EXTRACTION of TRANSVERSITY :
STATUS of the EIC SILVER MEASUREMENT

INFN Istituto Nazionale di Fisica Nucleare

Marco Radici
INFN - Pavia

the “silver” measurement

the EIC white paper

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

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	3^{rd} 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.

why transversity ?

the leading-twist PDF / TMD map

quark polarization

nucleon polarization	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**

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 $h_{1T}^\perp$

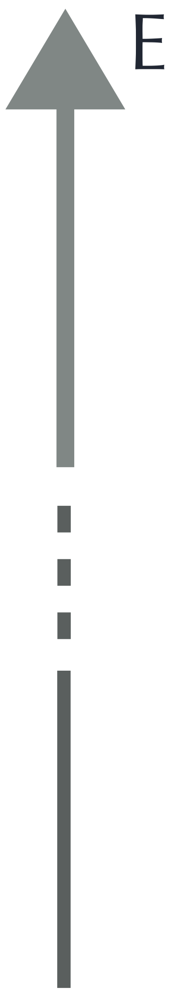
1- **h_1** needed as the 3rd basic quark **PDF** for spin-1/2 objects

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

3- tensor charge associated to tensor operator not in tree-level $\mathcal{L}_{\rm QCD}$

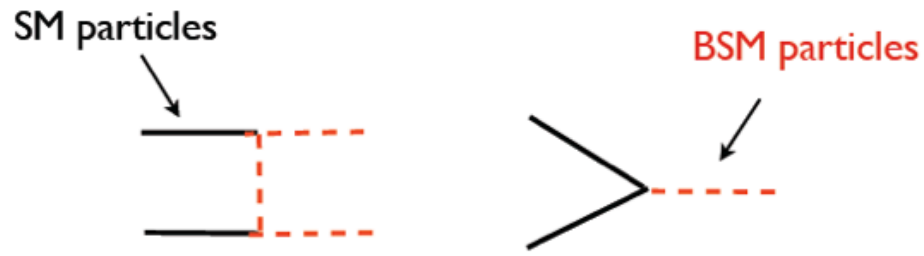
$$\delta q(Q^2) = \int_0^1 dx \;\left[h_1^q(x,Q^2) - h_1^{\bar{q}}(x,Q^2)\right]$$

potential for BSM discovery ?



at least, two ways of searching :

M_{BSM}
high energy



1- direct access
to new particles

potential for BSM discovery ?

E

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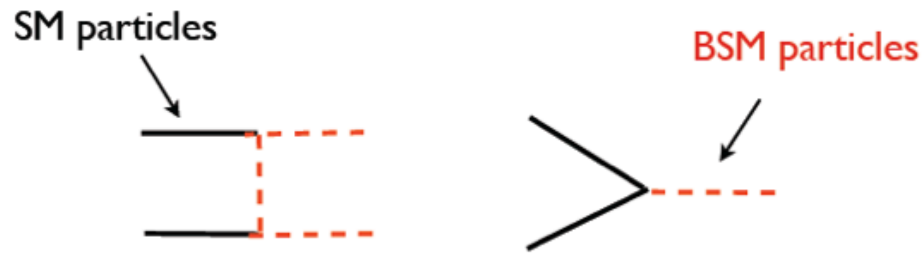
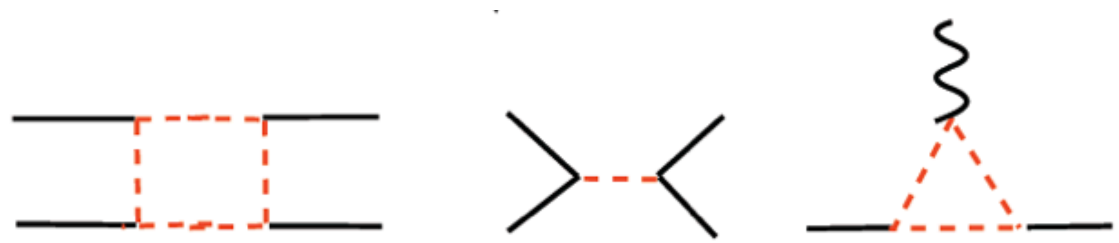


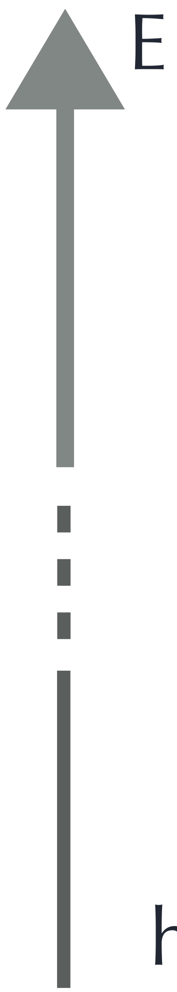
1- direct access
to new particles

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



2- indirect access
virtual effects

potential for BSM discovery ?



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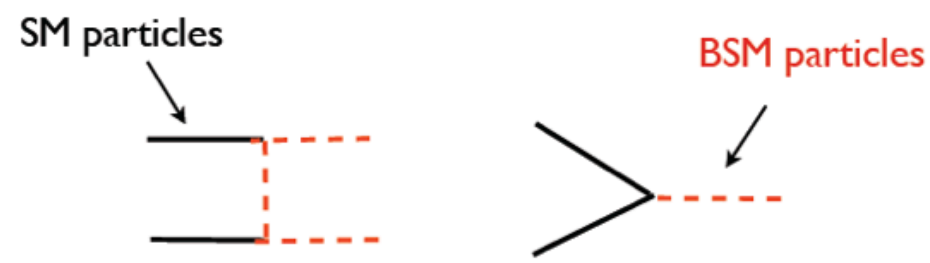

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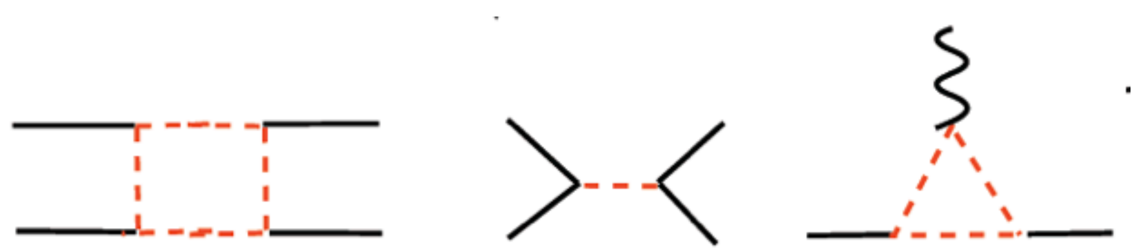

2- indirect access
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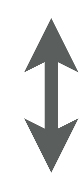
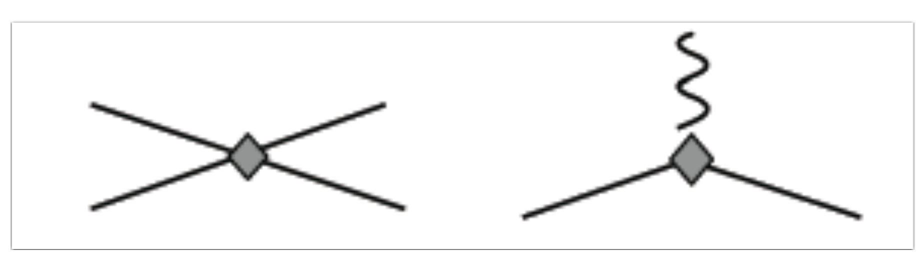
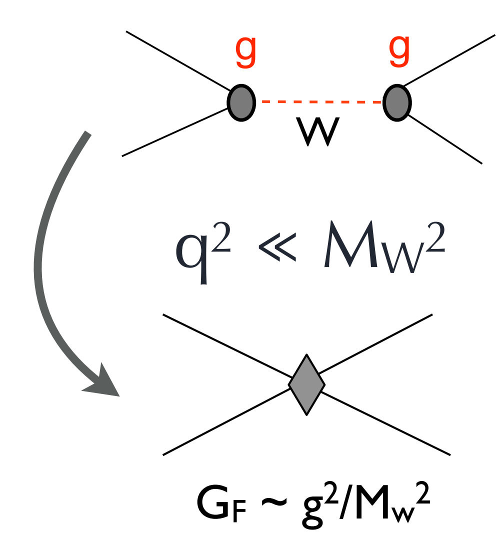


footprint:
new local
operators



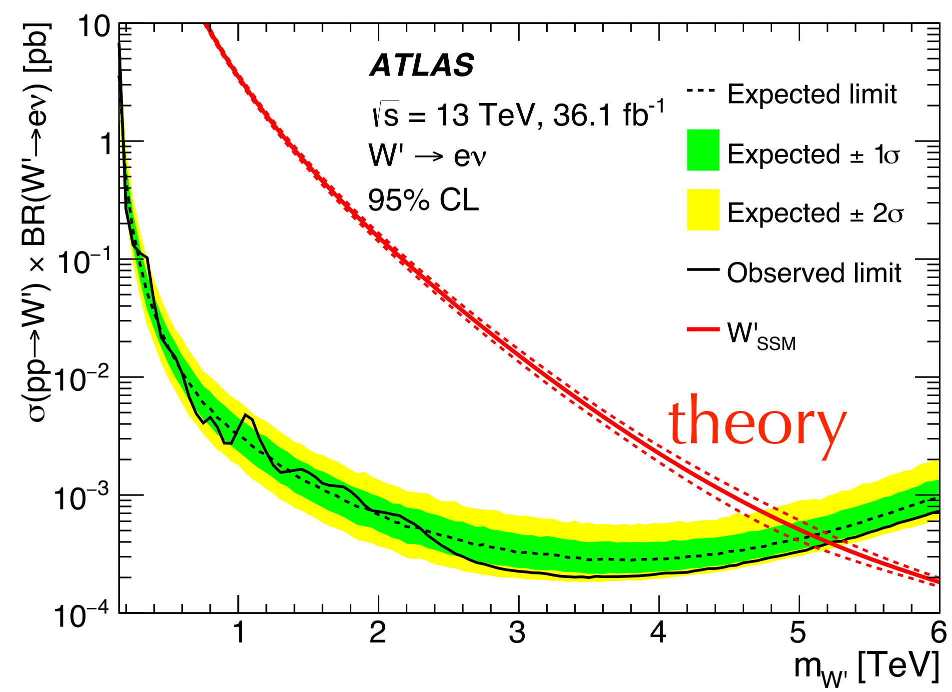
Example:
weak CC
interaction



Examples of direct access

- $\mathbf{p\,p \to e^- \nu + X}$ search for $W' \to e^- \nu$ with W' heavy partner of W

limits on cross section

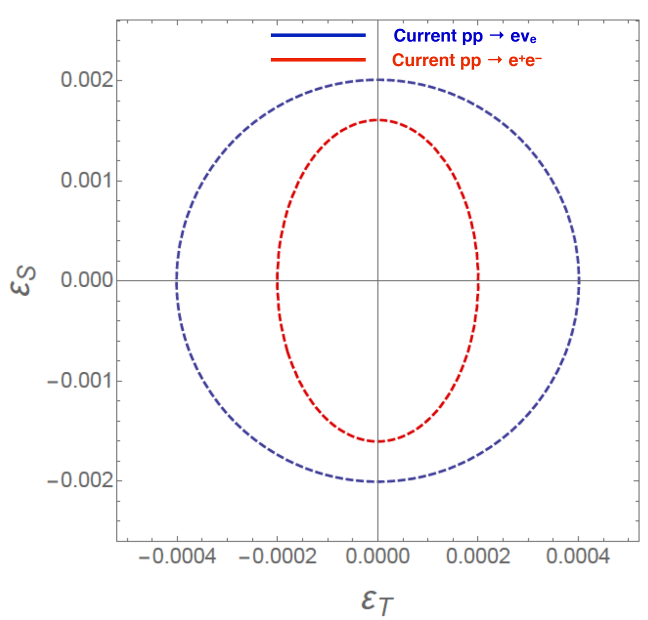


$\frac{\text{data}}{\text{background}}$

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 scalar (ε_S) & tensor (ε_T)



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

constraints reinforced including
$p\,p \to Z' \to e^- e^+ + X$

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

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- **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

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

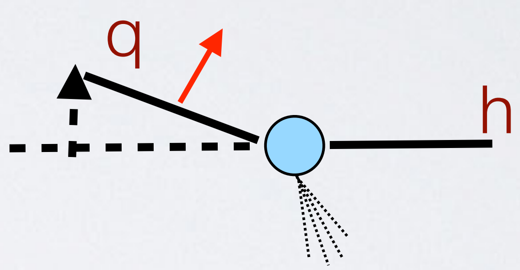
transversity

extraction of transversity

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

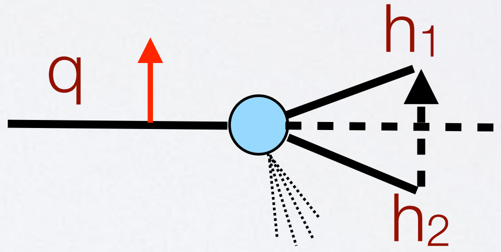
- itself : fully polarized Drell-Yan ✘

- 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**

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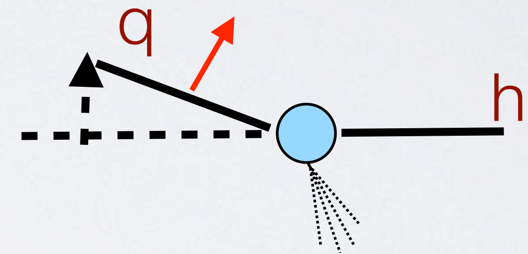

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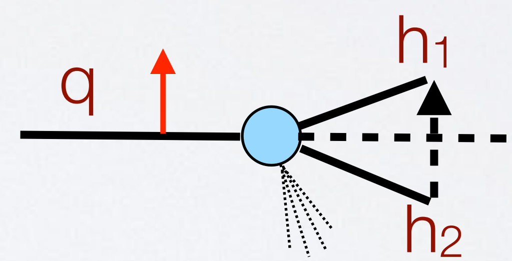

collinear framework **h_1 as PDF**

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

advantages of di-hadron mechanism

collinear framework

- simple product of PDF and IFF

Ex.: SIDIS

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

advantages of di-hadron mechanism

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x-dependence of A_{SIDIS} all in PDF

- flavor sum simplified by symmetries of IFF { isospin symmetry, charge conjugation }
  + data on proton and deuteron targets
  → separate valence up and down

advantages of di-hadron mechanism

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x-dependence of A_{SIDIS} all in PDF

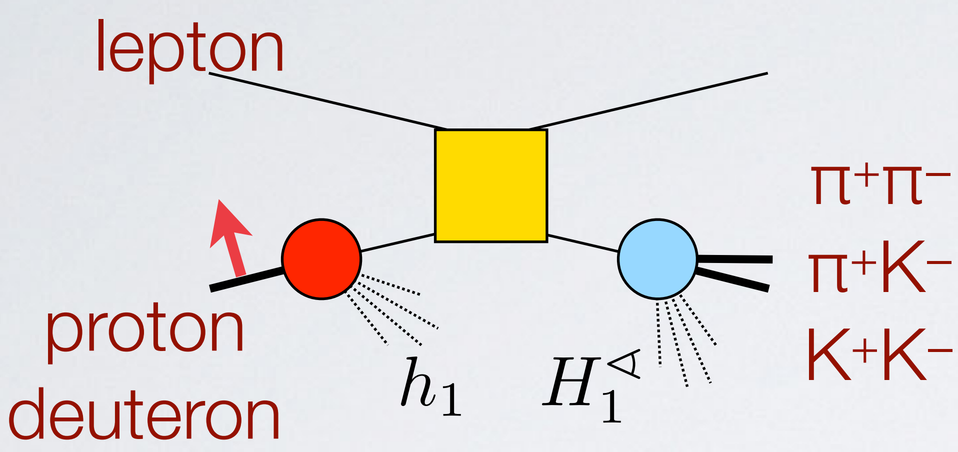
- flavor sum simplified by symmetries of IFF { isospin symmetry, charge conjugation }
  + data on proton and deuteron targets
  → separate valence up and down

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

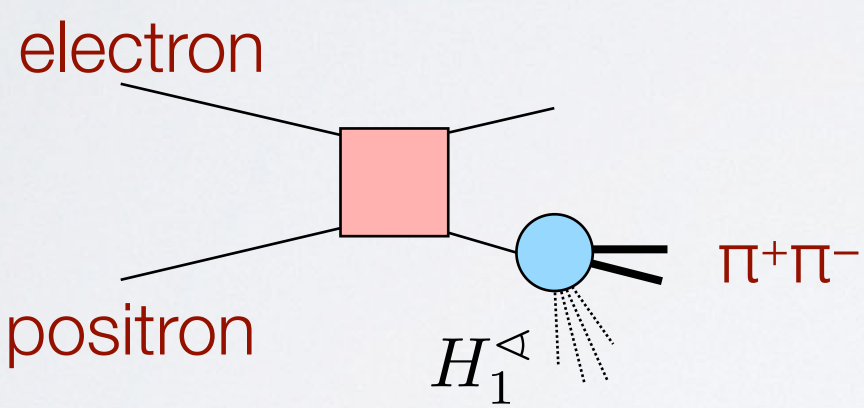
advantages of di-hadron mechanism

factorization theorems for all hard processes

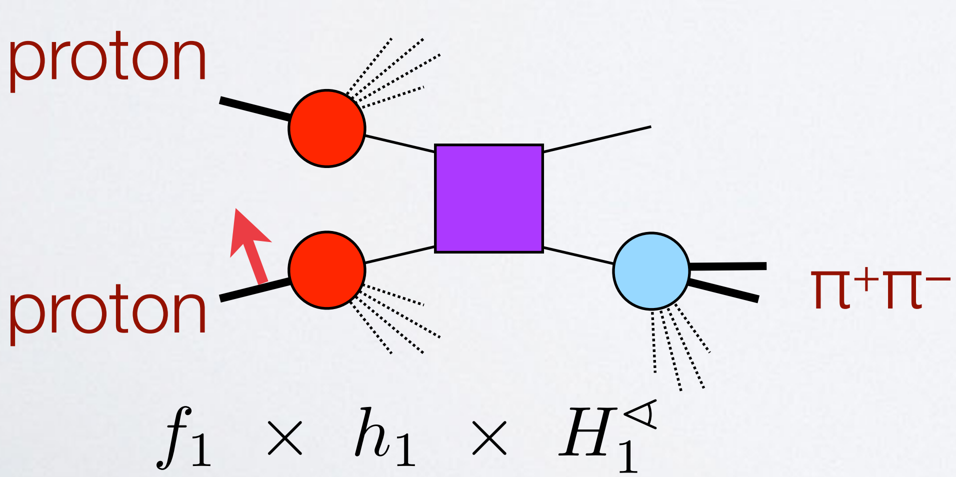
SIDIS



e+e−



p p↑

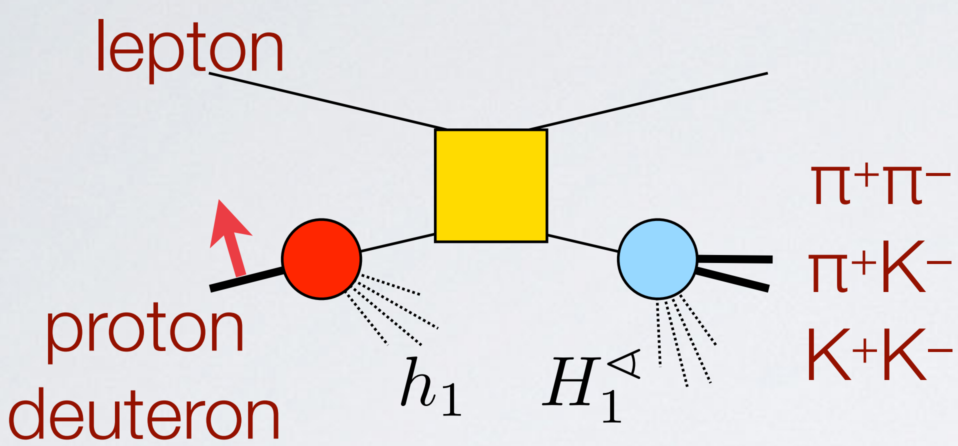


advantages of di-hadron mechanism

factorization theorems for all hard processes

data used in the global fit

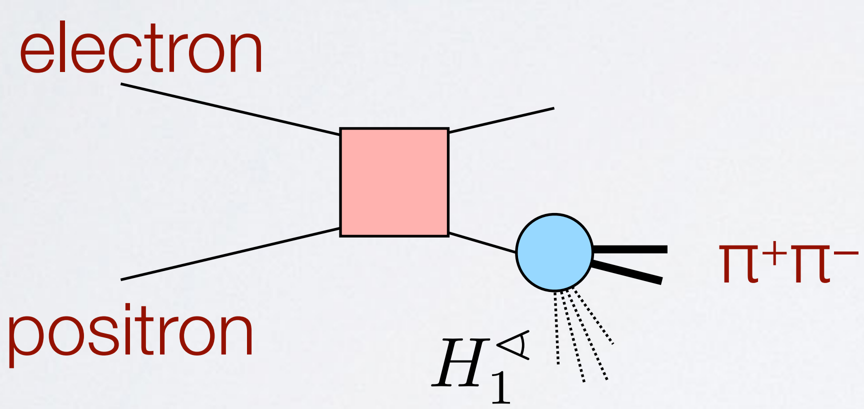
SIDIS



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

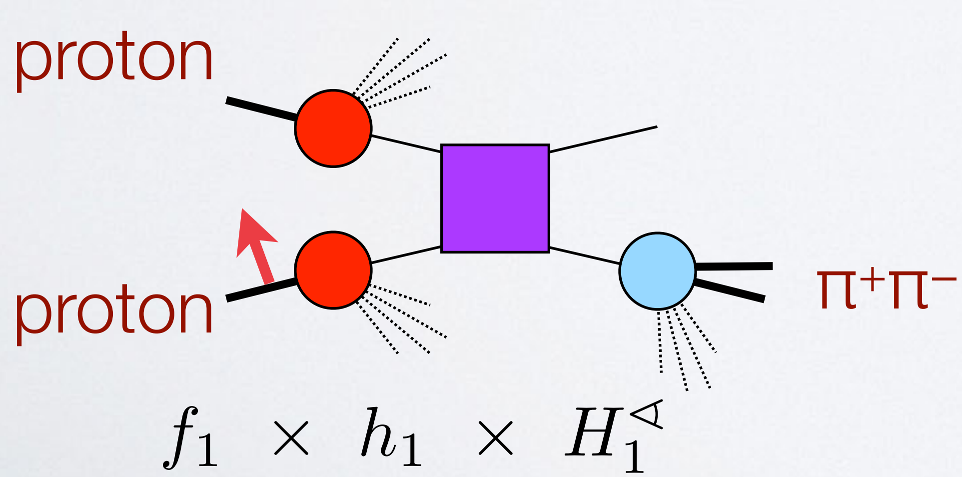
*Adolph et al., P.L. **B713** (12)*
*Braun et al., E.P.J. Web Conf. **85** (15)*

e+e−



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

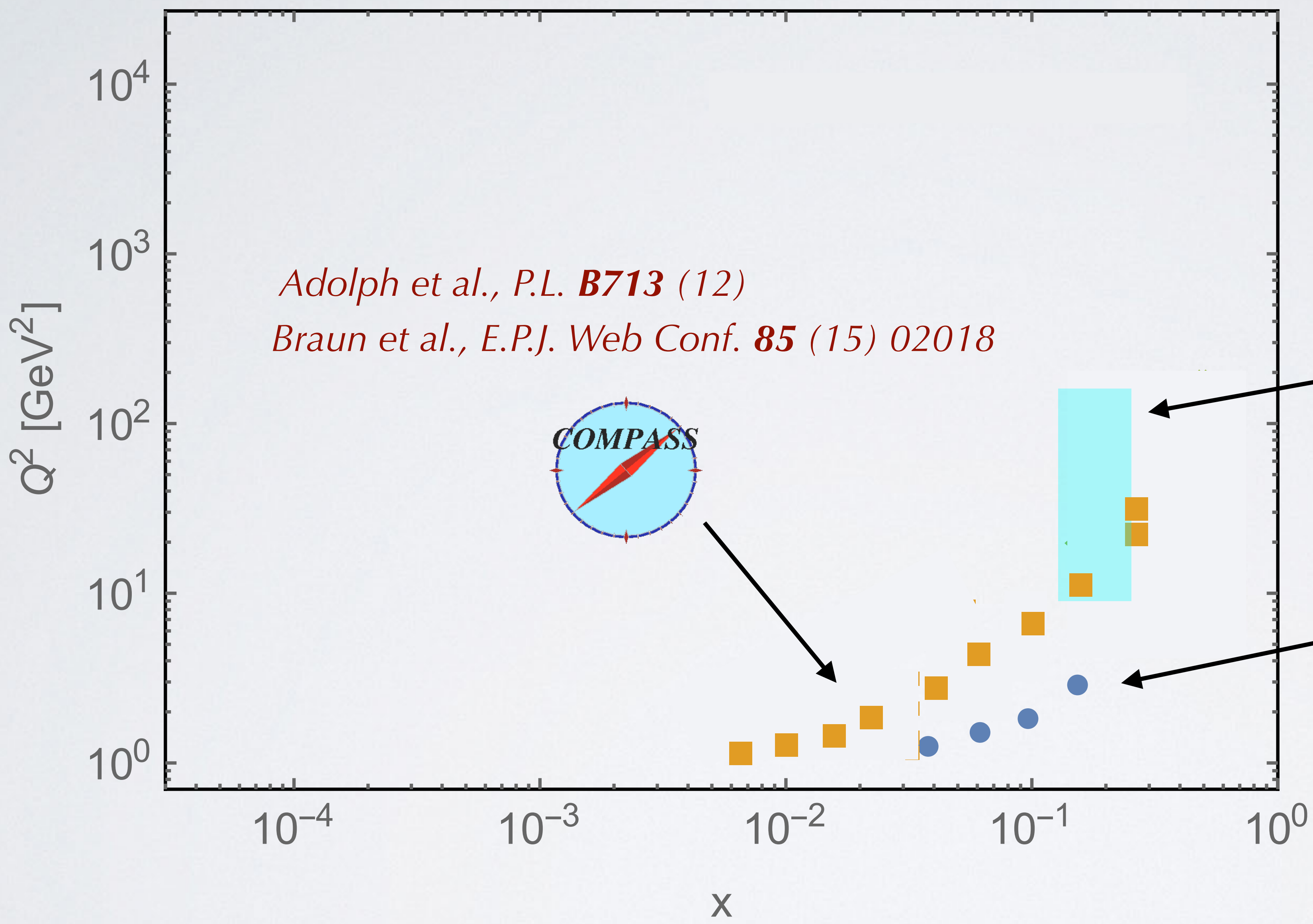
p p↑



run 2006 (s=200)

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

the phase space



STAR run 2006
s=200 GeV^2

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

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

- mostly medium/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

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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

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

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

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

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

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

constrain parameters

low-x behavior important

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Kovchegov & Sievert, arXiv:1808.10354

our choice $A_q + a_q > \frac{1}{3}$ $\left|\int_0^{x_{\min}} dx\right| \sim 1\%$ 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 $e^+e^- \to (\pi^+\pi^-)\,X$ (Montecarlo)
- **gluon** D_1^g is **not** constrained by $e^+e^- \to (\pi^+\pi^-)\,X$ (currently, LO analysis)
- **no data** available yet for $p\,p \to (\pi^+\pi^-)\,X$

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

our choice: set $D_1^g(Q_0) = \begin{cases} 0 \\ D_1^u(Q_0)/4 \\ D_1^u(Q_0) \end{cases}$ ← ~ 1-hadron $D_1^g(Q_0)$

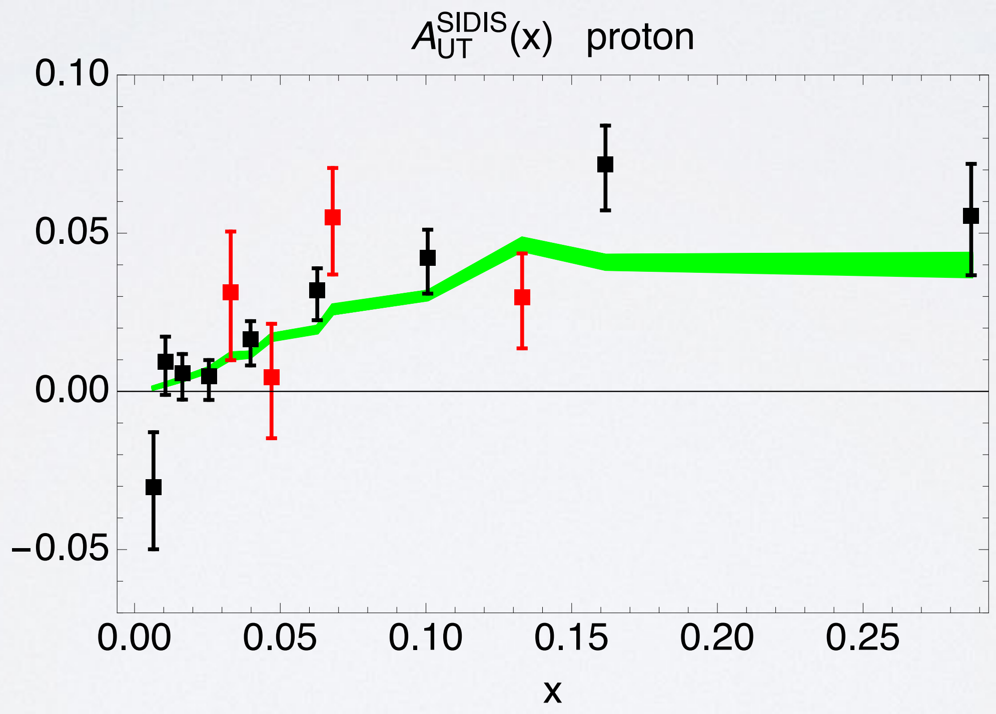
deteriorates our e^+e^- fit as $\chi^2/\text{dof} = \begin{cases} 1.69 & 1.28 \\ 1.81 & 1.37 \\ 2.96 & 2.01 \end{cases}$

background ρ channels

statistical uncertainty

the bootstrap method

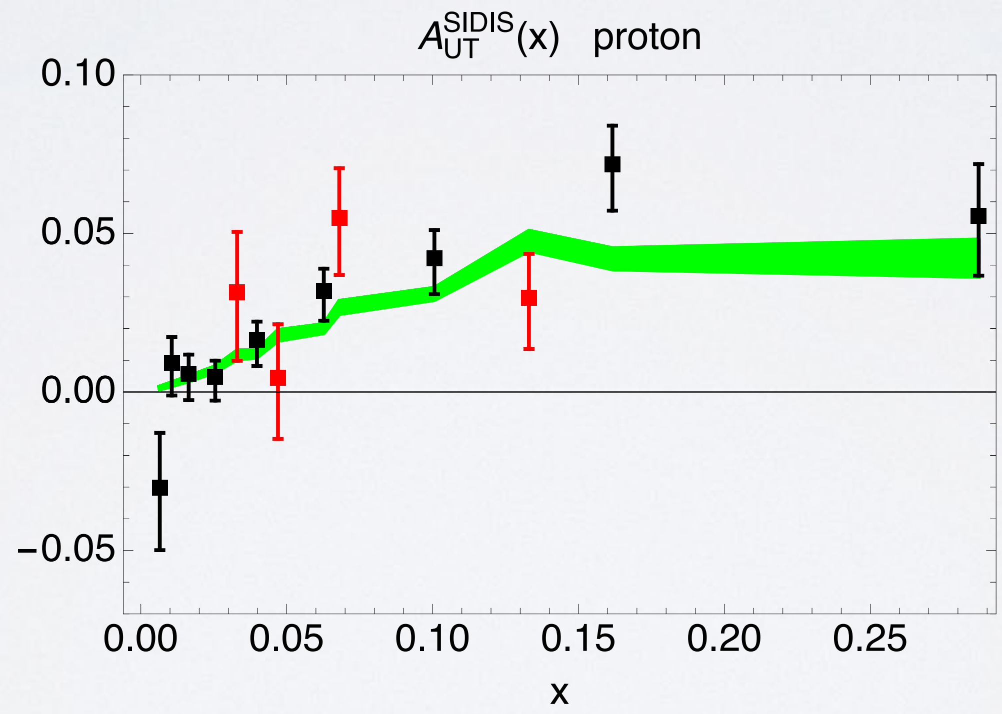
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50



statistical uncertainty

the bootstrap method

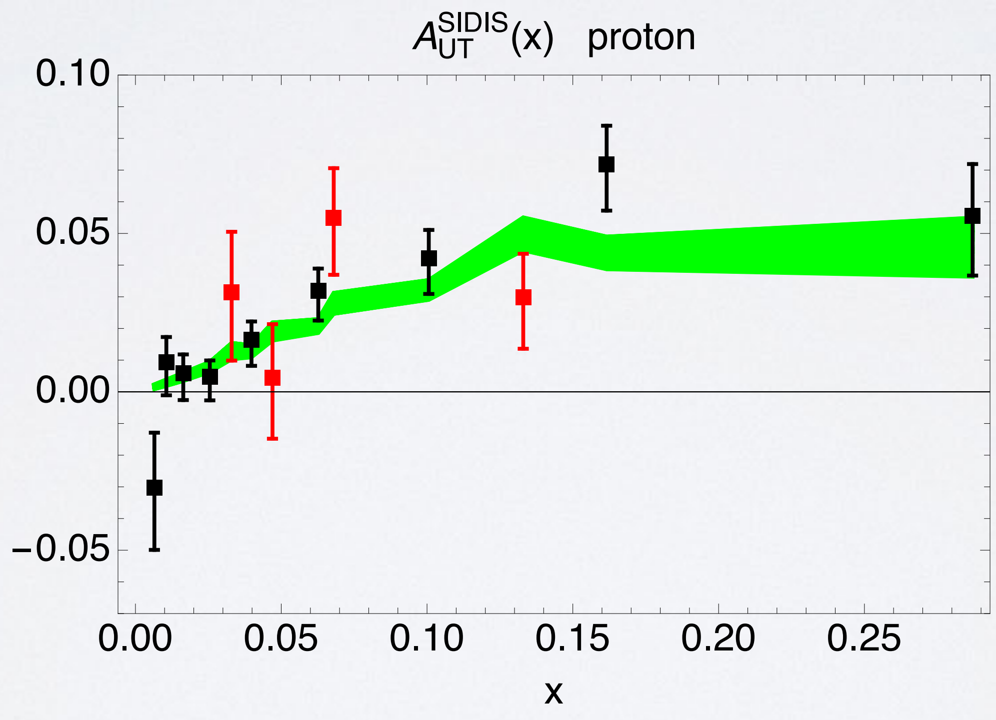
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50, 100



statistical uncertainty

the bootstrap method

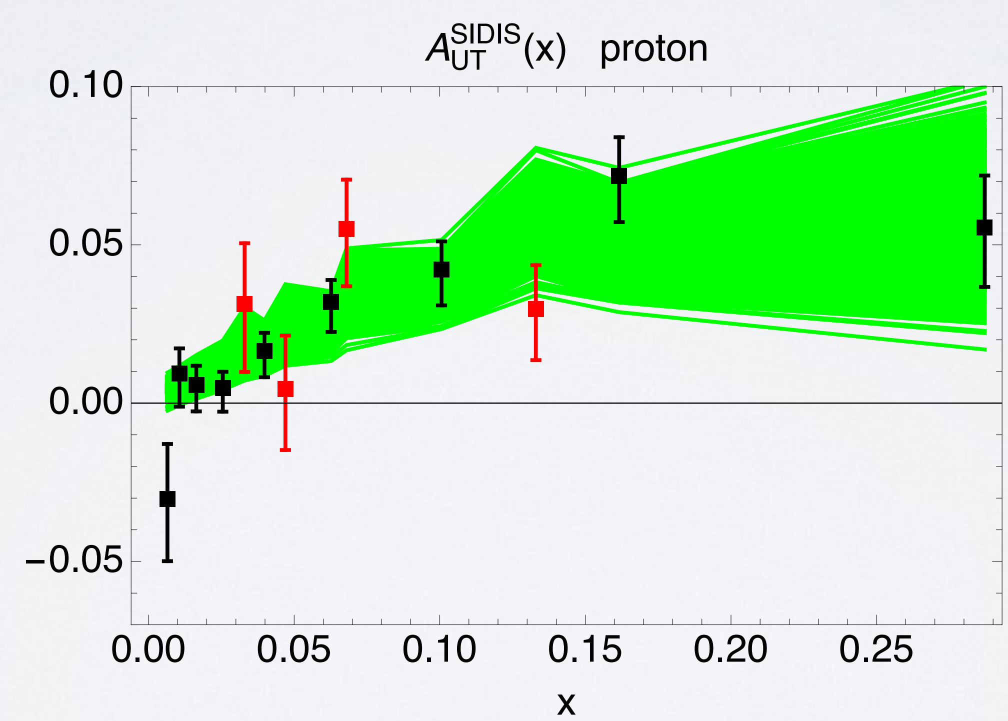
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50, 100, 200 sets…



statistical uncertainty

the bootstrap method

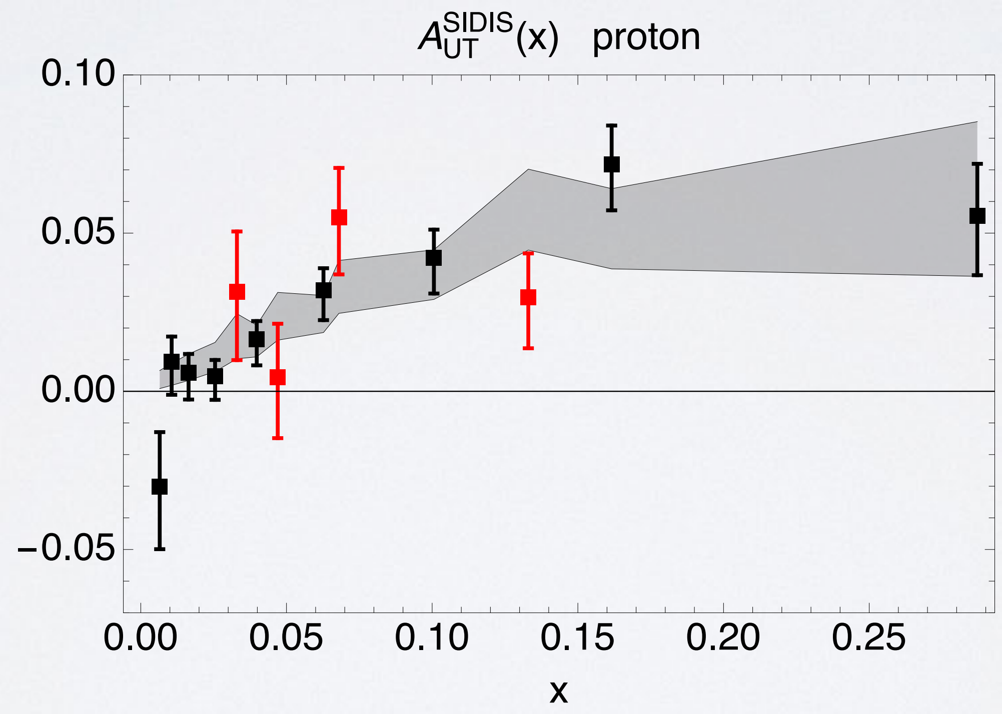
- shift each exp. point by Gaussian noise within exp. variance
- create sets of virtual points to be fitted: 50, 100, 200 sets… until average and standard deviation reproduce original exp. points (here, 200x3=600)



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

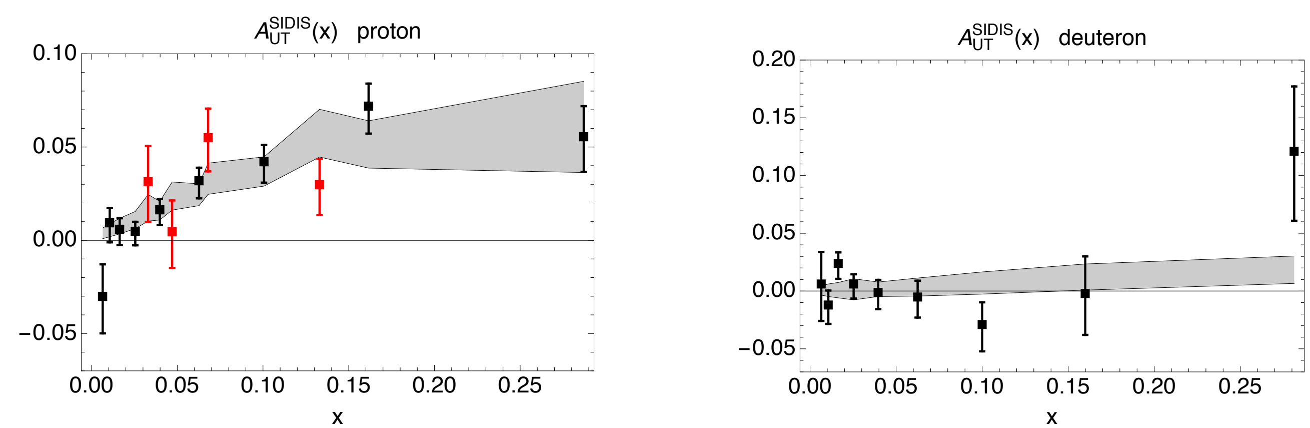
global fit published in

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

SIDIS

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

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

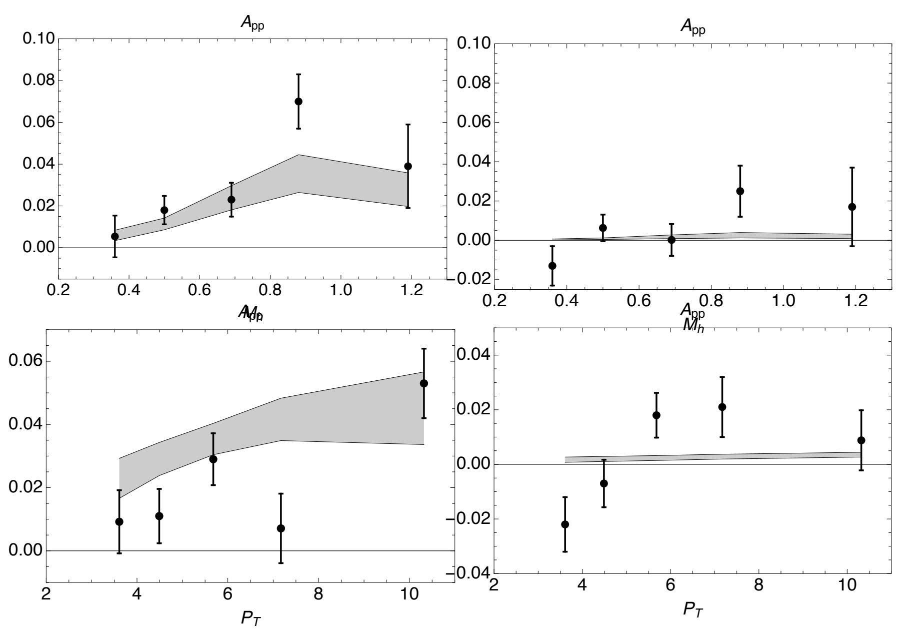


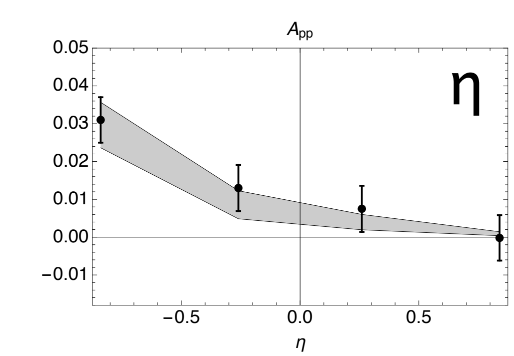
pp collisions

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

M_h, η<0

M_h, η>0





p_T, η<0

p_T, η>0

χ^2 of the fit

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

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

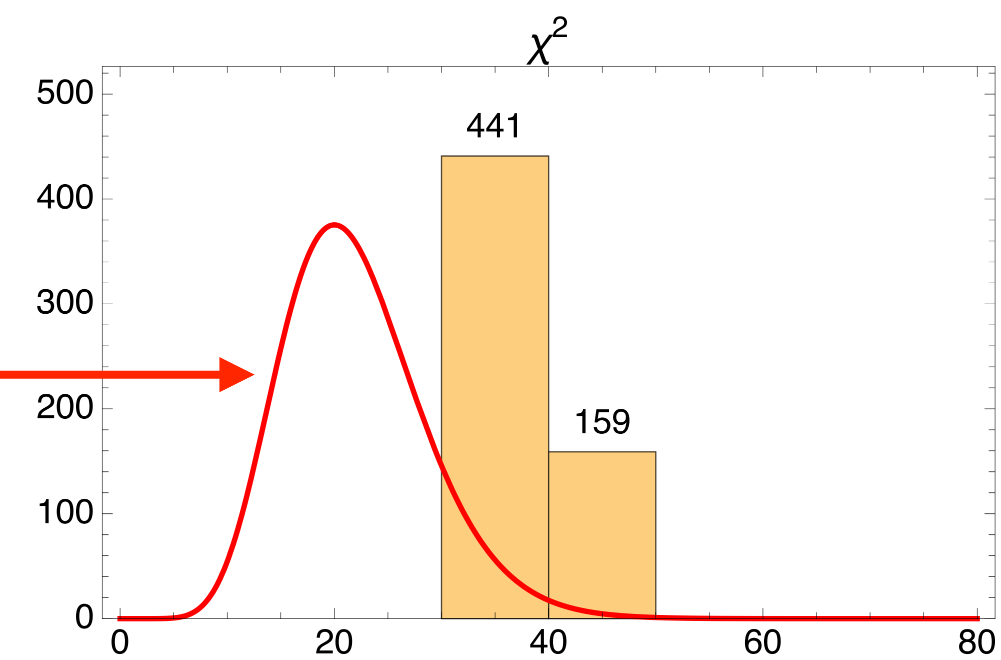
STAR **24** data points $(4\ \eta) \times \frac{4}{24} + (10\ M_h) \times \frac{10}{24} + (10\ p_T) \times \frac{10}{24}$

global fit **10** parameters

d.o.f. **22**

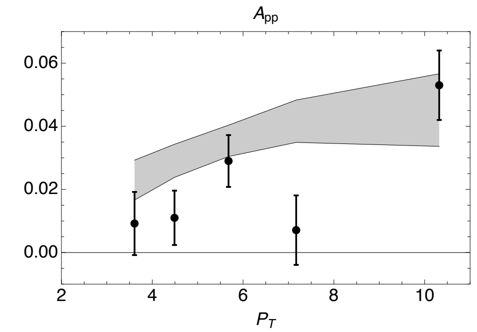
probability density function of χ^2 distribution for 22 d.o.f.

for $\chi^2/\text{dof} = 1$ perfect overlap



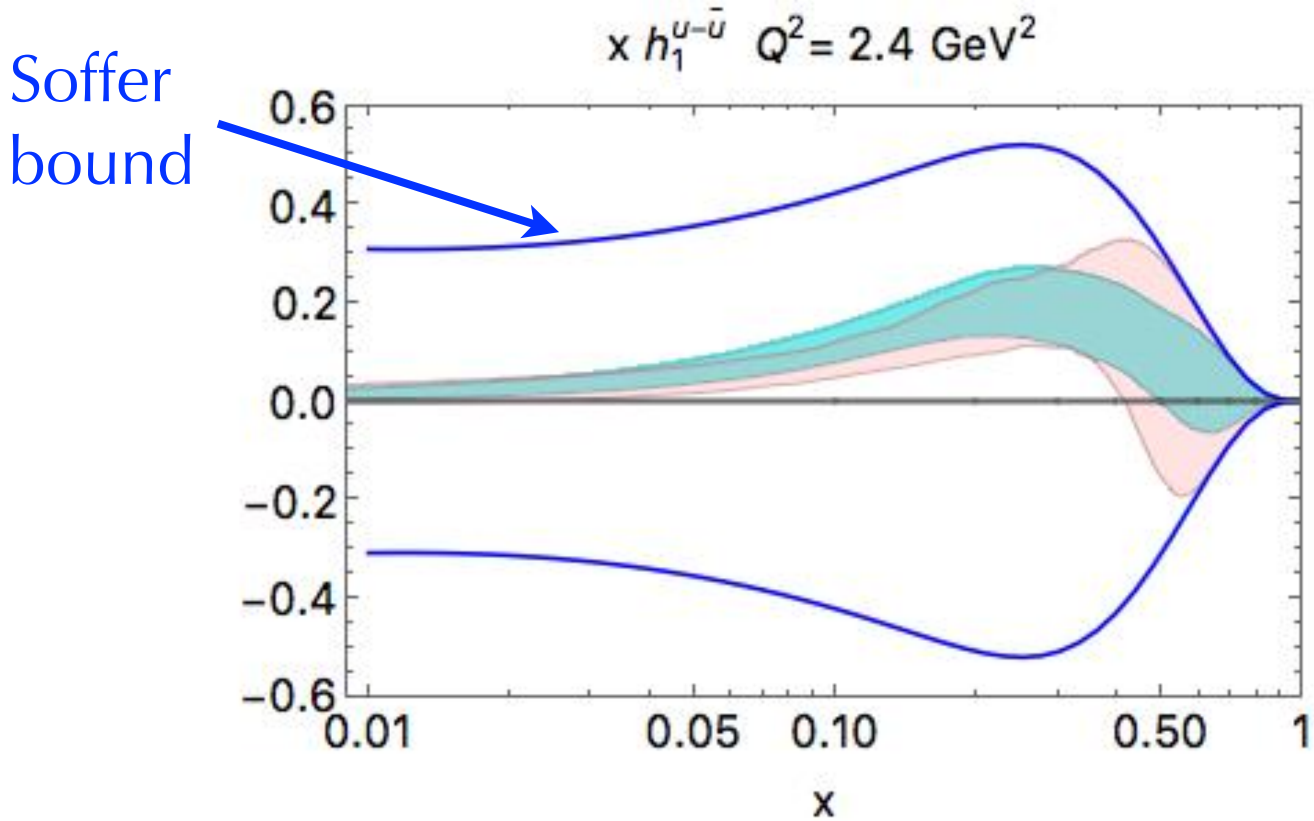
STAR

p_T, $\eta<0$



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

comparison with previous fit



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

global fit

up

higher precision

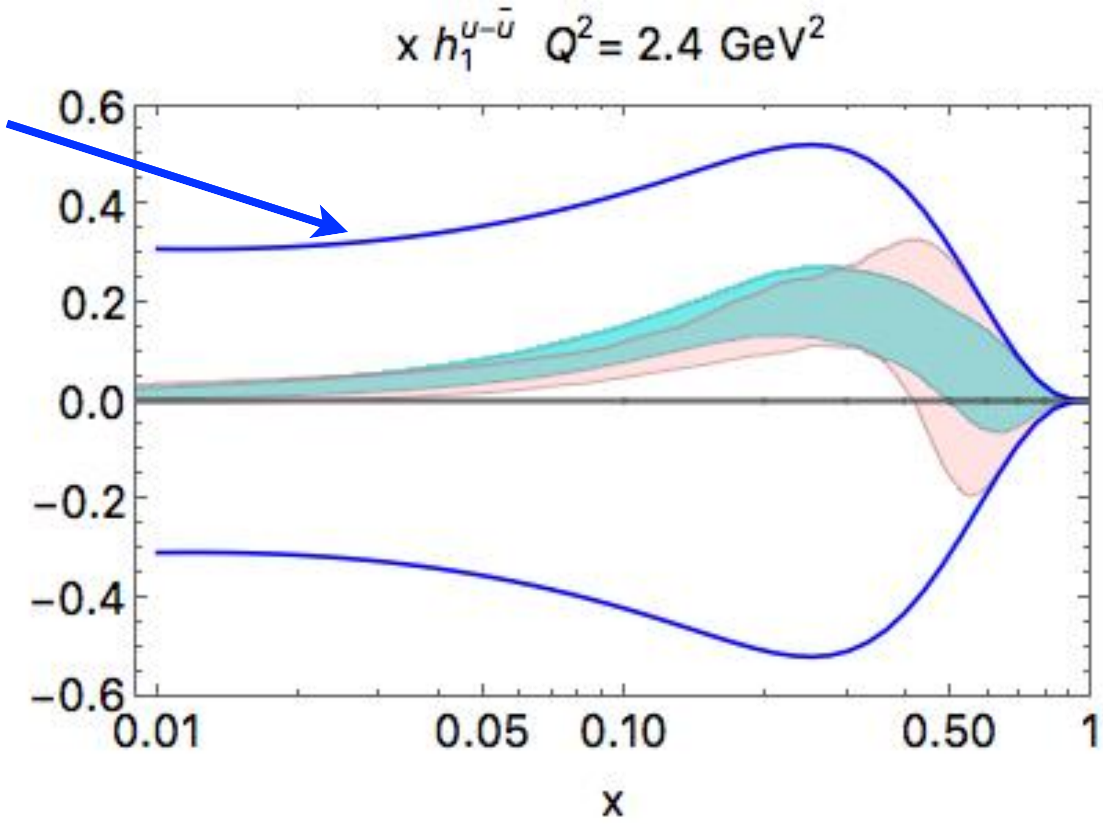
old fit (only SIDIS data)

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*

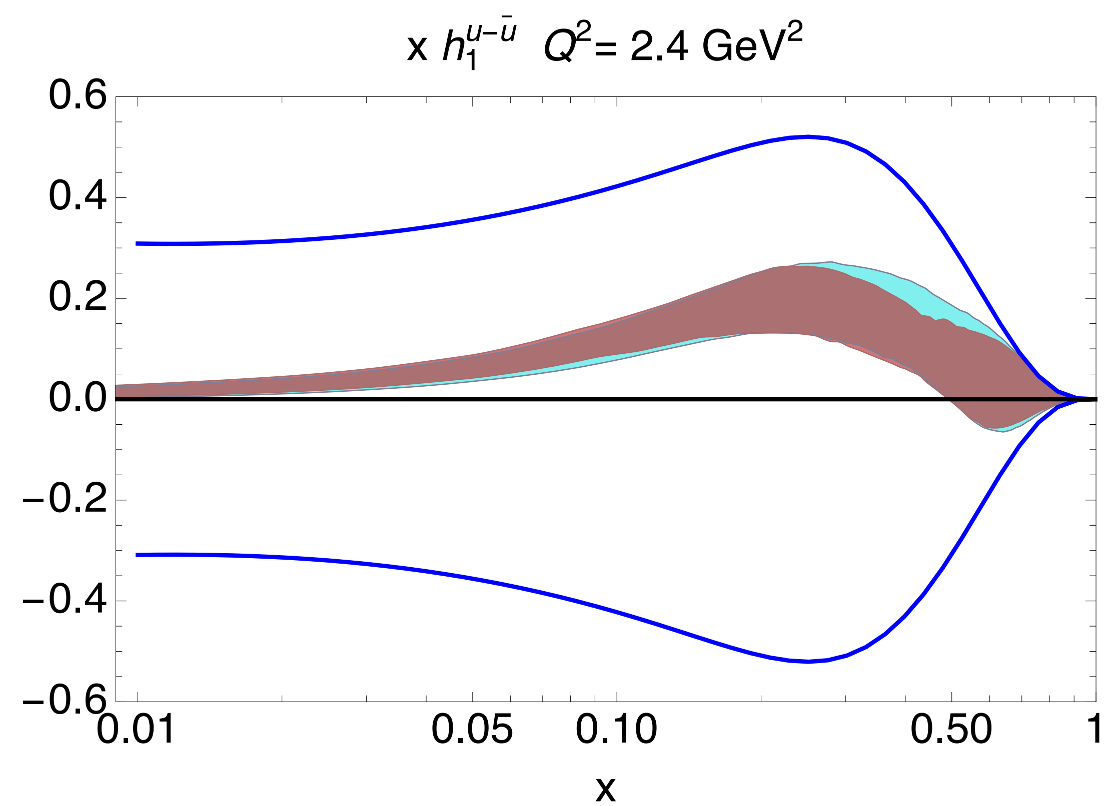
equivalent to Collins extraction

up

insensitive to uncertainty on gluon D_1

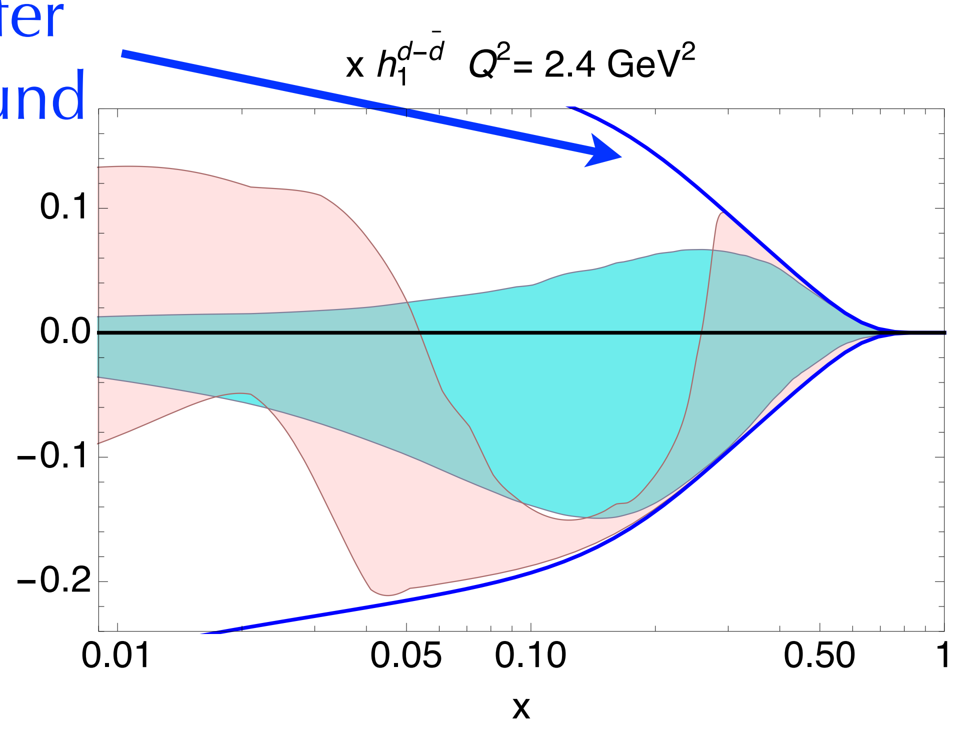
$D_1{}^g(Q_0) = 0$

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



comparison with previous fit

Soffer bound



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

global fit

old fit

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

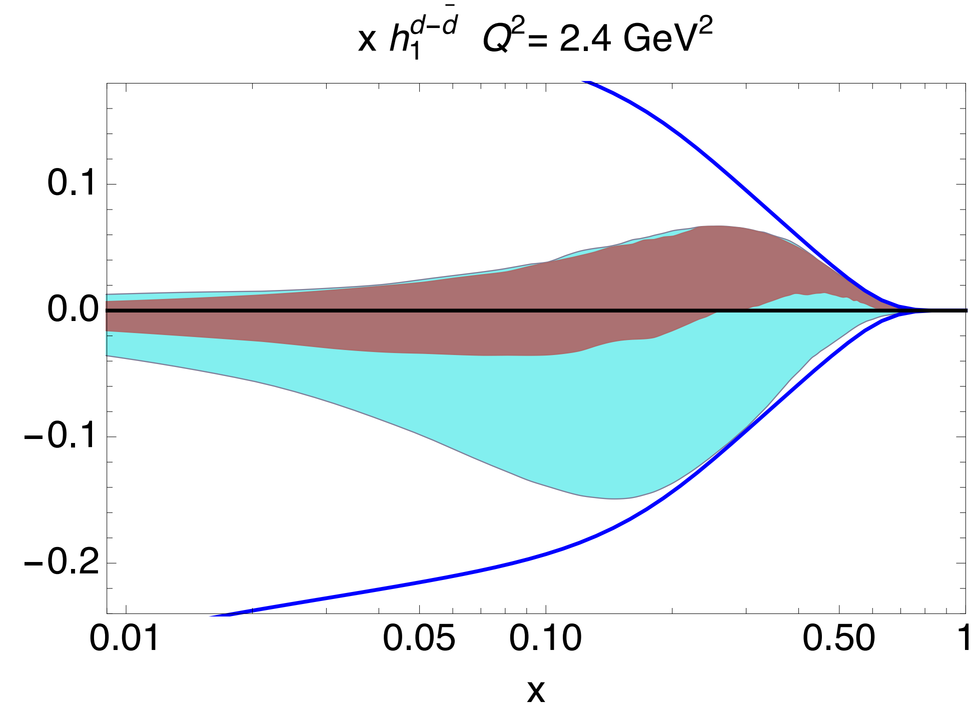
down

down

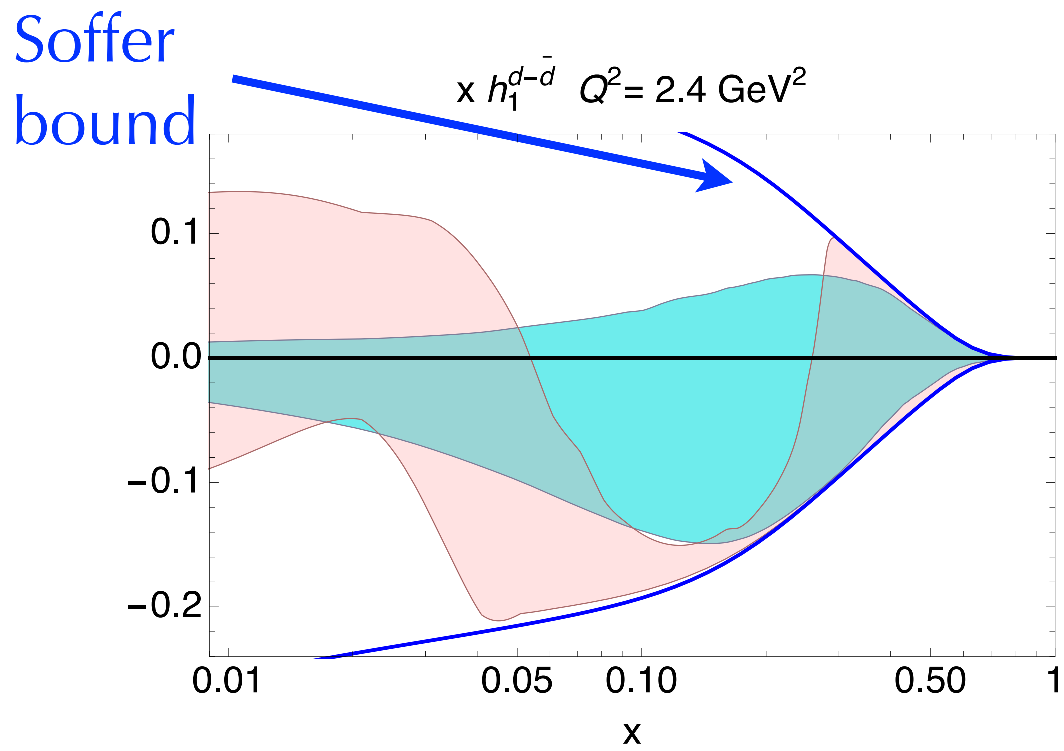
sensitive to uncertainty on gluon D_1

$D_1^g(Q_0) = 0$

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



comparison with previous fit



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

global fit

old fit

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

down

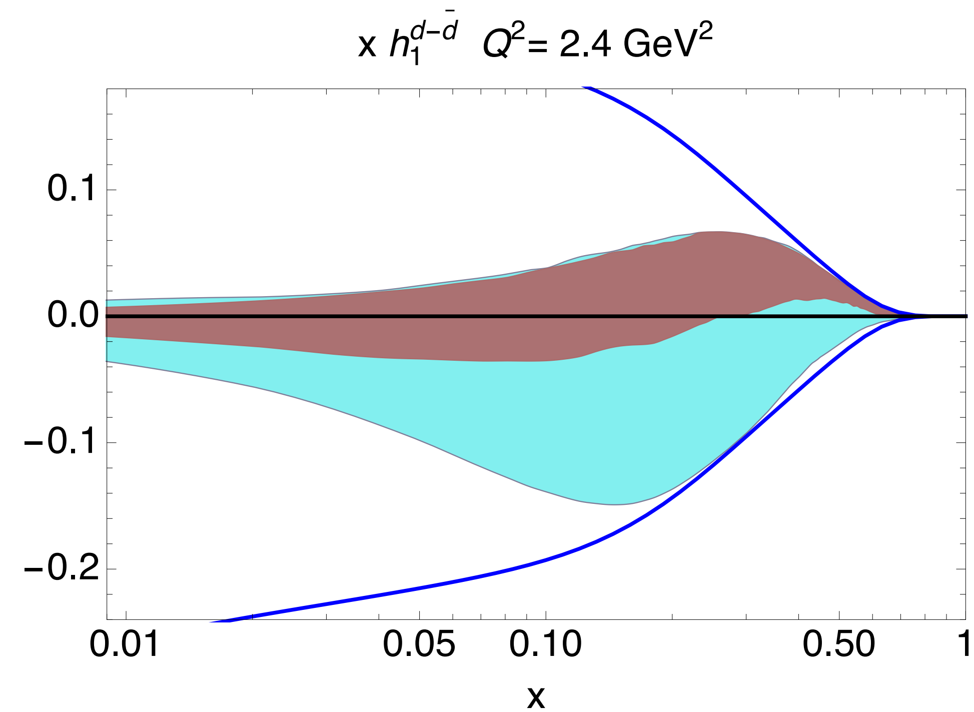
need better control on $g \to \pi^+\pi^-$

down

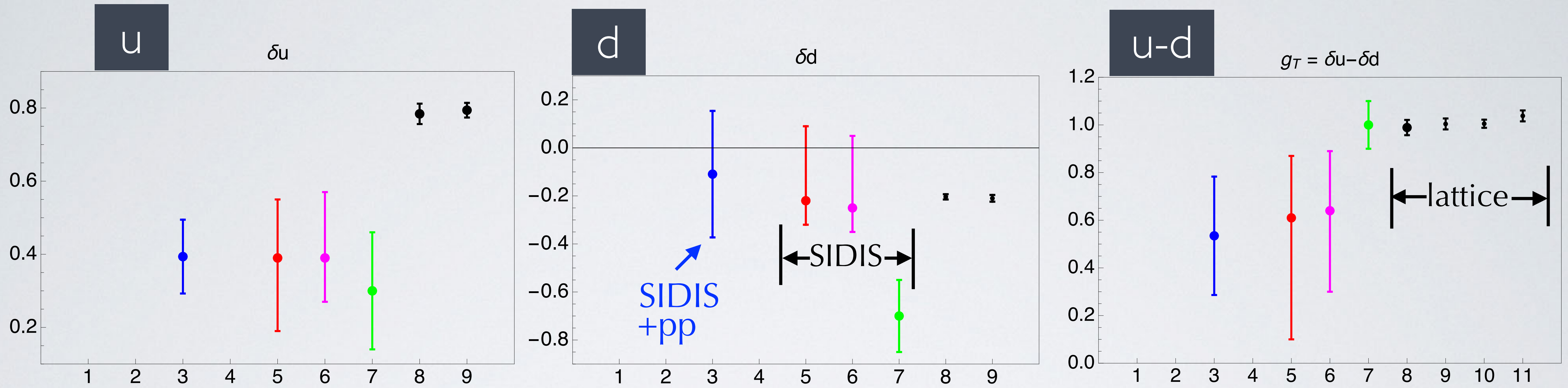
sensitive to uncertainty on gluon D_1

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

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



tensor charge



Q^2=4 GeV^2 *

JAM includes "lattice data"

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — **3) 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**

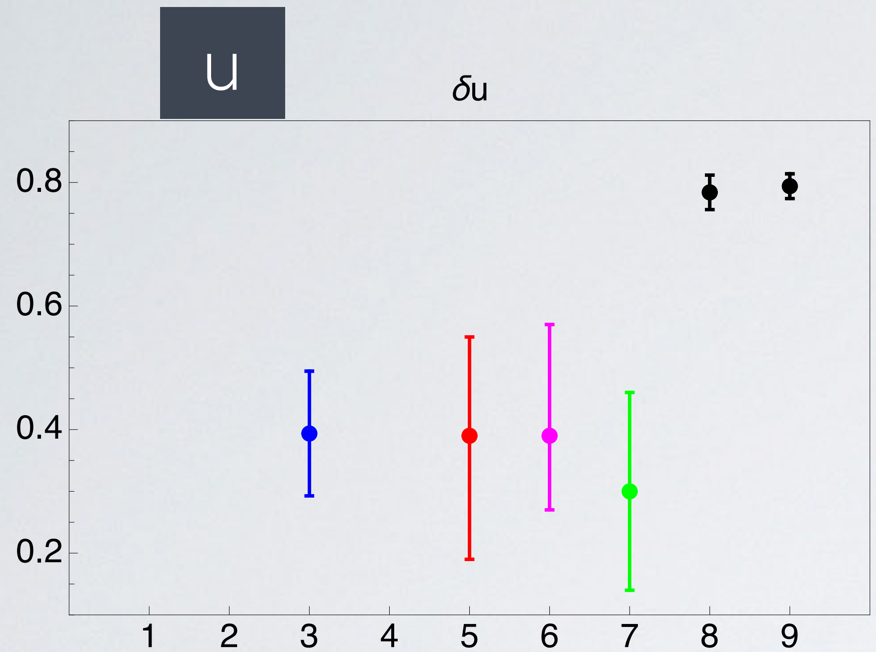
8) PNDME '18 — *Gupta et al., P.R. D**98** (18) 034503*

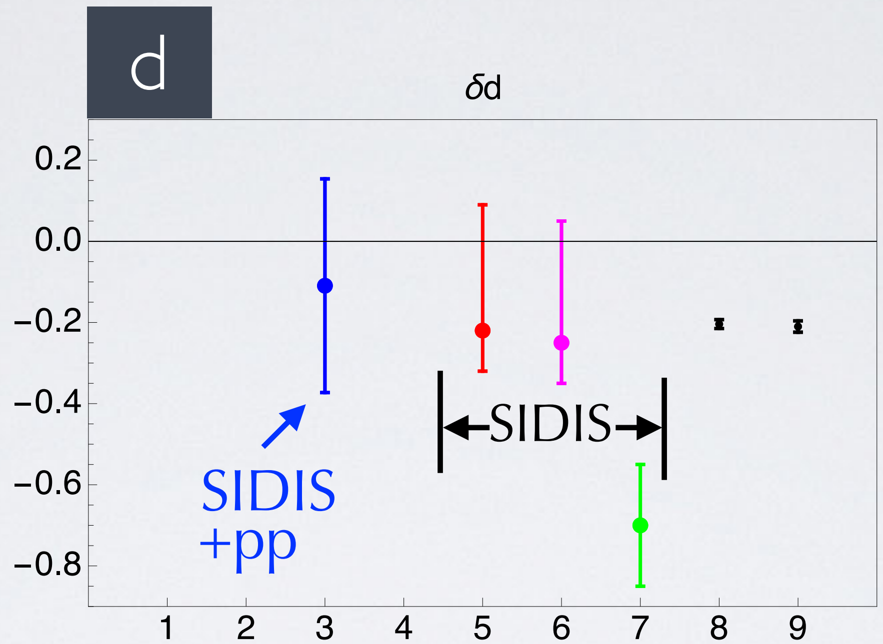
9) ETMC '17 — *Alexandrou et al., P.R. D**95** (17) 114514; E P.R. D**96** (17) 099906*

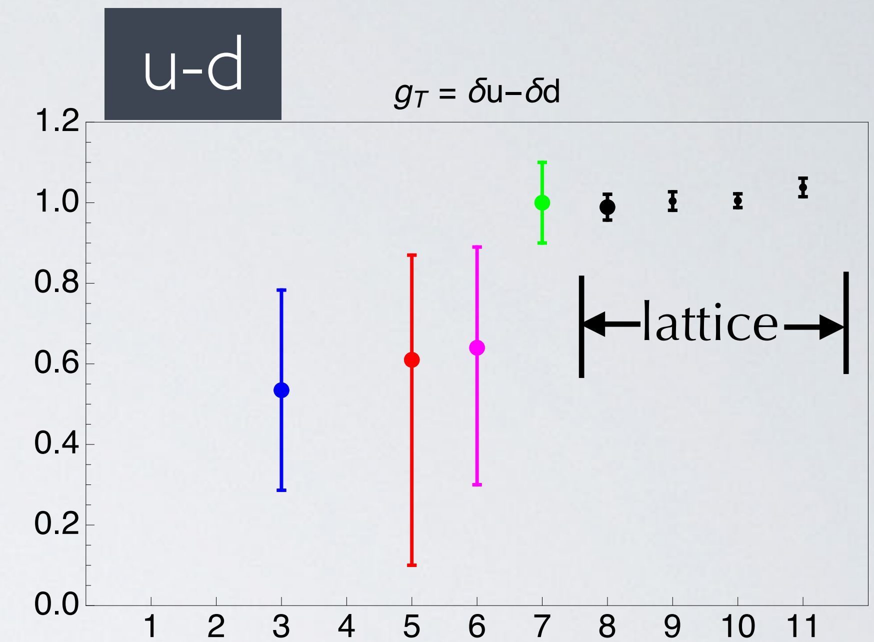
10) RQCD '14 — *Bali et al., P.R. D**91** (15)*

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

tensor charge







no simultaneous compatibility between lattice and phenomenology

Q^2=4 GeV^2 *

JAM includes "lattice data"

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001*	3)	**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*
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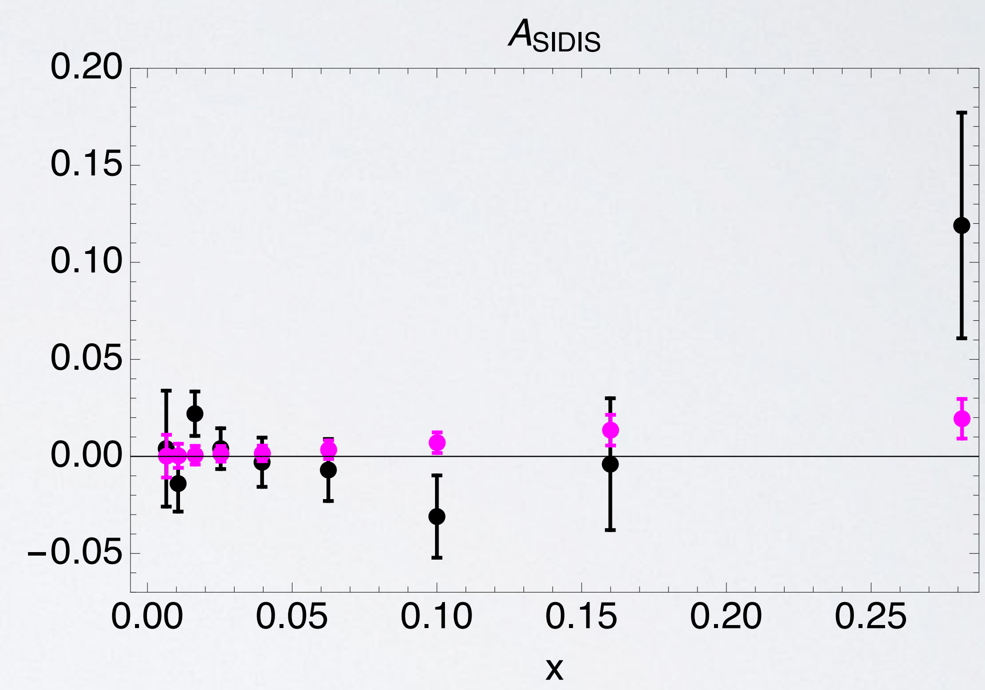
10)	**RQCD '14**	*Bali et al., P.R. D****91*** *(15)*
11)	**LHPC '12**	*Green et al., P.R. D****86*** *(12)*

Compass pseudo-data

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

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

COMPASS — pseudodata



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

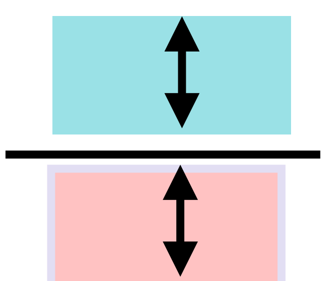
study impact on precision of previous global fit

impact of pseudo-data

global fit + pseudodata

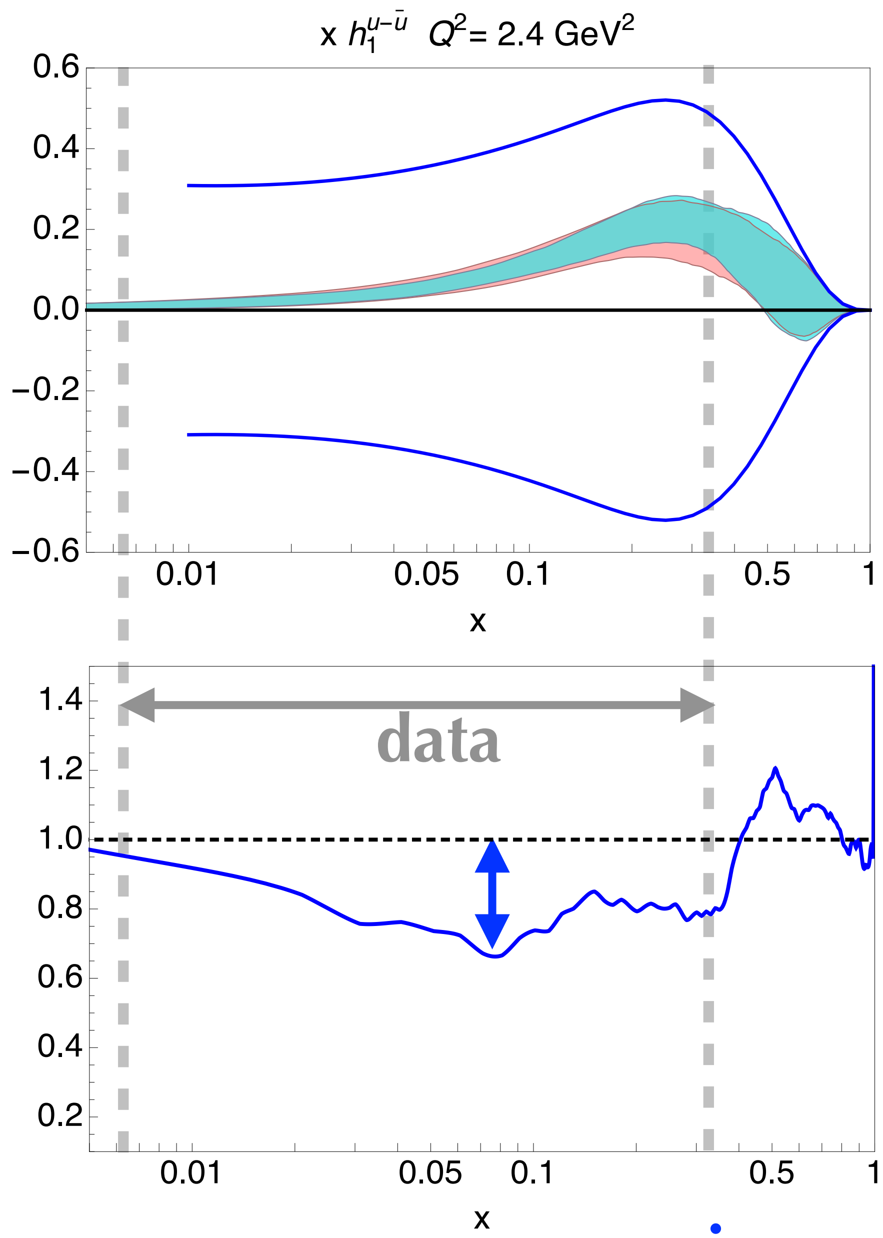
global fit

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

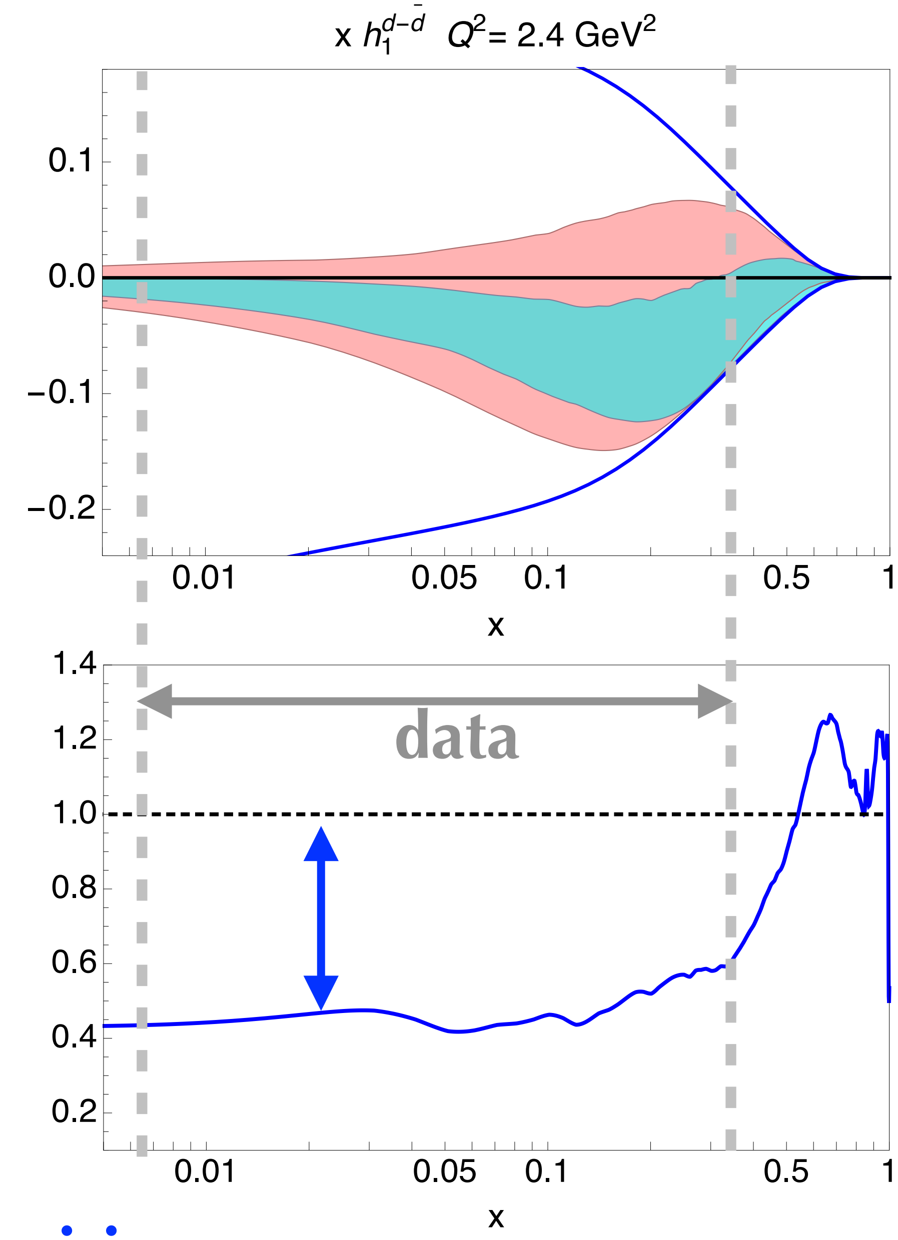


ratio of widths

up

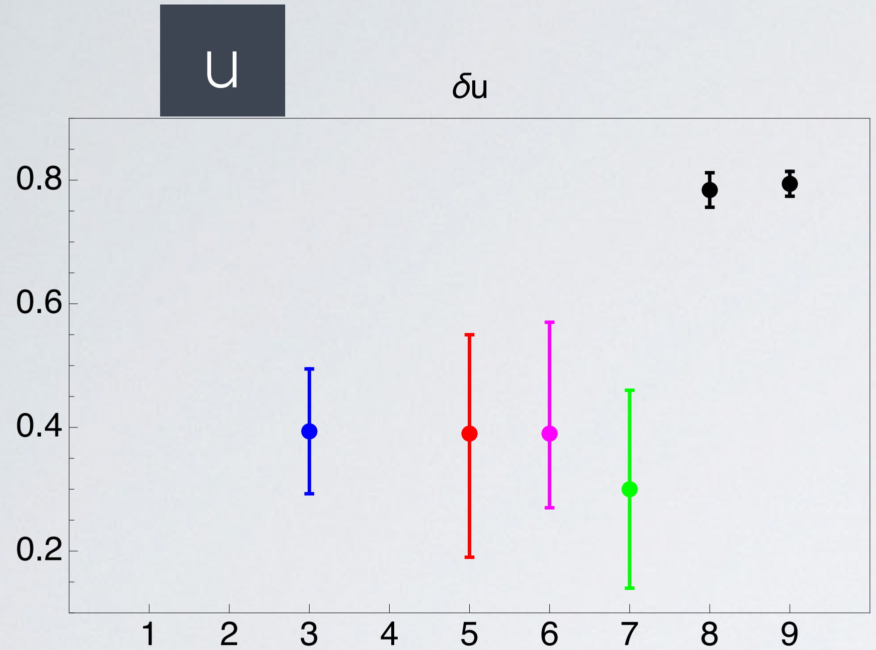


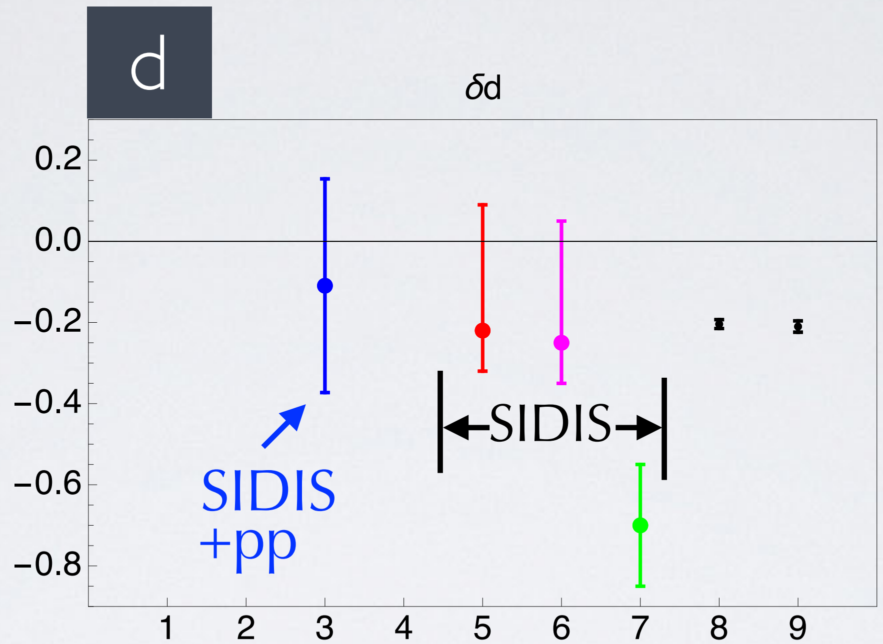
down

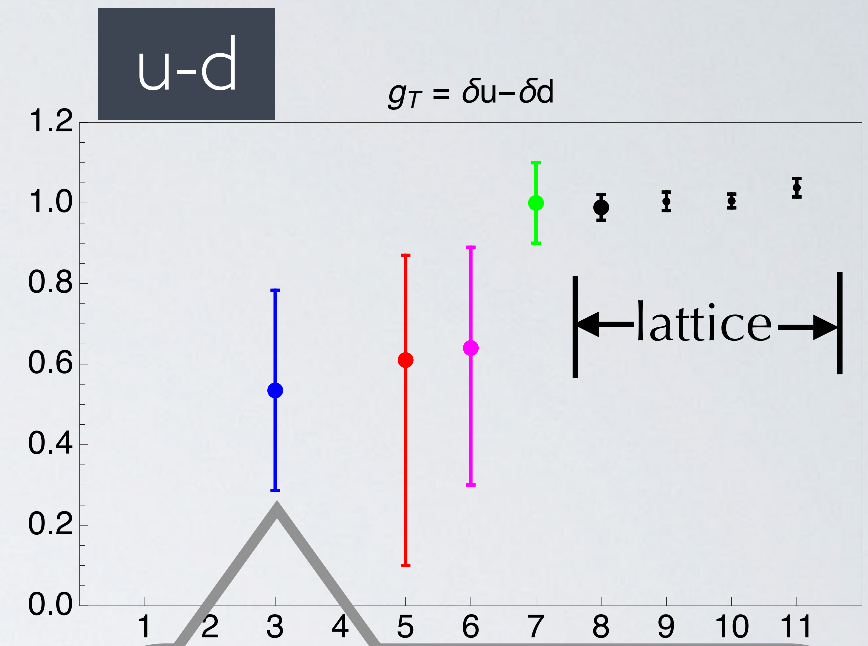


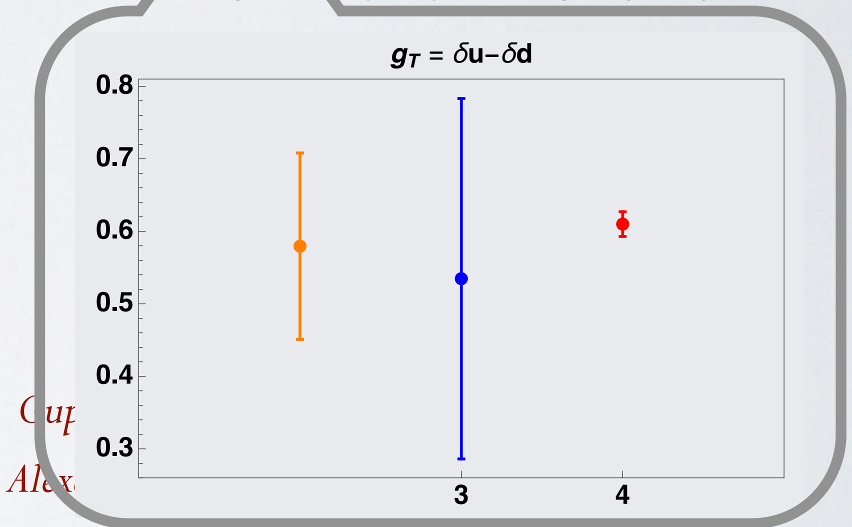
increase precision

tensor charge









Q^2=4 GeV^2 *

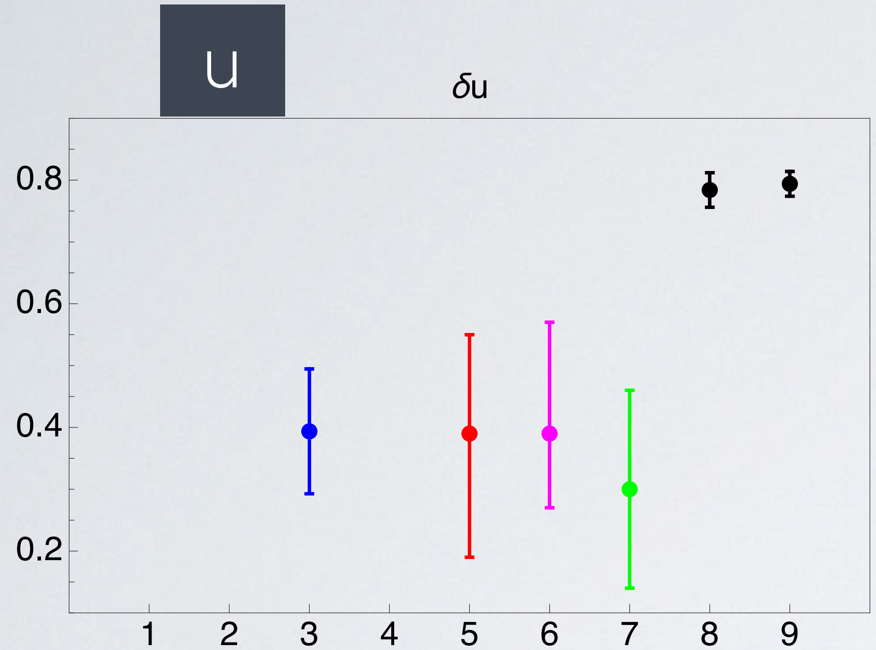
*Radici & Bacchetta, P.R.L. **120** (18) 192001*	3)	**global fit '17**
*Kang et al., P.R. D**93** (16) 014009*	5)	**"TMD fit" * Q^2=10**
*Anselmino et al., P.R. D**87** (13) 094019*	6)	**Torino fit * Q^2=1**
*Lin et al., P.R.L. **120** (18) 152502*	7)	**JAM fit '17 * Q_0^2=2**

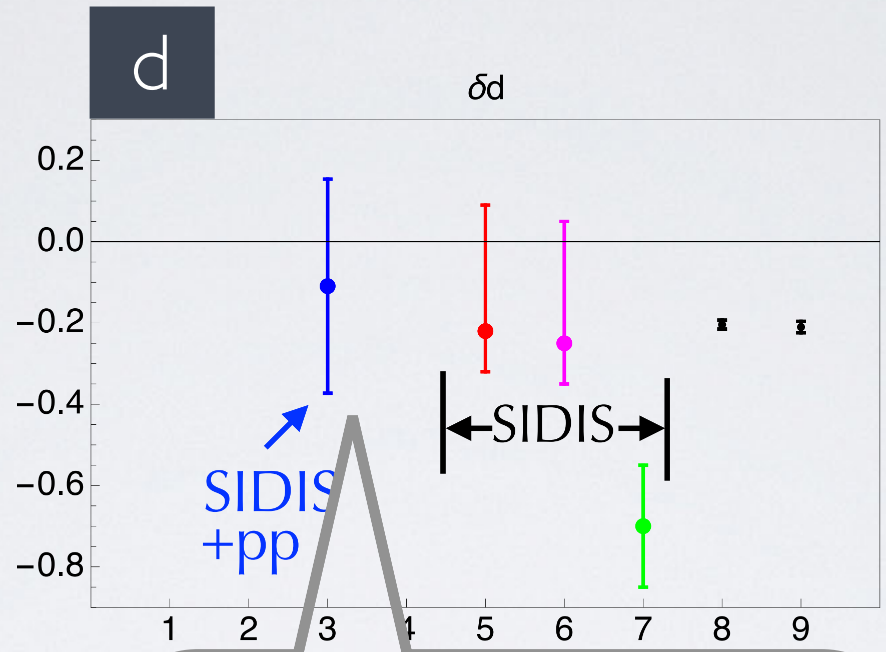
8)	**PNDME '18**	*Cup…*
9)	**ETMC '17**	*Alex… P.R. D**96** (17) 099906*
10)	**RQCD '14**	*Bali et al., P.R. D**91** (15)*
11)	**LHPC '12**	*Green et al., P.R. D**86** (12)*

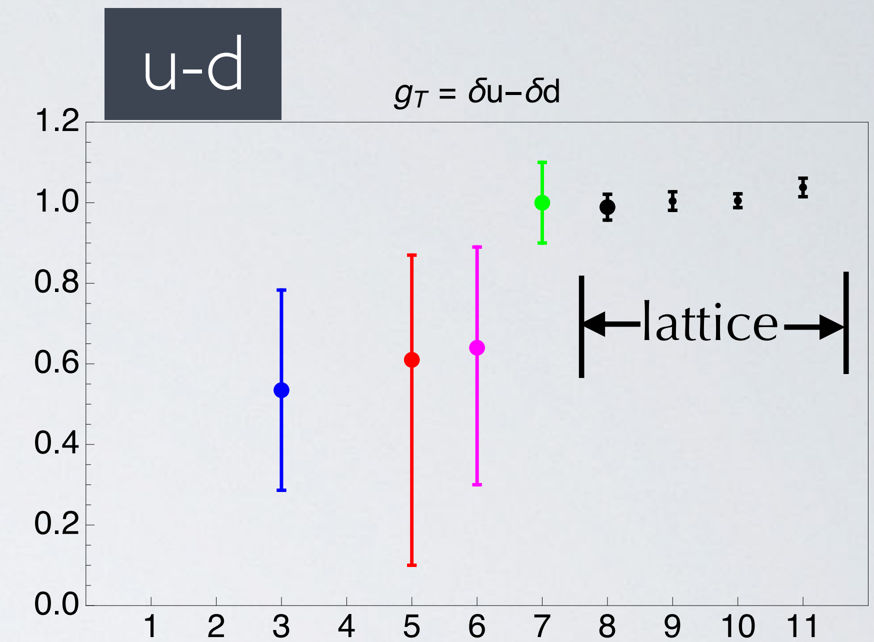
global fit + pseudodata

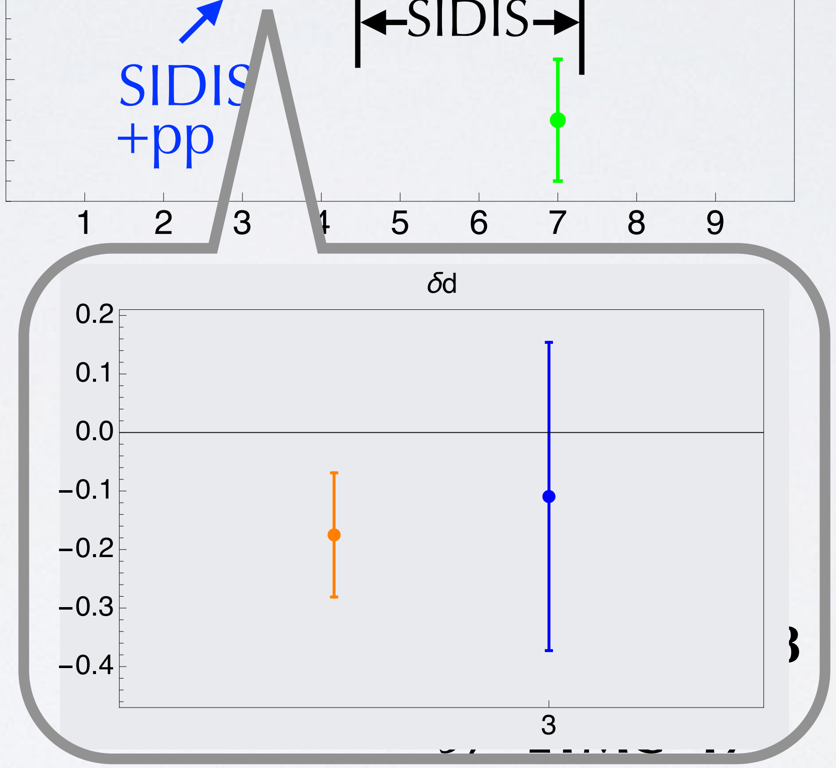
4) **SoLID** *Ye et al., P.L. **B767** (17) 91*

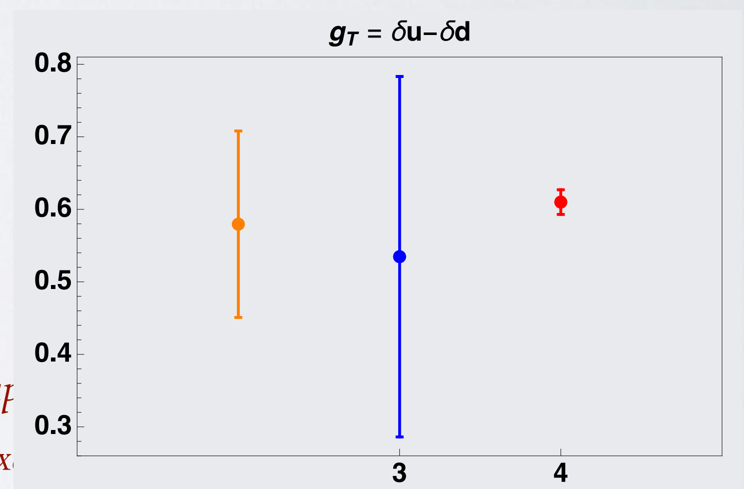
tensor charge











Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 3) **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**

Gup

Alex

*E P.R. D**96** (17) 099906*

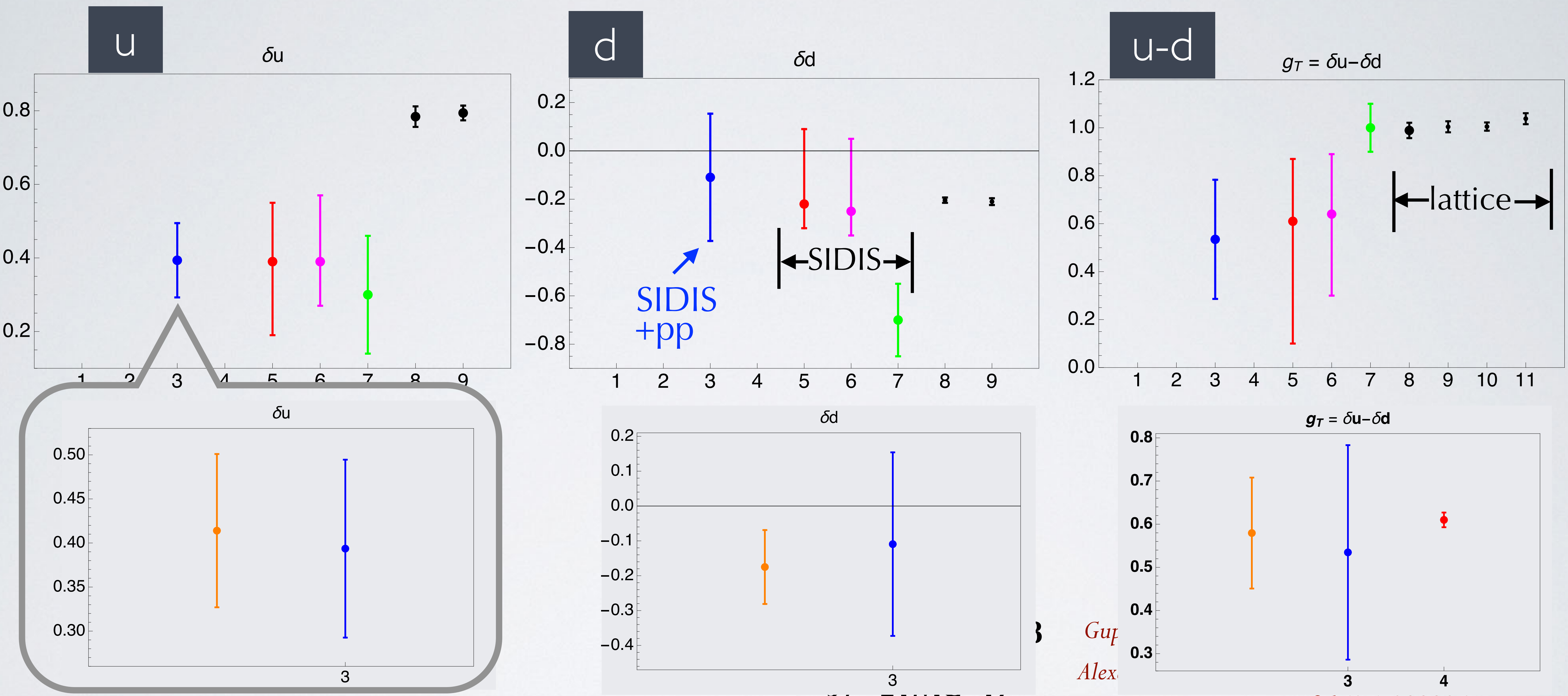
10) **RQCD '14** — *Bali et al., P.R. D**91** (15)*

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

global fit + pseudodata

4) **SoLID** — *Ye et al., P.L.* ***B767*** *(17) 91*

tensor charge



Gup…
Alex… E P.R. D96 (17) 099906

Radici & Bacchetta, P.R.L. **120** (18) 192001 — 3) global fit '17

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

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

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

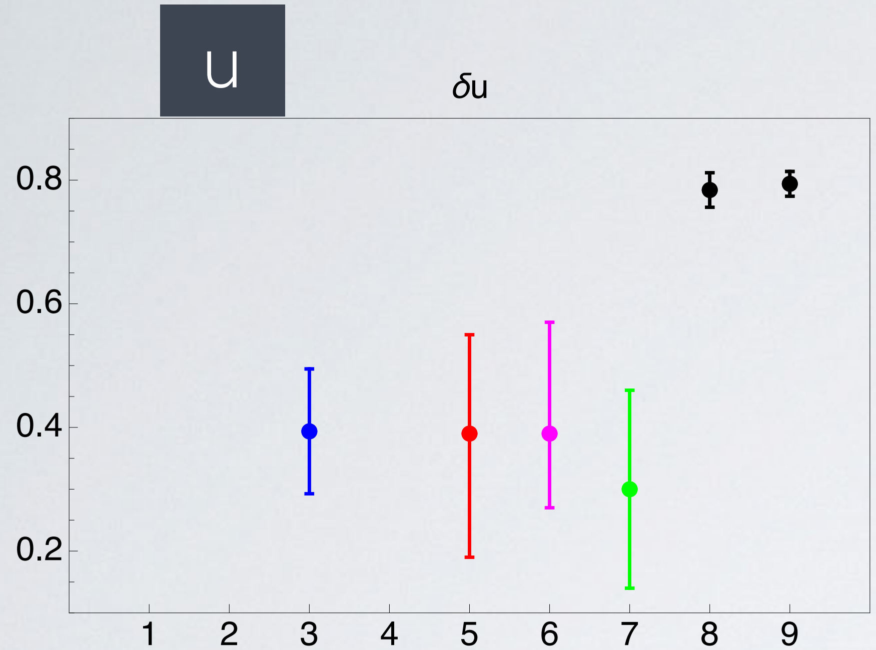
Anselmino et al., P.R. D**87** (13) 094019 — 6) Torino fit * Q^2=1

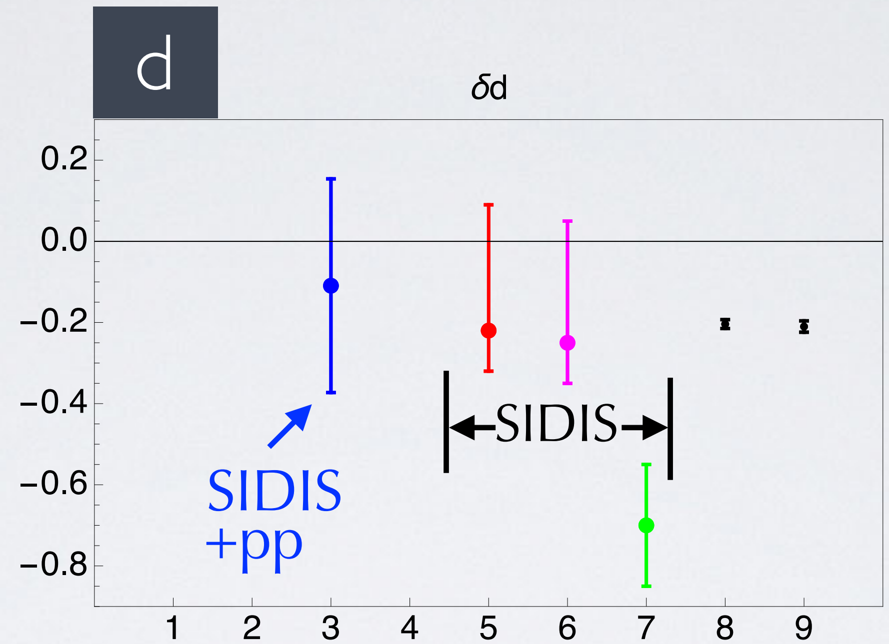
global fit + pseudodata

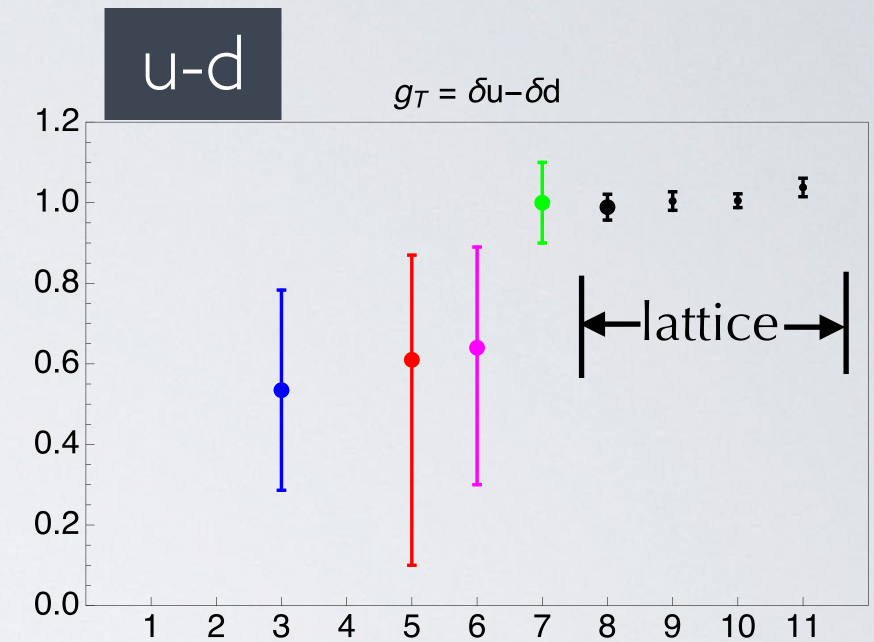
Lin et al., P.R.L. **120** (18) 152502 — 7) JAM fit '17 * Q_0^2=2

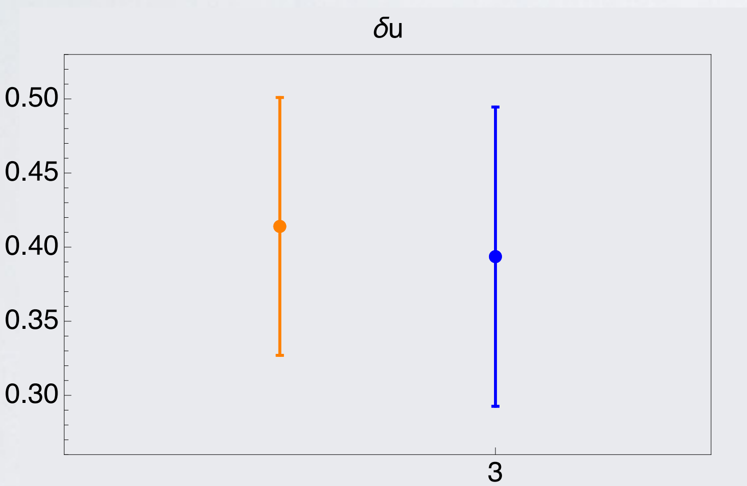
4) SoLID — Ye et al., P.L. **B767** (17) 91

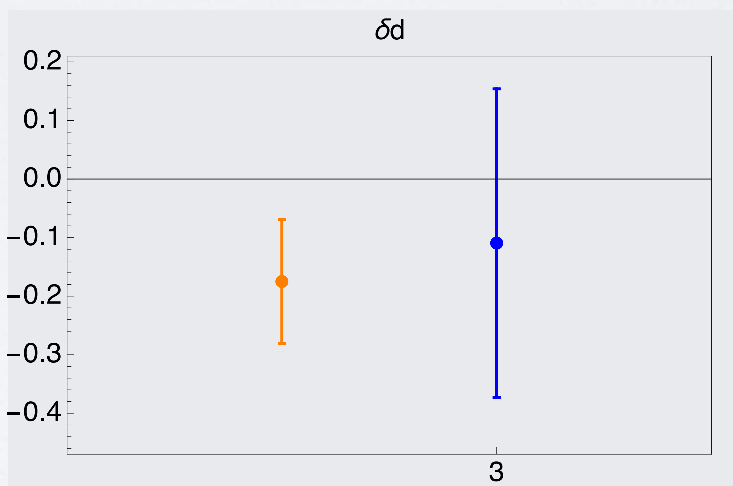
tensor charge

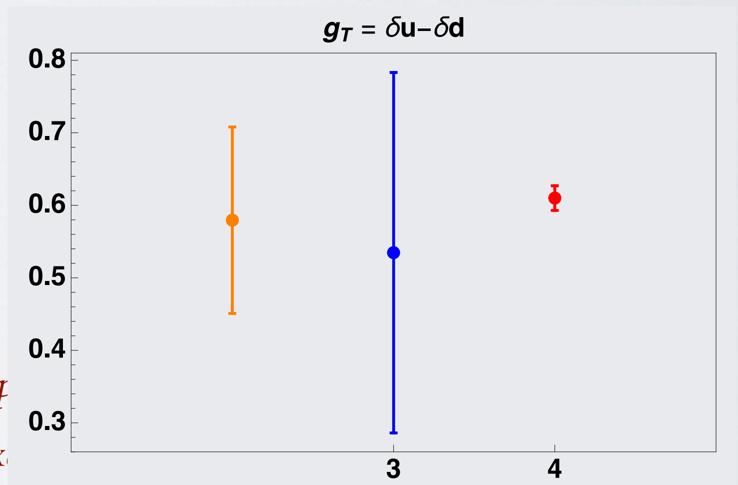












Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 3) **global fit '17**

Gu… Alex… E P.R. D**96** (17) 099906

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

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

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

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

global fit + pseudodata

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

…3767 (17) 91

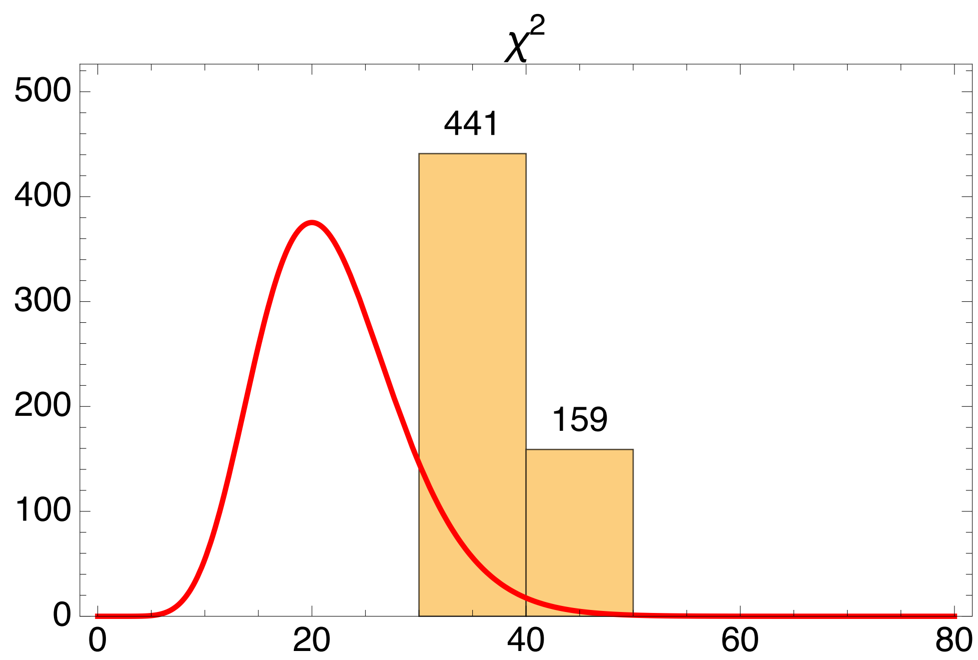
better precision

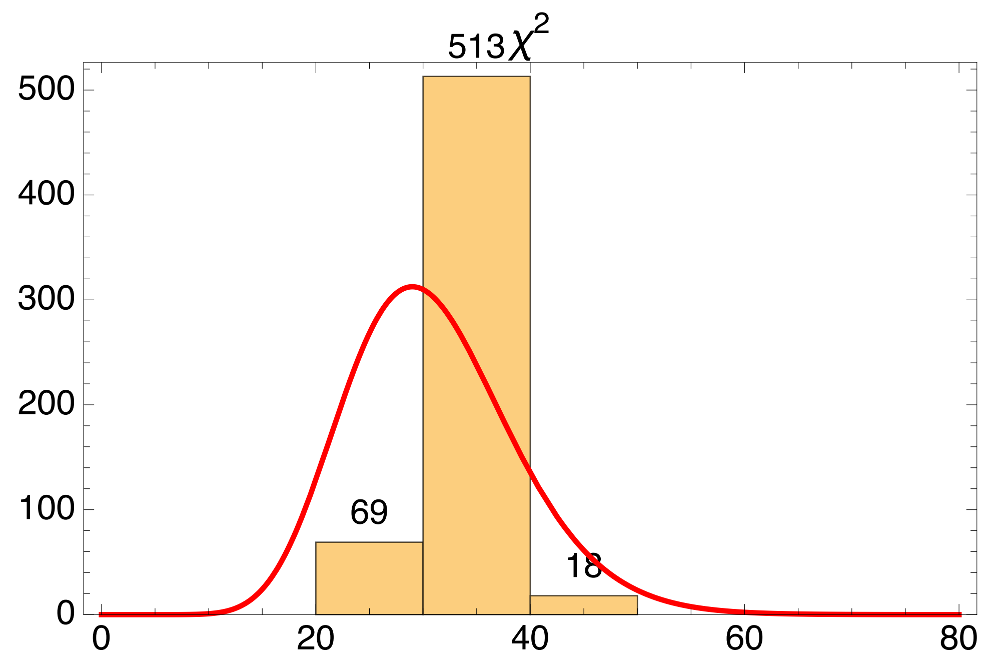
but general trend unchanged

better χ^2

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

$\chi^2/\text{dof} = 1.12 \pm 0.09$





probability density function of
χ^2 distribution for
22 d.o.f. 31 d.o.f.

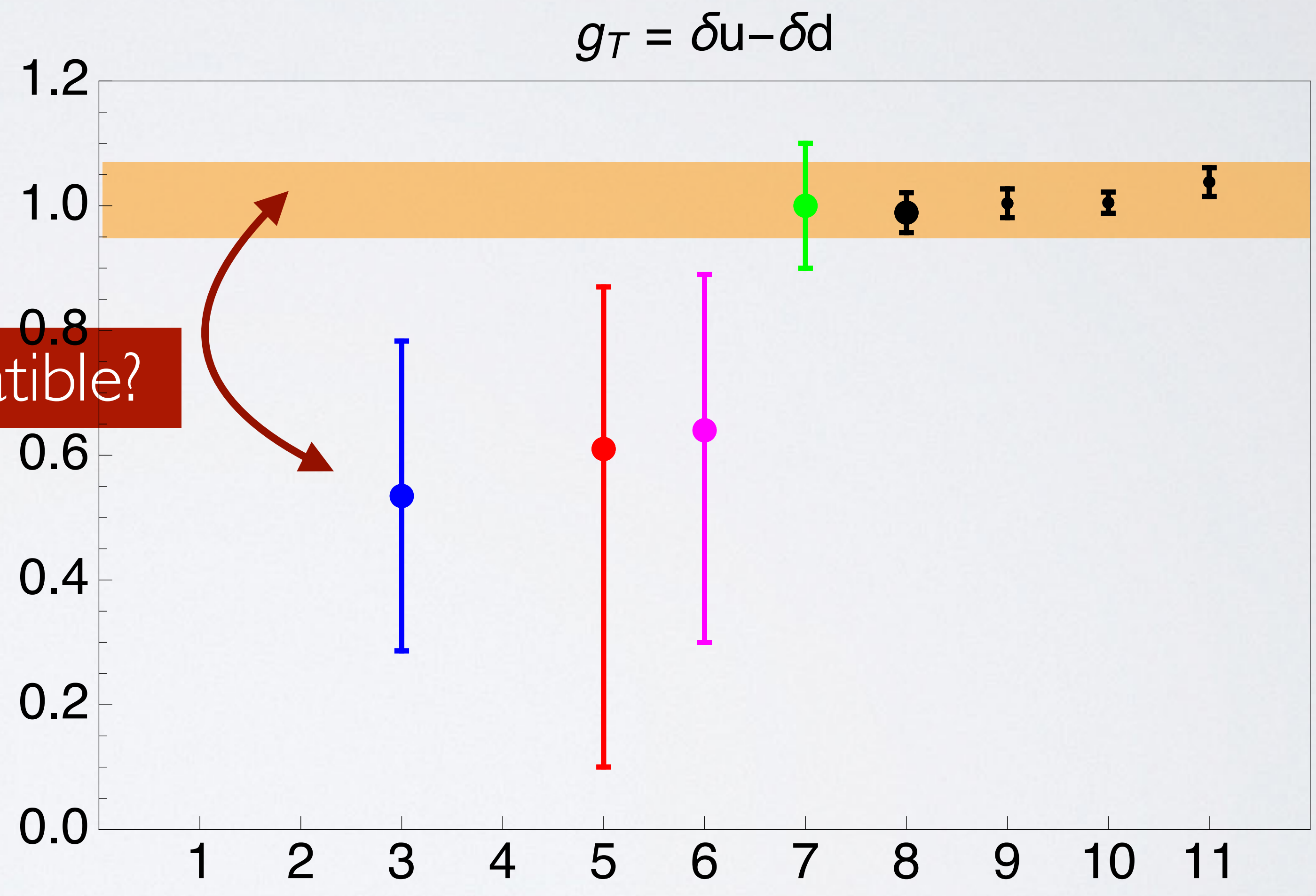
compatibility with lattice

add to SIDIS+pp data

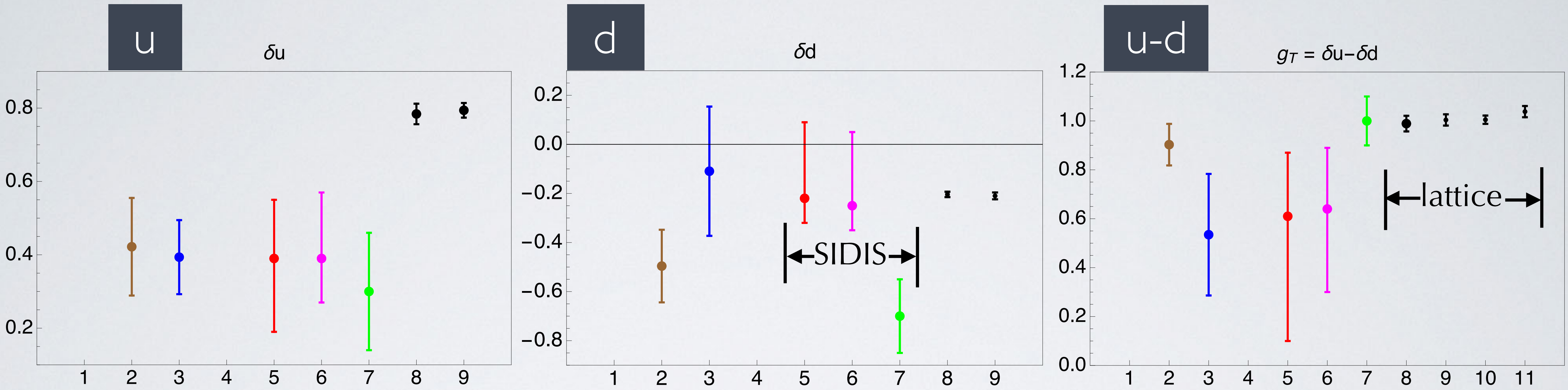
constraint to reproduce g_T from lattice

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

are they compatible?



tensor charge



Q^2=4 GeV^2 *

2) global fit + constrain g_T

Radici & Bacchetta, *P.R.L.* **120** (18) 192001 — 3) 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

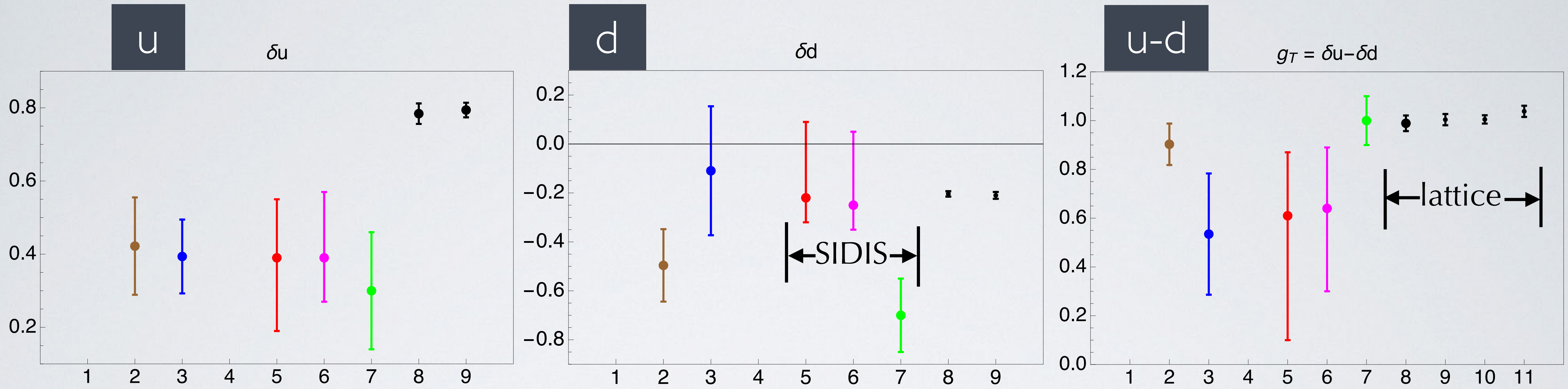
8) PNDME '18 — *Gupta et al., P.R. D***98** *(18) 034503*

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 + constrain g_T

Radici & Bacchetta, *P.R.L.* **120** (18) 192001 — 3) 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)

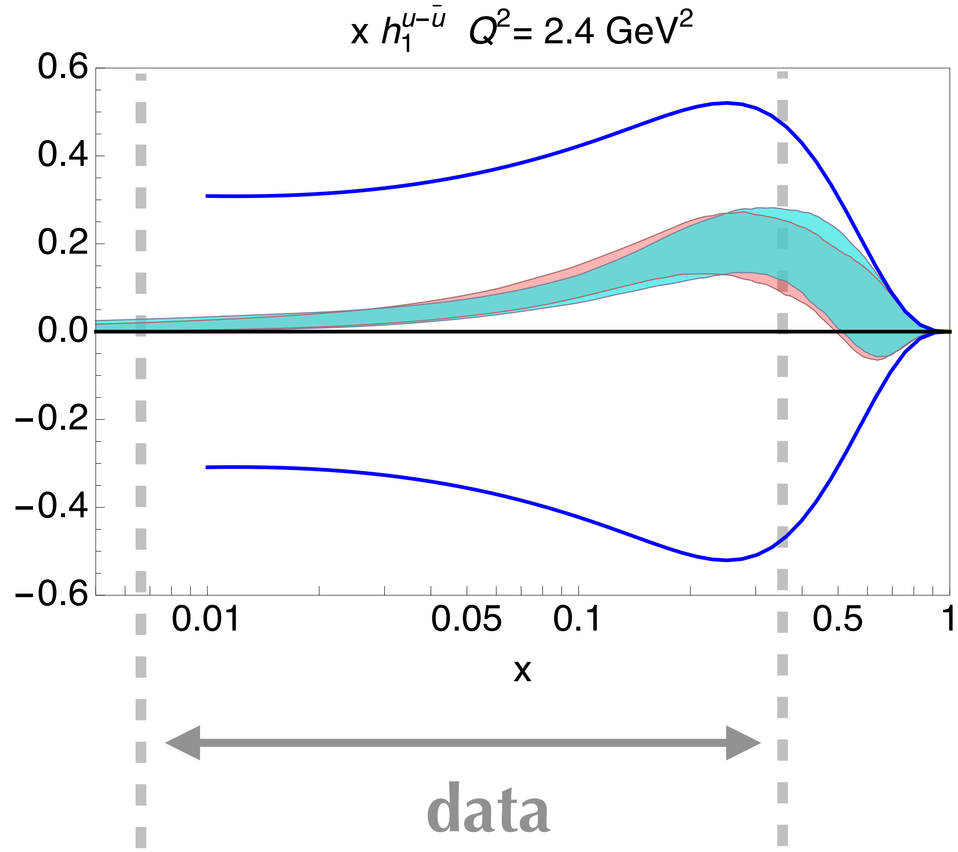
impact of lattice g_T constraint

global fit + lattice gT constraint

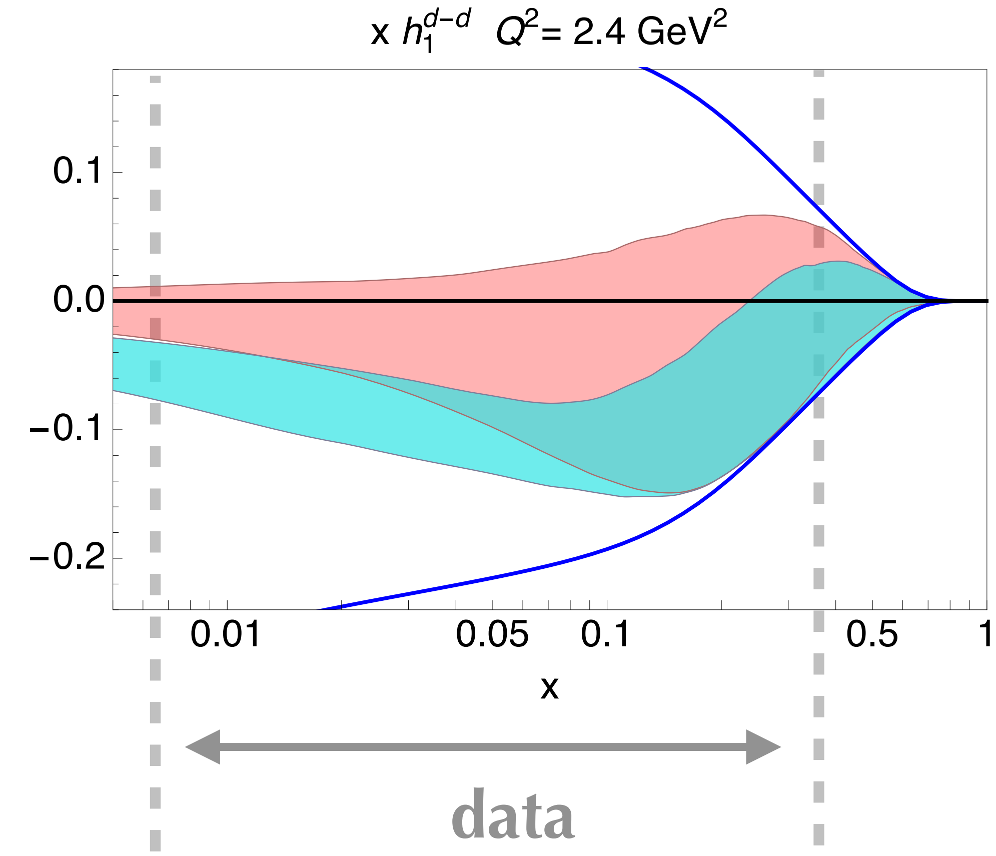
global fit

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

up

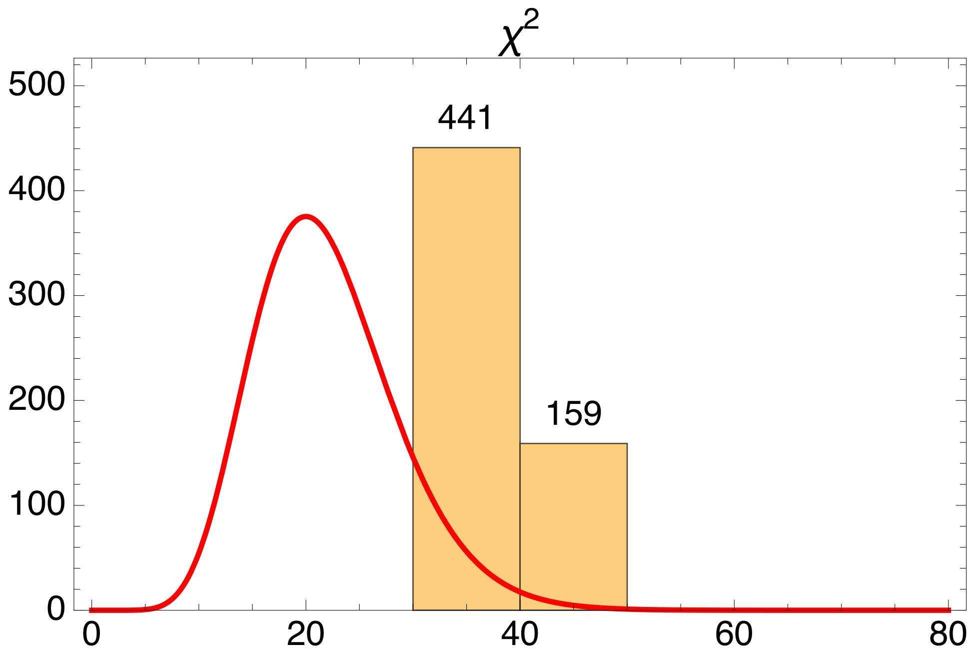


down

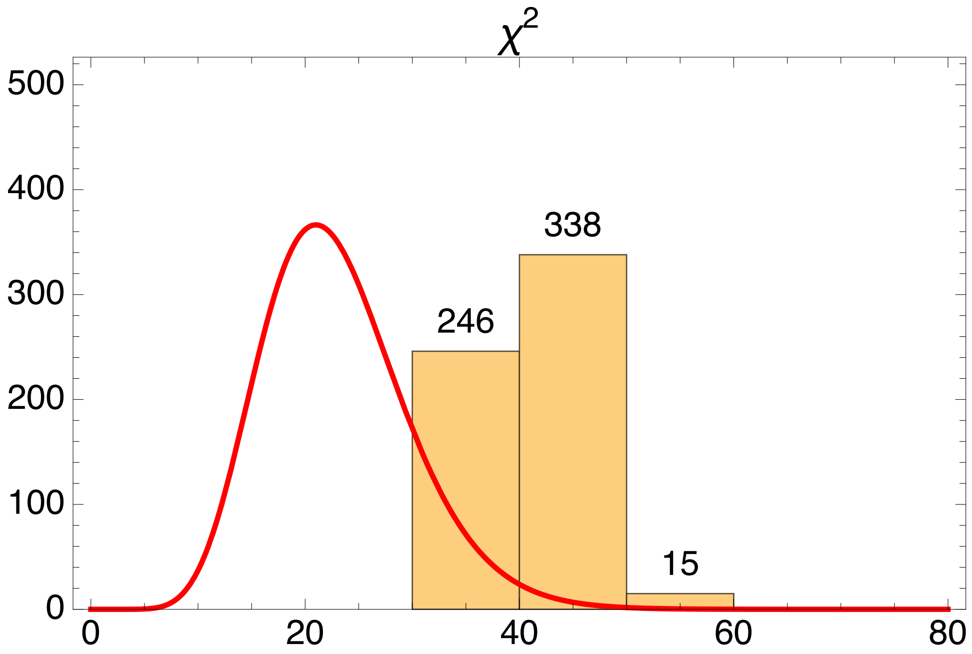


χ^2

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



$\chi^2/\text{dof} = 1.82 \pm 0.25$



probability density function of
χ^2 distribution for
22 d.o.f. 23 d.o.f.

compatibility with lattice

add to SIDIS+pp data

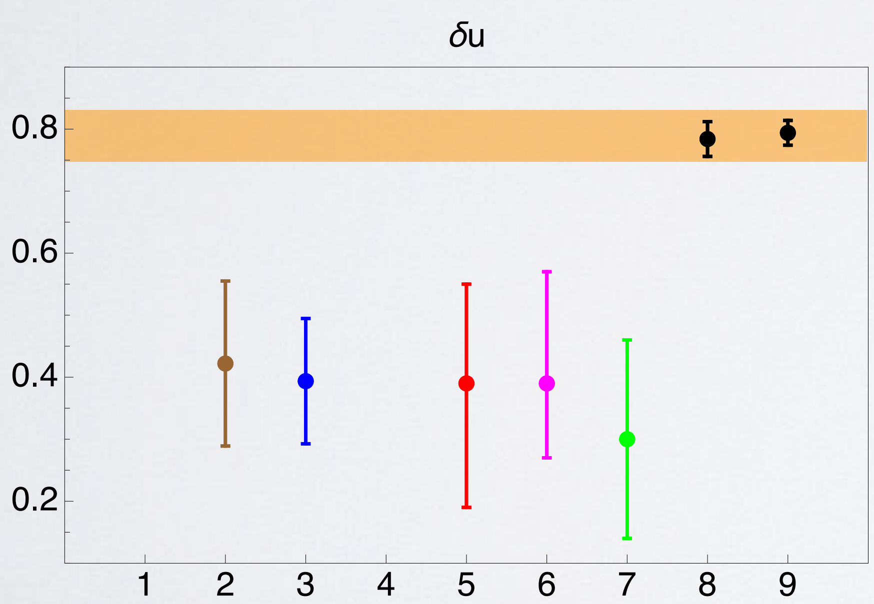
constraint to reproduce from lattice

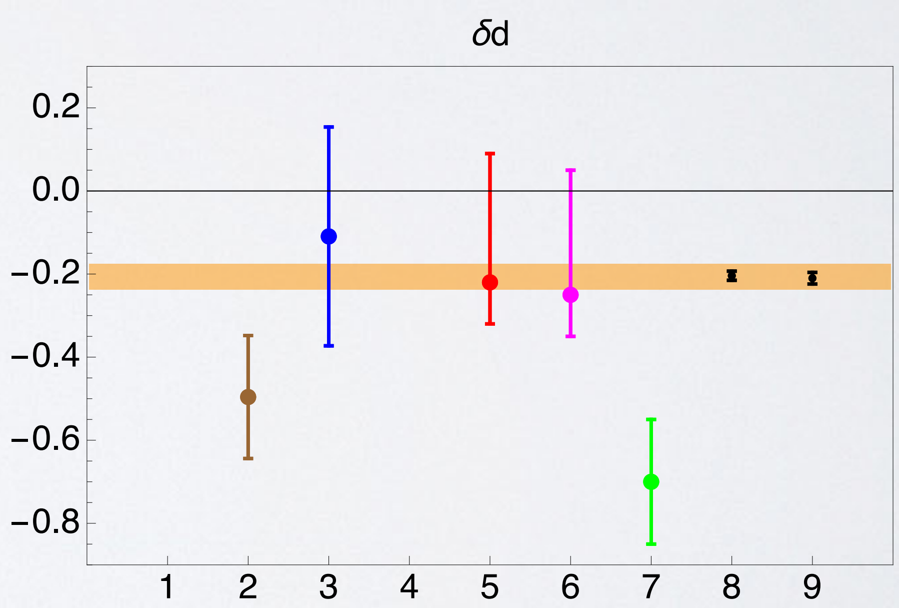
g_T , δu , δd

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

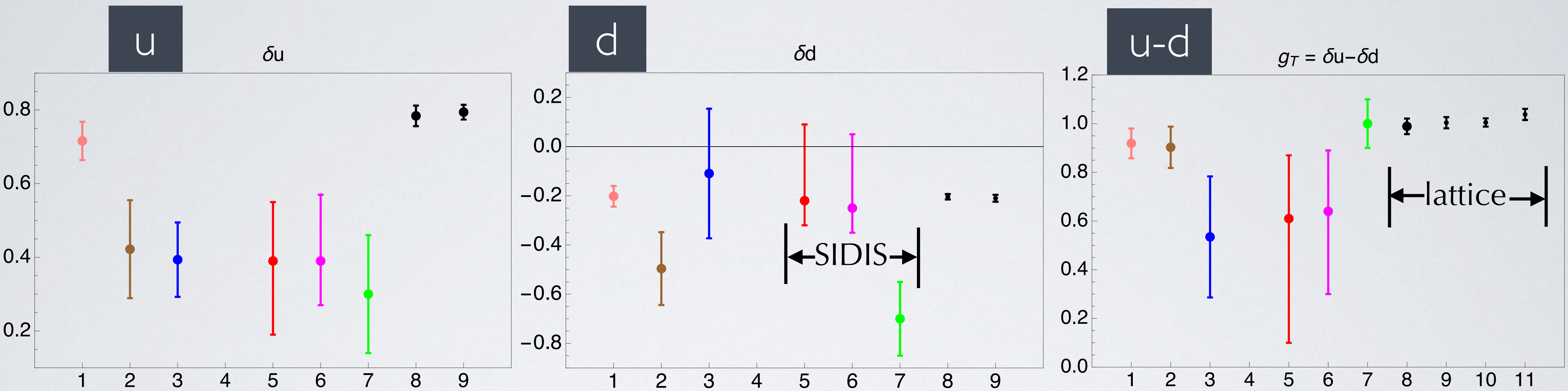
$\overline{\delta u}^{latt} = 0.782 \pm 0.031$

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





tensor charge



Q^2=4 GeV^2 *

1) global fit + constrain g_T , δu , δd

2) global fit + constrain g_T

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 3) 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

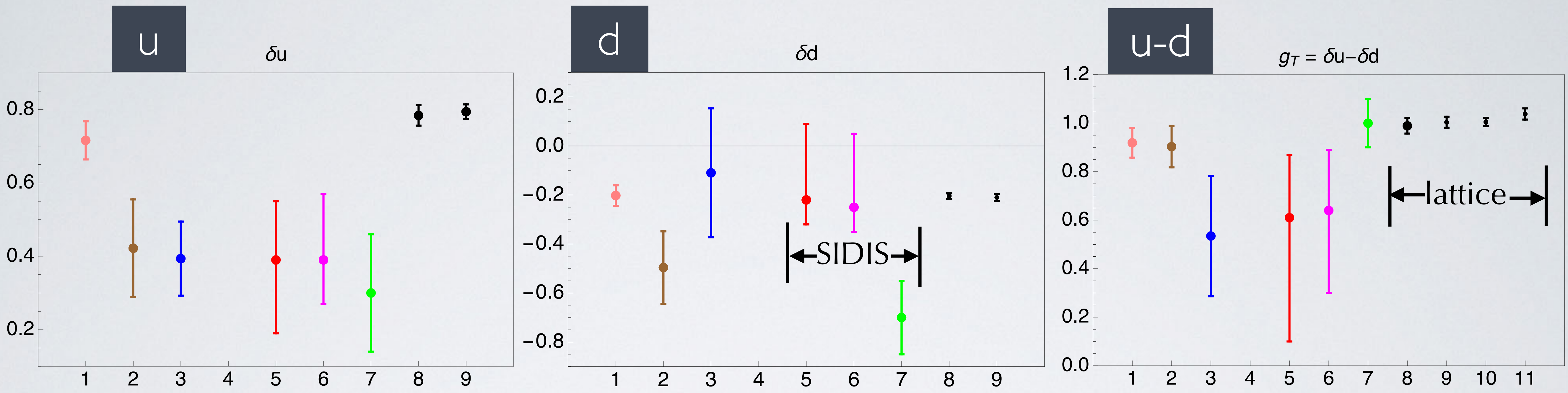
8) PNDME '18 — *Gupta et al., P.R. D**98** (18) 034503*

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 + constrain g_T , δu , δd

2) global fit + constrain g_T

Radici & Bacchetta, P.R.L. ***120*** *(18) 192001* — 3) global fit '17

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

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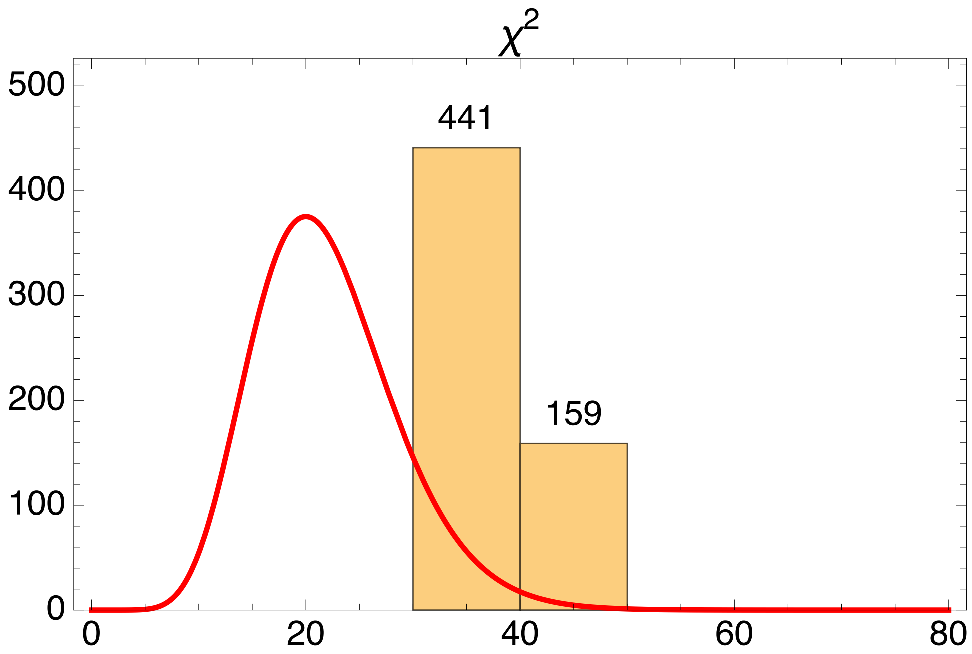
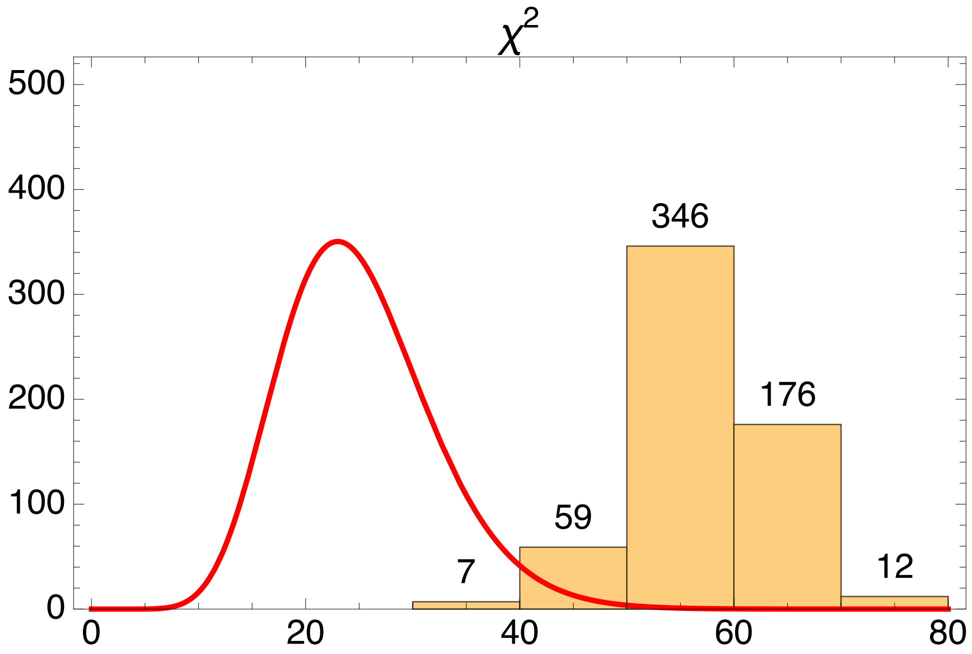
11) LHPC '12 — *Green et al., P.R. D**86** (12)*

χ^2

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

$\chi^2/\text{dof} = 2.29 \pm 0.25$

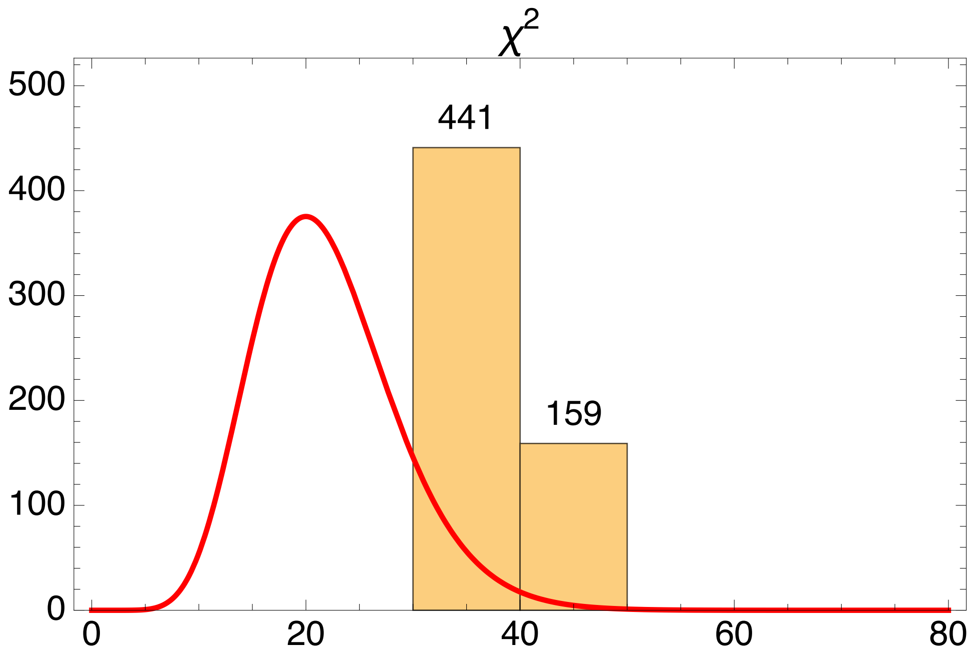




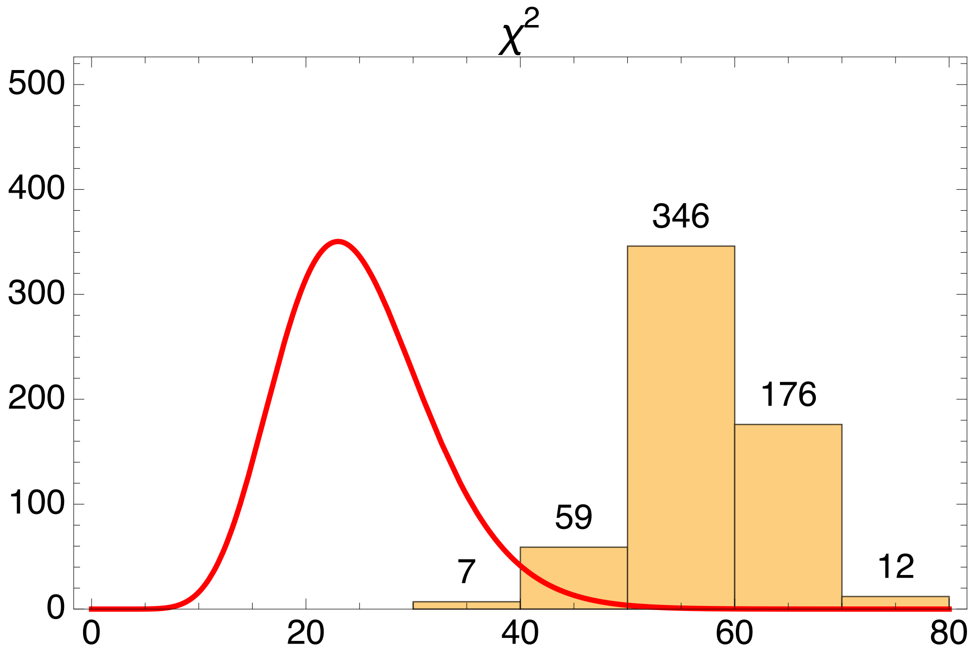
probability density function of
χ^2 distribution for
22 d.o.f. 25 d.o.f.

χ^2

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



$\chi^2/\text{dof} = 2.29 \pm 0.25$



probability density function of
χ^2 distribution for
22 d.o.f. 25 d.o.f.

compatible, but… statistically very unlikely !

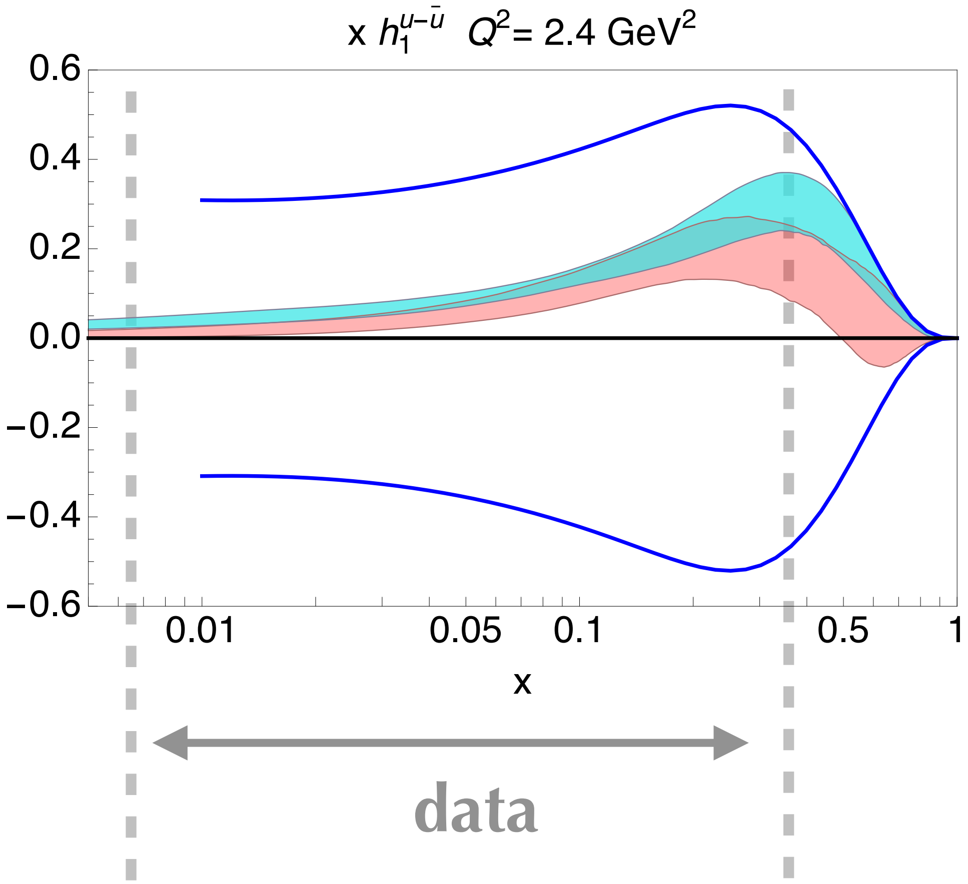
impact of "full" lattice constraint

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

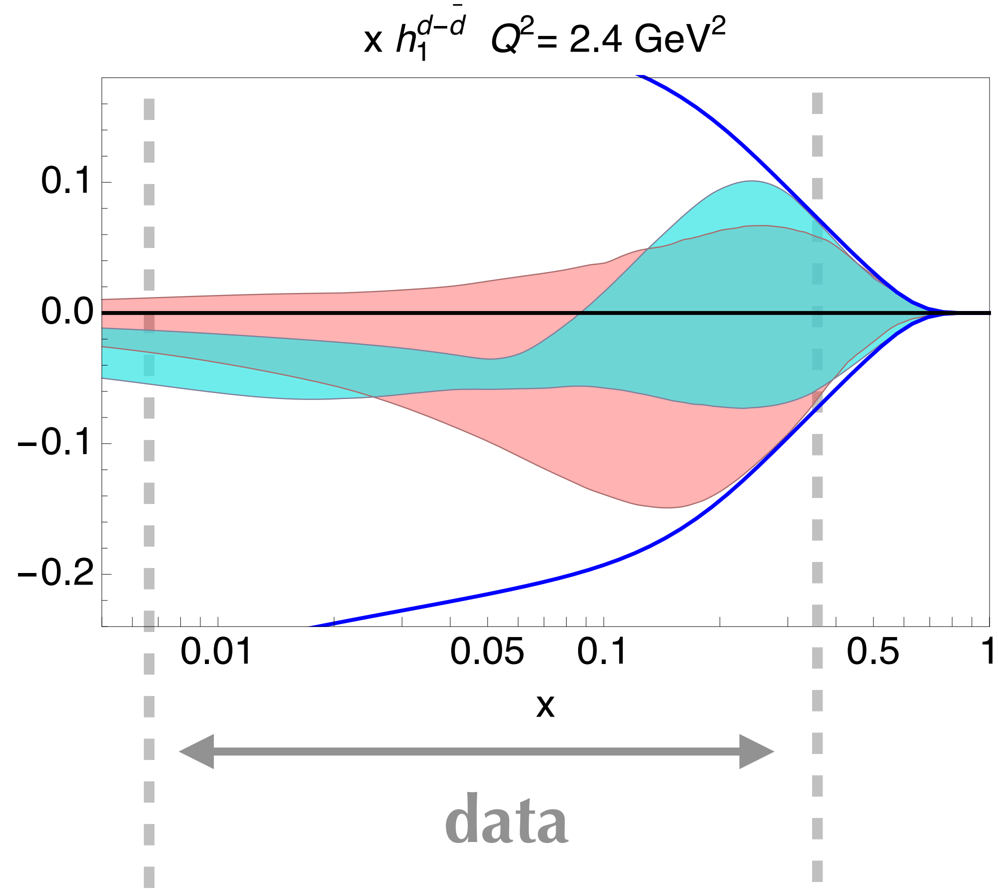
global fit

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

up



down



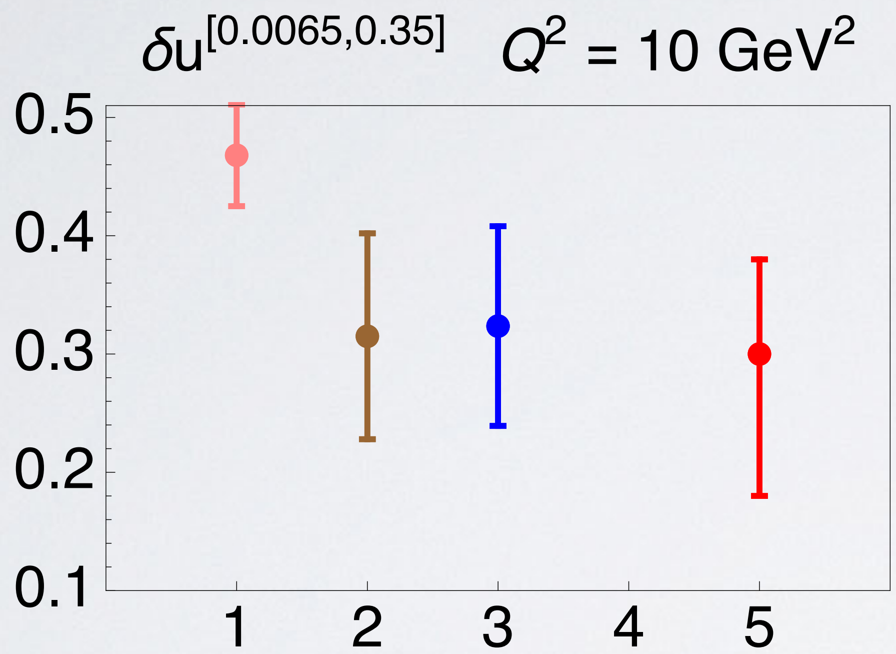
higher up, even within x-range of data

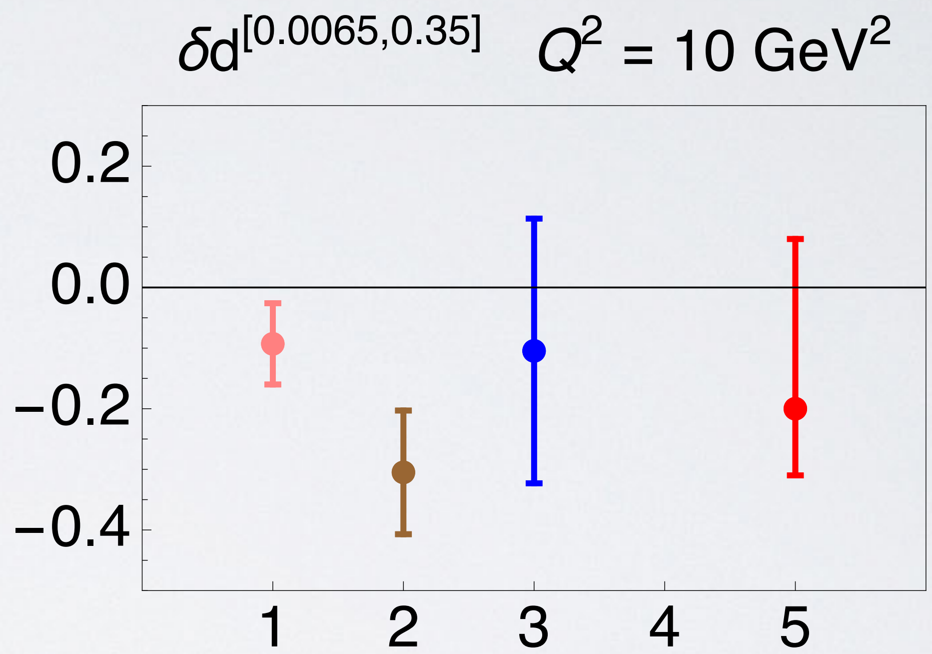
truncated tensor charge

truncated

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

up





down

1) global fit + constrain g_T , δu , δd

2) global fit + constrain g_T

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

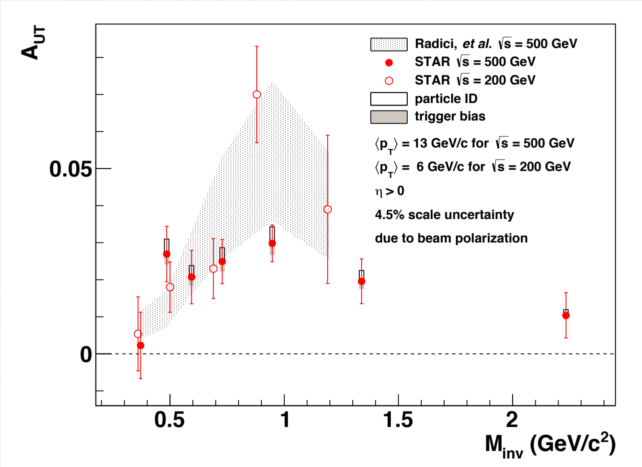
5) "TMD fit" *Kang et al., P.R. D****93*** *(16) 014009*

More data …

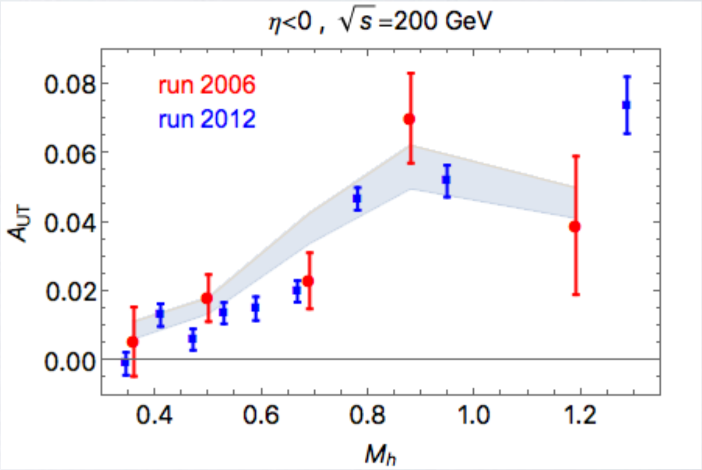
- refit di-hadron fragmentation functions using new data:
  $e^+e^- \to (\pi\pi)\,X$ constrains D_1^q
  (currently only by Montecarlo)

Seidl et al.,
*P.R. **D96** (17) 032005*

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



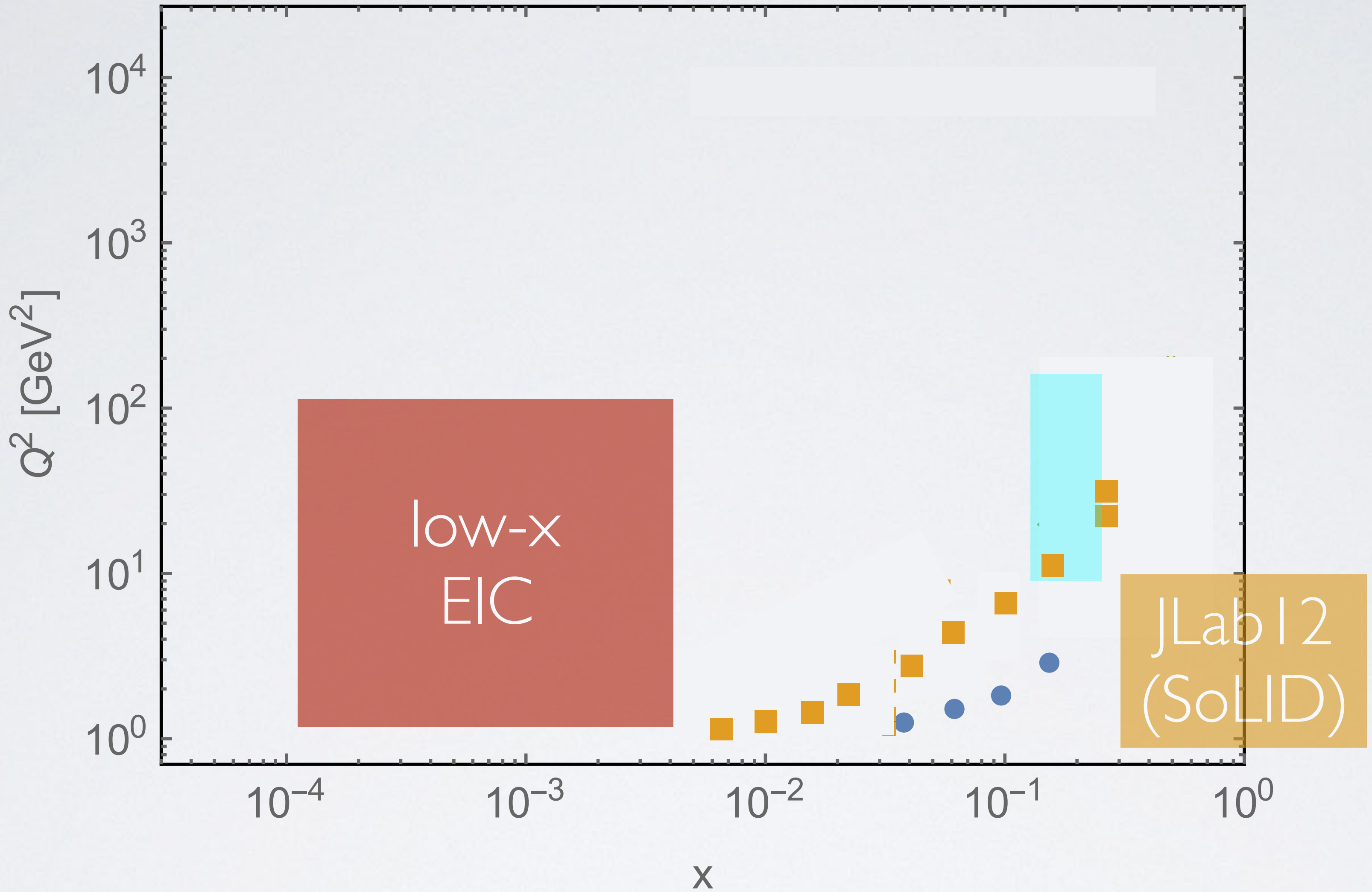
Adamczyk et al. (STAR),
*P.L. **B780** (18) 332*



Radici et al.,
*P.R. **D94** (16) 034012*

- use COMPASS data on πK and KK channels, and from $\Lambda^\uparrow$ fragmentation: constrain strange contribution ?

more constraints on extrapolation



- of course, data from STAR at s=500 and from Compass on deuterium will give more constraints, but x range is ~ the same
- need new data from at large x (JLab12) and at small x (EIC)

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 leaves this scenario unaltered
- 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 all lattice results but χ^2 worsens even more and situation is statistically very unlikely

THANK YOU

Back-up

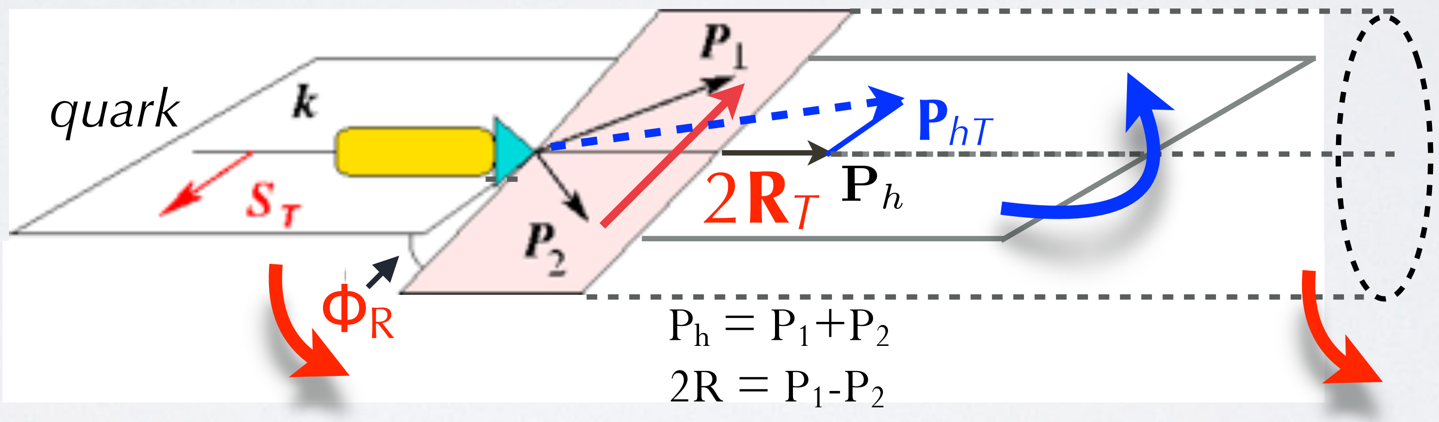
2-hadron-inclusive production

framework
collinear
factorization

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

$R_T \ll Q$ $\updownarrow$ M_h invariant mass

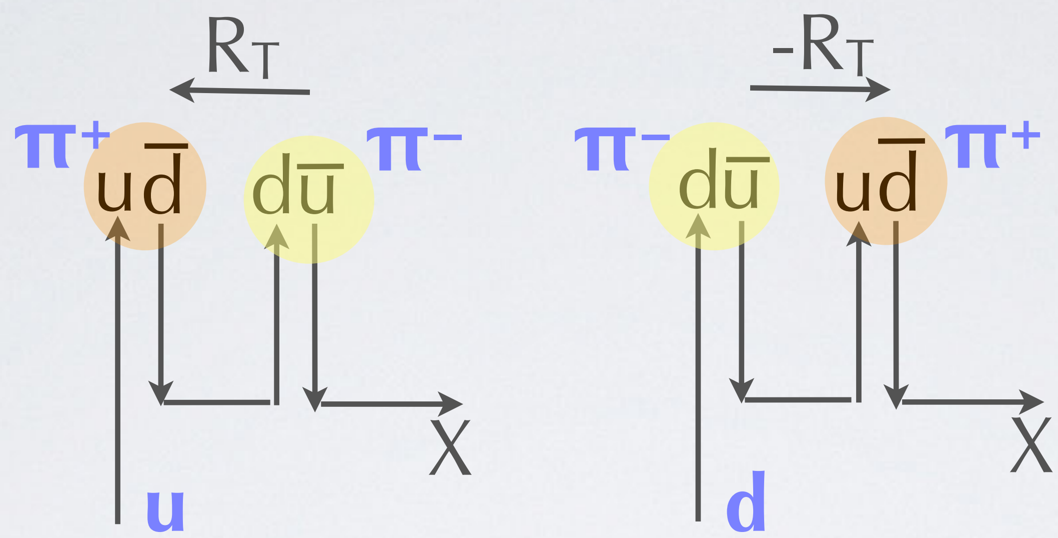
$H_1^{\sphericalangle}$



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

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

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