TRANSVERSITY DISTRIBUTION AND ITS EXTRACTION

INFN Istituto Nazionale di Fisica Nucleare

Marco Radici
INFN - Pavia

the "silver" measurement

Deliverables	Observables	What we learn
Sivers & unpolarized TMD quarks and gluon	SIDIS with Transverse polarization; di-hadron (di-jet)	Quantum Interference & Spin-Orbital correlations 3D Imaging of quark's motion: valence + sea 3D Imaging of gluon's motion QCD dynamics in a unprecedented Q^2 (P_{hT}) range
Chiral-odd functions: Transversity; Boer-Mulders	SIDIS with Transverse polarization	3rd basic quark PDF: valence + sea, tensor charge Novel spin-dependent hadronization effect QCD dynamics in a chiral-odd sector with a wide Q^2 (P_{hT}) coverage

Table 2.2: Science Matrix for TMD: 3D structure in transverse momentum space: (upper) the golden measurements; (lower) the silver measurements.

Accardi et al., E.P.J. ***A52*** *(16) 268*

why transversity ?

the leading-twist PDF / TMD map

quark polarization (columns) / nucleon polarization (rows)

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

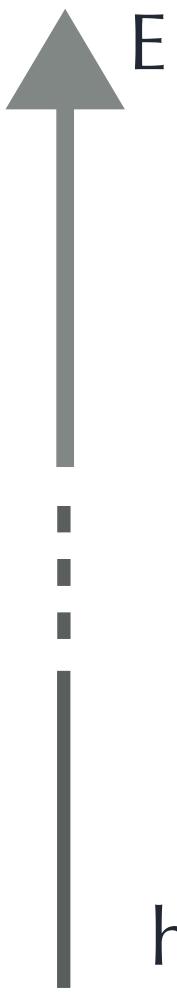
1- **h_1** needed as the 3rd basic quark **PDF** for spin-1/2 objects

2- address novel QCD dynamics in the chiral-odd sector, also as **TMD**

Moreover, tensor charge not associated to conserved current in $\mathcal{L}_{QCD}$

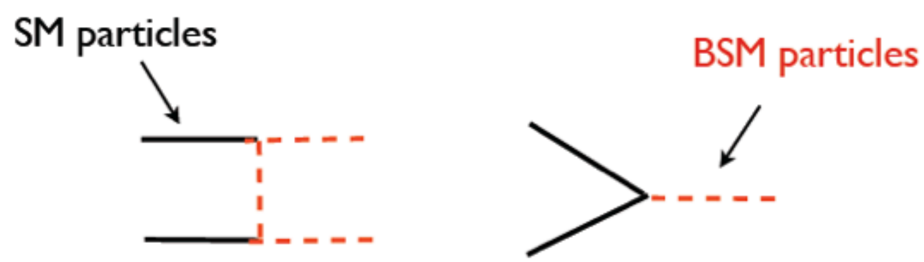
$$\delta q(Q^2) = \int_0^1 dx \ \left[h_1^q(x, Q^2) - h_1^{\bar{q}}(x, Q^2) \right]$$

potential for BSM discovery ?



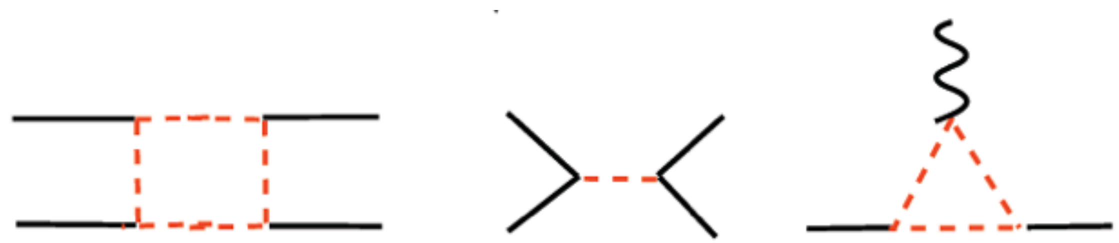
at least, two ways of searching :

M_{BSM}
high energy

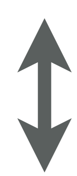


1- direct access
to new particles

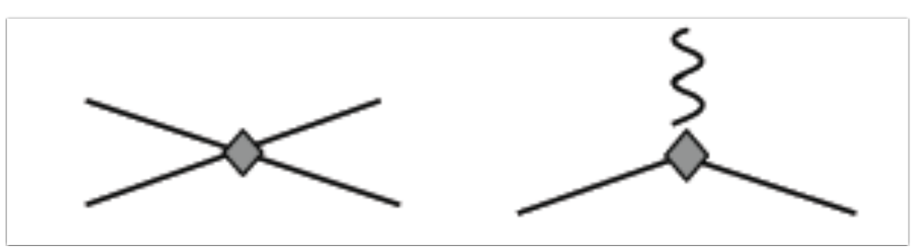
$E_{exp} \ll M_{BSM}$
low energy
high precision



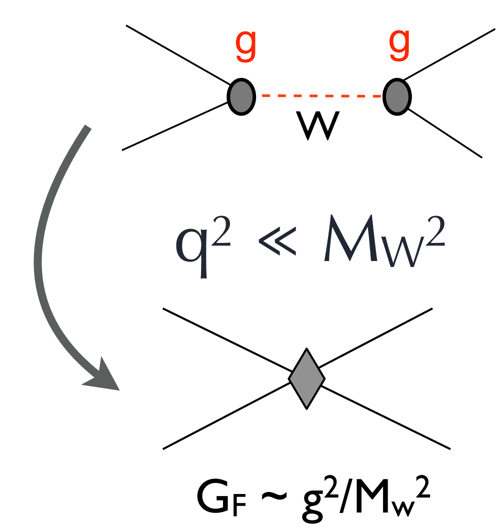
2- indirect access
virtual effects



footprint:
new local
operators



Example:
weak CC
interaction



Examples of indirect access

- **nuclear β-decay**: effective field theory including operators not in SM Lagrangian; for example, tensor operator

hadron level

$C_T\ \bar{p}\sigma^{\mu\nu}n\ \ \bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e$

exp. data

$$C_T \leftrightarrow g_T\,\epsilon_T$$

$$\approx \frac{M_W^2}{M_{\rm BSM}^2}$$

quark level

$\langle p|\,\bar{u}\,\sigma^{\mu\nu}\,d\,|n\rangle\ \ \epsilon_T\ \bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e$

?

$$g_T = \delta u - \delta d$$

isovector tensor charge

- **neutron EDM**: estimate CPV induced by quark chromo-EDM d_q

$$d_n = \delta u\, d_u + \delta d\, d_d + \delta s\, d_s$$

tensor charge

lattice

$$\langle P,S|\,\bar{q}\sigma^{\mu\nu}q\,|P,S\rangle = (P^\mu S^\nu - P^\nu S^\mu)\,\delta q$$

pheno

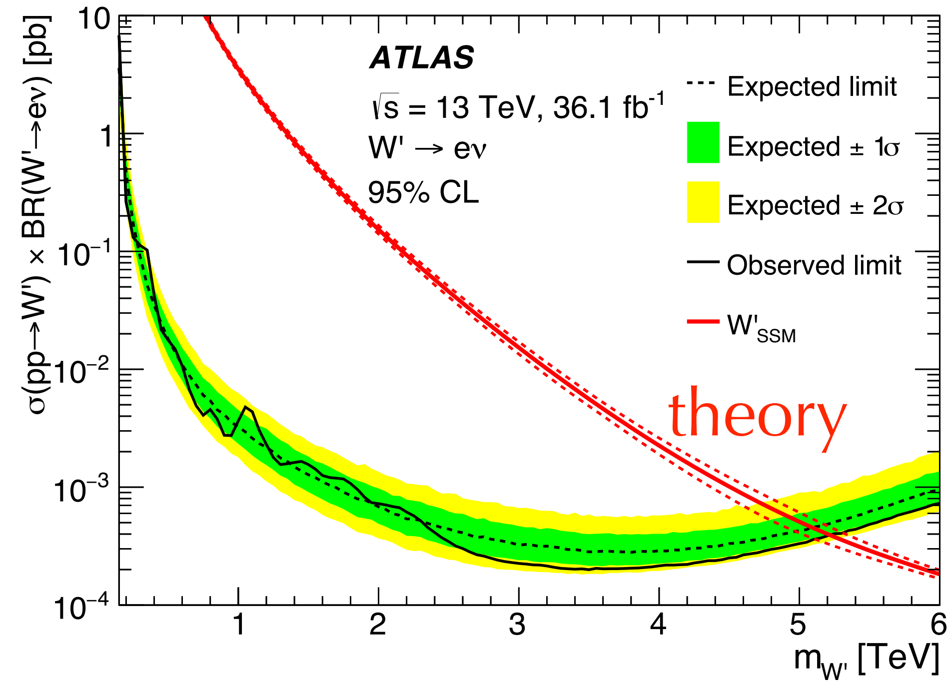
$$\delta q(Q^2) = \int_0^1 dx\, h_1^{q-\bar{q}}(x,Q^2)$$

transversity

Examples of direct access

- **p p → e⁻ ν + X** search for W′ → e⁻ ν with W′ heavy partner of W

limits on cross section



data / background

Aaboud et al. (ATLAS), E.P.J. ***C78*** *(18) 401*

$M_{W'} > 5.1–5.2$ TeV at 95% C.L.

puts contraints on BSM operators including tensor operator
[see *Gupta et al. (PNDME), P.R. D**98** (18) 034503*]

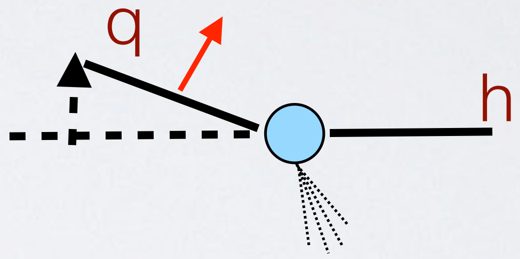
constraints reinforced in p p → Z′ → e⁻ e⁺ + X

extraction of transversity

transversity is chiral-odd → need a chiral-odd partner

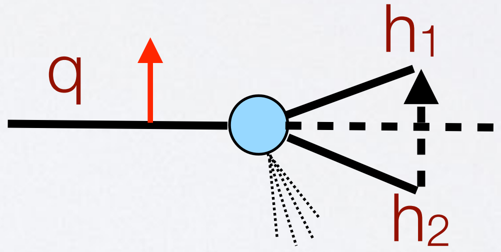
- itself : fully polarized Drell-Yan ✘

- Collins function : the Collins effect



TMD framework **h_1 as TMD**

- IFF : the di-hadron mechanism



collinear framework **h_1 as PDF**

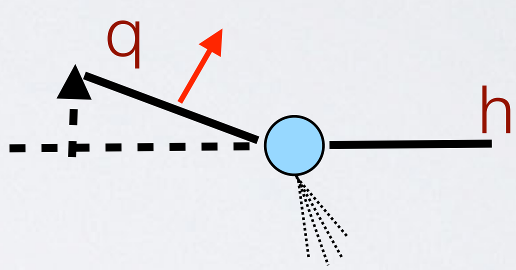
- hadron-in-jet mechanism : mixed framework **h_1 as PDF**

extraction of transversity

transversity is chiral-odd → need a chiral-odd partner

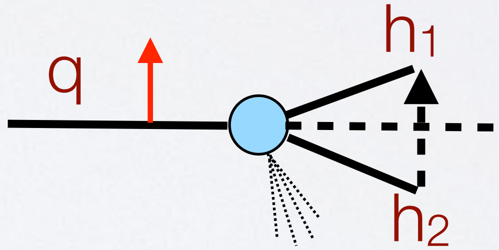
- itself : fully polarized Drell-Yan ✗

- Collins function : the Collins effect



TMD framework **h_1 as TMD**

- IFF : the di-hadron mechanism



collinear framework **h_1 as PDF**

- hadron-in-jet mechanism : mixed framework **h_1 as PDF**

advantages of di-hadron mechanism

$$A_{\text{SIDIS}}^{\sin(\phi_R+\phi_S)}(x,z,M_h^2) \sim -\frac{\sum_q e_q^2\ h_1^q(x)\ \frac{|\boldsymbol{R}_T|}{M_h}\ H_{1,q}^{\sphericalangle}(z,M_h^2)}{\sum_q e_q^2\ f_1^q(x)\ D_{1,q}(z,M_h^2)}$$

collinear framework → - simple product of PDF and IFF
- x-dependence of A_{SIDIS} all in PDF
- flavor sum simplified by symmetries of IFF

$\pi^+\pi^-$
tree level

$$H_1^{\sphericalangle\, u} = -H_1^{\sphericalangle\, d}$$ isospin symmetry

$$H_1^{\sphericalangle\, q} = -H_1^{\sphericalangle\, \overline{q}}, \qquad D_1^q = D_1^{\overline{q}}$$ } charge conjugation

advantages of di-hadron mechanism

$$A_{\mathrm{SIDIS}}^{\sin(\phi_R+\phi_S)}(x,z,M_h^2) \sim -\frac{\sum_q e_q^2\ h_1^q(x)\ \frac{|\boldsymbol{R}_T|}{M_h}\ H_{1,q}^{\sphericalangle}(z,M_h^2)}{\sum_q e_q^2\ f_1^q(x)\ D_{1,q}(z,M_h^2)}$$

collinear framework → - simple product of PDF and IFF
- x-dependence of A_{SIDIS} all in PDF
- flavor sum simplified by symmetries of IFF

$\pi^+\pi^-$ tree level

$$H_1^{\sphericalangle\, u} = -H_1^{\sphericalangle\, d} \quad \text{isospin symmetry}$$

$$\left.\begin{aligned} H_1^{\sphericalangle\, q} &= -H_1^{\sphericalangle\, \bar{q}} \\ D_1^q &= D_1^{\bar{q}} \end{aligned}\right\} \text{charge conjugation}$$

+ data on proton and deuteron targets

proton $\quad xh_1^{u-\bar{u}} - \frac{1}{4} xh_1^{d-\bar{d}} = F\,[A_{\mathrm{SIDIS}}^p \text{ data},\ H_1^{\sphericalangle\, u},\ f_1^q D_1^q]$

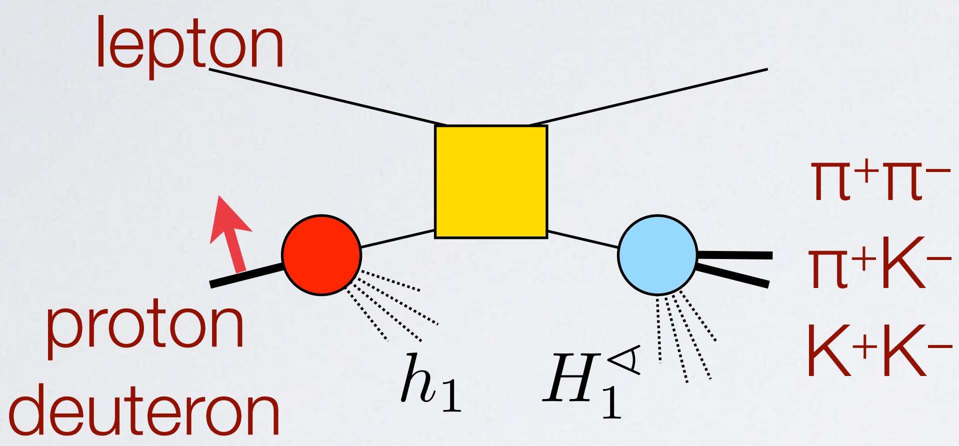
deuteron $\quad xh_1^{u-\bar{u}} + xh_1^{d-\bar{d}} = \tilde{F}\,[A_{\mathrm{SIDIS}}^D \text{ data},\ H_1^{\sphericalangle\, u},\ f_1^q D_1^q]$

separate valence up and down

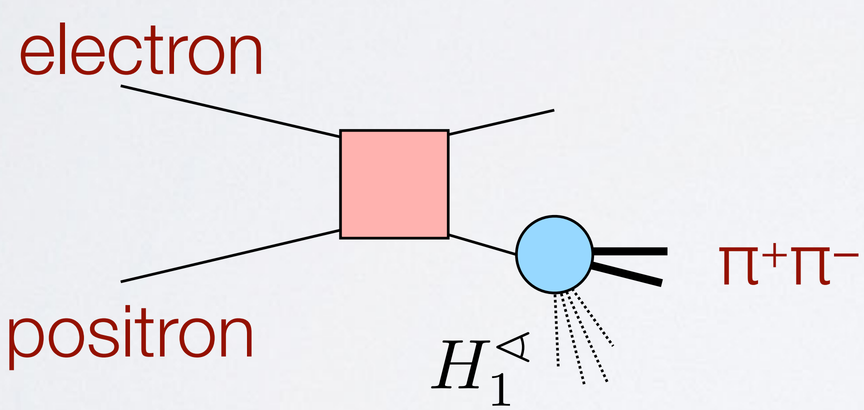
advantages of di-hadron mechanism

collinear framework → - factorization theorems for all hard processes
- universality of h_1 $H_1^{\sphericalangle}$ mechanism

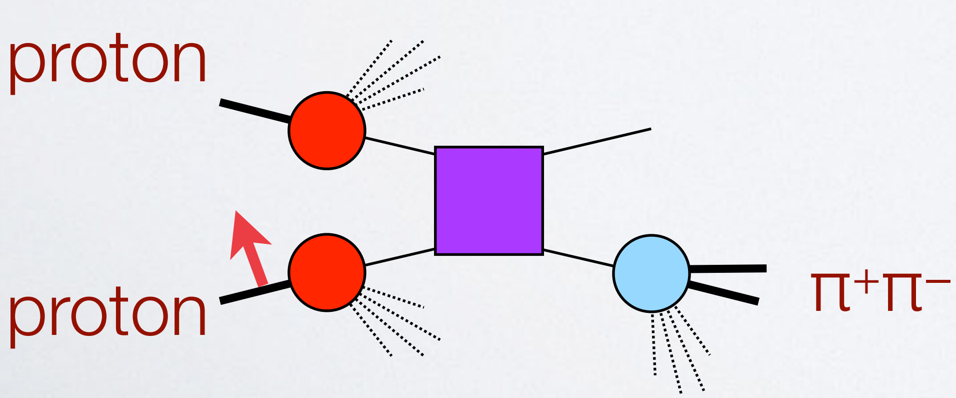
SIDIS



e+e−



p p↑

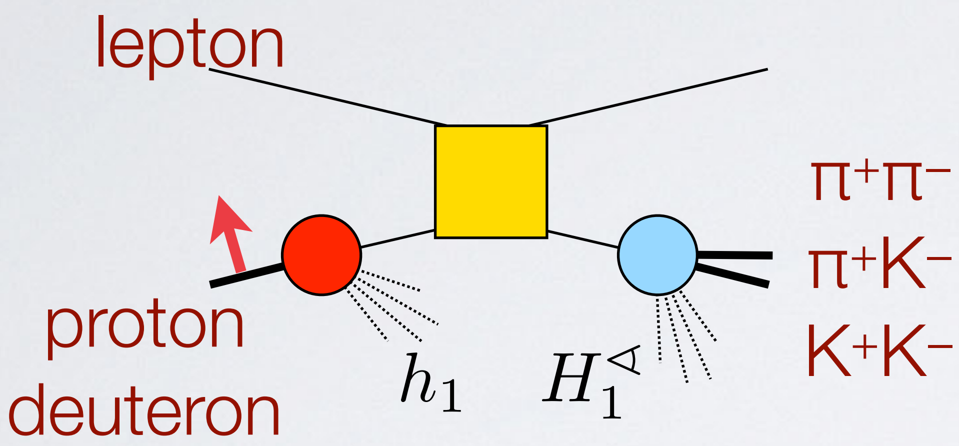


advantages of di-hadron mechanism

collinear framework → - factorization theorems for all hard processes
- universality of $h_1 \, H_1^{\sphericalangle}$ mechanism

data used in the global fit

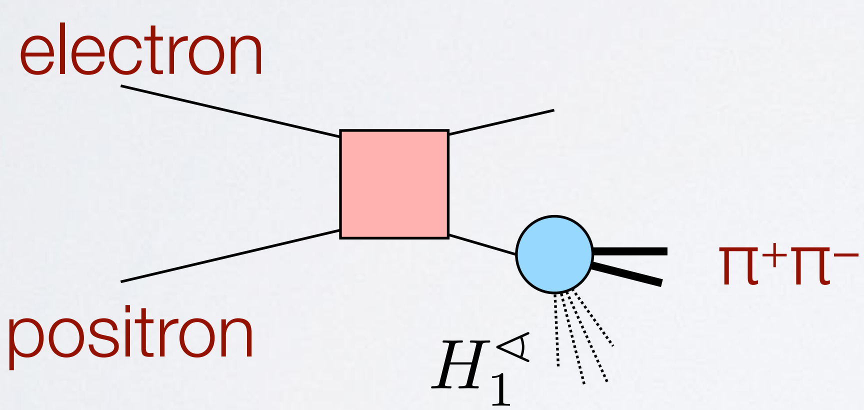
SIDIS



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

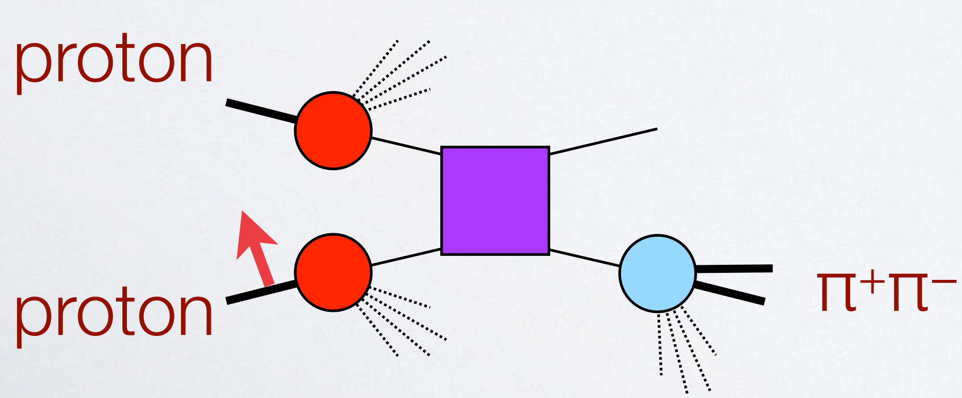
*Adolph et al., P.L. **B713** (12)*
*Braun et al., E.P.J. Web Conf. **85** (15)*

e+e−



*Vossen et al., P.R.L. **107** (11) 072004*

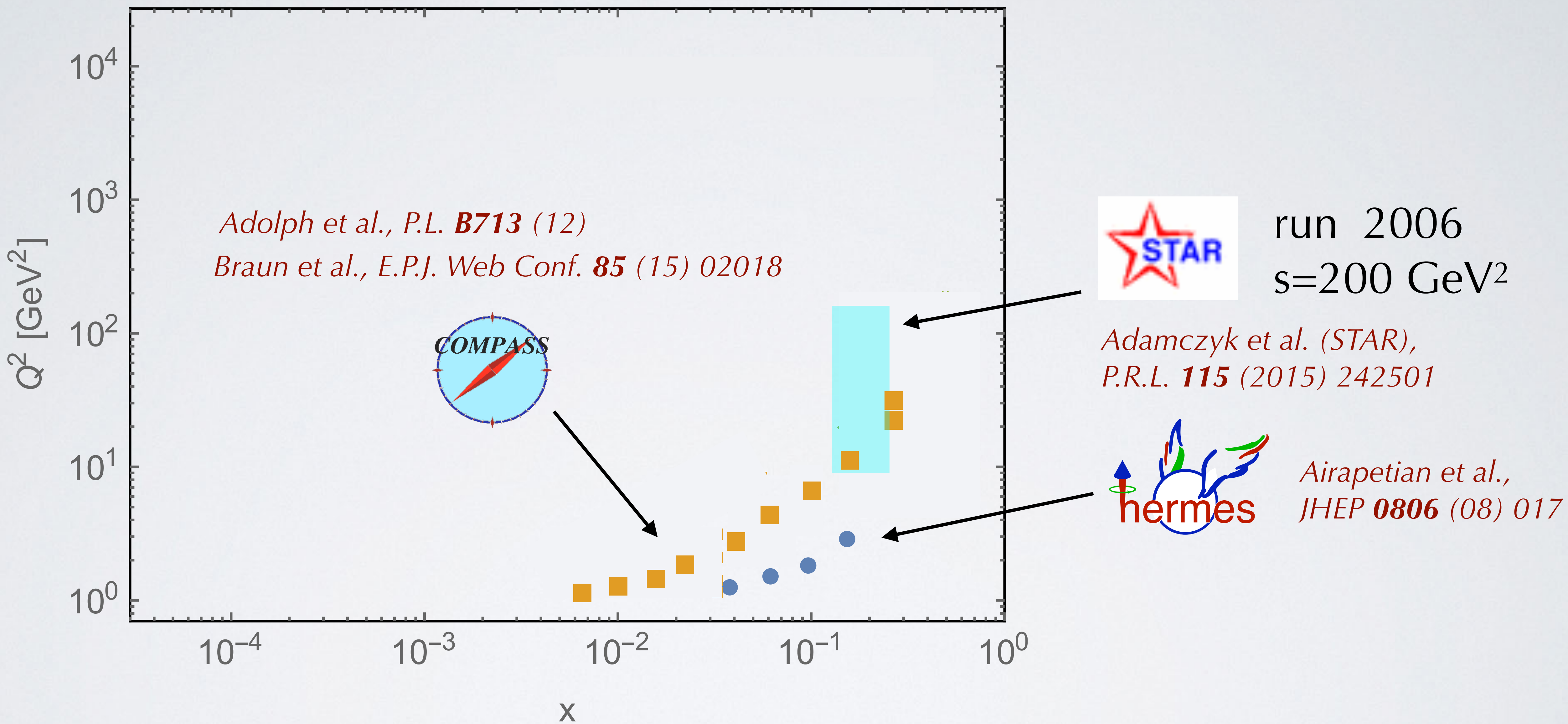
p p↑



run 2006 (s=200)

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

the phase space



- mostly high x → not enough for sea quark explorations
- guess low-x behavior (relevant for calculation of tensor charge)

choice of functional form

functional form whose Mellin transform can be computed analytically and complying with Soffer Bound at any x and scale Q^2

$$h_1^{q_v}(x; Q_0^2) = F^{q_v}(x) \left[\mathrm{SB}^q(x) + \overline{\mathrm{SB}}^{\bar{q}}(x) \right]$$

Soffer Bound

$$2|h_1^q(x, Q^2)| \leq 2\ \mathrm{SB}^q(x, Q^2) = |f_1^q(x, Q^2) + g_1^q(x, Q^2)|$$

MSTW08 DSSV

$$F^{q_v}(x) = \frac{N_{q_v}}{\max_x [|F^{q_v}(x)|]}\, x^{A_{q_v}}\ [1 + B_{q_v}\, \mathrm{Ceb}_1(x) + C_{q_v}\, \mathrm{Ceb}_2(x) + D_{q_v}\, \mathrm{Ceb}_3(x)]$$

$\mathrm{Ceb}_n(x)$ Cebyshev polynomial

10 fitting parameters

constrain parameters

$|N_{q_v}| \leq 1 \Rightarrow |F^{q_v}(x)| \leq 1$ Soffer Bound ok at any Q^2

low-x behavior

$$\lim_{x\to 0} x\mathrm{SB}^q(x) \propto x^{a_q}$$

$$\lim_{x\to 0} F^{q_v}(x) \propto x^{A_q}$$

$$h_1^q(x) \overset{x\to 0}{\approx} x^{A_q + a_q - 1}$$

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

constrain parameters

low-x behavior important

low-x behavior

$$\left.\begin{array}{l}\lim_{x\to 0} x\mathrm{SB}^q(x) \propto x^{a_q} \\ \lim_{x\to 0} F^{q_v}(x) \propto x^{A_q}\end{array}\right\} \quad h_1^q(x) \overset{x\to 0}{\approx} x^{A_q+a_q-1}$$

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

low-x behavior important

constrain parameters

1) δq finite => $A_q + a_q > 0$

2) "massive" jet in DIS → h_1 at twist 3

violation of Burkardt-Cottingham s.r. $\int_0^1 dx\, g_2(x) \propto \int_0^1 dx\, \frac{h_1(x)}{x} \longrightarrow A_q + a_q > 1$

*Accardi and Bacchetta, P.L. **B773** (17) 632*

3) small-x dipole picture => $h_1^{q_v}(x) \overset{x\to 0}{\approx} x^{1-2\sqrt{\frac{\alpha_s(Q^2)N_c}{2\pi}}} \longrightarrow$ at Q_0 $A_q + a_q \sim 1$

Kovchegov & Sievert, arXiv:1808.10354

low-x behavior

$$\left.\begin{array}{l}\lim_{x\to 0} x\mathrm{SB}^q(x) \propto x^{a_q} \\ \lim_{x\to 0} F^{q_v}(x) \propto x^{A_q}\end{array}\right\} \qquad h_1^q(x) \overset{x\,\to\,0}{\approx} x^{A_q + a_q - 1}$$

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

low-x behavior important

constrain parameters

1) δq finite => $A_q + a_q > 0$

2) "massive" jet in DIS → h_1 at twist 3
violation of Burkardt-Cottingham s.r. $\int_0^1 dx\, g_2(x) \propto \int_0^1 dx\, \frac{h_1(x)}{x} \longrightarrow A_q + a_q > 1$

Accardi and Bacchetta, P.L. ***B773*** *(17) 632*

3) small-x dipole picture => $h_1^{q_v}(x) \overset{x\,\to\,0}{\approx} x^{1-2\sqrt{\frac{\alpha_s(Q^2)N_c}{2\pi}}} \longrightarrow$ at Q_0 $A_q + a_q \sim 1$

Kovchegov & Sievert, arXiv:1808.10354

our choice $A_q + a_q > \frac{1}{3}$ $\qquad \left|\int_0^{x_{\min}} dx\right| \sim 1\%$ of $\left|\int_{x_{\min}}^1 dx\right|$

for $x_{\min}=10^{-6}$ from MSTW08

theoretical uncertainties

unpolarized Di-hadron Fragmentation Function D_1

- **quark** D_1^q is **well** constrained by $e^+e^- \rightarrow (\pi^+\pi^-)\,X$ (Montecarlo)
- **gluon** D_1^g is **not** constrained by $e^+e^- \rightarrow (\pi^+\pi^-)\,X$ (currently, LO analysis)
- **no data** available yet for $p\,p \rightarrow (\pi^+\pi^-)\,X$

we don't know anything about the gluon D_1^g

our choice: set $D_1^g(Q_0) = \begin{cases} 0 \\ D_1^u(Q_0)/4 \\ D_1^u(Q_0) \end{cases}$

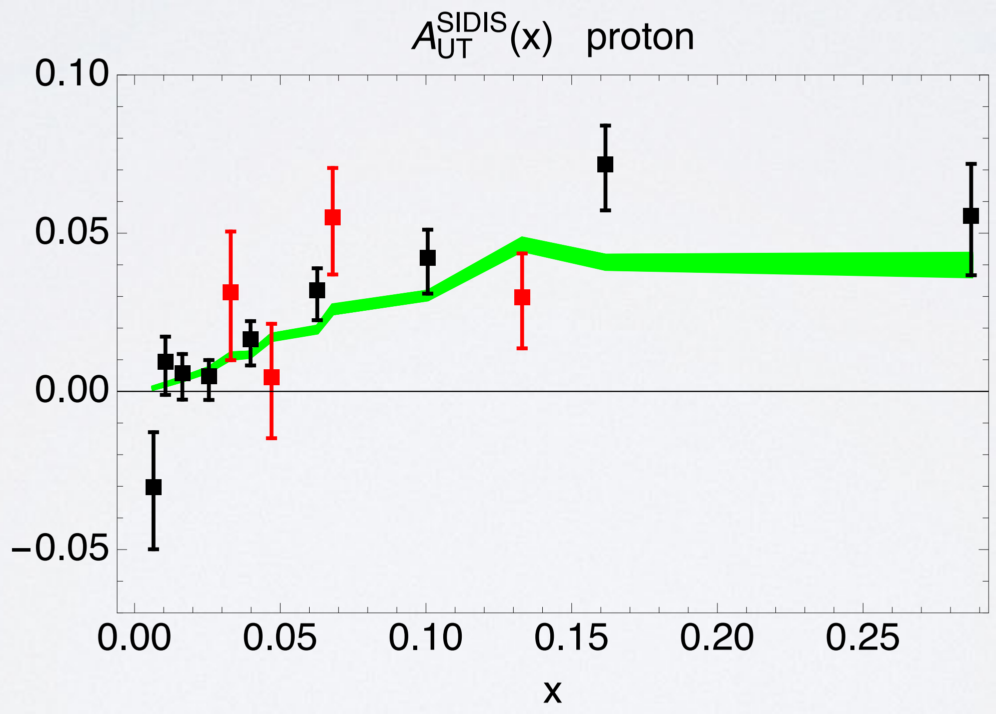
deteriorates our e^+e^- fit as $\chi^2/\text{dof} = \begin{cases} 1.69 & 1.28 \\ 1.81 & 1.37 \\ 2.96 & 2.01 \end{cases}$

background ρ channels

statistical uncertainty

the bootstrap method

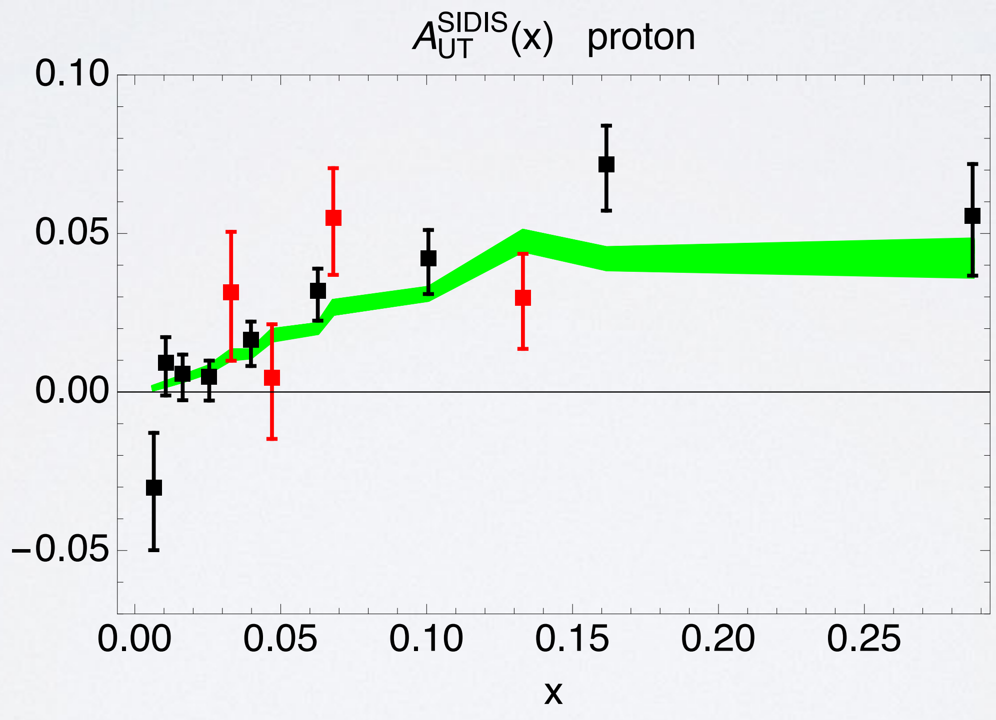
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50



statistical uncertainty

the bootstrap method

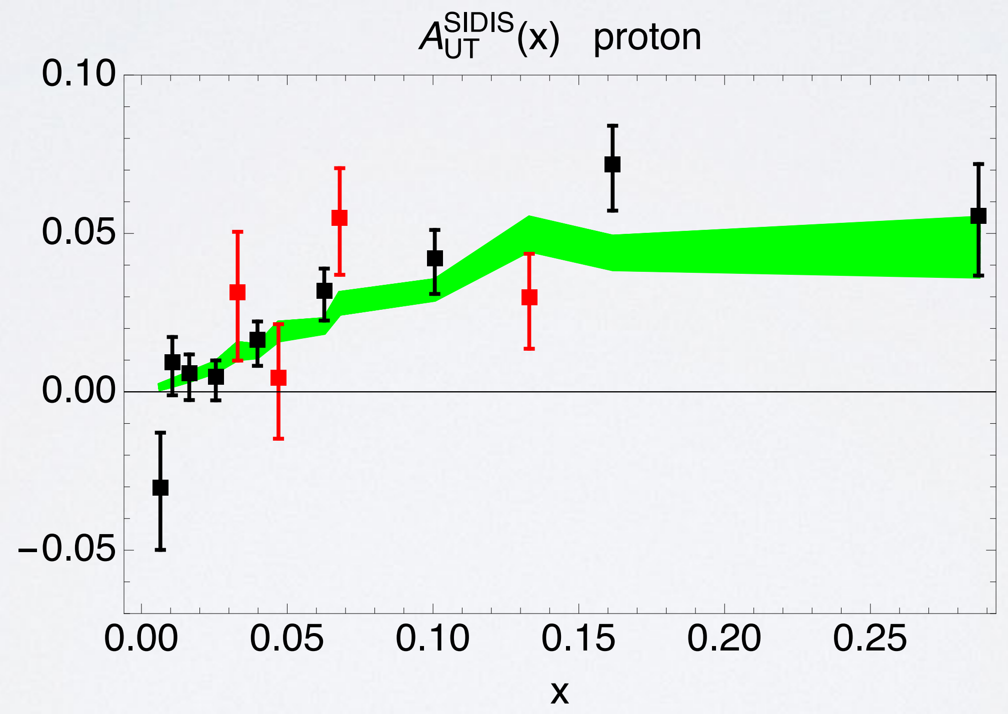
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50, 100



statistical uncertainty

the bootstrap method

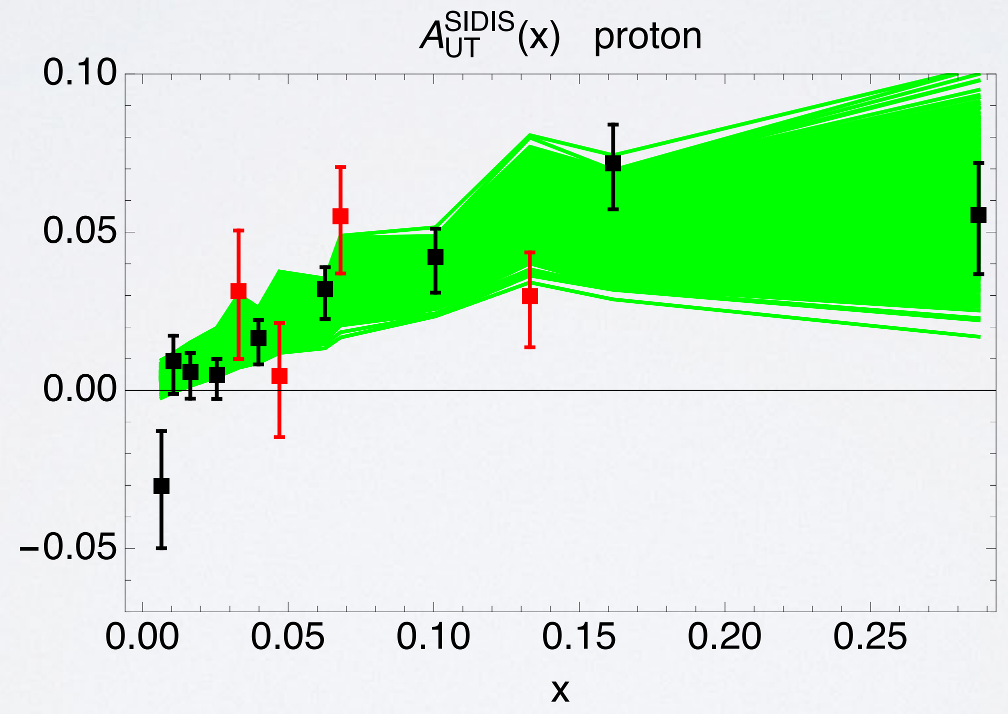
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50, 100, 200 sets…



statistical uncertainty

the bootstrap method

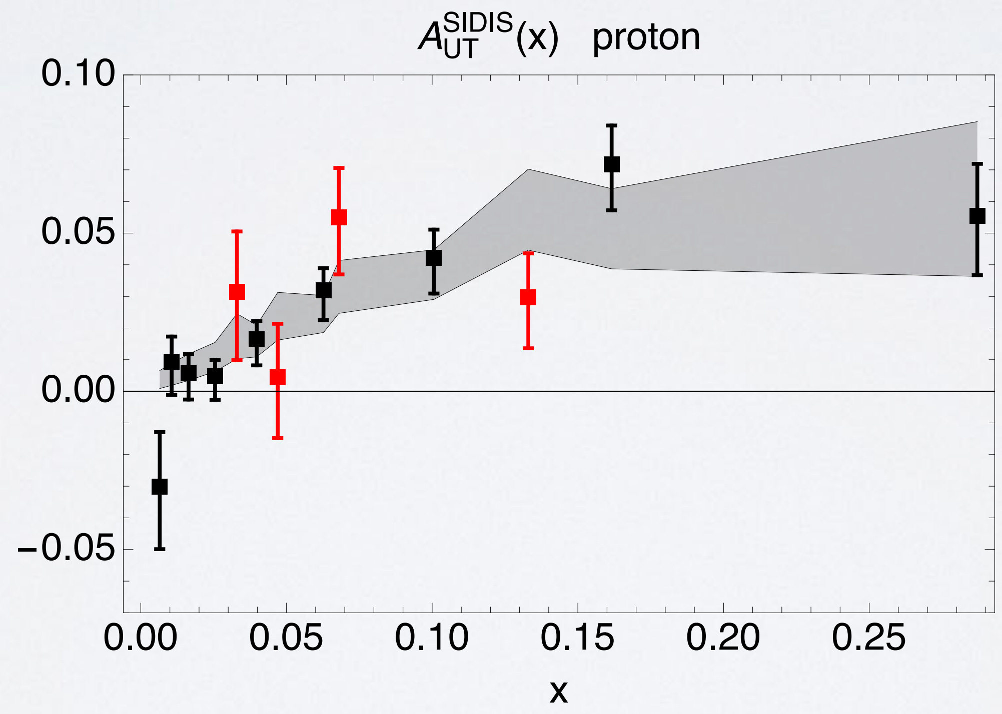
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50, 100, 200 sets… until average and standard deviation reproduce original exp. points (here, 200x3=600)



statistical uncertainty

the bootstrap method

- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50, 100, 200 sets… until average and standard deviation reproduce original exp. points (here, 200x3=600)
- exclude largest and smallest 5% => 90% band



automatically accounts for correlations

results

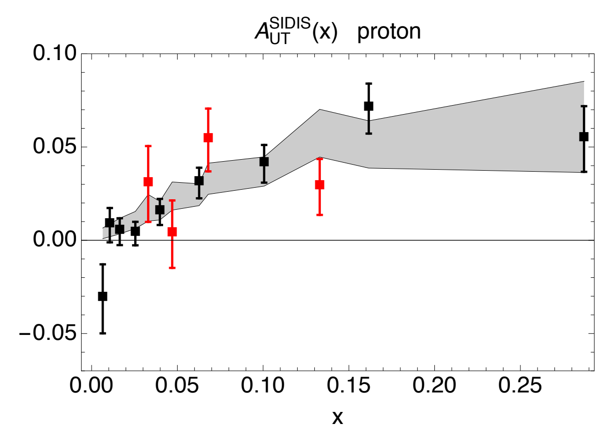
global fit published in

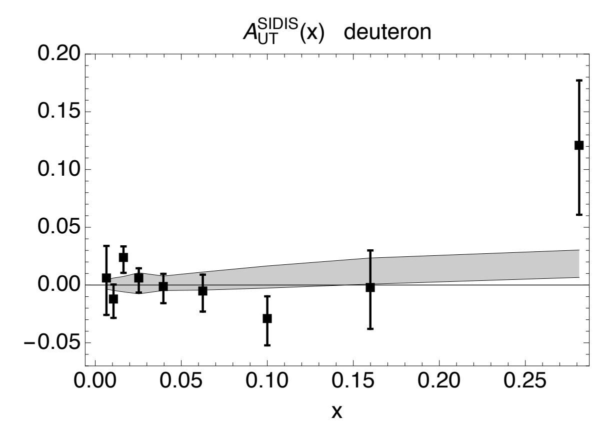
Radici and Bacchetta, P.R.L. ***120*** *(18) 192001*

SIDIS

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

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



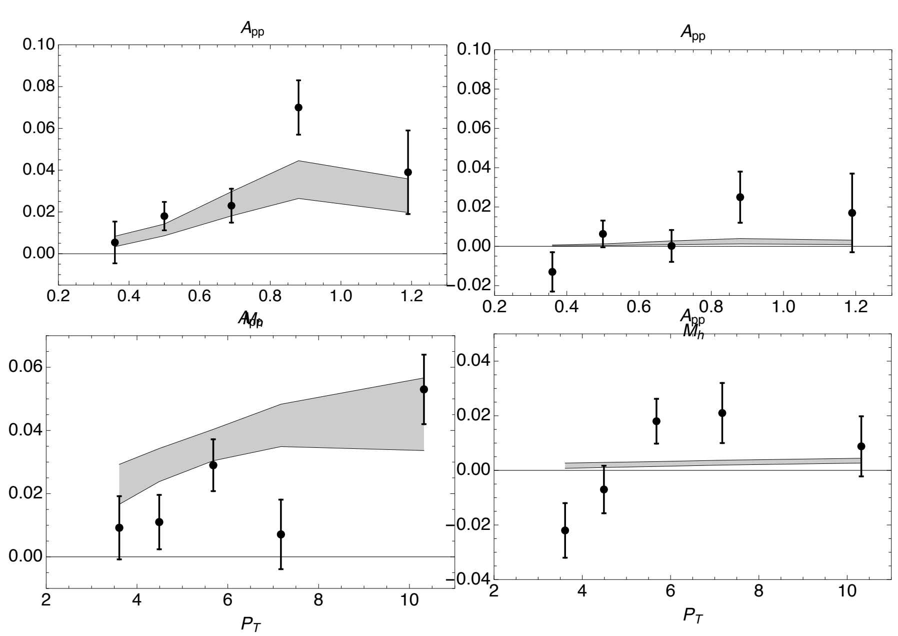


pp collisions

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

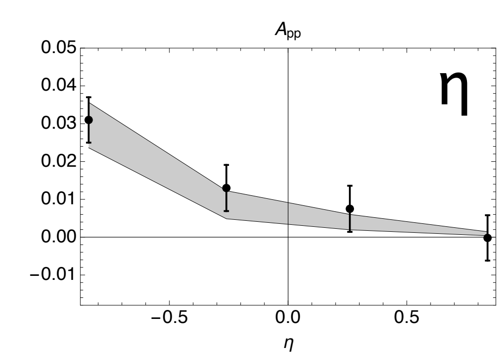
M_h, η<0

M_h, η>0



pT, η<0

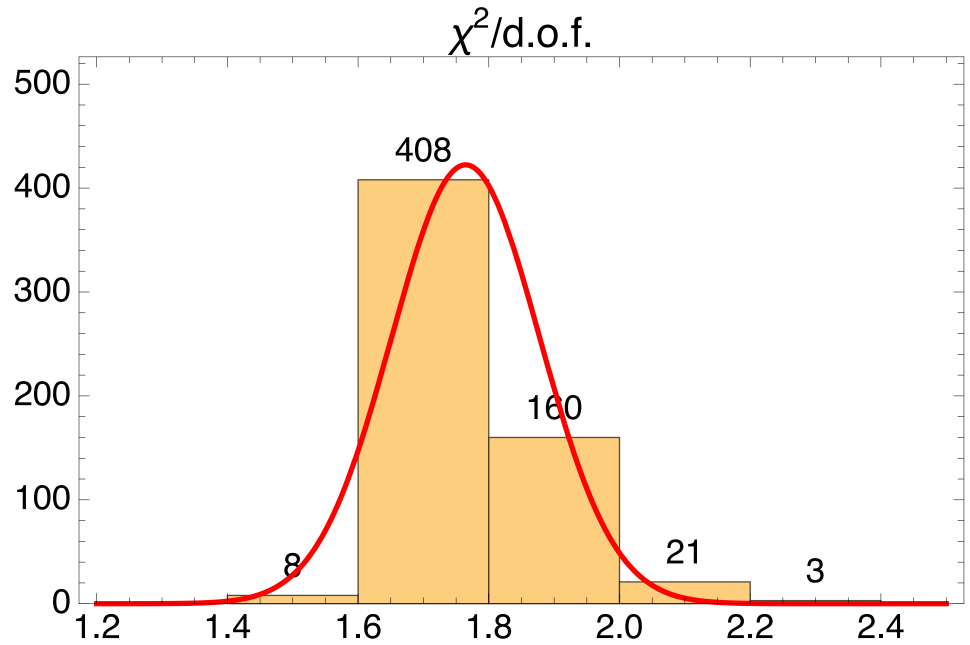
pT, η>0



η

χ^2 of the fit

$\chi^2/\text{dof} = 1.76 \pm 0.11$



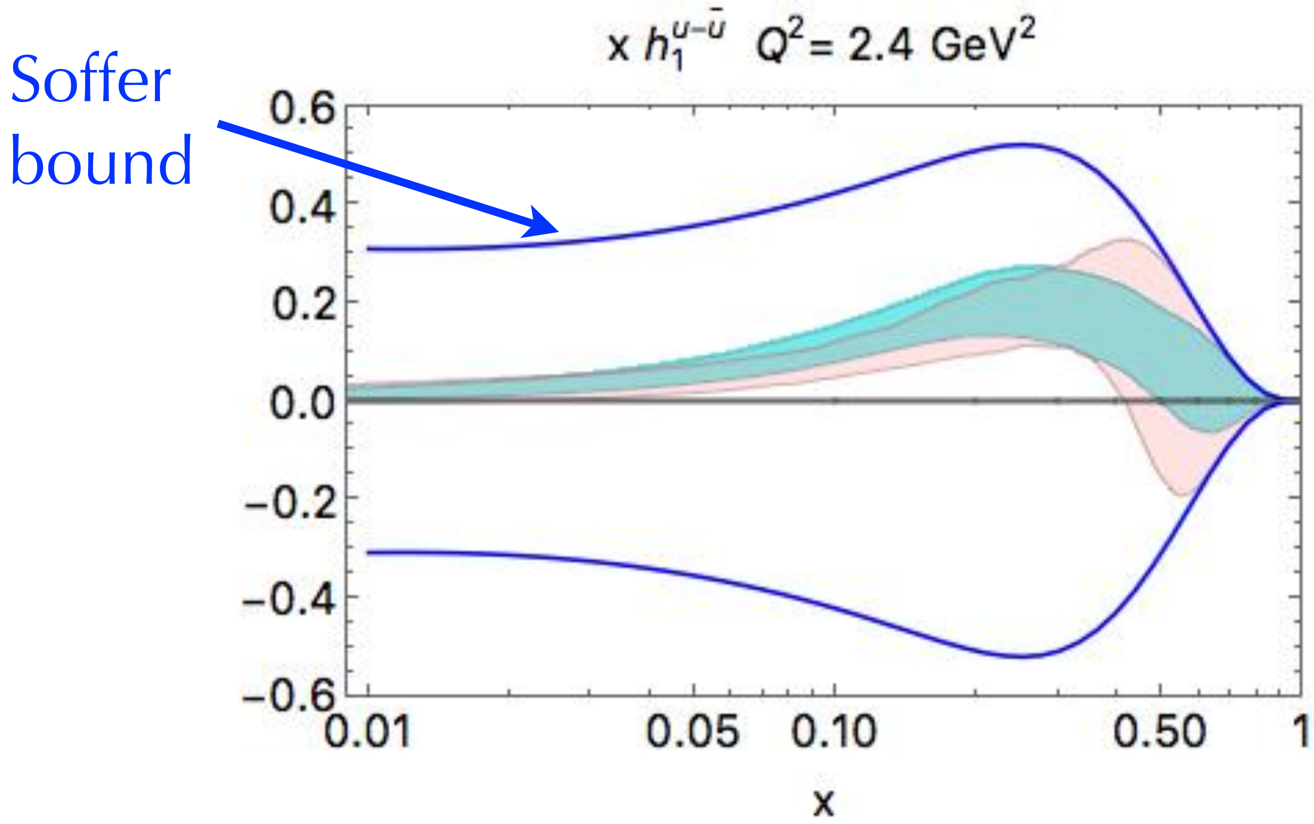
proton SIDIS **13** data points = **4** hermes + **9** COMPASS

deuteron SIDIS **9** data points = + **9**

STAR **24** data points $(\mathbf{4}\ \eta) \times \frac{\mathbf{4}}{\mathbf{24}} + (\mathbf{10}\ M_h) \times \frac{\mathbf{10}}{\mathbf{24}} + (\mathbf{10}\ p_T) \times \frac{\mathbf{10}}{\mathbf{24}}$

global fit **10** parameters

comparison with previous fit



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

global fit

up

higher precision

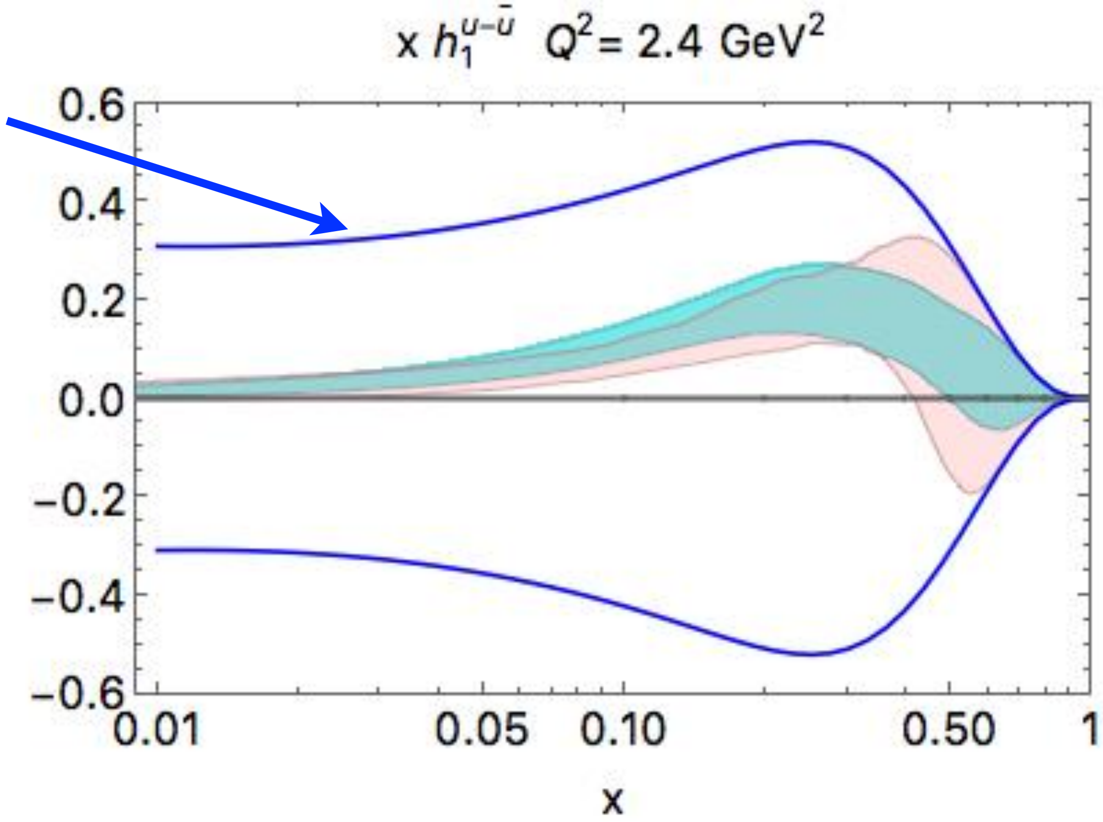
old fit (only SIDIS data)

Radici et al.,
*JHEP **1505** (15) 123*

equivalent to Collins extraction

comparison with previous fit

Soffer bound



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

global fit

up

higher precision

old fit (only SIDIS data)

Radici et al., JHEP ***1505*** *(15) 123*

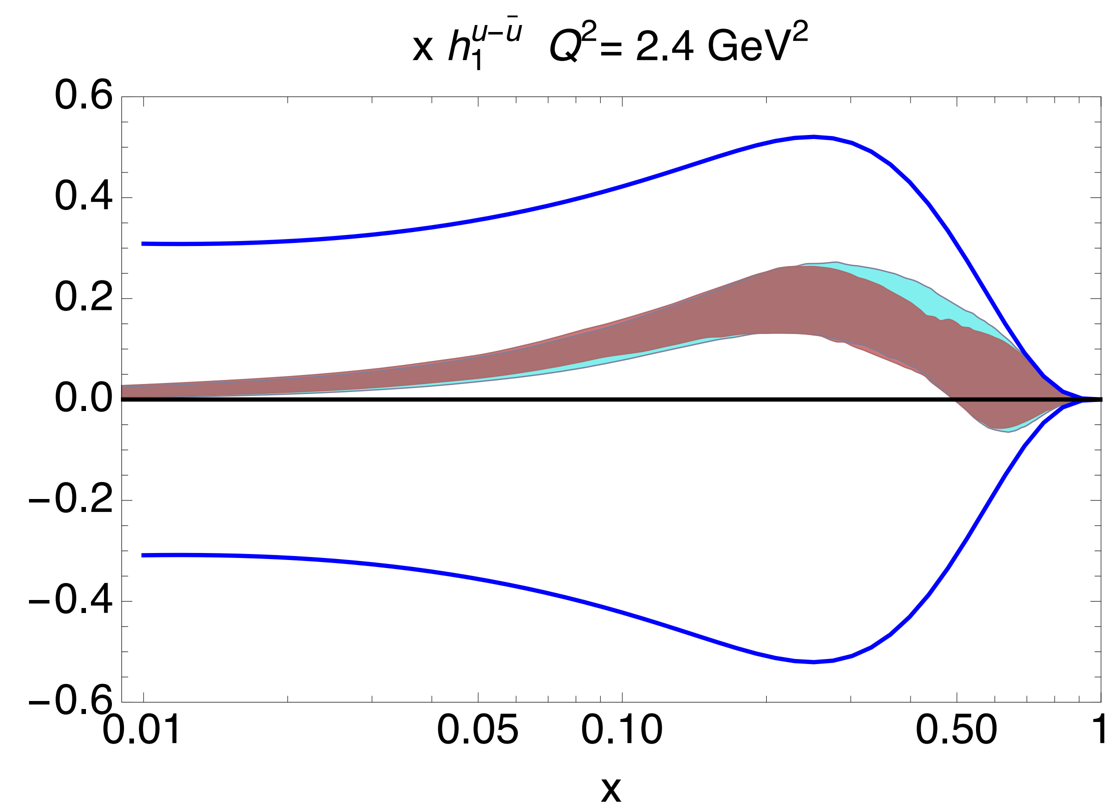
equivalent to Collins extraction

up

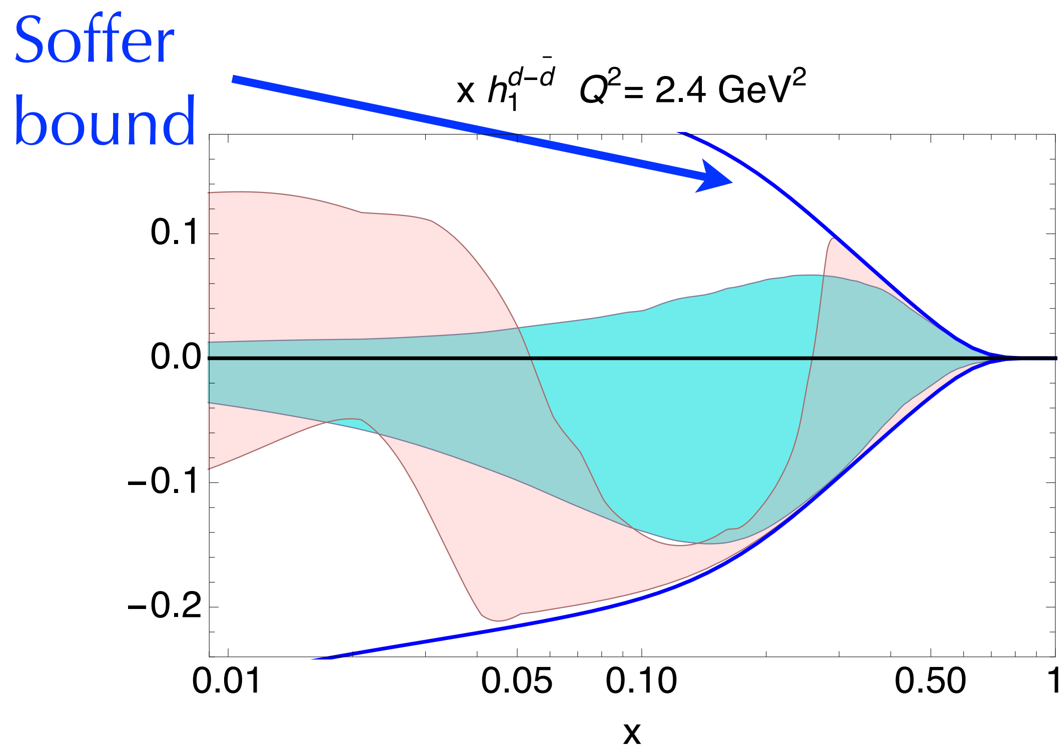
insensitive to uncertainty on gluon D_1

$D_1^g(Q_0) = 0$

$$D_1^g(Q_0) = \begin{cases} 0 \\ D_1^u/4 \\ D_1^u \end{cases}$$



comparison with previous fit



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

global fit

old fit

Radici et al., JHEP ***1505*** *(15) 123*

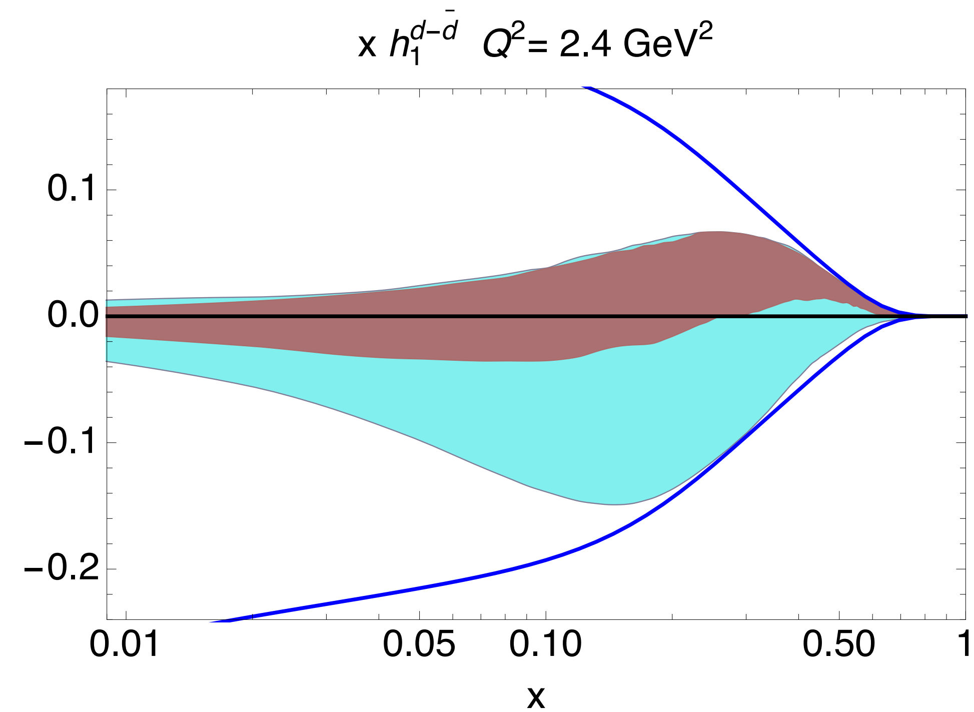
down

down

sensitive to uncertainty on gluon D_1

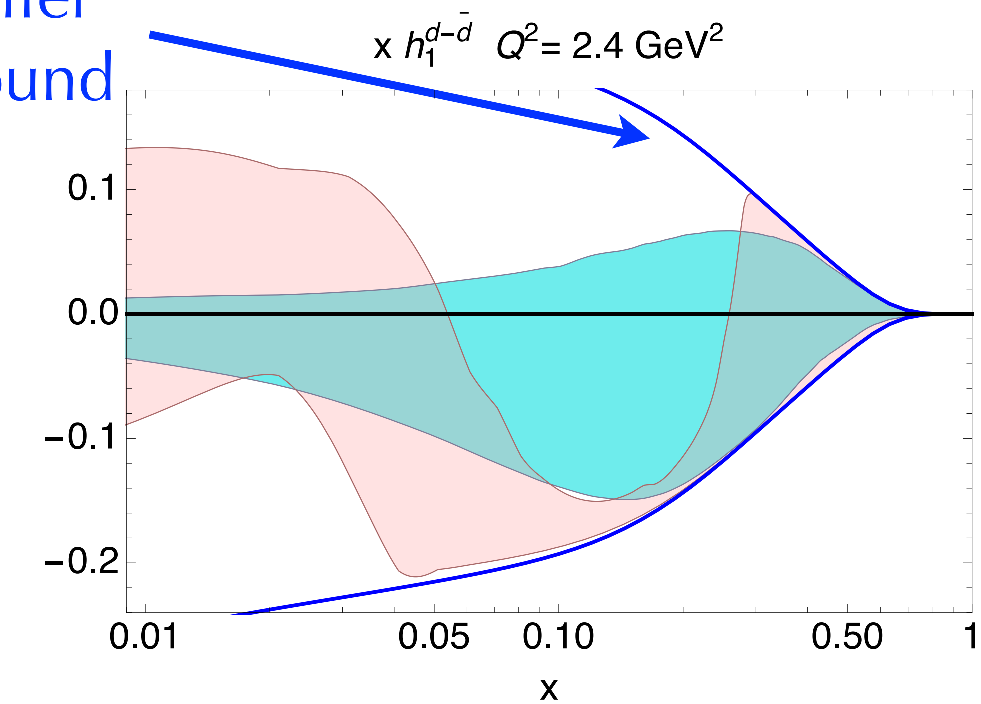
$D_1^g(Q_0) = 0$

$$D_1^g(Q_0) = \begin{cases} 0 \\ D_1^u/4 \\ D_1^u \end{cases}$$



comparison with previous fit

Soffer bound



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

global fit

old fit

Radici et al., JHEP ***1505*** *(15) 123*

down

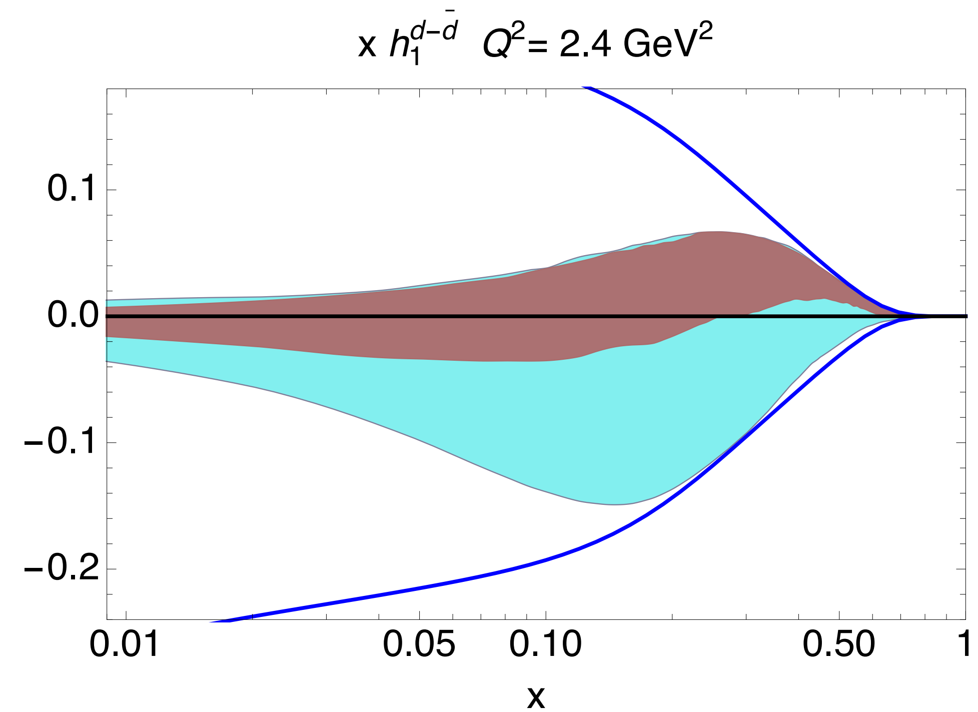
need better control on $g \to \pi^+\pi^-$

down

sensitive to uncertainty on gluon D_1

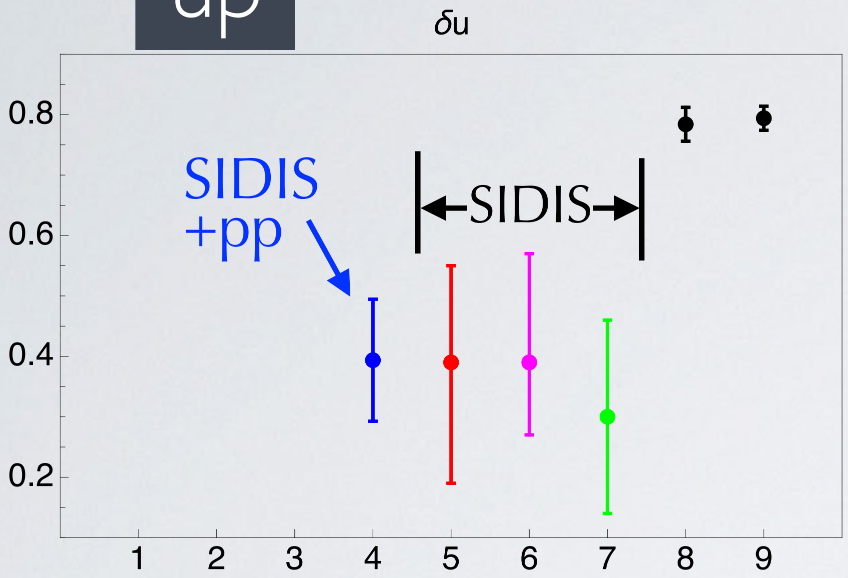
$D_1{}^g(Q_0) = 0$

$$D_1{}^g(Q_0) = \begin{cases} 0 \\ D_1{}^u/4 \\ D_1{}^u \end{cases}$$

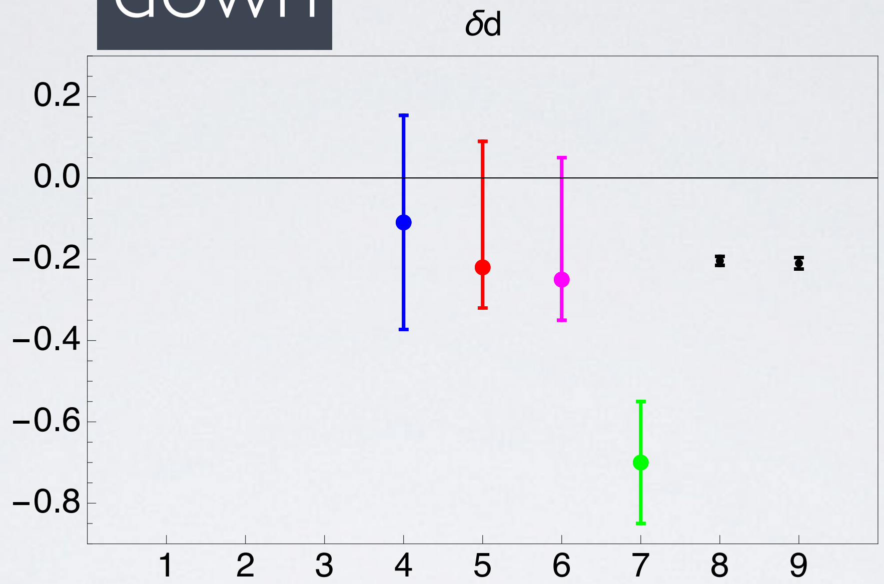


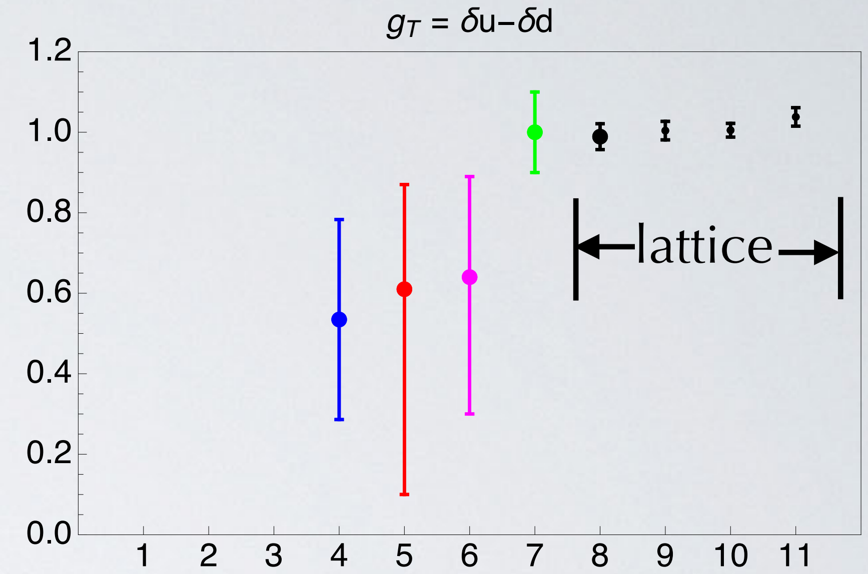
tensor charge

up



down





Q^2=4 GeV^2 *

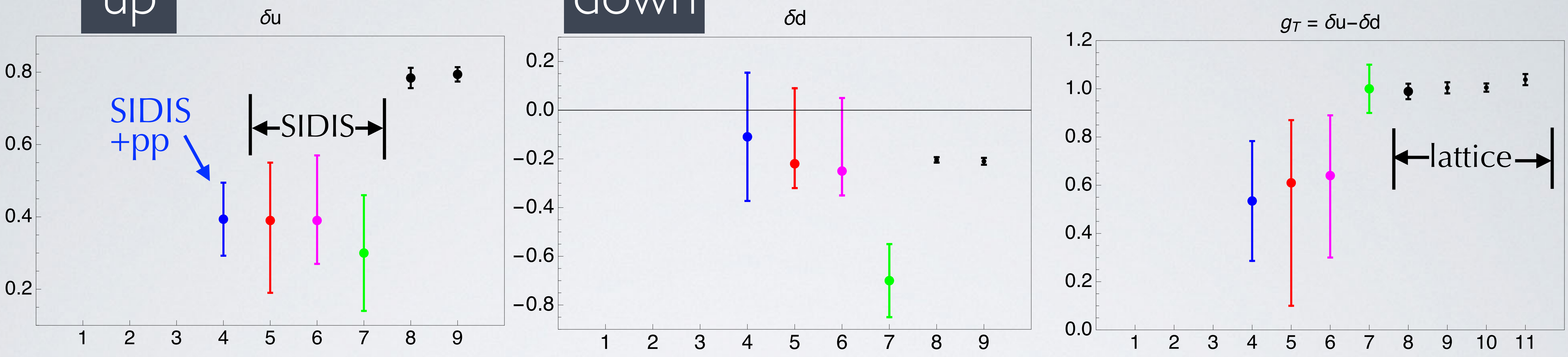
JAM includes "lattice data"

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001*	**4) global fit '17**	**8) PNDME '18**	*Gupta et al., P.R. D**98** (18) 034503*
*Kang et al., P.R. D**93** (16) 014009*	**5) "TMD fit" * Q^2=10**	**9) ETMC '17**	*Alexandrou et al., P.R. D**95** (17) 114514; E P.R. D**96** (17) 099906*
*Anselmino et al., P.R. D**87** (13) 094019*	**6) Torino fit * Q^2=1**	**10) RQCD '14**	*Bali et al., P.R. D**91** (15)*
Lin et al., P.R.L. ***120*** *(18) 152502*	**7) JAM fit '17 * Q_0^2=2**	**11) LHPC '12**	*Green et al., P.R. D**86** (12)*

tensor charge

up

down



no simultaneous compatibility between lattice and phenomenology

Q^2=4 GeV^2 *

JAM includes "lattice data"

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 4) **global fit '17**

*Kang et al., P.R. D**93** (16) 014009* — 5) **"TMD fit" * Q^2=10**

*Anselmino et al., P.R. D**87** (13) 094019* — 6) **Torino fit * Q^2=1**

Lin et al., P.R.L. ***120*** *(18) 152502* — 7) **JAM fit '17 * Q_0^2=2**

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

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

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

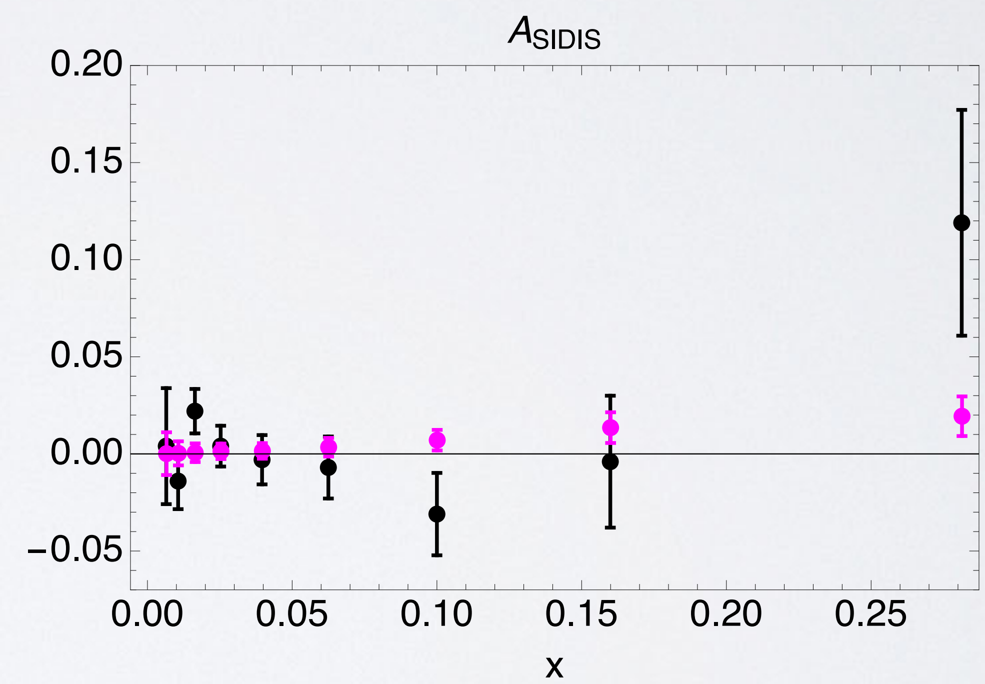
11) **LHPC '12** — *Green et al., P.R. D**86** (12)*

Compass pseudo-data

add to previous set of data
a new set of SIDIS pseudo-data for deuteron target

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

pseudodata



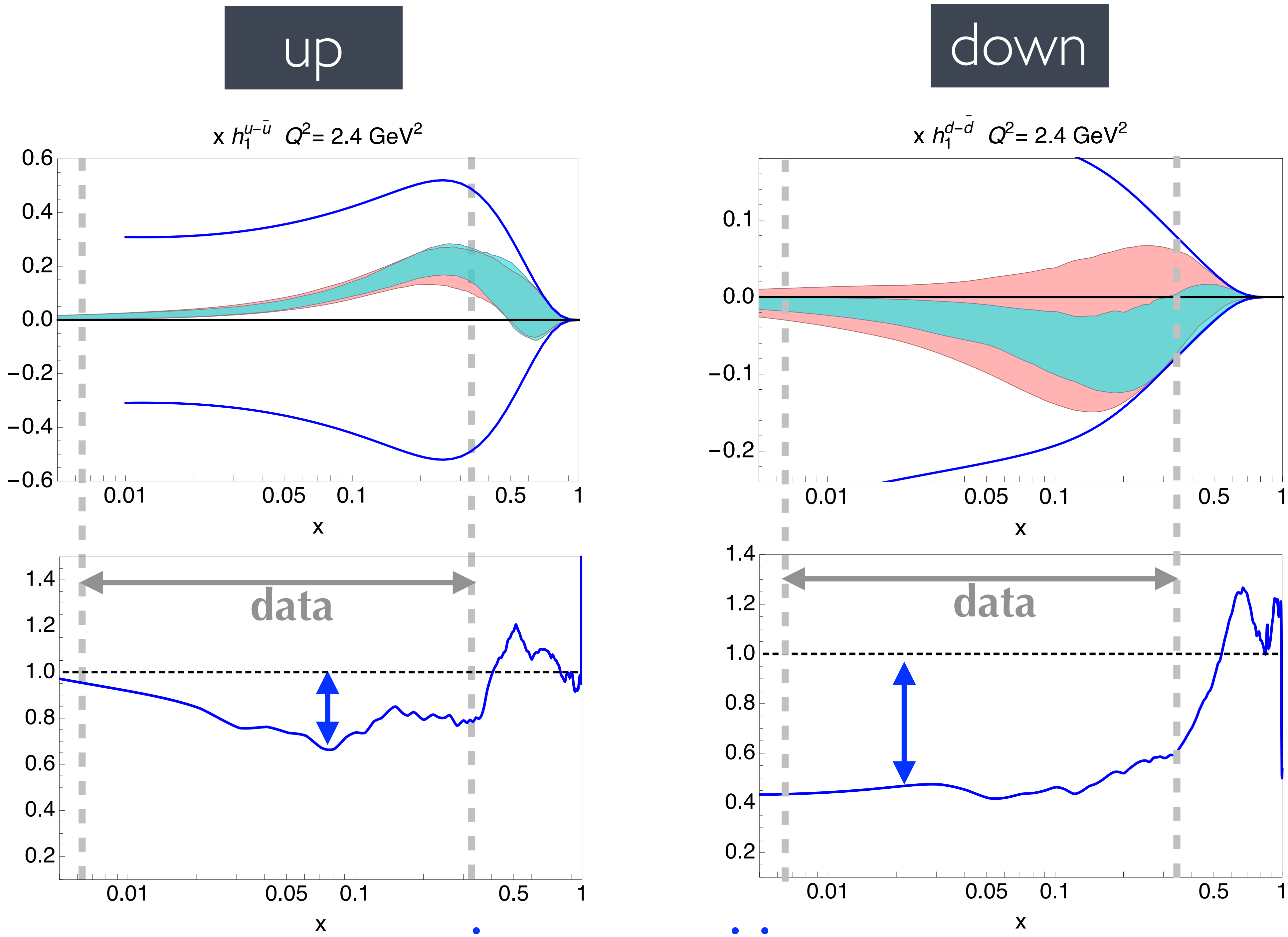
statistical error ~ 0.6 x [error in 2010 proton run]
<A> = average value of replicas in previous global fit

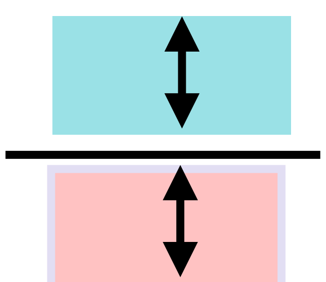
impact of pseudo-data

global fit + pseudodata

global fit

$$D_1^g(Q_0) = \begin{cases} 0 \\ D_1^u/4 \\ D_1^u \end{cases}$$

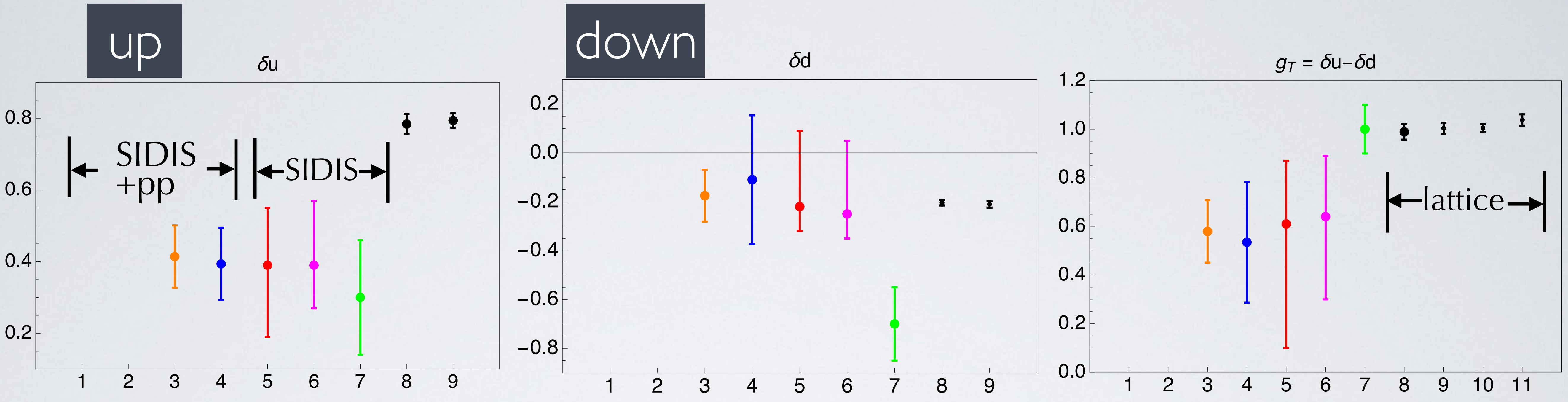




ratio of widths

increase precision

tensor charge



Q^2=4 GeV^2 *

JAM includes "lattice data"

3) **global fit + pseudodata**

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* 4) **global fit '17**

*Kang et al., P.R. D**93** (16) 014009* 5) **"TMD fit" * Q^2=10**

*Anselmino et al., P.R. D**87** (13) 094019* 6) **Torino fit * Q^2=1**

Lin et al., P.R.L. ***120*** *(18) 152502* 7) **JAM fit '17 * Q_0^2=2**

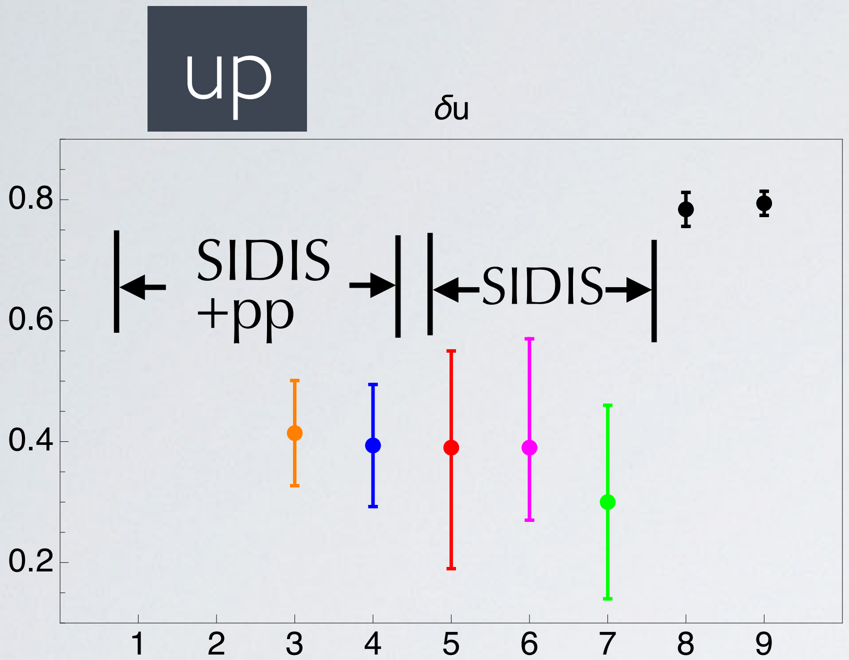
8) **PNDME '18** *Gupta et al., P.R. D**98** (18) 034503*

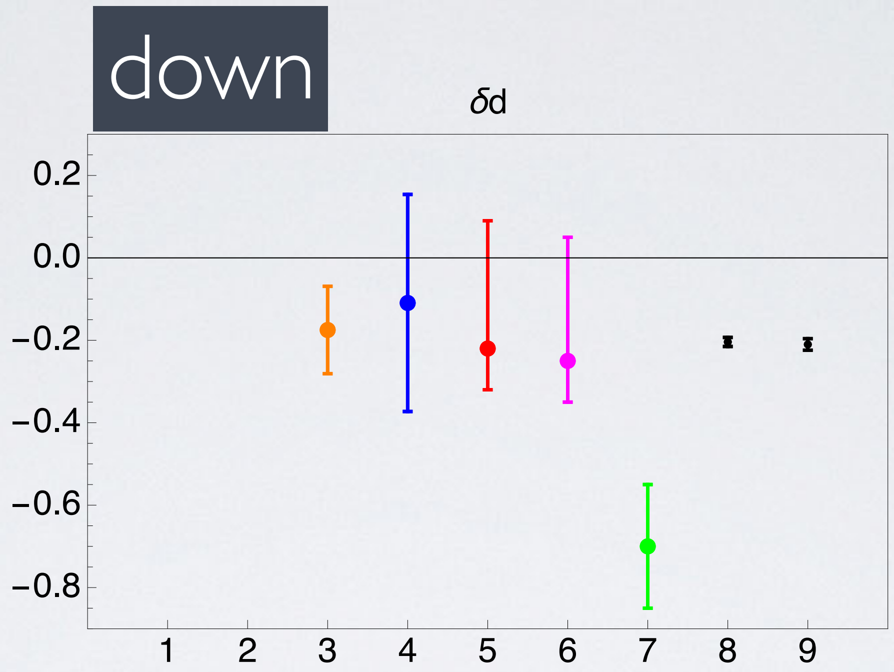
9) **ETMC '17** *Alexandrou et al., P.R. D**95** (17) 114514; E P.R. D**96** (17) 099906*

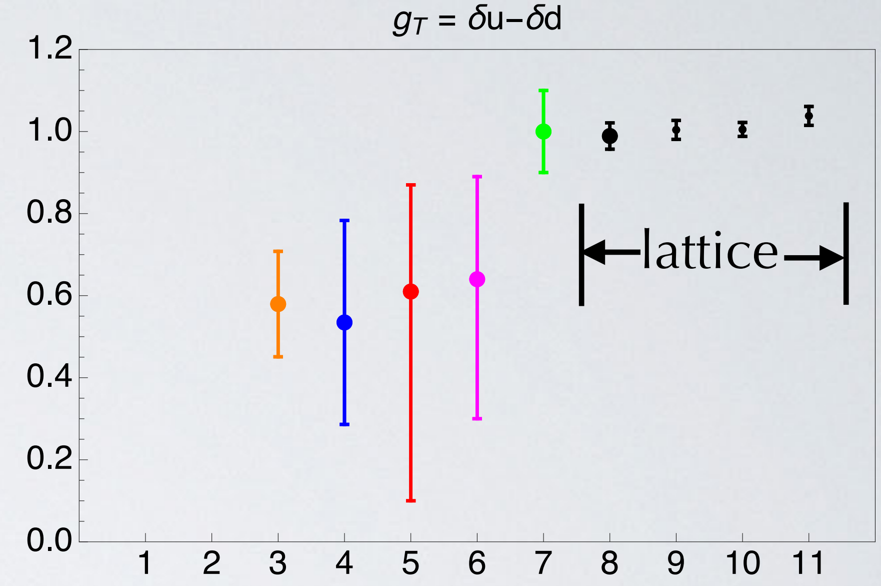
10) **RQCD '14** *Bali et al., P.R. D**91** (15)*

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

tensor charge







better precision but confirm general trend

Q^2=4 GeV^2 *

JAM includes "lattice data"

3) **global fit + pseudodata**

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* 4) **global fit '17**

*Kang et al., P.R. D****93*** *(16) 014009* 5) **"TMD fit" * Q^2=10**

*Anselmino et al., P.R. D****87*** *(13) 094019* 6) **Torino fit * Q^2=1**

Lin et al., P.R.L. ***120*** *(18) 152502* 7) **JAM fit '17 * Q_0^2=2**

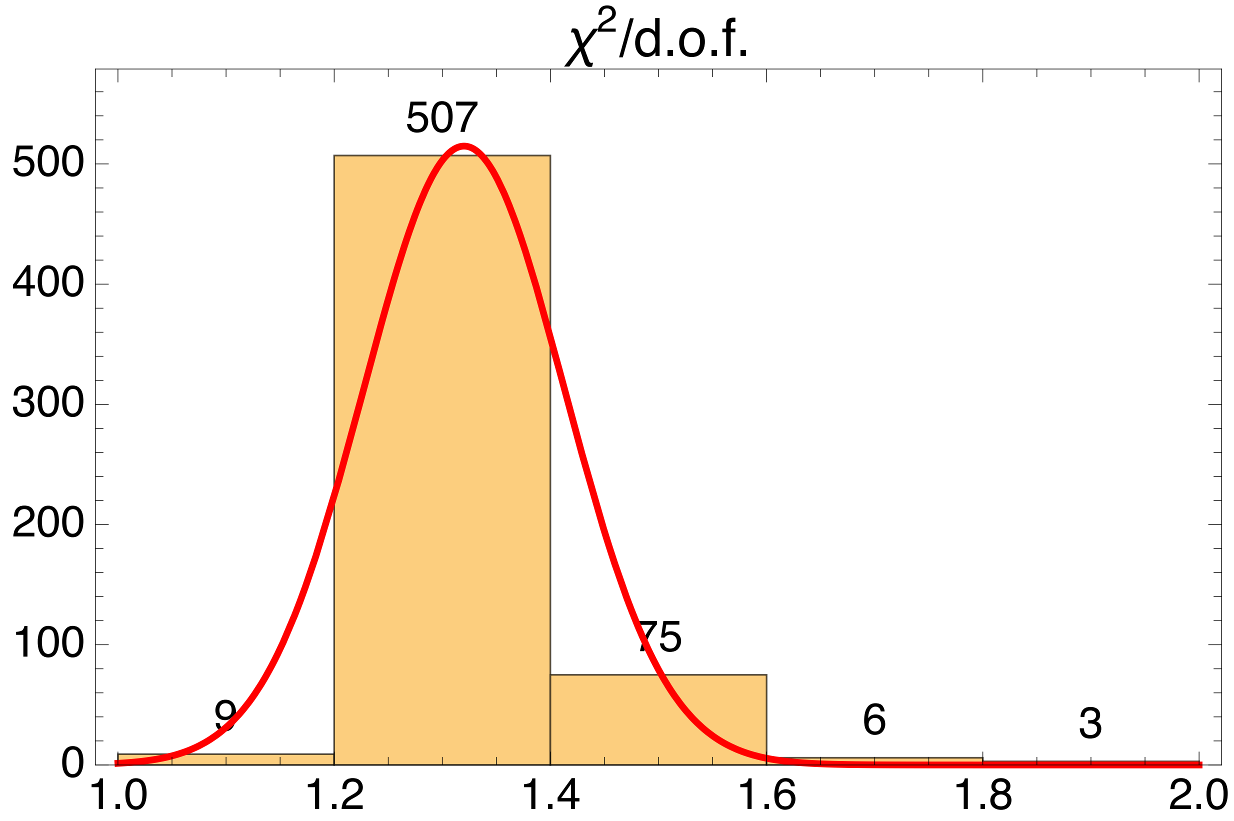
8) **PNDME '18** *Gupta et al., P.R. D****98*** *(18) 034503*

9) **ETMC '17** *Alexandrou et al., P.R. D****95*** *(17) 114514; E 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)*

better χ^2



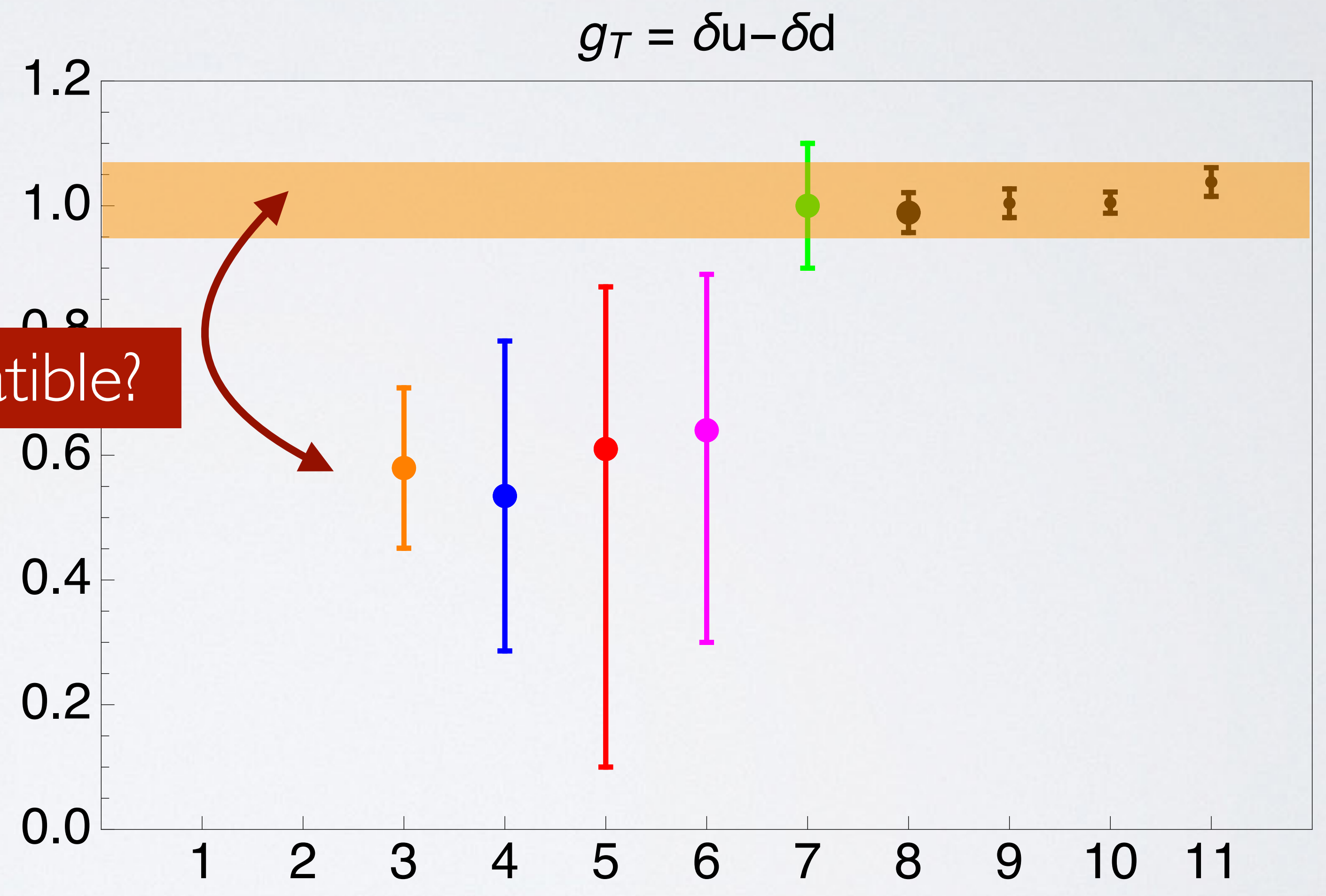
$\chi^2/\text{dof} = 1.32 \pm 0.09$

compatibility with lattice

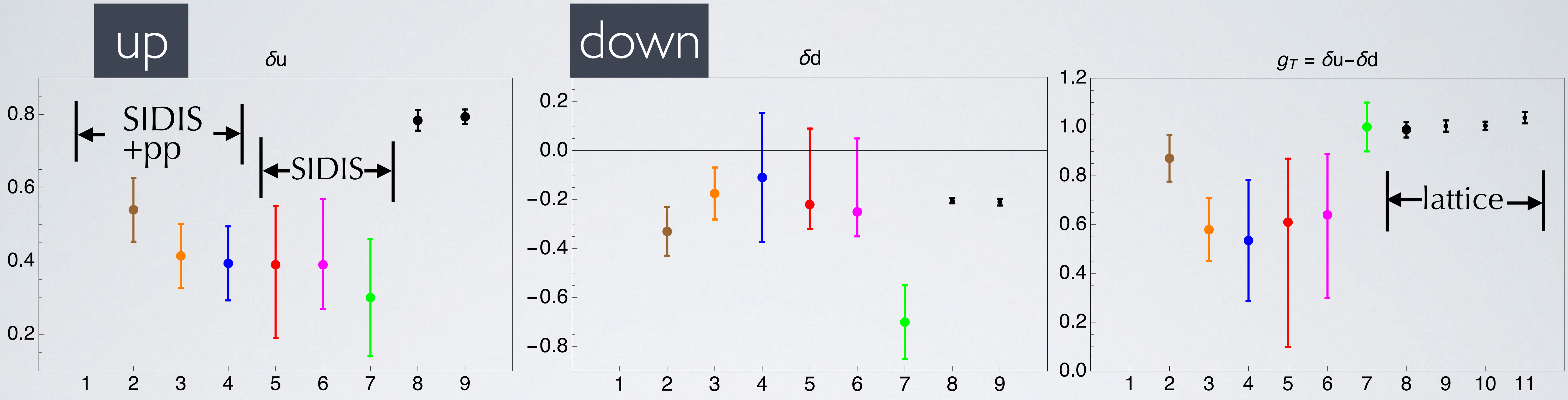
add to SIDIS+pp data + Compass SIDIS pseudo-data
constraint to reproduce g_T from lattice

$\overline{g_T}^{latt} = 1.004 \pm 0.057$

are they compatible?



tensor charge



Q^2=4 GeV^2 *

2) **global fit + pseudodata + constrain g_T**

3) **global fit + pseudodata**

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 4) **global fit '17**

*Kang et al., P.R. D**93** (16) 014009* — 5) **"TMD fit" * Q^2=10**

*Anselmino et al., P.R. D**87** (13) 094019* — 6) **Torino fit * Q^2=1**

Lin et al., P.R.L. ***120*** *(18) 152502* — 7) **JAM fit '17 * Q_0^2=2**

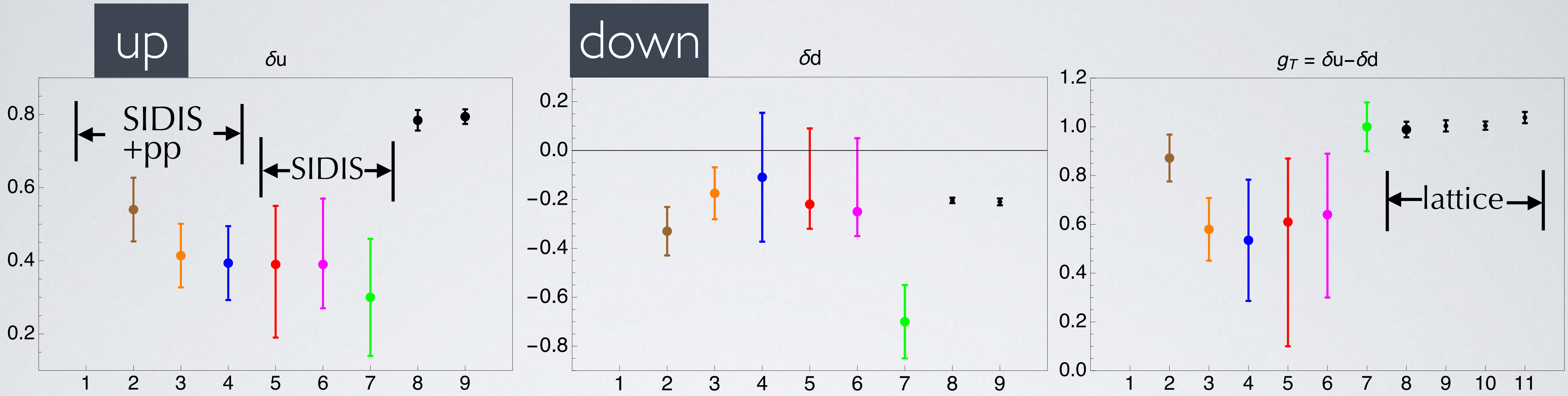
8) **PNDME '18** — *Gupta et al., P.R. D**98** (18) 034503*

9) **ETMC '17** — *Alexandrou et al., P.R. D**95** (17) 114514; E 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)*

tensor charge



not yet full compatibility

Q^2=4 GeV^2 *

2) **global fit + pseudodata + constrain g_T**

3) **global fit + pseudodata**

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 4) **global fit '17**

*Kang et al., P.R. D****93*** *(16) 014009* — 5) **"TMD fit" * Q^2=10**

*Anselmino et al., P.R. D****87*** *(13) 094019* — 6) **Torino fit * Q^2=1**

Lin et al., P.R.L. ***120*** *(18) 152502* — 7) **JAM fit '17 * Q_0^2=2**

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

9) **ETMC '17** — *Alexandrou et al., P.R. D****95*** *(17) 114514; E 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)*

impact of lattice g_T constraint

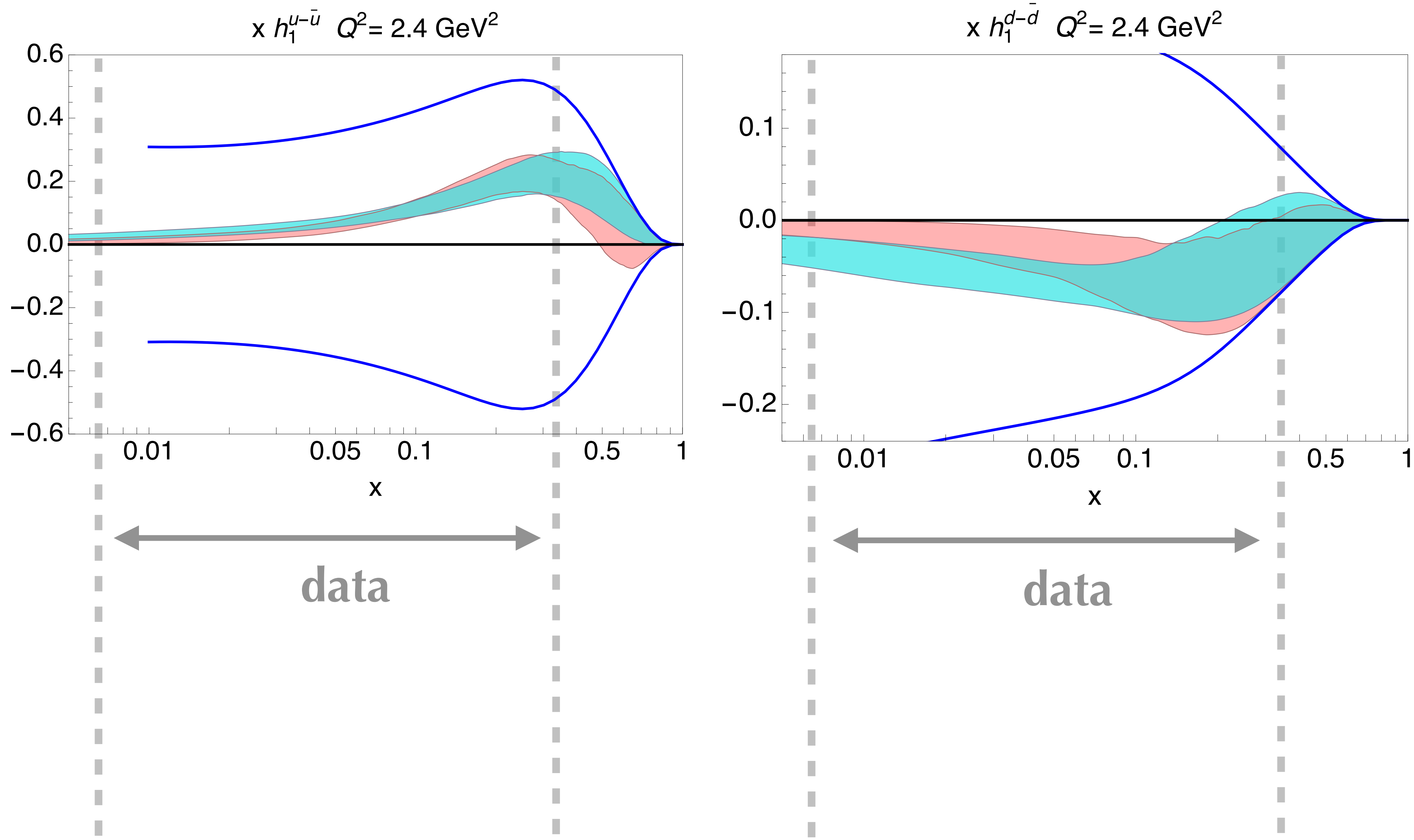
global fit + pseudodata + lattice gT constraint

global fit + pseudodata

up

down

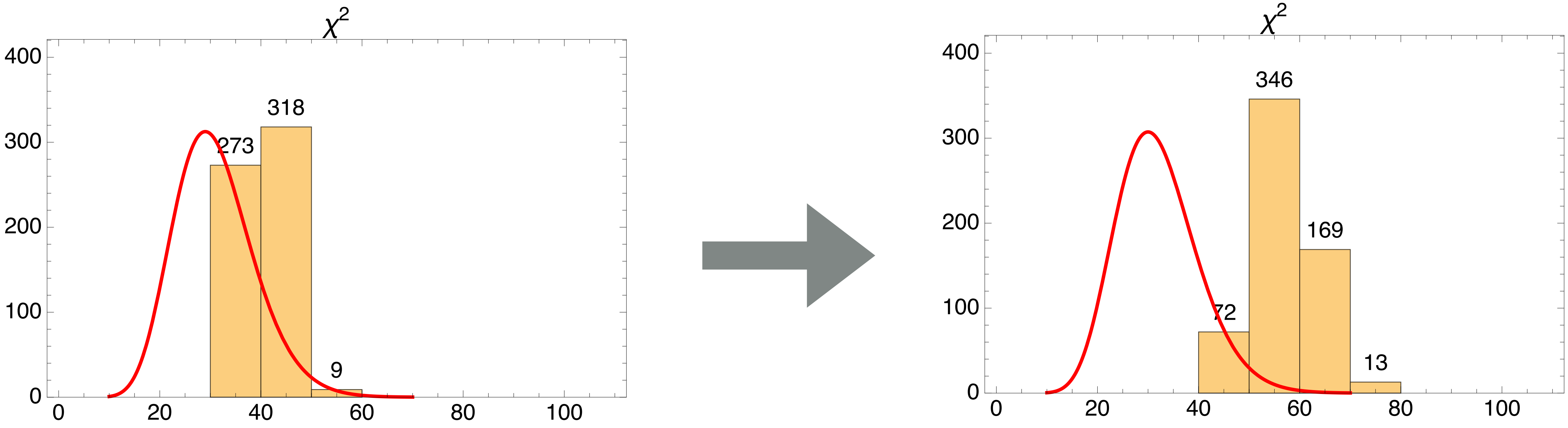
$$D_1^g(Q_0) = \begin{cases} 0 \\ D_1^u/4 \\ D_1^u \end{cases}$$



χ^2

$\chi^2/\text{dof} = 1.32 \pm 0.09$

$\chi^2/\text{dof} = 1.77 \pm 0.19$



probability density function for a χ^2 distribution with 31 and 32 dof, respectively

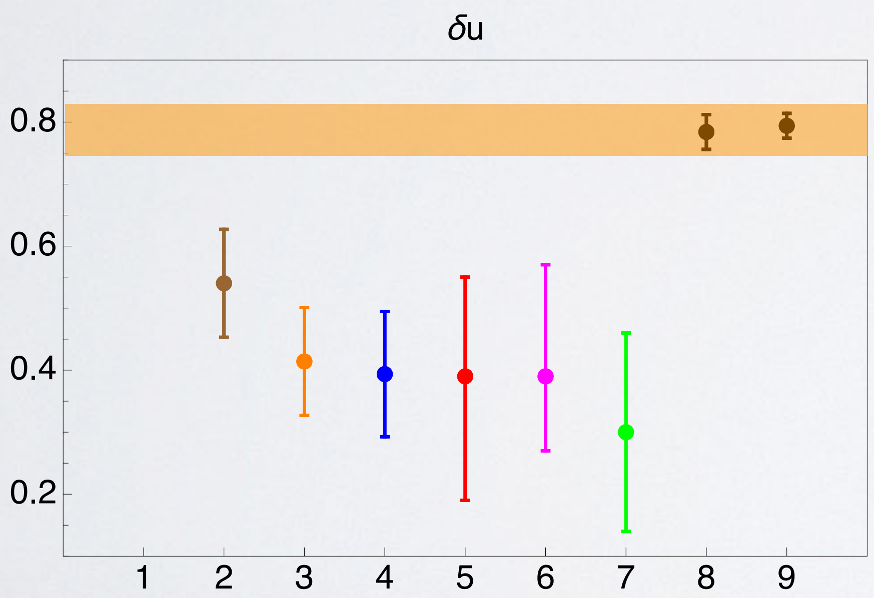
compatibility with lattice

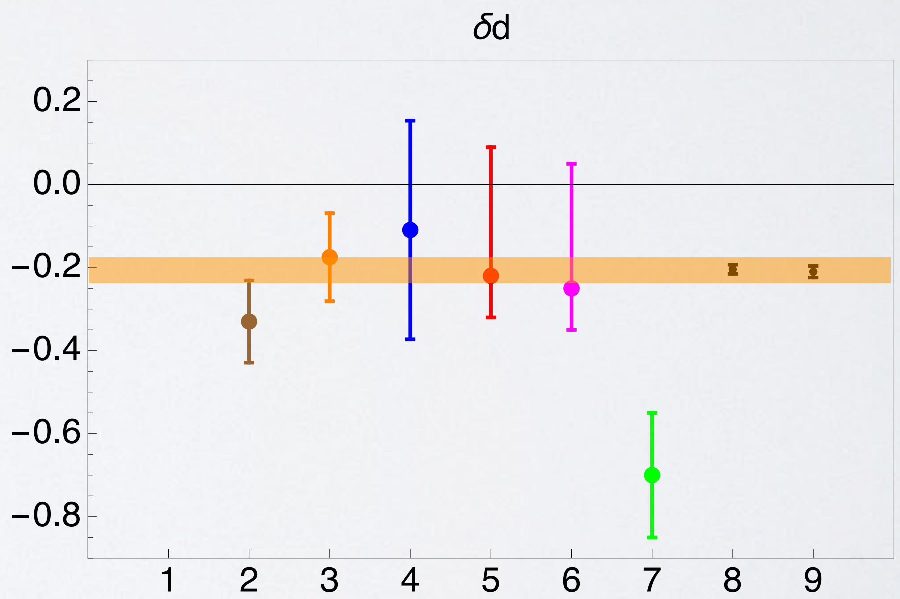
add to SIDIS+pp data + Compass SIDIS pseudo-data
constraint to reproduce from lattice
g_T , δu , δd

$\overline{g_T}^{latt} = 1.004 \pm 0.057$

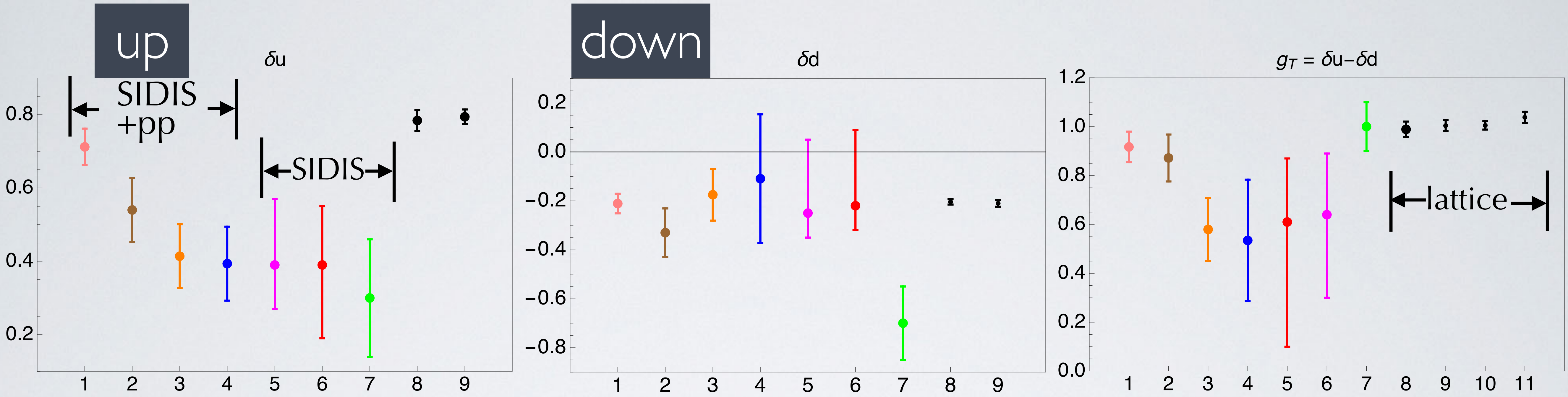
$\overline{\delta u}^{latt} = 0.782 \pm 0.031$

$\overline{\delta d}^{latt} = -0.218 \pm 0.026$





tensor charge



Q^2=4 GeV^2 *

1) global fit + pseudodata + constrain g_T , δu , δd

2) global fit + pseudodata + constrain g_T

3) global fit + pseudodata

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

4) global fit '17

*Kang et al., P.R. D****93*** *(16) 014009* — 5) "TMD fit" * Q^2=10

*Anselmino et al., P.R. D****87*** *(13) 094019* — 6) Torino fit * Q^2=1

Lin et al., P.R.L. ***120*** *(18) 152502* — 7) JAM fit '17 * Q_0^2=2

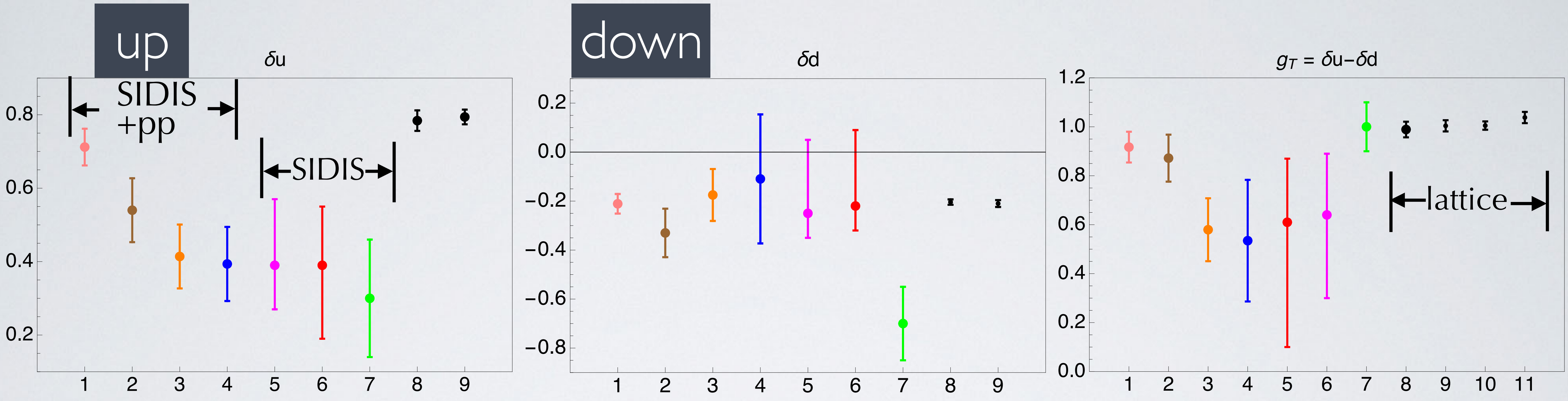
8) PNDME '18 — *Gupta et al., P.R. D****98*** *(18) 034503*

9) ETMC '17 — *Alexandrou et al., P.R. D****95*** *(17) 114514; E 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)*

tensor charge



Q^2=4 GeV^2 *

compatible, but…

1) global fit + pseudodata + constrain g_T , δu , δd

2) global fit + pseudodata + constrain g_T

3) global fit + pseudodata

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 4) global fit '17

*Kang et al., P.R. D**93** (16) 014009* — 5) "TMD fit" * Q^2=10

*Anselmino et al., P.R. D**87** (13) 094019* — 6) Torino fit * Q^2=1

Lin et al., P.R.L. ***120*** *(18) 152502* — 7) JAM fit '17 * Q_0^2=2

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

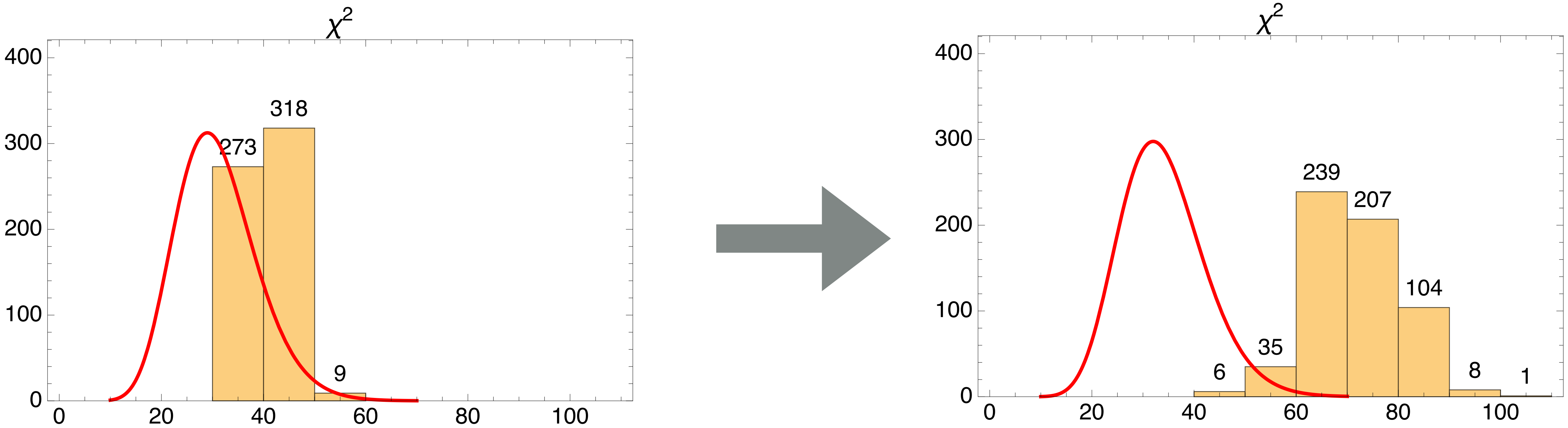
9) ETMC '17 — *Alexandrou et al., P.R. D**95** (17) 114514; E P.R. D**96** (17) 099906*

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

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

χ^2

$\chi^2/\text{dof} = 1.32 \pm 0.09$ $\chi^2/\text{dof} = 2.11 \pm 0.26$



probability density function for a χ^2 distribution with 31 and 34 dof, respectively

impact of “full” lattice constraint

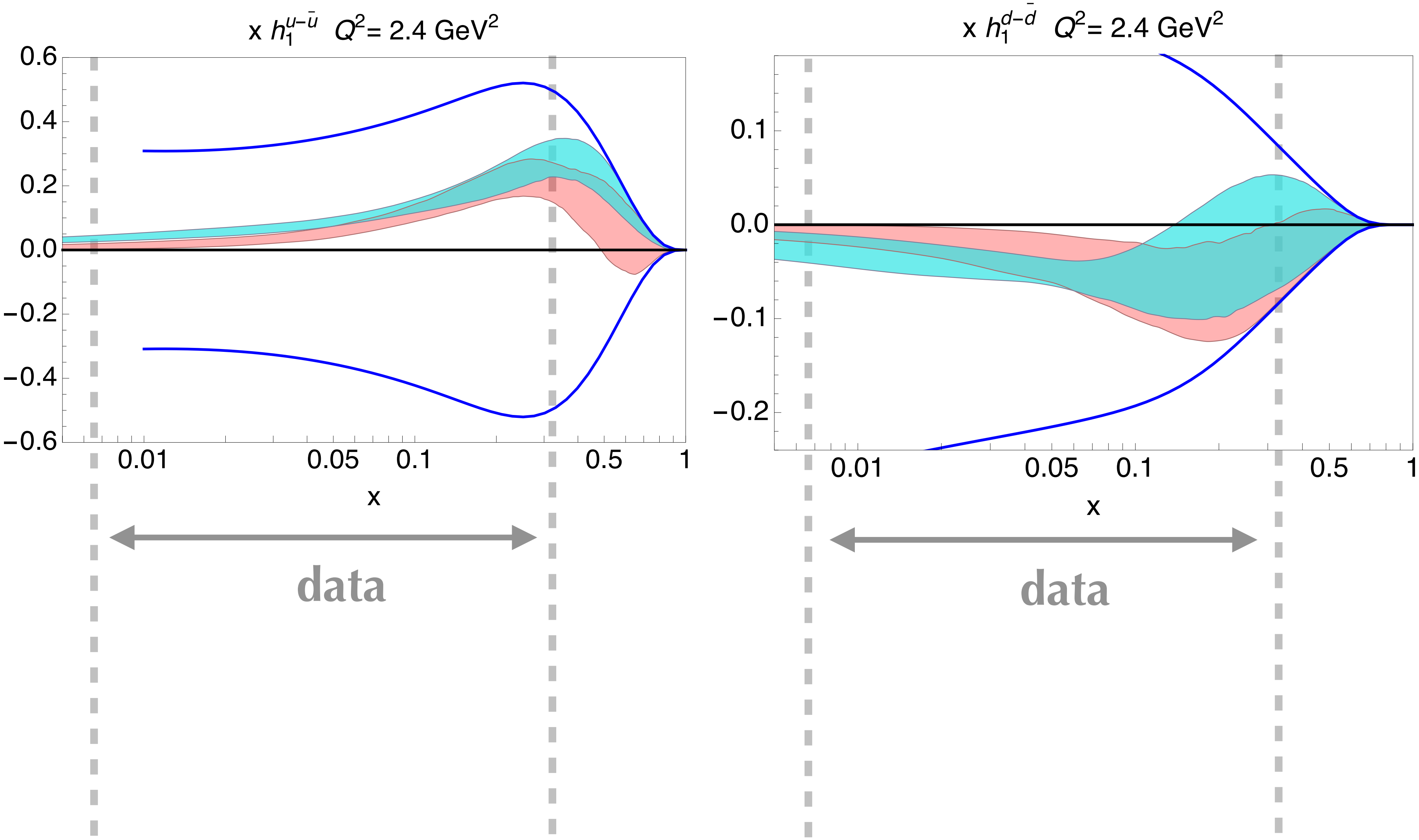
global fit + pseudodata + lattice (g_T, δu,δd) constraint

global fit + pseudodata

$$D_1^g(Q_0) = \begin{cases} 0 \\ D_1^u/4 \\ D_1^u \end{cases}$$

up

down

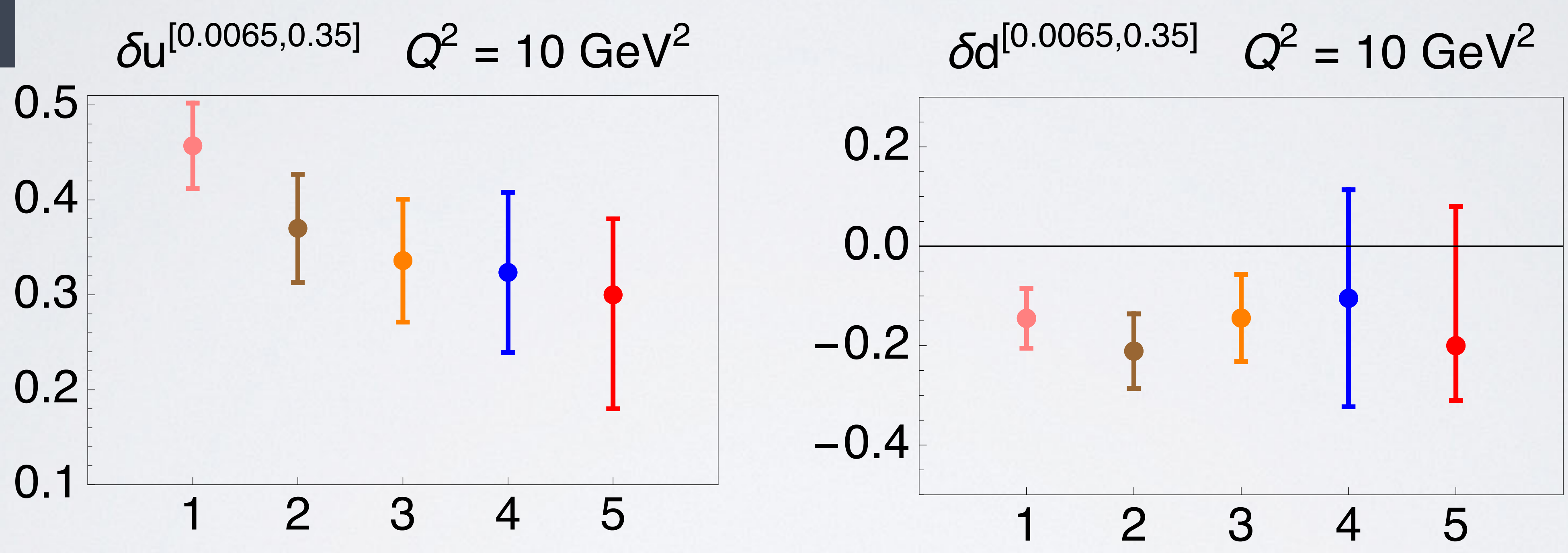


truncated tensor charge

truncated

$\delta q^{[0.0065,0.35]}$ $Q^2 = 10$

up



down

1) global fit + pseudodata + constrain g_T , δu , δd

2) global fit + pseudodata + constrain g_T

3) global fit + pseudodata

4) global fit '17 *Radici & Bacchetta, P.R.L.* ***120*** *(18) 192001*

5) "TMD fit" *Kang et al., P.R. D**93** (16) 014009*

Conclusions

- first global fit of di-hadron inclusive data leading to extraction of transversity as a PDF in collinear framework
- inclusion of STAR p-p$^{\uparrow}$ data increases precision of up channel; large uncertainty on down due to unconstrained gluon unpolarized di-hadron fragmentation function
- no apparent simultaneous compatibility with lattice for tensor charge in up, down, and isovector channels
- adding Compass SIDIS pseudo-data for deuteron increases precision, particularly for down, but seems to confirm this scenario
- forcing the fit to reproduce lattice isovector tensor charge is not enough to reach simultaneous compatibility; χ^2 worsens
- it is possible to reach simultaneous compatibility with lattice but χ^2 worsens even more and probabilistic distribution is very unlikely

THANK YOU

Back-up

2-hadron-inclusive production

framework
collinear
factorization

Collins, Heppelman, Ladinsky,
N.P. ***B420*** *(94)*

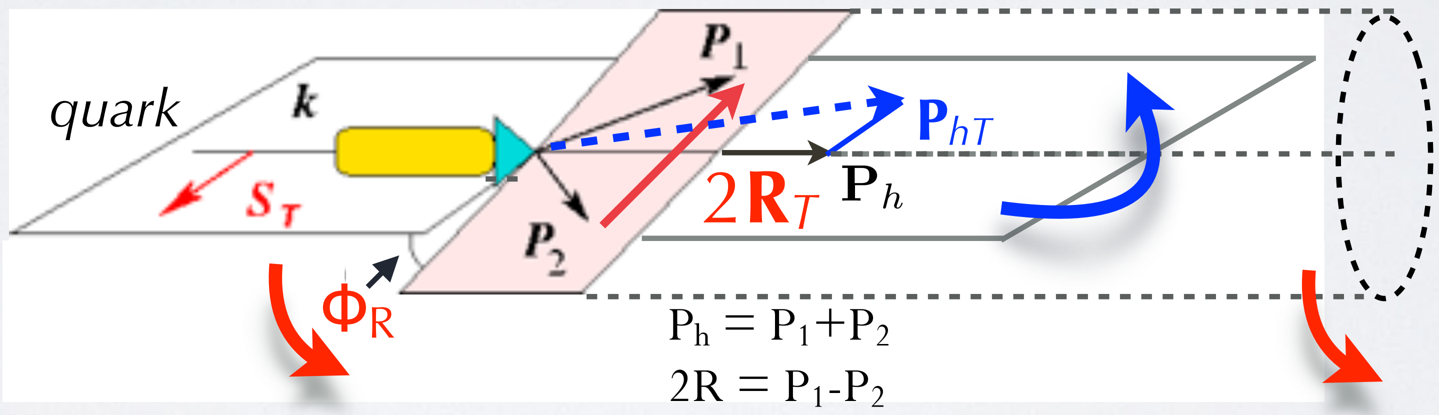
$R_T \ll Q$

$\updownarrow$

M_h

invariant mass

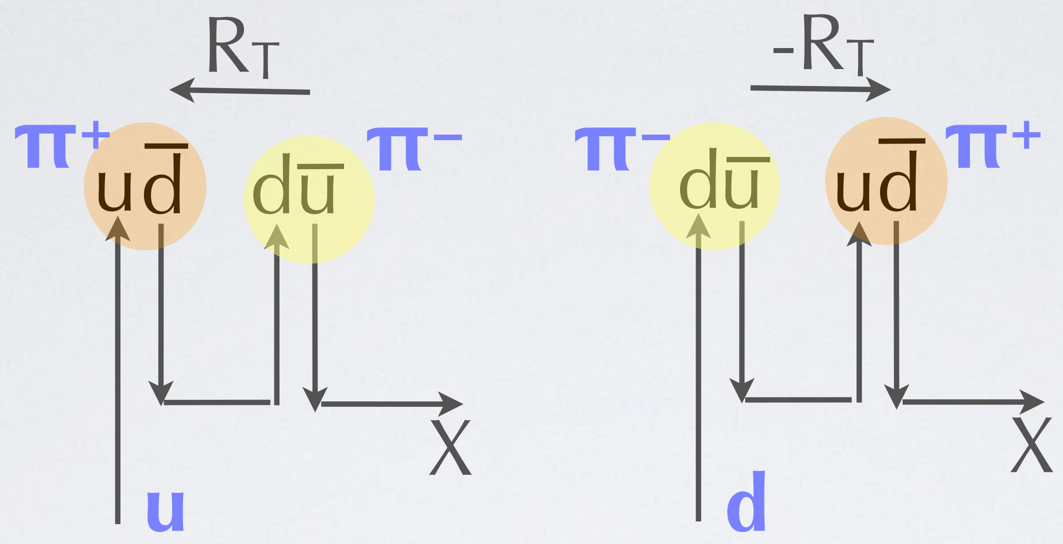
$H_1^{\sphericalangle}$



survives to
polar symmetry
($\int dP_{hT}$)

correlation S_T and R_T → **azimuthal asymmetry**

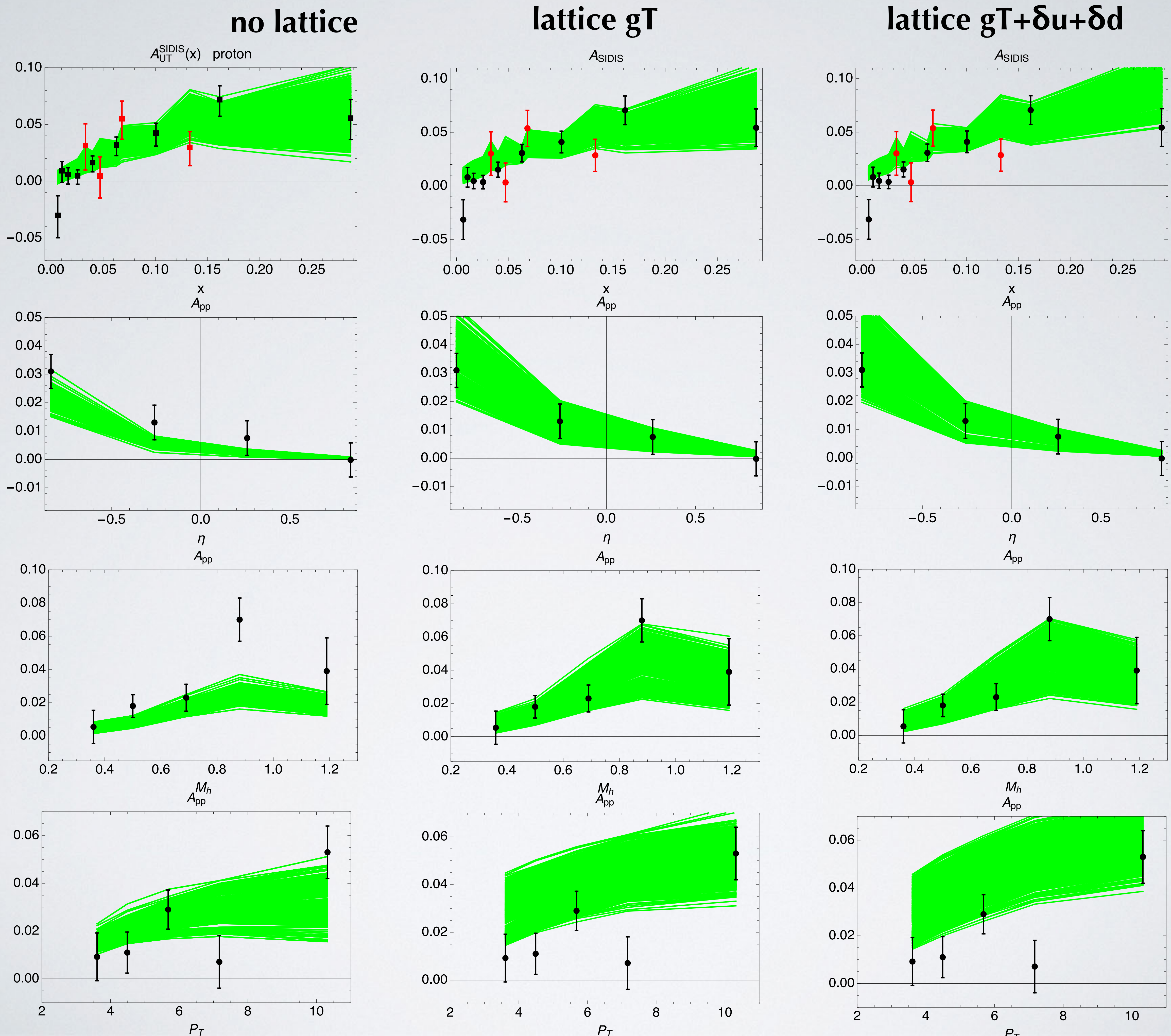
IFF symmetries



$$H_1^{\sphericalangle\, u} = -H_1^{\sphericalangle\, d}$$ isospin symmetry

$$\left.\begin{aligned} H_1^{\sphericalangle\, q} &= -H_1^{\sphericalangle\, \bar{q}} \\ D_1^{q} &= D_1^{\bar{q}} \end{aligned}\right\}$$ charge conjugation

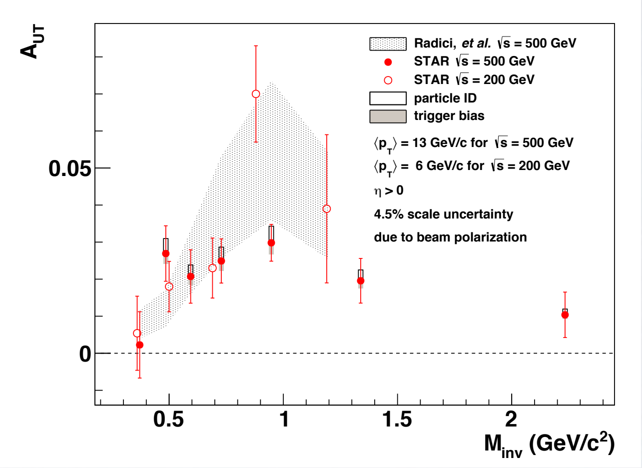
valid only for ($\pi^+\pi^-$) pairs and at tree level



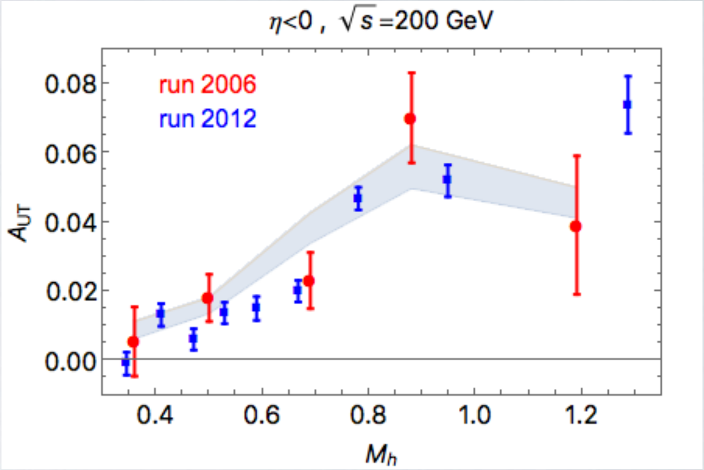
no lattice
lattice gT
lattice gT+δu+δd
A_UT^SIDIS(x) proton
A_SIDIS
A_SIDIS
x
x
x
A_pp
η
A_pp
η
A_pp
η
A_pp
M_h
A_pp
M_h
A_pp
M_h
A_pp
P_T
A_pp
P_T
A_pp
P_T

To do list

- use also other (multi-dimensional) data from STAR run 2011 (s=500) and (later) run 2012 (s=200)



Adamczyk et al. (STAR), P.L. ***B780*** *(18) 332*



*Radici et al., P.R. D***94** *(16) 034012*

- need data on p+p → (ππ) X constrains gluon D_1^g

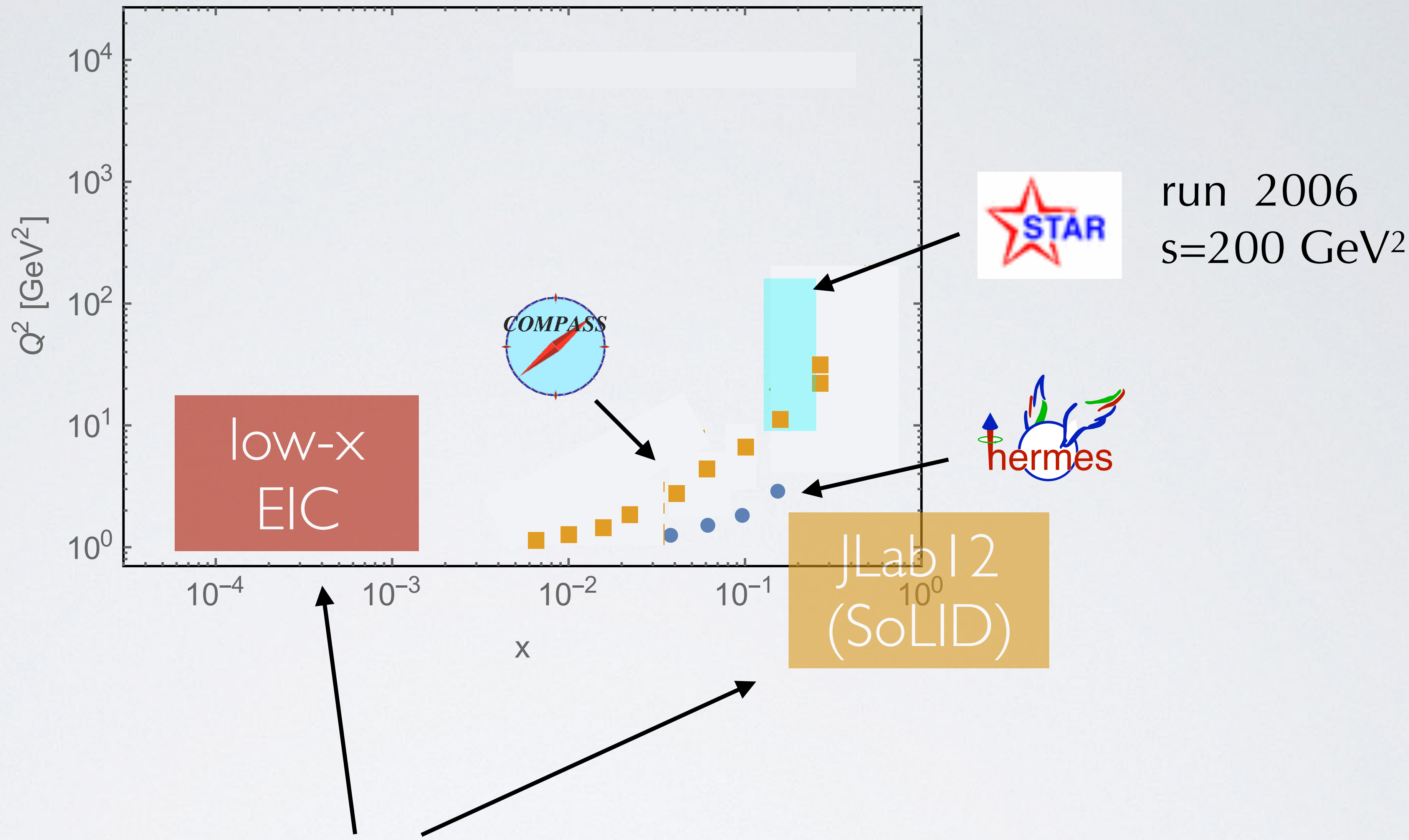
- refit di-hadron fragmentation functions using new data: e^+e^- → (ππ) X constrains D_1^q (currently only by Montecarlo)

*Seidl et al., P.R. D***96** *(17) 032005*

- use COMPASS data on πK and KK channels, and from Λ↑ fragmentation: constrain strange contribution ?

- explore other channels, like inclusive DIS via Jet fragm. funct.'s

more constraints on extrapolation



- of course, need more data