Comparative Analysis of Transversities and Longitudinally Polarized Distributions of the Nucleon

M. Wakamatsu, September 3, 2007, Dspin07

1. Introduction

- Transversity is one of 3 fundamental PDFs with the lowest twist

unpolarized PDF	$q(x)$	:	target spin average
longitudinally polarized PDF	$\Delta q(x)$	:	target helicity asymmetry
transversity	$\Delta_T q(x)$	:	target helicity flip

chiral-odd ⟹ little empirical information !

Very recently, Anselmino et al, succeded to get a first empirical information on the transversities from the combined global analysis of the azimuthal asymmetries in semi-inclusive DIS scatterings measured by HERMES and COMPASS groups, and those in $e^+ e^- \longrightarrow h_1 h_2 X$ processes by the Belle Collaboration.

Main observation for transversities

(1) $\Delta_T u(x)$ is positive and $\Delta_T d(x)$ is negative, with $|\Delta_T u(x)| \gg |\Delta_T d(x)|$

(2) Both of $\Delta_T u(x), \Delta_T d(x)$ are significantly smaller than the Soffer bounds

The 2nd observation seems only natural, because the magnitudes of unpolarized PDFs are generally much larger than the polarized PDFs.

What is more interesting from the physical viewpoint is the comparison of transversities with the longitudinally polarized distribution functions !

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Main purpose of our present study

2. Position of CQSM in nucleon structure function (DIS) physics

Factorization

- Hard part : Perturbative QCD
- Soft part : Nonpurturbative QCD

Black Box

Nonpurturbative QCD → Lattice QCD / Effective models of QCD

Lattice QCD

- most promising in the long run

  - still at incomplete stage -

- continuum limit & chiral limit ?
- only lower moments of PDF
- physical interpretation ?

Effective models of QCD

So many !

Necessary condition of good model, which has predictive power ?

- able to explain many observables with less parameters !

Advantages of Chiral Quark Soliton Model

$$\mathcal{L}_{CQSM} = \psi \left(i \not\partial - M e^{i \boldsymbol{\tau} \cdot \boldsymbol{\pi}(x)/f_\pi} \right) \psi$$

- only 1 parameter of the model (dynamical quark mass) was already fixed from low energy phenomenology $[\, M = (375 - 400)\,\mathrm{MeV}\,]$

parameter-free predictions for PDFs

- a nucleon is a composite of N_c valence quarks and infinitely many Dirac sea quarks moving in a slowly rotating M.F. of hedgehog shape
- field theoretical nature of the model (proper inclusiuon of polarized Dirac-sea quarks) enables reasonable estimation of antiquark dist.

Default

Lack of explicit gluon degrees of freedom

How to use predictions of this low energy model for parton distributions ?

We follow the spirit of

* M. Glueck, E. Reya, and A. Vogt, Z. Phys. C67 (1995) 433

They start the QCD evolution at the extraordinary low energy scales like

$$
\begin{aligned}
Q^2 &= 0.23\,\mathrm{GeV}^2 \quad \text{at LO case} \\
&= 0.35\,\mathrm{GeV}^2 \quad \text{at NLO case}
\end{aligned}
$$

Even at such low energy scales, their PDF fit turns out to need

nonperturbatively generated sea-quarks (and some gluons)

which may be connected with the effects of

meson clouds

Our general strategy

- use predictions of CQSM as initial-scale distributions of DGLAP eq.

$$u(x), \bar{u}(x), d(x), \bar{d}(x) \;;\; \Delta u(x), \Delta \bar{u}(x), \Delta d(x), \Delta \bar{d}(x)$$
$$s(x) = \bar{s}(x) = g(x) = 0 \;;\; \Delta s(x) = \Delta \bar{s}(x) = \Delta g(x) = 0$$

for flavor SU(2) CQSM

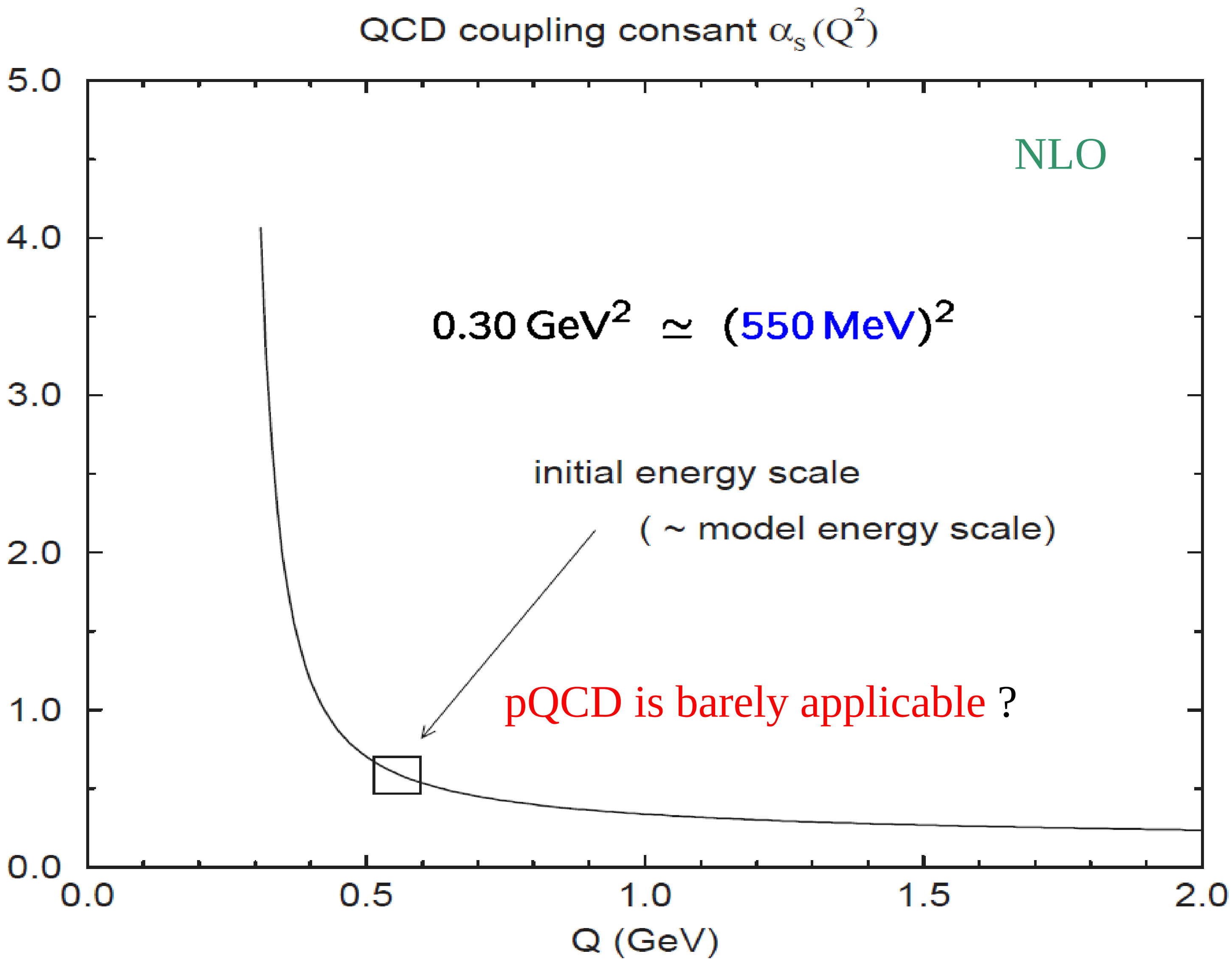
$$u(x), \bar{u}(x), d(x), \bar{d}(x), s(x), \bar{s}(x) \;;$$
$$\Delta u(x), \Delta \bar{u}(x), \Delta d(x), \Delta \bar{d}(x), \Delta s(x), \Delta \bar{s}(x)$$
$$g(x) = 0 \;;\; \Delta g(x) = 0$$

for flavor SU(3) CQSM

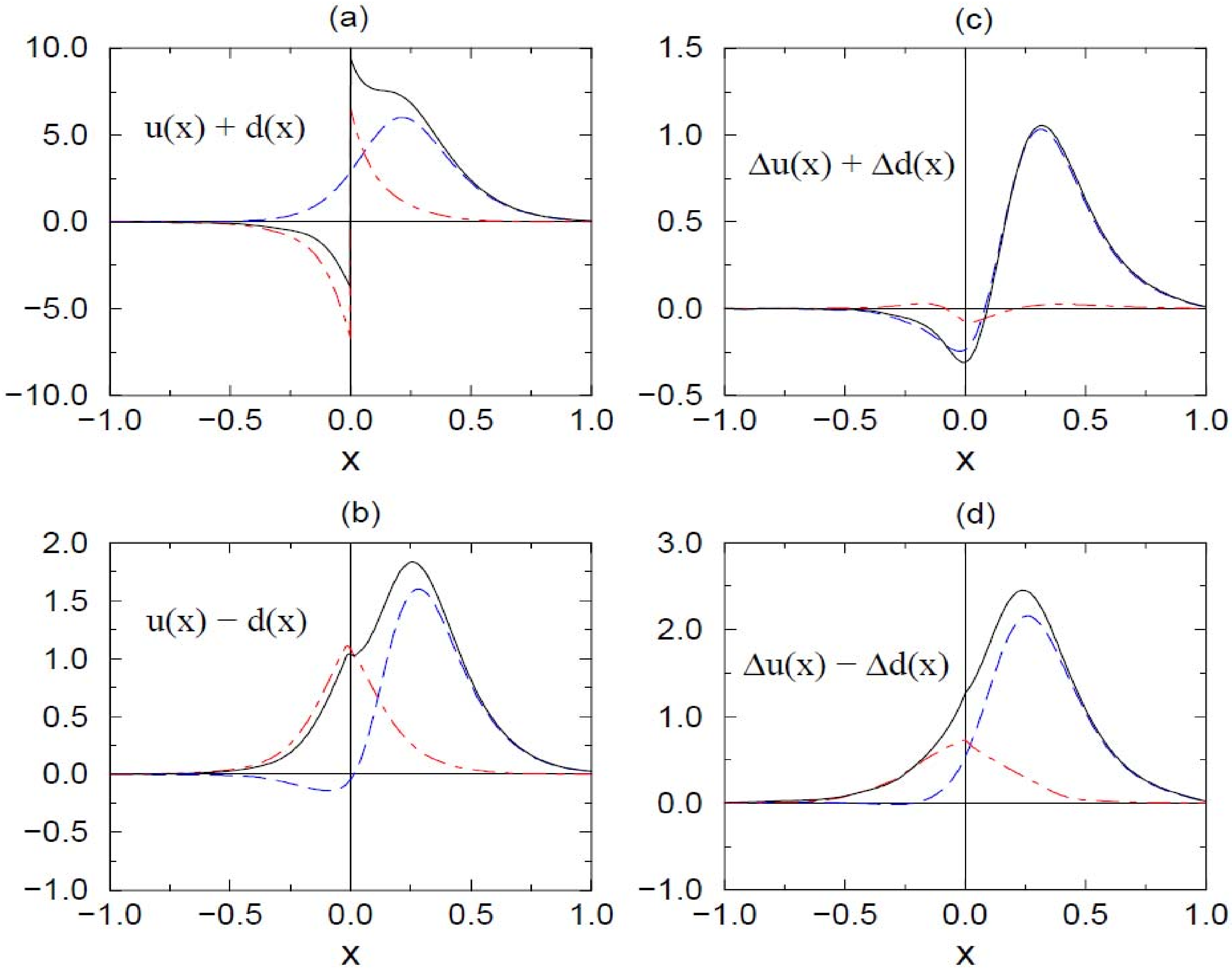
- initial energy scale is fixed to be

$$Q^2_{ini} = 0.30\,\mathrm{GeV}^2 \simeq (550\,\mathrm{MeV})^2$$

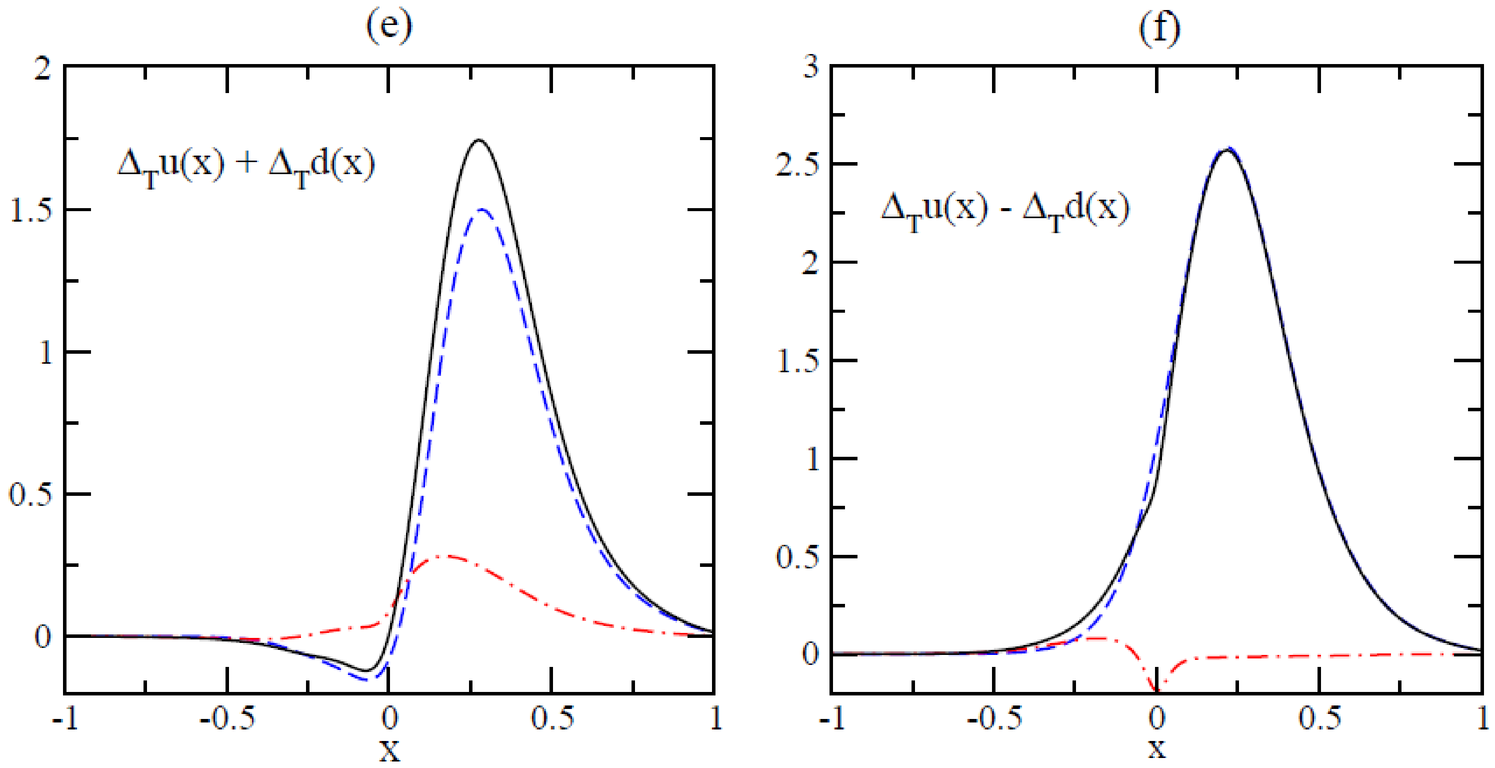
On the Applicability of pQCD ?



Parameter free predictions of the CQSM ： 3 twist-2 PDFs

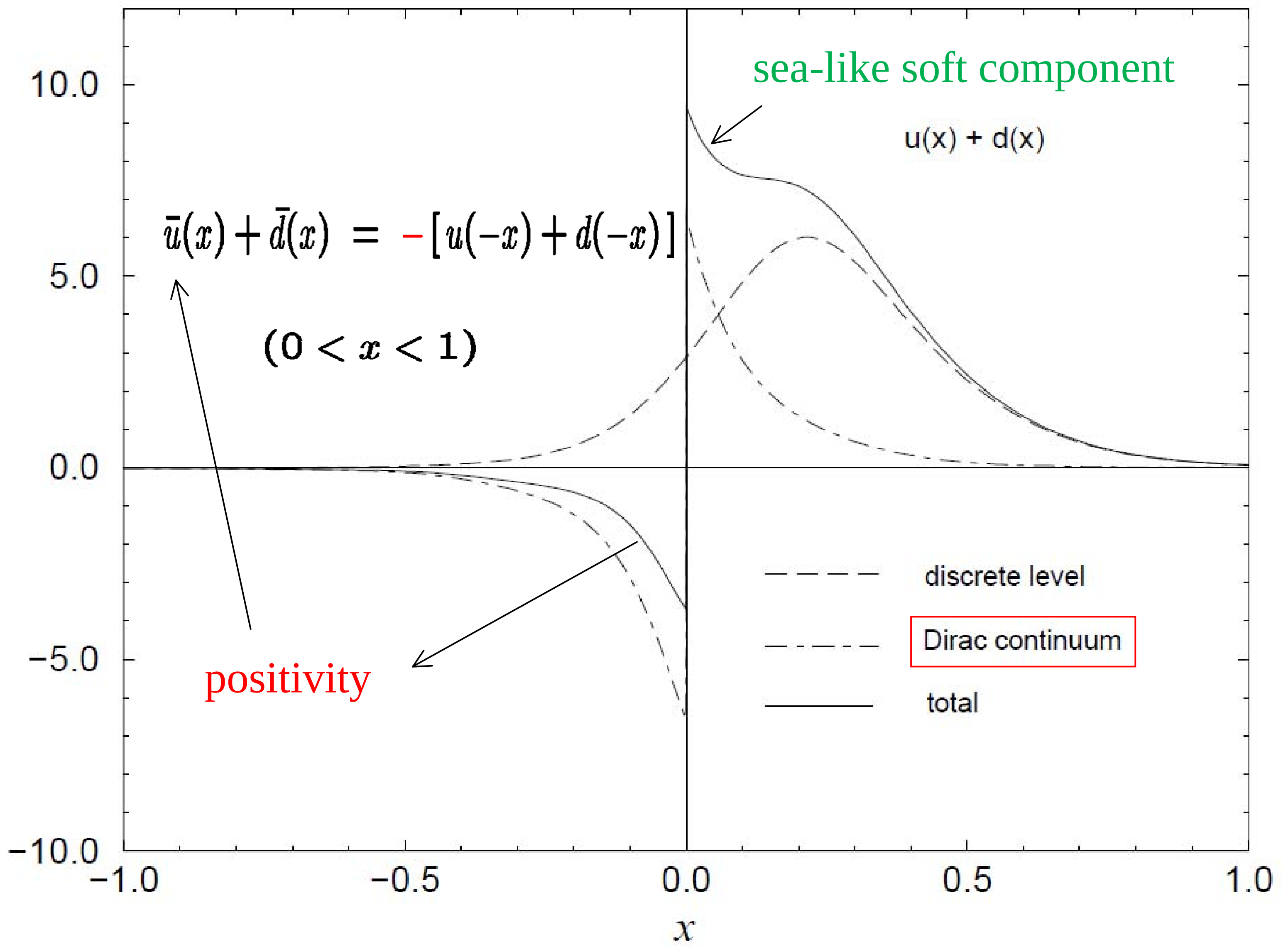


Transversities [3rd twist-2 PDF]

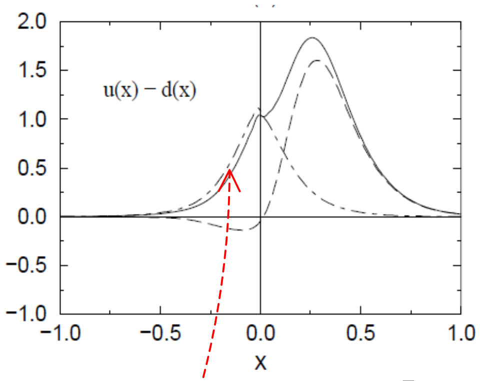


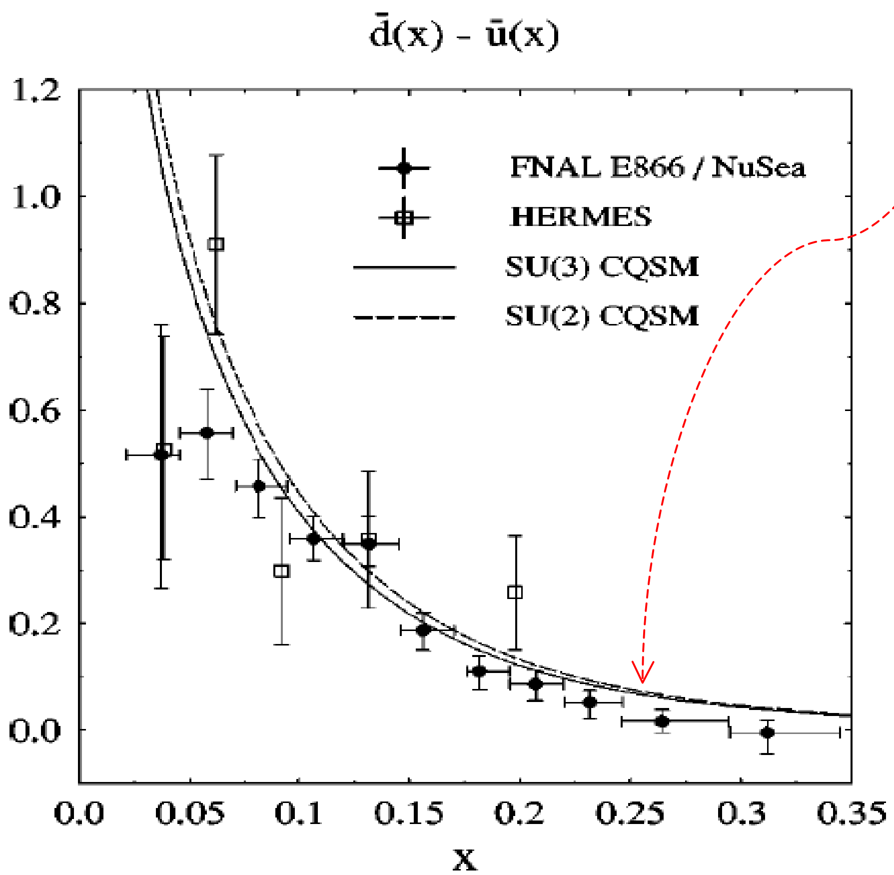
- Totally different behavior of Dirac-sea contributions in different PDFs !

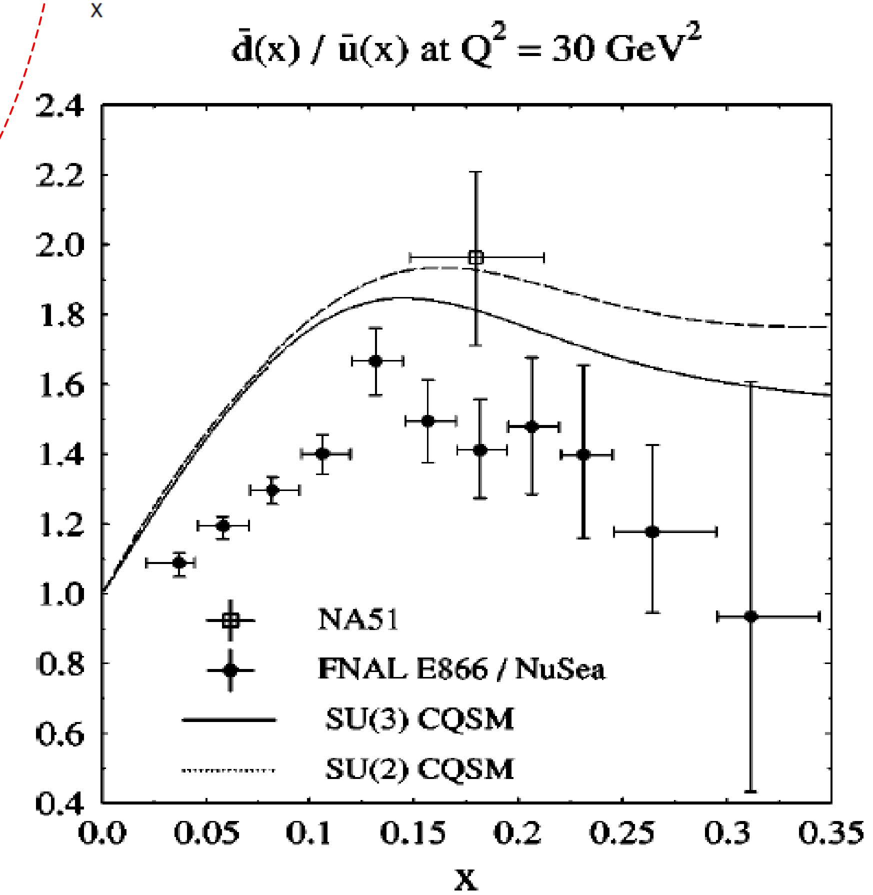
Isoscalar unpolarized PDF



Isovector unpolarized PDF



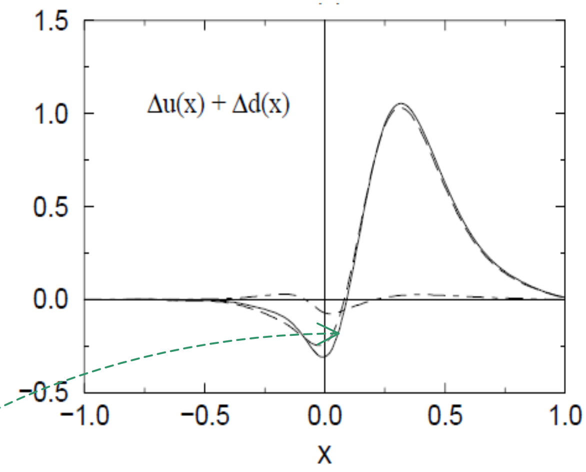


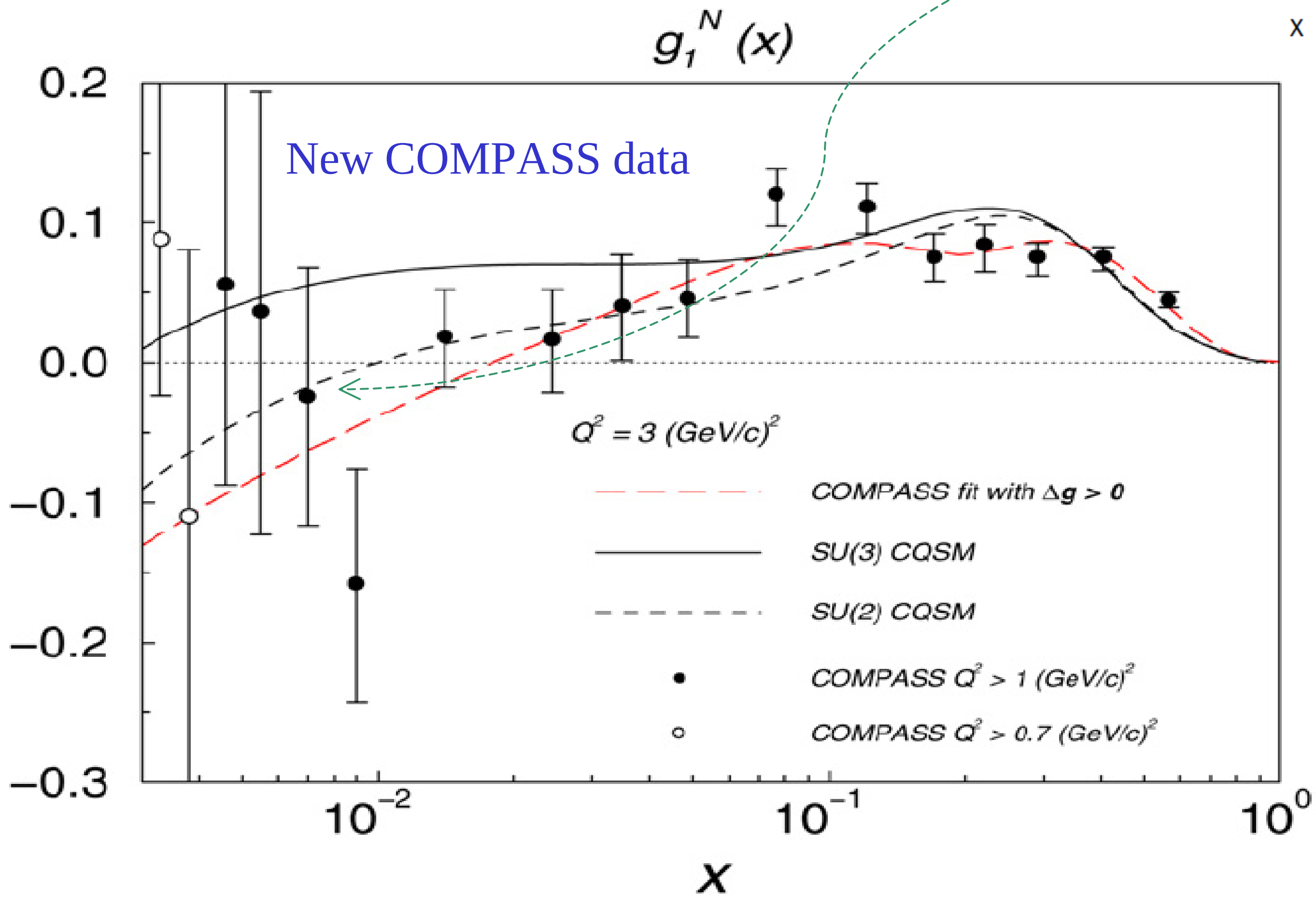


$$\bar{u}(x) - \bar{d}(x) = -[u(-x) - d(-x)] \quad (0 < x < 1)$$

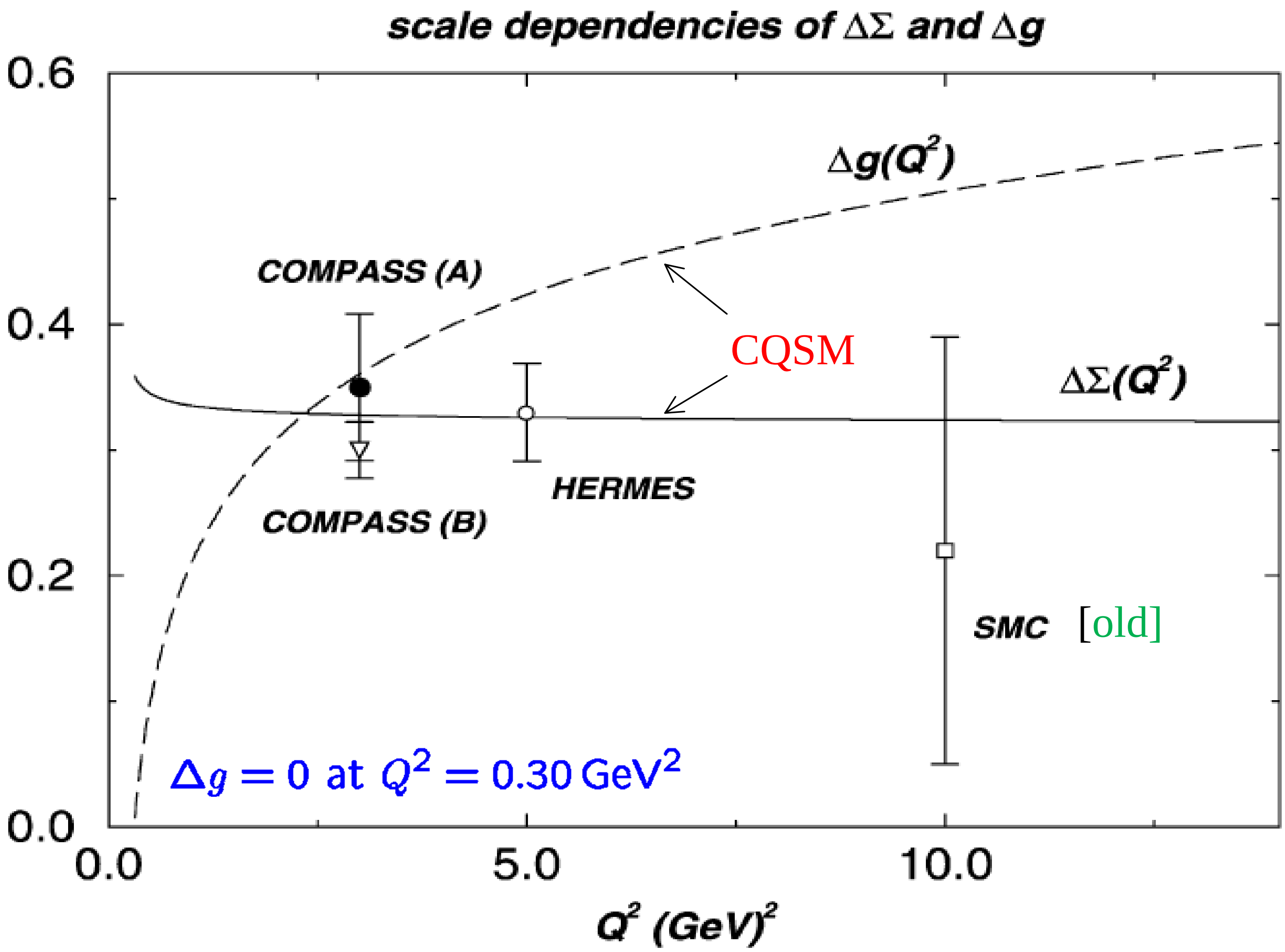
Isoscalar longitudinally polarized PDF

$$g_1^N(x) = g_1^d(x) \,/\, (\,1 - 1.5\,\omega_D\,)\ \ :$$





New COMPASS and HERMES fits for $\Delta\Sigma$ in comparison with CQSM prediction



Isovector longitudinally polarized PDF

CQSM predicts $\Delta\bar{u}(x) - \Delta\bar{d}(x) > 0$

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This means that antiquarks gives sizable positive contribution to Bjorken S.R.

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denied by the HERMES analysis of semi-inclusive DIS data

- HERMES Collabotation, Phys. Rev. D71 (2005) 012003

However, HERMES analysis also denies negative strange-quark polarization
favored by the global-analysis heavily depending on inclusive DIS data !

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We need more complete understanding of

spin-dependent fragmentation mechanism

3. Transversities versus longitudinally polarized distributions3

We are interested in the difference between

$$\Delta q(x) \quad \text{and} \quad \Delta_T q(x)$$

The most important quantities characterizing these are their 1st moments, called

axial charge g_A & **tensor charge** g_T

Understanding of isospin dependencies is crucially important for disentangling nonpertubative chiral dynamics hidden in the PDFs

$$g_A^{(I=0)} = \int_0^1 \left\{ [\Delta u(x) + \Delta d(x)] + [\Delta \bar{u}(x) + \Delta \bar{d}(x)] \right\} dx$$

$$g_A^{(I=1)} = \int_0^1 \left\{ [\Delta u(x) - \Delta d(x)] + [\Delta \bar{u}(x) - \Delta \bar{d}(x)] \right\} dx$$

$$g_T^{(I=0)} = \int_0^1 \left\{ [\Delta_T u(x) + \Delta_T d(x)] - [\Delta_T \bar{u}(x) + \Delta_T \bar{d}(x)] \right\} dx$$

$$g_T^{(I=1)} = \int_0^1 \left\{ [\Delta_T u(x) - \Delta_T d(x)] - [\Delta_T \bar{u}(x) - \Delta_T \bar{d}(x)] \right\} dx$$

Known basic facts

(A) Naïve quark model

$$g_A^{(I=1)} = g_T^{(I=1)} = \frac{5}{3}, \qquad g_A^{(I=0)} = g_T^{(I=0)} = 1$$

(B) MIT bag model

$$g_A^{(I=1)} = \frac{5}{3} \cdot \int \left(f^2 - \frac{1}{3} g^2 \right) r^2 \, dr, \qquad g_A^{(I=0)} = 1 \cdot \int \left(f^2 - \frac{1}{3} g^2 \right) r^2 \, dr$$

$$g_T^{(I=1)} = \frac{5}{3} \cdot \int \left(f^2 + \frac{1}{3} g^2 \right) r^2 \, dr \qquad g_T^{(I=0)} = 1 \cdot \int \left(f^2 + \frac{1}{3} g^2 \right) r^2 \, dr$$

$f(r), g(r)$: upper & lower components of g.s w.f.

Important observation

$$\frac{g_A^{(I=0)}}{g_A^{(I=1)}} = \frac{g_T^{(I=0)}}{g_T^{(I=1)}} = \frac{3}{5}$$

in both of NQM & MIT bag model

Comparison with the CQSM predictions

	MIT bag	CQSM	Experiment
$g_A^{(I=1)}$	1.06	1.31	1.267
$g_A^{(I=0)}$	0.64	0.35	$0.330 \pm 0.040 \quad (Q^2 = 5\text{GeV}^2)$
$g_T^{(I=1)}$	1.34	1.21	
$g_T^{(I=0)}$	0.88	0.68	
$g_A^{(I=0)} / g_A^{(I=1)}$	0.60	0.27	~ 0.26
$g_T^{(I=0)} / g_T^{(I=1)}$	0.60	0.56	

CQSM predicts for tensor and axial charges that

$$g_T^{(I=1)} \simeq g_A^{(I=1)}, \quad \text{while} \quad g_T^{(I=0)} \gg g_A^{(I=0)}$$

Expected features for transversities and longitudinally polarized PDF

$$\Delta_T q^{(I=1)}(x) \simeq \Delta q(x)^{(I=1)}, \quad \Delta_T q^{(I=0)}(x) \gg \Delta q^{(I=0)}(x)$$

In other words

$$|\Delta_T d(x)| \ll |\Delta d(x)|$$

This is because

$$\Delta_T d(x) \simeq 0, \quad \text{if} \quad \Delta_T q^{(I=0)}(x) \simeq \Delta_T q^{(I=1)}(x)$$

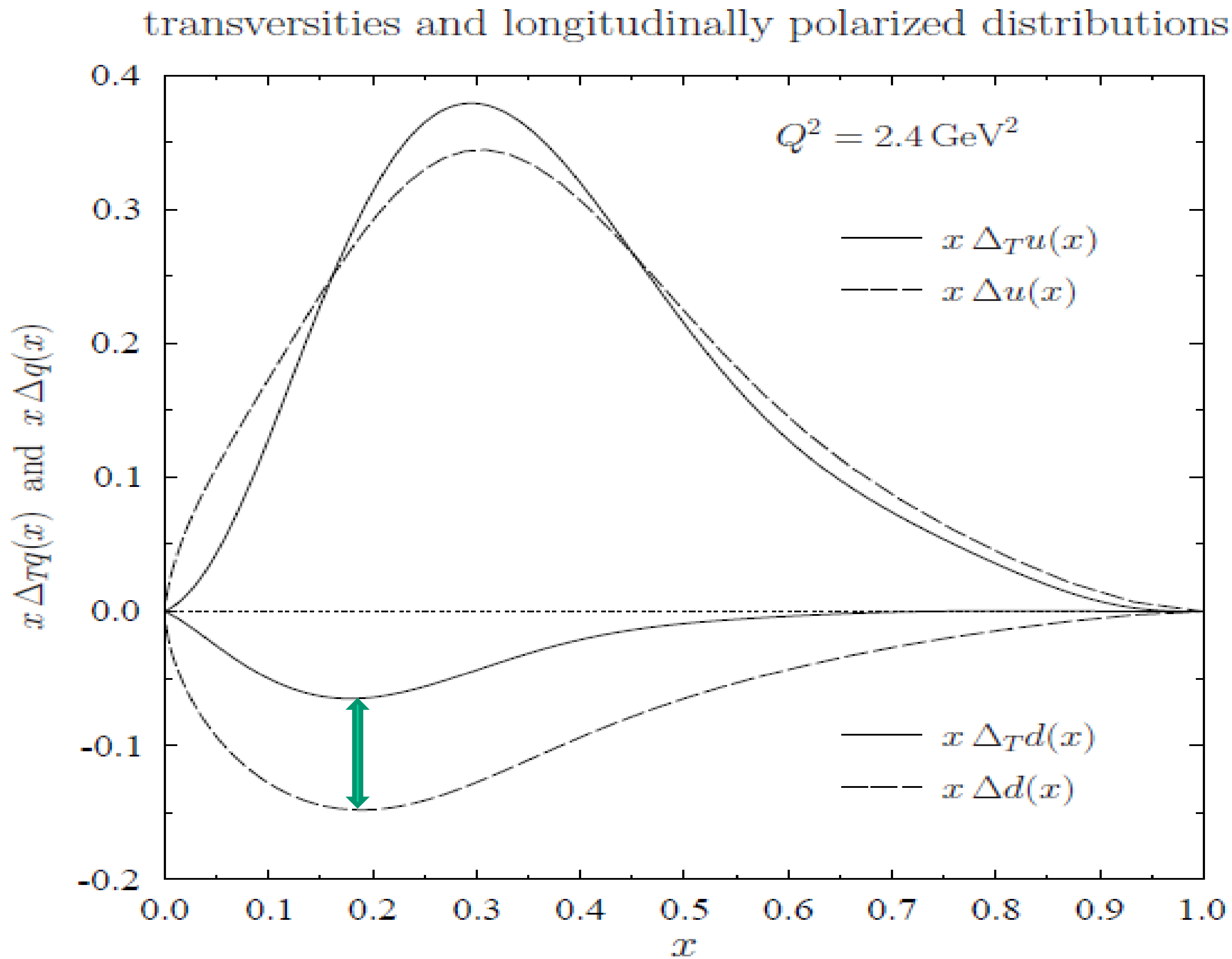
$$\Delta_T u(x) \simeq -\Delta_T d(x), \quad \text{if} \quad \Delta_T q^{(I=0)}(x) \simeq 0$$

from

$$\Delta_T u(x) = \frac{1}{2}\left[\Delta_T q^{(I=0)}(x) + \Delta_T q^{(I=1)}(x)\right]$$

$$\Delta_T d(x) = \frac{1}{2}\left[\Delta_T q^{(I=0)}(x) - \Delta_T q^{(I=1)}(x)\right]$$

CQSM predictions evolved to $Q^2 = 2.4\,\mathrm{GeV}^2$



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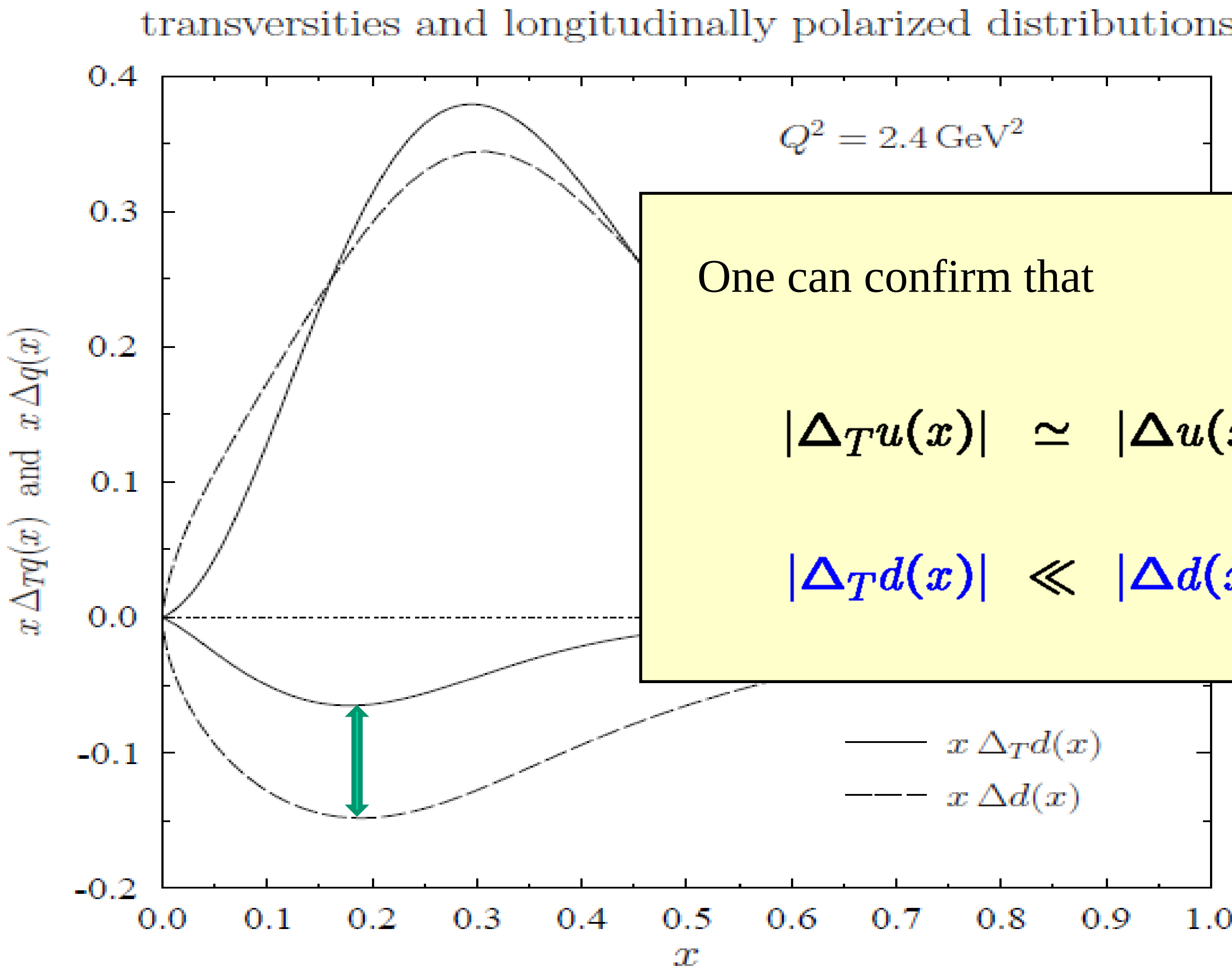
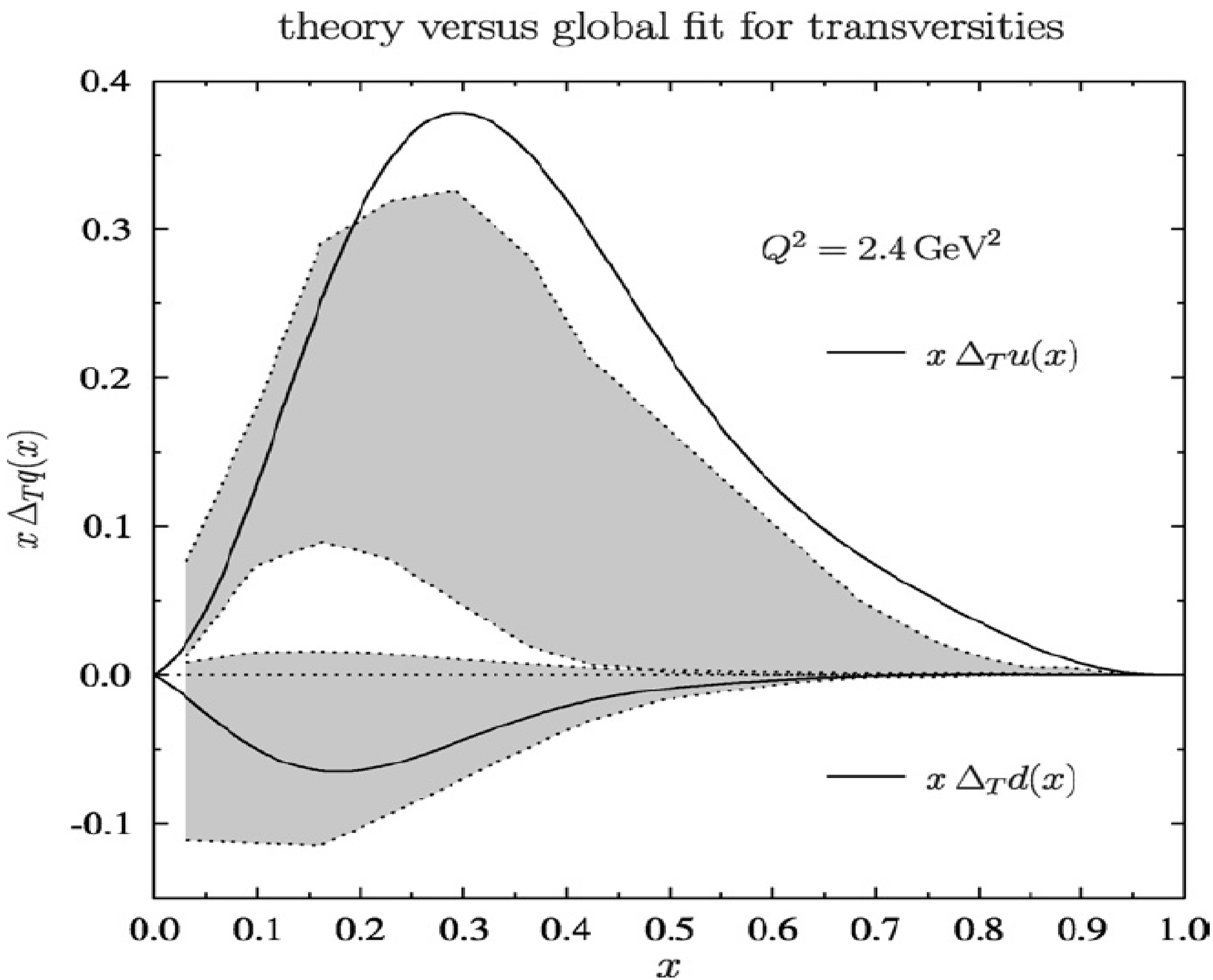


One can confirm that

$$|\Delta_T u(x)| \simeq |\Delta u(x)|$$

$$|\Delta_T d(x)| \ll |\Delta d(x)|$$

Comparison with global fit by Anselmino et al.



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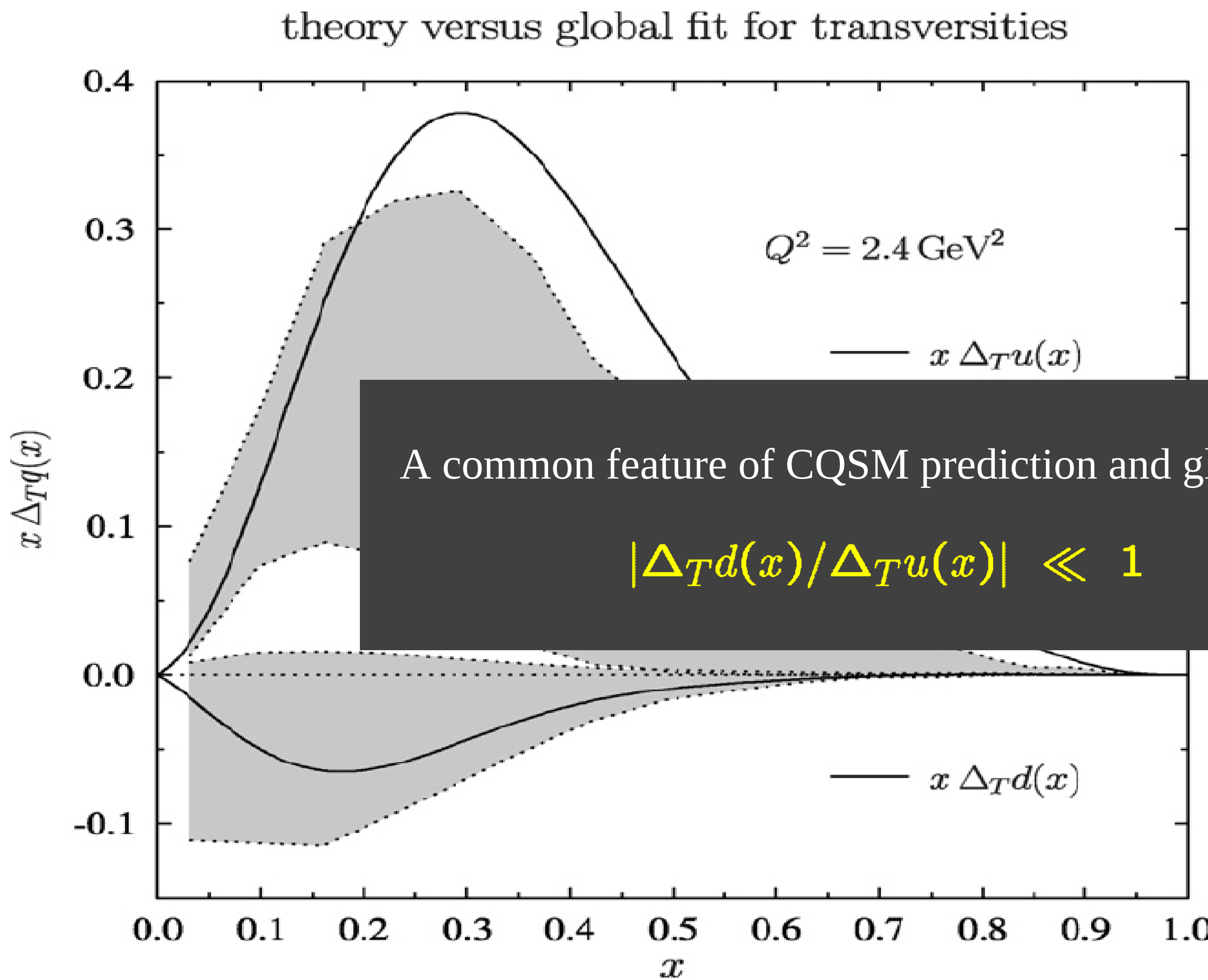
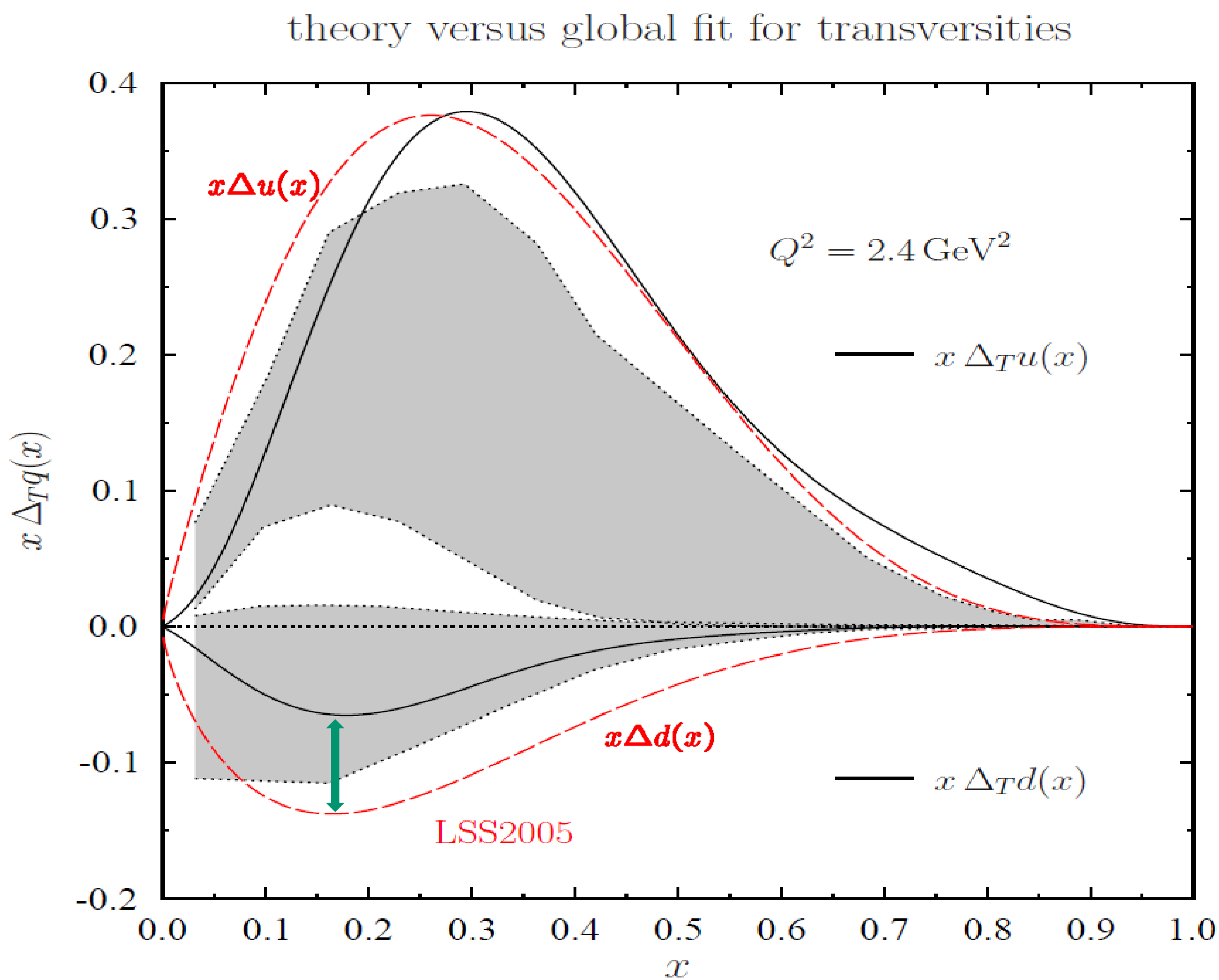


A common feature of CQSM prediction and global fit

$$|\Delta_T d(x)/\Delta_T u(x)| \ll 1$$

LSS2005 longitudinally polarized PDF for comparison



Why does the CQSM predicts very small $g_A^{(I=0)}$?

Nucleon spin sum rule in CQSM

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L^Q \quad \left(\Delta\Sigma = g_A^{(I=0)} \ \text{in} \ \overline{MS} \ \text{scheme} \right)$$

~ 35% ~ 65% at $Q^2 \simeq (600\,\text{MeV})^2$

Nucleon spin sum rule in QCD

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L^Q + \Delta g + L^g$$

Δg ~ likely to be small ? : a lot of evidences by now !

$\Delta\Sigma(Q^2 = 5\,\text{GeV}^2)^{HERMES} \simeq 0.330 \pm 0.040$: weakly scale dependent !

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$L^Q + L^q$ must be large !

Is there any sum rule that constrains the magnitude of $g_T^{(I=0)}$, then ?

Bakker-Leader-Trueman sum rule (2004)

$$\frac{1}{2} = \frac{1}{2} \sum_{a=q,\bar{q}} \int_0^1 \Delta_T q^a(x) + \sum_{a=q,\bar{q},g} \langle L_{s_T} \rangle^a$$

component of L along the transverse spin direction s_T

Peculiarity of BLT sum rule

- It is not such a sum rule, obtained as a 1st moment of PDF.

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r.h.s. does not correspond to a nucleon matrix element of local operator !

- The 1st term does not correspond to tensor charge.

$$\sum_{a=q,\bar{q}} \int_0^1 \Delta_T q^q(x)\, dx \;=\; \int_0^1 \left\{ [\Delta_T u(x) + \Delta_T d(x)] \;+\; \left[\Delta_T \bar{u}(x) + \Delta_T \bar{d}(x)\right] \right\}$$

$$\neq \qquad g_T^{(I=0)}$$

- Nonetheless, CQSM indicates that antiquark transversities are fairly small, so that

$$\sum_{a=q,\bar{q}} \int_0^1 \Delta_T q^q(x)\, dx \;\simeq\; g_T^{(I=0)}$$

Then, $g_T^{(I=0)} \gg g_A^{(I=0)}$ is in fact confirmed experimentally, it indicates

$$L_{s_T}^Q \;+\; L_{s_T}^g \;\ll\; L^Q \;+\; L^g$$

transverse OAM $\ll$ longitudinal OAM

On the discrepancy between the CQSM predictions and Alselmino et al.'s fit

We can estimate tensor charges from their central fit, under the assumption that the antiquark contributions to them are negligible (as justified by the CQSM)

–

Evolved down to the low energy model scale, by using the NLO evolution eq.

We recall that all the theoretical estimates in the past, based on the low energy models as well as the lattice QCD, gives

$$1 \; < \; g_T^{(I=1)} \; < \; 1.5$$

4. Summary and Conclusion

- We have carried out a comparative analysis of the transversities and the longitudinally polarized PDF in light of the new global fit of transversities and the Collins fragmentation functions carried out by Anselmino et al.

- Their results, although with large uncertainties, already indicates a remarkable qualitative difference between transversities and longitudinally polarized PDFs such that

$$|\Delta_T d(x) / \Delta d(x)| \ll |\Delta_T u(x) / \Delta u(x)|$$

- The cause of this feature can be traced back to the relation

$$g_T^{(I=0)} \gg g_A^{(I=0)} = \Delta\Sigma$$

- Combining with BLT sum sule, this would indicate

$$L^Q_{S_T} + L^g_{S_T} \ll L^Q + L^g$$

Dinamical effects of Lorentz Boost ?

- The global analysis by Anselmino et al. is just the 1st step to extract transversities.

- More complete understanding of the spin dependent fragmentation mechanism is mandatory, for getting more definite knowledge of the transversities.

- Also very desirable is some independent deternimation of transversities, for example, through double transverse spin asymetry

A_{TT} in $p\bar{p}$ Drell-Yan processes