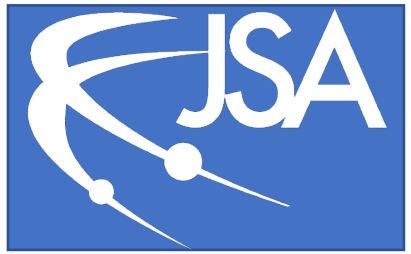
Exploring Neutron-Proton SRC Pair Dominance with a Real Photon Beam

Phoebe Sharp

Thursday, June 16

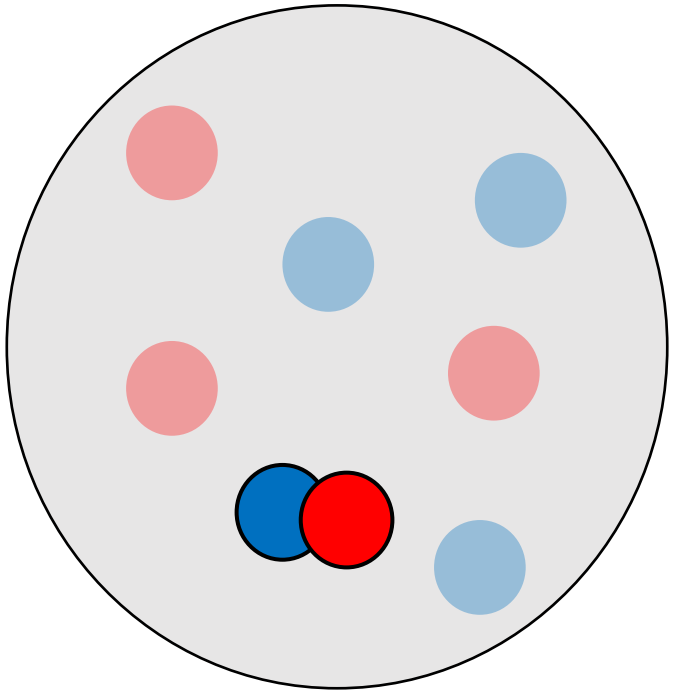
HUGS 2022



This work was supported by the US Department of Energy Office of Science, Office of Nuclear Physics, under contract no. DE-SC0016583 and the Jefferson Science Associates Fellowship.

Two nucleons are in a Short-Range Correlated (SRC) pair when:

- 2 nucleons overlap



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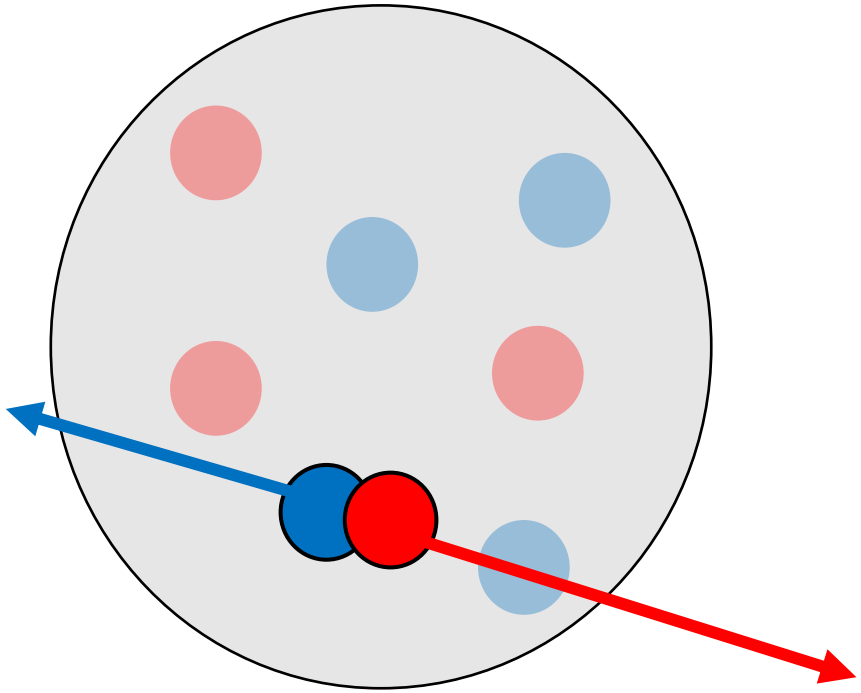

- 2 nucleons overlap
- Large relative momentum compared to the Fermi-momentum

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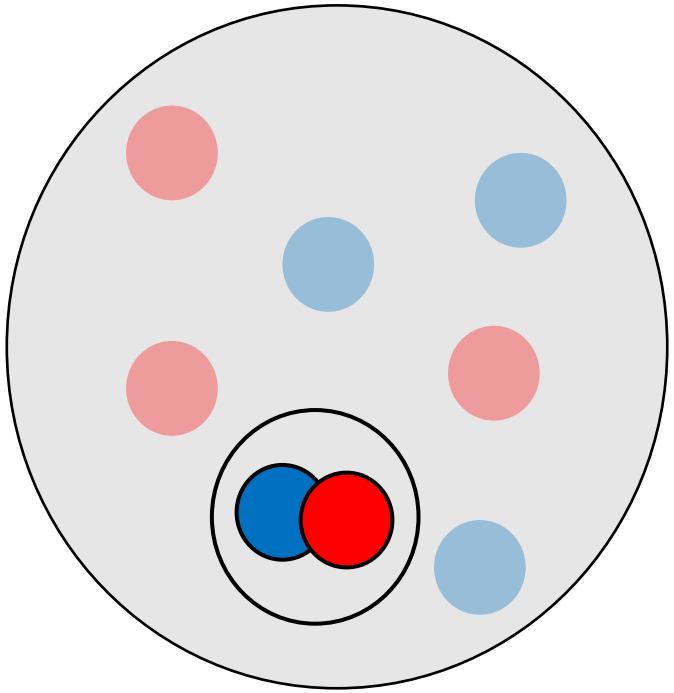
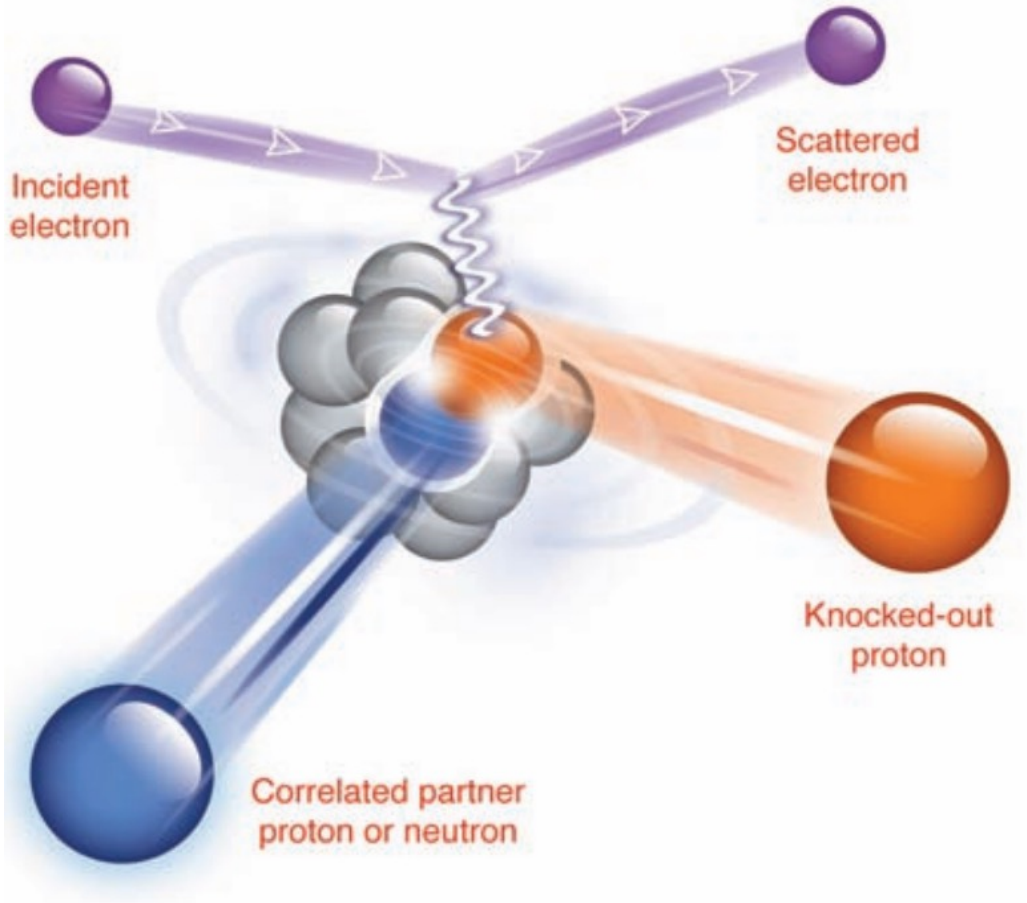


- 2 nucleons overlap
- Large relative momentum compared to the Fermi-momentum
- Force between the nucleons is stronger than the interactions between the rest of the nucleus

From previous SRC experiments we have learned:



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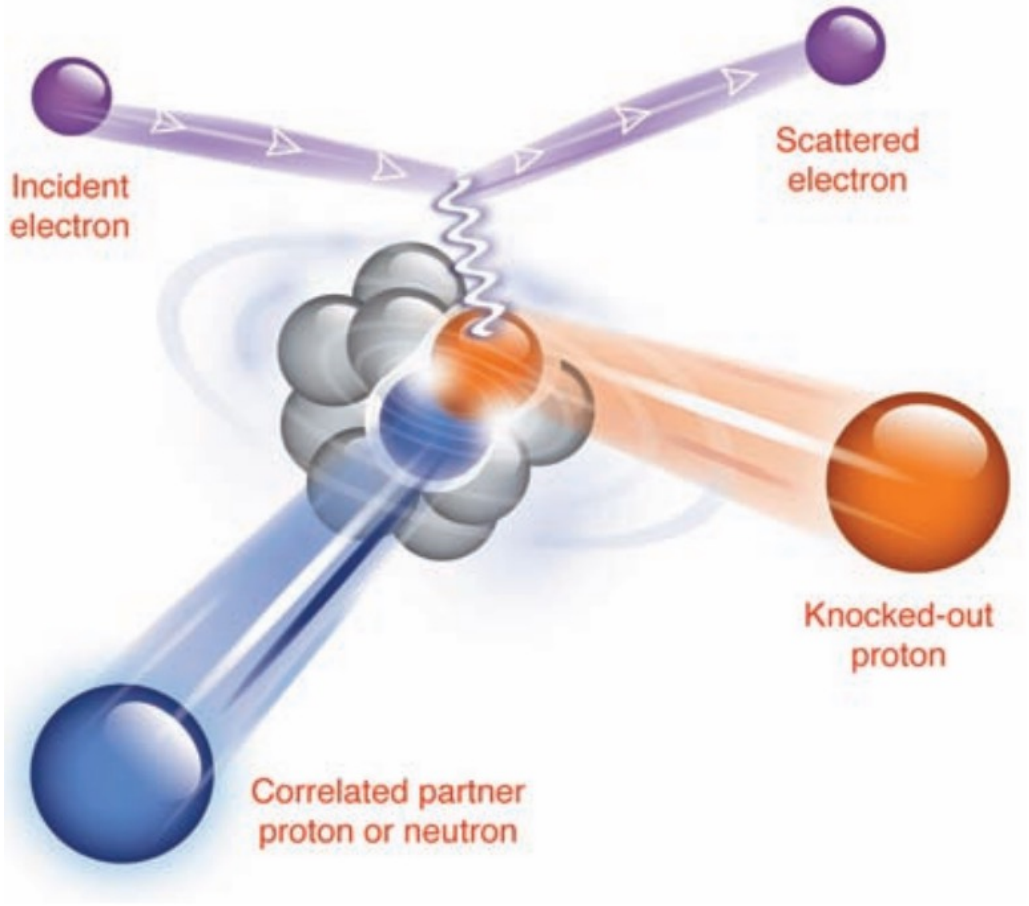
- SRCs are found in all nuclei



From previous SRC experiments we have learned:

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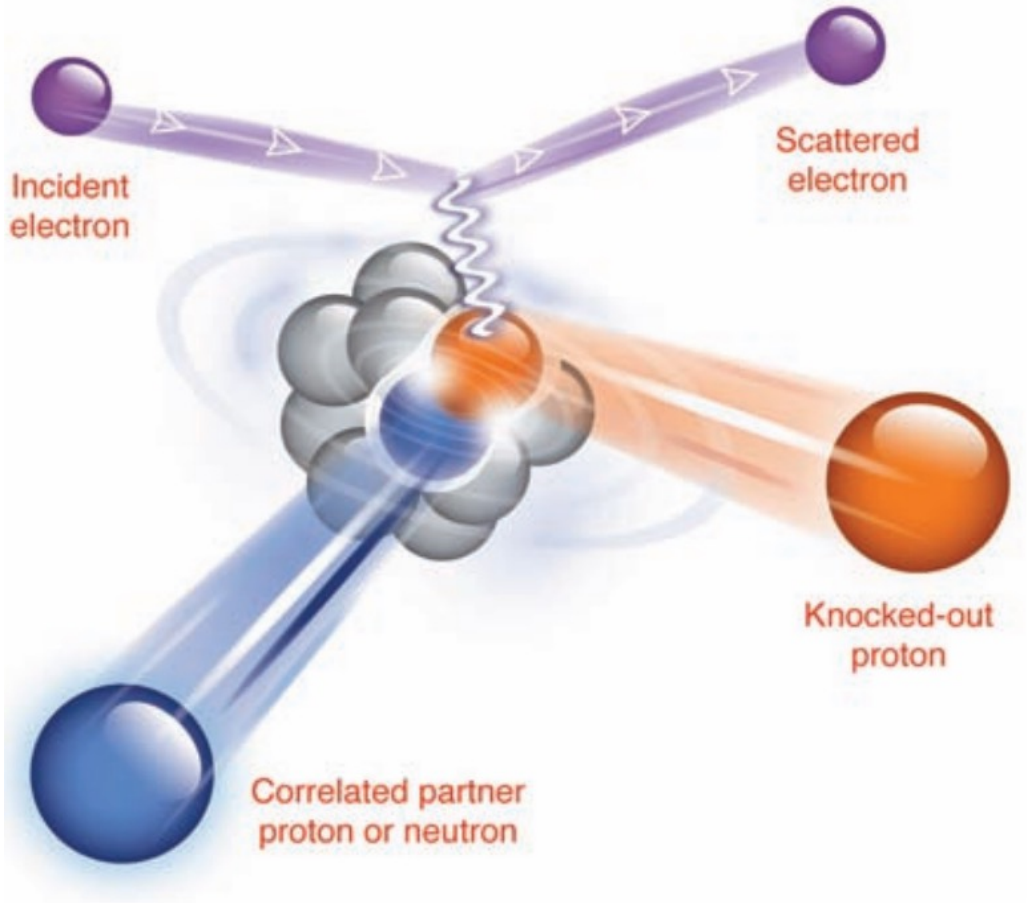
- 10-20% of nucleons are in SRC pairs



From previous SRC experiments we have learned:

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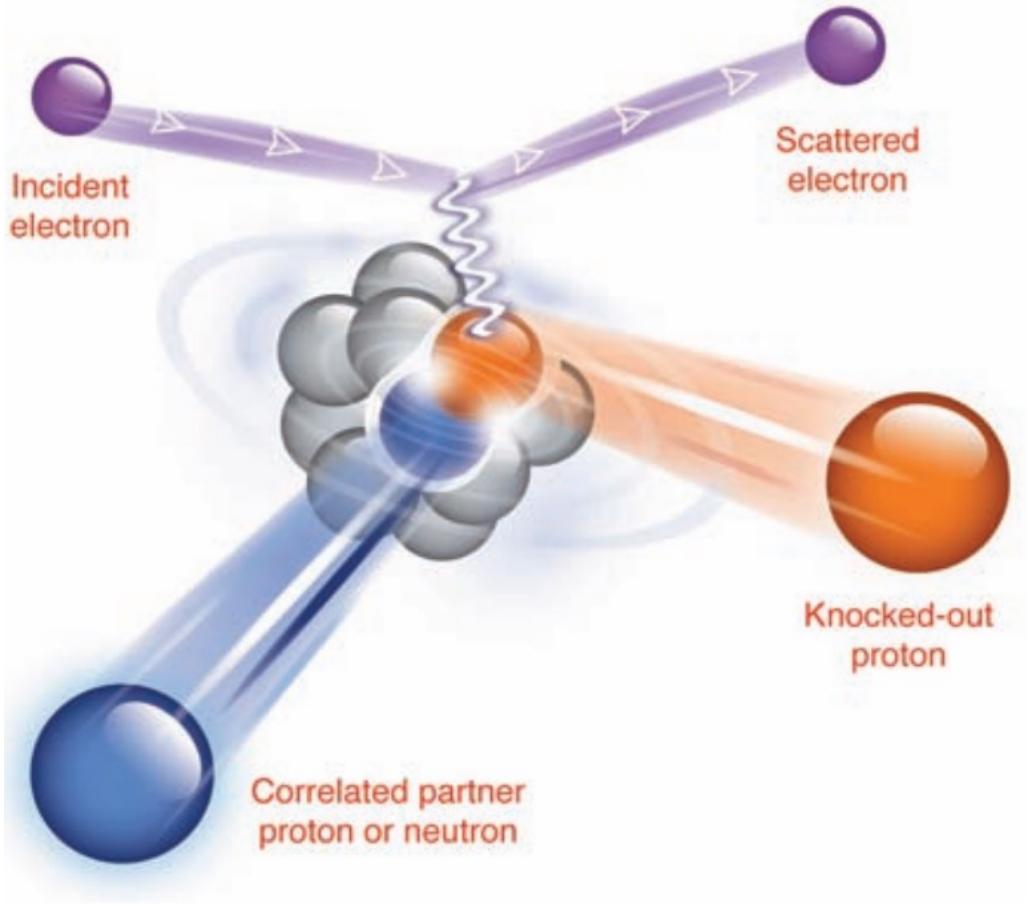
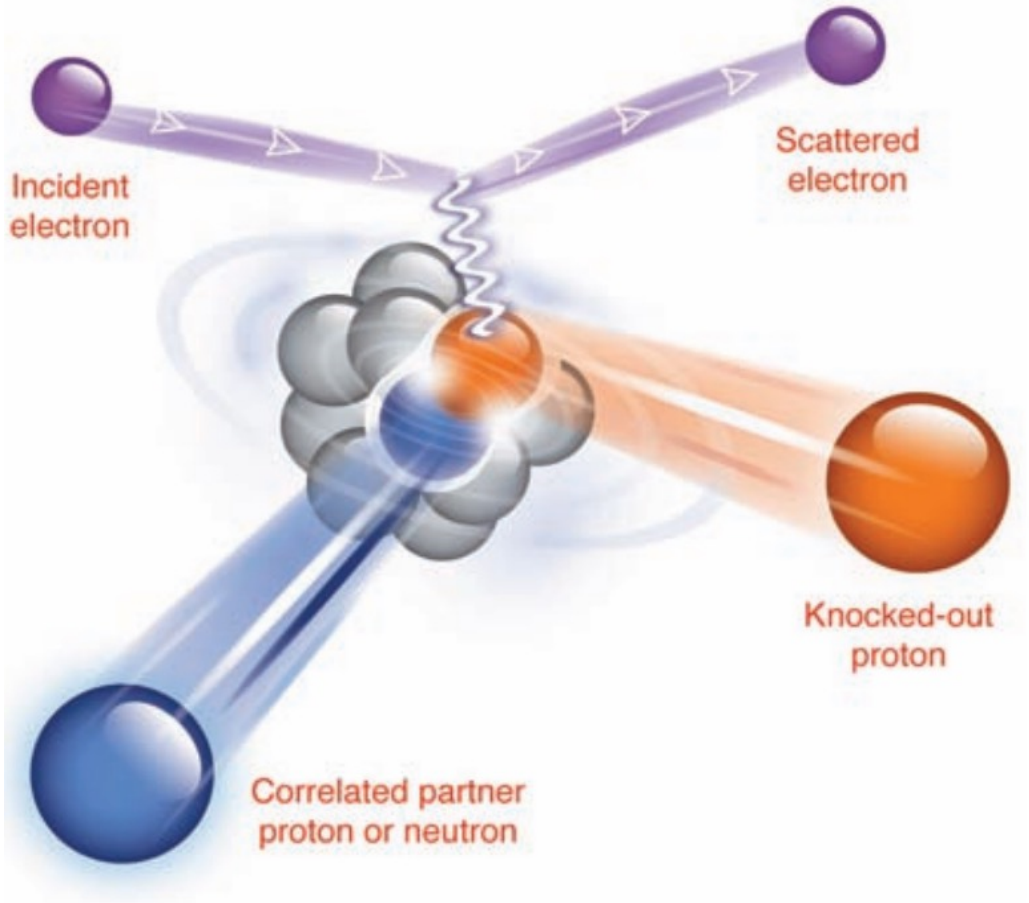
- SRCs have high relative momentum (compared to Fermi momentum)

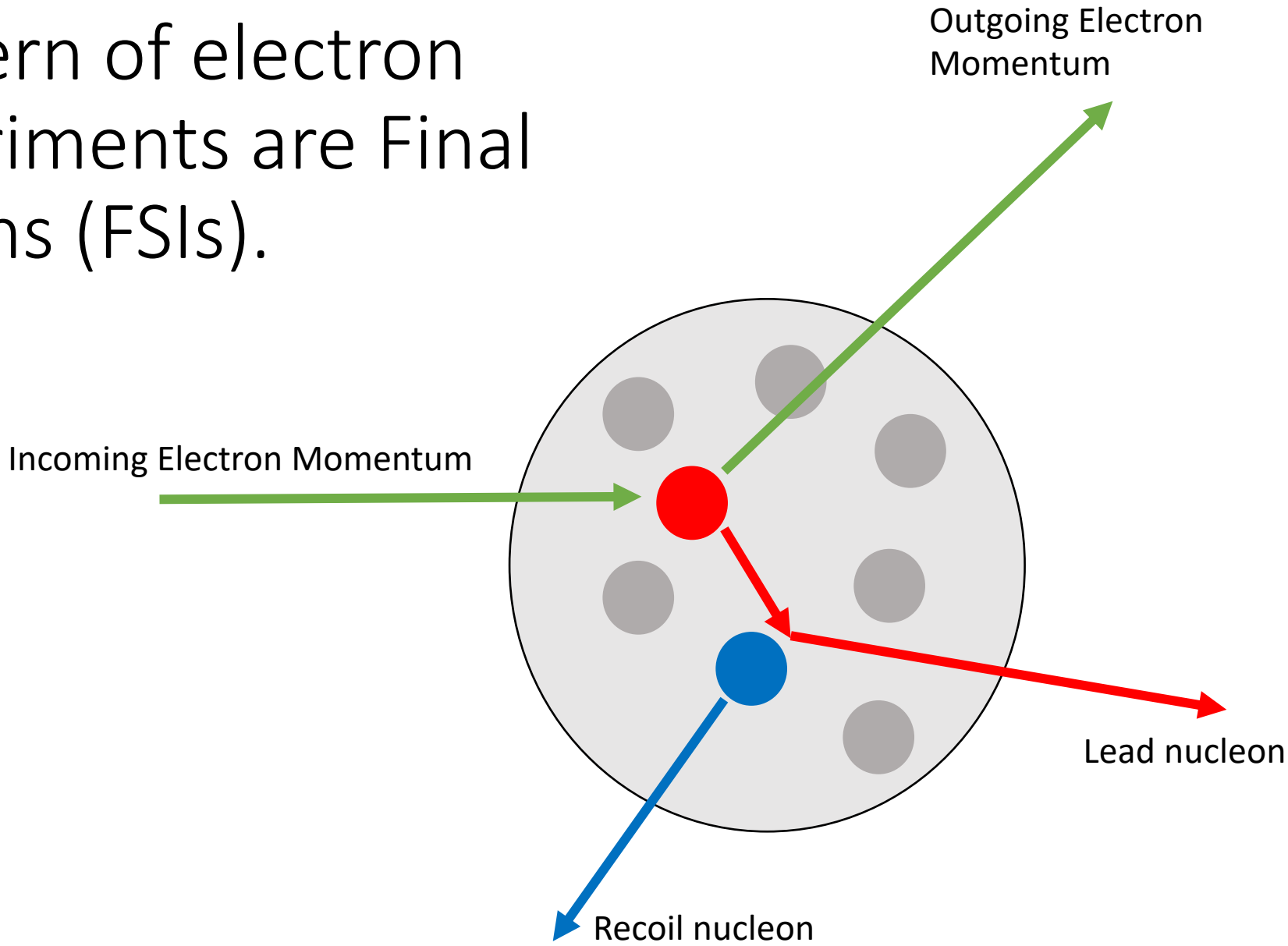


From previous SRC experiments we have learned:

- 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

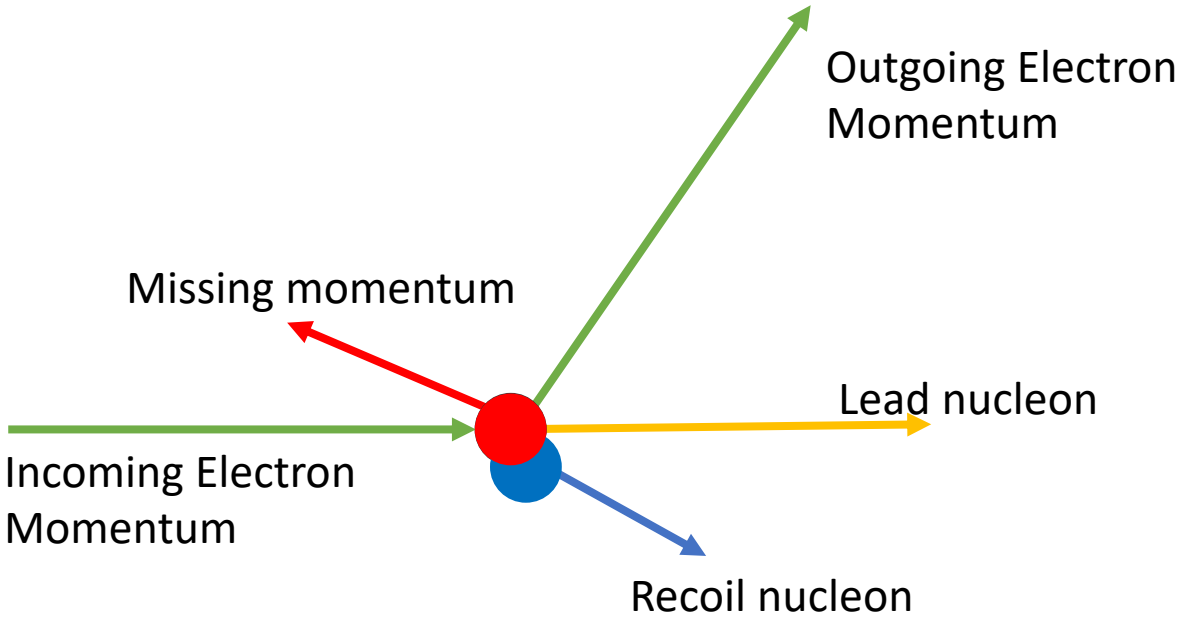


A primary concern of electron scattering experiments are Final State Interactions (FSIs).



Different SRC experiments isolate different kinematic regions.

Electron Probe:
Anti-Parallel Kinematics



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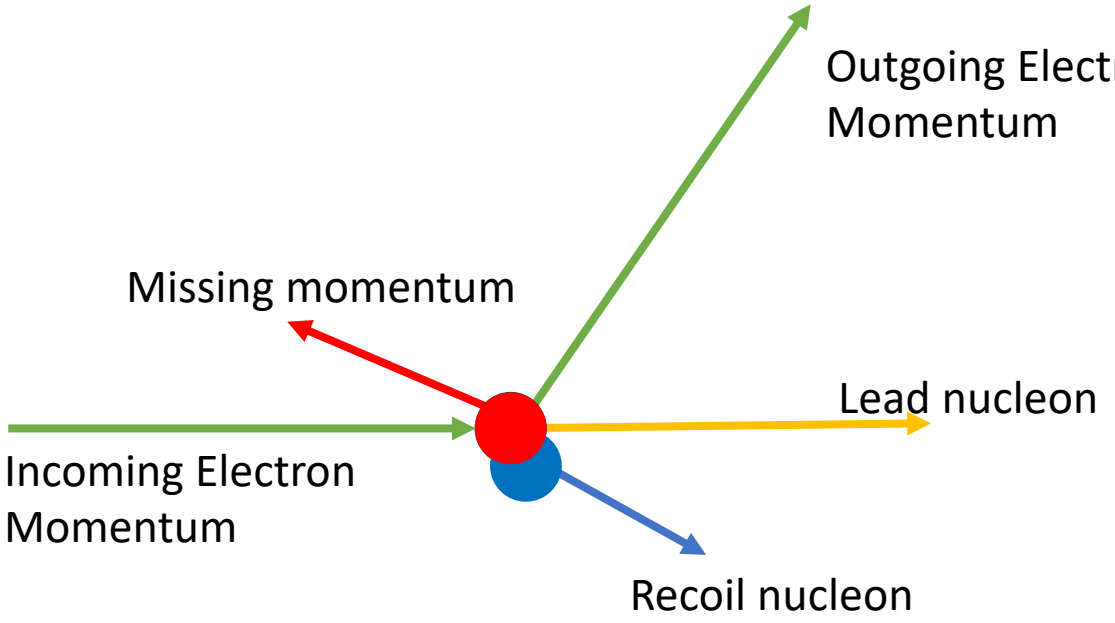
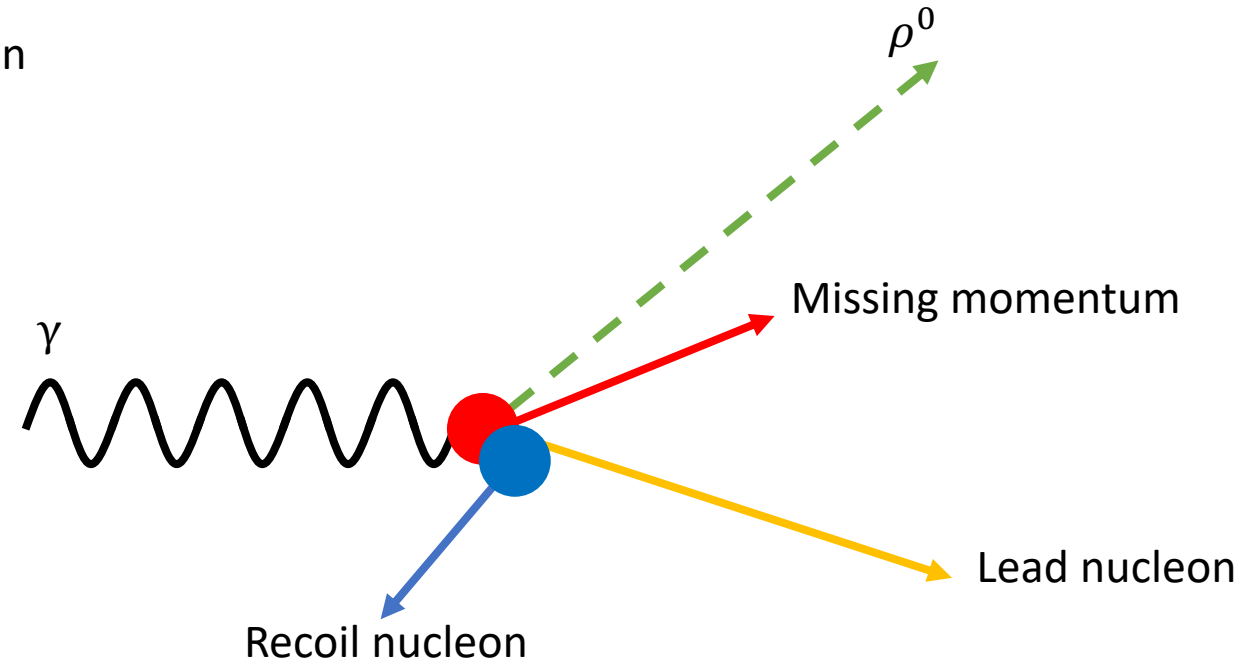
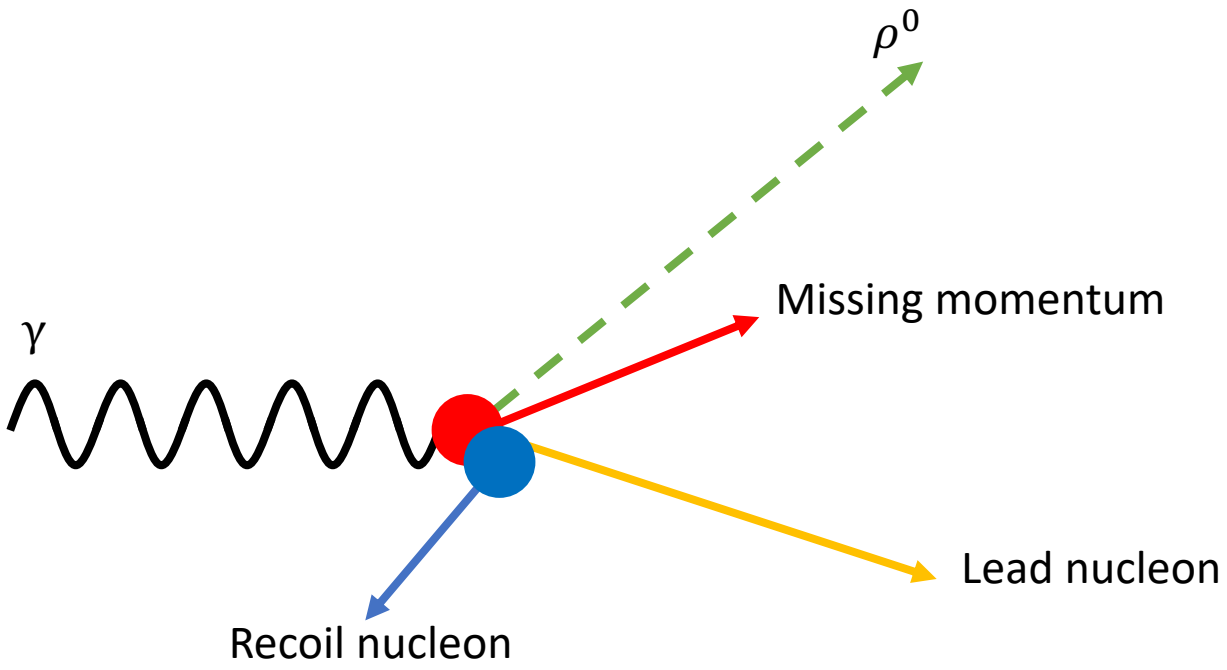


Real Photon Probe:
Parallel Kinematics



Using different reaction mechanisms, photons provide a new perspective to SRC experiments.



SRC @ GlueX: Experimental Details

SRC @ GlueX: Experimental Details

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

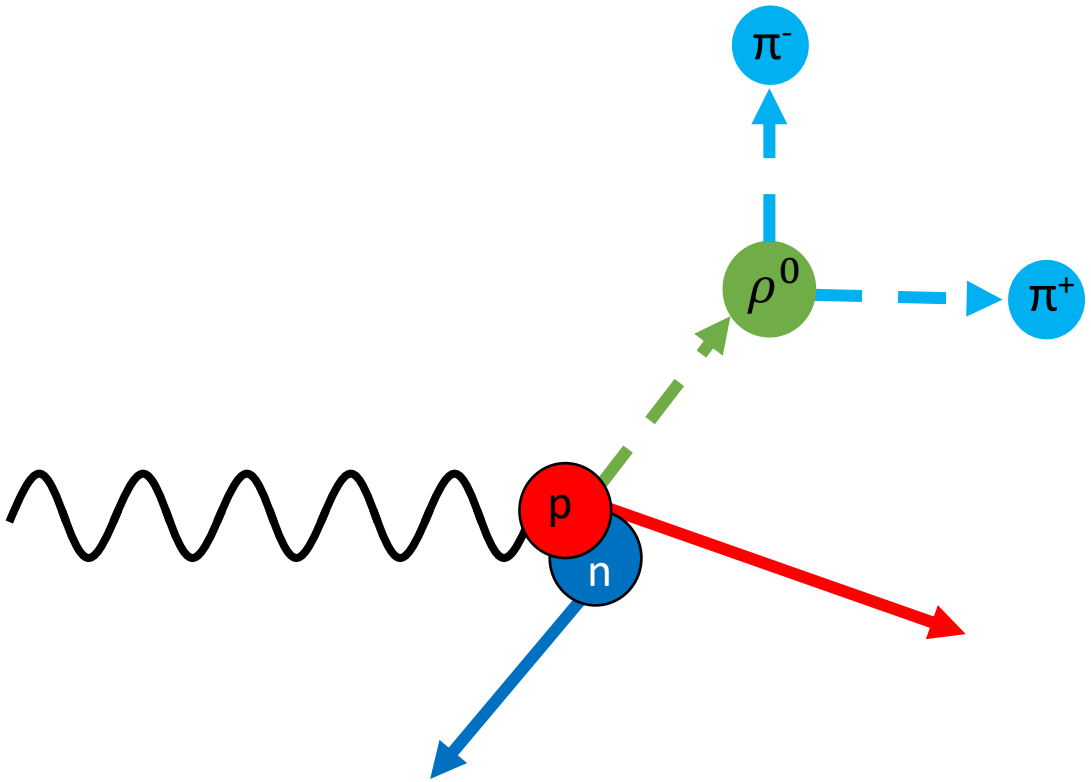
Target	Days on Beam
Liquid Helium 4	10
Liquid Deuterium	4
Carbon Multi-Foil	14

This experiment looked at a number of reaction channels.

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

This experiment looked at a number of reaction channels.

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



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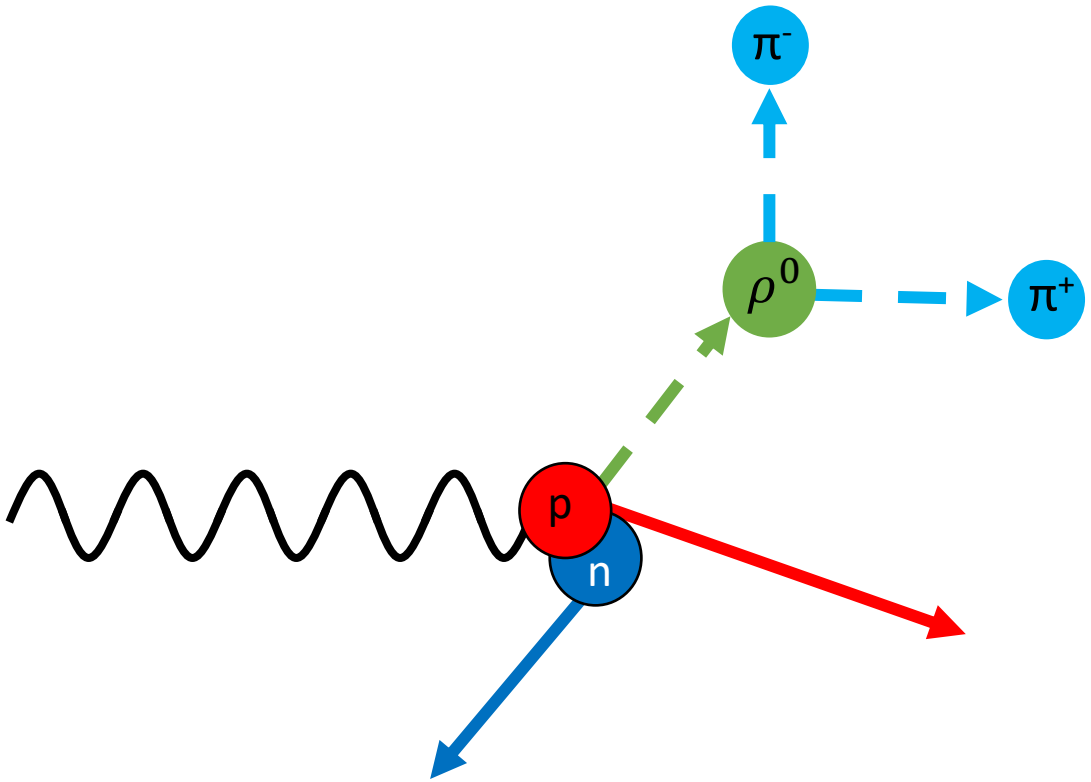
⋮	⋮

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

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



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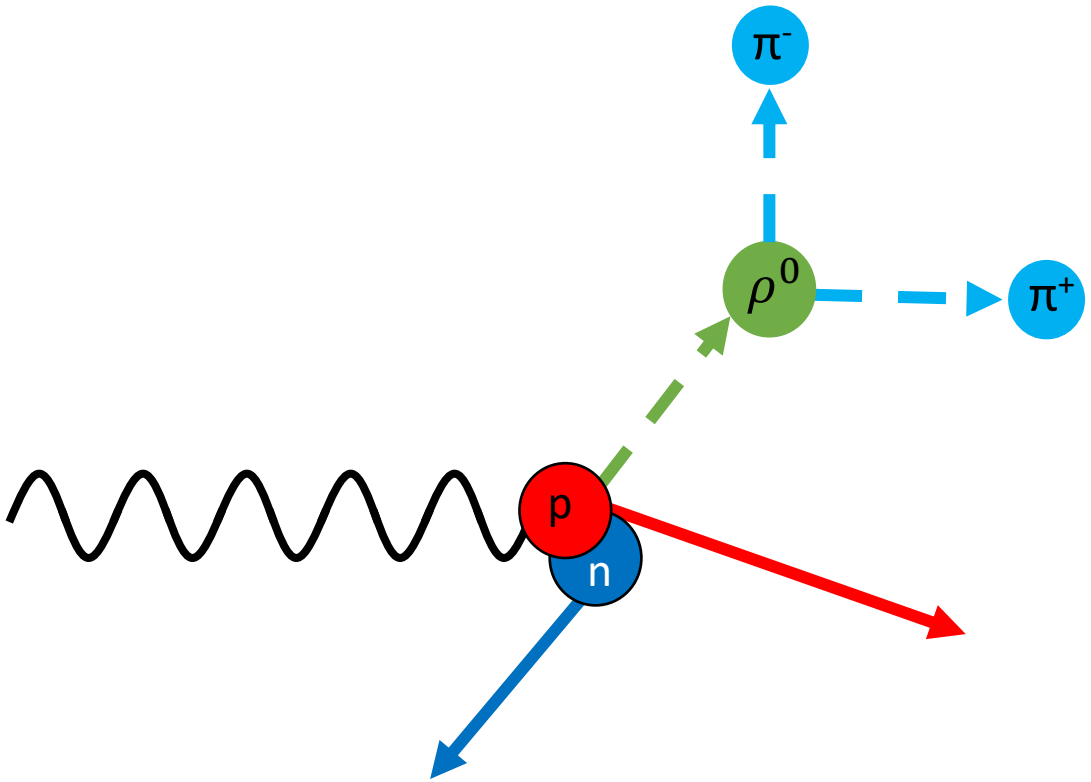

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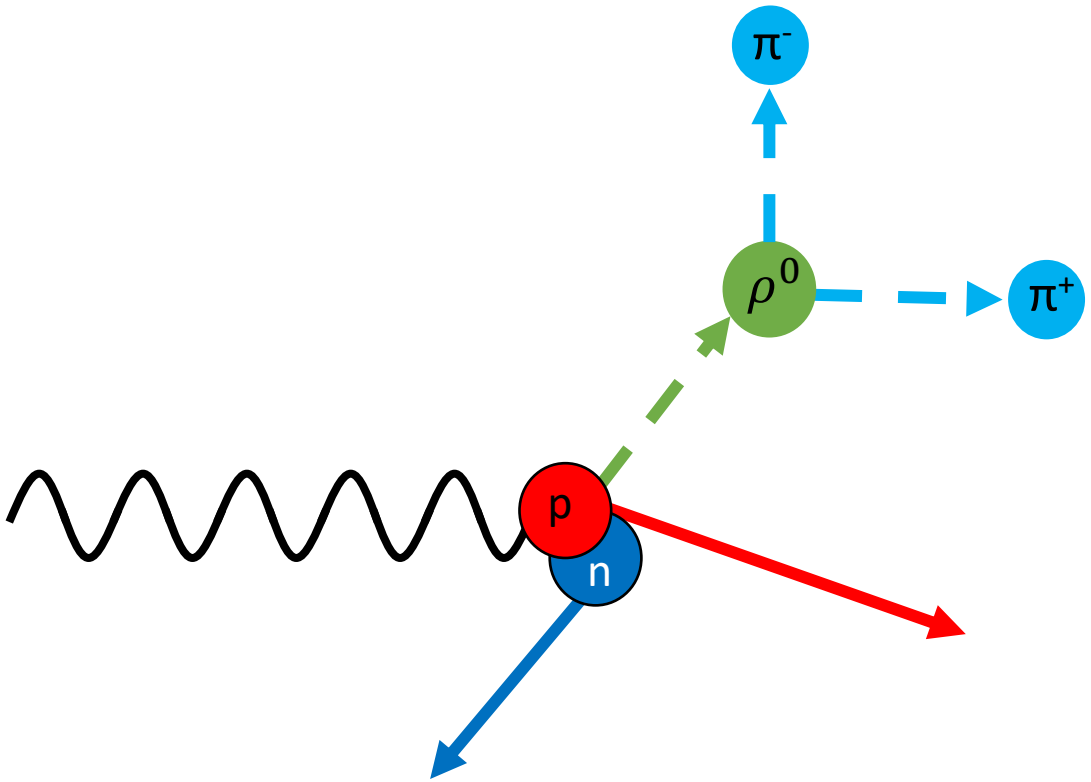

1. Can np-dominance be verified with photon scattering?
2. Can photoproduction confirm the abundances of SRC pairs?

Measuring ρ^0 in GlueX:

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

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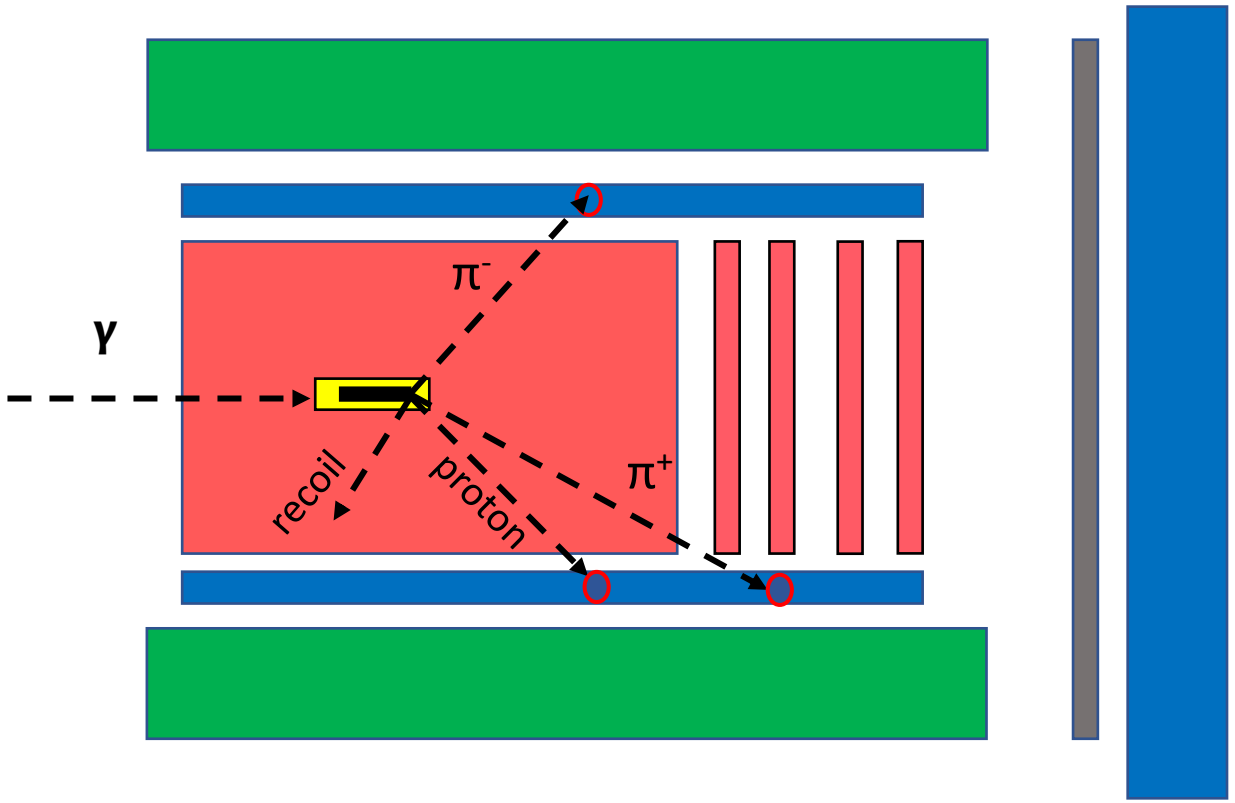
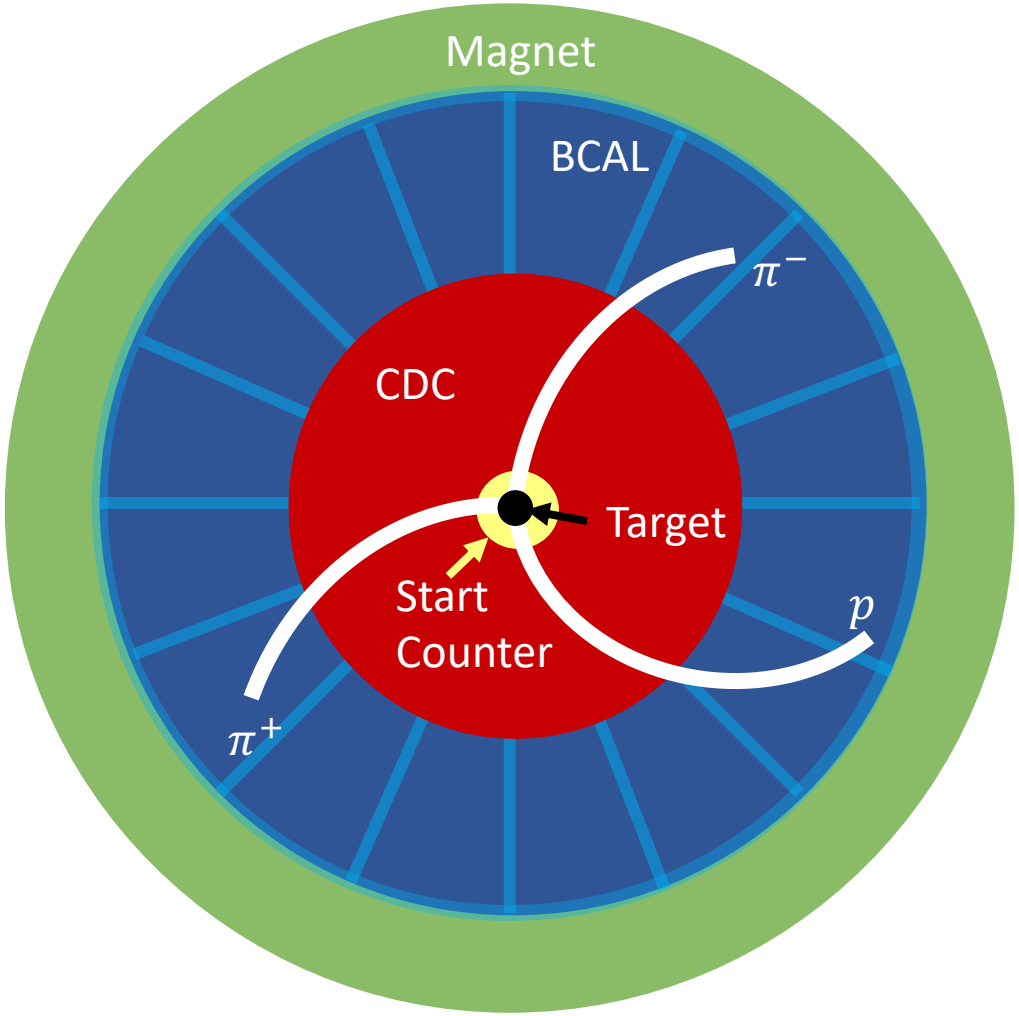
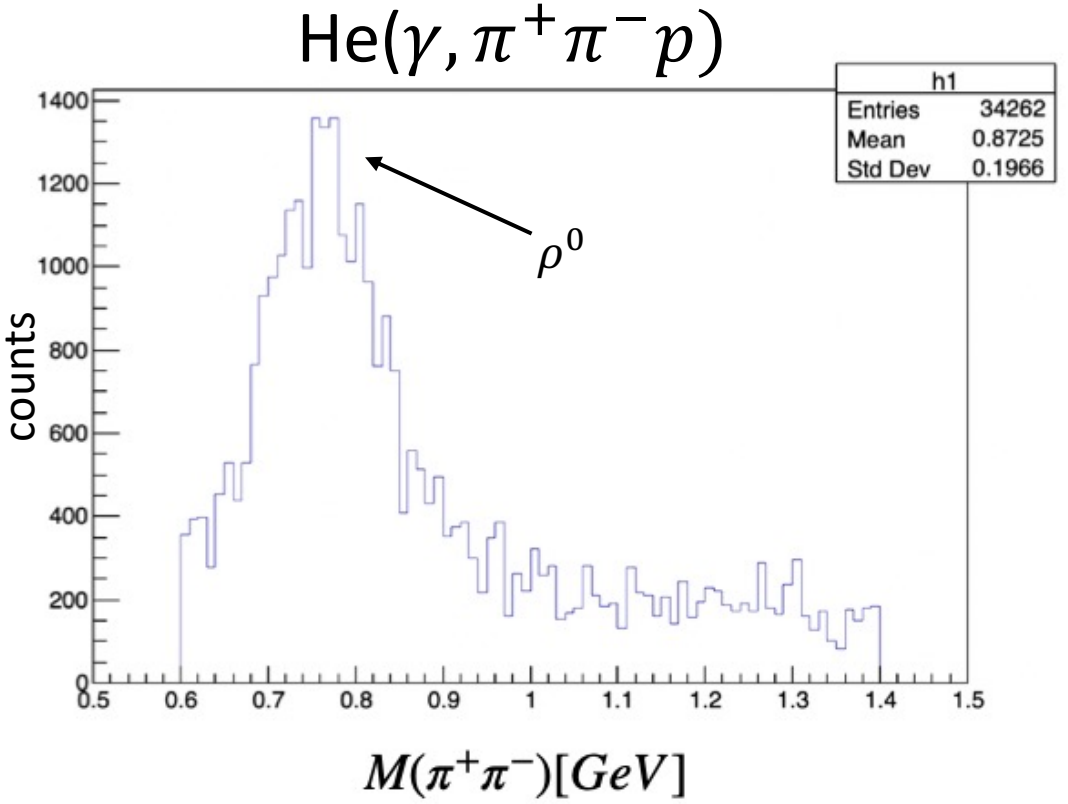




The ρ^0 meson is a great channel for my analysis goals.

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



N. Santiesteban. Fall 2021

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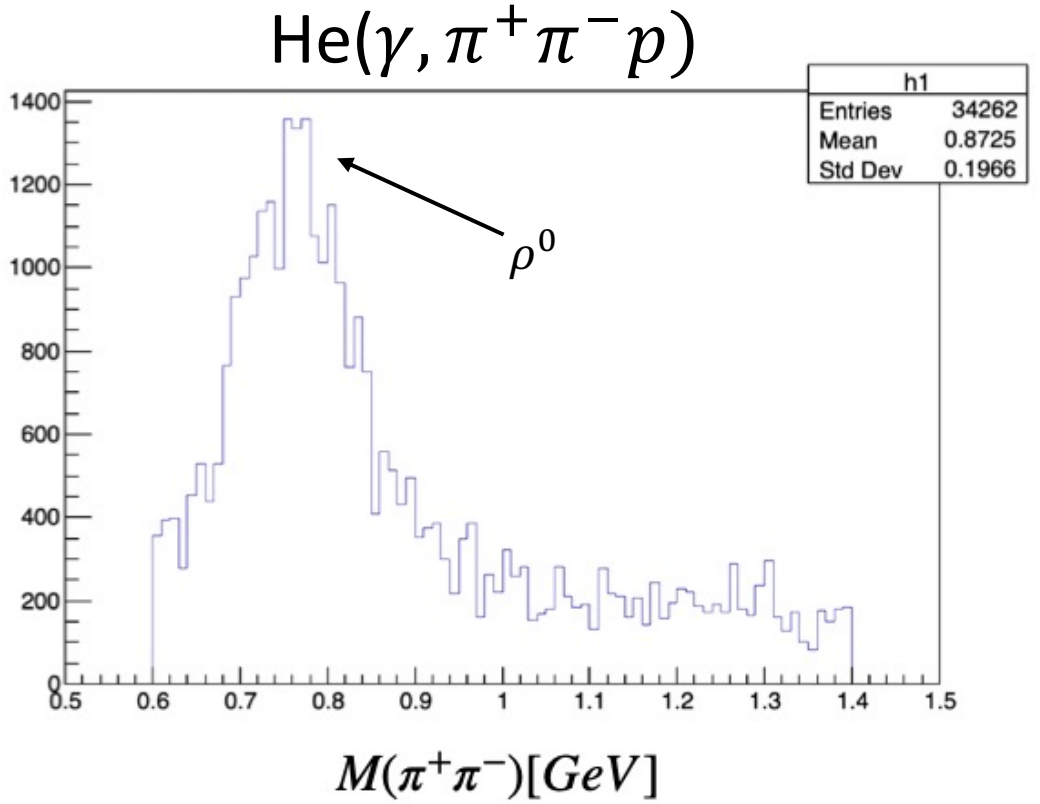
  - ρ^0 lifetime: ~4.5×10^{-24} s



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- Always decays into π^+ and π^-
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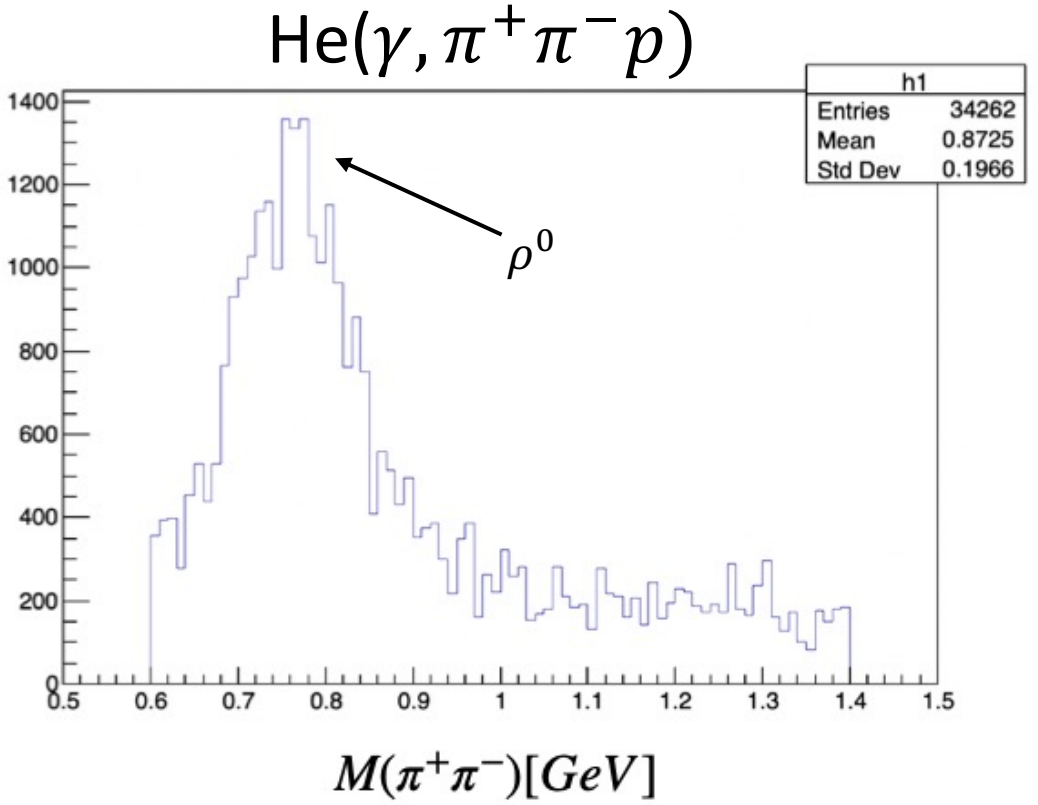
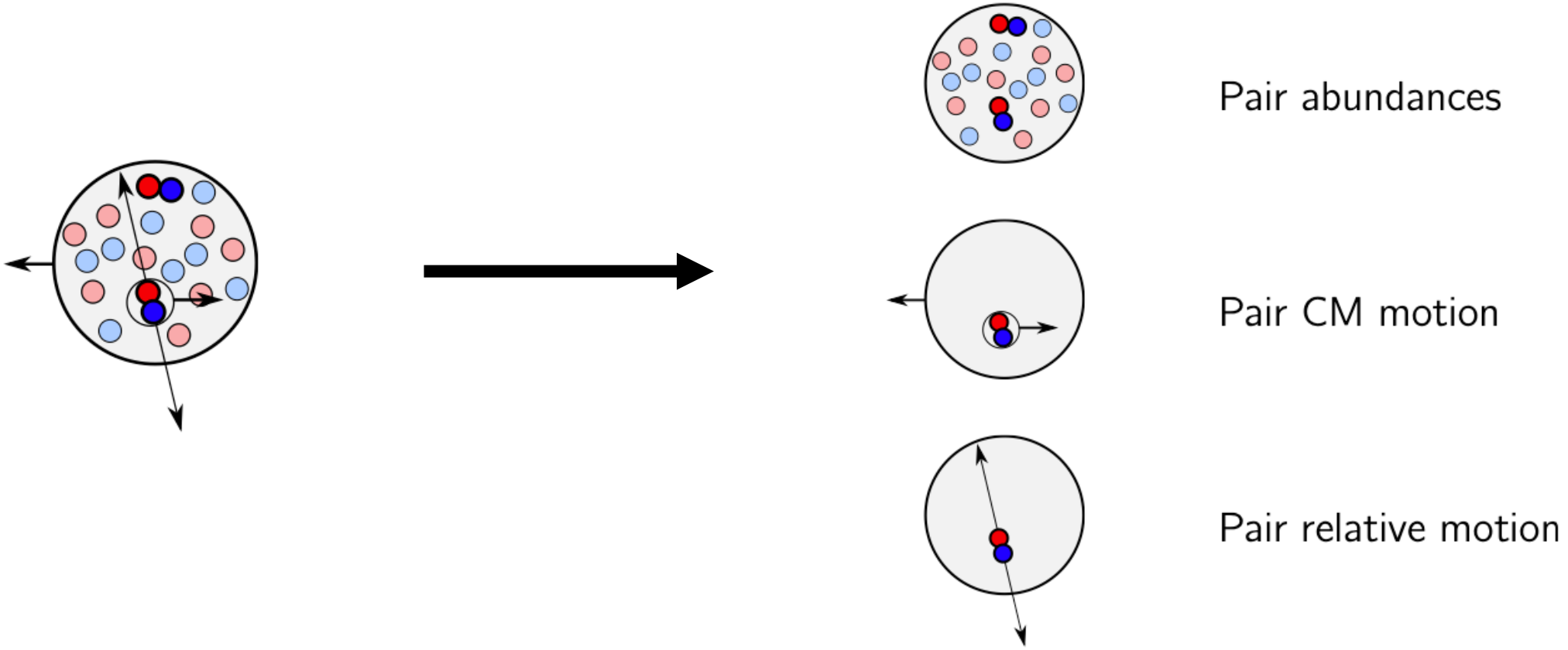
- Identified by invariant mass
  - ρ^0 mass: 0.775 GeV/c^2



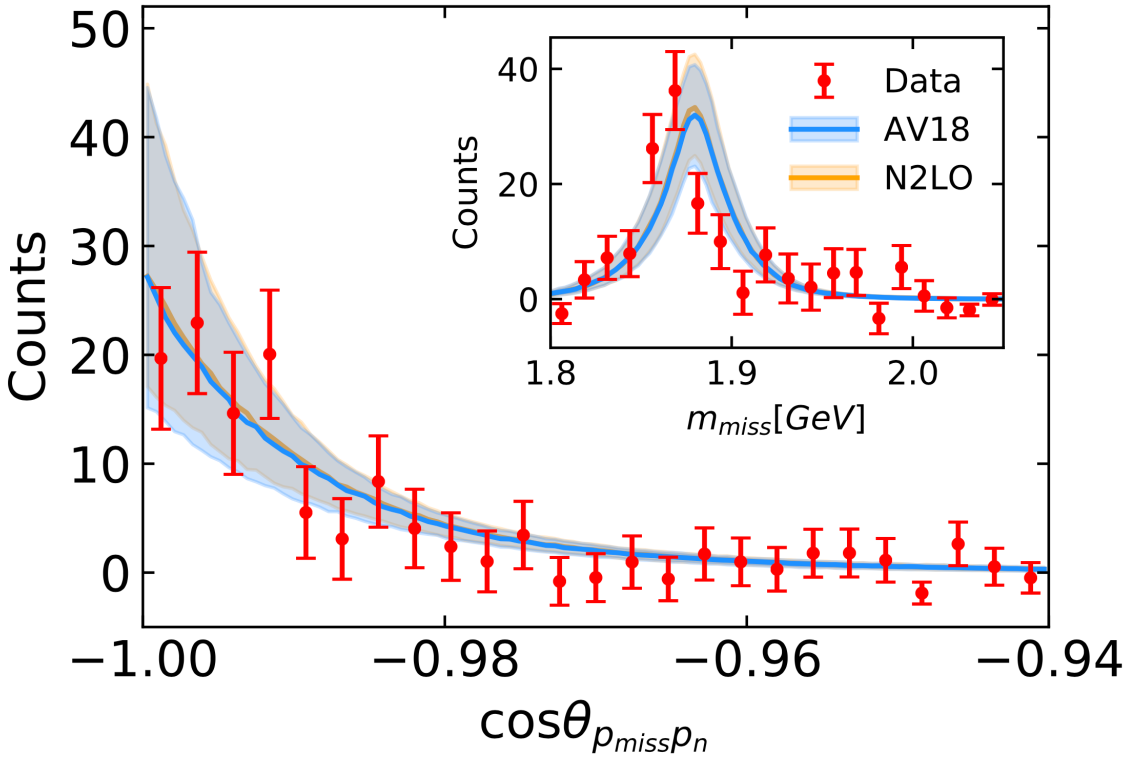
Plot Credit: N. Santiesteban. Fall 2021

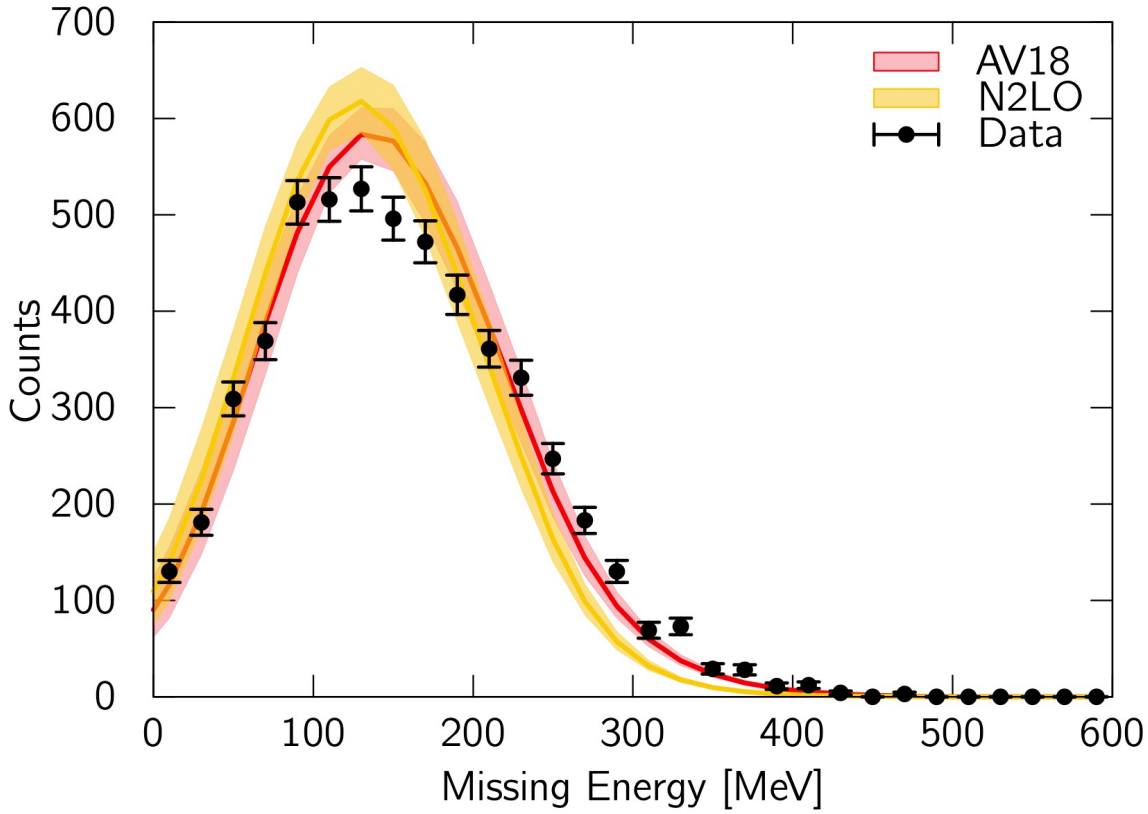
Generalized Contact Formalism (GCF)

Scale separated approach to Short-Range Correlations



GCF and Electron Scattering Experiments

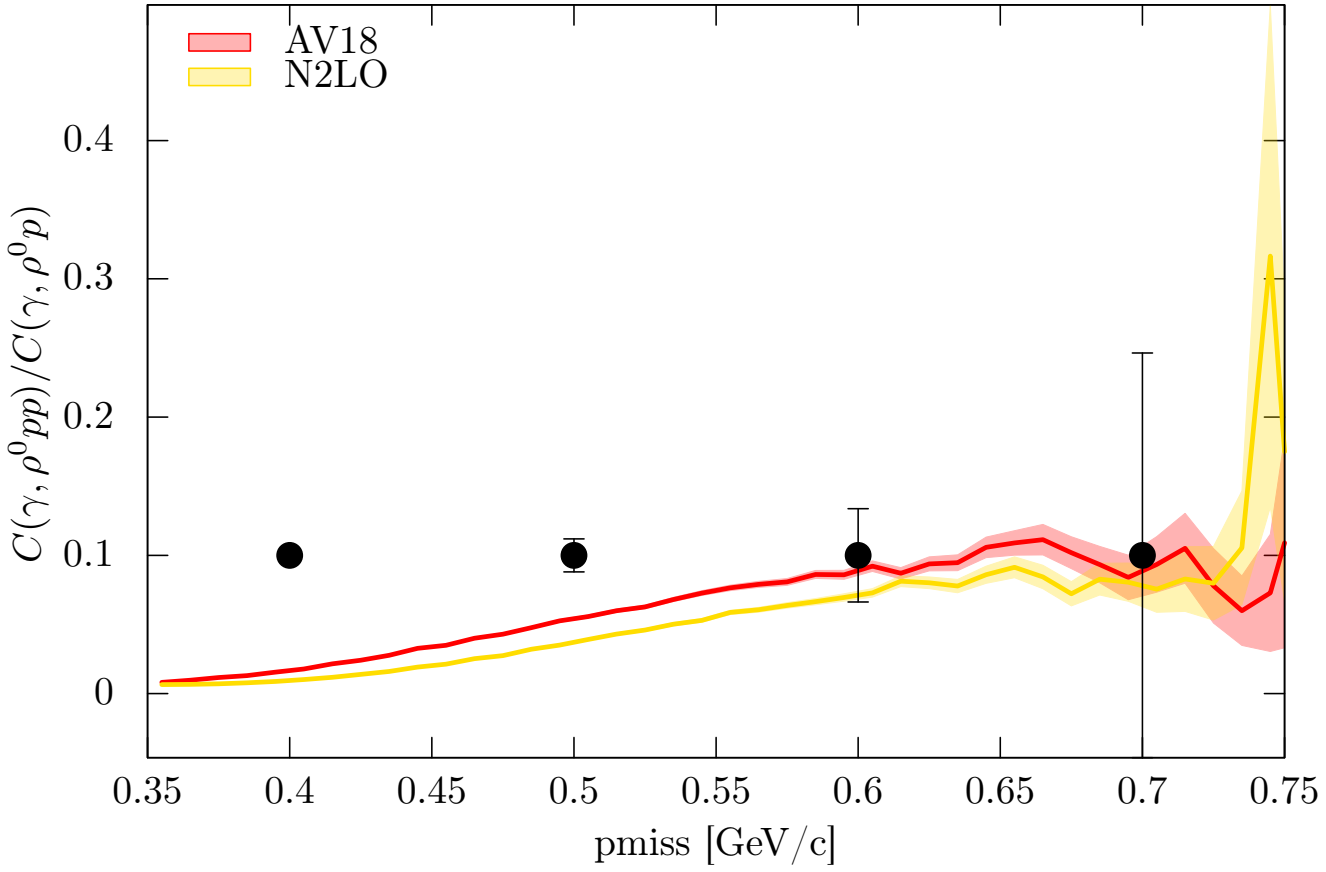




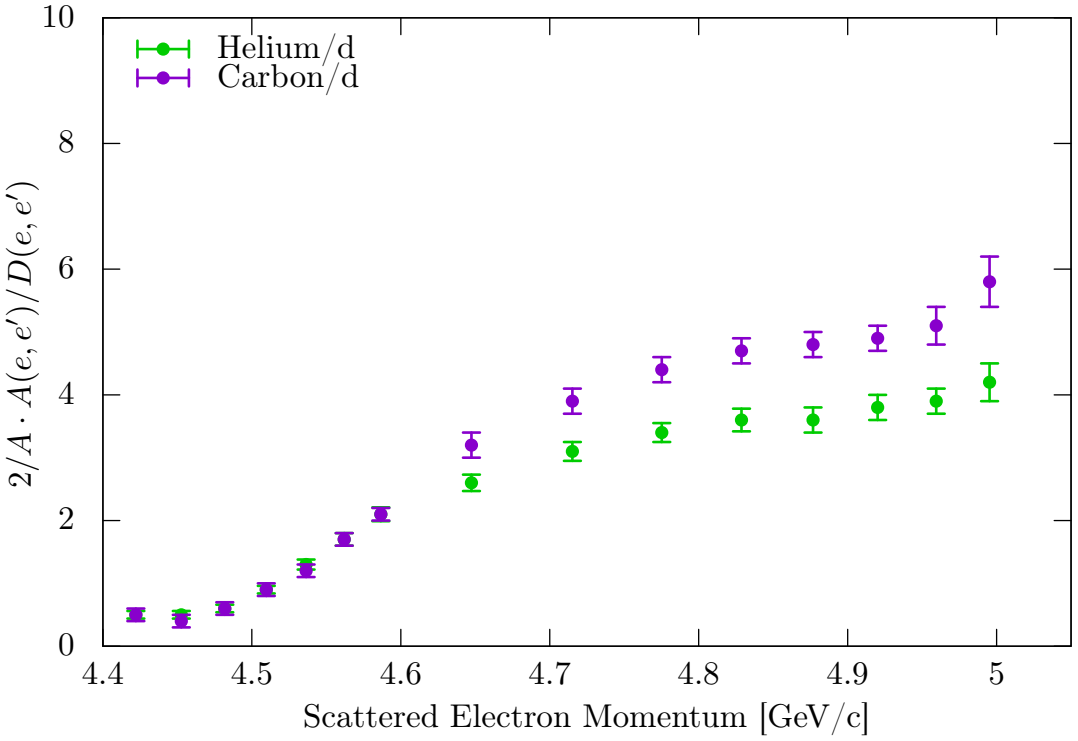
Pybus, J. R., et. al, (2020). Generalized contact formalism analysis of the 4 He (e , e pN) reaction. *Physics Letters B*, *805*, 135429.

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

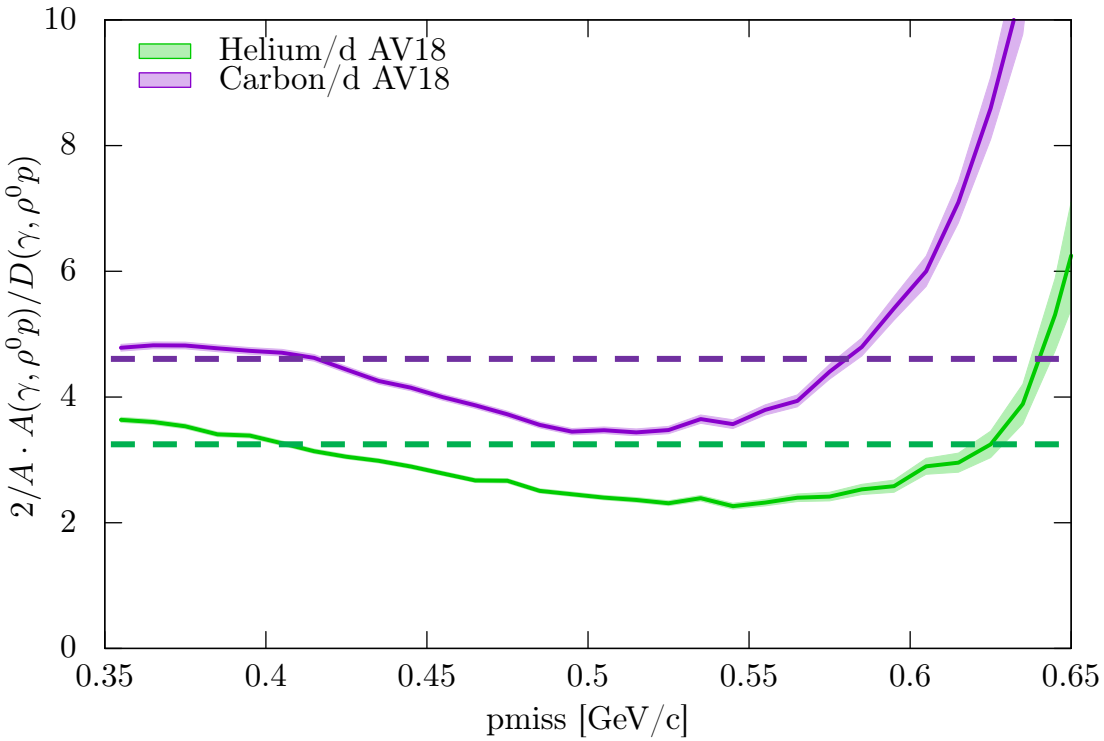
GCF Predictions of np-pair dominance using ρ^0 photoproduction.



GCF Predictions of pp-pair to np-pair abundances using ρ^0 photoproduction.



Previous electron scattering data

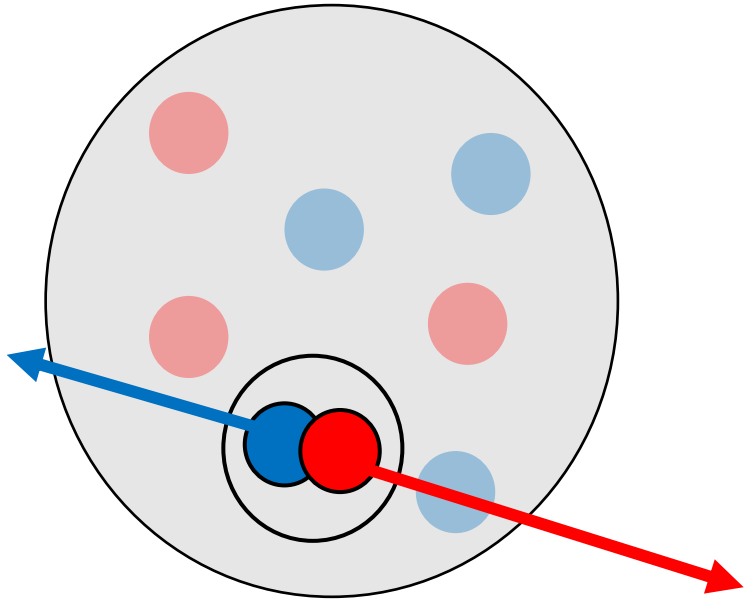


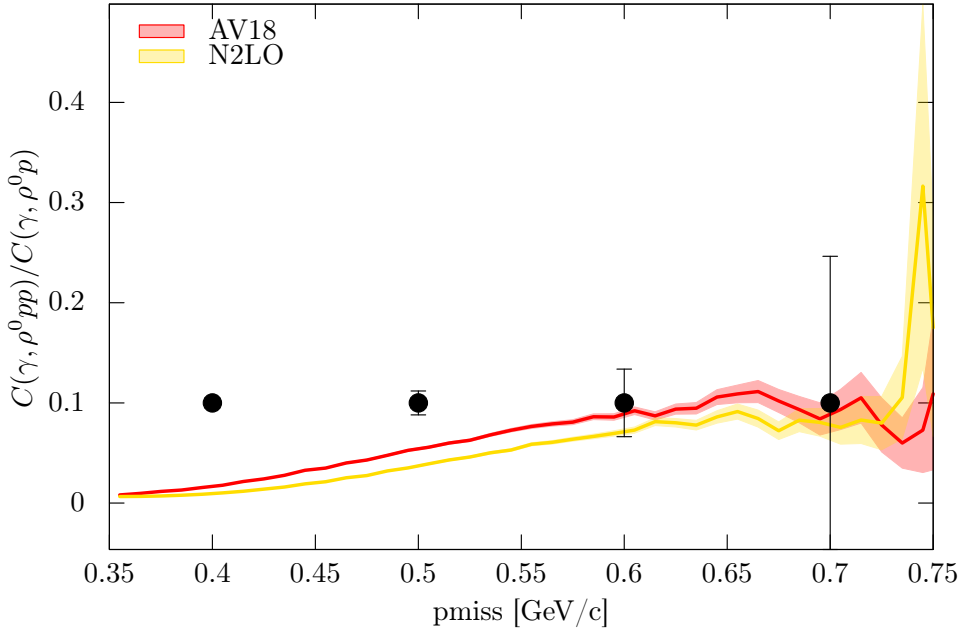
Photoproduction prediction

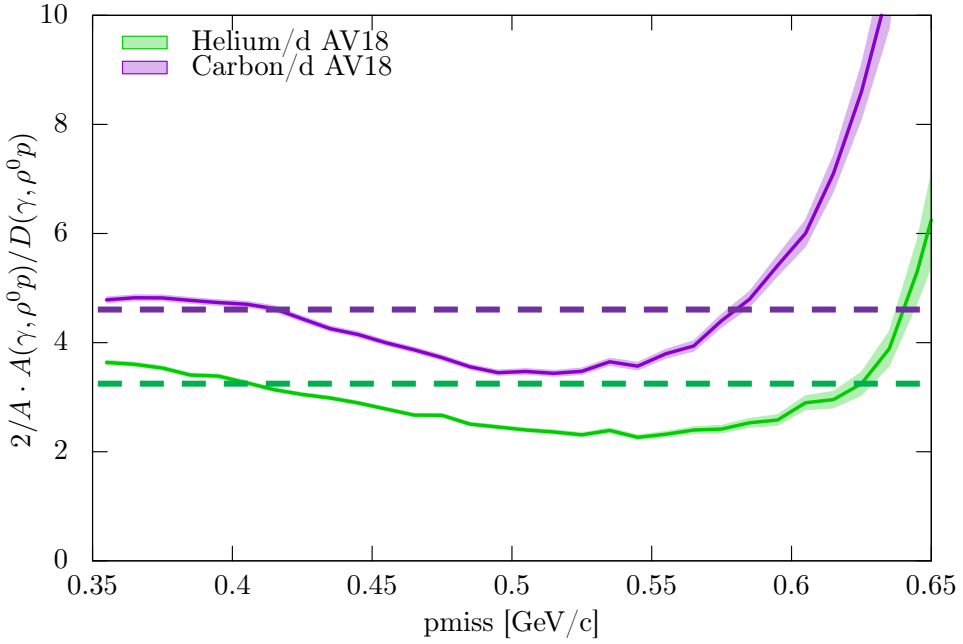
N. Fomin, J. Arrington, R. Asaturyan, F. Benmokhtar, W. Boeglin, P. Bosted et al., *New measurements of high-momentum nucleons and short-range structures in nuclei*, *Phys. Rev. Lett.* **108** (2012) 092502.

In summary,

- Electron scattering experiments have taught us about SRC pairs.
- Those experiments have assumptions we need to test.
- A photon beam can help us test our understanding of SRC pairs.
- Data was collected in Fall 2021.

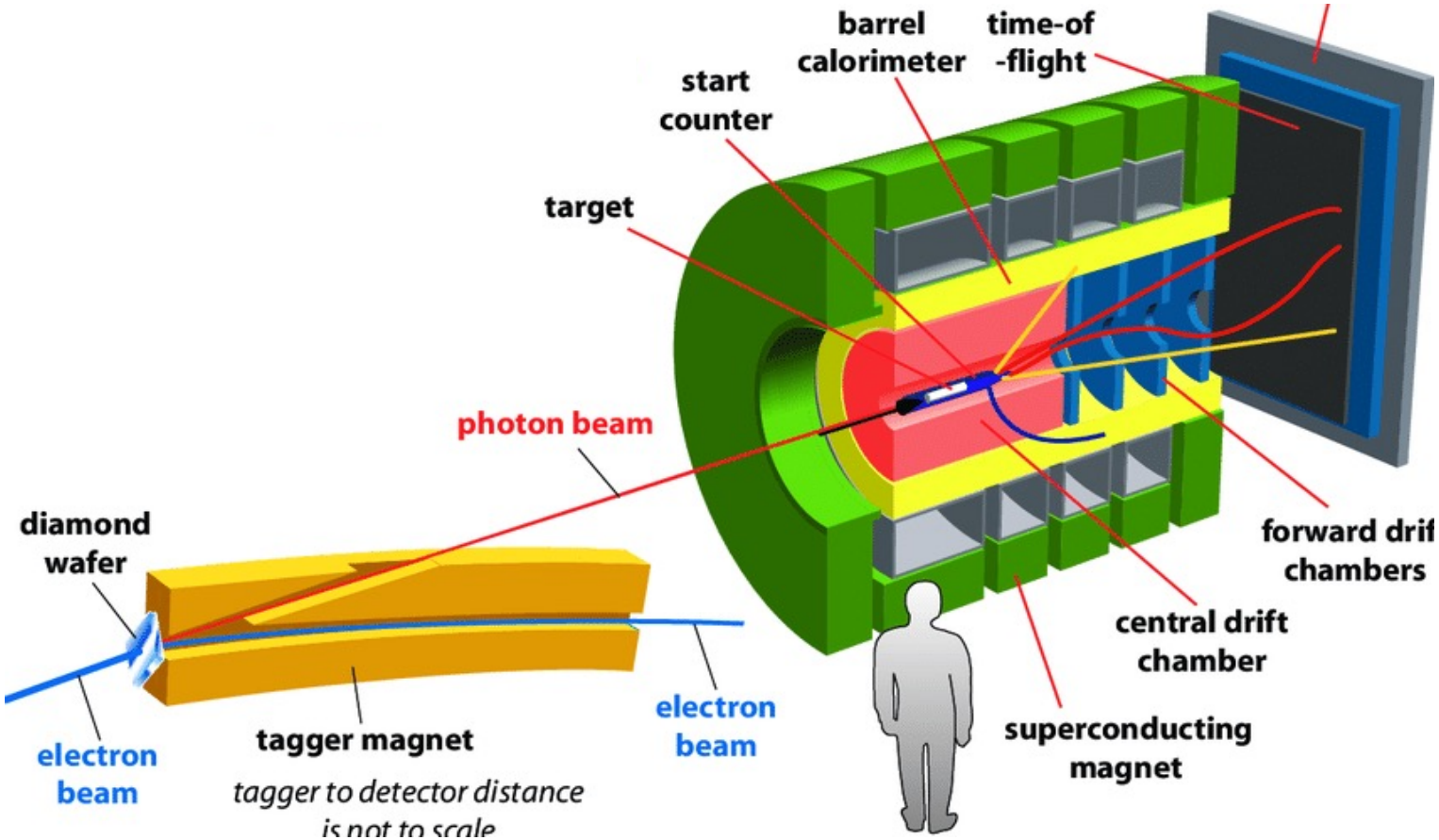


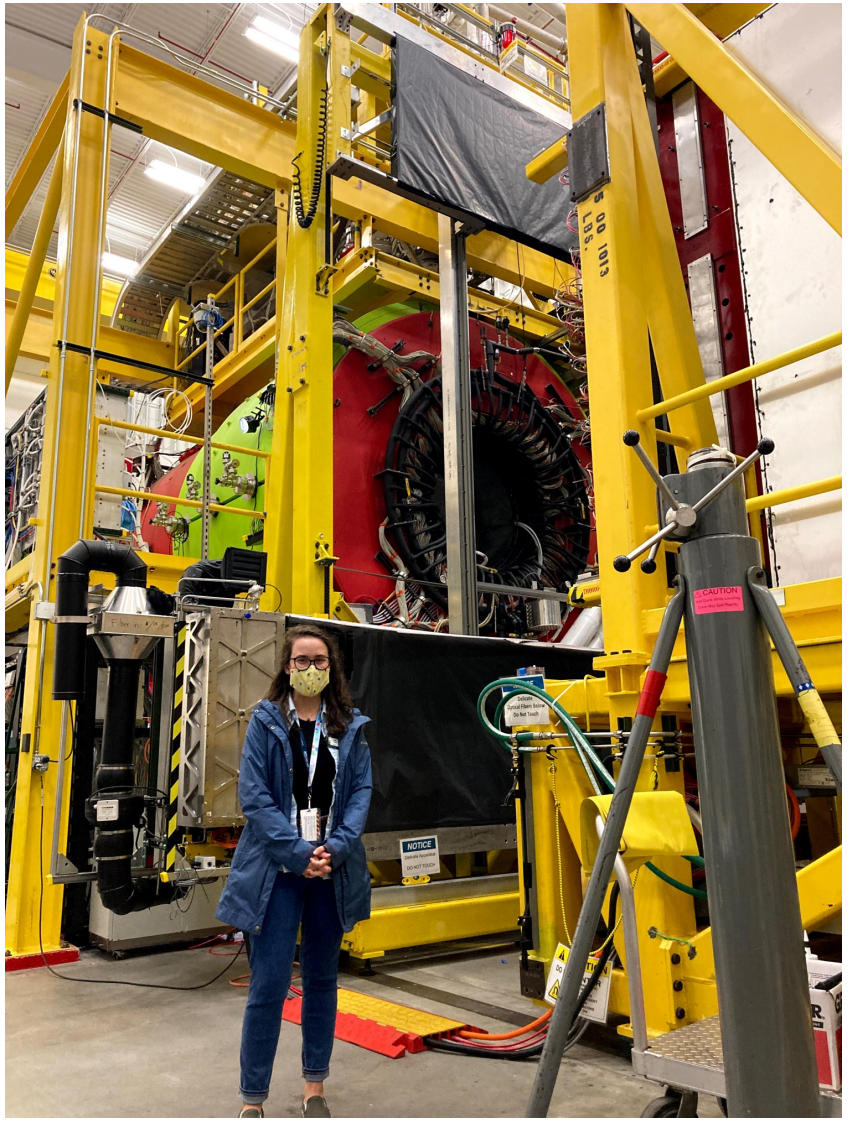




Backup slides

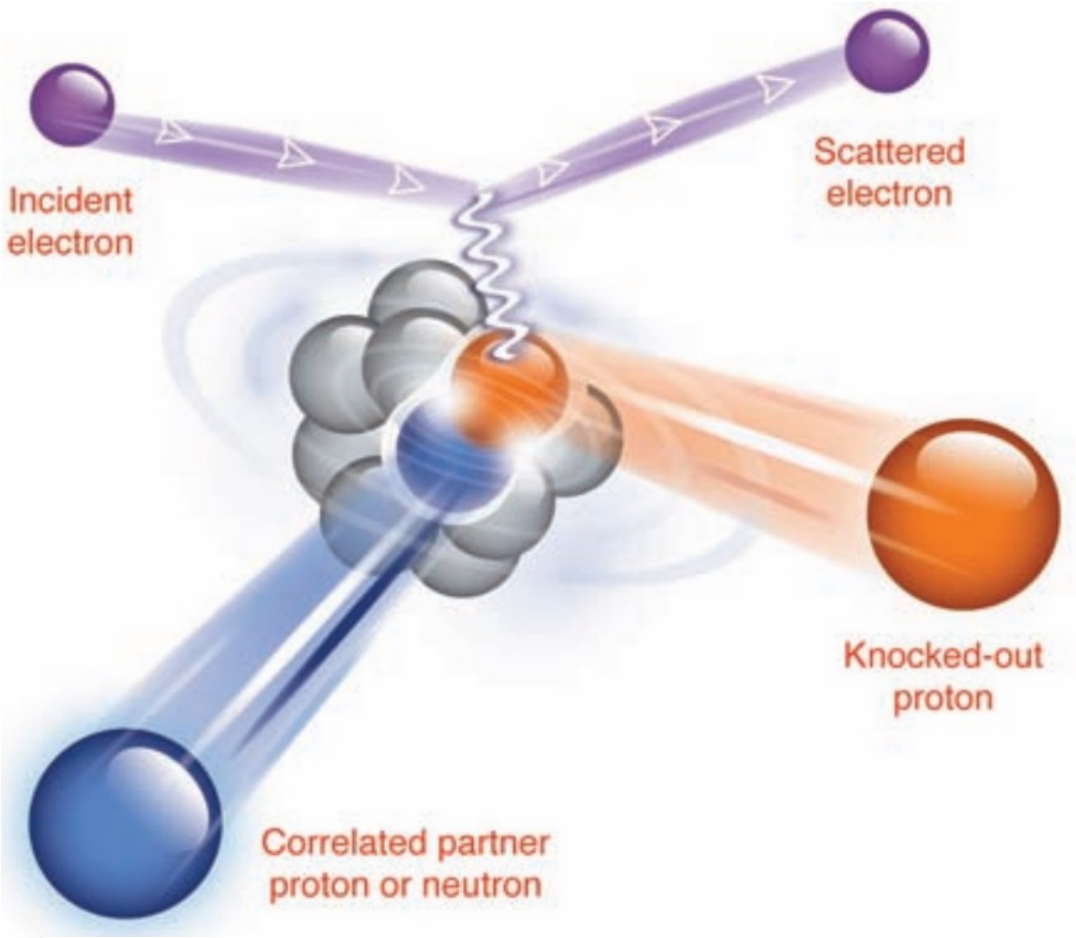
GlueX: Glossy Schematic





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

We have used 3 kinds of electron scattering experiments to study SRCs.



R. Subedi, R. Shneor, P. Monaghan, B.D. Anderson, K. Aniol, J. Annand et al., *Probing cold dense nuclear matter*, *Science* **320** (2008) 1476.

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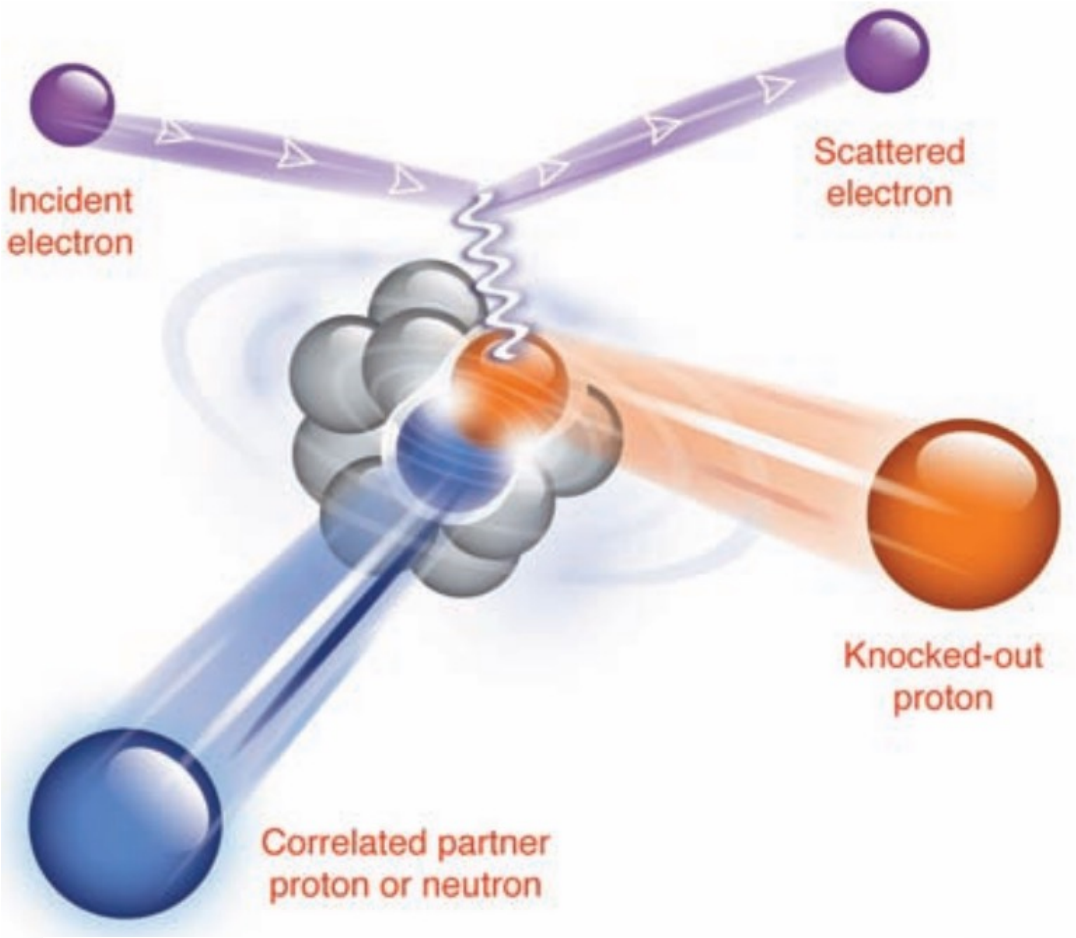
- Inclusive
- Semi-inclusive
- Exclusive



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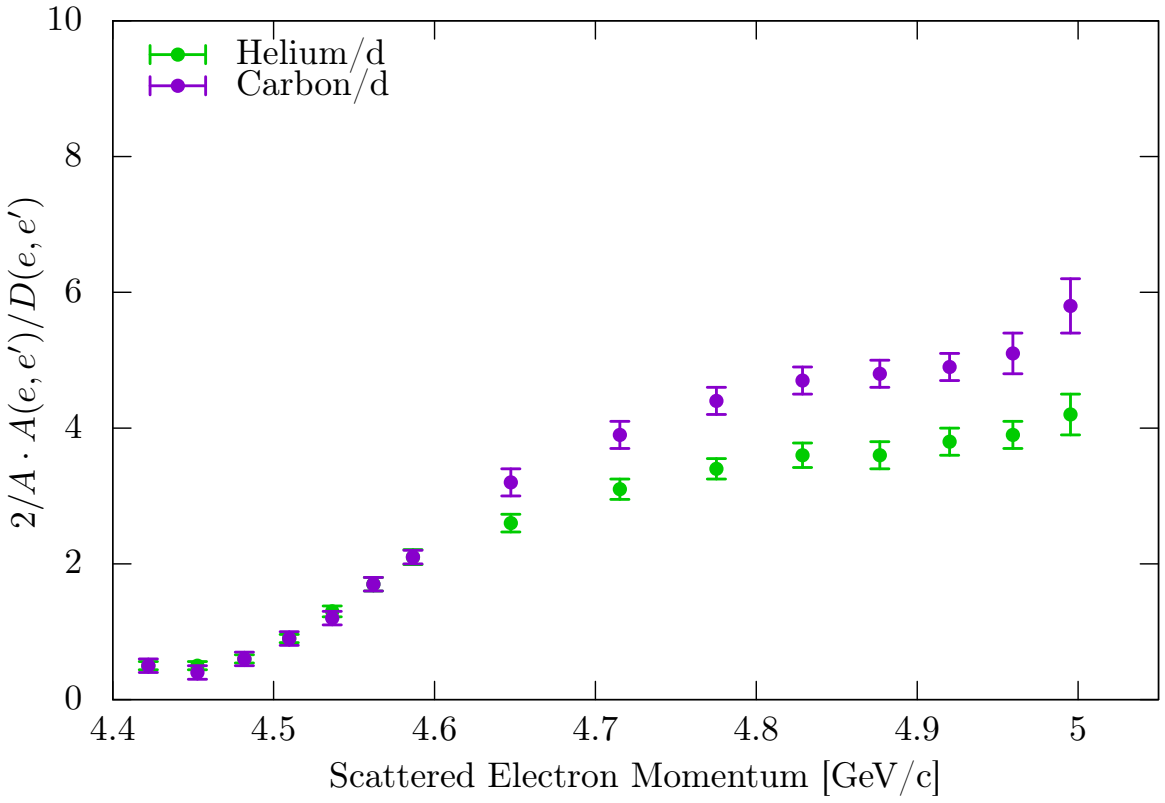
Inclusive Measurements



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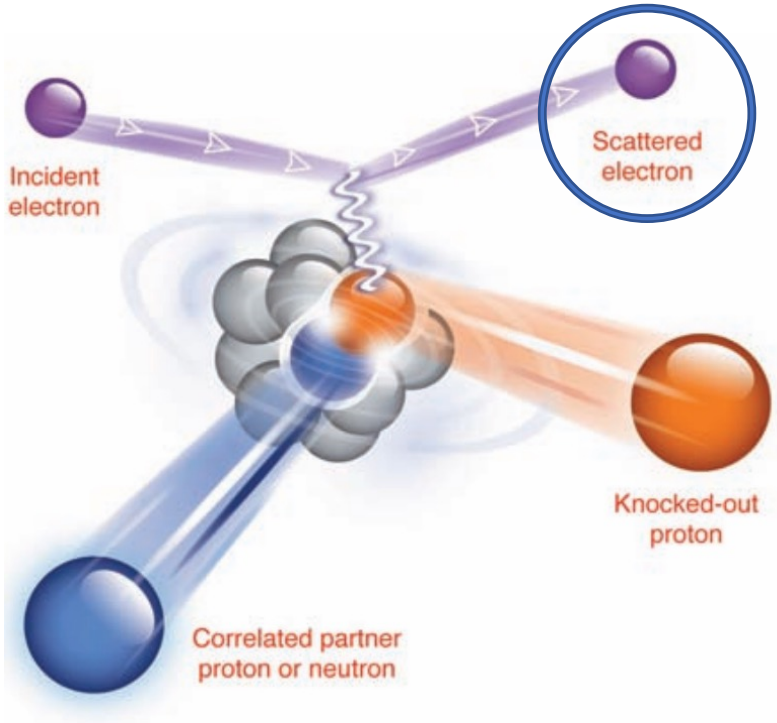

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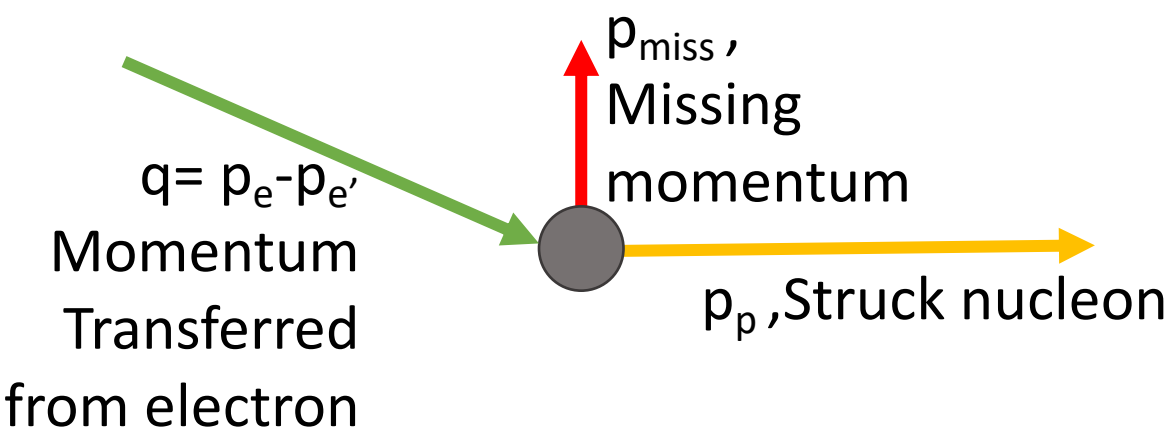
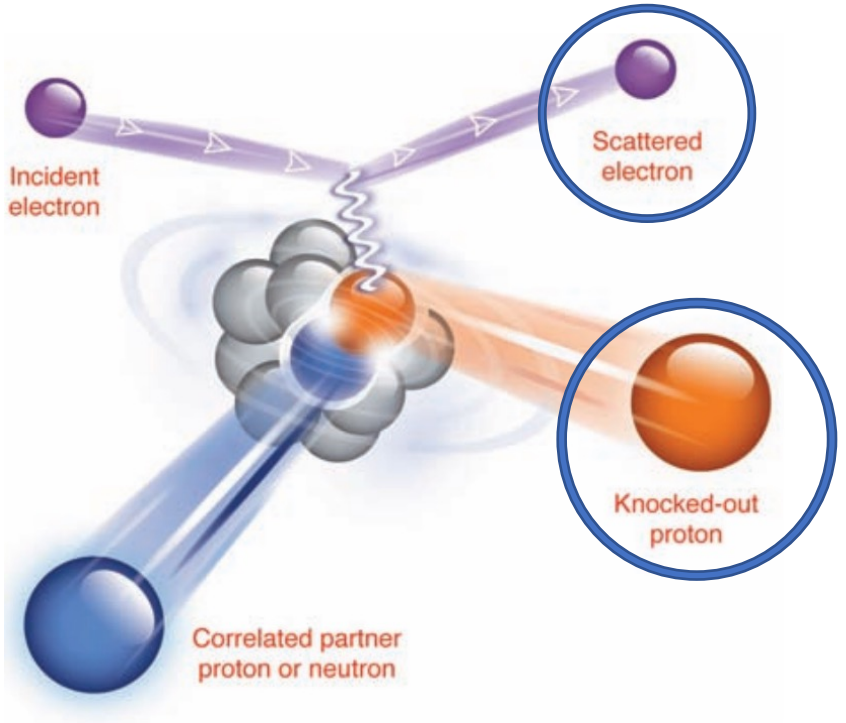
Semi-inclusive Measurements

$$P_{miss} = p_p - (p_e - p_{e'})$$





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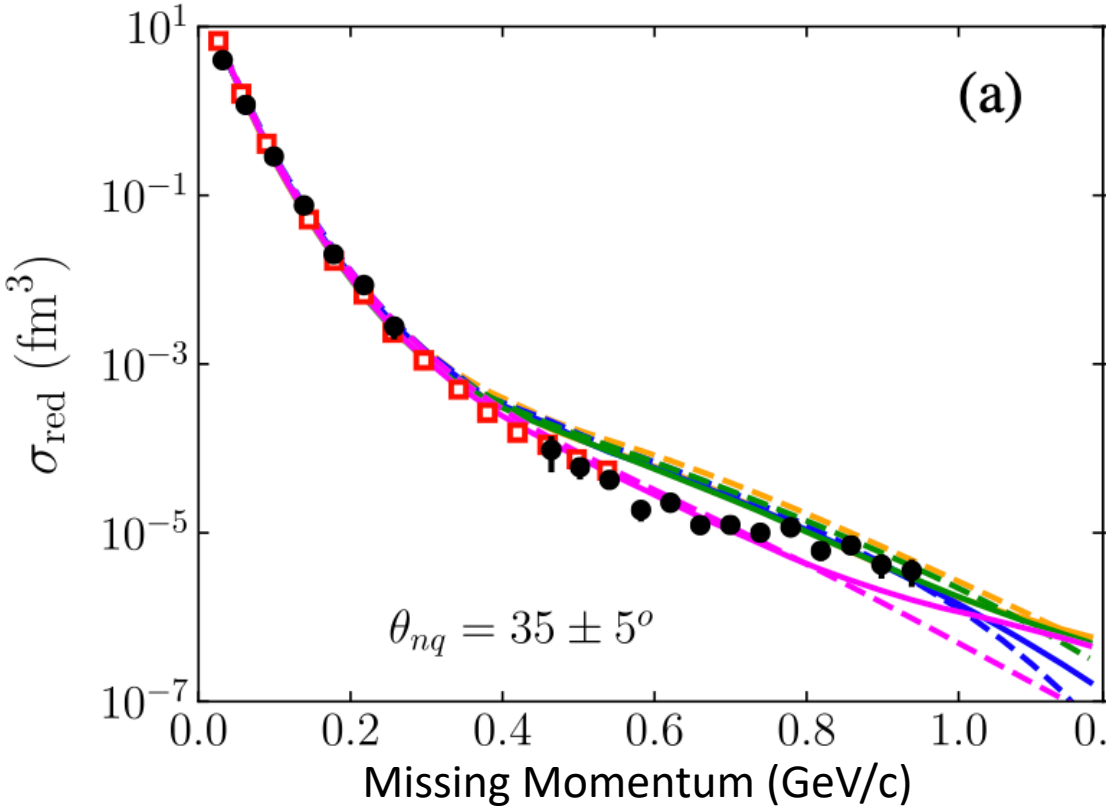

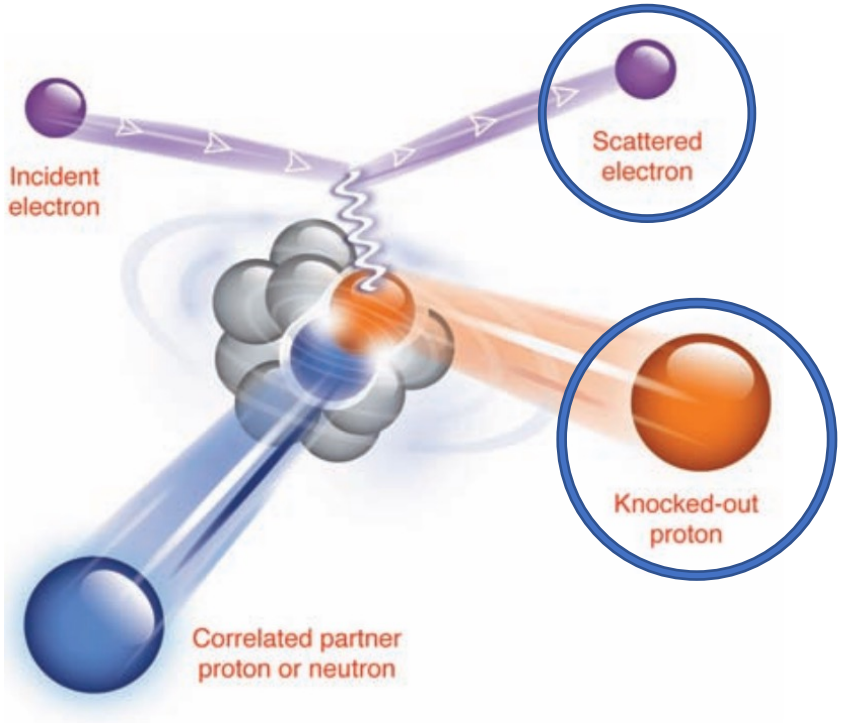

C. Yero, D. Abrams, Z. Ahmed, A. Ahmidouch, B. Aljawrneh, S. Alsalmi et al., *Probing the Deuteron at Very Large Internal Momenta*, *Physical Review Letters* **125** (2020) [2008.08058].

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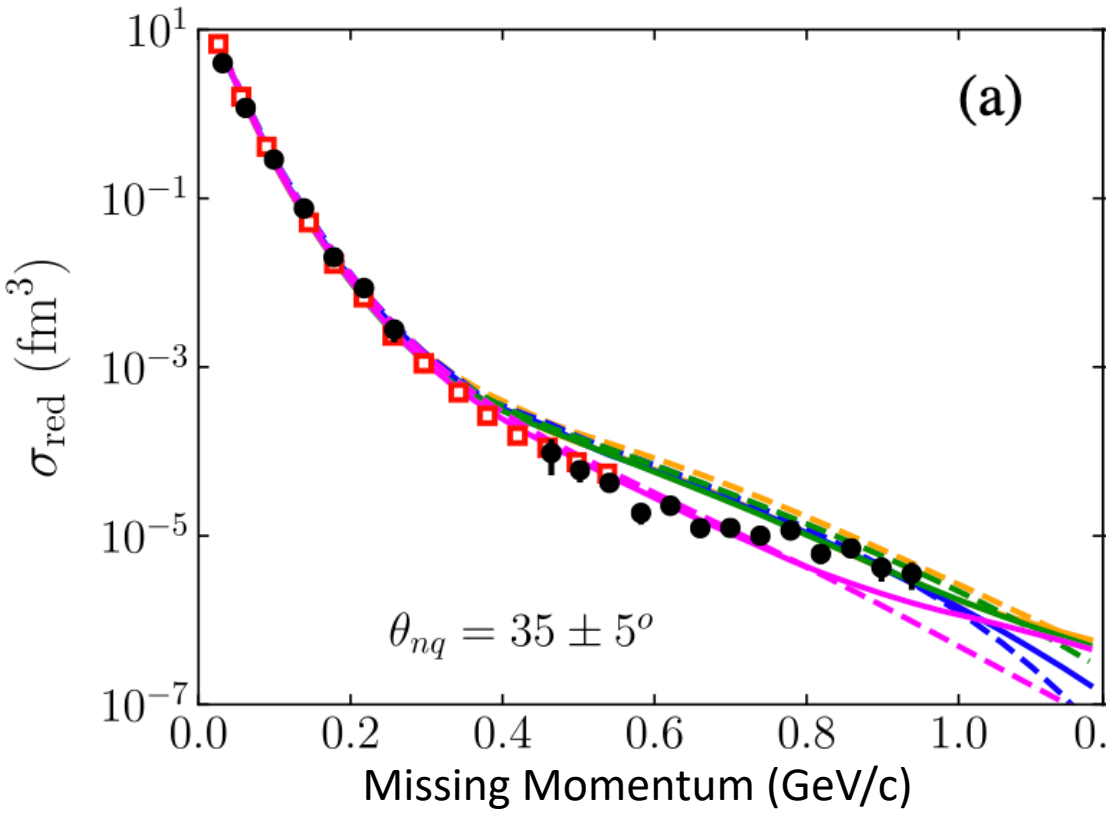

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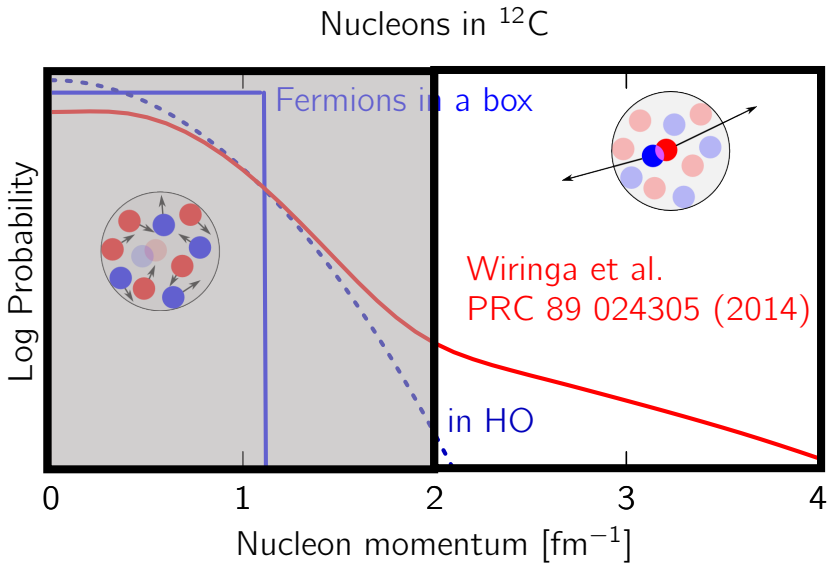
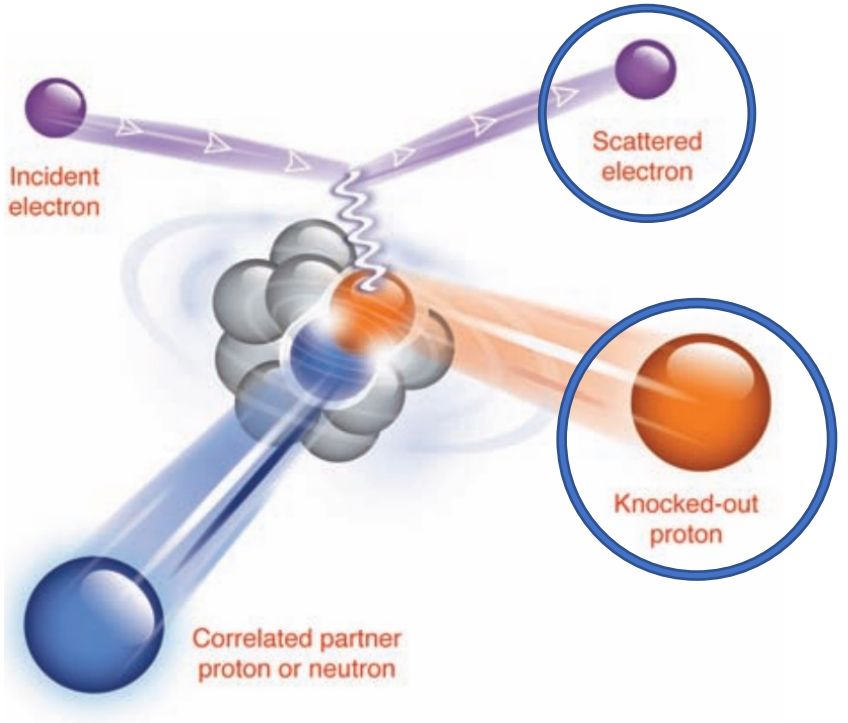
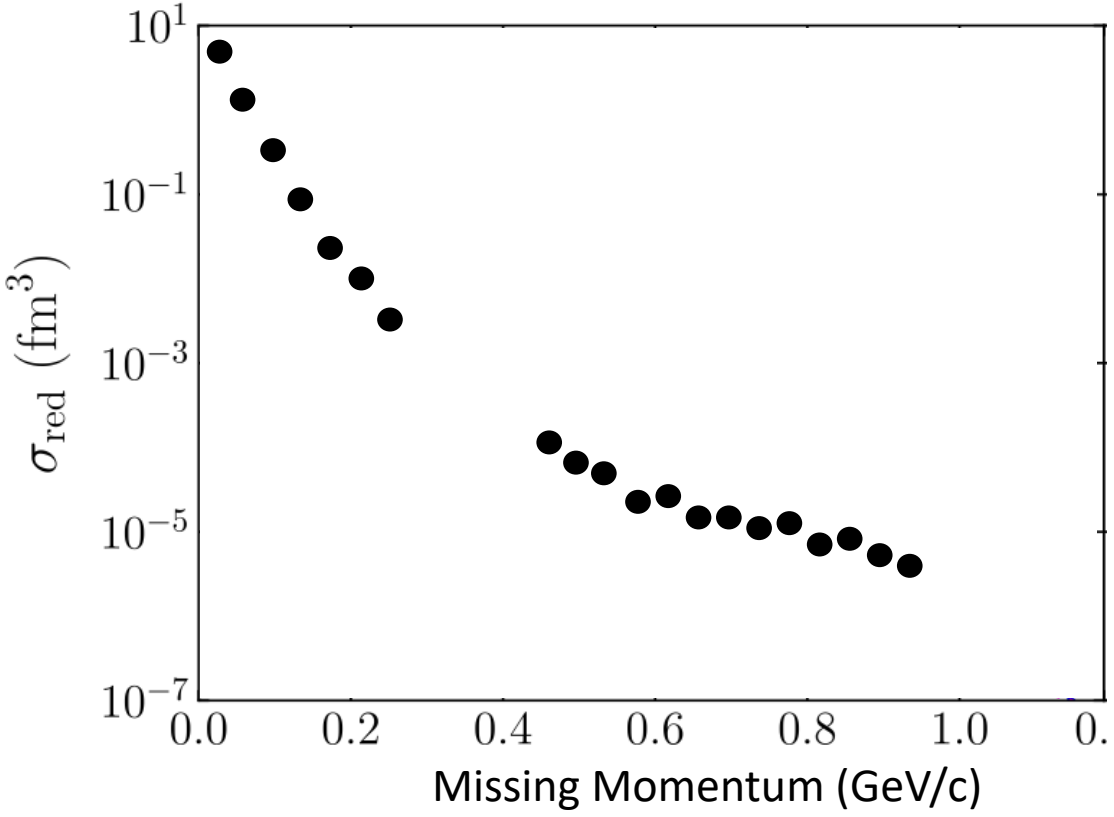
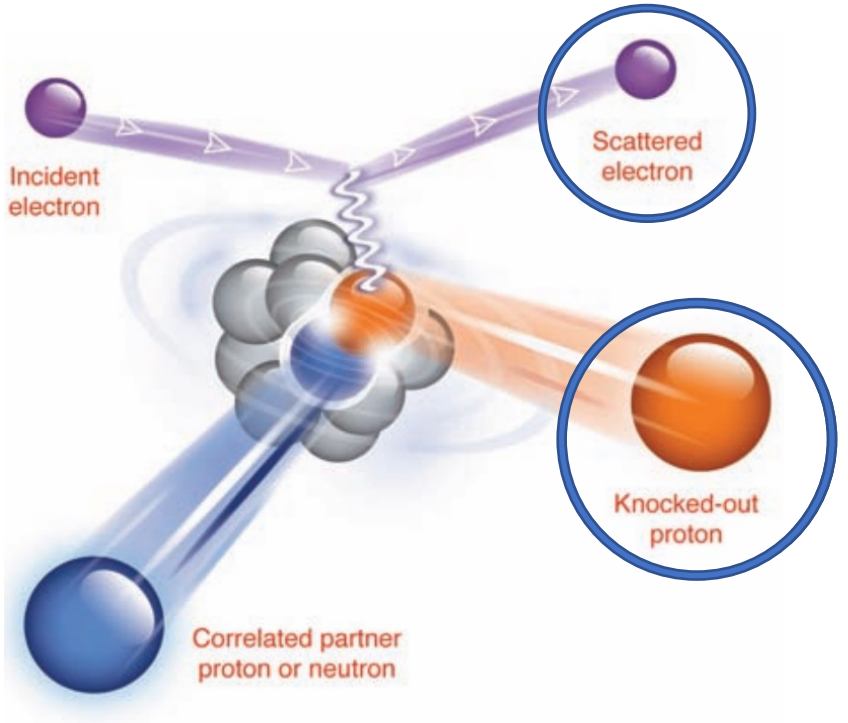




R. Subedi, R. Shneor, P. Monaghan, B.D. Anderson, K. Aniol, J. Annand et al., *Probing cold dense nuclear matter*, *Science* **320** (2008) 1476.

Semi-inclusive Measurements





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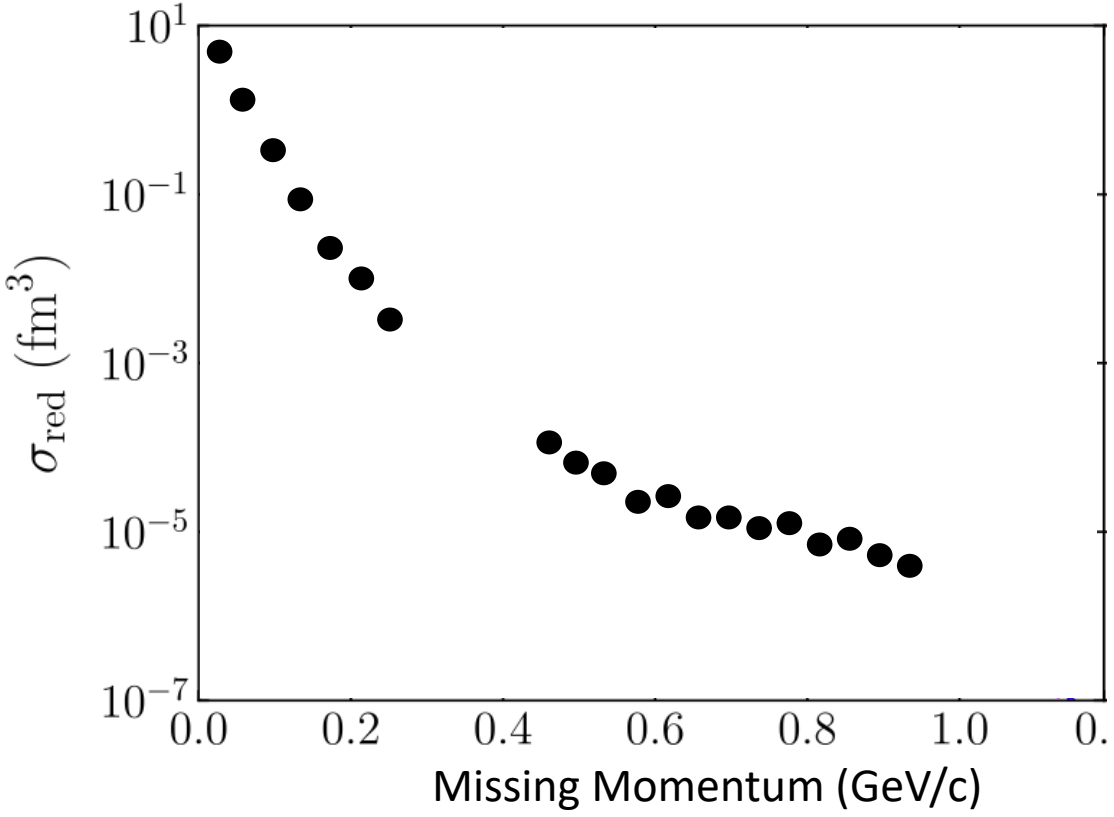

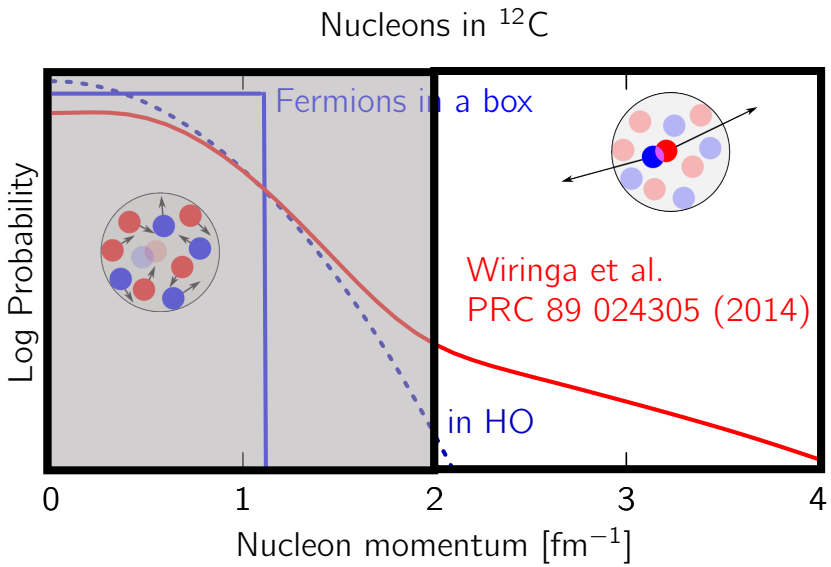

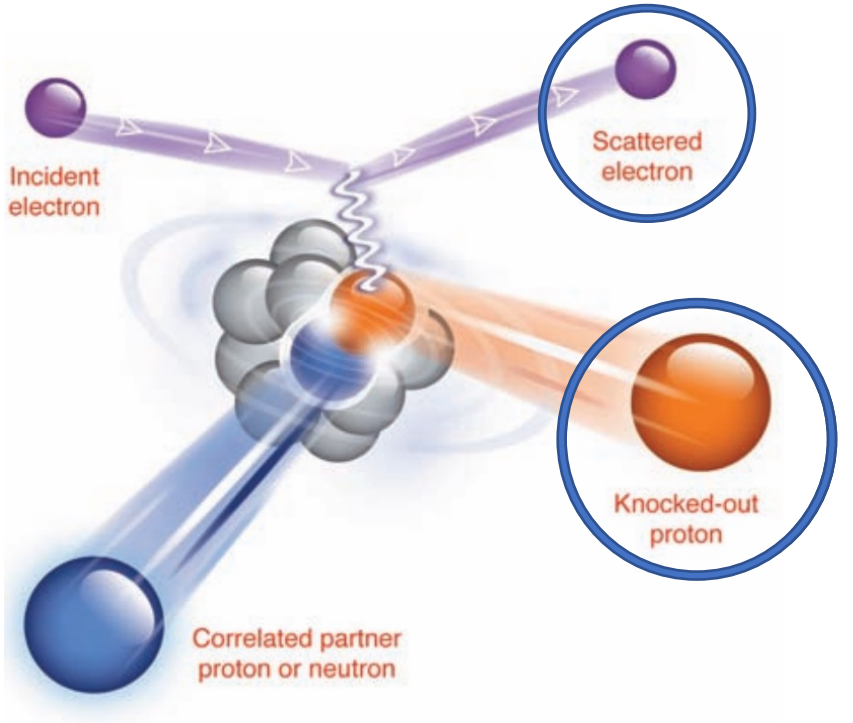

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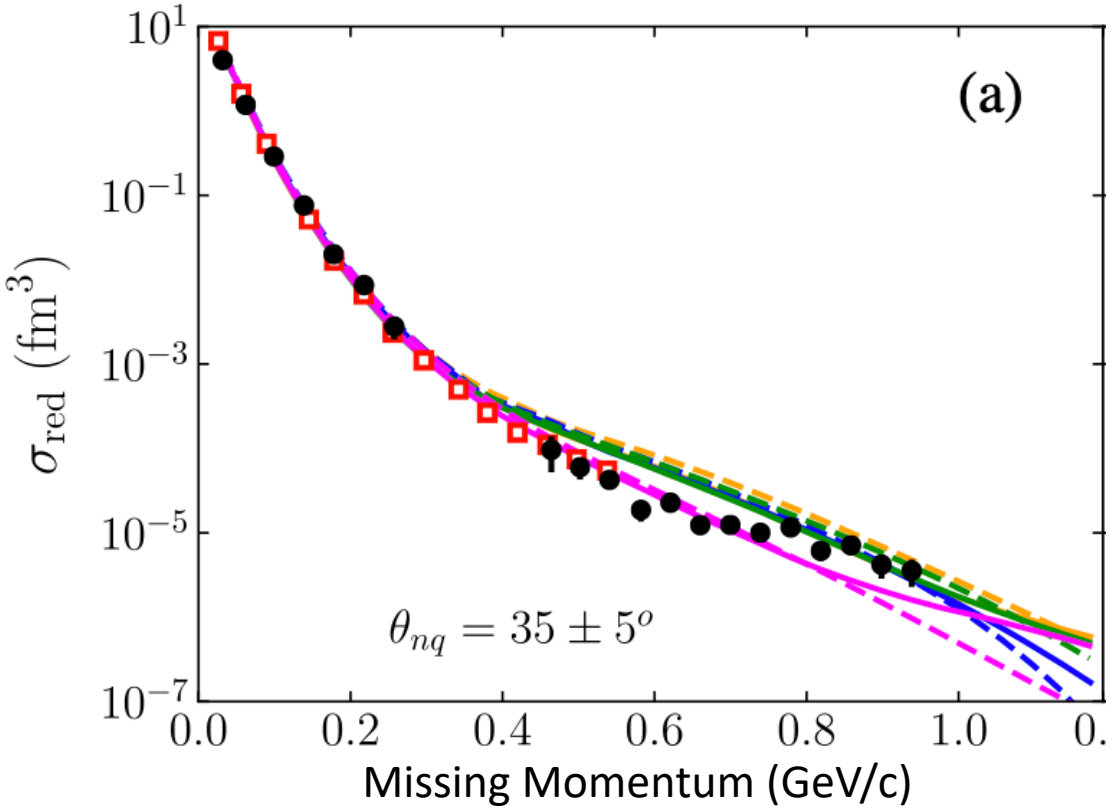

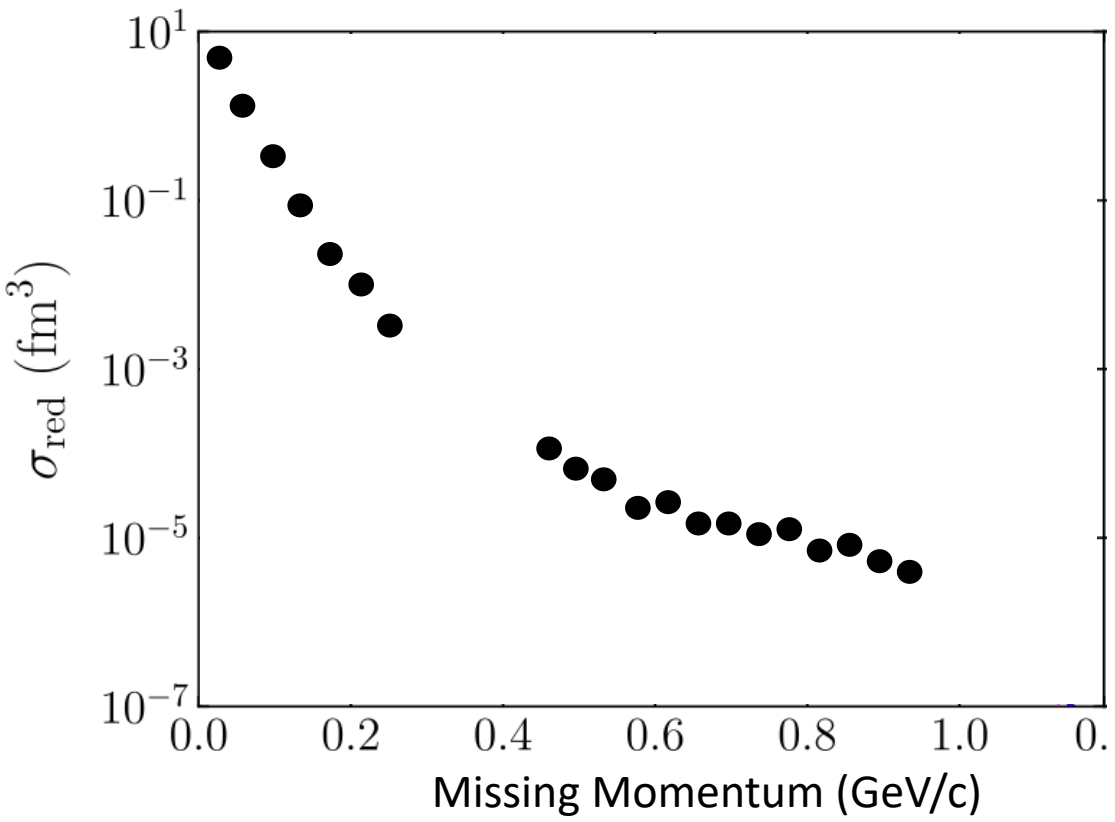

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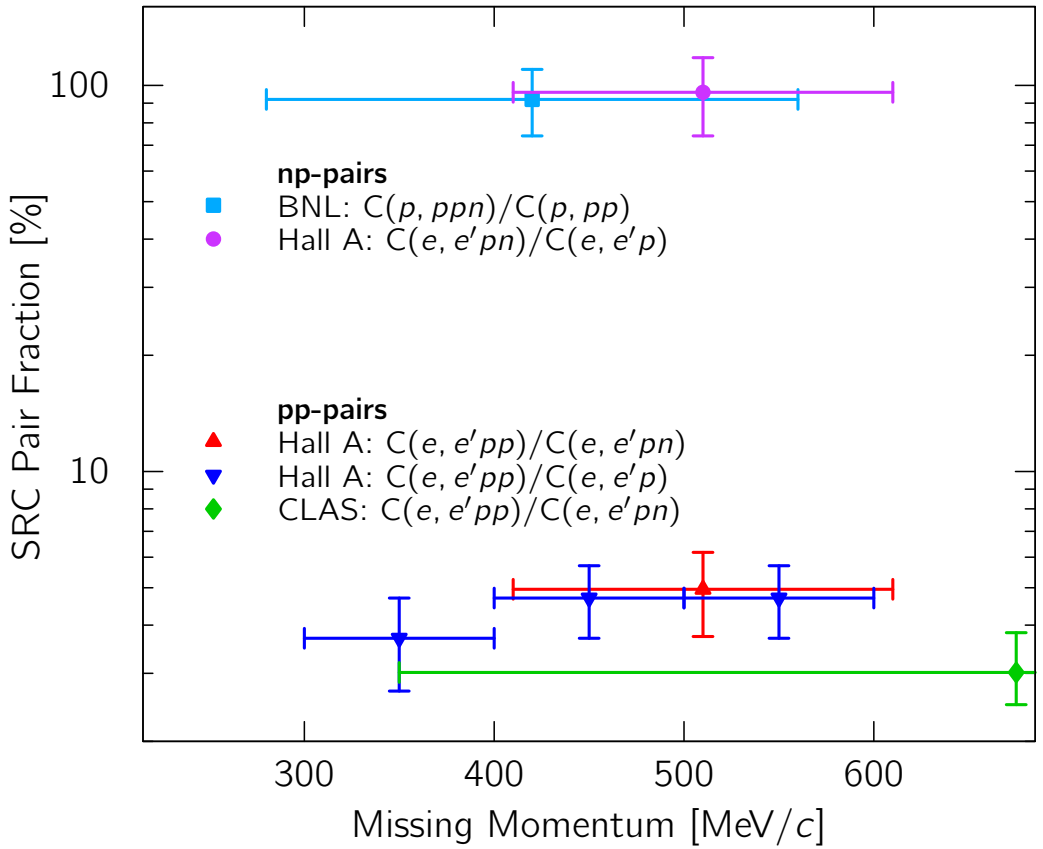
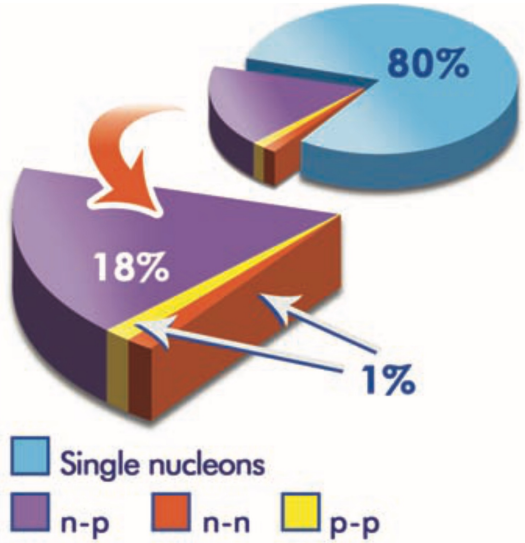
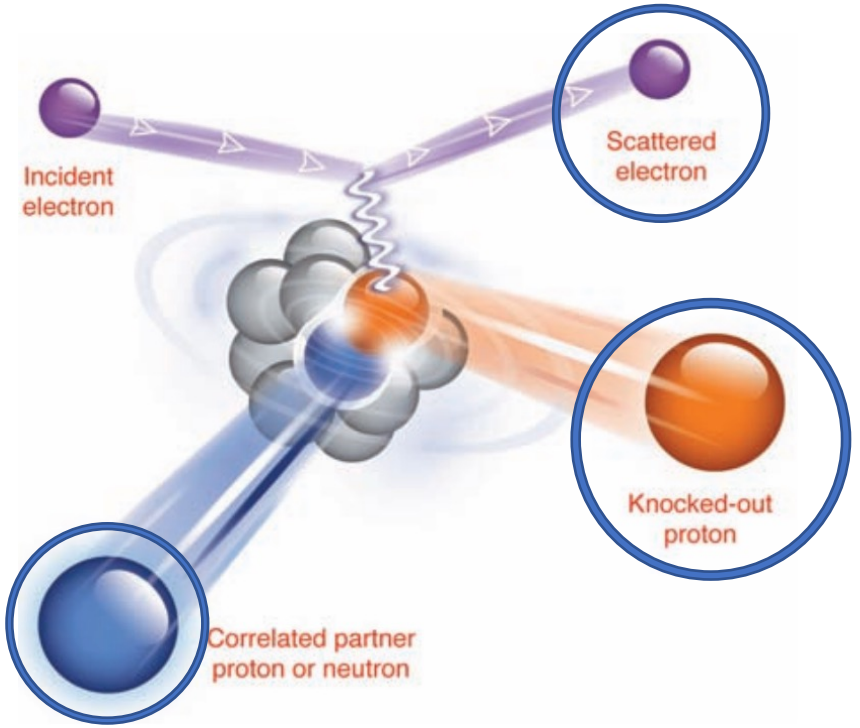
Exclusive Measurements







Add Duer PRL 2019 Direct observation of… citation

R. Subedi, R. Shneor, P. Monaghan, B.D. Anderson, K. Aniol, J. Annand et al.,
Probing cold dense nuclear matter, *Science* **320** (2008) 1476.

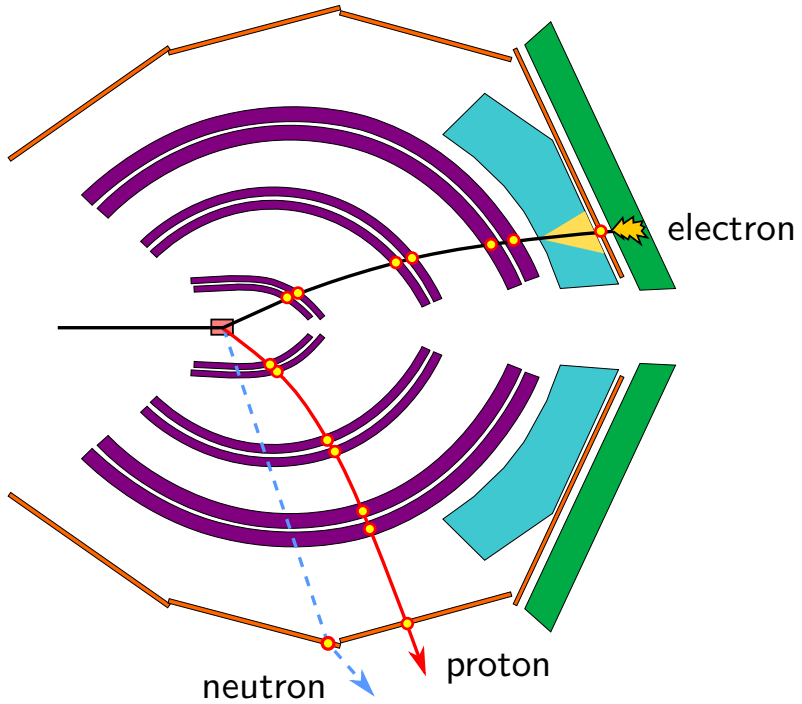
Almost everything we have learned comes from electron scattering in a narrow range of kinematics.

- FSI
  - Any distribution of momentum from the hit nuclei that messing with missing momentum
  - small wedge of anti-parallel kinematics.

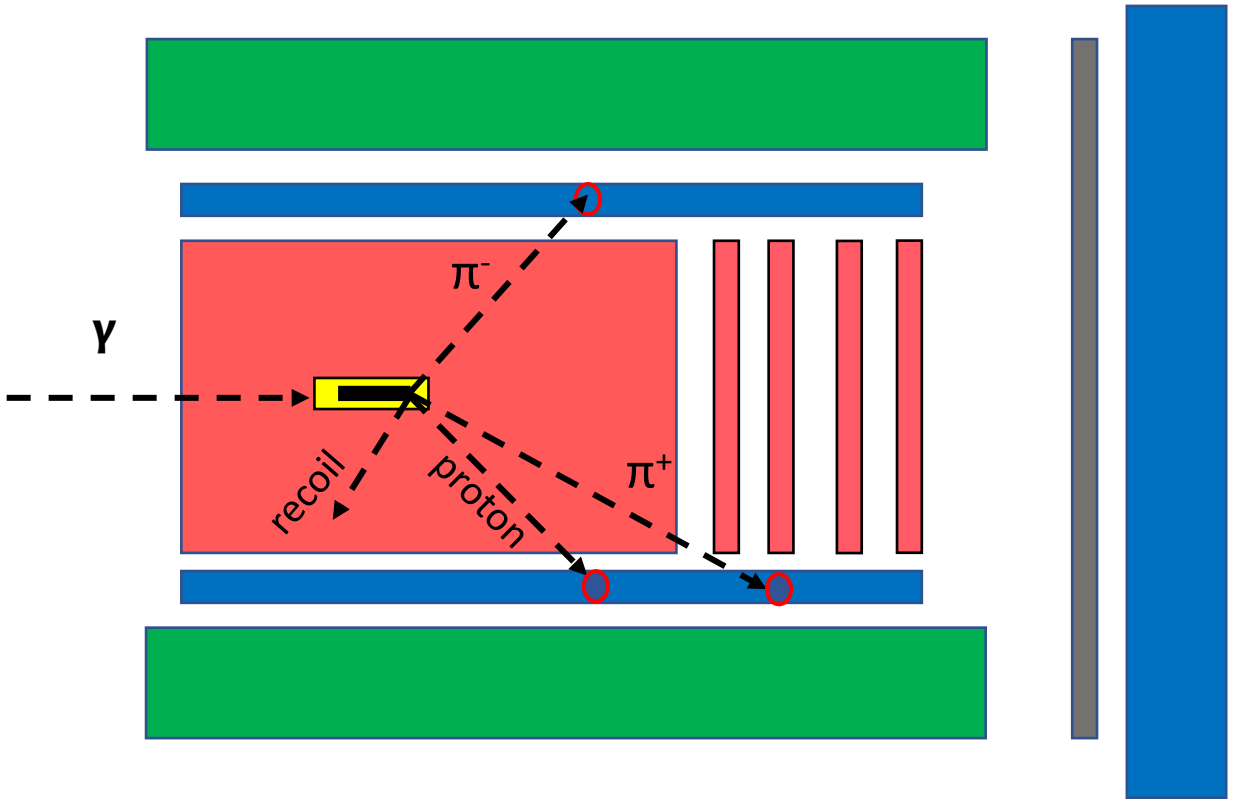
  - Try to see same thing with different probe, final state, kinematics, etc.

Different SRC experiments isolate different kinematic regions.

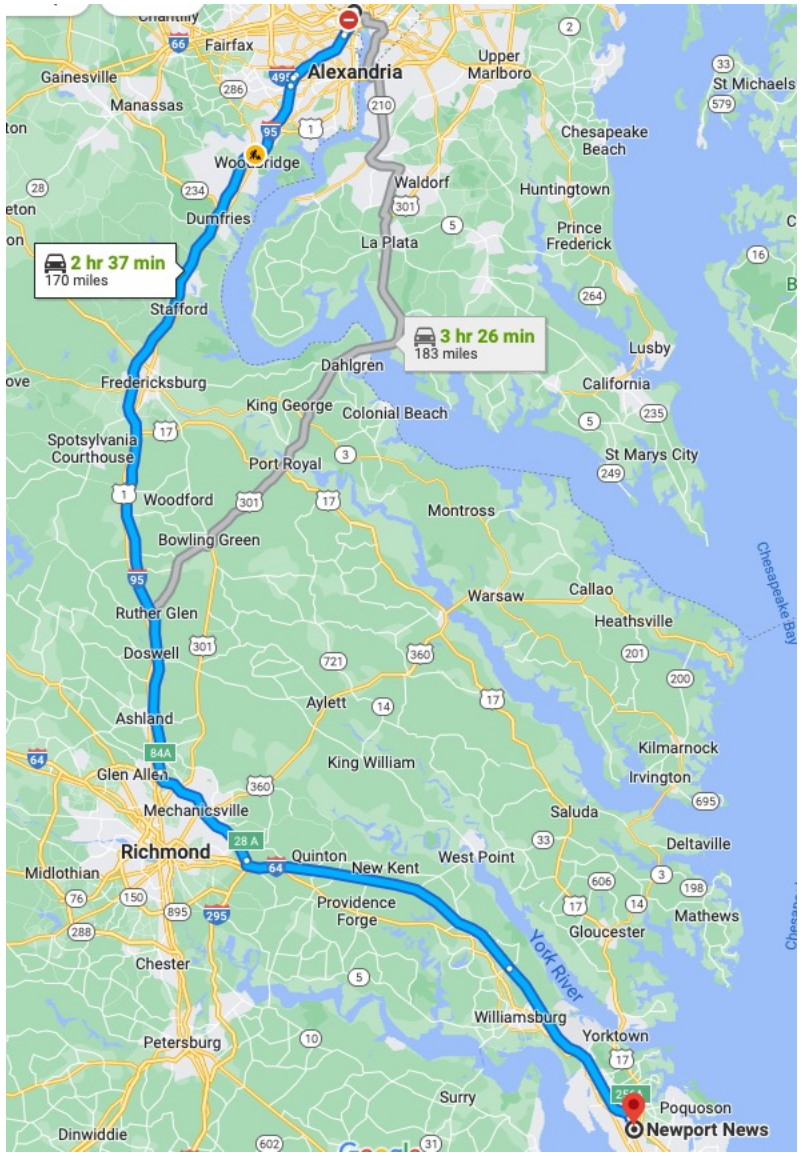
Electron Probe:
Anti-Parallel Kinematics



Real Photon Probe:
Parallel Kinematics



Jefferson Lab



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

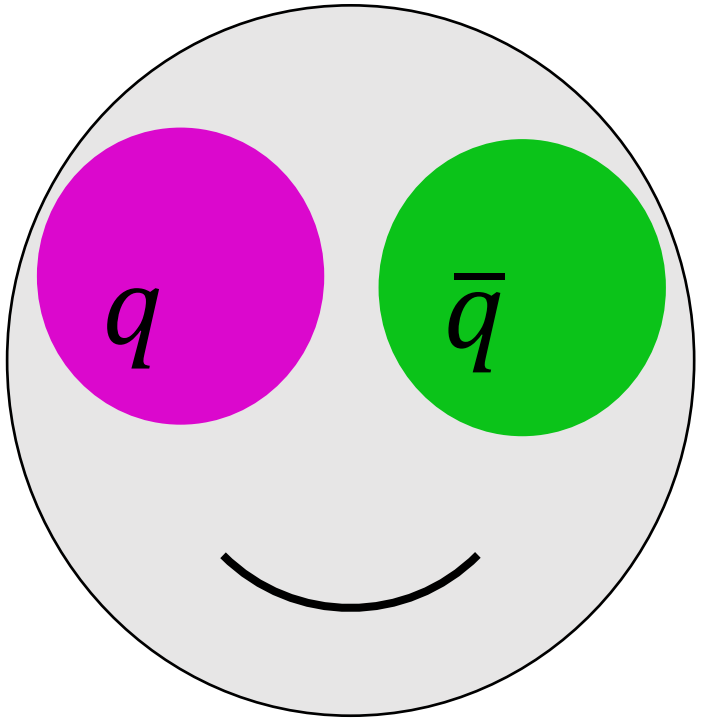
Using the ρ^0 reaction channel, I want to answer these question:

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

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

Some properties about the ρ^0 meson:

- Quantum Numbers: $J^{\pi C}_{\rho^0} = 1^{--}$
- Quark content: $\frac{1}{\sqrt{2}}[u\,\bar{u} - d\,\bar{d}]$
- Mean Lifetime: ~4.5×10^{-24} s
- Mass: 0.775 GeV/c^2
- Decay: $\rho^0 \rightarrow \pi^+ + \pi^-$



There are a number of steps we have to take to be able to analyze the data.

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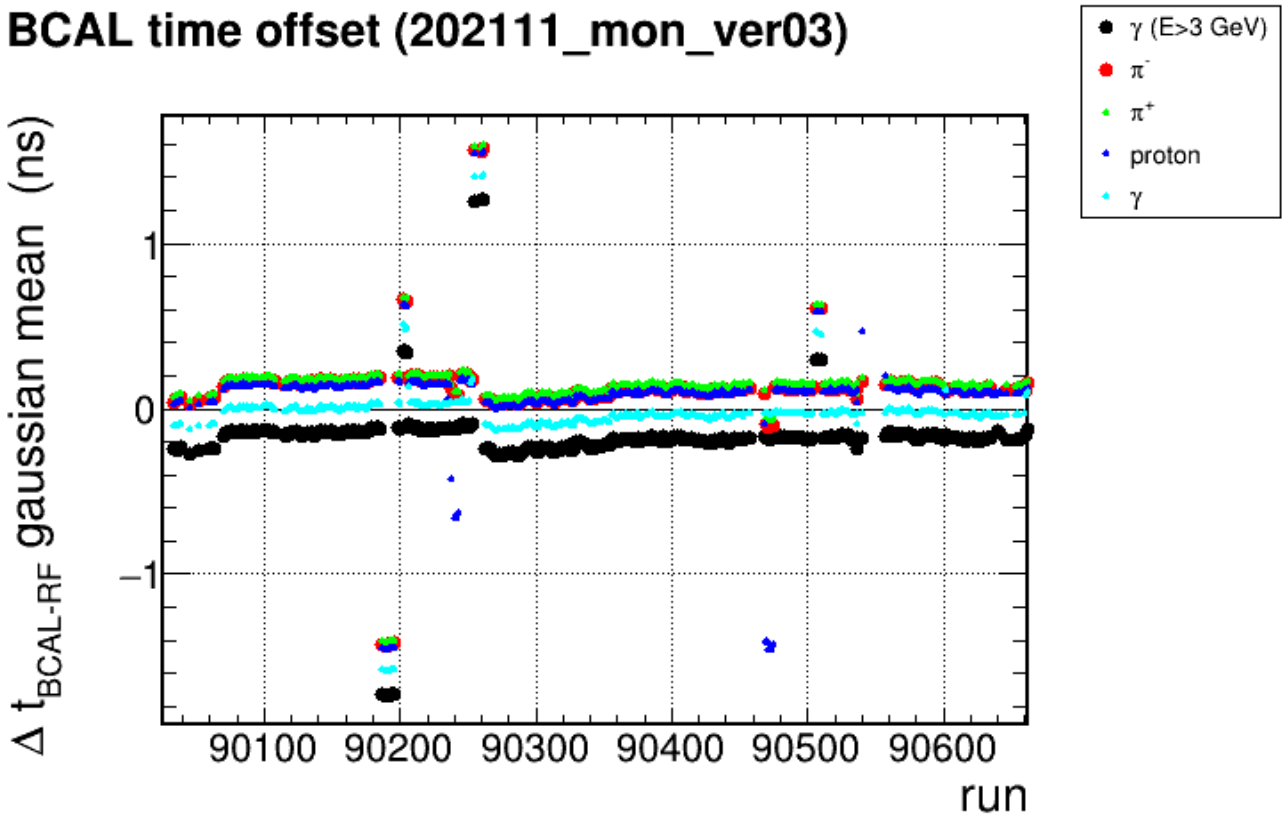
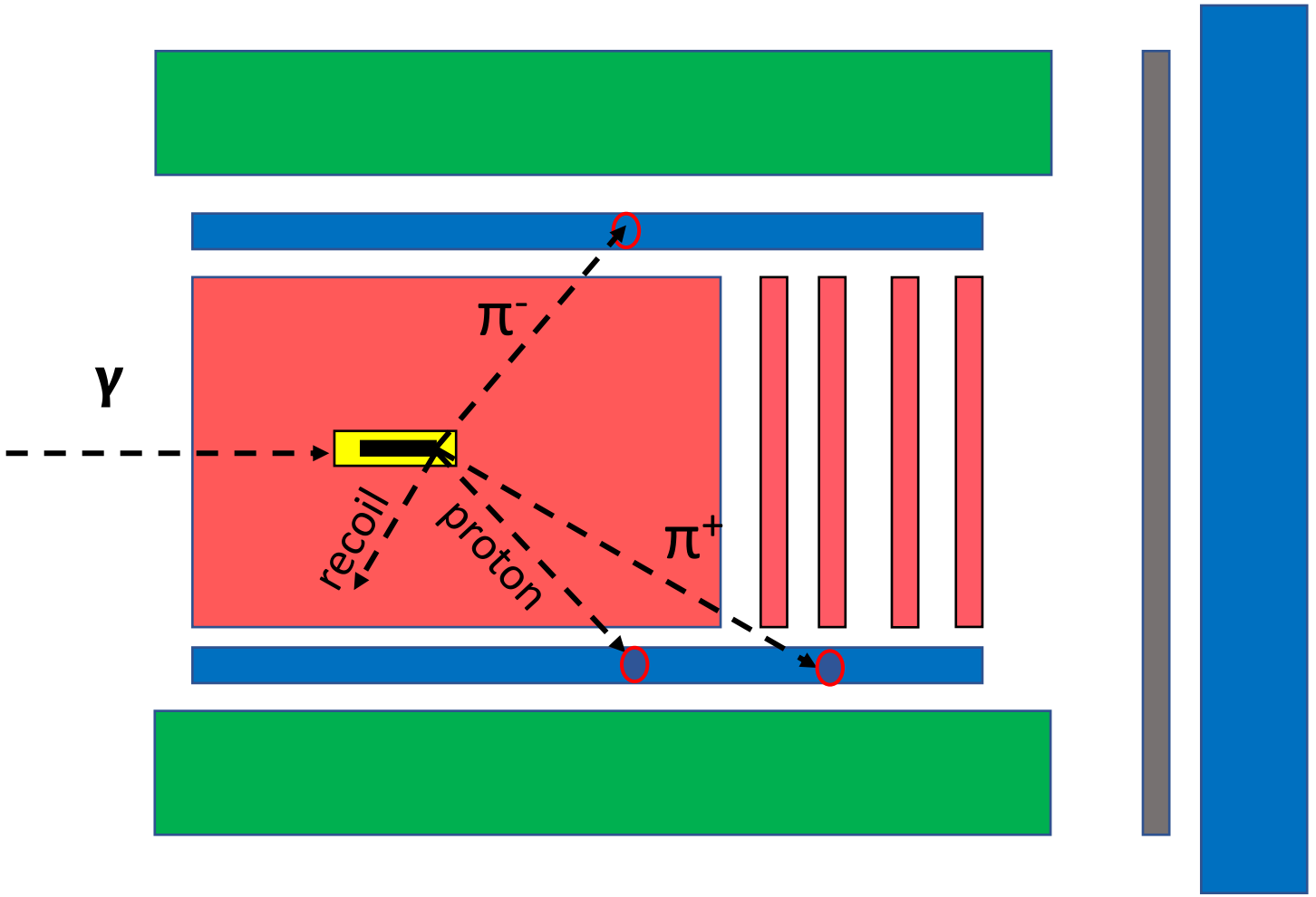
- Calibration



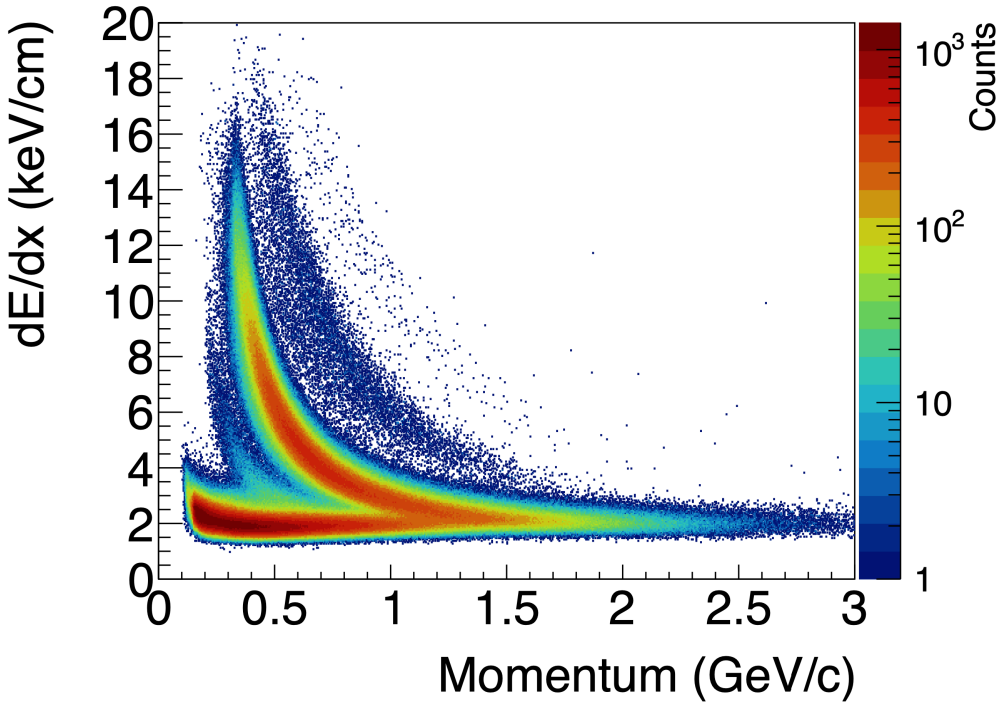
There are a number of steps we have to take to be able to analyze the data.

- Calibration
- Reconstruction



There are a number of steps we have to take to be able to analyze the data.

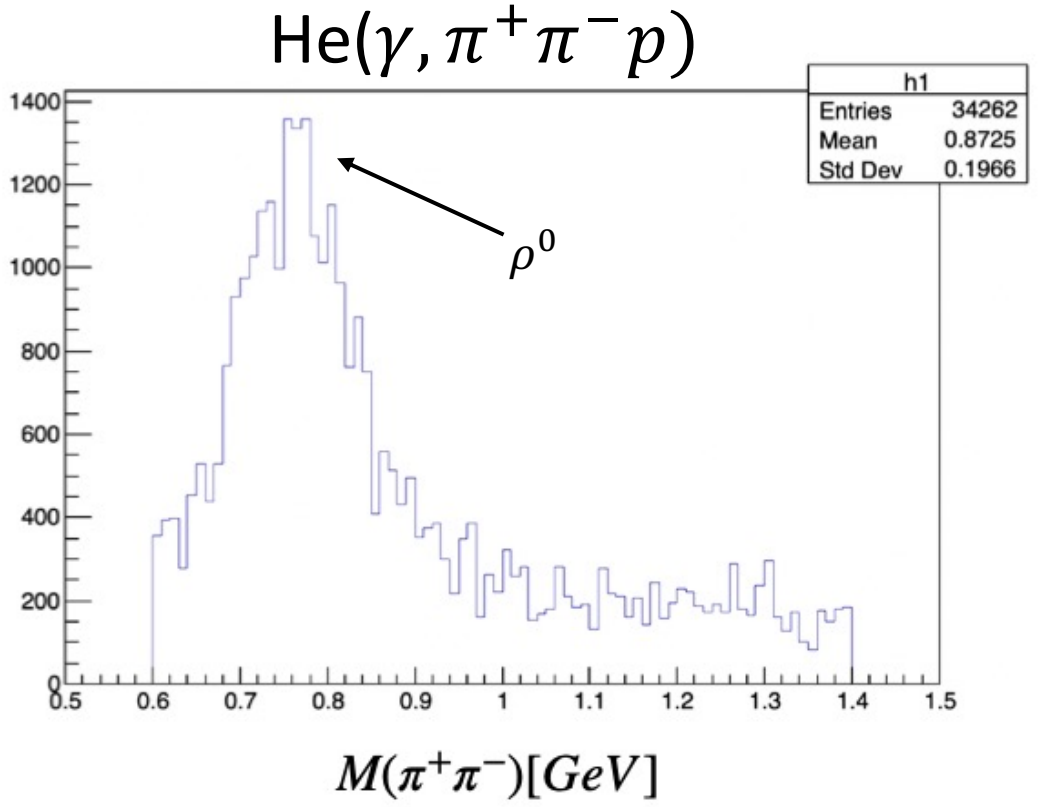
- Calibration
- Reconstruction
- Event Selection
  - Particle ID
  - Fiducial Volume
  - Recoil Acceptance
  - Background



S. Adhikari, C.S. Akondi, H. Al Ghoul, A. Ali, M. Amaryan, E.G. Anassontzis et al., *The GLUEX beamline and detector*, *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **987** (2021) 1 [2005.14272].

There are a number of steps we have to take to be able to analyze the data.

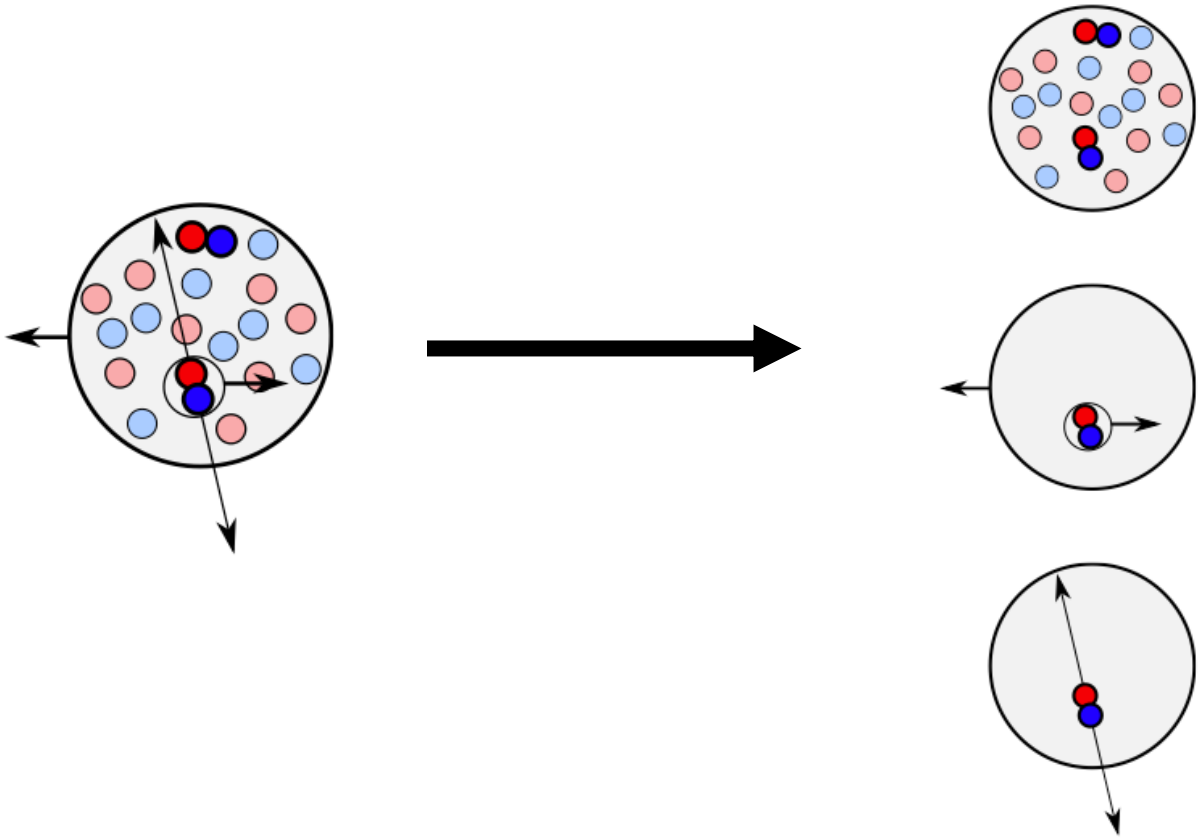
- Calibration
- Reconstruction
- Event Selection
  - Particle ID
  - Fiducial Volume
  - Recoil Acceptance
  - Background
- Analysis
  - Np-pair dominance
  - Abundance of SRC pairs
  - Comparison to Theory



N. Santiesteban. Fall 2021

Generalized Contact Formalism

Scale separated approach to Short-Range Correlations



Pair abundances

From inclusive scattering or VMC

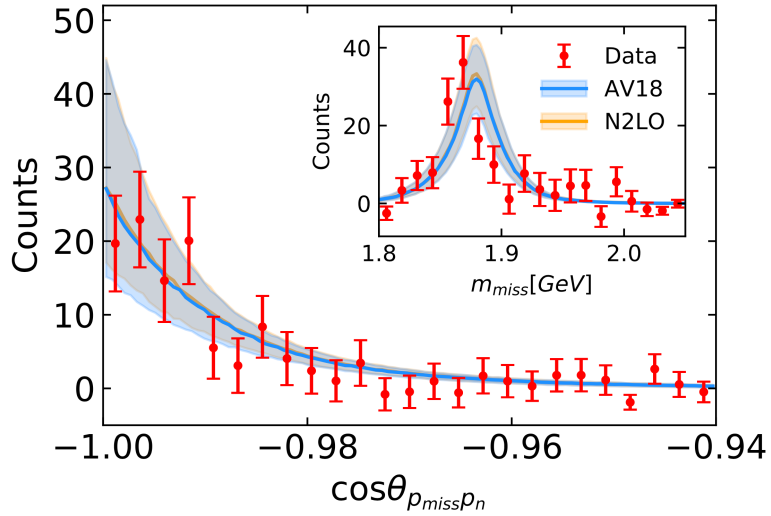
Pair CM motion

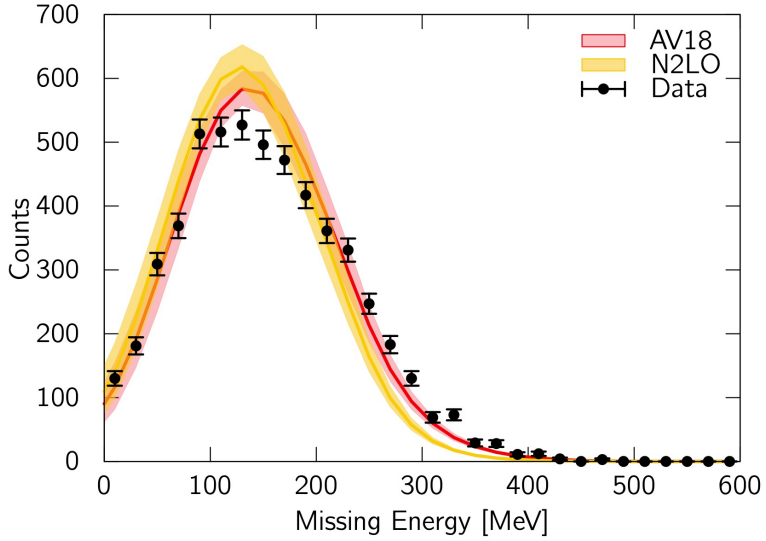
From experiment and theory

Pair relative motion

NN-interaction model: AV18/ N2LO
That is where we need input.

GCF and Previous SRC Experiments

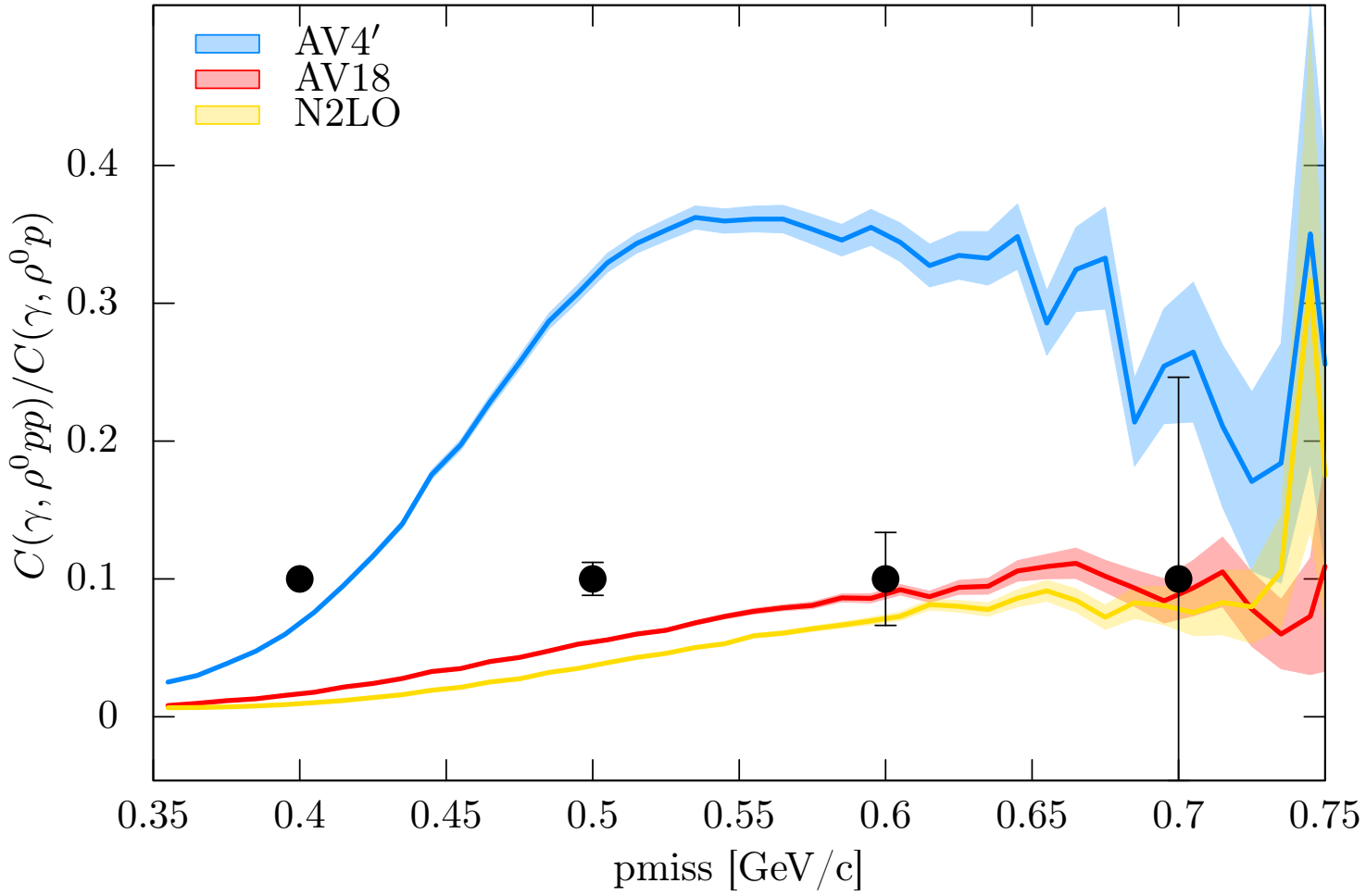




List of papers:

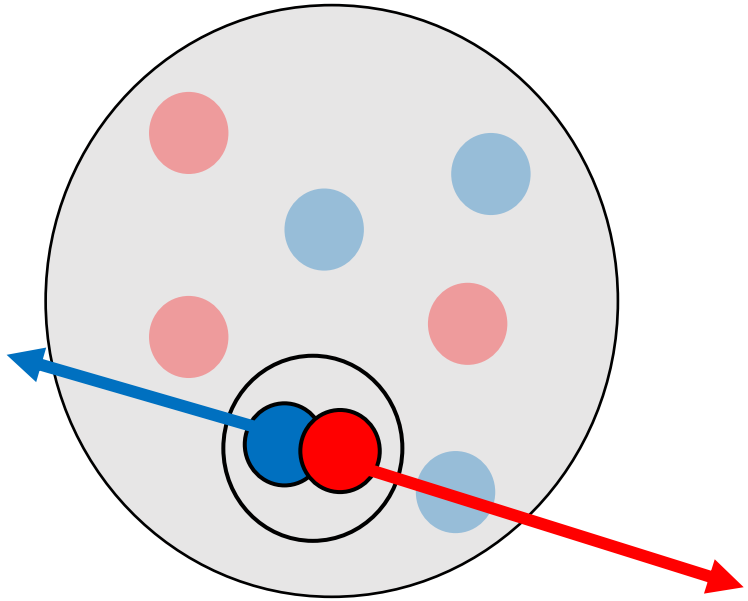
- Duer PRL 2019
- Schmidt Nature 2020
- Pybus PLB 2020
- Korover PLB 2021
- Weiss PRC 2021
- Patsyuk Nature Physics 2021
- *In preparation:*
  - *Wright arxiv 2021*
  - *Korover Science 2022*

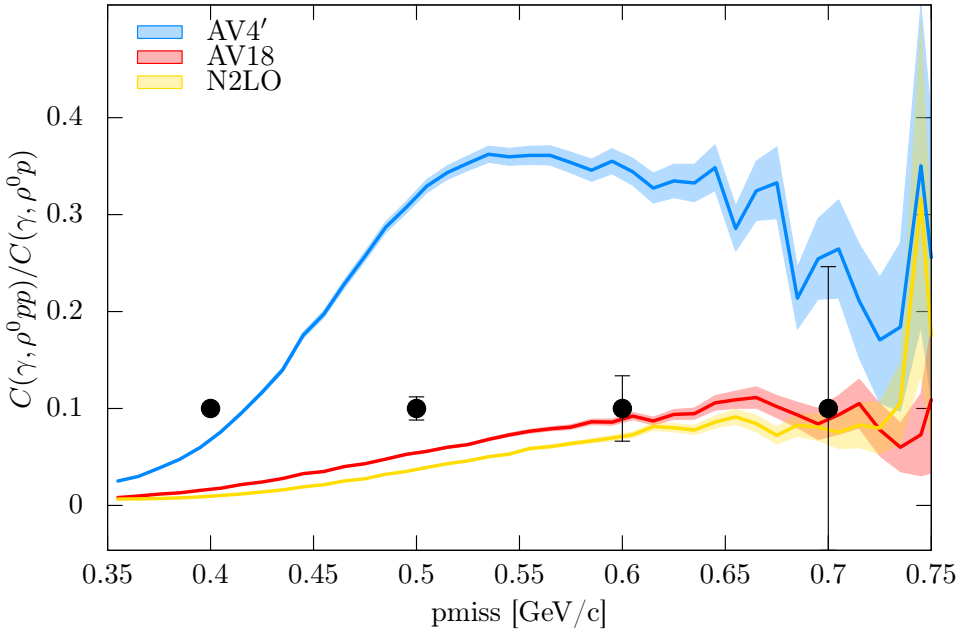
GCF Predictions of np-pair dominance using ρ^0 photoproduction.

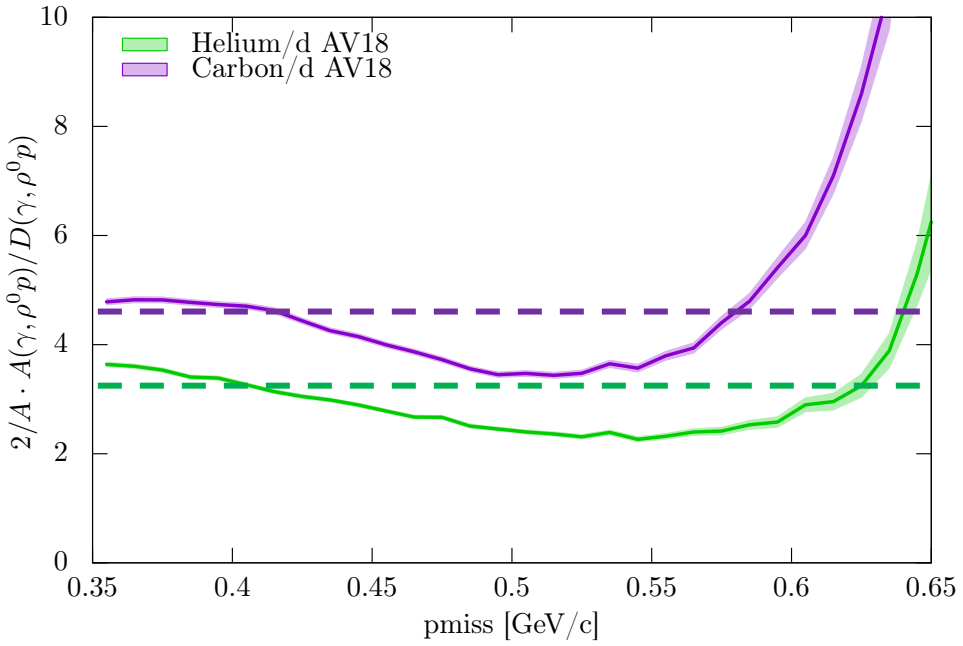


In summary,

- Electron scattering experiments have taught us about SRC pairs.
- Those experiments have assumptions we need to test.
- A photon beam can help us test our understanding of SRC pairs.
- Data was collected in Fall 2021.
- I plan to graduate in 2025.



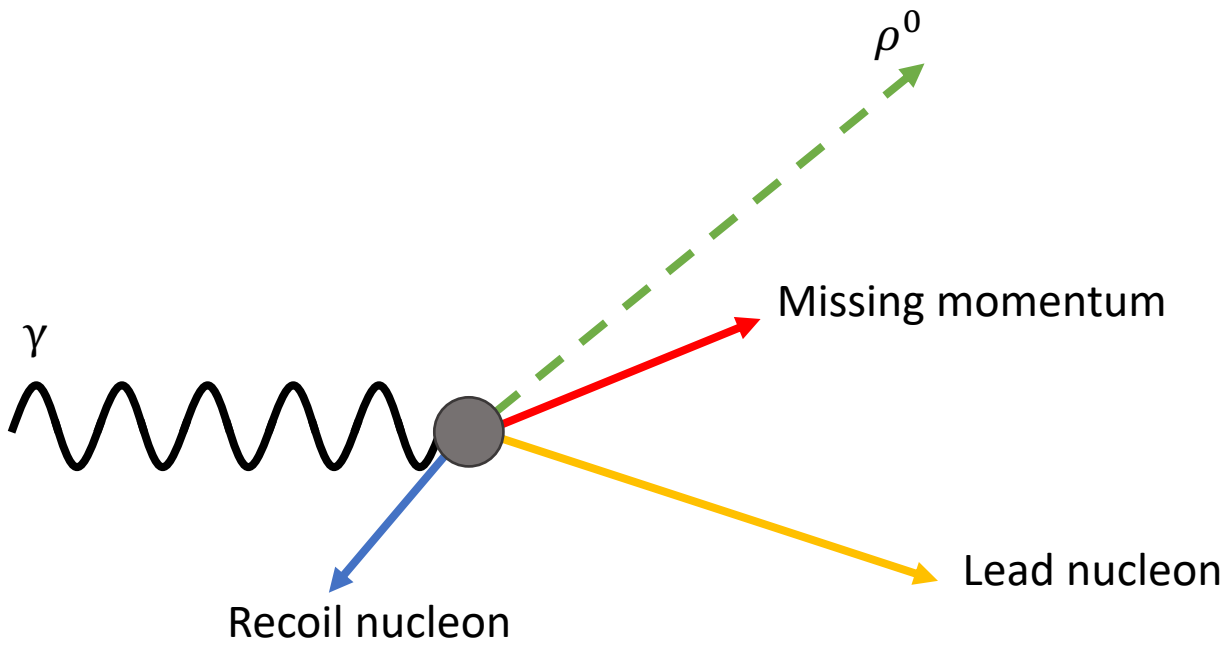




Using different reaction mechanisms, photons provide a new perspective to SRC experiments.

- Using parallel kinematics

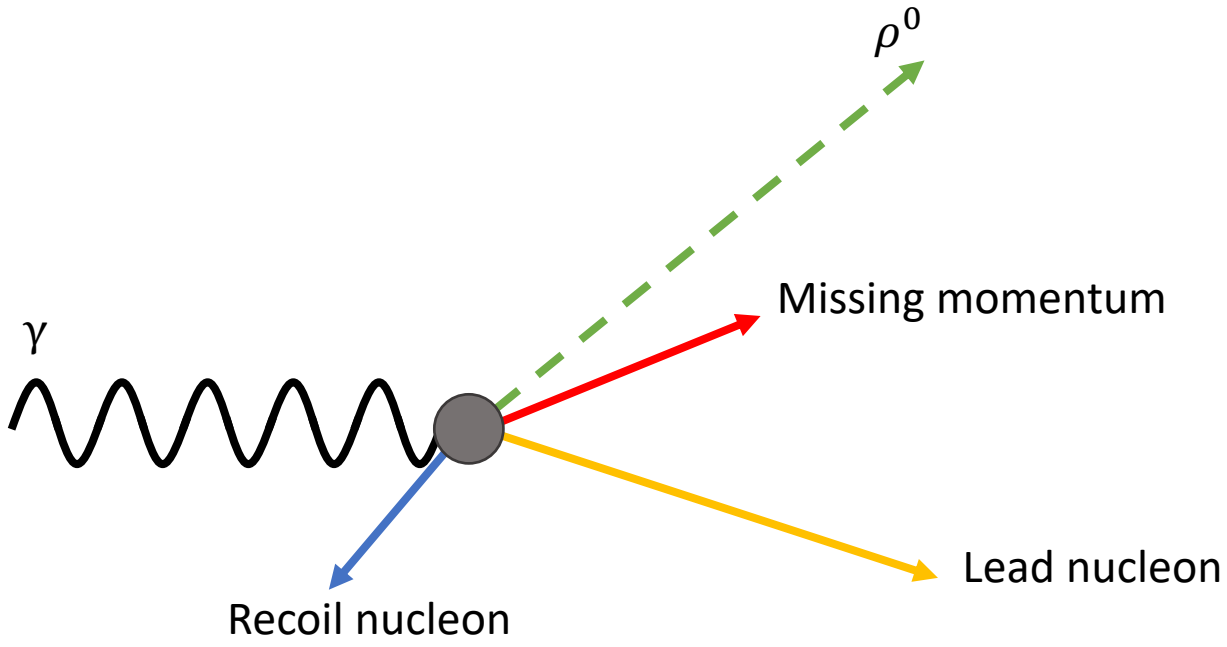
Real Photon Probe:
Parallel Kinematics



Using different reaction mechanisms, photons provide a new perspective to SRC experiments.

- Using parallel kinematics
- Different final states

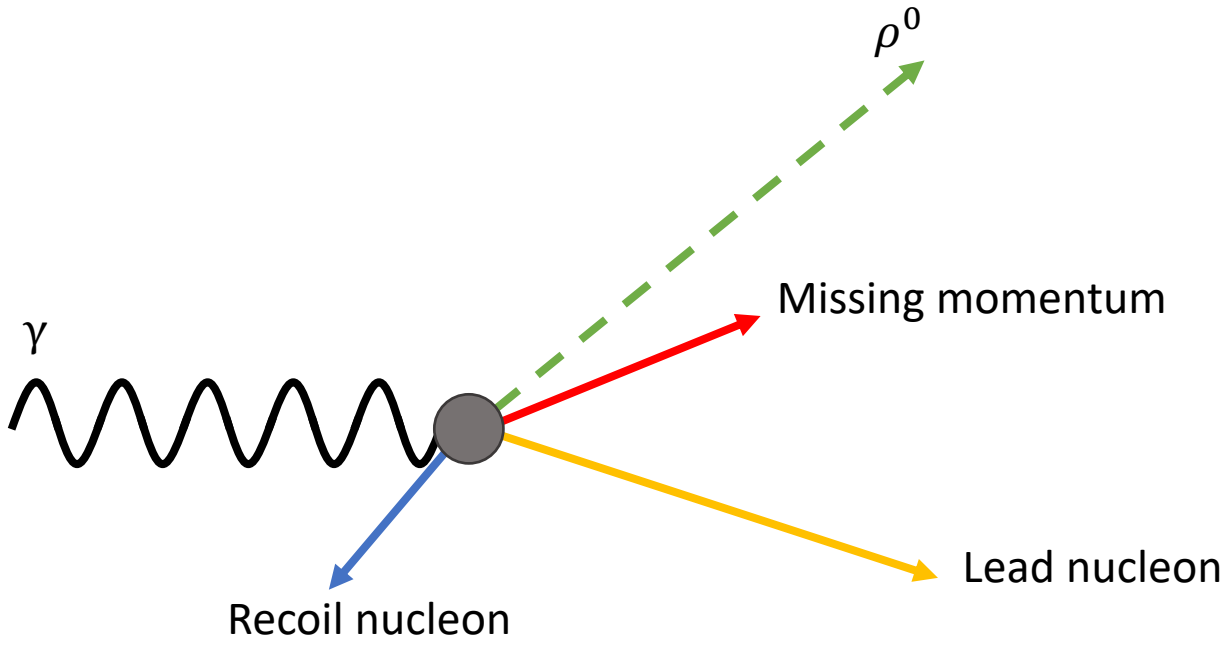
Real Photon Probe:
Parallel Kinematics



Using different reaction mechanisms, photons provide a new perspective to SRC experiments.

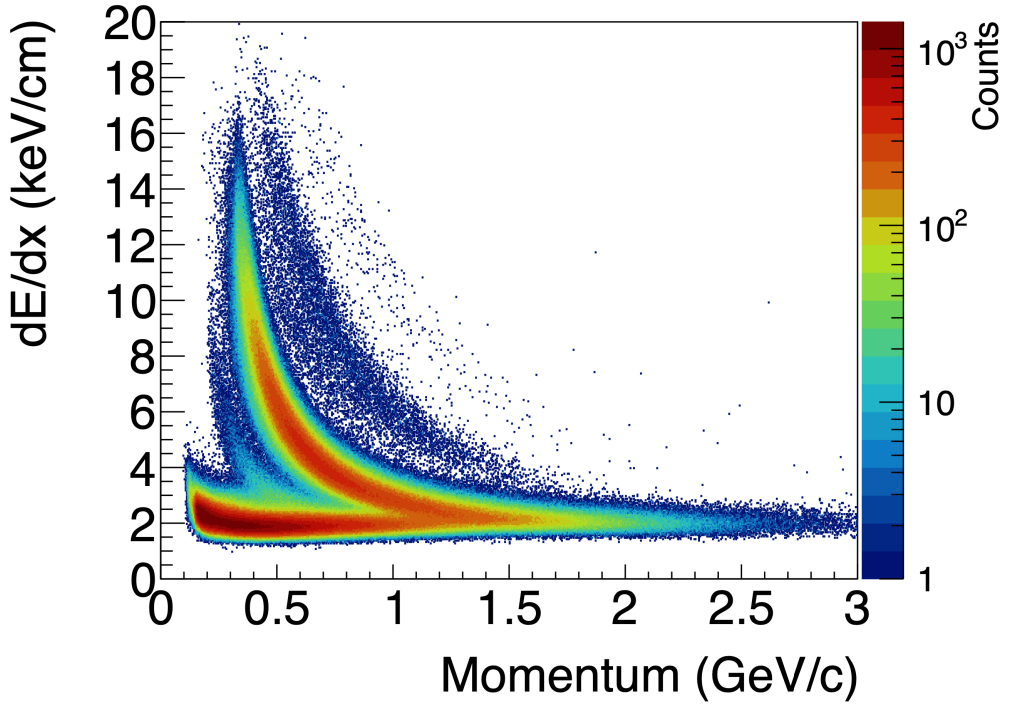
- Using parallel kinematics
- Different final states
- New probe interaction

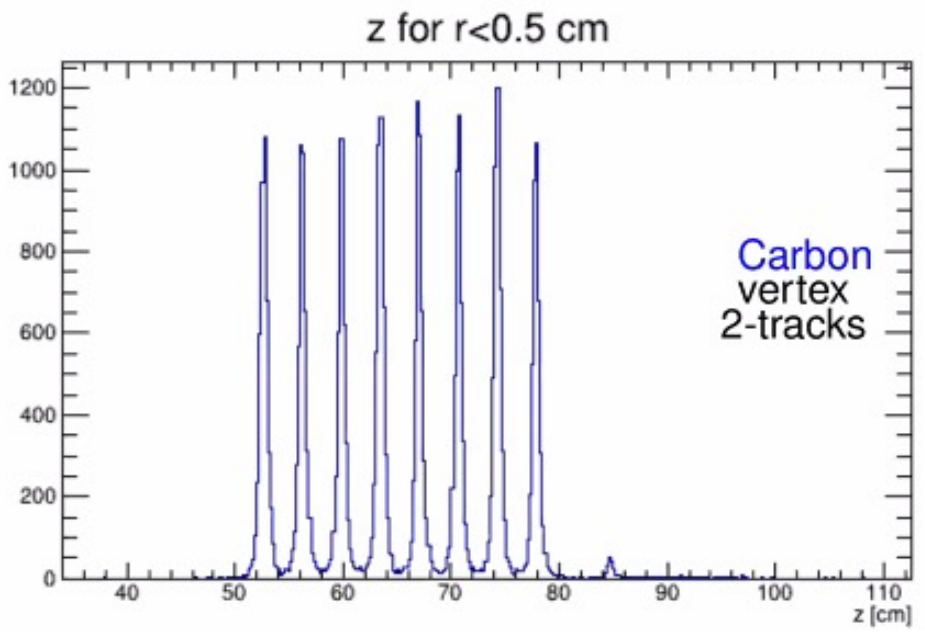
Real Photon Probe:
Parallel Kinematics



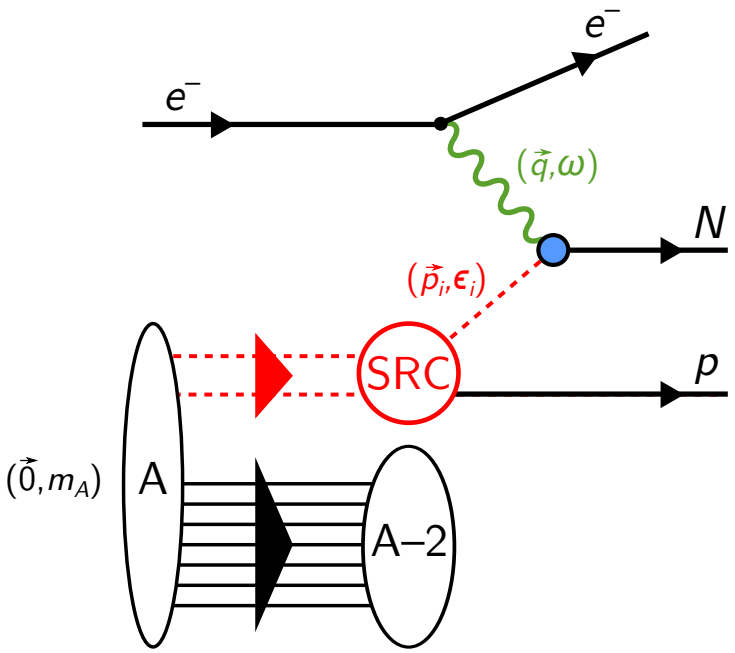
Data Chain

- Calibration
- Reconstruction
- Event Selection
  - Particle ID
  - Fiducial Volume
  - Recoil Acceptance
  - Background

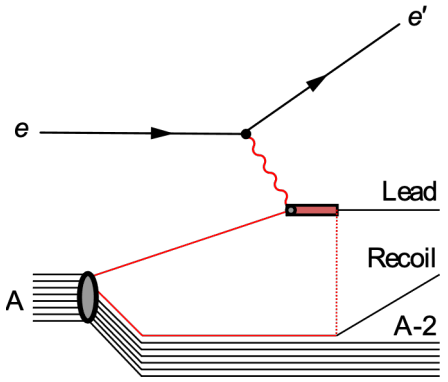




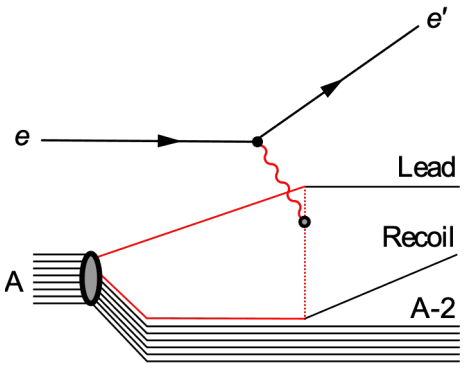
Uncertainties with e⁻ probes:



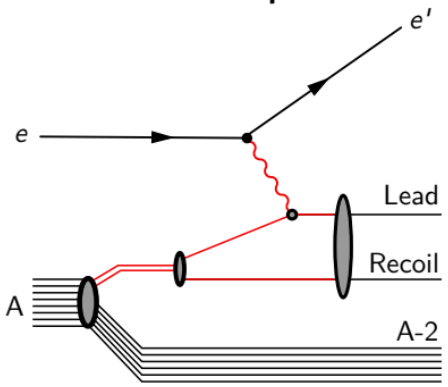
Isobaric Configuration



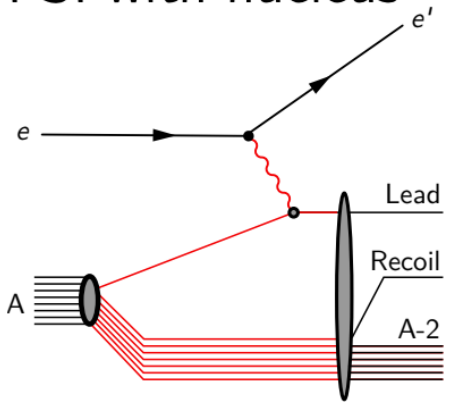
Meson Exchange Currents



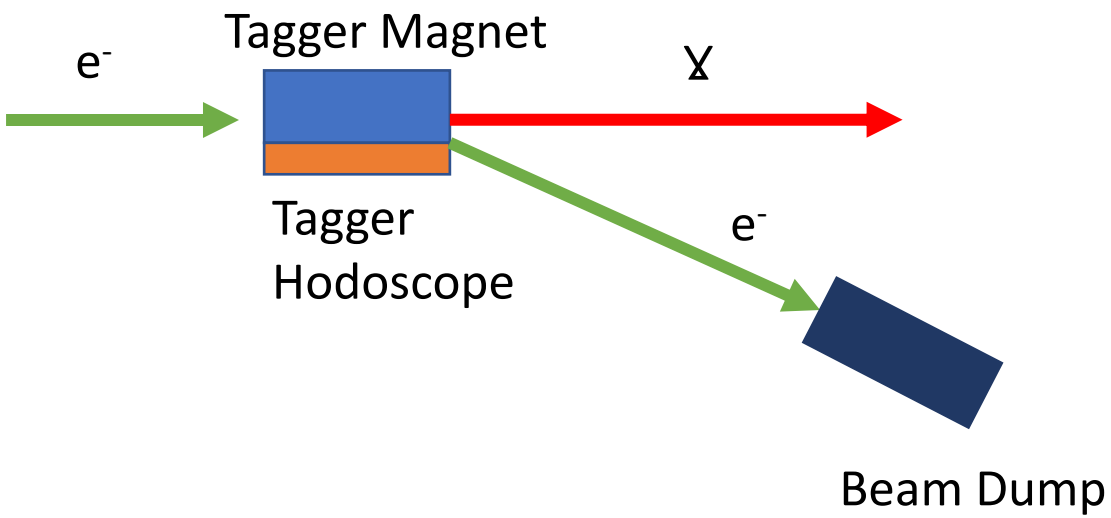
FSI within pair

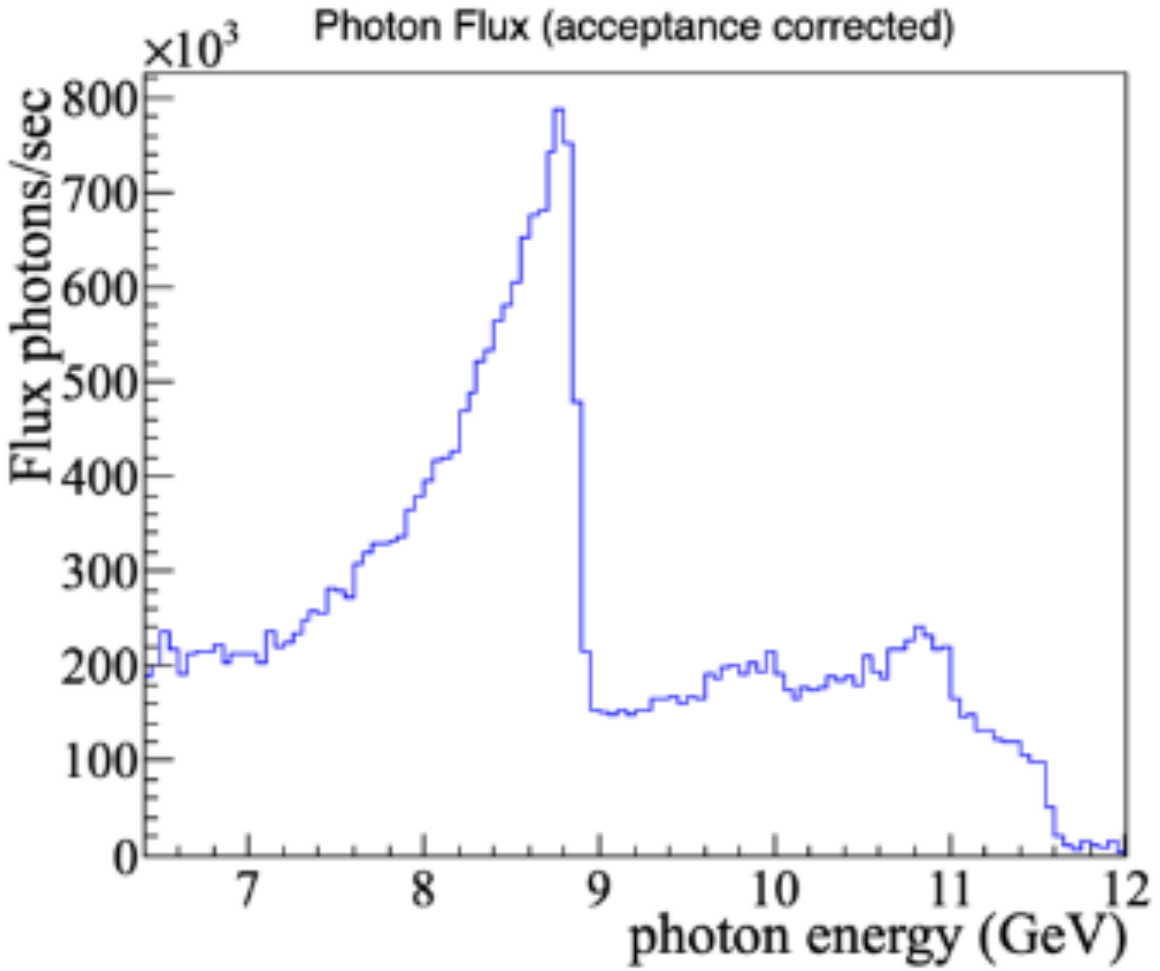


FSI with nucleus



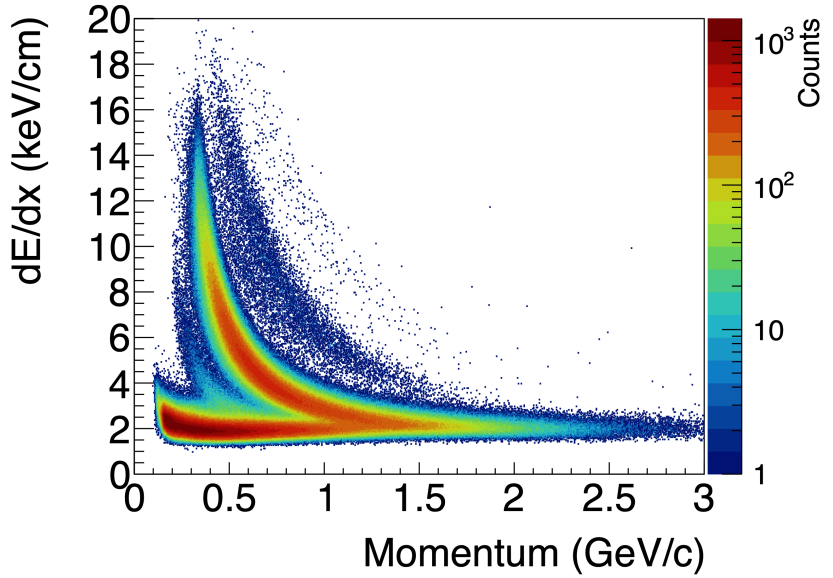
GlueX detector: A real photon beam

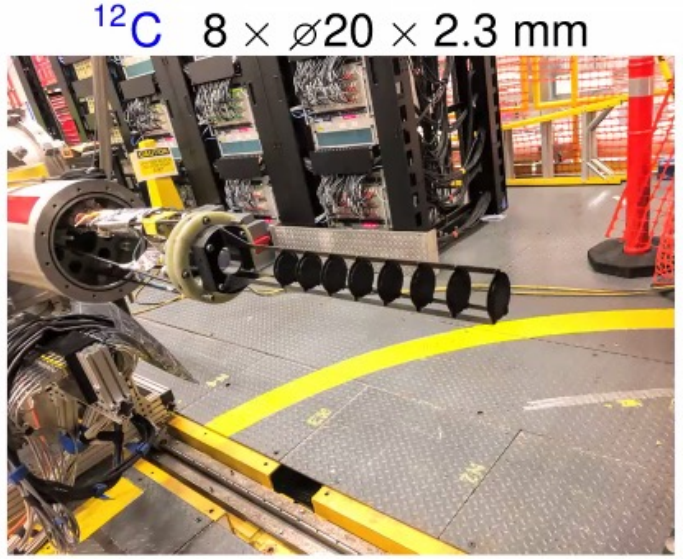


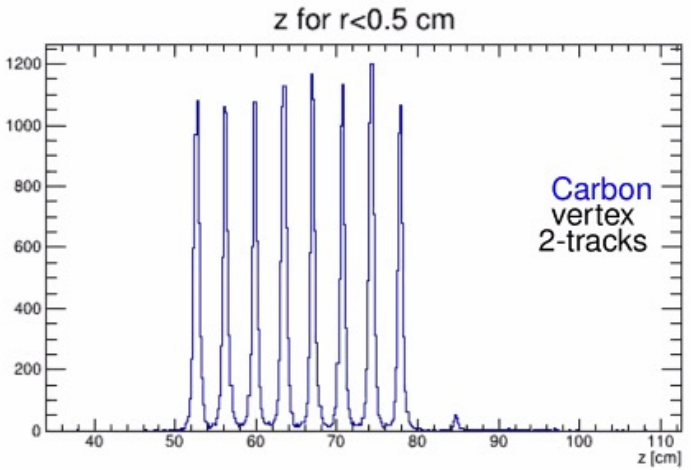


Plans and Considerations for Analysis

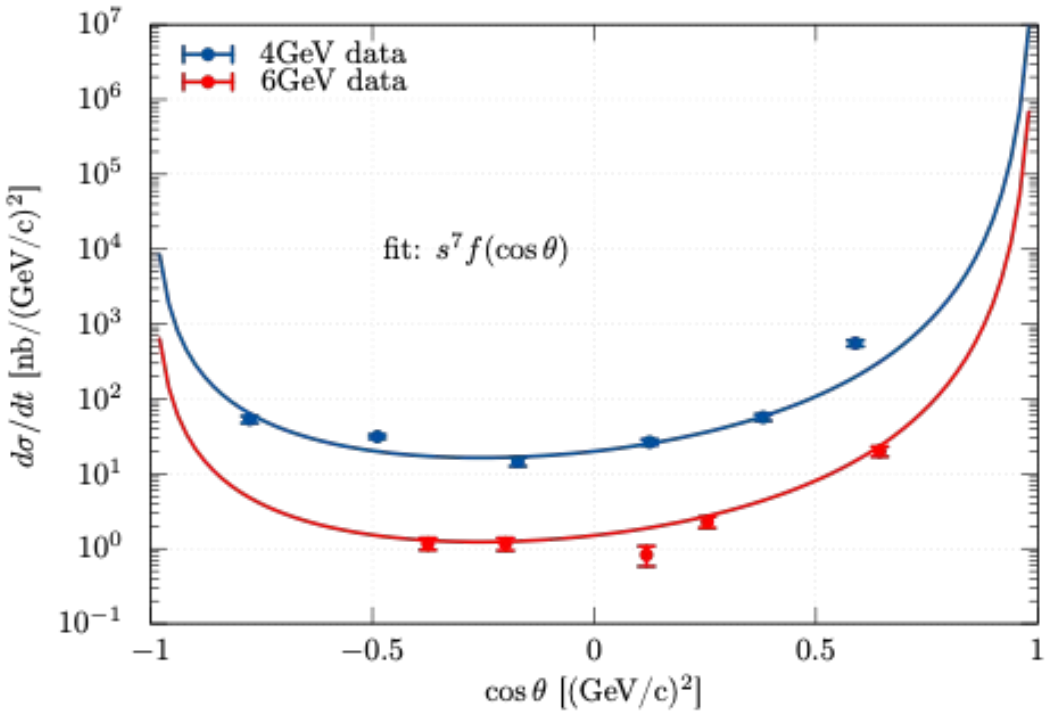
- Calibration
- Fiducial volume of detector
- Particle ID
- Recoil Acceptance
- Background

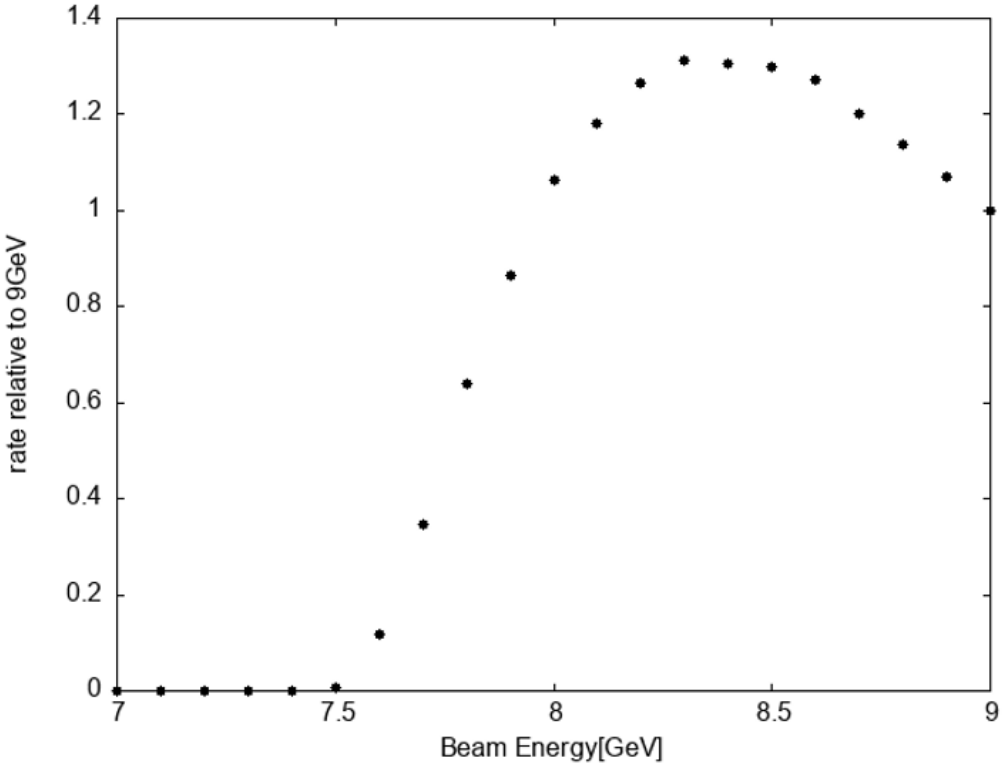






What I’ve already done





SRC @ GlueX: Experimental Details

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

Target	Days on Beam	Luminosity ($E\gamma$ > 7GeV)	Triggers (Billions)
Liquid Helium 4	10	16.1 pb^{-1}	29.5
Liquid Deuterium	4	6.9 pb^{-1}	16.4
Carbon Multi-Foil	14	17.1 pb^{-1}	46.7

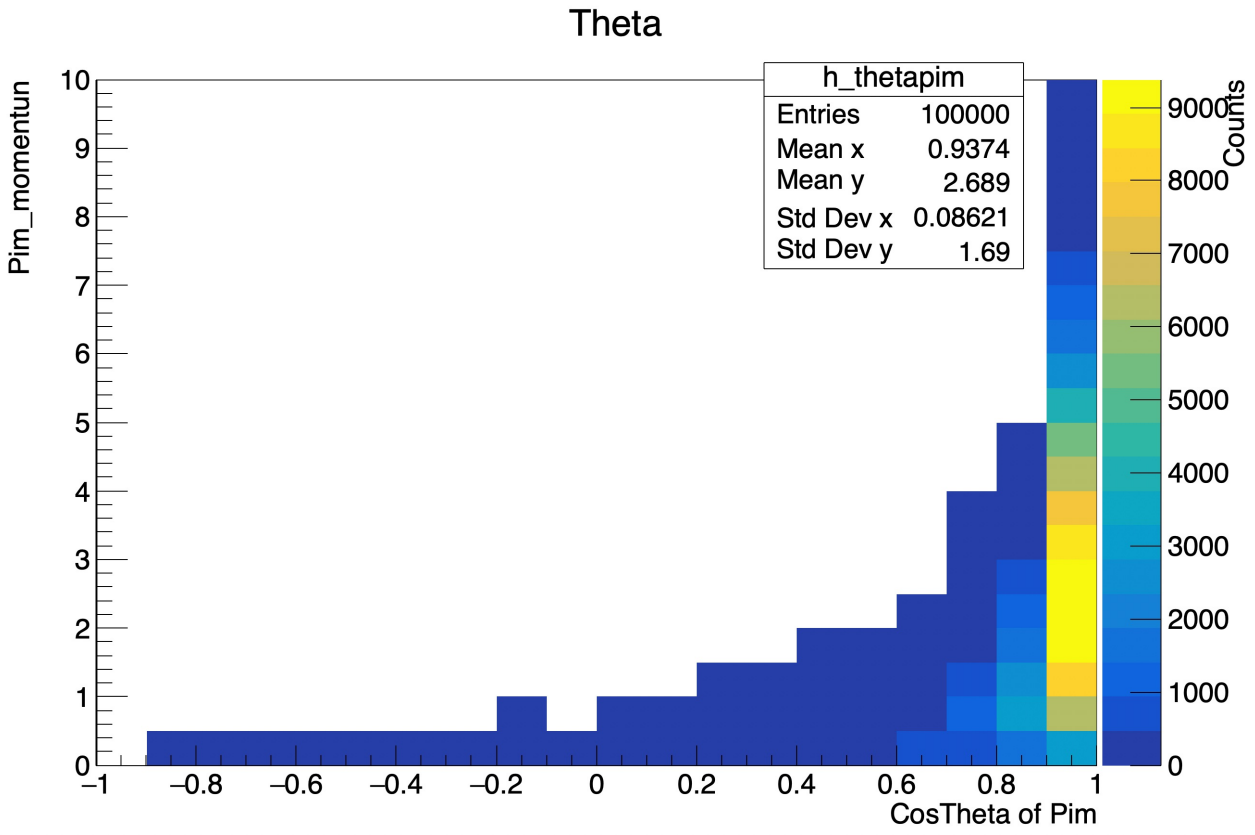
p reactions	n reactions
$\gamma p \to \pi^0 p$	$\gamma n \to \pi^- p$
$\gamma p \to \pi^- \Delta^{++}$	$\gamma n \to \pi^- \Delta^+$
$\gamma p \to \rho^0 p$	$\gamma n \to \rho^- p$
$\gamma p \to K^+ \Lambda$	$\gamma n \to K^0 \Lambda$
$\gamma p \to K^+ \Sigma^0$	$\gamma n \to K^0 \Sigma^0$
$\gamma p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

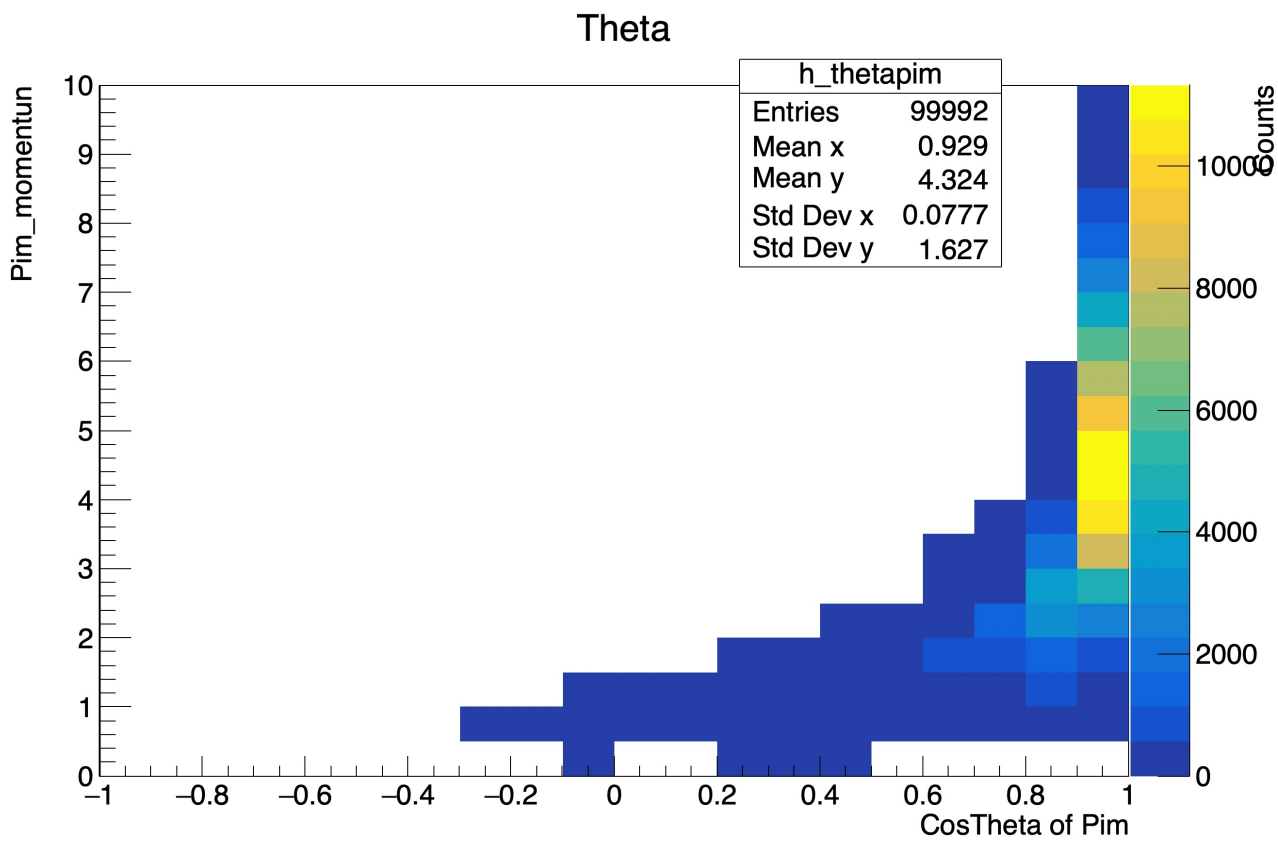
Methods

- $\gamma\, p \rightarrow \rho^0\, p \rightarrow \pi^-\, \pi^+\, p$
- $\gamma\, p \rightarrow \Delta^{++}\, \pi^- \rightarrow \pi^+\, p\, \pi^-$

- Simulated 100M events with a Helium target using GCF generator
- Resampled 100K
- |t| and |u| > 2GeV
- **Not** run through Geant4 yet
  - No smearing or inefficiency
  - Comparing kinematics at the generator level.

π^- Kinematics

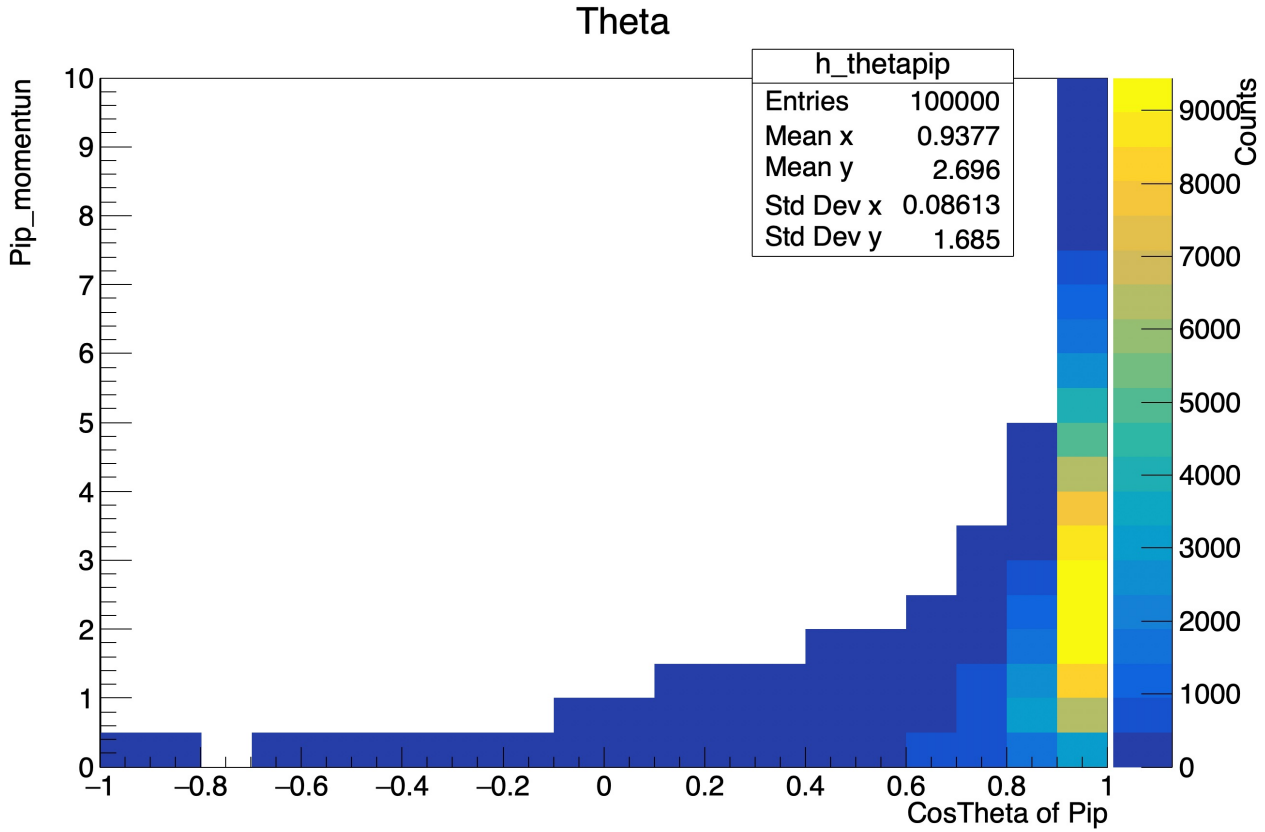




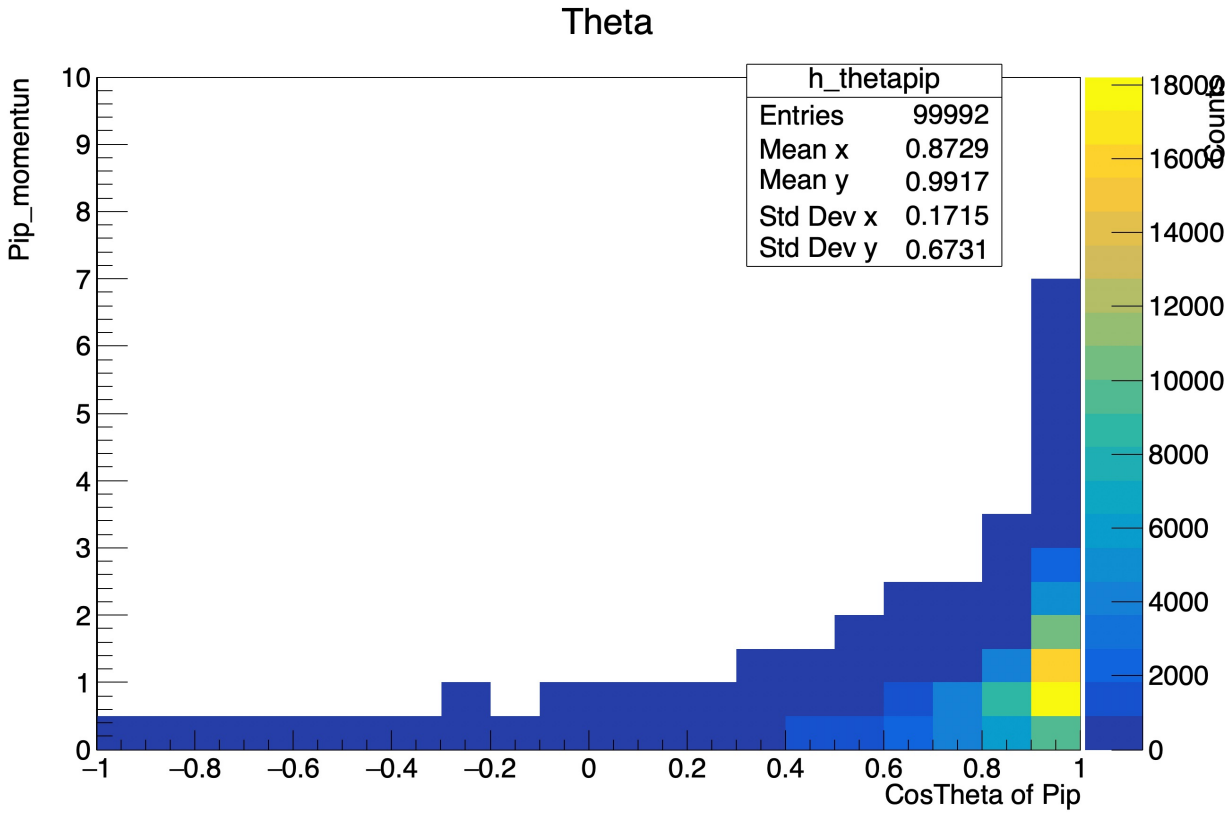
$p\rho^0 \rightarrow p\,\pi^+\pi^-$

$\Delta^{++}\pi^- \rightarrow p\,\pi^+\pi^-$

π^+ Kinematics

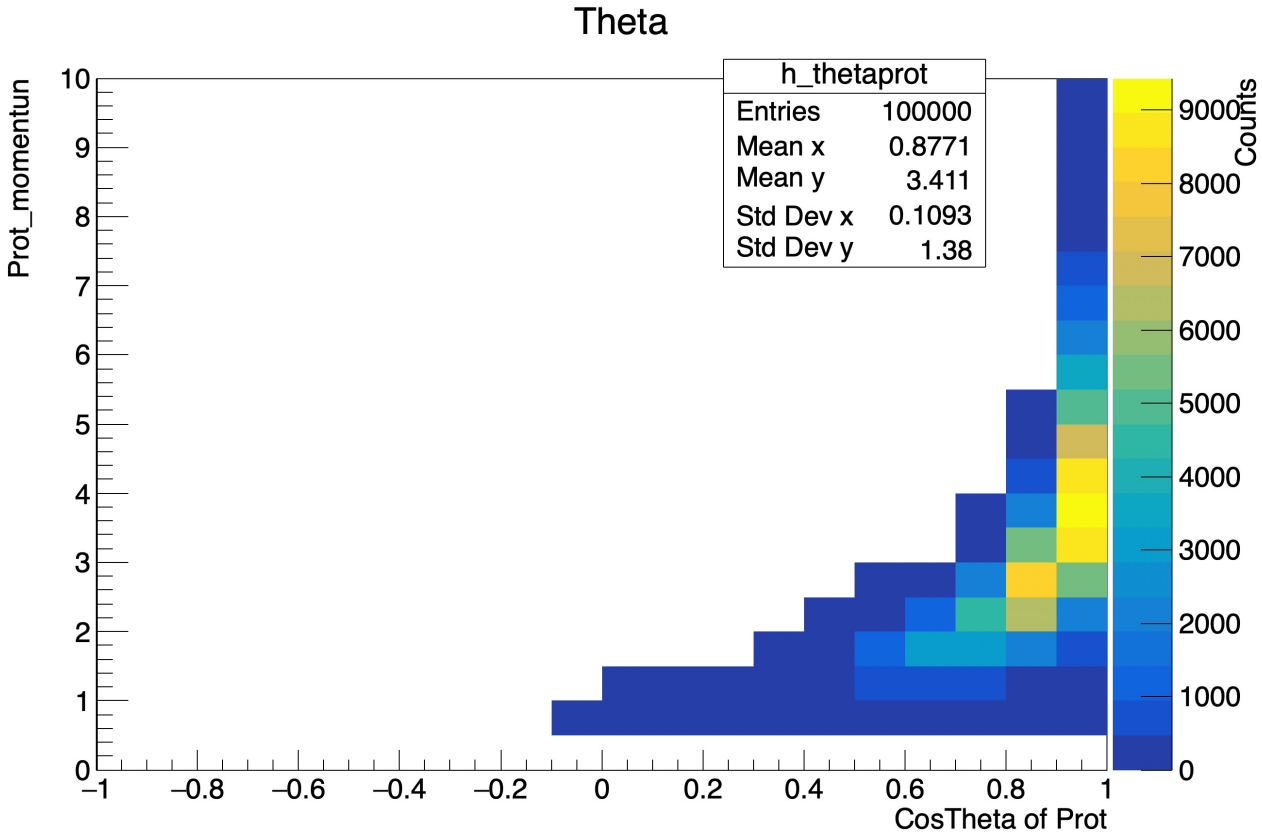


$p\rho^0 \rightarrow p\,\pi^+\pi^-$

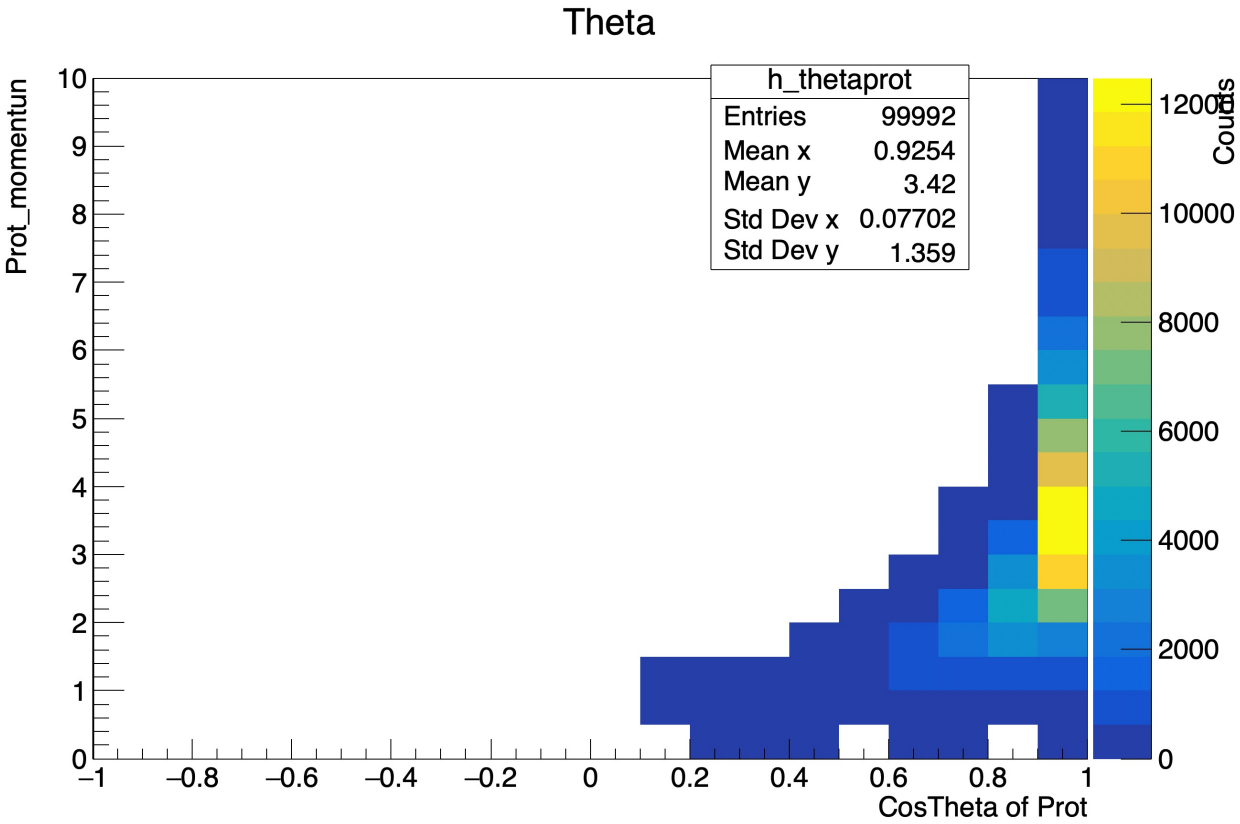


$\Delta^{++}\pi^- \rightarrow p\,\pi^+\pi^-$

Proton Kinematics

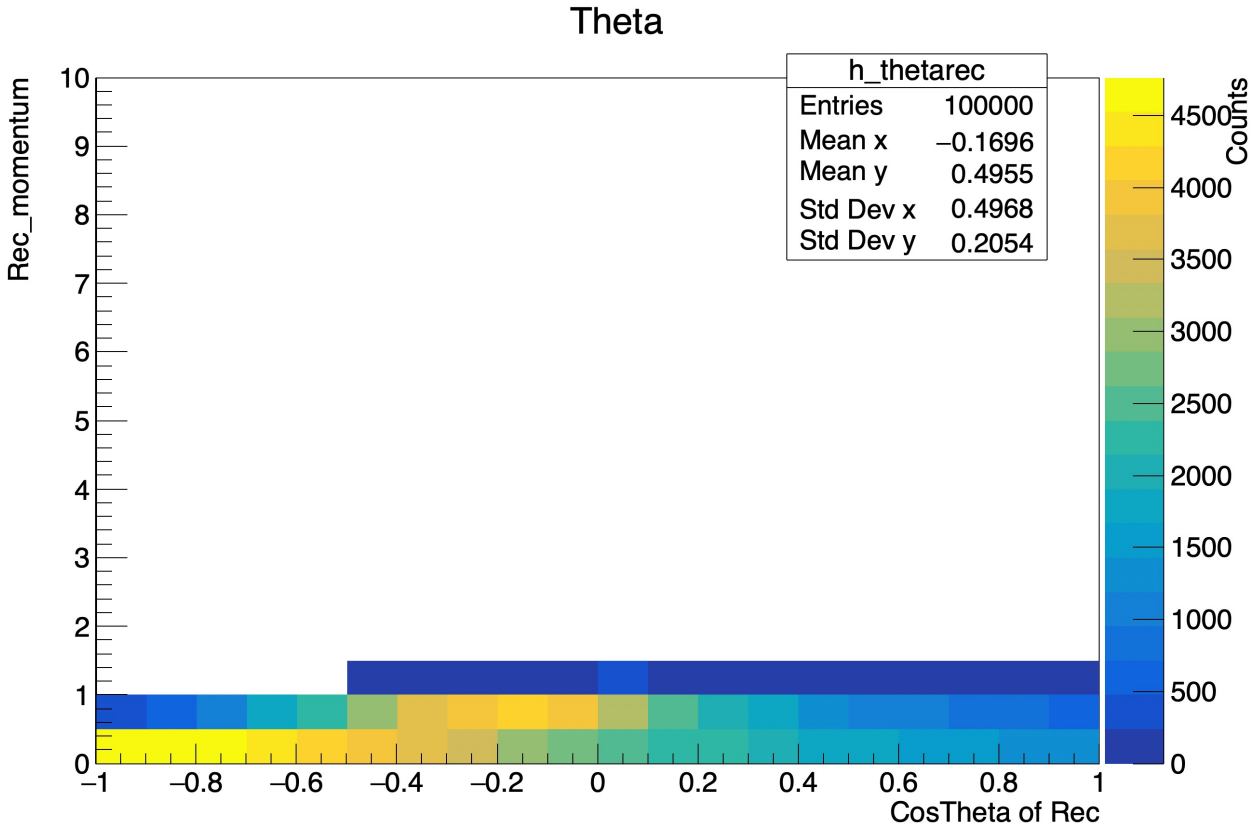


$p\rho^0 \rightarrow p\,\pi^+\pi^-$

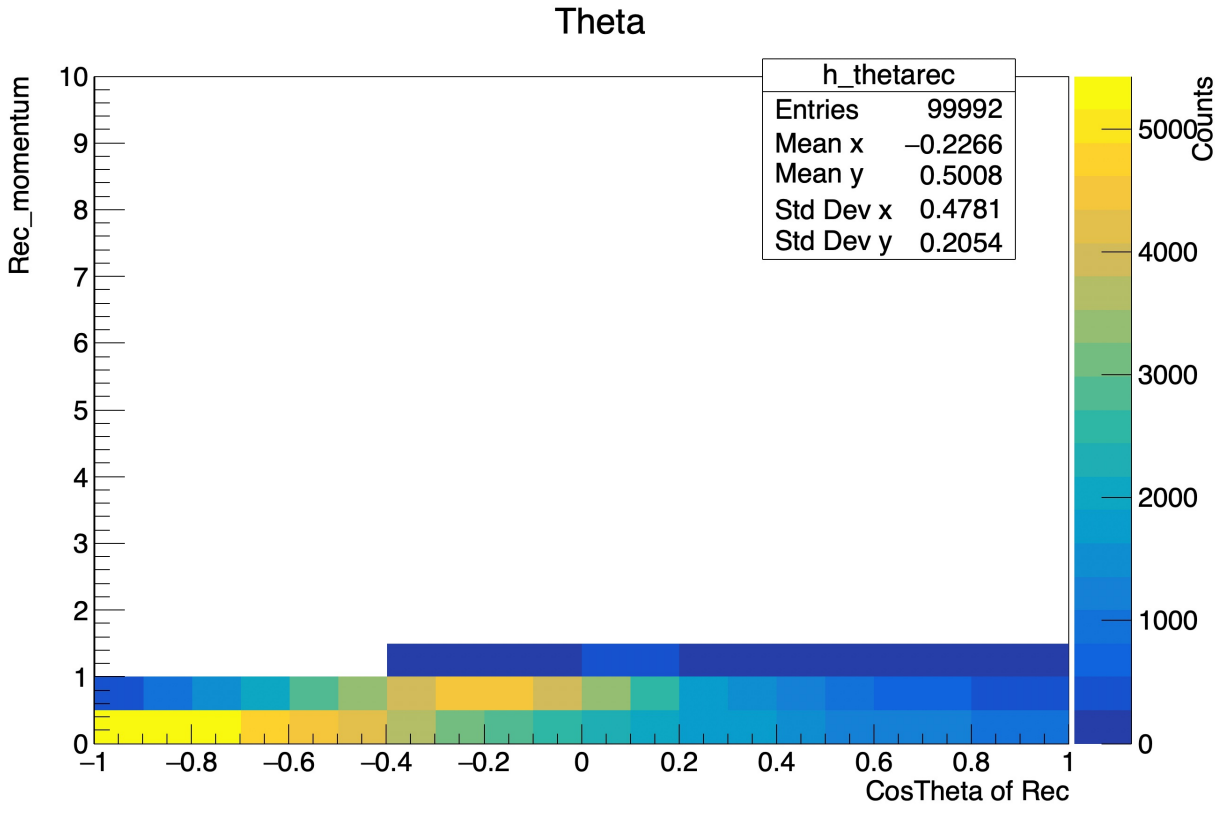


$\Delta^{++}\pi^- \rightarrow p\,\pi^+\pi^-$

Recoil Kinematics

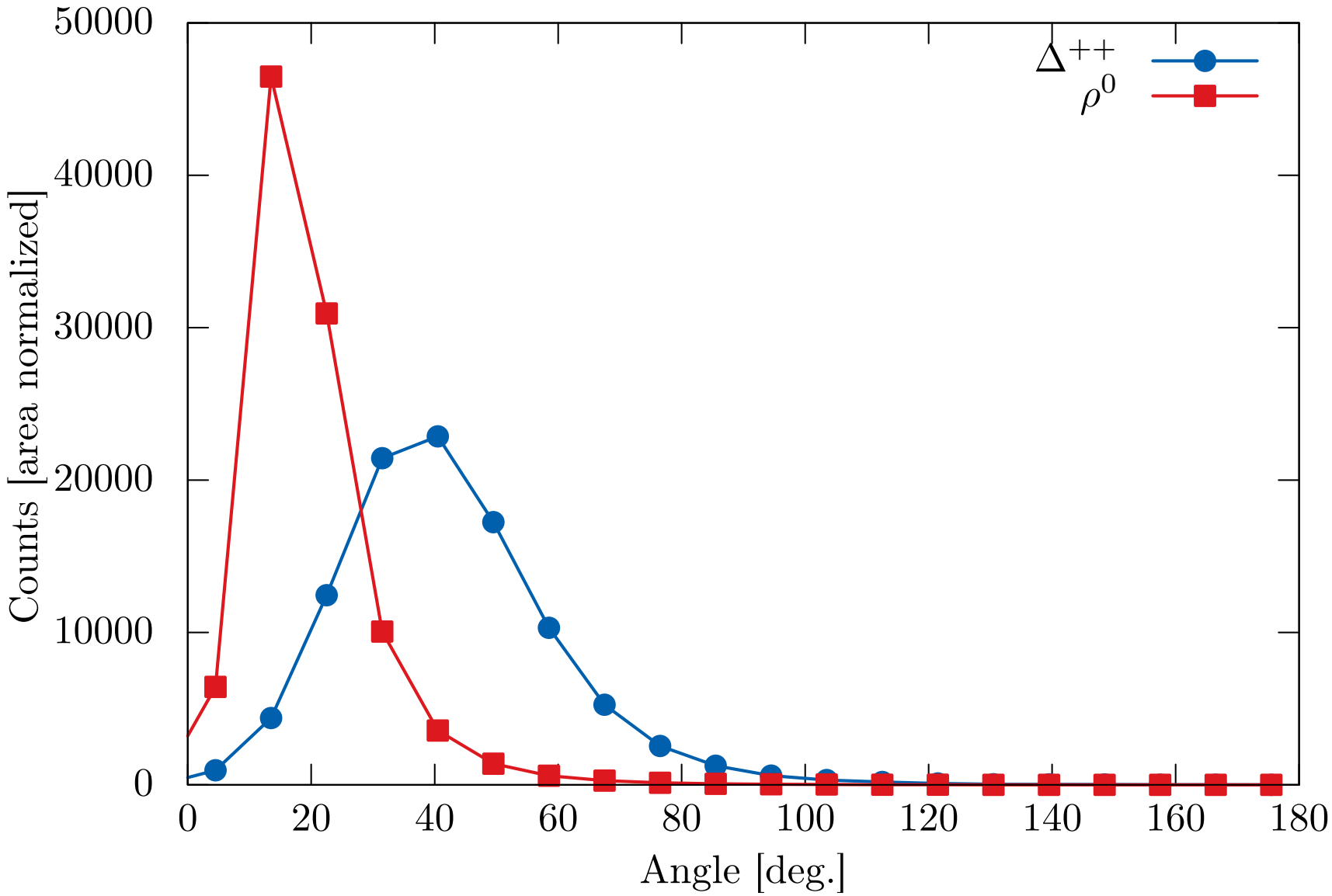


$p\rho^0 \rightarrow p\,\pi^+\pi^-$

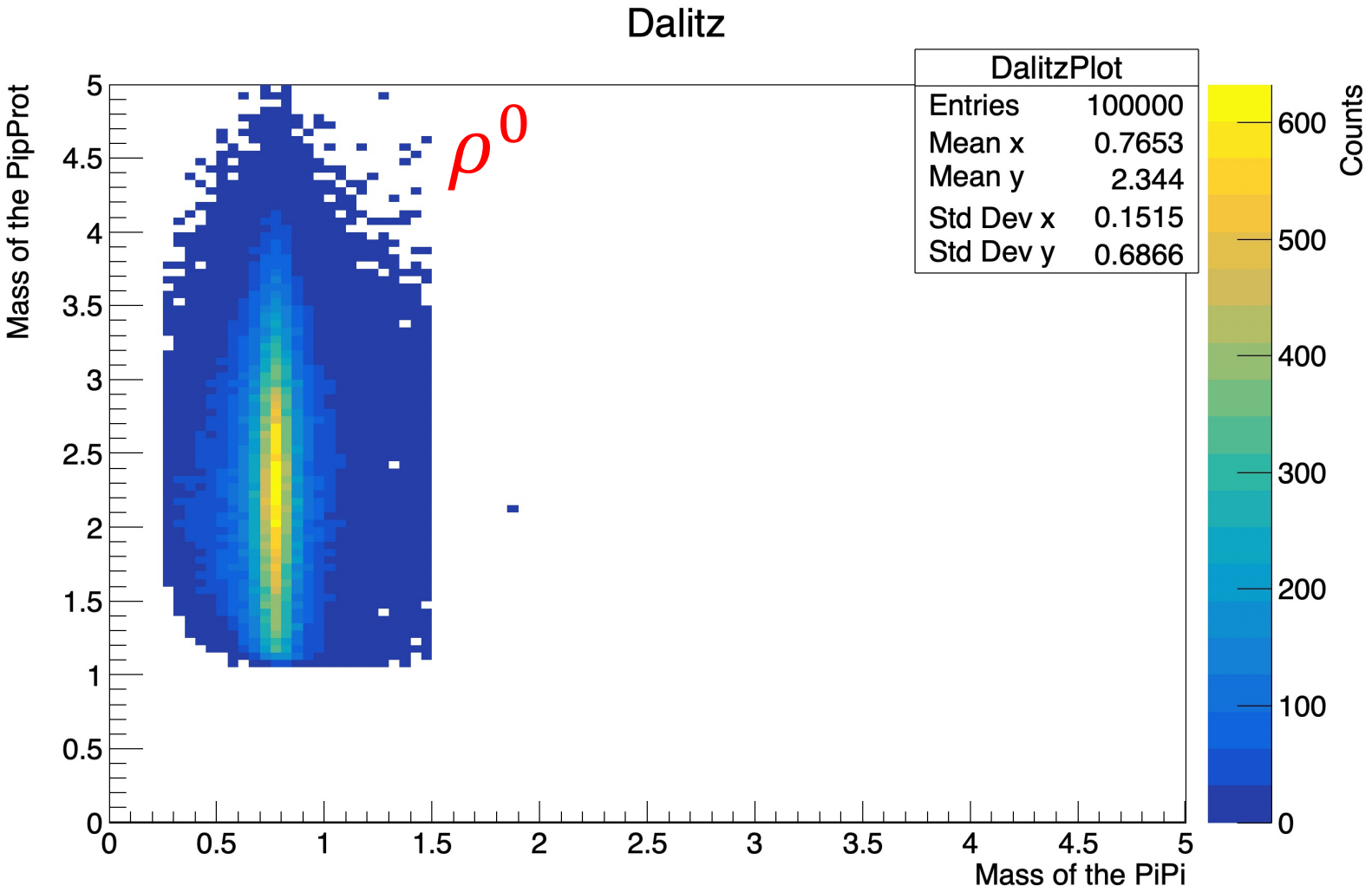


$\Delta^{++}\pi^- \rightarrow p\,\pi^+\pi^-$

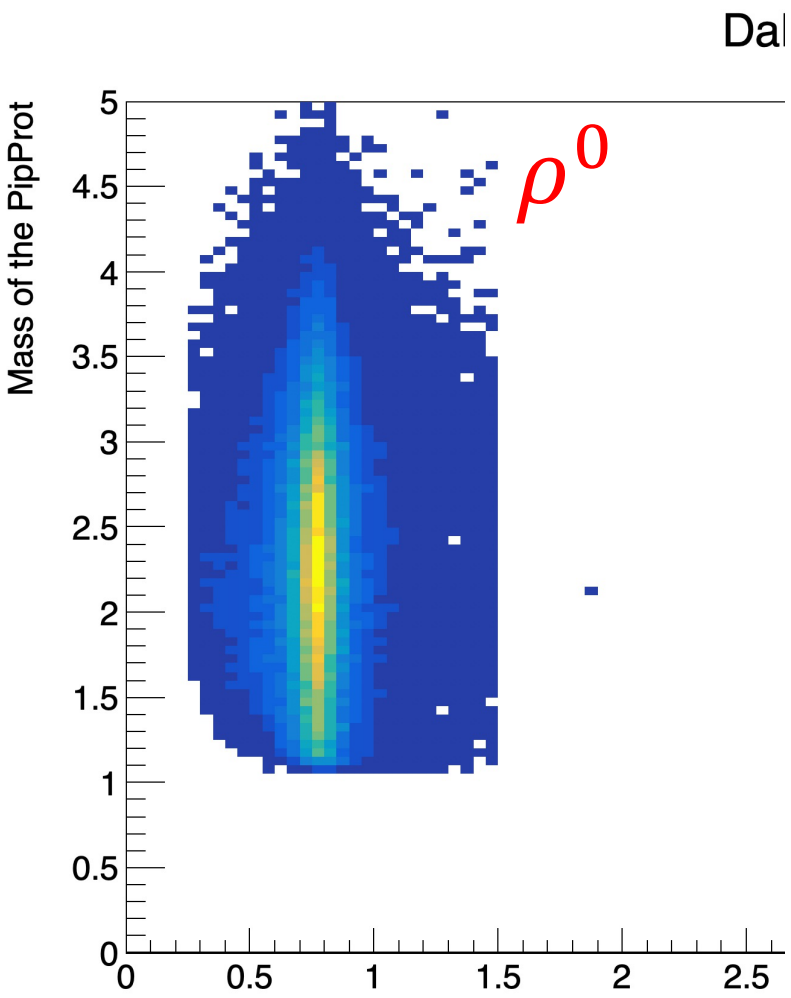
Opening angle between π^- and π^+

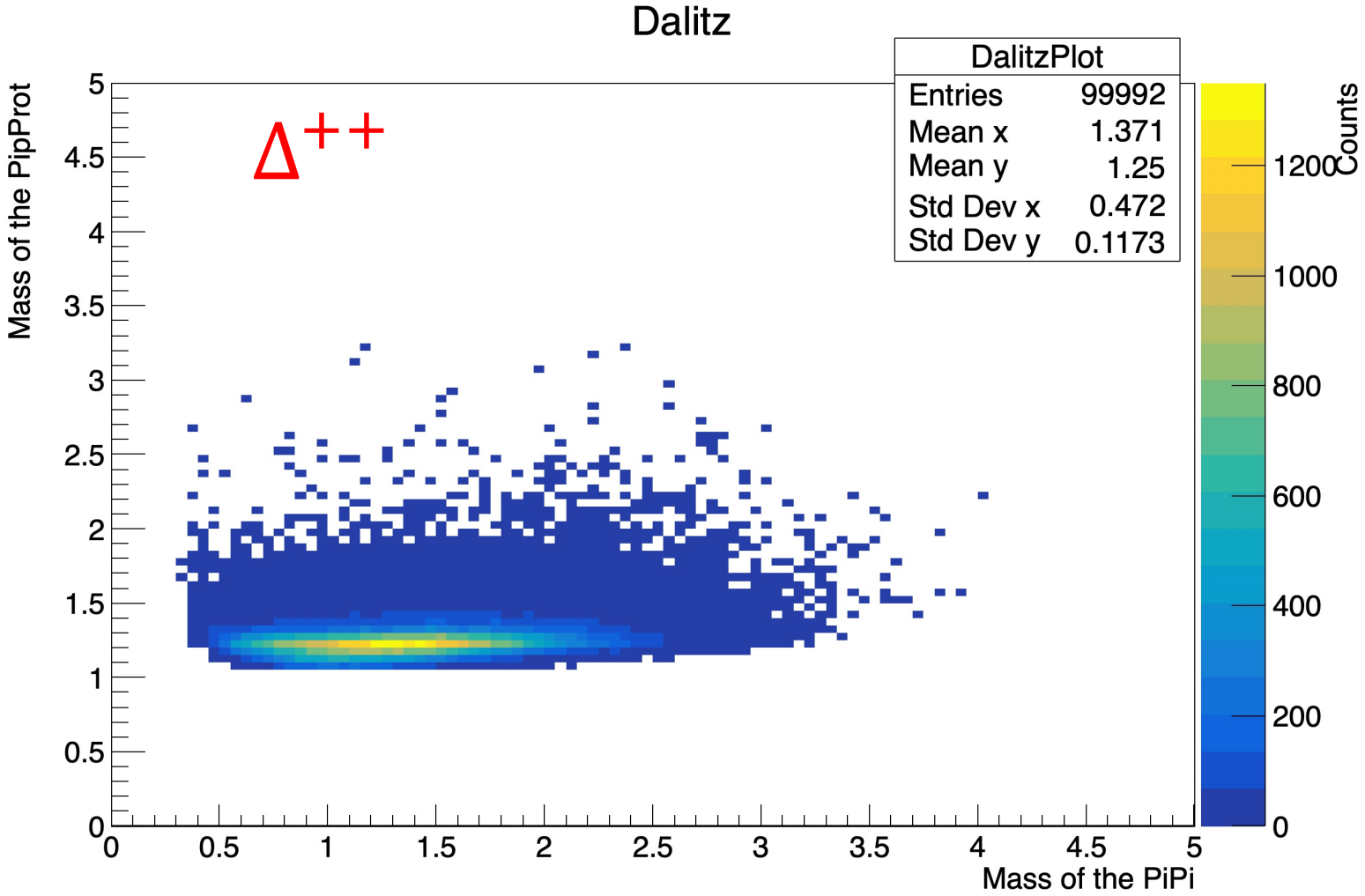


Dalitz Plot

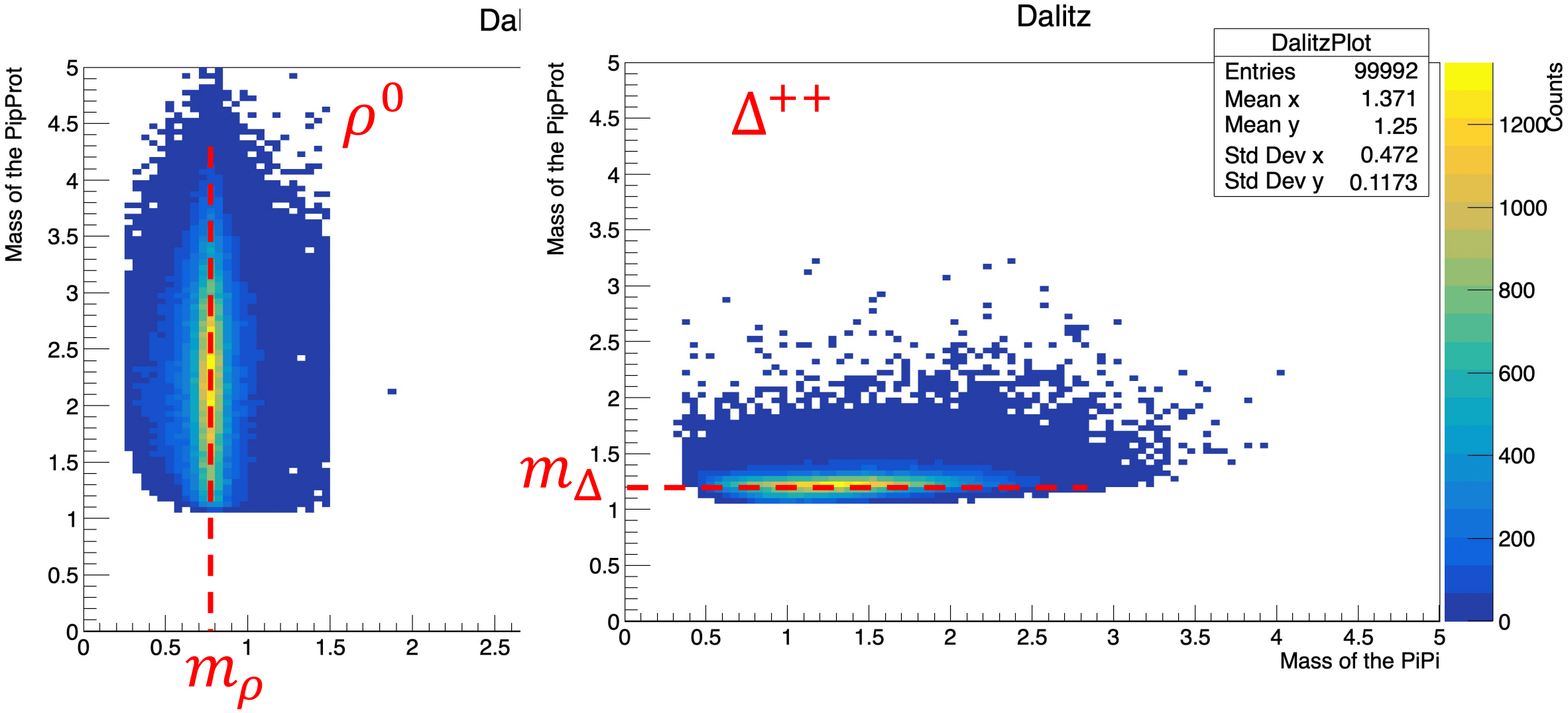

Dalitz
DalitzPlot
Entries 100000
Mean x 0.7653
Mean y 2.344
Std Dev x 0.1515
Std Dev y 0.6866
ρ^0
Mass of the PipProt
Mass of the PiPi
Counts
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
100
200
300
400
500
600

Dalitz Plot


Mass of the PipProt
ρ^0


Dalitz
DalitzPlot
Entries 99992
Mean x 1.371
Mean y 1.25
Std Dev x 0.472
Std Dev y 0.1173
Mass of the PipProt
Δ^{++}
Mass of the PiPi
Counts

Dalitz Plot


Dal
Mass of the PipProt
ρ^0
m_ρ
Dalitz
Δ^{++}
m_Δ
DalitzPlot
Entries 99992
Mean x 1.371
Mean y 1.25
Std Dev x 0.472
Std Dev y 0.1173
Counts
Mass of the PiPi