Studies of Final-State Interactions via Helicity Asymmetries in Exclusive Pseudoscalar Meson Photoproduction off Deuteron

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for the CLAS Collaboration

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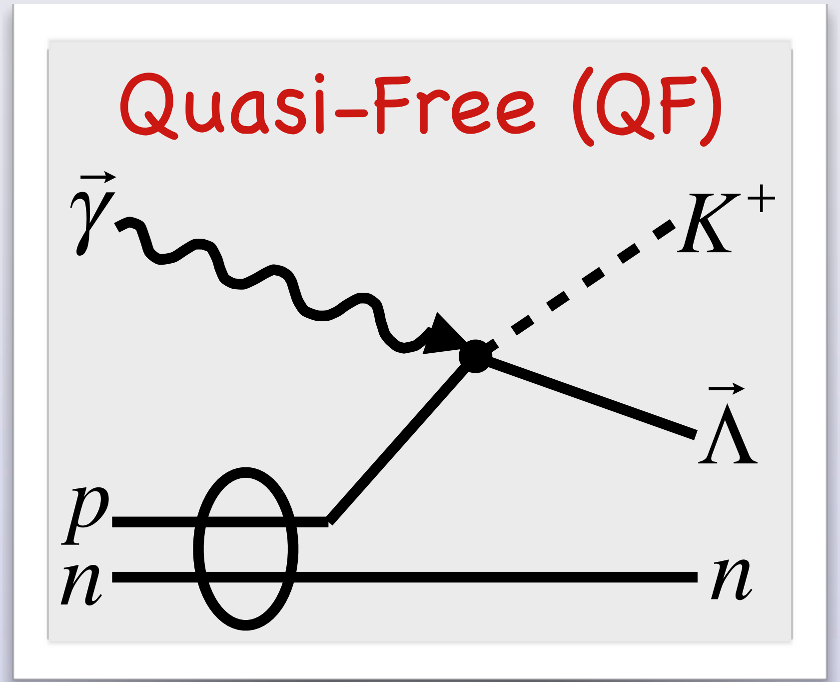
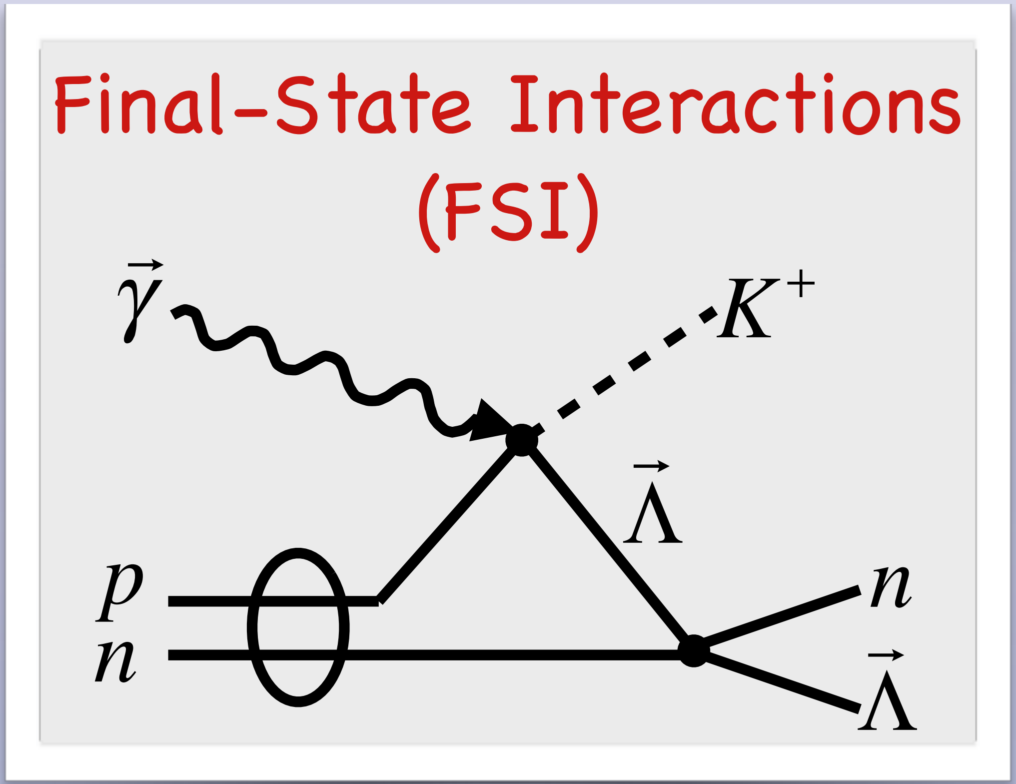
The Nucleus as an Experimental Laboratory





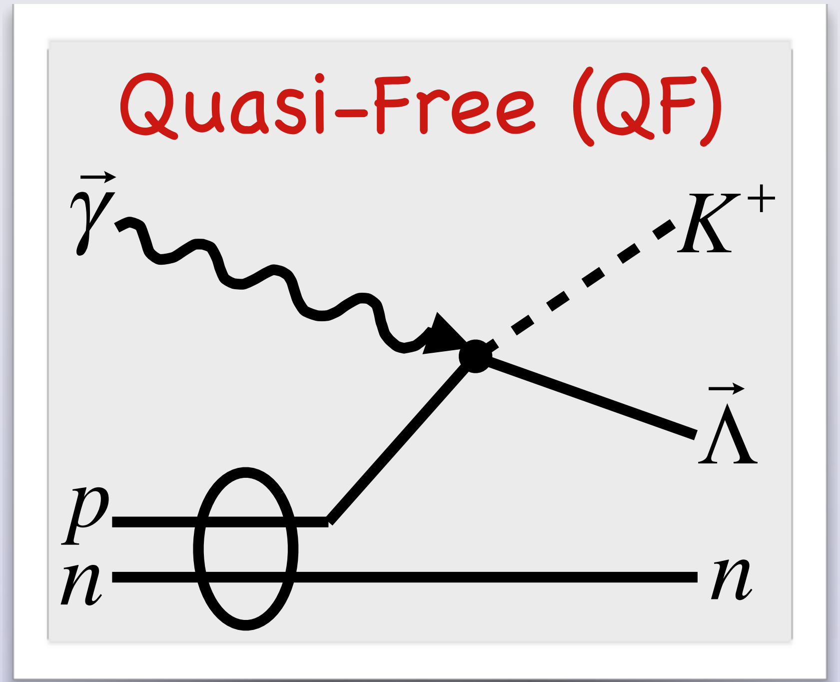
Access to Elementary Scattering off the bound nucleon

- Scattering off quasi-bound nucleons (neutrons).
- Extraction of observables for scattering off the free neutron.

Access to Second-Step Scattering

- Hadron Beam produced in first step.
- Hadrons scatter off neutrons in a second step.

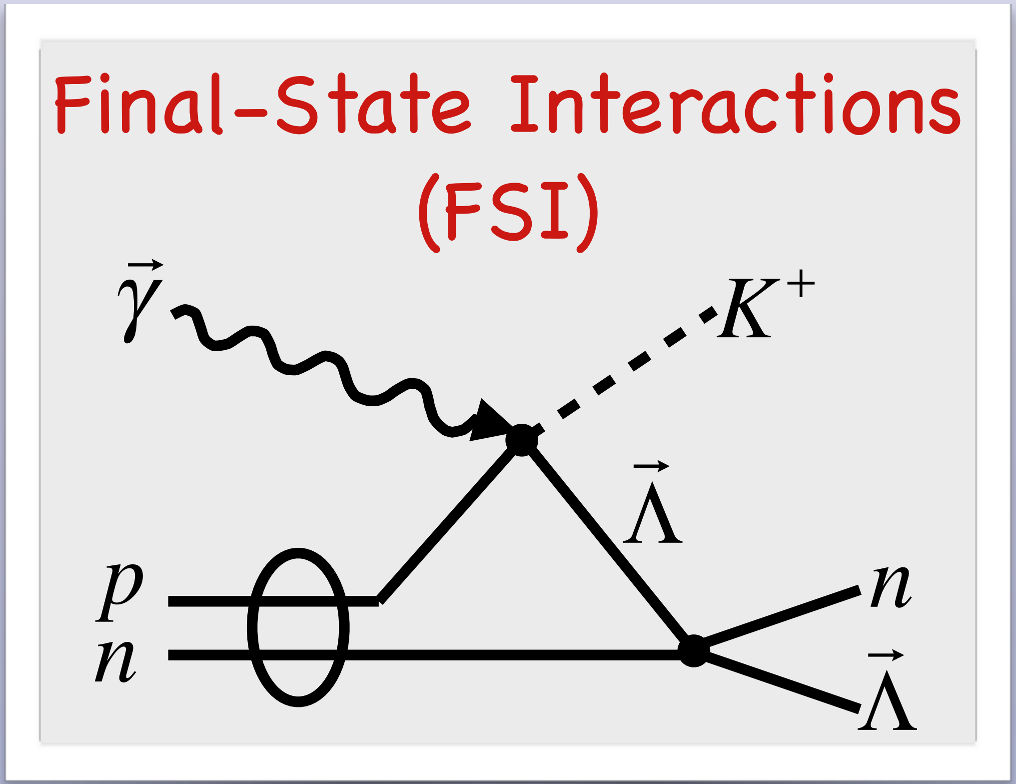
The Nucleus as an Experimental Laboratory



Challenges

- Contribution of FSI events to QF sample.
- Bound nucleon is not a free nucleon: off-shell and nuclear effects on observables.

Typically, theoretical corrections are needed.



Challenges

- Contributions of QF to FSI sample.
- Contributions of other FSI to re-scattering sample.

Theoretical interpretation of experimental observables is needed.

Outline

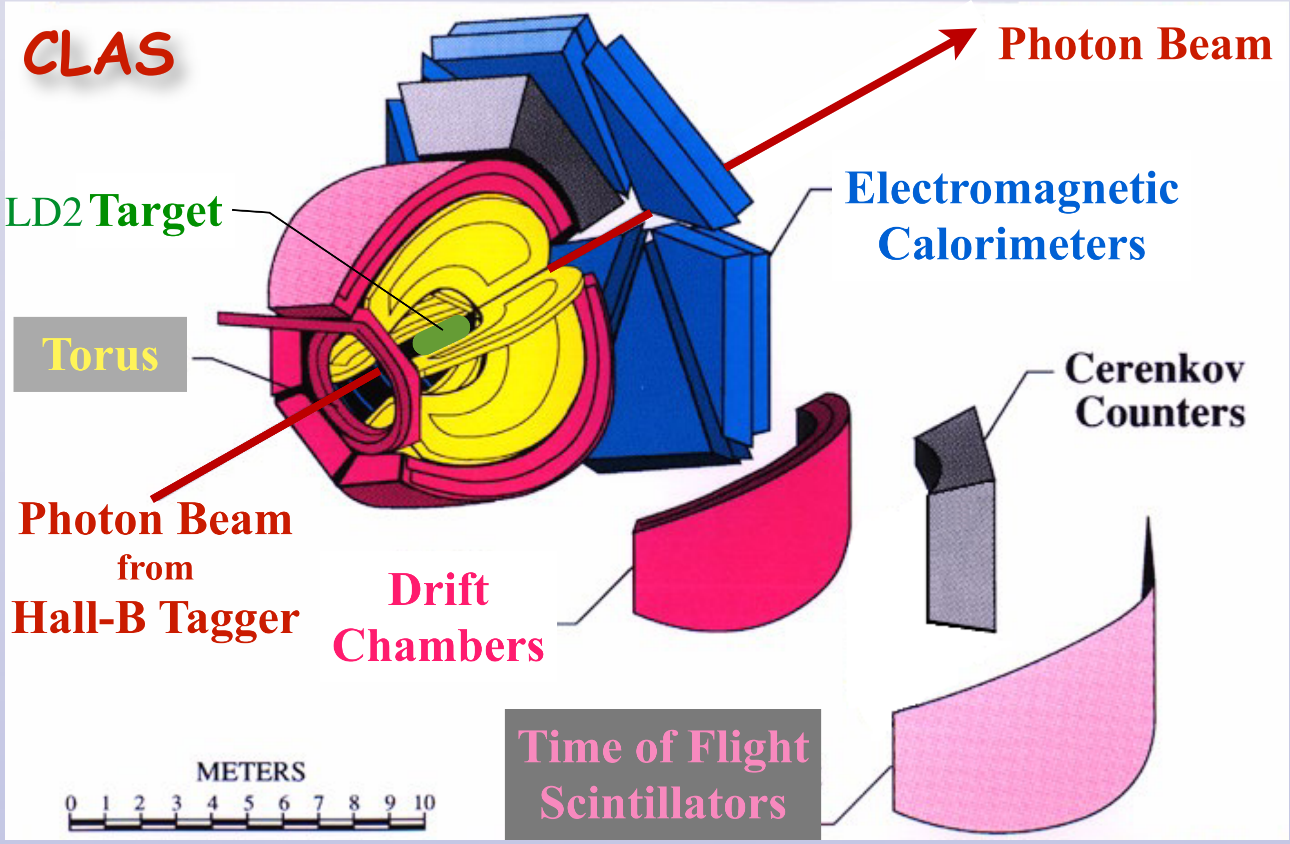
1. Experimental studies of extraction of observables off the free nucleon from data off the bound nucleon.
   - Determine the evolution of observables with target-nucleon Fermi momentum.
   - Test results for method
     - Helicity Asymmetries of $\gamma d \rightarrow p\pi^+\pi^-(n_s)$
     - Hyperon polarizations in $\gamma d \rightarrow K^+\Lambda(n_s)$
2. Experimental studies of specific FSI selection.
   - Kinematics.
   - Helicity Asymmetries of $\gamma d \rightarrow K^+\Lambda n$.
3. Summary and Outlook.

Experimental Facility: CLAS at Jefferson Lab

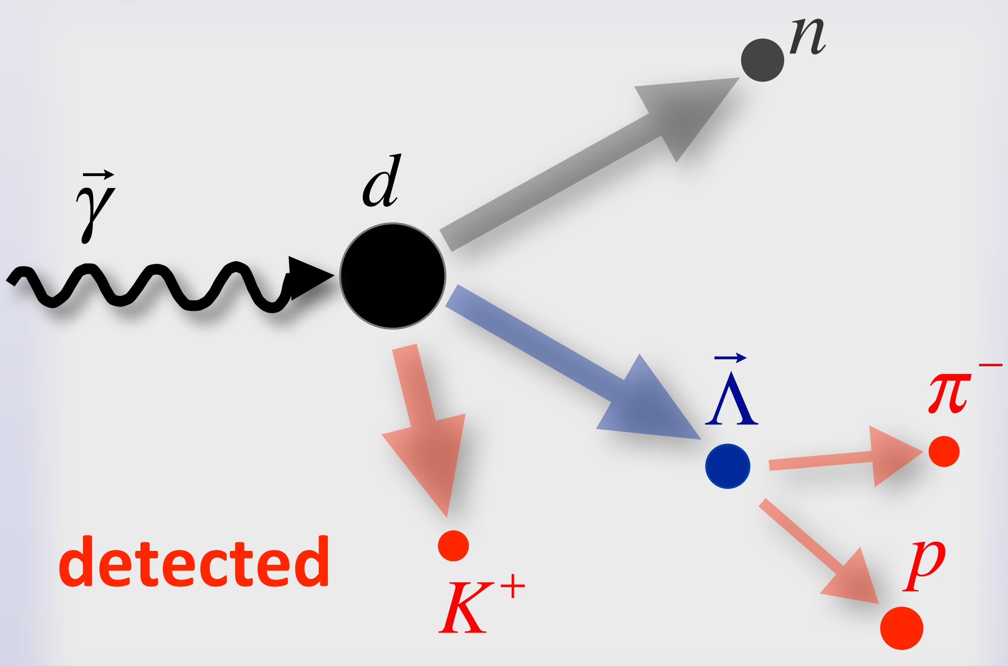
Experiment E06-103 (g13)

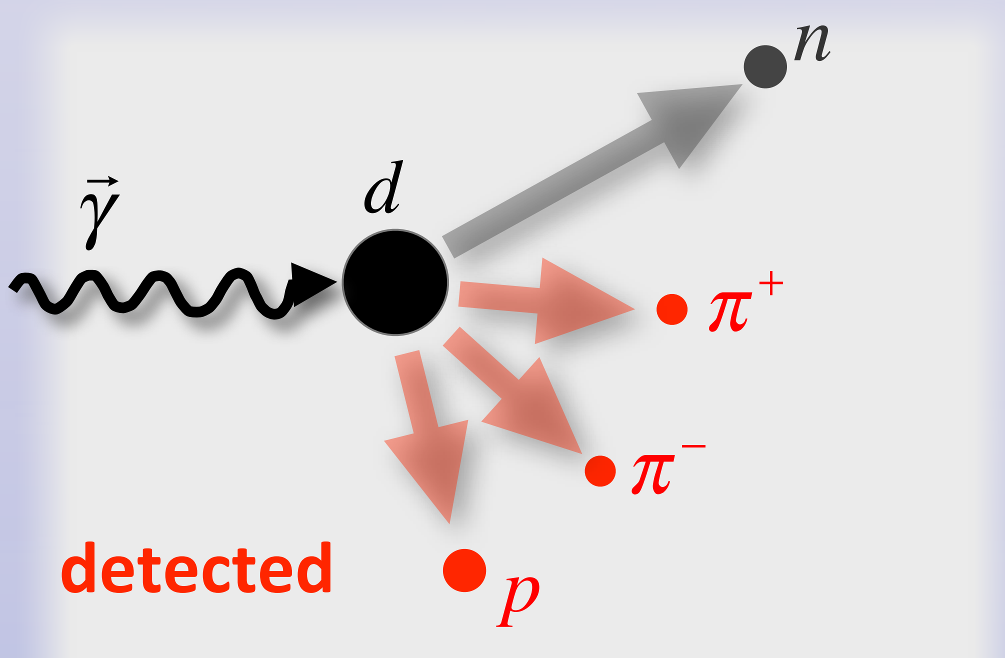
Circularly Polarized Photons (g13a)

- E_e = 2 GeV; 2.65 GeV
- electron polarization: ~ 80%
- triggers: ~20×10^9 triggers



Fully Exclusive Measurements



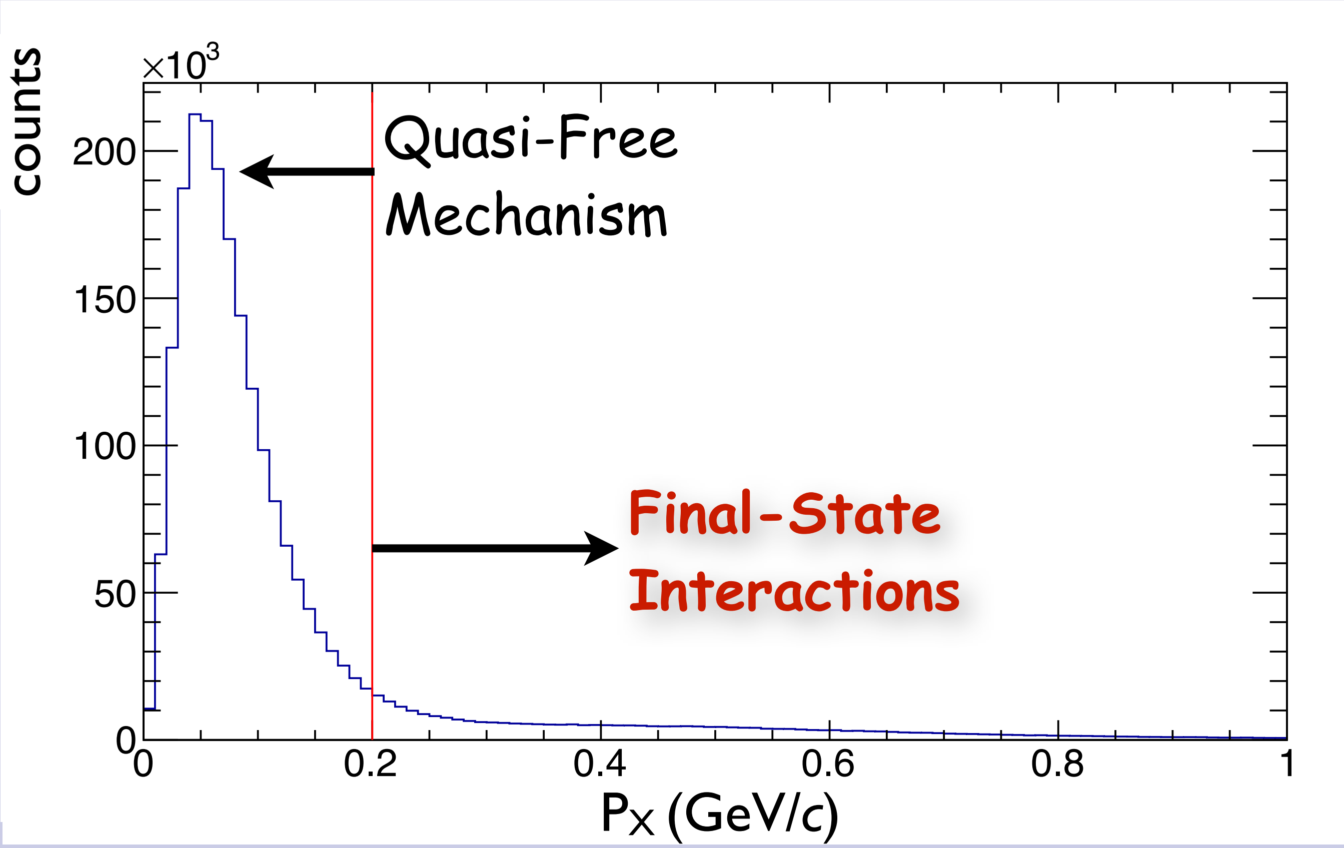


P. Nadel-Turonski, B. Berman, YI, D. Ireland, A. Tkabladze et al., E06-103: "Kaon Production on the Deuteron Using Polarized Photons"

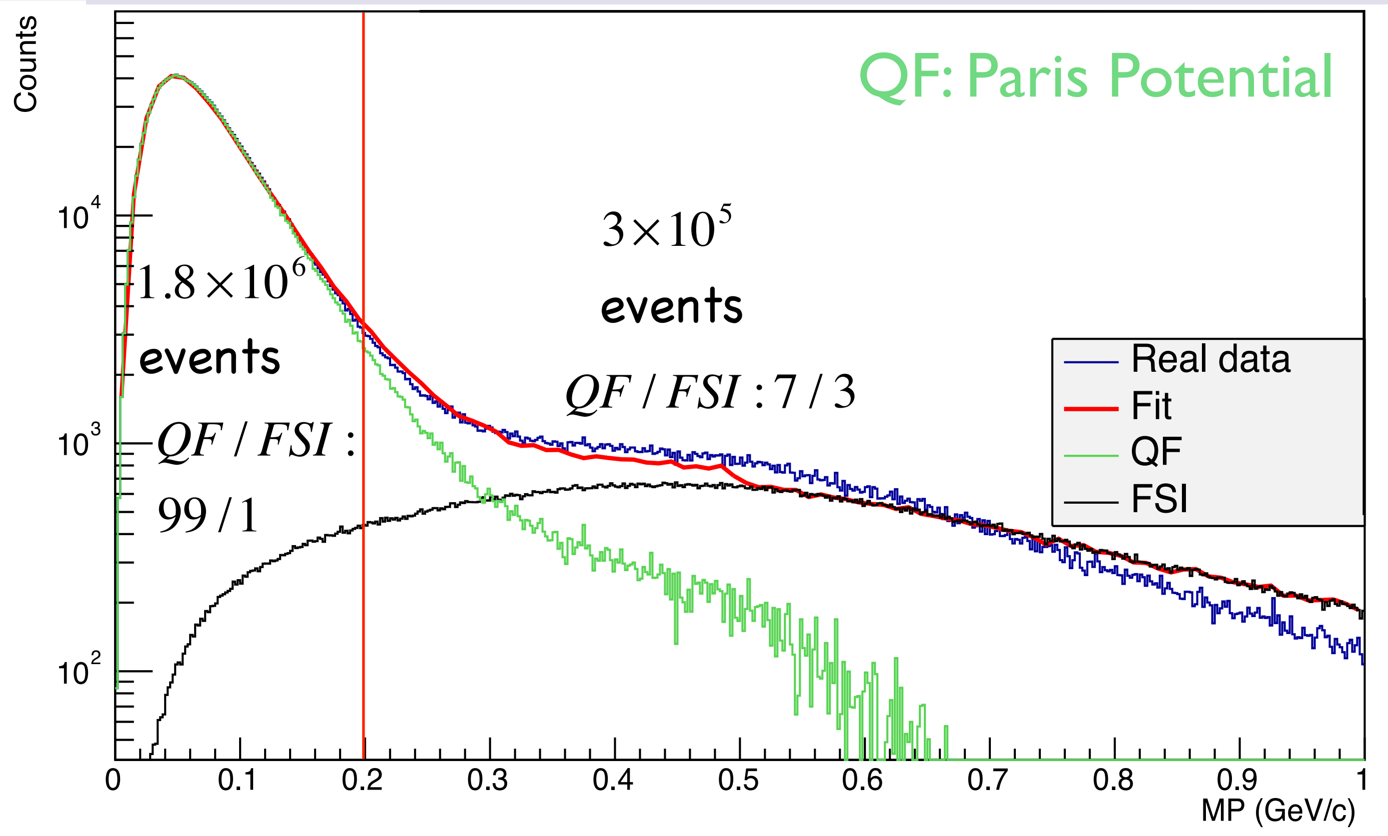
Suppression/Selection of Quasi-Free Mechanism/FSI

Event Distribution over Missing Momentum

$P_x\ (\gamma d \rightarrow K^+ \Lambda X)$



Comparison with Model Distribution

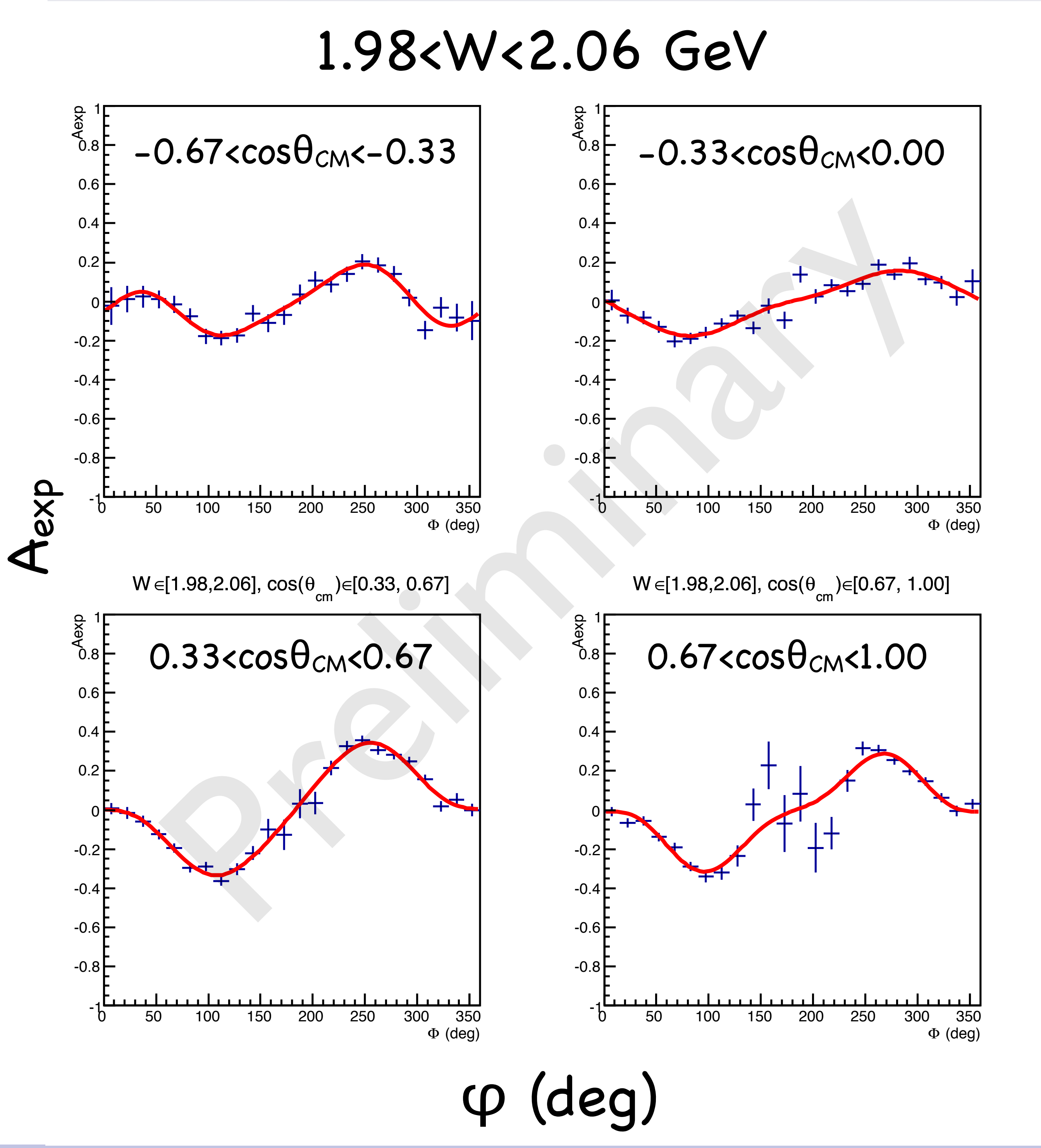


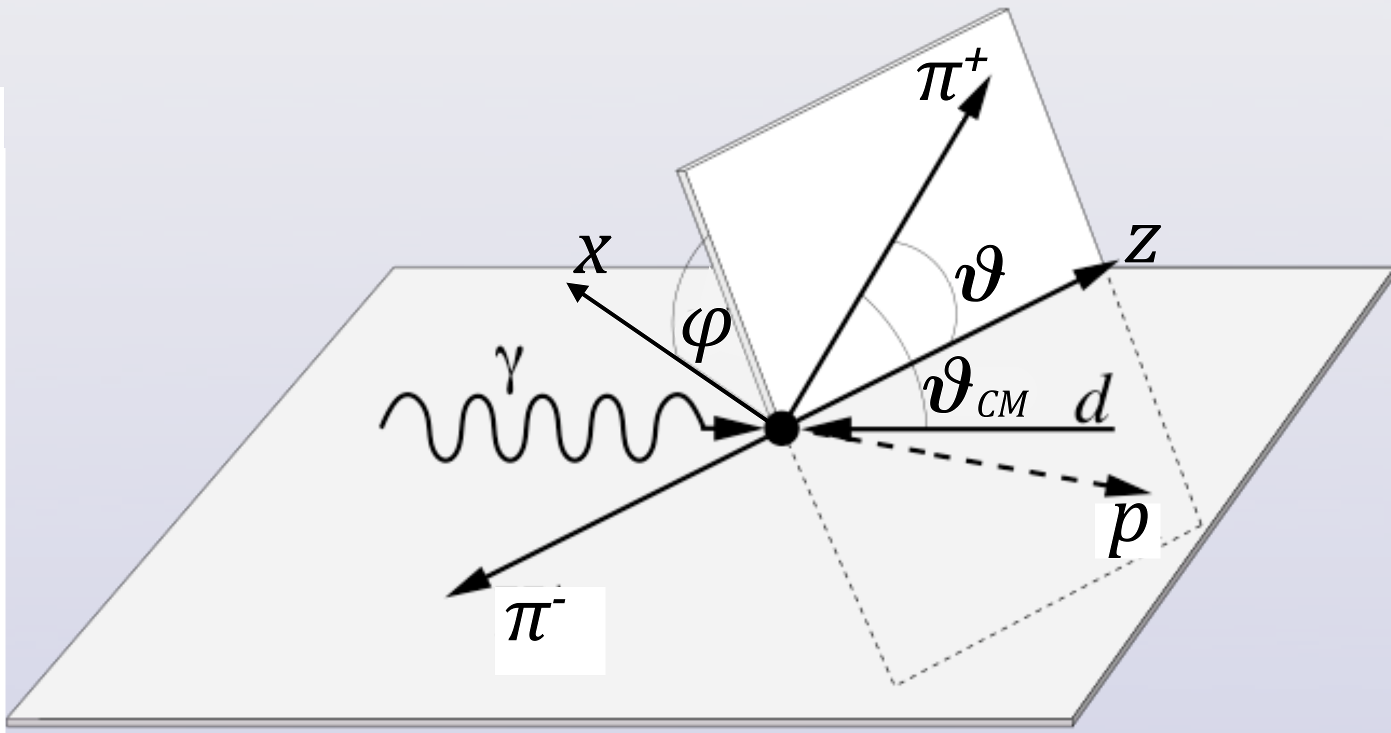
The removal of events with Px < 0.2 GeV/c provides a sample that is by far dominated by FSI events. Standard analysis procedure.

Paris Potential describes well low Px data. High-momentum tail drops off at ~0.6 GeV/c: effect on data interpretation.

Work of Tongtong Cao

Helicity Asymmetries: $\gamma(p_s)\rightarrow p\pi^+\pi^-$





$$A_{exp} = \frac{1}{P_\gamma}\frac{N^+ - N^-}{N^+ + N^-}$$

Fitted to:

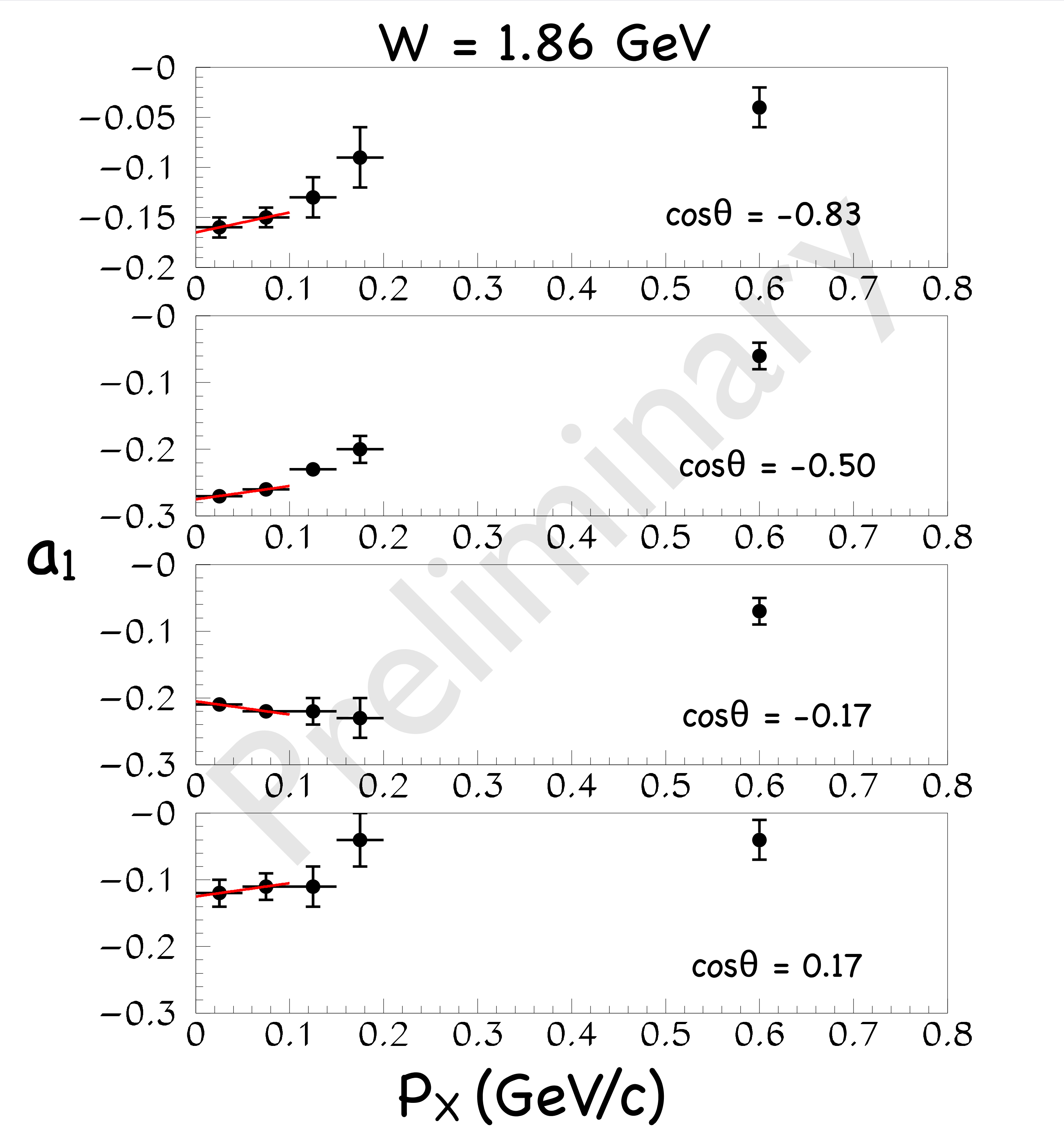
$$A_{exp}(\varphi) = \sum_{k=1}^{3} a_k \sin(k\varphi) + \sum_{k=1}^{3} b_k \cos(k\varphi)$$

$$b_k \sim 0$$

Work by Cameron Nickle

Evolution with Spectator-Nucleon Momentum

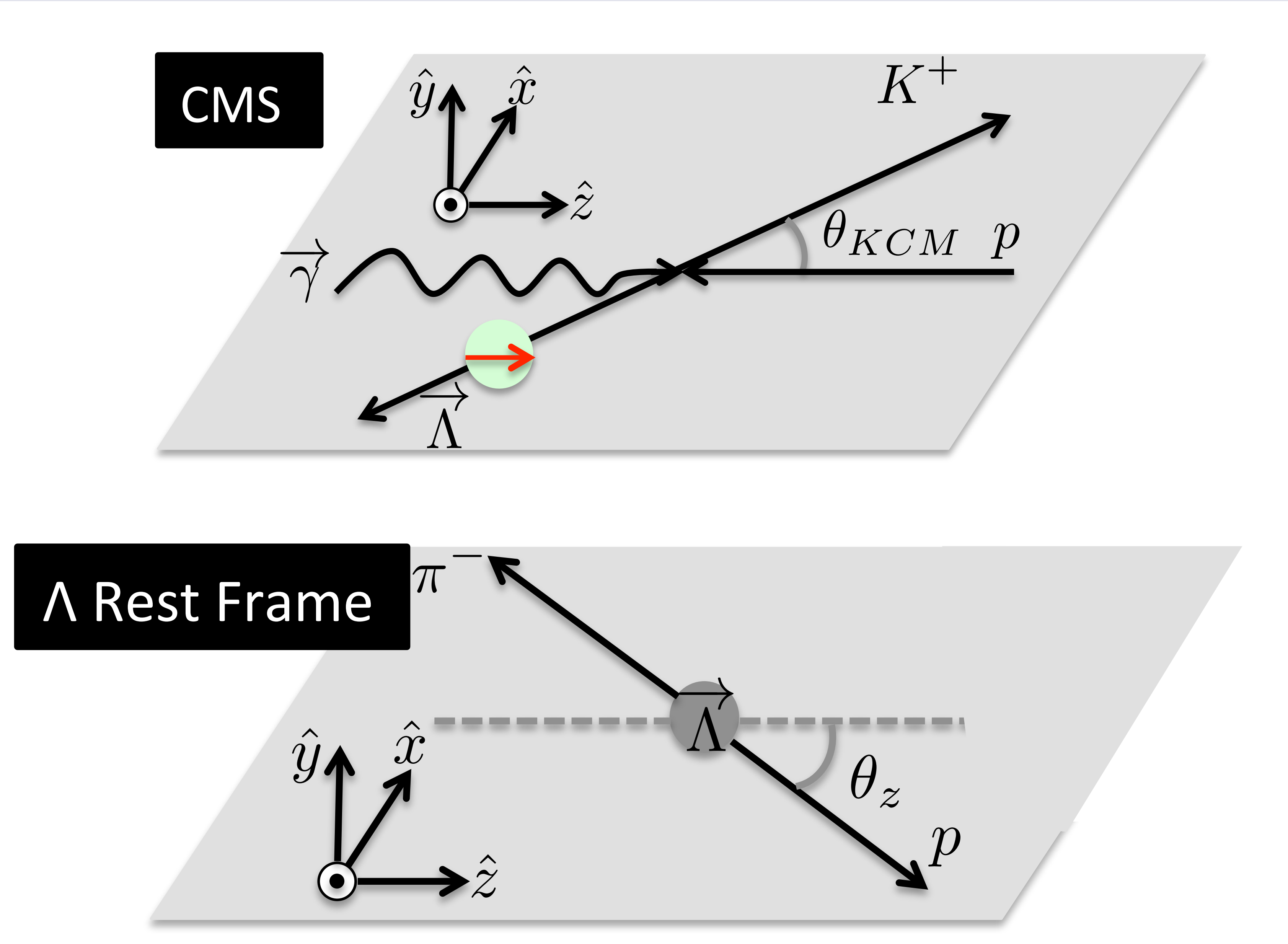
Helicity Asymmetries



Lin. Extrapolation	Average 0. - 0.2 GeV/c	Average 0. - 0.15 GeV/c	Average 0. - 0.1 GeV/c
-0.17±0.02	-0.15±0.01	-0.15±0.01	-0.16±0.01
-0.28±0.02	-0.25±0.01	-0.25±0.01	-0.27±0.01
-0.21±0.02	-0.22±0.01	-0.22±0.01	-0.22±0.01
-0.13±0.02	-0.11±0.01	-0.11±0.01	-0.12±0.01

Hyperon Polarizations: $\gamma(p_s) \to K^+\Lambda$

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_0}\left[1 - \alpha\cos\theta_x P_{circ} C_x - \alpha\cos\theta_z P_{circ} C_z + \alpha\cos\theta_y P\right]$$



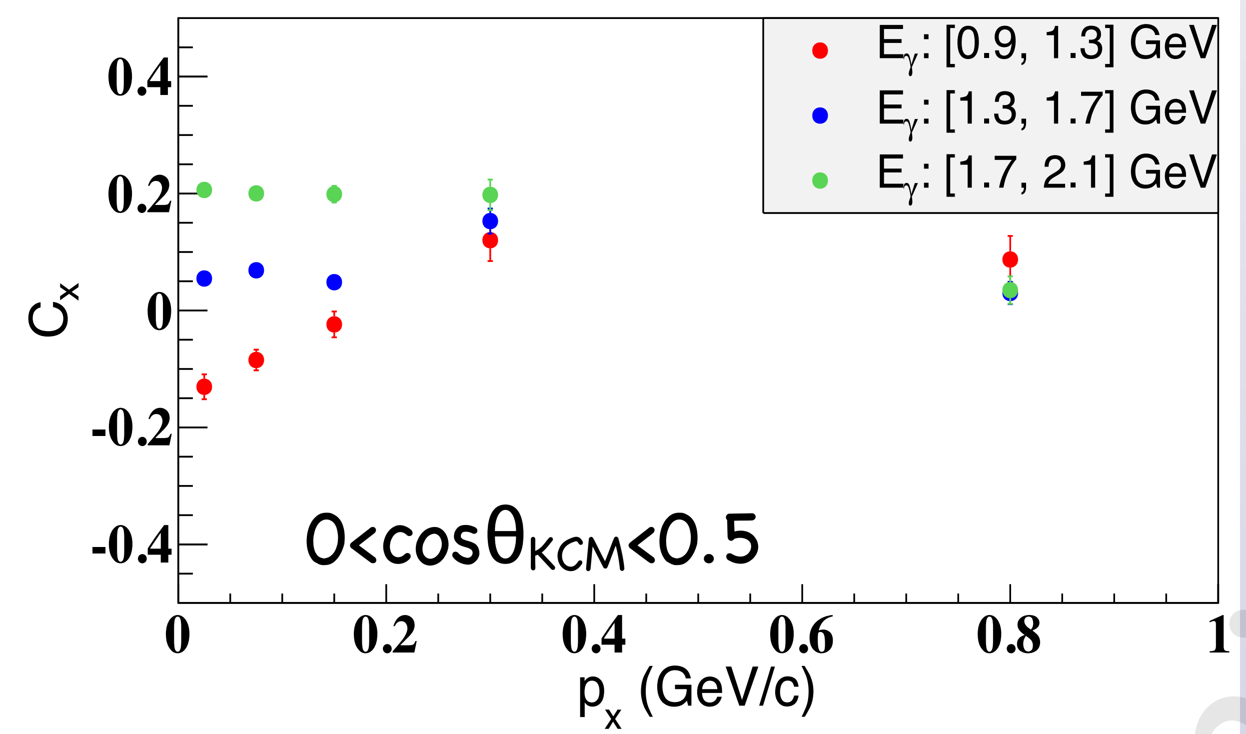
Λ self-analysing power:

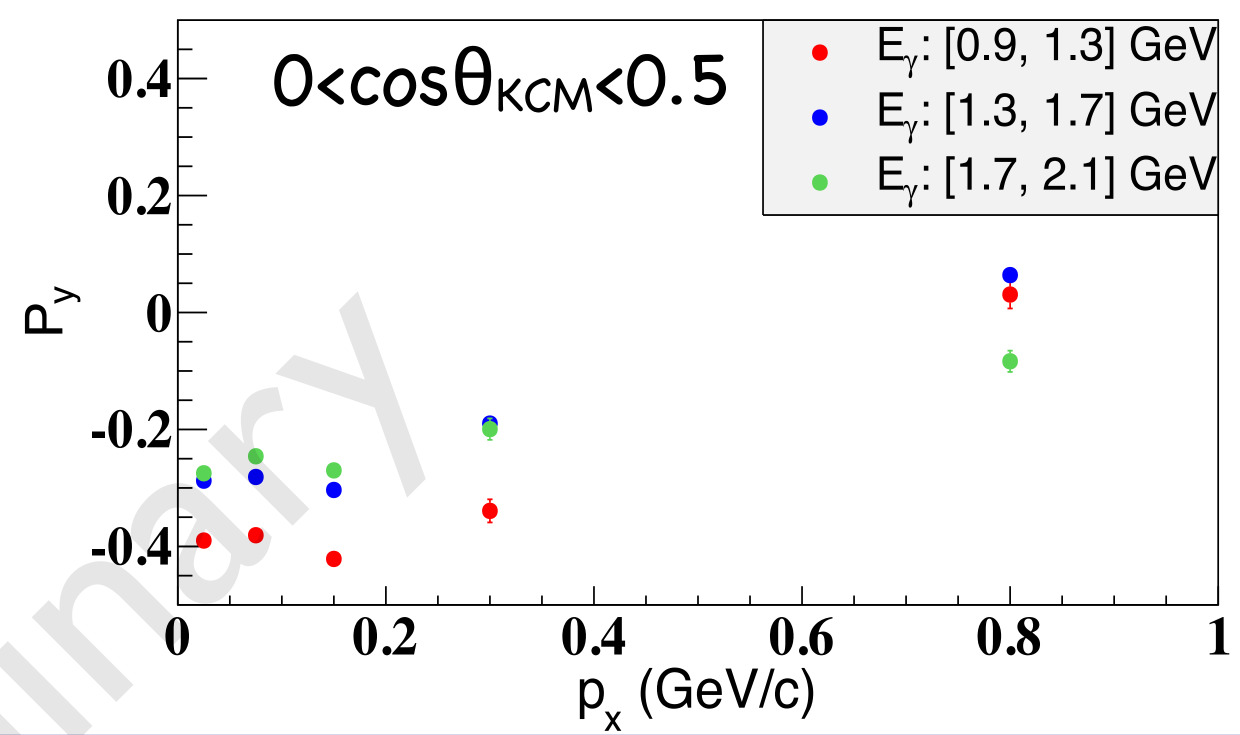
$\alpha = 0.642 \pm 0.013$

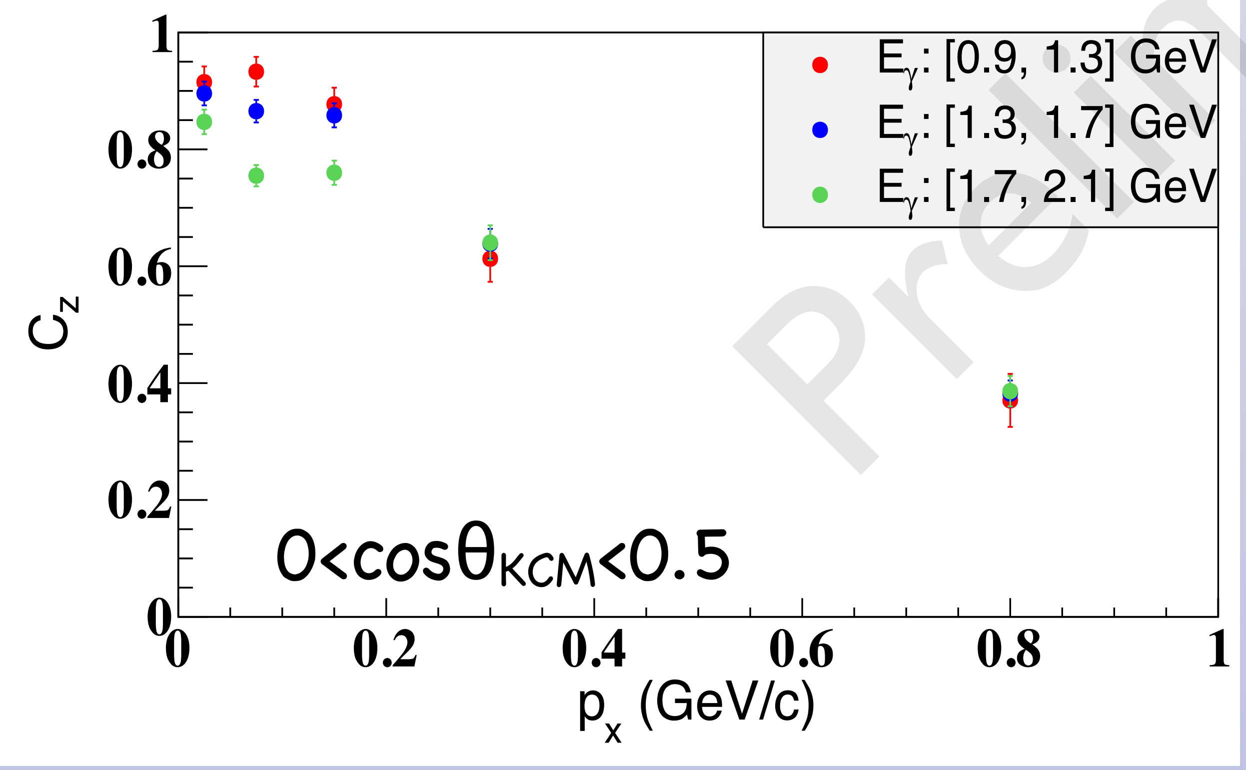
Figure courtesy of Tongtong Cao

Evolution with Spectator-Nucleon Momentum

Hyperon Polarizations



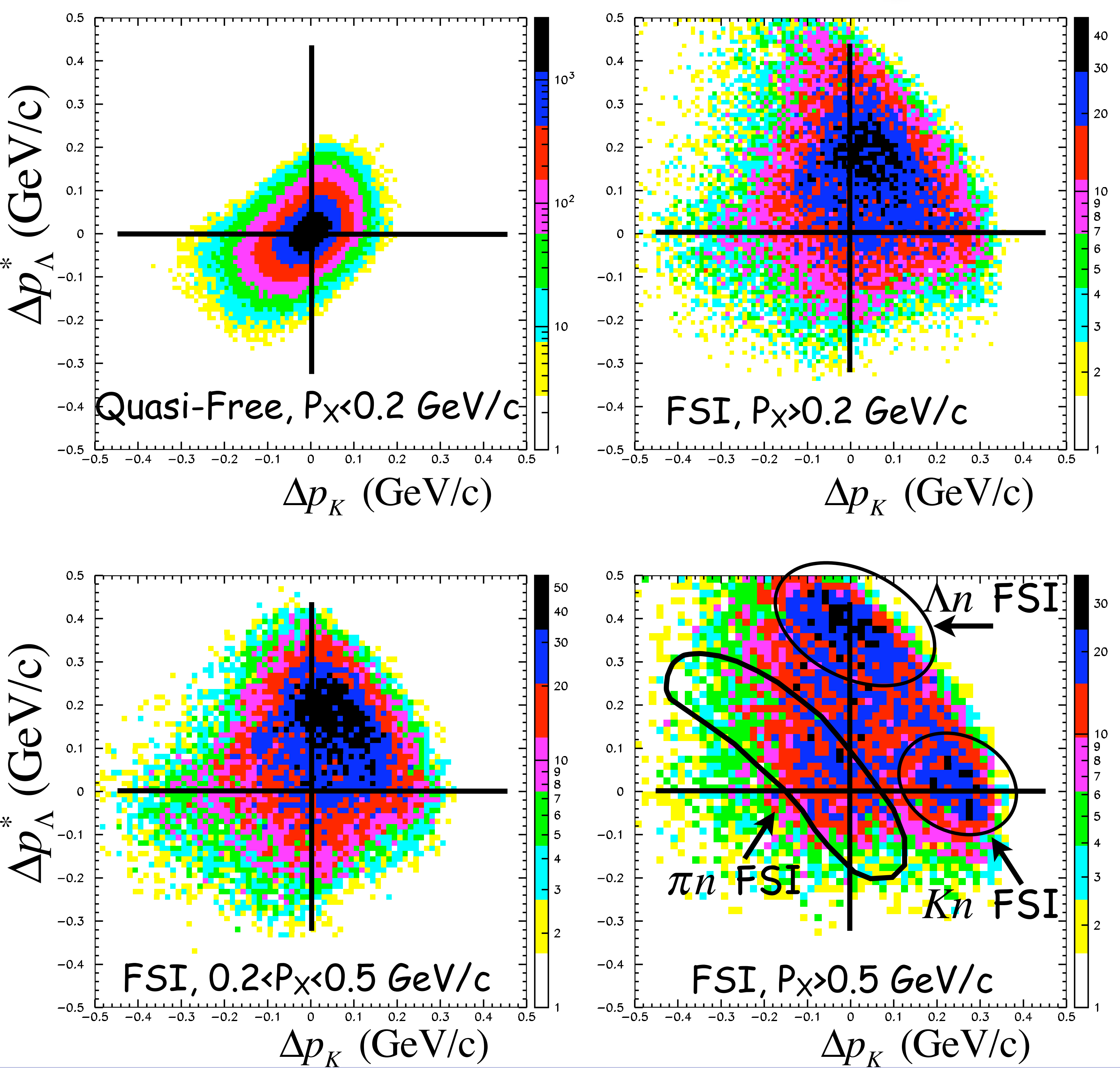




Work by Tongtong Cao

Studies of Specific FSI Selection

Kinematic Constraints by Two-Body Kinematics



Assumption: The sequential $2 \to 2$ scatterings occur on a nucleon at rest

Strategy: Test if the 3-vector of each particle obeys 2-body kinematics at first step:

$$\gamma p \to K^+ \Lambda$$

$$\Delta p^*_\Lambda = p^{CM-K\Lambda}_{\Lambda,meas} - p^{CM-K\Lambda}_{\Lambda,2body}$$

$$p^{CM-K\Lambda}_{\Lambda,2body} = F(E_\gamma, m_p, m_\Lambda, m_K)$$

$$\gamma p \to K^+ \Lambda$$

$$\Delta p_K = p^{LS}_{K,meas} - p^{LS}_{K,2body}$$

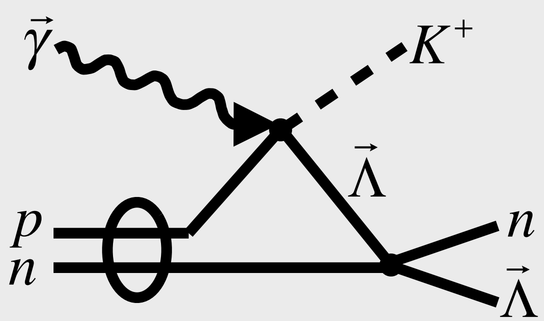
$$p^{LS}_{K,2body} = F(E_\gamma, \theta^{LS}_{meas})$$

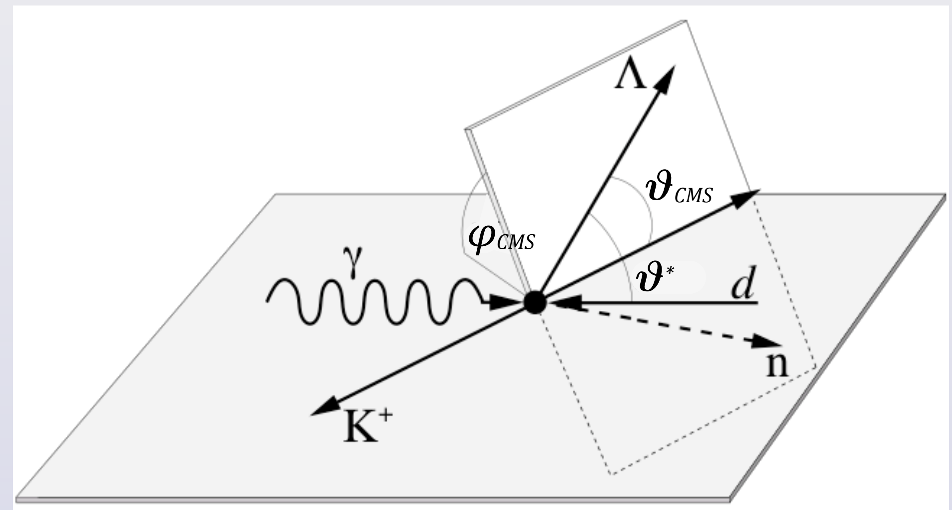
Work by Weizhi Xiong

Studies of Specific FSI Selection

Helicity Asymmetries: $\gamma d \to K^+ \Lambda n$

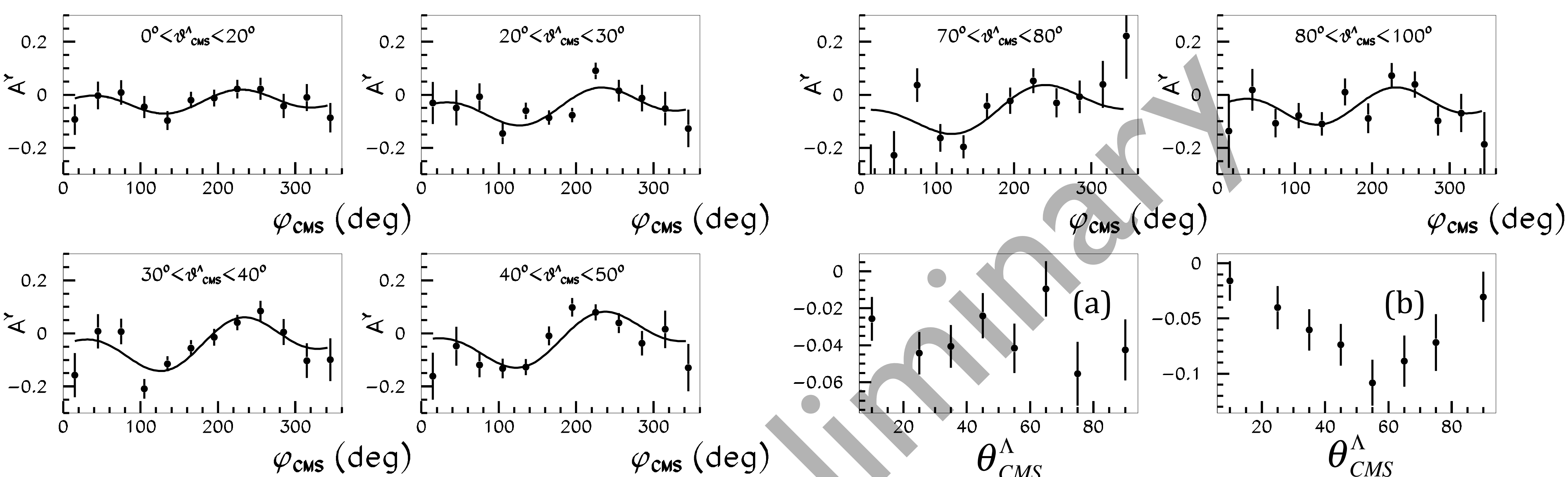
Λn Rescattering

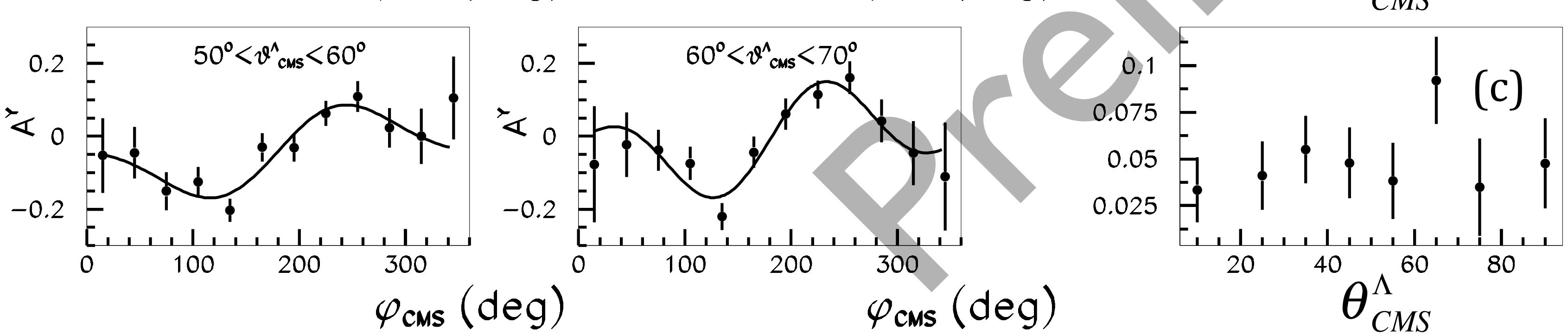




$P_n > 0.2$ GeV/c

Work by Weizhi Xiong





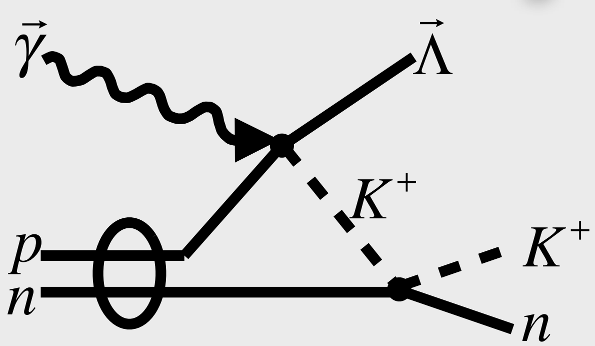
Fitted to:

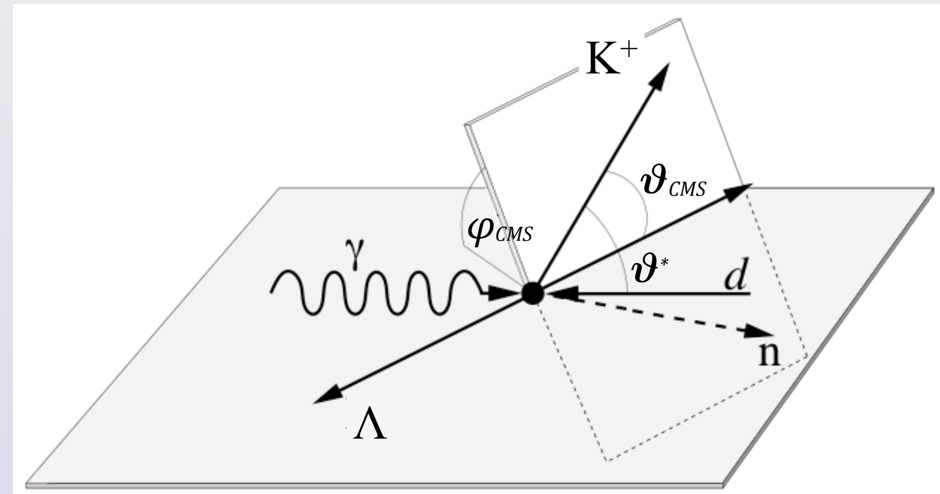
$$A^Y(\varphi_{CMS}) = a + b\sin\varphi_{CMS} + c\sin 2\varphi_{CMS}$$

Studies of Specific FSI Selection

Helicity Asymmetries: γd→K⁺Λn

Kn Rescattering





$P_n > 0.2$ GeV/c

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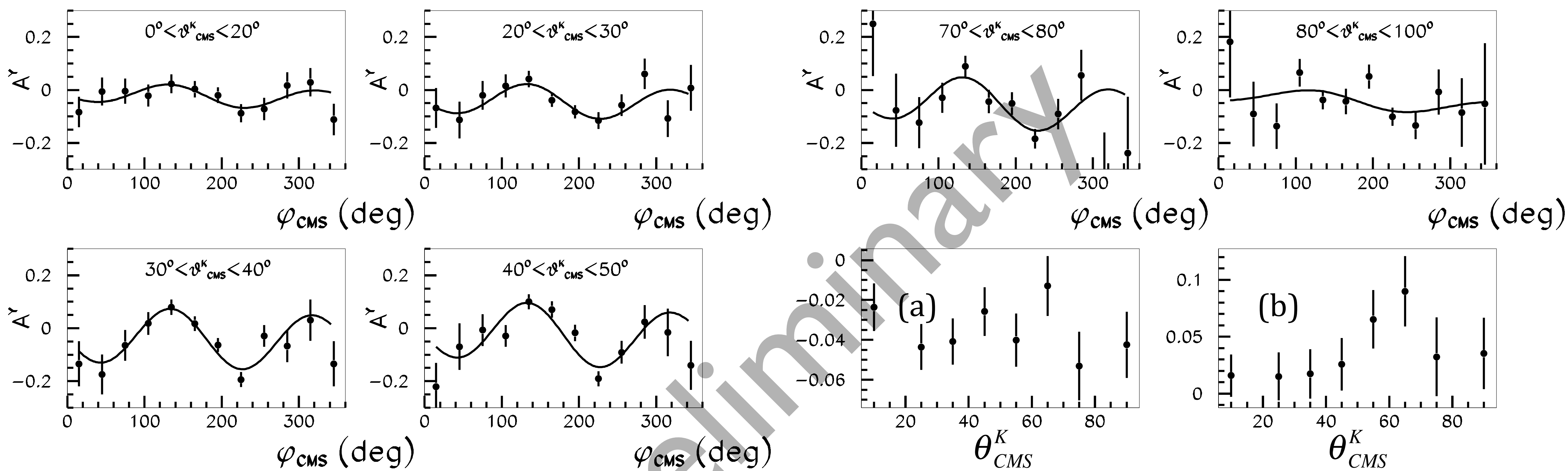

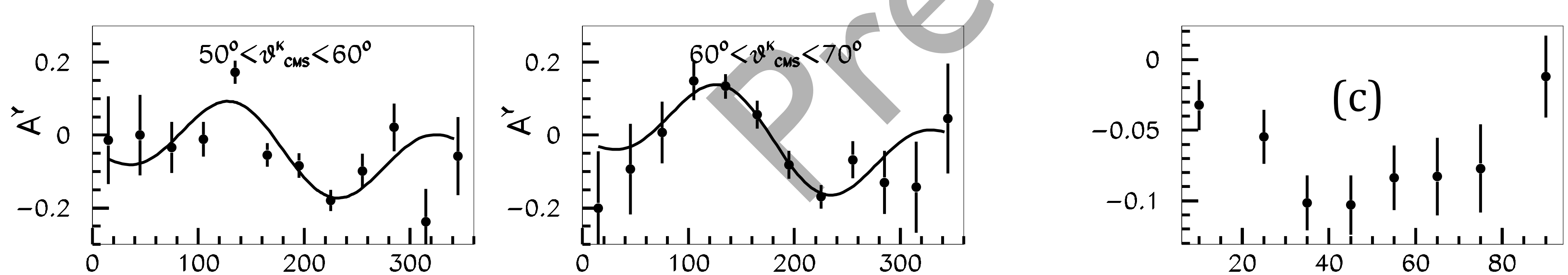

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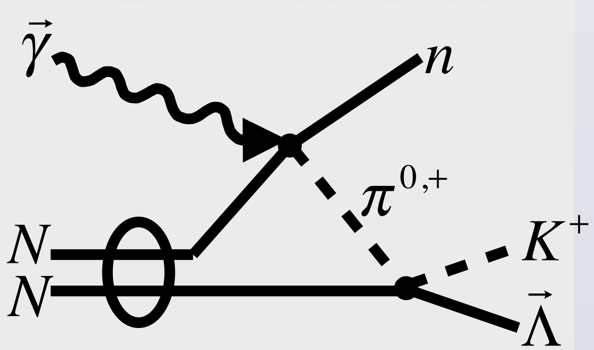
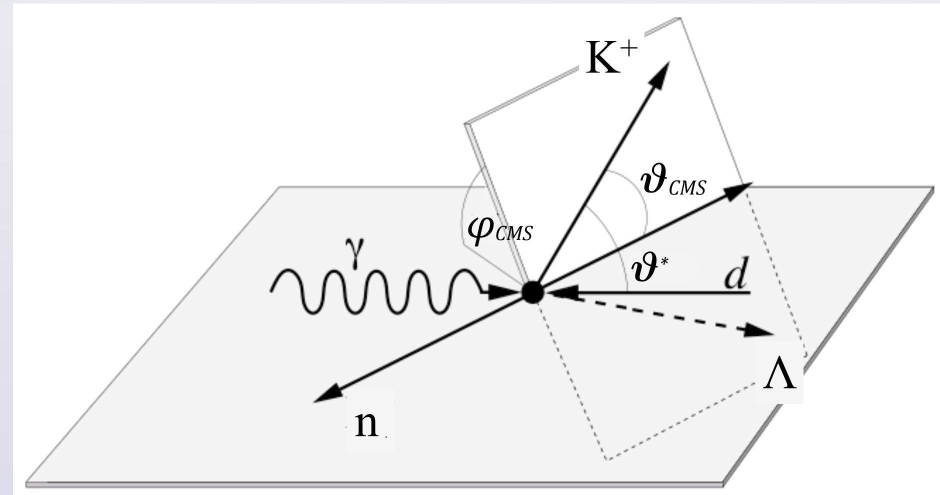
Studies of Specific FSI Selection

Helicity Asymmetries: $\gamma d \rightarrow K^+ \Lambda n$

Pion-Mediated





$P_n > 0.2$ GeV/c

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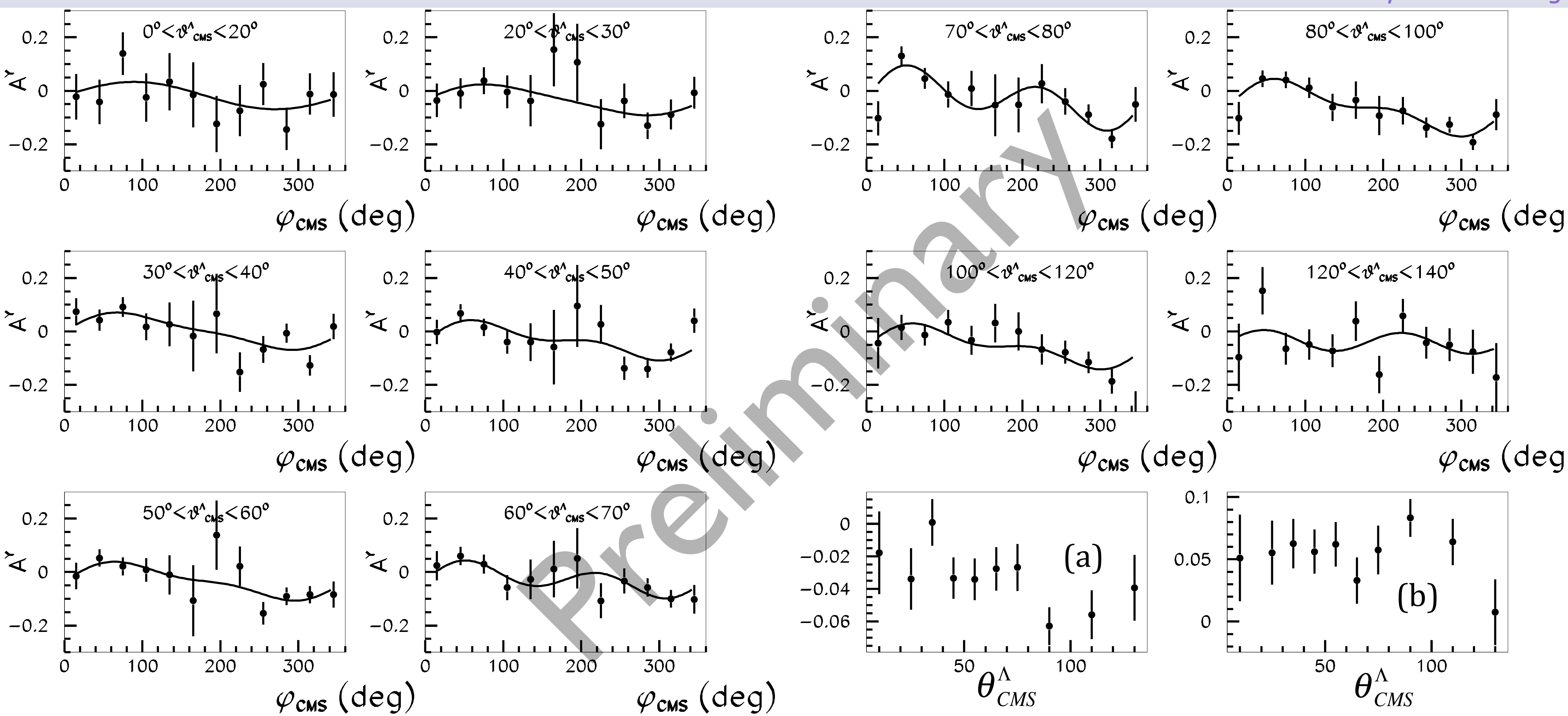
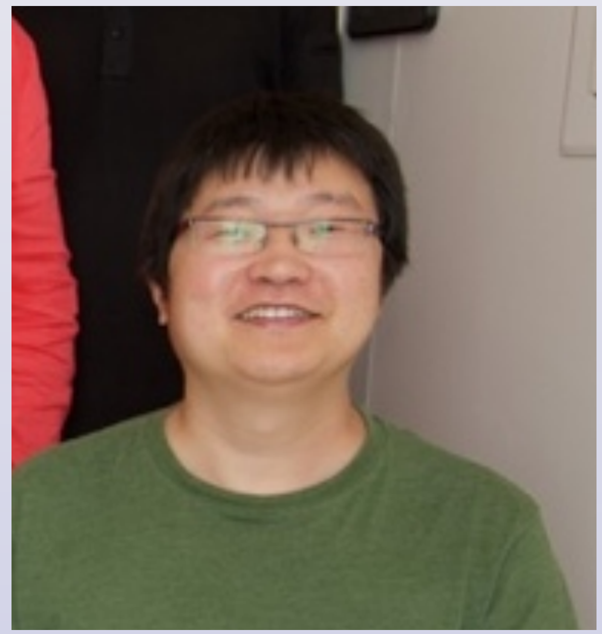


Summary and Outlook

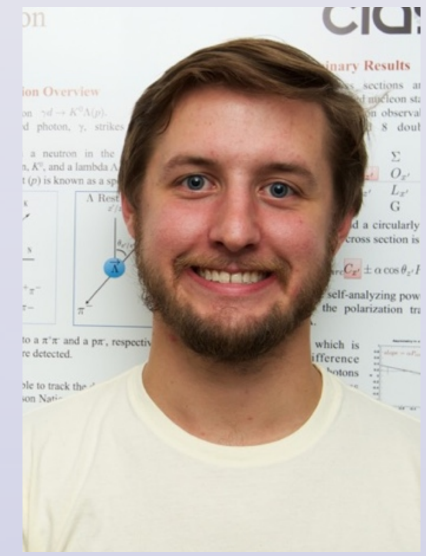
- High-Statistics Exclusive Measurements of scattering off the bound nucleon in deuteron allow for extraction of evolution of observables with target's Fermi momentum p.
- Polynomial extrapolation to p = 0 MeV/c allows to obtain more accurate estimates of observables for scattering off the free nucleon than integrating over a range of p. Important for very high-statistics samples.
- Kinematics constraints combined with studies of helicity asymmetries allow to identify kinematics where specific FSI may be dominant.
    - Large Λ scattering angles for Λn FSI.
    - Large K scattering angles for Kn FSI.
- Further validation with comprehensive simulation studies (realistic QF and FSI dynamics implemented for each step).
- Model interpretation is not obsolete: realistic deuteron wave functions are needed at high nucleon momenta; realistic model of reaction dynamics needed.

Acknowledgments

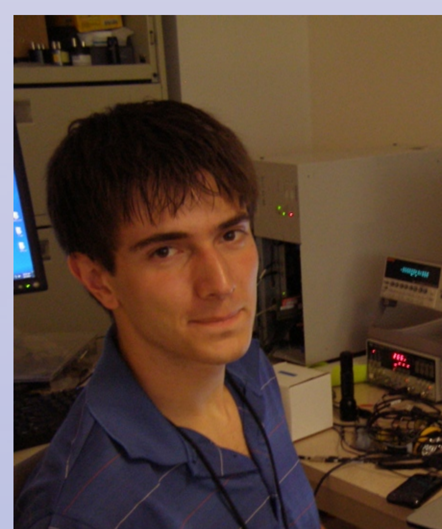
Nick Zachariou



Tongtong Cao



Colin Gleason



Cameron Nickle

Weizhi Xiong

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