Longitudinal target polarization dependent azimuthal asymmetries in SIDIS at COMPASS

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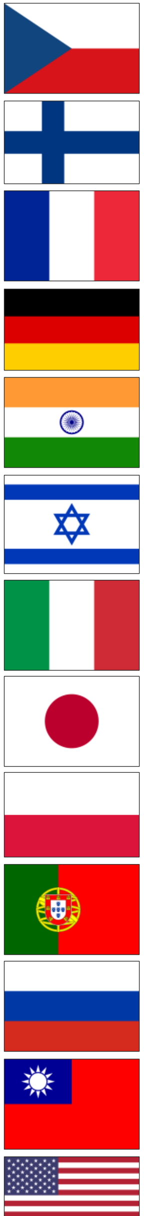
on behalf of the COMPASS Collaboration

"25th International Workshop on
Deep Inelastic Scattering
and Related Topics"

University of Birmingham
Birmingham, United Kingdom
3-7 April 2017

COMPASS collaboration



24 institutions from 13 countries – nearly 250 physicists

Common **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

- **CERN SPS north area**
- **Fixed target experiment**
- **Taking data since 2002**

Wide physics program

COMPASS-I

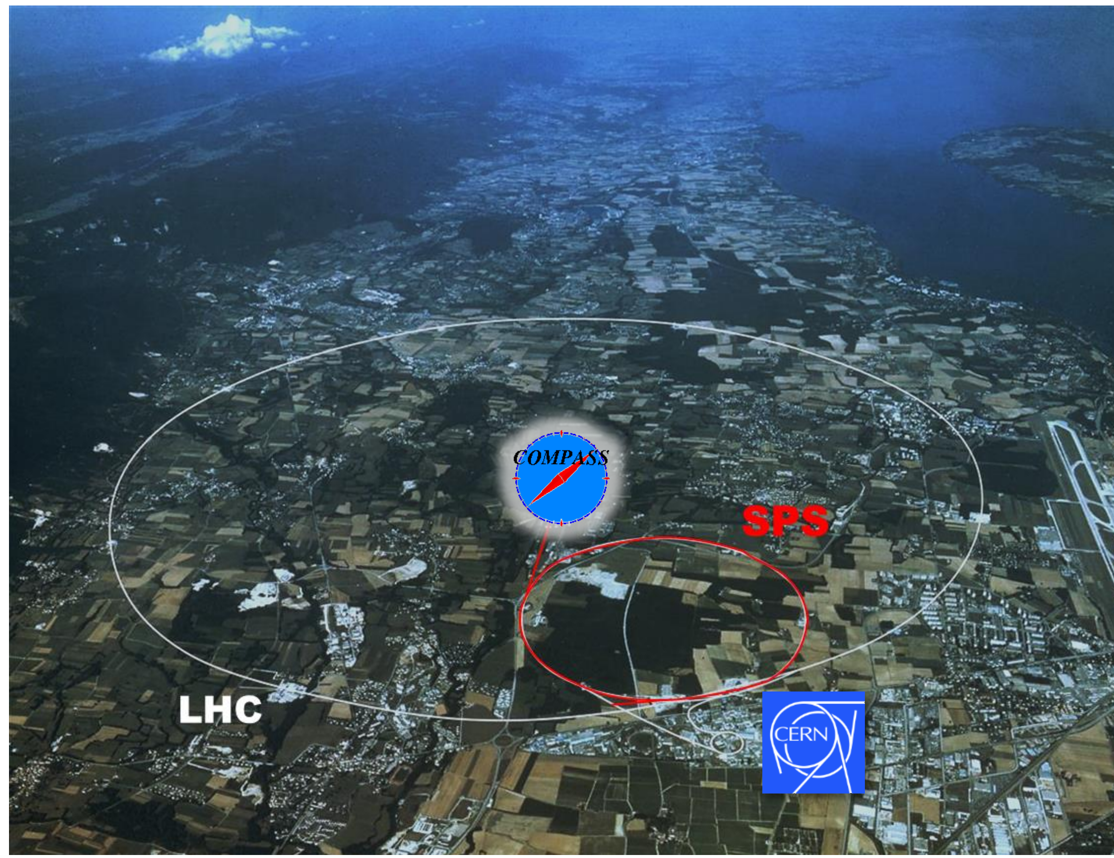
- **Data taking 2002-2011**
- **Muon and hadron beams**
- **Nucleon spin structure**
- **Spectroscopy**

See talks by B. Badelek, E. Kabuss, M. Stolarski, A. Szabelski and this talk

COMPASS-II

- **Data taking 2012-2018**
- **Primakoff**
- **DVCS (GPD+SIDIS)**
- **Polarized Drell-Yan**

See talks by A. Ferrero and B.P.



COMPASS web page: http://wwwcompass.cern.ch

COMPASS experimental setup: Phase I (muon program)

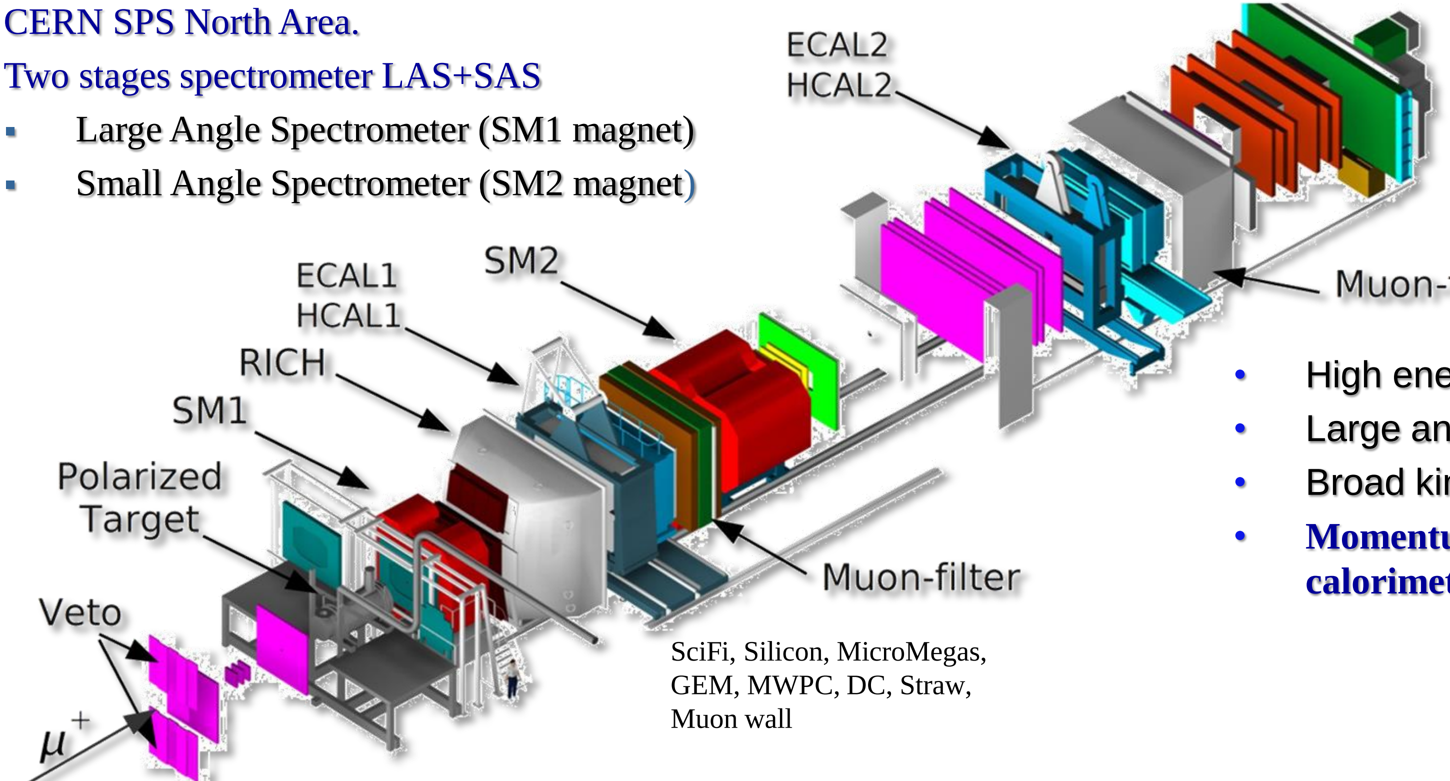
COmmon Muon Proton Apparatus for Structure and Spectroscopy

CERN SPS North Area.

Two stages spectrometer LAS+SAS

- Large Angle Spectrometer (SM1 magnet)
- Small Angle Spectrometer (SM2 magnet)

See talks by:
A. Bressan,
A. Martin
C. Quintans

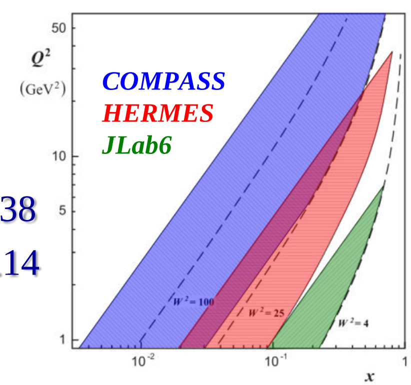


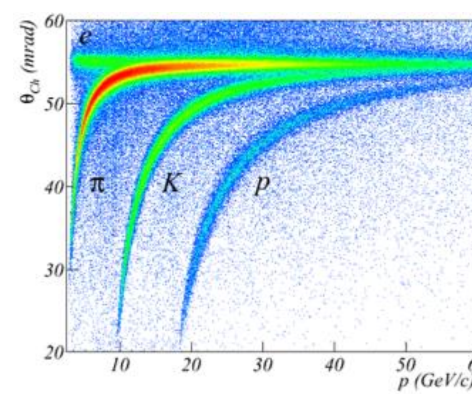
- High energy beam
- Large angular acceptance
- Broad kinematical range
- **Momentum, tracking and calorimetric measurements, PID**

Longitudinally polarized (80%) μ^+ beam:
Energy: 160/200 GeV/c, Intensity: $2 \cdot 10^8$ μ^+/spill (4.8s).

Target: Solid state (*^6LiD or NH_3*)

- ^6LiD 2-cell configuration. Polarization (L & T) ~ 50%, f ~ 0.38
- NH_3 3-cell configuration. Polarization (L & T) ~ 80%, f ~ 0.14





Data-taking years: 2002-2011

COMPASS experimental setup: Phase I (muon program)

COmmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

CERN SPS North Area.

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- Large Angle Spectrometer (SM1 magnet)
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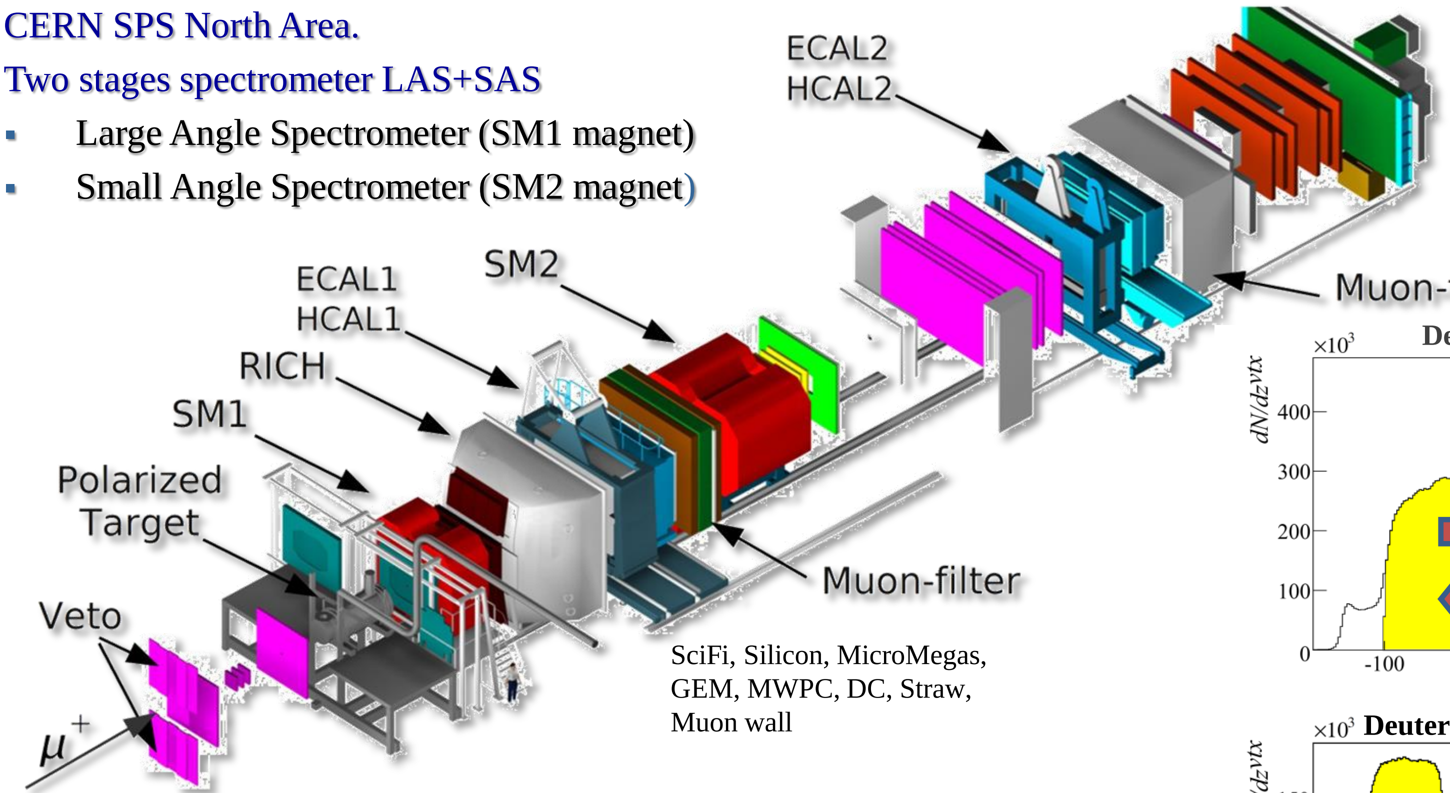
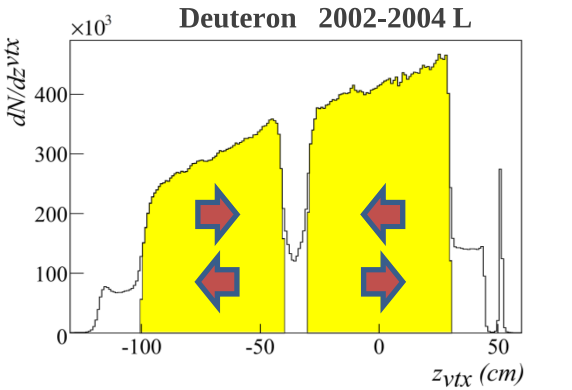
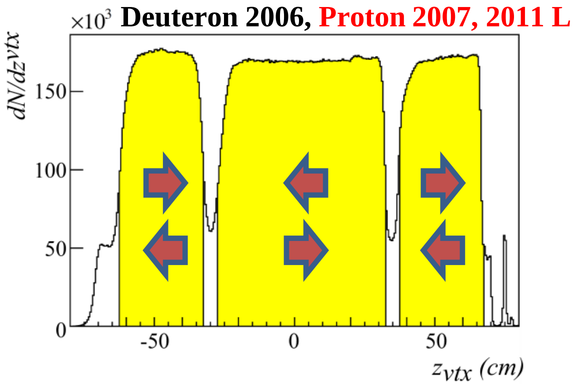






Longitudinally polarized (80%) μ^+ beam:
Energy: 160/200 GeV/c, Intensity: $2 \cdot 10^8$ μ^+/spill (4.8s).

Target: Solid state (*^6LiD or NH_3*)

- ^6LiD 2-cell configuration. Polarization (L & T) ~ 50%, f ~ 0.38
- NH_3 3-cell configuration. Polarization (L & T) ~ 80%, f ~ 0.14

Data-taking years: 2002-2011

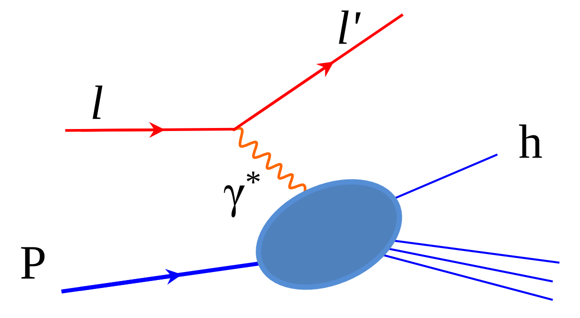
Data is collected simultaneously for the two target spin orientations
Polarization reversal after each ~1-2 days

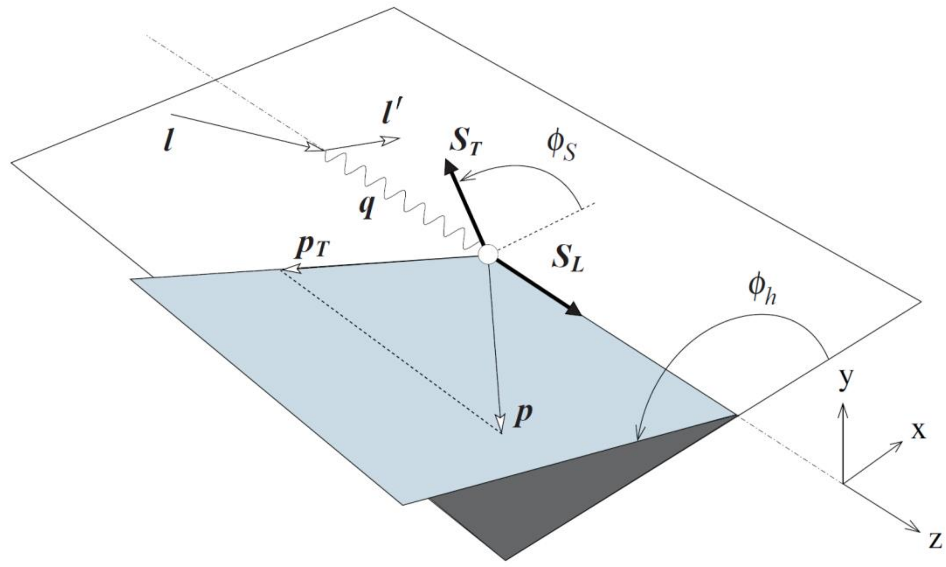
SIDIS x-section

A.Kotzinian, Nucl. Phys. B441, 234 (1995).
Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l}
1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\
+\ \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\
+\ S_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right] \\
+\ S_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right] \\
+\ S_T\left[\begin{array}{l}
A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S) \\
+\ \varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S) \\
+\ \varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S) \\
+\ \sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S \\
+\ \sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)
\end{array}\right] \\
+\ S_T\lambda\left[\begin{array}{l}
\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S) \\
+\ \sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S \\
+\ \sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)
\end{array}\right]
\end{array}\right\}$$





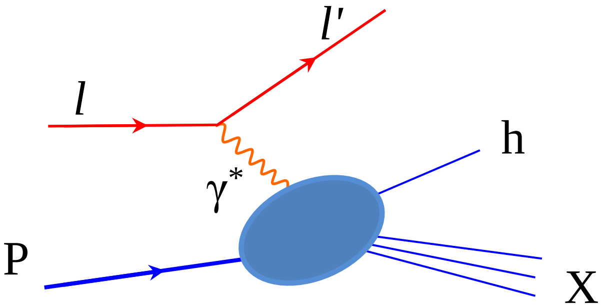
$$A_{U(L),T}^{w(\varphi_h,\varphi_s)} = \frac{F_{U(L),T}^{w(\varphi_h,\varphi_s)}}{F_{UU,T}+\varepsilon F_{UU,L}}; \quad \varepsilon = \frac{1-y-\frac{1}{4}\gamma^2 y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2 y^2}, \quad \gamma = \frac{2Mx}{Q}$$

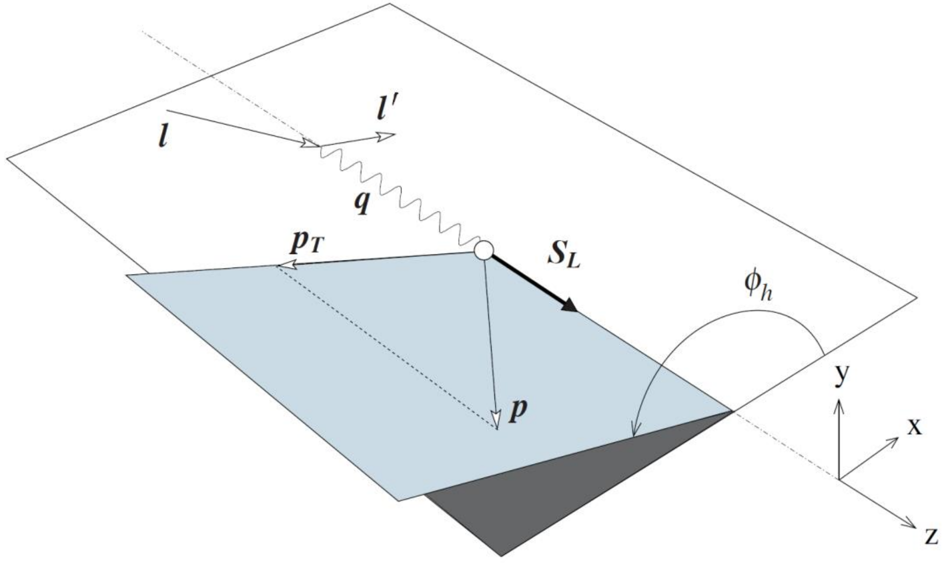
L-SIDIS x-section

A.Kotzinian, Nucl. Phys. B441, 234 (1995).
Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ \begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +S_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\end{array}\right] \\ +S_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\end{array}\right] \end{array} \right\}$$





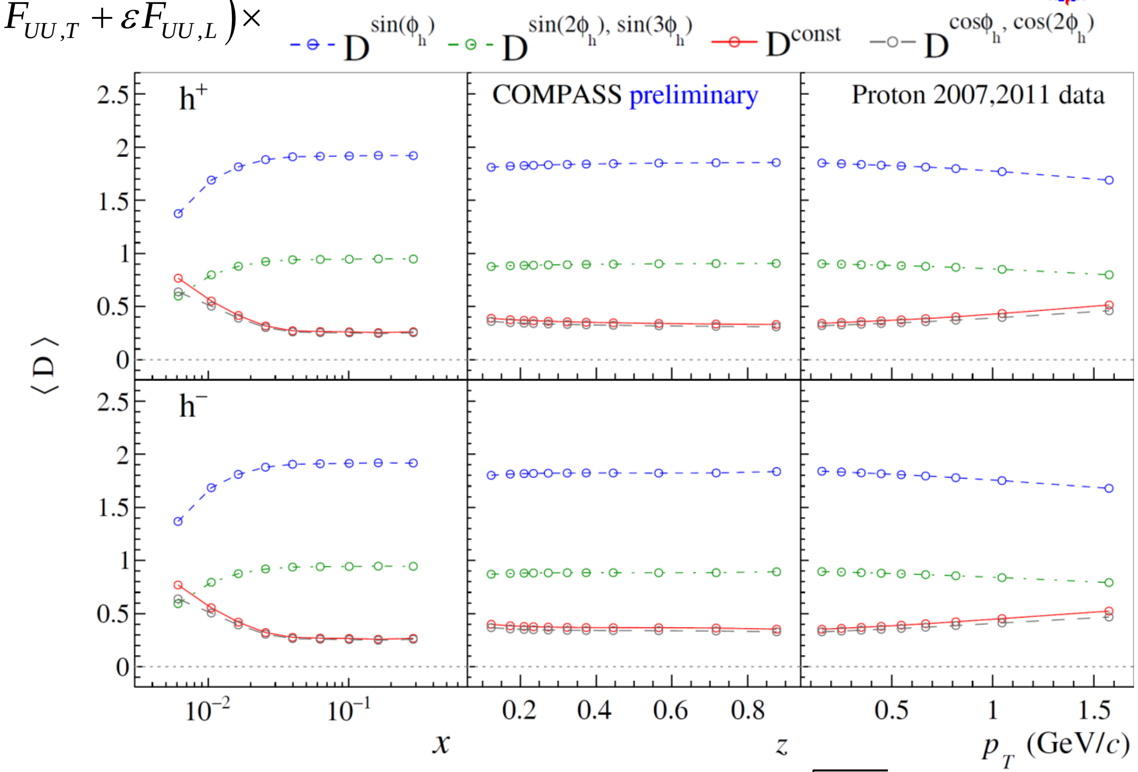
General SIDIS x-section expression contains four target longitudinal spin dependent asymmetries (LSA)

$$A_{U(L),T}^{w(\varphi_h,\varphi_s)} = \frac{F_{U(L),T}^{w(\varphi_h,\varphi_s)}}{F_{UU,T}+\varepsilon F_{UU,L}}; \quad \varepsilon = \frac{1-y-\frac{1}{4}\gamma^2 y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2 y^2}, \quad \gamma = \frac{2Mx}{Q}$$

L-SIDIS x-section: depolarization factors

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ \begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\ \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +\ S_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\ \varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\end{array}\right] \\ +\ S_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\ \sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\end{array}\right] \end{array} \right\}$$



Note: Along with effective target polarization and beam polarization COMPASS LSAs are corrected for D(y) depolarization factors.

$$A_{UL}^{w(\phi_h)} = \frac{A_{UL,raw}^{w(\phi_h)}}{D^{w(\phi_h)}\,f\,|P_L|},\quad A_{LL}^{w(\phi_h)} = \frac{A_{LL,raw}^{w(\phi_h)}}{D^{w(\phi_h)}\,\lambda\,f\,|P_L|}$$

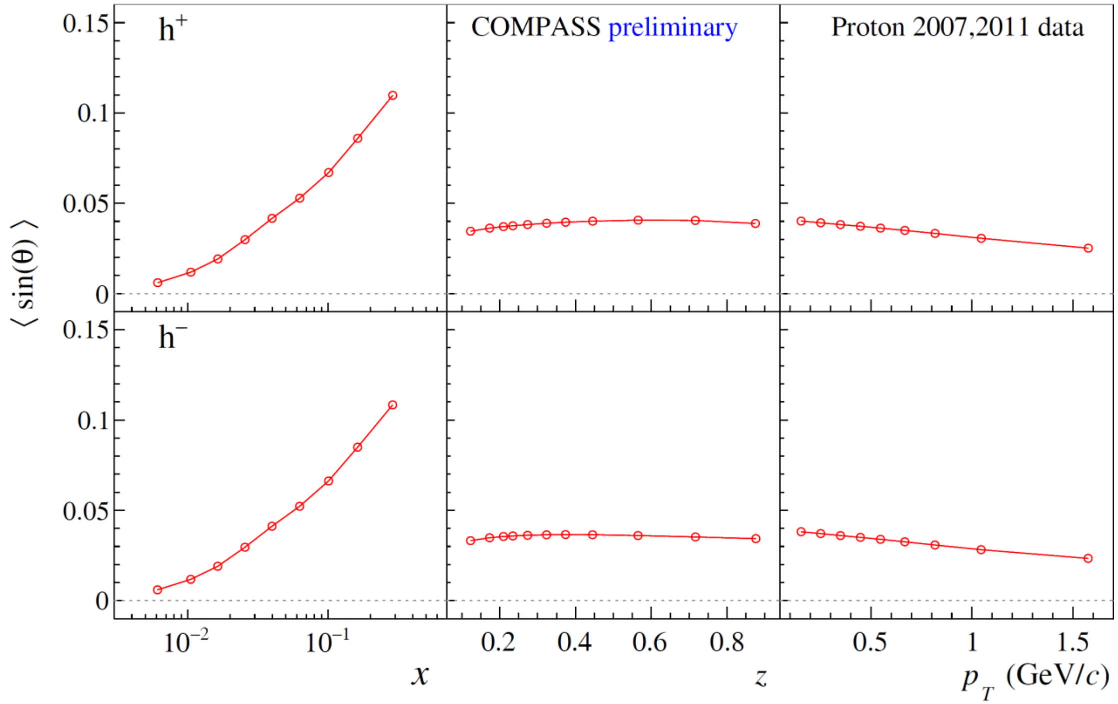
$$\begin{cases} D^{\sin(\phi_h)} = \sqrt{2\varepsilon(1+\varepsilon)} \approx \dfrac{2(2-y)\sqrt{1-y}}{1+(1-y)^2} \\ D^{\sin(2\phi_h)} = \varepsilon \approx \dfrac{2(1-y)}{1+(1-y)^2} \\ D^{1} = \sqrt{(1-\varepsilon^2)} \approx \dfrac{y(2-y)}{1+(1-y)^2} \\ D^{\cos(\phi_h)} = \sqrt{2\varepsilon(1-\varepsilon)} \approx \dfrac{2y\sqrt{1-y}}{1+(1-y)^2} \end{cases}$$

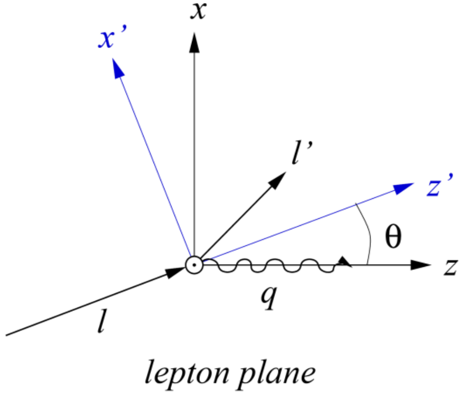
L-SIDIS x-section: from *lp* to $\gamma^* p$

Kotzinian et al.
hep-ph/9808368 (1998)
hep-ph/9908466 (1999)
M. Diehl and S. Sapeta,
Eur. Phys. J. C 41 (2005) 515

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S}=\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l}1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +S_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\end{array}\right] \\ +S_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\end{array}\right]\end{array}\right\}$$





$$\sin\theta=\gamma\sqrt{\frac{1-y-\frac{1}{4}\gamma^2y^2}{1+\gamma^2}},\ \gamma=\frac{2Mx}{Q};$$

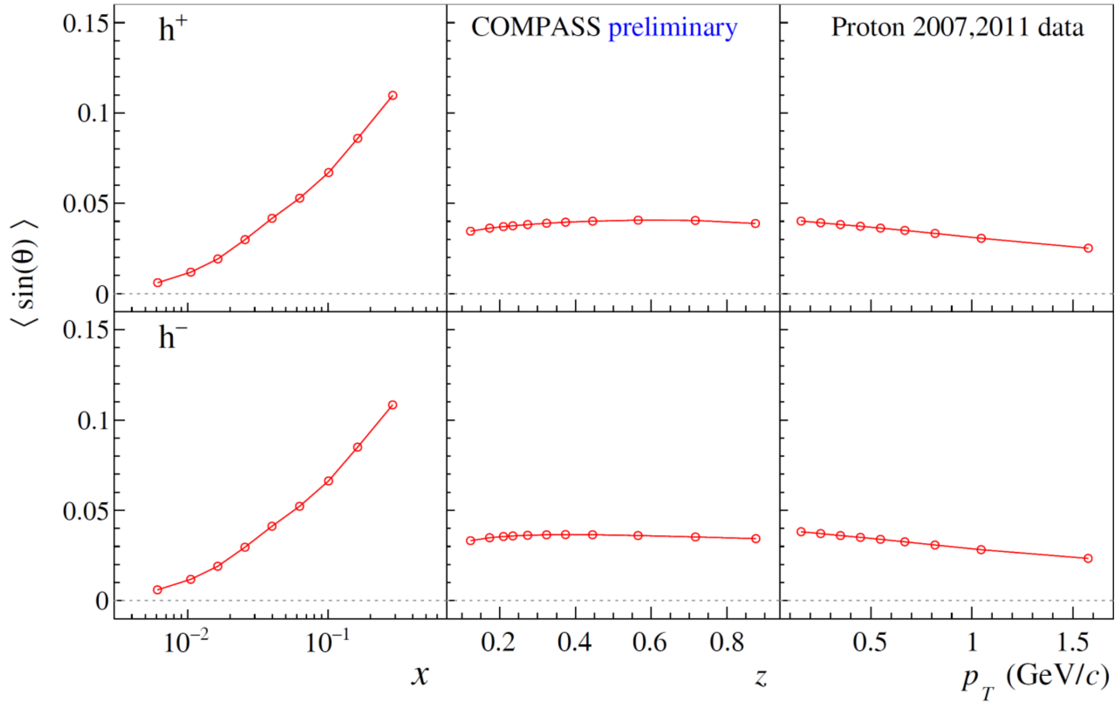
$$\theta\xrightarrow[\text{Bjorken limit}]{}0\Rightarrow S_T\simeq P_T,\ S_L\simeq P_L$$

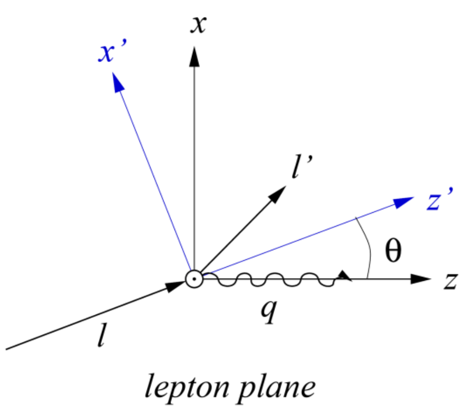
SIDIS x-section: from *lp* to $\gamma * p$ ($P_T=0$)

Kotzinian et al.
hep-ph/9808368 (1998)
hep-ph/9908466 (1999)
M. Diehl and S. Sapeta,
Eur. Phys. J. C 41 (2005) 515

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ \begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ +P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right] \end{array} \right\}$$





$$\sin\theta = \gamma\sqrt{\frac{1-y-\frac{1}{4}\gamma^2 y^2}{1+\gamma^2}},\ \gamma=\frac{2Mx}{Q};$$

$$\theta \xrightarrow{\text{Bjorken limit}} 0 \Rightarrow S_T \simeq P_T,\ S_L \simeq P_L$$

At COMPASS kinematics

$\sin\theta < 0.15$

$\cos\theta \approx 1$

SIDIS x-section: LSA-TSA mixing

Kotzinian et al.
hep-ph/9808368 (1998)
hep-ph/9908466 (1999)
M. Diehl and S. Sapeta,
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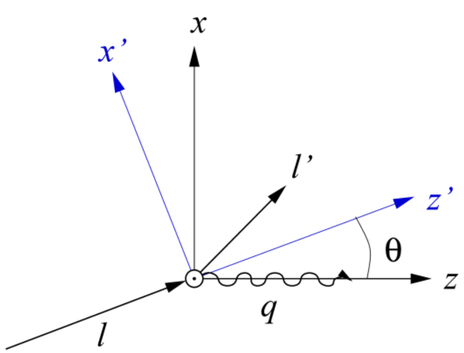
$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ \begin{aligned} &1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ &+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ &+P_L\left[\begin{aligned} &\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ &+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ &-\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h \end{aligned}\right] \\ &+P_L\lambda\left[\begin{aligned} &\sqrt{1-\varepsilon^2}A_{LL} \\ &+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ &-\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h \end{aligned}\right] \end{aligned} \right\}$$

LSA	**$C(\varepsilon,\theta)$ - factor**	**Contributing TSA**
$A_{UL}^{\sin\phi_h}$	$\sin\theta\frac{1}{\sqrt{2\varepsilon(1+\varepsilon)}}$	$A_{UT}^{\sin(\phi_h-\phi_S)}$
$A_{UL}^{\sin\phi_h}$	$\sin\theta\frac{\varepsilon}{\sqrt{2\varepsilon(1+\varepsilon)}}$	$A_{UT}^{\sin(\phi_h+\phi_S)}$
$A_{UL}^{\sin 2\phi_h}$	$\sin\theta\frac{\sqrt{2\varepsilon(1+\varepsilon)}}{\varepsilon}$	$A_{UT}^{\sin(2\phi_h-\phi_S)}$
A_{LL}	$\sin\theta\frac{\sqrt{2\varepsilon(1-\varepsilon)}}{\sqrt{(1-\varepsilon^2)}}$	$A_{LT}^{\cos\phi_S}$
$A_{LL}^{\cos\phi_h}$	$\sin\theta\frac{\sqrt{(1-\varepsilon^2)}}{\sqrt{2\varepsilon(1-\varepsilon)}}$	$A_{LT}^{\cos(\phi_h-\phi_S)}$



lepton plane

$$\sin\theta = \gamma\sqrt{\frac{1-y-\frac{1}{4}\gamma^2y^2}{1+\gamma^2}},\ \gamma=\frac{2Mx}{Q};$$

$$\theta \xrightarrow{\text{Bjorken limit}} 0 \Rightarrow S_T \simeq P_T,\ S_L \simeq P_L$$

$$A_L^{true} \approx \left(\frac{A_L^{fit}+C(\varepsilon,\theta)A_T}{\cos\theta}\right)$$

SIDIS x-section: LSA-TSA mixing

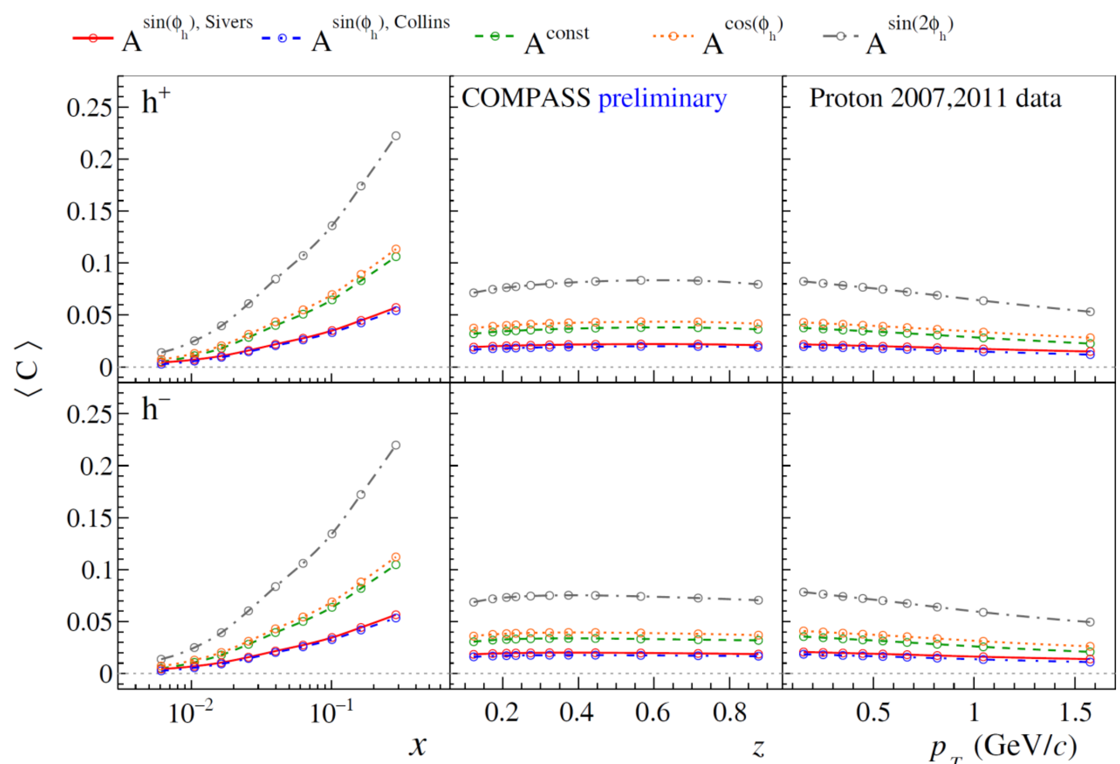
Kotzinian et al.
hep-ph/9808368 (1998)
hep-ph/9908466 (1999)
M. Diehl and S. Sapeta,
Eur. Phys. J. C 41 (2005) 515

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ \begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l} \sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\,\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h \end{array}\right] \\ +P_L\lambda\left[\begin{array}{l} \sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h \end{array}\right] \end{array} \right\}$$

LSA	Contributing TSA
$A_{UL}^{\sin\phi_h}$	$A_{UT}^{\sin(\phi_h-\phi_s)}$
$A_{UL}^{\sin\phi_h}$	$A_{UT}^{\sin(\phi_h+\phi_s-\pi)}$
$A_{UL}^{\sin 2\phi_h}$	$A_{UT}^{\sin(2\phi_h-\phi_s)}$
A_{LL}	$A_{LT}^{\cos\phi_s}$
$A_{LL}^{\cos\phi_h}$	$A_{LT}^{\cos(\phi_h-\phi_s)}$

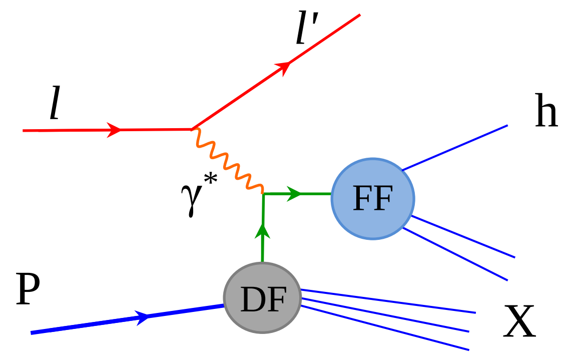
LSAs can get a contribution of up to 25 % of the size of the corresponding TSAs



Interpretation in terms of *twist-2* TMD PDFs and FFs

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h + \varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ + \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ + P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ + \varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ - \sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ + P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ + \sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ - \sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right]\end{array}\right\}$$



Quark / Nucleon	U	L	T
U	$f_1^q(x,\mathbf{k}_T^2)$ **number density**		$h_1^{q\perp}(x,\mathbf{k}_T^2)$ **Boer-Mulders**
L		$g_1^q(x,\mathbf{k}_T^2)$ **helicity**	$h_{1L}^{q\perp}(x,\mathbf{k}_T^2)$ **worm-gear L**
T	$f_{1T}^{q\perp}(x,\mathbf{k}_T^2)$ **Sivers**	$g_{1T}^{q\perp}(x,\mathbf{k}_T^2)$ **Kotzinian-Mulders worm-gear T**	$h_1^q(x,\mathbf{k}_T^2)$ **transversity** $h_{1T}^{q\perp}(x,\mathbf{k}_T^2)$ **pretzelosity**

+ two FFs: $D_{1q}^h(z,P_\perp^2)$ and $H_{1q}^{\perp h}(z,P_\perp^2)$

Access to various "twist-2,-3" functions
Different kinematic suppressions

Interpretation in terms of PDFs and FFs

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ +P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right]\end{array}\right\}$$

Twist-2 | Twist-3

$$\mathcal{C}[wfD] = x\sum_q e_q^2\int d^2\boldsymbol{k}_T d^2\boldsymbol{p}_T^q\delta^{(2)}\left(\boldsymbol{k}_T-\boldsymbol{p}_T^q-\frac{\boldsymbol{p}_T}{z}\right)w\left(\boldsymbol{k}_T,\boldsymbol{p}_T^q\right)f^q\left(x,\boldsymbol{k}_T^2\right)D_q^h\left(z,\boldsymbol{k}_T^2\right)$$

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q}{M_h}\left(xh_L^q H_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q\right)\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\right)-\boldsymbol{p}_T^q\cdot\boldsymbol{k}_T}{MM_h}h_{1L}^{\perp q}H_{1q}^{\perp h}\right\}$$

$$F_{LL}^{1} = \mathcal{C}\left\{g_{1L}^q D_{1q}^h\right\}$$

$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q}{M_h}\left(xe_L^q H_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{D}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xg_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp q}\frac{\tilde{E}_q^h}{z}\right)\right\}$$

Access to various "twist-2,-3" functions
Different kinematic suppressions

Interpretation in terms of *twist-2* TMD PDFs and FFs

Twist-2 | Twist-3

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ +P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right]\end{array}\right\}$$

$$A_{UL}^{\sin\phi_h} \overset{WW}{\propto} Q^{-1}\left(h_{1L}^{\perp q}\otimes H_{1q}^{\perp h}+\ldots\right)$$

$$A_{UL}^{\sin 2\phi_h} \propto h_{1L}^{\perp q}\otimes H_{1q}^{\perp h}$$

$$A_{UL}^{\sin 3\phi_h} \leftrightarrow A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q}\otimes H_{1q}^{\perp h}$$

$$A_{LL} \propto g_{1L}^{q}\otimes D_{1q}^{h}$$

$$A_{LL}^{\cos\phi_h} \overset{WW}{\propto} Q^{-1}\left(g_{1L}^{q}\otimes D_{1q}^{h}+\ldots\right)$$

$$A_{LL}^{\cos 2\phi_h} \leftrightarrow A_{LT}^{\cos(2\phi_h-\phi_s)} \overset{WW}{\propto} Q^{-1}\left(g_{1T}^{q}\otimes D_{1q}^{h}+\ldots\right)$$

Access to various “twist-2,-3” functions
Different kinematic suppressions

Interpretation in terms of *twist-2* TMD PDFs and FFs

Twist-2 | Twist-3

$$\frac{d\sigma}{dxdydzdp_T^2d\phi_h d\phi_S}=\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ +P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right]\end{array}\right\}$$

$$A_{UL}^{\sin\phi_h}\overset{WW}{\propto}Q^{-1}\left(h_{1L}^{\perp q}\otimes H_{1q}^{\perp h}+\ldots\right)\leftarrow\left\{\begin{array}{l}A_{UT}^{\sin(\phi_h-\phi_s)}\propto f_{1T}^{\perp q}\otimes D_{1q}^{h} \\ A_{UT}^{\sin(\phi_h+\phi_s)}\propto h_1^q\otimes H_{1q}^{\perp h}\end{array}\right.$$

$$A_{UL}^{\sin 2\phi_h}\propto h_{1L}^{\perp q}\otimes H_{1q}^{\perp h}\leftarrow\left\{A_{UT}^{\sin(2\phi_h-\phi_s)}\overset{WW}{\propto}Q^{-1}\left(h_1^q\otimes H_{1q}^{\perp h}+\ldots\right)\right.$$

$$A_{UL}^{\sin 3\phi_h}\leftrightarrow A_{UT}^{\sin(3\phi_h-\phi_s)}\propto h_{1T}^{\perp q}\otimes H_{1q}^{\perp h}$$

$$A_{LL}\propto g_{1L}^q\otimes D_{1q}^h\leftarrow\left\{A_{LT}^{\cos(\phi_s)}\overset{WW}{\propto}Q^{-1}\left(g_{1T}^q\otimes D_{1q}^h+\ldots\right)\right.$$

$$A_{LL}^{\cos\phi_h}\overset{WW}{\propto}Q^{-1}\left(g_{1L}^q\otimes D_{1q}^h+\ldots\right)\leftarrow\left\{A_{LT}^{\cos(\phi_h-\phi_s)}\propto g_{1T}^q\otimes D_{1q}^h\right.$$

$$A_{LL}^{\cos 2\phi_h}\leftrightarrow A_{LT}^{\cos(2\phi_h-\phi_s)}\overset{WW}{\propto}Q^{-1}\left(g_{1T}^q\otimes D_{1q}^h+\ldots\right)$$

Access to various “twist-2,-3” functions
Different kinematic suppressions
Mixing with TSAs

- Former HERMES, JLab and COMPASS experimental results on LSAs

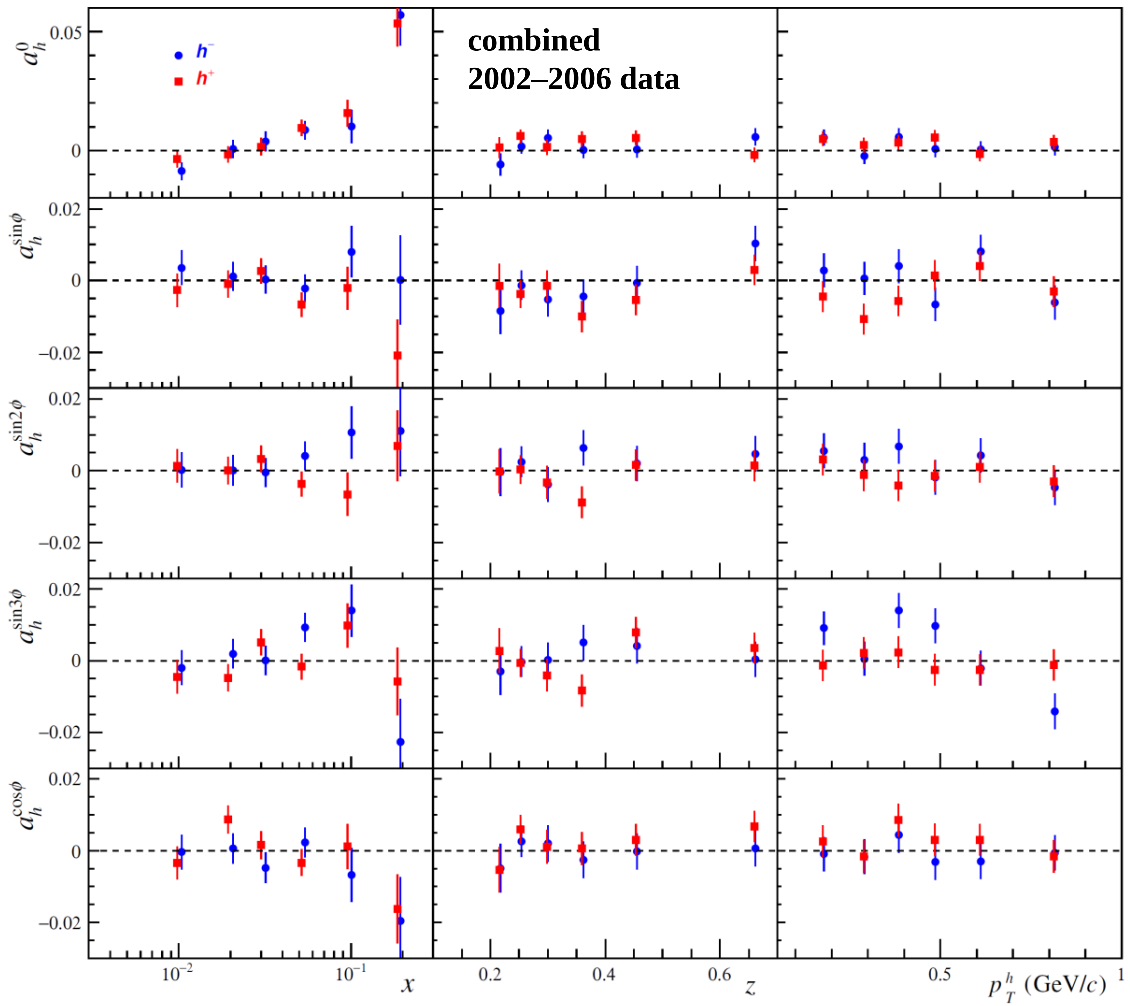
Existing measurements: COMPASS

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h + \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h + P_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h + \varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h - \sin\theta\,\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\right] + P_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h - \sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\right]\right\}$$

COMPASS combined D-sample

CERN-EP-2016–245, arXiv:1609.06062 [hep-ex]



- **COMPASS collected large amount of SIDIS data with longitudinally polarized D/P targets (2002-2011)**

Existing measurements: COMPASS

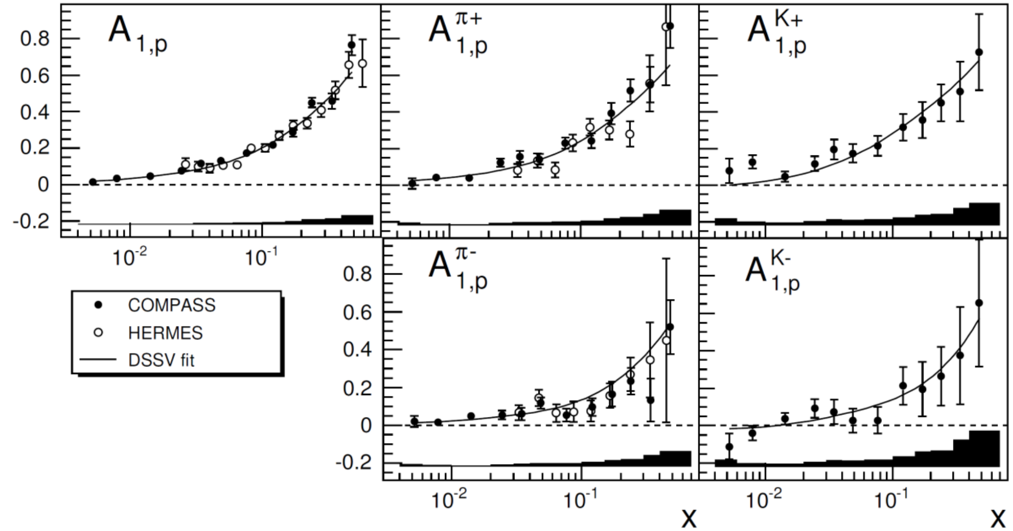
$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

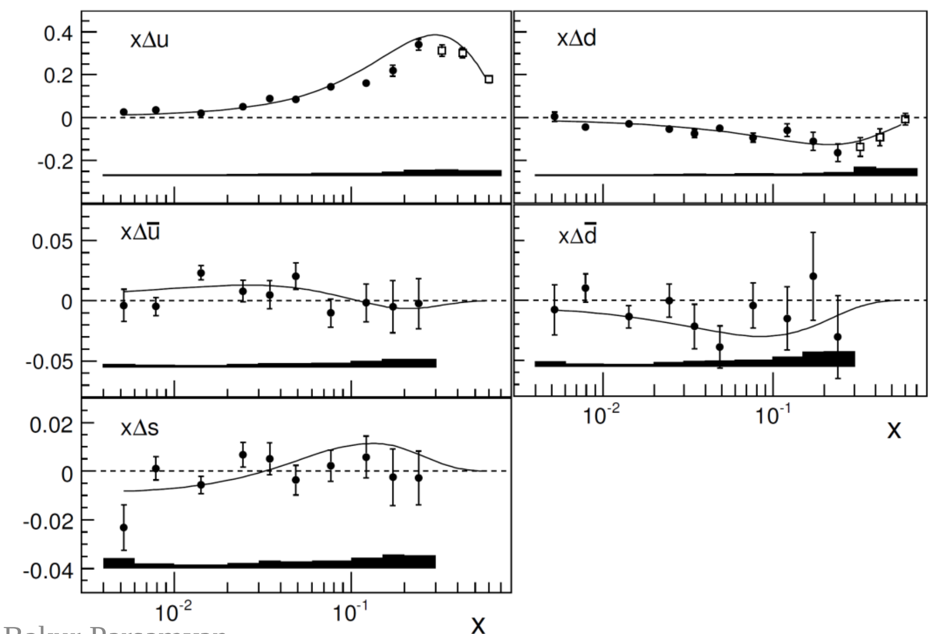
$$\left\{ 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h + \varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h + \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \right.$$

$$+ P_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h + \varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h - \sin\theta\,\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\right]$$

$$\left. + P_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h - \sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\right]\right\}$$

PLB 693 (2010) 227–235





- **COMPASS collected large amount of SIDIS data with longitudinally polarized D/P targets (2002-2011)**

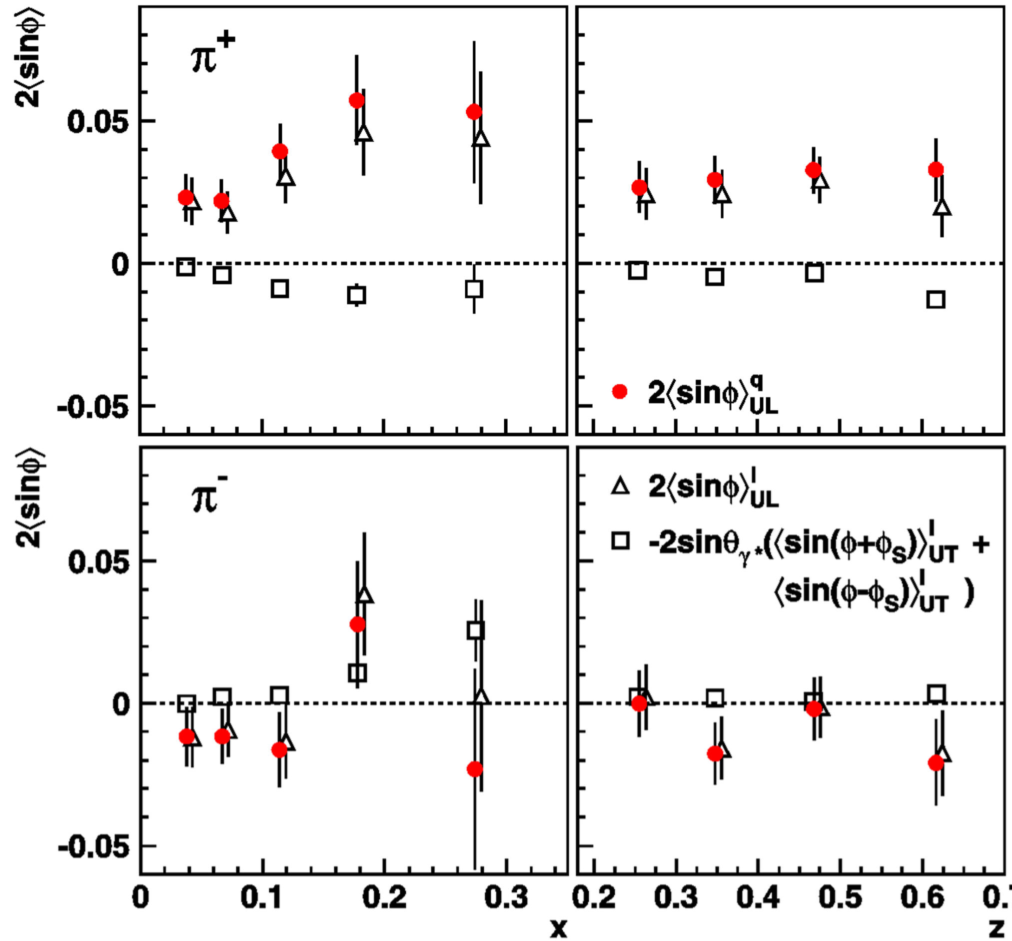
$$F_{LL}^{1} = \mathcal{C}\left\{g_{1L}^{q} D_{1q}^{h}\right\}$$

Existing measurements: HERMES

$$\frac{d\sigma}{dxdydzdp_T^2d\phi_hd\phi_S}=\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l}1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ +P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right]\end{array}\right\}$$

HERMES PLB 622 (2005) 14



- **COMPASS collected large amount of SIDIS data with longitudinally polarized D/P targets (2002-2011)**
- **Similar measurements have been performed by HERMES (P/D)**

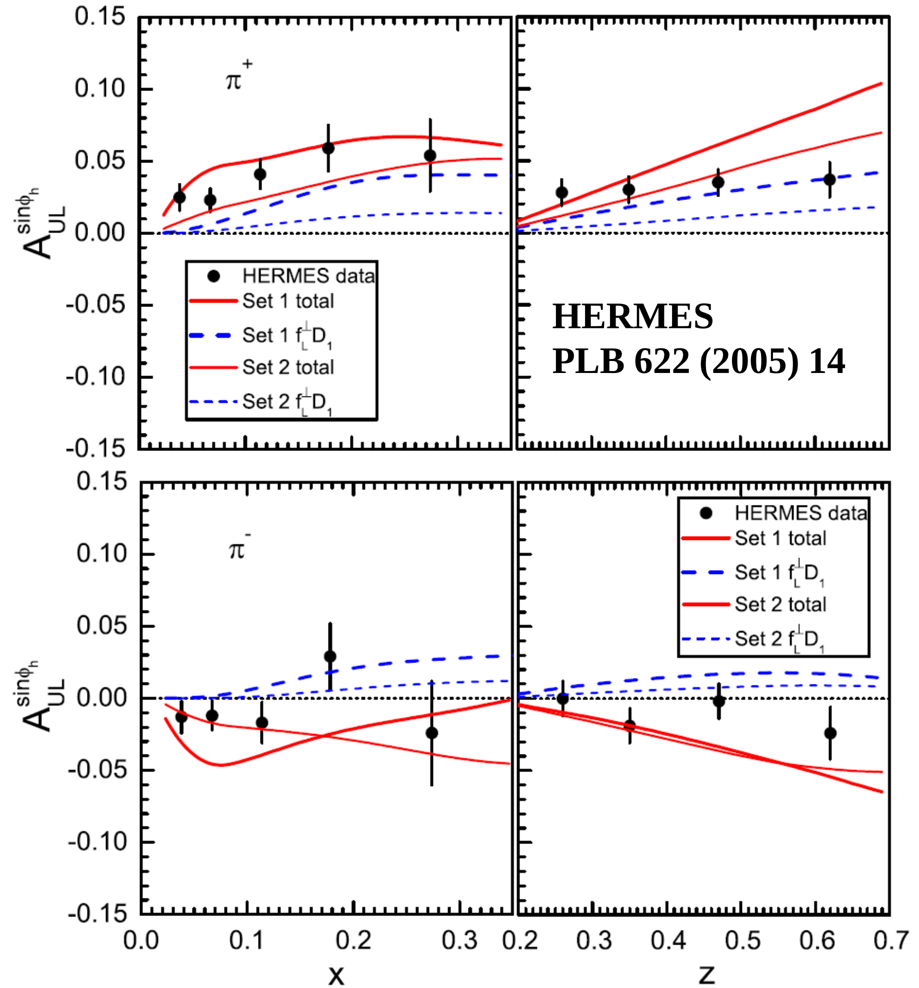
$$F_{UL}^{\sin\phi_h}=\frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q}{M_h}\left(xh_L^qH_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

Existing measurements: HERMES

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h + \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h + P_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h + \varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h - \sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\right] + P_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h - \sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\right]\right\}$$

Zhun Lu, Phys. Rev. D 90, 014037(2014)



- **COMPASS collected large amount of SIDIS data with longitudinally polarized D/P targets (2002-2011)**
- **Similar measurements have been performed by HERMES (P/D)**

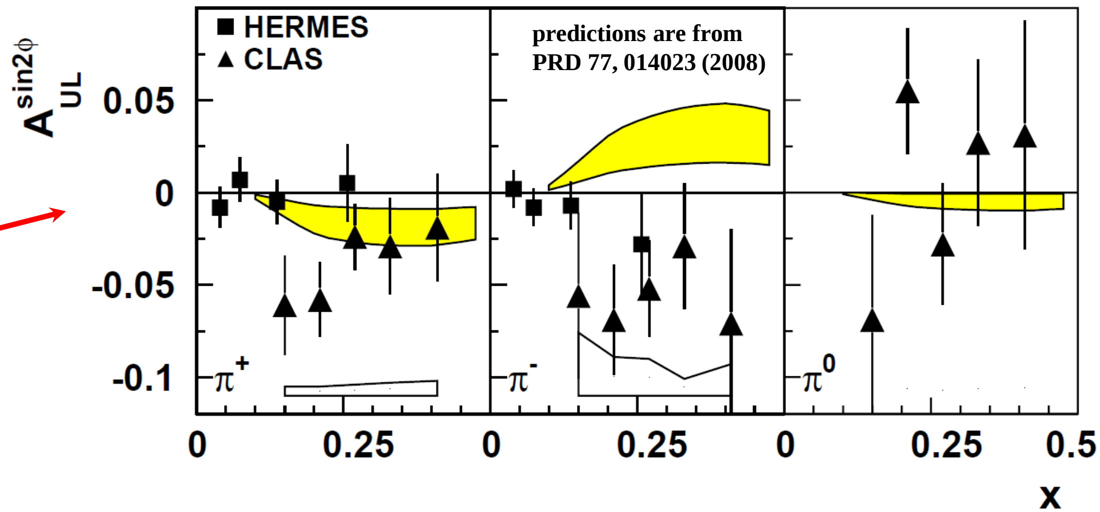
$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q}{M_h}\left(xh_L^q H_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

Existing measurements: HERMES, CLAS

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ \begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ +P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right] \end{array} \right\}$$

PRL 105, 262002(2010)



$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q\right)\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\right)-\boldsymbol{p}_T^q\cdot\boldsymbol{k}_T}{MM_h}h_{1L}^{\perp q}H_{1q}^{\perp h}\right\}$$

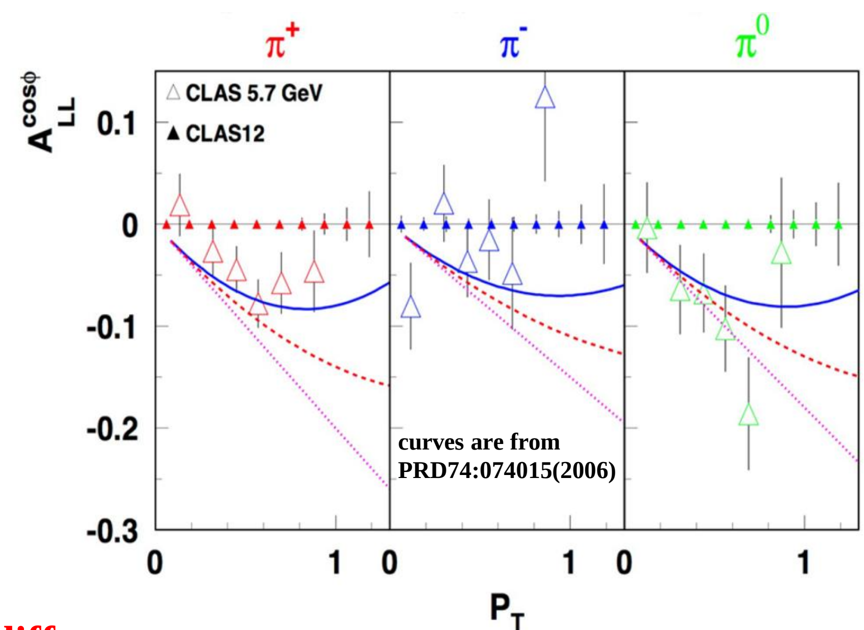
- **COMPASS collected large amount of SIDIS data with longitudinally polarized D/P targets (2002-2011)**
- **Similar measurements have been performed by HERMES (P/D) and Jlab (P)**
- **Non zero effects, interesting measurement**
- **Several theoretical predictions are available from different groups**
- **Prospects for future measurements**

Existing measurements: CLAS

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ +P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h\end{array}\right] \\ +P_L\lambda\left[\begin{array}{l}\sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h\end{array}\right]\end{array}\right\}$$

$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q}{M_h}\left(xe_L^q H_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{D}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xg_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp q}\frac{\tilde{E}_q^h}{z}\right)\right\}$$

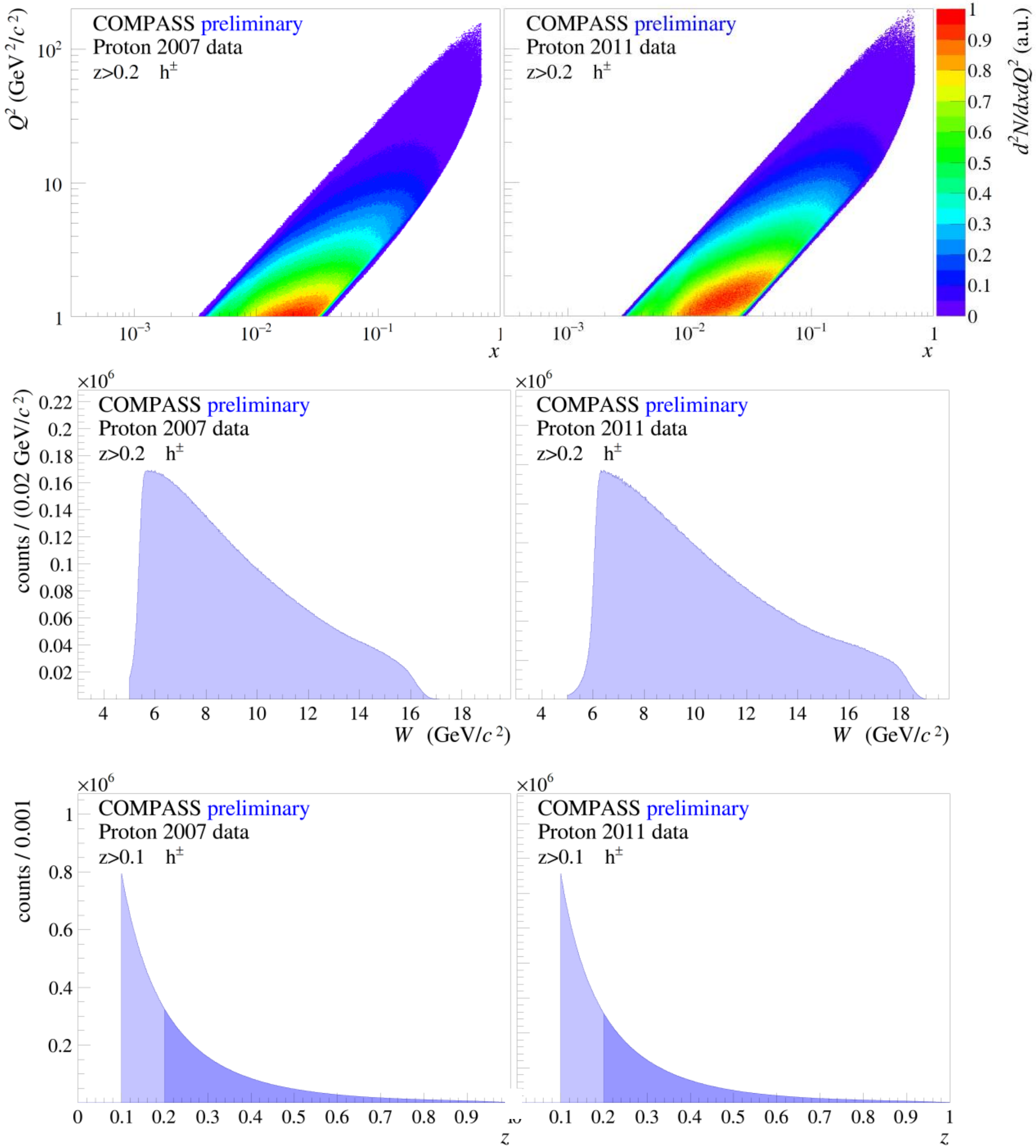


- **COMPASS collected large amount of SIDIS data with longitudinally polarized D/P targets (2002-2011)**
- **Similar measurements have been performed by HERMES (P/D) and Jlab (P)**
- **Non zero effects, interesting measurement**
- **Several theoretical predictions are available from different groups**
- **Prospects for future measurements**

- Proton SIDIS single-hadron azimuthal LSAs at COMPASS (only partially shown at SPIN-2016)

NEW!

Kinematics 2007(160 GeV/*c*), 2011 (200 GeV/*c*)



Two years of longitudinal data with NH_3 target:
2007: 160 GeV μ^+ – beam
2011: 200 GeV μ^+ – beam

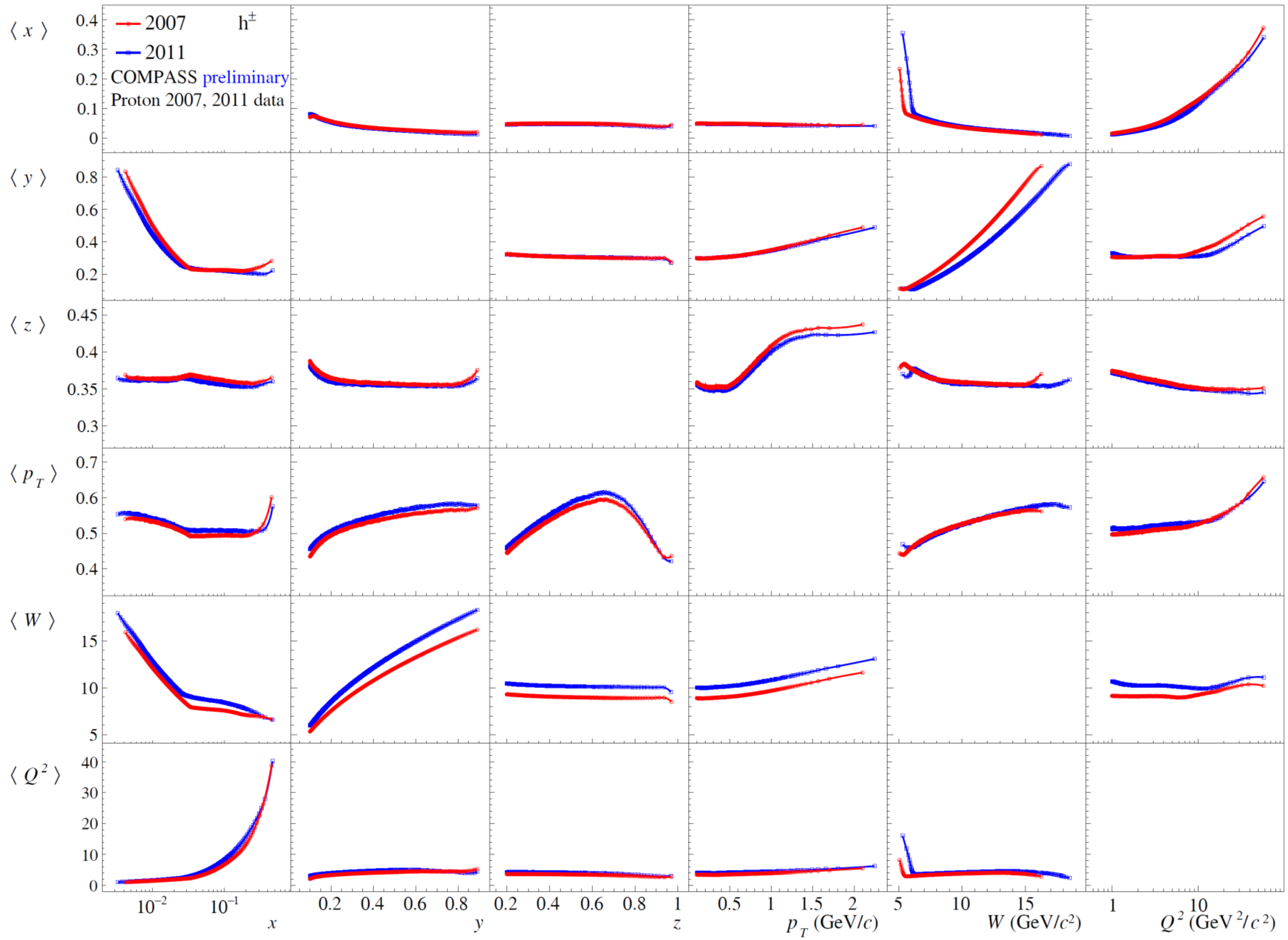
Kinematic cuts

DIS variables:
$Q^2 > 1$ (GeV/c)^2
$0.0025 < x < 0.7$
$0.1 < y < 0.9$
$W > 5$ GeV/c^2

Hadronic cuts:
z>0.2, 0.1<z<0.2
p_T>0.1 GeV/c

Comparable kinematic distributions

Kinematics 2007(160 GeV/c), 2011 (200 GeV/c)



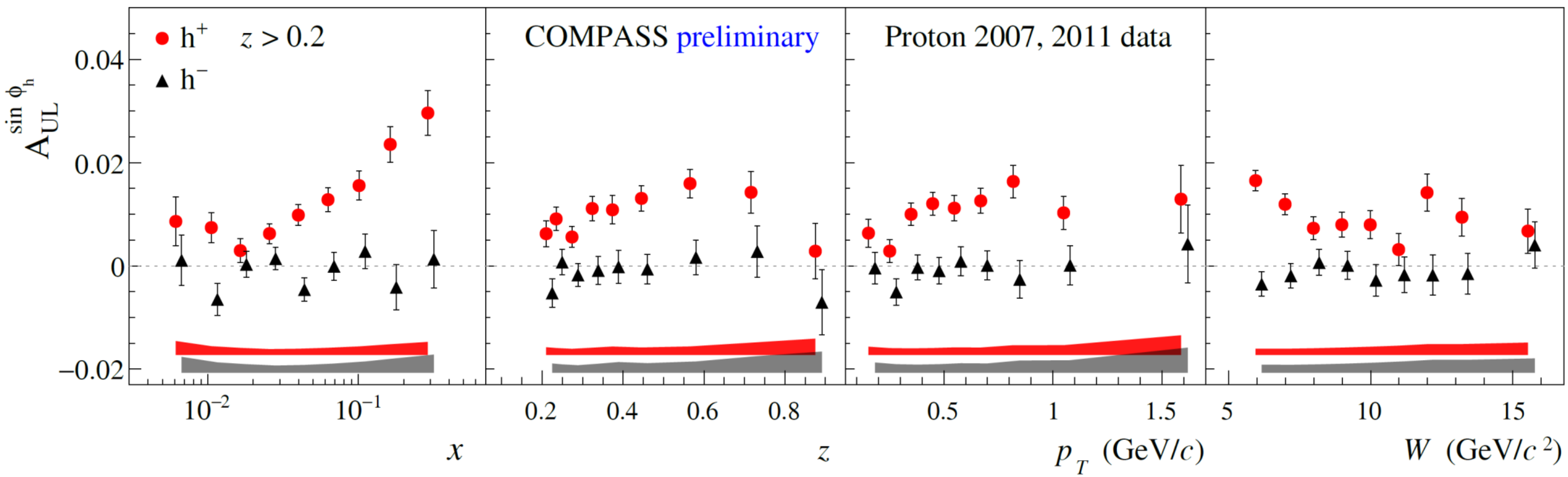
Comparable kinematic distributions

Only results from merged 2007+2011 sample are shown

The $A_{UL}^{\sin\phi_h}$ asymmetry

$$\frac{d\sigma}{dxdydzdp_T^2d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1+\ldots+ S_L \sqrt{2\varepsilon\left(1+\varepsilon\right)} A_{UL}^{\sin\phi_h} \sin\phi_h + \ldots\right\}$$

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(xh_L^q H_{1q}^{\perp h} + \frac{M_h}{M} g_{1L}^q \frac{\tilde{G}_q^{\perp h}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(xf_L^{\perp q} D_{1q}^h - \frac{M_h}{M} h_{1L}^{\perp q} \frac{\tilde{H}_q^h}{z}\right)\right\}$$

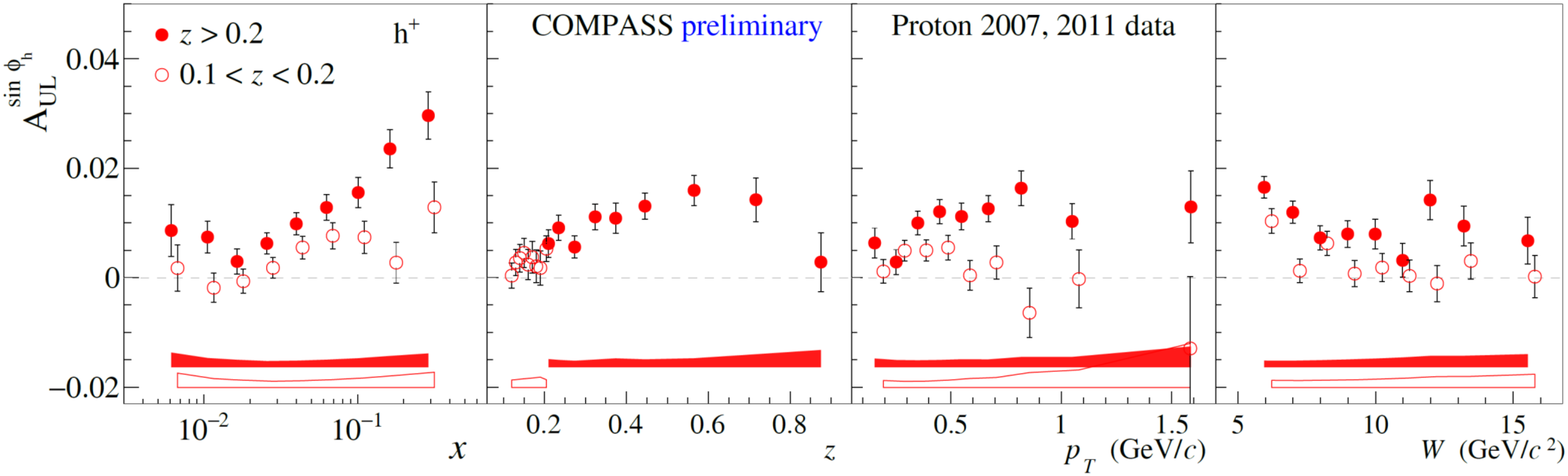


- Q-suppression, TSA-mixing
- Various different “twist” ingredients
- **Non-zero trend for h⁺, h⁻ compatible with zero**

The $A_{UL}^{\sin\phi_h}$ asymmetry

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \sqrt{2\varepsilon(1+\varepsilon)} A_{UL}^{\sin\phi_h} \sin\phi_h + \ldots\right\}$$

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\mathbb{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(x h_L^q H_{1q}^{\perp h} + \frac{M_h}{M} g_{1L}^q \frac{\tilde{G}_q^{\perp h}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(x f_L^{\perp q} D_{1q}^h - \frac{M_h}{M} h_{1L}^{\perp q} \frac{\tilde{H}_q^h}{z}\right)\right\}$$

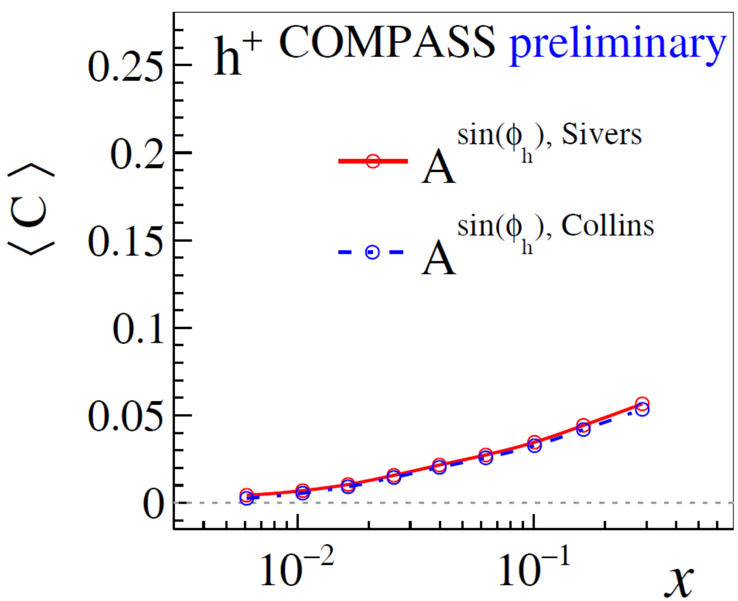


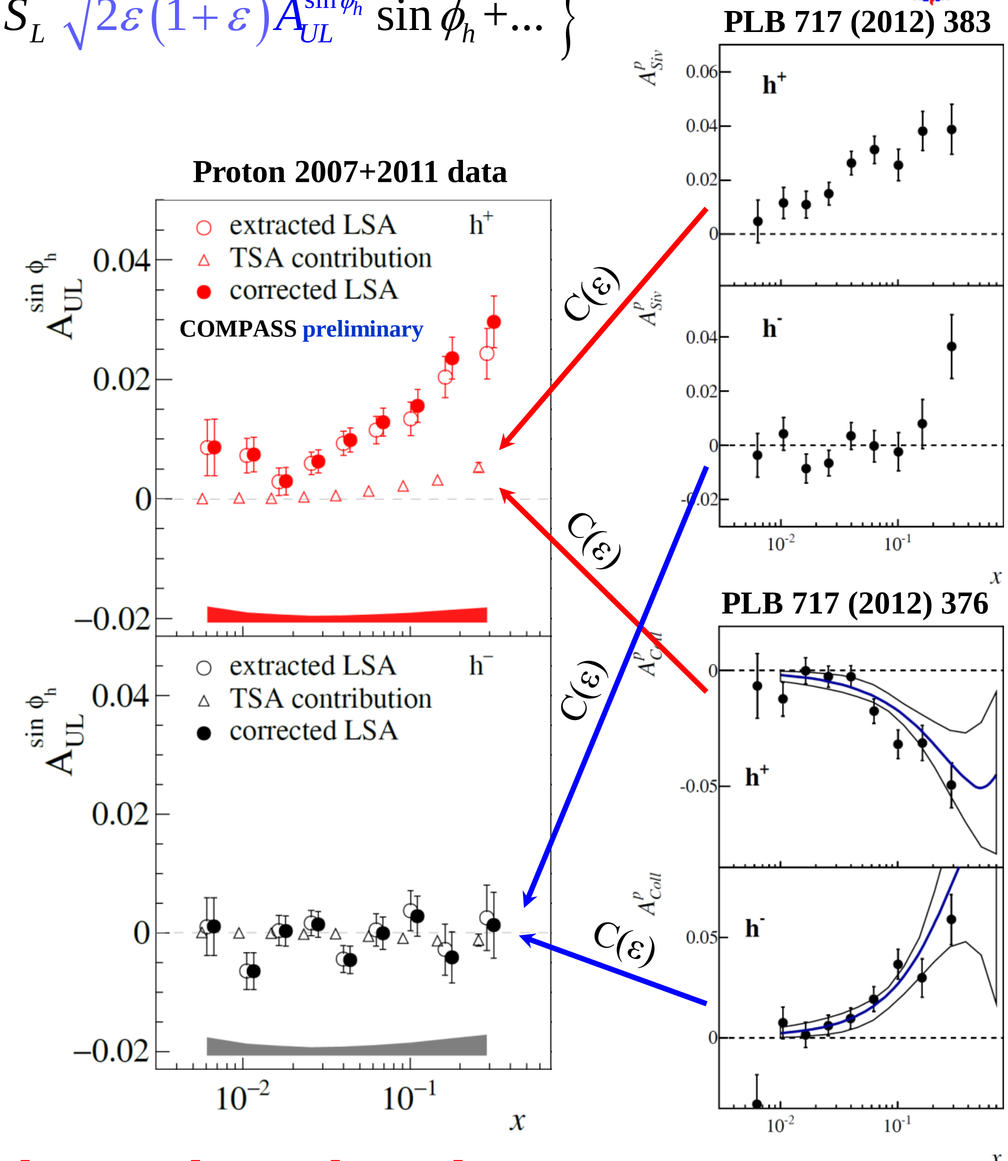
- Q-suppression, TSA-mixing
- Various different “twist” ingredients
- **Non-zero trend for h+, h− compatible with zero, clear z-dependence**

The $A_{UL}^{\sin\phi_h}$ asymmetry

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} \propto \left(F_{UU,T}+\varepsilon F_{UU,L}\right)\left\{1+\ldots+\ S_L\sqrt{2\varepsilon\left(1+\varepsilon\right)}A_{UL}^{\sin\phi_h}\sin\phi_h+\ldots\right\}$$

$$F_{UL}^{\sin\phi_h}=\frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(xh_L^q H_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$



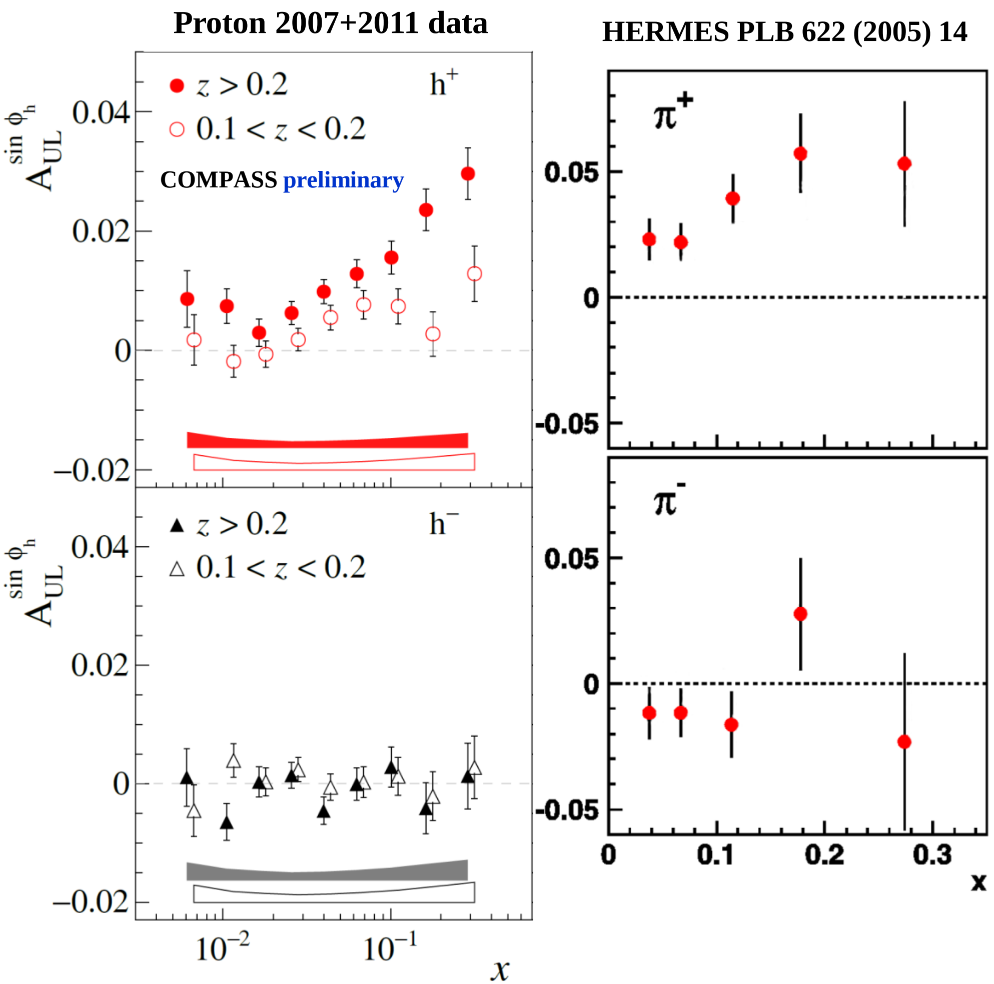


- Q-suppression, TSA-mixing
- Various different "twist" ingredients
- **Non-zero trend for h⁺, h⁻ compatible with zero, clear z-dependence**

The $A_{UL}^{\sin\phi_h}$ asymmetry

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \sqrt{2\varepsilon(1+\varepsilon)}\,A_{UL}^{\sin\phi_h}\sin\phi_h + \ldots\right\}$$

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(x h_L^q H_{1q}^{\perp h} + \frac{M_h}{M} g_{1L}^q \frac{\tilde{G}_q^{\perp h}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(x f_L^{\perp q} D_{1q}^h - \frac{M_h}{M} h_{1L}^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

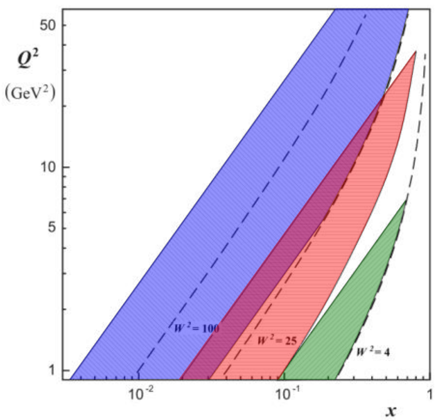


- Q-suppression, TSA-mixing
- Various different “twist” ingredients
- **Non-zero trend for h^+, h^- compatible with zero, clear z-dependence**

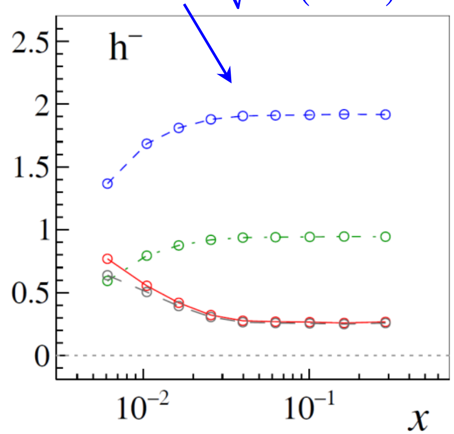
The $A_{UL}^{\sin\phi_h}$ asymmetry

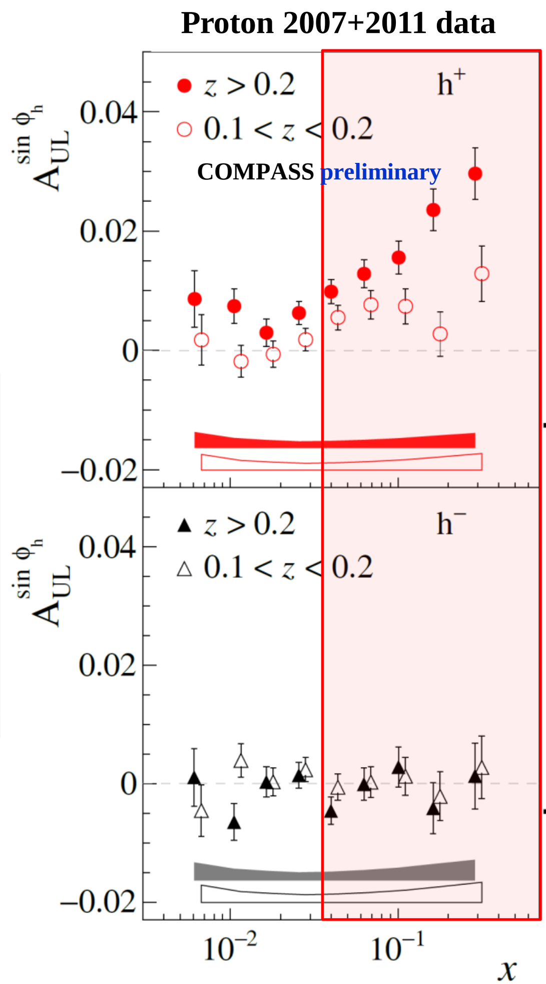
$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \sqrt{2\varepsilon(1+\varepsilon)}\, A_{UL}^{\sin\phi_h} \sin\phi_h + \ldots \right\}$$

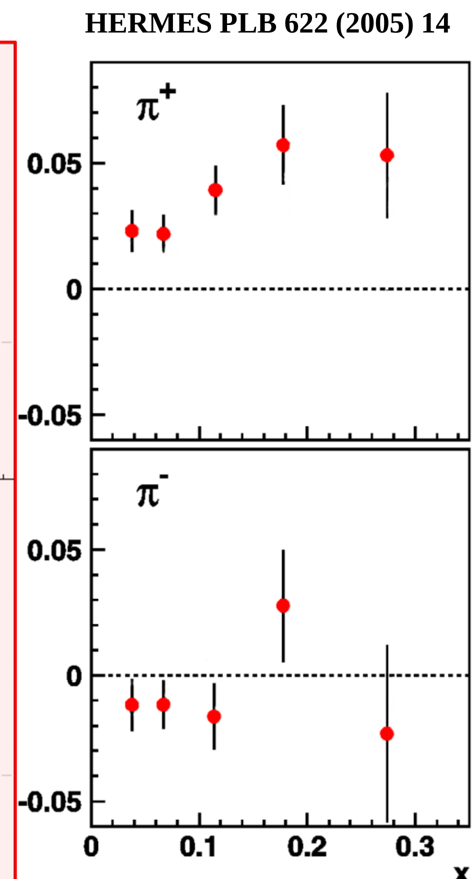
$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left\{ -\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(x h_L^q H_{1q}^{\perp h} + \frac{M_h}{M} g_{1L}^q \frac{\tilde{G}_q^{\perp h}}{z} \right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(x f_L^{\perp q} D_{1q}^h - \frac{M_h}{M} h_{1L}^{\perp q} \frac{\tilde{H}_q^h}{z} \right) \right\}$$



$$D^{\sin(\phi_h)} = \sqrt{2\varepsilon(1+\varepsilon)}$$





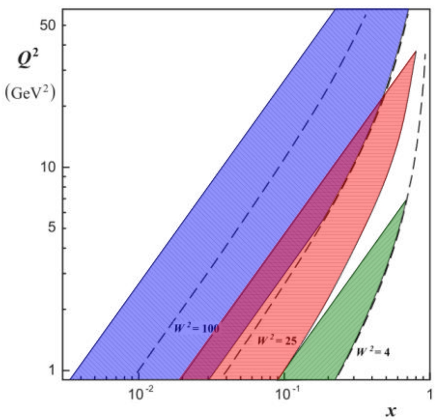


- Q-suppression, TSA-mixing
- Various different “twist” ingredients
- **Non-zero trend for h^+, h^- compatible with zero, clear z-dependence**

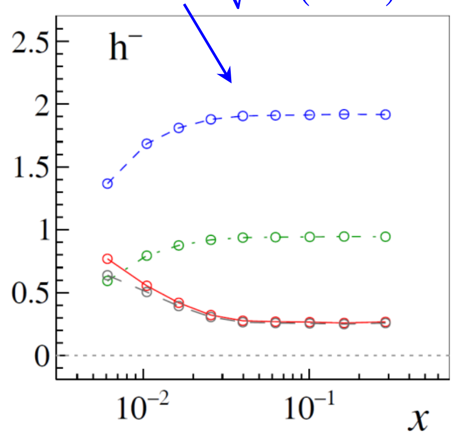
The $A_{UL}^{\sin\phi_h}$ asymmetry

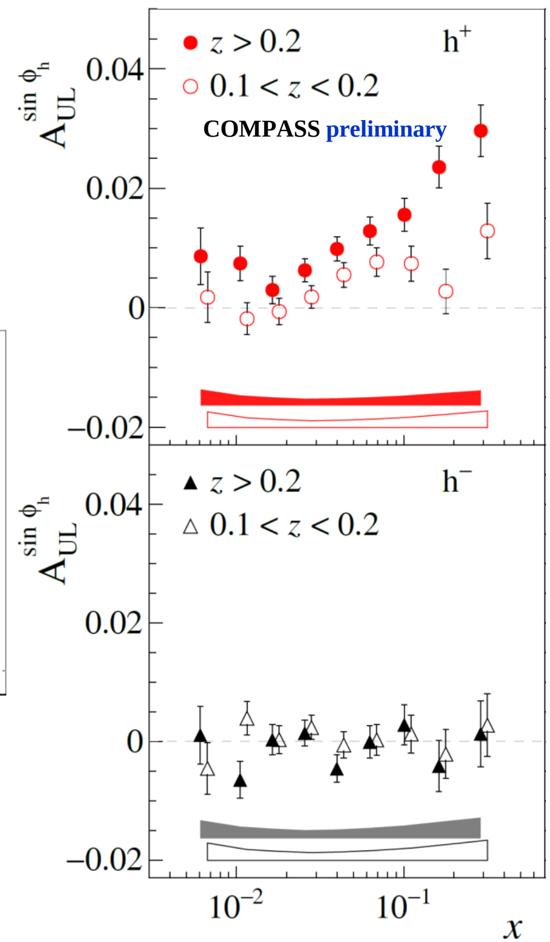
$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} \propto \left(F_{UU,T}+\varepsilon F_{UU,L}\right)\left\{1+\ldots+S_L\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\ldots\right\}$$

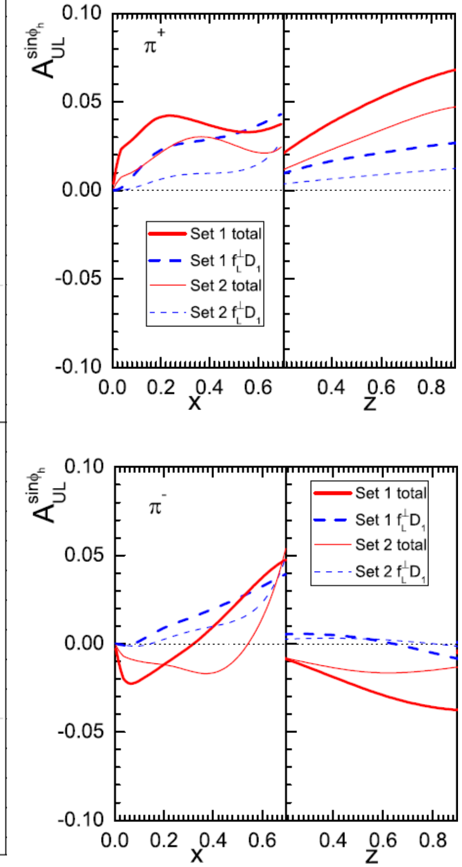
$$F_{UL}^{\sin\phi_h}=\frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(xh_L^q H_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$



$D^{\sin(\phi_h)}=\sqrt{2\varepsilon(1+\varepsilon)}$







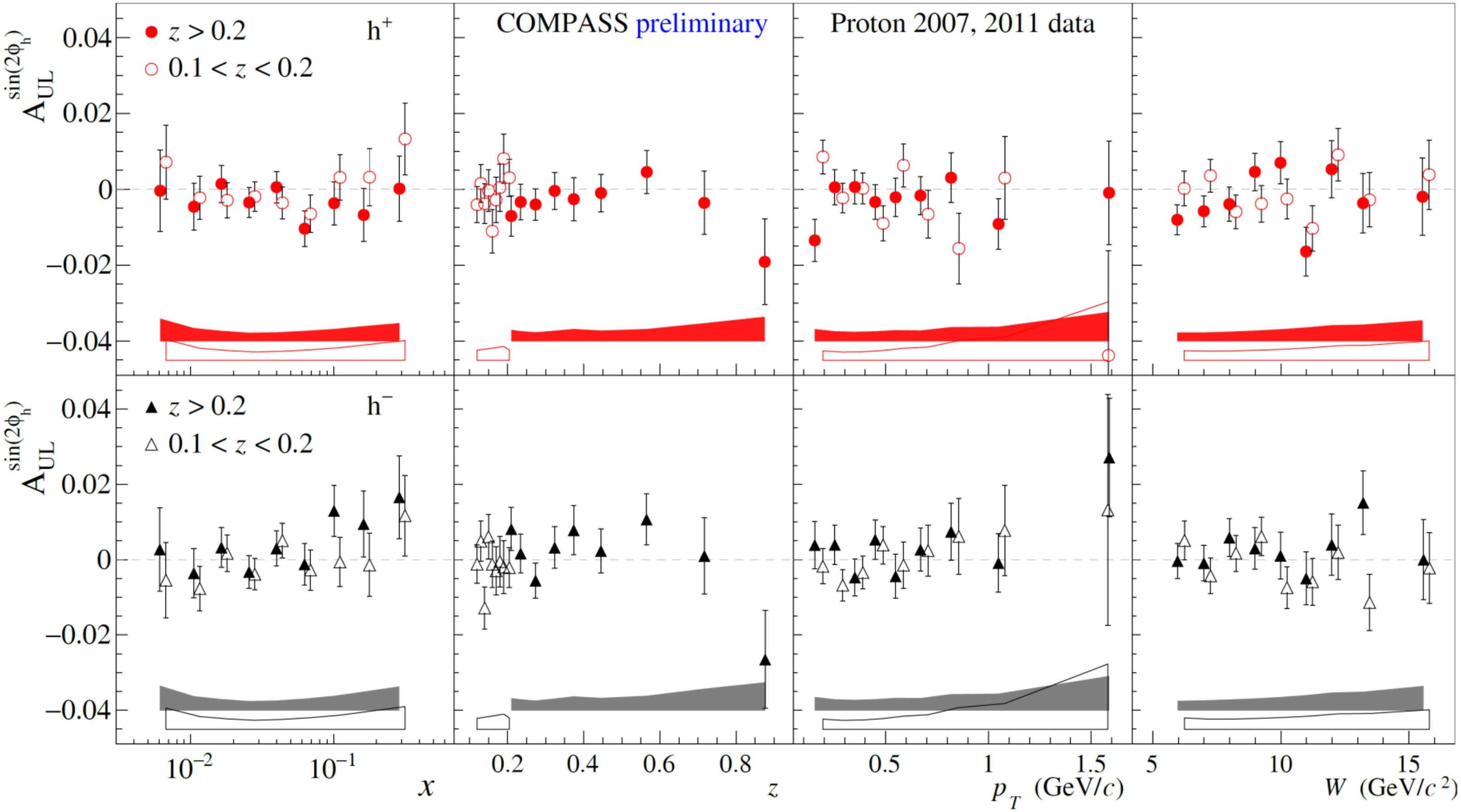
- Q-suppression, TSA-mixing
- Various different “twist” ingredients
- **Non-zero trend for h^+, h^- compatible with zero, clear z-dependence**

The $A_{UL}^{\sin 2\phi_h}$ asymmetry

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \, \varepsilon A_{UL}^{\sin 2\phi_h} \sin 2\phi_h + \ldots \right\}$$

$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\left\{-\frac{2\left(\hat{\boldsymbol{h}} \cdot \boldsymbol{p_T}\right)\left(\hat{\boldsymbol{h}} \cdot \boldsymbol{k_T}\right) - \boldsymbol{p_T} \cdot \boldsymbol{k_T}}{MM_h} h_{1L}^{\perp q} H_{1q}^{\perp h}\right\}$$

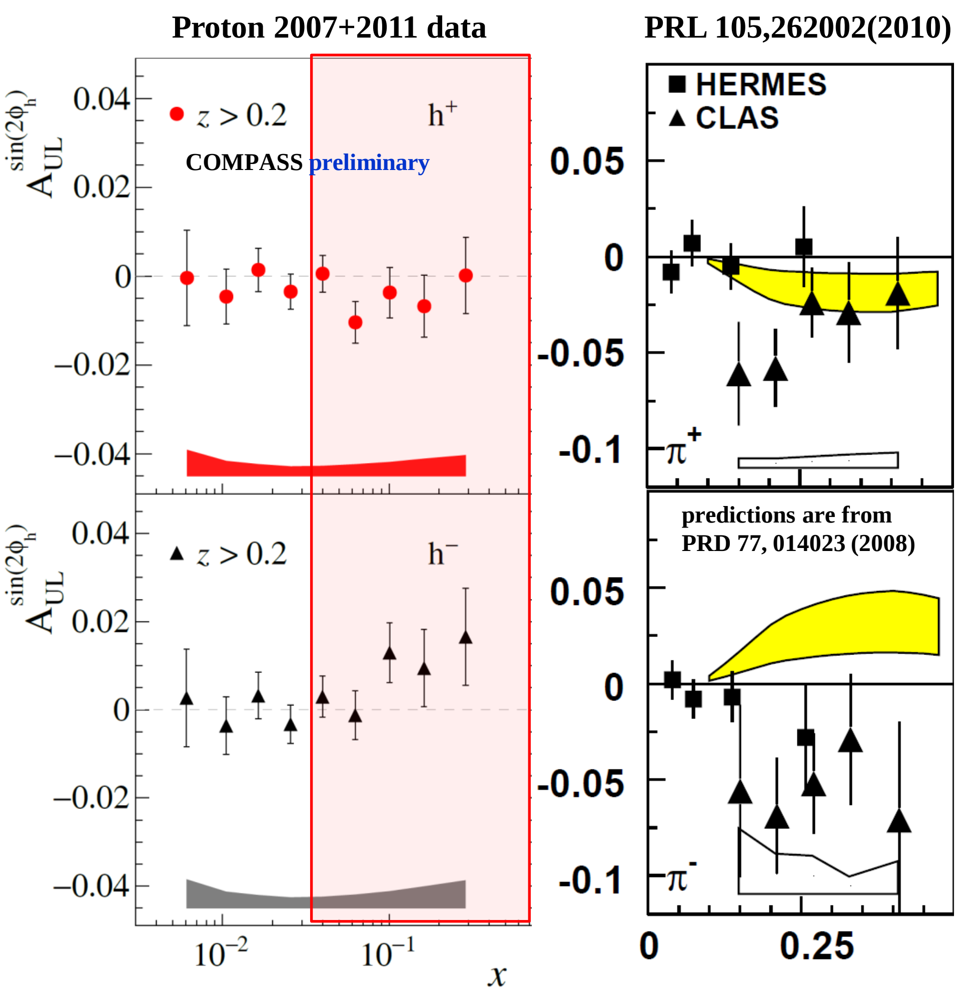
- Only "twist-2" ingredients
- Additional p_T-suppression



The $A_{UL}^{\sin 2\phi_h}$ asymmetry

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L\, \varepsilon A_{UL}^{\sin 2\phi_h} \sin 2\phi_h + \ldots\right\}$$

$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot \boldsymbol{p}_T\right)\left(\hat{\boldsymbol{h}}\cdot \boldsymbol{k}_T\right) - \boldsymbol{p}_T\cdot \boldsymbol{k}_T}{MM_h} h_{1L}^{\perp q} H_{1q}^{\perp h}\right\}$$

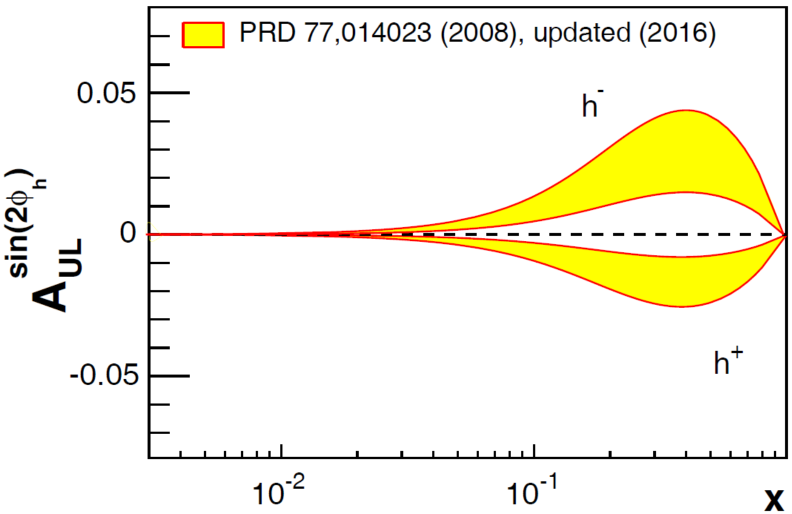


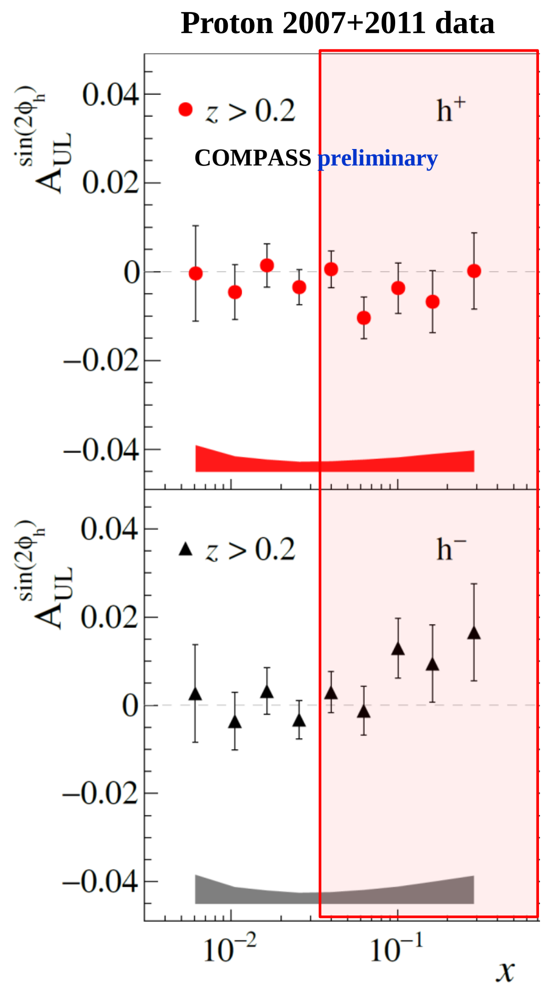
- Only “twist-2” ingredients
- Additional p_T-suppression
- **Collins-like behavior?**
- **In agreement with model predictions**
- **Discrepancy with HERMES and JLab?**

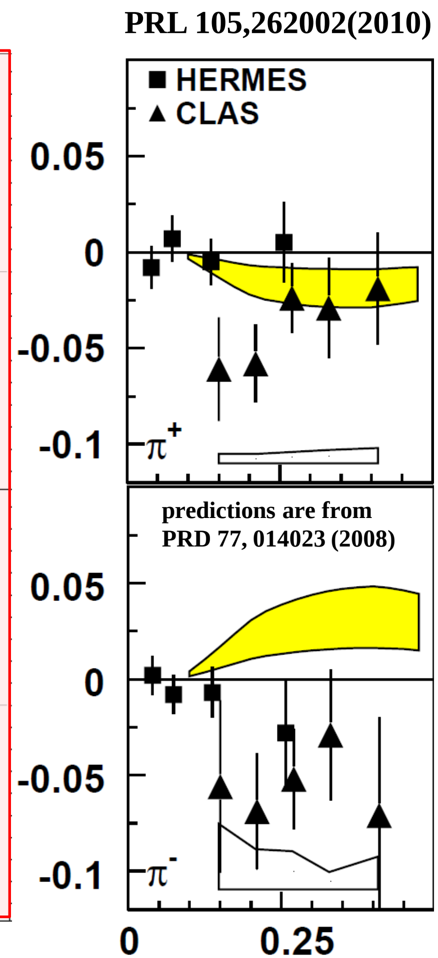
The $A_{UL}^{\sin 2\phi_h}$ asymmetry

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L\,\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h + \ldots\right\}$$

$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot \boldsymbol{p}_T\right)\left(\hat{\boldsymbol{h}}\cdot \boldsymbol{k}_T\right) - \boldsymbol{p}_T\cdot \boldsymbol{k}_T}{MM_h} h_{1L}^{\perp q} H_{1q}^{\perp h}\right\}$$





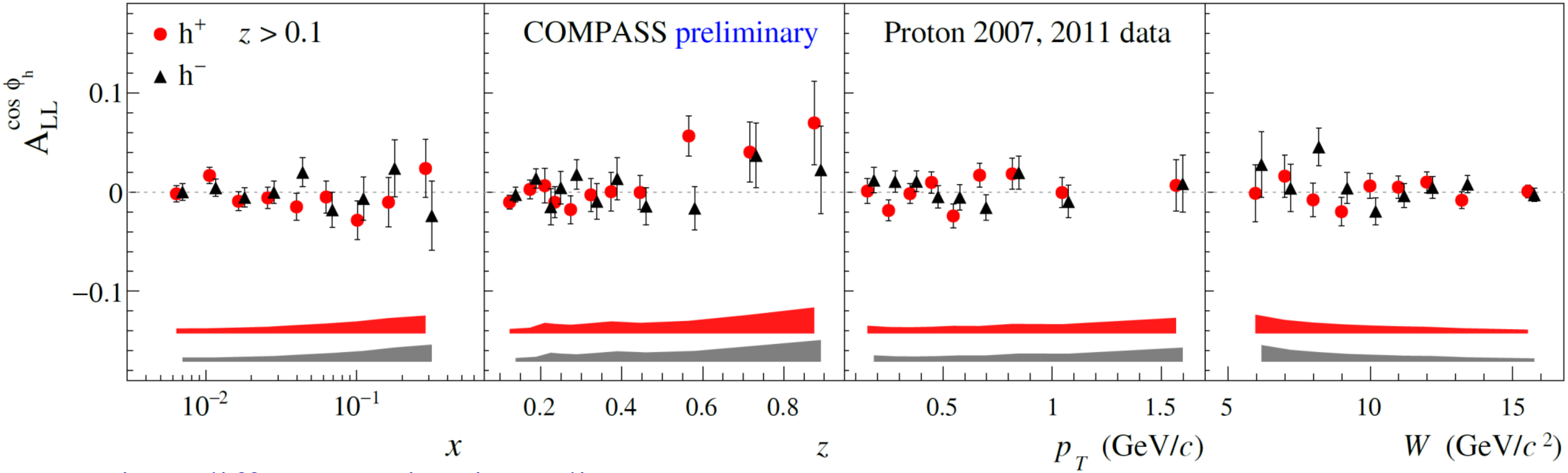


- Only “twist-2” ingredients
- Additional p_T-suppression
- **Collins-like behavior?**
- **In agreement with model predictions**
- **Discrepancy with HERMES and JLab?**

The $A_{LL}^{\cos\phi_h}$ asymmetry

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \lambda \sqrt{2\varepsilon(1-\varepsilon)} A_{LL}^{\cos\phi_h} \cos\phi_h + \ldots \right\}$$

$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(xe_L^q H_{1q}^{\perp h} + \frac{M_h}{M} g_{1L}^q \frac{\tilde{D}_q^{\perp h}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xg_L^{\perp q} D_{1q}^h - \frac{M_h}{M} h_{1L}^{\perp q} \frac{\tilde{E}_q^h}{z}\right)\right\}$$



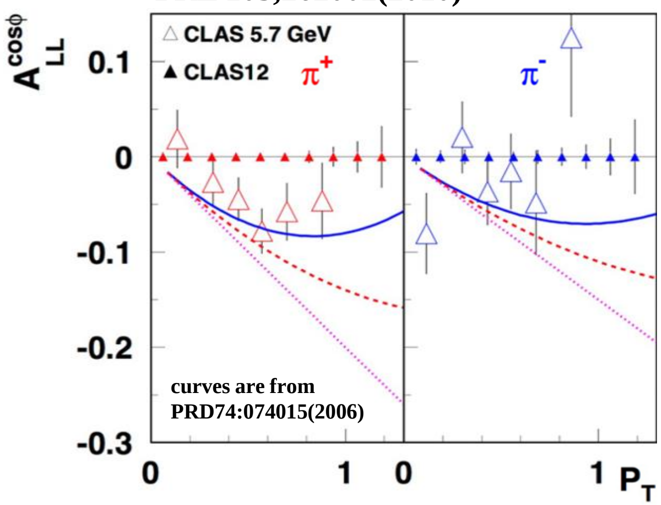
- Various different "twist" ingredients,
- Q-suppression

The $A_{LL}^{\cos\phi_h}$ asymmetry

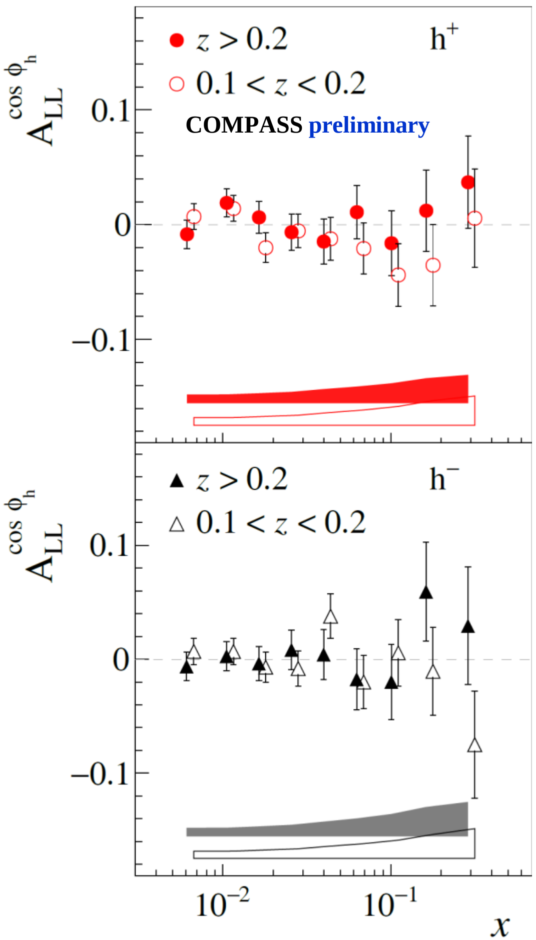
$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \lambda \sqrt{2\varepsilon(1-\varepsilon)} A_{LL}^{\cos\phi_h} \cos\phi_h + \ldots\right\}$$

$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(x e_L^q H_{1q}^{\perp h} + \frac{M_h}{M} g_{1L}^q \frac{\tilde{D}_q^{\perp h}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(x g_L^{\perp q} D_{1q}^h - \frac{M_h}{M} h_{1L}^{\perp q} \frac{\tilde{E}_q^h}{z}\right)\right\}$$

PRL 105,262002(2010)



Proton 2007+2011 data



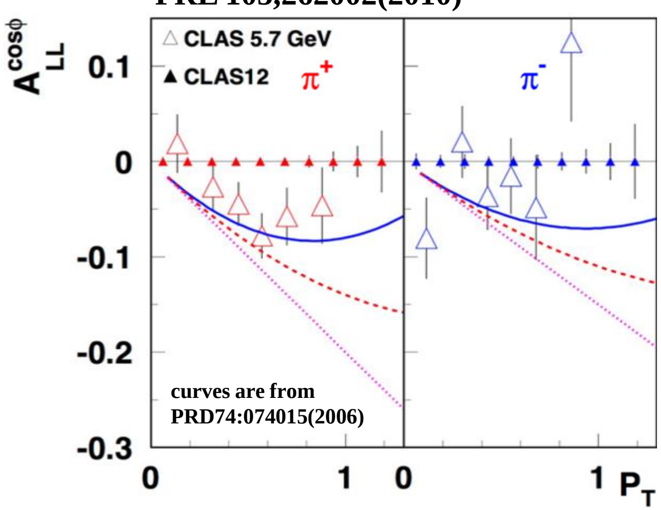
- Various different "twist" ingredients,
- Q-suppression
- Non zero at JLab

The $A_{LL}^{\cos\phi_h}$ asymmetry

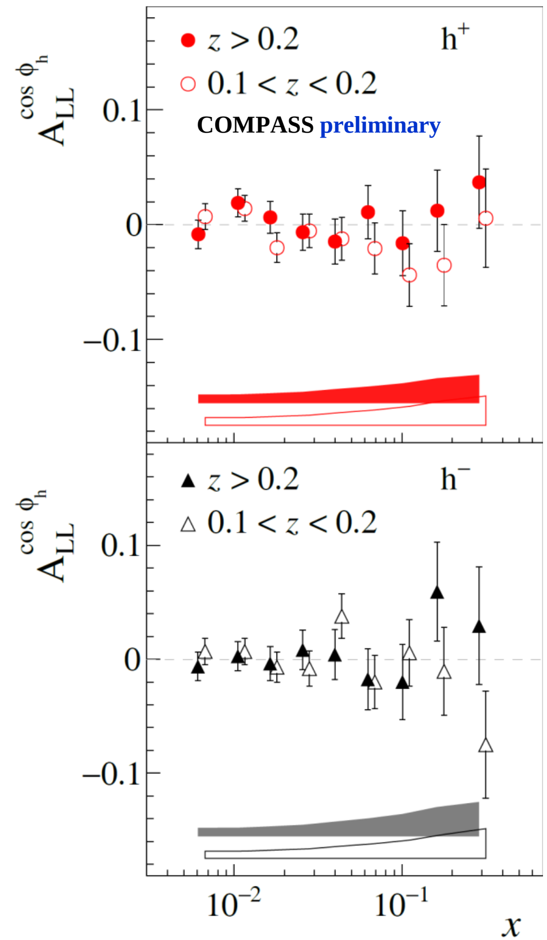
$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \lambda \sqrt{2\varepsilon(1-\varepsilon)} A_{LL}^{\cos\phi_h} \cos\phi_h + \ldots\right\}$$

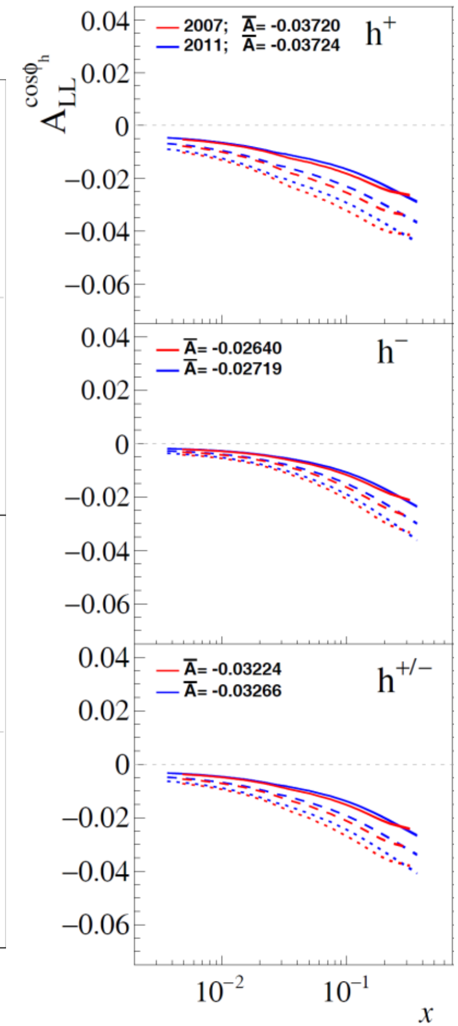
$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(x e_L^q H_{1q}^{\perp h} + \frac{M_h}{M} g_{1L}^q \frac{\tilde{D}_q^{\perp h}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(x g_L^{\perp q} D_{1q}^h - \frac{M_h}{M} h_{1L}^{\perp q}\frac{\tilde{E}_q^h}{z}\right)\right\}$$

PRL 105,262002(2010)



Proton 2007+2011 data





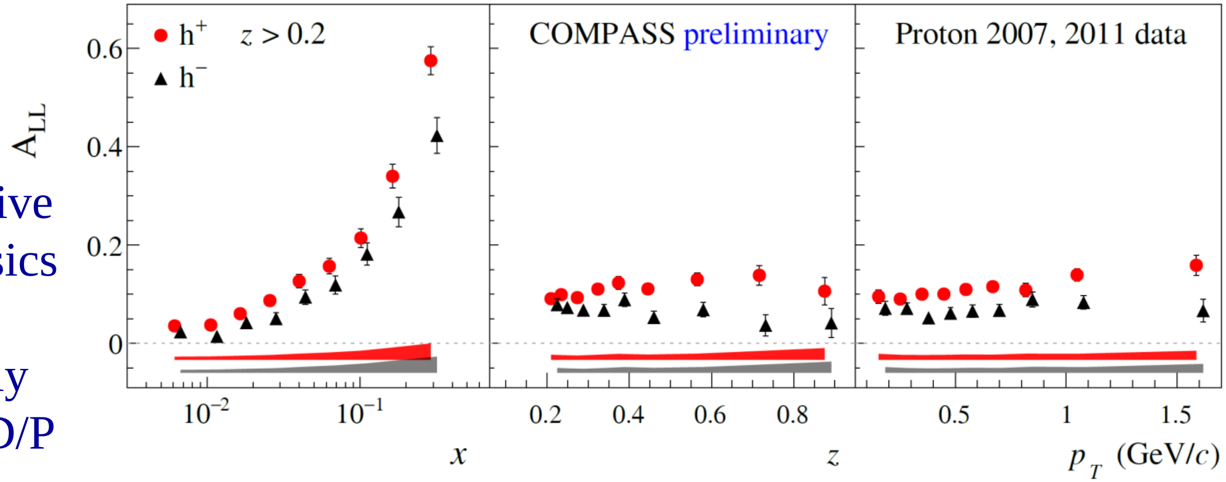
- Various different "twist" ingredients,
- Q-suppression
- Non zero at JLab
- **Small and compatible with zero, in agreement with model predictions**

The A_{LL} asymmetry

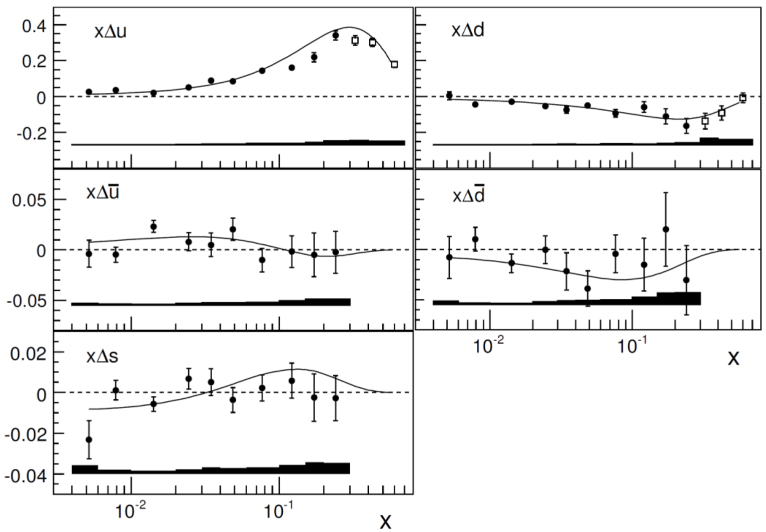
$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \lambda \sqrt{1-\varepsilon^2} A_{LL} + \ldots\right\}$$

$$F_{LL}^1 = \mathcal{C}\left\{g_{1L}^q D_{1q}^h\right\}$$

- Measurement of (semi-)inclusive $A_1(A_{LL})$ is one of the key physics topics of COMPASS
- Large amount of longitudinally polarized data collected with D/P targets (2002-2011)



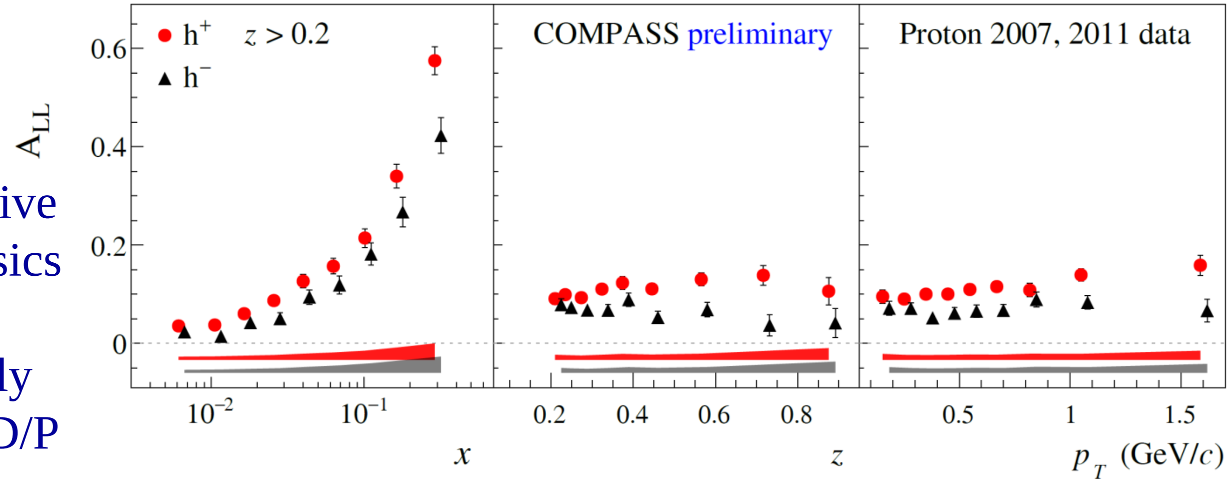
PLB 693 (2010) 227–235



The A_{LL} asymmetry

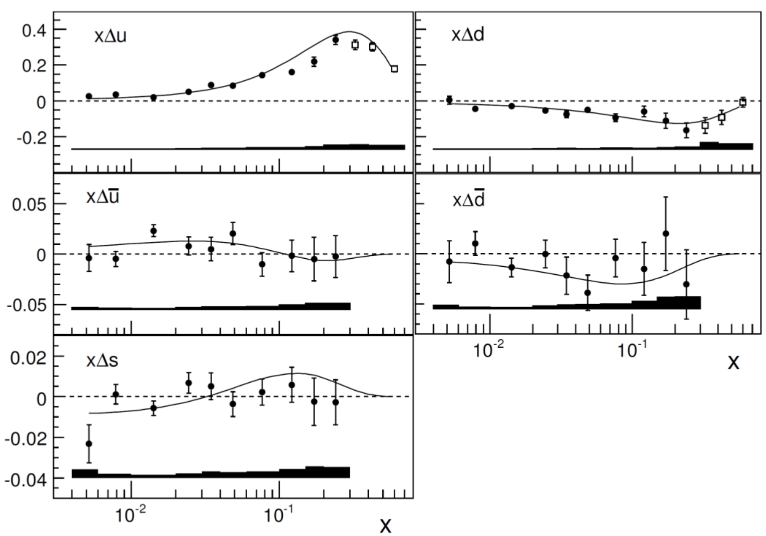
$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \lambda \sqrt{1-\varepsilon^2} A_{LL} + \ldots\right\}$$

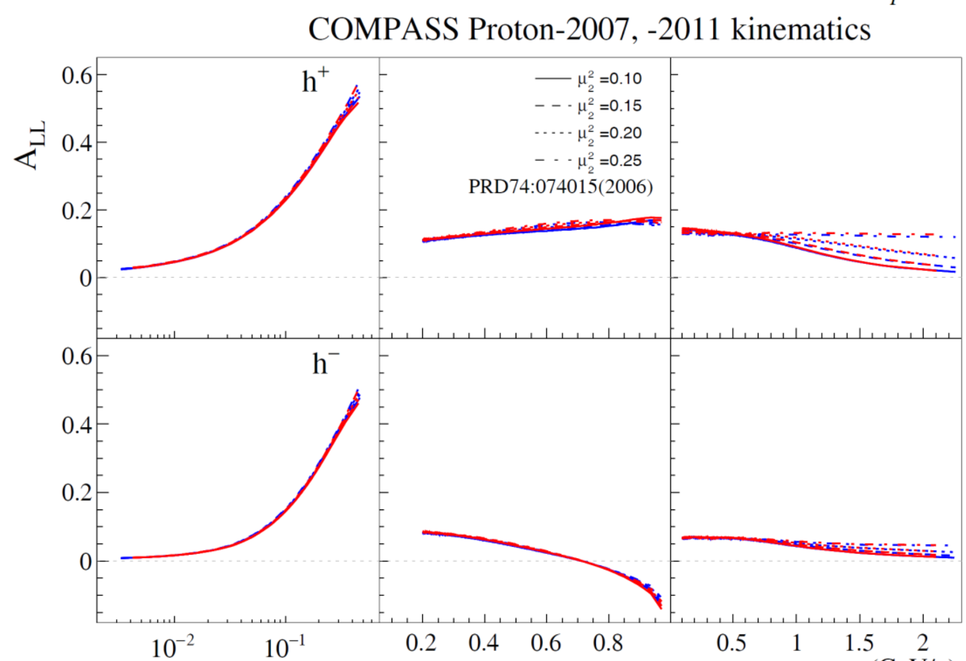
$$F_{LL}^1 = \mathcal{C}\left\{g_{1L}^q D_{1q}^h\right\}$$



- Measurement of (semi-)inclusive $A_1(A_{LL})$ is one of the key physics topics of COMPASS
- Large amount of longitudinally polarized data collected with D/P targets (2002-2011)

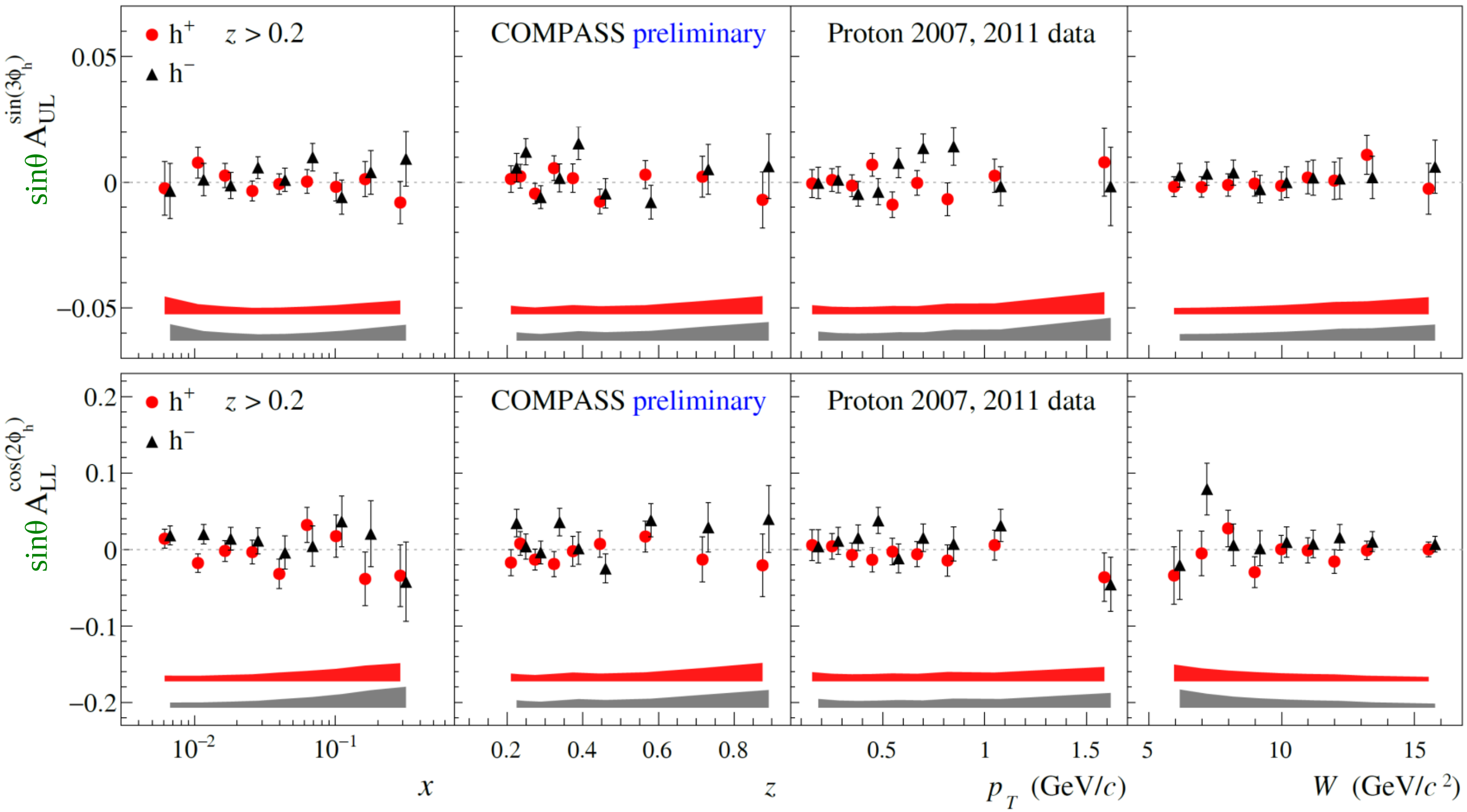
PLB 693 (2010) 227–235





COMPASS results for $A_{UL}^{\sin 3\phi_h}$ and $A_{LL}^{\cos 2\phi_h}$ asymmmetries

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left\{1+\ldots-\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h + P_L\lambda\left[-\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h+\ldots\right]\right\}$$



- Alternative way to access corresponding TSAs
- sin(θ) suppression
- Other suppressions at the "TSA"-level ($|p_T|^3$, Q^{-1})
- **Compatible with zero**

$$A_{UL}^{\sin 3\phi_h} \leftrightarrow A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$$

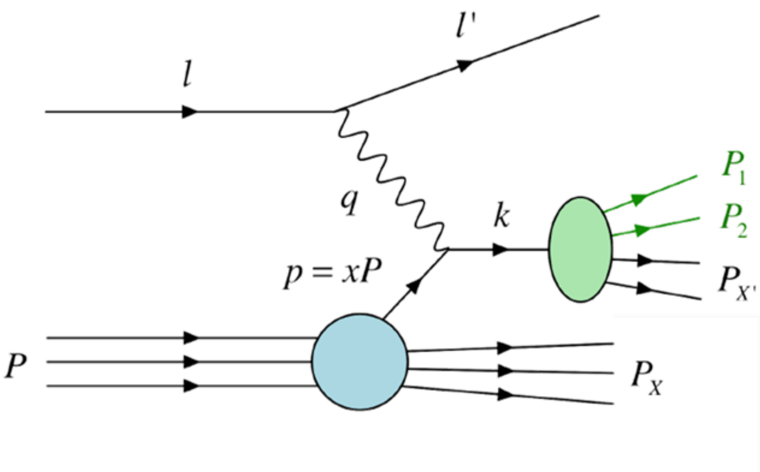
$$A_{LL}^{\cos 2\phi_h} \leftrightarrow A_{LT}^{\cos(2\phi_h-\phi_s)} \propto Q^{-1}\left(g_{1T}^{q} \otimes D_{1q}^{h}+\ldots\right)$$

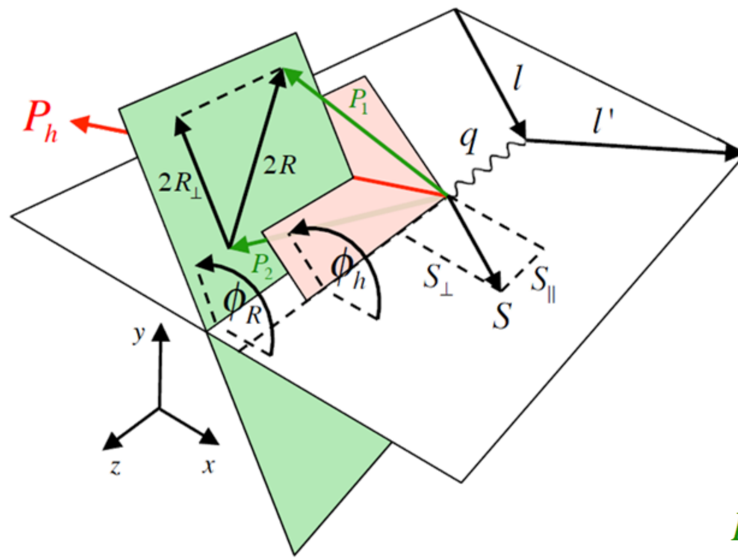
- Dihadron LSAs

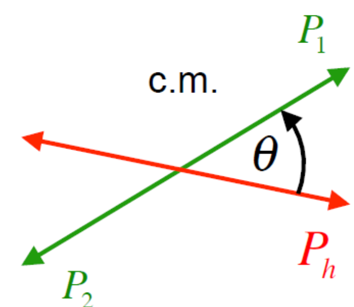
Theoretical Framework: Di-hadron SIDIS

Bacchetta & Radici: Phys. Rev. D69 094002
Bacchetta & Radici & Gliske: Phys. Rev. D90 114027

$$\mu(l) + p(P) \to \mu(l') + h_1^+(P_1) + h_2^-(P_2) + X$$







$$\langle \theta \rangle = \pi/2$$

- X-section modulated in azimuthal angles ϕ_h and ϕ_R

$$\boldsymbol{R}_\perp \leftrightarrow \boldsymbol{R}_T = \frac{z_2 \boldsymbol{P}_{1\perp} - z_1 \boldsymbol{P}_{2\perp}}{z_1 + z_2} \qquad \text{with} \qquad z_i = \frac{E_i}{E - E'}$$

- Negligible transverse polarization mixing $S_\perp \approx 0$
- Partial wave expansion in θ, restricted to s- & p-waves

θ is the emission angle between h^+ in the c.m. frame and the momentum of the di-hadron in the target rest frame

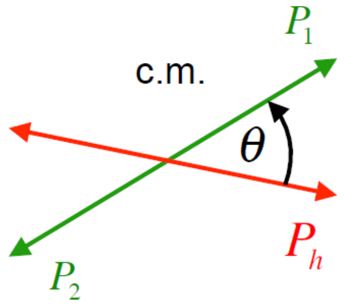
Theoretical Framework: Di-hadron SIDIS at twist-2

$$d\sigma = d\sigma_{UU} + \lambda d\sigma_{LU} + \boldsymbol{S}_L \left(d\sigma_{UL} + \lambda d\sigma_{LL} \right) + \boldsymbol{S}_L \left(d\sigma_{UT} + \lambda d\sigma_{LT} \right)$$

Bacchetta & Radici: Phys. Rev. D69 094002
Bacchetta & Radici & Gliske: Phys. Rev. D90 114027

$$\begin{aligned} d\sigma_{UL} \propto\ & \sin(\phi_h - \phi_R)\left(A_{UL}^{\sin(\phi_h-\phi_R)\sin\theta} \sin\theta + A_{UL}^{\sin(\phi_h-\phi_R)\sin 2\theta} \sin 2\theta \right) \\ & + \sin(2\phi_h - 2\phi_R) A_{UL}^{\sin(2\phi_h-2\phi_R)\sin^2\theta} \sin^2\theta \\ & + \varepsilon \left\{ \sin(2\phi_h)\left(A_{UL}^{\sin(2\phi_h)} + A_{UL}^{\sin(2\phi_h)\cos\theta} \cos\theta + A_{UL}^{\sin(2\phi_h)\frac{1}{3}(3\cos^2\theta-1)} \frac{1}{3}(3\cos^2\theta - 1) \right) \right. \\ & + \sin(\phi_h + \phi_R)\left(A_{UL}^{\sin(\phi_h+\phi_R)\sin\theta} \sin\theta + A_{UL}^{\sin(\phi_h+\phi_R)\sin 2\theta} \sin 2\theta \right) \\ & + \sin(2\phi_R) A_{UL}^{\sin(2\phi_R)\sin^2\theta} \sin^2\theta \\ & + \sin(3\phi_h - \phi_R)\left(A_{UL}^{\sin(3\phi_h-\phi_R)\sin\theta} \sin\theta + A_{UL}^{\sin(3\phi_h-\phi_R)\sin 2\theta} \sin 2\theta \right) \\ & \left. + \sin(4\phi_h - 2\phi_R) A_{UL}^{\sin(4\phi_h-2\phi_R)\sin^2\theta} \sin^2\theta \right\} \end{aligned}$$

$$\begin{aligned} d\sigma_{LL} \propto\ & \sqrt{1-\varepsilon^2} \left\{ A_{LL}^{1} + A_{LL}^{\cos\theta} \cos\theta + A_{LL}^{\frac{1}{3}(3\cos^2\theta-1)} \frac{1}{3}(3\cos^2\theta - 1) \right. \\ & + \cos(\phi_h - \phi_R)\left(A_{LL}^{\cos(\phi_h-\phi_R)\sin\theta} \sin\theta + A_{LL}^{\cos(\phi_h-\phi_R)\sin 2\theta} \sin 2\theta \right) \\ & \left. + \cos(2\phi_h - 2\phi_R) A_{LL}^{\cos(2\phi_h-2\phi_R)} \right\} \end{aligned}$$



$$\langle \theta \rangle = \pi/2$$

θ is the emission angle between h^+ in the c.m. frame and the momentum of the di-hadron in the target rest frame

Di-hadron SIDIS at twist-2

$$d\sigma = d\sigma_{UU} + \lambda d\sigma_{LU} + \boldsymbol{S}_L\left(d\sigma_{UL} + \lambda d\sigma_{LL}\right) + \boldsymbol{S}_L\left(d\sigma_{UT} + \lambda d\sigma_{LT}\right)$$

Bacchetta & Radici: Phys. Rev. D69 094002
Bacchetta & Radici & Gliske: Phys. Rev. D90 114027

$$d\sigma_{UL} \propto \sin(\phi_h - \phi_R)\, A_{UL}^{\sin(\phi_h-\phi_R)} \quad \sim g_{1L} \otimes G_{1,UT}^{\perp}$$

$$+\sin(2\phi_h - 2\phi_R)\, A_{UL}^{\sin(2\phi_h-2\phi_R)} \quad \sim g_{1L} \otimes G_{1,TT}^{\perp}$$

$$+\varepsilon\Big\{\sin(2\phi_h)\, A_{UL}^{\sin(2\phi_h)} \quad \sim h_{1L}^{\perp} \otimes H_{1,UU}^{\perp}$$

$$+\sin(\phi_h + \phi_R)\, A_{UL}^{\sin(\phi_h+\phi_R)} \quad \sim h_{1L}^{\perp} \otimes H_{1,UT}^{\angle}$$

$$+\sin(2\phi_R)\, A_{UL}^{\sin(2\phi_R)} \quad \sim h_{1L}^{\perp} \otimes H_{1,TT}^{\angle}$$

$$+\sin(3\phi_h - \phi_R)\, A_{UL}^{\sin(3\phi_h-\phi_R)} \quad \sim h_{1L}^{\perp} \otimes H_{1,UT}^{\perp}$$

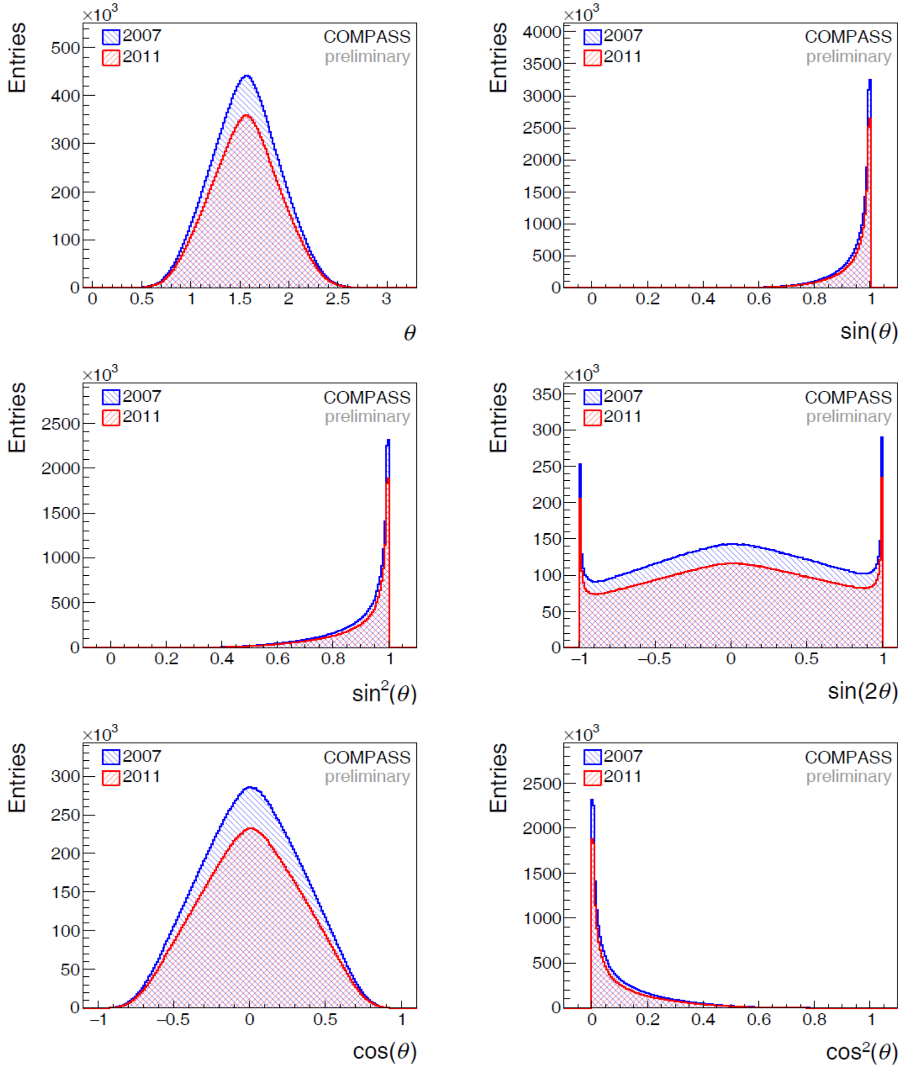
$$+\sin(4\phi_h - 2\phi_R)\, A_{UL}^{\sin(4\phi_h-2\phi_R)}\Big\} \quad \sim h_{1L}^{\perp} \otimes H_{1,TT}^{\perp}$$

$$d\sigma_{LL} \propto \sqrt{1-\varepsilon^2}\Big\{A_{LL}^{1} \quad \sim g_{1L} \otimes D_{1,UT}$$

$$+\cos(\phi_h - \phi_R)\, A_{LL}^{\cos(\phi_h-\phi_R)} \quad \sim g_{1L} \otimes D_{1,TT}$$

$$+\cos(2\phi_h - 2\phi_R)\, A_{LL}^{\cos(2\phi_h-2\phi_R)}\Big\} \quad \sim g_{1L} \otimes D_{1,UU}$$

- Clear dominance of $\sin\theta$- and $\sin^2\theta$-weighed partial amplitudes



Di-hadron SIDIS at twist-3

$$d\sigma = d\sigma_{UU} + \lambda d\sigma_{LU} + \boldsymbol{S}_L \left(d\sigma_{UL} + \lambda d\sigma_{LL} \right) + \boldsymbol{S}_L \left(d\sigma_{UT} + \lambda d\sigma_{LT} \right)$$

Bacchetta & Radici: Phys. Rev. D69 094002
Bacchetta & Radici & Gliske: Phys. Rev. D90 114027

$$d\sigma_{UU} \propto 1 + \sqrt{2\varepsilon(1+\varepsilon)} \cos(\phi_R) A_{UU}^{\cos(\phi_R)} + \varepsilon \cos(2\phi_R) A_{UU}^{\cos(2\phi_R)}$$

$$d\sigma_{LU} \propto \sqrt{2\varepsilon(1-\varepsilon)} \sin(\phi_R) A_{LU}^{\sin(\phi_R)}$$

Collinear Twist-3		Quark U	Quark L	Quark T
Nucleon	U	$f^{\perp}$	$g^{\perp}$	$h \quad e$
Nucleon	L	$f_L^{\perp}$	$g_L^{\perp}$	$h_L \quad e_L$
Nucleon	T	$f_T \quad f_T^{\perp}$	$g_T \quad g_T^{\perp}$	$h_T \quad e_T \quad h_T^{\perp} \quad e_T^{\perp}$

$$d\sigma_{UL} \propto \sqrt{2\varepsilon(1+\varepsilon)} \sin(\phi_R) A_{UL}^{\sin(\phi_R)} \sim Q^{-1}\left[h_L \cdot H_{1,UT}^{\angle} + g_1 \cdot G_{UT}^{\angle} \right]$$

$$+ \varepsilon \sin(2\phi_R) A_{UL}^{\sin(2\phi_R)}$$

Wandzura-Wilzcek approximation

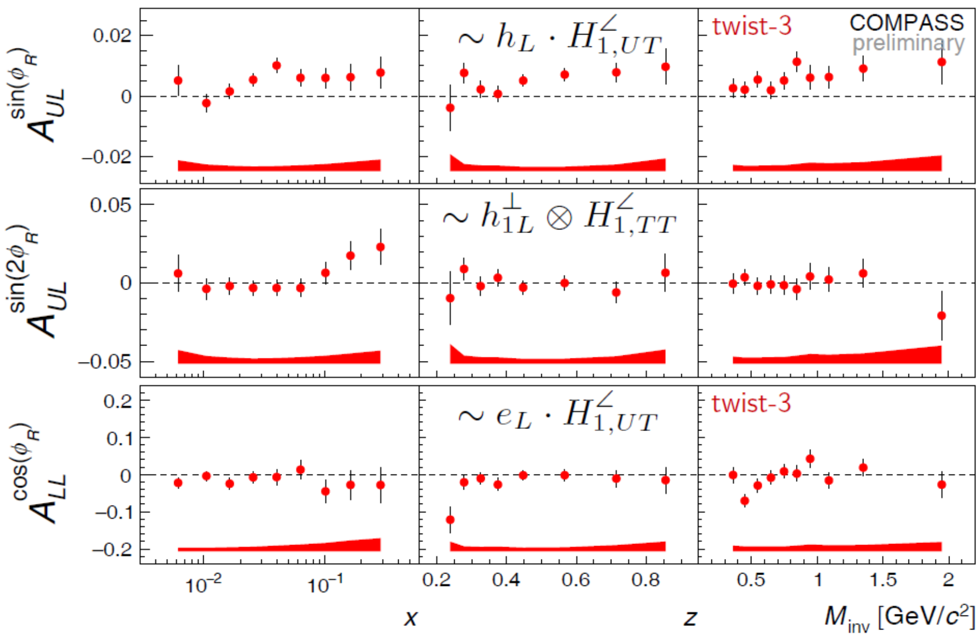
$$d\sigma_{LL} \propto \sqrt{1-\varepsilon^2} A_{LL}^{1}$$

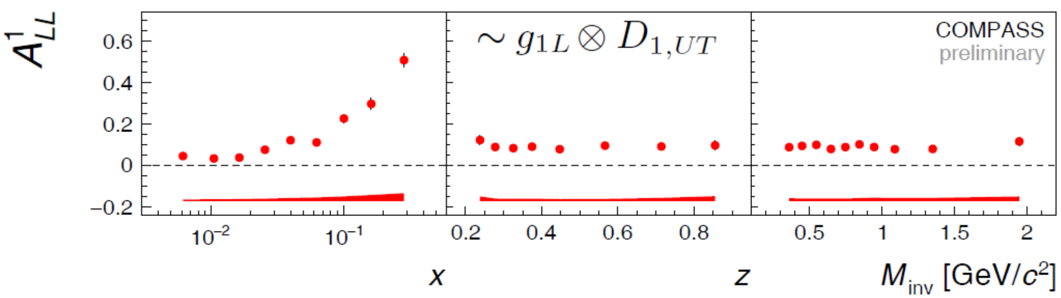
$$+ \sqrt{2\varepsilon(1-\varepsilon)} \cos(\phi_R) A_{LL}^{\cos(\phi_R)} \sim Q^{-1}\left[e_L \cdot H_{1,UT}^{\angle} + g_1 \cdot D_{UT}^{\angle} \right]$$

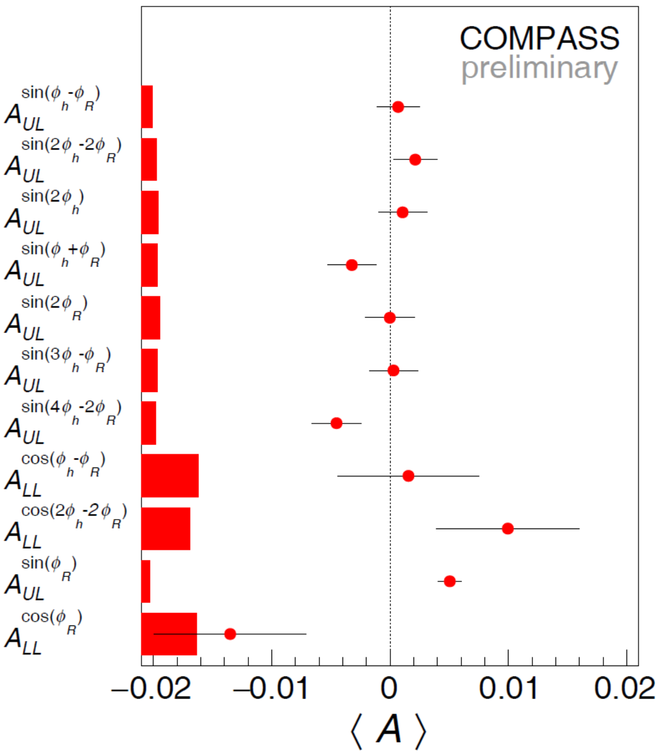
Selected results for di-hadron asymmetries

First shown at SPIN-2016, NEW!

COMPASS (NH_3) 2007+2011 data







- Alternative way to access various twist-2/-3 distributions
- Non zero signal for $A_{UL}^{\sin\phi_R}$ and A_{LL}^{1}

Selected results for di-hadron asymmetries

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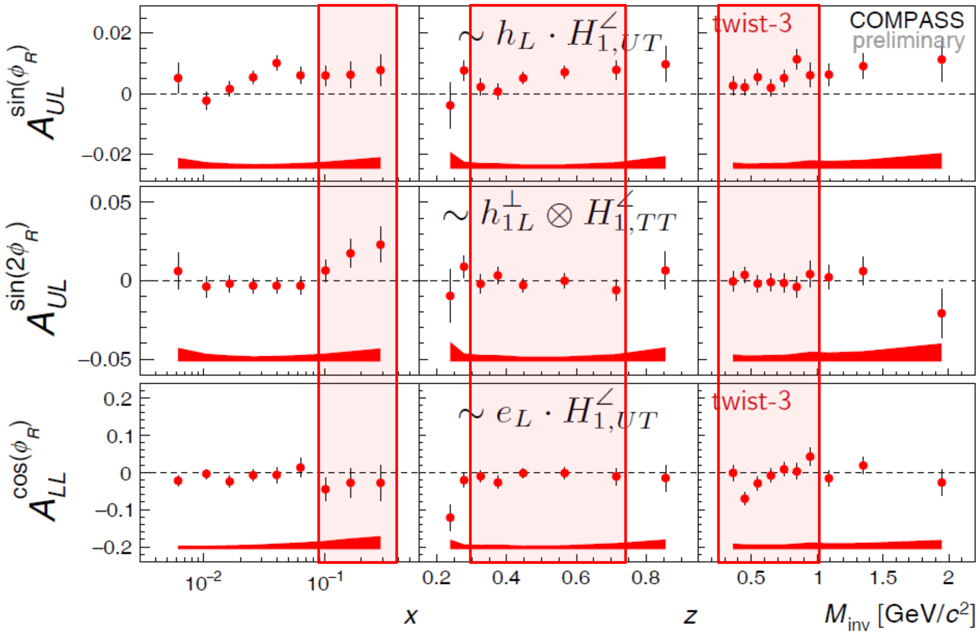

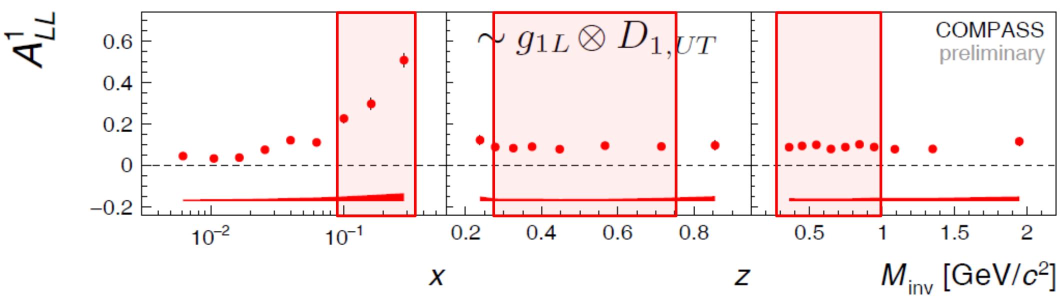

CLAS 6 GeV (NH_3)

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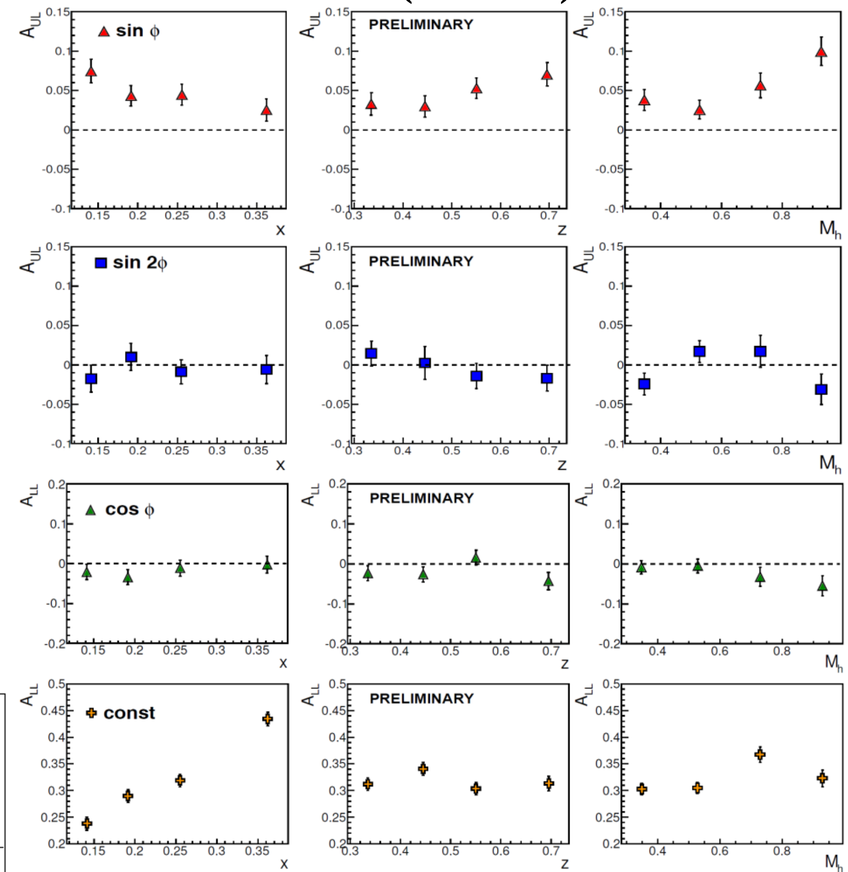
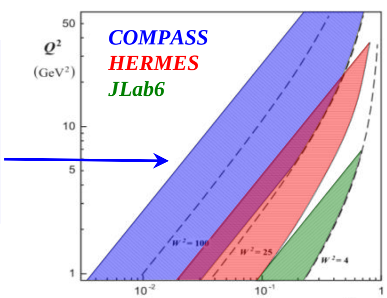


$Q^2 > 1\,(\mathrm{GeV}/c)^2$
$0.0025 < x < 0.7$
$0.1 < y < 0.9$
$W > 5\,\mathrm{GeV}/c^2$



- Alternative way to access various twist-2/-3 distributions
- Non zero signal for $A_{UL}^{\sin\phi_R}$ and A_{LL}^{1}
- CLAS-COMPASS: different behavior for $A_{UL}^{\sin 2\phi_R}$ at large x?

Conclusions

- COMPASS has measured all possible single-/di-hadron SIDIS LSAs from combined deuteron 2002-2006 and proton 2007/2011 data sample
- Together with existing measurements of proton TSAs these results complete the whole set of all possible proton SIDIS spin dependent azimuthal asymmetries
- This allowed us to evaluate the mixing between SIDIS LSAs and TSAs arising from the difference of target polarization components in *lp* and *γ*p* systems
- Whereas azimuthal LSAs on deuteron appear to be compatible with zero, for some of the proton LSAs non-zero signals are observed
- A clear effect was observed for $A_{UL}^{sin\phi_h}$ with positive hadrons, while for negative hadrons the asymmetry is found to be compatible with zero
    - in agreement with HERMES observations
- The $A_{UL}^{sin2\phi_h}$ appear to exhibit opposite sign “Collins-like” behavior for h^+ and h^-
    - in agreement with model predictions
    - possible positive signal for negative hadrons appears to contradict HERMES and Jlab observations
- The $A_{LL}^{cos\phi_h}$ asymmetry is found to be small and compatible with zero within statistical accuracy which does not contradict available model predictions
- Non-zero signal was observed for $A_{UL}^{sin\phi_R}$ and A_{LL}^{1} di-hadron asymmetries related to h_L and g_{1L} PDFs, correspondingly.

Thank you!