Extraction of worm-gear TMD g_{1T} from HERMES, COMPASS & JLab data on SIDIS

Shohini Bhattacharya

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In Collaboration with:

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Daniel Pitonyak (Lebanon Valley College)

TMDs @ TWIST 2

Quark polarization →

Nucleon polarization ↓

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

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One of the least known TMDs

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Phenomenological predictions

1.

2.

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1. Large N_c analysis: (Pobylitsa, hep-ph/ 0301236)

$$g_{1T}^{u}(x, \vec{k}_{\perp}^{2}) \;=-\; g_{1T}^{d}(x, \vec{k}_{\perp}^{2}) + 1/N_c\text{-suppressed}$$

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Large-N_c approx.

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2. Wandzura-Wilczek-type (WW-type) relation: (Avakian et. al., 0709.3253, Kanazawa et. al., 1512.07233, …)

$$g_{1T}^{(1)q}(x) \equiv \int d^2\vec{k}_\perp \left(\frac{k_\perp^2}{2M^2}\right) g_{1T}^{q}(x,\vec{k}_\perp^2) \overset{\text{EOM}}{=} x\int_x^1 \frac{dy}{y} g_1^q(y) + x\,\tilde{g}_T^q(x)$$

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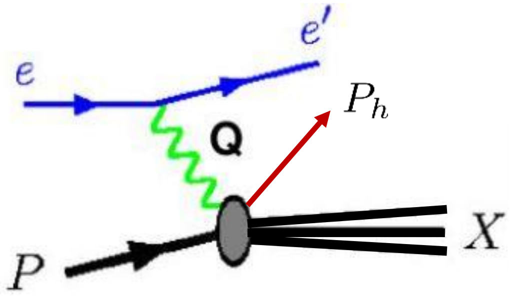
Fundamentals

Semi-inclusive Deep Inelastic Scattering: $\ell(l) + N(P,S) \rightarrow \ell'(l') + h(P_h) + X$



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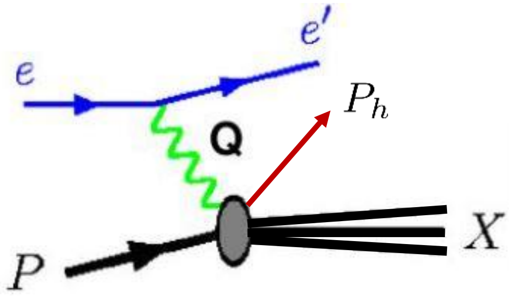

Model-independent decomposition of cross-section: **(Bacchetta et. al. 2007, …)**

$$\frac{d\sigma}{dx\,dy\,d\phi_S\,dz_h\,d\phi_h\,dP_{hT}^2} = \frac{\alpha_{\rm em}^2}{x\,y\,Q^2}\left\{\left(1-y+\frac{1}{2}y^2\right)F_{UU}\right.$$

$$\left. + \lambda_l\,|\vec{S}_\perp|\,y\left(1-\frac{1}{2}y\right)\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \ldots\right\}$$

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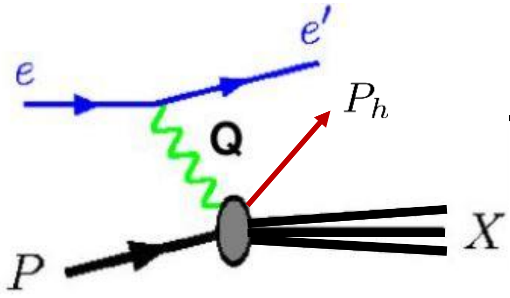
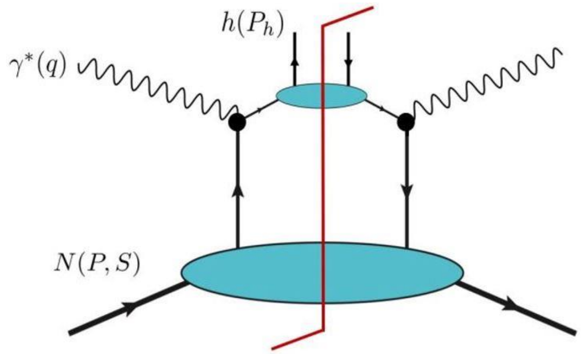


$P_{hT} \ll Q$



Connection between structure functions and TMDs: (Bacchetta et. al. 2007, …)

$$F_{UU} = C\left[f_1(x,\vec{k}_\perp^2)\, D_1(z,\vec{P}_\perp^2)\right] \qquad F_{LT}^{\cos(\phi_h-\phi_S)} = C\left[\frac{\vec{P}_{hT}\cdot\vec{k}_\perp}{|\vec{P}_{hT}|M}\, g_{1T}(x,\vec{k}_\perp^2)\, D_1(z,\vec{P}_\perp^2)\right]$$

$$A_{LT} \equiv \frac{F_{LT}}{F_{UU}}$$

$$C\big[w\, f\, D\big] = x\sum_q e_q^2 \int d^2\vec{k}_\perp \int d^2\vec{P}_\perp\, \delta^{(2)}\big(z\vec{k}_\perp + \vec{P}_\perp - \vec{P}_{hT}\big)\, w(\vec{k}_\perp,\vec{P}_\perp)\, f^q(x,\vec{k}_\perp^2)\, D^q(z,\vec{P}_\perp^2)$$

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Gaussian ansatz:

$$g_{1T}^{q}(x,\vec{k}_{\perp}^{2},Q^{2}) = g_{1T}^{(1)q}(x,Q^{2})\,\frac{2M_N^2\, e^{-\frac{\vec{k}_{\perp}^{2}}{\pi\langle k_{\perp}^{2}\rangle}}}{\pi\left(\langle k_{\perp}^{2}\rangle\right)^{2}}$$

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where, $$g_{1T}^{(1)}(x, Q^2) = \frac{n}{\int_0^1 dy\, y^{\alpha+1}(1-y)^{\beta} f_1(y, Q_0^2)}\, x^{\alpha}(1-x)^{\beta} f_1(x, Q^2)$$

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- **Fix TMD width:**

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- **Fix TMD width:** $$\frac{\langle k_\perp^2 \rangle \big|_{g_1}}{\langle k_\perp^2 \rangle \big|_{f_1}} \approx 0.76$$

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$$\therefore \langle k_\perp^2\rangle\big|_{g_{1T}} \approx 0.40$$

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Helicity & unpolarized PDFs have similar large-x behavior

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where, $g_{1T}^{(1)}(x \ldots x^{\alpha}(1-x)^{\beta} f_1(x, Q^2)$

3 free parameters:

$$n^u, \quad n^d, \quad \alpha$$

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Data

Dataset	Target	Identified hadron	No. of points
HERMES	p	π^+	26
Airapetian et. al., arXiv: 2007.07755		π^-	26
		π^0	8
COMPASS	p	$h^+ \approx (\pi^+, \mathrm{K}^+)$	33
Parsamyan, PoS: QCDEV2017		$h^- \approx (\pi^-, \mathrm{K}^-)$	31
JLab	${}^3\mathrm{He}$	π^+	2
Huang, arXiv: 1108.0489		π^-	2

Cut:

$$\frac{P_{hT}}{zQ} < 0.50$$

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Fitting procedure: Monte-Carlo technique

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Fit to exp. data

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Fit to exp. data

Minimize:

$$\chi^2 = \sum_{\mathrm{H+C+J}} \frac{(\mathrm{exp.\,data} - \mathrm{theory})^2}{(\mathrm{exp.\,error})^2}$$

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Fit to exp. data

Minimize weighted chi-squared:

$$\chi^2 = \sum_{\mathrm{H+C}} \frac{(\mathrm{exp.\,data} - \mathrm{theory})^2}{(\mathrm{exp.\,error})^2} + w \sum_{\mathrm{J}} \frac{(\mathrm{exp.\,data} - \mathrm{theory})^2}{(\mathrm{exp.\,error})^2}$$

(Echevarria, Kang, Terry, arXiv: 2009.10710)

Give JLab data similar weight to HERMES & COMPASS data

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

SB, Kang, Metz, Penn, Pitonyak, In preparation (2021)

Fitting procedure: Monte-Carlo technique

Theory

Fit to exp. data

Generate pseudo-data

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Fitting procedure: Monte-Carlo technique

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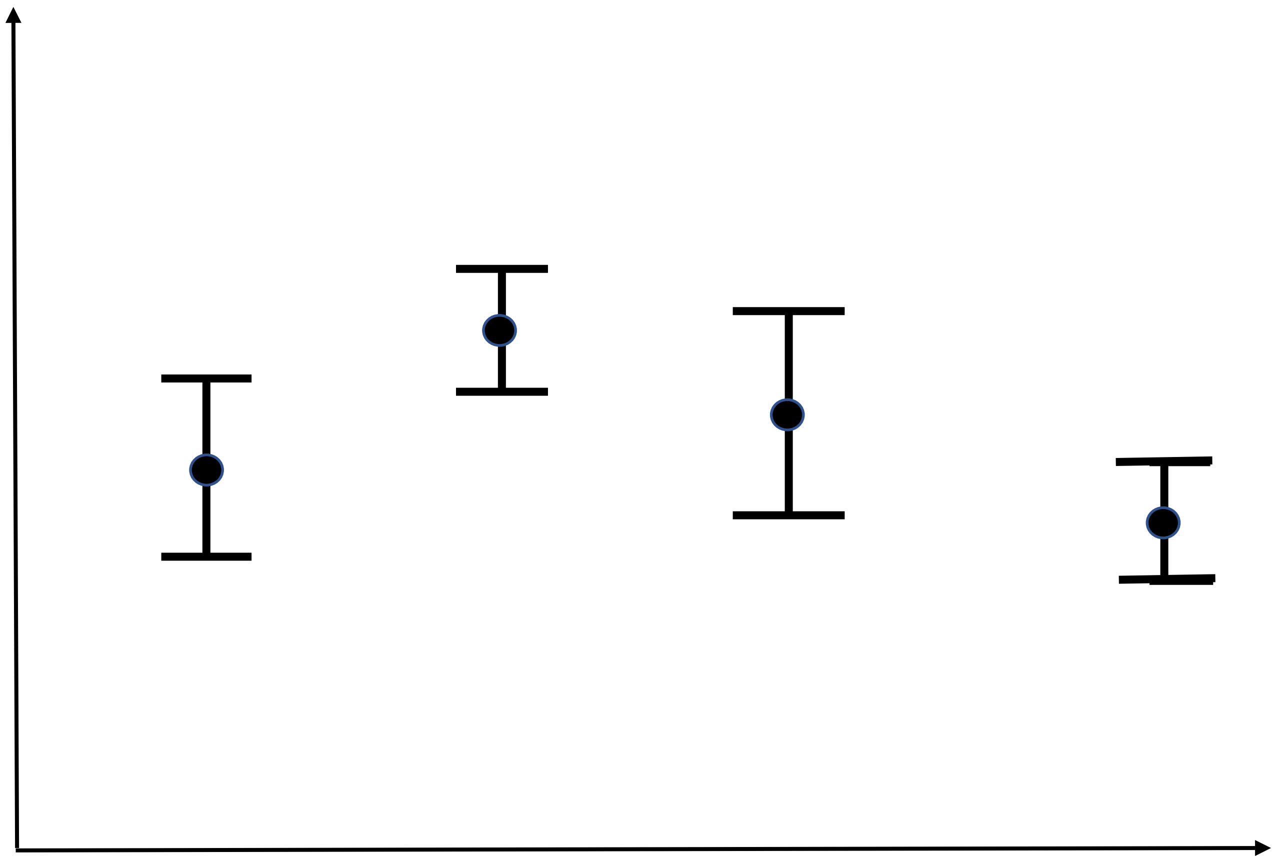
- Fit to exp. data
- Generate pseudo-data



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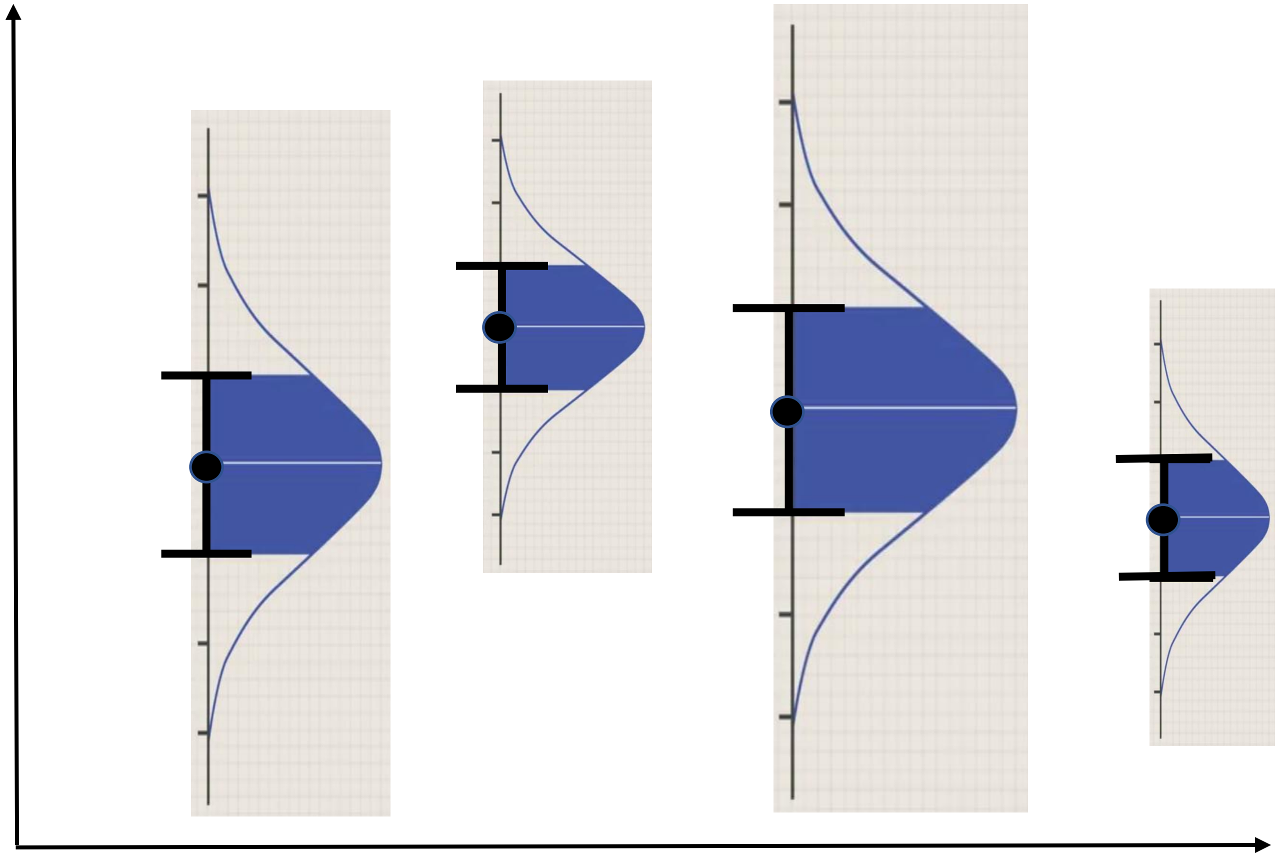

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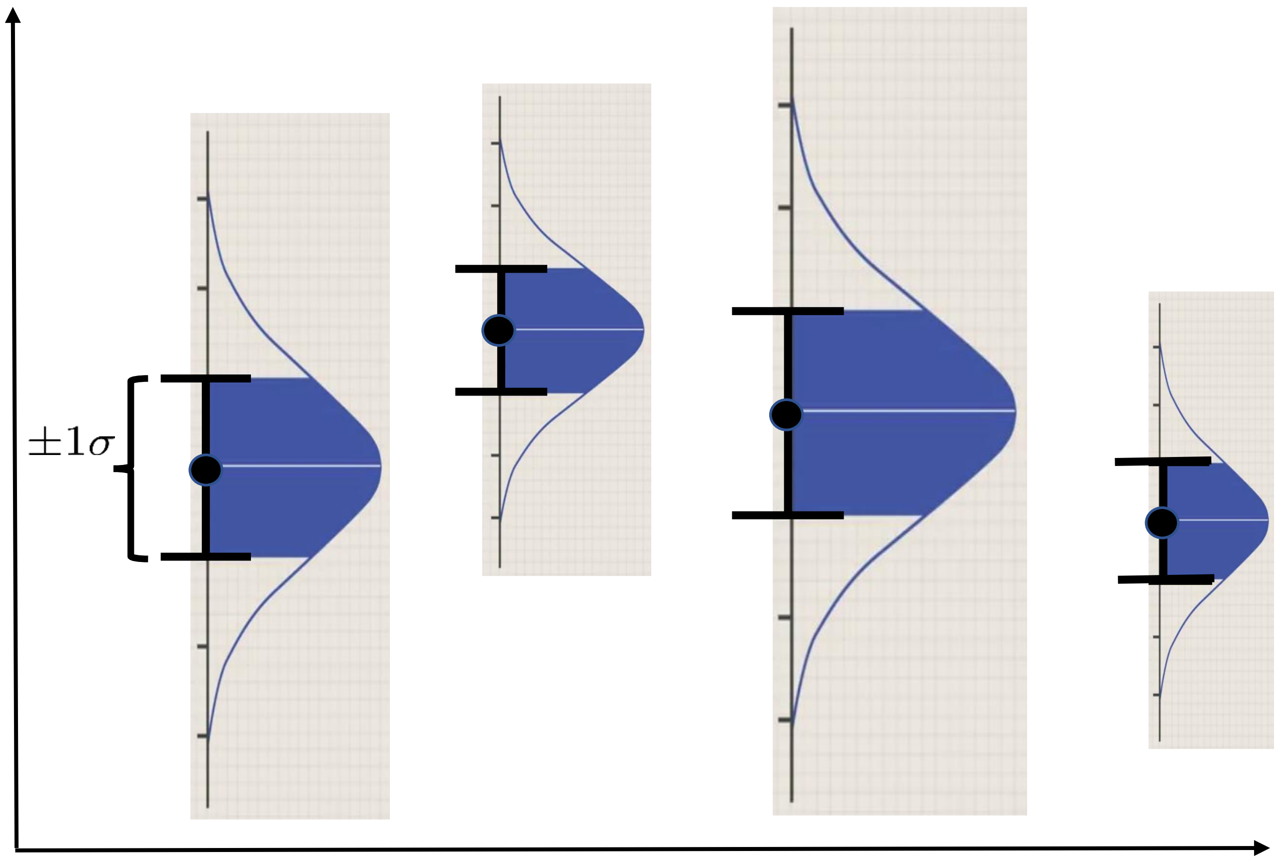

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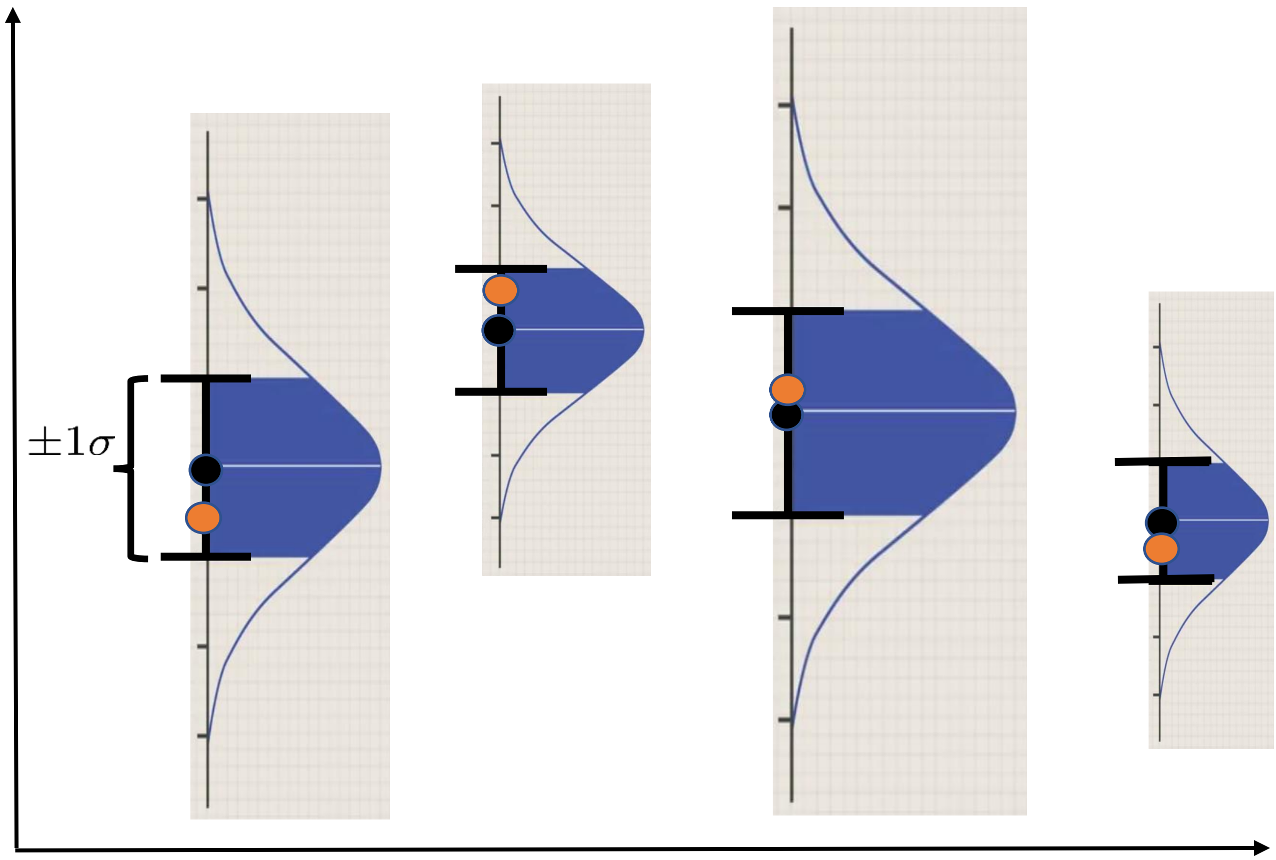

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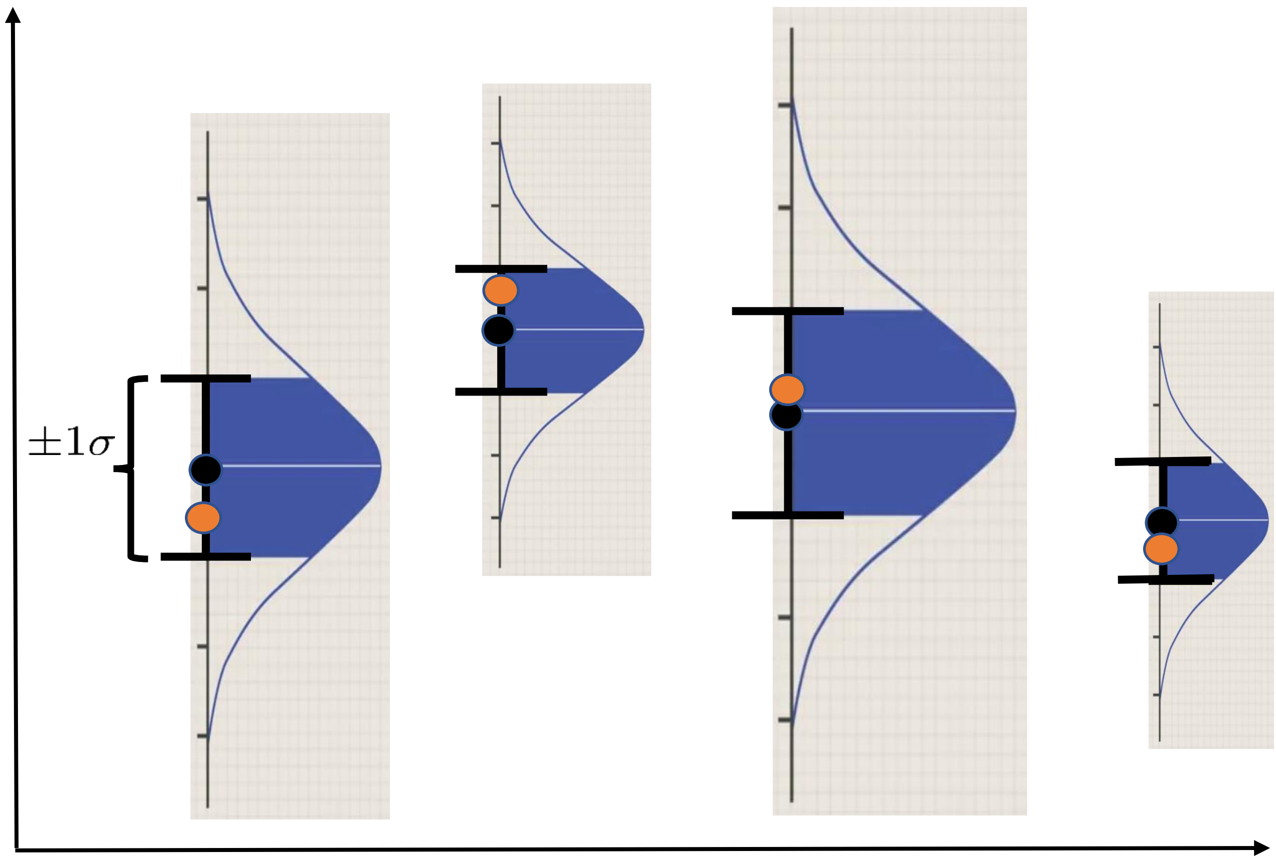
Fit to pseudo-data



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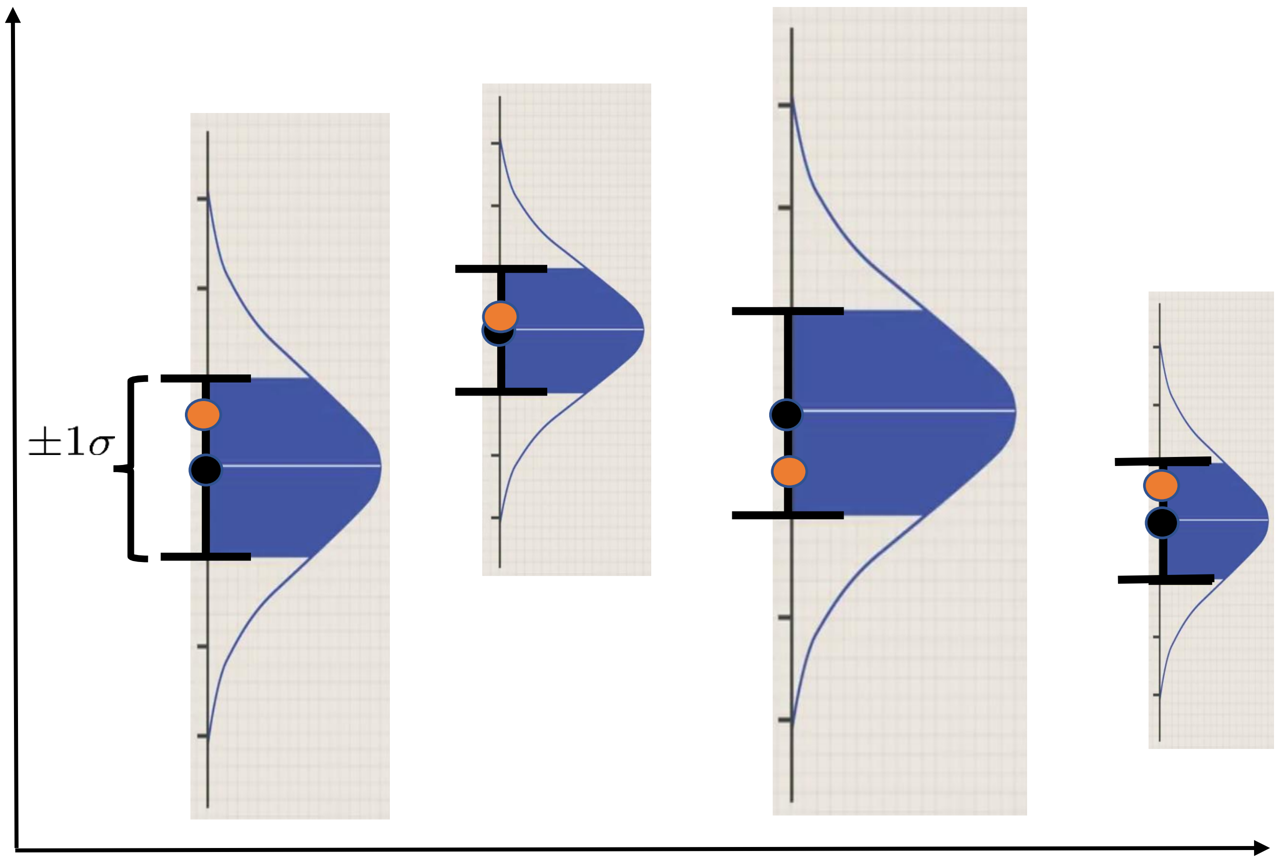

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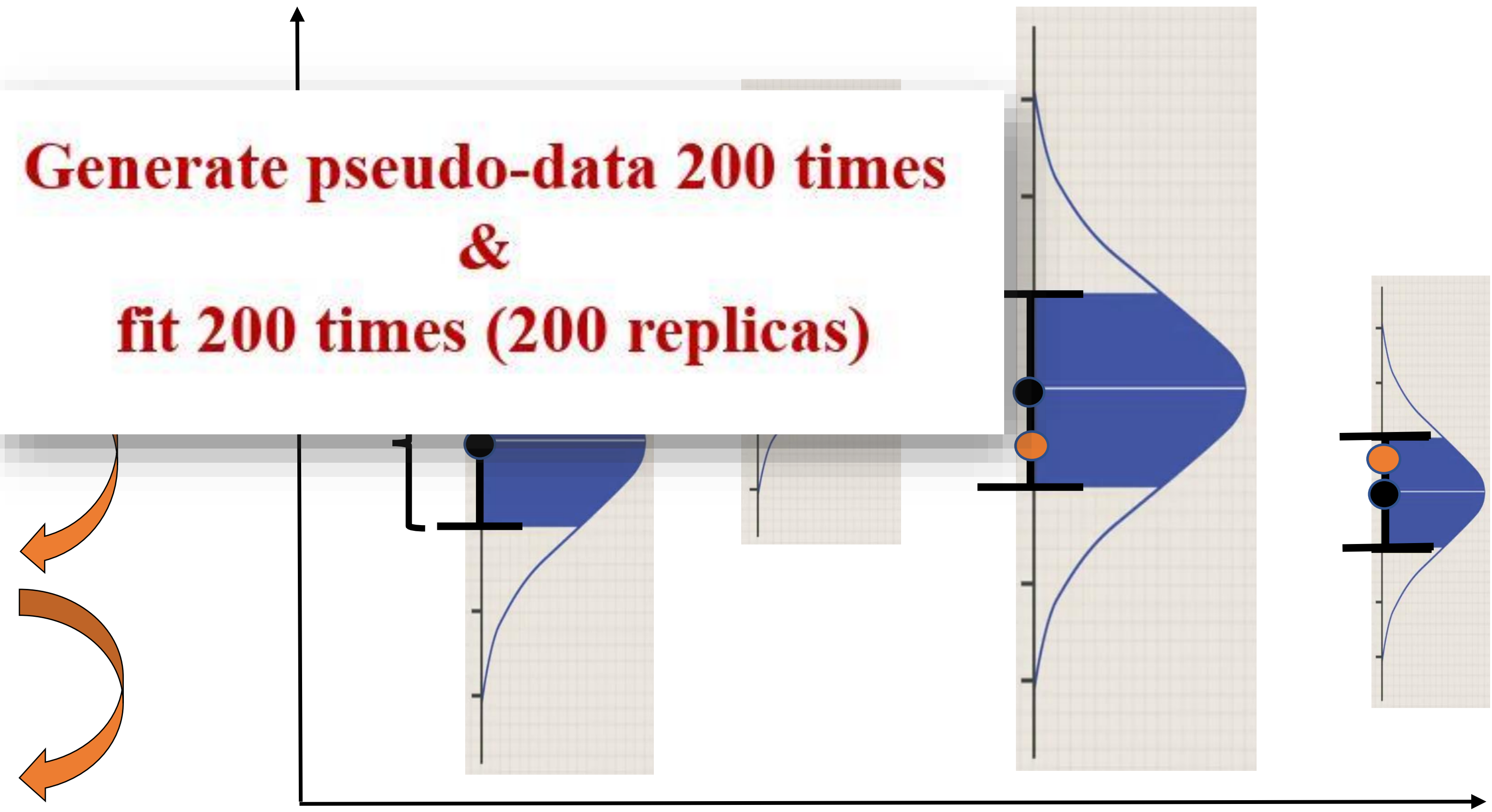
Fitting procedure: Monte-Carlo technique

- Theory
- Fit to exp. data
- Generate pseudo-data
- Fit to pseudo-data



Generate pseudo-data 200 times
&
fit 200 times (200 replicas)

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

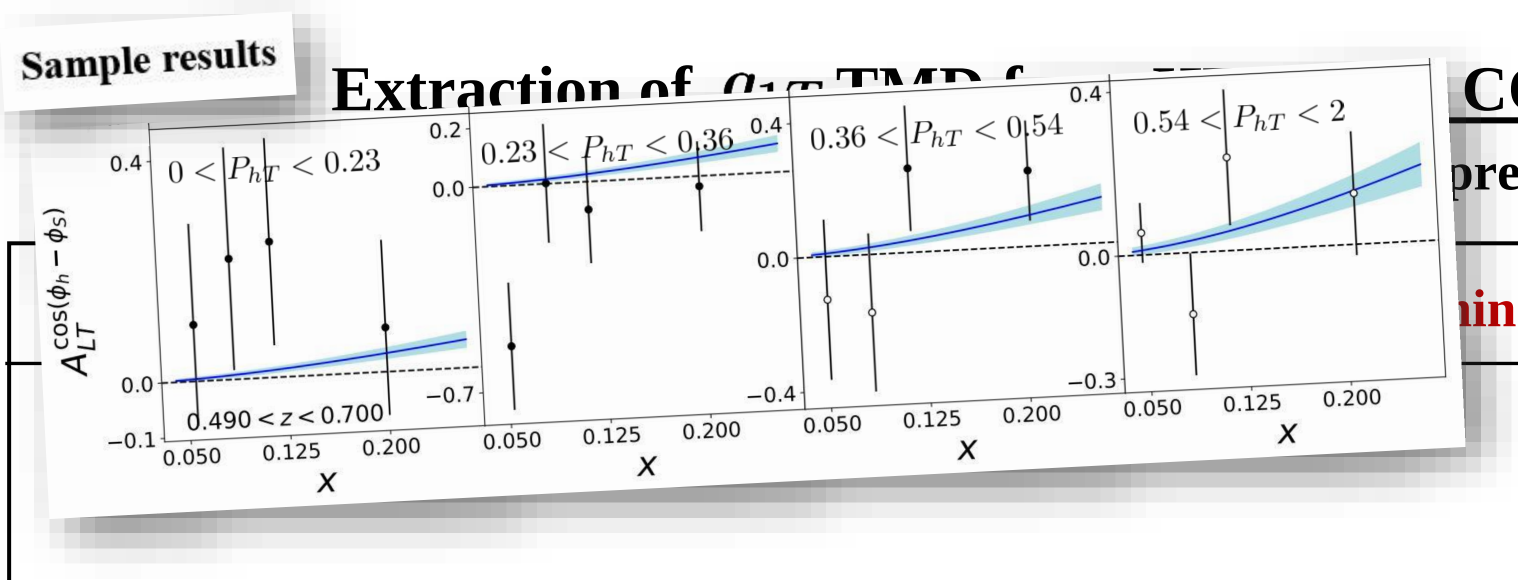
SB, Kang, Metz, Penn, Pitonyak, In preparation (2021)

Theory versus data (Preliminary)

Dataset	$\chi^2/N_{\mathrm{pts.}}$

Extraction of g_{1T} TMD f… COMPASS & JLab data

…preparation (2021)



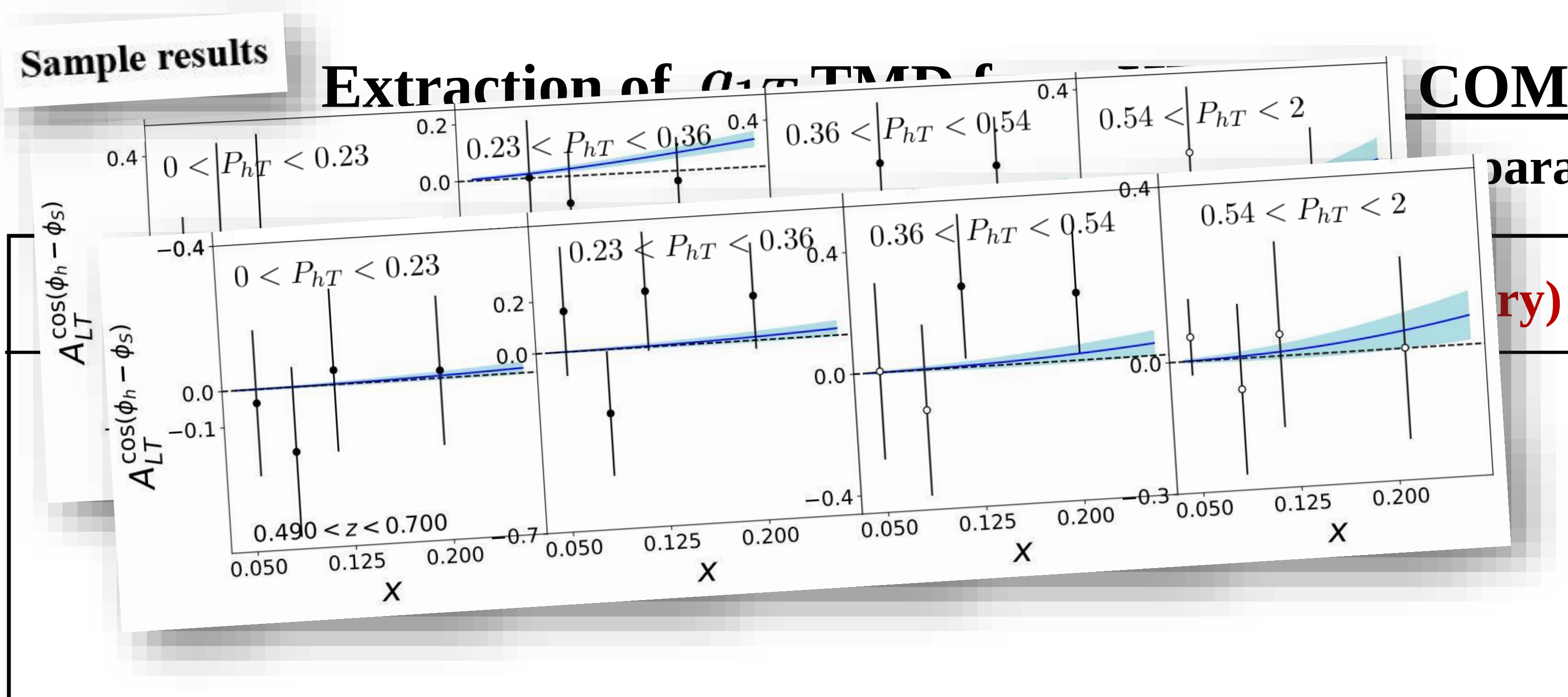
…inary)

Dataset	$\chi^2/N_{\text{pts.}}$
(H, π^+)	1.20

Extraction of g_{1T} TMD f... COMPASS & JLab data

...paration (2021)

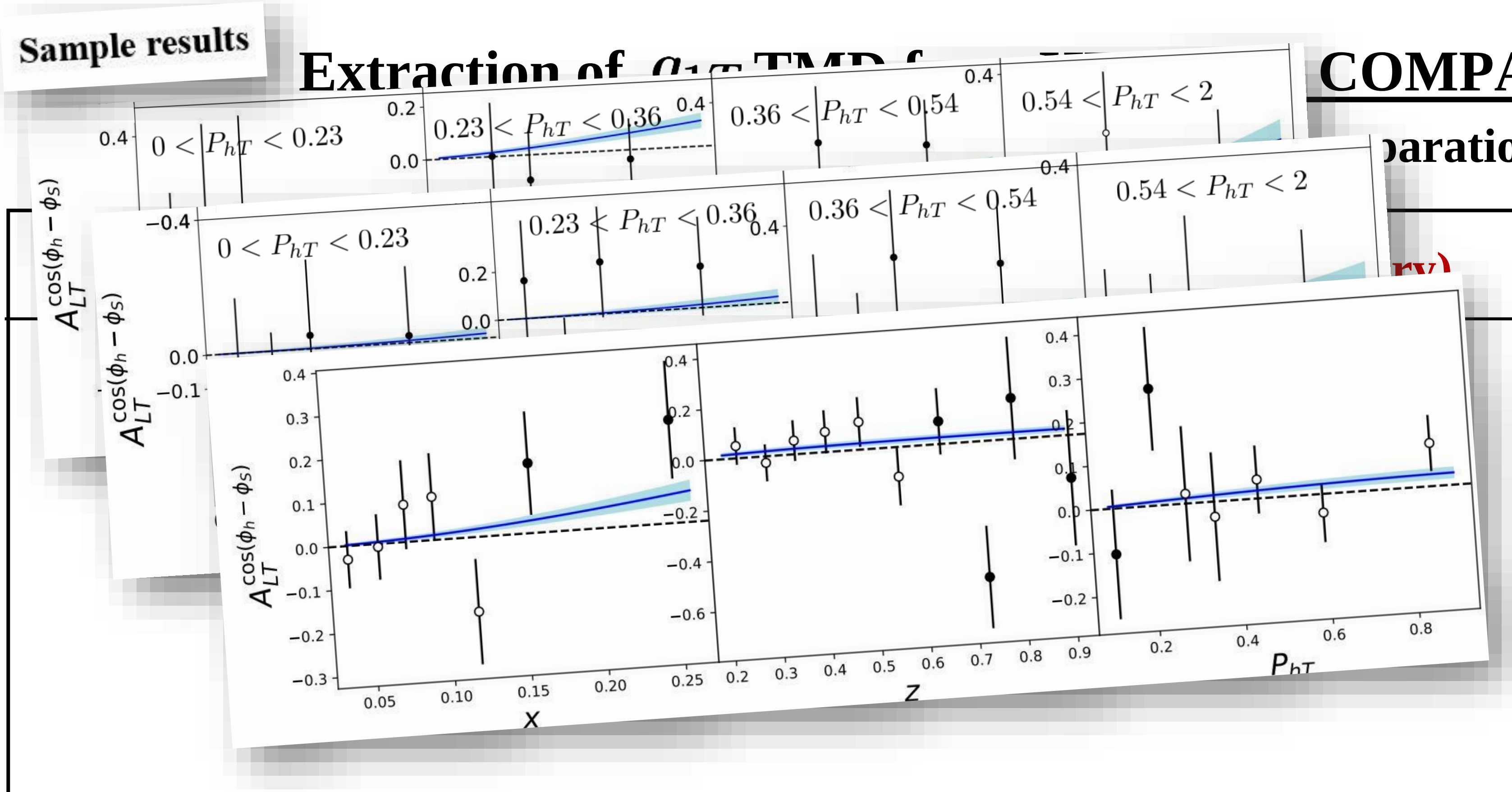
...ry)



Dataset	$\chi^2/N_{\text{pts.}}$
(H, π^+)	1.20
(H, π^-)	0.87

Extraction of ... COMPASS & JLab data

...paration (2021)

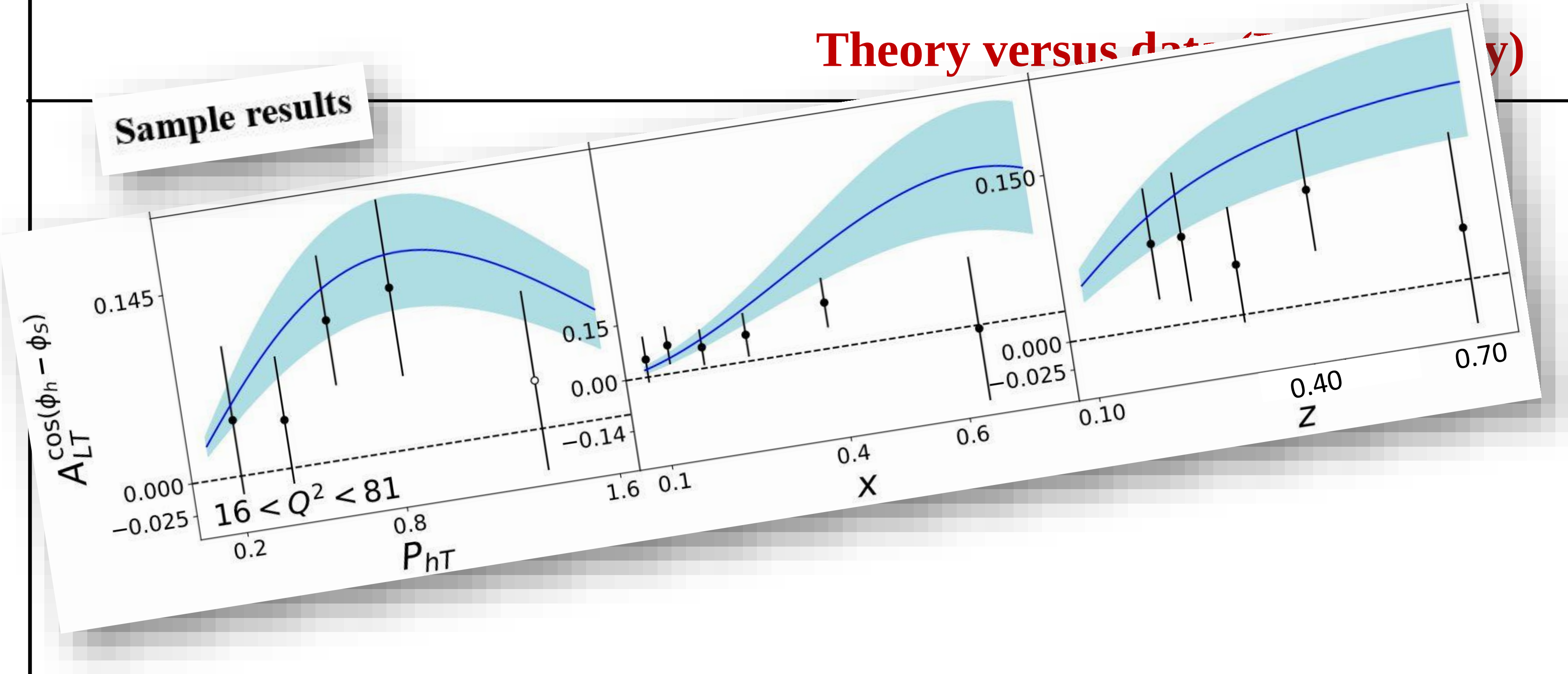


Dataset	$\chi^2/N_{\text{pts.}}$
(H, π^+)	1.20
(H, π^-)	0.87
(H, π^0)	1.93

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

SB, Kang, Metz, Penn, Pitonyak, In preparation (2021)

Theory versus d… …y)

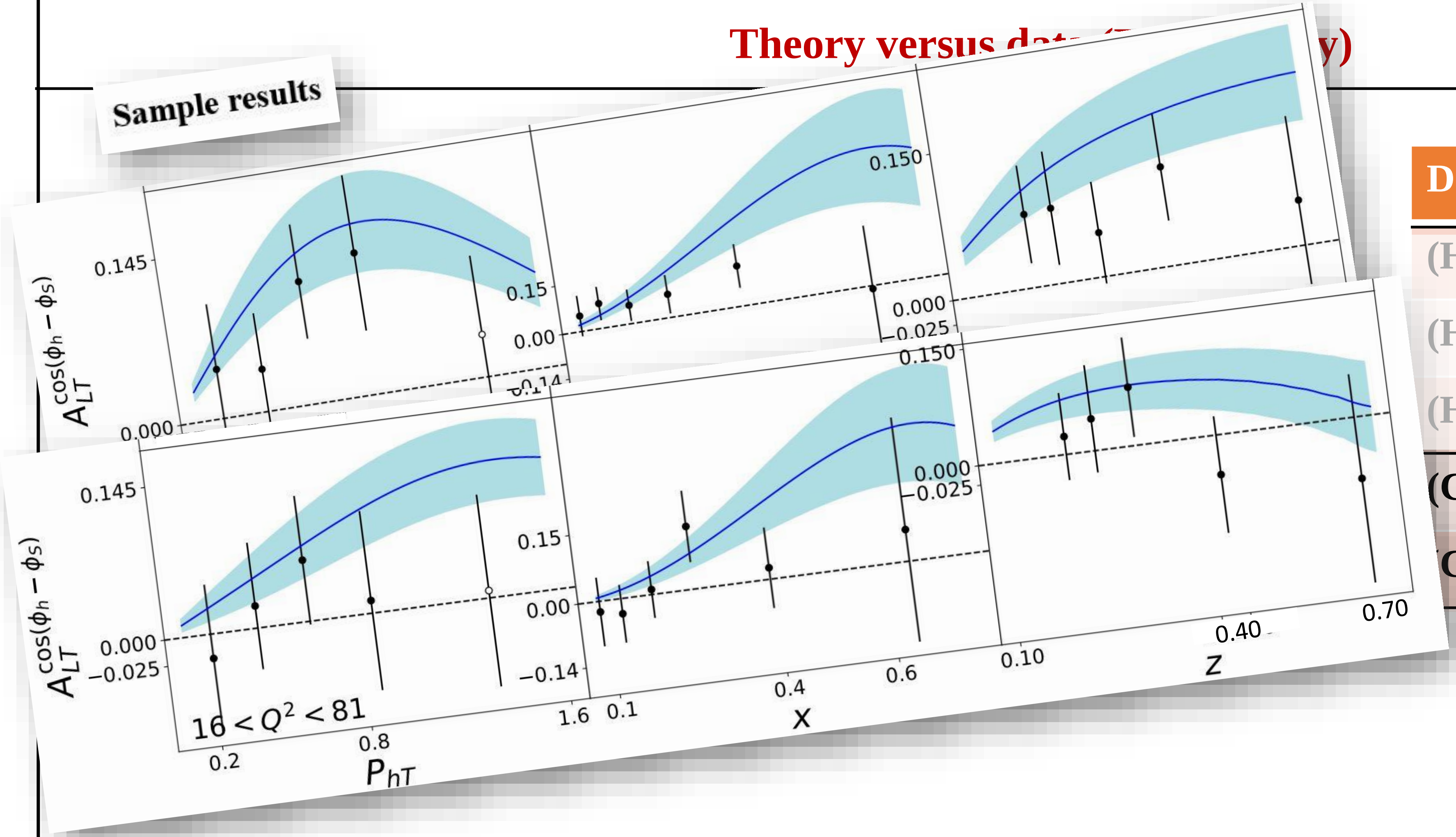


Dataset	$\chi^2/N_{\text{pts.}}$
(H, π^+)	1.20
(H, π^-)	0.87
(H, π^0)	1.93
(C, h^+)	0.96

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

SB, Kang, Metz, Penn, Pitonyak, In preparation (2021)

Theory versus data



Dataset	$\chi^2/N_{\text{pts.}}$
(H, π^+)	1.20
(H, π^-)	0.87
(H, π^0)	1.93
(C, h^+)	0.96
(C, h^-)	0.71

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

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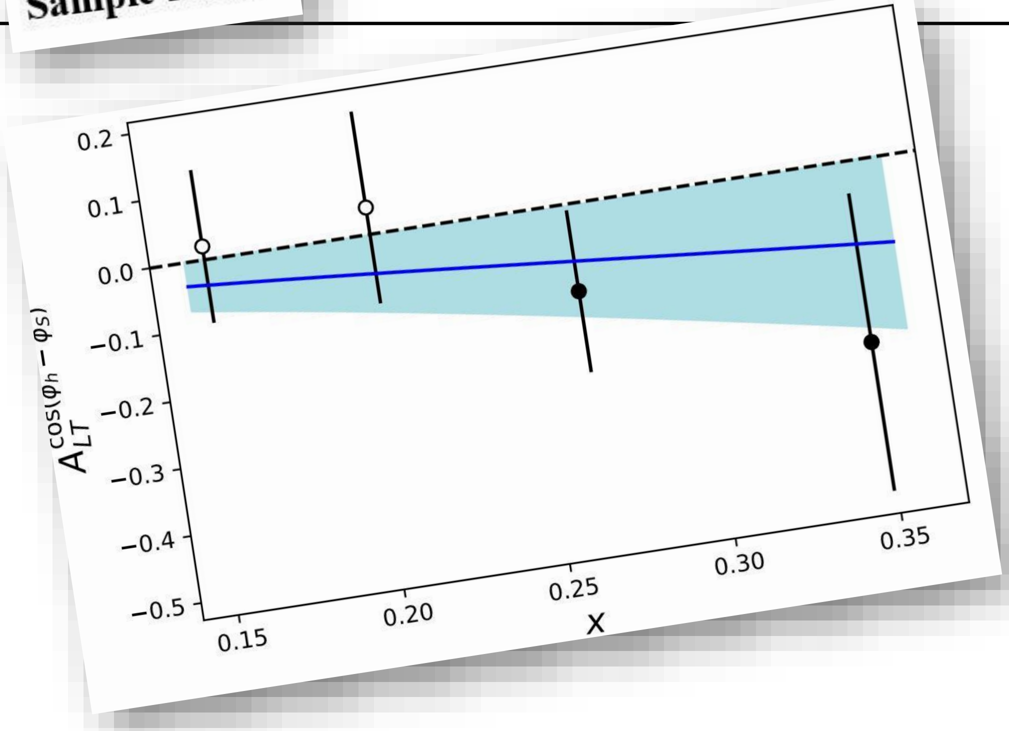
Theory versus data (Preliminary)

Sample results



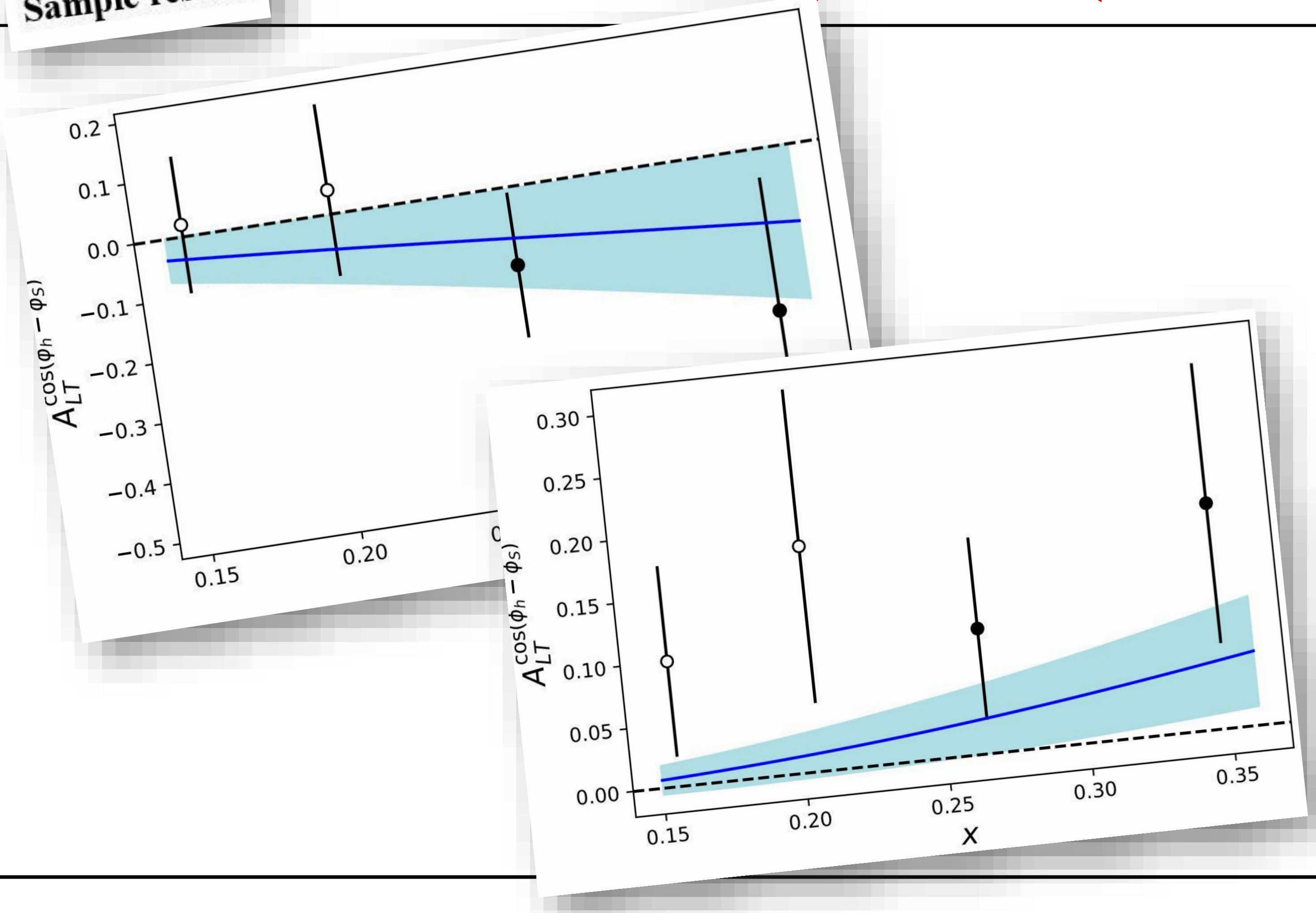
Dataset	$\chi^2/N_{\text{pts.}}$
(H, π^+)	1.20
(H, π^-)	0.87
(H, π^0)	1.93
(C, h^+)	0.96
(C, h^-)	0.71
(J, π^+)	0.30

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

SB, Kang, Metz, Penn, Pitonyak, In preparation (2021)

Sample results

Theory versus data (Preliminary)



Dataset	$\chi^2/N_{\mathrm{pts.}}$
(H, π^+)	1.20
(H, π^-)	0.87
(H, π^0)	1.93
(C, h^+)	0.96
(C, h^-)	0.71
(J, π^+)	0.30
(J, π^-)	1.13

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

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Theory versus data (Preliminary)

Global chi-squared:

$$\chi^2/N_{\text{pts.}} = 0.856$$

Dataset	$\chi^2/N_{\text{pts.}}$
(H, π^+)	1.20
(H, π^-)	0.87
(H, π^0)	1.93
(C, h^+)	0.96
(C, h^-)	0.71
(J, π^+)	0.30
(J, π^-)	1.13

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

SB, Kang, Metz, Penn, Pitonyak, In preparation (2021)

Preliminary results for the x-dependence

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

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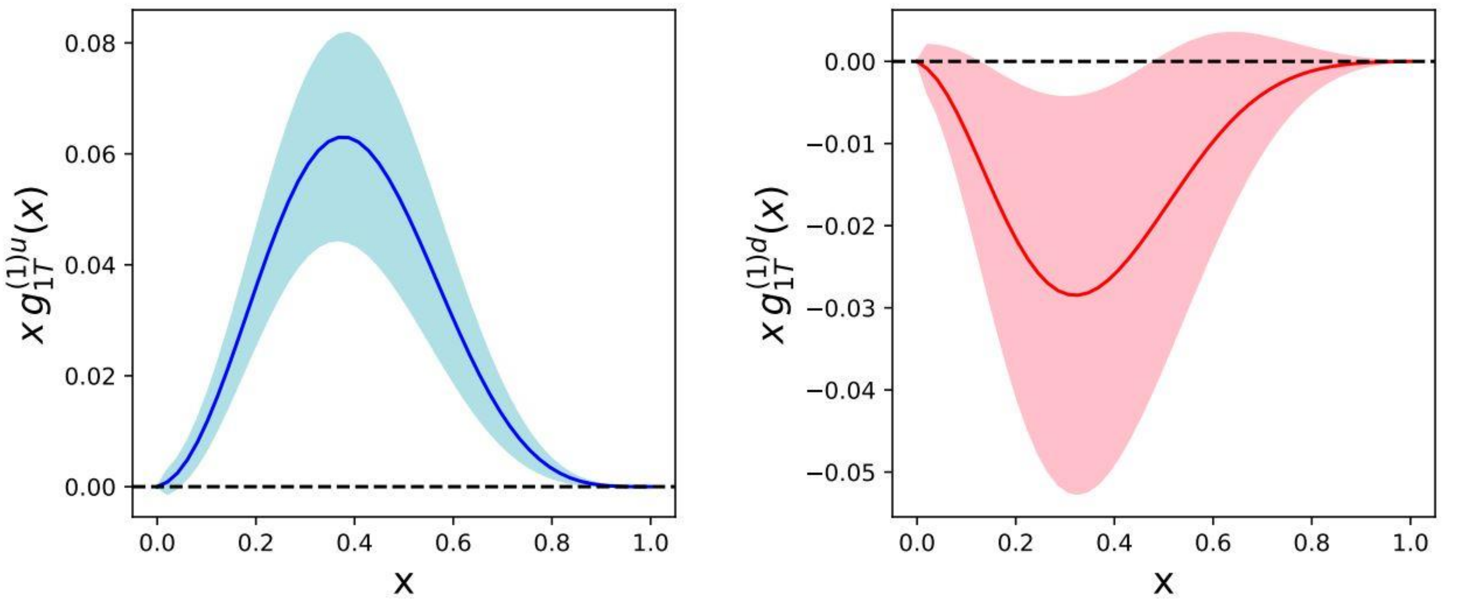
Preliminary results for the x-dependence



- **Features:**

1. **Up quark distribution is +ve**
2. **Down quark distribution is –ve**

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

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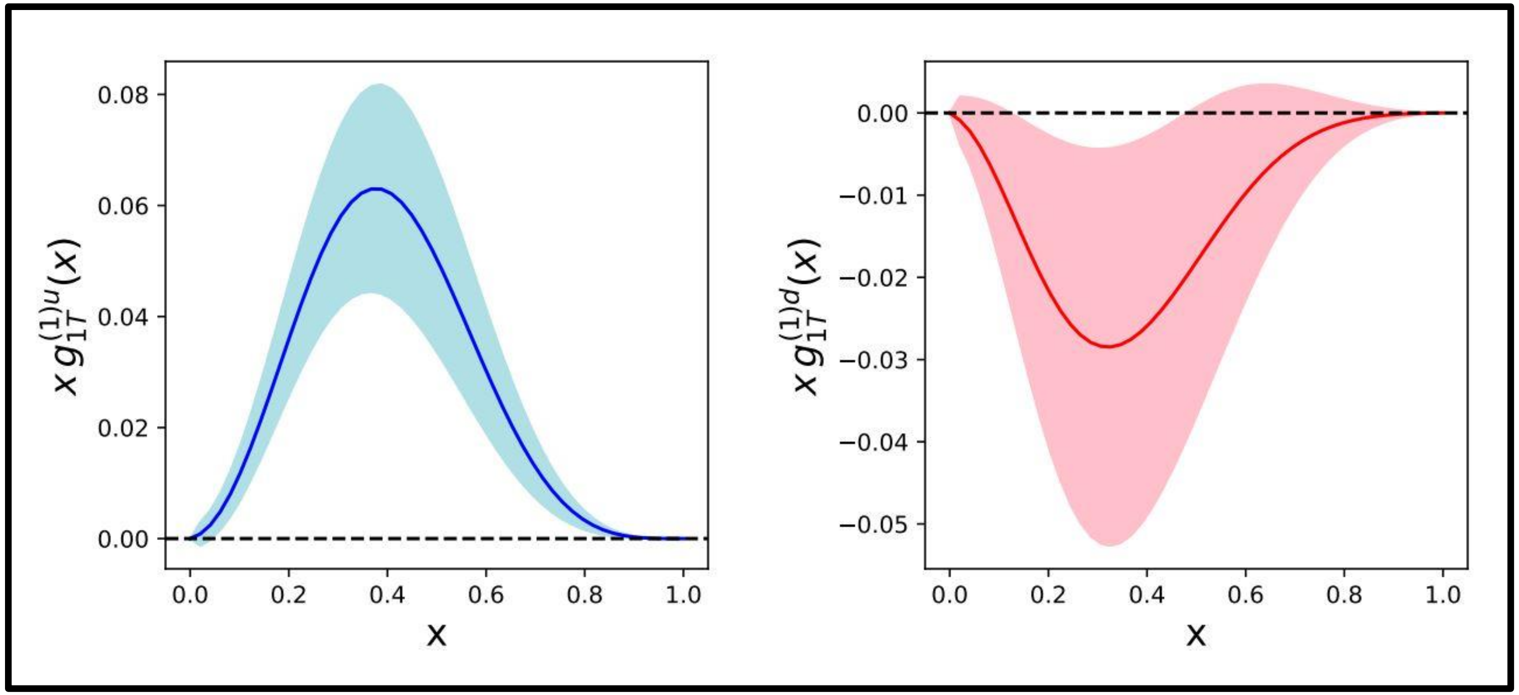
Preliminary results for the x-dependence



- **Features:**

  1. **Up quark distribution is +ve**
  2. **Down quark distribution is –ve**

- **Qualitative results consistent with large $\mathrm{N_c}$ approx.**

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

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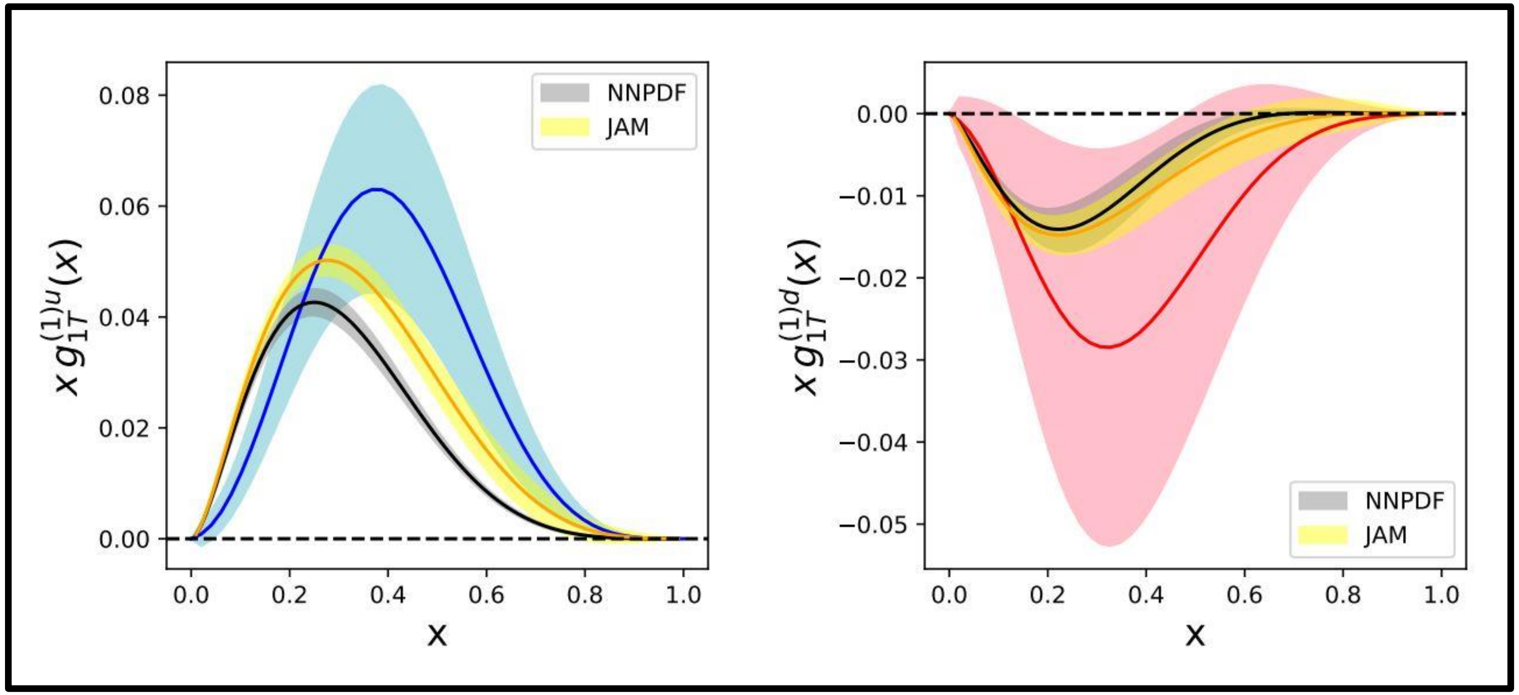
Preliminary comparison with WW approximation



- **Comparison with WW approx. from phenomenological fits from NNPDF (arXiv: 1406.5539) & JAM (arXiv: 1601.07782) (For DSSV, see backup)**
- **Qualitative agreement with WW approx.**
- **Hints of slight violation of WW approx. (indication of quark-gluon-quark correlations)**

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

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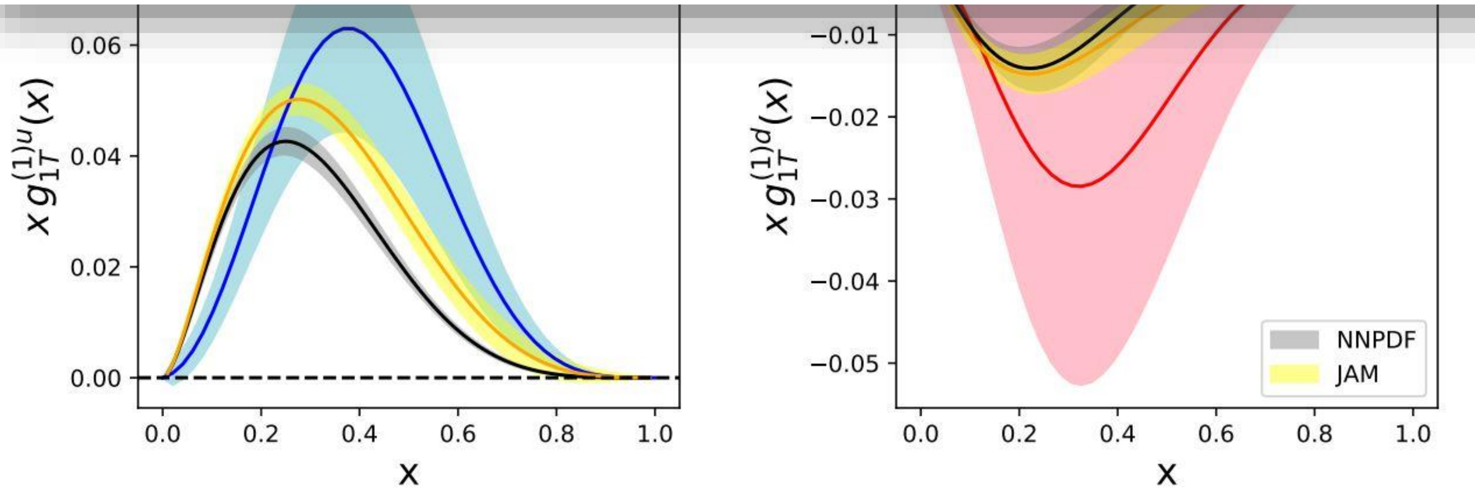
Preliminary comparison with WW approximation

Similar or better chi-squared than WW approx. for each dataset



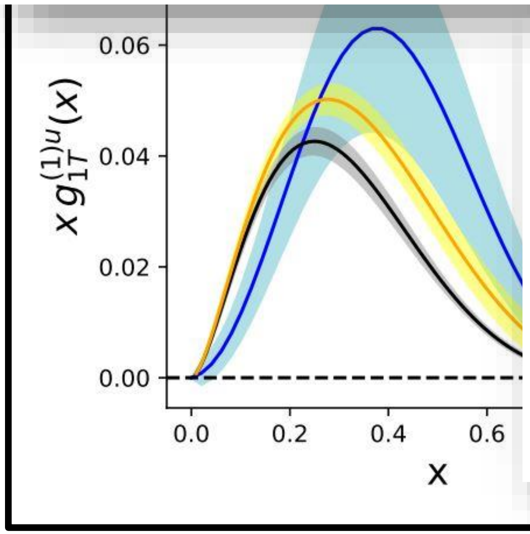
Dataset	$\chi^2/N_{\text{pts.}}\vert_{\text{fit}}$	$\chi^2/N_{\text{pts.}}\vert_{\text{WW}}$	
		NNPDF	JAM
(H, π^+)	1.20	1.19	1.18
(H, π^-)	0.87	0.85	0.85
(H, π^0)	1.93	1.97	1.95
(C, h^+)	0.96	0.71	1.01
(C, h^-)	0.71	0.70	0.81
(J, π^+)	0.30	0.80	0.78
(J, π^-)	1.13	1.15	0.92

Extraction of g_{1T} TMD from HERMES, COMPASS & JLab data

SB, Kang, Metz, Penn, Pitonyak, In preparation (2021)

Preliminary comparison with WW approximation

Similar or better chi-squared than WW approx. for each dataset



Global $\chi^2/N_{\text{pts.}}$		
Fit	WW	
	NNPDF	JAM
0.856	0.925	1.02

Dataset	$\chi^2/N_{\text{pts.}}\vert_{\text{fit}}$	$\chi^2/N_{\text{pts.}}\vert_{\text{WW}}$	
		NNPDF	JAM
(H, π^+)	1.20	1.19	1.18
(H, π^-)	0.87	0.85	0.85
(H, π^0)	1.93	1.97	1.95
(C, h^+)	0.96	0.71	1.01
(C, h^-)	0.71	0.70	0.81
(J, π^+)	0.30	0.80	0.78
(J, π^-)	1.13	1.15	0.92

Summary/ Outlook

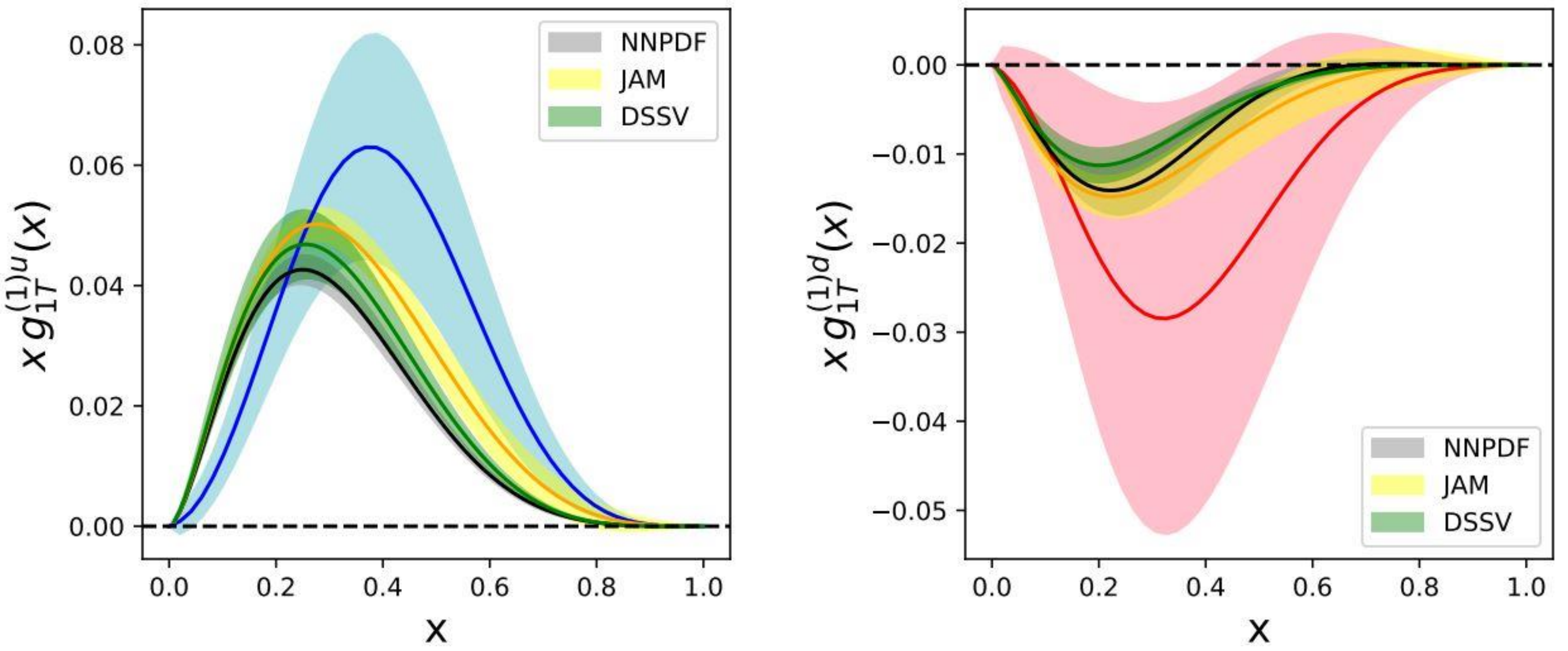
Summary

- We have shown preliminary results for g_{1T}, obtained from a simultaneous fitting to HERMES, COMPASS & JLab data on SIDIS
- Qualitative agreements with large $\mathrm{N_c}$ & WW approximation
- Indication of slight violation of WW approximation

Outlook

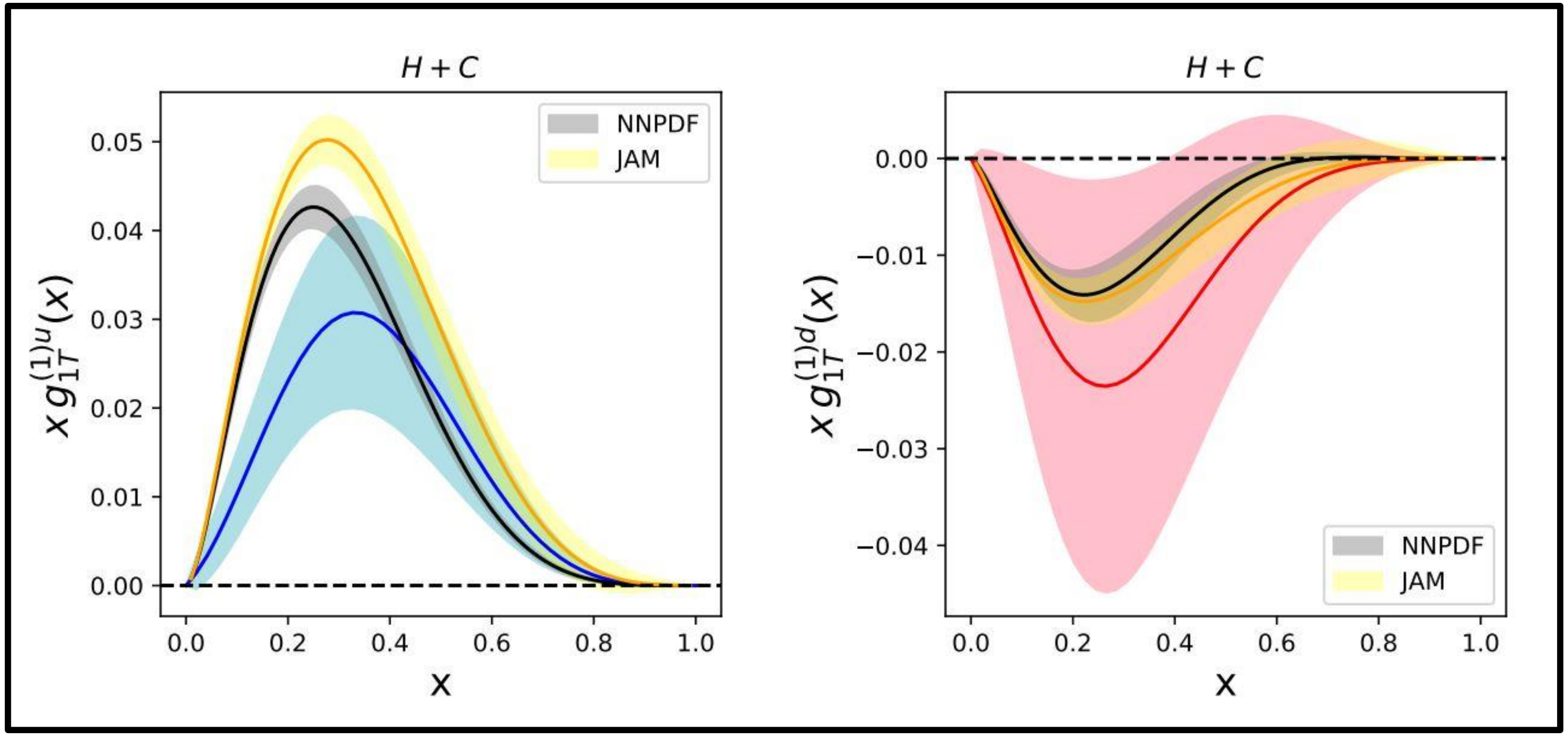
- Include TMD evolution
- Extract anti-quark distributions, including strangeness
- Extend analysis to extract $h_{1L}^{\perp}$, …

Backup slides



With DSSV (arXiv: 1902.10548)

Fitting without JLab dataset:



Dataset	$\chi^2/N_{\text{pts.}}\|_{\text{fit}}$	$\chi^2/N_{\text{pts.}}\|_{\text{WW}}$	
		NNPDF	JAM
(H, π^+)	1.23	1.19	1.18
(H, π^-)	0.88	0.85	0.85
(H, π^0)	2.03	1.97	1.95
(C, h^+)	0.39	0.71	1.01
(C, h^-)	0.53	0.70	0.81