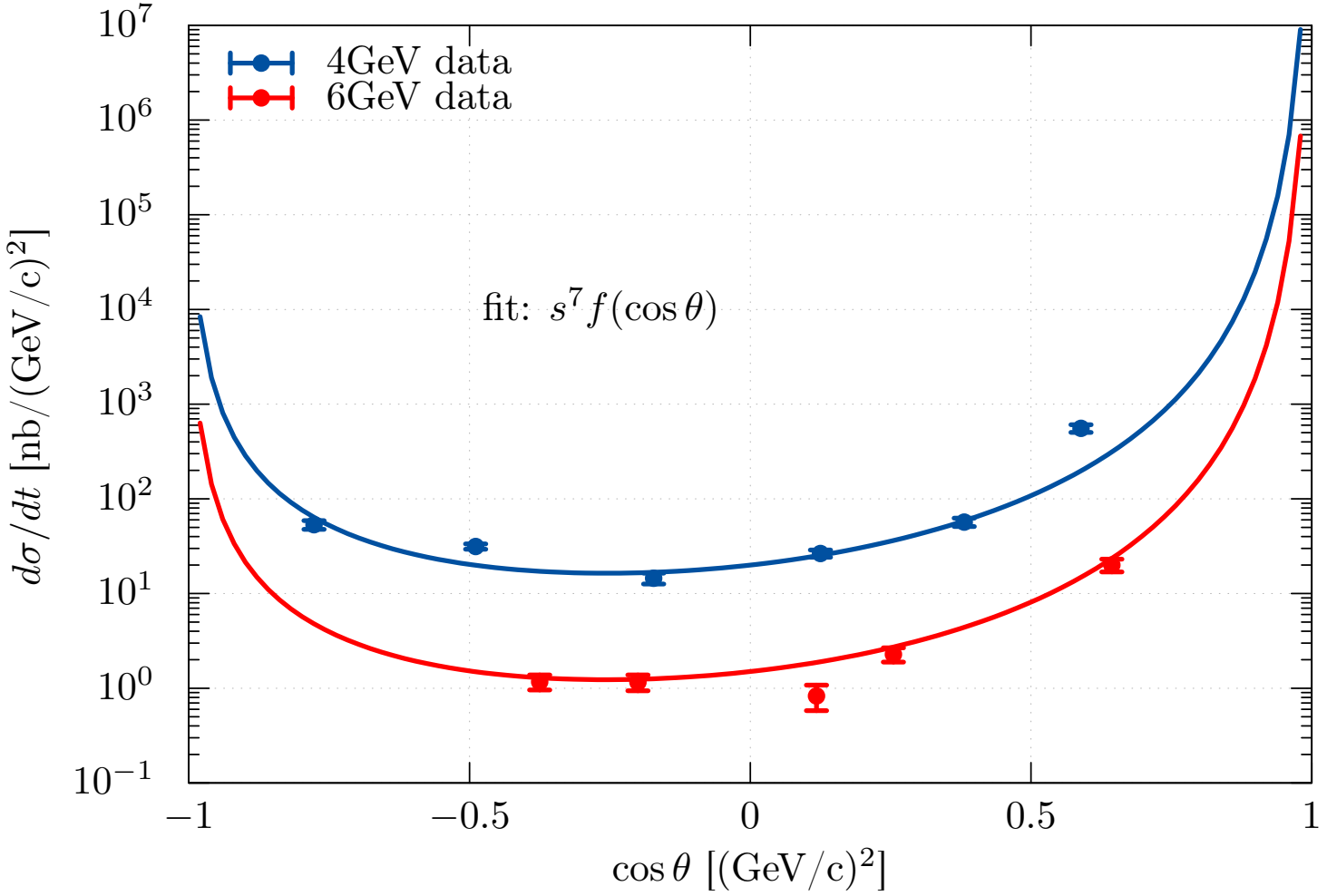


GCF predictions

- |u| and |t| > 2
- For lead proton:
  - $\theta_{baryon} > 1.5°$, $|p_{miss}| > 0.350$ GeV, and $\theta_{p_{miss}} < 45°$
- For recoil proton:
  - $\theta_{baryon} > 1.5°$, $|p_{miss}| > 0.350$ GeV, and $\theta_{p_{miss}} < 45°$
  - $\theta_{recoil} > 1.5°$, and $|p_{recoil}| > 0.350$ GeV

- No Geant yet

ρ^0 photoproduction cross sections have been measured, obey scaling laws



R.L. Anderson, D.B. Gustavson, D.M. Ritson, G.A. Weitsch, H.J. Halpern, R. Prepost et al.,
Measurements of exclusive photoproduction processes at large values of t and u from 4 to 7.5 gev,
Phys. Rev. D 14 (1976) 679.

Using the ρ^0 reaction channel, I want to answer these question:

$$\gamma + p \rightarrow \rho^0 + p \rightarrow \pi^+ + \pi^- + p$$

To do this, I will look at:

- $\gamma + p + (n) \rightarrow \rho^0 + p$
- $\gamma + p + (p) \rightarrow \rho^0 + p + p$
- $$\frac{\sigma(\rho^0 + p + p)}{\sigma(\rho^0 + p)}$$

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To do this, I will look at:

- $\frac{A(\rho^0 p)}{d(\rho^0 p)}$ for C12 and He4

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Analysis Workflow

- Skim for $\gamma\ d\ \rightarrow \pi^{+}\pi^{-}p(n)$
- Kinematic Fit constraining vertices, missing neutron mass
  - Confidence Level Cut
- Event Selection Criteria
  - Fiducial Cuts
  - Remove contaminates $(\phi, \Delta^{0}, \Delta^{++}, \dots)$
  - Select SRC events using p_{miss}, or p_{proxy}
  - Fit signal, background using $M_{\pi^{+}\pi^{-}}$