Longitudinal target polarization dependent azimuthal asymmetries at COMPASS

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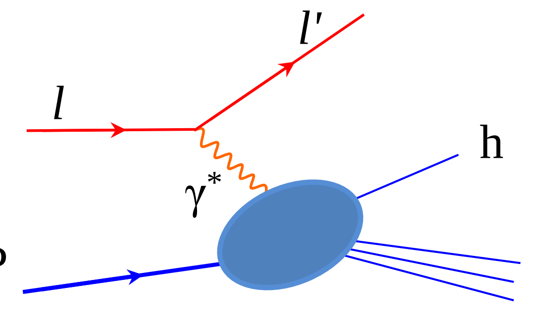
SIDIS x-section

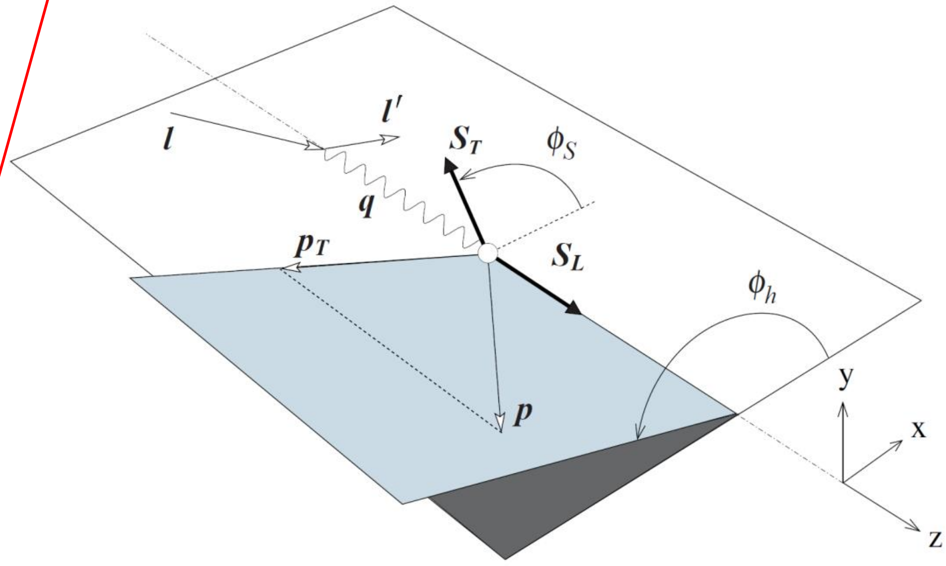
A.Kotzinian, Nucl. Phys. B441, 234 (1995).
Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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

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



See talks by:
A. Bressan, A. Martin



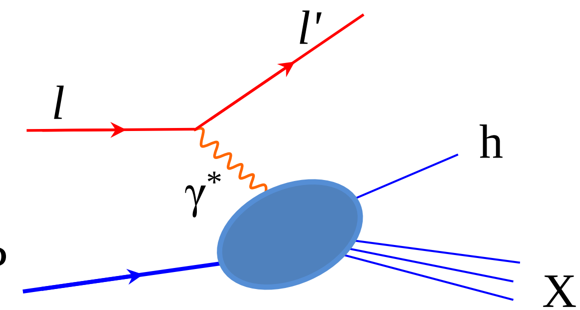
$$A_{U(L),T}^{w(\varphi_h,\varphi_s)}=\frac{F_{U(L),T}^{w(\varphi_h,\varphi_s)}}{F_{UU,T}+\varepsilon F_{UU,L}};\quad \varepsilon=\frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2},\quad \gamma=\frac{2Mx}{Q}$$

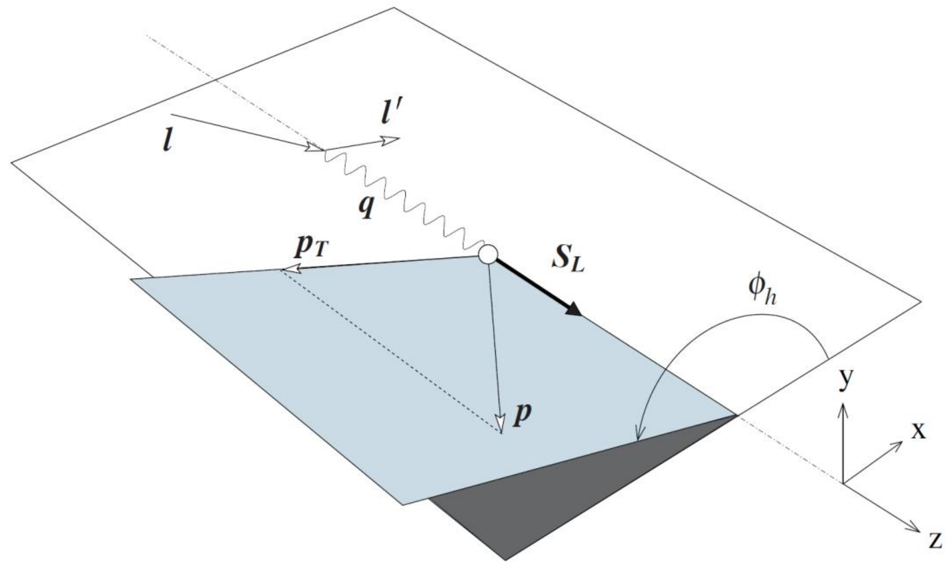
L-SIDIS x-section

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

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

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





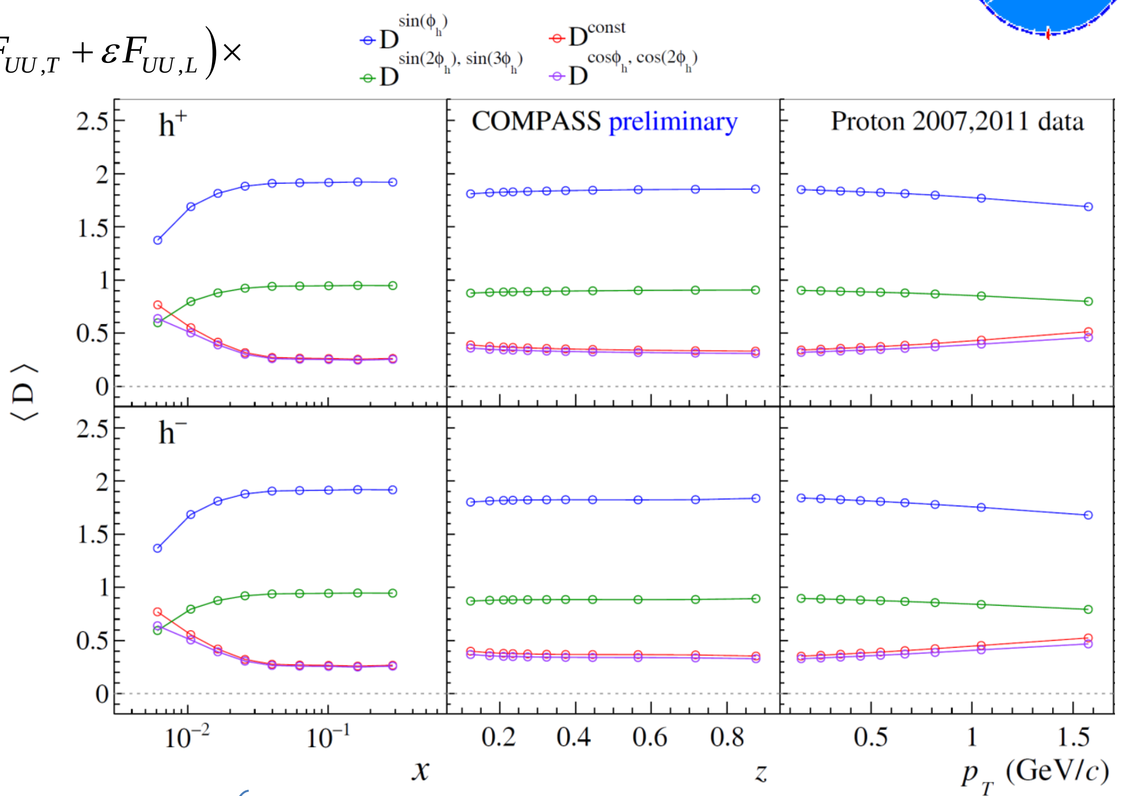
General SIDIS x-section expression contains four target longitudinal spin dependent asymmetries (LSA)

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

L-SIDIS x-section: depolarization factors

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

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



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

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

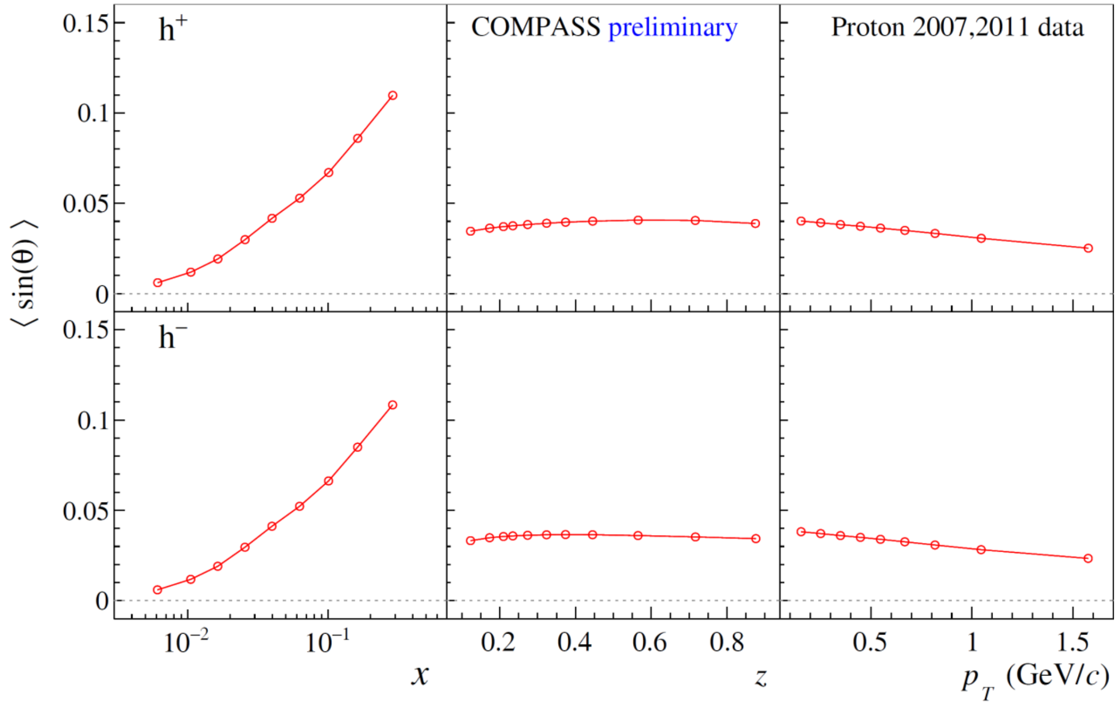
$$A_{UL}^{w(\phi_h)} = \frac{A_{UL,raw}^{w(\phi_h)}}{D^{w(\phi_h)} f\,|P_L|},\quad A_{LL}^{w(\phi_h)} = \frac{A_{LL,raw}^{w(\phi_h)}}{D^{w(\phi_h)}\lambda f\,|P_L|}$$

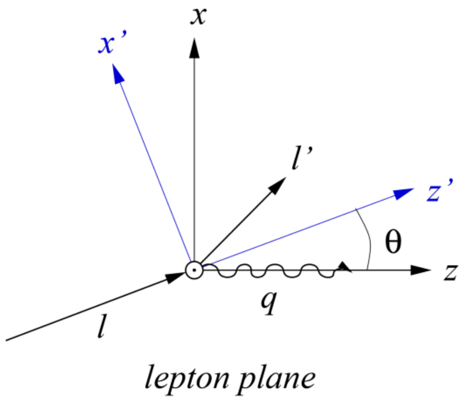
L-SIDIS x-section: from *lp* to $\gamma^* p$

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

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

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





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

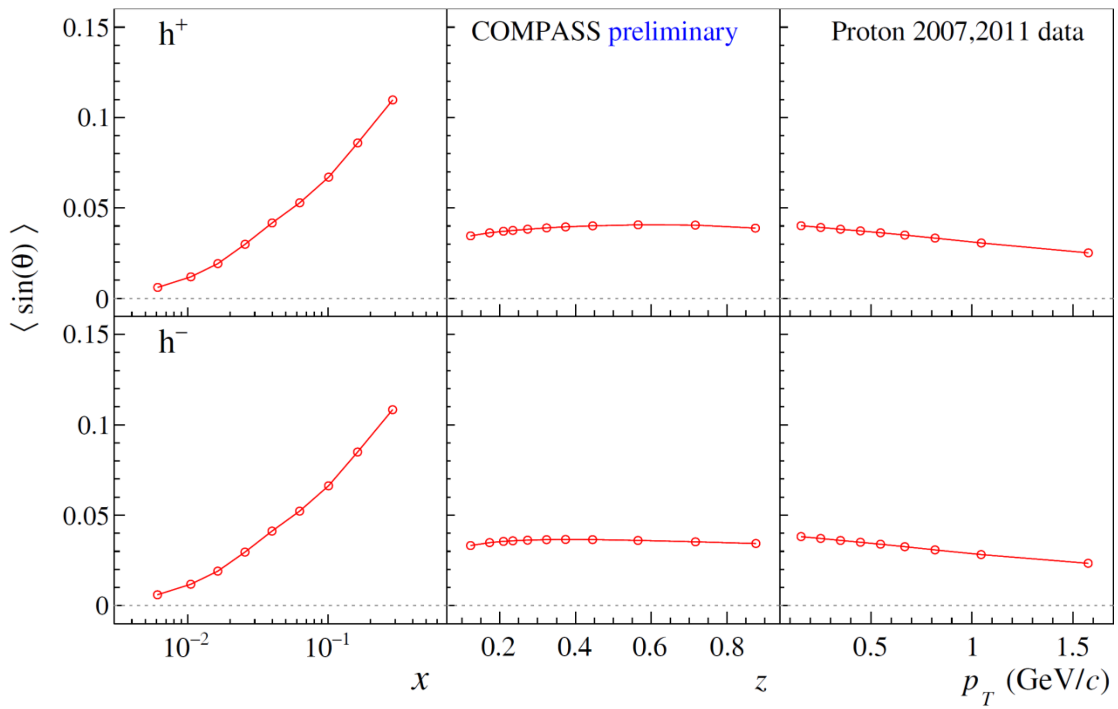
$$\theta \xrightarrow{\text{Bjorken limit}} 0 \Rightarrow S_T \simeq P_T,\; S_L \simeq P_L$$

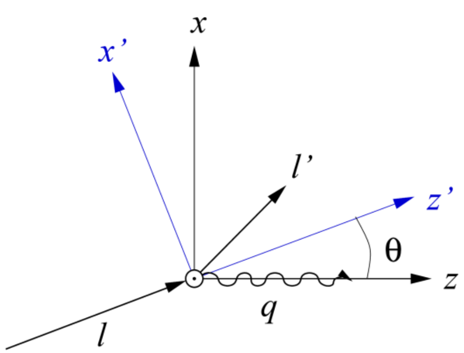
SIDIS x-section: from *lp* to $\gamma * p$ ($P_T=0$)

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

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

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





lepton plane

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

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

At COMPASS kinematics

$\sin\theta < 0.15$

$\cos\theta \approx 1$

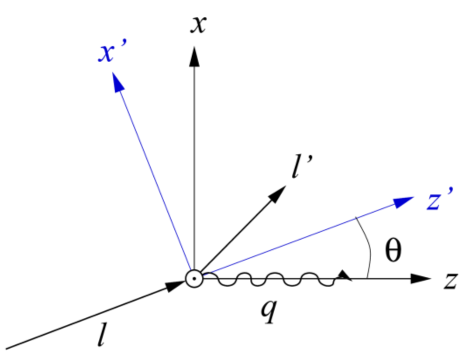
SIDIS x-section: LSA-TSA mixing

Kotzinian et al.
hep-ph/9808368 (1998)
hep-ph/9908466 (1999)
M. Diehl and S. Sapeta,
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	$C(\varepsilon,\theta)$ - 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}	$\sin\theta\frac{\sqrt{2\varepsilon(1-\varepsilon)}}{\sqrt{(1-\varepsilon^2)}}$	$A_{LT}^{\cos\phi_s}$
$A_{LL}^{\cos\phi_h}$	$\sin\theta\frac{\sqrt{(1-\varepsilon^2)}}{\sqrt{2\varepsilon(1-\varepsilon)}}$	$A_{LT}^{\cos(\phi_h-\phi_s)}$



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

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

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

SIDIS x-section: LSA-TSA mixing

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

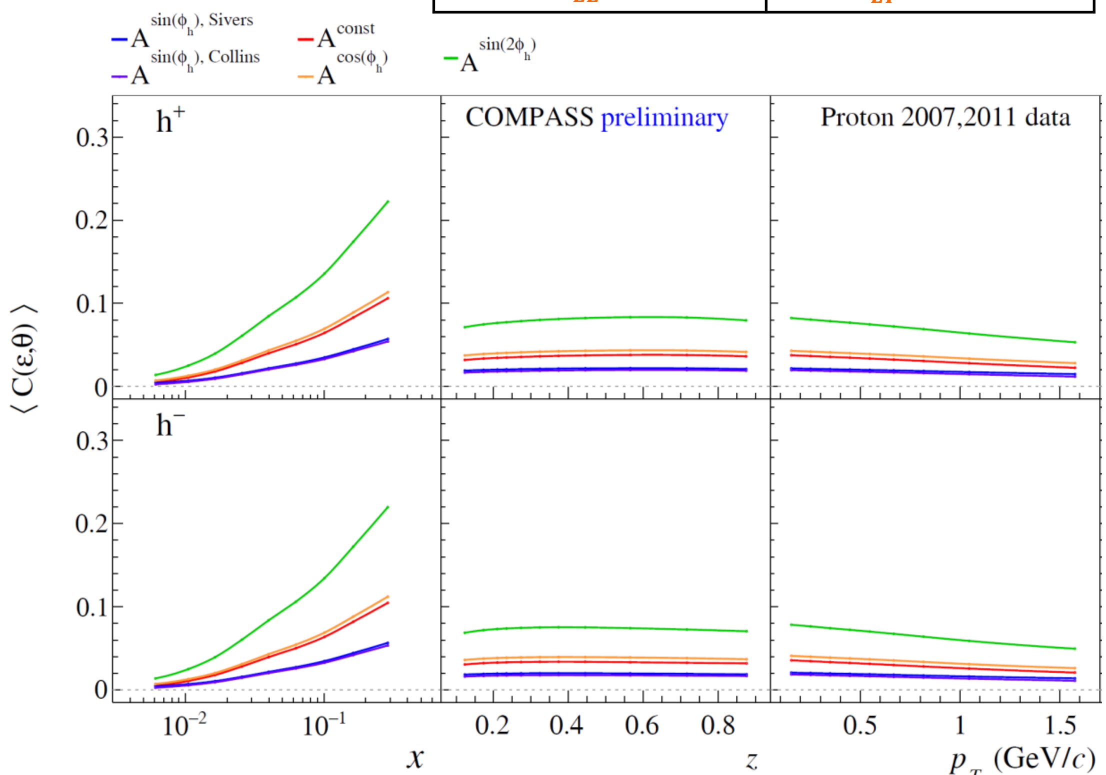
$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{ 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h + \varepsilon A_{UU}^{\cos2\phi_h}\cos2\phi_h + \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \right.$$

$$+ P_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h + \varepsilon A_{UL}^{\sin2\phi_h}\sin2\phi_h - \sin\theta\,\varepsilon A_{UL}^{\sin3\phi_h}\sin3\phi_h\right]$$

$$\left. + P_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h - \sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos2\phi_h}\cos2\phi_h\right]\right\}$$

LSA	Contributing TSA
$A_{UL}^{\sin\phi_h}$	$A_{UT}^{\sin(\phi_h-\phi_s)}$
$A_{UL}^{\sin\phi_h}$	$A_{UT}^{\sin(\phi_h+\phi_s-\pi)}$
$A_{UL}^{\sin2\phi_h}$	$A_{UT}^{\sin(2\phi_h-\phi_s)}$
A_{LL}	$A_{LT}^{\cos\phi_s}$
$A_{LL}^{\cos\phi_h}$	$A_{LT}^{\cos(\phi_h-\phi_s)}$

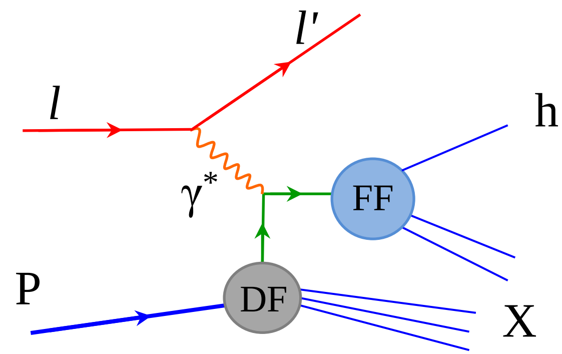


LSAs can get a contribution of up to 25 % of the size of the corresponding TSAs

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

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

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



Nucleon \ Quark	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

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

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

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

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

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

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

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

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

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

- Former HERMES, JLab and COMPASS experimental results on LSAs

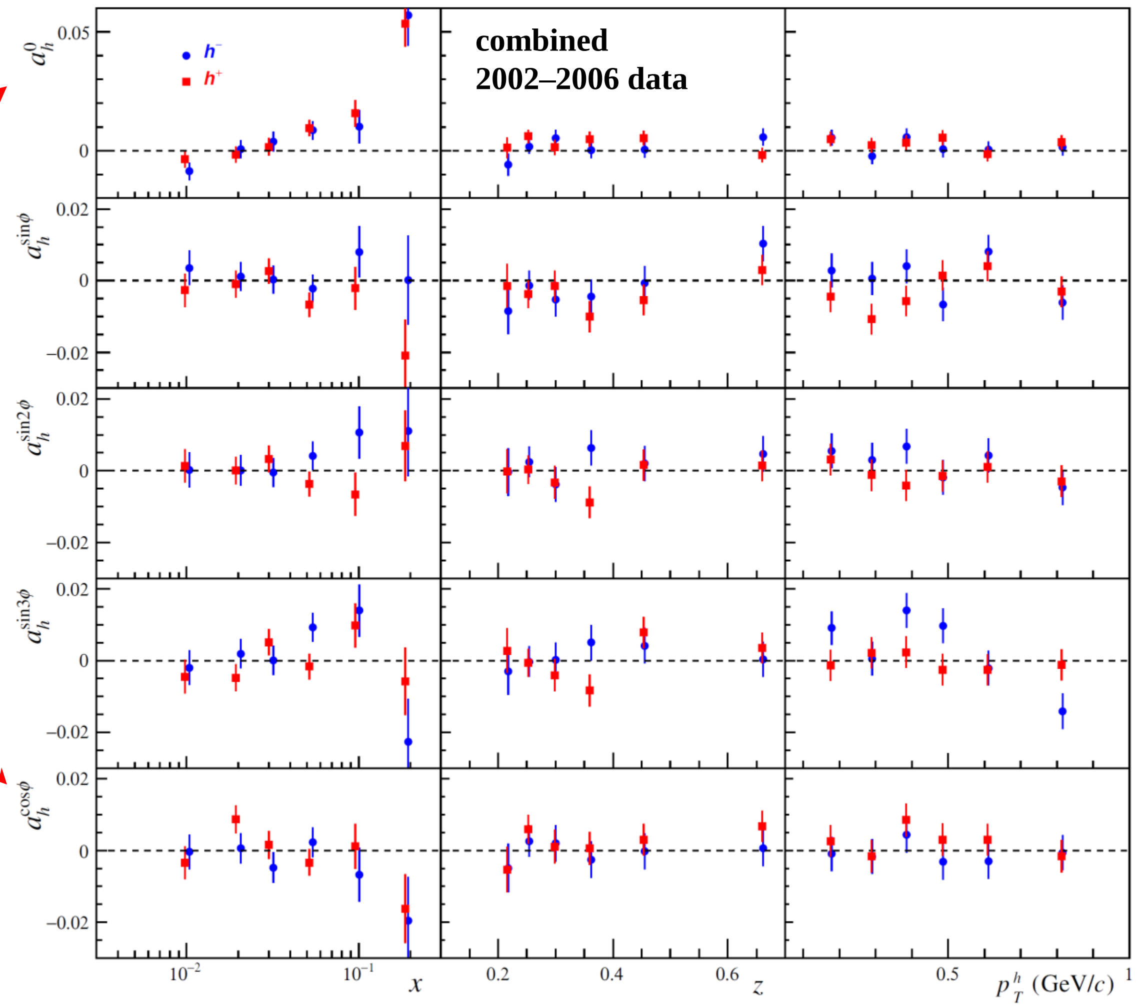
Existing measurements: COMPASS

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

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

Combined D-sample, **NEW!** 21/09/2016

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



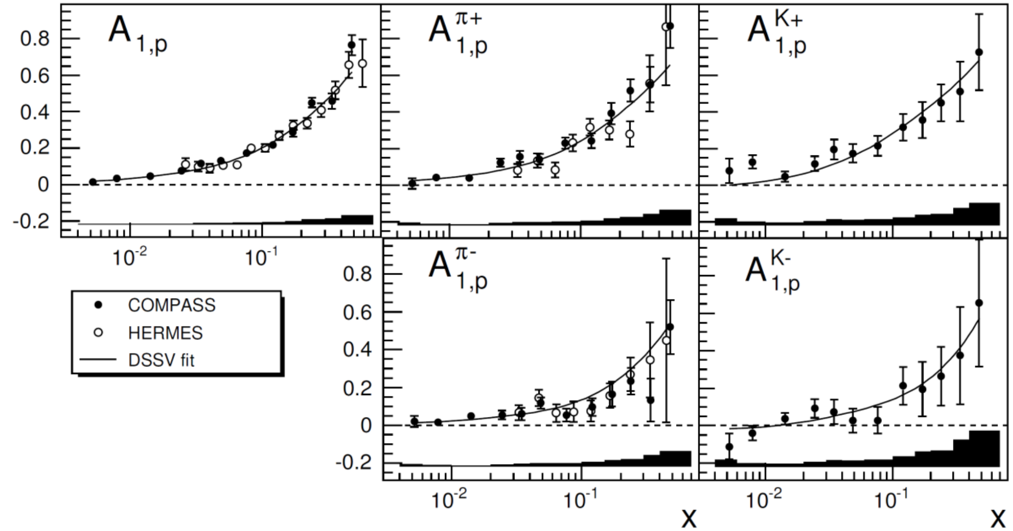
- **COMPASS collected large amount of SIDIS data with longitudinally polarized D/P targets (2002-2011)**

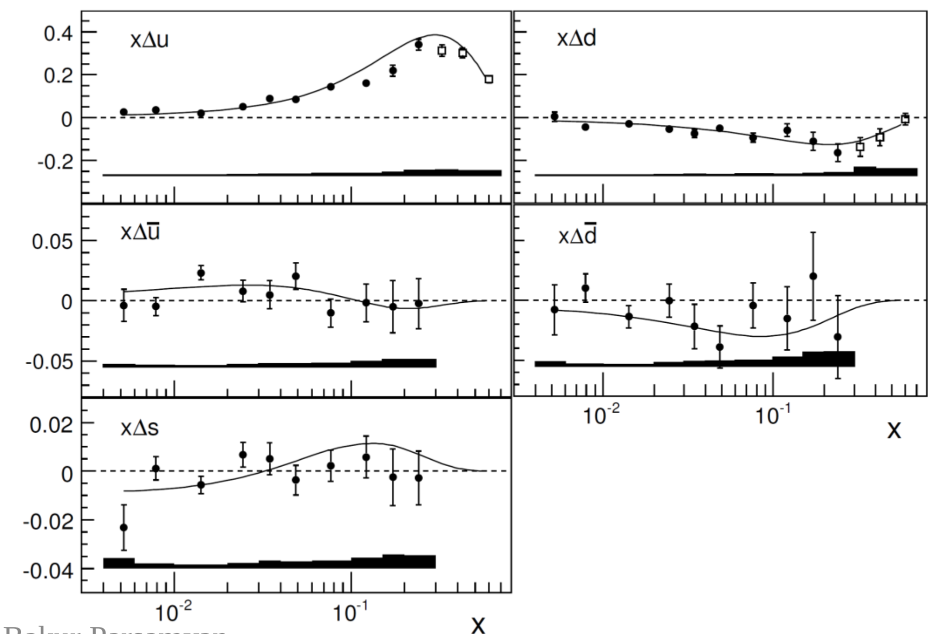
Existing measurements: COMPASS

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

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

PLB 693 (2010) 227–235





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

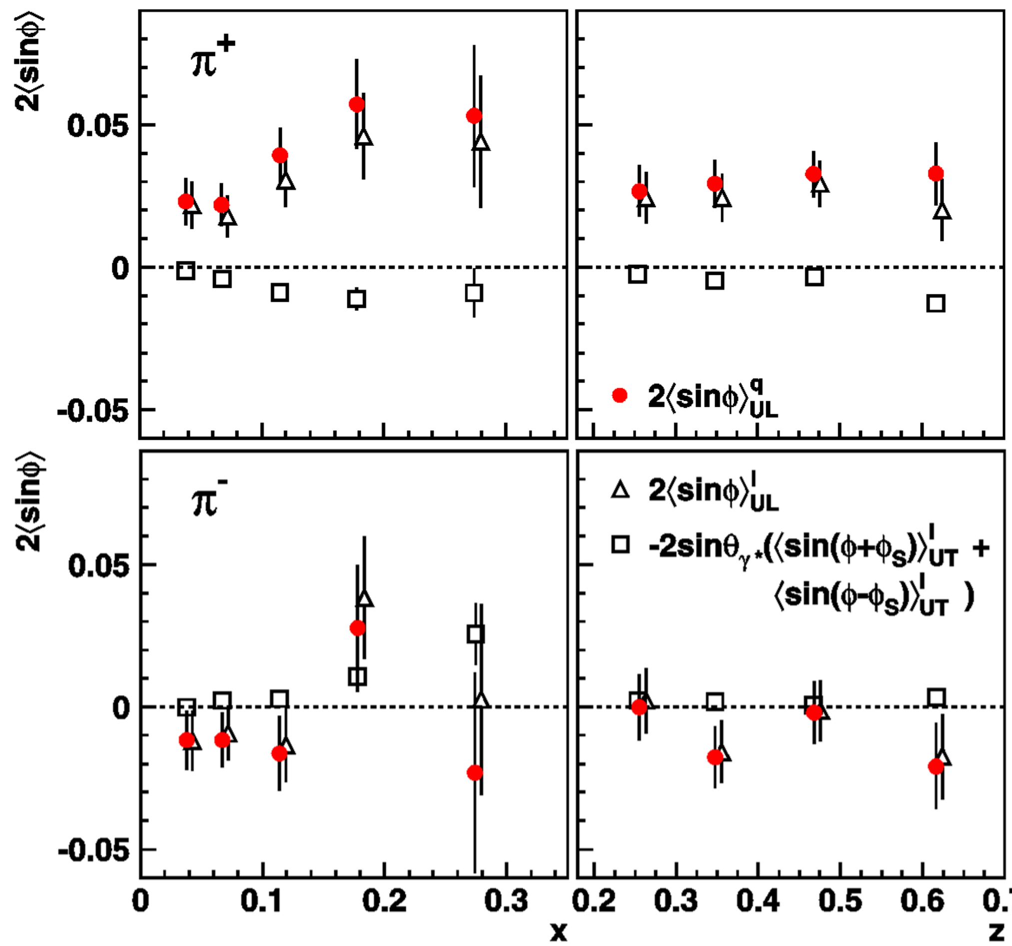
$$F_{LL}^{1} = \mathcal{C}\left\{g_{1L}^{q}D_{1q}^{h}\right\}$$

Existing measurements: HERMES

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

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

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)**

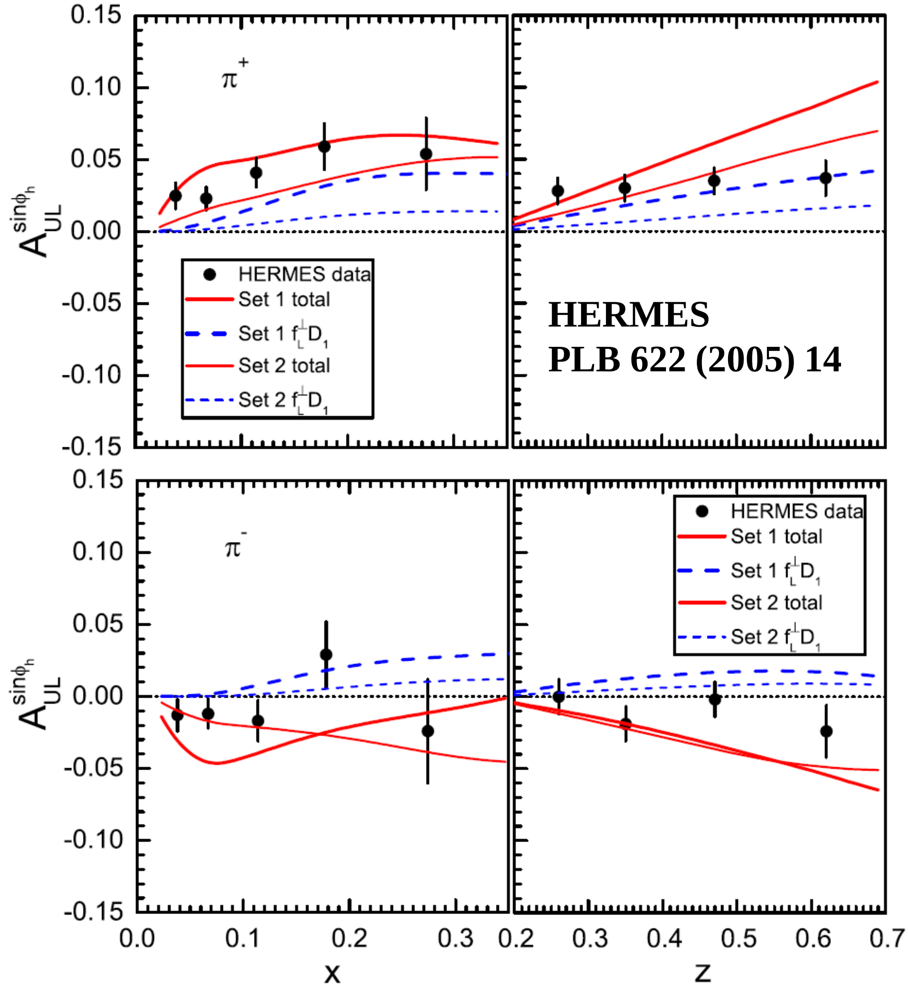
$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q}{M_h}\left(xh_L^q H_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp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

Existing measurements: HERMES

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

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

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



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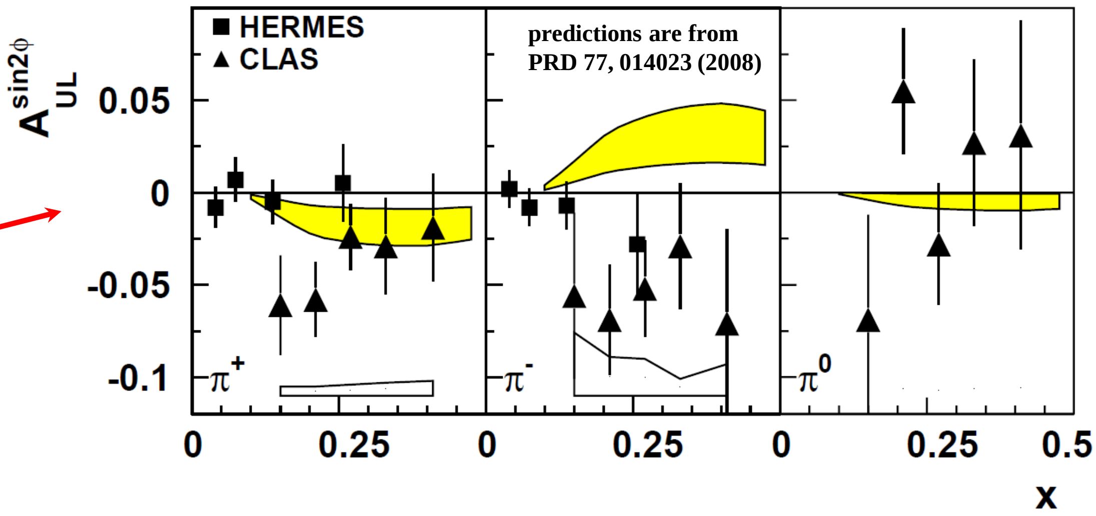
Existing measurements: HERMES, CLAS

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

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

PRL 105, 262002(2010)



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

- **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

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

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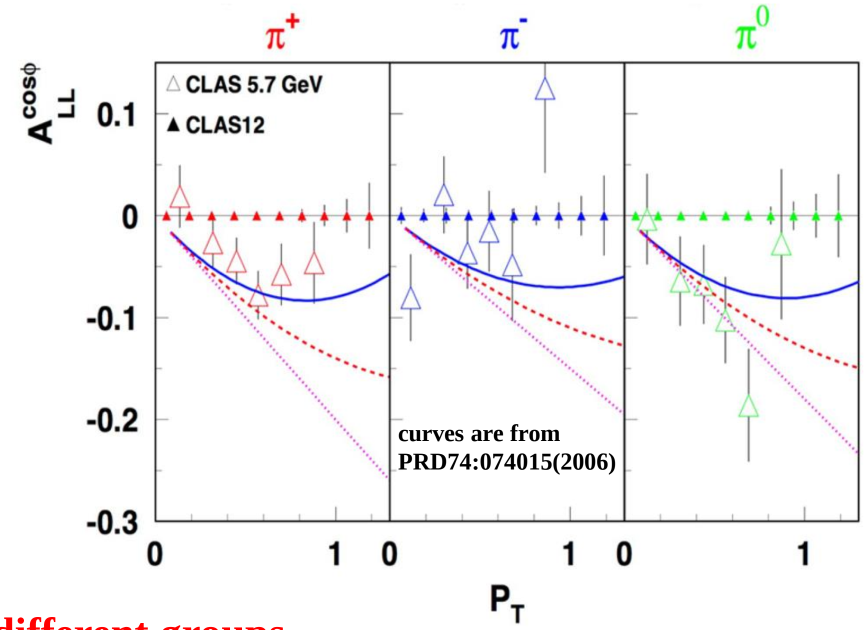
$$F_{LL}^{\cos\phi_h}=\frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T^q}{M_h}\left(xe_L^qH_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{D}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xg_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp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



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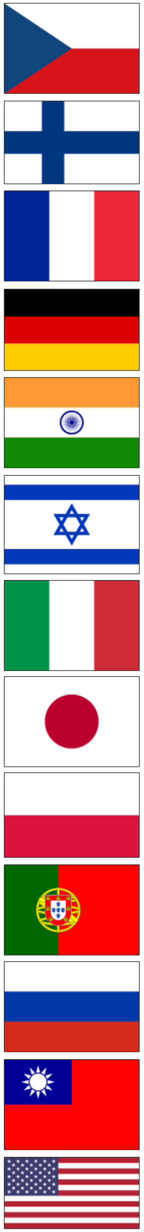
COMPASS collaboration



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

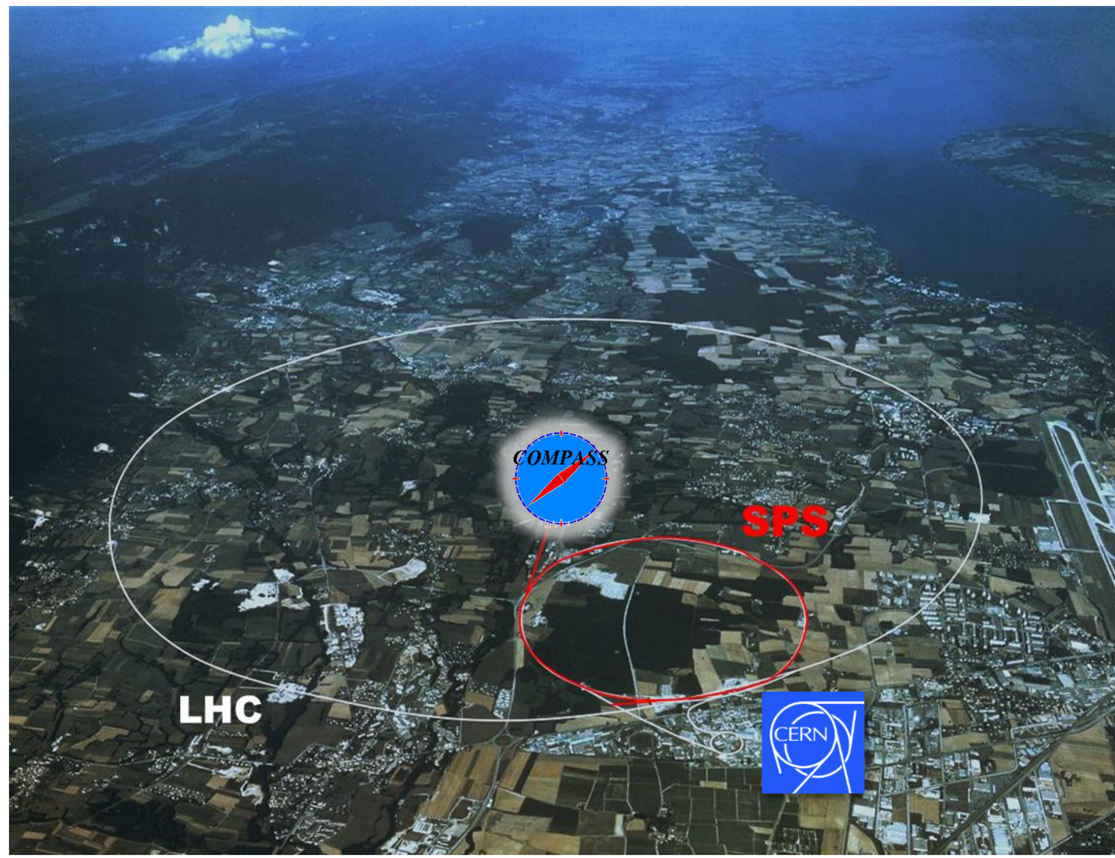
- **Data taking 2002-2011**
- **Muon and hadron beams**
- **Nucleon spin structure**
- **Spectroscopy**

See talks by A. Bressan and A. Martin

COMPASS-II

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

See talk by C. Quintans



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

COMPASS experimental setup: Phase I (muon program)

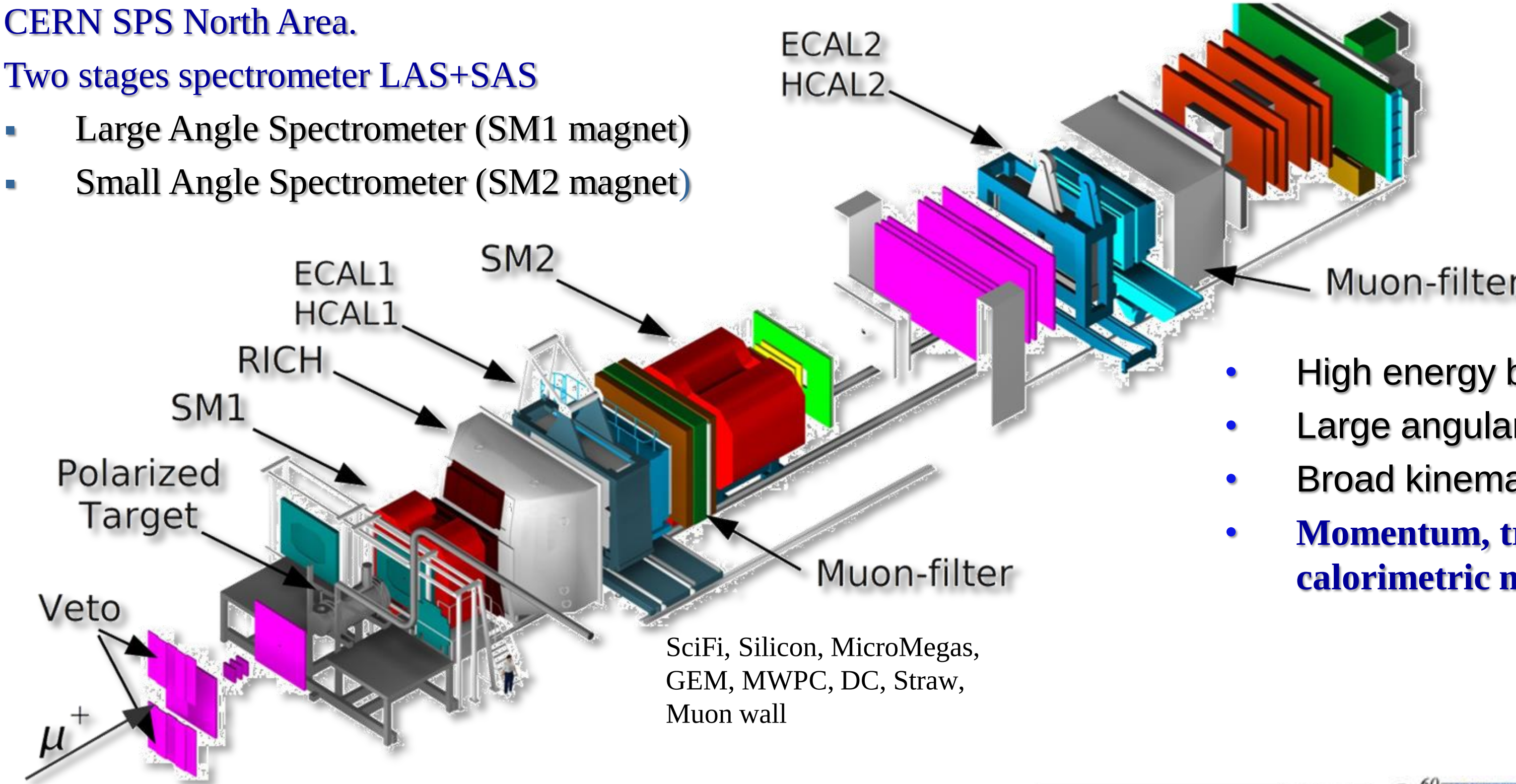
COmmon Muon Proton Apparatus for Structure and Spectroscopy

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



SciFi, Silicon, MicroMegas, GEM, MWPC, DC, Straw, Muon wall

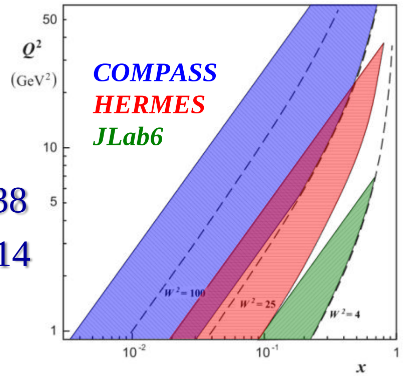
- High energy beam
- Large angular acceptance
- Broad kinematical range
- **Momentum, tracking and calorimetric measurements, PID**

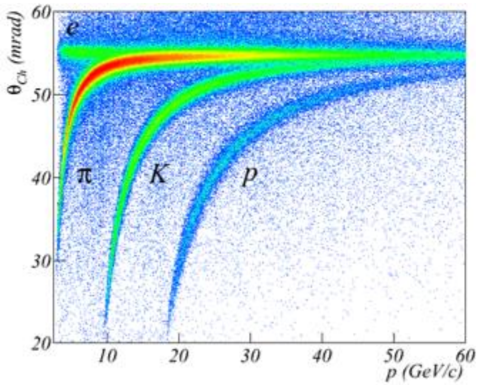
Longitudinally polarized (80%) μ^+ beam:
Energy: 160/200 GeV/c, Intensity: $2 \cdot 10^8$ μ^+/spill (4.8s).

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

- ^{6}LiD 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





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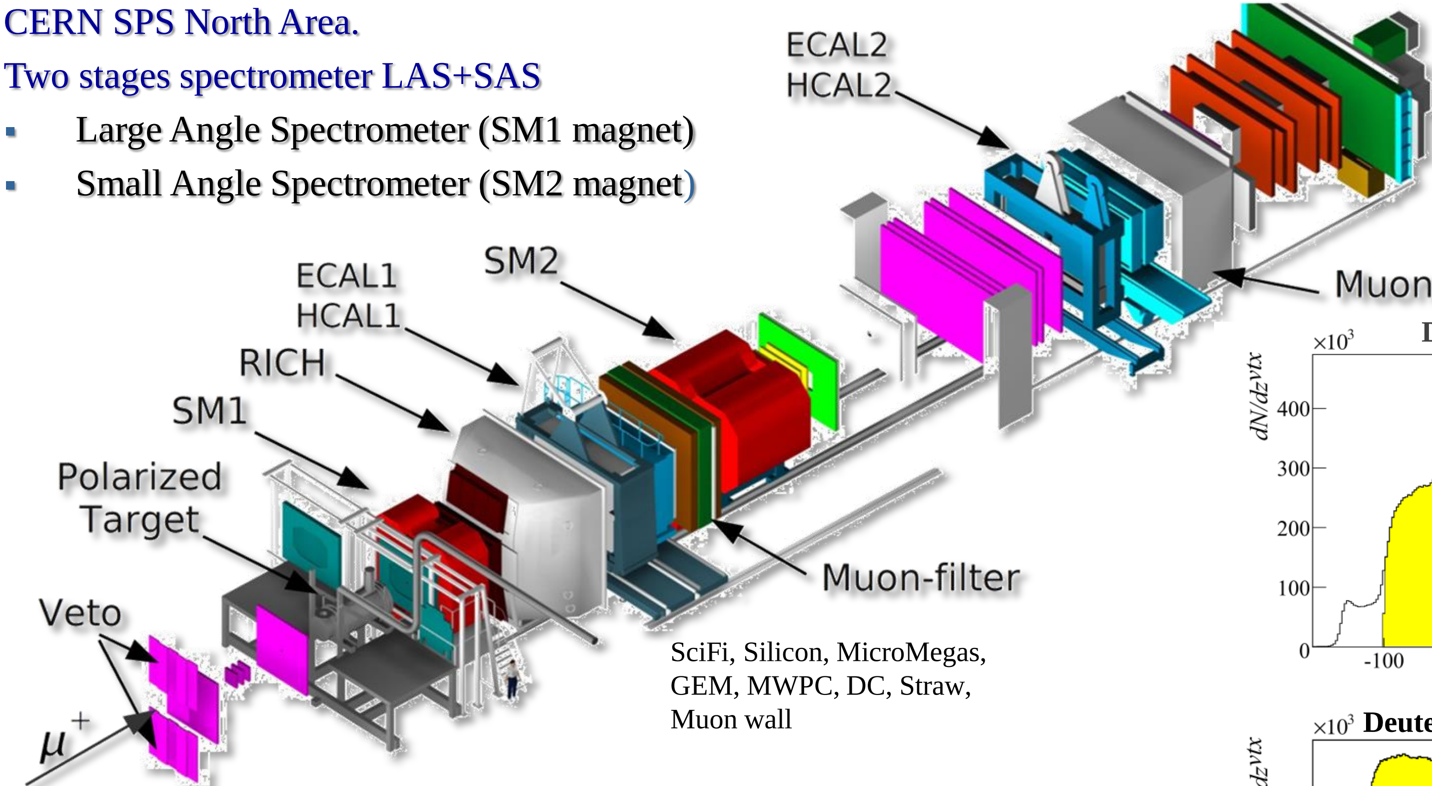

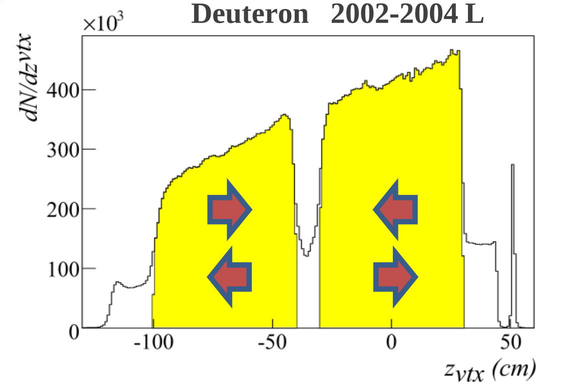

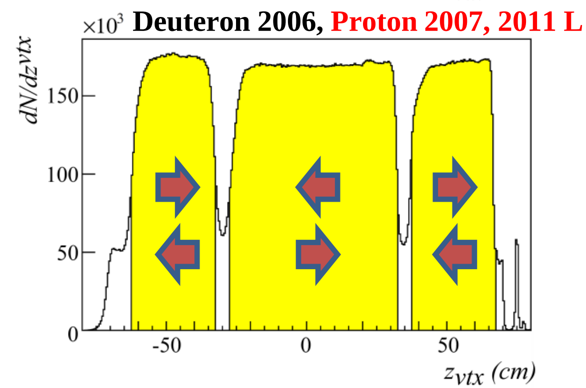

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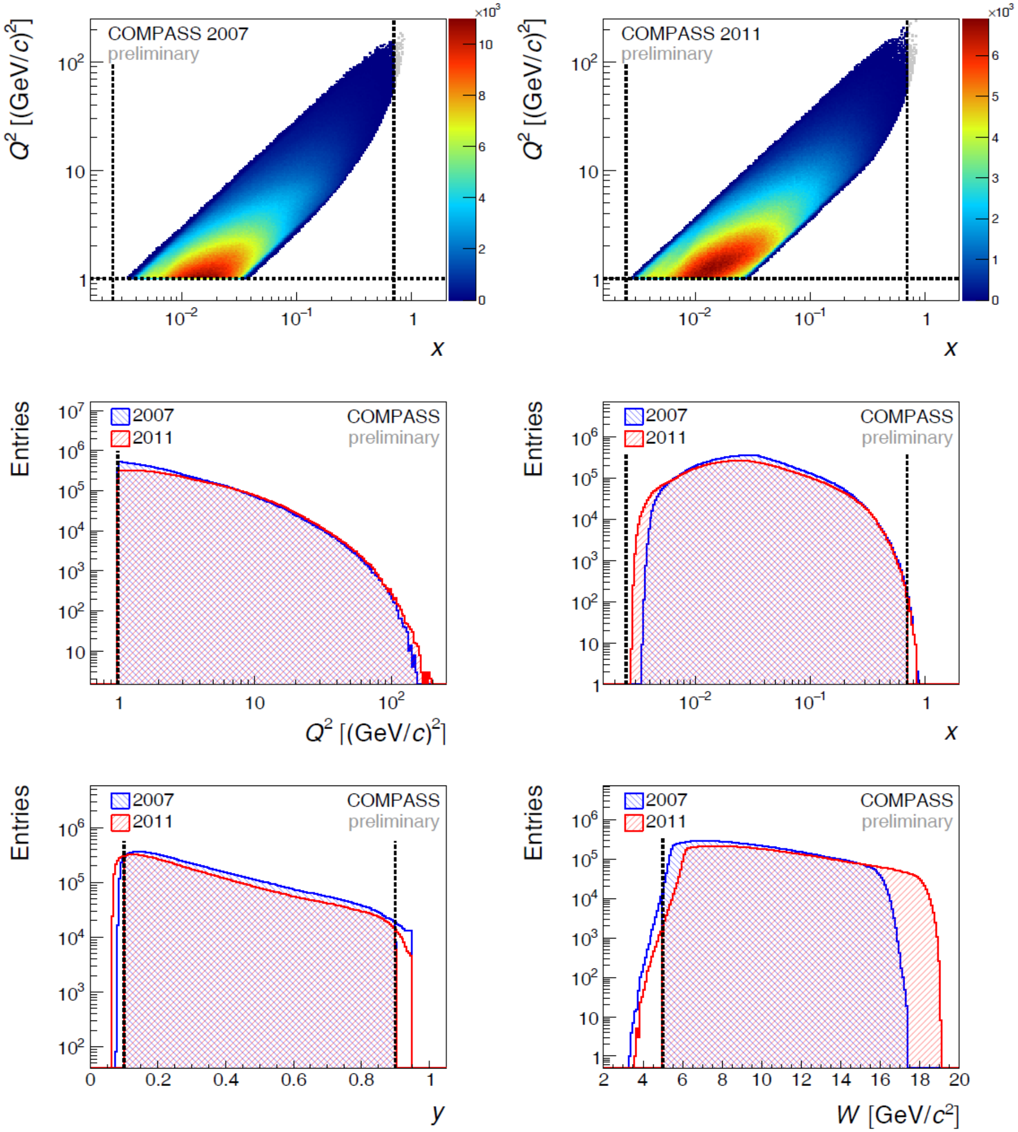
- ^{6}LiD 2-cell configuration. Polarization (L & T) ~ 50%, f ~ 0.38
- NH_3 3-cell configuration. Polarization (L & T) ~ 80%, f ~ 0.14

Data-taking years: 2002-2011

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

- Proton SIDIS single-hadron azimuthal LSAs at COMPASS: First 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

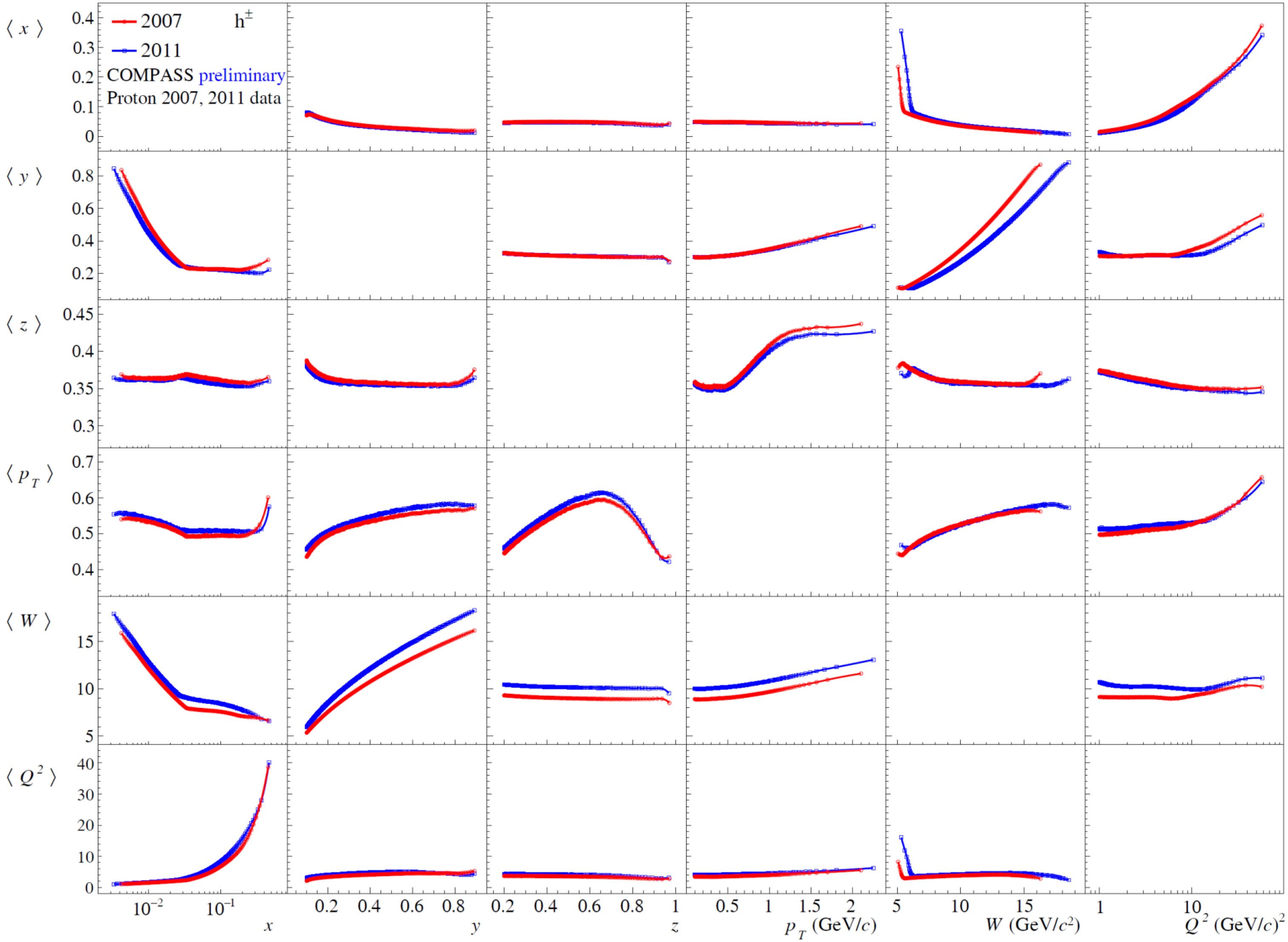
Kinematic cuts

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
Only results from merged 2007+2011 sample are shown

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



Comparable kinematic distributions

Only results from merged 2007+2011 sample are shown

COMPASS results for the $A_{UL}^{\sin\phi_h}$ asymmetry

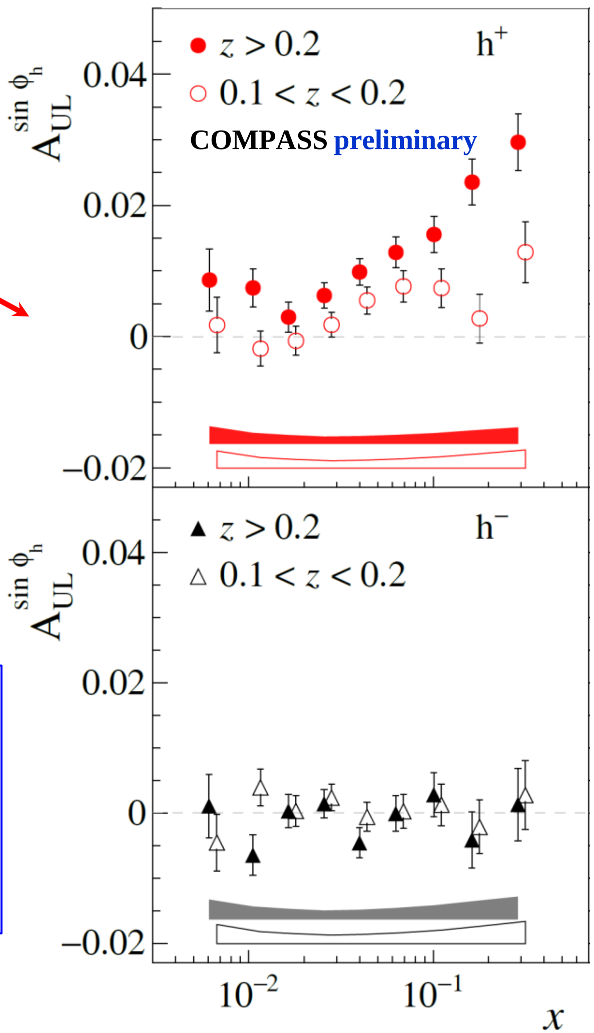
First shown at SPIN-2016, NEW!

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

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

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

Proton 2007+2011 data



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

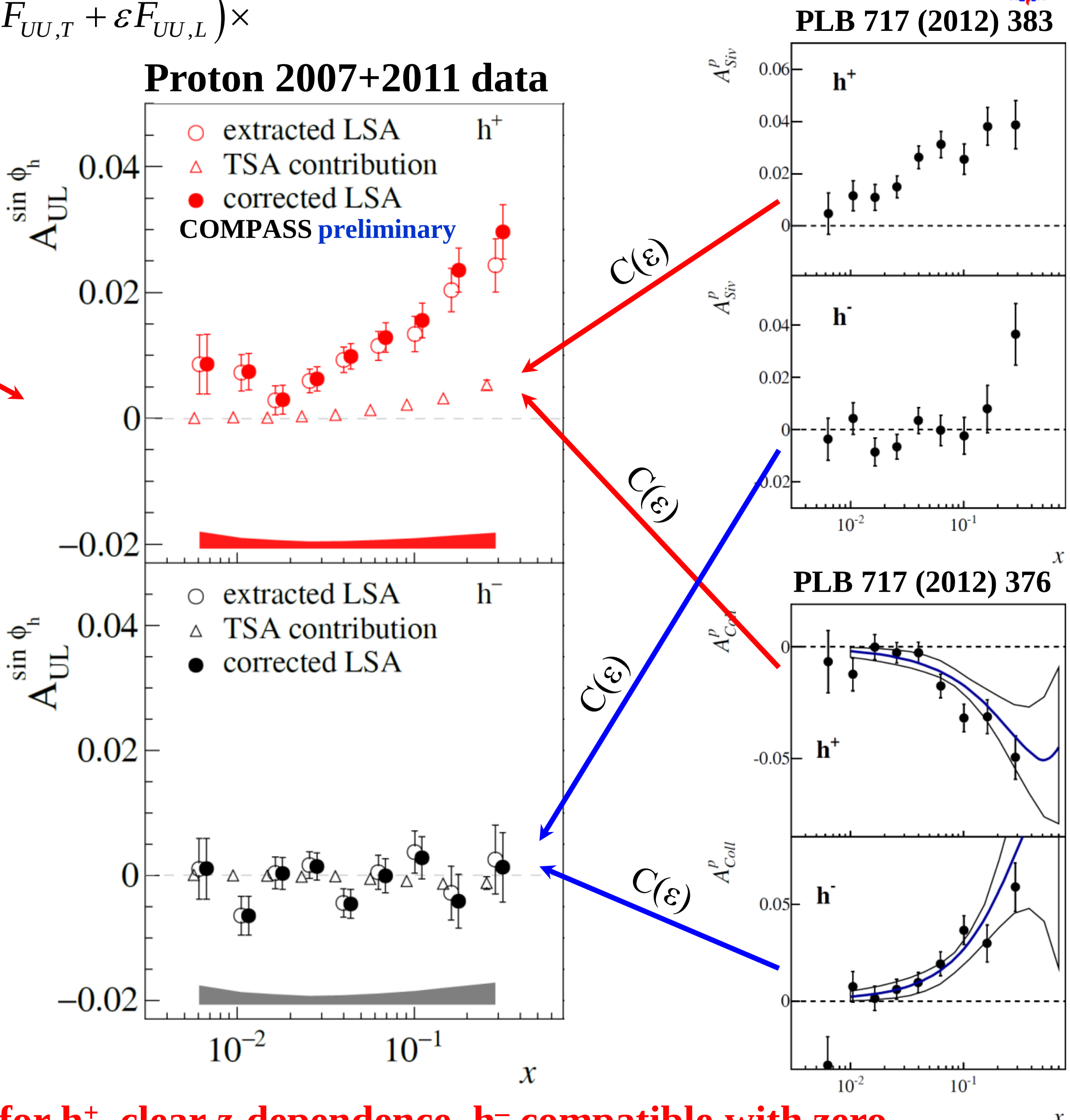
$A_{UL}^{\sin\phi_h}$ mixing with $A_{UT}^{\sin(\phi_h-\phi_s)}$ and $A_{UT}^{\sin(\phi_h+\phi_s)}$

First shown at SPIN-2016, NEW!

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

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

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



- Q-suppression, TSA-mixing
- Various different "twist" ingredients
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COMPASS results for the $A_{UL}^{\sin\phi_h}$ asymmetry

First shown at SPIN-2016, NEW!

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

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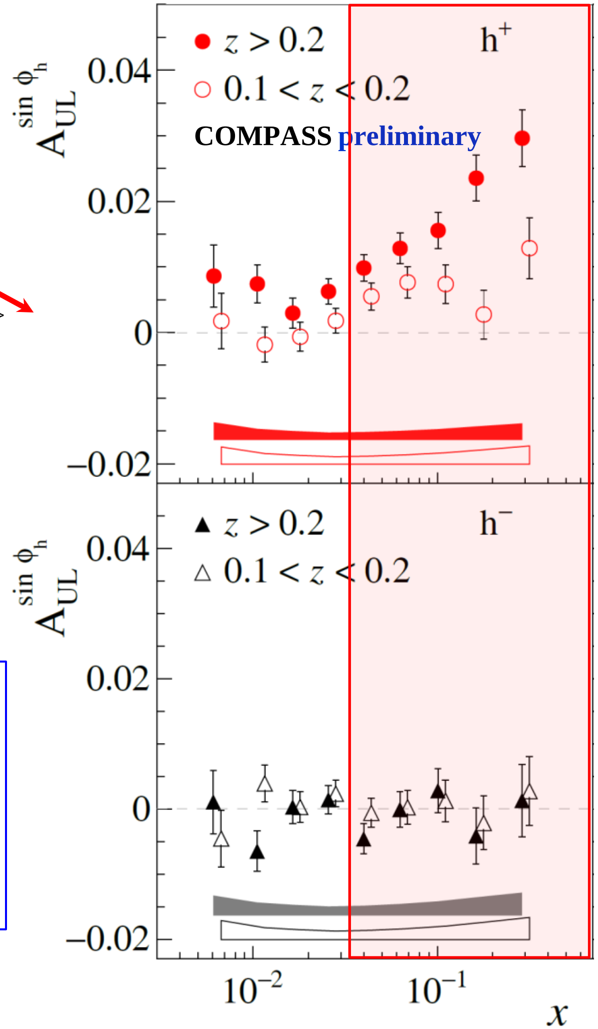
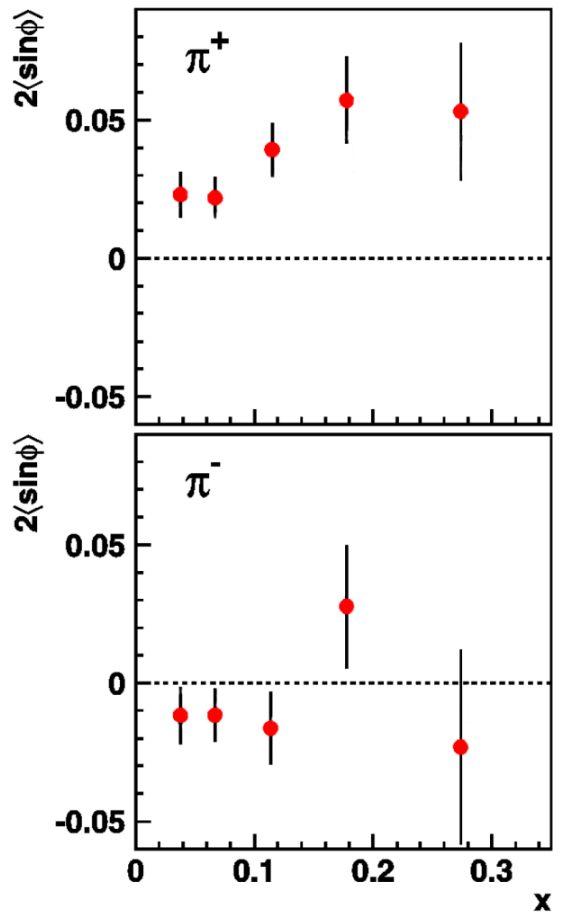
$$F_{UL}^{\sin\phi_h}=\frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(xh_L^qH_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp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

Proton 2007+2011 data



HERMES
PLB 622 (2005) 14



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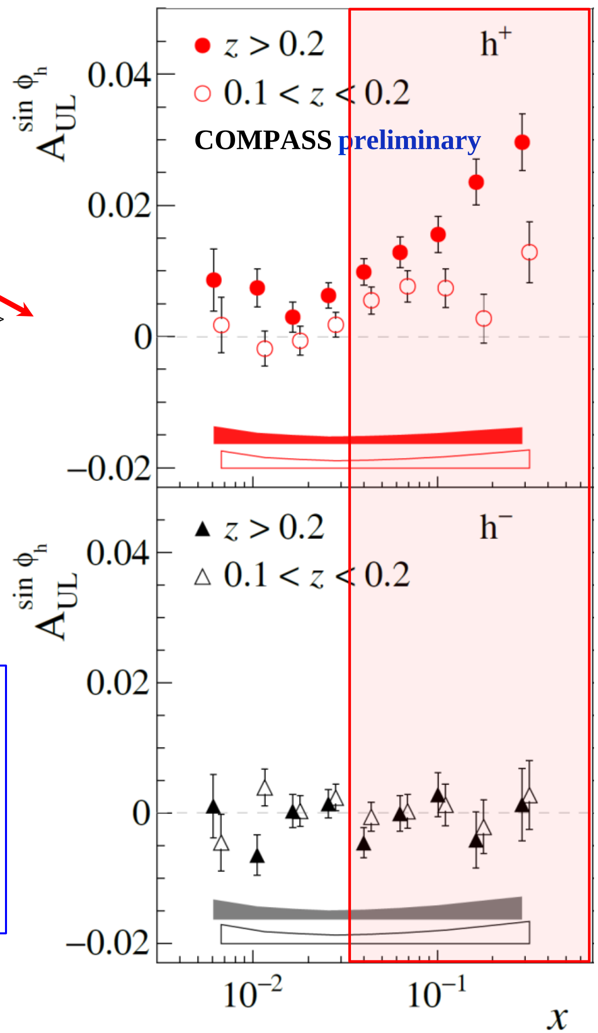
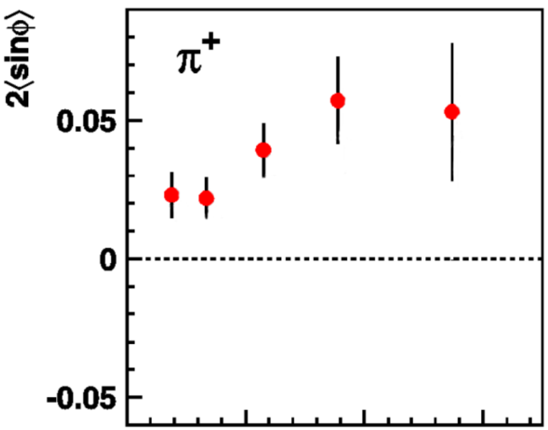
$$\begin{Bmatrix} 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\ +\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\ + P_L\begin{bmatrix} \sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h \\ -\sin\theta\varepsilon A_{UL}^{\sin 3\phi_h}\sin 3\phi_h \end{bmatrix} \\ + P_L\lambda\begin{bmatrix} \sqrt{1-\varepsilon^2}A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h \\ -\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos 2\phi_h}\cos 2\phi_h \end{bmatrix} \end{Bmatrix}$$

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

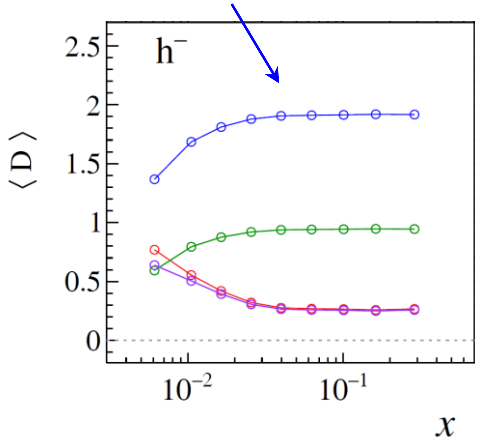
Proton 2007+2011 data



HERMES
PLB 622 (2005) 14



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



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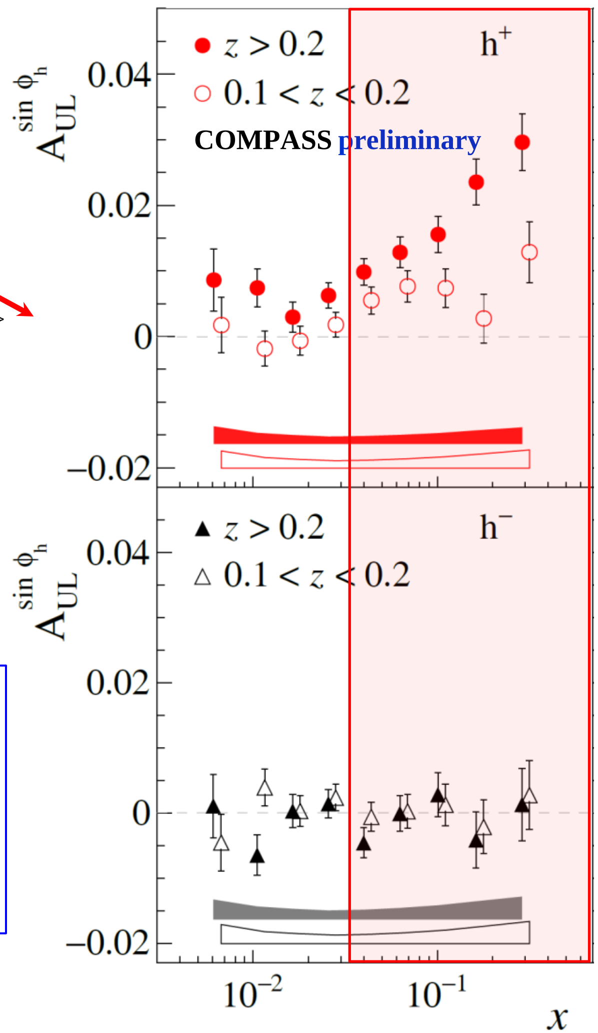
COMPASS results for the $A_{UL}^{\sin\phi_h}$ asymmetry

First shown at SPIN-2016, NEW!

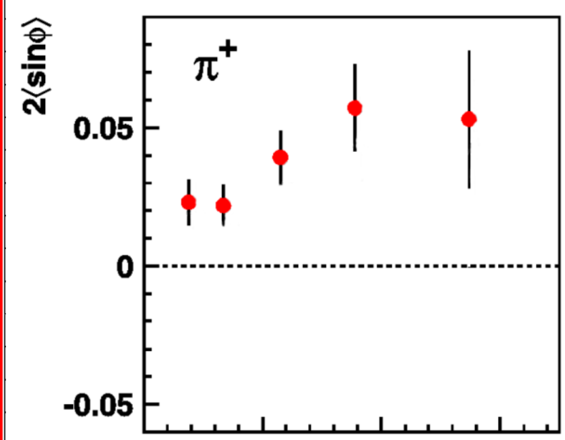
$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

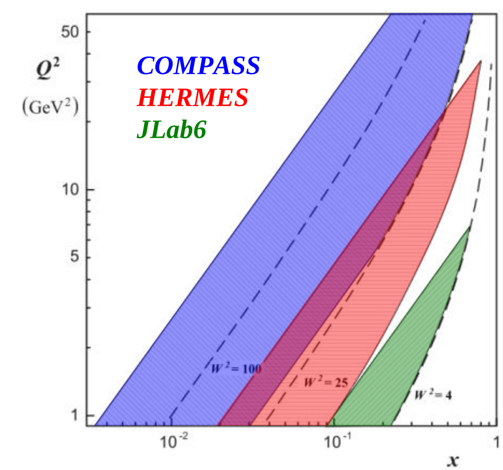
$$\left\{ 1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h + \lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h + P_L\left[\begin{array}{l}\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h \\ +\ \varepsilon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

Proton 2007+2011 data



HERMES
PLB 622 (2005) 14





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

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COMPASS results for the $A_{UL}^{\sin\phi_h}$ asymmetry

First shown at SPIN-2016, NEW!

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

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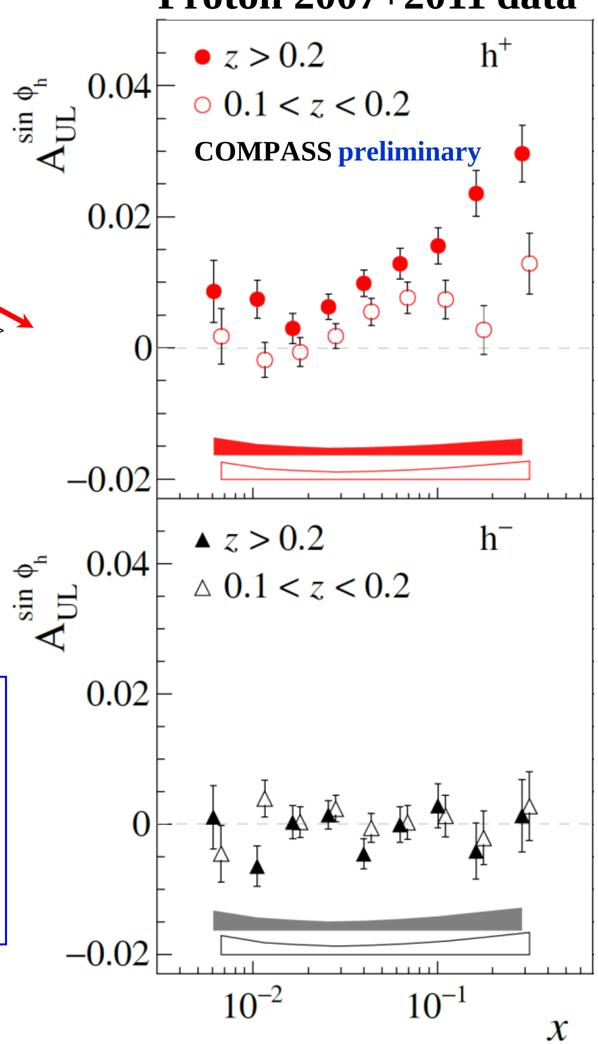
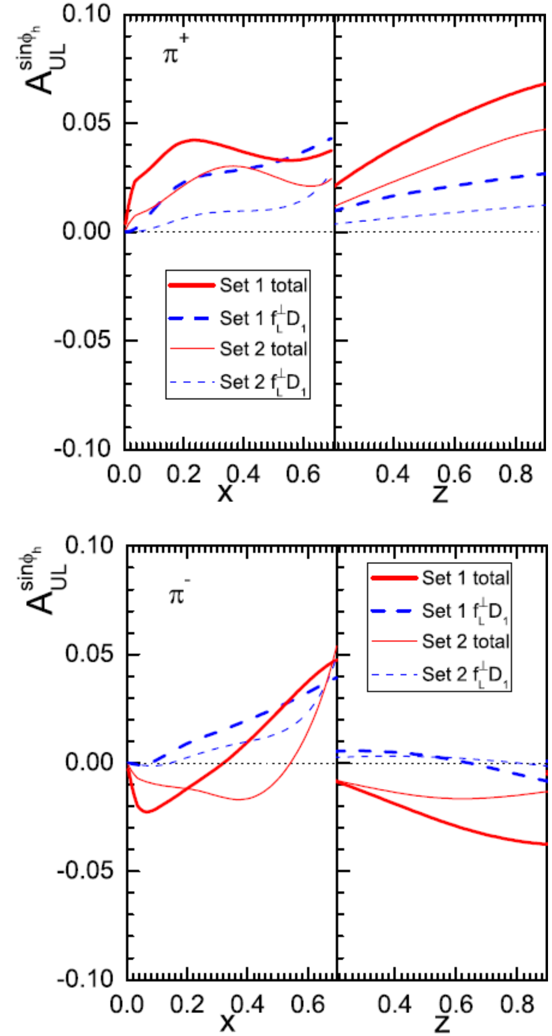
$$F_{UL}^{\sin\phi_h}=\frac{2M}{Q}\mathcal{C}\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(xh_L^qH_{1q}^{\perp h}+\frac{M_h}{M}g_{1L}^q\frac{\tilde{G}_q^{\perp h}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(xf_L^{\perp q}D_{1q}^h-\frac{M_h}{M}h_{1L}^{\perp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

Proton 2007+2011 data



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



- Q-suppression, TSA-mixing
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- **Similar to HERMES non-zero trend for h$^+$, clear z-dependence, h$^-$ compatible with zero**

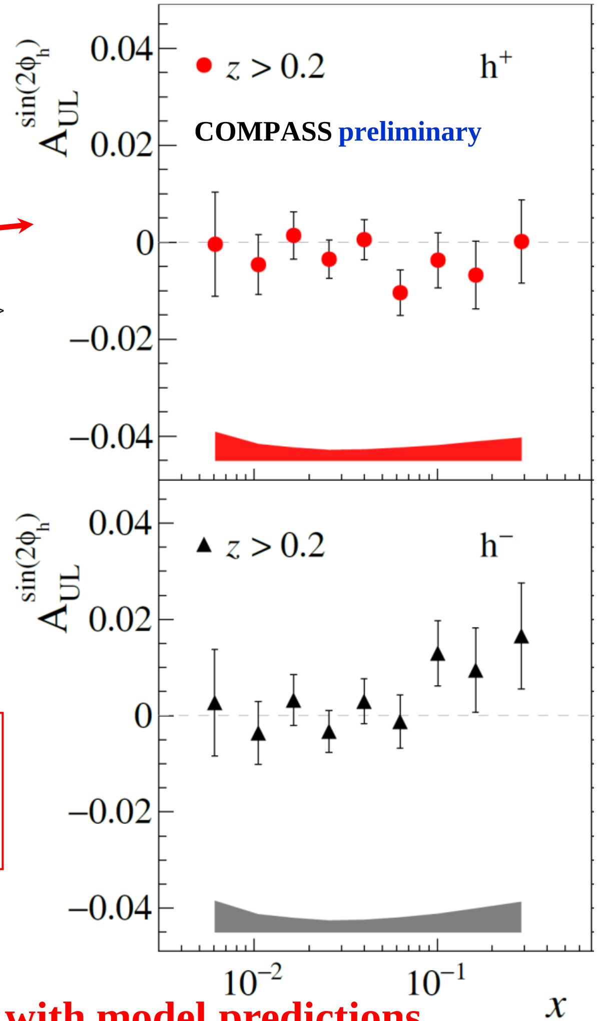
COMPASS results for the $A_{UL}^{\sin 2\phi_h}$ asymmmetry

First shown at SPIN-2016, NEW!

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

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

Proton 2007+2011 data



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

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

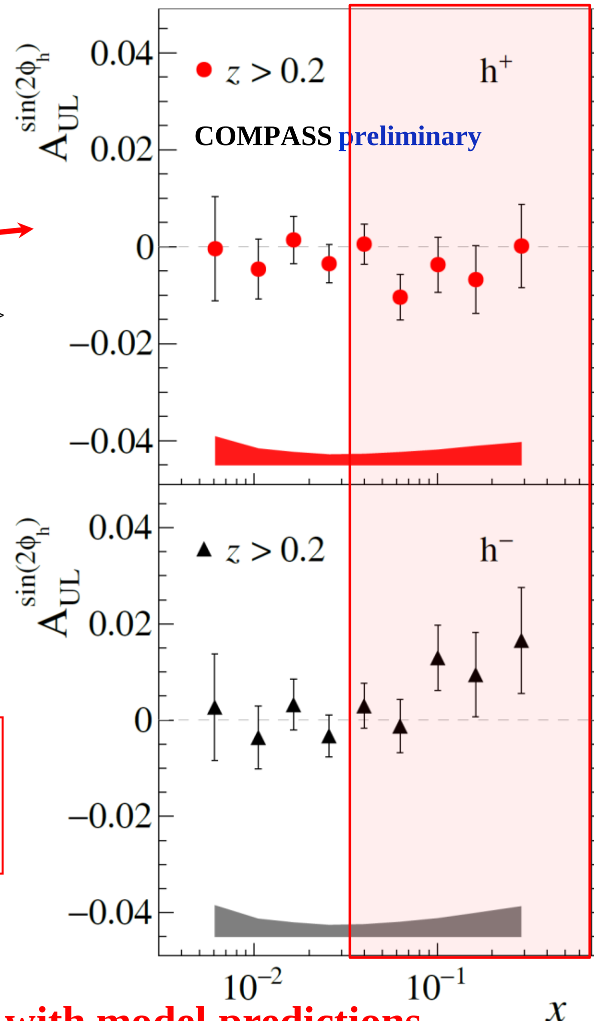
COMPASS results for the $A_{UL}^{\sin 2\phi_h}$ asymmmetry

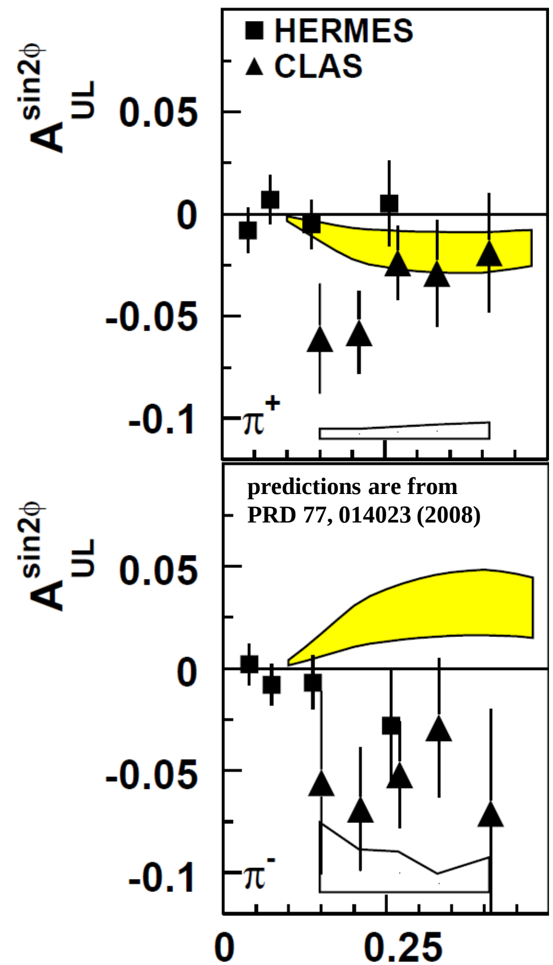
First shown at SPIN-2016, NEW!

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

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

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





- Only “twist-2” ingredients
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COMPASS results for the $A_{LL}^{\cos\phi_h}$ asymmmetry

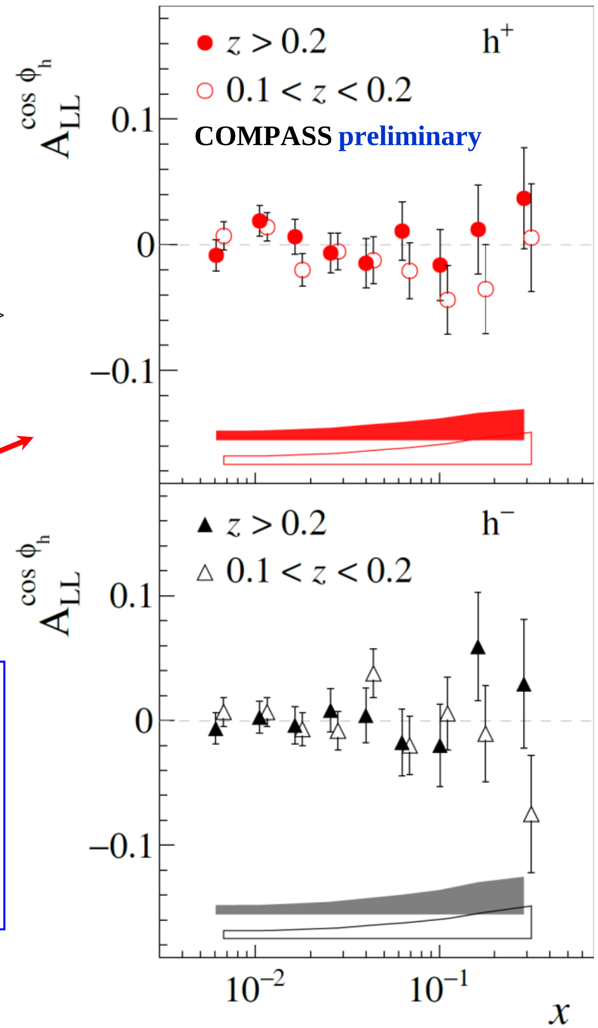
First shown at SPIN-2016, NEW!

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

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

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

Proton 2007+2011 data



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COMPASS results for the $A_{LL}^{\cos\phi_h}$ asymmmetry

First shown at SPIN-2016, NEW!

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

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

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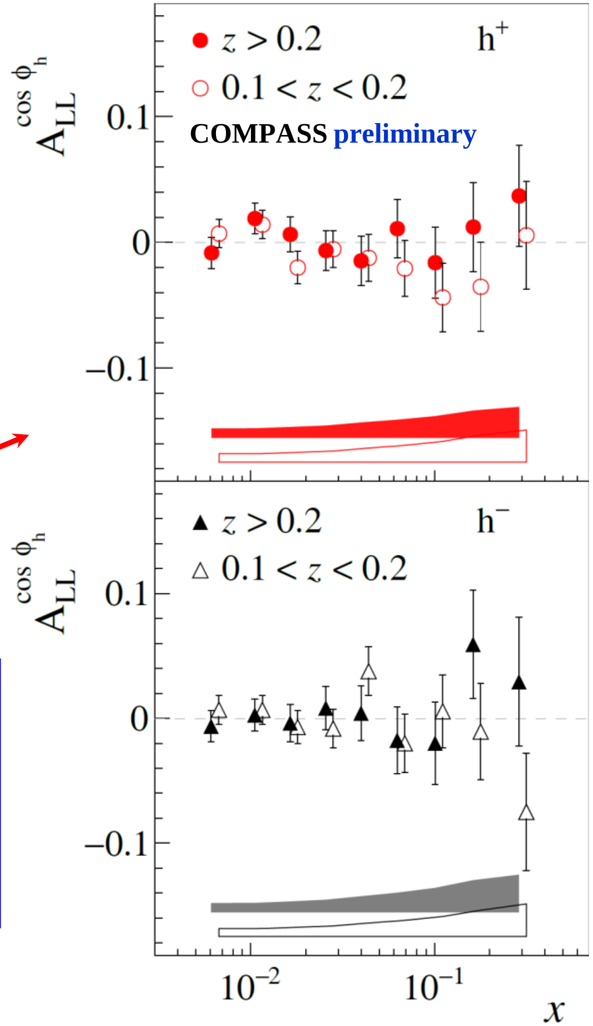
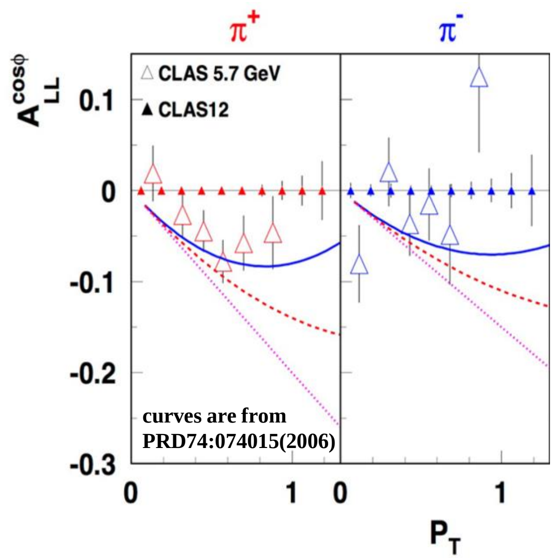


PRL 105,262002(2010)



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COMPASS results for the $A_{LL}^{\cos\phi_h}$ asymmmetry

First shown at SPIN-2016, NEW!

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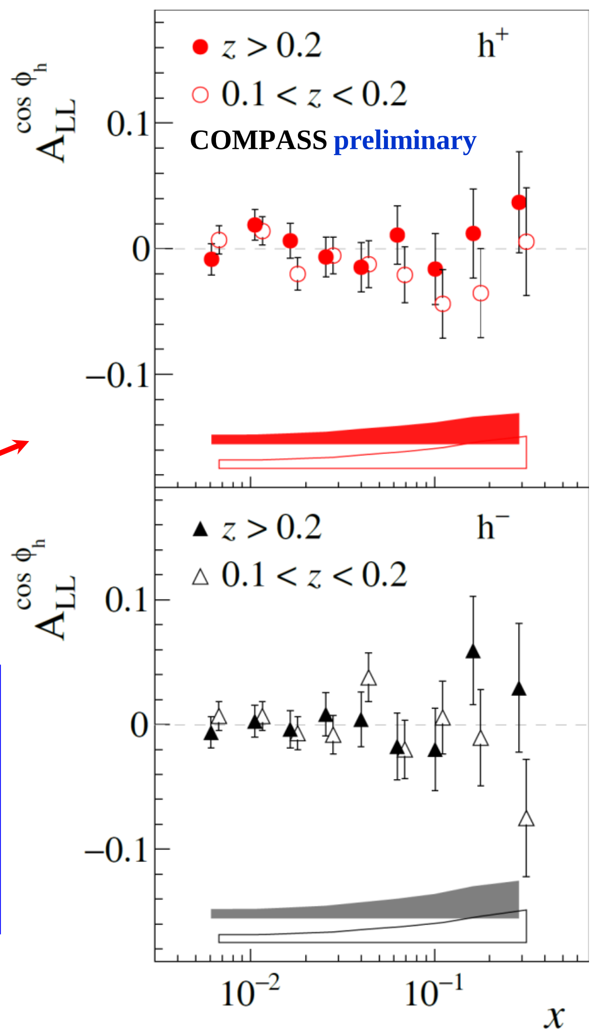
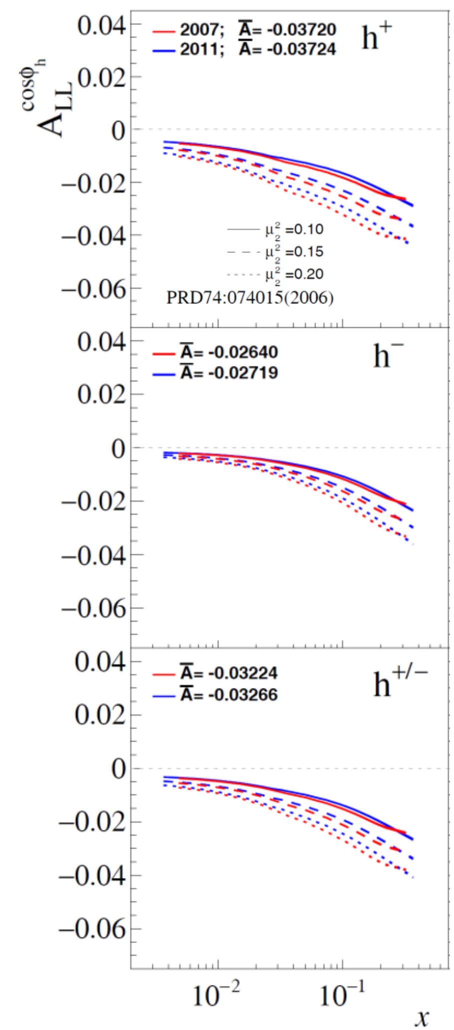
Proton 2007+2011 data



PRD74:074015(2006)



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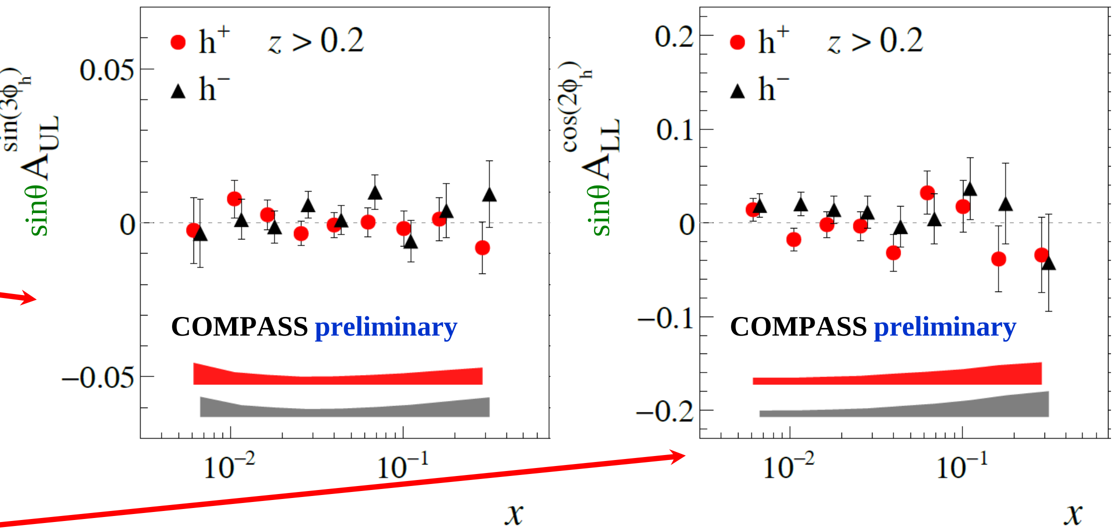
COMPASS results for $A_{UL}^{\sin 3\phi_h}$ and $A_{LL}^{\cos 2\phi_h}$ asymmmetries

First shown at SPIN-2016, NEW!

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

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

Proton 2007+2011 data



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

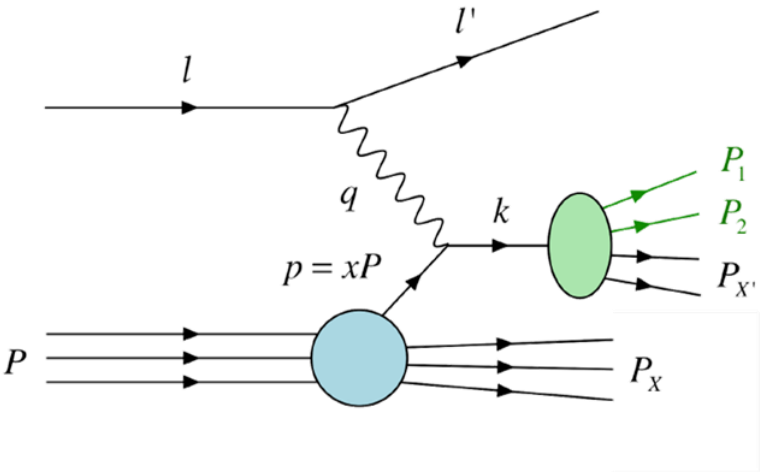
$$A_{LL}^{\cos 2\phi_h} \leftrightarrow A_{LT}^{\cos(2\phi_h-\phi_s)} \propto Q^{-1}\left(g_{1T}^{q}\otimes D_{1q}^{h}+\ldots\right)$$

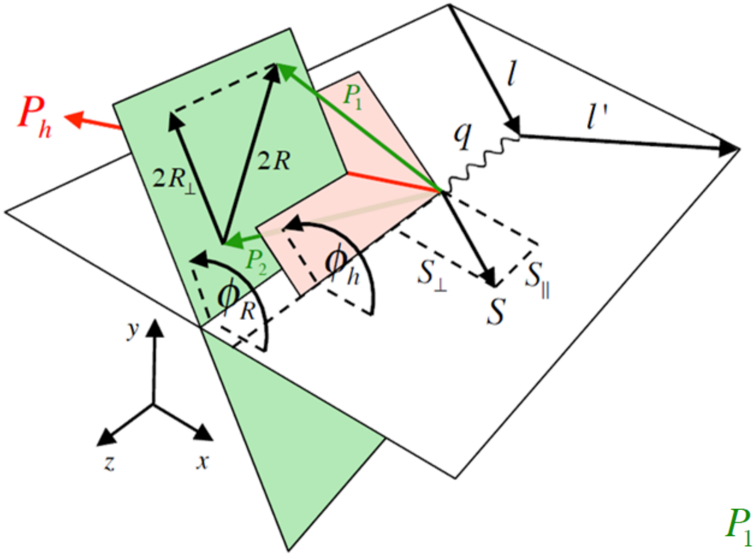
- Alternative way to access corresponding TSAs
- sin(θ) suppression
- Other suppressions at the "TSA"-level ($|p_T|^3$, Q^{-1})
- **Compatible with zero**

Theoretical Framework: Di-hadron SIDIS

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

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

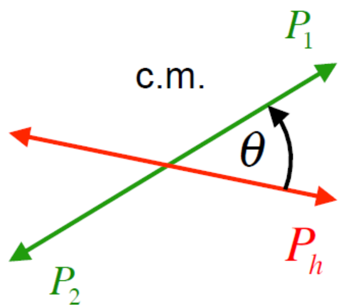




- X-section modulated in azimuthal angles ϕ_h and ϕ_R

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

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



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

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

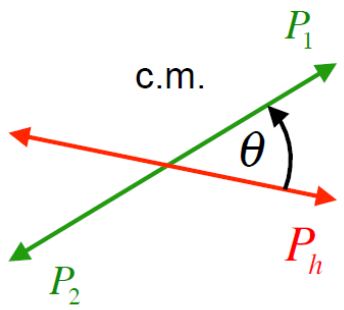
Theoretical Framework: Di-hadron SIDIS at twist-2

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

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

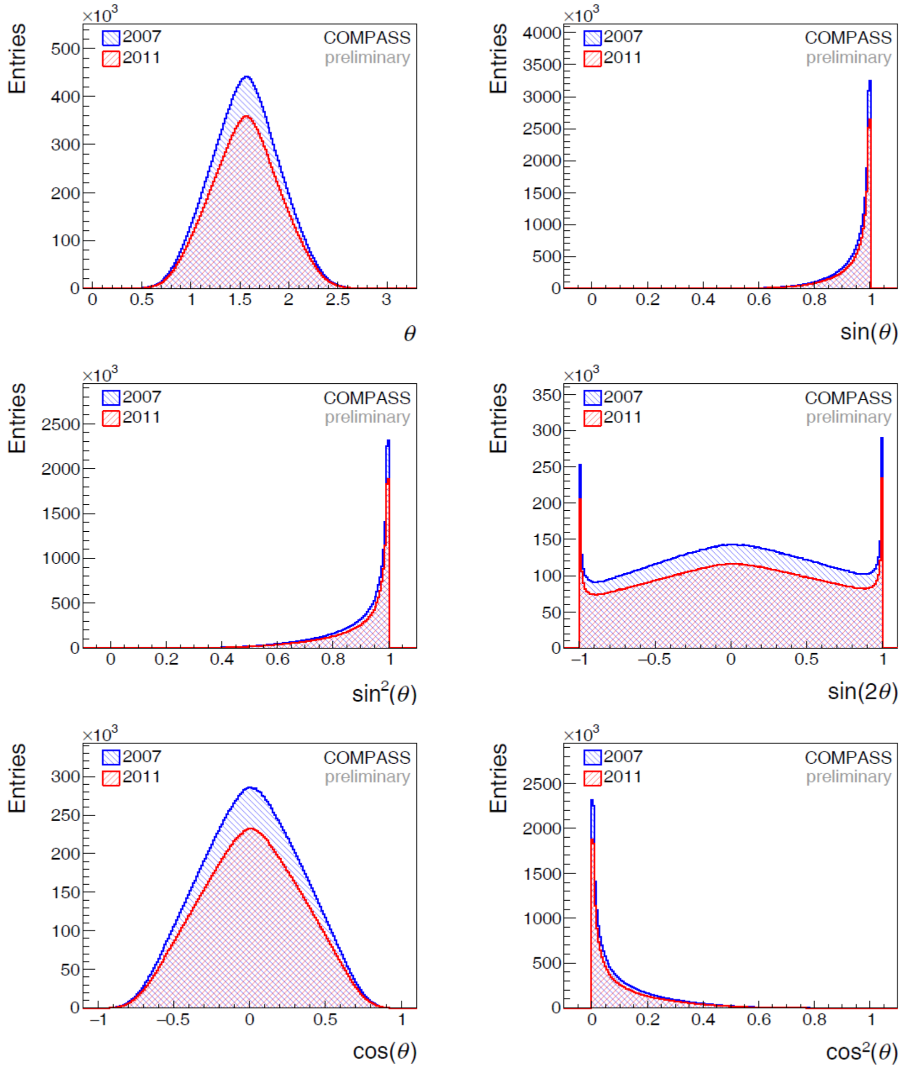
Di-hadron SIDIS at twist-2

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

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

$$\begin{aligned}
d\sigma_{UL} \propto\; & \sin(\phi_h - \phi_R)\, A_{UL}^{\sin(\phi_h-\phi_R)} && \sim g_{1L} \otimes G_{1,UT}^{\perp} \\
& + \sin(2\phi_h - 2\phi_R)\, A_{UL}^{\sin(2\phi_h-2\phi_R)} && \sim g_{1L} \otimes G_{1,TT}^{\perp} \\
& + \varepsilon \Big\{ \sin(2\phi_h)\, A_{UL}^{\sin(2\phi_h)} && \sim h_{1L}^{\perp} \otimes H_{1,UU}^{\perp} \\
& + \sin(\phi_h + \phi_R)\, A_{UL}^{\sin(\phi_h+\phi_R)} && \sim h_{1L}^{\perp} \otimes H_{1,UT}^{\angle} \\
& + \sin(2\phi_R)\, A_{UL}^{\sin(2\phi_R)} && \sim h_{1L}^{\perp} \otimes H_{1,TT}^{\angle} \\
& + \sin(3\phi_h - \phi_R)\, A_{UL}^{\sin(3\phi_h-\phi_R)} && \sim h_{1L}^{\perp} \otimes H_{1,UT}^{\perp} \\
& + \sin(4\phi_h - 2\phi_R)\, A_{UL}^{\sin(4\phi_h-2\phi_R)} \Big\} && \sim h_{1L}^{\perp} \otimes H_{1,TT}^{\perp}
\end{aligned}$$

$$\begin{aligned}
d\sigma_{LL} \propto\; & \sqrt{1-\varepsilon^2}\, \Big\{ A_{LL}^{1} && \sim g_{1L} \otimes D_{1,UT} \\
& + \cos(\phi_h - \phi_R)\, A_{LL}^{\cos(\phi_h-\phi_R)} && \sim g_{1L} \otimes D_{1,TT} \\
& + \cos(2\phi_h - 2\phi_R)\, A_{LL}^{\cos(2\phi_h-2\phi_R)} \Big\} && \sim g_{1L} \otimes D_{1,UU}
\end{aligned}$$



- 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

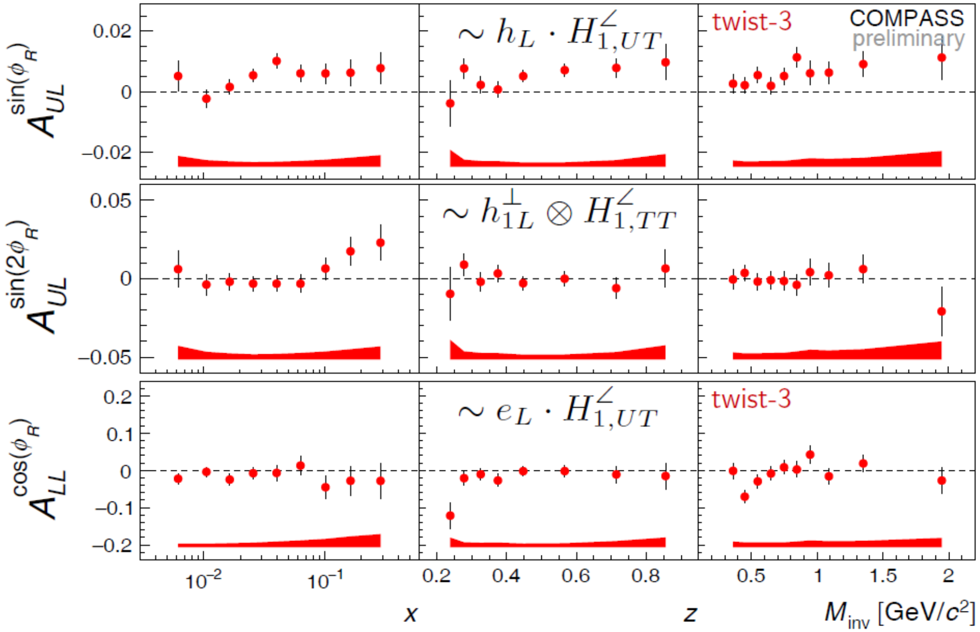
$$d\sigma_{LL} \propto \sqrt{1-\varepsilon^2}\,A_{LL}^{1}$$

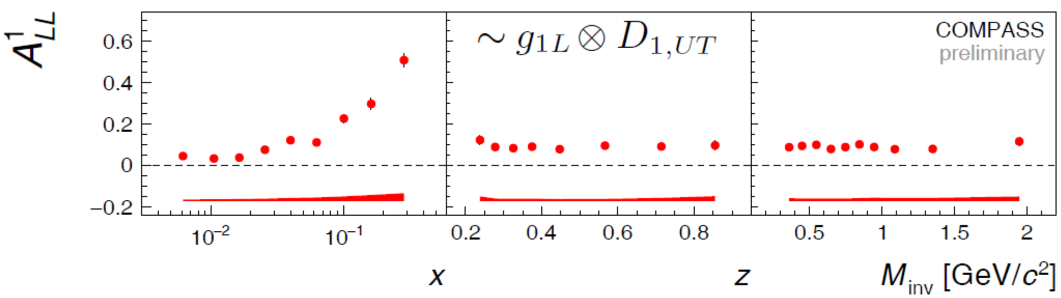
$$+\sqrt{2\varepsilon(1-\varepsilon)}\cos(\phi_R)\,A_{LL}^{\cos(\phi_R)} \sim Q^{-1}\left[e_L \cdot H_{1,UT}^{\angle} + g_1 \cdot D_{UT}^{\angle}\right]$$

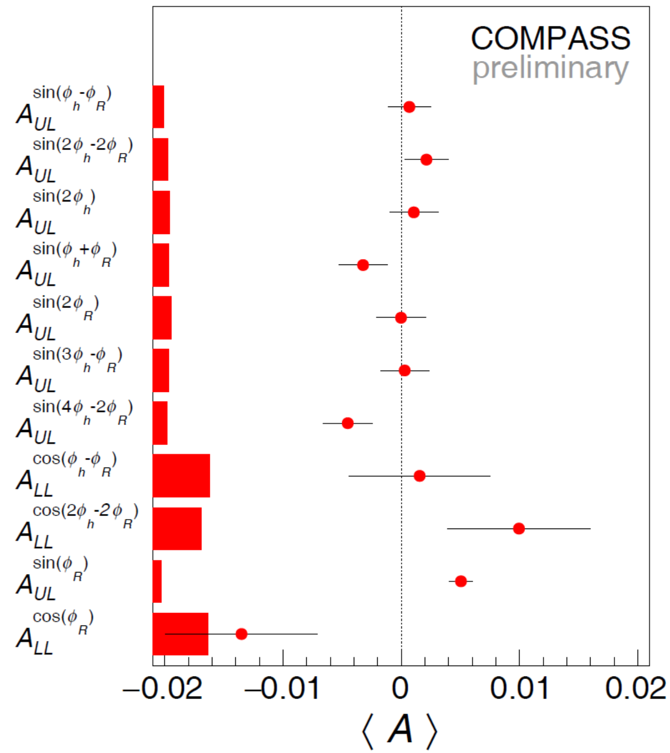
Selected results for di-hadron asymmetries

First shown at SPIN-2016, NEW!

COMPASS (NH_3) 2007+2011 data



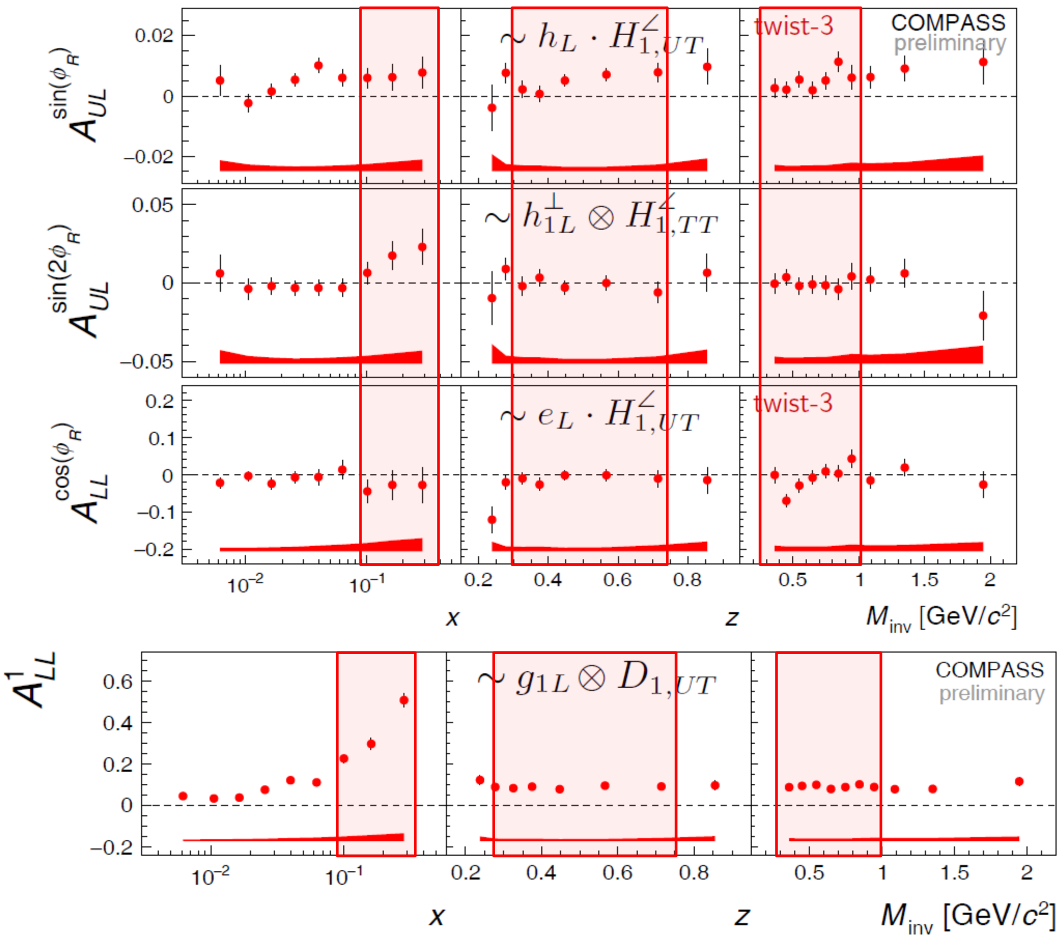




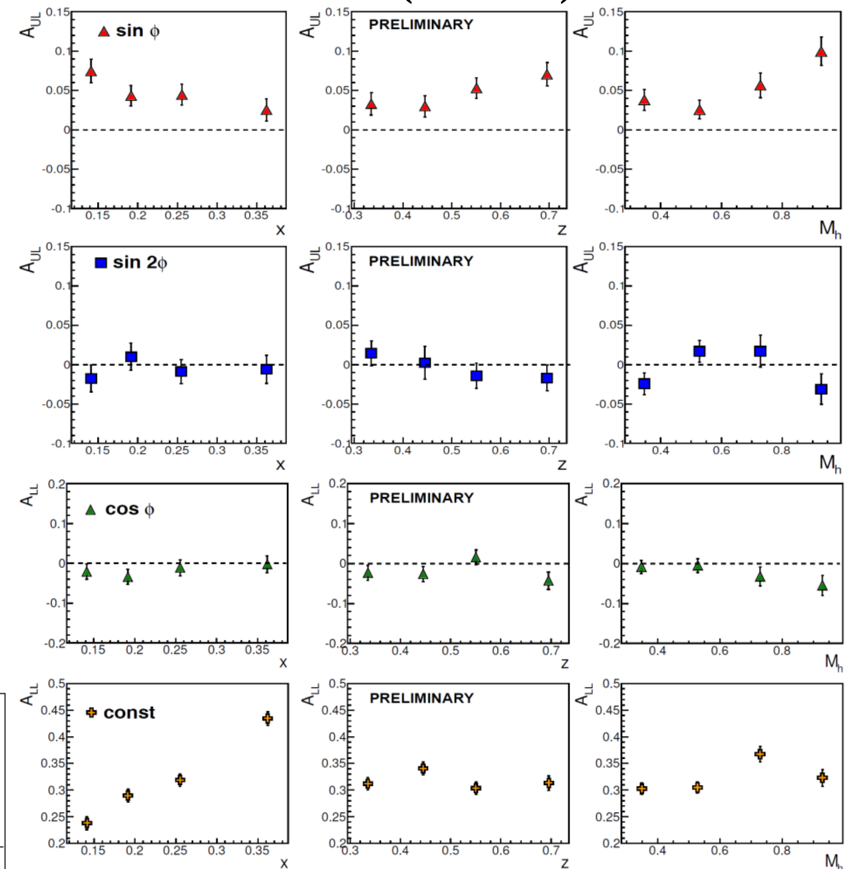
- Alternative way to access various twist-2/-3 distributions
- Non zero signal for $A_{UL}^{\sin\phi_R}$ and A_{LL}^{1}

Selected results for di-hadron asymmetries

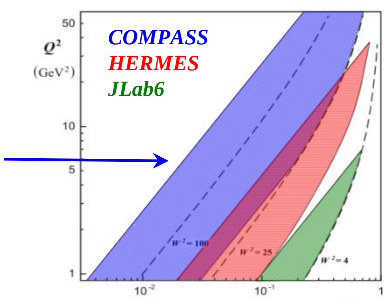
First shown at SPIN-2016, NEW!
COMPASS (NH_3) 2007+2011 data



CLAS 6 GeV (NH_3)
S. A. Pereira: PoS (DIS 2014) 231



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



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

http://iwhss17.to.infn.it

Announcement

The workshop occurs when a community of physicists is exploring high-energy particle physics opportunities for fixed-target experiments at CERN beyond 2020 (CERN Long Shutdown 2 2019-2020). These discussions already started with the "COMPASS beyond 2020" workshop in March 2016 and the "Physics Beyond Colliders" kick-off workshop organized by CERN in September 2016.

The physics discussed at the Workshop will mainly be related to the most recent results, open issues and short and long future programmes on Spectroscopy, Drell-Yan, DVCS and SIDIS, remaining open-minded to new possible programmes.

Physics topics:

- Longitudinal/Transverse Spin Structure of the Nucleon
- Fragmentation Functions
- Meson Spectroscopy
- Search for Glueballs, Hybrid Mesons and Multiquark States
- TMDs, GPDs and GTMDs
- New opportunities for physics beyond colliders
- Cosmic rays and accelerator physics

Date/place:

- April 2-5, 2017, Cortona, Italy