SIDIS Dihadron Beam Spin Asymmetries

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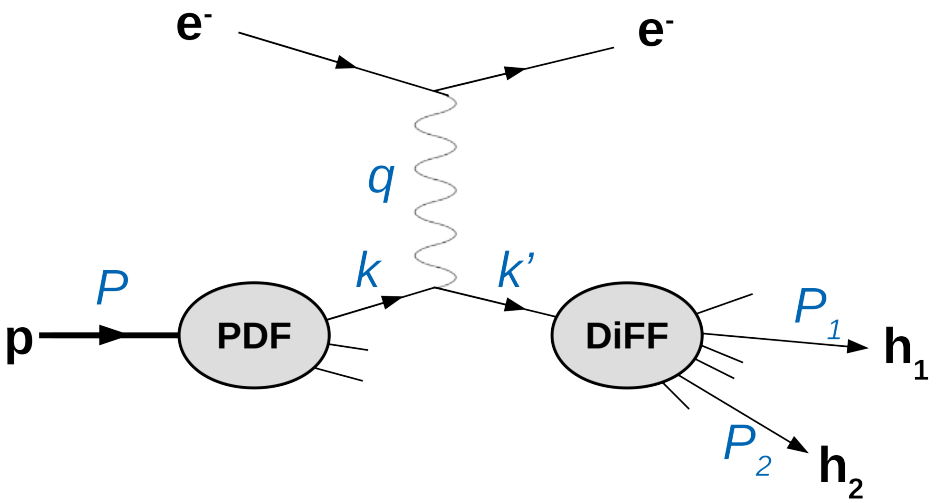
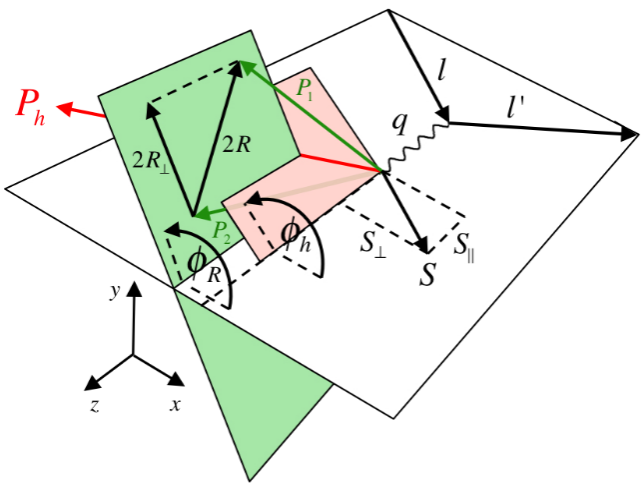
CLAS Collaboration Meeting

29 April 2020

Paper Plans

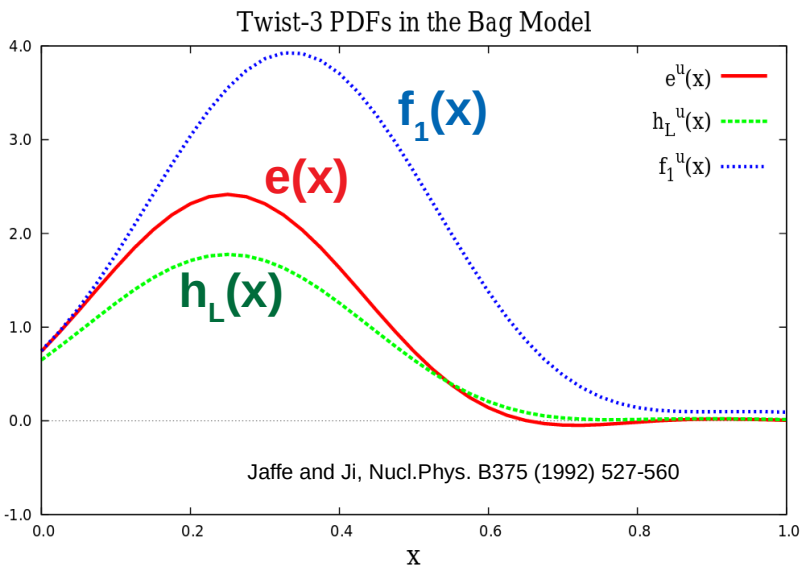
- **Aim to publish a PRL paper with CLAS12 dihadron beam spin asymmetries**
- Measurements:
  - **$\sin(\phi_R)$** modulation of A_{LU}, which improves constraints on the **twist-3 PDF e(x)**
  - **$\sin(\phi_h-\phi_R)$** modulation of A_{LU}, sensitive to the not-yet-constrained **helicity DiFF $G_1^{\perp}$**
  - Additional modulations, such as **$\sin(\phi_h)$**, which are included in a simultaneous fit to mitigate linear dependence between the amplitudes



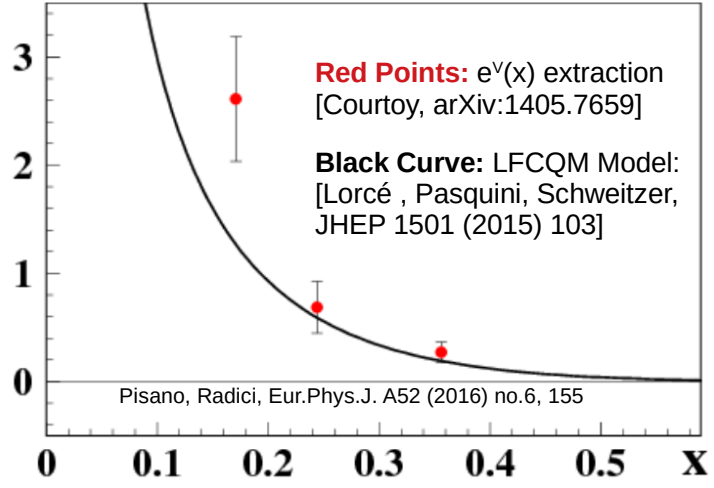


Twist-3 Collinear PDF e(x)

- e(x) decomposition: $e^q(x) = e^q_{\text{sing}}(x) + e^q_{\text{tw3}}(x) + e^q_{\text{mass}}(x)$
  - $e_{sing}(x)$ – proportional to δ(x), which could broaden at low Q^2 (LaMET model, XiangdongJi:arXiv:2003.04478)
  - $e_{tw3}(x)$ – pure twist-3 part → interference between scattering from |q> vs. |qg>
  - $e_{mass}(x)$ – proportional to current quark mass and moments of $f_1(x)$ [twist-2]
- Physical interpretation from moments of e(x):
  - Force exerted by gluon field on q↑ after scattering
  - Pion-nucleon σ term, representing the contribution to the nucleon mass from the finite quark masses



Extraction of $e^v(x)$ from CLAS6 preliminary A_{LU} and A_{UL}



Additional References:

Bacchetta and Radici, Phys.Rev. D69 (2004) 074026

Efremov and Schweitzer, JHEP 0308 (2003) 006

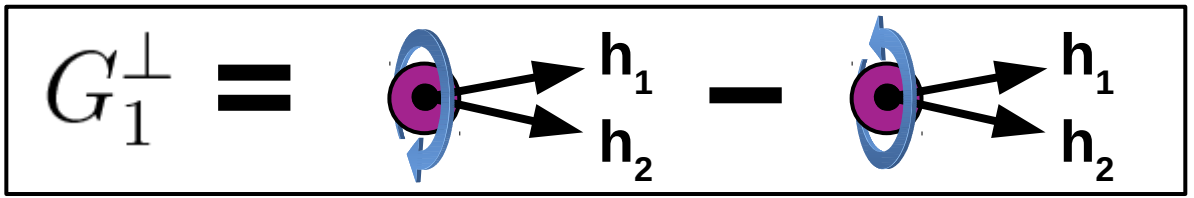
Burkardt, Phys.Rev. D88 (2013) 114502

Pereira, PoS (DIS2014) 231

Mulders, Tangerman, Nucl.Phys. B461 (1996) 197-237

Sirtl, PhD Thesis

Helicity Dependent DiFF: $G_1^\perp$



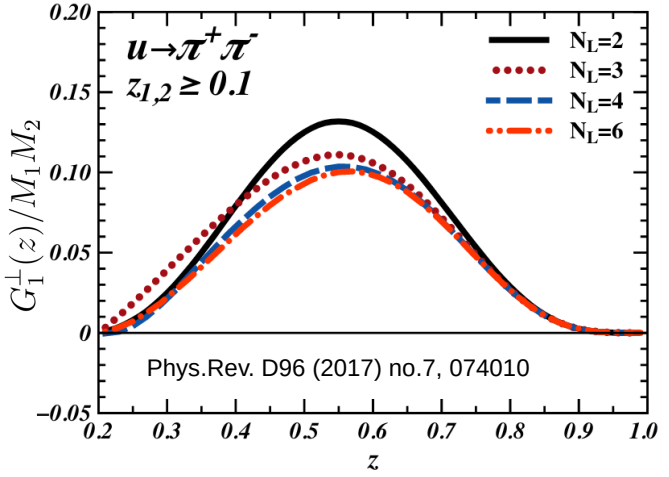
- **Accessible in the sin(Φ$_h$–Φ$_R$) modulation of dihadron longitudinal beam spin asymmetries, weighted by $P_h^\perp$ / M_h**
- **Sensitive to spin-orbit correlations in hadronization**
- **Not yet constrained by data; quark-jet hadronization model predicts sizable $G_1^\perp$**

$$A_{LU}(x,y,z,M_h) = \frac{\langle P_h^\perp \sin(\phi_h - \phi_R)/M_h \rangle_{LU}}{\langle 1 \rangle_{UU}}$$
$$= \lambda_l \frac{C'(y)}{A'(y)} \frac{\sum_a e_a^2 f_1^a(x)\, z\, G_1^{\perp a}(z,M_h^2)}{\sum_a e_a^2 f_1^a(x)\, D_1^a(z,M_h^2)}$$

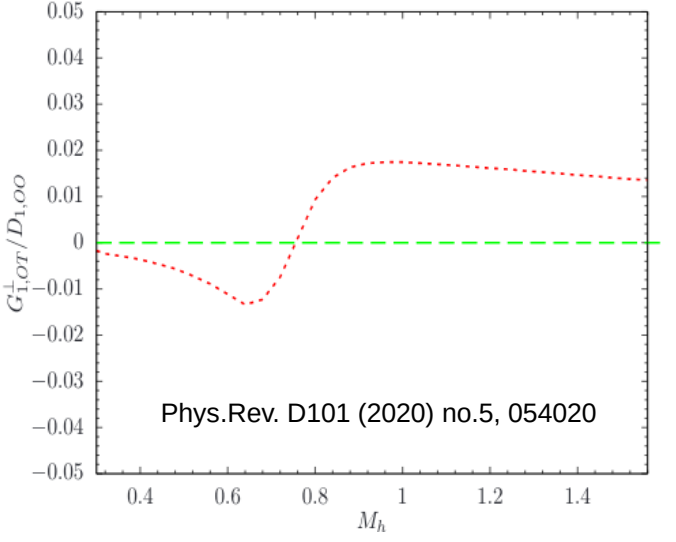
Matevosyan, et al.
- Phys.Rev. D96 (2017) no.7, 074010
- PoS DIS2018 (2018) 150

- **Recent spectator model calculation predicts sign change at the ρ mass** Luo, et al., Phys.Rev. D101 (2020) no.5, 054020

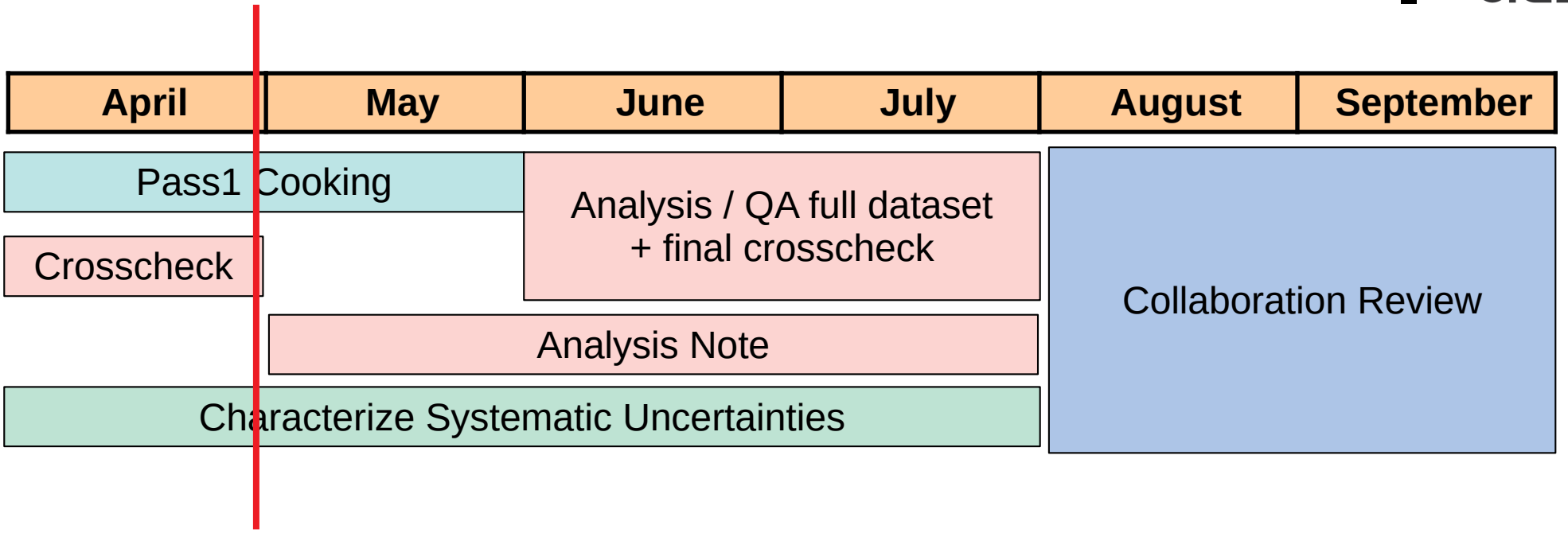
Quark-jet hadronization model prediction



Spectator Model Prediction

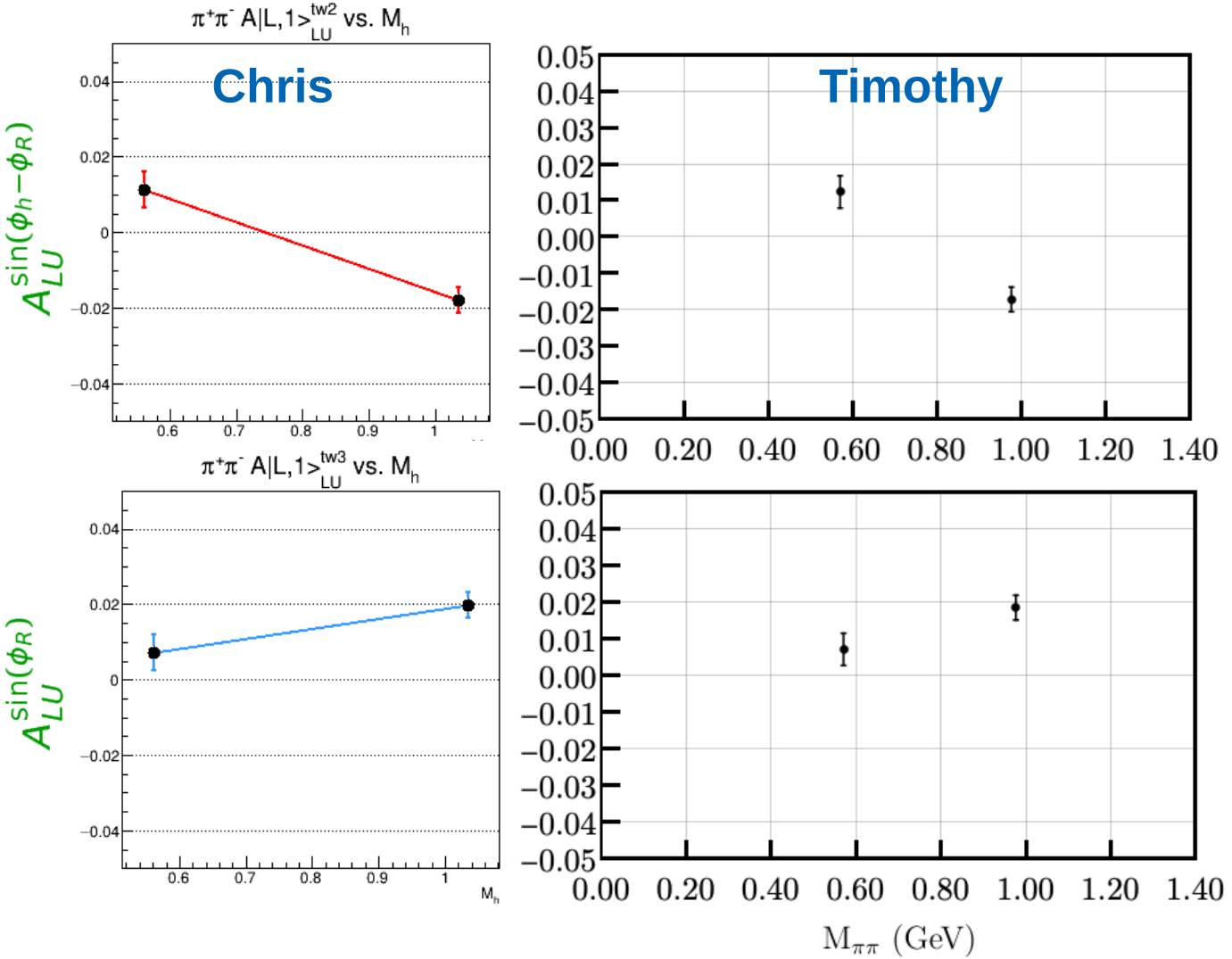


Estimated Timeline



- Crosscheck completed in early April
- Pass1 inbending data are cooked
- Cooking of outbending data is starting, and could be included in our analysis
- Currently working on estimating systematic uncertainties

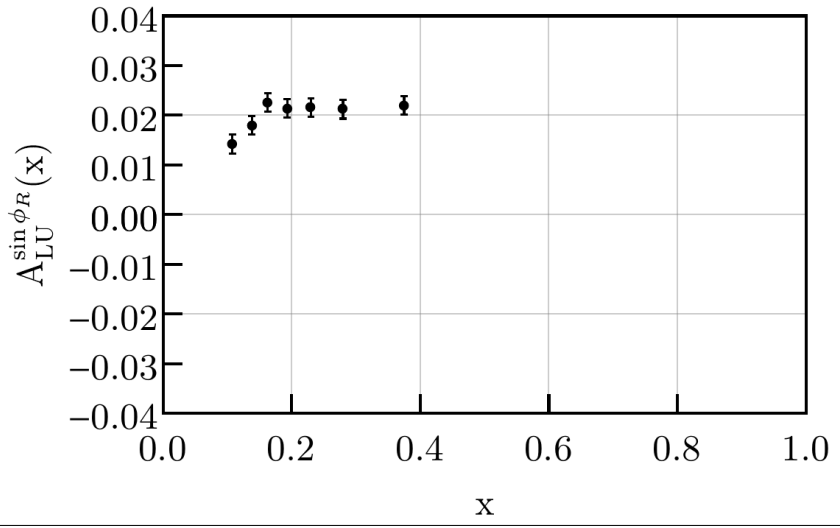
Crosscheck with Timothy Hayward



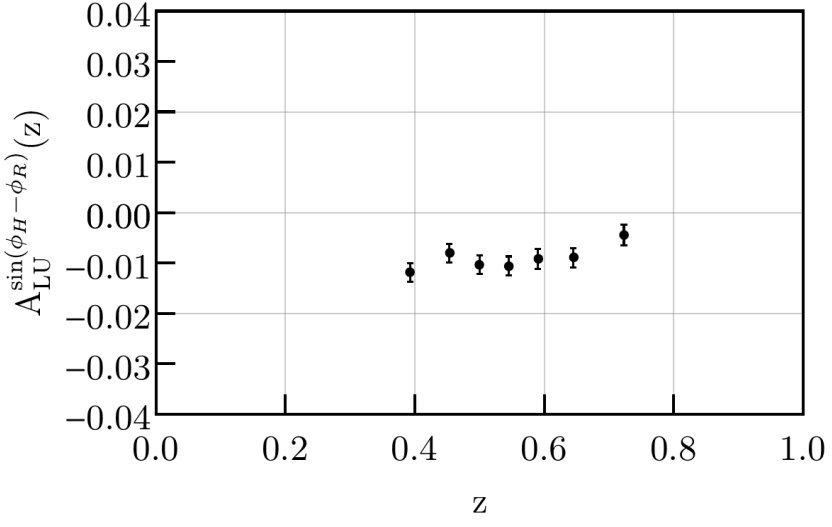
- All kinematic variables match up to at least 6 significant figures, and we have nearly the same yields
- Asymmetries amplitudes match as well

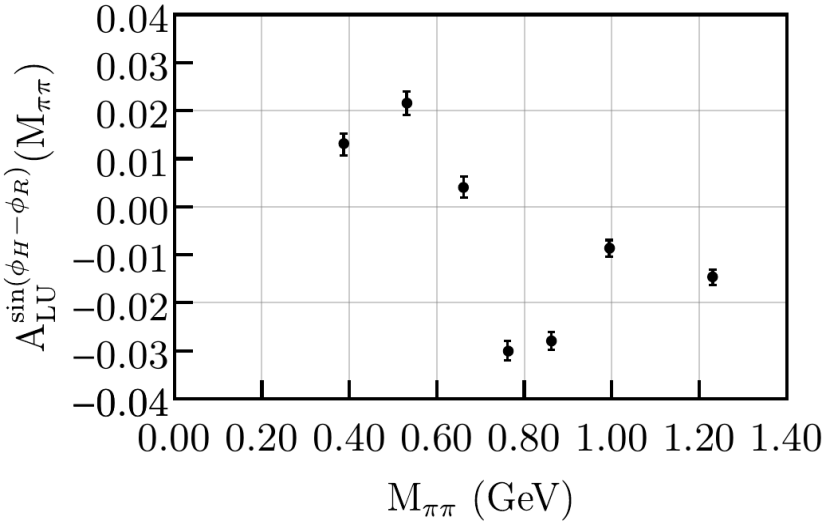
Full Statistics Asymmetries

(from Timothy)

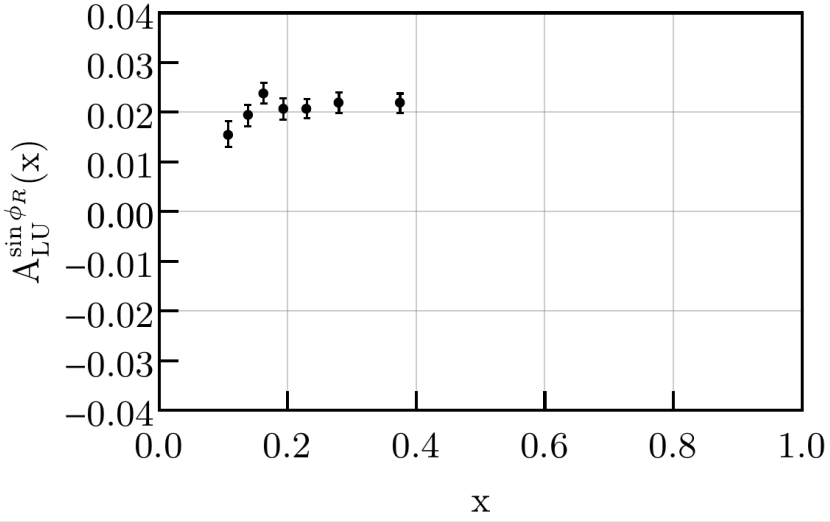


- Fiducial volume cuts disabled
- Run QA not yet performed
- These are raw asymmetries
  - Polarization & kinematic factors not divided out
- This represents an upper bound of the statistics for this measurement

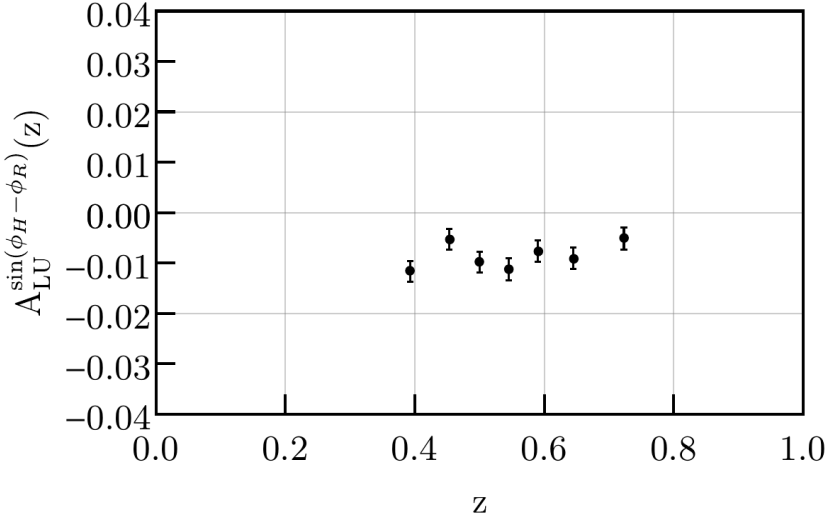


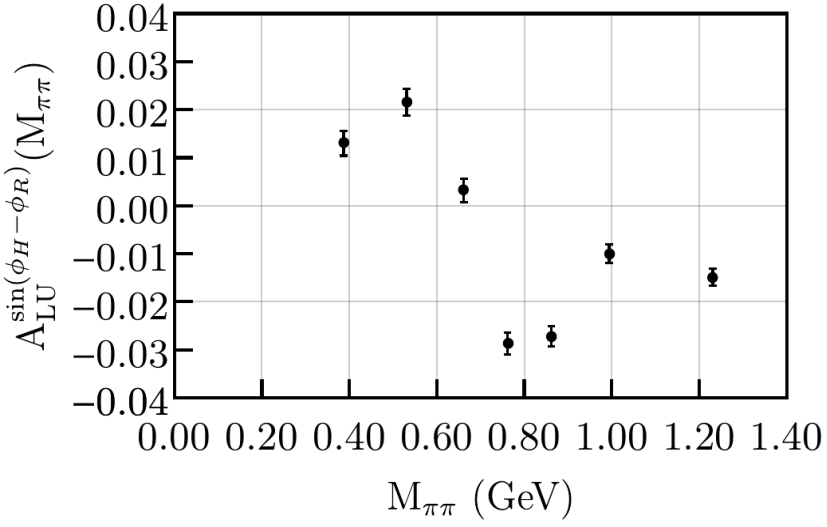


Loose Fiducial Volume Cuts (from Timothy)



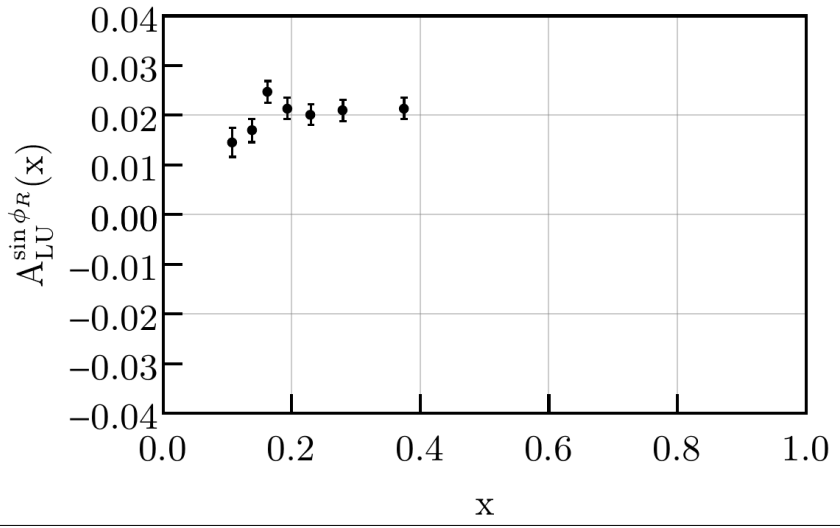
- Fiducial volume cuts: page through these next few slides to compare the effects of the cuts
- These are the DNP fiducial volume cuts, and need to be updated with Stefan's latest version

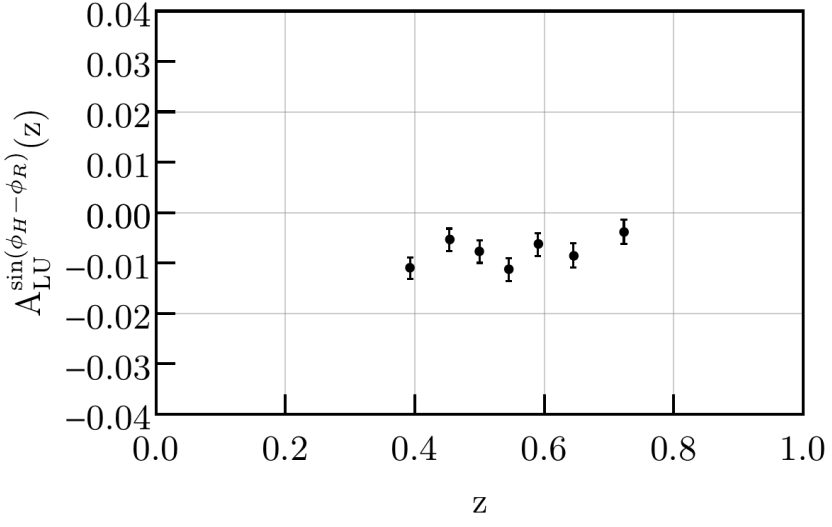


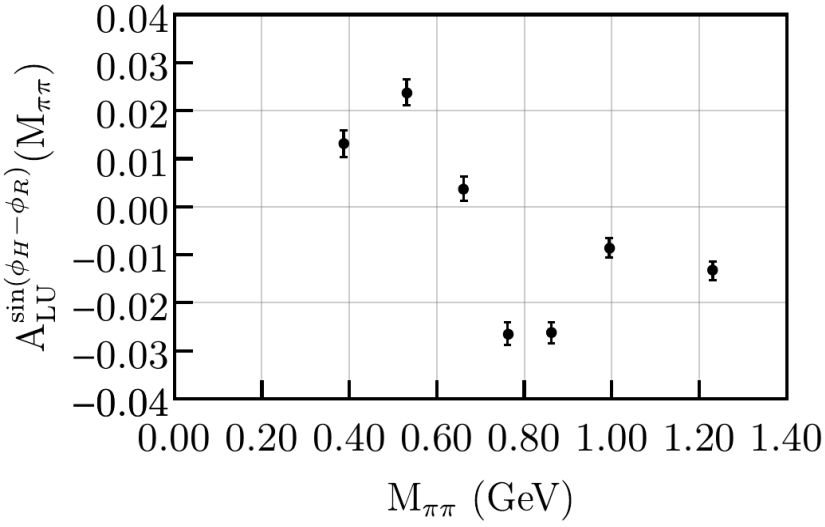


Medium Fiducial Volume Cuts

(from Timothy)

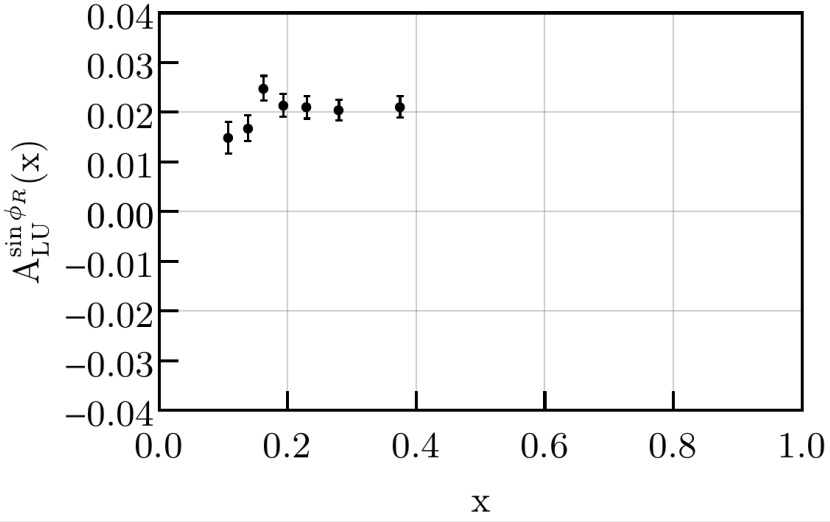




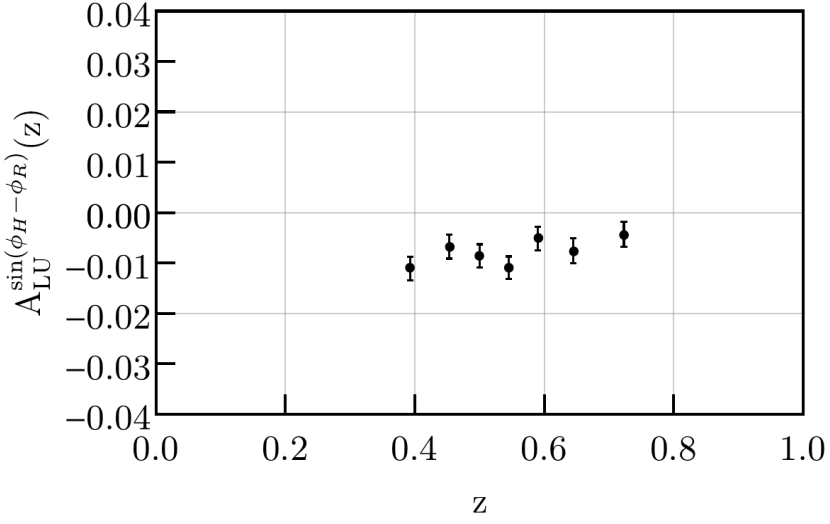


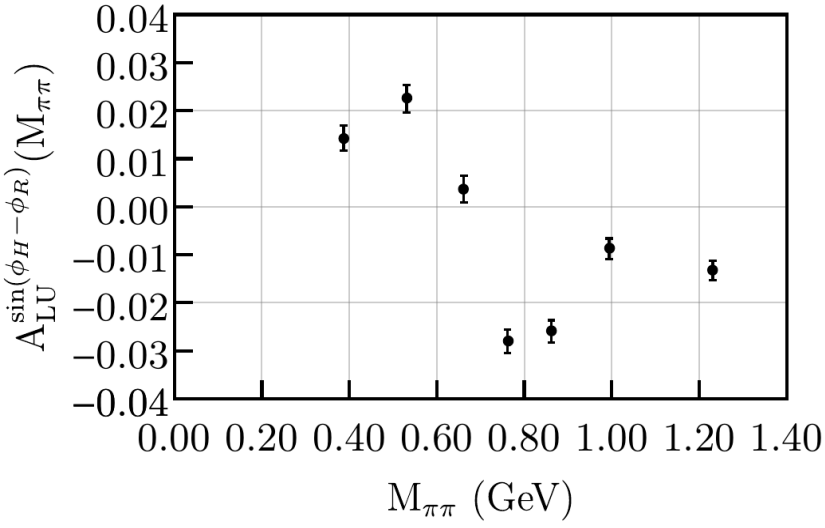
Tight Fiducial Volume Cuts

(from Timothy)



- Fiducial volume cuts impart small changes in the asymmetry, typically within the statistical uncertainty
- Impact on statistics is minor, so we suggest to just use the “tight” cuts to maximize data quality

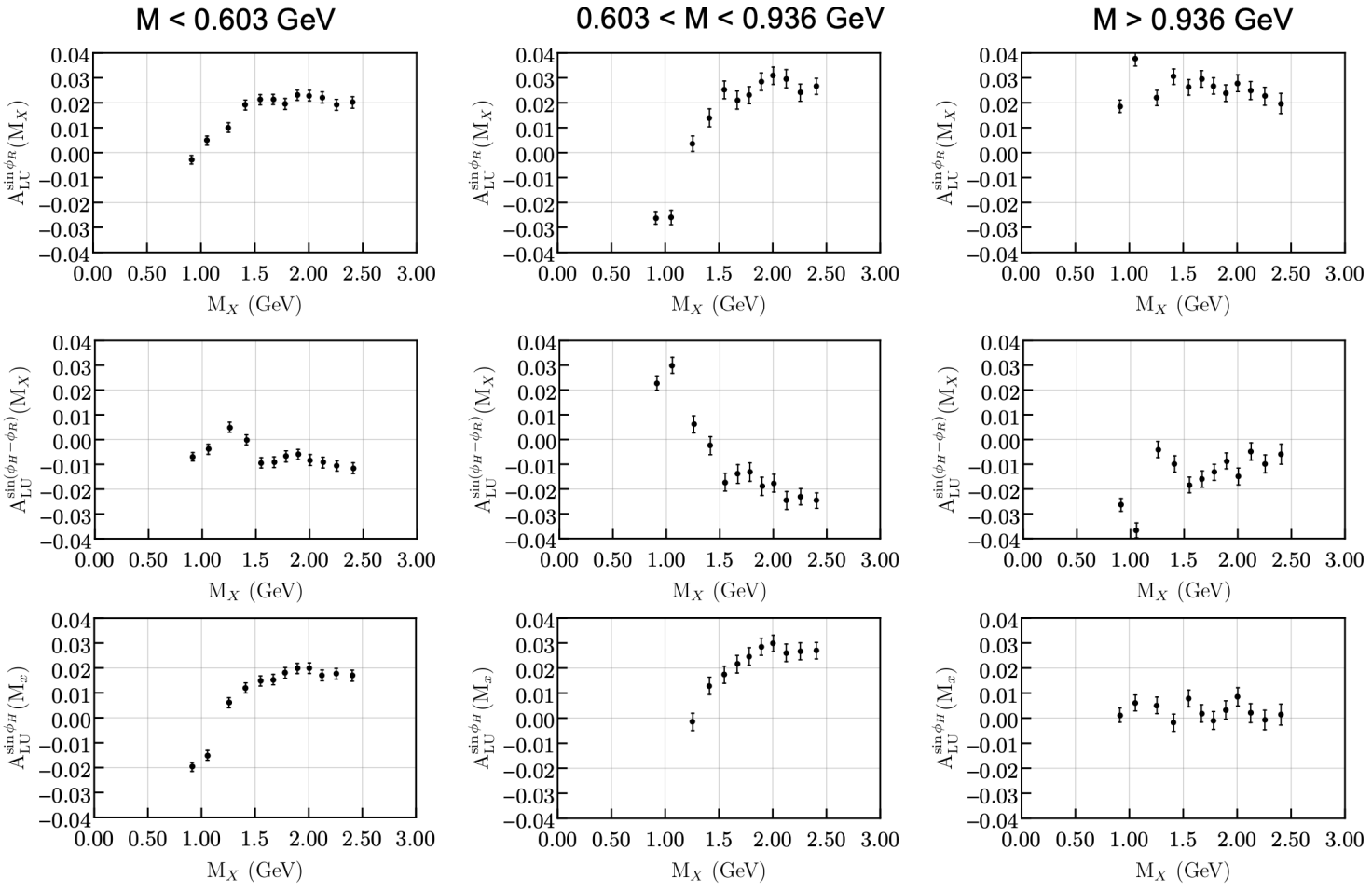




Systematic Uncertainties

Uncertainty	Estimate	Status / Comments
Beam Polarization	1.5–3% on scale	Straightforward: obtain from polarization measurements
Radiative Corrections	3% ?	In Progress
Acceptance	--	In Progress
PID / Matching Fraction	--	In Progress
Baryonic Resonances	~14% on scale	
Additional modulations of the unpolarized x-section	<40% on scale	In progress; 40% is likely too conservative
Horizontal Uncertainties / bin migration		In Progress

M_x-dependence of Asymmetries (from Timothy)



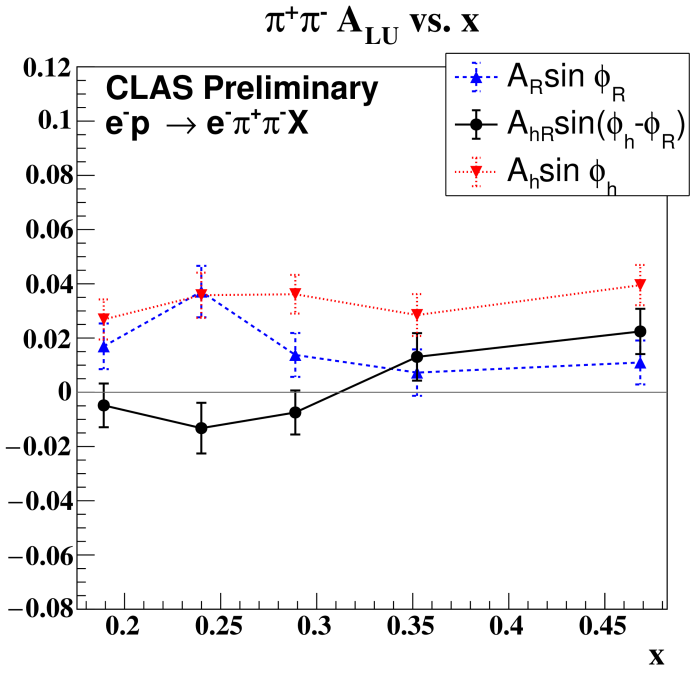
- Study missing mass dependence of asymmetries
- Explore exclusive limit, which may help constrain impact from high energy BH radiation on radiative corrections
- Strong dependence of A_{LU} on M_X seen for M_X<1.5 GeV
- Suggests improved cut for the paper of M_X>1.5 GeV

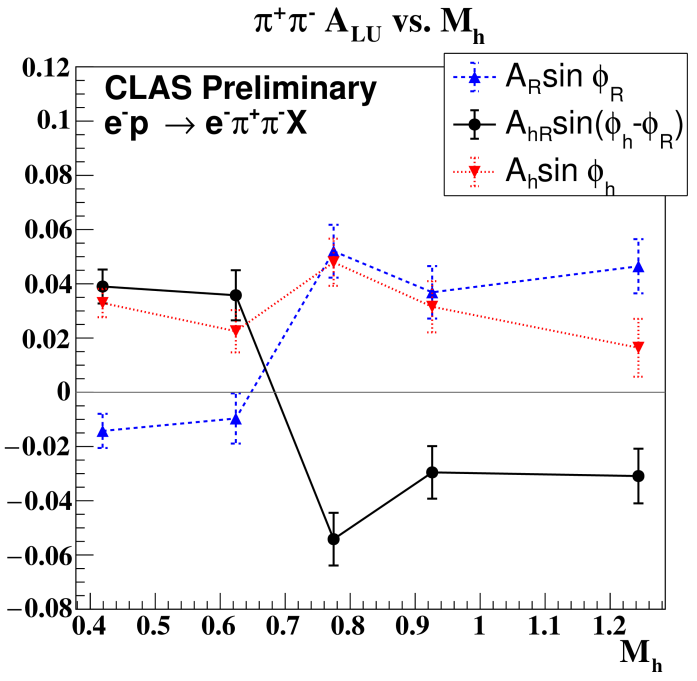
Summary and Outlook

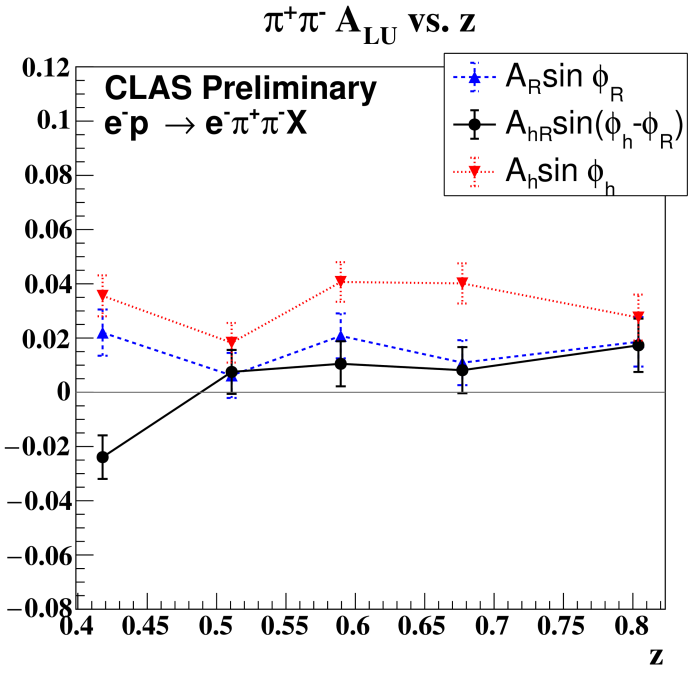
- This analysis is making steady progress
- Aspects of Common Interest for Asymmetry Analyses:
  - Fiducial volume cuts
  - PID cuts
  - Momentum corrections
- Current focus is on estimating systematic uncertainties
- Analysis note is in progress
- We hope to have the analysis and paper ready by the end of the summer

BACKUP

DNP2019 Preliminary Results







- Simultaneous fit to m=0,1 modulations
- There appears to be a sign change near M_ρ
- A_R has opposite M_h dependence to A_{hR}
- A_h is a constant 3-4%
- ±3.8% polarization scale uncertainty

$$A_{hR}\sin(\phi_h-\phi_R) + A_R\sin\phi_R + A_h\sin\phi_h$$

Simultaneous fit performed, because these modulations are **not orthogonal** within the acceptance limitations

https://www.jlab.org/indico/event/343/session/7/contribution/76

Structure Functions → PDFs and DiFFs

Structure Function	Twist	$m = 0$ Modulation	$m = 1$ Modulation	PDF $\otimes$ DiFF
$F_{LU,T}^{P_{\ell,m}\sin(m\phi_h - m\phi_R)}$	2	0	$\sin(\phi_h - \phi_R)$	$f_1 \otimes \mathbf{G_1^{\perp\|\ell,m\rangle}}$
$F_{LU}^{P_{\ell,m}\sin[(1-m)\phi_h + m\phi_R]}$	3	$\sin\phi_h$	$\sin\phi_R$	$\mathbf{e(x)} \otimes H_1^{\perp\|\ell,m\rangle} + g^{\perp} \otimes D_1^{\|\ell,m\rangle}$

- Differential cross sections are expanded in terms of modulations of ϕ_h, ϕ_R, and θ, with structure function coefficients
  - θ-dependent factors are for partial wave expansion of DiFFs → beyond the scope of this paper
  - ϕ_h, ϕ_R dependent functions are Fourier series functions → *focus on m=1 (and 0)*
- Structure functions contain convolutions of PDFs and Dihadron Fragmentation Functions (DiFFs)
  - m=1 azimuthal modulations are the *primary* dihadron A_{LU} modulations of interest, for accessing
    - **$G_1^{\perp}$**: the helicity-dependent DiFF
    - **e(x)**: the twist-3 collinear PDF
  - m=0 modulations can be identified with the single-hadron structure function modulations, and included as a *correction* in the multi-amplitude fit