Unpolarized azimuthal asymmetries in SIDIS: experimental overview

BAKUR PARSAMYAN

University of Turin and INFN section of Turin

UNIVERSITÀ DEGLI STUDI DI TORINO

ALMA UNIVERSITAS TAURINENSIS

INFN

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SIDIS x-section

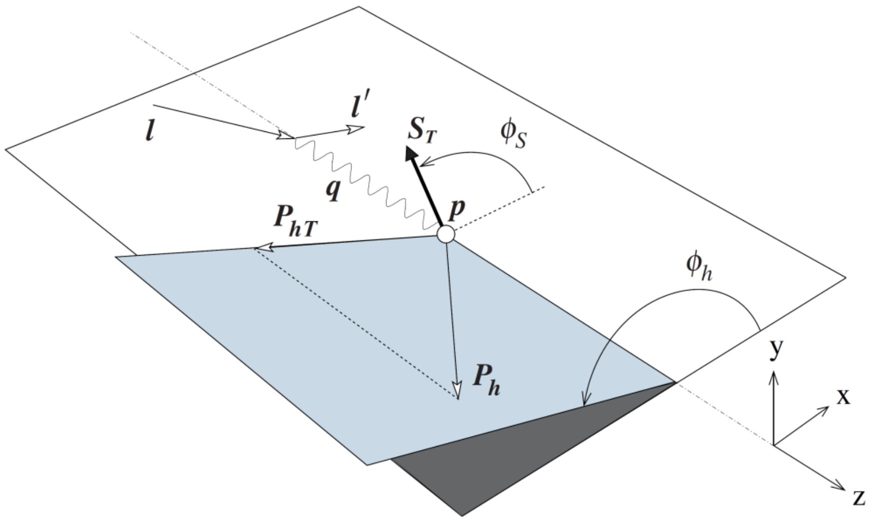
A.Kotzinian*, Nucl. Phys. B441**, 234 (1995). ***Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel *JHEP 0702:093 (2007)*

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

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

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

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



15 amplitudes:

2-"UU", 1-"LU", 2-"UL", 2-"LL", 5-"UT", 3-"LT"

SIDIS x-section

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

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

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

← This talk

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

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

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

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

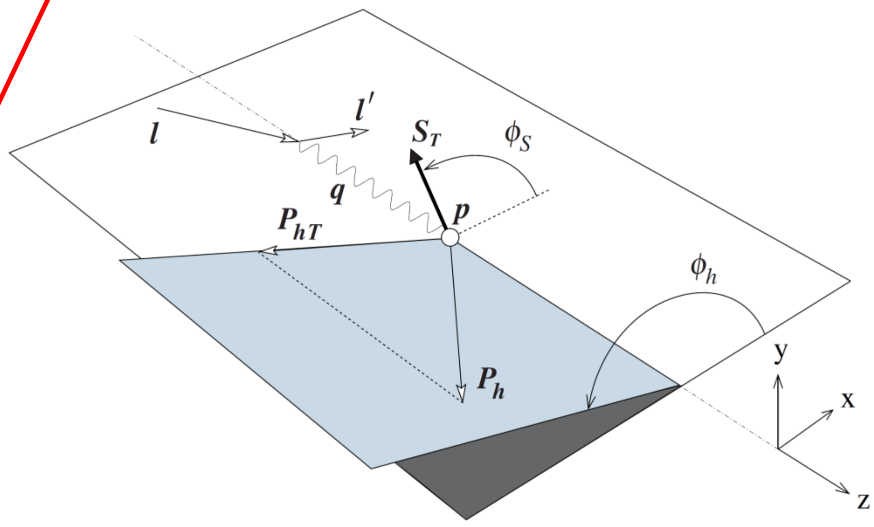
$$S_T\lambda\left[\begin{array}{l}\cos\varphi_S\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\varphi_S}\right)+\\ \cos(\varphi_h-\varphi_S)\times\left(\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\varphi_h-\varphi_S)}\right)+\\ \cos(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\varphi_h-\varphi_S)}\right)\end{array}\right]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

Presented by K. Kurek

Presented by G. Schnell

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

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



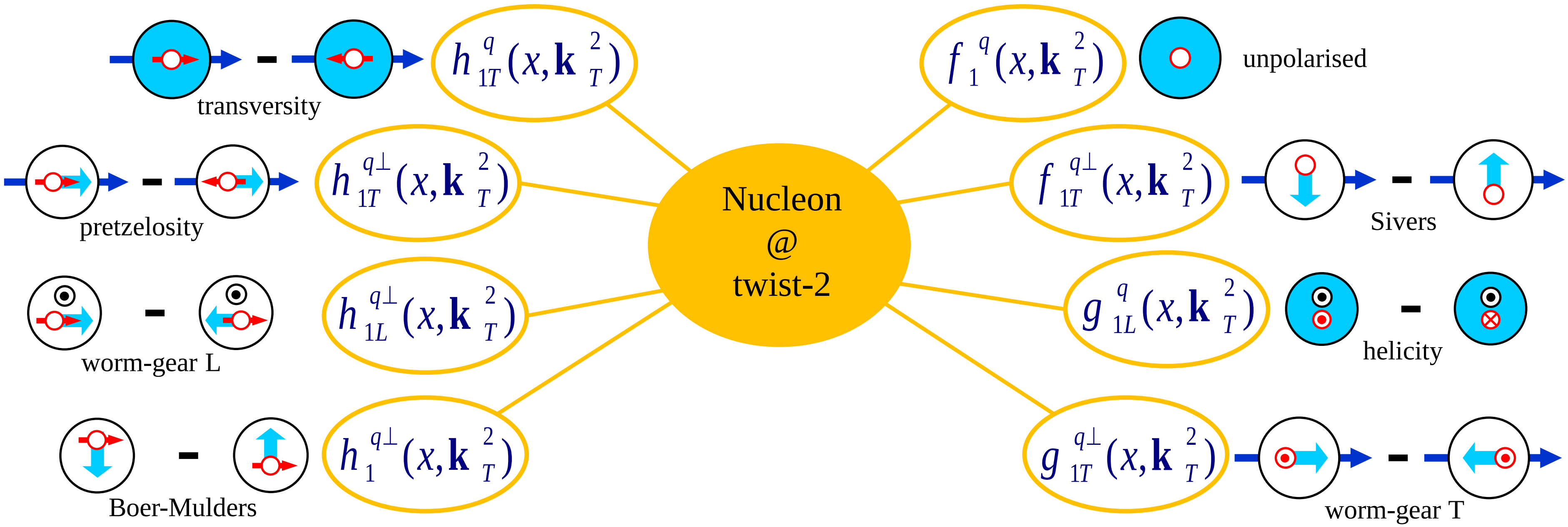
15 amplitudes:

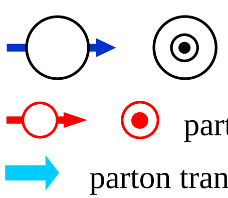
2-"UU", 1-"LU", 2-"UL", 2-"LL", 5-"UT", 3-"LT"

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



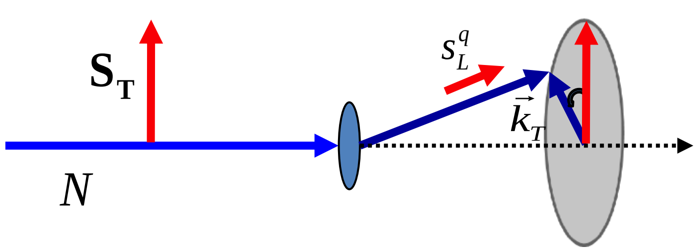


nucleon with transverse or longitudinal spin

parton with transverse or longitudinal spin

parton transverse momentum

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



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

TMD parton distribution functions and FFs

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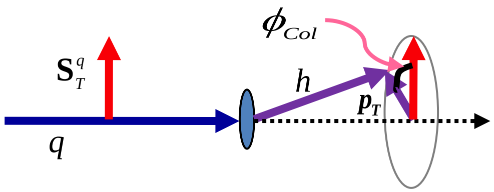
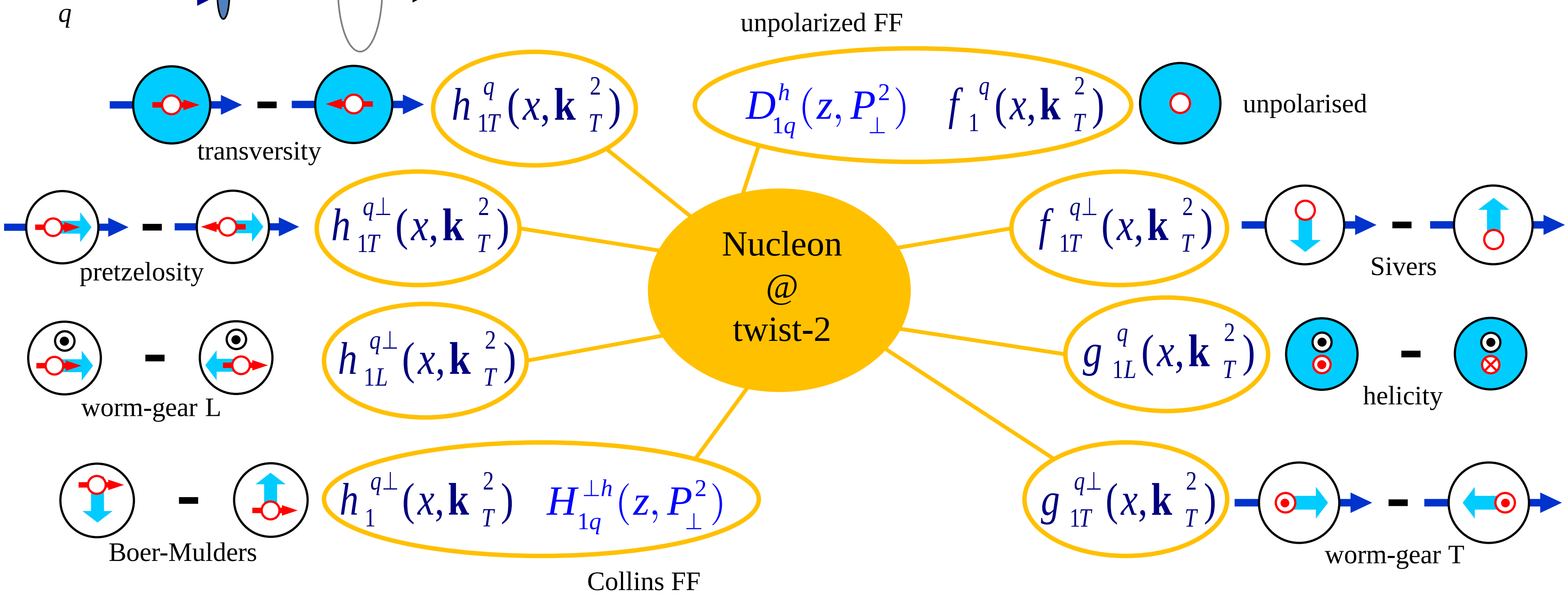


p_T – transverse momentum of the fragmenting quark w.r.t. the direction of the produced hadron



nucleon with transverse or longitudinal spin

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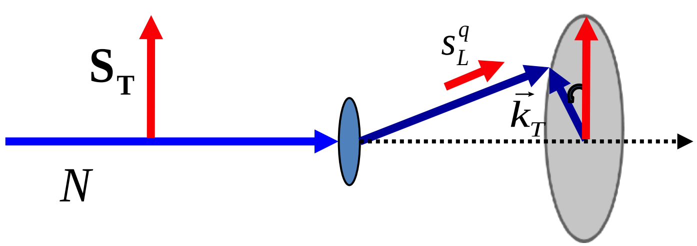

$\mathbf{k}_T$ – intrinsic transverse momentum of the quark

TMD parton distribution functions and FFs

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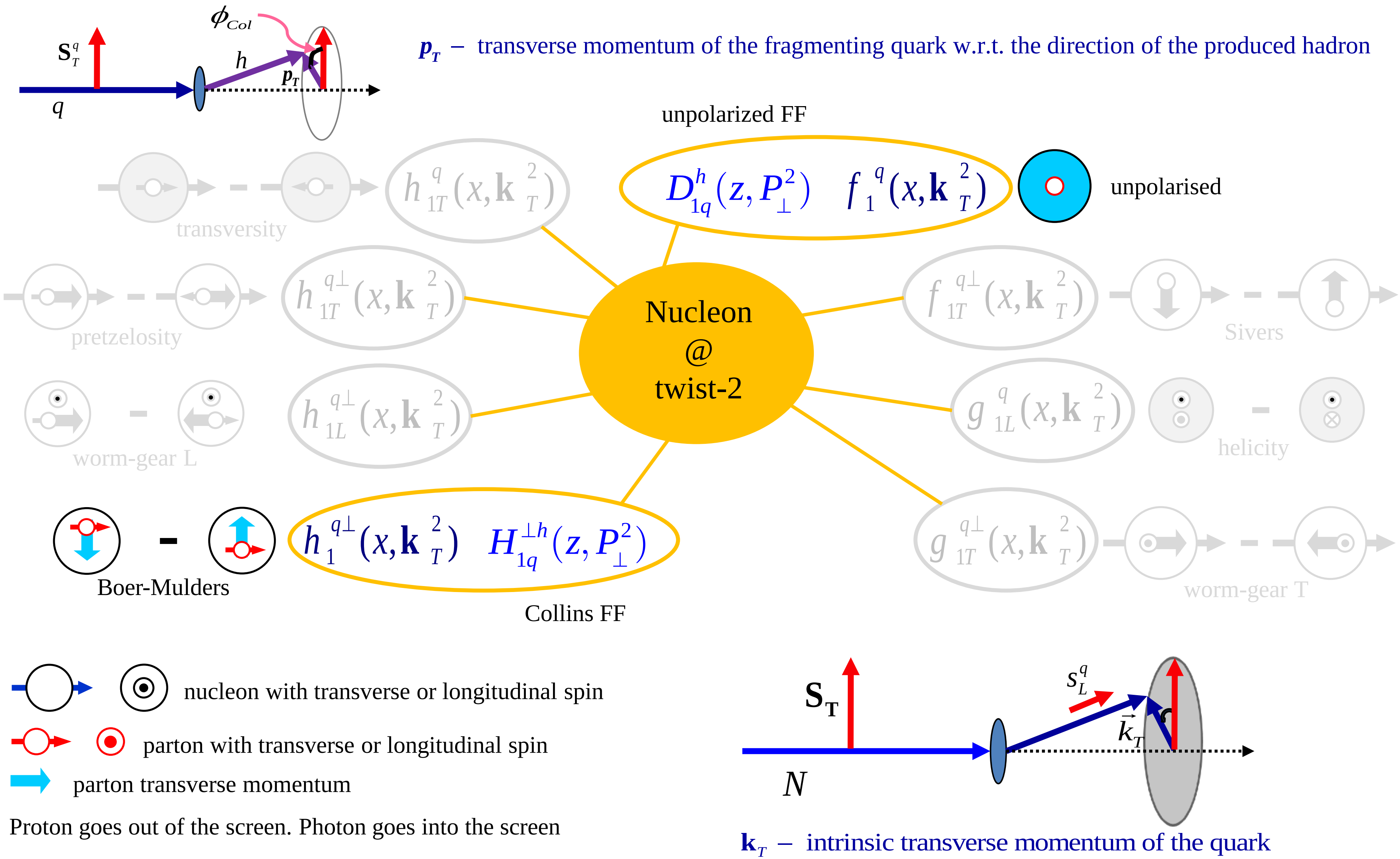
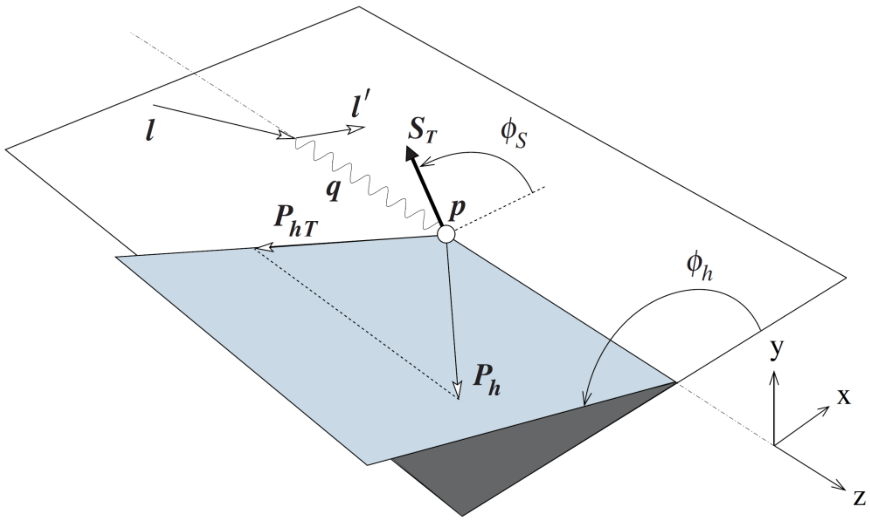


SIDIS x-section (unpolarized part)

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$



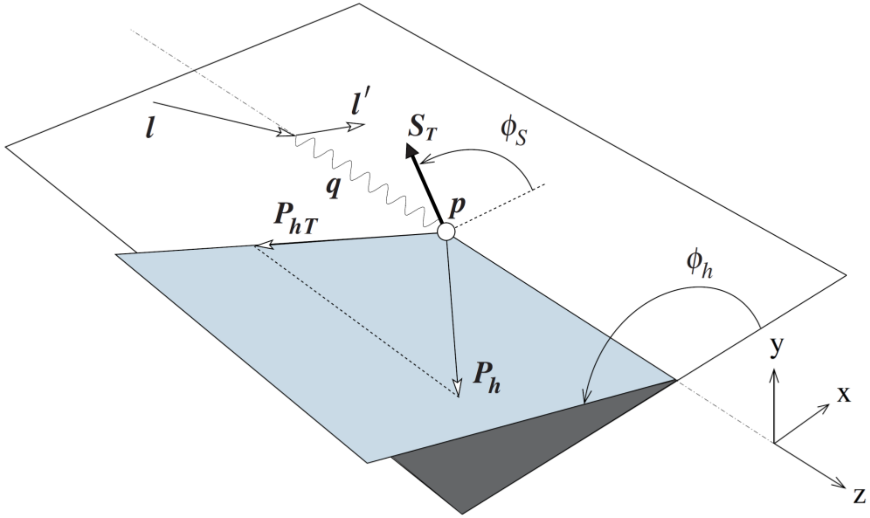
Cahn effect

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$

Cahn effect

***R. N. Cahn,* PLB 78 (1978)**



Cahn effect

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$

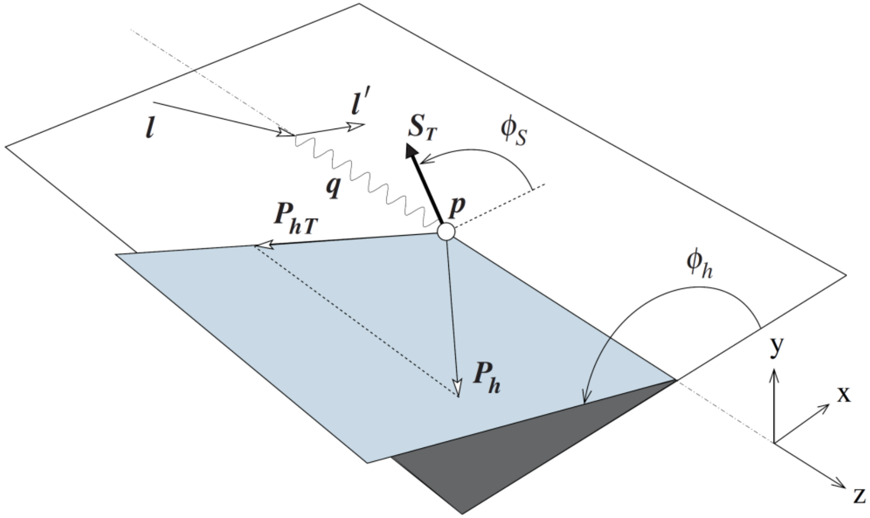
Cahn effect

***R. N. Cahn*, PLB 78 (1978)**

The point that there are azimuthal dependences which arise from the transverse momenta of the partons was clearly stated in this papers:

T.P. Cheng and A. Zee, Phys. Rev. D6 (1972) 885;
F. Ravndal, Phys. Lett. 43B (1973) 301.
R.L. Kingsley, Phys. Rev. D10 (1974) 1580;
A.M. Kotsinyan, Teor. Mat. Fiz. 24 (1975) 206;
Engl. transl. **Theor. Math. Phys. 24** (1976) 776.

A. Kotzinian On behalf of:
T.P. Cheng, A. Zee, F. Ravndal, R.L. Kingsley and himself



Cahn effect

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

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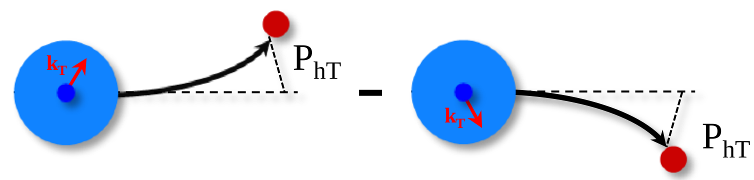


Cahn effect

***R. N. Cahn*, PLB 78 (1978)**

Kinematic effect: non-zero k_T induces an azimuthal modulation

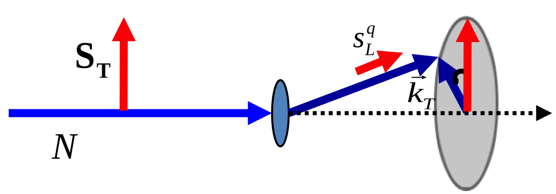
$$\hat{s} \simeq xs\left[1-2\sqrt{1-y}\,\frac{k_T}{Q}\cdot\cos\varphi_q\right]$$

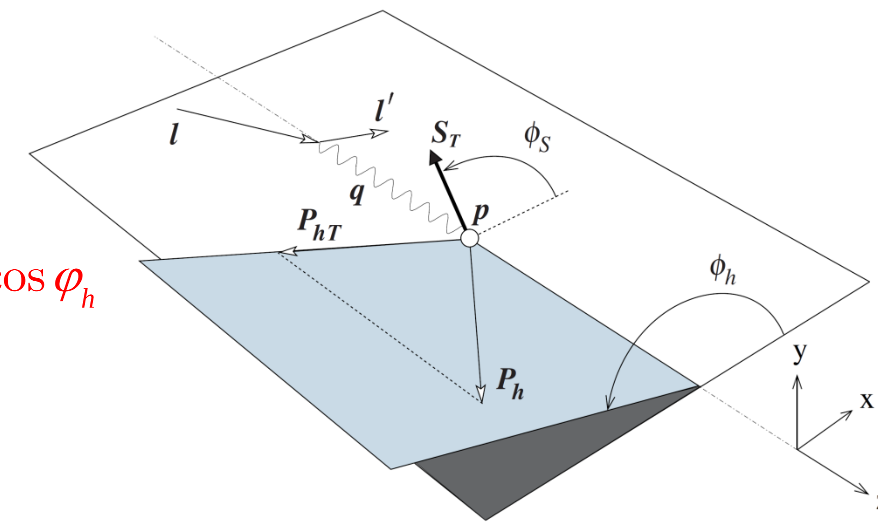
$$\hat{u} \simeq -xs(1-y)\left[1-\frac{2k_T}{Q\sqrt{1-y}}\cdot\cos\varphi_q\right]$$

$$\hat{t} = -Q^2 = -xys, \quad where \quad s=(l+P)^2$$

$$d\sigma^{lp\to l'hX} \propto d\sigma^{lq\to lq} \propto \frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$$

$$k_T \to \cos\varphi_q \to \cos\varphi_h$$

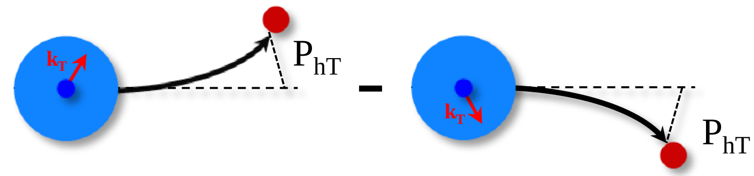




Cahn effect

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$



Kinematic effect: non-zero k_T induces an azimuthal modulation

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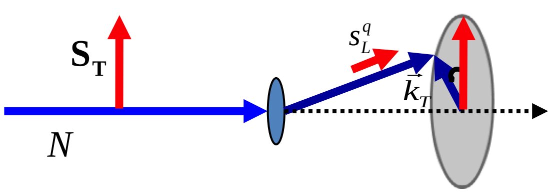
$$\hat{s} \simeq xs\left[1-2\sqrt{1-y}\,\frac{k_T}{Q}\cdot\cos\varphi_q\right]+O\left(\frac{k_T^2}{Q^2}\right)$$

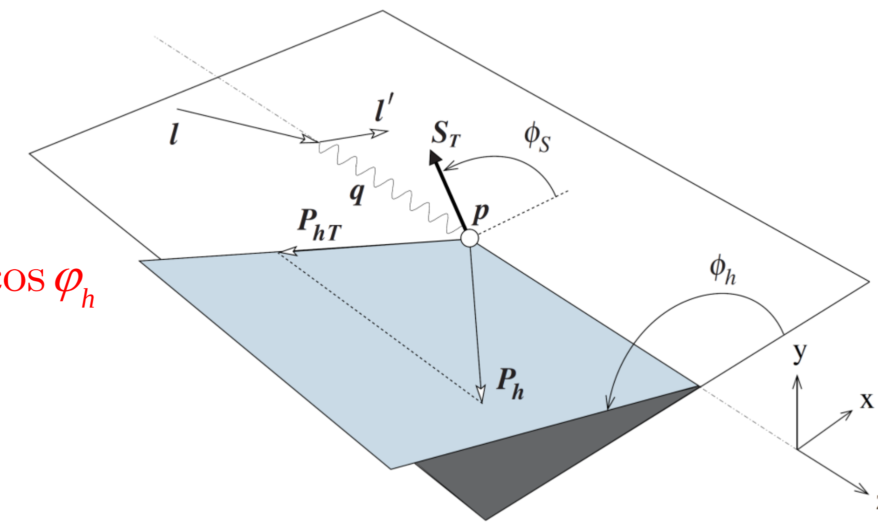
$$\hat{u} \simeq -xs(1-y)\left[1-\frac{2k_T}{Q\sqrt{1-y}}\cdot\cos\varphi_q\right]+O\left(\frac{k_T^2}{Q^2}\right)$$

$$\hat{t} = -Q^2 = -xys, \quad where \quad s=(l+P)^2$$

$$d\sigma^{lp\to l'hX} \propto d\sigma^{lq\to lq} \propto \frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$$

$$k_T \to \cos\varphi_q \to \cos\varphi_h$$



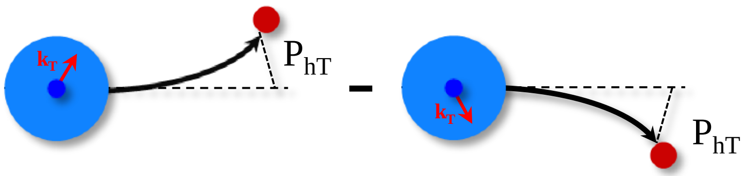


Cahn effect

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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

$$1+\cos\varphi_h \times \sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\dots$$



Cahn effect

***R. N. Cahn*, PLB 78 (1978)**

Kinematic effect: non-zero k_T induces an azimuthal modulation

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot \boldsymbol{p}_T}{M_h}\left(xhH_{1q}^{\perp h}+\frac{M_h}{M}f_1^q\frac{\tilde{D}_q^{\perp h}}{z}\right)-\frac{\hat{\boldsymbol{h}}\cdot \boldsymbol{k}_T}{M}\left(xf^{\perp q}D_{1q}^h+\frac{M_h}{M}h_1^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

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

$\hat{\boldsymbol{h}} = \vec{P}_{hT}/|\vec{P}_{hT}|$, $\boldsymbol{p}_T$ – *TM of the quark w.r.t. the direction of the produced hadron*

Cahn effect

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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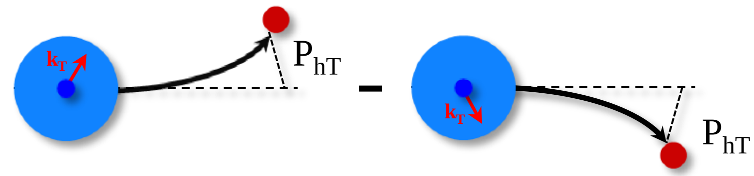
$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$



Cahn effect

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Kinematic effect: non-zero k_T induces an azimuthal modulation

***P. J. Mulders and R. D. Tangerman*,**
Nucl. Phys. B461 (1996) 197–237
***D. Boer, P. J. Mulders, and O. V. Teryaev*,**
Phys. Rev. D57 (1998) 3057–3064
***Bacchetta et al. JHEP** 0702:093,2007*

$$x\tilde{h}+\frac{k_T^2}{M^2}h_1^{\perp q} \quad\downarrow \qquad\qquad x f^{\perp q}+f_1^q \quad\downarrow$$

$$F_{UU}^{\cos\phi_h}=\frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(xhH_{1q}^{\perp h}+\frac{M_h}{M}f_1^q\frac{\tilde{D}_q^{\perp h}}{z}\right)-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(xf^{\perp q}D_{1q}^h+\frac{M_h}{M}h_1^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

$$\downarrow$$

$$F_{UU}^{\cos\phi_h}=\frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(\left(xh+\frac{k_T^2}{M^2}h_1^{\perp q}\right)H_{1q}^{\perp h}+\frac{M_h}{M}f_1^q\frac{\tilde{D}_q^{\perp h}}{z}\right)-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(\left(xf^{\perp q}+f_1^q\right)D_{1q}^h+\frac{M_h}{M}h_1^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

$$C[wfD]=x\sum_q e_q^2\int d^2\boldsymbol{k_T}d^2\boldsymbol{p_T}\delta^{(2)}\left(\boldsymbol{k_T}-\boldsymbol{p_T}-\boldsymbol{P_{hT}}/z\right)w\left(\boldsymbol{k_T},\boldsymbol{p_T}\right)f^q\left(x,\boldsymbol{k_T^2}\right)D_q^h\left(z,\boldsymbol{k_T^2}\right)$$

$\hat{\boldsymbol{h}}=\vec{P}_{hT}/\left|\vec{P}_{hT}\right|$, $\boldsymbol{p_T}$ – *TM of the quark w.r.t. the direction of the produced hadron*

Cahn effect

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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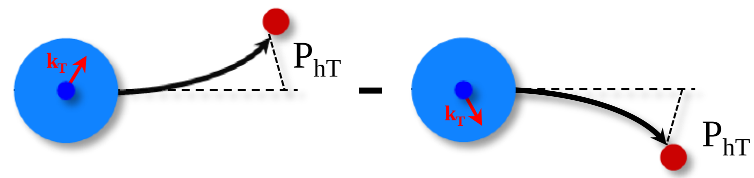
$$1+\cos\varphi_h \times \sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h} + \cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$



Cahn effect

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***D. Boer, P. J. Mulders, and O. V. Teryaev*, Phys. Rev. D57** (1998) 3057–3064
Bacchetta et al. JHEP *0702:093,2007*

$$x\tilde{h}+\frac{k_T^2}{M^2}h_1^{\perp q} \qquad\qquad x f^{\perp q}+f_1^q$$

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(xhH_{1q}^{\perp h}+\frac{M_h}{M}f_1^q\frac{\tilde{D}_q^{\perp h}}{z}\right)-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(xf^{\perp q}D_{1q}^h+\frac{M_h}{M}h_1^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

Wandzura-Wilczek approximation
neglecting quark-gluon-quark correlators
(setting all functions with a tilde to zero)

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h}\left(\left(x\tilde{h}+\frac{k_T^2}{M^2}h_1^{\perp q}\right)H_{1q}^{\perp h}+\frac{M_h}{M}f_1^q\frac{\tilde{D}_q^{\perp h}}{z}\right)-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}\left(\left(x\tilde{f}^{\perp q}+f_1^q\right)D_{1q}^h+\frac{M_h}{M}h_1^{\perp q}\frac{\tilde{H}_q^h}{z}\right)\right\}$$

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}C\left\{-\frac{\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}\right)k_T^2}{M_h M^2}h_1^{\perp q}H_{1q}^{\perp h}-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}f_1^q D_{1q}^h+\ldots\right\}$$

sub-leading Cahn+Boer-Mulders effect

$$C[wfD] = x\sum_q e_q^2\int d^2\boldsymbol{k_T}d^2\boldsymbol{p_T}\delta^{(2)}\left(\boldsymbol{k_T}-\boldsymbol{p_T}-\boldsymbol{P_{hT}}/z\right)w\left(\boldsymbol{k_T},\boldsymbol{p_T}\right)f^q\left(x,\boldsymbol{k_T^2}\right)D_q^h\left(z,\boldsymbol{k_T^2}\right)$$

$\hat{\boldsymbol{h}} = \vec{P}_{hT}/\left|\vec{P}_{hT}\right|$, $\boldsymbol{p_T}$ – TM of the quark w.r.t. the direction of the produced hadron

“Longitudinal” Cahn effect

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots+S_L\lambda\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi_h\times A_{LL}^{\cos\phi_h}+\ldots$$

Cahn effect

R. N. Cahn, **PLB 78 (1978)**

"Longitudinal" Cahn effect

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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

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Cahn effect

***R. N. Cahn*, PLB 78 (1978)**

Longitudinal Cahn effect

***Kotzinian et al.* Phys. Rev. D 74,** 074015 (2006)

$$\hat{s}\simeq xs\left[1-2\sqrt{1-y}\,\frac{k_T}{Q}\cdot\cos\varphi_q\right]+O\left(\frac{k_T^2}{Q^2}\right)$$

$$\hat{u}\simeq -xs(1-y)\left[1-\frac{2k_T}{Q\sqrt{1-y}}\cdot\cos\varphi_q\right]+O\left(\frac{k_T^2}{Q^2}\right)$$

$$\hat{t}=-Q^2=-xys,\quad where\quad s=(l+P)^2$$

$$d\sigma^{lp\to l'hX}\propto d\sigma^{lq\to lq}\propto\frac{\hat{s}^2+\hat{u}^2+\lambda\lambda_q\left(\hat{s}^2-\hat{u}^2\right)}{\hat{t}^2}$$

$$x\tilde{e}_L \downarrow \qquad x\tilde{g}_L^{\perp q}+\frac{m}{M}h_{1L}^{\perp q}+g_{1L}^q \downarrow$$

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

$\downarrow$

Wandzura-Wilczek approximation

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

+ neglecting m_q scaled terms

$\downarrow$

$$F_{LL}^{\cos\phi_h}=\frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}g_{1L}^q D_{1q}^h+\ldots\right\}$$

sub-leading effect

$$C[wfD]=x\sum_q e_q^2\int d^2\boldsymbol{k_T}d^2\boldsymbol{p_T}\delta^{(2)}\left(\boldsymbol{k_T}-\boldsymbol{p_T}-\boldsymbol{P_{hT}}/z\right)w\left(\boldsymbol{k_T},\boldsymbol{p_T}\right)f^q\left(x,\boldsymbol{k_T^2}\right)D_q^h\left(z,\boldsymbol{k_T^2}\right)$$

$\hat{\boldsymbol{h}}=\vec{P}_{hT}/\left|\vec{P}_{hT}\right|$, $\boldsymbol{p_T}$ – *TM of the quark w.r.t. the direction of the produced hadron*

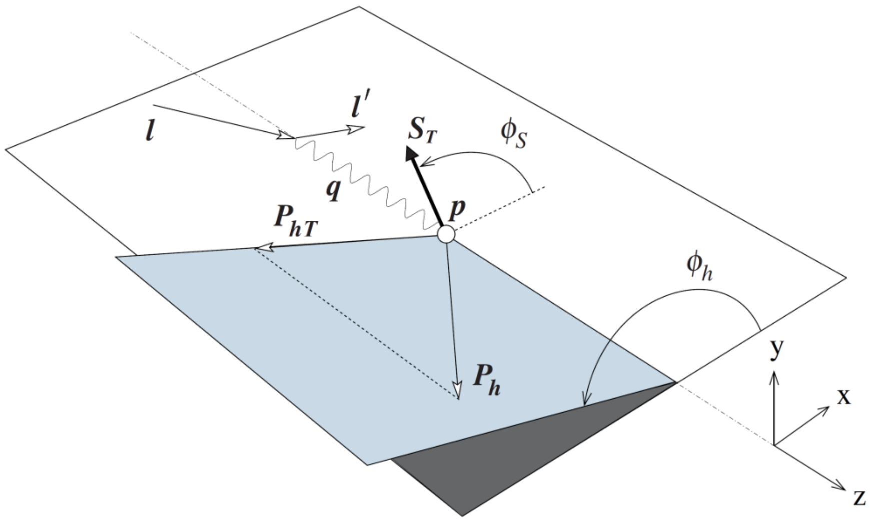
Boer-Mulders effect

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\underbrace{\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}}+\ldots$$

Boer-Mulders effect

D. Boer and P. J. Mulders, **PRD 57 (1998)**



Boer-Mulders effect

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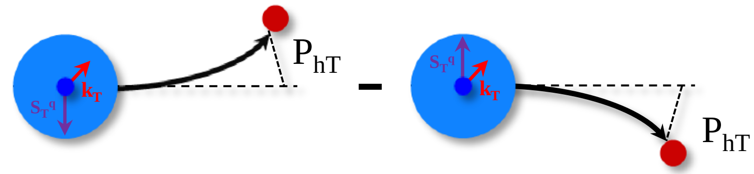
$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\dots$$

Boer-Mulders-Collins effect

***D. Boer and P. J. Mulders*, PRD 57 (1998)**

Boer-Mulders PDF Collins FF

$$F_{UU}^{\cos 2\phi_h} = C\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T\right)\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\right)-\boldsymbol{p}_T\cdot\boldsymbol{k}_T}{MM_h}h_1^{\perp q}H_{1q}^{\perp h}\right\}$$



Arises due to the correlations between quark transverse spin and intrinsic transverse momentum

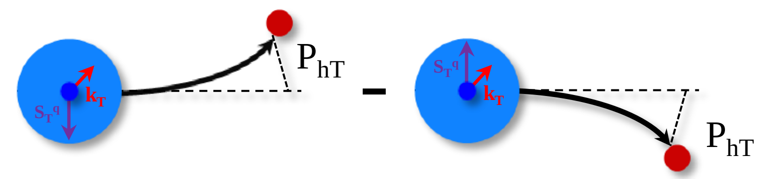
Is a leading order effect

Boer-Mulders effect

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$



Arises due to the correlations between quark transverse spin and intrinsic transverse momentum

Boer-Mulders-Collins effect

***D. Boer and P. J. Mulders*, PRD 57 (1998)**

Boer-Mulders PDF   Collins FF

$$F_{UU}^{\cos 2\phi_h} = C\left\{-\frac{2(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T)(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)-\boldsymbol{p}_T\cdot\boldsymbol{k}_T}{MM_h}h_1^{\perp q}H_{1q}^{\perp h}\right\}$$

Cahn effect

$$F_{UU}^{\cos 2\phi_h} = C\left\{-\frac{2(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T)(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)-\boldsymbol{p}_T\cdot\boldsymbol{k}_T}{MM_h}h_1^{\perp q}H_{1q}^{\perp h}\right\}+\left(\frac{M}{Q}\right)^2 C\left\{-\frac{2(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)^2-k_T^2}{M^2}f_1^q D_{1q}^h+\ldots\right\}$$

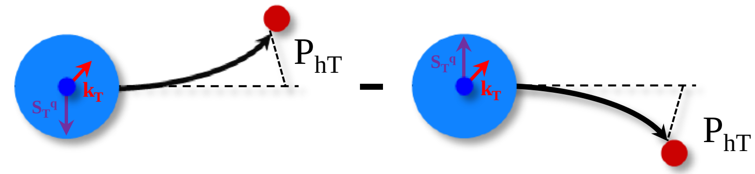
Boer-Mulders effect + twist-4 Cahn effect

Boer-Mulders effect

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\dots$$



Arises due to the correlations between quark transverse spin and intrinsic transverse momentum


Boer-Mulders-Collins effect

***D. Boer and P. J. Mulders*, PRD 57 (1998)**

Boer-Mulders PDF Collins FF

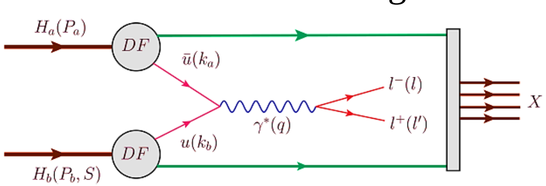
$$F_{UU}^{\cos 2\phi_h} = C\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T\right)\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\right)-\boldsymbol{p}_T\cdot\boldsymbol{k}_T}{MM_h}h_1^{\perp q}H_{1q}^{\perp h}\right\}$$

Cahn effect

$$F_{UU}^{\cos 2\phi_h} = C\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T\right)\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\right)-\boldsymbol{p}_T\cdot\boldsymbol{k}_T}{MM_h}h_1^{\perp q}H_{1q}^{\perp h}\right\}+\left(\frac{M}{Q}\right)^2 C\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\right)^2-k_T^2}{M^2}f_1^q D_{1q}^h+\dots\right\}$$

Boer-Mulders effect + twist-4 Cahn effect

can be accessed also through DY



SIDIS hermes COMPASS …

e^+e^- BELLE BABAR

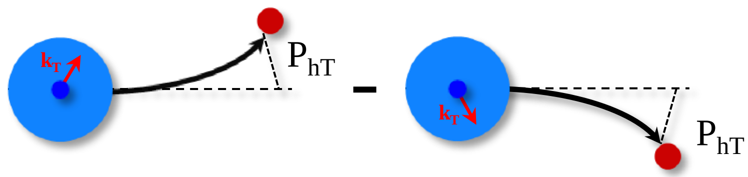
Cahn and Boer-Mulders effects

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\dots$$

Cahn effect

***R. N. Cahn,* PLB 78 (1978)**



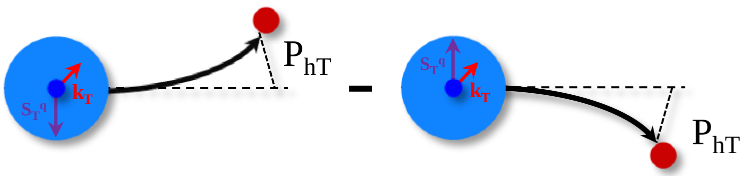
Cahn effect: kinematic effect arising due to the intrinsic transverse motion of quark

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}f_1^q D_{1q}^h - \frac{(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T)k_T^2}{M_h M^2}h_1^{\perp q}H_{1q}^{\perp h}\right\}$$

sub-leading Cahn + Boer-Mulders effects

Boer-Mulders effect

***D. Boer and P. J. Mulders,* PRD 57 (1998)**



Boer-Mulders effect: correlations between quark transverse spin and intrinsic transverse momentum

$$F_{UU}^{\cos 2\phi_h} = C\left\{-\frac{2(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T)(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)-\boldsymbol{p}_T\cdot\boldsymbol{k}_T}{MM_h}h_1^{\perp q}H_{1q}^{\perp h}\right\}+\left(\frac{M}{Q}\right)^2 C\left\{-\frac{2(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)^2-k_T^2}{M^2}f_1^q D_{1q}^h+\dots\right\}$$

Boer-Mulders effect + twist-4 Cahn effect

Cahn and Boer-Mulders effects

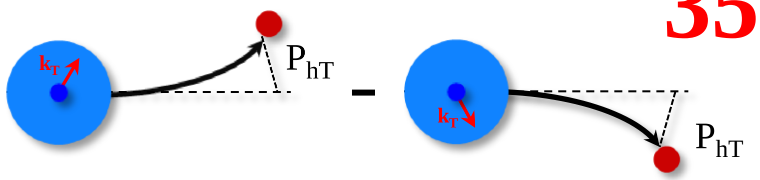
$$\frac{d\sigma}{dxdydzdP_{hT}^2 d\varphi_h d\psi} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots$$

35 years !!!

Cahn effect

***R. N. Cahn,* PLB 78 (1978)**



Cahn effect: kinematic effect arising due to the intrinsic transverse motion of quark

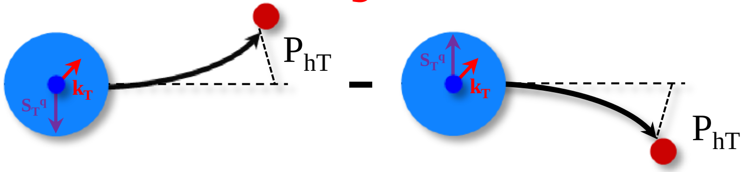
$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}f_1^{\,q}D_{1q}^h-\frac{\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}\right)k_T^2}{M_hM^2}h_1^{\perp q}H_{1q}^{\perp h}\right\}$$

sub-leading Cahn + Boer-Mulders effects

15 years !!!

Boer-Mulders effect

***D. Boer and P. J. Mulders,* PRD 57 (1998)**



Boer-Mulders effect: correlations between quark transverse spin and intrinsic transverse momentum

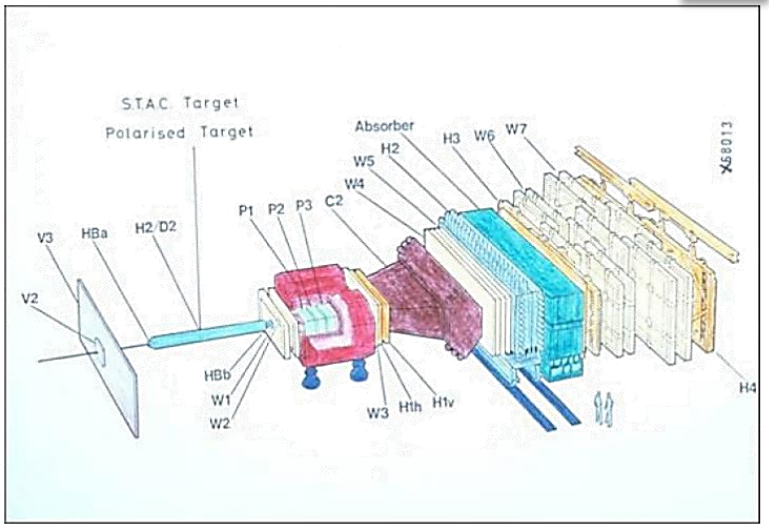
$$F_{UU}^{\cos 2\phi_h} = C\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}\right)\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}\right)-\boldsymbol{p_T}\cdot\boldsymbol{k_T}}{MM_h}h_1^{\perp q}H_{1q}^{\perp h}\right\}+\left(\frac{M}{Q}\right)^2C\left\{-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}\right)^2-k_T^2}{M^2}f_1^{\,q}D_{1q}^h+\ldots\right\}$$

Boer-Mulders effect + twist-4 Cahn effect

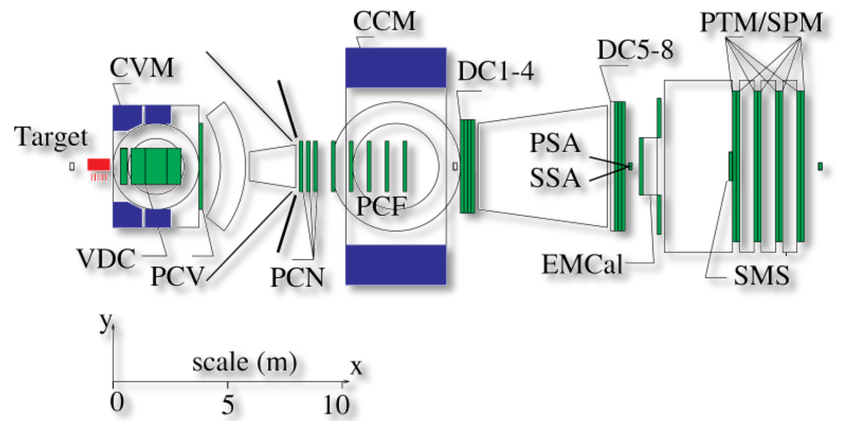
Experimental data: part I
"First" results (year $\leq$ 2009)

Experiments in last 35 years: part I

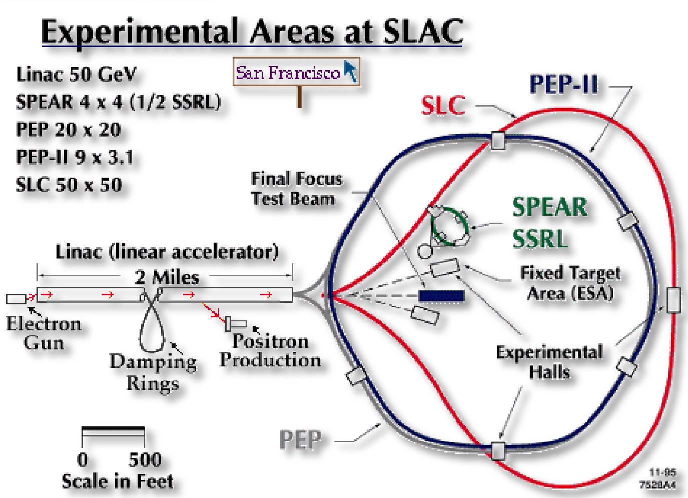
EMC CERN (μ-p, μ-d) @ 280 GeV



Fermilab E665 (μ-p, μ-d) @ 490 GeV

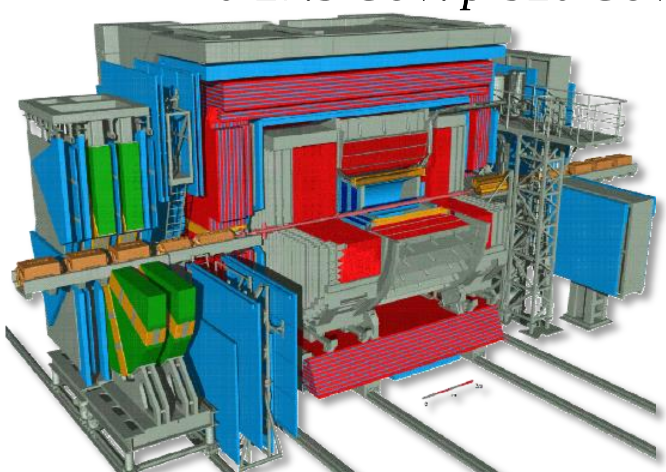


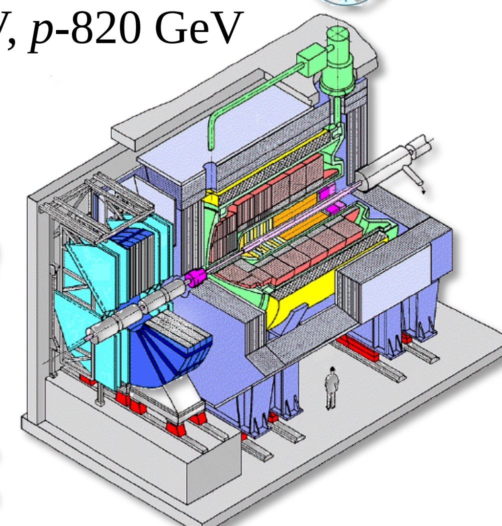
SLAC (e-p, e-d) @ 19.5 GeV



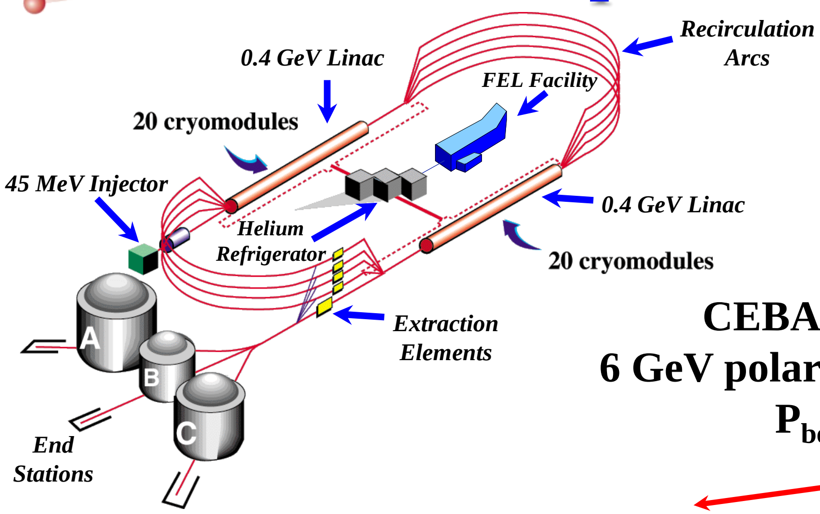
ZEUS *and* H1 e-p collider HERA, DESY

e-27.5 GeV: p-920 GeV, p-820 GeV

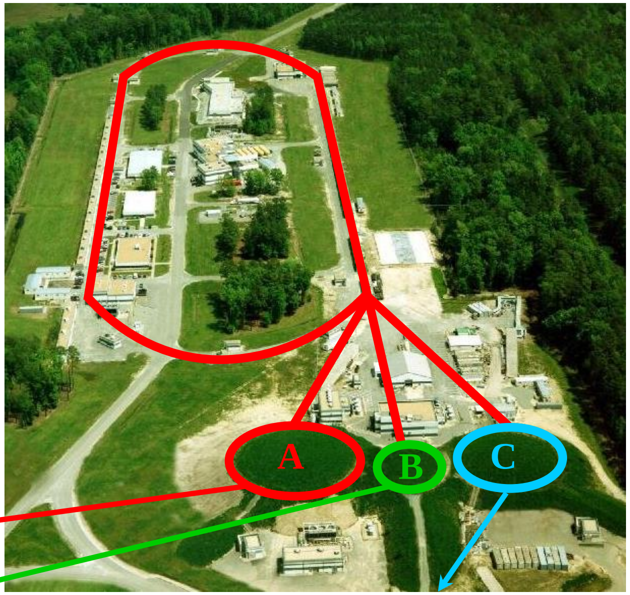




Jefferson Lab experimental halls

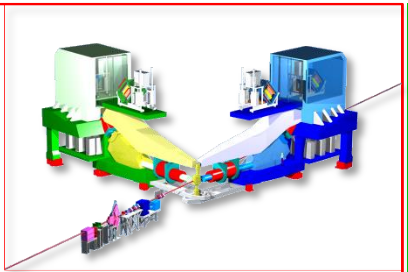


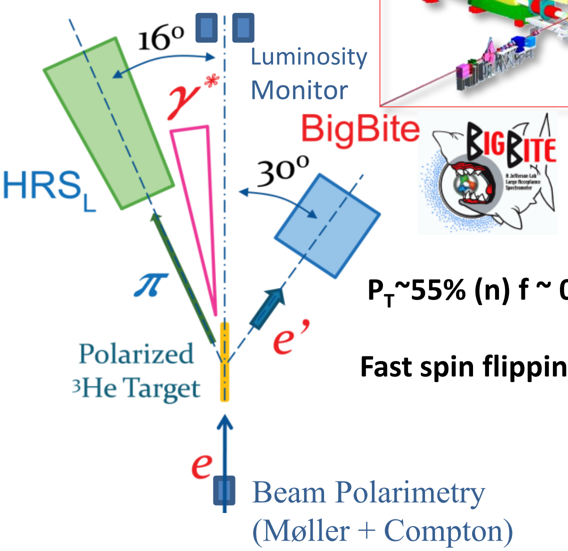
CEBAF accelerator
6 GeV polarized electron beam
$P_{beam} \approx 85\%$



Hall A: two HRS'

$^3\overrightarrow{He}$ gas target (40 cm)



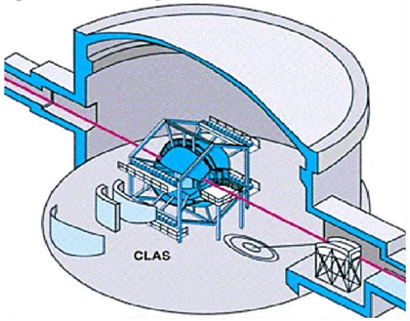


P_T~55% (n) f ~ 0.1-0.3

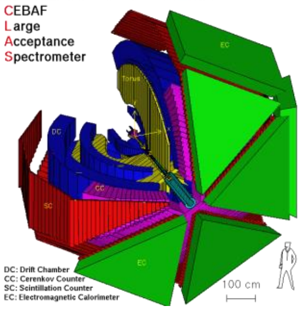
Fast spin flipping (30 Hz)

Hall B: CLAS

$N\vec{H}_3$ and $N\vec{D}_3$ HD-Ice targets

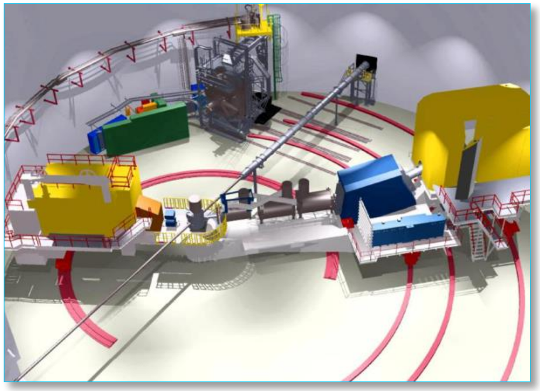


Polarizations
Beam: ~80%
NH_3 proton 80%
ND_3 ~30%
HD-Ice
(H-75%,D-25%)
f ~ 0.15

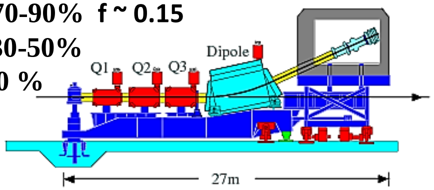


Hall C: HMS+SOS

$N\vec{H}_3$ and $N\vec{D}_3$ LiD targets



Polarizations
NH3: ~70-90% f ~ 0.15
ND3: ~30-50%
LiD: ~30 %



Experiments in last 35 years: first results

(SLAC) Phys. Rev. Lett. 31, 786 (1973)
(EMC) Phys. Lett. B 130 (1983) 118,
(EMC) Z. Phys. C34 (1987) 277
(EMC) Z. Phys. C52, 361 (1991).
(E665) Phys. Rev. D48 (1993) 5057
(ZEUS) Eur. Phys. J. C11, 251 (1999)
(ZEUS) Phys. Lett. B 481, 199 (2000)
(H1) Phys. Lett. B654, 148 (2007)

EMC, E665, H1 and ZEUS	High beam energy, broad kinematic range No hadron type and charge distinction (averaged over any possible flavor dependence) EMC, ZEUS – only hydrogen target E665 – combined hydrogen and deuterium targets Not enough statistics to look at differential x-sections in more than two kinematic variables
SLAC, JLab hall C	Relatively low beam energy, restricted kinematic range x-sections measured only at a few kinematic points
CLAS Collaboration (JLab hall B)	Relatively low beam energy access to 4D multi-differential x-section

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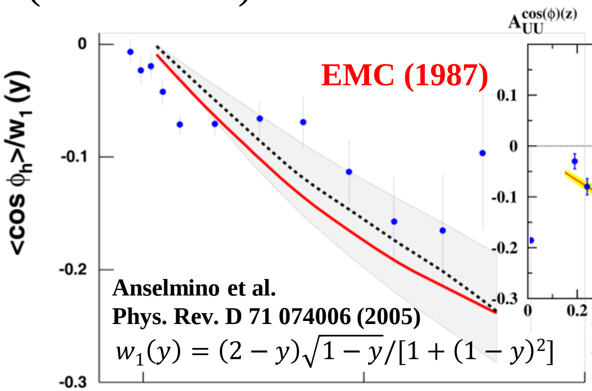
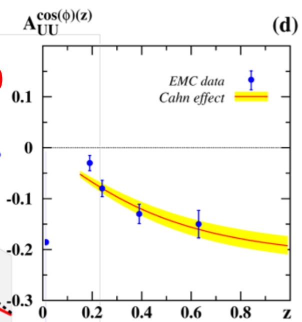
EMC, E665, H1 and ZEUS
- High beam energy, broad kinematic range
- No hadron type and charge distinction (averaged over any possible flavor dependence)
- EMC, ZEUS – only hydrogen target
- E665 – combined hydrogen and deuterium targets
- Not enough statistics to look at differential x-sections in more than two kinematic variables

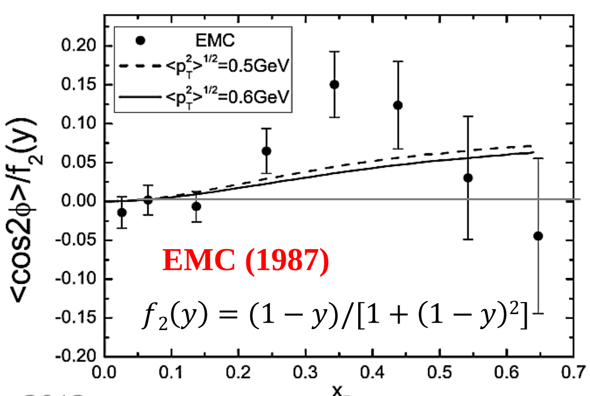
SLAC, JLab hall C
- Relatively low beam energy, restricted kinematic range
- x-sections measured only at a few kinematic points

CLAS Collaboration (JLab hall B)
- Relatively low beam energy
- access to 4D multi-differential x-section





P. Schweitzer et al.
Phys. Rev. D 81, 094019



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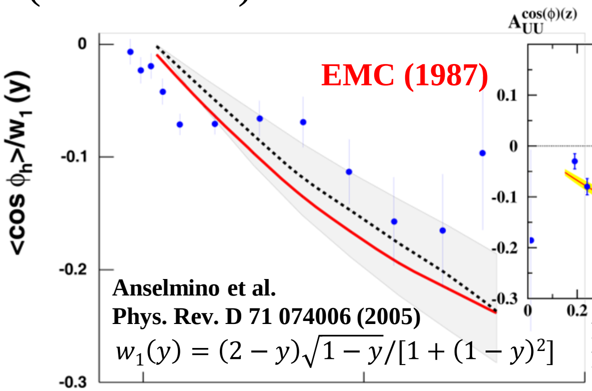
(averaged over any possible flavor dependence)
EMC, ZEUS – only hydrogen target
E665 – combined hydrogen and deuterium targets
Not enough statistics to look at differential x-sections in more than two kinematic variables

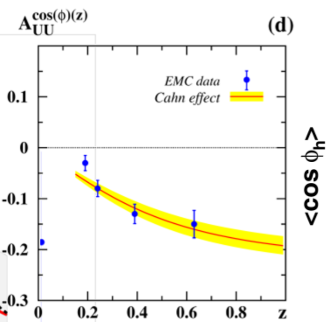
SLAC, JLab hall C

Relatively low beam energy, restricted kinematic range
x-sections measured only at a few kinematic points

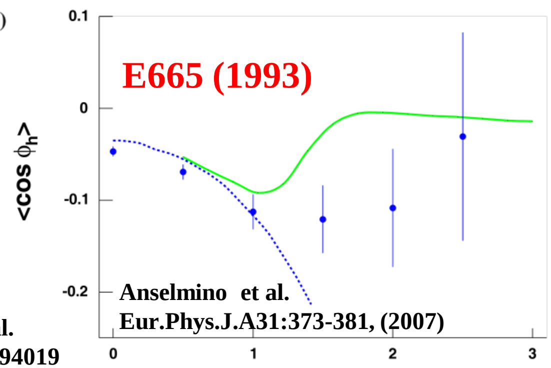
CLAS Collaboration (JLab hall B)

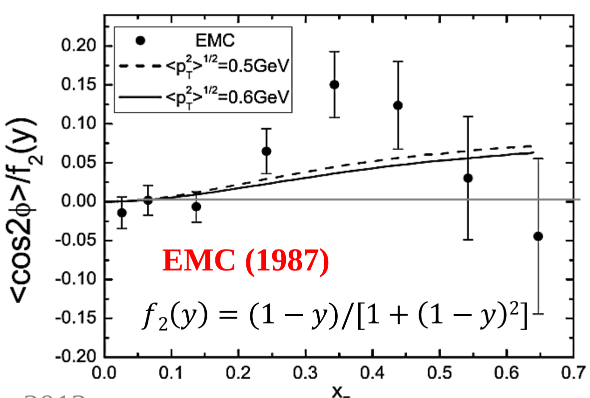
Relatively low beam energy
access to 4D multi-differential x-section

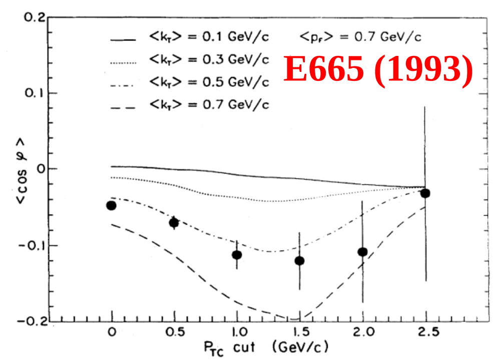




P. Schweitzer et al.
Phys. Rev. D 81, 094019





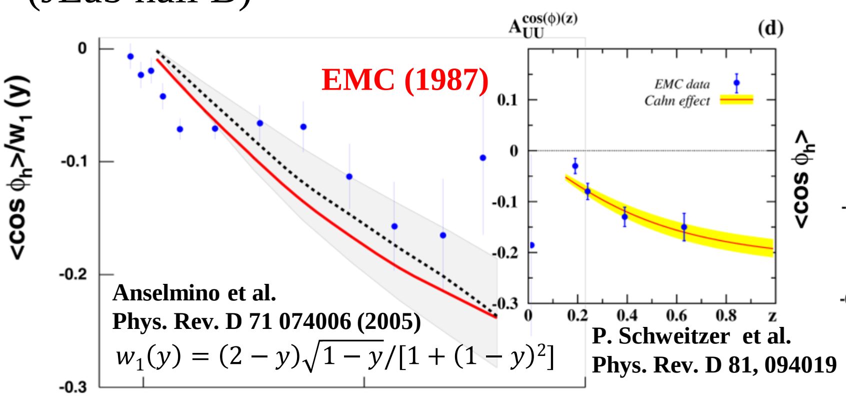


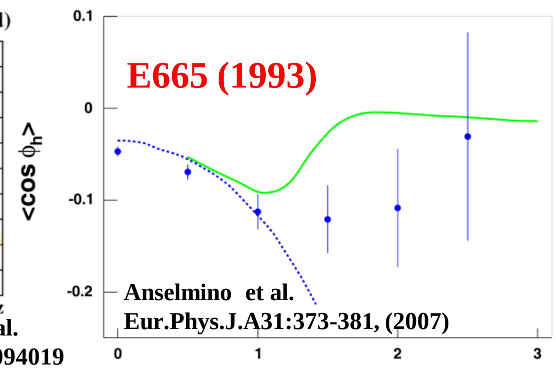
J. Chay, S. D. Ellis, and J. W. Stirling,
Phys. Rev. D 45, 46 (1992), Phys. Lett. B 269, 175 (1991).

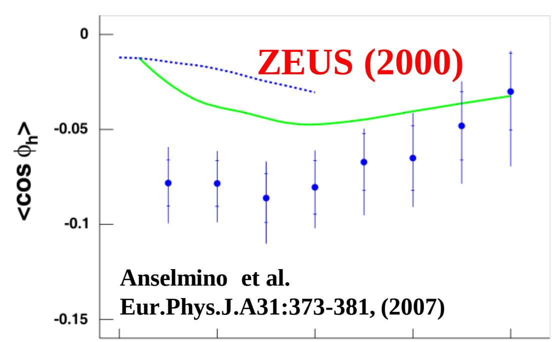
Experiments in last 35 years: first results

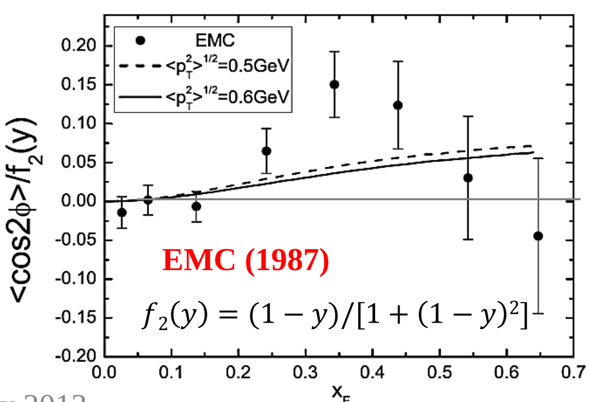
(SLAC) **Phys. Rev. Lett. 31,** 786 (1973)
(EMC) **Phys. Lett. B** 130 (1983) 118,
(EMC) **Z. Phys. C34** (1987) 277
(EMC) **Z. Phys. C52**, 361 (1991).
(E665) **Phys. Rev. D48** (1993) 5057
(ZEUS) **Eur. Phys. J. C11**, 251 (1999)
(ZEUS) **Phys. Lett. B 481,** 199 (2000)
(H1) **Phys. Lett. B654,** 148 (2007)

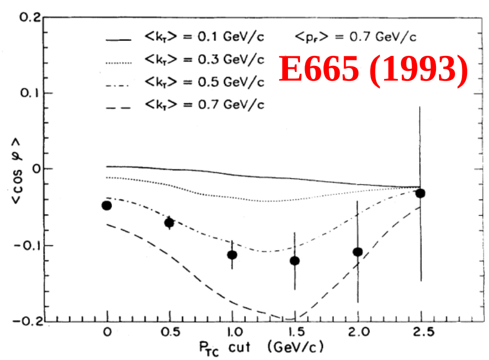
EMC, E665, H1 and ZEUS	High beam energy, broad kinematic range No hadron type and charge distinction (averaged over any possible flavor dependence) EMC, ZEUS – only hydrogen target E665 – combined hydrogen and deuterium targets Not enough statistics to look at differential x-sections in more than two kinematic variables
SLAC, JLab hall C	Relatively low beam energy, restricted kinematic range x-sections measured only at a few kinematic points
CLAS Collaboration (JLab hall B)	Relatively low beam energy access to 4D multi-differential x-section



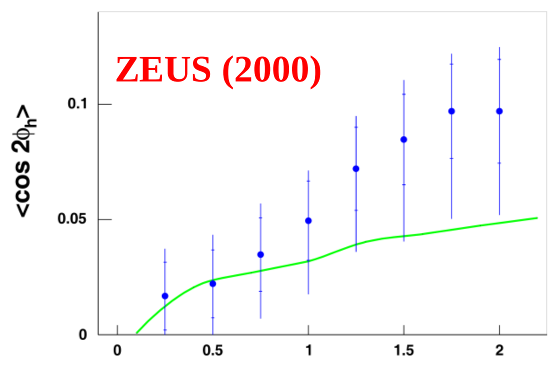








J. Chay, S. D. Ellis, and J. W. Stirling,
Phys. Rev. D 45, 46 (1992), Phys. Lett. B 269, 175 (1991).



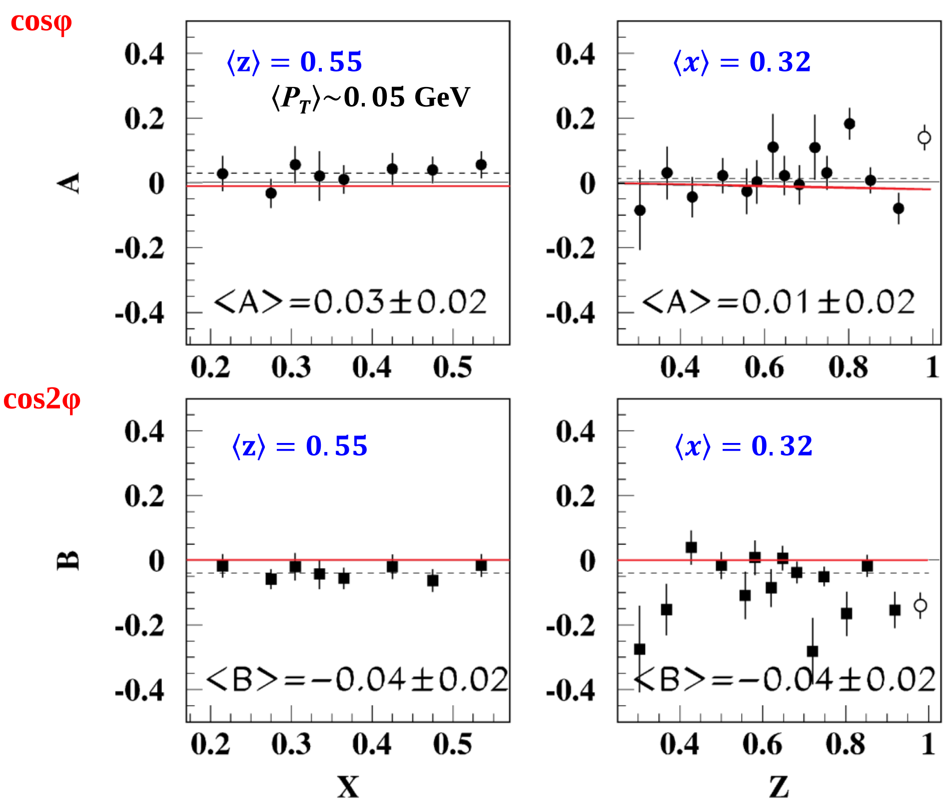
Anselmino et al.
Eur.Phys.J.A31:373-381, (2007)

JLab 6: Hall C results

Jefferson Lab

H. Mkrtchyan et al., **Phys. Lett. B** 665, 20 (2008).

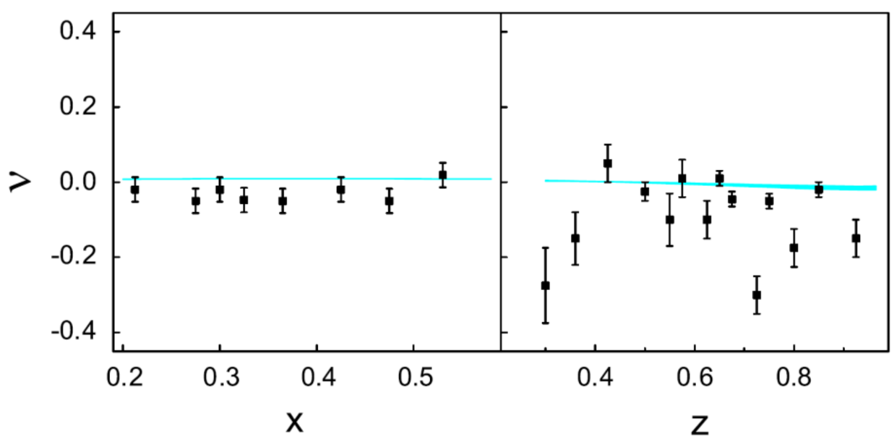
Kinematics:
$2 < Q^2 < 4$ (GeV/c)^2; $0.2 < x < 0.5$; $0.3 < z < 1$
$P_{hT}^2 < 0.2$ (GeV/c)^2



Semi-inclusive electro-production of charged pions ($\pi\pm$) from both proton and deuteron targets, using 5.5 GeV *electron* beam

Small effects, consistent with theoretical predictions
Amplitudes are averaged over $\pi+$ and $\pi-$ detected from proton and deuteron targets

Zhang et al. **Phys. Rev. D78**:034035, 2008



Systematic errors are estimated at ~0.03 on both A and B

Solid red lines are the theoretical predictions:
***R.N. Cahn*, Phys. Lett. B 78** (1978) 269**;**
***R.N. Cahn*, Phys. Rev. D 40** (1989) 3107

Ingridients:
- Boer-Mulders functions parameterized from unpolarized *p D* Drell-Yan data by the FNAL E866/NuSea Collaboration
- combined with extracted Collins functions from
  ***M. Anselmino et. al*, Phys. Rev. D 75,** 054032 (2007).

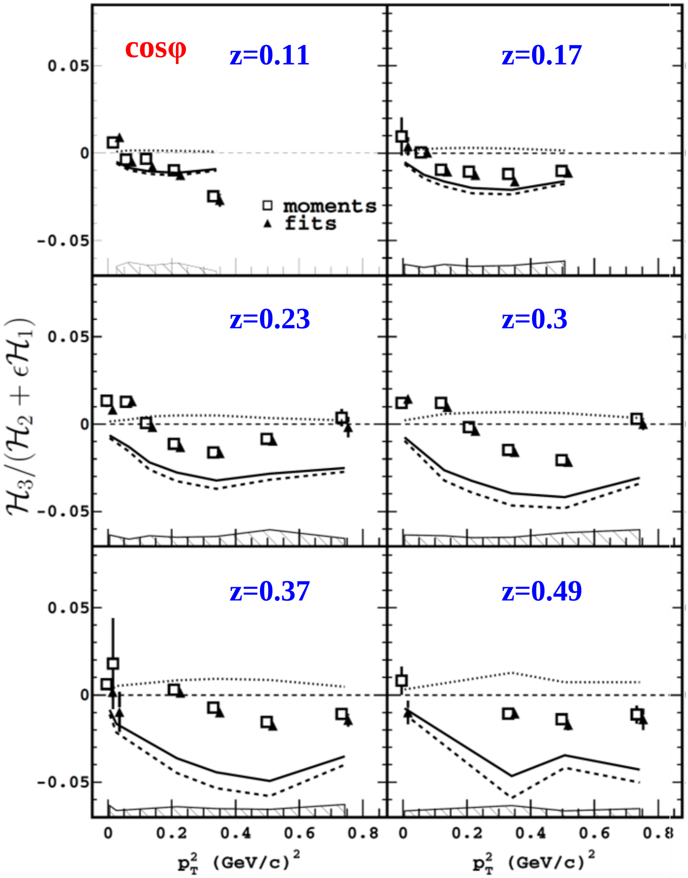
CLAS (JLab hall B) results

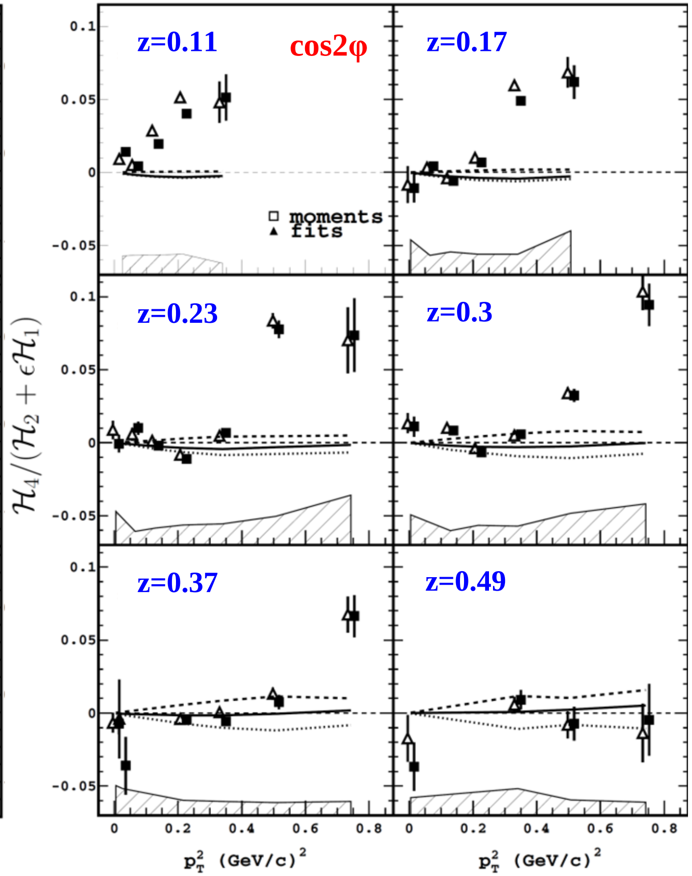
Jefferson Lab

M. Osipenko et al. **(CLAS Collaboration)**
Phys.Rev.D80:032004,2009

Positive pions

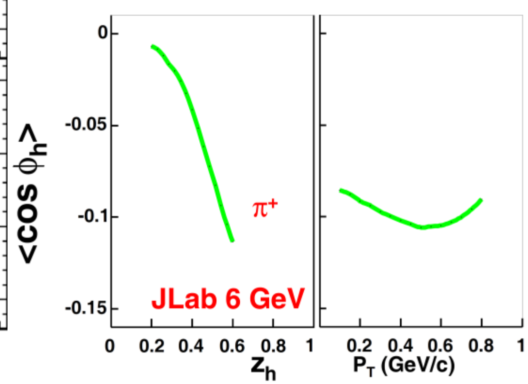
$1.4 < Q^2 < 7$ (GeV/c)^2
$0.15 < x < 1$
$0.07 < z < 1$
$0.005 < P_{hT}^2 < 1.5$ (GeV/c)^2
Beam energy 5.75 GeV





cosφ amplitude **(**nonzero**)**
is in strong disagreement with the theoretical predictions

cos2φ amplitude
is compatible with zero except low z region where it is positive



Theoretical predictions: Cahn effect + Berger effect
***R. N. Cahn*, Phys. Rev. D40,** 3107 (1989).
***M. Anselmino et al.*, Phys. Rev. D71,** 074006 (2005).
***A. Brandenburg, V. V. Khoze, and D. Mueller*, Phys. Lett. B347,** 413 (1995).

Curves for Cahn contribution only
Anselmino et al. Eur. Phys. J. A 31, 373-381 (2007)

Experimental data: part I

“First” results (year $\leq$ 2009)

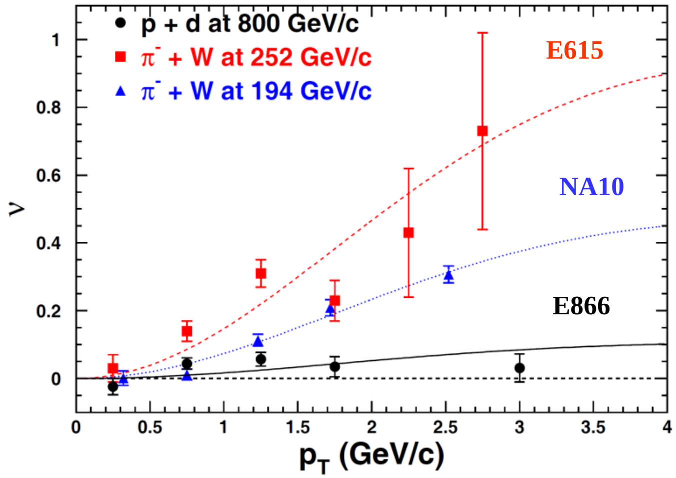
Boer-Mulders PDF from the Drell-Yan data

Boer-Mulders from Drell-Yan

S. Arnold, A. Metz and M. Schlegel, **Phys. Rev. D 79**, 034005 (2009).

DY x-section (single-polarized)

$$\frac{d\sigma}{d\Omega}=\frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U\left\{\begin{array}{l}\left(1+D_{[\sin 2\theta]}A_U^{\cos\varphi}\cos\varphi+D_{[\sin^2\theta]}A_U^{\cos 2\varphi}\cos 2\varphi\right)\\ +S_L\left(D_{[\sin 2\theta]}A_L^{\sin\varphi}\sin\varphi+D_{[\sin^2\theta]}A_L^{\sin 2\varphi}\sin 2\varphi\right)\\ \pm\left|\vec{S}_T\right|\left[\begin{array}{l}\left(D_{[1]}A_T^{\sin\varphi_S}+D_{[\cos^2\theta]}\tilde{A}_T^{\sin\varphi_S}\right)\sin\varphi_S\\ +D_{[\sin 2\theta]}\left(A_T^{\sin(\varphi+\varphi_S)}\sin(\varphi+\varphi_S)+A_T^{\sin(\varphi-\varphi_S)}\sin(\varphi-\varphi_S)\right)\\ +D_{[\sin^2\theta]}\left(A_T^{\sin(2\varphi+\varphi_S)}\sin(2\varphi+\varphi_S)+A_T^{\sin(2\varphi-\varphi_S)}\sin(2\varphi-\varphi_S)\right)\end{array}\right]\end{array}\right\}$$



$$\hat{\sigma}_U=\left(F_U^1+F_U^2\right)\left(1+A_U^1\cos^2\theta\right);\qquad D_{[f(\theta)]}=\frac{f(\theta)}{1+A_U^1\cos^2\theta};\lambda=A_U^1,\mu=A_U^{\cos\varphi},\nu=2A_U^{\cos 2\varphi}\propto h_{1q}^{\perp}\otimes h_{1\bar{q}}^{\perp}$$

Experimental results:

NA10 Collaboration (***π⁻ N @ 194 GeV/c***)
S. Falciano et al., **Z. Phys. C 31**,513 (1986).
M. Guanziroli et al., **Z. Phys. C 37**, 545 (1988).

E615 Collaboration (***π⁻ N @ 252 GeV/c***)
J. S. Conway et al., **Phys. Rev. D 39**, 92 (1989).

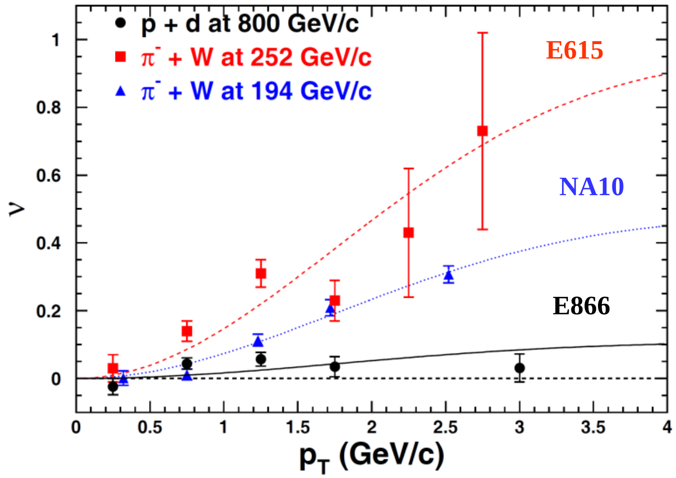
E866/NuSea Collaboration at **FNAL** ***(pd, pp @ 194 GeV/c)***
pd **-FNAL-E866/NuSea**, L. Y. Zhu et al., **Phys. Rev. Lett. 99**, 082301 (2007
pp **- FNAL E866/NuSea**, L. Y. Zhu et al., **Phys. Rev. Lett. 102**, 182001 (2009)

Boer-Mulders from Drell-Yan

S. Arnold, A. Metz and M. Schlegel, **Phys. Rev. D 79**, 034005 (2009).

DY x-section (single-polarized)

$$\frac{d\sigma}{d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U \left\{ \begin{array}{l} \left(1 + D_{[\sin 2\theta]} A_U^{\cos\varphi}\cos\varphi + D_{[\sin^2\theta]} A_U^{\cos 2\varphi}\cos 2\varphi\right) \\ + S_L\left(D_{[\sin 2\theta]}A_L^{\sin\varphi}\sin\varphi + D_{[\sin^2\theta]}A_L^{\sin 2\varphi}\sin 2\varphi\right) \\ \pm\left|\vec{S}_T\right| \left[\begin{array}{l} \left(D_{[1]}A_T^{\sin\varphi_S} + D_{[\cos^2\theta]}\tilde{A}_T^{\sin\varphi_S}\right)\sin\varphi_S \\ + D_{[\sin 2\theta]}\left(A_T^{\sin(\varphi+\varphi_S)}\sin(\varphi+\varphi_S) + A_T^{\sin(\varphi-\varphi_S)}\sin(\varphi-\varphi_S)\right) \\ + D_{[\sin^2\theta]}\left(A_T^{\sin(2\varphi+\varphi_S)}\sin(2\varphi+\varphi_S) + A_T^{\sin(2\varphi-\varphi_S)}\sin(2\varphi-\varphi_S)\right) \end{array}\right] \end{array}\right\}$$



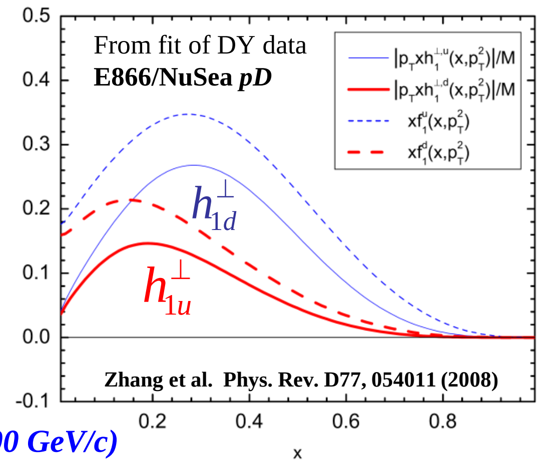
$$\hat{\sigma}_U = \left(F_U^1 + F_U^2\right)\left(1 + A_U^1\cos^2\theta\right); \quad D_{[f(\theta)]} = \frac{f(\theta)}{1 + A_U^1\cos^2\theta}; \lambda = A_U^1, \mu = A_U^{\cos\varphi}, \nu = 2A_U^{\cos 2\varphi} \propto h_{1q}^{\perp}\otimes h_{1\bar{q}}^{\perp}$$

Experimental results:

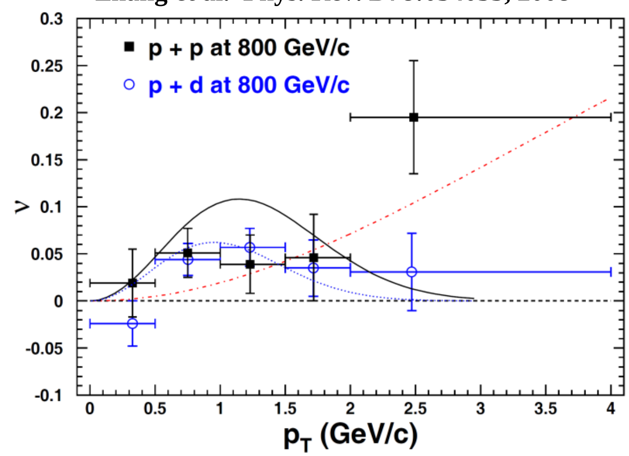
NA10 Collaboration ***($\pi^- N$ @ 194 GeV/c)***
S. Falciano et al., **Z. Phys. C 31**,513 (1986).
M. Guanziroli et al., **Z. Phys. C 37**, 545 (1988).

E615 Collaboration ***($\pi^- N$ @ 252 GeV/c)***
J. S. Conway et al., **Phys. Rev. D 39**, 92 (1989).

E866/NuSea Collaboration at **FNAL** ***(pd, pp @ 800 GeV/c)***
pd **-FNAL-E866/NuSea**, L. Y. Zhu et al., **Phys. Rev. Lett. 99**, 082301 (2007
pp - **FNAL E866/NuSea**, L. Y. Zhu et al., **Phys. Rev. Lett. 102**, 182001 (2009)



Theroretical curves are from:
Zhang et al. Phys. Rev. D78:034035, 2008

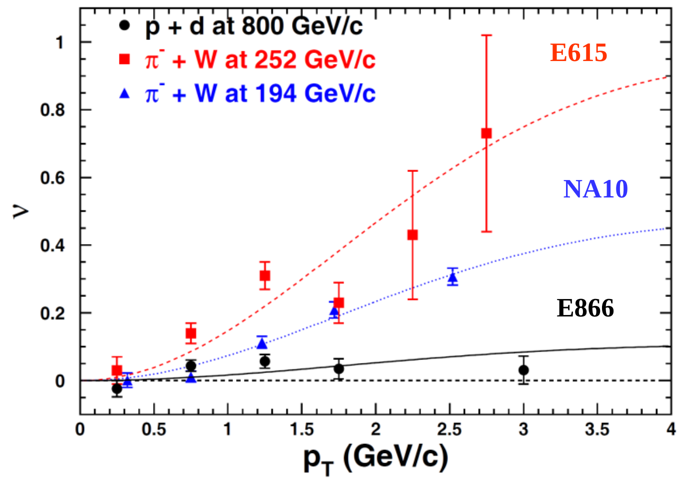


Boer-Mulders from Drell-Yan

S. Arnold, A. Metz and M. Schlegel, **Phys. Rev. D 79**, 034005 (2009).

DY x-section (single-polarized)

$$\frac{d\sigma}{d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U \left\{ \begin{aligned} &\left(1 + D_{[\sin 2\theta]} A_U^{\cos\varphi} \cos\varphi + D_{[\sin^2\theta]} A_U^{\cos 2\varphi} \cos 2\varphi\right) \\ &+ S_L \left(D_{[\sin 2\theta]} A_L^{\sin\varphi} \sin\varphi + D_{[\sin^2\theta]} A_L^{\sin 2\varphi} \sin 2\varphi \right) \\ &\pm |\vec{S}_T| \left[\begin{aligned} &\left(D_{[1]} A_T^{\sin\varphi_S} + D_{[\cos^2\theta]} \tilde{A}_T^{\sin\varphi_S} \right) \sin\varphi_S \\ &+ D_{[\sin 2\theta]} \left(A_T^{\sin(\varphi+\varphi_S)} \sin(\varphi+\varphi_S) + A_T^{\sin(\varphi-\varphi_S)} \sin(\varphi-\varphi_S) \right) \\ &+ D_{[\sin^2\theta]} \left(A_T^{\sin(2\varphi+\varphi_S)} \sin(2\varphi+\varphi_S) + A_T^{\sin(2\varphi-\varphi_S)} \sin(2\varphi-\varphi_S) \right) \end{aligned} \right] \end{aligned} \right\}$$



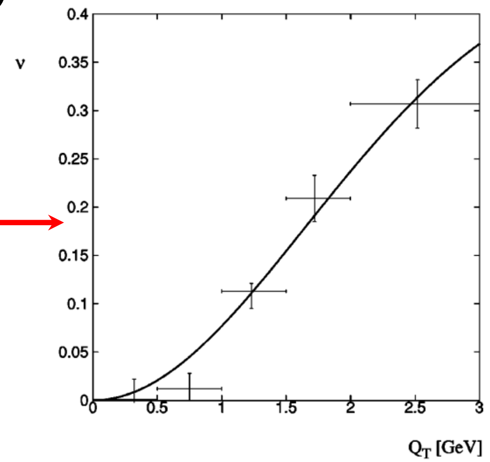
$$\hat{\sigma}_U = \left(F_U^1 + F_U^2\right)\left(1 + A_U^1 \cos^2\theta\right); \quad D_{[f(\theta)]} = \frac{f(\theta)}{1 + A_U^1 \cos^2\theta}; \lambda = A_U^1, \mu = A_U^{\cos\varphi}, \nu = 2A_U^{\cos 2\varphi} \propto h_{1q}^{\perp} \otimes h_{1\bar{q}}^{\perp}$$

***D. Boer*, Phys. Rev. D 60,** 014012 (1999)

"crude" model for the BM function of the pion from the fit of the NA10 data

$$h_1^{\perp a}(x, \boldsymbol{p}_T^2) = \frac{\alpha_T}{\pi} c_H^a \frac{M_C M_H}{\boldsymbol{p}_T^2 + M_C^2} e^{-\alpha_T \boldsymbol{p}_T^2} f_1(x)$$

$$M_C = 2.3 \;\; \text{GeV}, \;\; c_H^a = 1 \;\; \text{and} \;\; \alpha_T = 1 \;\; \text{GeV}^{-2},$$

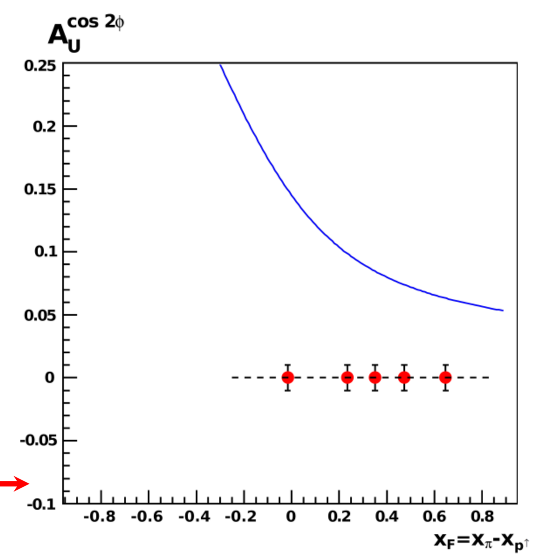


+

The parameterization of the BM for the proton from

Zhang et al. Phys. Rev. D77, 054011 (2008)

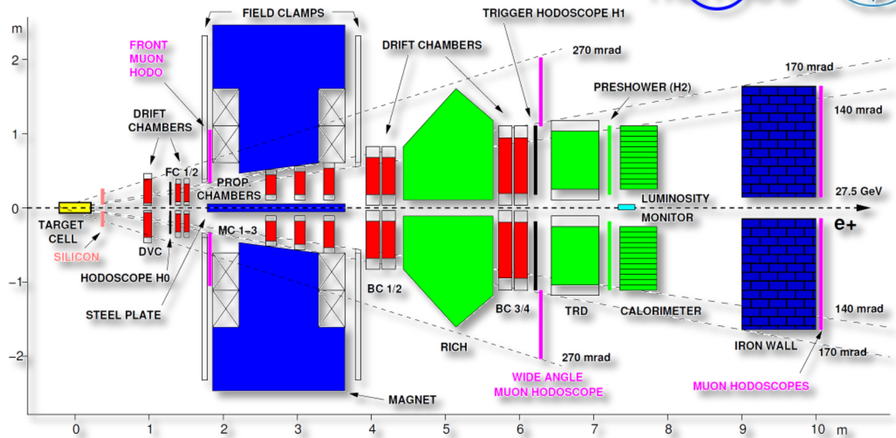
For the $A_U^{\cos 2\varphi}$ at COMPASS



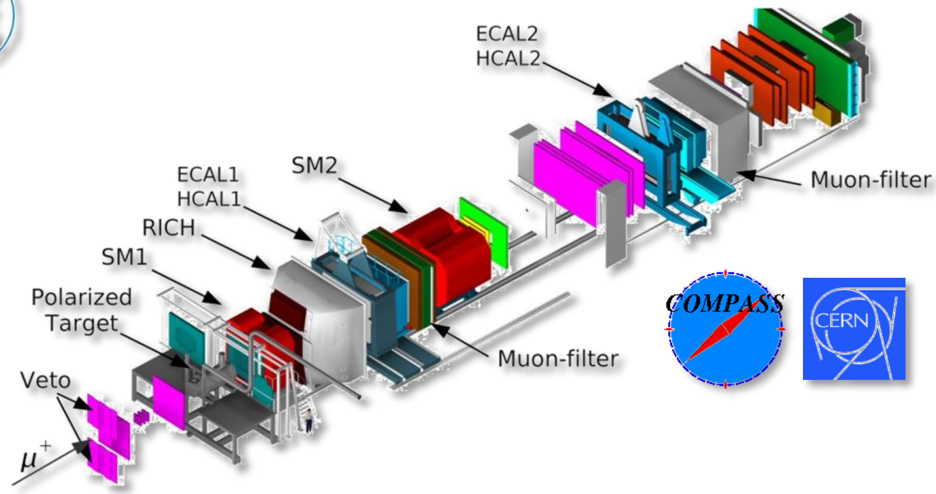
Experimental data: part II
Recent results

Experiments in last 35 years: part II

HERA MEasurement of Spin



COmmon Muon Proton Apparatus for Structure and Spectroscopy



Location: DESY, HERA

Beam: *e^+/e^-, polarized (both helicity states)(<60%), 27.5 GeV*

Target: *Gaseous target (H/D)*

- H/D Polarization (L & T) ~ 70-85%, f ~ 1
- Direct access to hydrogen or deuterium

Fast spin reversal (<1s)

- Same acceptance for different polarization states
- single cell configuration
- Hydrogen - measurements only with transverse polarization
- Deuterium - both transverse and longitudinal polarization measurements

Location: CERN SPS North Area. (2-stage spectrometer LAS-SAS)

Beam: *μ^+, longitudinally polarized (~80%), 160 GeV*

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

- ^6LiD Polarization (L & T) ~ 50%, f ~ 0.38
- NH_3 Polarization (L & T) ~ 80%, f ~ 0.14

2-cell target configuration for ^6LiD and 3-cell for NH_3

Neighboring cells are polarized in opposite directions

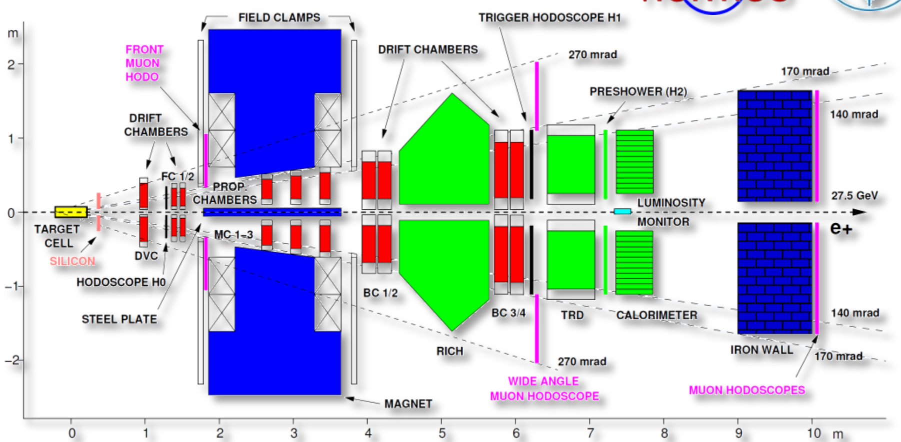
- Data is collected simultaneously for the two target spin orientations
- Spin reversal after each ~4-5 days
- Such a construction allows to reduce systematic effects due to the acceptance

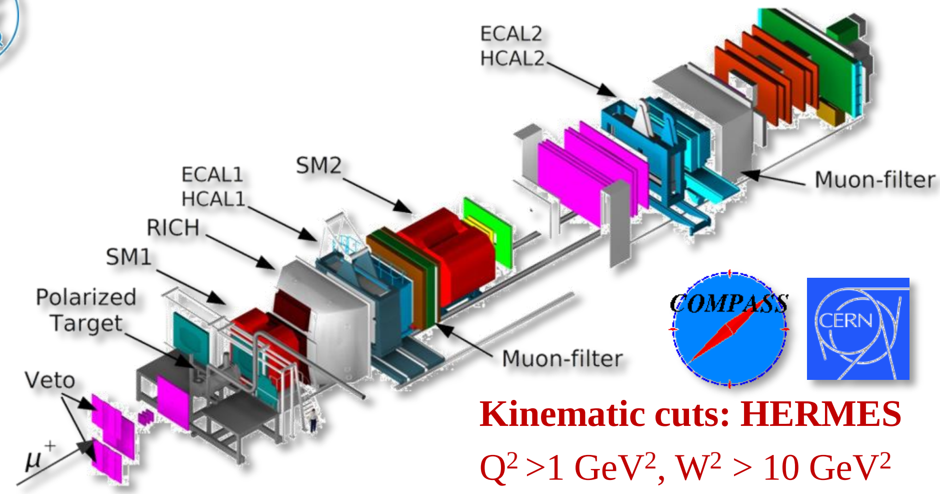
Both collaborations have put a substantial effort in the study of possible acceptance effects

Experiments in last 35 years: part II

HERA MEasurement of Spin

COmmon Muon Proton Apparatus for Structure and Spectroscopy





Kinematic cuts: HERMES

$Q^2 > 1$ GeV^2, $W^2 > 10$ GeV^2

$0.023 < x < 0.6$, $0.2 < y < 0.85$

$z > 0.2$ and $x_F > 0.2$

Pions 1 GeV$< P_h <$ 15 GeV

Kaons 2 GeV$< P_h <$15 GeV

Kinematic cuts: COMPASS

$Q^2 > 1$ GeV^2, $W^2 > 25$ GeV

$\theta_\gamma^{lab} < 0.06$

$0.003 < x < 0.13$, $0.2 < y < 0.9$

$0.2 < z < 0.85$

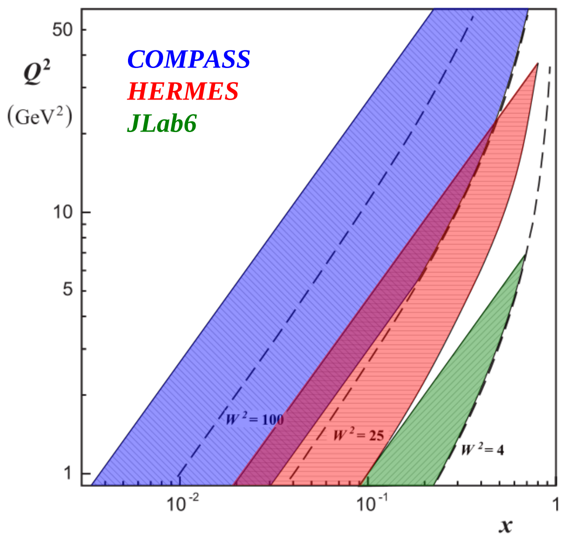
$0.1 < P_{hT} < 1$ GeV/c

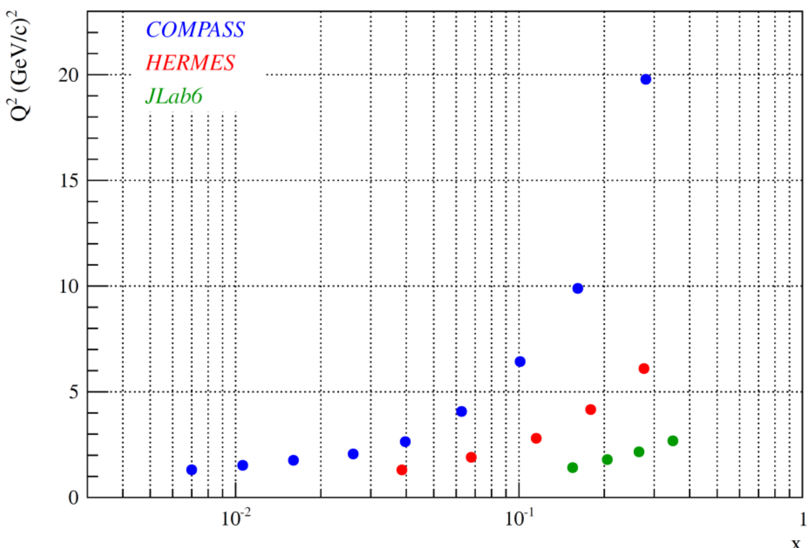
Kinematic cuts: JLab

$Q^2 > 1$ GeV^2, $W^2 > 4$ GeV^2

$0.14 < x < 0.48$, $0.4 < y < 0.7$

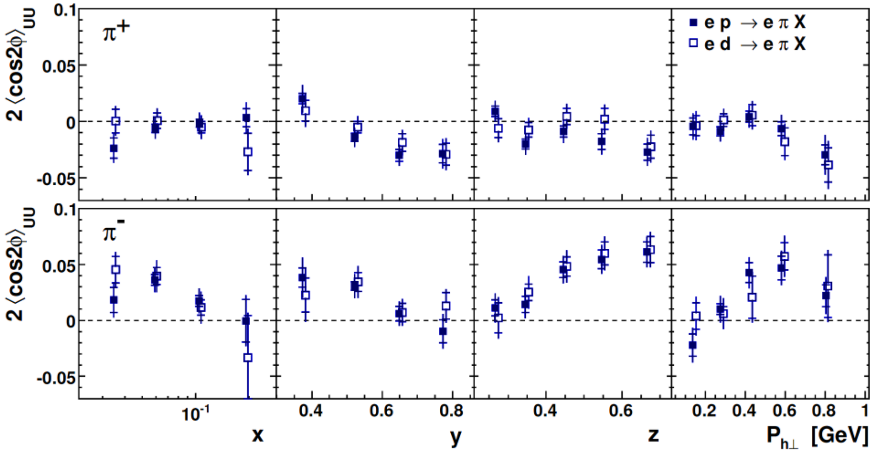
$0.4 < z < 0.7$





Experimental data: part II
HERMES results
(Proton, Deuteron, π^+/π^-, K^+/K^-, h^+/h^-)

$A_{UU}^{\cos 2\varphi}$-amplitude on p & d: pions



***HERMES Collaboration*, Phys. Rev. D 87,** 012010 (2013)

- Zero or negative for π^+
- Positive amplitudes for π^-

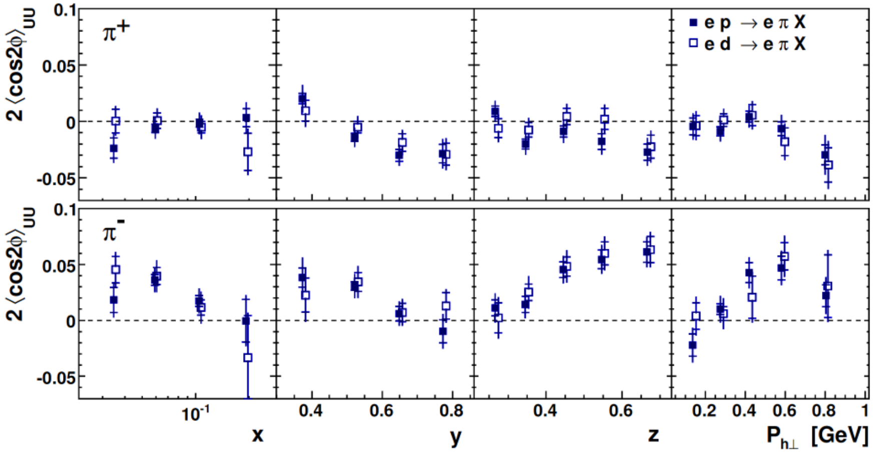
} increase with P_{hT}

Data is available at:

Durham HEP database, ttp://durpdg.dur.ac.uk

INSPIRE,http://inspirebeta.net/record/1111237/

$A_{UU}^{\cos 2\varphi}$-amplitude on p & d: pions



***HERMES Collaboration*, Phys. Rev. D 87,** 012010 (2013)

← Zero or negative for π^+

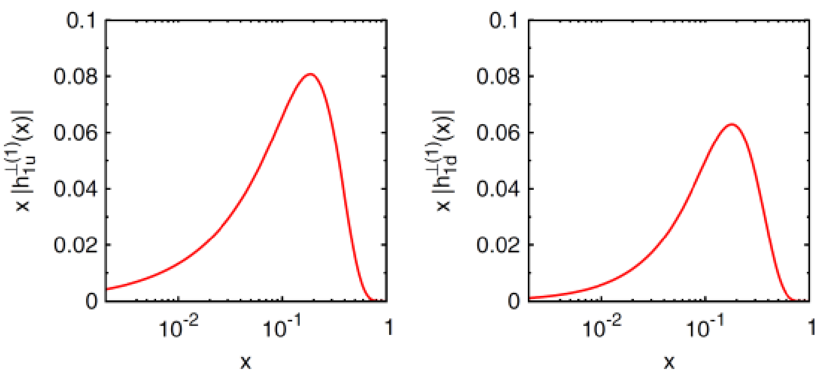
← Positive amplitudes for π^-

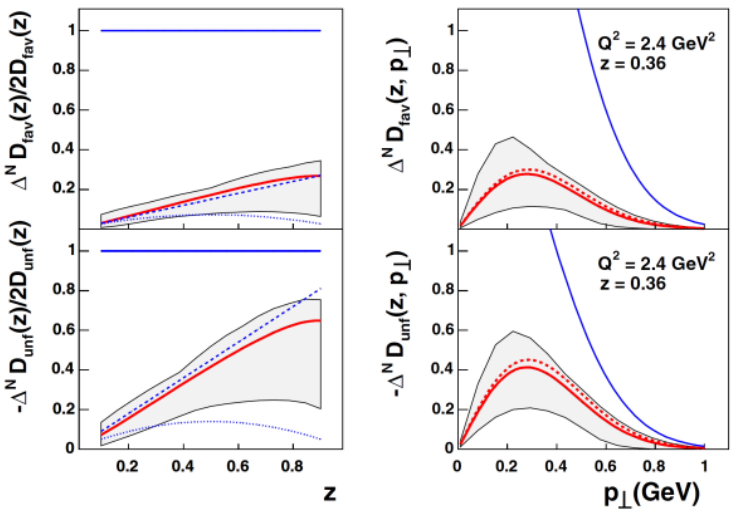
} increase with P_{hT}

$$A_{UU}^{\cos 2\phi_h} \propto -h_1^{\perp q} \otimes H_{1q}^{\perp h} + \left(\frac{M}{Q}\right)^2 f_1^q \otimes D_{1q}^h + \ldots.$$

Opposite sign for favored - disfavored Collins FF

Similarity of H & D ↔ BM PDF has same sign for *u* and *d* quarks

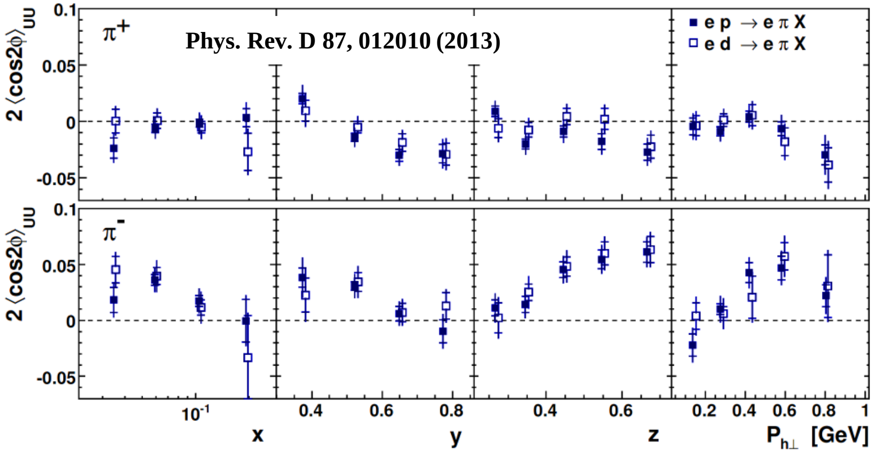




***Barone, Melis and Prokudin* Phys. Rev. D 81,** 114026 (2010)

***Anselmino et al.* Phys. Rev. D 75,** 054032 (2007)

$A_{UU}^{\cos 2\varphi}$-amplitude on p & d: pions



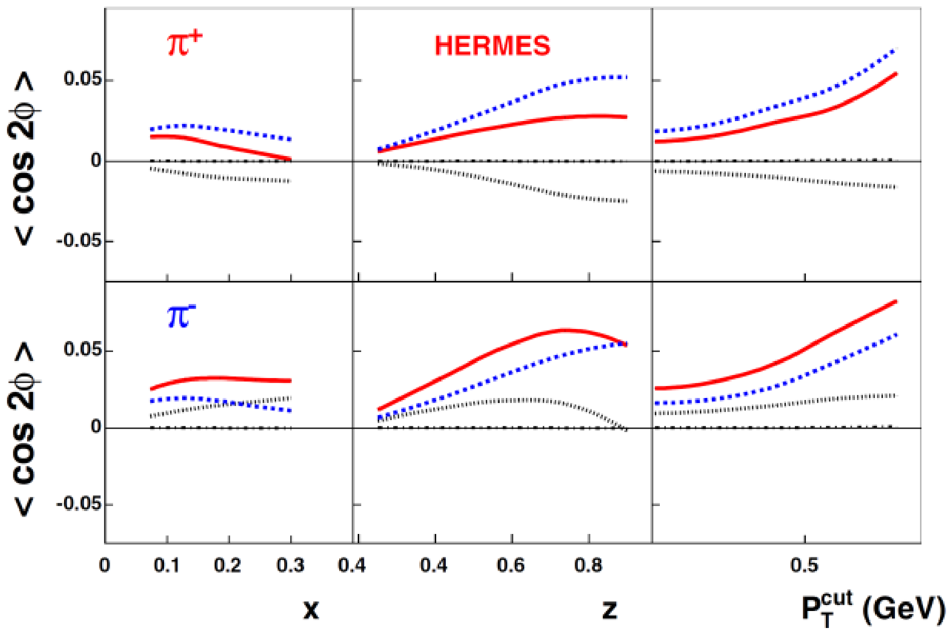
***HERMES Collaboration*, Phys. Rev. D 87,** 012010 (2013)

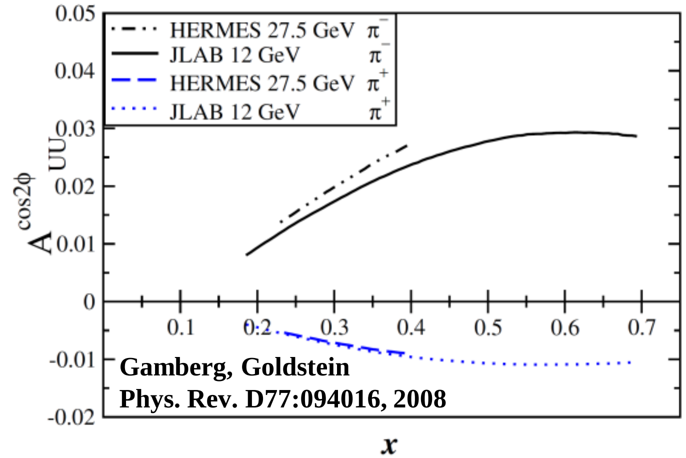
← Zero or negative for π^+

← Positive amplitudes for π^-

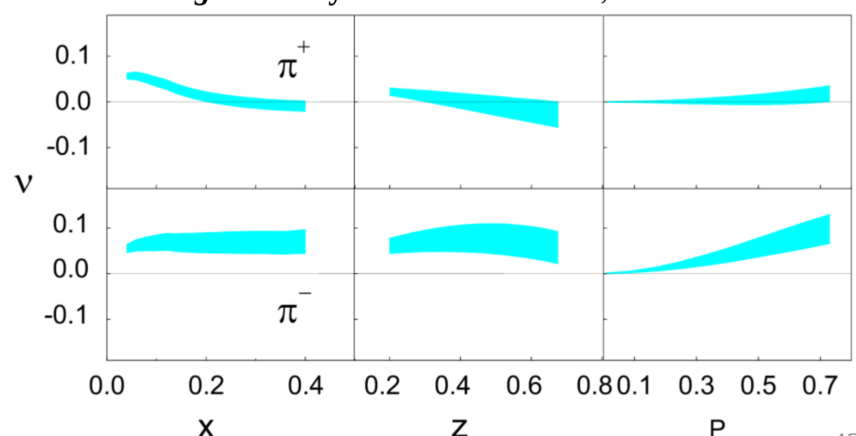
} increase with P_{hT}

***Barone, Prokudin, and Ma*, Phys. Rev. D 78,** 045022 (2008).

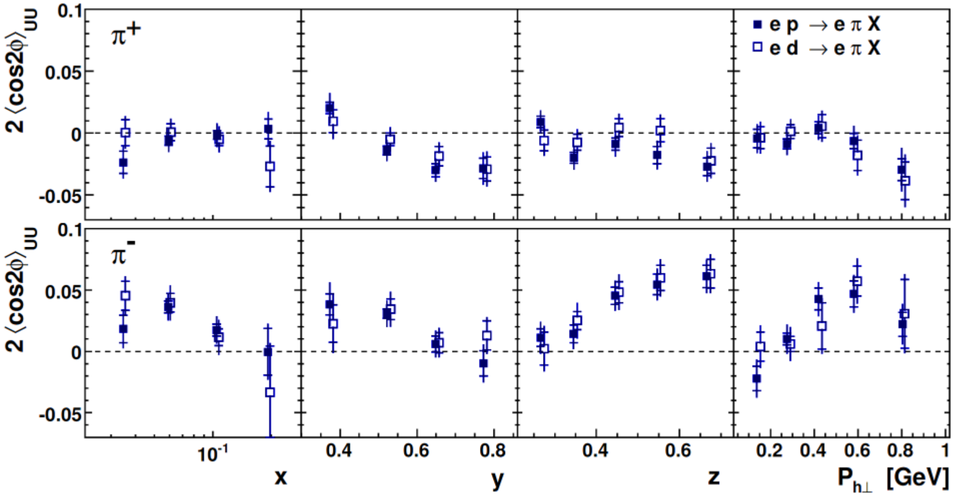




***Zhang et al.* Phys. Rev. D78**:034035, 2008



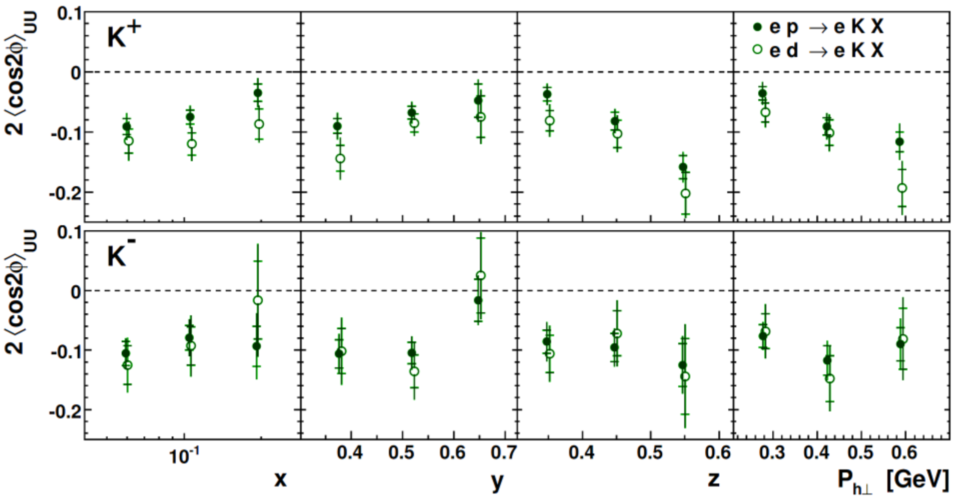
$A_{UU}^{\cos 2\varphi}$-amplitude on p & d: pions, kaons



***HERMES Collaboration*, Phys. Rev. D 87, 012010 (2013)**

- Large amplitude ↔ non-zero BM PDF (spin effect)
- Opposite sign for π^+/π^- ↔ opposite sign for favored - disfavored Collins FF
- Similarity of H & D ↔ $h_1^{\perp,u} \approx h_1^{\perp,d}$

$$A_{UU}^{\cos 2\phi_h} \propto -h_1^{\perp q} \otimes H_{1q}^{\perp h} + \left(\frac{M}{Q}\right)^2 f_1^q \otimes D_{1q}^h + \ldots$$

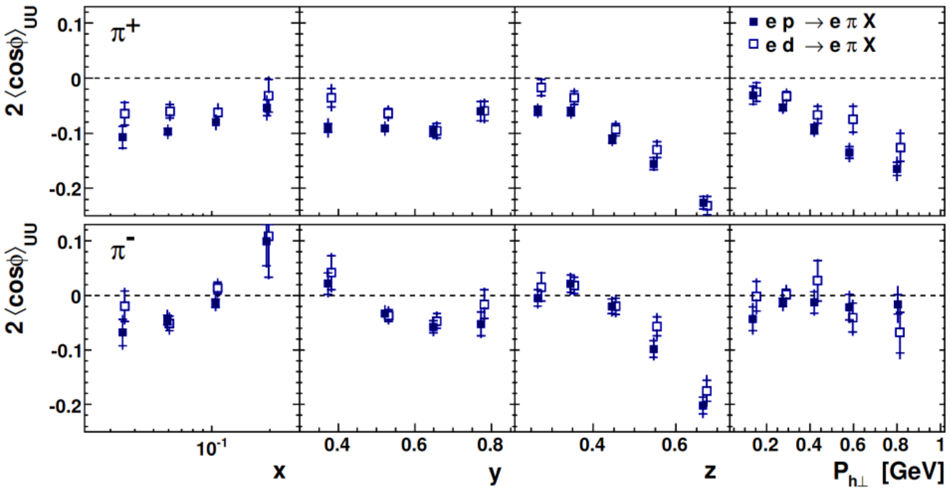


- K^+/K^- amplitudes are larger than π^+/π^-
- Different trends, but same sign as for π^+/π^-
- K^+ - *u*-dominance (same sign with π^+)
- K^- - fully sea object
- Collins FF for kaons – unknown
- As well as strange quark contribution

Kinematic range *Pions (all hadrons)*			
x	**y**	**z**	**P_{hT}**
0.023–0.27	**0.3–0.85**	**0.2–0.75**	**0.05–1.0**
Kinematic range *Kaons*			
x	**y**	**z**	**P_{hT}**
0.042–0.27	**0.3–0.7**	**0.2–0.6**	**0.2–0.7**

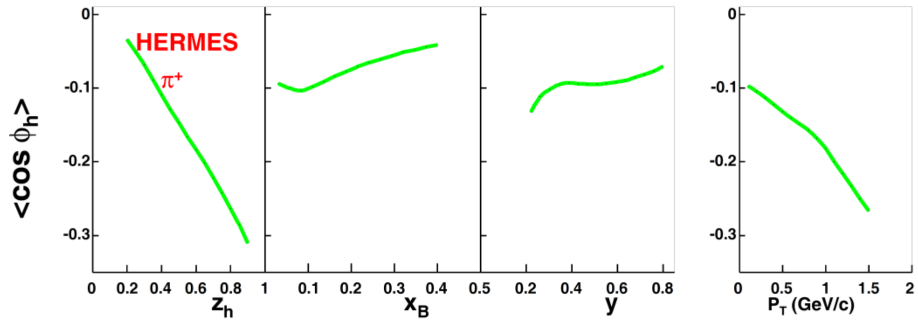
Data is available at:
Durham HEP database, ttp://durpdg.dur.ac.uk
INSPIRE,http://inspirebeta.net/record/1111237/

$A_{UU}^{\cos\phi}$-amplitude on p & d: pions, kaons



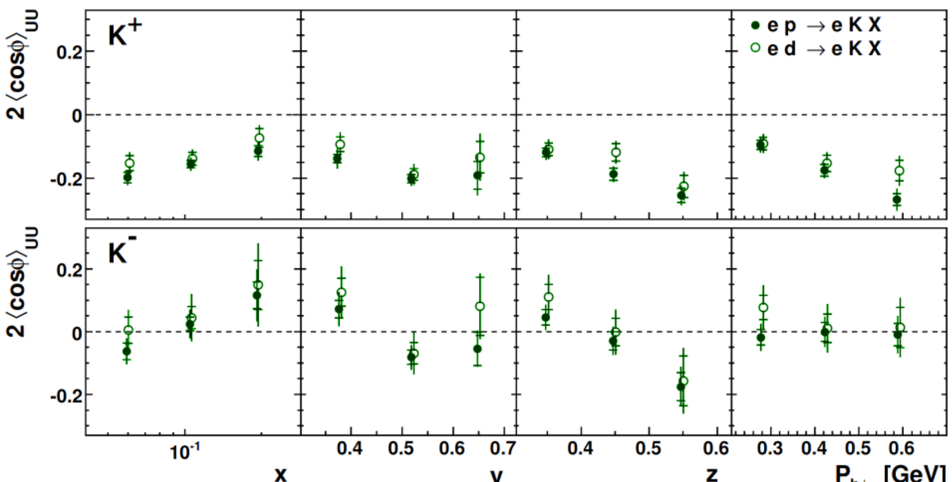
***HERMES Collaboration*, Phys. Rev. D 87,** 012010 (2013)

- Negative amplitudes
- π^+/π^- difference ↔ due to the BM effect (Cahn expected to be flavor blind)
- Predictions for Cahn only are much larger BM contribution…



Curves for Cahn contribution only
***Anselmino et al.* Eur. Phys. J. A 31,** 373-381 (2007)

$$A_{UU}^{\cos\phi_h} \propto \frac{2M}{Q}\left\{-f_1^q \otimes D_{1q}^h - h_1^{\perp q} \otimes H_{1q}^{\perp h}\right\}$$



- K^+ amplitudes are larger than π^+ contribution from BM which is large for K^+
- K^- amplitudes are compatible with zero while K^- BM is large… non trivial

Kinematic range *Pions (all hadrons)*			
x	**y**	**z**	**P_{hT}**
0.023–0.27	**0.3–0.85**	**0.2–0.75**	**0.05–1.0**
Kinematic range *Kaons*			
x	**y**	**z**	**P_{hT}**
0.042–0.27	**0.3–0.7**	**0.2–0.6**	**0.2–0.7**

Data is available at:
Durham HEP database, ttp://durpdg.dur.ac.uk
INSPIRE,http://inspirebeta.net/record/1111237/

Multi-dimensional analysis

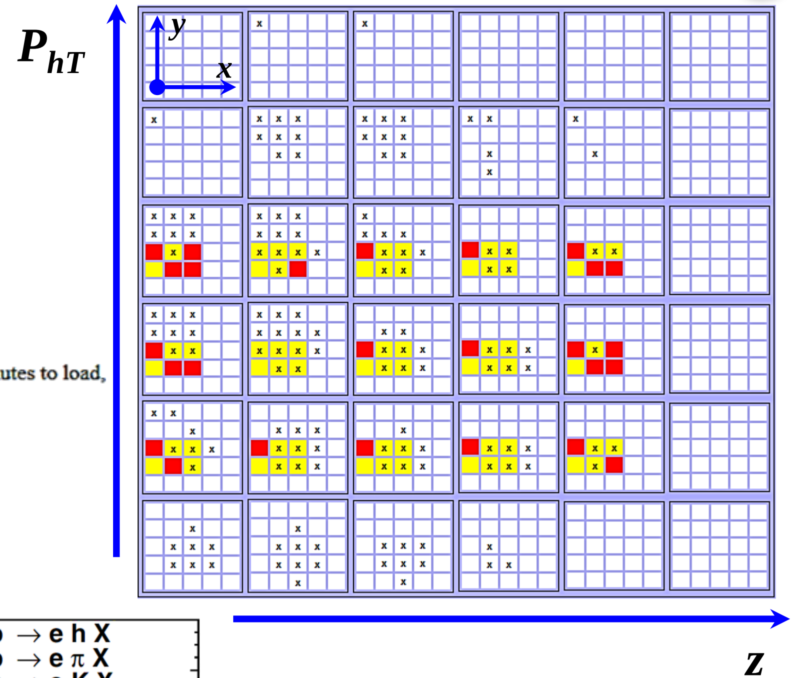
http://www-hermes.desy.de/cosnphi/

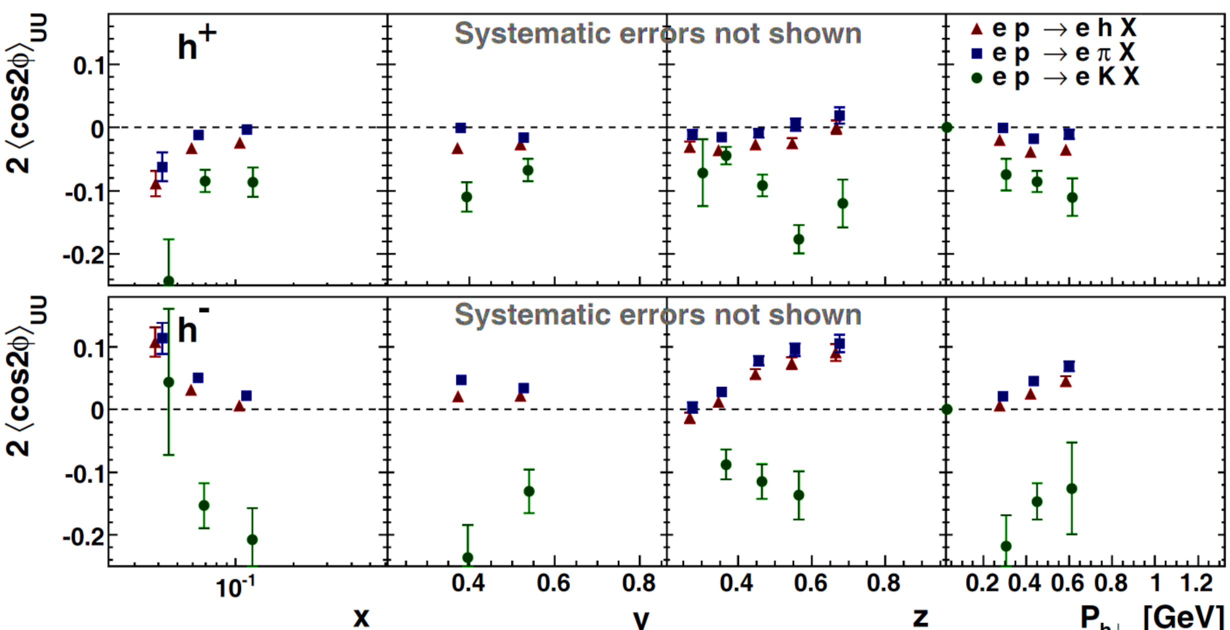
Binning *900 kinematic bins x 12 φ -bins*								
Variable	Bin limits							#
x	0.023	0.042	0.078	0.145	0.27	0.6		5
y	0.2	0.3	0.45	0.6	0.7	0.85		5
z	0.2	0.3	0.4	0.5	0.6	0.75	1	6
P_{hT}	0.05	0.2	0.35	0.5	0.7	1	1.3	6

x: ☑ ☑ ☑ ☐ ☐
y: ☐ ☑ ☑ ☐ ☐
z: ☑ ☑ ☑ ☑ ☑ ☐
pt: ☐ ☑ ☑ ☑ ☐ ☐

Plot this range!

Please enable pop-ups
Results may take several minutes to load, please do not refresh

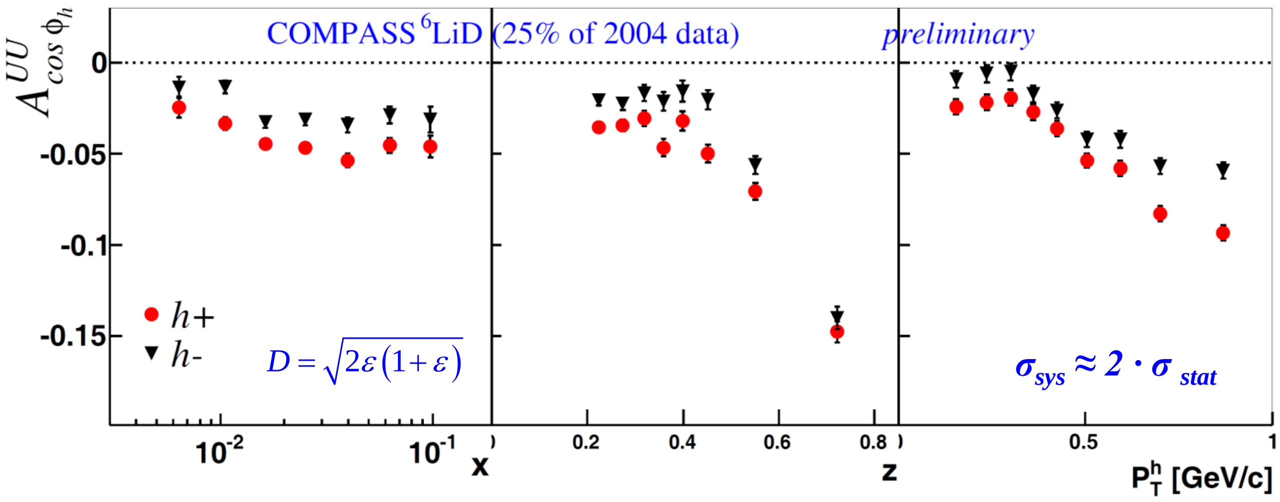




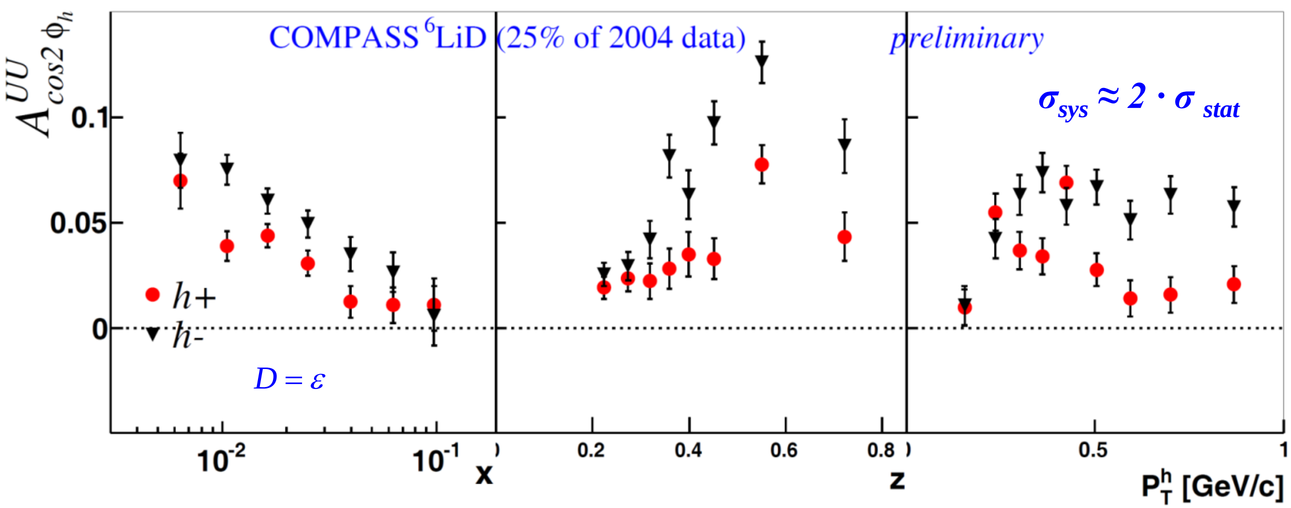
Experimental data: part II

COMPASS results (Deuteron, h^+/h^-)

$A_{UU}^{\cos\varphi}$ and $A_{UU}^{\cos2\varphi}$ amplitudes h^+/h^-



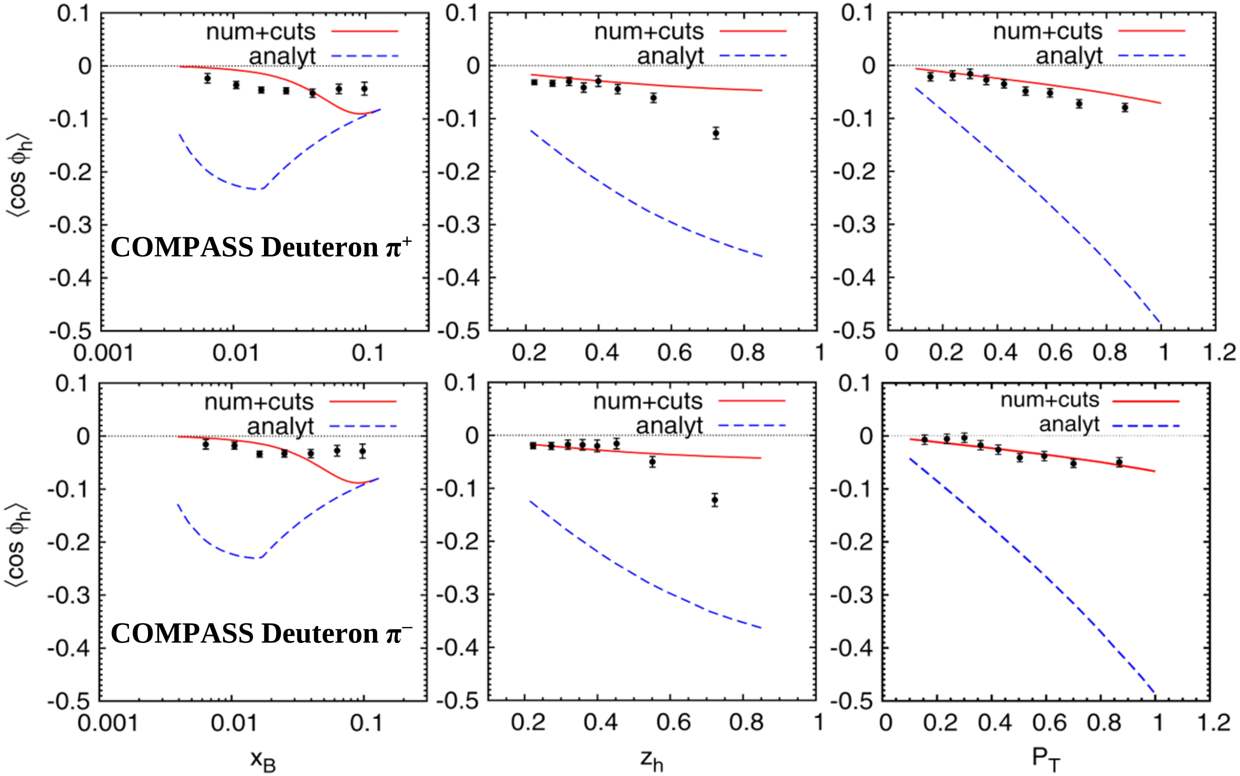
- Negative amplitudes h^+/h^-
- Clear differences between h^+/h^-
  - Larger amplitude for h^+

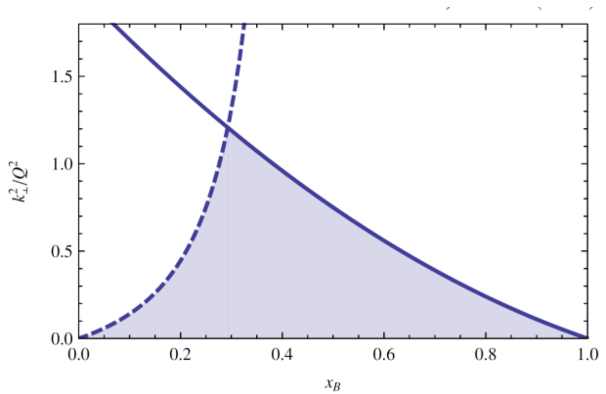


- Positive amplitudes h^+/h^-
- Clear differences between h^+/h^-
  - Larger amplitude for h^-

$A_{UU}^{\cos\varphi}$-amplitude: comparison with theory

***M. Boglione, S. Melis, and A. Prokudin*, Phys. Rev. D 84,** 034033 (2011)





$$f_{q/p}(x, k_\perp) = f_{q/p}(x)\,\frac{1}{1 - e^{-(k_\perp^{\max})^2/\langle k_\perp^2\rangle}}\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}$$

1) the energy of the parton to be less than the energy of the parent hadron

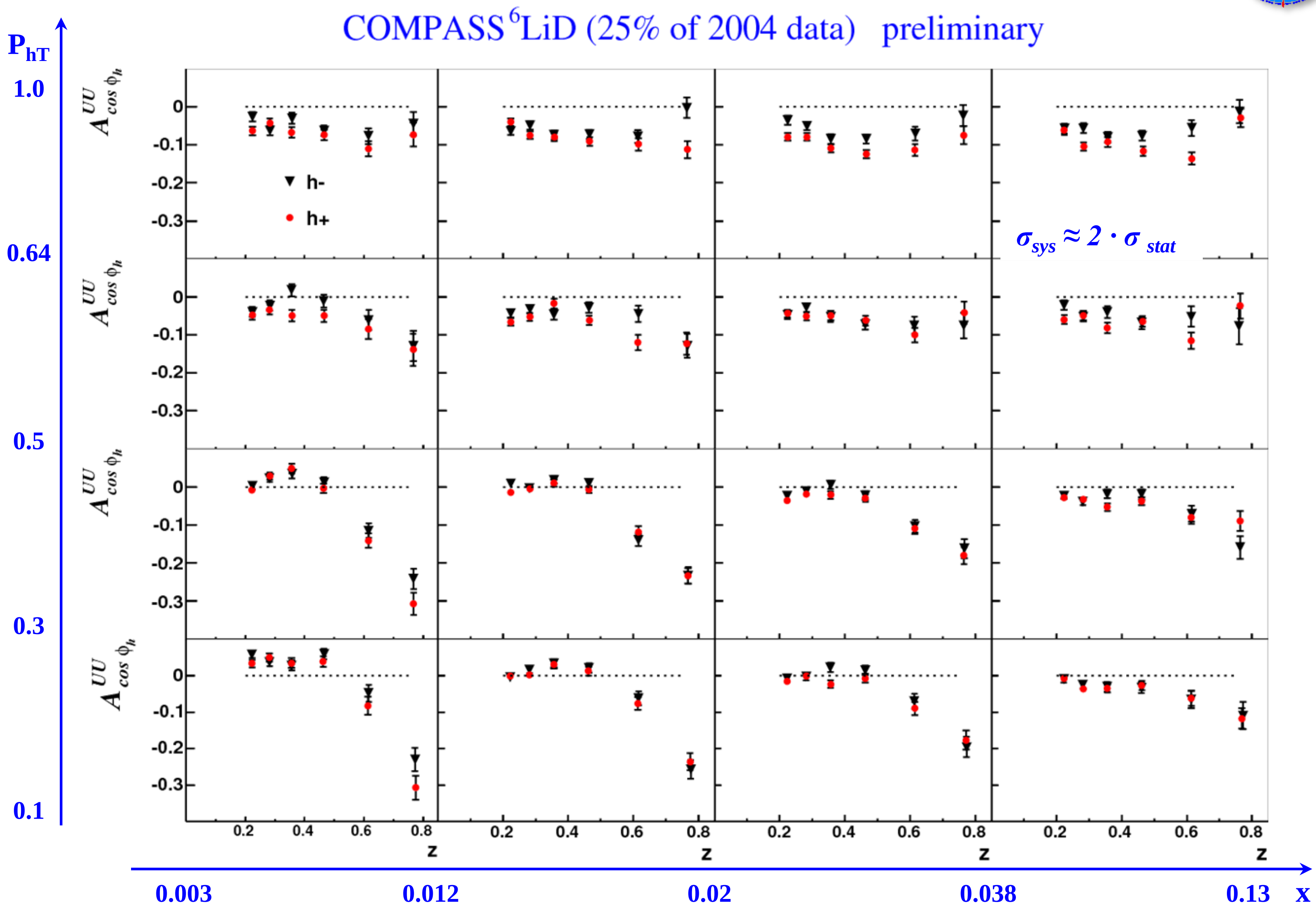
$$k_\perp^2 \le (2 - x_B)(1 - x_B)Q^2, \qquad 0 < x_B < 1.$$

2) the parton to move in the forward direction with respect to the parent hadron

$$k_\perp^2 \le \frac{x_B(1 - x_B)}{(1 - 2x_B)^2}\,Q^2, \qquad x_B < 0.5.$$

Description improves a lot

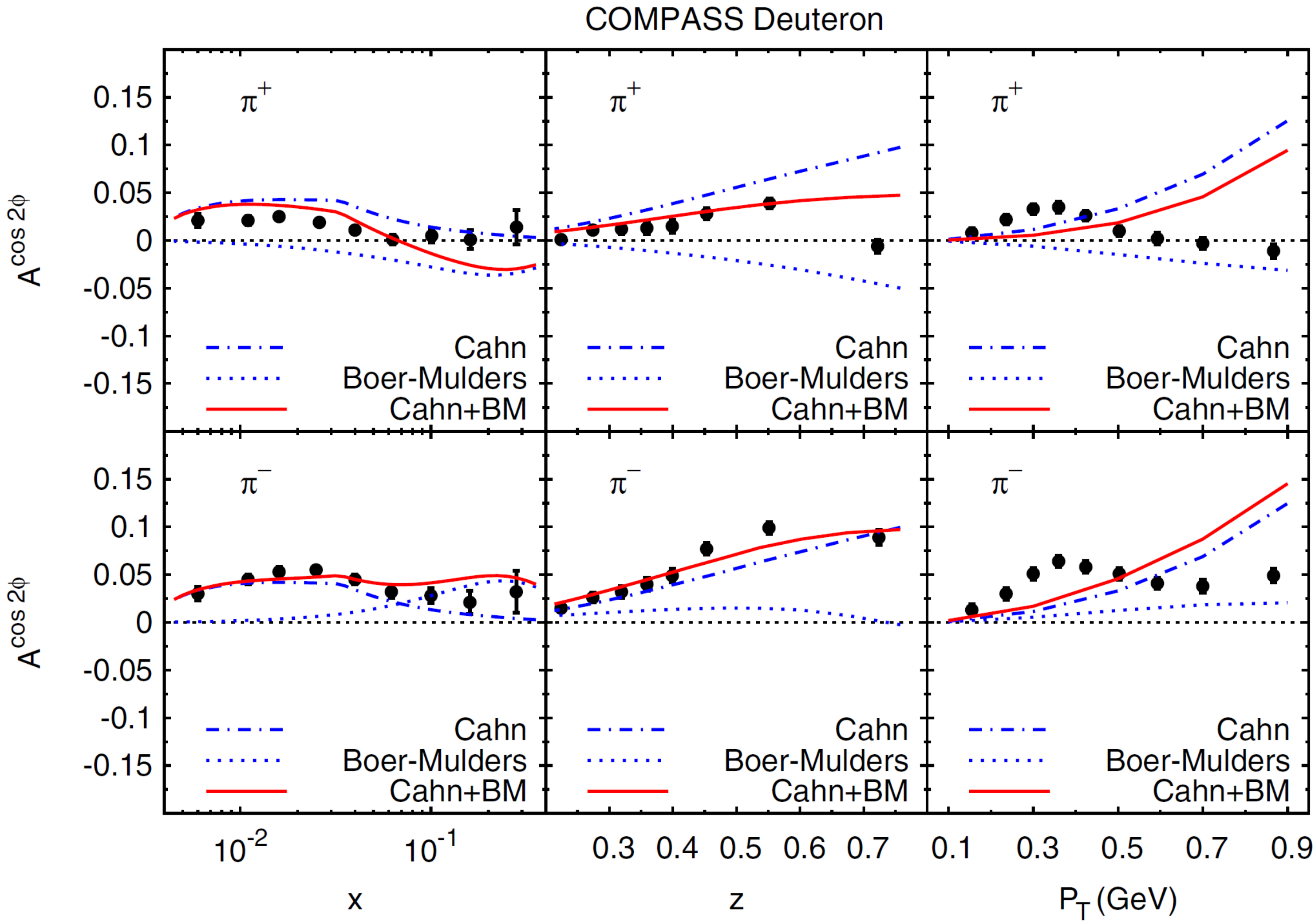
$A_{UU}^{cos\varphi_h}$ - asymmetry (z - dependence)



z strong dependence more evident at small x and small P_{hT}

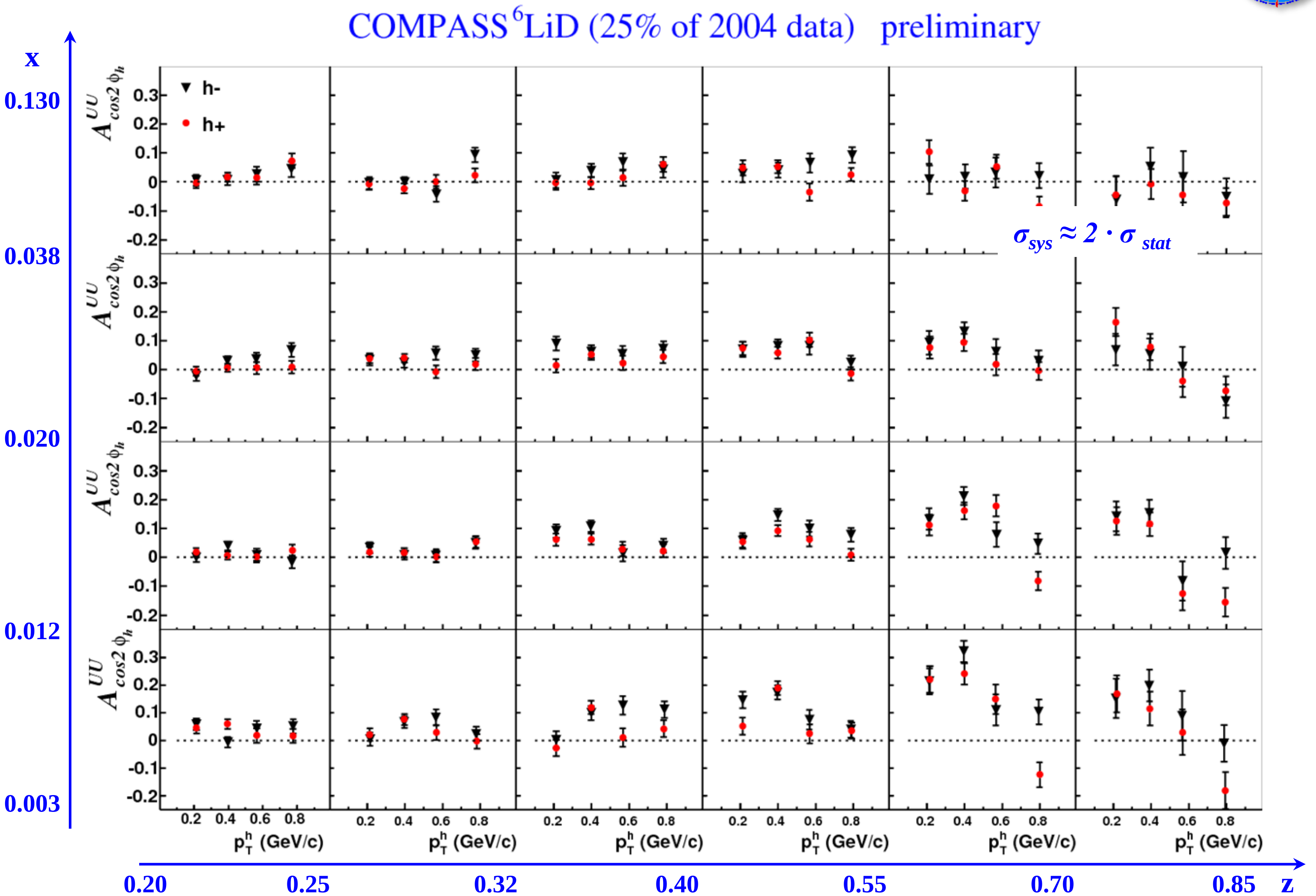
$A_{UU}^{\cos 2\varphi}$-amplitude

***V. Barone, S. Melis and A. Prokudin,* Phys. Rev. D 81,** 114026 (2010)



P_{hT} dependence difficult to reproduce

$A_{UU}^{cos2\varphi_h}$ - asymmetry (P_{hT} - dependence)

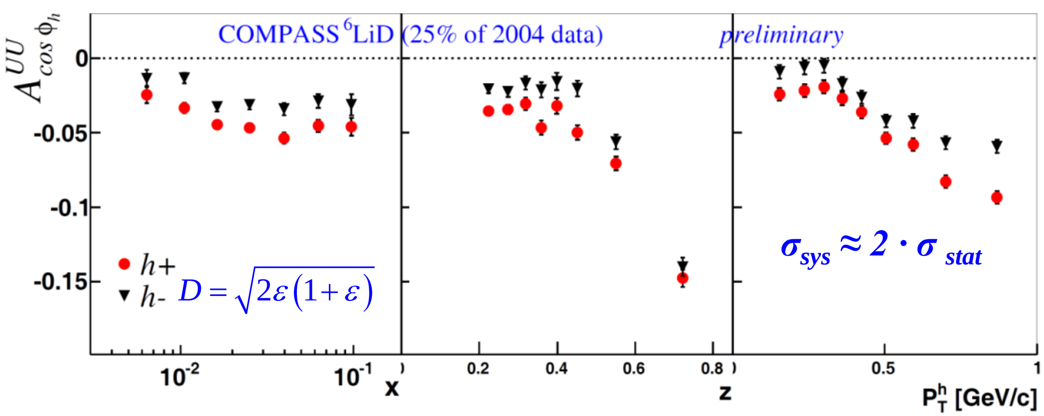


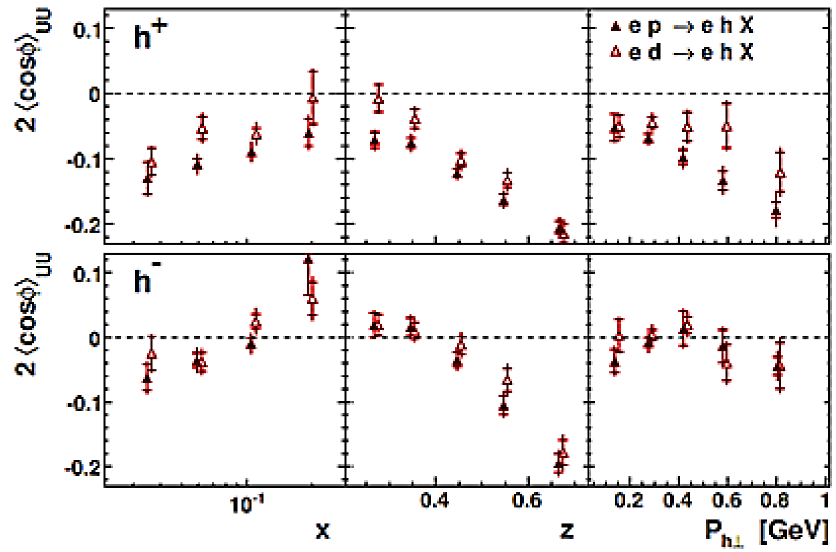
P_{hT} trend not discribed by the models arises in large z and low x region

Experimental data: part II
Comparison of COMPASS and HERMES results

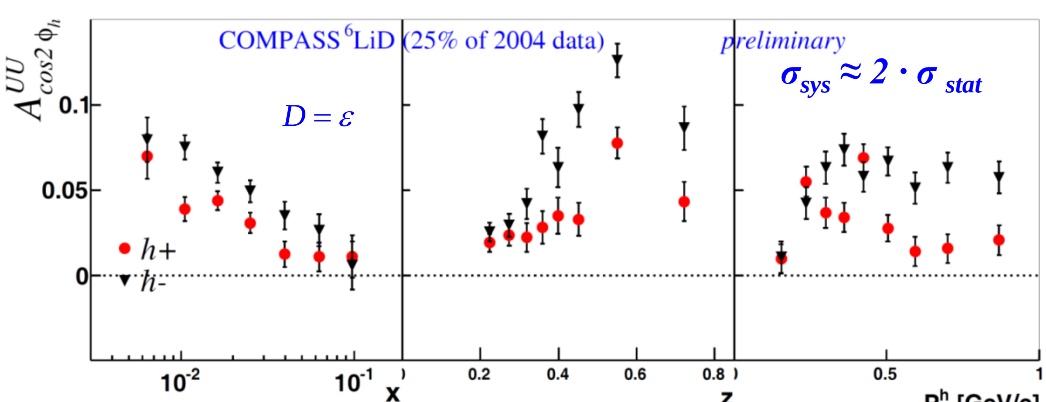
$A_{UU}^{\cos\varphi}$ and $A_{UU}^{\cos2\varphi}$ amplitudes h^+/h^-

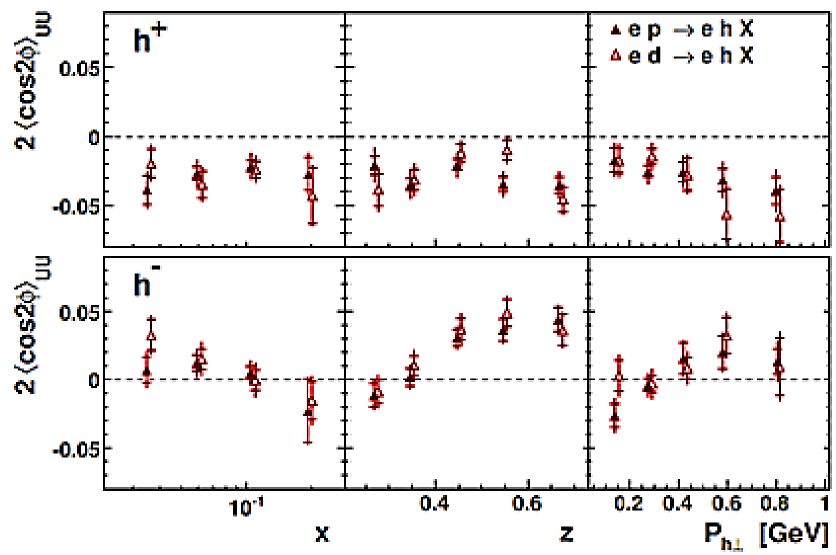
Different kinematic regions!





- Similar trends for h^+/h^-

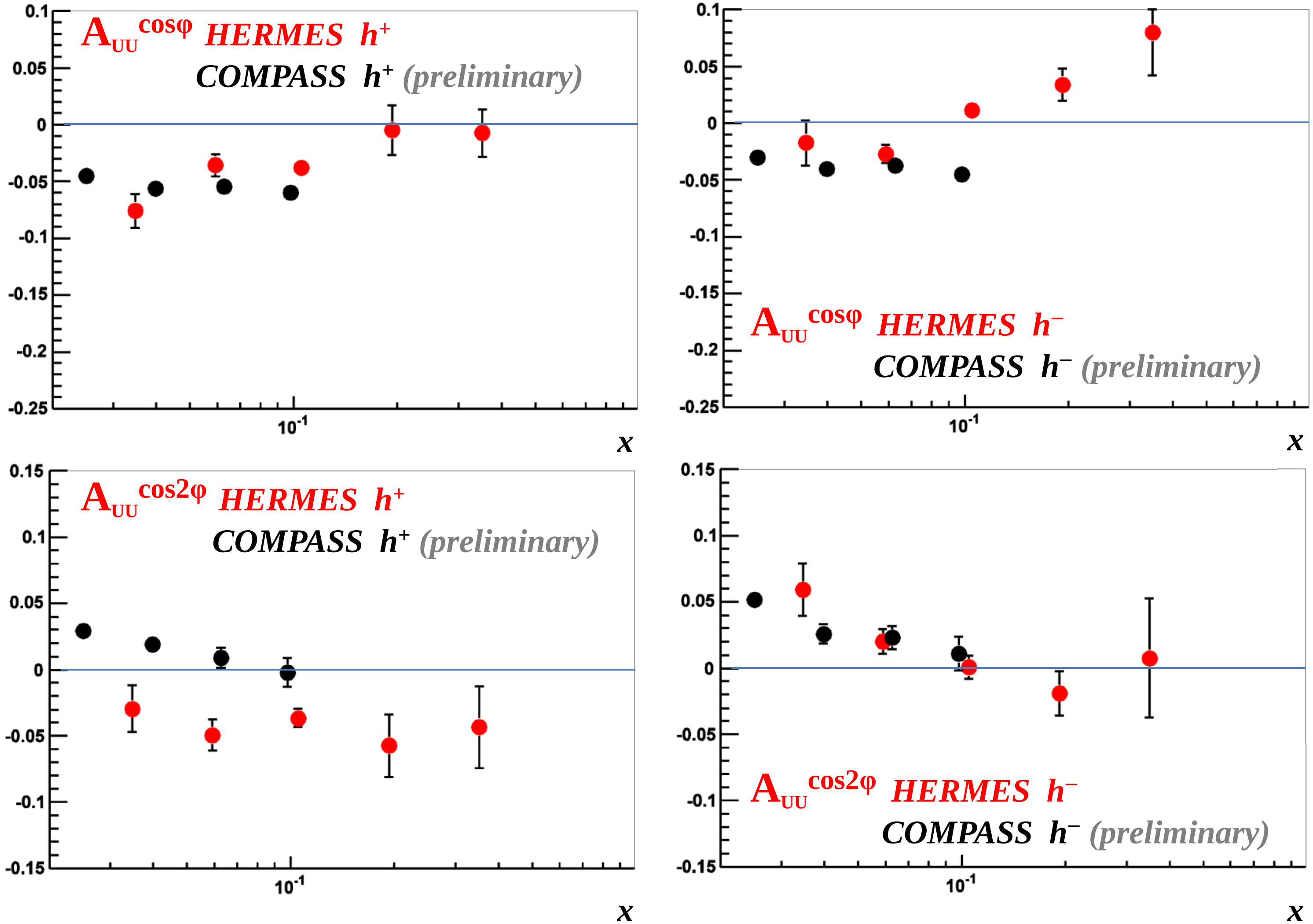




- Similar trends for h^+/h^-
- No sign change for h^+/h^- at COMPASS

$A_{UU}^{\cos\varphi}$ and $A_{UU}^{\cos2\varphi}$ amplitudes h^+/h^-

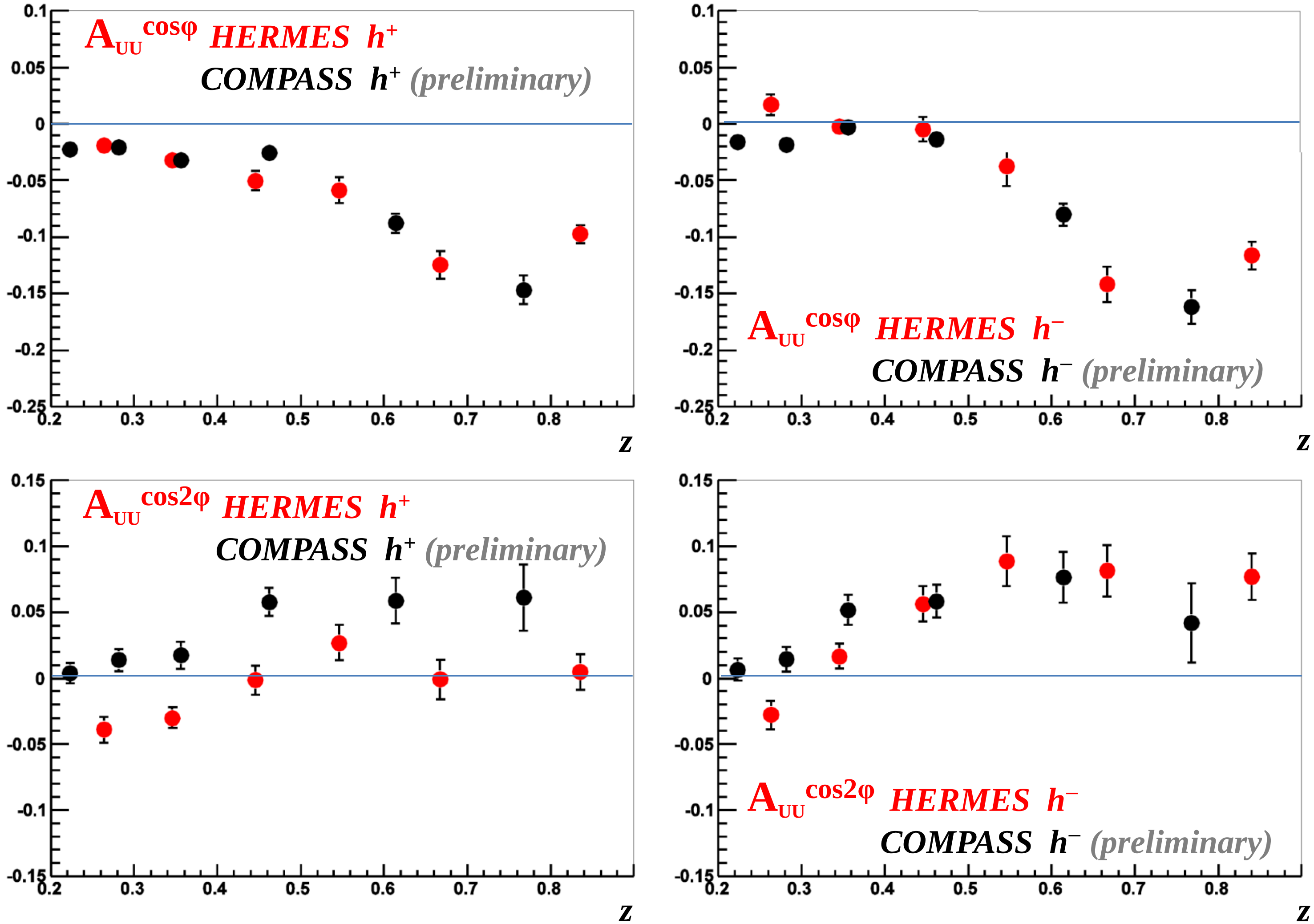
Shrinking to the same range



Selected range for COMPASS-HERMES: $0.2<z<1$; $0.05< P_{hT}<1$

$A_{UU}^{\cos\varphi}$ and $A_{UU}^{\cos2\varphi}$ amplitudes h^+/h^-

Shrinking to the same range



COMPASS 0.02<x<0.13 $(\langle Q^2\rangle \approx 4)$**; HERMES 0.023<x<0.145;** $(\langle Q^2\rangle \approx 2)$

COMPASS-HERMES 0.05< P_{hT}**<1**

Longitudinal Cahn effect

$A_{LL}^{\cos(\varphi_h)}$ "Longitudinal" Cahn effect

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots+S_L\lambda\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi_h\times A_{LL}^{\cos\phi_h}+\ldots$$

Longitudinal Cahn effect

$$F_{LL}^{\cos\phi_h}=\frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}g_{1L}^{q}D_{1q}^{h}\right\}$$

Kotzinian et al**. Phys. Rev. D 74,** 074015 (2006)

$A_{LL}^{\cos(\varphi_h)}$ "Longitudinal" Cahn effect

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

$$1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\varphi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\ldots+S_L\lambda\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi_h\times A_{LL}^{\cos\phi_h}+\ldots$$

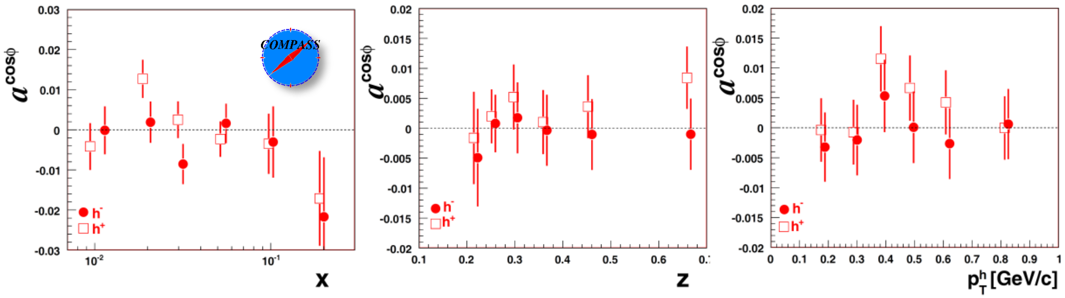
Longitudinal Cahn effect

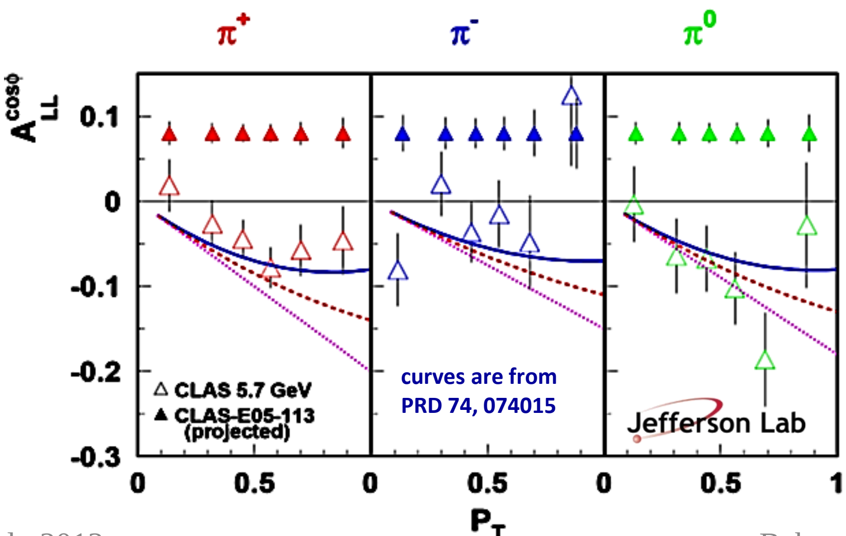
Kotzinian et al. **Phys. Rev. D 74,** 074015 (2006)

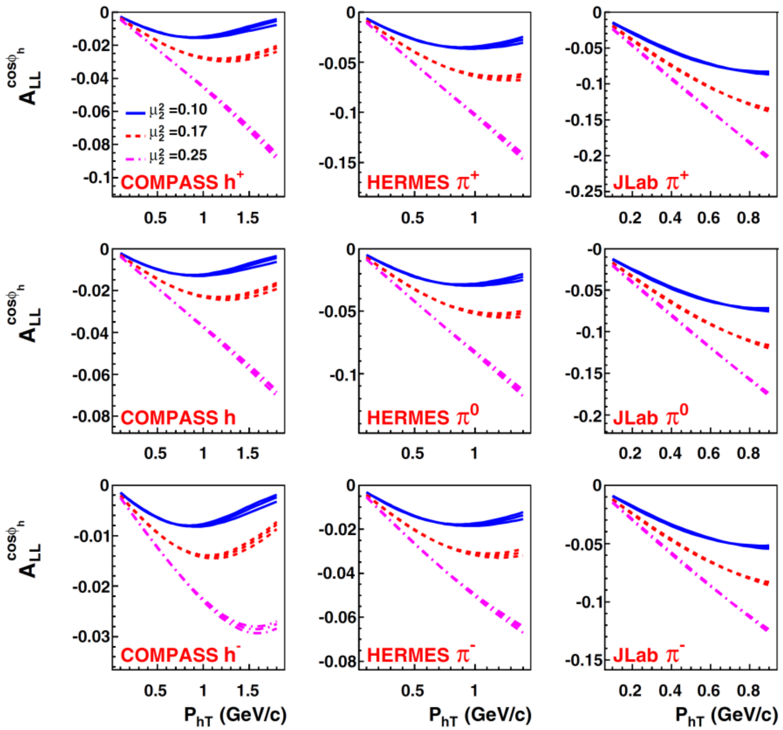
$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}C\left\{-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M}g_{1L}^q D_{1q}^h\right\}$$

$$g_{1L}^q(x,k_T) = g_1^q(x)\frac{1}{\pi\mu_2^2}\exp\left(-\frac{k_T^2}{\mu_2^2}\right)$$

COMPASS Collaboration
Eur.Phys.J.C70:39-49,2010







Summary

Experiment

- In past 35 years a lot of data accumulated from different experiments
- Both $A_{UU}^{\cos\varphi}$ and $A_{UU}^{\cos2\varphi}$ are not zero!
- Interesting behavior for pion and kaon asymmetries from HERMES
- Trends measured at HERMES are in general confirmed by COMPASS
- Multidimensional approach
  - **The ball is on the "theoretical" side of the court!**
- Promising future measurements JLab12, COMPASS (LH), EIC..

Theory

- In past years, in parallel to the experimental efforts, a lot of theoretical and phenomenological studies
- Many attempts for extractions and fits
- Intriguing predictions for future measurements

Thank you!

While “googleing” for Robert Cahn’s photo…

2001 UEFA Champions League Final

Bayern Munich 1–1 Valencia

penalties 5–4

Man of the Match:
Oliver Kahn (Bayern Munich)
During his career:
139 penalties 34 (24,46 %) saved.

It was not a SIDIS reaction and it had nothing to do with the “Cahn-effect”, but an educated guess about the size of the transverse component played a crucial role!

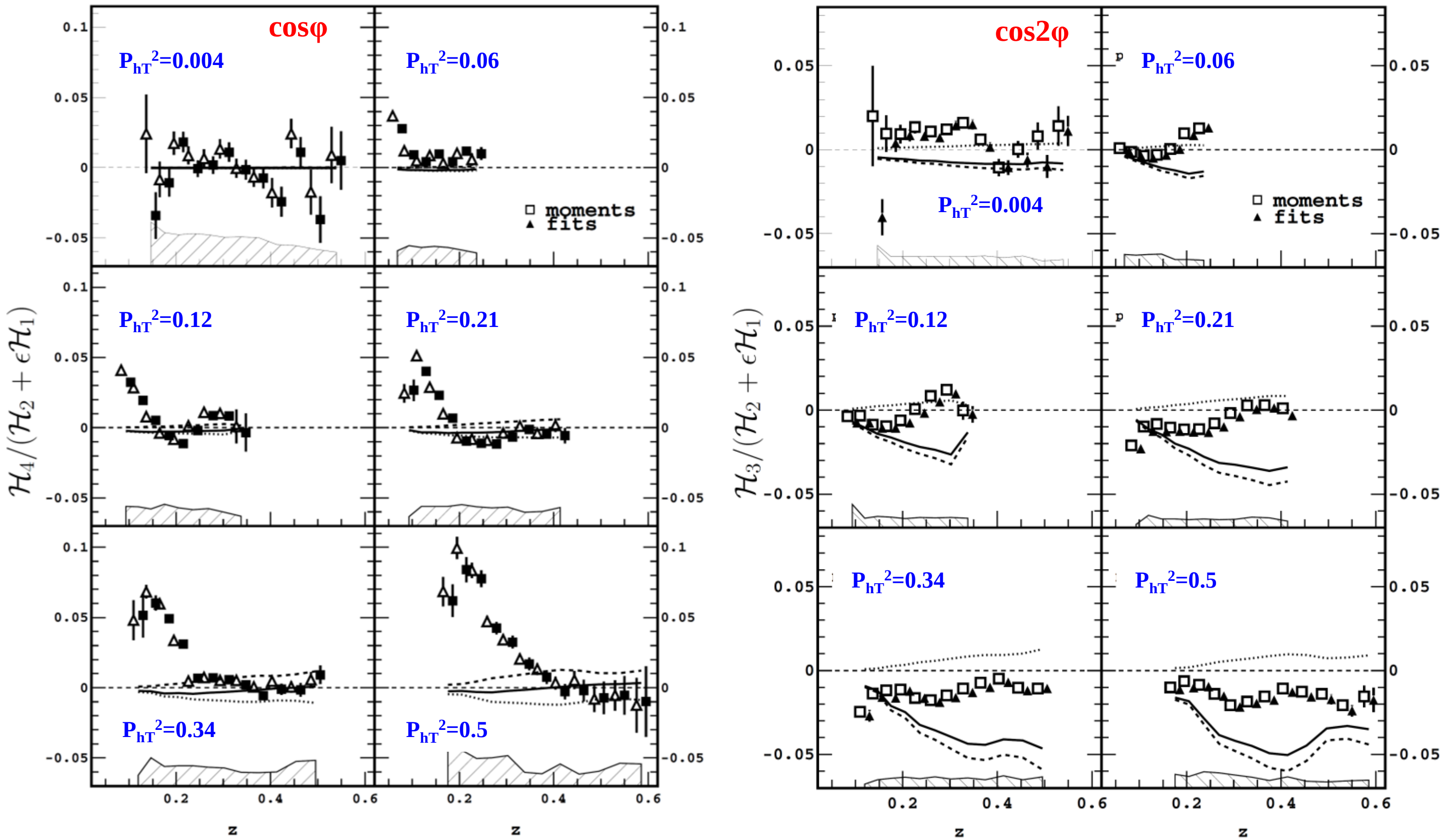
Spare slides

CLAS (Jlab hall B) results z-dependence

Jefferson Lab

M. Osipenko et al. **(CLAS Collaboration)**
Phys.Rev.D80:032004,2009

Positive pions

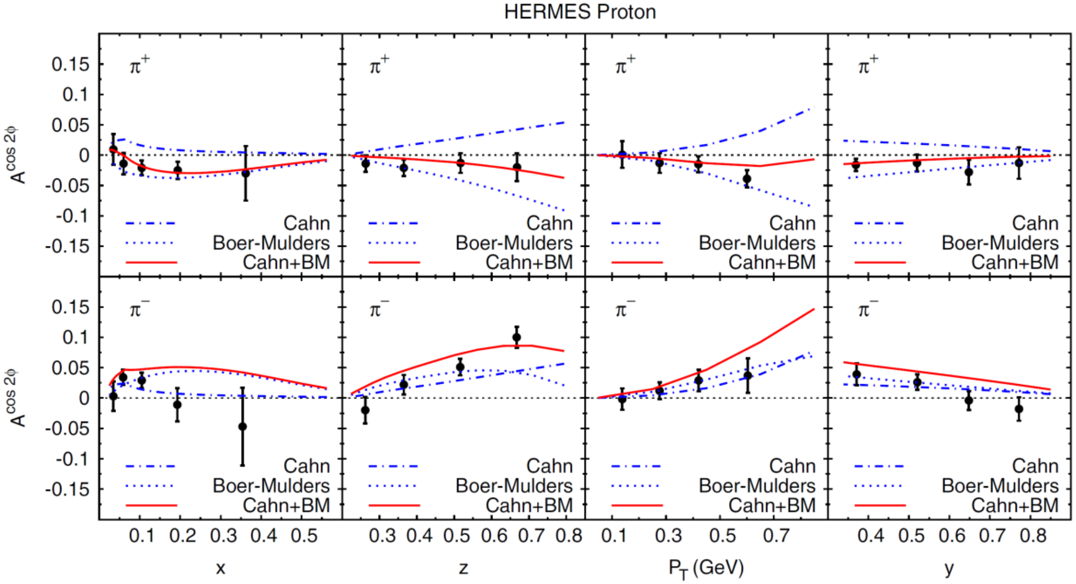


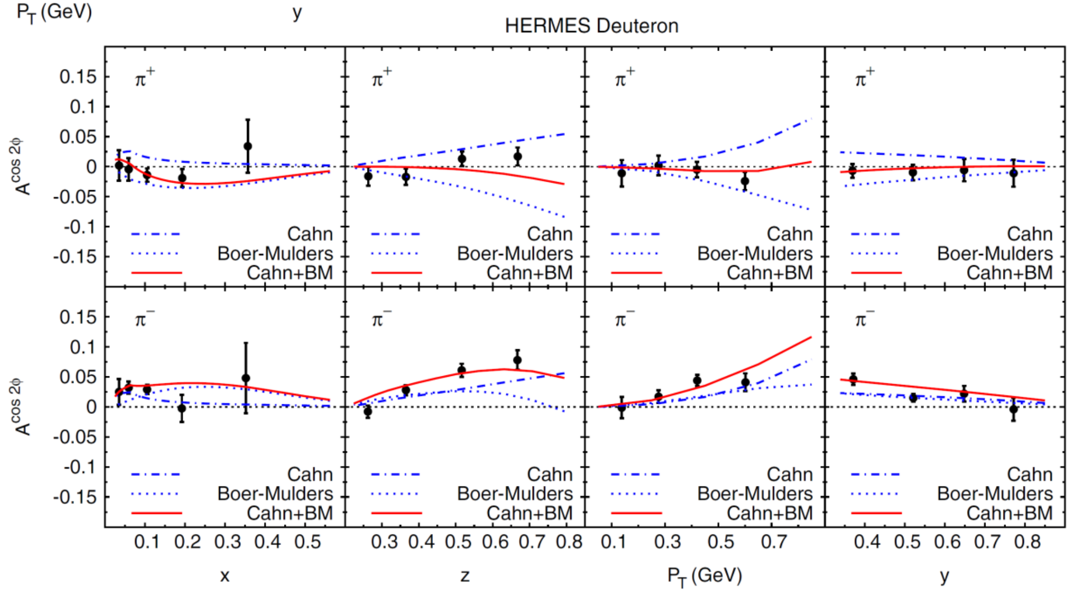
Theoretical predictions: Cahn effect + Berger effect
***R. N. Cahn*, Phys. Rev. D40,** 3107 (1989).
***M. Anselmino et al.*, Phys. Rev. D71,** 074006 (2005).
***A. Brandenburg, V. V. Khoze, and D. Mueller*, Phys. Lett. B347,** 413 (1995).

The Berger effect is the exclusive production of a single pion from a free, struck quark that radiates a gluon, produces a q¯q pair, and recombines with the ¯q.

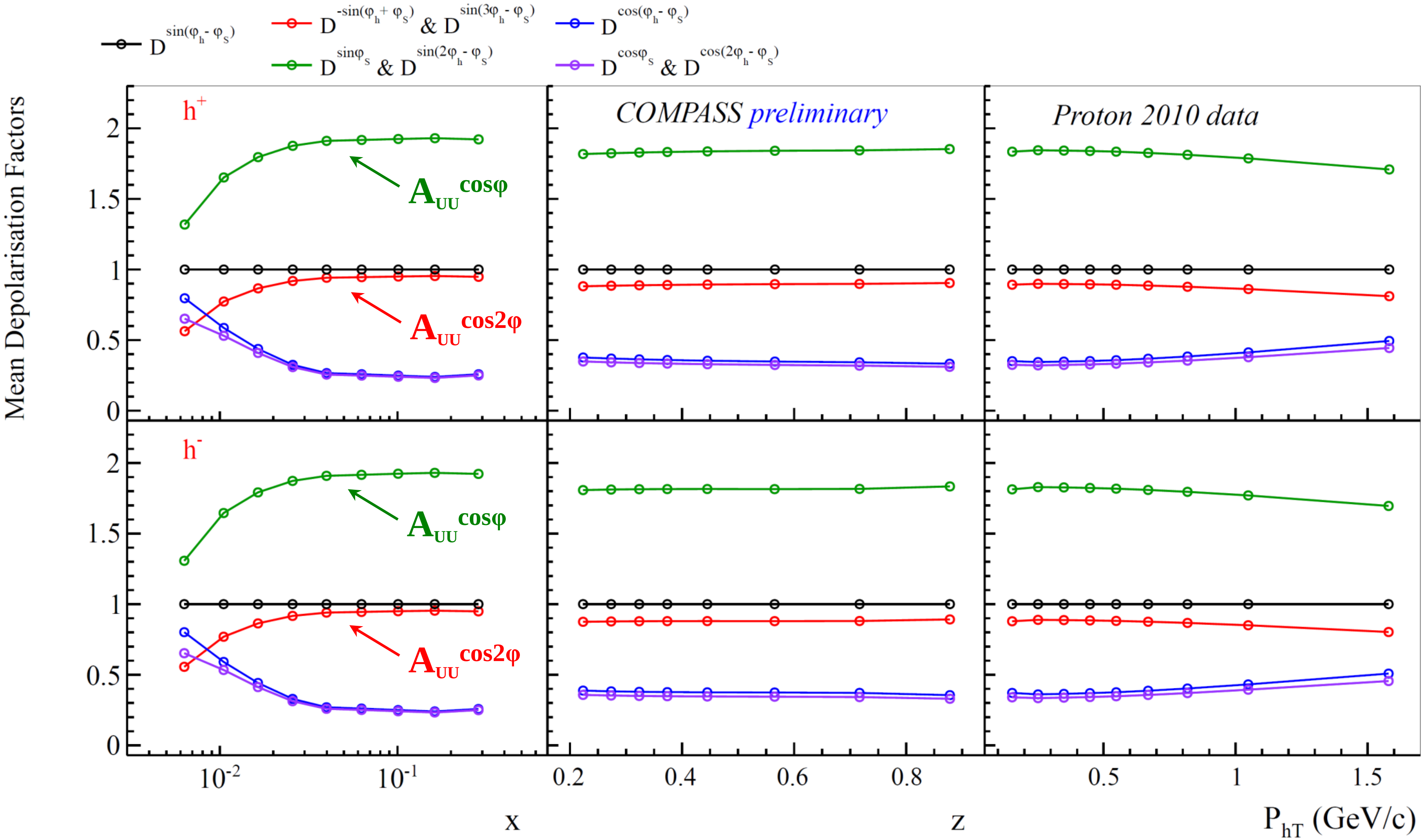
$A_{UU}^{\cos 2\varphi}$-amplitude

Barone, Melis and Prokudin Phys. Rev. D 81, 114026 (2010)



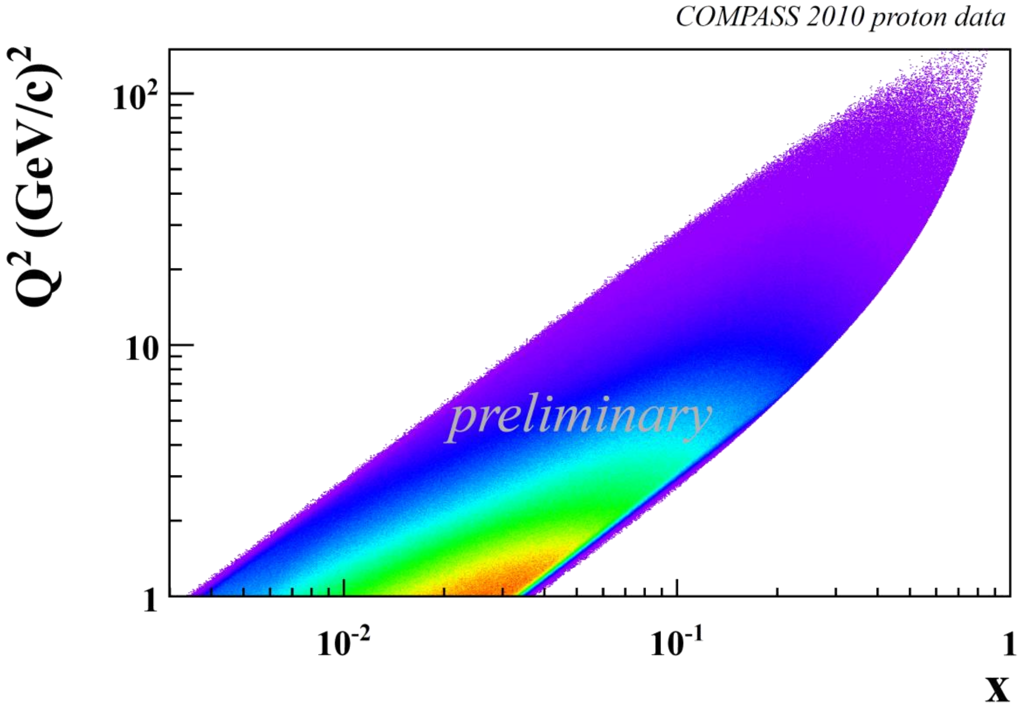


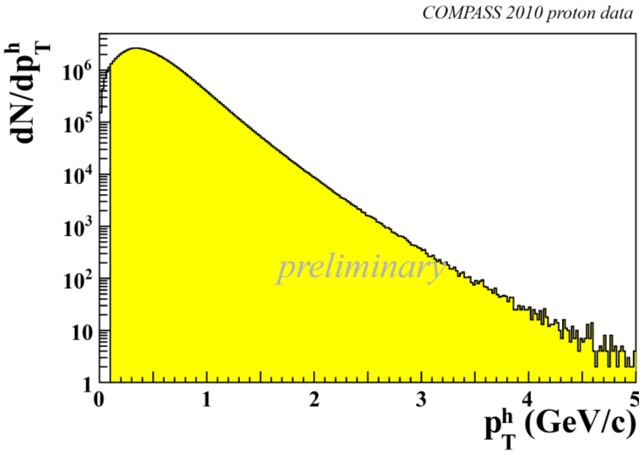
Mean Depolarization Factors

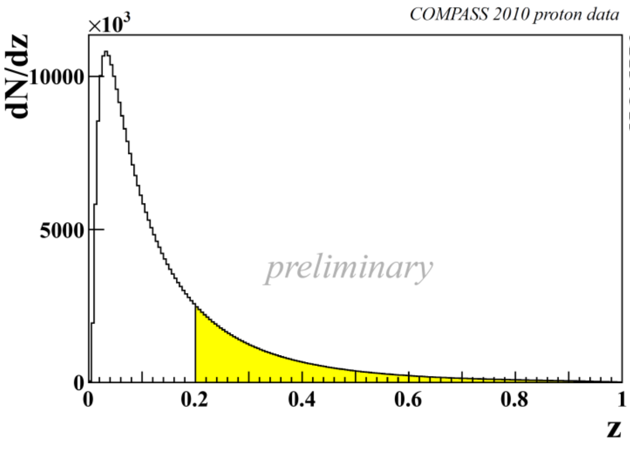


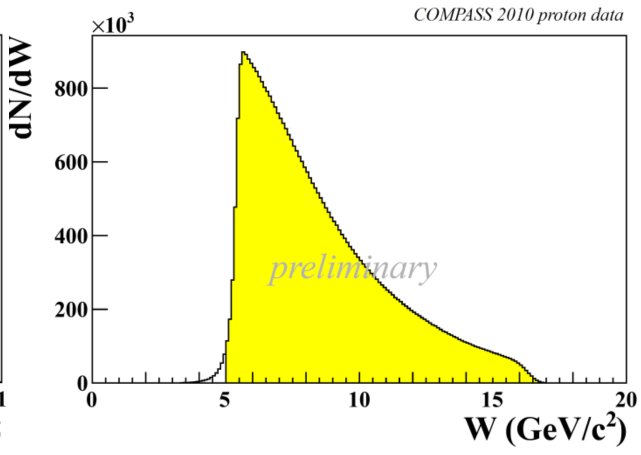
Data selection

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

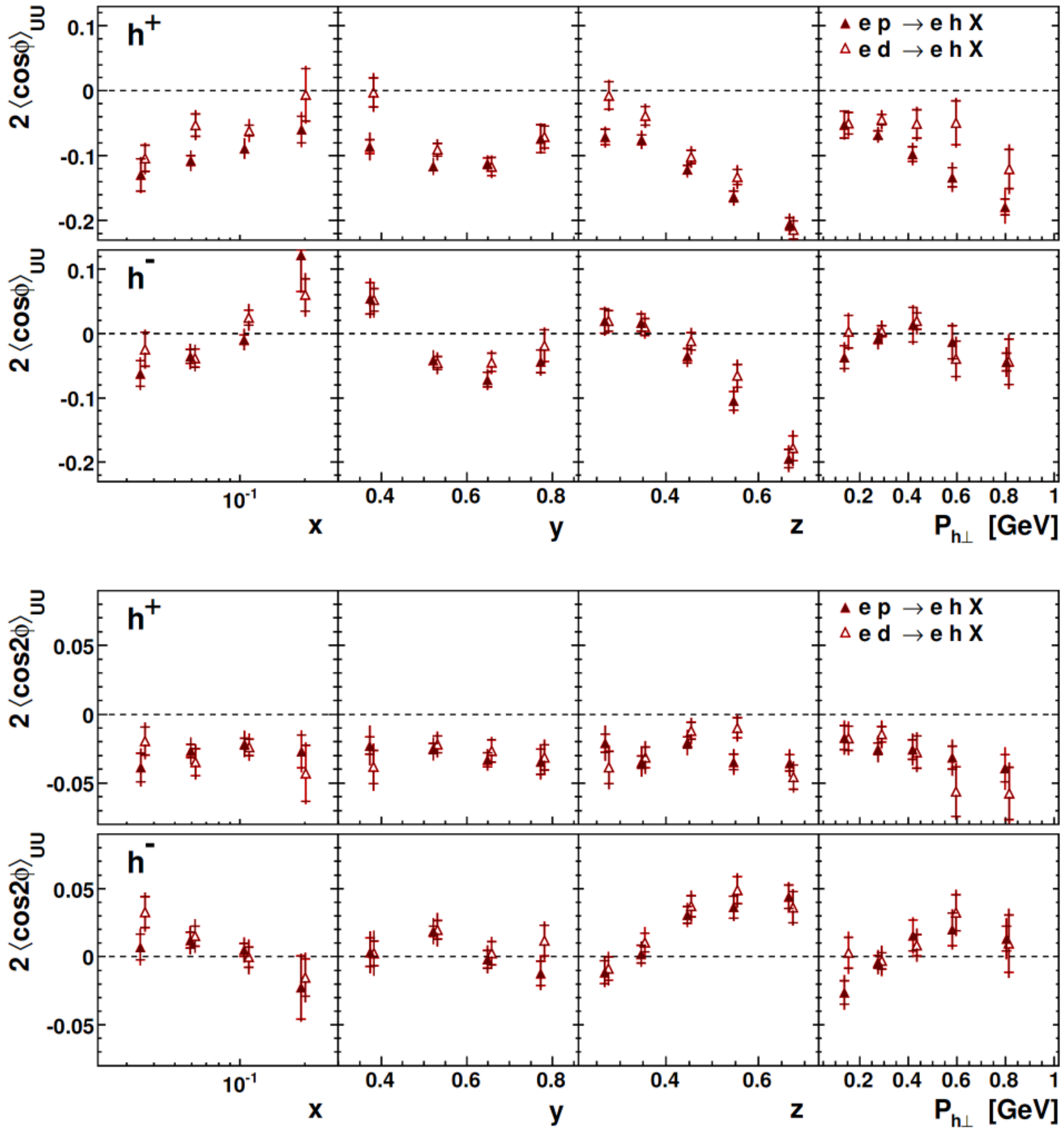




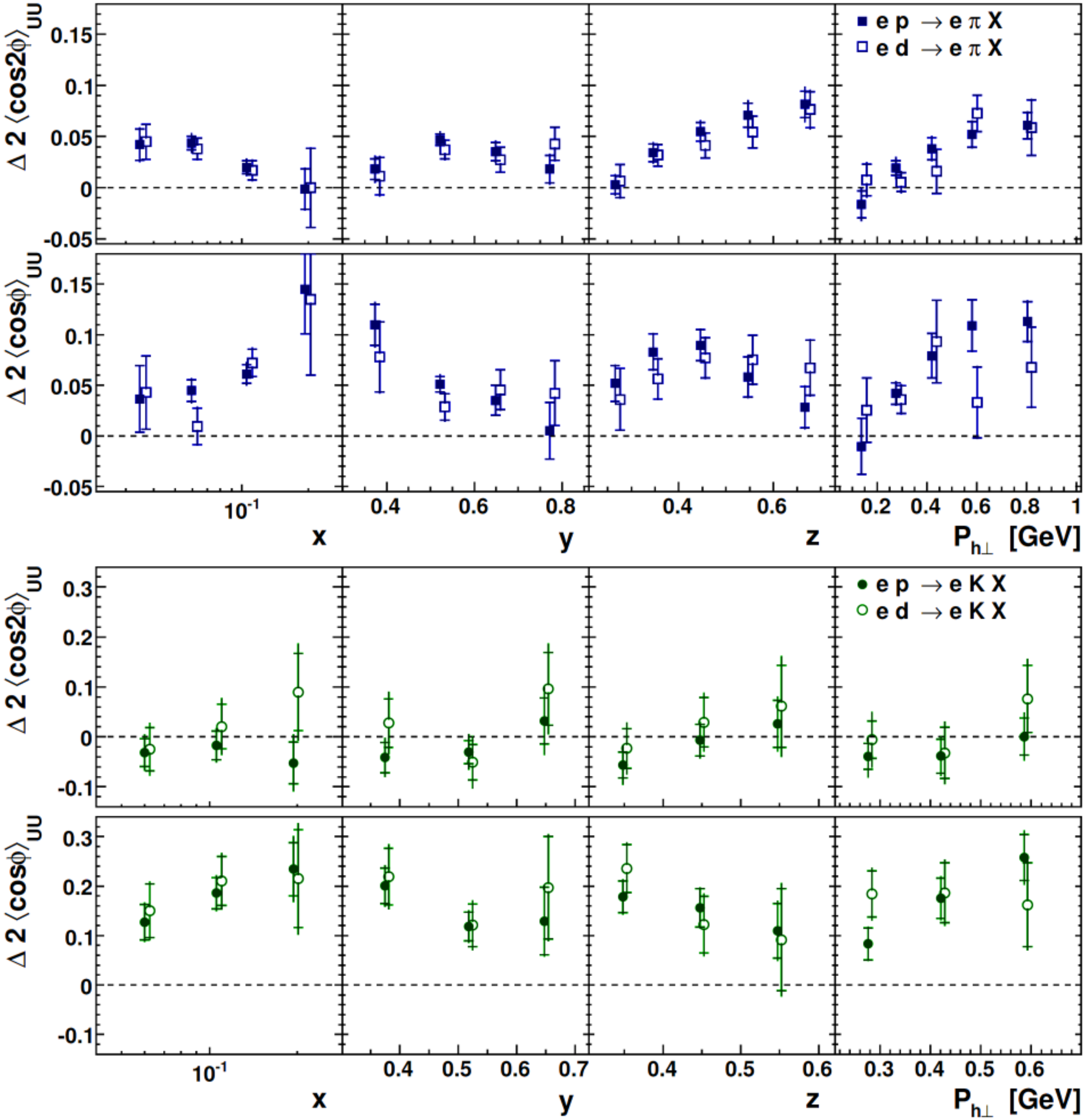




$A_{UU}^{\cos\varphi}$ and $A_{UU}^{\cos2\varphi}$-amplitude on p & d: all hadrons

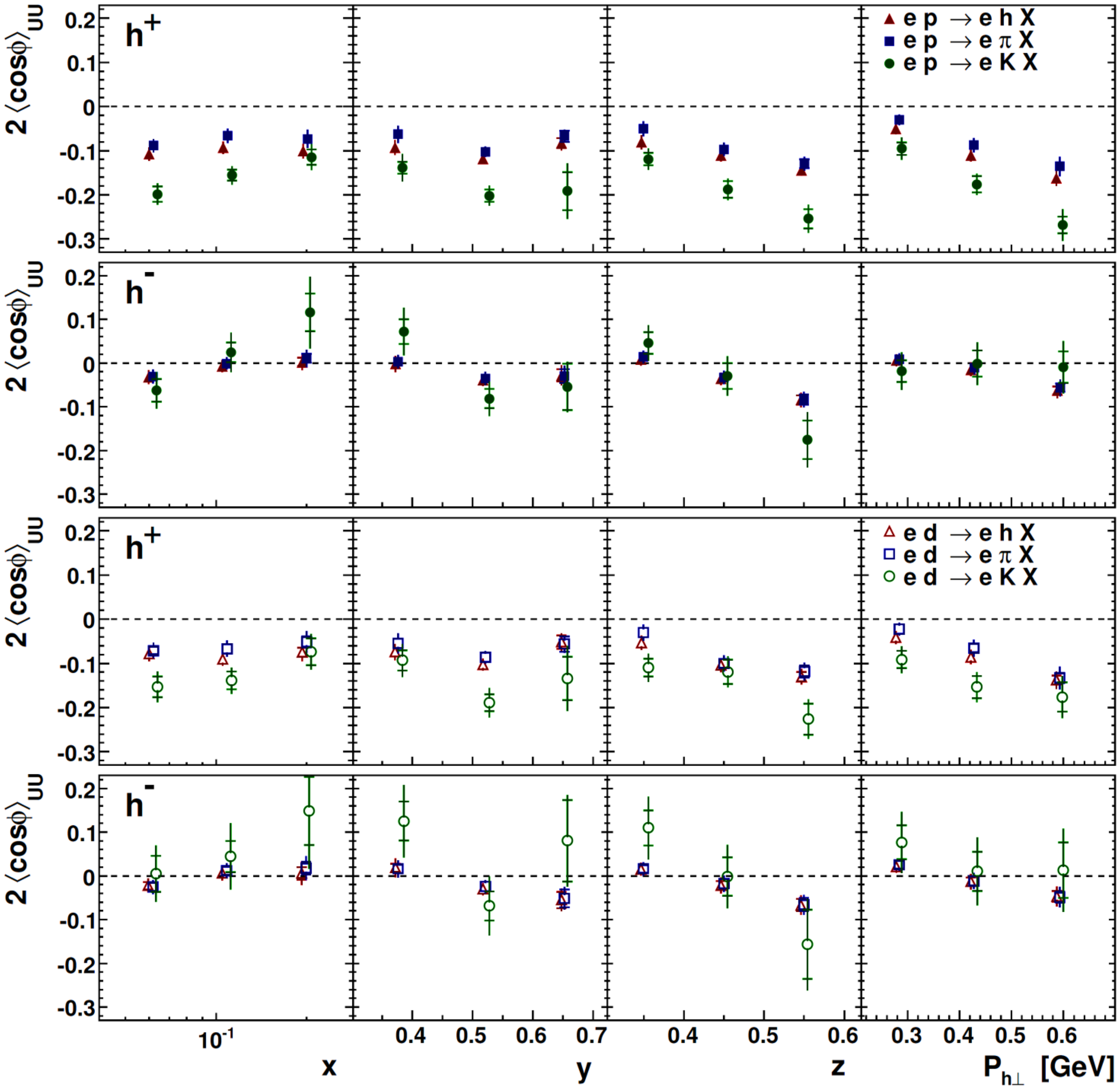


$A_{UU}^{\cos\varphi}$ and $A_{UU}^{\cos 2\varphi}$ h+/- difference on p & d

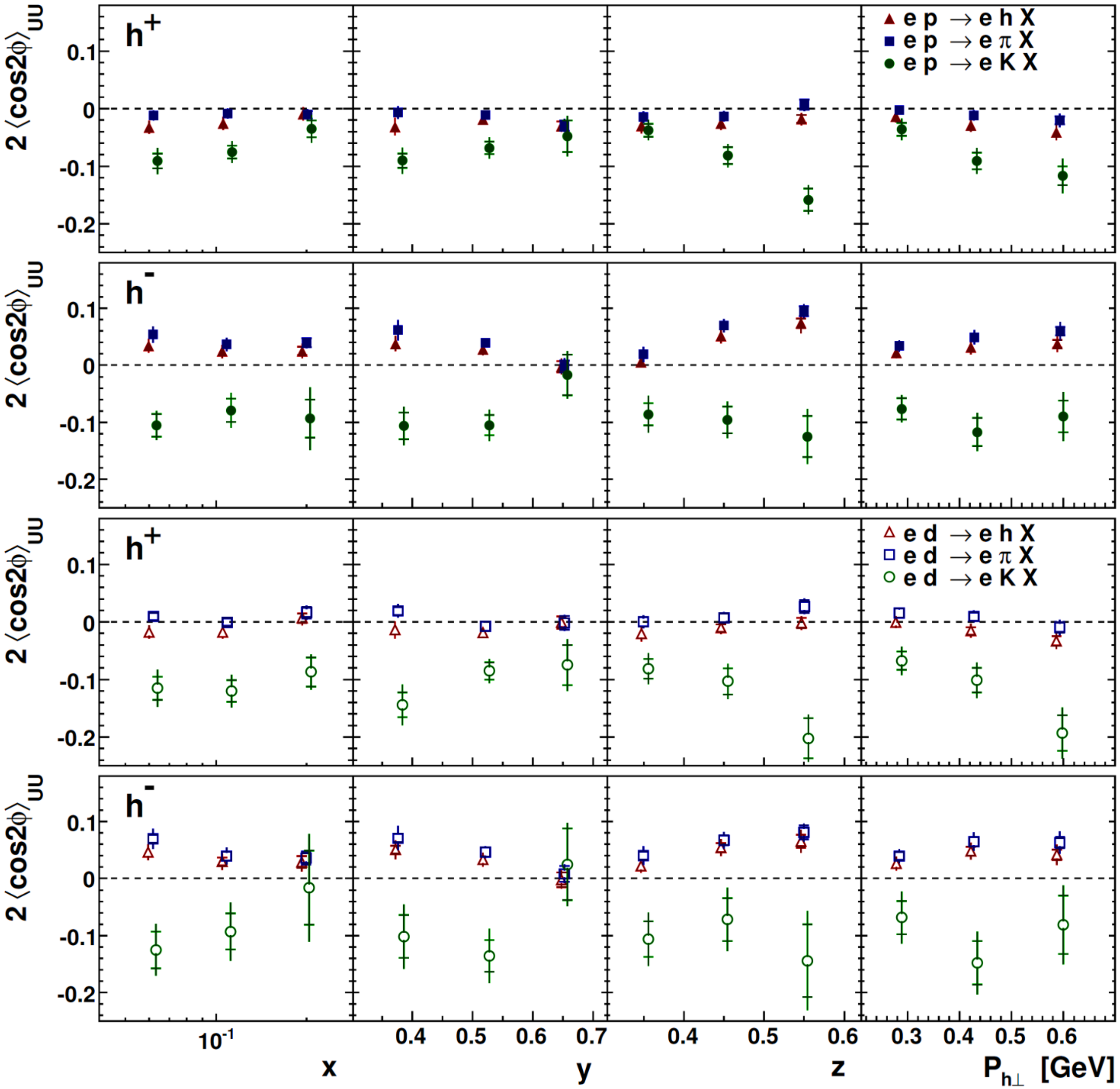


Kinematic range *Pions (all hadrons)*			
x	y	z	P_{hT}
0.023–0.27	0.3–0.85	0.2–0.75	0.05–1.0
Kinematic range *Kaons*			
x	y	z	P_{hT}
0.042–0.27	0.3–0.7	0.2–0.6	0.2–0.7

$A_{UU}^{\cos\varphi}$-amplitude on p & d (all hadrons, pions, kaons)

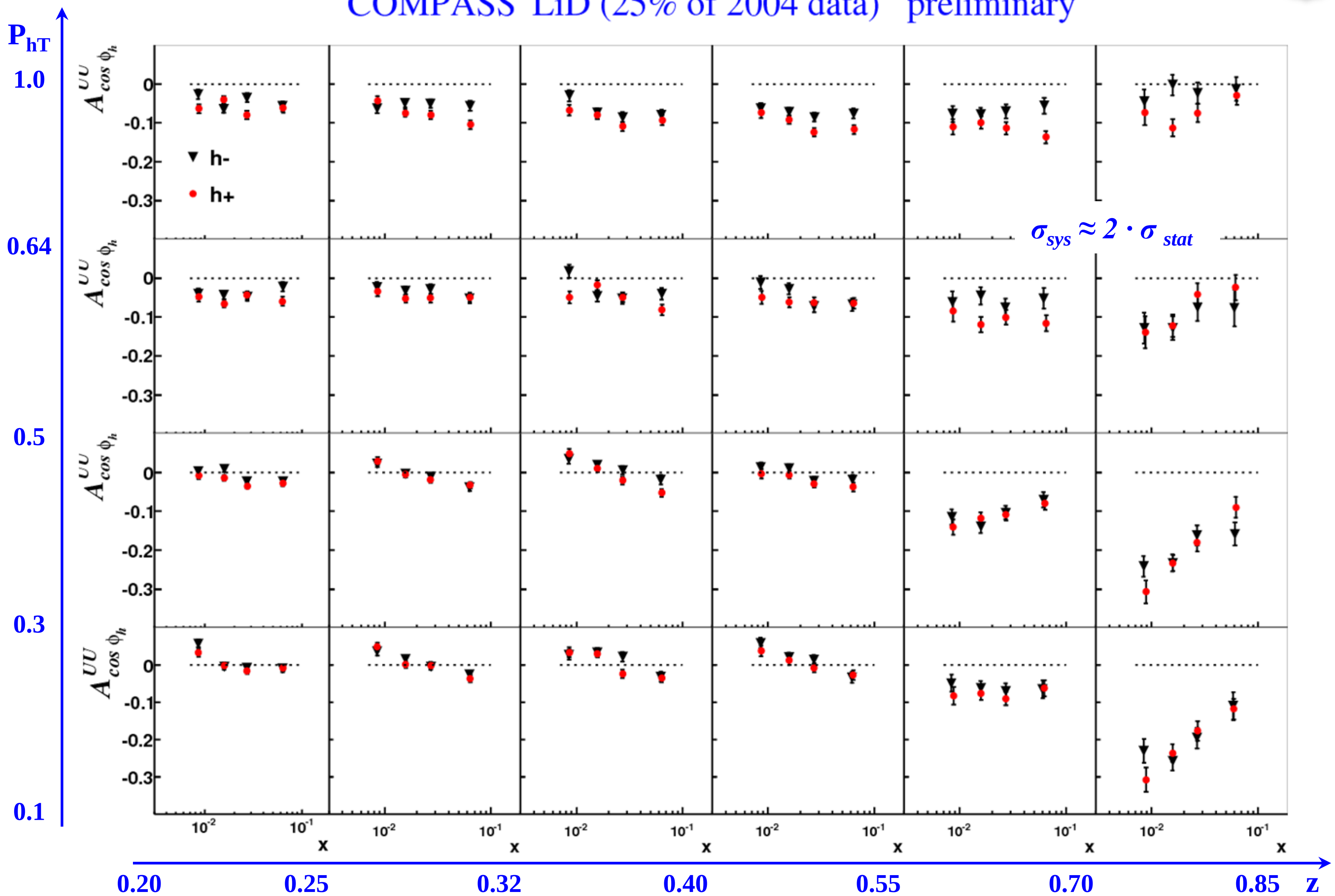


$A_{UU}^{\cos 2\varphi}$-amplitude on p & d (all hadrons, pions, kaons)



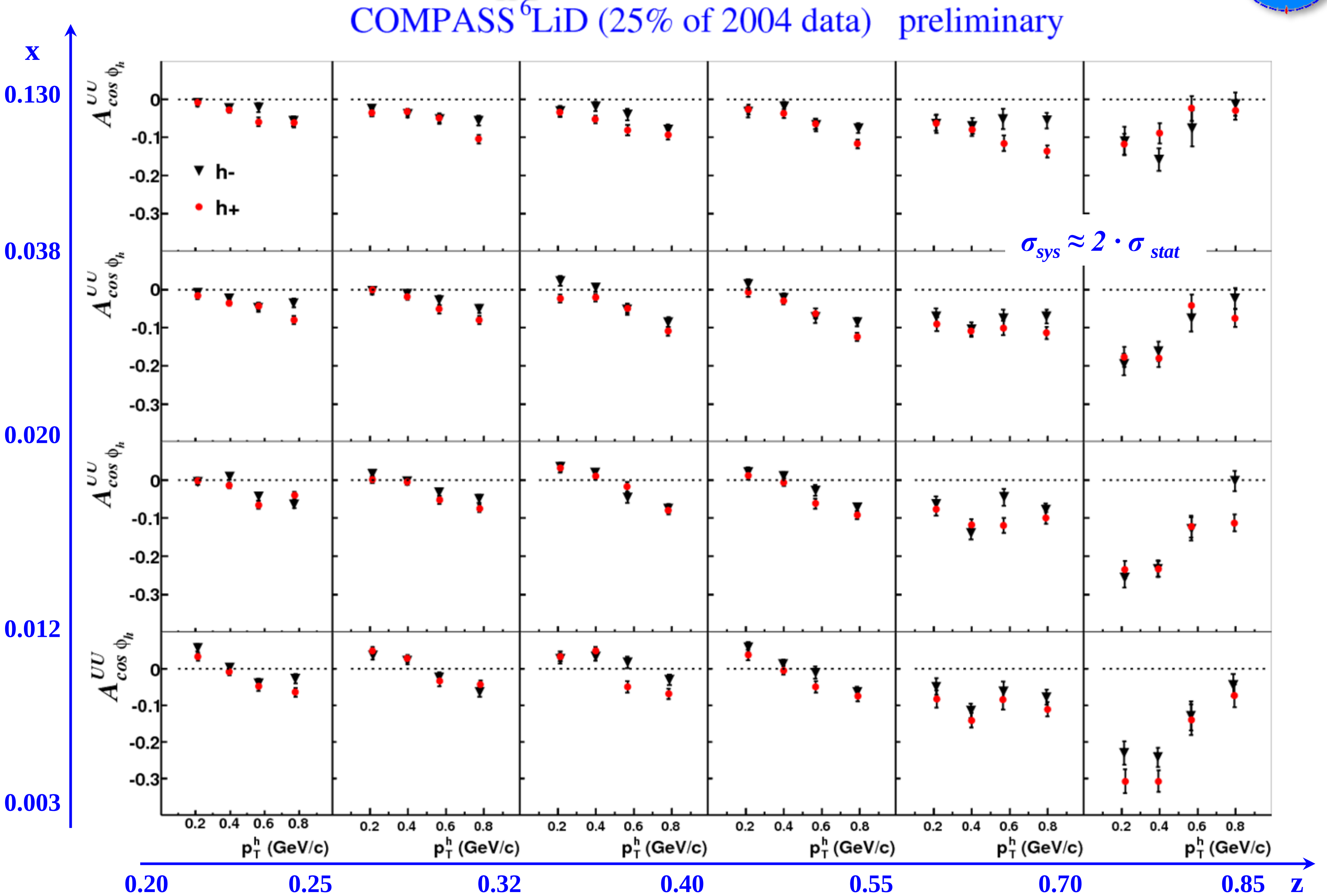
$A_{UU}^{\cos\varphi_h}$ - asymmetry (x - dependence)

COMPASS ^{6}LiD (25% of 2004 data) preliminary



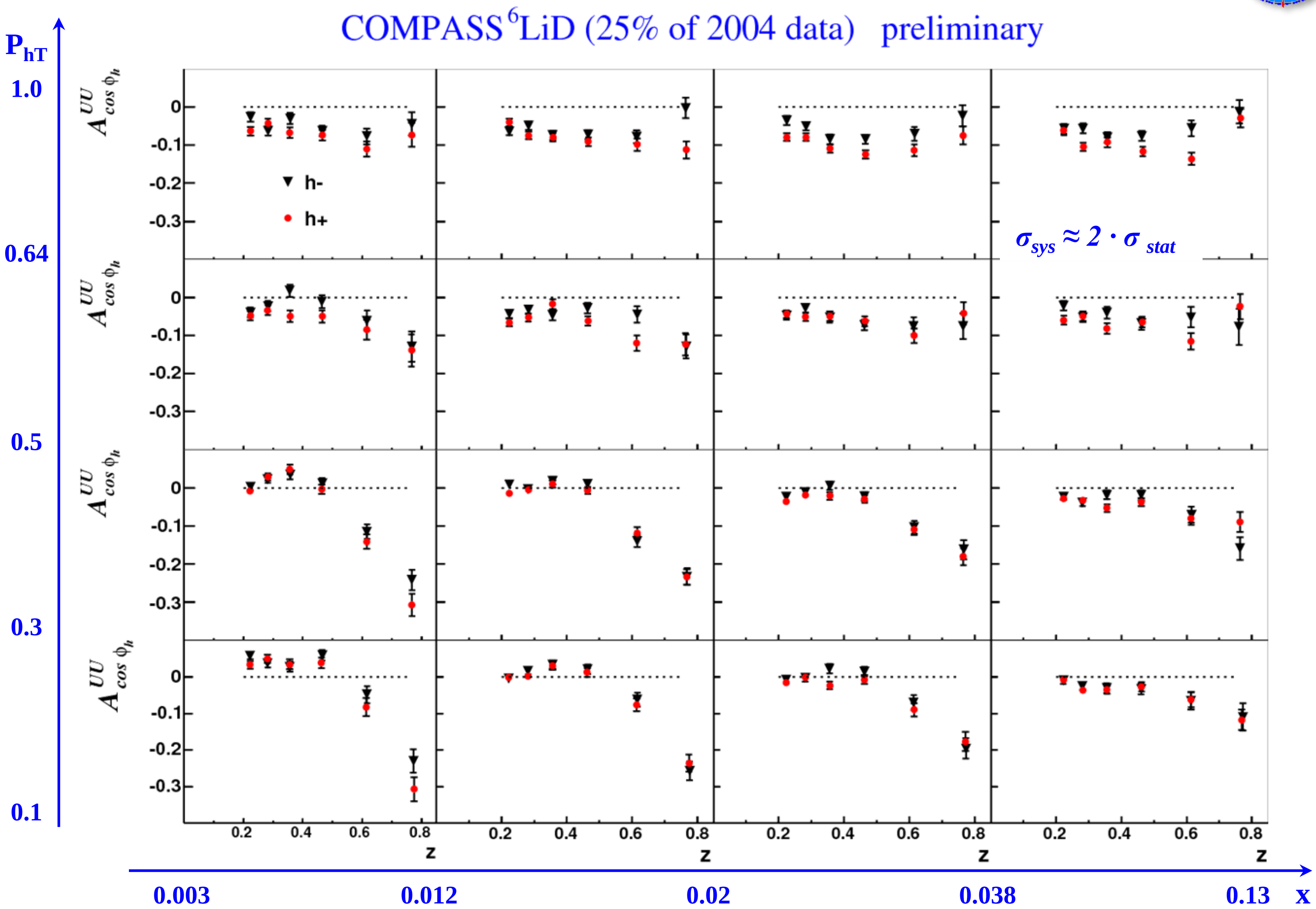
largest difference between positive and negative hadrons at large P_{hT} *x*-trend changes going from small to large z values

$A_{UU}^{\cos\varphi_h}$ - asymmetry (P_{hT} - dependence)



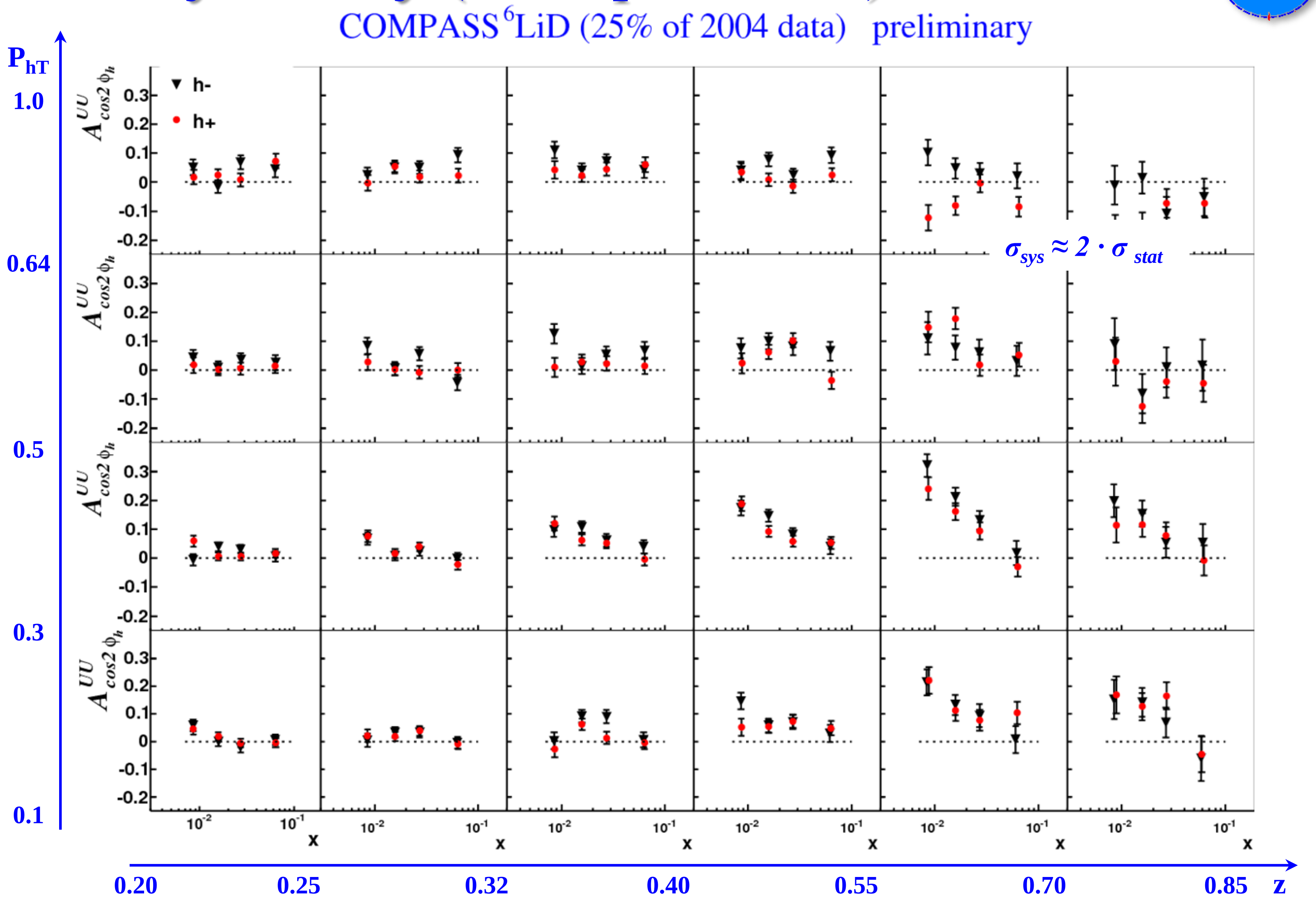
P_{hT} trend changes going from small to large z values and it is roughly the same for all x intervals

$A_{UU}^{\cos\varphi_h}$ - asymmetry (z - dependence)



z strong dependence more evident at small x and small P_{hT}

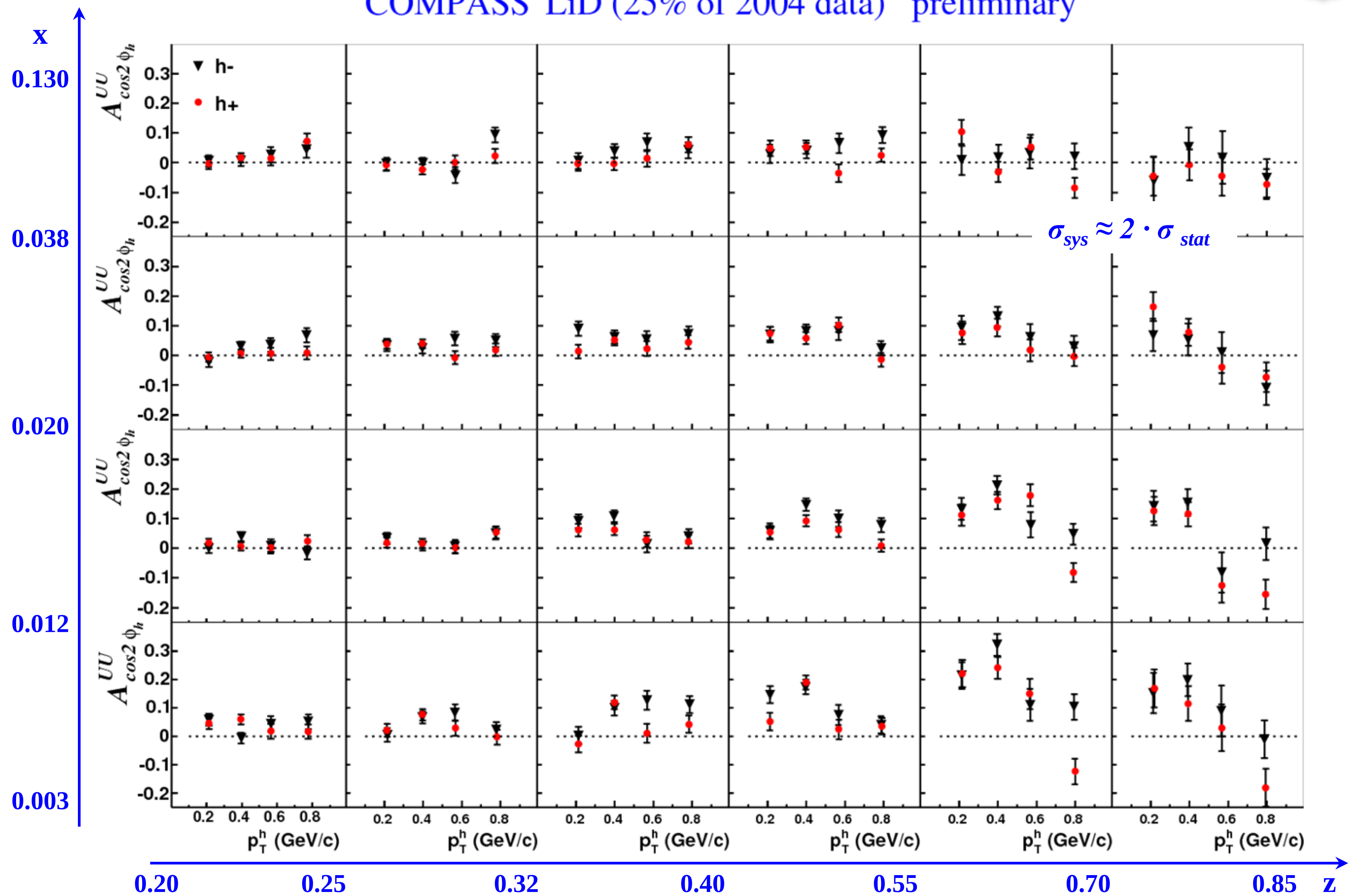
$A_{UU}^{cos2\varphi_h}$ - asymmetry (x - dependence)



x trend changes from small to large z values

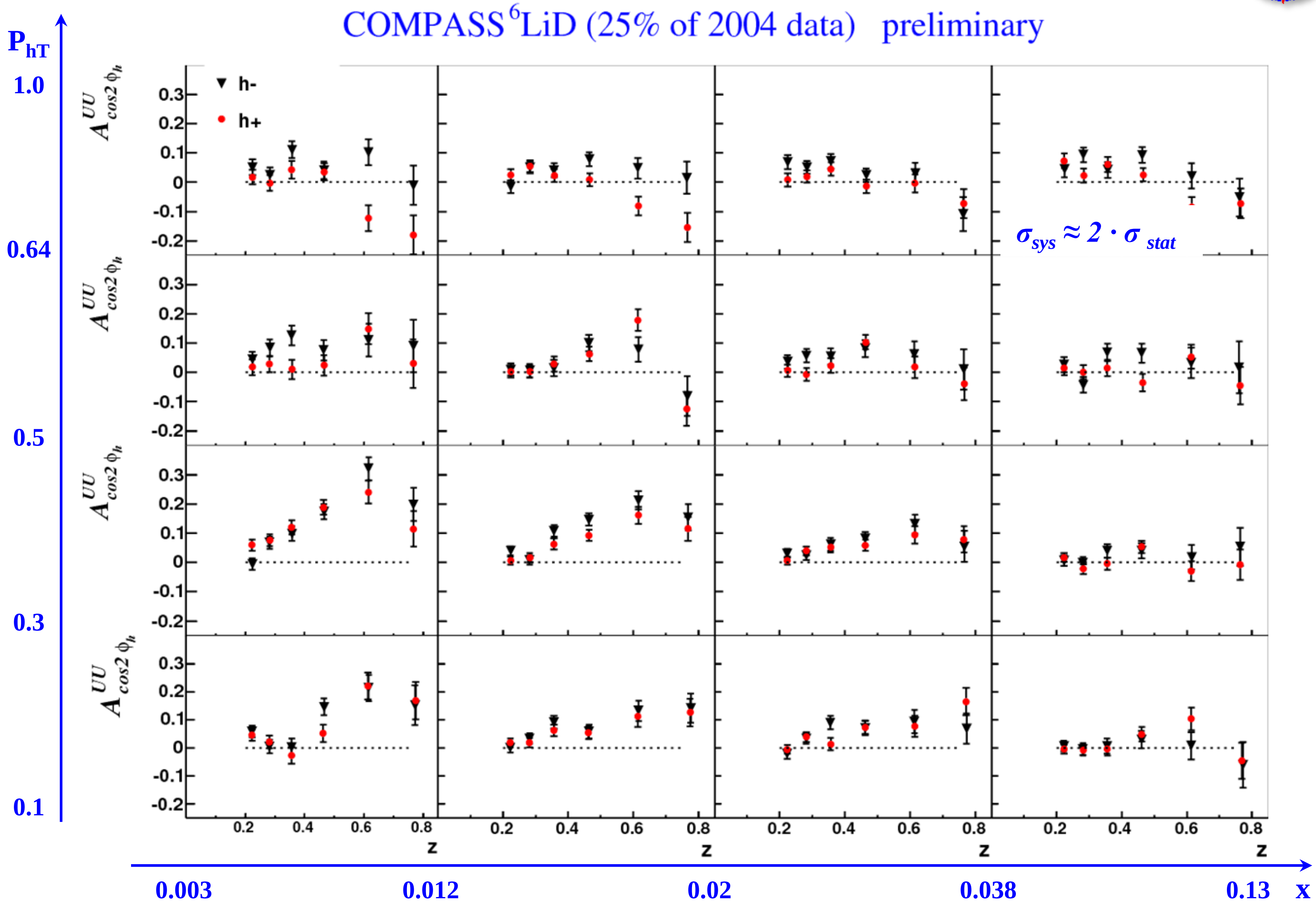
$A_{UU}^{cos2\varphi_h}$ - asymmetry (P_{hT} - dependence)

COMPASS ^{6}LiD (25% of 2004 data) preliminary



the P_{hT} trend difficult to reproduce by models is there for large z and low x

$A_{UU}^{\cos 2\varphi_h}$ - asymmetry (z - dependence)

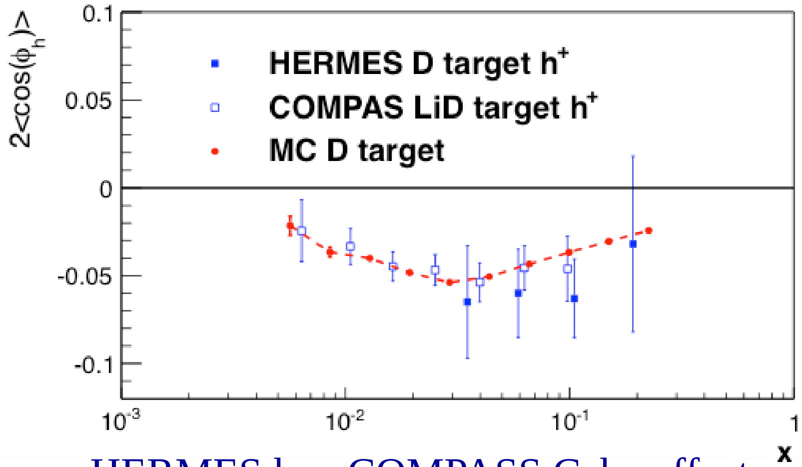


strongest effect at low x and low P_{hT}

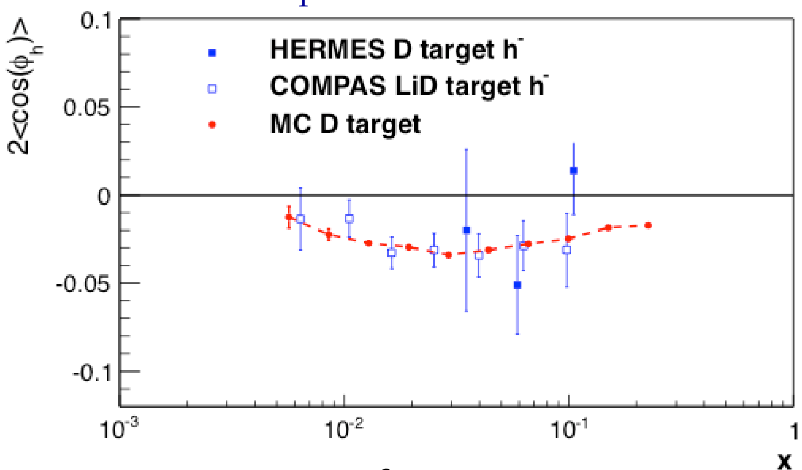
Cahn from HERMES and COMPASS (MC studies)

M. Aghasyan **arXiv:1307.3500v1 [hep-ex]**

Procedure: fit HERMES Cahn → extract k_T-widths → use it in MC with correct phase space description and describe the P_T distribution and Cahn effect for COMPASS and HERMES



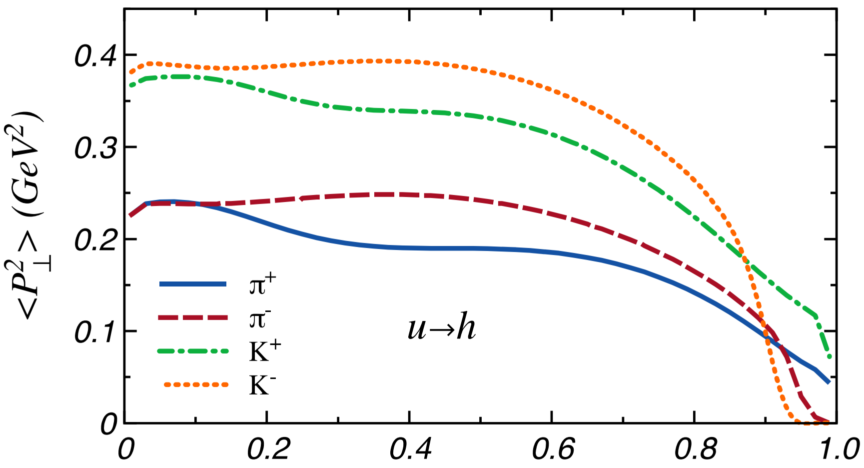
HERMES k_T - COMPASS Cahn effect



$f_{1,q}(x)$ **Fixed MSTW**

$D_1^{q\to h}(z)$ **Fixed DSS**

Fixed - **Matevosyan:PRD85,014021 (2012)**



The averaged transverse momentum of π and K mesons emitted by a u quark

Using parameters from HERMES proton data, the Cahn asymmetry for positive and negative hadrons from D target is presented from COMPASS, HERMES and MC.