XV International Conference on Science, Arts and Culture

International Workshop

TMDe2015

A PATH TOWARDS TMD EXTRACTION

2-4 September 2015

Trieste - Italy

ECSAC

European Centre for Science Arts and Culture

TMD Fragmentation Functions in e^+e^- and SIDIS processes

Phenomenological overview

Marco Radici
INFN - Pavia

INFN Istituto Nazionale di Fisica Nucleare

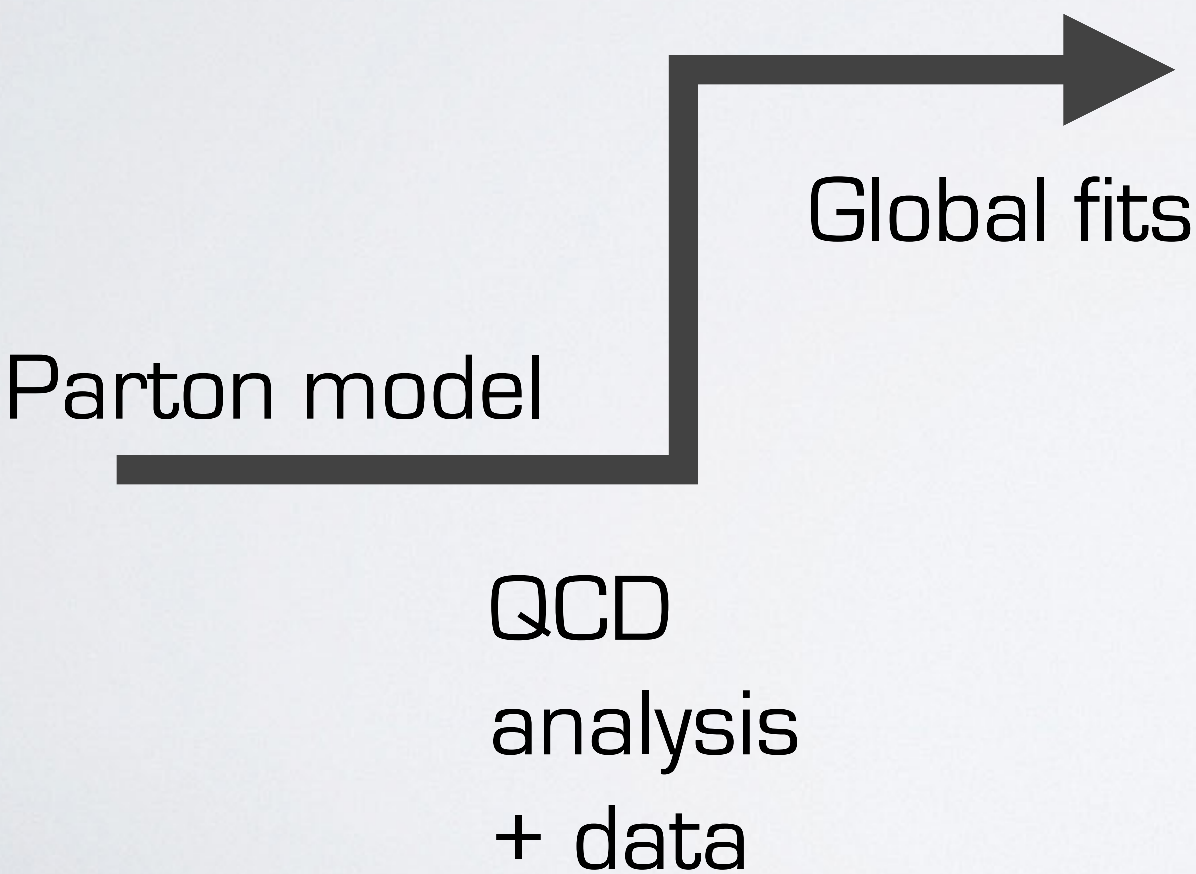
a phase transition in 3D studies

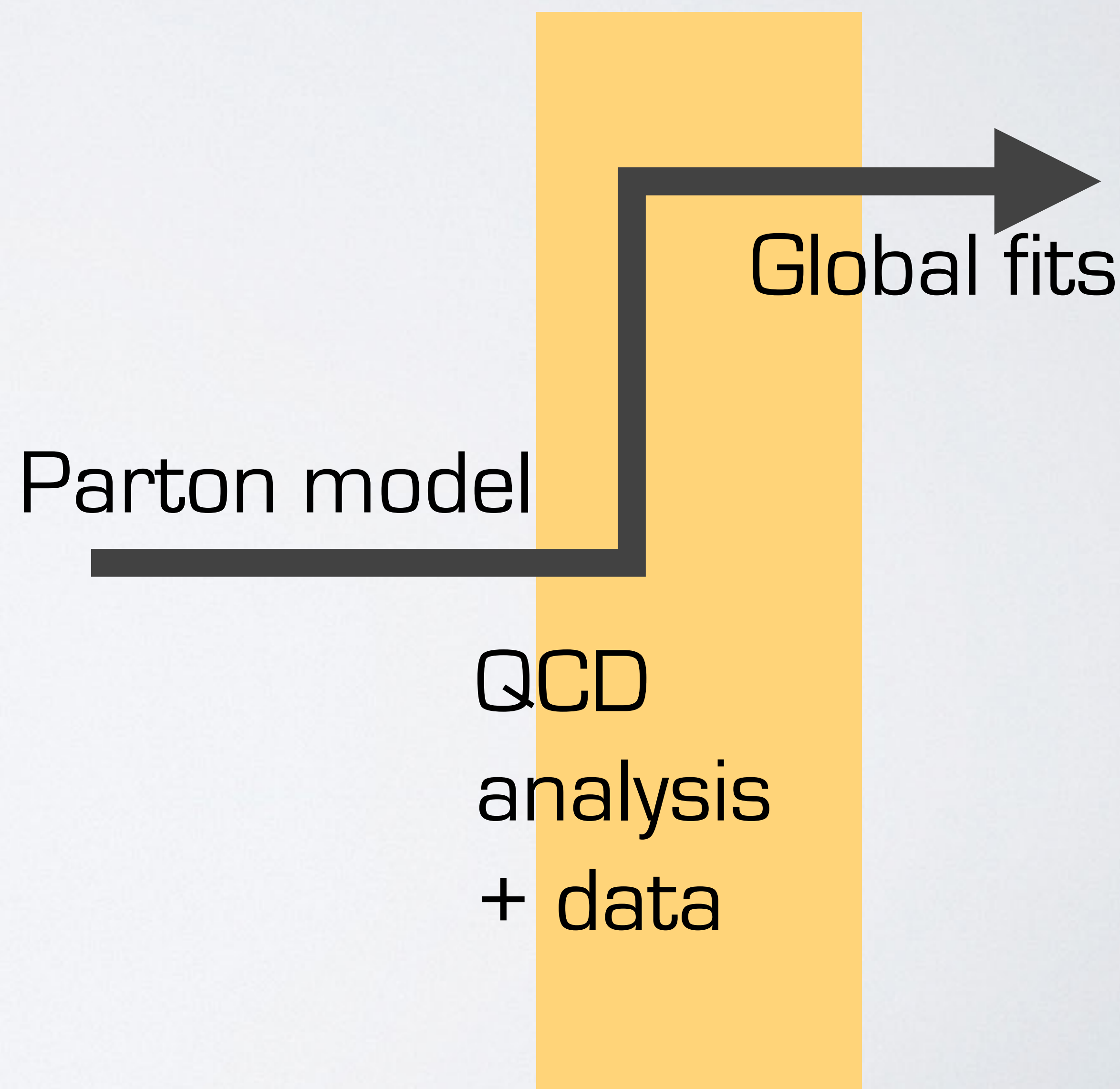
1D

(standard parton distribution functions - PDFs)

3D

(transverse momentum distributions - TMDs)





key results of QCD

factorization

test TMDs by comparing different processes

universality

evolution

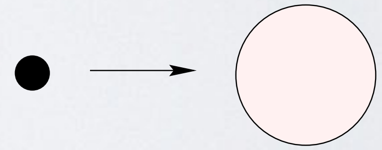
test TMDs by analyzing experiments at
at different energies

Single-hadron Fragmentation Functions (SiFF)

1. Status of collinear parametrization of $D_1^{q \to h}(z; Q^2)$

quark pol.

U	L	T
D_1		$H_1^{\perp}$

$D_1 =$ 

a new step

before 2007

- AKK (Albino, Kniehl, Kramer, 2005)
- BKK (Binnewies, Kniehl, Kramer, 1995)
- BFG (Bourhis, Fontannaz, Guillet, 1998)
- BFGW (Bourhis, Fontannaz, Guillet,, Werlen, 2001)
- CGRW (Chiappetta, Greco, Guillet, Rolli, Werlen, 1994)
- GRV (Glück, Reya, Vogt, 1993)
- KKP (Kniehl, Kramer, Potter, 2000)
- Kr (Kretzer, 2000)

after 2007

global fits

error analysis

- AKK08 (Albino, Kniehl, Kramer, 2008)
- HKNS (Hirai, Kumano, Nagai, Sudoh, 2007)
- DSS (De Florian, Sassot, Stratmann, 2007)

2015

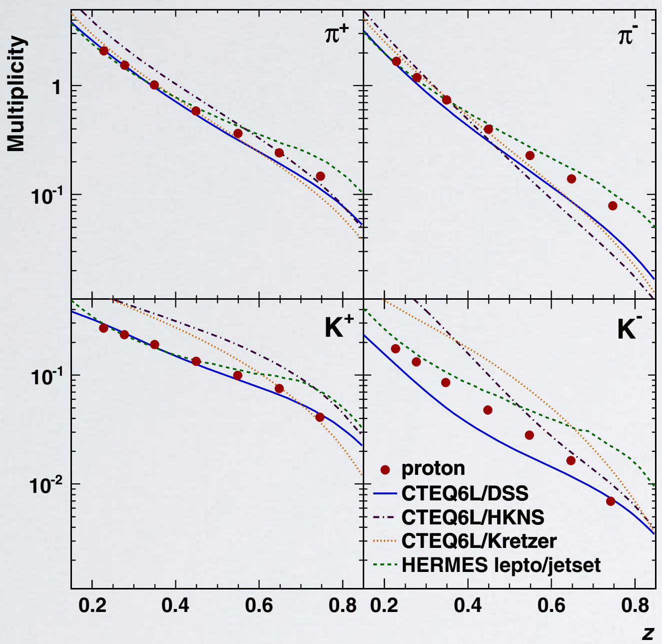
major update

for $q \to \pi$

- DSEHPS (De Florian, Sassot, Epele, Hernández-Pinto, Stratmann, P.R. D**91** (2015) 014035)
  - more/better data for e^+e^- (Belle, BaBar), SIDIS (Hermes, Compass), LHC (Alice), RHIC (STAR)
  - new error analysis
  - global χ^2/dof ~ 2.2 → 1.2

is collinear description good ?

when fitting unintegrated multiplicities to extract TMD FF, main assumption is that fitting integrated multiplicities gives good collinear FF…

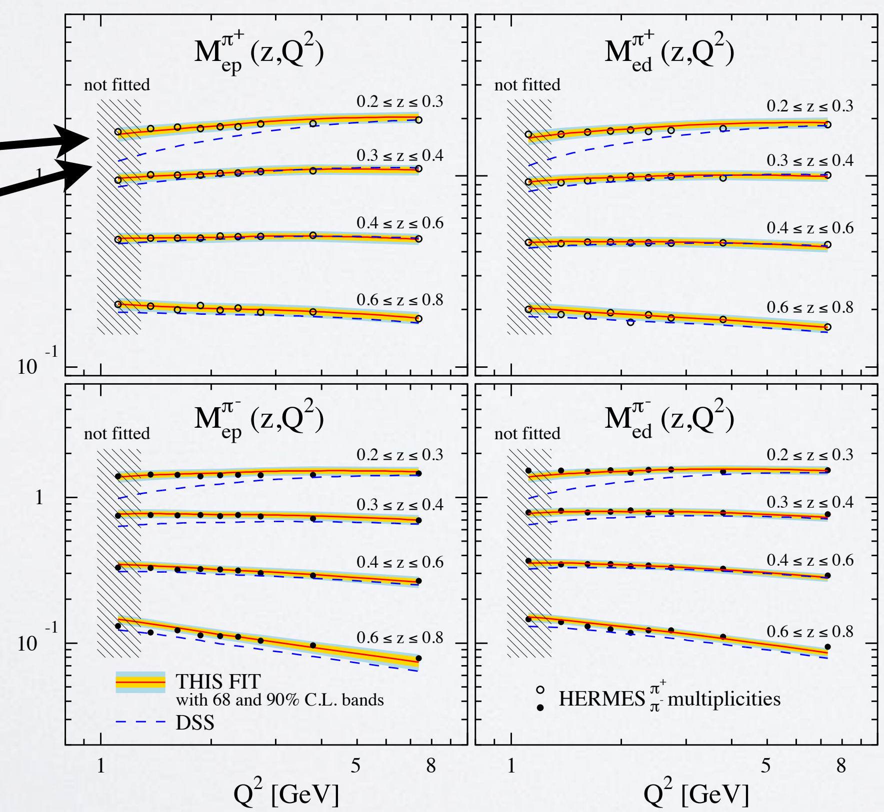


χ^2/d.o.f.				
	$Q^2 > 1.4\,\mathrm{GeV}^2$	$Q^2 > 1.4\,\mathrm{GeV}^2$ (no VM subtr.)	$Q^2 > 1.4\,\mathrm{GeV}^2$ (with evolution)	$Q^2 > 1.6\,\mathrm{GeV}^2$
global	2.86	3.90	3.55	2.29
$p \to K^-$	2.25	2.27	1.38	2.38
$p \to \pi^-$	3.39	6.58	5.03	2.70
$p \to \pi^+$	1.87	2.45	2.74	1.16
$p \to K^+$	0.89	0.85	1.13	0.59
$D \to K^-$	4.26	4.22	2.81	4.45
$D \to \pi^-$	5.05	8.66	7.96	3.42
$D \to \pi^+$	3.33	4.61	5.19	2.29
$D \to K^+$	1.80	1.57	2.17	1.31

MSTW08 +
DSS 2007

from
Signori *et al.*,
JHEP **1311** (13) 194

DSEHPS 2015
DSS 2007

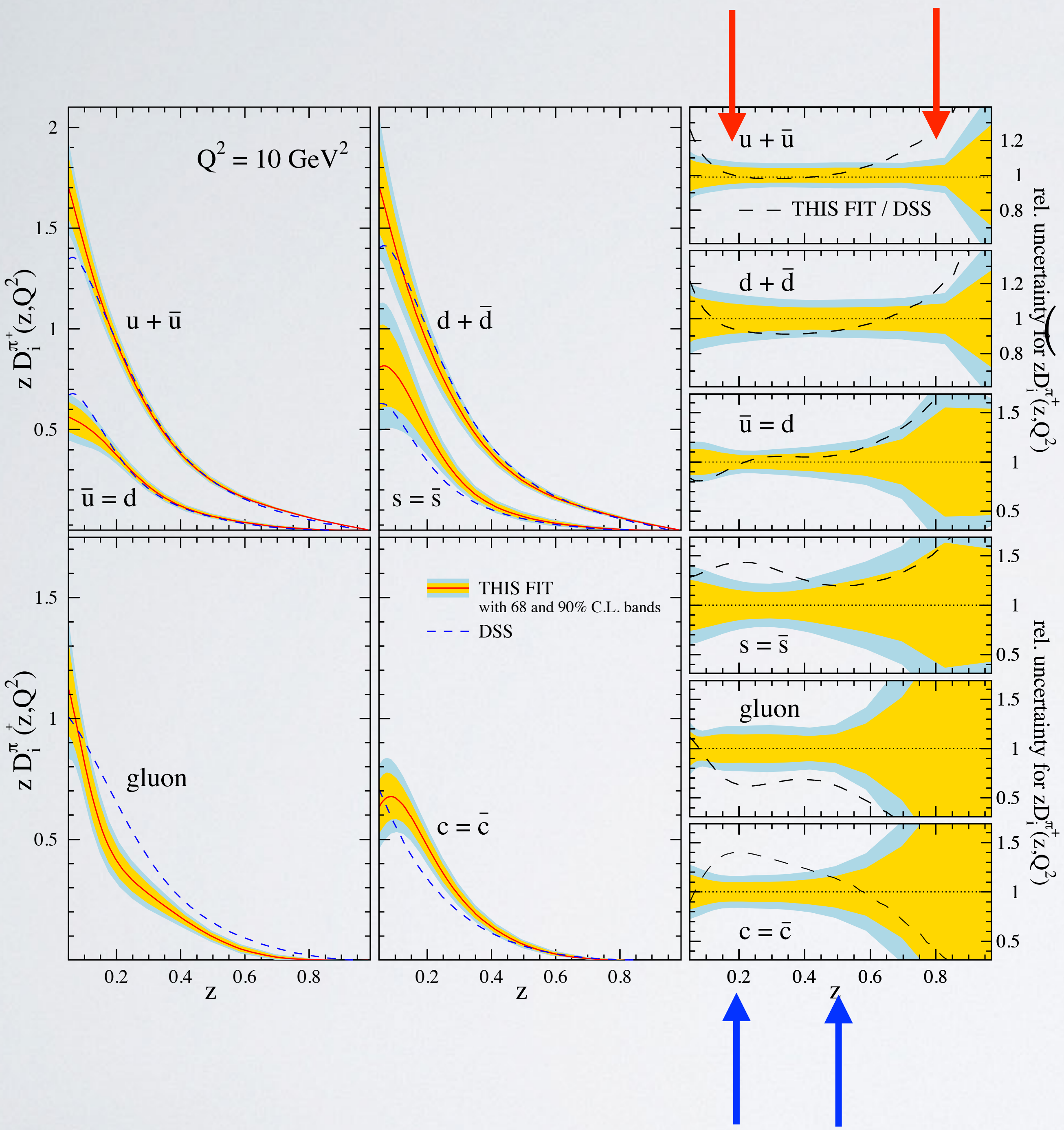


MSTW +
DSEHPS 2015

HERMES SIDIS multiplicities
$\chi^2 \sim 2.86 \rightarrow 1.37$

is collinear description good ?

De Florian *et al.*, P.R. D**91** (2015) 014035



<u>caveat</u>

- major improvement for total up & down channels: rel. uncertainty ≲10% for 0.2< z< 0.8

- for other channels, improvement upon DSS only for 0.2< z< 0.5

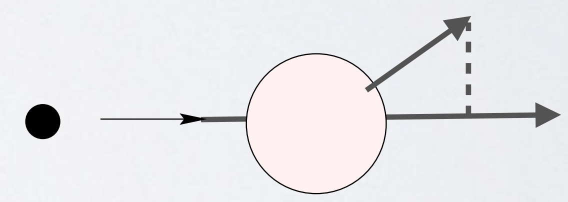
- Compass data for SIDIS multiplicities for deuteron target only
- Kaon fragmentation data not included

Single-hadron **F**ragmentation **F**unctions (**SiFF**)

2. Multidimensional description of $D_1^q\,(z, \mathbf{p}_T; Q^2)$ through SIDIS multiplicities

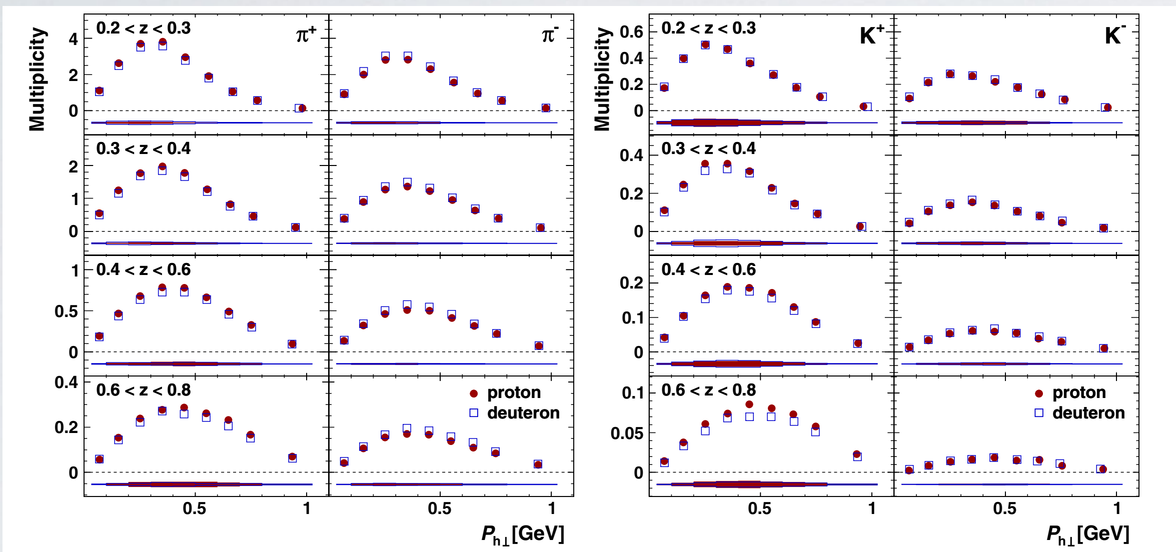
quark pol.

U	L	T
D_1		$H_1^{\perp}$

$D_1 =$ 

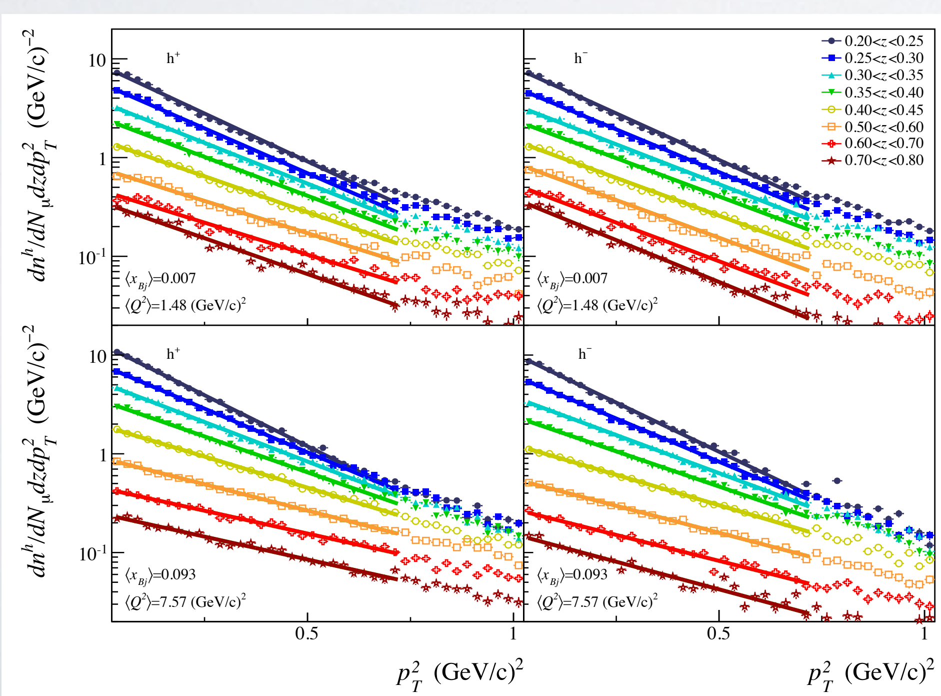
recent **data** on SIDIS multiplicities

Airapetian *et al.*, P.R. D**87** (13) 074029



- target: proton, deuteron
- final state: π^+, π^-, K^+, K^-
- 2688 points

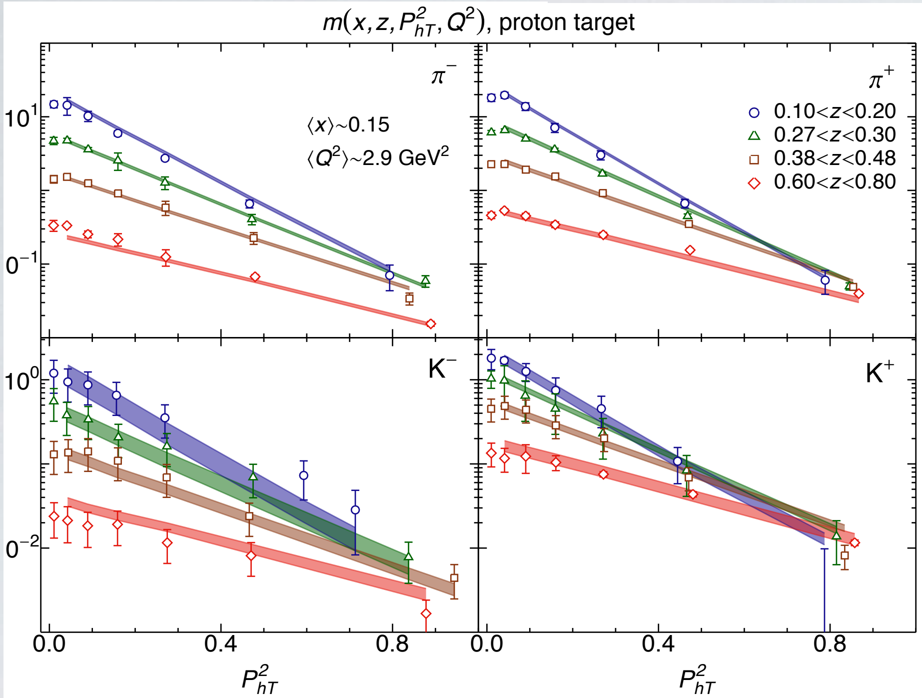
Adolph *et al.*, E.P.J. **C73** (13) 2531



about 20000 data points (!)

- target: deuteron
- final state:
  - h^+, h^- unidentified (run 2004)
  - π^+,π^-,K^+,K^- (run 2006) ongoing analysis

Pavia and Torino fits

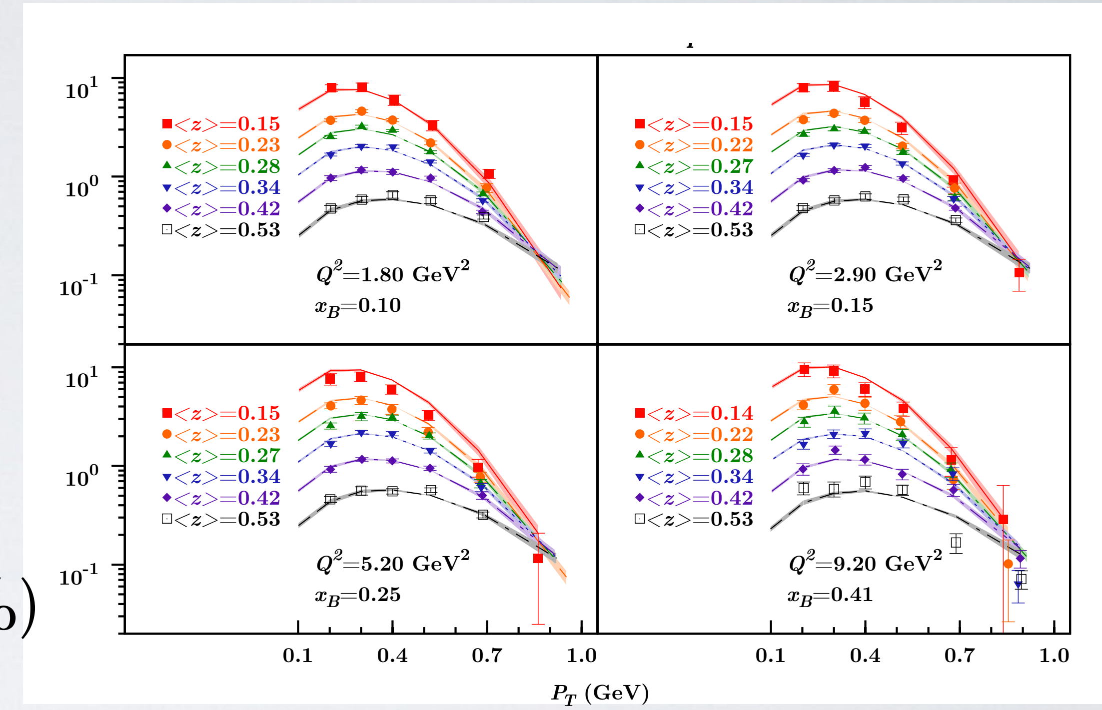


Signori *et al.*, JHEP **1311** (13) 194

almost
similar cuts

1538
points
(≈ 60 %)

~ 550
points
(≈ 20 %)



Anselmino *et al.*, JHEP **1404** (14) 005

- flavor dependent Gaussian widths,
  7 parameters
- multiplicity = sum of Gaussians

- no QCD evolution

- error analysis: replica method

- simple Gaussians, 2 parameters

- only collinear DGLAP evolution

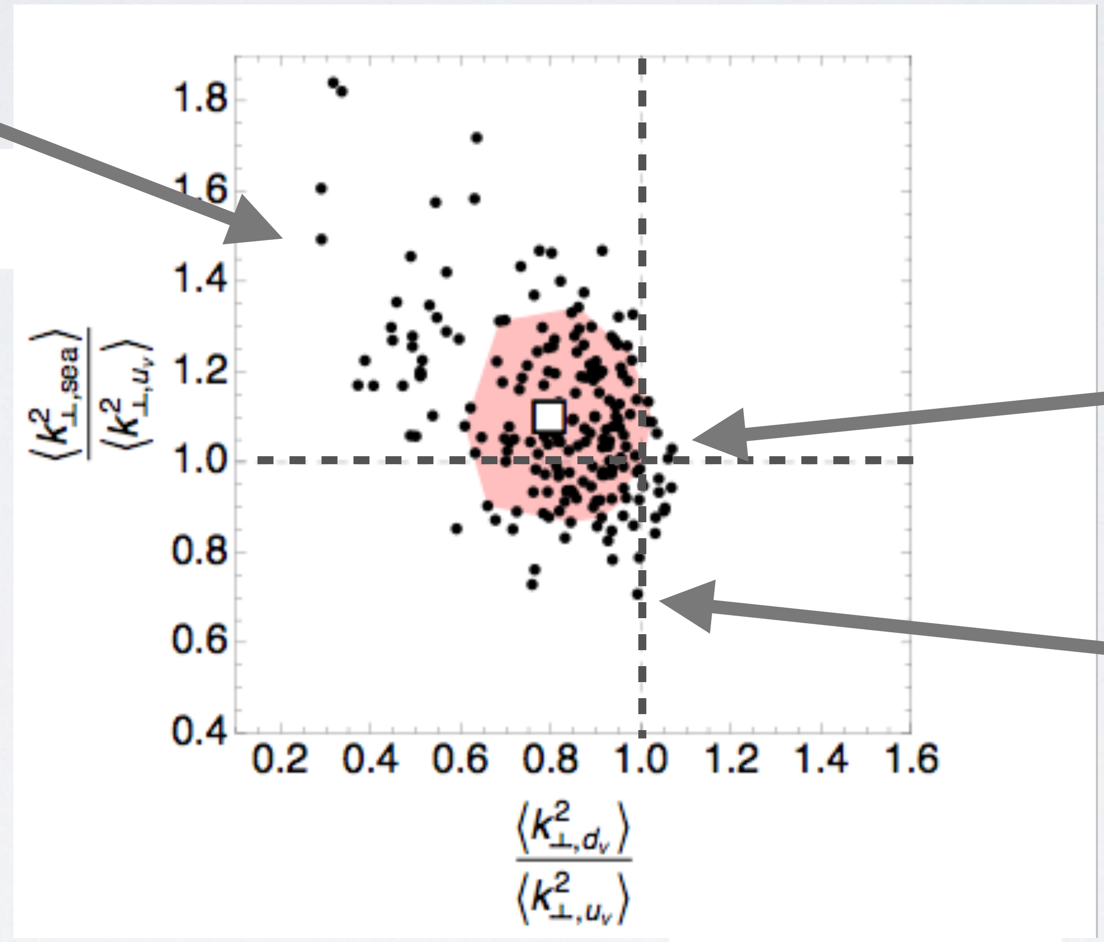
Pavia fit

Signori *et al.*,
JHEP **1311** (13) 194

with flavor dep. χ^2 = 1.63 ± 0.12
with no flavor dep. 1.72 ± 0.11

replica 73
χ^2/dof = 1.70

sea / up



TMD PDF

replica 130
χ^2/dof = 1.77

replica 186
χ^2/dof = 1.38

point of
no flavor dep.

down / up

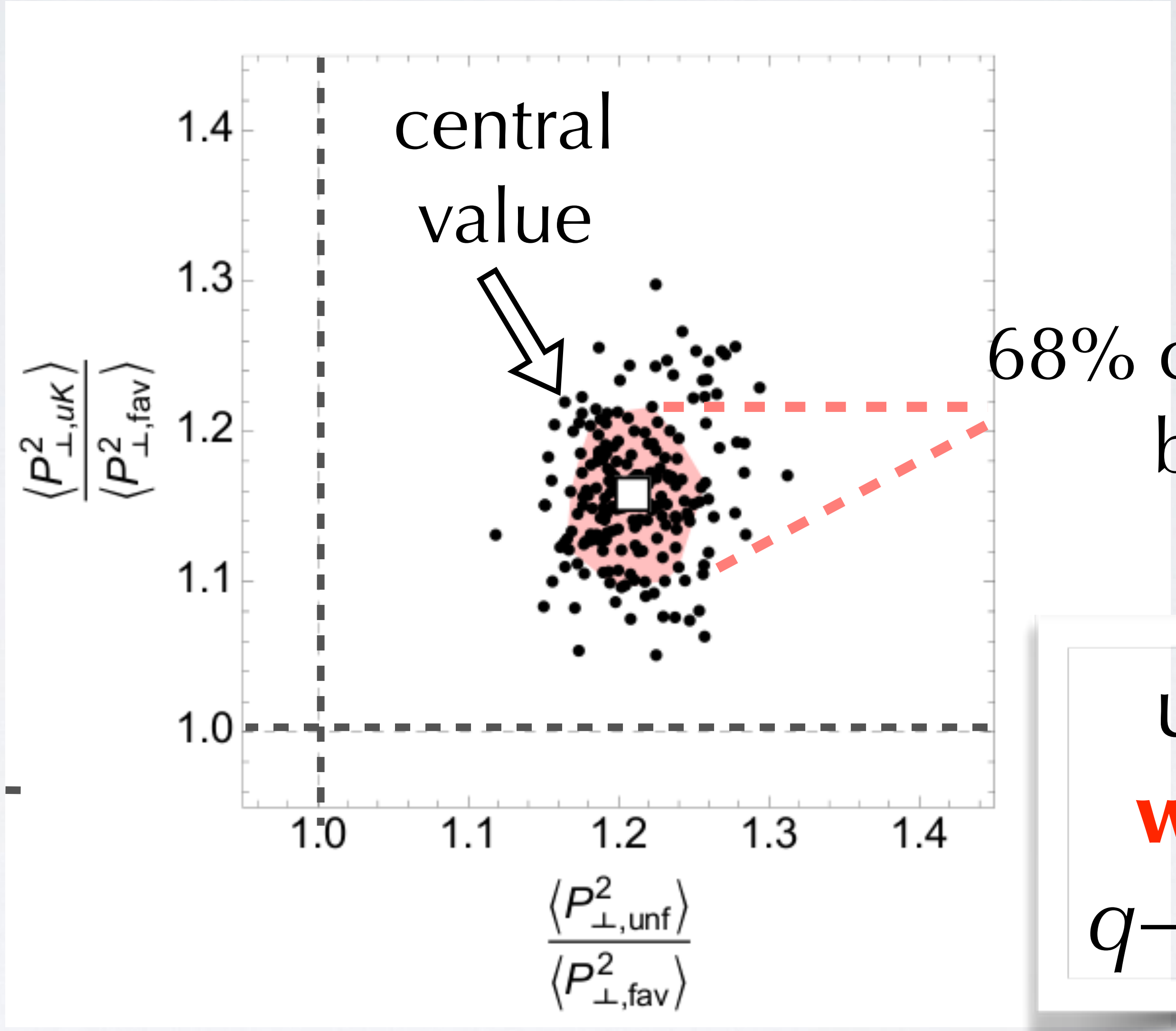
HERMES SIDIS data not enough selective

Pavia fit

Signori *et al.*,
JHEP **1311** (13) 194

fit clearly prefers TMD FF with flavor dep.

favored $q \to K$
wider than
favored $q \to \pi$



68% confidence band

point of
no flavor dep.

unfavored
wider than
$q \to \pi$ favored

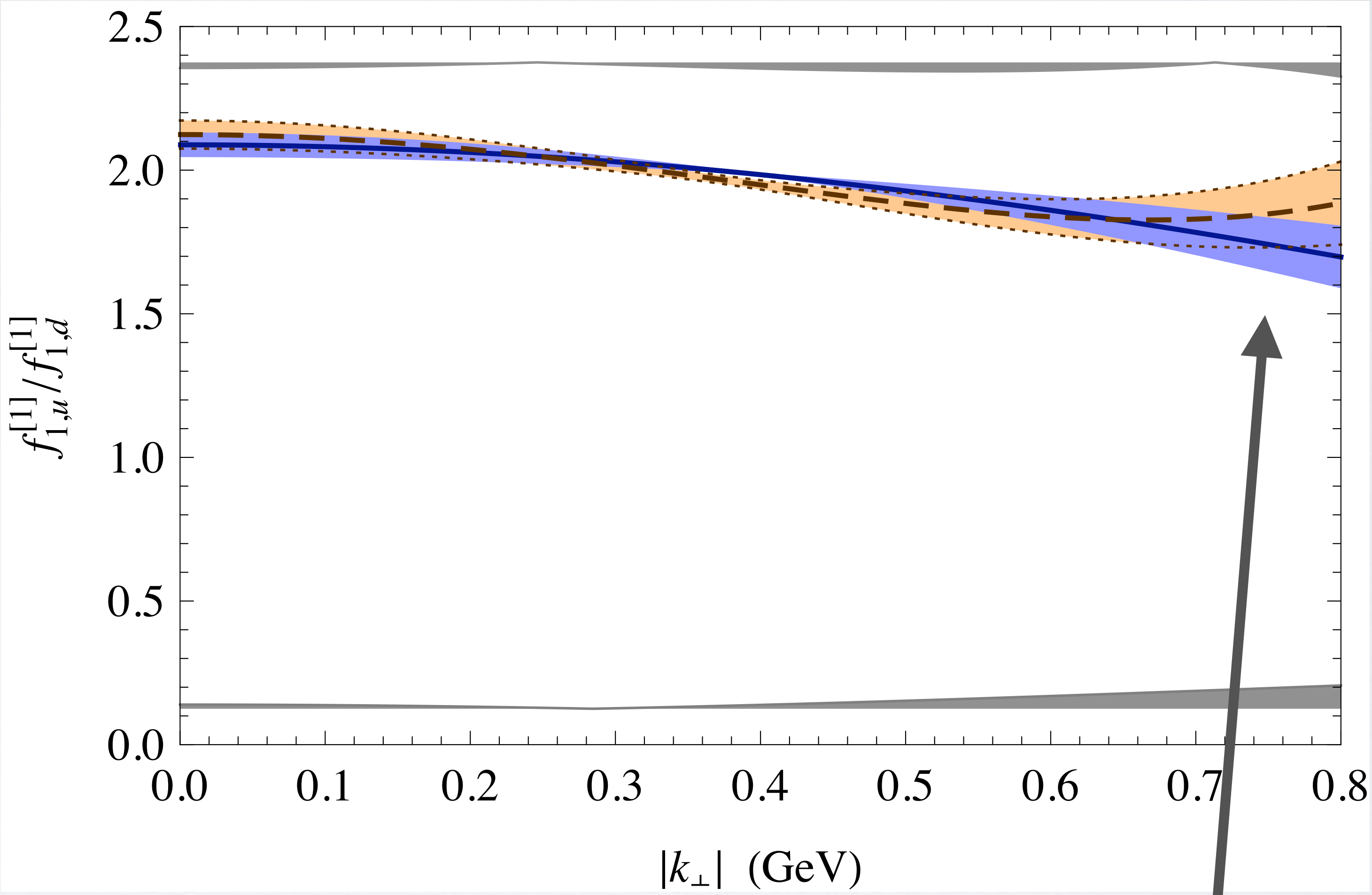
confirmed by Torino fit: if favored < unfavored

$\Rightarrow$ from $\chi^2 = 1.69$ to $\chi^2 = 1.60$

evidence from lattice

valence picture of proton : #u / #d = 2

ratio of
number densities
(moments of f_1^q)
depends upon $|\boldsymbol{k}_\perp|$

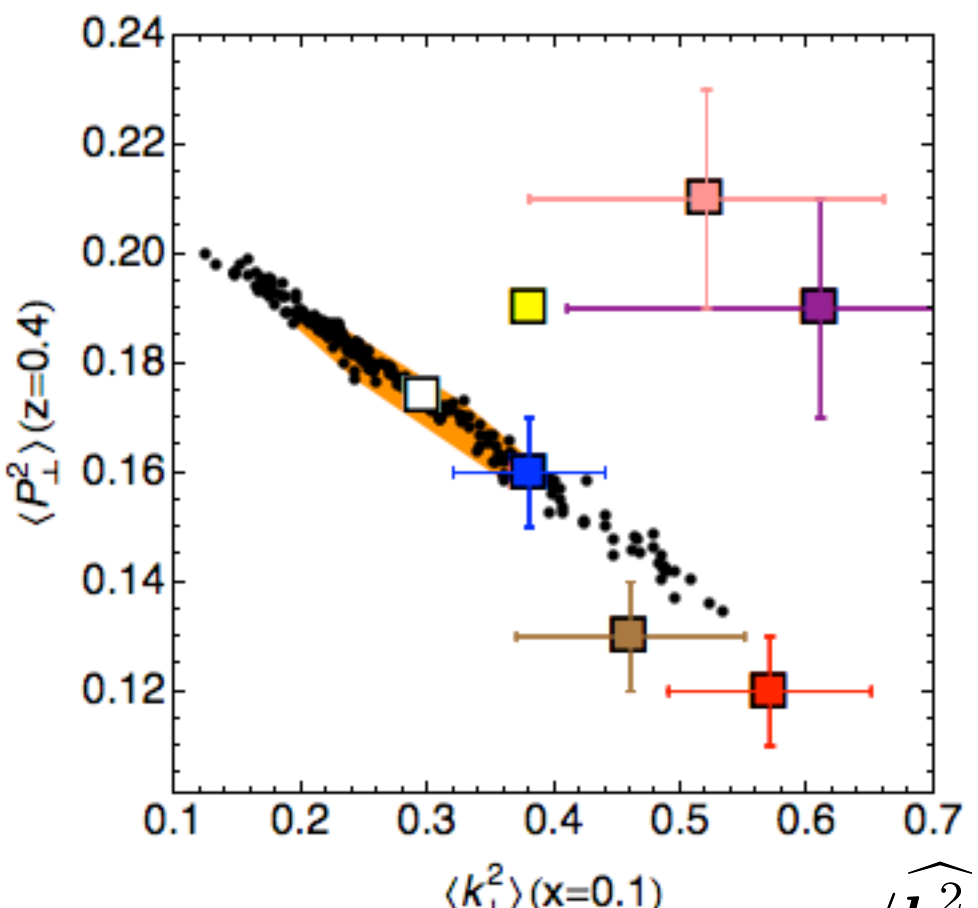


“less” up at large $|\boldsymbol{k}_\perp|$

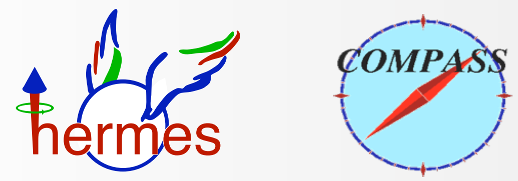
Musch *et al.*, P.R. D**83** (11) 094507

strong anticorrelation

TMD FF $\langle \widehat{\boldsymbol{P}_\perp^2} \rangle$



$\langle \widehat{\boldsymbol{k}_\perp^2} \rangle$ **TMD PDF**

need combined fit of 

Signori *et al.*,
JHEP **1311** (13) 194

Schweitzer, Teckentrup, Metz
P.R.D**81** (2010) 094019

Anselmino et al., HERMES
" " " , high *z*

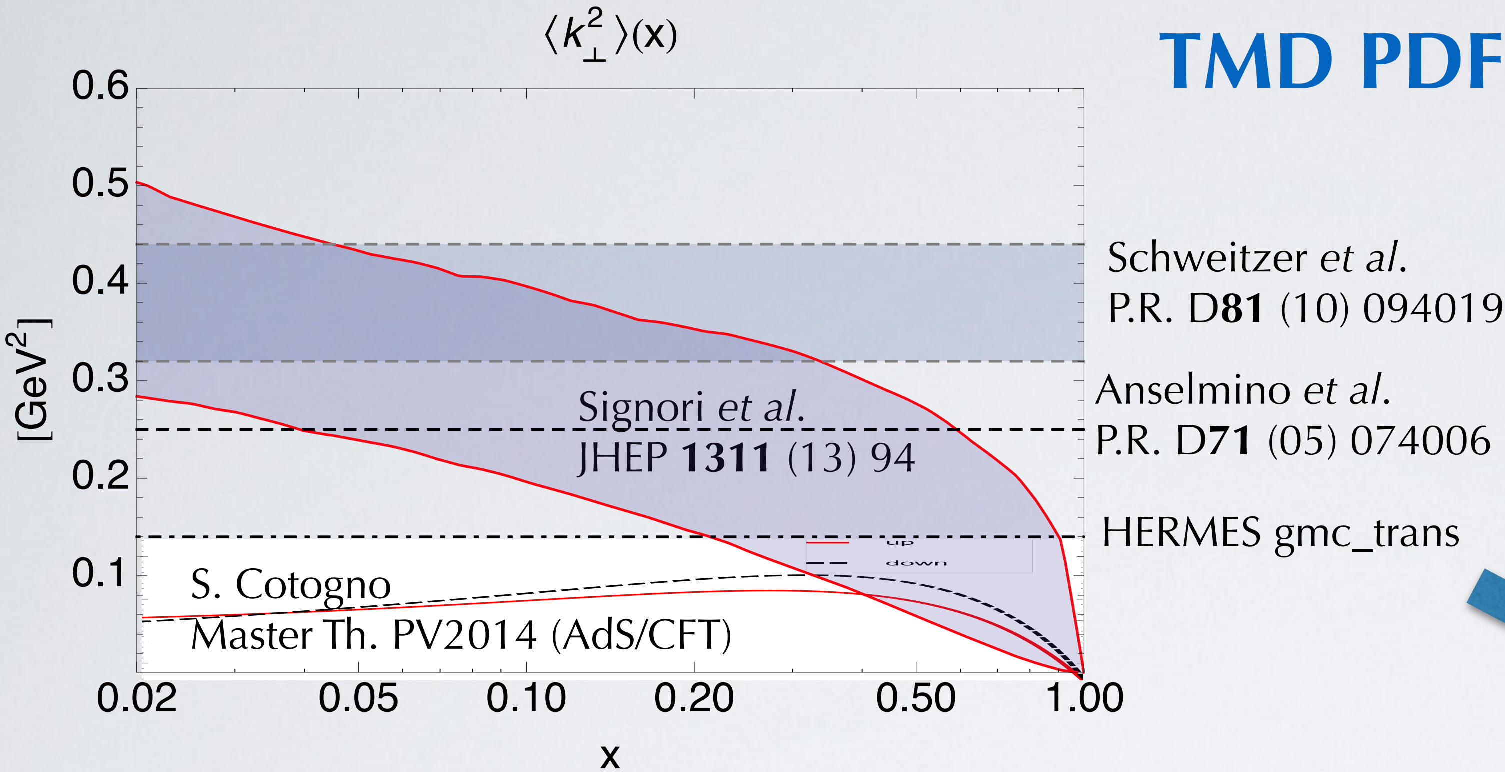
Anselmino et al., COMPASS
" " , high *z*, *y*-norm

JHEP **1404** (2014) 005

Echevarria *et al.*,
P.R.D**89** (2014) 074013

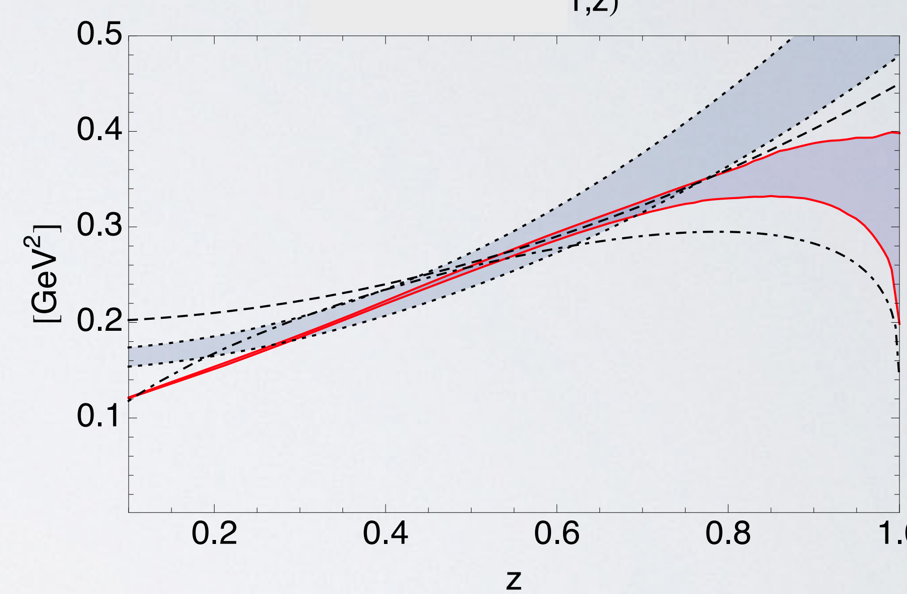
anticorrelation and 68% band

TMD PDF



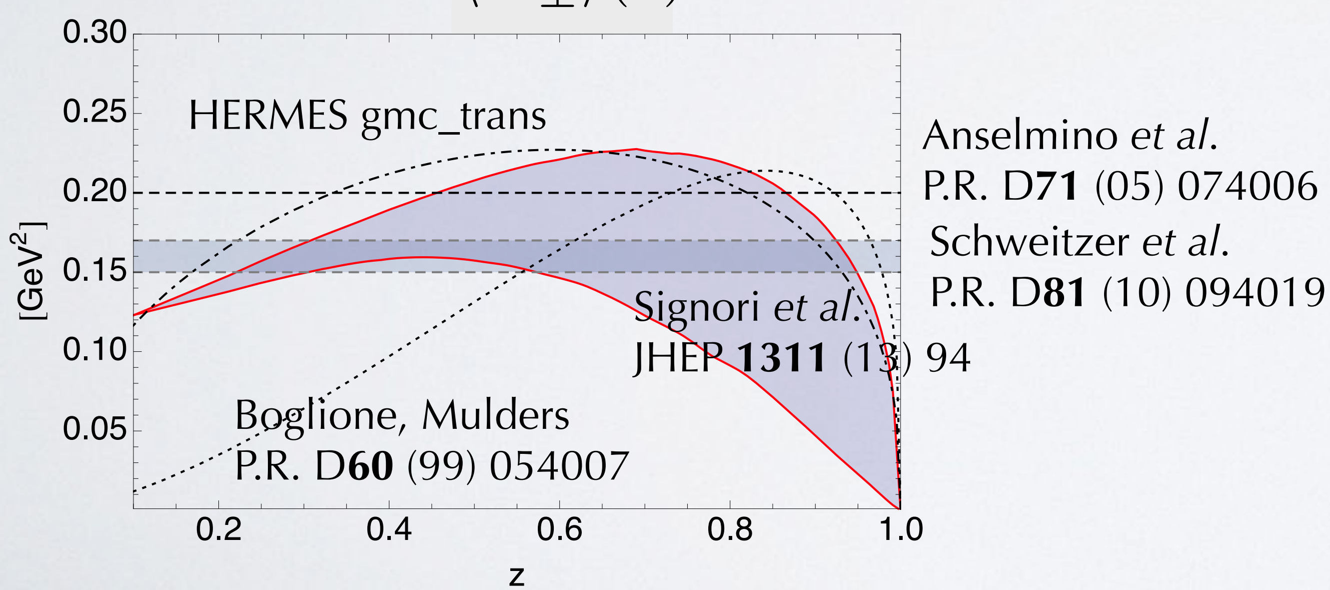
observed

$$\langle \boldsymbol{P}_{hT}^2 \rangle (x = 0.1, z)$$



$$\langle \boldsymbol{P}_{hT}^2 \rangle = z^2 \langle \boldsymbol{k}_\perp^2 \rangle + \langle \boldsymbol{P}_\perp^2 \rangle$$

TMD FF $\langle \boldsymbol{P}_\perp^2 \rangle (z)$



several $\{\boldsymbol{k}_\perp, \boldsymbol{P}_\perp\}$
give same $\boldsymbol{P}_{hT}$

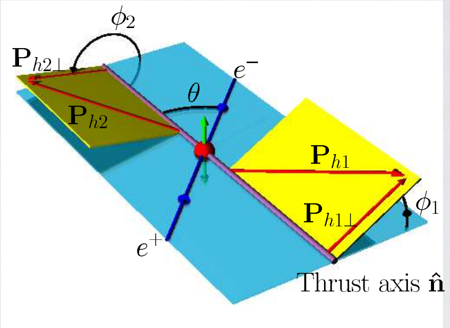
- limited Q^2 range ⇒ weak sensitivity to QCD evolution

- strong anticorrelation between average transverse momenta in **TMD PDF** & **TMD FF**

need e^+e^- data for **TMD FF**

issues with e$^+$e$^-$ measurements

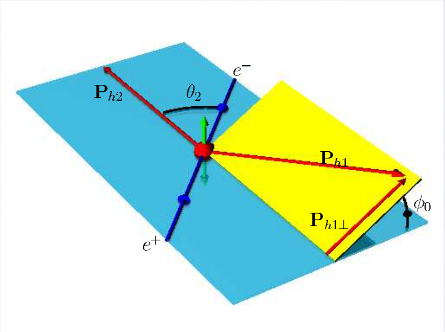
- which frame ? “thrust axis”



TMD factorization ?

“fixed hadron”

(see talk Vossen)



- which kinematics ? recall $\dfrac{P_{1T}^2}{z_1^2} = q_T^2 + \mathcal{O}\left(\dfrac{1}{Q^2}\right)$ $\quad q_T^2 \ll Q^2$

example: $Q^2 = 100$ GeV^2 $\Rightarrow q_T^2 \lesssim 10$ GeV^2

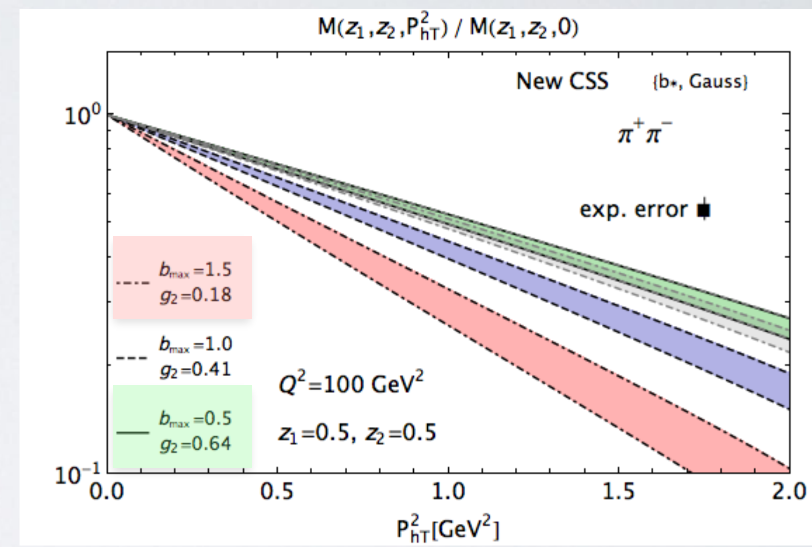
z_1=0.5 $\leftrightarrow$ $P_{1T}^2 \lesssim 2.5$ GeV^2

z_1=0.3 $\leftrightarrow$ $P_{1T}^2 \lesssim 1.2$ GeV^2….

issues with e$^+$e$^-$ measurements

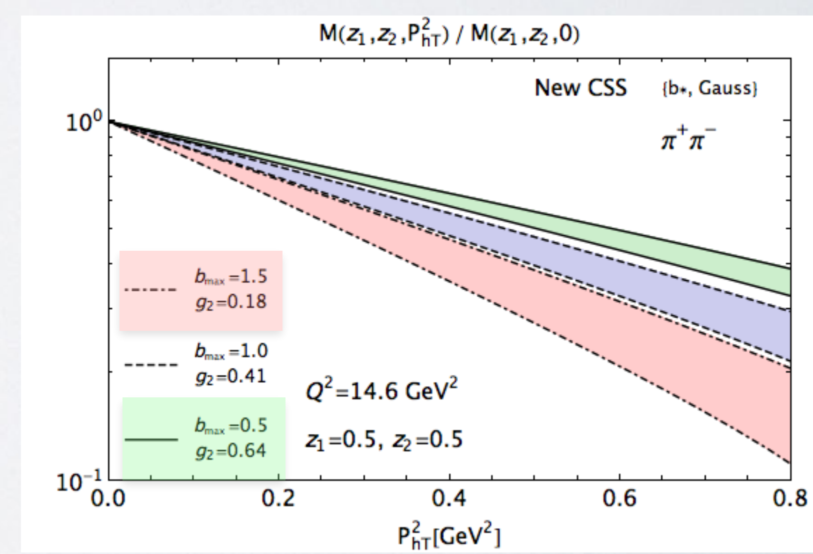
- virtuality fixed by c.m. energy $Q = \sqrt{s}/2$
  $\Rightarrow$ need and to test evolution

- at scale, a 7% error can discriminate evolution schemes and nonpert. evolution parameters
  (with full *z* dependence; see talk Signori)



Bacchetta *et al.*, arXiv:1508.00402

- at scale, discriminate intrinsic parameters of TMD FF at input hadronic scale



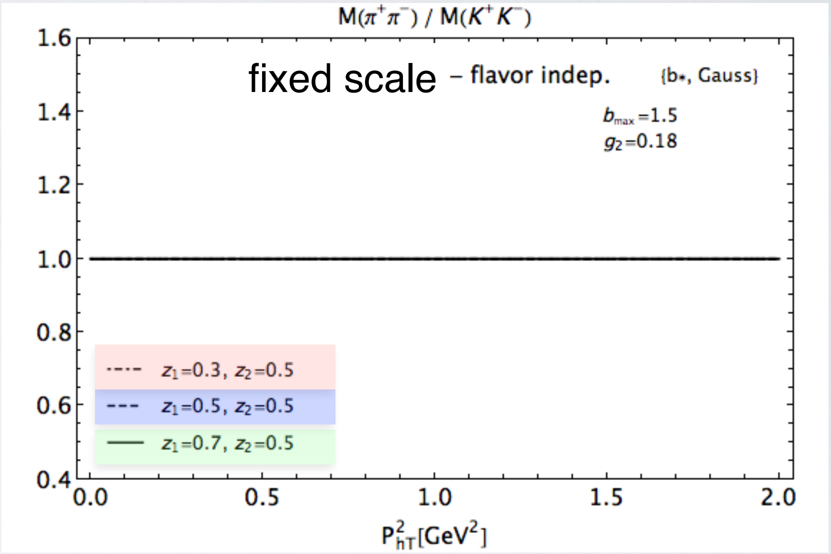
issues with e^+e^- measurements

- double ratios of like-sign and unlike-sign final hadrons to kill false asymmetries

- at Belle scale, use also ratios of multiplicities for ππ, KK, πK to constrain flavor dep. of instrinsic parameters in TMD FF at input scale

  (see talk Signori)

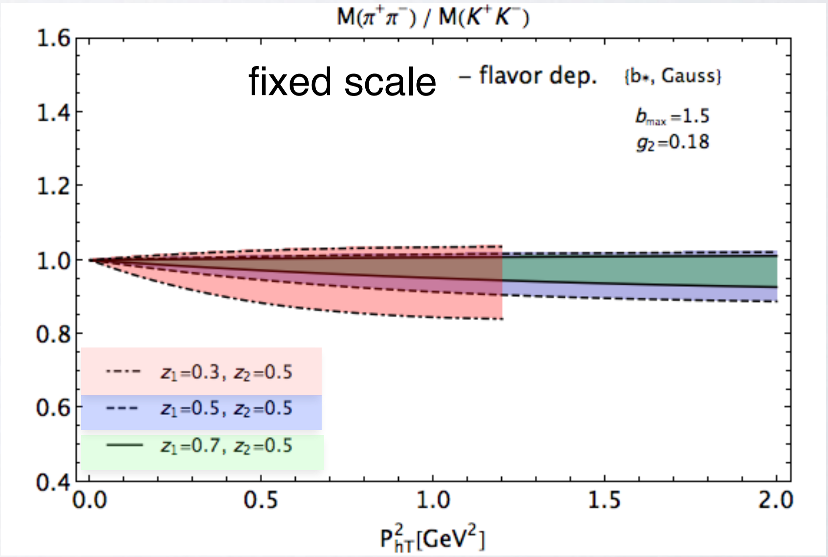
no flavor



π+π− / K+K−

Bacchetta *et al.*, arXiv:1508.00402

with flavor

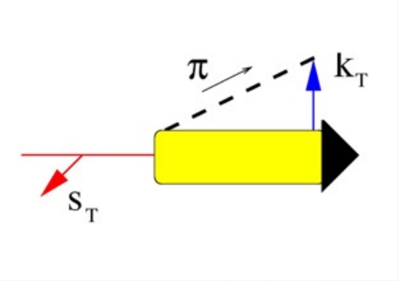


Single-hadron Fragmentation Functions (SiFF)

3. The Collins function $H_1^{\perp q}(z, \mathbf{p}_T; Q^2)$

quark pol.

U	L	T
D_1		$H_1^\perp$

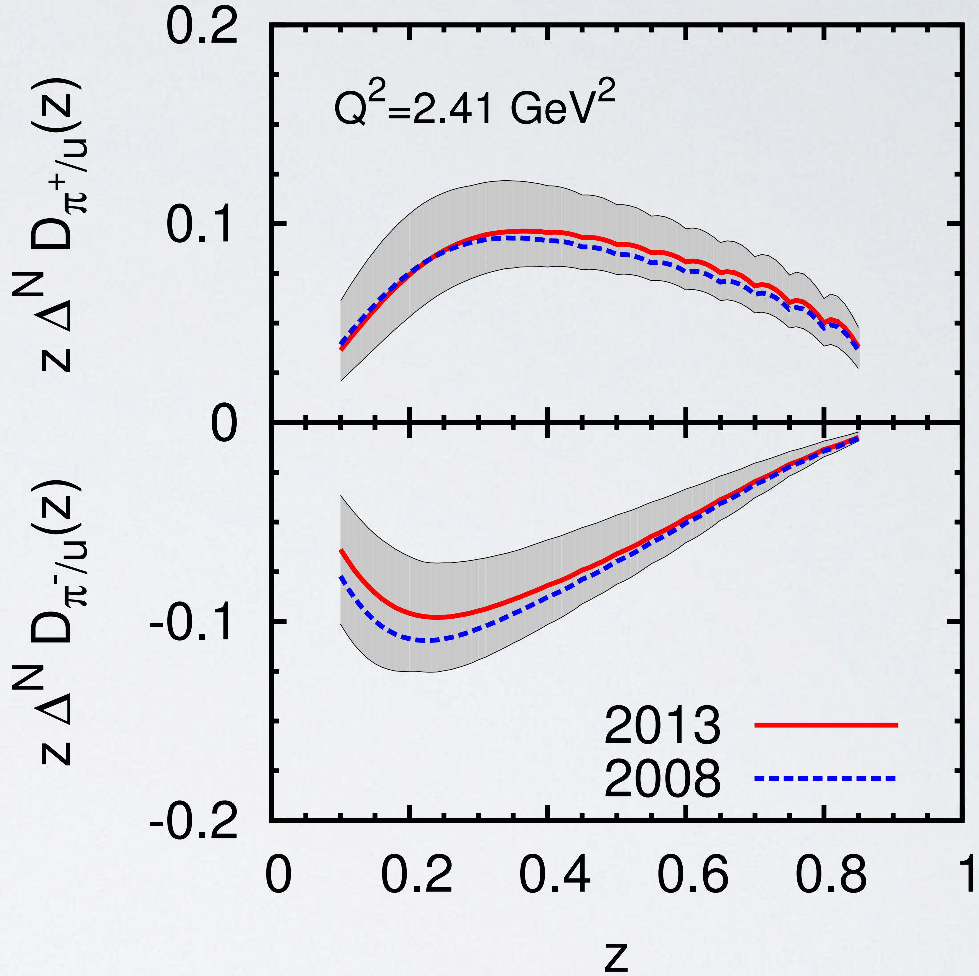


Torino fit 2013

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

$$\Delta^N D_{h/q}(z) = 4\, H_1^{\perp(1/2)q\to h}(z)$$

$$H_1^{\perp(n)}(z) = \int d\boldsymbol{P}_\perp \,\frac{1}{2}\left(\frac{\boldsymbol{P}_\perp^2}{z^2 m_h^2}\right)^n H_1^\perp(z, \boldsymbol{P}_\perp^2)$$



favored

unfavored

combined fit of
SIDIS Collins effect
and
e+e– asymmetry
(9 fit parameters)

- Gaussian ansatz with **TMD PDF** $\langle k^2_\perp\rangle$ = 0.25 GeV^2 (0.57 ± 0.08)
  TMD FF $\langle P^2_\perp\rangle$ = 0.20 GeV^2 (0.12 ± 0.01)

different from
multiplicity analysis

- only DGLAP evolution of collinear part of TMD

- extracted transversity ≈ independent extraction
  based on collinear fact.

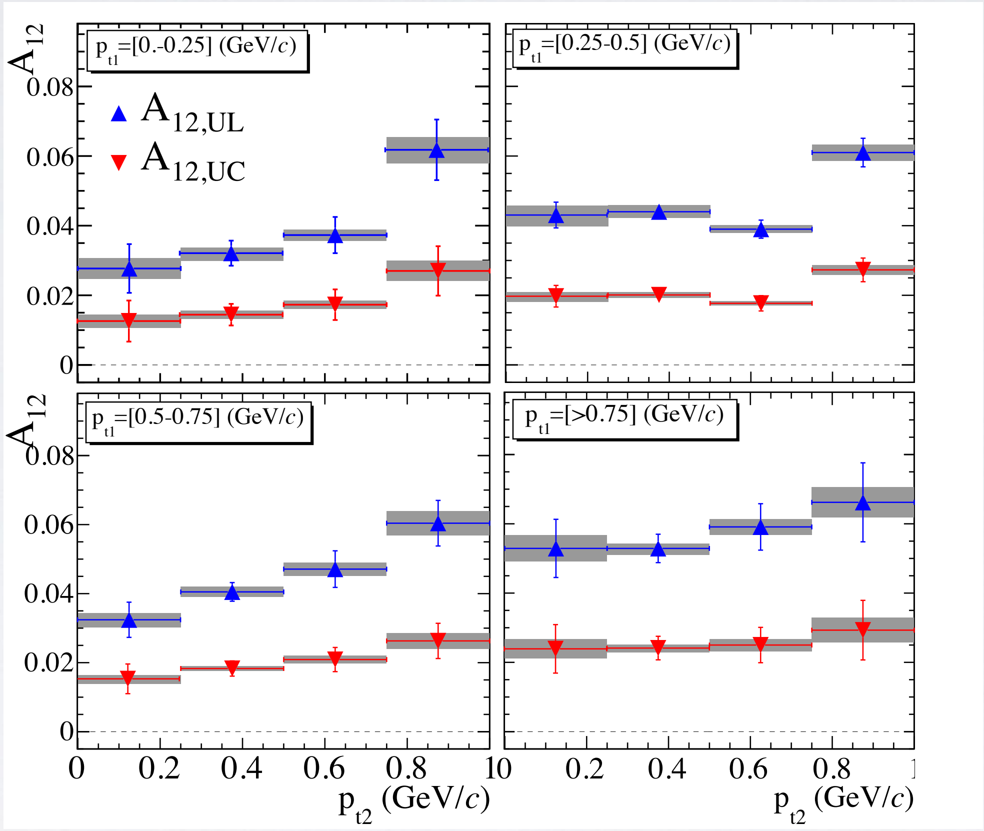
recent **data** on Collins effect

$e^+e^- \rightarrow \pi\pi X$

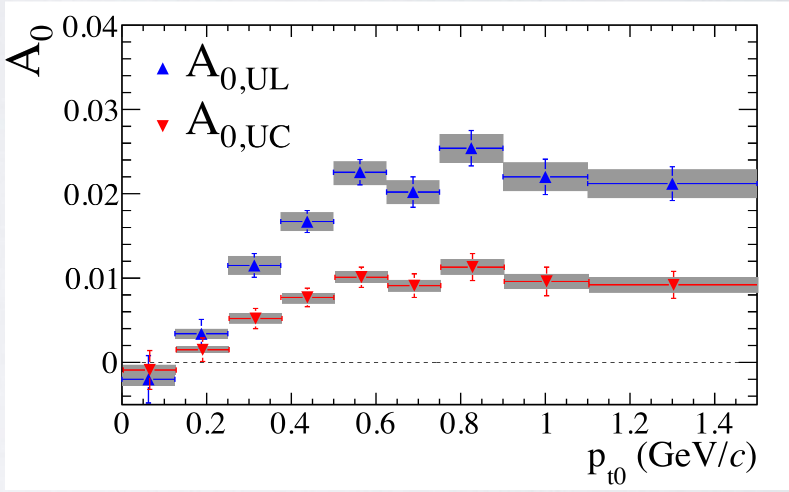
binning in
$\{z, P_{hT}\}_i$ i=1,2

(see talk by Garzia)

"thrust axis"



"fixed hadron"



Lees *et al.*, P.R. D**90** (14) 052003

binning in $\{z_1, z_2\}$ also for Kπ and KK

Lees *et al.*, arXiv:1506:05864

fit of Kang, Prokudin, Sun, Yuan

Kang *et al.*,
P.R. D**91** (15) 071501
arXiv:1505.05589

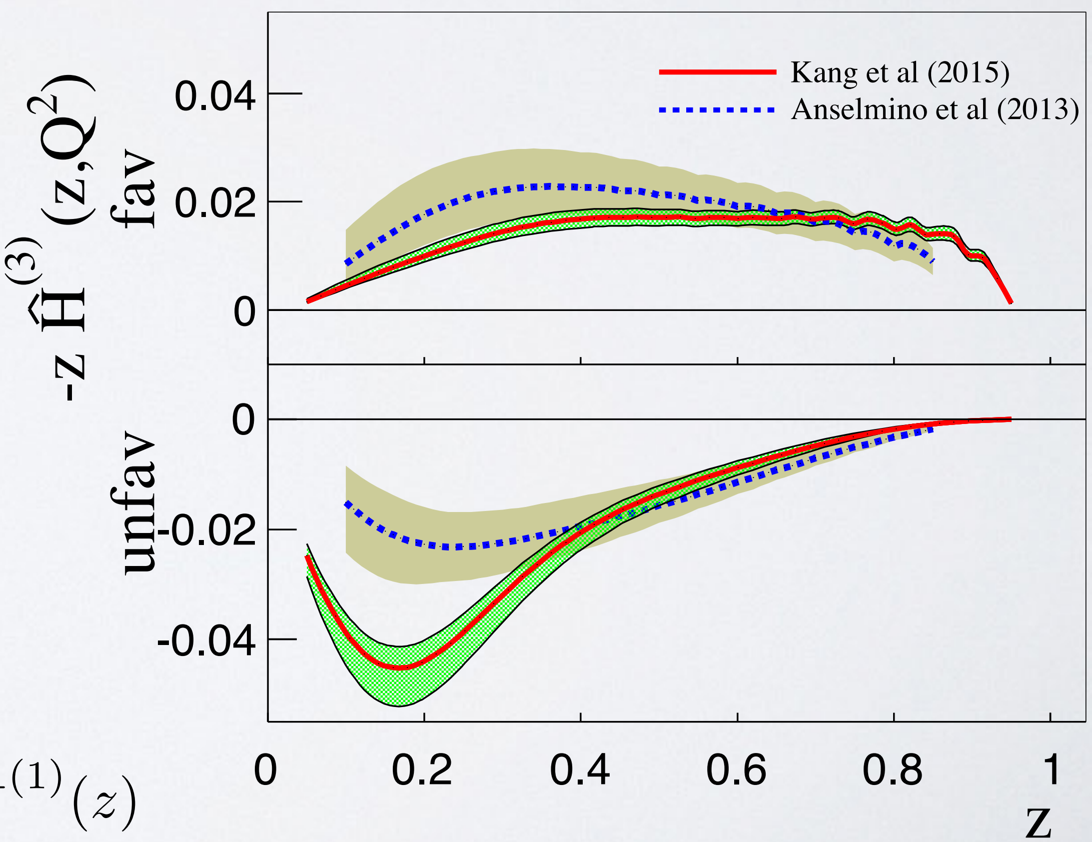
first combined fit of SIDIS Collins effect and e^+e^- asymmetry

with TMD evolution

- NLO+NLL formalism, but only homogeneous evo eqs. for $H_1^\perp$
- 13 parameters, global χ^2/dof = 0.88

Comparison with Torino fit

favored < - unfavored ?

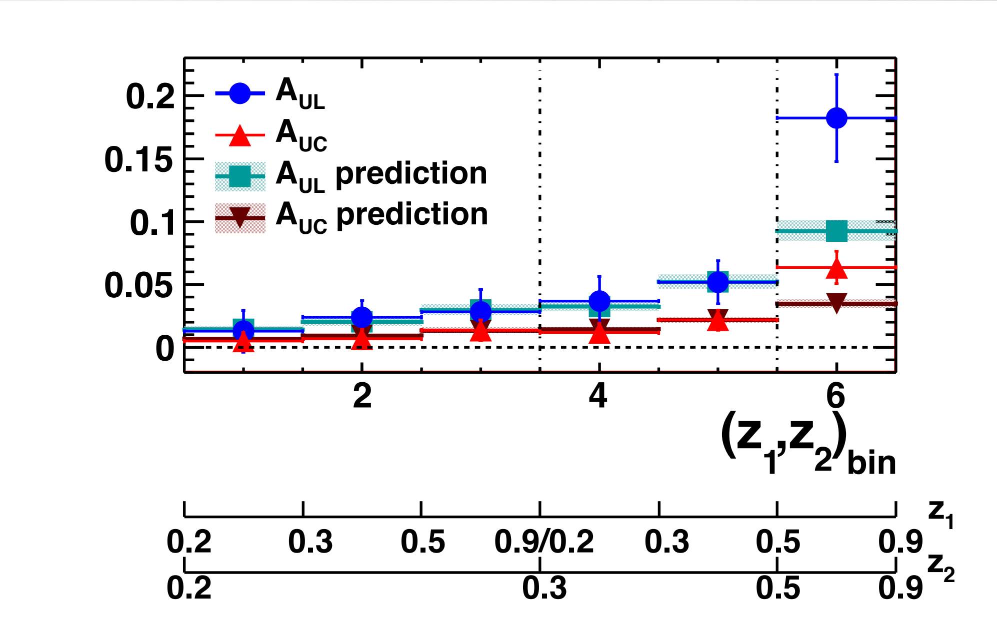


$$-z\hat{H}^{(3)}(z) = \frac{1}{2m_h} H_1^{\perp(1)}(z)$$

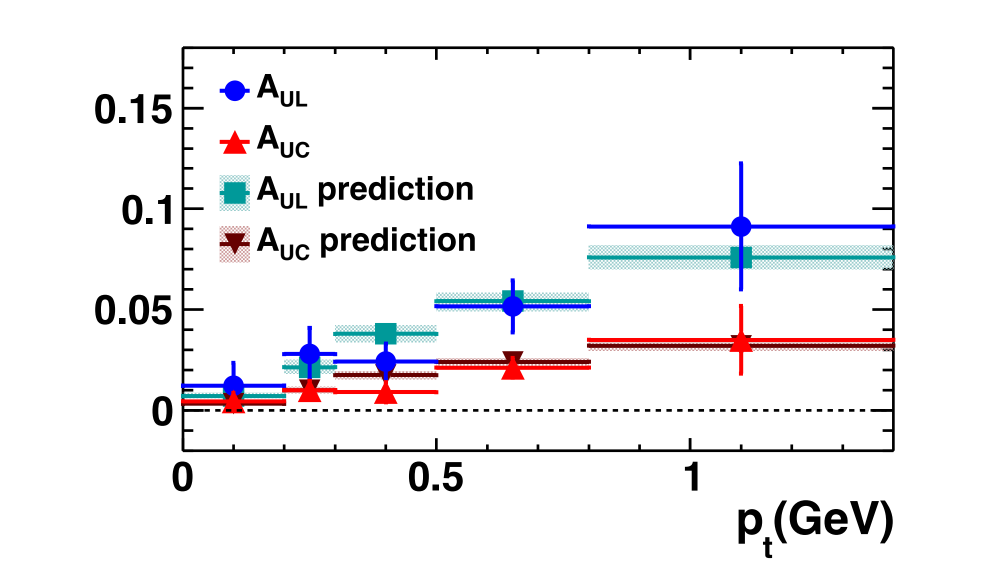
recent **data** on Collins effect

$e^+e^- \to \pi\pi X$
"fixed hadron" method

binning in {$z1$, $z2$}



binning in {z, P_{hT}}



(see talk by Garzia)

prediction from
Kang, Prokudin, Sun, Yuan

Kang *et al.*, arXiv:1505.05589

Ablikim *et al.*, arXiv:1507.06824

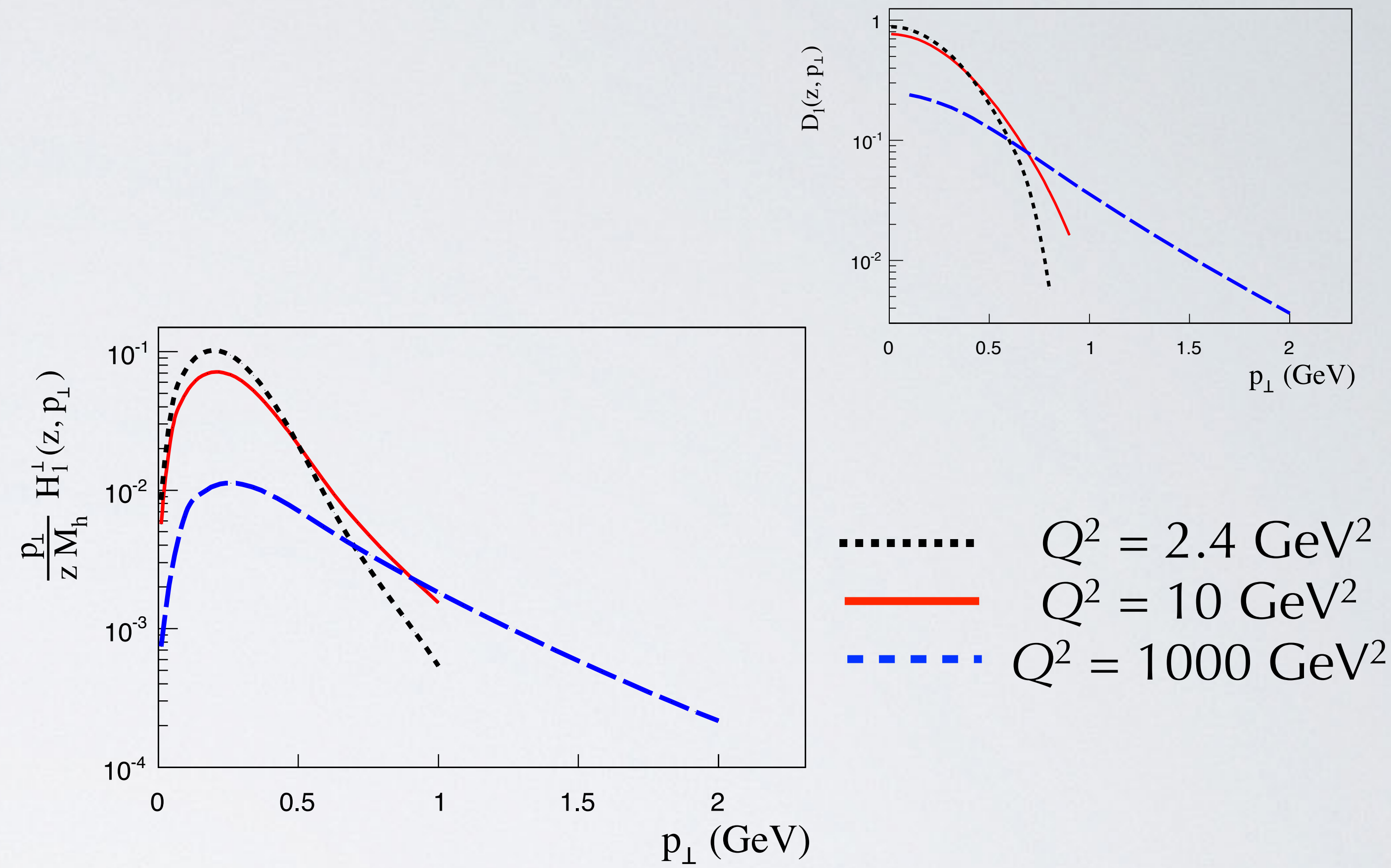
is Collins function under control ?

TMD evo effects from

Kang, Prokudin, Sun, Yuan

Kang *et al.*, arXiv:1505.05589

large broadening only at large Q^2

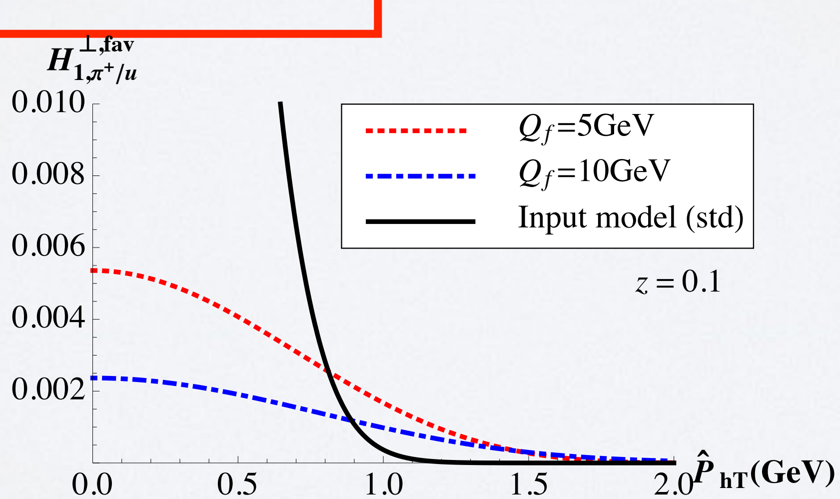


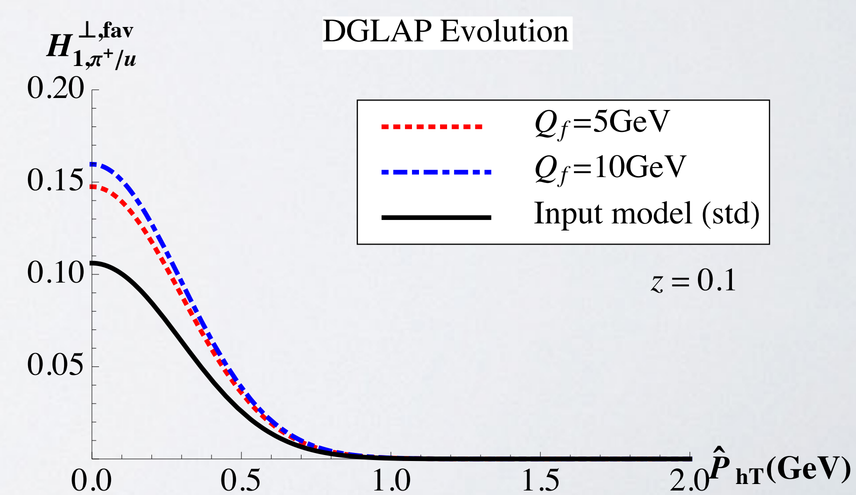
)

Echevarria, Idilbi, Scimemi

Echevarria *et al.*,
P.R. D**90** (14) 014003

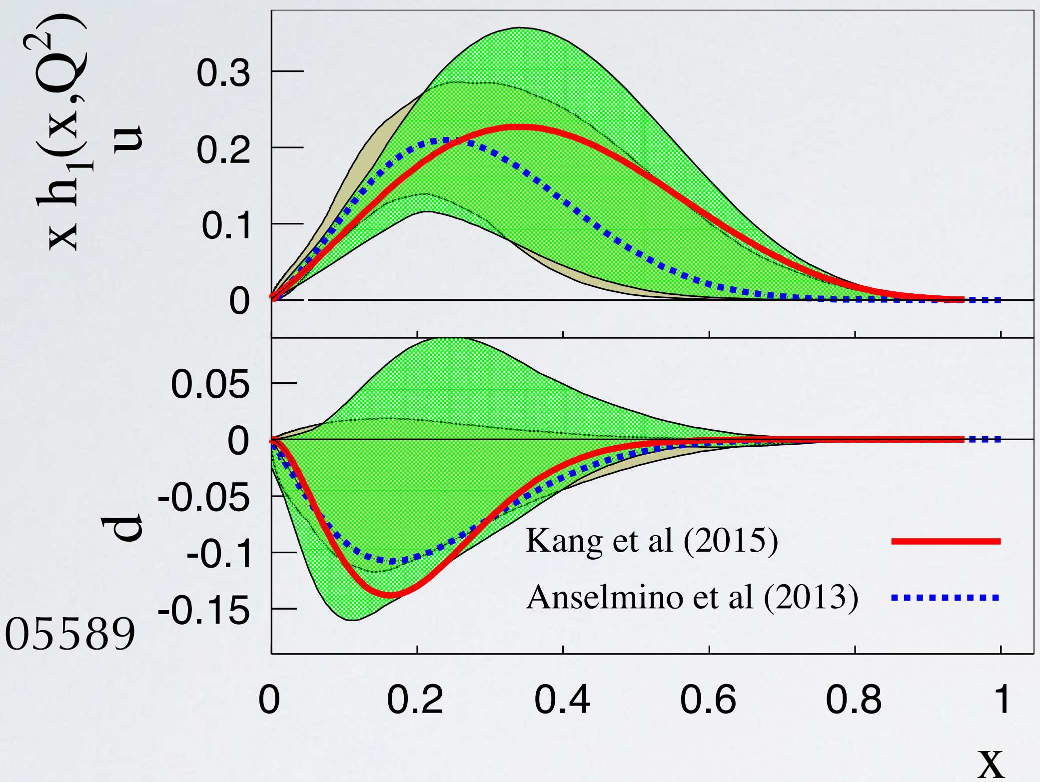
large reduction





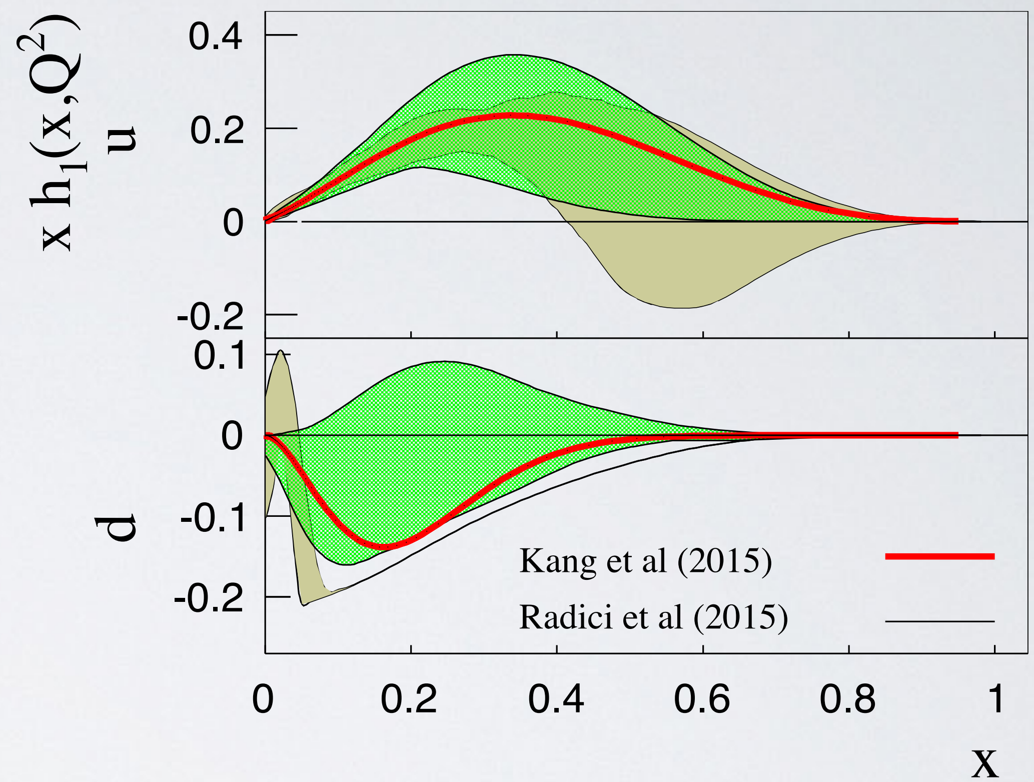
extraction of transversity

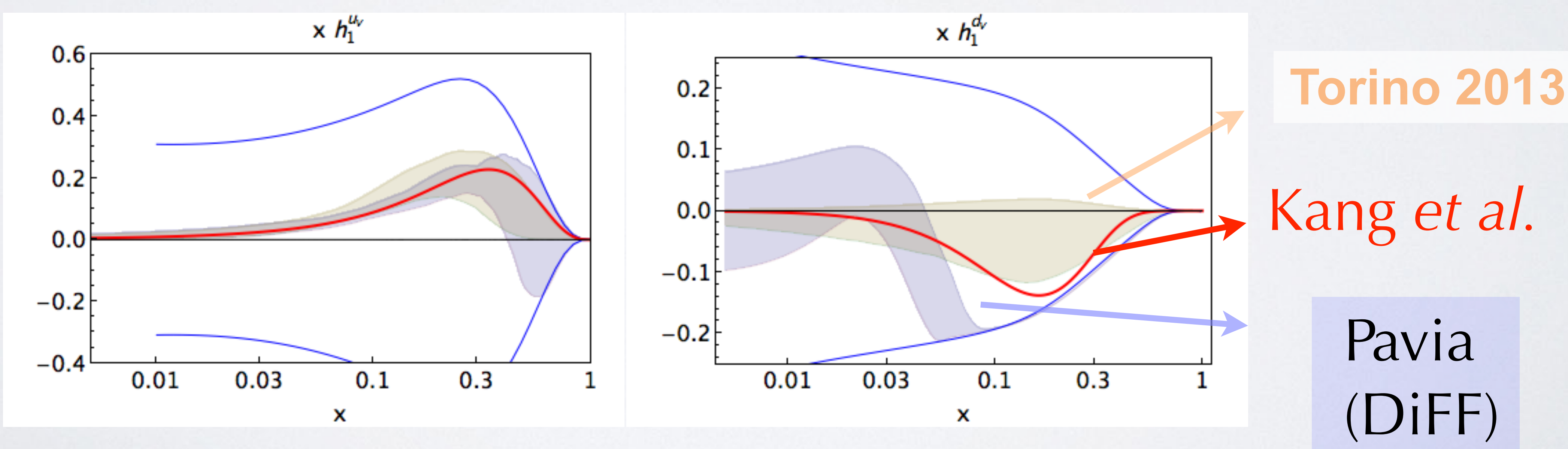
Kang *et al.* ↔ Torino



Kang *et al.*,
arXiv:1505.05589

Kang *et al.* ↔ Pavia (DiFF)

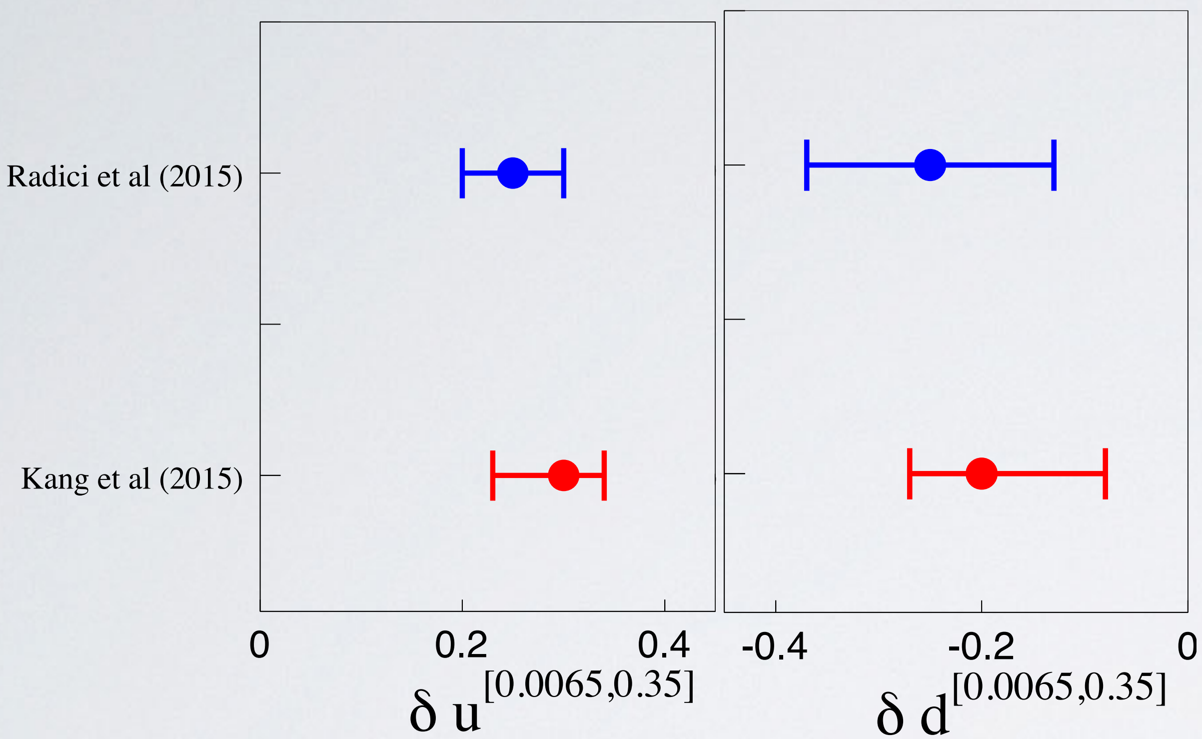


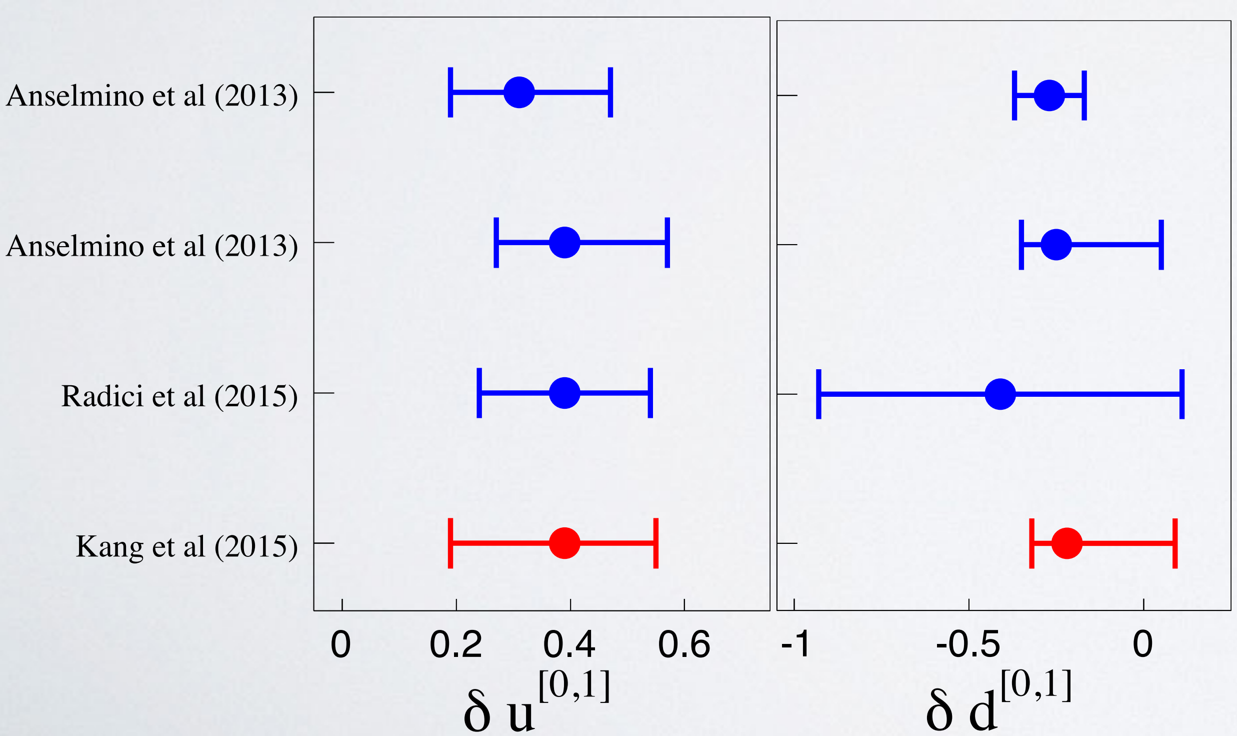


Radici *et al.*, JHEP **1505** (15) 123

tensor charge

$Q^2 = 10\ \mathrm{GeV}^2$





$\}\ Q^2 = 0.8$

$Q^2 = 1$

$Q^2 = 10$

isovector tensor charge

$g_T = \delta u - \delta d$

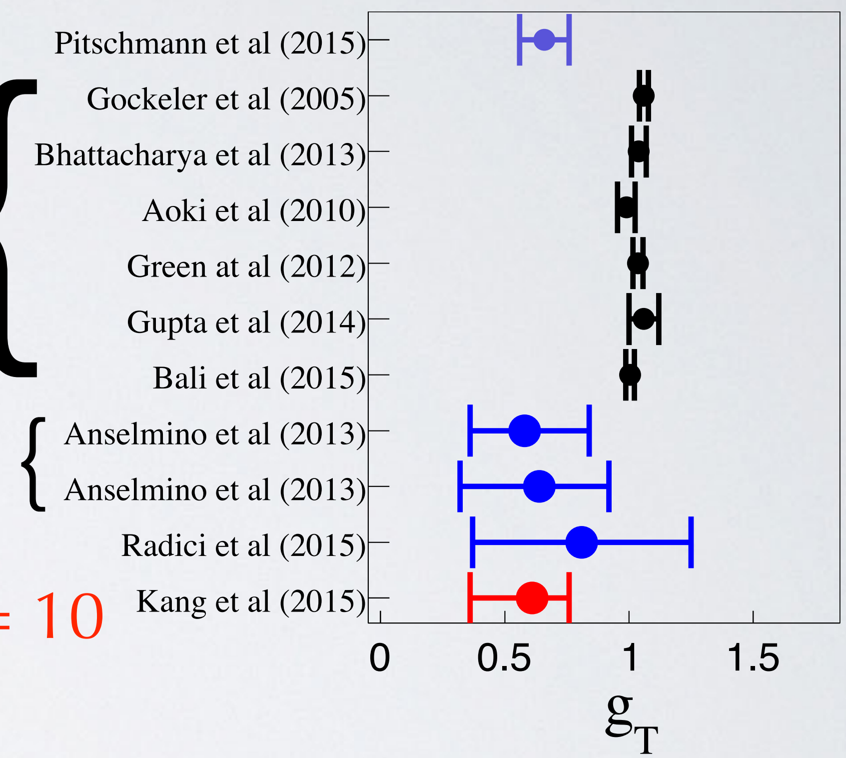
$Q^2 = 4\ \mathrm{GeV}^2$

DSE

lattice

$Q^2 = 0.8$

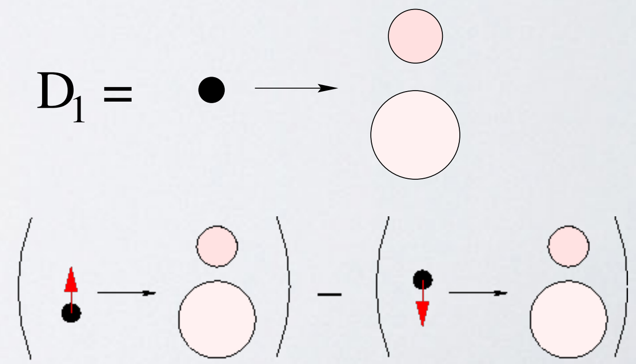
$Q^2 = 10$



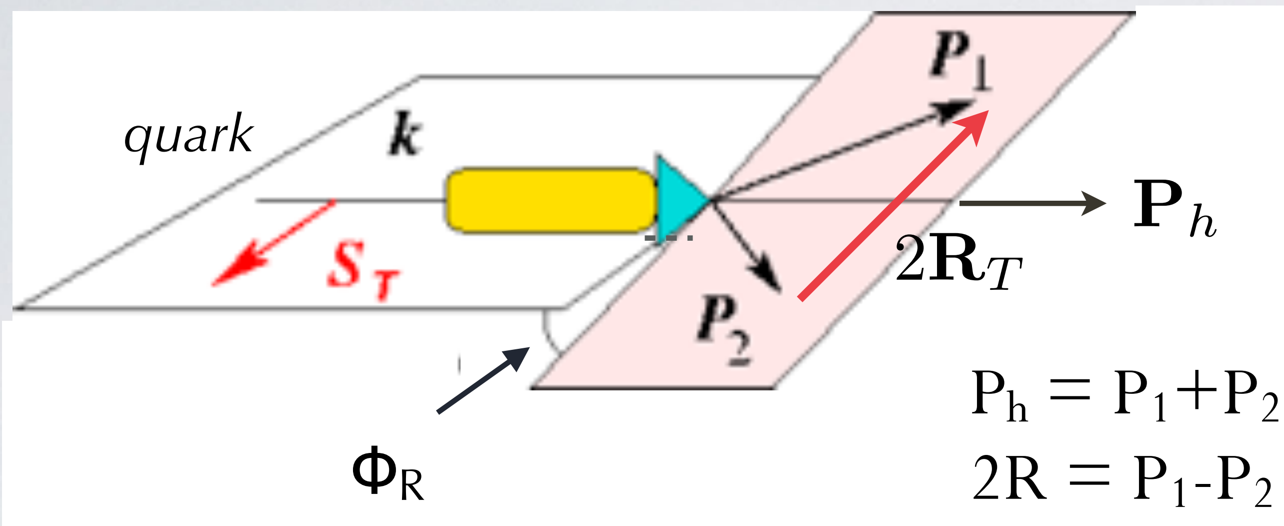
Kang *et al.*,
arXiv:1505.05589

Di-hadron Fragmentation Functions (DiFF)

quark pol.		
U	L	T
D_1		$H_1^{\sphericalangle}$



the DiFF effect



$S_T \leftrightarrow R_T$

$\int dP_{hT} \leftrightarrow P_{hT}=0 \to k_T=0$

collinear factorization

	quark pol.	
U	L	T
D_1		$H_1^{\sphericalangle}$

2 DiFF $(z_1, z_2, R_T^2; Q^2)$

$\boxed{\text{SIDIS}}$ $e\, p^{\uparrow} \to e' \, (\pi,\pi)\, X$

Radici, Jakob, Bianconi
P.R. D**65** (02)
Bacchetta & Radici,
P.R. D**67** (03)

$$d\sigma \sim d\sigma^0 + \sin(\Phi_R+\Phi_S)\, h_1\, H_1^{\sphericalangle}$$

DGLAP evolution

Ceccopieri, Radici, Bacchetta,
P.L. **B650** (07)

$\boxed{e^+ e^-}$ $e^+ e^- \to (\pi^+\pi^-)\,(\pi^+\pi^-)\, X$

Boer, Jakob, Radici
P.R. D**67** (03) 094003
Artru & Collins,
Z.Ph. C**69** (96) 277

$$d\sigma \sim d\sigma^0 + \cos(\Phi_R+\Phi_{\bar{R}})\, H_1^{\sphericalangle}\, \bar{H}_1^{\sphericalangle}$$

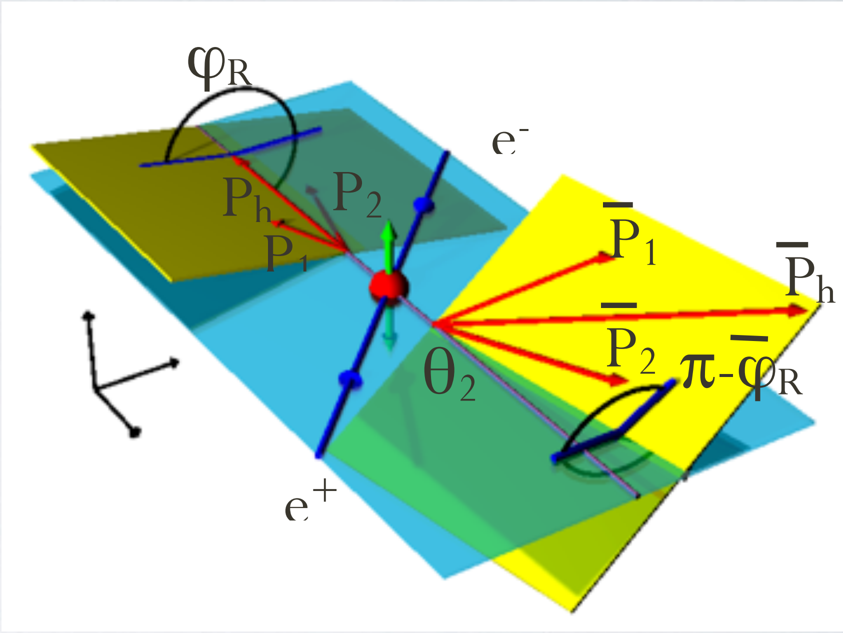
extraction of **DiFF**

$e^+ e^- \to (\pi^+\pi^-)\ (\pi^+\pi^-)\ X$

first measurement of

$$A^{\cos(\Phi_R+\Phi_{\bar{R}})} \sim \frac{H_1^{\sphericalangle}\ \bar{H}_1^{\sphericalangle}}{D_1\ \bar{D}_1}$$

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

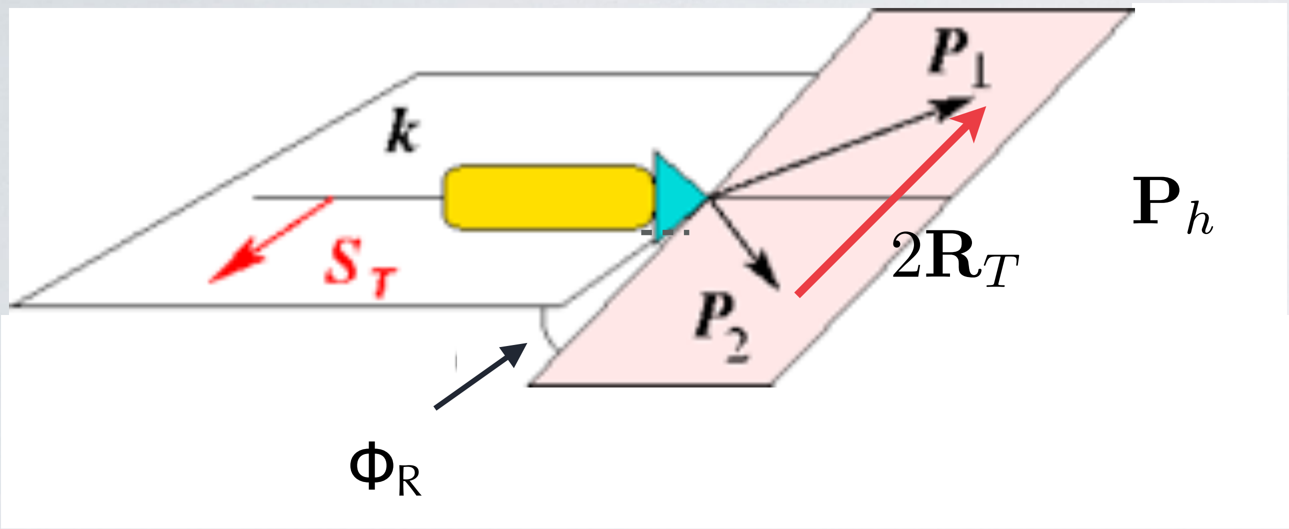


fit of $A^{\cos(\Phi_R+\Phi_{\bar{R}})} \to$ extract $H_1^{\sphericalangle}$ Courtoy *et al.*, P.R. D**85** (12) 114023

but D_1 fitted to PYTHIA (adapted to Belle kin.)

$\boxed{\text{need di-hadron multiplicities}}$

expansion of DiFF in partial waves

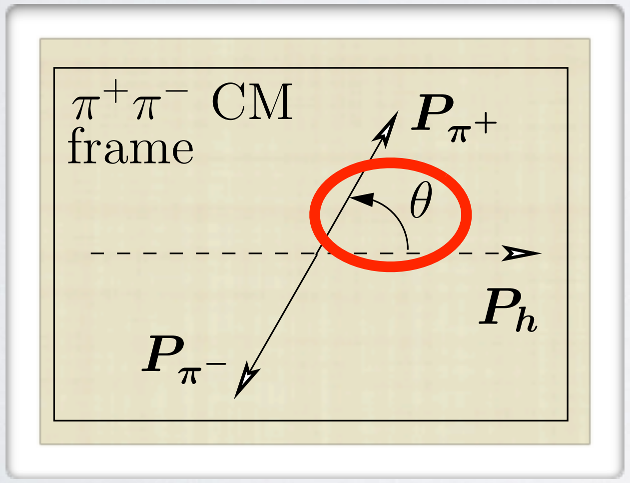


Bacchetta & Radici, P.R. D**67** (03) 094002

for low pair invariant masses, the system $(h_1,h_2)_L$ can be in relative L = 0 (*s*) or 1 (*p*) interference → model T-odd $H_1^{\sphericalangle}$

DiFF (z_1, z_2, $\boldsymbol{R}_T^2$) ↔ DiFF ($z=z_1+z_2$, ζ, M_h^2)

(h_1,h_2) c.m. frame



change of variable $\zeta = \dfrac{z_1 - z_2}{z} \longleftrightarrow \cos\theta$

expansion in cosθ

$$D_1^q(z,\zeta,M_h^2) \approx D_1^q(z,M_h^2) + D_{1\,sp}^q(z,M_h^2)\cos\theta + \ldots$$

$$H_1^{\sphericalangle\,q}(z,\zeta,M_h^2) \approx H_{1,sp}^{\sphericalangle\,q}(z,M_h^2) + H_{1,pp}^{\sphericalangle\,q}(z,M_h^2)\cos\theta + \ldots$$

these are really measured … maybe …

(see talk Vossen)

extraction of valence $h_1^{q_v}$ and future

$e^+ e^-$

$(\pi^+\pi^-)$

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

SIDIS

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

first point-by-point extraction of
u_v - 1/4 d_v

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

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

u_v - 1/4 d_v
u_v + d_v

fit of
u_v and d_v

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

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

new fit of u_v and d_v
Radici *et al.*, JHEP **1505** (15) 123

Future

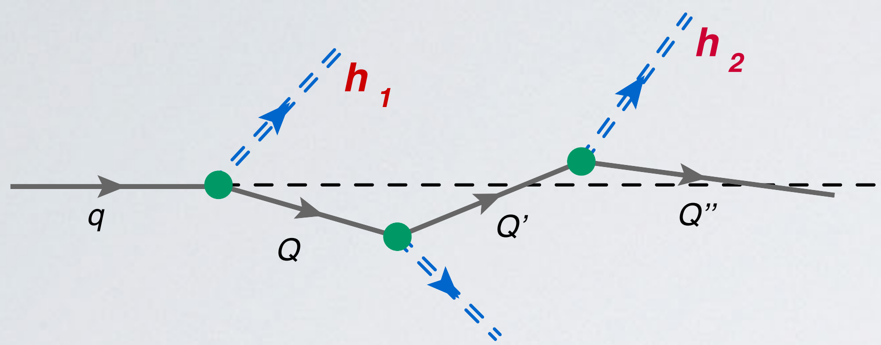
data for p p$^\uparrow \rightarrow$ $(\pi\pi)$ X
Adamczyk *et al.*, arXiv:1504.00415

ongoing analysis
test of universality

data with $K\pi$, KK pairs $\Rightarrow$ data with KK and $K\pi$?

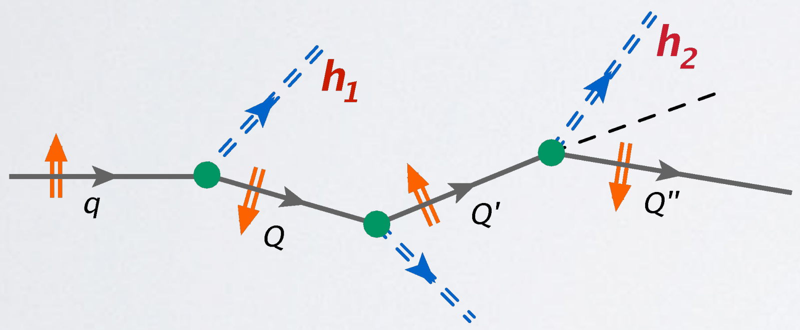
explore contribution of sea quarks to transversity

parallel model studies: the NJL-jet model



quark hadronization chain
NJL assumed at each vertex
DiFF = MC averages of proper multiplicities
results for q=u,d,s and
h= ππ, πK, KK pairs and
decay of vector mesons

Casey *et al.*, P.R. D**85** (12) 114049
P.R. D**86** (12) 114018
Matevosyan *et al.*, P.R. D**88** (13) 094022

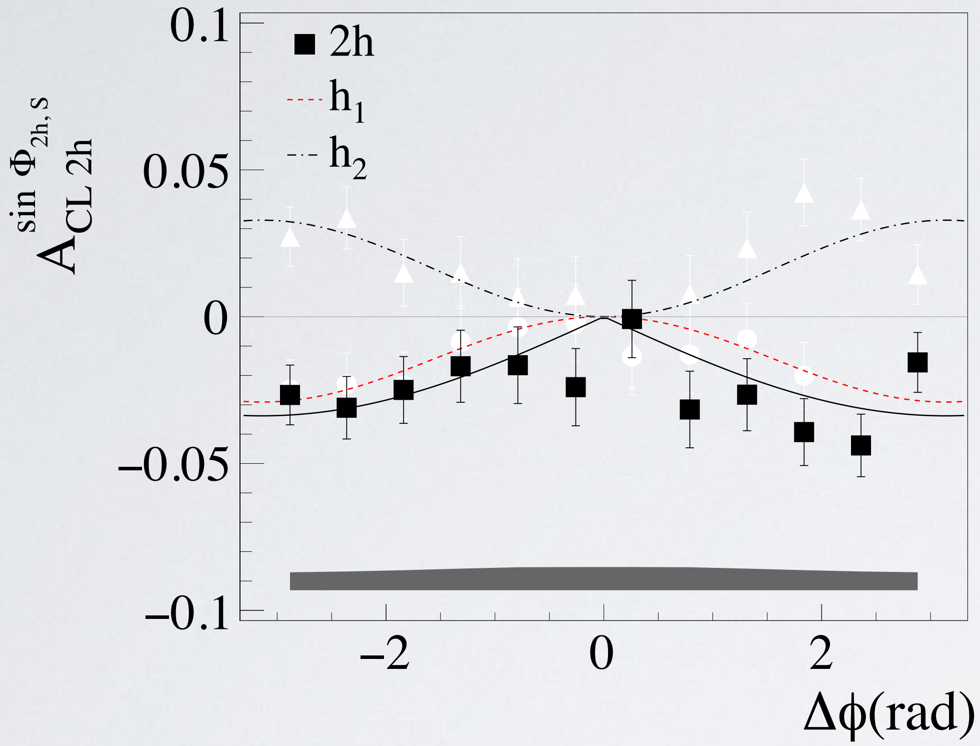


recently extended to include effects of
transverse polarization of fragmenting quark
and
transverse momentum-spin correlations

Matevosyan *et al.*, P.L. **B731** (14) 208
Kotzinian *et al.*, P.R.L. **113** (14) 062003
P.R. D**90** (14) 074006
Matevosyan *et al.*, arXiv:1502.02669

(see talk Matevosyan)

similar origin for Collins and DiFF effects ?



Adolph *et al.*, arXiv:1507.07593

fit to Collins-like asymmetry for h_2

fit to Collins-like asymmetry for h_1

■ sin φ_{2h} asymmetry $\varphi_{2h} \leftrightarrow \boldsymbol{R} = \boldsymbol{p}_1 - \boldsymbol{p}_2$

$\Delta\varphi = \varphi_1 - \varphi_2$ $\varphi_1 \leftrightarrow \boldsymbol{p}_1$ $\varphi_2 \leftrightarrow \boldsymbol{p}_2$

(see talk Bradamante)

in agreement with $3P^0$ string fragmentation model Artru *et al.*, Z.Ph. **C73** (97) 527

supported by MC calculations of DiFF in NJL-jet model:
elementary Collins mechanism generates sinφ_R modulation

Matevosyan *et al.*, P.L. **B731** (14) 208

a detour from phenomenology to theory..

Gliske, Bacchetta, Radici,
P.R. D**90** (14) 114027

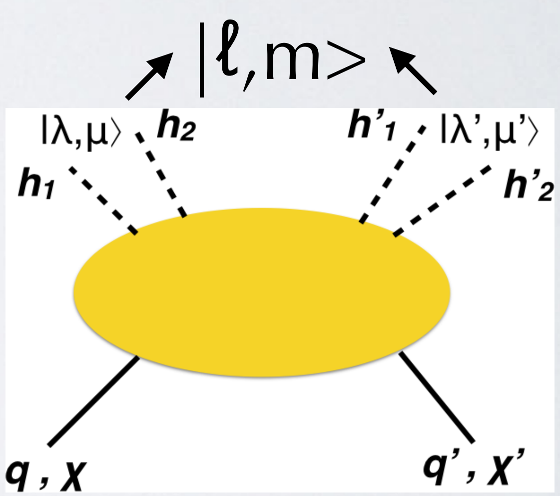
general di-hadron SIDIS cross section
up to twist 3 for any partial wave

$$d\sigma_{XY} \sim \sum_{\ell=0}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} P_{\ell m}(\cos\theta)\, f_m(\cos\phi_h,\, \cos\phi_R)\, \boxed{F_{XY}^{P_{\ell m}\, f_m}}$$

$$F_{XY}^{P_{\ell m}\, f_m}(x, z, P_{h\perp}^2, M_h^2) = \mathrm{TMD}(x, \boldsymbol{k}_\perp) \otimes_{\boldsymbol{k}_\perp, \boldsymbol{p}_\perp} \mathrm{DiFF}^{\ell m}(z, M_h^2, |\boldsymbol{p}_\perp|)$$

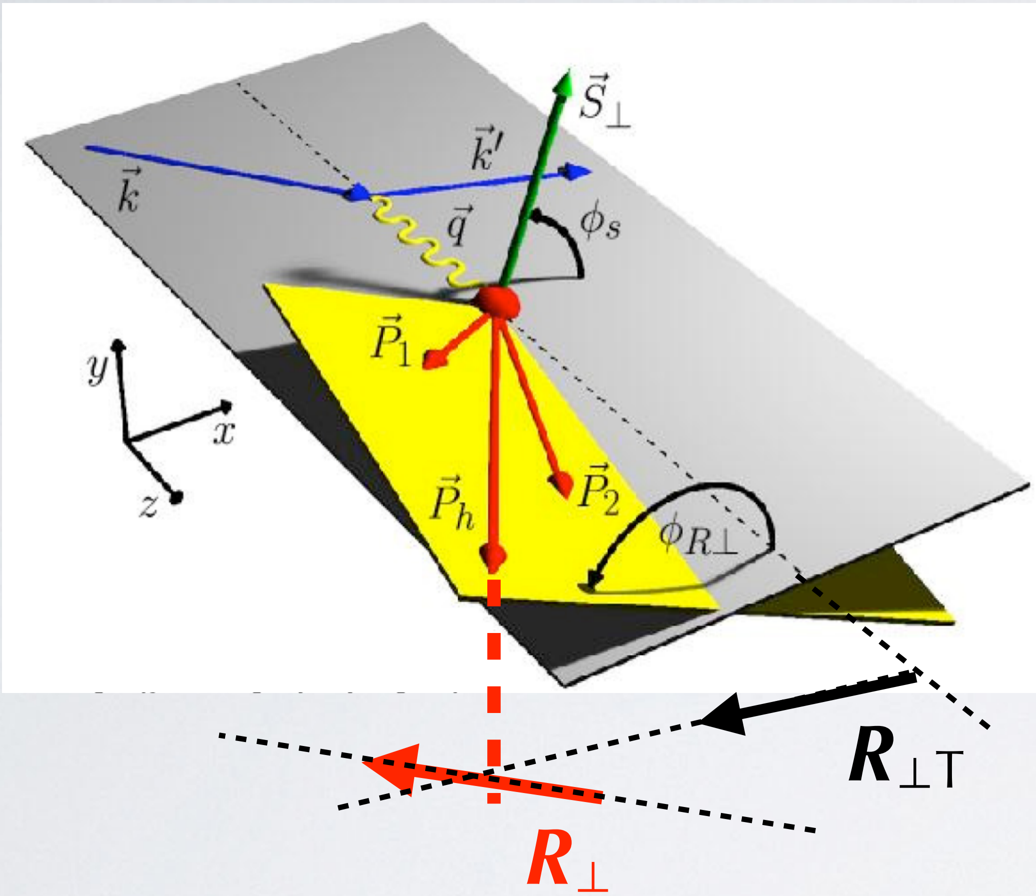
(assuming factorization th. also for 2-hadron SIDIS)

- $\ell = \lambda \oplus \lambda'$ total partial wave of final hadronic system
  $\ell_{\max}$ in principle not limited, because hadronic tensor not linear in *R*
- 3 classes of DiFF$^{\ell m}$: $D^{\ell m} \leftrightarrow \chi=\chi'=1/2 \;+\; \chi=\chi'=-1/2$
  $G^{\ell m} \leftrightarrow \chi=\chi'=1/2 \;-\; \chi=\chi'=-1/2$
  $H^{\ell m} \leftrightarrow \chi \neq \chi'$



definition of azimuthal angles

Gliske, Bacchetta, Radici, P.R. D**90** (14) 114027



$$R_\perp^\mu = g_\perp^{\mu\nu} R_\nu \qquad \ell_T^\mu = g_T^{\mu\nu} \ell_\nu$$

$$R_{\perp T}^\mu = g_T^{\mu\nu} R_{\perp\nu}$$

covariant definition

$$\cos\phi_{R_T} = -\frac{\ell_\mu R_{\perp\nu} g_T^{\mu\nu}}{\sqrt{\ell_T^2\, R_{\perp T}^2}}$$

$$\sin\phi_{R_T} = -\frac{\ell_\mu R_{\perp\nu} \epsilon_T^{\mu\nu}}{\sqrt{\ell_T^2\, R_{\perp T}^2}}$$

covariant definition

→ TRF $\quad \boldsymbol{R}_{\perp T}\big|_{\mathrm{TRF}} = \dfrac{z_2 \boldsymbol{P}_{1T} - z_1 \boldsymbol{P}_{2T}}{z} + \mathcal{O}\left(\dfrac{1}{Q^3}\right)$ by Artru & Collins COMPASS

$$= (\boldsymbol{R} - \boldsymbol{R}\cdot\hat{\boldsymbol{P}}_h\,\hat{\boldsymbol{P}}_h)_T + \left(\frac{1}{Q^3}\right)$$ HERMES , BELLE

→ IMF $\quad$ " " $\quad +\mathcal{O}\left(\dfrac{1}{Q^2}\right)$

γ*-P Breit frame

definition of azimuthal angles

Gliske, Bacchetta, Radici,
P.R. D**90** (14) 114027

covariant definition → TRF $\quad \phi_{R_T} = \frac{(\boldsymbol{q}\times\boldsymbol{\ell})\cdot\boldsymbol{R}_\perp}{|(\boldsymbol{q}\times\boldsymbol{\ell})\cdot\boldsymbol{R}_\perp|} \arccos\frac{(\boldsymbol{q}\times\boldsymbol{\ell})\cdot(\boldsymbol{q}\times\boldsymbol{R}_\perp)}{|\boldsymbol{q}\times\boldsymbol{\ell}|\,|\boldsymbol{q}\times\boldsymbol{R}_\perp|}$

with this choice, if $\int d\boldsymbol{P}_{hT}$ then no di-hadron Sivers or Collins effects arise

→ no $\boldsymbol{k}_T$ ⇒ $\boldsymbol{k}\times\boldsymbol{P}\cdot\boldsymbol{S}=0$ and $\boldsymbol{k}\times\boldsymbol{P}_h\cdot\boldsymbol{S}_q=0$

choice of

Kotzinian, Matevosyan, Thomas,
P.R.L. **113** (14) 062003
P.R. D90 (14) 074006
P.L. **B731** (14) 208

Matevosyan *et al.*,
arXiv:1502.02669

$$\boldsymbol{R}_T = \frac{\boldsymbol{P}_{1T}-\boldsymbol{P}_{2T}}{2} = \boldsymbol{R}_\perp + \frac{z_1-z_2}{2}\boldsymbol{k}_T$$

non covariant choice: depending on the frame, TMD effects can arise…

claim of Sivers effect and Collins-induced sin φ_R modulation in di-hadron SIDIS even without sensitivity to quark $\boldsymbol{k}_T$ ($\int d\boldsymbol{P}_{hT}$)
(see talk Kotzinian & Matevosyan)

are really Sivers and Collins-like effects ?