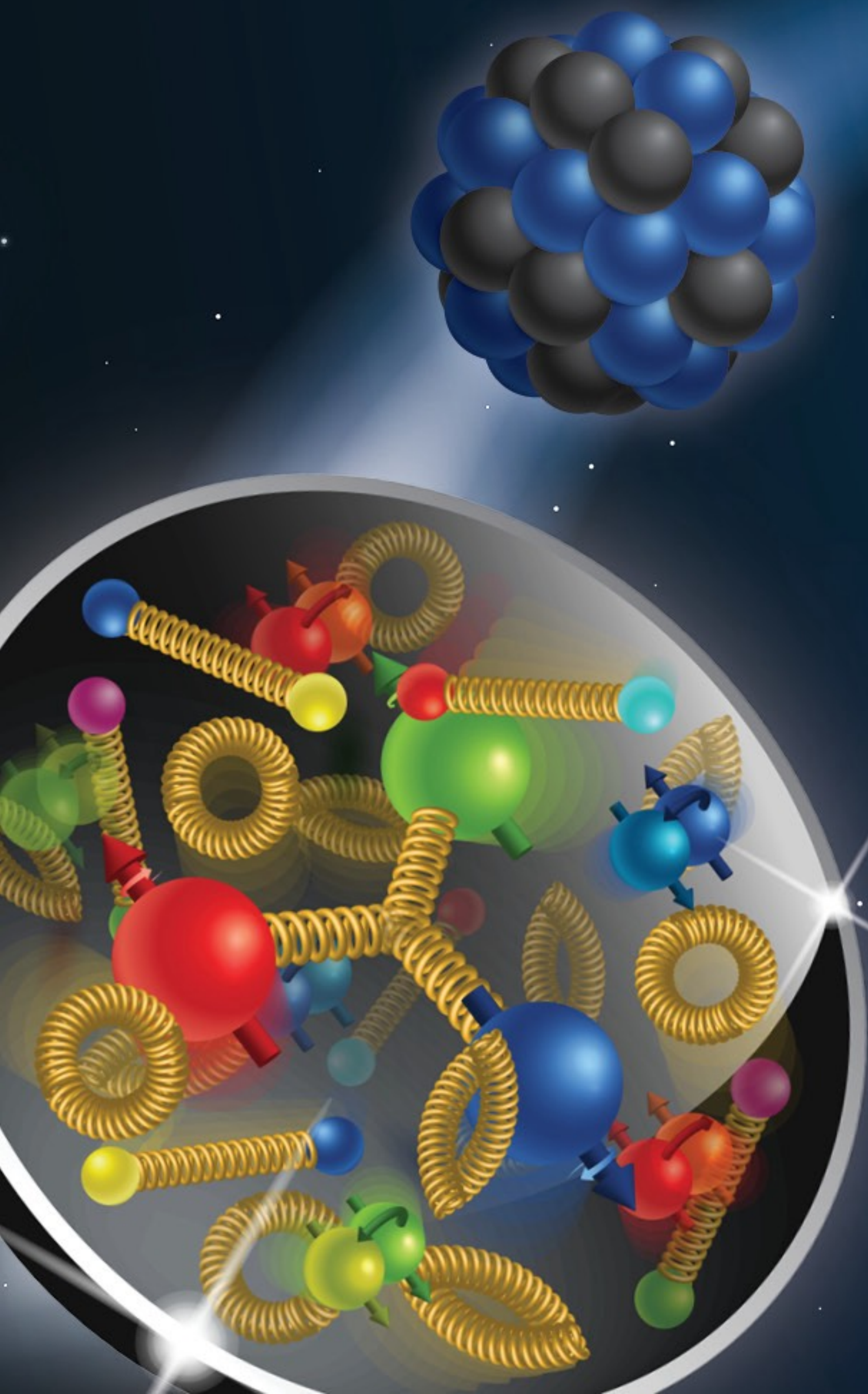


Giornata nazionale EIC_NET 2022

Transversity 2022 highlights and the Physics of SIDIS

Marco Radici

INFN Pavia

Istituto Nazionale di Fisica Nucleare

Transversity 2022 in numbers

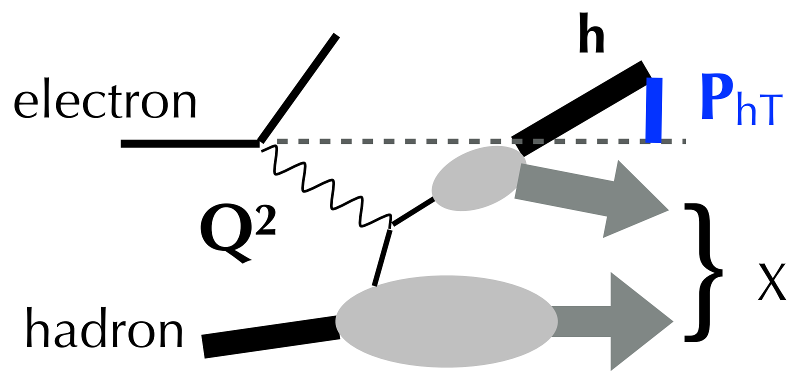
65 registered
49 in person, **16** remote

57 talks, **8** from remote
16 short talks
+
Piet Mulders' fest for
his 70th birthday

Transversity 2022 outline

Mostly focus on

Semi-Inclusive Deep-Inelastic Scattering (SIDIS)



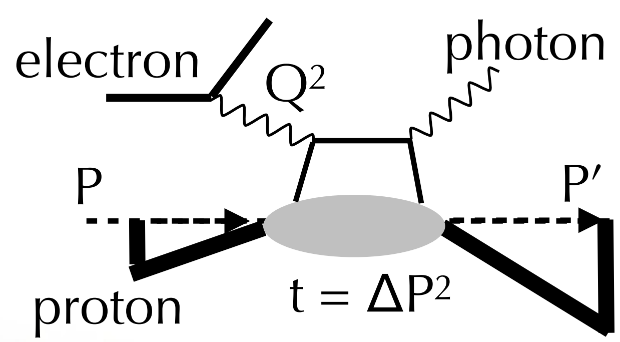
with various final states "**h**" :

- light- / heavy-quark hadrons
- jets, hadron-in-jet, etc..

Factorization th.'s available (not everywhere!) for $P_{hT}^2/z^2 \ll Q^2$

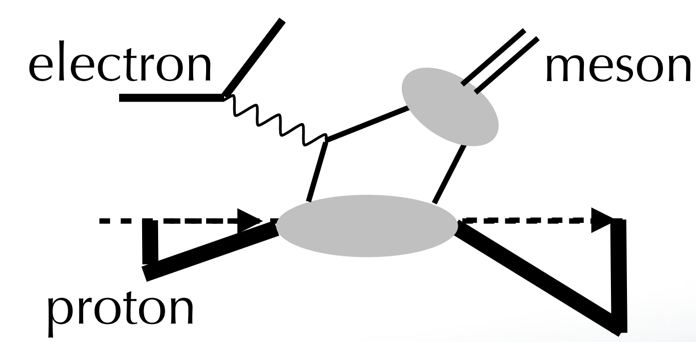
but also exclusive processes…

DVCS



$t \ll Q^2$

DVMP

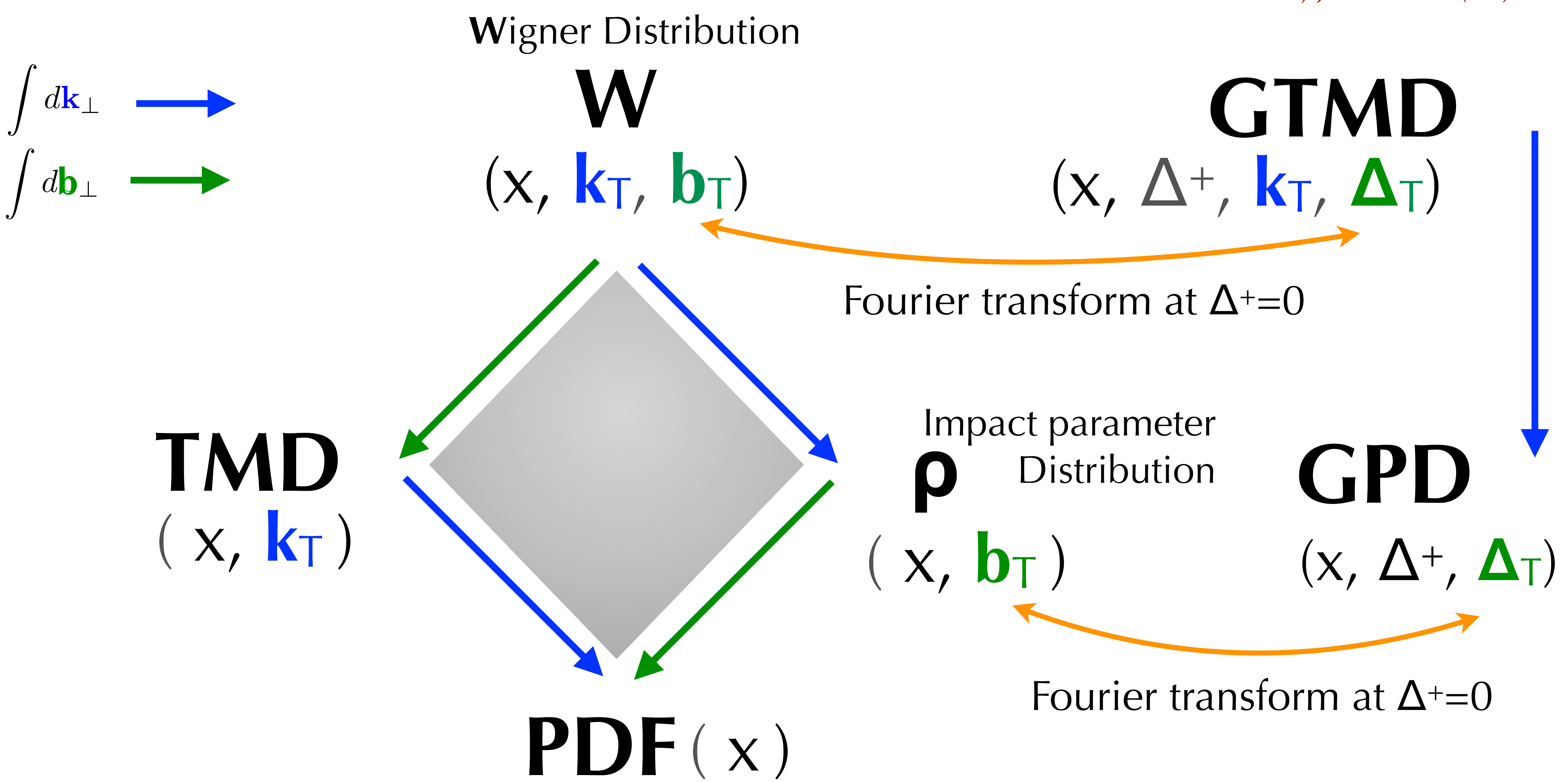


and specific diffractive channels

Electron-Ion Collider

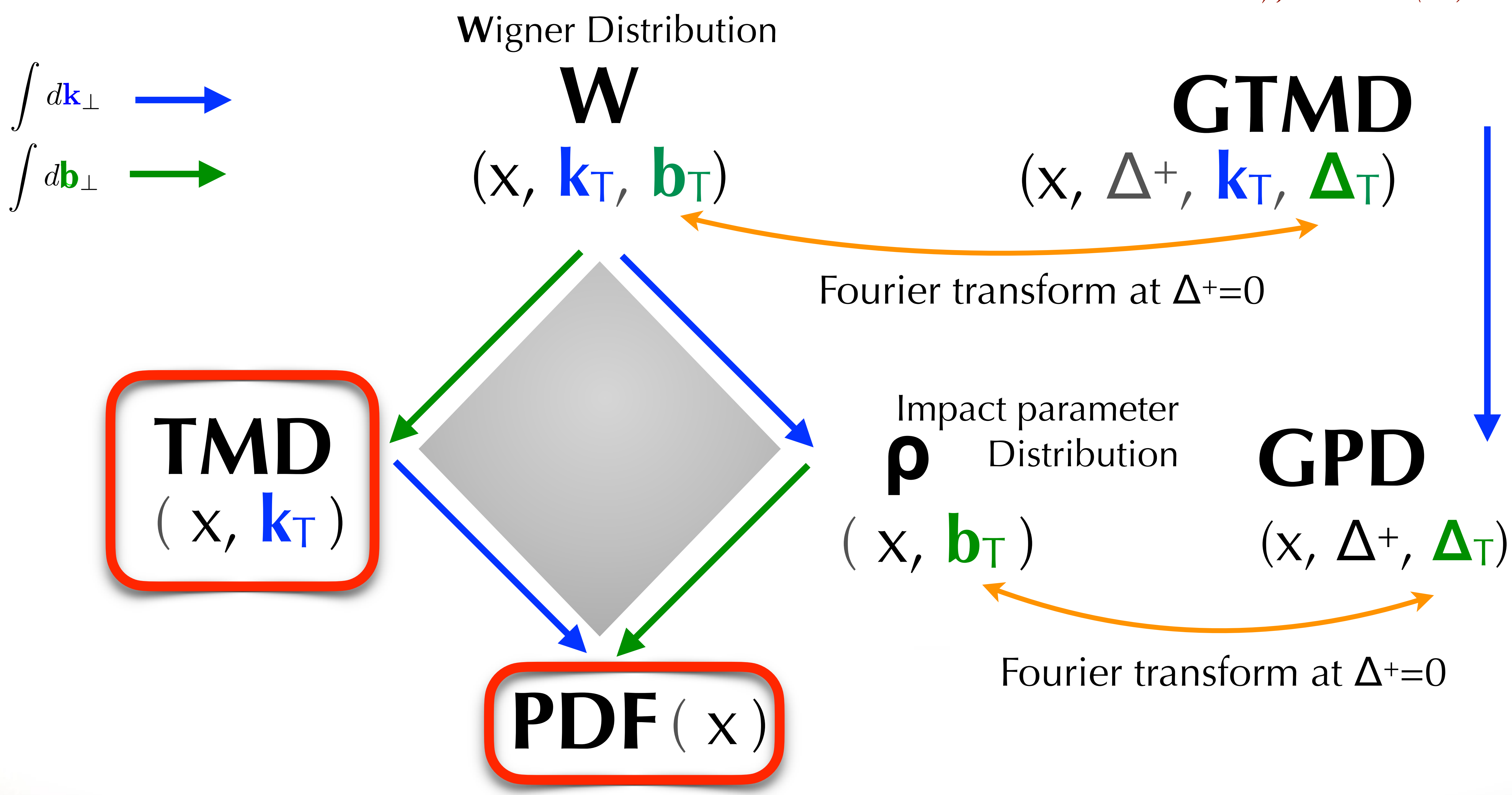
From the point of view of a theoretician…

Lorcé et al., JHEP ***1105*** *(11) 041*



From the point of view of a theoretician…

*Lorcé et al., JHEP **1105** (11) 041*

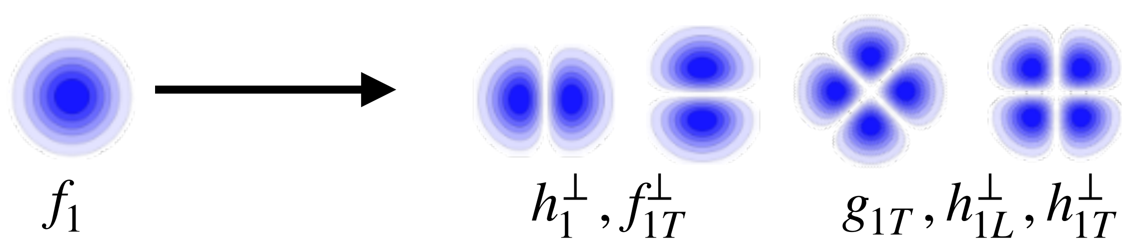


What do we know about them ?
Where do we learn more ?

The TMD "zoo" at leading twist

Nucleon Polarization		Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
	U	$f_1 =$	✗	$h_1^{\perp} =$
	L	✗	$g_1 =$	$h_{1L}^{\perp} =$
	T	$f_{1T}^{\perp} =$	$g_{1T} =$	$h_1 =$ $h_{1T}^{\perp} =$

deformations induced by spin-momentum correlations



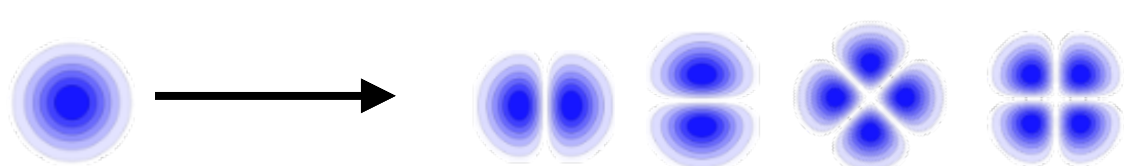
each TMD is connected to a specific measurable SIDIS spin asymmetry

The TMD "zoo" at leading twist

		Quark polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	f_1 =	✘	$h_1^{\perp}$ = –
	L	✘	g_1 = –	$h_{1L}^{\perp}$ = –
	T	$f_{1T}^{\perp}$ = –	g_{1T} = –	h_1 = – $h_{1T}^{\perp}$ = –

exist as collinear PDFs

deformations induced by spin-momentum correlations



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

each TMD is connected to a specific measurable SIDIS spin asymmetry

Transversity

		Quark polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	$f_1 =$	✗	$h_1^\perp =$ -
	L	✗	$g_1 =$ -	$h_{1L}^\perp =$ -
	T	$f_{1T}^\perp =$ -	$g_{1T} =$ -	$h_1 =$ - (transversity) $h_{1T}^\perp =$ -

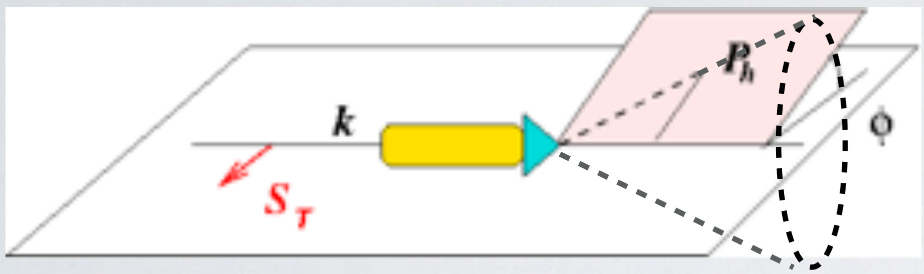
transversity

- chiral-odd structure also in collinear kin.
- only way to determine the tensor charge $\delta^q(Q^2) = \int_0^1 dx\, h_1^{q-\bar{q}}(x, Q^2)$
- no chiral-odd structures in SM Lagrangian; potential doorway to BSM

Example: in SMEFT's, neutron EDM d_n is source of strong CP violation

bounds from exp. ⟶ $d_n = \delta u\, d_u + \delta d\, d_d + \delta s\, d_s$ tensor charges

Mechanisms for transversity



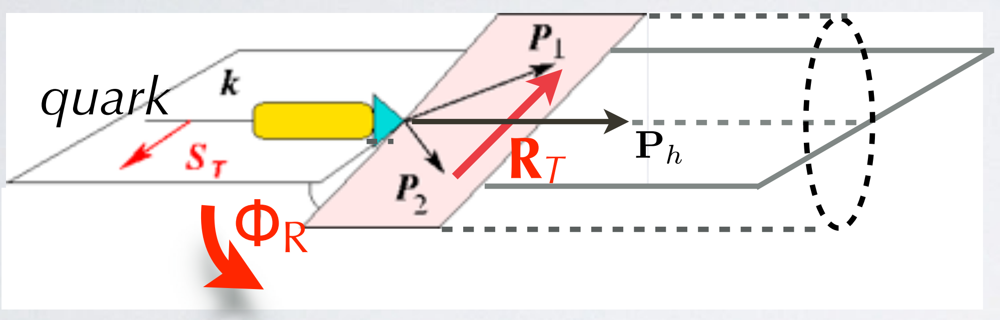
Collins effect

$\mathbf{S_T \cdot k \times P_{hT}}$

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

$h_1(x, k_\perp) \otimes H_1^\perp(z, P_\perp)$

transversity as TMD



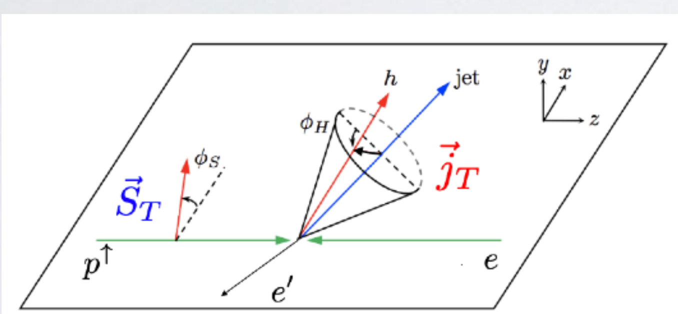
di-hadron mechanism

$\mathbf{S_T \cdot P_2 \times P_1 = S_T \cdot P_h \times R_T}$

*Collins et al., N.P. **B420** (94)*

$h_1(x)\, H_1^{\sphericalangle}(z, R_T^2)$

transversity as PDF

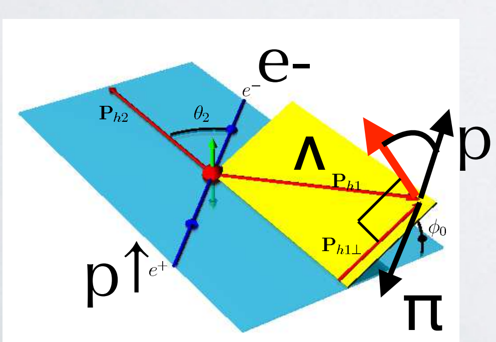


hadron-in-jet Collins effect

$j_T^2 \ll Q^2 = (P_T^{jet})^2$ hybrid factorisation:

$h_1(x)\,[C(z,\mu) \otimes H_1^\perp(z_h, j_T, P_T^{\mathrm{jet}} R)]$

transversity as PDF



Λ spin transfer

$h_1(x)\, H_1(z)$

transversity as PDF

and also in π p↑ Drell-Yan

$h_1^\perp(x_1, k_{1\perp}) \otimes h_1(x_2, k_{2\perp})$

transversity as TMD

Phenomenology of Transversity

most recent extractions

	Mechanism	Framework	SIDIS	e+e-	p-p collisions	N pts
PV 2018 arXiv:1802.05212	collinear DiFF	LO	✔	✔	✔	78
JAM 2020 arXiv:2002.08384	Collins effect	generalized parton model	✔	✔	✔	517
MEX 2019 arXiv:1912.03289	collinear DiFF	LO	✔	✔	✘	68
CA 2020 arXiv:2001.01573	Collins effect	generalized parton model	✔	✔	✘	76
JAM 2022 arXiv:2205.00999	Collins effect	generalized parton model	✔	✔	✔	634

Phenomenology of Transversity

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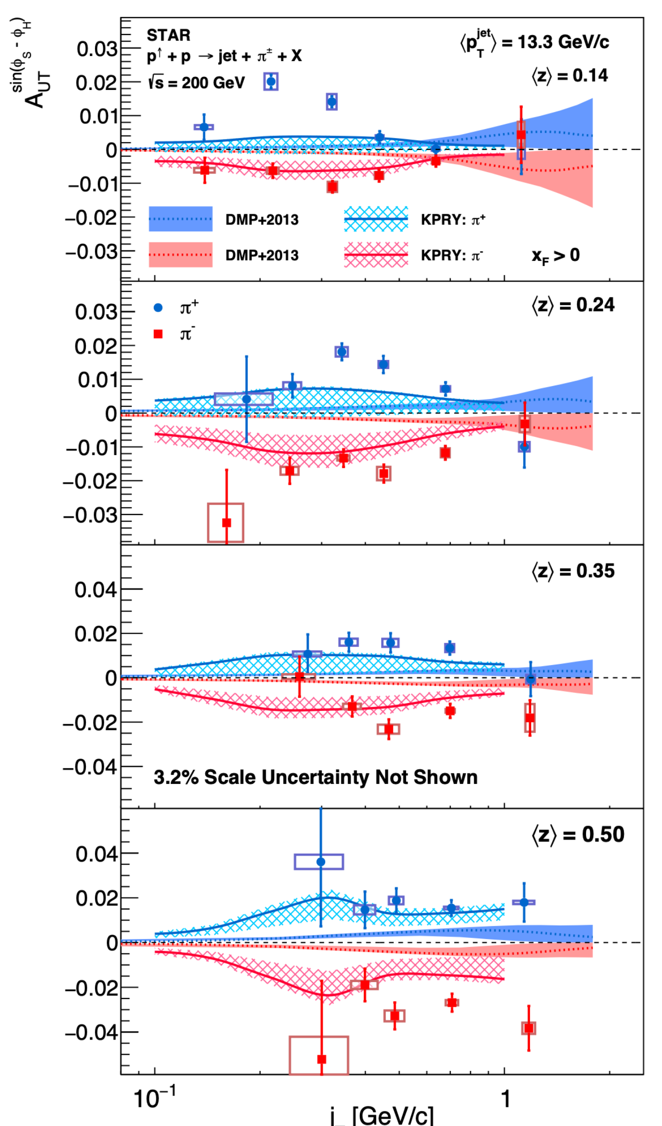


other works with STAR data

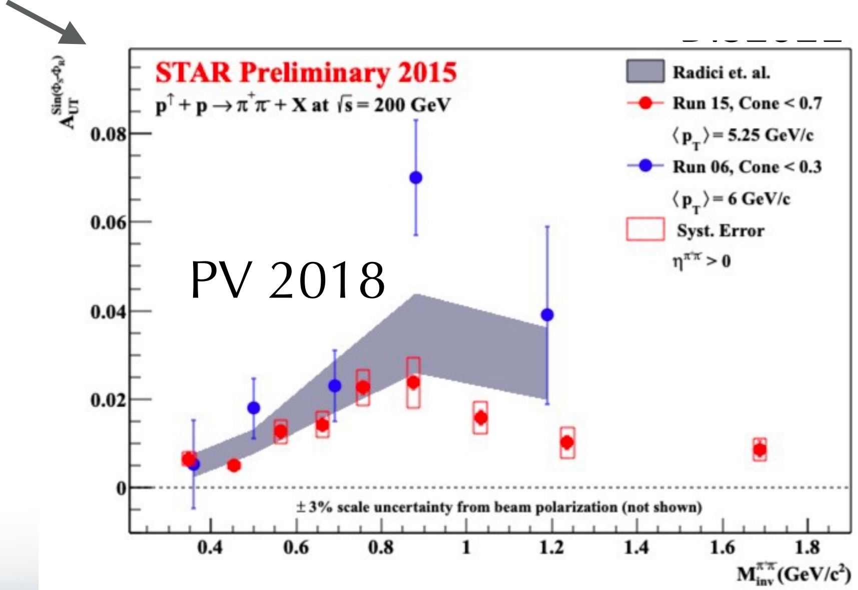
hadron-in-jet
Collins effect

di-hadron mechanism

talks by M. Grosse-Perdekamp
W.W. Jacobs

KPRY *Kang et al., P.L.* ***B774*** *(17) 635*

DMP *D'Alesio et al., P.L.* ***B773*** *(17) 300*



Tensor charge

talk by D. Pitonyak

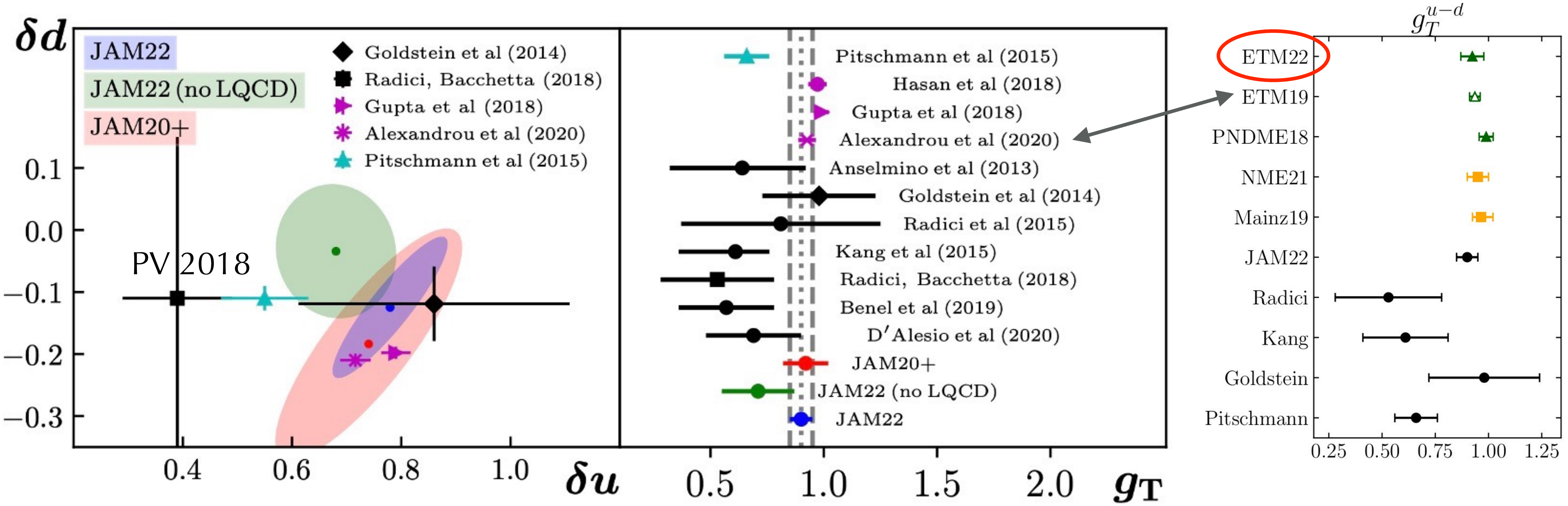
$$\delta^q(Q^2) = \int_0^1 dx\, h_1^{q-\bar{q}}(x, Q^2)$$

$g_T = \delta u - \delta d$

talk by S. Bacchio

arXiv:2202.09871

Q=2 GeV

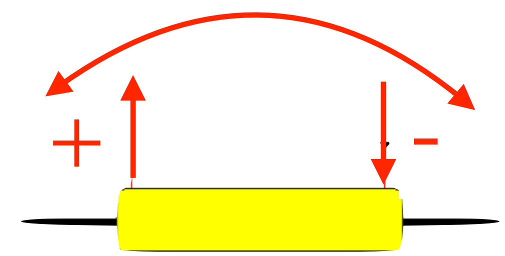


- JAM22 includes Soffer bound => δ^d similar to others, δ^u still larger (effect of A_N data?)
- JAM22 includes lattice g_T results in the fit => statistically compatible by construction
- JAM22 and PV 2018 do not => tension with lattice **why??**

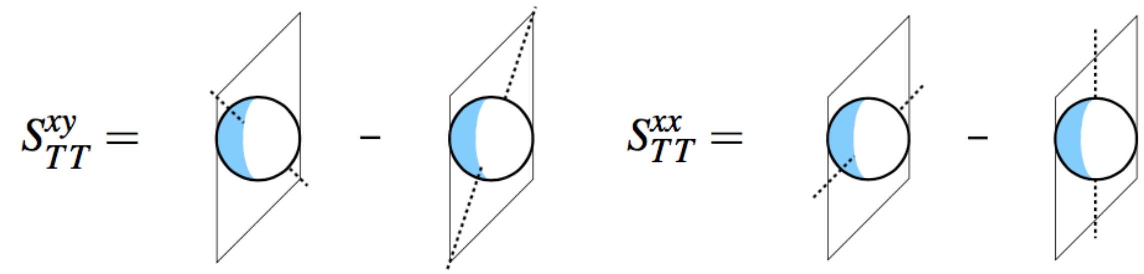
What about gluons ?

in spin-1/2 proton → no gluon transversity

max $\Delta s_L = |S'_L - S_L|$



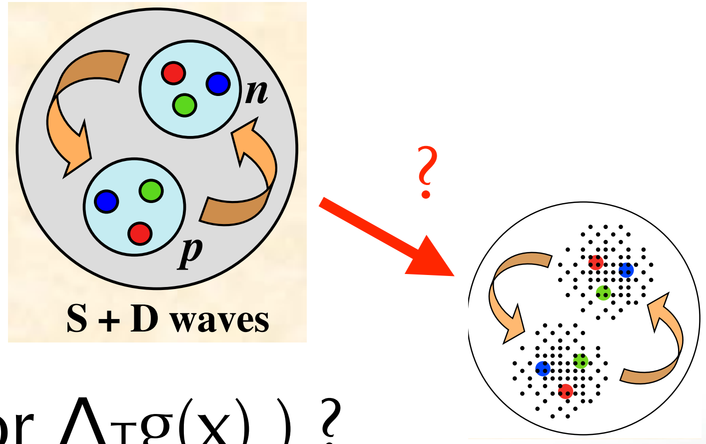
in spin-1 deuteron → gluon "transversity"
because for transverse tensor polarization
it can be $\Delta s_L = 2$



Jaffe & Manohar (1989), Artru & Mekhfi (1990), Bacchetta & Mulders (2000)

talks by D. Boer and S. Kumano

since standard convolution model for deuteron
does not reproduce data for the tensor struct. fnct. $b_1(x)$



what is the mechanism for the gluon transversity $h_{1TT}^g(x)$ (or $\Delta_T g(x)$) ?

an objective of the EIC

New and future data for transversity studies

- new 3-D analysis of Collins effect from Hermes, with final h = π , K, p, pbar

  talk by G. Schnell

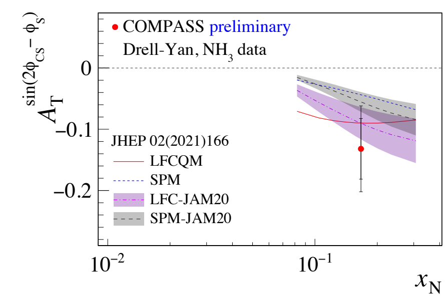
  *Airapetian et al., JHEP**12** (2020) 010*

- Collins effect for ρ^0 measured by Compass
- transversity induced by Λ polarization *P.L. **B824** (22) 136834*

talks by A. Bressan
F. Bradamante

- π p↑ DY by Compass: $h_{1,\pi}^{\perp} \otimes h_{1,p}$

  talk by R. Longo



Electron-Ion Collider

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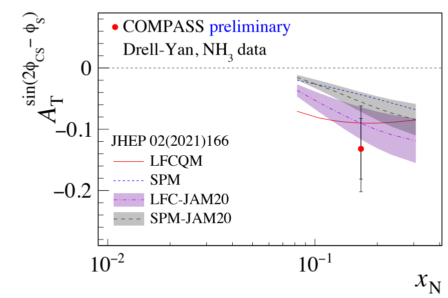


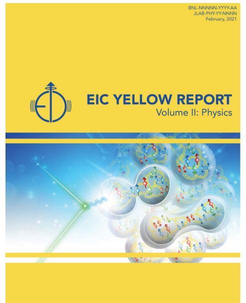
- Compass run with transversely polarized ^{6}LiD => will improve h_1^d
- JLab12 Hall-A TSSA with "neutron target" (SoLID) => improve $h_1^{u,d}$
- LHCspin => p-p↑ DY => $h_{1,p}^{\perp} \otimes h_{1,p}$

talk by P. Di Nezza

- Amber => π , K DY => $h_{1,\pi,K}^{\perp} \otimes h_{1,p}$
- FermiLab "LongQuest" spin-1 => pD↑ => $h_{1,p}^{\perp} \otimes h_{1,D}$

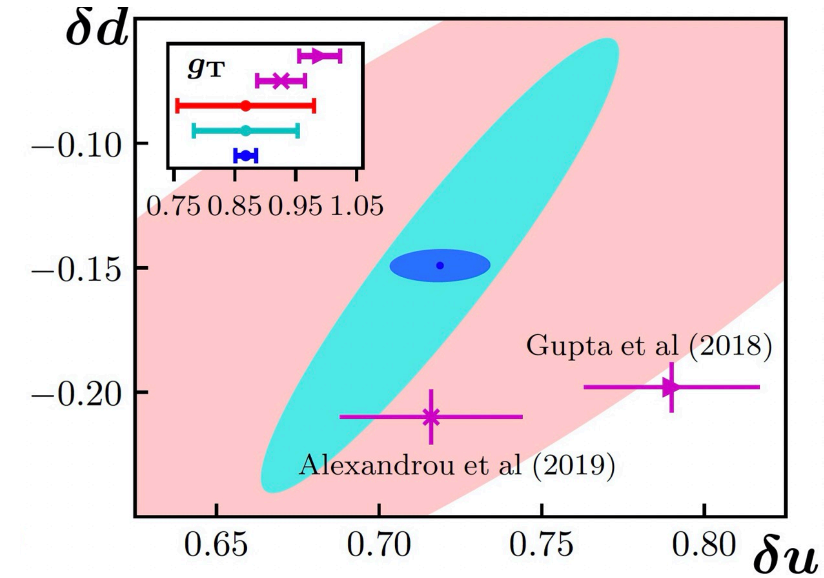
talk by N. Wuerfel

The EIC impact



*arXiv:2103.05419, N.P.**A** in press*

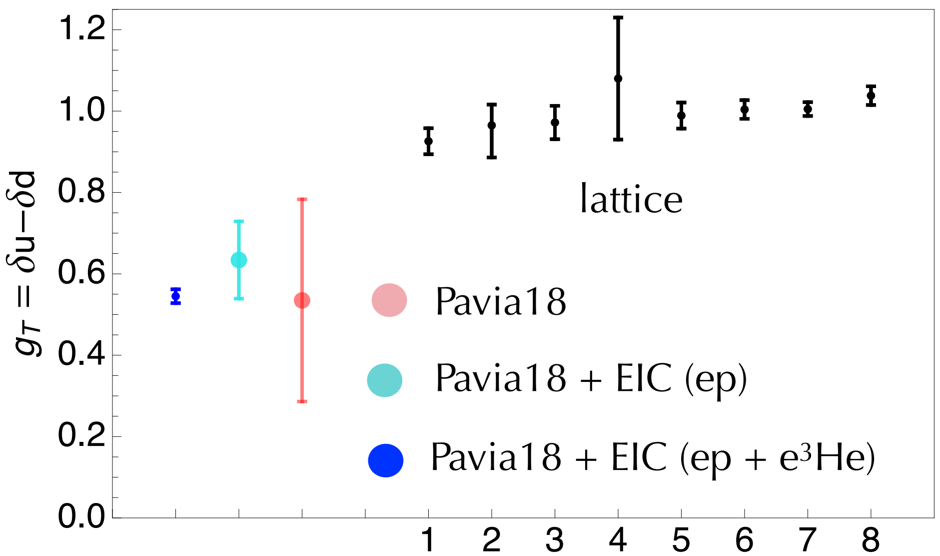
Collins effect



$\mathcal{L}$=10 fb^{-1} , 8223 data pts.

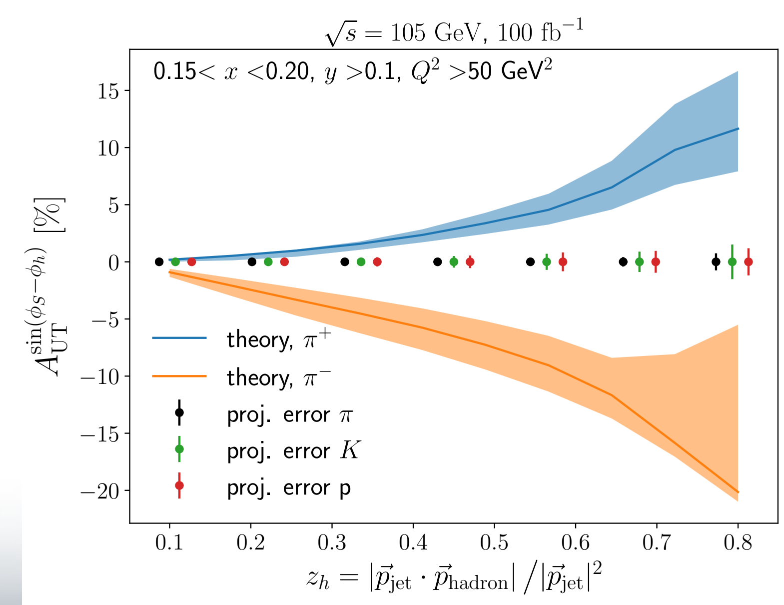
proton [GeV]: 5x41, 5x100, 10x100, 18x275

^{3}He [GeV]: 5x41, 5x100, 18x100



di-hadron mechanism

$\mathcal{L}$=10 fb^{-1} , 3852 data pts, proton&^{3}He [GeV]: 10x100



hadron-in-jet Collins effect

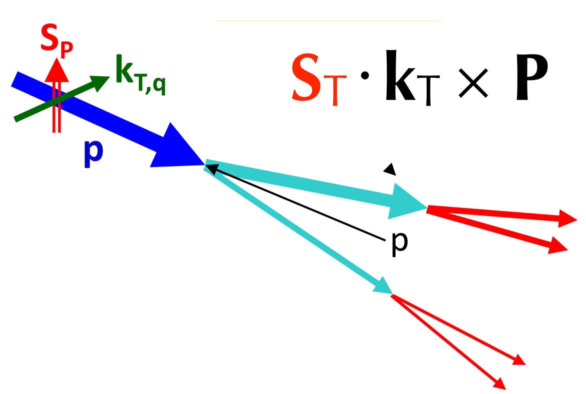
Arratia et al., arXiv:2007.07281

Electron-Ion Collider

Sivers effect

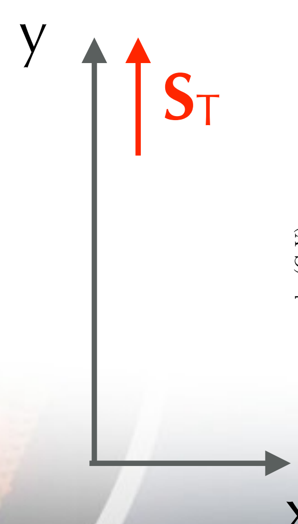
		Quark polarization		
		Unpolarized (U)	**Longitudinally Polarized (L)**	**Transversely Polarized (T)**
Nucleon Polarization	**U**	$f_1 =$ ⊙	✘	$h_1^{\perp} =$ ⊙ − ⊙
	L	✘	$g_1 =$ ⊙ − ⊙	$h_{1L}^{\perp} =$ ⊙ − ⊙
	T	$f_{1T}^{\perp} =$ ⊙ − ⊙	$g_{1T} =$ ⊙ − ⊙	$h_1 =$ ⊙ − ⊙ $h_{1T}^{\perp} =$ ⊙ − ⊙

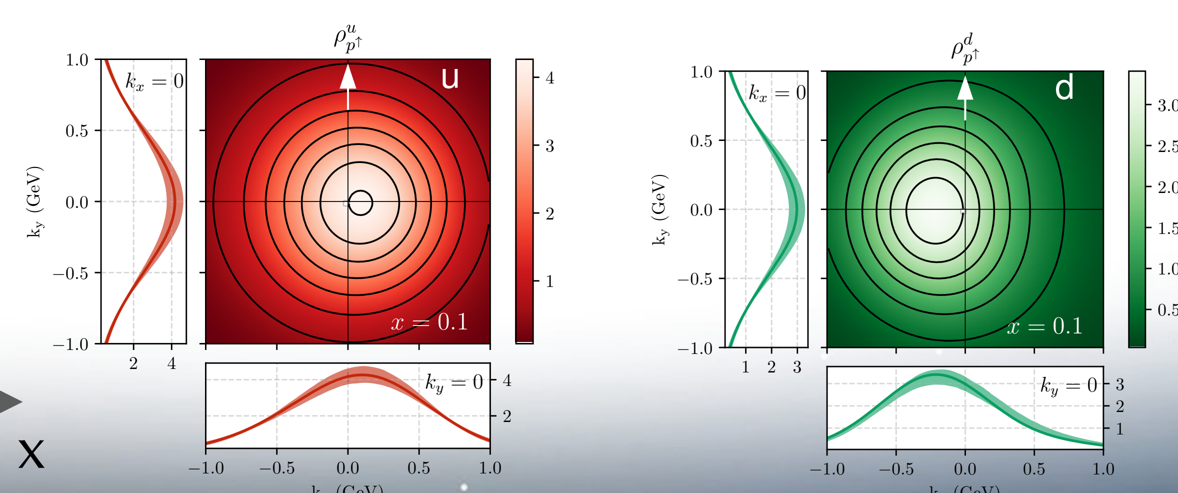
Sivers



distortion of quark momentum distribution by nucleon spin

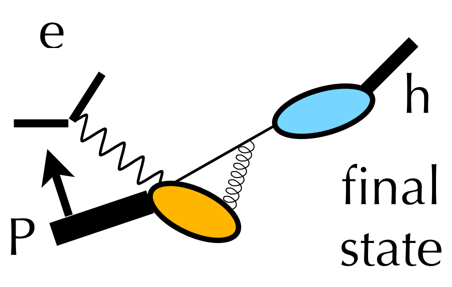
Bacchetta et al., P.L. ***B827*** *(22) 136961, arXiv:2004.14278*





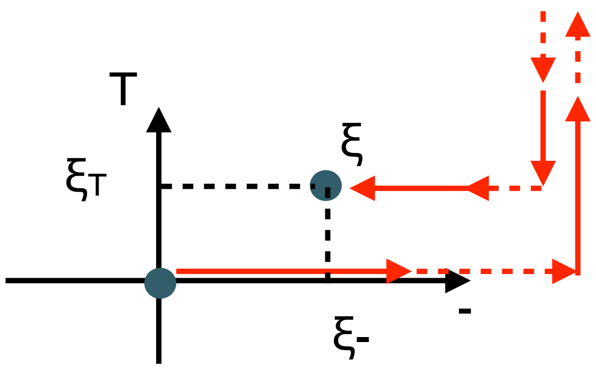
Sivers

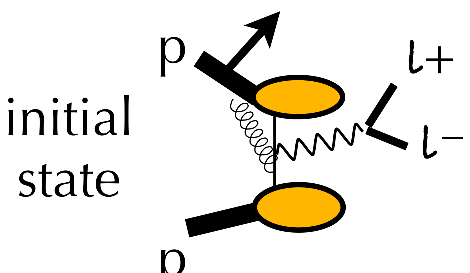
the quark Sivers TMD is not universal !



SIDIS

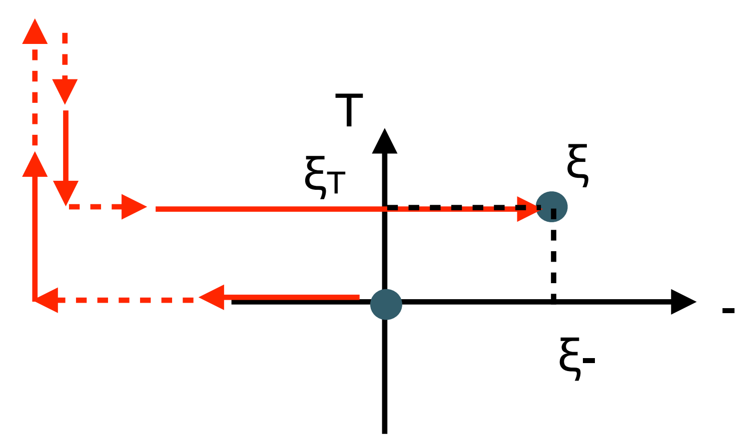
in SIDIS, gauge link structure
is “future pointing” → describes
residual color final-state interactions





Drell-Yan

in Drell-Yan, gauge link structure
is “past pointing” → describes
color initial-state interactions



Prediction of QCD:

Sivers TMD (SIDIS) = - Sivers TMD (Drell-Yan)

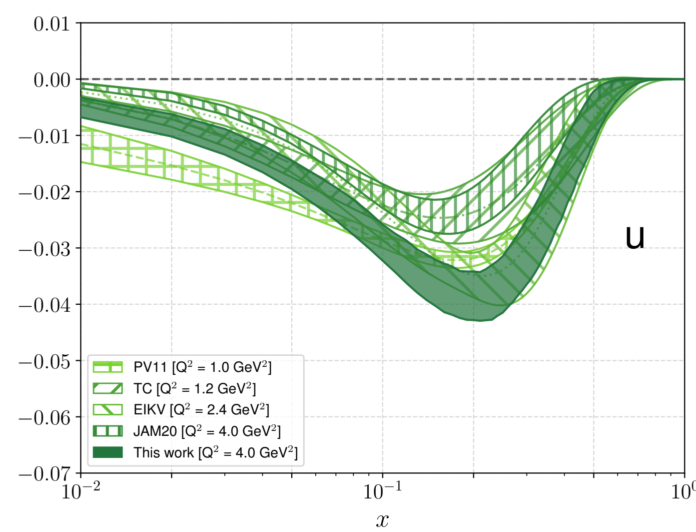
Sivers Phenomenology

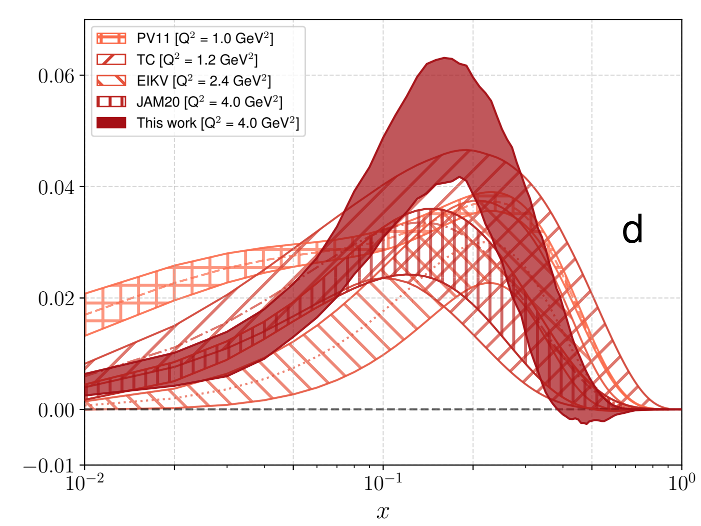
most recent extractions of quark Sivers

	Framework	SIDIS	DY	W/Z production	e+e-	N of points
JAM 2020 arXiv:2002.08384	extended parton model	✔	✔	✔	✔	517
Pavia 2020 arXiv:2004.14278	LO+NLL	✔	✔	✔	✘	150
EKT 2020 arXiv:2009.10710	NLO+N²LL	✔	✔	✔	✘	243
BPV 2020 arXiv:2012.05135 arXiv:2103.03270	ζ prescription	✔	✔	✔	✘	76

all parametrizations are in fair agreement for valence flavors

sea-quarks ~ $O(10^{-3})$ smaller



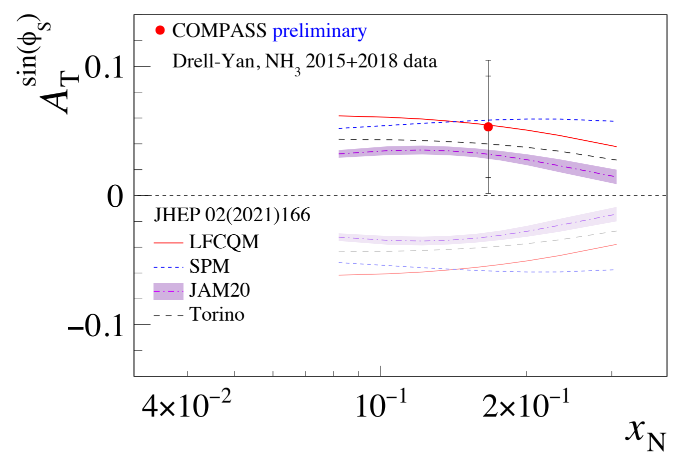


Bacchetta et al., arXiv:2004.14278

The Sign Change Puzzle

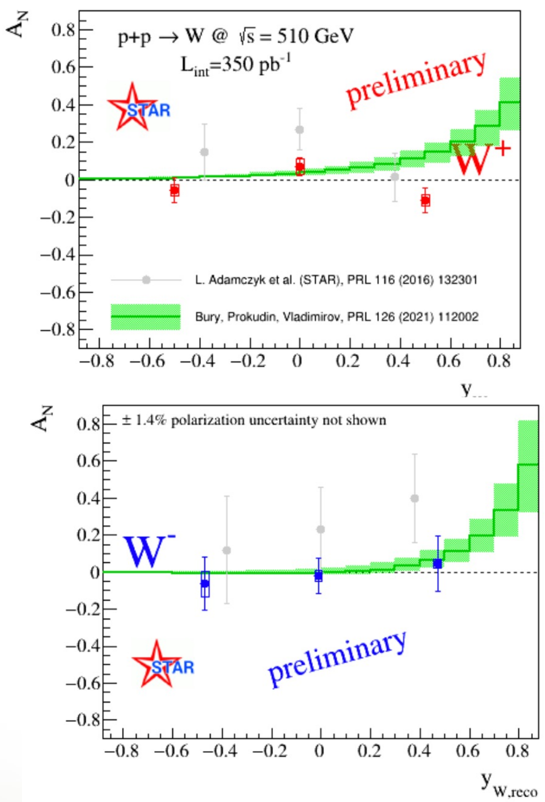
- π p↑ DY by Compass: $f_{1,\pi} \otimes f_{1T,p}^{\perp}$ compatible with sign change

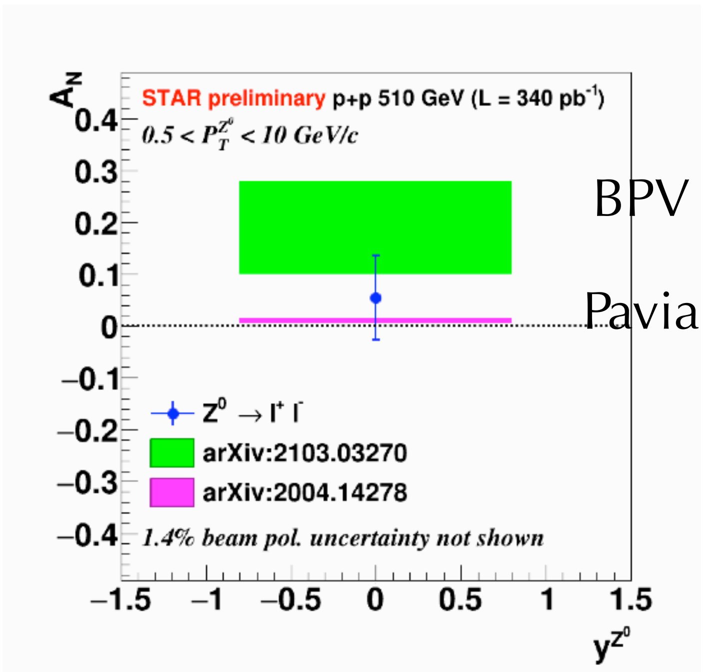
talk by R. Longo



sign change

no sign change





BPV 2020

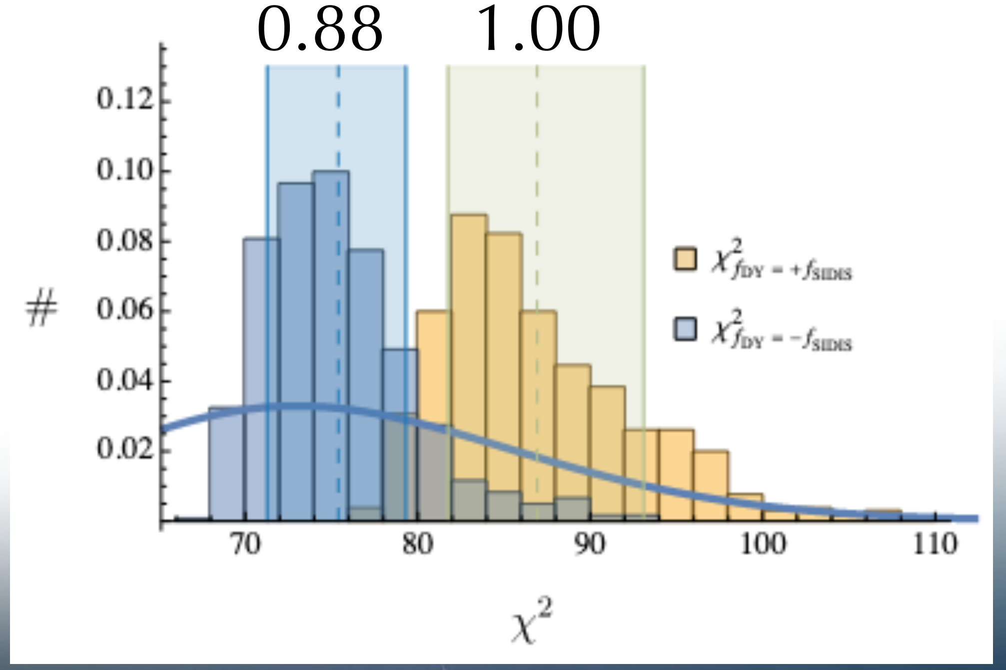
Pavia 2020

predictions on recent STAR DY data

talk by W.W. Jacobs

BPV 2020

Bury et al., arXiv:2103.03270



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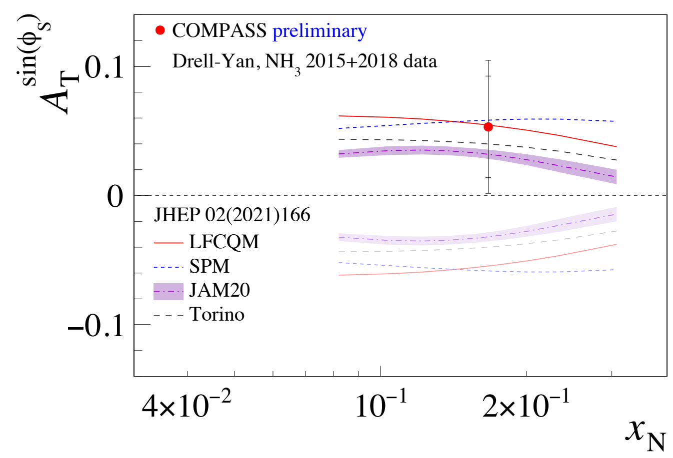
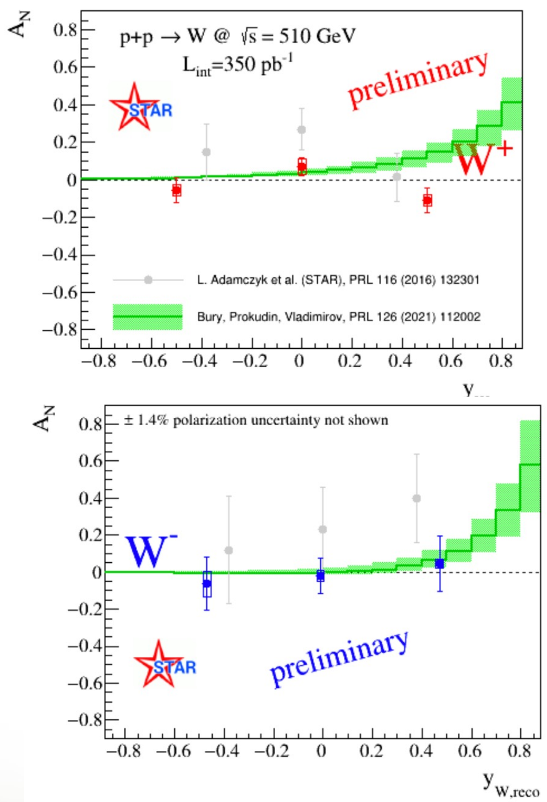
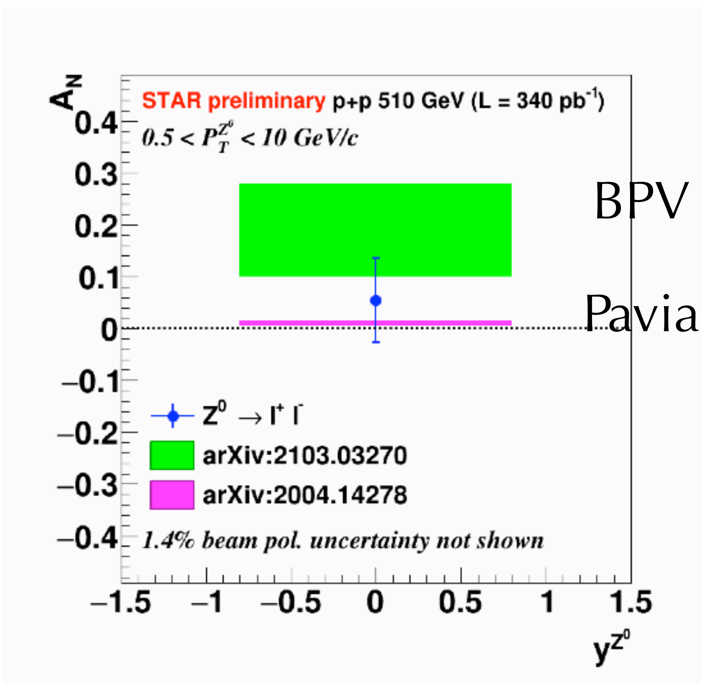


sign change

no sign change





BPV 2020

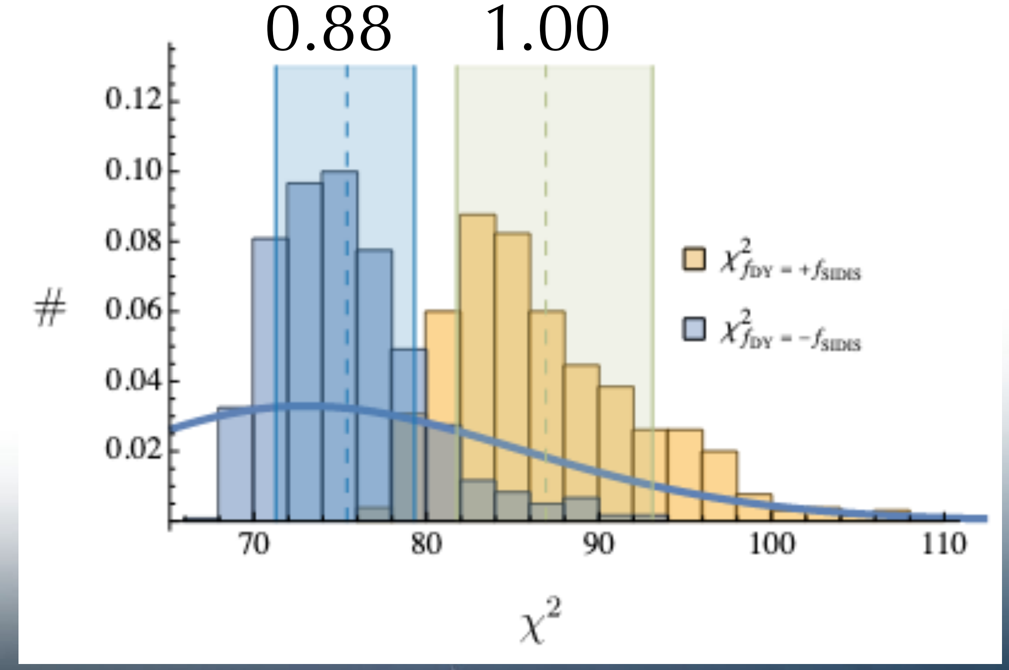
Pavia 2020

predictions on recent STAR DY data

talk by W.W. Jacobs

BPV 2020 *Bury et al., arXiv:2103.03270*

0.88 1.00



still not enough to confirm sign change:

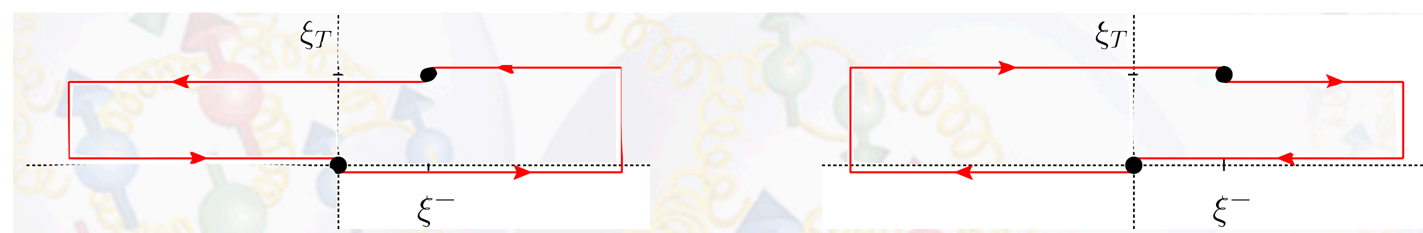
What about gluons ?

- TMDs are related to hadronic matrix elements of bilocal operators; color gauge links must connect the two points to restore color gauge invariance;
gluons have a more complicated structure than quarks:

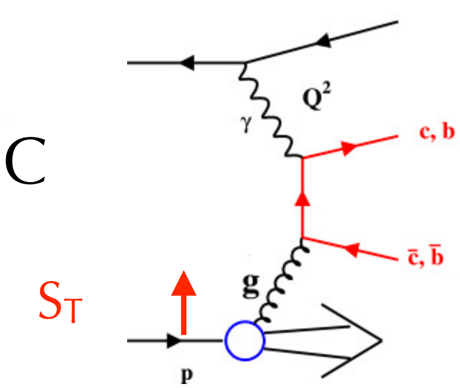
different processes ↓ **different TMDs !**

f-type (WW)
[+,+] , [-,-]

d-type (dipole)
[+,-] , [-,+]



- $f_{1T}^{\perp,g[+,+]}$ can be extracted in $ep^\uparrow \to e'Q\bar{Q}X$ at the EIC



talk by D. Boer

- $f_{1T}^{\perp,g[+,-]}$ at small x related to the spin-dep. Odderon
only contribution to $pp^\uparrow \to h^\pm X$ at $x_F < 0$; RHIC / NICA ?

$f_{1T}^{\perp g\,[+,+]}$	$e\,p^\uparrow \to e'\,Q\,\overline{Q}\,X$	EIC
	$e\,p^\uparrow \to e'$ jet jet X	EIC
$f_{1T}^{\perp g\,[-,-]}$	$p^\uparrow p \to \gamma\,\gamma\,X$	RHIC
$f_{1T}^{\perp g\,[+,-]}$	$p^\uparrow A \to \gamma^{(*)}$ jet X	RHIC
	$p^\uparrow\,A \to h\,X\ (x_F < 0)$	RHIC & NICA

New and future data for Sivers studies

- new 3-D analysis of Collins effect from Hermes, with final h = π , K, p, pbar

  talk by G. Schnell

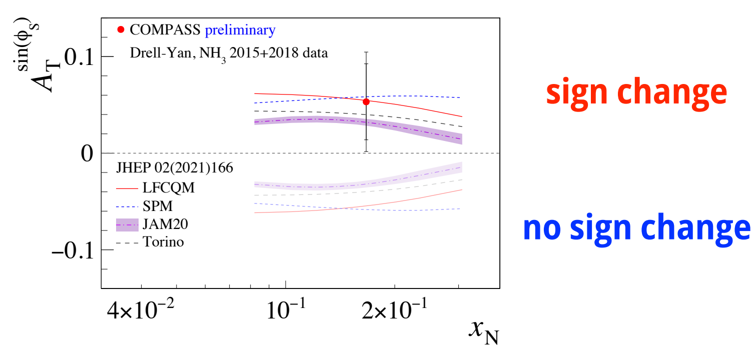
  *Airapetian et al., JHEP **12** (2020) 010*

- Sivers effect for ρ^0 measured by Compass

  talks by A. Bressan
  F. Bradamante

- π p↑ DY by Compass: $f_{1,\pi} \otimes f_{1T,p}^{\perp}$

  talk by R. Longo



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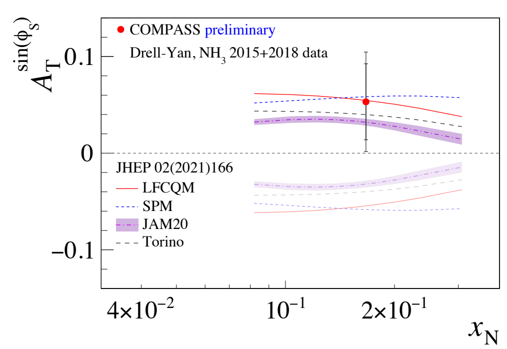


sign change

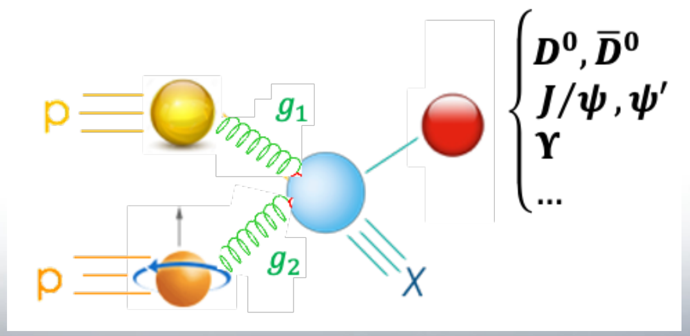
no sign change

talk by R. Longo

- FermiLab E1039 "SpinQuest" => pp↑ & pD↑ => $f_{1,p} \otimes f_{1T,p,D}^{\perp}$

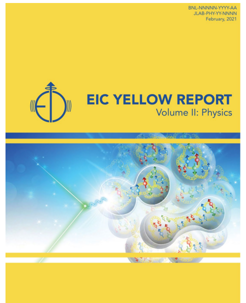
talk by N. Wuerfel

- LHCspin => p-p↑ DY => $f_{1,p} \otimes f_{1T,p}^{\perp}$

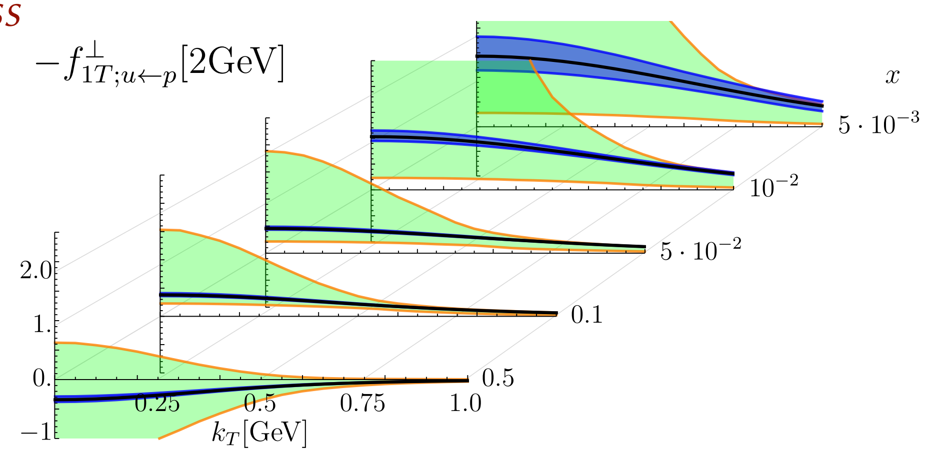


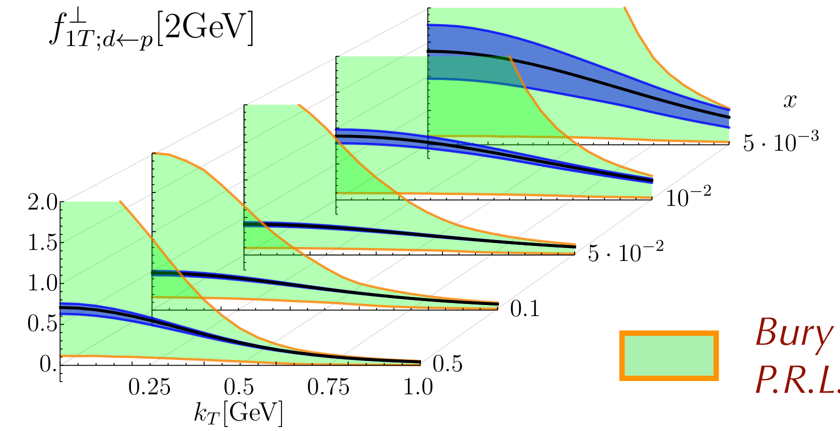
talk by P. Di Nezza

The EIC Impact



arXiv:2103.05419,
*N.P.**A** in press*

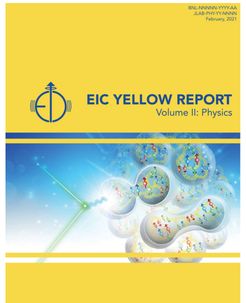




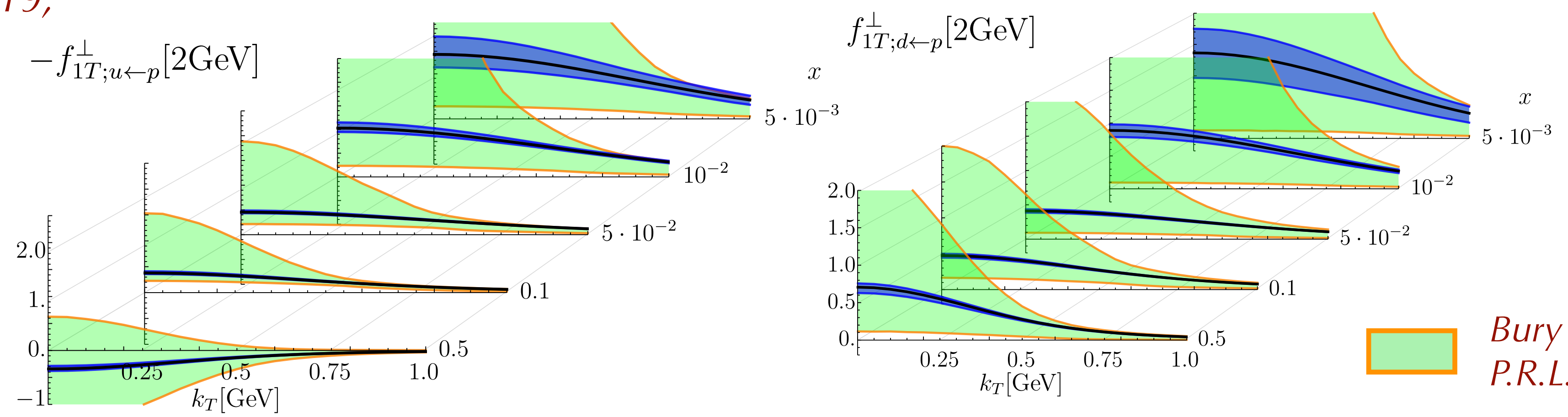
Bury et al.,
P.R.L. ***126*** *(21) 112002*

+ EIC 5×41 GeV
18×275

The EIC Impact



*arXiv:2103.05419, N.P.**A** in press*

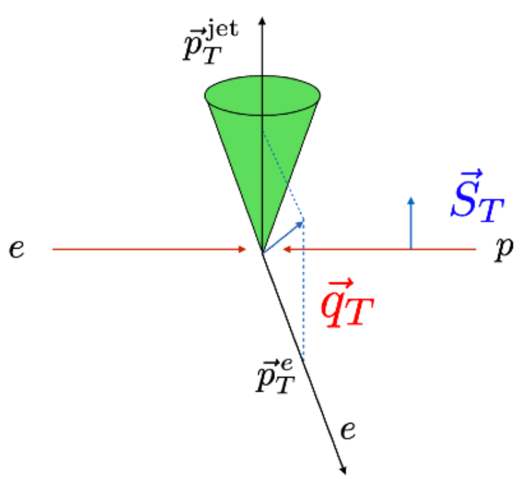


*Bury et al., P.R.L. **126** (21) 112002*

+ EIC 5×41 GeV, 18×275

opportunities with jets and Heavy Flavors

talk by F. Ringer



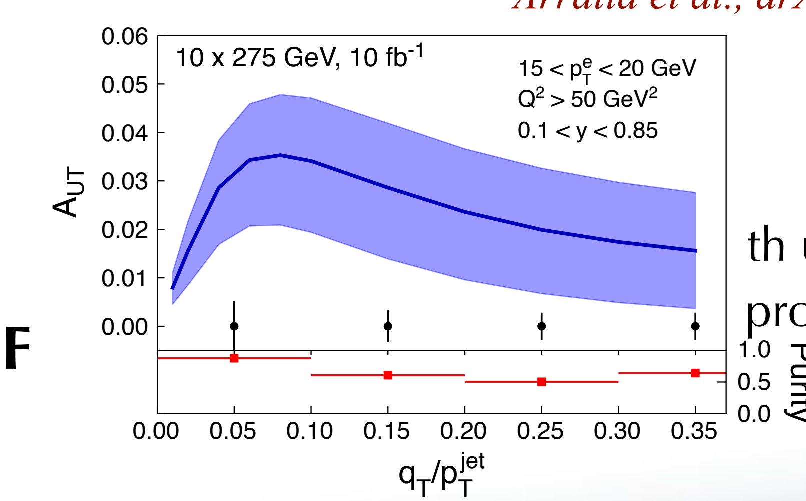
electron-jet azimuthal correlations

$$|\vec{q}_T| = |\vec{p}_T^{\,e} + \vec{p}_T^{\,jet}| \ll |\vec{p}_T^{\,jet}|$$

$A_{UT} \sim d\sigma(S_T) - d\sigma(-S_T)$

Sivers effect free from TMD FF

Arratia et al., arXiv:2007.07281



th uncertainty

projected precision

also access to gluon Sivers TMD from $D^0\bar{D}^0$, charm di-jets and J/ψ production

Zheng et al., arXiv:1805.05290

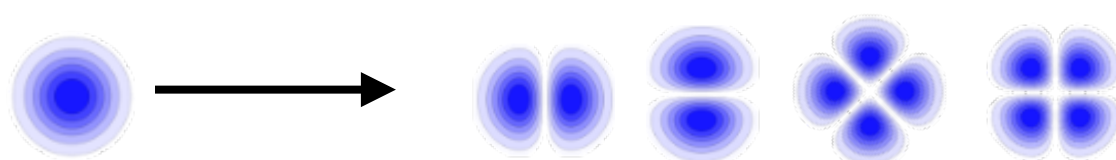
Rajesh et al., arXiv:2108.04866

Electron-Ion Collider

The TMD "zoo" at leading twist

Nucleon Polarization	Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
U	$f_1 =$	✘	$h_1^\perp =$
L	✘	$g_1 =$	$h_{1L}^\perp =$
T	$f_{1T}^\perp =$	$g_{1T} =$	$h_1 =$ $h_{1T}^\perp =$

deformations induced by spin-momentum correlations



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

each TMD is connected to a specific measurable SIDIS spin asymmetry

The unpolarized quark TMD f_1^q

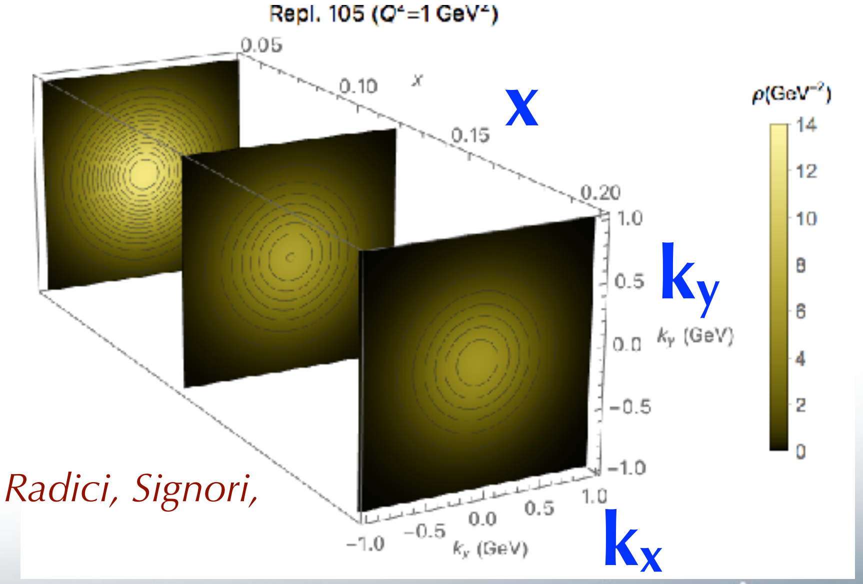
the best known TMD (most recent fits)

	Framework	HERMES	COMPASS	DY	Z production	N of points	χ^2/N_{points}
PV 2017 arXiv:1703.10157	NLL	✔	✔	✔	✔	8059	1.5
SV 2017 arXiv:1706.01473	NNLL'	✘	✘	✔	✔	309	1.23
BSV 2019 arXiv:1902.08474	NNLL'	✘	✘	✔	✔	457	1.17
SV 2019 arXiv:1912.06532	N³LL	✔	✔	✔	✔	1039	1.06
PV 2019 arXiv:1912.07550	N³LL	✘	✘	✔	✔	353	1.07
SV19 + flavor dep. arXiv:2201.07114	N³LL	✘	✘	✔	✔	309	<1.08>
MAPTMD 2022 arXiv:2206.07598	N³LL	✔	✔	✔	✔	2031	1.06

Lessons to be learnt :

- non-perturbative k_T dependence is not a simple Gaussian
- average $\langle k_T^2 \rangle$ strongly depends on x, and might depend on flavor (in particular for fragmentation; recent attempt on SV19)
- Gaussian non perturbative evolution seems preferred
- modern fits can reach N³LL+NNLO perturbative accuracy with reduced $\chi^2 \sim 1$ on thousands data points

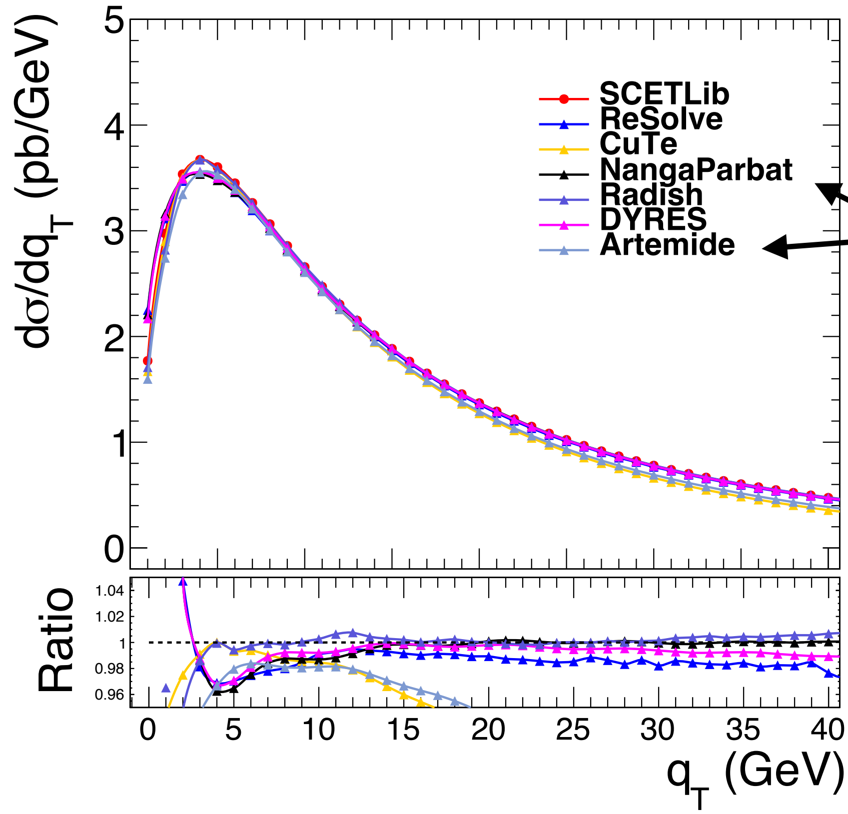
tomography in momentum space



PV 2017
Bacchetta, Delcarro, Pisano, Radici, Signori,
*JHEP **06** (17) 081*

The unpolarized quark TMD f_1^q

same accuracy as PDF
benchmarking codes @LHC



Z production at η=0 (ATLAS kin)

G. Bozzi, I. Scimemi (eds.) et al., Yellow Report of CERN EW WG, in preparation

the best known TMD (most recent fits)

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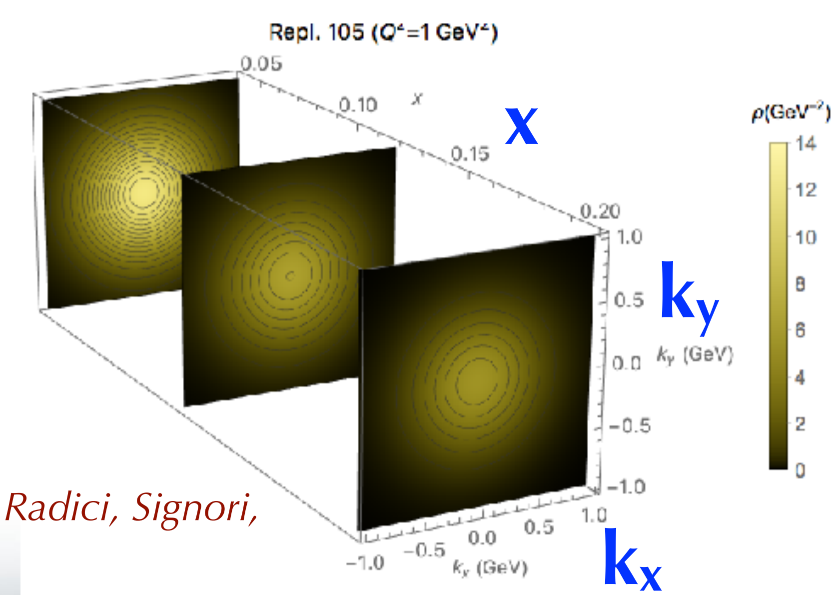

PV 2017
*Bacchetta, Delcarro, Pisano, Radici, Signori, JHEP **06** (17) 081*

The MAPTMD22 fit

the best known TMD (most recent fits)

	Framework	HERMES	COMPASS	DY	Z production	N of points	χ^2/N_{points}
PV 2017 arXiv:1703.10157	NLL	✔	✔	✔	✔	8059	1.5
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SV19 + flavor dep. arXiv:2201.07114	N^3LL	✘	✘	✔	✔	309	<1.08>
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Bacchetta et al., arXiv:2206.07598

the new MAPTMD22 fit

talk by V. Bertone

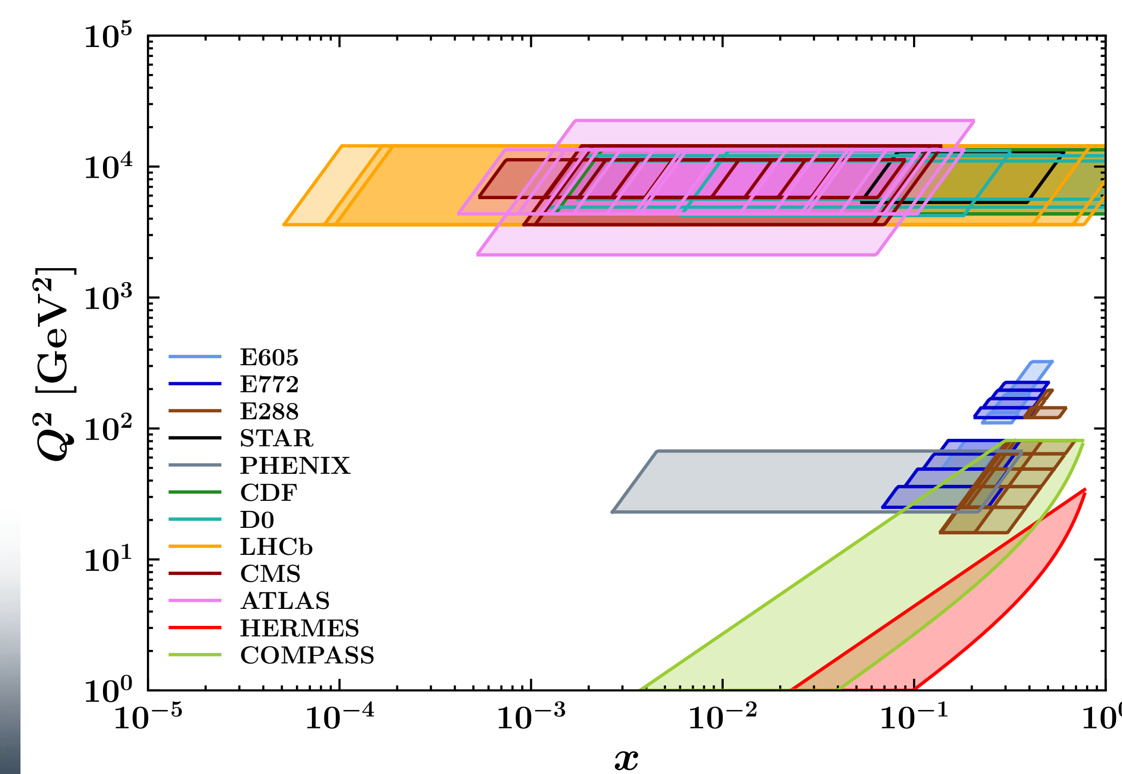
<u>kin. cuts and coverage</u>

DY $q_T/Q < 0.2$

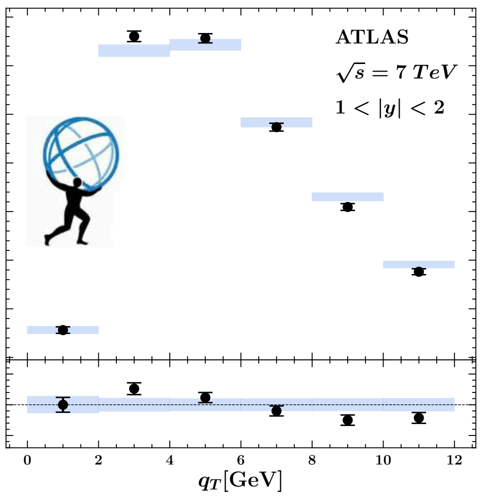
SIDIS $P_{hT} = \min[\,\min[\,0.2\,Q\,,0.5\,zQ] + 0.3\,,zQ]$

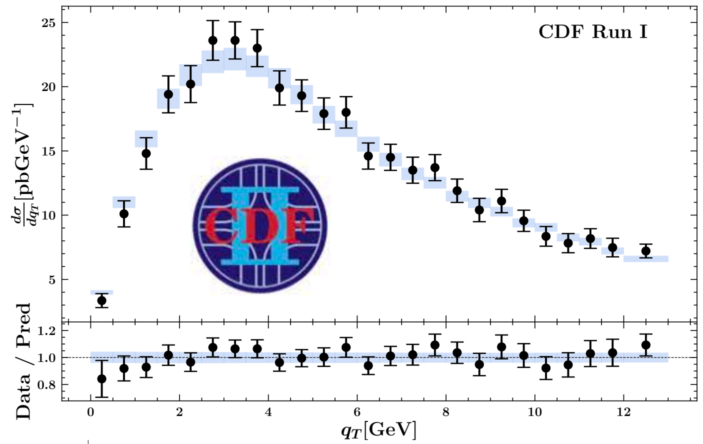
$Q > 1.4\,\mathrm{GeV}\,, 0.2 < z < 0.7$

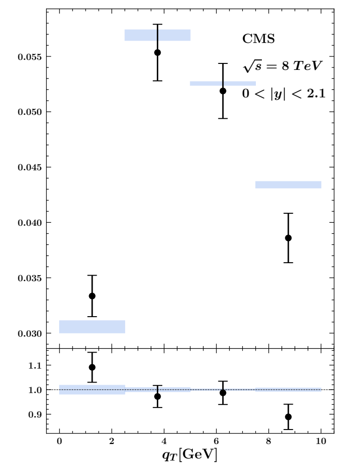
2031 exp. pts., 21 parameters

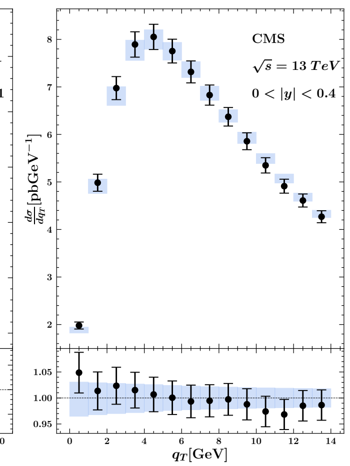


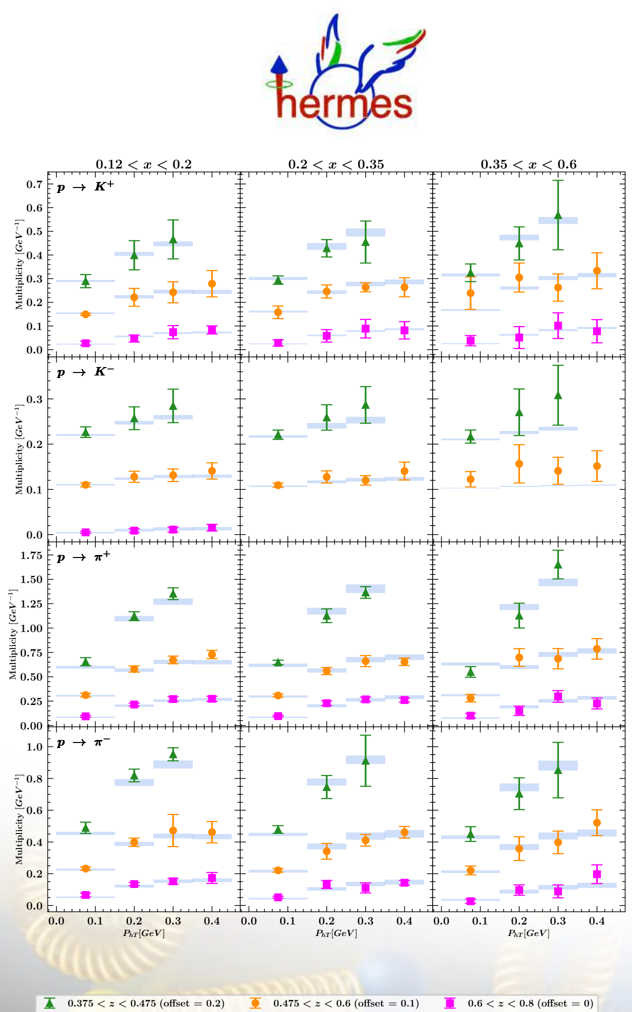
The MAPTMD22 fit

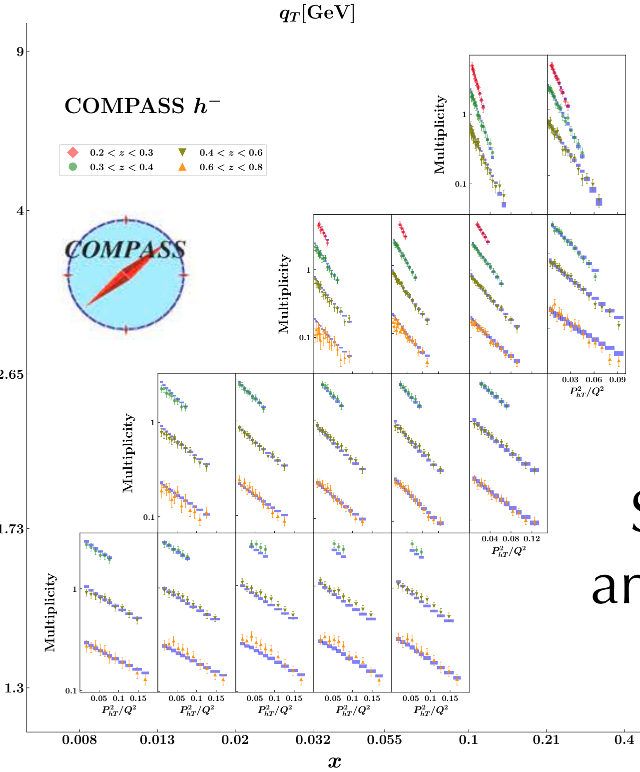






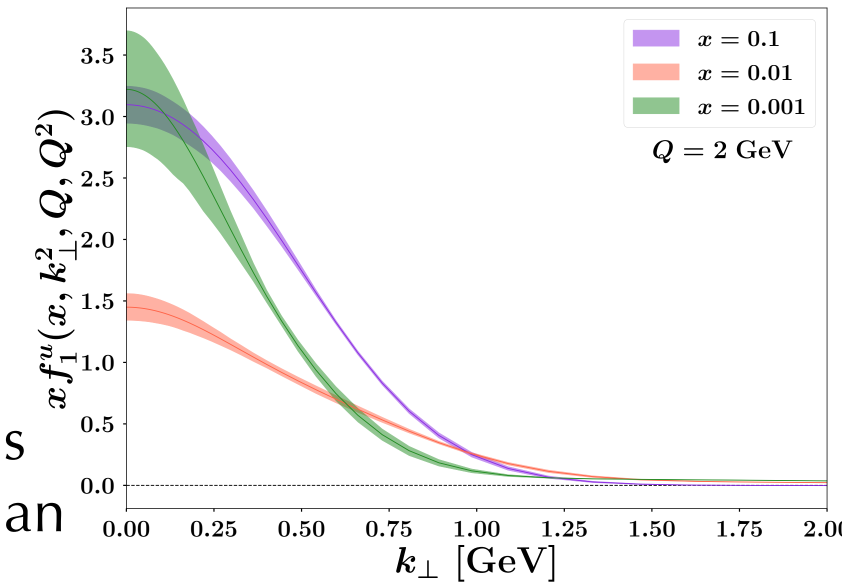






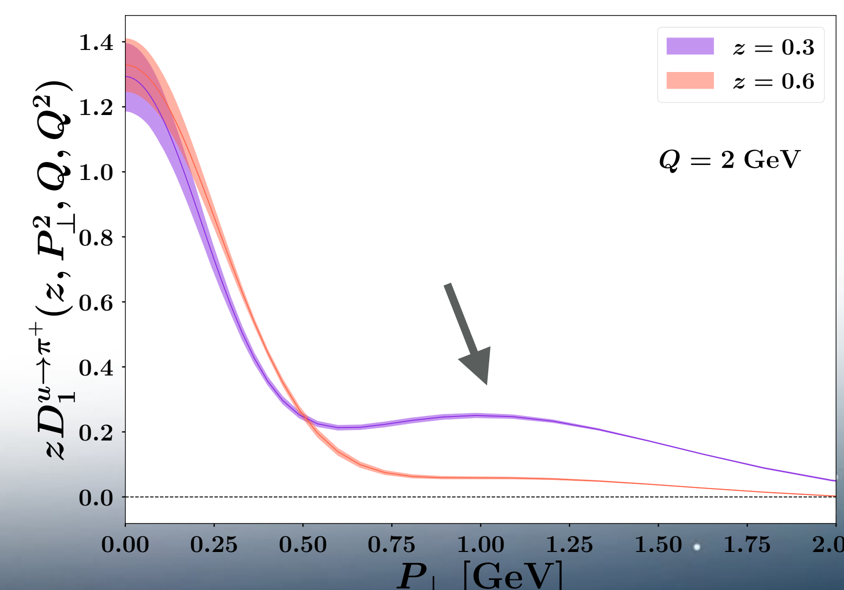
TMD PDF

Sum of two Gaussians
and a weighted Gaussian
x-dep. widths



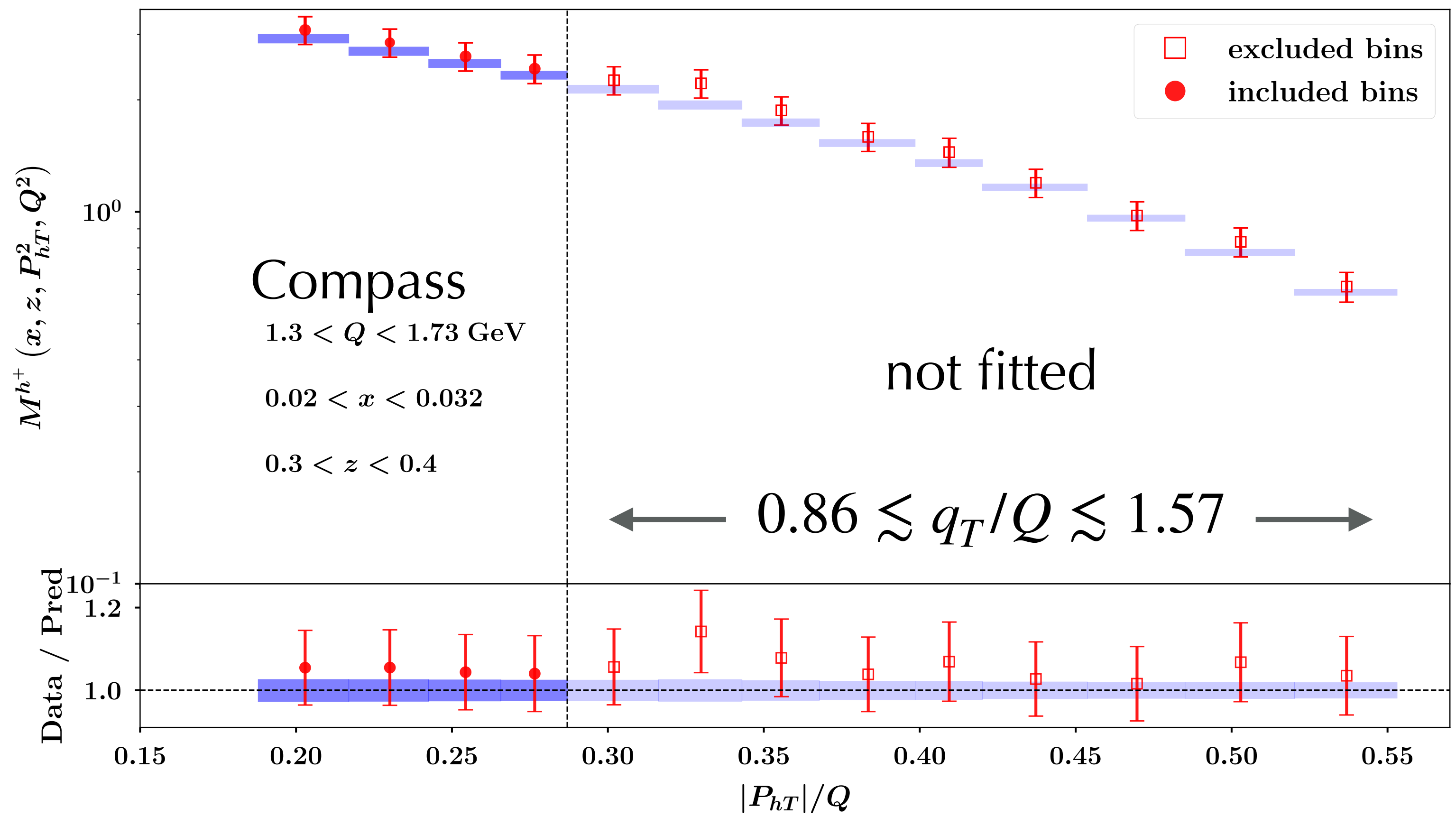
TMD FF

Sum of a Gaussians and
a weighted Gaussian
z-dep. widths

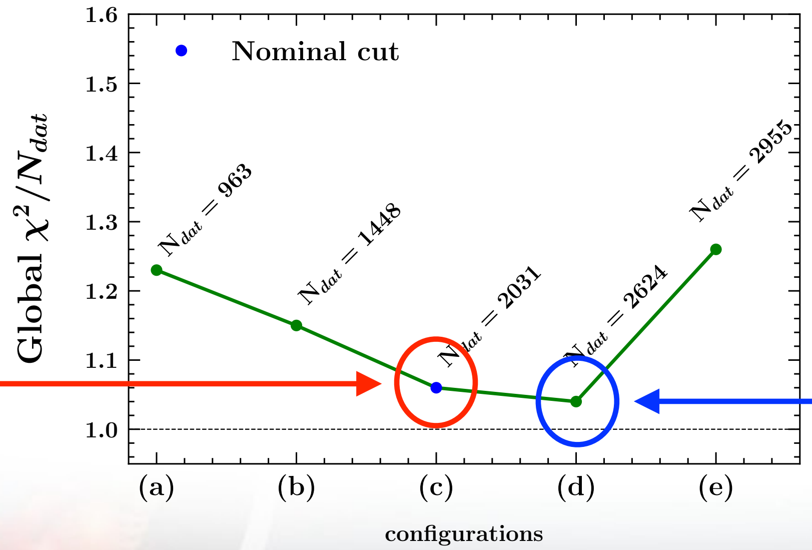


Electron-Ion Collider

The MAPTMD22 fit



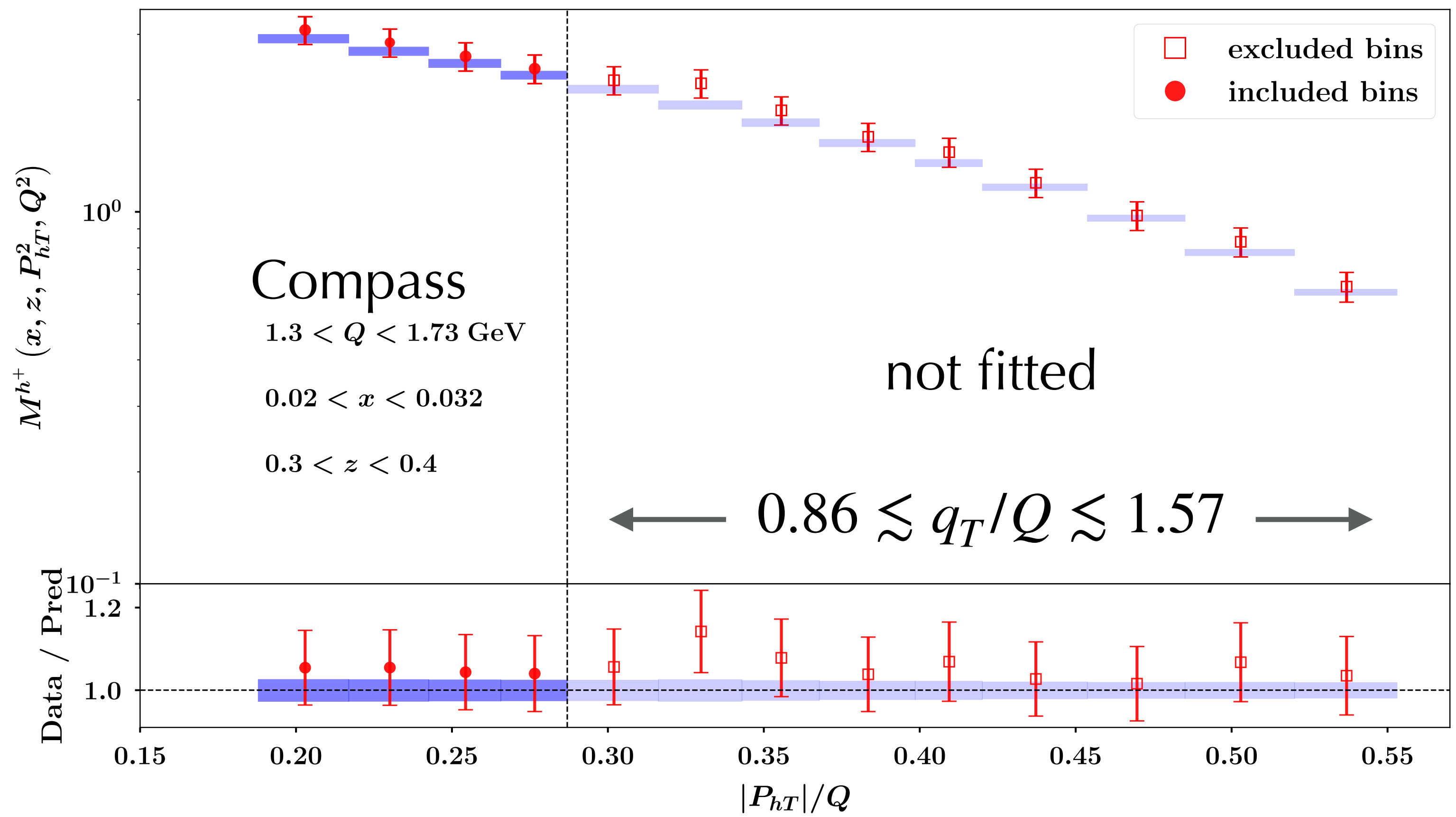
it happens also in other bins and for Hermes data as well



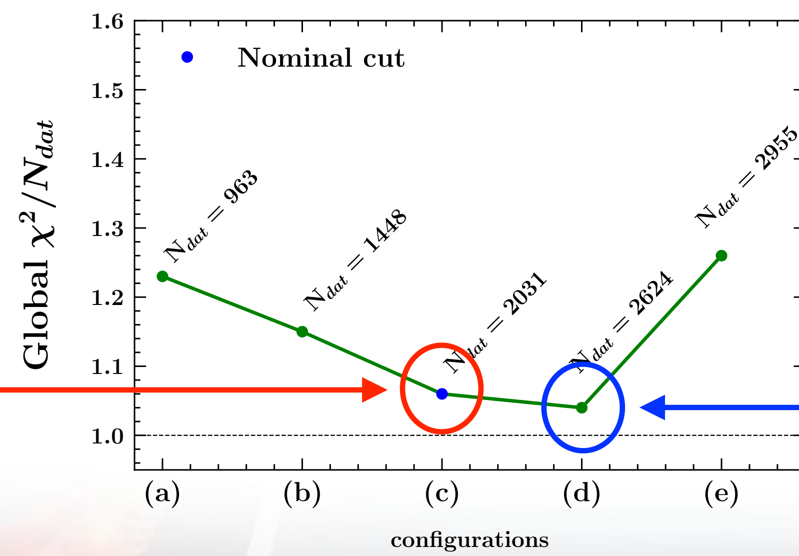
The MAPTMD22 fit

Where is the limit of applicability of the TMD formalism ?!

it happens also in other bins and for Hermes data as well



baseline fit



without $q_T < Q$

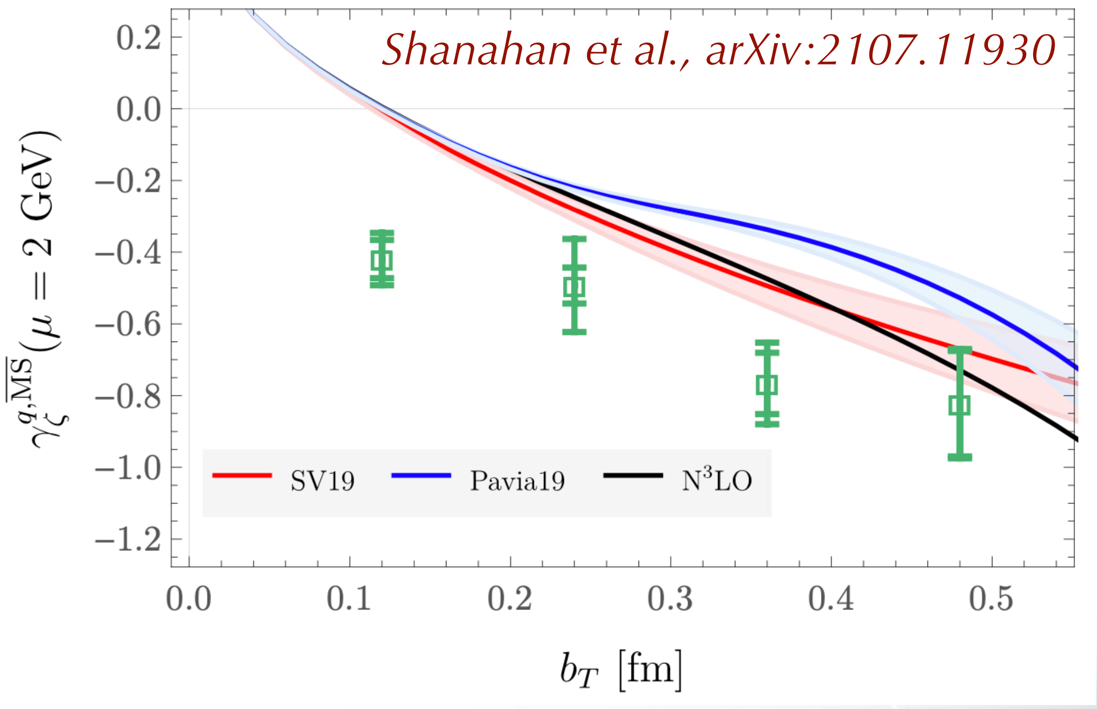
The TMD evolution of f_1^q

$$\mathrm{TMD}(x, b_T; \mu_f, \zeta_f) = \mathrm{Evo}(\mu_f, \zeta_f; \mu_i, \zeta_i)\ \mathrm{TMD}(x, b_T; \mu_i, \zeta_i)$$

$$\mathrm{Evo}(\mu_f, \zeta_f; \mu_i, \zeta_i) = \exp\left[S_{\mathrm{pert}}(\mu_f, \mu_i; \zeta_f)\right]\ \exp\left[\frac{1}{2} K(b_T, \mu_b)\ \ln(\zeta_f/\zeta_i)\right]$$

Collins-Soper kernel $K = \gamma_\zeta = -2\mathscr{D}$ drives the evolution in rapidity ζ (including the unknown non perturbative part); can be computed on lattice

talk by M. Wagman



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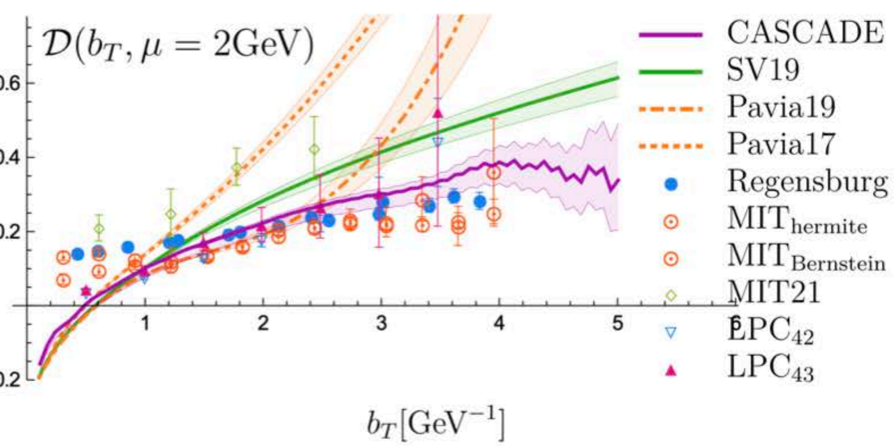
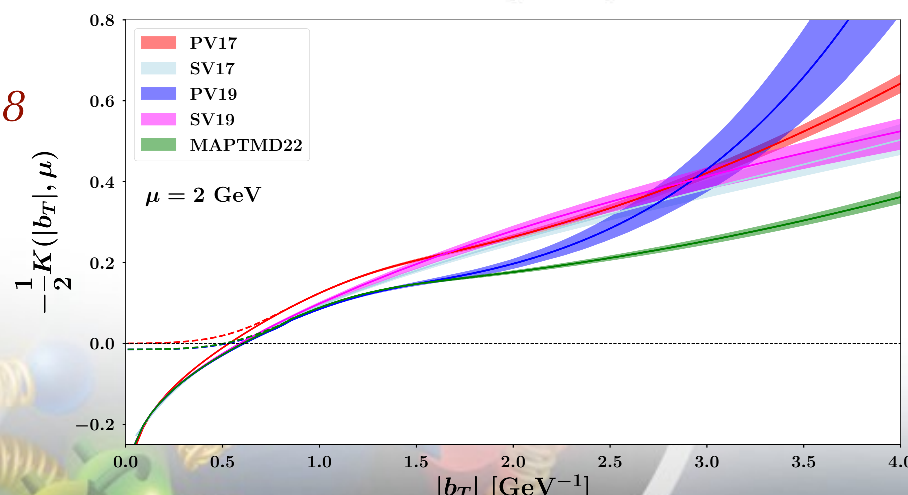
Martinez & Vladimirov, arXiv:2206.01105

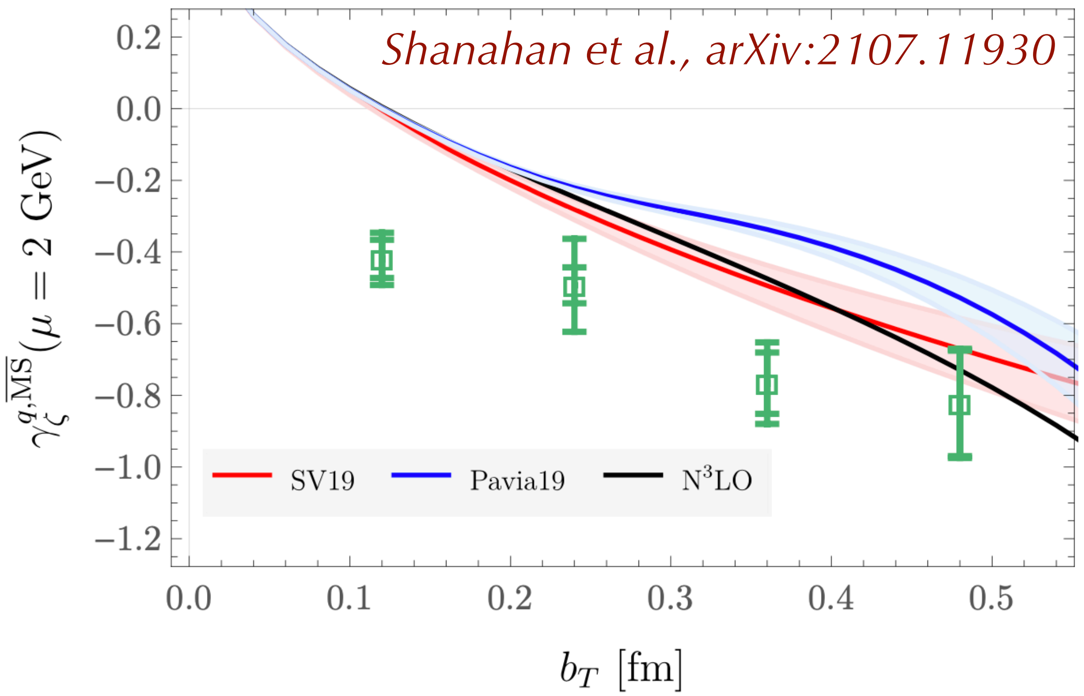
A. Vladimirov talk (CPHI 2022)



Bacchetta et al., arXiv:2206.07598



talk by M. Wagman



What about gluons ?

- useful channels: heavy-quarkonium production

talk by M. Echevarria

$$p + p \to \eta_{c,b} + X$$
$$p + p \to \chi_{c,b} + X$$
$$p + p \to H^0 + X$$
$$p + p \to \gamma + \gamma + X$$
$$p + p \to J/\psi + \gamma^* + X$$
$$p + p \to J/\psi + Z + X$$
$$p + p \to J/\psi + J/\psi + X$$
$$p + p \to \eta_c + \eta_c + X$$
$$e + p \to e + c + \bar{c} + X$$
$$e + p \to e + J/\psi + jet + X$$
$$e + p \to e + J/\psi + \pi + X$$
$$e + p \to e + J/\psi + X$$
$$e^+ + e^- \to J/\psi + \pi + X$$

factorization proven

ansatz

2 soft mechanisms:
- soft gluon resum.
- formation of bound state

What about gluons ?

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talk by M. Echevarria

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factorization proven

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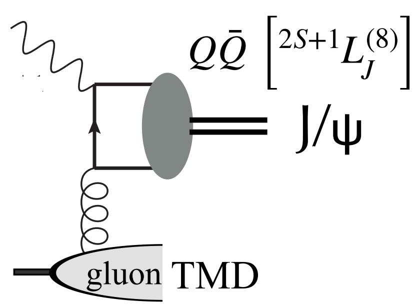
- example: J/ψ production



Bacchetta et al., arXiv:1809.02056
D'Alesio et al., arXiv:1908.00446

- cross section has same structure for quarks: $d\sigma^0 \longrightarrow f_1^g \otimes A\left[\gamma^* g \to J/\psi\right] + \cos 2\phi_{J/\psi}\, h_1^{\perp g} \otimes B\left[\gamma^* g \to J/\psi\right]$

Boer et al., arXiv:2004.06740
Boer et al., arXiv:2102.00003
D'Alesio et al., arXiv:2110.07529

talks by C. Pisano
L. Maxia
R. Kishore

What about gluons ?

- useful channels: heavy-quarkonium production

talk by M. Echevarria

$p+p \to \eta_{c,b} + X$	factorization proven
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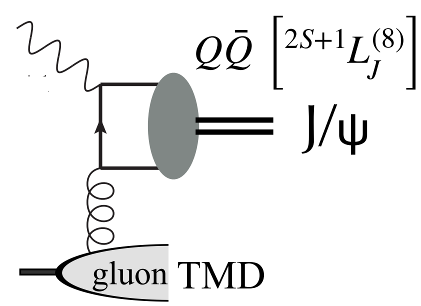

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Boer et al., arXiv:2004.06740
Boer et al., arXiv:2102.00003
D'Alesio et al., arXiv:2110.07529

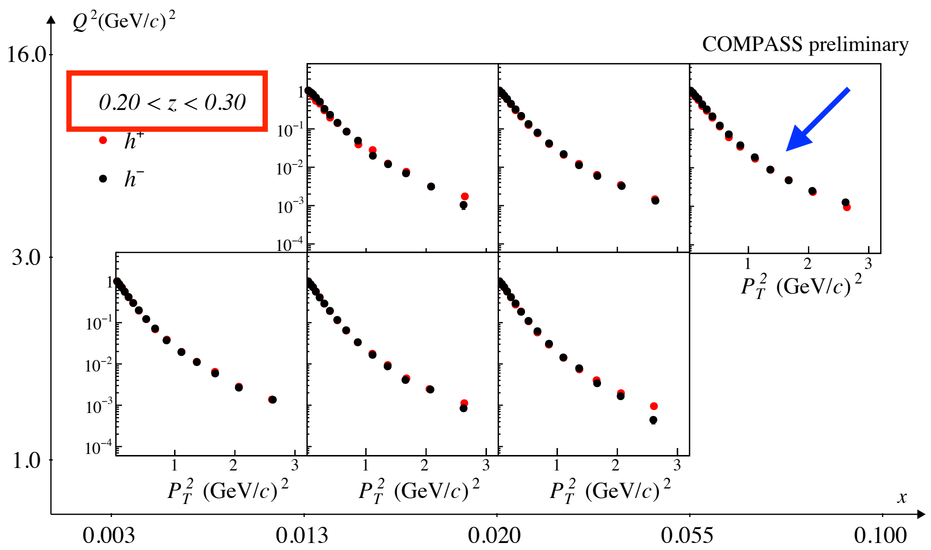
unknown "Shape Function"
depend on process and (color) structure of $Q\bar{Q}$
must be extracted from experiment
opportunity at the EIC

Echevarria, arXiv:1907.06494
Fleming et al., arXiv:1910.03586
....

talks by C. Pisano
L. Maxia
R. Kishore

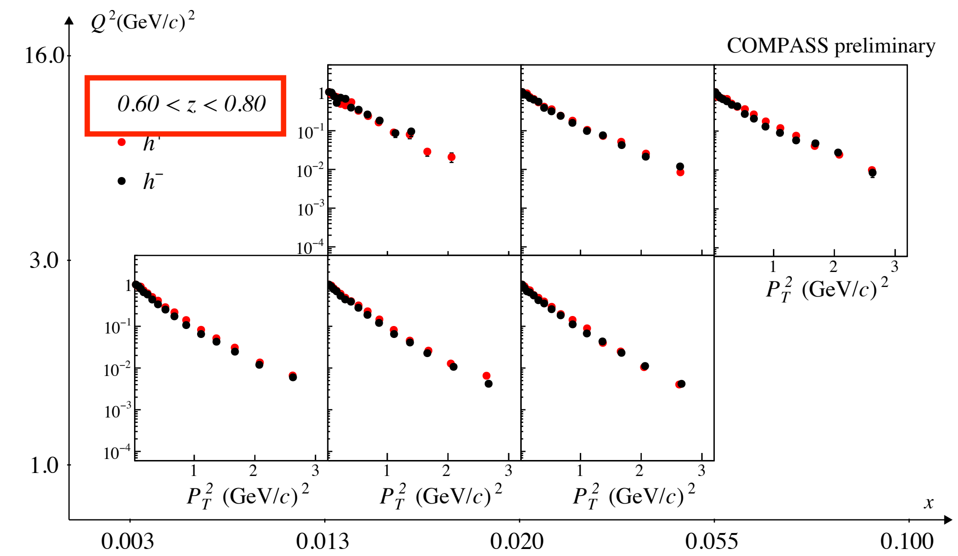
New SIDIS data for unpol. proton target

Compass: 2016-17 run on unpol. LH_2 target; only 11% of data analyzed
4-D analysis (x, Q^2, z, P_{hT}) bins; unidentified charged hadrons $h^{\pm}$
QED radiative corrections included
contamination from exclusive VM decay subtracted bin by bin



P_{hT}-distributions

- no evidence of flavor dep.
- clear z, Q^2, x dep.
- deviation from Gaussian at P_{hT} >1 GeV



talks by A. Bressan
J. Matousek

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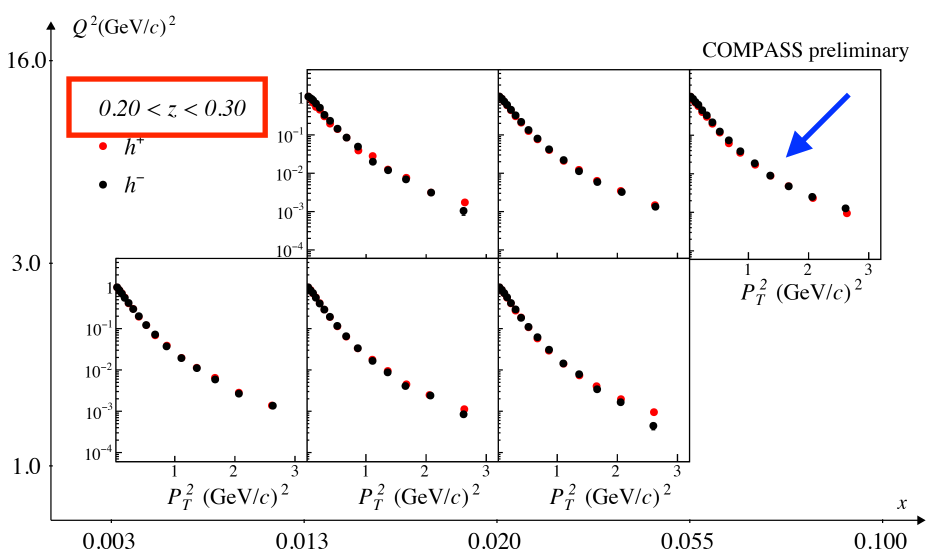

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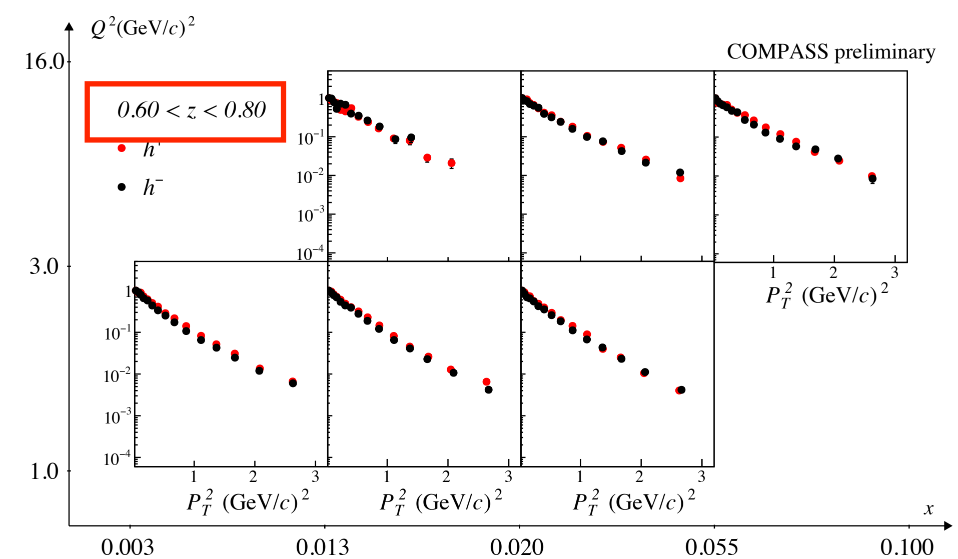
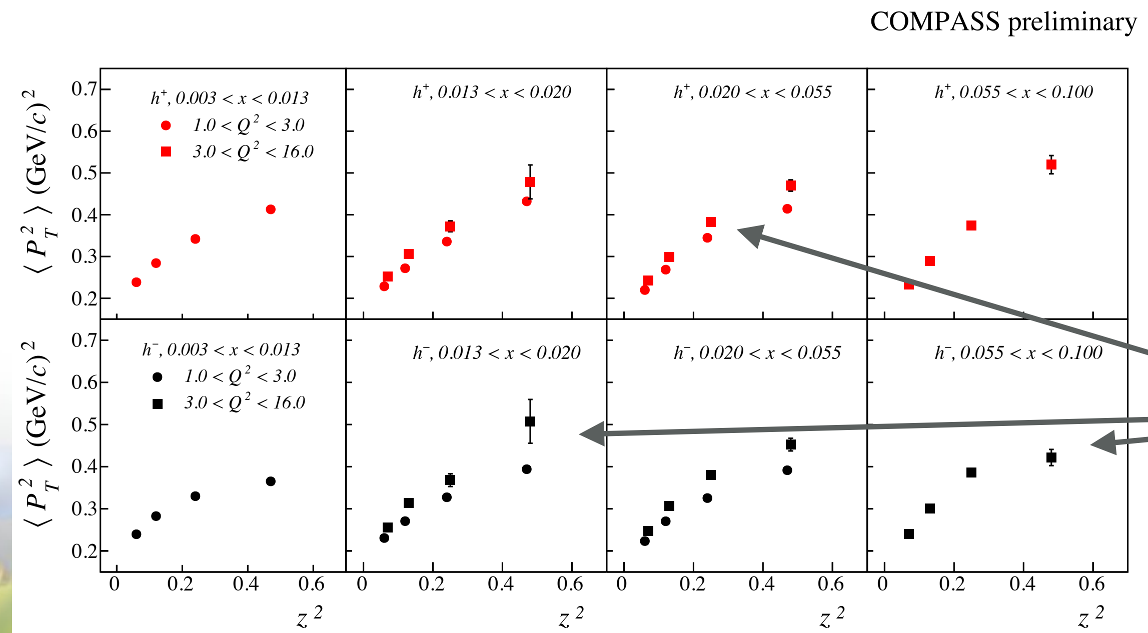


$\langle P_{hT}^2 \rangle (z^2)$



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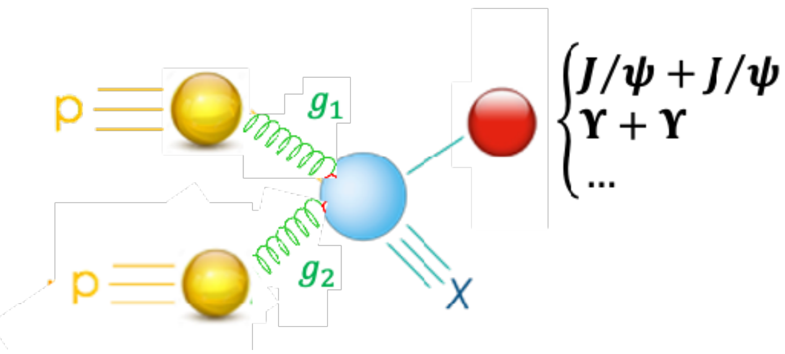
parton model: $\langle P_{hT}^2 \rangle = z^2 \langle k_\perp^2 \rangle + \langle P_\perp^2 \rangle$

deviations : $\langle k_\perp^2 \rangle (x)$?
$\langle P_\perp^2 \rangle (z)$?

Future data for unpol. gluon TMDs

- LHCspin => ex. $pp^{(\uparrow)} \to J/\psi + J/\psi + X$

talk by P. Di Nezza



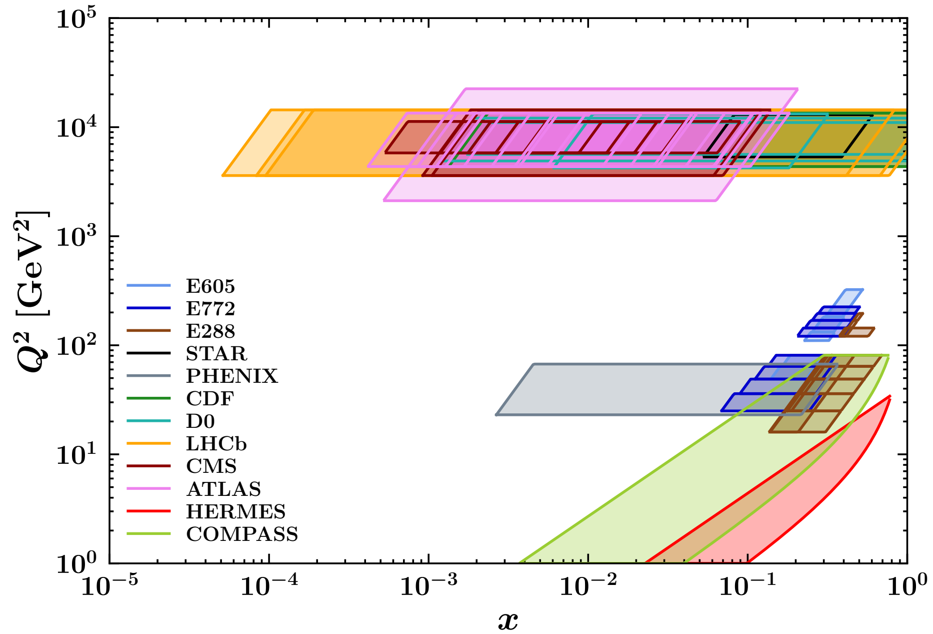
- also complementarity of colliders:

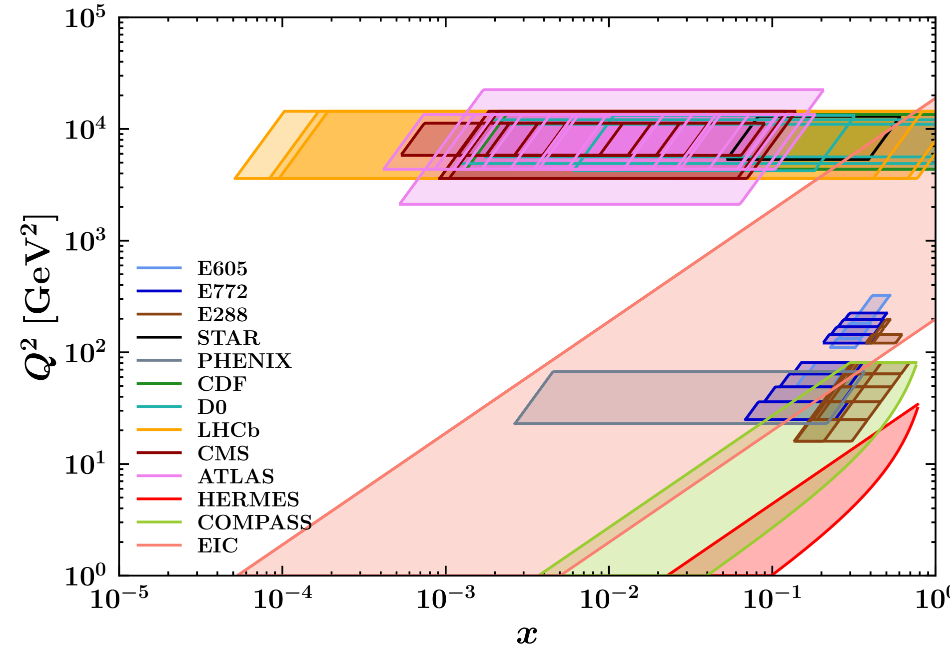
$f_1^{g\,[+,+]}$ $f_1^{g\,[+,-]}$	$pp \to \gamma\, J/\psi\, X$ $pp \to \gamma\, \Upsilon\, X$ $pp \to \gamma\, \text{jet}\, X$	LHC LHC LHC & RHIC
$h_1^{\perp\, g\,[+,+]}$ $h_1^{\perp\, g\,[+,-]}$	$e\,p \to e'\, Q\,\overline{Q}\, X$ $e\,p \to e'\, \text{jet}\,\text{jet}\, X$ $pp \to \eta_{c,b}\, X$ $pp \to H\, X$ $pp \to \gamma^*\, \text{jet}\, X$	EIC EIC LHC & NICA LHC LHC & RHIC

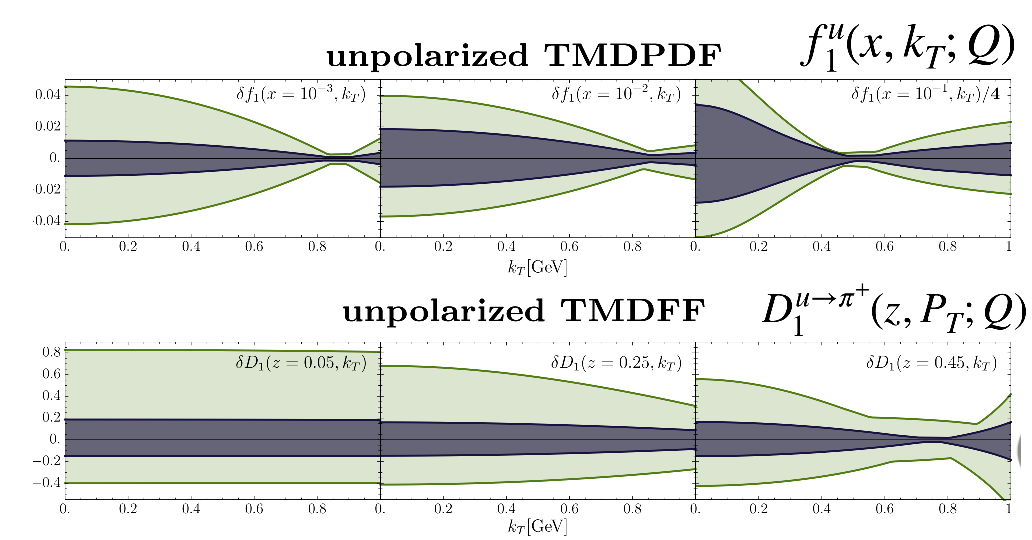
Boer, talk at IWHSS2020

The EIC impact

MAPTMD22 coverage





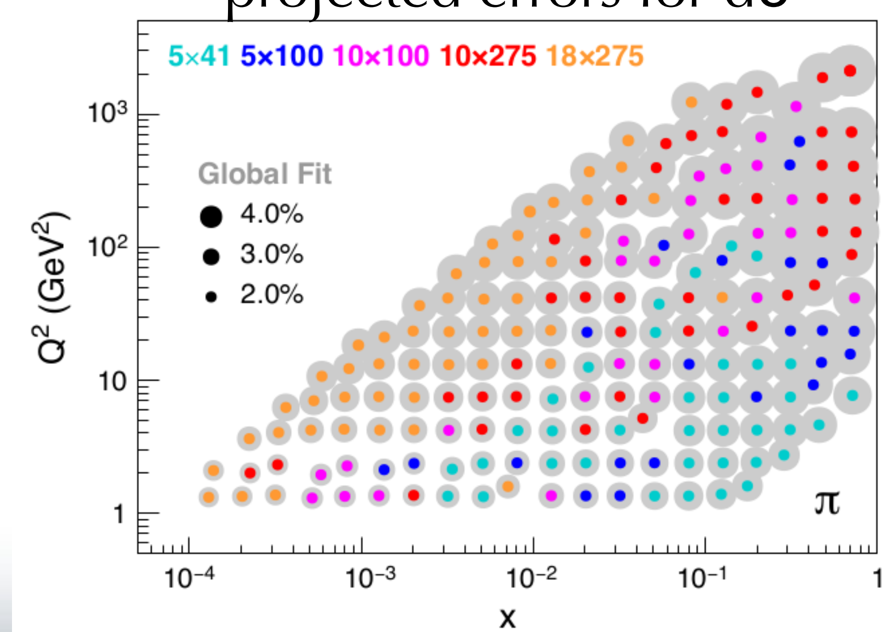


SV19

+ EIC

PV17

projected errors for $d\sigma^0$



*Abdul Khalek et al., arXiv:2103.05419, N.P.**A** in press*

Adam et al., ATHENA Coll.

Electron-Ion Collider

More stuff …

- unpolarized azimuthal asymm.: 3-D analysis of $A_{UU}^{\cos\phi}$, $A_{UU}^{\cos 2\phi}$ from Compass
  also for di-hadron final state
  talk by A. Moretti

- twist-3 beam spin asymm. (BSA): $A_{LU}^{\sin\phi}$ from Compass and Hermes
  contains $e(x, k_\perp) \otimes H_1^\perp(z, P_\perp)$
  talks by A. Moretti, G. Schnell

- twist-3 BSA: $A_{LU}^{\sin\phi}$ from CLAS(6+12) with di-hadron final state
  contains $e(x)\, H_1^{\sphericalangle}(z, M_{\pi\pi})$
  + decomposition of di-hadron FF in partial waves
  talks by C. Dilks, A. Courtoy

- JLab BSA with 2 back-to-back hadrons: first evidence of Fracture Funct.
  talks by T. Hayward, F. Benmokhtar

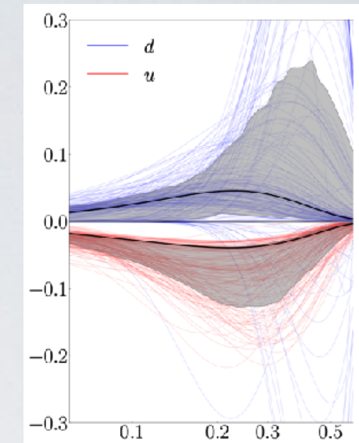
- exclusive processes for GPD extraction
  talks by Dupre', d'Hose, Hobart, Kumericki, Sznajder

- strategies for GTMD: quark => exclusive double DY
  gluon => exclusive di-jet in (pol.) e-p at the EIC
  GTMD => access to OAM of quarks and gluons
  talks by S. Bhattacharya, F. Yuan


THANK YOU
for your
ATTENTION!

Backup

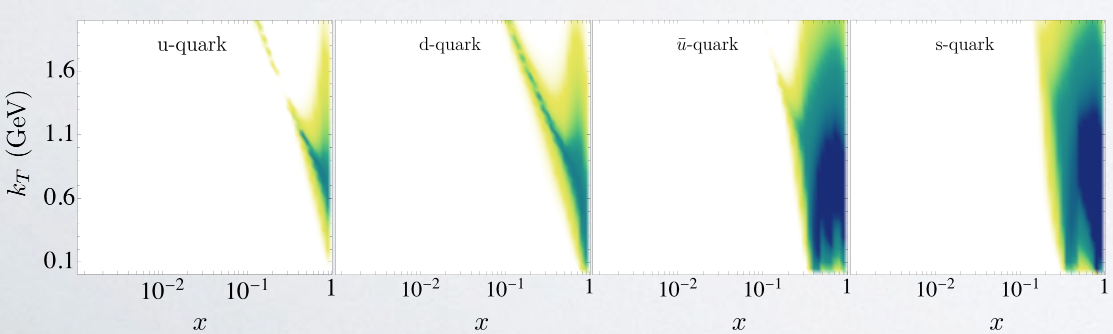
Remarks on Sivers extractions



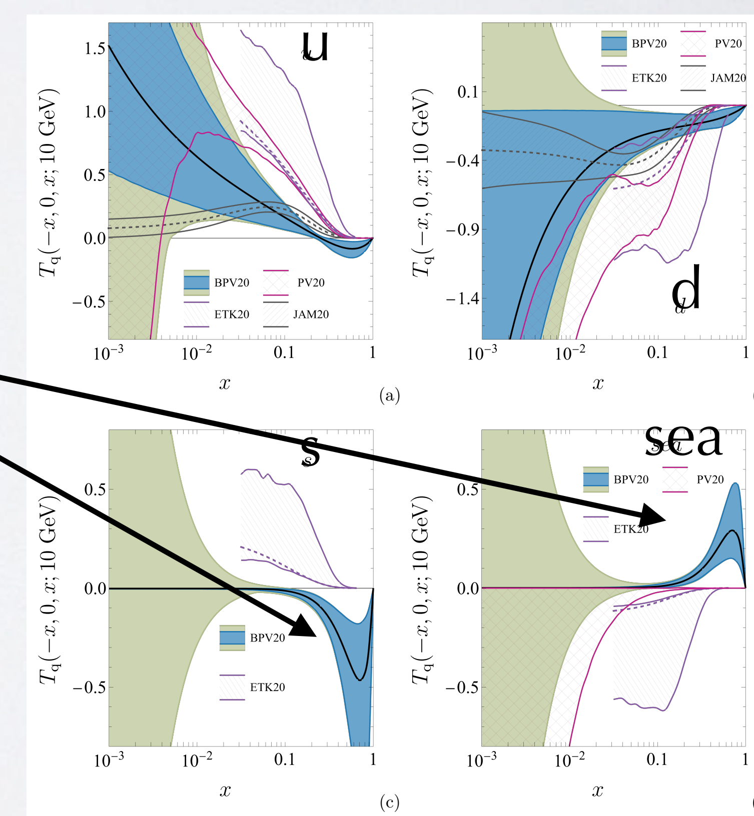
- Most fits use all correlated projections of same data set; moreover, EKT20 artificially enhance weight of STAR data by factor 13, still getting tension between STAR and SIDIS data (χ^2/Npts = 1.44)

- JAM20 and TO-CA use Generalized Parton Model (GPM) with no TMD evolution and incompatible with Sivers sign change SIDIS-DY; TO-CA use GPM and version CGI-GPM (compatible with sign change), but they get better χ^2 with GPM

- Hard to compare BPV20 with rest of works in CSS formalism; in any case, there are violations of positivity bound for sea quarks at large x



coloured areas



Bury et al., arXiv:2103.03270