RIKEN

Fragmentation 2012
RIKEN, Nov. 09-11 2012

di-hadron based transversity extraction

or

the importance of di-hadron fragmentation (DiFF or IFF)

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In collaboration with
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A. Bianconi (Univ. Brescia)
A. Courtoy (Univ. Liege)

Outline

- What are DiFF and Where to extract them

- Why do we need them ?
the quest for transversity: Collins vs. IFF

- Who did what ? (= the present situation)

- Which are the latest "press news" ?

- Perspectives

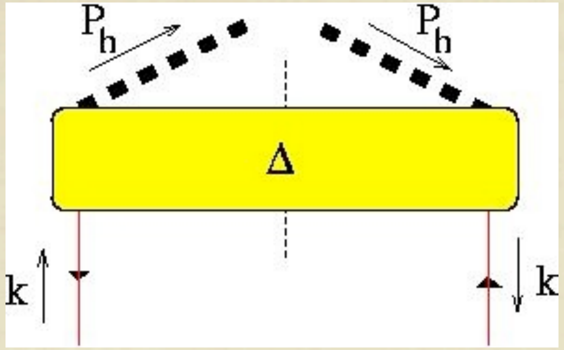
the $\boxed{\text{What}}$ and the $\boxed{\text{Where}}$

General framework

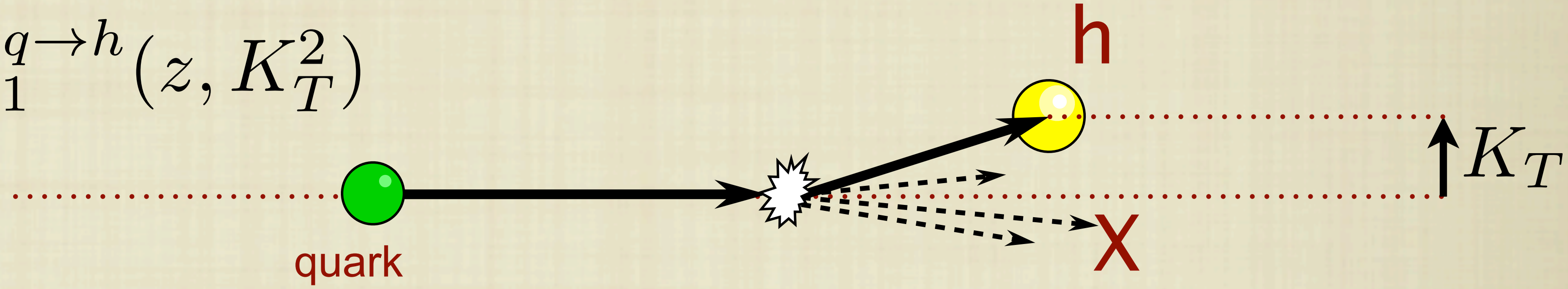
Single-hadron fragmentation

- K_T-dependent fragmentation functions

from q-q correlator Δ
project out :

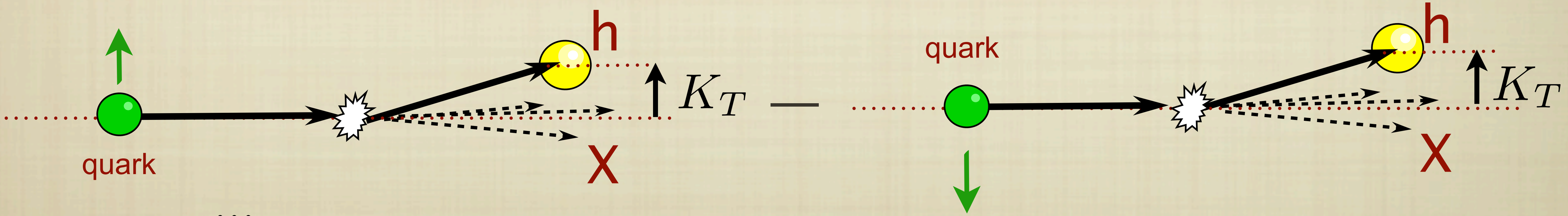


$$\mathrm{Tr}\left[\Delta\,\gamma^-\right] \quad \longrightarrow D_1^{q\to h}(z, K_T^2)$$



...

$$\mathrm{Tr}\left[\Delta\, i\sigma^{i-}\gamma_5\right] \quad \longrightarrow H_1^{\perp\, q\to h}(z, K_T^2)$$



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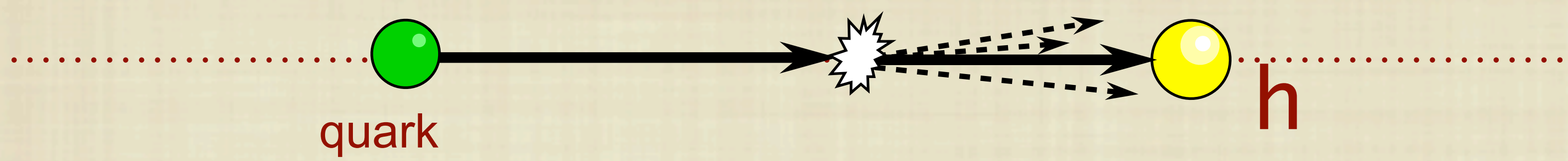
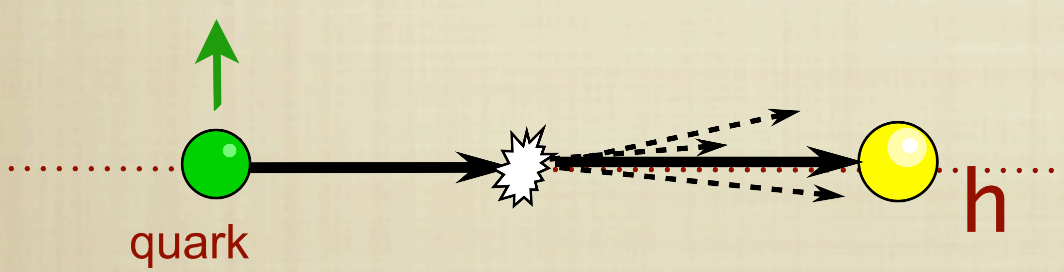
Single-hadron fragmentation

- Integrate over the transverse momentum



- Standard fragmentation functions $D_1^{q\to h}(z)$

- No Collins fragmentation function $H_1^{\perp\, q\to h}(z)$



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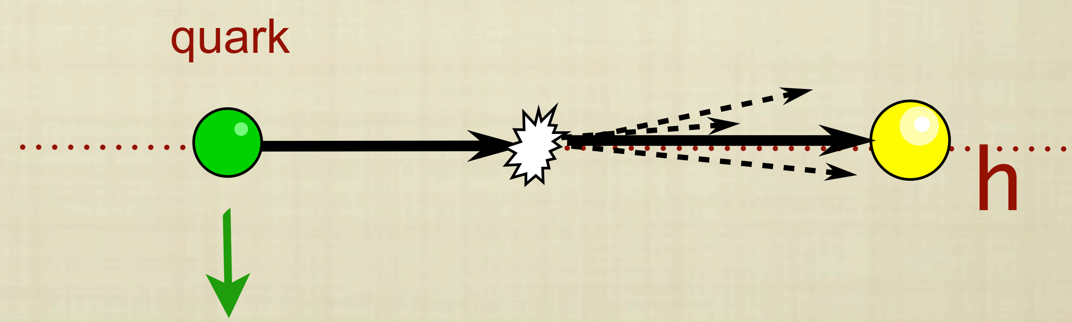

Single-hadron fragmentation

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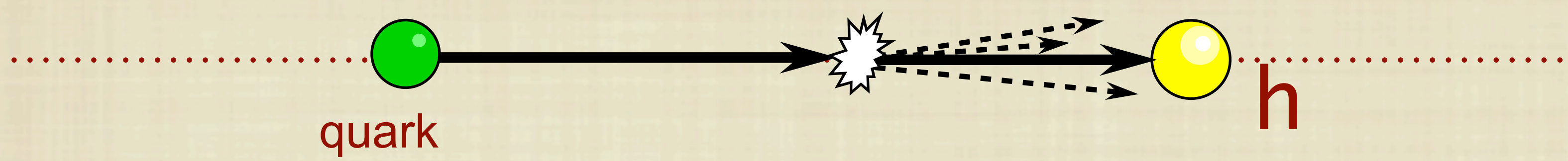
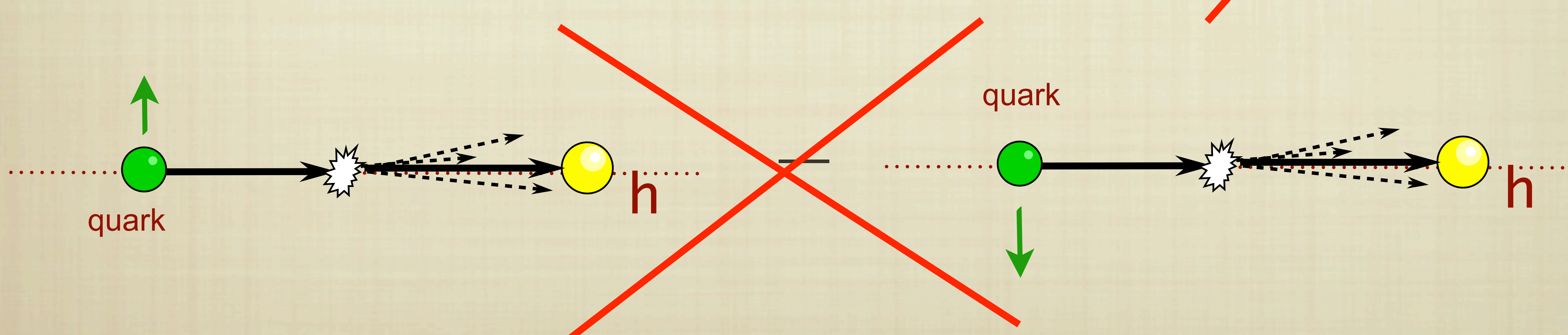


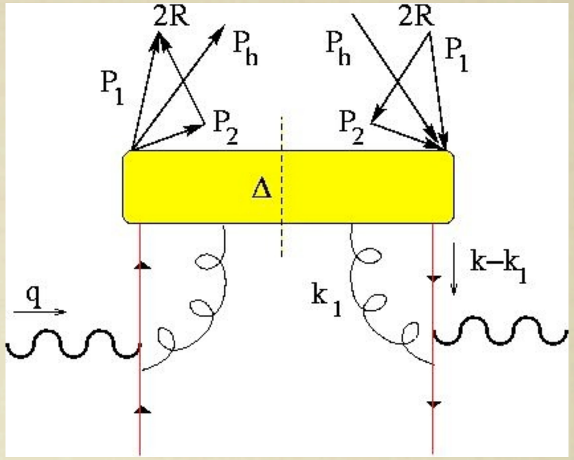
- Standard fragmentation functions $D_1^{q\to h}(z)$

- No Collins fragmentation function $\cancel{H_1^{\perp\, q\to h}(z)}$



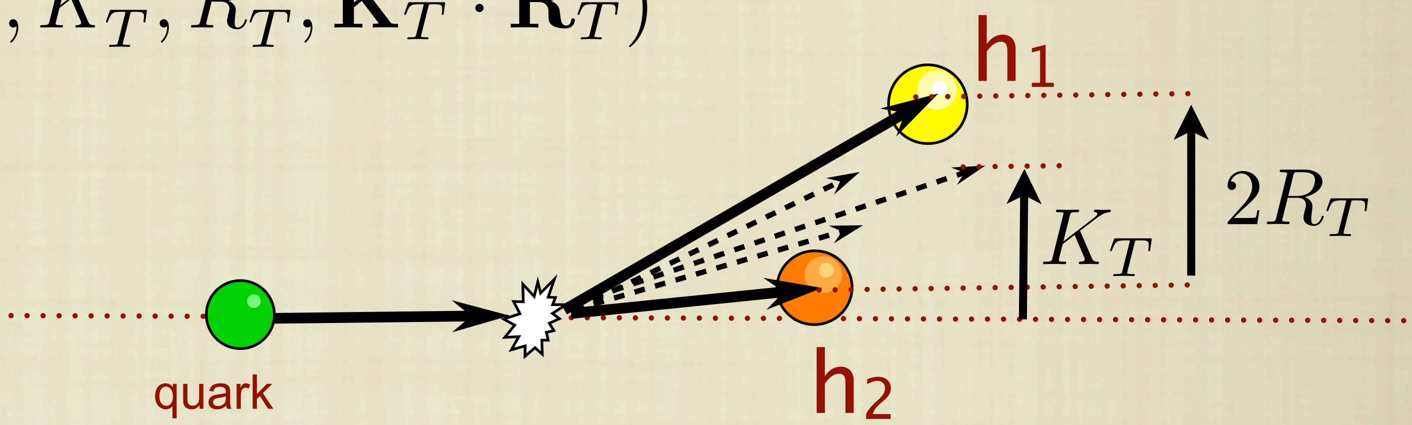
Di-hadron fragmentation

- K_T-dependent DiFF



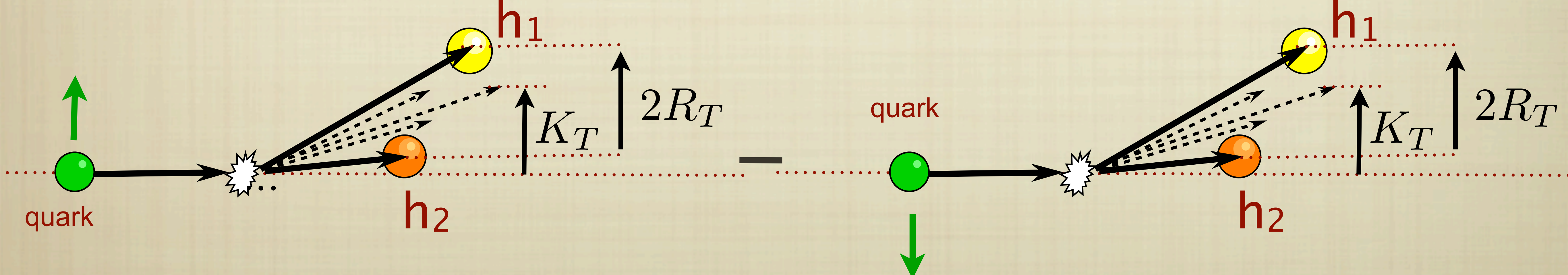
from q-q correlator $\Delta(z_1,z_2,\mathbf{K}_T,\mathbf{R}_T)$
project out :

$$\mathrm{Tr}\left[\Delta\,\gamma^-\right] \quad \longrightarrow \quad D_1^{q\to h_1 h_2}(z_1, z_2, K_T^2, R_T^2, \mathbf{K}_T\cdot\mathbf{R}_T)$$



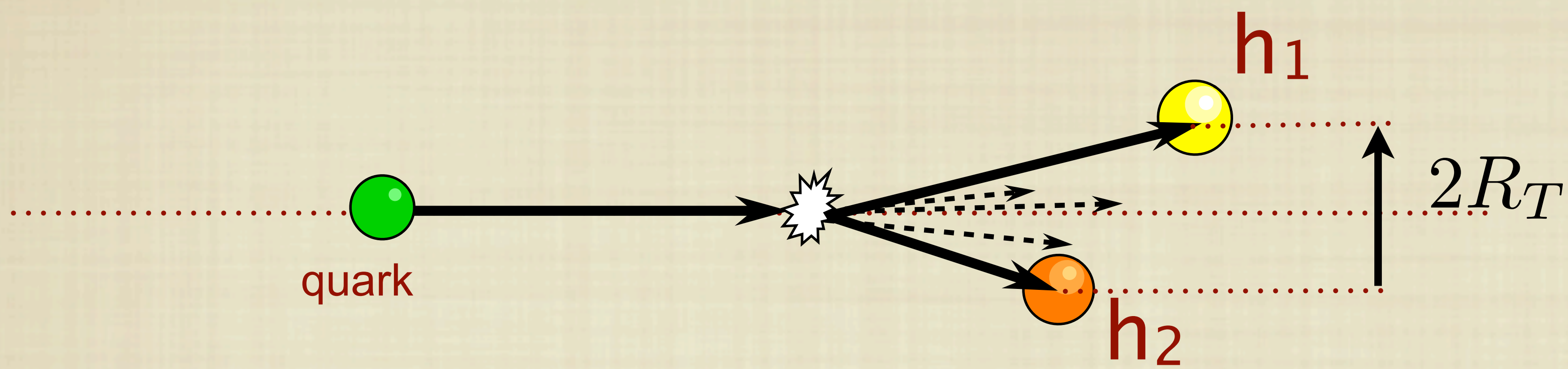
...

$$\mathrm{Tr}\left[\Delta\, i\sigma^{i-}\gamma_5\right] \quad \longrightarrow \quad (\mathbf{S}_T^q\times\mathbf{K}_T)\, H_1^{\perp\, q\to h_1 h_2} \;+\; (\mathbf{S}_T^q\times\mathbf{R}_T)\, H_1^{\sphericalangle\, q\to h_1 h_2}$$



Di-hadron fragmentation

- Integrate over the transverse momentum



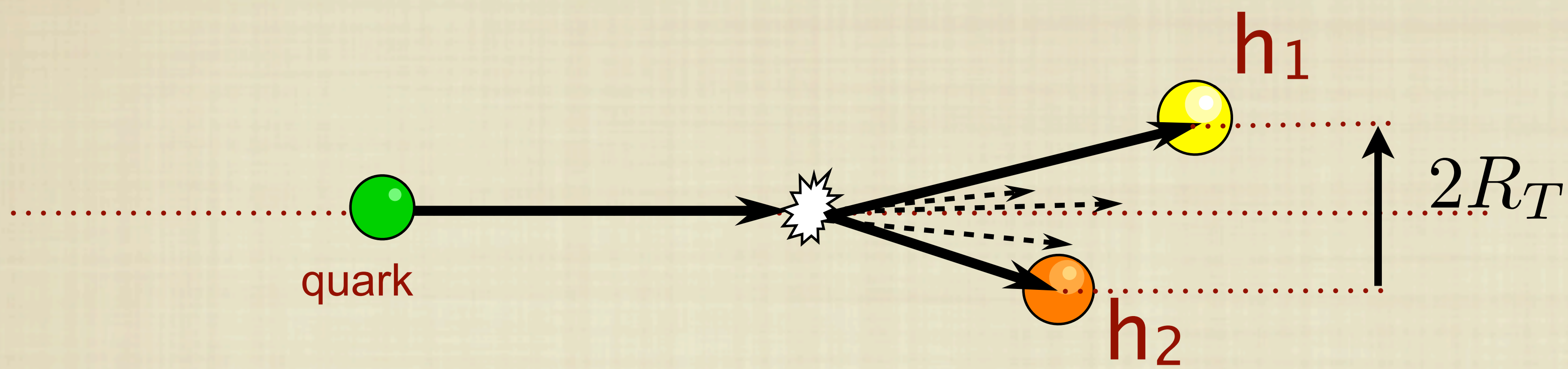
$$|\boldsymbol{R}| = \frac{M_h}{2}\sqrt{1-\frac{4m_\pi^2}{M_h^2}}$$

$$\int d\mathbf{K}_T\, D_1^{q\to h_1 h_2}(z_1, z_2, K_T^2, R_T^2, \mathbf{K}_T\cdot\mathbf{R}_T) \quad\longrightarrow\quad D_1^{q\to h_1 h_2}(z_1, z_2, R_T^2)$$

$$\int d\mathbf{K}_T\,(\mathbf{S}_T^q\times\mathbf{K}_T)\,H_1^{\perp\, q\to h_1 h_2} \;+\; (\mathbf{S}_T^q\times\mathbf{R}_T)\,H_1^{\sphericalangle\, q\to h_1 h_2} \quad\longrightarrow\quad (\mathbf{S}_T^q\times\mathbf{R}_T)\,H_1^{\sphericalangle\, q\to h_1 h_2}(z_1, z_2, R_T^2)$$

Di-hadron fragmentation

- Integrate over the transverse momentum



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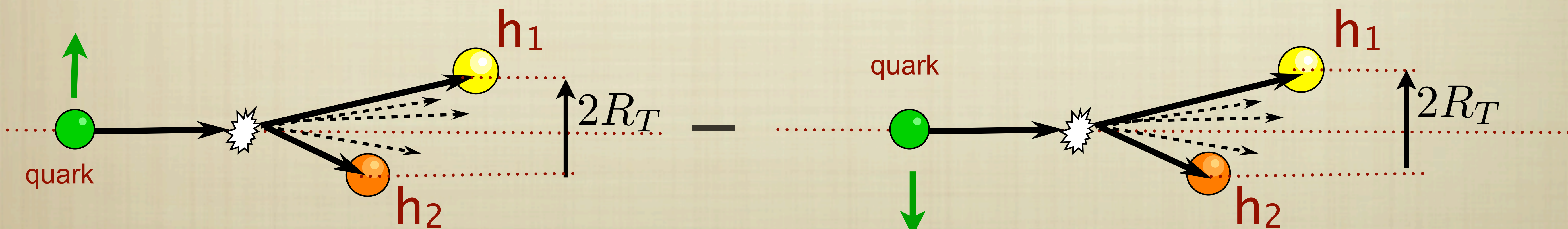
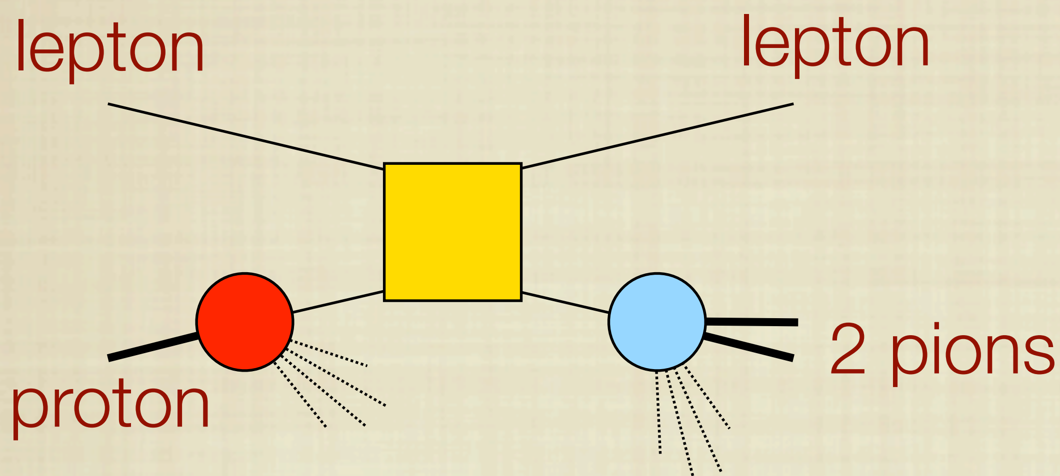
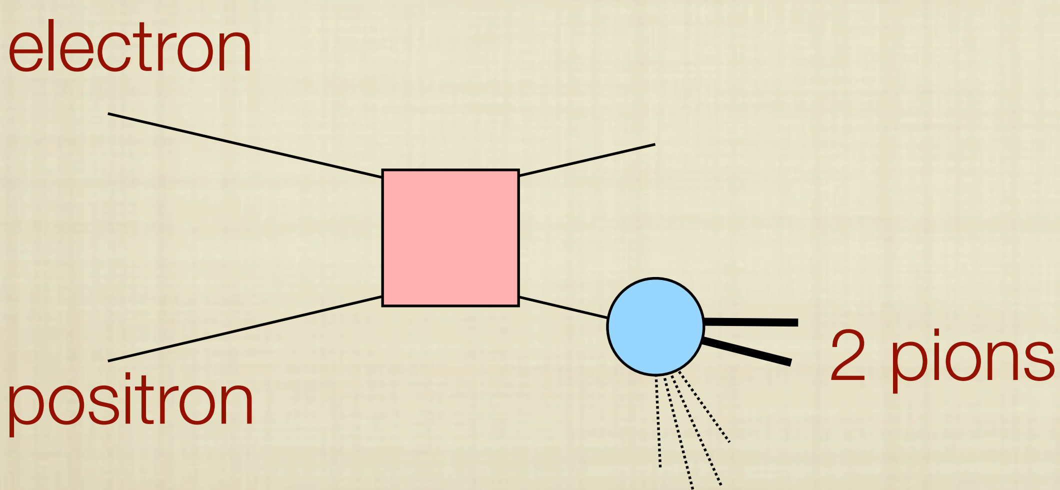
- Chiral-odd $H_1^{\sphericalangle\, q\to h_1 h_2}$ survives ! (memo: h_1,h_2 must be distinguishable!)



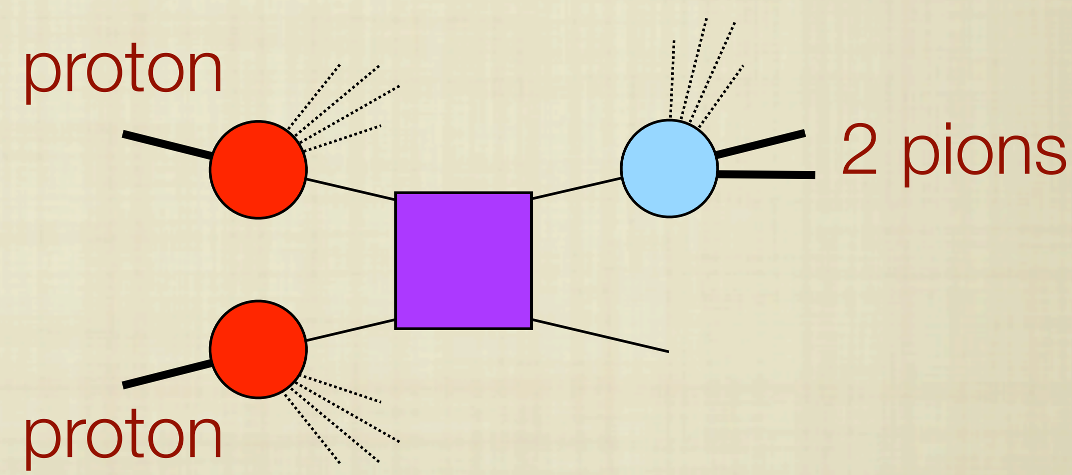
Where do DiFF occur?



SIDIS



e^-e^+ to pions



p-p to pions

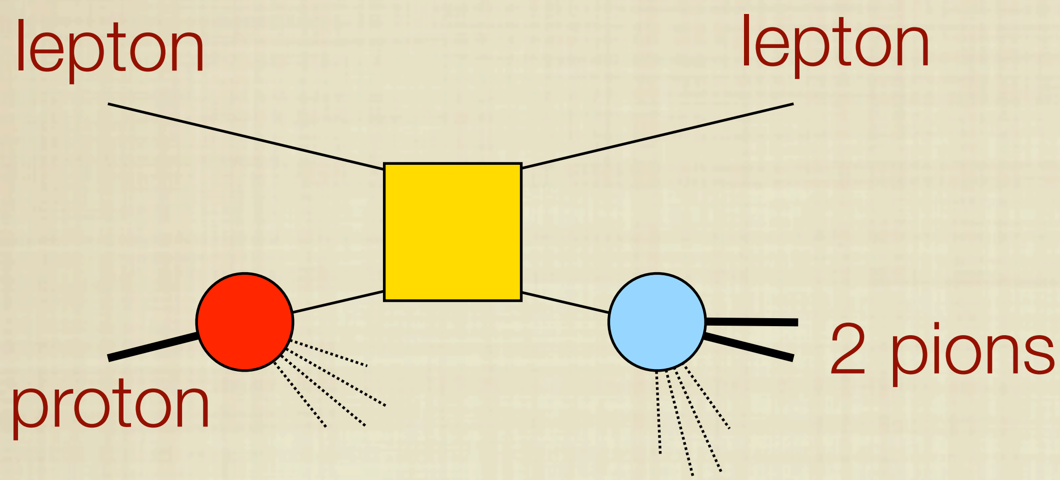
Where do DiFF occur?

Factorization

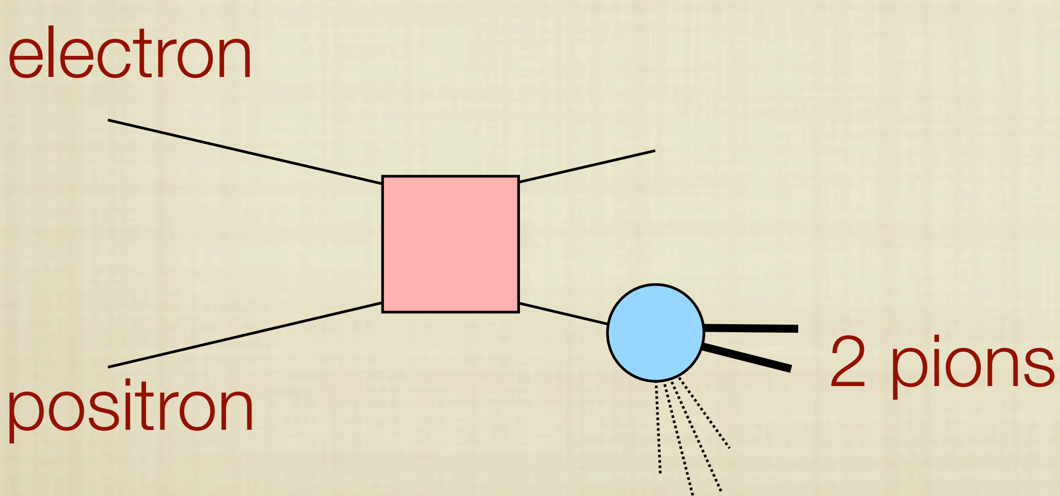
(at NLO & LL, same DGLAP as single-h case

F.Ceccopieri, M.R., A.Bacchetta, P.L. ***B650****(07)*)

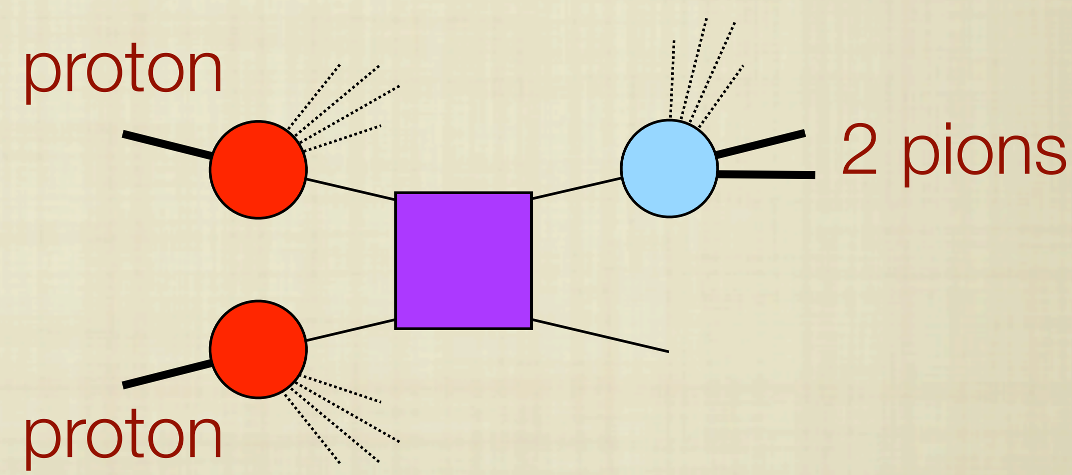
Universality



SIDIS



e^-e^+ to pions



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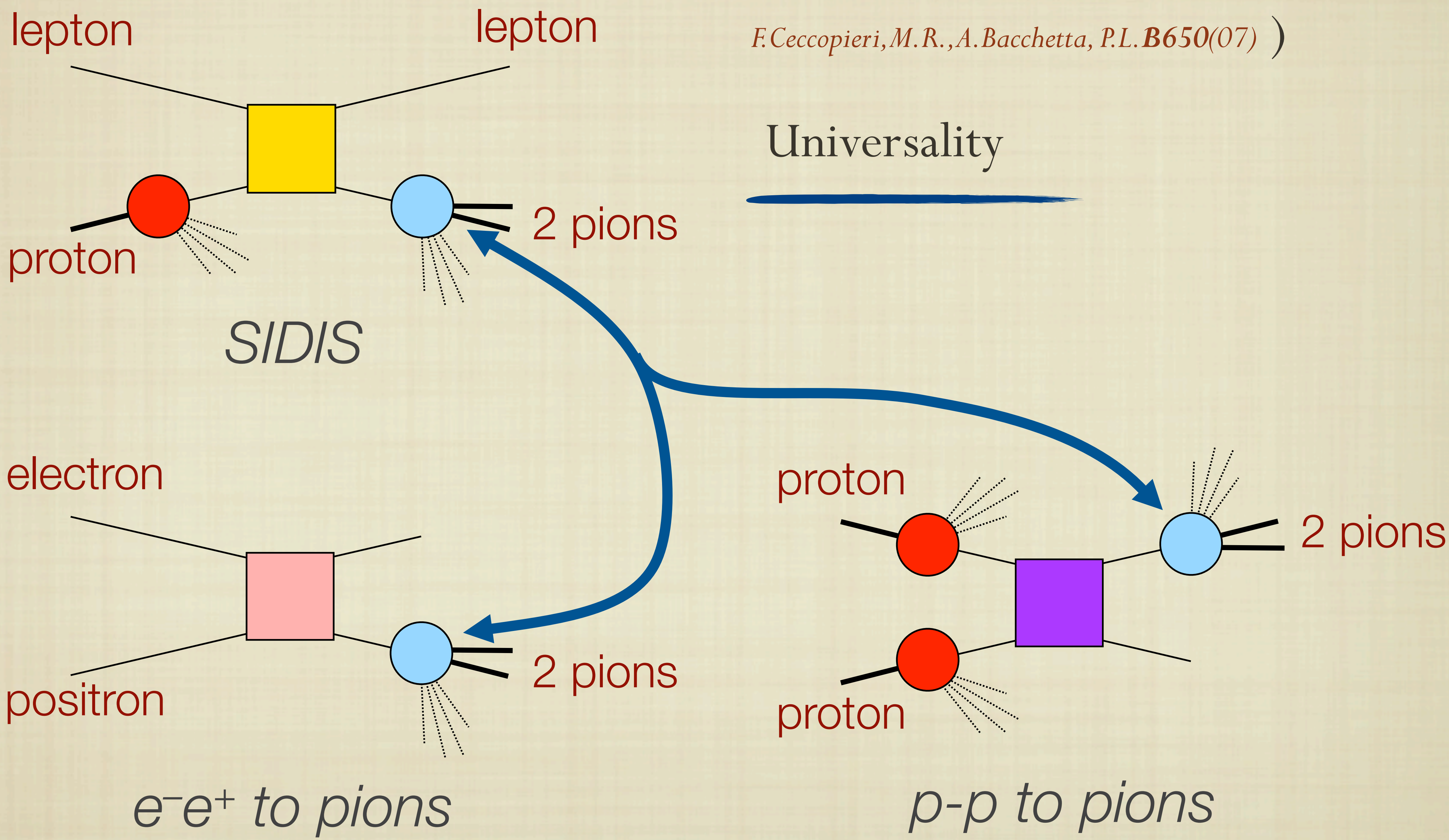
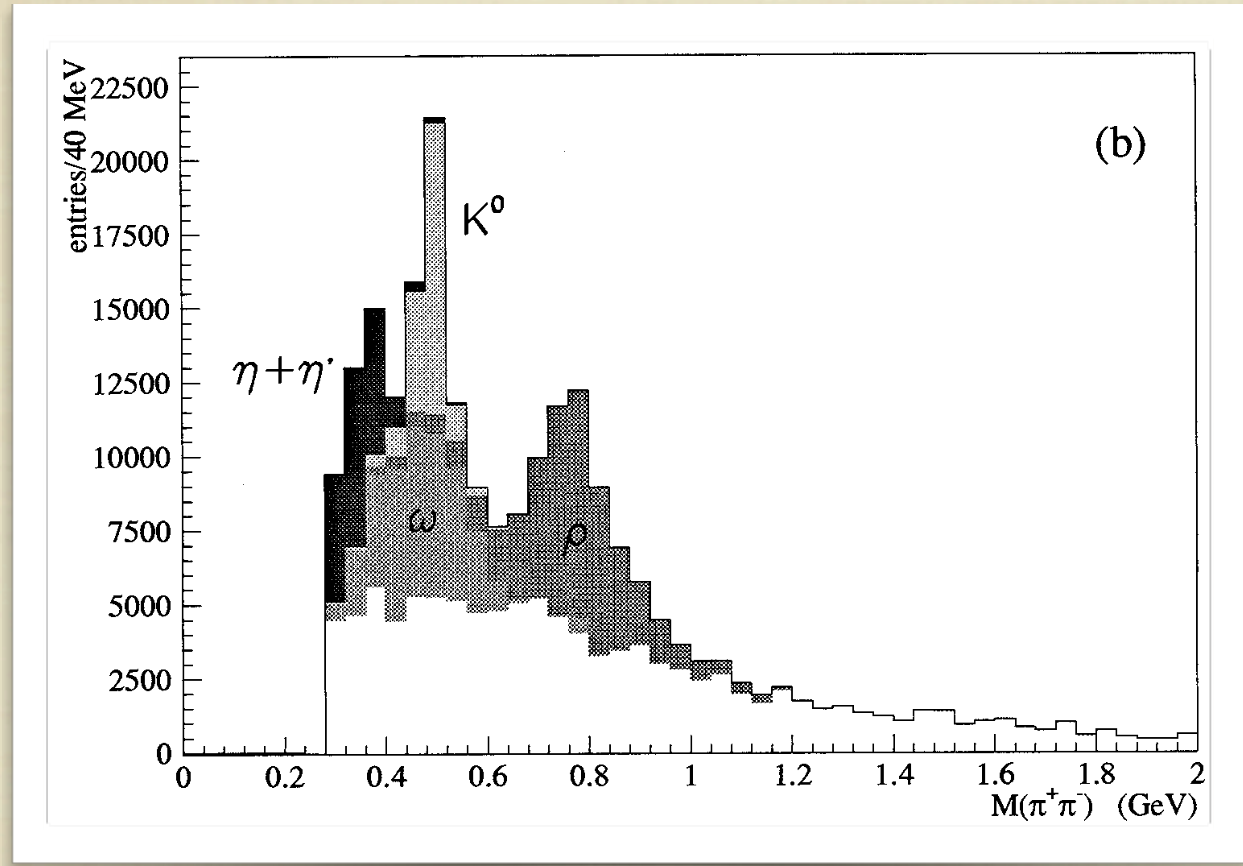


e+e-

- Invariant mass spectrum

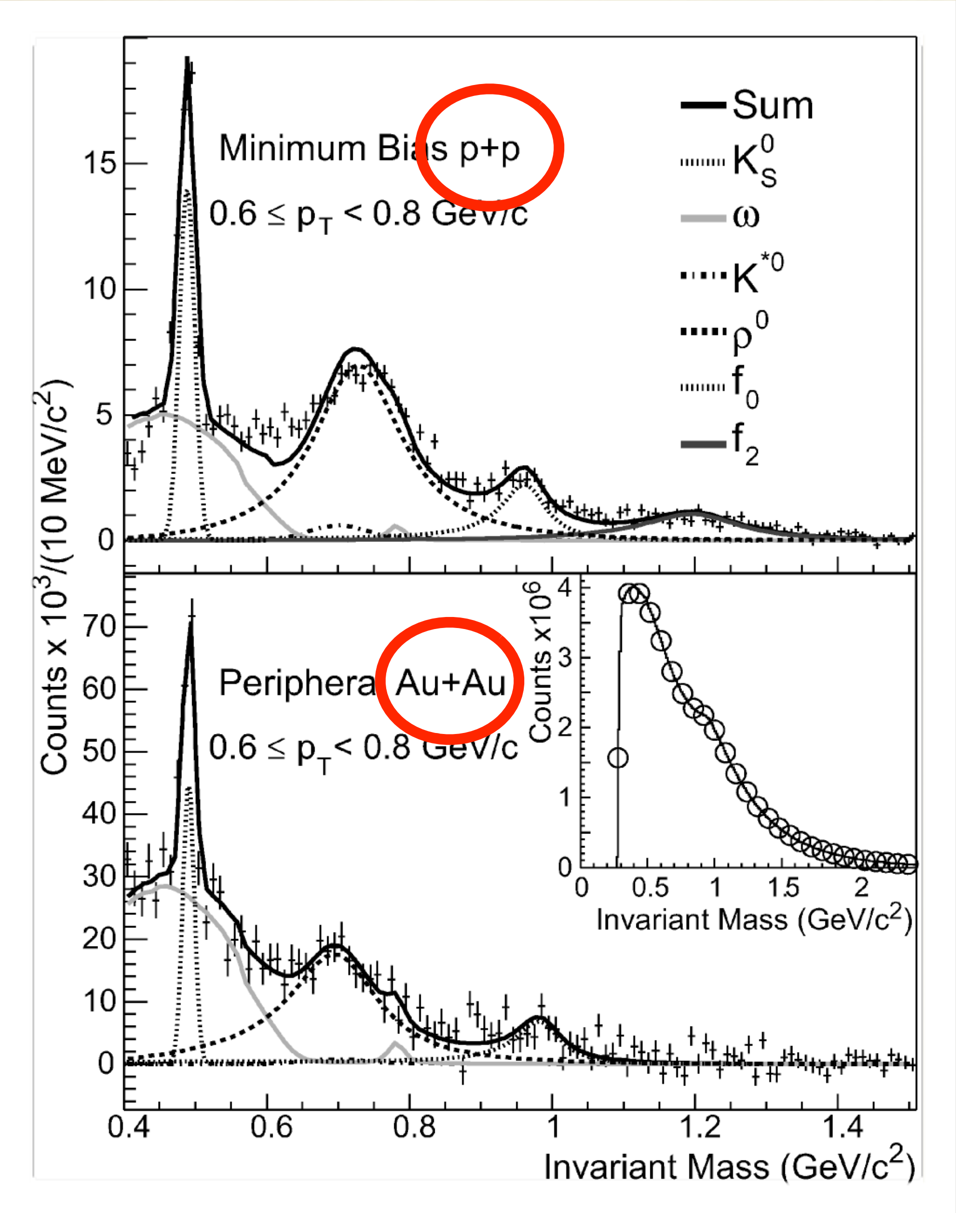


*OPAL, ZP**C56** (92)*

Non trivial !

hadron collisions

- Invariant mass spectrum



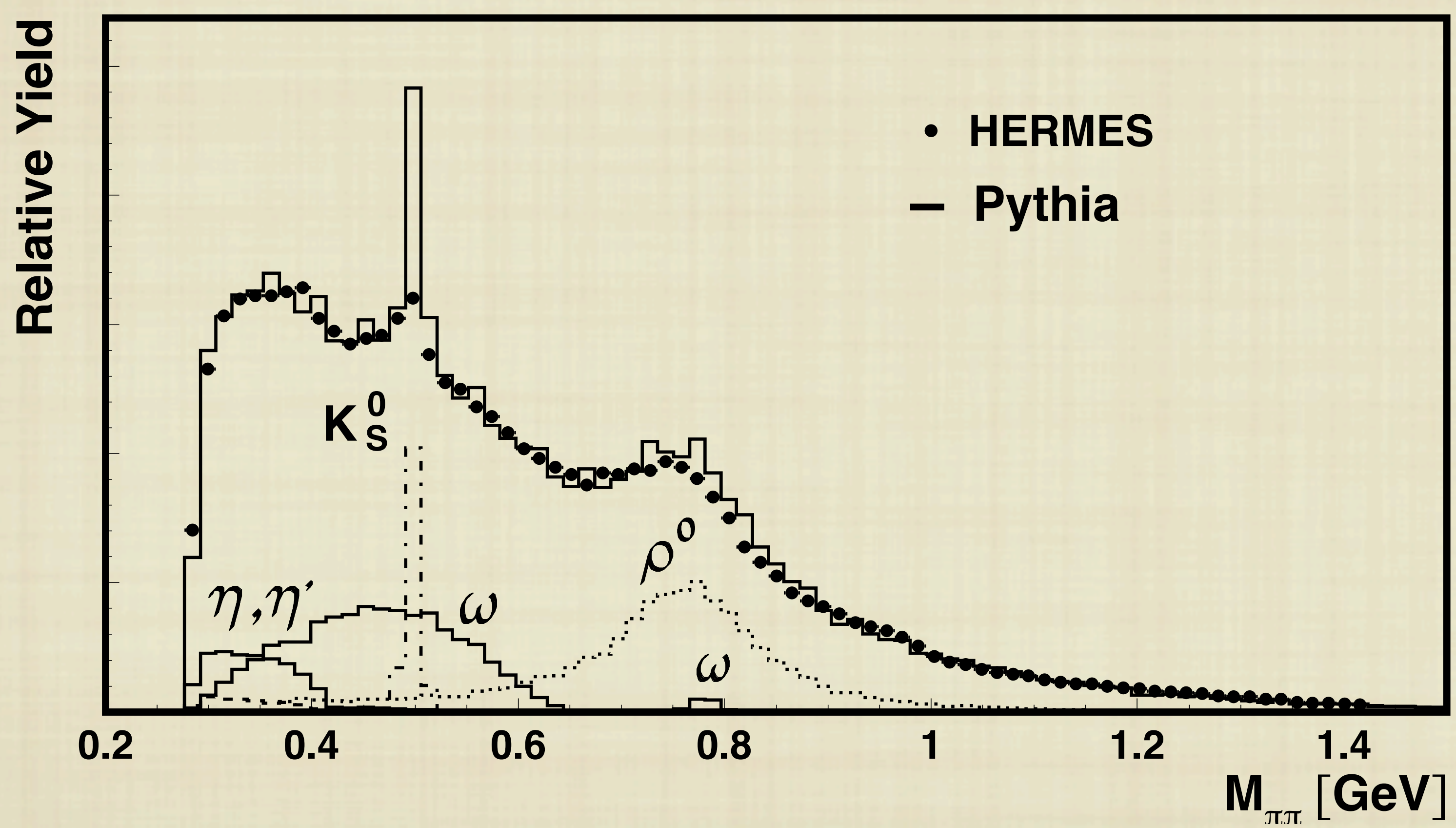
STAR, PRL92 (04)

- In-medium modifications
- Mass shifts (ϱ)
- Jet quenching

SIDIS

- Invariant mass spectrum

HERMES, JHEP06 (08)



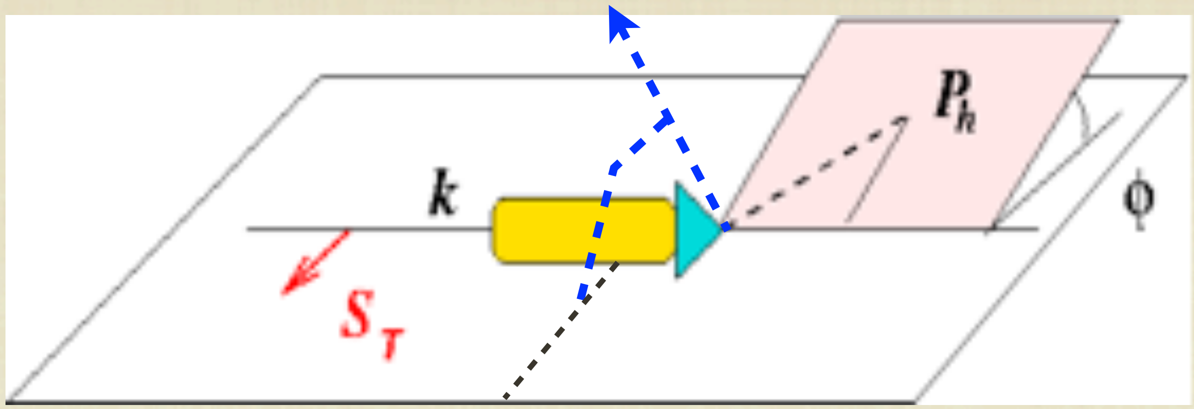
the Why

how to extract transversity:

Collins vs. IFF

The Collins mechanism

*J. Collins, NP**B396** (93)*



Collins angle

$$\mathbf{k} \times \mathbf{P}_h \cdot \mathbf{S}_T \propto \cos\left(\frac{\pi}{2} - \phi\right) = \sin\phi$$

transverse motion of hadron

=

spin analyzer of fragmenting quark

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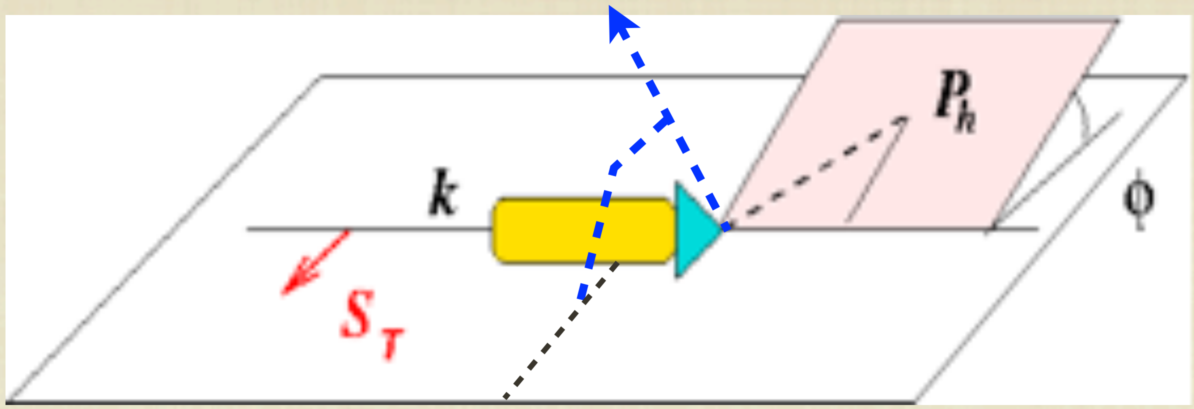

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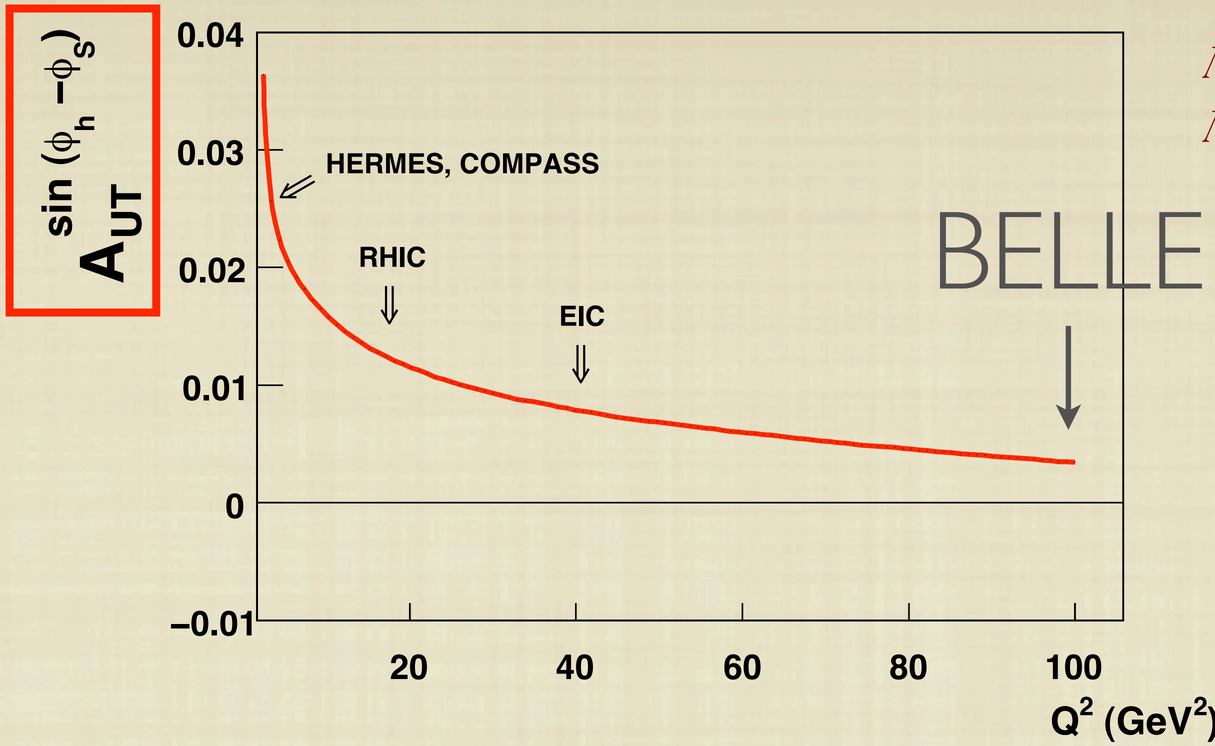
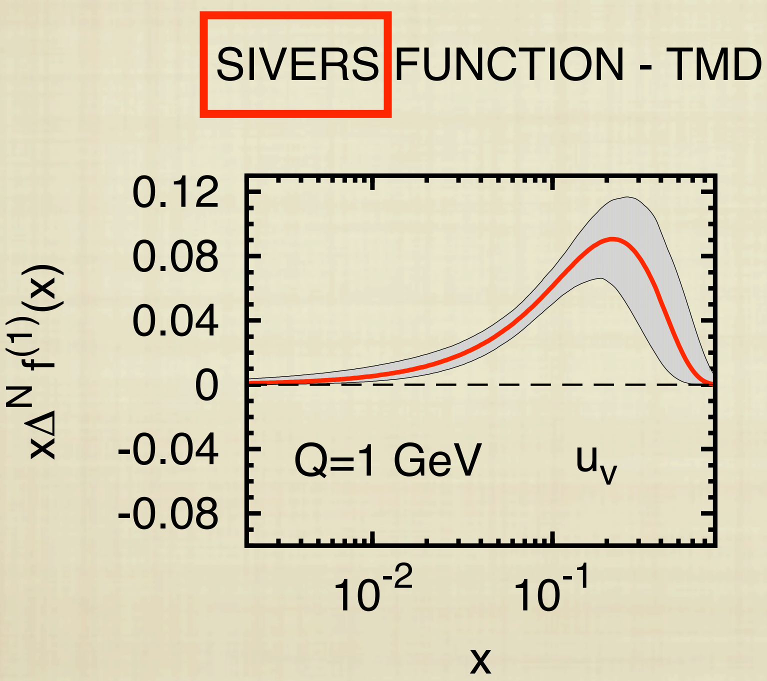
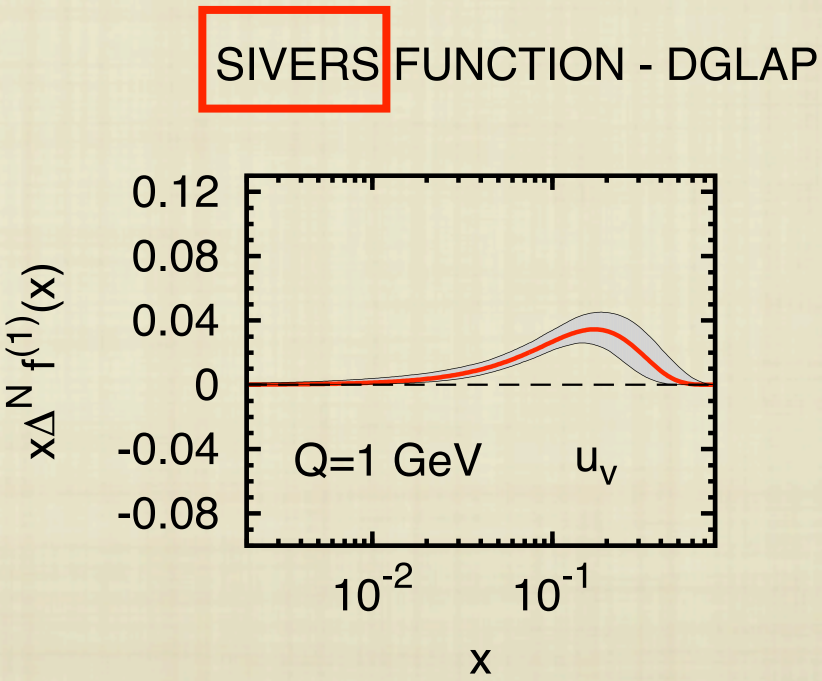
Effects of TMD evolution



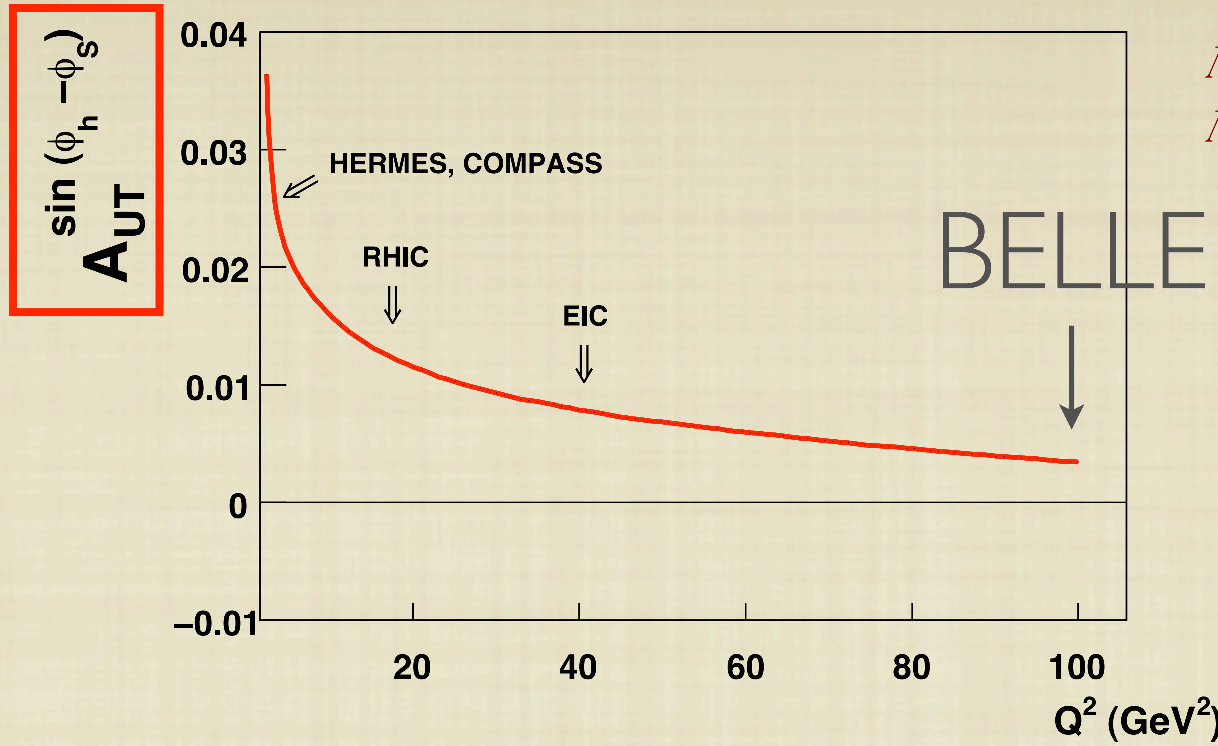
M. Aybat, T. Rogers, PRD 85 (12)
*M. Aybat, A. Prokudin, T. Rogers, PRL **108** (12)*

*M. Anselmino, E. Boglione, S. Melis, PRD **86** (12)*





Effects of TMD evolution



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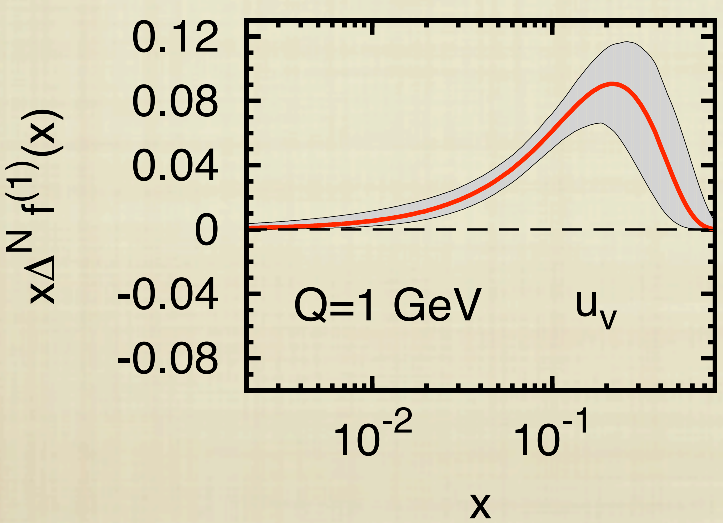
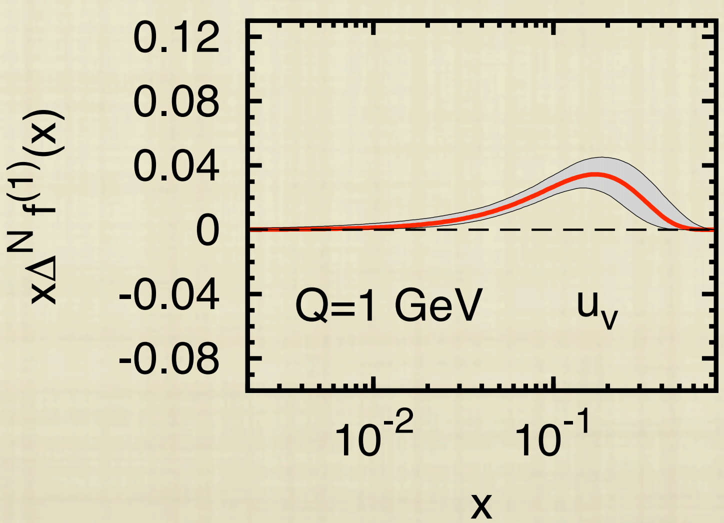
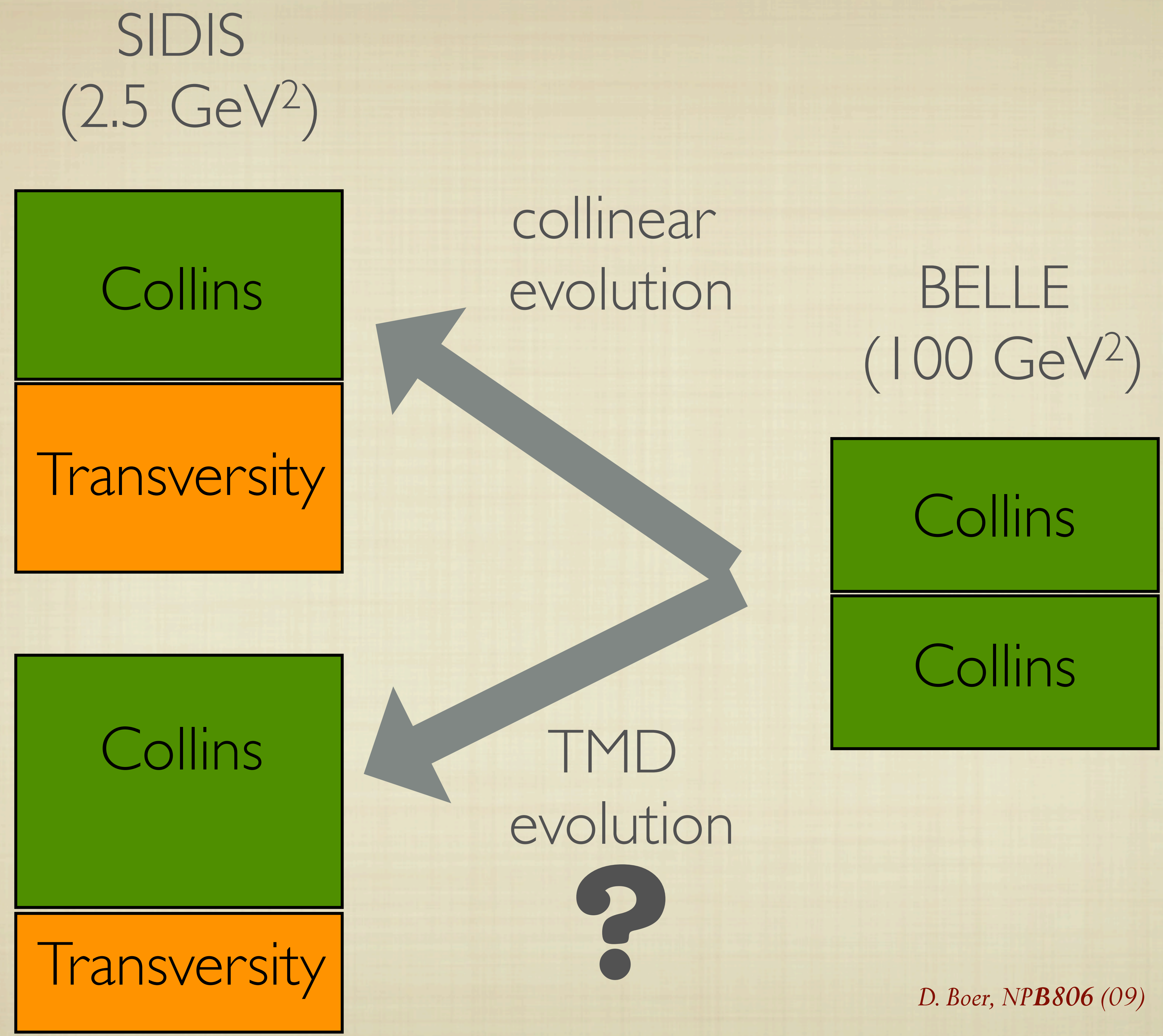
SIVERS FUNCTION - TMD



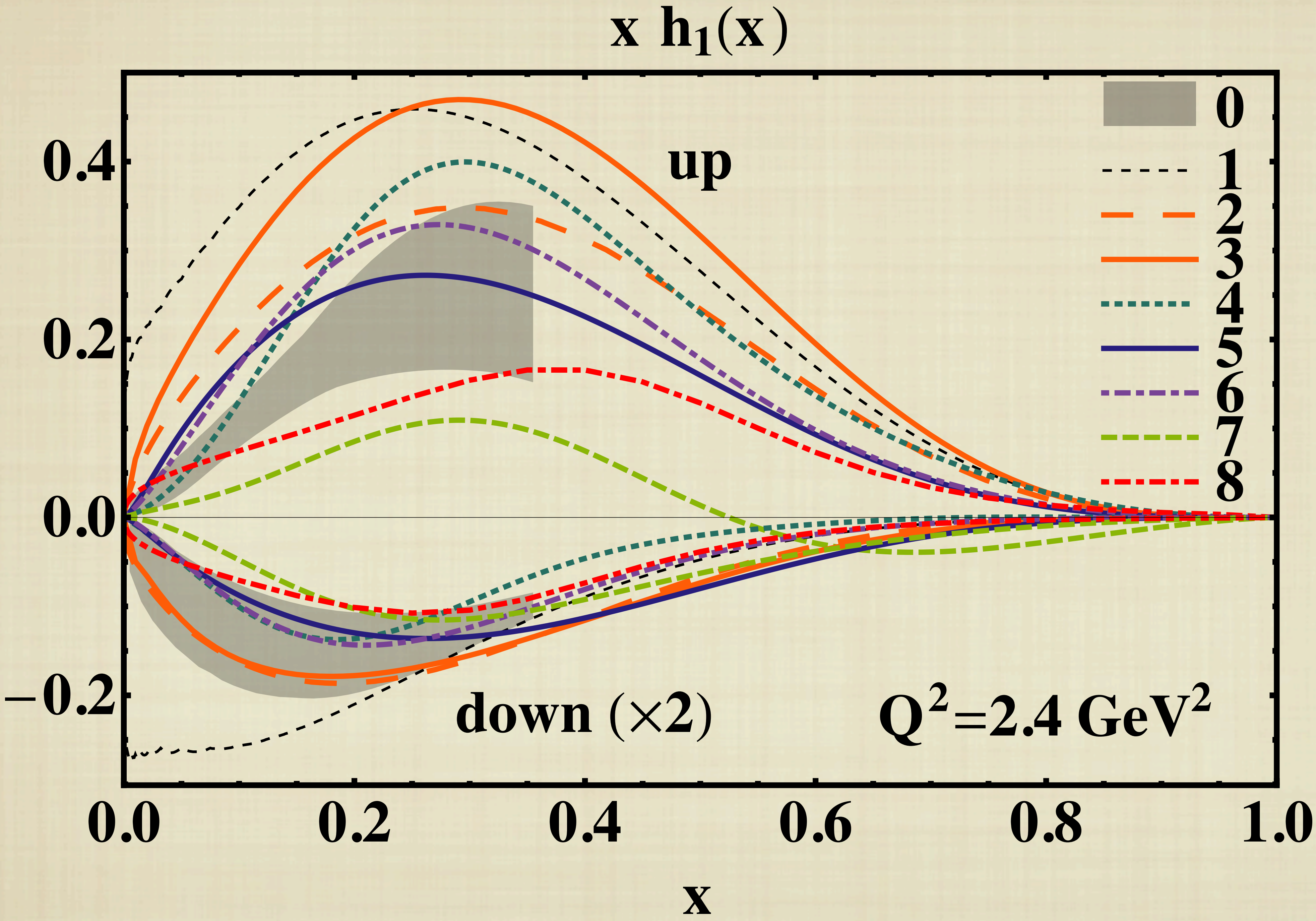
SIVERS FUNCTION - DGLAP



is it similar for Collins effect ? Need to check..


SIDIS
(2.5 GeV^2)
Collins
Transversity
collinear
evolution
BELLE
(100 GeV^2)
Collins
Collins
Collins
Transversity
TMD
evolution
?
D. Boer, NP**B806** (09)

Comparison with models



[0] M. Anselmino et al., arXiv:0812.4366

[1-8] models

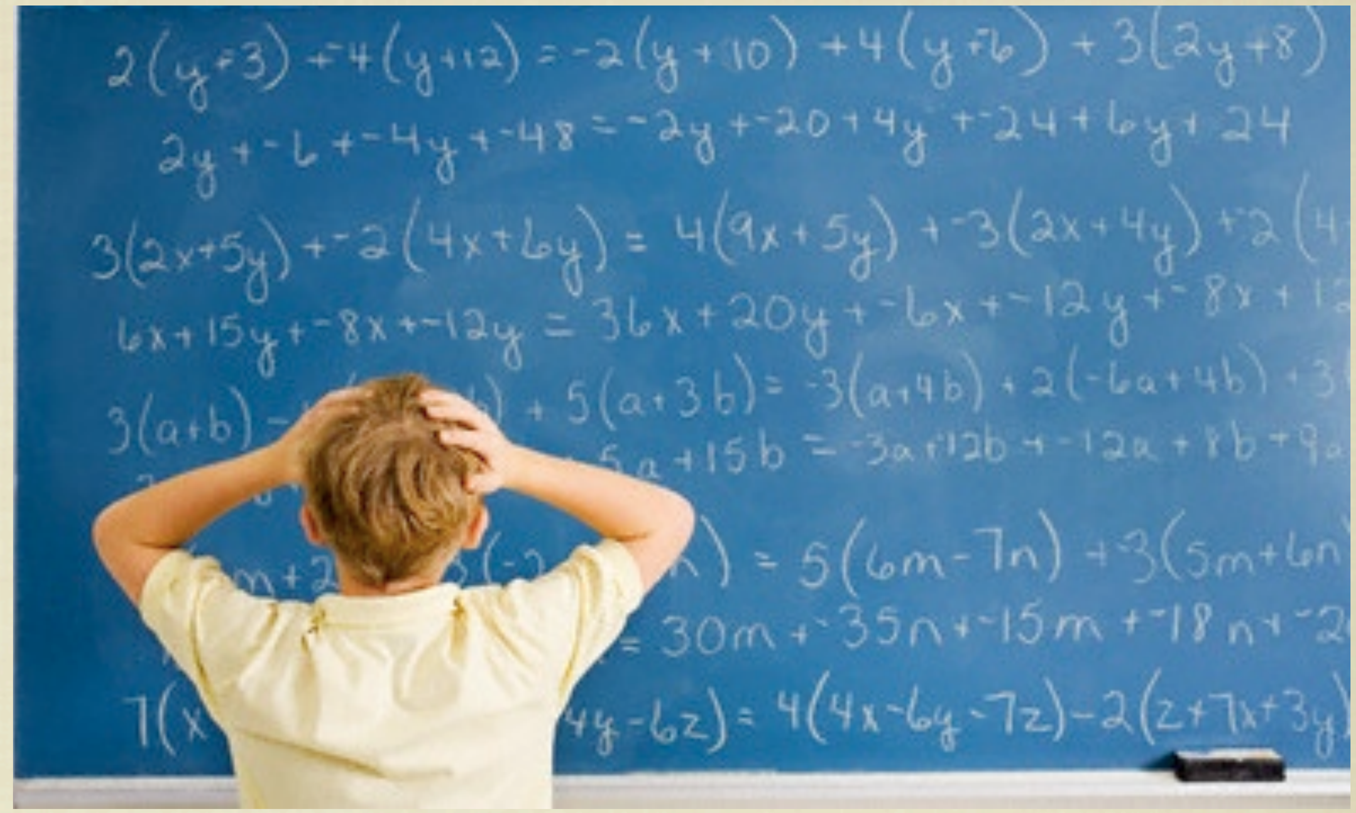
TMD factorization $\rightarrow$ TMD evolution

- Convolution
- Soft factors
- Evolution and Sudakov form factors

is there a way to skip all this ?

TMD factorization $\rightarrow$ TMD evolution

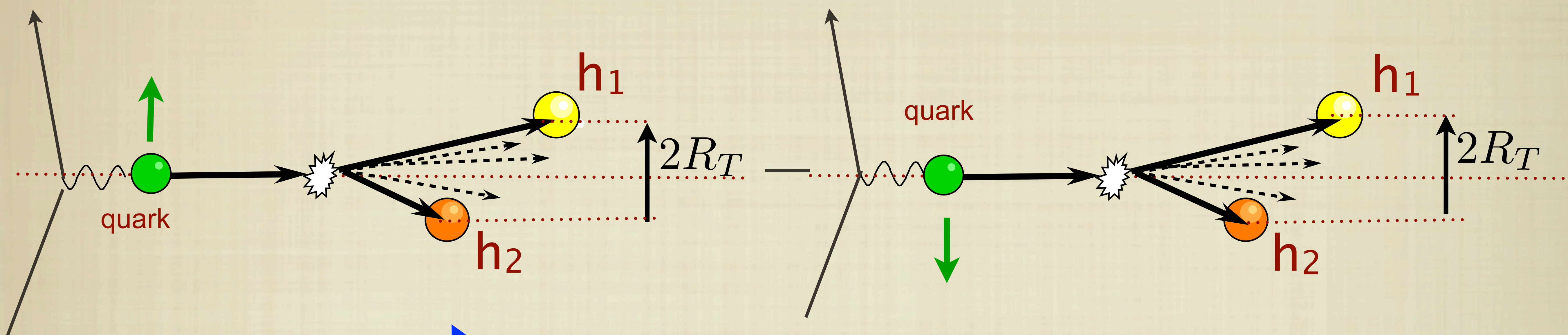
- Convolution
- Soft factors
- Evolution and Sudakov form factors

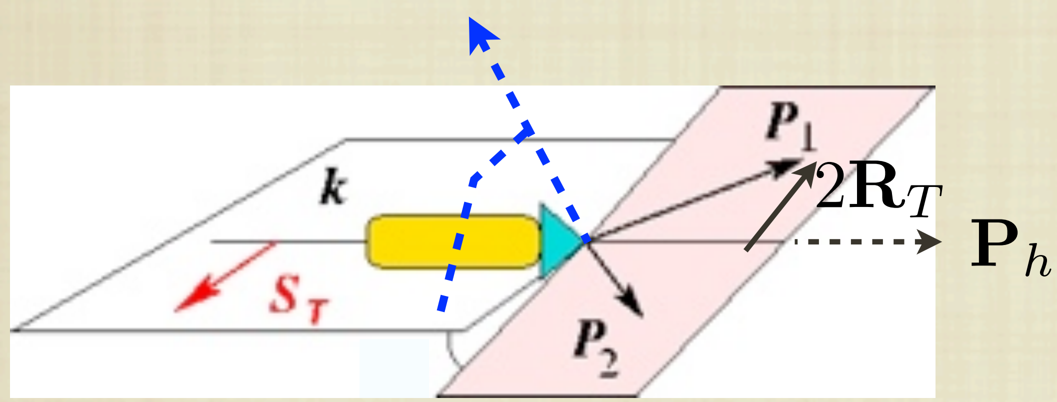


is there a way to skip all this ?

The IFF mechanism

*Collins, Heppelman, Ladinsky, NP **B420** (94)*





$$\begin{aligned}\mathbf{P}_h \times \mathbf{R}_T \cdot \mathbf{S}'_T \quad &\propto \quad \cos(\phi_{\mathbf{S}'_T} - (\phi_{R_T} + \pi/2)) \\ &= \quad \cos(\pi - \phi_S - (\phi_{R_T} + \pi/2)) \\ &= \quad \sin(\phi_{R_T} + \phi_S)\end{aligned}$$

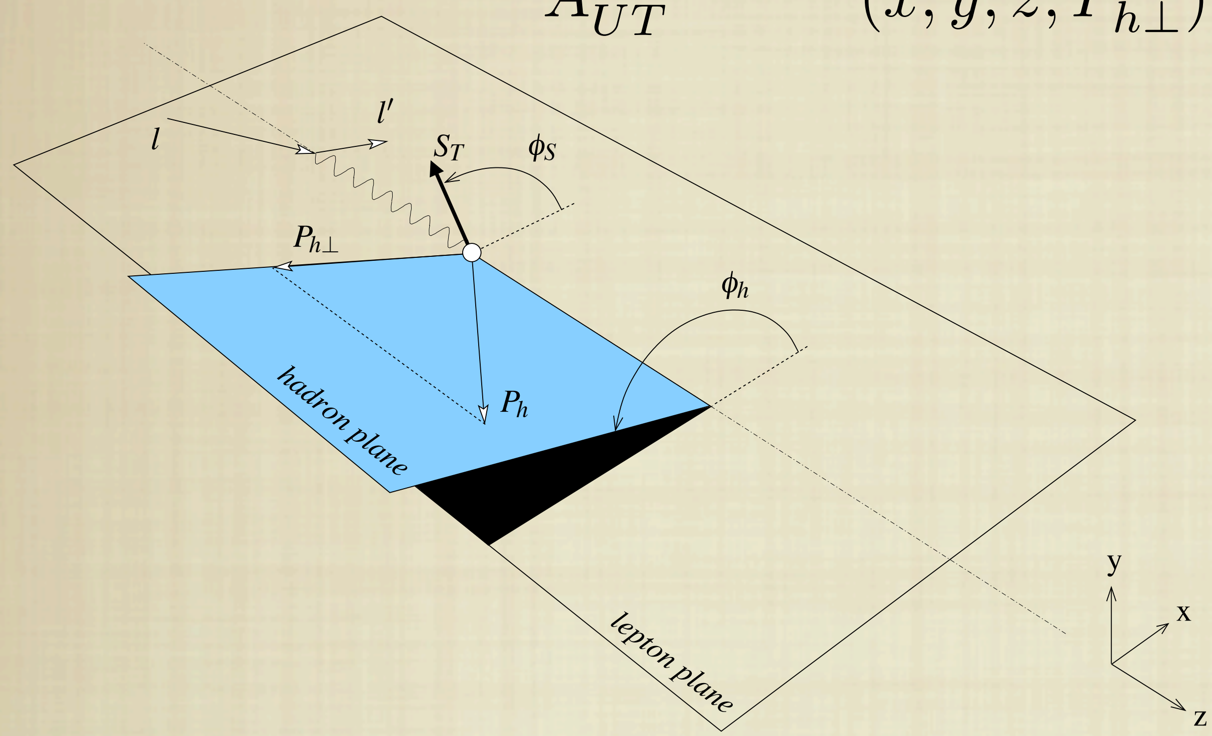
azimuthal orientation of hadron pair

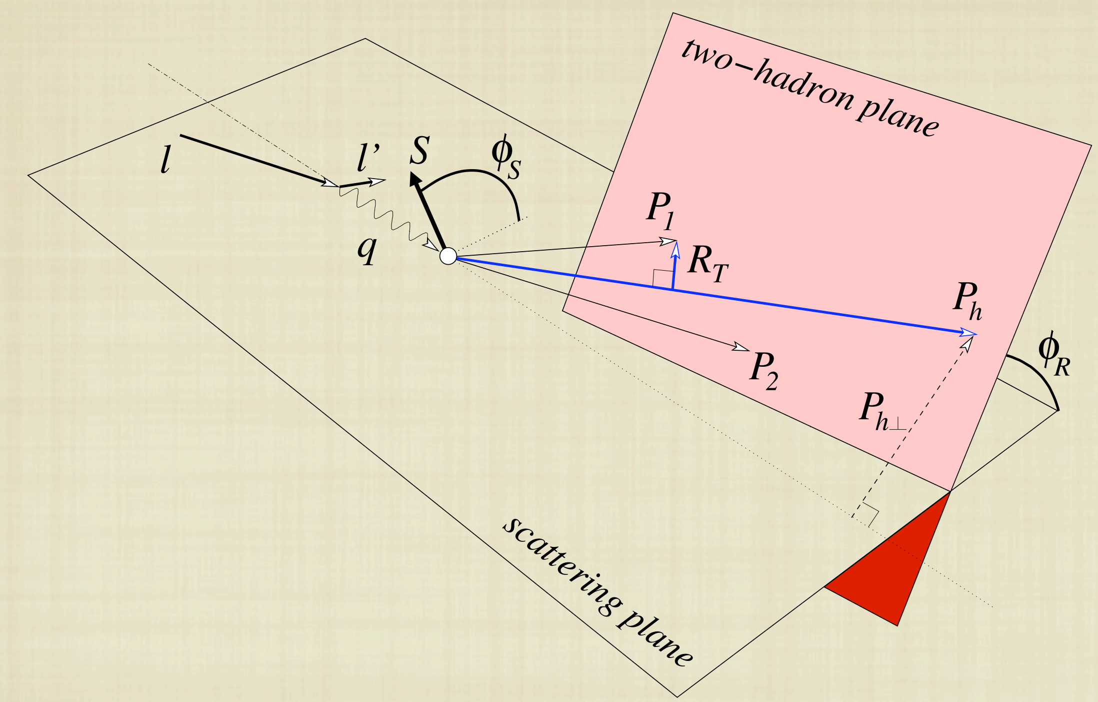
=

spin analyzer of fragmenting quark

SIDIS SSA: Collins vs. IFF

$$A_{UT}^{\sin(\phi_h+\phi_S)}(x,y,z,P_{h\perp}^2) = -\frac{1-y}{1-y+y^2/2}\,\frac{\sum_q e_q^2\left[h_1^q\otimes H_{1,q\to h}^{\perp}\right](x,z,P_{h\perp}^2)}{\sum_q e_q^2\, f_1^q(x)\; D_{1,q\to\pi}(z)}$$





*M.R. et al., PR D**65** (02); A. Bacchetta & M.R., PR D**67** (03)*

$$A_{UT}^{\sin(\phi_R+\phi_S)\,\sin\theta}(x,y,z,M_h^2) = -\frac{1-y}{1-y+y^2/2}\,\frac{|\boldsymbol{R}|}{M_h}\,\frac{\sum_q e_q^2\, h_1^q(x)\; H_{1,q\to\pi^+\pi^-}^{\sphericalangle}(z,M_h^2)}{\sum_q e_q^2\, f_1^q(x)\; D_{1,q\to\pi^+\pi^-}(z,M_h^2)}$$

$$|\boldsymbol{R}| = \frac{M_h}{2}\sqrt{1-\frac{4m_\pi^2}{M_h^2}}$$

SIDIS SSA: Collins vs. IFF

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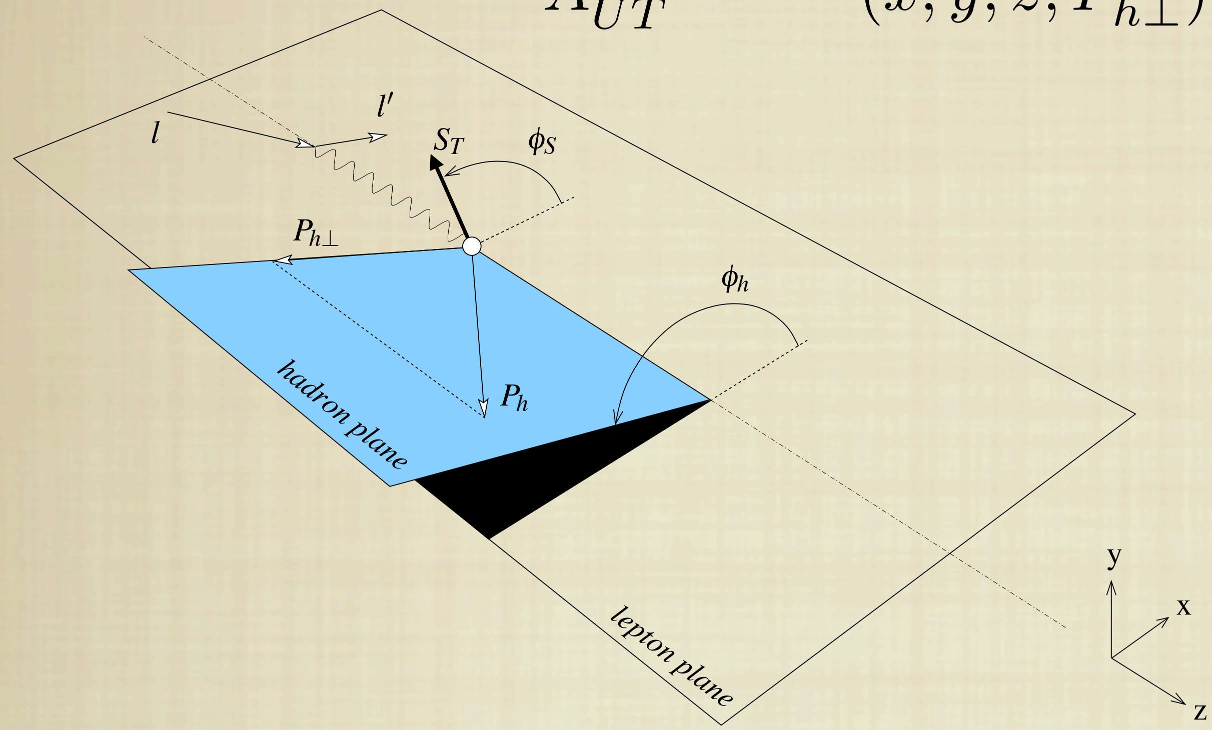

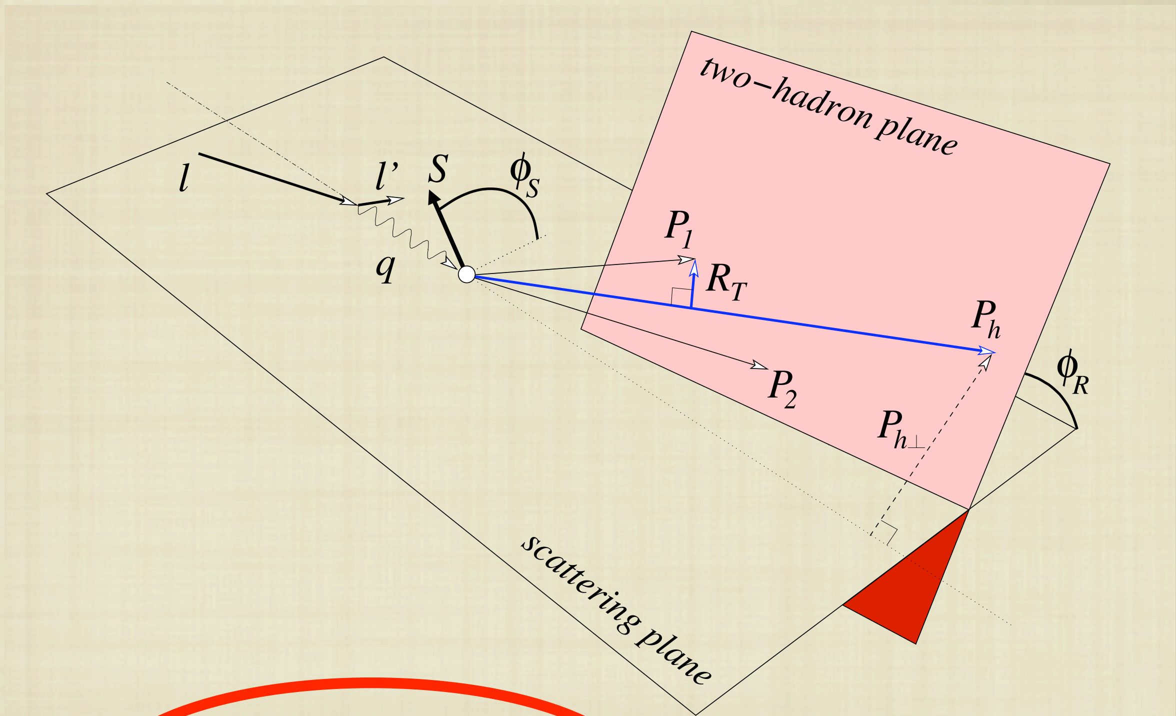

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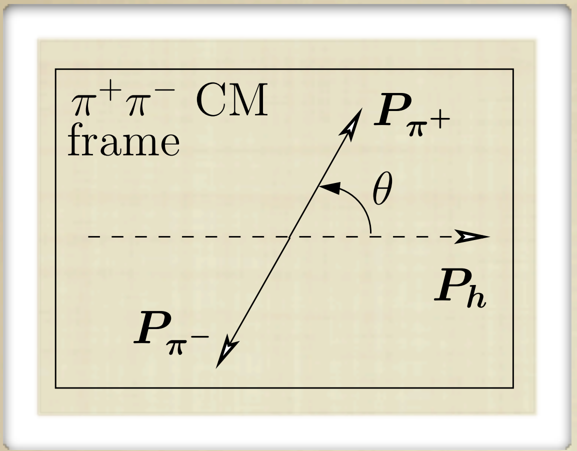
$$|\boldsymbol{R}| = \frac{M_h}{2}\sqrt{1-\frac{4m_\pi^2}{M_h^2}}$$

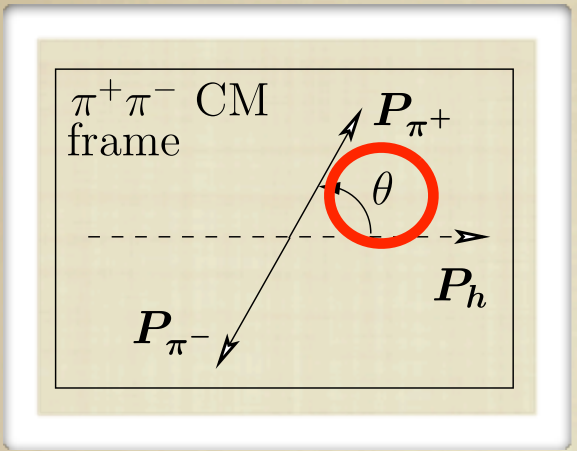
one technical detail, first..



$$H_1^{\sphericalangle\, q}(z_1, z_2, M_h^2) \to z = z_1 + z_2 \qquad \approx H_{1,sp}^{\sphericalangle\, q}(z, M_h^2) + \cos\theta H_{1,pp}^{\sphericalangle\, q}$$

$$\zeta = \frac{z_1 - z_2}{z} = a + b\cos\theta$$

one technical detail, first..



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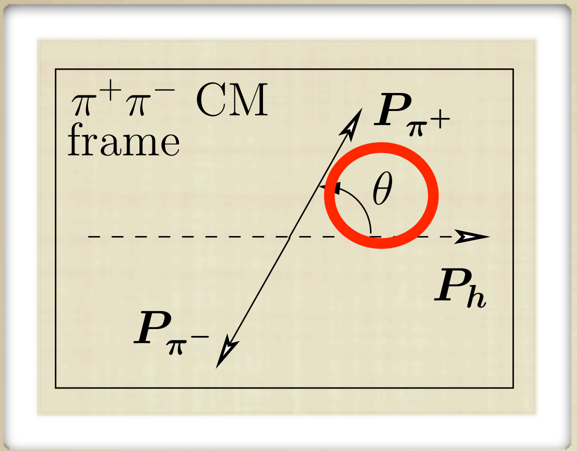


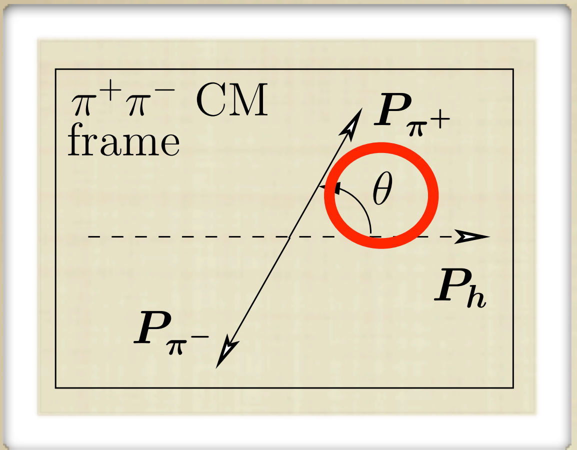
$$H_1^{\sphericalangle\, q}(z_1, z_2, M_h^2) \rightarrow z = z_1 + z_2 \qquad \approx H_{1,sp}^{\sphericalangle\, q}(z, M_h^2) + \cos\theta H_{1,pp}^{\sphericalangle\, q}$$

$$\zeta = \frac{z_1 - z_2}{z} = a + b\cos\theta$$

partial wave expansion in Legendre polinomials of cosθ

weight of interference $(\pi^+\pi^-)_s$ and $(\pi^+\pi^-)_p$

one technical detail, first..



$$H_1^{\sphericalangle\, q}(z_1, z_2, M_h^2) \to z = z_1 + z_2 \qquad \approx H_{1,sp}^{\sphericalangle\, q}(z, M_h^2) + \cos\theta H_{1,pp}^{\sphericalangle\, q}$$

$$\zeta = \frac{z_1 - z_2}{z} = a + b\cos\theta$$

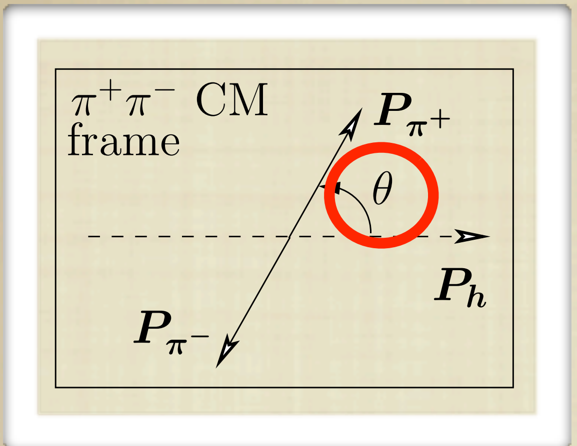
partial wave expansion in Legendre polinomials of $\cos\theta$

weight of interference $(\pi^+\pi^-)_s$ and $(\pi^+\pi^-)_p$

SIDIS

$$A_{UT}^{\sin(\phi_R+\phi_S)\,\sin\theta}(x, y, z, M_h^2) = -\frac{1-y}{1-y+y^2/2}\,\frac{|\boldsymbol{R}|}{M_h}\,\frac{\sum_q e_q^2\, h_1^q(x)\ H_{1,sp}^{\sphericalangle\, q}(z, M_h^2)}{\sum_q e_q^2\, f_1^q(x)\ D_1^q(z, M_h^2)}$$

one technical detail, first..



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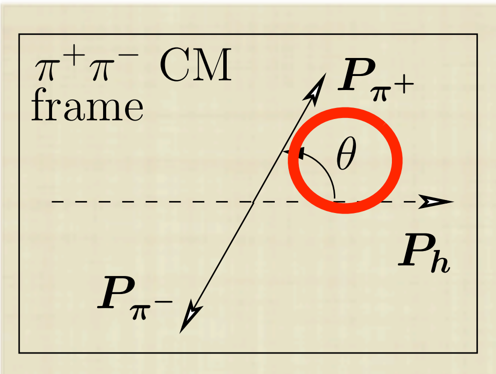
e^+e^-

$$A^{\cos(\phi_R+\bar{\phi}_R)}(\cos\theta_2, z, M_h^2, \bar{z}, \overline{M}_h^2) = \qquad a_{12} = \qquad \text{notation of Belle paper}$$

$$\frac{\sin^2\theta_2}{1+\cos^2\theta_2}\,\frac{|\boldsymbol{R}|\sin\theta}{M_h}\,\frac{|\overline{\boldsymbol{R}}|\sin\bar{\theta}}{\overline{M}_h}\,\frac{\sum_q e_q^2\, H_{1,sp}^{\sphericalangle q}(z, M_h^2)\, H_{1,sp}^{\sphericalangle \bar{q}}(\bar{z}, \overline{M}_h^2)}{\sum_q e_q^2\, D_1^q(z, M_h^2)\, D_1^{\bar{q}}(\bar{z}, \overline{M}_h^2)}$$

*X.Artru, J.Collins, ZPC **69** (96)*
*D.Boer, R.Jakob, M.R., PR D**67** (03)*

one technical detail, first..



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notation of Belle paper

$$\frac{\sin^2\theta_2}{1+\cos^2\theta_2}\,\frac{|\boldsymbol{R}|\sin\theta}{M_h}\,\frac{|\overline{\boldsymbol{R}}|\sin\bar\theta}{\overline{M}_h}\,\frac{\sum_q e_q^2\, H_{1,sp}^{\sphericalangle\, q}(z, M_h^2)\, H_{1,sp}^{\sphericalangle\, \bar q}(\bar z, \overline{M}_h^2)}{\sum_q e_q^2\, D_1^q(z, M_h^2)\, D_1^{\bar q}(\bar z, \overline{M}_h^2)}$$

need two pairs
for polariz. IFF

X.Artru, J.Collins, ZPC ***69*** *(96)*
*D.Boer, R.Jakob, M.R., PR D**67** (03)*

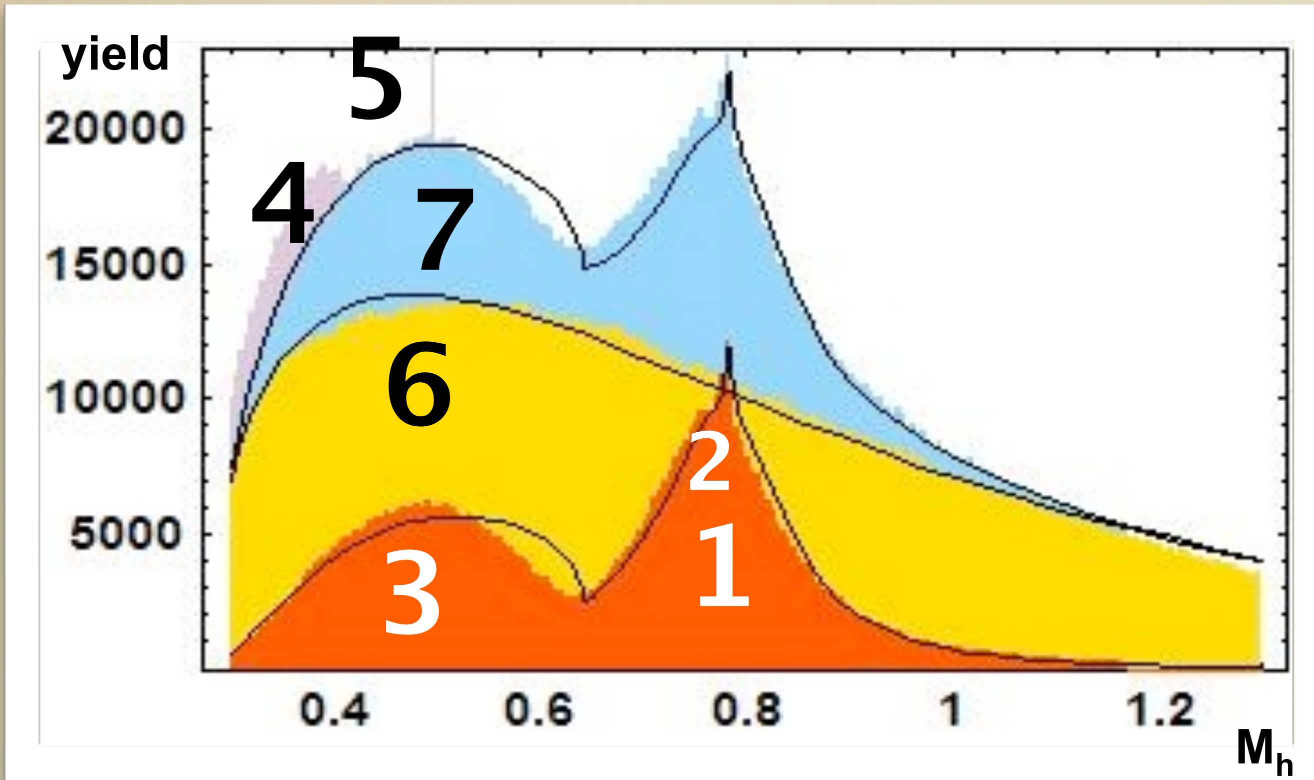
Advantages of IFF mechanism

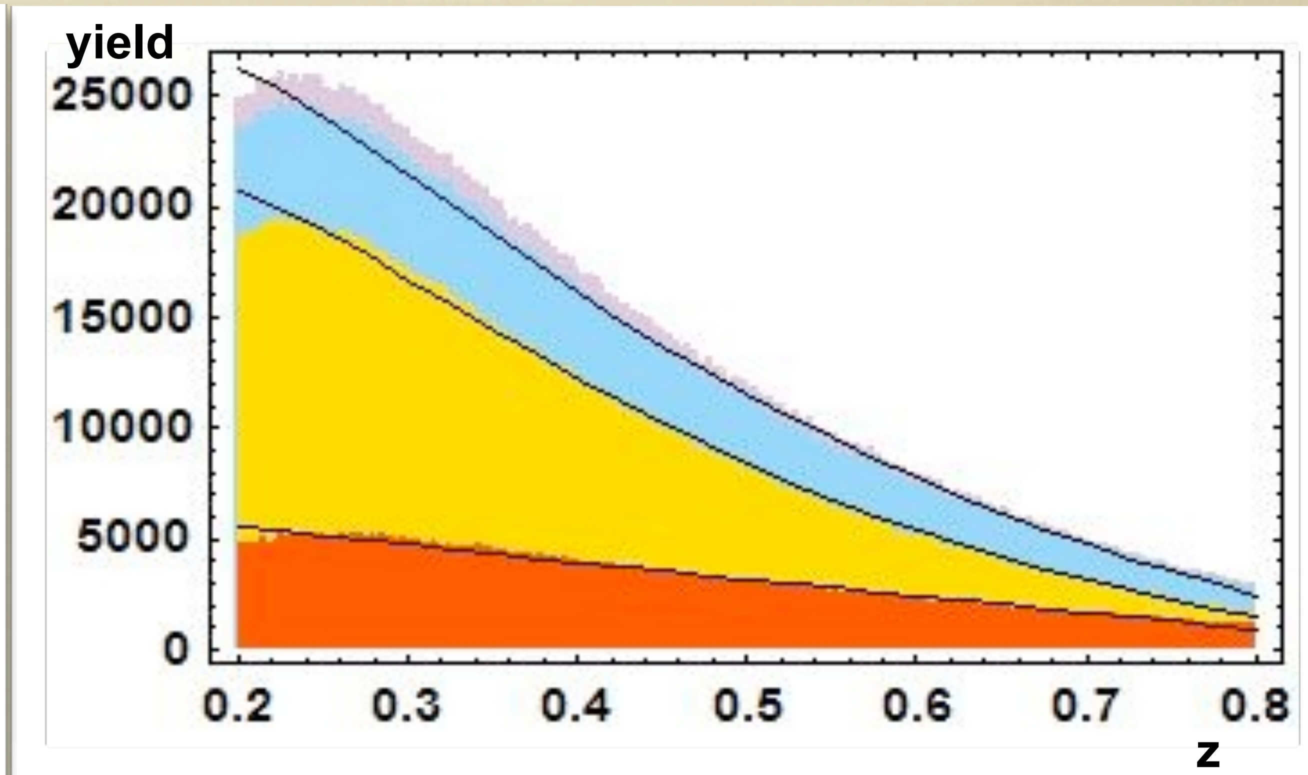
- Simple products instead of convolutions
- No complications in factorization
- Evolution equations understood
- Universality ok
- “cleaner” e+e- extraction (less background)

$\boxed{\text{Who}}$ did what ?

<2008 : the "model" era

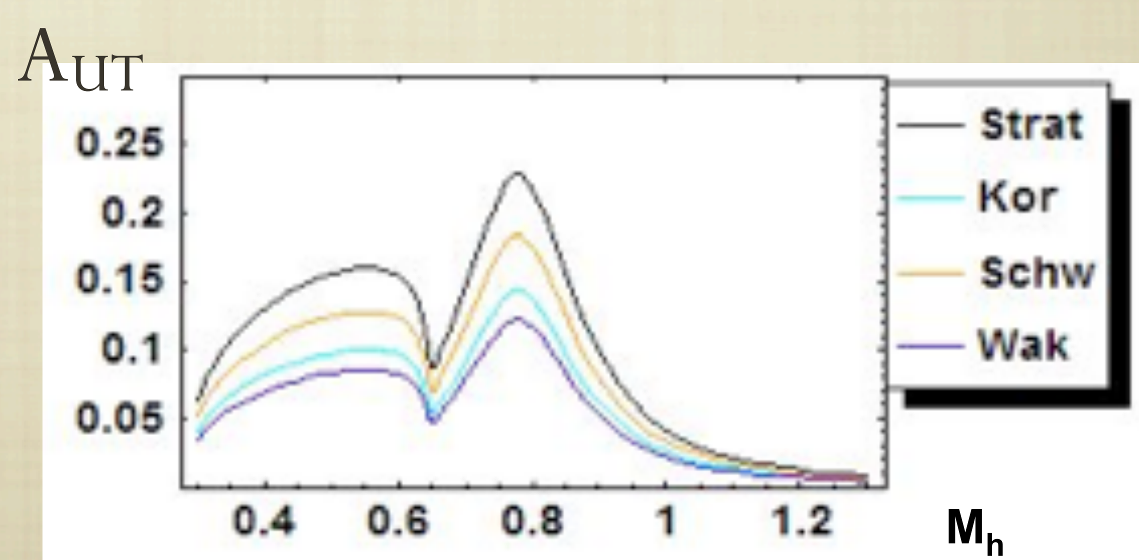
A. Bacchetta & M.R., PR D74 (06)





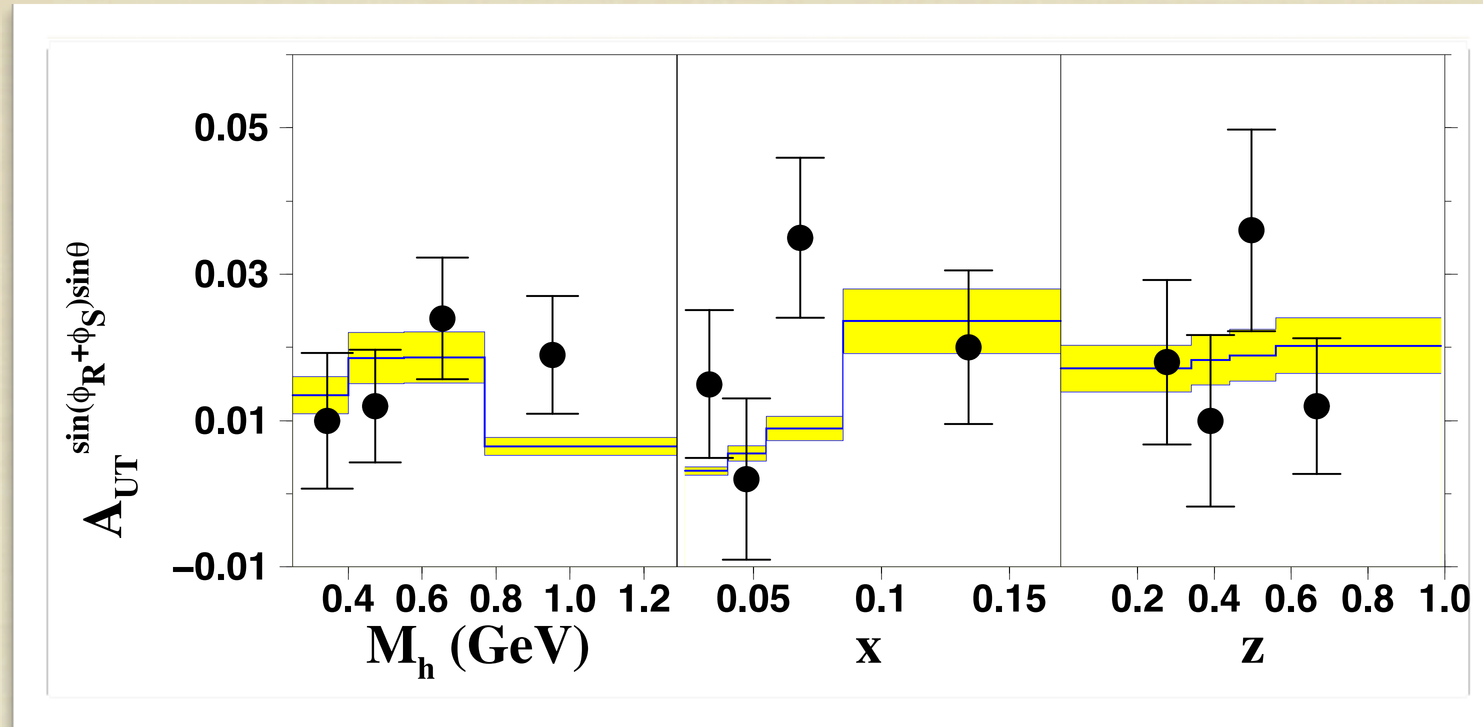
1. $q \to \rho X_1 \to \pi^+\pi^- X_1$
2. $q \to \omega X_2 \to \pi^+\pi^- X_2$
3. $q \to \omega X'_3 \to \pi^+\pi^- (\pi^0 X_3)$
4. $q \to \eta X_4 \to \pi^+\pi^- X_4$
5. $q \to K^0 X_5 \to \pi^+\pi^- X_5$
6. All-(1.+2.+3.)=backgr
7. All

parameters tuned to HERMES MC
$\to$ predict asymmetry



2008 : the “data” era
HERMES

HERMES, JHEP06 (08)



$0.2 \leq z$

$0.5 \leq M_h \leq 1$ GeV

- flavor symmetry:

$$D_1^u = D_1^d = D_1^{\bar{u}} = D_1^{\bar{d}} \quad ; \quad H_1^{\sphericalangle\, u} = H_1^{\sphericalangle\, \bar{d}} = -H_1^{\sphericalangle\, d} = -H_1^{\sphericalangle\, \bar{u}}$$

- Using Torino’s transversity without errors

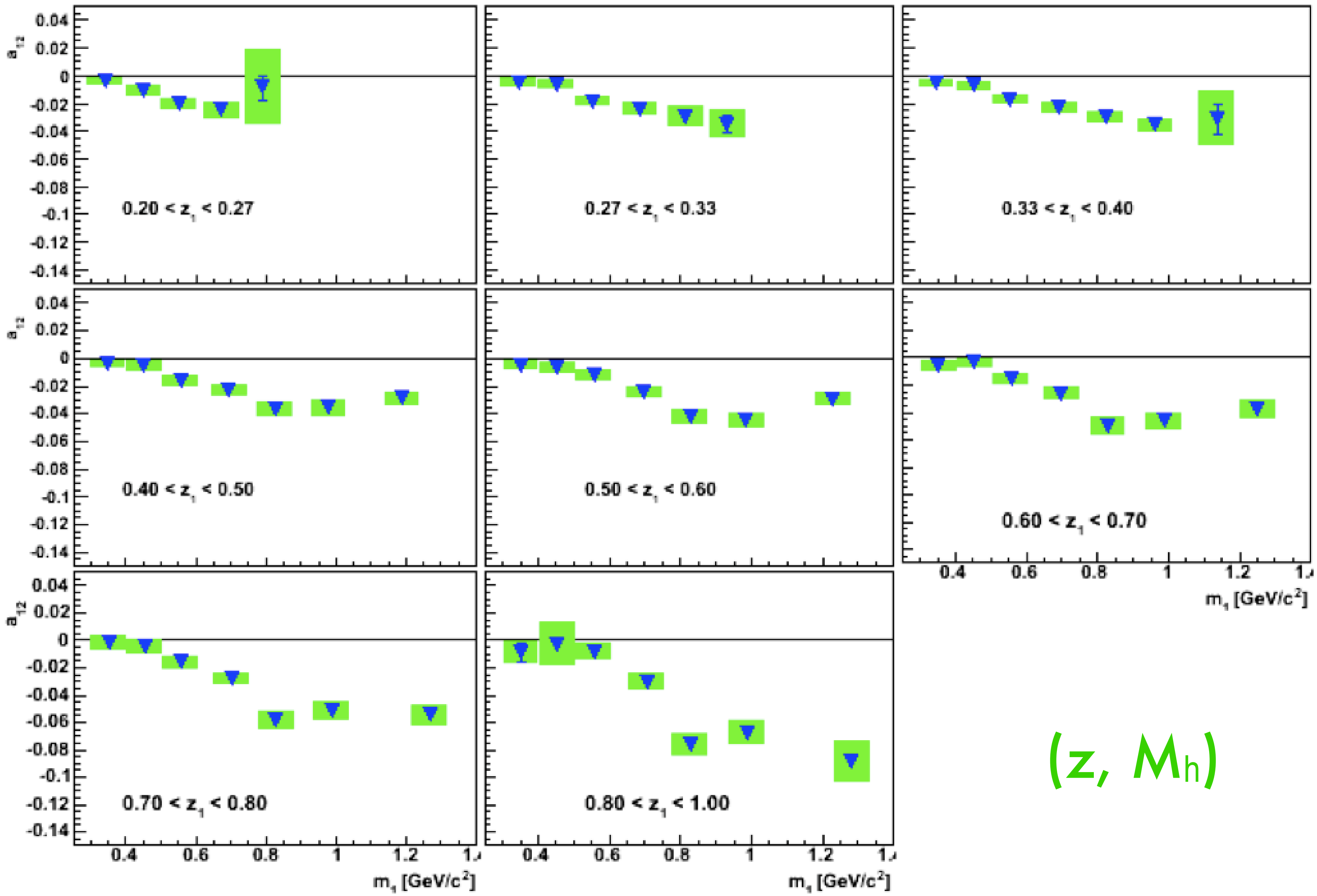
- Model has to be reduced by a factor 0.32 ± 0.06 (χ^2/d.o.f.=1.26)

model prediction + fitting normalization

*A.Bacchetta, F.Ceccopieri, A.Mukherjee, M.R., PR D**79** (09)*

2011 : the "parametrization" era
e^+e^- Belle data

*A. Vossen et al. (Belle), PRL **107** (11)*



(z, M_h)

fitting the Belle data

*A.Courtoy, A.Bacchetta, M.R., A.Bianconi, PRD **85** (12)*

$$d\sigma(\text{two pairs}) = \frac{1}{4\pi^2}\, d\sigma^0 \left(1 + \cos(\phi_R + \overline{\phi}_R)\, A\right)$$

fitting the Belle data

A.Courtoy, A.Bacchetta, M.R., A.Bianconi, PRD 85 (12)

$$d\sigma(\text{two pairs}) = \frac{1}{4\pi^2}\, d\sigma^0 \left(1 + \cos(\phi_R + \overline{\phi}_R)\, A\right)$$

1. parametrize DiFF(z,M_h) at Q_0^2=1 GeV inspired by model

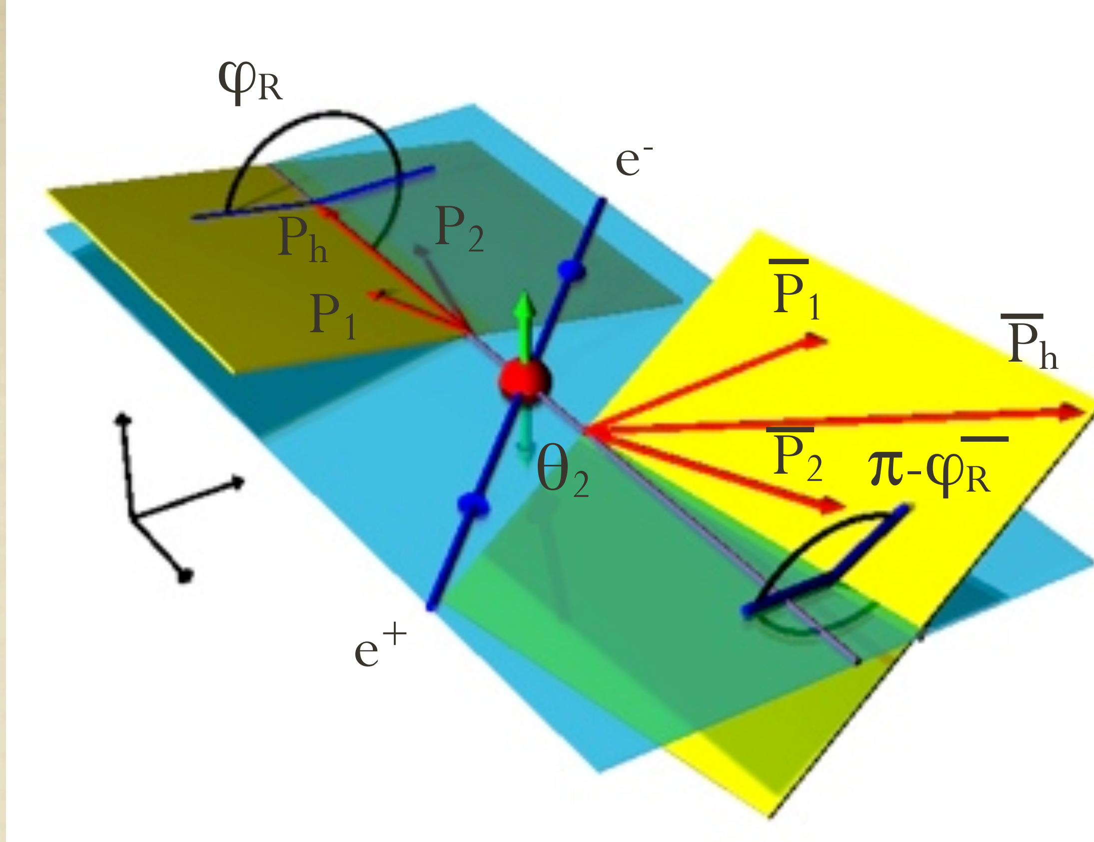
2. evolve DiFF's at Q_{Belle}^2 = 100 GeV (LO, no gluons)

3. integrate $d\sigma^0$ to get $d\sigma^0$(1 pair) $\propto D_1(z,M_h)$
no unpol. data ⇒ fit output of PYTHIA Monte Carlo for (π^+,π^-) emission at Belle kin.

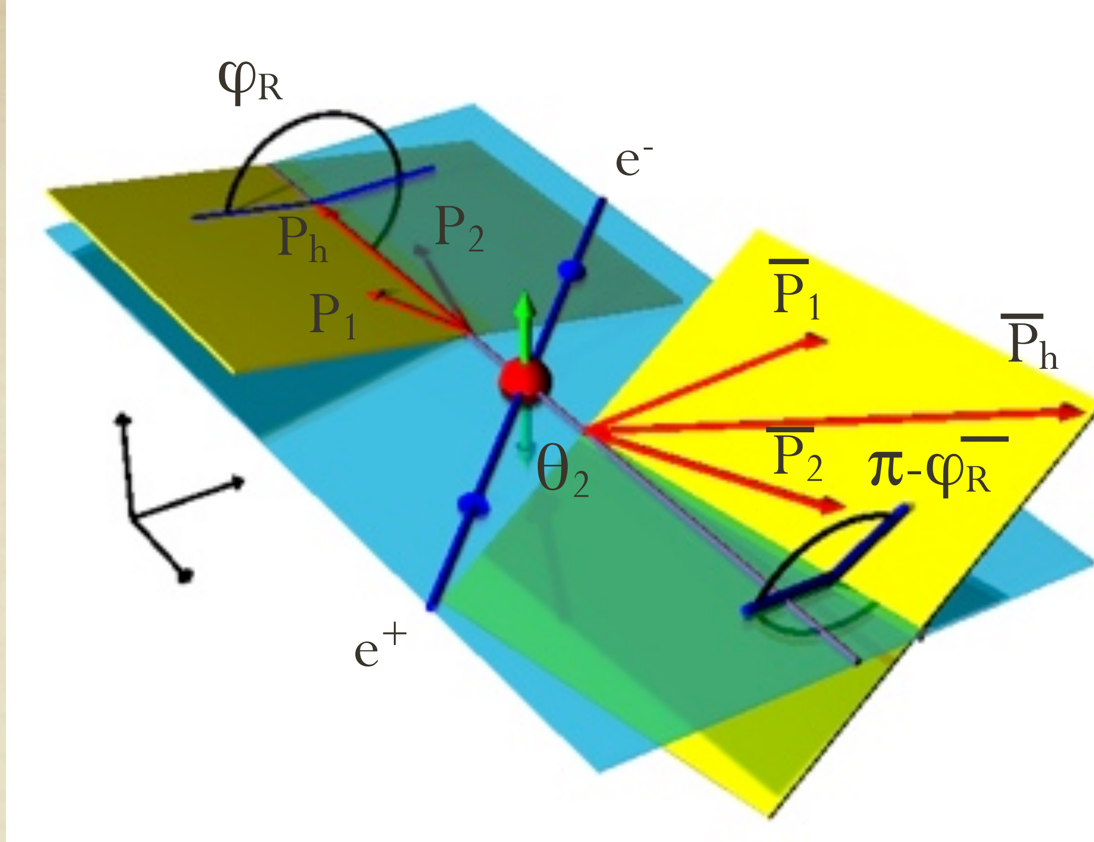
4. fit Belle data for asymmetry A ⇒ extract $H_1^{\sphericalangle\, q}$

fitting D₁ from M.C.

$$\frac{d\sigma^0}{dz dM_h} = \frac{4\pi\alpha^2}{Q^2} \sum_q e_q^2 \, D_1^q(z, M_h)$$



fitting D_1 from M.C.



$$\frac{d\sigma^0}{dz dM_h} = \frac{4\pi\alpha^2}{Q^2} \sum_q e_q^2 D_1^q(z, M_h)$$

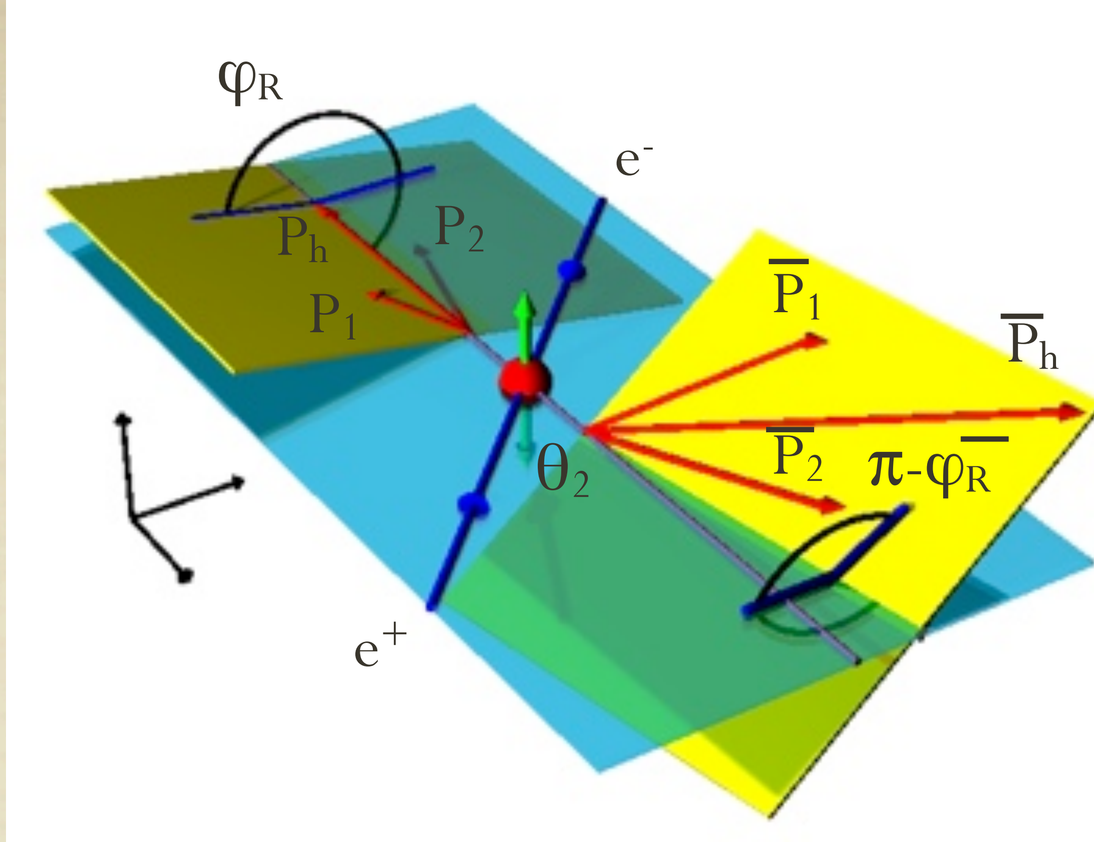
- $\mathcal{L}_{MC}$ = 647.26 pb^{-1} ⇔ >2M events ~ 2 $n_{\pi+\pi-}$ no cuts in acceptance
- **40**(z) × **50**(Mh) × **4** flavors × **4** channels = **32K** bins

  (u,d,s,c) (ϱ,ω,K^0 decays + continuum)
- $2m_\pi \leq M_h \leq 1.3$ GeV $0.2 \leq z$ $1 >> 2M_h/zQ$ (⇒ 31585 bins)
- isospin symmetry + charge conjugation: $u = \bar{u} = d = \bar{d}$ $s = \bar{s}$ $c = \bar{c}$

  (except $K^0 \rightarrow \pi^+\pi^-$)
- general form:

  parameters **17**(continuum) + **20**(ϱ) + **20**(ω) + **22**(K^0) = **79**
- 1.69 1.28 1.68 1.85 1.62

fitting D_1 from M.C.



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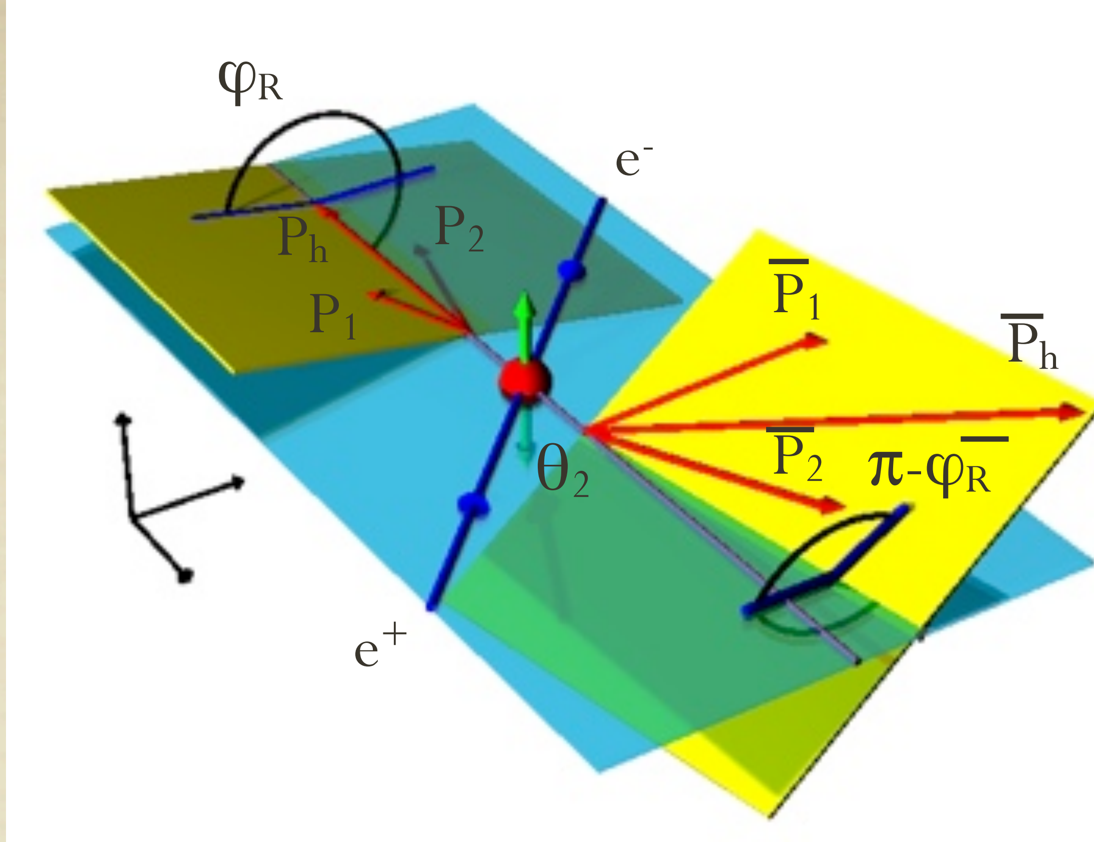

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  parameters **17**(continuum) + **20**(ϱ) + **20**(ω) + **22**(K^0) = **79**
- $\chi^2_{\mathrm{ch}} = \sum_q \sum_{ij} \frac{(N_{ij}^{\mathrm{ch},q} - \mathcal{L}_{MC}(d\sigma^{0,q}_{\mathrm{ch}})_{ij})^2}{\mathcal{L}_{MC}(d\sigma^{0,q}_{\mathrm{ch}})_{ij}}$ 1.69 1.28 1.68 1.85 1.62

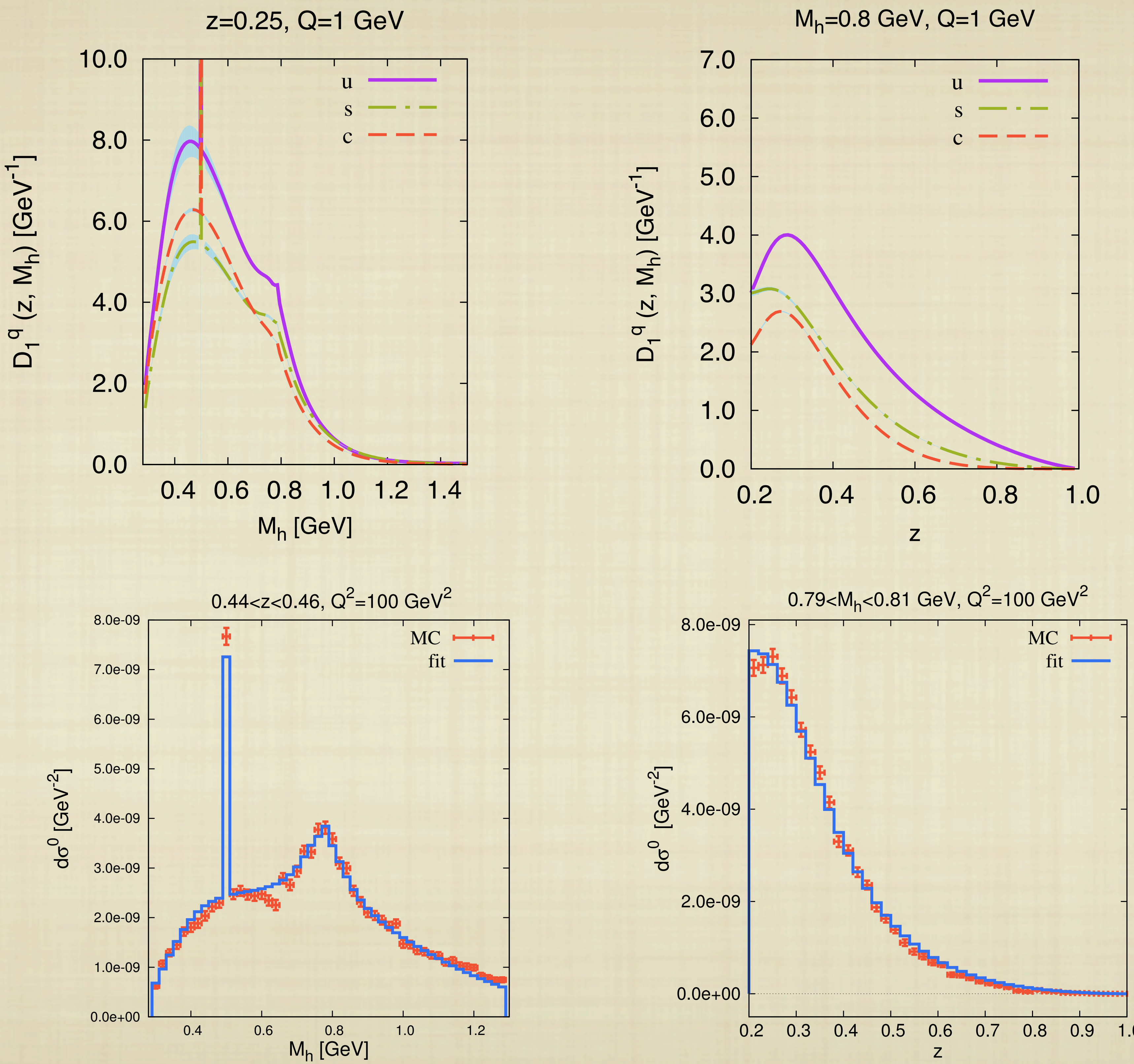
results for unpolarized DiFF D_1^q

$Q_0^2=1$

D_1^q

$Q^2=100$

$d\sigma^0$



A.Courtoy, A.Bacchetta, M.R., A.Bianconi, PRD 85 (12)

fitting Belle Asymmetry

$$A(\cos\theta_2, z, M_h^2, \overline{z}, \overline{M}_h^2) = \frac{\sin^2\theta_2}{1+\cos^2\theta_2}\, \frac{|\boldsymbol{R}|\sin\theta}{M_h}\, \frac{|\overline{\boldsymbol{R}}|\sin\overline{\theta}}{\overline{M}_h}\, \frac{\sum_q e_q^2\, H_{1,sp}^{\sphericalangle\, q}(z, M_h^2)\, H_{1,sp}^{\sphericalangle\, \bar{q}}(\overline{z}, \overline{M}_h^2)}{\sum_q e_q^2\, D_1^q(z, M_h^2)\, D_1^{\bar{q}}(\overline{z}, \overline{M}_h^2)}$$

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< > average bin value of each angle

(π^+,π^-) pairs

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

pol. (π^+,π^-) pairs

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

fitting Belle Asymmetry

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$\downarrow$

\# (π^+,π^-) pairs $\quad n_q(Q^2) = \int dz \int dM_h^2 D_1^q(z, M_h^2, Q^2)$

\# pol. (π^+,π^-) pairs $\quad n_q^\uparrow(Q^2) = \int dz \int dM_h^2 \frac{|\mathbf{R}|}{M_h}\, H_{1,sp}^{\sphericalangle\, q}(z, M_h^2, Q^2)$

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fitting Belle Asymmetry

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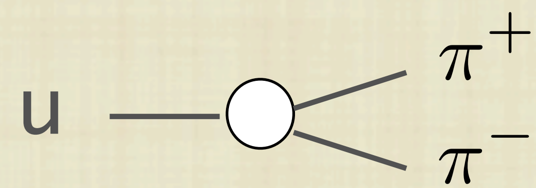
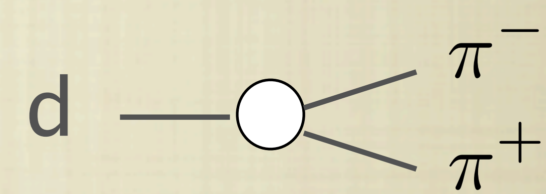
isospin symmetry +
charge conjugation
$u = -d = -\bar{u} = \bar{d}$





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isospin symmetry +
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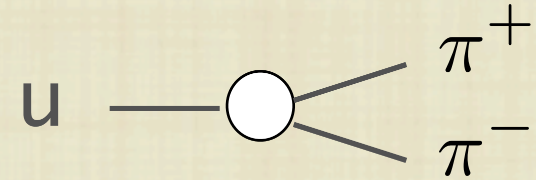
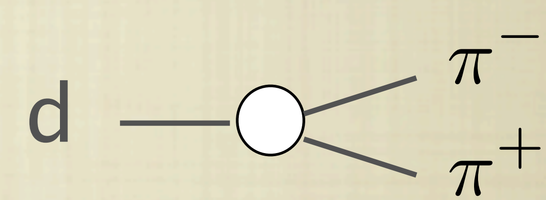
$u = -d = -\overline{u} = \overline{d}$

$\downarrow$





$$A(z, M_h^2, Q^2) \approx -\frac{\langle\sin^2\theta_2\rangle}{\langle 1+\cos^2\theta_2\rangle}\,\langle\sin\theta\rangle\langle\sin\overline{\theta}\rangle\,\frac{5}{9}\,\frac{\frac{|\boldsymbol{R}|}{M_h}\, H_{1,sp}^{\sphericalangle\, u}(z,M_h^2)\, n_u^{\uparrow}(Q^2)}{\sum_q e_q^2\, D_1^q(z,M_h^2)\, n_q(Q^2)}$$

continued

$$A(z, M_h^2, Q^2) \approx -\frac{\langle \sin^2\theta_2 \rangle}{\langle 1 + \cos^2\theta_2 \rangle} \langle \sin\theta \rangle \langle \sin\overline{\theta} \rangle \, \frac{5}{9} \, \frac{\frac{|\boldsymbol{R}|}{M_h} \, H_{1,sp}^{\sphericalangle\, u}(z, M_h^2) \, n_u^{\uparrow}(Q^2)}{\sum_q e_q^2 \, D_1^q(z, M_h^2) \, n_q(Q^2)}$$

continued

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continued

$$A(z, M_h^2, Q^2) \approx -\frac{\langle \sin^2\theta_2 \rangle}{\langle 1+\cos^2\theta_2 \rangle} \langle \sin\theta \rangle \langle \sin\overline{\theta} \rangle \frac{5}{9} \frac{\boxed{\frac{|\boldsymbol{R}|}{M_h} H_{1,sp}^{\sphericalangle\, u}(z, M_h^2)}\, \boxed{n_u^{\uparrow}(Q^2)}}{\sum_q e_q^2\, D_1^q(z, M_h^2)\, n_q(Q^2)}$$

$$\int dz \int dM_h^2\, A(z, M_h^2, Q^2) \times \left[\sum_q e_q^2\, D_1^q(z, M_h^2)\, n_q(Q^2) \right] \times \left[-\frac{\langle 1+\cos^2\theta_2 \rangle}{\langle \sin^2\theta_2 \rangle} \frac{1}{\langle \sin\theta \rangle \langle \sin\overline{\theta} \rangle} \frac{9}{5} \right] = \left[n_u^{\uparrow}(Q^2) \right]^2$$

continued

$$A(z, M_h^2, Q^2) \approx -\frac{\langle \sin^2\theta_2\rangle}{\langle 1+\cos^2\theta_2\rangle}\langle \sin\theta\rangle\langle\sin\overline{\theta}\rangle\,\frac{5}{9}\,\frac{\boxed{\frac{|\boldsymbol{R}|}{M_h}\,H_{1,sp}^{\sphericalangle\, u}(z, M_h^2)}\,\boxed{n_u^{\uparrow}(Q^2)}}{\sum_q e_q^2\, D_1^q(z, M_h^2)\, n_q(Q^2)}$$

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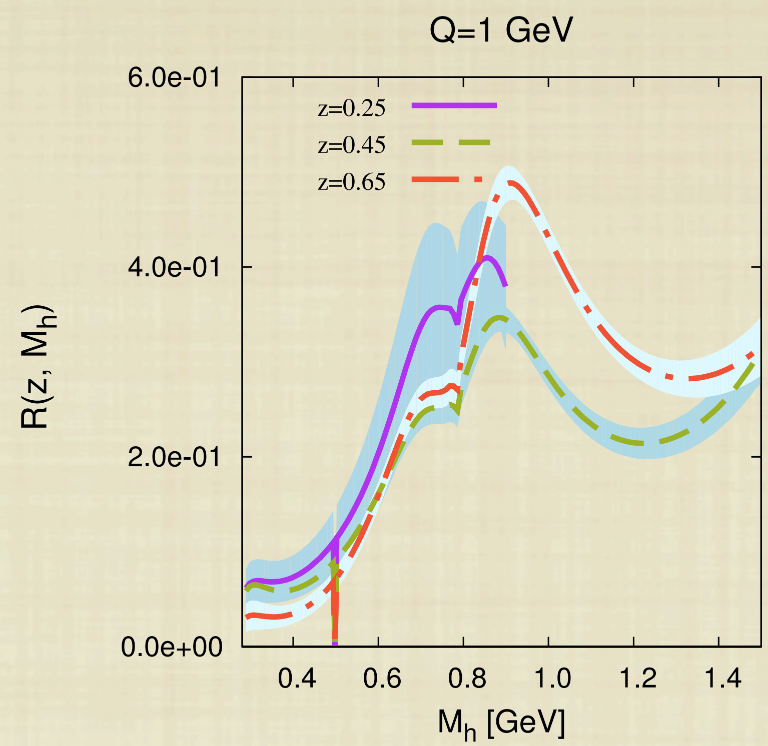
- general form at $Q_0^2=1$: $H_{1,sp}^{\sphericalangle\, q}(z, M_h) \sim (1-z)\, 2|\mathbf{R}|\, \mathrm{BW}(M_h)\, \exp[d_{\{\delta\}}(z) + h_{\{\lambda\}}(M_h)]\, f_{\{\gamma\}}(zM_h)$
- **9** parameters
- chiral-odd LO evolution with *ad-hoc* modified HOPPET *(M.Guagnelli-Pavia)*
- **8**(z) × **8**(M_h) − {z∈[0.8,1], M_h∈[1.5,2]} = **46** bins
- χ^2/dof = 0.57
- errors dominated by Belle exp. A

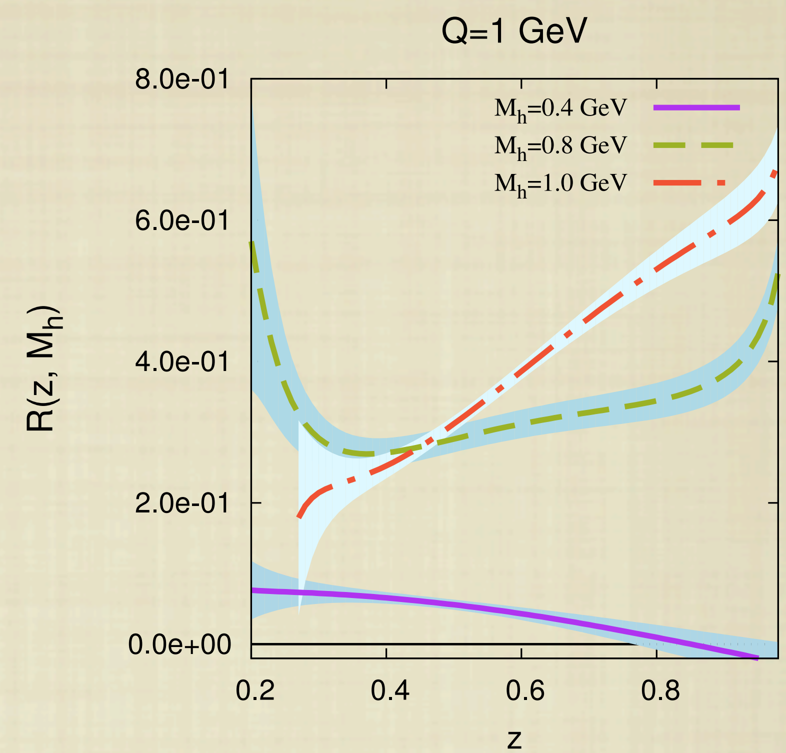
results for polarized DiFF $H_1^{\sphericalangle\, q}$

*A. Courtoy, A. Bacchetta, M.R., A. Bianconi, PRD **85** (12)*

$Q_0{}^2 = 1$

$$\frac{|\mathbf{R}|}{M_h}\,\frac{H_1^{\sphericalangle\, u}}{D_1^u}$$

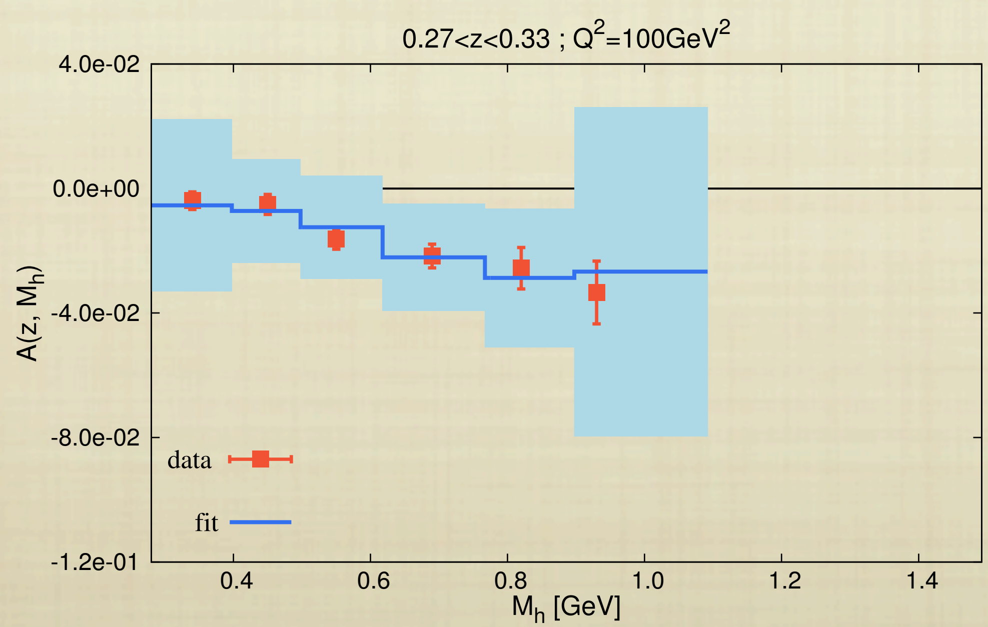




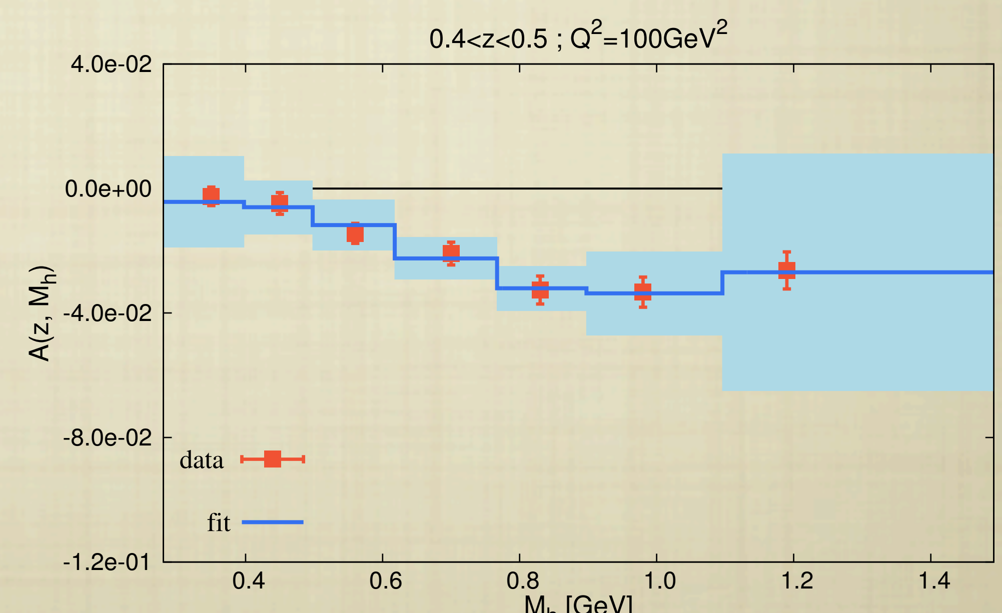
$Q^2 = 100$

A

$0.27 \leq z \leq 0.33$



$0.4 \leq z \leq 0.5$



first glances at transversity via HERMES data

A.Bacchetta, A. Courtoy, M.R., PRL ***107*** *(11)*

$$A_{UT}^{\sin(\phi_R+\phi_S)\,\sin\theta}(x,y,z,M_h^2) = -\frac{1-y}{1-y+y^2/2}\,\frac{|\boldsymbol{R}|}{M_h}\,\frac{\sum_q e_q^2\, h_1^q(x)\;\, H_{1,sp}^{\sphericalangle\, q}(z,M_h^2)}{\sum_q e_q^2\, f_1^q(x)\;\, D_1^q(z,M_h^2)}$$

recall

$$D_1^u = D_1^d = D_1^{\bar u} = D_1^{\bar d}$$
$$D_1^s = D_1^{\bar s}$$
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$$H_1^{\sphericalangle u} = -H_1^{\sphericalangle d} = -H_1^{\sphericalangle \bar u} = H_1^{\sphericalangle \bar d}$$
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first glances at transversity via HERMES data

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evolved from
down to
<Q²>=2.5

$$A_{UT} \approx -\langle C(y)\rangle\, \frac{x h_1^{u_v}(x,Q^2) - \frac{1}{4} x h_1^{d_v}(x,Q^2)}{x f_1^{u+\overline{u}}(x,Q^2) + \frac{1}{4}\, x f_1^{d+\overline{d}}(x,Q^2) + \frac{1}{4}\,\frac{n_s(Q^2)}{n_u(Q^2)}\, x f_1^{s+\overline{s}}(x,Q^2)}\,\frac{n_u^{\uparrow}(Q^2)}{n_u(Q^2)} = -0.259$$

(11% error)

first glances at transversity via HERMES data

A.Bacchetta, A. Courtoy, M.R., PRL ***107*** *(11)*

$$A_{UT}^{\sin(\phi_R+\phi_S)\,\sin\theta}(x,y,z,M_h^2) = -\frac{1-y}{1-y+y^2/2}\,\frac{|\boldsymbol{R}|}{M_h}\,\frac{\sum_q e_q^2\, h_1^q(x)\;\, H_{1,sp}^{\sphericalangle\, q}(z,M_h^2)}{\sum_q e_q^2\, f_1^q(x)\;\, D_1^q(z,M_h^2)}$$

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(11% error)

from data

MSTW08LO

sabato 10 novembre 2012

first glances at transversity via HERMES data

A.Bacchetta, A. Courtoy, M.R., PRL ***107*** *(11)*

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(11% error)

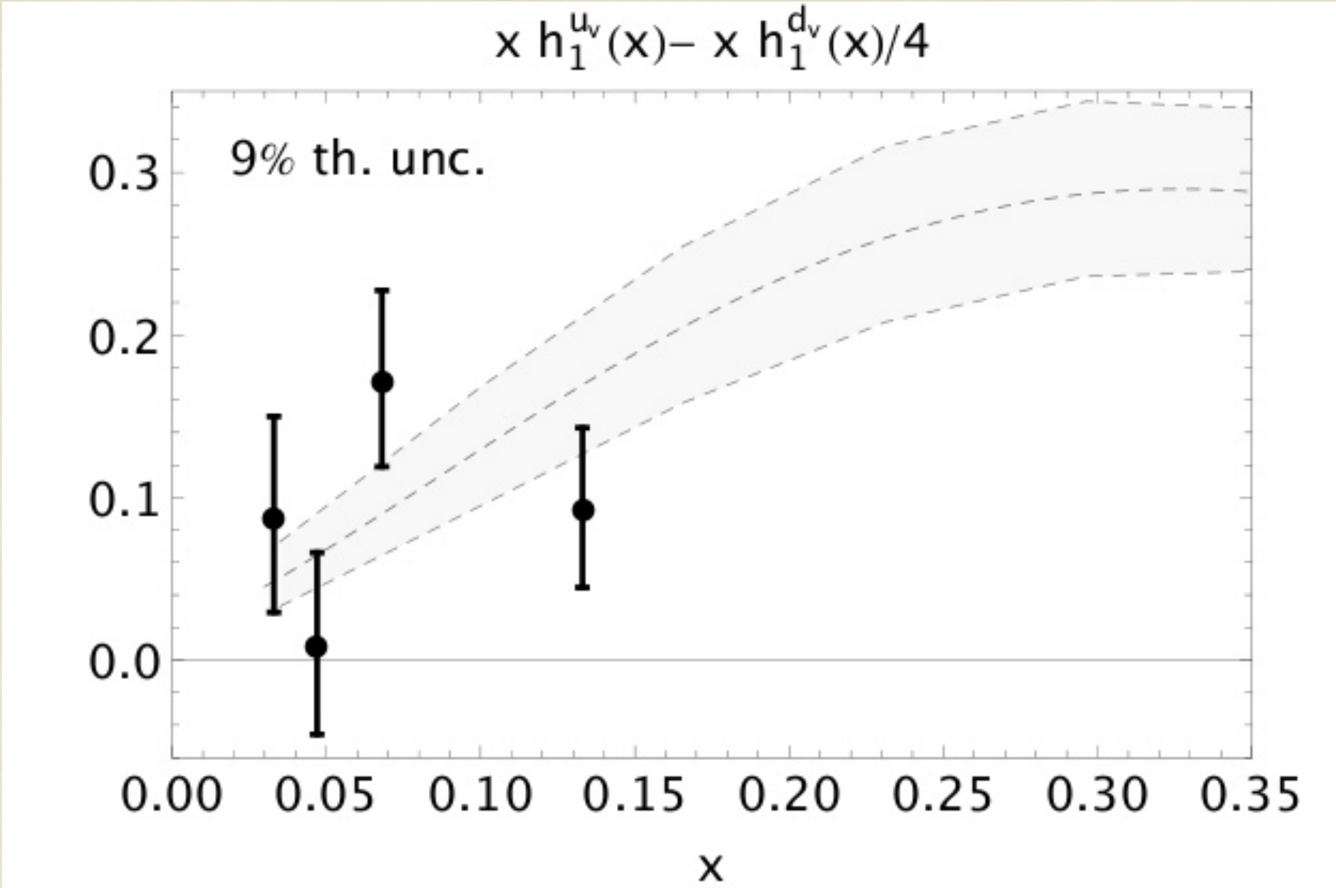
from data

MSTW08LO

sabato 10 novembre 2012

2011 : the "collinear transversity" era

*A.Bacchetta, A. Courtoy, M.R., PRL **107** (11)*



based on data from hermes

uncertainty band from Collins effect

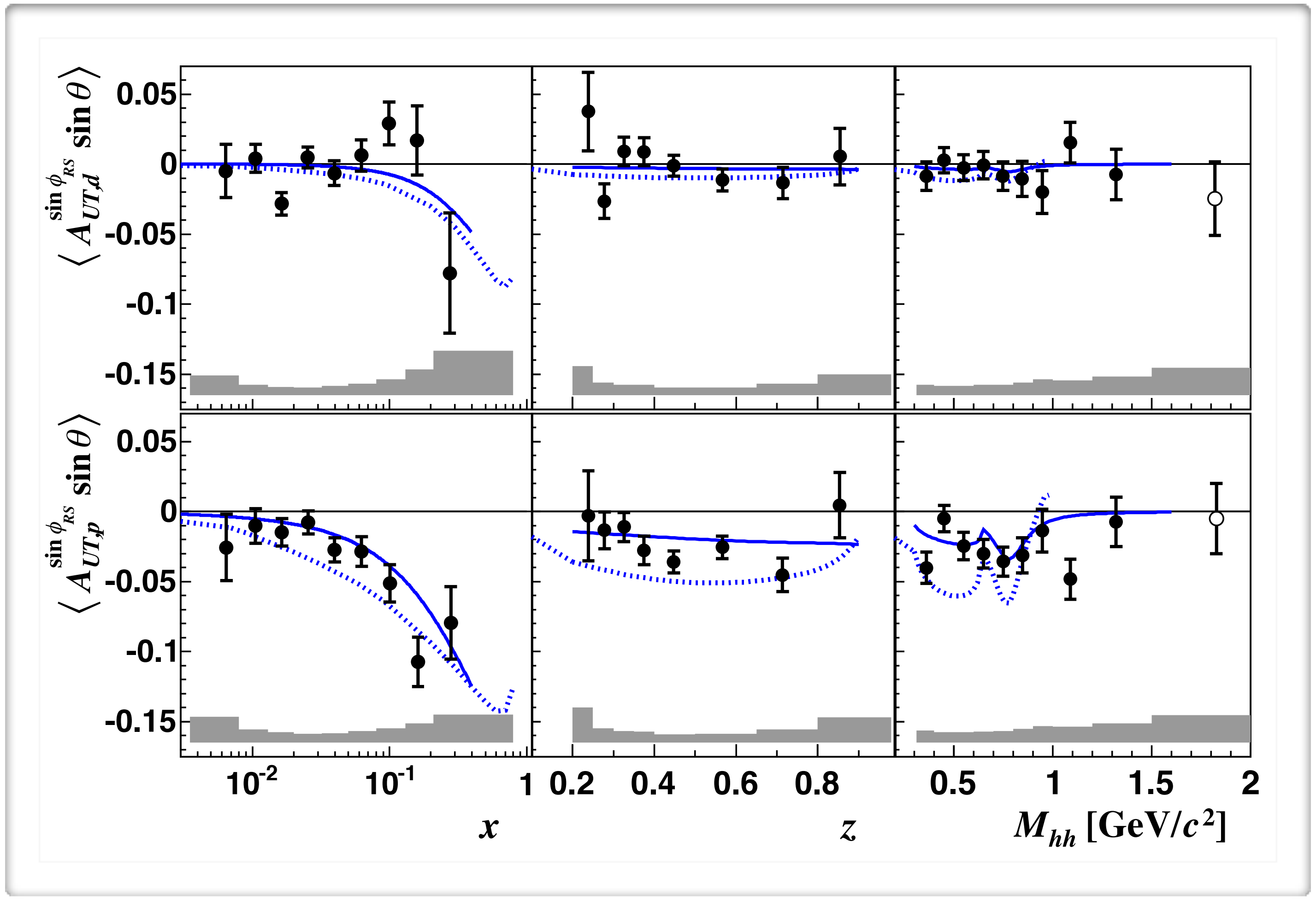
*M.Anselmino et al., NP **B191** (Proc.Supp.) (09)*

2012 : COMPASS data officially released

C.Adolph et al. (Compass), PL ***B713*** *(12)*

2002-4 Deuteron Data

2007 Proton Data



$0.2 \leq z$

$0.28 \leq M_h \leq 1.2$ GeV

Pavia model prediction

A. Bacchetta & M.R., PR D74 (06)

Which are the latest “press” news ?

New extraction : proton data

$$A_{UT} \approx -\langle C(y)\rangle \, \frac{x h_1^{u_v}(x,Q^2) - \frac{1}{4} x h_1^{d_v}(x,Q^2)}{x f_1^{u+\overline{u}}(x,Q^2) + \frac{1}{4}\, x f_1^{d+\overline{d}}(x,Q^2) + \frac{1}{4}\, \frac{n_s(Q^2)}{n_u(Q^2)}\, x f_1^{s+\overline{s}}(x,Q^2)} \, \frac{n_u^{\uparrow}(Q^2)}{n_u(Q^2)}$$

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from data

New extraction : proton data

$$A_{UT} \approx -\langle C(y)\rangle \frac{xh_1^{u_v}(x,Q^2) - \frac{1}{4}xh_1^{d_v}(x,Q^2)}{xf_1^{u+\overline{u}}(x,Q^2) + \frac{1}{4}\,xf_1^{d+\overline{d}}(x,Q^2) + \frac{1}{4}\,\frac{n_s(Q^2)}{n_u(Q^2)}\,xf_1^{s+\overline{s}}(x,Q^2)} \frac{n_u^{\uparrow}(Q^2)}{n_u(Q^2)} = -0.208$$

(9% error)

from data

COMPASS

New extraction : proton data

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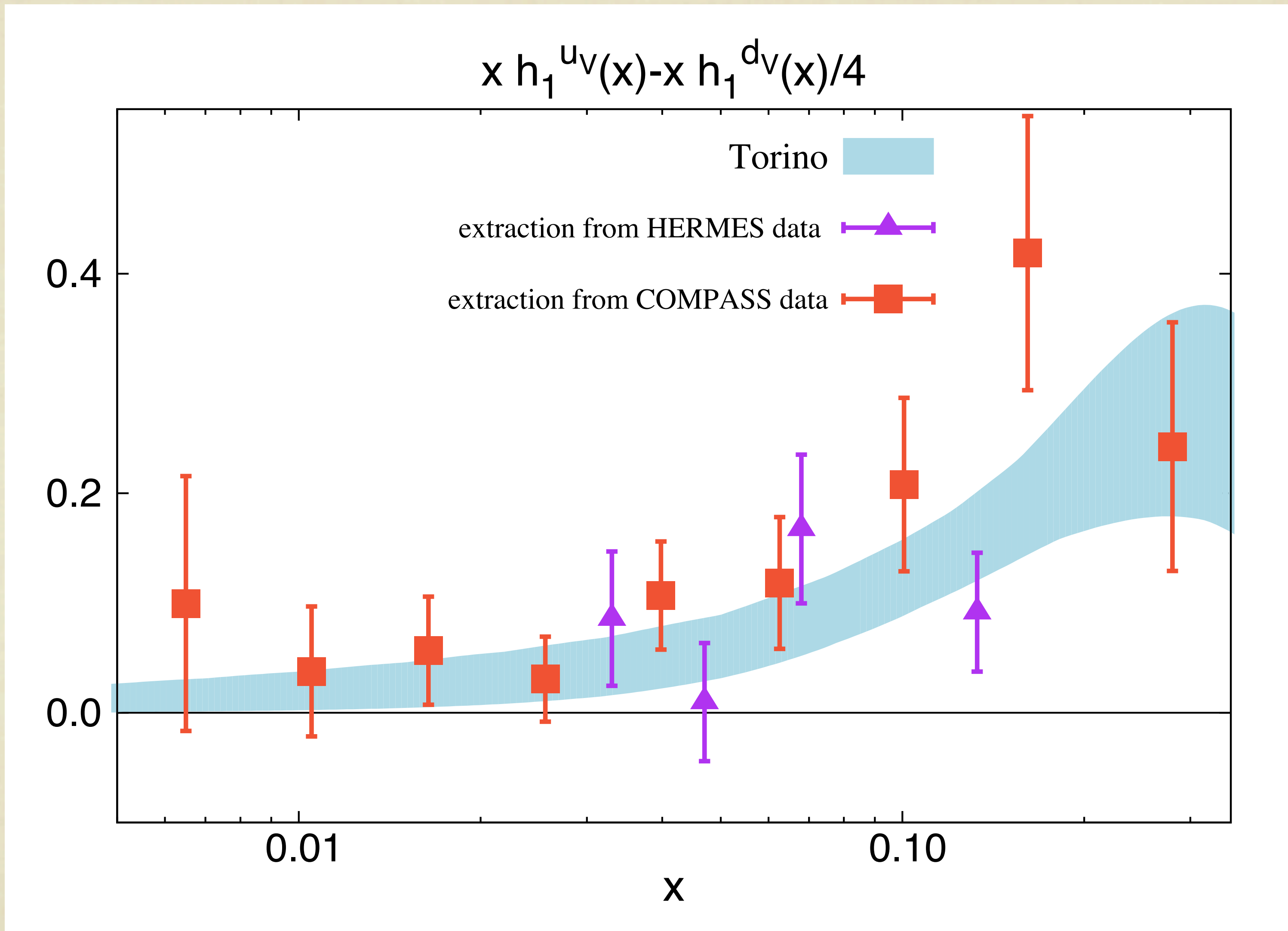
(9% error)

from data



uncertainty band from Collins effect

M.Anselmino et al.,
*NP **B191** (Proc.Supp.) (09)*

New extraction : deuteron data

$$A_{UT} \approx -\langle C(y)\rangle \, \frac{3}{5} \, \frac{x h_1^{u_v}(x,Q^2) + x h_1^{d_v}(x,Q^2)}{x f_1^{u+\bar{u}}(x,Q^2) + x f_1^{d+\bar{d}}(x,Q^2) + \frac{2}{5}\frac{n_s(Q^2)}{n_u(Q^2)} x f_1^{s+\bar{s}}(x,Q^2)} \, \frac{n_u^{\uparrow}(Q^2)}{n_u(Q^2)} = -0.208 \;\; (9\% \text{ error})$$

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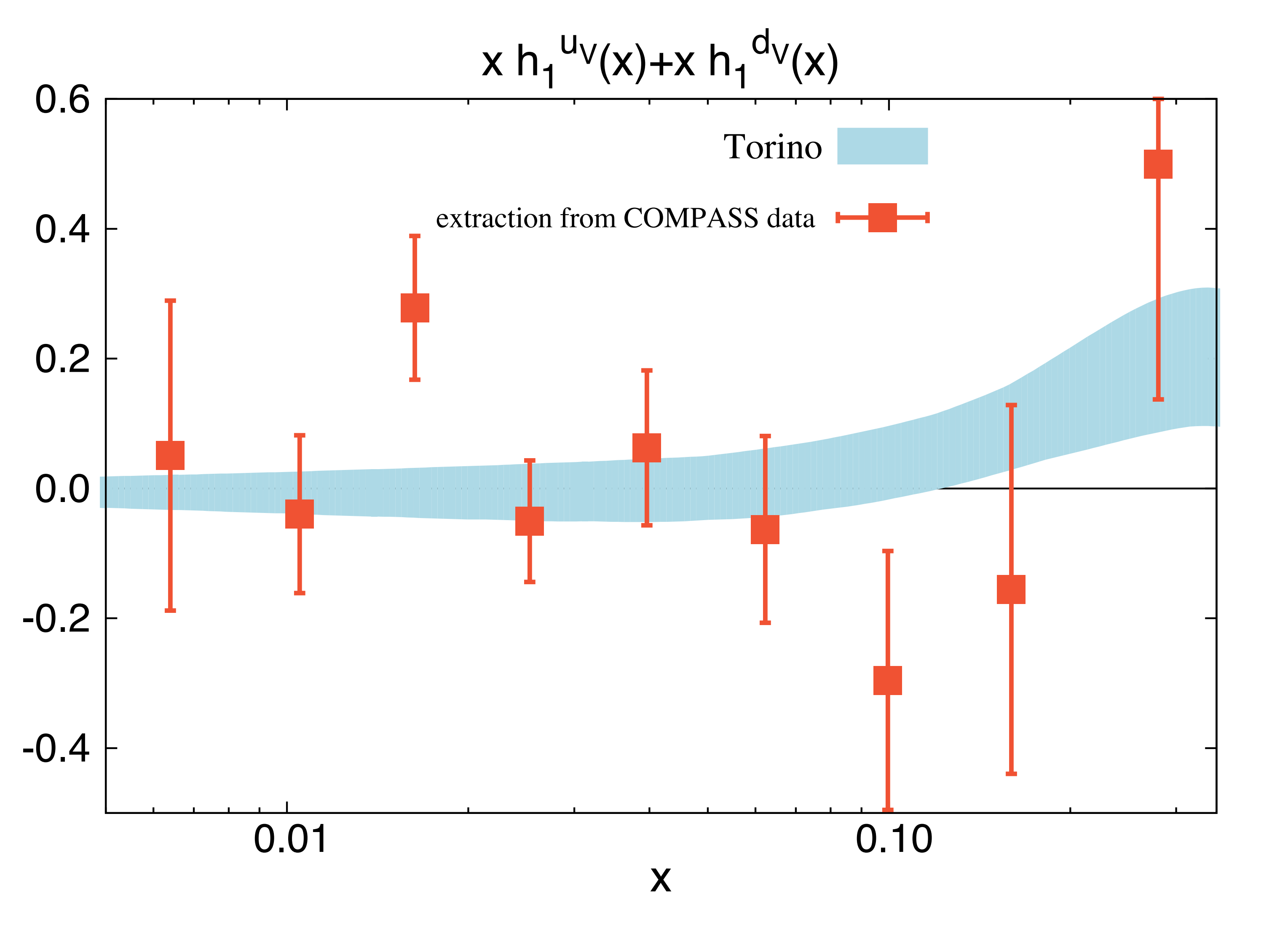

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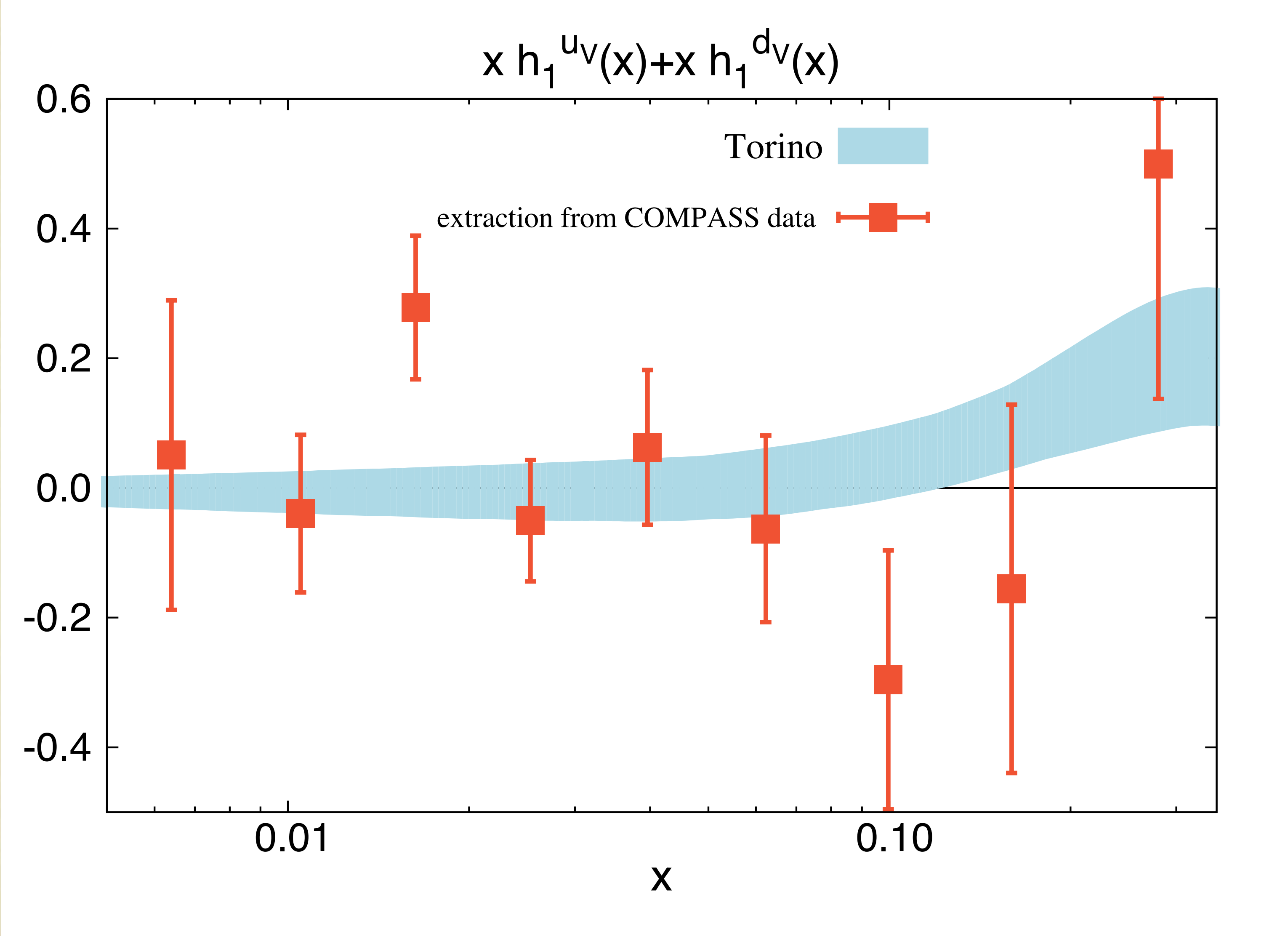

uncertainty band from Collins effect

*M.Anselmino et al., NP **B191** (Proc.Supp.) (09)*

2012 : the "collinear transversity fitting" era

combining proton and deuteron data

$\Rightarrow$ separate u_v and d_v components of h_1

$\Rightarrow$ separately fit each component

–

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$\Rightarrow$ separate u_v and d_v components of h_1

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<u>functional form</u>

$$x h_1^{q_v}(x) = \tanh\left[\sqrt{x}\,\left(A_q + B_q x + C_q x^2\right)\right]\,\left[\mathrm{SB}_q(x) + \mathrm{SB}_{\bar{q}}(x)\right]$$

–

Soffer bound

$$\mathrm{SB}_q(x) = \frac{1}{2}\,\left|f_1^q(x) + g_1^q(x)\right|$$

2012 : the "collinear transversity fitting" era

combining proton and deuteron data
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MSTW08LO DSSV

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$\mathrm{SB_q + SB_{\bar{q}}} \to \infty \quad x \to 0$
grants finite and stable tensor charge

Soffer bound

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MSTW08LO DSSV

2012 : the "collinear transversity fitting" era

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functional form

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$\mathrm{SB}_q + \mathrm{SB}_{\bar{q}} \to \infty$ $x \to 0$
grants finite and stable
tensor charge

"flexible" form (2 nodes)
we tried also
$(A_q + B_q\, x)$ "rigid" form

Soffer bound

$$\mathrm{SB}_q(x) = \frac{1}{2}\,\left|f_1^q(x) + g_1^q(x)\right|$$

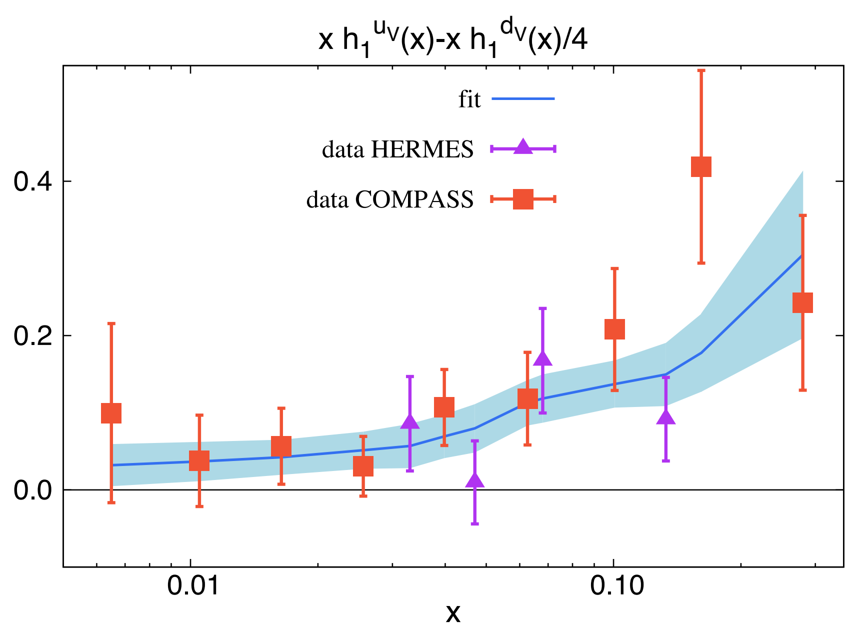
MSTW08LO DSSV

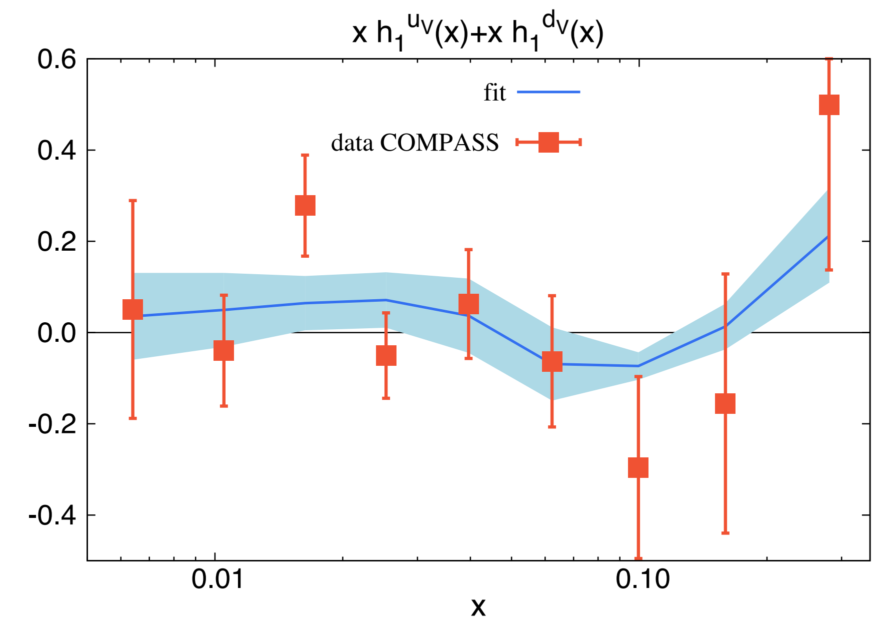
New results from fitting both p and D data
1) Hessian method

A. Bacchetta, A. Courtoy, M.R., in preparation

PROTON

DEUTERON

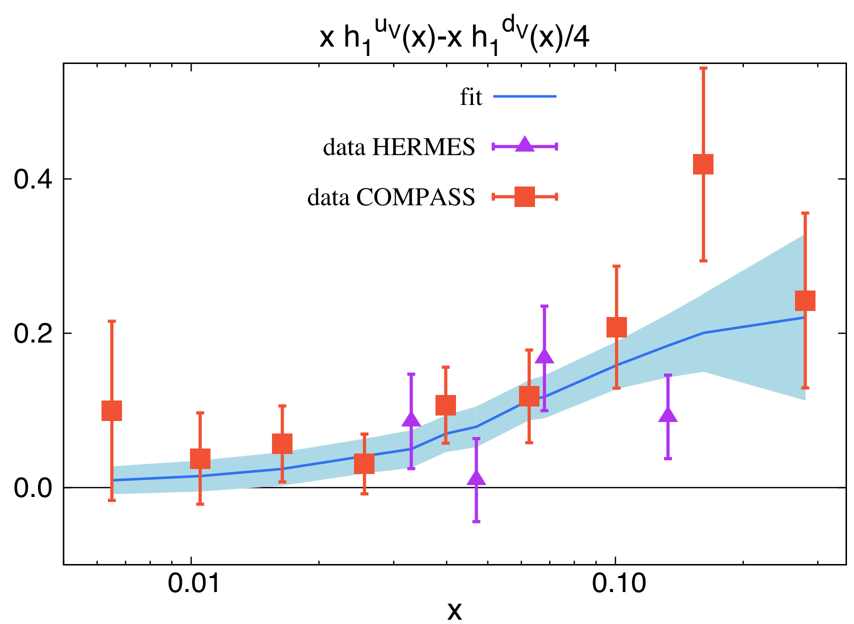


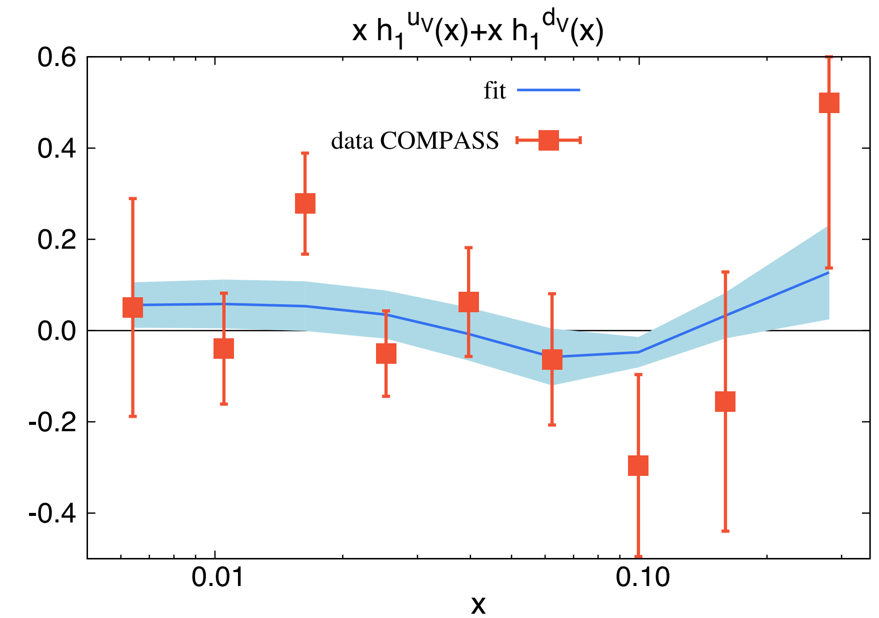


flexible functional form

$$\chi^2/\mathrm{dof} \sim 1.1$$

rigid functional form





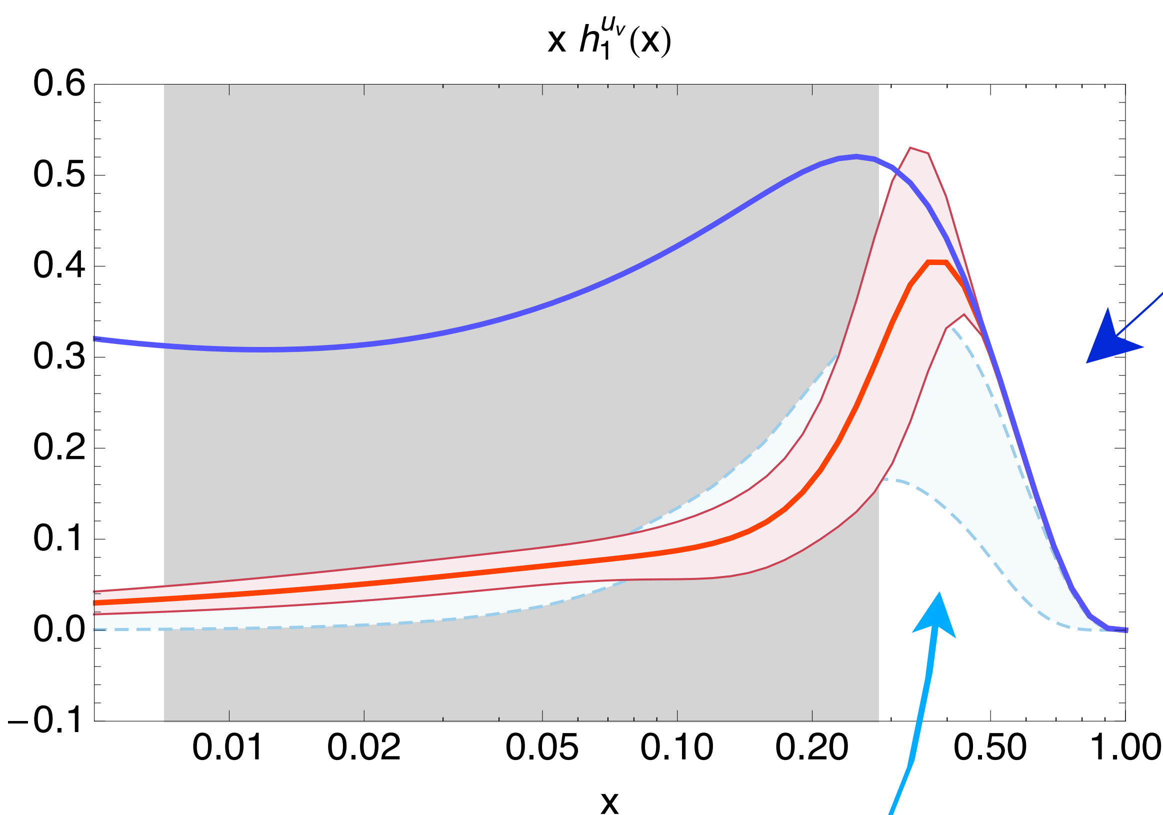
New results for $h_1^{u_v}$ and $h_1^{d_v}$

1) Hessian method

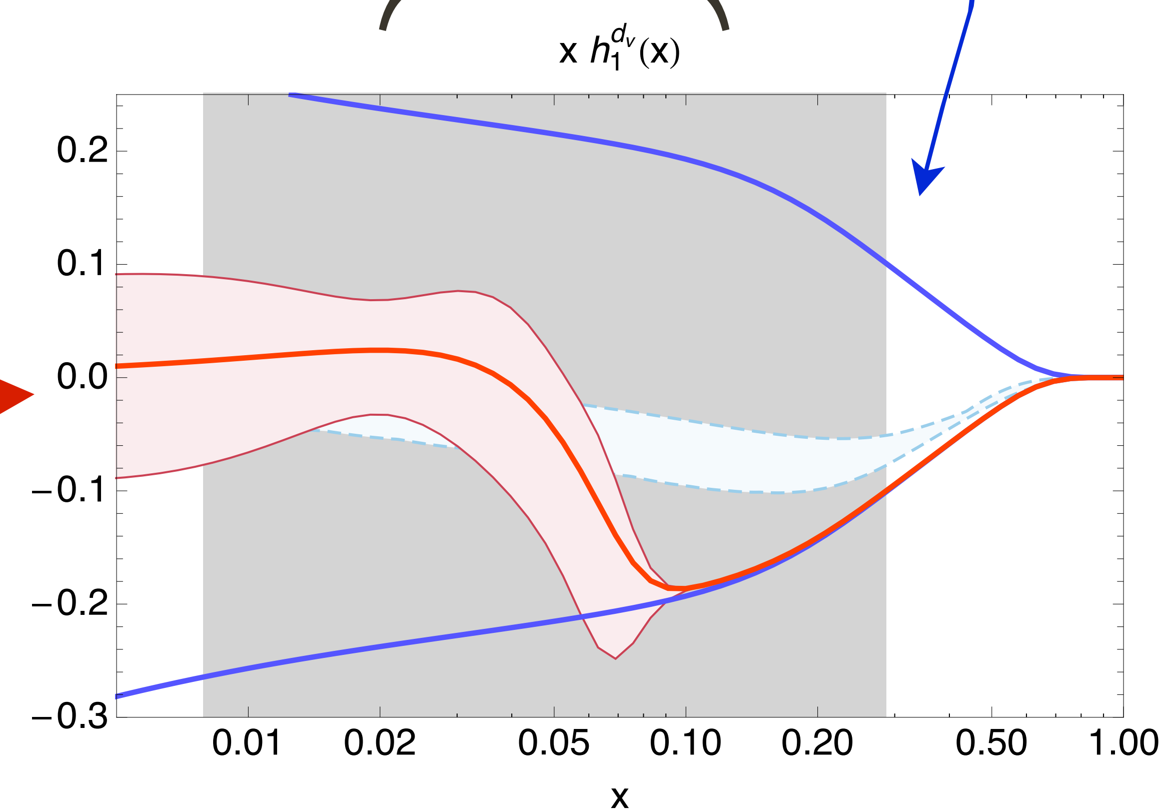
A. Bacchetta, A.Courtoy, M.R., in preparation

"flexible" form

Soffer Bound @ 2.4 GeV^2



data



Band: Torino 2009 transversity

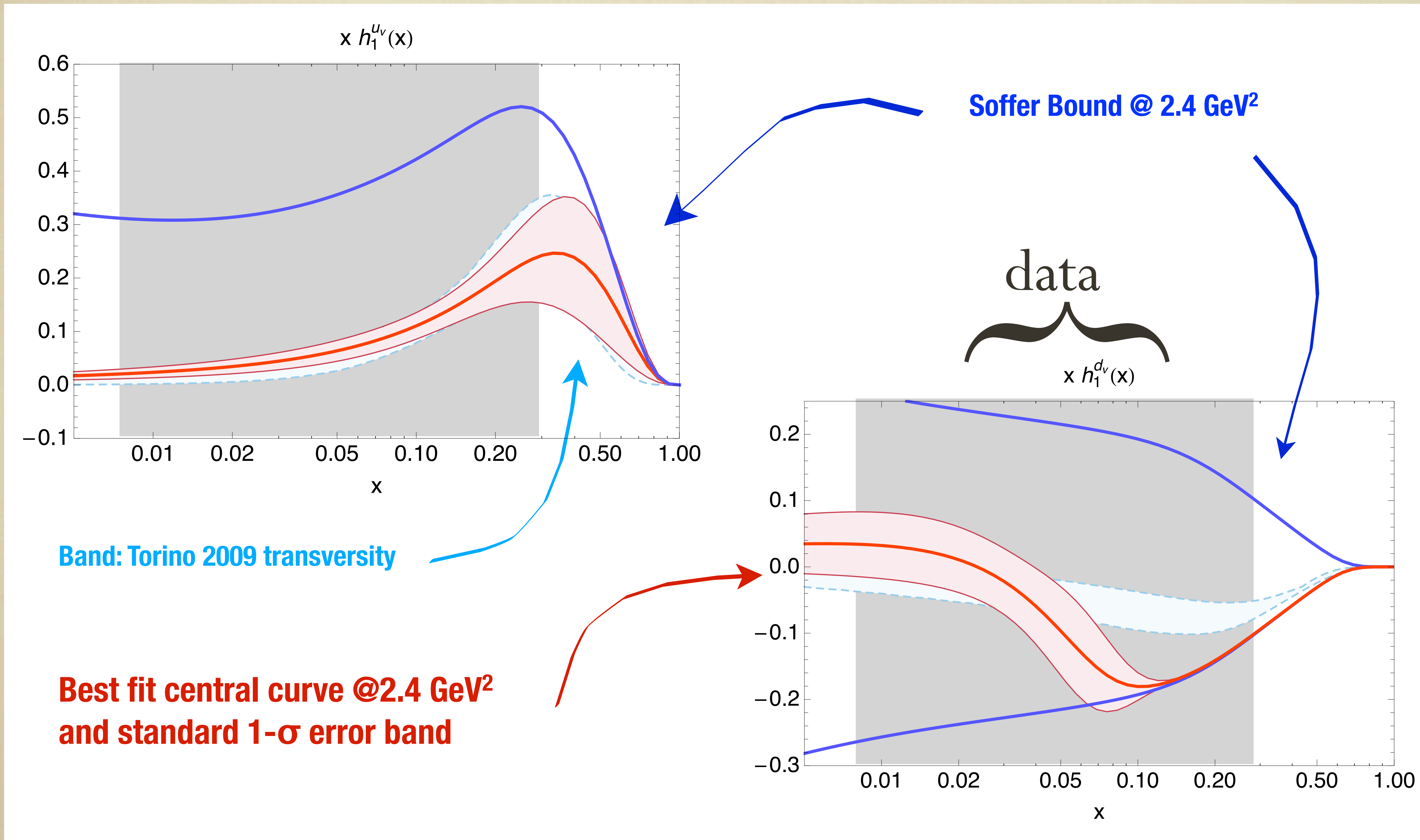
Best fit central curve @2.4 GeV^2 and standard 1-σ error band

New results for $h_1^{u_v}$ and $h_1^{d_v}$

1) Hessian method

A. Bacchetta, A. Courtoy, M.R., in preparation

"rigid" form



New results from fitting both p and D data
2) Monte Carlo method

A. Bacchetta, A.Courtoy, M.R., in preparation

1. generate N replicas of data with Gaussian noise at 1σ
2. choose N such that keep same mean and std. deviation of data
3. fit N times the data $\Rightarrow$ N different transversities
4. take 1σ confidence interval of the whole set
   (if Gaussian-distributed, it's = 68%)

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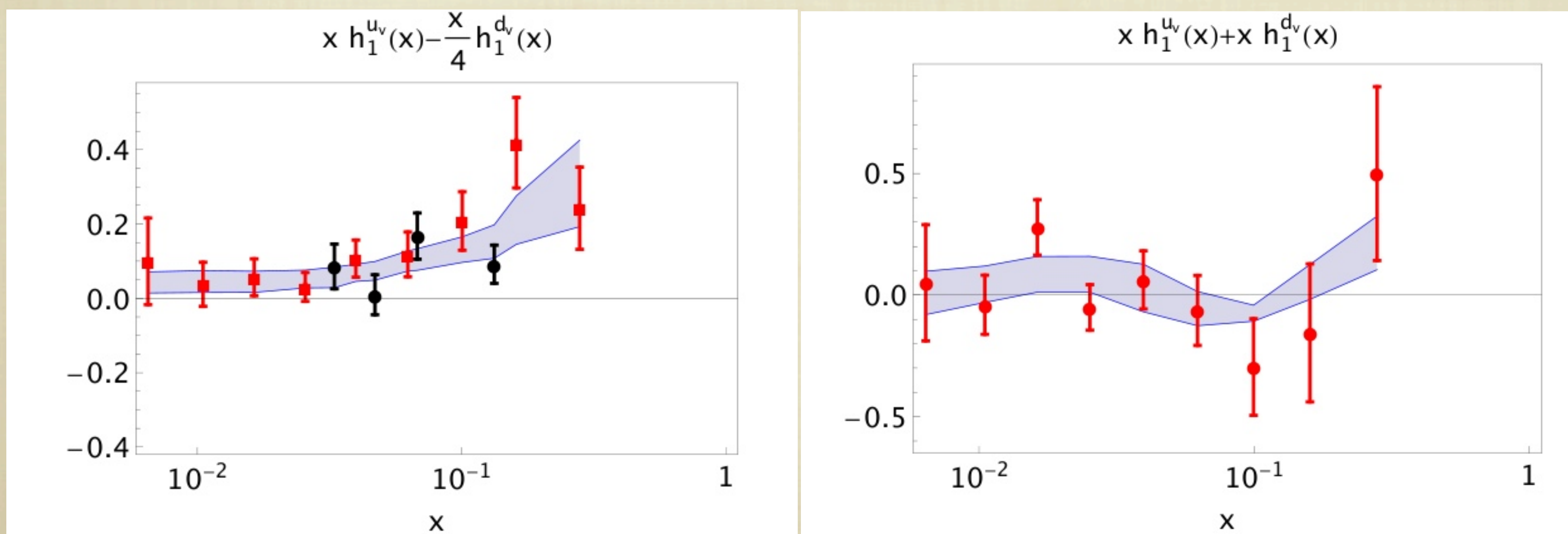

"flexible" form

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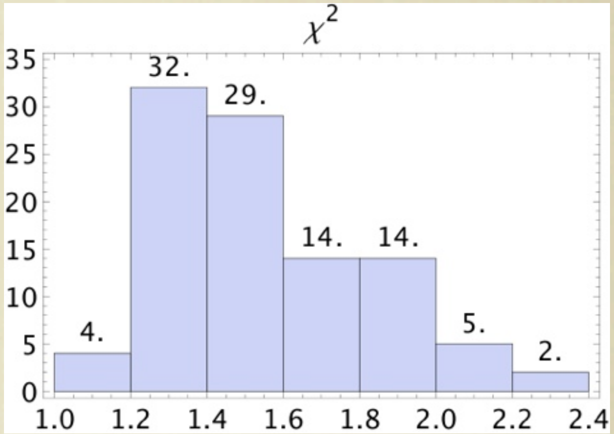
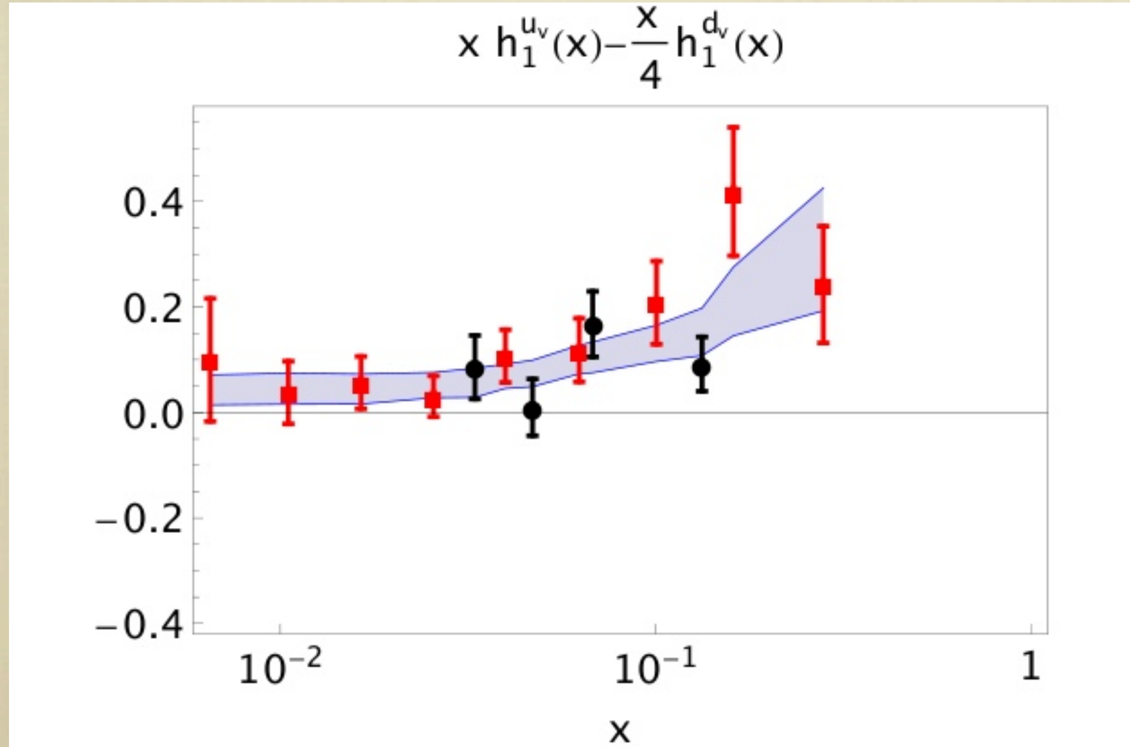
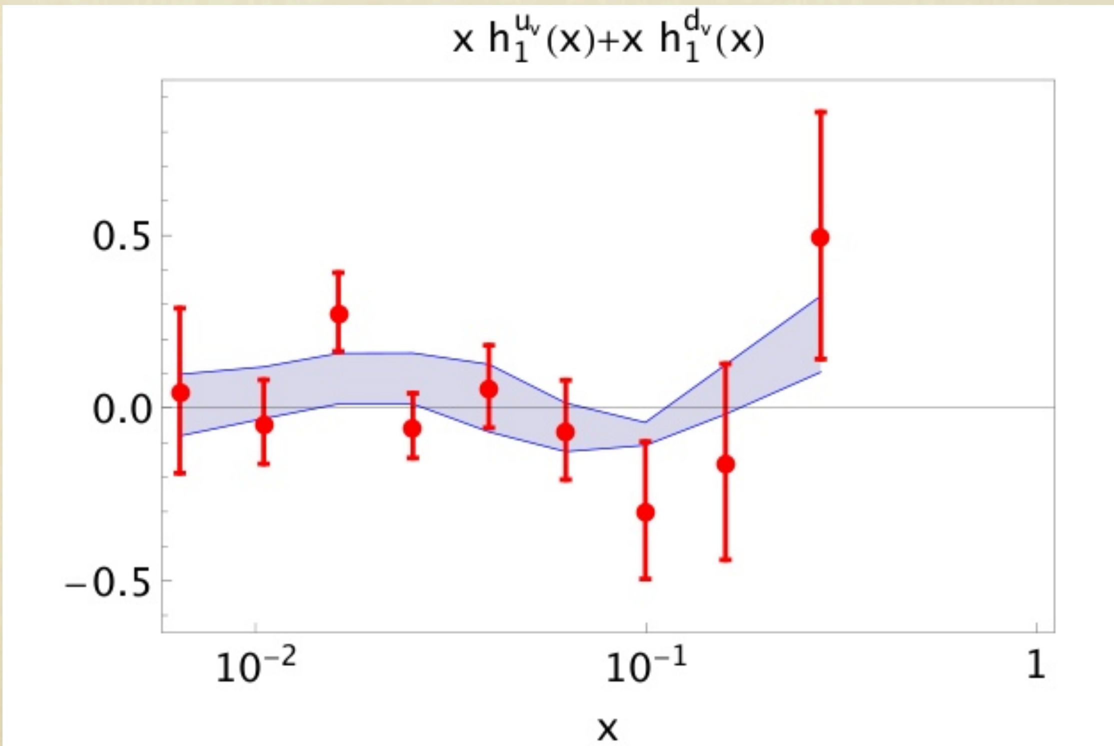
   (if Gaussian-distributed, it's = 68%)







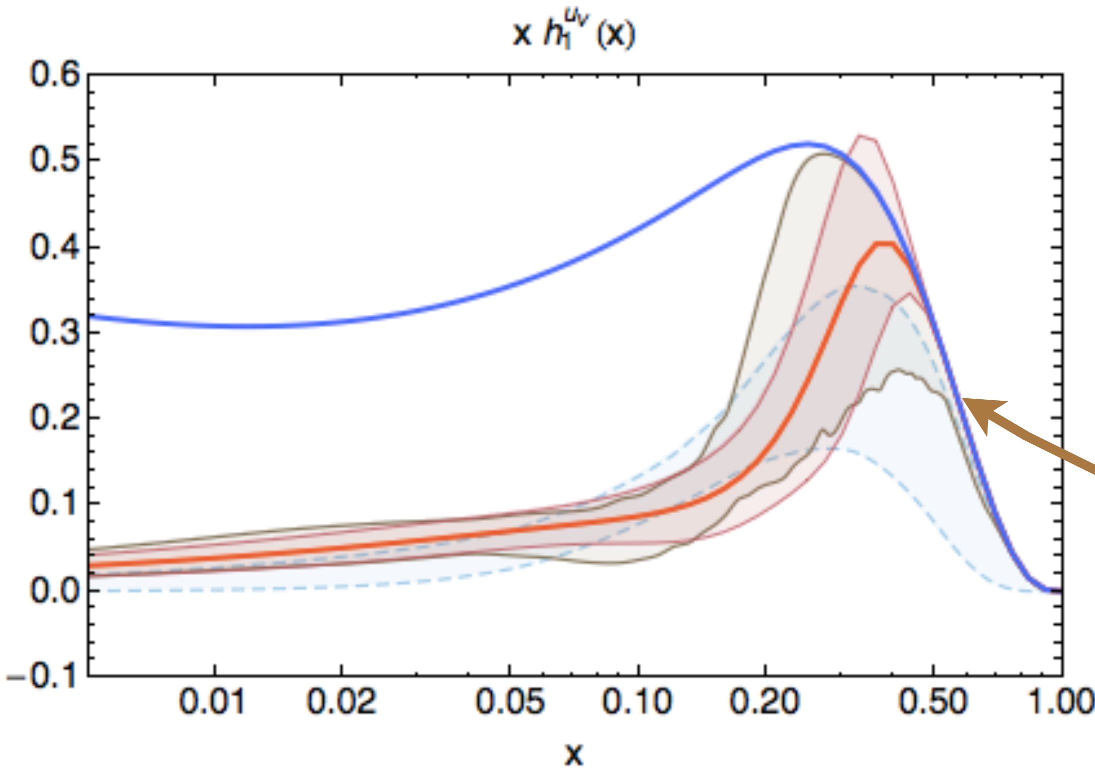
"flexible" form

New results for $h_1^{u_v}$ and $h_1^{d_v}$

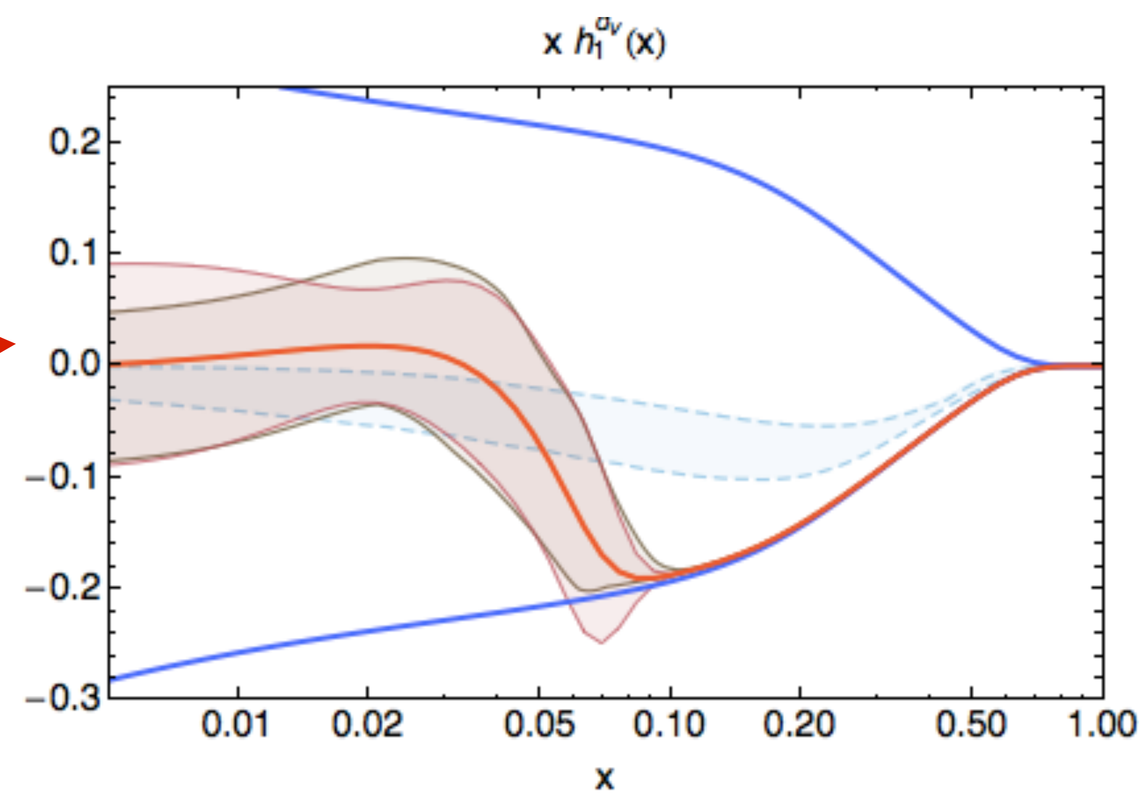
2) Monte Carlo method

A. Bacchetta, A.Courtoy, M.R., in preparation

“flexible” form



1σ error band from replicas @2.4 GeV^2



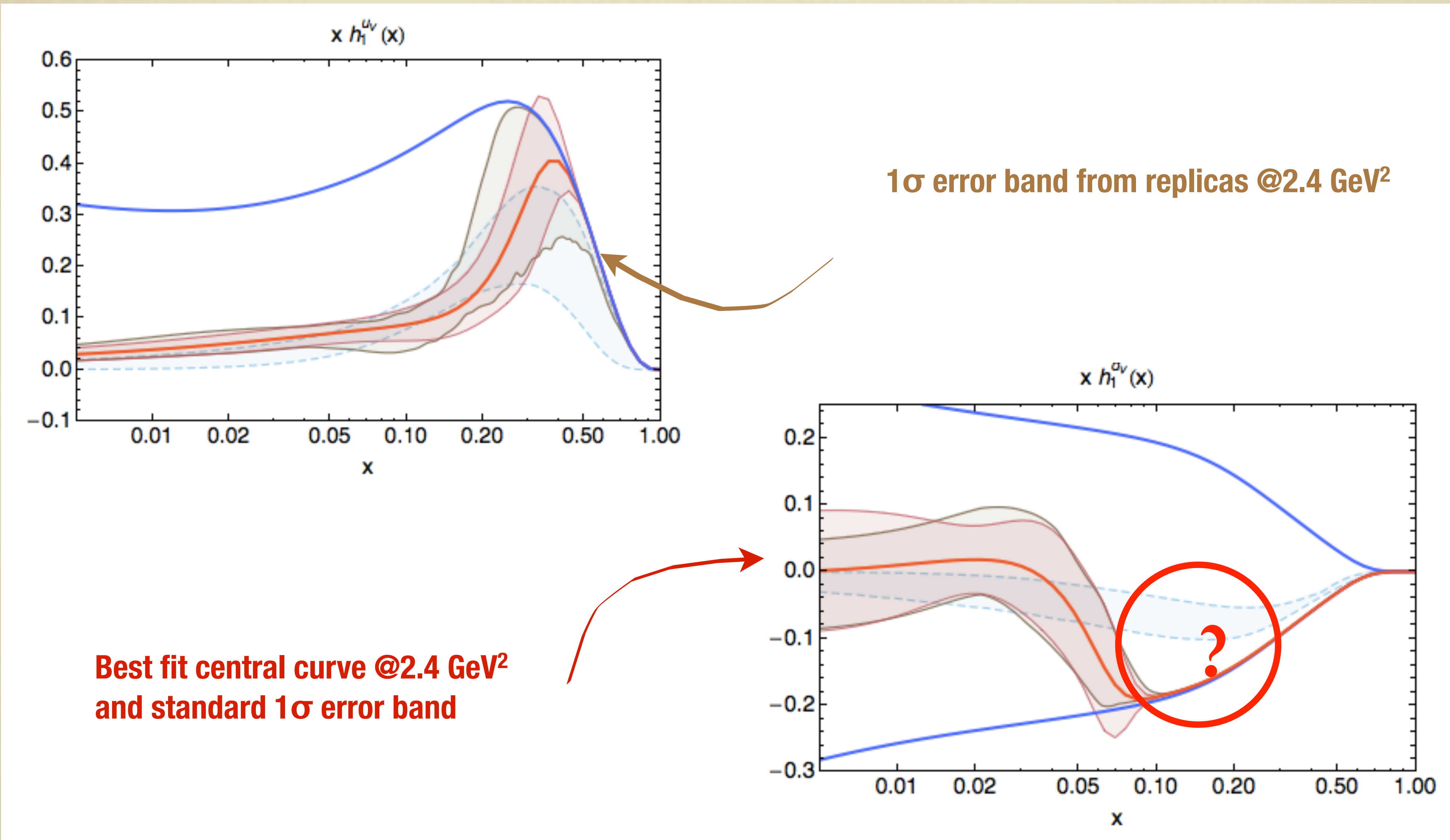
Best fit central curve @2.4 GeV^2
and standard 1σ error band

New results for $h_1^{u_v}$ and $h_1^{d_v}$

2) Monte Carlo method

A. Bacchetta, A.Courtoy, M.R., in preparation

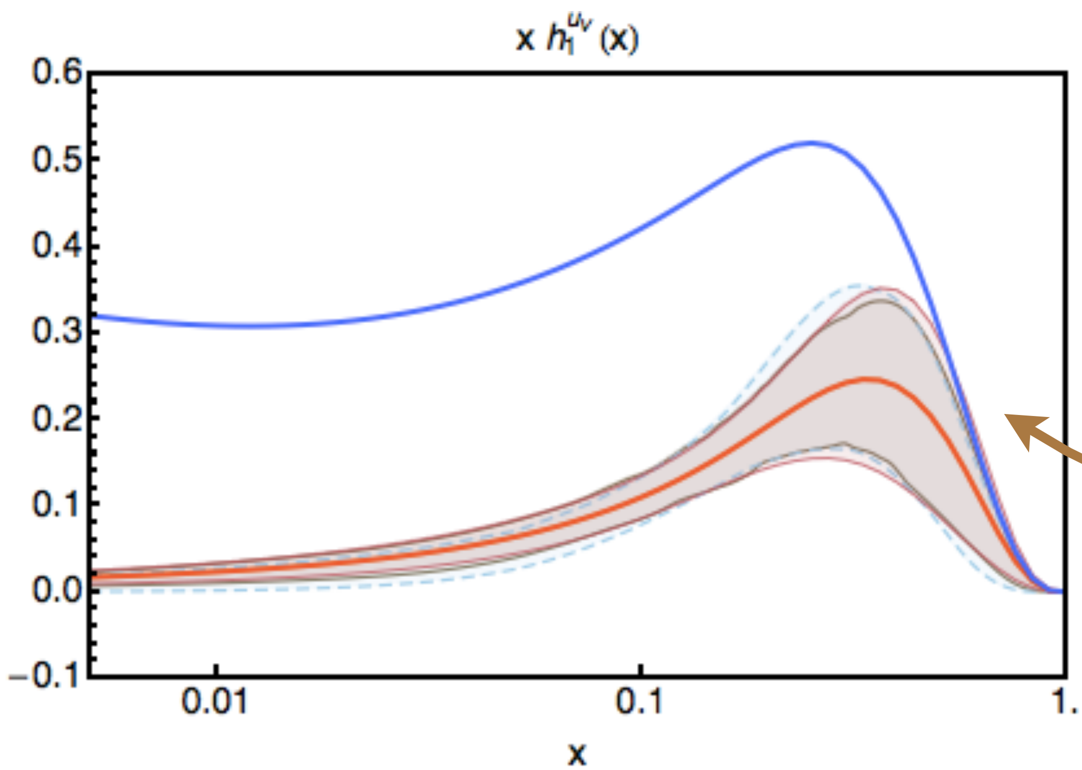
"flexible" form



New results for $h_1^{u_v}$ and $h_1^{d_v}$
2) Monte Carlo method

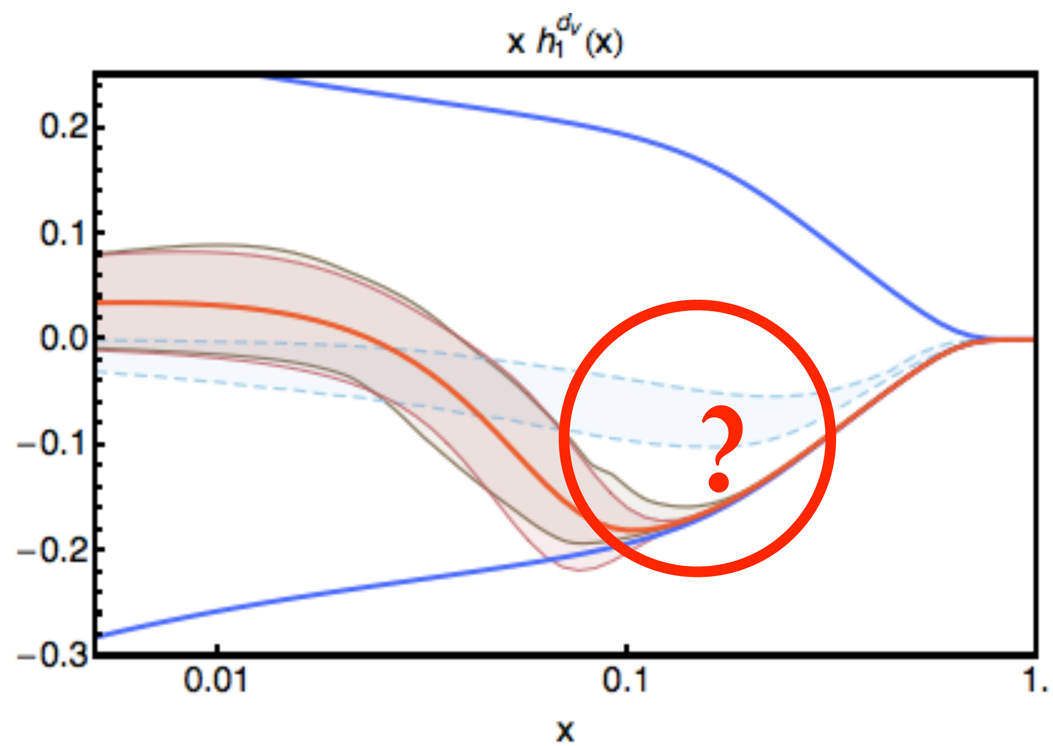
A. Bacchetta, A.Courtoy, M.R., in preparation

"rigid" form

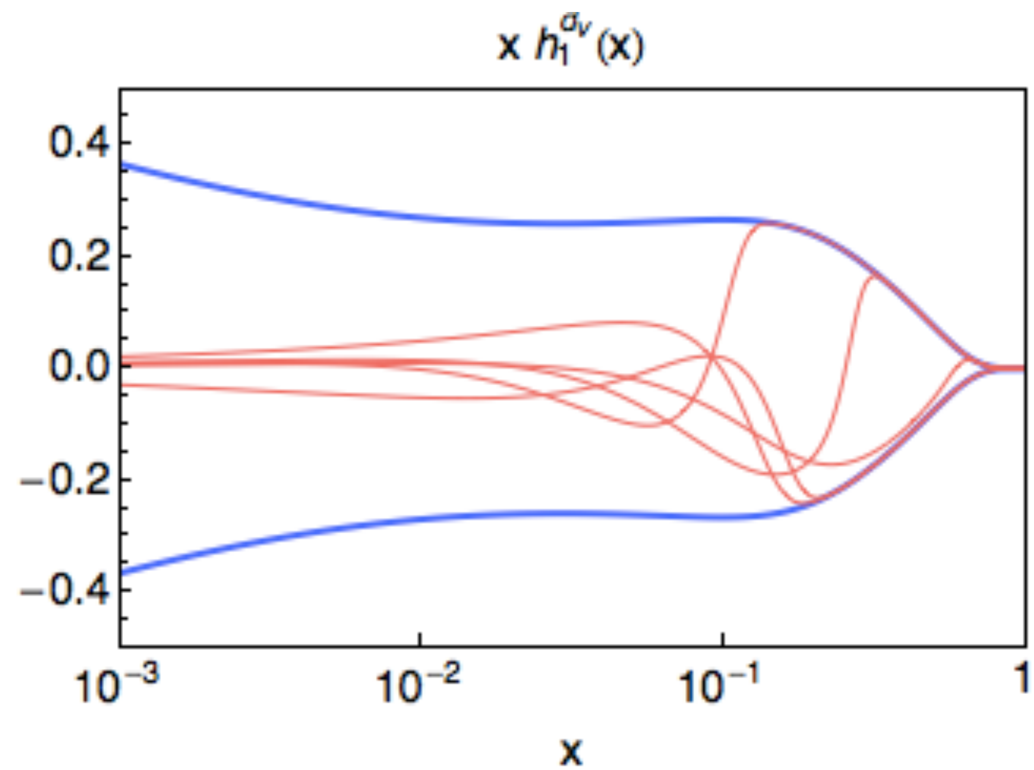


1σ error band from replicas @2.4 GeV²

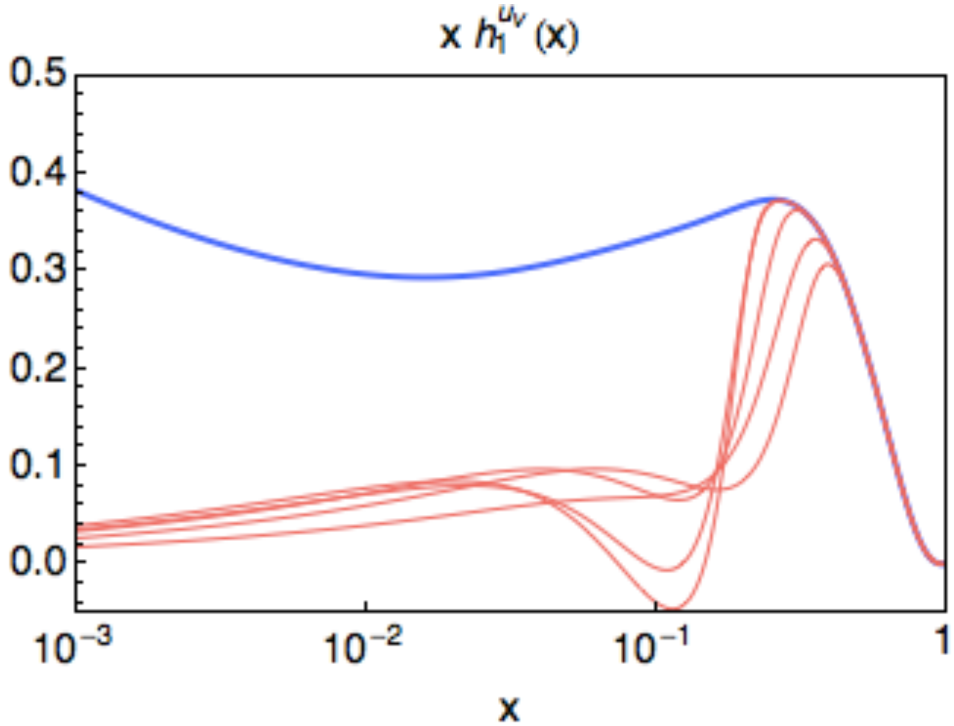
Best fit central curve @2.4 GeV²
and standard 1σ error band



Can we find “unforeseen” replica?



Yes, here at 1GeV^2

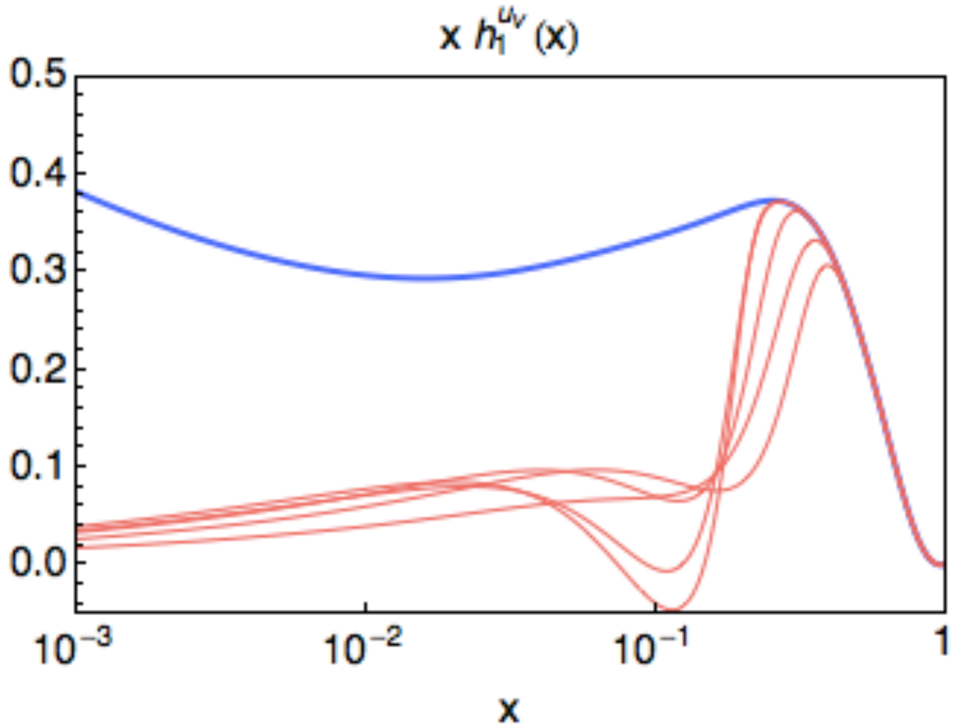


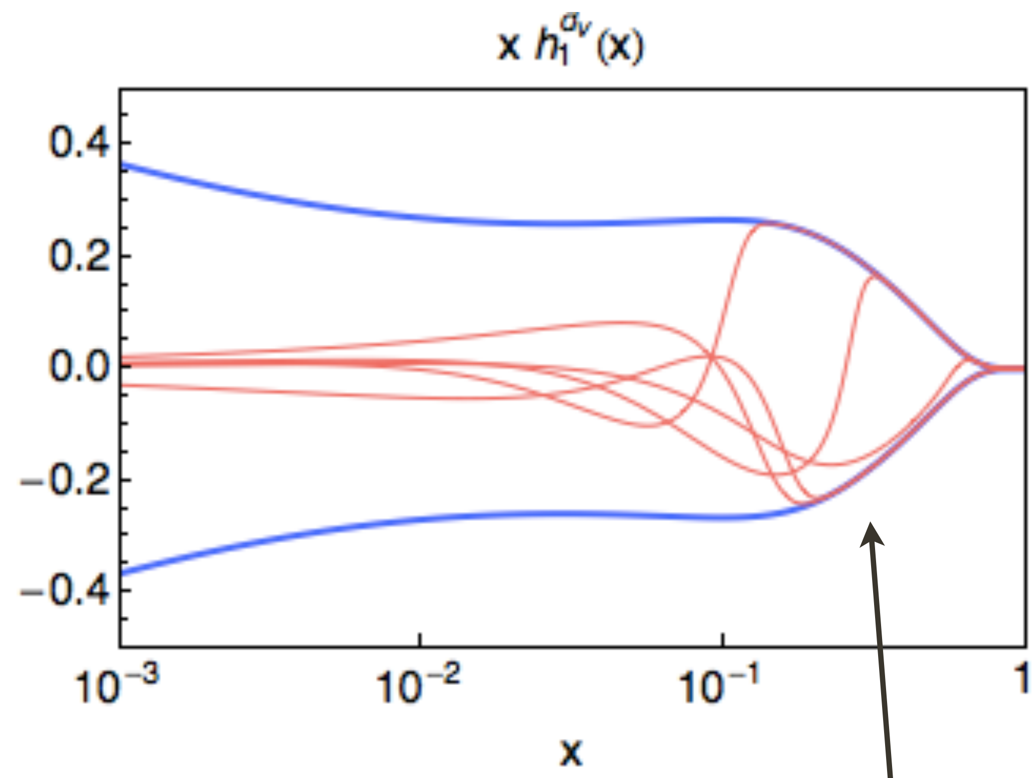
X^2/dof

1.56557
1.42199
1.79911
2.07397
1.75523

Can we find “unforeseen” replica?

Yes, here at 1GeV^2

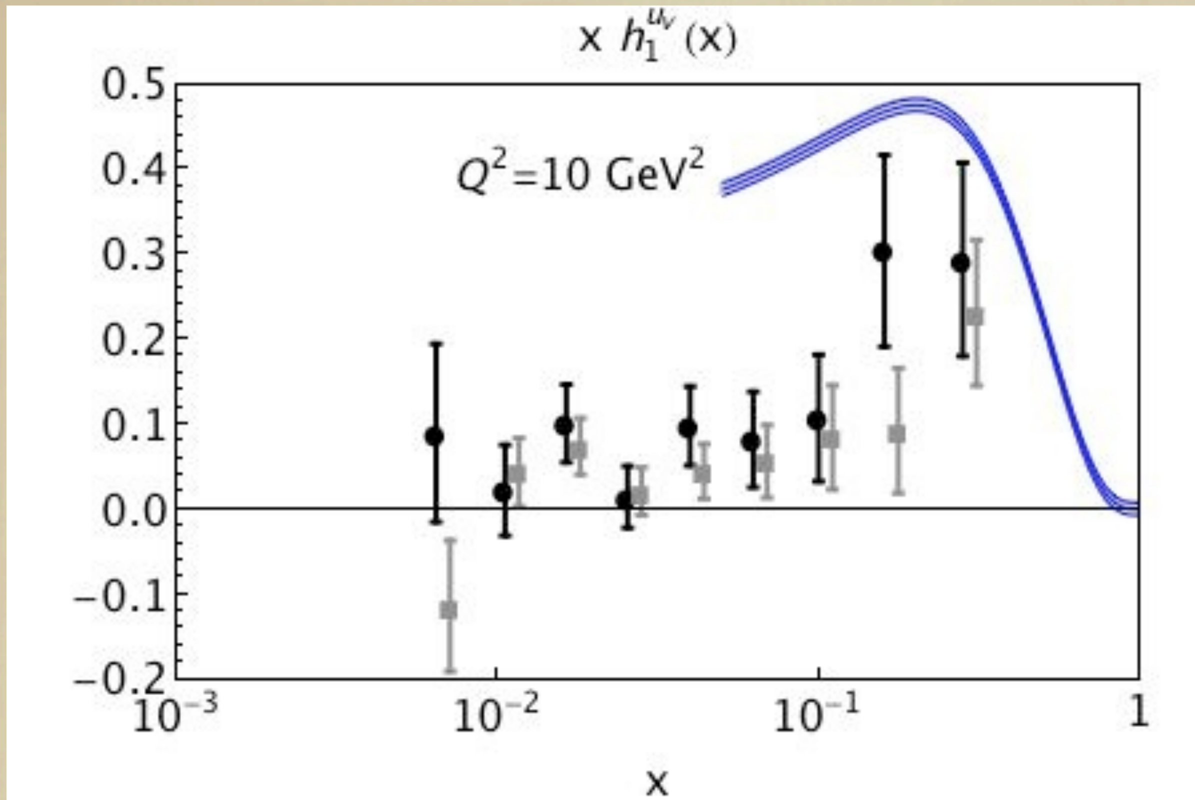


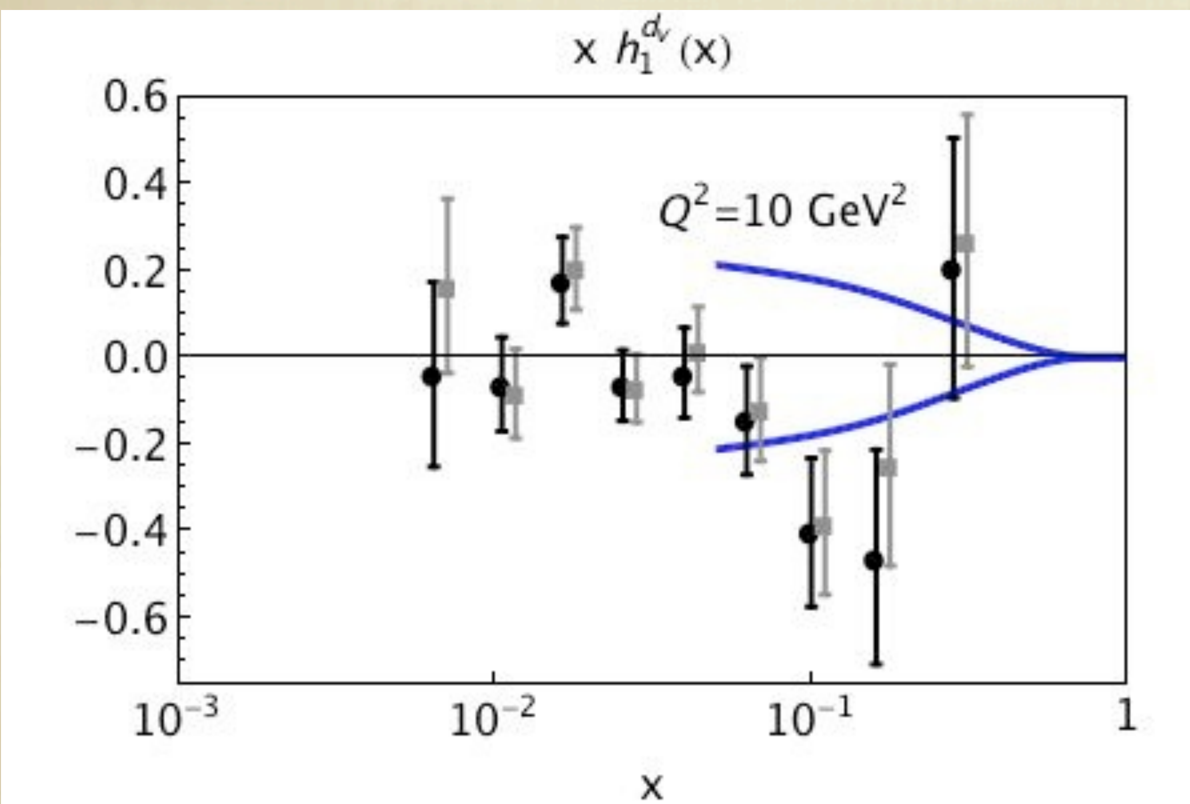


X^2/dof

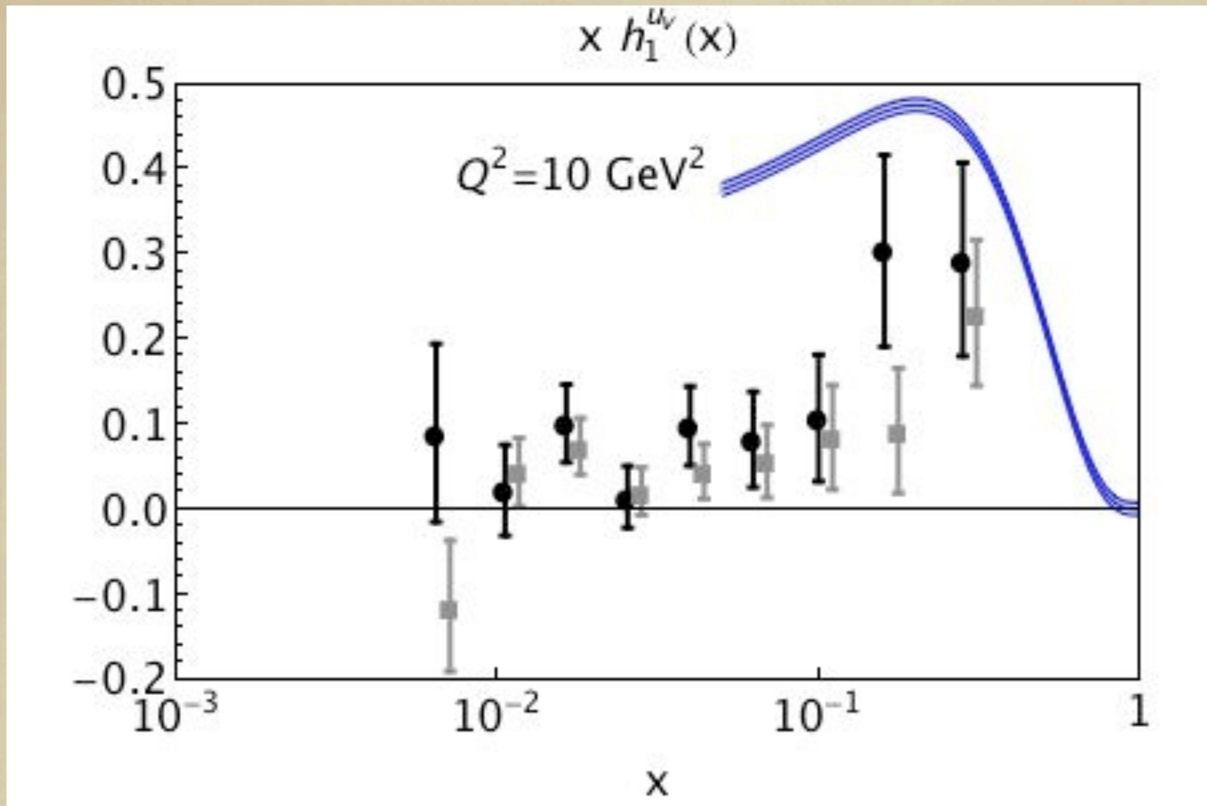
1.56557
1.42199
1.79911
2.07397
1.75523

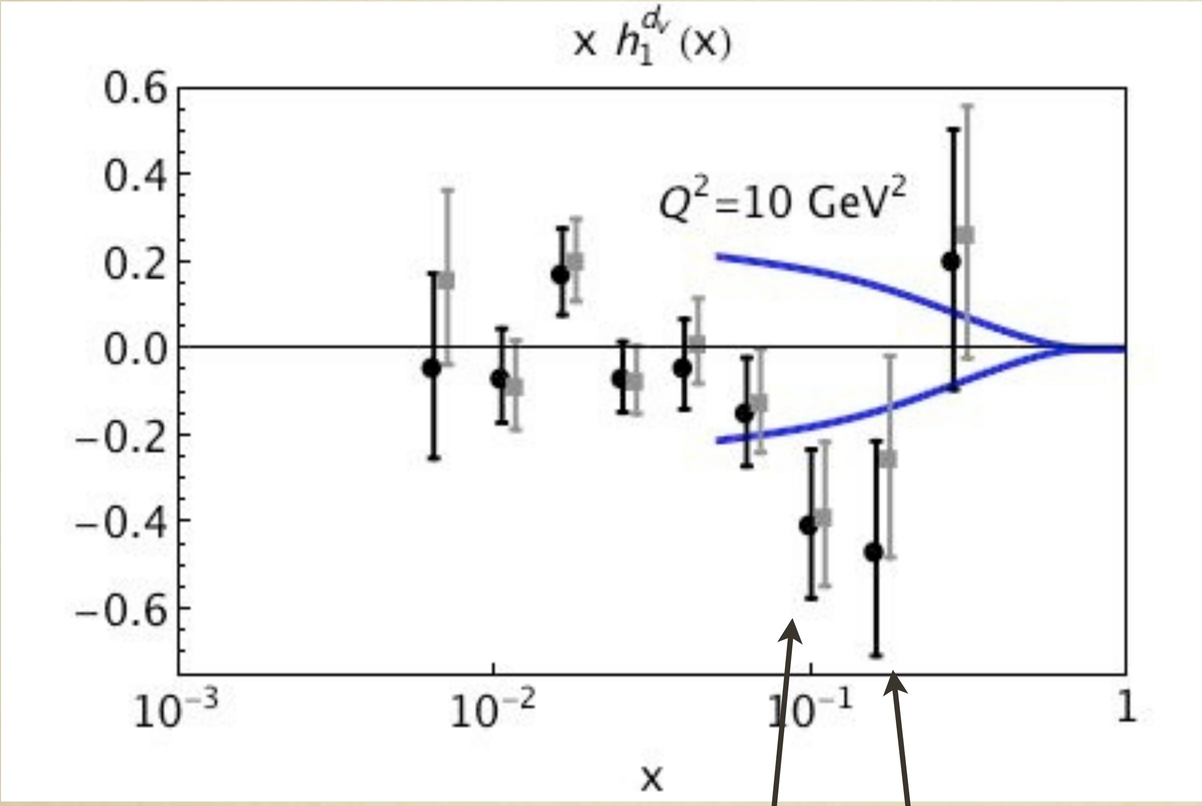
but most replicas “want” to merge
to lower Soffer bound,
driven by deuteron data





- Compass 2007 p + 2004 D
- Compass 2010 p + 2004 D





$Q^2 \sim 9$, 15 GeV^2

Soffer bound evolved at Q^2=10 GeV^2 including error estimate Δg_1 from

De Florian, Sassot, Stratmann, Vogelsang, PR D80 (09)

- Compass 2007 p + 2004 D
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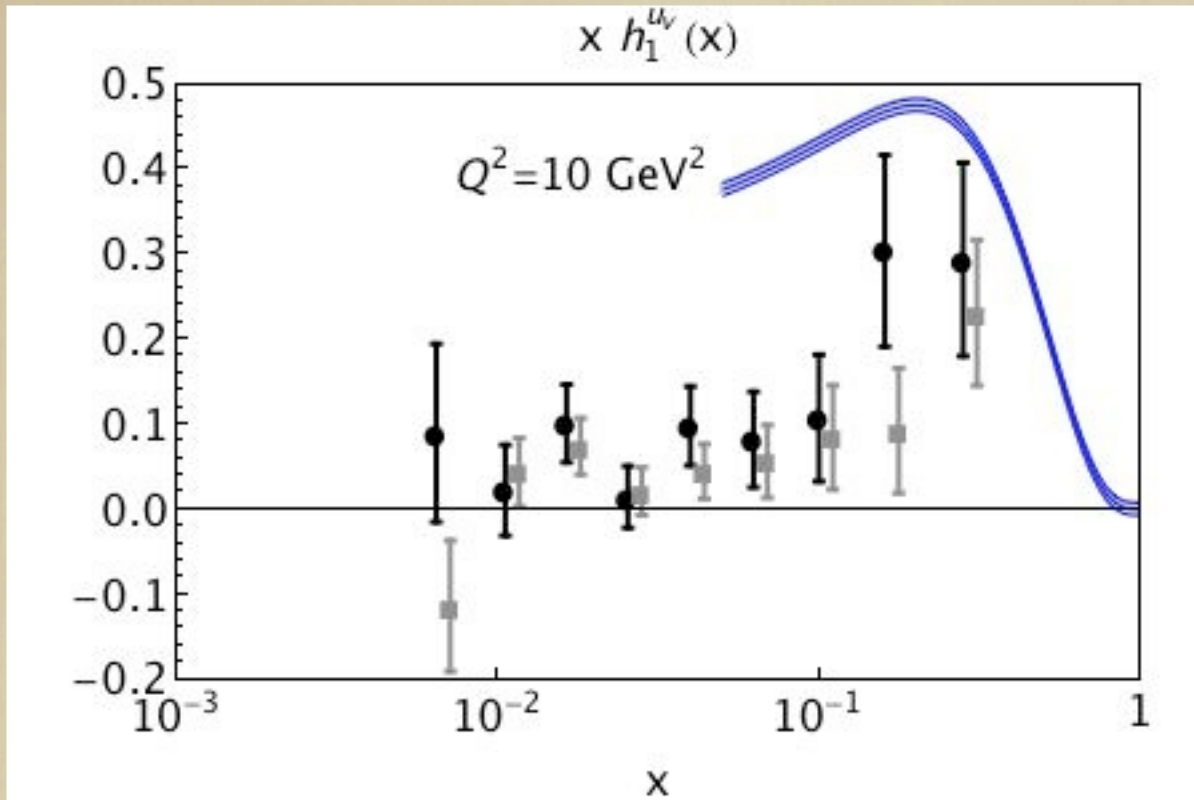
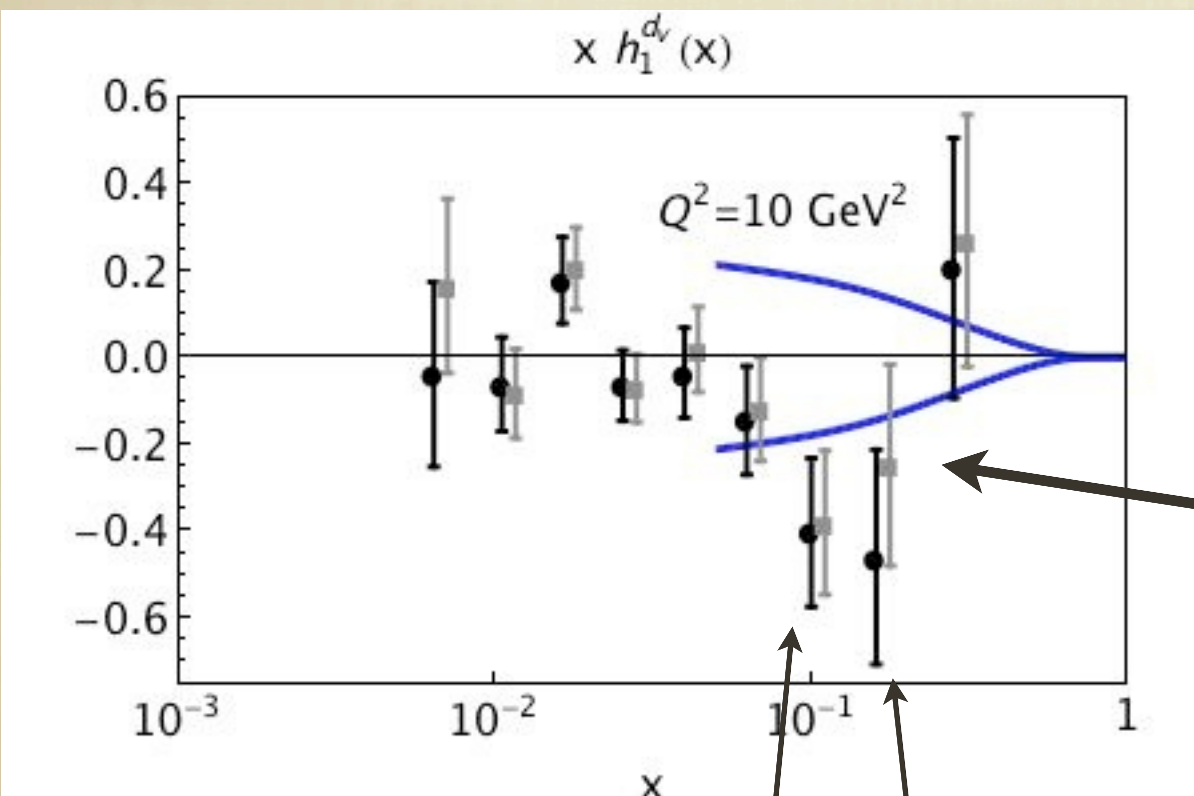




Soffer bound evolved at Q^2=10 GeV^2 including error estimate Δg_1 from

De Florian, Sassot, Stratmann, Vogelsang, PR D80 (09)

- Compass 2007 p + 2004 D
- Compass 2010 p + 2004 D

is there anything going on ?

$Q^2 \sim 9$, 15 GeV^2

see Ralston, arXiv:0810.0871

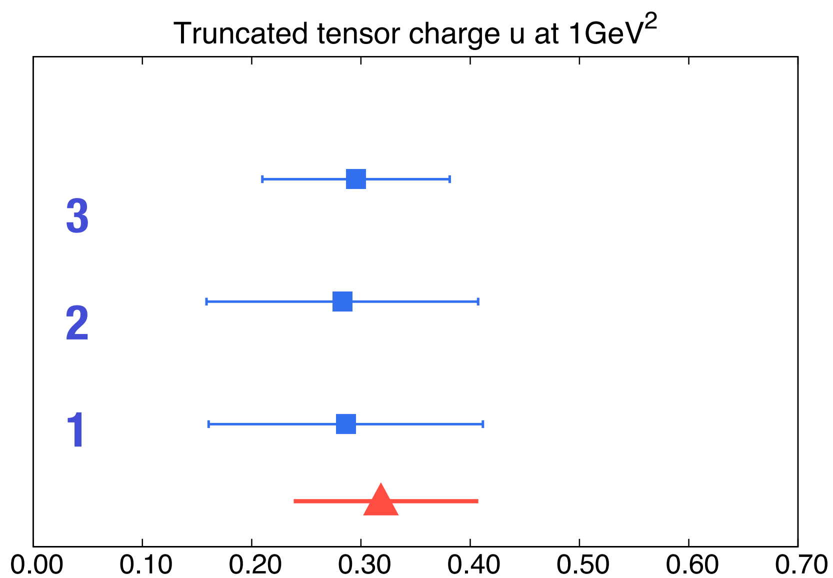
A confining gauge theory violates the completeness of asymptotic states held as foundation points of the *S*-matrix. Spin-dependent experiments can yield results that appear to violate quantum mechanics. The point is illustrated by violation of the Soffer bound in *QCD*....

tensor charges

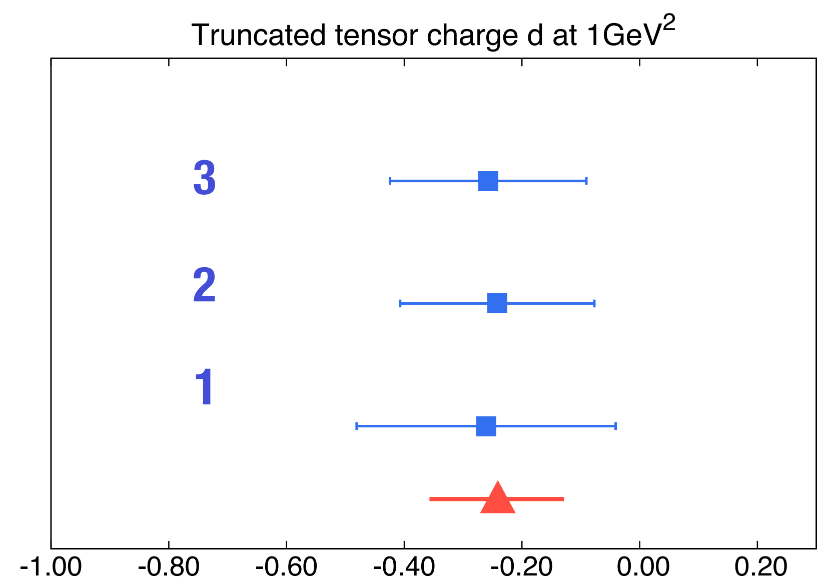
A. Bacchetta, A.Courtoy, M.R., in preparation

Tensor Charge

where we have data



$$\delta q = \int_{6.4\times10^{-3}}^{0.28} dx\, h_1^q(x)$$



1-flexible
2-hybrid
3-rigid

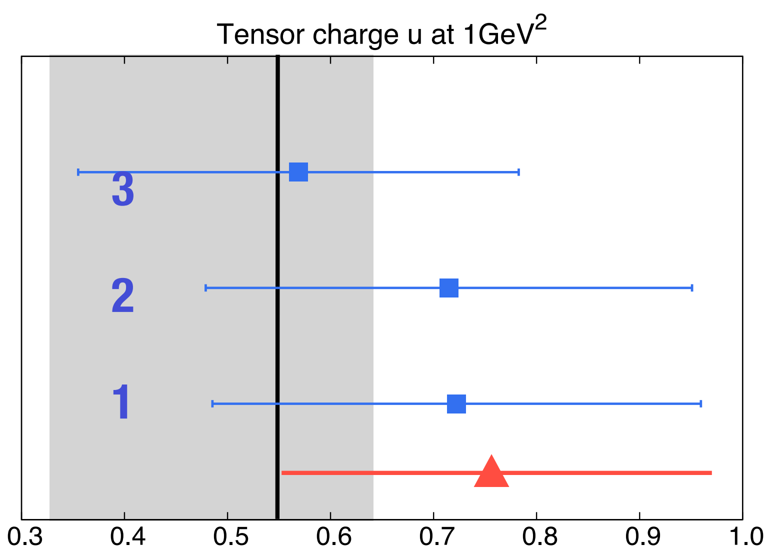
MC flexible

tensor charges

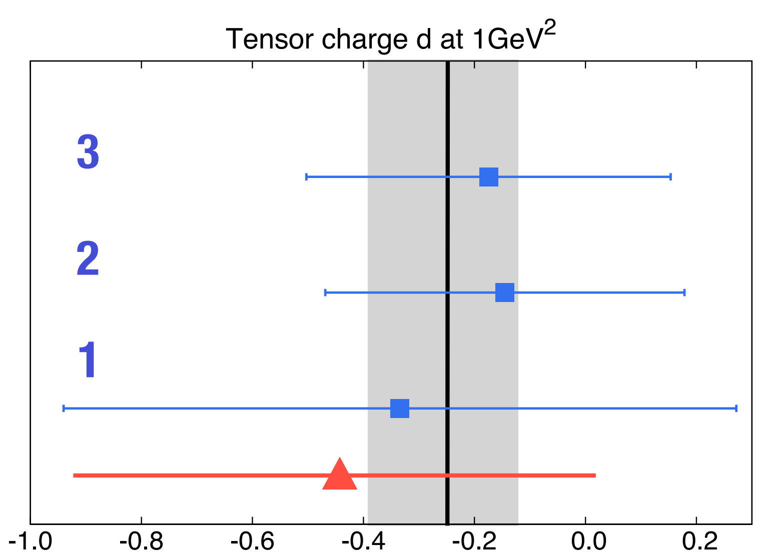
A. Bacchetta, A. Courtoy, M.R., in preparation

Tensor Charge

full range 10^{-10}- 1



Torino result @ different scale (0.8 GeV^2)



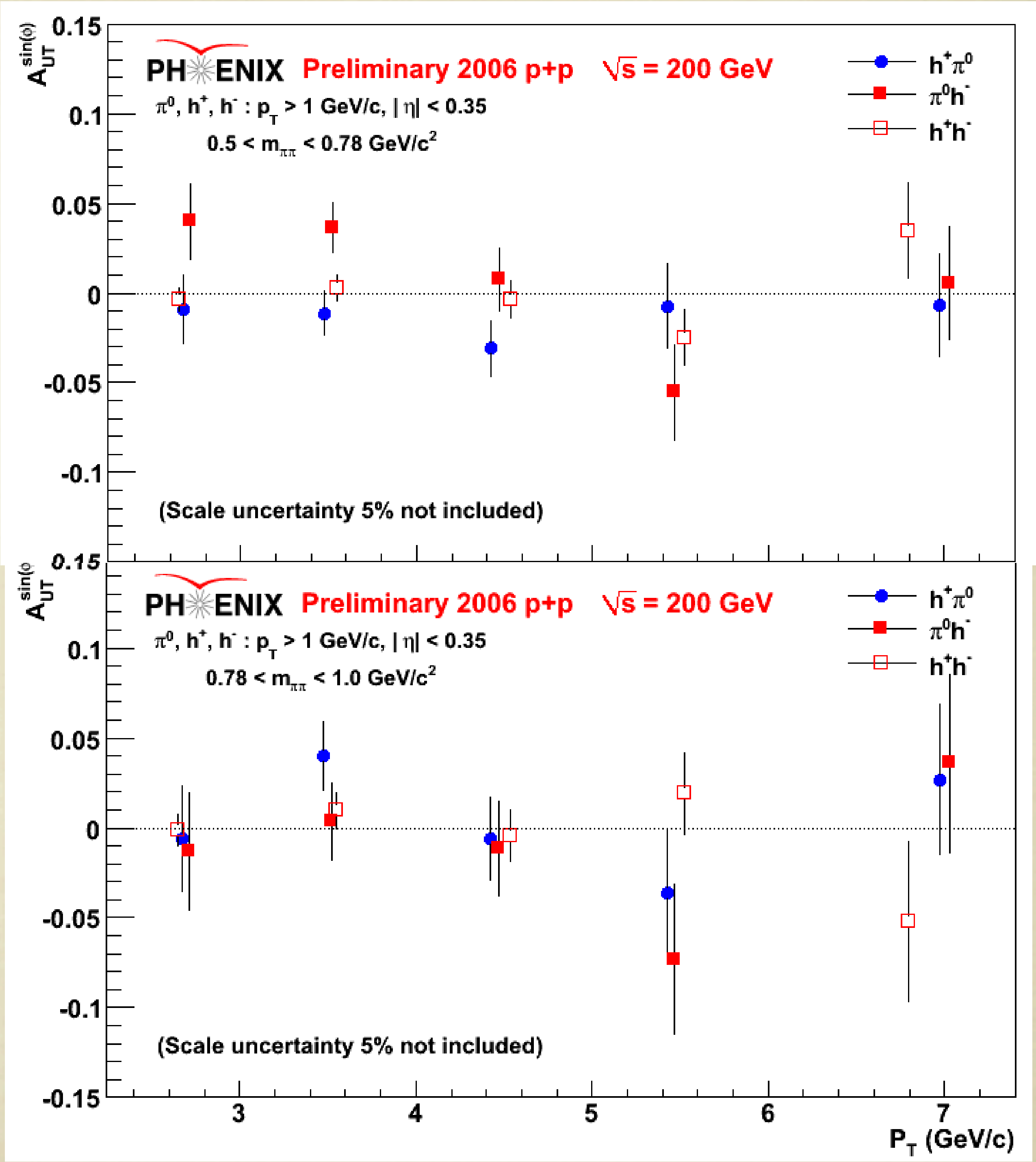
1-flexible
2-hybrid
3-rigid

MC flexible

Future ?

PHENIX data

R.Yang, Beijing Transversity Workshop (08)



work on predictions for
$pp^{\uparrow} \rightarrow (\pi^+\pi^-)X$
still in progress..

Status of transversity studies