Models for TMDs and transversity

Alessandro Bacchetta
Pavia University and INFN Pavia

Coming up during the week

MON: Mert Aybat, “*Universality and evolution of TMDs and FFs*”

MON: Marc Schlegel, “*FSI and T-odd TMD PDFs* ”

TUE: Petr Zavada, “*Relation between TMDs and PDFs in the covariant parton model approach*”

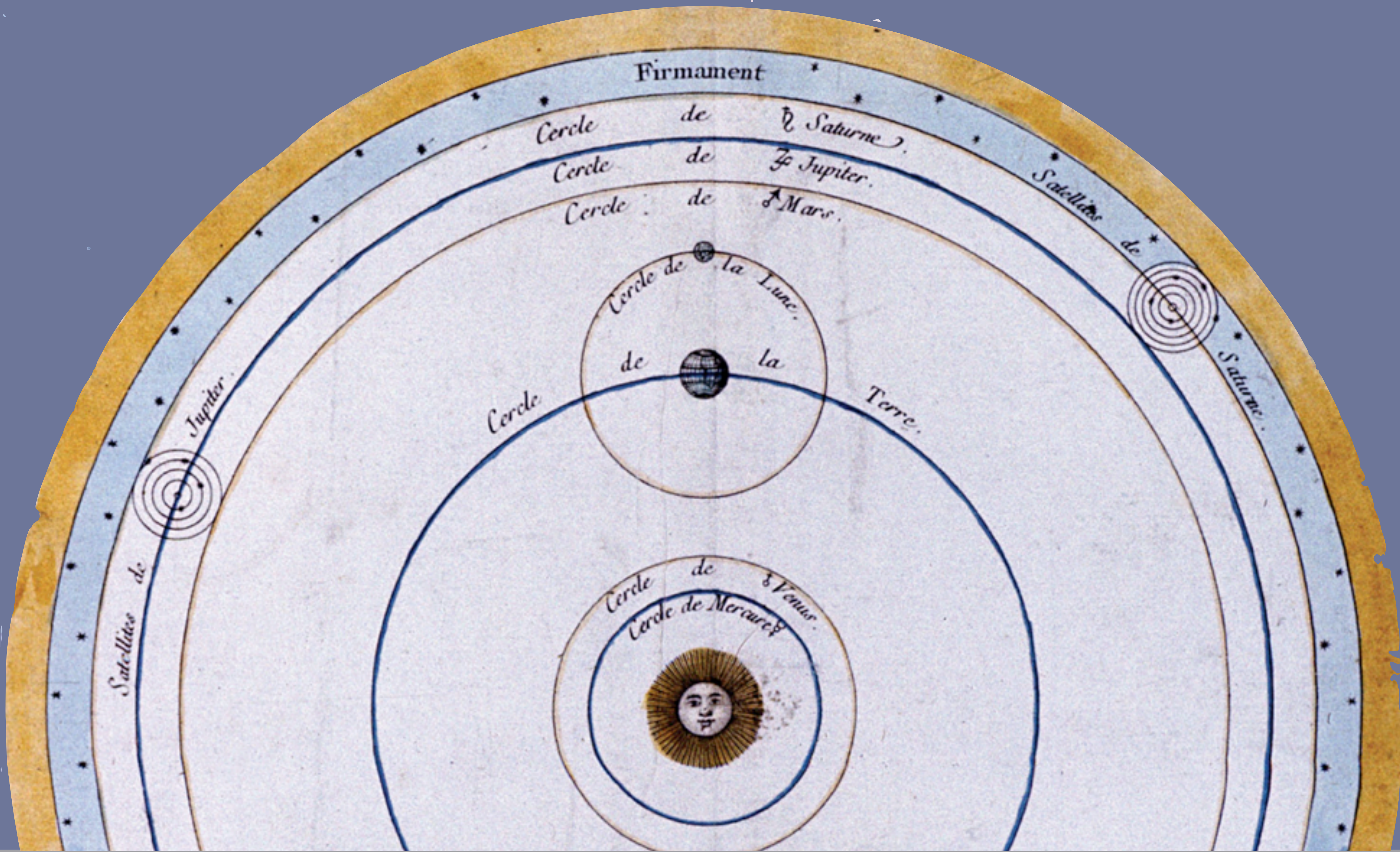
THU: Masashi Wakamatsu, “*Recent work on orbital angular momentum*”

THU: Matthias Burkardt, “*Accessing orbital angular momentum from TMDs and GPDs*”

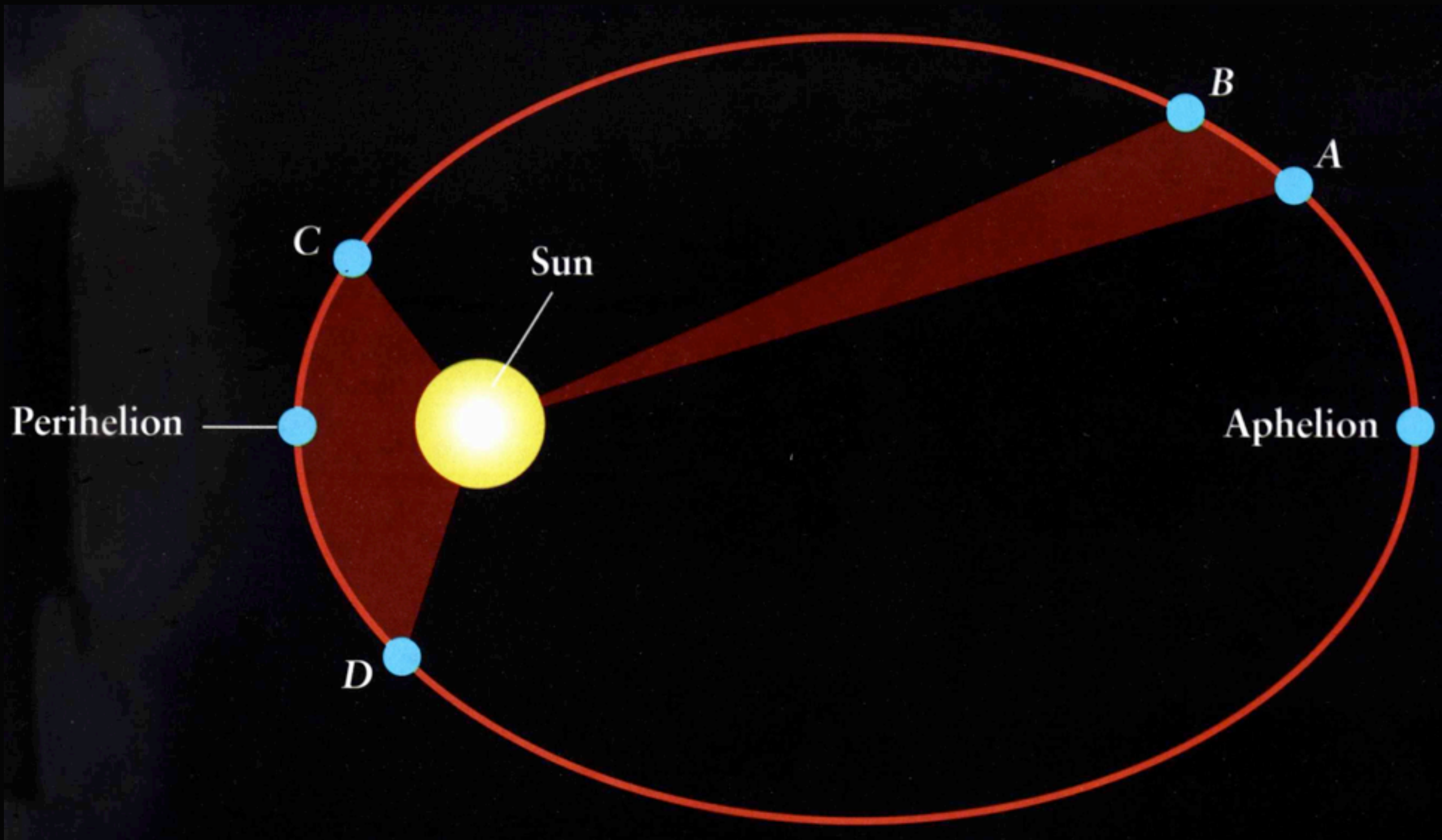
FRI: Cédric Lorcé, “*Hadron tomography through Wigner distributions*”

Why models?

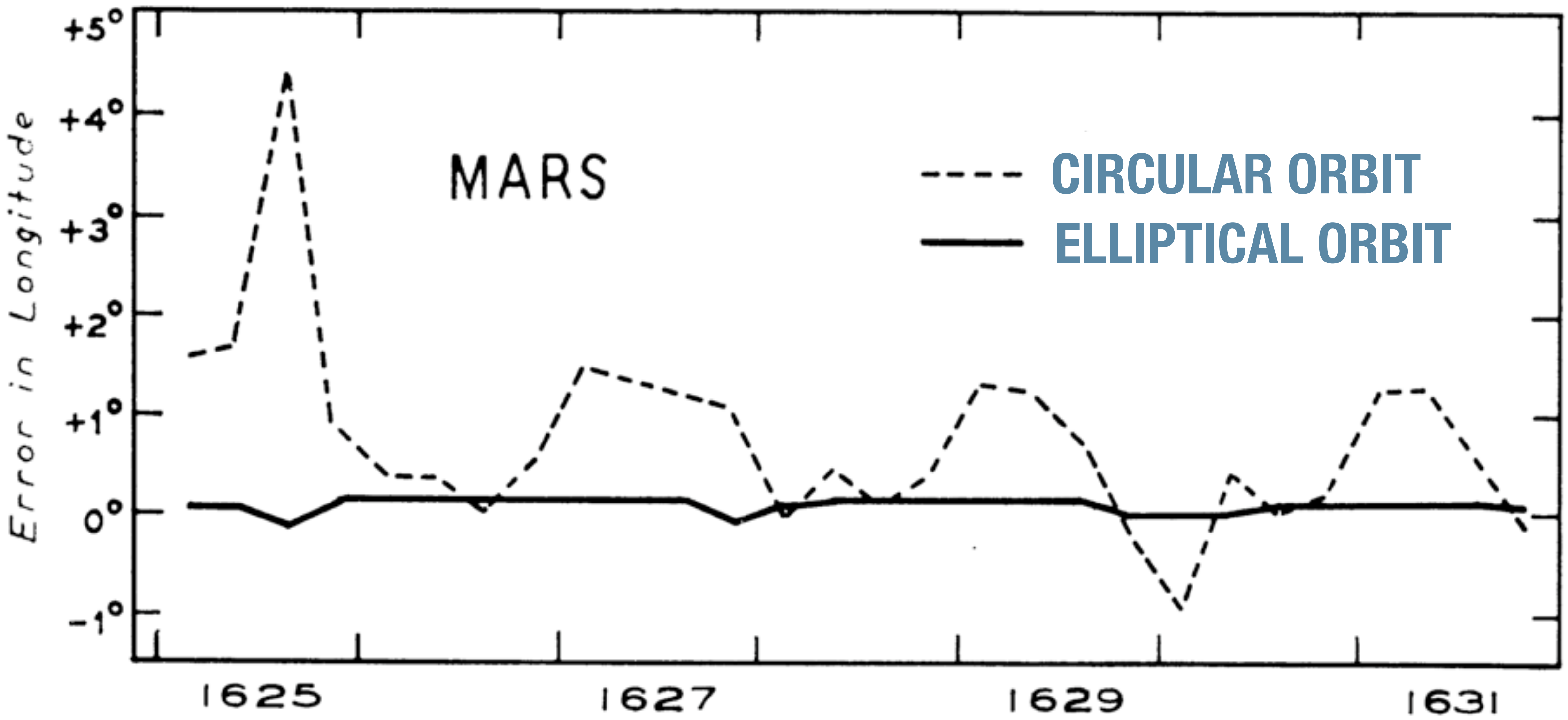
Copernican "model"



Kepler's "model"



Comparison between them



Models are predictive (and can be falsified)

Models open the way to full theories

- We have more and more data

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- We can't use first principles calculations yet (lattice?)

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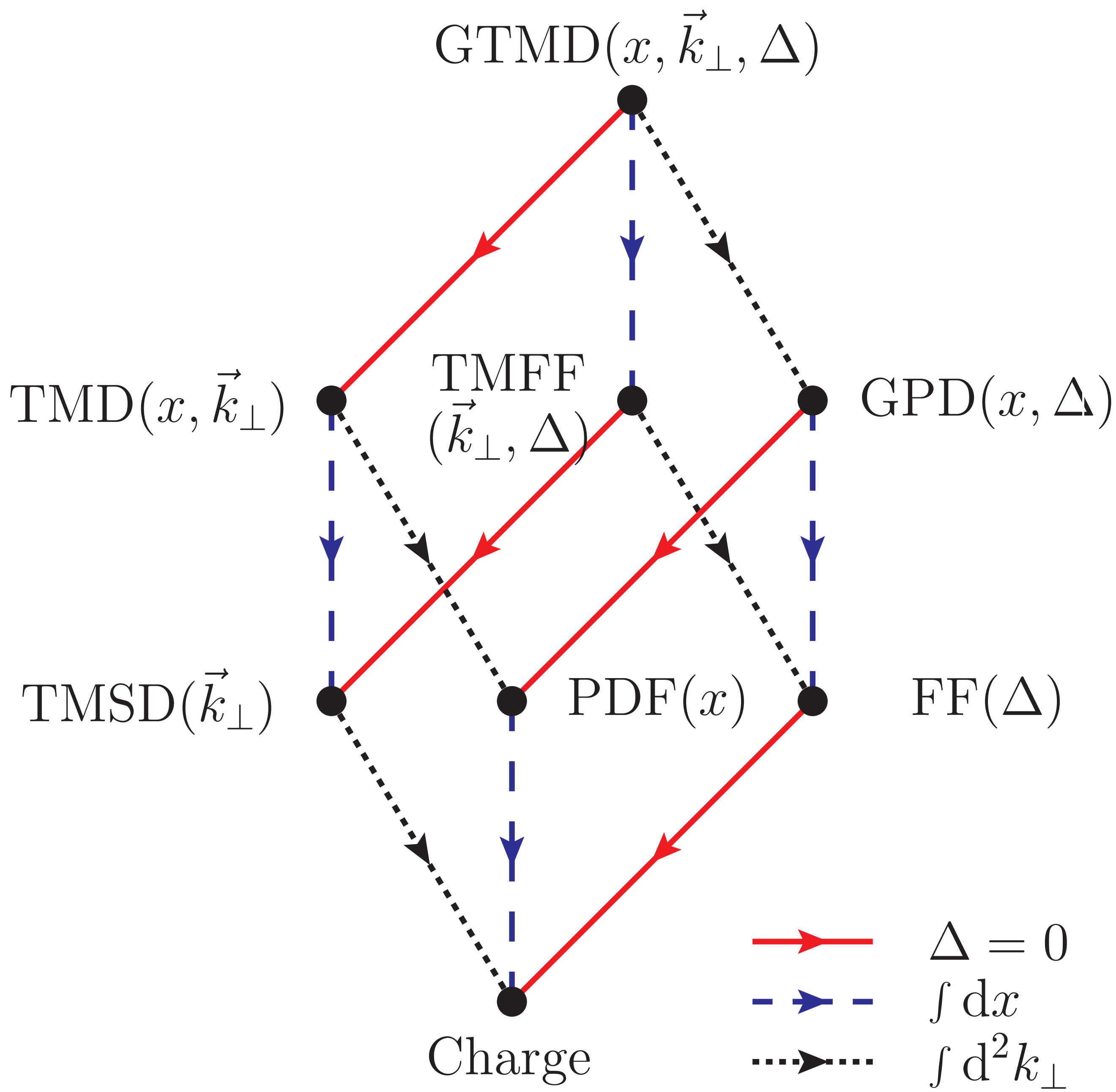
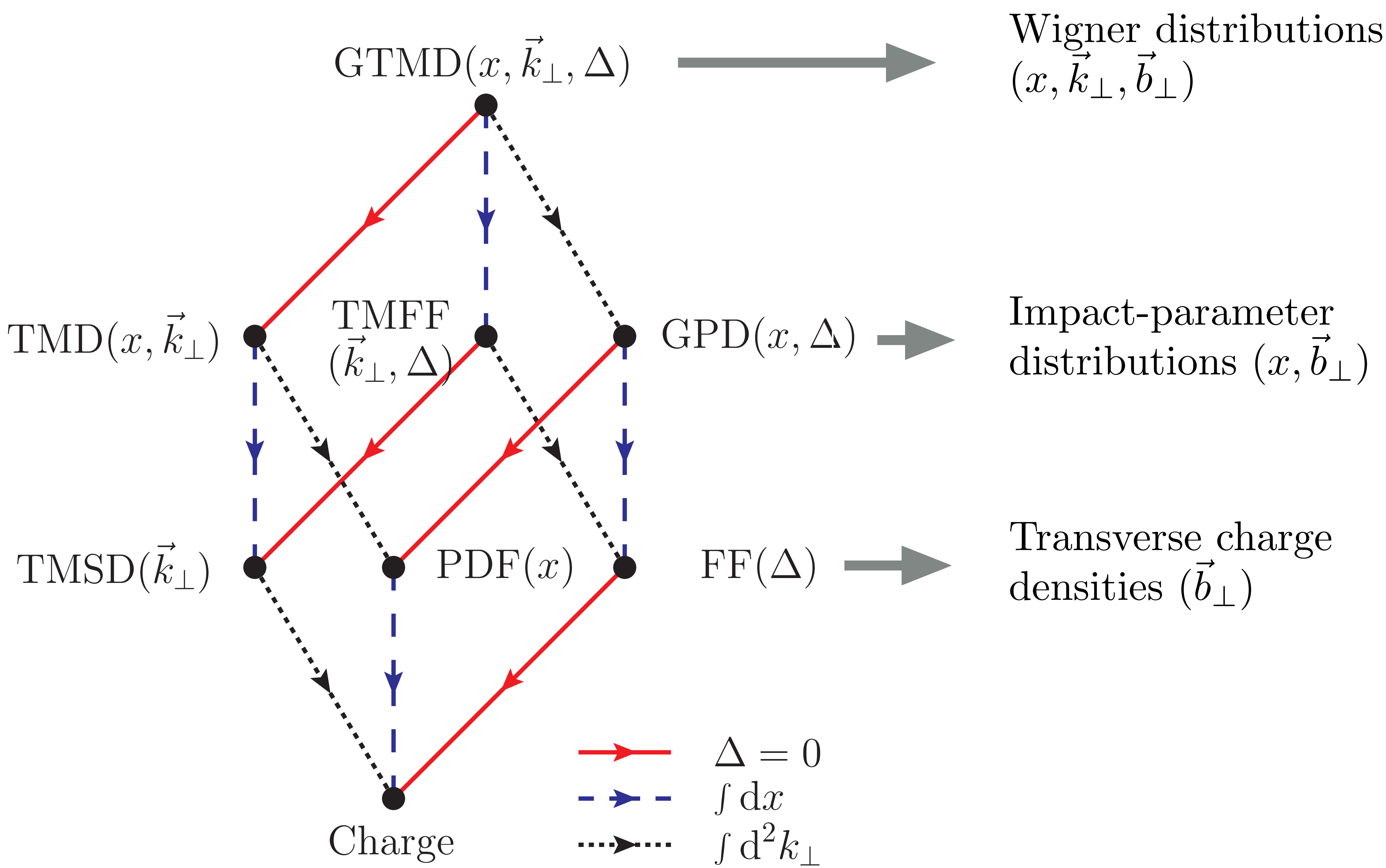
- We can't use first principles calculations yet (lattice?)
- We need models



- *C. Lorcé, B. Pasquini, M. Vanderhaeghen, JHEP 1105 (11)*
- *See talk by C. Lorcé*



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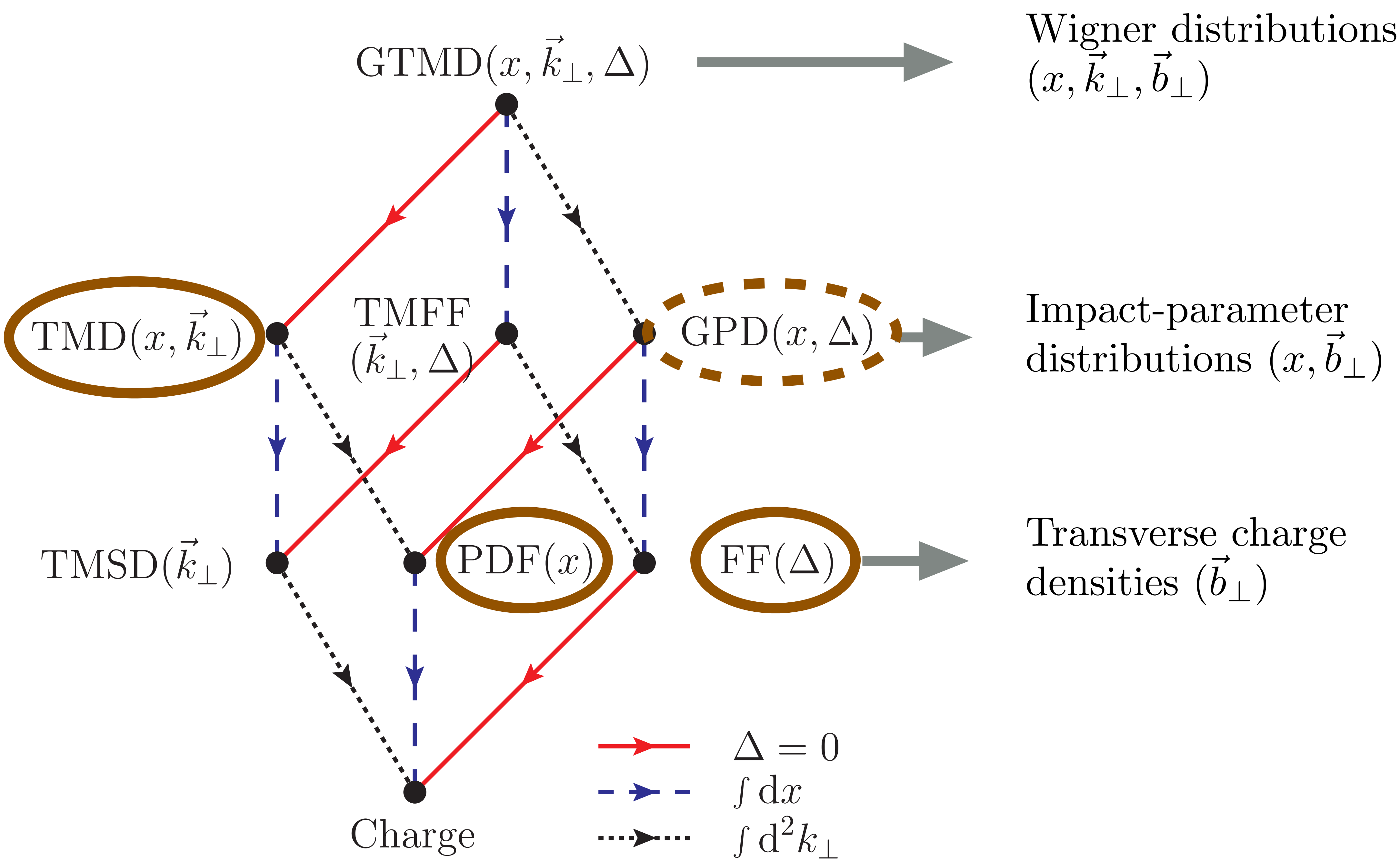

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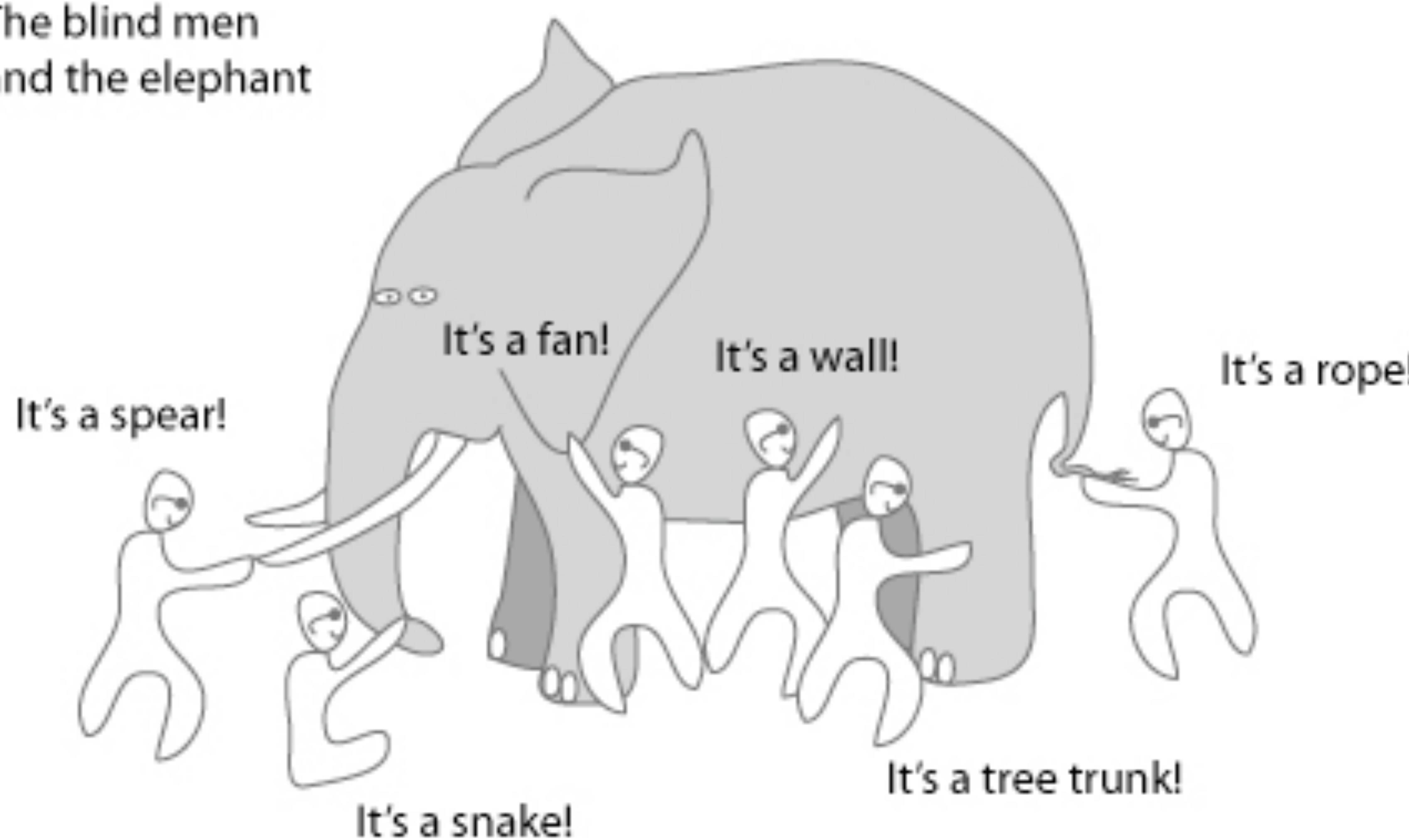
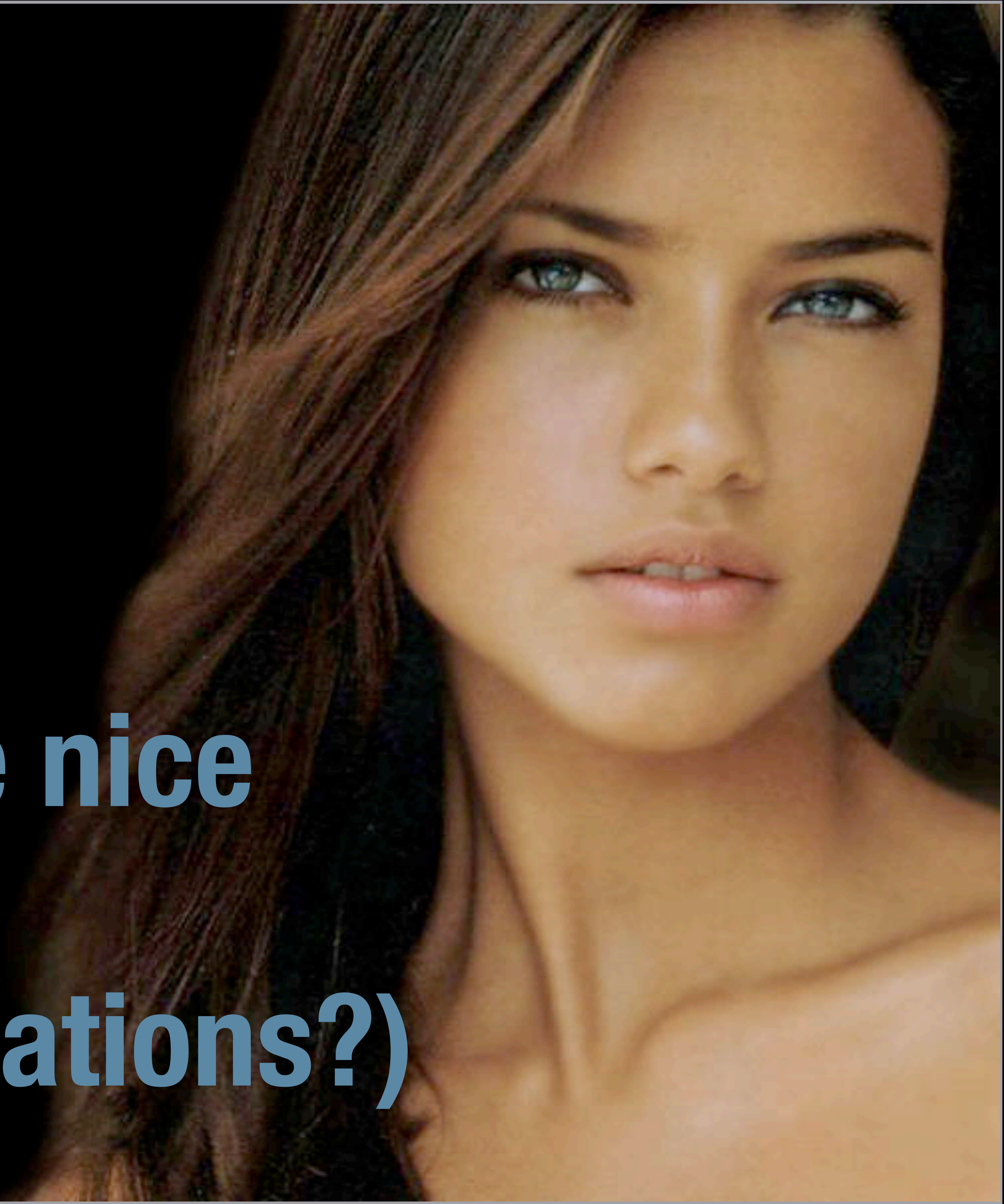
The blind men and the elephant



Models
(or model-based assumptions)
are needed to get the full picture



Models are nice (nicer than parametrizations?)

How well do models reproduce data?

Models on the market

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- Light-cone constituent quark models *(ask Pasquini, Lorcé, Scopetta)*

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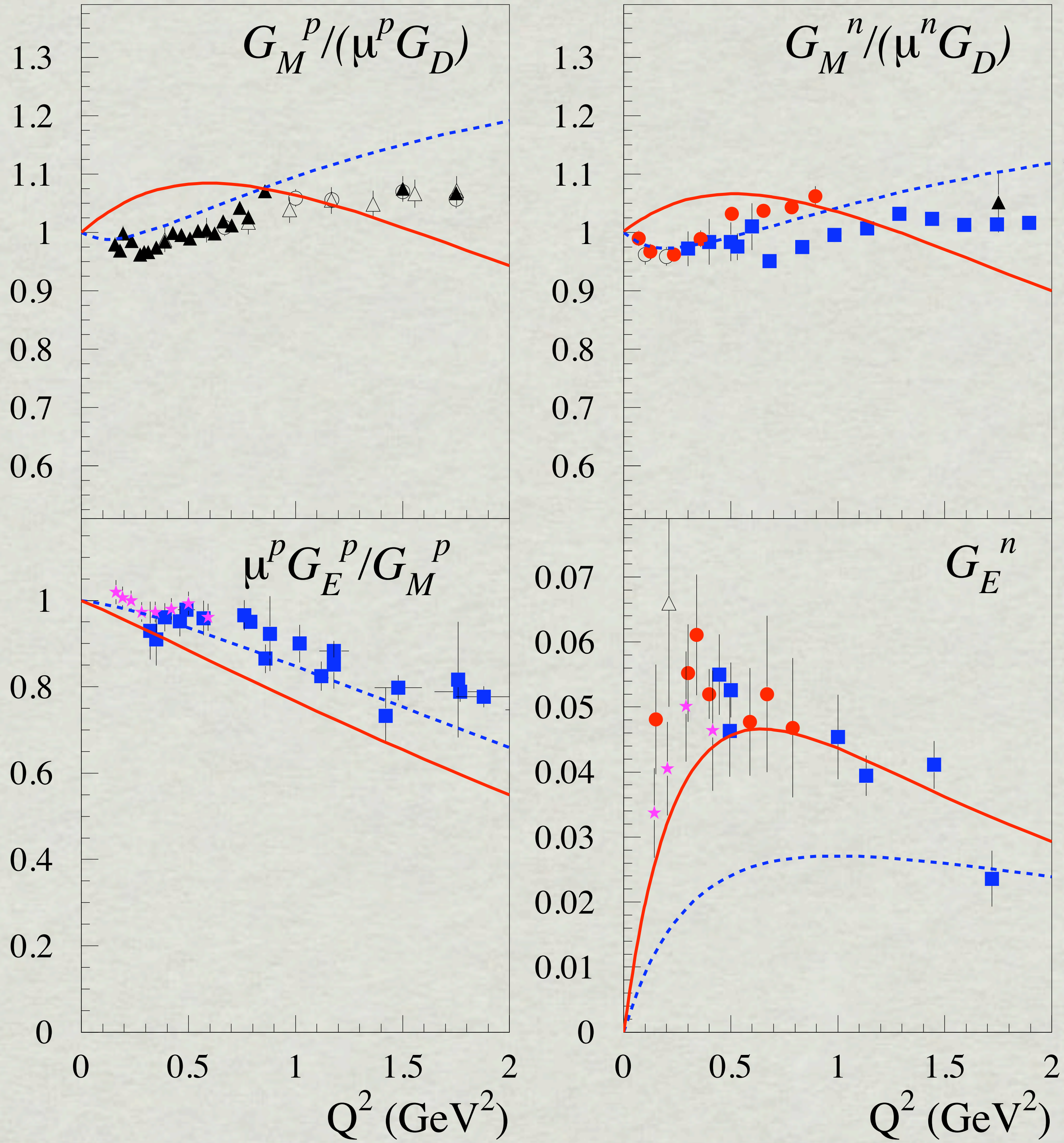
- Chiral quark-soliton model *(ask Wakamatsu, Lorcé)*
- Covariant parton model *(ask Zavada)*

Form factors

Form factors

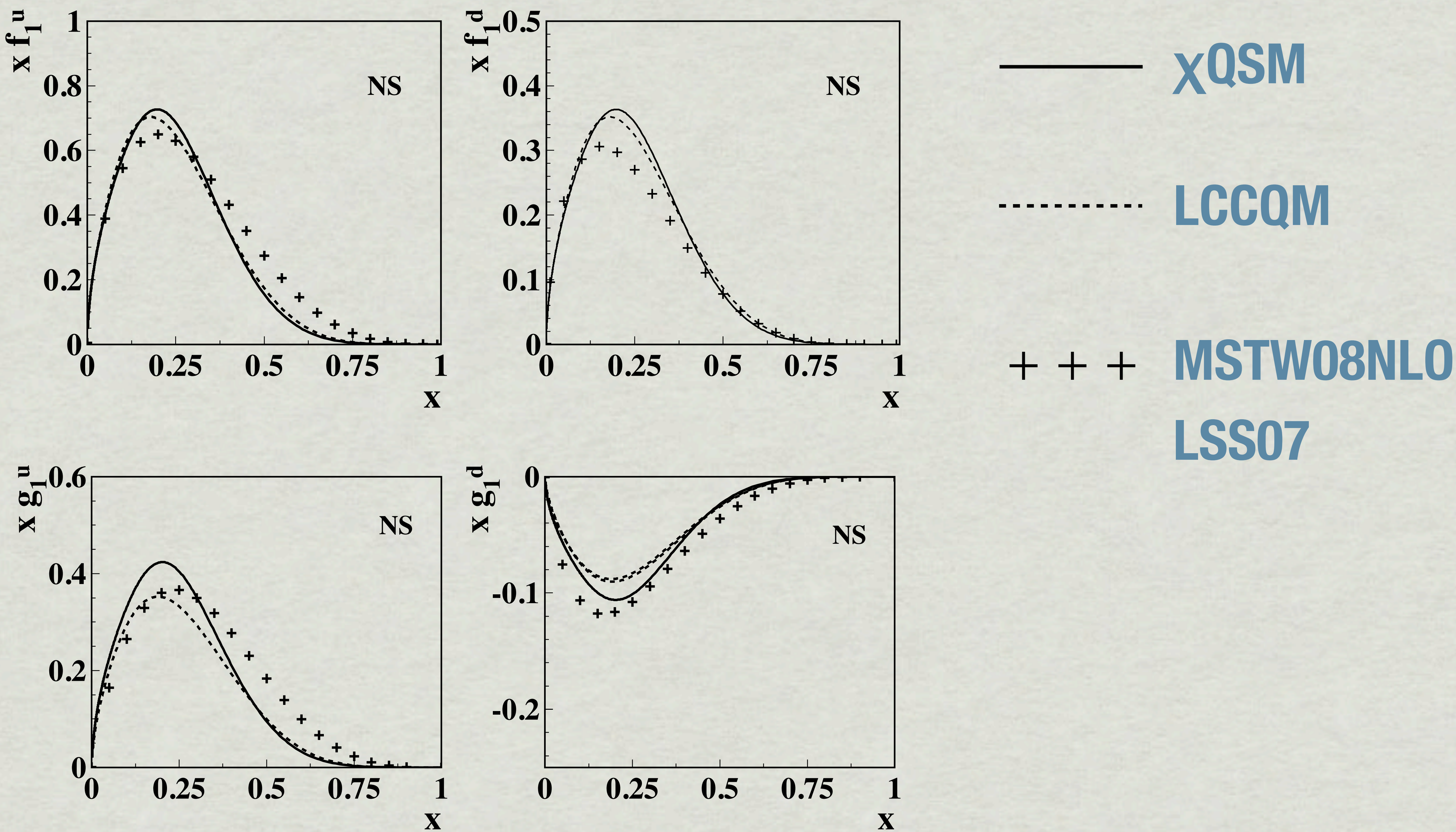


LCCQM

χQSM (without sea quarks)

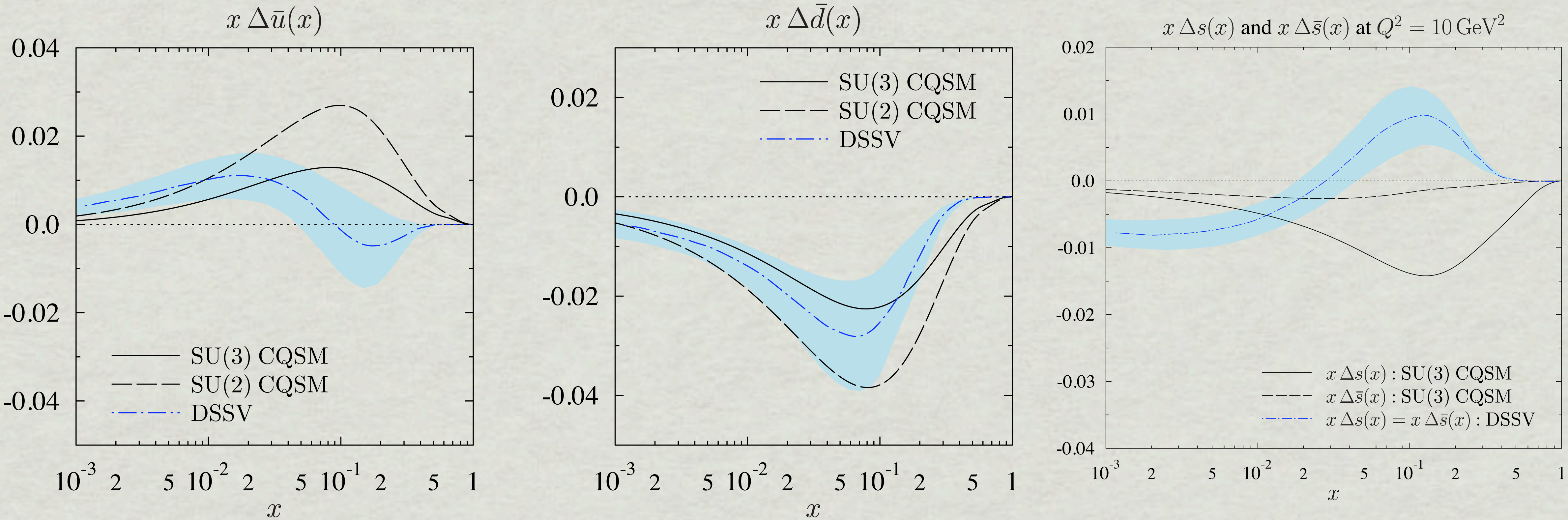
- *C. Lorcé, B. Pasquini, M. Vanderhaeghen, JHEP 1105 (11)*

Unpolarized and helicity PDFs



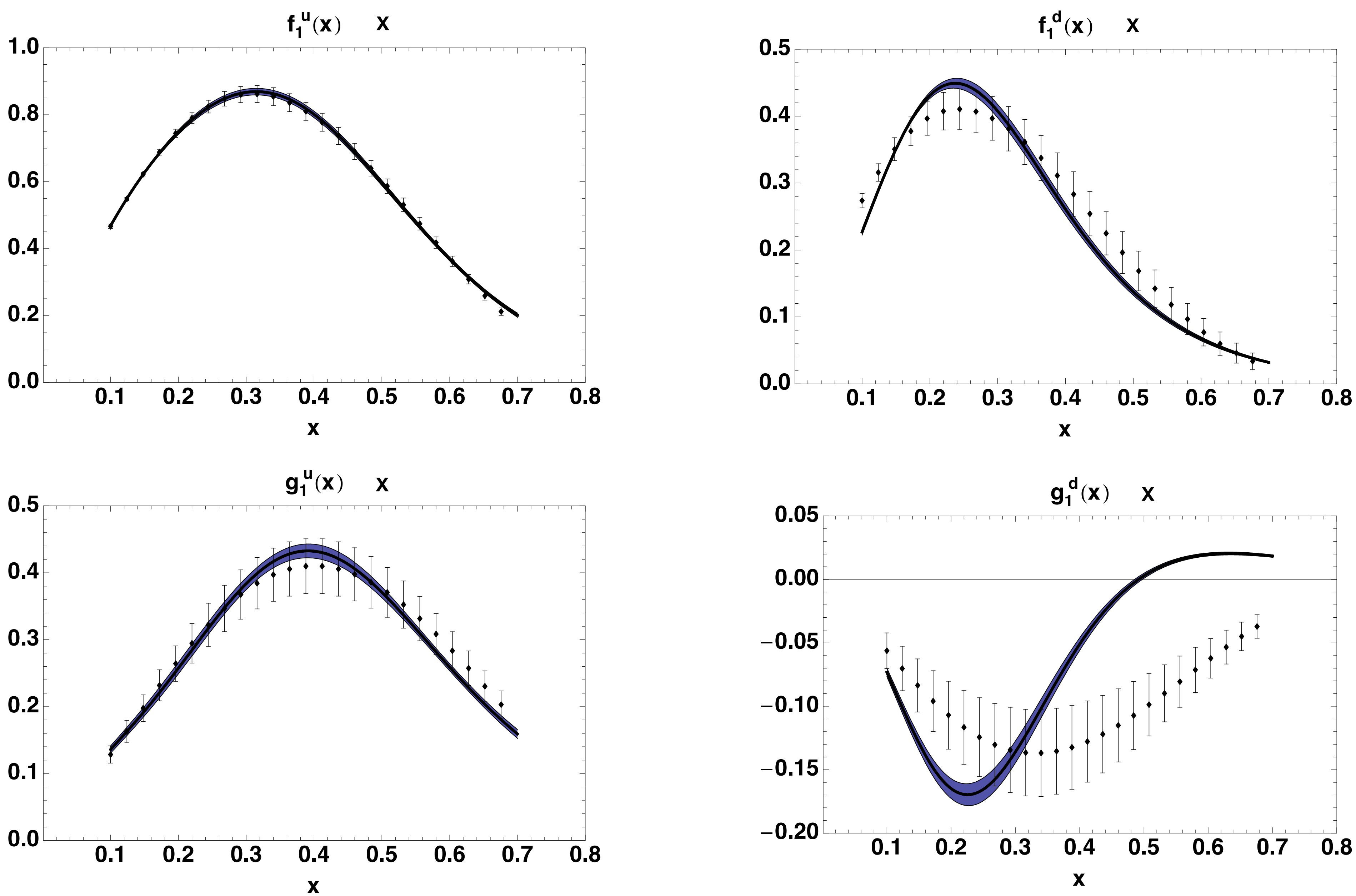
❋ *C. Lorcé, B. Pasquini, M. Vanderhaeghen, JHEP 1105 (11)*

Sea quarks from χQSM



- *M. Wakamatsu, arXiv:0910.5271*

Unpolarized and helicity PDFs

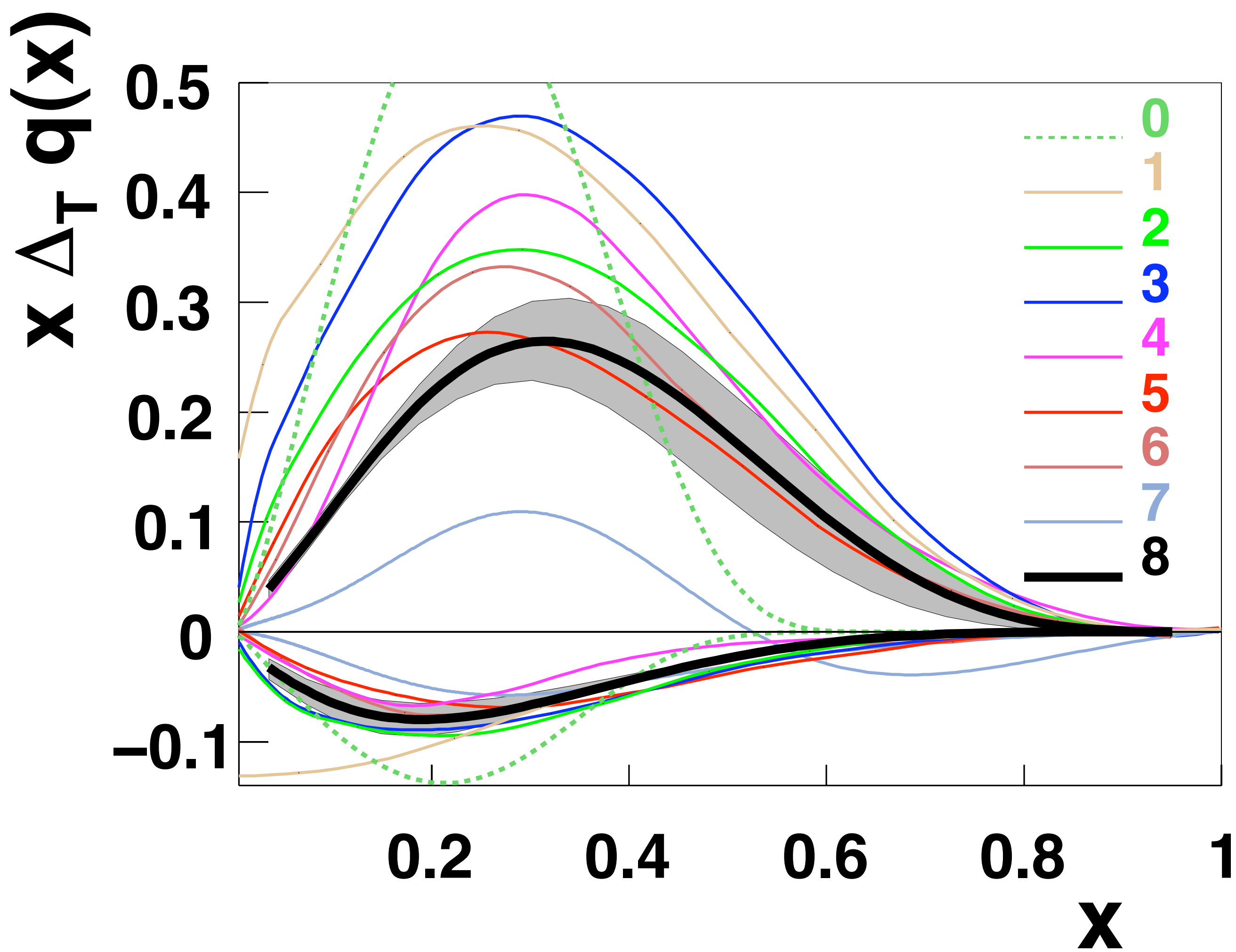


SPECTATOR
VS.
ZEUS02 PDFS

SPECTATOR
VS.
GRSV00 PDFS

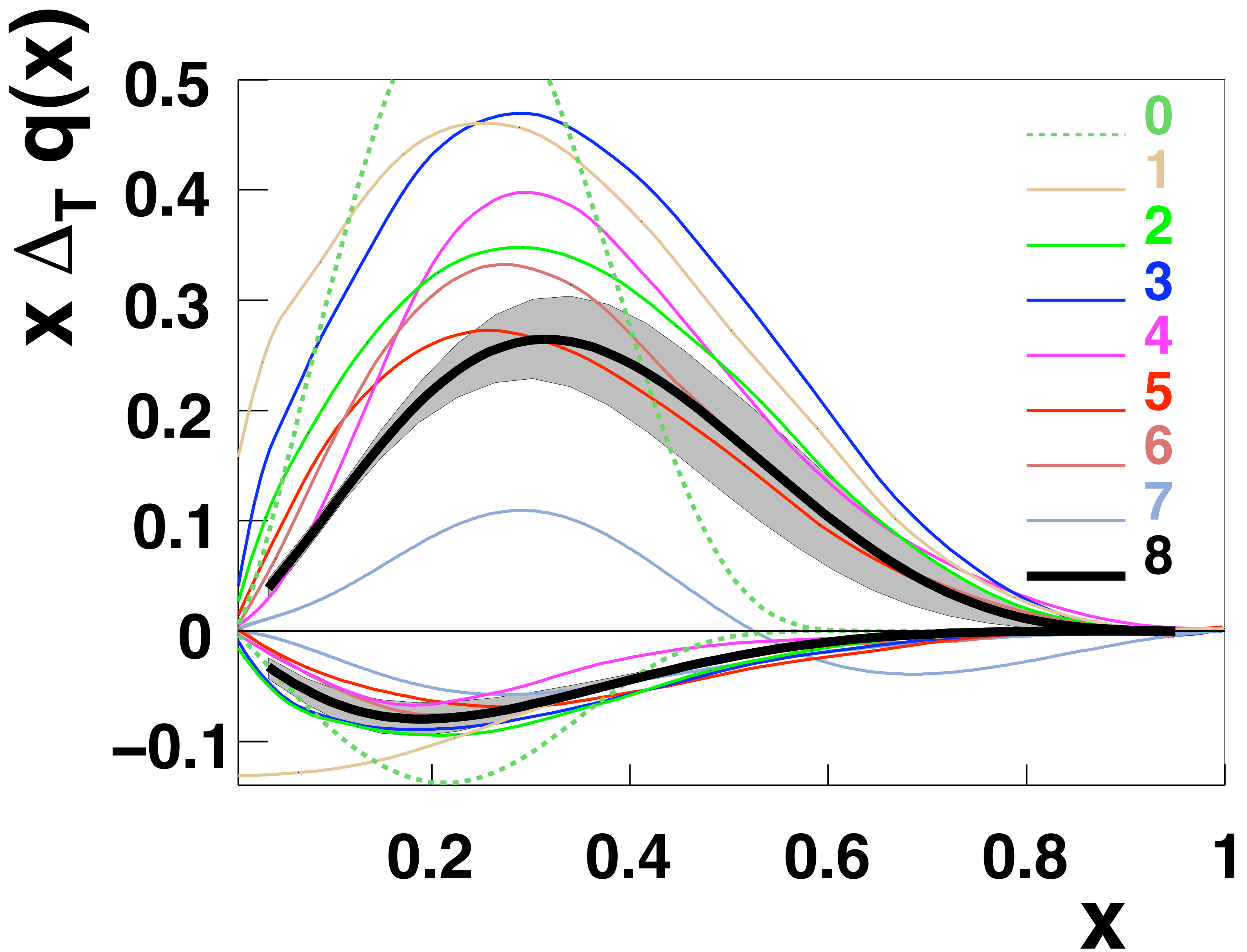
- *Bacchetta, Conti, Radici, PRD*

Transversity

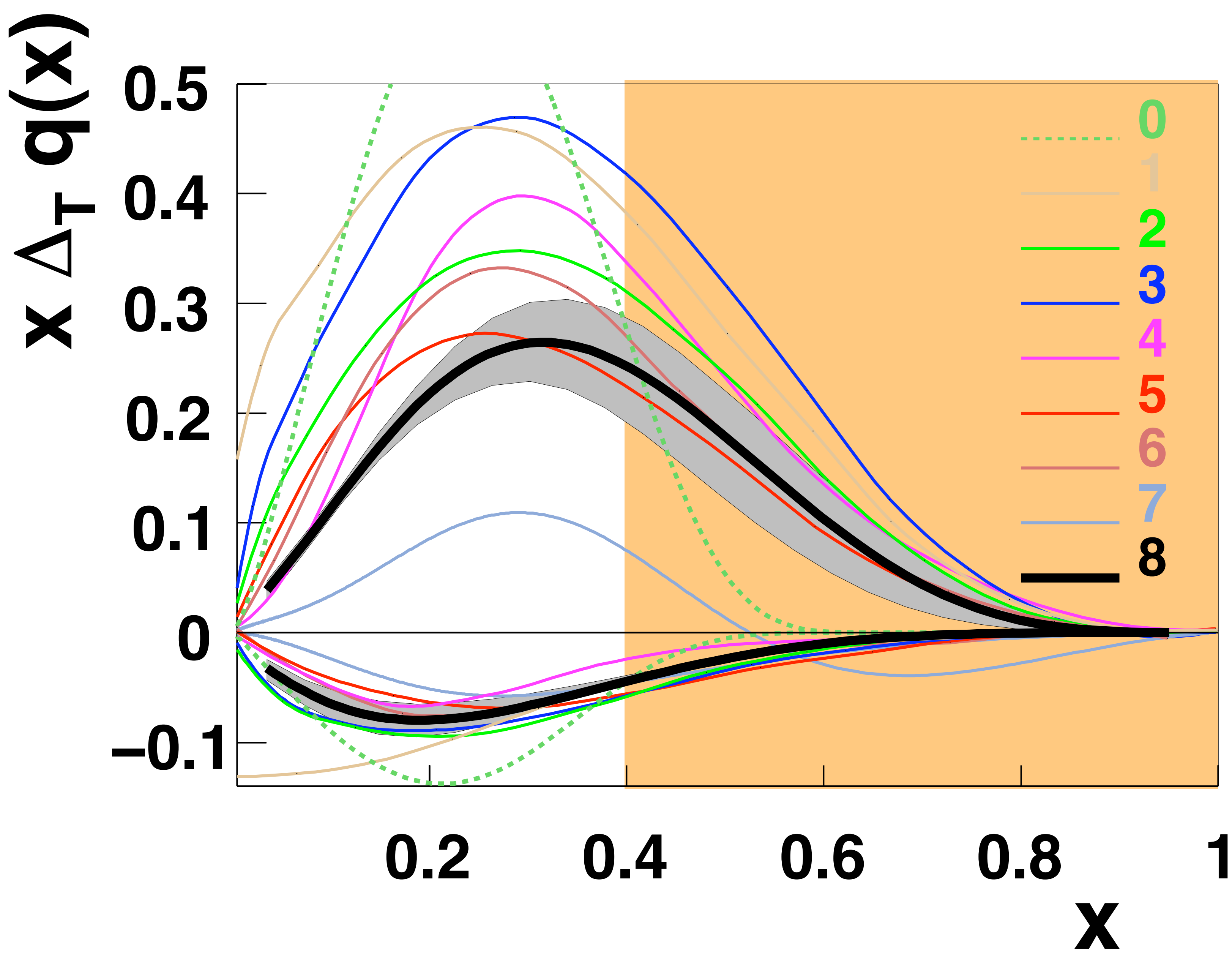


* *image: courtesy of A. Prokudin*

0. chiral color-dielectric model [Barone et al. PLB 390 (97)]
1. Soffer bound [Soffer et al. PRD 65 (02)]
2. $h_1 = g_1$ [Korotkov et al. EPJC 18 (01)]
3. chiral quark-soliton model [Schweitzer et al., PRD 64 (01)]
4. chiral quark-soliton model [Wakamatsu, PLB 509 (01)]
5. light-cone constituent quark model [Pasquini et al., PRD 72 (05)]
6. quark-diquark model [Cloet, Bentz, Thomas, PLB 659 (08)]
7. quark-diquark model [Bacchetta, Conti, Radici, PRD 78 (08)]
8. parametrization [Anselmino et al., arXiv:0807.0173]



x Δ_T q(x)
0.5
0.4
0.3
0.2
0.1
0
–0.1
0.2
0.4
0.6
0.8
1
x
0
1
2
3
4
5
6
7
8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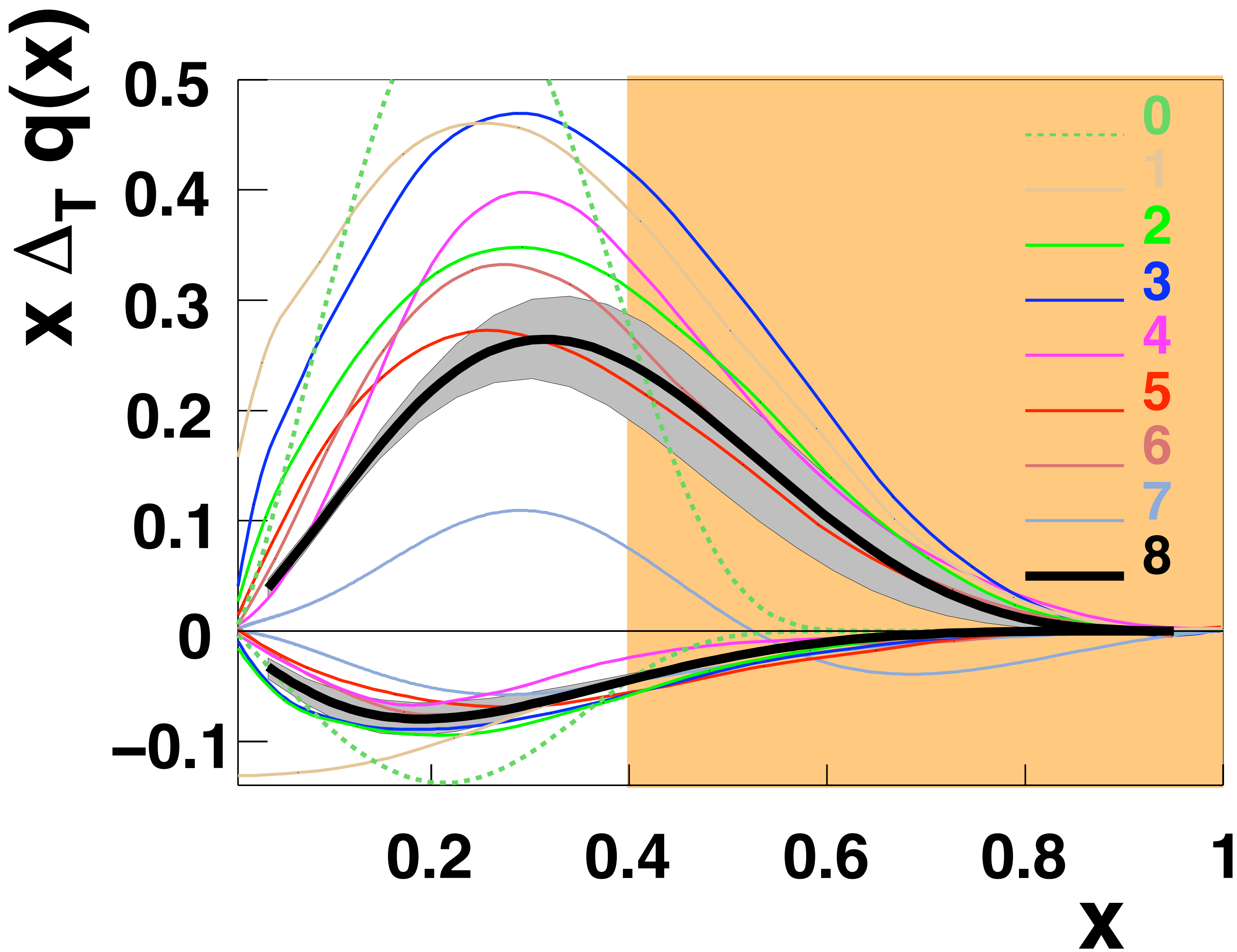
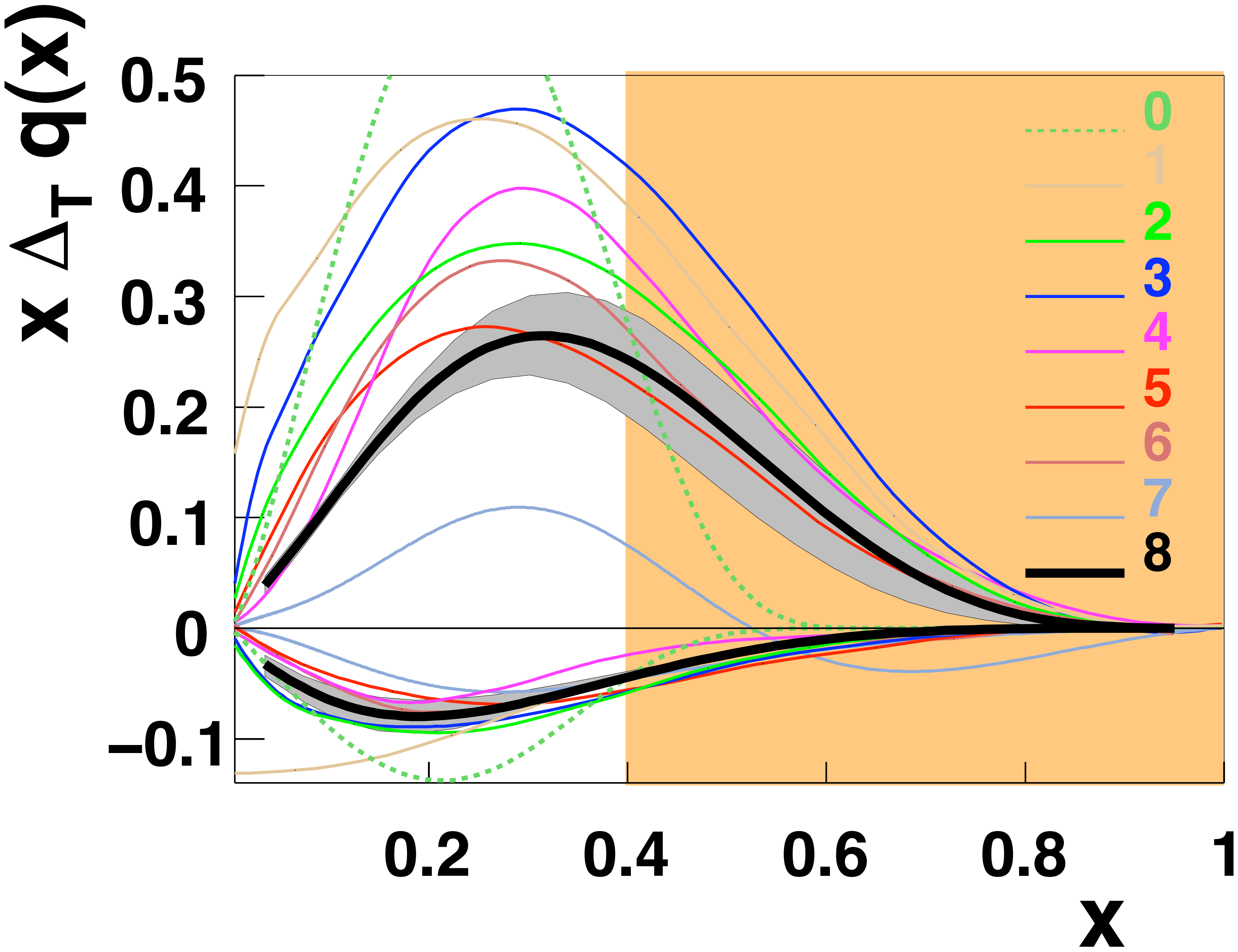
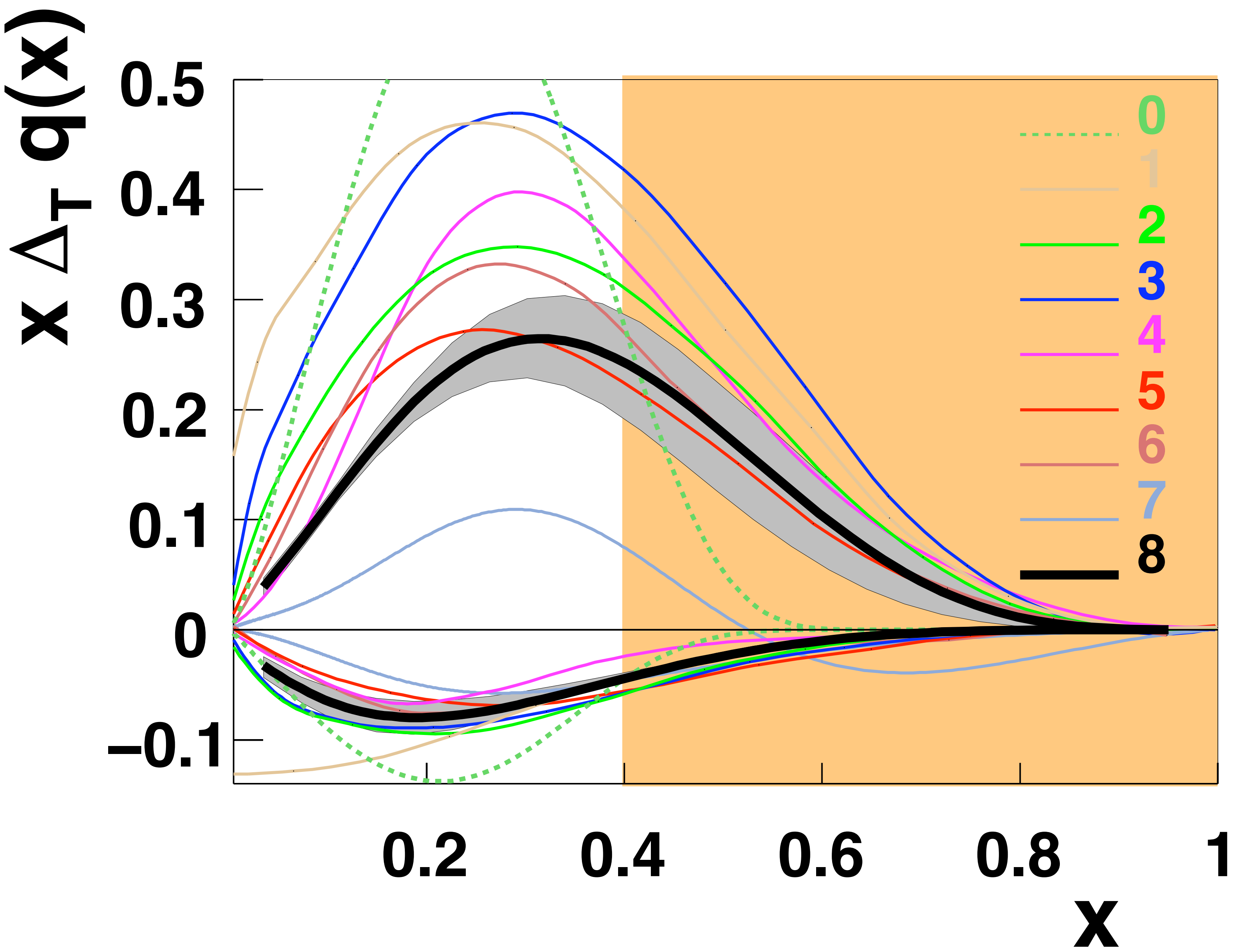


THE SIGN OF TRANSVERSITY IS FIXED BY THE MODELS



THE SIGN OF TRANSVERSITY IS FIXED BY THE MODELS

MODELS TEND TO OVERSHOOT THE PARAMETRIZATION



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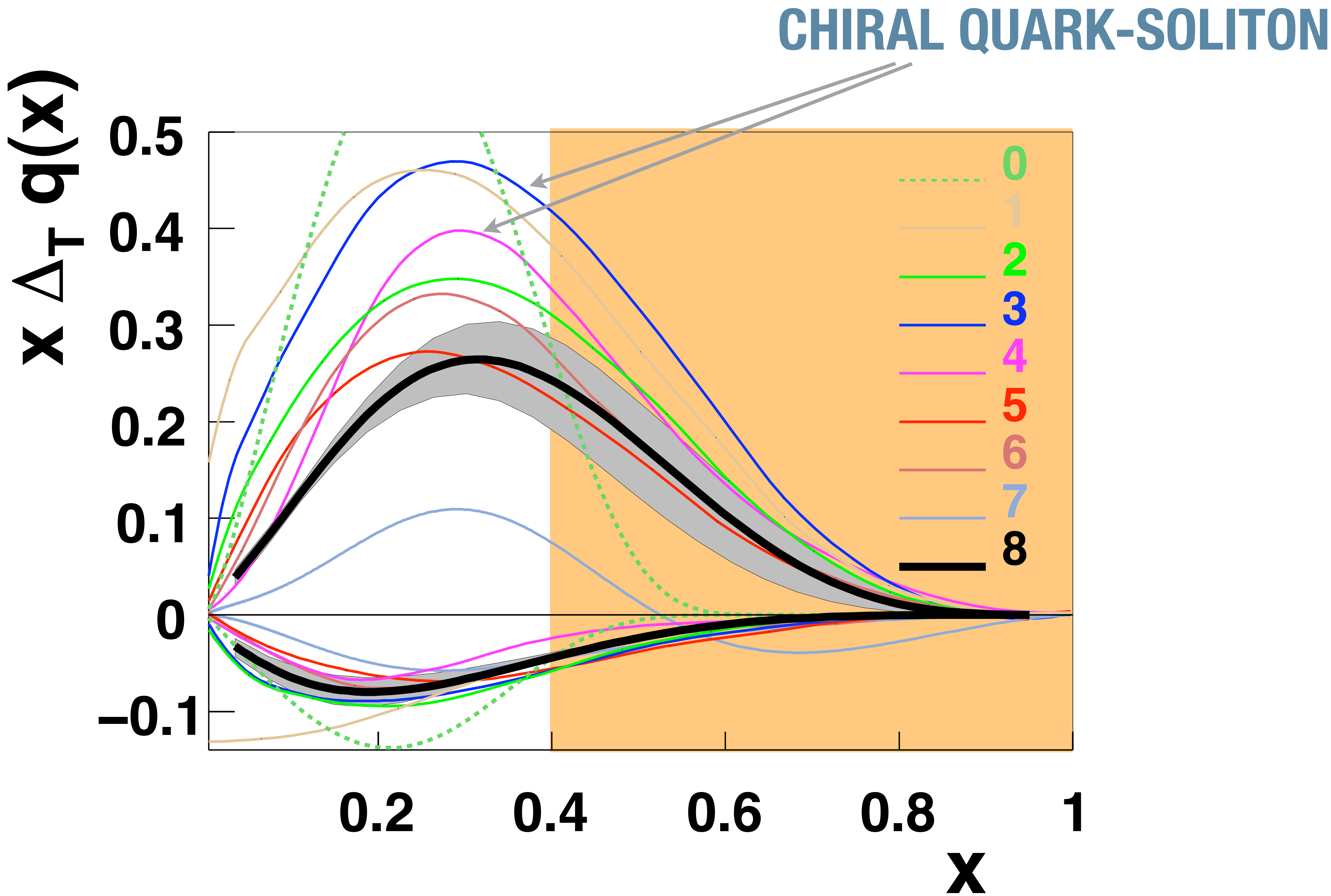
CHIRAL QUARK-SOLITON
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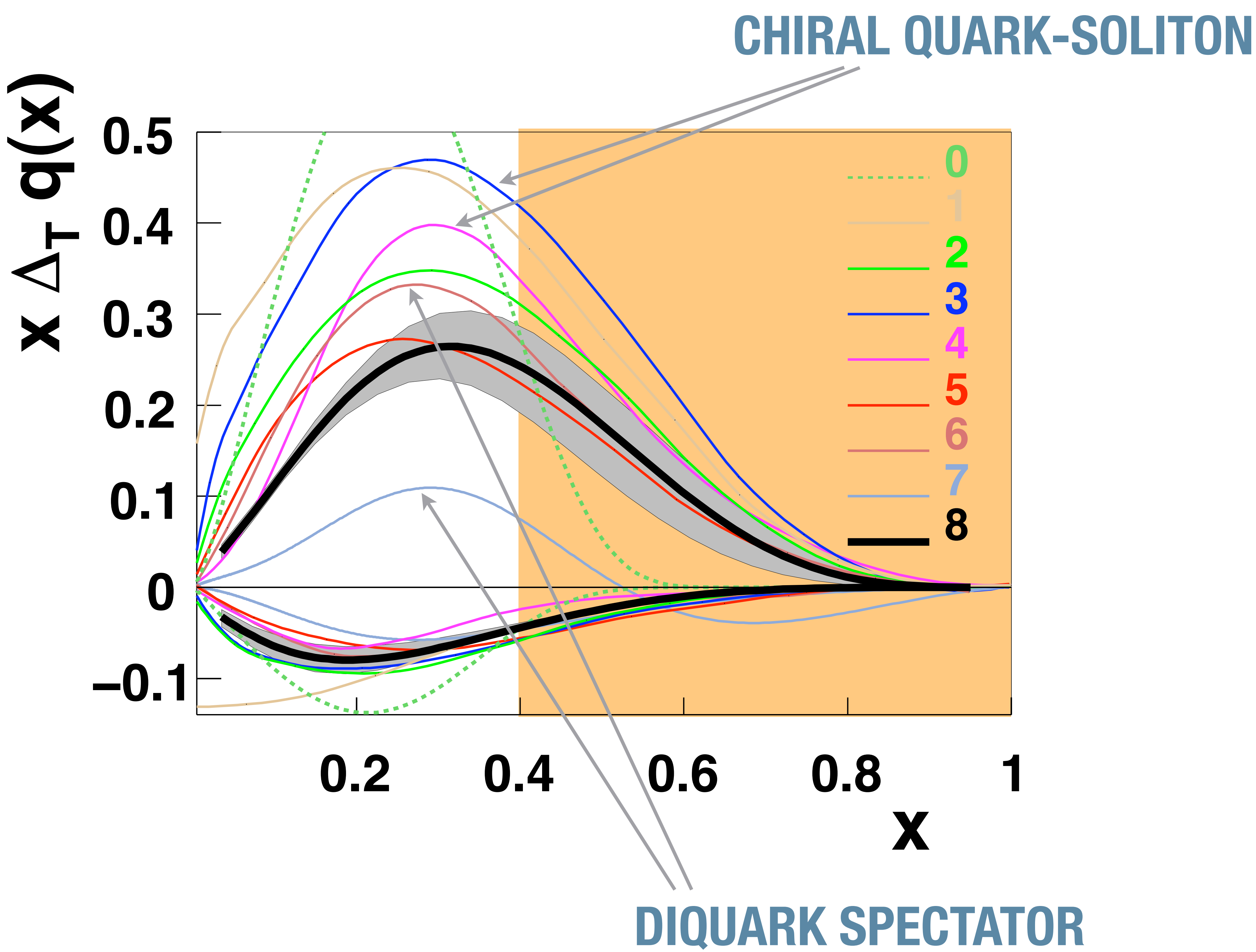

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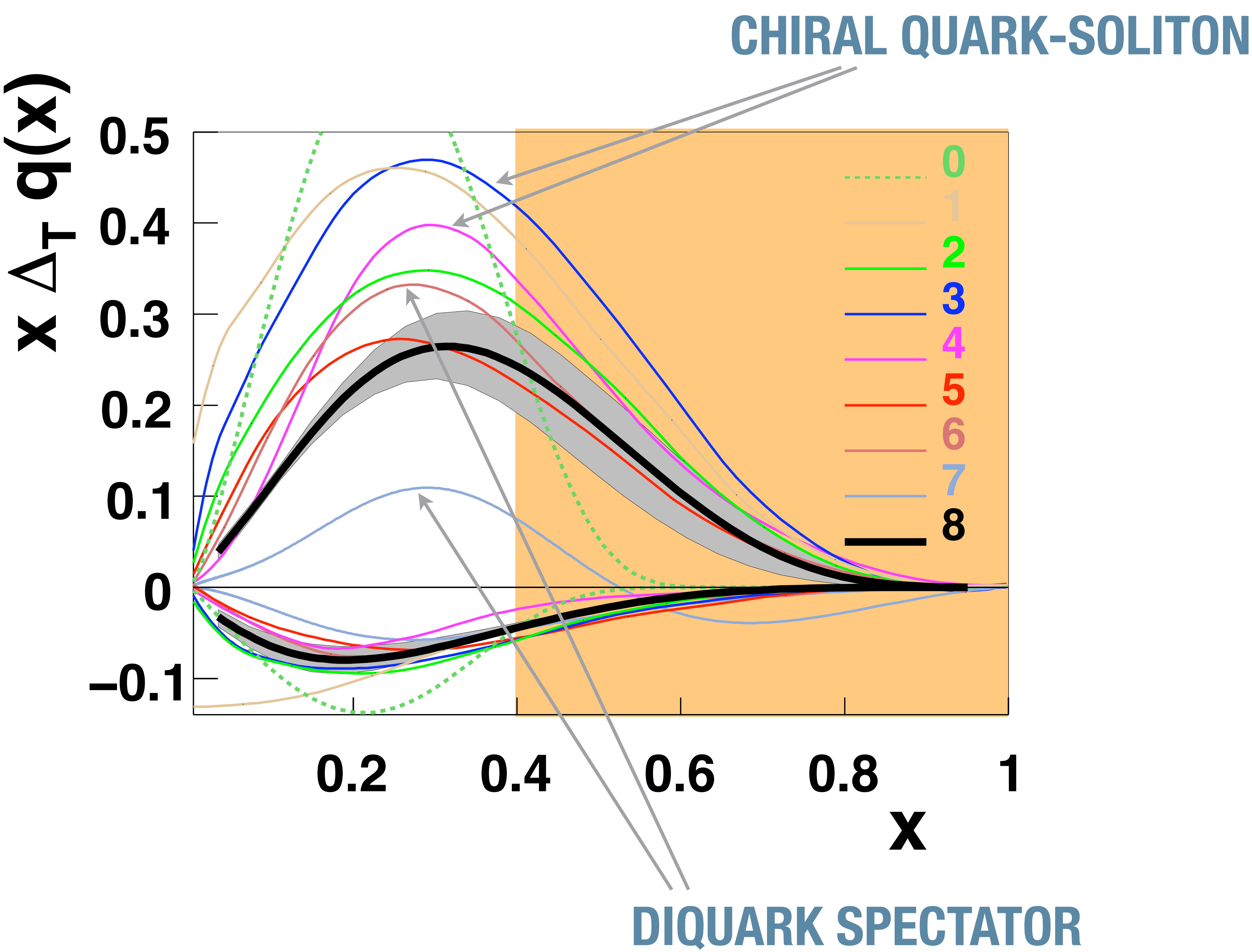
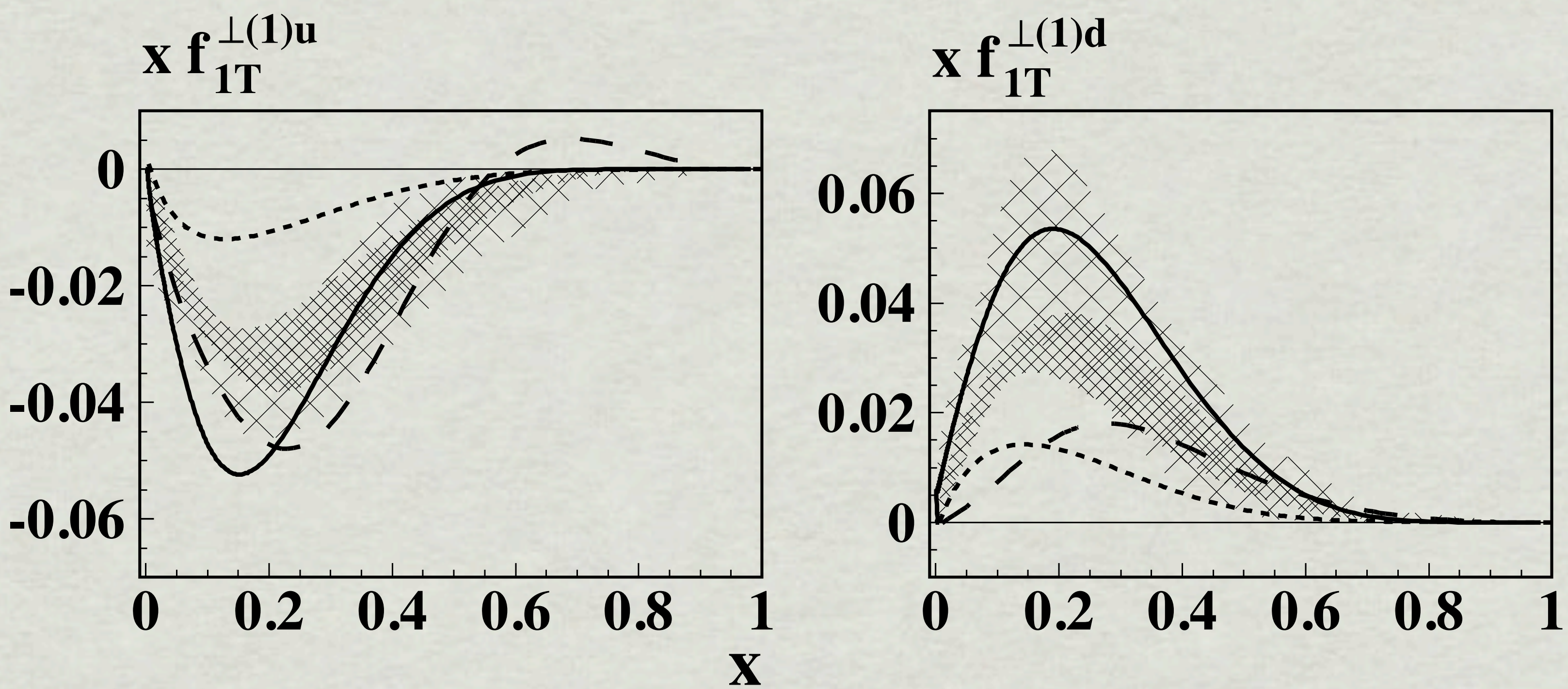
0.4
0.6
0.8
1
x
0
1
2
3
4
5
6
7
8
DIQUARK SPECTATOR



WITHIN THE SAME MODELS, DIFFERENT CHOICES CAN LEAD TO DIFFERENT RESULTS

Sivers function



FITS
(Anselmino et al., Collins et al.)

LCCQM
(Pasquini, Yuan)

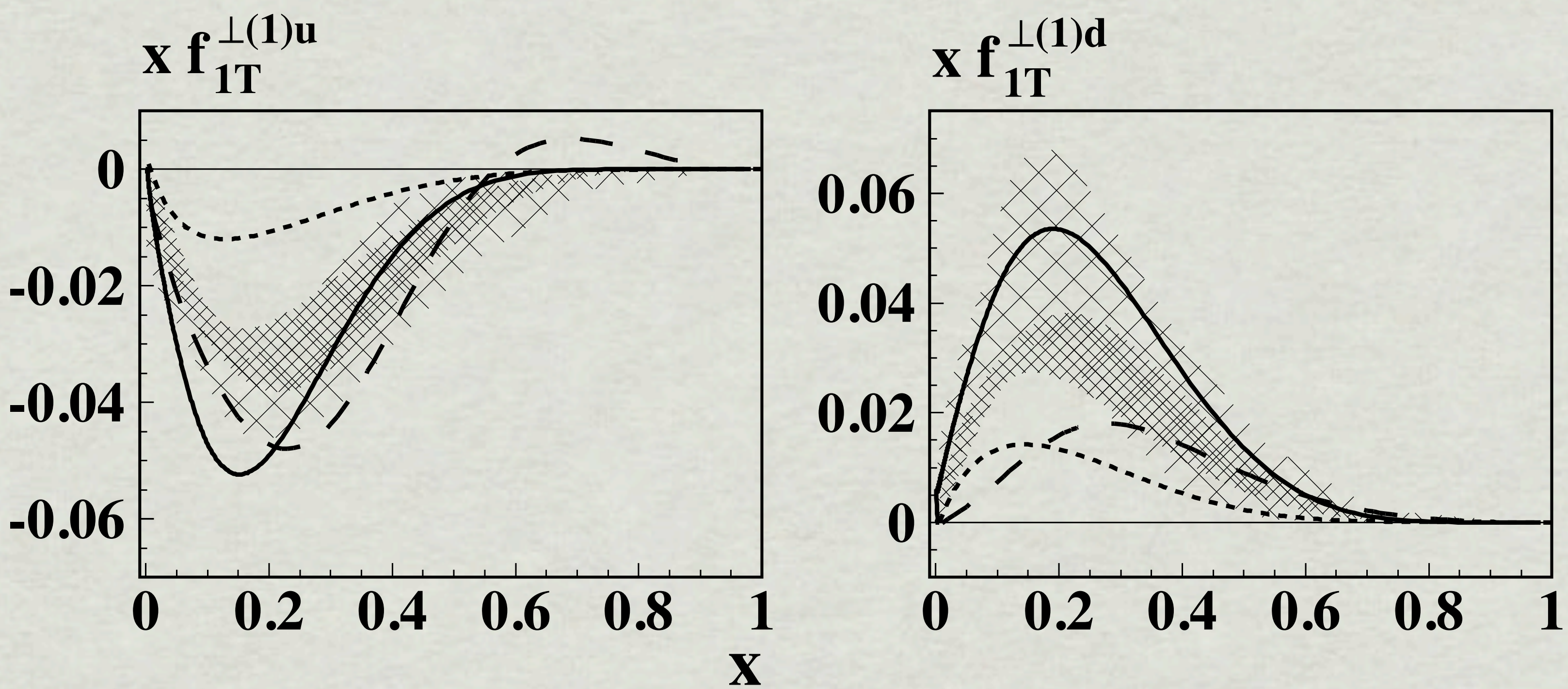
BAG
(Courtoy, Scopetta, Vento)

DIQUARK
(Bacchetta, Conti, Radici, Guagnelli)

- *INT writeup, Boer et al., arXiv:1108.1713 (fig. 2.22)*

Sivers function

SIGN (AND SOMETIMES SIZE) PREDICTED CORRECTLY



FITS
(Anselmino et al., Collins et al.)

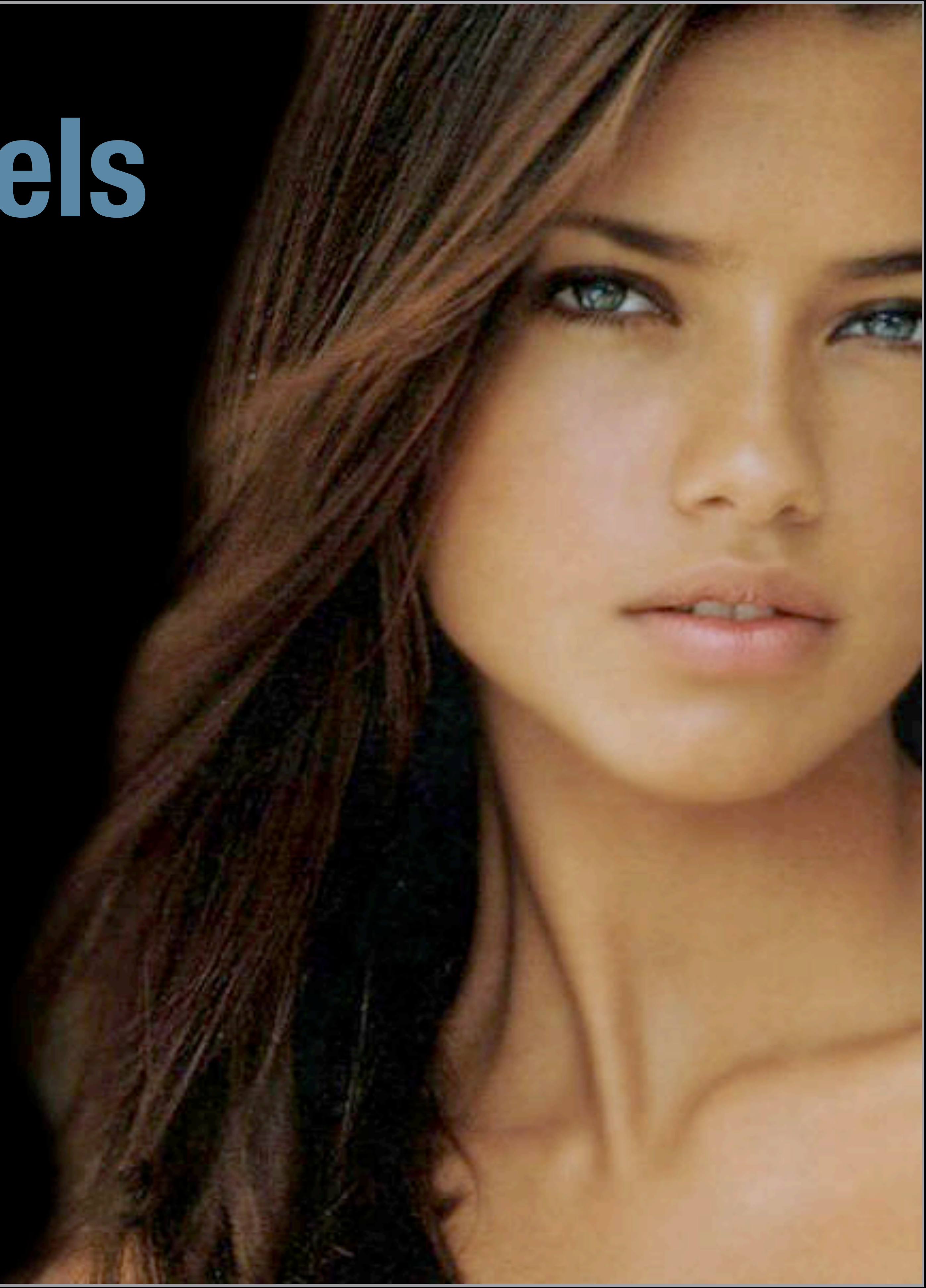
LCCQM (solid line)
(Pasquini, Yuan)

BAG (dotted line)
(Courtoy, Scopetta, Vento)

DIQUARK (dashed line)
(Bacchetta, Conti, Radici, Guagnelli)

- *INT writeup, Boer et al., arXiv:1108.1713 (fig. 2.22)*

Present models give only a qualitative description



Open questions

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- Tune parameters in the best way

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- Include contributions from sea quarks and gluons

Open questions

* Tune parameters in the best way
* Include contributions from sea quarks and gluons
* Study the matching with pQCD

Model relations

Wandzura-Wilczek relations

$$g_T = g_{1T}^{(1)}/x + \widetilde{g}_T$$

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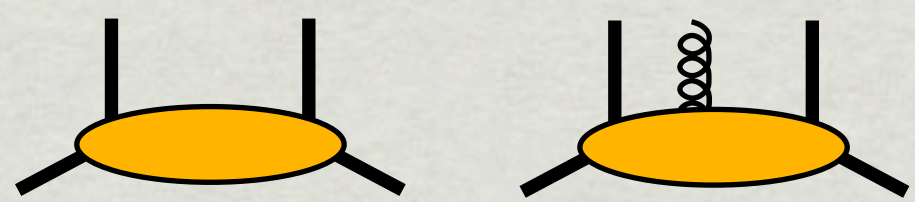

TMD Pure twist-3

Wandzura-Wilczek relations

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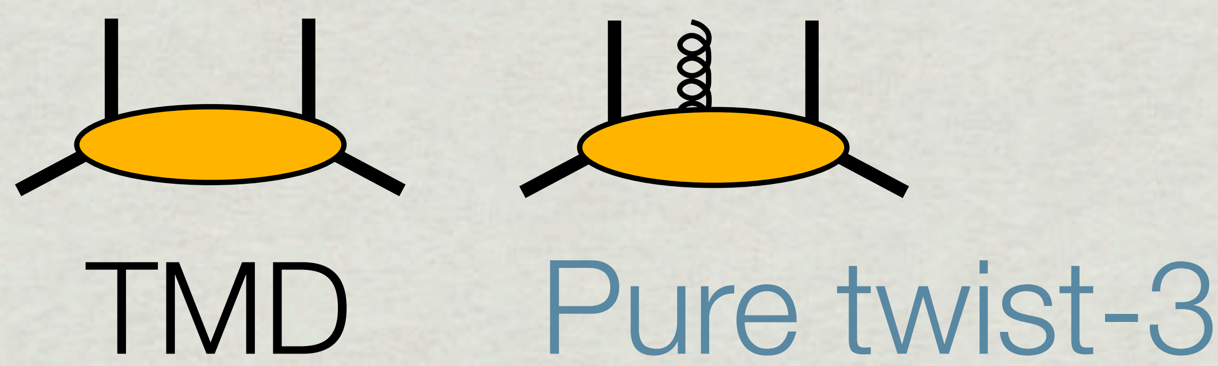

WW APPROXIMATION: REMOVE ALL PURE TWIST-3 (I.E., REMOVE INTERACTIONS)

Wandzura-Wilczek relations

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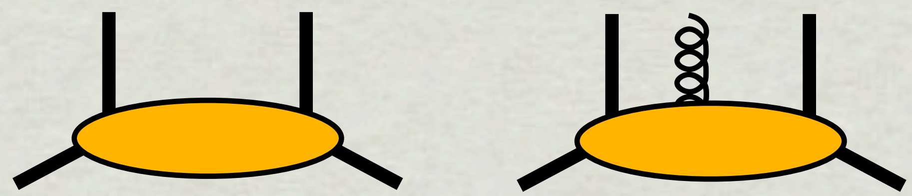
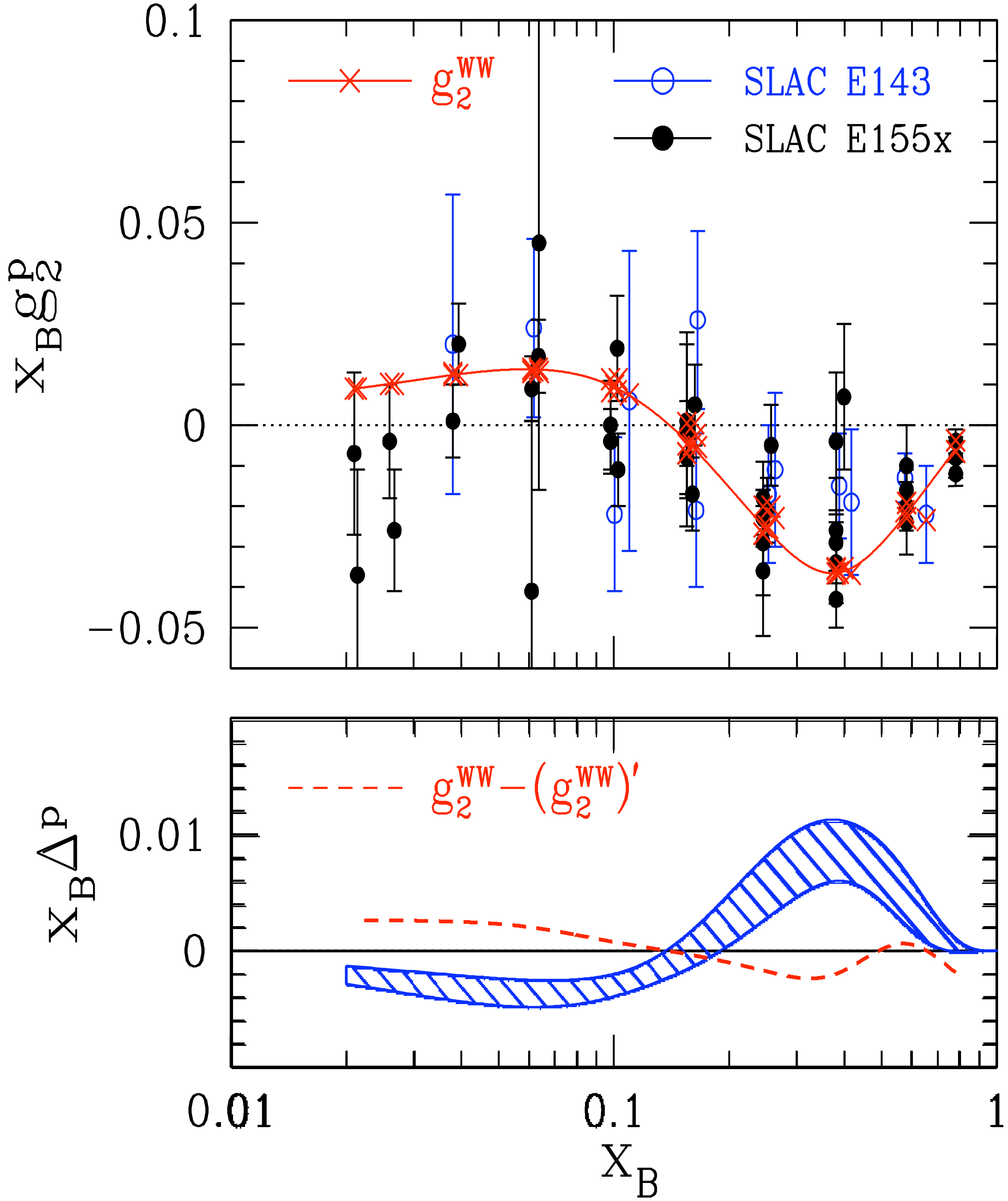


TMD Pure twist-3

WW APPROXIMATION: REMOVE ALL PURE TWIST-3 (I.E., REMOVE INTERACTIONS)

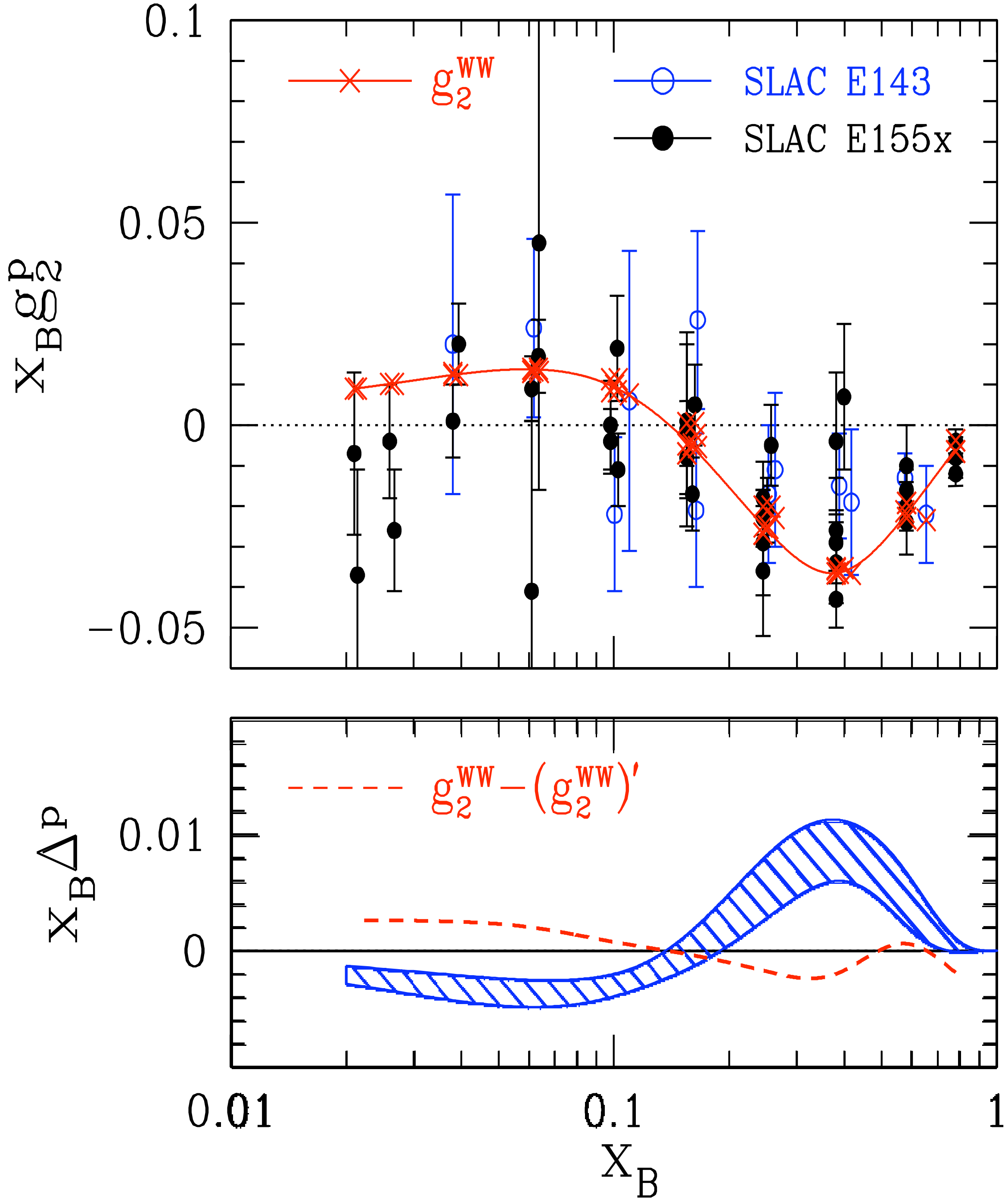
implies also $f_{1T}^{\perp} = 0$

Experimental evidence?



* *Accardi, Bacchetta, Melnitchouk, Schlegel, JHEP 11 (09)*

Experimental evidence?



2 SIGMA BREAKING

* *Accardi, Bacchetta, Melnitchouk, Schlegel, JHEP 11 (09)*

Lorentz-invariance relations

$$g_T = g_{1L} + \frac{d}{dx}\, g_{1T}^{(1)} + \widehat{g}_T$$

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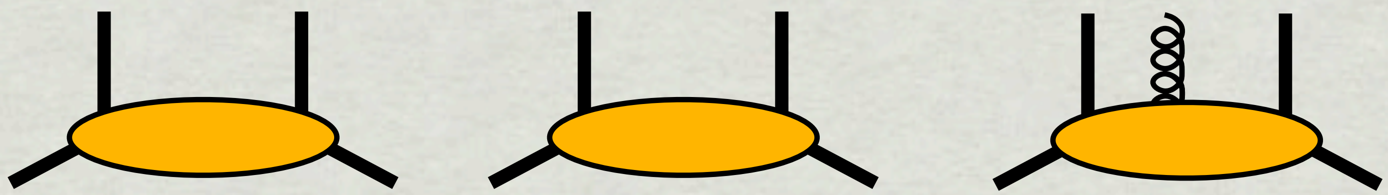

Twist-2 PDF TMD Pure twist-3

Lorentz-invariance relations

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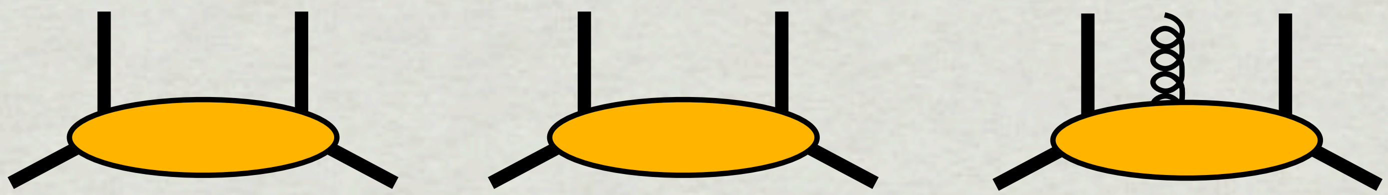

Twist-2 PDF   TMD   Pure twist-3

LI APPROXIMATION: REMOVE SOME KIND OF PURE TWIST-3 (I.E., REMOVE GAUGE FIELDS)

Lorentz-invariance relations

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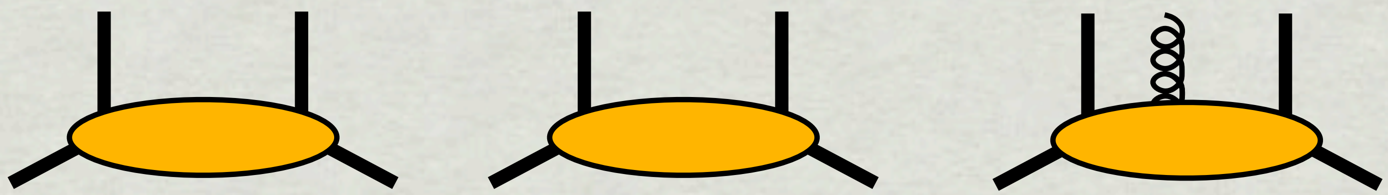

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Spherical-symmetry relations

- *C. Lorcé, B. Pasquini, arXiv:1104.5651*

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$$g_1 - h_1 = h_{1T}^{\perp(1)}$$

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HELICITY -TRANSVERSITY= PRETZELOSITY

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Spherical-symmetry relations

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WORM GEARS

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WORM GEARS

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SIVERS

- *C. Lorcé, B. Pasquini, arXiv:1104.5651*

Spherical-symmetry relations

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HELICITY -TRANSVERSITY= PRETZELOSITY

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WORM GEARS

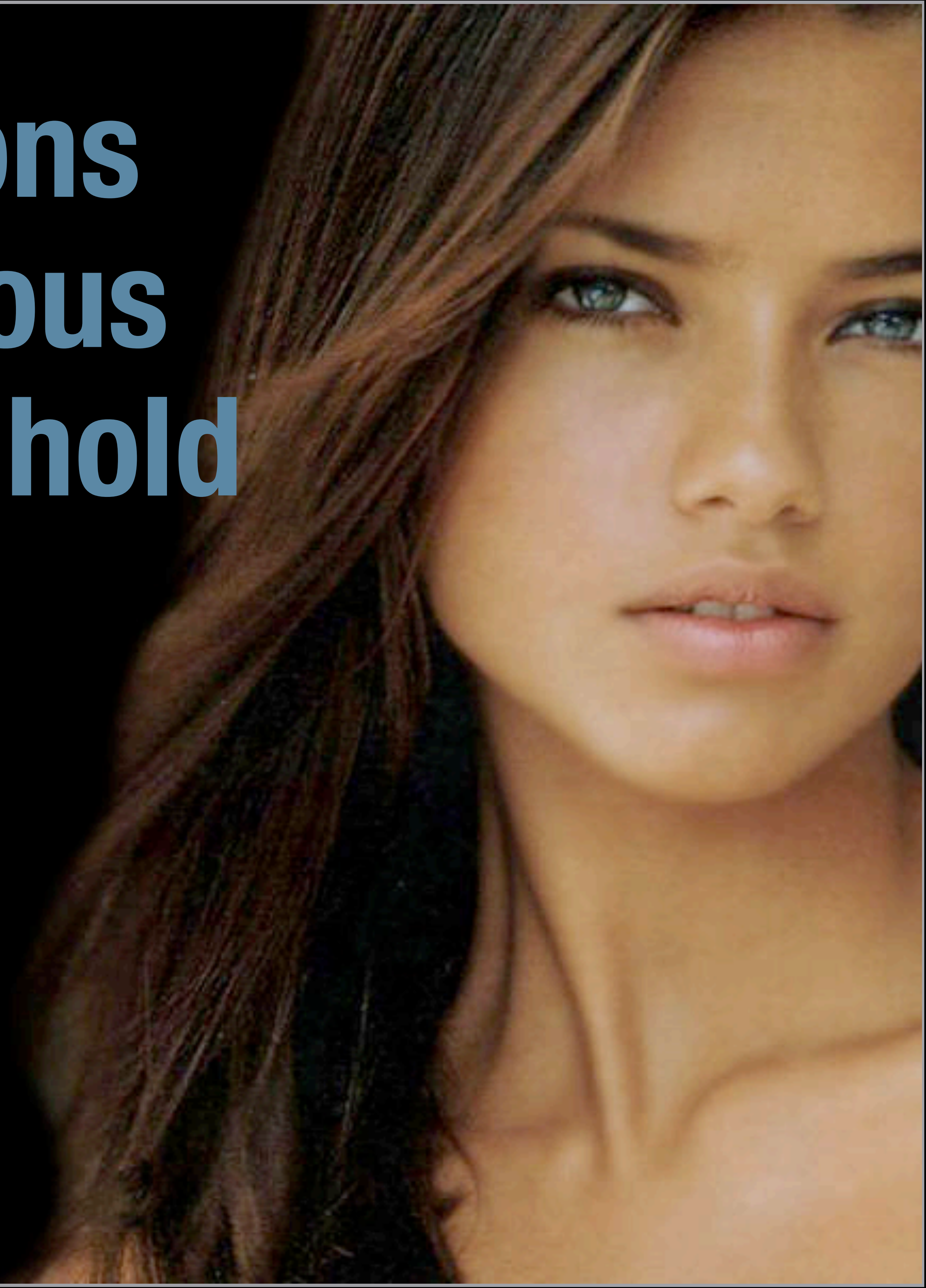
$$f_{1T}^{\perp} = 0$$

SIVERS

VIOLATED BY VECTOR INTERACTIONS (E.G., WITH GLUONS)

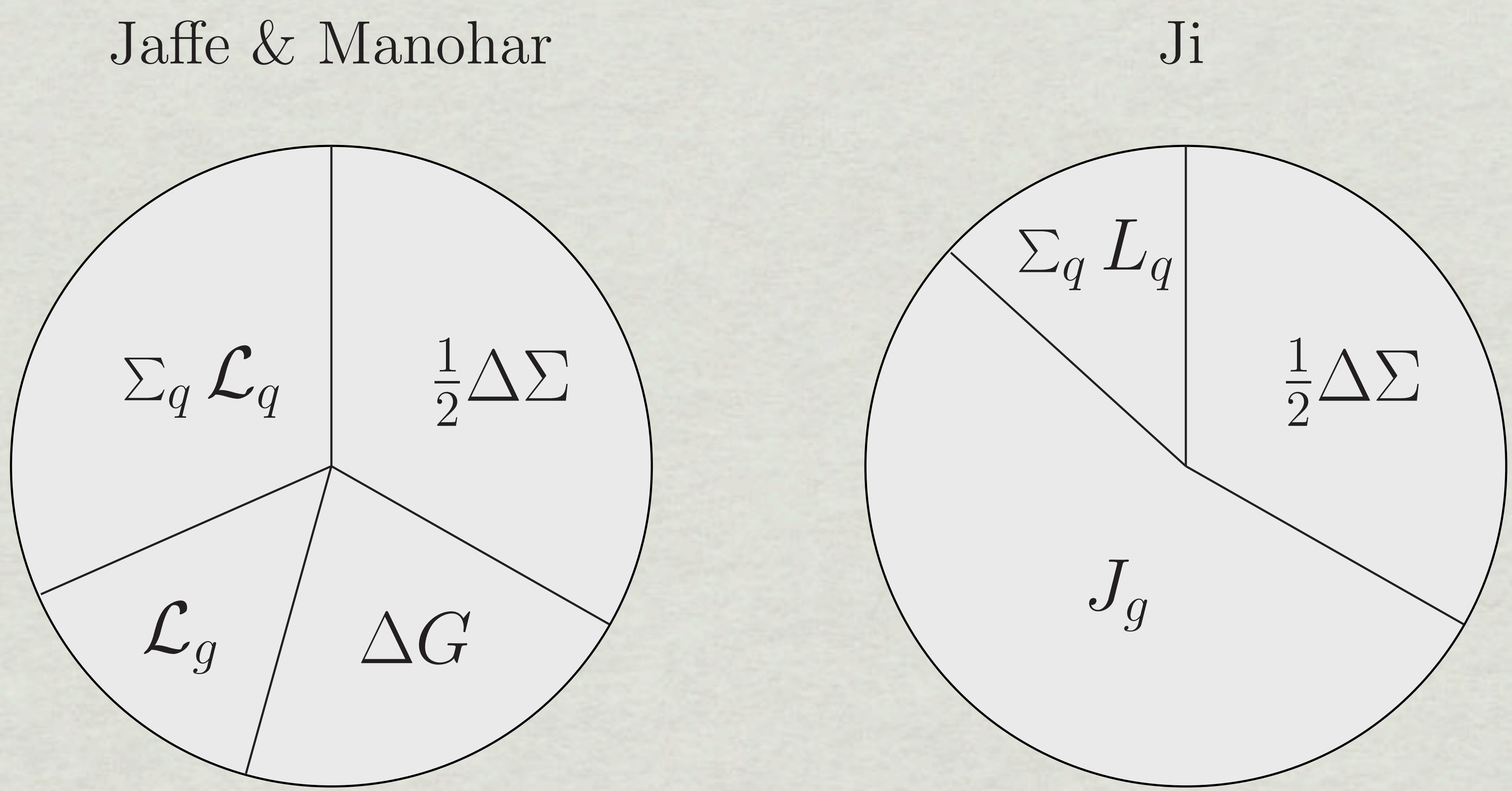
- *C. Lorcé, B. Pasquini, arXiv:1104.5651*

Model relations are not rigorous but may still hold (especially at low scales)



TMDs and quark angular momentum

Ji vs. Jaffe-Manohar



- *see talk by M. Burkardt*

TMDs & Jaffe-Manohar OAM

$$\mathcal{L}^q = -h_{1T}^{\perp(1)q}$$

JAFFE-MANOHAR OAM IS CONNECTED TO PRETZELOSITY?

- *Avakian, Efremov, Schweitzer, Yuan, PRD 81 (10)*

Ji's total angular momentum

$$J^q = \frac{1}{2}\int_0^1 dx\, x\left(H^q(x,0,0) + E^q(x,0,0)\right)$$

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$$-\int d^2\vec{k}_T\, k_T^i\, \frac{\epsilon_T^{jk} k_T^j S_T^k}{M}\, f_{1T}^{\perp q}(x,\vec{k}_T^2) \;\; \simeq \int d^2\vec{b}_T\, \mathcal{I}^{q,i}(x,\vec{b}_T)\, \frac{\epsilon_T^{jk} b_T^j S_T^k}{M}\, \Big(\mathcal{E}^q(x,\vec{b}_T^2)\Big)'$$

- *Burkardt, PRD66 (02)*
- *Meissner, Metz, Goeke, PRD76 (07)*
- *see talk by M. Schlegel*

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SIVERS FUNCTION **LENSING FUNCTION** **F.T. OF E(x,0,0)**

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- *Meissner, Metz, Goeke, PRD76 (07)*
- *see talk by M. Schlegel*

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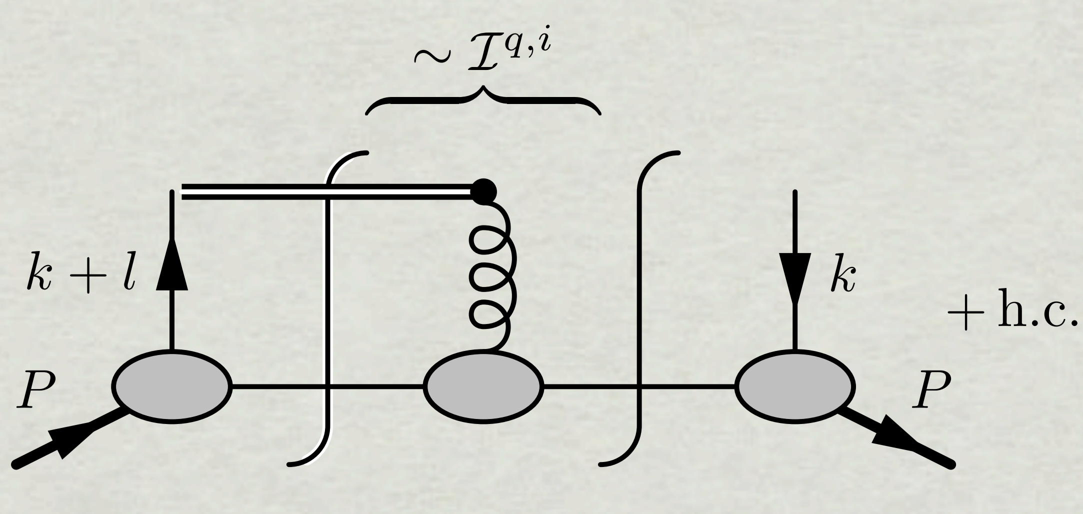

- *Burkardt, PRD66 (02)*
- *Meissner, Metz, Goeke, PRD76 (07)*
- *see talk by M. Schlegel*

Simplified relation

$$f_{1T}^{\perp(0)a}(x;Q_L^2) = -L(x)\,E^a(x,0,0;Q_L^2),$$

- *Burkardt, Hwang, PRD69 (04)*
  Lu, Schmidt, PRD75 (07)
  A.B., F. Conti, M. Radici, PRD 78 (08)

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Fitting data

NEWS

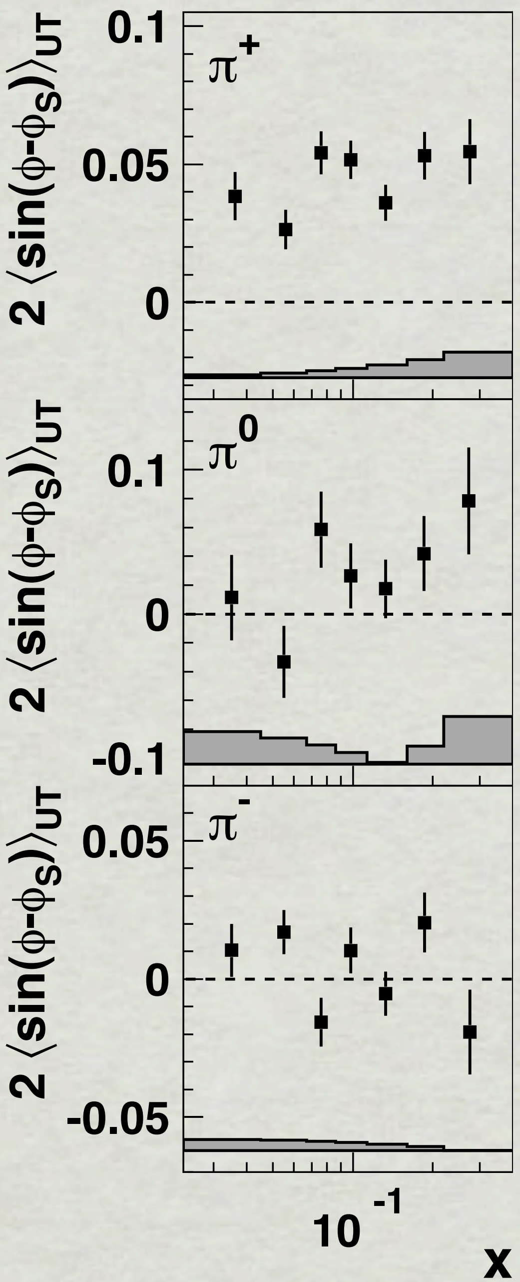
$$f_{1T}^{\perp(0)a}(x;Q_L^2) = -L(x)\,E^a(x,0,0;Q_L^2),$$

- *Bacchetta, Radici, arXiv:1107.5755*

Fitting data

NEWS

$$f_{1T}^{\perp(0)a}(x;Q_L^2) = -L(x)\,E^a(x,0,0;Q_L^2),$$



- *Bacchetta, Radici, arXiv:1107.5755*

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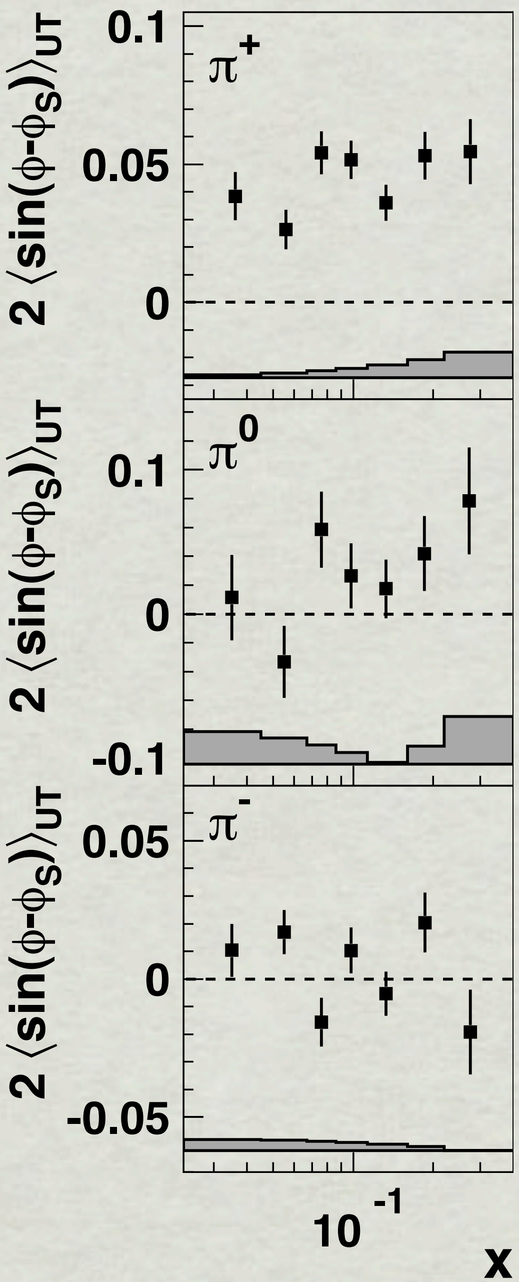

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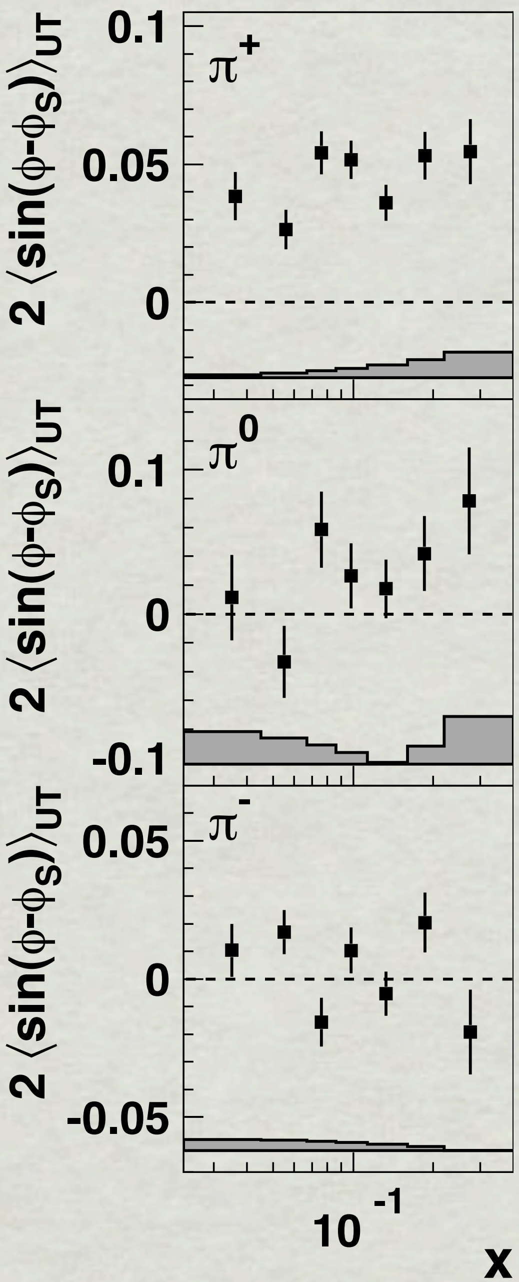

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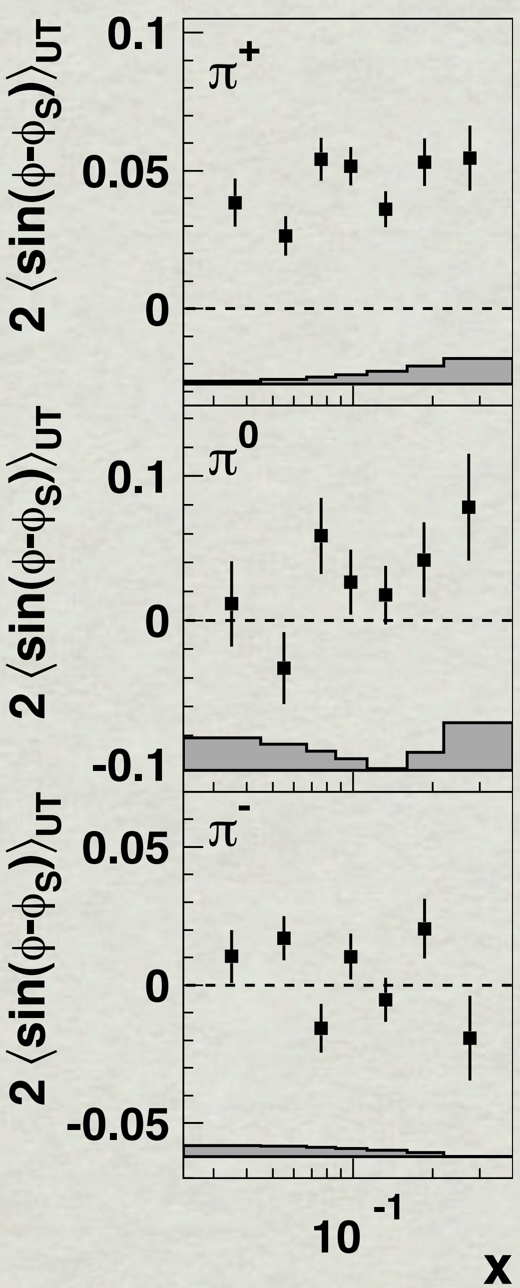

USE SIDIS ASYMMETRY DATA TO CONSTRAIN SHAPE

- *Bacchetta, Radici, arXiv:1107.5755*

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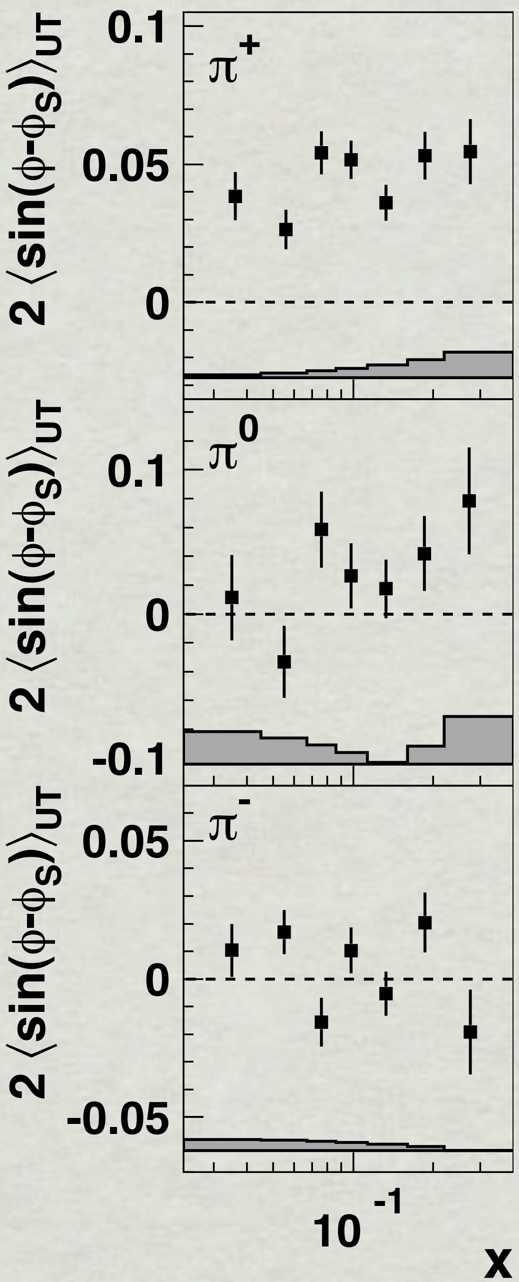

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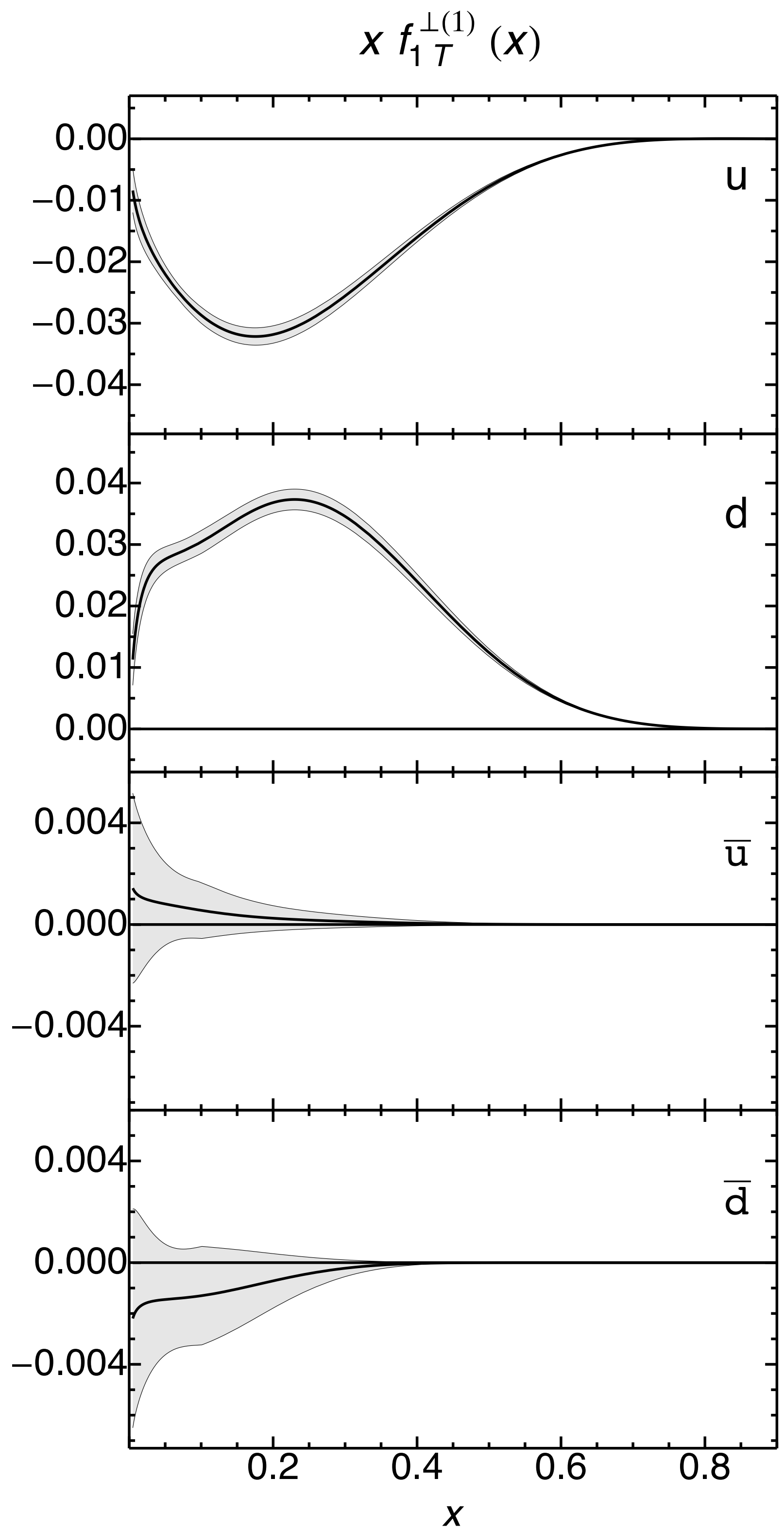
USE ANOMALOUS MAGNETIC MOMENTS TO CONSTRAIN INTEGRAL

USE SIDIS ASYMMETRY DATA TO CONSTRAIN SHAPE

- *Bacchetta, Radici, arXiv:1107.5755*

Results for the Sivers function



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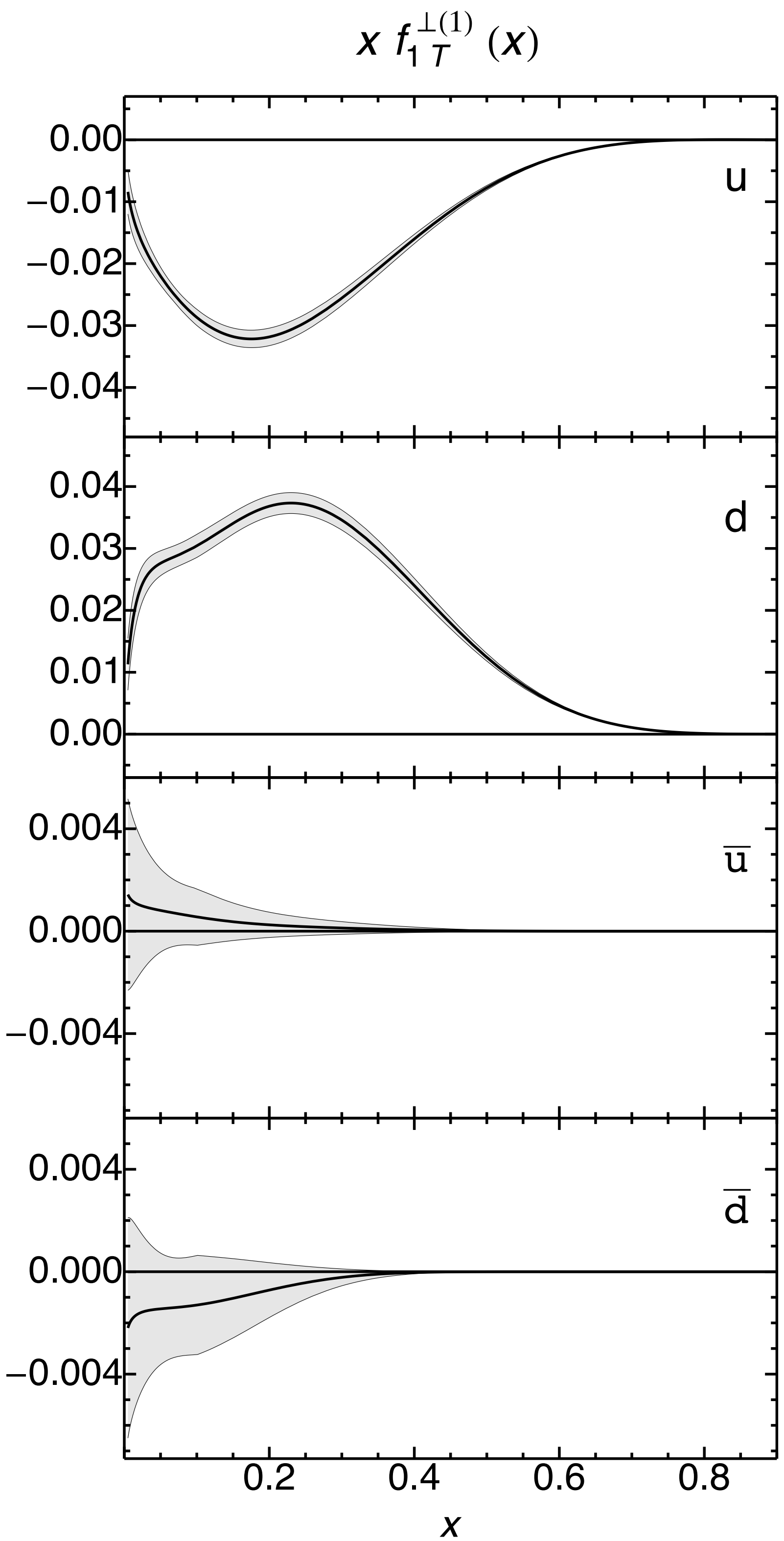

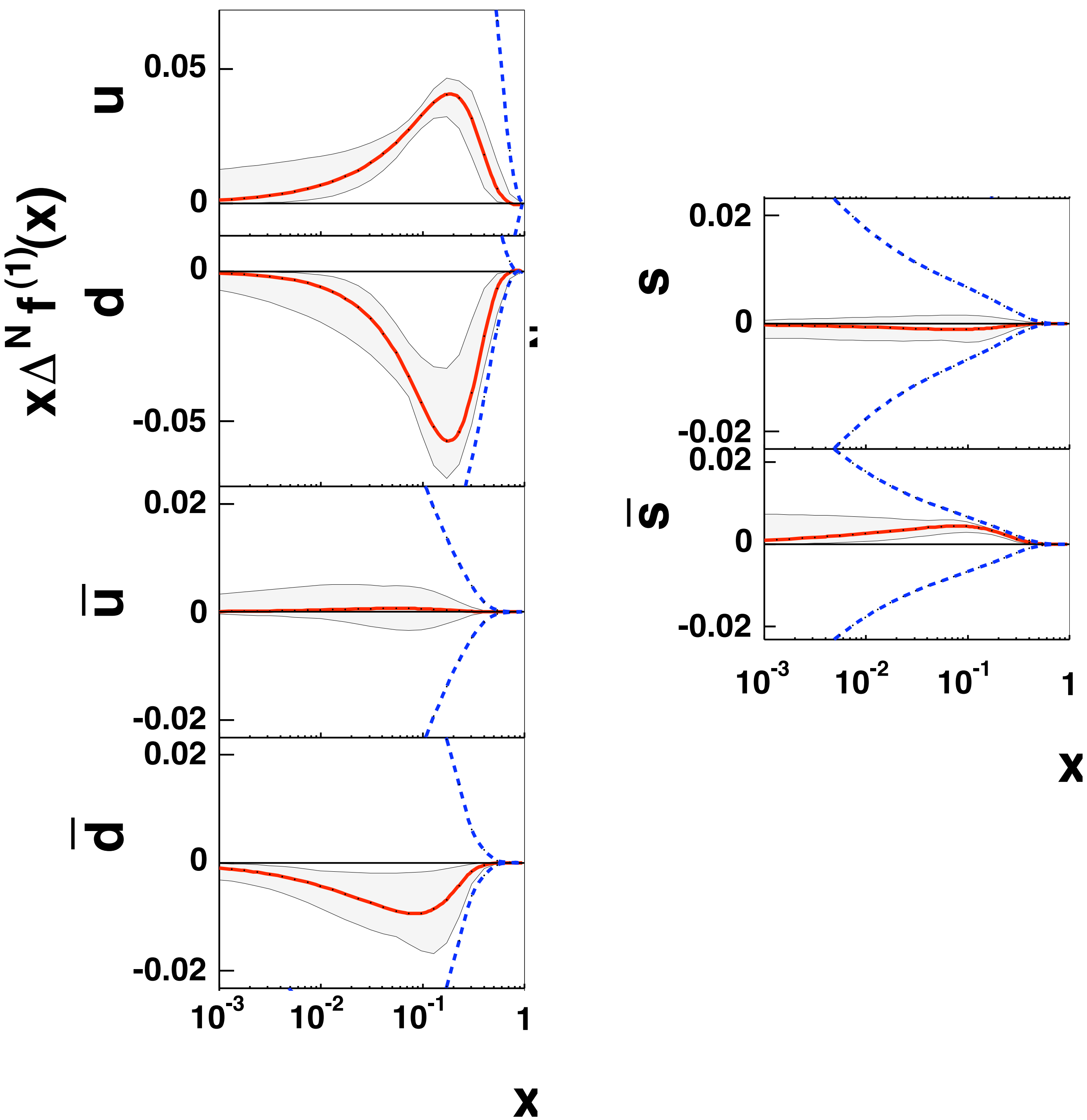

* *Anselmino et al., EPJA 39 (09)*
(note opposite sign convention)

Angular momenta from TMDs

$$J^u = 0.266 \pm 0.002^{+0.009}_{-0.014}, \qquad J^{\bar{u}} = 0.014 \pm 0.004^{+0.001}_{-0.000},$$

$$J^d = -0.012 \pm 0.003^{+0.024}_{-0.006}, \qquad J^{\bar{d}} = 0.022 \pm 0.006^{+0.001}_{-0.000},$$

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$$Q^2 = 1\ \mathrm{GeV}^2$$

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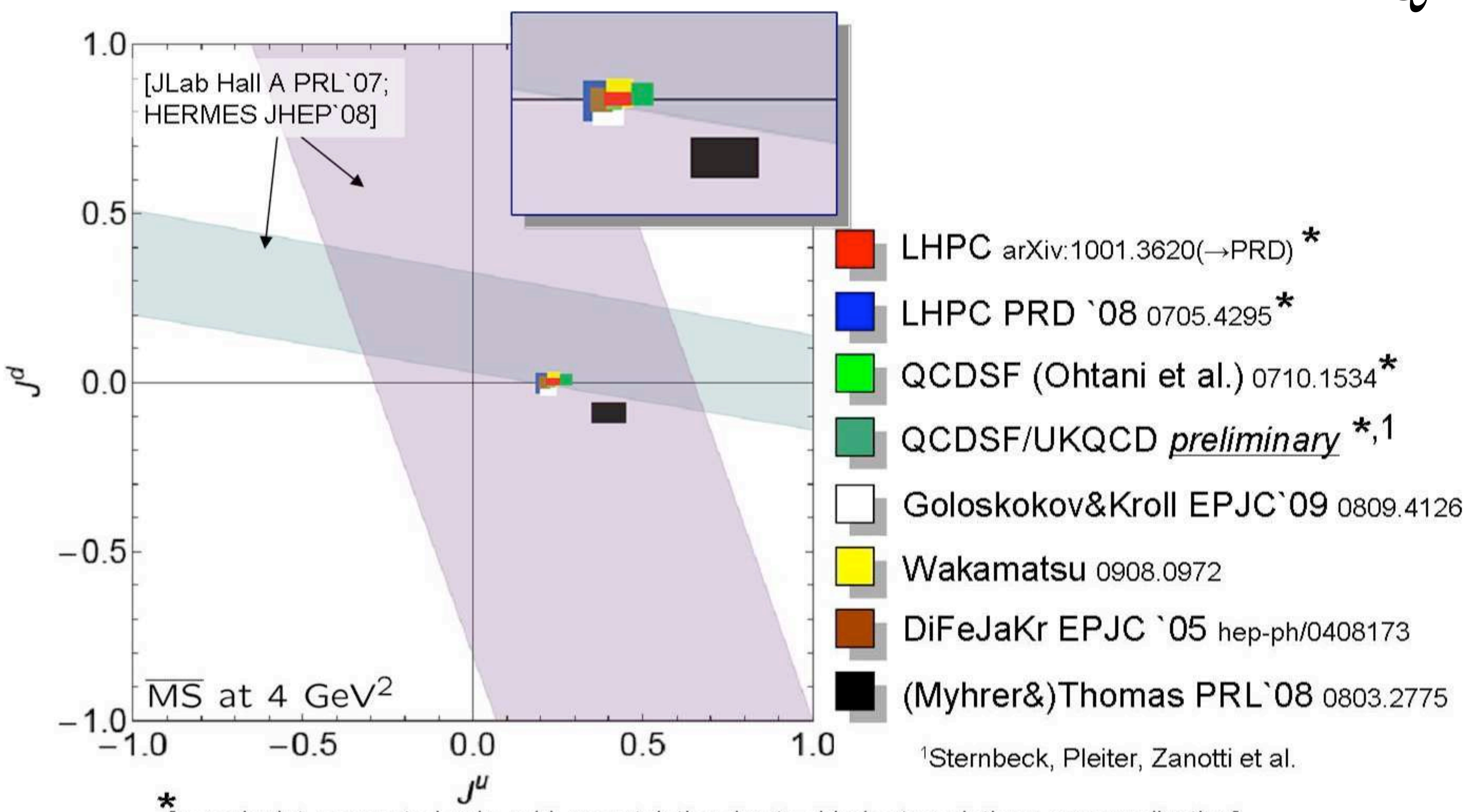

[1]Sternbeck, Pleiter, Zanotti et al.

* [non-singlet, connected only; add. uncertainties due to chiral extrapolations, renormalization]

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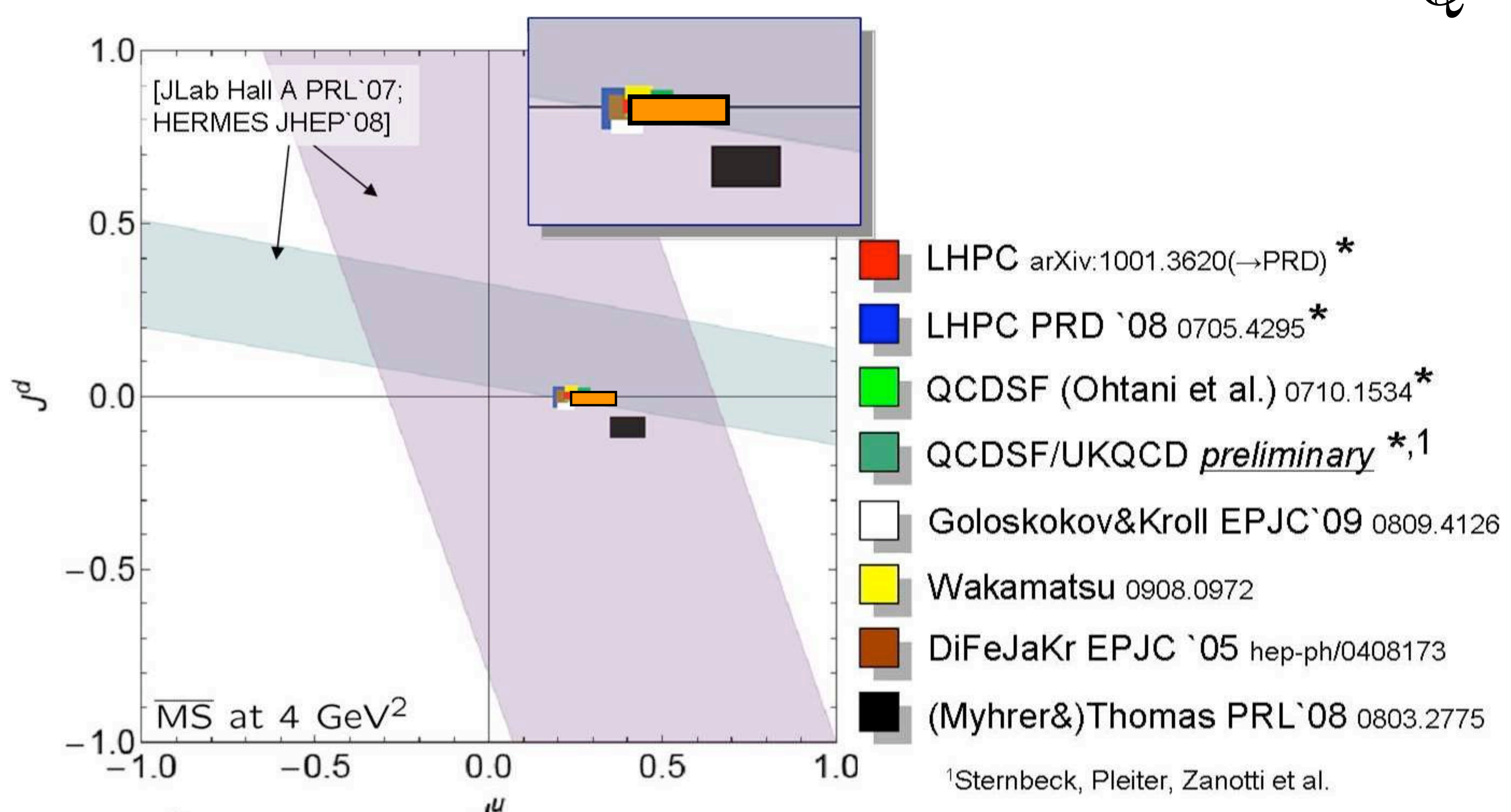

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Using model relations, we can obtain information on angular momentum from TMDs