Dihadron fragmentation functions

Alessandro Bacchetta, in collaboration with M. Radici

Funded by

3DSPIN
MAPPING
THE PROTON IN 3D

erc
European Research Council

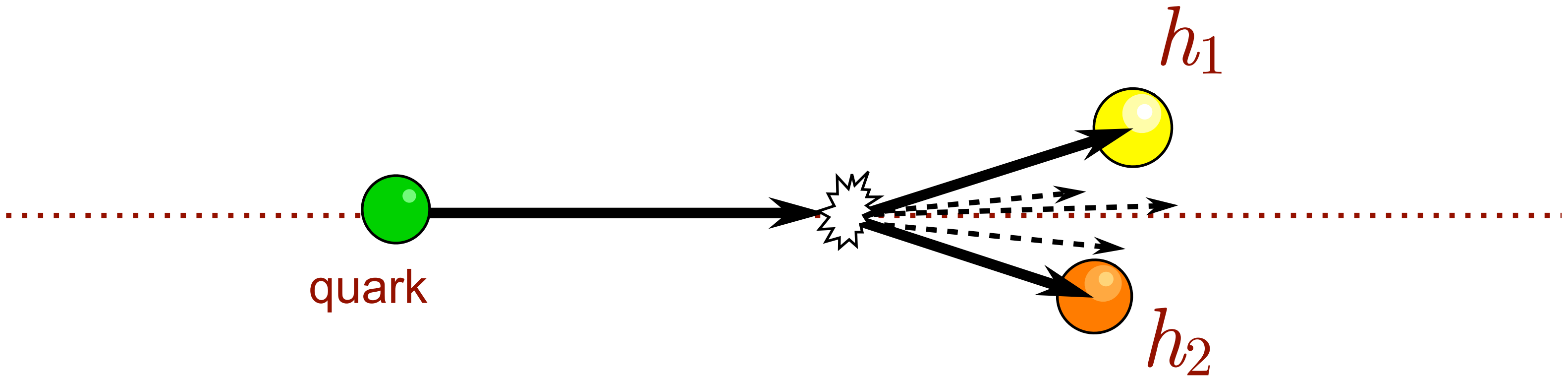
INFN
Istituto Nazionale
di Fisica Nucleare

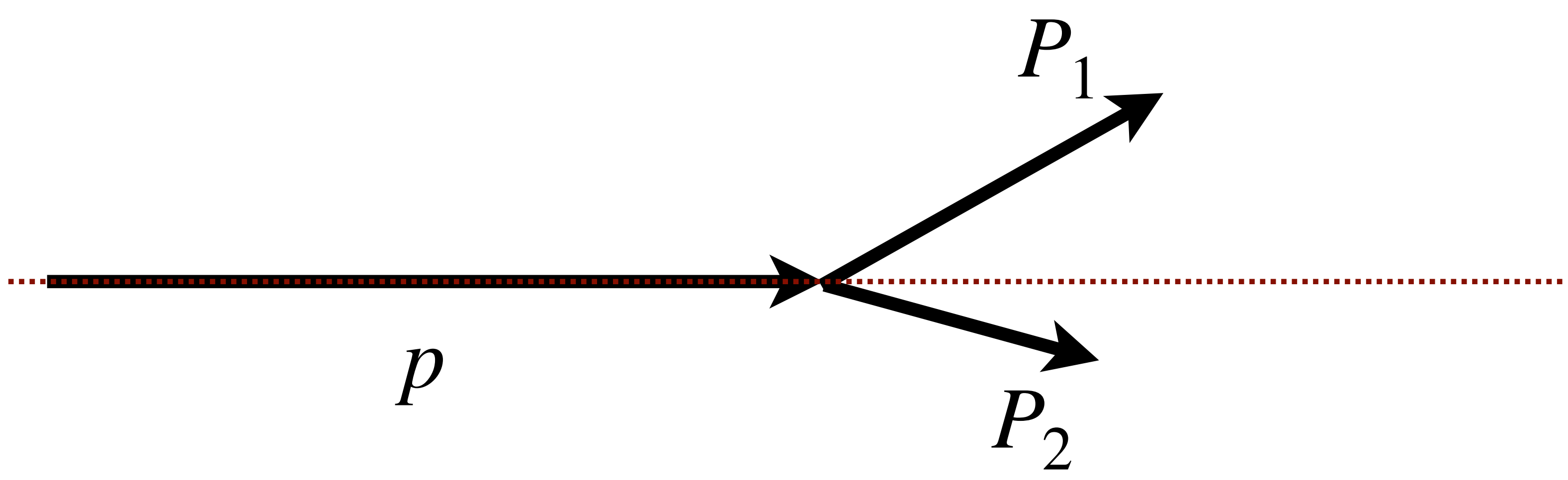
UNIVERSITÀ
DI PAVIA

Outline

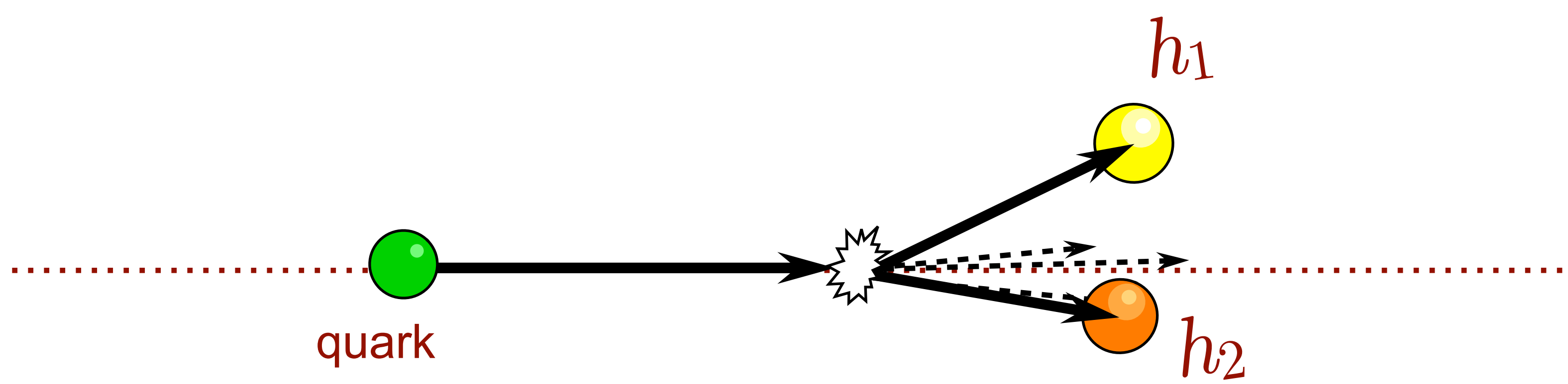
- Part 1: transversity from dihadron fragmentation functions
- Part 2 (brainstorming): analogies between dihadron fragmentation functions and hadron-in-jet fragmentation functions

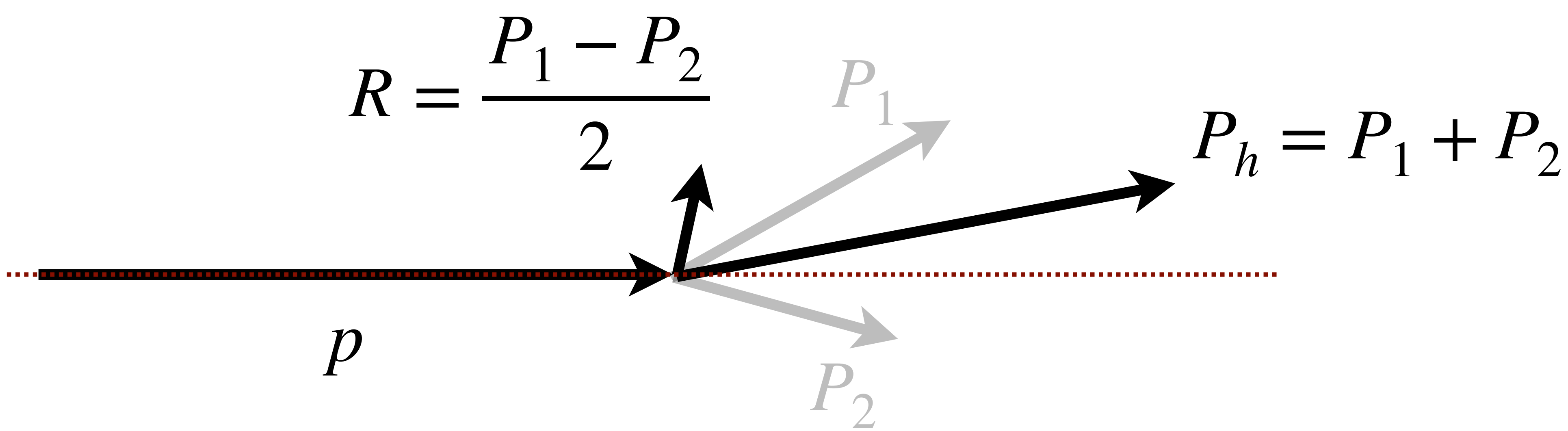
Vectors in dihadron production



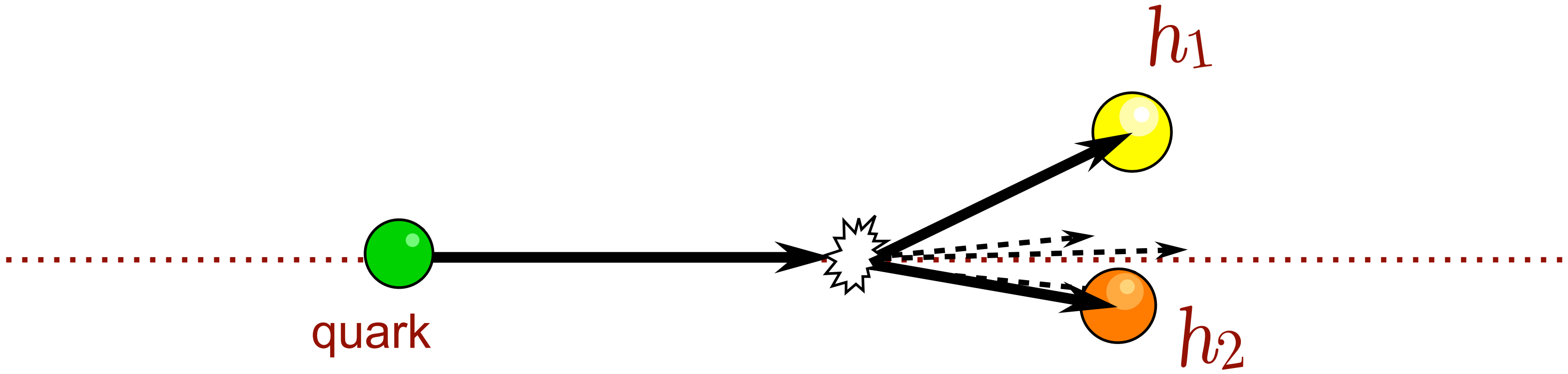


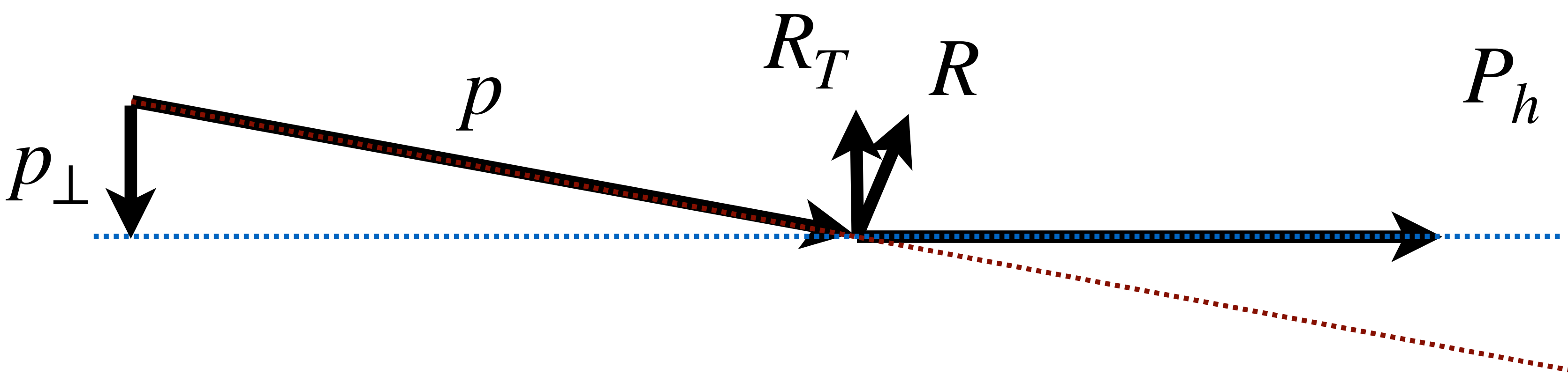
Vectors in dihadron production





Vectors in dihadron production





(Leading-twist) TMD dihadron FFs

Bianconi, Boffi, Jakob, Radici, hep-ph/9907475
Matevosyan et al., arXiv:1802.01578

	D_1
$(s_T \times R_T) \cdot P_h$	$H_1^{\sphericalangle}$
$(s_T \times p_\perp) \cdot P_h$	$H_1^{\perp}$
$(p_\perp \times R_T) \cdot s_L$	$G_1^{\perp}$

Red functions are T-odd

In this situation, beside the transverse quark spin (s_T), we have two transverse vectors

One of them is the parton transverse momentum, requiring TMD factorization

Collinear dihadron FFs

D_1

$\left(s_T \times R_T\right) \cdot P_h$ $\qquad H_1^{\sphericalangle}$

A.k.a. "interference fragmentation function"

In this situation, beside the transverse quark spin, we have only one transverse vector

The parton transverse momentum is not involved and collinear factorization can be used

TMD single-hadron FFs

D_1

$(s_T \times p_\perp) \cdot P_h$ $H_1^\perp$

In this situation, we have again only one transverse vector

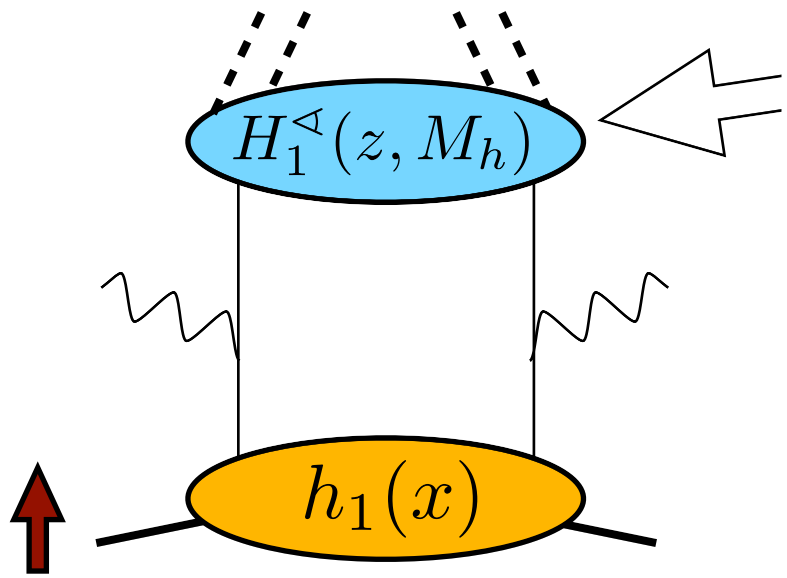
Since it is the parton transverse momentum, TMD factorization is required

The nicest application of DiFFs (so far)

DiFFs offer the possibility of accessing transversity and tensor charge in collinear factorization

Semi-inclusive DIS

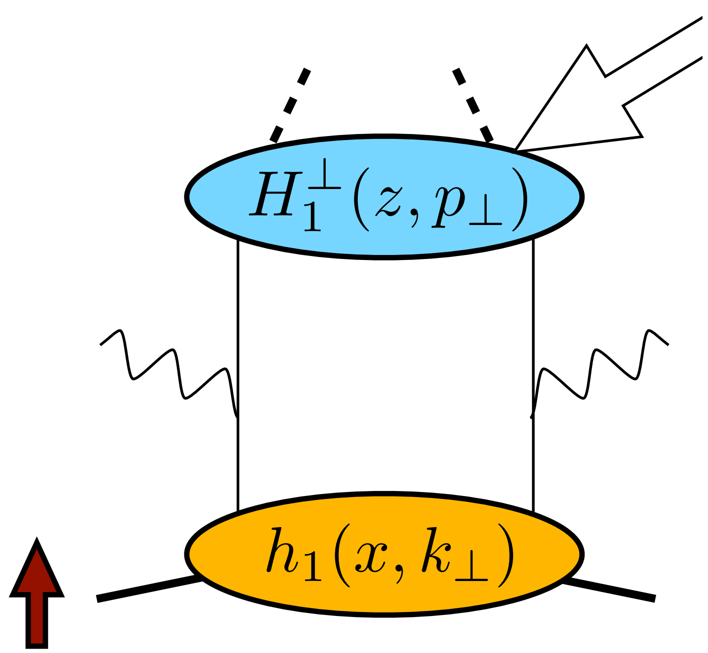
Collinear
factorization



dihadron
interference FF

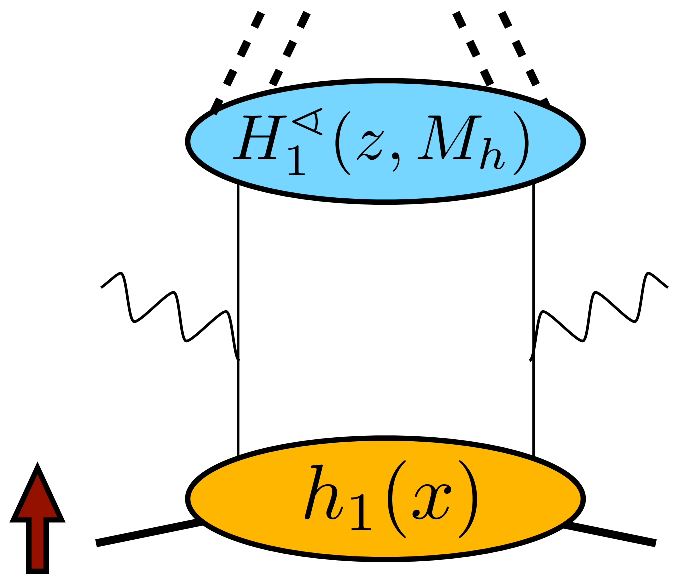
Collins FF

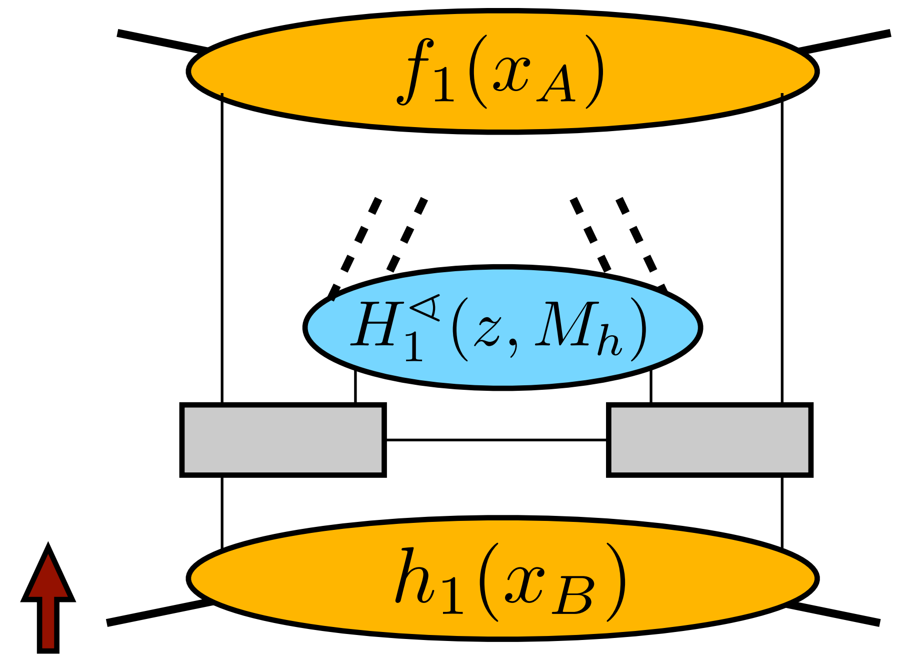
TMD
factorization



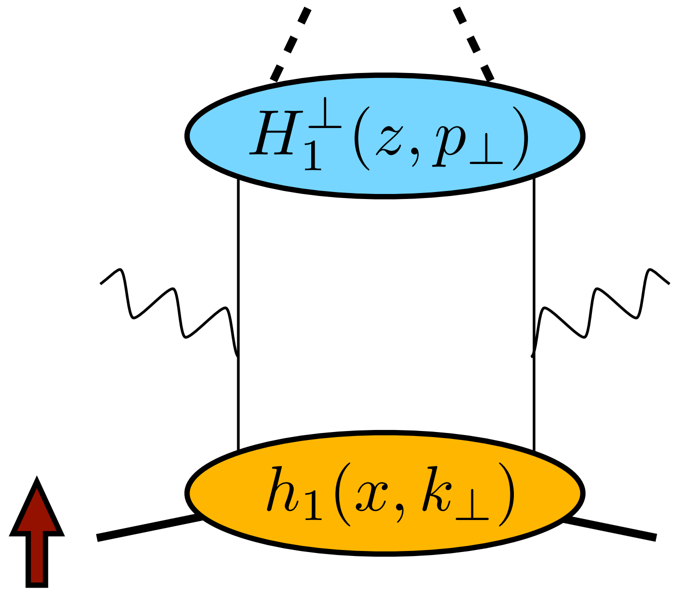
Proton-proton collisions

Collinear factorization



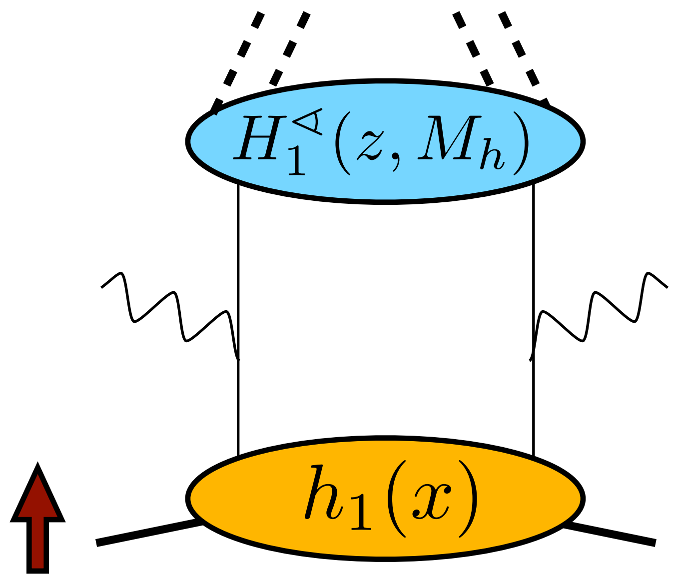


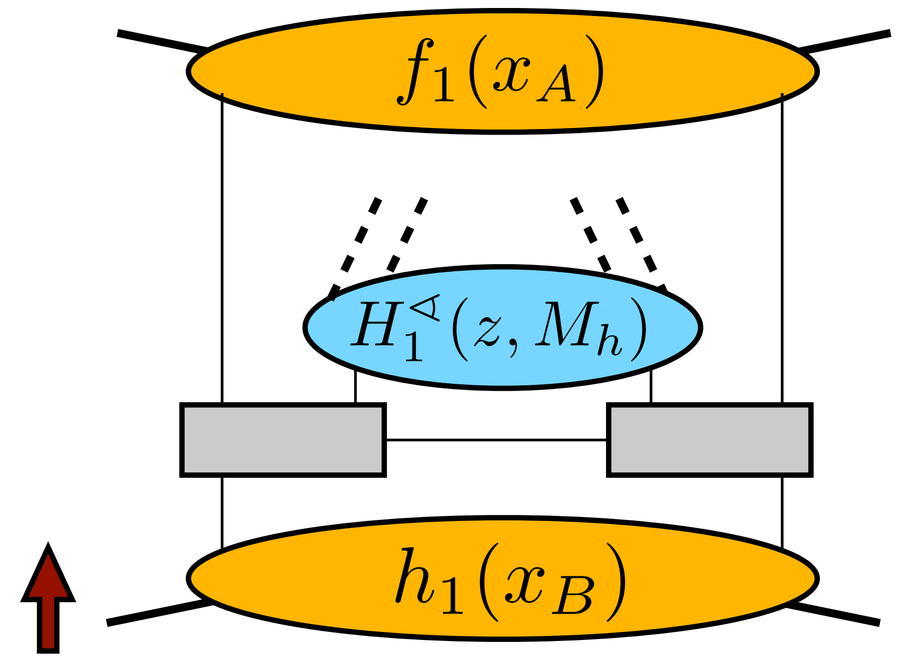
TMD factorization



Possibility of a "global" extraction

Collinear factorization





Adolph et al., P.L. ***B713*** *(12)*

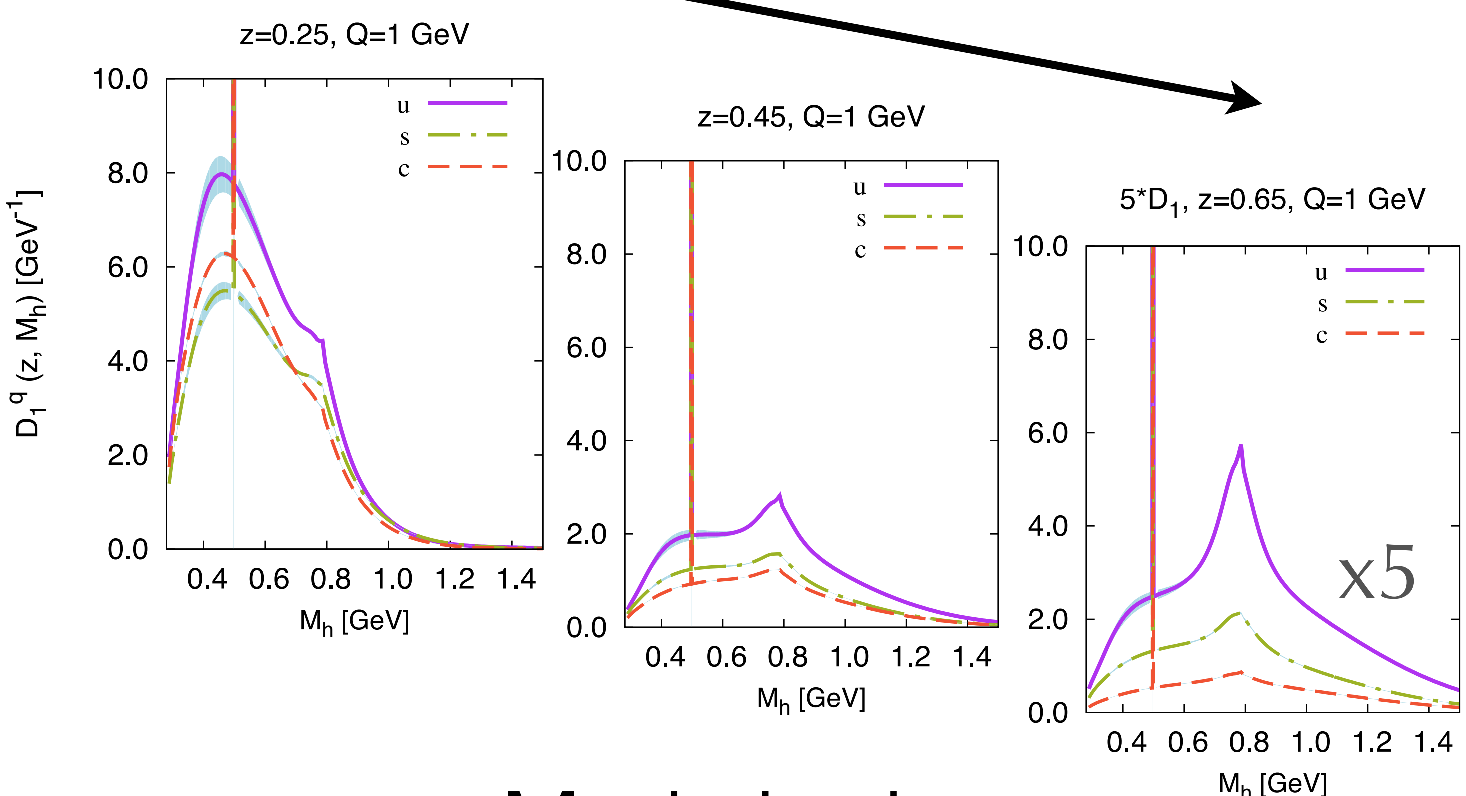
Airapetian et al., JHEP ***0806*** *(08) 017*

Adamczyk et al., P.R.L. ***115*** *(2015) 242501*

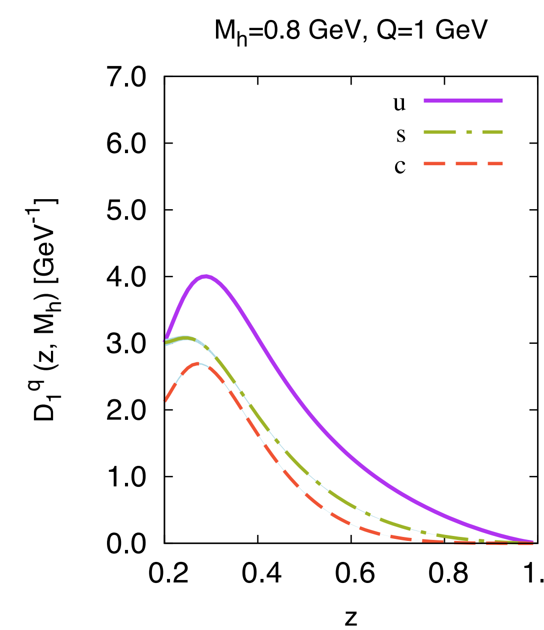
Unpolarized DiFFs (from MC)

Courtoy et al., P.R. D85 (12) 114023

increasing z



M_h behavior



z behavior

Q_0^2 = 1 GeV^2

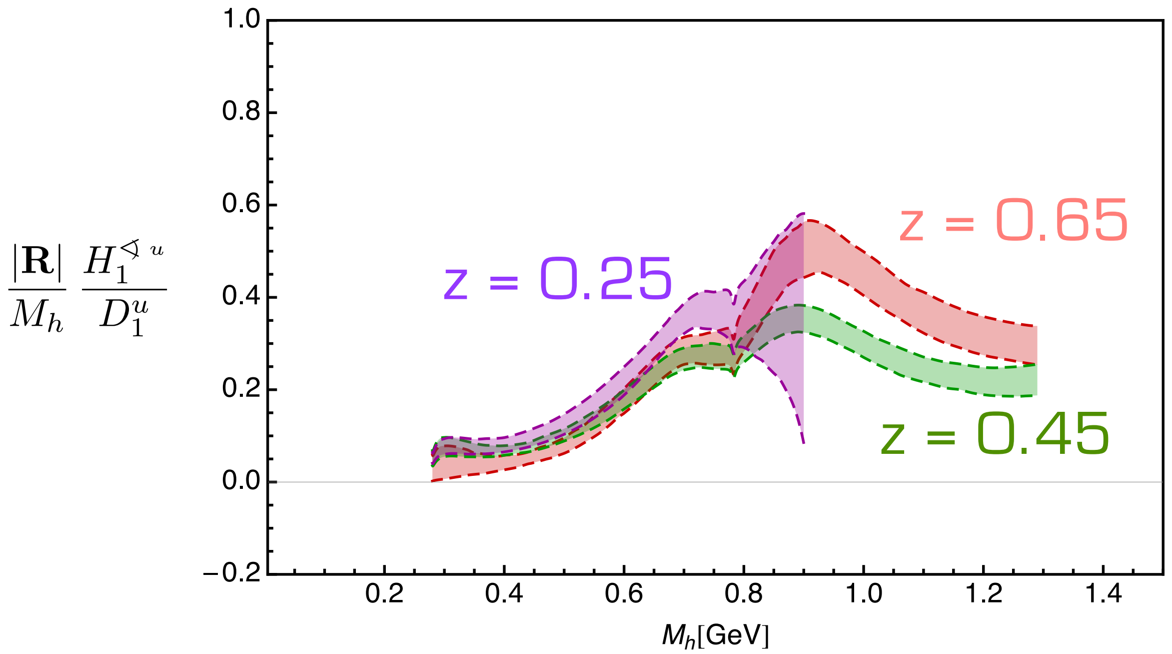
Note: DiFFs depend in general on z, cos$\boldsymbol{\theta}$, M_h^2

Interference DiFFs

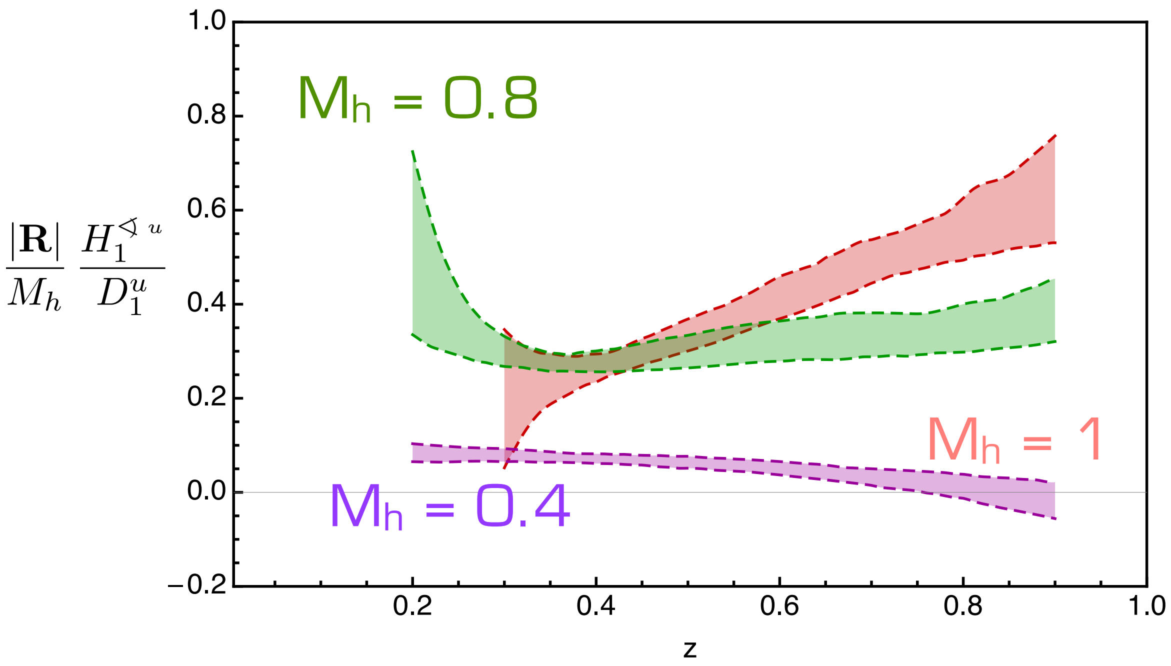
Radici et al., JHEP 1505 (15) 123

Q_0^2 = 1 GeV^2

M_h behavior

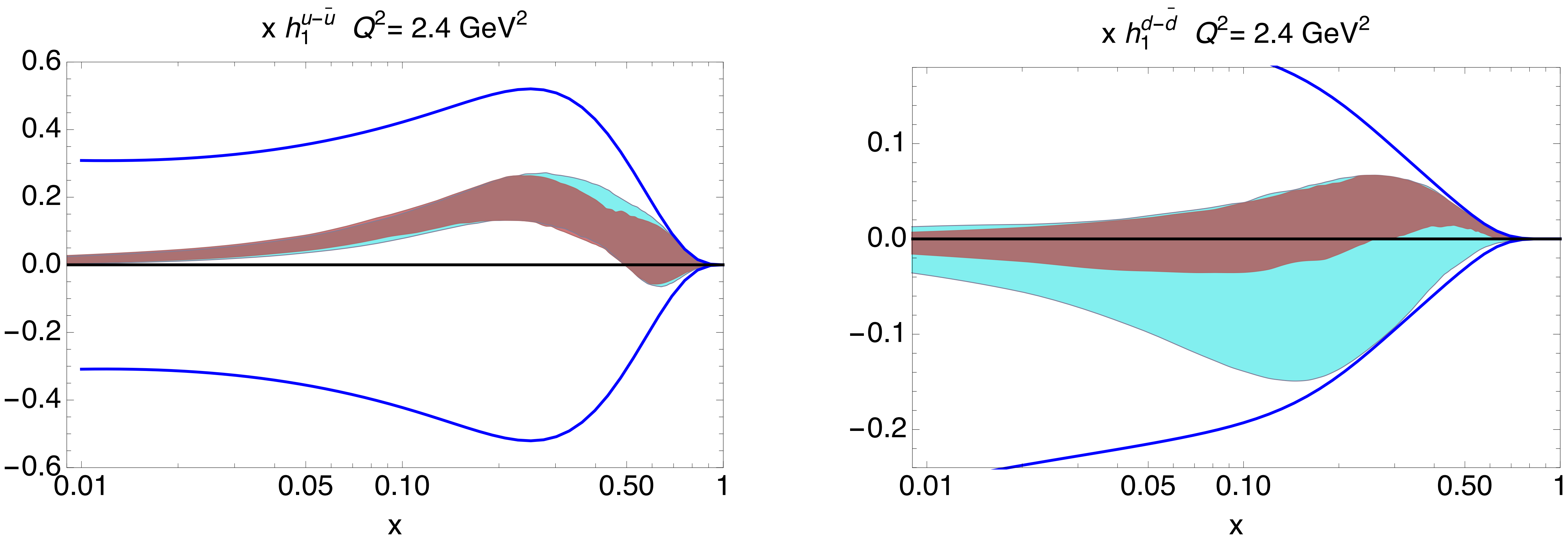


z behavior



Dihadron transversity extraction

Radici, Bacchetta, arXiv:1802.05212

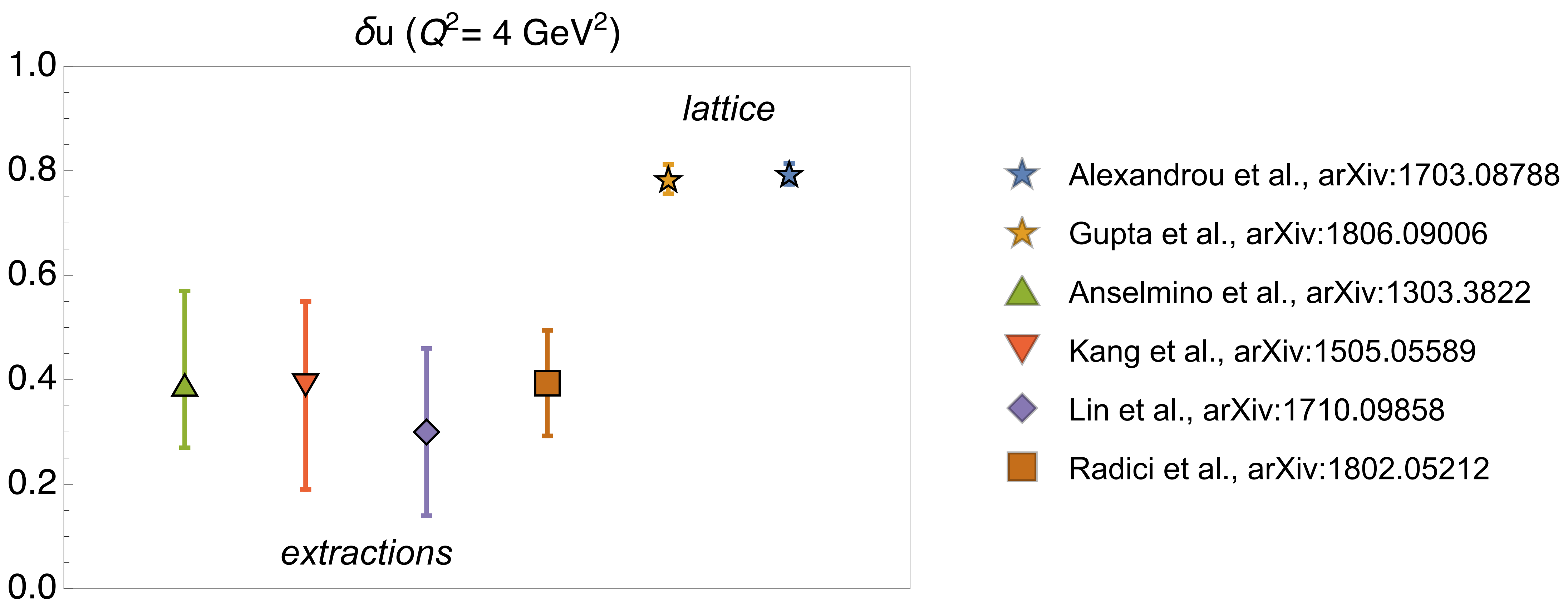


The bands are determined by statistical errors and by different scenarios concerning the gluon unpolarized DiFF

$$D_1^g \text{ @1 GeV} = 0$$

$$D_1^g \text{ @1 GeV} = \begin{cases} 0 \\ D_1^u \\ D_1^u/4 \end{cases}$$

Tensor charge status



At the moment, there is a clear tension between extractions and lattice calculations

To-do list

- Use new dihadron BELLE data to fit the unpolarized DiFFs (currently derived from Monte Carlo generators)
- Refit interference fragmentation function
- Go from LO to NLO (one of Rodolfo's requests…)
- Include new data when available (e.g., new 500 GeV STAR data)

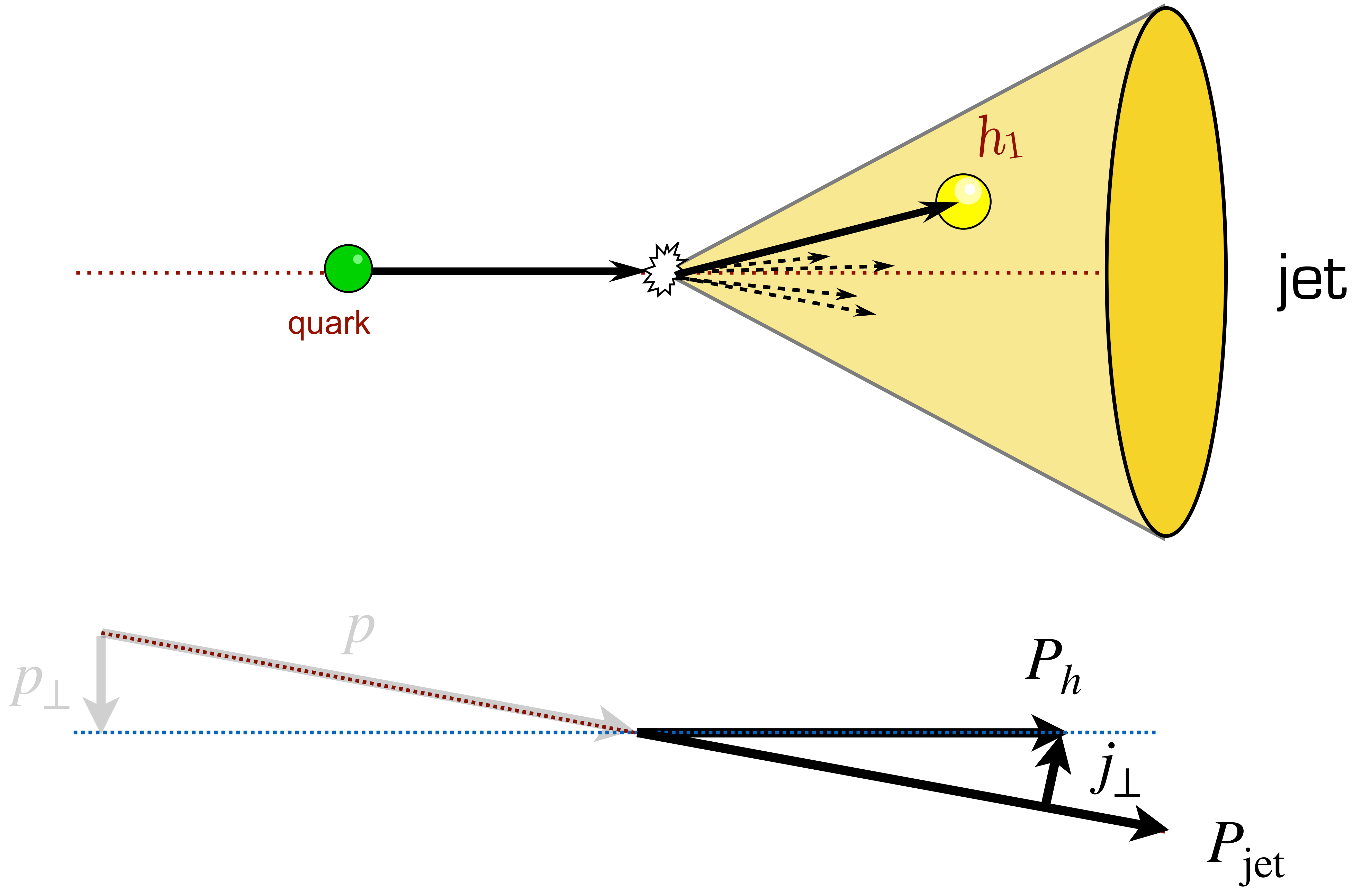
TMD single-hadron FFs

$$D_1$$

$$\left(s_T \times p_\perp\right) \cdot P_h \qquad H_1^\perp$$

We cannot use proton-proton data in this case, due to the breaking of TMD factorization

But there is a way out...



Hadron-in-jet FFs

Yuan, arXiv:0709.3272
see F. Ringer and Y. Makris's talks

D_1^{hj}

$\left(s_T \times j_\perp\right) \cdot P_h$ $\quad H_1^{\perp \mathrm{hj}}$

In this case, a hybrid between TMD and collinear factorization is needed, but the possible observables are analogous to dihadron FFs.

Dihadron and hadron-in-jet FFs

Transversity

$$\sigma_{UT} \propto \sin(\phi_S - \phi_R)\, f_1(x_a) \otimes h_1(x_b) \otimes \Delta\sigma_{ab^\uparrow \to c^\uparrow d} \otimes H_1^{\sphericalangle}(z_c, \cos\theta, R_T^2)$$

Bacchetta, Radici, hep-ph/0409174

$$\sigma_{UT} \propto \sin(\phi_S - \phi_H)\, f_1(x_a) \otimes h_1(x_b) \otimes \Delta\sigma_{ab^\uparrow \to c^\uparrow d} \otimes H_1^{\perp \mathrm{hj}}(z_c, z_h, j_\perp^2)$$

Kang, Prokudin, Ringer, Yuan, arXiv:1707.00913

How can we further exploit the analogy between dihadron and hadron-in-jet FFs?

Application n.1

Hadron-in-jet FFs can be used to access the collinear transversity in semi-inclusive DIS

$$A_{\mathrm{SIDIS}}^{\sin(\phi_R+\phi_S)} \sim \frac{h_1(x)\ \frac{|R_T|}{M_h}\ H_1^{\sphericalangle}(z,\cos\theta,R_T^2)}{f_1(x)\ D_1(z,\cos\theta,R_T^2)}$$

$$A_{\mathrm{SIDIS}}^{\sin(\phi_H+\phi_S)} \sim \frac{h_1(x)\ \frac{|j_\perp|}{z_h M_h}\ H_1^{\perp\mathrm{hj}}(z,z_h,j_\perp^2)}{f_1(x)\ D_1^{\mathrm{hj}}(z,z_h,j_\perp^2)}$$

Application n. 2

From the knowledge of polarized gluon dihadron FFs, we can infer something about polarized gluon hadron-in-jet FFs

gluon pol.

U	$\circlearrowright$	$\updownarrow$
D_1		$H_1^{\sphericalangle}$

gluon pol.

U	$\circlearrowright$	$\updownarrow$
D_1^{hj}		$H_1^{\perp\text{hj}}$

Bacchetta, Radici, hep-ph/0409174

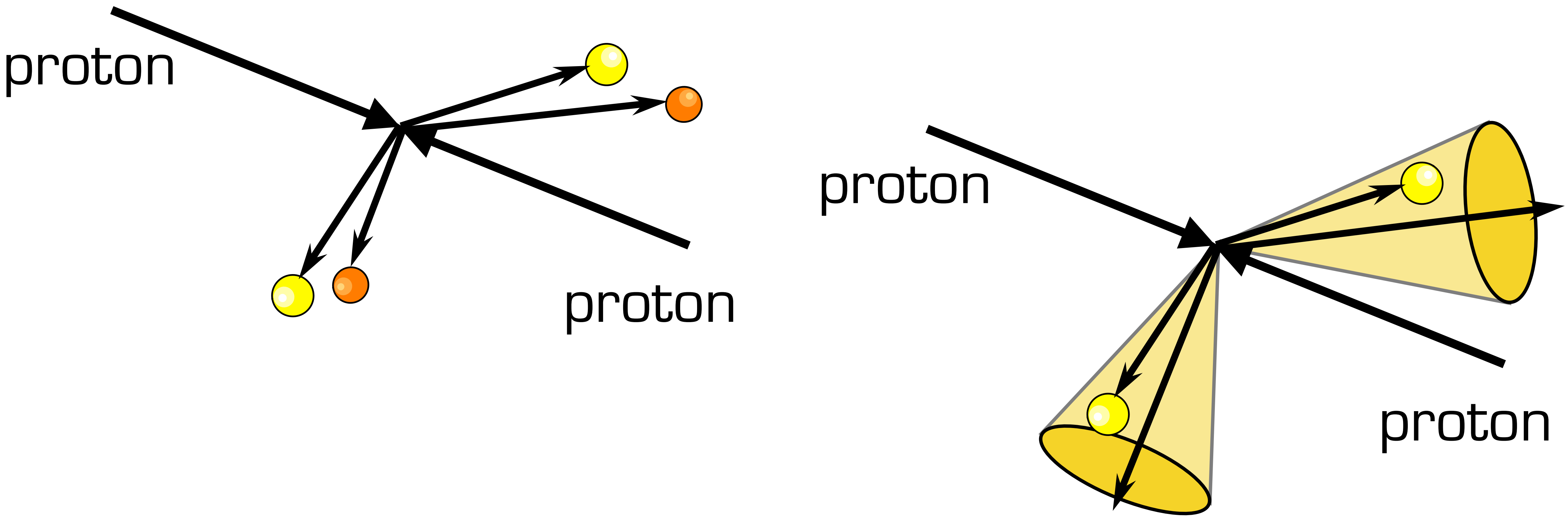
$H_1^{\sphericalangle}$ was called $\delta\hat{G}^{\sphericalangle}$

note that in this case they are not T-odd

Application n. 2

$$\sigma_{UU} \propto \ldots + \cos(2\phi_{R_C} - 2\phi_{R_D})\, f_1(x_a) \otimes f_1(x_b) \otimes \Delta\sigma_{ab\to g^\uparrow g^\uparrow} \otimes H_1^{\sphericalangle}(z_c, \cos\theta_C, R_{TC}^2) \otimes H_1^{\sphericalangle}(z_d, \cos\theta_D, R_{TD}^2)$$

Bacchetta, Radici, hep-ph/0409174



$$\sigma_{UU} \propto \ldots + \cos(2\phi_{H_C} - 2\phi_{H_D})\, f_1(x_a) \otimes f_1(x_b) \otimes \Delta\sigma_{ab\to g^\uparrow g^\uparrow} \otimes H_1^{\perp \mathrm{hj}}(z_c, z_{hc}, j_{\perp C}^2) \otimes H_1^{\perp \mathrm{hj}}(z_d, z_{hd}, j_{\perp D}^2)$$

Application n. 3

We know subleading twist dihadron FFs, so we can infer subleading twist hadron-in-jet FFs

quark pol.

U	L	T
$D^{\sphericalangle}$	$G^{\sphericalangle}$	E, H

quark pol.

U	L	T
$D^{\perp \mathrm{hj}}$	$G^{\perp \mathrm{hj}}$	E^{hj}, H^{hj}

Bacchetta, Radici, hep-ph/0311173

Application n. 3

Scalar-charge distribution

see, e.g., Pasquini, Rodini, arXiv:1806.10932 and references therein

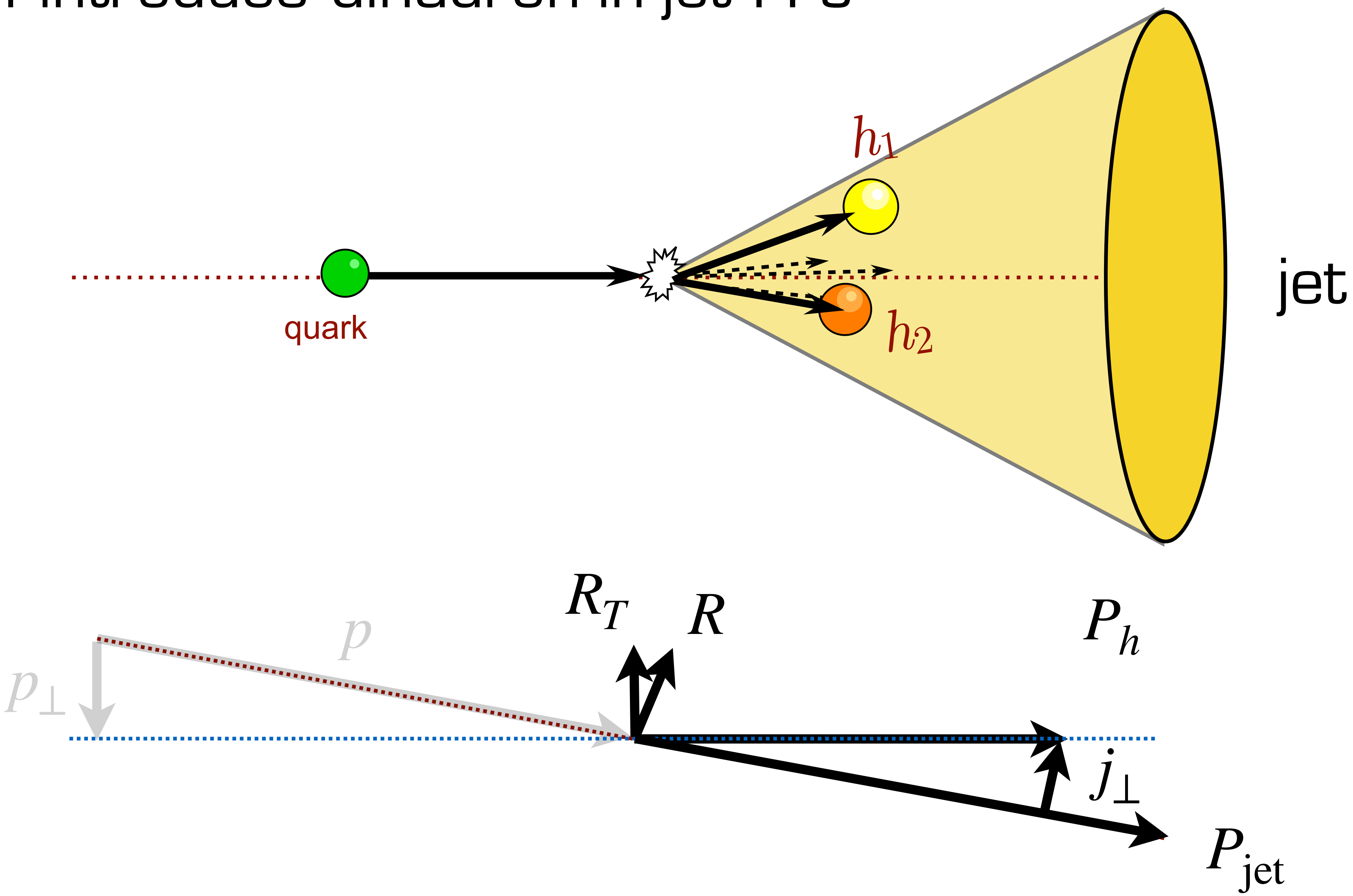
$$\sigma_{LU} \propto \sin\phi_R \frac{M}{Q}\left[x\, e(x)\, H_1^{\sphericalangle}\big(z, \cos\theta, R_T^2\big) + \frac{M_h}{M}\, f_1(x)\, \frac{\tilde{G}^{\sphericalangle}}{z}\big(z, \cos\theta, R_T^2\big)\right]$$

Bacchetta, Radici, hep-ph/0311173

$$\sigma_{LU} \propto \sin\phi_H \frac{M}{Q}\left[x\, e(x)\, H_1^{\perp \mathrm{hj}}\big(z, z_h, j_\perp^2\big) + \frac{|j_\perp|}{M}\, f_1(x)\, \frac{\tilde{G}^{\perp \mathrm{hj}}}{z}\big(z, z_h, j_\perp^2\big)\right]$$

Application n. 4

We can introduce dihadron-in-jet FFs



Application n. 4

We can introduce dihadron-in-jet FFs

quark pol.

U	L	T
D_1^{2hj}	$G_1^{\perp 2hj}$	$H_1^{\sphericalangle 2hj}$, $H_1^{\perp 2hj}$

gluon pol.

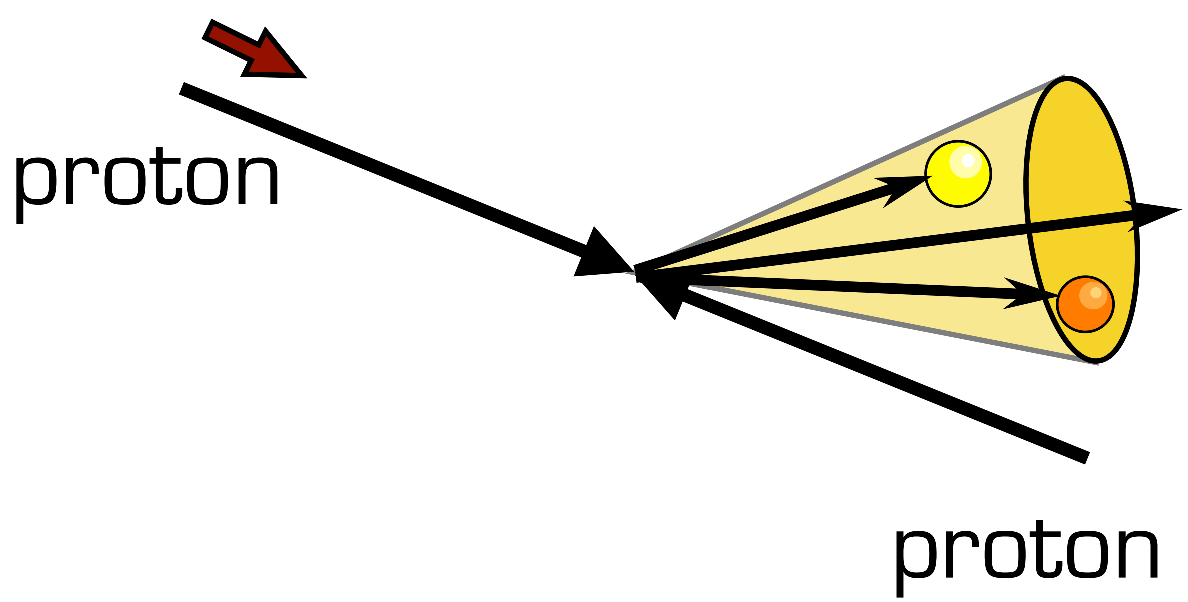
U	$\circlearrowright$	$\updownarrow$
D_1^{2hj}	$G_1^{\perp 2hj}$	$H_1^{\sphericalangle 2hj}$, $H_1^{\perp 2hj}$

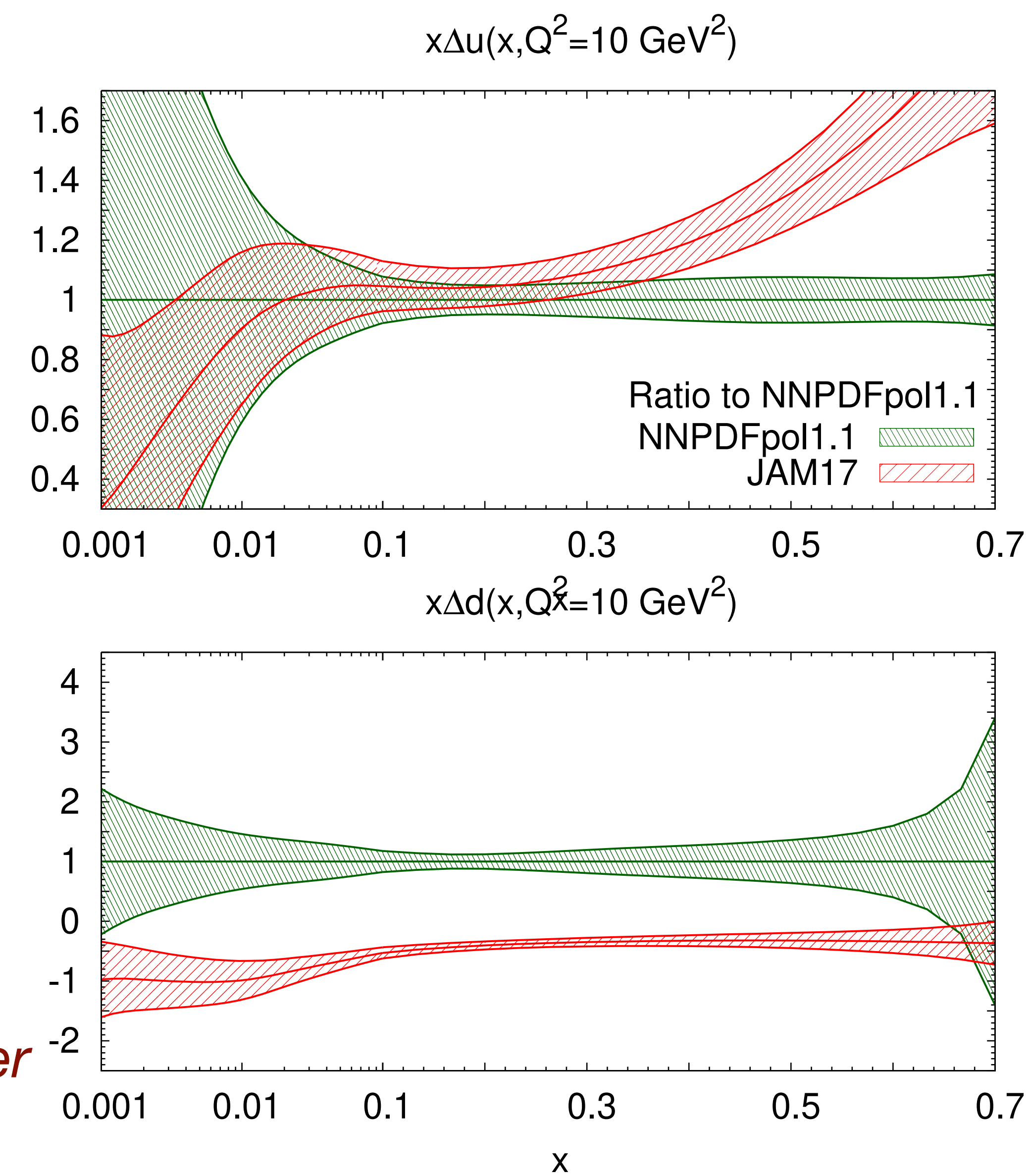
The nice feature is that we obtain functions that are sensitive to parton helicity

Expected asymmetry

Helicity distribution

$$\sigma_{UL} \propto \sin(\phi_H - \phi_R)\, f_1(x_a) \otimes g_1(x_b) \otimes \Delta\sigma_{ab^{\rightarrow} \rightarrow c^{\rightarrow} d} \otimes G_1^{\perp 2\mathrm{hj}}\left(z_c, z_h, \cos\theta, j_\perp^2, R_T^2, j_\perp \cdot R_T\right)$$





It may have an impact on global helicity PDF extractions

courtesy of E. Nocera and J. Ethier

Application n. ?

This is what we could think of with our “sensibility” to spin physics.

Vice-versa, a lot of work in the hadron-in-jet field went into unpolarized physics: can we use this extended expertise to use with DiFFs?

Conclusions

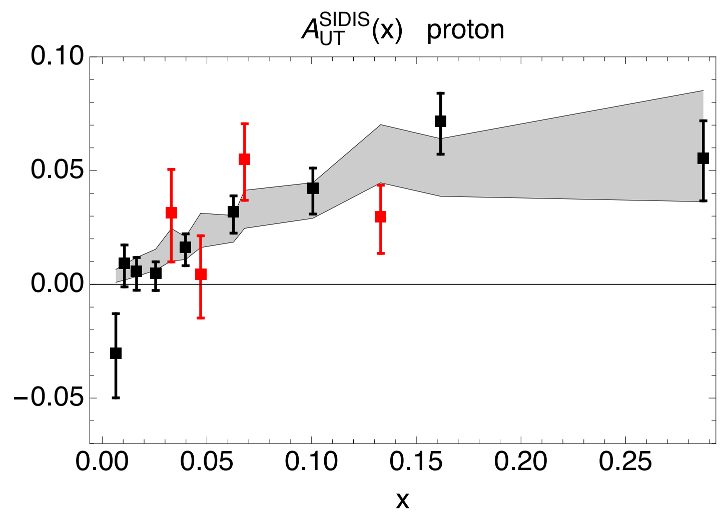
- DiFFs offer rich possibilities, in particular to access transversity
- The analogy with hadron-in-jet can help identifying interesting observables
- They can be used to access also the function e(x) and the helicity distribution

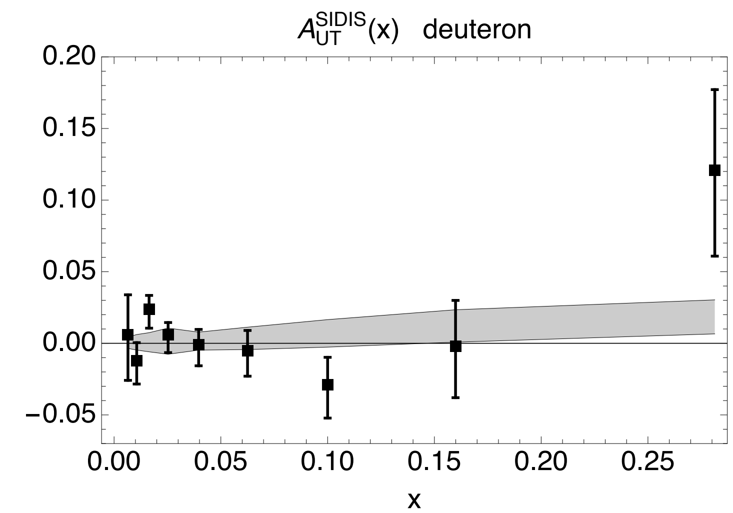
Data vs theory plots

SIDIS

Adolph et al., P.L. ***B713*** *(12)*

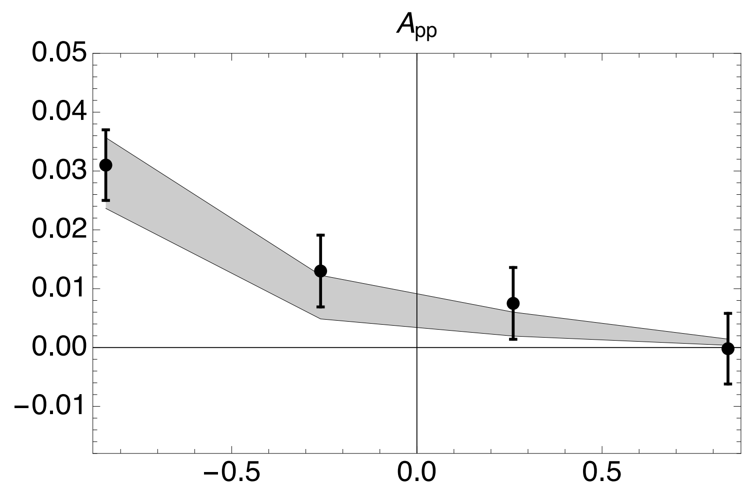
Airapetian et al., JHEP ***0806*** *(08) 017*



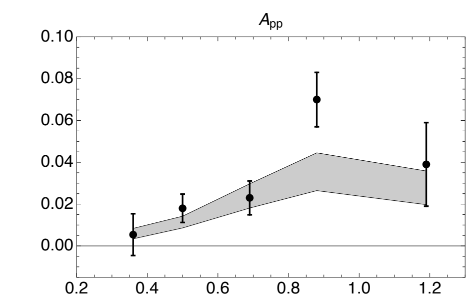


pp collisions

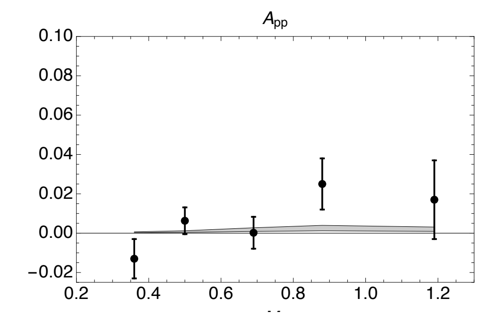
Adamczyk et al., P.R.L. ***115*** *(2015) 242501*



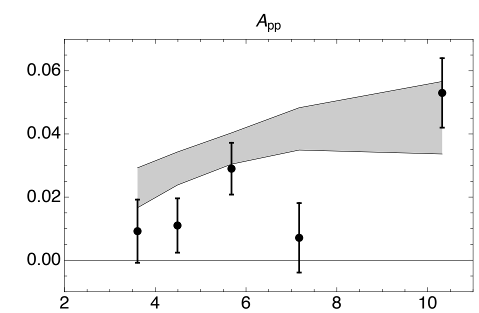
η



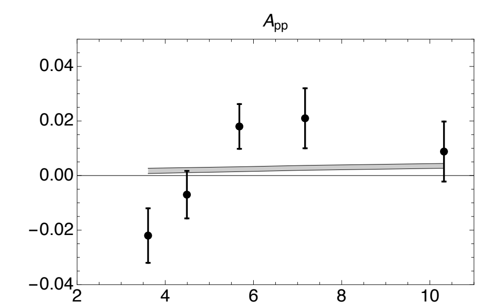
M_h, η<0



M_h, η>0

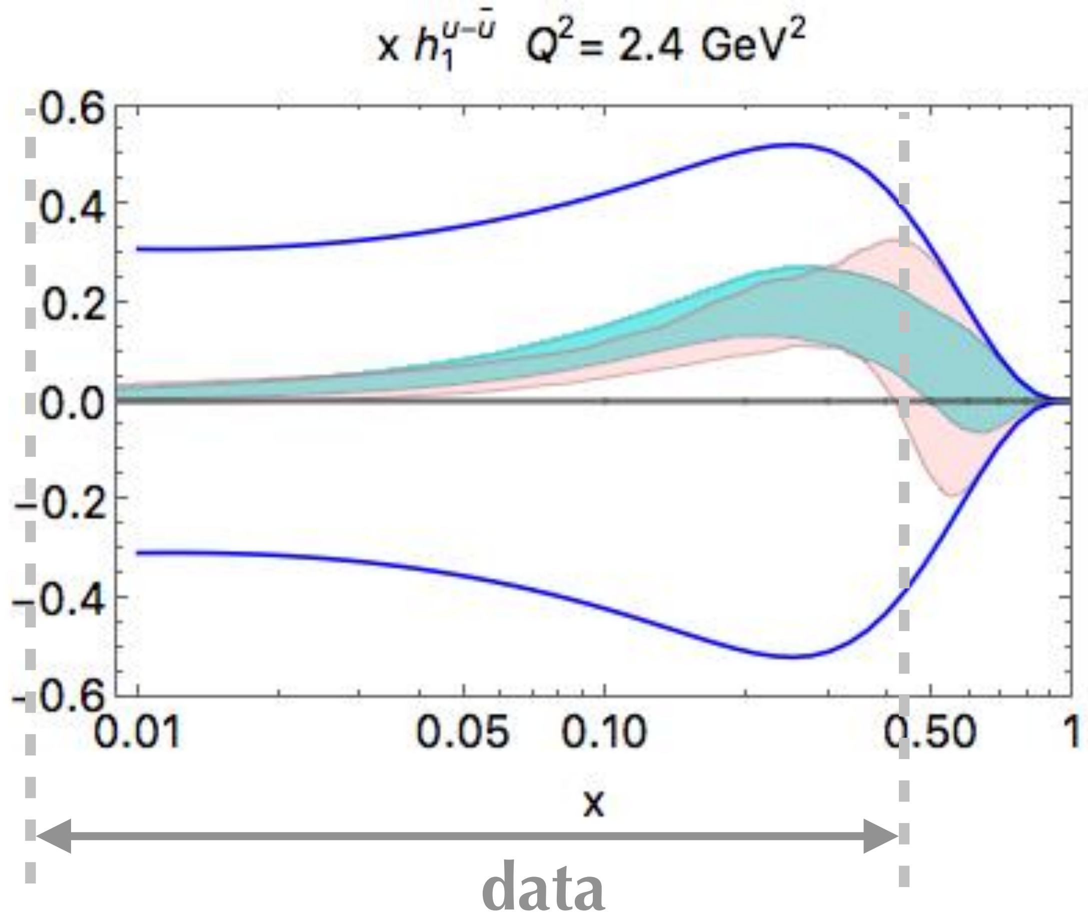


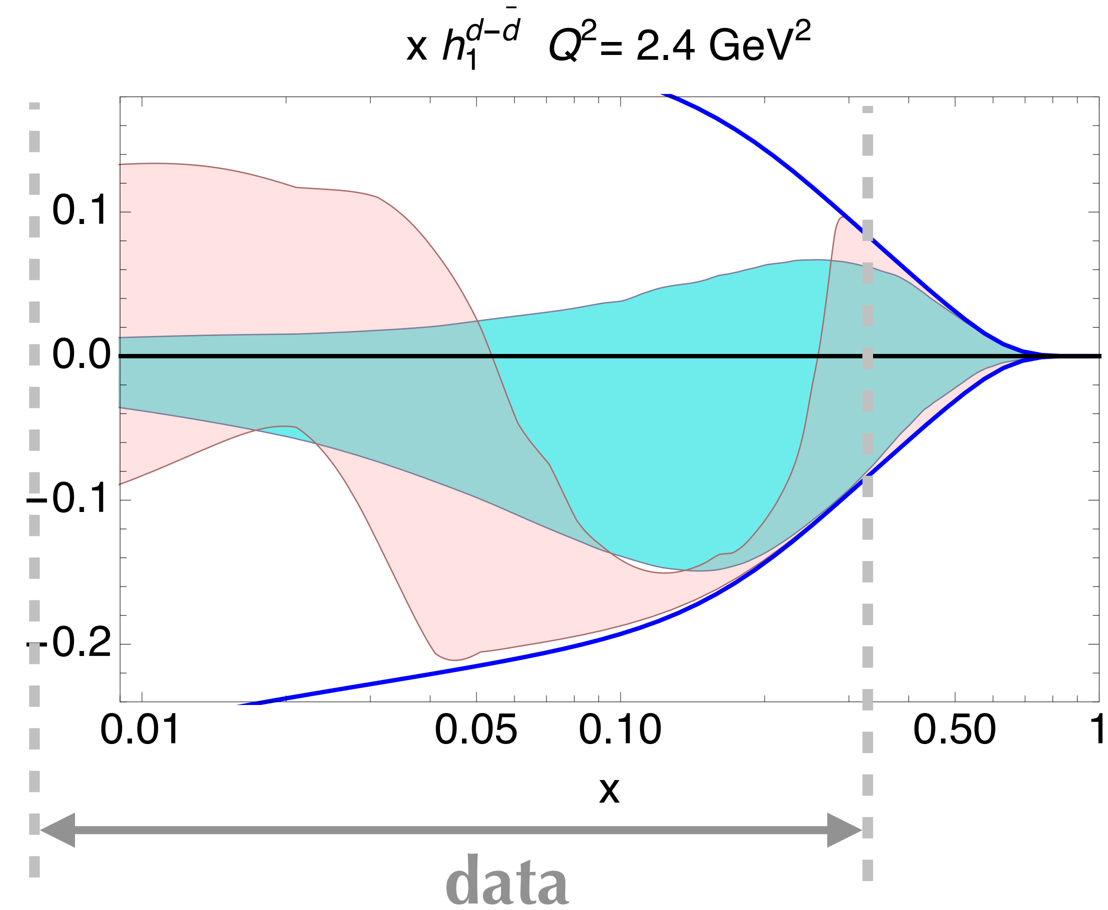
p_T, η<0



p_T, η>0

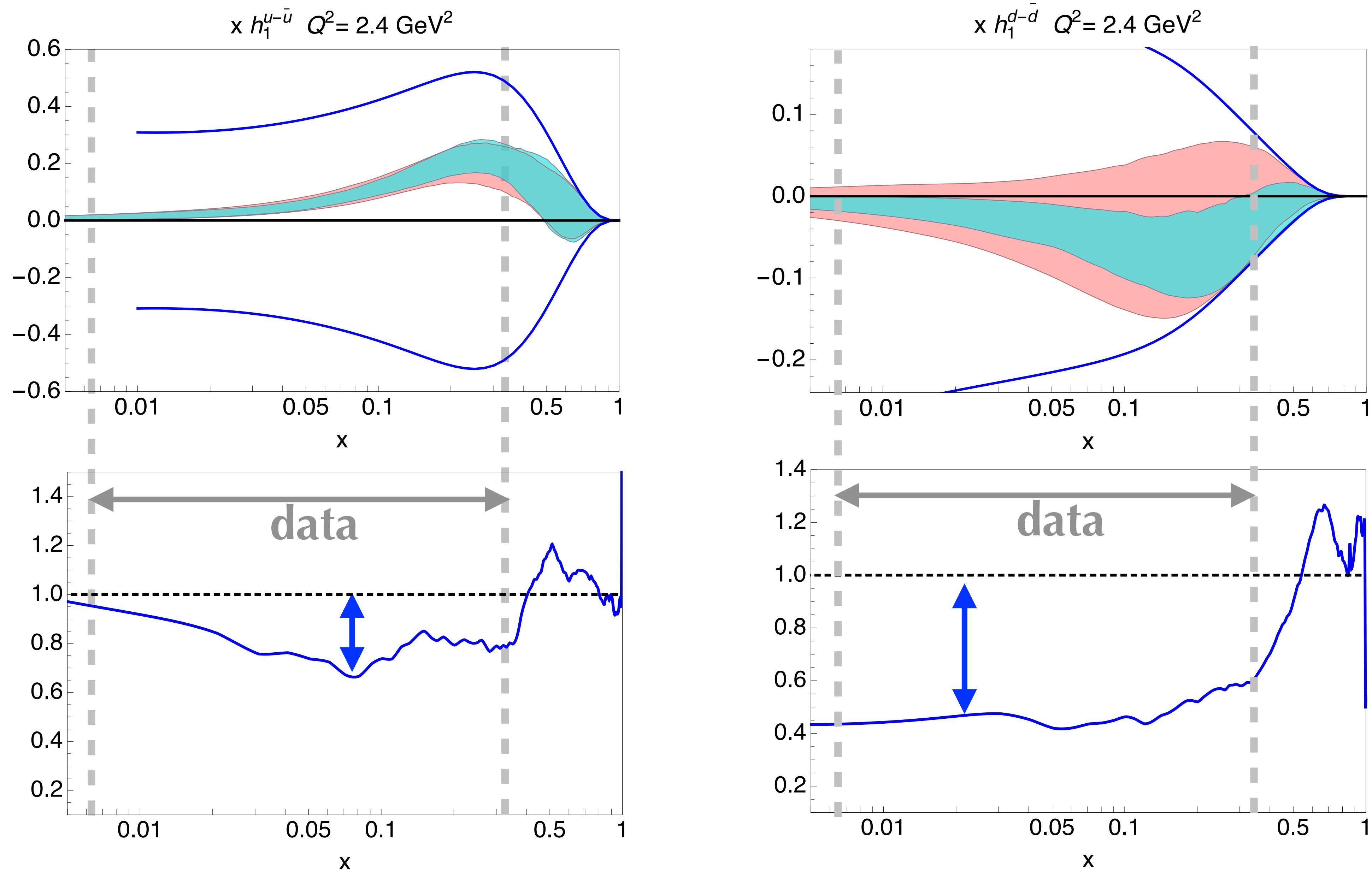
Comparison with previous fit





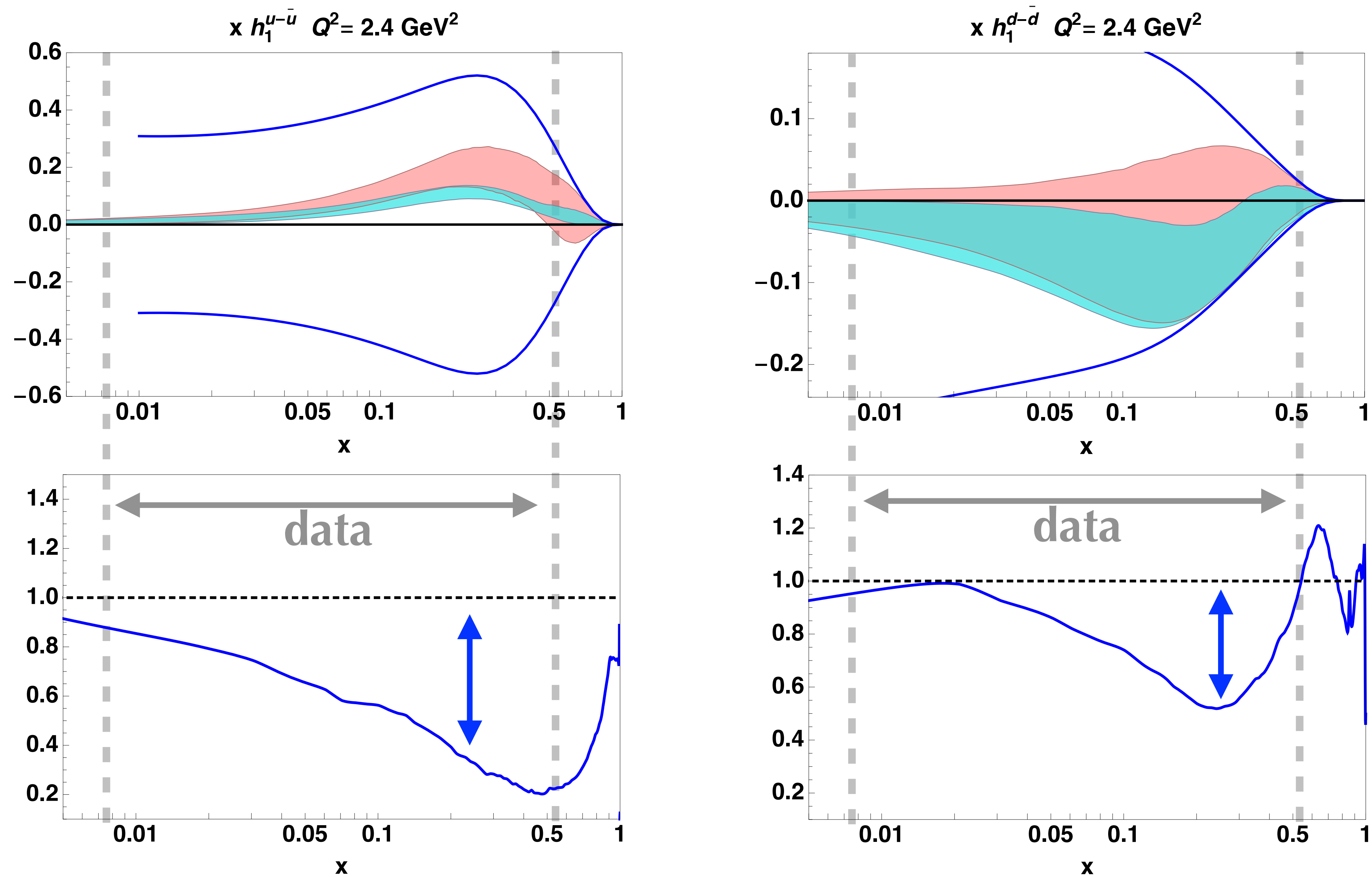
Impact of future COMPASS data

Possible new run with deuterium in 2021,
with higher statistics than proton data



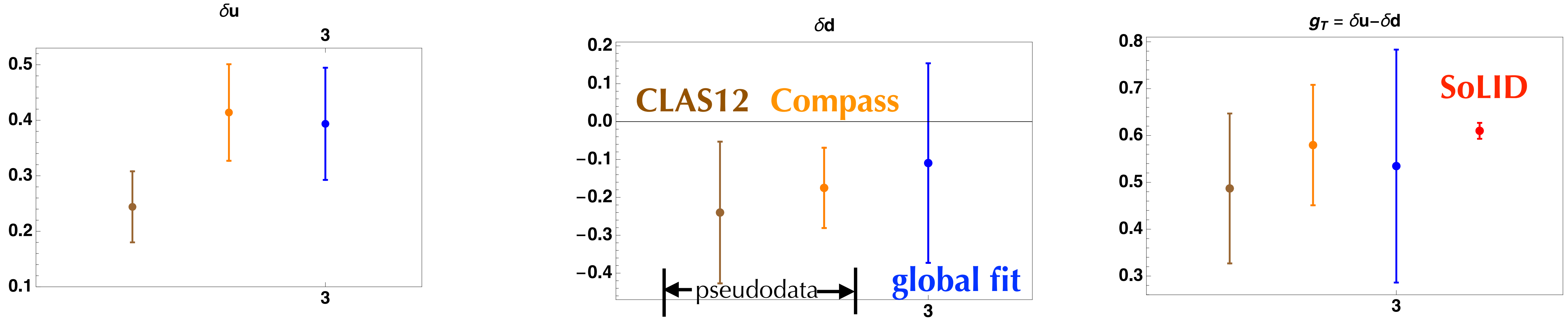
Impact of future CLAS data

With expected CLAS12 statistics



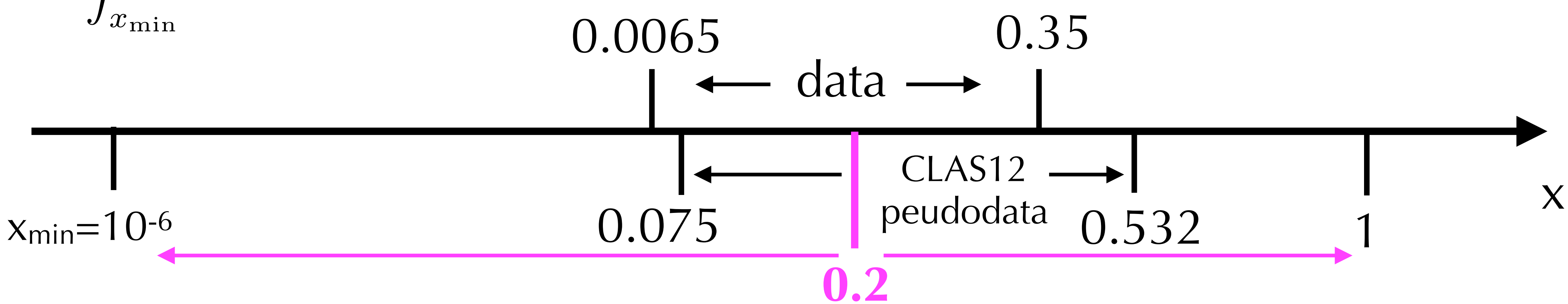
Tensor charge improvement

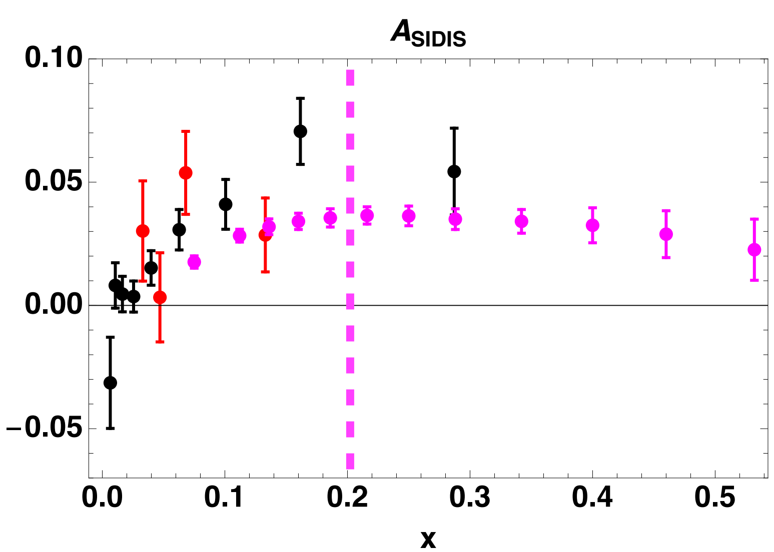
Impact of the inclusion of new CLAS and COMPASS data

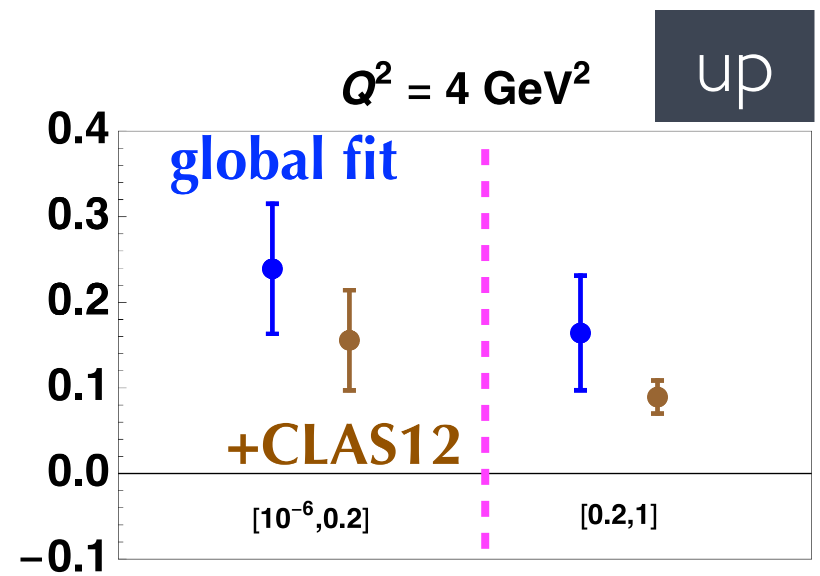


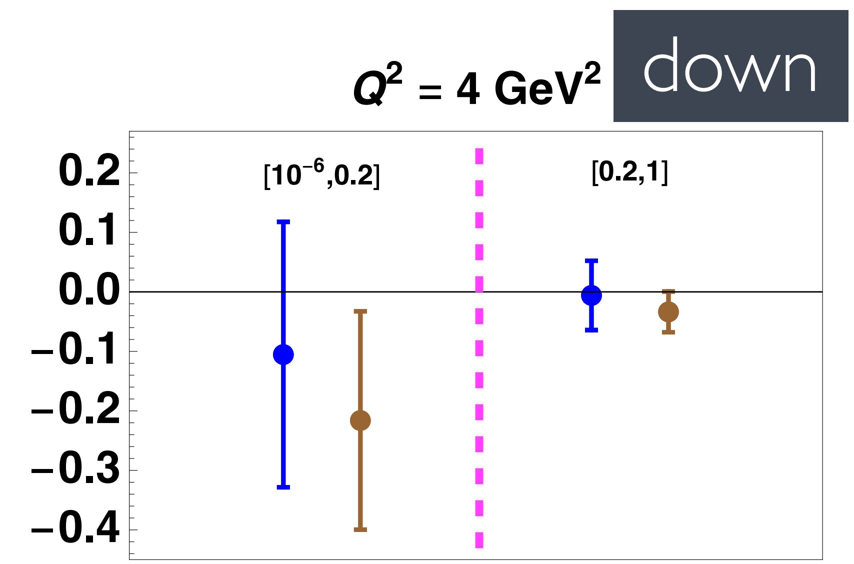
Tensor charge contributions

$$\delta q(Q^2) = \int_{x_{\min}}^{1} dx\, h_1^{q-\bar{q}}(x, Q^2)$$



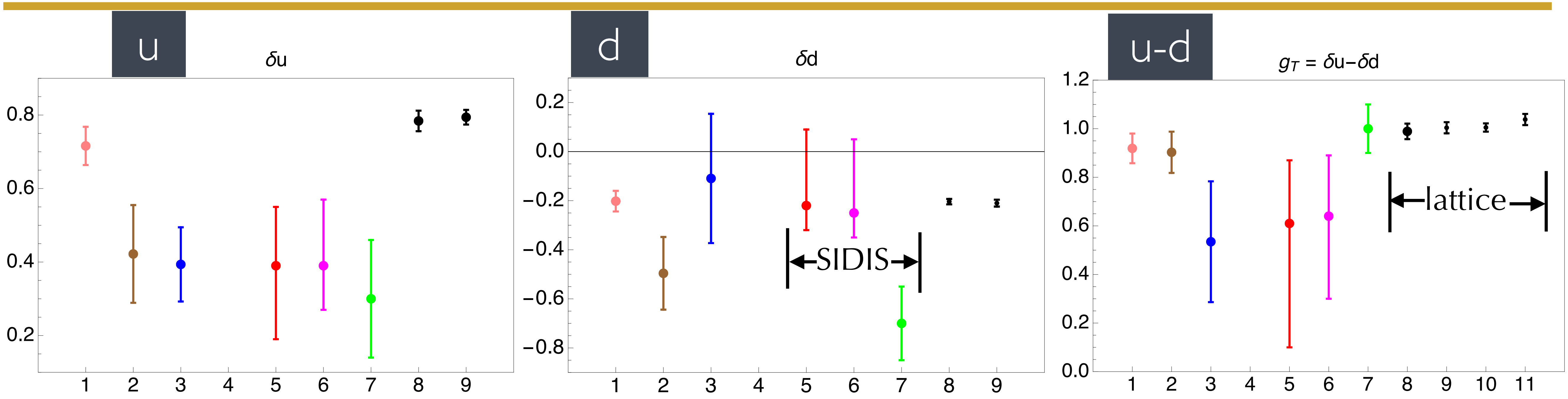






impact of CLAS12 pseudodata at large x (>0.2)
gives ~50% of up tensor charge
relative error $\Delta g_T/g_T$ from 82% → 43%

Inclusion of lattice constraints



$\chi^2/\mathrm{dof} = 1.76 \pm 0.11$ ⇒ $\chi^2/\mathrm{dof} = 2.29 \pm 0.25$

1) global fit + constrain g_T , δu , δd

2) global fit + constrain g_T

3) global fit '17

5) "TMD fit" * Q^2=10

6) Torino fit * Q^2=1

7) JAM fit '17 * Q_0^2=2

*Radici & Bacchetta, P.R.L. **120** (18) 192001*

*Kang et al., P.R. D**93** (16) 014009*

*Anselmino et al., P.R. D**87** (13) 094019*

*Lin et al., P.R.L. **120** (18) 152502*

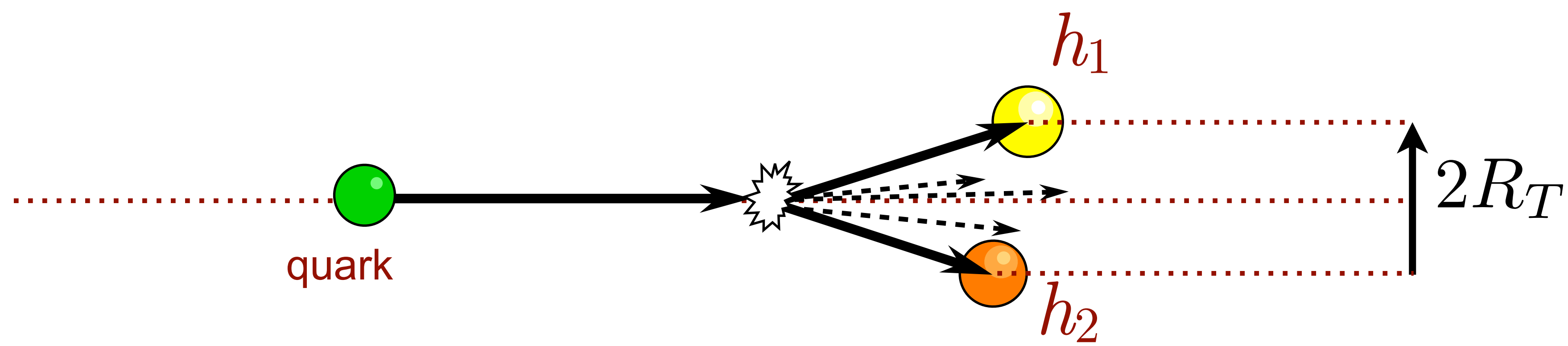
8) PNDME '18 — *Gupta et al., P.R. D**98** (18) 034503*

9) ETMC '17 — *Alexandrou et al., P.R. D**95** (17) 114514 and P.R. D**96** (17) 099906*

10) RQCD '14 — *Bali et al., P.R. D**91** (15)*

11) LHPC '12 — *Green et al., P.R. D**86** (12)*

DiFFs variables



$$R_T^\mu = g_T^{\mu\nu} R_\nu = R^\mu - \frac{\zeta_h}{2} P_h^\mu + x_B \frac{\zeta_h M_h^2 - (M_1^2 - M_2^2)}{Q^2 z_h} P^\mu$$

$$D_1^{q \to h_1 h_2}(z_1, z_2, R_T^2)$$

or

$$D_1^{q \to h_1 h_2}(z, \cos\theta, M_h)$$

Unpolarized DiFF