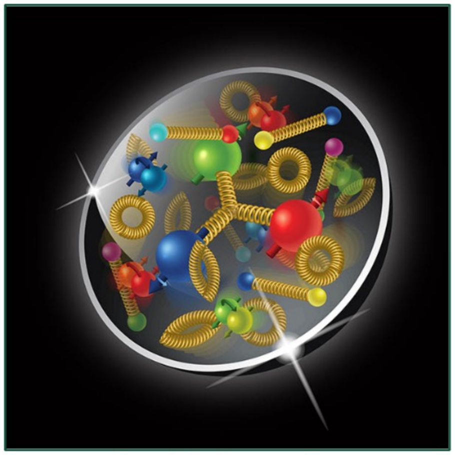
(Very) Selected SIDIS Results from Hall-B

Timothy B. Hayward

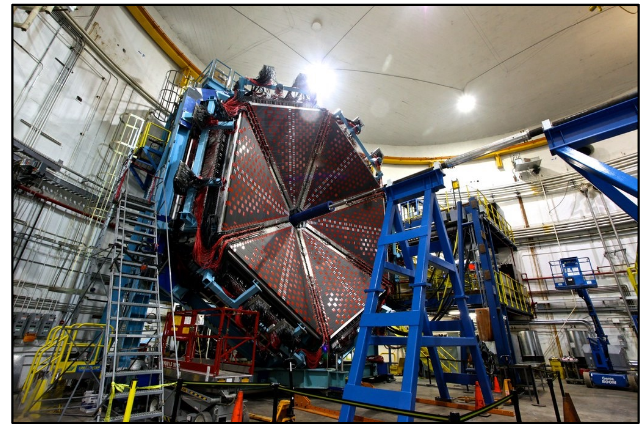
June 26, 2023

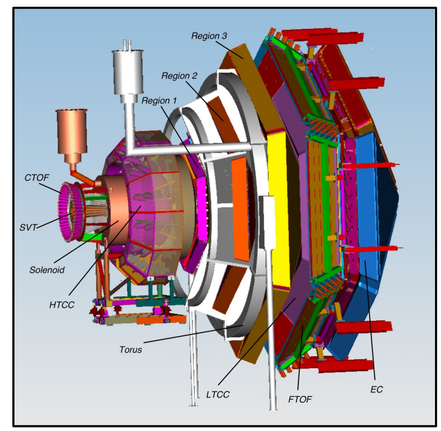
CLAS12 (Hall B) Physics Program



Stony Brook University News, August 2017

- International collaboration with more than 40 member institutions and 200 full members.
- CLAS(12) is the world's only large acceptance and high luminosity spectrometer for fixed target lepton scattering experiments.





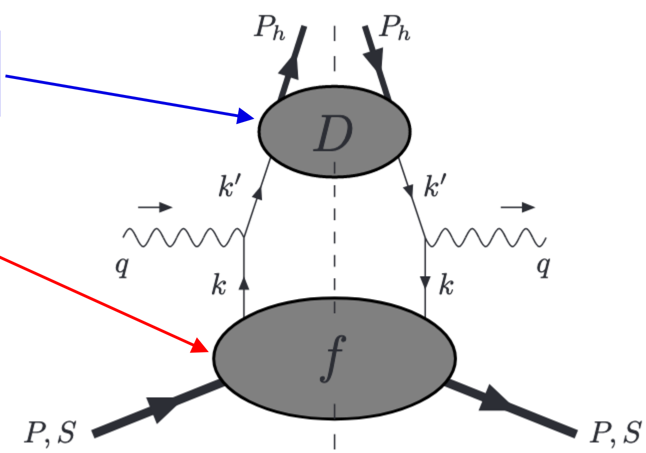
1. Study of the nucleon resonance structure at photon virtualities from 2.0 to 12 GeV^2
2. Study of Generalized Parton Distributions (GPDs), (2 +1) D imaging of the proton and the study of its gravitational and mechanical structure.
3. Study of the Transverse Momentum Dependence (TMDs) and the of 3D structure in momentum space.
4. Study of J/ψ Photoproduction, LHCb Pentaquarks and Timelike Compton Scattering.
5. Study of meson spectroscopy in search of hybrid mesons
6. Much more!

SIDIS measurements

- Decades of study have led to detailed mappings of the momentum distribution of partons in the nucleon in terms of 1-D and 3-D (TMD) parton distribution functions (PDFs).
- SIDIS measurements rely on the assumption that measured hadrons are produced in the CFR.
- Cross section factorized as a convolution of PDFs and Fragmentation Functions (FFs)[1].

A. Bacchetta et al., JHEP 02 (2007) 093 [hep-ph] 0611265,

$$\frac{d\sigma^{CFR}}{dx_B\, dy\, dz_h} = \sum_a e_a^2 \boxed{f_a(x_B)} \frac{d\hat{\sigma}}{dy} \boxed{D_a(z_h)}$$



M. Anselmino et al., Phys. Lett. B. 706 (2011), 46-52, [hep-ph] 1109.1132

- PDFs
  - Confined motion of quarks and gluons inside the nucleus
  - Orbital motion of quarks, correlations between quarks and gluons
- Fragmentation Functions
  - Probability for a quark to form particular final state particles
  - Insight into transverse momenta and polarization

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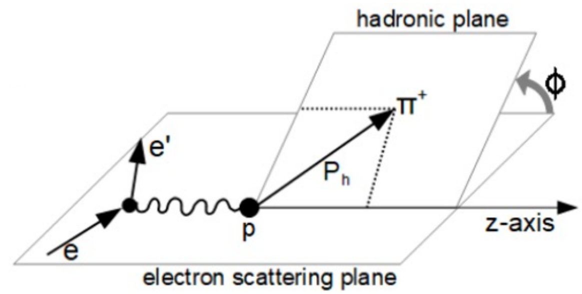
Single Hadron Production

twist-3 pdf, unpolarized PDF, twist-3 t-odd PDF, Boer-Mulders

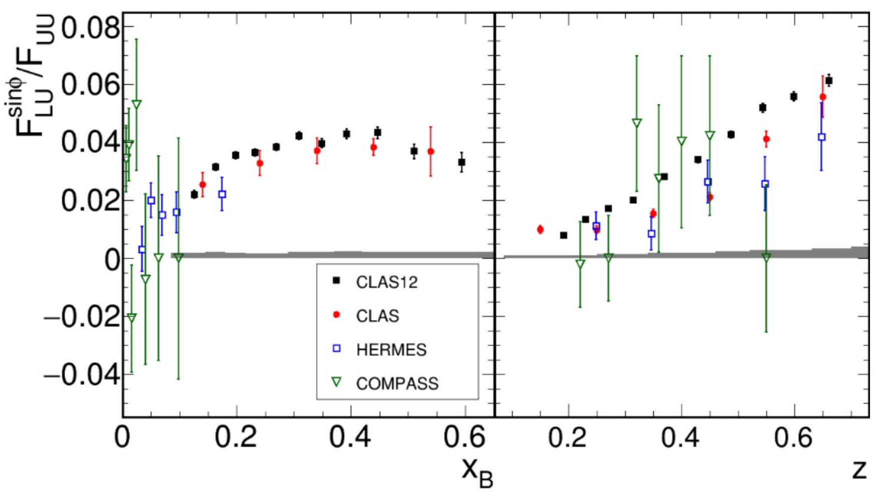
$$F_{LU}^{\sin\phi_h} = \frac{2M}{Q}\mathcal{C}\left[-\frac{\hat{h}\cdot k_T}{M_h}\left(xeH_1^{\perp} + \frac{M_h}{M}f_1\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{h}\cdot p_T}{M}\left(xg^{\perp}D_1 + \frac{M_h}{M}h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

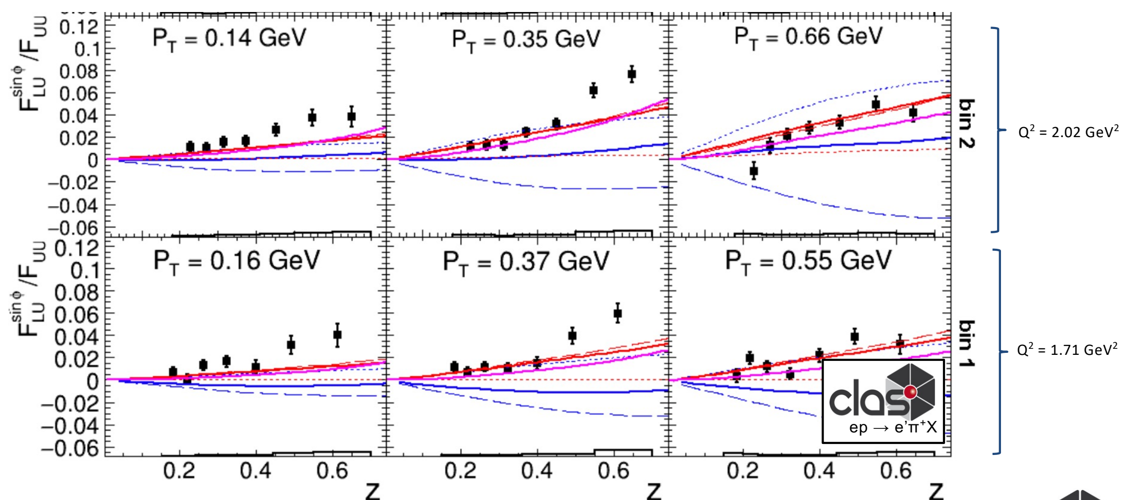
Collins FF, twist-3 FF, unpolarized FF, twist-3 FF

A. Bacchetta et al., *JHEP 0702*, 093 (2007).



First high-precision multidimensional study: important for constraints of PDFs.

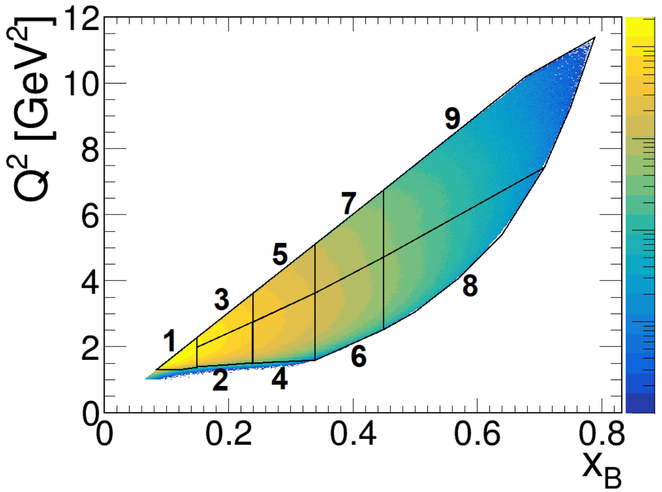


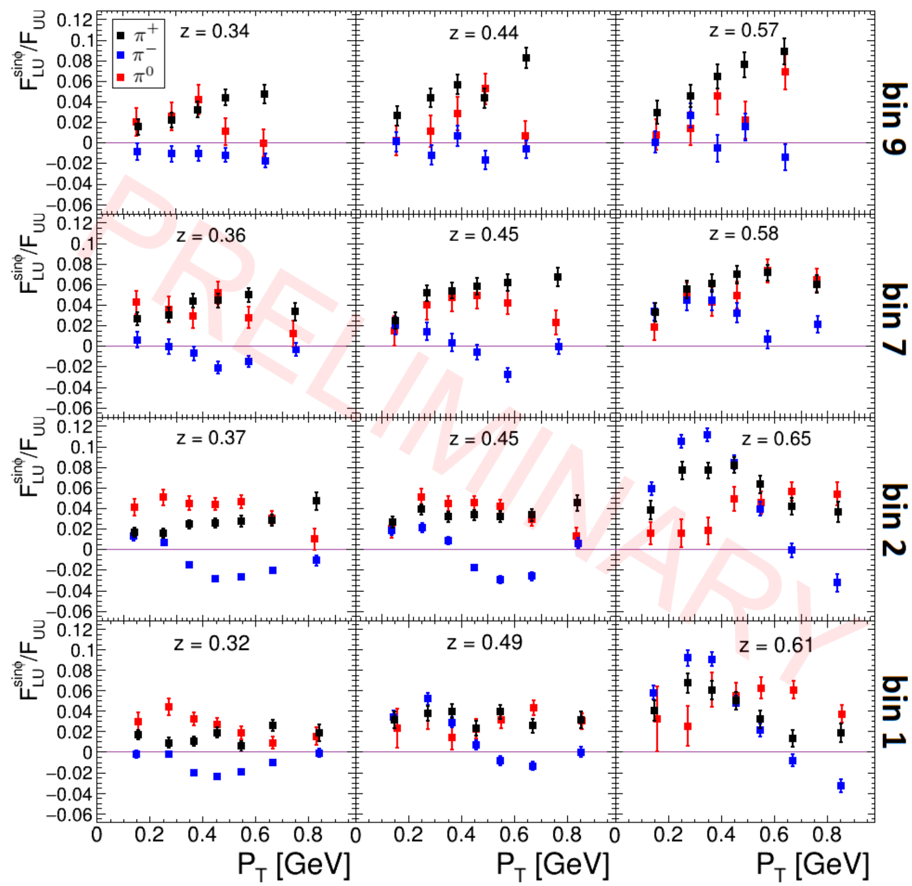


S. Diehl et al., *Phys. Rev. Lett.*, 128, 062005, (2022), [hep:ex] 2101.03544

Flavor Decomposition

➔ Measurement of all 3 pions allows a flavor decomposition of TMDs and FFs





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■ π^+ ■ π^0 ■ π^-

preliminary

S. Diehl

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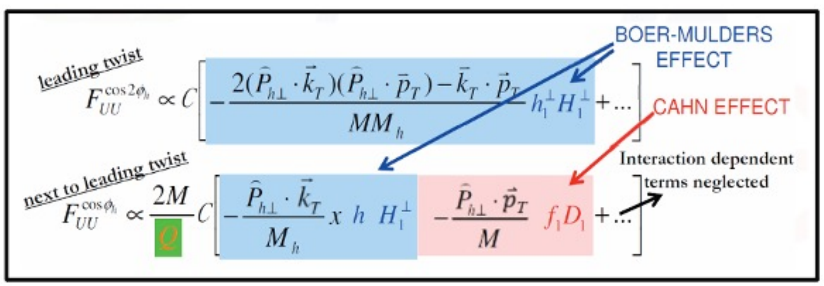
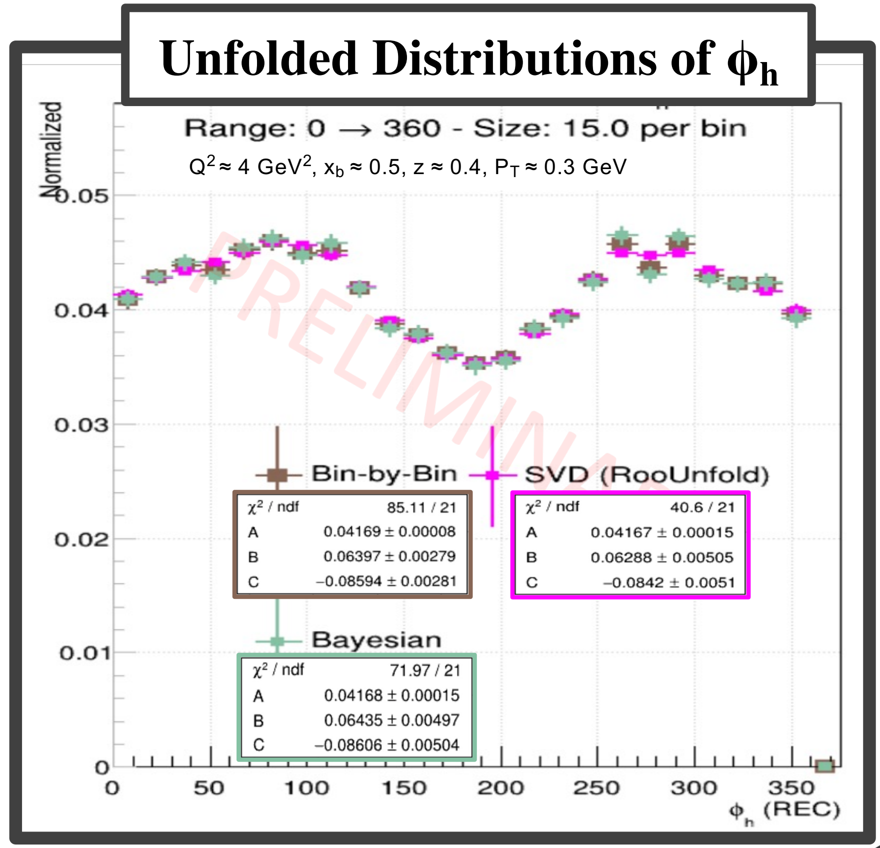
Moments of the Unpolarized SIDIS π⁺ Cross-section

- **Boer-Mulders Effect:** Sensitive to the correlation between the quark's transverse momentum and intrinsic transverse spin in an unpolarized nucleon; requires quark orbital angular momentum contributions to the proton spin

- **Cahn Effect:** Sensitive to the transverse motion of quarks inside the nucleon

$$\frac{d^5\sigma}{dx\,dQ^2\,dz\,d\phi_h\,dP_{h\perp}^2} = \underbrace{\frac{2\pi\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)(F_{UU,T}+\epsilon F_{UU,L})}_{A_0}\left\{1+\underbrace{\frac{\sqrt{2\epsilon(1+\epsilon)}F_{UU}^{\cos\phi_h}}{(F_{UU,T}+\epsilon F_{UU,L})}}_{A_{UU}^{\cos\phi_h}}\cos\phi_h+\underbrace{\frac{\epsilon F_{UU}^{\cos 2\phi_h}}{(F_{UU,T}+\epsilon F_{UU,L})}}_{A_{UU}^{\cos 2\phi_h}}\cos 2\phi_h\right\}$$





R. Capobianco

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Neutral Pion Multiplicities

- **Goal**
  - Measure neutral pion multiplicities

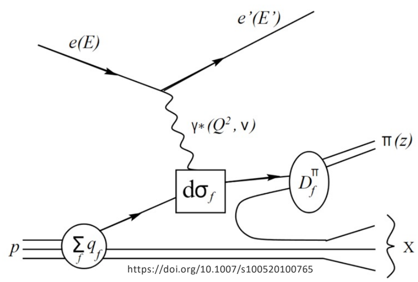
$$M_h = \frac{d\sigma^h}{dxdQ^2dzdp_T^2} \Big/ \frac{d\sigma^{DIS}}{dxdQ^2}$$

  - Related to the non-perturbative proton structure, i.e., PDFs and FFs

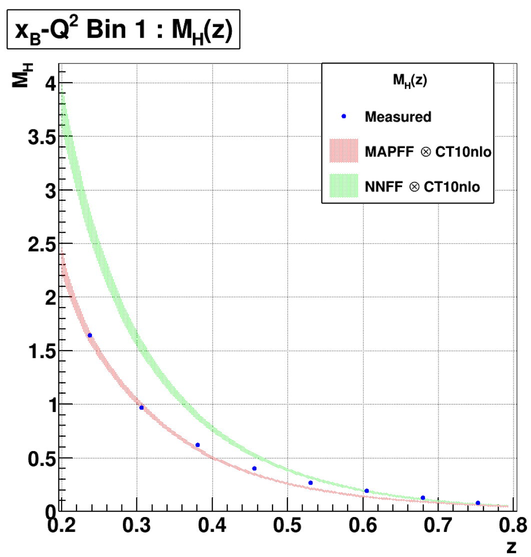
$$\sigma^{\pi^0} \approx \sigma^{DIS} \otimes f^p(x, Q^2) \otimes D^{p\to\pi^0}(z, Q^2)$$

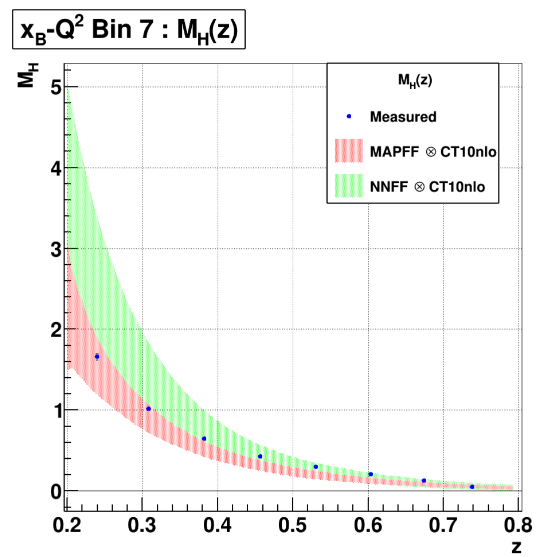
  - Connected to charged pion multiplicities

$$D_1^{\pi^0/q} = \frac{1}{2}\left(D_1^{\pi^+/q} + D_1^{\pi^-/q}\right)$$



The p_T^2 integrated multiplicities have been extracted and shown to be inline with the MAPFF⊗CT10nlo leading order predictions.





M. B. C. Scott

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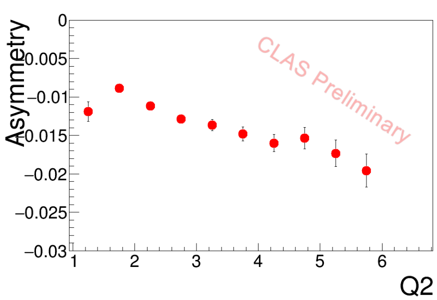
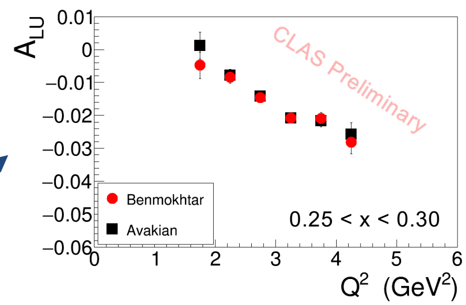
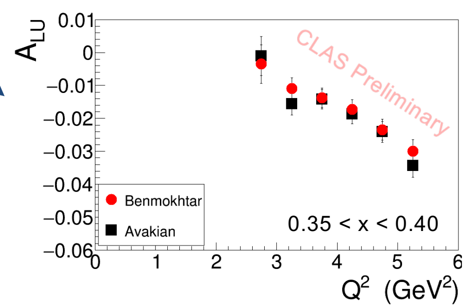
Mapping the Q^2 dependence

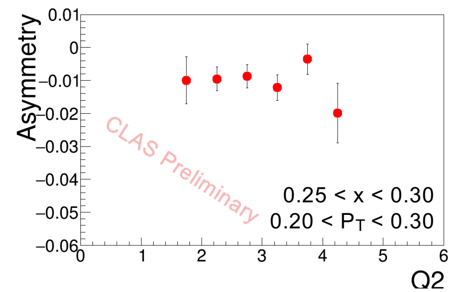
- SSAs in single hadron production are twist-3 (M/Q suppression).
- ”Twist 3” asymmetries not behaving as expected (EMC, COMPASS, CLAS12 etc!)
- Proper interpretation of the Q^2 dependence is crucial for our understanding of the underlying dynamics.

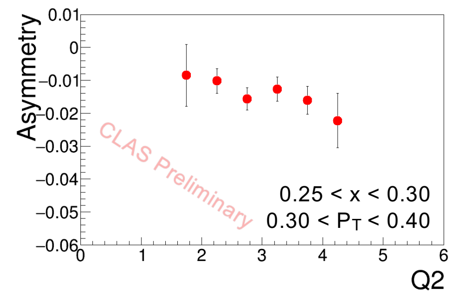
ep → e’pX

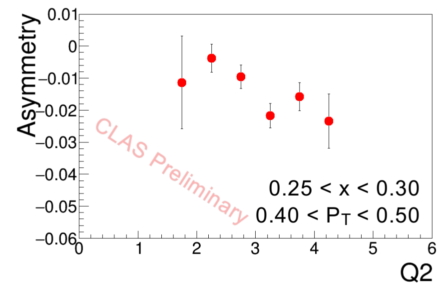












Onward to 4D

Observing the expected Q^2 behavior for subleading twist objects may require high precision multidimensional bins… or maybe our theory is wrong.

All plots $x_F < 0$.

Only about 1/3(1/6) of statistics collected(approved) on H_2 with CLAS12!

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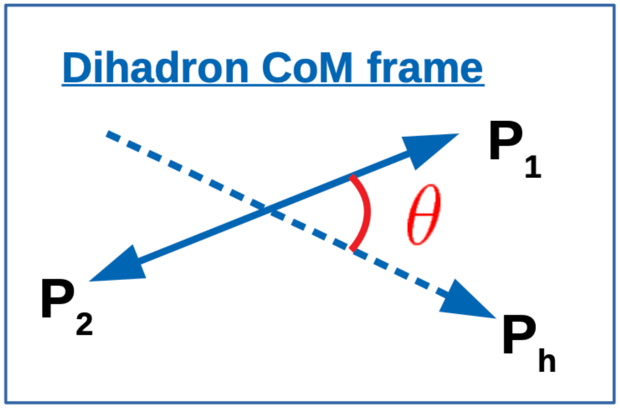
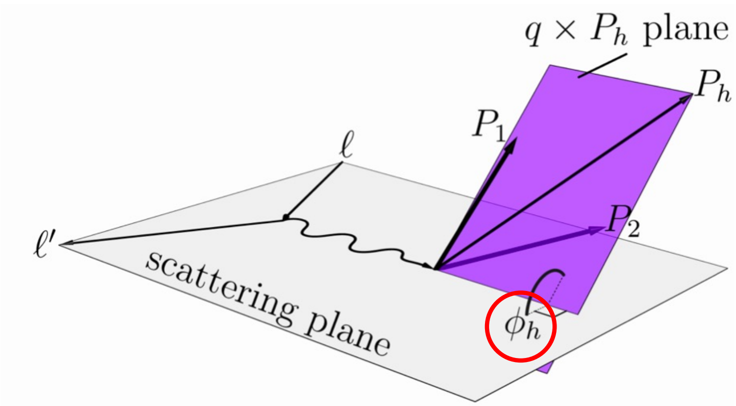
Dihadron Kinematics

$$P_h = P_1 + P_2 \qquad \text{or} \qquad R = \frac{1}{2}(P_1 - P_2)$$

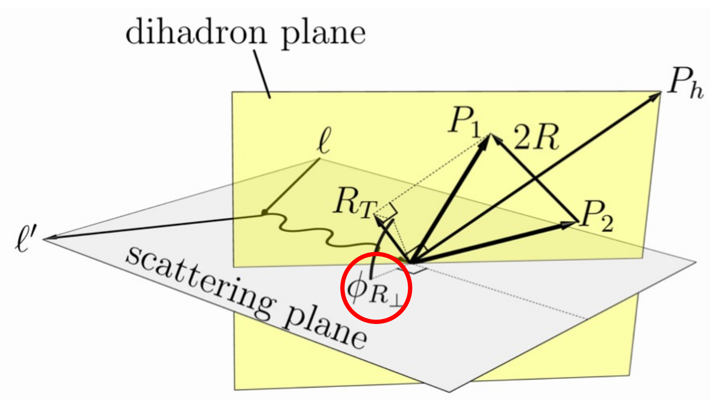
$$\phi_h = \frac{(\boldsymbol{q}\times\boldsymbol{l})\cdot\boldsymbol{P}_h}{|(\boldsymbol{q}\times\boldsymbol{l})\cdot\boldsymbol{P}_h|}\arccos\left(\frac{(\boldsymbol{q}\times\boldsymbol{l})\cdot(\boldsymbol{q}\times\boldsymbol{P}_h)}{|\boldsymbol{q}\times\boldsymbol{l}|\cdot|\boldsymbol{q}\times\boldsymbol{P}_h|}\right)$$

$$\phi_R = \frac{(\boldsymbol{q}\times\boldsymbol{l})\cdot\boldsymbol{R}_\perp}{|(\boldsymbol{q}\times\boldsymbol{l})\cdot\boldsymbol{R}_\perp|}\arccos\left(\frac{(\boldsymbol{q}\times\boldsymbol{l})\cdot(\boldsymbol{q}\times\boldsymbol{R}_\perp)}{|\boldsymbol{q}\times\boldsymbol{l}|\cdot|\boldsymbol{q}\times\boldsymbol{R}_\perp|}\right)$$



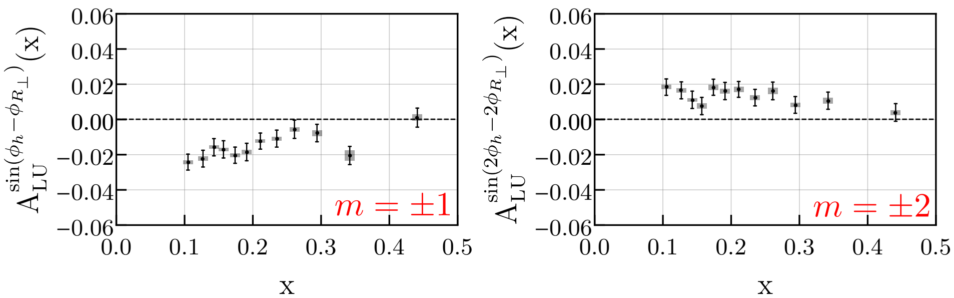


cf. single-hadron ϕ_h

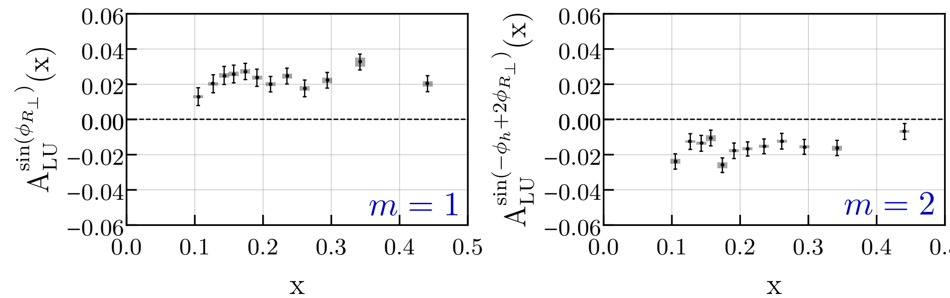


$A_{LU}(x)$ Amplitudes

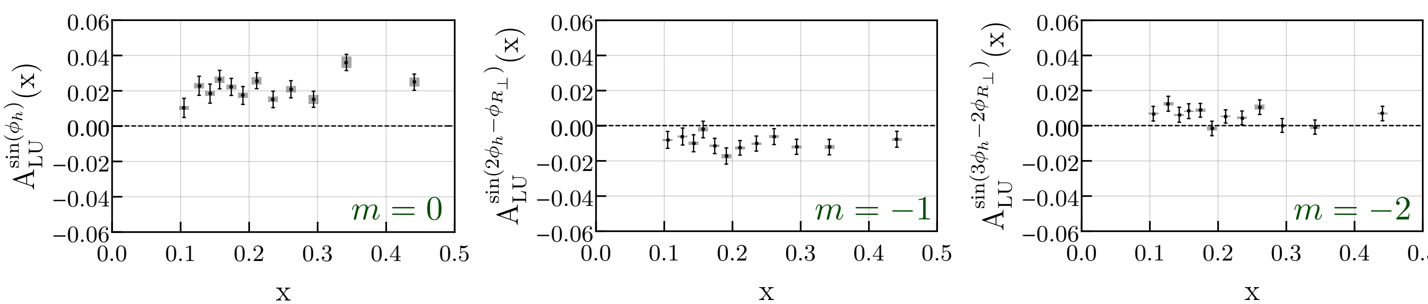
Twist 2, $f_1(x) \otimes G_1^{\perp|\ell,m>}$



Twist 3, $e(x) \otimes H_1^{\sphericalangle|\ell,m>}$



Twist 3, $e(x) \otimes H_1^{\perp|\ell,m>}$



T. B. Hayward et al., *Phys. Rev. Lett.*, 126, 152501, (2021), hep:ex/2101.04842

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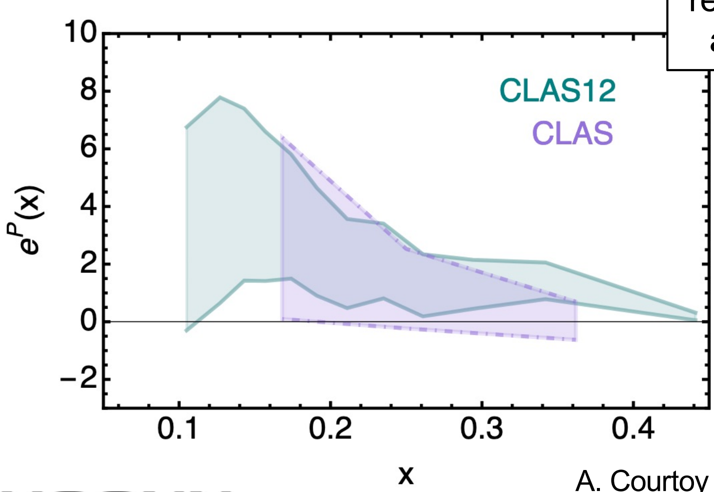
Extraction of e^p(x), beyond WW

$$A_{LU}^{\sin\phi_R} \propto \frac{M}{Q} \frac{\sum_q e_q^2 \left[x e^q(x)\, H_{1,sp}^{\sphericalangle,q}(z, m_{\pi\pi}) + \frac{m_{\pi\pi}}{zM} f_1^q(x)\, \tilde{G}_{sp}^{\sphericalangle,q}(z, m_{\pi\pi}) \right]}{\sum_q e_q^2 f_1^q(x)\, D_{1,ss+pp}^q(z, m_{\pi\pi})}$$

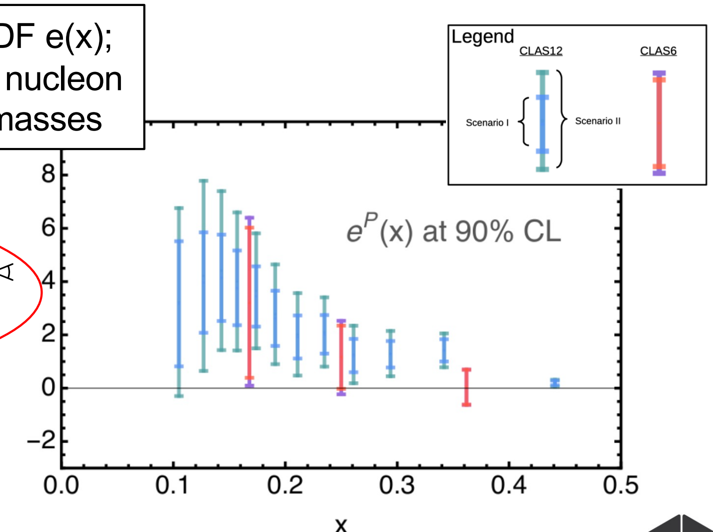
twist-3 DiFF

- **Scenario II: Beyond WW approximation**
  - Estimate max integrated twist-3 DiFF from COMPASS A_{UL} and A_{LL}

First extraction of the twist-3 collinear PDF e(x); related to the strangeness content of the nucleon and the contributions from finite quark masses



$$0.05 n^{H_1^{\sphericalangle}} \approx n^{\tilde{D}^{\sphericalangle}} > n^{\tilde{G}^{\sphericalangle}}$$



A. Courtoy et al., *Phys. Rev. D.,* 106, 014027, (2022), hep:ph/2203.14975
also A. Courtoy at CPHI2022

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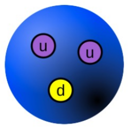
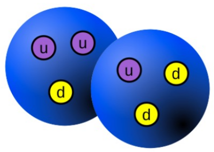
Twist-3 PDF Flavor Dependence

Proton Target



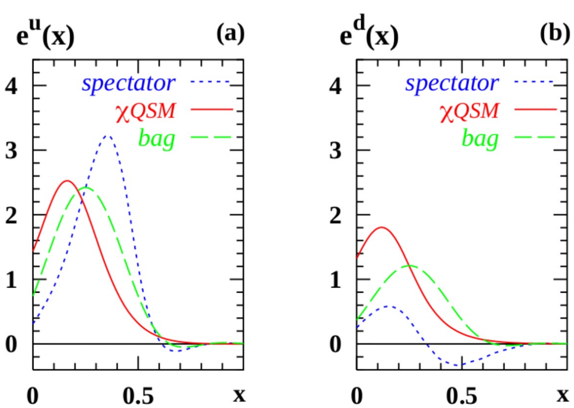
$$A_{LU,\mathbf{p}}^{\text{twist 3}} \propto 4xe^{u_V}(x) - xe^{d_V}(x)$$

Deuteron Target

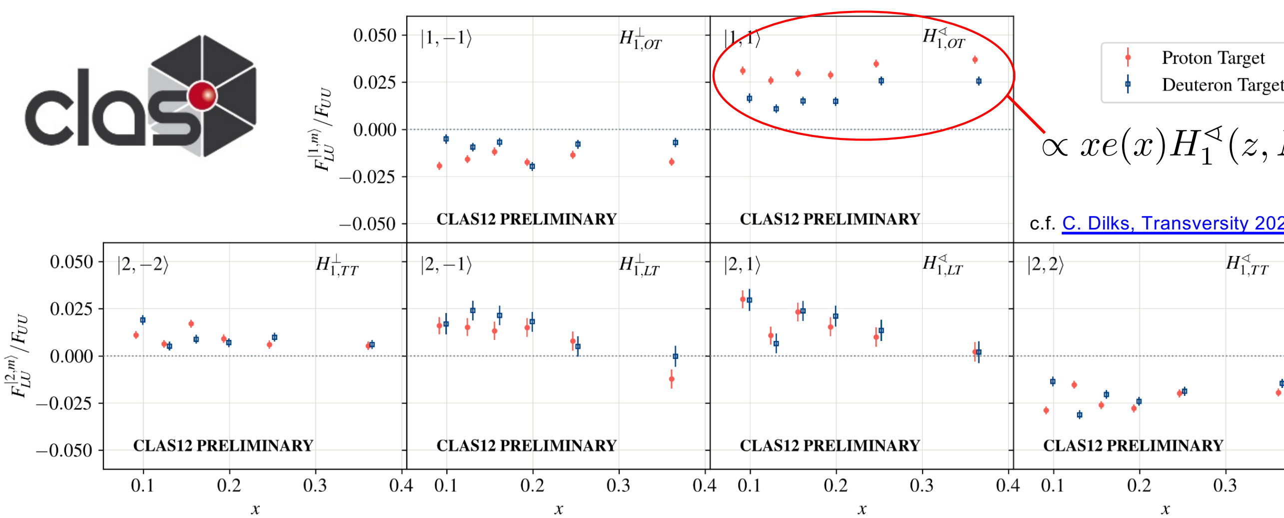


$$A_{LU,\mathbf{d}}^{\text{twist 3}} \propto xe^{u_V}(x) + xe^{d_V}(x)$$

Ongoing full partial wave analysis and comparison between proton and deuteron targets could lead to the flavor decomposition of the scalar PDF.



Bag Model: Nucl.Phys.B 375 (1992) 527-560
Nucl.Phys.B 497 (1997) 415-434
Spectator Model: Nucl.Phys.A 626 (1997) 937-965
Chiral Quark Soliton Model (χQSM): Acta Phys.Polon.B 39 (2008) 609-640



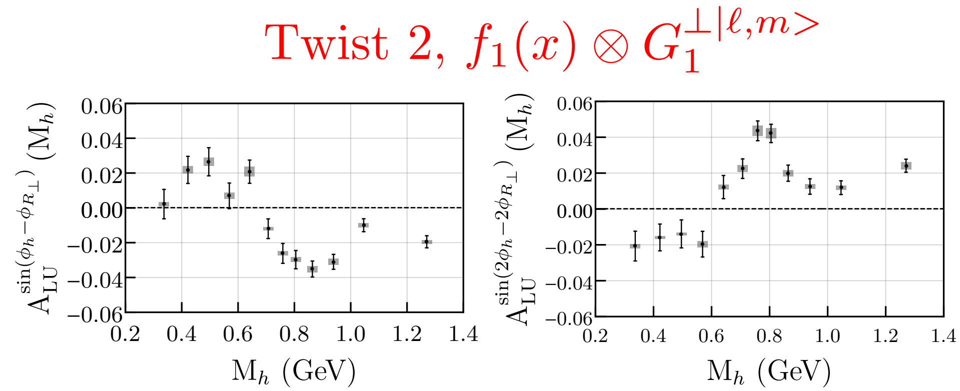
$$\propto xe(x)H_1^{\sphericalangle}(z, M_h)$$

c.f. C. Dilks, Transversity 2022

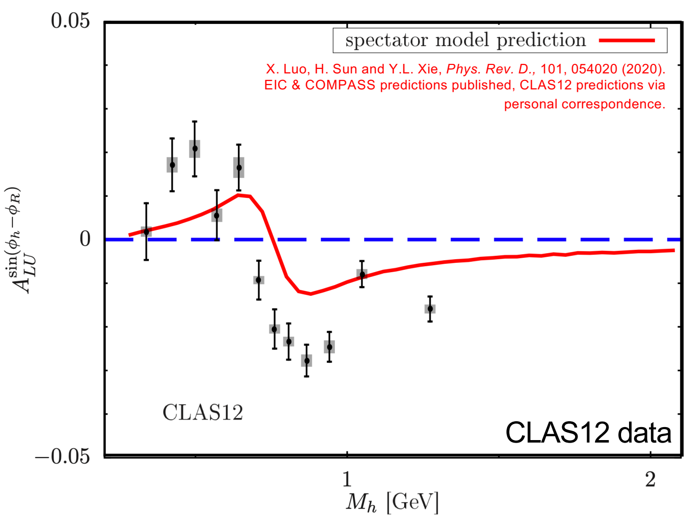
C. Dilks & T.B. Hayward

First Observation of TMD DiFF $G_1^{\perp}$

- Results correspond to the first ever experimental signal sensitive to the helicity dependent DiFF.
- Confirmation that the produced pions depend on the helicity of the fragmenting quark.



T. B. Hayward et al., *Phys. Rev. Lett.*, 126, 152501, (2021), hep:ex/2101.04842



- Results are consistent with model predictions for a sign change around the ρ-meson mass.
- This corresponds to an interference term between s- and p- wave dihadron production.

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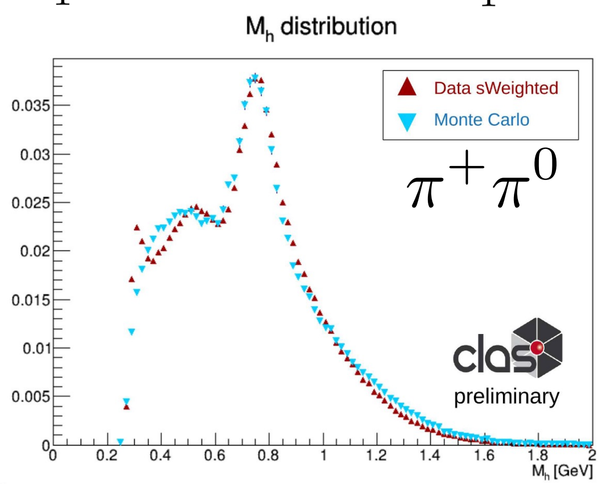
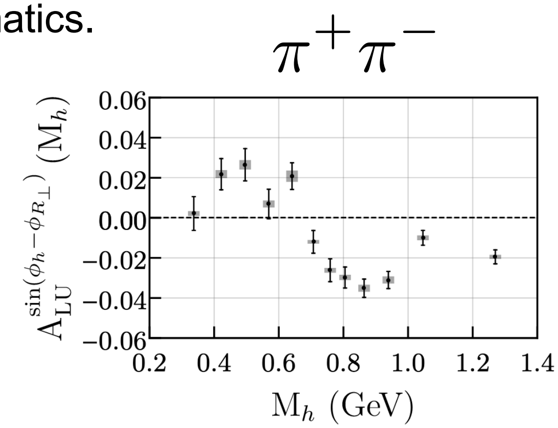
Channel Dependence of DiFFs

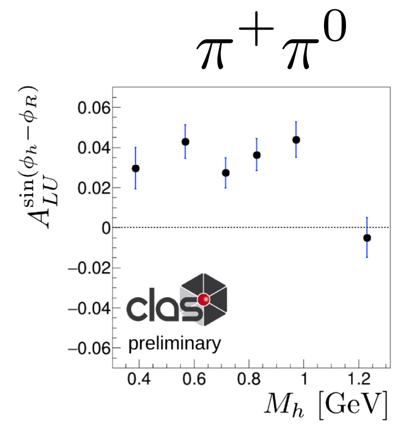
The study of other pion flavor combinations gives access to the flavor dependence of DiFFs while testing the effects of different systematics.

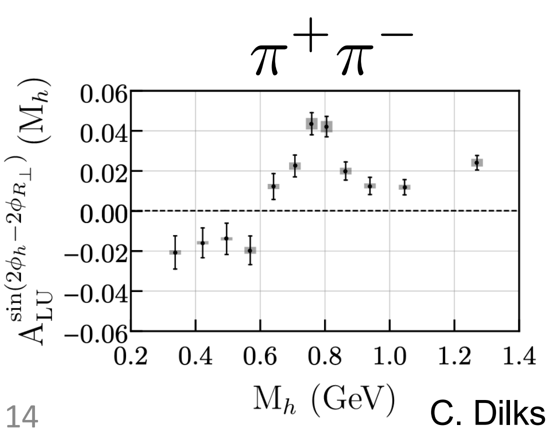
Channel dependence of DiFFs

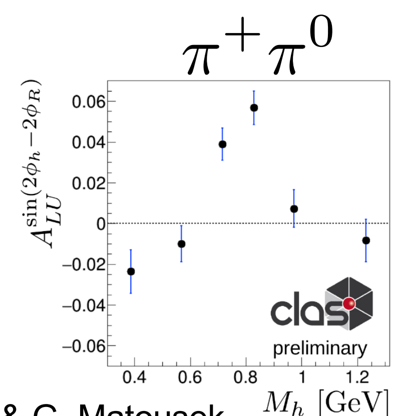
$$\begin{matrix} D_1^{q/\pi^+\pi^-} \\ G_1^{q/\pi^+\pi^-} \\ H_1^{q/\pi^+\pi^-} \end{matrix} \neq \begin{matrix} D_1^{q/\pi^\pm\pi^0} \\ G_1^{q/\pi^\pm\pi^0} \\ H_1^{q/\pi^\pm\pi^0} \end{matrix}$$







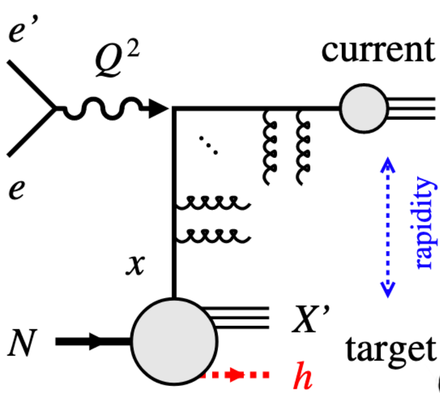


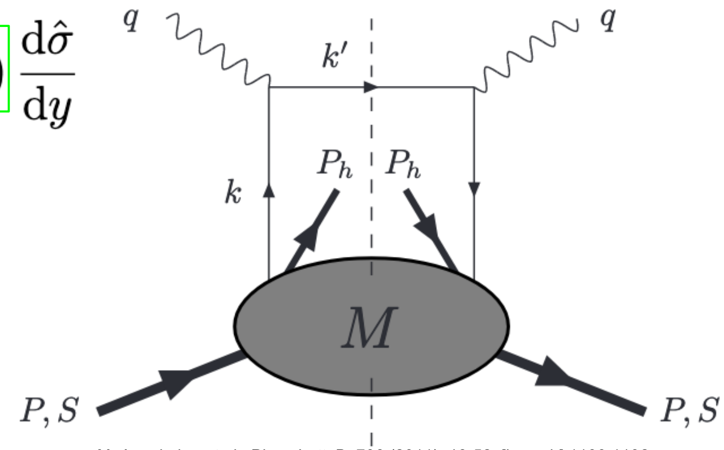


The Neglected Hemisphere – Target Fragmentation

- Final state hadrons also form from the left-over target remnant (TFR) whose partonic structure is defined by "fracture functions"[1,2]: the probability for the target remnant to form a certain hadron given a particular ejected quark.
- In the TFR, factorization into x and z does not hold because it is not possible to separate quark emission from hadron production.

$$\frac{\mathrm{d}\sigma^{\mathrm{TFR}}}{\mathrm{d}x_B\,\mathrm{d}y\,\mathrm{d}z} = \sum_a e_a^2\,(1-x_B)\boxed{M_a(x_B,(1-x_B)z)}\,\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}y}$$





M. Anselmino et al., Phys. Lett. B. 706 (2011), 46-52, [hep-ph] 1109.1132

1. L. Trentadue and G. Veneziano, Phys. Lett. B323 (1994) 201,
2. M. Anselmino et al., Phys. Lett. B. 699 (2011), 108-118, [hep-ph] 1102.4214
3. TFR/CFR Fig. from EIC Yellow Report, (2021) [physics.ins-det] 2103.05419

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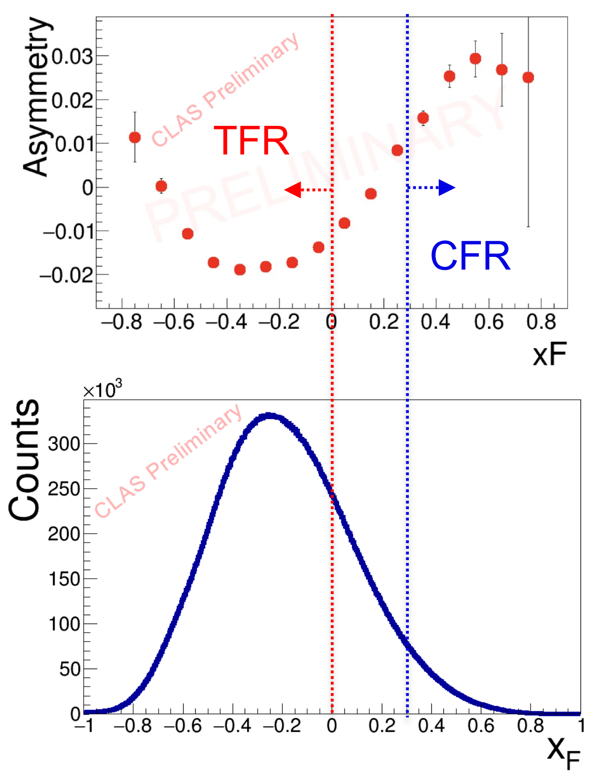
Can We Separate Target and Current?

ep → e'pX



F. Benmokhtar, H. Avakian, T.B. Hayward

Feynman variable

$$x_F = \frac{p_h^z}{p_h^z(\text{max})} \quad \text{in CM frame } \mathbf{p} = -\mathbf{q}, \qquad -1 < x_F < 1$$

Rapidity

$$y = \frac{1}{2}\log\frac{p_h^+}{p_h^-} = \frac{1}{2}\log\frac{E_h + p_h^z}{E_h - p_h^z}$$

- No clear *experimental* definition of what constitutes current production versus target production.
- Structure functions, with different production mechanisms in both regions, give a possible clue.
- Protons (as opposed to mesons) at CLAS12 kinematics give a unique opportunity because they have extensive coverage in both regions.

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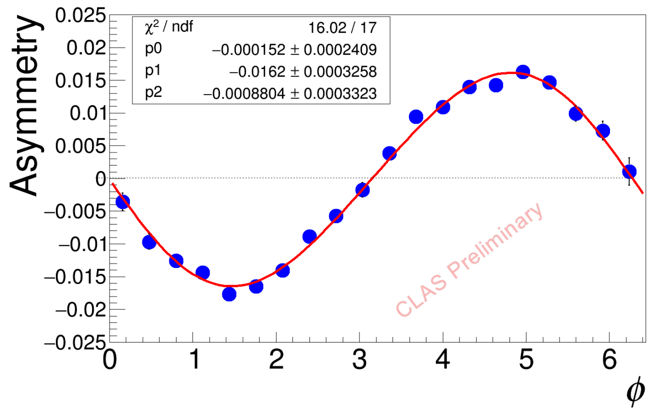
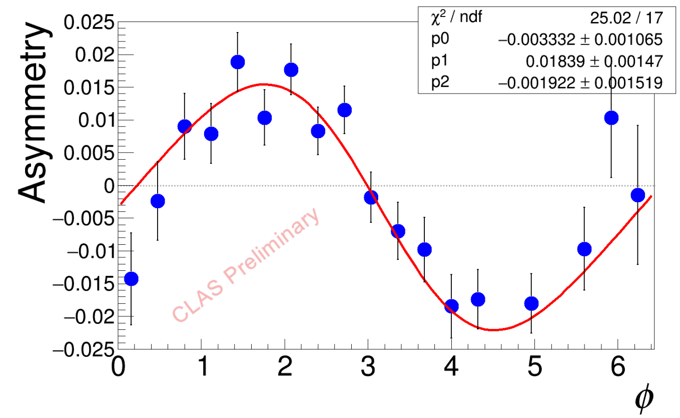
Separate Signals

TFR



CFR



$$F_{LU}^{\sin\phi} \propto \frac{2M}{Q}\left[\tilde{l}_2^{\perp h} + \dots \right]$$

Need more theory calculations!

$$F_{LU}^{\sin\phi} \propto \frac{2M}{Q}\mathcal{C}\left[-\frac{\hat{h}\cdot k_T}{M_h}\left(xeH_1^{\perp} + \frac{M_h}{M}f_1\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{h}\cdot p_T}{M}\left(xg^{\perp}D_1 + \frac{M_h}{M}h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

F. Benmokhtar, H. Avakian, T.B. Hayward

- Sinusoidal modulations (that are probably) coming from the struck quark and the spectator partons appear with roughly equal amplitudes but opposite signs.

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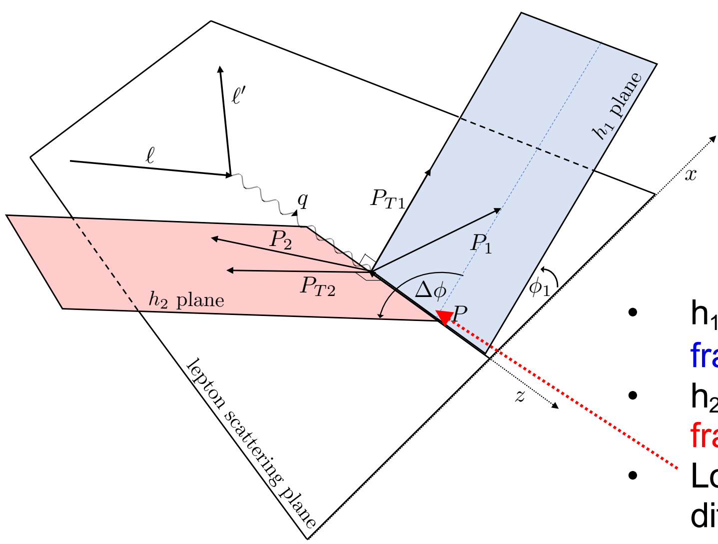
Back-to-back (dSIDIS) Formalism

- When two hadrons are produced "back-to-back"[1,2] with one in the CFR and one in the TFR the structure function contains a convolution of a fracture function and a fragmentation function.
- Leading twist beam(target)-spin asymmetry.

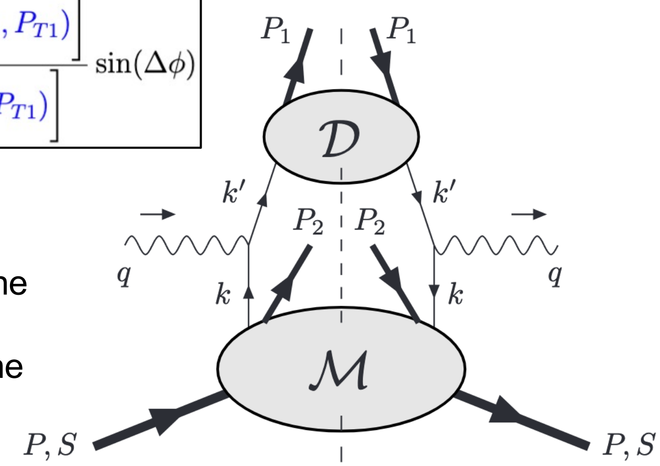
$\hat{l}_1^{\perp h}$ Unique access to longitudinally polarized quarks in unpolarized nucleon… no corresponding PDF!

$$A_{LU} = -k(\epsilon)\frac{P_{T1}P_{T2}}{m_1 m_2}\frac{\mathcal{C}\left[w_5 \hat{l}_1^{\perp h}(x,\zeta_2,P_{T2})D_1(z_1,P_{T1})\right]}{\mathcal{C}\left[\hat{u}_1(x,\zeta_2,P_{T2})D_1(z_1,P_{T1})\right]}\sin(\Delta\phi)$$



Kinematic plane for b2b dihadron production.

- h_1 in the CFR with production dictated by the fragmentation function
- h_2 in the TFR with production dictated by the fracture function
- Long range correlation depends on the difference in azimuthal angles of both hadrons



Handbag diagram for dihadron production; lower blob contains FrFs and upper blob contains the FFs.

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1. M. Anselmino et al., Phys. Lett. B. 706 (2011), 46-52, [hep-ph] 1109.1132
2. M. Anselmino et al., Phys. Lett. B. 713 (2012), 317-320, [hep-ph] 1112.2604

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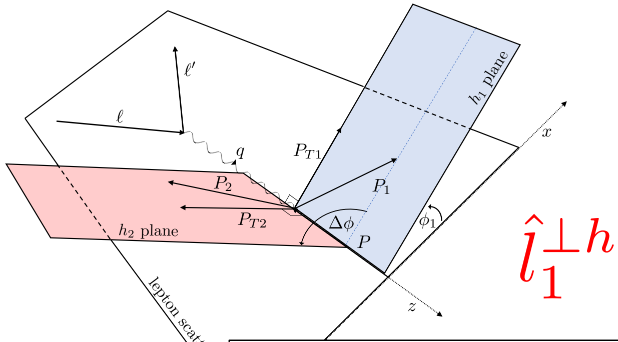
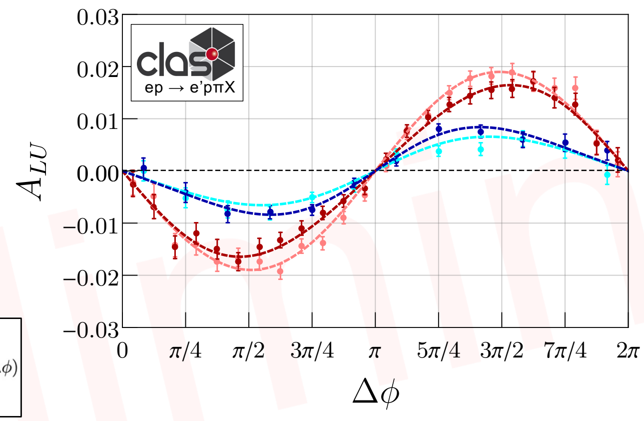
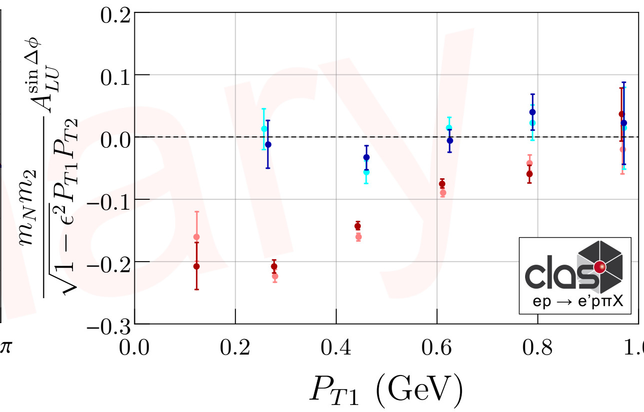
Back-to-back (dSIDIS) Measurements

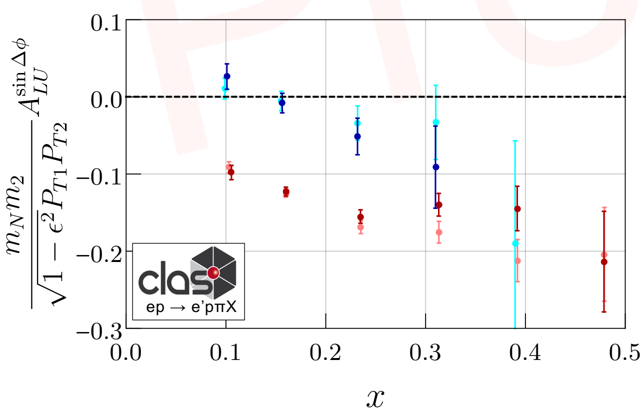


$$\hat{l}_1^{\perp h}$$

$$A_{LU} = -k(\epsilon)\frac{P_{T1}P_{T2}}{m_1 m_2}\frac{\mathcal{C}\left[w_5 \hat{l}_1^{\perp h}(x,\zeta_2,P_{T2})D_1(z_1,P_{T1})\right]}{\mathcal{C}\left[\hat{u}_1(x,\zeta_2,P_{T2})D_1(z_1,P_{T1})\right]}\sin(\Delta\phi)$$







H_2 pπ+, D_2 pπ+
H_2 pπ-, D_2 pπ-

- Unique access to longitudinally polarized quarks in unpolarized nucleon… no corresponding PDF!
- Continued evidence that the driving force behind SIDIS asymmetries is determined by the struck quark.
- Small π- asymmetries are consistent with cancellation between u and d quark.
- Studying the transverse momentum dependence can give insight into the role played by vector mesons.

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Conclusions

- CLAS12 is an ideal place to study the multiparticle final state processes that are critical to SIDIS.
- The Hall-B and CLAS12 physics program features a diverse set of analyses covering many different target types and final state observables.
- Several high-quality publications already with many more in progress including upcoming polarized target measurements.

Back up

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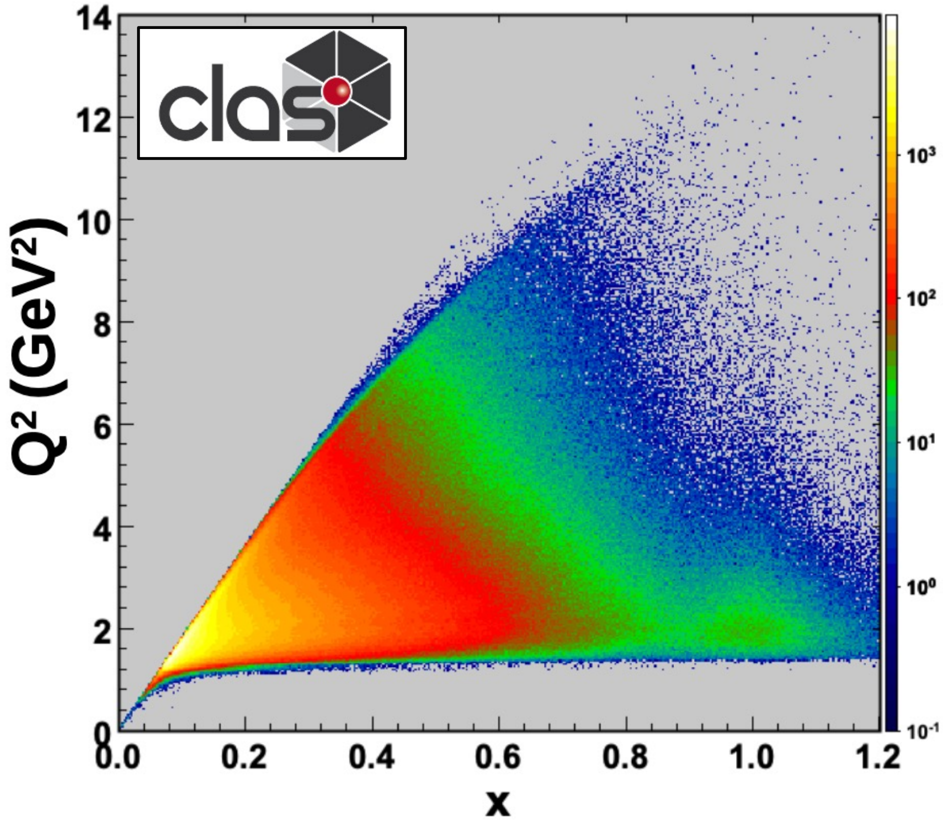
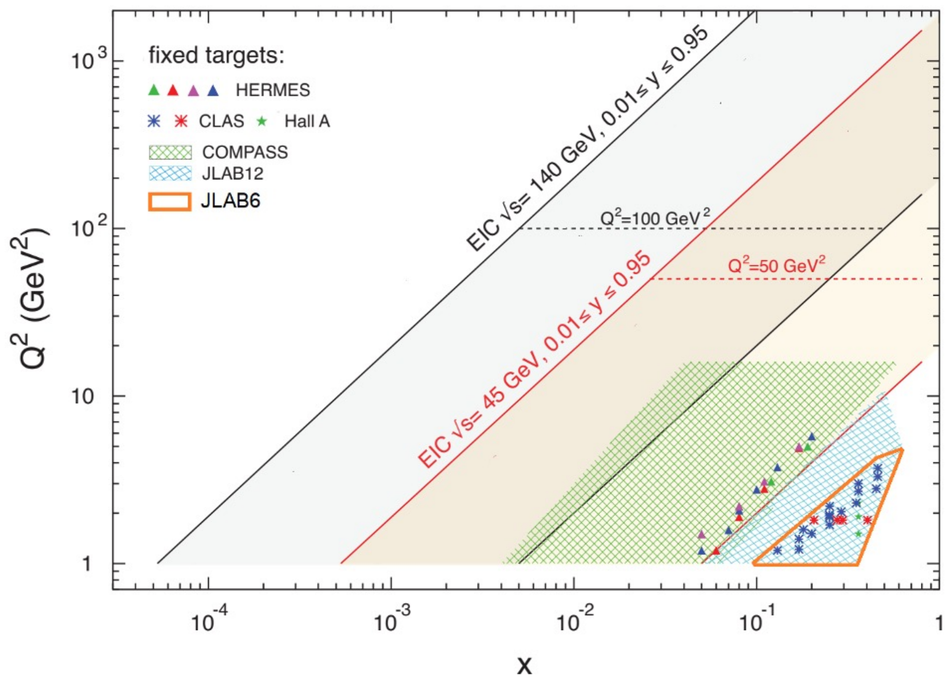
CLAS12 Kinematic Reach





JLab: Valence quark distribution
Compass: Sea quark distribution
EIC: Gluon distribution

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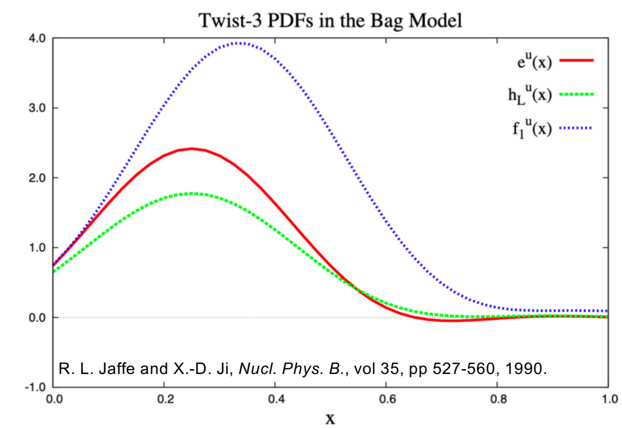
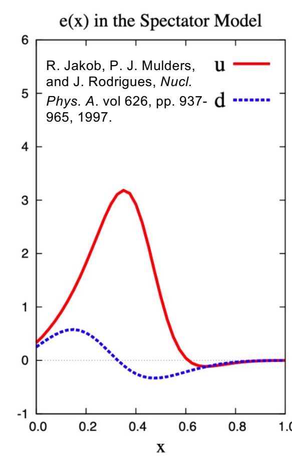
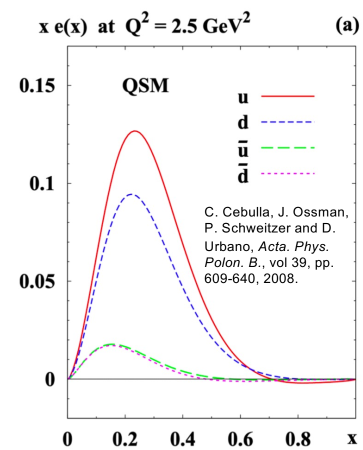
The twist-3 TMD/PDF e(x)

- One of the six collinear PDFs; offers insight into largely unexplored quark-gluon correlations.
- $\int e(x)dx \rightarrow$ related to the strangeness content of the nucleon and the contributions from finite quark masses; arises in chiral perturbation theory to measure explicit symmetry breaking due to nonzero masses of the light quarks. (Also appears in dark matter studies!)
- $\int x\, e(x)dx \rightarrow$ proportional to the number of valence quarks in the nucleus.
- $\int x^2 e(x)dx \rightarrow \perp$ force on $\perp$ polarized quarks in a unpolarized nucleon, related to the "Boer-Mulders"
- Although the PDF e(x) has been studied extensively in models, direct experimental access has remained relatively scarce







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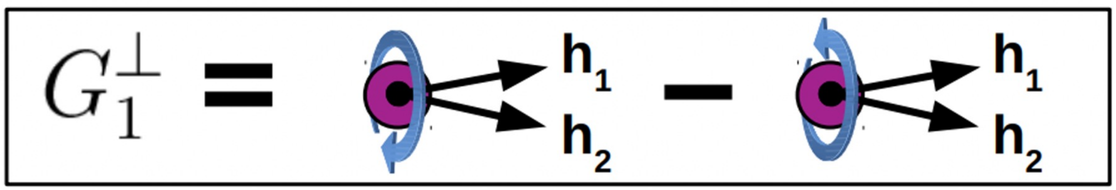
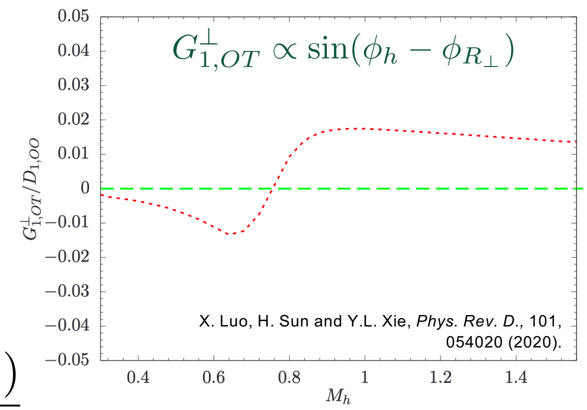
Helicity Dependent DiFF

- Dihadron studies allow for the existence of FFs with no single hadron analog.
- The TMD DiFF $G_1^{\perp}$ describes the azimuthal dependence of an unpolarized hadron pair on the helicity of the struck quark, "jet handedness".[1]

1. D. Boer, R. Jakob, and M. Radici, Phys. Rev. D67 (2003) 094003, hep-ph/0302232

- Completely unmeasured; exciting opportunity to study spin-momentum dynamics in hadronization.





unpolarized PDF

$$A_{LU}^{\sin(\phi_h-\phi_{R_\perp})} = \frac{\int d_{LU}(P_h^{\perp}/M_h)\sin(\phi_h-\phi_{R_\perp})}{\int d_{UU}} \propto \frac{\sum z f_1(x) G_1^{\perp}(z, M_h)}{\sum f_1(x) D_1(z, M_h)}$$

H. H. Matevosyan, A. Kotzinian, and A. W. Thomas, *Phys. Rev. Lett.*, 120, 252001 (2018)

unpolarized FF

24

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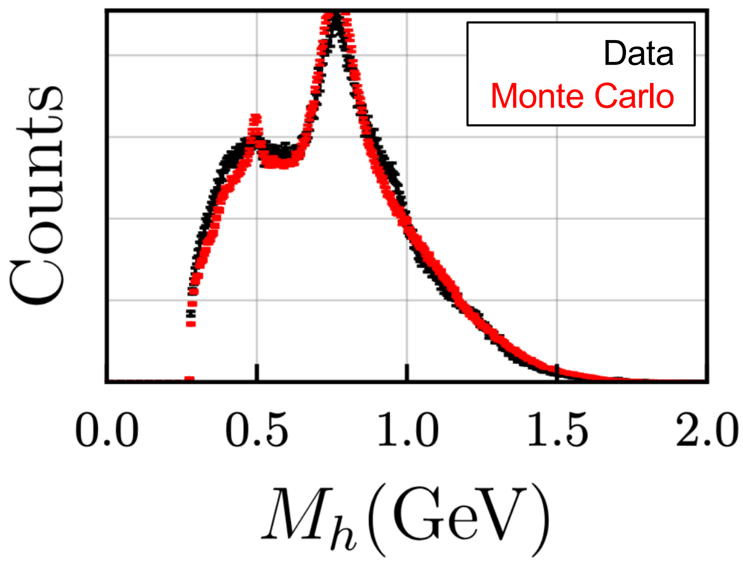
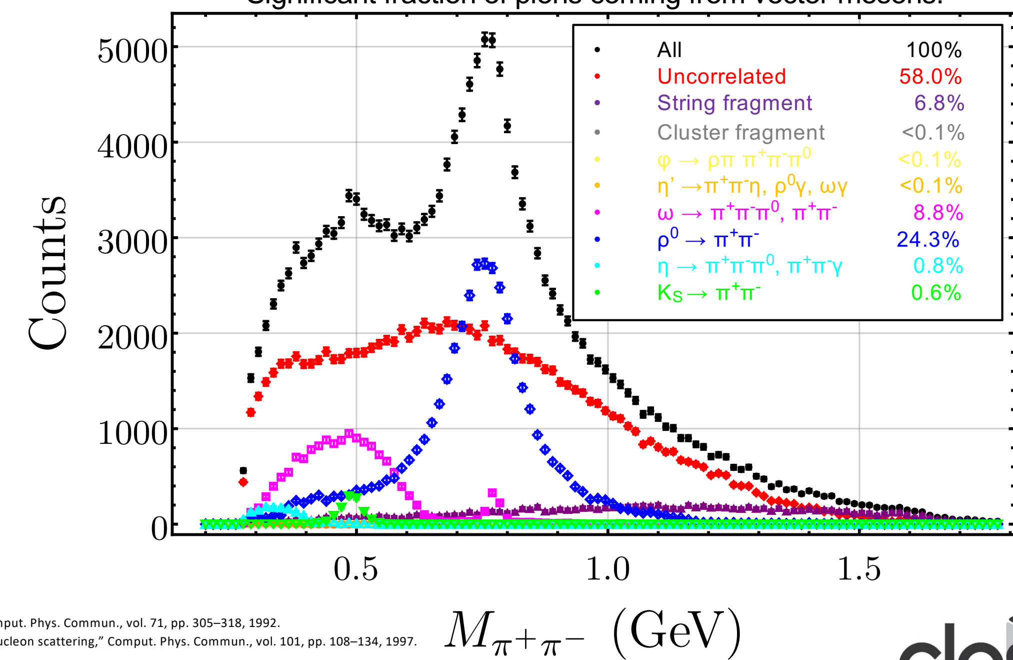
Monte Carlo and Vector Mesons

- SIDIS MC “clasdis”[1] based on PEPSI[2] generator, the polarized version of the well-known LEPTO[3] generator.
- Parameters changed to reproduce observed distributions include average transverse momentum, fraction of spin-1 light mesons and fraction of spin-1 strange mesons.
- CLAS12 detector system described in “GEMC”[4], a detailed GEANT4 simulation package.



Significant fraction of pions coming from vector mesons!



1. H. Avakian, “clasdis.” https://github.com/JeffersonLab/clasdis, 2020.
2. L. Mankiewicz, A. Schafer, and M. Veltri, “Pepsi: A monte carlo generator for polarized leptoproduction,” Comput. Phys. Commun., vol. 71, pp. 305–318, 1992.
3. G. Ingelman, A. Edin, and J. Rathsman, “LEPTO 6.5: A Monte Carlo generator for deep inelastic 912 lepton - nucleon scattering,” Comput. Phys. Commun., vol. 101, pp. 108–134, 1997.
4. M. Ungaro et al., “The CLAS12 Geant4 simulation,” Nucl. Instrum. Meth. A, vol. 959, p. 163422, 2020.

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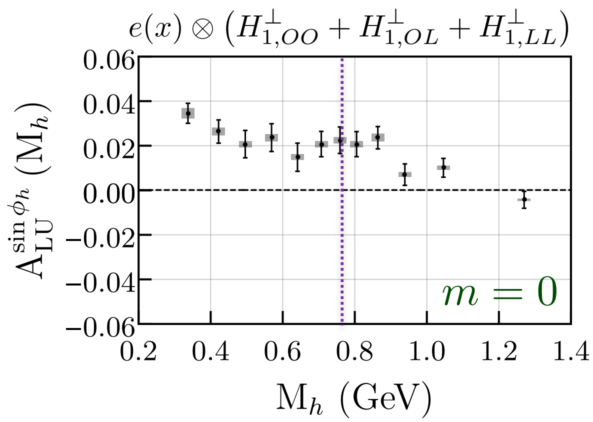
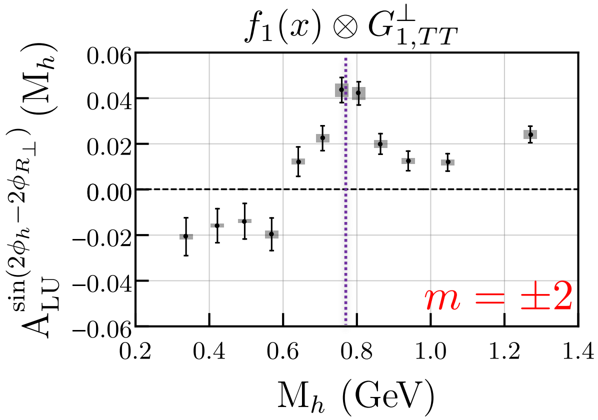
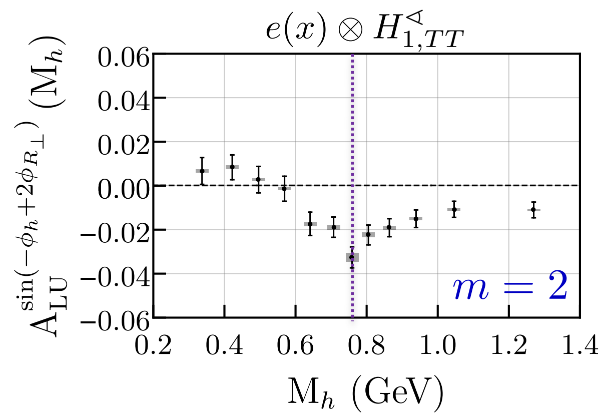
Significant Effects From Vector Mesons

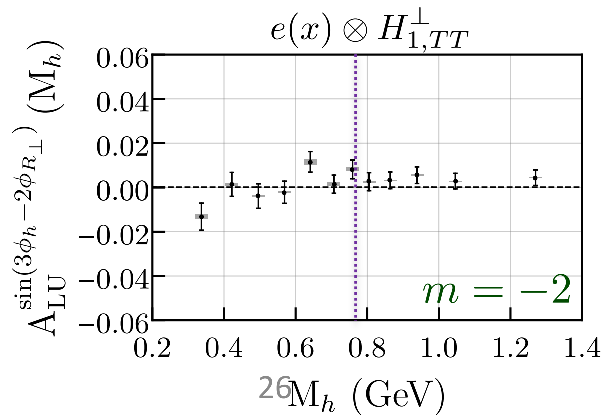
Recall that l = 0, 1 and 2 terms correspond to ss, sp and pp wave dihadron interference. Enhancement is seen around the ρ-meson mass for several modulations.

- m=0, ss term is relatively flat.









- m = 2 amplitudes increasing rapidly around the ρ mass
- twist-3, m = -2 amplitude is relatively small $H^{\perp}_{1,TT} \approx 0$?

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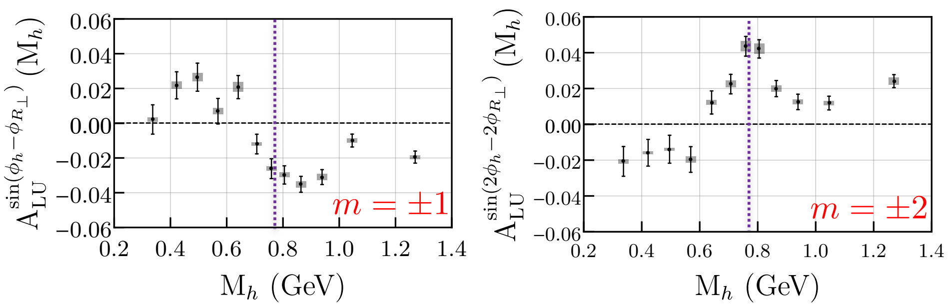
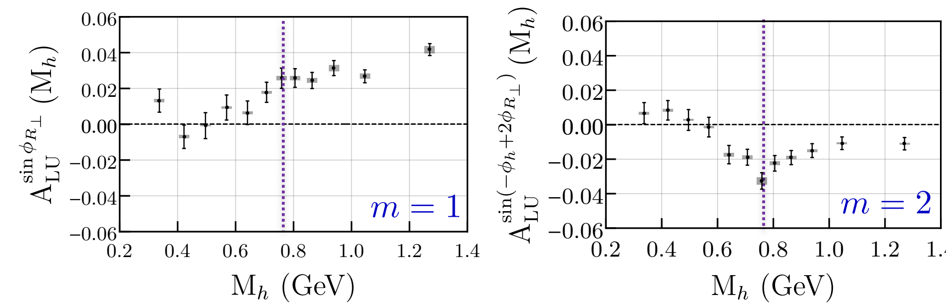
$A_{LU}(M_h)$ Amplitudes

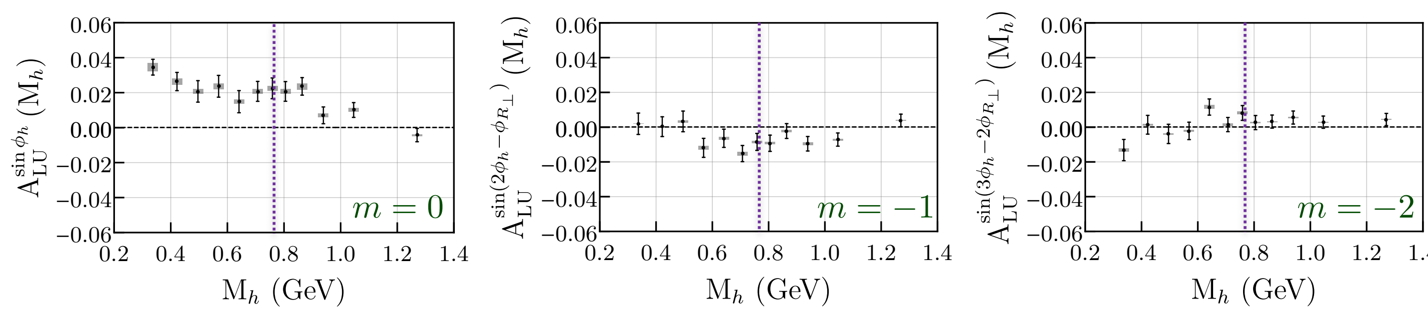
Twist 2, $f_1(x) \otimes G_1^{\perp|\ell,m>}$



Twist 3, $e(x) \otimes H_1^{\sphericalangle|\ell,m>}$



Twist 3, $e(x) \otimes H_1^{\perp|\ell,m>}$



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T. B. Hayward et al., *Phys. Rev. Lett.* 126, 152501, (2021), hep:ex/2101.04842

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A_{LL} – The Best of Both Worlds

$$\frac{d\sigma}{dx\,dy\,d\zeta\,dP_T^2} = 2\pi\hat{\sigma}_U \sum_q e_q^2 \left[F_{UU,T} + \lambda S_L \sqrt{1-\varepsilon^2} F_{LL}\right]$$

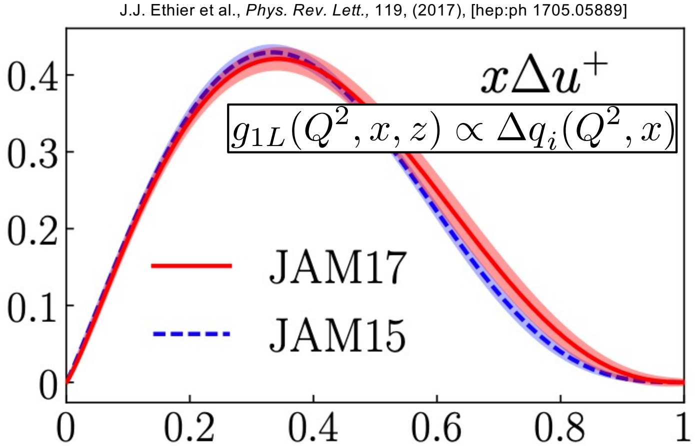
M. Anselmino et al., Phys. Lett. B. 699 (2011), 108, [hep-ph] 1102.4214

At leading twist for the case of a longitudinally polarized target and a single hadron produced in the TFR, only two terms appear:

$$F_{UU,T} \propto \tilde{u}_1(x,\zeta,P_T^2) = \int d^2k_T \hat{u}_1$$

$$F_{LL} \propto \tilde{l}_{1L}(x,\zeta,P_T^2) = \int d^2k_T \hat{l}_{1L}$$

J.J. Ethier et al., *Phys. Rev. Lett.*, 119, (2017), [hep:ph 1705.05889]



Double Spin Asymmetry: $A_{LL} = \lambda_\ell S_L \frac{\sqrt{1-\epsilon^2} F_{LL}}{F_{UU,T}}$

1. Single hadron → Highest statistics
2. Leading twist → Simple interpretation
3. Linked to g_1 → easiest test of FrF prediction

$$\sum_h \int \zeta d\zeta \int d^2P_T \hat{l}_{1L} = (1-x) g_{1L}(x,k_T^2)$$

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Collinear twist-3 PDF $h_L(x)$

$$A_{UL}^{\sin\phi_R}(x, M_h, z; Q, y) = -\frac{W(y)}{A(y)}\frac{M}{Q}\frac{|\mathbf{R}|}{M_h}\frac{\sum_q e_q^2\left(x h_L^q(x)\, H_1^{\sphericalangle,q}(z, M_h) + \frac{M_h}{zM}\, g_1^q(x)\, \tilde{G}_{sp}^{\sphericalangle,q}(z, M_h)\right)}{\sum_q e_q^2\, f_1^q(x)\, D_{1,ss+pp}^q(z, M_h)}$$

A. Bacchetta and M. Radici, Phys.Rev. D69, 074026 (2004), arXiv:hep-ph/0311173 [hep-ph]

$h_L(x)$

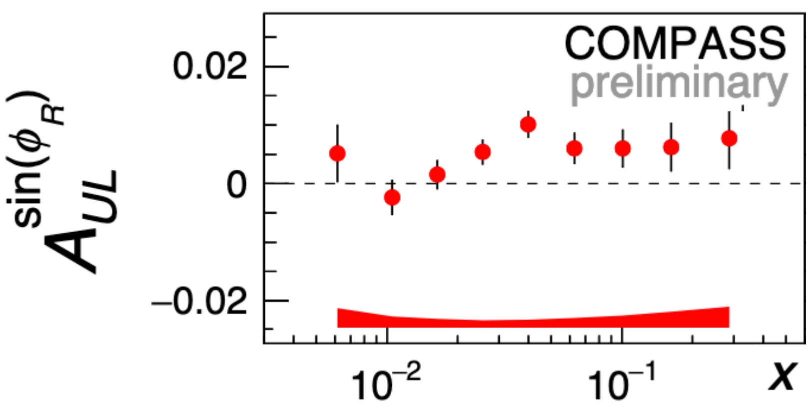
- Average longitudinal gradient of the transverse force on a **transversely** polarized struck quark in a **longitudinally** polarized nucleon

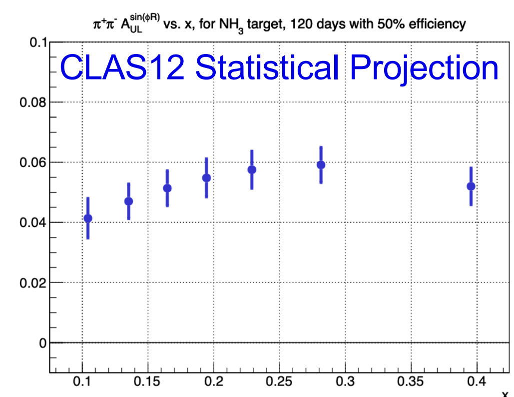
$$\mathcal{L}_{\mathrm{JM}}^q - L_{\mathrm{Ji}}^q = \Delta L_{\mathrm{FSI}}^q$$

Expressible in terms of the change in quark OAM as it leaves the target

- Phys.Rev.D 94 (2016) 9, 094040
- Phys.Rev.D 66 (2002) 114005
- Nucl.Phys.B 461 (1996) 197-237

- CLAS12 began taking data on a longitudinally polarized target last year.
- Will access additional twist-3 collinear PDF with similar or better statistical precision as COMPASS but at higher x.





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Why fracture functions?

- Sometimes possible to kinematically separate CFR and TFR (some jets, high energy DY, etc) … but not always clear (fixed target experiments).
- Without an understanding of the signals we expect from target fragmentation we may misinterpret results that we expect are from the current.
- Studying the TFR tests our complete understanding of the SIDIS production mechanism while also providing access to information not available in the CFR.
- Access to more familiar TMD/PDFs through momentum sum rules, but with different systematics.

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