Opportunities for SIDIS Dihadrons at CLAS 22

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JLab at 22 GeV Workshop

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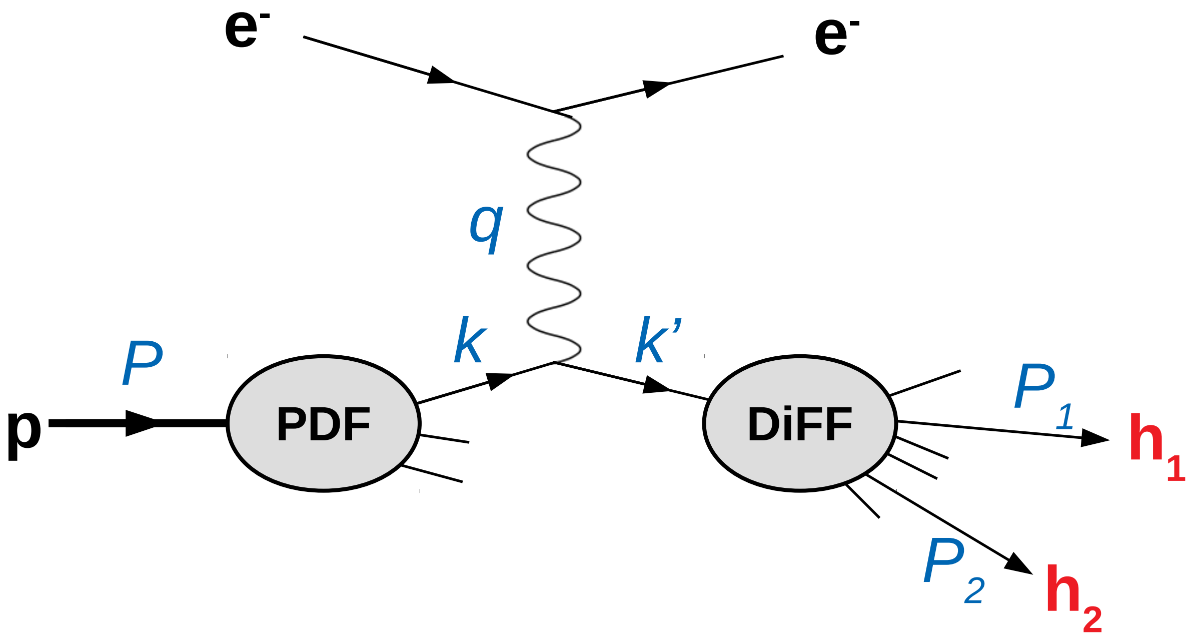
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- **Dihadron Introduction**
  - Kinematics
  - Cross Section
  - Observables
- **Depolarization**
  - Accessibility at CLAS 22 GeV
  - Comparisons to ePIC
- **Recent Measurements at CLAS**
  - Beam spin asymmetry
  - Partial waves
  - Kinematic comparisons 10.6 → 22 GeV

SIDIS Dihadron Process

$$eN \to e + h_1(P_1) + h_2(P_2) + X$$



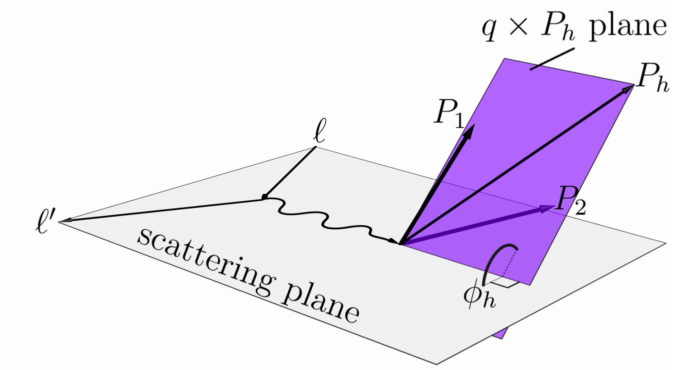
Dihadron Kinematics

Dihadrons:

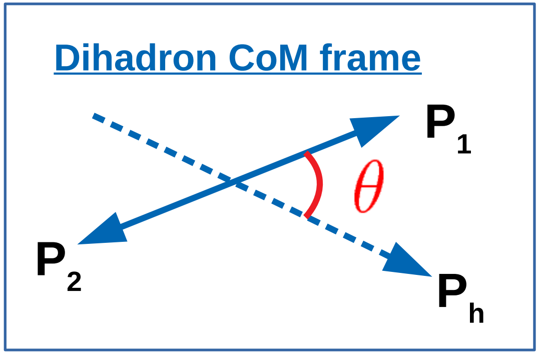
$$\text{momentum: } P_h = P_1 + P_2$$

$$\text{kinematics: } M_h,\ z,\ p_T$$

$$\text{angles: } \phi_h,\ \phi_R,\ \phi_S,\ \theta$$



cf. single-hadron ϕ_h

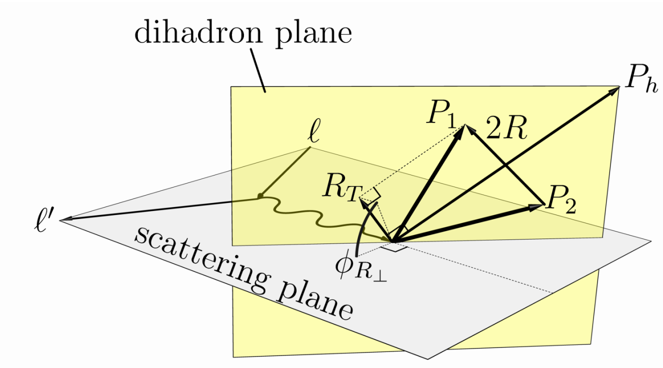


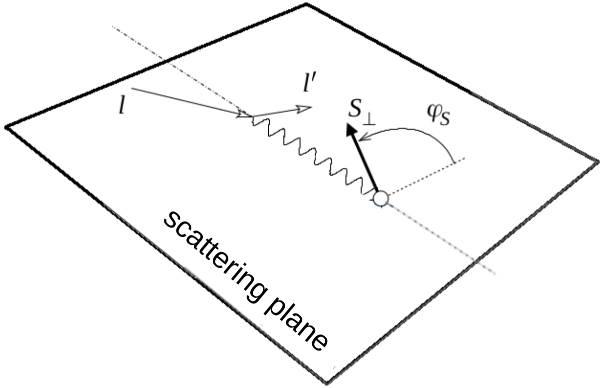
Dihadron CoM frame

Inclusive:

$$x_B = \frac{Q^2}{2\,P \cdot q}, \quad y = \frac{P \cdot q}{P \cdot l}$$

$$\gamma = \frac{2Mx_B}{Q}$$





Online 3D View:
https://c-dilks.github.io/dihadronAngleDefs/dihadronAngleDefs.html

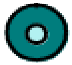
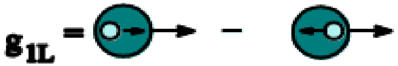
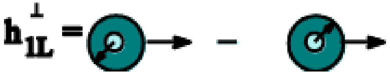
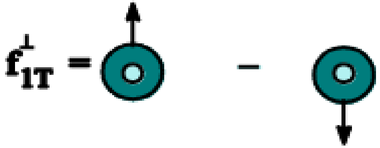
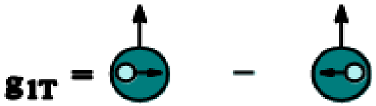
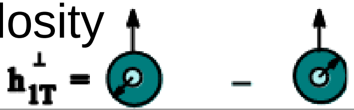
Differential Cross Section

General form of each term:

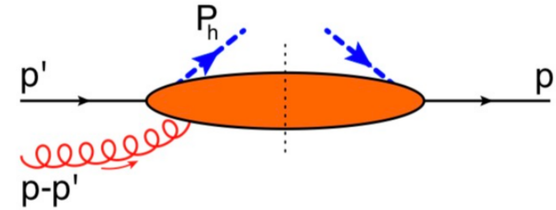
$$d\sigma_{XY} \propto \underset{\substack{\uparrow \\ \textbf{Depolarization}}}{D(x,y,Q^2)} \cdot \underset{\substack{\uparrow \\ \textbf{Sinusoidal modulation}}}{S(\phi_h,\phi_R,\phi_S,\theta)} \cdot \underset{\substack{\uparrow \\ \textbf{Structure Function}}}{F_{XY}^{S(\phi,\dots)}} + \dots$$

- Several of these terms per polarization configuration ‘XY’
  - X = electron polarization, Y = proton polarization $X, Y \in \{U, L, T\}$
- Separate terms at twist-2 and twist-3
  - Twist-3 asymmetries ~1/Q
- **Structure function → TMD Distribution x Fragmentation Function**

Leading Twist TMDs

		Quark Polarization		
		U	**L**	**T**
Nucleon Polarization	**U**	Unpolarized PDF $f =$ 		Boer-Mulders $h_1^\perp =$ 
	L		Helicity $g_{1L} =$ 	Kotzinian-Mulders Wormgear $h_{1L}^\perp =$ 
	T	Sivers $f_{1T}^\perp =$ 	Kotzinian-Mulders Wormgear $g_{1T} =$ 	Transversity $h_{1T} =$  Pretzelosity $h_{1T}^\perp =$ 

Collinear Twist-3 Distributions

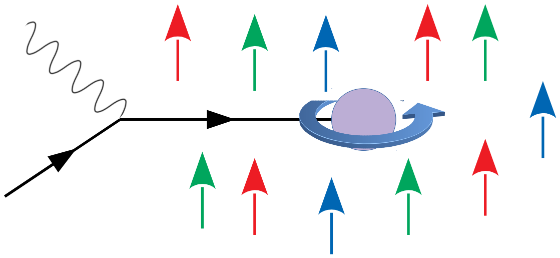


Semi-classical interpretation via x-moments

e(x)

- Pion-nucleon σ term: $m_q \rightarrow m_N$
- "Boer-Mulders Force": Transverse force exerted by color field on a **transversely** polarized struck quark in an **unpolarized** nucleon

Phys.Rev.D 88 (2013) 114502



g_T(x)

- Average transverse force on an **unpolarized** struck quark in a **transversely** polarized nucleon

Phys.Rev.D 94 (2016) 9, 094040

h_L(x)

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

$$\mathcal{L}^q_{\mathrm{JM}} - L^q_{\mathrm{Ji}} = \Delta L^q_{\mathrm{FSI}}$$

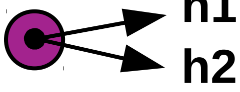
Expressible in terms of the change in quark OAM as it leaves the target

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

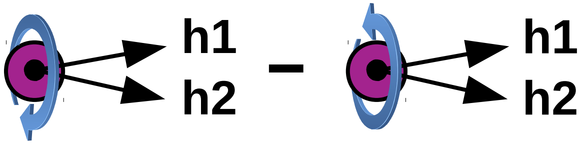
Dihadron Fragmentation Functions (DiFFs)

Twist 2

$D_1 =$



$G_1^{\perp} =$



$H_1^{\perp},\ H_1^{\sphericalangle} =$

Twist 3

$\tilde{D}^{\perp}$ $\tilde{G}^{\perp}$

$\tilde{H}$ $\tilde{E}$

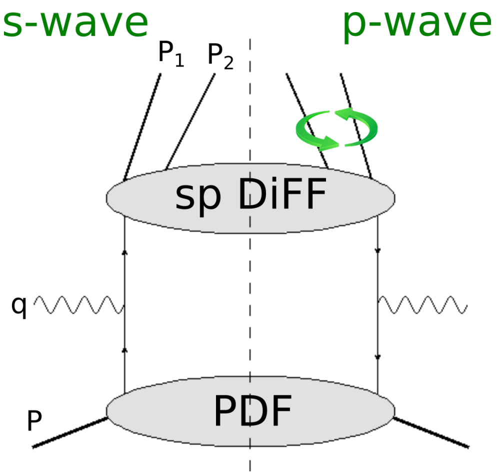
Thought to be small…
see, for example:

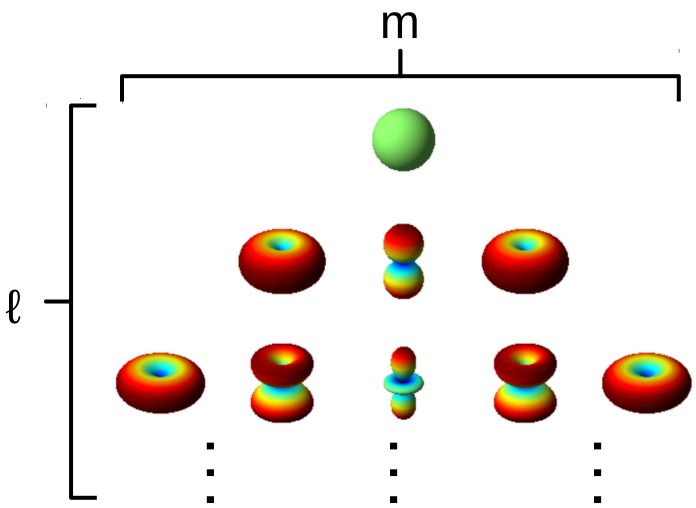
PoS DIS2014 (2014) 231

Phys.Rev.D 99 (2019) 5, 054003

arXiv: 1405.7659 [hep-ph]

DiFF Partial Waves





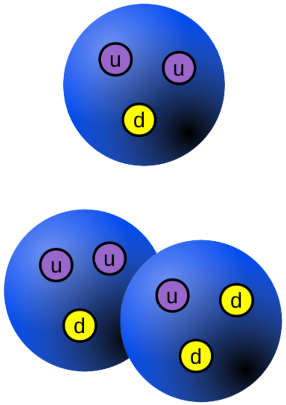
- Expand DiFFs into spherical harmonics (Legendre Polynomials ‘$P_{l,m}$’)

$$H_1^{\perp} = \sum_{\ell=0}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} P_{\ell,m}(\cos\vartheta)\, e^{im\left(\phi_{R_\perp}-\phi_p\right)}\, H_1^{\perp|\ell,m\rangle}(z, M_h, |\boldsymbol{p}_T|)\ ,$$

- Angular Momentum (AM) eigenvalues |ℓ,m>
- Terms for *s*-wave and *p*-wave interference: *ss, sp, pp* (up to ℓ=2)
- Correlations of dihadron AM with fragmenting quark AM

Even more from dihadrons...

Flavor-dependence of twist-3 PDFs



Proton Target

Deuteron Target

Channel dependence of DiFFs

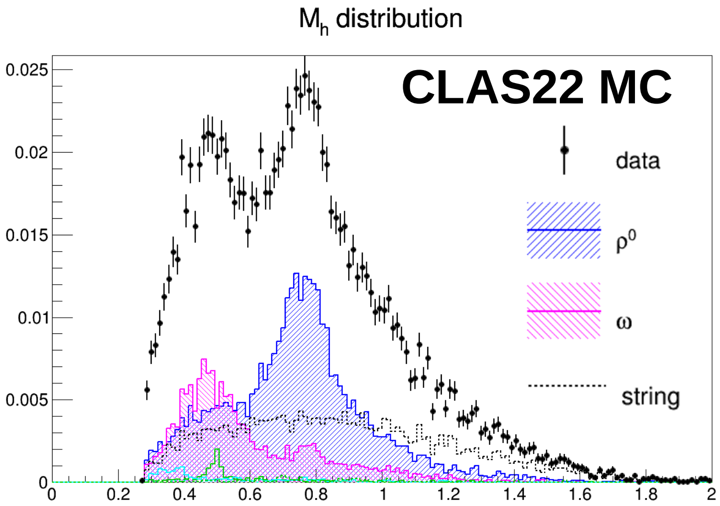
$$\begin{matrix} D_1^{q/\pi^+\pi^-} & & D_1^{q/\pi^\pm\pi^0} \\ G_1^{q/\pi^+\pi^-} & \neq & G_1^{q/\pi^\pm\pi^0} \\ H_1^{q/\pi^+\pi^-} & & H_1^{q/\pi^\pm\pi^0} \end{matrix}$$

Vector Mesons: a significant fraction of dihadrons

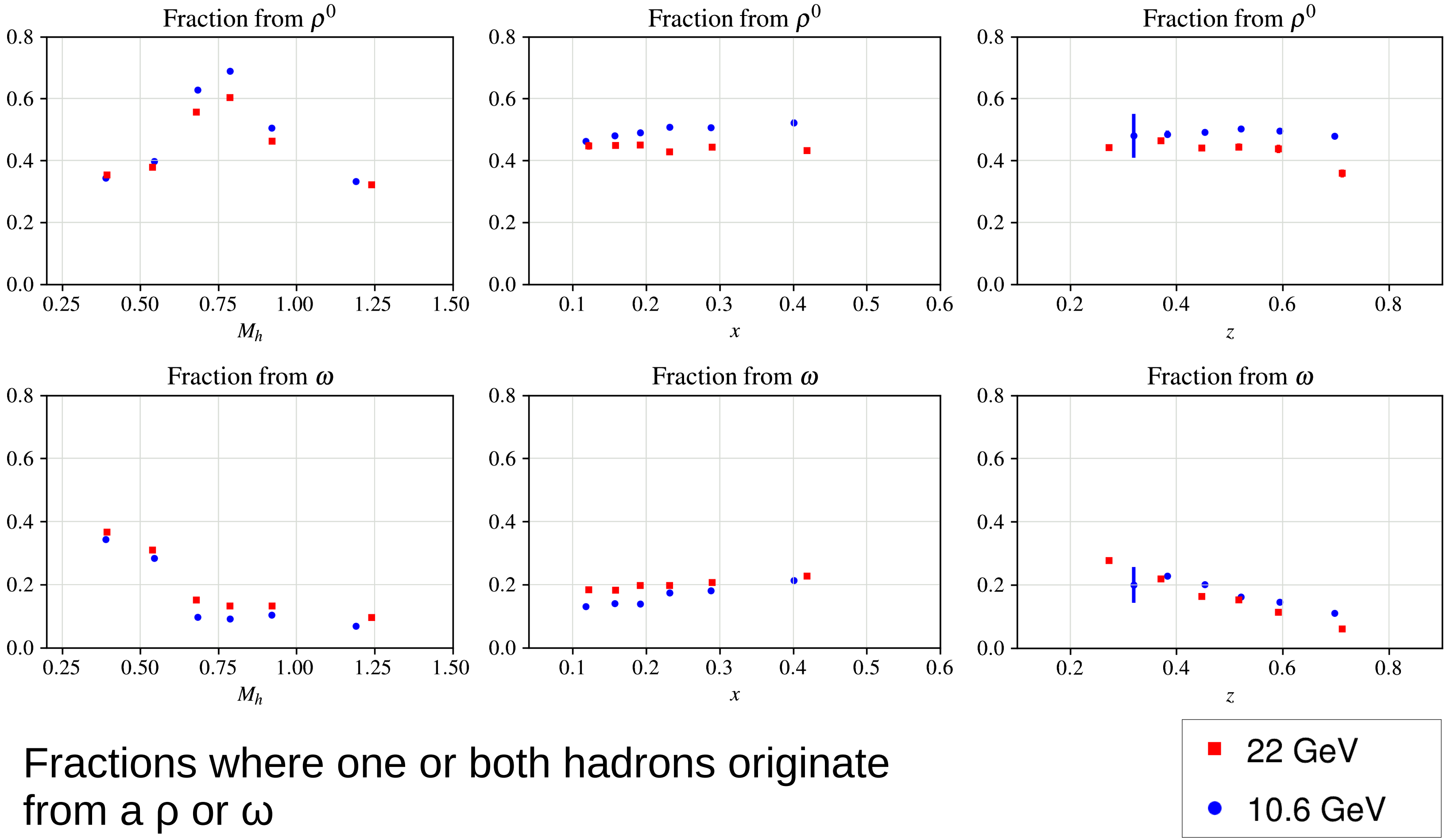
$$\rho \to \pi\pi$$

$$K^* \to \pi K$$

$$\phi \to KK$$



Fractions from Vector Mesons at CLAS



Fractions where one or both hadrons originate from a ρ or ω

Full Dihadron Cross Section

Twist 2

Target Polarization

Beam Polarization

	U	**L**	**T**
U	$f_1 D_1$ $h_1^\perp H_1$	$h_{1L}^\perp H_1$ $g_{1L} G_1$	$f_{1T}^\perp D_1$ $g_{1T} G_1$ $h_1 H_1$ $h_{1T}^\perp H_1$
L	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

Twist 3

Target Polarization

Beam Polarization

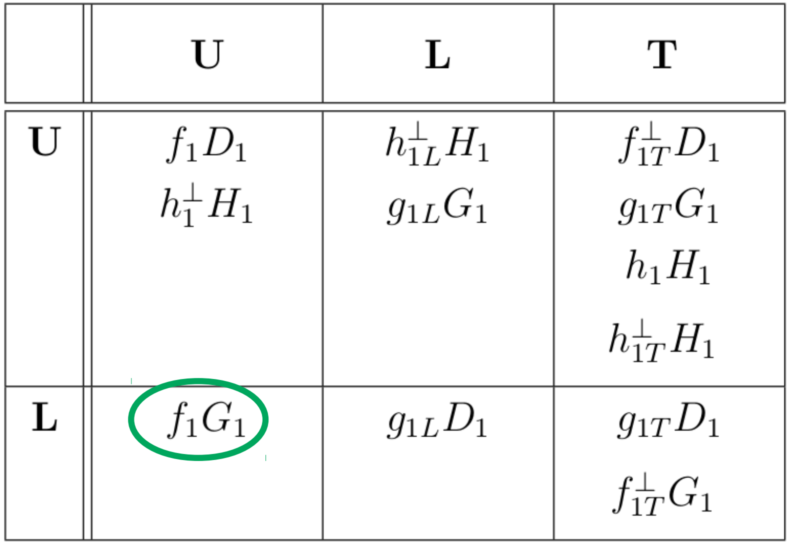
	U	**L**	**T**
U	$h H_1 \quad f_1 \tilde{D}$ $f^\perp D_1 \quad h_1^\perp \tilde{H}$	$h_L H_1 \quad g_{1L} \tilde{G}$ $f_L^\perp D_1 \quad h_{1L}^\perp \tilde{H}$	$f_T D_1 \quad h_1 \tilde{H}$ $h_T H_1 \quad g_{1T} \tilde{G}$ $h_T^\perp H_1 \quad f_{1T}^\perp \tilde{D}$ $f_T^\perp D_1 \quad h_{1T}^\perp \tilde{H}$
L	$e H_1 \quad f_1 \tilde{G}$ $g^\perp D_1 \quad h_1^\perp \tilde{E}$	$e_L H_1 \quad g_{1L} \tilde{D}$ $g_L^\perp D_1 \quad h_{1L}^\perp \tilde{E}$	$g_T D_1 \quad h_1 \tilde{E}$ $e_T H_1 \quad g_{1T} \tilde{D}$ $e_T^\perp H_1 \quad f_{1T}^\perp \tilde{G}$ $g_T^\perp D_1 \quad h_{1T}^\perp \tilde{E}$

Full Dihadron Cross Section

Twist 2

Target Polarization

Beam Polarization



	U	L	T
U	$f_1 D_1$ $h_1^\perp H_1$	$h_{1L}^\perp H_1$ $g_{1L} G_1$	$f_{1T}^\perp D_1$ $g_{1T} G_1$ $h_1 H_1$ $h_{1T}^\perp H_1$
L	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

A_{LU}

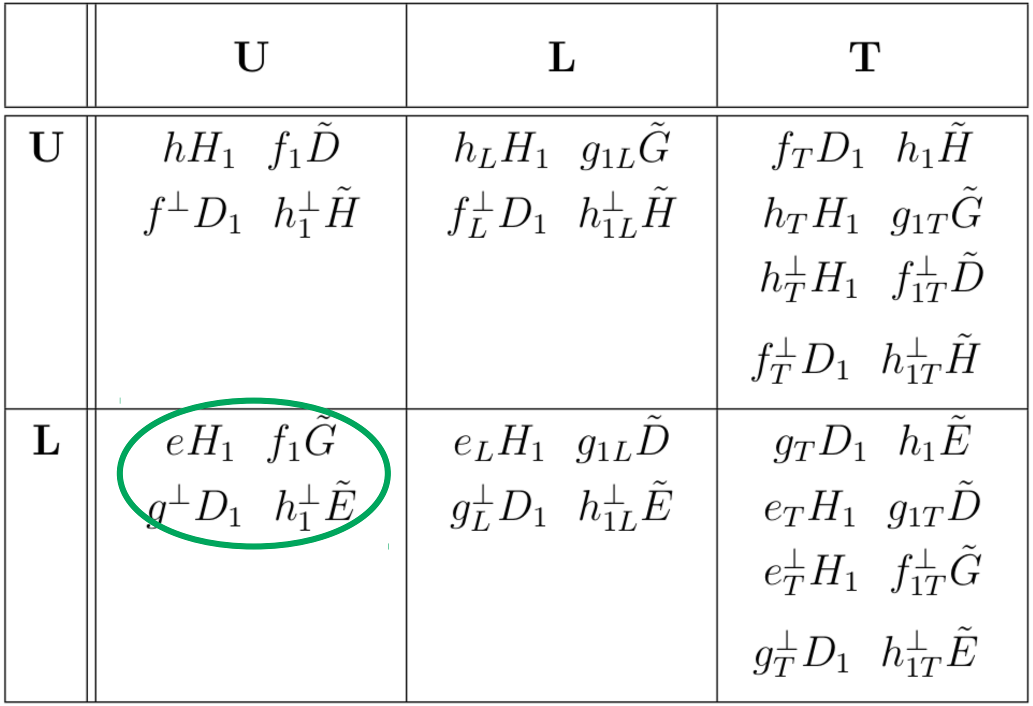
- **2018-2020**
- **RG-A, RG-B**

- Helicity DiFF G_1
- Twist-3 e(x)

Twist 3

Target Polarization

Beam Polarization



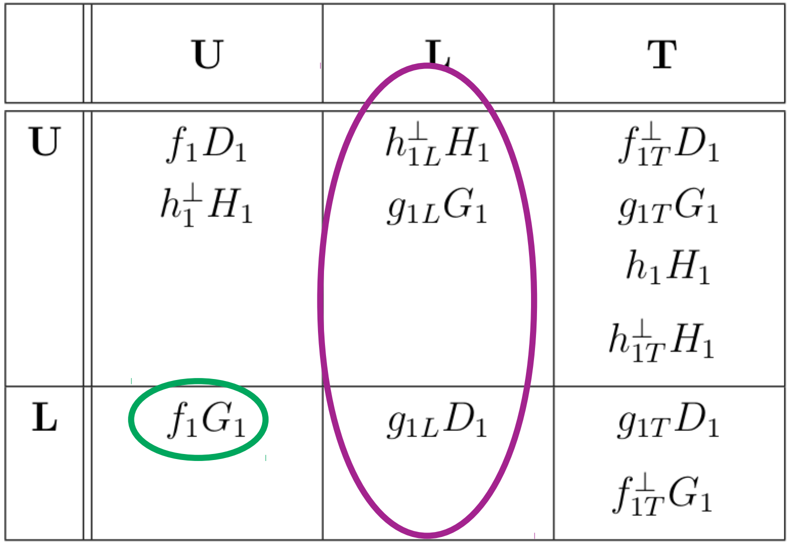
	U	L	T
U	hH_1 $f_1\tilde{D}$ $f^\perp D_1$ $h_1^\perp \tilde{H}$	$h_L H_1$ $g_{1L}\tilde{G}$ $f_L^\perp D_1$ $h_{1L}^\perp \tilde{H}$	$f_T D_1$ $h_1\tilde{H}$ $h_T H_1$ $g_{1T}\tilde{G}$ $h_T^\perp H_1$ $f_{1T}^\perp \tilde{D}$ $f_T^\perp D_1$ $h_{1T}^\perp \tilde{H}$
L	eH_1 $f_1\tilde{G}$ $g^\perp D_1$ $h_1^\perp \tilde{E}$	$e_L H_1$ $g_{1L}\tilde{D}$ $g_L^\perp D_1$ $h_{1L}^\perp \tilde{E}$	$g_T D_1$ $h_1\tilde{E}$ $e_T H_1$ $g_{1T}\tilde{D}$ $e_T^\perp H_1$ $f_{1T}^\perp \tilde{G}$ $g_T^\perp D_1$ $h_{1T}^\perp \tilde{E}$

Full Dihadron Cross Section

Twist 2

Target Polarization

Beam Polarization



	U	L	T
U	$f_1 D_1$ $h_1^\perp H_1$	$h_{1L}^\perp H_1$ $g_{1L} G_1$	$f_{1T}^\perp D_1$ $g_{1T} G_1$ $h_1 H_1$ $h_{1T}^\perp H_1$
L	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

$A_{UL},\ A_{LL}$

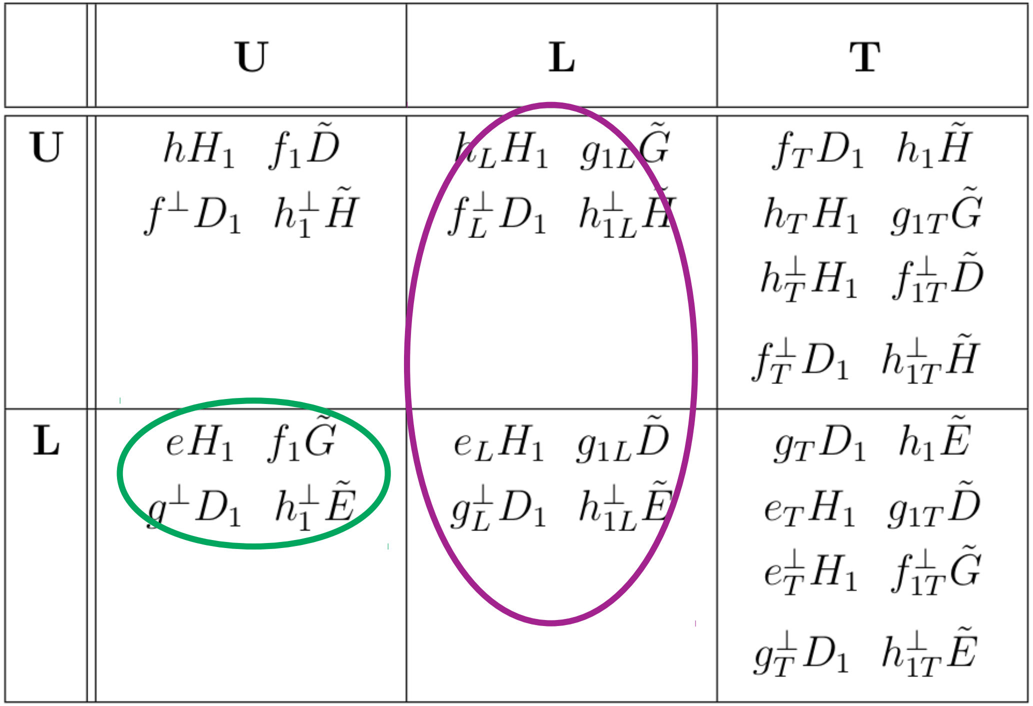
- **2022-2023**
- **RG-C**

- Twist-3 $h_L(x)$
- Helicity $g_{1L}(x)$
- Kotzinian-Mulders
- Constrain twist-3 DiFFs

Twist 3

Target Polarization

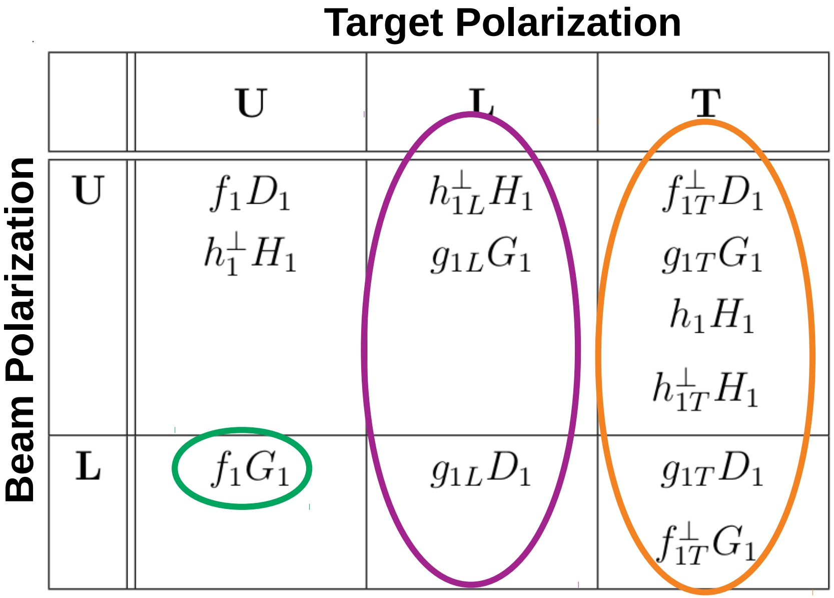
Beam Polarization



	U	L	T
U	$h H_1 \quad f_1 \tilde{D}$ $f^\perp D_1 \quad h_1^\perp \tilde{H}$	$h_L H_1 \quad g_{1L} \tilde{G}$ $f_L^\perp D_1 \quad h_{1L}^\perp \tilde{H}$	$f_T D_1 \quad h_1 \tilde{H}$ $h_T H_1 \quad g_{1T} \tilde{G}$ $h_T^\perp H_1 \quad f_{1T}^\perp \tilde{D}$ $f_T^\perp D_1 \quad h_{1T}^\perp \tilde{H}$
L	$e H_1 \quad f_1 \tilde{G}$ $g^\perp D_1 \quad h_1^\perp \tilde{E}$	$e_L H_1 \quad g_{1L} \tilde{D}$ $g_L^\perp D_1 \quad h_{1L}^\perp \tilde{E}$	$g_T D_1 \quad h_1 \tilde{E}$ $e_T H_1 \quad g_{1T} \tilde{D}$ $e_T^\perp H_1 \quad f_{1T}^\perp \tilde{G}$ $g_T^\perp D_1 \quad h_{1T}^\perp \tilde{E}$

Full Dihadron Cross Section

Twist 2



Target Polarization

Beam Polarization

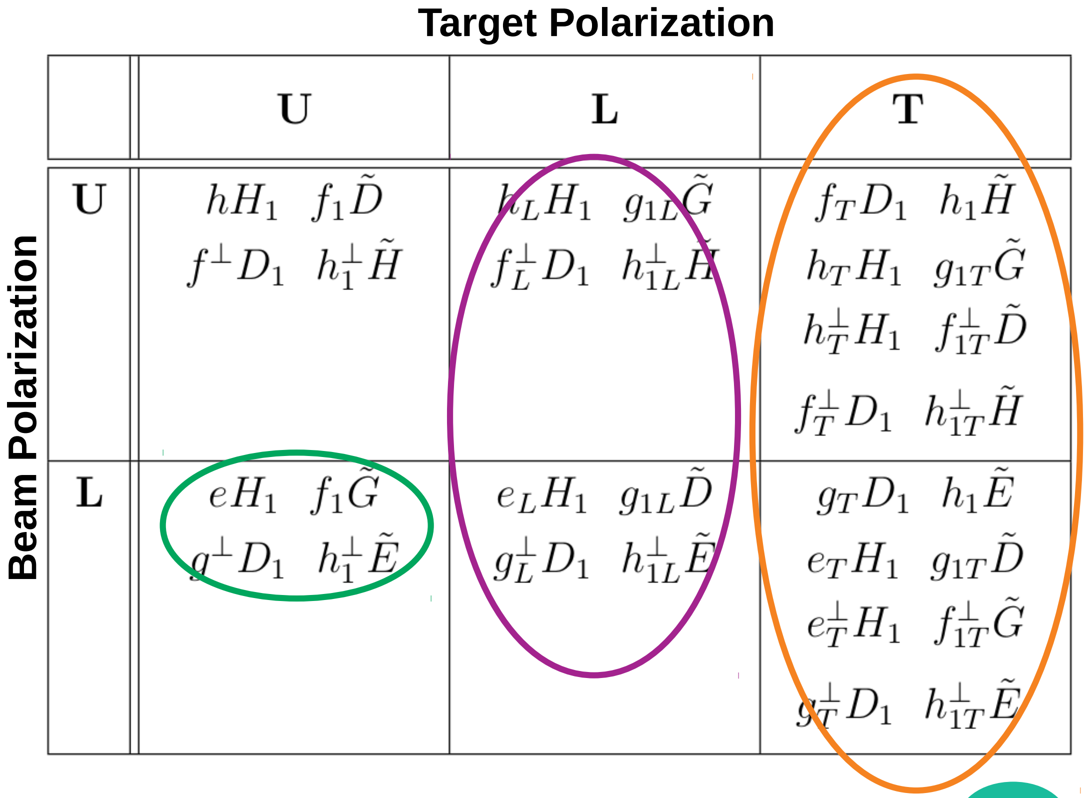
	U	L	T
U	$f_1 D_1$ $h_1^\perp H_1$	$h_{1L}^\perp H_1$ $g_{1L} G_1$	$f_{1T}^\perp D_1$ $g_{1T} G_1$ $h_1 H_1$ $h_{1T}^\perp H_1$
L	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

$A_{UT}, \ A_{LT}$

- TO DO

- Many more observables
- Sivers
- Transversity x Collins
- Twist-3 $g_T(x)$

Twist 3



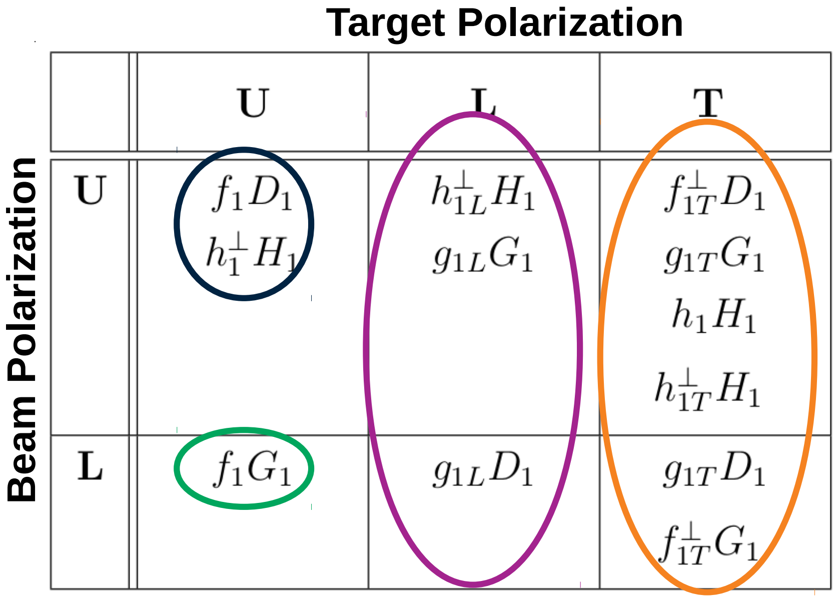
Target Polarization

Beam Polarization

	U	L	T
U	hH_1 $f_1\tilde{D}$ $f^\perp D_1$ $h_1^\perp \tilde{H}$	$h_L H_1$ $g_{1L}\tilde{G}$ $f_L^\perp D_1$ $h_{1L}^\perp \tilde{H}$	$f_T D_1$ $h_1\tilde{H}$ $h_T H_1$ $g_{1T}\tilde{G}$ $h_T^\perp H_1$ $f_{1T}^\perp \tilde{D}$ $f_T^\perp D_1$ $h_{1T}^\perp \tilde{H}$
L	eH_1 $f_1\tilde{G}$ $g^\perp D_1$ $h_1^\perp \tilde{E}$	$e_L H_1$ $g_{1L}\tilde{D}$ $g_L^\perp D_1$ $h_{1L}^\perp \tilde{E}$	$g_T D_1$ $h_1\tilde{E}$ $e_T H_1$ $g_{1T}\tilde{D}$ $e_T^\perp H_1$ $f_{1T}^\perp \tilde{G}$ $g_T^\perp D_1$ $h_{1T}^\perp \tilde{E}$

Full Dihadron Cross Section

Twist 2



Target Polarization

Beam Polarization

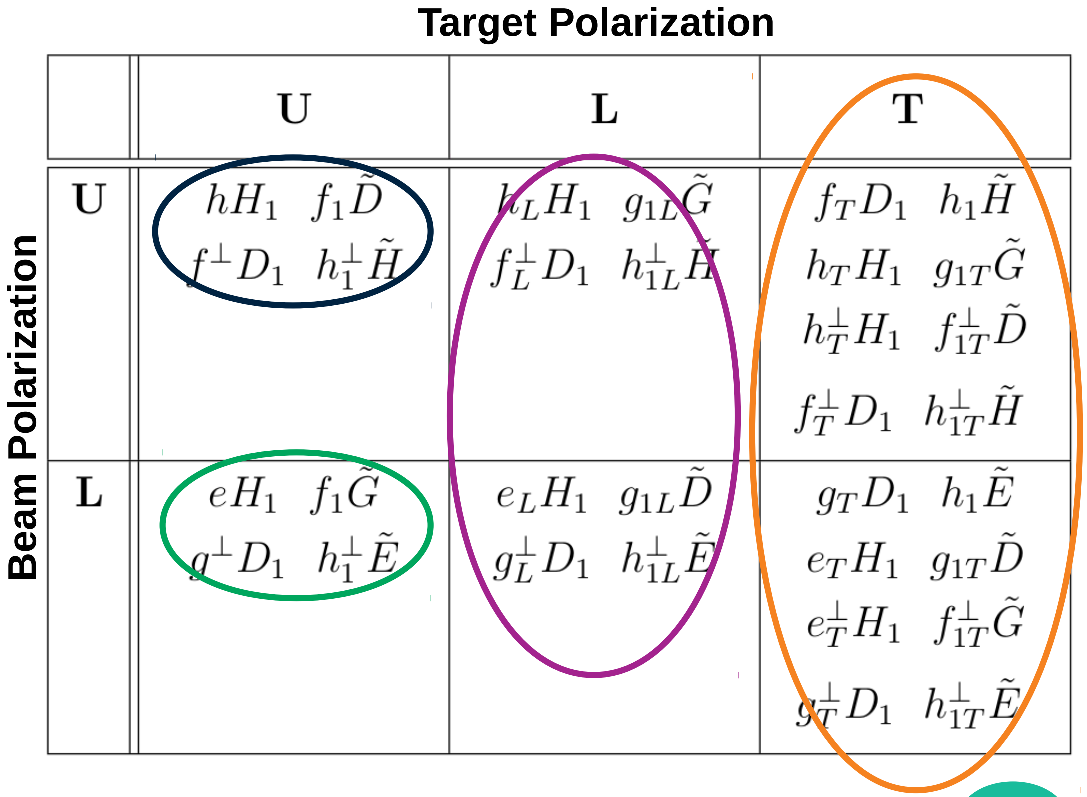
	U	L	T
U	$f_1 D_1$ $h_1^\perp H_1$	$h_{1L}^\perp H_1$ $g_{1L} G_1$	$f_{1T}^\perp D_1$ $g_{1T} G_1$ $h_1 H_1$ $h_{1T}^\perp H_1$
L	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

F_{UU}

- **Anytime!**

- Boer-Mulders
- $F_{UU,L}$
- …

Twist 3



Target Polarization

Beam Polarization

	U	L	T
U	$h H_1$ $f_1 \tilde{D}$ $f^\perp D_1$ $h_1^\perp \tilde{H}$	$h_L H_1$ $g_{1L} \tilde{G}$ $f_L^\perp D_1$ $h_{1L}^\perp \tilde{H}$	$f_T D_1$ $h_1 \tilde{H}$ $h_T H_1$ $g_{1T} \tilde{G}$ $h_T^\perp H_1$ $f_{1T}^\perp \tilde{D}$ $f_T^\perp D_1$ $h_{1T}^\perp \tilde{H}$
L	$e H_1$ $f_1 \tilde{G}$ $g^\perp D_1$ $h_1^\perp \tilde{E}$	$e_L H_1$ $g_{1L} \tilde{D}$ $g_L^\perp D_1$ $h_{1L}^\perp \tilde{E}$	$g_T D_1$ $h_1 \tilde{E}$ $e_T H_1$ $g_{1T} \tilde{D}$ $e_T^\perp H_1$ $f_{1T}^\perp \tilde{G}$ $g_T^\perp D_1$ $h_{1T}^\perp \tilde{E}$

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  - Comparisons to ePIC
- **Recent Measurements at CLAS**
  - Beam spin asymmetry
  - Partial waves
  - Kinematic comparisons 10.6 → 22 GeV

Depolarization

$$d\sigma_{XY} \boxed{\propto D(x,y,Q^2)} \cdot S(\phi_h, \phi_R, \phi_S, \theta) \cdot F_{XY}^{S(\phi,\dots)} + \dots$$

Depolarization

Sinusoidal modulation

Structure Function

Ratio of longitudinal and transverse photon flux

$$\epsilon = \frac{1 - y - \frac{1}{4}\gamma^2 y^2}{1 - y + \frac{1}{2}y^2 + \frac{1}{4}\gamma^2 y^2}$$

Depolarization factors at twist-2

$$\boxed{A(\epsilon, y)} = \frac{y^2}{2(1-\epsilon)} \qquad \boxed{B(\epsilon, y)} = \frac{y^2}{2(1-\epsilon)}\epsilon$$

$$\boxed{C(\epsilon, y)} = \frac{y^2}{2(1-\epsilon)}\sqrt{1-\epsilon^2}$$

at twist-3

$$\boxed{V(\epsilon, y)} = \frac{y^2}{2(1-\epsilon)}\sqrt{2\epsilon(1+\epsilon)}$$

$$\boxed{W(\epsilon, y)} = \frac{y^2}{2(1-\epsilon)}\sqrt{2\epsilon(1-\epsilon)}$$

Depolarization

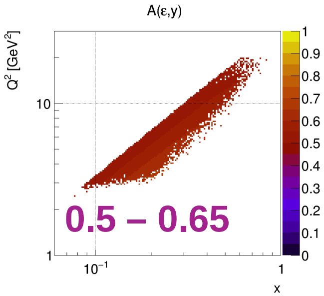
		Twist 2	Twist 3
unpolarized	**UU**	A, B	V
unpolarized electron	**UL, UT**	B/A	V/A
longitudinally polarized electron	**LU, LL, LT**	C/A	W/A

Depolarization at CLAS22

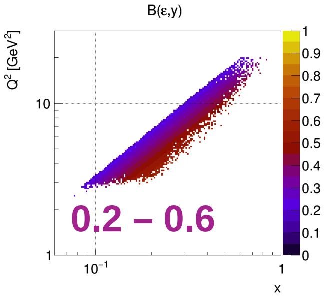
Twist 2 | **Twist 3**

unpolarized

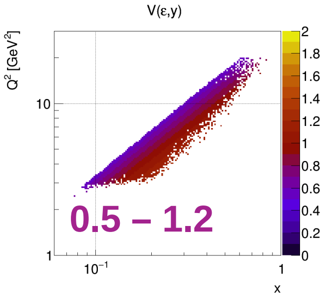
UU



0.5 – 0.65



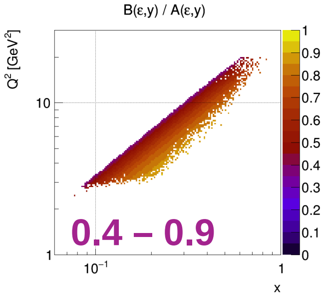
0.2 – 0.6



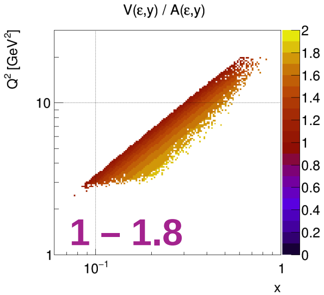
0.5 – 1.2

unpolarized electron

UL, UT



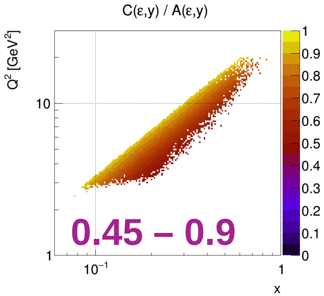
0.4 – 0.9



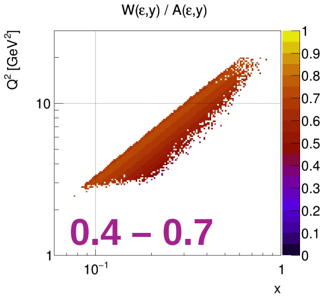
1 – 1.8

longitudinally polarized electron

LU, LL, LT



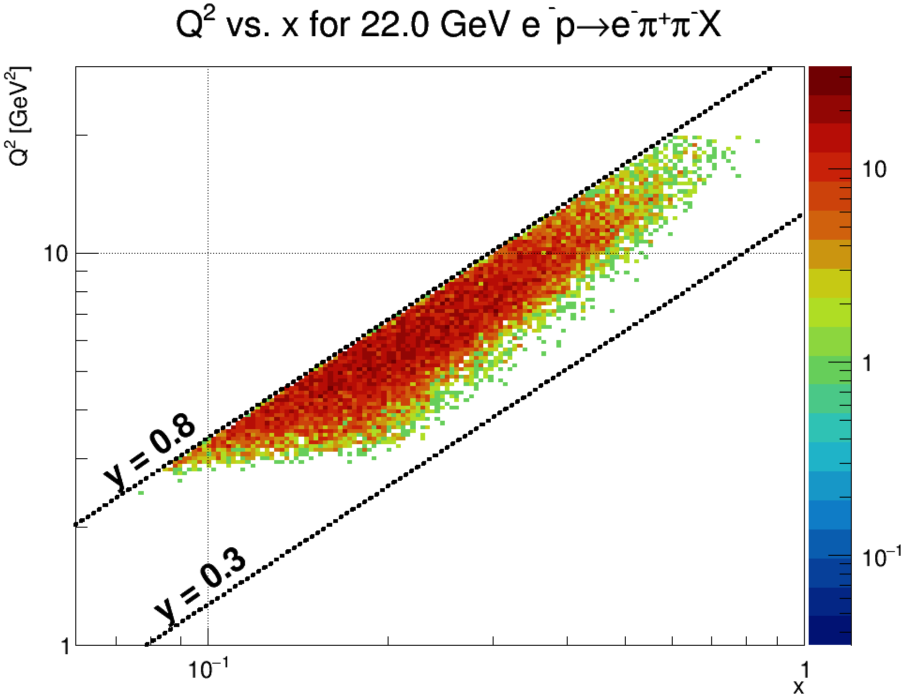
0.45 – 0.9



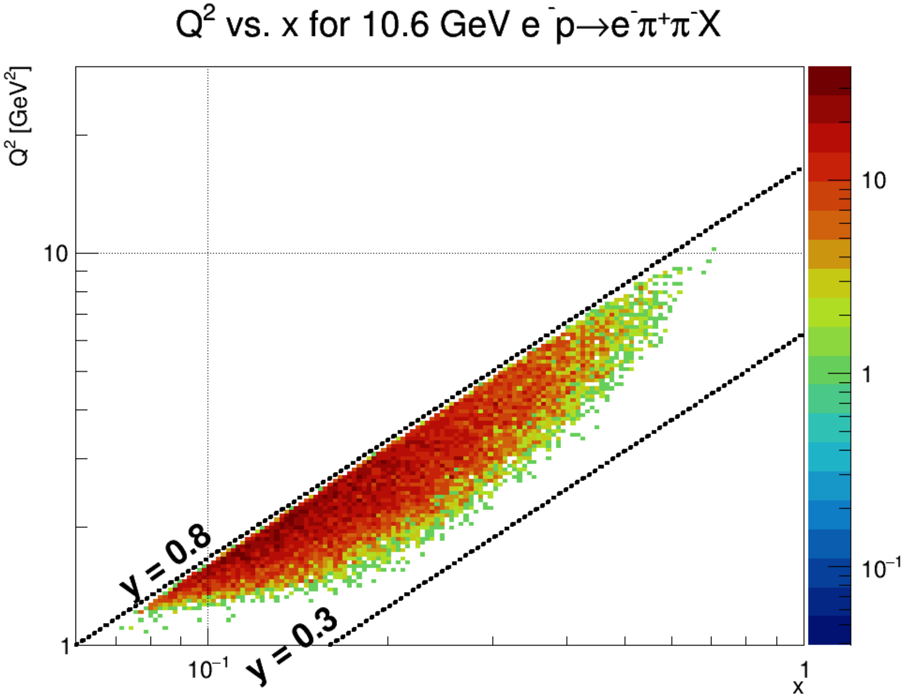
0.4 – 0.7

- Depolarization vs. (x,Q^2) plane
- Moderate range of depolarization factors (approx. ranges labeled on plots)
- Reasonably large values overall
- B is a bit small

Q² vs. x at CLAS22



cf. CLAS12



Depolarization & Statistics → Impact at CLAS22

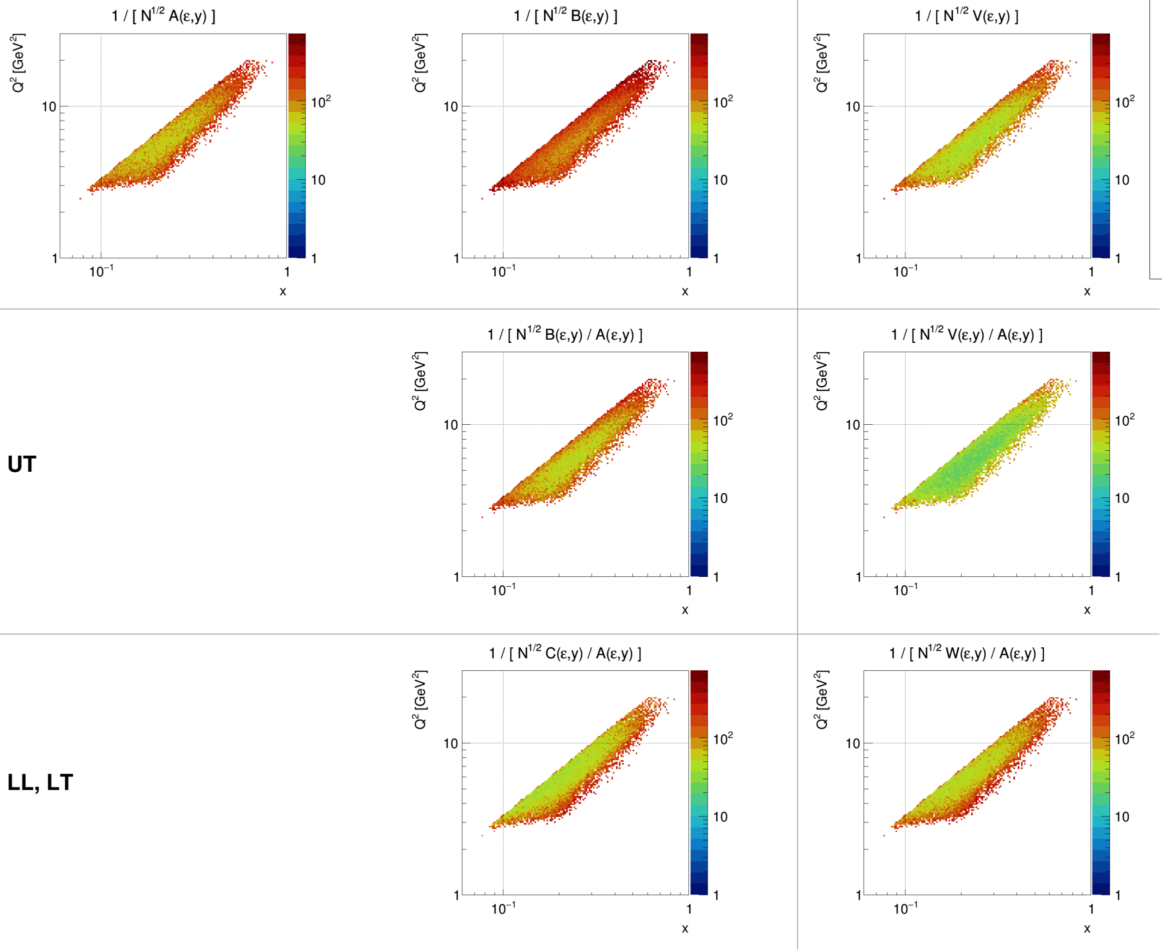
- Impact shown is proportional to expected stat. unc. (smaller is better)
- Good impact in particular for twist 3

Twist 2 **Twist 3**

unpolarized **UU**

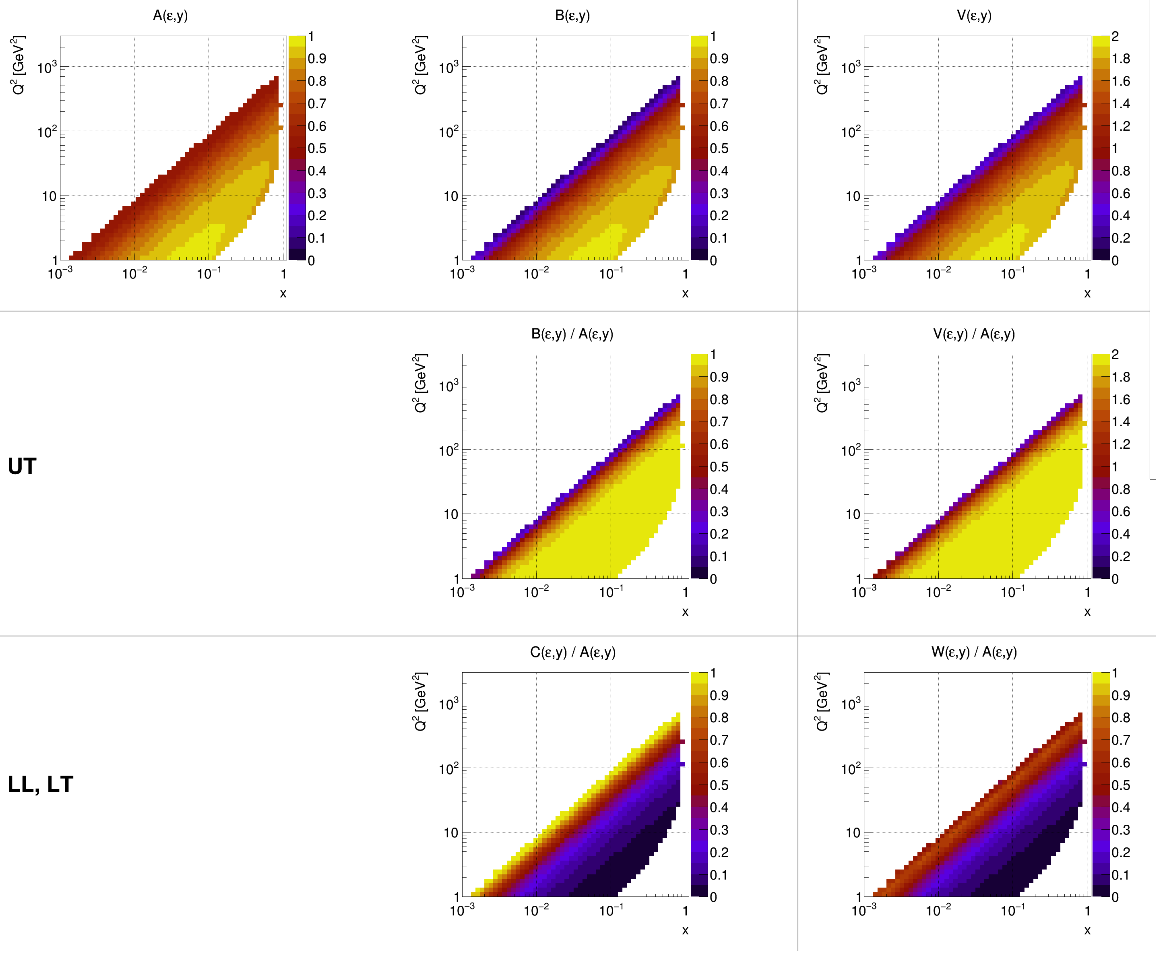
unpolarized electron **UL, UT**

longitudinally polarized electron **LU, LL, LT**



Depolarization at ePIC – 5x41

Twist 2 **Twist 3**



unpolarized

UU

unpolarized electron

UL, UT

longitudinally polarized electron

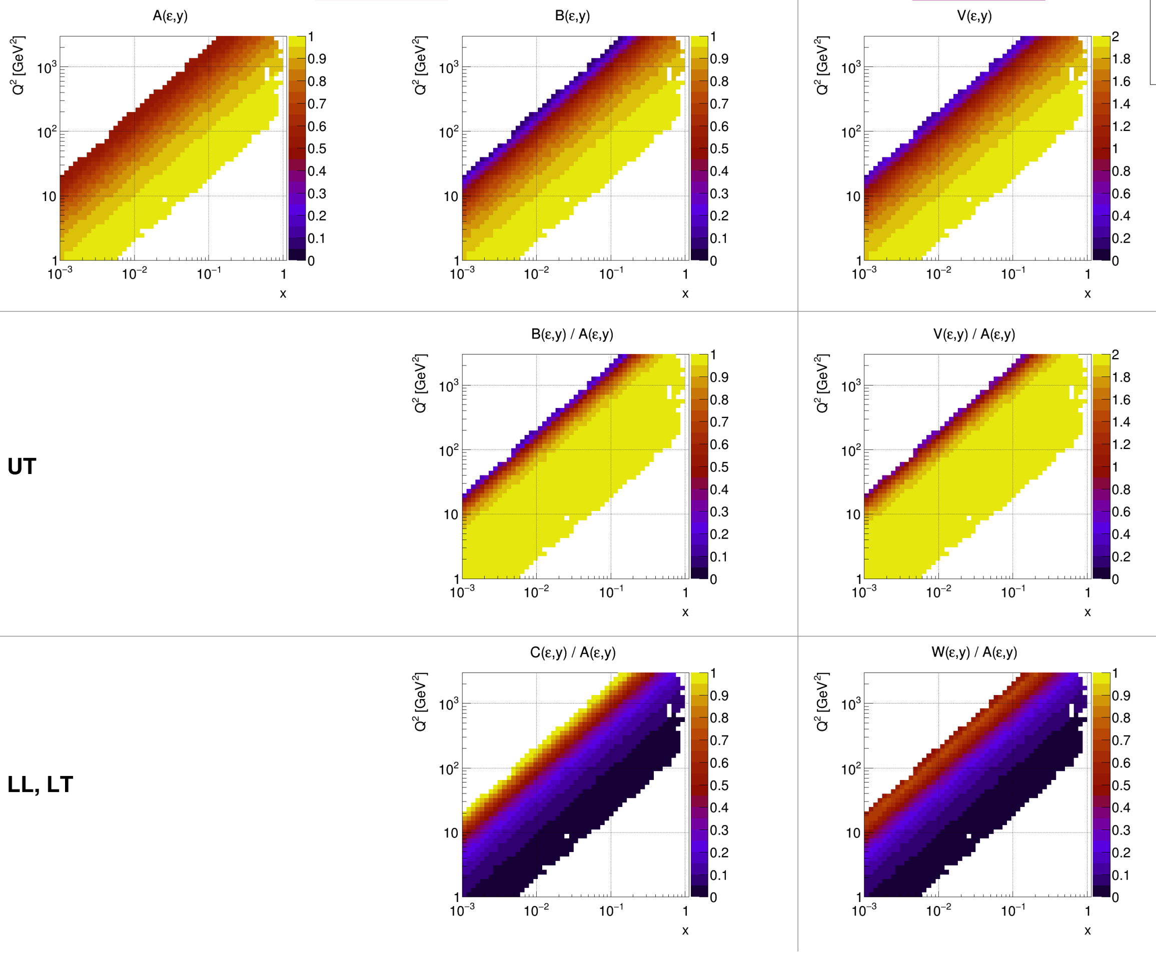
LU, LL, LT

- Most depol. factors are reasonably large; opportunity for complementarity
- C/A and W/A at ePIC are relatively smaller
- Restricted impact of asymmetries with a longitudinally polarized electron

Depolarization at ePIC – 18x275

Twist 2

Twist 3



unpolarized

UU

unpolarized electron

UL, UT

longitudinally polarized electron

LU, LL, LT

- Similar story at high energy

Depolarization and Accessibility

		Polarization	Depolarization
Twist 2	Boer-Mulders	UU	B
	Sivers	UT	1
	Transversity	UT	B/A
	Kotzinian-Mulders	UL	B/A
	Wormgear (LT)	LT	C/A
	Helicity DiFF $G_1^\perp$	LU	C/A
		UL	1
Twist 3	e(x)	LU	W/A
	h_L(x)	UL	V/A
	g_T(x)	LT	W/A

Longitudinally polarized electron?
More accessible at JLab than at higher √s

Depolarization and Accessibility

Twist 2

	Polarization	Depolarization
Boer-Mulders	UU	B
Sivers	UT	1
Transversity	UT	B/A
Kotzinian-Mulders	UL	B/A
Wormgear (LT)	LT	C/A
Helicity DiFF $G_1^{\perp}$	LU	C/A
	UL	1
e(x)	LU	W/A
$h_L(x)$	UL	V/A
$g_T(x)$	LT	W/A

Twist 3

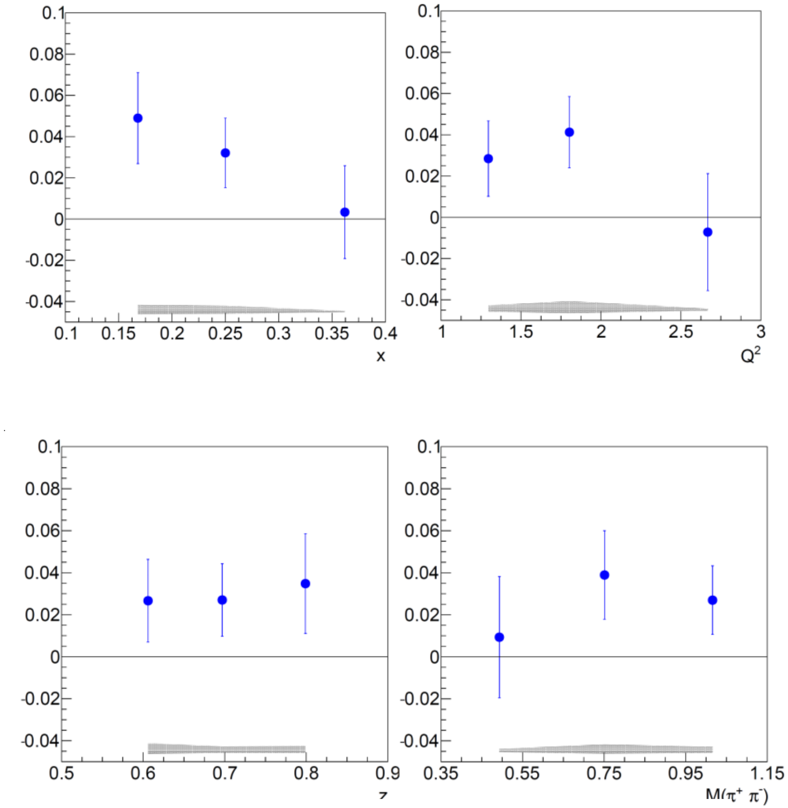
Accessible at JLab and EIC, in complementary (x,Q2) regions

Outline

- **Dihadron Introduction**
  - Kinematics
  - Cross Section
  - Observables
- **Depolarization**
  - Accessibility at CLAS 22 GeV
  - Comparisons to ePIC
- **Recent Measurements at CLAS**
  - Beam spin asymmetry
  - Partial waves
  - Kinematic comparisons 10.6 → 22 GeV

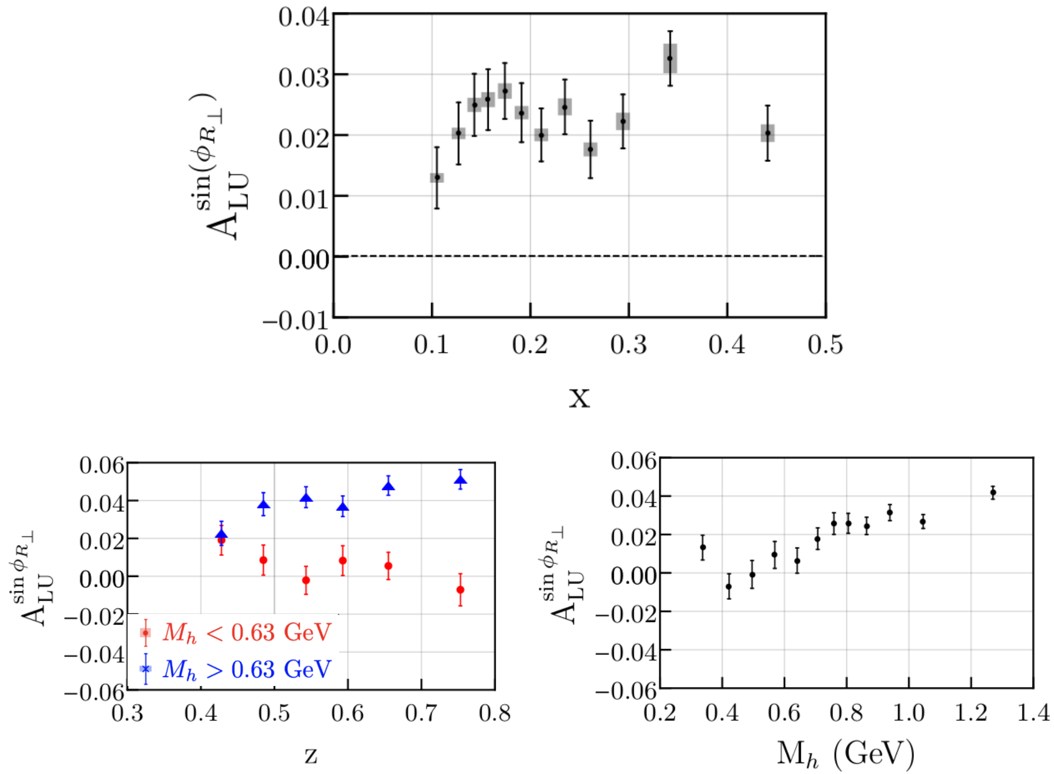
Dihadron Beam Spin Asymmetry at CLAS

$\text{CLAS6 } \pi^+\pi^- \; A_{LU}^{\sin\phi_R}$



Phys.Rev.Lett. 126 (2021) 6, 062002

$\text{CLAS12 } \pi^+\pi^- \; A_{LU}^{\sin\phi_R}$

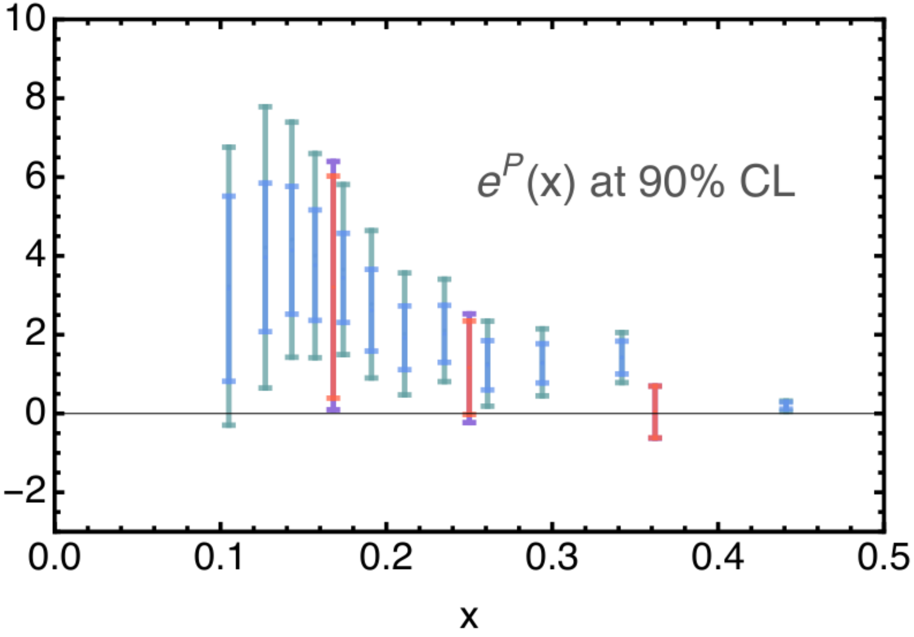


Phys.Rev.Lett. 126 (2021) 152501

Recent e(x) extraction (proton flavor)

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

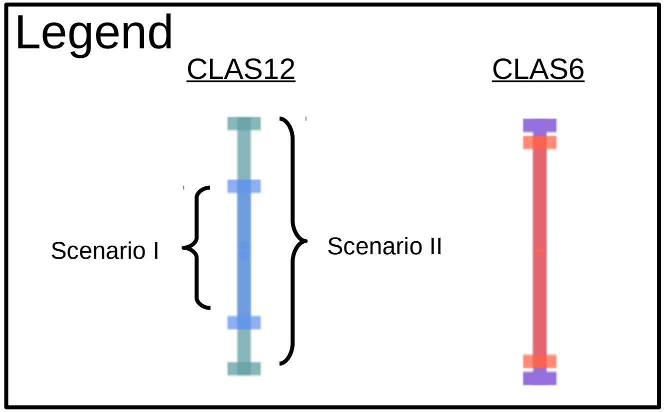
twist-3 DiFF



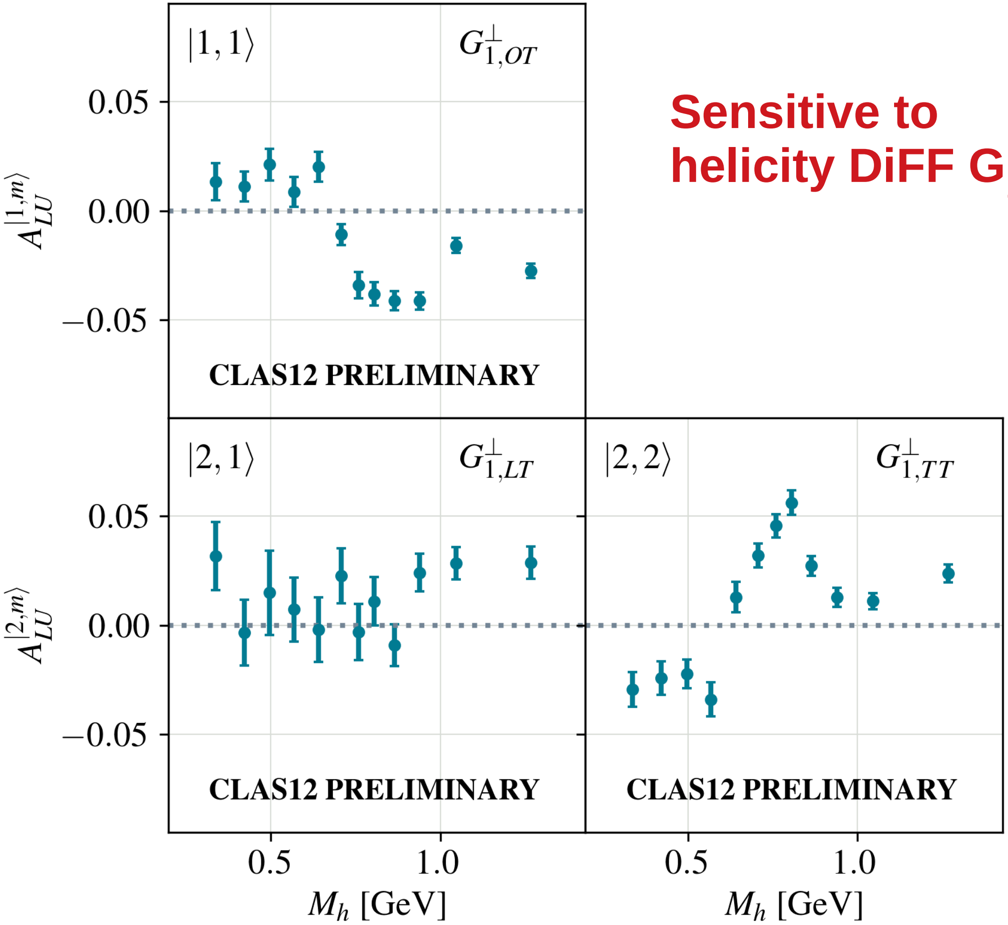
Courtoy, Aurore, et al. e-Print: 2203.14975 [hep-ph]

Courtoy, Aurore – CPHI 2022

- **Scenario I: Wandzura-Wilczek (WW) Approximation**
  - Drop twist-3 DiFF
- **Scenario II: Beyond WW approximation**
  - Estimate max integrated twist-3 DiFF from COMPASS A_{UL} and A_{LL}



Twist-2 A_{LU} Partial Waves

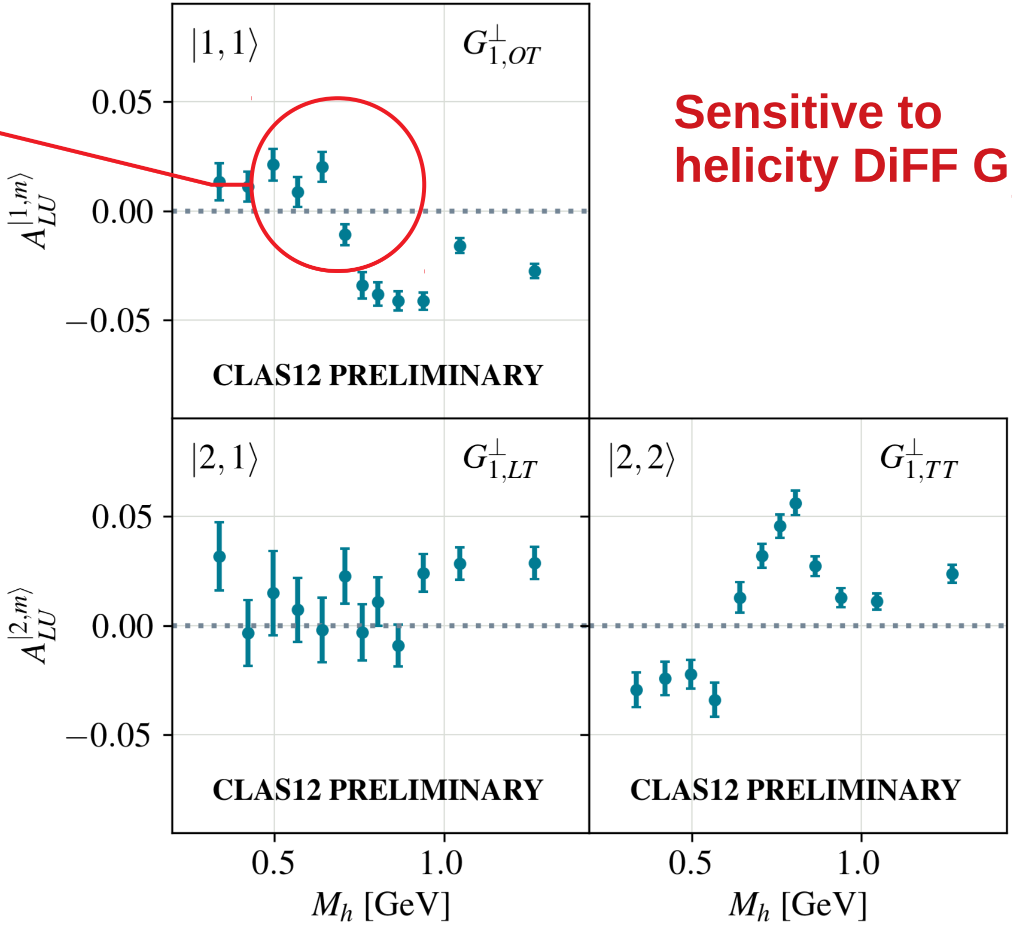


Sensitive to helicity DiFF G_1

e-Print: 2107.12965 [hep-ex]

Twist-2 A_{LU} Partial Waves

Sign change near ρ mass



Sensitive to helicity DiFF G_1

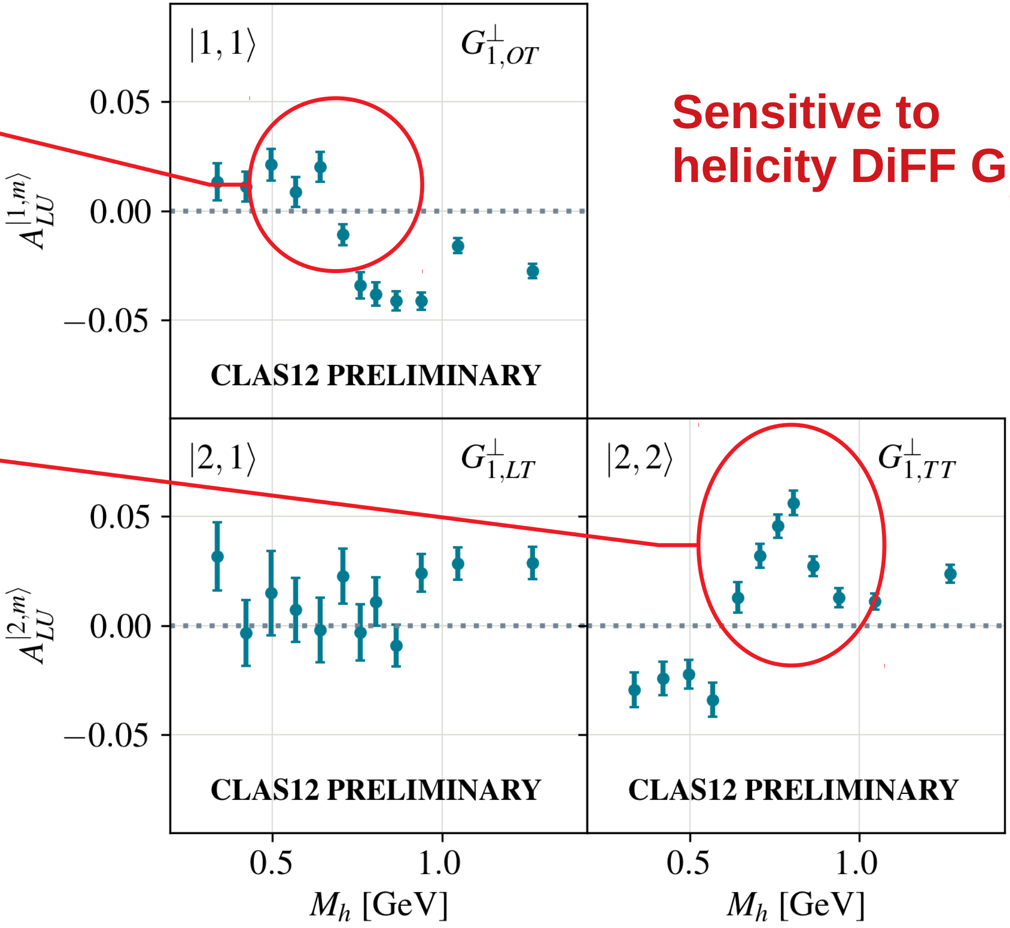
e-Print: 2107.12965 [hep-ex]

Twist-2 A_{LU} Partial Waves

Sign change near ρ mass

Enhancement at ρ mass (and a sign change)

ρ meson → p-wave $\pi^+\pi^-$

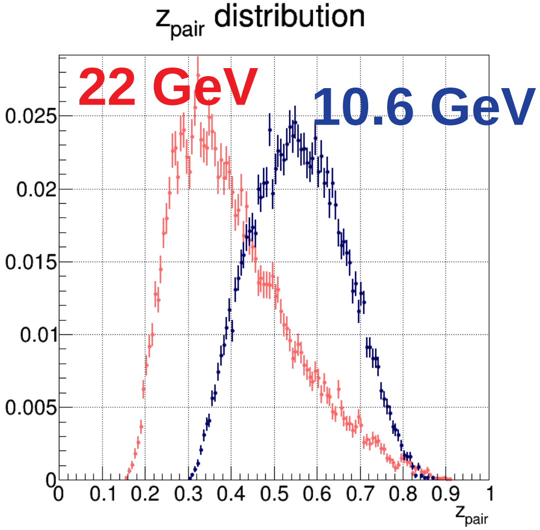


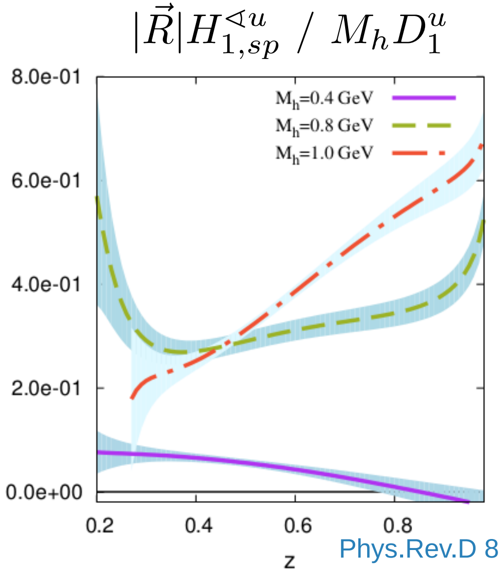
Sensitive to helicity DiFF G_1

e-Print: 2107.12965 [hep-ex]

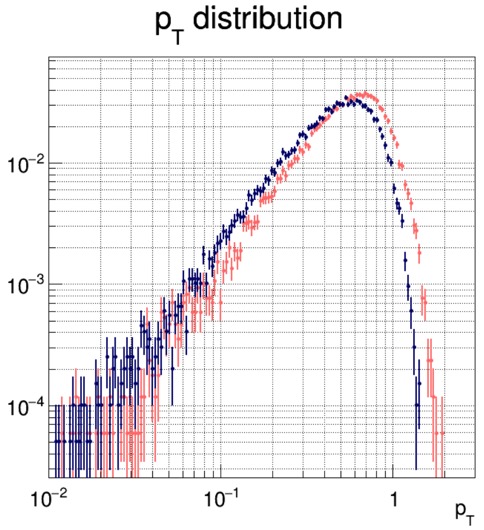
z and p_T

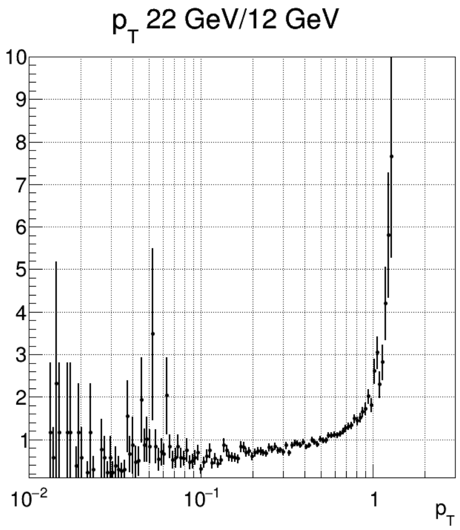
- Access DiFFs at lower z at 22 GeV
- H_1 large at low z around M_ρ?
- Higher p_T at 22 GeV





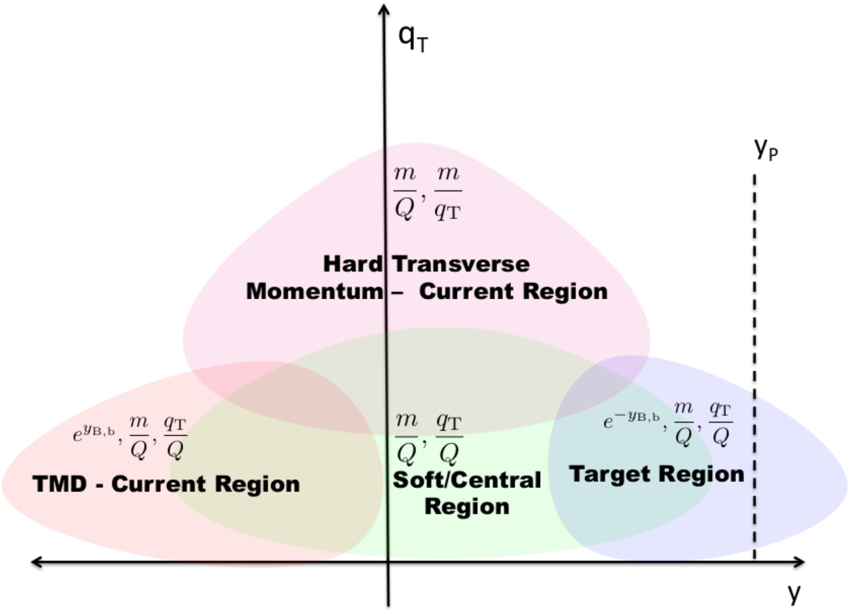
Phys.Rev.D 85 (2012) 114023

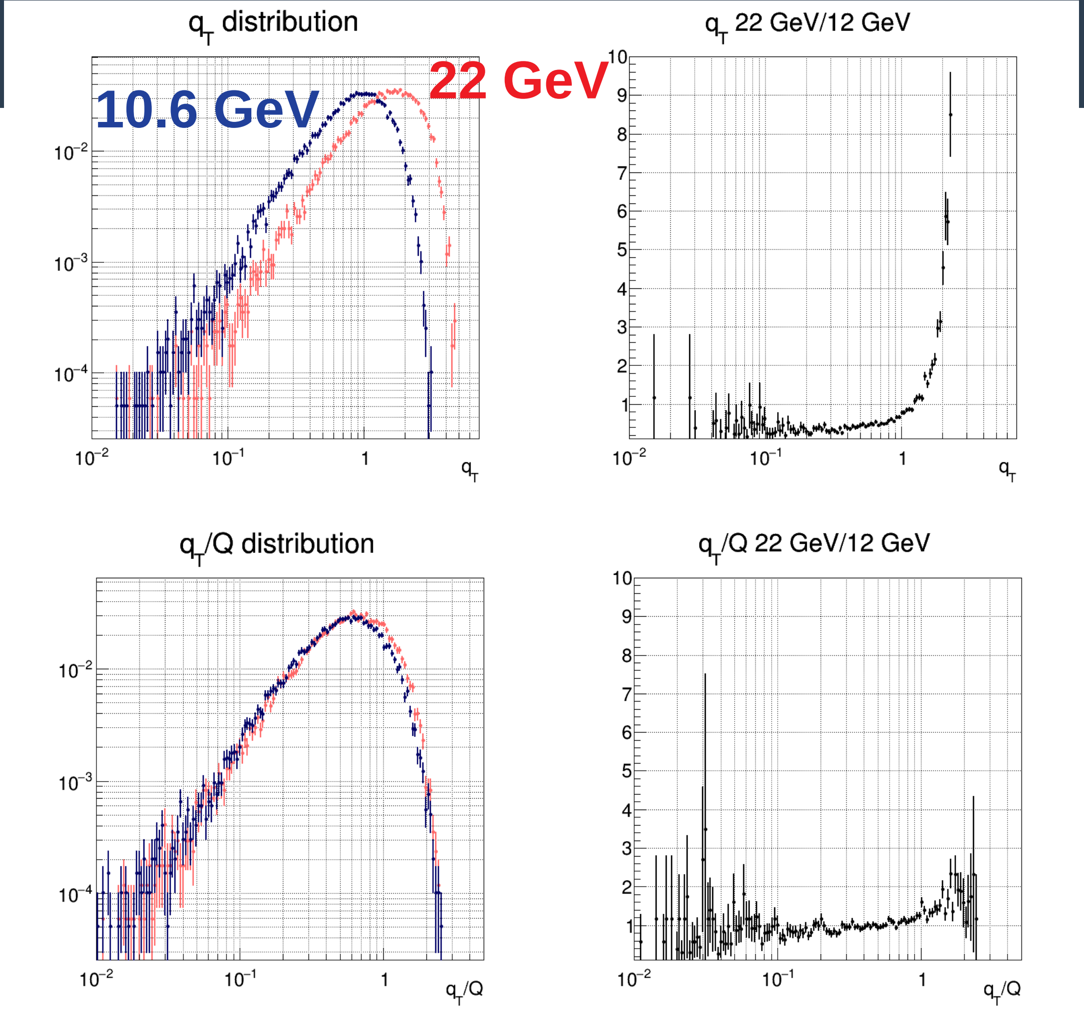




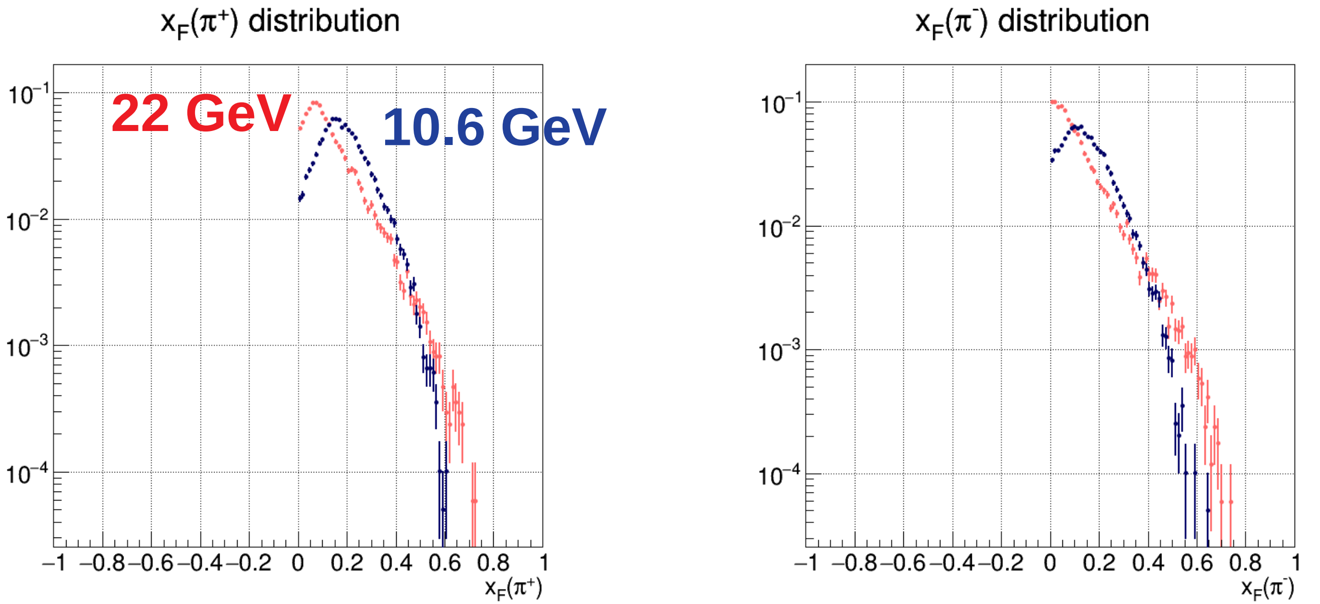
q_T and q_T/Q

- Higher q_T at 22 GeV
- Similar q_T/Q





Feynman-x



- Smaller average x_F at 22 GeV
  - (note: cutting on $x_F>0$)
- Careful about TFR/CFR separation…

Summary

- **Dihadrons probe a wide range of TMDs and fragmentation functions**
  - Ongoing analyses and ongoing experiments
  - A lot to do…
- **CLAS experiment ideal for constraining collinear twist-3 PDFs**
  - Especially for beam spin and double spin asymmetries
- **For dihadrons, a 22 GeV Upgrade would provide:**
  - Improved overlap between ePIC, JLab, and other SIDIS experiments
  - Probe DiFFs at lower z, higher p_T, and higher q_T

backup

Differential Cross Section

General form of each term:

$$d\sigma_{XY} \boxed{\propto D(x,y,Q^2)} \cdot S(\phi_h,\phi_R,\phi_S,\theta) \cdot F_{XY}^{S(\phi,\dots)} + \dots$$

Depolarization

Sinusoidal modulation

Structure Function

Ratio of longitudinal and transverse photon flux

$$\epsilon = \frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2}$$

Depolarization factors at twist-2

$$\boxed{A(\epsilon,y)} = \frac{y^2}{2(1-\epsilon)} \qquad \boxed{B(\epsilon,y)} = \frac{y^2}{2(1-\epsilon)}\epsilon$$

$$\boxed{C(\epsilon,y)} = \frac{y^2}{2(1-\epsilon)}\sqrt{1-\epsilon^2}$$

at twist-3

$$\boxed{V(\epsilon,y)} = \frac{y^2}{2(1-\epsilon)}\sqrt{2\epsilon(1+\epsilon)}$$

$$\boxed{W(\epsilon,y)} = \frac{y^2}{2(1-\epsilon)}\sqrt{2\epsilon(1-\epsilon)}$$

Differential Cross Section

General form of each term:

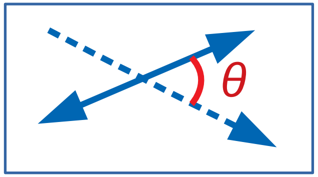
$$d\sigma_{XY} \propto D(x,y,Q^2) \cdot \boxed{S(\phi_h,\phi_R,\phi_S,\theta)} \cdot F_{XY}^{S(\phi,\dots)} + \dots$$

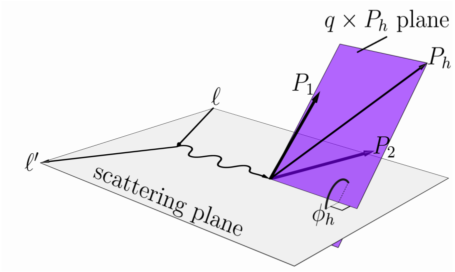
Depolarization

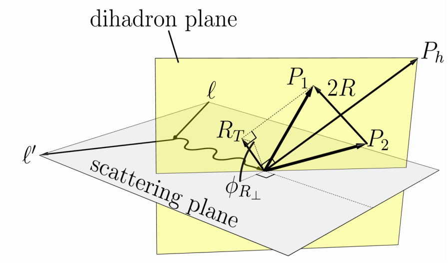
Sinusoidal modulation

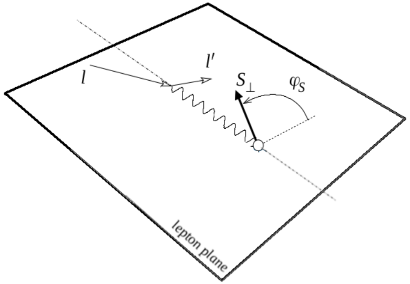
Structure Function

Legendre Polynomial x Sine (Cosine) azimuthal modulation









Differential Cross Section

General form of each term:

$$d\sigma_{XY} \propto D(x,y,Q^2)\cdot S(\phi_h,\phi_R,\phi_S,\theta)\cdot \boxed{F_{XY}^{S(\phi,\dots)}} + \dots$$

Depolarization

Sinusoidal modulation

Structure Function

Structure Function

$$F_{XY} = \mathcal{I}\left[w(\mathbf{k}_T,\mathbf{p}_T,x,z,M_h,\dots)\cdot f(x,k_T)\cdot D(z,M_h,pT)+\dots\right]$$

$$\mathcal{I}\left[wfD\right]$$

quark transverse
momentum convolution

kinematic factor
(usually quark momentum
vector products)

TMD
PDF

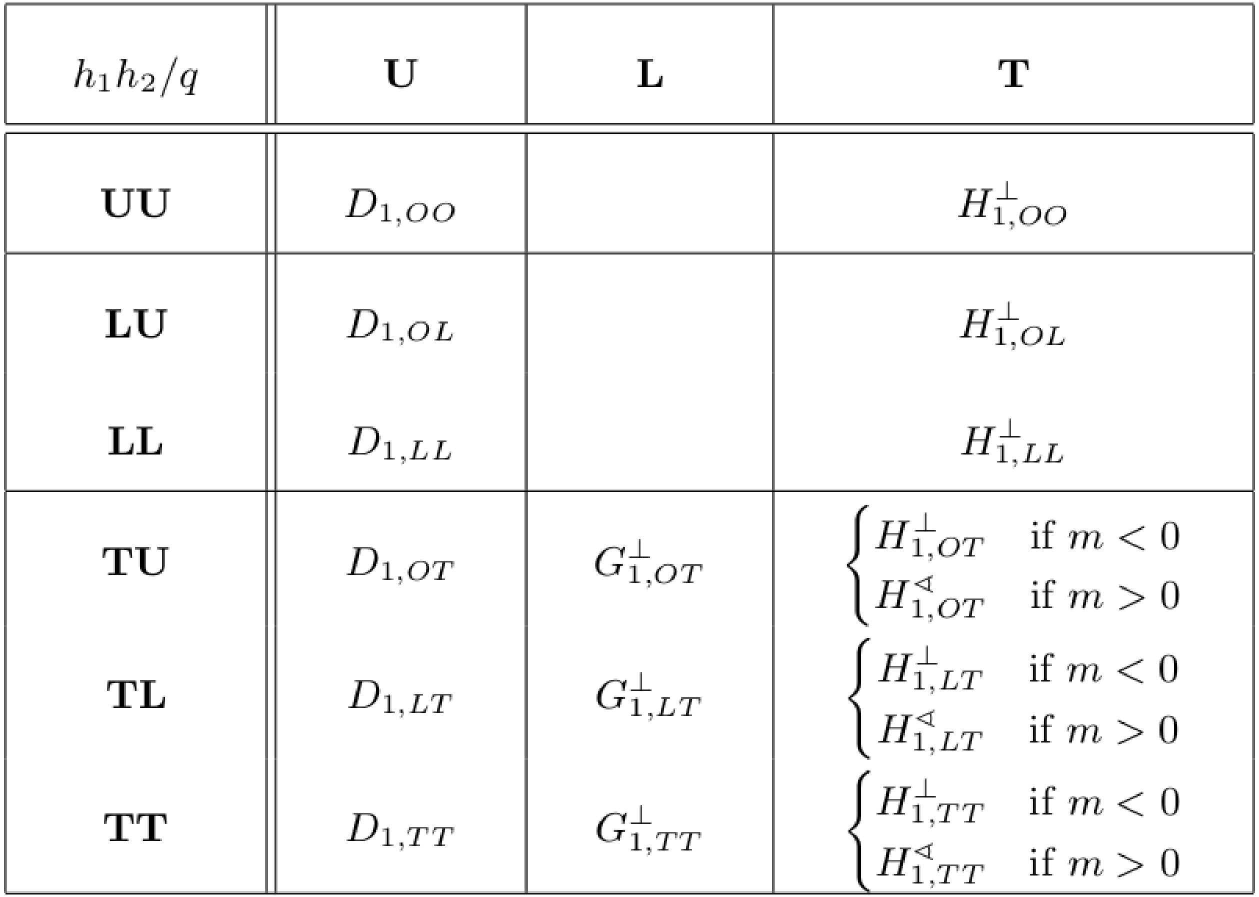
DiFF

Dihadron
Fragmentation Function

DiFF Partial Waves

Fragmenting Quark Polarization

Dihadron Interference Polarizations



$h_1 h_2/q$	**U**	**L**	**T**
UU	$D_{1,OO}$		$H_{1,OO}^{\perp}$
LU	$D_{1,OL}$		$H_{1,OL}^{\perp}$
LL	$D_{1,LL}$		$H_{1,LL}^{\perp}$
TU	$D_{1,OT}$	$G_{1,OT}^{\perp}$	$\begin{cases} H_{1,OT}^{\perp} & \text{if } m < 0 \\ H_{1,OT}^{\sphericalangle} & \text{if } m > 0 \end{cases}$
TL	$D_{1,LT}$	$G_{1,LT}^{\perp}$	$\begin{cases} H_{1,LT}^{\perp} & \text{if } m < 0 \\ H_{1,LT}^{\sphericalangle} & \text{if } m > 0 \end{cases}$
TT	$D_{1,TT}$	$G_{1,TT}^{\perp}$	$\begin{cases} H_{1,TT}^{\perp} & \text{if } m < 0 \\ H_{1,TT}^{\sphericalangle} & \text{if } m > 0 \end{cases}$

Partial Wave Fit for Beam Spin Asymmetries

Twist 2

3 terms

$$G_1^{\perp,|\ell,0\rangle} = 0$$

$$G_1^{\perp,|\ell,m\rangle} = G_1^{\perp,|\ell,-m\rangle}$$

$\|1,1\rangle$ $G_{1,OT}^{\perp}$	
$\|2,1\rangle$ $G_{1,LT}^{\perp}$	$\|2,2\rangle$ $G_{1,TT}^{\perp}$

Twist 3

9 terms

		$\|0,0\rangle$ $H_{1,OO}^{\perp}$		
	$\|1,-1\rangle$ $H_{1,OT}^{\perp}$	$\|1,0\rangle$ $H_{1,OL}^{\perp}$	$\|1,1\rangle$ $H_{1,OT}^{\sphericalangle}$	
$\|2,-2\rangle$ $H_{1,TT}^{\perp}$	$\|2,-1\rangle$ $H_{1,LT}^{\perp}$	$\|2,0\rangle$ $H_{1,LL}^{\perp}$	$\|2,1\rangle$ $H_{1,LT}^{\sphericalangle}$	$\|2,2\rangle$ $H_{1,TT}^{\sphericalangle}$

12 Parameter Simultaneous Fit

Depolarization

- Depolarization factors depend on (x,y,Q^2)
- Asymmetry denominator:

$\int d\sigma_{UU} \sim A$

Depolarization Factors

	Twist 2	Twist 3
Unpolarized Beam	***A, B***	***V***
Longitudinal Beam	***C***	***W***

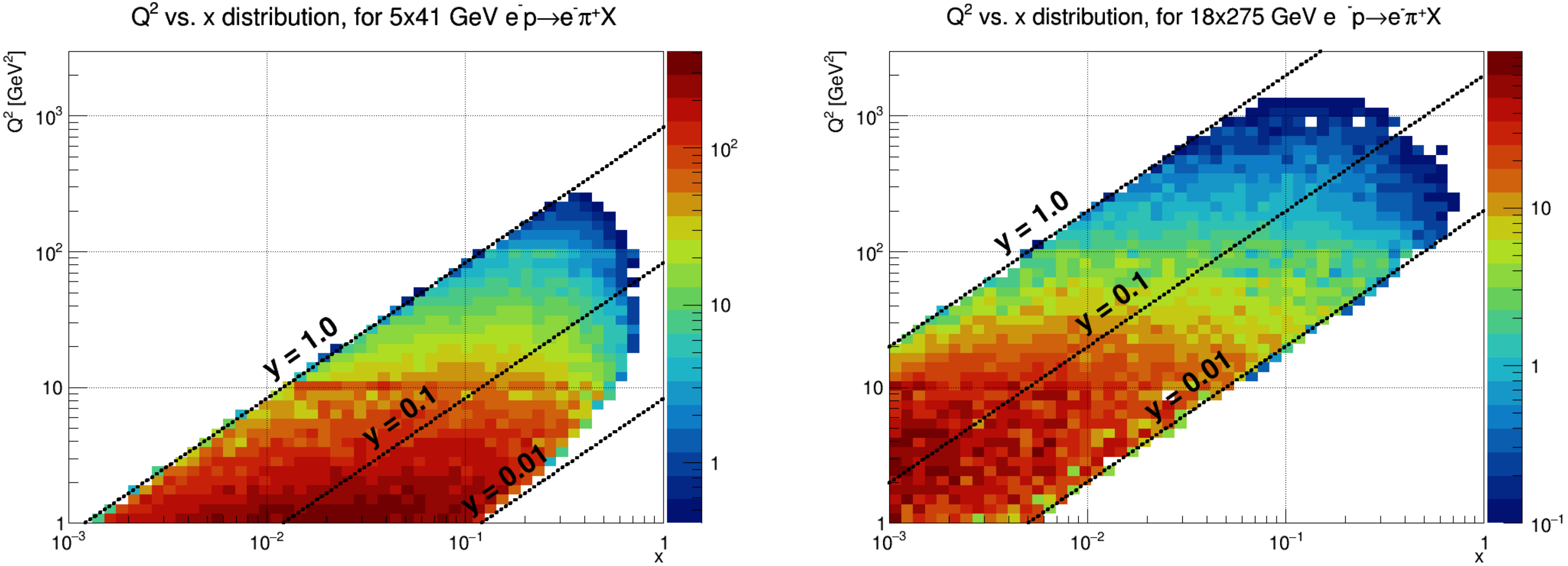
Asymmetry, for modulation $M(\theta, \phi_h, \phi_R, \phi_S)$

$D \in \{A, B, C, V, W\}$

Structure Functions

$$A_{XY}^{M} \propto \frac{D_{XY}^{M}}{A} \cdot \frac{F_{XY}^{M}}{F_{UU,T}^{\mathrm{const}} + \epsilon F_{UU,L}^{\mathrm{const}}}$$

Q² vs. x at ePIC

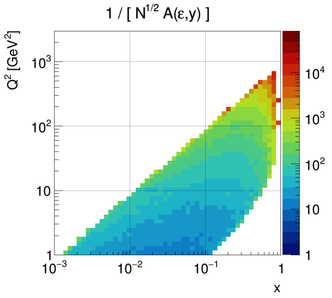


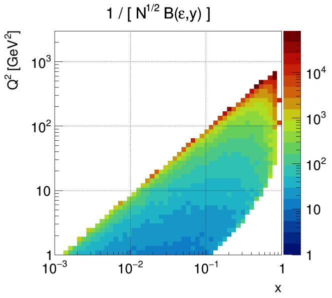
Depolarization & Statistics → Impact at ePIC 5x41

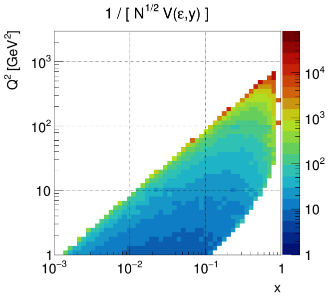
Twist 2

Twist 3

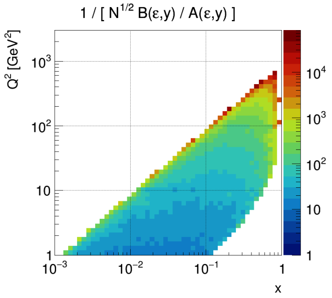
UU

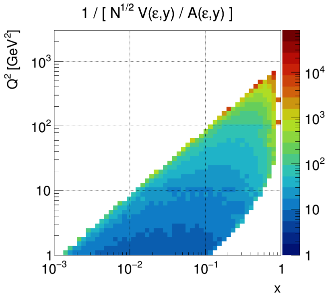




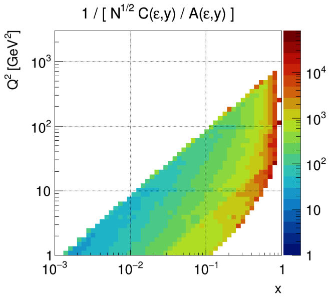


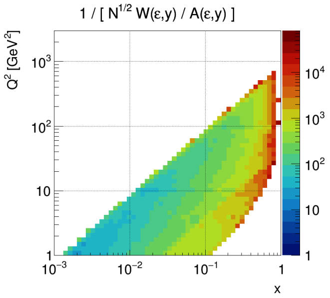
UL, UT





LU, LL, LT





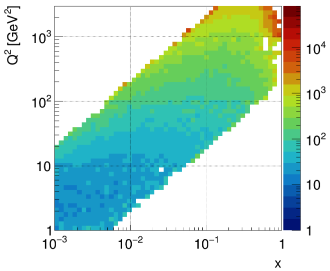
Depolarization & Statistics → Impact at ePIC 18x275

Twist 2

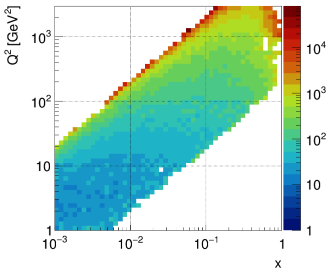
Twist 3

UU

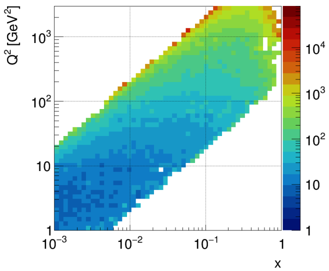
1 / [$N^{1/2}$ A(ε,y)]



1 / [$N^{1/2}$ B(ε,y)]

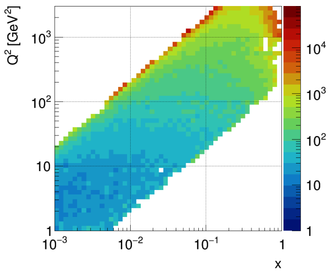


1 / [$N^{1/2}$ V(ε,y)]

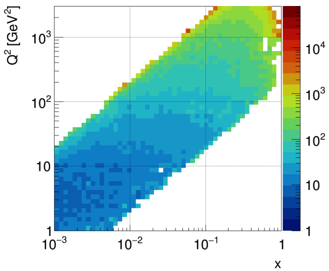


UL, UT

1 / [$N^{1/2}$ B(ε,y) / A(ε,y)]

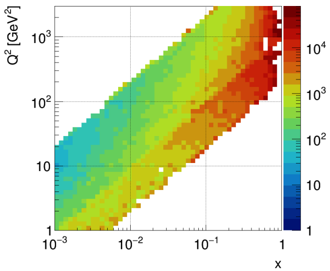


1 / [$N^{1/2}$ V(ε,y) / A(ε,y)]



LU, LL, LT

1 / [$N^{1/2}$ C(ε,y) / A(ε,y)]



1 / [$N^{1/2}$ W(ε,y) / A(ε,y)]