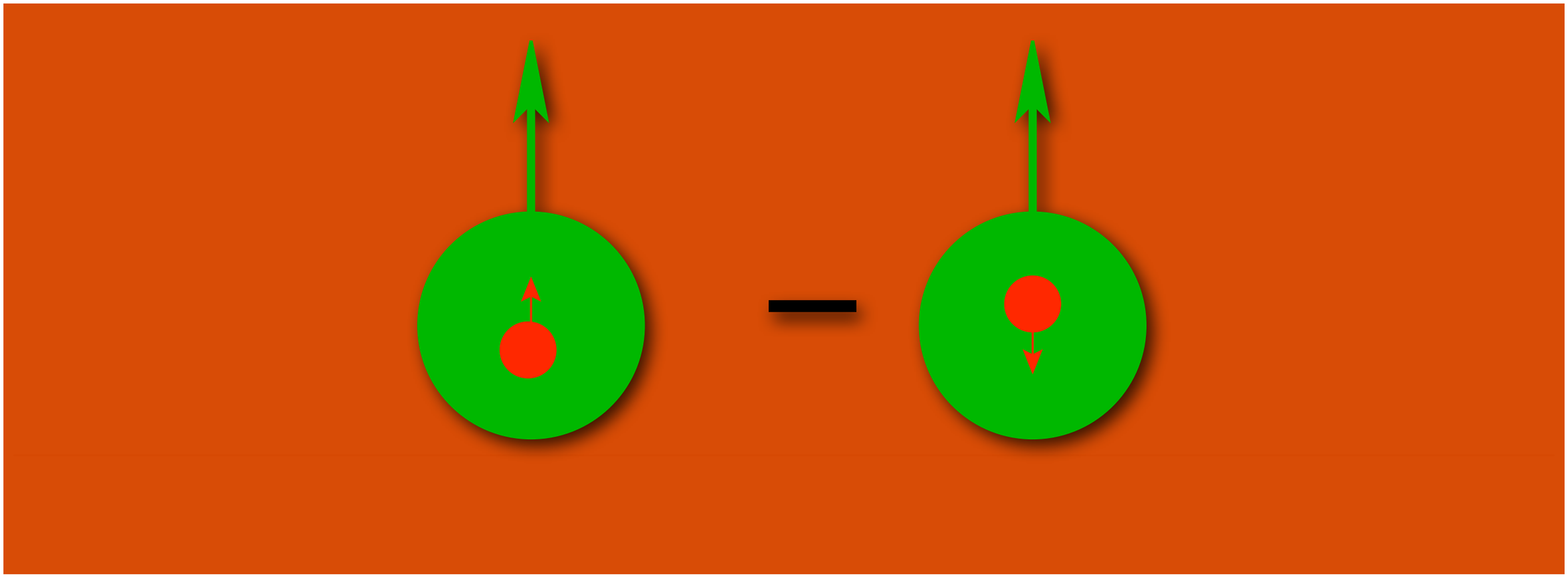

Interference Fragmentation Functions and Transverse Spin Studies.

DIS 2012

Aurore Courtoy
IFPA-Université de Liège (Belgium)

in collaboration with Alessandro Bacchetta and Marco Radici in Pavia

Can Transversity Be Measured?

R. L. Jaffe

R.L. Jaffe, Xue-min Jin, Jian Tang (MIT, LNS).
Phys.Rev.Lett. 80 (1998) 1166-1169
Interference fragmentation functions and the nucleon's transversity.

Invited paper, presented at the 2nd Topical Workshop,
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- Drell-Yan → h_1 h_1
- Final State Interaction:
  - Single-Particle Fragmentation → $h_1 \otimes H_1^{\perp}$
  - Two-Particle Fragmentation → h_1 $H_1^{<}$

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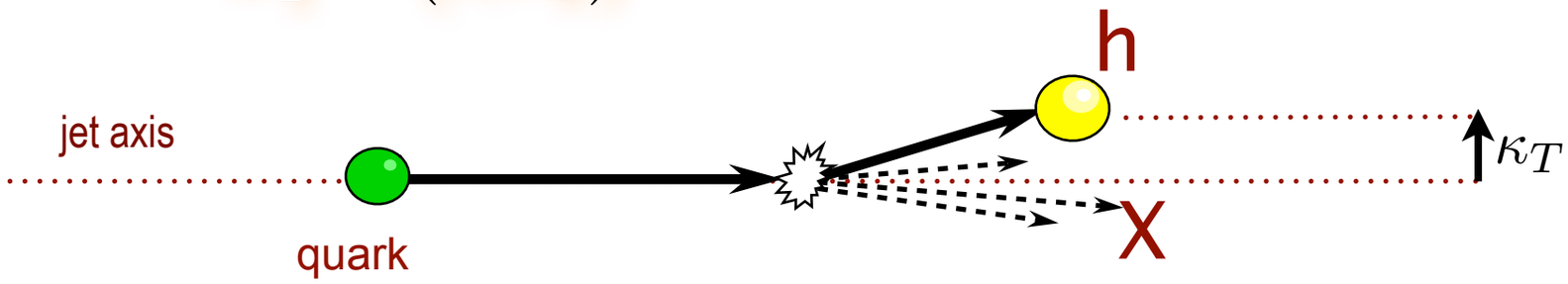
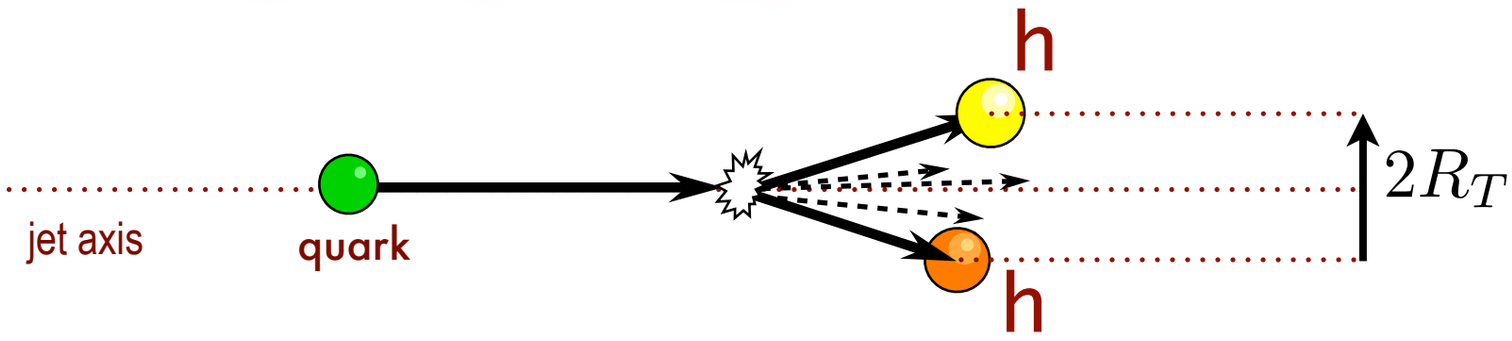
Transverse Correlations from Fragmentation Functions

✦ **TMD FF** $D_1^{q\to h}\left(z,\kappa_T^2\right)$



TMD factorization

✦ **DiFF** $D_1^{q\to h_1h_2}\left(z_1,z_2,R_T^2\right)$



Collinear factorization

Transverse Correlations from Fragmentation Functions

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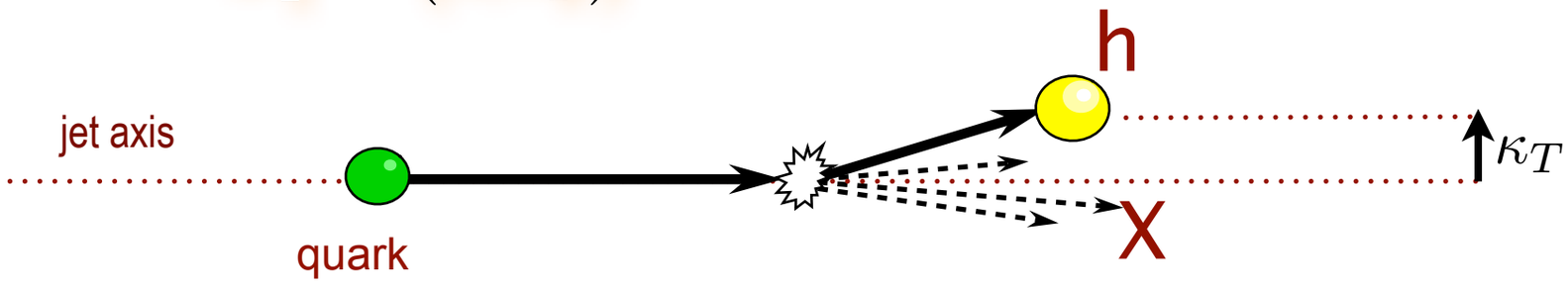

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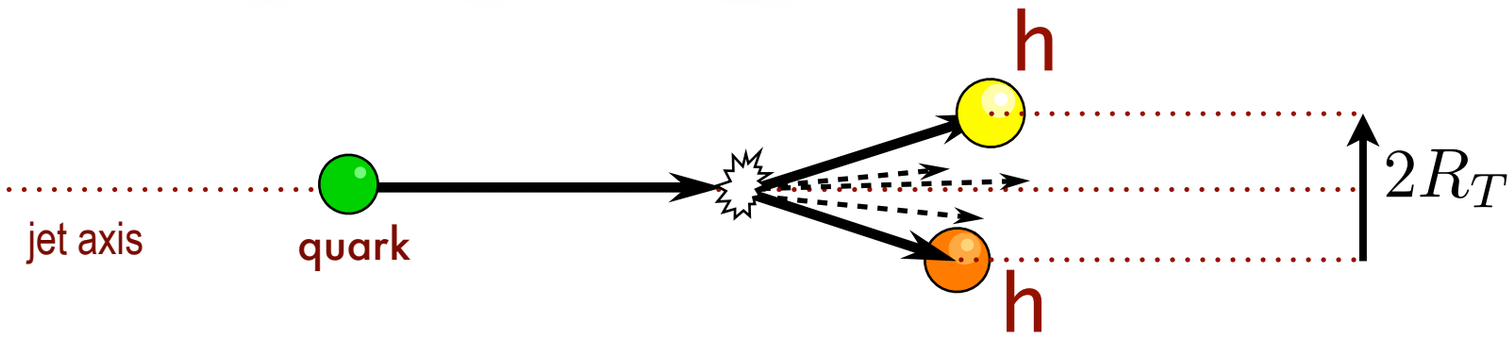


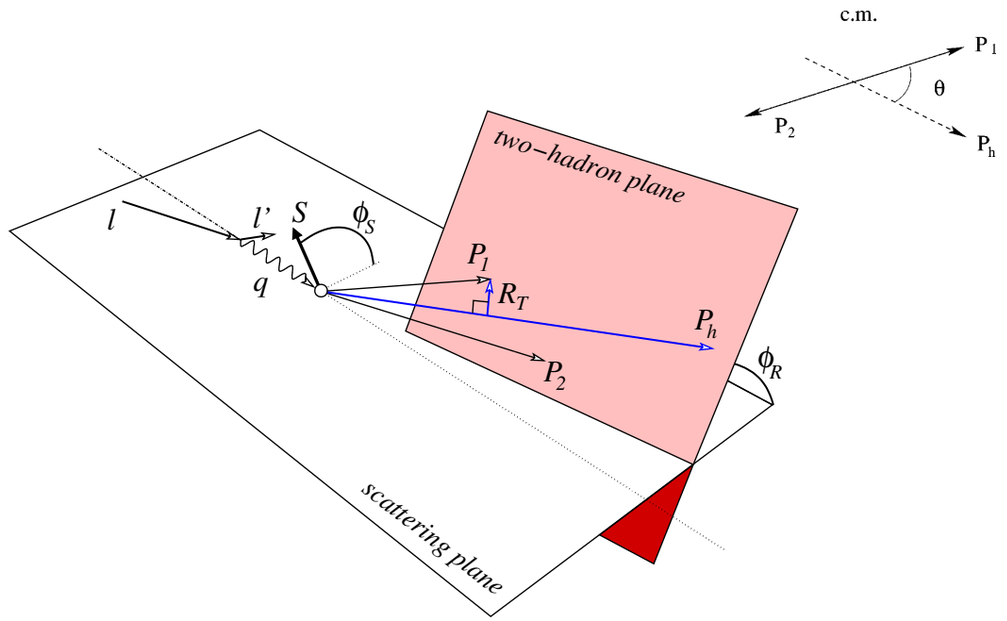
Collinear factorization

Here: $D_1^{q\to\pi^+\pi^-}(z,M_h)$ $\quad z=z_1+z_2$ $\quad 2\,|\mathbf{R}|=\sqrt{M_h^2-4m_\pi^2}$

$A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$:

$e\, p^{\uparrow} \rightarrow e'\, (\pi^+\pi^-)\, X$

Chiral-off DiFF:
Distribution of hadrons inside the jet



Direction of
the transverse polarization of the fragmenting quarks

$$A_{\rm DIS}(x,z,M_h^2,Q^2) = -C_y\, \frac{\sum_q e_q^2\, h_1^q(x,Q^2)\, \frac{|\bar{R}|}{M_h}\, H_{1,sp}^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2) \qquad D_1^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}$$

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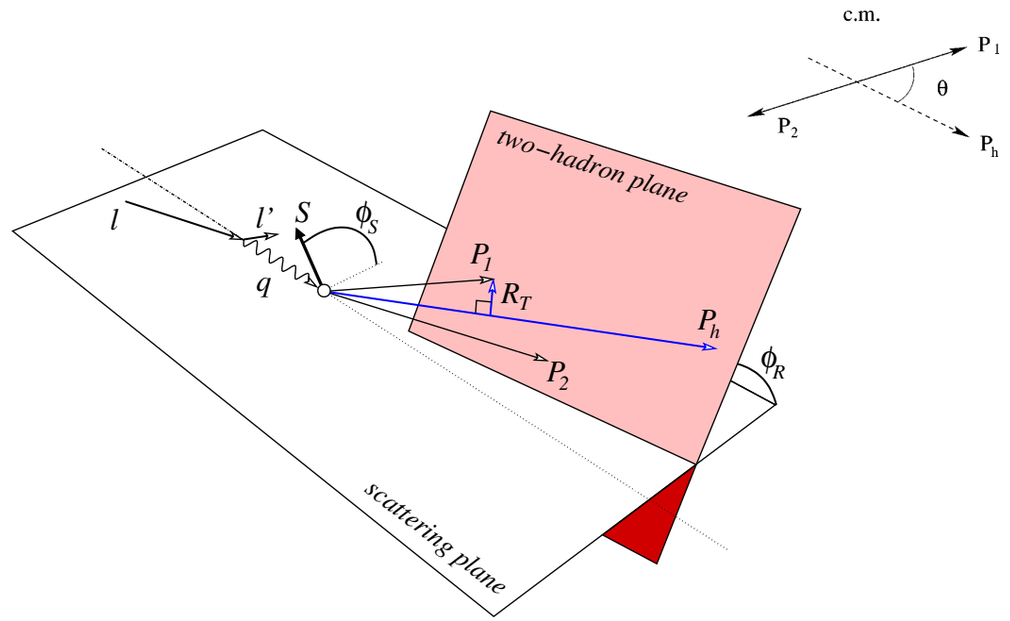

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Knowledge on DiFFs leads to $h_1(x, Q^2)$

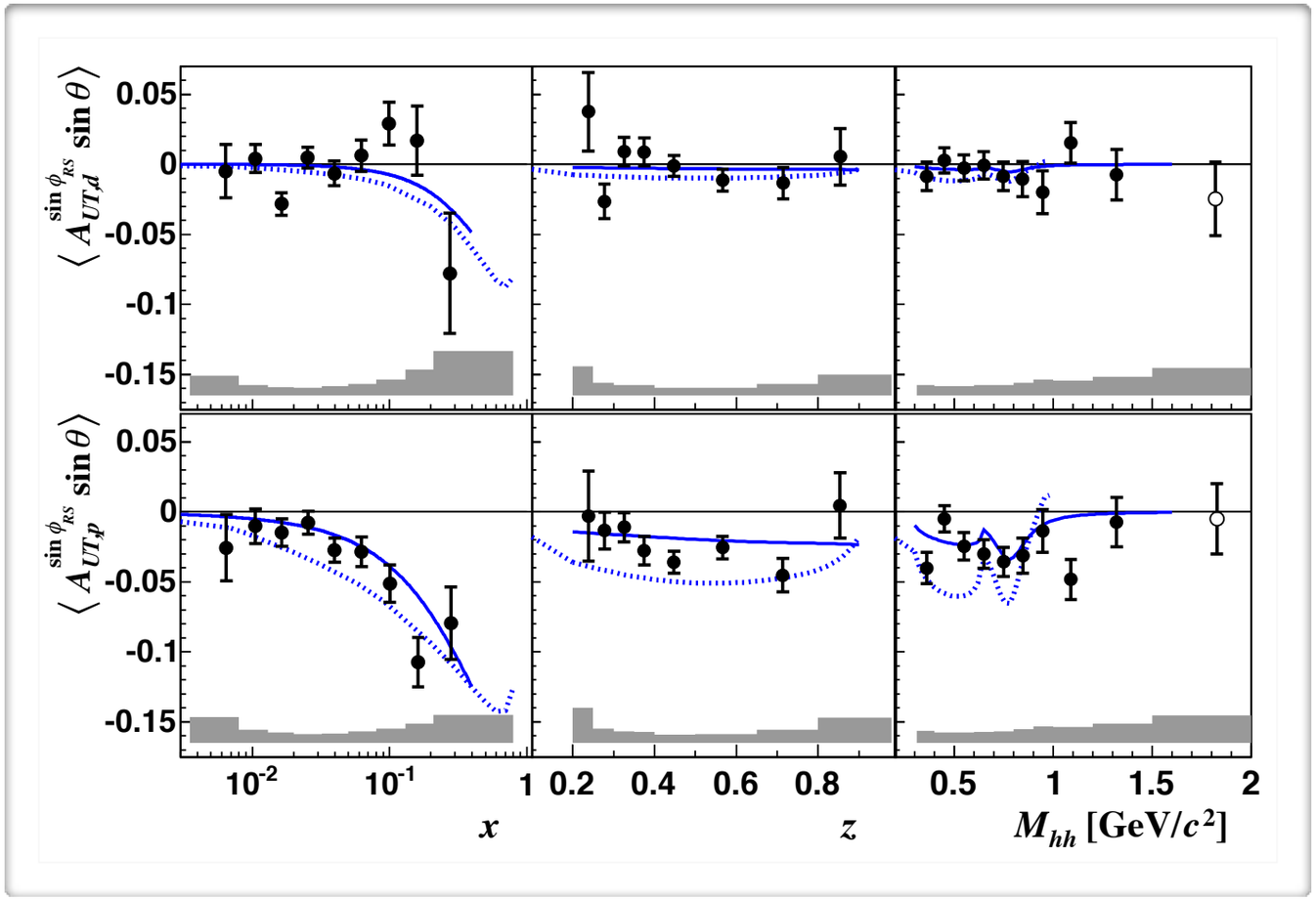
$A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$ @ COMPASS

See C. Braun's talk

[arXiv;1202.6150]

2002-4 Deuteron Data

2007 Proton Data



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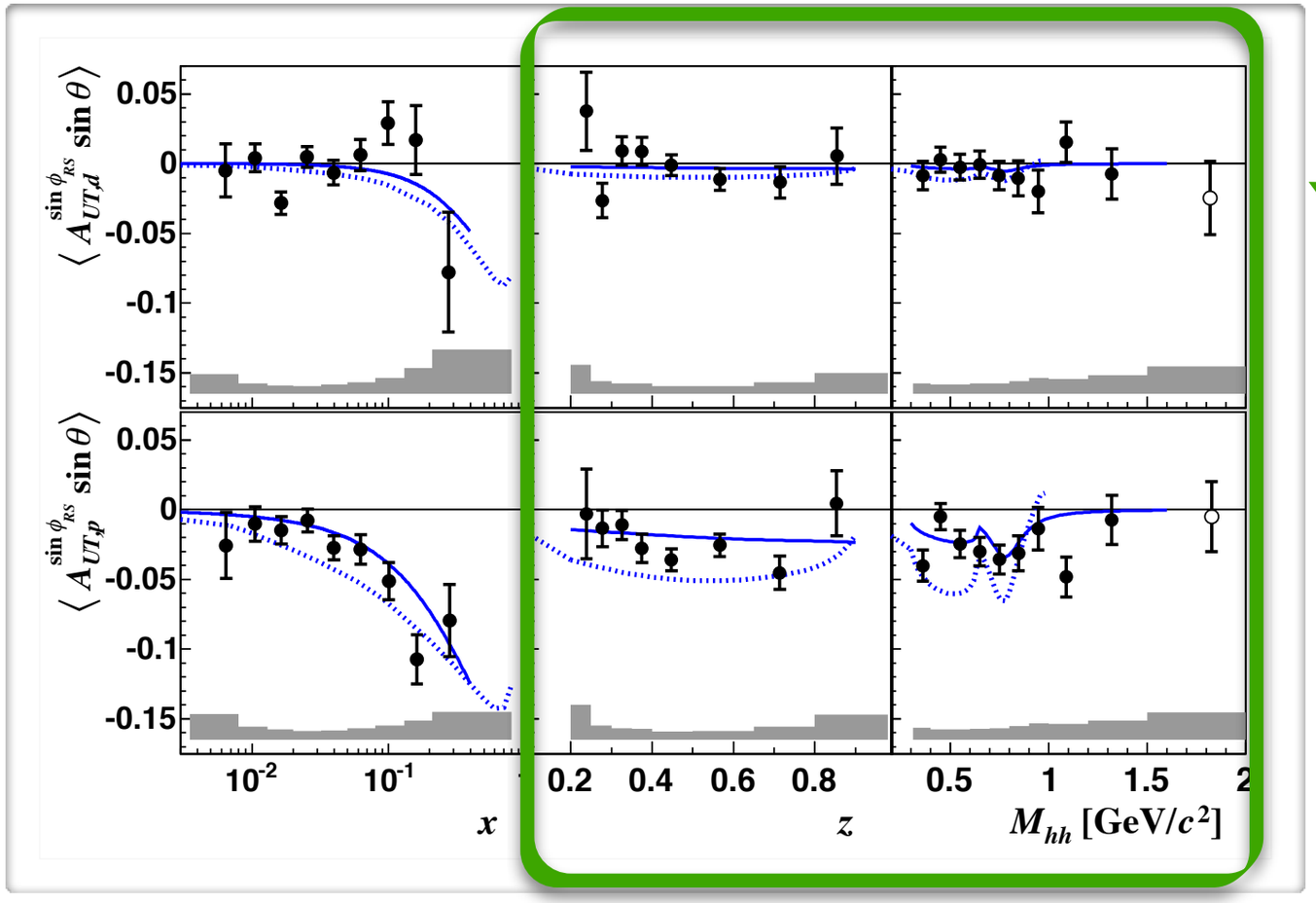

(z, M_h)-dpdence determined by DiFF from Belle

[arXiv:1202.0323]

$A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$ @ COMPASS

See C. Braun's talk

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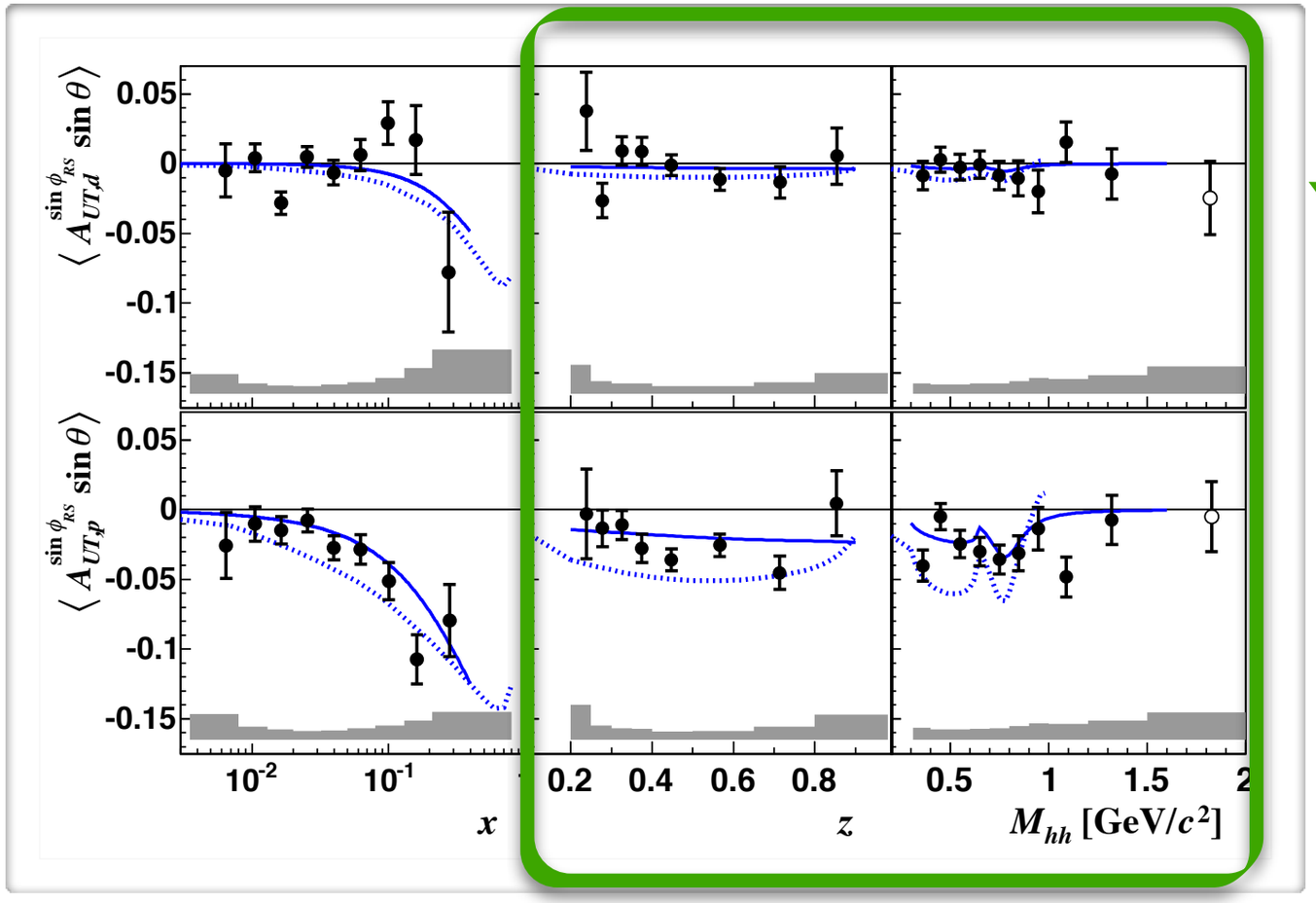

(z, M_h)-dpdence determined by DiFF from Belle
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COMPASS range: 0.2<z<1 & 0.29<M_h<1.29 GeV

$$n_q(Q^2) = \int dz dM_h \, D_1^q(z, M_h; Q^2)$$

$$n_q^{\uparrow}(Q^2) = \int dz dM_h \, \frac{|\mathbf{R}|}{M_h} \, H_{1,sp}^{\sphericalangle q}(z, M_h; Q^2)$$

$A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$ @ COMPASS

See C. Braun's talk

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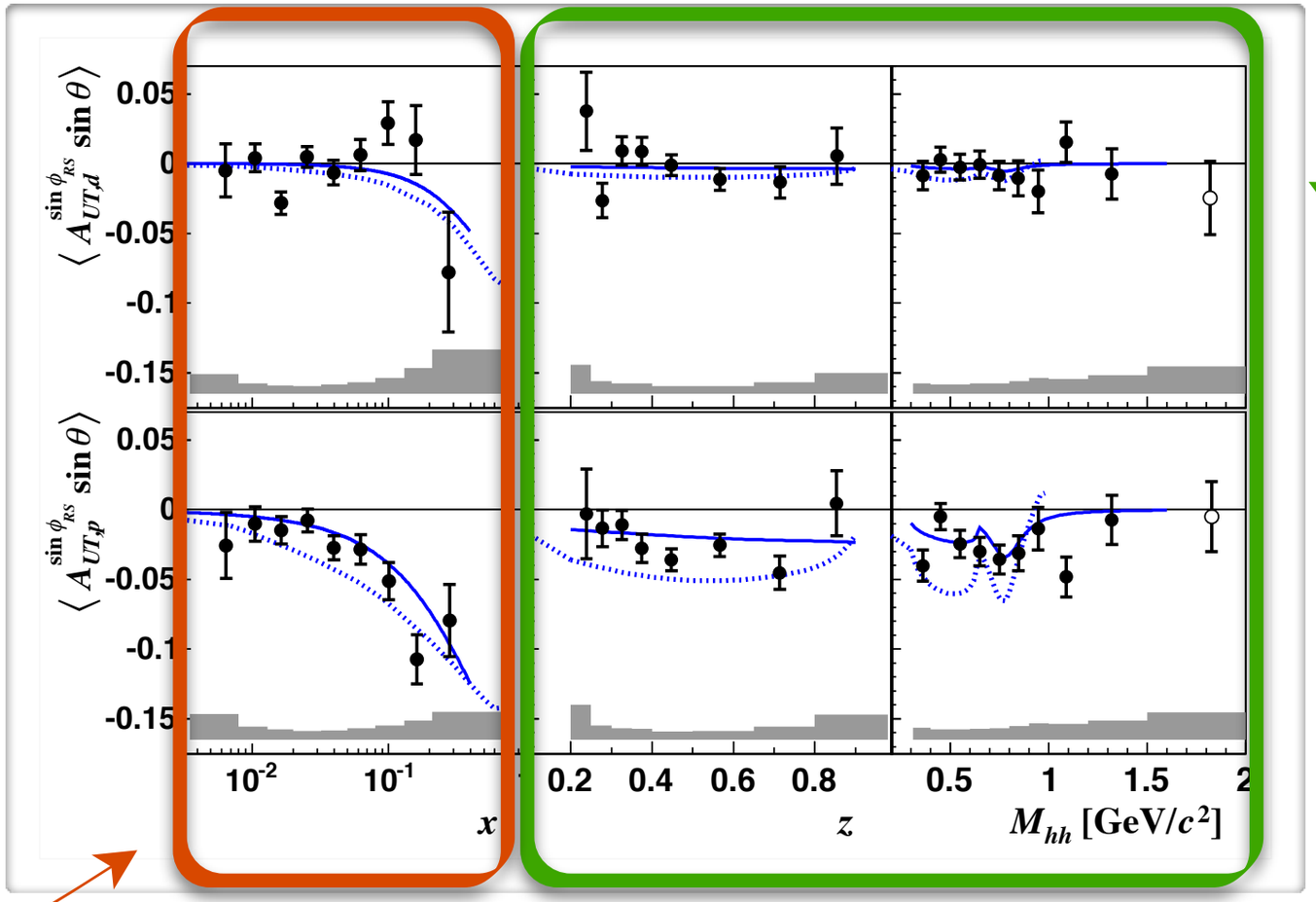
2002-4 Deuteron Data



2007 Proton Data

x-dependence only from Transversity

(z, M_h)-dpdence determined by DiFF from Belle [arXiv:1202.0323]

COMPASS range: 0.2<z<1 & 0.29<M_h<1.29 GeV

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Transversity from $A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$

$$A_{\rm DIS}(x,Q^2) = -C_y \frac{\sum_q e_q^2\, h_1^q(x,Q^2)\, n_q^{\uparrow}(Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2)\, n_q(Q^2)}$$

Using symmetries for DiFFs:

$$H_1^{\sphericalangle,\,u} = -H_1^{\sphericalangle,\,d} = -\overline{H}_1^{\sphericalangle,\,u} = \overline{H}_1^{\sphericalangle,\,d}$$

$$D_1^u = D_1^d = \overline{D}_1^u = \overline{D}_1^d \,;$$
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Proton

$$x h_1^{u_v}(x,Q^2) - \tfrac{1}{4}\, x h_1^{d_v}(x,Q^2) = -C_y^{-1}\, A_{\rm DIS}(x,Q^2)\, \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar{q}}(x,Q^2)$$

Deuteron

$$x h_1^{u_v}(x,Q^2) + x h_1^{d_v}(x,Q^2) = \frac{5}{3} A_{\rm DIS}(x,Q^2) \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)}\, x \left(f_1^{u+\bar{u}} + f_1^{d+\bar{d}} + \frac{2}{5} f_1^{s+\bar{s}} \right)$$

and combinations of both ...

Transversity from $A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$

$$A_{\rm DIS}(x,Q^2) = -C_y \frac{\sum_q e_q^2\, h_1^q(x,Q^2)\, n_q^{\uparrow}(Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2)\, n_q(Q^2)}$$

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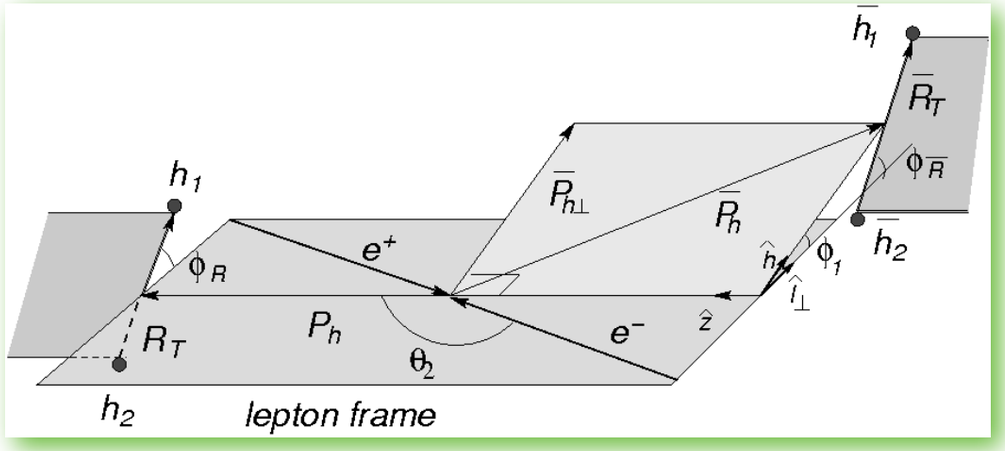
and combinations of both ...

$A^{\cos(\Phi_R+\Phi_{\check{R}})}$

$e^+e^- \to (\pi^+\pi^-)_{jet1}\ (\pi^+\pi^-)_{jet2}\ X$ @ Belle

See M. Leitgab's talk

[PhysRevLett.107.072004]



$$A_{e+e-}(z, M_h^2, \bar{z}, \bar{M}_h^2, Q^2)$$
$$= -\frac{\langle \sin^2\theta_2 \rangle}{\langle 1+\cos^2\theta_2 \rangle} \frac{\langle \sin\theta \rangle \langle \sin\bar{\theta} \rangle\, 5\, \frac{|\bar{R}|}{M_h}\, H_1^{\sphericalangle\, u}(z, M_h^2, Q^2)\, \frac{|\bar{\bar{R}}|}{\bar{M}_h}\, H_1^{\sphericalangle\, u}(\bar{z}, \bar{M}_h^2, Q^2)}{6\, D_1^u(z, M_h^2, Q^2)\, D_1^u(\bar{z}, \bar{M}_h^2, Q^2) + 4\, D_1^c(z, M_h^2, Q^2)\, D_1^c(\bar{z}, \bar{M}_h^2, Q^2)}$$

- 2 hemispheres
- azimuthal modulation between the 2 hemispheres

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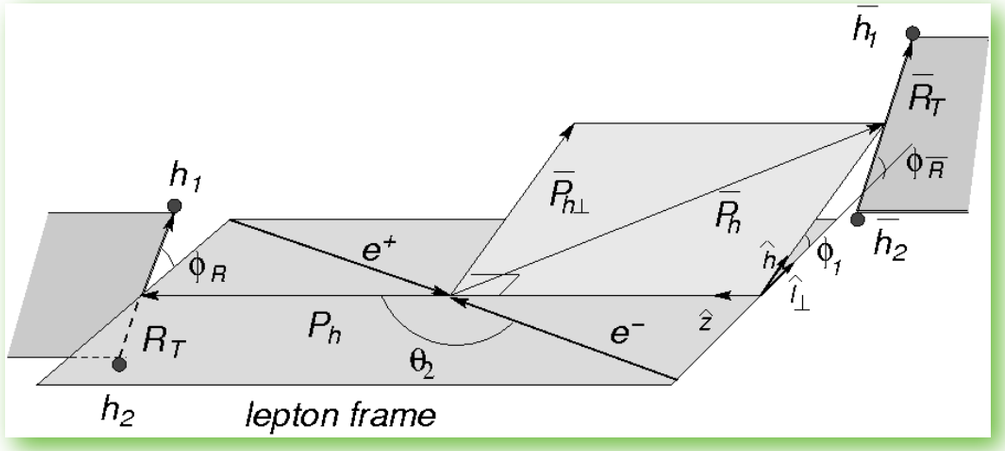

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- 2 hemispheres
- azimuthal modulation between the 2 hemispheres

Two ways of analyzing the DiFFs

- direct analysis from experimental data → stick to exp. binning [PRL 107 (2011) 012001]
- analysis from fit of the data → more flexibility [arXiv:1202.0323]

$A^{\cos(\Phi_R+\Phi_{\bar{R}})}$

$e^+e^- \rightarrow (\pi^+\pi^-)_{jet1}\ (\pi^+\pi^-)_{jet2}\ X$ @ Belle

---

From Belle data & for HERMES range (in particular M_{h1}-M_{h2} asymmetries):

0.871

$$(A_{e+e-})_H = -\frac{\langle \sin^2\theta_2 \rangle}{\langle 1+\cos^2\theta_2 \rangle} \frac{\langle \sin\theta \rangle \langle \sin\bar{\theta} \rangle 5\,(n_u^{\uparrow})^2}{6\,(n_u)^2 + 4\,(n_c)^2}$$

-0.0307±0.0011

$4\,n_c^2/6\,n_u^2=0.415$

0.753

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Evolution effects : From Belle's scale to HERMES and COMPASS'scale

→ needs analytical expression and gluon DiFF → fits → [arXiv:1202.0323]

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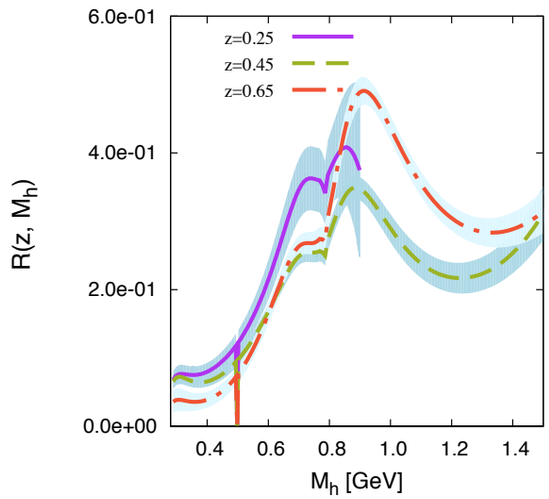
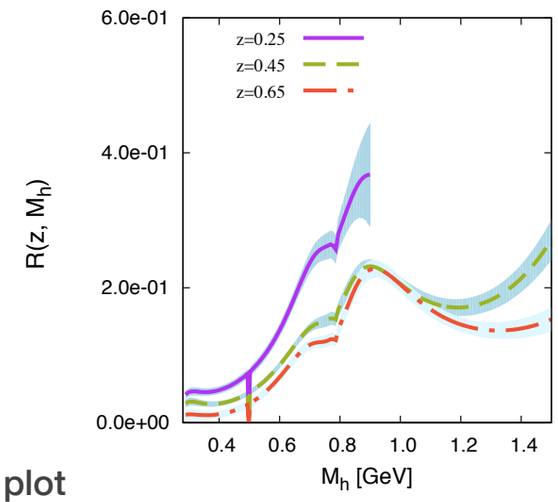
Q^2=1GeV^2



Q^2=100GeV^2



only $H_1^<$ evolution on plot

DIS2011

Transversity from e $p^{\uparrow} \rightarrow e'$ $(\pi^+\pi^-)$ X @ HERMES

$$xh_1^{u_v}(x,Q^2) - \tfrac{1}{4}\, xh_1^{d_v}(x,Q^2) = -C_y^{-1}\, A_{\mathrm{DIS}}(x,Q^2) \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar{q}}(x,Q^2)$$

with 1-to-100 GeV² evolution correction: small corrections

HERMES range: -0.251^{-1} (± 9% theo. err.) from BELLE

DIS2011

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HERMES range: -0.251^{-1} (± 9% theo. err.) from BELLE

Transversity from e $p^{\uparrow} \rightarrow e'$ $(\pi^+\pi^-)$ X @ COMPASS 2007

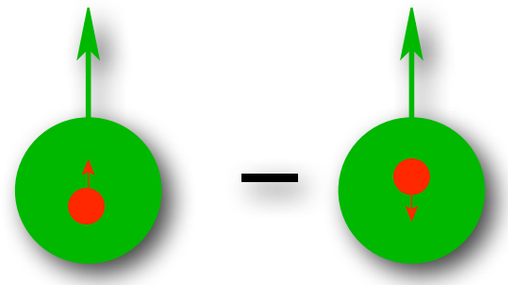
$$xh_1^{u_v}(x,Q^2) - \tfrac{1}{4}\, xh_1^{d_v}(x,Q^2) = -C_y^{-1}\, A_{\mathrm{DIS}}(x,Q^2) \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar{q}}(x,Q^2)$$

with 1-to-100 GeV² evolution correction: negligible corrections

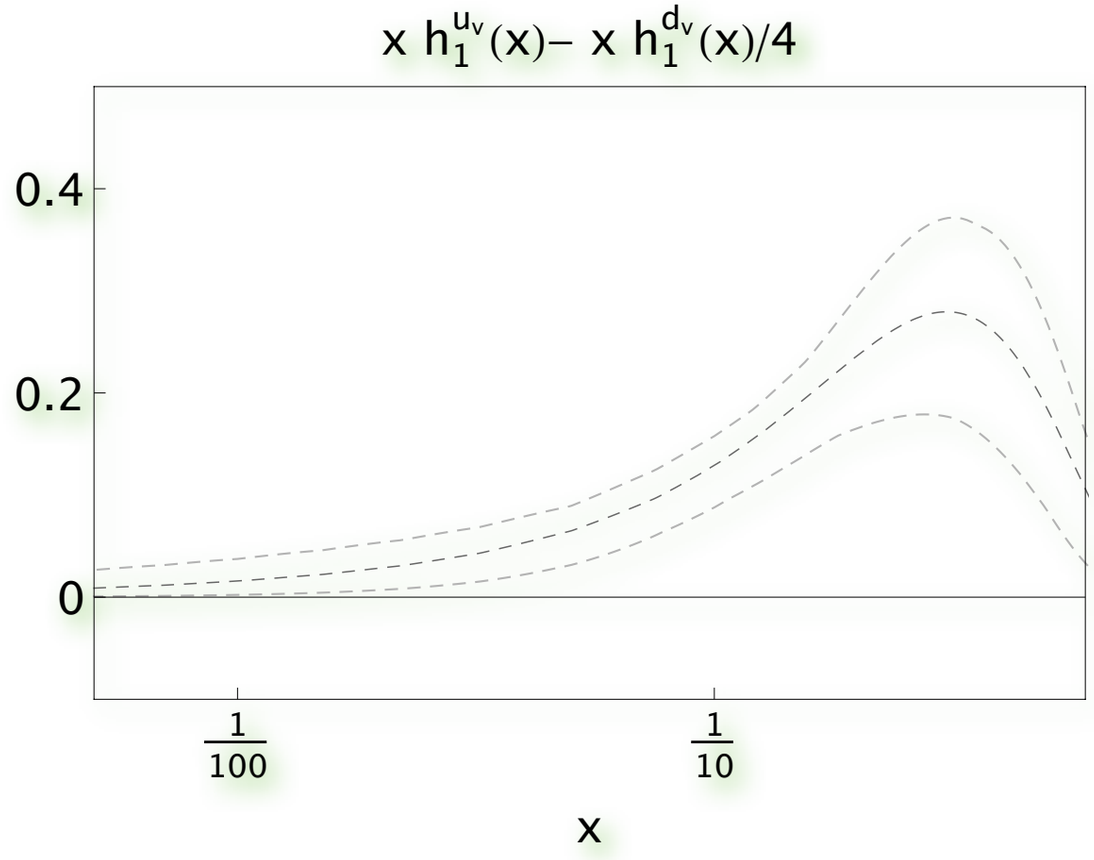
COMPASS range: -0.221^{-1} (± 5% theo. err.) from BELLE

PRELIMINARY

Transversity from Proton data

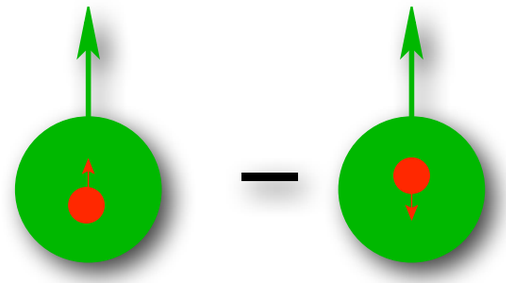


Transversity from pion pair production SIDIS off transversely polarized target



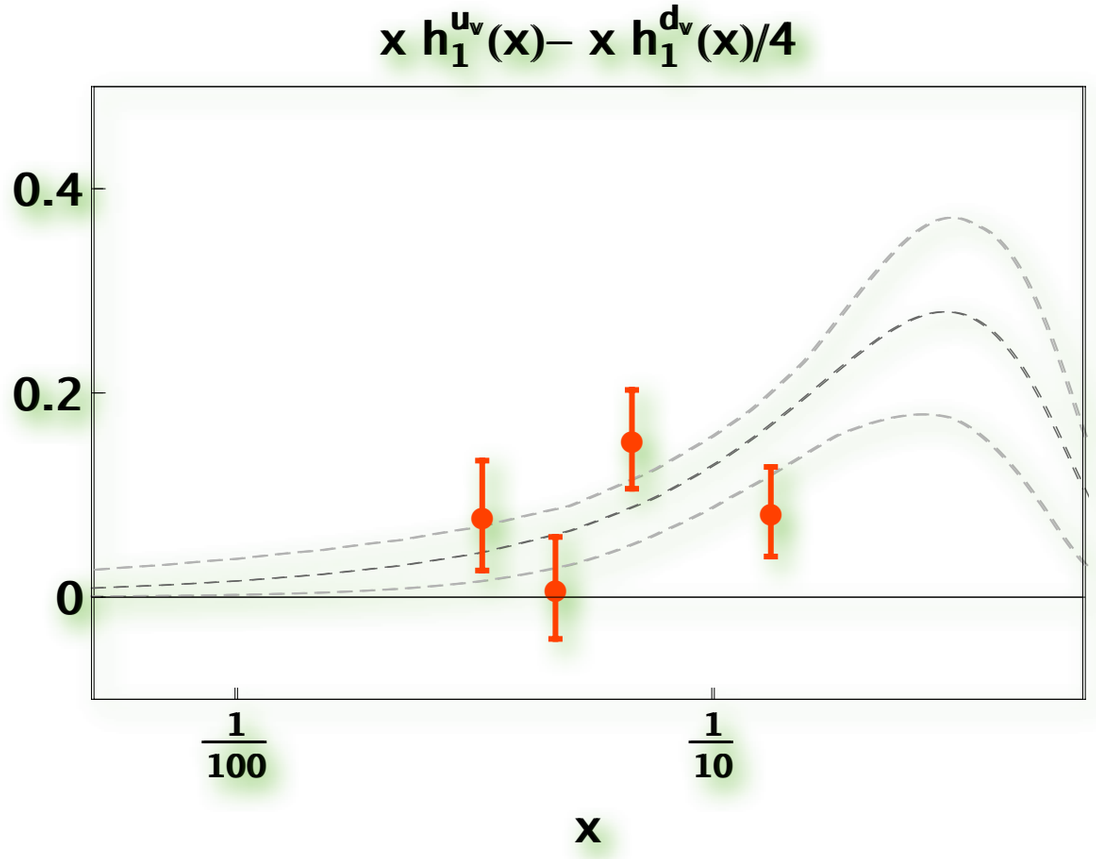
Band:
Torino 2009 transversity

Transversity from Proton data



Transversity from pion pair production SIDIS off transversely polarized target

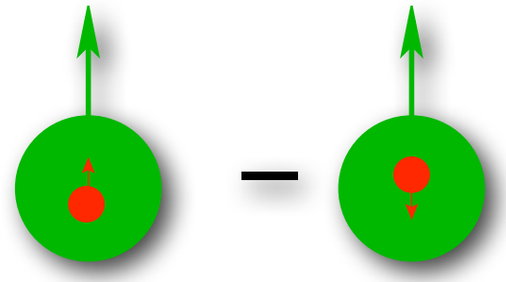
- from HERMES data
- DiFF analysis
  - from BELLE data
- $f_1(x)$ from MSTW
- **PRL107 & arXiv:1202.0323**



11% theo. err.

Band:
Torino 2009 transversity

Transversity from Proton data



Transversity from pion pair production SIDIS off transversely polarized target

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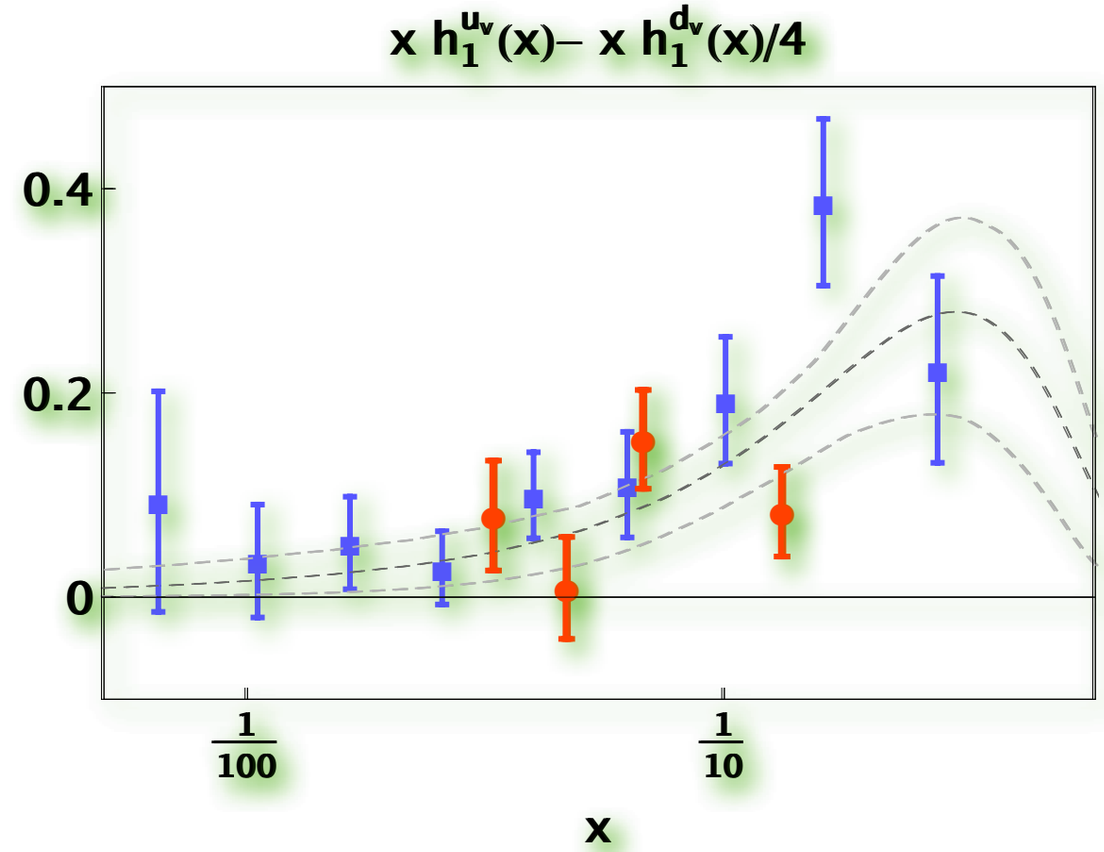
- DiFF analysis
  - from BELLE data
- $f_1(x)$ from MSTW
- PRL107 & arXiv:1202.0323

- from COMPASS data
- DiFF analysis
  - from BELLE data
- $f_1(x)$ from MSTW
- new analysis



11% theo. err.

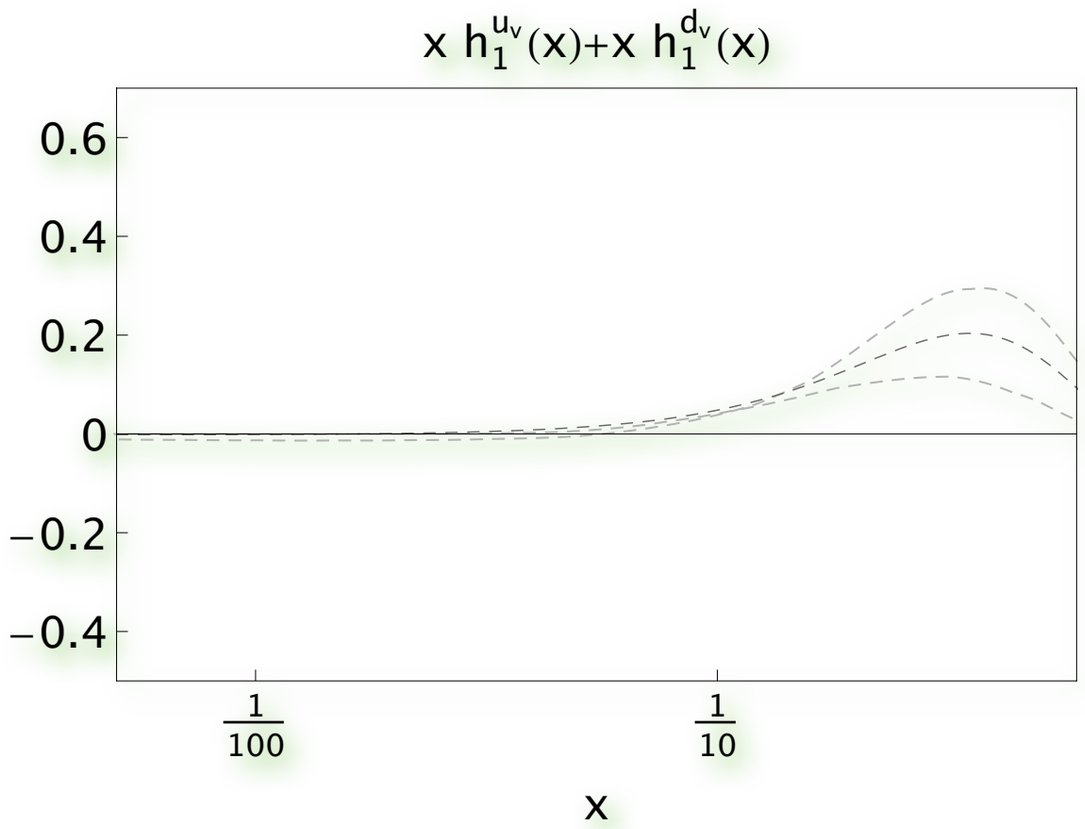
5% theo. err.

Band:
Torino 2009 transversity

PRELIMINARY

Transversity from Deuteron data

COMPASS 2002-2004

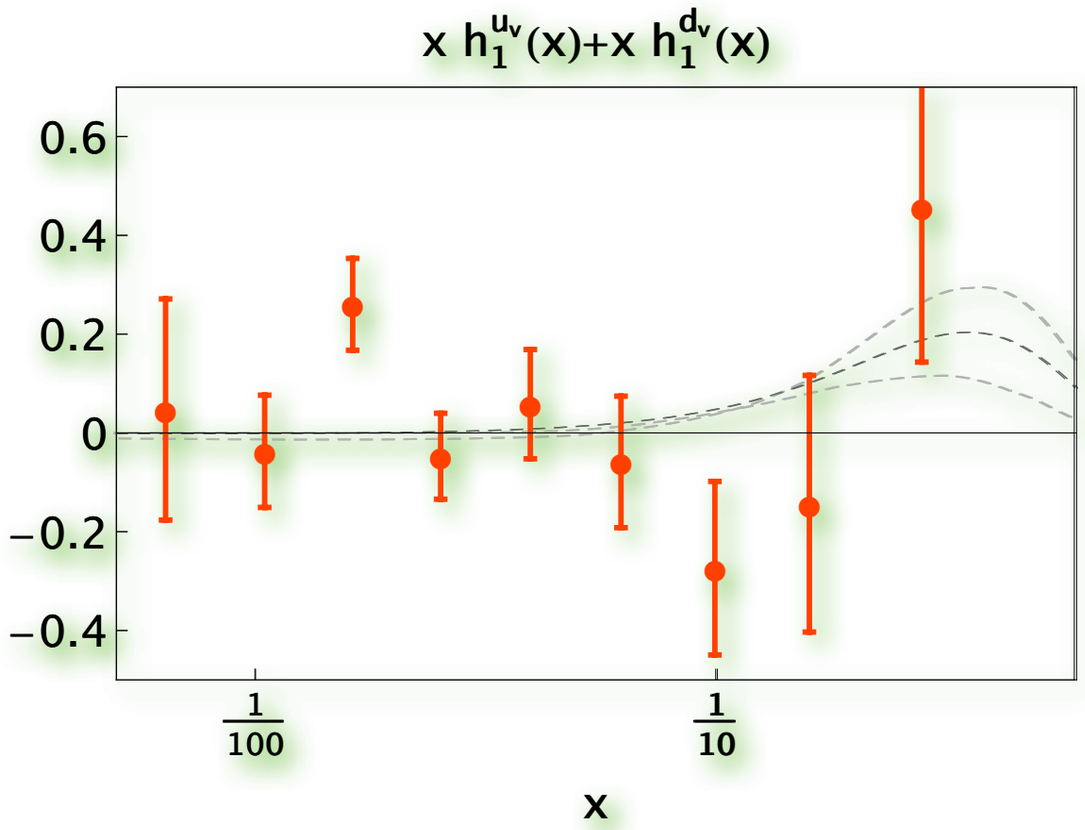


Band:
Torino 2009 transversity

Transversity from Deuteron data

COMPASS 2002-2004

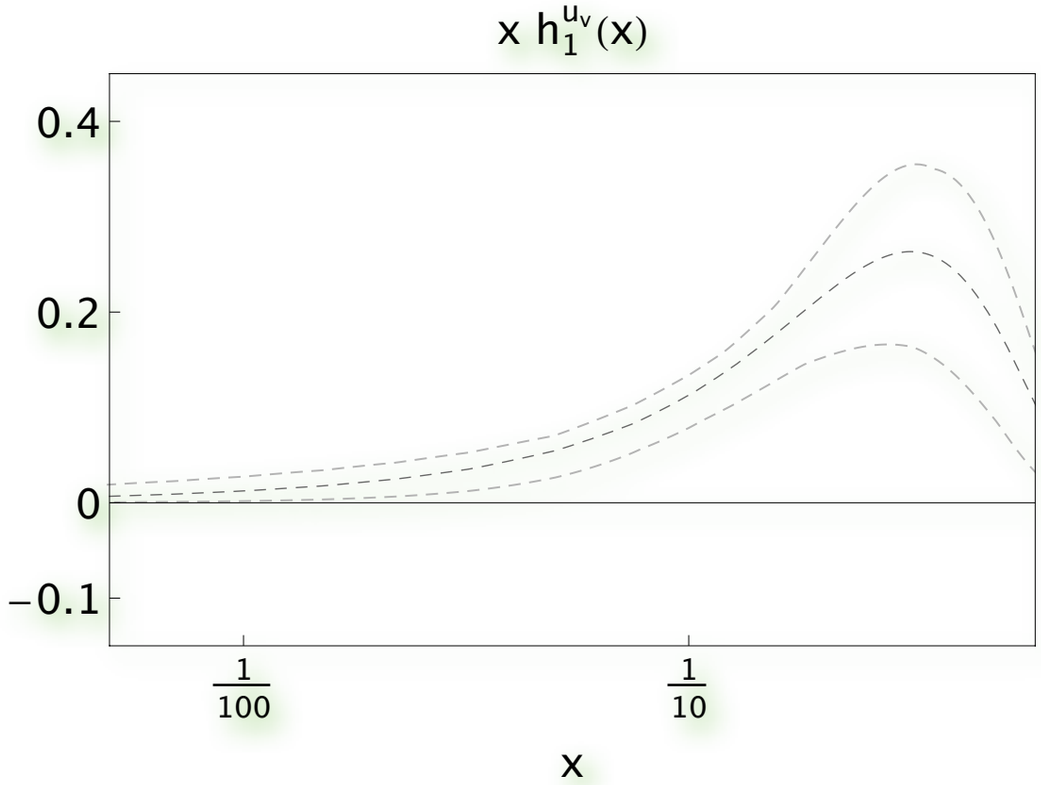
5% theo. err.



Band:
Torino 2009 transversity

PRELIMINARY

Transversity : flavor decomposition

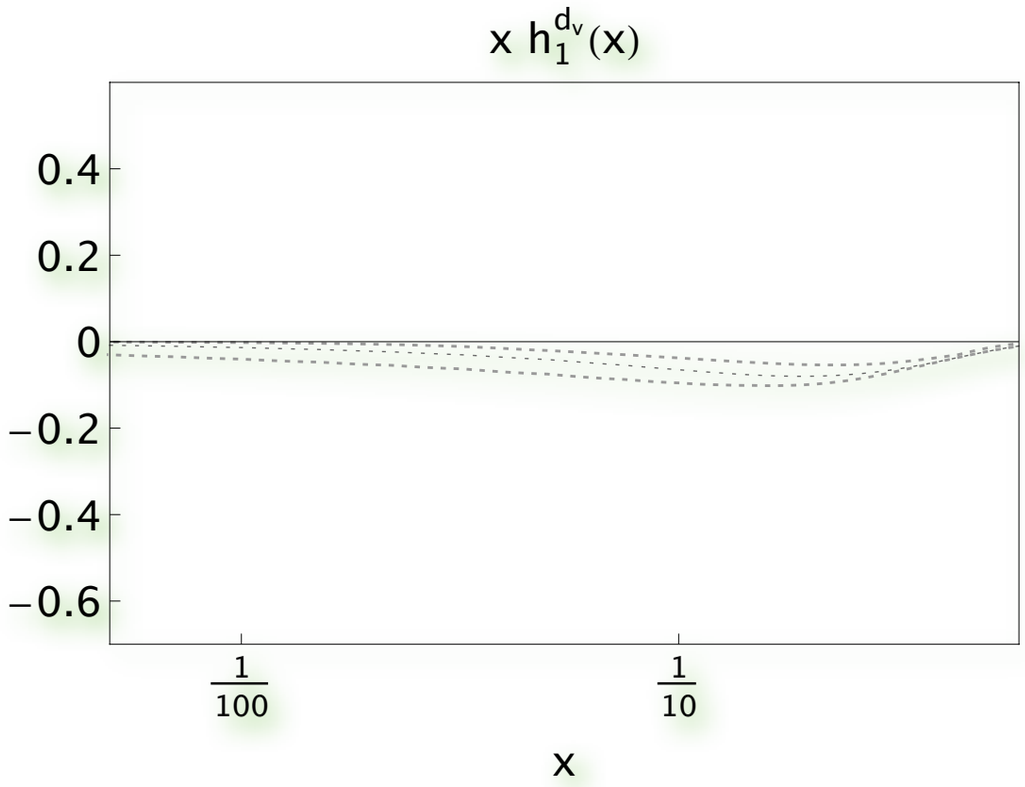


COMPASS

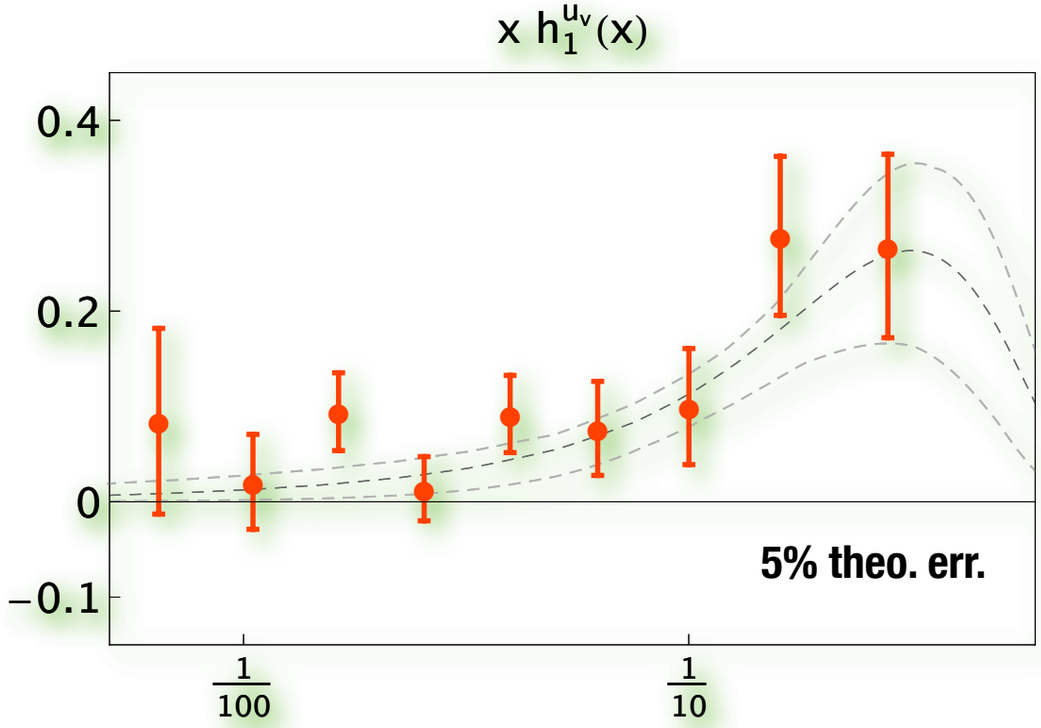
Deuteron 2002-2004

Proton 2007

Band: Torino 2009 transversity



Transversity : flavor decomposition



COMPASS

Deuteron 2002-2004

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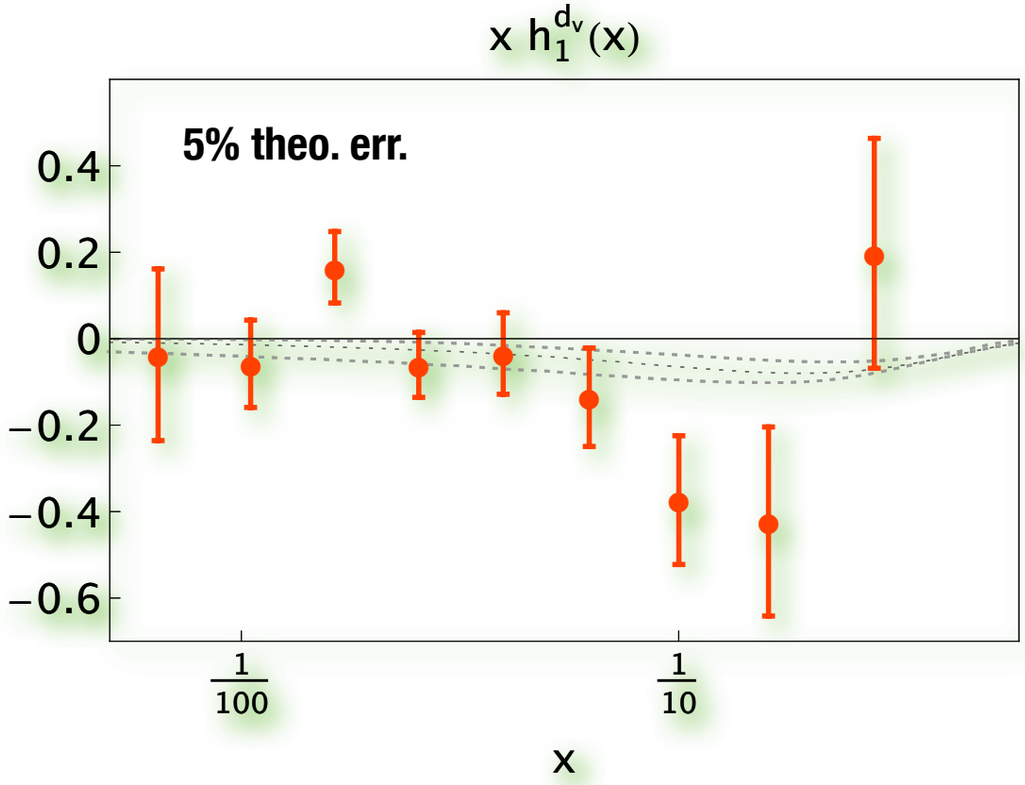
Band: Torino 2009 transversity



PRELIMINARY

Conclusion & Outlook

Extraction of transversity from collinear framework

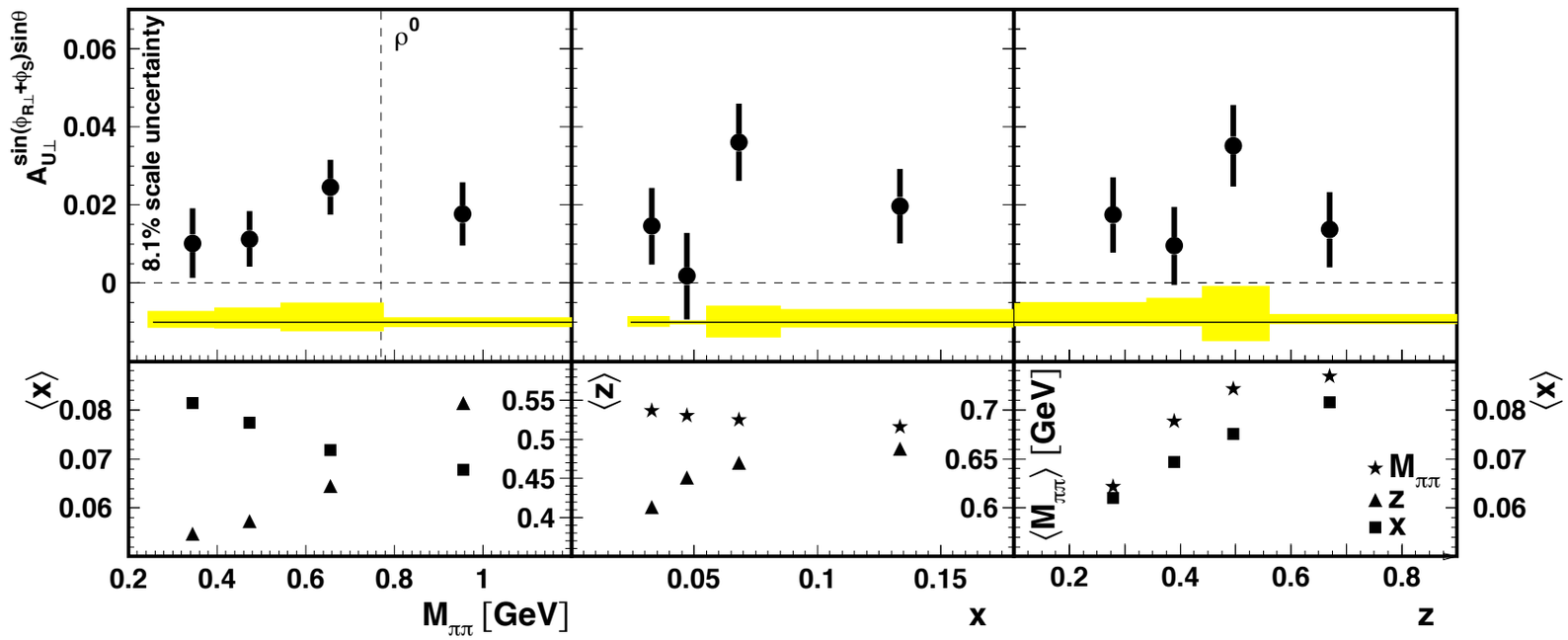
- **Dihadron Fragmentation Functions**
  - **Fits** in (z, M_h, Q^2) with more accurate Q^2 evolution **[Bacchetta, Bianconi, Courtoy, Radici]**
  - Data for Unpolarized DiFF?
- **Transversity via DiFF**
  - Flavor decomposition **Preliminary**

    ➡ access to h_1^u & h_1^d
  - Fits for h_1^u & h_1^d **work in progress** **[Bacchetta, Courtoy, Radici]**
  - Complete analysis from DiFF fits **work in progress** **[Bacchetta, Courtoy, Radici]**

Back-up slides

$A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$ @ HERMES

[JHEP 06, 017 (2008)]



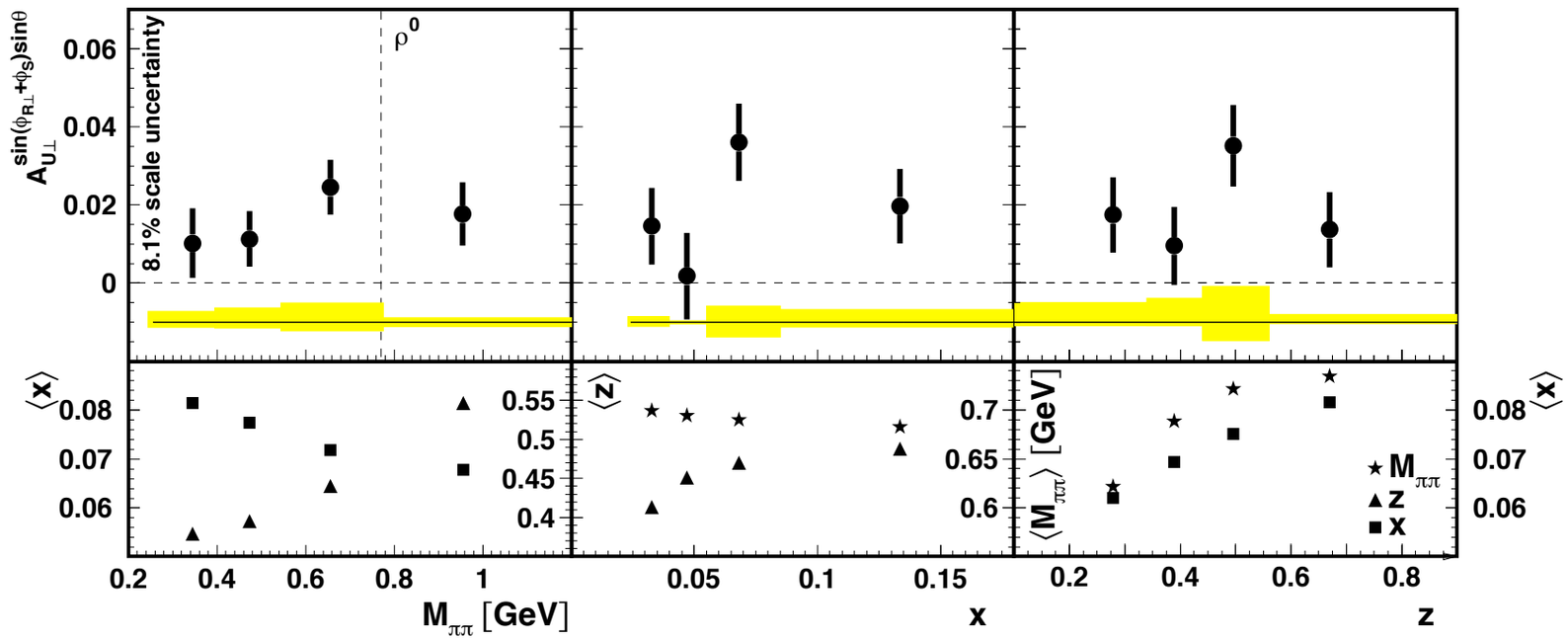
- integrated over 0.5<Mh<1GeV
- integrated over 0.2<z<1

$$n_q(Q^2) = \int dz\, dM_h^2\, D_1^{q\to\pi^+\pi^-}(z, M_h^2, Q^2)$$

$$A_{\mathrm{DIS}}(x,Q^2) = -C_y \frac{\sum_q e_q^2\, h_1^q(x,Q^2)\, n_q^{\uparrow}(Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2)\, n_q(Q^2)}$$

$A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$ @ HERMES

[JHEP 06, 017 (2008)]



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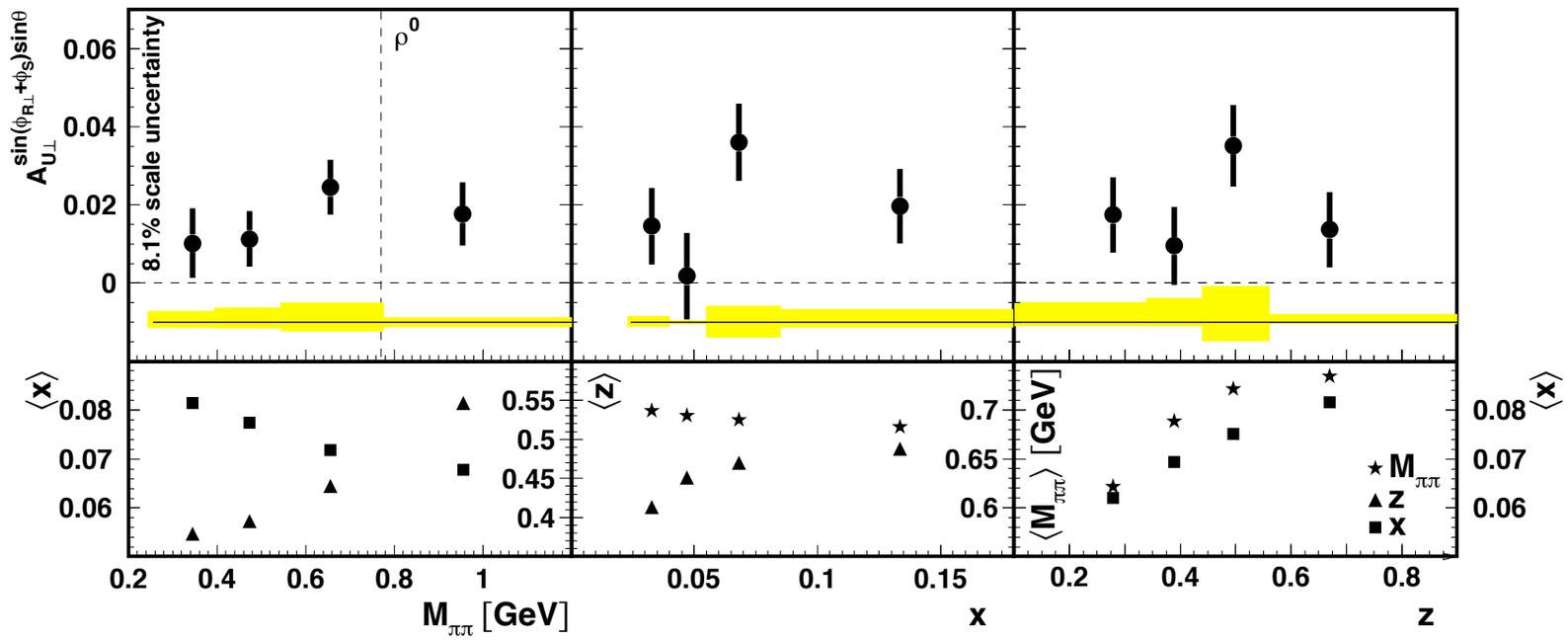

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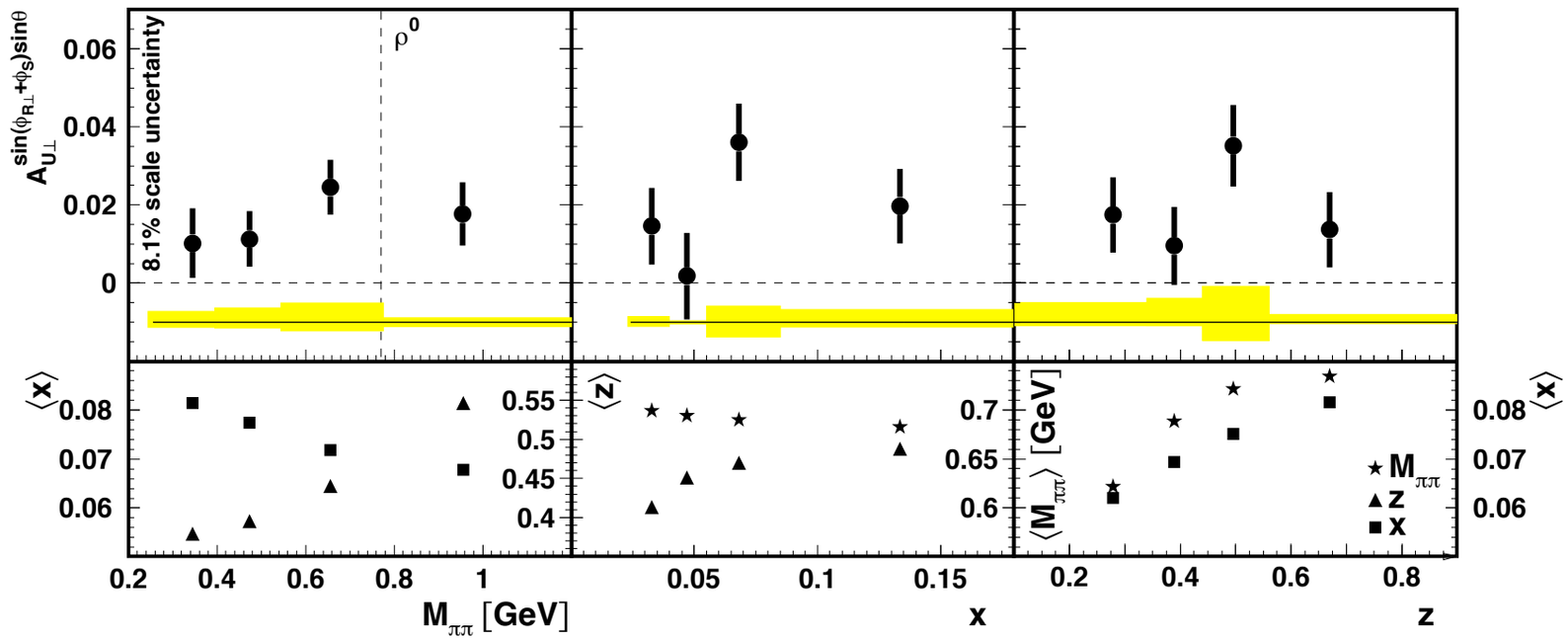

$$A_{\mathrm{DIS}}(x,Q^2) = -C_y \frac{\sum_q e_q^2\, h_1^q(x,Q^2)\, n_q^{\uparrow}(Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2)\, n_q(Q^2)}$$

$$x h_1^{u_v}(x,Q^2) - \tfrac{1}{4}\, x h_1^{d_v}(x,Q^2) = -C_y^{-1}\, A_{\mathrm{DIS}}(x,Q^2)\, \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar{q}}(x,Q^2)$$

$A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$ @ HERMES

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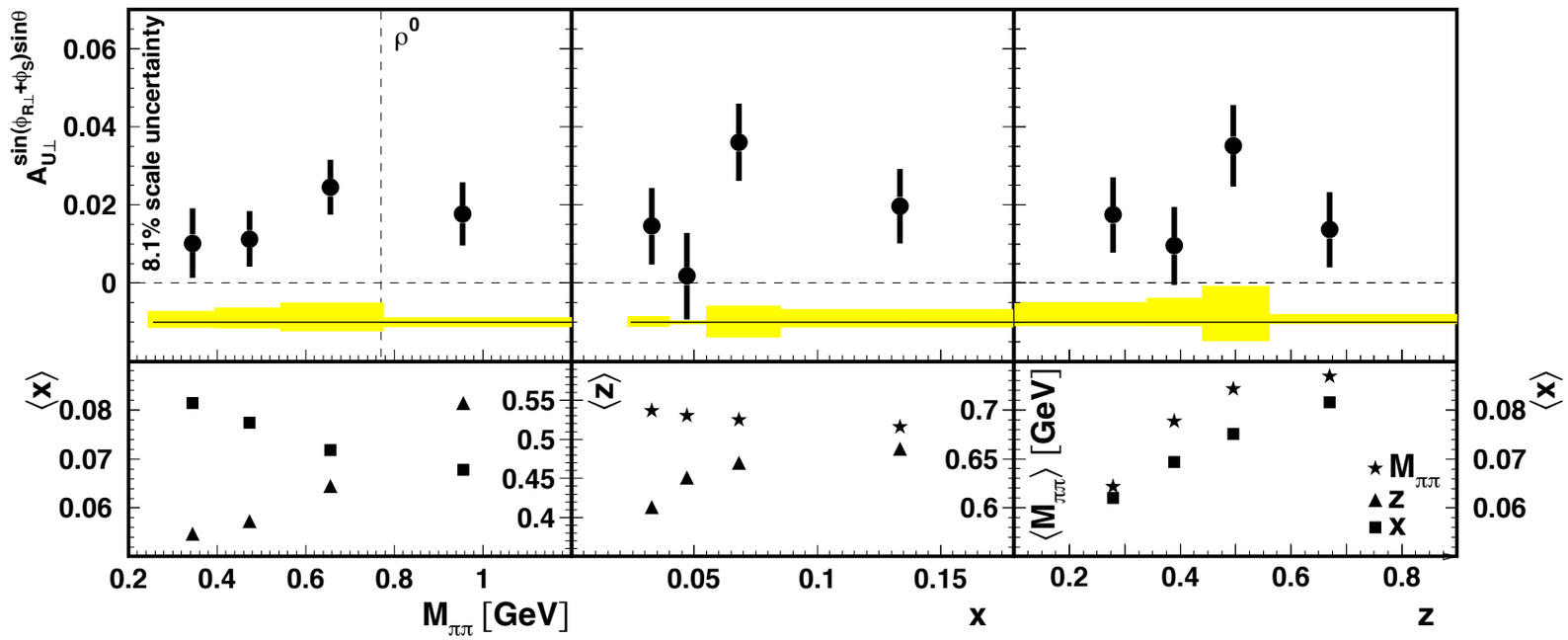

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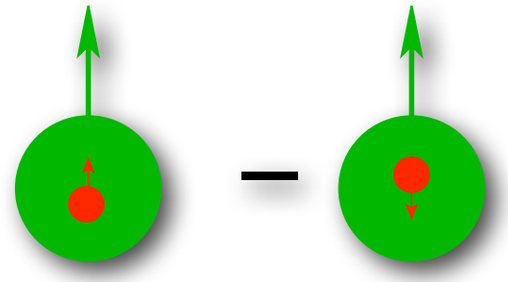
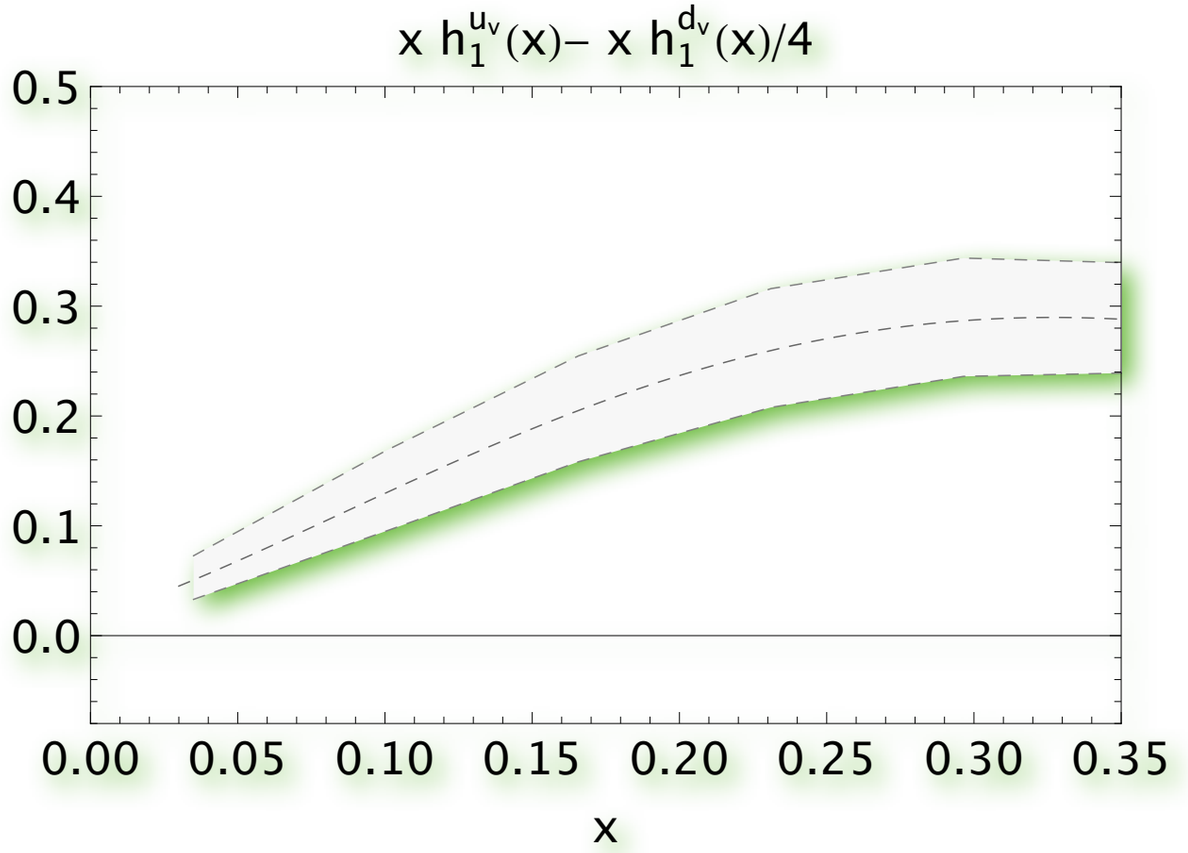
Outline



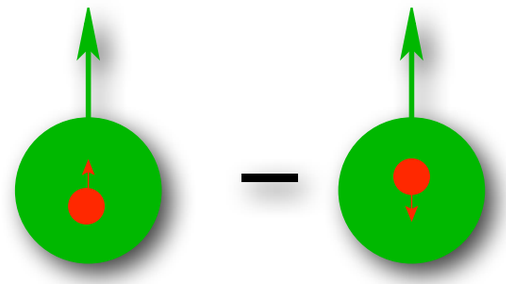
Transversity from pion pair production SIDIS off transversely polarized target



Torino group's transversity

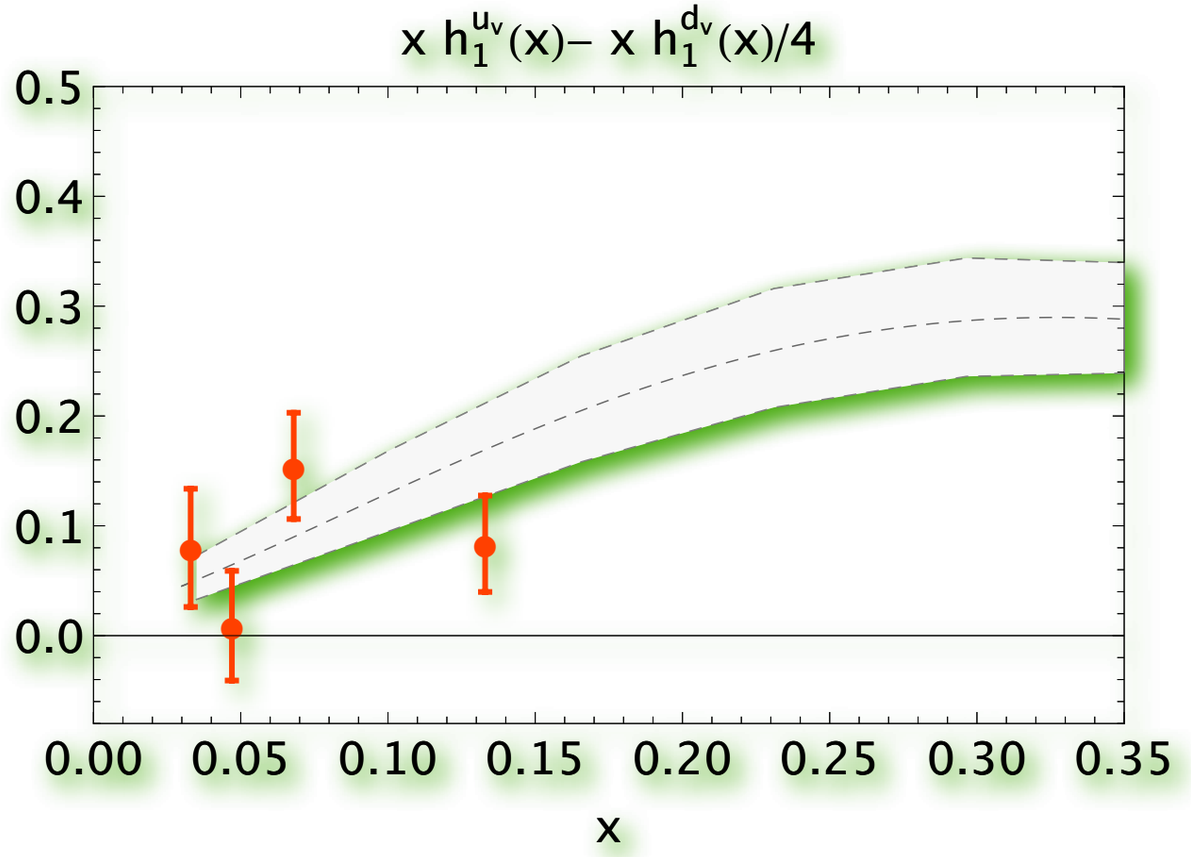
in collaboration with Alessandro Bacchetta and Marco Radici in Pavia

Outline



Transversity from pion pair production SIDIS off transversely polarized target

- **from HERMES data**
- **DiFF analysis**
  - **from BELLE data**
- $f_1(x)$ from MSTW
- **PRL107 &** **arXiv:1202.0323**



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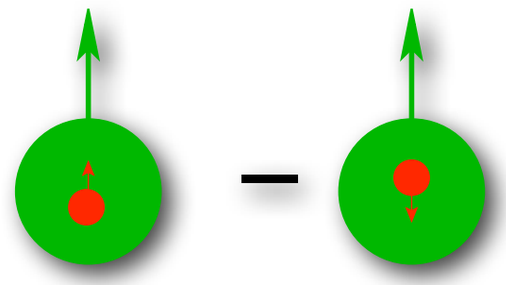

Transversity from pion pair production SIDIS off transversely polarized target

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- **from COMPASS data**
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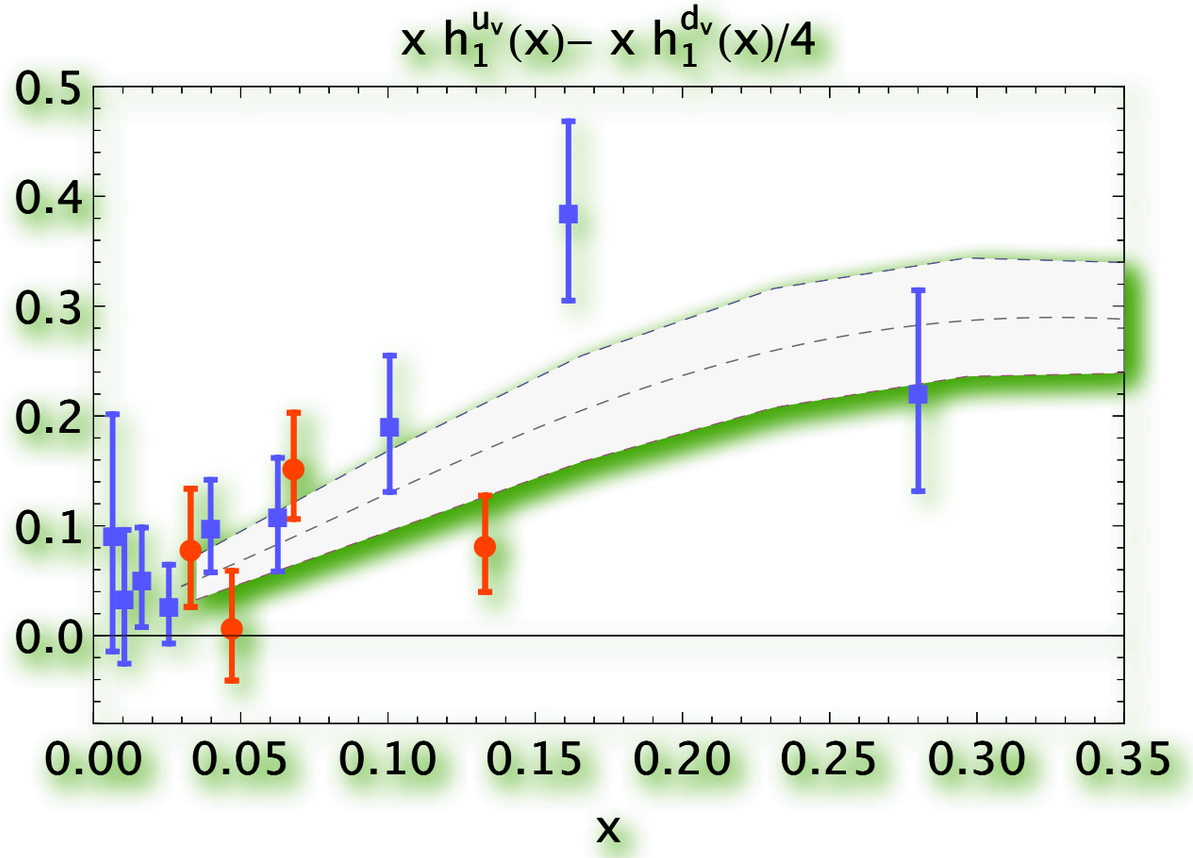
  - **from BELLE data**
- $f_1(x)$ from MSTW
- **new analysis**



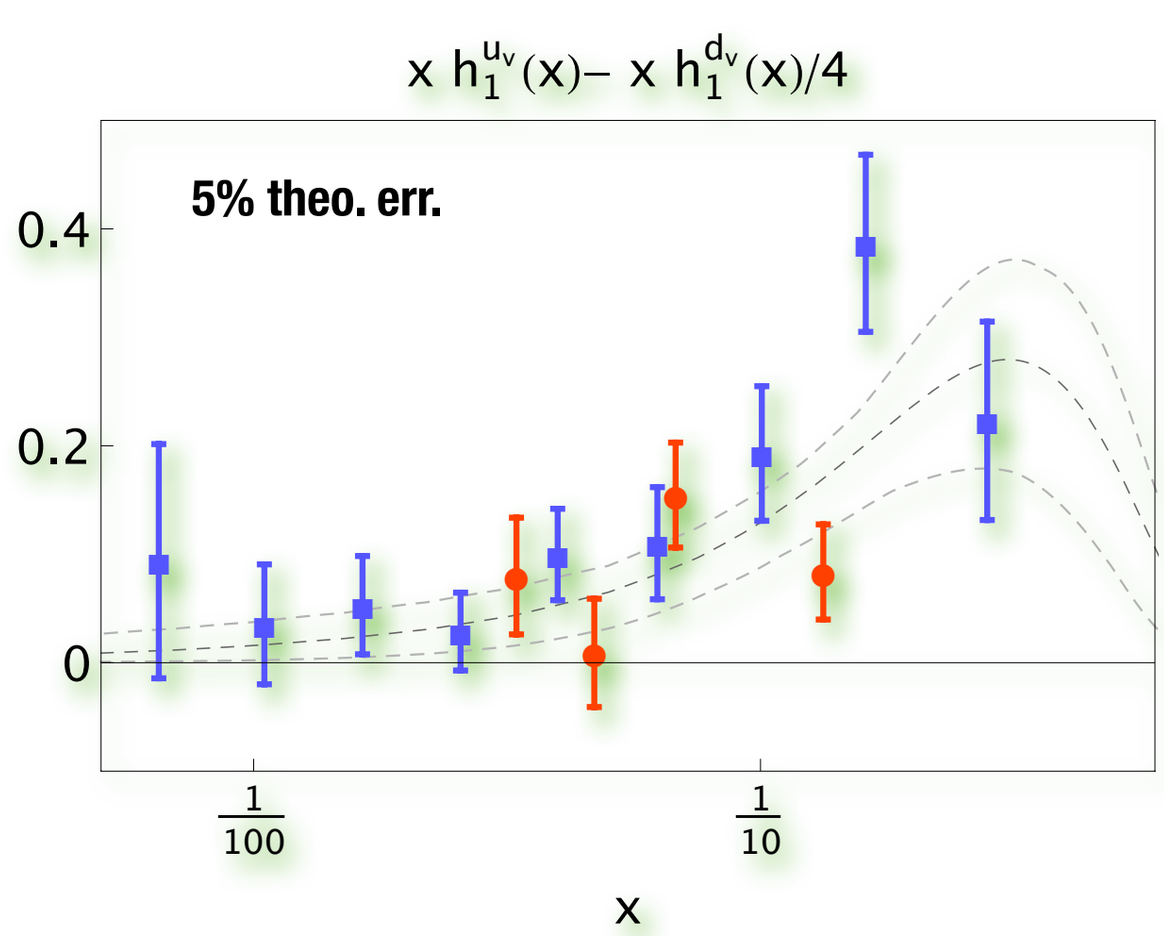
Torino group's transversity

in collaboration with Alessandro Bacchetta and Marco Radici in Pavia

Transversity from e p$^{\uparrow}$ → e' ($\pi^+\pi^-$) X @ COMPASS 2007

$$x h_1^{u_v}(x,Q^2) - \tfrac{1}{4}\, x h_1^{d_v}(x,Q^2) = -C_y^{-1}\, A_{\rm DIS}(x,Q^2) \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar{q}}(x,Q^2)$$

COMPASS range: -0.221^{-1} (± 5% theo. err.) from BELLE



Band: Anselmino *et al.* 2009

PRELIMINARY