CLAS Collaboration Meeting, November 2019

Dihadron beam-spin asymmetries for a CLAS12 first publication

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Research supported by the U.S. DEPARTMENT OF ENERGY | Office of Science

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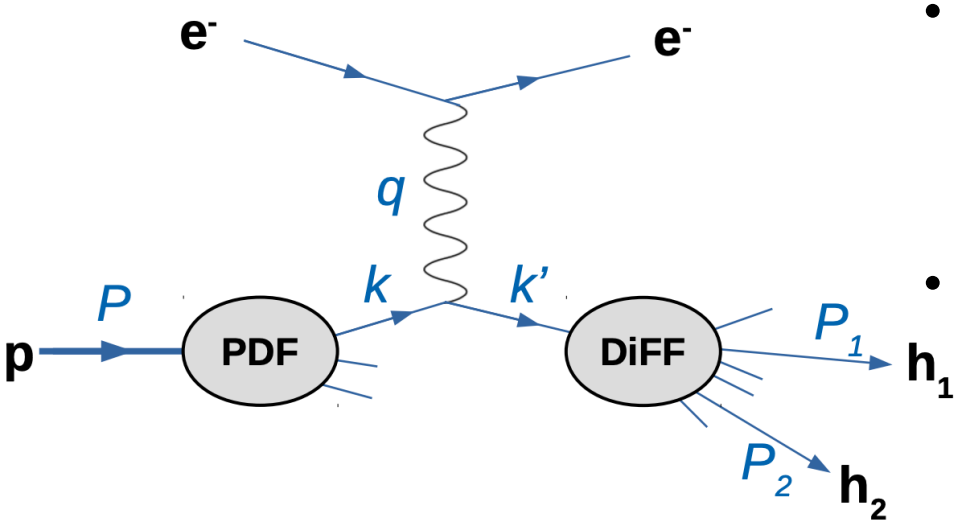
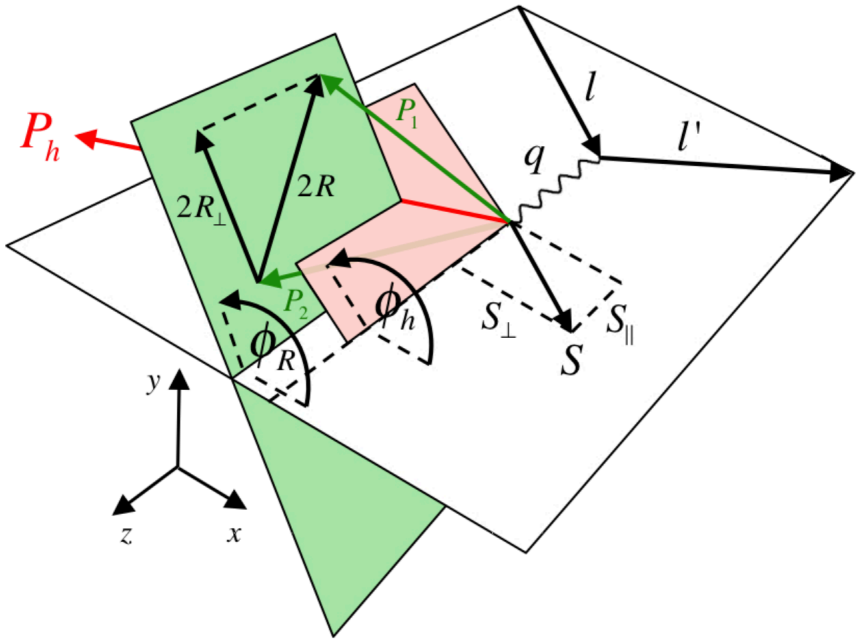
Dihadrons in SIDIS



- Parton Distribution Functions (PDFs)
  - Descriptions of the colored fields inside of nucleons.
- Dihadron Fragmentation Functions (FFs)
  - Likelihood of forming specific hadrons.

PDFs and FFs sensitive to modulations in azimuthal angles of the hadron pairs.



$$\phi_H \rightarrow P_H = P_{\pi+} + P_{\pi-}$$

$$\phi_R \rightarrow P_R = P_{\pi+} - P_{\pi-}$$

- The subject, the physics topic of the publication, observables, physics quantities and science questions to be addressed..

Toward a full collinear description of the nucleon

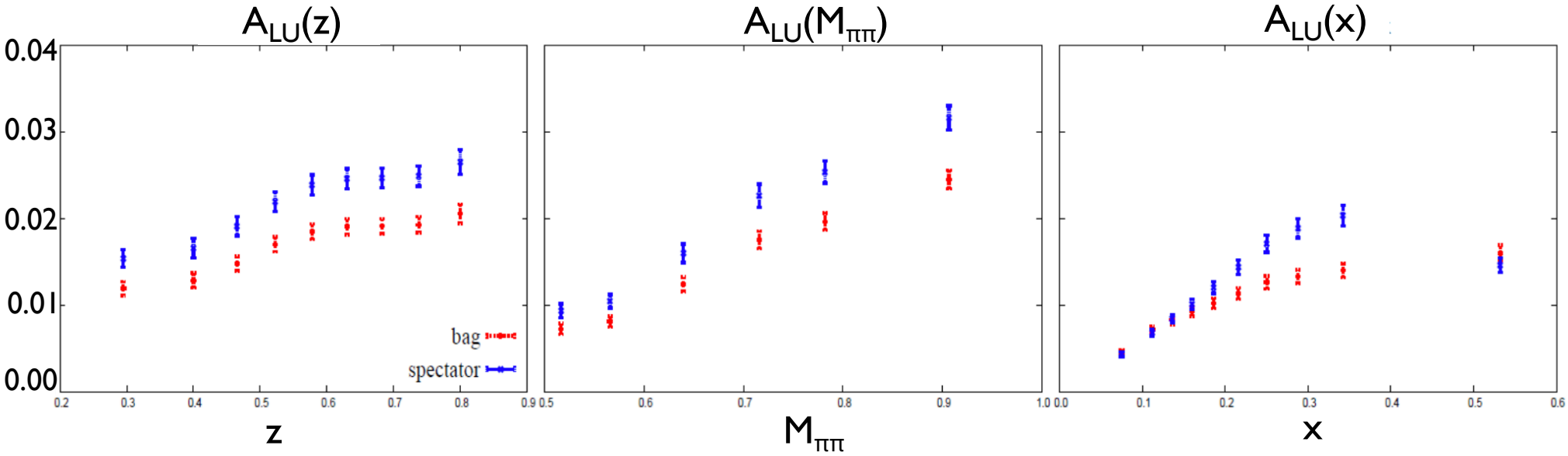
- At **twist-3**, the nucleon is described by 6 collinear PDFs.

twist-2	f(x)	g(x)	$h_1(x)$
twist-3	e(x)	$h_L(x)$	$g_T(x)$

- f(x), g(x) and $g_T(x)$ are measured through DIS.
- The transversity distribution, $h_1(x)$, is chiral-odd and so must be accessed through SIDIS where it couples to a chiral-odd fragmentation function.
- **e(x)** and $h_L(x)$ are poorly known.
- The golden channels to access these poorly known PDFs are through the SIDIS **dihadron** asymmetries $\mathbf{A_{LU}}$ and A_{UL}.

Colinear twist 3 PDF e(x)

- Insight into largely unexplored quark-gluon correlations.
- $\int x^2 e(x) dx$ → ⊥ force on ⊥ polarized quarks in an unpolarized nucleon, "Boer-Mulders force".
- x integral related to the marginally known scalar-charge of the nucleon and the pion-nucleon sigma term.
- BSAs sensitive to e(x) has sizable model predictions:



Jaffe, Ji. Nucl. Phys. **B375**, 527-560 (1992).

Jakob, Mulders, Rodrigues. Nucl. Phys. **A626**, 937-965 (1997).

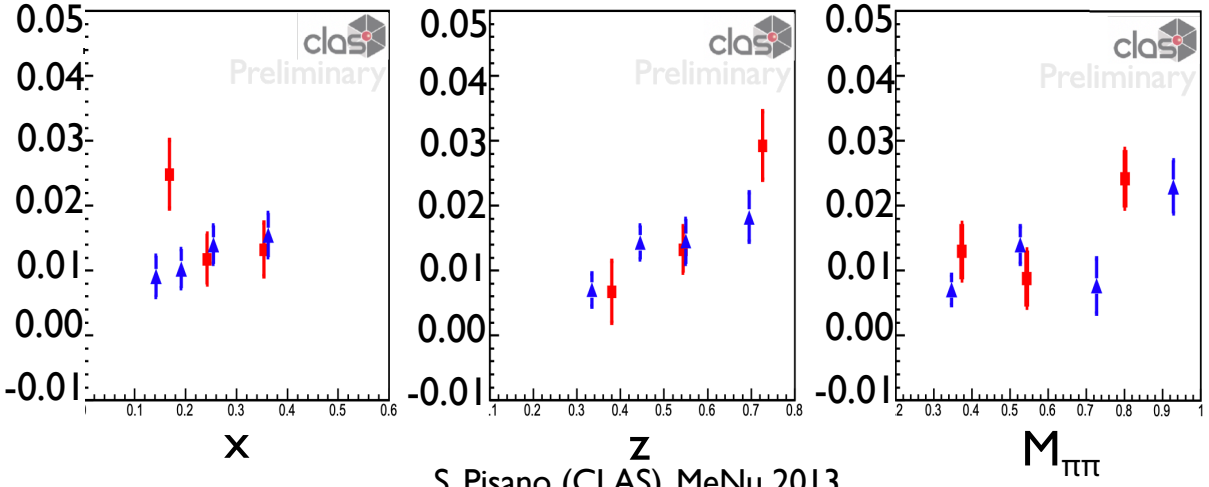
$BSA\ ep \rightarrow e'\pi^+\pi^- + X$: Clean access to e(x)

- See e.g. Aurore Courtoy, arXiv:1405.7659

$$F_{LU}^{\sin\phi_R} = -x\frac{|\vec{R}|\sin\theta}{Q}\left[\frac{M}{M_{\pi\pi}}xe^q(x)H_1^{\sphericalangle q}(z, cos\theta, M_{\pi\pi}) + \frac{1}{z}f_1^q(x)\tilde{G}(z, \cos\theta, M_{\pi\pi})\right]$$

- The PDF e(x) appears coupled to the Interference Fragmentation Function.
- Evidence for non-zero BSA

  $A_{LU}^{sin\phi_R} = \frac{F_{LU}^{\sin\phi_R}}{F_{UU}}$ from CLAS6:



S. Pisano (CLAS), MeNu 2013

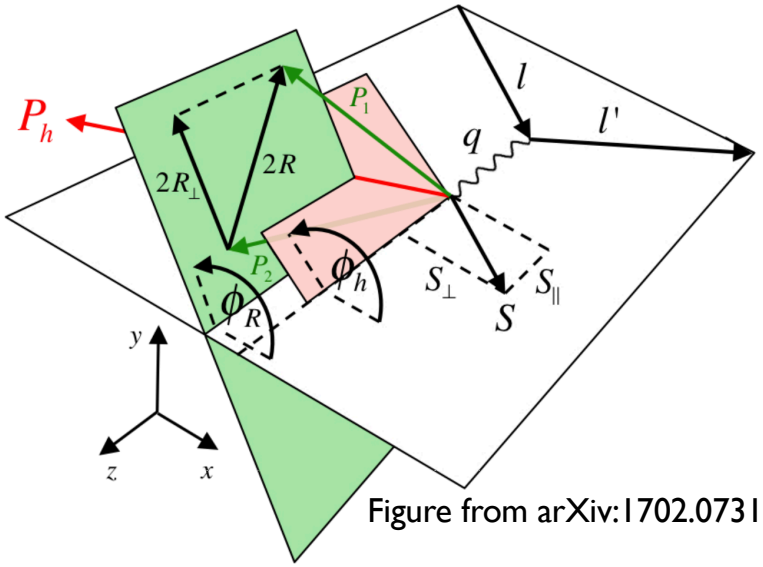


Figure from arXiv:1702.07317

$$\overrightarrow{P_h} = \overrightarrow{P_\pi^+} + \overrightarrow{P_\pi^-}, \qquad \vec{R} = \overrightarrow{P_\pi^+} - \overrightarrow{P_\pi^-}$$

Other extractions are possible

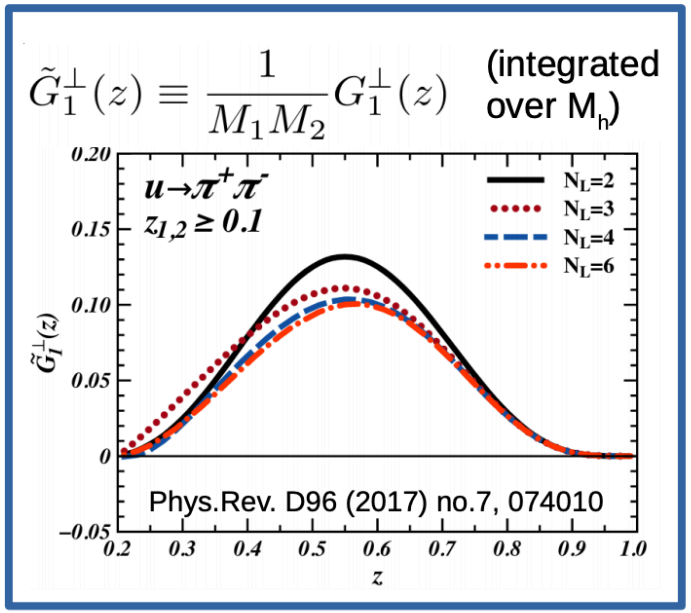
Accessing $G_1^{\perp}$ in Beam Spin Asymmetries

$$d^9\sigma_{LO} = -\sum_a \frac{\alpha^2 e_a^2}{2\pi Q^2 y} |\lambda_e| C(y) \frac{|\vec{R}_T|}{M_h} \left\{ \sin(\phi_h - \phi_R) \mathcal{I}\left[\frac{\vec{k}_T \cdot \hat{P}_{h\perp}}{M_h} f_1 G_1^{\perp}\right] + \cos(\phi_h - \phi_R) \mathcal{I}\left[\frac{\hat{P}_{h\perp} \wedge \vec{k}_T}{M_h} f_1 G_1^{\perp}\right] \right\}$$

Accessible in the $\sin(\Phi_h - \Phi_R)$ modulation in dihadron longitudinal single spin asymmetries, weighted by $P_h^{\perp} / M_h$

$$\left\langle \frac{P_{h\perp} \sin(\phi_h - \phi_R)}{M_h} \right\rangle = \int d\sigma_{LU} \frac{P_{h\perp} \sin(\phi_h - \phi_R)}{M_h} \propto \sum_a f_1^a(x) G_1^{\perp a}(z, M_h^2)$$

$$\langle 1 \rangle = \int d\sigma_{UU} = \sum_a \frac{2\alpha^2 e_a^2}{y\, Q^2} A'(y) f_1^a(x) z^2 D_1^a(z, M_h^2)$$



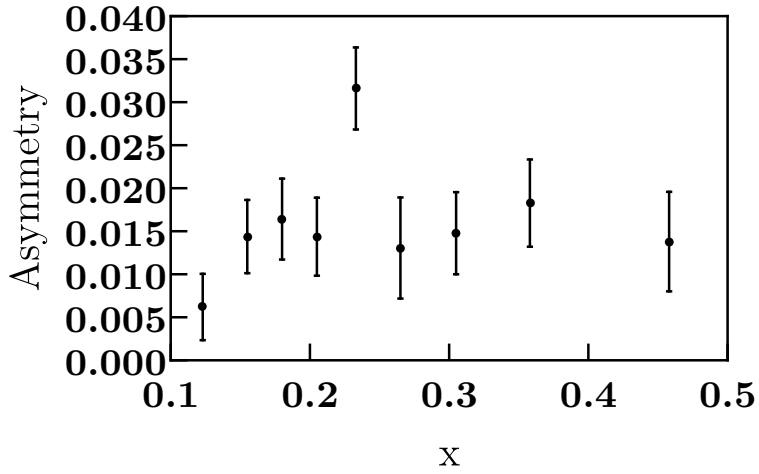
$$A_{LU}^{\Rightarrow}(x, y, z, M_h^2) = \frac{1}{M_h} \frac{\langle P_{h\perp} \sin(\varphi_h - \varphi_R) \rangle}{\langle 1 \rangle} = \lambda_l \frac{C'(y)}{A'(y)} \frac{\sum_a e_a^2 \boxed{f_1^a(x)} z \boxed{G_1^{\perp a}(z, M_h^2)}}{\sum_a e_a^2 f_1^a(x) D_1^a(z, M_h^2)}$$

https://arxiv.org/pdf/1807.11485.pdf

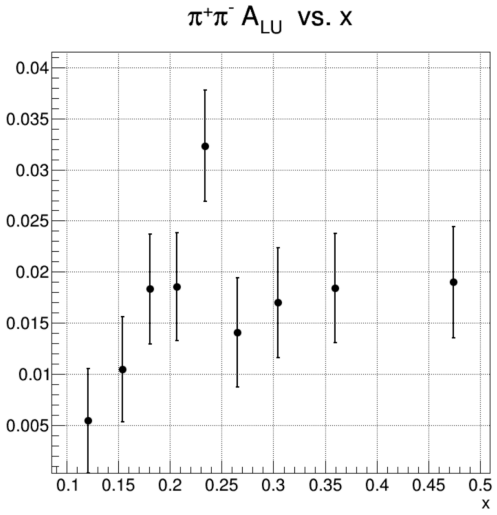
Slide from Chris Dilks's DNP Presentation

Team to complete timely data analysis

- Timothy Hayward, Christopher Dilks, Anselm Vossen, Harut Avakian



Extensive cross checks between Tim and Chris.



Collaboration with theorists

- Aurore Courtoy is a co-spokesperson on the CLAS12 e(x) proposal.
- Is actively involved in the extraction of e(x) from CLAS6 data.
  - arXiv:1405.7659

Impact of Results

- Would be first published dihadron beam-spin asymmetries (A_{LU}).
  - Some preliminary CLAS6 results were never published.
  - DNP dataset already comparable statistics to CLAS6.
  - Fall 2018 dataset alone would be enough for a detailed multidimensional study.

- Cleaner extraction of e(x) and other observables than previous single hadron measurements.

- Opportunity to simultaneously extract several previously unconstrainted dihadron fragmentation functions.

Is the current release adequate for the publication in PRL

- Proposed channel is ideal for a first publication from CLAS12
  - Asymmetries not sensitive to minor improvements in momenta resolution.
  - Does not rely on the central tracking system.
  - Possibly only focused on charged tracks.

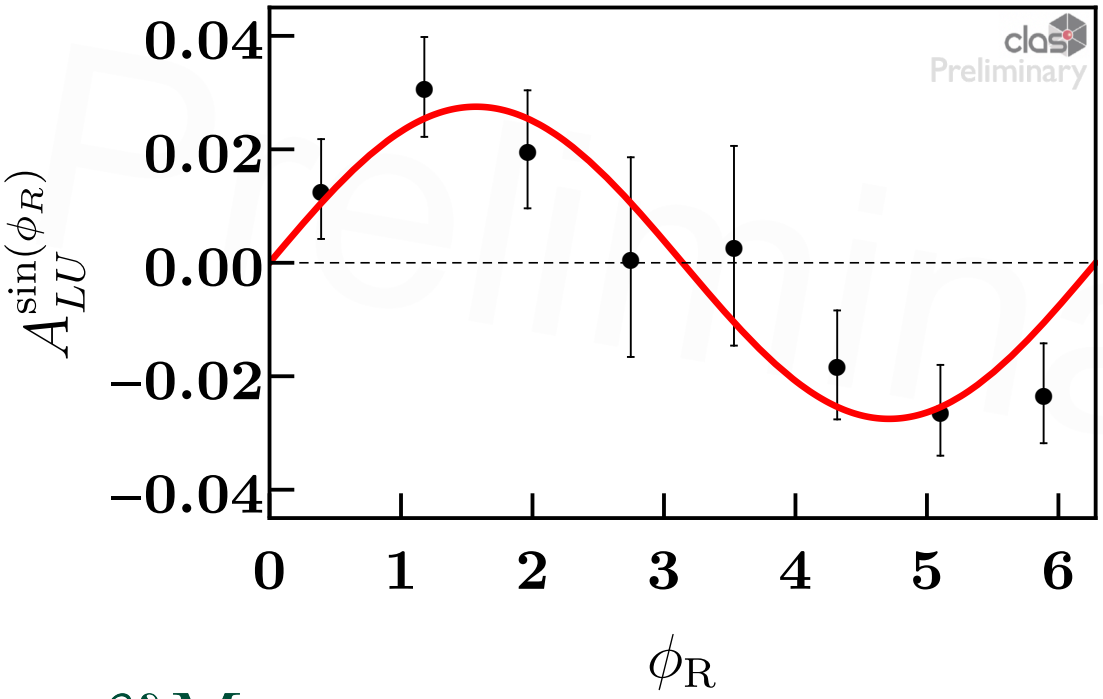
What is the required statistics?

- We aim for the first publication on dihadron A_{LU} so no strict statistics requirements.
- DNP2019 had 1.5m events and was already comparable to full CLAS6 statistics.
- Estimate of ~30m events for data taken so far or ~10m from Fall2018.
- Solely cooking Fall2018 would be more than adequate for publication.

- Present briefly the current status of the analysis

Extracting A_{LU}

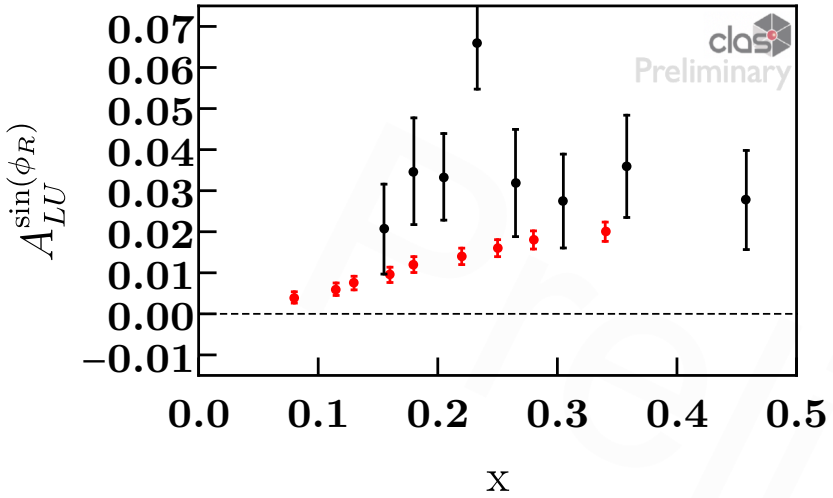
- Select $ep \rightarrow e'\pi^+\pi^- + X$.
- Calculate ϕ_R angle of pion pair.
- Fit to asymmetry $\frac{N^+ - N^-}{N^+ + N^-}(\phi_R) \rightarrow A_{LU}^{sin\phi_R}$.
- Correct with kinematic factor and P_{beam}~86%.
- Example for 0.22 < x < 0.25:



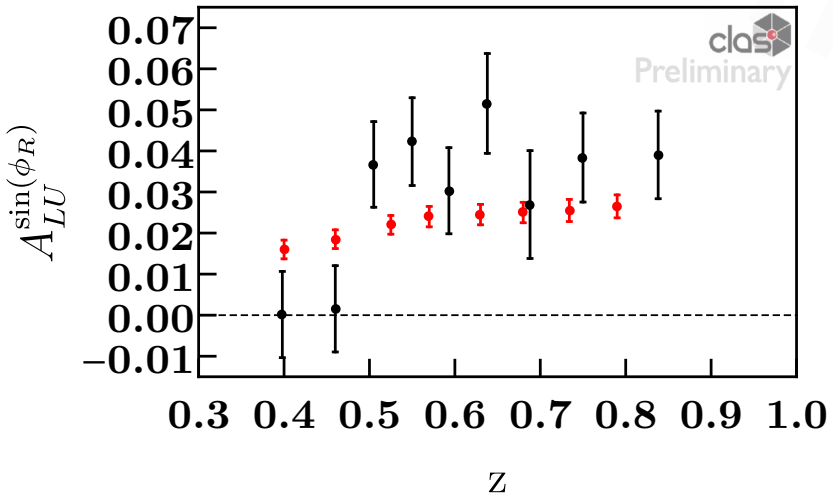
Channel selection
- Q^2>1.0 GeV^2
- W>2.0 GeV
- z_i>0.1
- z<0.95
- M_{miss}>1.05 GeV
- x_F>0
- y<0.8
- $p_{\pi i}$ > 1.25 GeV
- p_e > 2.00 GeV

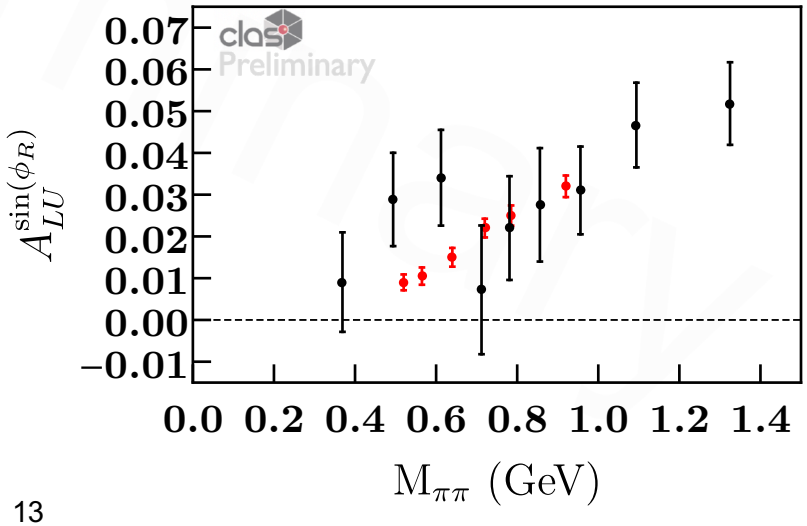
Preliminary results on ϕ_R modulations

- A_{LU} approximately 3% asymmetries.
- Trend of increasing asymmetries in x, z and $M_{\pi\pi}$ expected.

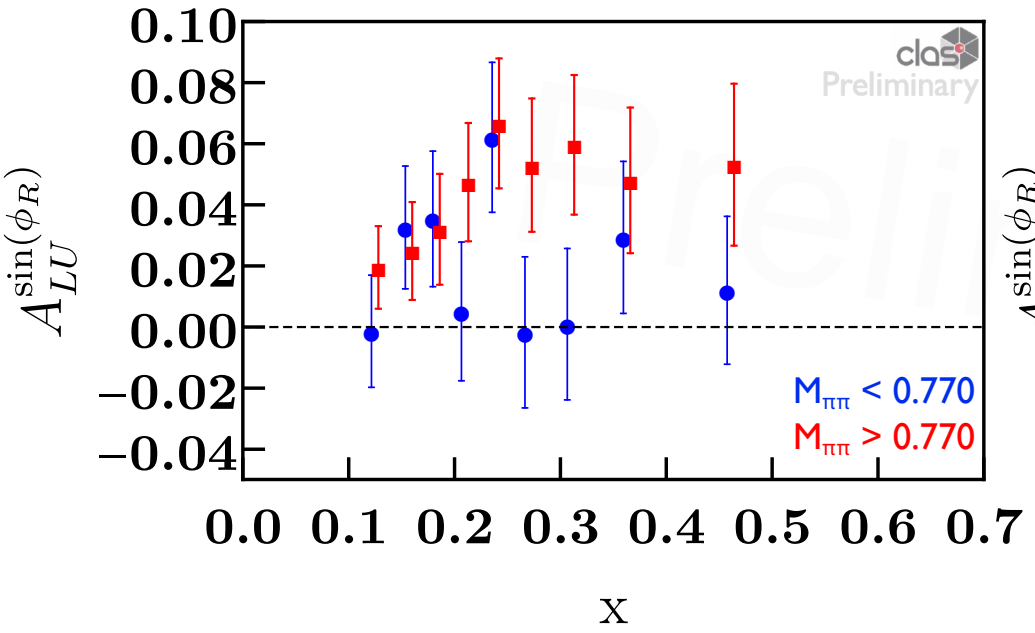


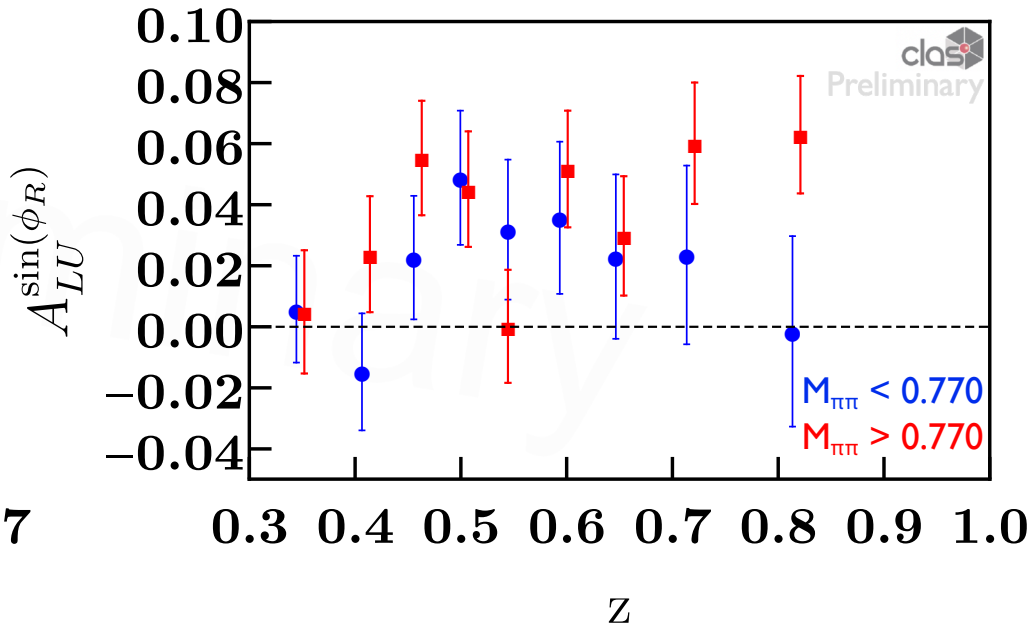
- CLAS12 (Data)
- Spectator (Model)





Multidimensional binning





- Asymmetries enhanced when binned in $M_{\pi\pi}$.
- Much finer multidimensional binning coming with more statistics.

Simultaneous Fitting of Multiple Modulations

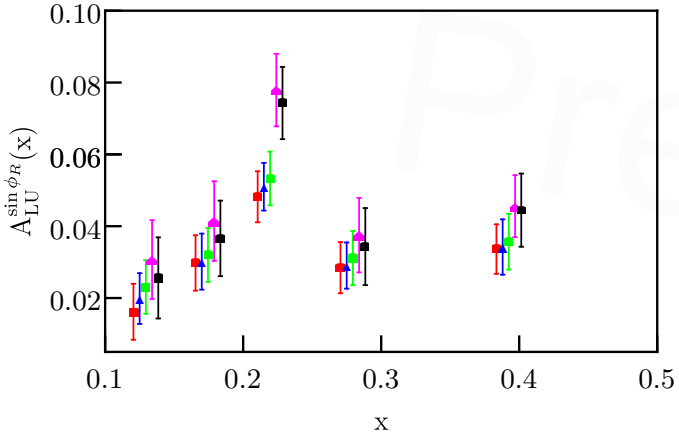
$$A_R \sin(\phi_R)$$

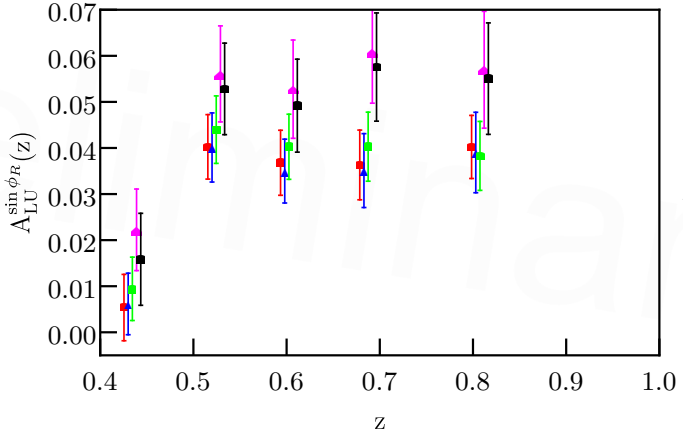
$$A_R \sin(\phi_R) + A_{HR} \sin(\phi_H - \phi_R)$$

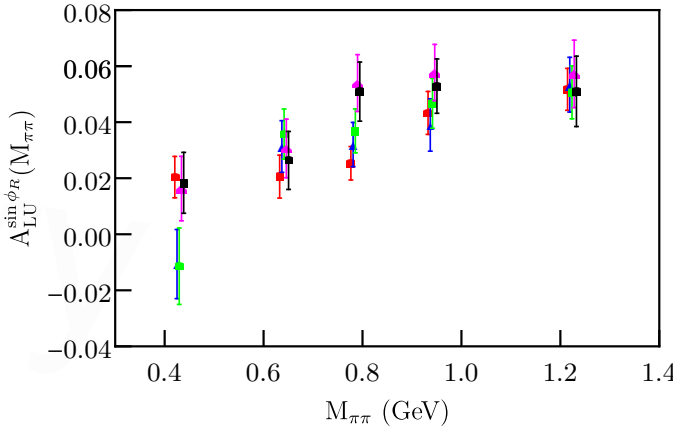
$$A_R \sin(\phi_R) + A_{HR} \sin(\phi_H - \phi_R) + A_H \sin(\phi_H)$$

$$\sum_{t=2}^{3} \sum_{\ell=1}^{1} \sum_{m=-\ell}^{\ell} P_\ell^m \Phi_t^m \qquad \sum_{t=2}^{3} \sum_{\ell=1}^{2} \sum_{m=-\ell}^{\ell} P_\ell^m \Phi_t^m$$

$\pi^+\pi^-$





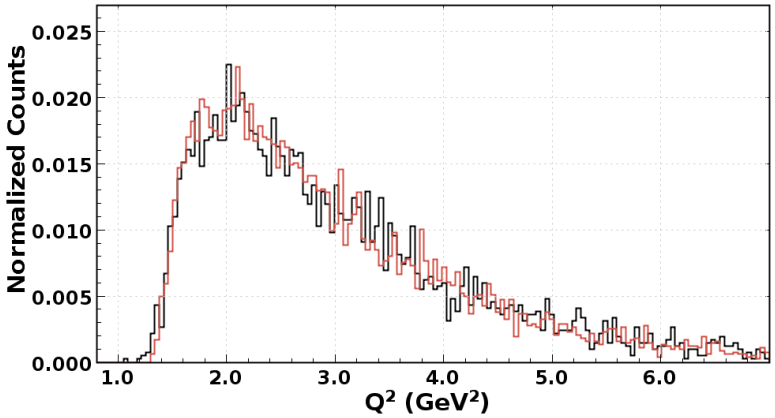


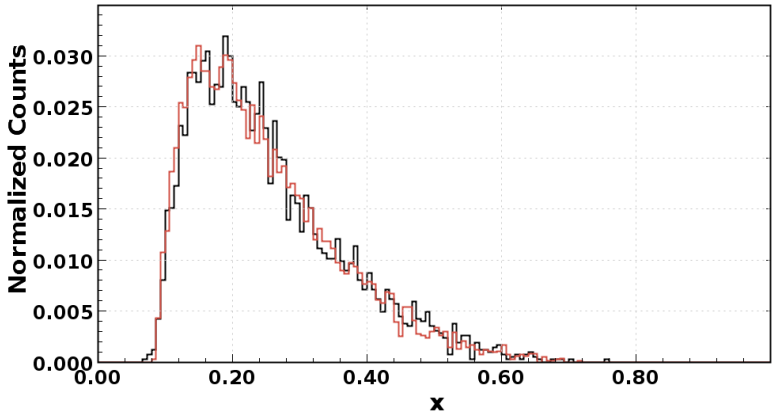
- Other modulations in the cross section can affect the extraction.
- Simultaneously fitting multiple moments leads to a richer understanding.

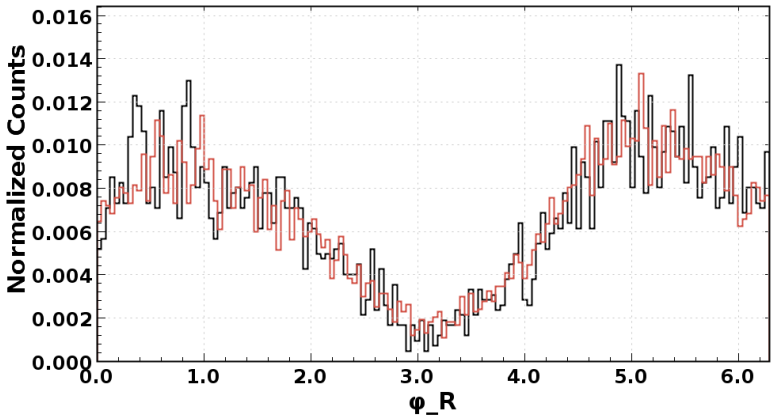
Monte Carlo

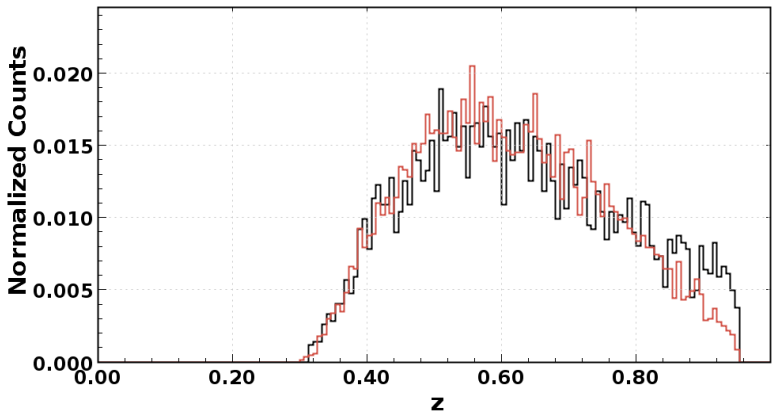
- MC provided by Giovanni Angelini and Harut Avakian.
- CLASDIS based on Lepto and LUND fragmentation.
- About 120m events already available.

Data
Monte Carlo



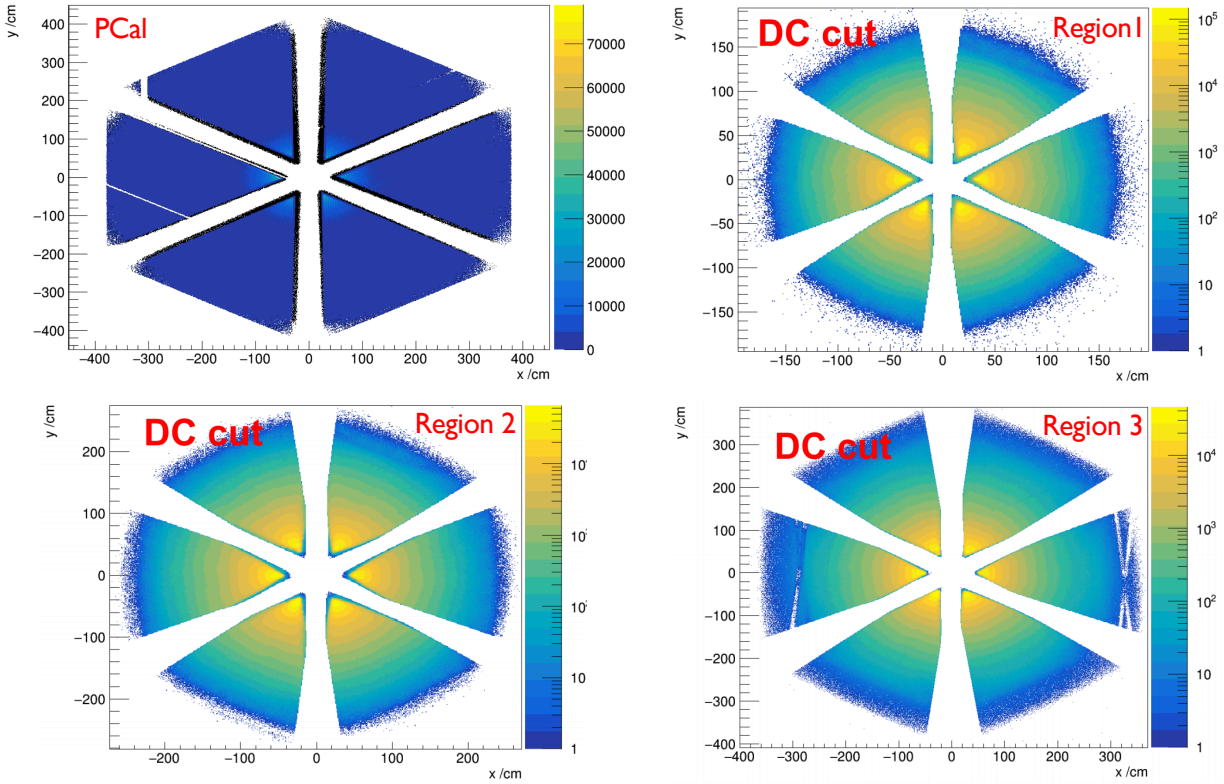






Fiducial Volume Studies

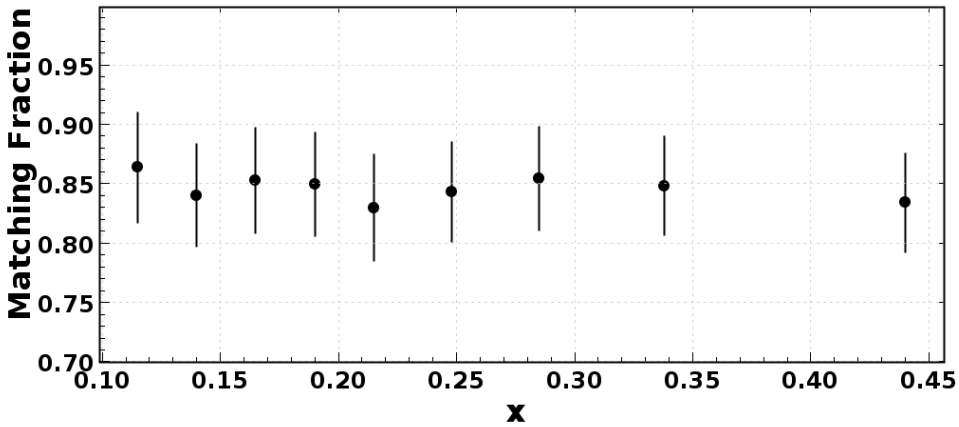
- Fiducial cuts developed by Stefan, FX and others and approved by DPWG.
- Refinement to come with future cooking.



Plots from Stefan's DPWG Presentation

Systematics

- Matching fractions of pion pairs studied in Monte Carlo. Refinement in terms of different effects to come.



- Radiative corrections: estimated to be small (e.g. from $y < 0.8$). More specifics to come.
- Binning effects: studied by adjusting bin widths and centers.
- Multiple modulations: studied with a full binning in θ, ϕ_R and ϕ_H and separate amplitudes fitted for each partial wave.

Publication Possibilities

- Multiple modulations are sensitive to different PDFs and FFs.
- Separate experiment and theory papers?
- PRL is possible and worth aiming for but limits the amount of information that can be included.
  - Publish just ϕ_R modulations for charged pions with follow up ϕ_H- ϕ_R modulation and full partial wave analysis?
  - Attempt to include ϕ_R and ϕ_H- ϕ_R together?

Timeline

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun

Data
- Cooking + trains
- Quality check
- Run list

Monte Carlo
- Production and Analysis
  - PID Efficiency, injected Asymmetries, validity of extraction, radiative effects

Analysis Note
- PID + fiducial cuts
- Channel selection
- Systematic studies
- Proposed results

Review by DPWG

Preparing the Paper
- Submission late May

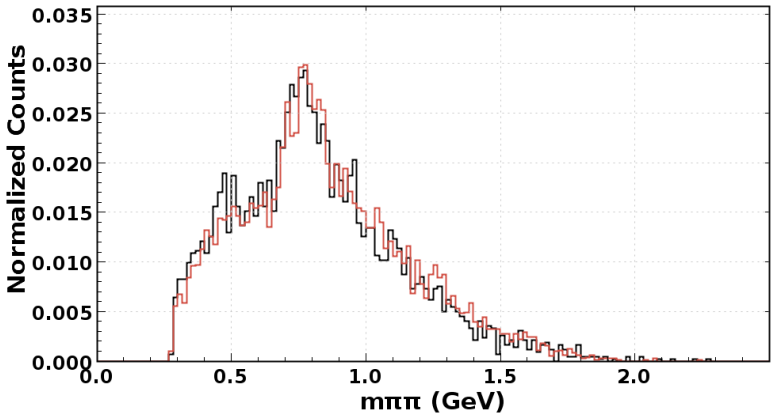
Note: All SIDIS proposals share *many* common features and will benefit from the collaborative effort.

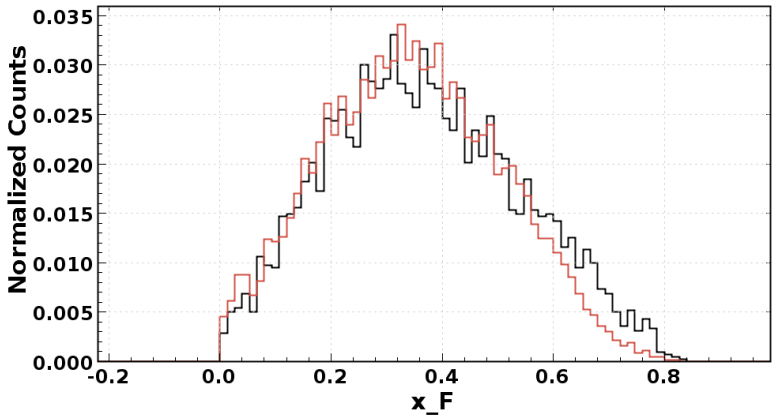
Backup Slides

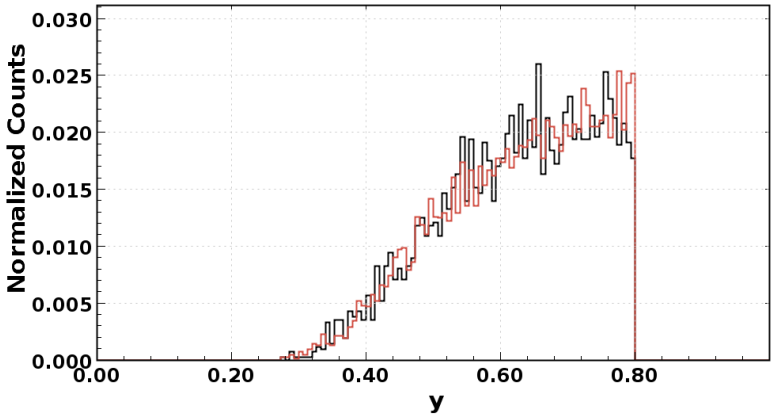
Comparison between data and MC

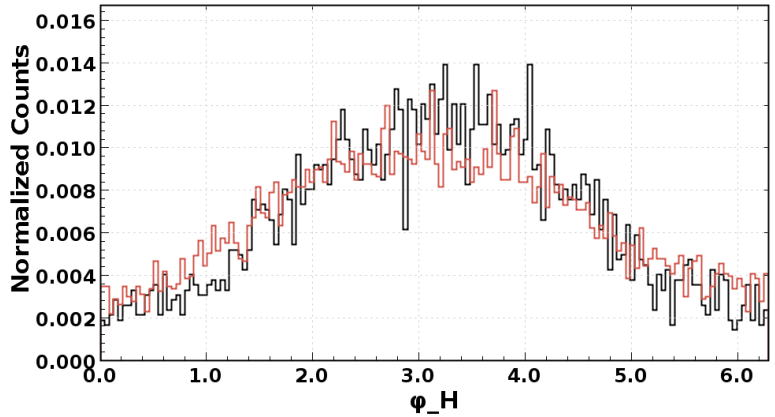
- MC provided by Giovanni Angelini and Harut Avakian.
- Very good agreement.
- About 100m SIDIS events already available.

Data
Monte Carlo









Extension to other channels in progress

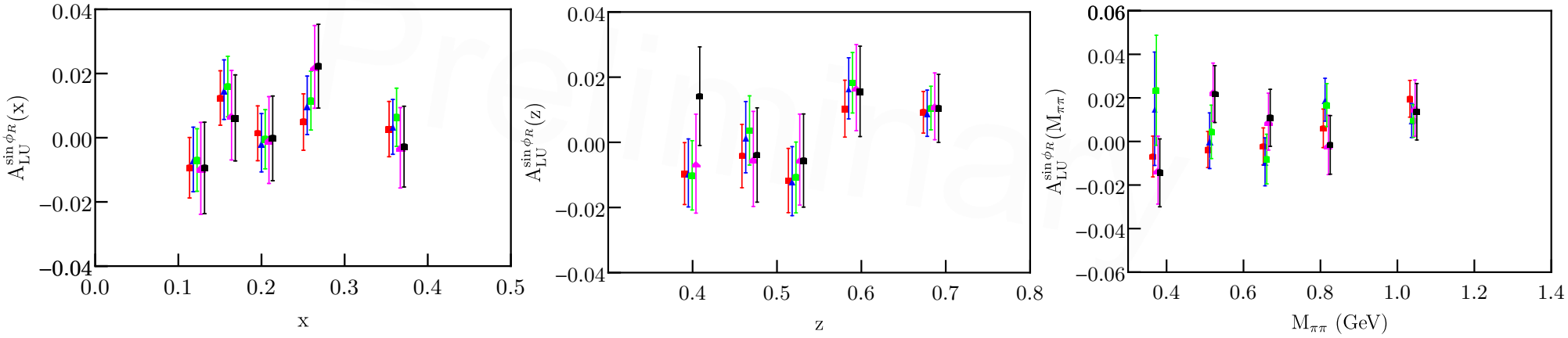
$\pi^+\pi^+$

$$A_R \sin(\phi_R)$$

$$A_R \sin(\phi_R) + A_{HR} \sin(\phi_H - \phi_R)$$

$$A_R \sin(\phi_R) + A_{HR} \sin(\phi_H - \phi_R) + A_H \sin(\phi_H)$$

$$\sum_{t=2}^{3} \sum_{\ell=1}^{1} \sum_{m=-\ell}^{\ell} P_\ell^m \Phi_t^m \qquad \sum_{t=2}^{3} \sum_{\ell=1}^{2} \sum_{m=-\ell}^{\ell} P_\ell^m \Phi_t^m$$



- A_{LU} for same sign pairs consistent with zero.

Comparison between data and MC

- MC for other channels.

$\pi^+\pi^+$

Data
Monte Carlo