

# Effects of intrinsic parton motion in SIDIS

Alexei Prokudin

Università di Torino and INFN Sezione di Torino

## XVI International Workshop on Deep-Inelastic Scattering DIS2008



In collaboration with M. Anselmino, M. Boglione, U. D'Alesio, F. Murgia, A. Kotzinian, C. Turk, and S. Melis

# The fundamental distributions of partons inside a nucleon

## Unpolarised Distribution

$$f_1(x) \text{ or } q(x)$$



Distribution of unpolarised partons in an unpolarised nucleon.  
Well known

## Helicity Distribution

$$g_1(x) \text{ or } \Delta q(x)$$



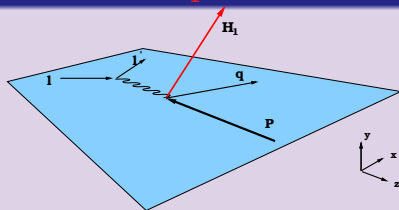
Distribution of longitudinally polarised partons in a longitudinally polarised nucleon.  
Known

## Transversity Distribution

$$h_1(x) \text{ or } \Delta_T q(x)$$



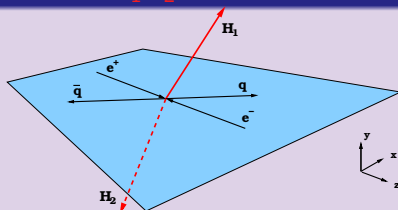
Distribution of transversely polarised quarks in a transversely polarised nucleon.  
Little known!  
HERMES and COMPASS  
experimental measurements

SIDIS and  $e^+e^-$  annihilationSIDIS  $IN \rightarrow l'H_1X$ 

Collins effect gives rise to azimuthal Single Spin Asymmetry

$$\begin{aligned}
 & \begin{array}{c} \uparrow \\ \circ \\ \uparrow \end{array} - \begin{array}{c} \uparrow \\ \circ \\ \downarrow \end{array} = \Delta_T q(x, Q^2) \\
 & \begin{array}{c} \uparrow \\ \circ \\ \uparrow \end{array} - \begin{array}{c} \uparrow \\ \circ \\ \downarrow \end{array} = \Delta^N D_{h/q\uparrow}(z, Q^2)
 \end{aligned}$$

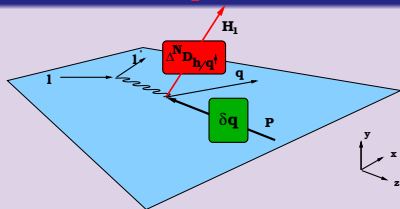
J. C. Collins, *Nucl. Phys.* **B396** (1993) 161

 $e^+e^- \rightarrow H_1H_2X$ 

Collins effect gives rise to azimuthal asymmetry,  $q$  and  $\bar{q}$  Collins functions are present in the process:

$$\begin{aligned}
 & \Delta^N D_{h/q\uparrow}(z_1, Q^2) \\
 & \Delta^N D_{h/\bar{q}\uparrow}(z_2, Q^2)
 \end{aligned}$$

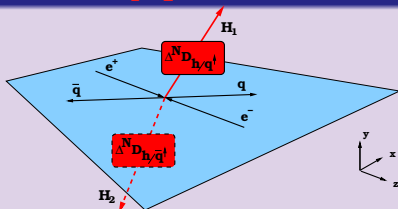
D. Boer, R. Jacob and P. J. Mulders *Nucl. Phys.* **B504** (1997) 345

SIDIS and  $e^+e^-$  annihilationSIDIS  $IN \rightarrow l' H_1 X$ 

Cross Section  $\sim \sin(\phi_H + \phi_S) \cdot$   
 $\Delta_T q(x, Q^2) \otimes \Delta^N D_{h/q^\uparrow}(z, Q^2)$

We extract (PRD75:054032,2007)

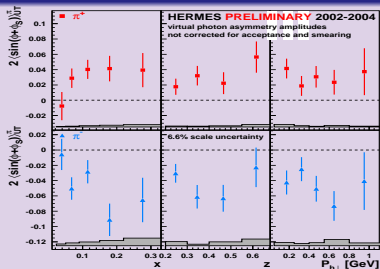
$\Delta_T q(x, Q^2)$  ,  $\Delta^N D_{h/q^\uparrow}(z, Q^2)$

 $e^+e^- \rightarrow H_1 H_2 X$ 

Cross Section  $\sim \cos(\phi_{H_1} + \phi_{H_2}) \cdot$   
 $\Delta^N D_{h/q^\uparrow}(z_1) \otimes \Delta^N D_{h/\bar{q}^\uparrow}(z_2)$

We extract (PRD75:054032,2007)

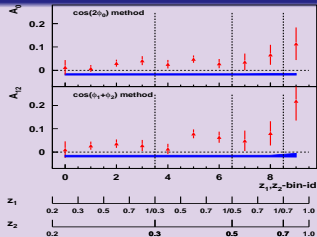
$\Delta^N D_{h/q^\uparrow}(z_1, Q^2)$  ,  
 $\Delta^N D_{h/\bar{q}^\uparrow}(z_2, Q^2)$

SIDIS and  $e^+e^-$  annihilationSIDIS  $IN \rightarrow l'H_1X$ 

HERMES, **proton** target,  
 $p_{lab} = 27.5$  (GeV)

## HERMES

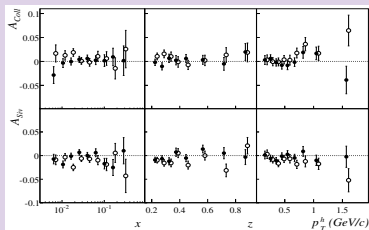
HERMES Collaboration, A. Airapetian  
*et al.* *Phys. Rev. Lett.* **94** 94 (2005) 012002

 $e^+e^- \rightarrow H_1H_2X$ 

BELLE,  $\sqrt{s} = 10.52$  (GeV),

## BELLE

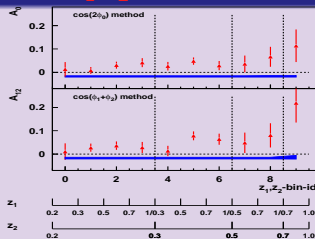
Belle Collaboration,  
K. Abe *et al.*, *Phys. Rev. Lett.* **96**(2006)232002

SIDIS and  $e^+e^-$  annihilationSIDIS  $IN \rightarrow l'H_1X$ 

COMPASS, **deuteron** target  
 $p_{lab} = 160$  (GeV)

## COMPASS

COMPASS Collaboration, E. S. Ageev *et al.*,  
*Nucl. Phys.* **B765**, 31 (2007).

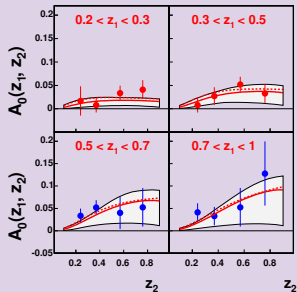
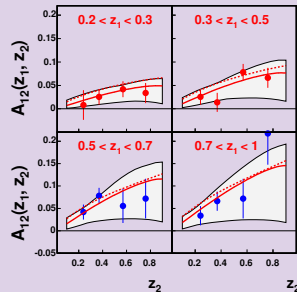
 $e^+e^- \rightarrow H_1H_2X$ 

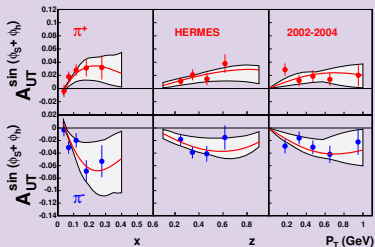
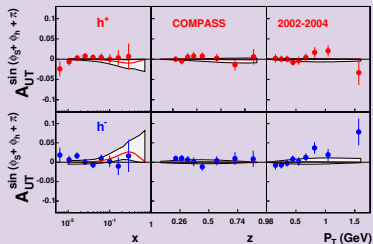
BELLE,  $\sqrt{s} = 10.52$  (GeV),

## BELLE

Belle Collaboration,  
 K. Abe *et al.*, *Phys. Rev. Lett.* **96**(2006)232002

## Description of BELLE data

BELLE  $\cos(2\varphi_0)$ BELLE  $\cos(\varphi_1 + \varphi_2)$ 

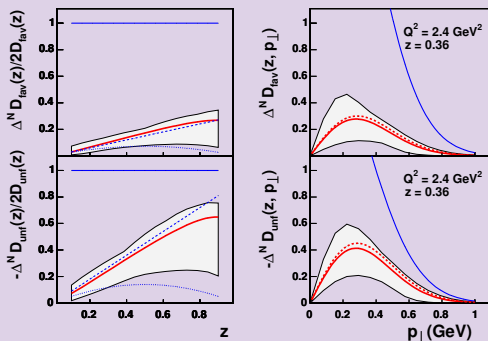
Description of SIDIS data  $A_{UT}^{\sin(\phi_h+\phi_S)}$ HERMES  $A_{UT}^{\sin(\phi_h+\phi_S)}$ COMPASS  $A_{UT}^{\sin(\phi_h+\phi_S+\pi)}$ 

HERMES Collaboration, L. Pappalardo *et al.*, in the proceedings of the XIV International Workshop on Deep Inelastic Scattering, Tsukuba city, Japan, April 20th - April 24th. (2006).

COMPASS Collaboration, E. S. Ageev *et al.*, Nucl. Phys. **B765**, 31 (2007).



## Collins fragmentation function



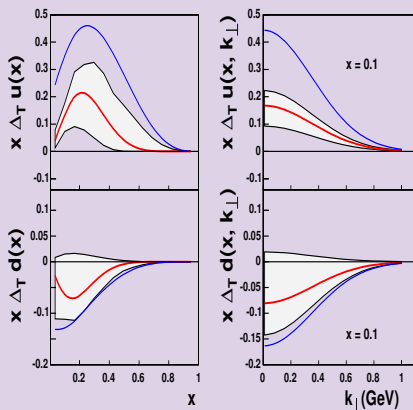
compared to Ref. [1] (dashed line) and Ref. [2] (dotted line)

[1] A. V. Efremov, K. Goeke, and P. Schweitzer, Phys. Rev. **D73**, 094025 (2006).

[2] W. Vogelsang and F. Yuan, Phys. Rev. **D72**, 054028, (2005).

# Transversity

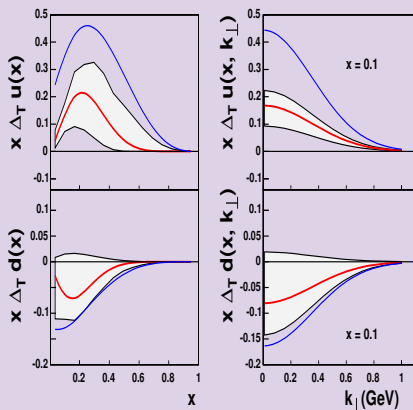
M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. P., C. Turk,  
Phys.Rev.D75:054032,2007



- This is the first extraction of **transversity** from experimental data.
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$
- Neither  $\Delta_T u(x)$  nor  $\Delta_T d(x)$  saturates Soffer bound.

# Transversity

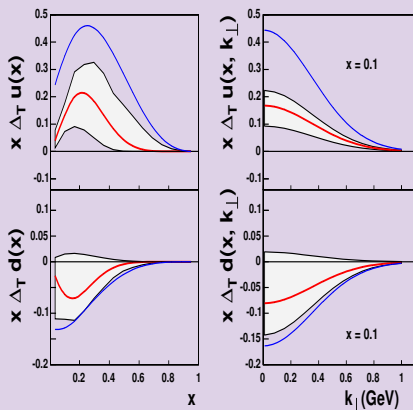
M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. P., C. Turk,  
Phys.Rev.D75:054032,2007



- This is the first extraction of transversity from experimental data.
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$
- Neither  $\Delta_T u(x)$  nor  $\Delta_T d(x)$  saturates Soffer bound.

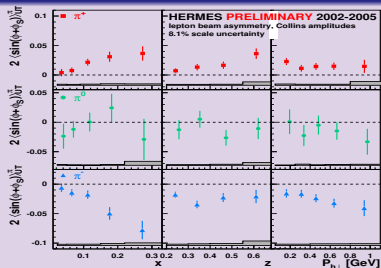
# Transversity

M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. P., C. Turk,  
Phys.Rev.D75:054032,2007



- This is the first extraction of transversity from experimental data.
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$
- Neither  $\Delta_T u(x)$  nor  $\Delta_T d(x)$  saturates Soffer bound.

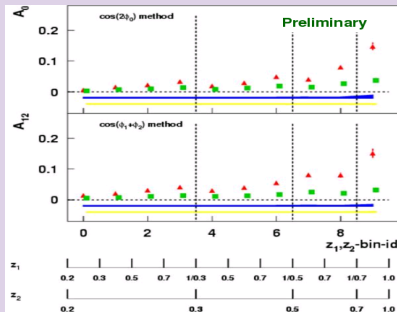
## NEW DATA APPEAR

SIDIS  $IN \rightarrow l' H_1 X$ 

HERMES, **proton** target,  
 $p_{lab} = 27.5$  (GeV)

## HERMES

New precise data 2002 - 2005  
HERMES results for Collins Asymmetries,  
M. Dieffenthaler, DIS 2007, Munich  
arXiv:0706.2242v2

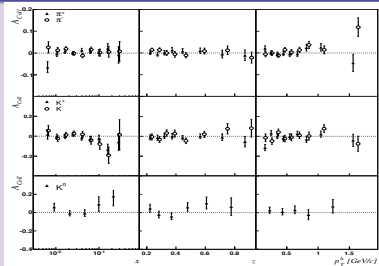
 $e^+e^- \rightarrow H_1 H_2 X$ 

BELLE,  $\sqrt{s} = 10.52$  (GeV),

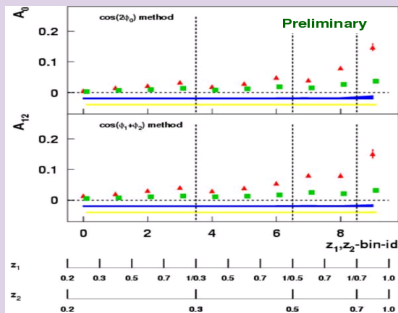
## BELLE

Small errors, high statistics data.  
Belle Collaboration, A. Ogawa et al. AIP  
Conf.Proc.915:575-578,2007

## NEW DATA APPEAR

SIDIS  $IN \rightarrow l' H_1 X$ COMPASS, **deuteron** $p_{lab} = 160$  (GeV)

COMPASS

New precise data,  $\pi$  and  $K$  separated.COMPASS Collaboration, M. Alekseev *et al.*, arXiv:0802.2160 $e^+e^- \rightarrow H_1 H_2 X$ BELLE,  $\sqrt{s} = 10.52$  (GeV),

BELLE

Small errors, high statistics data.

Belle Collaboration, A. Ogawa *et al.* AIP Conf.Proc.915:575-578,2007

# Problems and solutions

- What is the impact of new experimental data on our analysis?
- What is the dependence of our results on the choice of PDF and FF function set?
- The data on  $A_{UT}^{\sin(\phi_h+\phi_S)}$  are not independent.  $x$ ,  $z$  and  $P_T$  dependences are correlated as far as they result from a projection of a unique set of data onto a particular variable averaging over other two variables.

We need a wider collaboration to attempt a new global fit of HERMES, COMPASS and BELLE data.

## TORINO SPIN GROUP



**COMPASS:** Trieste University and INFN Trieste, ...



**HERMES:** INFN Frascati, University of Ferrara and INFN Ferrara, ...



**BELLE:** University of Illinois, ...

# Collins function

## Model for Collins FF

For  $\Delta^N D_{h/q^\uparrow}(z, |p_\perp|) = \frac{2|p_\perp|}{zM_\pi} H_1^{\perp q}(z, |p_\perp|)$  we use factorization of  $z$  and  $p_\perp$  and Gaussian dependence on  $p_\perp$

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

with

$$\mathcal{N}_q^C(z) = N_q^C z^\gamma (1-z)^\delta \frac{(\gamma + \delta)(\gamma + \delta)}{\gamma \delta^2}$$

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

where  $N_q^C$ ,  $\gamma$ ,  $\delta$ , and  $M$  are parameters.



# Collins function

## Model for Collins FF

For  $\Delta^N D_{h/q\uparrow}(z, |p_\perp|) = \frac{2|p_\perp|}{zM_\pi} H_1^{\perp q}(z, |p_\perp|)$  we use factorization of  $z$  and  $p_\perp$  and Gaussian dependence on  $p_\perp$

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

with

$$\mathcal{N}_q^C(z) \leq 1$$

$$h(p_\perp) \leq 1$$

positivity constraint  $|\Delta^N D_{h/q\uparrow}(z, \mathbf{p}_\perp)| \leq 2D_{h/q}(z, \mathbf{p}_\perp)$  is fulfilled.

# Transversity

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

where

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

$N_q^T$ ,  $\alpha$ ,  $\beta$  and  $\langle k_\perp^2 \rangle_T$  are parameters.

$$\mathcal{N}_q^T(x) \leq 1$$

thus Soffer bound

$$|\Delta_T q(x)| \leq \frac{1}{2} [f_{q/p}(x) + \Delta q(x)]$$

is fulfilled.

Description of  $A_{UT}^{\sin(\phi_h+\phi_S)}$ 

We use HERMES and COMPASS data sets on  $A_{UT}^{\sin(\phi_h+\phi_S)}$  in the fitting procedure, we use one of the two sets of data from BELLE corresponding to either  $\cos(\varphi_1 + \varphi_2)$  or  $\cos(2\varphi_0)$  extraction method.

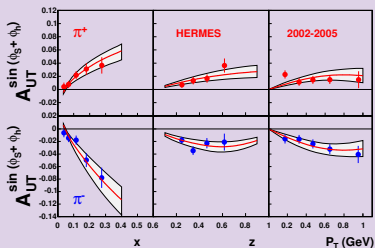
Favored and unfavored fragmentation functions are defined as follows:

$$D^{fav}(z) \equiv D^{u \rightarrow \pi^+}(z) = D^{d \rightarrow \pi^-}(z) = D^{\bar{u} \rightarrow \pi^-}(z) = D^{\bar{d} \rightarrow \pi^+}(z)$$

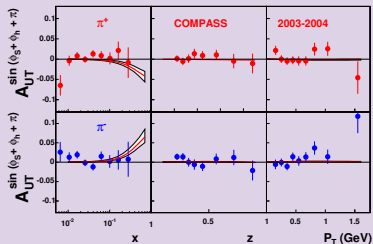
$$D^{unfav}(z) \equiv D^{u \rightarrow \pi^-}(z) = D^{d \rightarrow \pi^+}(z) = D^{\bar{u} \rightarrow \pi^+}(z) = D^{\bar{d} \rightarrow \pi^-}(z)$$

# Preliminary results

## HERMES $A_{UT}^{\sin(\phi_h + \phi_S)}$

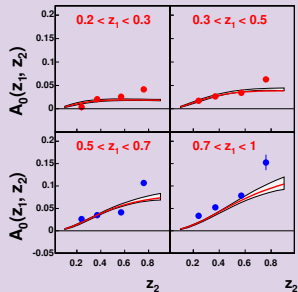


## COMPASS $A_{UT}^{\sin(\phi_h + \phi_S + \pi)}$

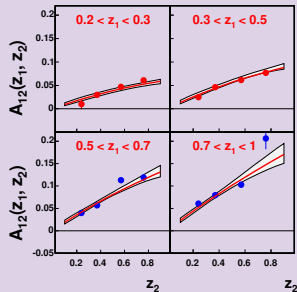


# Preliminary results

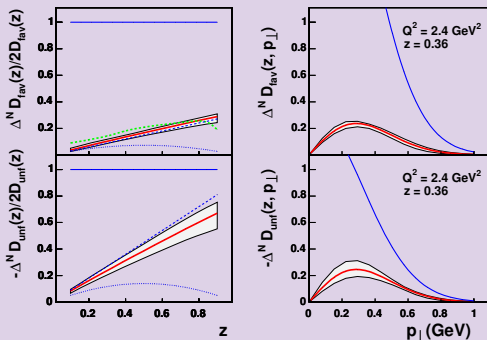
## BELLE $\cos(2\varphi_0)$



## BELLE $\cos(\varphi_1 + \varphi_2)$





## Collins fragmentation function



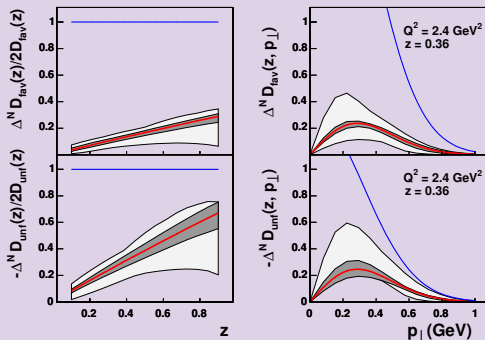
compared to Ref. [1] (dashed line), Ref. [2] (dotted line), and Ref. [3] (dashed green line)

[1] A. V. Efremov, K. Goeke, and P. Schweitzer, Phys. Rev. **D73**, 094025 (2006).

[2] W. Vogelsang and F. Yuan, Phys. Rev. **D72**, 054028 (2005).

[3] A. Bacchetta, L. Gamberg, G. R. Goldstein, A. Mukherjee, PLB659:234-243, 2008.  

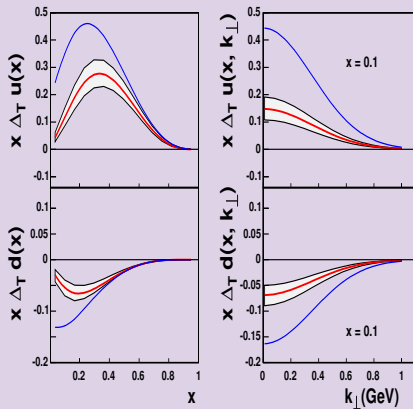
## Collins fragmentation function



Compared to the first extraction. Uncertainty is significantly reduced.

M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. P., C. Turk, Phys.Rev.D75:054032,2007

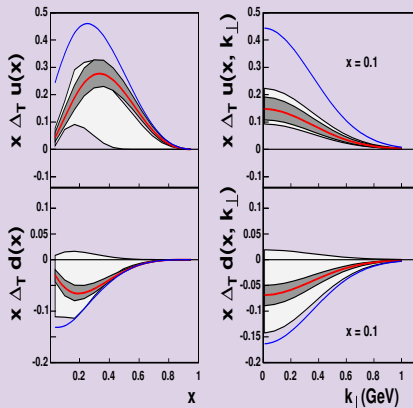
# Transversity



- This is the extraction of **transversity** from new experimental data.
- Compared to previous extraction  
PRD75:054032,2007
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$  The errors are diminished significantly.
- $\Delta_T u(x)$  became larger than that of the previous fit.

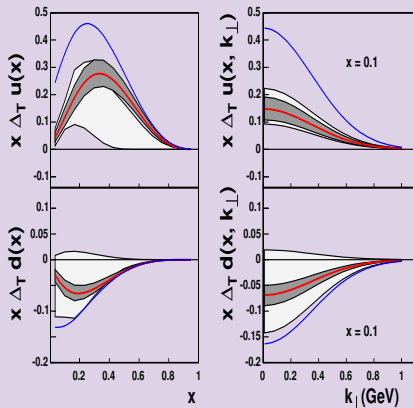


# Transversity



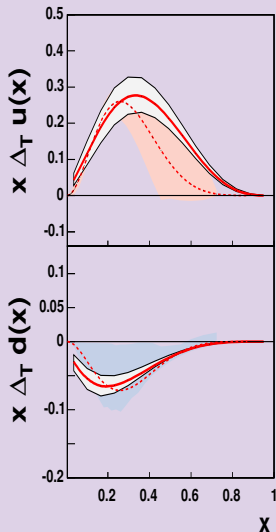
- This is the extraction of **transversity** from new experimental data.
- Compared to previous extraction  
PRD75:054032,2007
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$  The errors are diminished significantly.
- $\Delta_T u(x)$  became larger than that of the previous fit.

# Transversity



- This is the extraction of **transversity** from new experimental data.
- Compared to previous extraction  
PRD75:054032,2007
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$  The errors are diminished significantly.
- $\Delta_T u(x)$  became larger than that of the previous fit.

# Transversity

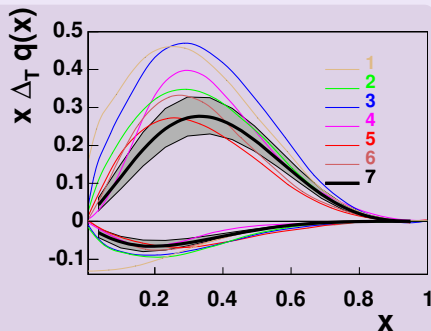


If we use only  $x$  dependence in fitting procedure, errors grow, especially in case of  $d$  quark.

$u$  quark transversity does not change. Dashed lines – extraction of Trieste group, courtesy of F. Sozzi.

# Transversity, comparison with models

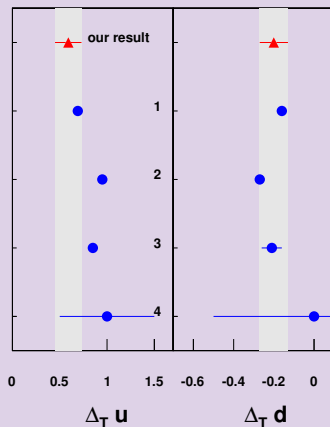
New extraction is close to most of the models.



- ① Soffer et al. PRD 65 (02)
- ② Korotkov et al. EPJC 18 (01)
- ③ Schweitzer et al. PRD 64 (01)
- ④ Wakamatsu, PLB B653 (07)
- ⑤ Pasquini et al., PRD 72 (05)
- ⑥ Cloet, Bentz and Thomas PLB 659 (08)
- ⑦ This analysis.

# Tensor charges

$$\Delta_T u = 0.59^{+0.14}_{-0.13}, \quad \Delta_T d = -0.20^{+0.05}_{-0.07} \text{ at } Q^2 = 0.8 \text{ GeV}^2$$



- 1 Quark-diquark model:  
Cloet, Bentz and Thomas  
PLB **659**, 214 (2008),  $Q^2 = 0.4 \text{ GeV}^2$
- 2 CQSM:  
M. Wakamatsu, PLB B **653** (2007) 398  
 $Q^2 = 0.3 \text{ GeV}^2$
- 3 Lattice QCD:  
M. Gockeler et al.,  
Phys.Lett.B627:113-123,2005 ,  $Q^2 = \text{GeV}^2$
- 4 QCD sum rules:  
Han-xin He, Xiang-Dong Ji,  
PRD 52:2960-2963,1995,  $Q^2 \sim 1 \text{ GeV}^2$

# CONCLUSIONS

- Extraction of transversity for  $u$  and  $d$  quarks,  $\Delta_{\mathcal{T}}u(x)$  and  $\Delta_{\mathcal{T}}d(x)$ , from HERMES, COMPASS and BELLE data is presented.
- New data from HERMES, COMPASS and BELLE improve significantly quality of the fit.
- $\Delta_{\mathcal{T}}u(x) > 0$  and  $\Delta_{\mathcal{T}}d(x) < 0$  and much closer to most of the model predictions.
- The Collins fragmentation functions for favoured and unfavoured fragmentation have been obtained.  
 $\Delta^N D_h^{fav}(z, |p_{\perp}|) > 0$  and  $\Delta^N D_h^{unf}(z, |p_{\perp}|) < 0$

# CONCLUSIONS

- Extraction of transversity for  $u$  and  $d$  quarks,  $\Delta_T u(x)$  and  $\Delta_T d(x)$ , from HERMES, COMPASS and BELLE data is presented.
- New data from HERMES, COMPASS and BELLE improve significantly quality of the fit.
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$  and much closer to most of the model predictions.
- The Collins fragmentation functions for favoured and unfavoured fragmentation have been obtained.  
 $\Delta^N D_h^{fav}(z, |p_\perp|) > 0$  and  $\Delta^N D_h^{unf}(z, |p_\perp|) < 0$

# CONCLUSIONS

- Extraction of transversity for  $u$  and  $d$  quarks,  $\Delta_{\mathcal{T}}u(x)$  and  $\Delta_{\mathcal{T}}d(x)$ , from HERMES, COMPASS and BELLE data is presented.
- New data from HERMES, COMPASS and BELLE improve significantly quality of the fit.
- $\Delta_{\mathcal{T}}u(x) > 0$  and  $\Delta_{\mathcal{T}}d(x) < 0$  and much closer to most of the model predictions.
- The Collins fragmentation functions for favoured and unfavoured fragmentation have been obtained.  
 $\Delta^N D_h^{fav}(z, |p_{\perp}|) > 0$  and  $\Delta^N D_h^{unf}(z, |p_{\perp}|) < 0$



# CONCLUSIONS

- Extraction of transversity for  $u$  and  $d$  quarks,  $\Delta_T u(x)$  and  $\Delta_T d(x)$ , from HERMES, COMPASS and BELLE data is presented.
- New data from HERMES, COMPASS and BELLE improve significantly quality of the fit.
- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$  and much closer to most of the model predictions.
- The Collins fragmentation functions for favoured and unfavoured fragmentation have been obtained.  
 $\Delta^N D_h^{fav}(z, |p_\perp|) > 0$  and  $\Delta^N D_h^{unf}(z, |p_\perp|) < 0$

# CONCLUSIONS

- Extraction of transversity for  $u$  and  $d$  quarks,  $\Delta_T u(x)$  and  $\Delta_T d(x)$ , from HERMES, COMPASS and BELLE data is

THANK YOU!

significantly quality of the fit.

- $\Delta_T u(x) > 0$  and  $\Delta_T d(x) < 0$  and much closer to most of the model predictions.
- The Collins fragmentation functions for favoured and unfavoured fragmentation have been obtained.  
 $\Delta^N D_h^{fav}(z, |p_\perp|) > 0$  and  $\Delta^N D_h^{unf}(z, |p_\perp|) < 0$