25th International Workshop on
Deep Inelastic Scattering
and Related Topics

April 3-7, 2017 at Birmingham (UK)

Update on extraction of transversity PDF from inclusive di-hadron production

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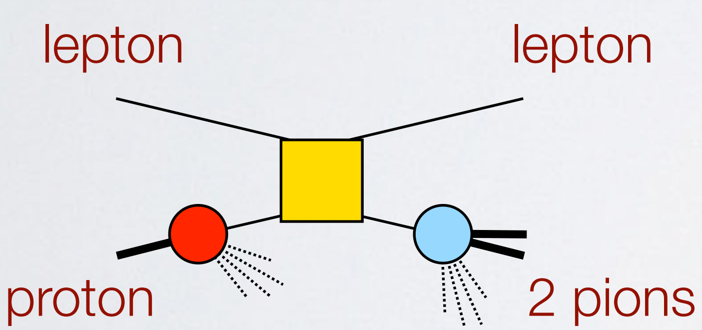
in collaboration with
A. Bacchetta (Univ. Pavia)

Outline (very simple..)

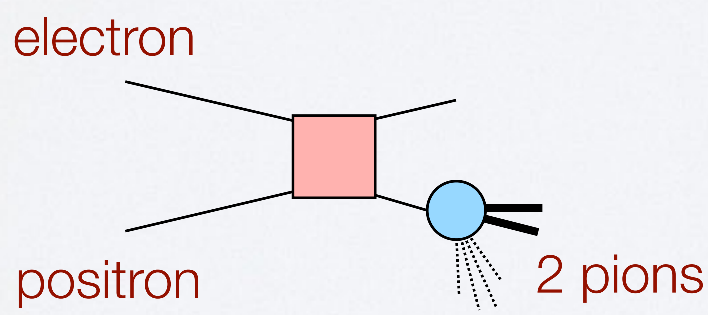
first extraction of transversity PDF from a global fit of semi-inclusive data

PRELIMINARY !

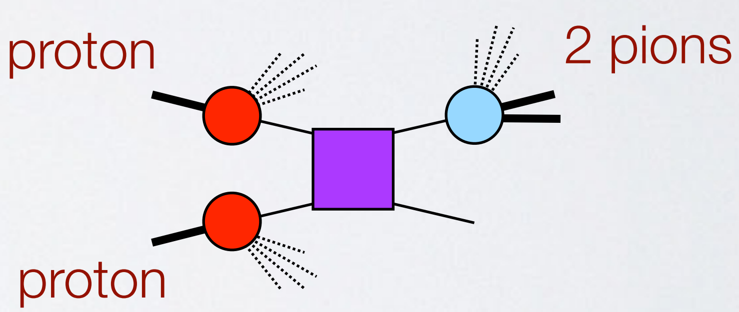
SIDIS



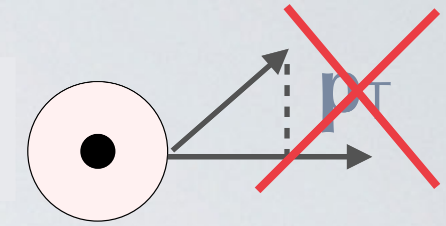
e+e−



p-p collisions

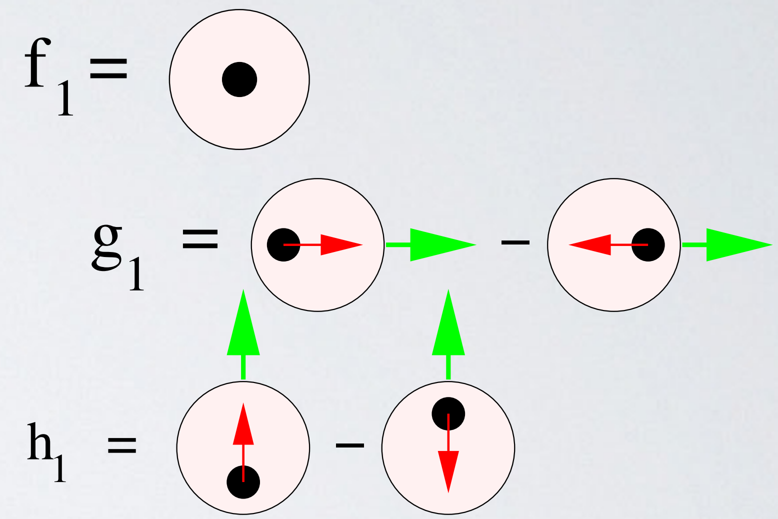


leading-twist PDF map



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 $h_{1T}^{\perp}$



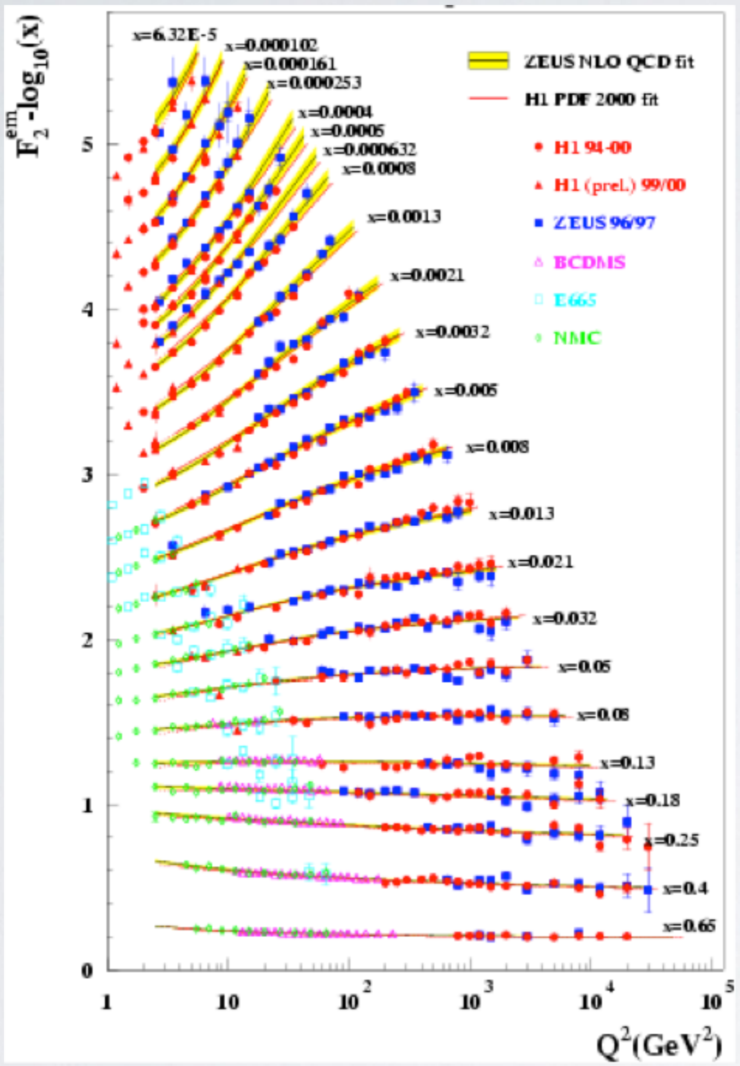
transversity distribution $h_1(x)$

flips helicity (chiral-odd)
→ suppressed in inclusive DIS

all three PDFs needed for a complete description of proton (spin) structure at leading order

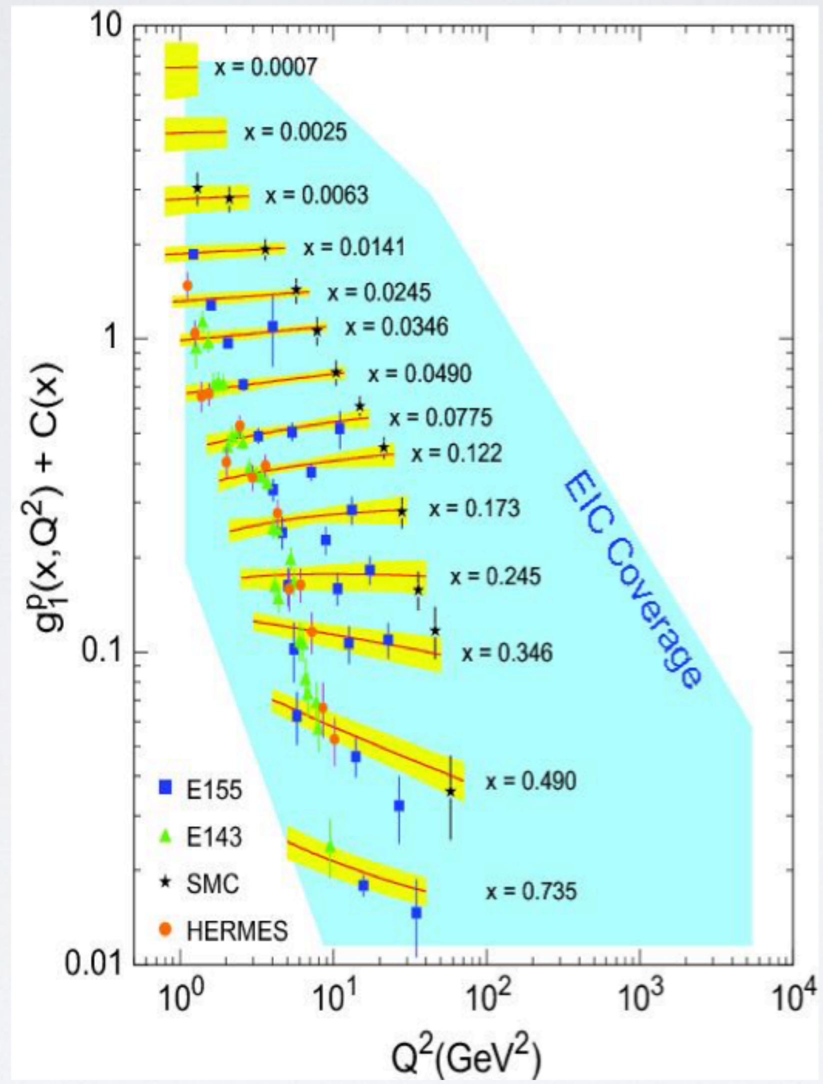
Transversity poorly known

World data for F_2^p



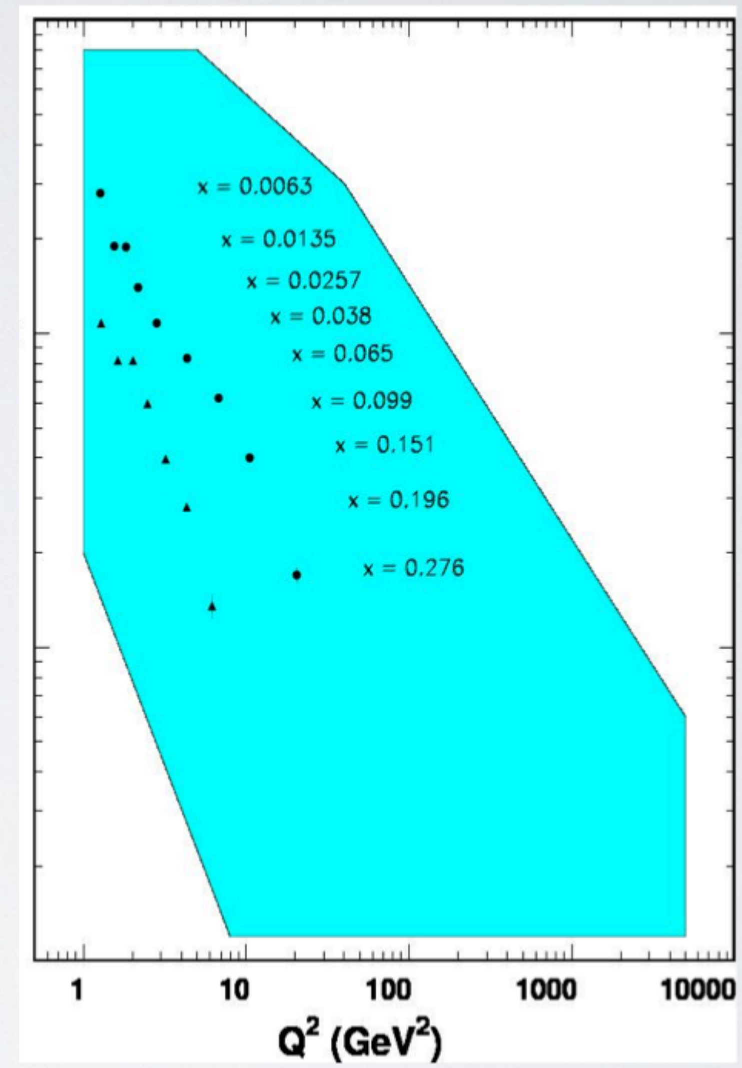
f_1 from fits of **thousands** data

World data for g_1^p



g_1 from fits of **hundreds** data

World data for **h_1**



h_1 from fits of **tens** data

slide from H.Montgomery, QCD Evolution 2016

But transversity is interesting !

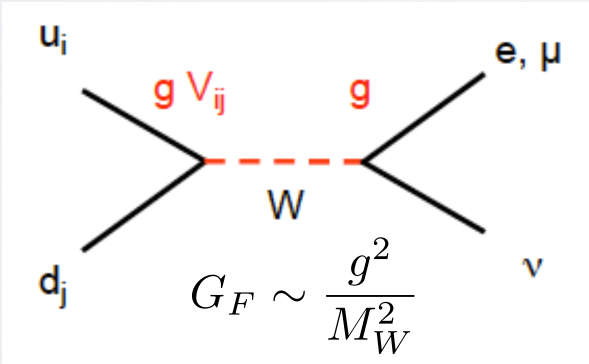
1st Mellin moment of transversity $\Rightarrow$ tensor "charge"

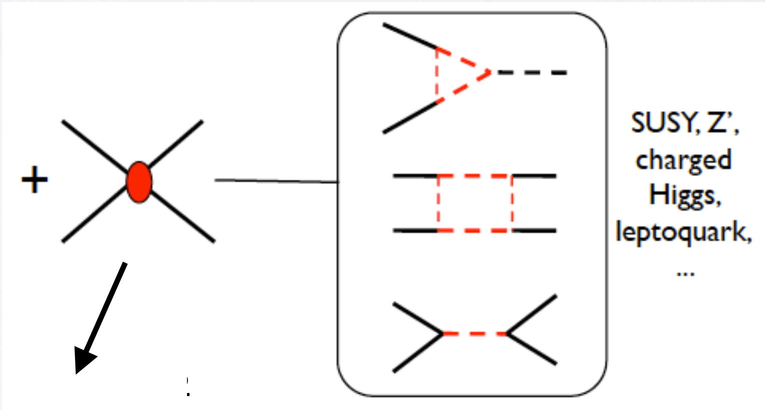
$$P^{[\mu}S^{\nu]}\, g_T^q(Q^2) = P^{[\mu}S^{\nu]} \int_0^1 dx\ \left[h_1^q(x,Q^2) - h_1^{\bar{q}}(x,Q^2)\right]$$
$$= \langle P,S|\, \bar{q}\, \sigma^{\mu\nu}\, q\, |P,S\rangle$$

tensor charge not directly accessible in $\mathcal{L}_{SM}$
low-energy footprint of new physics at higher scales ?

Example: neutron β–decay $n \to p\, e^- \bar{\nu}_e$

SM





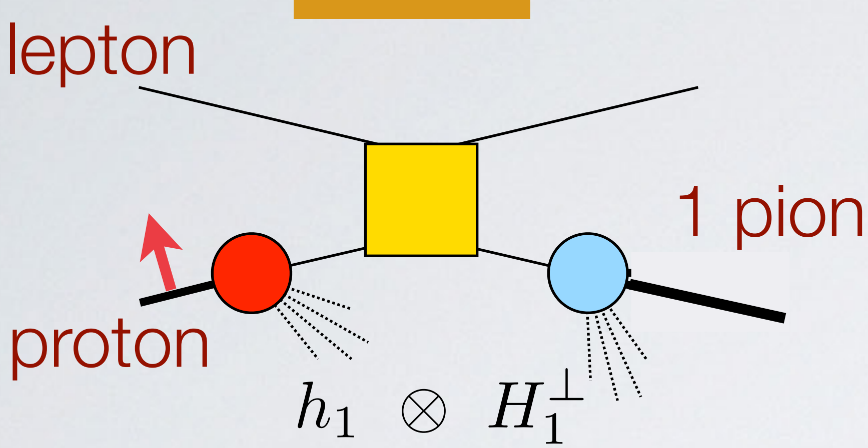
BSM

$$\varepsilon_T\, g_T \approx M_W^2 / M_{BSM}^2$$

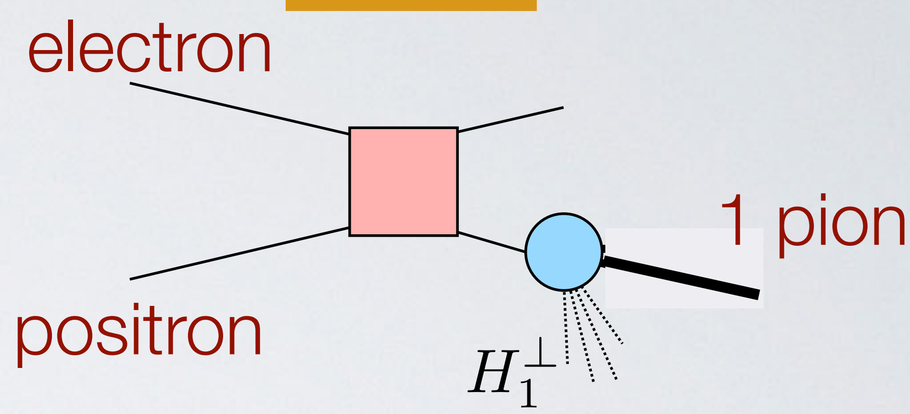
precision of 0.1% $\Rightarrow$ [3-5] TeV bound for BSM scale

extraction from 1-hadron-inclusive data

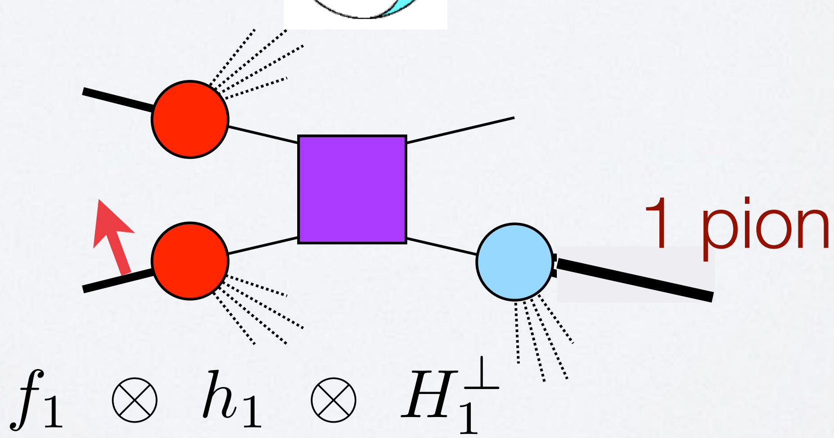
SIDIS



e+e−

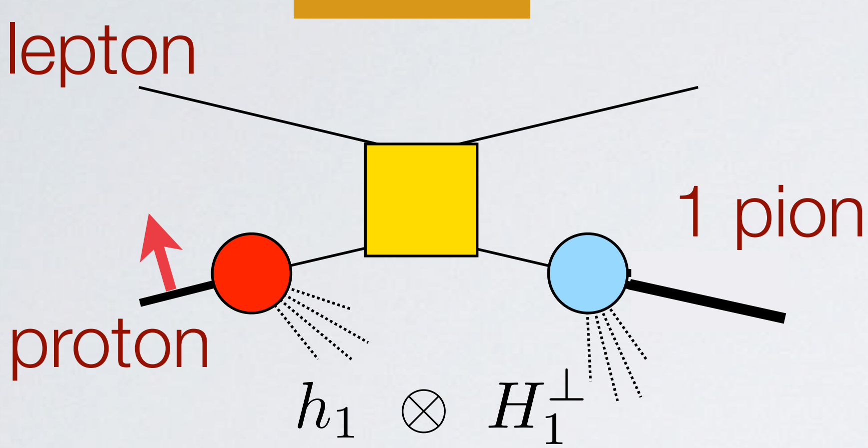


p-p↑

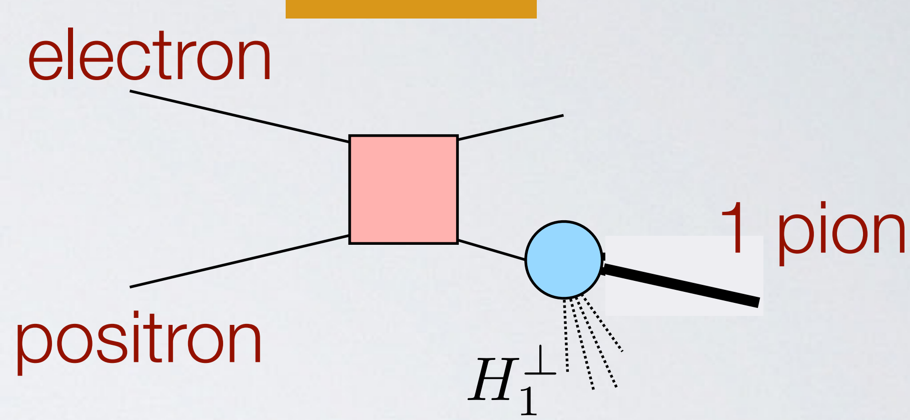


extraction from 1-hadron-inclusive data

SIDIS

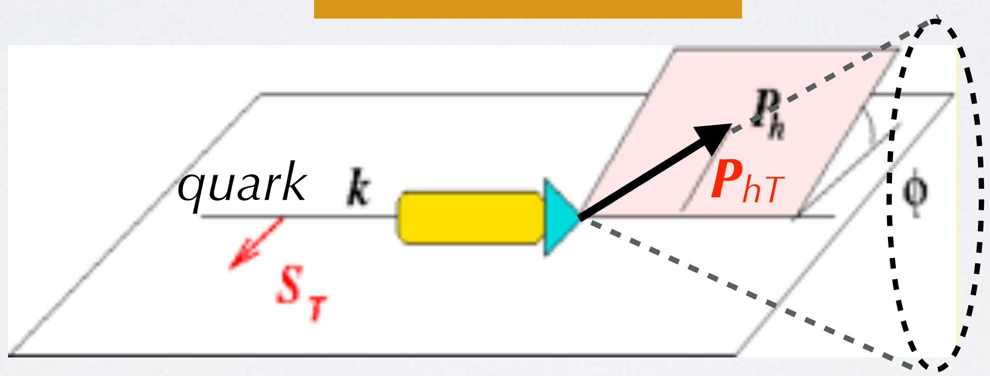


e+e−



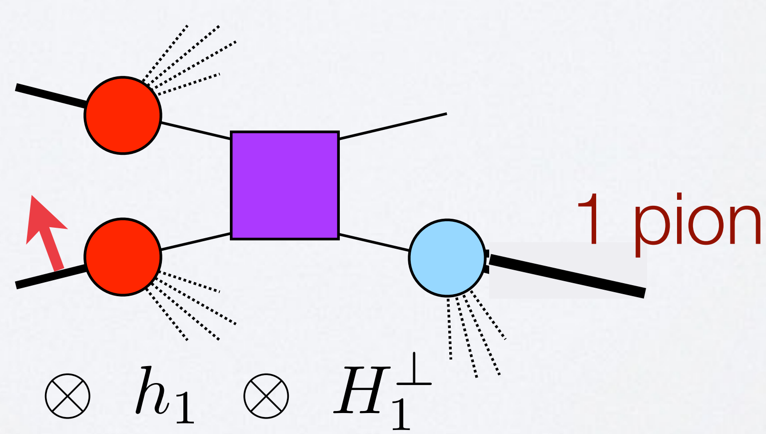
Collins effect

Collins,
N.P. ***B396*** *(93) 161*



correlation $\boldsymbol{S}_T$ and $\boldsymbol{P}_{hT}$ → azimuthal asymmetry

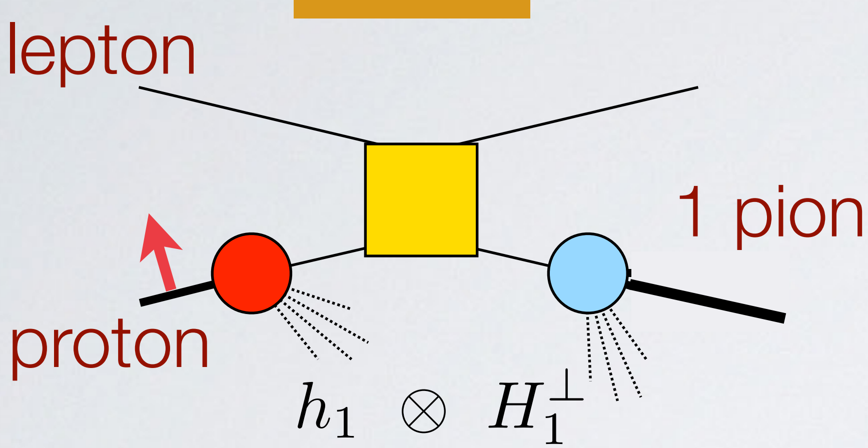
p-p↑



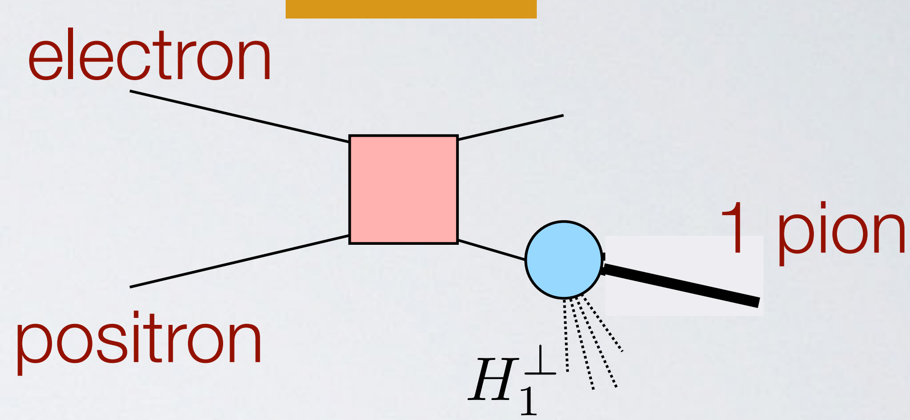
framework
TMD
factorization
$P_{hT} \ll Q$

extraction from 1-hadron-inclusive data

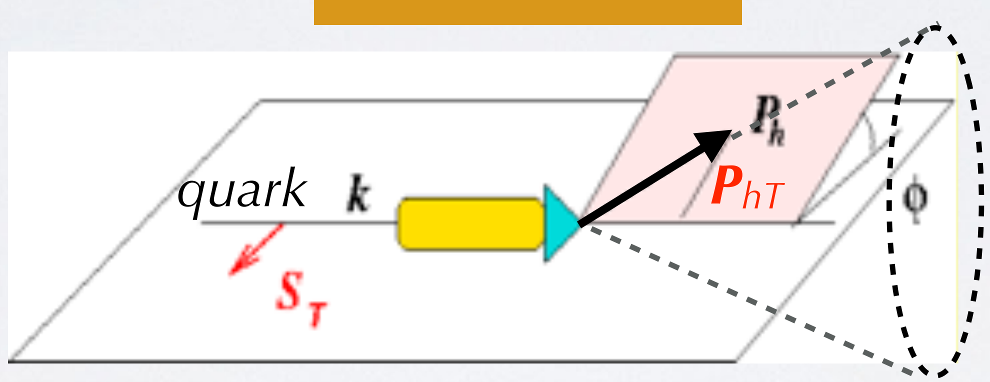
SIDIS



e+e−



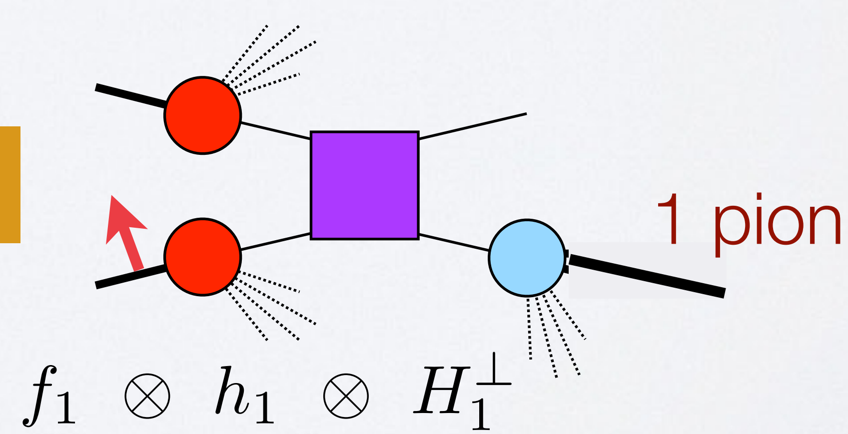
Collins effect



correlation S_T and P_{hT} → azimuthal asymmetry

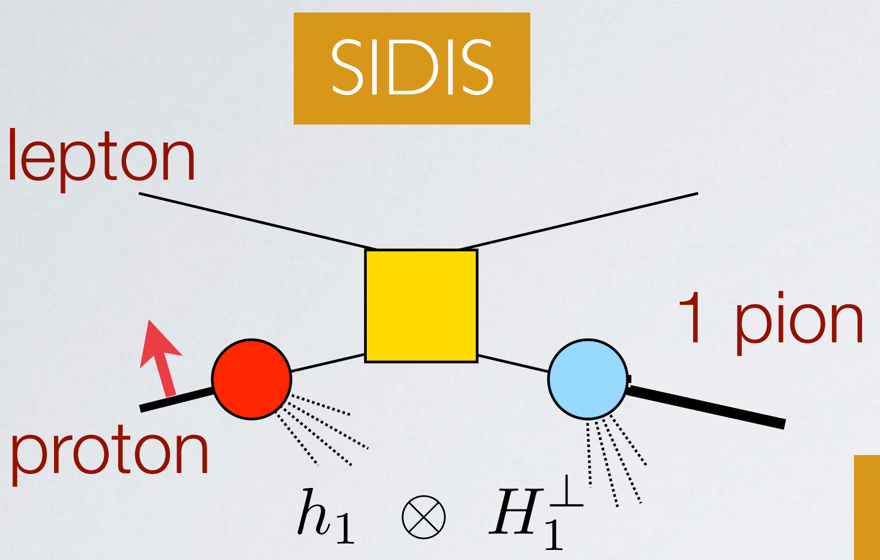
only one hard scale P_{hT} factorization not yet proved

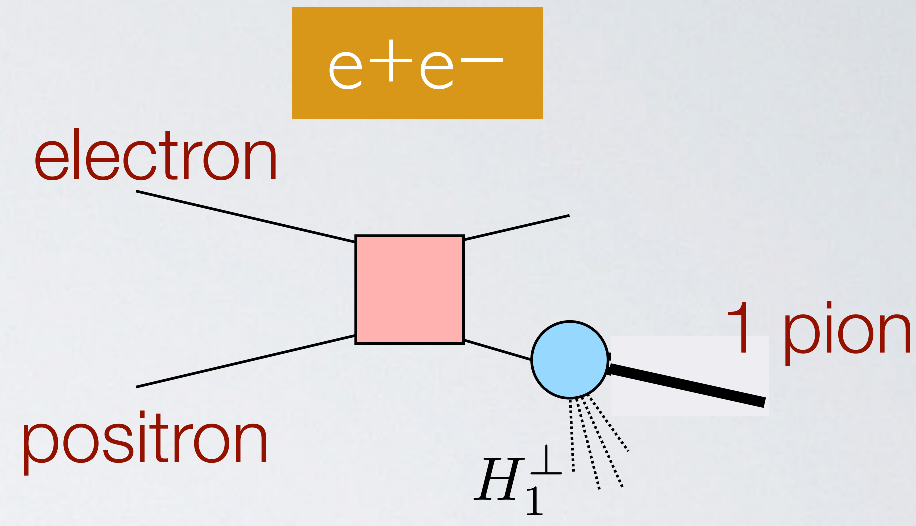
p-p↑



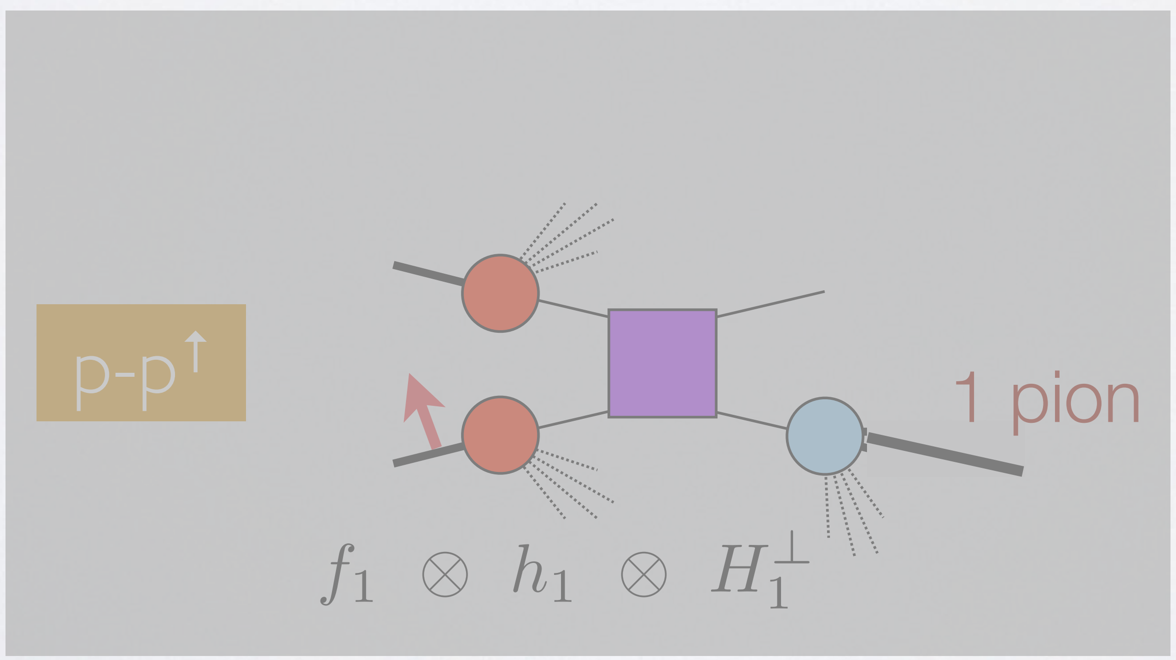
framework TMD factorization $P_{hT} \ll Q$

extraction from 1-hadron-inclusive data

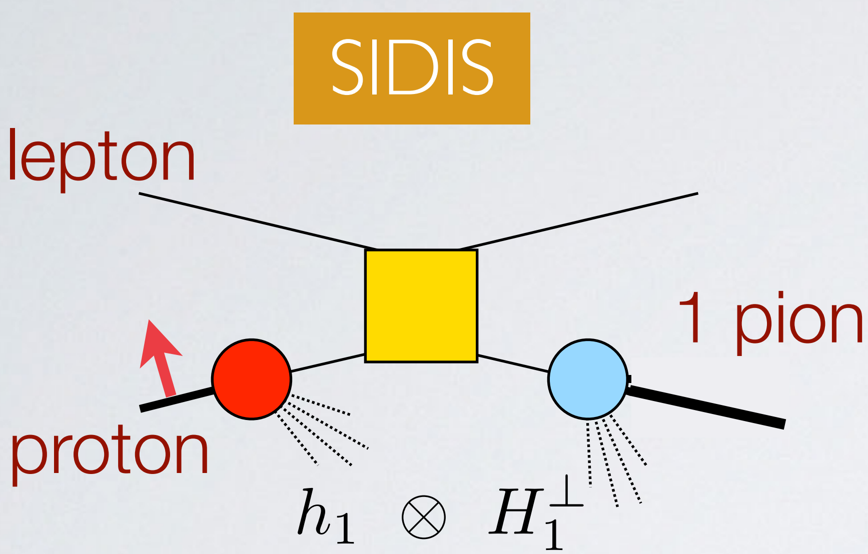


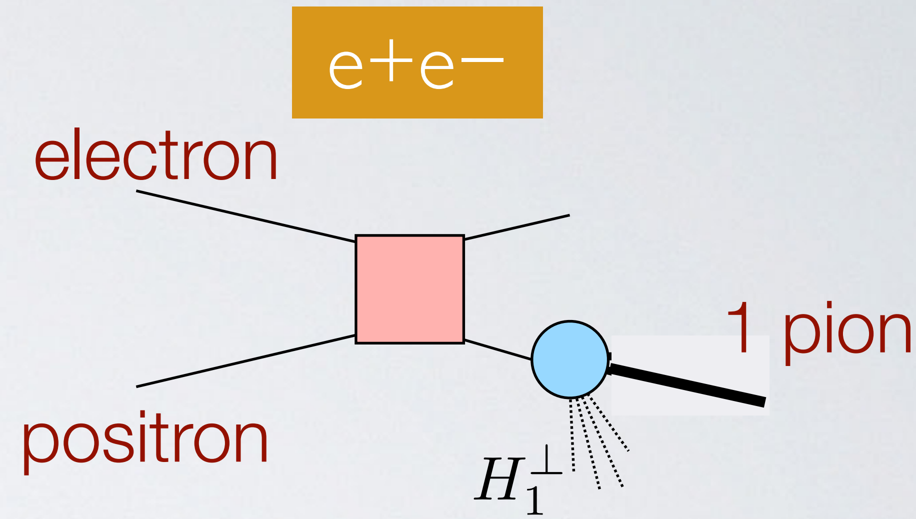


TMD evolution
connects h_1 & $H_1^\perp$
at different scales



extraction from 1-hadron-inclusive data





$$h_1(x, p_T) = h_1(x)\, \frac{1}{\pi \langle p_T^2 \rangle}\, e^{-p_T^2/\langle p_T^2 \rangle}$$

DGLAP

no evolution

Torino group

Kang, Prokudin, Sun, Yuan

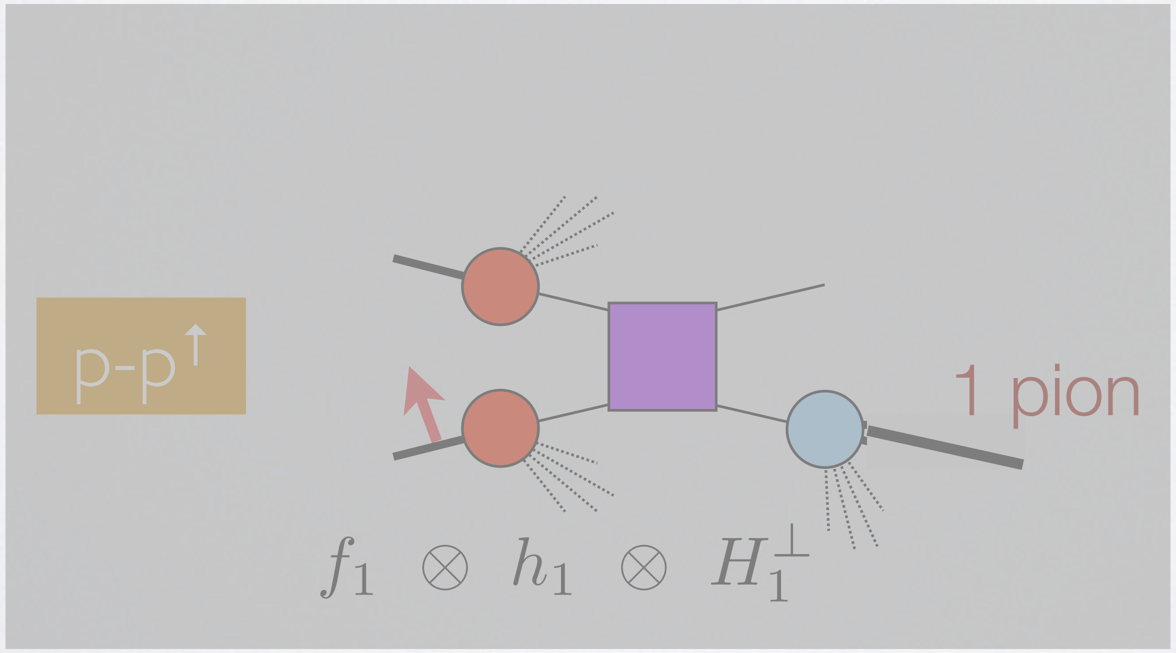
includes effects from TMD evolution

....

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

Anselmino et al.,
*P.R. D**92** (15) 114023*

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



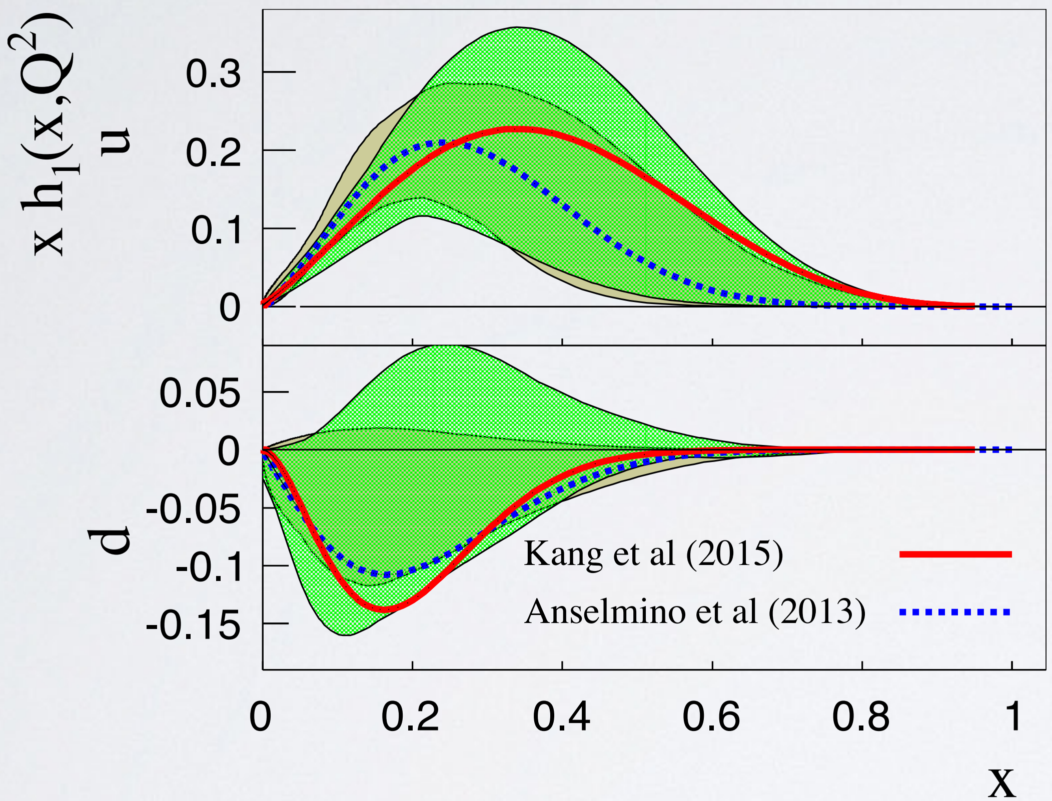
Transversity from Collins effect

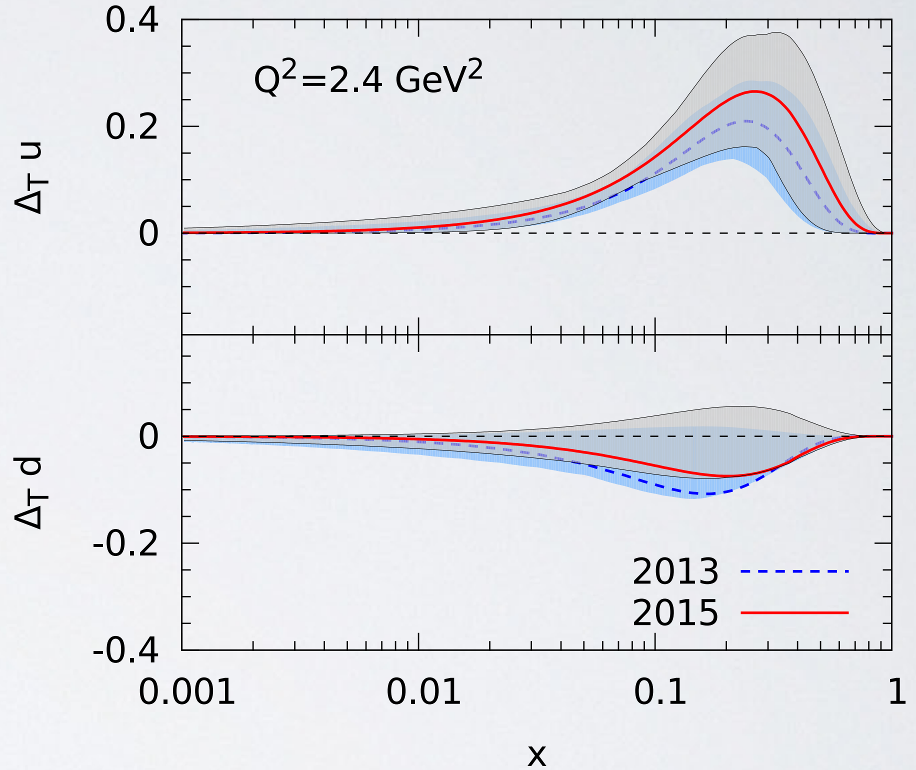
*Kang et al., P.R. D**93** (16) 014009*

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

recent TO update

*Anselmino et al., P.R. D**92** (15) 114023*

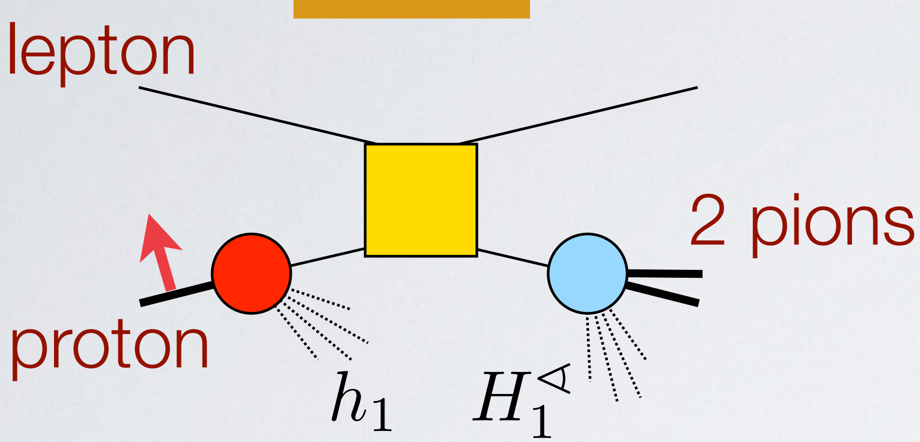




very compatible
no sensitivity to evolution

extraction from 2-hadron-inclusive data

SIDIS

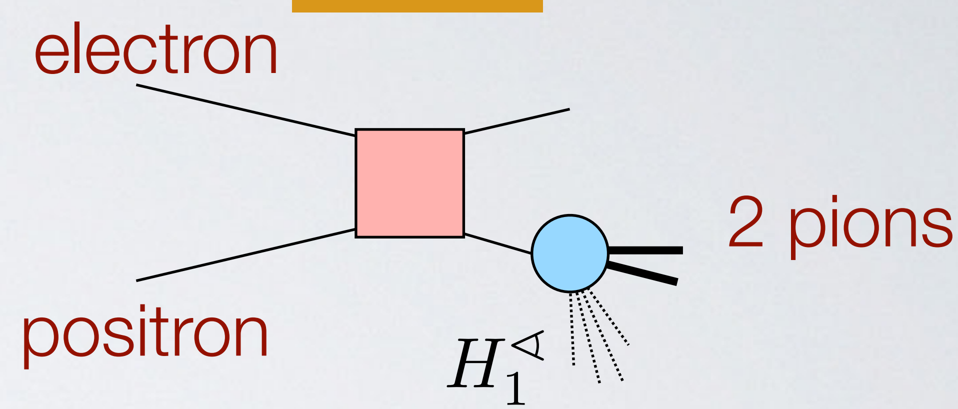


*Airapetian et al., JHEP **0806** (08) 017*

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

*Braun et al., E.P.J. Web Conf. **85** (15) 02018*

e+e−

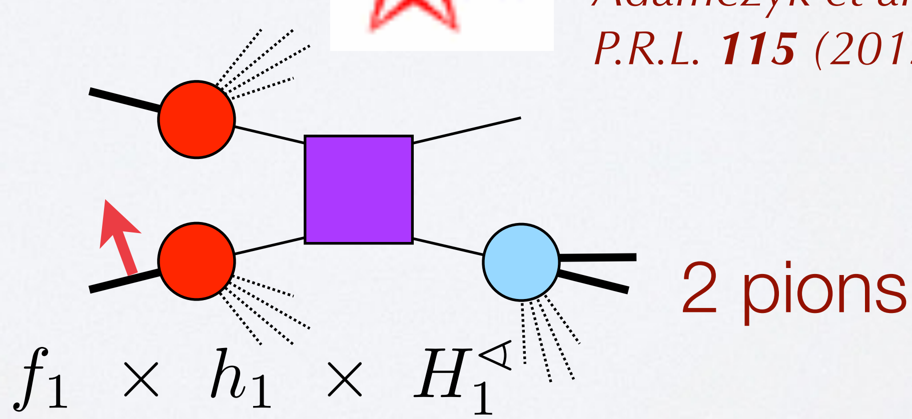


*Vossen et al., P.R.L. **107** (11) 072004*

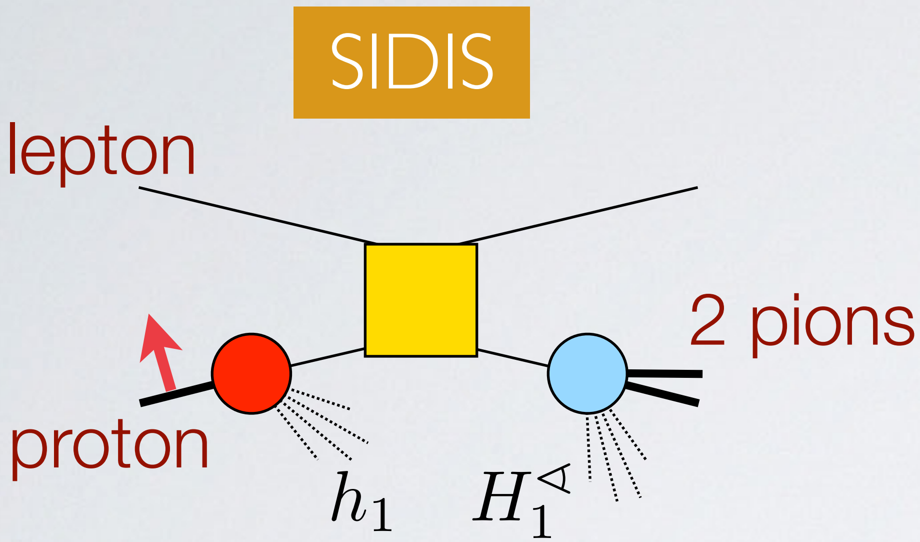
run 2006

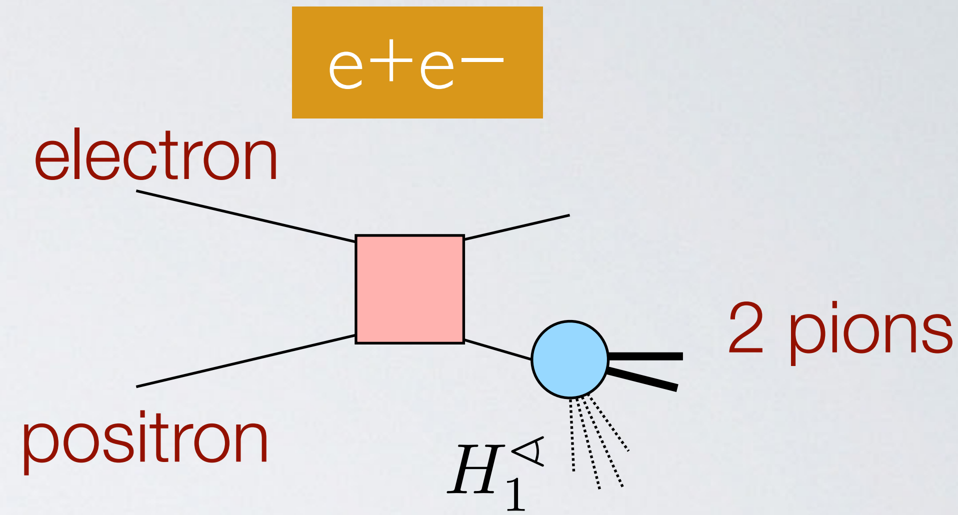
*Adamczyk et al. (STAR), P.R.L. **115** (2015) 242501*

p-p↑

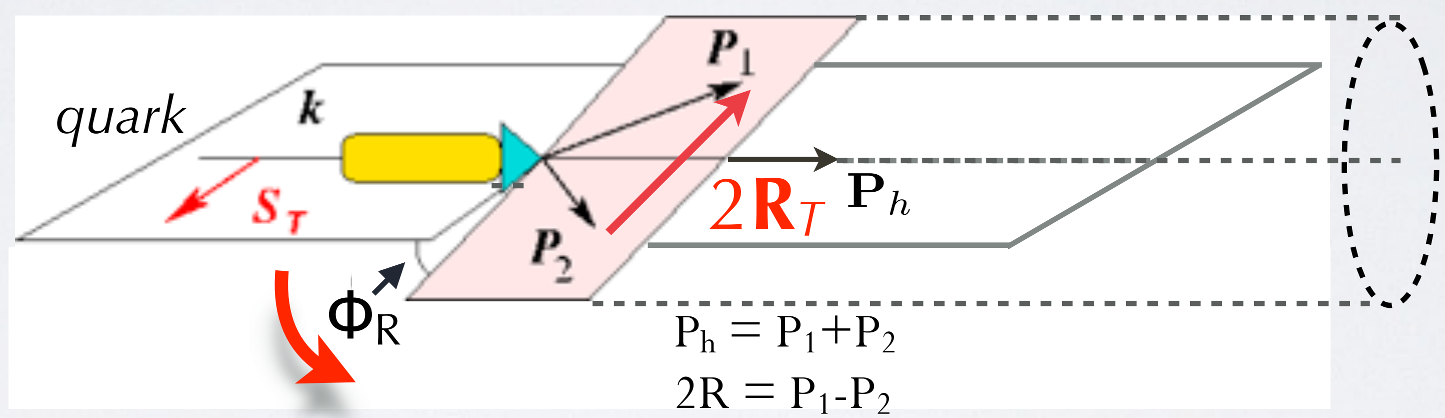


extraction from 2-hadron-inclusive data

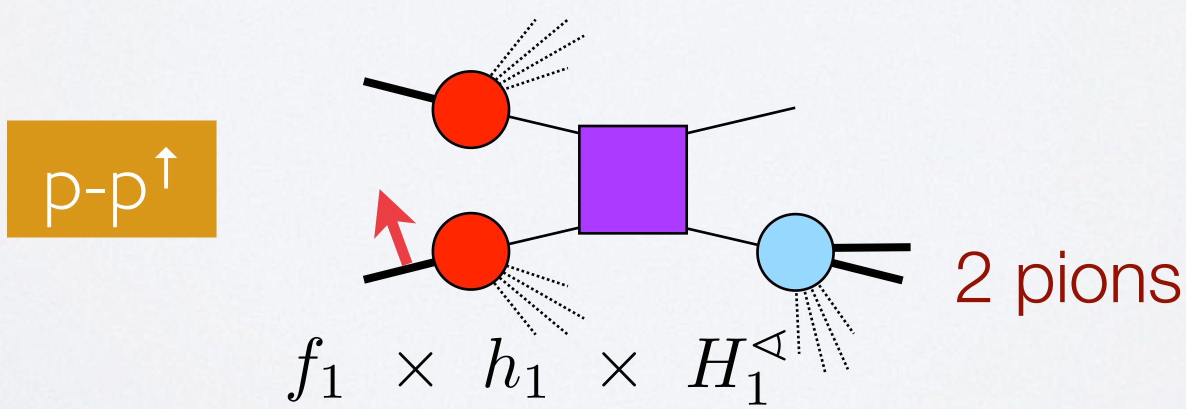




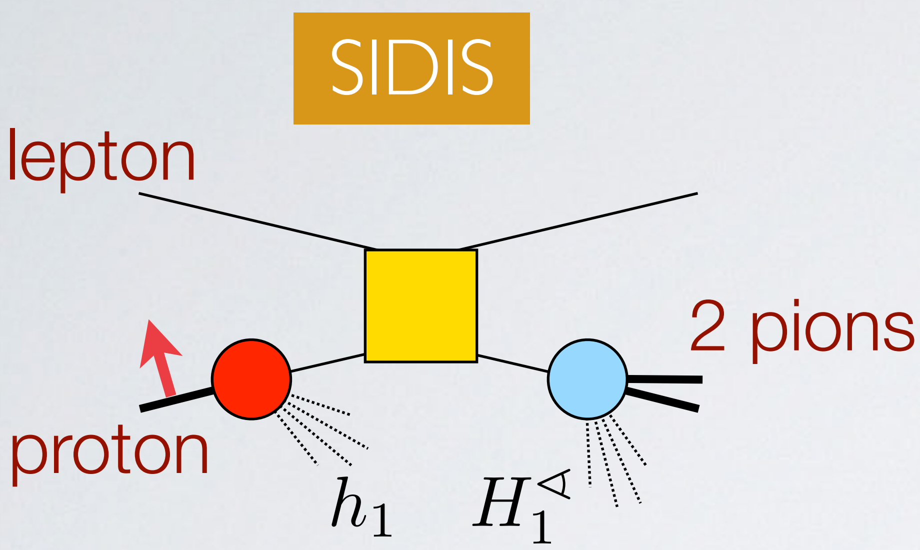
Collins, Heppelman, Ladinsky,
N.P. ***B420*** *(94)*

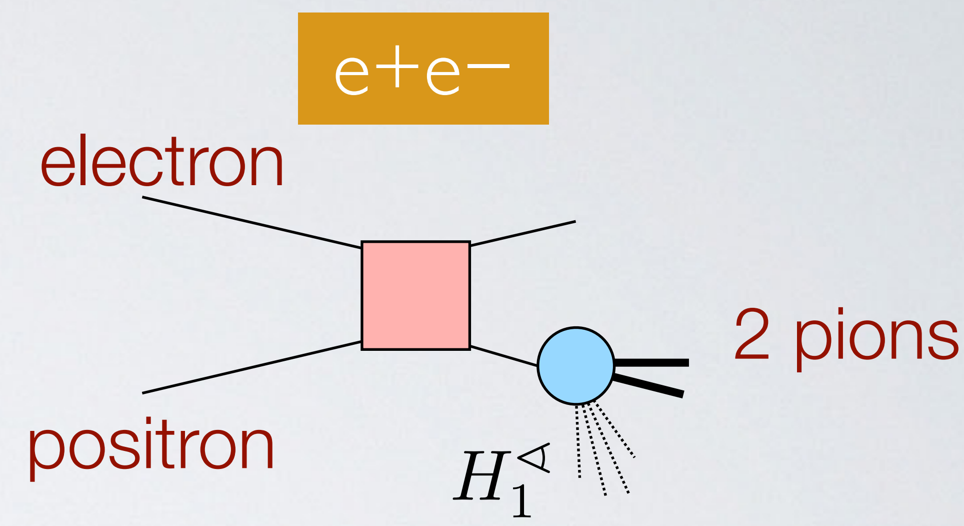


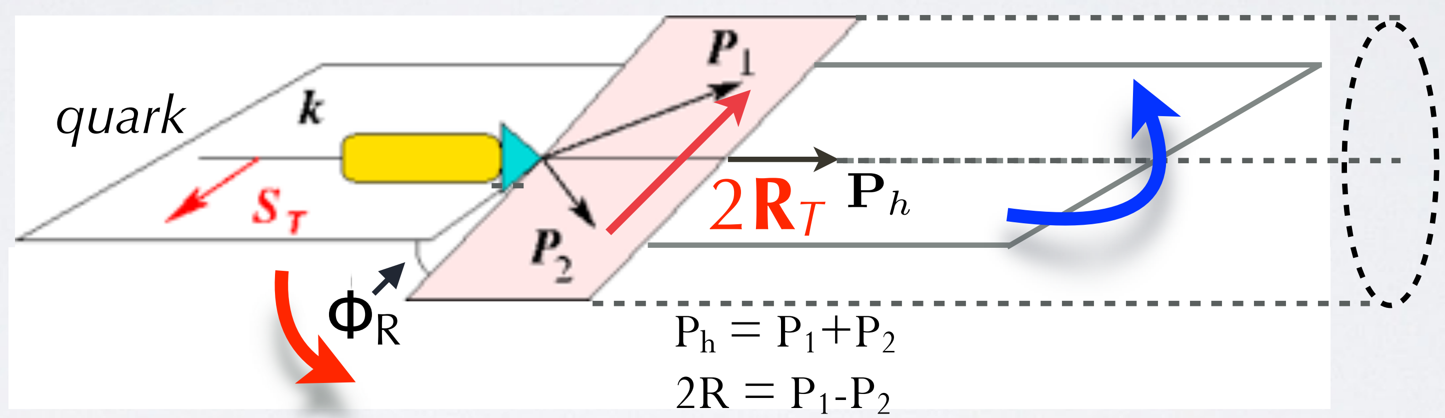
correlation $\boldsymbol{S}_T$ and $\boldsymbol{R}_T$ → azimuthal asymmetry



extraction from 2-hadron-inclusive data

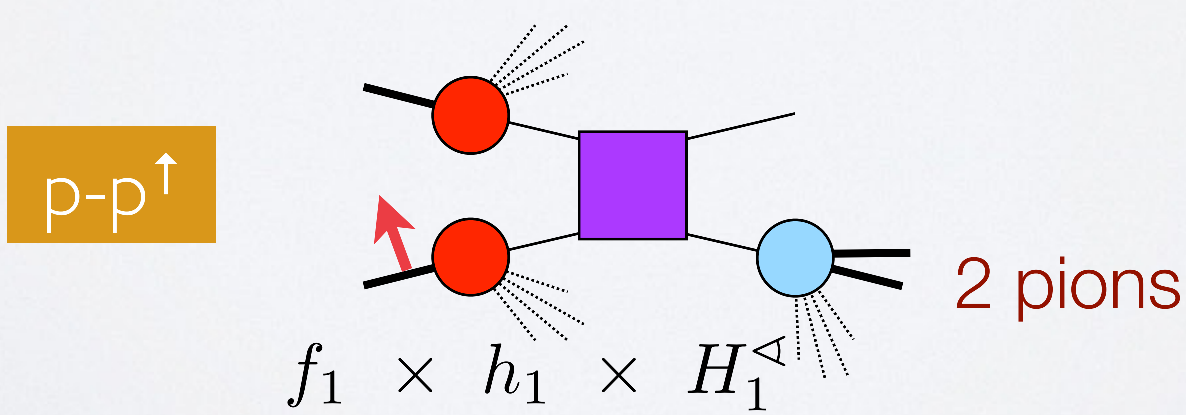






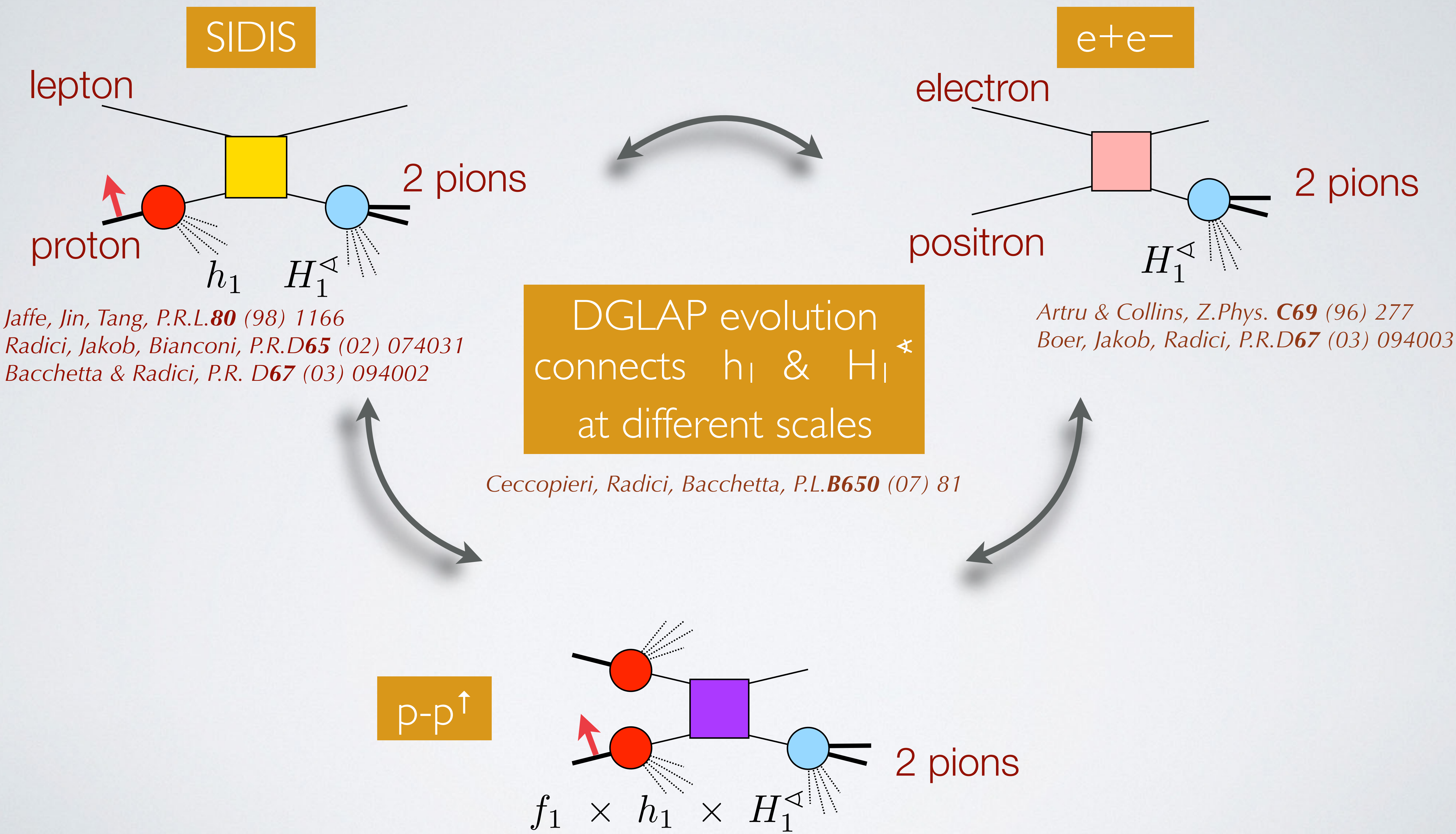
survives to polar symmetry ($\int d\boldsymbol{P}_{hT}$)

correlation $\boldsymbol{S}_T$ and $\boldsymbol{R}_T$ → azimuthal asymmetry



framework
collinear
factorization
$R_T \ll Q$

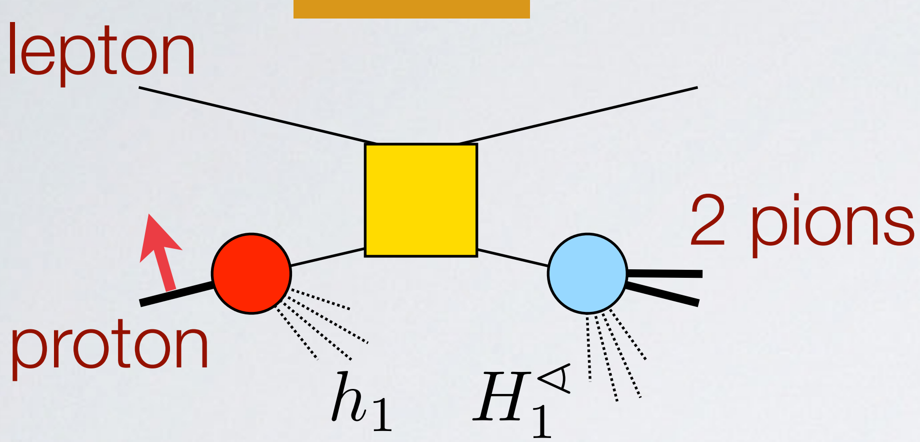
extraction from 2-hadron-inclusive data



Bacchetta & Radici, P.R. D**70** (04) 094032

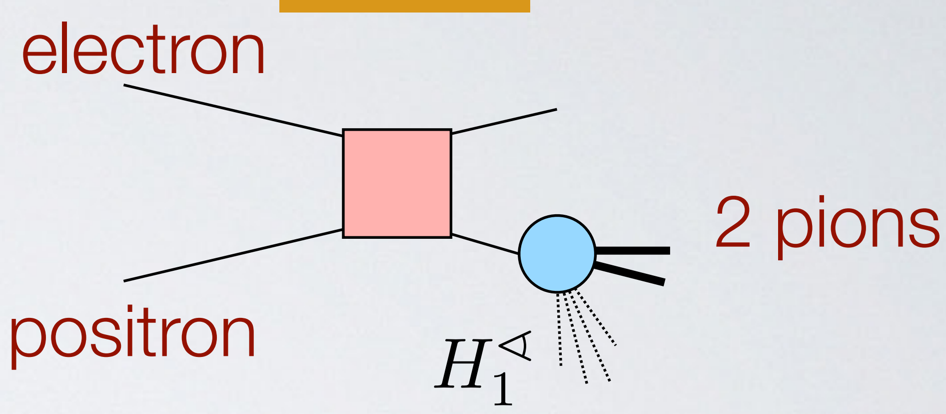
extraction from 2-hadron-inclusive data

SIDIS



fit with
SIDIS + e^+e^-

e+e−



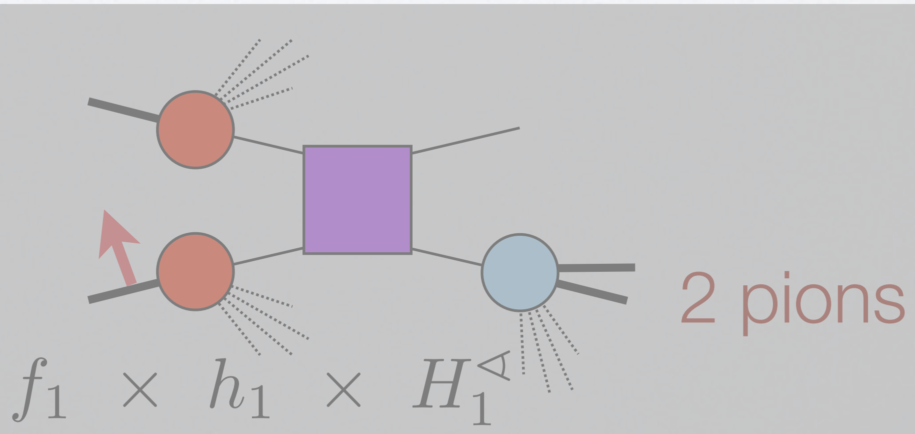
Pavia
group

Bacchetta, Courtoy, Radici,
P.R.L. ***107*** *(11) 012001*

Bacchetta, Courtoy, Radici,
JHEP ***1303*** *(13) 119*

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

p-p$^{\uparrow}$

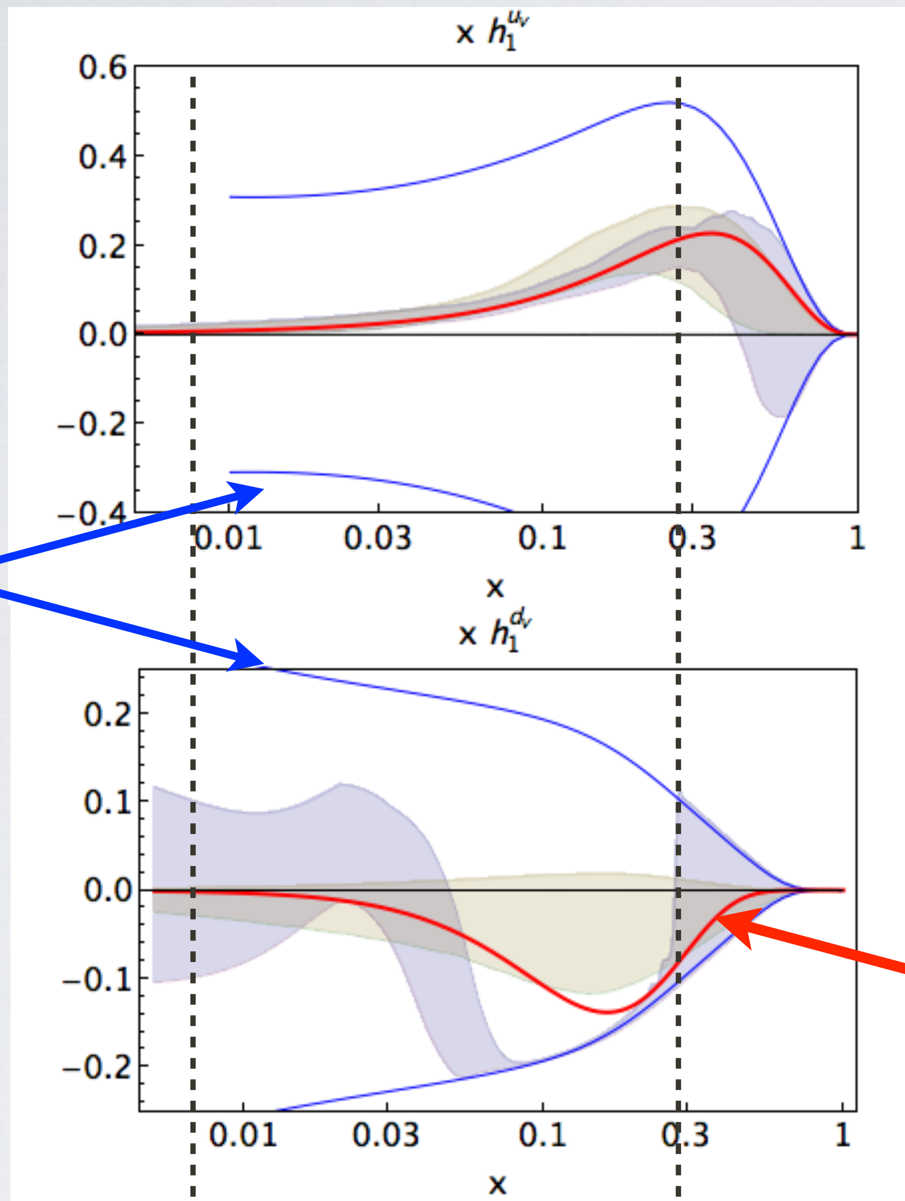


comparison with Collins effect

up

down

Soffer bound

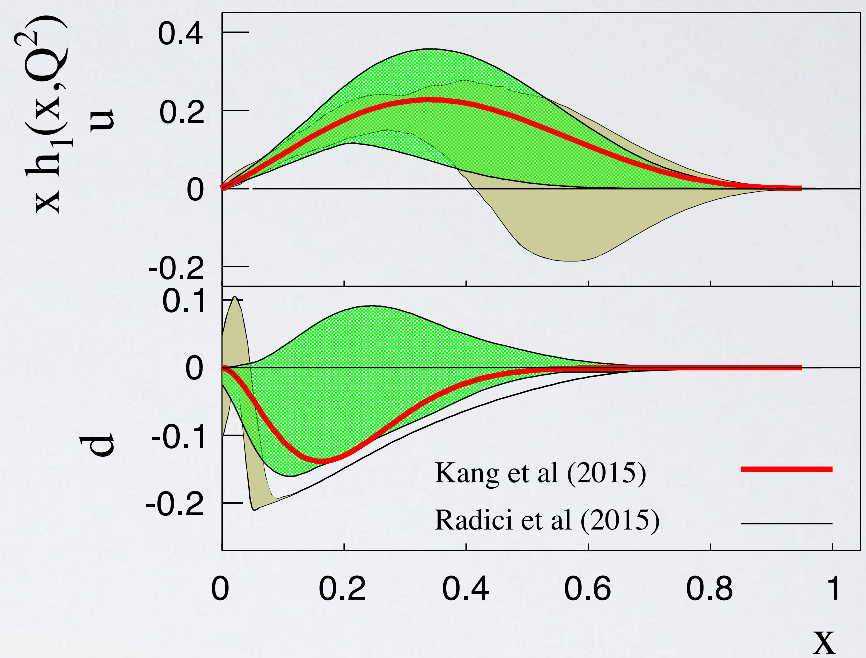


data

68% uncertainty bands

Kang et al. 2016 <-> Pavia 2015

Q^2=2.4 GeV^2



linear scale

Anselmino et al., ***2013***

Kang et al., ***2016***

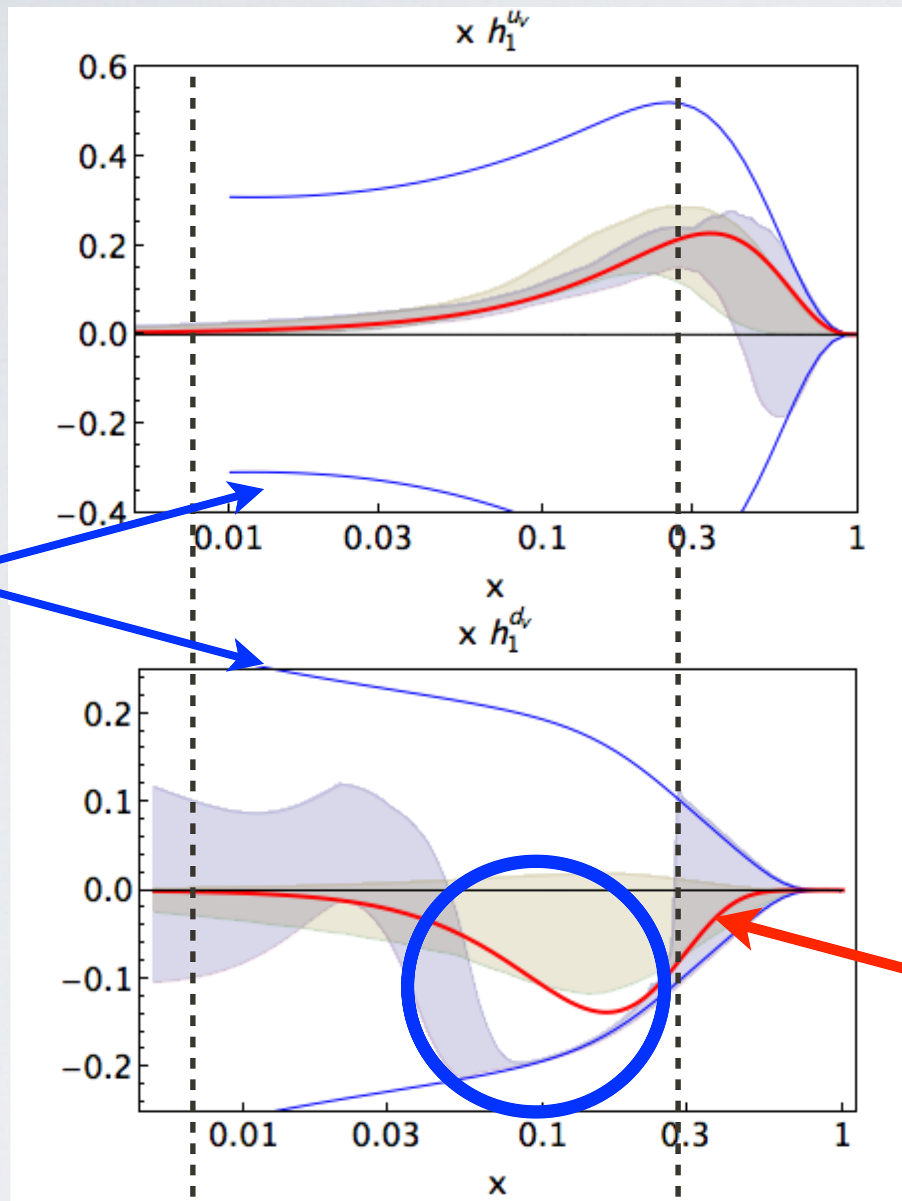
Radici et al.,
JHEP ***1505*** *(15) 123*

comparison with Collins effect

up

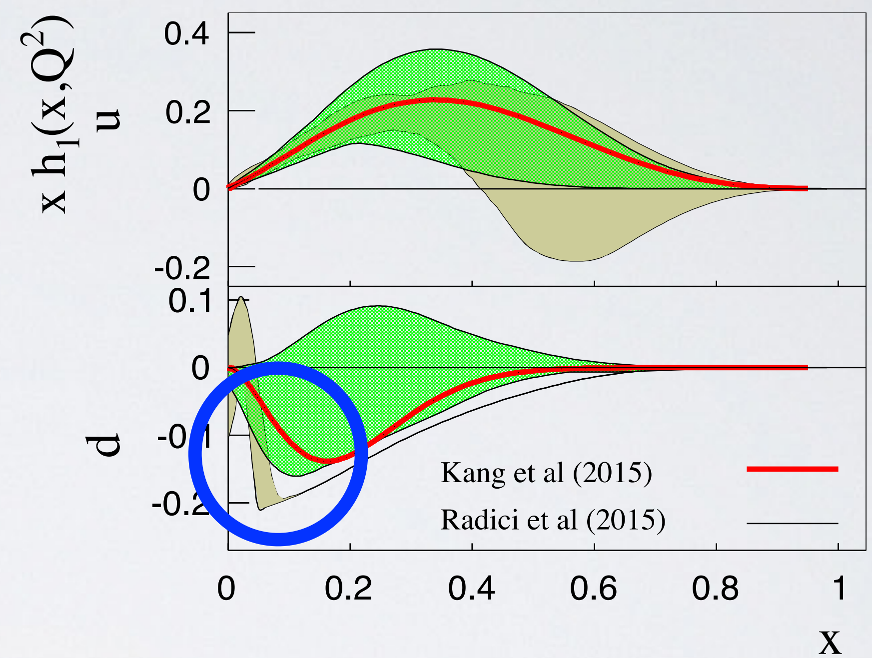
down

Soffer bound



data

Kang et al. 2016 <-> Pavia 2015



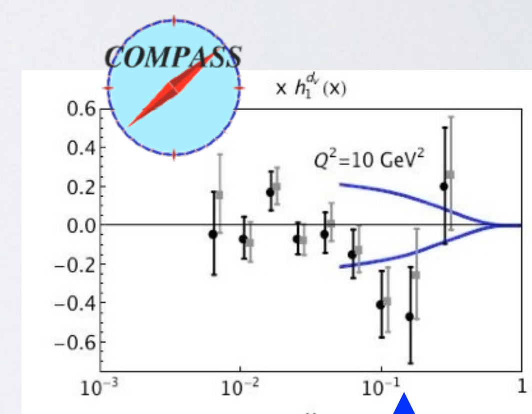
Q^2=2.4 GeV^2

linear scale

Anselmino et al., ***2013***

Kang et al., ***2016***

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



unusual saturation of Soffer bound for down

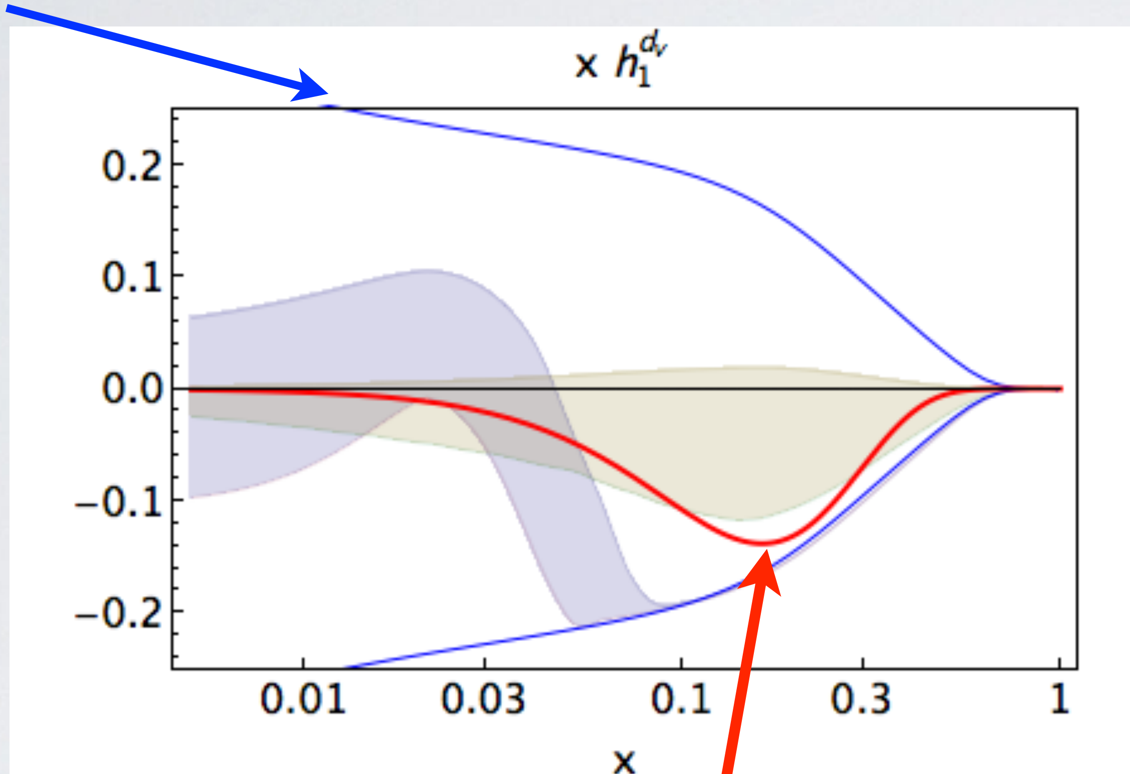
driven by two specific bins of Compass data for deuteron

origin of saturation of Soffer bound

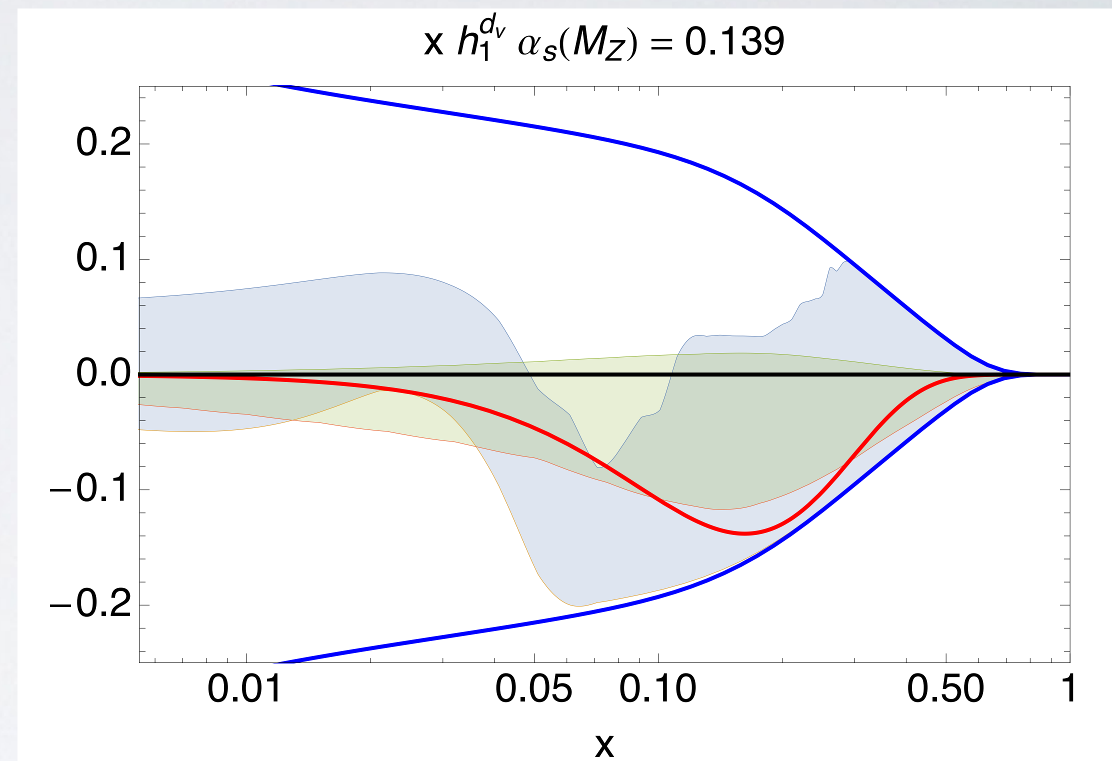
full SIDIS fit

Soffer bound

down



"reduced" SIDIS fit :
no bins #7,8 with deuteron



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

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

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

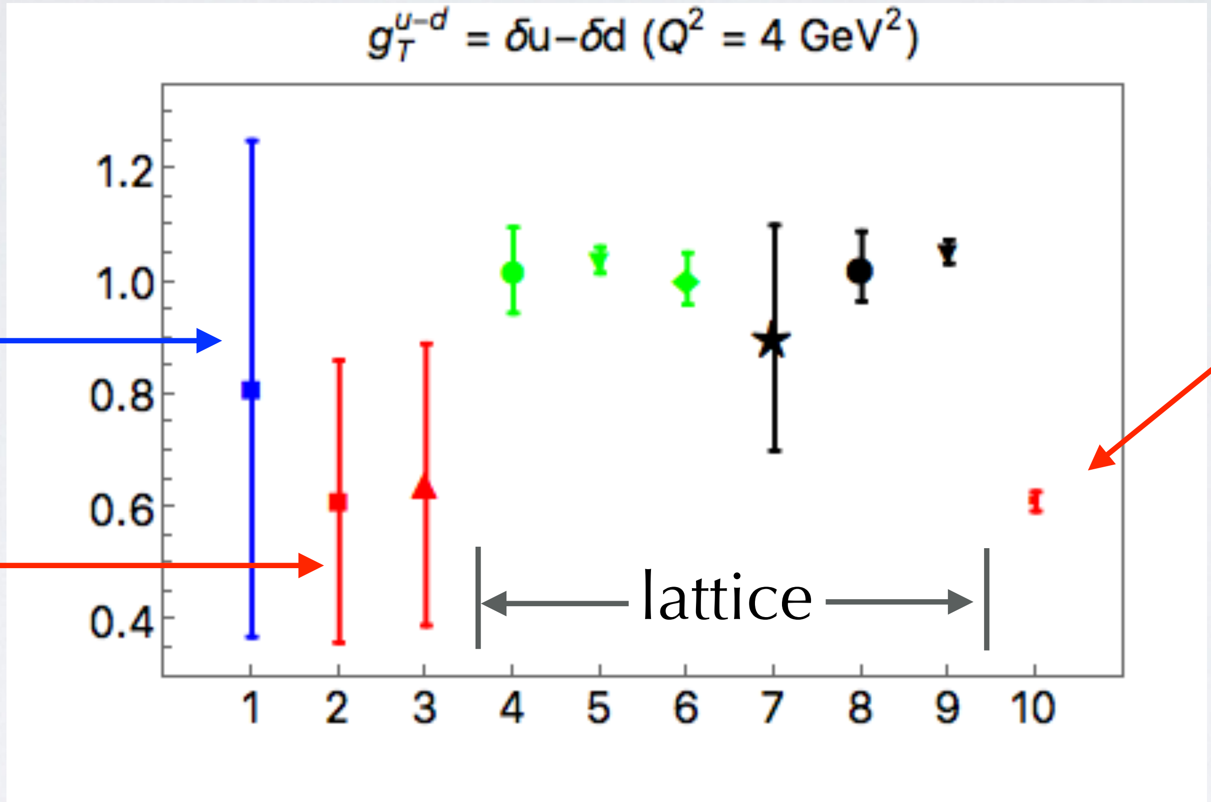
more flexibility
for down

no appreciable difference
for up

neutron β-decay <—> isovector tensor charge

status of g_T^{u-d}

$Q^2 = 4$ GeV^2



1) Radici et al. 2015

2) Kang et al. 2016
$Q^2 = 10$

3) Anselmino et al. 2013
$Q^2 = 0.8$

10) SoLID 2016
pseudo-data based on 2) Kang et al. 2016
$Q^2 = 10$

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

current most stringent constraints on BSM tensor coupling from $\pi^+ \to e^+ \nu_e \gamma$ and neutron β-decay is

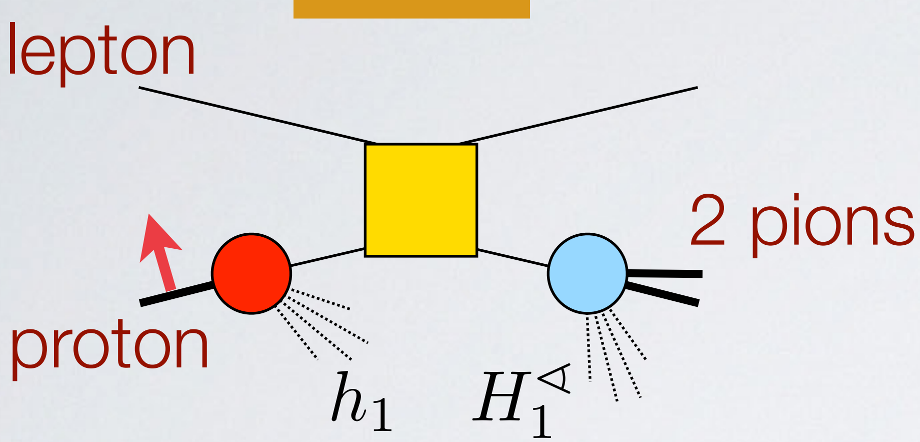
$$|\varepsilon_T \, g_T| \lesssim 5 \times 10^{-4}$$

Bychkov et al. (PIBETA), P.R.L. ***103*** *(09) 051802*
Pattie et al., P.R. ***C88*** *(13) 048501*

4) PNDME '15 — *Bhattacharya et al., P.R. D**92** (15)*
5) LHPC '12 — *Green et al., P.R. D**86** (12)*
6) RQCD '14 — *Bali et al., P.R. D**91** (15)*
7) RBC-UKQCD — *Aoki et al., P.R. D**82** (10)*
8) ETMC '15 — *Abdel-Rehim et al., P.R.D**92** (15);*
9) " " — *E P.R.D**93** (16)*

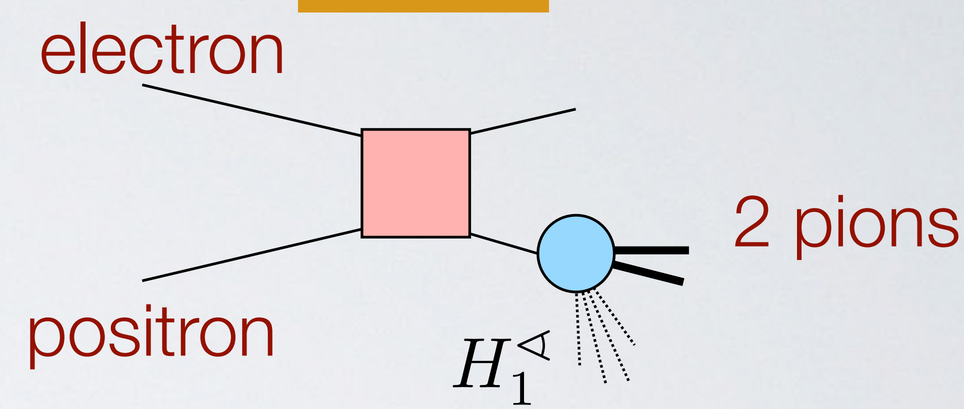
extraction from 2-hadron-inclusive data

SIDIS



fit with
SIDIS + e^+e^-

e+e−



Bacchetta, Courtoy, Radici,
P.R.L. ***107*** *(11) 012001*

Bacchetta, Courtoy, Radici,
JHEP ***1303*** *(13) 119*

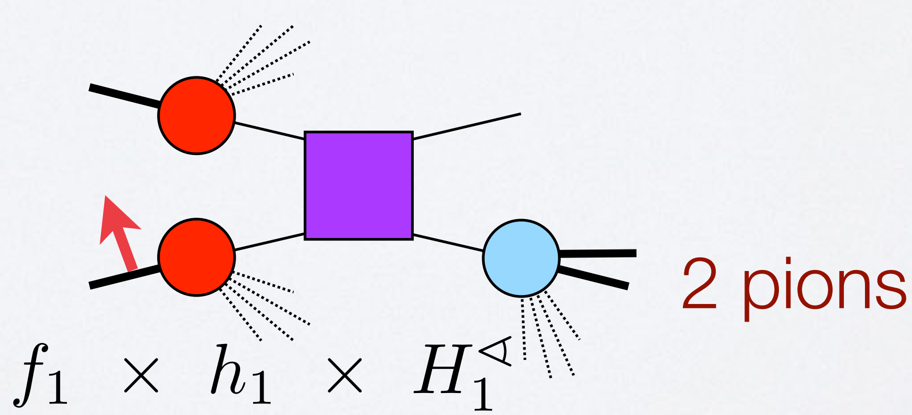
Radici et al.,
JHEP ***1505*** *(15) 123*

Pavia
group

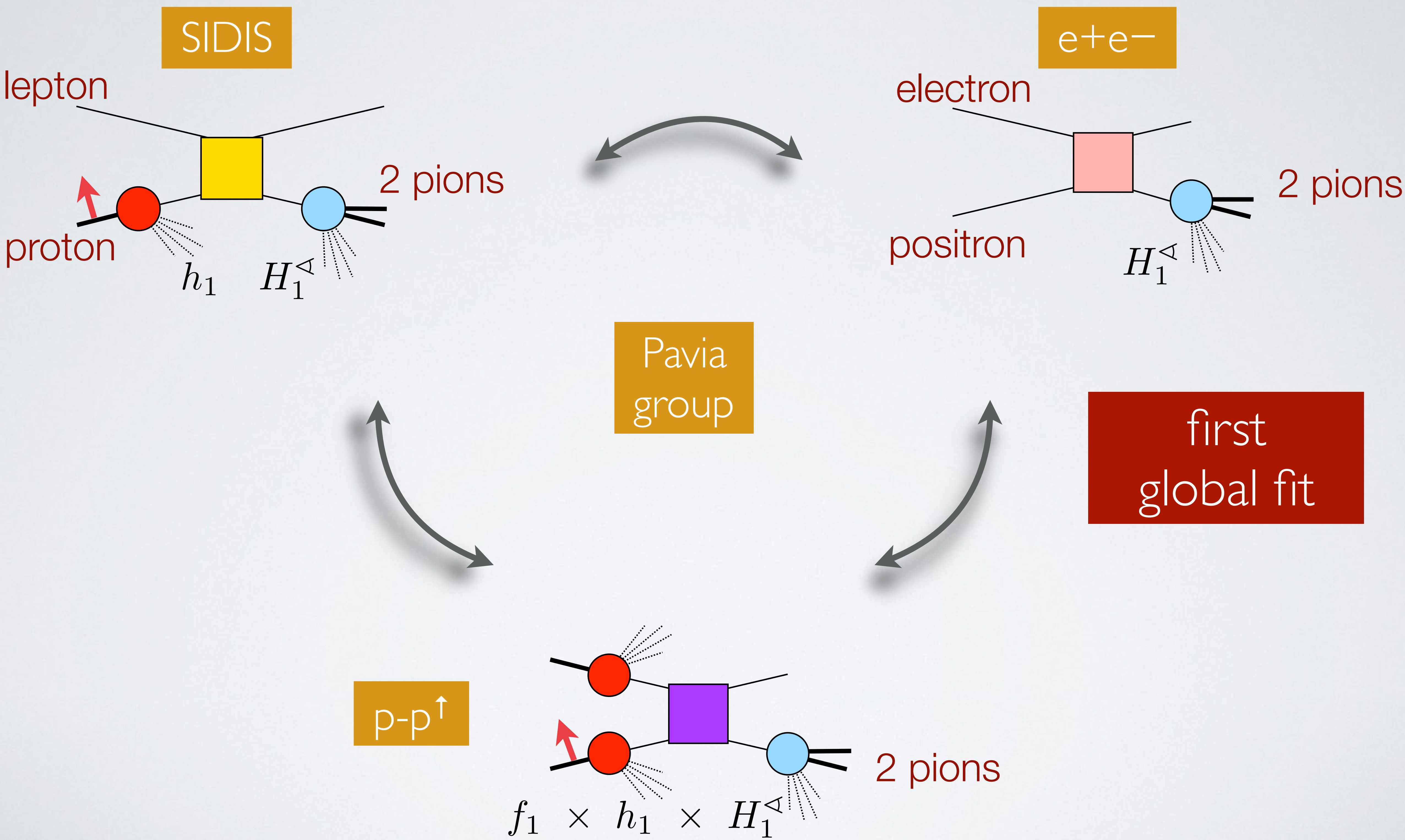
Radici et al.,
*P.R. D**94*** *(16) 034012*

exploratory
predictions
for p-p$^{\uparrow}$

p-p$^{\uparrow}$



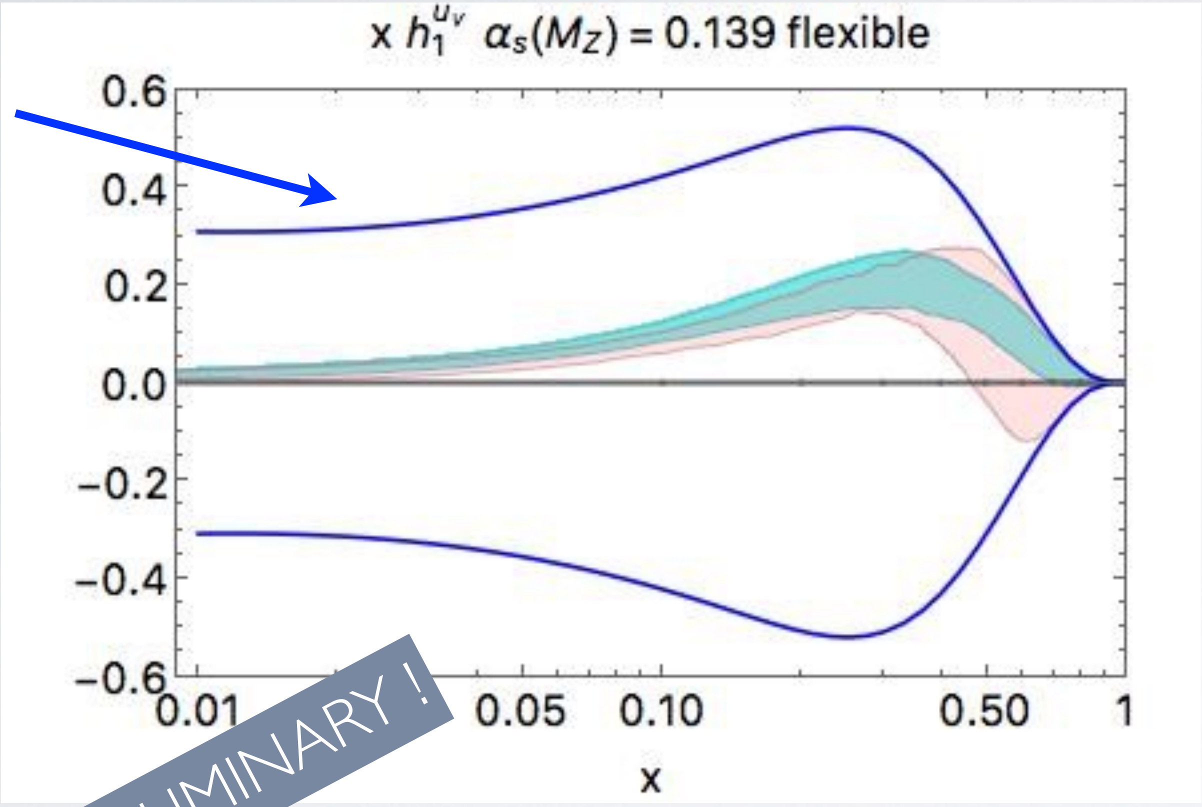
extraction from 2-hadron-inclusive data



comparison with previous fit

Soffer bound

up



PRELIMINARY !

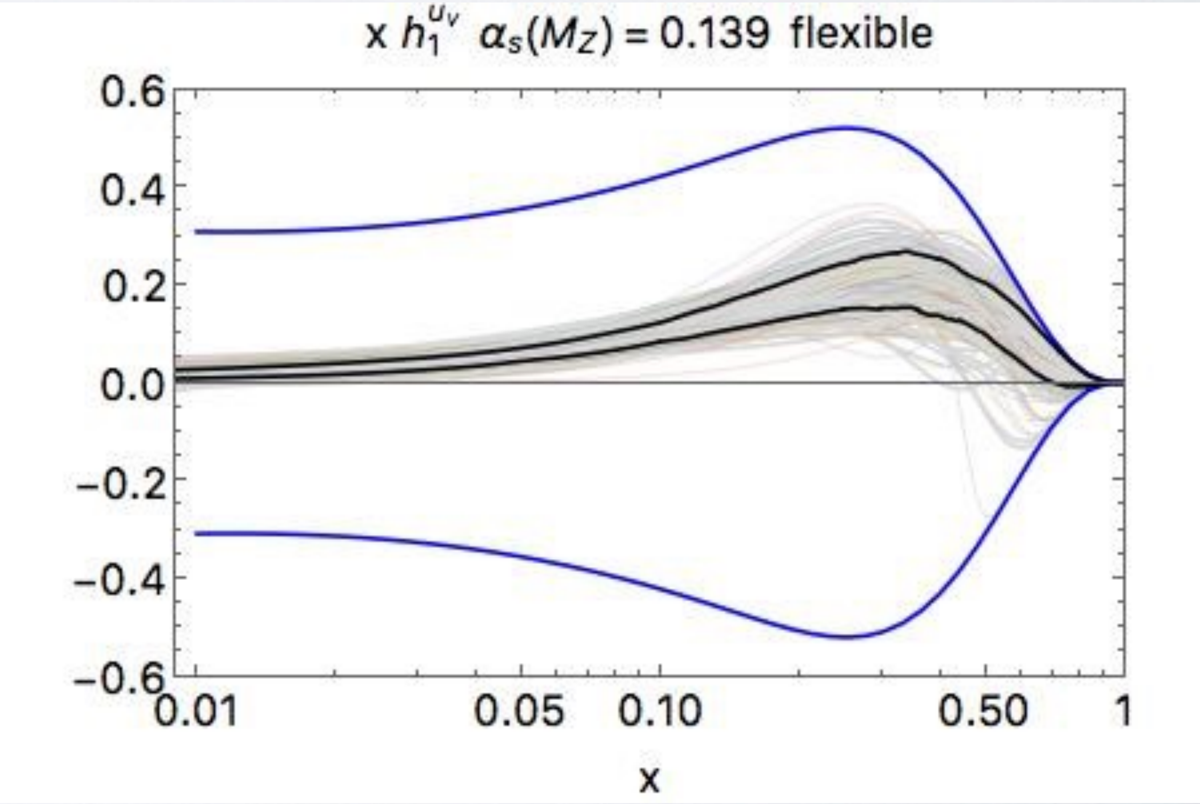
global fit

old fit

higher precision

all 200 replicas

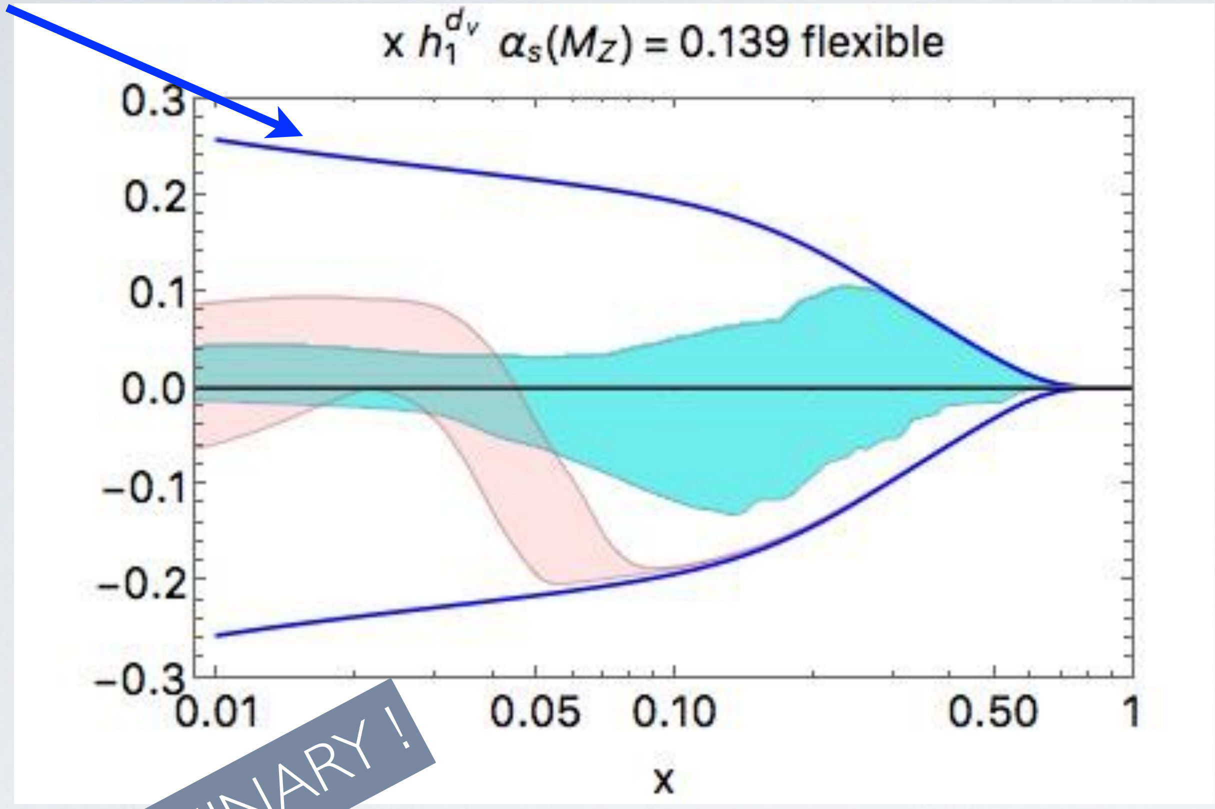
68% band



comparison with previous fit

Soffer bound

down



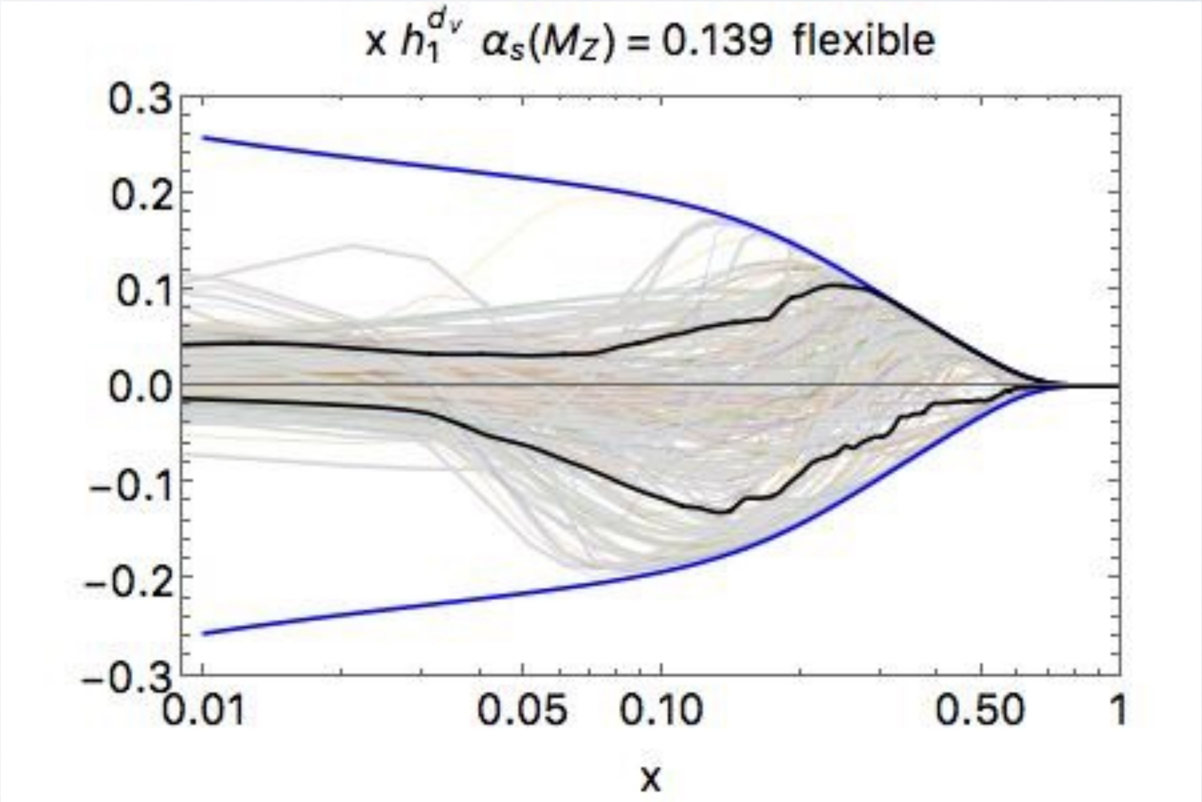
PRELIMINARY !

global fit

old fit

all 200 replicas

68% band

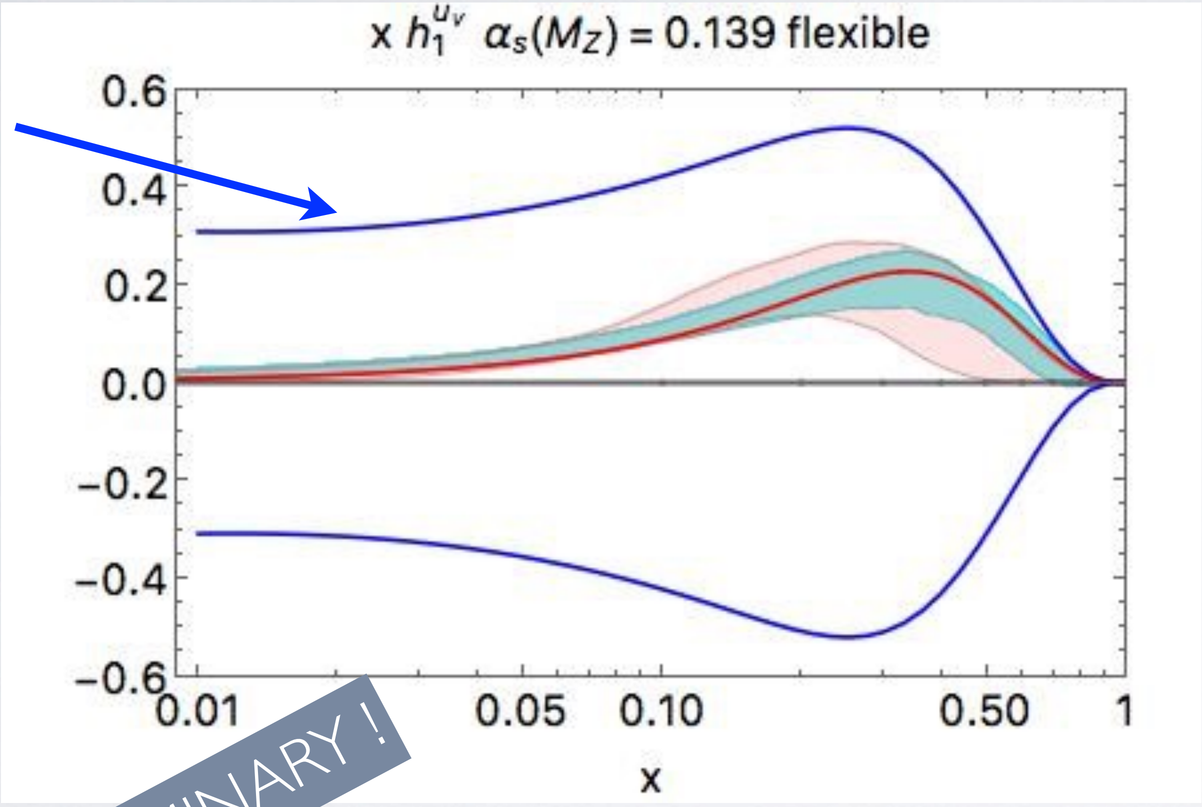


effect of STAR data :
saturation of Soffer bound
only for some replicas

comparison with Collins effect

Soffer bound

up



PRELIMINARY !

Kang et al.

Torino

this work

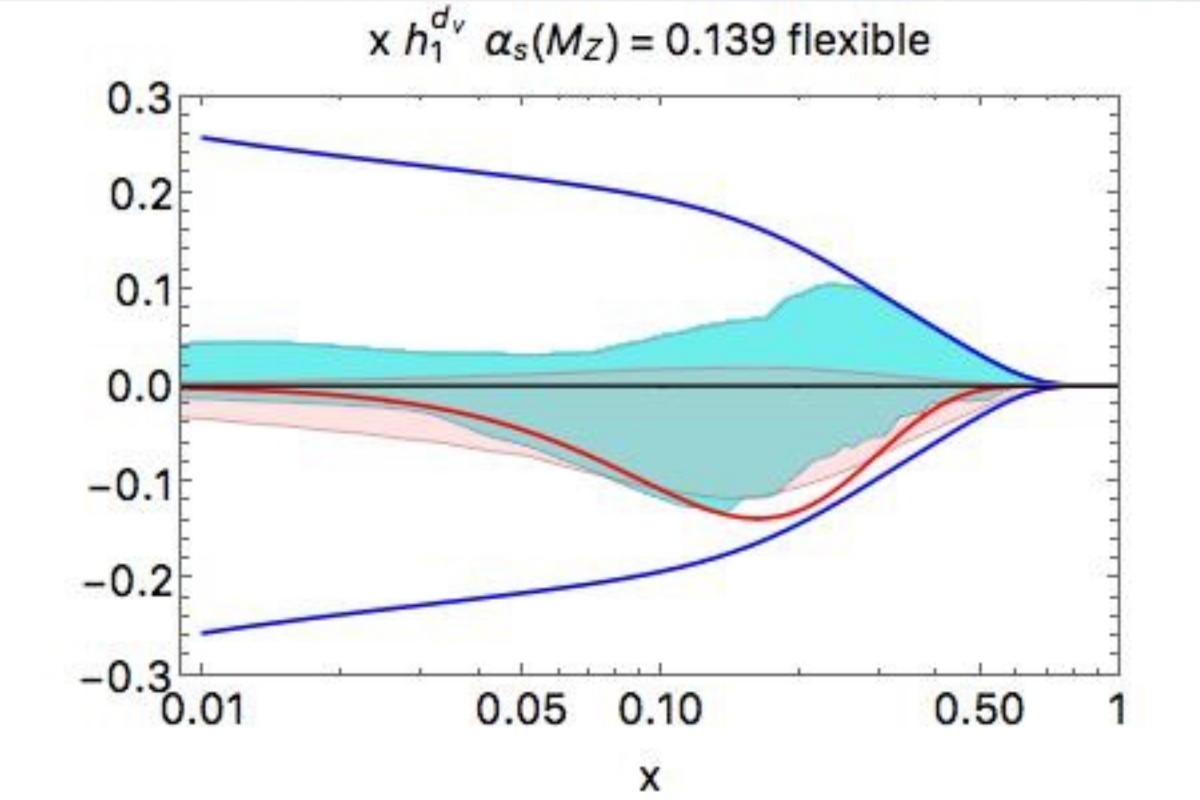
*Kang et al., P.R. D**93** (16) 014009*

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

higher precision

better compatibility

down



Conclusions

- first global fit of di-hadron inclusive data leading to extraction of transversity in collinear framework (PRELIMINARY!)
- inclusion of STAR $p\text{-}p^{\uparrow}$ data increases precision of extracted transversity up and makes transversity down more compatible with one from Collins effect (with respect to our previous extraction from SIDIS + e^+e^- data only)
- tensor charge useful for low-energy explorations of BSM new physics ⇒ precision is an issue

N.B. to this goal, need $d\sigma^0$ for e^+e^- and p-p to constrain di-hadron fragm. funct. D_1, particularly for gluons

Conclusions

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THANK YOU

backup slides

minimization of p-p matrix element

*Bacchetta & Radici, P.R. D**70** (04) 094032*

$d\sigma \sim d\sigma^0 + \sin(\Phi_S - \Phi_R)\, d\sigma_{UT}$

$$A_{UT} = \frac{d\sigma_{UT}}{d\sigma^0}$$

$$\frac{d\sigma_{UT}}{d\eta\, d|\boldsymbol{P}_T|\, dM} = |\boldsymbol{S}_{BT}|\, 2\, |\boldsymbol{P}_T|\, \frac{|\boldsymbol{R}|}{M} \sin\theta \sum_{a,b,c,d} \int \frac{dx_a\, dx_b}{8\pi^2 \bar{z}}\, f_1^a(x_a)\, h_1^b(x_b)\, \frac{d\Delta\hat{\sigma}_{ab^\uparrow \to c^\uparrow d}}{d\hat{t}}\, H_1^{\sphericalangle c}(\bar{z}, M)$$

$$\hat{t} = t\, x_a/\bar{z}$$

$A_{UT}(\eta) \rightarrow$ (((5-dimensional integral ($\langle\eta\rangle_{bin}$, P_T, M, x_a, x_b) + evolution in each P_T) for each set of parameters chosen by MINUIT) for each replica)

need a super-computer !

minimization of p-p matrix element

usual trick: use Mellin transform
& anti-transform

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

$$h_1(x,Q^2) = \int_{\mathcal{C}_N} dN\, x^{-N}\, h_1^N(Q^2)$$

$N \in \mathbb{C}$

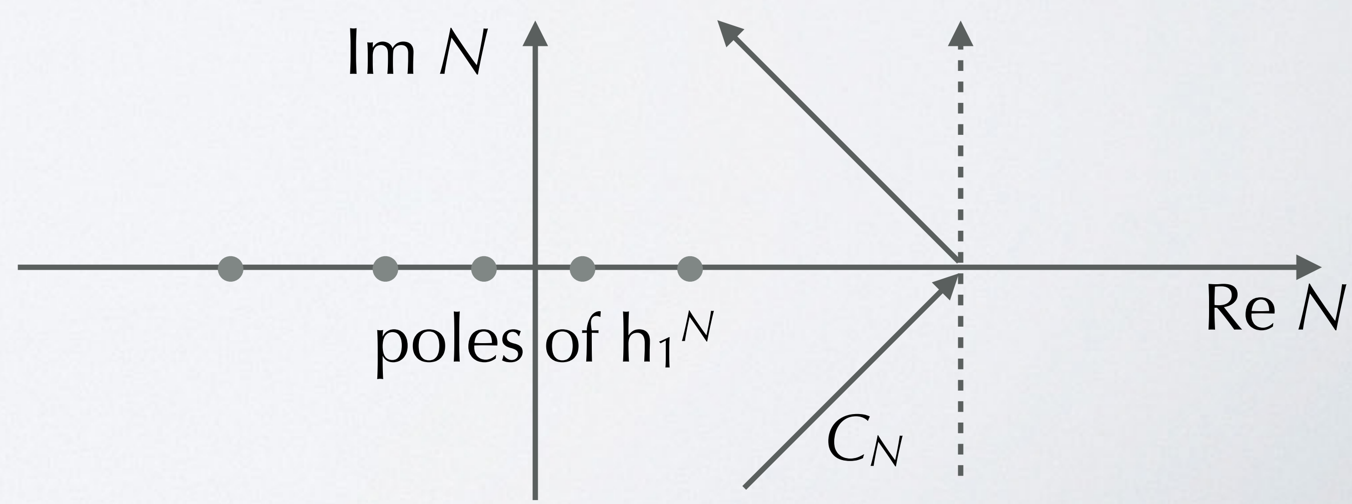
*Stratmann & Vogelsang, P.R. D**64** (01) 114007*

$$\frac{d\sigma_{UT}}{d\eta\, d|\boldsymbol{P}_T|\, dM} = |\boldsymbol{S}_{BT}|\, 2\, |\boldsymbol{P}_T|\, \frac{|\boldsymbol{R}|}{M}\, \sin\theta \sum_{a,b,c,d} \int \frac{dx_a\, dx_b}{8\pi^2 \bar{z}}\, f_1^a(x_a)\, h_1^b(x_b)\, \frac{d\Delta\hat{\sigma}_{ab^\uparrow \to c^\uparrow d}}{d\hat{t}}\, H_1^{\sphericalangle c}(\bar{z}, M)$$

$$d\sigma_{UT}(\eta) = \int_{\mathcal{C}_N} dN\, h_1^N(P_T^2) \int d|\boldsymbol{P}_T| dM\, dx_a dx_b\, x_b^{-N}\, F(\eta, N;\, |\boldsymbol{P}_T|, M, x_a, x_b)$$

for each η bin, pre-compute integrals on contour

this speeds up convergence
and facilitates ∫ dN , provided
that h_1^N is known analytically

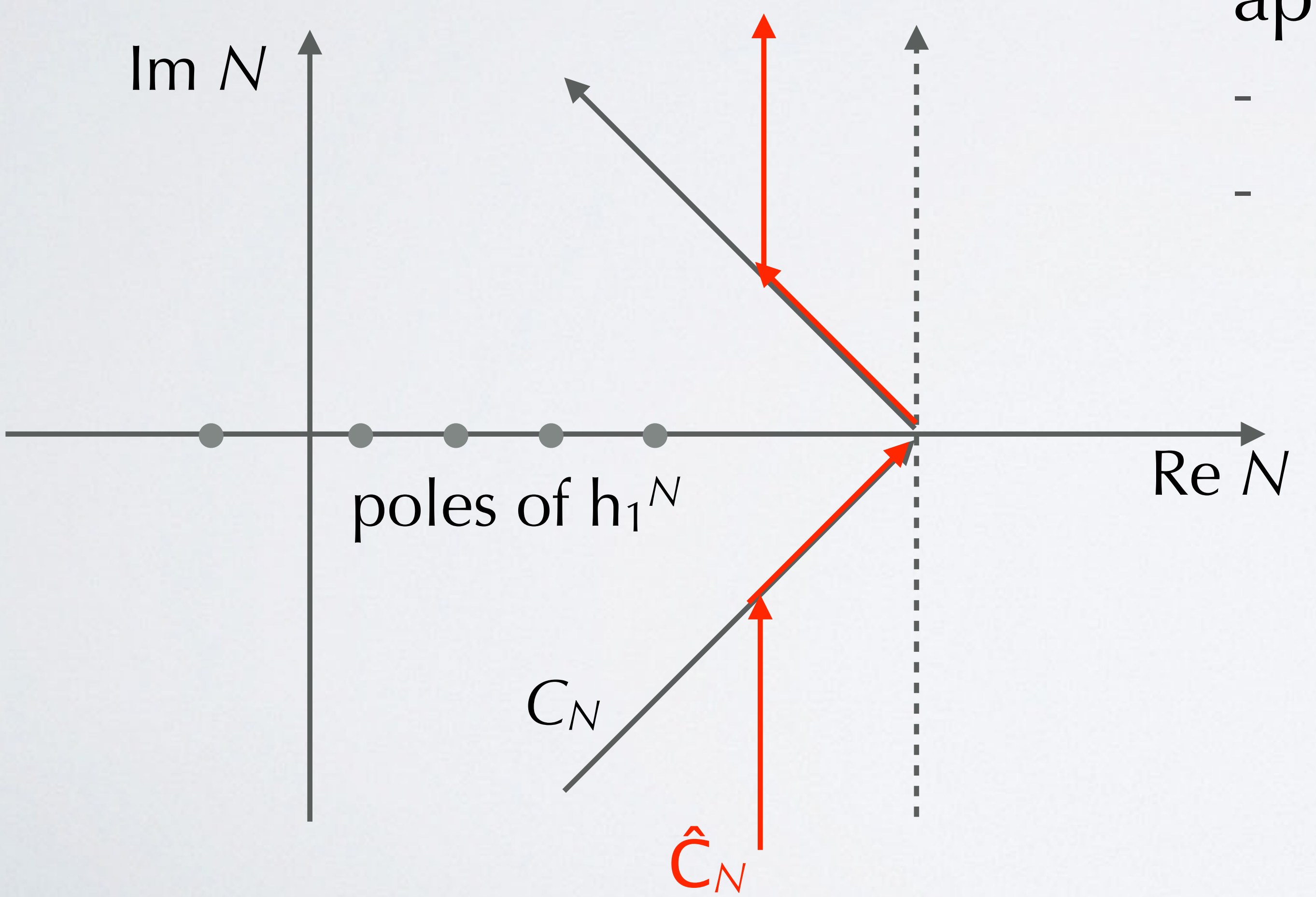


minimization of p-p matrix element

$$d\sigma_{UT}(\eta) = \int_{\mathcal{C}_N} dN\, h_1^N(P_T^2) \int d|\boldsymbol{P}_T| dM\, dx_a dx_b\, x_b^{-N} F(\eta, N; |\boldsymbol{P}_T|, M, x_a, x_b)$$

numerical Mellin transform

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



opposite convergence criteria

approximation:

- pre-compute integrals on C_N
- compute Mellin transform on $\hat{C}_N$

$\hat{C}_N = C_N$ for Re $N \geq 1.7$