Correlations in Partonic and Hadronic Interactions – (2020 CPHI)

Charged dihadron beam-spin asymmetries from CLAS12

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Toward a full collinear description of the nucleon

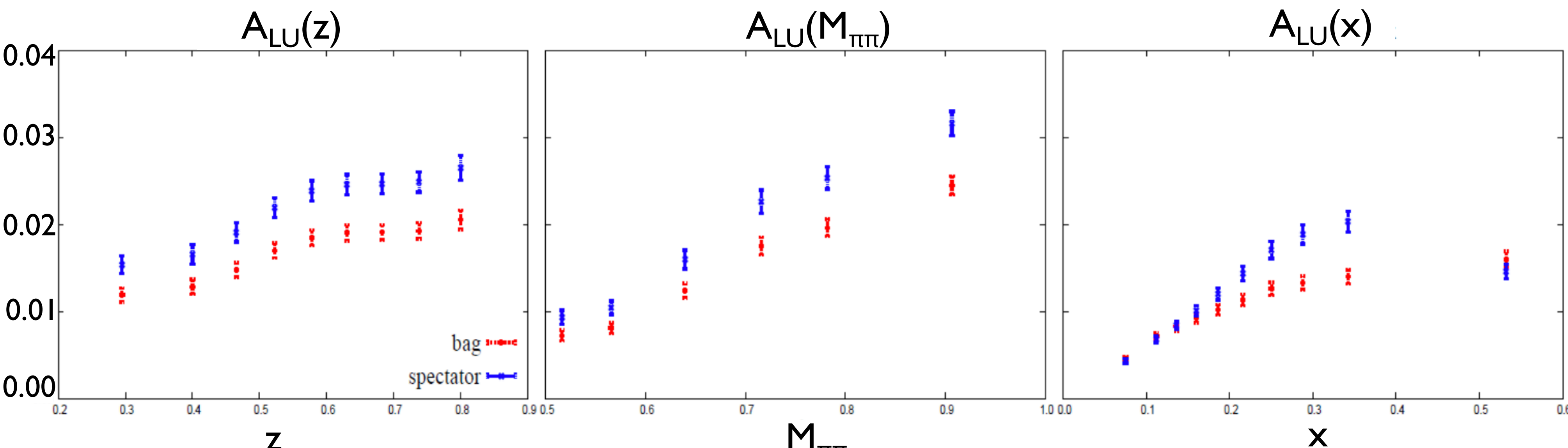
- At **twist-3**, the nucleon is described by 6 collinear PDFs.

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 **A_{LU}** and A_{UL}.

Colinear twist 3 PDF e(x)

- Insight into largely unexplored quark-gluon correlations.
- $\int x^2 e(x)dx \rightarrow \perp$ force on $\perp$ 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).

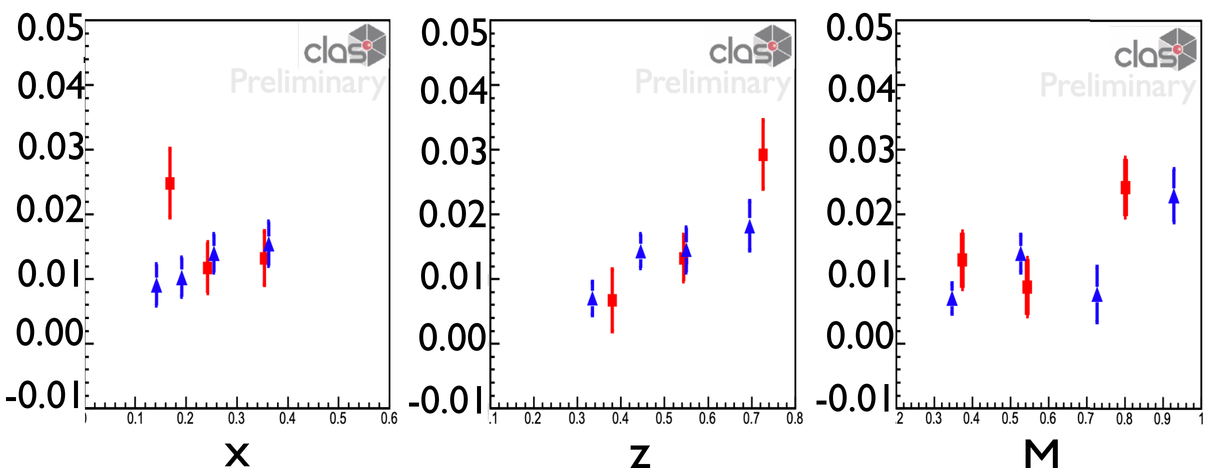
$BSA\ ep \rightarrow e'\pi^+\pi^- + X$: Clean access to e(x)

- 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

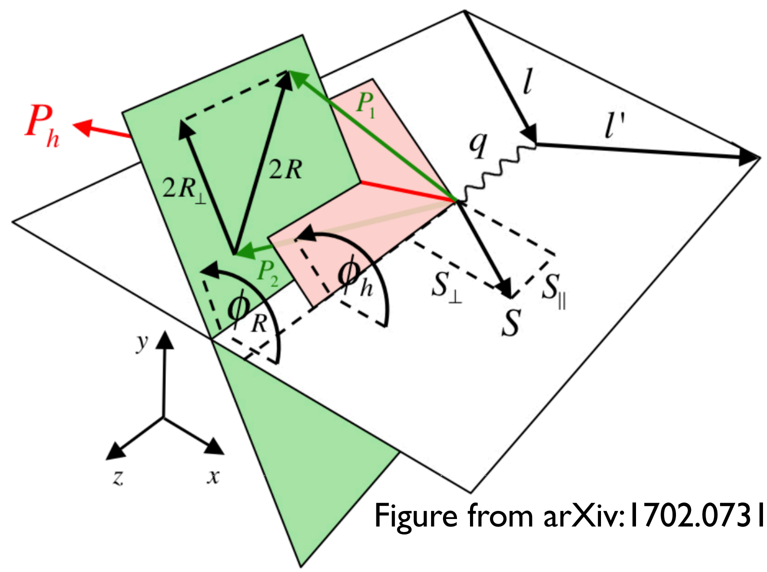


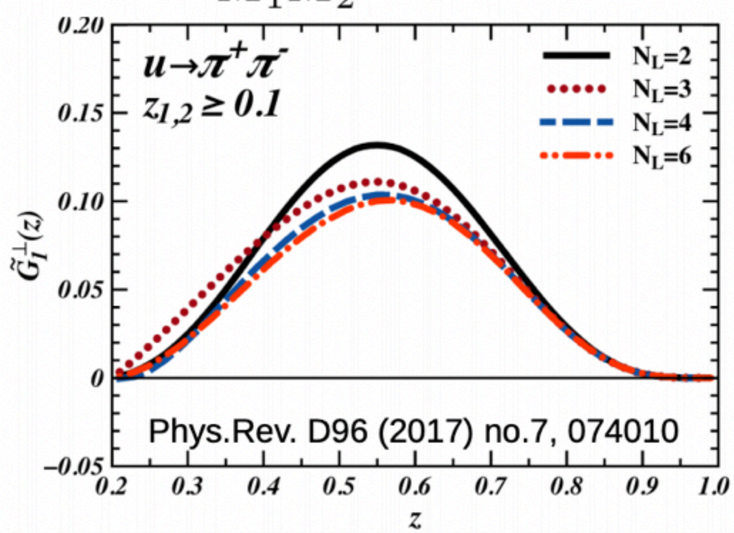
Figure from arXiv:1702.07317

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

Other extractions are possible

- Dihadron studies allow for the existence of DiFFs with no single hadron analog.
- $G_1^{\perp}$ describes the azimuthal dependence of an unpolarized hadron pair on the helicity of the outgoing quark.
- Completely unmeasured.

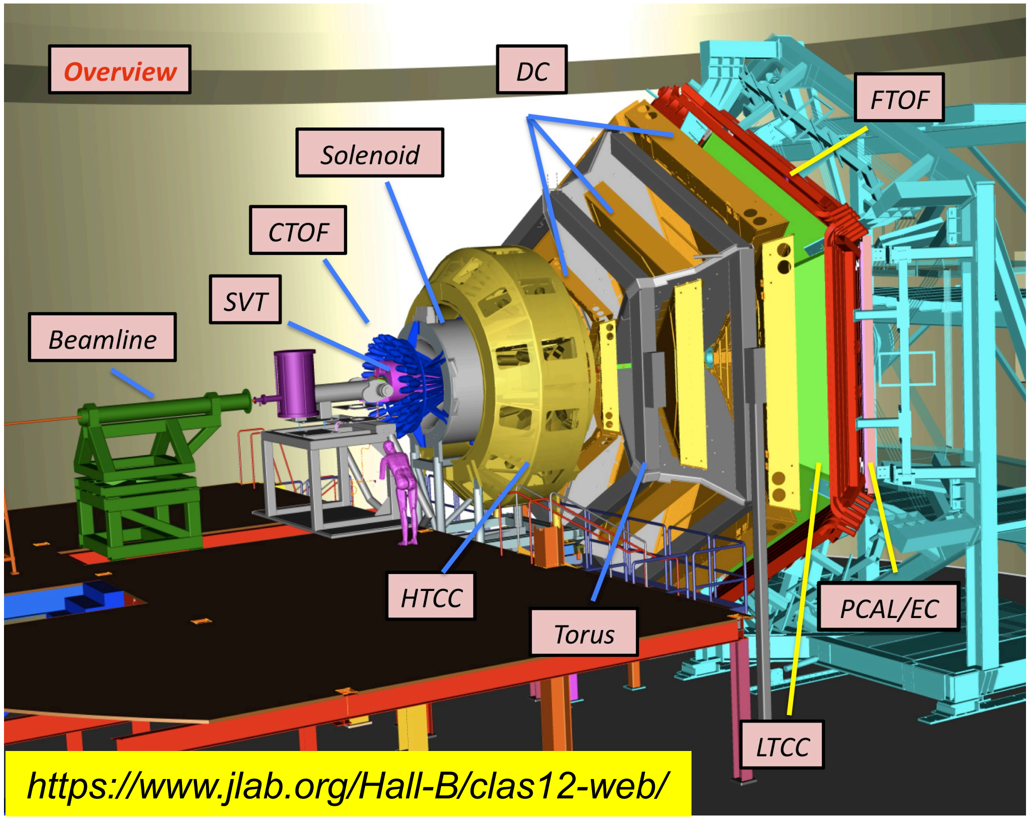
$$\tilde{G}_1^{\perp}(z) \equiv \frac{1}{M_1 M_2} G_1^{\perp}(z)$$ (integrated over M_h)

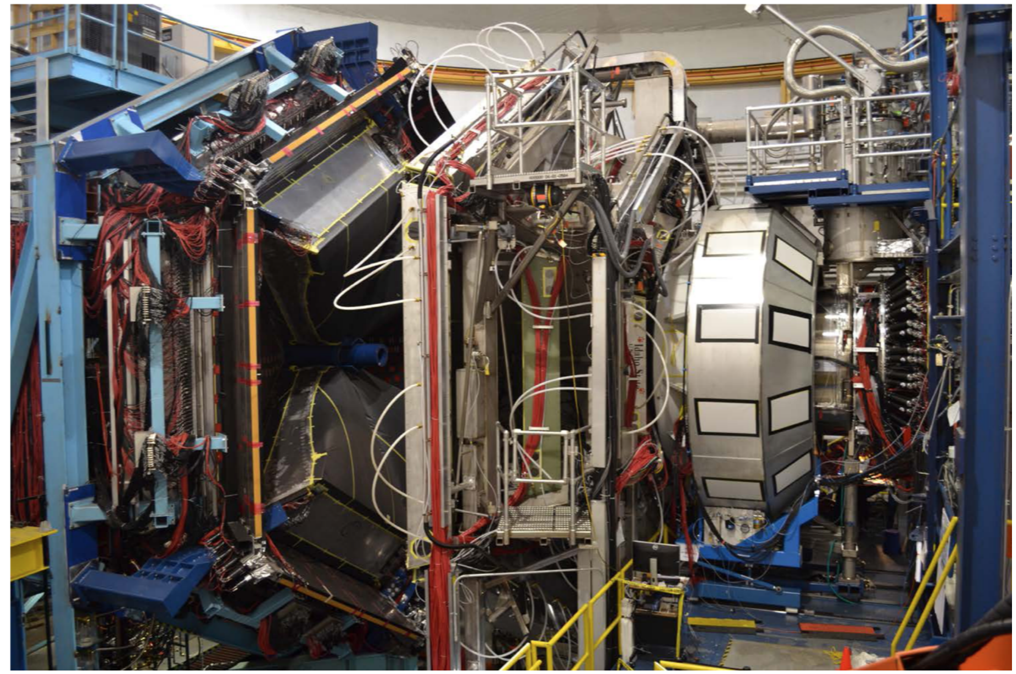


Accessible in the $\sin(\Phi_h - \Phi_R)$ modulation in dihadron longitudinal single spin asymmetries, weighted by $P_h^{\perp} / M_h$

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

CLAS12 Experimental Setup



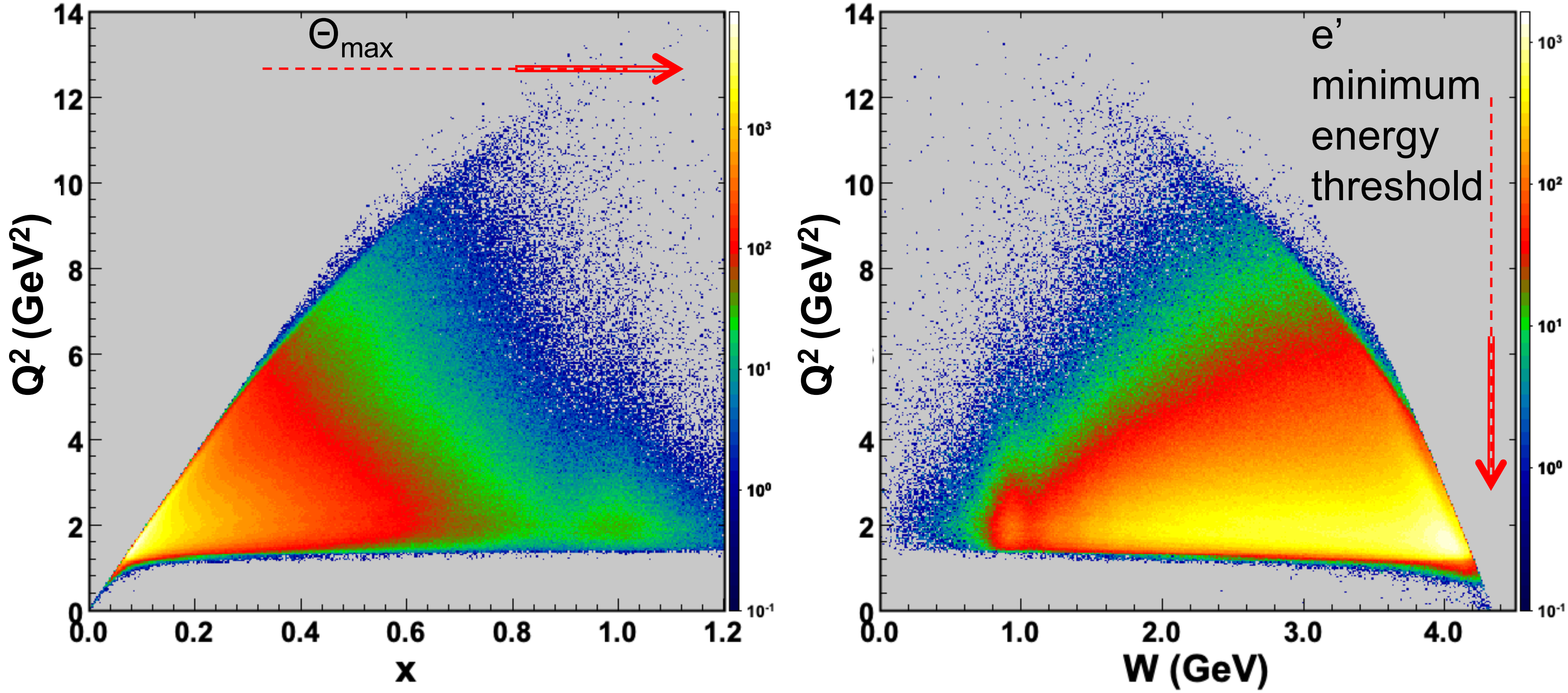


- Data taken during Fall 2018.
- 10.6 GeV, longitudinally polarized beam, H_2 target.
- Analyzed data ~3% of approved beam time.

CLAS12 kinematic reach

- The low Q^2 range of Jefferson Lab is ideal for extraction of twist-3 quantities.

p(e,e')X

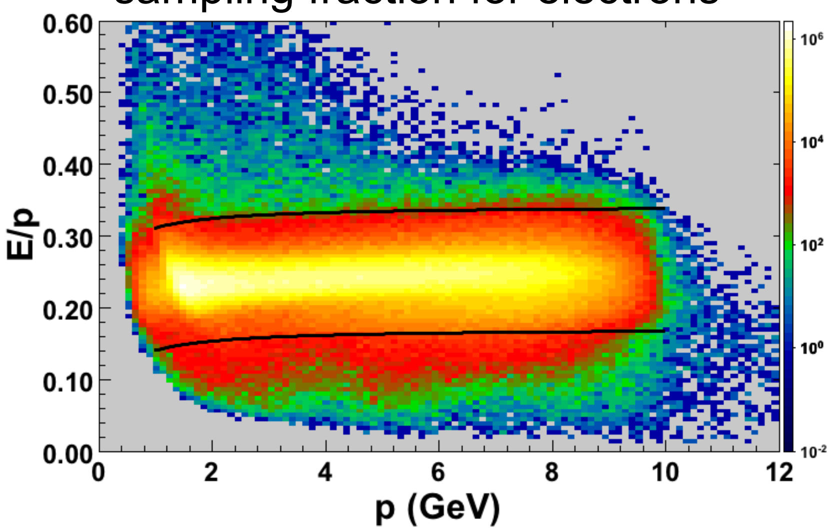


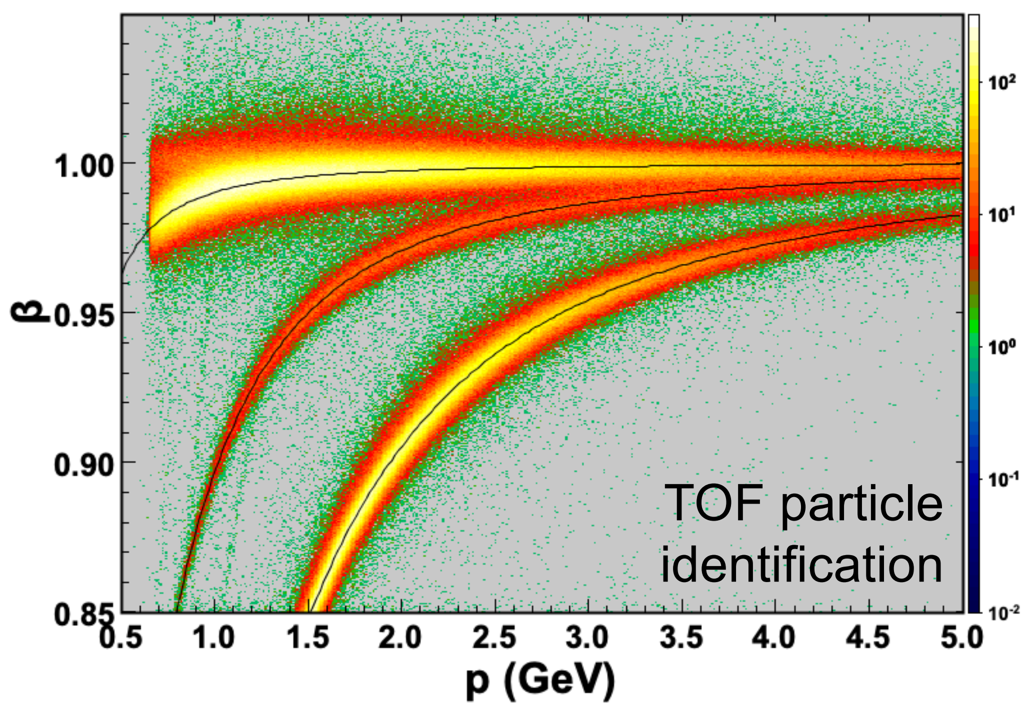
Plots based on 200 min. of data taking

Particle ID

- Electron
  - Electromagnetic calorimeter.
  - Cherenkov detector.
  - Vertex and fiducial cuts.
- Hadron
  - β vs p comparison between vertex timing and event start time.
  - Vertex and fiducial cuts.

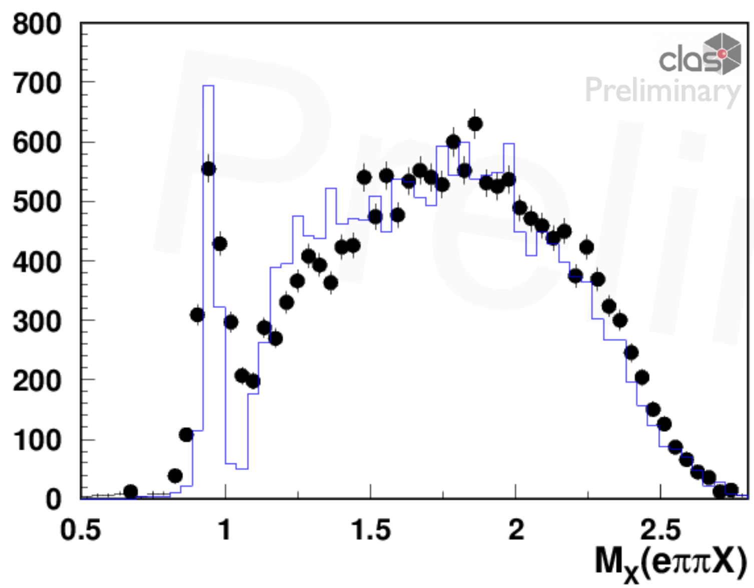
Forward Calorimeter
sampling fraction for electrons

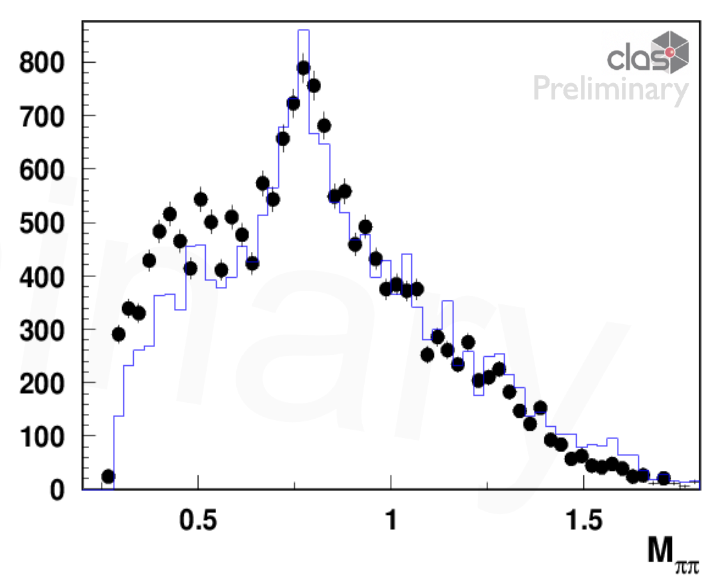




Tuning the Monte Carlo

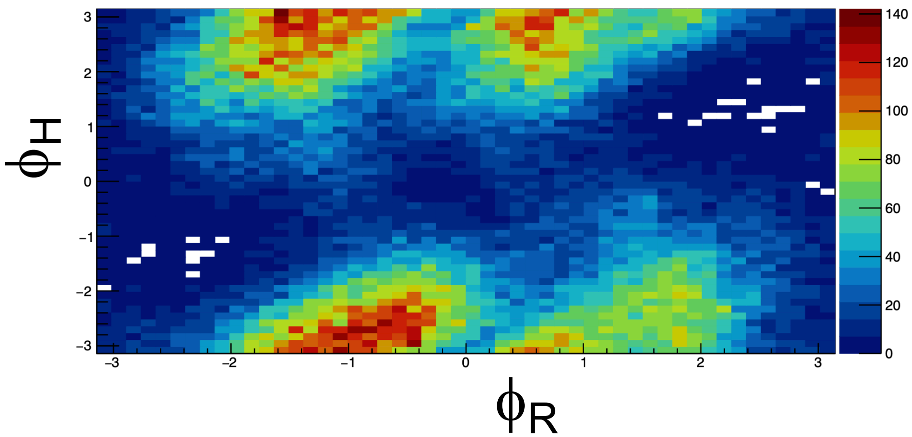
- Long term CLAS goal to study the multiplicities of dihadrons.
- Lund string fragmentation MC tuned by altering the widths and fraction of events coming from vector mesons.
- Comparison between files produced with 30% and 70% VM decay indicates a large percentage of events coming from decays.





Orthogonality of Modulations

- If the yield data do not cover the full ϕ_R, ϕ_H and θ ranges the orthogonality of amplitudes can be impacted.



$\lvert \ell, m\rangle$	twist-2	twist-3
$\lvert 0,0\rangle$	0	$\sin\phi_h$

$\lvert \ell, m\rangle$	twist-2	twist-3
$\lvert 1,1\rangle$	$\sin\theta\sin(\phi_h-\phi_R)$	$\sin\theta\sin\phi_R$
$\lvert 1,0\rangle$	0	$\cos\theta\sin\phi_h$
$\lvert 1,-1\rangle$		$\sin\theta\sin(2\phi_h-\phi_R)$

$\lvert \ell, m\rangle$	twist-2	twist-3
$\lvert 2,2\rangle$	$\sin^2\theta\sin(2\phi_h-2\phi_R)$	$\sin^2\theta\sin(-\phi_h+2\phi_R)$
$\lvert 2,1\rangle$	$\sin\theta\cos\theta\sin(\phi_h-\phi_R)$	$\sin\theta\cos\theta\sin\phi_R$
$\lvert 2,0\rangle$	0	$(3\cos^2\theta-1)\sin\phi_h$
$\lvert 2,-1\rangle$		$\sin\theta\cos\theta\sin(2\phi_h-\phi_R)$
$\lvert 2,-2\rangle$		$\sin^2\theta\sin(3\phi_h-2\phi_R)$

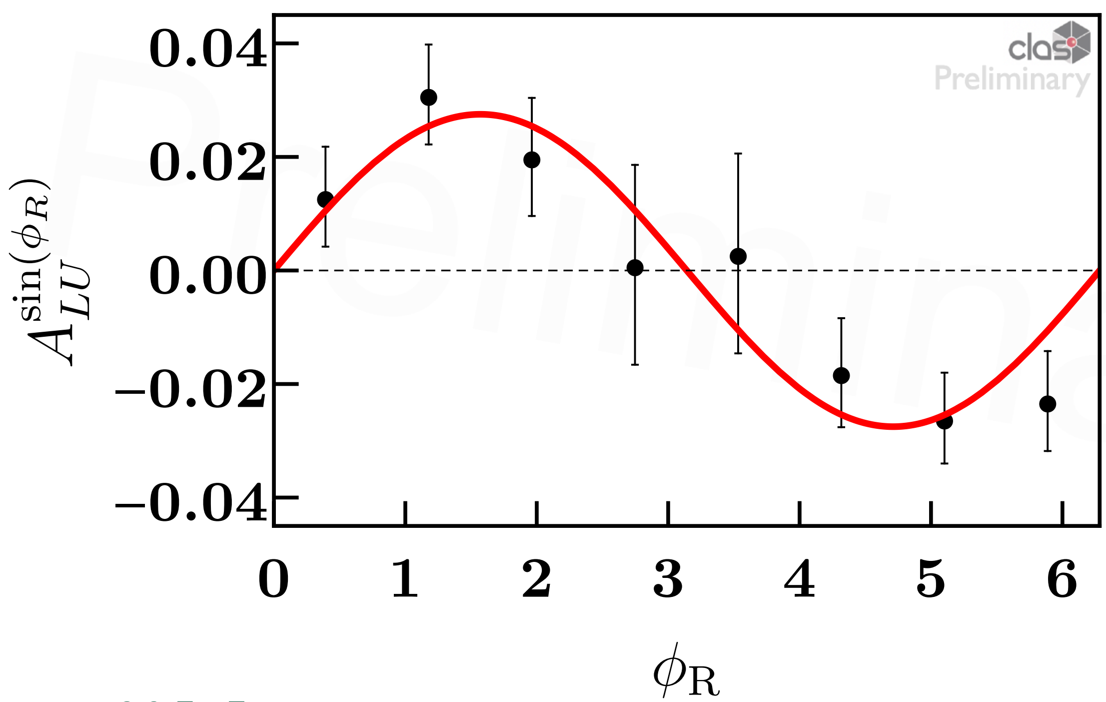
Gliske et. al: https://arxiv.org/pdf/1408.5721.pdf

- Long term plan… evaluate a full orthogonality matrix.
- For now… fit to the modulations with the largest contributions:

$$A_r\sin(\phi_R)+A_{hr}\sin(\phi_H-\phi_R)+A_h\sin(\phi_H)$$

Extracting A_{LU}

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

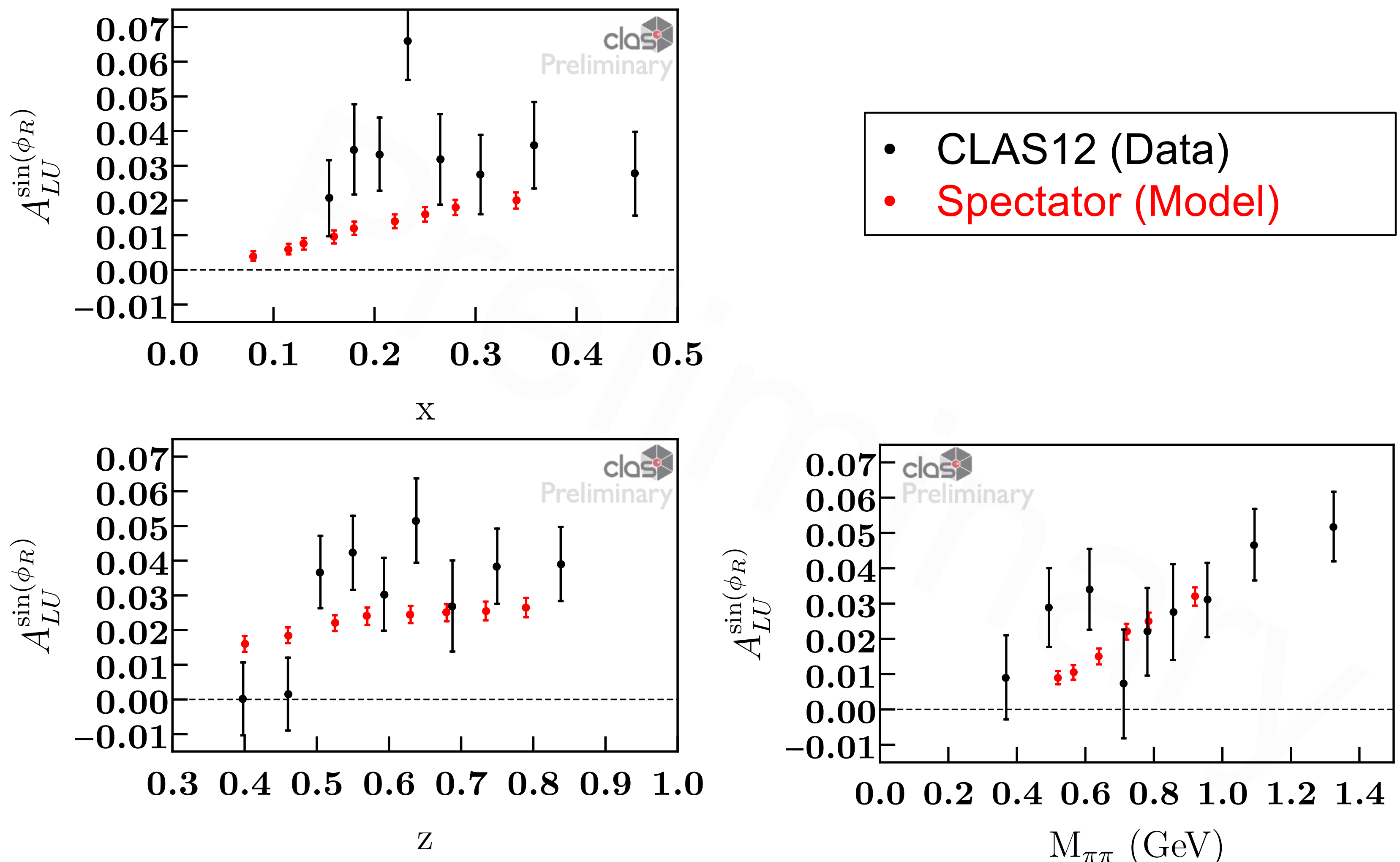


Channel selection

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

Preliminary results on ϕ_R modulations

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



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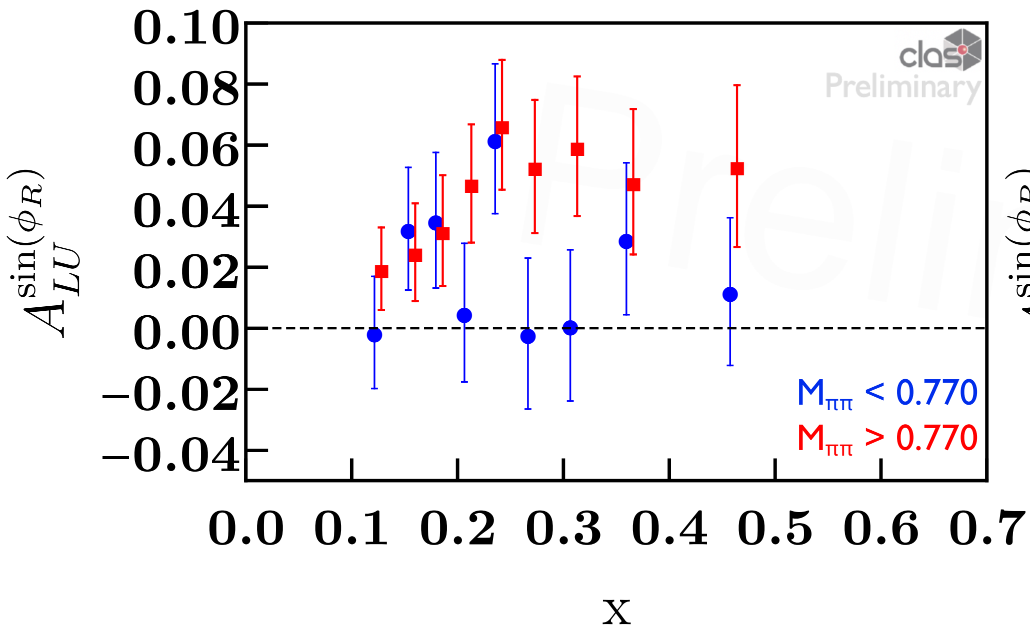
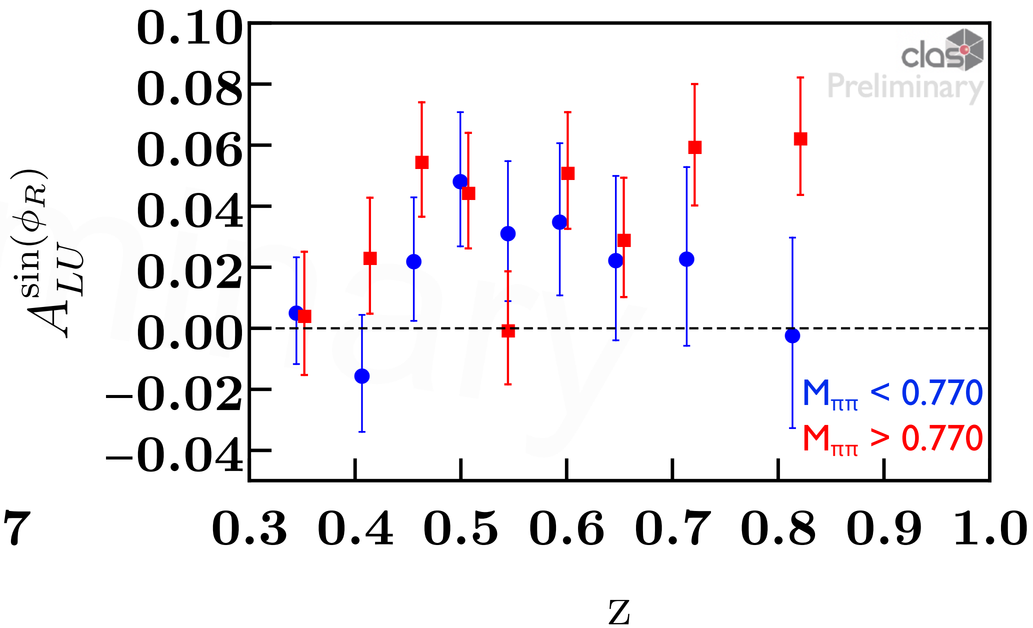
Multidimensional binning





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

Summary

- Preliminary results of ϕ_R and $\phi_H - \phi_R$ modulations in dipion events from the CLAS12 Fall 2018 dataset shown.
- Indications of nonzero signal, particularly for ϕ_R's $A_{LU}(x)$ which is sensitive to e(x).
- Likely a significant fraction of dihadron events are coming from vector meson decay.
- Full statistics will enable a rich multidimensional analysis.

- Possible future efforts
  - Expansion to other pion combinations ($\pi^+ \pi^0$, $\pi^- \pi^0$, etc.)
  - Same sign pairs to test the ρ-resonance model.
  - Kaon asymmetries with improved RICH detector calibrations.
  - Flavor separation when data combined with CLAS12 deuterium target experiments.