First JAM results on polarized PDFs

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(for the JAM collaboration)

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Jefferson Lab Angular Momentum Collaboration

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About JAM

The **JAM (Jefferson Lab Angular Momentum)** Collaboration is an enterprise involving theorists and experimentalists from the Jefferson Lab community to study the quark and gluon spin structure of the nucleon by performing global fits of spin-dependent parton distribution functions (PDFs).

Because of the unique capabilities of Jefferson Lab's CEBAF accelerator in measuring small cross sections at extreme kinematics, the JAM spin PDFs are particularly tailored for studies of the **large Bjorken-*x*** region, as well as the resonance-deep inelastic transition region at low and intermediate values of W and Q^2.

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Parallel effort to our unpolarized PDFs: CJ and JR

Who's who

www.jlab.org/jam

Theory:

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- Alberto Accardi (Hampton U. / JLab)
- Wally Melnitchouk (JLab)

Experiment:

- Peter Bosted (JLab / William&Mary)
- Jian-ping Chen (JLab)
- Keith Griffioen (William&Mary)
- Sebastian Kuhn (Old Dominion U.)
- Oscar Rondon (U. of Virginia)
- Brad Sawatzky (JLab)

The JAM database

www.jlab.org/jam

Public database with all data on polarized scattering experiments (DIS for now)

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Experiments

- All data
- proton
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JAM database - Experiments

Experiment	Description
COMPASS	proton and deuteron A1, g1
EMC	proton A1, g1
HERMES	proton, deuteron, and 3He A_par, neutron A1
HERMES2012	proton A2 and g2
JLab Hall A (E01-012)	3He A_par, A1, g1
JLab Hall A (E97-103)	3He (and neutron) asymmetries, g1, g2
JLab Hall A (E99-117)	3He (and neutron) asymmetries, g1, g2
JLab Hall B (EG1b)	proton and deuteron A1
JLab Hall C (E01-006 "RSS")	proton and deuteron A_par and A_perp (resonance region)
SLAC E142	3He A1, A2, g1, g2
SLAC E143	proton and deuteron A_par, A_perp
SLAC E154	3He A_par, A_perp
SLAC E155	proton and deuteron A1, A2, g1, g2
SLAC E155x	proton and deuteron A2, g2
SLAC E80/E130	proton A_par
SMC	proton and deuteron A1, g1

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Data and theory comparison with other groups

	DIS	SIDIS	hadron collider	nuclear smearing	TMCs	HT g_1	HT g_2
DSSV 09	✓	✓	✓				
AAC 09	✓		✓				
BB 10	✓				✓	✓	~
LSS 10	✓	✓			✓	✓	
NNPDF 13	✓				✓		
JAM 13	✓			✓	✓	✓	✓

Presently concentrating on DIS theoretical description

Long-term objective: tick all the boxes (include SIDIS and collider data)

Data considered at this (first) stage

World data on polarized DIS (for $Q^2 \geq 1\ \mathrm{GeV}^2$, $W^2 \geq 3.5\ \mathrm{GeV}^2$)

PROTON	**SLAC E80/E130:** G. Baum et al., Phys. Rev. Lett. **51**, 1135 (1983)
	EMC: J. Ashman et al., Nucl. Phys. **B328**, 1 (1989)
	SMC: B. Adeva et al., Phys. Rev. D **58**, 112001 (1998)
	Phys. Rev. D **60**, 072004 (1999)
	Erratum-ibid. Phys. Rev. D **62**, 079902 (2000)
	COMPASS: M.G. Alekseev et al., Phys. Lett. B **690**, 466 (2010)
	SLAC E143: K. Abe et al., Phys. Rev. D **58**, 112003 (1998)
	SLAC E155: P.L. Anthony et al., Phys. Lett. B **493**, 19 (2000)
	Phys. Lett. B **458**, 529 (2000)
	SLAC E155x: P.L. Anthony et al., Phys. Lett. B **553**, 18 (2003)
	HERMES: A. Airapetian et al., Phys. Rev. D **75**, 012007 (2007)
	[**JLab Hall B (EG1b):** Y. Prok et al., Phys. Lett. B **672**, 12 (2009)]
	HERMES: A. Airepetian et al., Eur. Phys. J. C **72**, 1921 (2012)
DEUTERON	**SMC:** B. Adeva et al., Phys. Rev. D **58**, 112001 (1998)
	Phys. Rev. D **60**, 072004 (1999)
	Erratum-ibid. Phys. Rev. D **62**, 079902 (2000)
	COMPASS: V.Yu. Alexakhin et al., Phys. Lett. B **647**, 8 (2007)
	SLAC E143: K. Abe et al., Phys. Rev. D **58**, 112003 (1998)
	SLAC E155: P.L. Anthony et al., Phys. Lett. B **463**, 339 (1999)
	Phys. Lett. B **458**, 529 (2000)
	SLAC E155x: P.L. Anthony et al., Phys. Lett. B **553**, 18 (2003)
	HERMES: A. Airapetian et al., Phys. Rev. D **75**, 012007 (2007)
	[**JLab Hall B (EG1b):** Y. Prok et al., Phys. Lett. B **672**, 12 (2009)]
HELIUM-3	**SLAC E142:** P.L. Anthony et al., Phys. Rev. D **54**, 6620 (1996)
	SLAC E154: K. Abe et al., Phys. Rev. Lett. **79**, 26 (1997)
	Yu. Kolomensky, Ph.D. thesis, U. Massachusetts (1997),SLAC-Rep-503
	HERMES: K. Ackerstaff et al., Phys. Lett. B **404**, 383 (1997)
	JLab Hall A (E99-117): X. Zhang et al., Phys. Rev. Lett. **92**, 012004 (2004)
	Phys. Rev. C **70**, 065207 (2004)
	[**JLab Hall A (E97-103):** K. Kramer et al., Phys. Rev. Lett. **95**, 142002 (2005)]
	[K. Kramer, Ph.D. thesis, Coll. of William & Mary (2003)]
	[**JLab Hall A (E01-012):** P. Solvignon et al., Phys. Rev. Lett. **101**, 182502 (2008)]

Mainly on *measured* asymmetries:

$$A_{\parallel} = D(A_1 + \eta A_2)$$

$$A_{\perp} = d(A_2 - \xi A_1)$$

D, d depend on

$$R = \frac{F_L}{(1+\gamma^2)F_2 - F_L}$$

$$\gamma^2 = 4\frac{M^2}{Q^2}x^2$$

We *consistently* develop our own unpolarized analysis in parallel (JR)

Dedicated analyses of the impact of *individual* data sets from JLab

Underlying QCD description

Asymmetries from (un)polarized structure functions:

$$A_1 = (g_1 - \gamma^2 g_2)\frac{2x}{(1+\gamma^2)F_2 - F_L} \qquad A_2 = \gamma(g_1 + g_2)\frac{2x}{(1+\gamma^2)F_2 - F_L}$$

Calculations and RGE evolution using Mellin *moments* (truncated solutions)

$$f(n) = \int_0^1 dx\ x^{n-1} f(x)$$

Leading-twist structure functions in OPE from NLO QCD computations:

$$g_1^{\tau=2}(n, Q^2) = \frac{1}{2}\sum_{q,\bar{q}} e_q^2\ (\Delta C_{qq}^1 \Delta q + \Delta C_g^1 \Delta g)$$

$$g_2^{\tau=2}(n, Q^2) = g_2^{WW} = -\frac{n-1}{n} g_1(n, Q^2)$$ [Wandzura, Wilczek 77]

Parametrization

Only *two* independent combinations of **quark distributions** contribute:

$$x\Delta u^+(x,\mu_0^2) = N_u\, x^{a_u}(1-x)^{b_u}(1+B_u\, x)$$

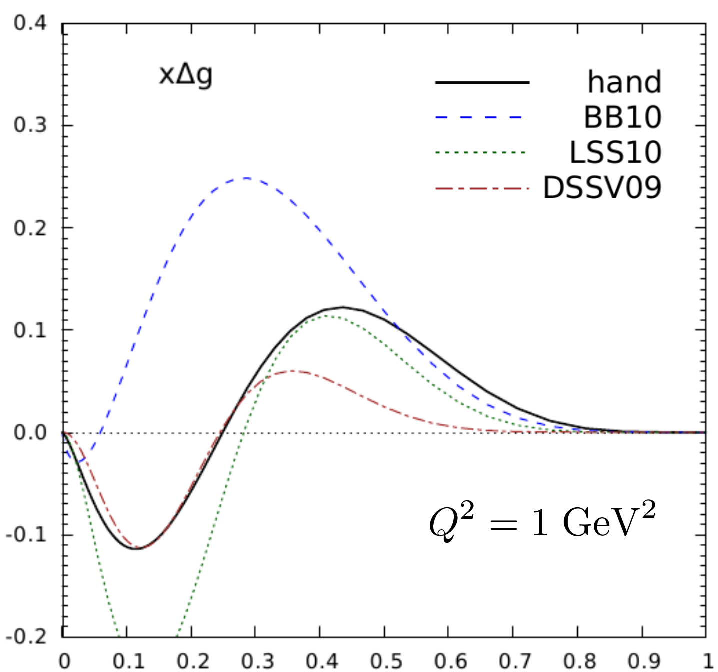
$$x\Delta d^+(x,\mu_0^2) = N_d\, x^{a_d}(1-x)^{b_d}(1+B_d\, x)$$

$$\Delta q^+ \equiv \Delta q + \Delta\bar{q}$$

Constrains from hyperon decays relate N_u and N_d and fix N_s

$$\int_0^1 (\Delta u^+ - \Delta d^+)dx = 1.269 \pm 0.003 \qquad \int_0^1 (\Delta u^+ + \Delta d^+ - 2\Delta s^+)dx = 0.586 \pm 0.031$$

Sea quarks fixed ($\lim_{x\to 0}\Delta\bar{q} = 2\lim_{x\to 0}\Delta q^+$ and counting rules)



Gluons initially fixed to a reasonable function (will be released in subsequent analyses)

Formally Δg enters through QCD evolution
→ in practice current DIS data give only mild constraints $\Delta\chi^2_{glue} \ll \Delta\chi^2_{1\sigma}$

Statistical estimation

9 (LT) + 20 (HT) = 29 parameters to be determined

Least-squares estimator with a *complete treatment* of systematic uncertainties (equivalent to the correlation matrix approach) [CTEQ]:

$$\chi^2 = \sum_{i=1}^{N} \frac{1}{\Delta_i^2} \left(D_i + \sum_{j=1}^{M} r_j \Delta_{ji} - T_i \right)^2 + \sum_{j=1}^{M} r_j^2$$

Here the systematic shifts are calculated *analytically*

Unfortunately most experiments do not provide enough information

Errors estimated with the *Hessian* approach (linear propagation, works well):

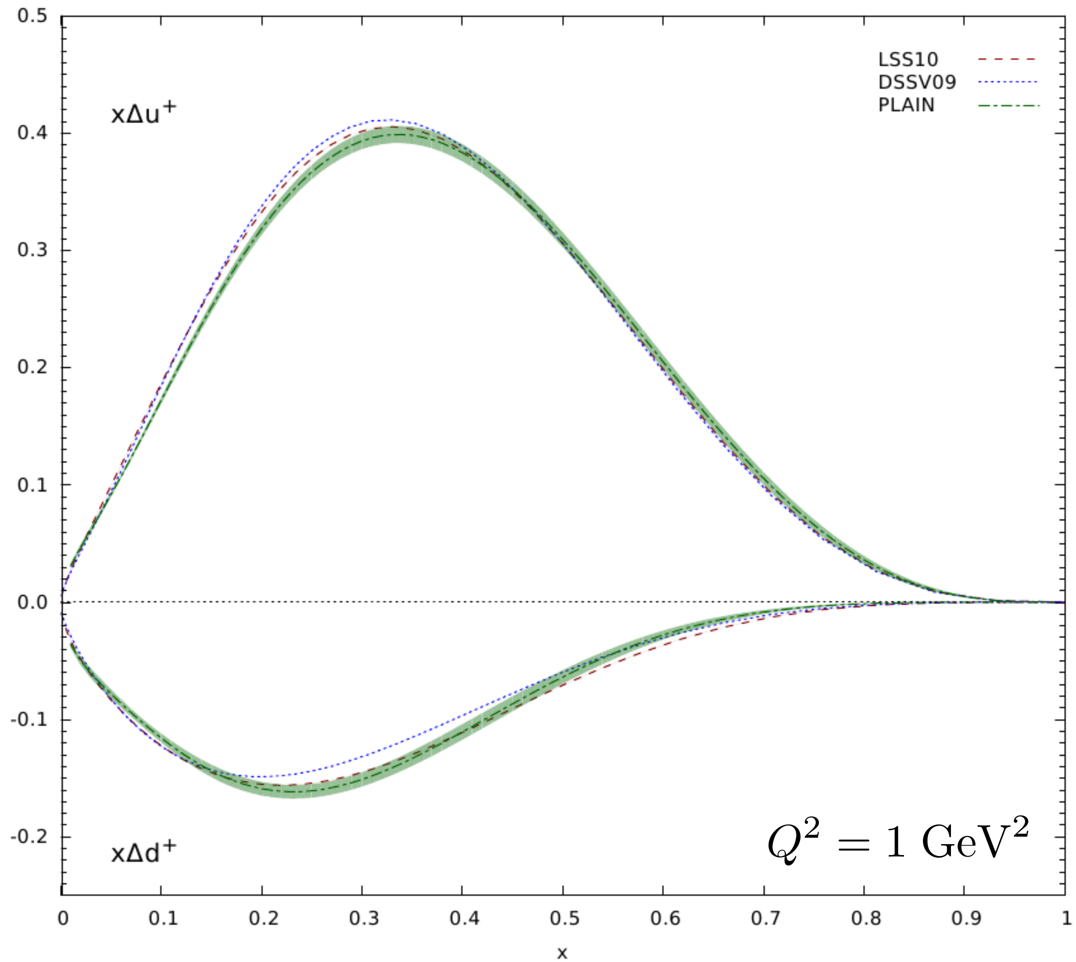
"Vicinity" of the minimum (tolerance) characterized by:

$$\Delta\chi^2 = \chi^2 - \chi^2_{min} \leq T^2 = 1$$

Simple fit without further corrections: PLAIN

For nuclear targets the "effective polarizations" approximation has been used:

$$g_1^d = (1 - \tfrac{3}{2}0.06)(g_1^p + g_1^n) \qquad g_1^{He3} = 0.86\, g_1^n - 0.059\, g_1^p$$



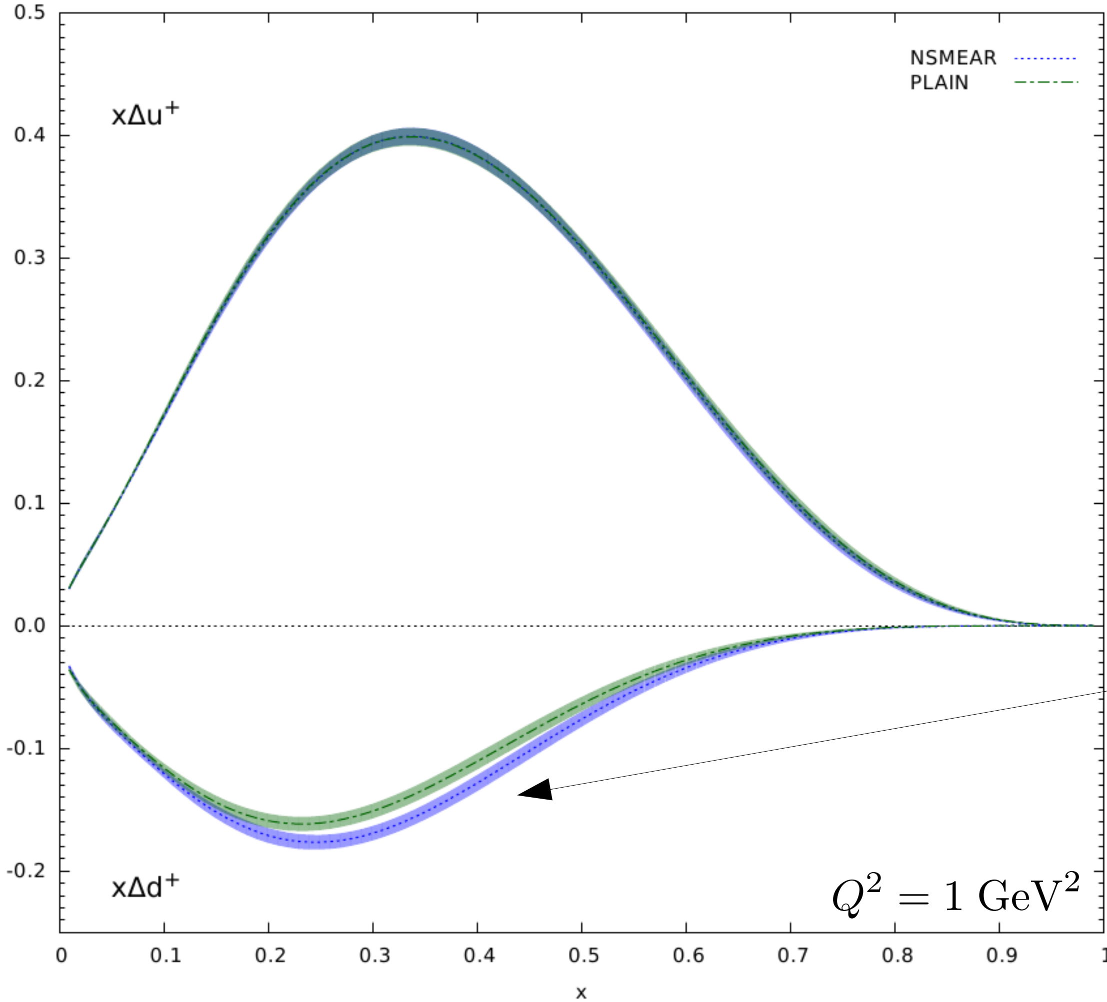
Baseline for assessing impact of theoretical corrections

Improved description of nuclear targets: NSMEAR

Binding, Fermi motion included in "smearing" formalism [Kulagin, Petti 06]

→ smearing functions f_{jN} derived from nuclear spectral functions

$$g_i^A(x) = \sum_{\substack{j=1,2 \\ N=p,n}} \int dy\; f_{jN}(y,\gamma)\; g_j^N\left(\frac{x}{y}\right) \qquad \gamma^2 = 1 + 4\frac{M^2}{Q^2}x^2$$



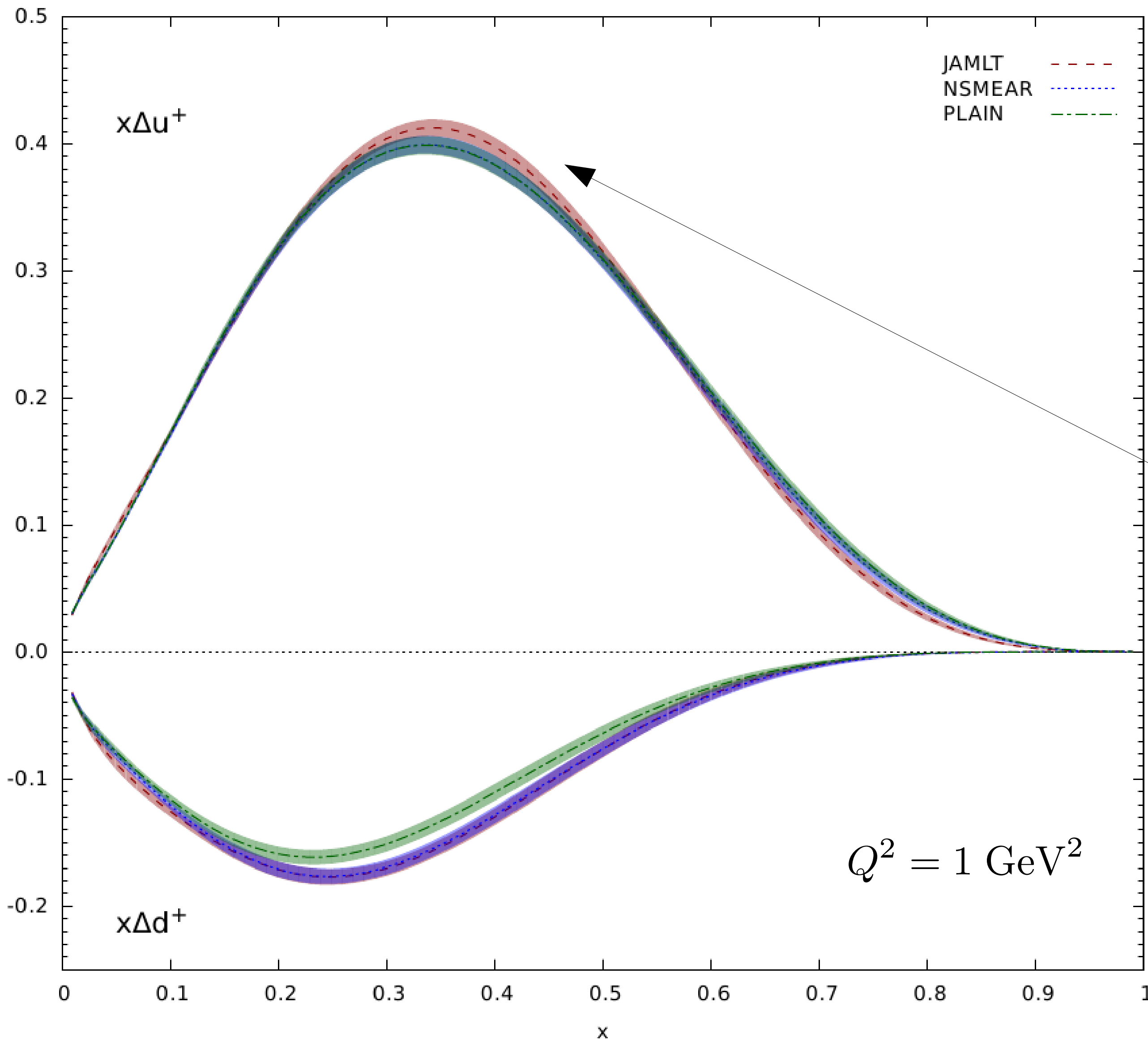
Relevant **for Δd in the medium- to large-*x* region**

Plus target-mass corrections: JAMLT

We use power corrections from finite target mass calculated in the OPE approach:

$$g_1^{\mathrm{TMC}}(n) = g_1(n) + \frac{M^2}{Q^2}\frac{n^2(n+1)}{(n+2)^2}g_1(n+2) + \mathcal{O}(\frac{M^4}{Q^4})$$

[Bluemlein, Tkabladze 99]



Note that the Wandzura-Wilzceck relation holds also after TMCs

[Bluemlein, Tkabladze 99]

Relevant **for** Δu **at medium- to large-*x***

Both nuclear and TMC corrections should be included in global fits

Higher twist contributions

We consider also corrections from higher twist contributions:

$$g_1 = g_1^{\tau=2} + g_1^{\tau=3} + g_1^{\tau=4}$$

$$g_2 = g_2^{\tau=2} + g_2^{\tau=3}$$

[Bluemlein, Tkabladze 99]

The Bluemlein-Tkabladze relation: $g_1^{\tau=3}(x,Q^2) = 4x^2 \frac{M^2}{Q^2}\left(g_2^{\tau=3}(x,Q^2) - 2\int_x^1 \frac{dy}{y} g_2^{\tau=3}(y,Q^2)\right)$

With a very flexible phenomenological parametrization [Braun *et al.* 09:]

$$g_2^{\tau=3} = A[\ln x + (1-x) + \tfrac{1}{2}(1-x)^2] + (1-x)^3[B + C(1-x) + D(1-x)^2 + E(1-x)^3]$$

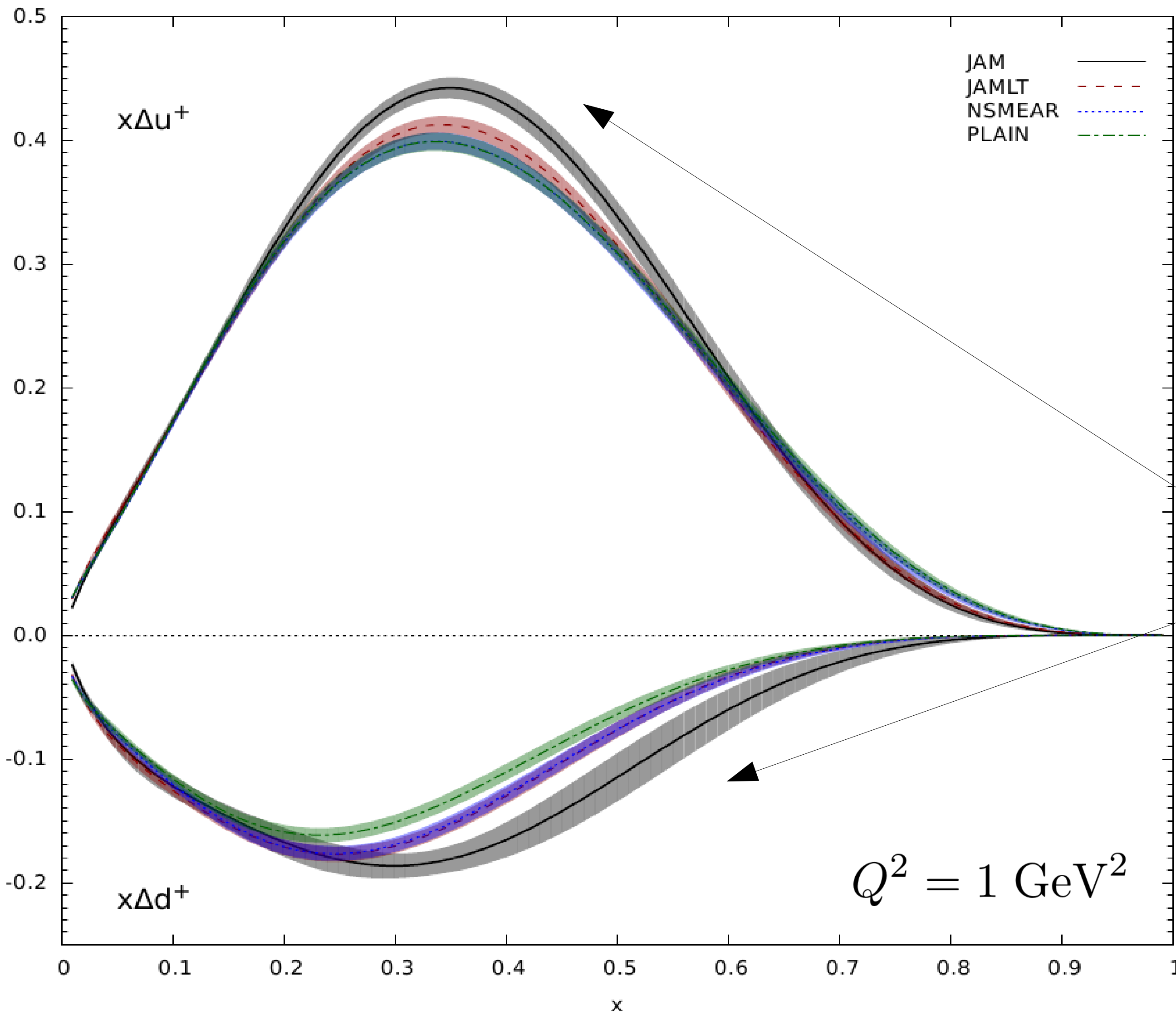
And a splines approximation for: $g_1^{\tau=4} = \frac{h(x)}{Q^2}$

Possible scale dependence in h and $g_2^{\tau=3}$ have been neglected

Including all corrections: JAM

Considerable improvement of χ^2 for JLab and some SLAC data sets

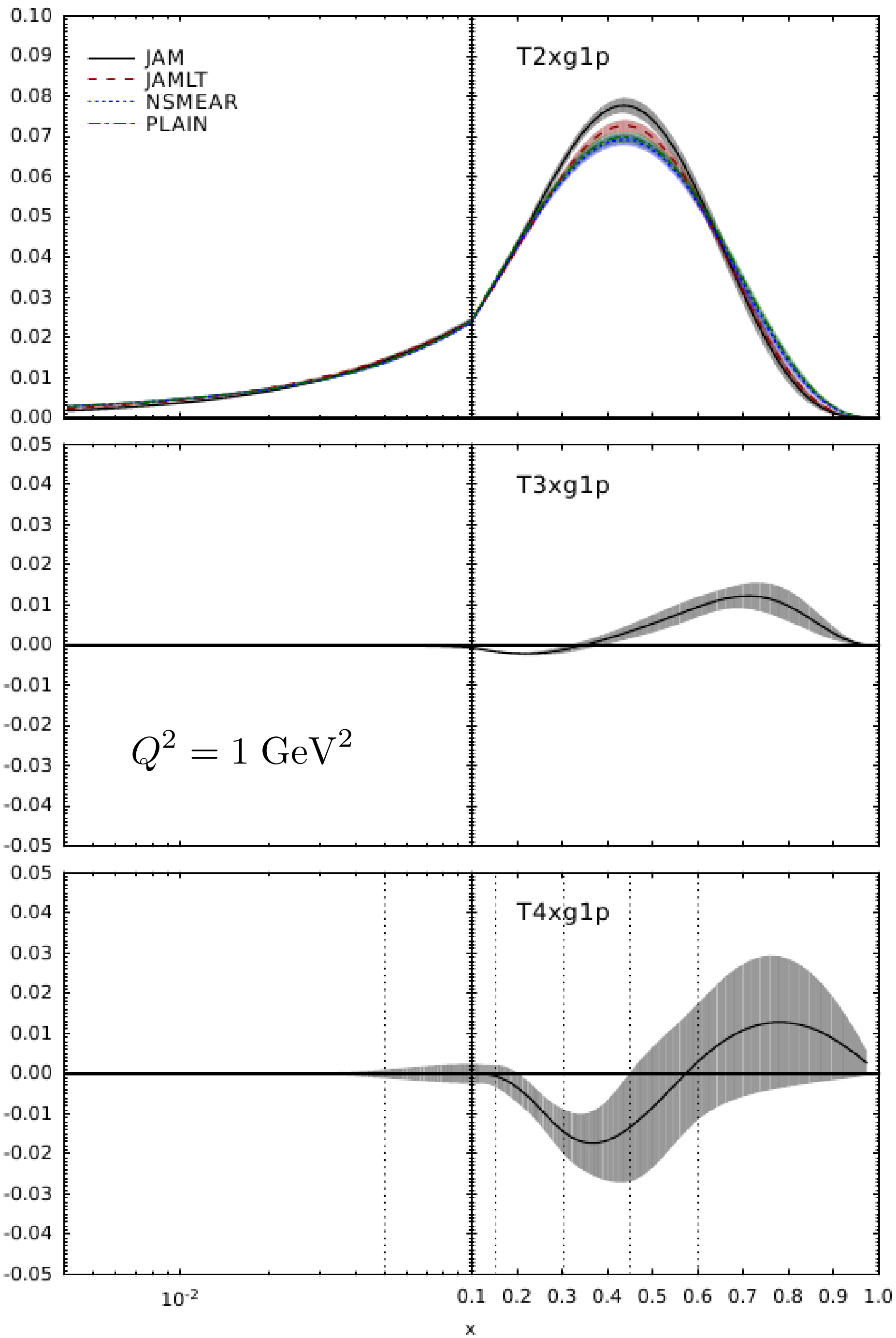
(globally $1.07 \rightarrow 0.95$, 3σ)



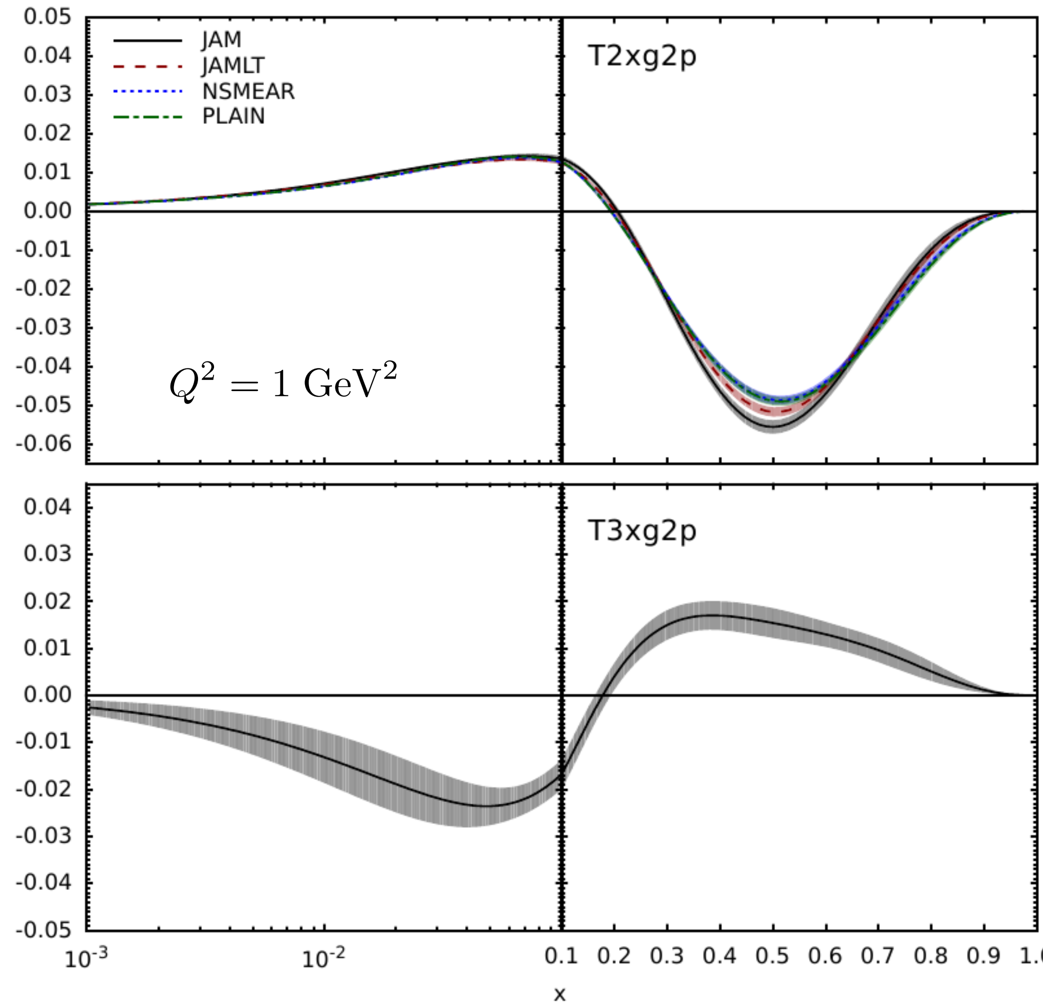
Relevant **for both** Δu **and** Δd

Higher twist contributions are manifestly important for current DIS data

Including all corrections: JAM



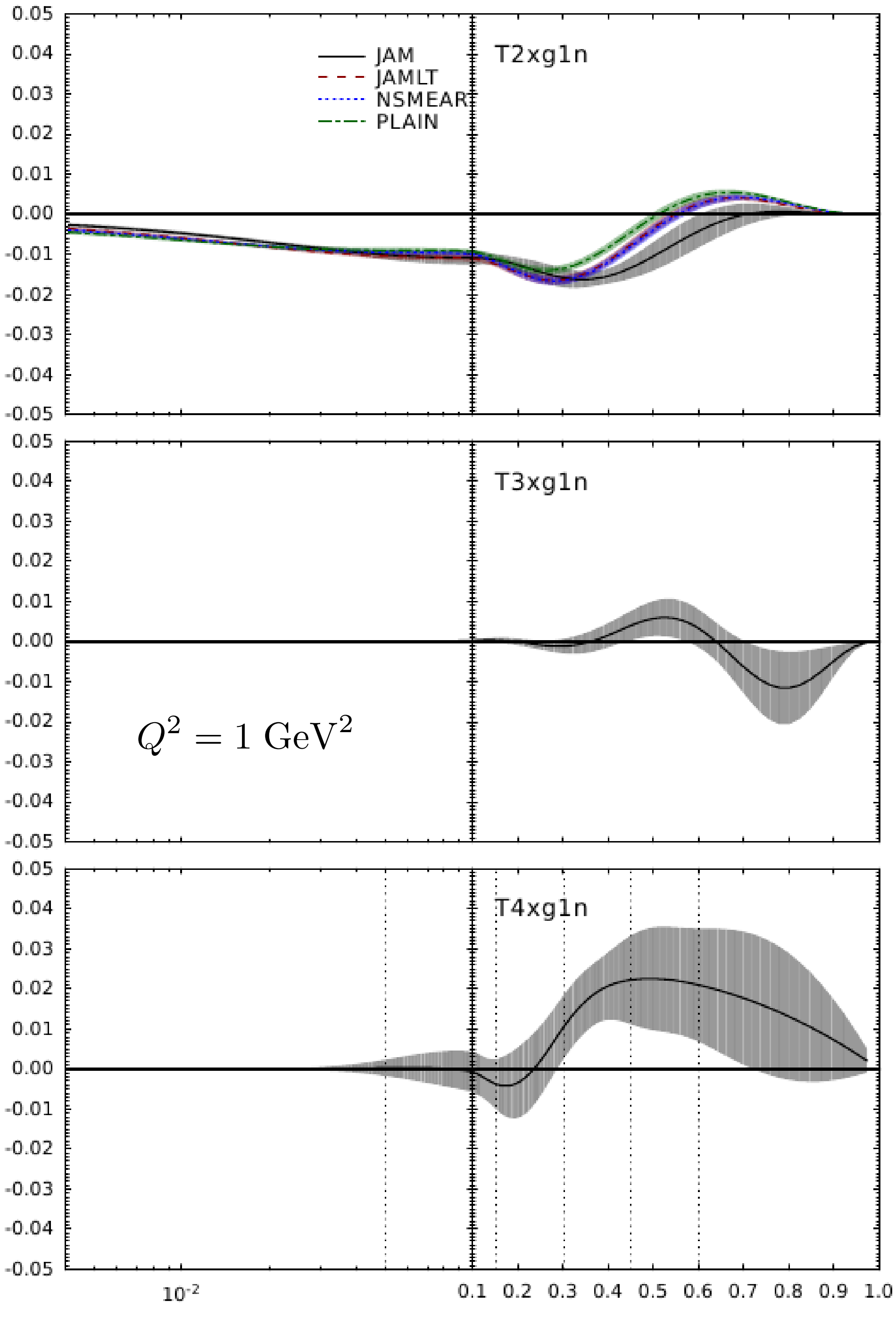
It is possible to determine *simultaneously* higher-twist contributions for g_1 and g_2



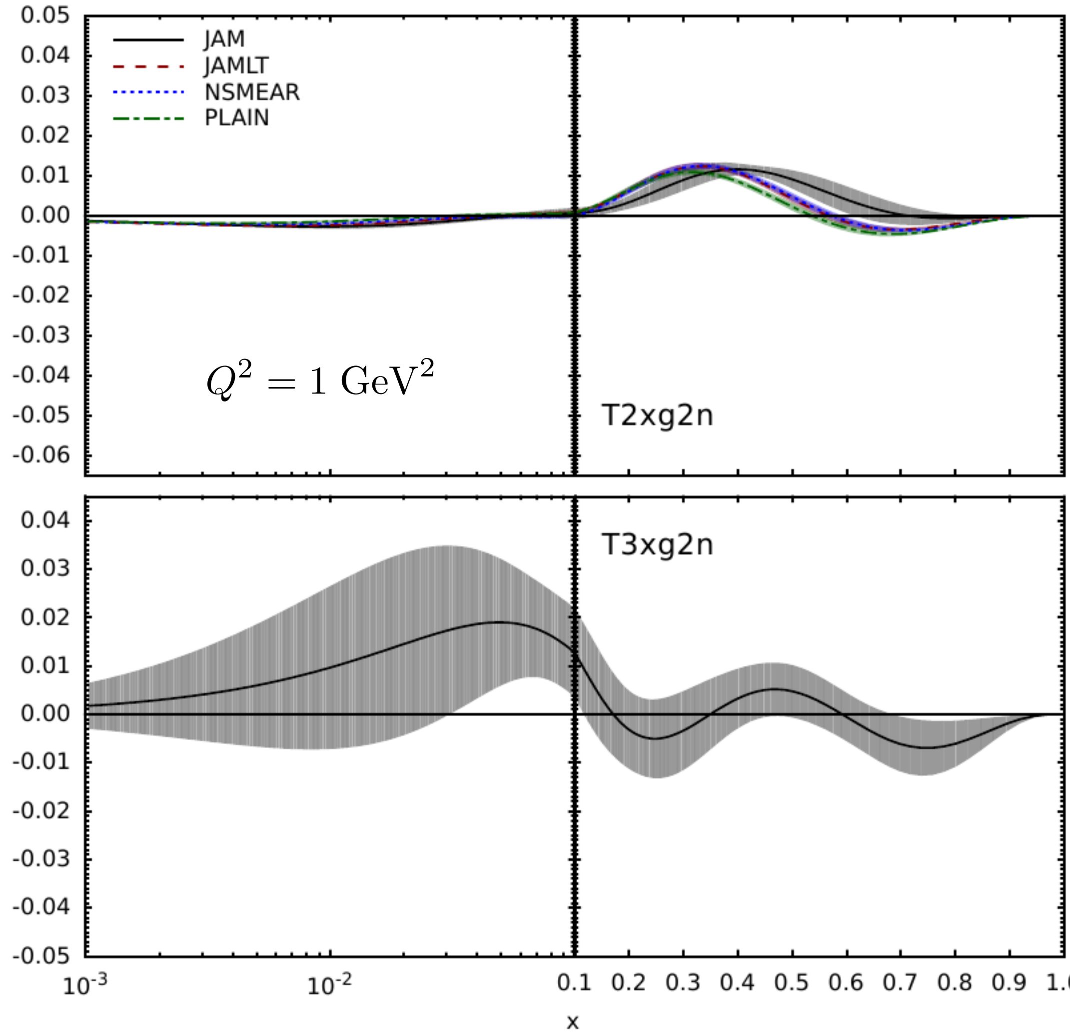
Qualitative agreement with [LSS 10] on g_1 ; and [BB 12], [ABMS 09] on g_2

[Accardi,Bacchetta,Melnitchouck,Schlegel JHEP 2009]

Including all corrections: JAM



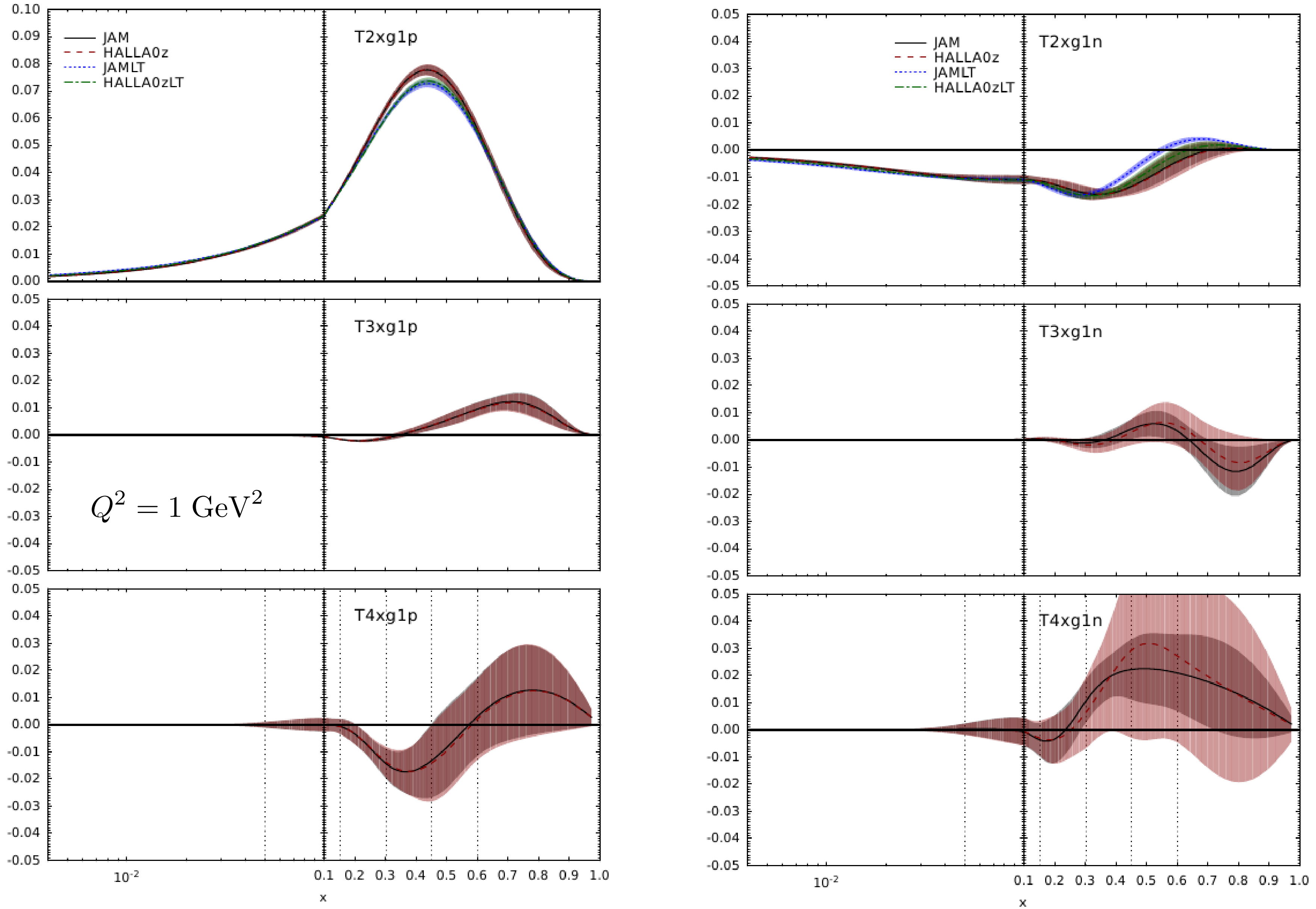
As well as for proton and neutron (which are rather different)



Disagreement with [LSS 10] on g_1 ;
g_2 more or less compatible with zero

Impact of Jefferson Lab data: HALLA0z

What happens if we remove E99-117 [X. Zhang et al., Phys. Rev.Lett. **92**, 012004 (2004)]?



Very important for g_1 neutron; practically determine the higher twist part at large *x*

Summary and outlook

New polarized PDF fitting group: JAM

Several studies completed:

- More accurate nuclear corrections relevant
- Target mass corrections should be used
- Complete inclusion of higher-twist possible and needed

In progress:

- Impact of JLab data
- symmetric sea, gluon constraints, ...

Longer term goal: inclusion of SIDIS and RHIC data