
# Mini-review of PDFs and TMDs (experimental aspect)

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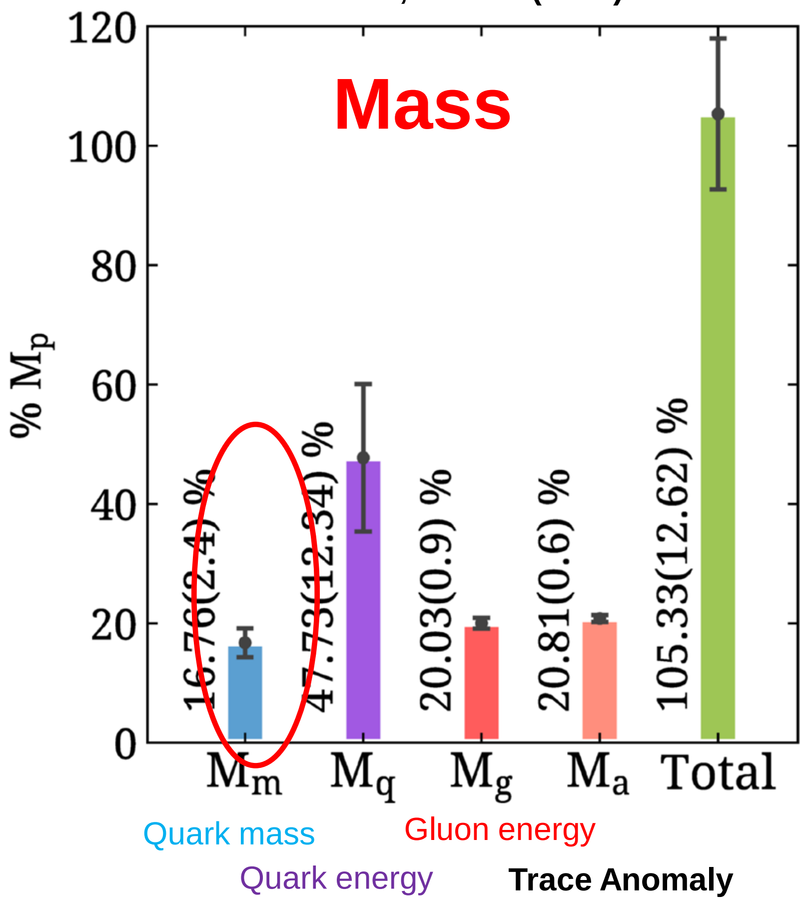
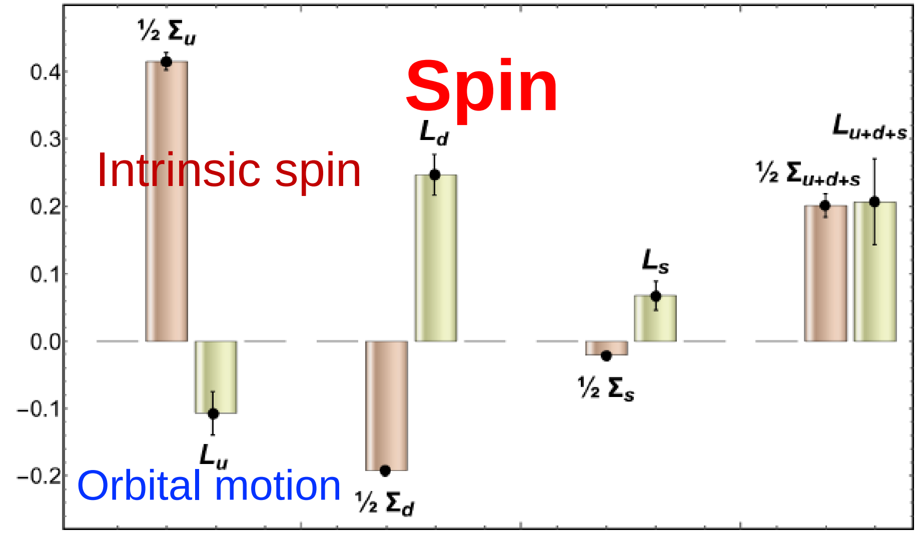
# Mass/Spin Decomposition of Proton (Lattice QCD)

PRL 116, 252001 (2016)
PRL 119, 142002 (2017)




PRL 119, 142002 (2017)

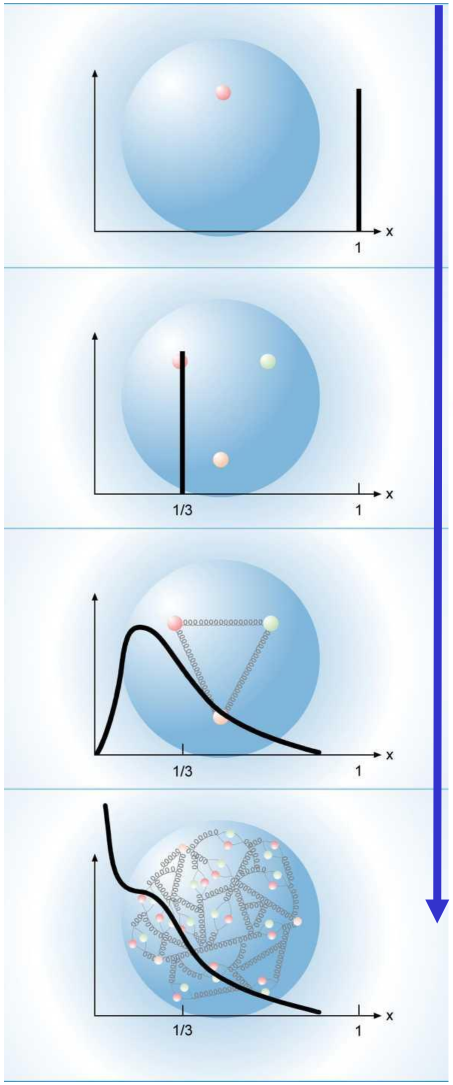


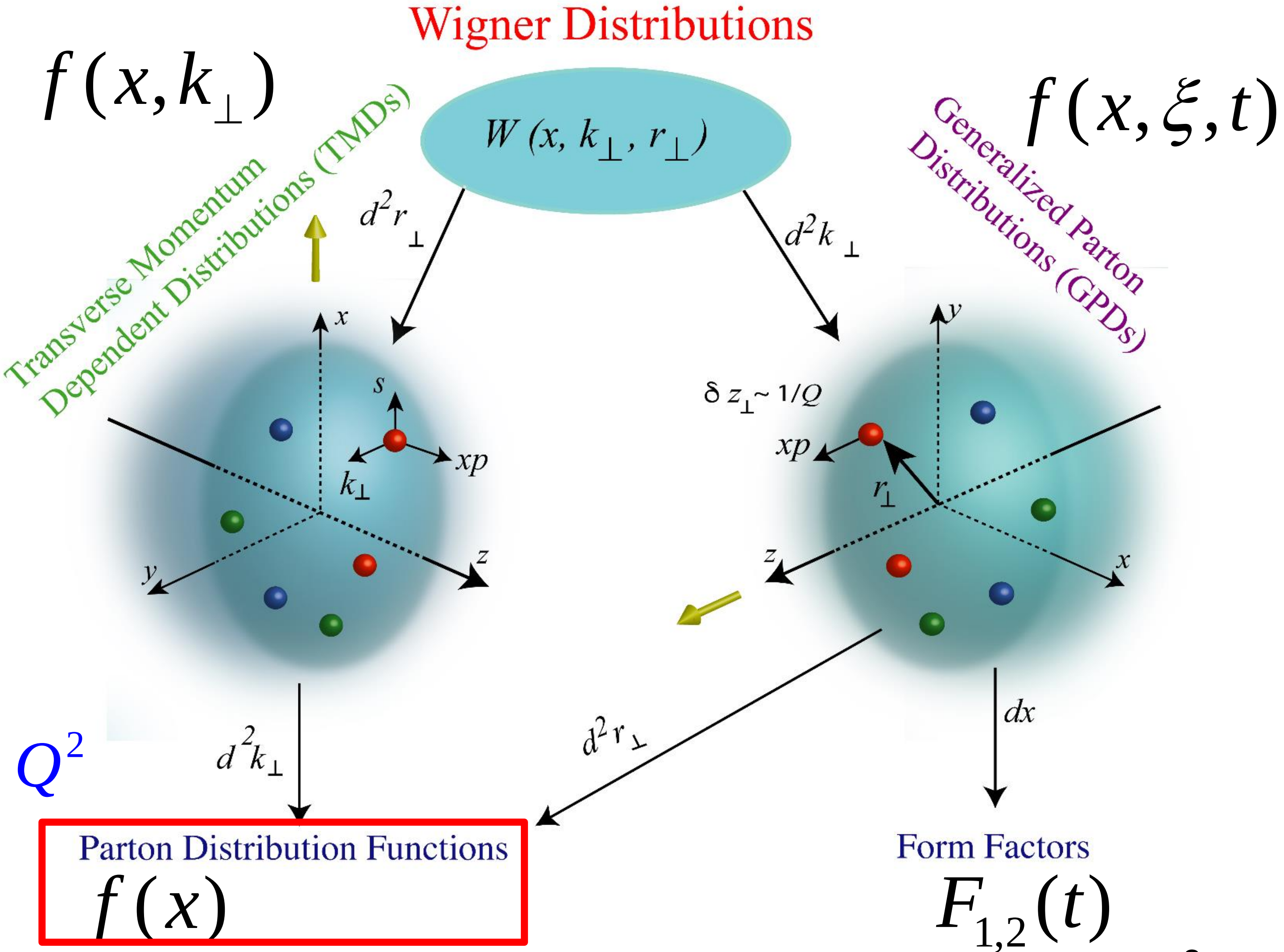

Quark orbital angular momentum extracted indirectly ($L_q = J_q - \Sigma_q$)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{Q+G}$$

**Can the origin of nucleon mass and spin be understood by its partonic structure?**

# Multi-dimensional Partonic Structures

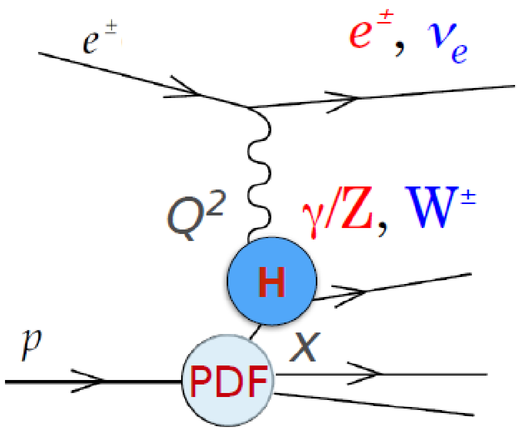


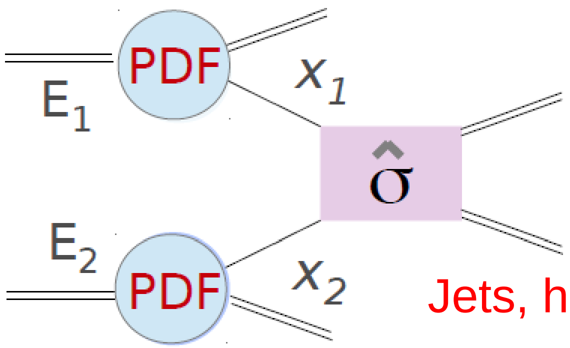

http://www.int.washington.edu/PROGRAMS/17-3/

# Experimental Approach

**DIS**




**Hadron-hadron**

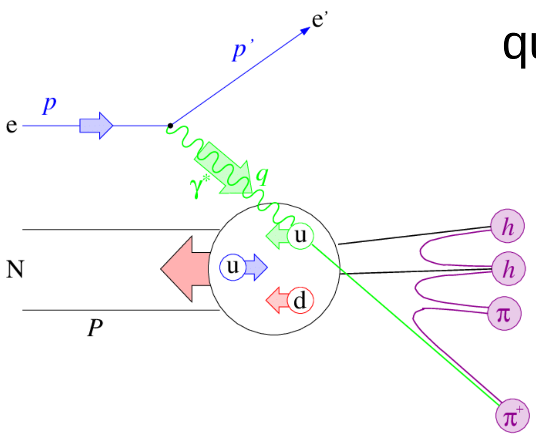


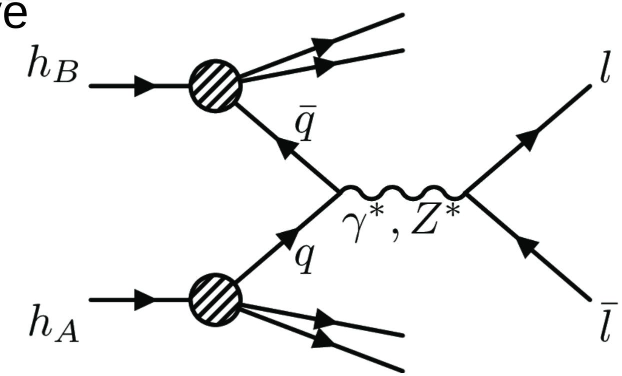

Jets, heavy quarks, $\gamma$

**Semi-inclusive DIS**

quark flavor sensitive

**Drell-Yan**



# Unpolarized PDF Analysis

Eur. Phys. J. C (2009) 63:189

| Process | Subprocess | Partons | $x$ range |
|---|---|---|---|
| $\ell^{\pm}\{p,n\} \to \ell^{\pm} X$ | $\gamma^* q \to q$ | $q, \bar{q}, g$ | $x \gtrsim 0.01$ |
| $\ell^{\pm} n/p \to \ell^{\pm} X$ | $\gamma^* d/u \to d/u$ | $d/u$ | $x \gtrsim 0.01$ |
| $pp \to \mu^+\mu^- X$ | $u\bar{u}, d\bar{d} \to \gamma^*$ | $\bar{q}$ | $0.015 \lesssim x \lesssim 0.35$ |
| $pn/pp \to \mu^+\mu^- X$ | $(u\bar{d})/(u\bar{u}) \to \gamma^*$ | $\bar{d}/\bar{u}$ | $0.015 \lesssim x \lesssim 0.35$ |
| $\nu(\bar{\nu})N \to \mu^-(\mu^+)X$ | $W^* q \to q'$ | $q, \bar{q}$ | $0.01 \lesssim x \lesssim 0.5$ |
| $\nu N \to \mu^-\mu^+ X$ | $W^* s \to c$ | $s$ | $0.01 \lesssim x \lesssim 0.2$ |
| $\bar{\nu} N \to \mu^+\mu^- X$ | $W^* \bar{s} \to \bar{c}$ | $\bar{s}$ | $0.01 \lesssim x \lesssim 0.2$ |
| $e^{\pm} p \to e^{\pm} X$ | $\gamma^* q \to q$ | $g, q, \bar{q}$ | $0.0001 \lesssim x \lesssim 0.1$ |
| $e^+ p \to \bar{\nu} X$ | $W^+\{d,s\} \to \{u,c\}$ | $d, s$ | $x \gtrsim 0.01$ |
| $e^{\pm} p \to e^{\pm} c\bar{c} X$ | $\gamma^* c \to c,\ \gamma^* g \to c\bar{c}$ | $c, g$ | $0.0001 \lesssim x \lesssim 0.01$ |
| $e^{\pm} p \to \text{jet} + X$ | $\gamma^* g \to q\bar{q}$ | $g$ | $0.01 \lesssim x \lesssim 0.1$ |
| $p\bar{p} \to \text{jet} + X$ | $gg, qg, qq \to 2j$ | $g, q$ | $0.01 \lesssim x \lesssim 0.5$ |
| $p\bar{p} \to (W^{\pm} \to \ell^{\pm}\nu)X$ | $ud \to W,\ \bar{u}\bar{d} \to W$ | $u, d, \bar{u}, \bar{d}$ | $x \gtrsim 0.05$ |
| $p\bar{p} \to (Z \to \ell^+\ell^-)X$ | $uu, dd \to Z$ | $d$ | $x \gtrsim 0.05$ |

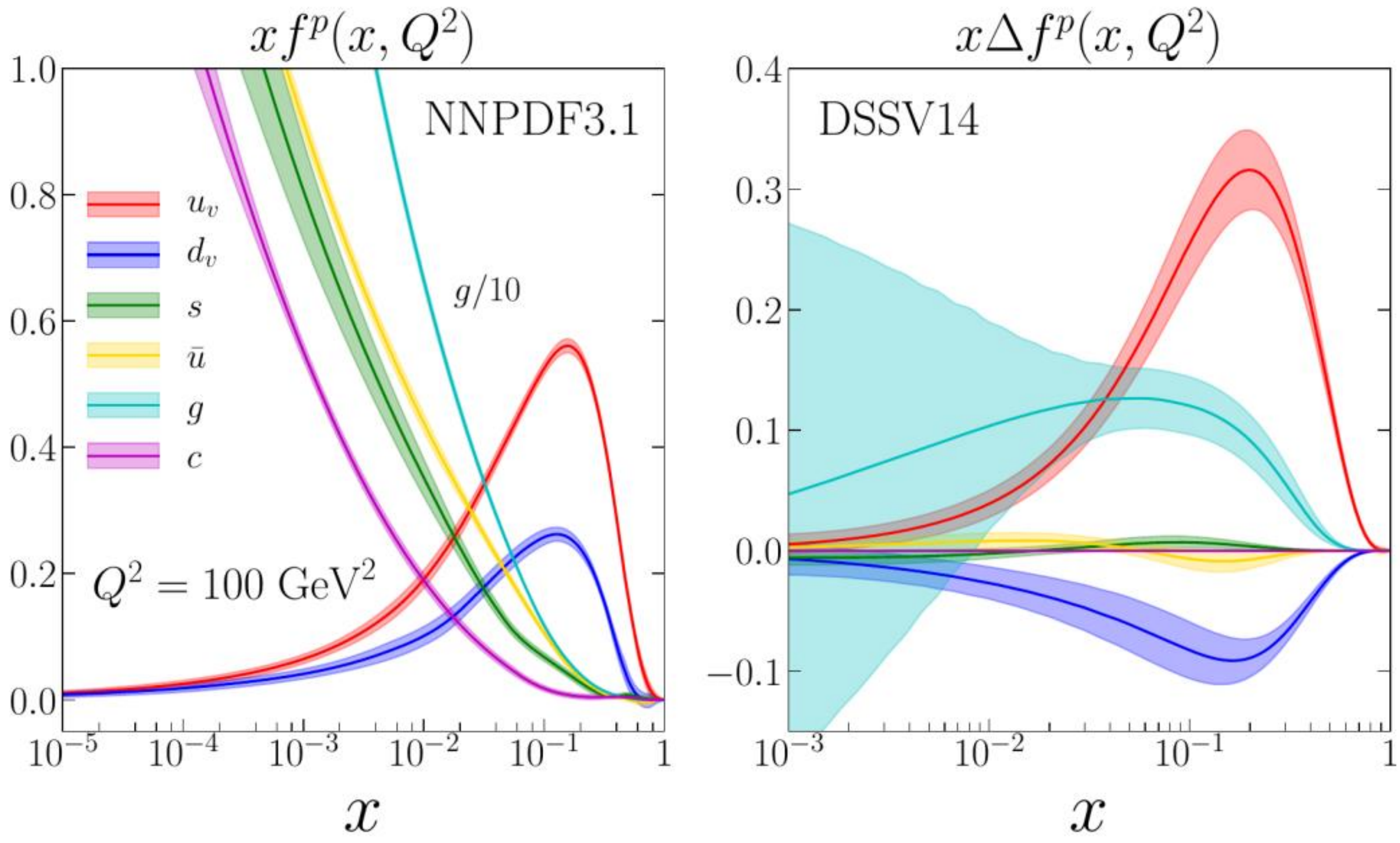
DIS, Drell-Yan, Jets

| Hadronic Process | Partonic Process | Probed Partons | U | P | N |
|---|---|---|---|---|---|
| Fixed Target DIS | | | | | |
| $\ell^{\pm}\{p,n\} \to \ell^{\pm} + X$ | $\gamma^* q \to q$ | $\mathrm{q}^+, \mathrm{q}, \bar{\mathrm{q}}, \mathrm{g}$ | ✓ | ✓ | ✓ |
| $\ell^{\pm}\{n,A\}/p \to \ell^{\pm} + X$ | $\gamma^* d/u \to d/u$ | d/u | ✓ | | ✓ |
| $\nu(\bar{\nu})A \to \mu^-(\mu^+) + X$ | $W^* q \to q'$ | $\mathrm{q}, \bar{\mathrm{q}}$ | ✓ | | ✓ |
| $\nu A \to \mu^-\mu^+ + X$ | $W^* s \to c$ | s | ✓ | | ✓ |
| $\bar{\nu} A \to \mu^+\mu^- + X$ | $W^* \bar{s} \to \bar{c}$ | $\bar{\mathrm{s}}$ | ✓ | | ✓ |
| Collider DIS | | | | | |
| $e^{\pm}p \to e^{\pm} + X$ | $\gamma^* q \to q$ | $\mathrm{g}, \mathrm{q}, \bar{\mathrm{q}}$ | ✓ | | |
| $e^+ p \to \bar{\nu} + X$ | $W^+\{d,s\} \to \{u,c\}$ | d, s | ✓ | | |
| $e^{\pm}p \to e^{\pm}c\bar{c} + X$ | $\gamma^* c \to c, \gamma^* g \to c\bar{c}$ | c, g | ✓ | | |
| $e^{\pm}p \to \text{(di-)jet(s)} + X$ | $\gamma^* g \to q\bar{q}$ | g | ✓ | | |
| Fixed Target SIDIS | | | | | |
| $\ell^{\pm}\{p,d\} \to \ell^{\pm} + h + X$ | $\gamma^* q \to q$ | $\mathrm{u}, \bar{\mathrm{u}}, \mathrm{d}, \bar{\mathrm{d}}, \mathrm{g}$ | ✓ | ✓ | |
| $\ell^{\pm}\{p,d\} \to \ell^{\pm}c\bar{c} \to \ell^{\pm}D + X$ | $\gamma^* g \to c\bar{c}$ | g | | ✓ | |
| Fixed Target DY | | | | | |
| $pp \to \mu^+\mu^- + X$ | $u\bar{u}, d\bar{d} \to \gamma^*$ | $\bar{\mathrm{q}}$ | ✓ | | |
| $p\{n,A\}/pp \to \mu^+\mu^- + X$ | $(u\bar{d})/(u\bar{u}) \to \gamma^*$ | $\bar{\mathrm{d}}/\bar{\mathrm{u}}$ | ✓ | | ✓ |
| Collider DY | | | | | |
| $p\bar{p} \to (W^{\pm} \to \ell^{\pm}\nu) + X$ | $ud \to W^+, \bar{u}\bar{d} \to W^-$ | $\mathrm{u}, \mathrm{d}, \bar{\mathrm{u}}, \bar{\mathrm{d}}$ | ✓ | | |
| $p\{p,A\} \to (W^{\pm} \to \ell^{\pm}\nu) + X$ | $u\bar{d} \to W^+, d\bar{u} \to W^-$ | $\mathrm{u}, \mathrm{d}, \bar{\mathrm{u}}, \bar{\mathrm{d}}$ | ✓ | ✓ | ✓ |
| $p\bar{p}(p\{p,A\}) \to (Z \to \ell^+\ell^-) + X$ | $uu, dd(u\bar{u}, d\bar{d}) \to Z$ | u, d, g | ✓ | ✓ | ✓ |
| $pp \to (W + c) + X$ | $gs \to W^- c, g\bar{s} \to W^+\bar{c}$ | $\mathrm{s}, \bar{\mathrm{s}}, \mathrm{g}$ | ✓ | | |
| $pp \to (\gamma^* \to \ell^+\ell^-)X$ | $u\bar{u}, d\bar{d} \to \gamma^*, u\gamma, d\gamma \to \gamma^*$ | $\bar{\mathrm{q}}, \mathrm{g}, \gamma$ | ✓ | | |
| Jet and hadron production | | | | | |
| $p\bar{p}(p\{p,A\}) \to \text{(di-)jet(s)} + X$ | $gg, qg, qq \to \text{jet(s)}$ | $g, q$ | ✓ | ✓ | ✓ |
| $p\bar{p}(pp) \to h + X$ | $gg, qg, qq \to \pi, K, D$ | $g, q$ | ✓ | ✓ | |
| Top Production | | | | | |
| $pp \to t\bar{t} + X$ | $gg \to t\bar{t}$ | $g$ | ✓ | | |
| $pp \to t + X$ | $W^* q \to q'$ | $\mathrm{q}, \bar{\mathrm{q}}$ | ✓ | | |

https://arxiv.org/abs/2001.07722

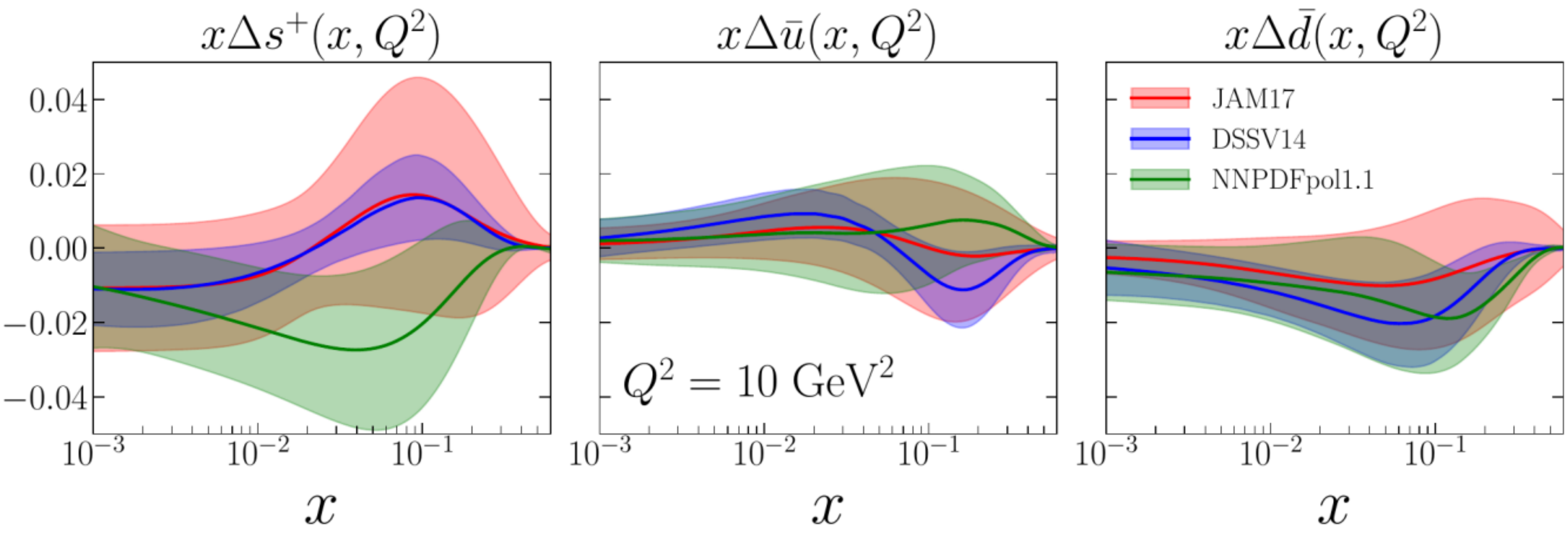
# Unpolarized and Polarized PDFs

Much larger uncertainties!




https://arxiv.org/abs/2001.07722

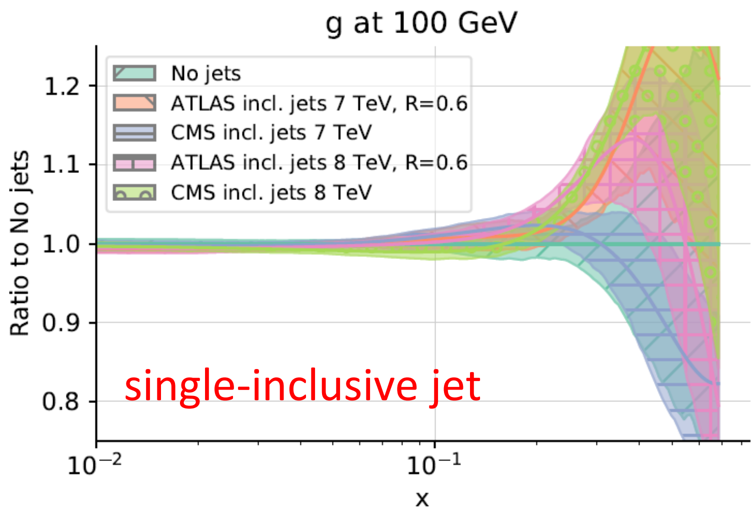
# Polarized Sea

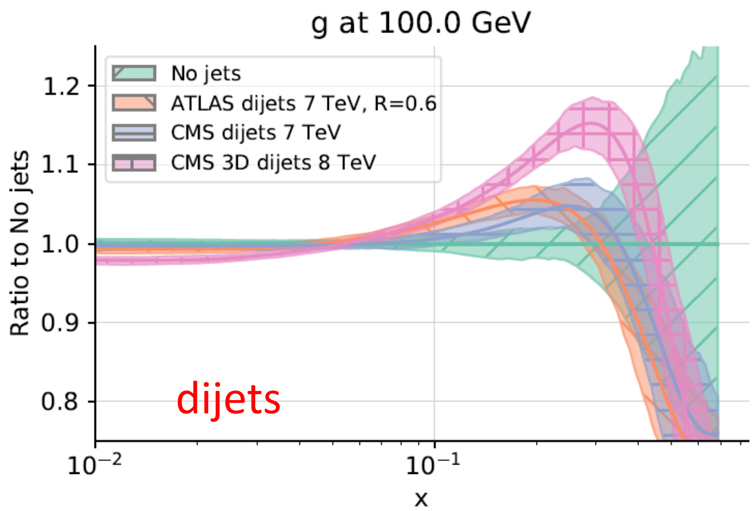


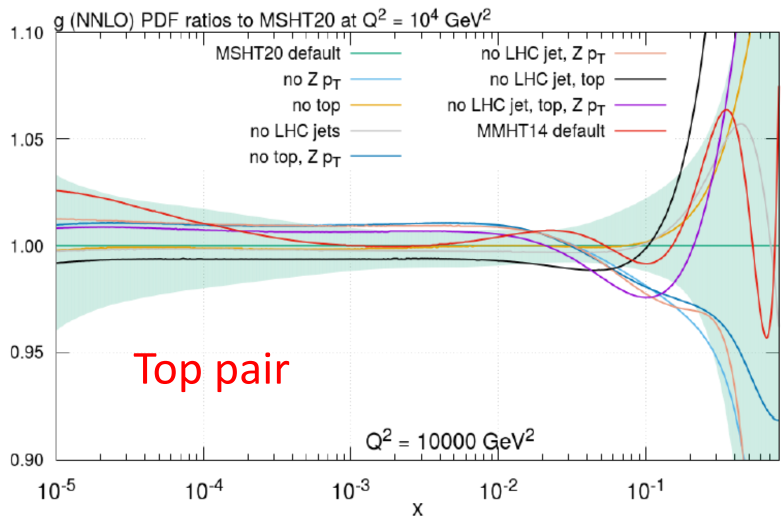

https://arxiv.org/abs/2001.07722

# Gluons

NNPDF 4.0: https://arxiv.org/abs/2109.02653

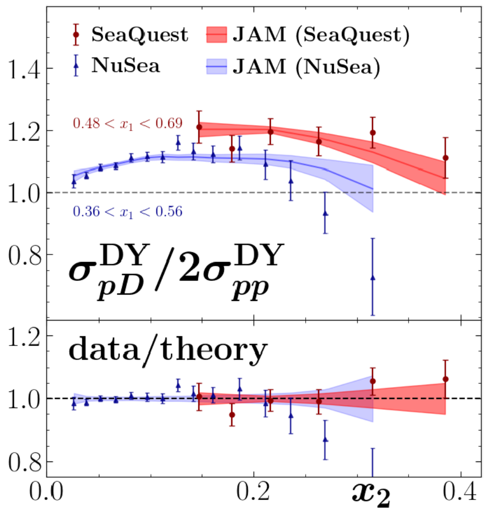


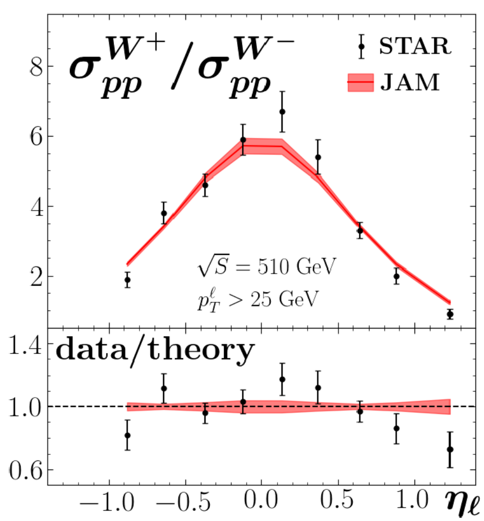



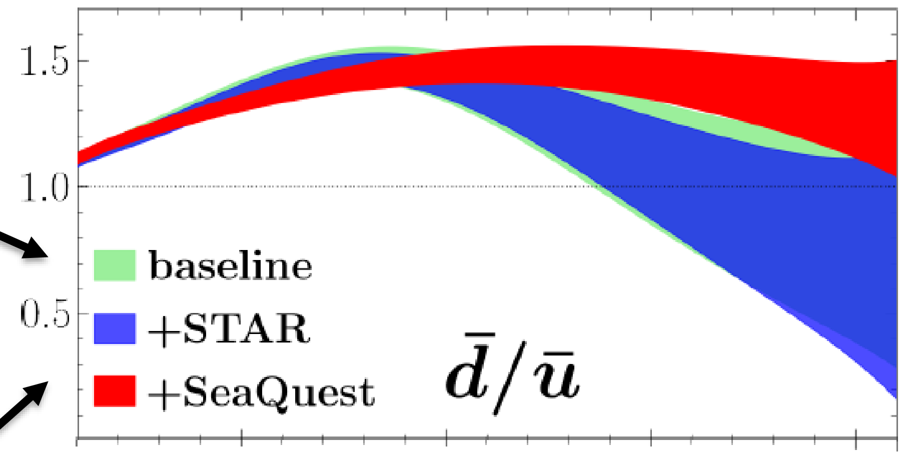

MHST20: https://arxiv.org/abs/2012.04684

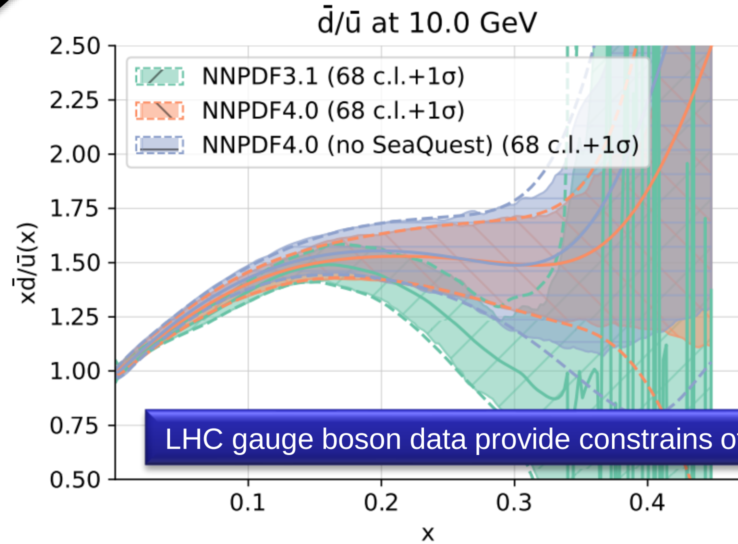
# Light Sea Asymmetry




JAM (NLO) https://arxiv.org/abs/2109.00677



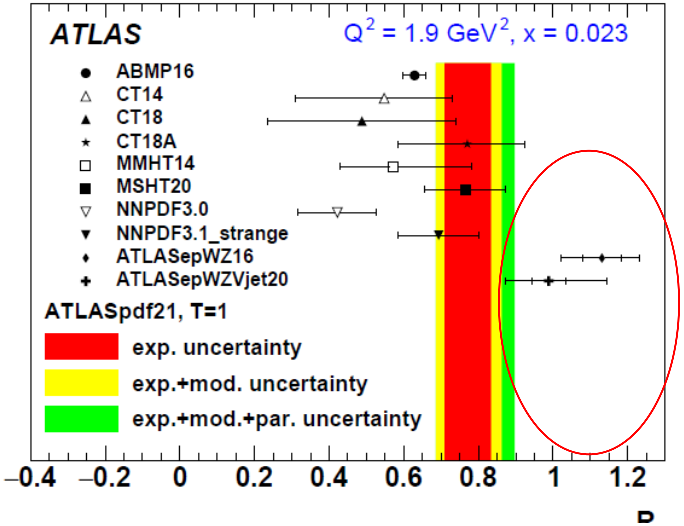

LHC gauge boson data provide constrains of $\bar{d}/\bar{u}(x)$.

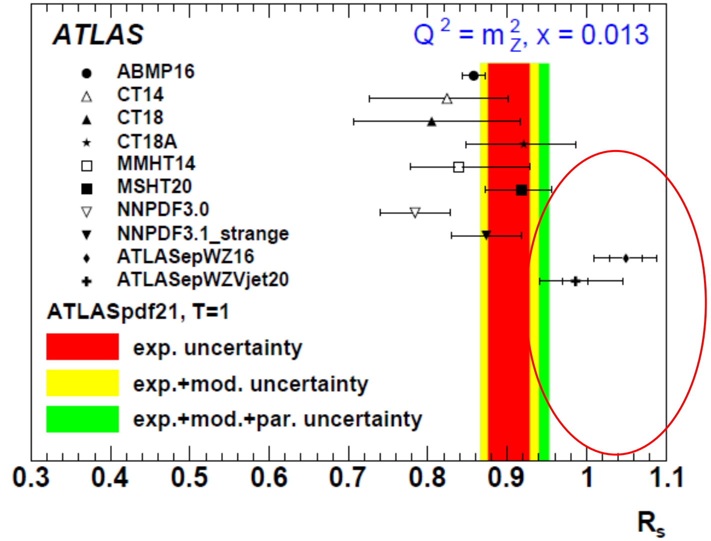
NNPDF4.0 (NNLO) https://arxiv.org/abs/2109.02653

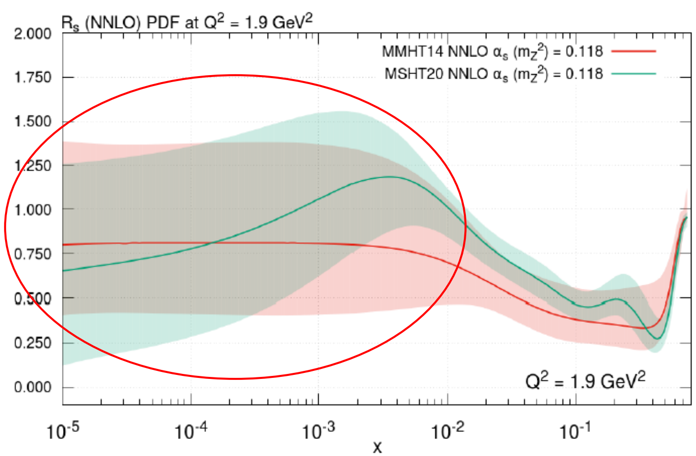
# Strange Sea

## Is SU(3) symmetry valid for light sea quarks?

LHC: W, Z, V+jet https://arxiv.org/abs/2112.11266



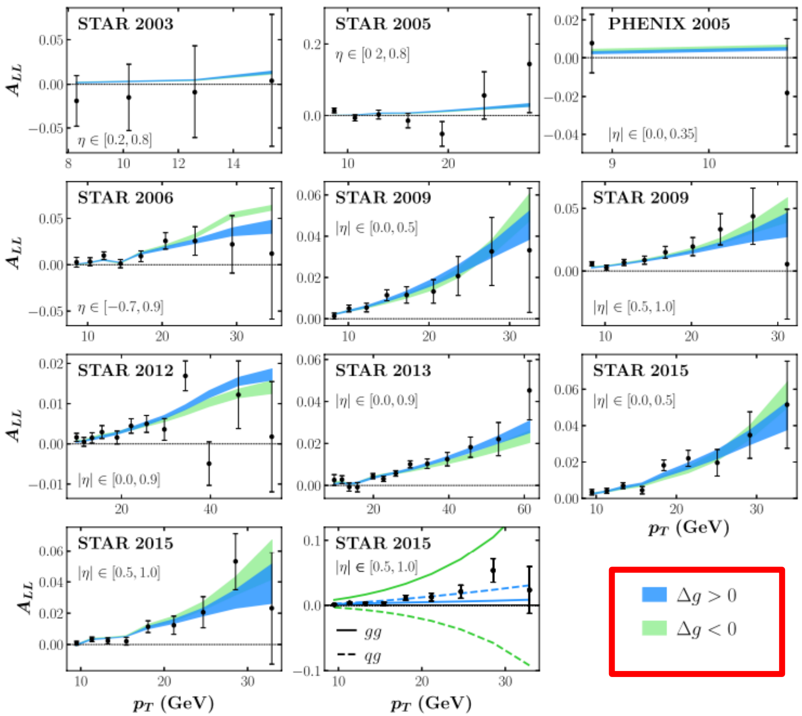




$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

MHST20: https://arxiv.org/abs/2012.04684

# Polarized Gluons and Quarks

Double longitudinal spin asymmetries $A_{LL}$



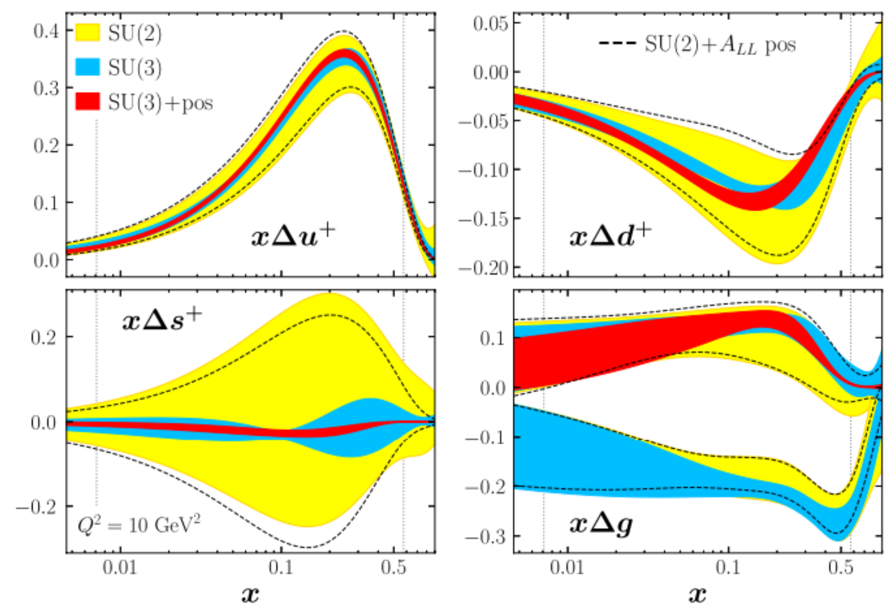

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\Delta\sigma}{\sigma},$$

Not sensitive to the sign of $\Delta g$!

Much larger uncertainties, in comparison with the unpolarized PDFs!

JAM: https://arxiv.org/abs/2201.02075

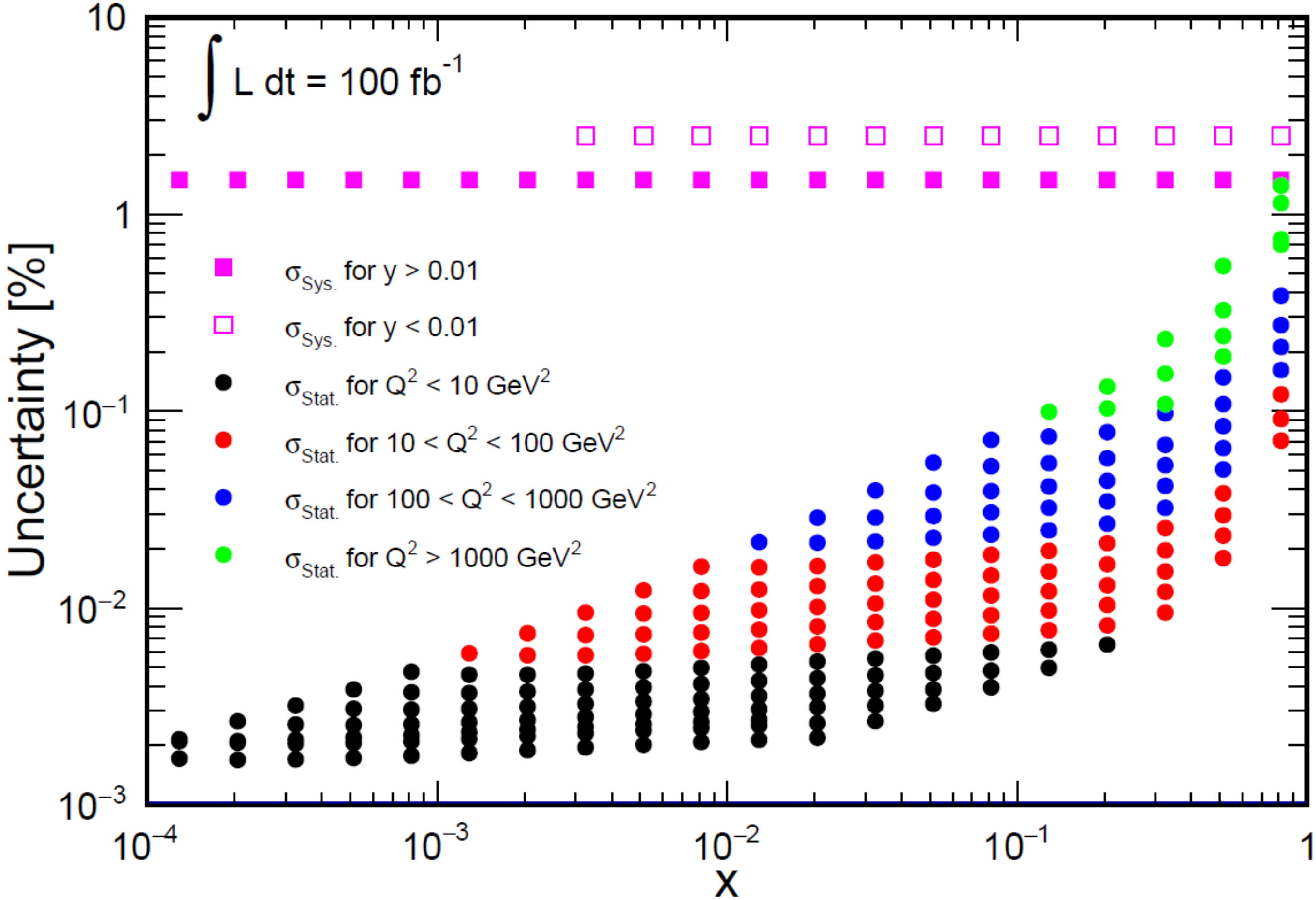
$$\Delta q^+ = \Delta q + \Delta\bar{q}.$$




$$\Delta\bar{u} = \Delta\bar{d} = \Delta s = \Delta\bar{s} \equiv \Delta\bar{q} \quad SU(3)$$

$$|\Delta f_i(x, Q^2)| \leq f_i(x, Q^2), \qquad \text{[positivity]}$$

# Uncertainties of EIC for DIS

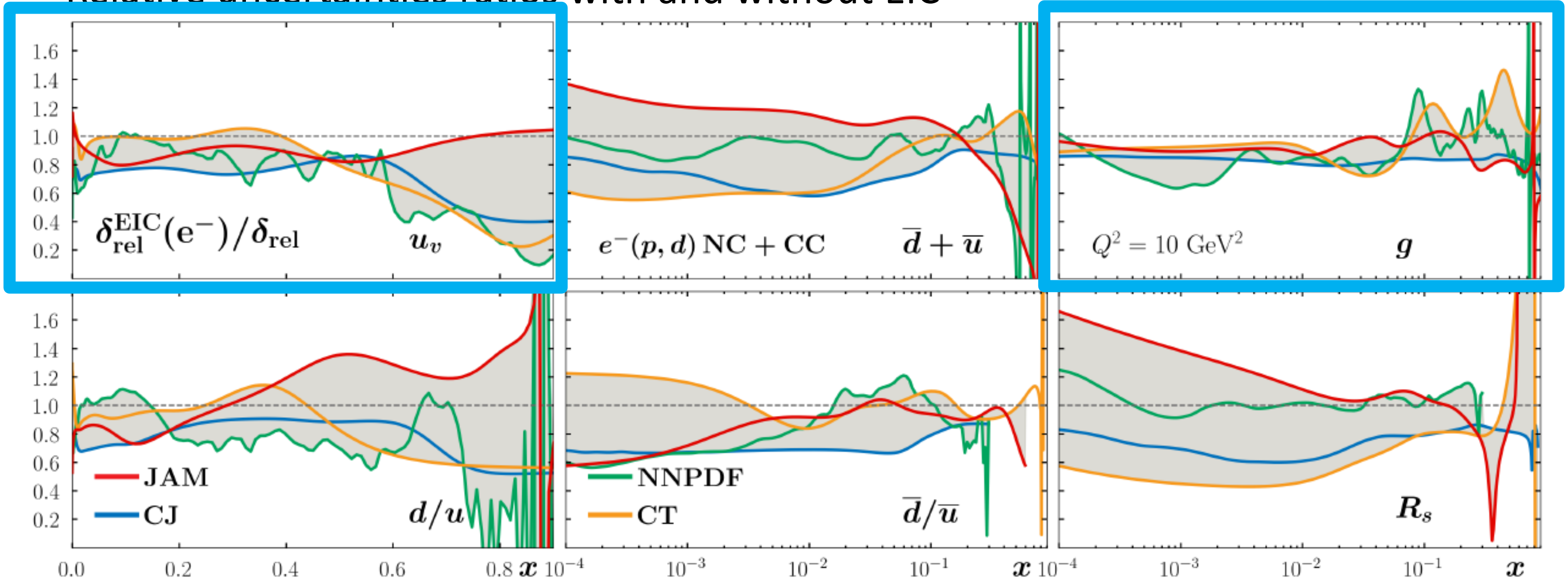





EIC Yellow report: https://arxiv.org/abs/2103.05419

# Unpolarized PDFs

Relative uncertainties ratios with and without EIC

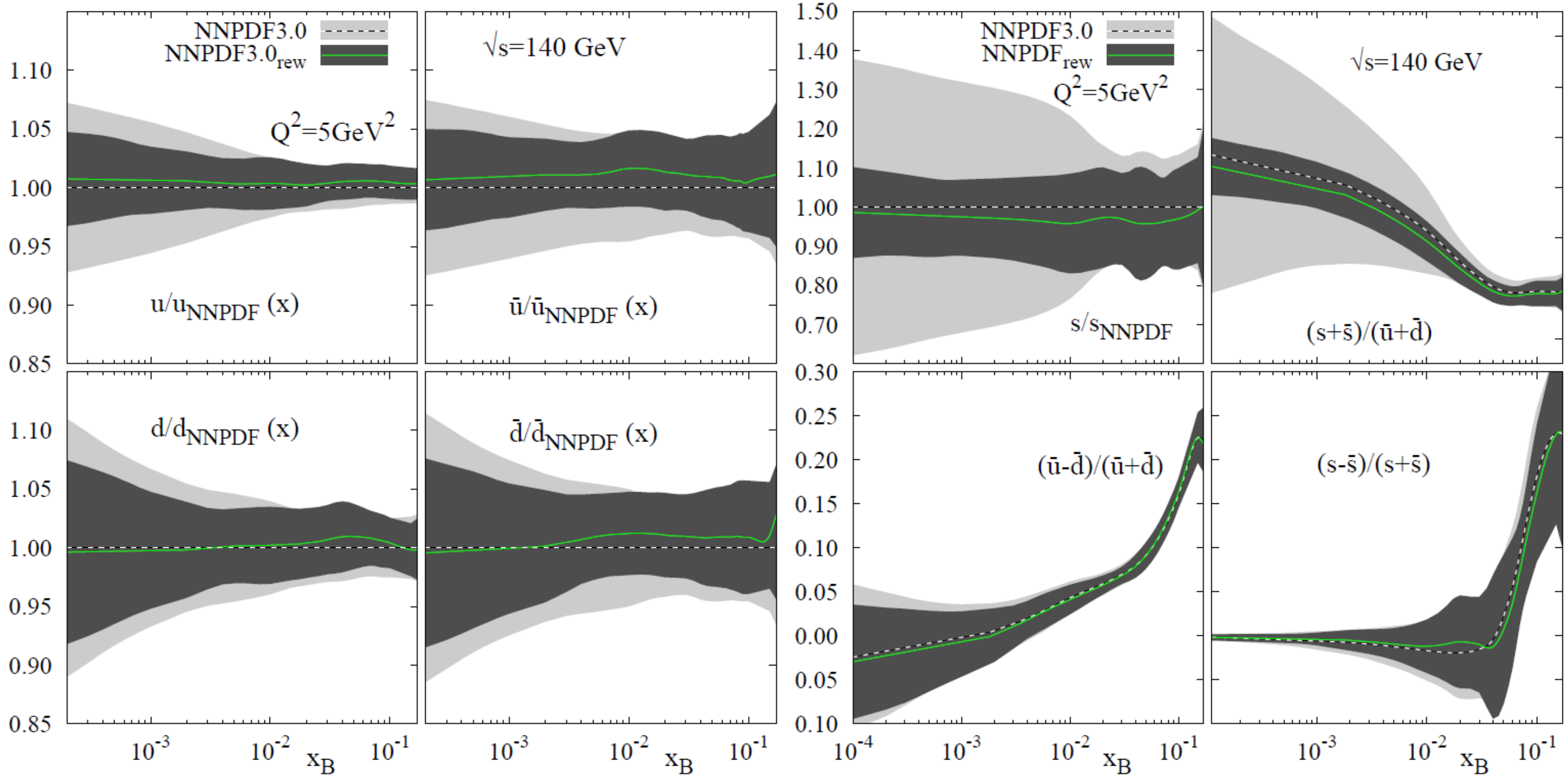



*"Note that the ratios are not bound to be less than one since the inclusion of new data can change the relative strength of the flavor channels on the differential cross sections."*

Improved valence quarks and gluon at small x.

EIC Yellow report: https://arxiv.org/abs/2103.05419

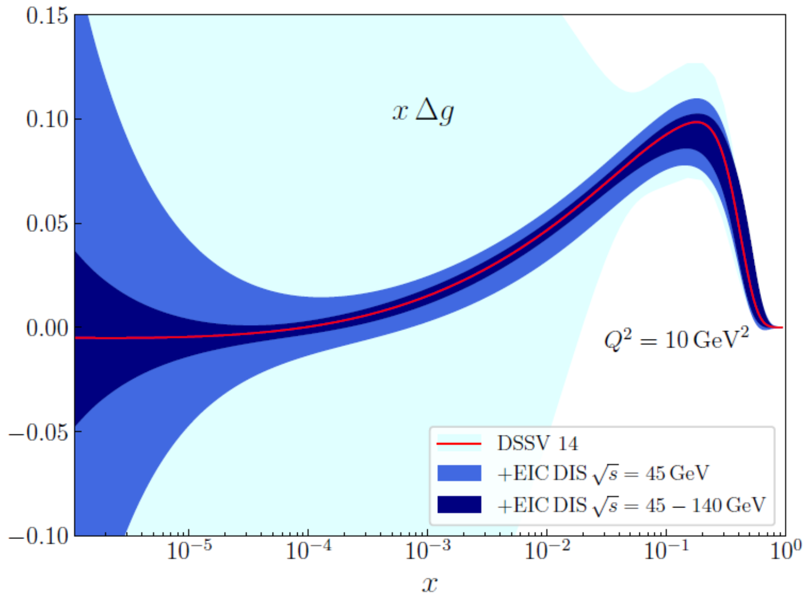
# SIDIS: Unpolarized Sea

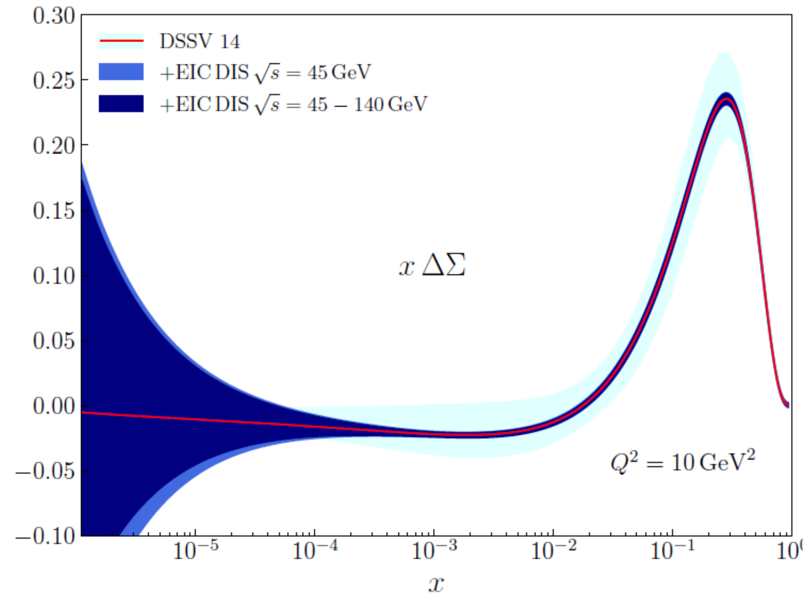


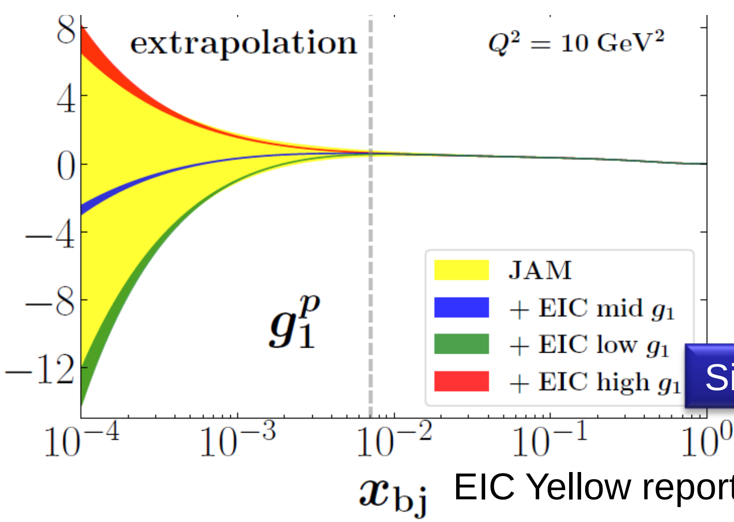

Improved sea quarks with SIDIS.

EIC Yellow report: https://arxiv.org/abs/2103.05419

# Polarized Gluon and Quark



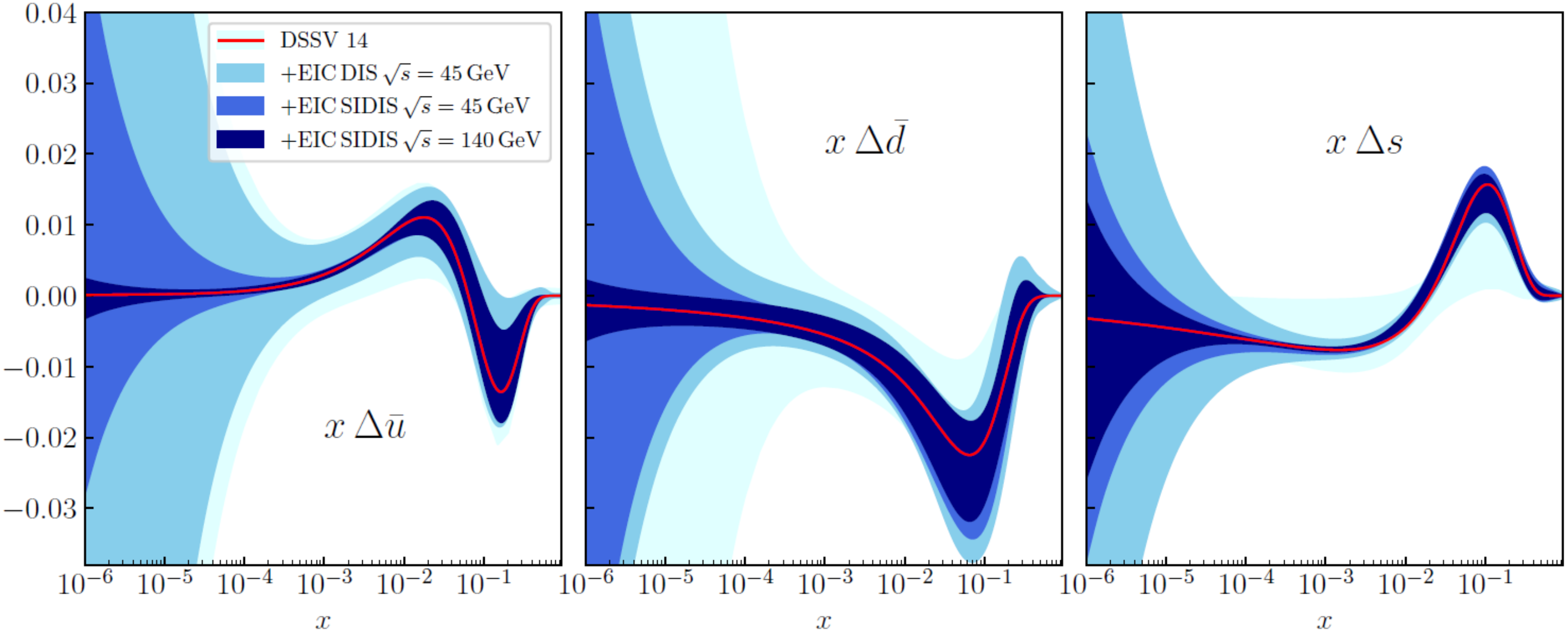




$$g_1(x) = \frac{1}{2}\sum_q e_q^2 \Delta q(x)$$

**Significantly improved uncertainties of gluons and quarks helicities**

EIC Yellow report: https://arxiv.org/abs/2103.05419

# SIDIS: Polarized Sea

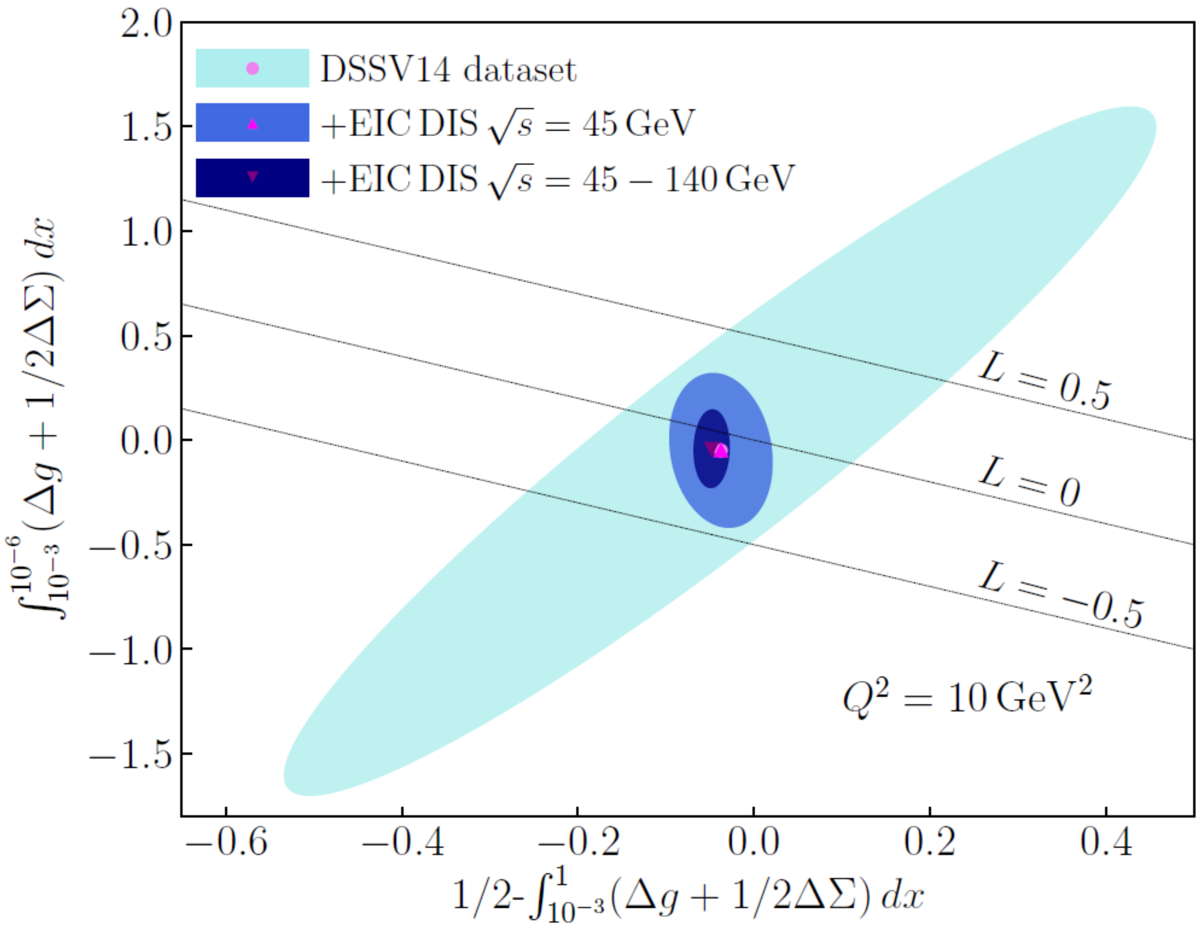



Significantly improved uncertainties of sea quarks helicities



EIC Yellow report: https://arxiv.org/abs/2103.05419

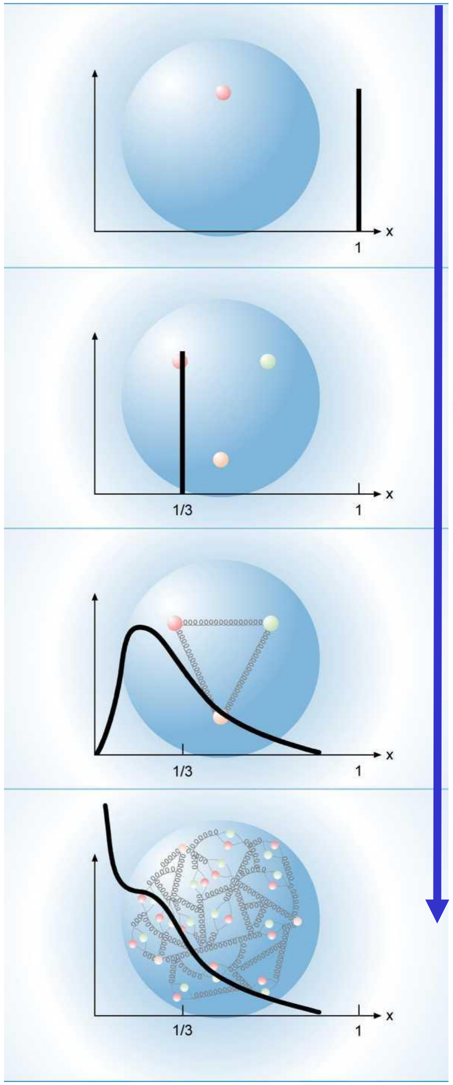
# Room for Orbital Angular Momentum (OAM)

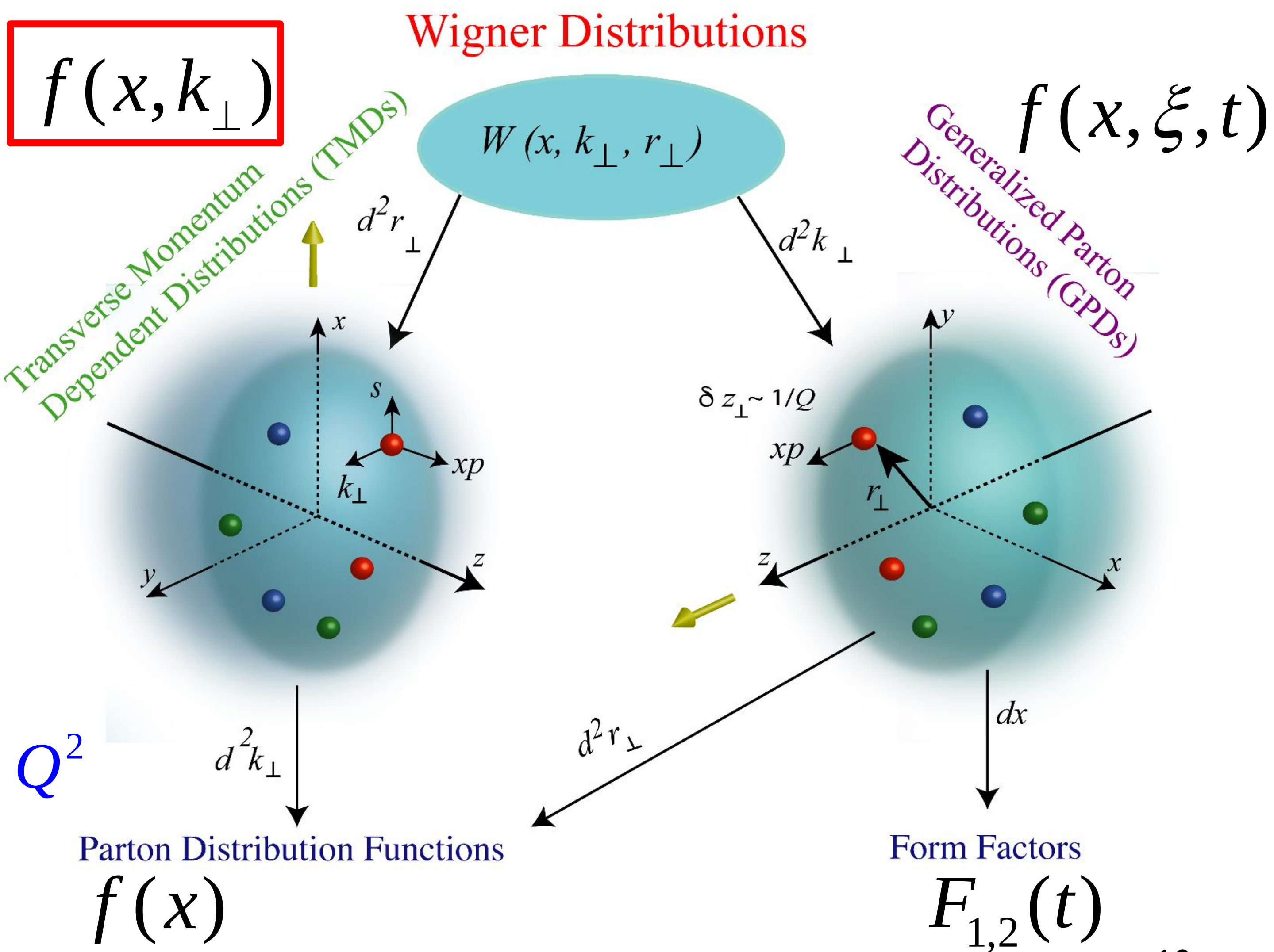



Significantly improved constraints of OAM contribution

EIC Yellow report: https://arxiv.org/abs/2103.05419

# Multi-dimensional Partonic Structures

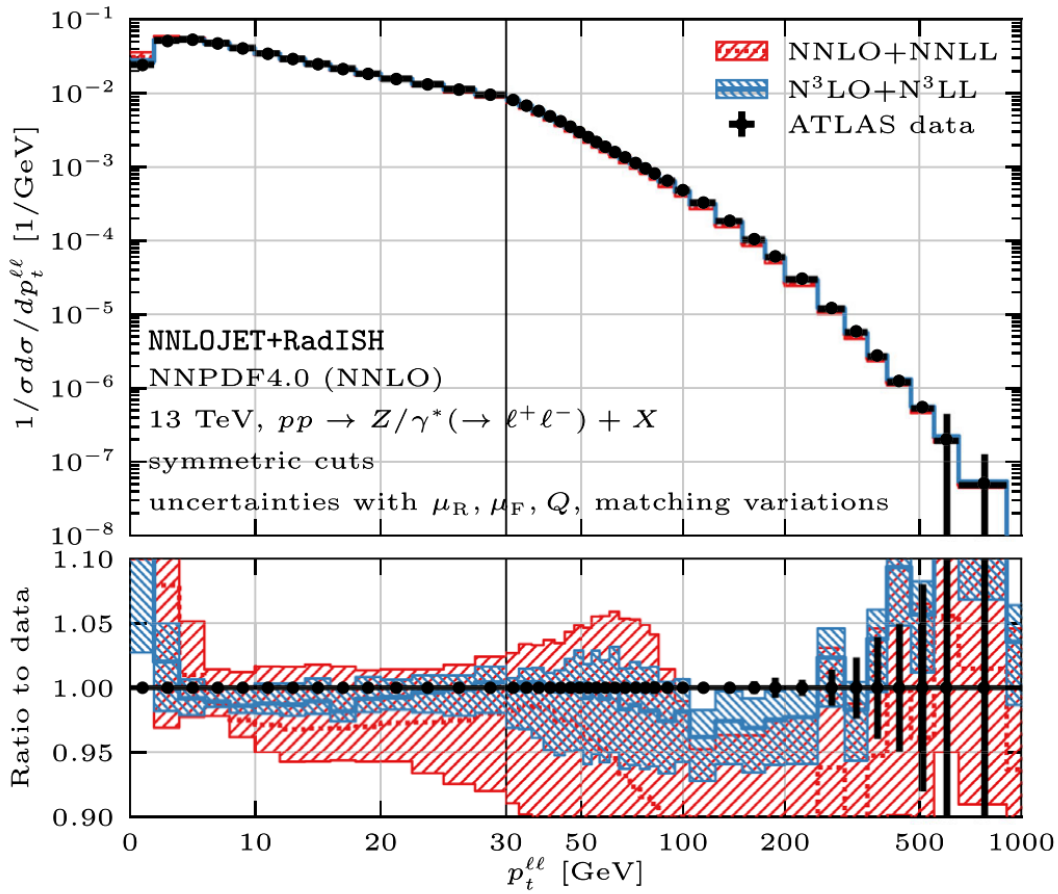



http://www.int.washington.edu/PROGRAMS/17-3/

# State-of-Art pQCD Calculations

PRL, 128, 252001 (2022)




## Why TMDs?

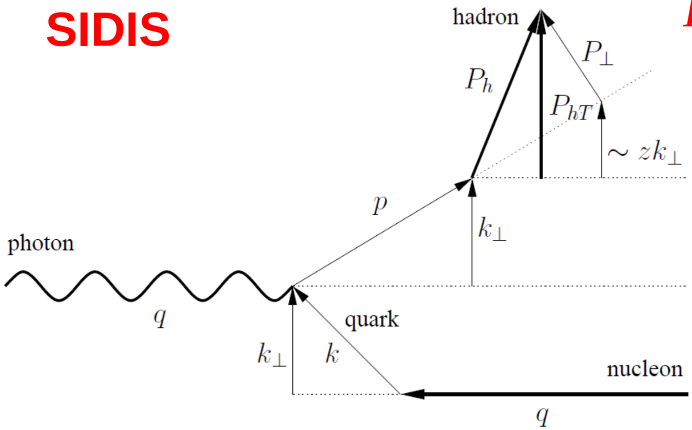
- At large pT, fixed-order pQCD describes the data very well.
- At small pT, pQCD calculation fails due to non-perturbative QCD effect.

<5% deviation for pT>5 GeV!

$$d\sigma_{\rm DY}^{\rm N^3LO+N^3LL} \equiv d\sigma_{\rm DY}^{\rm N^3LL} + d\sigma_{\rm DY+jet}^{\rm NNLO} - [d\sigma_{\rm DY}^{\rm N^3LL}]_{\mathcal{O}(\alpha_s^3)},$$

# Unpolarized Quark Transverse Momentum distributions $f_1^q(x, k_T^2)$

**SIDIS**




$P_{hT} = zk_\perp + P_\perp$

$$F_{UU,T}(x,z,\boldsymbol{P}_{hT}^2,Q^2) = \sum_a \mathcal{H}^a_{UU,T}(Q^2) \times x \int d^2\boldsymbol{k}_\perp \, d^2\boldsymbol{P}_\perp \, f_1^a(x,\boldsymbol{k}_\perp^2;Q^2) \, D_1^{a\to h}(z,\boldsymbol{P}_\perp^2;Q^2) \, \delta^{(2)}(z\boldsymbol{k}_\perp - \boldsymbol{P}_{hT} + \boldsymbol{P}_\perp) + Y_{UU,T}(Q^2,\boldsymbol{P}_{hT}^2) + \mathcal{O}(M^2/Q^2).$$

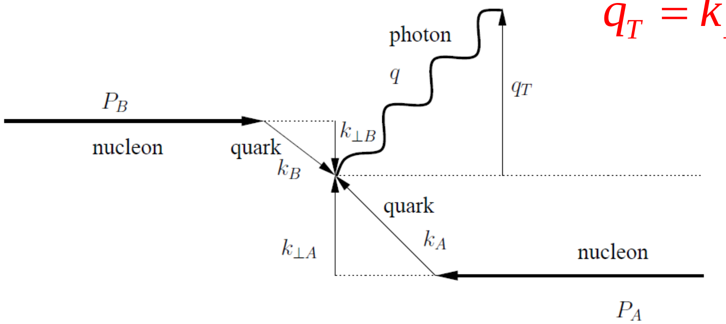
FF

$k_\perp$ : intrinsice parton transverse momentum

$P_\perp$ : transverse momentum gained during fragmentation

Difficult to separate $k_\perp$ and $P_\perp$ in SIDIS only.

**Drell-Yan**




$q_T = k_{\perp A} + k_{\perp B}$

$$\frac{d\sigma}{dQ^2 \, dq_T^2 \, d\eta} = \sigma_0^{\gamma,Z}\left(F^1_{UU} + \frac{1}{2}F^2_{UU}\right)$$

$$F^1_{UU}(x_A,x_B,\boldsymbol{q}_T^2,Q^2) = \sum_a \mathcal{H}^{1a}_{UU}(Q^2) \times x_A x_B \int d^2\boldsymbol{k}_{\perp A} \, d^2\boldsymbol{k}_{\perp B} \, f_1^a(x_A,\boldsymbol{k}_{\perp A}^2;Q^2) \, f_1^{\bar{a}}(x_B,\boldsymbol{k}_{\perp B}^2;Q^2) \, \delta^{(2)}(\boldsymbol{k}_{\perp A} - \boldsymbol{q}_T + \boldsymbol{k}_{\perp B}) + Y^1_{UU}(Q^2,\boldsymbol{q}_T^2) + \mathcal{O}(M^2/Q^2).$$

# Parameterizations of TMDs

$$f_{1\mathrm{NP}}^{a}(x, \boldsymbol{k}_{\perp}^{2}) = \frac{1}{\pi} \frac{(1+\lambda \boldsymbol{k}_{\perp}^{2})}{g_{1a}+\lambda\, g_{1a}^{2}}\, e^{-\frac{\boldsymbol{k}_{\perp}^{2}}{g_{1a}}},$$

a: parton flavor

FF

$$D_{1\mathrm{NP}}^{a\to h}(z, \boldsymbol{P}_{\perp}^{2}) = \frac{1}{\pi} \frac{1}{g_{3a\to h}+(\lambda_F/z^2)g_{4a\to h}^{2}} \left( e^{-\frac{\boldsymbol{P}_{\perp}^{2}}{g_{3a\to h}}} + \lambda_F \frac{\boldsymbol{P}_{\perp}^{2}}{z^2}\, e^{-\frac{\boldsymbol{P}_{\perp}^{2}}{g_{4a\to h}}} \right).$$

$$g_1(x) = N_1 \frac{(1-x)^{\alpha}\ x^{\sigma}}{(1-\hat{x})^{\alpha}\ \hat{x}^{\sigma}}$$

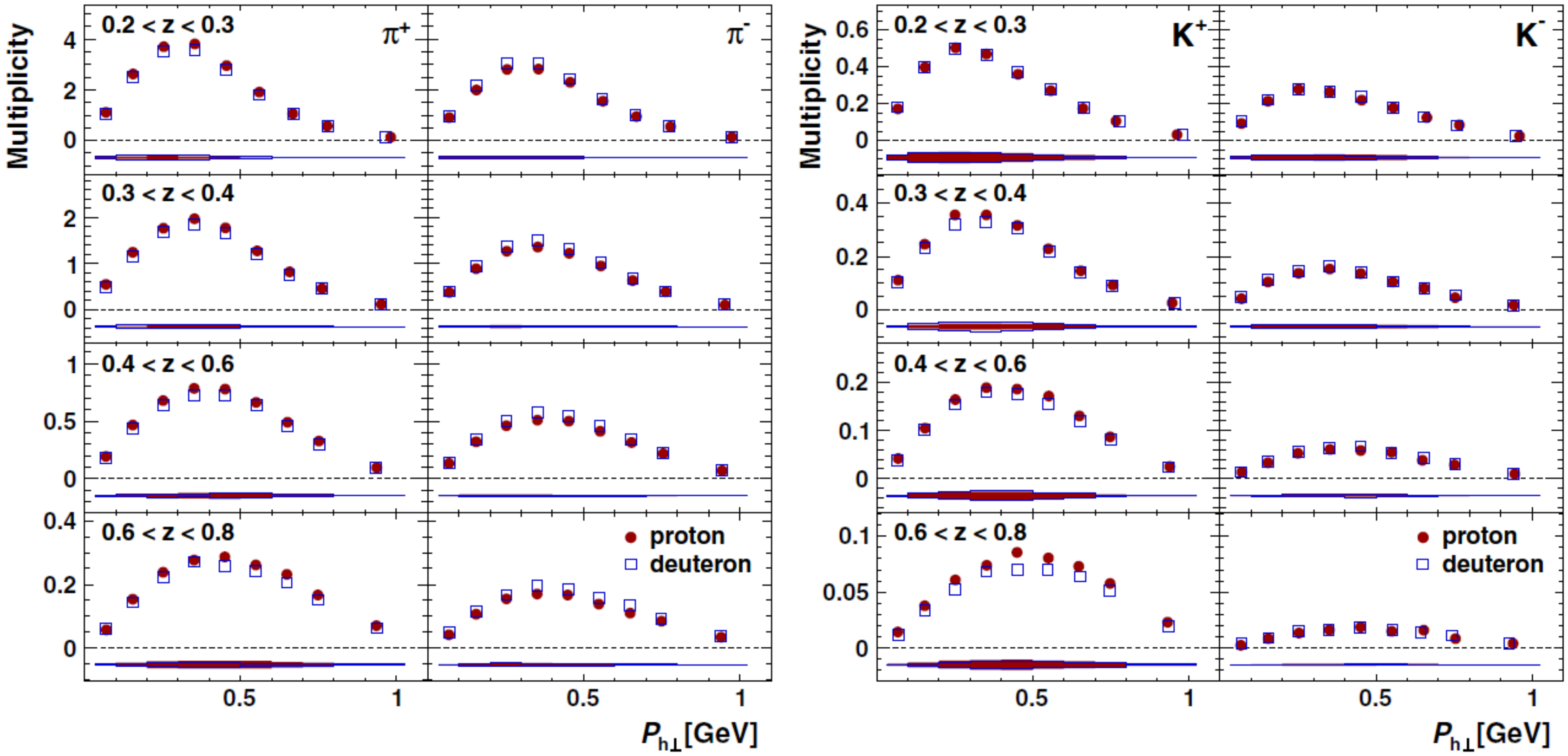
$$g_{3,4}(z) = N_{3,4} \frac{(z^{\beta}+\delta)\ (1-z)^{\gamma}}{(\hat{z}^{\beta}+\delta)\ (1-\hat{z})^{\gamma}}$$

$$\langle \boldsymbol{k}_{\perp}^{2} \rangle(x) = \frac{g_1(x)+2\lambda g_1^2(x)}{1+\lambda g_1(x)}$$

$$\langle \boldsymbol{P}_{\perp}^{2} \rangle(z) = \frac{g_3^2(z)+2\lambda_F g_4^3(z)}{g_3(z)+\lambda_F g_4^2(z)}$$

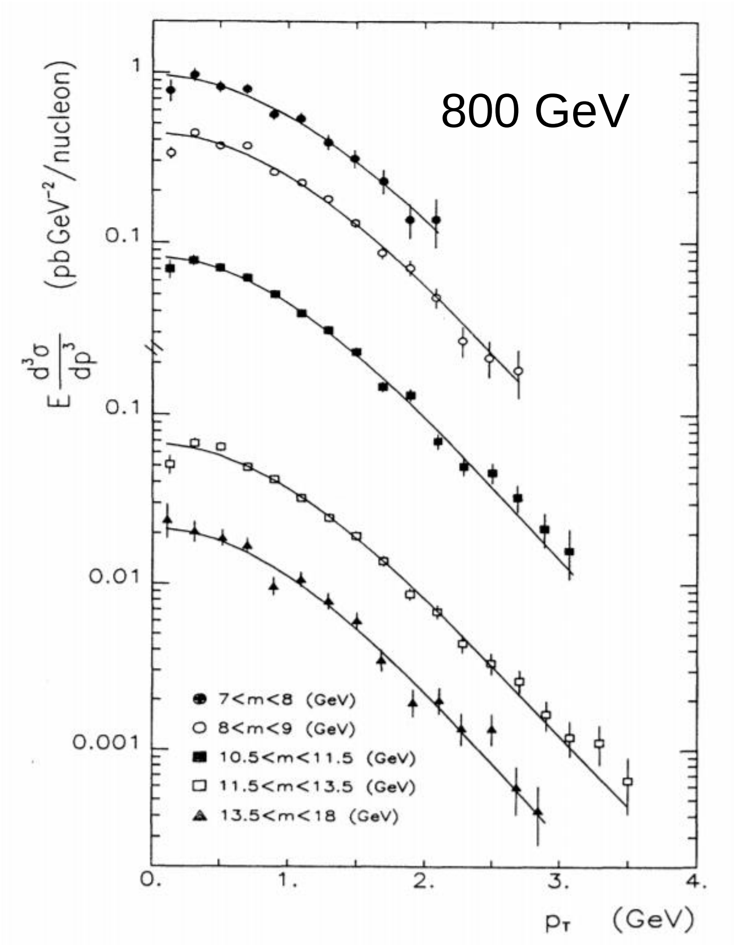
Bacchetta et al., https://arxiv.org/abs/1703.10157

# SIDIS

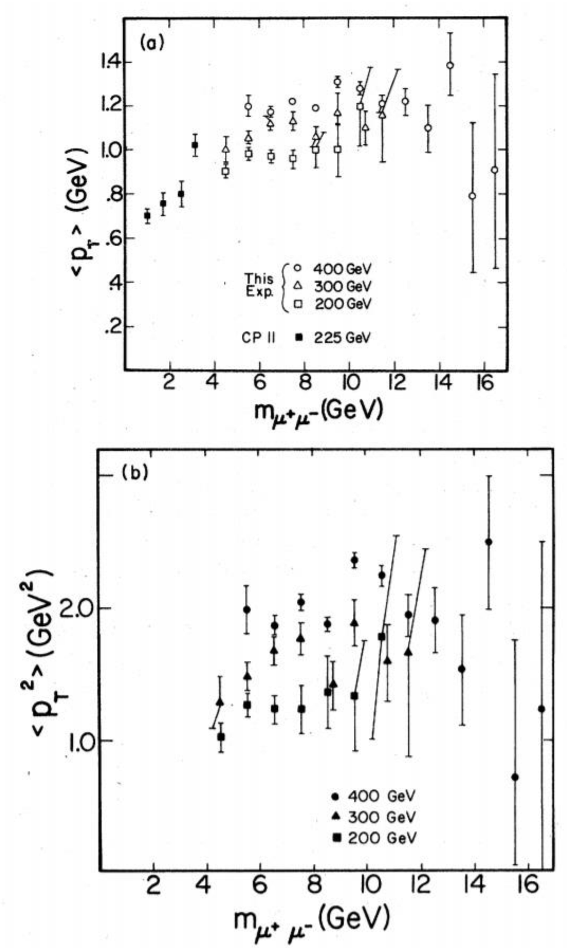



HERMES: PRD 87, 074029 (2013) [arXiv:1212.5407]

# Fixed-Target Drell-Yan

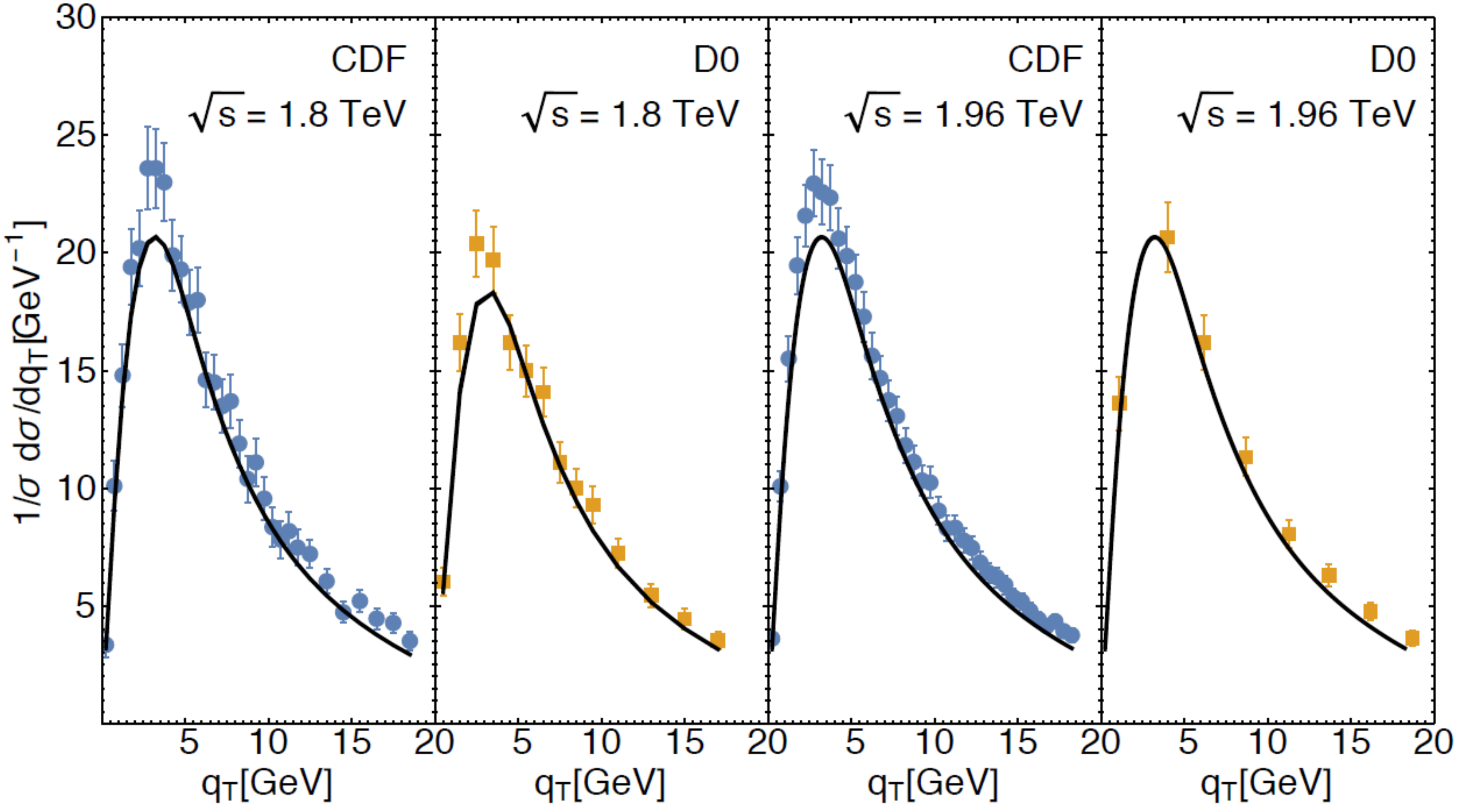



E615, Phys. Rev. D43, 2815 (1991)




E288, Phys. Rev. D23, 604 (1981)

# Collider Z Production

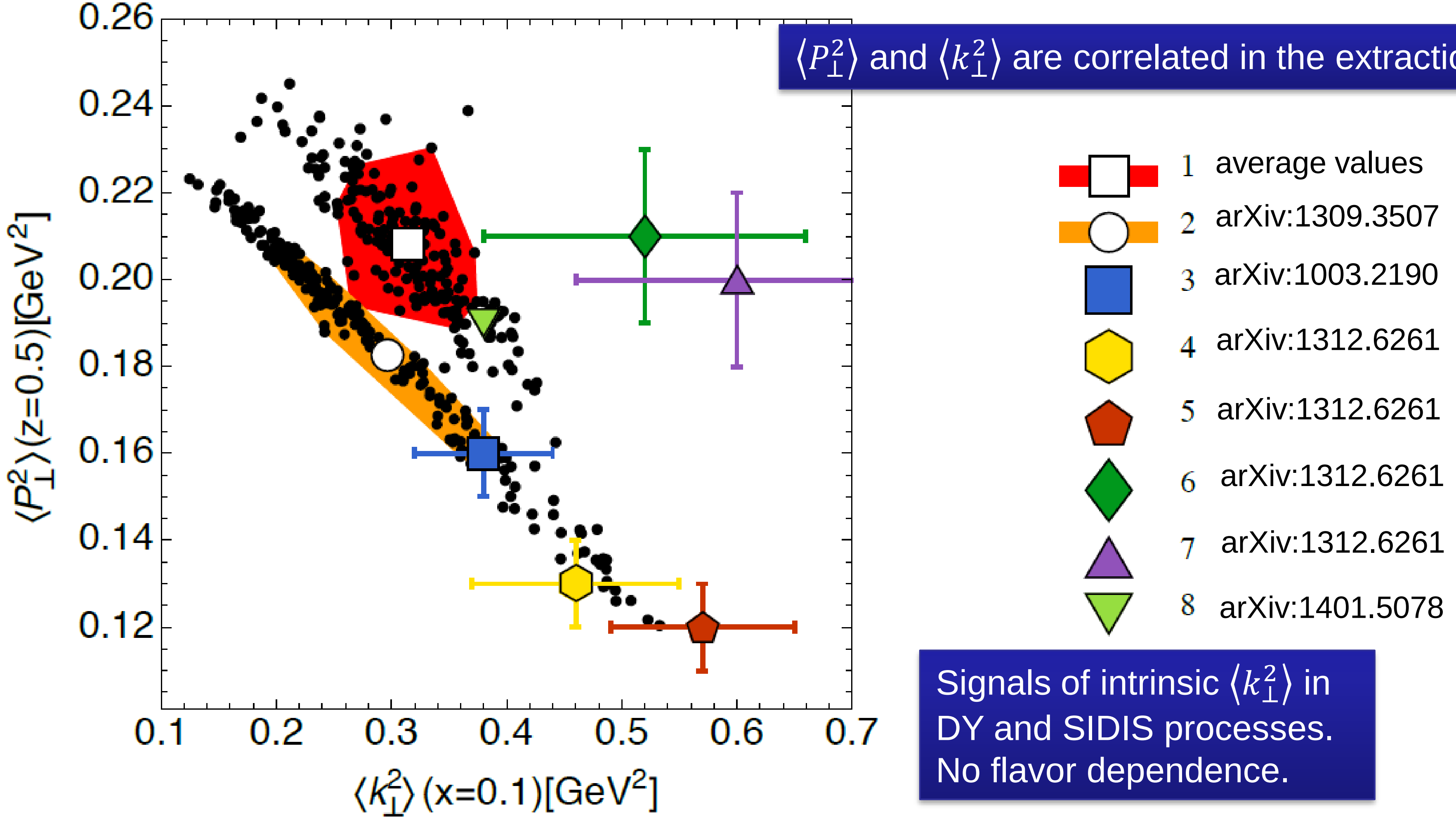



Bacchetta et al., https://arxiv.org/abs/1703.10157

# Global Analysis of $f_1^q(x, k_T^2)$

FFs for SIDIS: NLO DSEHS for $\pi$; LO DSS for K.

$\langle P_\perp^2 \rangle$ and $\langle k_\perp^2 \rangle$ are correlated in the extraction.

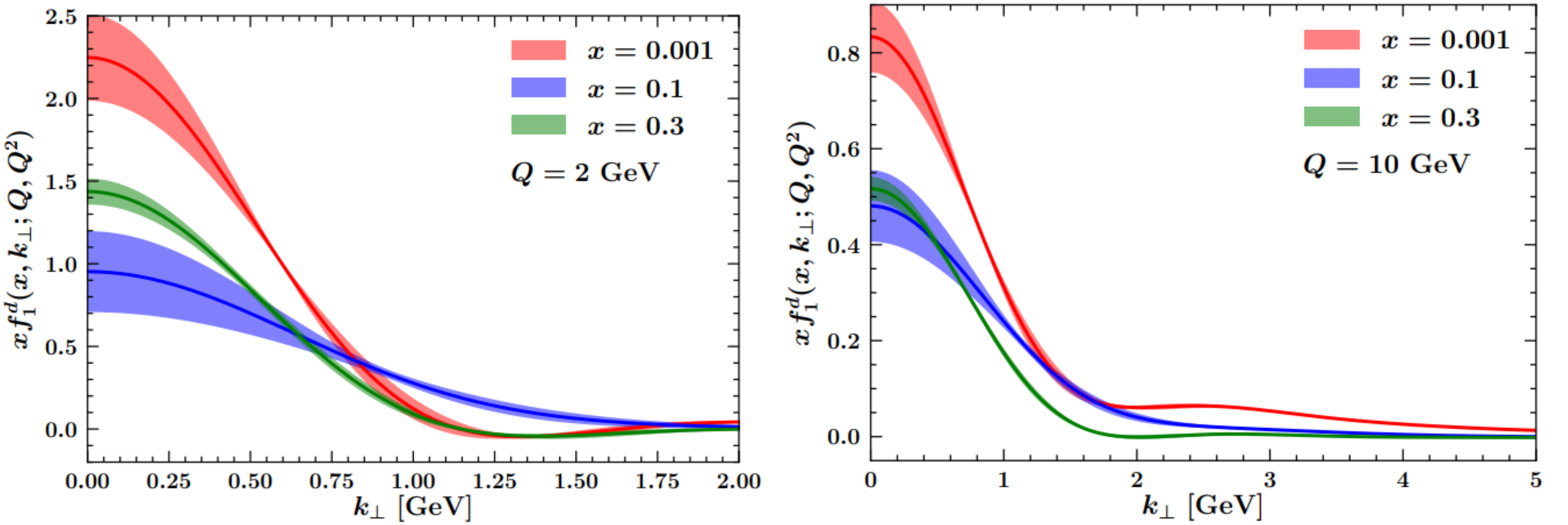



Signals of intrinsic $\langle k_\perp^2 \rangle$ in DY and SIDIS processes. No flavor dependence.

Bacchetta et al., https://arxiv.org/abs/1703.10157

# Global Analysis of $f_1^q(x, k_T^2)$

Drell-Yan ONLY




https://arxiv.org/abs/1912.07550

# Leading-Twist Transverse-momentum Dependent **Parton Density Function** (TMDs)

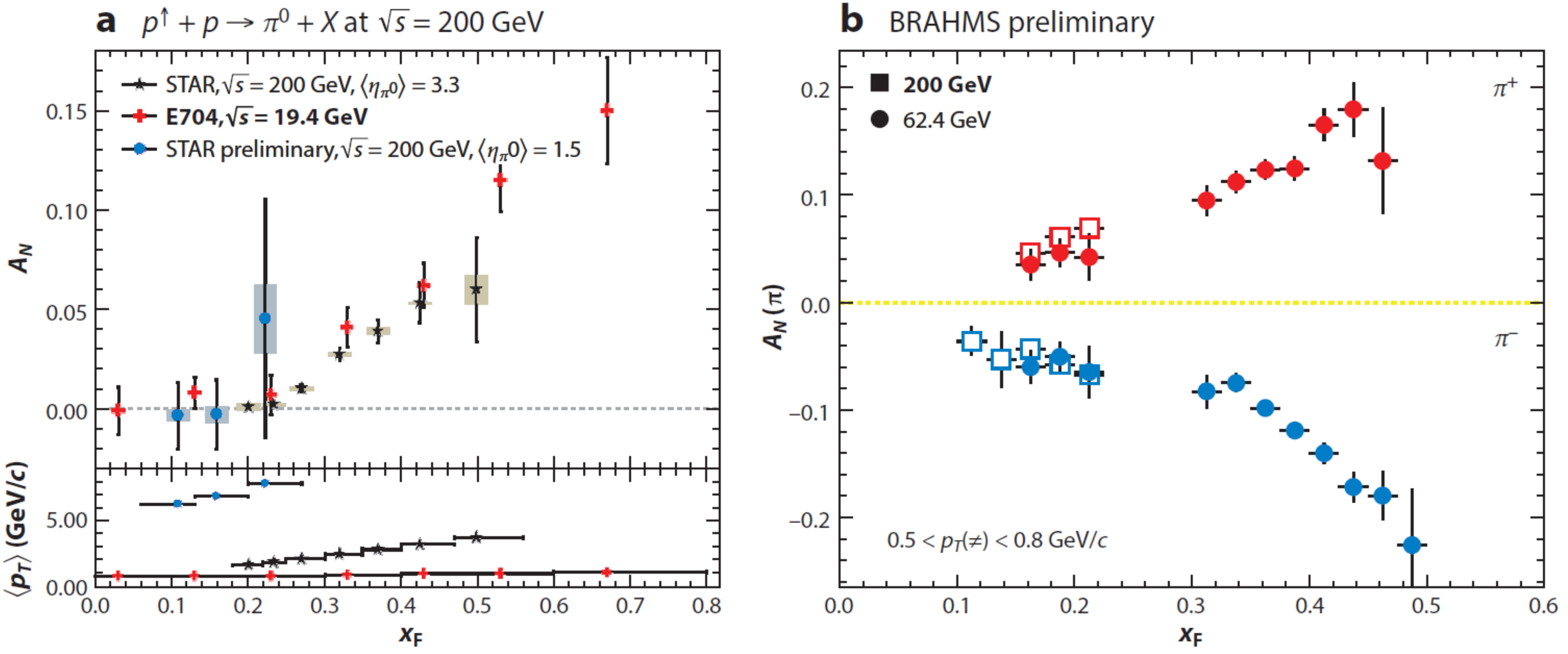
- spin of the nucleon
- spin of the parton
- $k_T$ of the parton

| Nucleon \ Quark, Gluon | U | L | T |
|---|---|---|---|
| **U** | number density $f_1^{q,g}(x, k_T^2)$ | | Boer-Mulders $h_1^{\perp q,g}(x, k_T^2)$ |
| **L** | | Helicity $g_{1L}^{q,g}(x, k_T^2)$ | worm-gear L $h_{1L}^{\perp q,g}(x, k_T^2)$ |
| **T** | Sivers $f_{1T}^{\perp q,g}(x, k_T^2)$ | Kotzinian-Mulders worm-gear T $g_{1T}^{\perp q,g}(x, k_T^2)$ | Transversity $h_1^{q,g}(x, k_T^2)$<br>Pretzelosity $h_{1T}^{\perp q,g}(x, k_T^2)$ |

# Transverse Single Spin Asymmetry

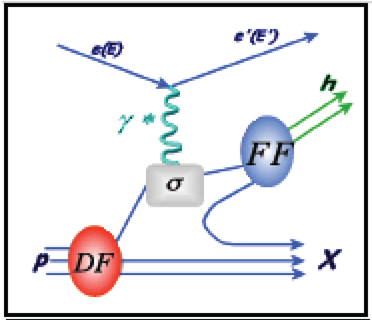
Left/Right Asymmetry

$$A_N = \frac{d\sigma(S_\perp) - d\sigma(-S_\perp)}{d\sigma(S_\perp) + d\sigma(-S_\perp)}$$



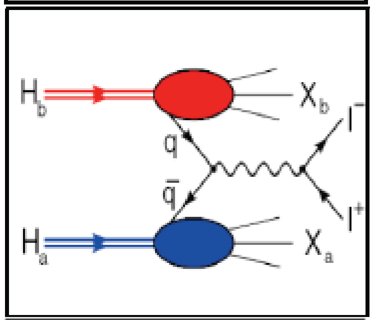

https://arxiv.org/abs/1510.06783

# Accessing TMDs



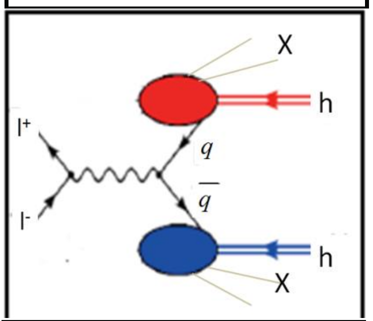

**SIDIS: $ep \rightarrow ehX$**

$$\sigma^{ep\rightarrow ehX} = \sum_q DF \otimes \sigma^{eq\rightarrow eq} \otimes FF$$



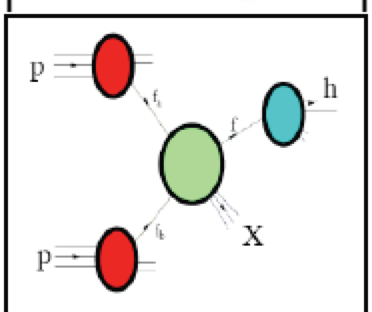

**Drell-Yan: $pp \rightarrow e^+e^-X$**

$$\sigma^{pp\rightarrow eeX} = \sum_q DF \otimes DF \otimes \sigma^{qq\rightarrow ee}$$




**Dihadron in e+e-: $e^+e^- \rightarrow h_1\, h_2\, X$**

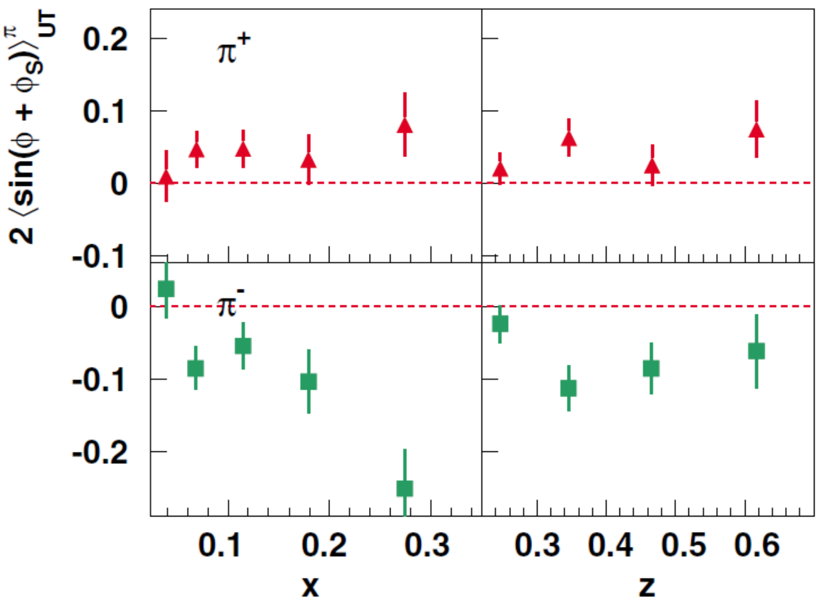
$$\sigma^{ee\rightarrow hhX} = \sum_q \sigma^{qq\rightarrow ee} \otimes FF \otimes FF$$

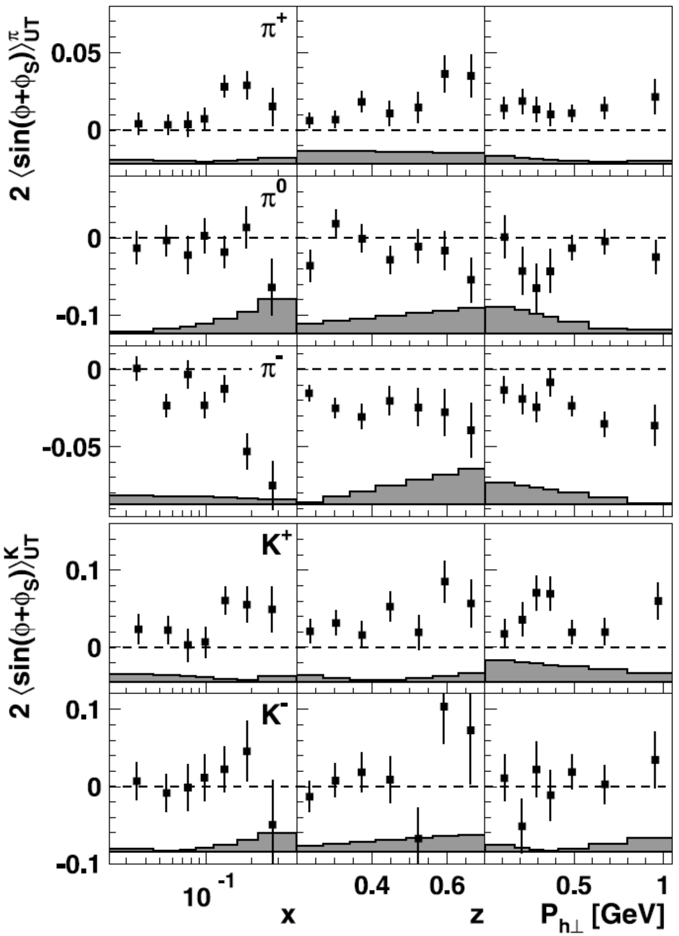



**Hadron production in pp: $pp \rightarrow hX$**

$$\sigma^{pp\rightarrow hX} = \sum_q DF \otimes DF \otimes \sigma^{qq\rightarrow qq} \otimes FF$$

# Collins Azimuthal Asymmetry off Polarized Protons



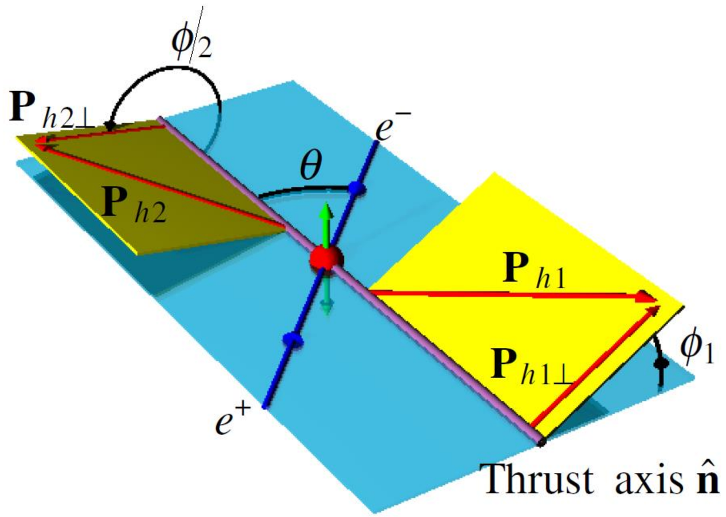



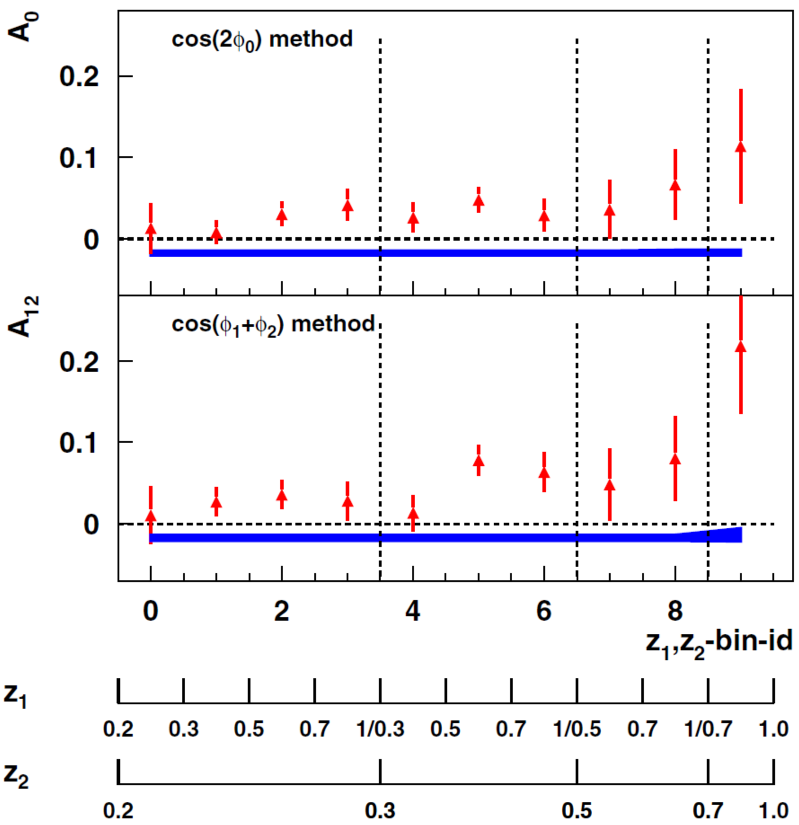

PRL 94, 012002 (2005) [hep-ex/0408013]

PLB 693, 11 (2010) [arXiv:1006.4221]

# Belle: Two-pion Azimuthal Correlation

$H_{1q}^{\perp h}$:Collins FFs

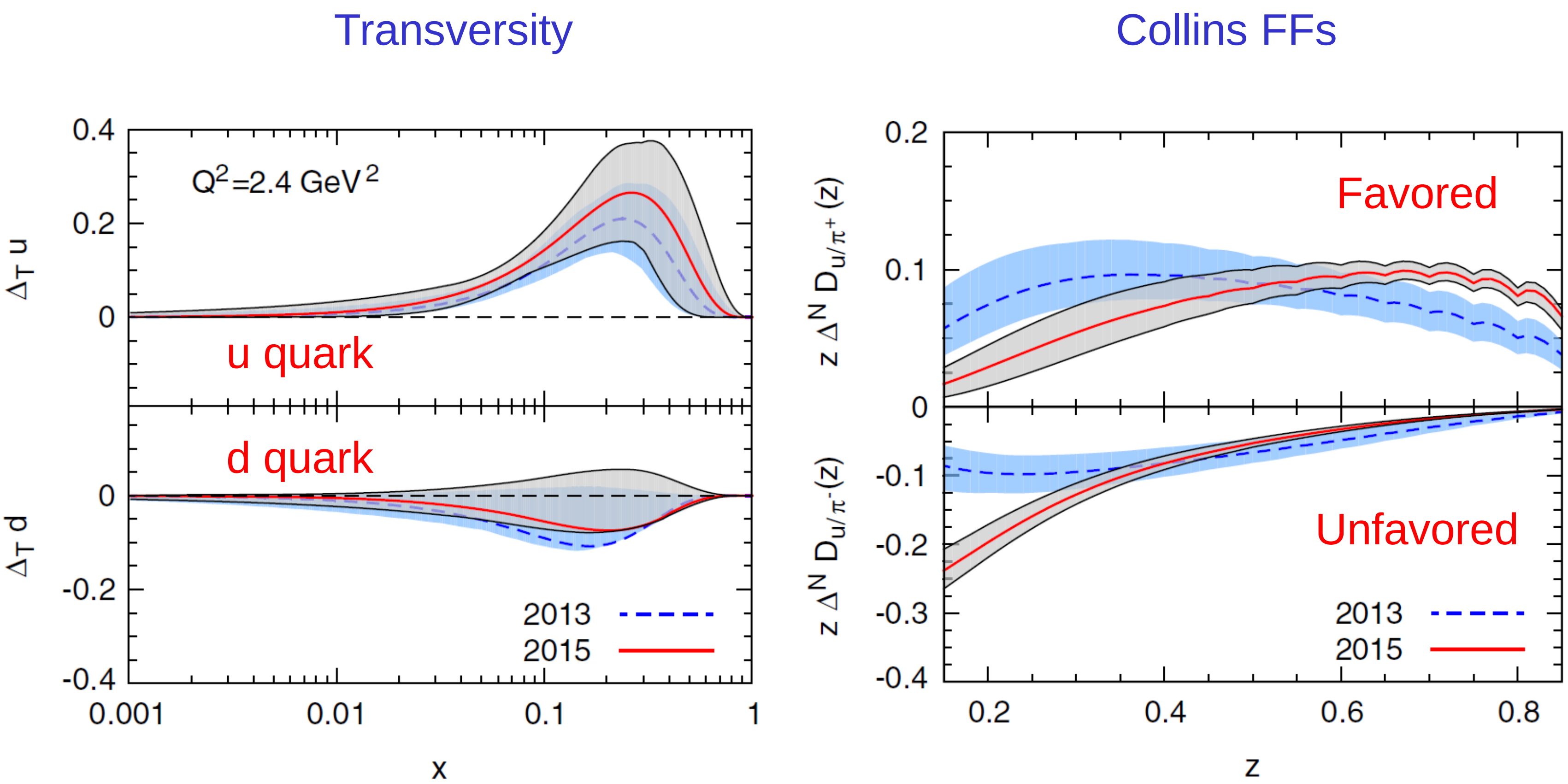



$$\frac{R^{unlike-sign}}{R^{like-sign}} = 1 + A\cos(2\phi)\frac{\sin^2\theta}{1+\cos^2\theta}$$

$$A_0, A_{12} \propto \left\{ \frac{f(H_1^{\perp,\mathrm{fav}}\bar{H}_1^{\perp,\mathrm{fav}} + H_1^{\perp,\mathrm{dis}}\bar{H}_1^{\perp,\mathrm{dis}})}{(D_1^{\mathrm{fav}}\bar{D}_1^{\mathrm{fav}} + D_1^{\mathrm{dis}}\bar{D}_1^{\mathrm{dis}})} - \frac{f(H_1^{\perp,\mathrm{fav}}\bar{H}_1^{\perp,\mathrm{dis}})}{(D_1^{\mathrm{fav}}\bar{D}_1^{\mathrm{dis}})} \right\};$$

# Extraction of Transversity and Collins FFs from SIDIS, Belle and Barbar data

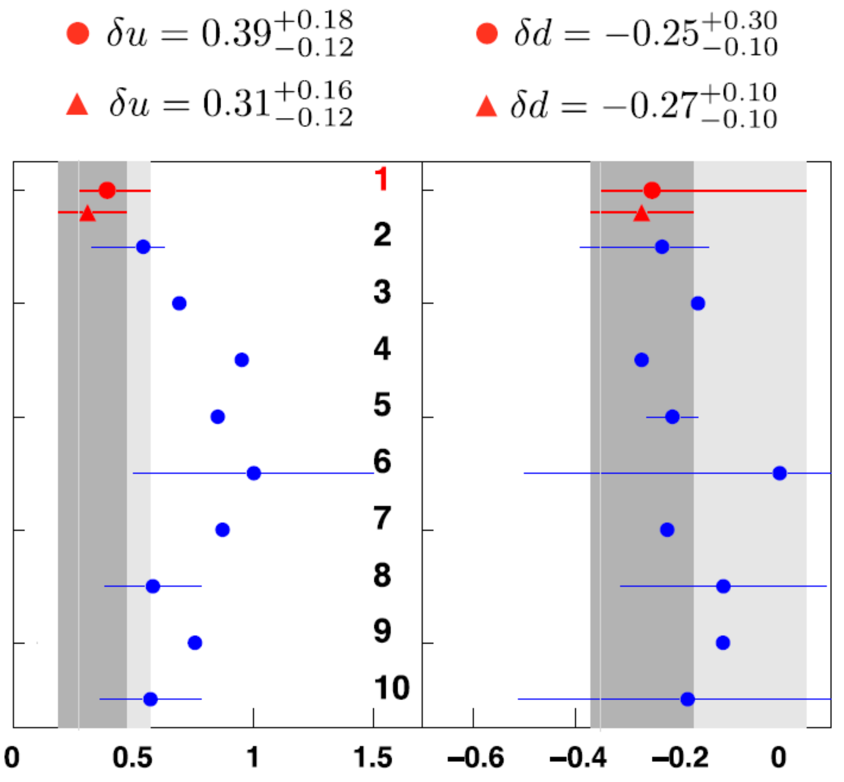



Anselmino et al., PRD 92, 114023 (2015) [arXiv:1510.05389]

Signals of transversity and Collins FFs s in SIDIS and ee processes.
Flavor dependence.

# Nucleon Tensor Charge from Extracted Transversity

Tensor Charge $\delta q = \int_0^1 [\Delta_T q(x) - \Delta_T \bar{q}(x)]\, dx$




$\Delta u = 0.787$ $\Delta d = -0.319$

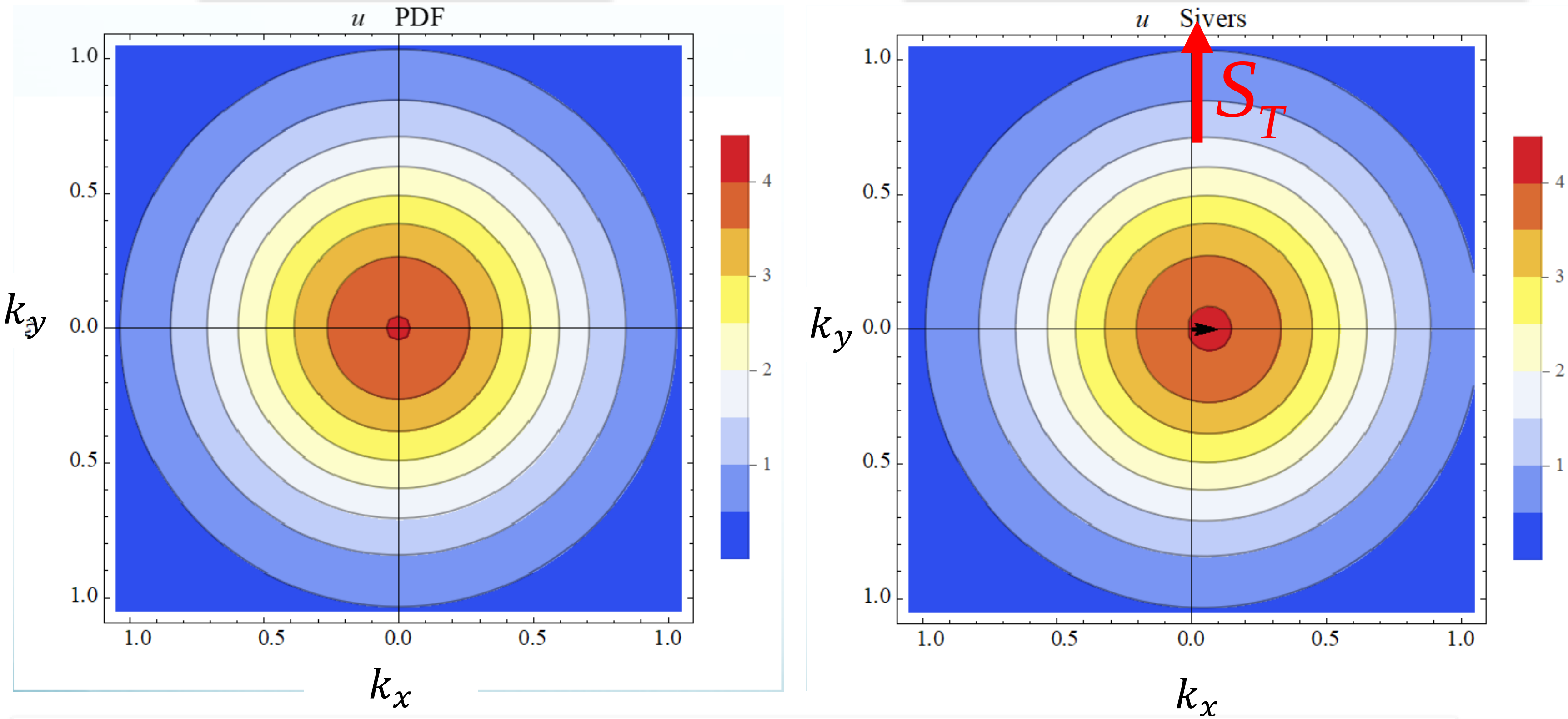
- Tensor charges:
  - **1** : Extractions from global fits (using two different Collins FF parameterizations)
  - **2-10**: Predictions from various models (including LQCD)
  - Discrepancy could be caused by neglecting sea quark transversity in the fit
- Tensor charges are smaller than axial charge.

# TMD Sivers Function

$$f_{q/p\uparrow}(x,k_T,\vec{S_T}) = f_{q/p}(x,k_T) - \frac{1}{M} f_{1T}^{\perp q}(x,k_T)\vec{S_T}\cdot(\hat{p}_N \times k_T)$$

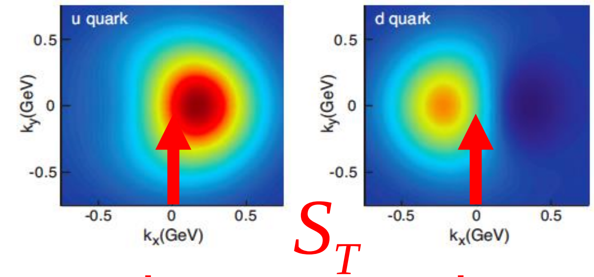
Unpolarized proton

Transversely-polarized proton



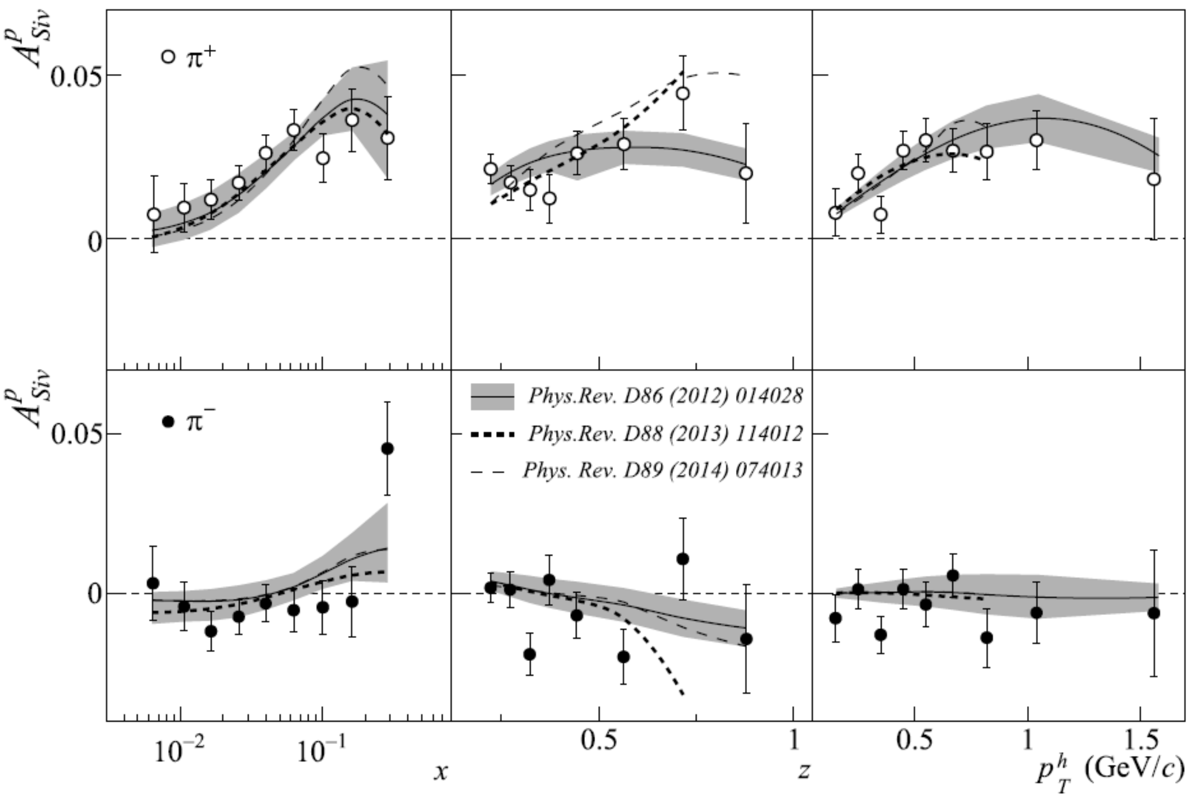

- **A nonzero Sivers function is considered to be strong evidence for the presence of quark orbital angular momentum.**

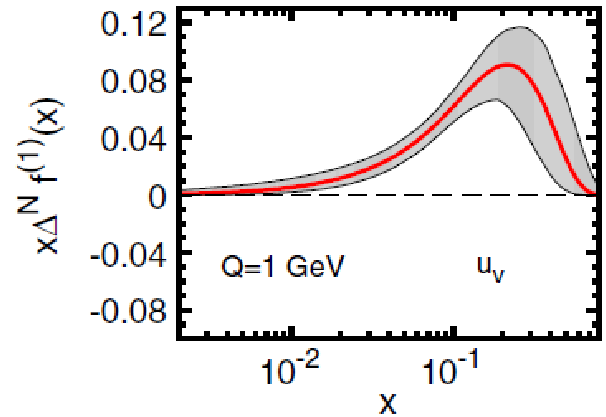
# Nonzero Sivers Asymmetries from SIDIS

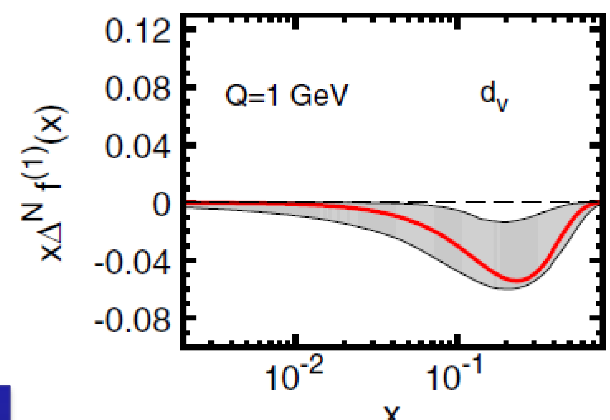



Sivers Functions

COMPASS, PLB 744 (2015) 250



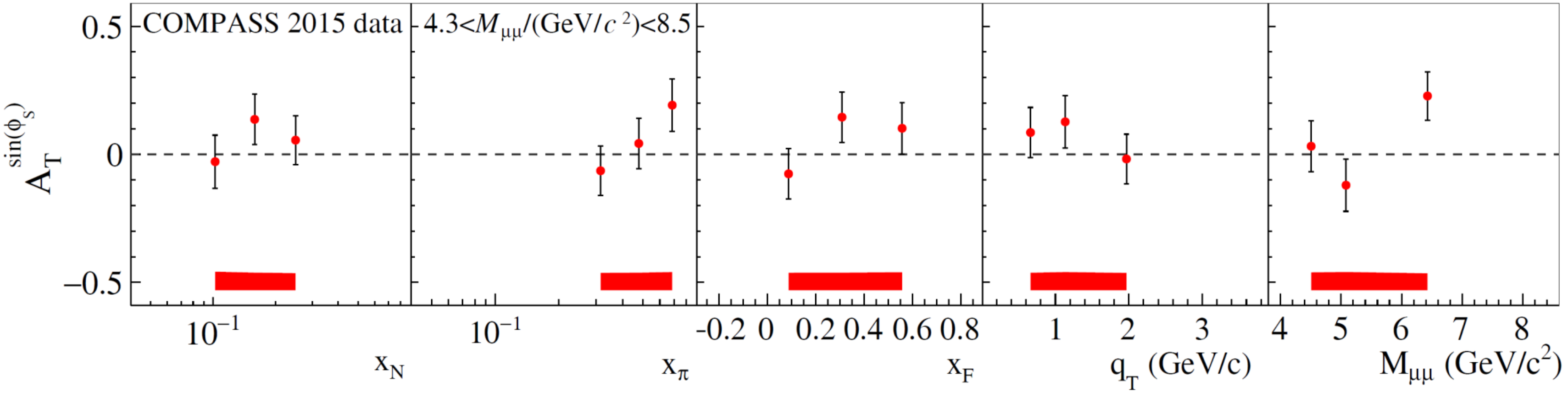

Signals of Sivers functions in SIDIS.
Flavor dependence.

PRD 86, 014028 (2012)
[arXiv:1204.1239]

# Sivers Asymmetry in Drell-Yan:

$$A_T^{\sin\varphi_s} \propto \text{Density}(f_1)\big|_{h_A} \otimes \text{Sivers}(f_{1T}^{\perp})\big|_{h_B}$$

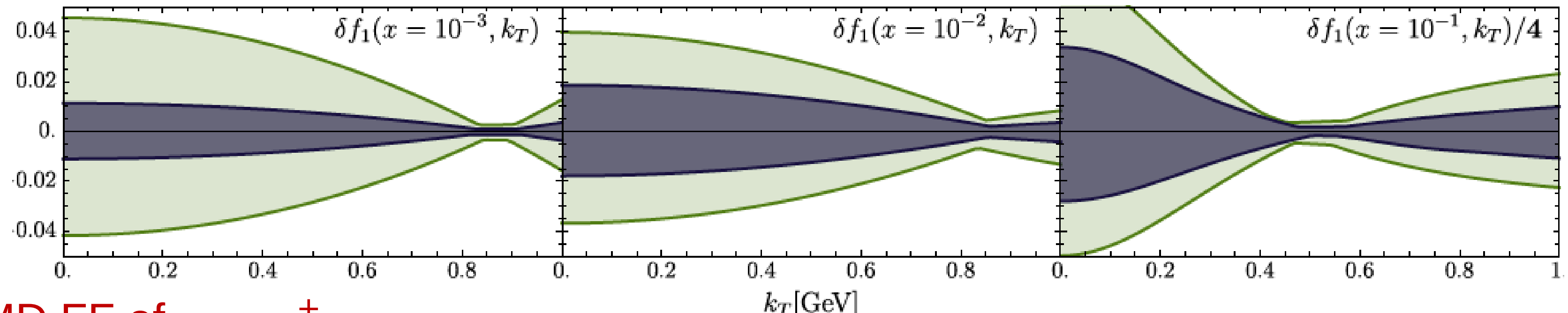
$$\frac{d\sigma^{LO}}{d^4q\,d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U^{LO}\left\{\left(1 + D_{[\sin^2\theta]}^{LO} A_U^{\cos 2\varphi}\cos 2\phi\right) + \left|\vec{S}_T\right|\left[A_T^{\sin\phi_s}\sin\phi_s + D_{[\sin^2\theta]}^{LO}\left(A_T^{\sin(2\phi+\phi_s)}\sin(2\phi+\phi_s) + A_T^{\sin(2\phi-\phi_s)}\sin(2\phi-\phi_s)\right)\right]\right\}$$



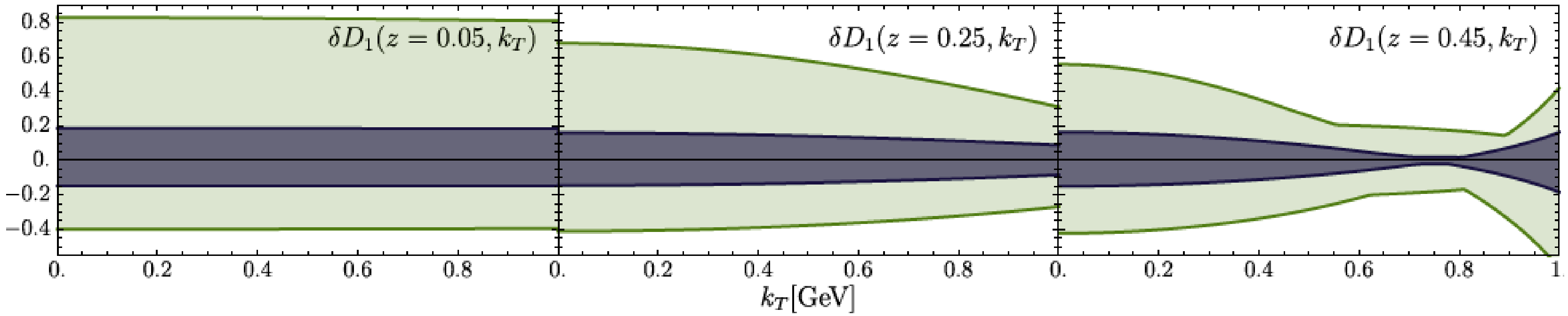

COMPASS, PRL 119 (2017) 112002

# Unpolarized TMDs at EIC (SIDIS)

Unpolarized TMD of $u$




TMD FF of $u \to \pi^+$



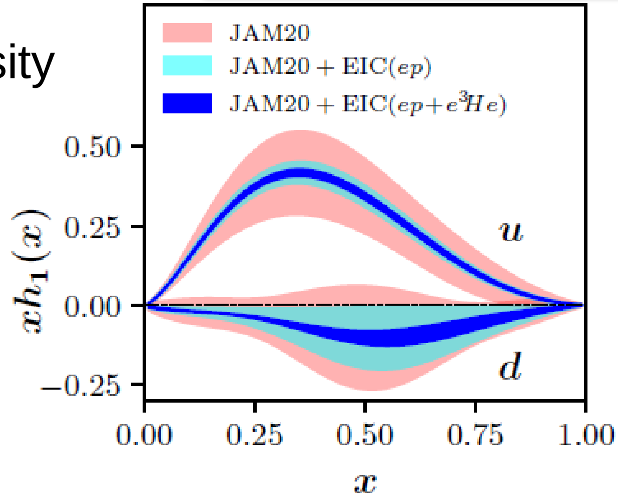

Significantly Improved uncertainties of unpolarized TMDs at small x

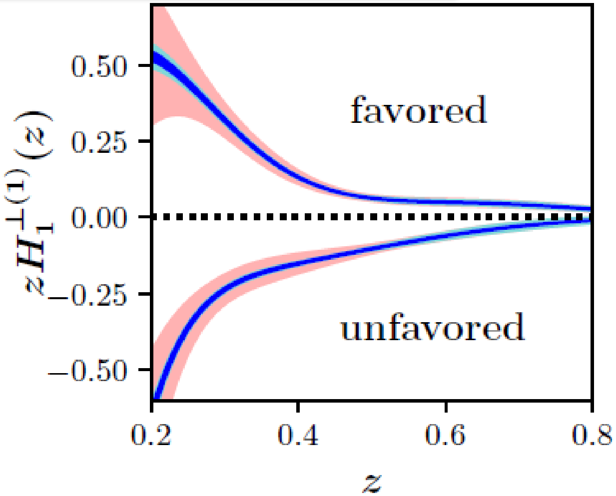
EIC Yellow report: https://arxiv.org/abs/2103.05419

# Polarized TMDs at EIC (SIDIS)

Significantly Improved uncertainties of transversity

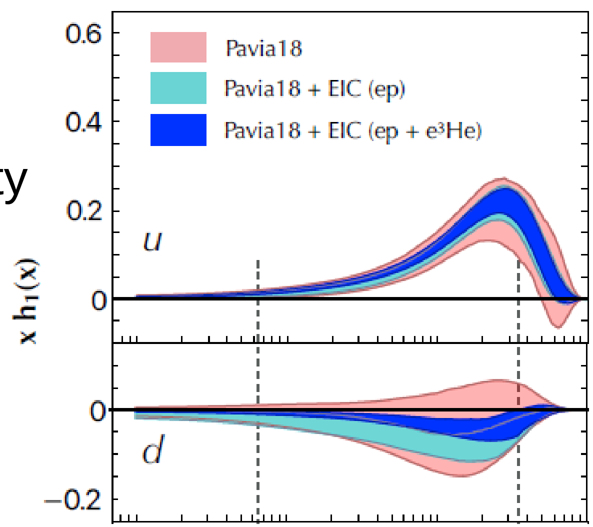
Transversity

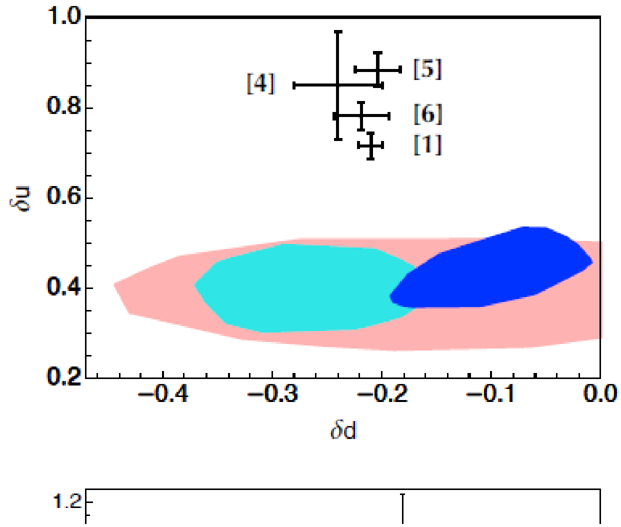



Collins FF

Transversity



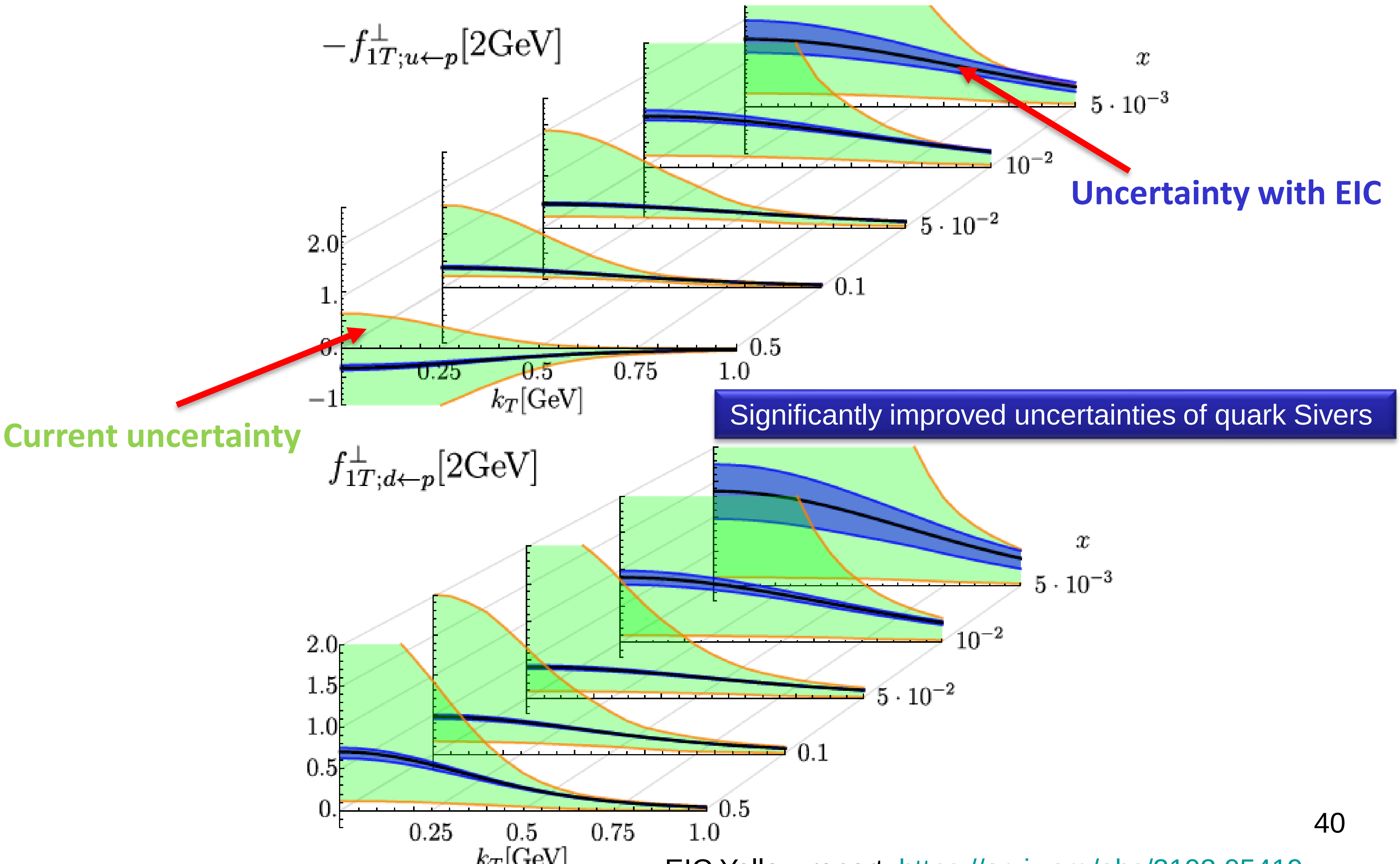




Tensor charge



EIC Yellow report: https://arxiv.org/abs/2103.05419

# Quark Sivers at EIC (SIDIS)




EIC Yellow report: https://arxiv.org/abs/2103.05419

# What EIC could help PDFs & TMDs MOST?

- Unpolarized Nuclear PDFs (DIS)
  - Sea quark and gluon at small x
- Polarized Nucleon PDFs (SIDIS)
  - Quark, sea quark and gluon at small x
- TMDs (SIDIS)
  - Transversity and Sivers
- Pion and Kaon PDFs (tagged-DIS)
- Trace anomaly (threshold Jpsi and Upsilon photoproduction)

# Review Articles

- Unpolarized PDFs:
  - https://arxiv.org/abs/1709.04922
  - https://arxiv.org/abs/1905.06957
  - https://arxiv.org/abs/2001.07722
- Polarized PDFs:
  - https://arxiv.org/abs/1209.2803
  - https://arxiv.org/abs/1807.05250
- TMDs:
  - https://arxiv.org/abs/1507.05267
  - https://arxiv.org/abs/1510.06783
  - https://arxiv.org/abs/1607.02521
  - https://arxiv.org/abs/2001.05415
- GPDs:
  - https://arxiv.org/abs/hep-ph/0106012
  - https://arxiv.org/abs/hep-ph/0307382
  - https://arxiv.org/abs/1303.6600
  - https://arxiv.org/abs/1602.02763