TMD Parametrizations

Probing Strangeness in Hard Processes
Frascati, October 18-21, 2010

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In collaboration with
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U. D'Alesio, F. Murgia, A. Kotzinian, A. Prokudin

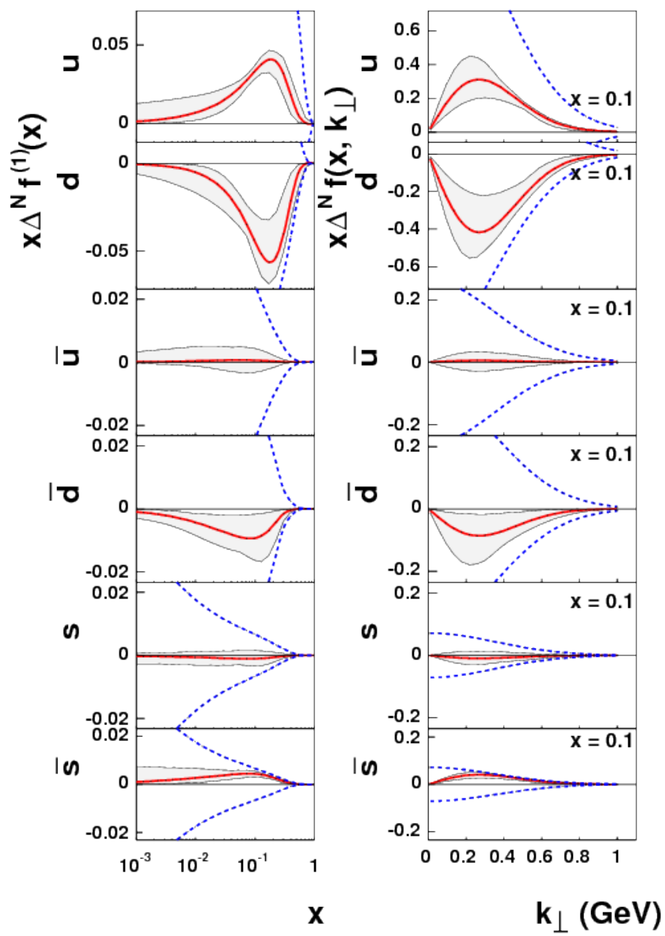
Summary

- Role of sea quarks in the Sivers asymmetry in SIDIS
- Transversity & Collins function
- Boer-Mulders functions

Polarized SIDIS $lp^{\uparrow} \rightarrow l'h+X$

Sea quarks sivers functions

Extracted Sivers Functions



Anselmino et al.
Eur. Phys. J. A39,89 (2009)

✔Valence quark

- $\Delta^N f_{u/p^\uparrow} > 0 \quad \Rightarrow f_{1T}^{\perp u} < 0$
- $\Delta^N f_{d/p^\uparrow} < 0 \quad \Rightarrow f_{1T}^{\perp d} > 0$

✔Sea quarks

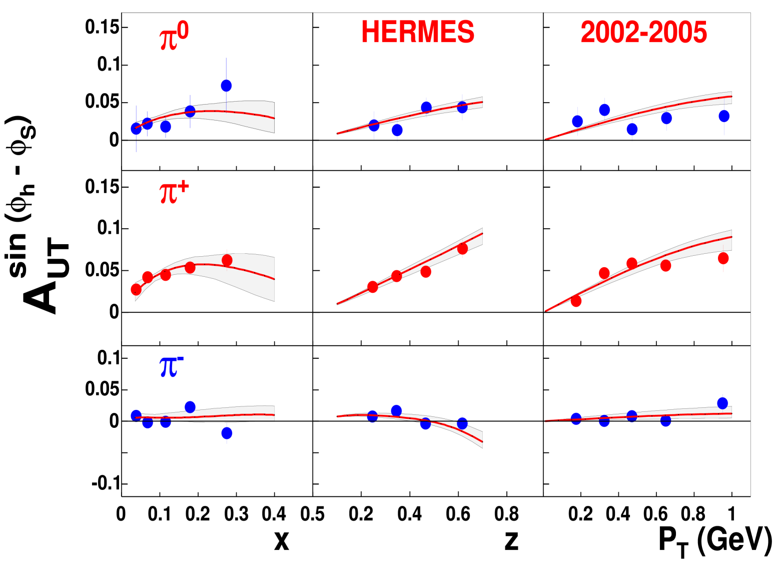
- $\Delta^N f_{\bar{s}/p^\uparrow} > 0 \quad \Rightarrow f_{1T}^{\perp \bar{s}} < 0$

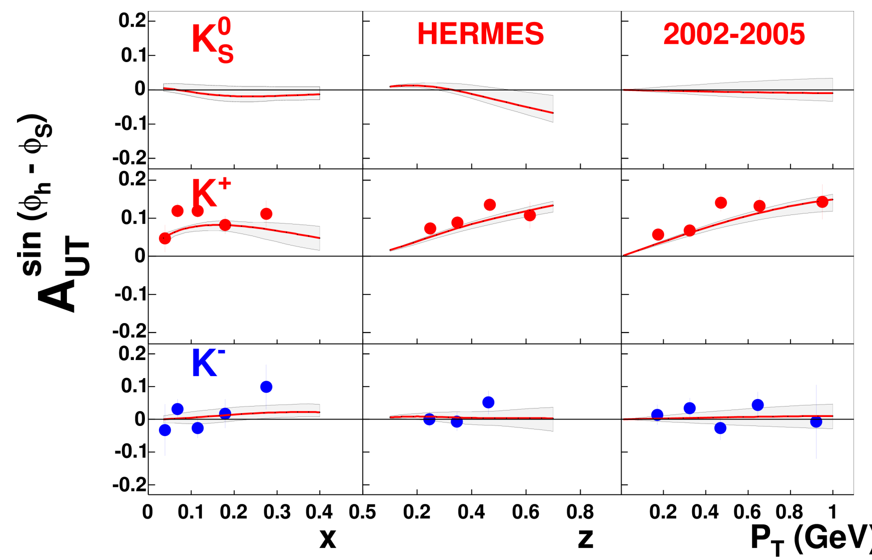
$\chi^2/d.o.f = 1$		
$N_u = 0.35^{+0.078}_{-0.079}$ $N_{\bar{u}} = 0.037^{+0.22}_{-0.24}$ $\alpha_u = 0.73^{+0.72}_{-0.58}$ $\beta = 3.5^{+4.9}_{-2.9}$	$N_d = -0.9^{+0.43}_{-0.098}$ $N_{\bar{d}} = -0.4^{+0.33}_{-0.44}$ $\alpha_d = 1.1^{+0.82}_{-0.65}$ $M_1^2 = 0.34^{+0.3}_{-0.16}$ GeV^2	$N_s = -0.24^{+0.62}_{-0.5}$ $N_{\bar{s}} = 1^{+0}_{-0.0001}$ $\alpha_{sea} = 0.79^{+0.56}_{-0.47}$

→ $\Delta^N f_q^{(1)}(x) \equiv \int d^2 \boldsymbol{k}_\perp \frac{k_\perp}{4m_p} \Delta^N f_{q/p^\uparrow}(x, k_\perp) = -f_{1T}^{\perp(1)q}(x)$

Extracted Sivers Functions

HERMES Proton Target

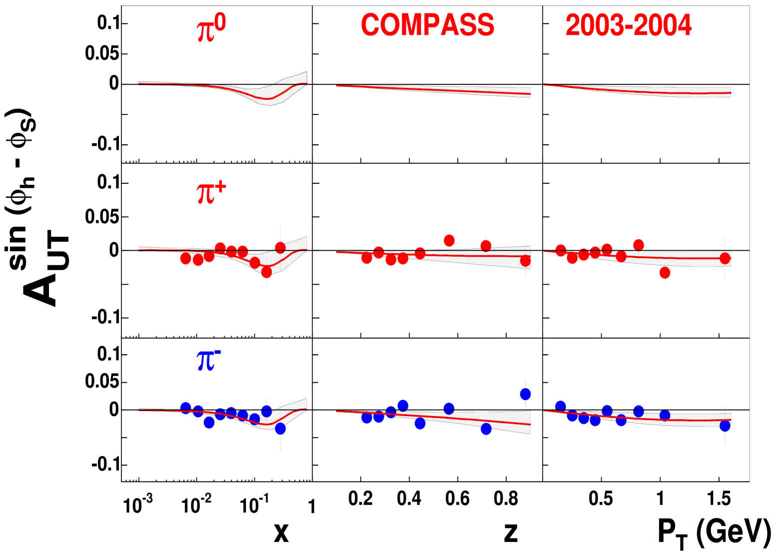


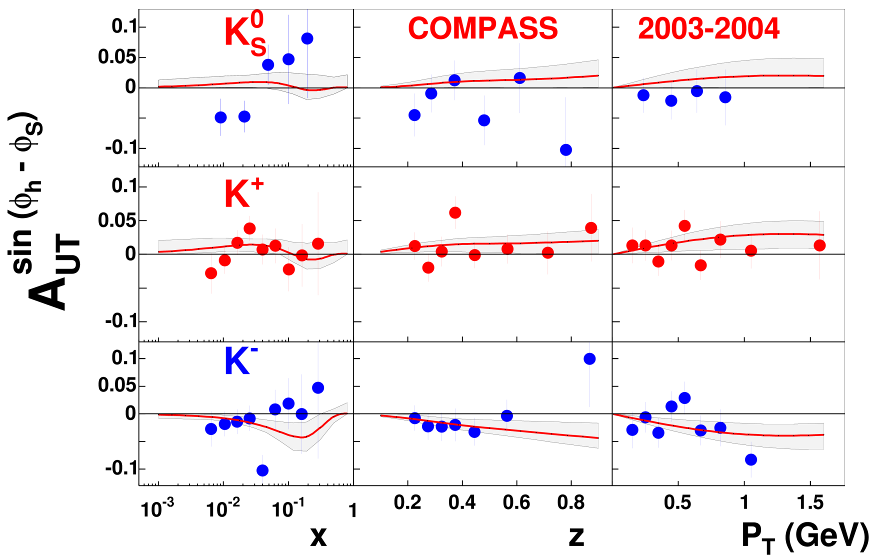


HERMES Collaboration (M. Diefenthaler), arXiv:0706.2242 [hep-ex].

Extracted Sivers Functions

COMPASS Deuteron Target





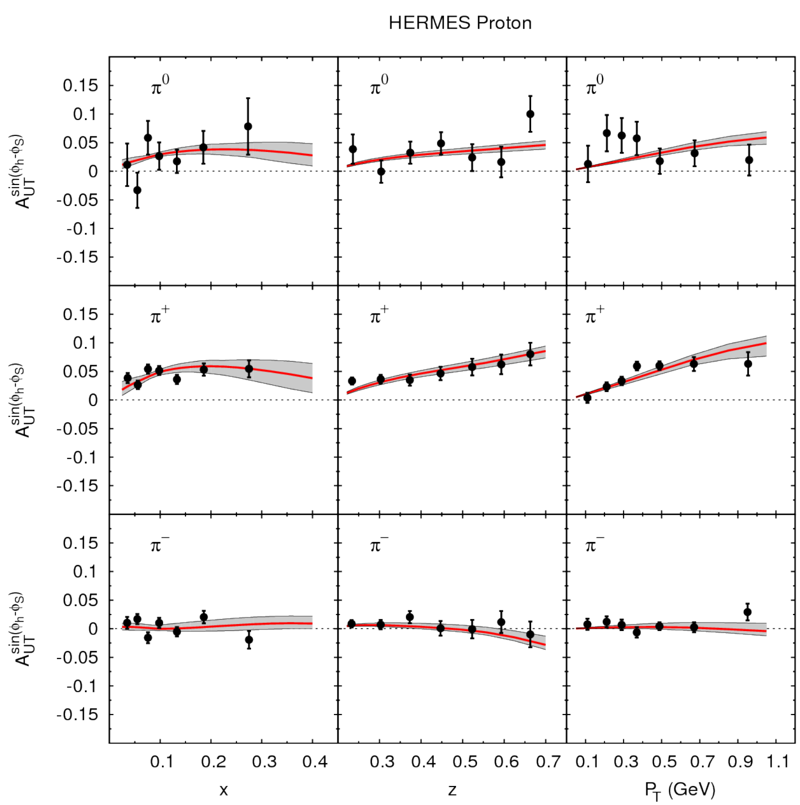
COMPASS Collaboration (A. Martin), Czech. J. Phys. 56, F33 (2006)

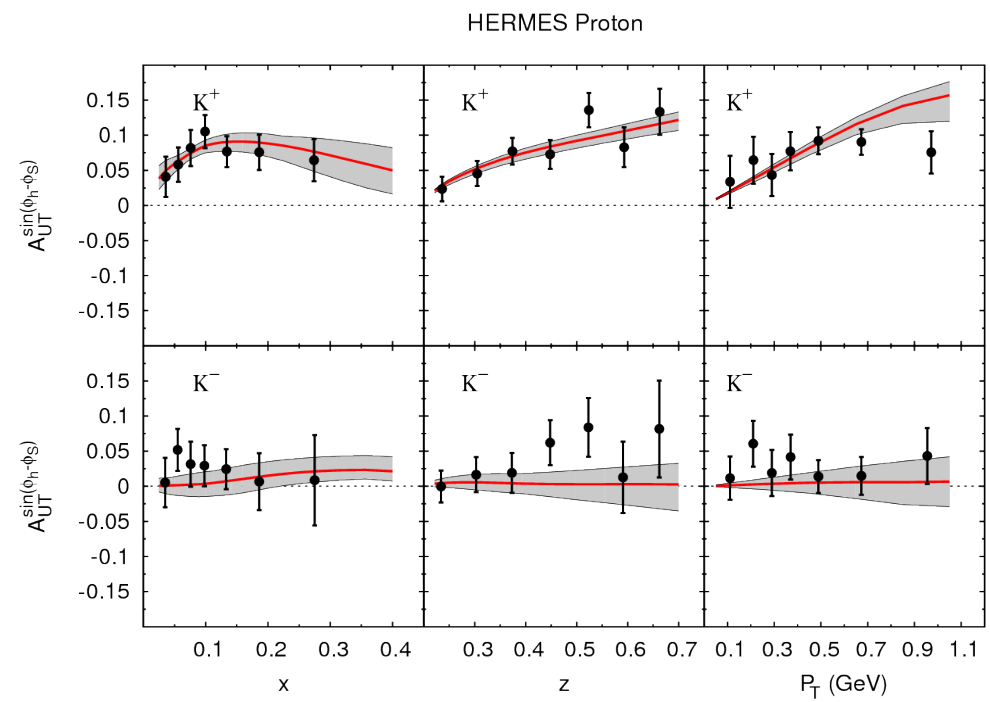
COMPASS Collaboration (M. Alekseev et al.), arXiv:0802.2160 [hep-ex].

New HERMES and COMPASS DATA!

New data-old fit

HERMES Proton Target-2009



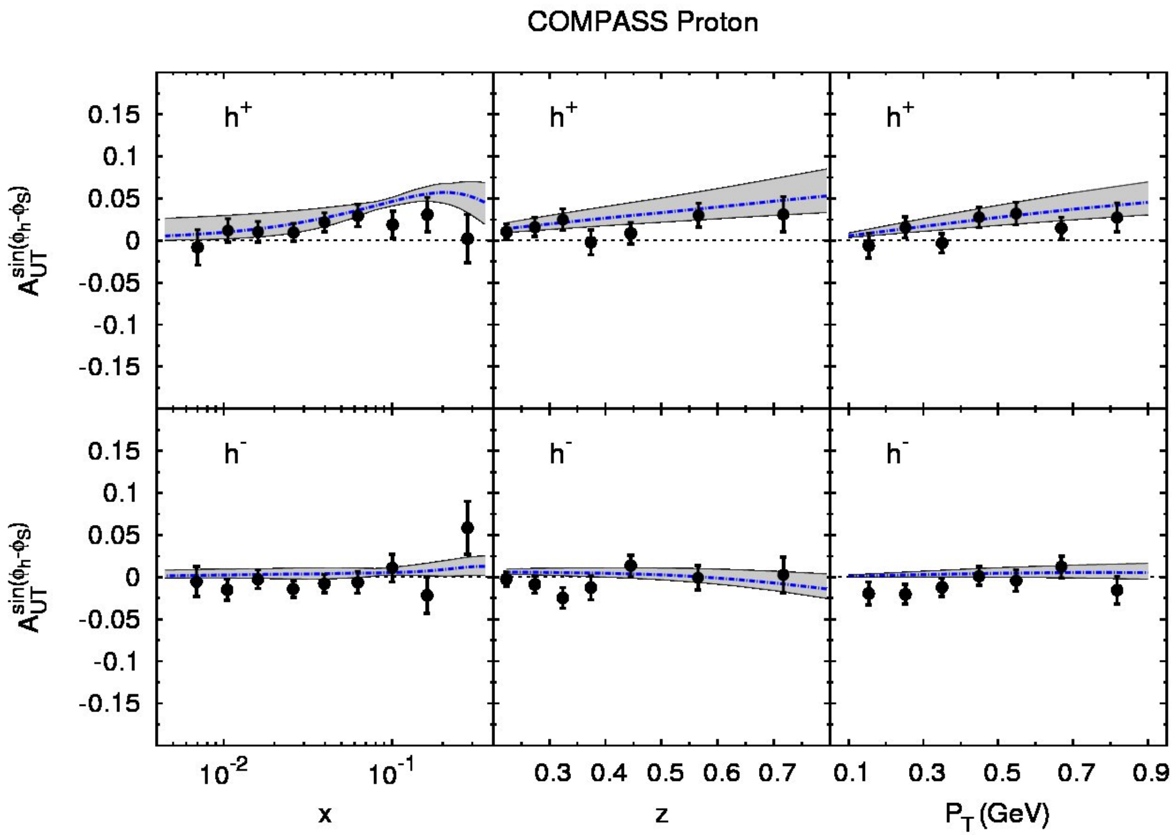


- A. Airapetian et al., Phys. Rev. Lett. 103 (2009) 152002

χ^2/dof=.96

New data-old fit

COMPASS Proton Target

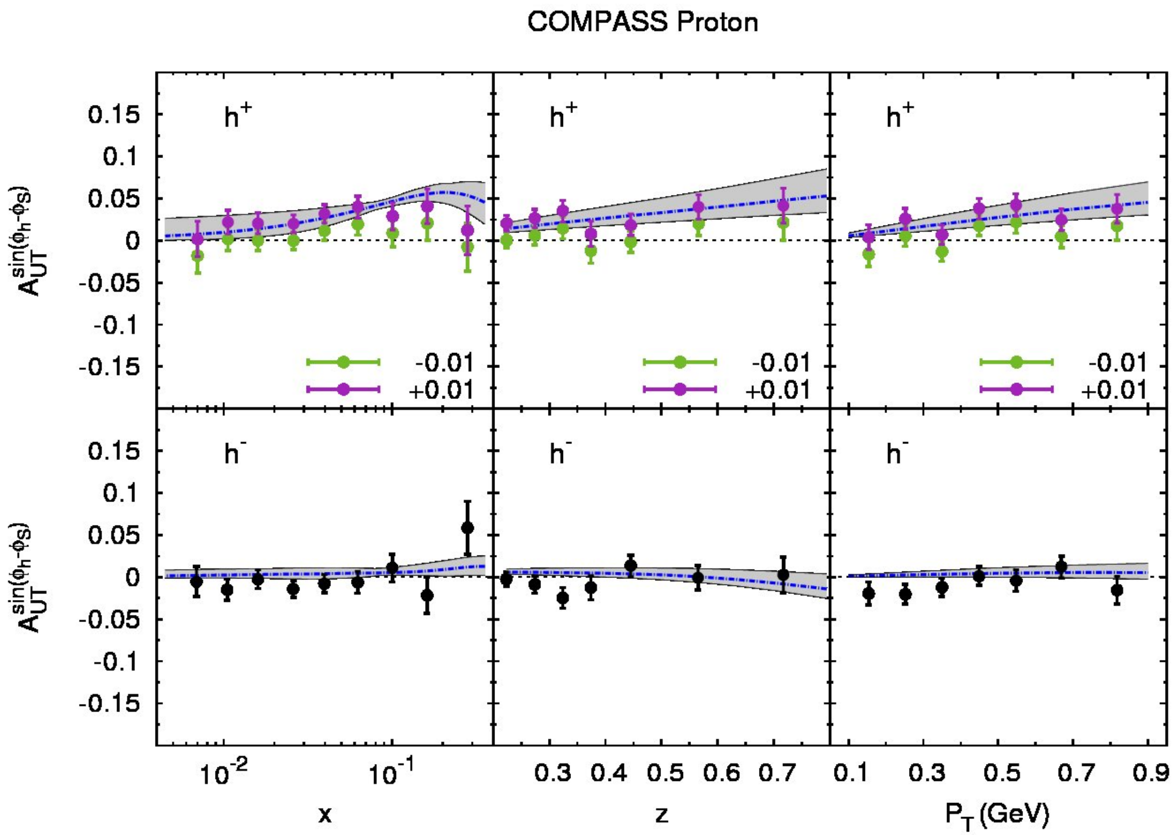


arXiv:1005.5609

Statistical and systematic errors added in quadrature, no scale error

New data-old fit

COMPASS Proton Target



Statistical and systematic errors added in quadrature + scale error

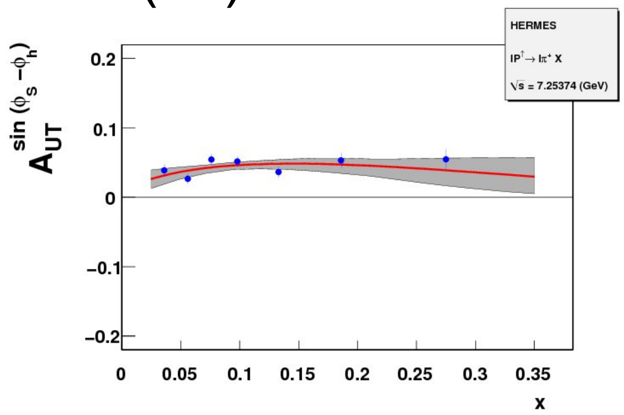
New data-new fit!

FIT I — Valence only, no sea quarks

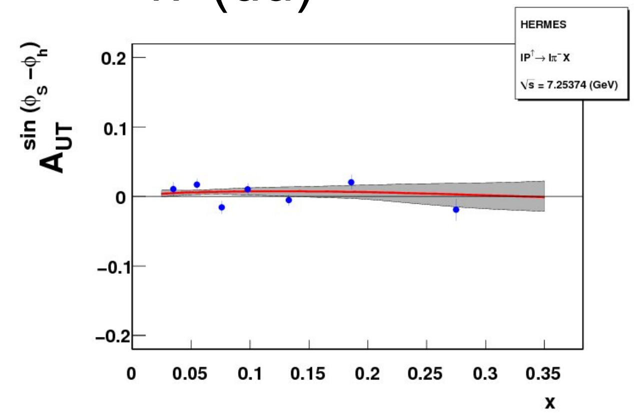
FIT II — Valence + sea

Valence only -No sea

$\pi^{+}\,(u\bar{d})$

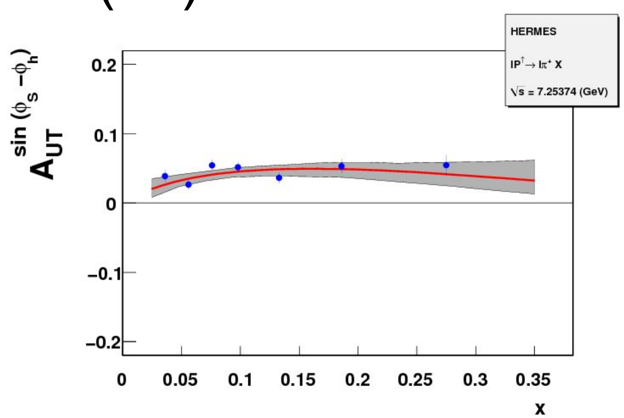


$\pi^{-}\,(d\bar{u})$

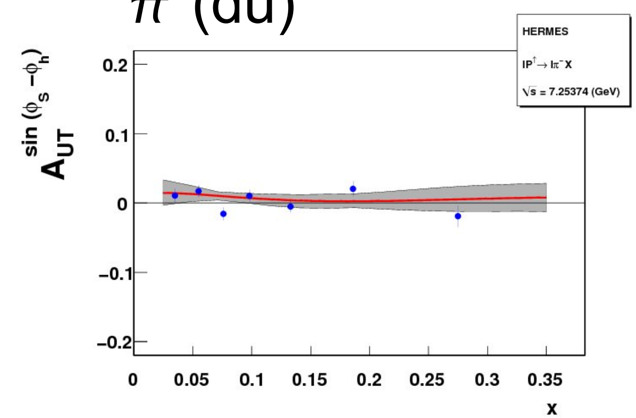


Valence+ sea

$\pi^{+}\,(u\bar{d})$

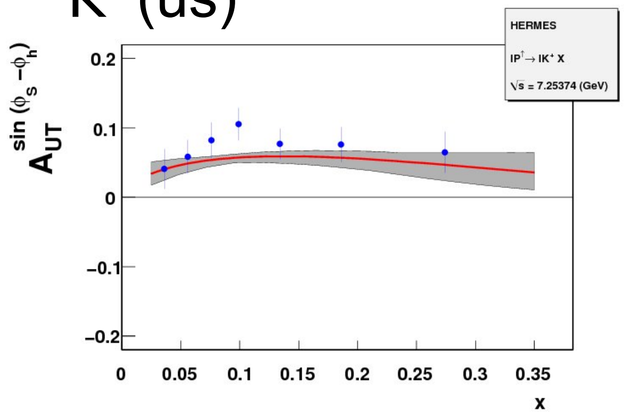


$\pi^{-}\,(d\bar{u})$

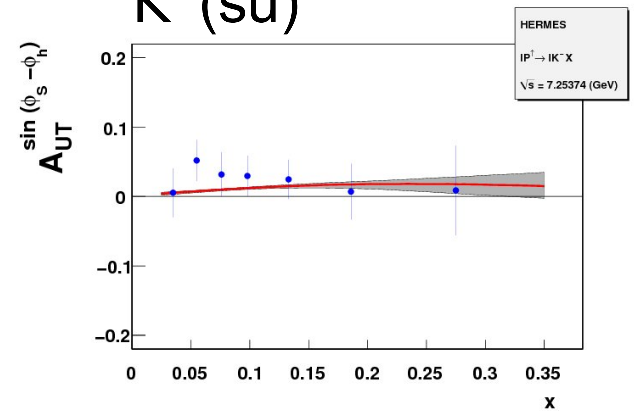


Valence only -No sea

$K^+ (u\bar{s})$



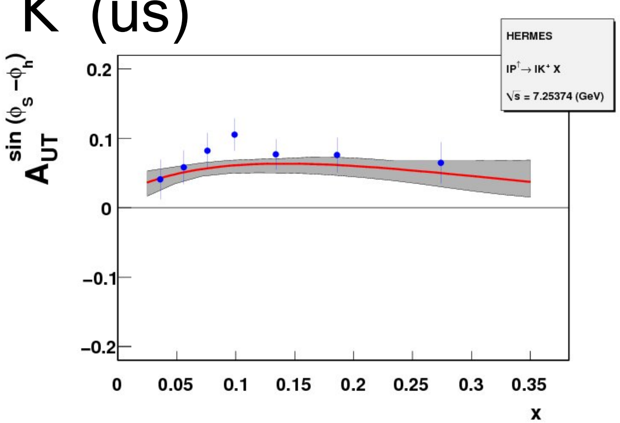
$K^- (s\bar{u})$



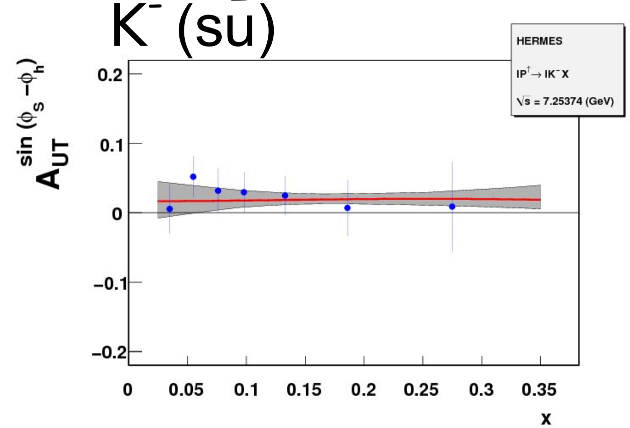
hermes

Valence+ sea

$K^+ (u\bar{s})$



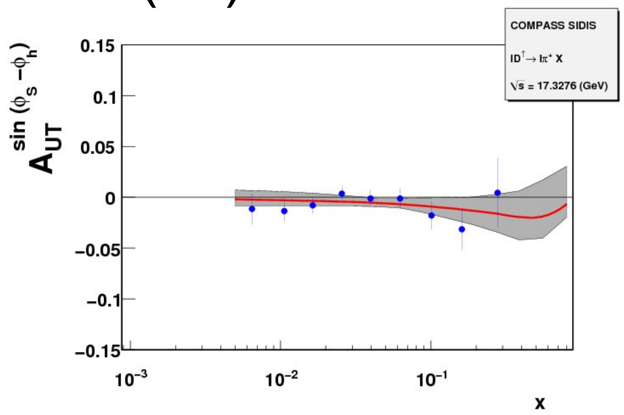
$K^- (s\bar{u})$



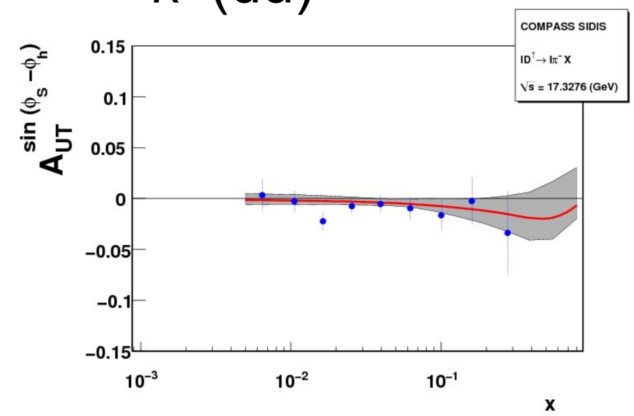
hermes

Valence only -No sea

$\pi^+ (u\bar{d})$

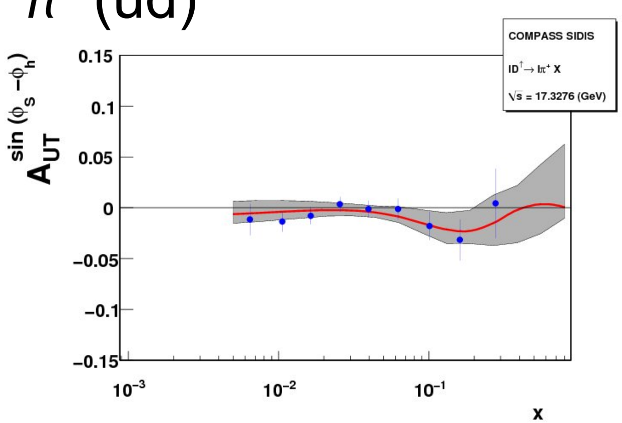


$\pi^- (d\bar{u})$

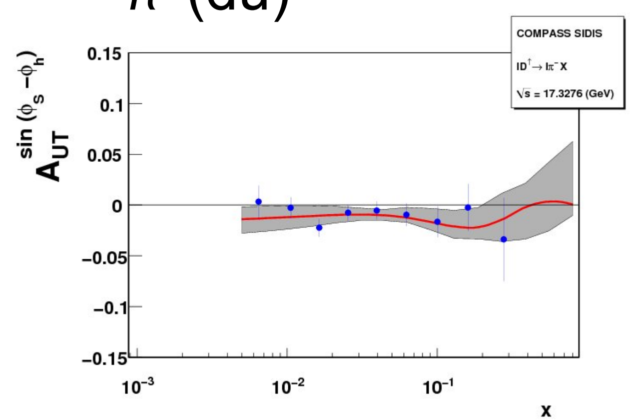


Valence+ sea

$\pi^+ (u\bar{d})$

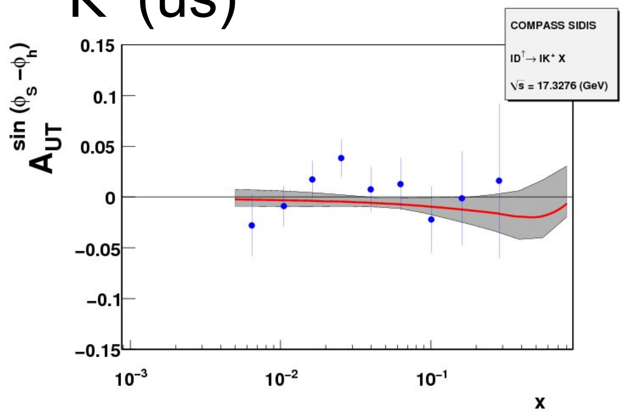


$\pi^- (d\bar{u})$

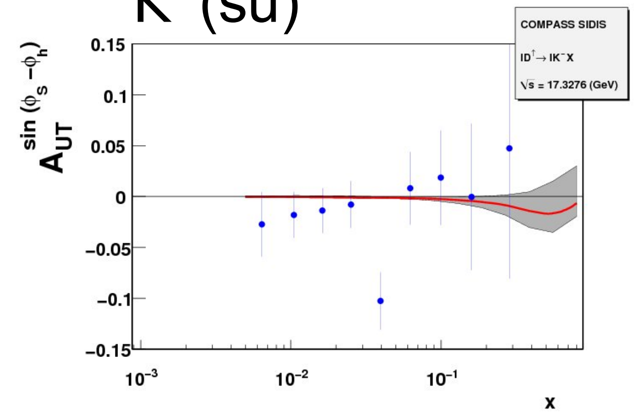


Valence only -No sea

K⁺ $(u\bar{s})$

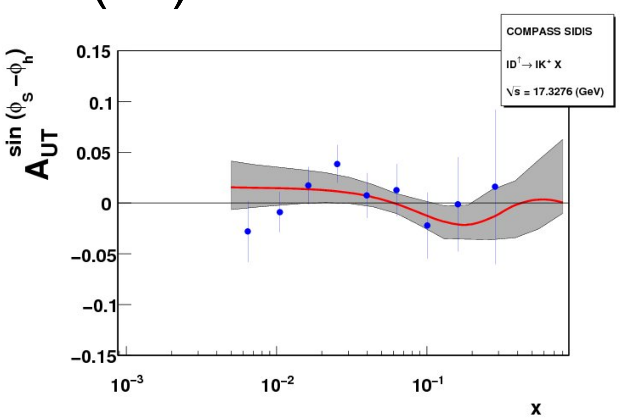


K⁻ $(s\bar{u})$

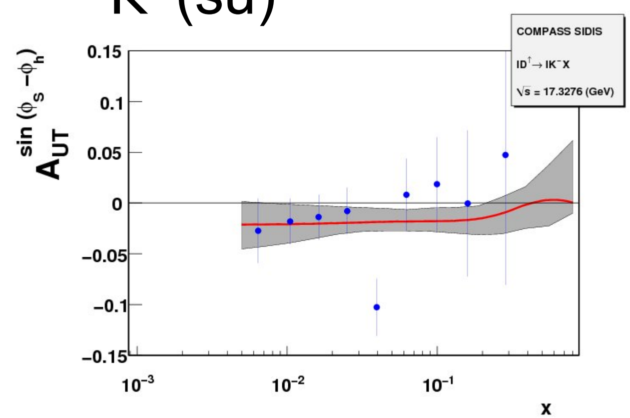


Valence+ sea

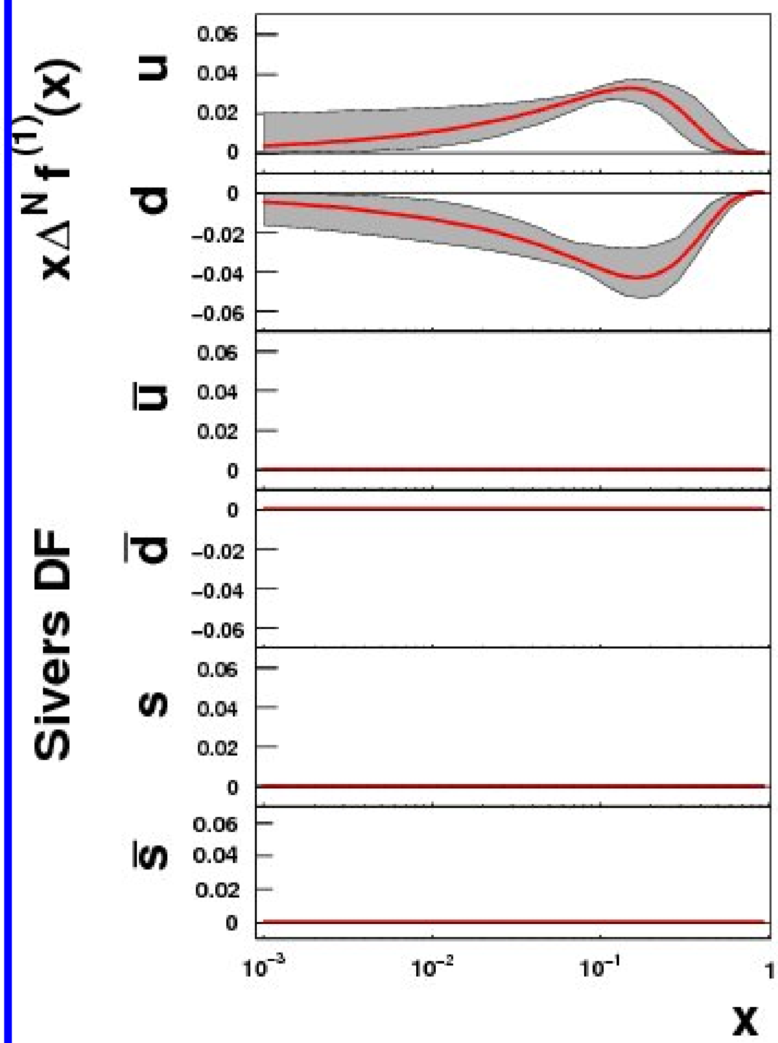
K⁺ $(u\bar{s})$



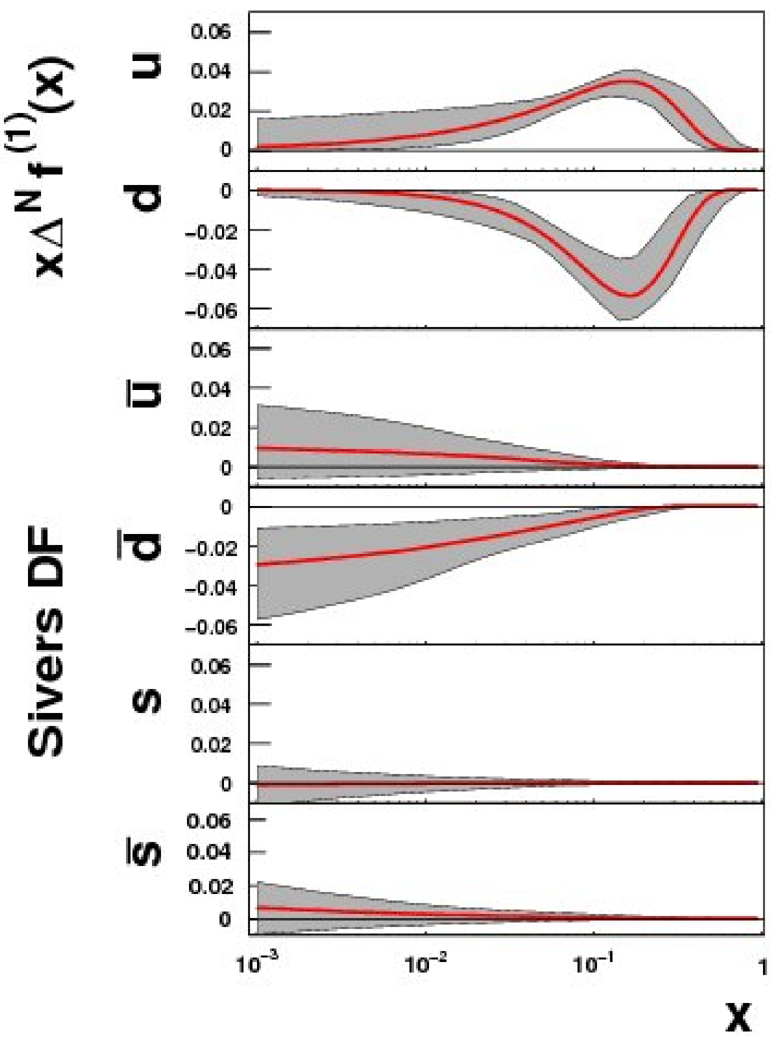
K⁻ $(s\bar{u})$



Valence only -No sea



Valence+ sea

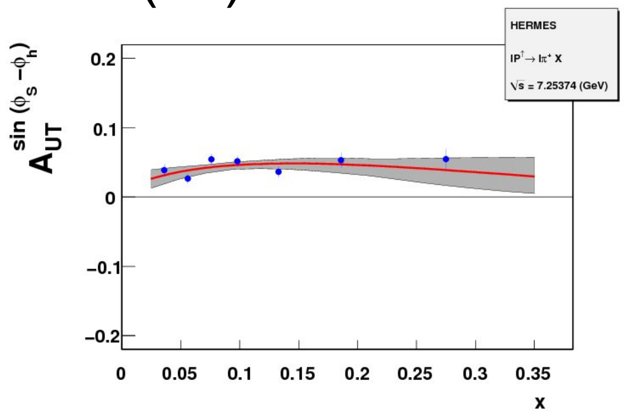


χ^2 /dof=1.07

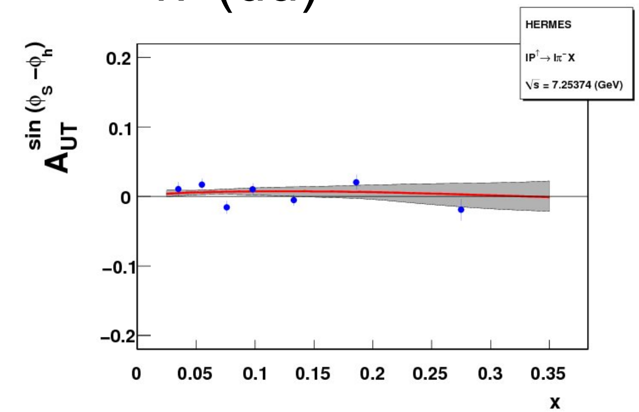
χ^2 /dof=.91

Valence only -No sea

$\pi^+ (u\bar{d})$

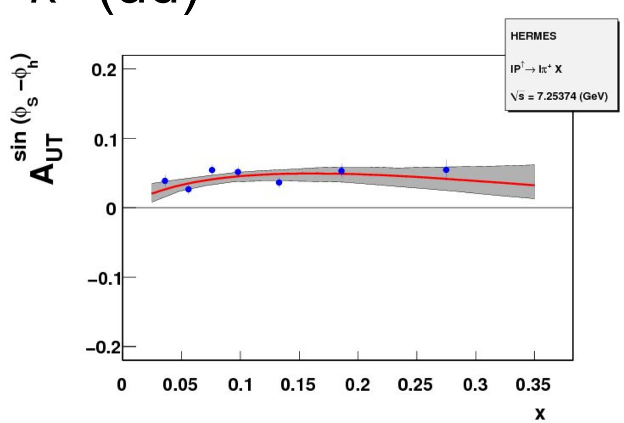


$\pi^- (d\bar{u})$

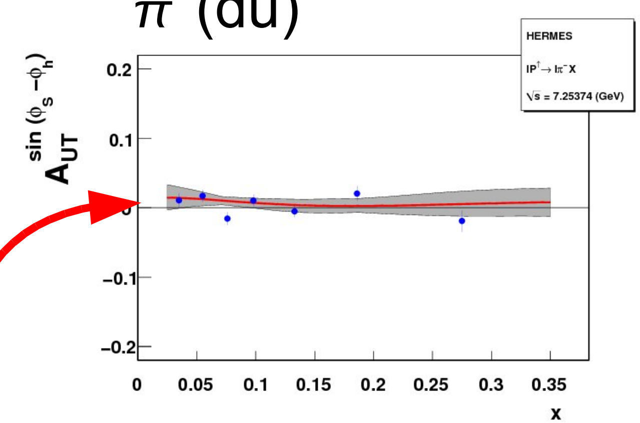


Valence+ sea

$\pi^+ (u\bar{d})$



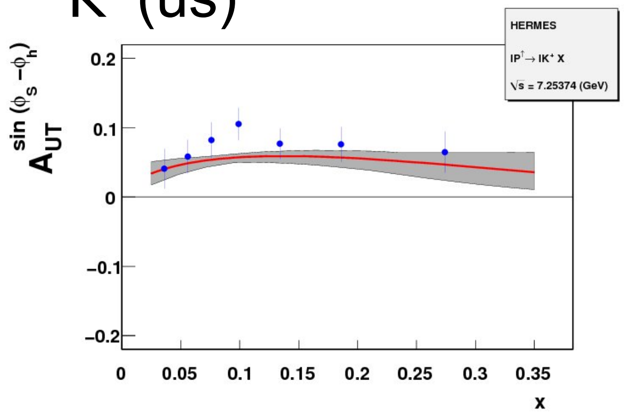
$\pi^- (d\bar{u})$



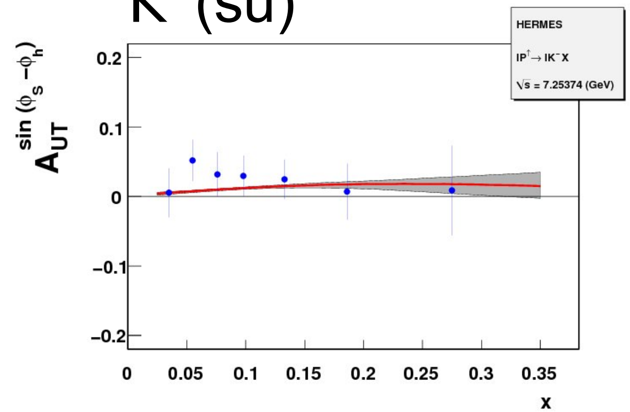
$\Delta^N f_{\bar{u}/p^\uparrow} > 0$

Valence only -No sea

K⁺ ($u\bar{s}$)

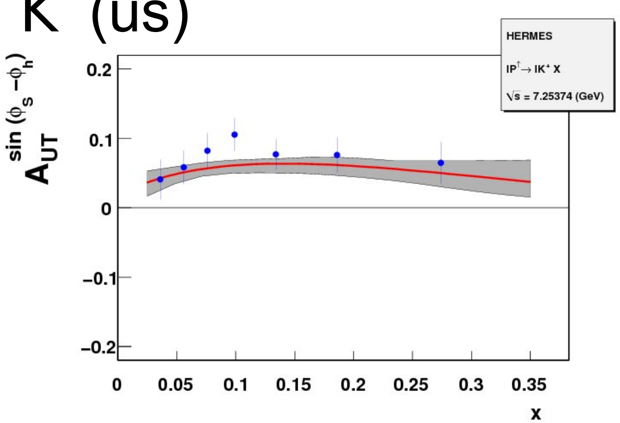


K⁻ ($s\bar{u}$)

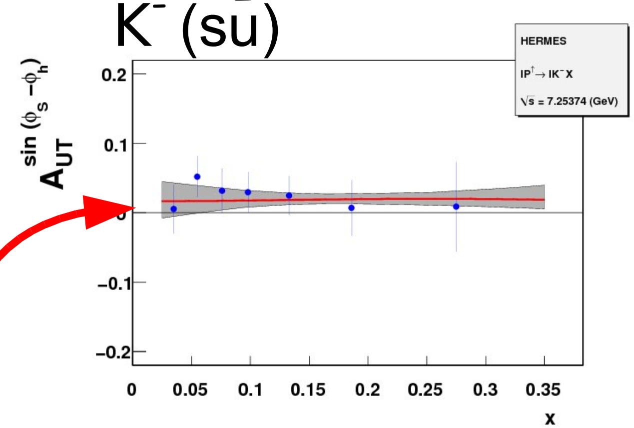


Valence+ sea

K⁺ ($u\bar{s}$)



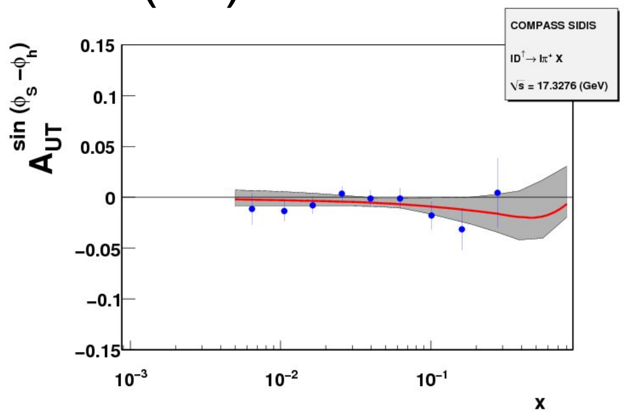
K⁻ ($s\bar{u}$)



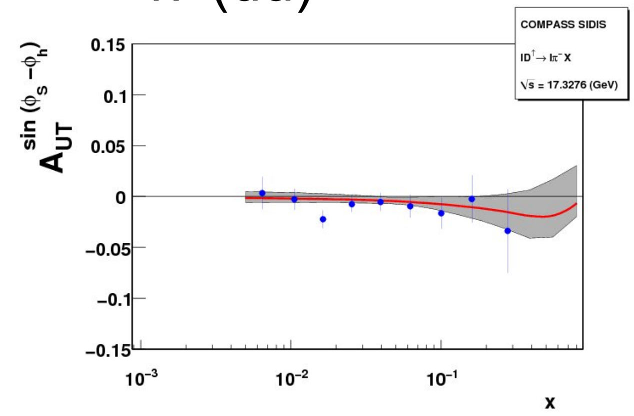
$$\Delta^N f_{\bar{u}/p^\uparrow} > 0$$

Valence only -No sea

$\pi^+ (u\bar{d})$

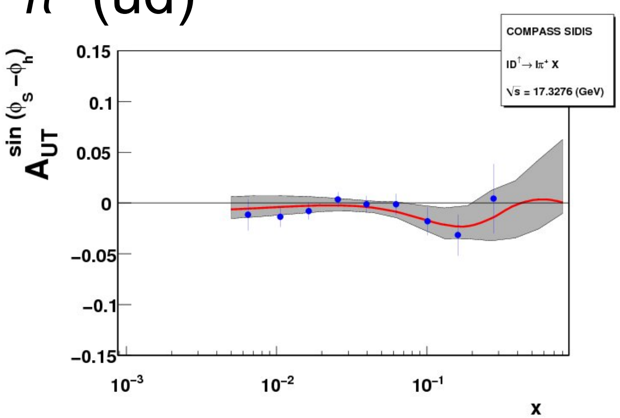


$\pi^- (d\bar{u})$

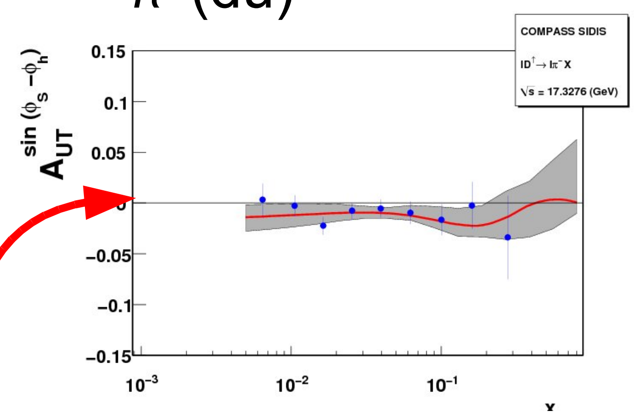


Valence+ sea

$\pi^+ (u\bar{d})$



$\pi^- (d\bar{u})$

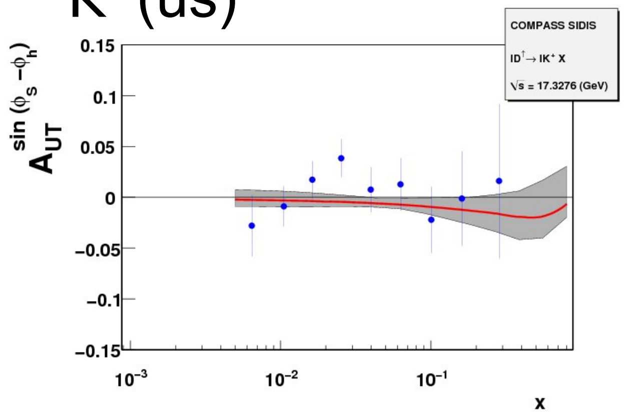


$$\Delta^N f_{\bar{u}/D^\uparrow} \equiv \Delta^N f_{\bar{d}/D^\uparrow} = (\Delta^N f_{\bar{d}/p^\uparrow} + \Delta^N f_{\bar{u}/p^\uparrow}) < 0$$

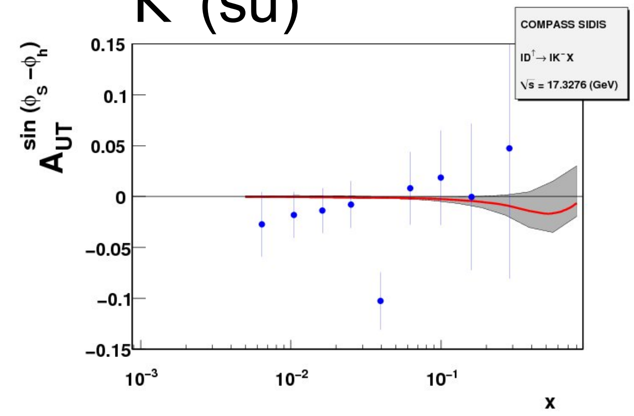
$$\Delta^N f_{\bar{d}/p^\uparrow} < 0 \quad |\Delta^N f_{\bar{d}/p^\uparrow}| > \Delta^N f_{\bar{u}/p^\uparrow}$$

Valence only -No sea

$K^+ (u\bar{s})$

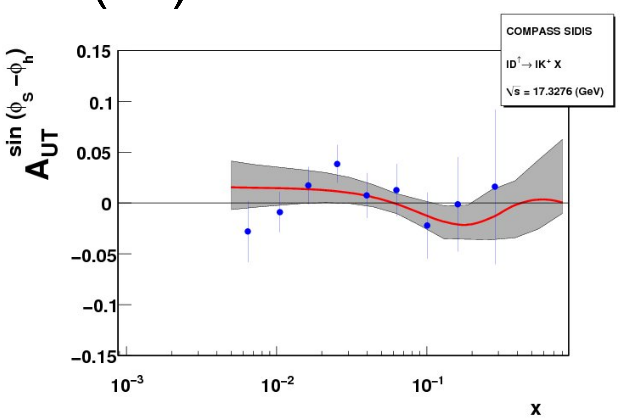


$K^- (s\bar{u})$

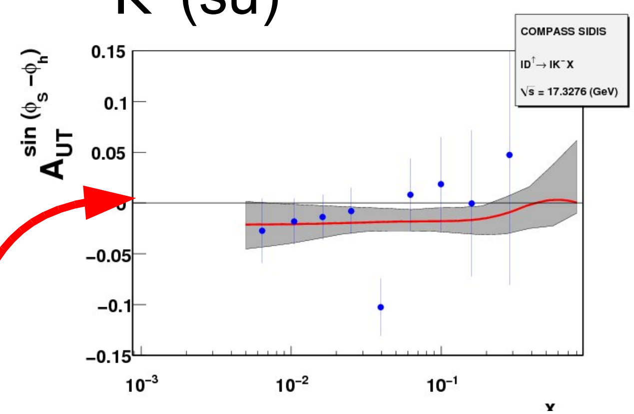


Valence+ sea

$K^+ (u\bar{s})$

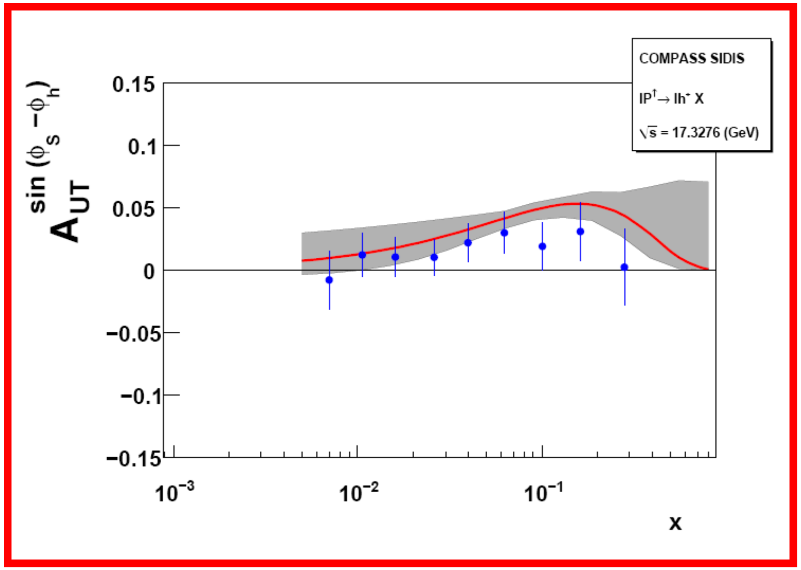


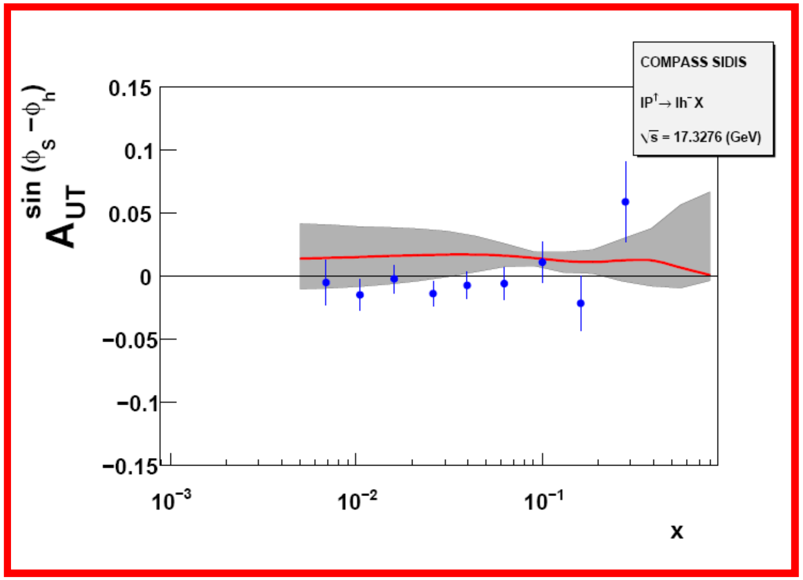
$K^- (s\bar{u})$



$$\Delta^N f_{\bar{u}/D^\uparrow} \equiv \Delta^N f_{\bar{d}/D^\uparrow} = (\Delta^N f_{\bar{d}/p^\uparrow} + \Delta^N f_{\bar{u}/p^\uparrow}) < 0 \qquad \Delta^N f_{\bar{d}/p^\uparrow} < 0 \quad |\Delta^N f_{\bar{d}/p^\uparrow}| > \Delta^N f_{\bar{u}/p^\uparrow}$$

COMPASS proton





Conclusions I

- The old fit still describes well new HERMES and COMPASS data
- Sea quarks can improve the description of the data but are not well constrained
- A large anti-strange contribution is not more required

Polarized SIDIS& e+e- data:

Extraction of Collins function & Transversity

Polarized SIDIS& e+e- data:

Extraction of Collins function & Transversity

- Azimuthal asymmetry in polarized SIDIS

$$\mathrm{d}\sigma^{\uparrow} - \mathrm{d}\sigma^{\downarrow} = \sum_q h_{1q}(x, k_\perp) \otimes \mathrm{d}\Delta\hat{\sigma}(y, \boldsymbol{k}_\perp) \otimes \Delta^N D_{h/q^\uparrow}(z, \boldsymbol{p}_\perp)$$

Transversity — Collins function

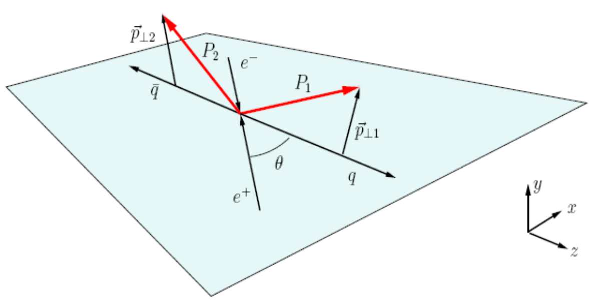
$$A_{UT}^{\sin(\phi+\phi_S)} \equiv 2\,\frac{\int \mathrm{d}\phi\,\mathrm{d}\phi_S\,[\mathrm{d}\sigma^{\uparrow} - \mathrm{d}\sigma^{\downarrow}]\,\sin(\phi+\phi_S)}{\int \mathrm{d}\phi\,\mathrm{d}\phi_S\,[\mathrm{d}\sigma^{\uparrow} + \mathrm{d}\sigma^{\downarrow}]}$$

Polarized SIDIS& e+e- data:

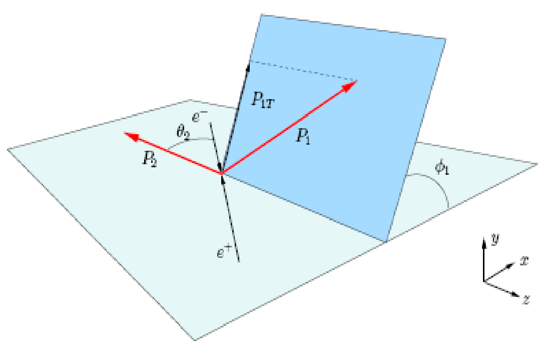
Extraction of Collins function & Transversity

- e^+e^- -> h_1 h_2 X BELLE Data

Thrust axis method



$$A(z_1,z_2,\theta,\varphi_1+\varphi_2) \equiv \frac{1}{\langle d\sigma\rangle}\frac{d\sigma^{e^+e^-\to h_1 h_2 X}}{dz_1\,dz_2\,d\cos\theta\,d(\varphi_1+\varphi_2)} = 1+\frac{1}{8}\frac{\sin^2\theta}{1+\cos^2\theta}\cos(\varphi_1+\varphi_2)\frac{\sum_q e_q^2\,\Delta^N D_{h_1/q^\uparrow}(z_1)\,\Delta^N D_{h_2/\bar{q}^\uparrow}(z_2)}{\sum_q e_q^2 D_{h_1/q}(z_1)\,D_{h_2/\bar{q}}(z_2)}.$$



Hadronic plane method

$$A(z_1,z_2,\theta_2,\phi_1) = 1+\frac{1}{\pi}\frac{z_1\,z_2}{z_1^2+z_2^2}\frac{\sin^2\theta_2}{1+\cos^2\theta_2}\cos(2\,\phi_1)\frac{\sum_q e_q^2\,\Delta^N D_{h_1/q^\uparrow}(z_1)\,\Delta^N D_{h_2/\bar{q}^\uparrow}(z_2)}{\sum_q e_q^2 D_{h_1/q}(z_1)\,D_{h_2/\bar{q}}(z_2)}$$

Polarized SIDIS& e+e- data:

Extraction of Collins function & Transversity

- Parametrization of Transversity function:

$$\Delta_T q(x, k_\perp) = \frac{1}{2}\mathcal{N}_q^T(x)[f_{q/p}(x) + \Delta q(x)]\, \frac{1}{\pi\langle k_\perp^2\rangle}\, e^{-k_\perp^2/\langle k_\perp^2\rangle}$$

Unpolarized PDF

Helicity PDF

$$\mathcal{N}_q^T(x) = N_q^T\, x^{\alpha_q}(1-x)^{\beta_q}\, \frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\,\beta_q^{\beta_q}}$$

N_q^T, α, β free parameters

Polarized SIDIS& e+e- data:

Extraction of Collins function & Transversity

- Parametrization of the Collins function:

$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) = 2\mathcal{N}_q^C(z)\, h(p_\perp)\, D_{\pi/q}(z,k_\perp)$$

- $$\mathcal{N}_q^C(z) = N_q^C\; z^\gamma (1-z)^\delta \, \frac{(\gamma+\delta)^{(\gamma+\delta)}}{\gamma^\gamma \delta^\delta}$$

- $$h(p_\perp) = \sqrt{2e}\,\frac{p_\perp}{M_h}\, e^{-p_\perp^2/M_h^2}$$

Unpolarized FF

N_q^C, γ, δ, M_h free parameters

✔Bound:

$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) \le 2\, D_{\pi/q}(z,k_\perp)$$

✔Torino vs Amsterdam notation

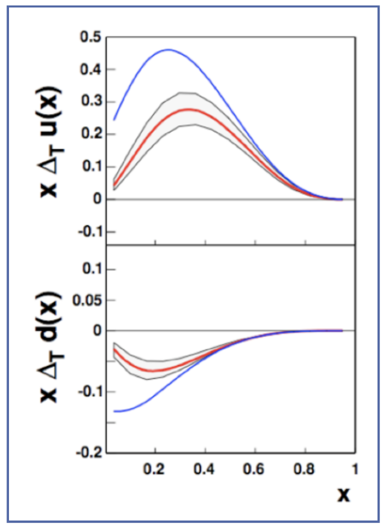
$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) = \frac{2p_\perp}{zM} H_1^\perp(z,p_\perp)$$

Polarized SIDIS& e+e- data:

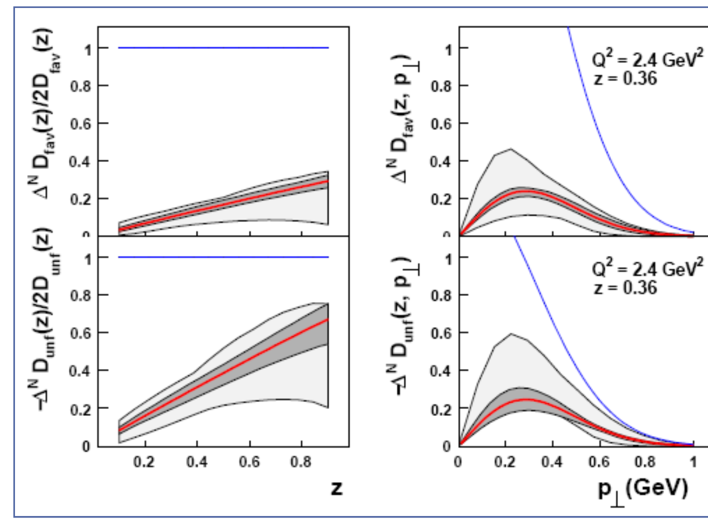
Extraction of Collins function & Transversity

- Simultaneous fit of HERMES, COMPASS and BELLE data

χ^2_{dof}=1.3



Transversity



Collins functions

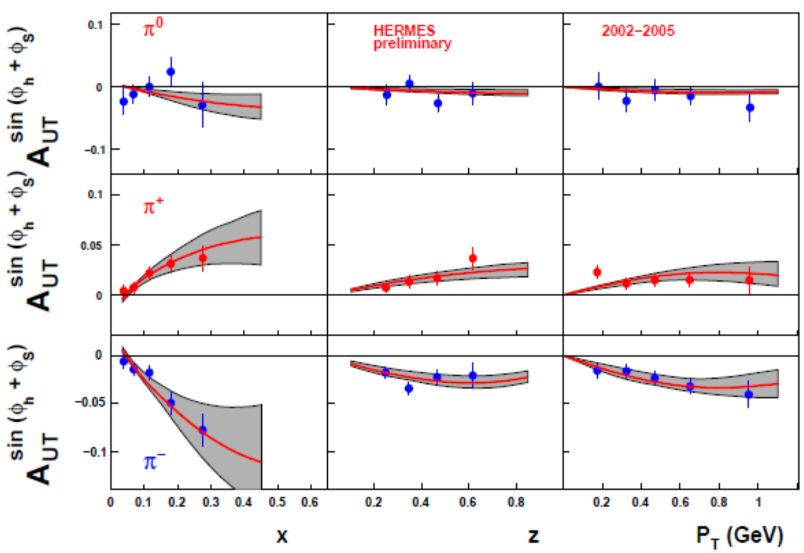
$N_u^T = 0.64 \pm 0.34$	$N_d^T = -1.00 \pm 0.02$
$\alpha = 0.73 \pm 0.51$	$\beta = 0.84 \pm 2.30$
$N_{fav}^C = 0.44 \pm 0.07$	$N_{unf}^C = -1.00 \pm 0.06$
$\gamma = 0.96 \pm 0.08$	$\delta = 0.01 \pm 0.05$
$M_h^2 = 0.91 \pm 0.52\ \text{GeV}^2$	

- Anselmino et. al arXiv: 0812.4366v1

Polarized SIDIS& e+e- data:

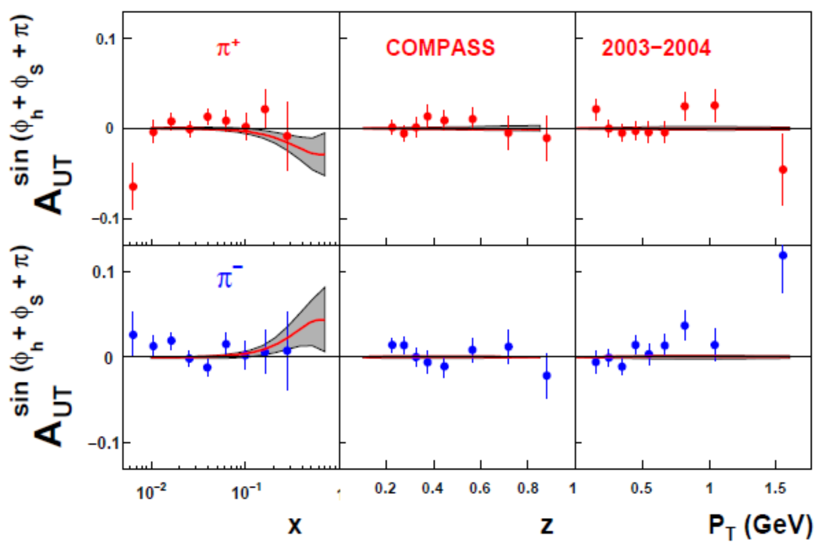
Extraction of Collins function & Transversity

HERMES



◇ M. Diefenthaler, (2007),arXiv:0706.2242

COMPASS



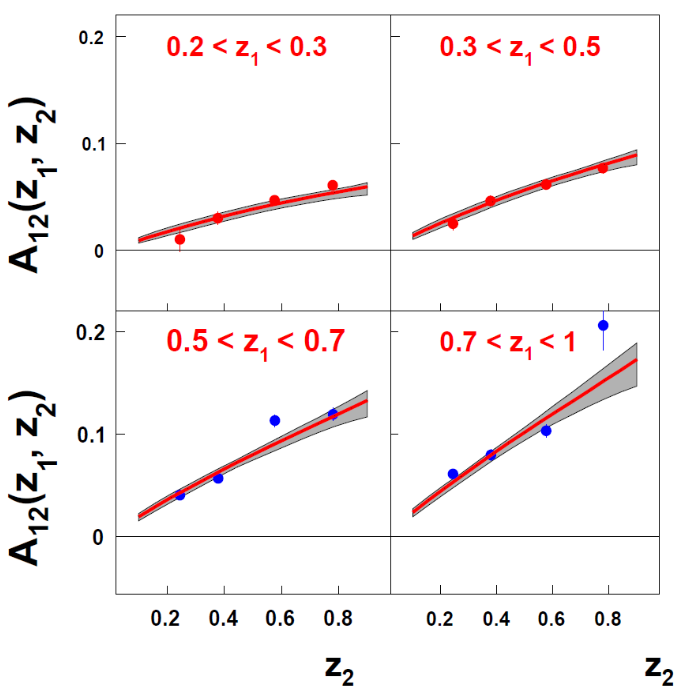
◇ M. Alekseev et al., (2008), arXiv:0802.2160

• Anselmino et. al arXiv: 0812.4366v1

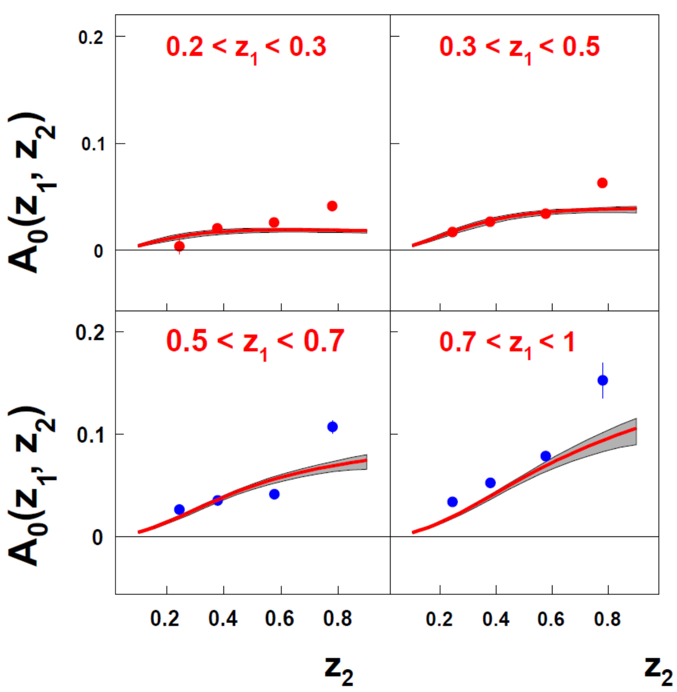
Polarized SIDIS& e+e- data:

Extraction of Collins function & Transversity

BELLE A_{12} (FIT)



BELLE A_0 (Predicted)



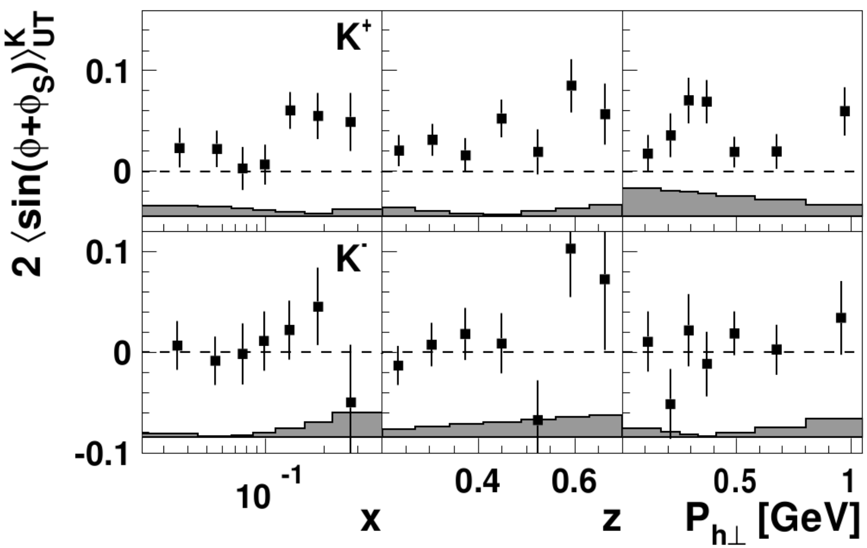
◇ R. Seidl et al., Phys. Rev. D78

- Anselmino et. al arXiv: 0812.4366v1

Polarized SIDIS& e+e- data: Kaons?

HERMES Coll. arXiv:1006.4221

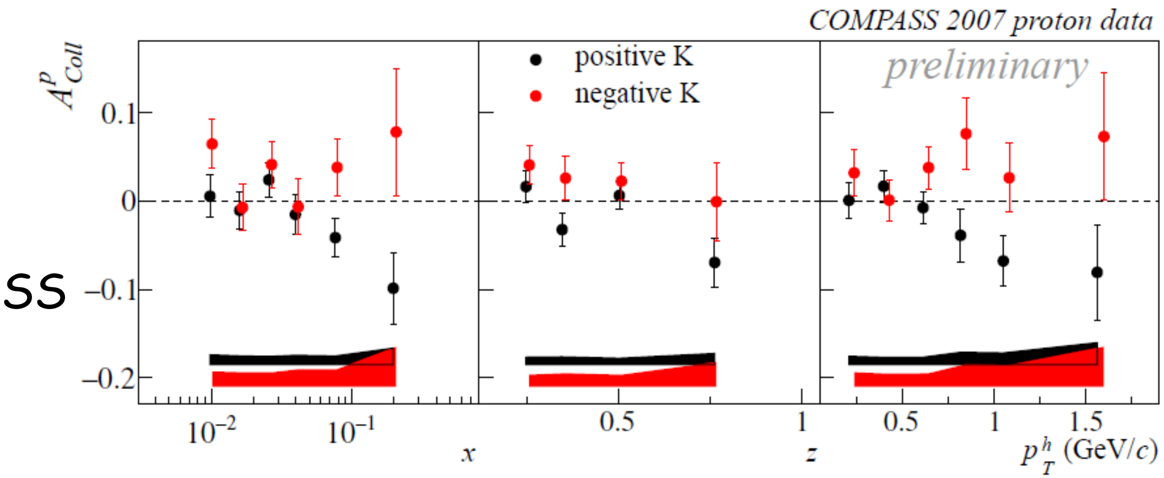
K⁺ (u$\bar{s}$)



K⁻ (s$\bar{u}$)

- ➢Kaons production mainly driven by u quark fragmentation
- ➢Favored & Unfavored kaon Collins functions both positive

•Different sign convection between HERMES and COMPASS



COMPASS Coll. PLB 692 (2010)

Conclusions II

- Extraction of u and d transversity functions
- Extraction of the pion Collins functions
- Coming next: extraction of the kaon Collins functions (rough extraction! No BELLE data!)

Boer-Mulders function extraction from $A^{\cos 2\phi}$ in unpolarized SIDIS

Extraction of the Boer-Mulders functions

➢ The angular distribution in the unpolarized SIDIS can be written as

$$d\sigma = A + B\cos\phi + C\cos 2\phi$$

- $A =\propto f_1 \otimes D_1$ is the usual ϕ-independent contribution
- $C \propto h_1^\perp \otimes H_1^\perp + \frac{1}{Q^2} f_1 \otimes D_1$ BM effect+Twist-4 Cahn effect

$$A^{\cos 2\phi} = 2\frac{\int d\sigma \cos 2\phi}{\int d\sigma} = \frac{C}{A}$$

Extraction of the Boer-Mulders functions

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Unpolarized PDF&FF gaussian as in Anselmino et al. [1]

[1] Anselmino et. Phys. ReV D71, 074006 (2005)

Extraction of the Boer-Mulders functions

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Collins function as in Anselmino et. al arXiv: 0812.4366v1

Extraction of the Boer-Mulders functions

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BM that we want to extract from the fit of $A^{\cos 2\phi}$ data

Extraction of the Boer-Mulders functions

- Simple parametrization of the Boer-Mulders functions:
  - $h_1^{\perp q}(x, k_\perp) = \lambda_q \, f_{1T}^{\perp q}(x, k_\perp)$ for valence quarks
  - $h_1^{\perp q}(x, k_\perp) = -|f_{1T}^{\perp q}(x, k_\perp)|$ for sea quarks

V. Barone, S. Melis and A. Prokudin Phys. Rev. D81, 114026 (2010)

Extraction of the Boer-Mulders functions

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  - $h_1^{\perp q}(x, k_\perp) = -\left| f_{1T}^{\perp q}(x, k_\perp) \right|$ for sea quarks

- Inspired by models:

Tensor magnetic moment

$$h_1^{\perp q}(x, k_\perp) = \frac{\mathcal{K}_T^q}{\mathcal{K}^q} f_{1T}^{\perp q}(x, k_\perp)$$

Anomalous magnetic moment

Burkardt, Phys. Rev. D72, 094020 (2005)

Gockeler, Phys.Rev.Lett.98:222001,2007.

Extraction of the Boer-Mulders functions

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  - $h_1^{\perp q}(x, k_\perp) = \lambda_q \, f_{1T}^{\perp q}(x, k_\perp)$ for valence quarks
  - $h_1^{\perp q}(x, k_\perp) = -|f_{1T}^{\perp q}(x, k_\perp)|$ for sea quarks

- Models inspired:

$$h_1^{\perp q}(x, k_\perp) = \frac{\mathcal{K}_T^q}{\mathcal{K}^q} f_{1T}^{\perp q}(x, k_\perp)$$

  - $h_1^{\perp u}(x, k_\perp) \simeq 1.80 f_{1T}^{\perp u}(x, k_\perp) < 0$
  - $h_1^{\perp d}(x, k_\perp) \simeq -0.94 f_{1T}^{\perp d}(x, k_\perp) < 0$

Extraction of the Boer-Mulders functions

FIT I

- HERMES proton and deuteron target (x,z,P_T) charged hadrons
- COMPASS deuteron target (x,z) charged hadrons
- 2 free parameters:

  $\lambda_u \quad \lambda_d$

✔GRV98 PDF

✔DSS FF

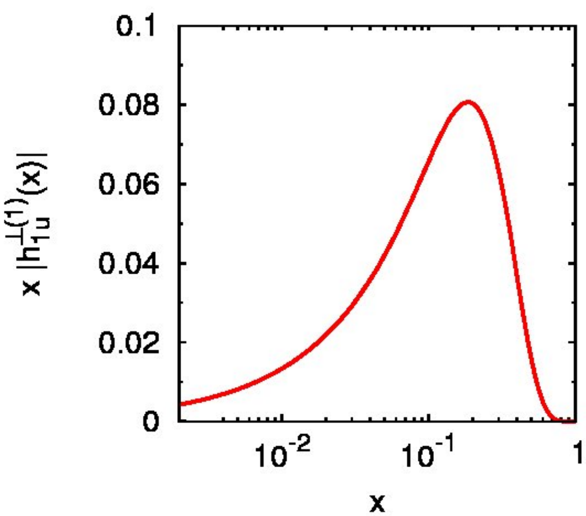
✔Gaussians: $\langle k_\perp^2\rangle = 0.25\ (\mathrm{GeV}/c)^2$
$\langle p_\perp^2\rangle = 0.20\ (\mathrm{GeV}/c)^2$
(from Cahn effect)

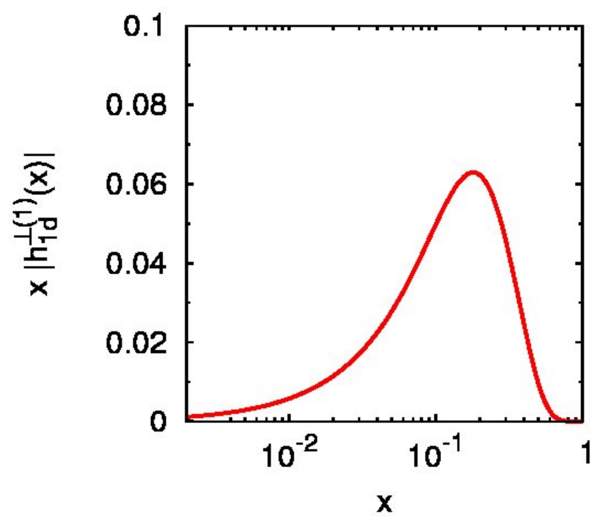
✔ $h_1^{\perp q}(x, k_\perp) = \lambda_q\, f_{1T}^{\perp q}(x, k_\perp)$

✔ $h_1^{\perp q}(x, k_\perp) = -|f_{1T}^{\perp q}(x, k_\perp)|$

Sivers functions from
Anselmino et al. Eur. Phys. J. A39,89

Extraction of the Boer-Mulders functions



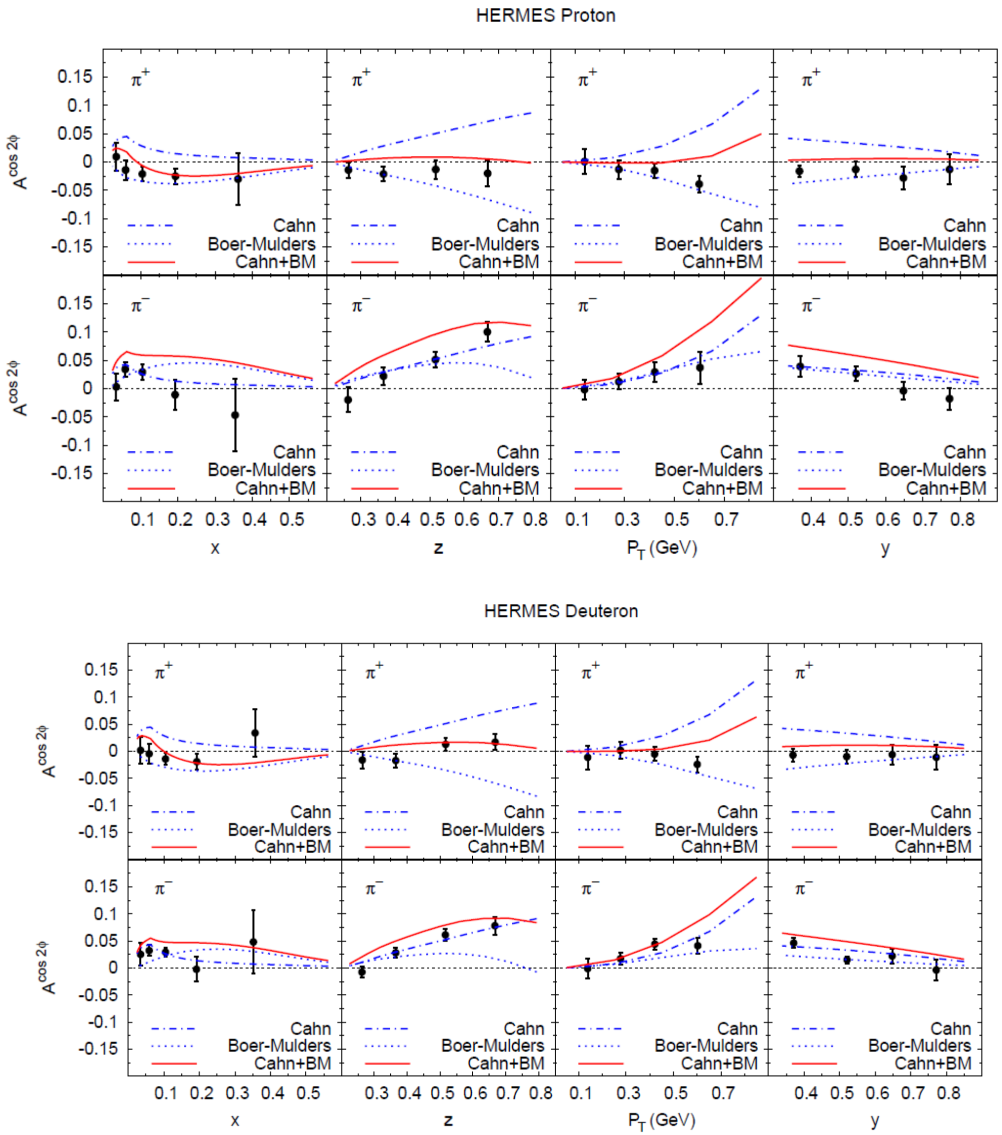


- $\diamond\, \chi^2/d.o.f. = 3.73$
- $\bullet\, \lambda_u = 2.0 \pm 0.1$
- $\bullet\, \lambda_d = -1.11^{+0.00}_{-0.02}$

$\Rightarrow$ $h_1^{\perp d}$ and $h_1^{\perp u}$ both negative

Compatible with models predictions

Extraction of the Boer-Mulders functions



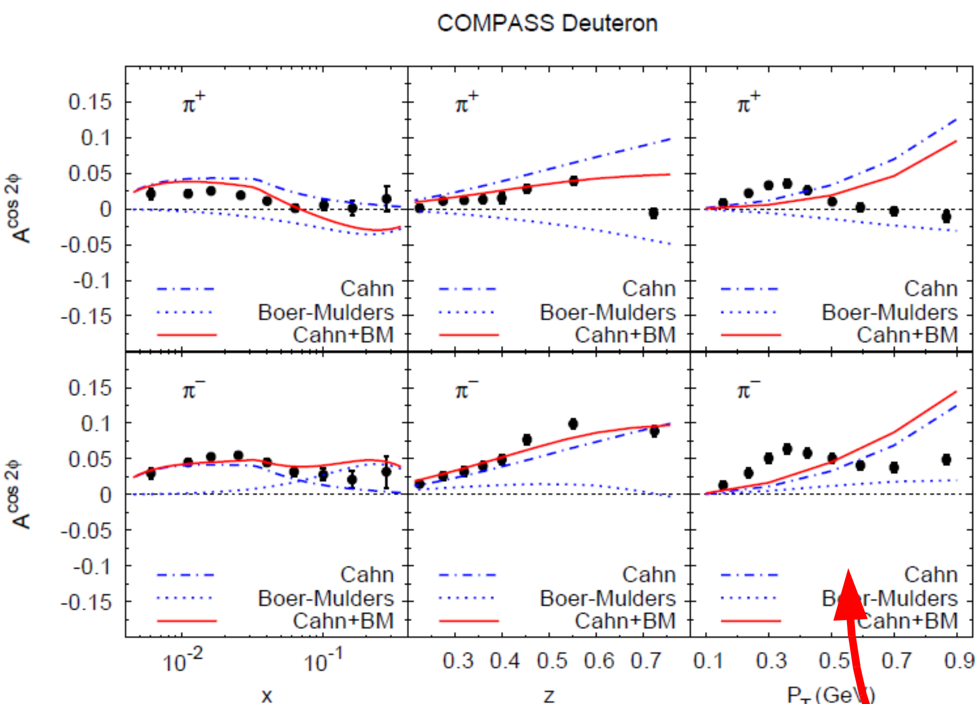
✔Cahn effect (Twist-4)comparable to BM effect

✔Same sign of Cahn contribution for positive and negative pions

✔BM contribution opposite in sign for positive and negative pions

HERMES, Giordano:arXiv:0901.2438

Extraction of the Boer-Mulders functions



✔Cahn effect (Twist-4)comparable to BM effect

✔Same sign of Cahn contribution for positive and negative pions

✔BM contribution opposite in sign for positive and negative pions

Data in p_T not included in the fit

COMPASS, Kafer: arXiv 0808.0114

Extraction of the Boer-Mulders Function

- The Cahn effect is a crucial ingredient

✔Gaussians: $\langle k_\perp^2 \rangle = 0.25\ (GeV/c)^2$
$\langle p_\perp^2 \rangle = 0.20\ (GeV/c)^2$
} From Ref.[*]: analysis of Cahn $\cos\phi$ effect form EMC data

COMPASS	HERMES
$\langle k_\perp^2 \rangle = 0.25\ (GeV/c)^2$	$\langle k_\perp^2 \rangle = 0.18\ (GeV/c)^2$
$\langle p_\perp^2 \rangle = 0.20\ (GeV/c)^2$	$\langle p_\perp^2 \rangle = 0.20\ (GeV/c)^2$
~EMC	~HERMES MC

[*] Anselmino et al. Phys. Rev. D71 074006 (2005)

Extraction of the Boer-Mulders Function

- FIT II

COMPASS

$\langle k_\perp^2 \rangle = 0.25\ (GeV/c)^2$

$\langle p_\perp^2 \rangle = 0.20\ (GeV/c)^2$

~EMC

HERMES

$\langle k_\perp^2 \rangle = 0.18\ (GeV/c)^2$

$\langle p_\perp^2 \rangle = 0.20\ (GeV/c)^2$

~HERMES MC

FIT II

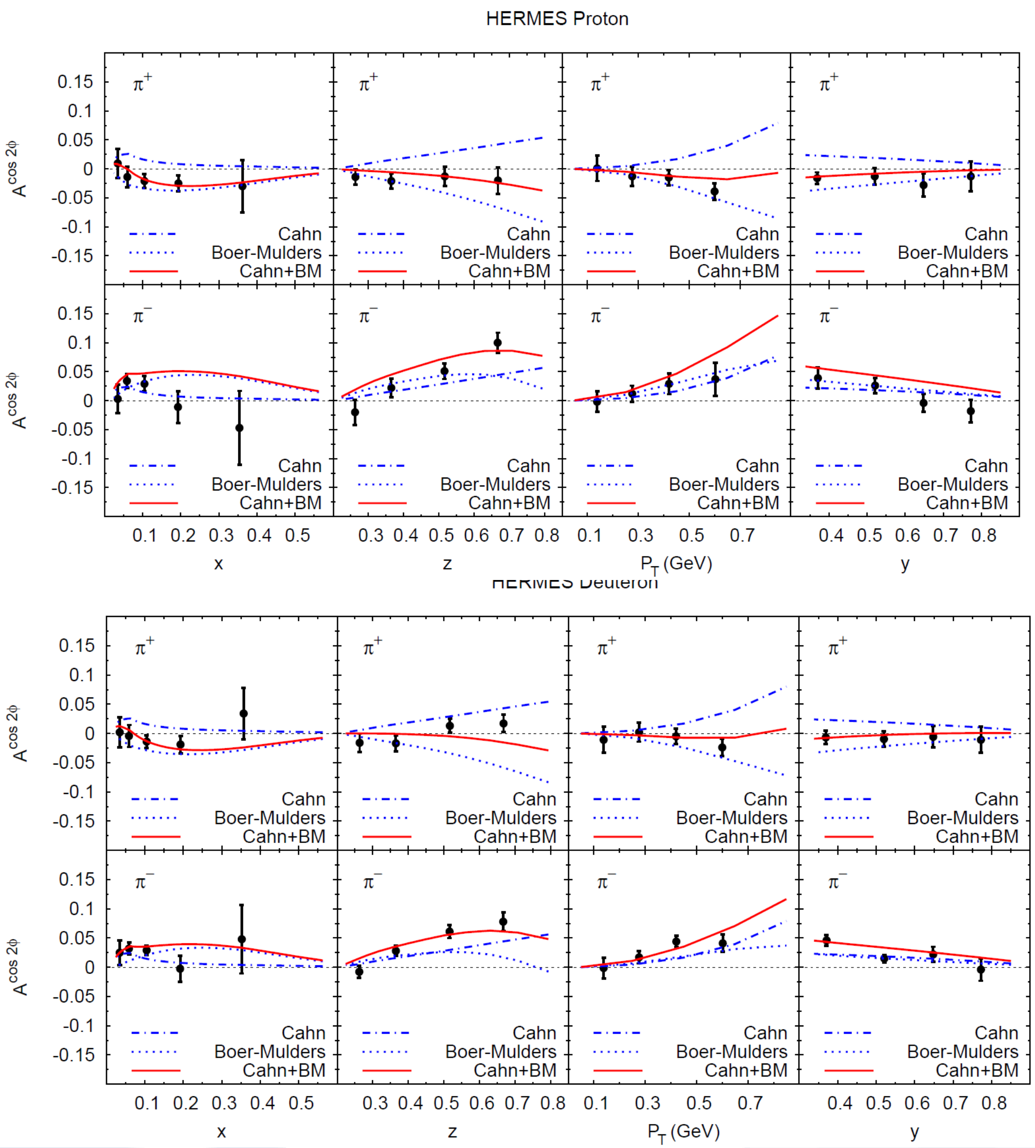
$\diamond \chi^2/d.o.f. = 2.41$

$\bullet \lambda_u = 2.1 \pm 0.1$

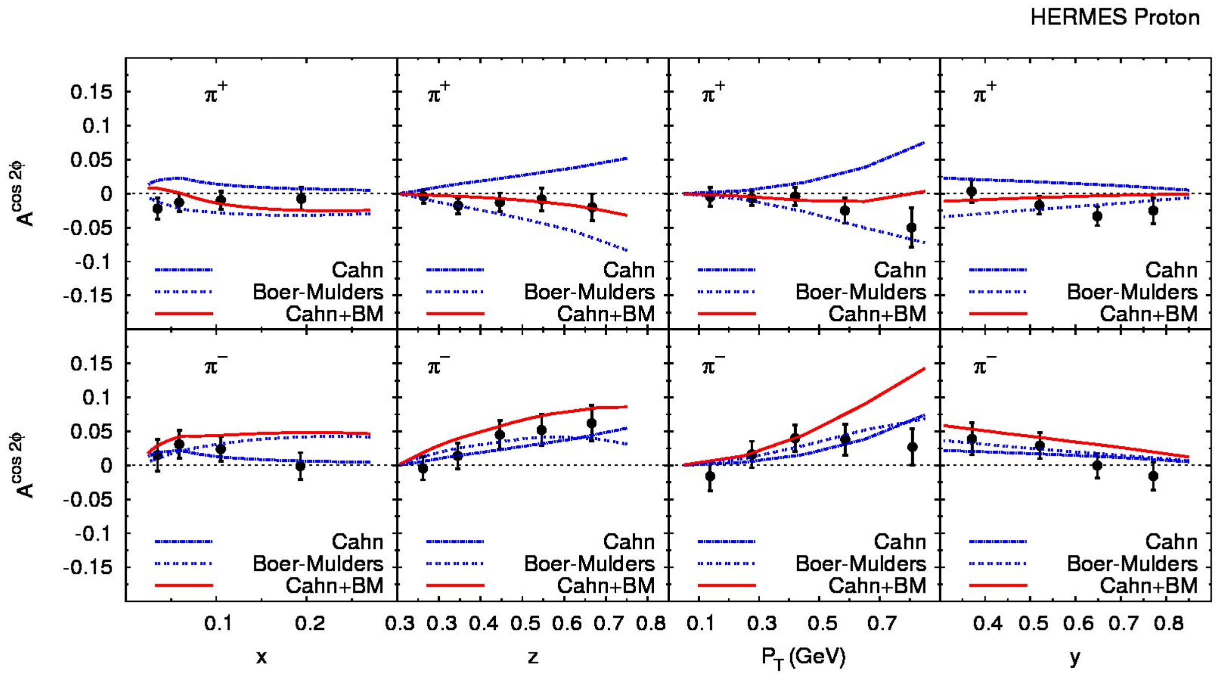
$\bullet \lambda_d = -1.11^{+0.00}_{-0.02}$

Better description of HERMES but the BM is unchanged

Extraction of the Boer-Mulders Function



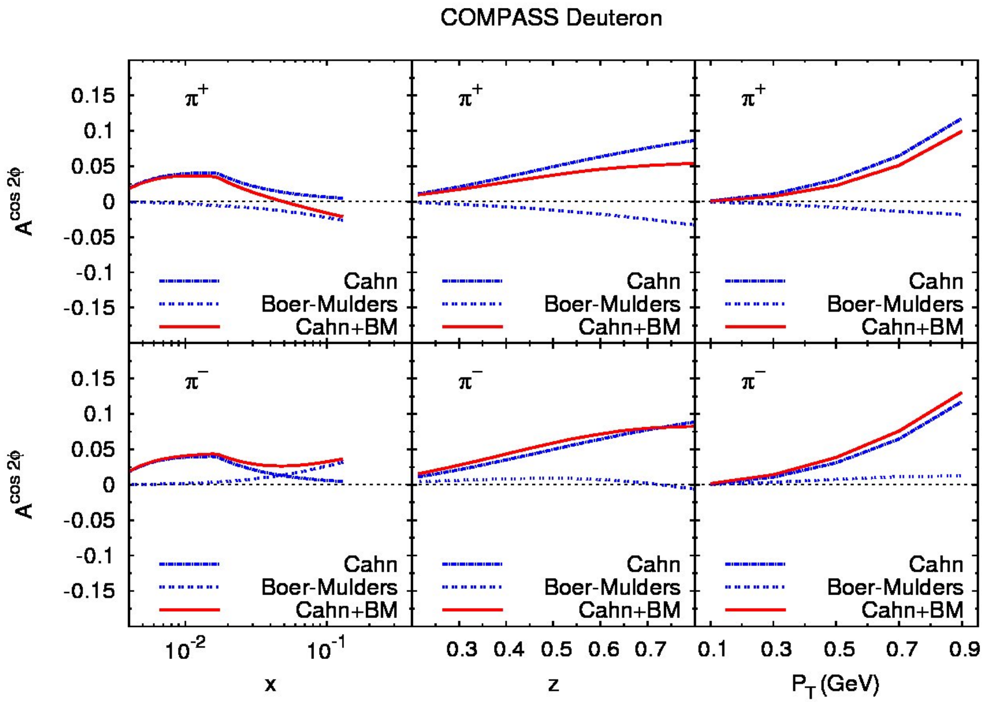
Extraction of the Boer-Mulders Function



New HERMES data! Presented at SPIN2010

See talk by Francesca Giordano

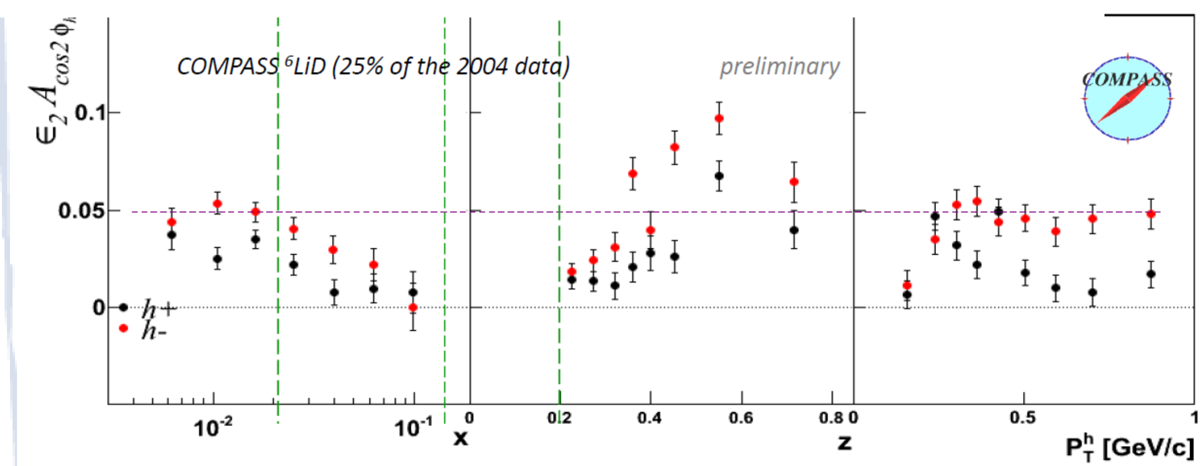
Extraction of the Boer-Mulders Function



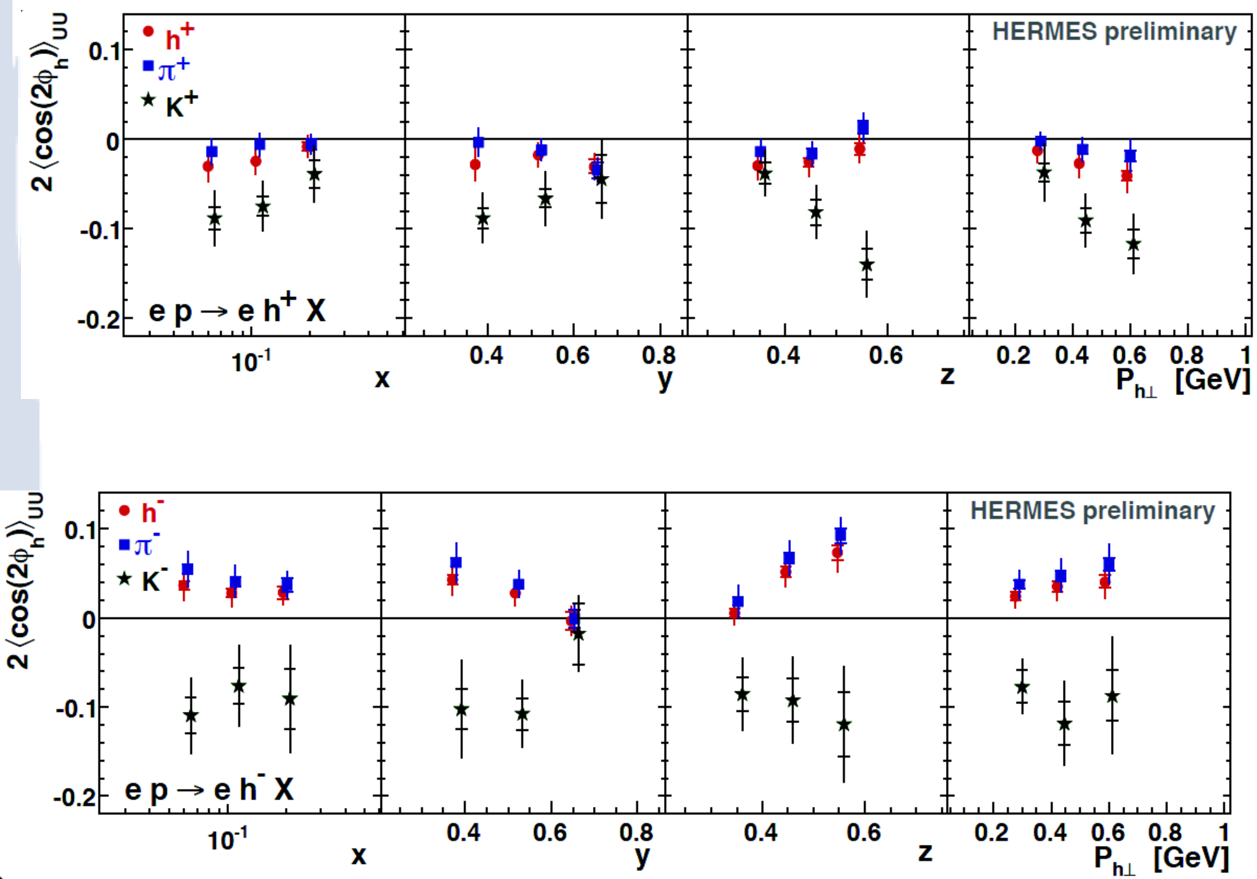
New COMPASS data!

Presented at SPIN2010 (Sbrizzai)

See Anna Martin's talk



Extraction of the Boer-Mulders Function
Kaons!



- Kaons production mainly driven by u quark fragmentation
- Favored & Unfavored kaon Collins functions both positive

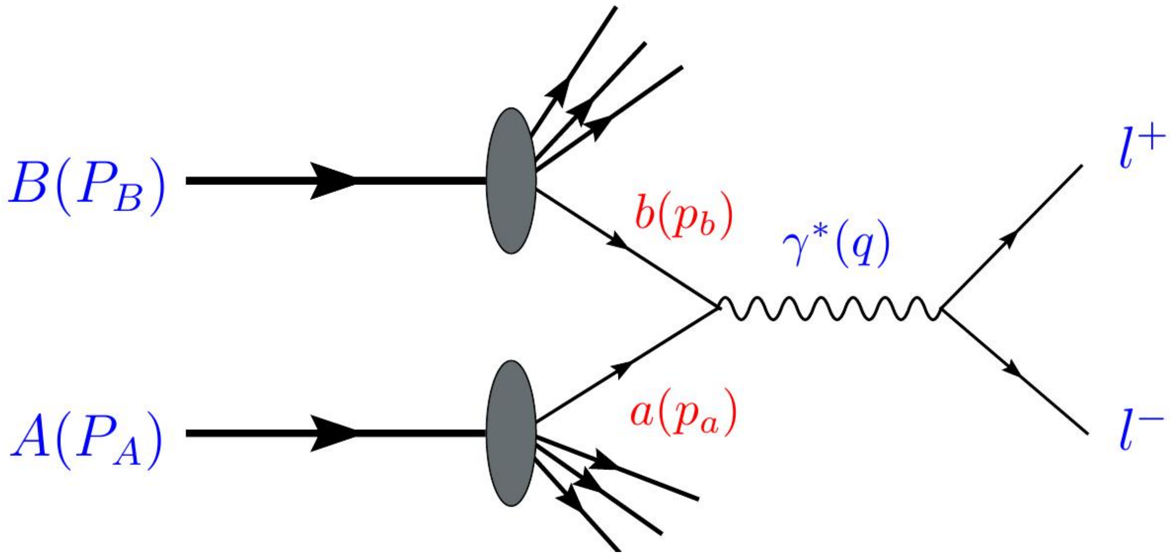
New HERMES data! Presented at SPIN2010

See talks by Francesca Giordano

Conclusions III

- u and d BM functions have the same sign. They are compatible with models
- Twist-4 Cahn effect cannot be neglected at HERMES and COMPASS.
- Different average transverse momenta for different experiments?
- Coming next: new fit HERMES & COMPASS
- Coming next: Kaons?

Boer-Mulders function extraction from ν in unpolarized DY processes



Boer-Mulders function in DY from fits

- General expression for the dilepton angular distributions in the dilepton rest frame:

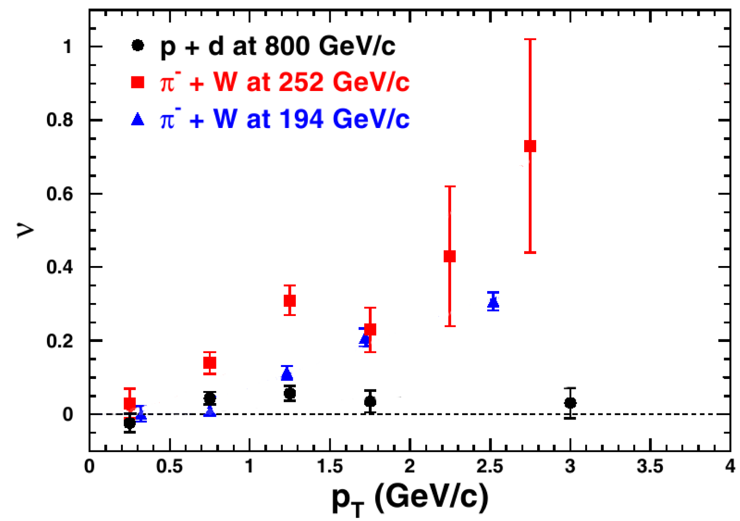
$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi(\lambda+3)}\left[1 + \lambda\cos^2\theta + \mu\sin 2\theta\cos\phi + (\nu/2)\ \sin^2\theta\cos 2\phi\right]$$

Boer-Mulders function in DY from fits

➢ General expression for the dilepton angular distributions in the dilepton rest frame:

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi(\lambda+3)}\left[1 + \lambda\cos^2\theta + \mu\sin 2\theta\cos\phi + (\nu/2)\ \sin^2\theta\cos 2\phi\right]$$

ν



Boer-Mulders function in DY from fits

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- TMDs approach

Boer-Mulders functions

$$\nu \propto \frac{h_1^{\perp a} \otimes h_1^{\perp b}}{f_1^a \otimes f_1^b}$$

Unpolarized PDFs

Boer-Mulders function in DY from fits

- We performed an analysis of E866 data on pp and pD Drell-Yan

$$\nu \propto \frac{h_1^{\perp a} \otimes h_1^{\perp b}}{f_1^a \otimes f_1^b}$$

Boer-Mulders function in DY from fits

- We performed an analysis of E866 data on pp and pD Drell-Yan

$$\nu \propto \frac{h_1^{\perp a} \otimes h_1^{\perp b}}{f_1^a \otimes f_1^b}$$

✎ Gaussian smearing for PDFs

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

[*]$\langle k_\perp^2 \rangle = 0.25\ (\mathrm{GeV}/c)^2$

[*]Anselmino et. Phys. ReV D71, 074006 (2005)

Boer-Mulders function in DY from fits

- We performed an analysis of E866 data on pp and pD Drell-Yan

$$\nu \propto \frac{h_1^{\perp a} \otimes h_1^{\perp b}}{f_1^a \otimes f_1^b}$$

✎ u and d Boer-Mulders functions as extracted from SIDIS

- $h_1^{\perp q}(x, k_\perp) = \lambda_q \, f_{1T}^{\perp q}(x, k_\perp)$ [*]

$$\lambda_u = 2.0 \pm 0.1$$

$$\lambda_d = -1.11^{+0.00}_{-0.02}$$

[*]Sivers functions from Anselmino et al. Eur. Phys. J. A39,89

Boer-Mulders function in DY from fits

- We performed an analysis of E866 data on pp and pD Drell-Yan

$$\nu \propto \frac{h_1^{\perp a} \otimes h_1^{\perp b}}{f_1^a \otimes f_1^b}$$

✎ $\bar{u}$ and $\bar{d}$ Boer-Mulders parametrized similarly:

$$h_1^{\perp \bar{q}}(x, k_\perp) = \lambda_{\bar{q}} f_{1T}^{\perp q}(x, k_\perp)$$ [*]

[*]Sivers functions from Anselmino et al. Eur. Phys. J. A39,89

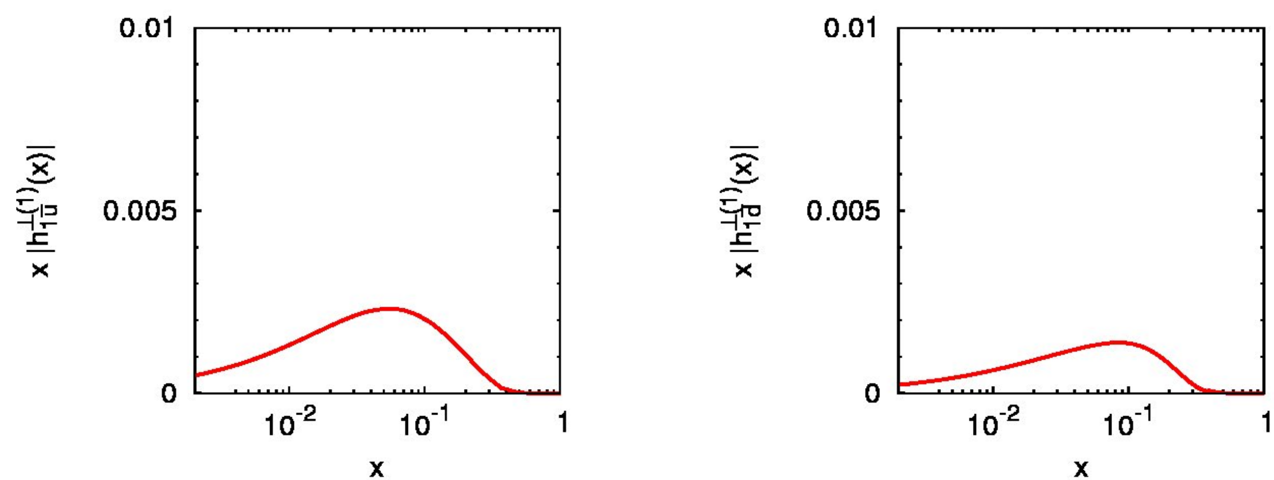
Boer-Mulders function in DY from fits

- Results of the analysis of E866 data on pp and pD Drell-Yan

$$h_1^{\perp\bar{q}}(x,k_\perp) = \lambda_{\bar{q}} f_{1T}^{\perp q}(x,k_\perp)$$ [*]

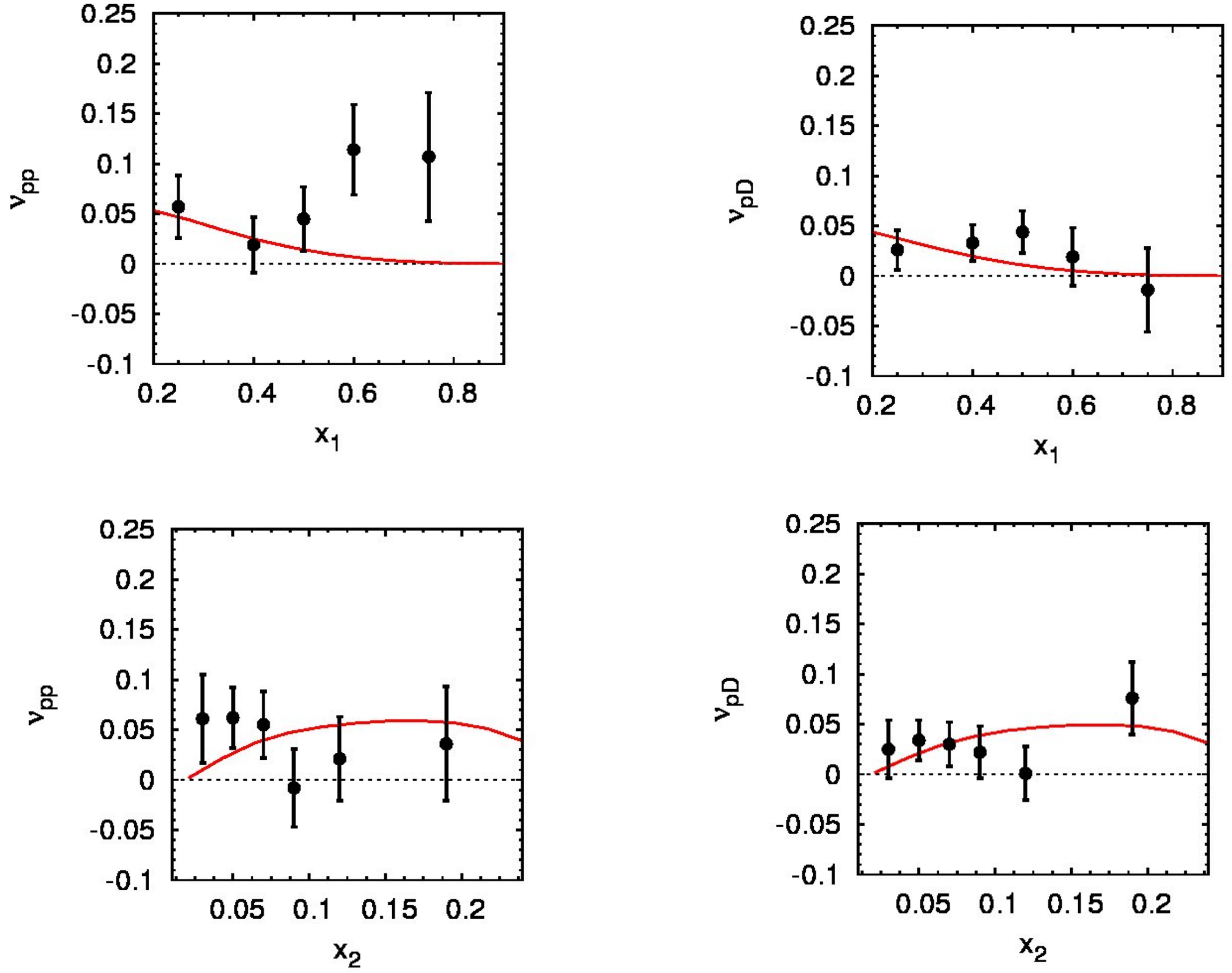
$$\lambda_{\bar{u}} = 3.25 \pm 0.75 \qquad \chi^2_{d.o.f} = 1.24$$
$$\lambda_{\bar{d}} = -0.15 \pm 0.13$$

FIT I

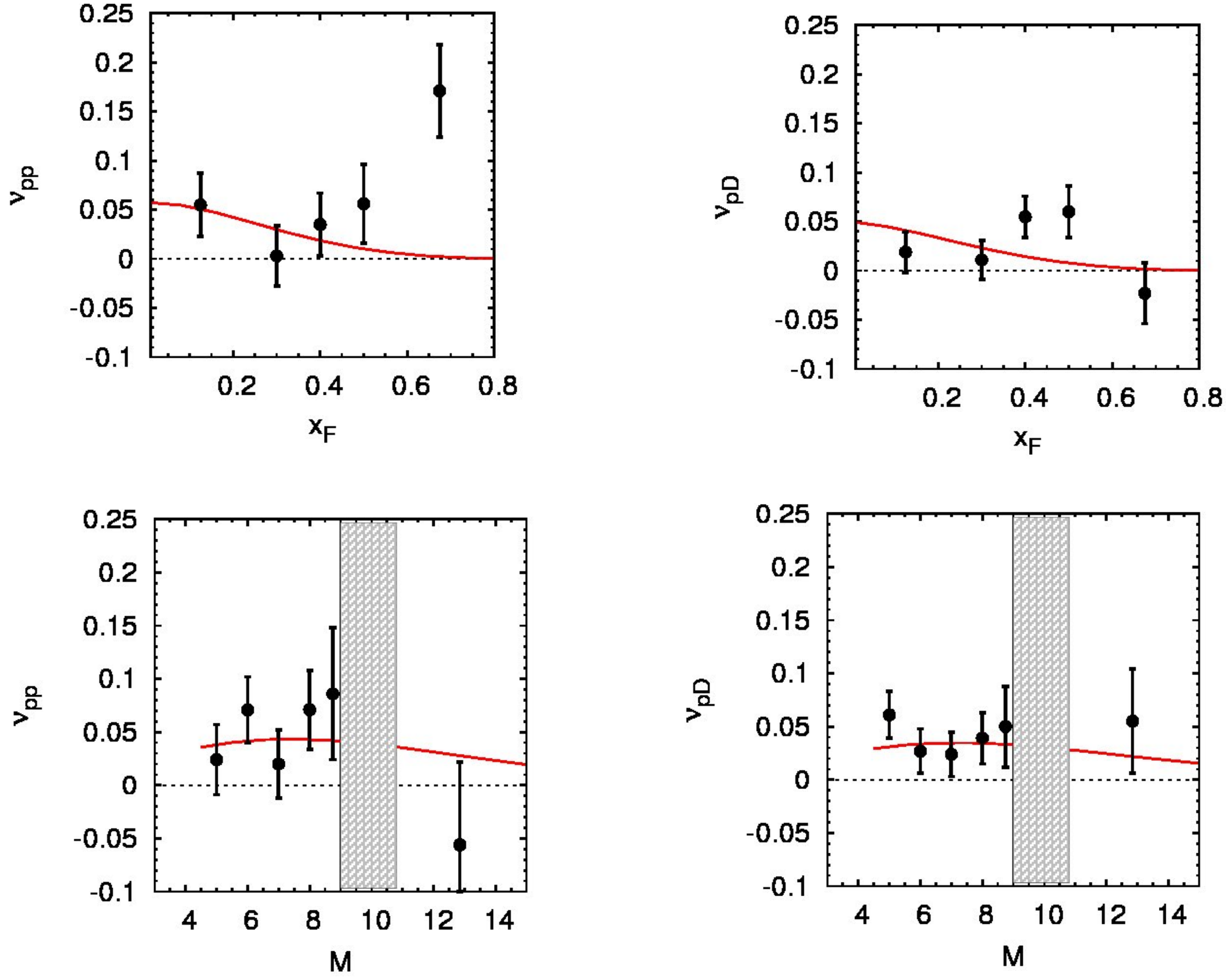


[*] Sivers functions from Anselmino et al. Eur. Phys. J. A39,89

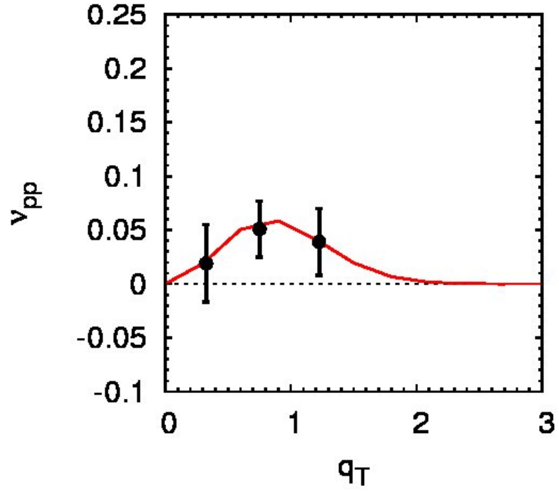
Boer-Mulders function in DY from fits

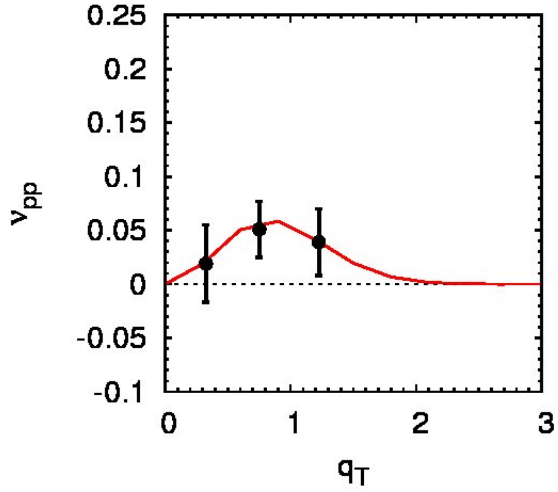


Boer-Mulders function in DY from fits



Boer-Mulders function in DY from fits





Boer-Mulders function in DY from fits

- Can we safely assume that the average transverse momentum is the same in SIDIS and in DY?

✎ Gaussian smearing for unpolarized PDFs

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

From SIDIS: $\langle k_\perp^2 \rangle = 0.25\ (\mathrm{GeV}/c)^2$

Typical DY : $\langle k_\perp^2 \rangle \simeq 0.5 - 1\ (\mathrm{GeV}/c)^2$

➔ Let us try to change this value

Boer-Mulders function in DY from fits

- Notice taht BM functions are proportional to the unpolarized pdf

$$h_1^{\perp q}(x,k_T^2) = \lambda_q\, f_{1T}^{\perp q}(x,k_T^2) = \lambda_q\, \rho_q(x)\, \eta(k_T)\, f_1^q(x,\mathbf{k}_T^2)$$

Unpolarized PDF

[*]Sivers functions from Anselmino et al. Eur. Phys. J. A39,89

Boer-Mulders function in DY from fits

- As an exercise let us assume different average transverse momentum in the unpolarized PDF.

FIT II as Fit I but with $\langle k_\perp^2 \rangle \simeq 0.64\ (\mathrm{GeV}/c)^2$ [*]

[*] U. D'Alesio and F. Murgia, Phys. Rev. D67,

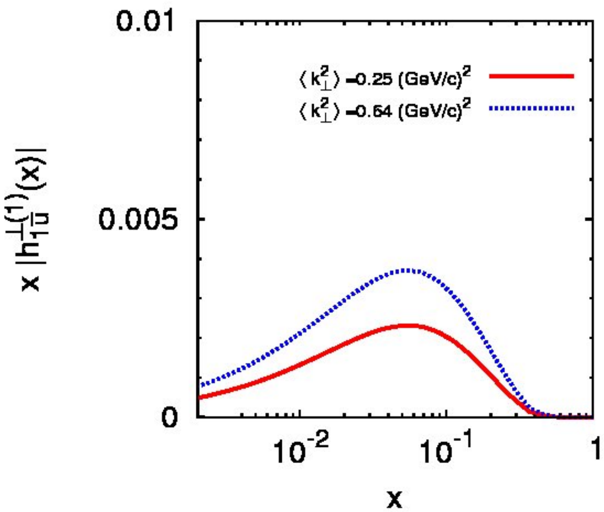
Boer-Mulders function in DY from fits

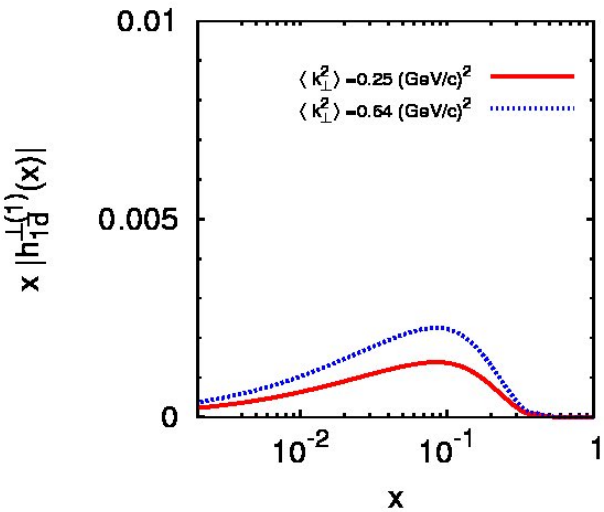
$$\lambda_{\bar{u}} = 5.5 \pm 1.5$$
$$\lambda_{\bar{d}} = -0.25 \pm 0.20$$

$$\chi^2_{d.o.f} = 1.24$$

FIT II

Same description of the data!





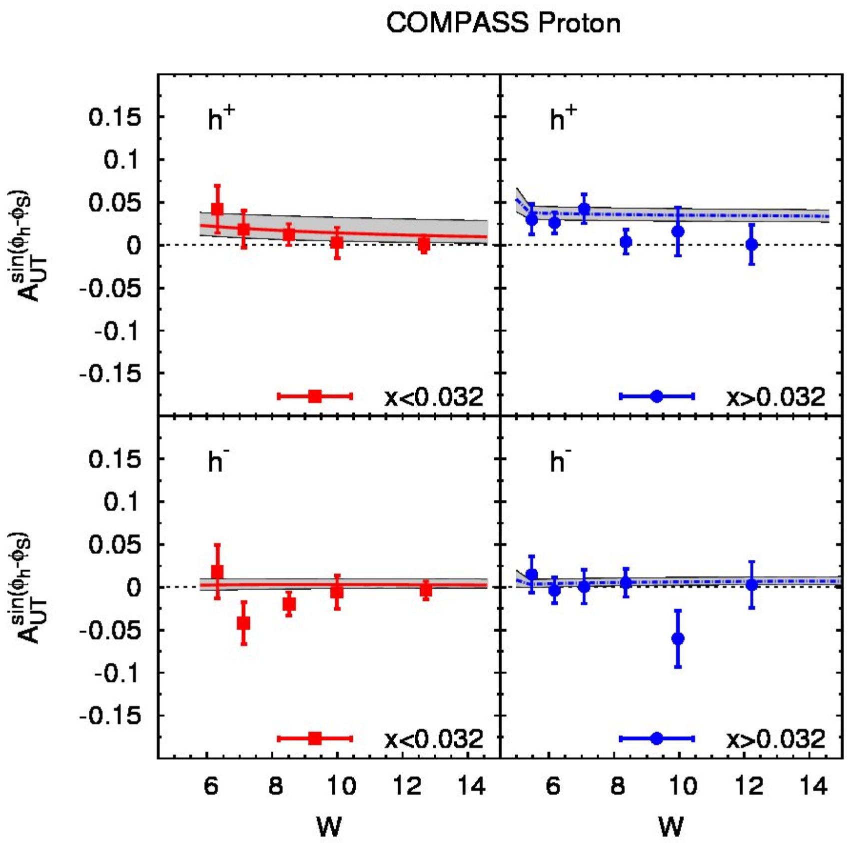
Conclusions IV

- $\bar{u}$ and $\bar{d}$ BM functions are different from zero but not well constrained from E866 data alone.

- Different average transverse momenta for different processes?
  We need more theory and more experiments!

New data-old fit

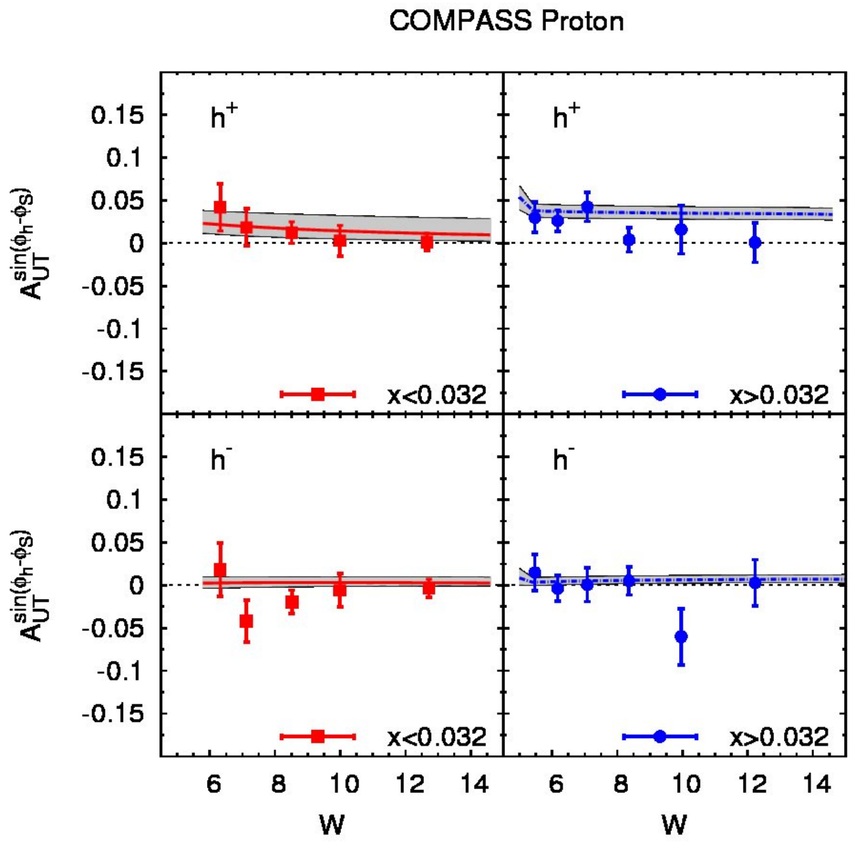
COMPASS Proton Target

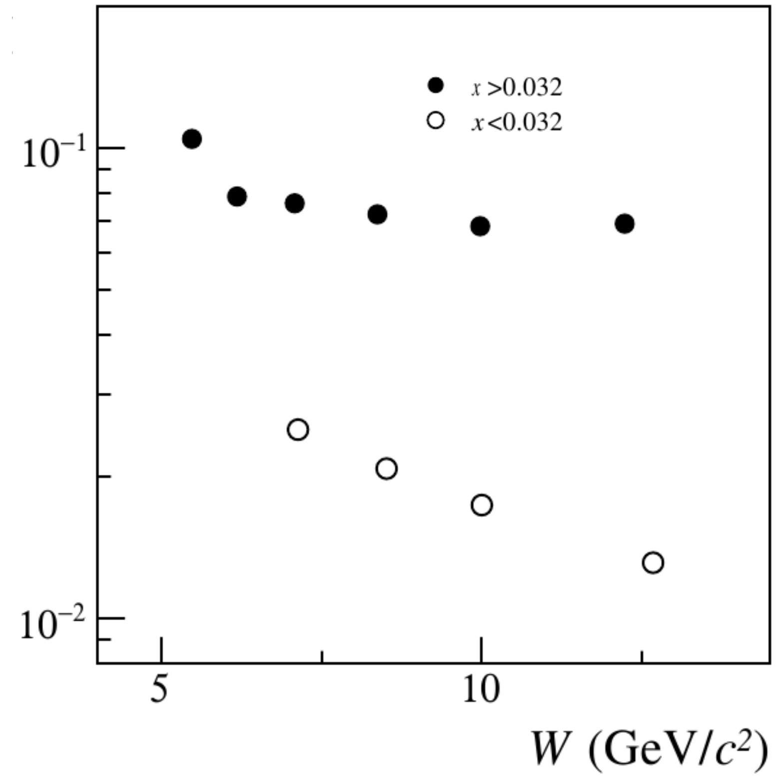


Statistical and systematic errors added in quadrature, no scale error

New data-old fit

COMPASS Proton Target





Statistical and systematic errors added in quadrature, no scale error

Polarized SIDIS:

Extraction of the Sivers Function

- 11 free parameters:

N_u N_d $N_{\bar{u}}$ $N_{\bar{d}}$ N_s $N_{\bar{s}}$

α_u α_d α_{sea}

β M_1

- ✔GRV98 PDF
- ✔DSS FF
- ✔Gaussians: $\langle k_\perp^2 \rangle = 0.25\ (GeV/c)^2$
  $\langle p_\perp^2 \rangle = 0.20\ (GeV/c)^2$
  (from Cahn effect)
- ✔Simulated evolution (unp.)

- HERMES (2002-5)
  (x,z,P_T) π&K

- COMPASS (2004)
  (x,z,P_T) π&K

✔ $$\Delta^N f_{q/p^\uparrow}(x,k_\perp) = 2\mathcal{N}_q(x)\, h(k_\perp)\, f_{q/p}(x,k_\perp)$$

✔ $$\mathcal{N}_q(x) = N_q\, x^{\alpha_q}(1-x)^{\beta_q}\, \frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\,\beta_q^{\beta_q}}$$

✔ $$h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M_1}\, e^{-k_\perp^2/M_1^2}$$

•[1] Anselmino et al. Eur. Phys. J. A39,89

Polarized SIDIS:

Extraction of the Sivers Function

- Gaussian smearing for both unpolarized PDF and FF

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

GRV98 set

[*] $\langle k_\perp^2 \rangle = 0.25\ (\mathrm{GeV}/c)^2$

✎ $$D_q^h(z, p_\perp) = D_q^h(z) \frac{1}{\pi \langle p_\perp^2 \rangle} e^{-p_\perp^2/\langle p_\perp^2 \rangle}$$

DSS set

[*] $\langle p_\perp^2 \rangle = 0.20\ (\mathrm{GeV}/c)^2$

[*]Anselmino et. Phys. ReV D71, 074006 (2005)

Polarized SIDIS:

Extraction of the Sivers Function

- Simple parametrization of the Sivers function

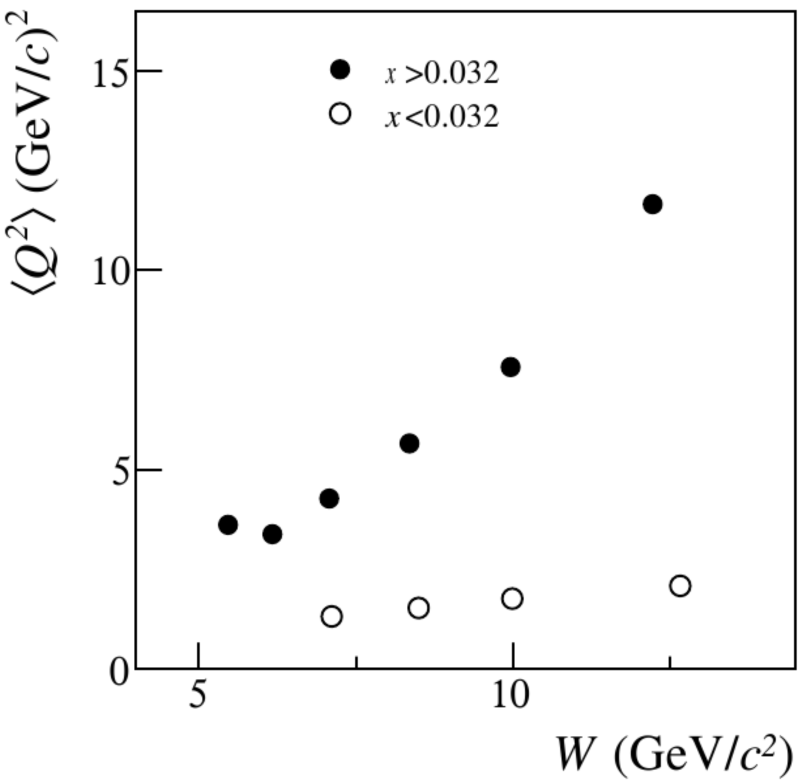
$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = 2\,\mathcal{N}_q(x)\, h(k_\perp)\, f_{q/p}(x, k_\perp)$$

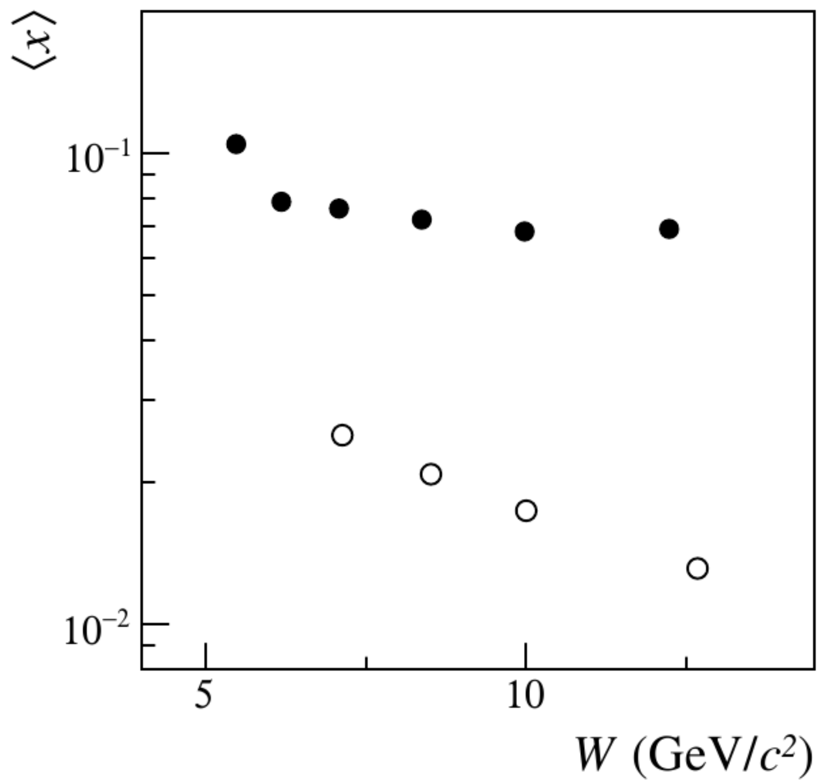
Unpolarized PDF

$$\mathcal{N}_q(x) = N_q\, x^{\alpha_q}(1-x)^{\beta_q}\, \frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\,\beta_q^{\beta_q}} \le 1$$

$$h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M_1}\, e^{-k_\perp^2/M_1^2} \le 1$$

N_q, α_q, β_q & M_1 free parameters





$$W^2 = \frac{1 - x_B}{x_B} Q^2 + m_p^2 \qquad y = \frac{P \cdot q}{P \cdot \ell} = \frac{Q^2}{x_B (s - m_p^2)}$$

$$x_B = \frac{Q^2}{2P \cdot q} = \frac{Q^2}{W^2 + Q^2 - m_p^2}$$