JLab Upgrade Opportunities for SIDIS Dihadrons at CLAS

Christopher Dilks

APCTP Focus Program

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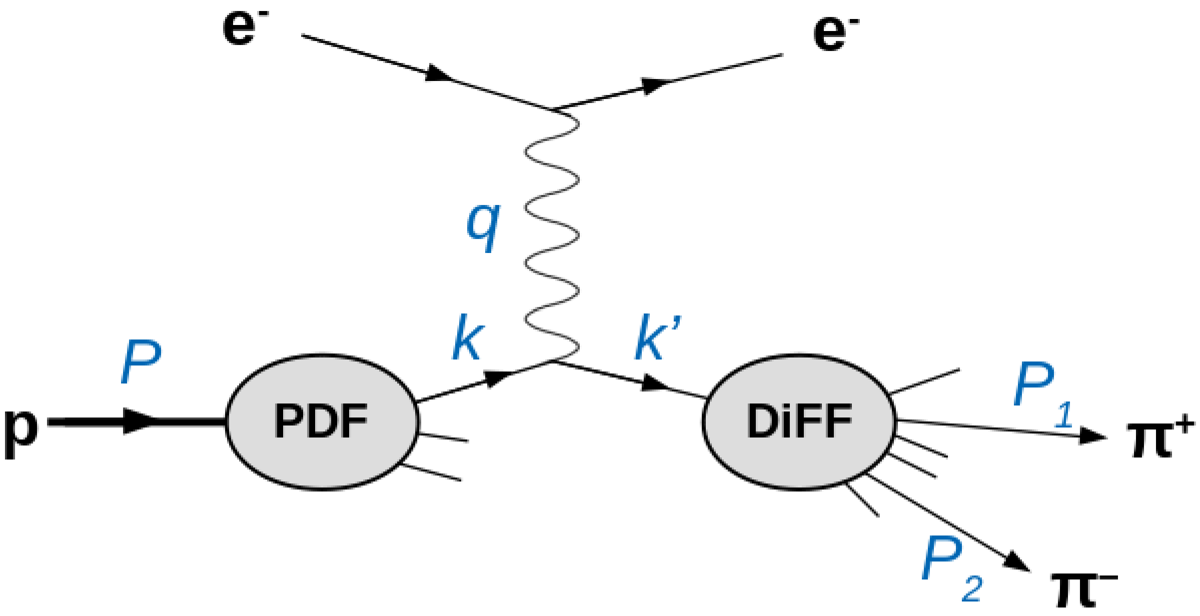
Outline

- Introduction to SIDIS dihadrons at CLAS
- Dihadron Cross Section
- Depolarization
- Comparison of kinematics: 10.6 GeV vs. 22 GeV

SIDIS Dihadrons

$$eN \to e + \pi^+(P_1) + \pi^-(P_2) + X$$



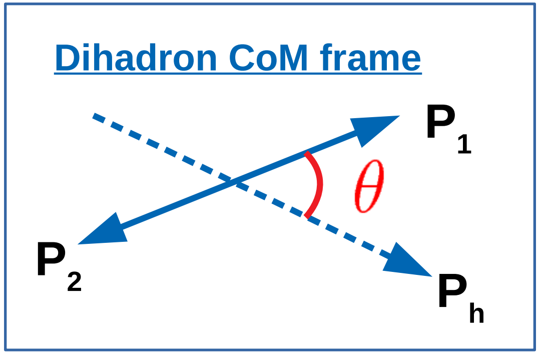
Dihadron Kinematics

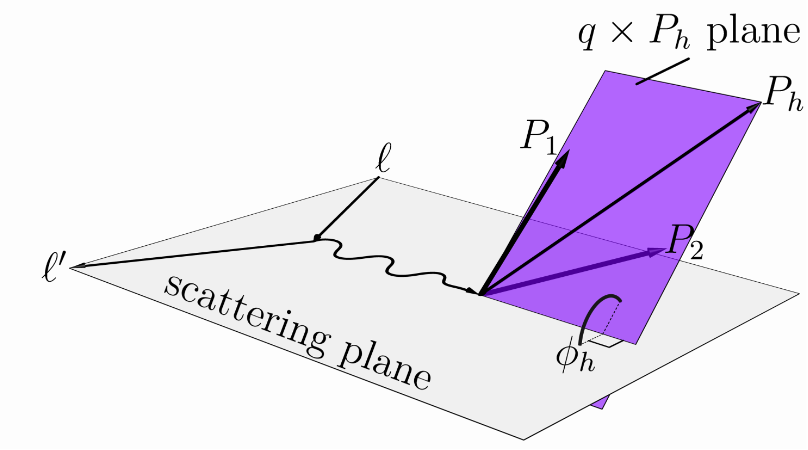
$$eN \rightarrow e + \pi^+(P_1) + \pi^-(P_2) + X$$

dihadron momentum: $P_h = P_1 + P_2$

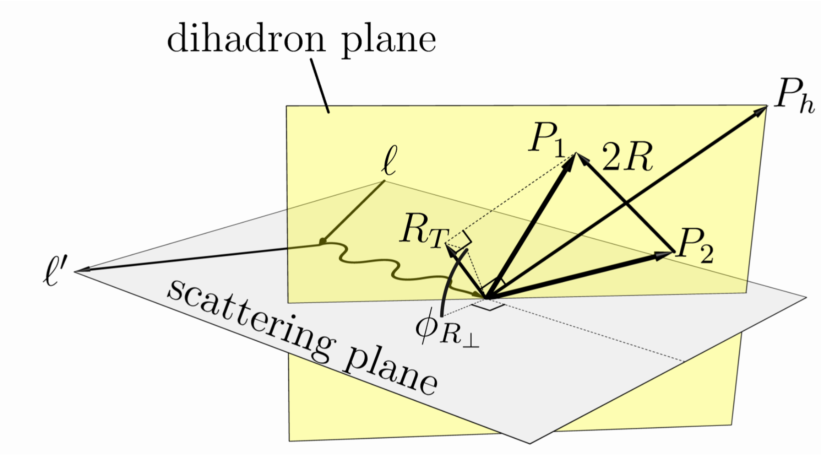
kinematics: $M_h, \; z, \; p_T$

angles: $\phi_h, \; \phi_R, \; \theta$


Dihadron CoM frame



cf. single-hadron ϕ_h

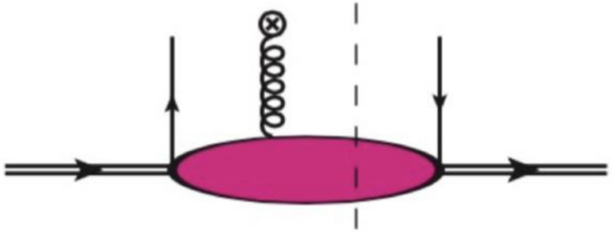


Twist-3 Collinear PDFs

Collinear PDFs
– **Twist-2**
– **Twist-3**

		Quark Polarization		
		U	**L**	**T**
Nucleon Polarization	**U**	f_1		e
	L		g_1	h_L
	T		g_T	h_1

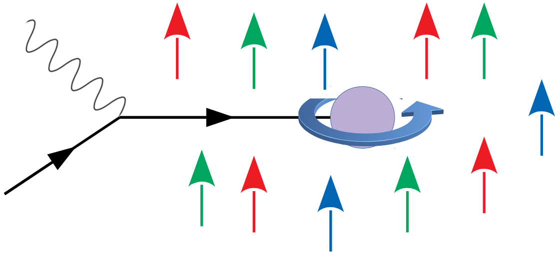
- Twist-3 TMDs are expressible in terms of multi-parton correlators
- Fundamental to understanding TMDs in general
- Physical interpretation through *x-moments*



e(x) accessible in Beam Spin Asymmetry A_{LU}

- Physical interpretation via moments:
  - Pion-nucleon σ term: $m_q \rightarrow m_N$
  - “Boer-Mulders Force”: Transverse force exerted by color field on q↑ after scattering, in an unpolarized nucleon

Phys.Rev.D 88 (2013) 114502

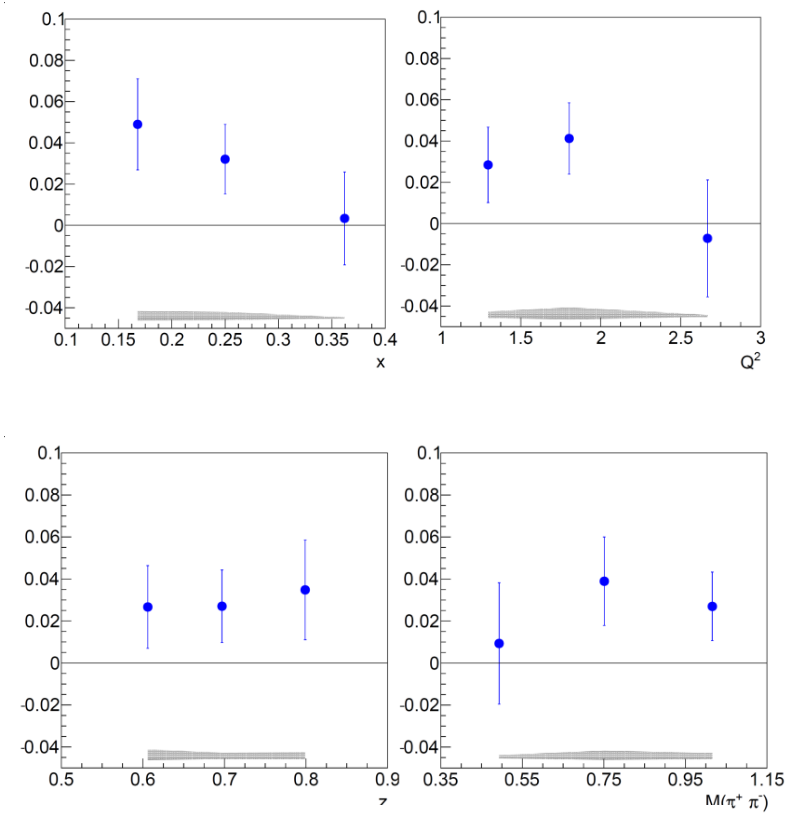


Target Spin Asymmetry A_{UL}

Ongoing measurement in Run Group C

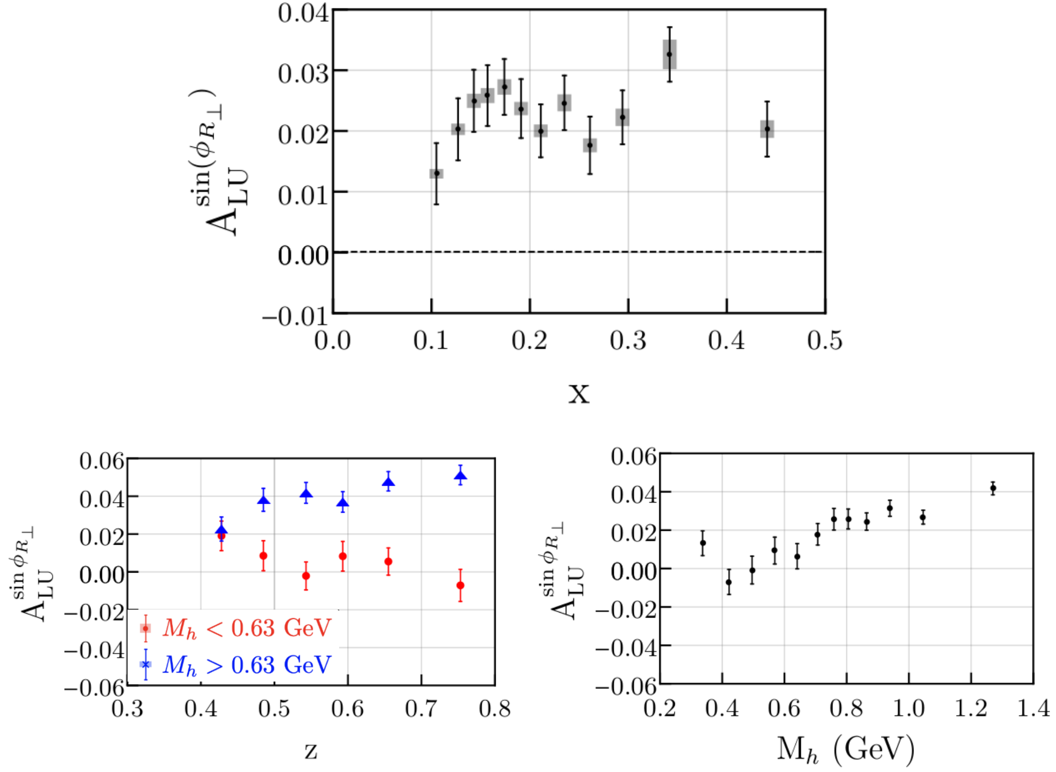
Dihadron A_{LU} Measurements – Proton Target

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



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

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

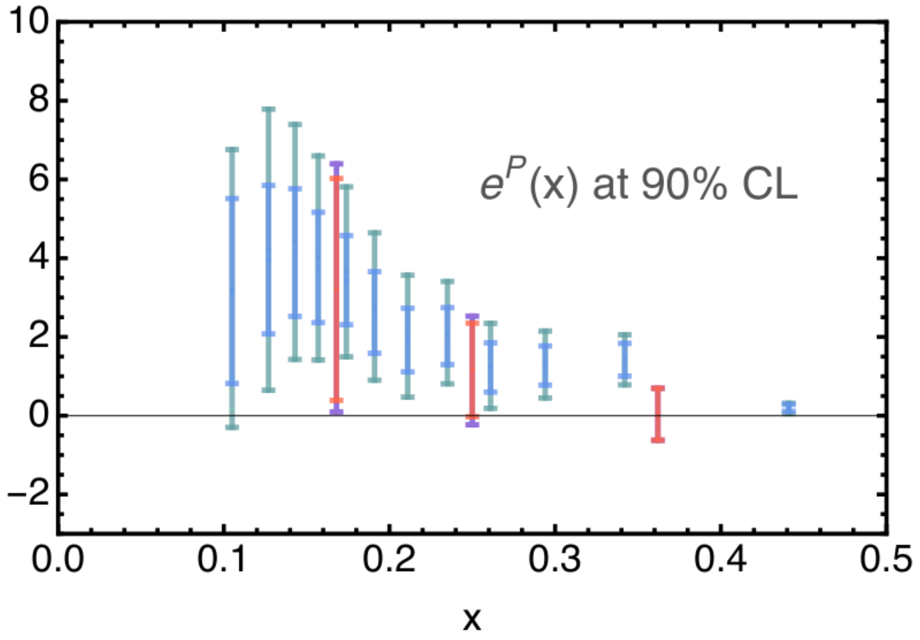


Phys.Rev.Lett. 126 (2021) 152501

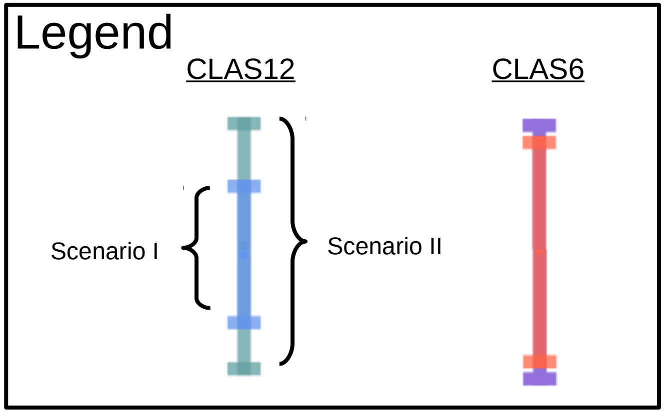
New e(x) Extraction – Proton Flavor Combination

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

twist-3 DiFF



- **Scenario 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}



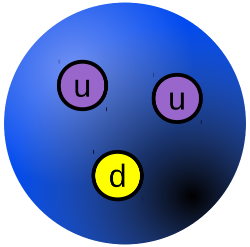
Courtoy, Aurore, et al. e-Print: 2203.14975 [hep-ph]

Courtoy, Aurore – CPHI 2022

Accessing Flavor Dependence of e(x)

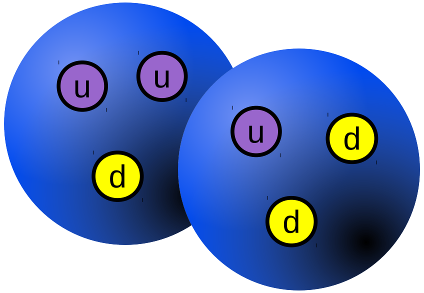
Different targets → flavor dependence

Proton Target



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

Deuteron Target



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

2 equations and 2 unknowns: decouple flavor dependence of e(x) → $\boxed{e^{uv}(x) \text{ and } e^{dv}(x)}$

CLAS12 data taken 2018–2020

Twist-3 Collinear PDF $h_L(x)$

Components:

$$h_L(x) \equiv \int d^2\boldsymbol{p}_T\, h_L(x,\boldsymbol{p}_T^2) = -2\overbrace{\frac{h_{1L}^{\perp(1)}(x)}{x} + \frac{m}{M}\frac{g_1(x)}{x}}^{\text{twist 2 PDFs}} + \overset{\text{pure twist 3}}{\tilde{h}_L(x)}$$

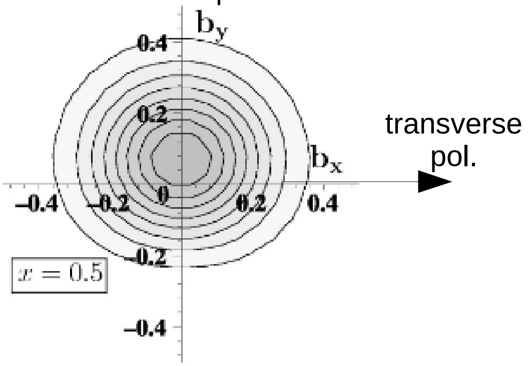
$$\downarrow$$

$$\leftarrow \boxed{\int dx\, x^3}$$

“Average longitudinal gradient of the transverse force that acts on transversely polarized [struck] quark”

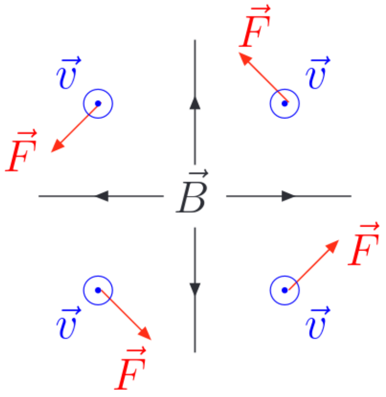
– M. Abdallah and M. Burkardt

u(x,b$_T$)



Accessible in Target Spin Asymmetries

→ Experiment currently running!



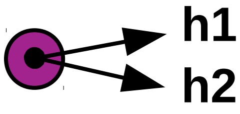
$$\mathcal{L}^q_{\mathrm{JM}} - L^q_{\mathrm{Ji}} = \Delta L^q_{\mathrm{FSI}}$$

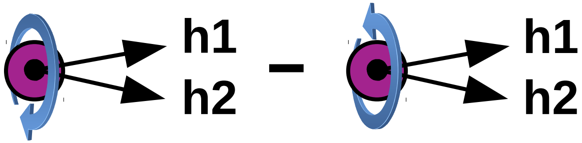
Expressible in terms of the change in quark OAM as it leaves the target

- 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

$D_1 =$ 

$G_1 =$ 

$H_1 =$ 

(notation):

$$G_1 = G_1^{\perp}$$
$$H_1 = \left\{ H_1^{\perp}, H_1^{\sphericalangle} \right\}$$

Twist 3

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

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

small ?
see, for example,

PoS DIS2014 (2014) 231

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

arXiv: 1405.7659 [hep-ph]

Accessing Flavor Dependence of DiFFs

$$D_1^{u/\pi^+\pi^-} = D_1^{\bar{d}/\pi^+\pi^-} = D_1^{d/\pi^+\pi^-} = D_1^{\bar{u}/\pi^+\pi^-}$$

$$G_1^{u/\pi^+\pi^-} = G_1^{\bar{d}/\pi^+\pi^-} = G_1^{d/\pi^+\pi^-} = G_1^{\bar{u}/\pi^+\pi^-}$$

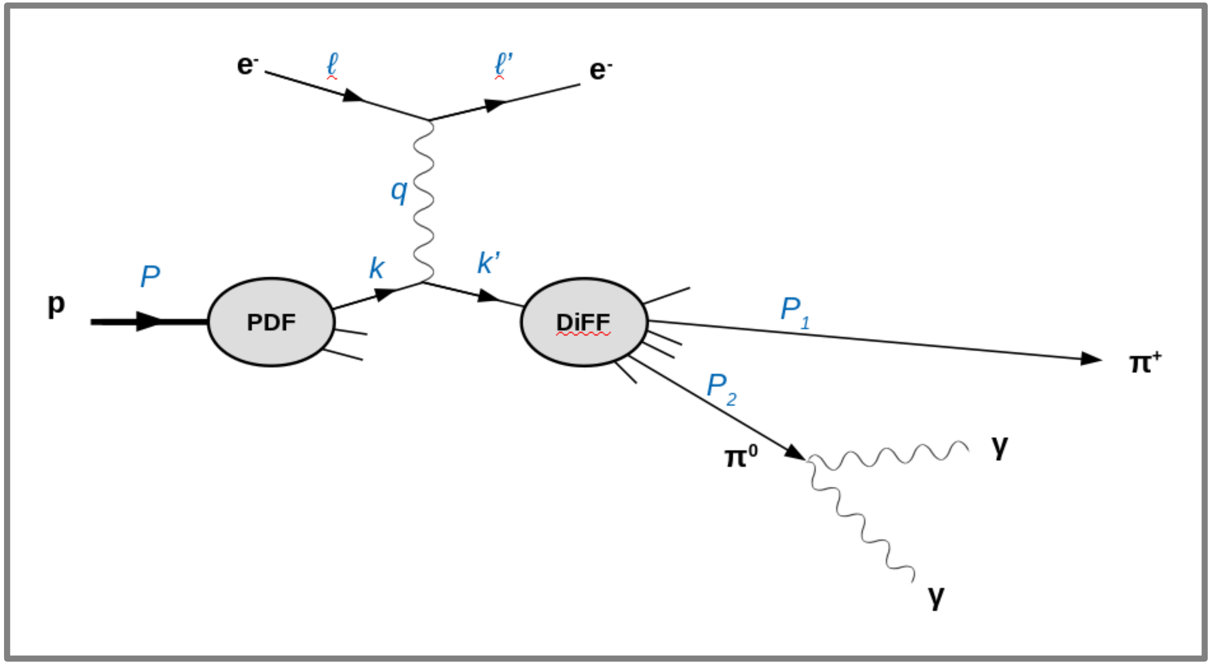
$$H_1^{u/\pi^+\pi^-} = H_1^{\bar{d}/\pi^+\pi^-} = -H_1^{d/\pi^+\pi^-} = -H_1^{\bar{u}/\pi^+\pi^-}$$

$$\neq$$

$$D_1^{q/\pi^\pm\pi^0}$$

$$G_1^{q/\pi^\pm\pi^0}$$

$$H_1^{q/\pi^\pm\pi^0}$$



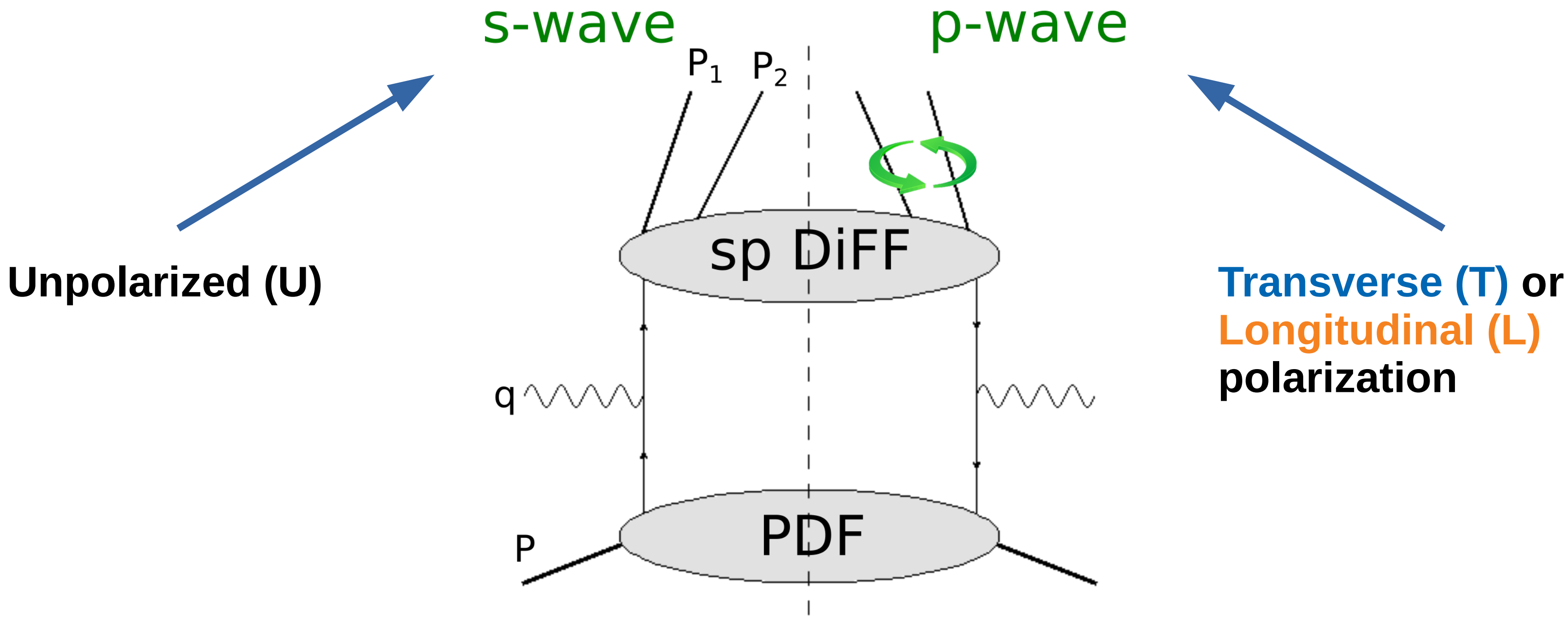
$$\pi^+\pi^-$$

$$\pi^+\pi^0$$

$$\pi^-\pi^0$$

$$\ldots$$

Partial Wave Expansion



Unpolarized (U)

Transverse (T) or Longitudinal (L) polarization

- **DiFFs expand on a basis of spherical harmonics**
- **Angular momentum eigenvalues | ℓ, m >**
- **Explore dihadron fragmentation depending on relative angular momentum**

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

Partial Waves in A_{LU}

12 Parameter Simultaneous Fit

Twist 2

3 terms

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

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

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

Twist 3

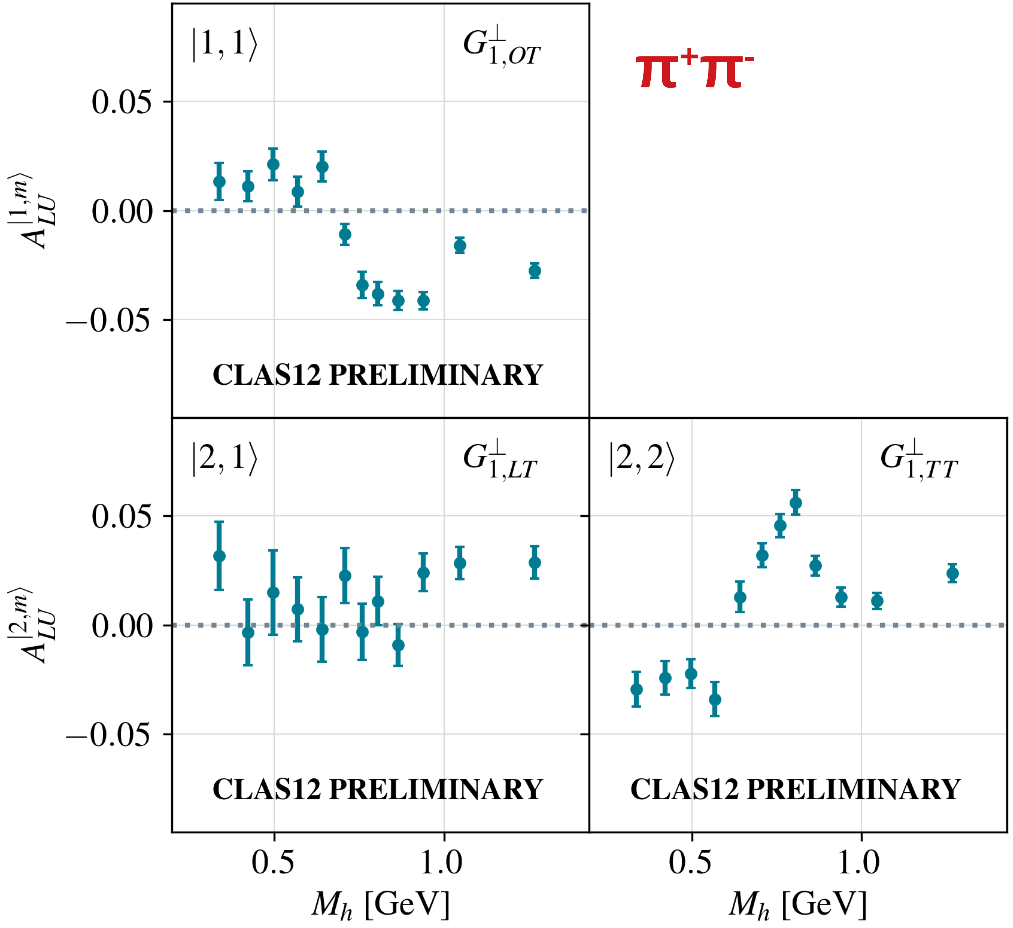
9 terms

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

Twist-2 A_{LU} at M_h Bins

Sensitive to $f_1 \cdot G_1^{\perp}$

Twist-2 A_{LU} Amplitudes

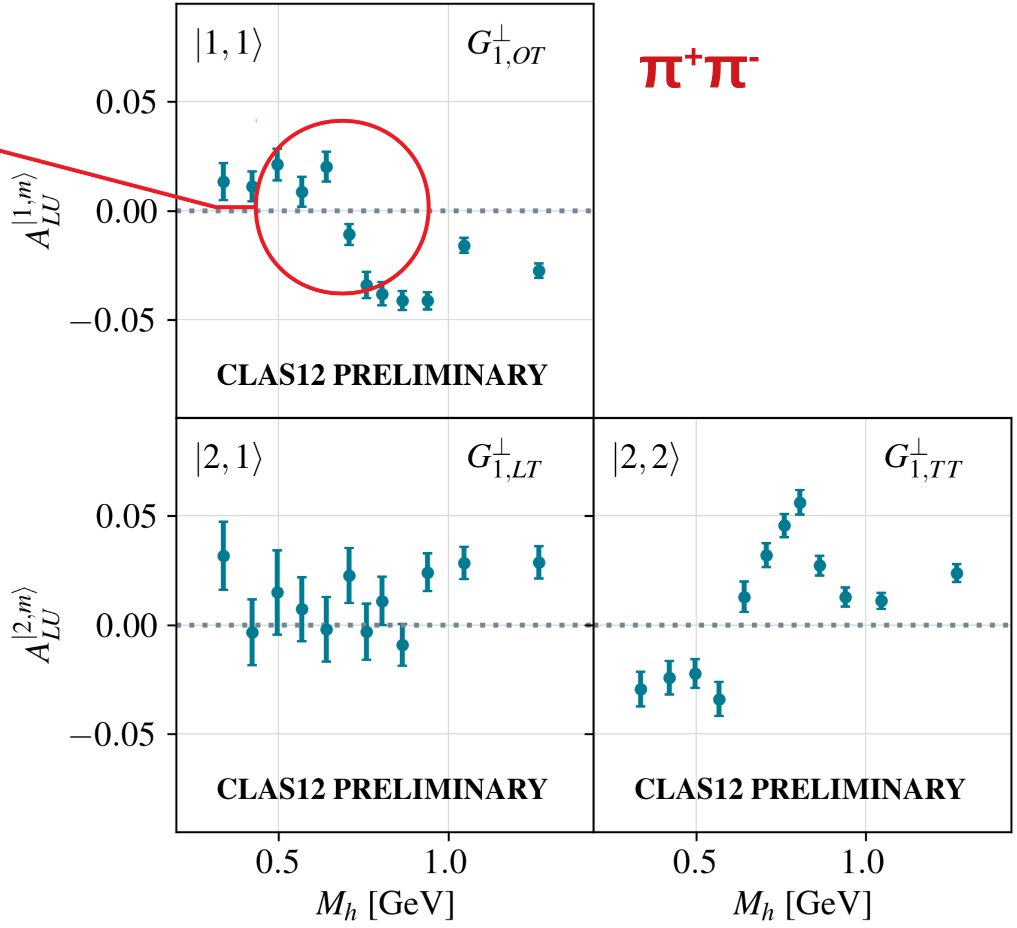


$\pi^+\pi^-$

e-Print: 2107.12965 [hep-ex]

Twist-2 A_{LU} at M_h Bins

Sign change near ρ mass



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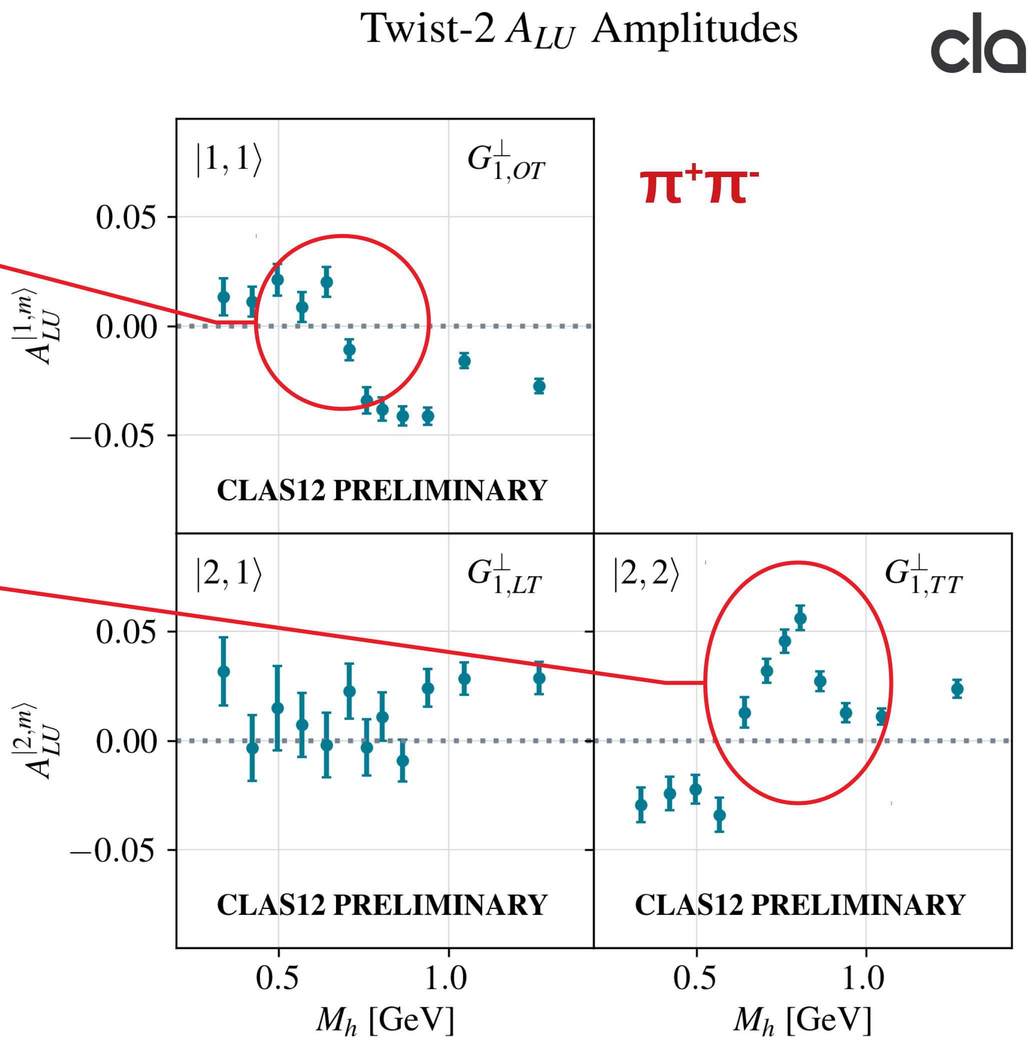
Twist-2 A_{LU} at M_h Bins

Sign change near ρ mass

Enhancement at ρ mass (and a sign change)

ρ meson → p-wave $\pi^+\pi^-$



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Outline

- Introduction to SIDIS dihadrons at CLAS
- **Dihadron Cross Section**
- Depolarization
- Comparison of kinematics: 10.6 GeV vs. 22 GeV

Full Dihadron Cross Section

$$\begin{aligned} d\sigma_{UU} = {} & \frac{\alpha^2}{4\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right) \\ & \times \sum_{\ell=0}^{\ell_{\max}} \left\{ A(x,y) \sum_{m=0}^{\ell} \left[P_{\ell,m} \cos(m(\phi_h - \phi_{R_\perp})) \left(F_{UU,T}^{P_{\ell,m} \cos(m(\phi_h-\phi_{R_\perp}))} + \epsilon F_{UU,L}^{P_{\ell,m} \cos(m(\phi_h-\phi_{R_\perp}))} \right) \right] \right. \\ & \quad + B(x,y) \sum_{m=-\ell}^{\ell} P_{\ell,m} \cos((2-m)\phi_h + m\phi_{R_\perp}) F_{UU}^{P_{\ell,m} \cos((2-m)\phi_h+m\phi_{R_\perp})} \\ & \quad \left. + V(x,y) \sum_{m=-\ell}^{\ell} P_{\ell,m} \cos((1-m)\phi_h + m\phi_{R_\perp}) F_{UU}^{P_{\ell,m} \cos((1-m)\phi_h+m\phi_{R_\perp})} \right\} . \end{aligned}$$

$$\begin{aligned} d\sigma_{LU} = {} & \frac{\alpha^2}{4\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right) \lambda_e \\ & \times \sum_{\ell=0}^{\ell_{\max}} \left\{ C(x,y) \sum_{m=1}^{\ell} \left[P_{\ell,m} \sin(m(\phi_h - \phi_{R_\perp}))\, 2 \left(F_{LU,T}^{P_{\ell,m} \cos(m(\phi_h-\phi_{R_\perp}))} + \epsilon F_{LU,L}^{P_{\ell,m} \cos(m(\phi_h-\phi_{R_\perp}))} \right) \right] \right. \\ & \quad \left. + W(x,y) \sum_{m=-\ell}^{\ell} P_{\ell,m} \sin((1-m)\phi_h + m\phi_{R_\perp}) F_{LU}^{P_{\ell,m} \sin((1-m)\phi_h+m\phi_{R_\perp})} \right\} . \end{aligned}$$

$$\begin{aligned} d\sigma_{UL} = {} & \frac{\alpha^2}{4\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right) S_L \\ & \times \left\{ A(x,y) \sum_{\ell=1}^{\ell_{\max}} \sum_{m=1}^{\ell} P_{\ell,m} \sin(-m\phi_h + m\phi_{R_\perp}) F_{UL}^{P_{\ell,m} \sin(-m\phi_h+m\phi_{R_\perp})} \right. \\ & \quad + B(x,y) \sum_{\ell=0}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} P_{\ell,m} \sin((2-m)\phi_h + m\phi_{R_\perp}) F_{UL}^{P_{\ell,m} \sin((2-m)\phi_h+m\phi_{R_\perp})} \\ & \quad \left. + V(x,y) \sum_{\ell=0}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} P_{\ell,m} \sin((1-m)\phi_h + m\phi_{R_\perp}) F_{UL}^{P_{\ell,m} \sin((1-m)\phi_h+m\phi_{R_\perp})} \right\} . \end{aligned}$$

$$\begin{aligned} d\sigma_{LL} = {} & \frac{\alpha^2}{4\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right) \lambda_e S_L \\ & \times \sum_{\ell=0}^{\ell_{\max}} \left\{ C(x,y) \sum_{m=0}^{\ell} 2^{2-\delta_{m0}}\, P_{\ell,m} \cos(m(\phi_h - \phi_{R_\perp})) F_{LL}^{P_{\ell,m} \cos(m(\phi_h-\phi_{R_\perp}))} \right. \\ & \quad \left. + W(x,y) \sum_{m=-\ell}^{\ell} P_{\ell,m} \cos((1-m)\phi_h + m\phi_{R_\perp}) F_{LL}^{P_{\ell,m} \cos((1-m)\phi_h+m\phi_{R_\perp})} \right\} . \end{aligned}$$

$$\begin{aligned} d\sigma_{UT} = {} & \frac{\alpha^2}{4\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right) |\boldsymbol{S}_\perp| \\ & \times \sum_{\ell=0}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} \left\{ A(x,y) \Big[P_{\ell,m} \sin((m+1)\phi_h - m\phi_{R_\perp} - \phi_S)) \right. \\ & \qquad \times \left(F_{UT,T}^{P_{\ell,m} \sin((m+1)\phi_h-m\phi_{R_\perp}-\phi_S)} + \epsilon F_{UT,L}^{P_{\ell,m} \sin((m+1)\phi_h-m\phi_{R_\perp}-\phi_S)} \right) \Big] \\ & \quad + B(x,y) \Big[P_{\ell,m} \sin((1-m)\phi_h + m\phi_{R_\perp} + \phi_S) F_{UT}^{P_{\ell,m} \sin((1-m)\phi_h+m\phi_{R_\perp}+\phi_S)} \\ & \qquad + P_{\ell,m} \sin((3-m)\phi_h + m\phi_{R_\perp} - \phi_S) F_{UT}^{P_{\ell,m} \sin((3-m)\phi_h+m\phi_{R_\perp}-\phi_S)} \Big] \\ & \quad + V(x,y) \Big[P_{\ell,m} \sin(-m\phi_h + m\phi_{R_\perp} + \phi_S) F_{UT}^{P_{\ell,m} \sin(-m\phi_h+m\phi_{R_\perp}+\phi_S)} \\ & \qquad \left. + P_{\ell,m} \sin((2-m)\phi_h + m\phi_{R_\perp} - \phi_S) F_{UT}^{P_{\ell,m} \sin((2-m)\phi_h+m\phi_{R_\perp}-\phi_S)} \Big] \right\} . \end{aligned}$$

$$\begin{aligned} d\sigma_{LT} = {} & \frac{\alpha^2}{4\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right) \lambda_e |\boldsymbol{S}_\perp| \sum_{\ell=0}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} \left\{ \vphantom{\sum} \right. \\ & \quad C(x,y)\, 2\, P_{\ell,m} \cos((1-m)\phi_h + m\phi_{R_\perp} - \phi_S)) F_{LT}^{P_{\ell,m} \cos((1-m)\phi_h+m\phi_{R_\perp}-\phi_S))} \\ & \quad + W(x,y) \Big[P_{\ell,m} \cos(-m\phi_h + m\phi_{R_\perp} + \phi_S) F_{LT}^{P_{\ell,m} \cos(-m\phi_h+m\phi_{R_\perp}+\phi_S)} \\ & \qquad \left. + P_{\ell,m} \cos((2-m)\phi_h + m\phi_{R_\perp} - \phi_S) F_{LT}^{P_{\ell,m} \cos((2-m)\phi_h+m\phi_{R_\perp}-\phi_S)} \Big] \right\} . \end{aligned}$$

C. Dilks

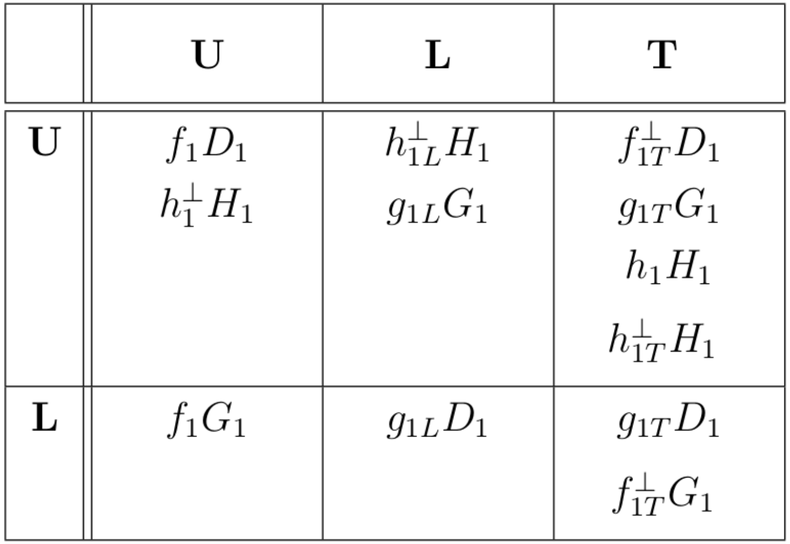
Phys.Rev.D 90 (2014) 11, 114027

Full Dihadron Cross Section

Twist 2

Target Polarization

Beam Polarization

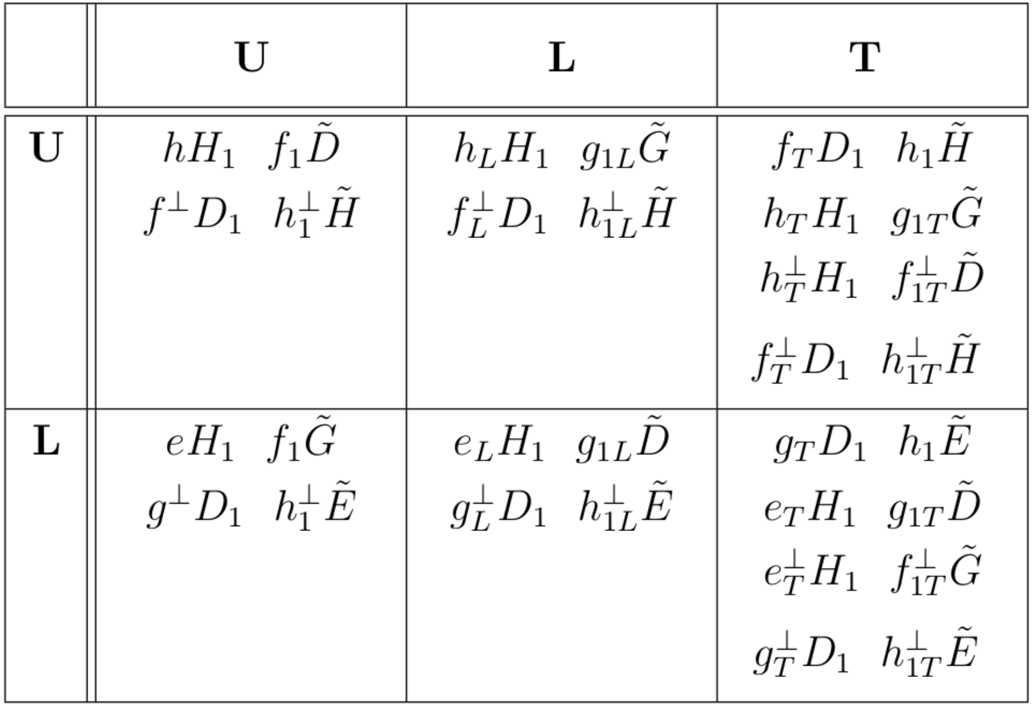


	U	L	T
U	$f_1 D_1$ $h_1^\perp H_1$	$h_{1L}^\perp H_1$ $g_{1L} G_1$	$f_{1T}^\perp D_1$ $g_{1T} G_1$ $h_1 H_1$ $h_{1T}^\perp H_1$
L	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

Twist 3

Target Polarization

Beam Polarization



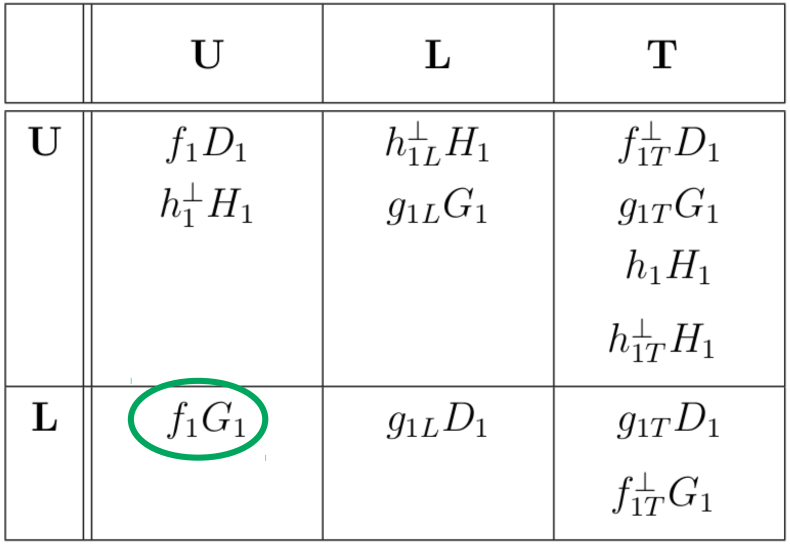
	U	L	T
U	$hH_1 \quad f_1 \tilde{D}$ $f^\perp D_1 \quad h_1^\perp \tilde{H}$	$h_L H_1 \quad g_{1L} \tilde{G}$ $f_L^\perp D_1 \quad h_{1L}^\perp \tilde{H}$	$f_T D_1 \quad h_1 \tilde{H}$ $h_T H_1 \quad g_{1T} \tilde{G}$ $h_T^\perp H_1 \quad f_{1T}^\perp \tilde{D}$ $f_T^\perp D_1 \quad h_{1T}^\perp \tilde{H}$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

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	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

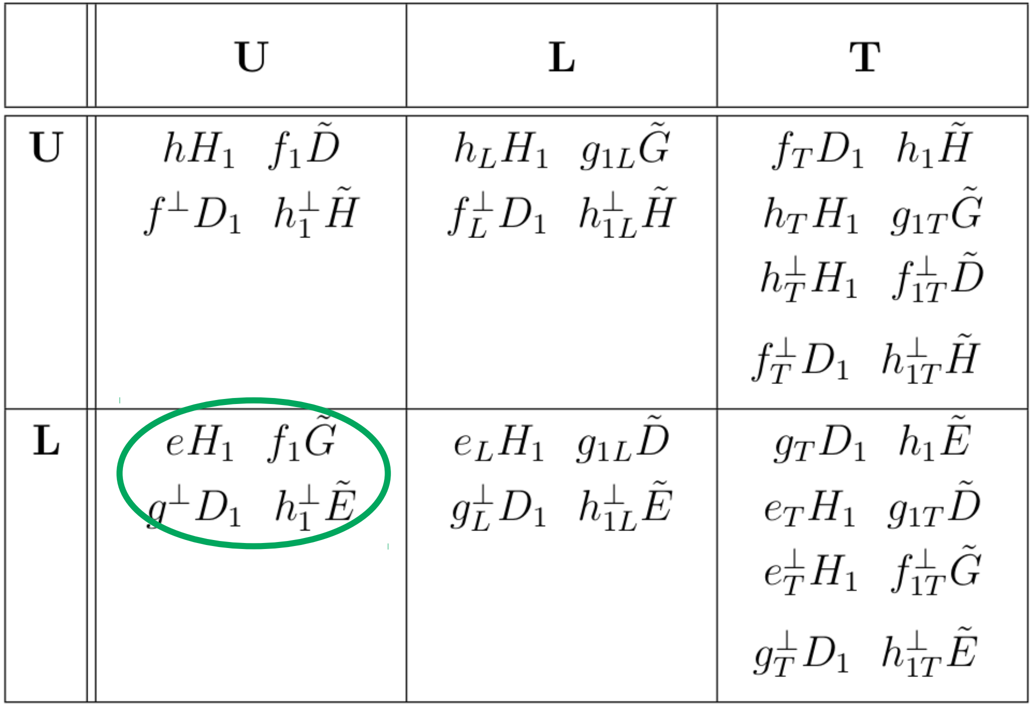
- **2018-2020** A_{LU}

- Helicity DiFF
- e(x)

Twist 3

Target Polarization

Beam Polarization



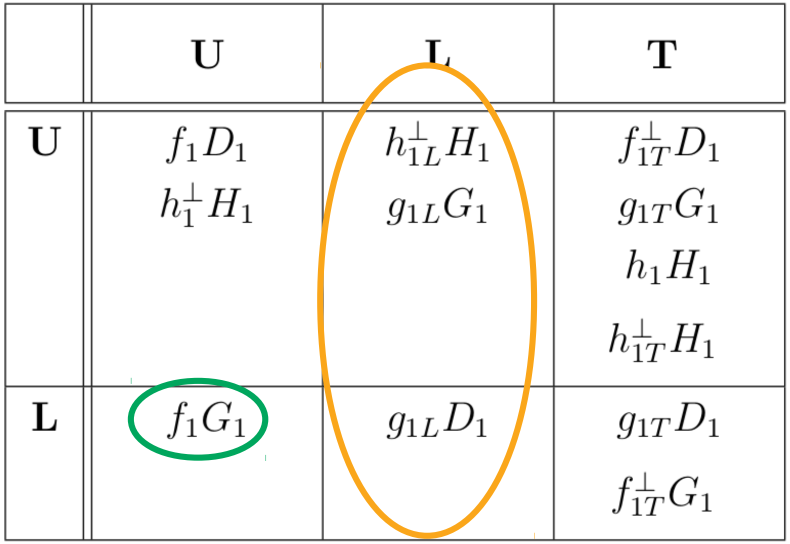
	U	L	T
U	hH_1 $f_1\tilde{D}$ $f^\perp D_1$ $h_1^\perp \tilde{H}$	$h_L H_1$ $g_{1L}\tilde{G}$ $f_L^\perp D_1$ $h_{1L}^\perp \tilde{H}$	$f_T D_1$ $h_1 \tilde{H}$ $h_T H_1$ $g_{1T}\tilde{G}$ $h_T^\perp H_1$ $f_{1T}^\perp \tilde{D}$ $f_T^\perp D_1$ $h_{1T}^\perp \tilde{H}$
L	eH_1 $f_1\tilde{G}$ $g^\perp D_1$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

Full Dihadron Cross Section

Twist 2

Target Polarization

Beam Polarization



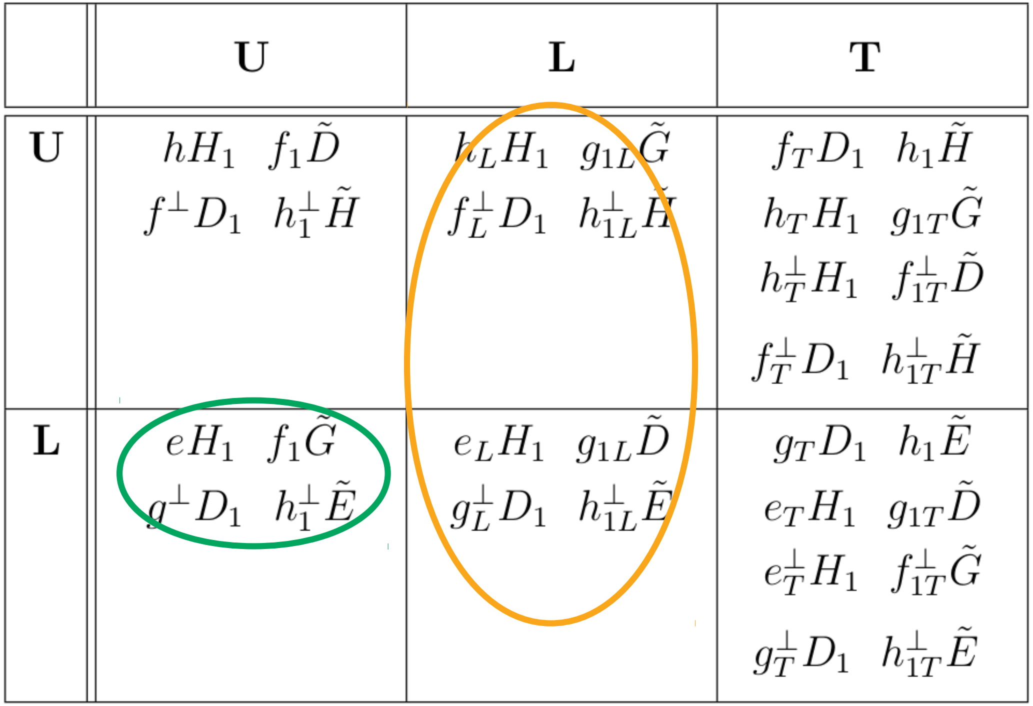
	U	L	T
U	$f_1 D_1$ $h_1^\perp H_1$	$h_{1L}^\perp H_1$ $g_{1L} G_1$	$f_{1T}^\perp D_1$ $g_{1T} G_1$ $h_1 H_1$ $h_{1T}^\perp H_1$
L	$f_1 G_1$	$g_{1L} D_1$	$g_{1T} D_1$ $f_{1T}^\perp G_1$

- 2018-2020 A_{LU}
- 2022-2023 $A_{UL},\ A_{LL}$
  - $h_L(x)$, …
  - Kotzinian-Mulders
  - Constrain twist-3 DiFFs

Twist 3

Target Polarization

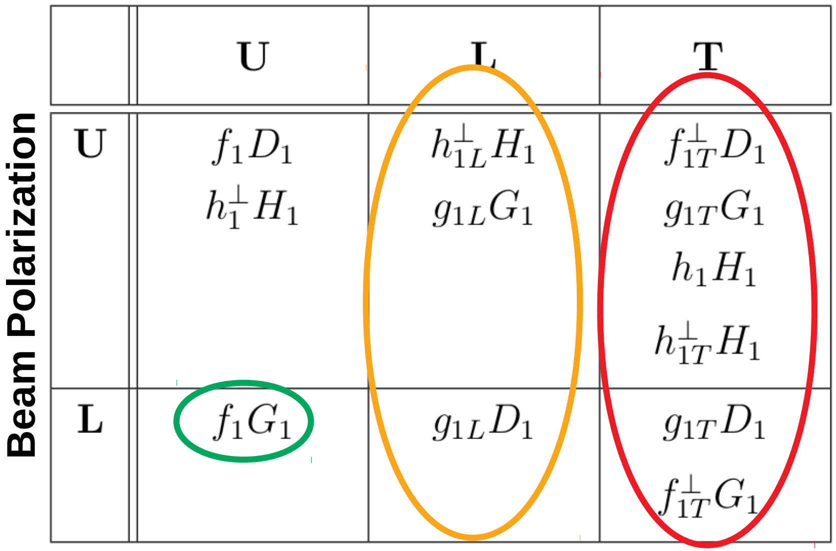
Beam Polarization



	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	$e H_1$ $f_1 \tilde{G}$ $g^\perp D_1$ $h_1^\perp \tilde{E}$	$e_L H_1$ $g_{1L} \tilde{D}$ $g_L^\perp D_1$ $h_{1L}^\perp \tilde{E}$	$g_T D_1$ $h_1 \tilde{E}$ $e_T H_1$ $g_{1T} \tilde{D}$ $e_T^\perp H_1$ $f_{1T}^\perp \tilde{G}$ $g_T^\perp D_1$ $h_{1T}^\perp \tilde{E}$

Full Dihadron Cross Section

Twist 2

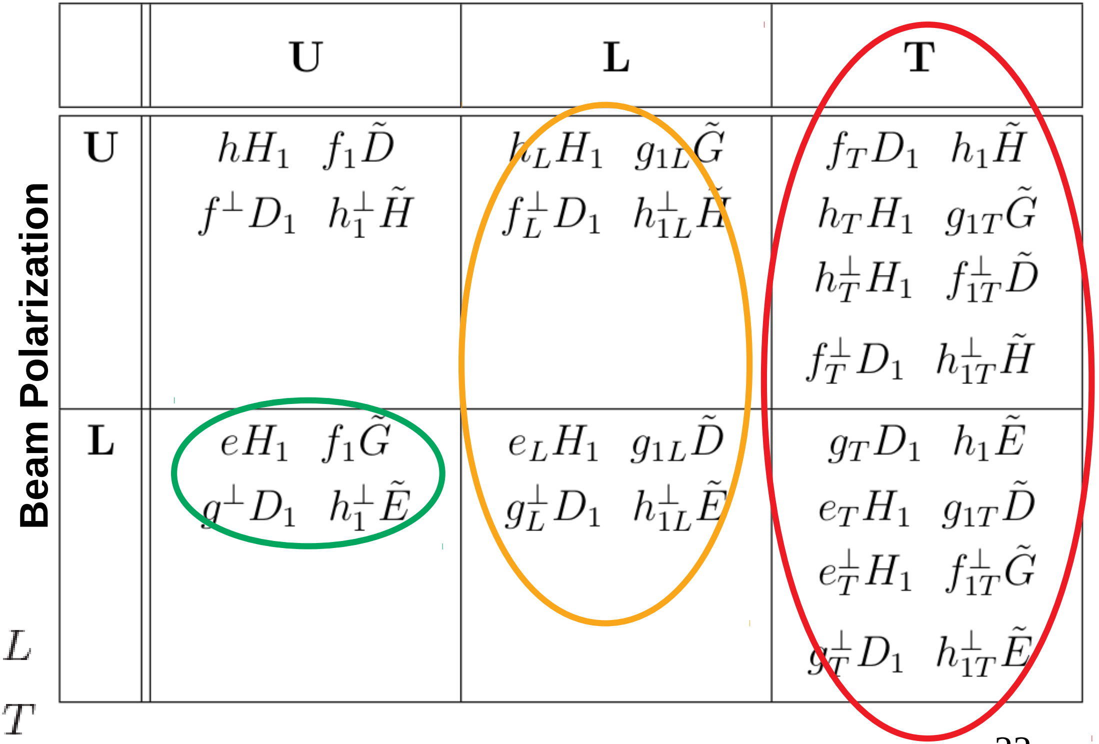


Target Polarization

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

- **2018-2020** A_{LU}
- **2022-2023** $A_{UL}, \ A_{LL}$
- **Future (?)** $A_{UT}, \ A_{LT}$

- Many observables: Sivers, Transversity*Collins, $g_T(x)$, …

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	$e H_1 \quad f_1 \tilde{G}$ $g^\perp D_1 \quad h_1^\perp \tilde{E}$	$e_L H_1 \quad g_{1L} \tilde{D}$ $g_L^\perp D_1 \quad h_{1L}^\perp \tilde{E}$	$g_T D_1 \quad h_1 \tilde{E}$ $e_T H_1 \quad g_{1T} \tilde{D}$ $e_T^\perp H_1 \quad f_{1T}^\perp \tilde{G}$ $g_T^\perp D_1 \quad h_{1T}^\perp \tilde{E}$

- 2018-2020 A_{LU}
- 2022-2023 $A_{UL}, \; A_{LL}$
- Future (?) $A_{UT}, \; A_{LT}$
- (any time) F_{UU}

- Boer-Mulders, $F_{UU,L}$ (?), …

Outline

- Introduction to SIDIS dihadrons at CLAS
- Dihadron Cross Section
- **Depolarization**
- Comparison of kinematics: 10.6 GeV vs. 22 GeV

Depolarization Factors

- Depolarization factors (and ε) 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(θ, ϕ_h, ϕ_R, ϕ_S)

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

Structure Functions

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

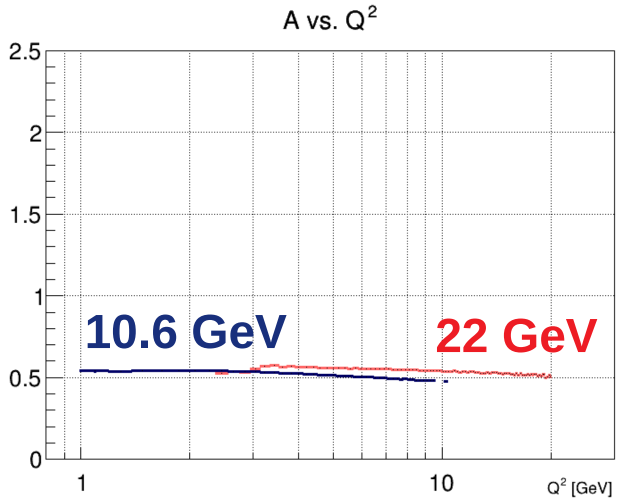
Depolarization Factors

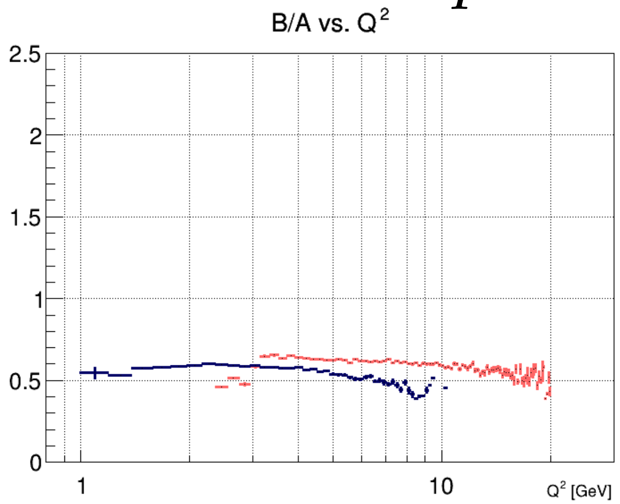
		Polarization	Depolarization
Twist 2	Boer-Mulders	UU	B
	Sivers	UT	1
	Transversity	UT	B/A
	Kotzinian-Mulders	UL	B/A
	Wormgear (LT)	LT	C/A
	Helicity DiFF $G_1^\perp$	LU	C/A
		UL	1
Twist 3	e(x)	LU	W/A
	$h_L(x)$	UL	V/A
	$g_T(x)$	LT	W/A

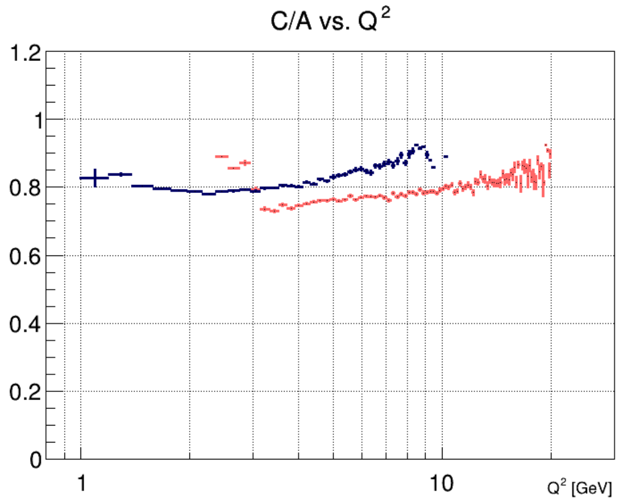
Depolarization Factors

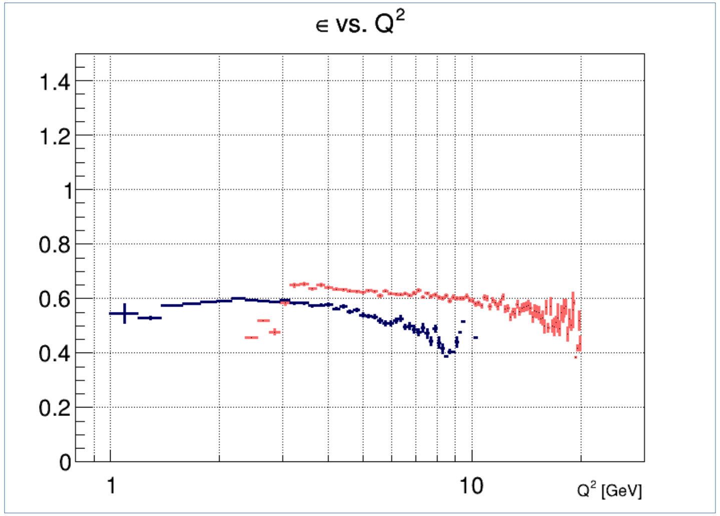
JLab Monte Carlo

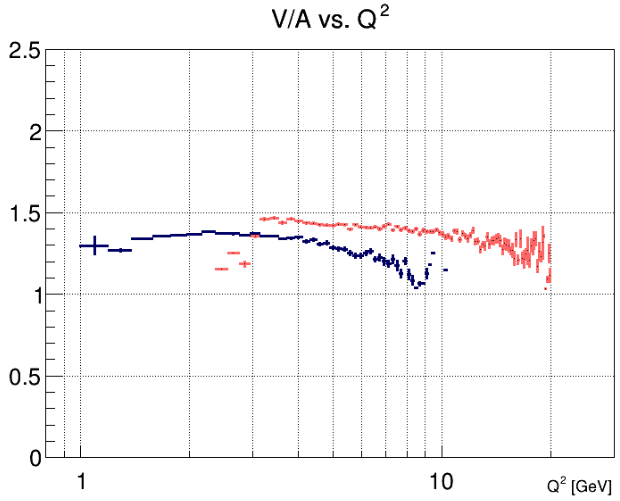
$$ep \rightarrow e\pi^+\pi^- X$$

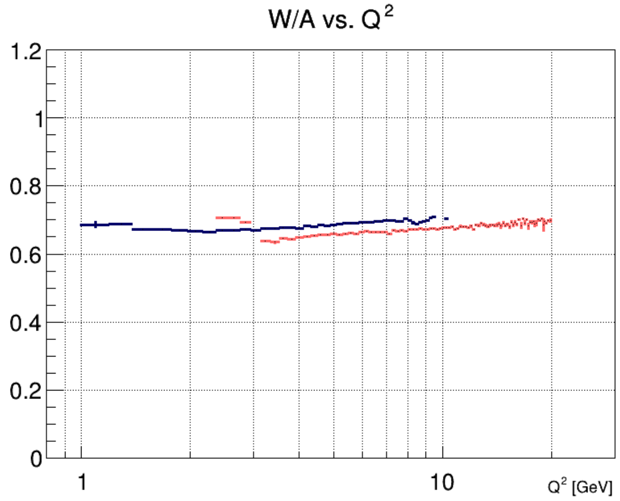








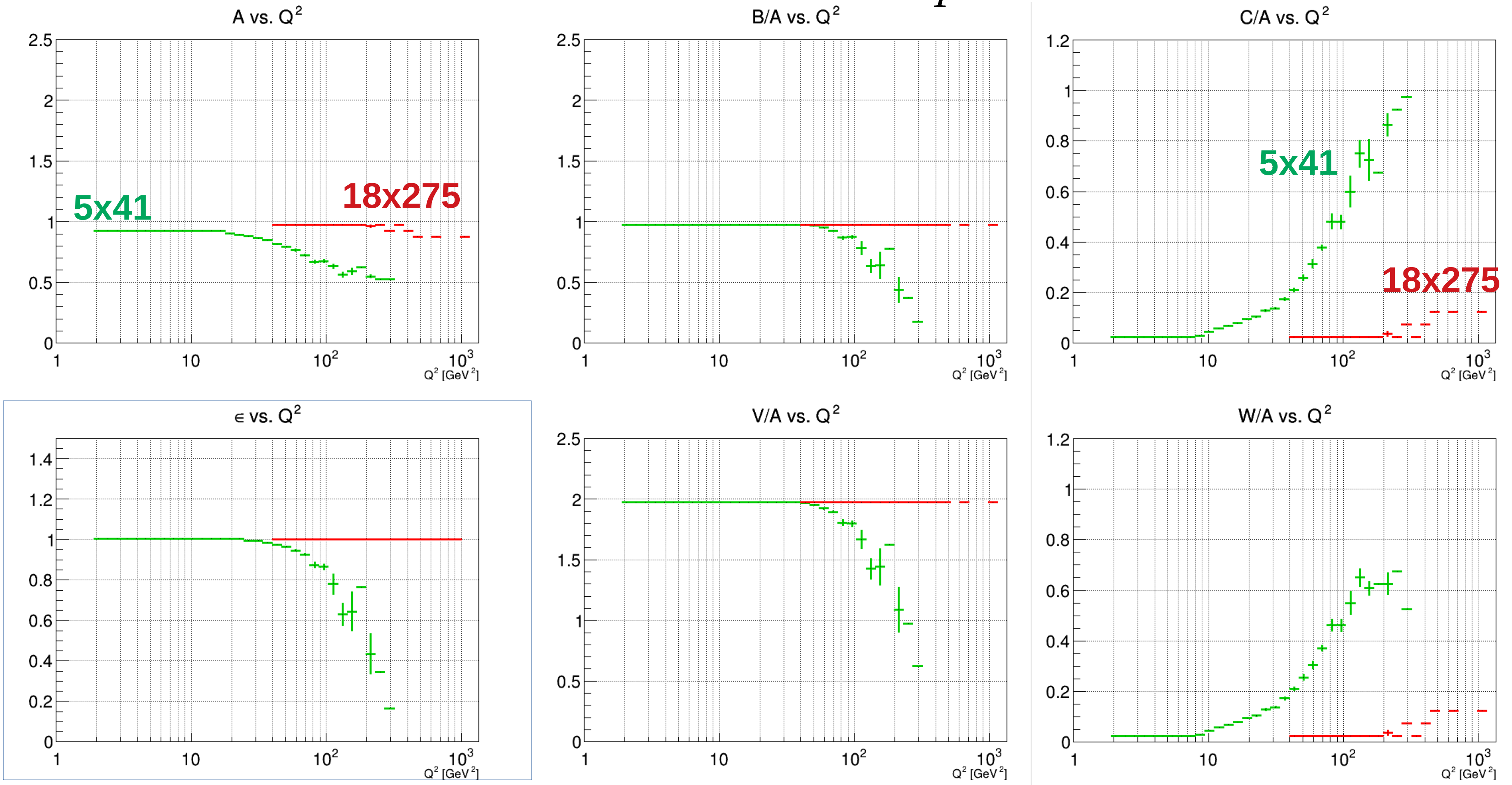




Depolarization Factors

EIC (ATHENA) Fast Simulation

$$ep \rightarrow e\pi^+ X$$



Depolarization Factors

Twist 2

Twist 3

	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

More accessible at JLab

Outline

- Introduction to SIDIS dihadrons at CLAS
- Dihadron Cross Section
- Depolarization
- **Comparison of kinematics: 10.6 GeV vs. 22 GeV**

Event Selection Criteria

General Cuts

- $Q^2 > 1$ GeV^2
- $W > 2$ GeV
- $y < 0.8$
- $5° < \theta < 35°$ (applied to $e^-, \pi^\pm$)

Pion and Dihadron Cuts

- $x_F(\pi^\pm) > 0$
- $p(\pi^\pm) > 1.25$ GeV
- $z_{pair} < 0.95$
- $M_{miss} > 1.5$ GeV

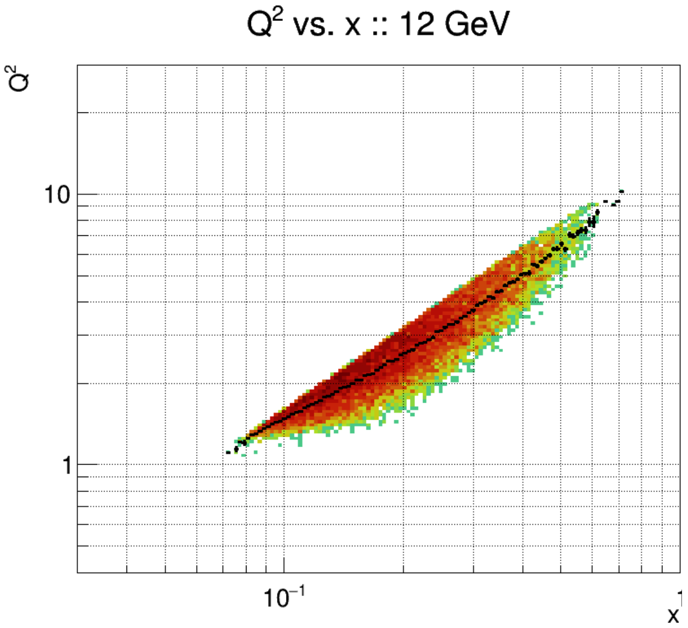
Additional Cuts

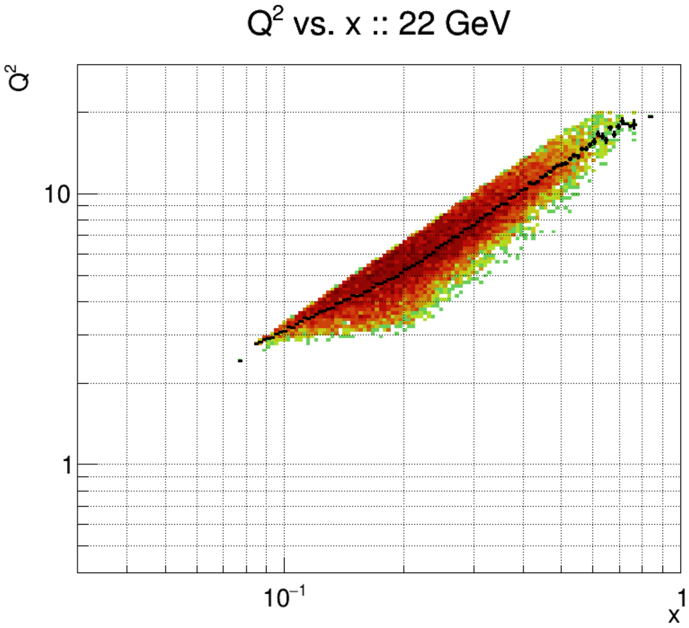
- PID Refinement
- Vertex
- Fiducial volume

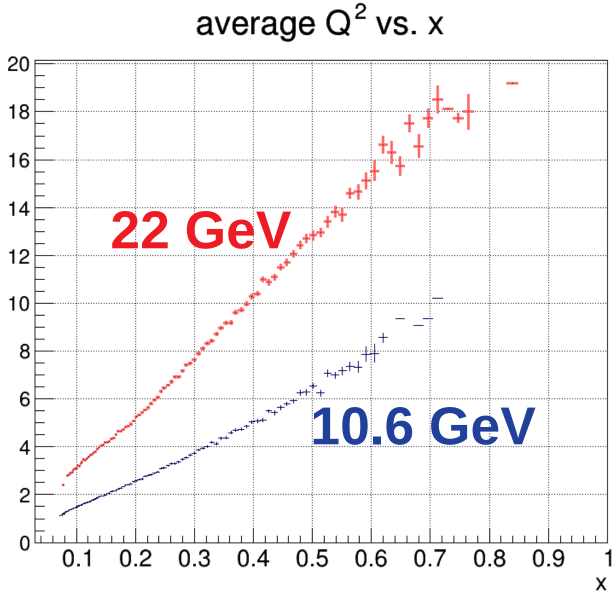
Data Sets

- Proton Target, Longitudinally Polarized (Run Group C configuration)
- Inbending Torus
- Beam Energies: **10.6 GeV** vs. **22 GeV**

(x,Q^2) Comparison

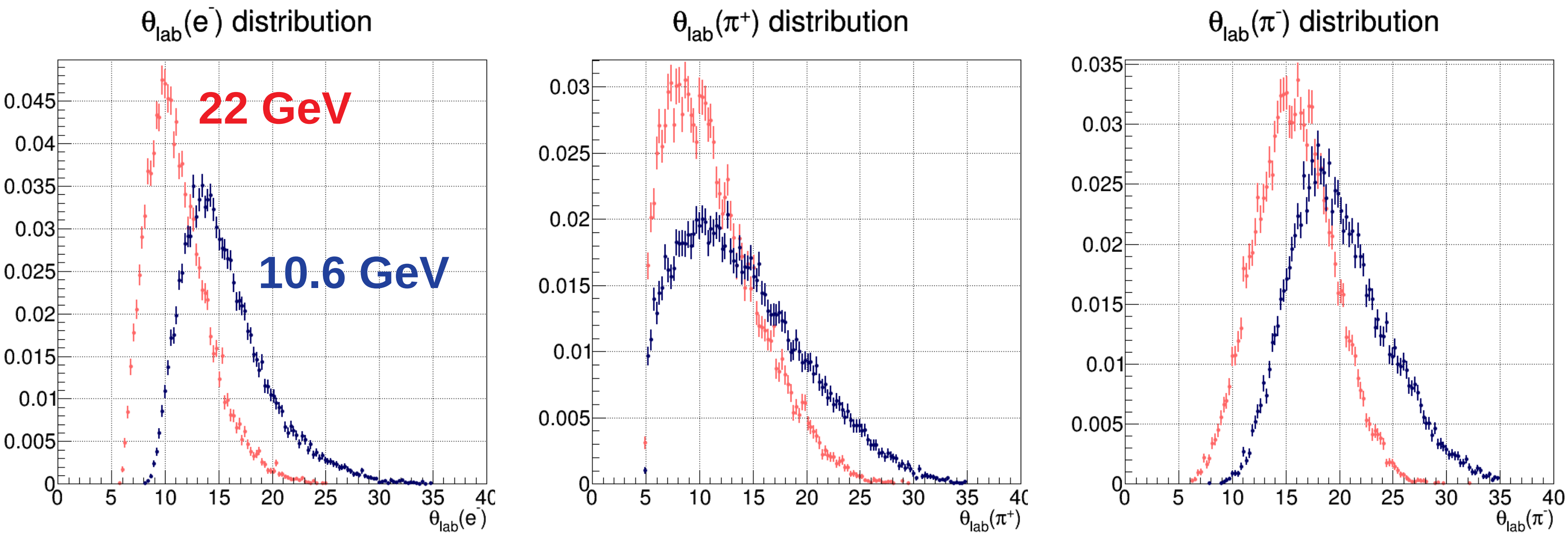






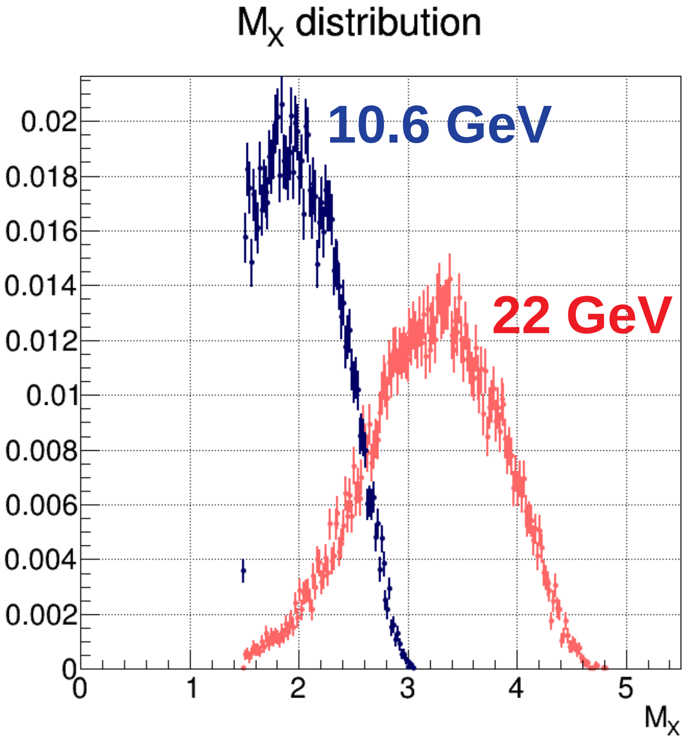
- Higher Q2 → evolution of e(x), $h_L(x)$, …
- Similar x-range (<x> is slightly higher)

Scattering Angles



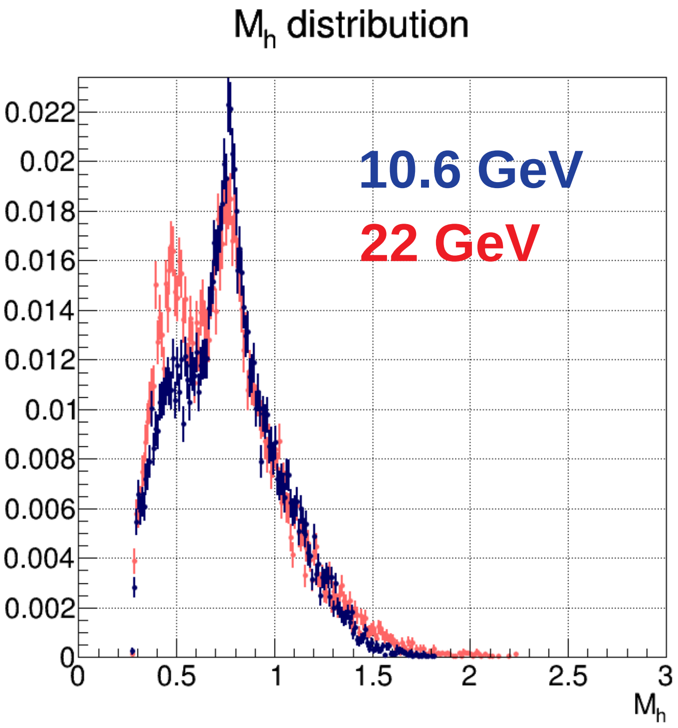
- Electrons and pions more forward at 22 GeV
- Distributions normalized by electron yield
- Note that θ_{lab}>5° cut is applied

Missing Mass Comparison



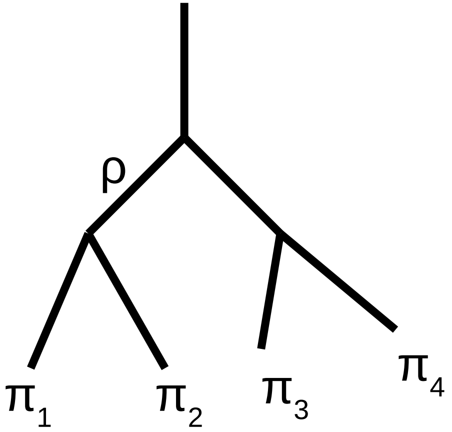
- Higher missing mass → less impact from radiative effects from exclusive production?

Dihadron Invariant Mass Comparison



- Similar invariant mass
- Consider the parent particles

MC Decay Tree



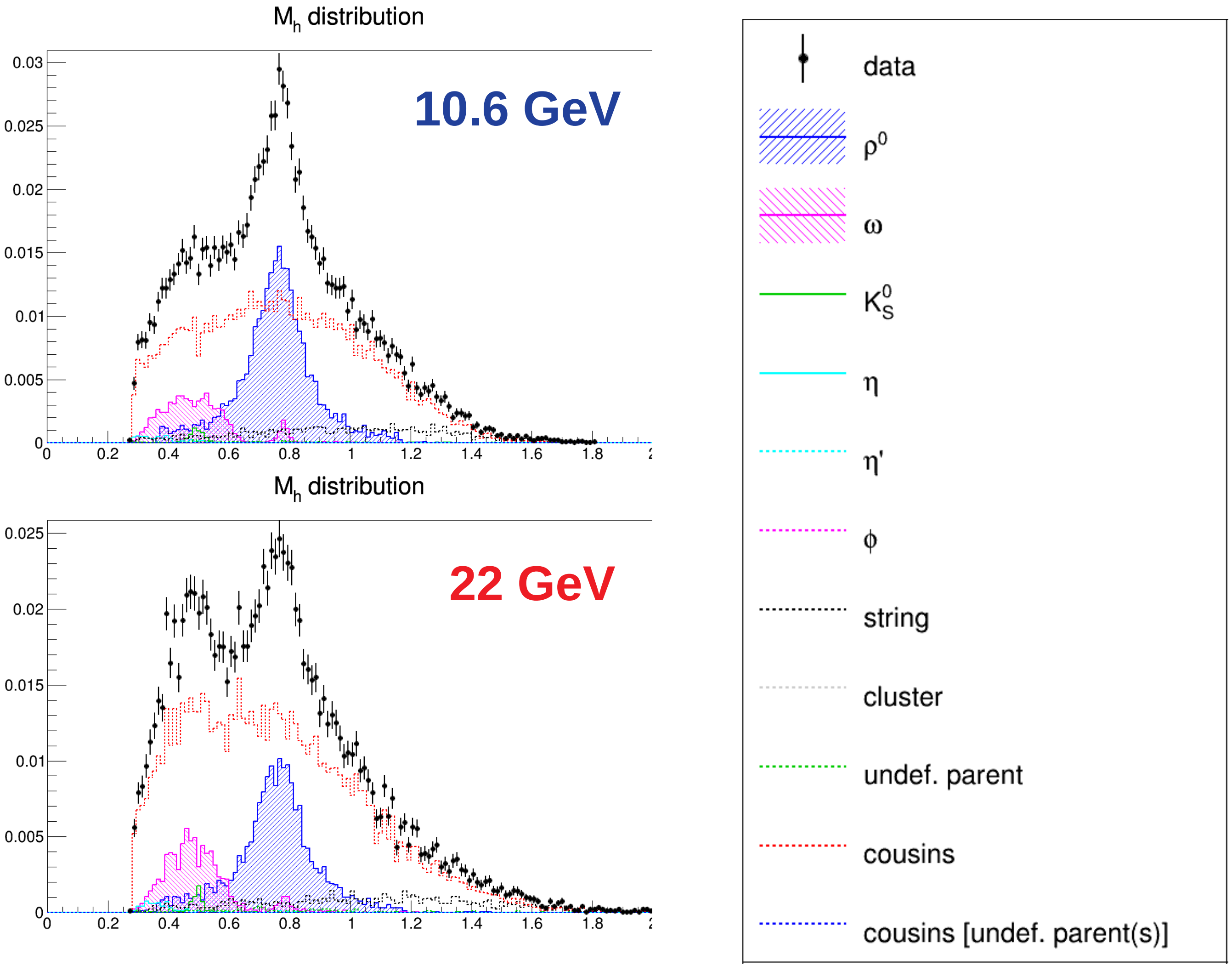
Two types of dihadrons:

– Siblings: same parent, e.g., $\rho \rightarrow \pi_1\pi_2$

– Cousins: different parents, e.g. π_1, π_3

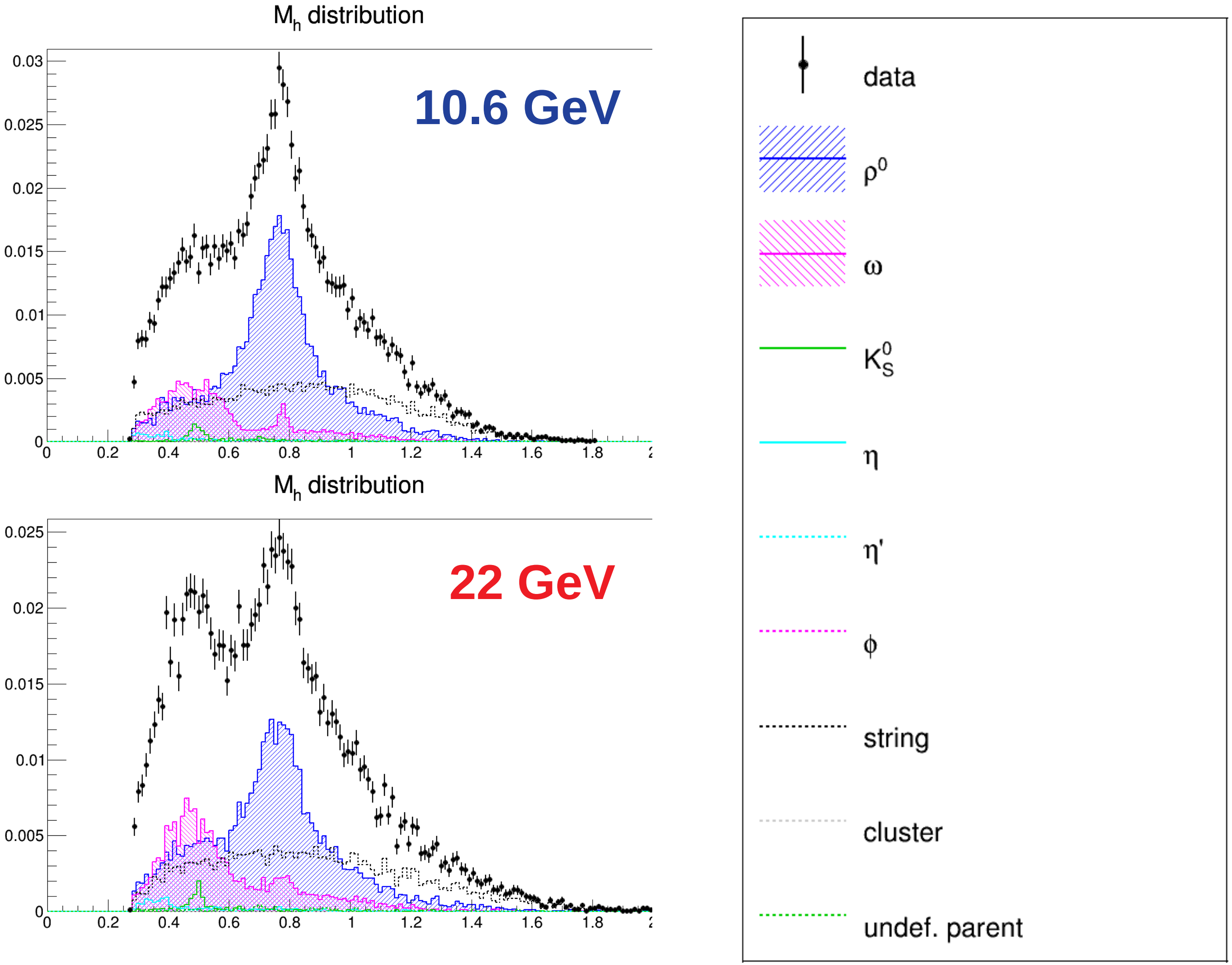
Dihadron Invariant Mass Comparison

- Only siblings in component (colored) distributions; cousins are instead combined in their own distribution
- Besides ρ mesons, we also see pions from ω decays
- Relatively more ω decays at 22 GeV?

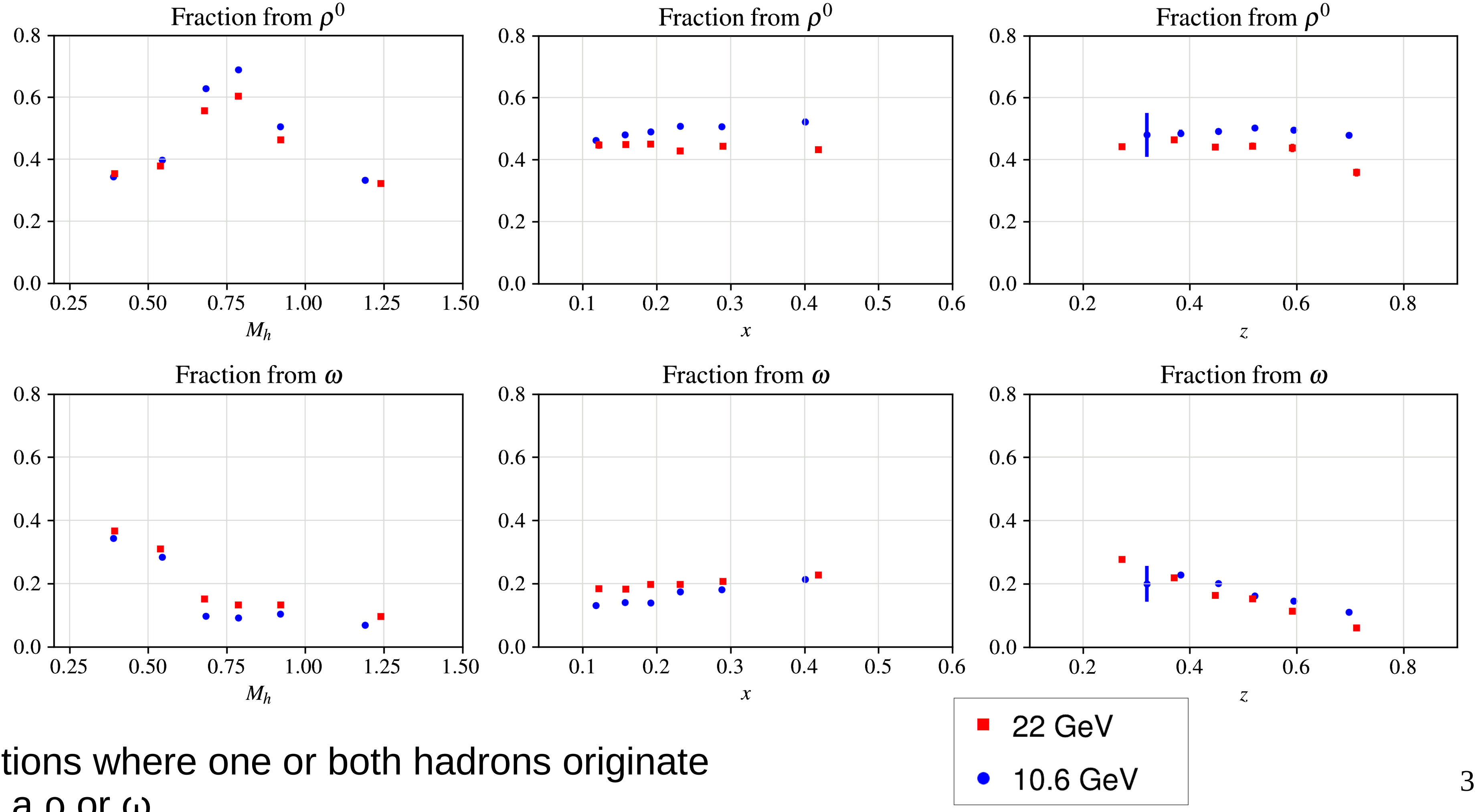


Dihadron Invariant Mass Comparison

- Both siblings and cousins in component (colored) distributions
- One histogram entry per *hadron*
- Broad distribution of cousin dihadrons from ρ and/or ω decays
- Many pions from ρ decays at low M_h



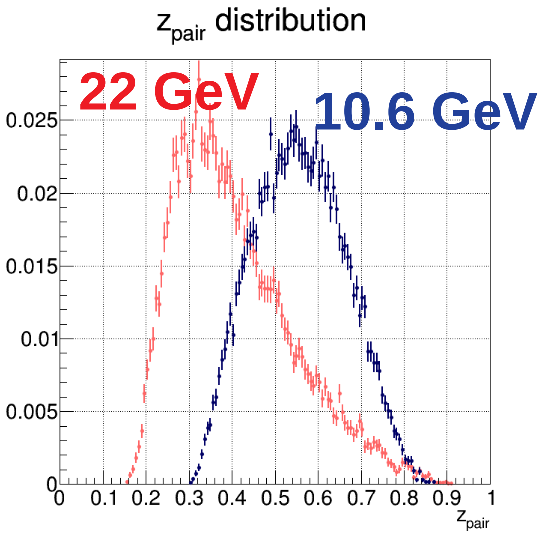
Dihadron Invariant Mass Comparison

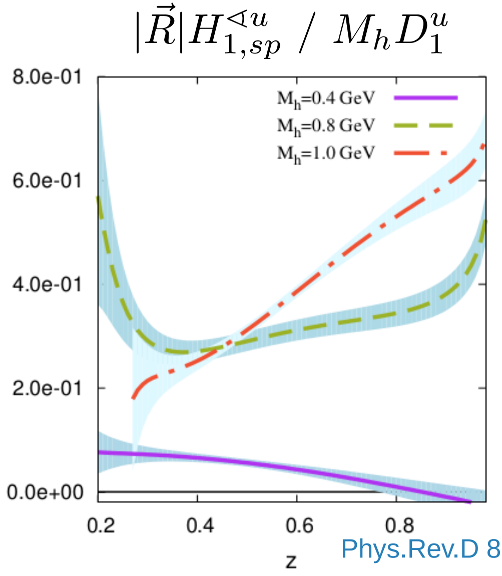


Fractions where one or both hadrons originate from a ρ or ω

z and p_T Comparisons

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





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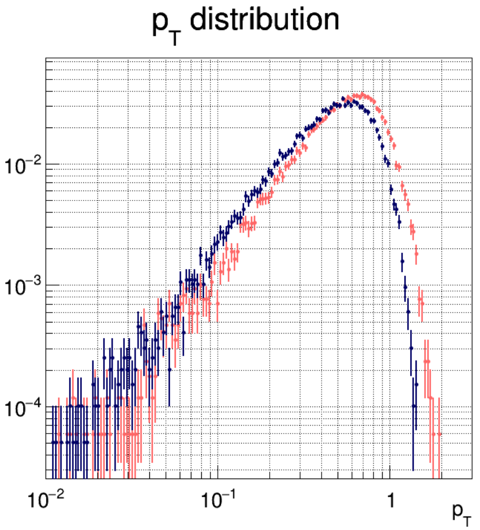
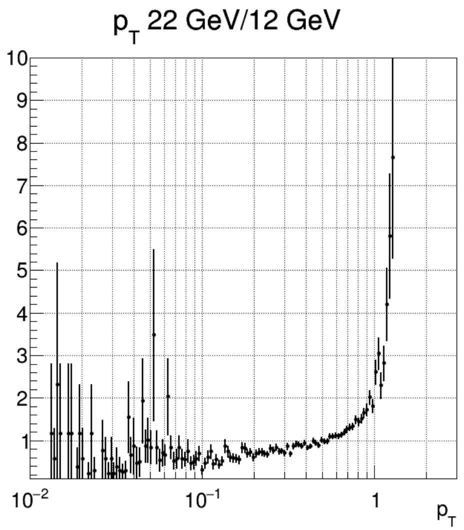
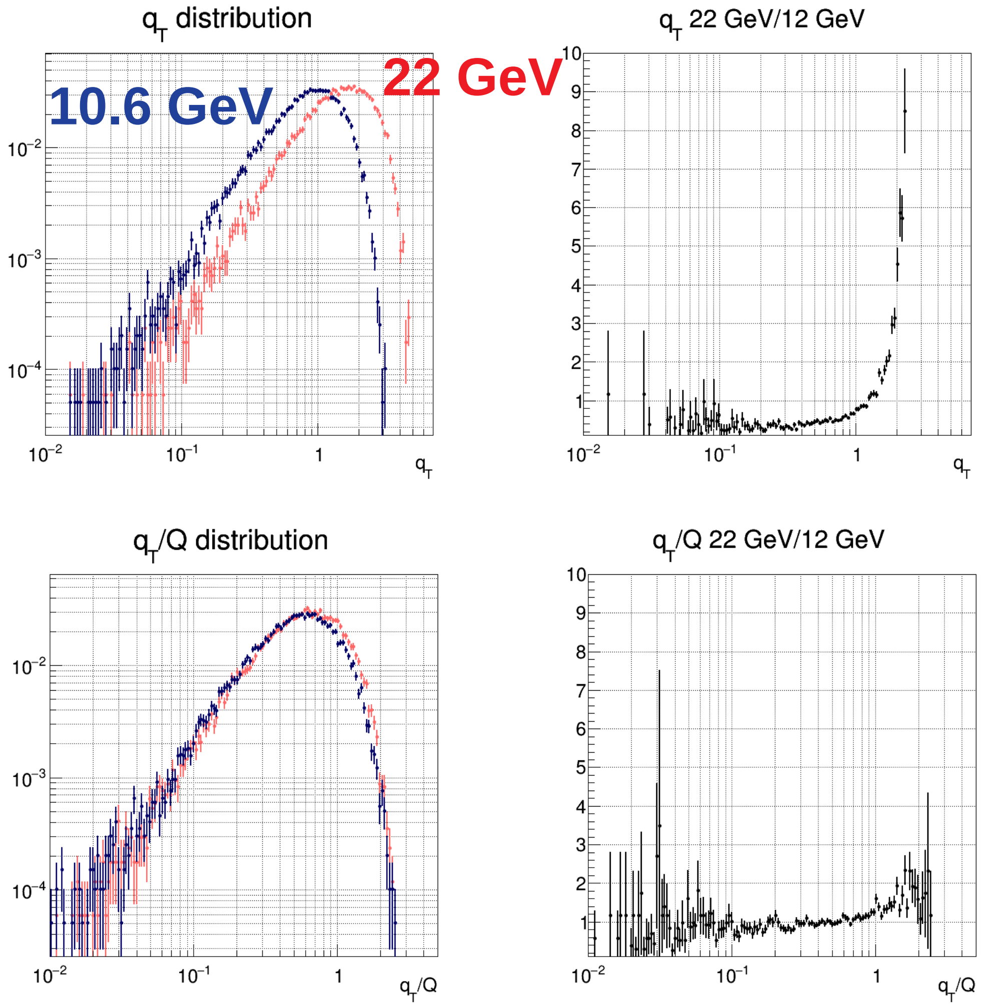


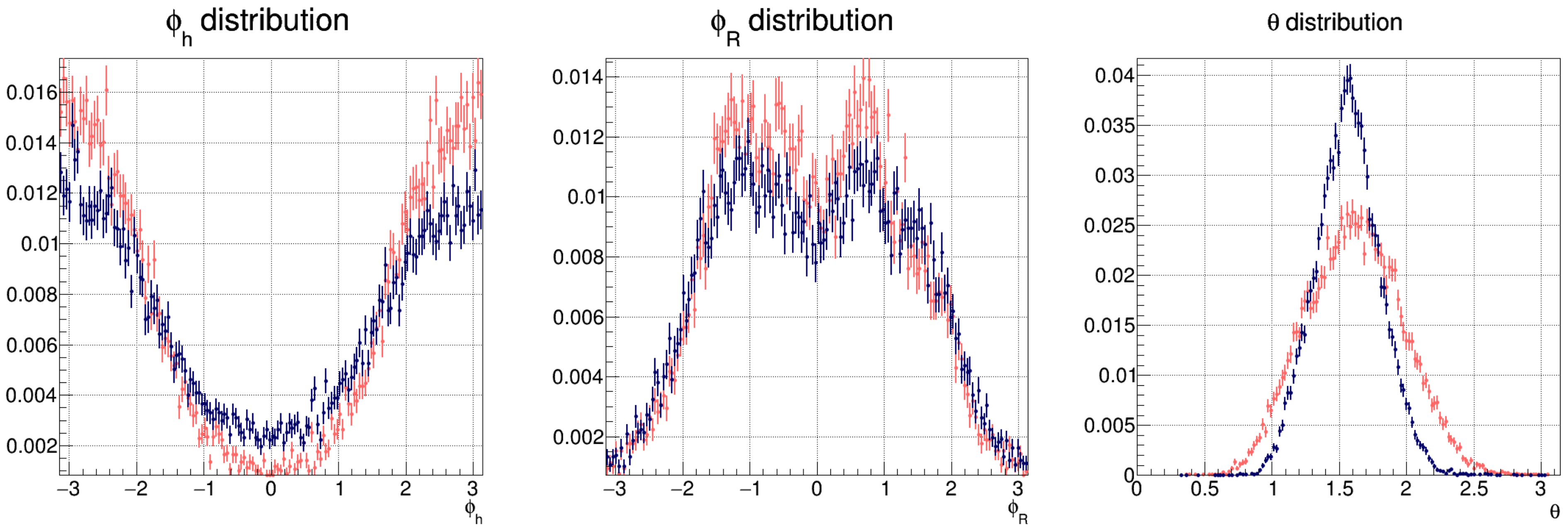


q_T and q_T/Q Comparison

- Higher q_T at 22 GeV
- Similar q_T/Q

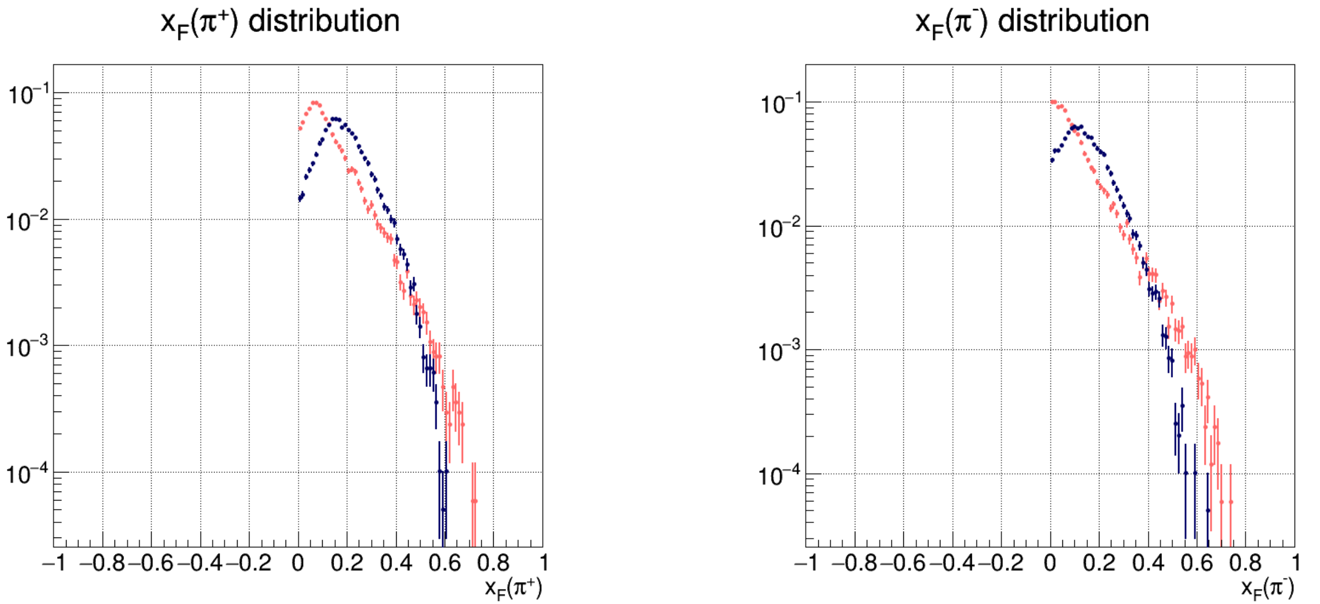


Dihadron Angles Comparison



- Similar ϕ_h and ϕ_R
- Broader θ
- Any impact on partial wave correlations and sensitivity?

Dihadron Angles Comparison



- Smaller $\langle x_F \rangle$ at 22 GeV
- Careful about TFR/CFR separation…

$\Lambda \rightarrow p\pi^-$ Comparisons

- Outbending data
- Similar BG and feed-down contributions for 10.6 and 22 GeV
- Similar 10.6→22 GeV kinematic trends as ππ dihadrons, e.g., lower z and x_F
- More target production at 22 GeV?

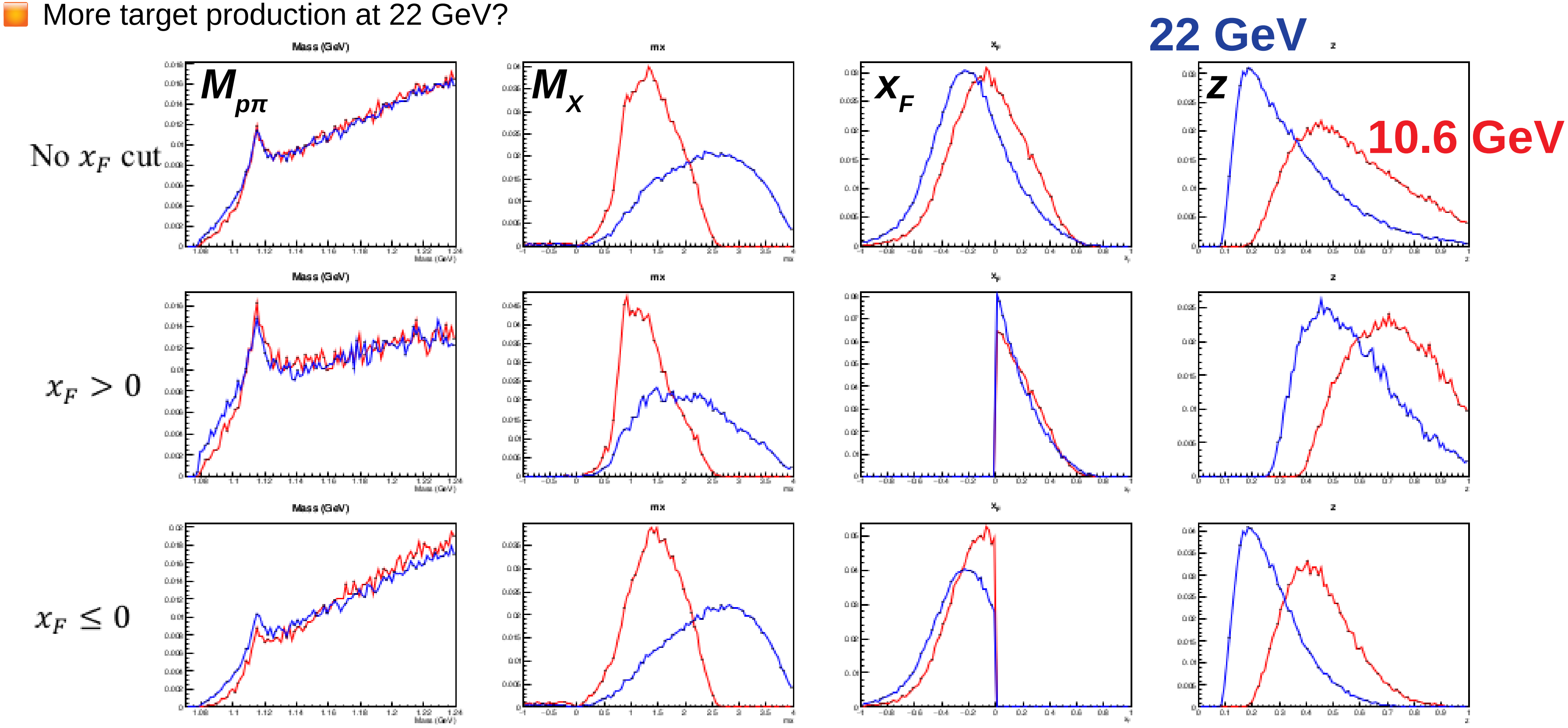
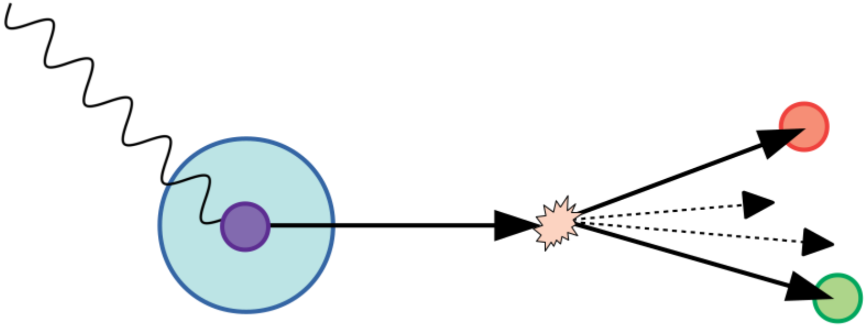


Figure from Matthew McEneaney

Summary

- SIDIS dihadrons access a wide range of PDFs and DiFFs, at leading and *subleading* twist
- Asymmetries with a longitudinally polarized electron beam are less suppressed by depolarization pre-factors at JLab kinematics than at EIC kinematics
- Dihadrons JLab 20+ will help constrain twist-3 PDFs and their Q^2 evolution, along with comparisons to COMPASS and HERMES
- Higher beam energy → lower z and x_F
  - Access DiFFs at lower z
  - More target fragmentation?
- Similar contributions from meson decays
- Trends seen in Λ production are similar



backup

Full Dihadron Cross Section – Depolarization Factors

Twist 2

Target Polarization

Beam Polarization

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

Twist 3

Target Polarization

Beam Polarization

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