SPIN2021 The 24th International Spin Symposium

Matsue, Japan

18-22 October 2021
Matsue, Shimane Prefecture, Japan

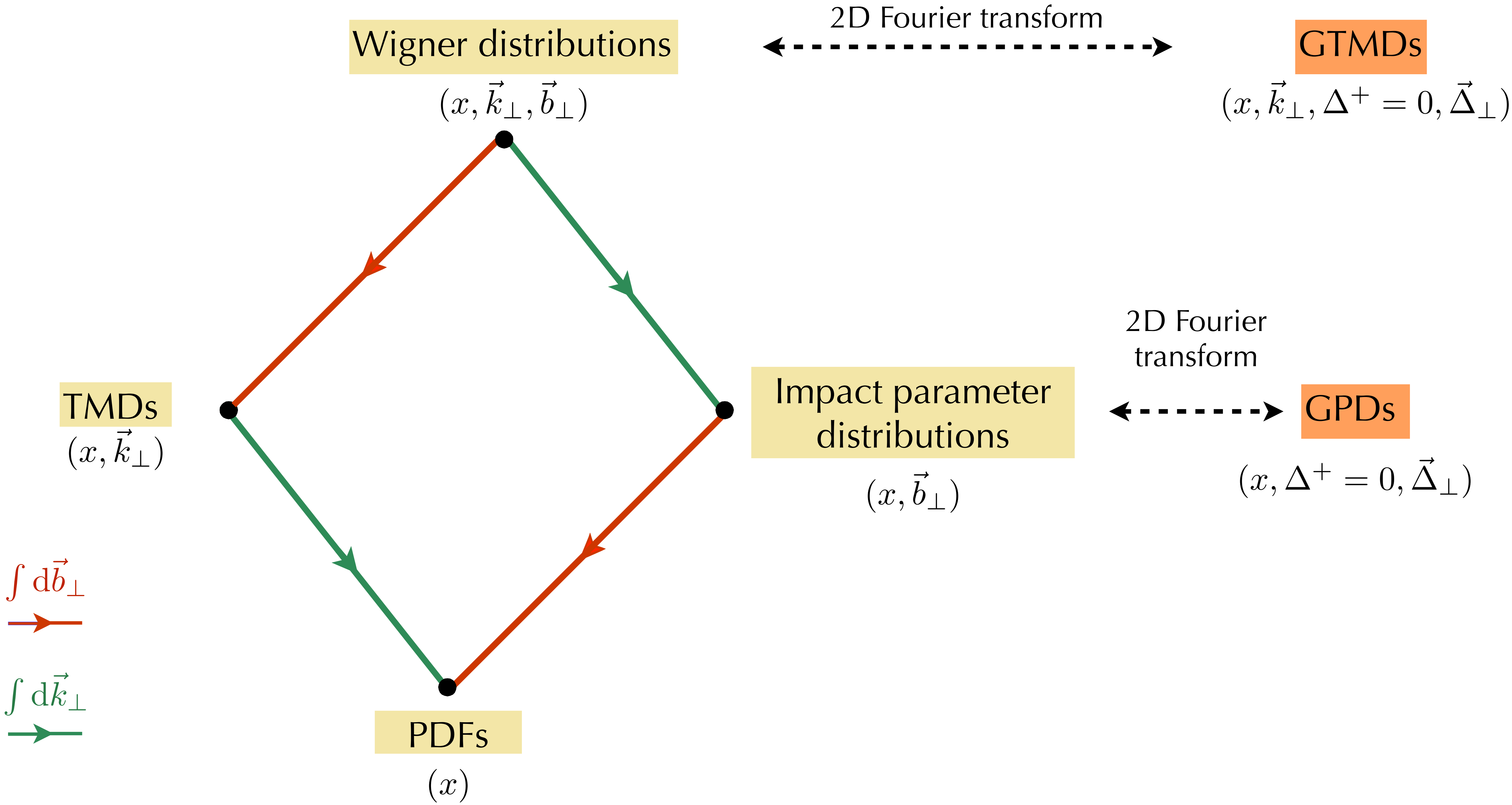
THEORETICAL STUDIES ON THE 3D STRUCTURE OF THE NUCLEON

BARBARA PASQUINI

University of Pavia and INFN Pavia

UNIVERSITÀ DI PAVIA

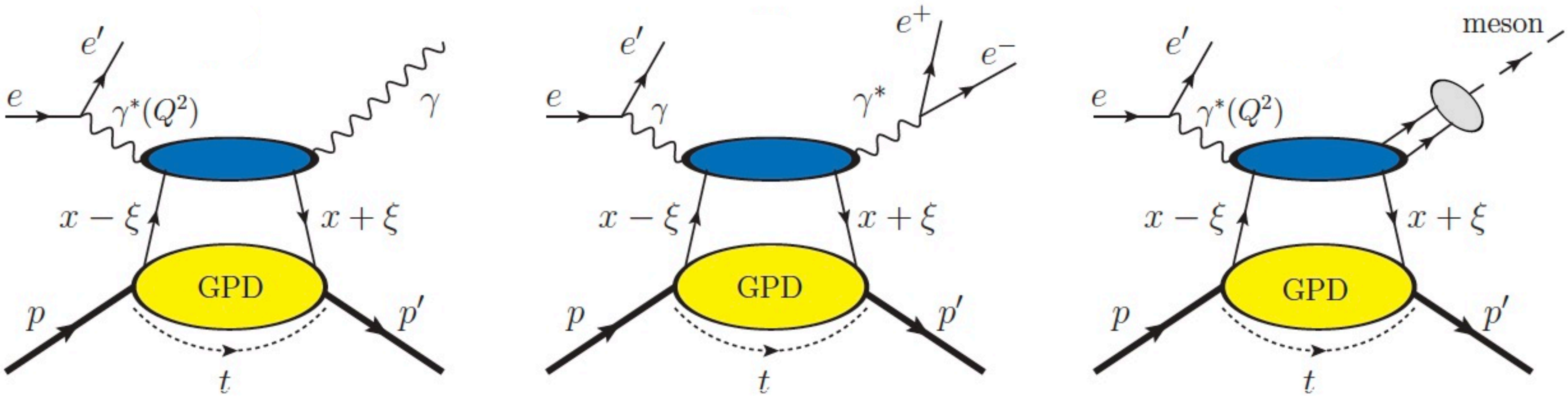
INFN Istituto Nazionale di Fisica Nucleare



- map the nucleon's constituent both in space and in momentum
- study the interplay of quark and gluon dynamics
- assessments of spin and orbital angular momentum content of the nucleon
- how the proton spin is correlated with the motion of quarks and gluons

Lorcé, BP, Vanderhaeghen, JHEP05 (2011) 041

How to measure GPDs



- accessible in exclusive reactions: universality of GPDs
- factorization for large Q^2, $|t| \ll Q^2$, W^2
- depend on 3 variables: $x,\ \xi,\ t = \Delta^2$
- Compton form factors $\quad \mathrm{Im}\mathcal{H} \stackrel{\mathrm{LO}}{=} H(\xi,\xi,t) \quad \mathrm{Re}\mathcal{H} \stackrel{\mathrm{LO}}{=} \mathcal{P}\int_{-1}^{1} \mathrm{d}x \frac{H(x,\xi,t)}{x-\xi}$

quark polarization

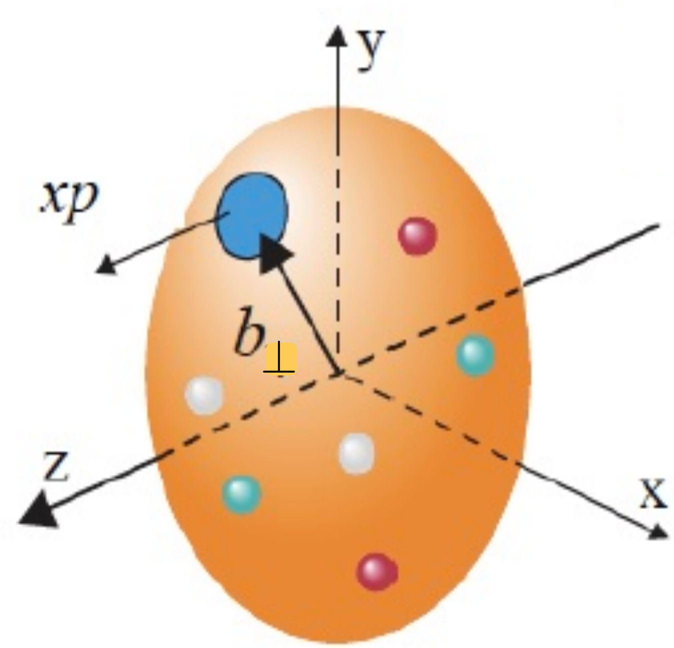
nucleon polarization

GPD	U	L	T
U	H		$\mathcal{E}_T$
L		$\tilde{H}$	$\tilde{E}_T$
T	E	$\tilde{E}$	$H_T, \ \tilde{H}_T$

the distributions in **red** vanish if there is no quark orbital angular momentum

the distributions in **black** survive in the collinear limit

(at $\xi = 0$) $\vec{\Delta}_\perp \xleftrightarrow{\text{FT}} \vec{b}_\perp$ Impact Parameter Distributions



Burkardt., IJMA 18 (2003)173

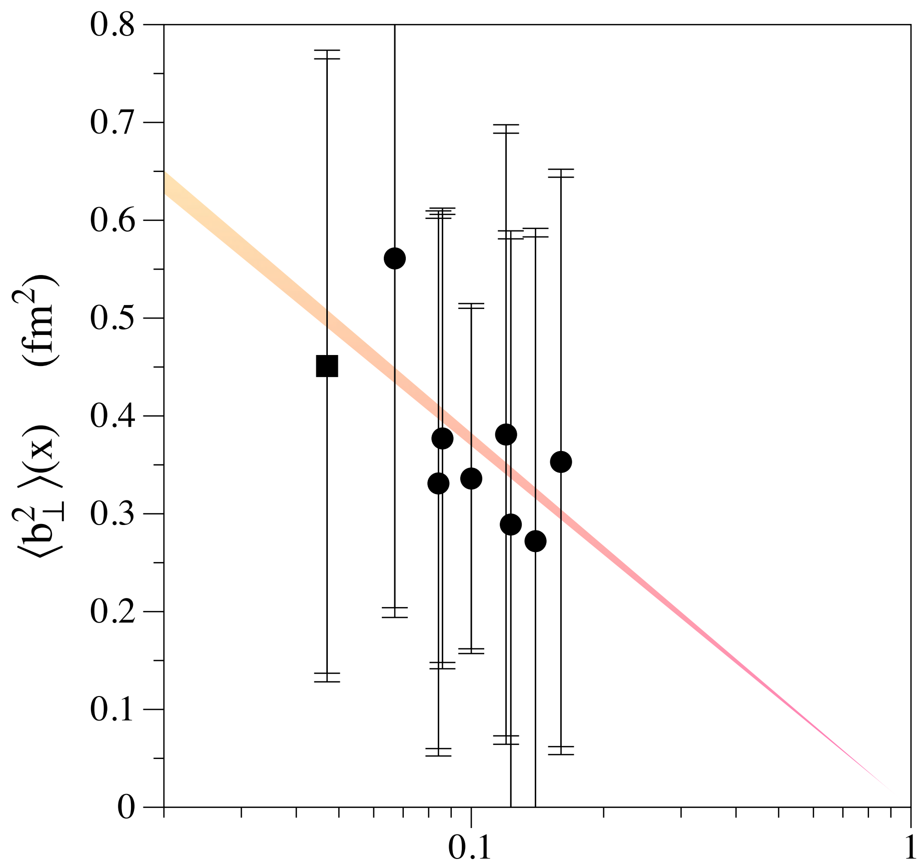
x-dependent transverse squared charge radius

$$H(x,0,\vec{b}_\perp) = \int_{-\infty}^{+\infty} \mathrm{d}^2\vec{\Delta}_\perp \, H(x,0,t)\, e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp} \longrightarrow \langle \vec{b}_\perp^2(x)\rangle = \frac{\int \mathrm{d}^2\vec{b}_\perp\, \vec{b}_\perp^2\, H(x,0,b_\perp)}{\int \mathrm{d}^2\vec{b}_\perp H(x,0,b_\perp)}$$

$(t = -\vec{\Delta}_\perp^2)$ $\xi = 0$ extrapolation from data

x-dependent transverse squared radius

CLAS and Hall A data



x-range of data: $0.05 \leq x \leq 0.2$

The errors are large,
but slowly we are getting some 3D information

Dupré et al., PRD95(2017)011501

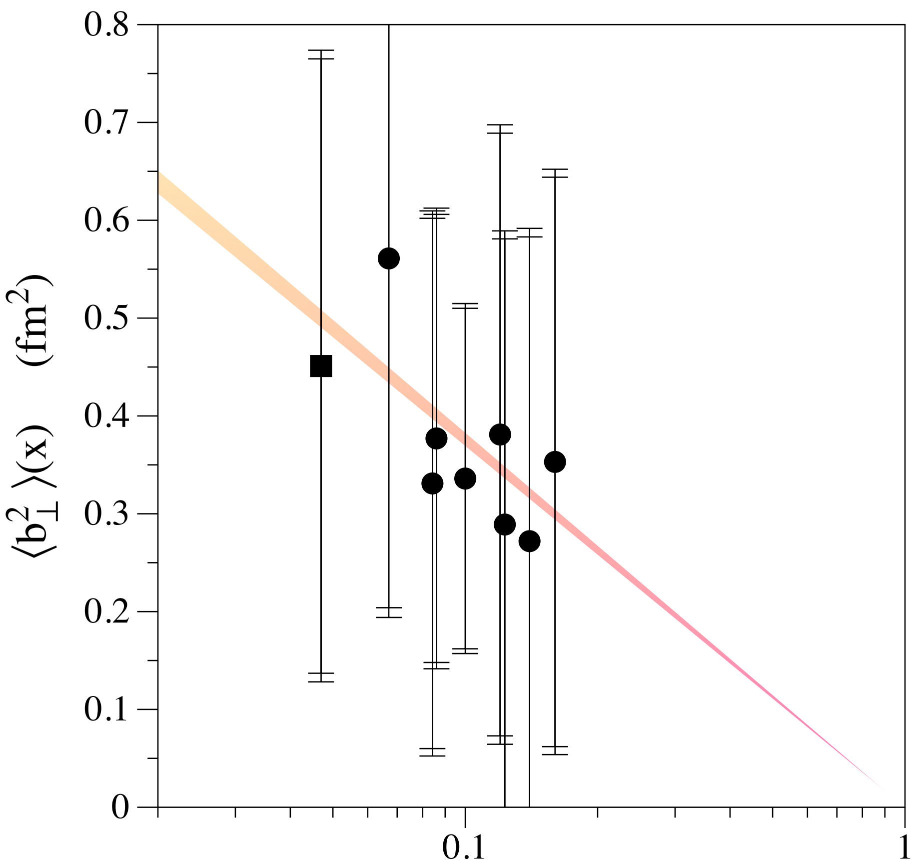
x-dependent transverse squared charge radius

$$H(x,0,\vec{b}_\perp) = \int_{-\infty}^{+\infty} \mathrm{d}^2\vec{\Delta}_\perp\, H(x,0,t)\, e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp} \longrightarrow \langle \vec{b}_\perp^{\,2}(x)\rangle = \frac{\int \mathrm{d}^2\vec{b}_\perp\, \vec{b}_\perp^{\,2}\, H(x,0,b_\perp)}{\int \mathrm{d}^2\vec{b}_\perp H(x,0,b_\perp)}$$

$(t = -\vec{\Delta}_\perp^2)$ $\xi = 0$ extrapolation from data

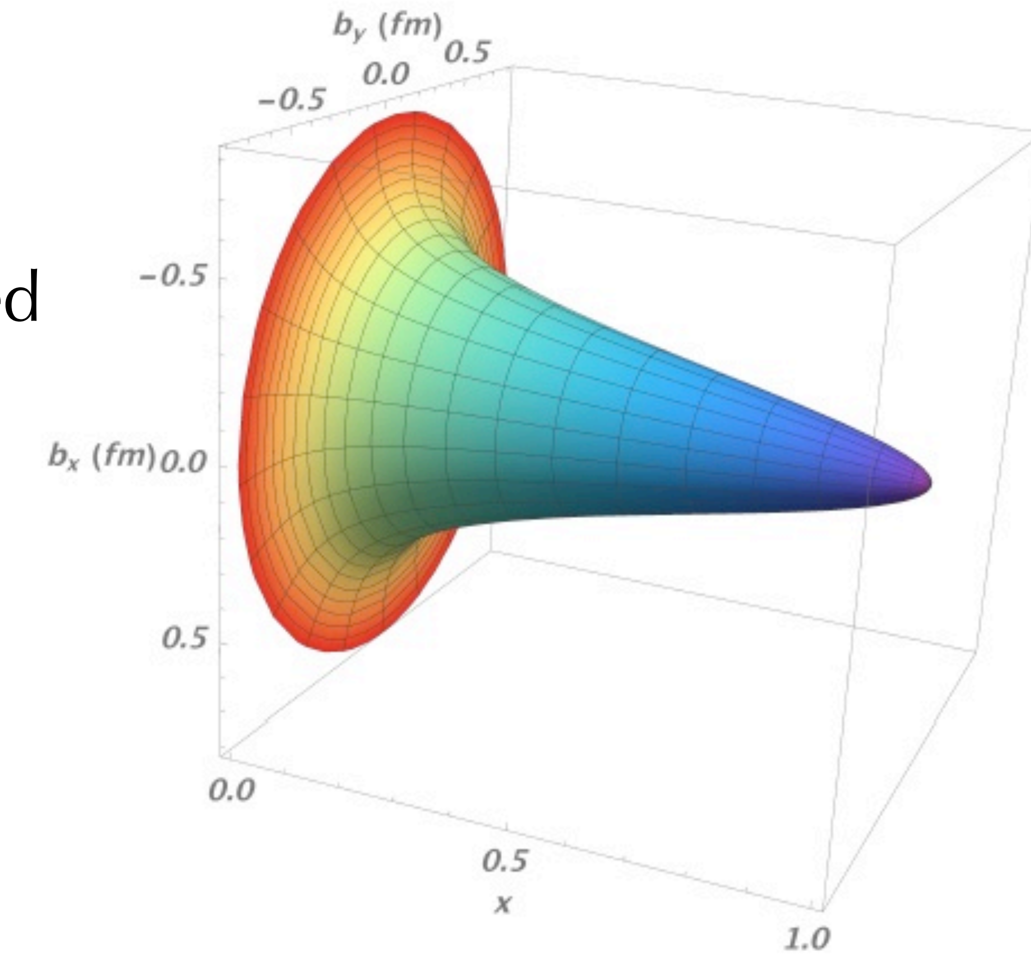
x-dependent transverse squared radius

CLAS and Hall A data



x-range of data: $0.05 \le x \le 0.2$

extrapolating
in the unmeasured
x-range

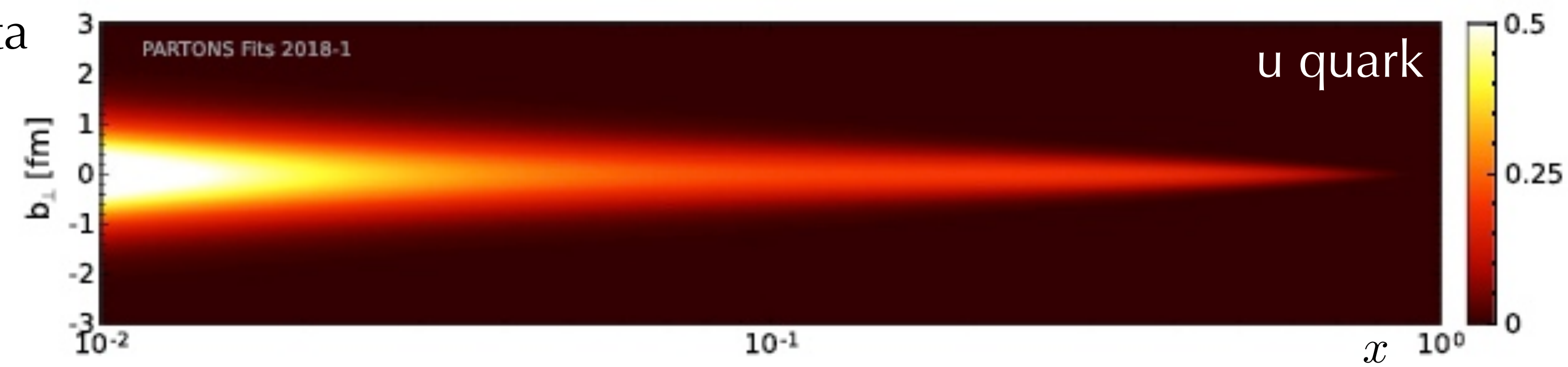


As x ⟶ 1, the active parton carries all the momentum
and represents the centre of momentum

Dupré et al., PRD95(2017)011501

New parametrization based on DRs: reduce problems related to the extrapolation to $\xi = 0$

CLAS and HERMES data



Moutarde et al., EPJC78(2018)890

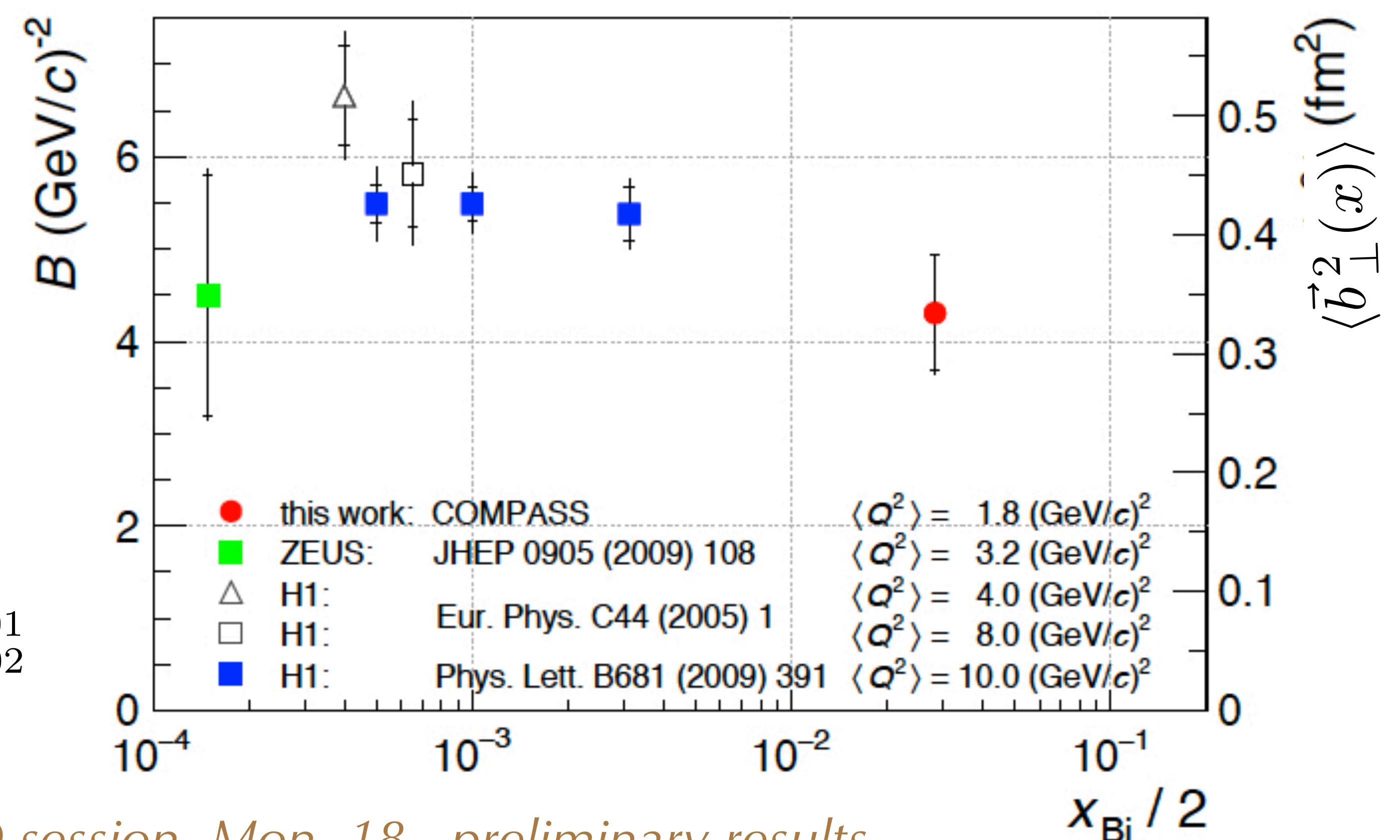
Results from COMPASS Coll.: Phys. Lett. B793 (2019) 188

$$\frac{d\sigma}{dt} \approx e^{-B(x)|t|}$$

$$\langle \vec{b}_\perp^{\,2}(x)\rangle = 2\langle B(x)\rangle$$

at $x = 0.056$:

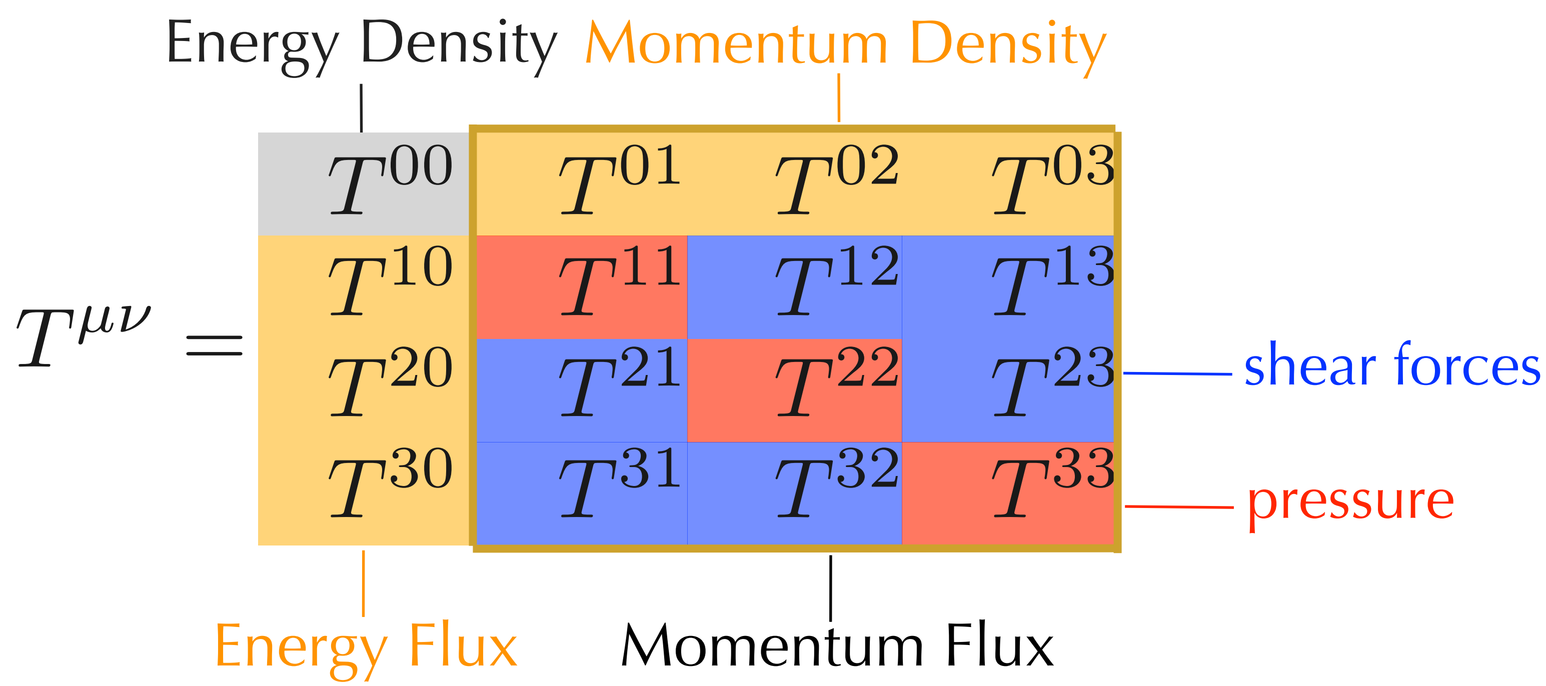
$$\sqrt{\langle \vec{b}_\perp^{\,2}\rangle} = 0.58 \pm 0.04^{+0.01}_{-0.02}$$



→ *Talk of J. Giarra, GPD session, Mon. 18., preliminary results from 2016/2017 Compass run*

Model dependence can not be avoided, but different fit methods and parametrizations can help to constraint the theoretical uncertainties

Form Factors of Energy Momentum Tensor



$$\langle p | T^{Q,G}_{\mu\nu} | p' \rangle = \bar{u}(p') \left[M_2^{Q,G}(t) \frac{P_\mu P_\nu}{M_N} + J^{Q,G}(t) \frac{i(P_\mu \sigma_{\nu\rho} + P_\nu \sigma_{\mu\rho})\Delta^\rho}{2M_N} + d_1^{Q,G}(t) \frac{\Delta_\mu \Delta_\nu - g_{\mu\nu}\Delta^2}{5M_N} \pm \bar{c}(t) g_{\mu\nu} \right] u(p)$$

Relation with second-moments of GPDs:

$$\sum_q \int \mathrm{d}x \, x \, H^q(x,\xi,t) = M_2^Q(t) + \frac{4}{5} d_1^Q(t) \xi^2$$

$$\sum_q \int \mathrm{d}x \, x \, E^q(x,\xi,t) = 2J^Q(t) - M_2^Q(t) - \frac{4}{5} d_1^Q(t) \xi^2$$

"Charges" of the EMT Form Factors at t=0

$M_2(0)$ nucleon momentum carried by parton

$J(0)$ angular momentum of partons

$d_1(0)$ D-term ("stability" of the nucleon)

Form Factors of Energy Momentum Tensor

Energy Density | Momentum Density

$$T^{\mu\nu} = \begin{pmatrix} T^{00} & T^{01} & T^{02} & T^{03} \\ T^{10} & T^{11} & T^{12} & T^{13} \\ T^{20} & T^{21} & T^{22} & T^{23} \\ T^{30} & T^{31} & T^{32} & T^{33} \end{pmatrix}$$

shear forces

pressure

Energy Flux | Momentum Flux

Fourier transform in coordinate space

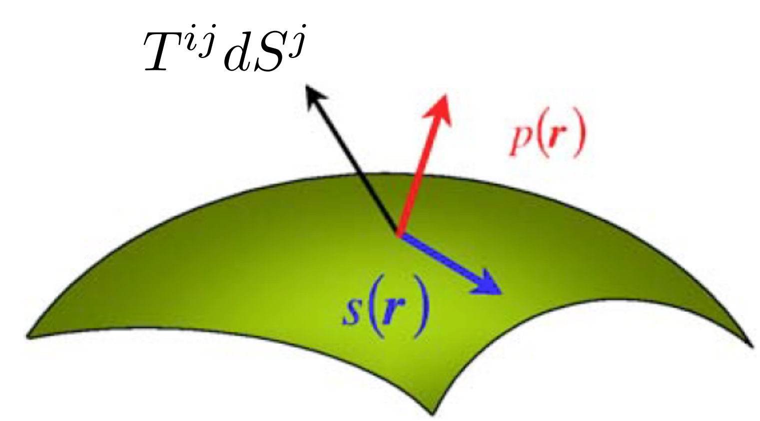
$$T_{ij}^{Q}(\vec{r}) = s(\vec{r})\left(\frac{r_i r_j}{r^2} - \frac{1}{3}\delta_{ij}\right) + p(\vec{r})\,\delta_{ij}$$

shear forces

pressure

$$d_1^Q(0) = 5\pi M_N \int_0^\infty \mathrm{d}r\, r^4\, p(r)$$

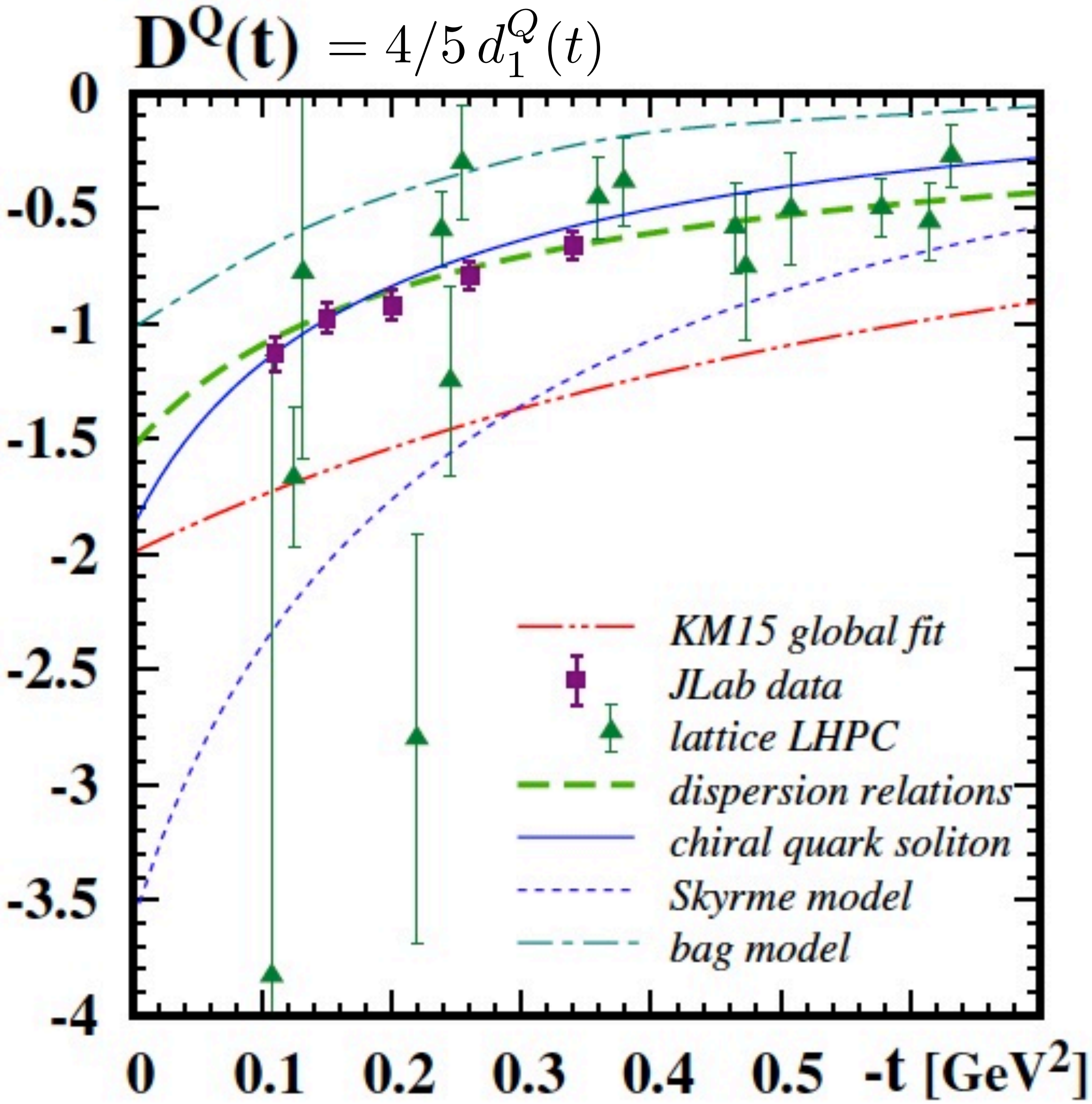
"mechanical properties" of nucleon



M. Polyakov, PLB 555 (2003) 57

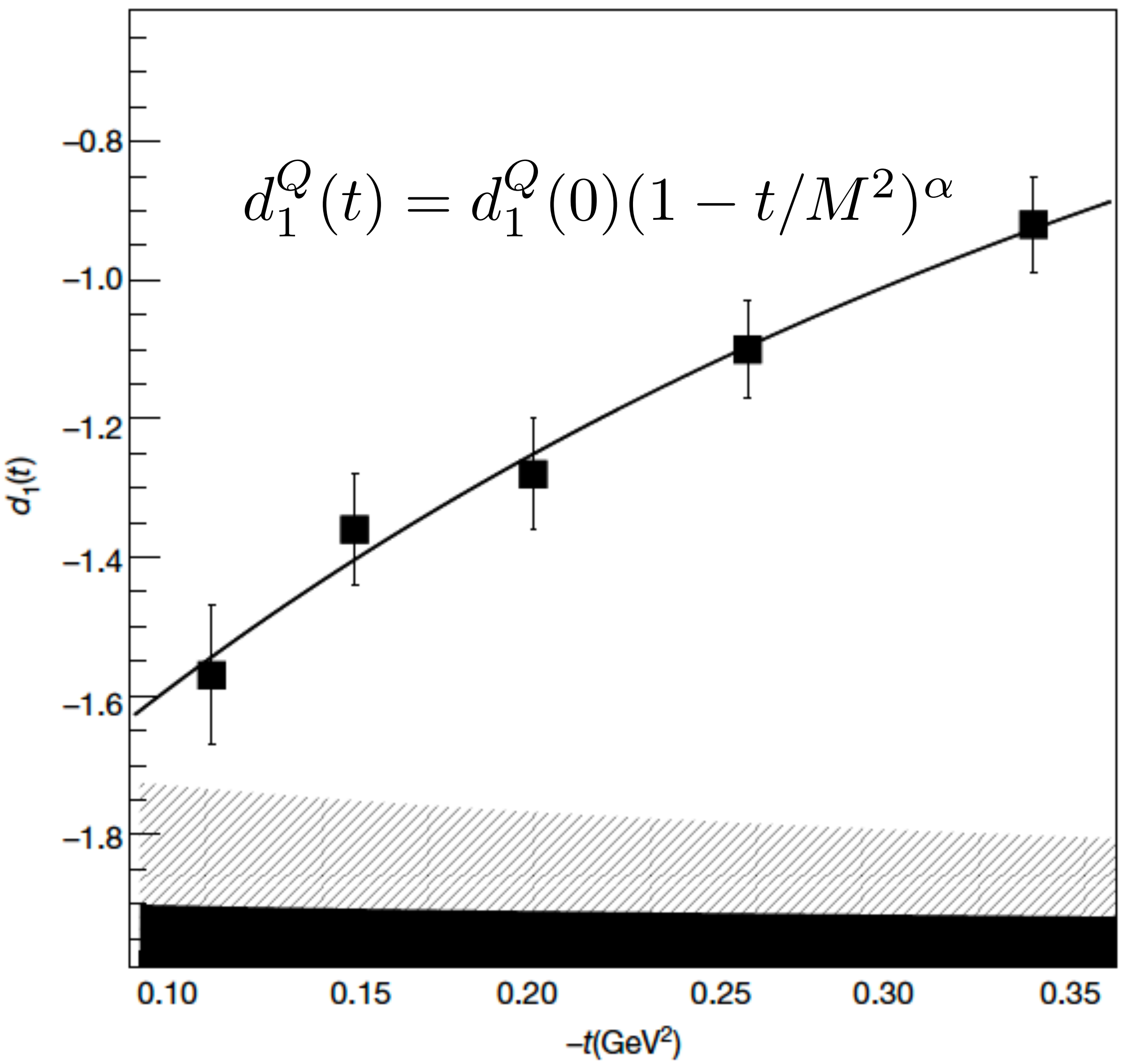
D(t) form factor from data

Girod, Elouadrhiri,Burkert, Nature 557 (2018) 7705
and arXiv: 2104.02031;
CLAS 6GeV data



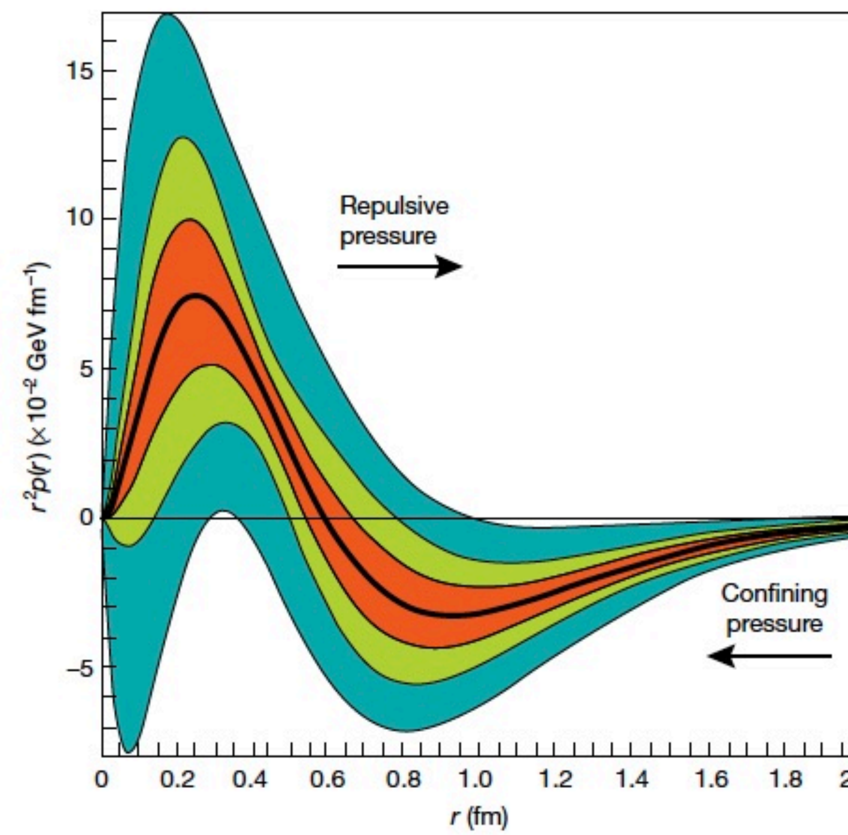
D(t) form factor from data

Girod, Elouadrhiri, Burkert, Nature 557 (2018) 7705
and arXiv: 2104.02031;
CLAS 6GeV data

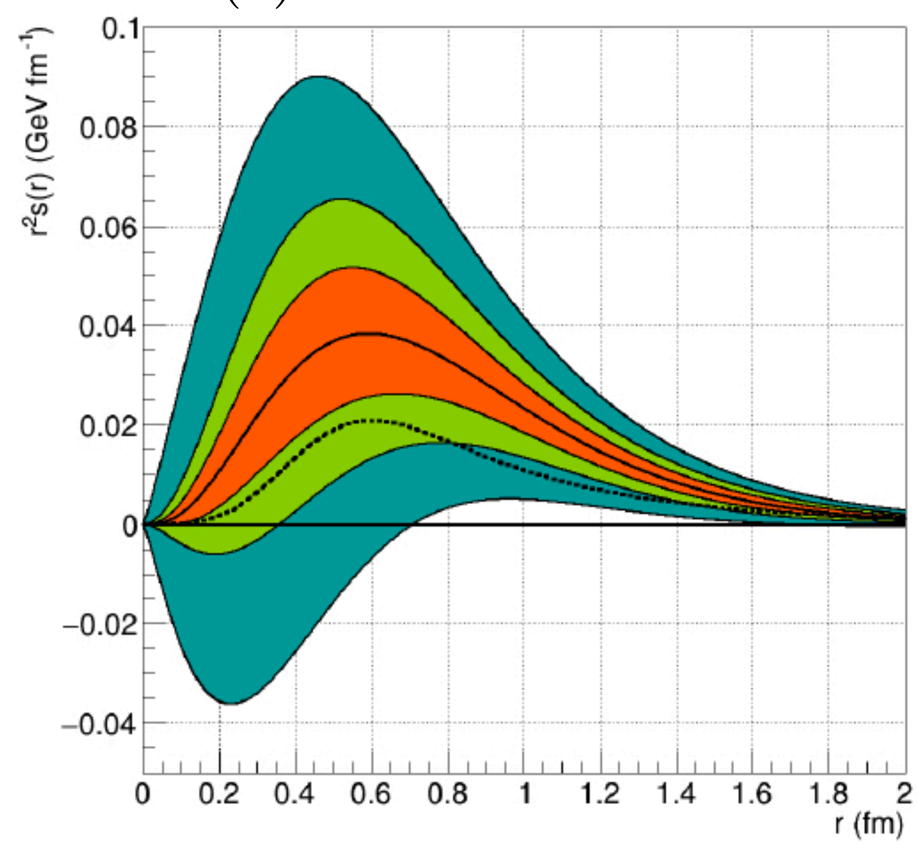


FT

$r^2 p(r)$ radial pressure distribution



$r^2 s(r)$ shear forces distribution



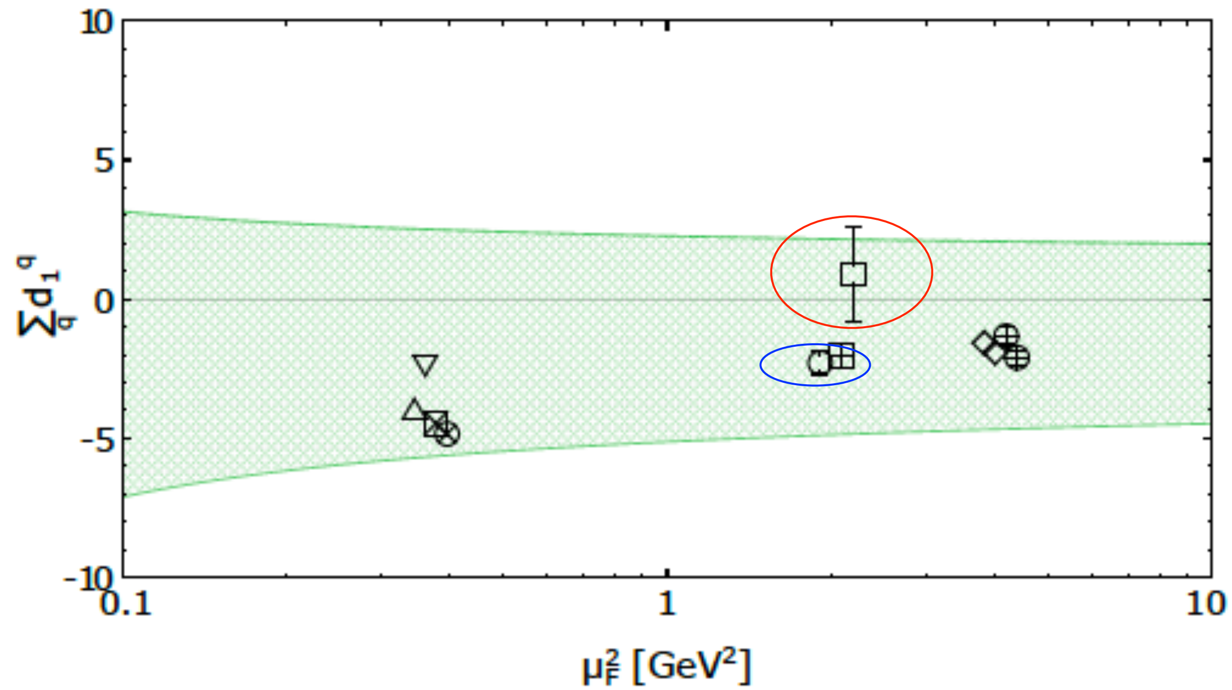
- data before 6 GeV JLab
- 6 GeV JLab data
- projected 12 GeV JLab data

Necessary to verify model assumptions in the exp extraction
with more data coming from JLab, COMPASS and the future EIC, EIcC

Kumericki, Nature 570 (2019) 7759; Dutrieux et al, Eur. Phys. J. C81 (2021) 4

Talk of Dutrieux, Moutarde, Sznajder, GPD sessions, Mon. and Wend.

global fit to DVCS data
with artificial neural networks



CLAS data, with fixed param.,
Girod et al.

CLAS data, with neural networks
Kumericki

$$\sum_q d_1^q < 0$$

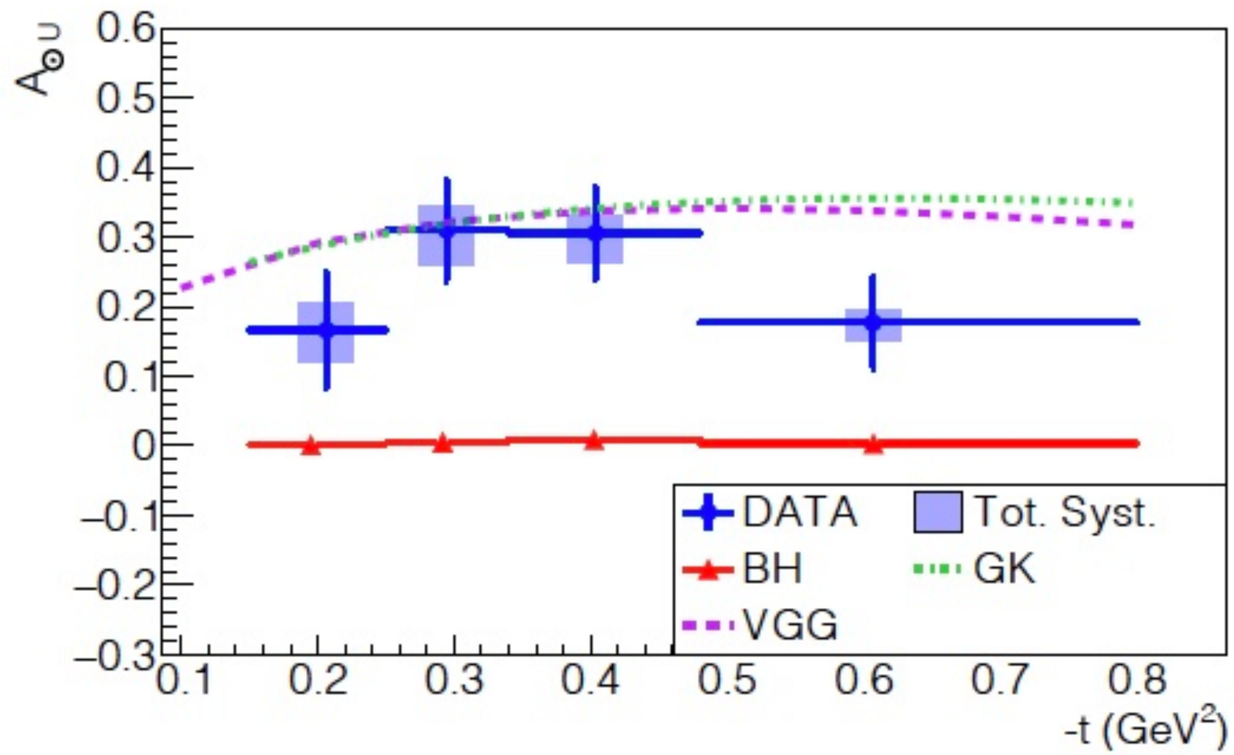
in all model calculations
for a stable proton

Marker in Fig. 3	$\sum_q d_1^q(\mu_F^2)$	μ_F^2 in GeV^2	# of flavours	Type
○	$-2.30 \pm 0.16 \pm 0.37$	2.0	3	from experimental data
□	0.88 ± 1.69	2.2	2	from experimental data
◇	-1.59	4	2	t-channel saturated model
	-1.92	4	2	t-channel saturated model
△	-4	0.36	3	χQSM
▽	-2.35	0.36	2	χQSM
⊠	-4.48	0.36	2	Skyrme model
⊞	-2.02	2	3	LFWF model
⊗	-4.85	0.36	2	χQSM
⊕	-1.34 ± 0.31	4	2	lattice QCD ($\overline{\text{MS}}$)
	-2.11 ± 0.27	4	2	lattice QCD ($\overline{\text{MS}}$)

Timelike Compton scattering

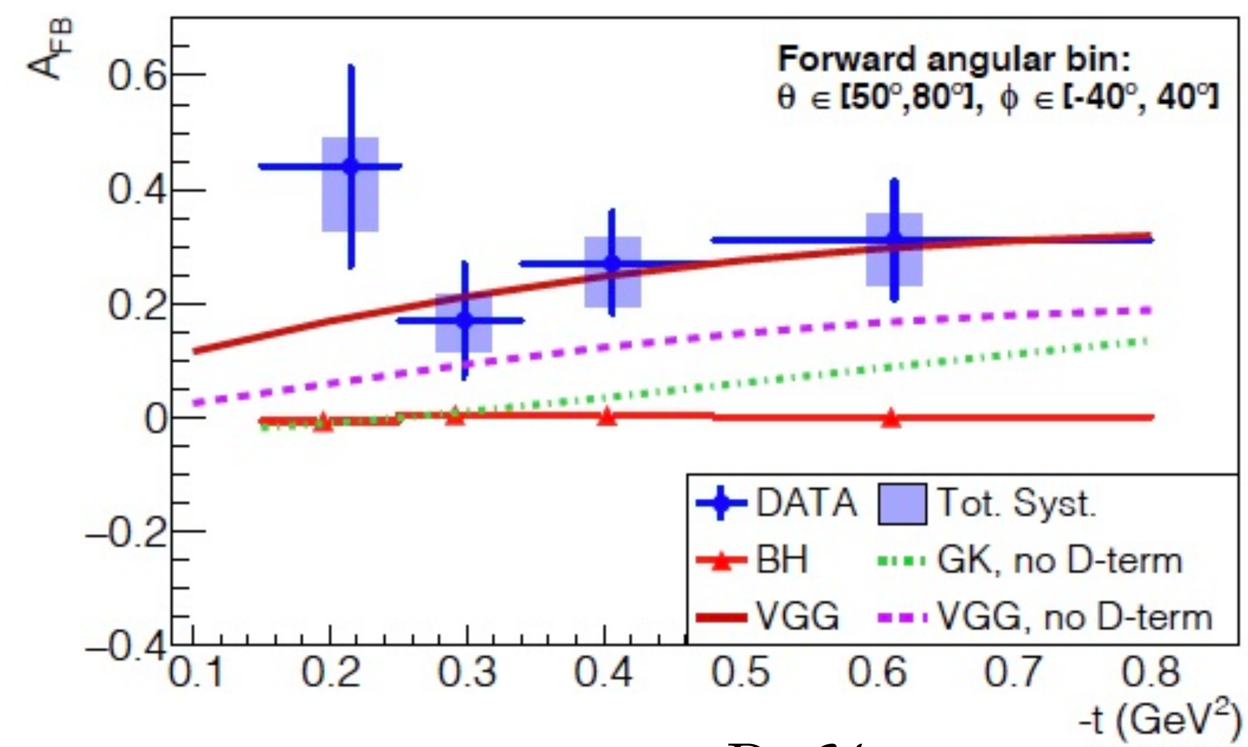
Chatagnon et al. (CLAS12 Coll.), arXiv: 2108.11746

photon polarization asymmetry



access to $\mathrm{Im}\,\mathcal{H}$

forward-backward asymmetry



access to $\mathrm{Re}\,\mathcal{H}$

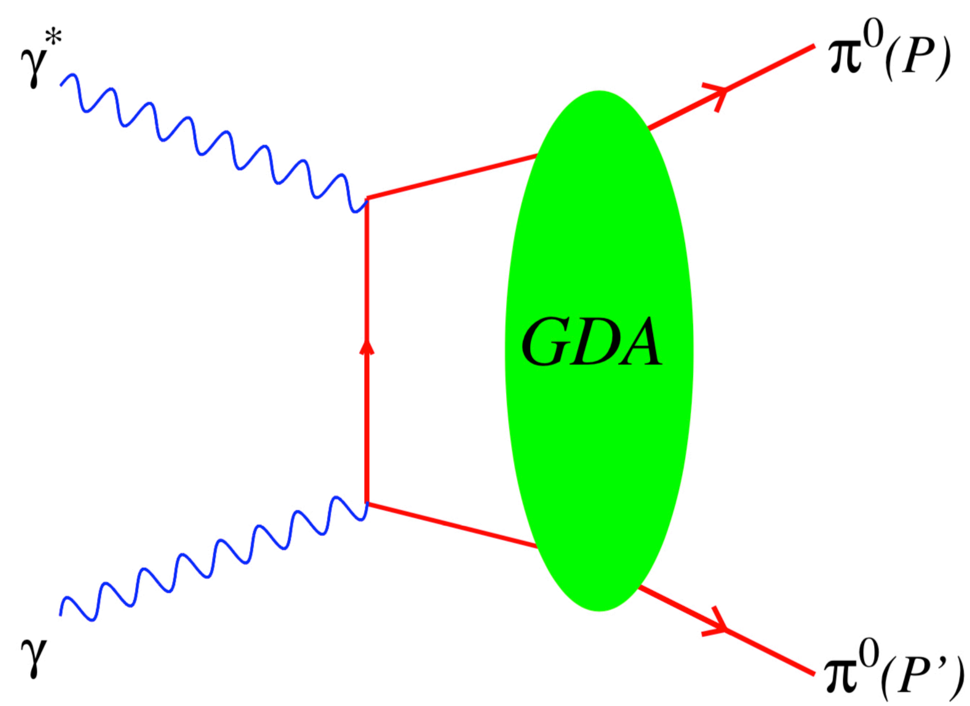
✓ Test of the universality of GPDs

✓ Further data from JLab12 and future EIC

✓ New promising path towards the extraction of $\mathrm{Re}\,\mathcal{H}$ and then the D-term

Generalized Distribution Amplitudes (GDAs)

GPDs $\xleftrightarrow{s-t \text{ crossing}}$ GDAs



Access form factors of EMT of unstable particle through GDA via $\gamma^*\gamma \to \pi^0\pi^0$ in e^+e^-

Belle Coll., PRD93 (2016) 032003

Best fit of GDAs to Belle data $\longrightarrow$ timelike EMT form factors of the pion

Dispersion relations $\longrightarrow$ spacelike EMT form factors

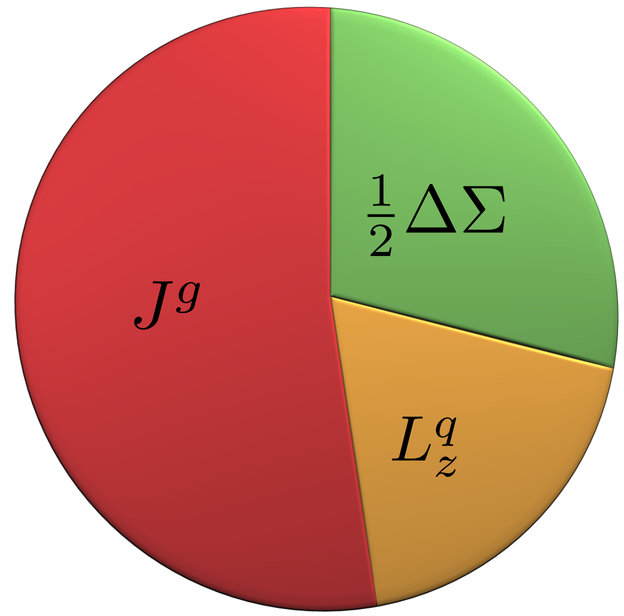
at $< Q^2 >= 16.6 \text{ GeV}^2 \longrightarrow D^Q_{\pi^0} \approx -0.7$ (compatible with soft pion theorem)

Kumano, Song, Teryaev, PRD97 (2018) 014020

→ *Talk of Teryaev, GPD, Form factors session, Mon. 18;*
pion GPDs from Sullivan process at EIC, talk of Morgado Chávex, GPD session, Mon. 18

Ji's Relation

X. Ji, PRL 78 (1997) 610



$\frac{1}{2} = J^q + J^g$ $\quad\quad$ $L_z^q = J^q - \frac{1}{2}\Delta\Sigma$

$$J^{q,g} = \frac{1}{2}\int_{-1}^{1} dx\, x\, \left(H^{q,g}(x,\xi,0) + E^{q,g}(x,\xi,0)\right)$$

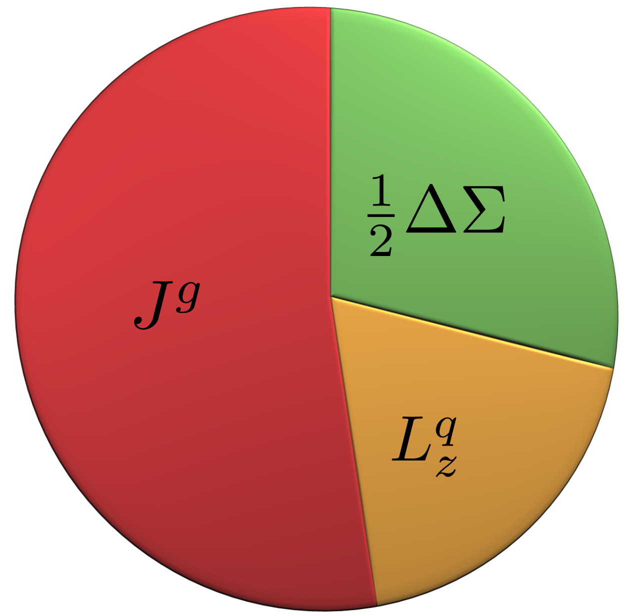
$H^{q,g}$: at $\xi = 0$ unpolarized PDF $\quad$ $E^{q,g}$: not directly accessible

- $H(x,\xi,t), E(x,\xi,t)$: twist-2 GPDs

X. Ji, F. Yuan, Y. Zhao, Nature Rev. Phys. 3 (2021) 1 ⟶ *Talk of X. Ji , Joint GPD - Helicity sessions, Thurs. 21*

Ji's Relation

X. Ji, PRL 78 (1997) 610



$$\frac{1}{2} = J^q + J^g \qquad\qquad L_z^q = J^q - \frac{1}{2}\Delta\Sigma$$

$$J^{q,g} = \frac{1}{2}\int_{-1}^{1} dx\, x\, \left(H^{q,g}(x,\xi,0) + E^{q,g}(x,\xi,0)\right)$$

$H^{q,g}$: at $\xi = 0$ unpolarized PDF

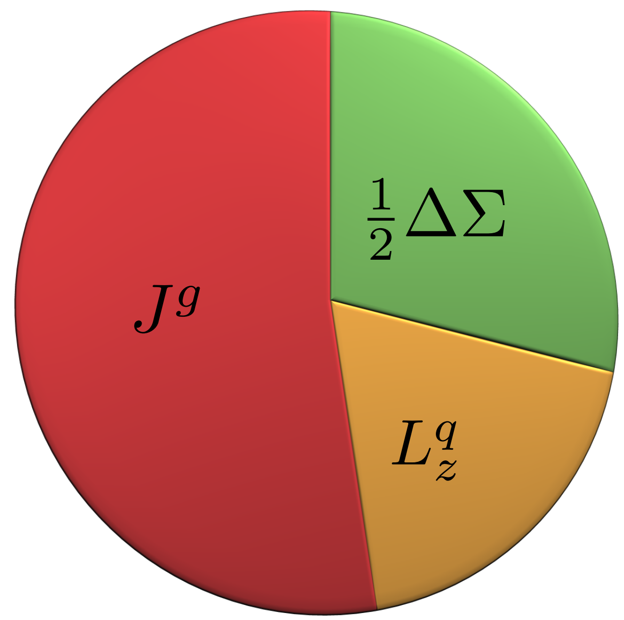
$E^{q,g}$: not directly accessible

- $H(x,\xi,t), E(x,\xi,t)$: twist-2 GPDs
- Requires extrapolation to t=0

X. Ji, F. Yuan, Y. Zhao, Nature Rev. Phys. 3 (2021) 1 → *Talk of X. Ji , Joint GPD - Helicity sessions, Thurs. 21*

Ji's Relation

X. Ji, PRL 78 (1997) 610



$$\frac{1}{2} = J^q + J^g \qquad L_z^q = J^q - \frac{1}{2}\Delta\Sigma$$

$$J^{q,g} = \frac{1}{2}\int_{-1}^{1} dx\, x\, \left(H^{q,g}(x,\xi,0) + E^{q,g}(x,\xi,0)\right)$$

$H^{q,g}$ → at $\xi = 0$ unpolarized PDF

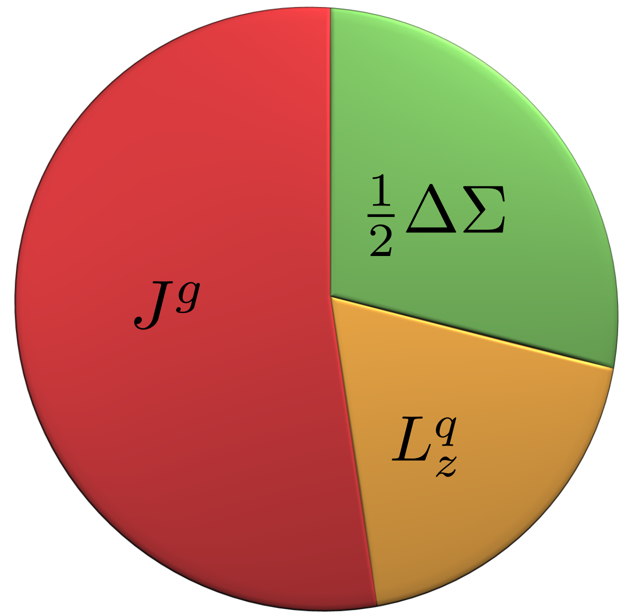
$E^{q,g}$ → not directly accessible

- $H(x,\xi,t), E(x,\xi,t)$: twist-2 GPDs
- Requires extrapolation to t=0
- Requires spanning x at fixed values of ξ ($\xi = 0$ is the most convenient)

X. Ji, F. Yuan, Y. Zhao, Nature Rev. Phys. 3 (2021) 1 ⟶ *Talk of X. Ji , Joint GPD - Helicity sessions, Thurs. 21*

Ji's Relation

X. Ji, PRL 78 (1997) 610



$\frac{1}{2} = J^q + J^g$ $\qquad$ $L_z^q = J^q - \frac{1}{2}\Delta\Sigma$

$$J^{q,g} = \frac{1}{2}\int_{-1}^{1} dx\, x\, \left(H^{q,g}(x,\xi,0) + E^{q,g}(x,\xi,0)\right)$$

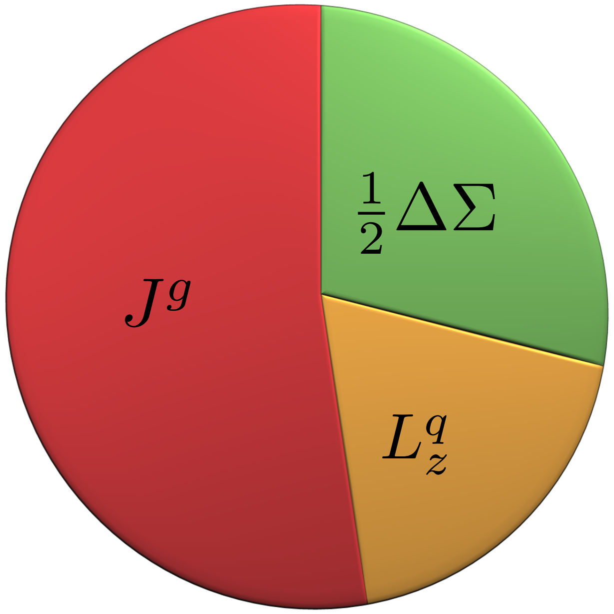
$H^{q,g}$ → at $\xi = 0$ unpolarized PDF $\qquad$ $E^{q,g}$ → not directly accessible

- $H(x,\xi,t), E(x,\xi,t)$: twist-2 GPDs
- Requires extrapolation to t=0
- Requires spanning x at fixed values of ξ ($\xi = 0$ is the most convenient)
- $J^{q,g}(x) \neq \frac{1}{2}[xH^{q,g}(x,0,0) + E^{q,g}(x,0,0)]$ ⟶ not angular momentum density

X. Ji, F. Yuan, Y. Zhao, Nature Rev. Phys. 3 (2021) 1 ⟶ *Talk of X. Ji , Joint GPD - Helicity sessions, Thurs. 21*

Ji's Relation

X. Ji, PRL 78 (1997) 610



$\frac{1}{2} = J^q + J^g$ $\qquad$ $L_z^q = J^q - \frac{1}{2}\Delta\Sigma$

$$J^{q,g} = \frac{1}{2}\int_{-1}^{1} dx\, x\, \left(H^{q,g}(x,\xi,0) + E^{q,g}(x,\xi,0)\right)$$

$H^{q,g}$: at $\xi = 0$ unpolarized PDF $\qquad$ $E^{q,g}$: not directly accessible

- $H(x,\xi,t), E(x,\xi,t)$: twist-2 GPDs
- Requires extrapolation to t=0
- Requires spanning x at fixed values of ξ ($\xi = 0$ is the most convenient)
- $J^{q,g}(x) \neq \frac{1}{2}[xH^{q,g}(x,0,0) + E^{q,g}(x,0,0)]$ ⟶ not angular momentum density
- OAM can be related to twist-3 GPDs: not simple partonic interpretation, but definition of a gauge-invariant covariant OAM density

X. Ji, F. Yuan, Y. Zhao, Nature Rev. Phys. 3 (2021) 1 ⟶ *Talk of X. Ji , Joint GPD - Helicity sessions, Thurs. 21*

Orbital Angular momentum of the proton from available GPD measurements

$$J^{q,g} = \frac{1}{2}\int_{-1}^{1} dx\, x\, \left(H^{q,g}(x,\xi,0) + E^{q,g}(x,\xi,0)\right) \qquad L^q = J^q - \frac{1}{2}\Delta\Sigma$$

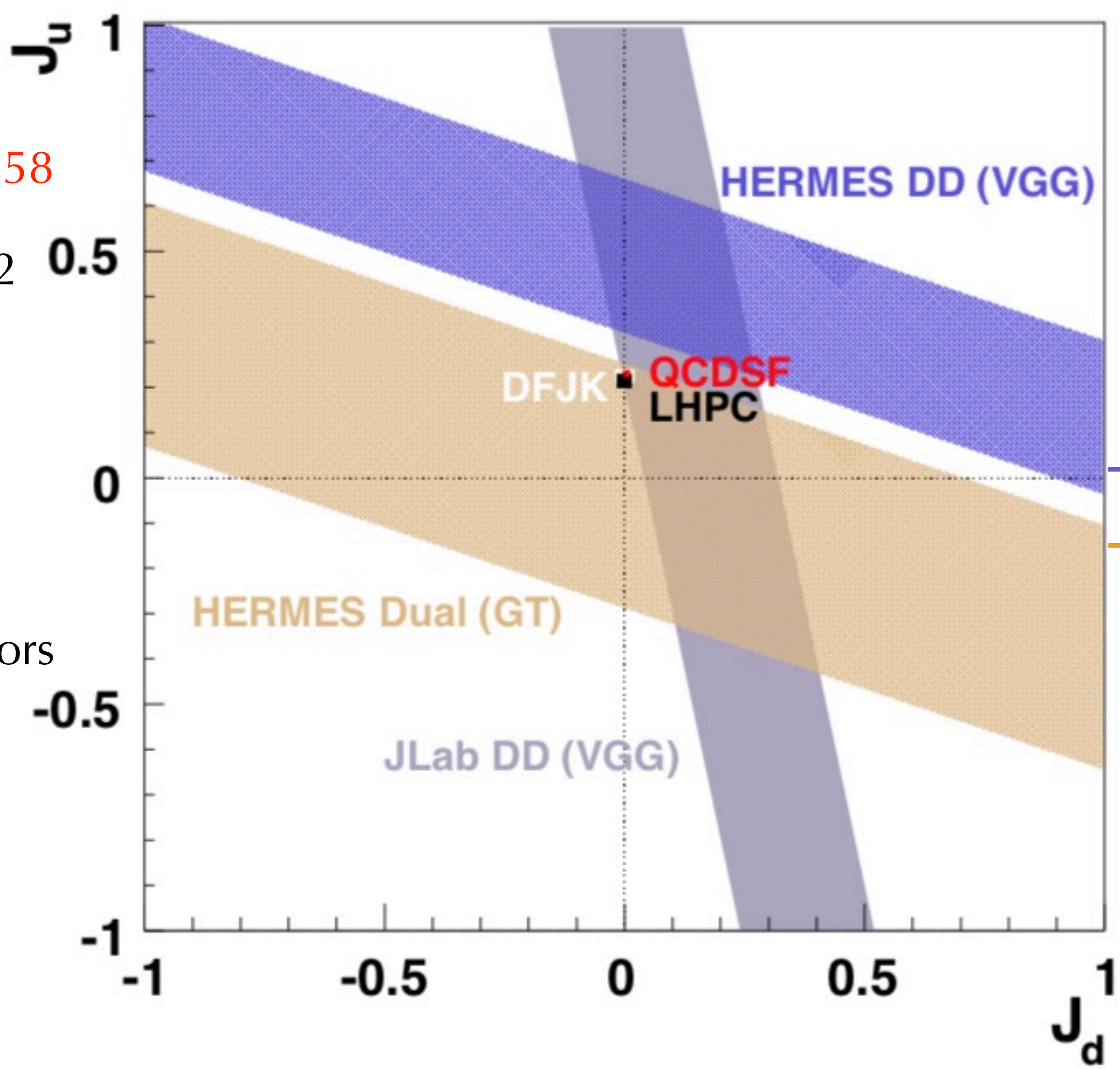
Lattice results

QCDSF: PoS (Lattice 2007) 158

LHPC: PRD77 (2008) 094502

GPDs extracted from form factors

DFJK, EPJC39 (2005) 1



extractions from HERMES data using two different models

JLab Hall A, Phys. Rev. Lett. 99 (2007) 242501

Hermes Coll., JHEP 06 (2008) 066

Improved accuracy with JLab12 and future EIC measurements!

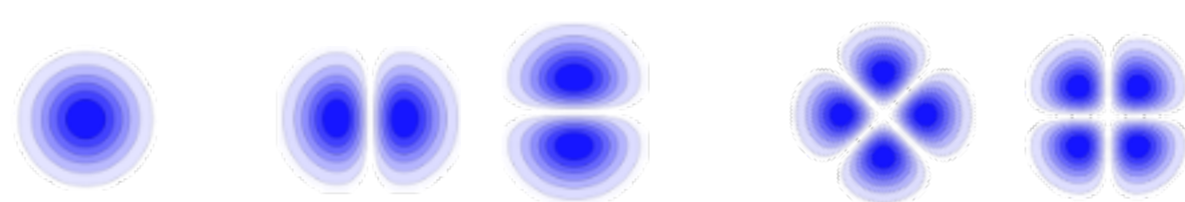
Key information from Transverse Momentum Dependent PDFs

- Complete momentum spectrum of single particle
- Transverse momentum size as function of x (3D map)
- Spin-Spin and Spin-Orbit Correlations of partons
- Information on parton orbital angular momentum
  (no direct model-independent relation)

quark polarization (columns); nucleon polariz. (rows)

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

*similar classification for gluon TMDs



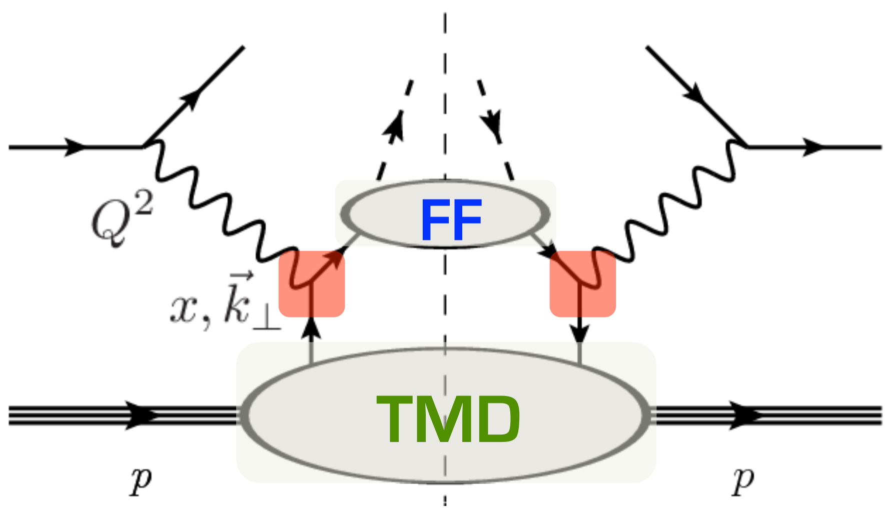
unpolarized
target and partons

deformation due to
spin-spin and spin-orbit correlations

How to measure TMDs

SIDIS

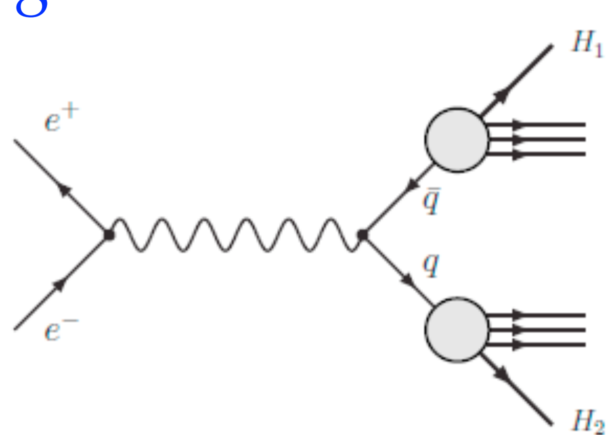
$$\ell(l) + N(P) \to \ell(l') + h(P_h) + X$$



$$d\sigma \sim \sum \mathrm{TMD}(x, \vec{k}_\perp) \otimes d\hat{\sigma}_{hard} \otimes \mathrm{FF}(z, \vec{p}_\perp) + \mathcal{O}(\frac{P_T}{Q})$$

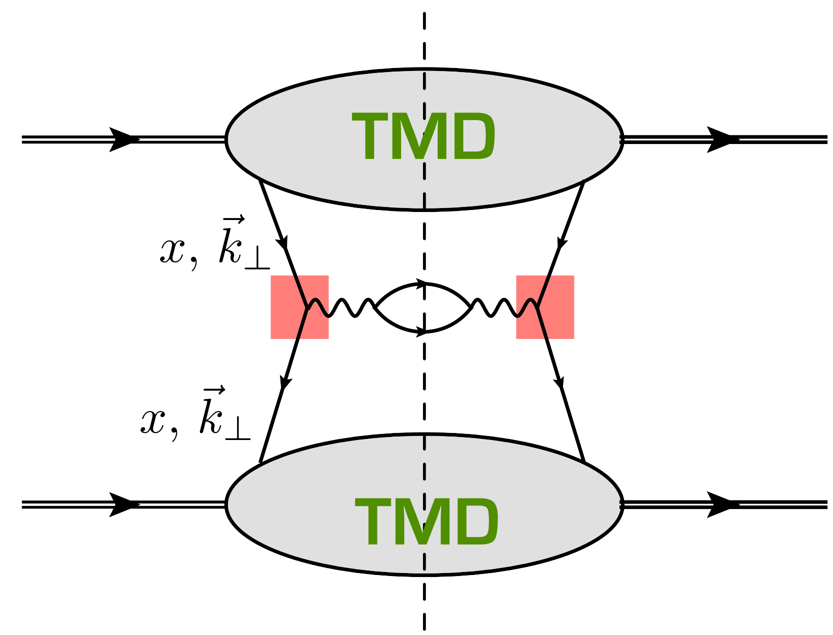
Fragmentation Functions

$e^+e^- \to hh'X$



Drell-Yan

$$h(P_1) + h(P_2) \to \ell^+(l) + \ell^-(l')$$



$$d\sigma \sim \sum \mathrm{TMD}(x, \vec{k}_\perp) \otimes \overline{\mathrm{TMD}}(x, \vec{k}_\perp) \otimes d\hat{\sigma}_{hard}$$

✓Factorization

✓Universality

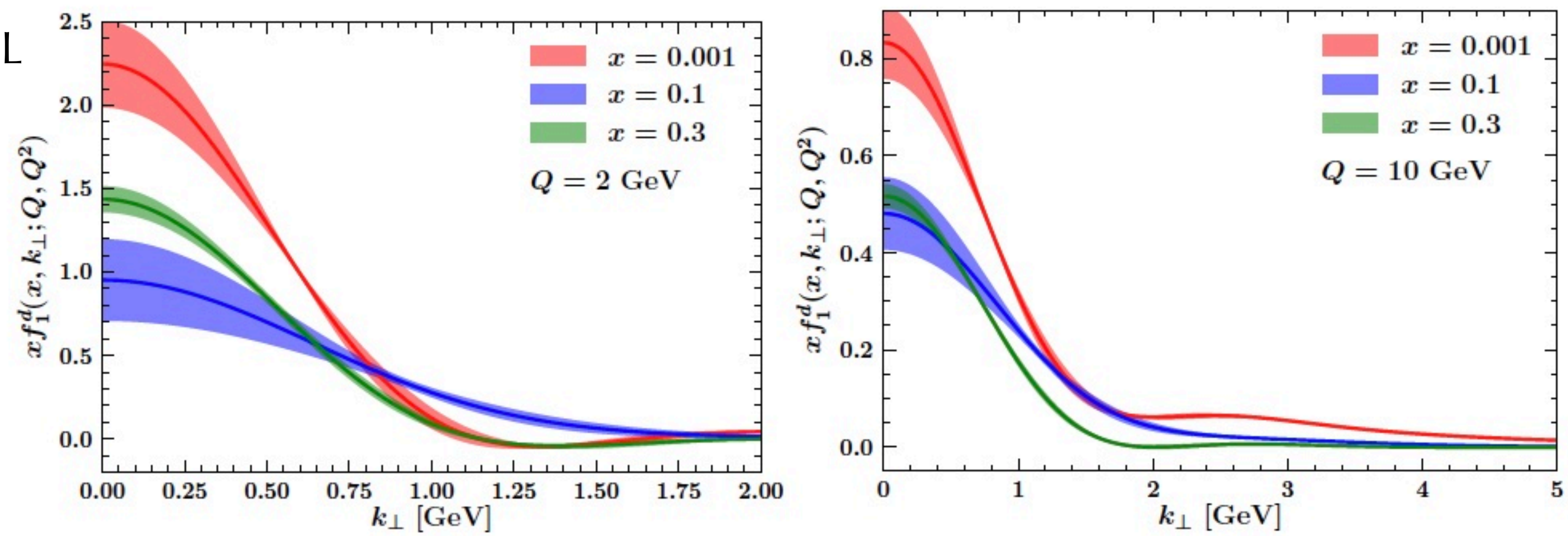
Quark unpolarized TMD extractions

	Framework	HERMES	COMPASS	DY	Z Production	N of points
Pavia 2016 arXiv:1703.10157	NLL	✓	✓	✓	✓	8059
SV 2017 arXiv:1706.01473	NNLL	✗	✗	✓	✓	309
BSV 2019 arXiv:1902.08474	NNLL	✗	✗	✓	✓	457
Pavia 2019 arXiv:1912.07550	NNNLL	✗	✗	✓	✓	353
SV 2020 arXiv:1912.06532	NNNLL	✓	✓	✓	✓	1039
MAP 2022 in progress	NNNLL	✓	✓	✓	✓	>1500

→ *Talk of M. Cerutti, TMD session, Tue. 19.*

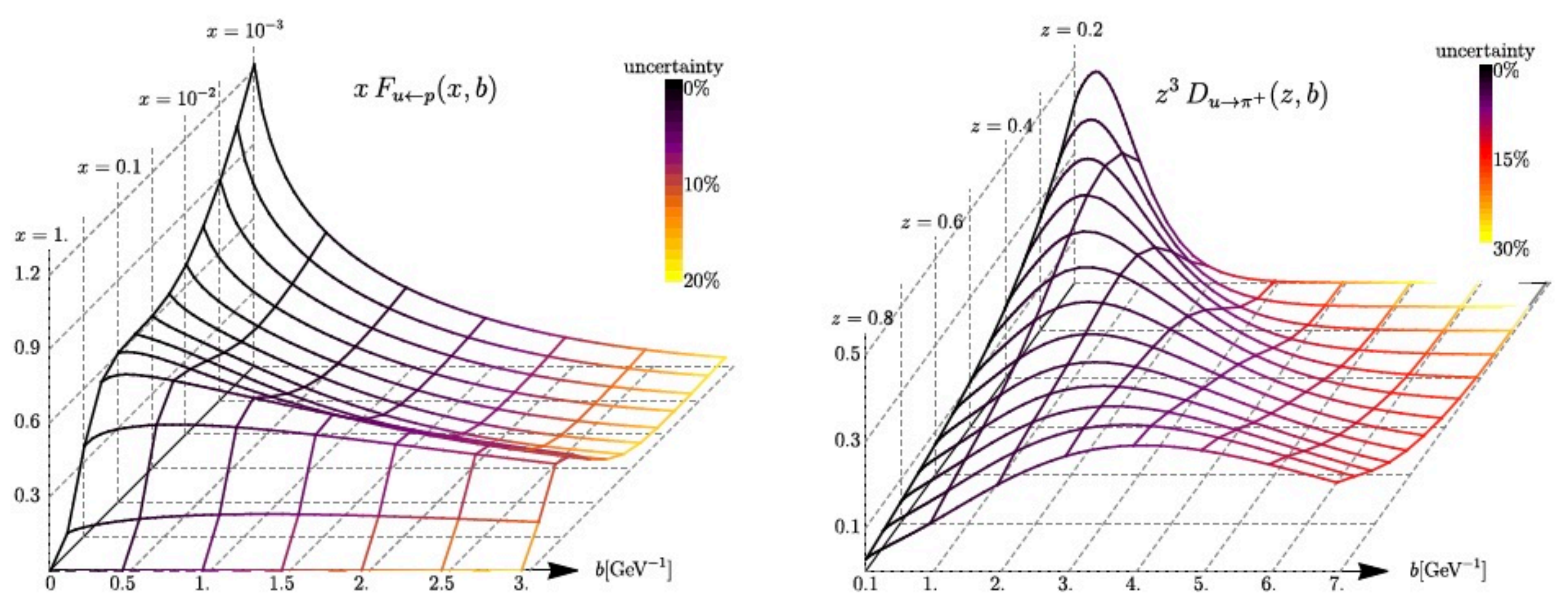
Quark unpolarized TMD extractions $f_1(x, \vec{k}_\perp)$

DY data at NNNLL



Bacchetta, Bertone, Bissolotti, Bozzi, Delcarro, Piacenza, Radici, JHEP 07 (2020) 117

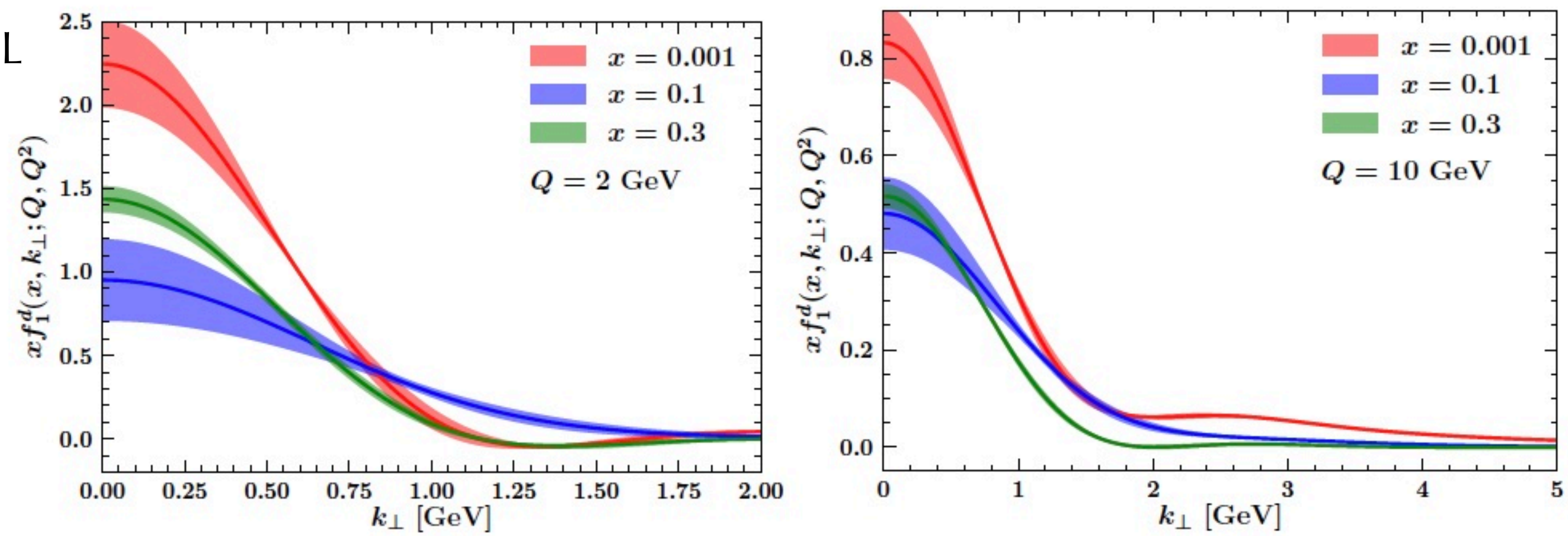
DY+ SIDIS data at NNNLL



Scimemi, Vladimirov, JHEP 06 (2020)137

Quark unpolarized TMD extractions $f_1(x, \vec{k}_\perp)$

DY data at NNNLL

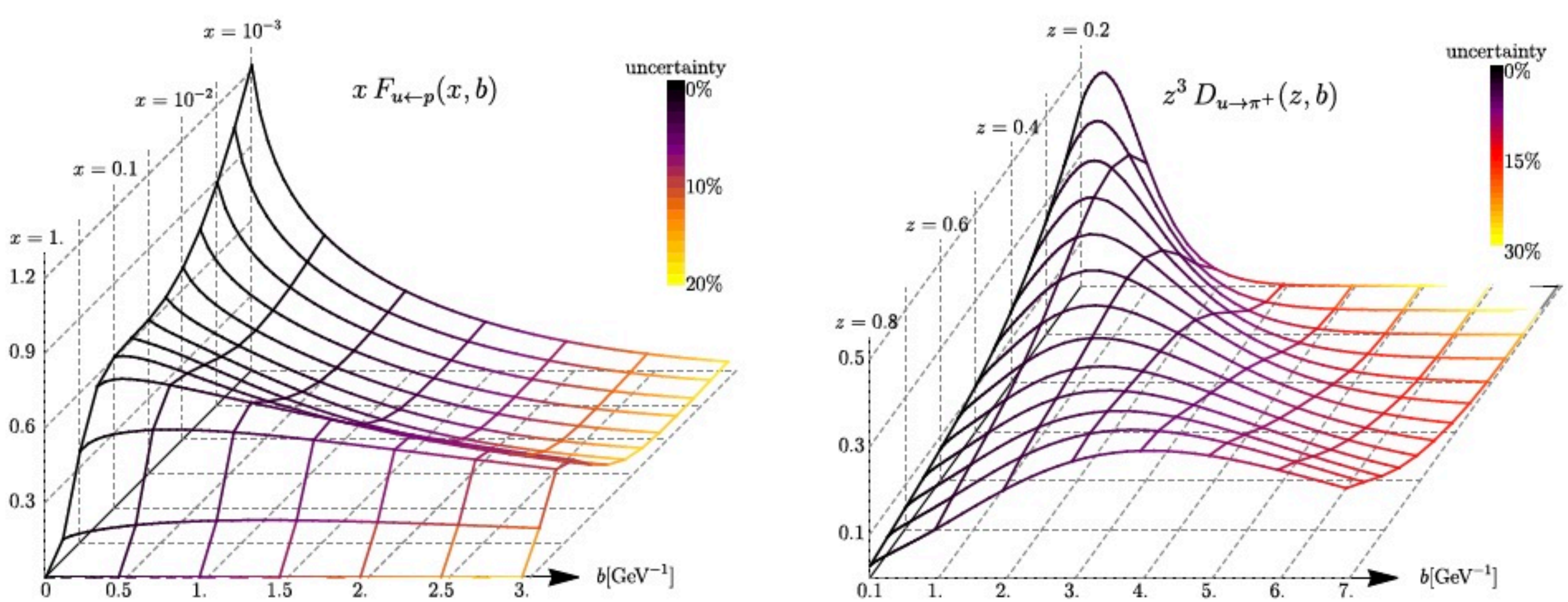


Bacchetta, Bertone, Bissolotti, Bozzi, Delcarro, Piacenza, Radici, JHEP 07 (2020) 117

Open issues:

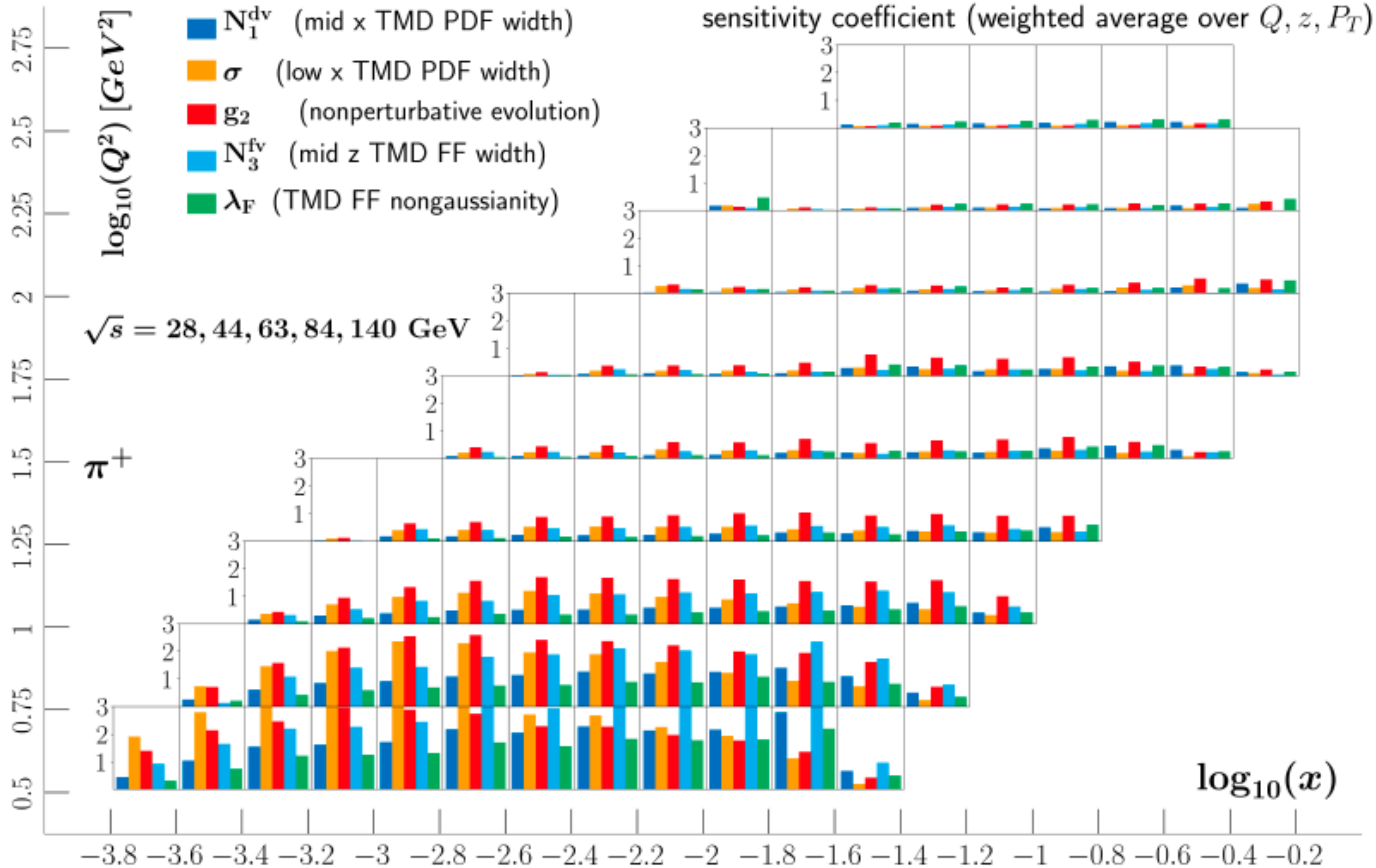
- ❏ Flavor dependence and more flexible functional forms
- ❏ Different choices in implementation of TMD formalism
- ❏ More data needed to test the formalism and functional form of parametrizations
- ❏ Improvements on the knowledge of the fragmentation functions

DY+ SIDIS data at NNNLL



Scimemi, Vladimirov, JHEP 06 (2020)137

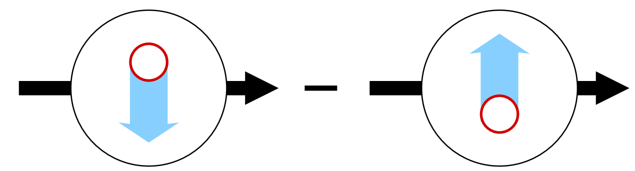
Foreseen EIC impact on unp. TMDs: SIDIS measurements



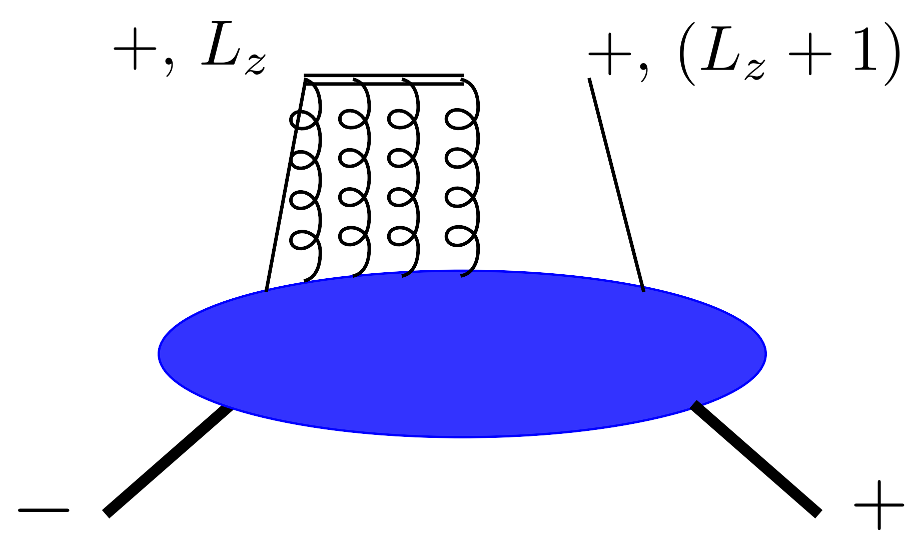
Sensitivity coefficients: measure of the correlation between fit parameters and measurable quantities at EIC

EIC Yellow Report: arXiv: 2103.05419
based on Bacchetta, et al., JHEP 07 (2020) 117 → *Talk of M. Cerutti, Joint TMD-GPD-Future facilities sessions, Tue. 19.*

Sivers function

$f_{1T}^{\perp} =$ 

unpolarized quarks in ⊥ pol. nucleon



the helicity mismatch requires orbital angular momentum (OAM)

non trivial correlation between quark OAM and nucleon transverse spin

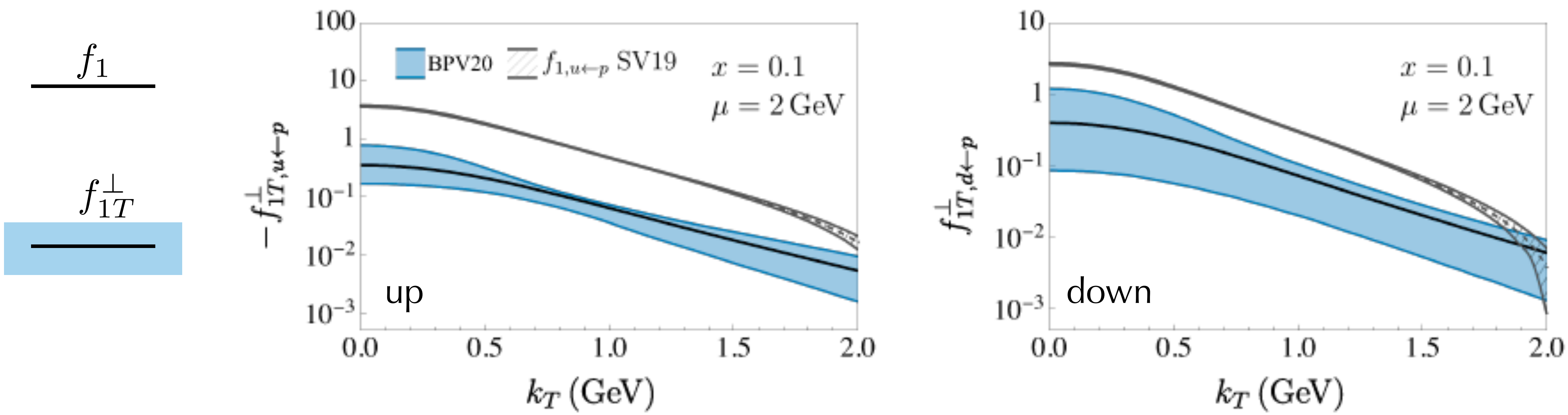
no counterpart in IPD and PDF case

non-zero ONLY with final-state interaction

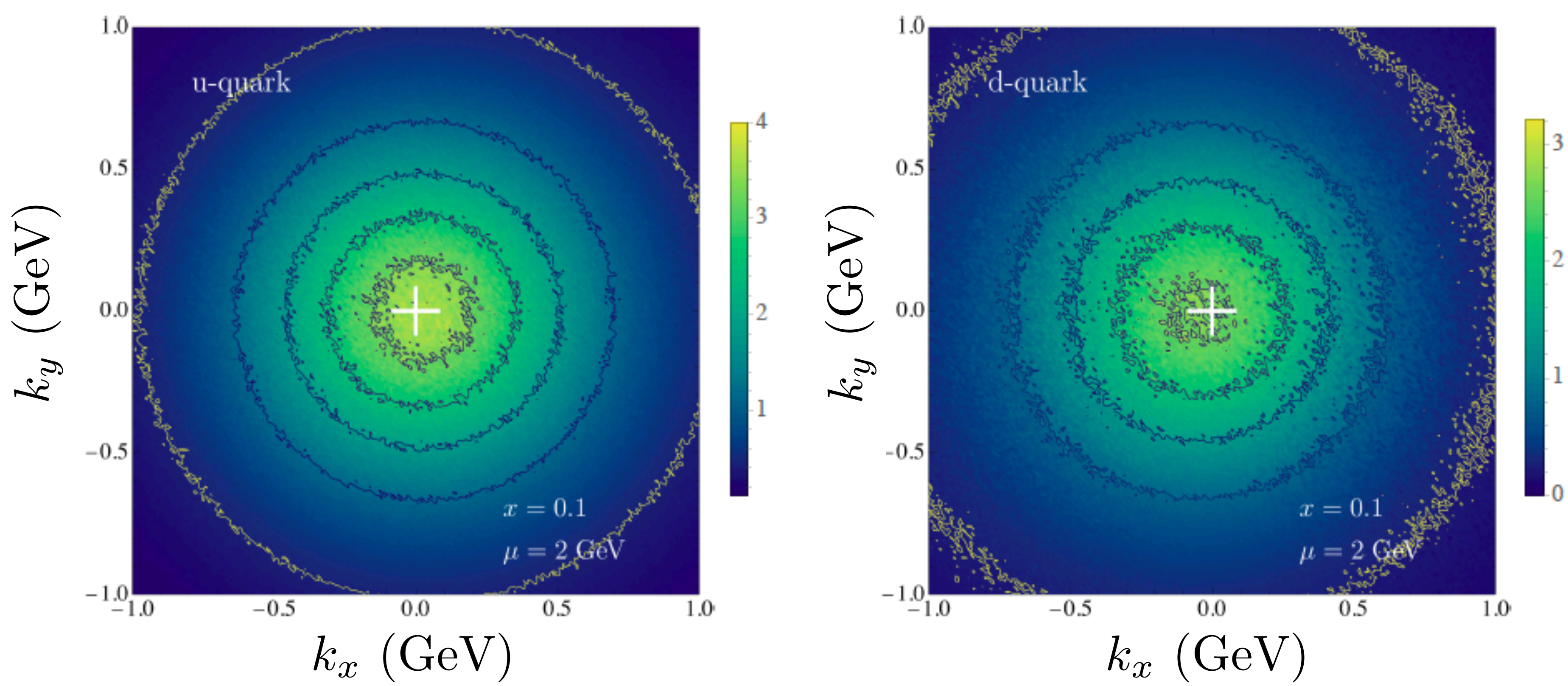
$$f_{1T}^{\mathrm{SIDIS}}(x,k_\perp) = -f_{1T}^{\mathrm{DY}}(x,k_\perp)$$

first hints of sign change from STAR and COMPASS data

Global fit to SIDIS, DY, $W^{\pm}/Z$ boson production



$$\rho_{UT_y}(x, \vec{k}_\perp, S_y) = f_1(x, k_\perp) - \frac{k_x}{M} f_{1T}^{\perp}(x, k_\perp)$$



M. Bury, A. Prokudin, A. Vladimirov, JHEP 05 (2021) 151

→ *more on quark and gluon Sivers, TMD session, Tue. 19*

TMDs and OAM

TMDs are sensitive to various aspects of OAM

NO model-independent relations between TMDs and OAM

$\longrightarrow$ any quantitative statement must rely on model assumptions

TMDs and OAM

TMDs are sensitive to various aspects of OAM

NO model-independent relations between TMDs and OAM
⟶ any quantitative statement must rely on model assumptions

Sivers TMD ⬅ **lensing function** ➡ **GPD E**

- valid only in two-body bound systems with restrictive conditions on the quark-gluon vertex interaction
- lensing relation is unlikely to survive the full complexity of QCD

Burkardt, PRD66 (2002); Pasquini, Rodini, Bacchetta, PRD 100(2019)

TMDs and OAM

TMDs are sensitive to various aspects of OAM

NO model-independent relations between TMDs and OAM
⟶ any quantitative statement must rely on model assumptions

Sivers TMD ⟵ lensing function ⟶ GPD E

- valid only in two-body bound systems with restrictive conditions on the quark-gluon vertex interaction
- lensing relation is unlikely to survive the full complexity of QCD

Burkardt, PRD66 (2002); Pasquini, Rodini, Bacchetta, PRD 100(2019)

Pretzelosity and OAM

$$\mathcal{L}_z = -\int \mathrm{d}x \mathrm{d}^2\vec{k}_\perp \frac{k_\perp^2}{2M^2}\, h_{1T}^\perp(x, k_\perp^2)$$

- valid in quark models with spherical symmetry in the rest frame (bag model, lift-front quark models)

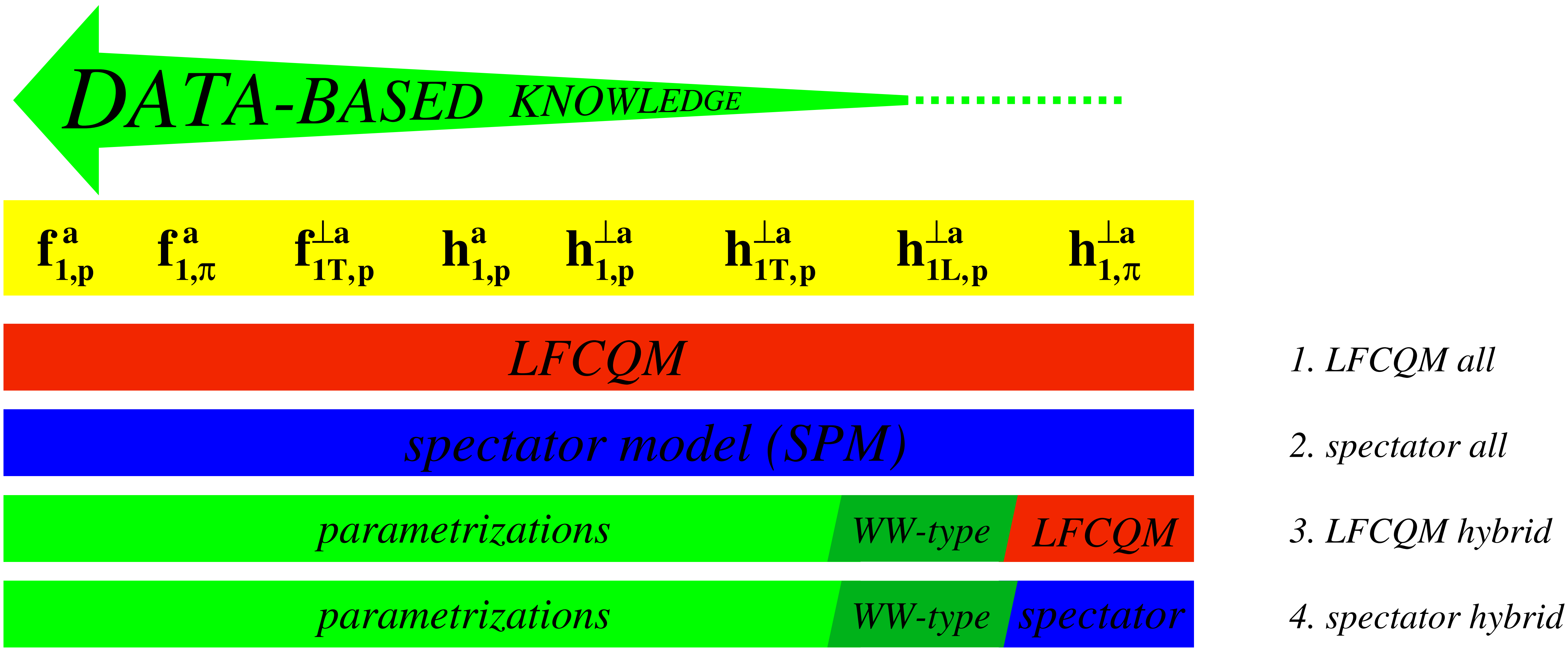
She, Zhu, Ma, PRD79, 2009; Avakian, Efremov, Schweitzer, Yuan, PRD81, 2010; Lorcé and Pasquini, PLB710, 2012

Pion induced Drell-Yan

$$\pi^- + \vec{p} \to \ell^+ \ell^- + X$$

New insights in the partonic structure of **both** the pion and the nucleon

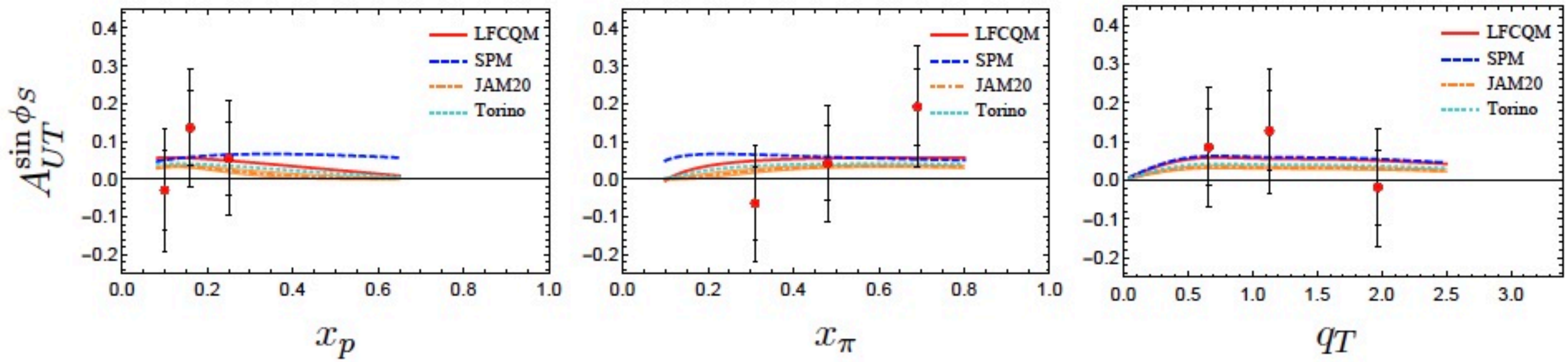
Ongoing analysis of COMPASS DY data → *Talk of A. Chumakov, TMD session, Mon. 18*



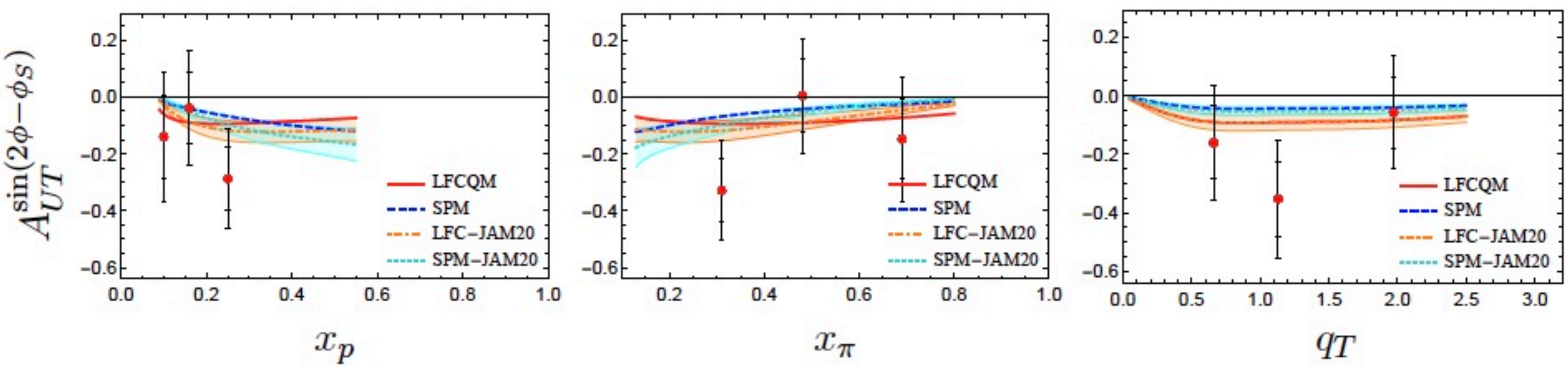
Complete description of polarized DY at leading twist using TMD evolution at NLL accuracy

Bastami, Gamberg, Pasquini, Prokudin, Schweitzer, JHEP 02 (2021) 166

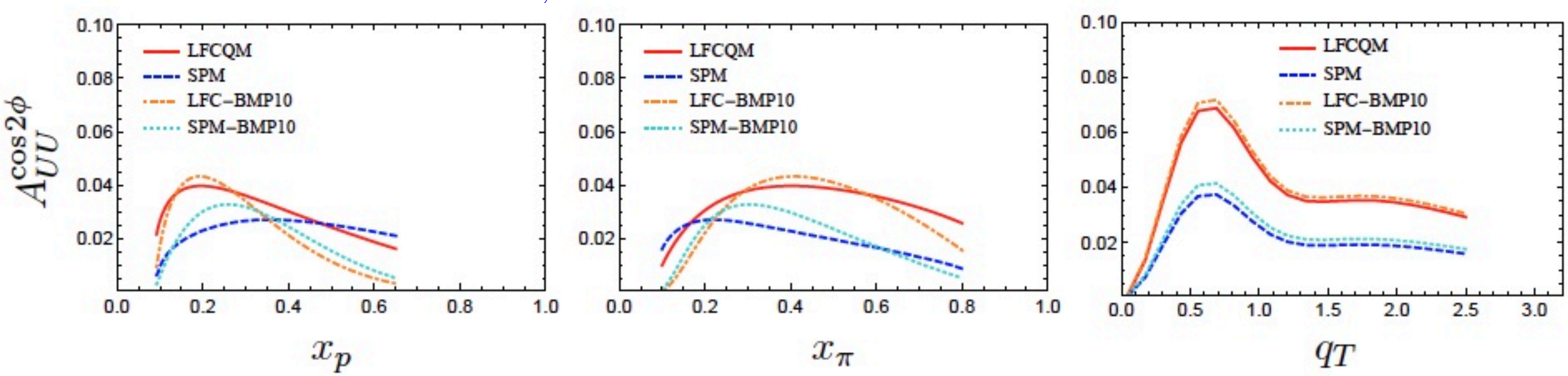
$$A_{UT}^{\sin\phi_s} \propto f_{1T}^{\perp u}(x_p) > 0 \Longrightarrow f_{1T}^{\perp u}(x_p) > 0$$



$$A_{UT}^{\sin(2\phi-\phi_s)} \propto -h_{1,\pi^-}^{\perp(1)\bar{u}}(x_\pi)h_{1,p}^{u}(x_p) < 0 \Longrightarrow h_{1,\pi^-}^{\perp\bar{u}} > 0$$



$$A_{UU}^{\cos 2\phi} \propto h_{1,\pi^-}^{\perp(1)\bar{u}}(x_\pi)h_{1,p}^{\perp(1)u}(x_p) > 0 \Longrightarrow h_{1,p}^{\perp u}(x_p) > 0$$



→ *Consistent with ongoing analysis of COMPASS data, Talk of A. Chumakov, TMD session, Mon. 18*

Library and Plotting tools for collinear parton distributions

LHAPDF
lhapdf.hepforge.org

xFitter
www.xfitter.org

APFEL++
github.com/vbertone/apfelxx
apfel.mi.infn.it

Dedicated Softwares to study GPDs

PARTONS
partons.cea.fr

PARtonic
Tomography
Of
Nucleon
Software

GeParD

not yet public

Dedicated software to study and fit TMDs

arTeMiDe
teorica.fis.ucm.es/artemide

TMD lib and TMD Plotter
tmdlib.hepforge.org

NangaParbat
MapCollaboration/NangaParbat

Efforts to combine different inputs to understand PDFs, TMDs and GPDs in an unified framework