Six "beyond Collins & Sivers" transverse spin asymmetries at COMPASS

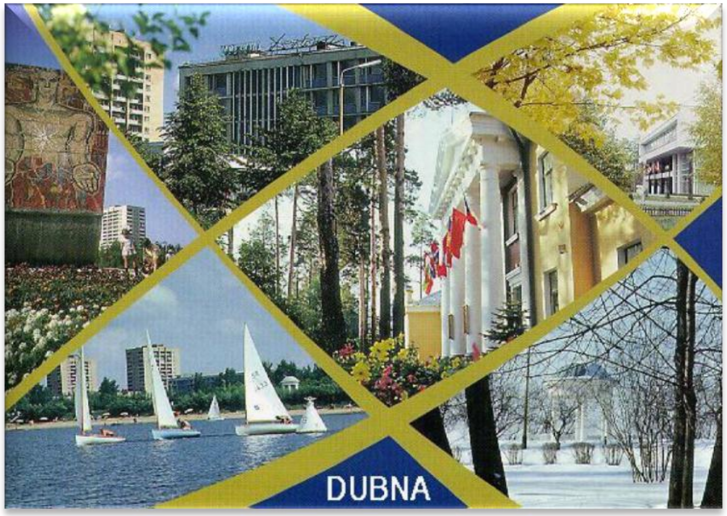
BAKUR PARSAMYAN

University of Turin and INFN section of Turin

on behalf of the COMPASS Collaboration

UNIVERSITÀ
DEGLI STUDI
DI TORINO

*ALMA UNIVERSITAS
TAURINENSIS*



The 20th INTERNATIONAL SYMPOSIUM
on Spin Physics (SPIN2012)
JINR, Dubna, Russia
September 17 - 22, 2012

Outline

- Introduction
- COMPASS experiment
- Measured asymmetries and theory expectations
  - Re-evaluation of $A_{LT}^{\cos\varphi_S}$ from the *lp* to $\gamma^* p$ cross-section
  - Theory expectations
- Summary

Outline

- Introduction
- COMPASS experiment
- Measured asymmetries and theory expectations
  - Re-evaluation of $A_{LT}^{\cos\varphi_S}$ from the *lp* to *γ*p* cross-section
  - Theory expectations
- Summary

SIDIS x-section

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

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

$$\Big\{ 1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\lambda\sin\varphi_h\times\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\varphi_h}+$$

$$S_L\left[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h A_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)A_{UL}^{\sin(2\phi_h)}\right]+$$

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

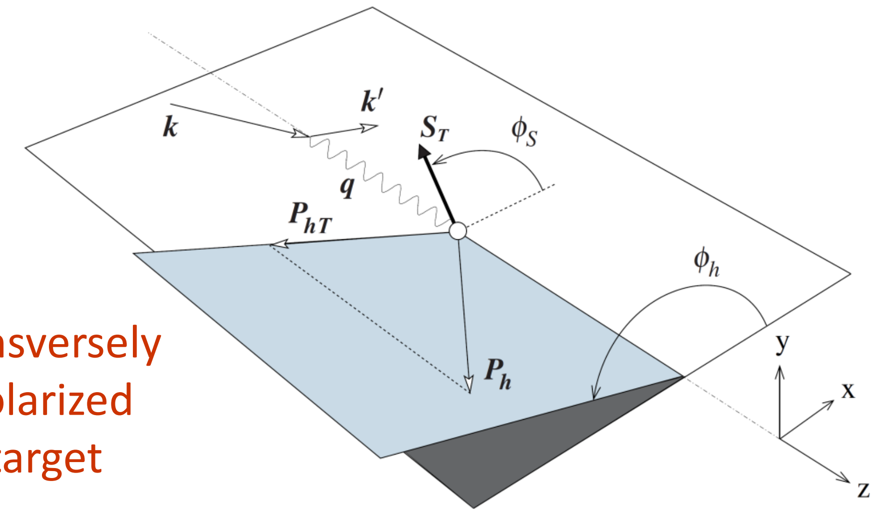
$$S_T\left[\begin{array}{l}\sin\varphi_S\times\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\varphi_S}\right)+\\ \sin(\varphi_h-\varphi_S)\times\left(A_{UT}^{\sin(\varphi_h-\varphi_S)}\right)+\\ \sin(\varphi_h+\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(\varphi_h+\varphi_S)}\right)+\\ \sin(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\varphi_h-\varphi_S)}\right)+\\ \sin(3\varphi_h-\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(3\varphi_h-\varphi_S)}\right)\end{array}\right]+$$

$$S_T\lambda\left[\begin{array}{l}\cos\varphi_S\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\varphi_S}\right)+\\ \cos(\varphi_h-\varphi_S)\times\left(\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\varphi_h-\varphi_S)}\right)+\\ \cos(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\varphi_h-\varphi_S)}\right)\end{array}\right]\Big\}$$

transversely polarized target

$$A_{U(L),T}^{w(\varphi_h,\varphi_s)} = \frac{F_{U(L),T}^{w(\varphi_h,\varphi_s)}}{F_{UU,T}+\varepsilon F_{UU,L}}$$

$$\varepsilon = \frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2},\quad \gamma=\frac{2Mx}{Q}$$



SIDIS x-section

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

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

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

← See talk by G. Sbrizzai

← See talk by E. Zemlyanichkina

Sivers & Collins

← Presetned by A. Martin

Twist-2

SSA

DSA

SIDIS x-section

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

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

$$\Bigg\{ 1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\lambda\sin\varphi_h\times\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\varphi_h}+$$

$$S_L\left[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h A_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)A_{UL}^{\sin(2\phi_h)}\right]+$$

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

$$S_T\left[\begin{array}{l}\sin\varphi_S\times\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\varphi_S}\right)+\\ \sin(\varphi_h-\varphi_S)\times\left(A_{UT}^{\sin(\varphi_h-\varphi_S)}\right)+\\ \sin(\varphi_h+\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(\varphi_h+\varphi_S)}\right)+\\ \sin(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\varphi_h-\varphi_S)}\right)+\\ \sin(3\varphi_h-\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(3\varphi_h-\varphi_S)}\right)\end{array}\right]+$$

$$S_T\lambda\left[\begin{array}{l}\cos\varphi_S\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\varphi_S}\right)+\\ \cos(\varphi_h-\varphi_S)\times\left(\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\varphi_h-\varphi_S)}\right)+\\ \cos(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\varphi_h-\varphi_S)}\right)\end{array}\right]\Bigg\}$$

Sivers & Collins

Pretzelosity

Worm-gear

SSA

DSA

Twist-2

SIDIS x-section

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

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

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

Sivers & Collins

Pretzelosity

Worm-gear

Higher twists

SSA

DSA

Twist-2

Twist-3

SIDIS x-section

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

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

$$\Big\{ 1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}\,A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\lambda\sin\varphi_h\times\sqrt{2\varepsilon(1-\varepsilon)}\,A_{LU}^{\sin\varphi_h}+$$

$$S_L\left[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h A_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)A_{UL}^{\sin(2\phi_h)}\right]+$$

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

$$S_T\left[\begin{array}{l}\sin\varphi_S\times\left(\sqrt{2\varepsilon(1+\varepsilon)}\,A_{UT}^{\sin\varphi_S}\right)+\\ \sin(\varphi_h-\varphi_S)\times\left(A_{UT}^{\sin(\varphi_h-\varphi_S)}\right)+\\ \sin(\varphi_h+\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(\varphi_h+\varphi_S)}\right)+\\ \sin(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1+\varepsilon)}\,A_{UT}^{\sin(2\varphi_h-\varphi_S)}\right)+\\ \sin(3\varphi_h-\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(3\varphi_h-\varphi_S)}\right)\end{array}\right]+$$

$$S_T\lambda\left[\begin{array}{l}\cos\varphi_S\times\left(\sqrt{2\varepsilon(1-\varepsilon)}\,A_{LT}^{\cos\varphi_S}\right)+\\ \cos(\varphi_h-\varphi_S)\times\left(\sqrt{(1-\varepsilon^2)}\,A_{LT}^{\cos(\varphi_h-\varphi_S)}\right)+\\ \cos(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1-\varepsilon)}\,A_{LT}^{\cos(2\varphi_h-\varphi_S)}\right)\end{array}\right]\Big\}$$

Sivers & Collins

Pretzelosity

Worm-gear

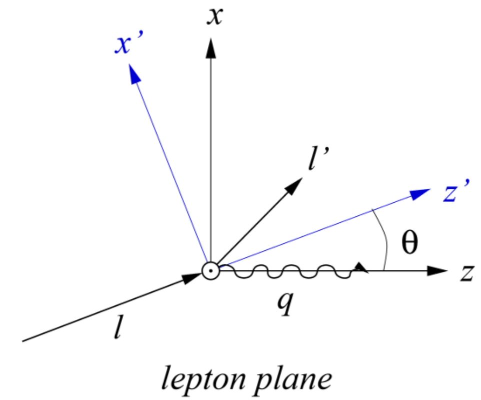
Higher twists

SSA

DSA

Twist-2

Twist-3



SIDIS x-section: from *lp* to *γ*p* (P_L=0)

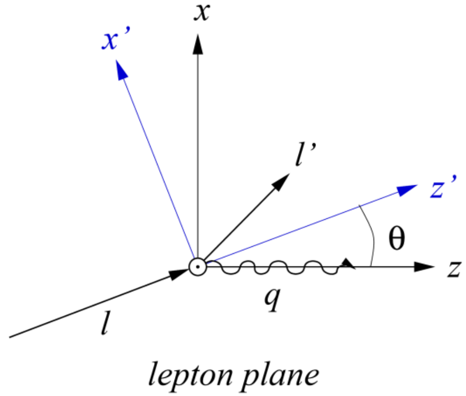
Kotzinian et al.
hep-ph/9808368 (1998)
hep-ph/9908466 (1999)
M. Diehl and S. Sapeta,
Eur. Phys. J. C 41 (2005) 515

$$\frac{d\sigma}{dx\,dy\,dz\,dP_{hT}^2\,d\varphi_h\,d\varphi_S}=\left[\frac{\cos\theta}{1-\sin^2\theta\sin^2\varphi_S}\right]\times\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\Bigg[1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\lambda\sin\varphi_h\times\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\varphi_h}+$$

$$\frac{P_T}{\sqrt{1-\sin^2\theta\sin^2\varphi_S}}\left[\begin{array}{l}\sin\varphi_S\times\left(\cos\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\varphi_S}\right)+\\ \sin(\varphi_h-\varphi_S)\times\left(\cos\theta A_{UT}^{\sin(\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\varphi_h}\right)+\\ \sin(\varphi_h+\varphi_S)\times\left(\cos\theta\varepsilon A_{UT}^{\sin(\varphi_h+\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\varphi_h}\right)+\\ \sin(2\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\varepsilon A_{UL}^{\sin 2\varphi_h}\right)+\\ \sin(2\varphi_h+\varphi_S)\times\left(\frac{1}{2}\sin\theta\varepsilon A_{UL}^{\sin 2\varphi_h}\right)+\\ \sin(3\varphi_h-\varphi_S)\times\left(\cos\theta\varepsilon A_{UT}^{\sin(3\varphi_h-\varphi_S)}\right)\end{array}\right]+$$

$$\frac{P_T\lambda}{\sqrt{1-\sin^2\theta\sin^2\varphi_S}}\left[\begin{array}{l}\cos\varphi_S\times\left(\cos\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\varphi_S}+\sin\theta\sqrt{(1-\varepsilon^2)}A_{LL}\right)+\\ \cos(\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\varphi_h}\right)+\\ \cos(\varphi_h+\varphi_S)\times\left(\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\varphi_h}\right)+\\ \cos(2\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\varphi_h-\varphi_S)}\right)\end{array}\right]\Bigg]$$

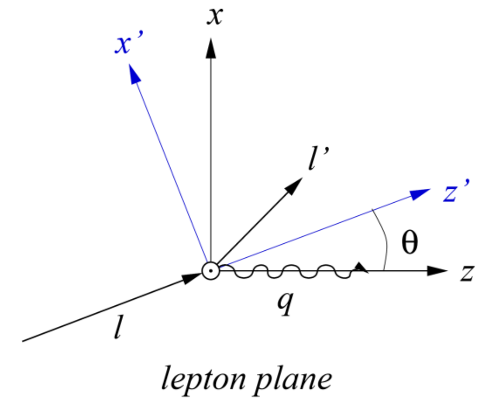


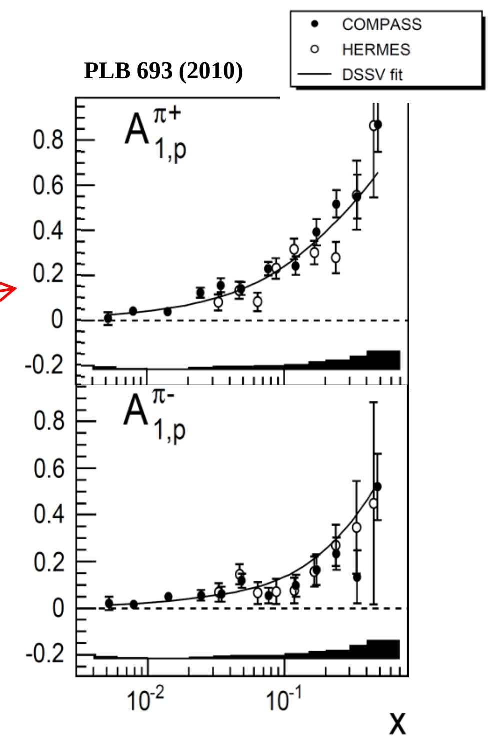
SIDIS x-section: from *lp* to *γ*p* ($P_L=0$)

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

$$\frac{d\sigma}{dx\,dy\,dz\,dP_{hT}^2\,d\varphi_h\,d\varphi_S} = \left[\frac{\cos\theta}{1-\sin^2\theta\sin^2\varphi_S}\right]\times\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\begin{aligned}
\Bigg[\, & 1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\lambda\sin\varphi_h\times\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\varphi_h}+ \\
& \frac{P_T}{\sqrt{1-\sin^2\theta\sin^2\varphi_S}}\Bigg[\sin\varphi_S\times\left(\cos\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\varphi_S}\right)+ \\
& \quad \sin(\varphi_h-\varphi_S)\times\left(\cos\theta A_{UT}^{\sin(\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\varphi_h}\right)+ \\
& \quad \sin(\varphi_h+\varphi_S)\times\left(\cos\theta\varepsilon A_{UT}^{\sin(\varphi_h+\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\varphi_h}\right)+ \\
& \quad \sin(2\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\varepsilon A_{UL}^{\sin 2\varphi_h}\right)+ \\
& \quad \sin(2\varphi_h+\varphi_S)\times\left(\frac{1}{2}\sin\theta\varepsilon A_{UL}^{\sin 2\varphi_h}\right)+ \\
& \quad \sin(3\varphi_h-\varphi_S)\times\left(\cos\theta\varepsilon A_{UT}^{\sin(3\varphi_h-\varphi_S)}\right)\Bigg]+ \\
& \frac{P_T\lambda}{\sqrt{1-\sin^2\theta\sin^2\varphi_S}}\Bigg[\cos\varphi_S\times\left(\cos\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\varphi_S}+\sin\theta\sqrt{(1-\varepsilon^2)}A_{LL}\right)+ \\
& \quad \cos(\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\varphi_h}\right)+ \\
& \quad \cos(\varphi_h+\varphi_S)\times\left(\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\varphi_h}\right)+ \\
& \quad \cos(2\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\varphi_h-\varphi_S)}\right)\Bigg]\,\Bigg]
\end{aligned}$$

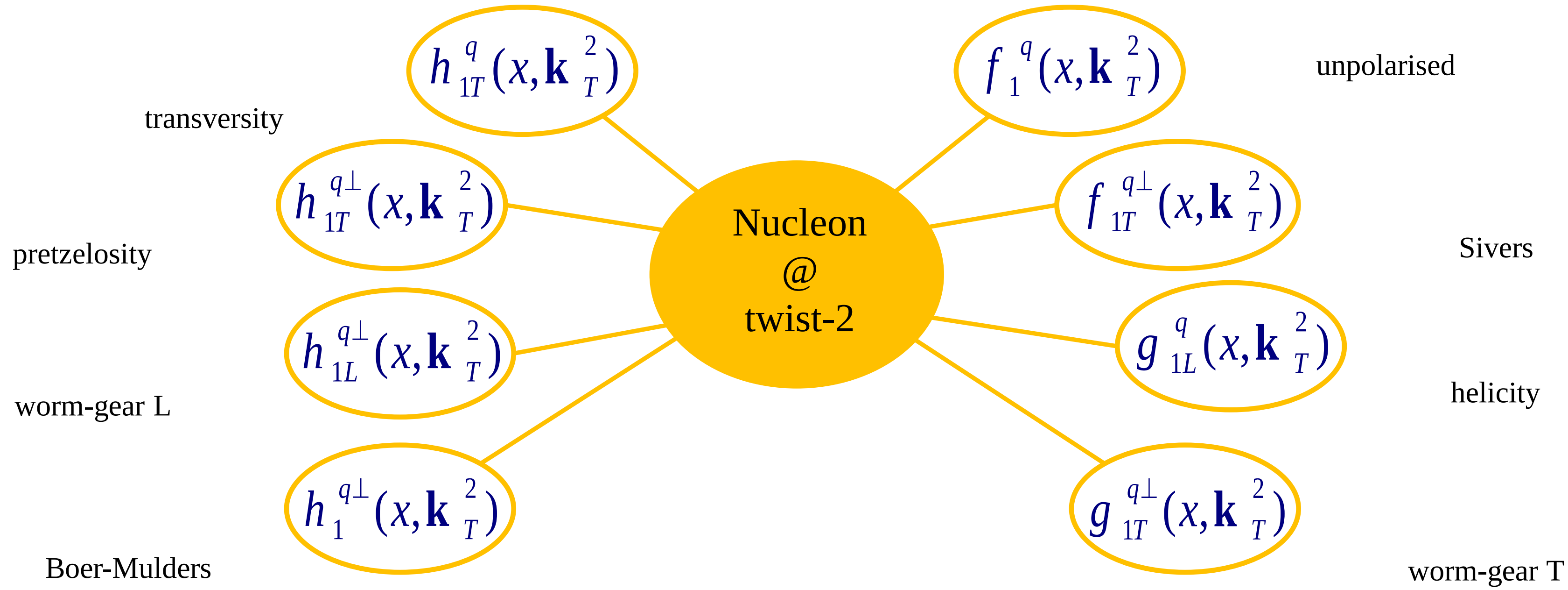


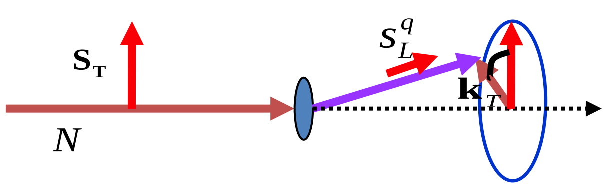


TMD parton distribution functions

Collins, Soper (81,82); Ji, Ma, Yuan (03, 04); Collins, Metz (04) – Definition of TMD DF's and FF's & QCD factorization of SIDIS.

LO QCD = Simple parton model + Factorized twist-2 PDF & FF



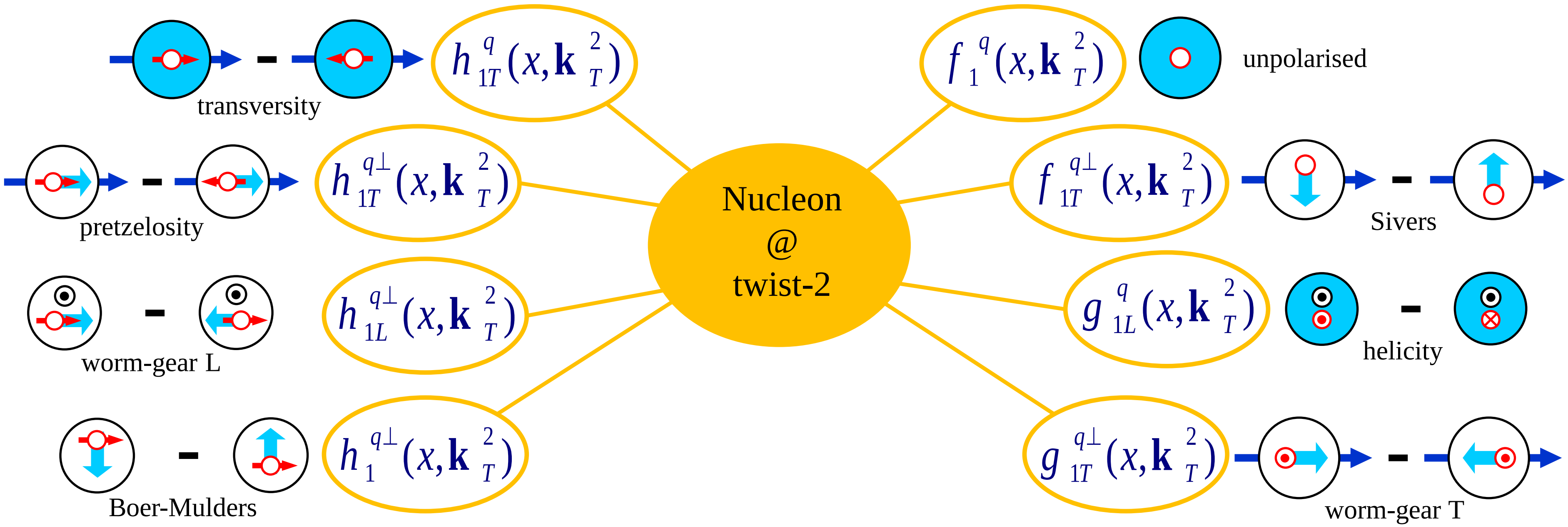


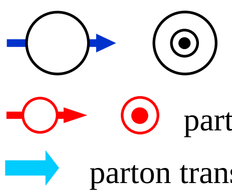
$\mathbf{k}_T$ – intrinsic transverse momentum of the quark

TMD parton distribution functions

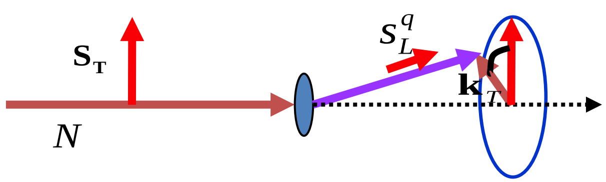
Collins, Soper (81,82); Ji, Ma, Yuan (03, 04); Collins, Metz (04) – Definition of TMD DF's and FF's & QCD factorization of SIDIS.

LO QCD = Simple parton model + Factorized twist-2 PDF & FF





Proton goes out of the screen. Photon goes into the screen



$\mathbf{k}_T$ – intrinsic transverse momentum of the quark

Interpretation of the transverse asymmetries

Within QCD parton model $A_i \propto DF \otimes FF \quad (i = 1,..8)$

Twist-2:

$$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^q \otimes H_{1q}^{\perp h}$$

$$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^h$$

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

$$A_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^q \otimes D_{1q}^h$$

single spin

double spin

Twist-2 + k_T/Q kinematical corrections:

$$A_{UT}^{\sin(\phi_s)} \propto \frac{M}{Q}\left(h_1^q \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^h\right)$$

$$A_{UT}^{\sin(2\phi_h-\phi_s)} \propto \frac{M}{Q}\left(h_{1T}^{\perp q} \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^h\right)$$

$$A_{LT}^{\cos(\phi_s)} \propto \frac{M}{Q} g_{1T}^q \otimes D_{1q}^h$$

$$A_{LT}^{\cos(2\phi_h-\phi_s)} \propto \frac{M}{Q} g_{1T}^q \otimes D_{1q}^h$$

From "raw" to physics asymmetries

$$A_{UT}^{w(\phi_h,\phi_s)} = \frac{A_{UT,raw}^{w(\phi_h,\phi_s)}}{D^{w(\phi_h,\phi_s)}(y)\, f\, |P_T|},\ A_{LT}^{w(\phi_h,\phi_s)} = \frac{A_{LT,raw}^{w(\phi_h,\phi_s)}}{D^{w(\phi_h,\phi_s)}(y)\, f P_{beam}\, |P_T|}$$

$$D^{\sin(\phi_h-\phi_S)}(y) = 1$$

$$D^{\sin(\phi_h+\phi_S)}(y) = D^{\sin(3\phi_h-\phi_S)}(y) = \varepsilon \approx \frac{2(1-y)}{1+(1-y)^2}$$

$$\varepsilon = \frac{1-y-\frac{1}{4}\gamma^2 y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2 y^2}, \quad \gamma = \frac{2Mx}{Q}$$

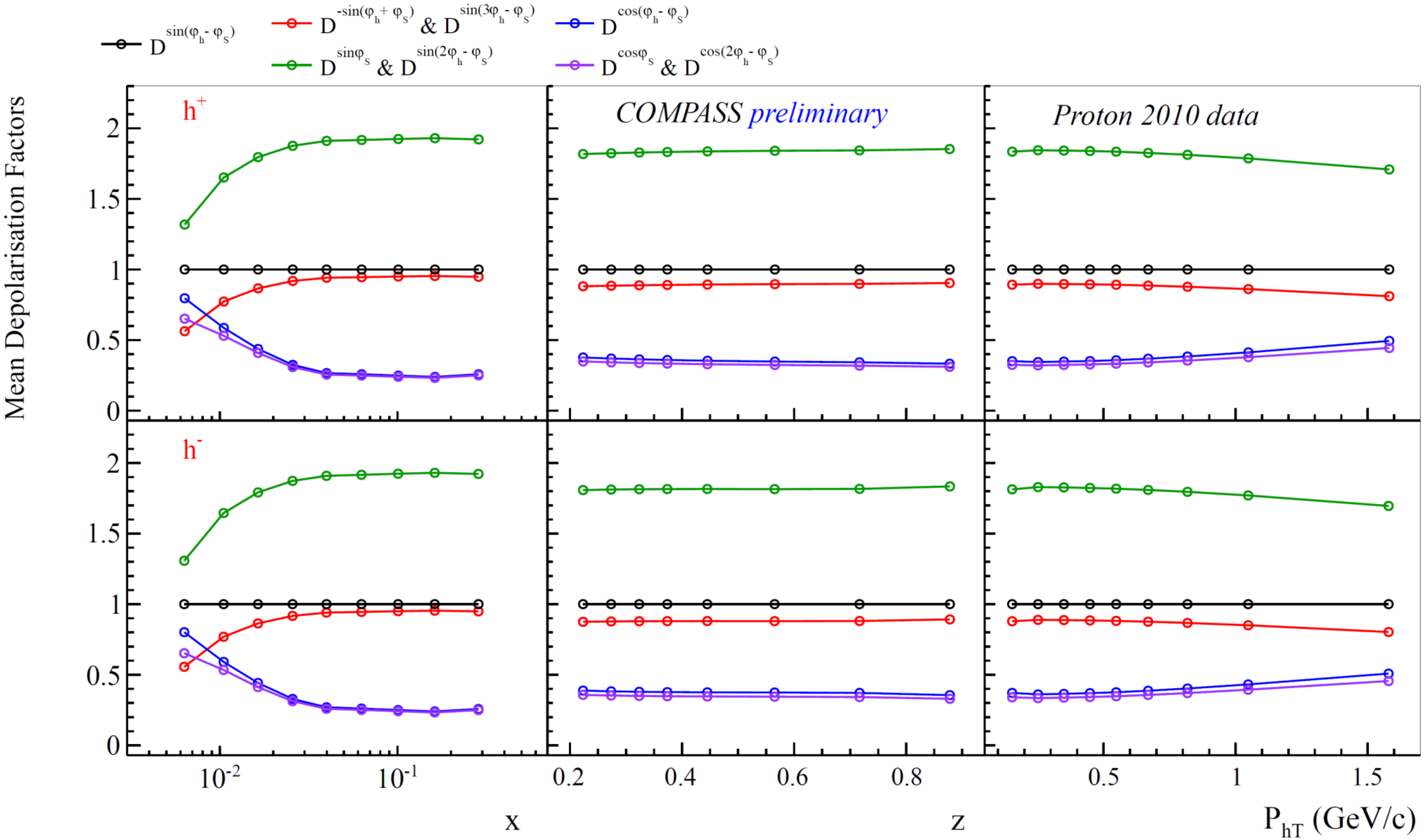
$$D^{\sin(2\phi_h-\phi_S)}(y) = D^{\sin(\phi_S)}(y) = \sqrt{2\varepsilon\left(1+\varepsilon\right)} \approx \frac{2(2-y)\sqrt{1-y}}{1+(1-y)^2}$$

$$D^{\cos(2\phi_h-\phi_S)}(y) = D^{\cos(\phi_S)}(y) = \sqrt{2\varepsilon\left(1-\varepsilon\right)} \approx \frac{2y\sqrt{1-y}}{1+(1-y)^2}$$

$$D^{\cos(\phi_h-\phi_S)}(y) = \sqrt{\left(1-\varepsilon^2\right)} \approx \frac{y(2-y)}{1+(1-y)^2}$$

$D^{w_i(\phi_h,\phi_s)}$ – Depolarization factor, f - target dilution factor, P_T - target polarization, P_{beam} - beam polarization

Mean Depolarization Factors



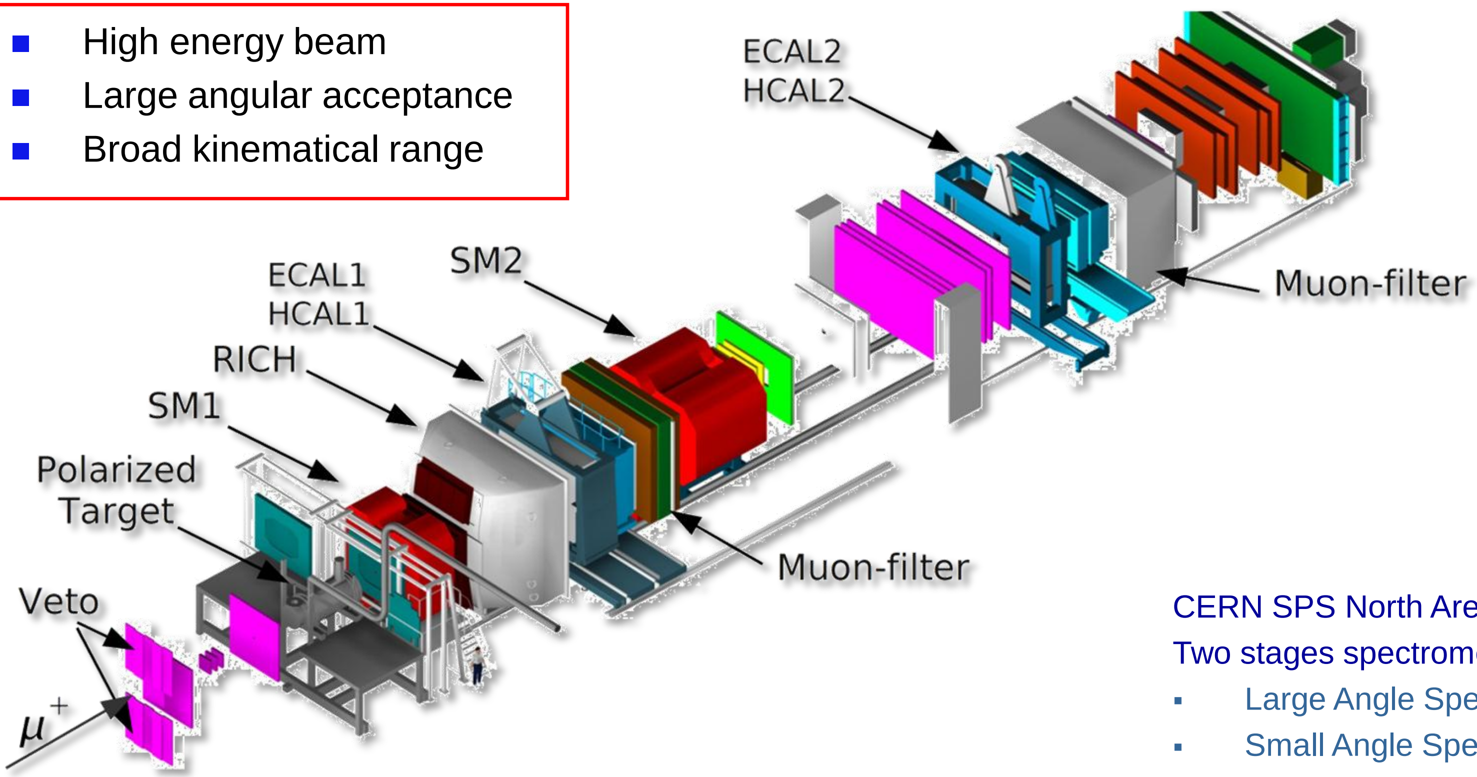
Outline

- Introduction
- COMPASS experiment
- Measured asymmetries and theory expectations
  - Re-evaluation of $A_{LT}^{\cos\varphi_S}$ from the *lp* to $\gamma^* p$ cross-section
  - Theory expectations
- Summary

COMPASS experimental setup

COmmon Muon Proton Apparatus for Structure and Spectroscopy

- High energy beam
- Large angular acceptance
- Broad kinematical range



CERN SPS North Area.

Two stages spectrometer

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

Hadron & Muon high energy beams.

Beam rates: 10^8 muons/s, $5 \cdot 10^7$ hadrons/s.

Longitudinally polarized μ^+ beam (160 Gev/c).

Longitudinally or Transversely polarized ^{6}LiD or NH_3 target

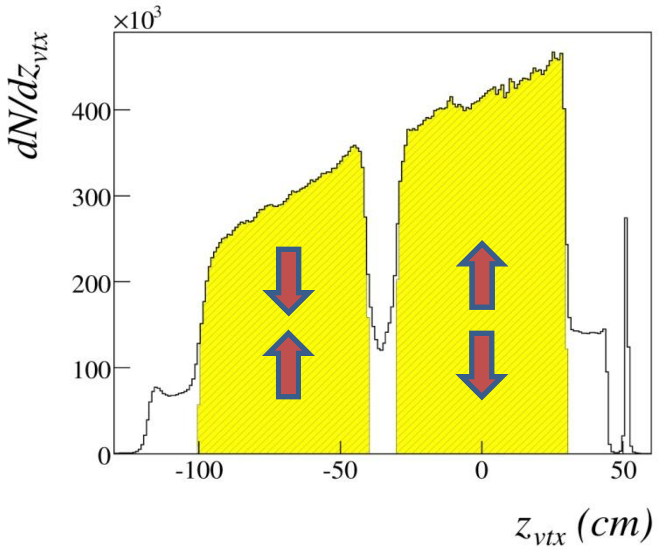
Momentum, tracking and calorimetric measurements, PID

COMPASS Polarized target system

solid state target operated in frozen spin mode

Years 2002-2004

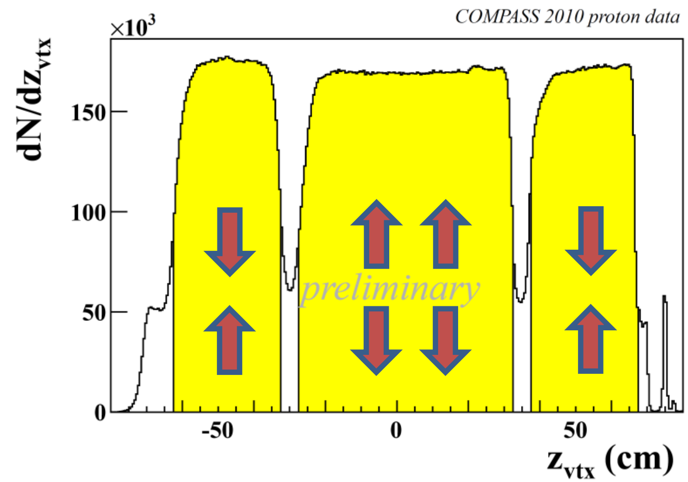
Deuteron - ^{6}LiD:
- Two 60 cm long ^{6}LiD cells with opposite polarization
- Polar angle acceptance – 70 mrad
- Target Polarization ±50%
- dilution factor f = 0.38



Data is collected simultaneously for the two target spin orientations
Polarization reversal after each ~4-5 days

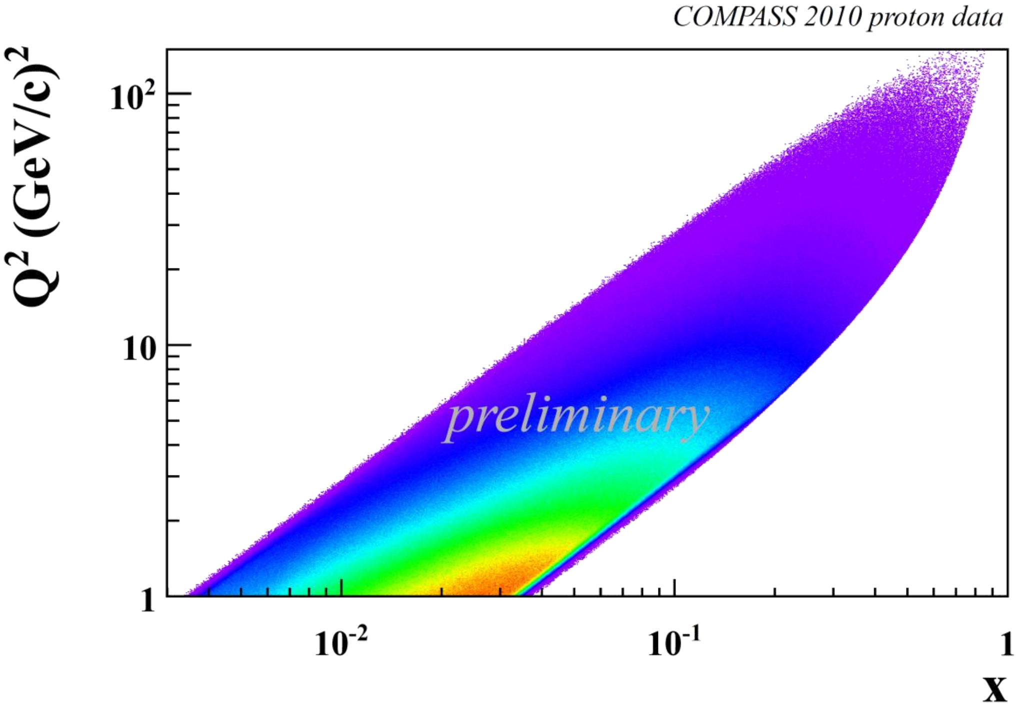
Years 2007 and 2010

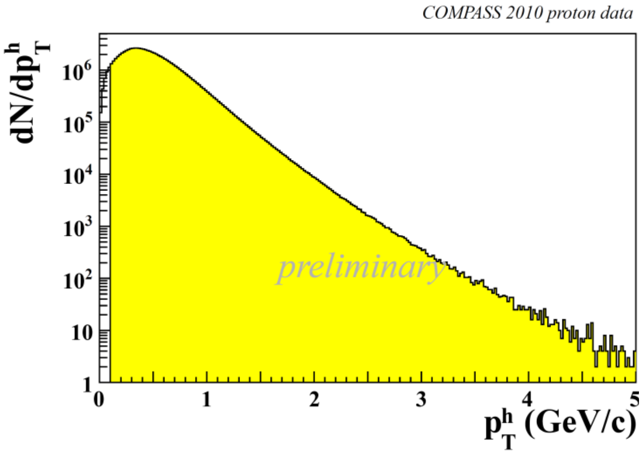
Proton - NH_3:
- Three cells system (30 cm,60cm, 30cm)
- Polar angle acceptance – 180 mrad (new magnet in 2006)
- Target Polarization ±90%
- dilution factor f = 0.14

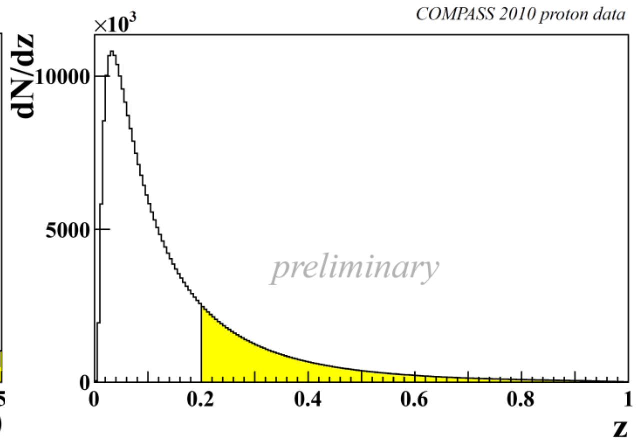


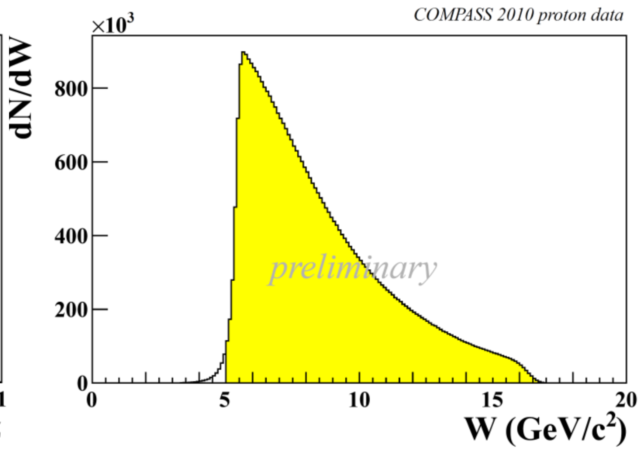
Data selection

- DIS cuts :
  - $Q^2 > 1\ GeV^2$
  - $0.1 < y < 0.9$
  - $W > 5$ GeV
- Hadron cuts :
  - $z > 0.2$
  - $P_{hT} > 0.1$ GeV/c





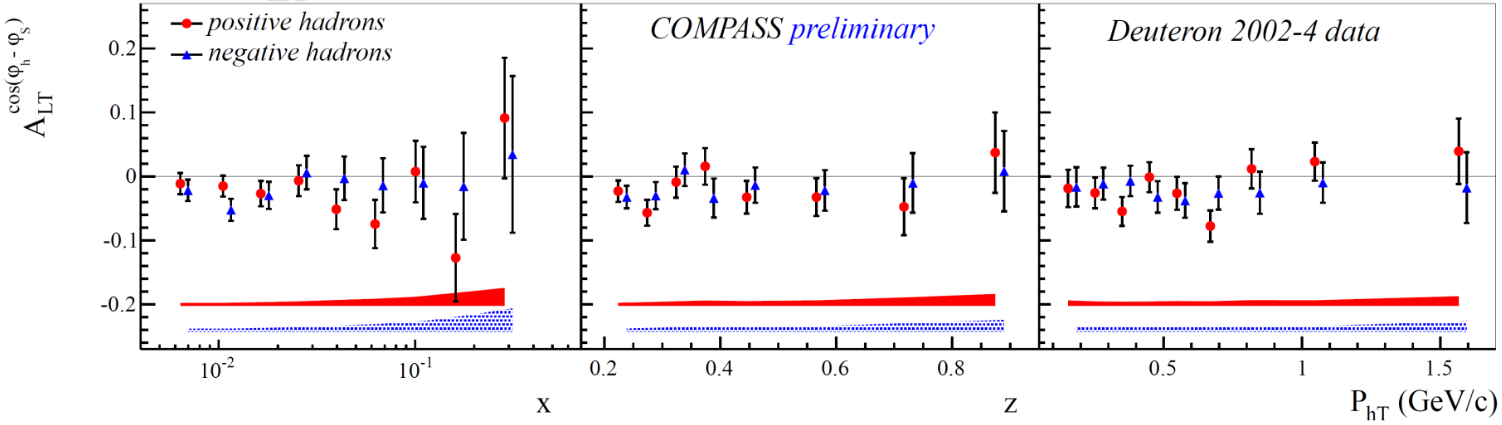


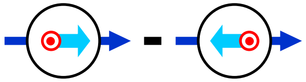


Outline

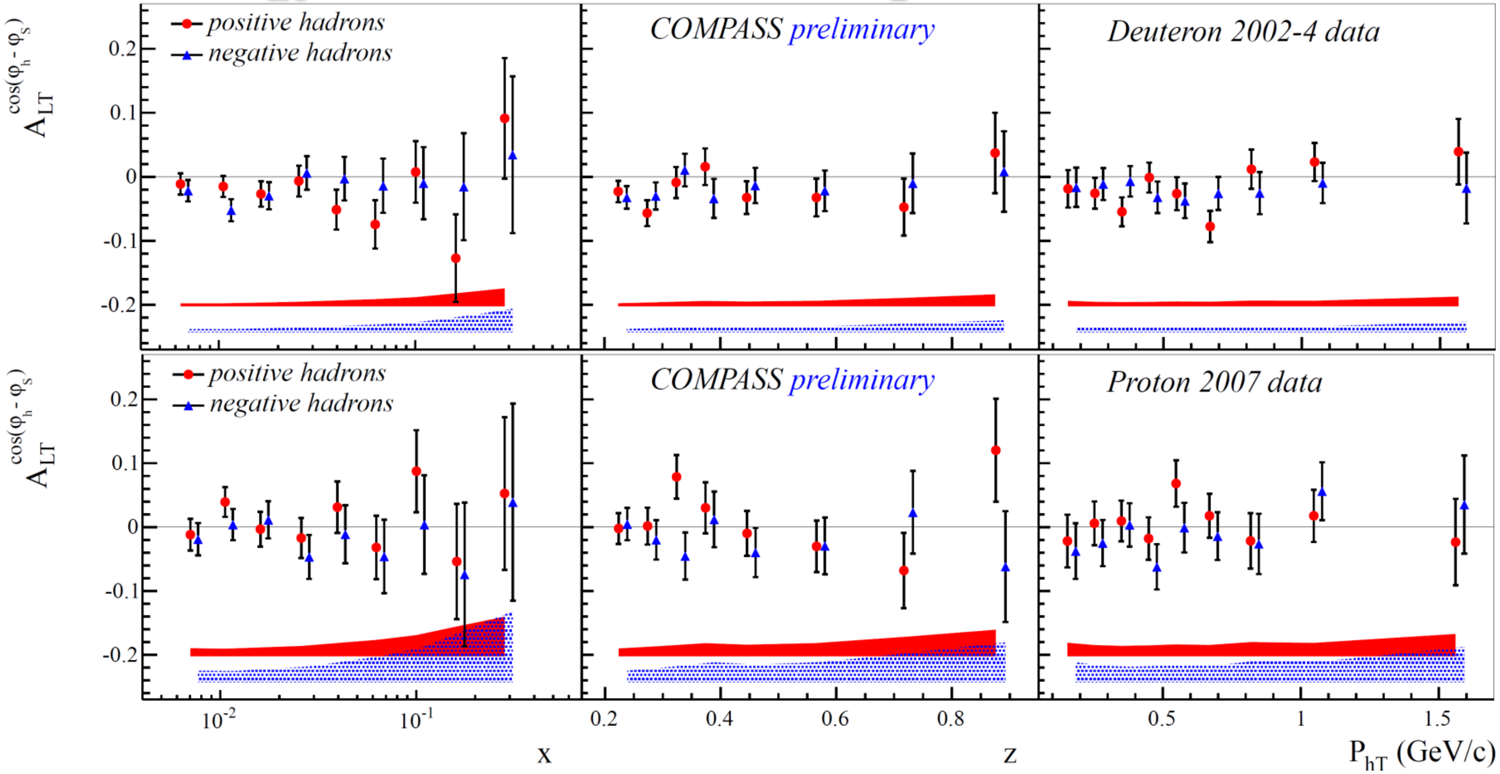
- Introduction
- COMPASS experiment
- **Measured asymmetries and theory expectations**
  - Re-evaluation of $A_{LT}^{\cos\varphi_S}$ from the *lp* to *γ*p* cross-section
  - Theory expectations
- Summary

Results for $A_{LT}^{cos(\varphi_h-\varphi_S)}$ deuteron



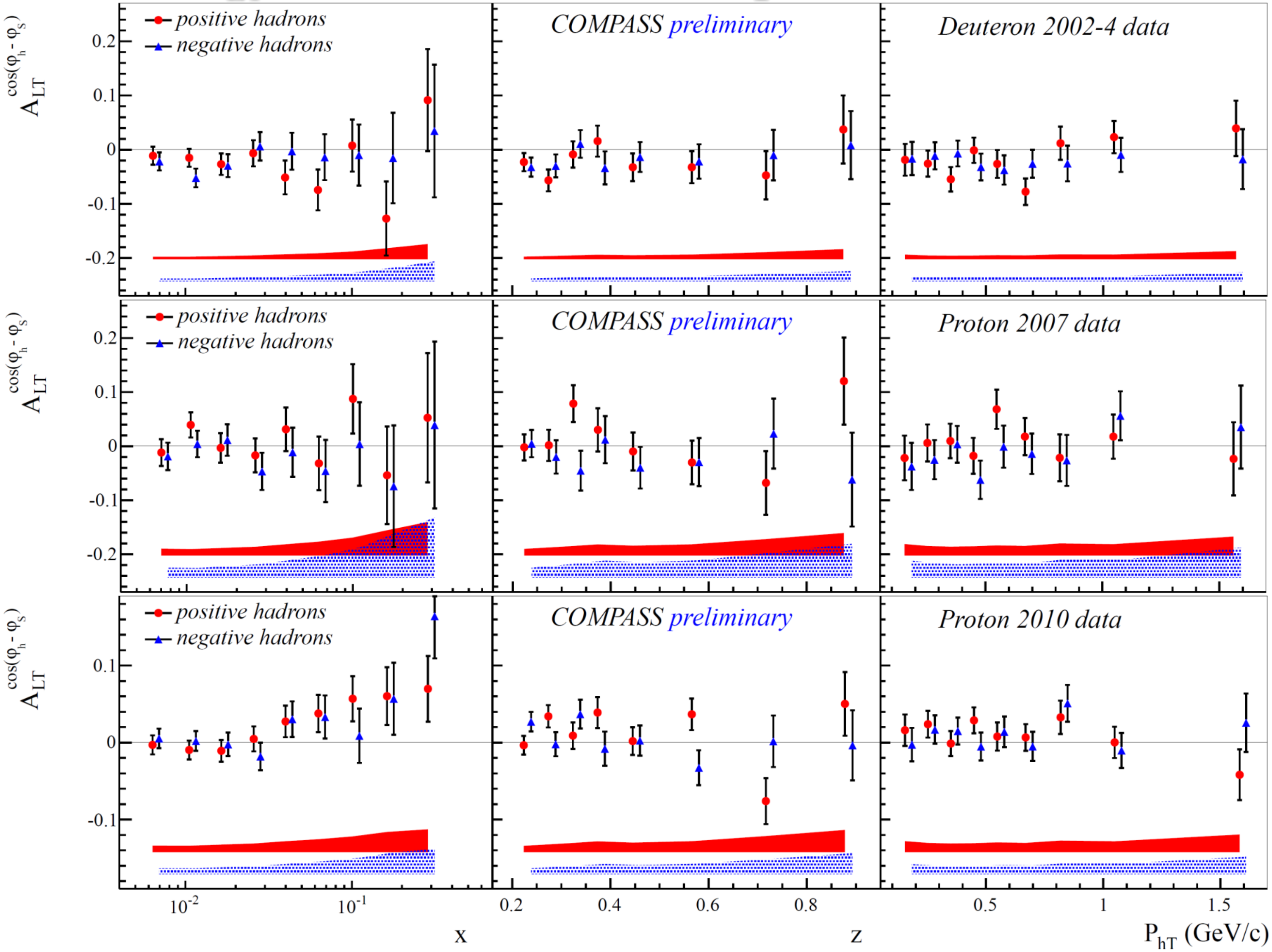
$A_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^q \otimes D_{1q}^h$, "Worm Gear" PDF g_{1T}^q : 

Results for $A_{LT}^{cos(\varphi_h-\varphi_S)}$ deuteron & proton 2007

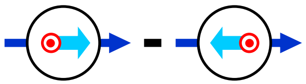


$A_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^{q} \otimes D_{1q}^{h}$, "Worm Gear" PDF g_{1T}^{q} :

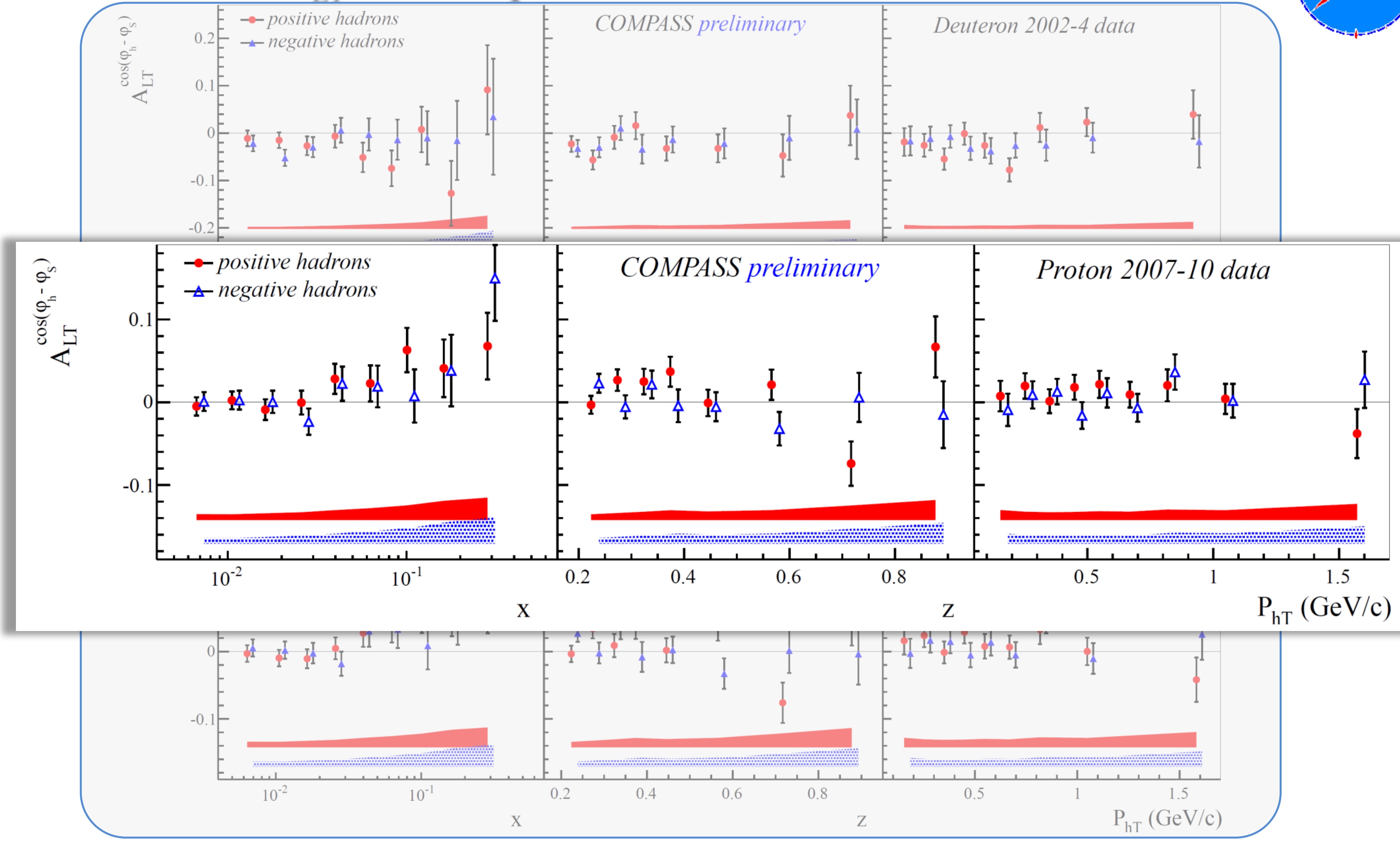
Results for $A_{LT}^{\cos(\varphi_h - \varphi_S)}$ deuteron & proton



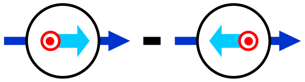
$A_{LT}^{\cos(\phi_h - \phi_s)} \propto g_{1T}^{q} \otimes D_{1q}^{h}$, "Worm Gear" PDF g_{1T}^{q} :



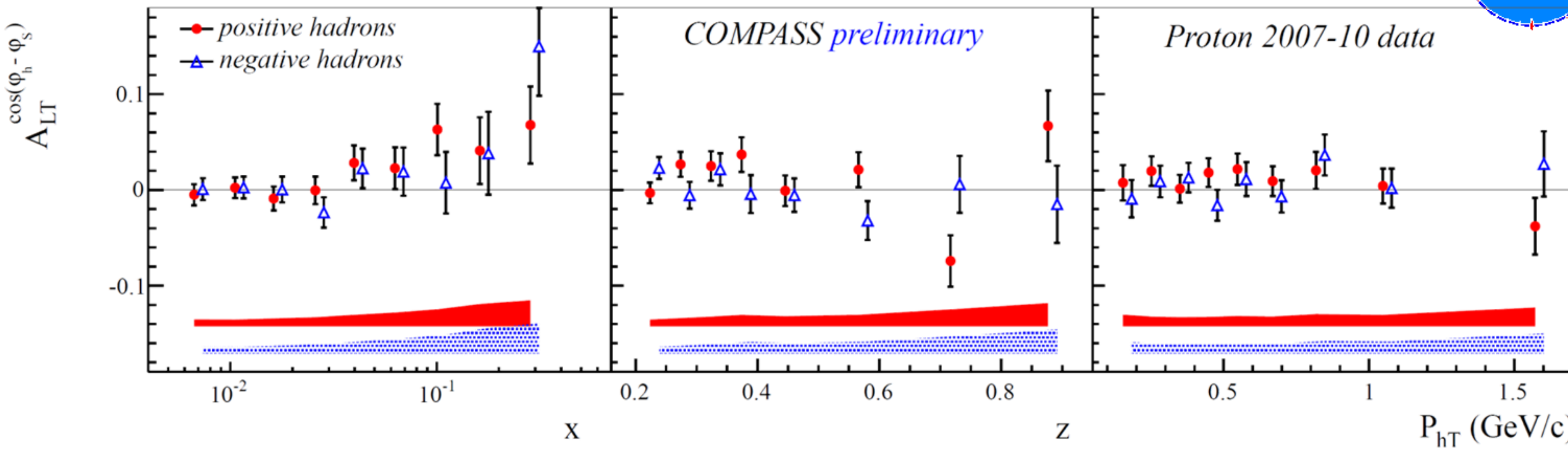
Results for $A_{LT}^{\cos(\varphi_h-\varphi_S)}$ proton 2007-2010

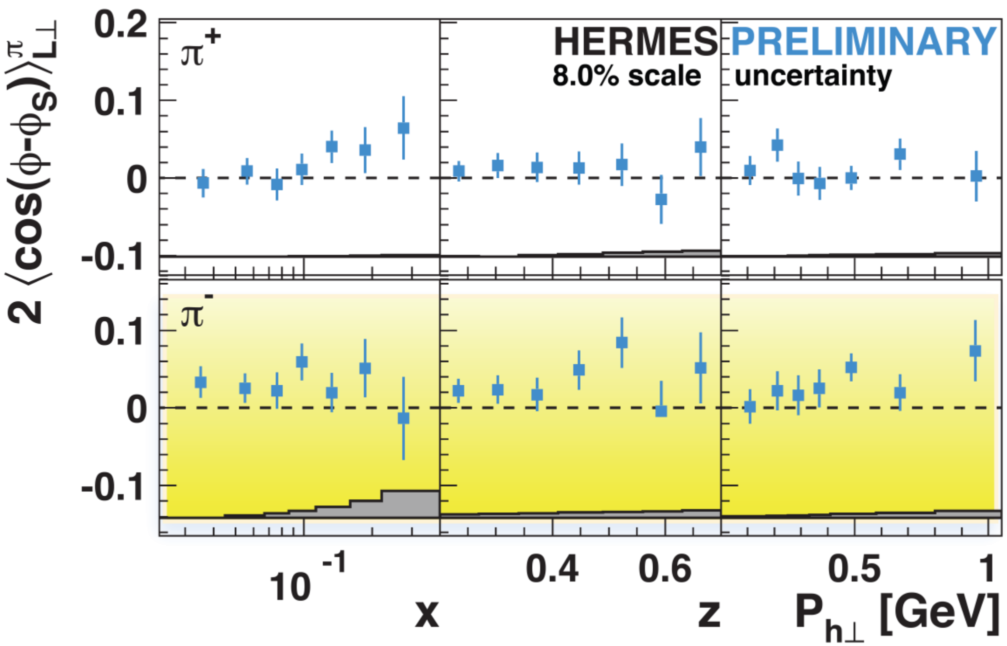


$A_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^q \otimes D_{1q}^h$, "Worm Gear" PDF g_{1T}^q :



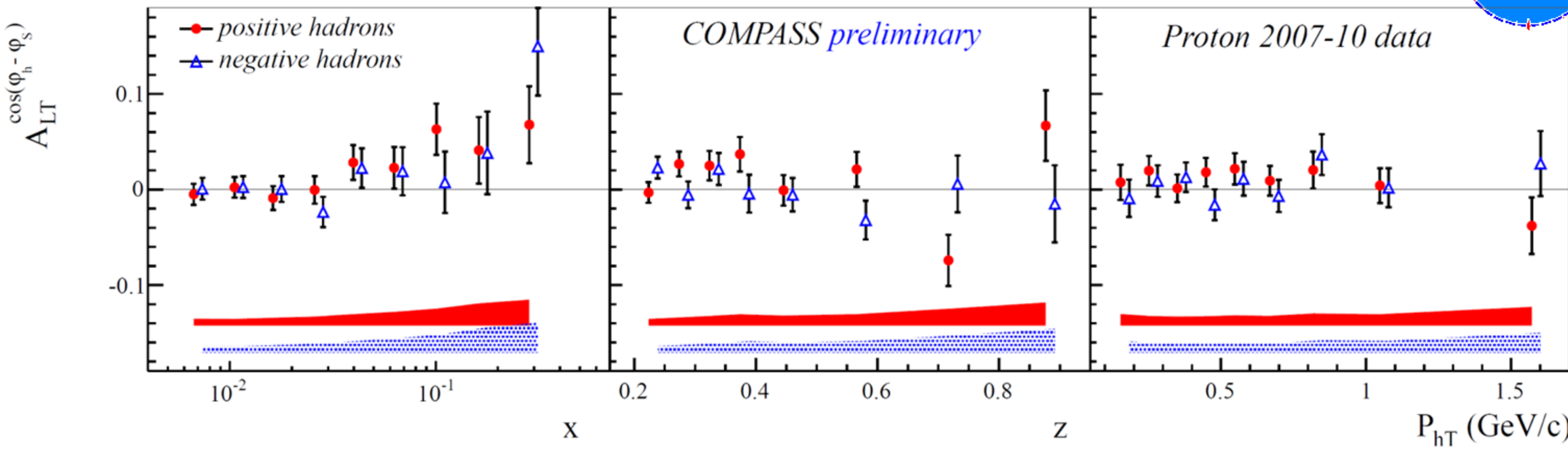
Results for $A_{LT}^{\cos(\varphi_h-\varphi_S)}$ COMPASS - HERMES



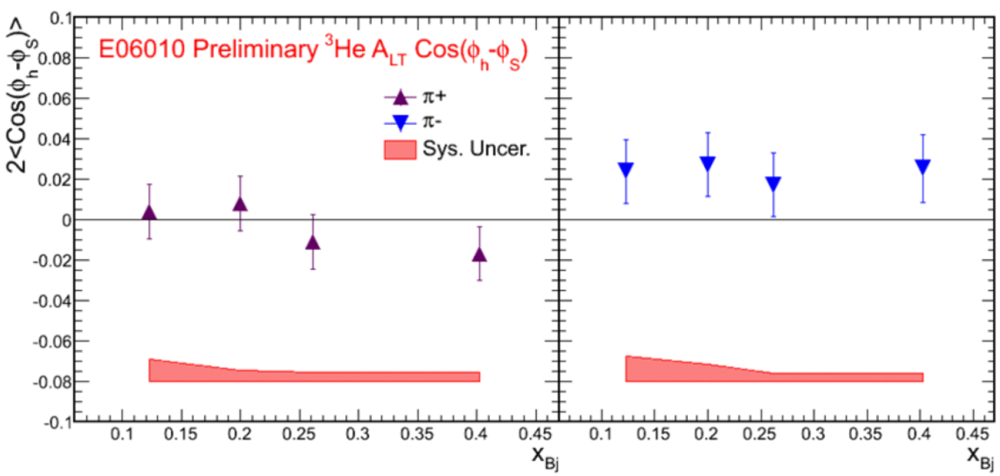


Similar trend for $A_{LT}^{\cos(\varphi_h-\varphi_S)}$ asymmetry is present in HERMES preliminary results.

Results for $A_{LT}^{\cos(\varphi_h-\varphi_S)}$ COMPASS - JLab



^{3}He double-spin asymmetry A_{LT}

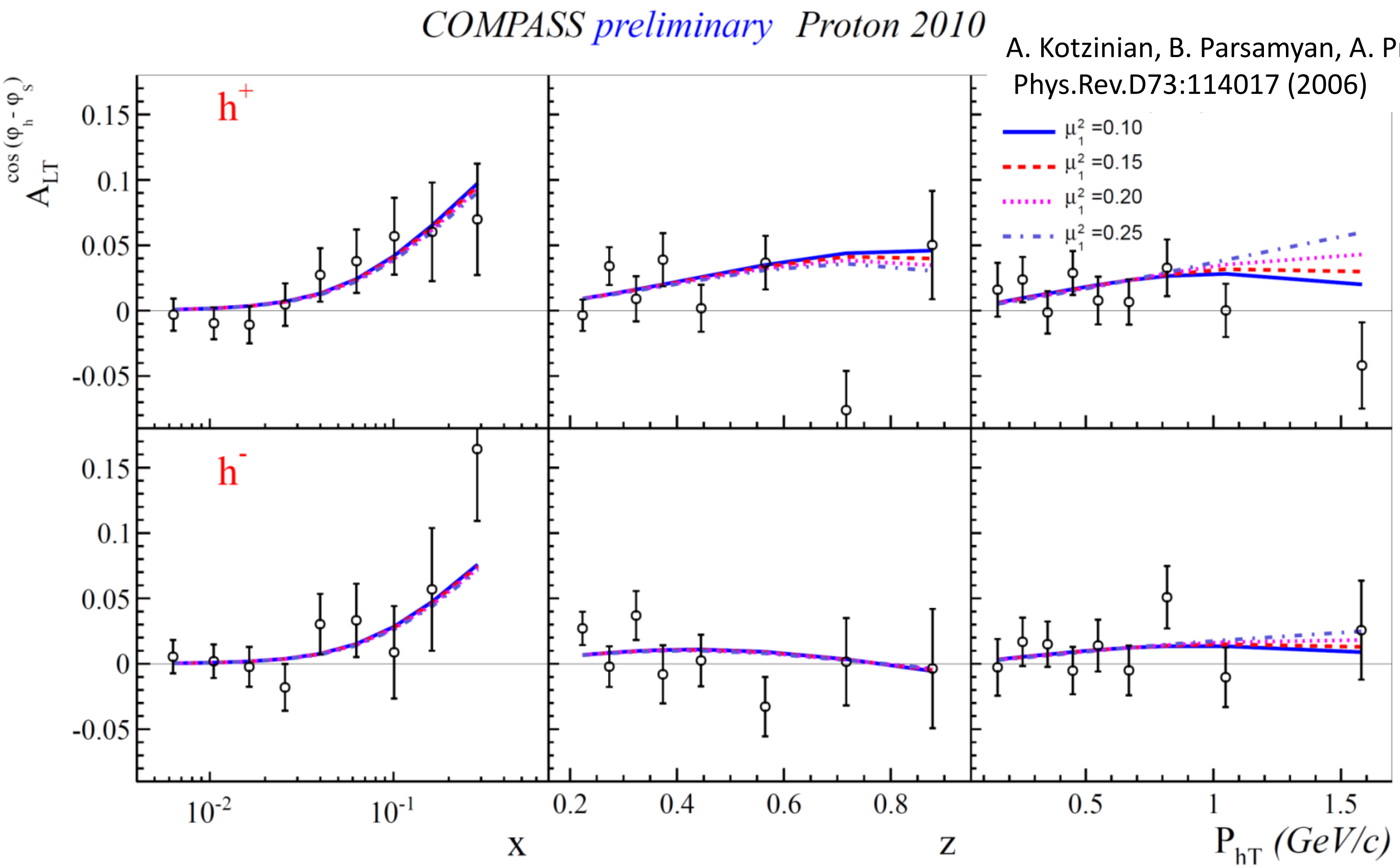


$$\propto \frac{g_{1T}^{\perp q}(x) \otimes D_{1q}^{h}(z)}{f_1^{q}(x) \otimes D_{1q}^{h}(z)}$$

- First observation of a none-zero A_{LT}.
- First measurement on neutron(^{3}He).
- Relate to quark TMD $g_{1T}(x, k_T)$.
- The real part of quark L=0 ✖ L=1 interference, “twin-brother” of Sivers.

Ph.D. thesis of J. Huang (MIT 2011).

$A_{LT}^{\cos(\varphi_h-\varphi_S)}$ and predictions from PRD 73, 114017(2006)



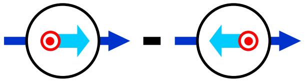
A. Kotzinian, B. Parsamyan, A. Prokudin
Phys.Rev.D73:114017 (2006)

Calculations are done using:
for g_{1T} the model:

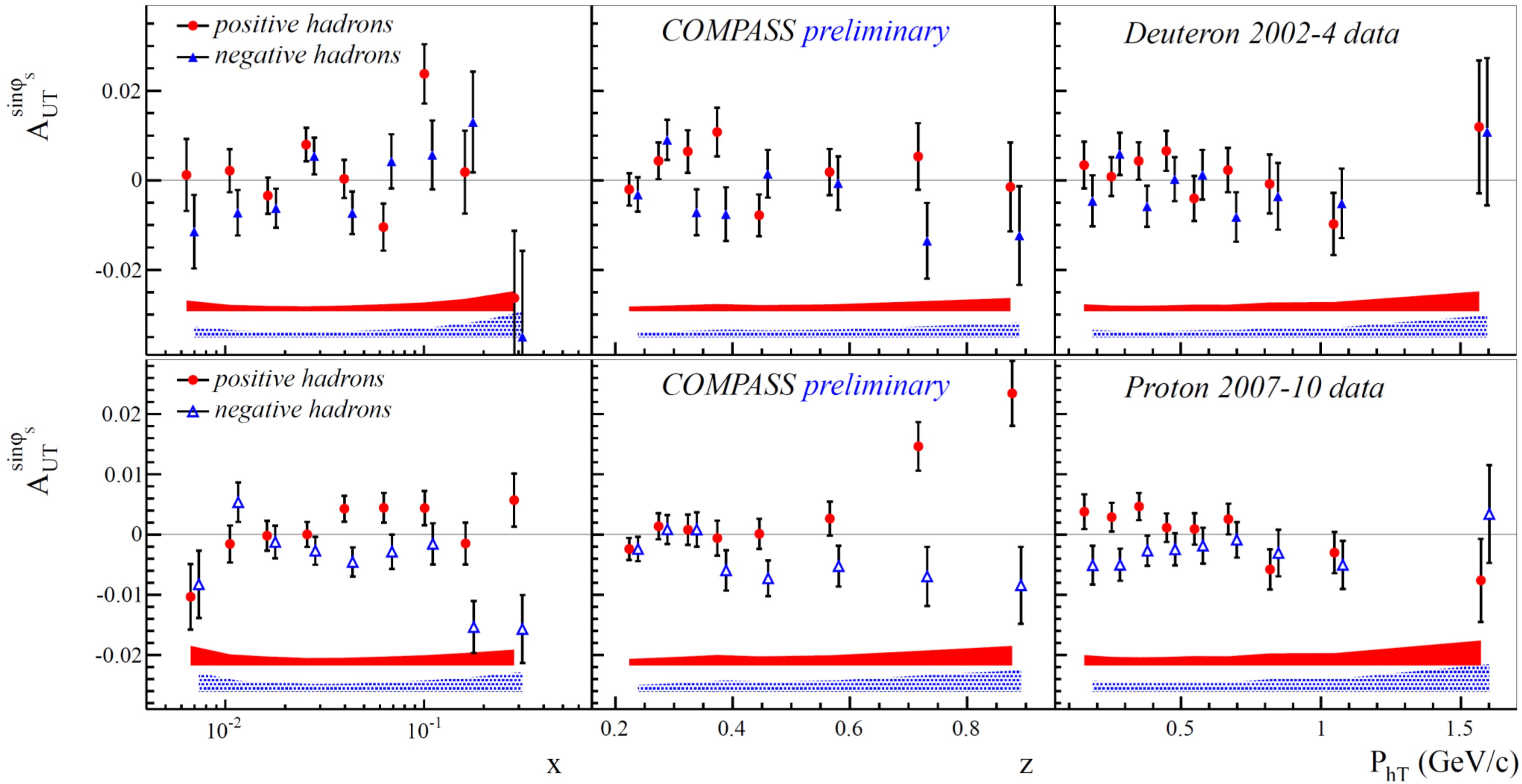
$$g_{1T}^{q(1)}(x,k_T^2) \approx x\int_x^1 dy \frac{g_1^q(y)}{y}$$

based on the Wandzura and Wilczek approximation;
Gaussian parameterization for k_T dependence;
LO GRV, GRSV2000 DFs and Kretzer FFs

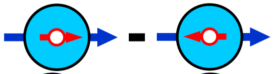
Asymmetry is evaluated in COMPASS specific mean kinematic points extracted from the data.
The predictions shows a good level of agreement with the experimentally extracted asymmetry

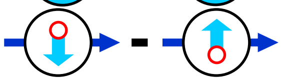
$A_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^q \otimes D_{1q}^h$, "Worm Gear" PDF g_{1T}^q : 

Results for $A_{UT}^{\sin\varphi_S}$ on deuteron and proton

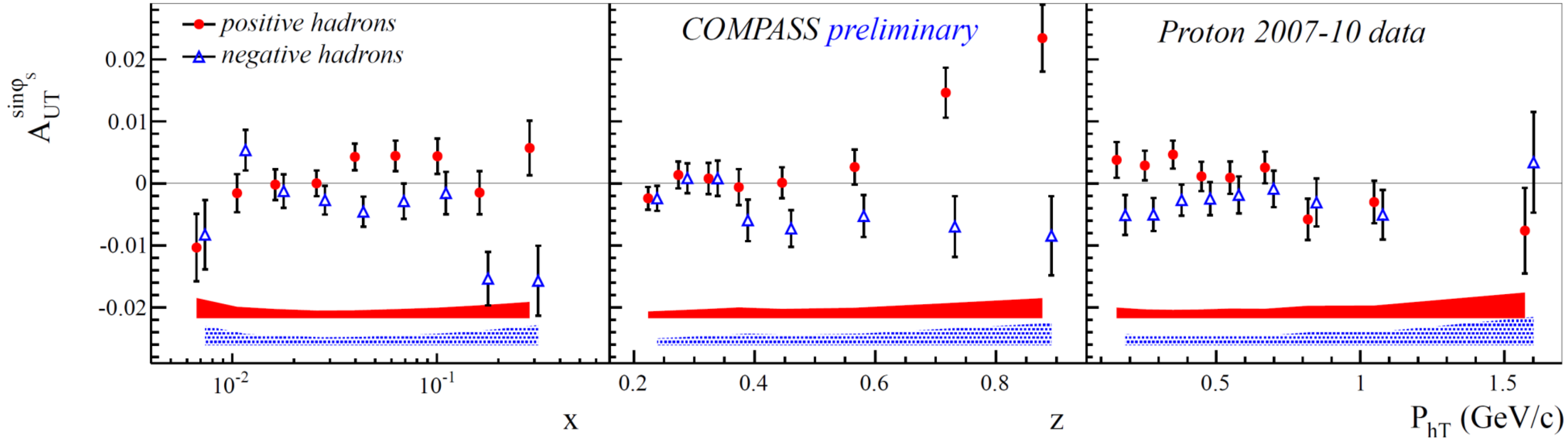


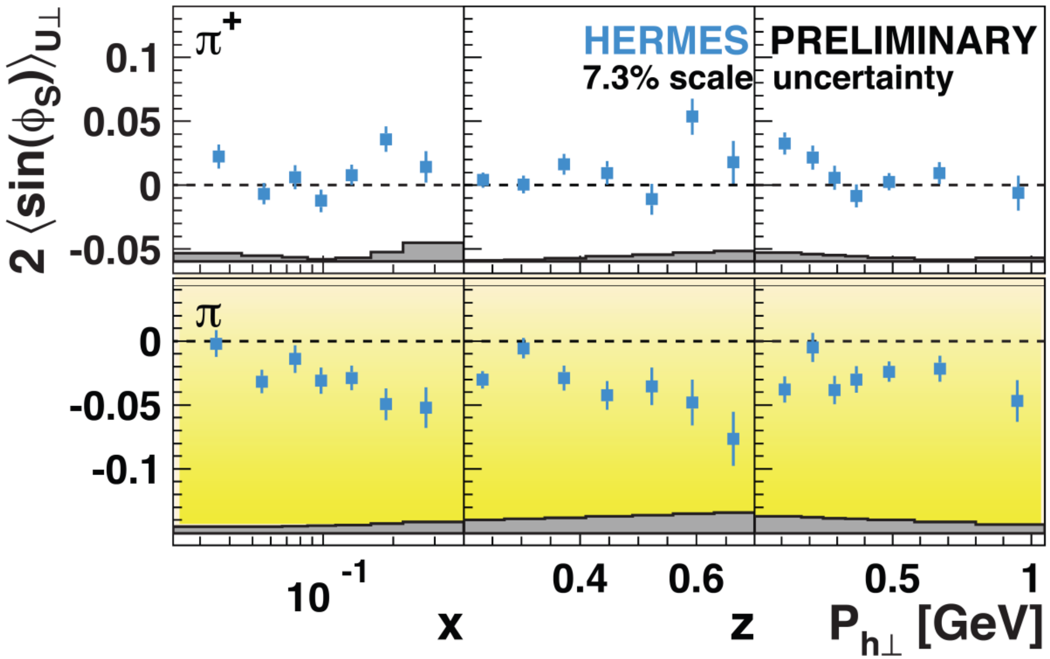
$$A_{UT}^{\sin\phi_s} \propto \frac{M}{Q}\left(h_1^q \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^h\right) + \ldots,$$

"Transversity" PDF h_1^q : 

"Sivers" PDF $f_{1T}^{\perp q}$: 

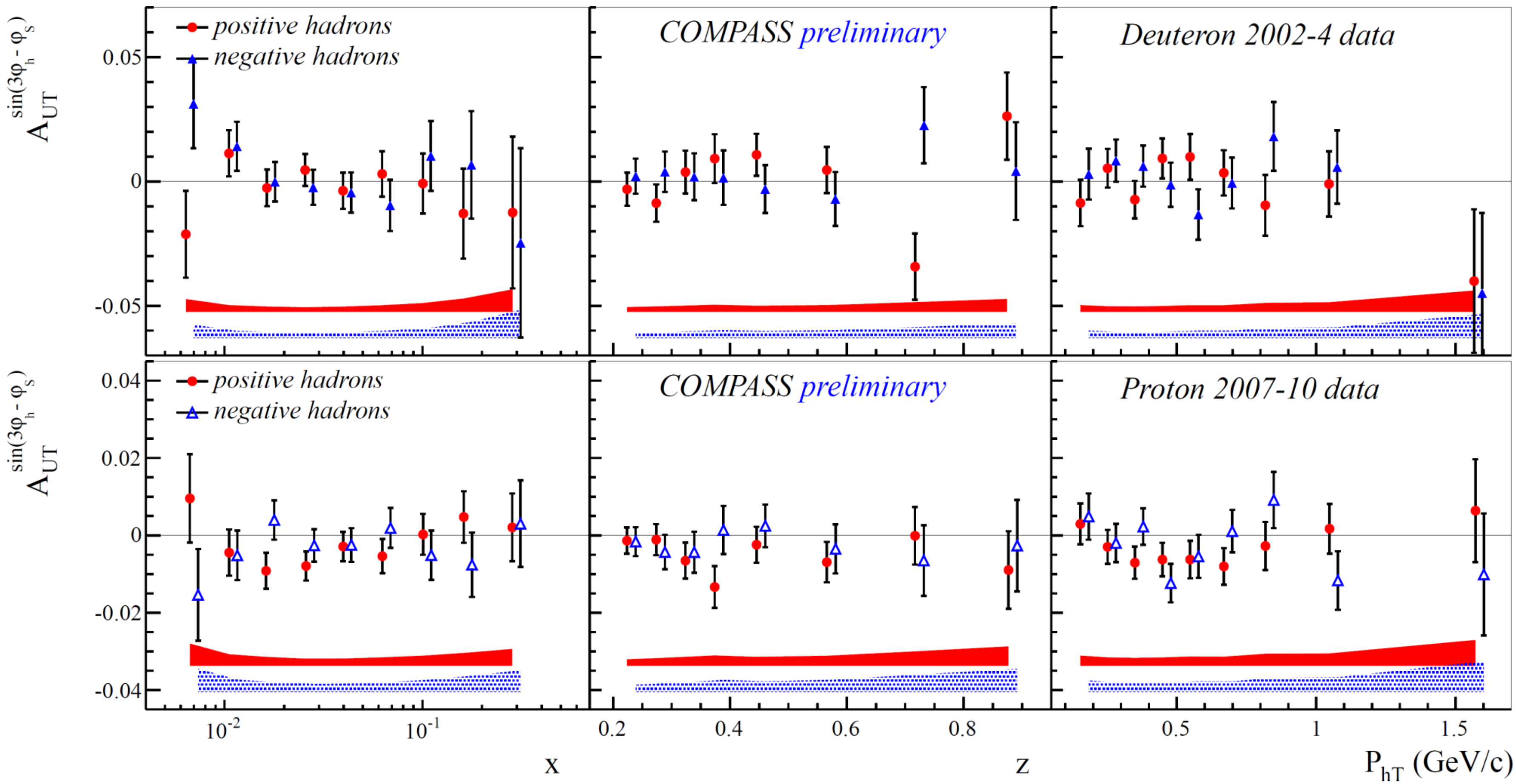
Results for $A_{UT}^{sin\varphi_S}$ COMPASS - HERMES



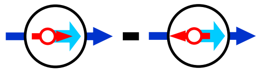


Signs of a non-zero $A_{UT}^{sin\varphi_S}$ asymmetry have been observed both by HERMES and COMPASS.

Results for $A_{UT}^{\sin(3\varphi_h-\varphi_S)}$ deuteron & proton

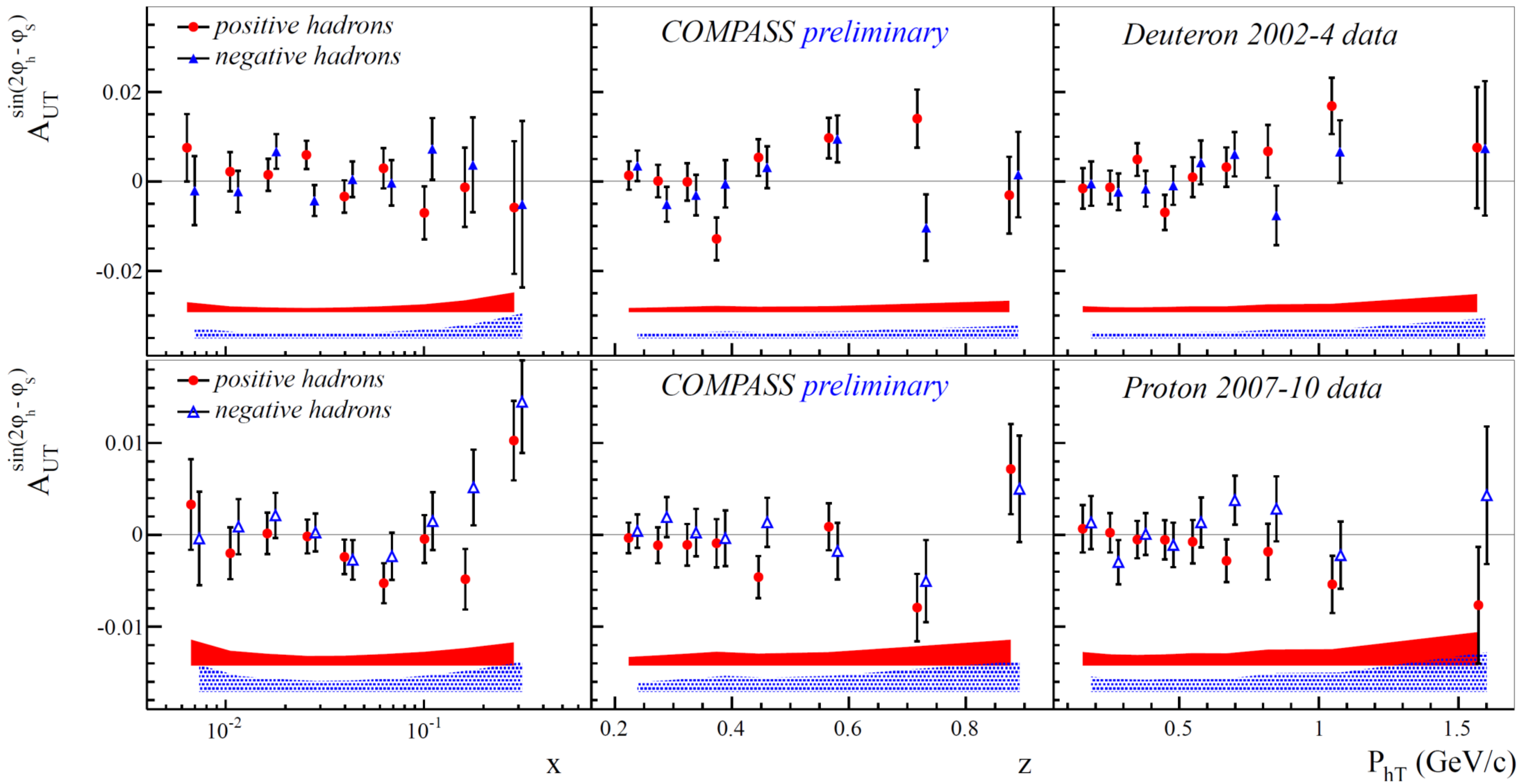


$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$, "Pretzelosity" PDF $h_{1T}^{\perp q}$:

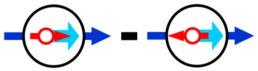


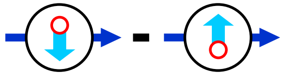
Asymmetries for both proton and deuteron are compatible with zero within uncertainties

Results for $A_{UT}^{\sin(2\varphi_h-\varphi_S)}$ deuteron & proton



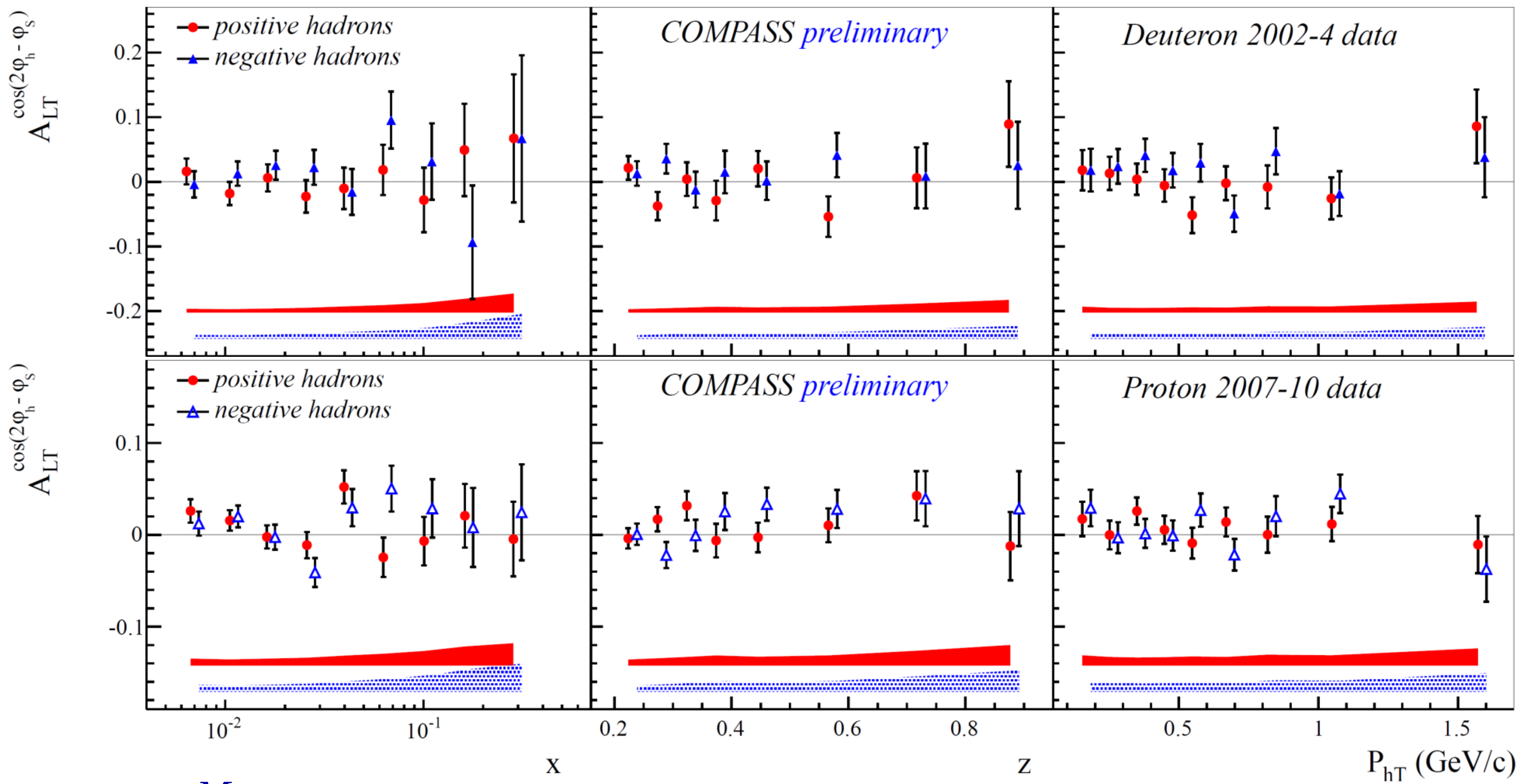
$$A_{UT}^{\sin(2\phi_h-\phi_s)} \propto \frac{M}{Q}\left(h_{1T}^{\perp q} \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^{h}\right)+\ldots,$$

"Pretzelosity" PDF $h_{1T}^{\perp q}$: 

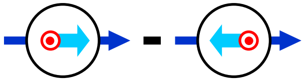
"Sivers" PDF $f_{1T}^{\perp q}$: 

Asymmetries for both proton and deuteron are compatible with zero within uncertainties

Results for $A_{LT}^{\cos(2\varphi_h-\varphi_S)}$ deuteron & proton



$$A_{LT}^{\cos(2\phi_h-\phi_s)} \propto \frac{M}{Q} g_{1T}^q \otimes D_{1q}^h + \ldots,$$ "Worm Gear" PDF g_{1T}^q :



Asymmetries for both proton and deuteron are compatible with zero within uncertainties

Outline

- Introduction
- COMPASS experiment
- **Measured asymmetries and theory expectations**
  - Re-evaluation of $A_{LT}^{\cos\varphi_S}$ from the *lp* to $\gamma{*}p$ cross-section
  - Theory expectations
- Summary

SIDIS x-section: from *lp* to *γ*p* (P_L=0)

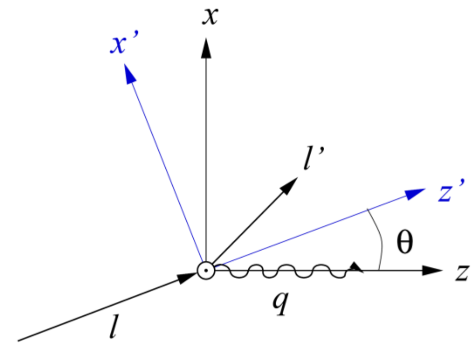
Kotzinian et al.
hep-ph/9808368 (1998)
hep-ph/9908466 (1999)
M. Diehl and S. Sapeta,
Eur. Phys. J. C 41 (2005) 515

$$\frac{d\sigma}{dx\,dy\,dz\,dP_{hT}^2\,d\varphi_h\,d\varphi_S}=\left[\frac{\cos\theta}{1-\sin^2\theta\sin^2\varphi_S}\right]\times\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

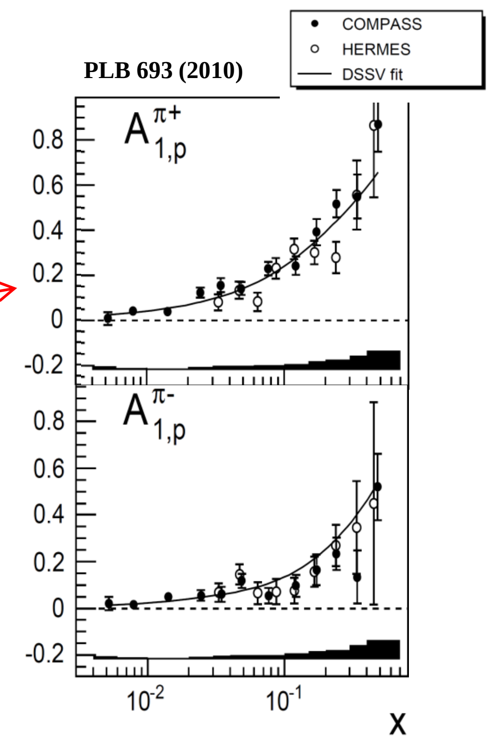
$$\Bigg[1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\lambda\sin\varphi_h\times\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\varphi_h}+$$

$$\frac{P_T}{\sqrt{1-\sin^2\theta\sin^2\varphi_S}}\left[\begin{array}{l}\sin\varphi_S\times\left(\cos\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\varphi_S}\right)+\\ \sin(\varphi_h-\varphi_S)\times\left(\cos\theta A_{UT}^{\sin(\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\varphi_h}\right)+\\ \sin(\varphi_h+\varphi_S)\times\left(\cos\theta\varepsilon A_{UT}^{\sin(\varphi_h+\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\varphi_h}\right)+\\ \sin(2\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\varepsilon A_{UL}^{\sin 2\varphi_h}\right)+\\ \sin(2\varphi_h+\varphi_S)\times\left(\frac{1}{2}\sin\theta\varepsilon A_{UL}^{\sin 2\varphi_h}\right)+\\ \sin(3\varphi_h-\varphi_S)\times\left(\cos\theta\varepsilon A_{UT}^{\sin(3\varphi_h-\varphi_S)}\right)\end{array}\right]+$$

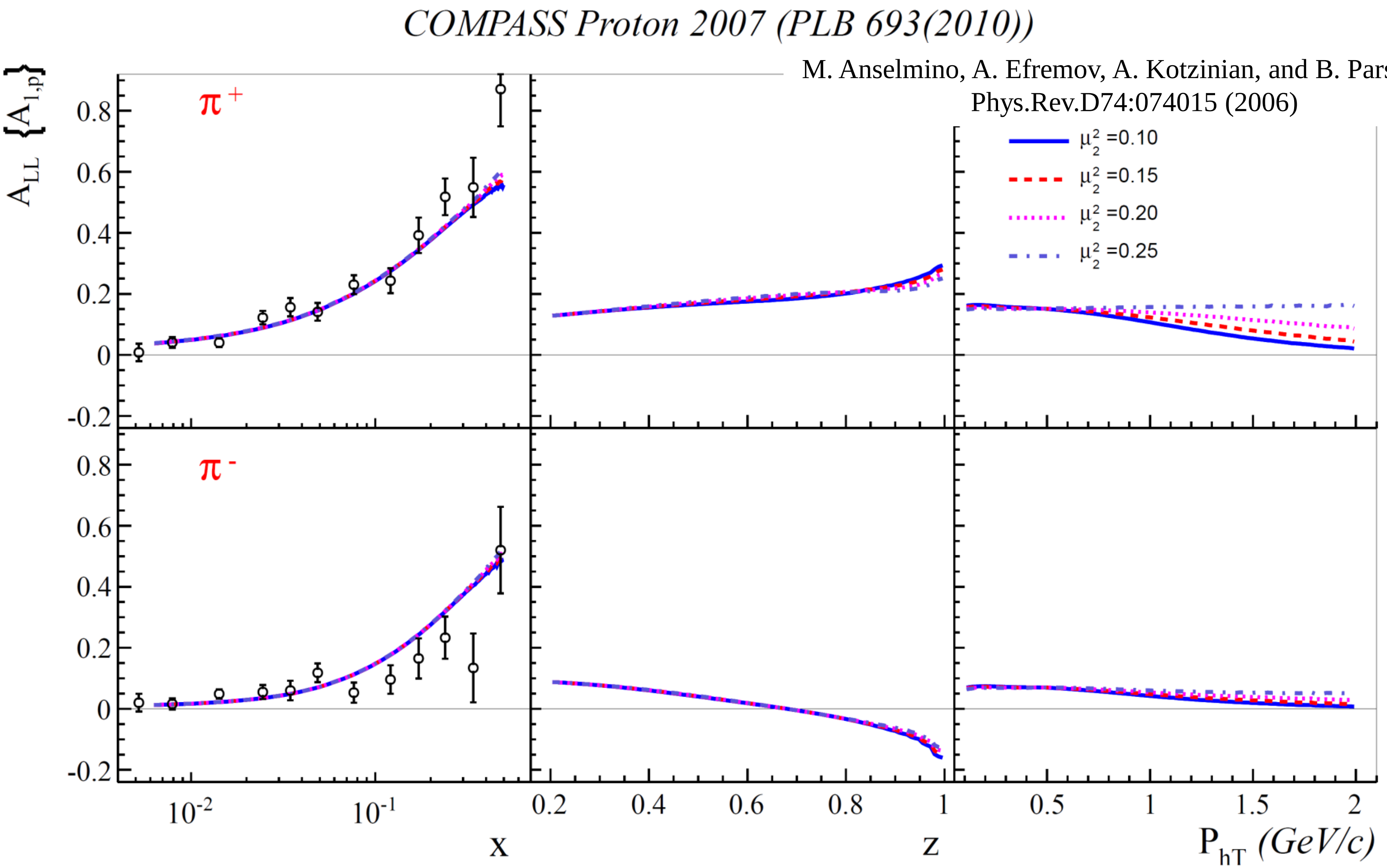
$$\frac{P_T\lambda}{\sqrt{1-\sin^2\theta\sin^2\varphi_S}}\left[\begin{array}{l}\cos\varphi_S\times\left(\cos\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\varphi_S}+\sin\theta\sqrt{(1-\varepsilon^2)}A_{LL}\right)+\\ \cos(\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\varphi_h-\varphi_S)}+\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\varphi_h}\right)+\\ \cos(\varphi_h+\varphi_S)\times\left(\frac{1}{2}\sin\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\varphi_h}\right)+\\ \cos(2\varphi_h-\varphi_S)\times\left(\cos\theta\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\varphi_h-\varphi_S)}\right)\end{array}\right]\Bigg]$$



lepton plane

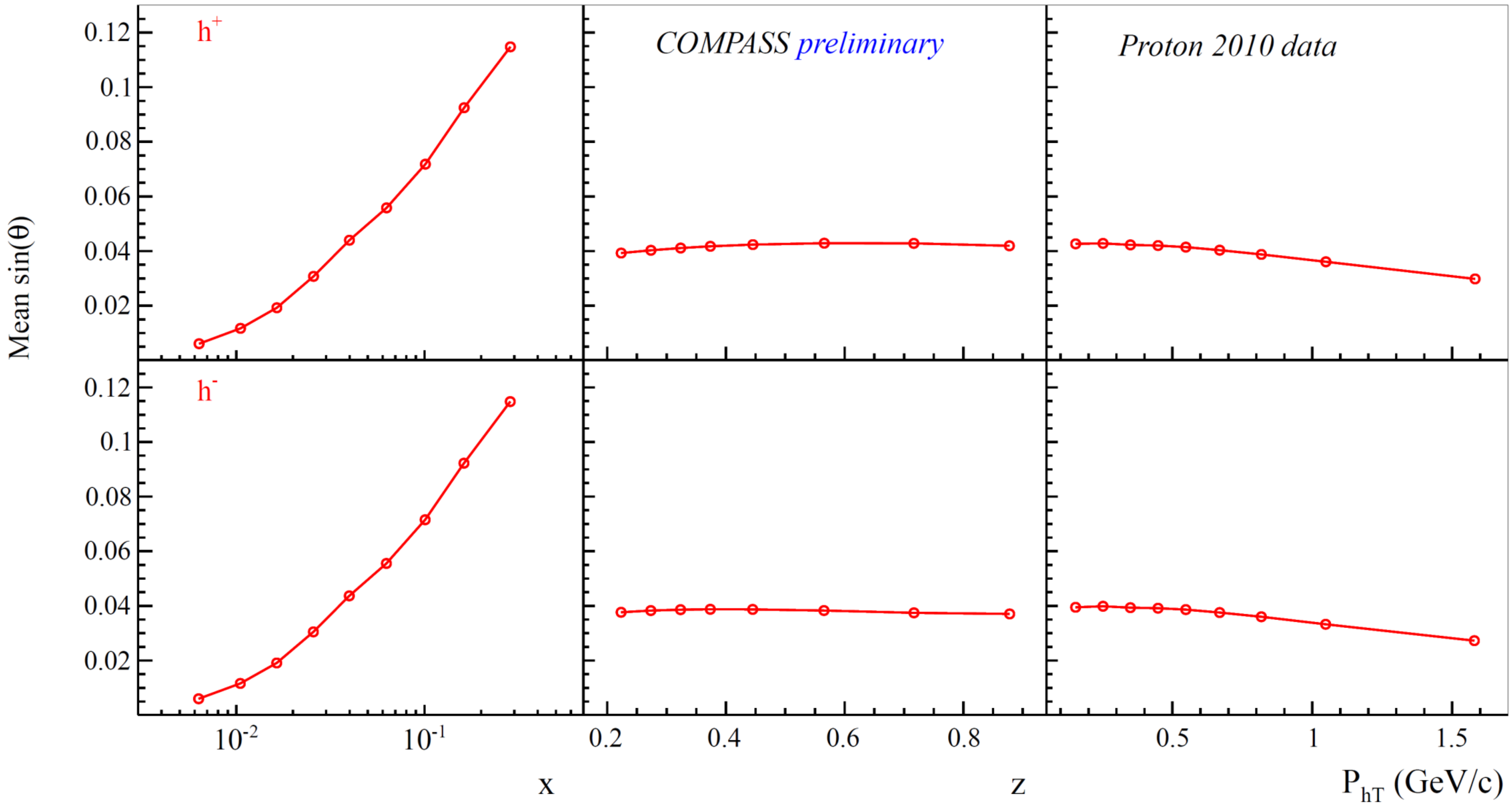


A_{LL} evaluated according to the PRD **74,** 074015 (2006)



Asymmetry is evaluated in COMPASS specific mean kinematic points extracted from the data.
Good level of agreement up to x≈0.3, which allows us to use the predicted z and P_{hT} – dependencies in $A_{LT}^{\cos(\varphi_S)}$*-correction.*

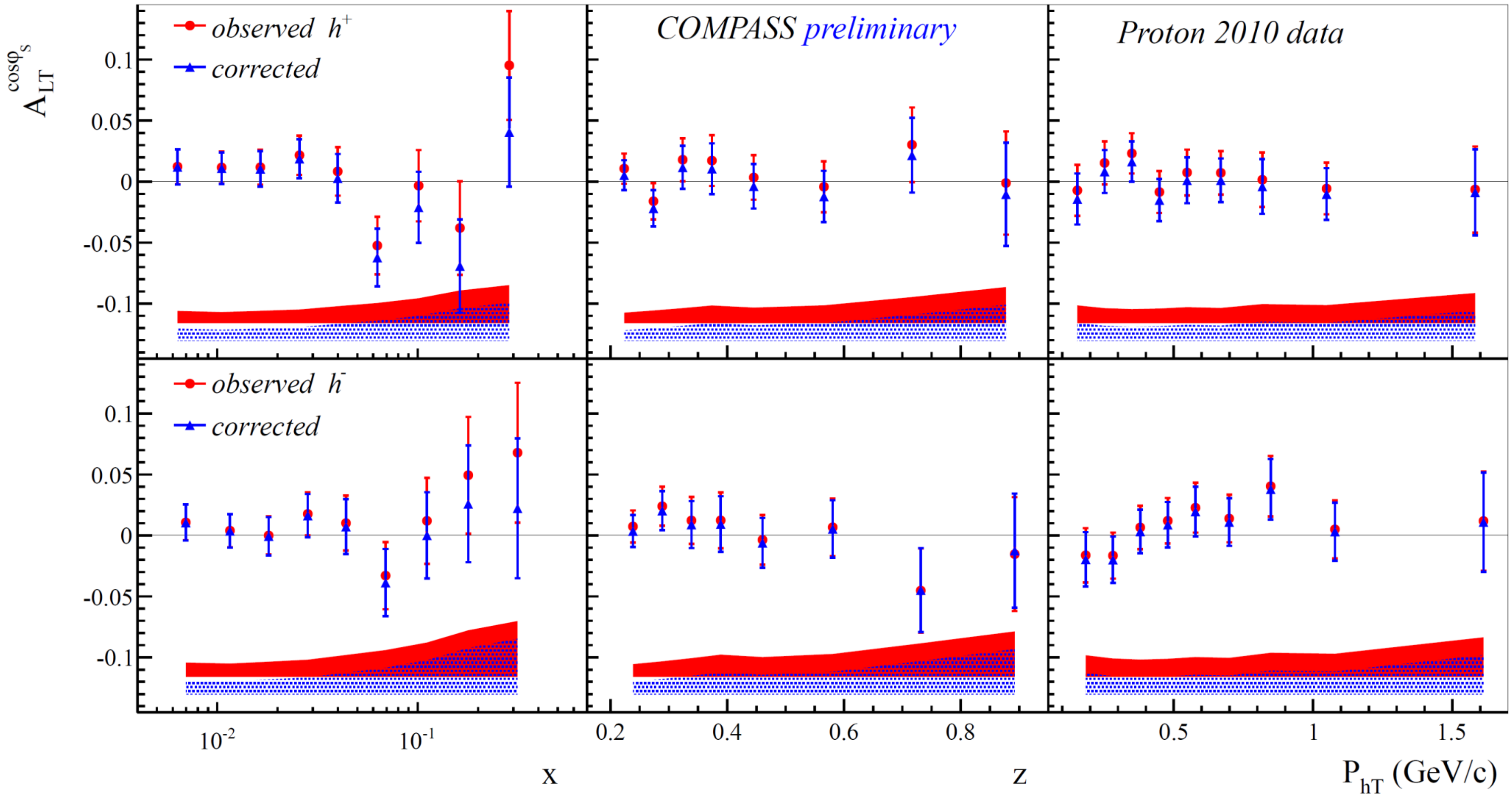
Mean sinθ-values



The sinθ is small at COMPASS kinematics. The maximum reached value is ~ 0.12 and the mean is around 0.04 (cosθ ≈ 1).

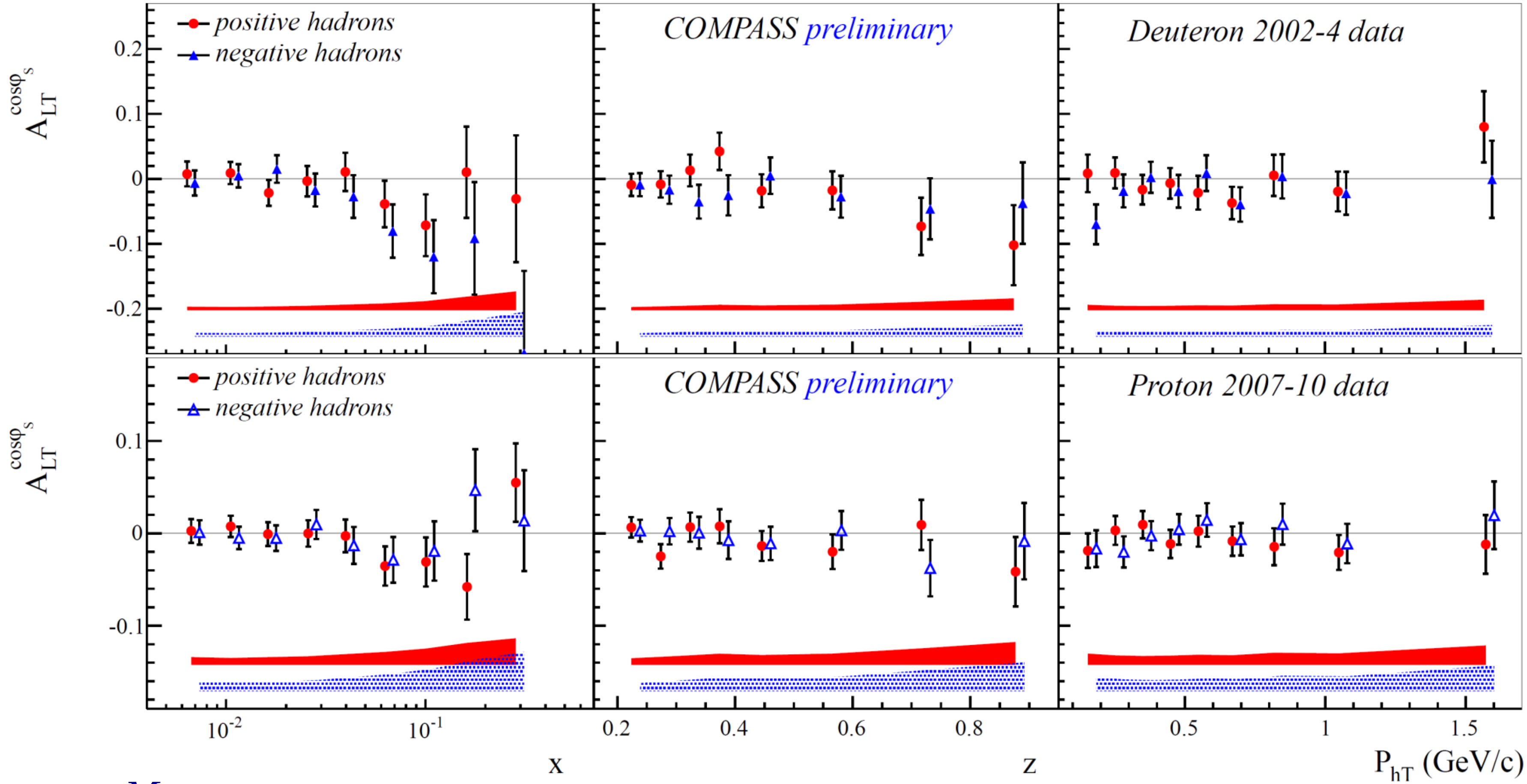
Corrected $A_{LT}^{\cos\varphi_S}$

$$A_{LT}^{\cos\varphi_S\prime} \approx \left(\cos\theta A_{LT}^{\cos\varphi_S} - \sin\theta \frac{\sqrt{(1-\varepsilon^2)}}{\sqrt{2\varepsilon(1-\varepsilon)}} A_{LL} \right)$$

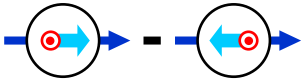


As expected, at large *x* the corrections become sizable.

Results for $A_{LT}^{\cos\varphi_S}$ deuteron & proton



$A_{LT}^{\cos\phi_s} \propto \frac{M}{Q} g_{1T}^{q} \otimes D_{1q}^{h} + \ldots,$ "Worm Gear" PDF g_{1T}^{q} :



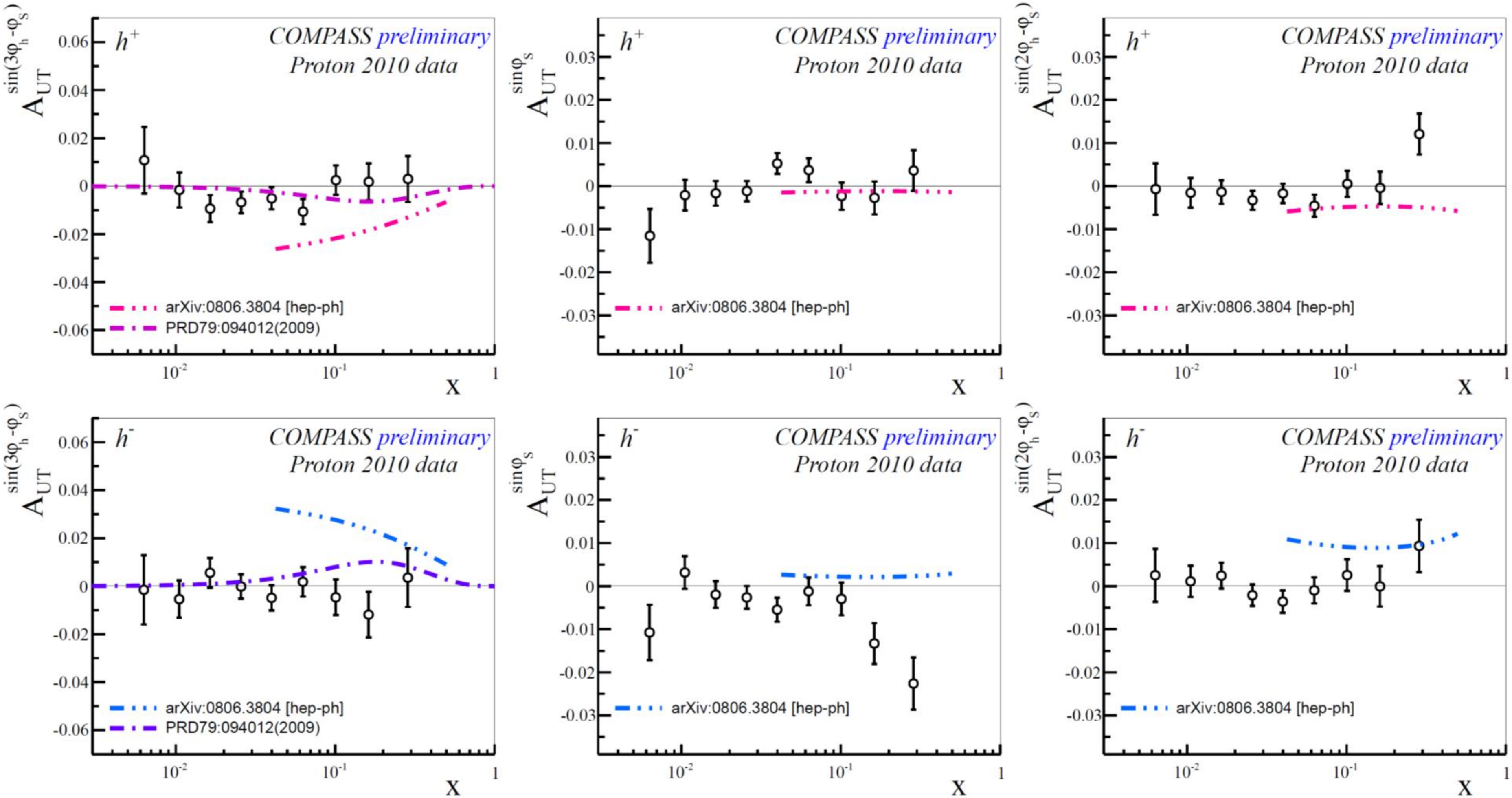
Asymmetries for both proton and deuteron are compatible with zero within uncertainties

Outline

- Introduction
- COMPASS experiment
- Measured asymmetries and theory expectations
  - Re-evaluation of $A_{LT}^{\cos\varphi_S}$ from the *lp* to γ^*p cross-section
  - Theory expectations
- Summary

“UT” asymmetries and theoretical predictions x-dependence only

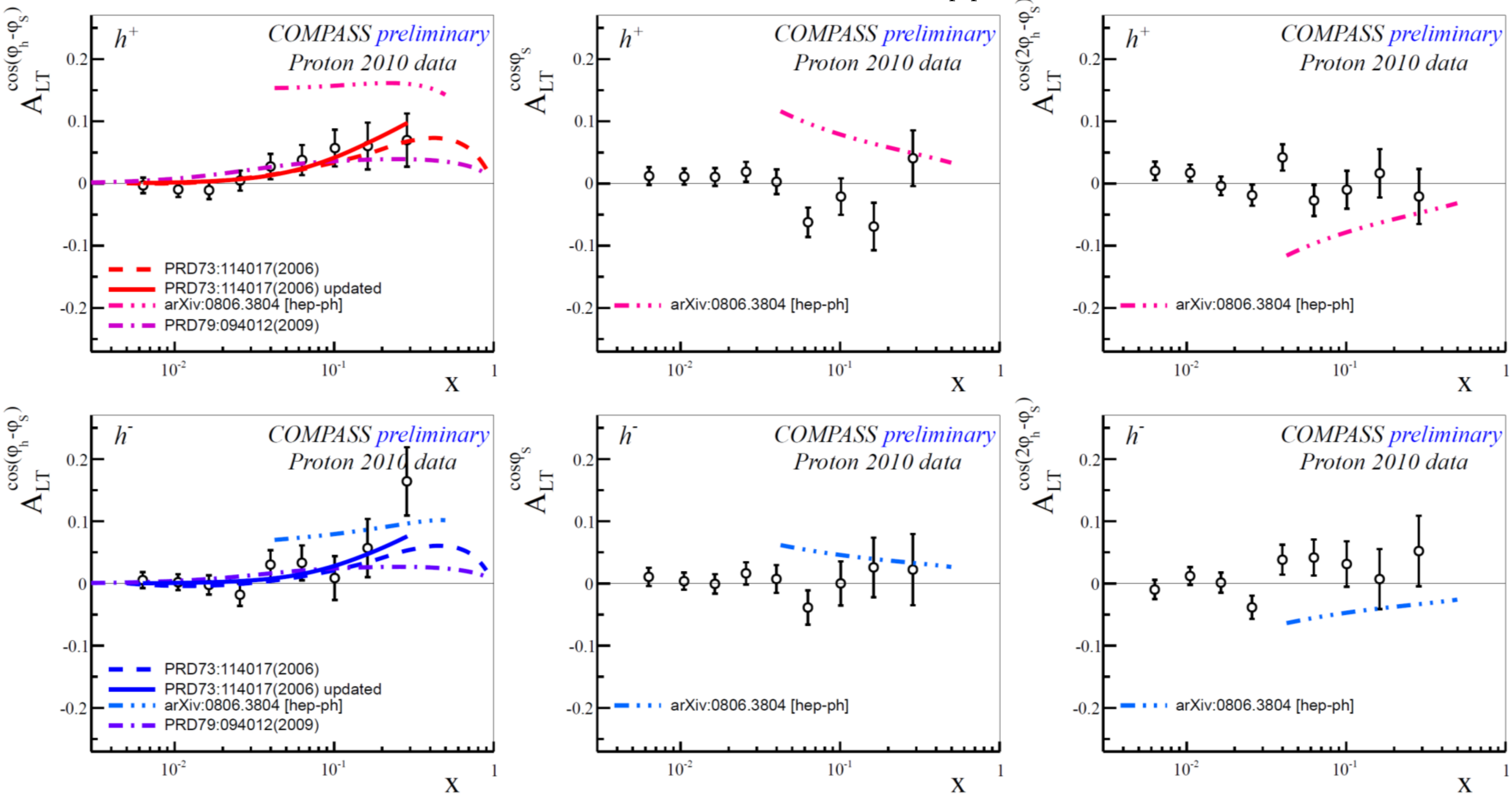
S. Boffi, A.V. Efremov, B. Pasquini and P. Schweitzer PRD79:094012(2009)
A. Kotzinian arXiv:0806.3804[hep-ph]



“LT” asymmetries and theoretical predictions

x-dependence only

A. Kotzinian, B. Parsamyan, A. Prokudin Phys.Rev.D73:114017 (2006)
S. Boffi, A.V. Efremov, B. Pasquini and P. Schweitzer PRD79:094012(2009)
A. Kotzinian arXiv:0806.3804[hep-ph]



The predictions for $A_{LT}^{\cos(\varphi_h-\varphi_S)}$ shows a good level of agreement with the experimentally extracted asymmetry.

Outline

- Introduction
- COMPASS experiment
- Measured asymmetries and theory expectations
    - Re-evaluation of $A_{LT}^{\cos\varphi_S}$ from the lp to $\gamma{*}p$ cross-section
    - Theory expectations
- Summary

Summary

- Six "beyond Collins and Sivers" transverse spin asymmetries

$$A_{UT}^{\sin(3\varphi_h-\varphi_s)},\ A_{UT}^{\sin\varphi_s},\ A_{UT}^{\sin(3\varphi_h-\varphi_s)},\ A_{LT}^{\cos(\varphi_h-\varphi_s)},\ A_{LT}^{\cos\varphi_s}\ \&\ A_{LT}^{\cos(2\varphi_h-\varphi_s)}$$

have been extracted from COMPASS deuteron 2002-2004, proton 2007 and now also proton 2010 data.

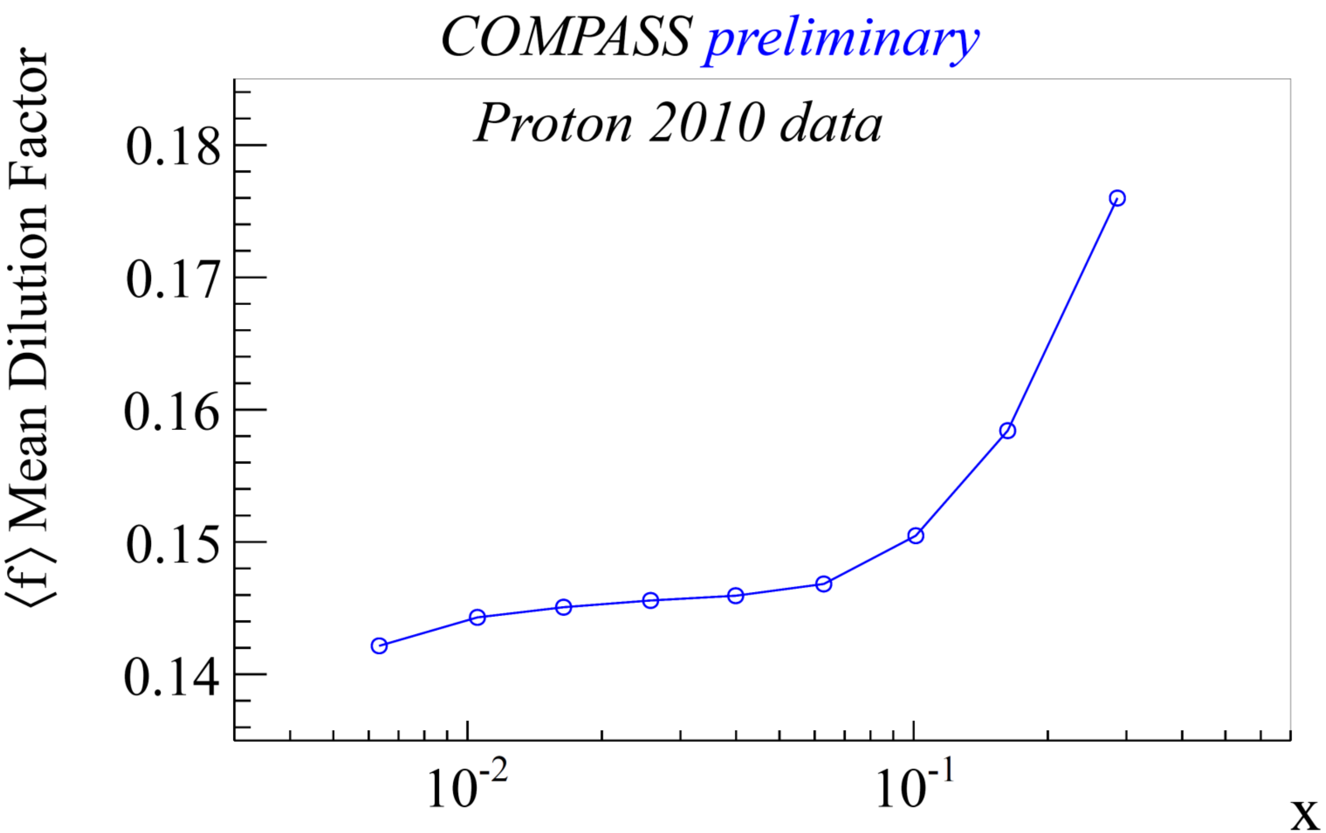
- "Deuteron" and "proton 2007" asymmetries found to be consistent with zero within the statistical accuracy of the measurement.
- Higher statistics and improved quality of the 2010 proton data allowed to reveal a non-zero trend for the $A_{LT}^{cos(\varphi_h-\varphi_S)}$ and $A_{UT}^{sin\varphi_S}$ amplitudes.
- Observed effects confirm HERMES preliminary results.
- COMPASS results for the $A_{LT}^{cos(\varphi_h-\varphi_S)}$ showed a good level of agreement with the theoretical predictions.

- Next → Six asymmetries for pions and kaons.

Thank you!

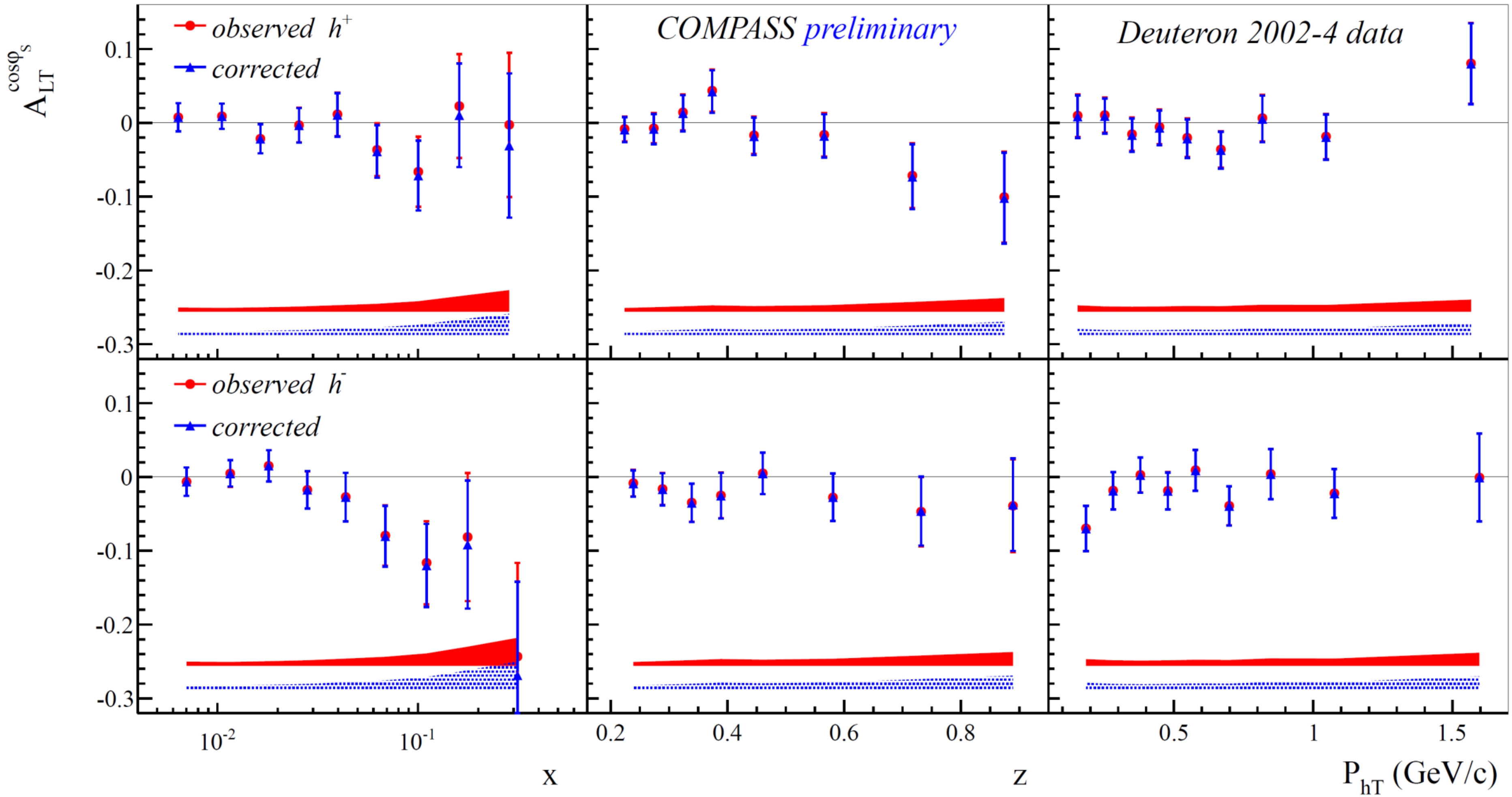
Spare slides

Dilution factor



Corrected $A_{LT}^{\cos\varphi_S}$ deuteron

$$A_{LT}^{\cos\varphi_S\prime} \approx \left(\cos\theta A_{LT}^{\cos\varphi_S} - \sin\theta \frac{\sqrt{\left(1-\varepsilon^2\right)}}{\sqrt{2\varepsilon\left(1-\varepsilon\right)}} A_{LL} \right)$$



$A_{LT}^{\cos(\varphi_h-\varphi_S)}$ asymmetry *PRD73:114017,(2006)*

COMPASS

There exists a relation between first momentum of g_{1T} and g_2 (follows from Lorentz invariance, Tangerman & Mulders) :

$$g_{1T}^{q(1)}(x) \equiv \int_0^x g_2^q(y)dy = -\int_x^1 g_2^q(y)dy = (WW-appr) = x\int_x^1 \frac{g_1^q(y)}{y}dy$$

$$f_1^q(x,k_T^2) = f_1^q(x)\frac{1}{\pi\mu_0^2}\exp(-\frac{k_T^2}{\mu_0^2}),$$

$$D_q^h(z,P_{hT}^2) = D_q^h(z)\frac{1}{\pi\mu_D^2}\exp(-\frac{P_{hT}^2}{\mu_D^2}),$$

$$g_{1T}^q(x,k_T^2) = g_{1T}^q(x)N\exp(-\frac{k_T^2}{\mu_1^2})$$

N is fixed by

$$g_{1T}^{q(1)}(x) = \int d^2k_T\frac{k_T^2}{2M^2}g_{1T}^q(x,k_T^2)$$

$$g_{1T}^q(x,k_T^2) = g_{1T}^{q(1)}(x)\frac{2M^2}{\pi\mu_1^4}\exp(-\frac{k_T^2}{\mu_1^2})$$

From analysis of unpolarized P_{hT} dependence and Cahn effect

$$\mu_0^2 = 0.25(GeV/c)^2, \quad \mu_D^2 = 0.2(GeV/c)^2$$

Naïve positivity constraint: $\frac{|k_T|}{M}\left|g_{1T}^q(x,k_T^2)\right| < f_1^q(x,k_T^2)$

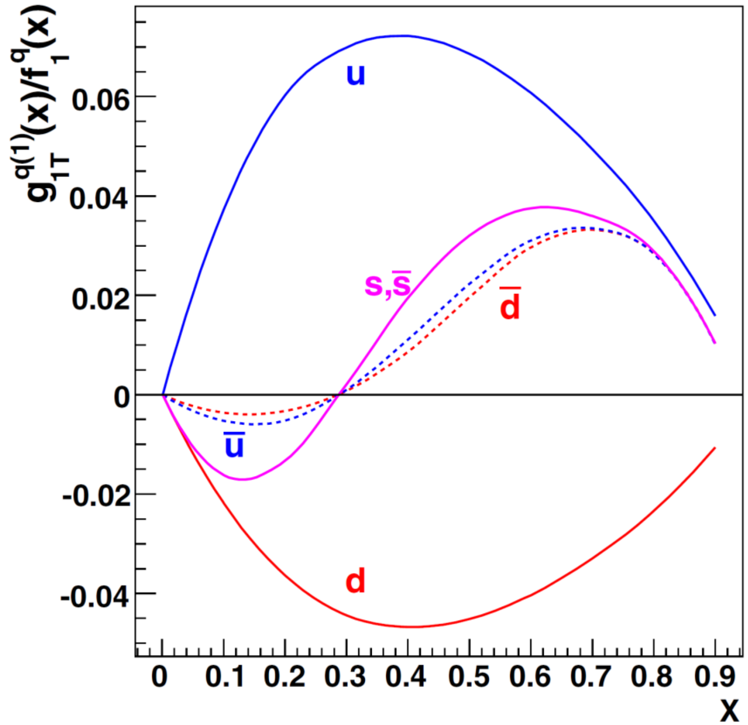
holds if $\mu_1^2 \le 0.246\ (\mathrm{GeV/c})^2$

Predictions done for: $\mu_1^2 = 0.1, 0.15\ and\ 0.25(GeV/c)^2$

$$A_{LT}^{\cos\phi_h^S}(x,y,z,P_{hT}) = 2\frac{\int_0^{2\pi}d\phi_h^S(d\sigma^{\to\Uparrow}-d\sigma^{\to\Downarrow})\cos\phi_h^S}{\int_0^{2\pi}d\phi_h^S(d\sigma^{\to\Uparrow}+d\sigma^{\to\Downarrow})} = 2\frac{\frac{2-y}{xy}\frac{Mz|P_{hT}|}{(\mu_D^2+\mu_1^2z^2)^2}\exp(-\frac{P_{hT}^2}{\mu_D^2+\mu_1^2z^2})\sum_q e_q^2 g_{1T}^{q(1)}(x)D_q^h(z)}{\frac{1+(1-y)^2}{xy^2}\frac{1}{\mu_D^2+\mu_0^2z^2}\exp(-\frac{P_{hT}^2}{\mu_D^2+\mu_0^2z^2})\sum_q e_q^2 f_1^q(x)D_q^h(z)}$$

$A_{LT}^{\cos(\varphi_h-\varphi_S)}$ asymmetry *PRD73:114017,(2006)*

$$A_{TMD} = \frac{\text{Low } x, y, z \,\&\, p_T \; + \; \text{High } x, y, z \,\&\, p_T}{\text{Low } x, y, z \,\&\, p_T \; + \; \text{High } x, y, z \,\&\, p_T}$$



GRV98+GRSV2000 LO, std DFs Kretzer FFs

COMPASS - Q^2>1.0 (GeV/c)^2, W^2>25 GeV^2, 0.05<x_{Bj}<0.6, 0.5 < y < 0.9, 0.4 < z < 0.9, $|P_{h,T}|$ > 0.5GeV/c

HERMES - Q^2>1.0 (GeV/c)^2, W^2>10 GeV^2, 0.1<x_{Bj}<0.6, 0.45 < y < 0.85, 0.4 < z < 0.9, $|P_{h,T}|$ > 0.5GeV/c

JLab - Q^2>1.0 (GeV/c)^2, W^2>4 GeV^2, 0.2<x_{Bj}<0.6, 0.4 < y < 0.7, 0.4 < z < 0.7, $|P_{h,T}|$ > 0.5GeV/c