Delineating polarized and unpolarized parton distribution functions

Nuclear Physics & RIKEN Theory Seminar,
BNL, Mar 14, 2014

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Jefferson Lab

Overview

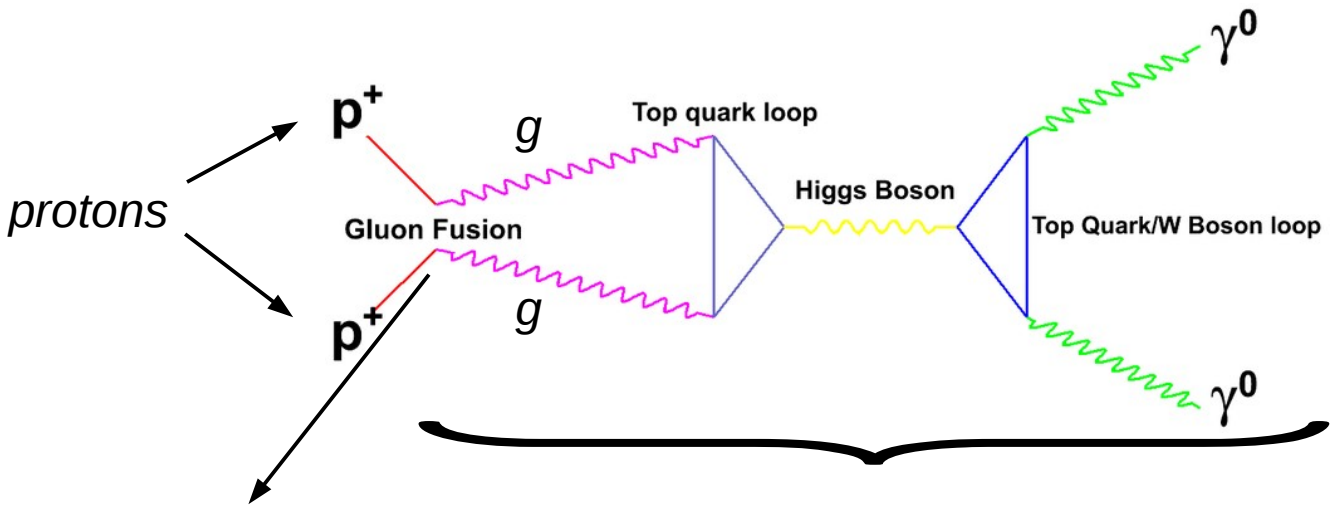
- Introduction to parton distribution functions
- Overview of current global extractions

- Overview of unpolarized PDFs
- Updating the unpolarized distributions: ***JR14***
- The role of the input scale and *procedural* bias

- The *Jefferson Lab Angular Momentum* collaboration: ***JAM***
- Improving the description of polarized DIS
- Large x constraints and impact of (future) data from JLab
- Moving forwards: Including RHIC data

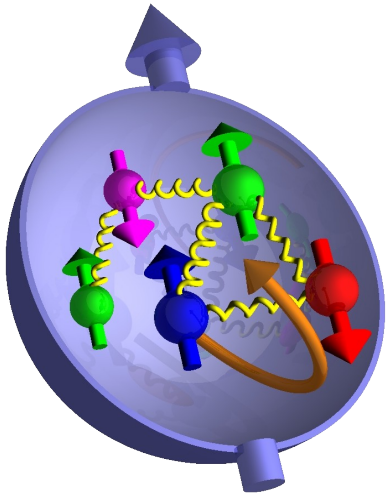
Scattering events in high-energy collisions

Diphoton production in gluon-gluon fusion: $gg \to H \to \gamma\gamma$



Nucleon structure

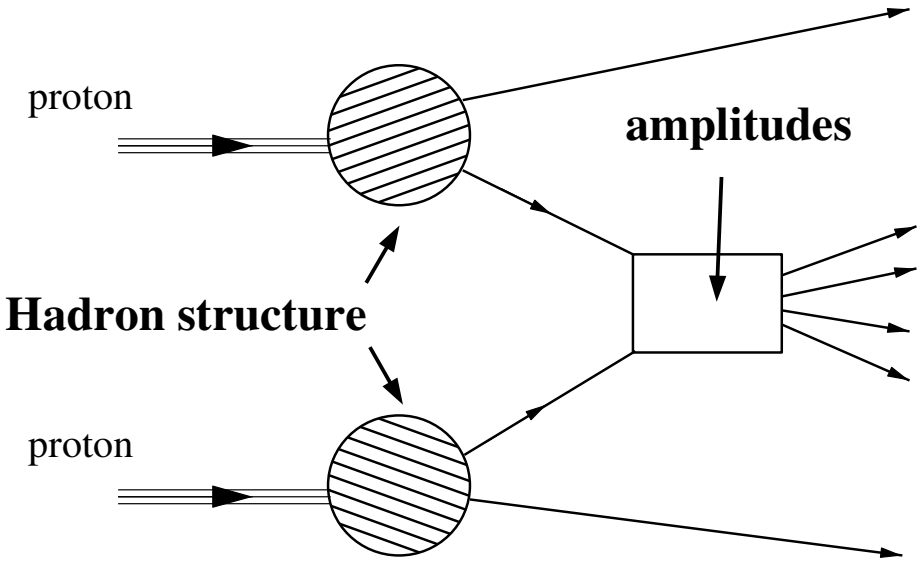
Scattering amplitudes



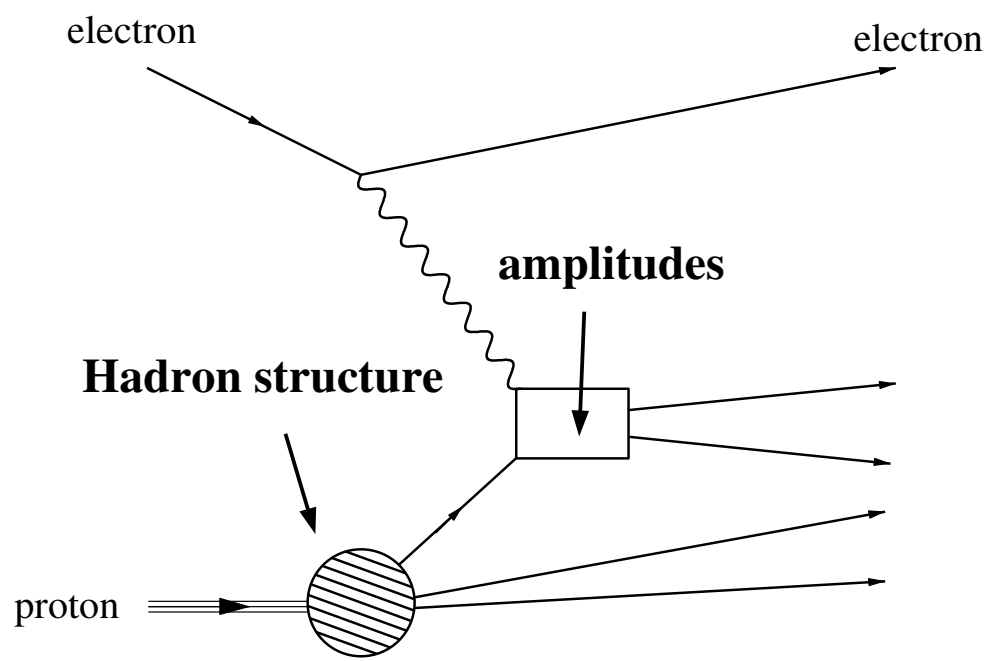
Hadrons are ***bound states*** of quarks and gluons

Hadron-hadron vs lepton-hadron collisions

At the LHC there are *two* protons



Nucleon structure can also be studied in electron-proton scattering

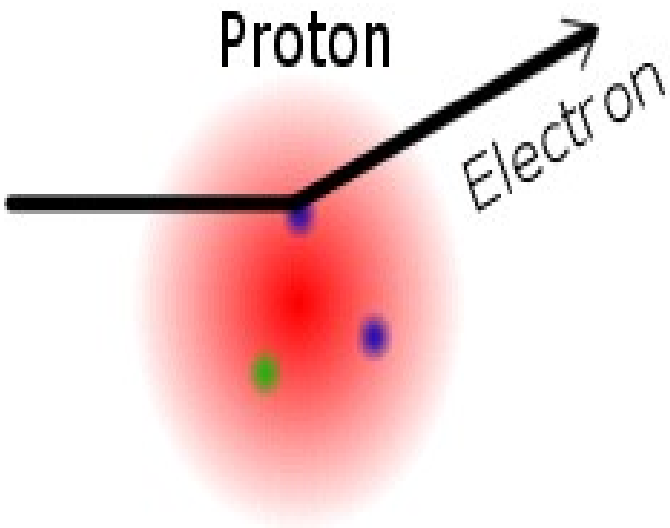


Deep Inelastic Scattering

use the electrons to "look" *deep* inside the nucleons (at the quark and gluons)

The parton model

Hadrons regarded as a compound of point-like constituents (partons)

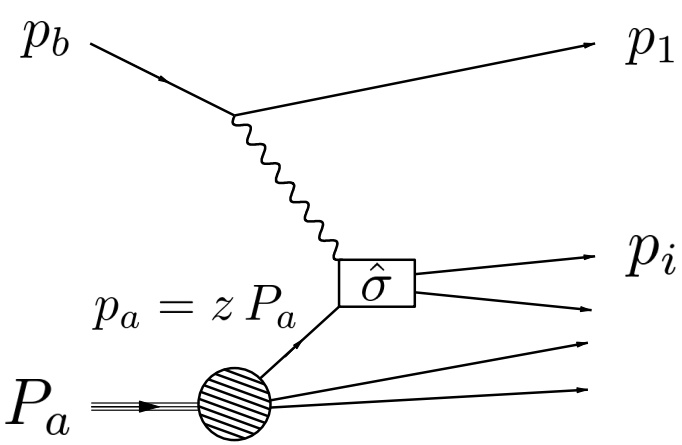


Plausible if the hard interaction is much faster than the structural interactions (justified by time dilatation); i.e., at high energies

Thus the incoming particles scatter *incoherently off partons*:

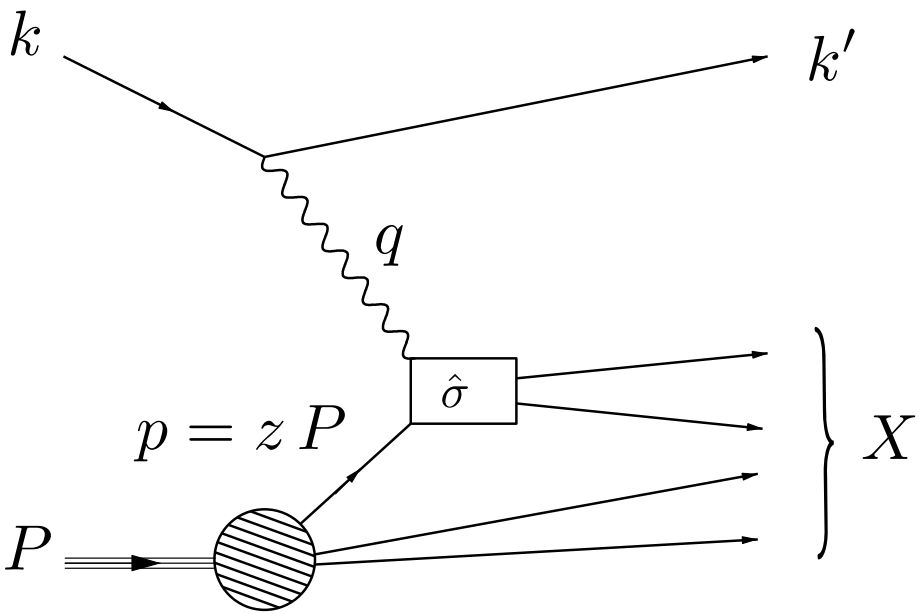
Parton distribution functions

$$\sigma = \sum_{\text{partons}} \int_0^1 dz\, \hat{\sigma}\, f_{\text{parton}}(z)$$



Kinematics for inclusive DIS

One can consider ***inclusive*** DIS, thus a *reduced* number of variables:



Virtuality: $Q^2 \equiv -q^2$

Bjorken-x: $x \equiv \dfrac{Q^2}{2P_0 \cdot q}$ $(0 \leq x \leq 1)$

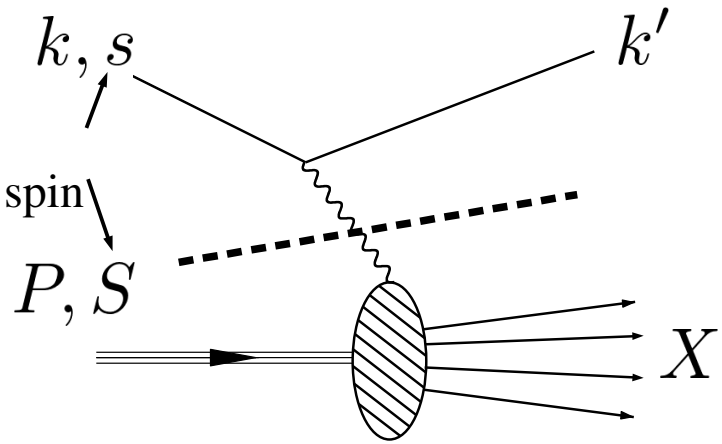
Inelasticity: $y \equiv \dfrac{P_0 \cdot q}{P_0 \cdot k}$ $(0 \leq y \leq 1)$

Q^2 sets the scale at which one is "looking" (larger Q^2, smaller distances, deeper)

In the *parton model* the $\hat{\sigma}$'s are delta functions: $z = x$

Structure Functions

One can consider *inclusive* DIS, thus a *reduced* number of variables:



$$\frac{d\sigma}{dx\,dy} \propto L_{\mu\nu} W^{\mu\nu}$$

Leptonic tensor (calculated)

Hadronic tensor (parametrized)

Nucleon structure in ***Structure Functions:***

$$W_{\mu\nu}(P,q,S) = (-g^{\mu\nu} + \tfrac{q^\mu q^\nu}{q^2}) F_1(x,Q^2) + (P^\mu - \tfrac{P\cdot q}{q^2} q^\mu)(P^\nu - \tfrac{P\cdot q}{q^2} q^\nu) F_2(x,Q^2)$$
$$+ iM\epsilon^{\mu\nu\rho\sigma} q_\rho [\tfrac{S_\sigma}{P\cdot q} g_1(x,Q^2) + \tfrac{S_\sigma (P\cdot q) - P_\sigma (S\cdot q)}{(P\cdot q)^2} g_2(x,Q^2)]$$

The spin-averaged double differential cross-section:

$$\frac{d^2\sigma}{dx\,dy} = \frac{2\pi\alpha^2}{xyQ^2}(1 + (1-y)^2 F_2 - y^2 F_L)$$

$F_L \simeq F_2 - 2xF_1$ and g_2 are much smaller than F_2, g_1

Spin-averaged and spin-dependent

To measure the polarized structure functions one makes asymmetries:

$$A_{\parallel} = \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Uparrow}} \qquad A_{\perp} = \frac{\sigma^{\uparrow\Rightarrow} - \sigma^{\uparrow\Leftarrow}}{\sigma^{\uparrow\Rightarrow} + \sigma^{\uparrow\Leftarrow}} \qquad \sigma^{\uparrow\Rightarrow}$$

nucleon spin orientation

electron spin orientation

Then $A_{\parallel} \propto \frac{g_1}{F_1}$, $A_{\perp}$ is again much smaller

How to relate them to PDFs?

Partons can have same (f_+) or opposite (f_-) helicity as nucleon

$\sigma^+ + \sigma^- \propto f \equiv f_+ + f_-$ ⟵ Spin-averaged or ***unpolarized*** PDFs

$\sigma^+ - \sigma^- \propto \Delta f \equiv f_+ - f_-$ ⟵ Spin-dependent or ***polarized*** (or helicity) PDFs

In the *parton model*:

$$F_2 = x \sum_q e_q^2 (q(x) + \bar{q}(x)) \qquad g_1 = \frac{1}{2} \sum_q e_q^2 (\Delta q(x) + \Delta \bar{q}(x))$$

QCD radiation complicates things: Q^2-*evolution*

Global analysis of parton distributions

Goal: determination of the ***input distributions*** (for light quarks and gluons):

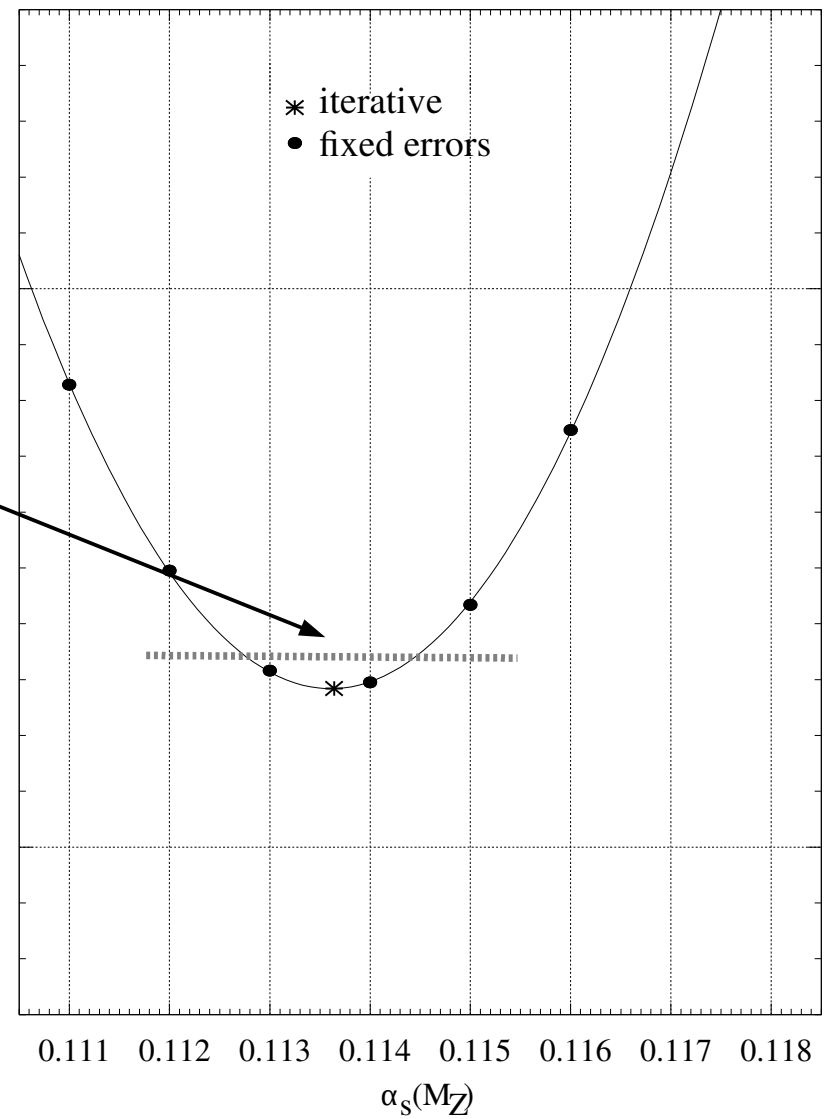
Method: Parametrizations $xf(x, Q_0^2) = Nx^a(1-x)^b \,\mathrm{function}(x)$
and usual *statistical estimation* (fits):

$$\chi^2(p) = \sum_{i=1}^{N} \left(\frac{\mathrm{data}(i) - \mathrm{theory}(i,p)}{\mathrm{error}(i)} \right)^2$$

Position of minimum gives the value and curvature gives the error (region within a certain "tolerance" $\Delta\chi^2 = 1$)

(Monte Carlo methods can also be used)

Usually the chi-square definition is more sophisticated, experimental correlations are also treated, etc.



Data for unpolarized distributions

Pre-LHC data:

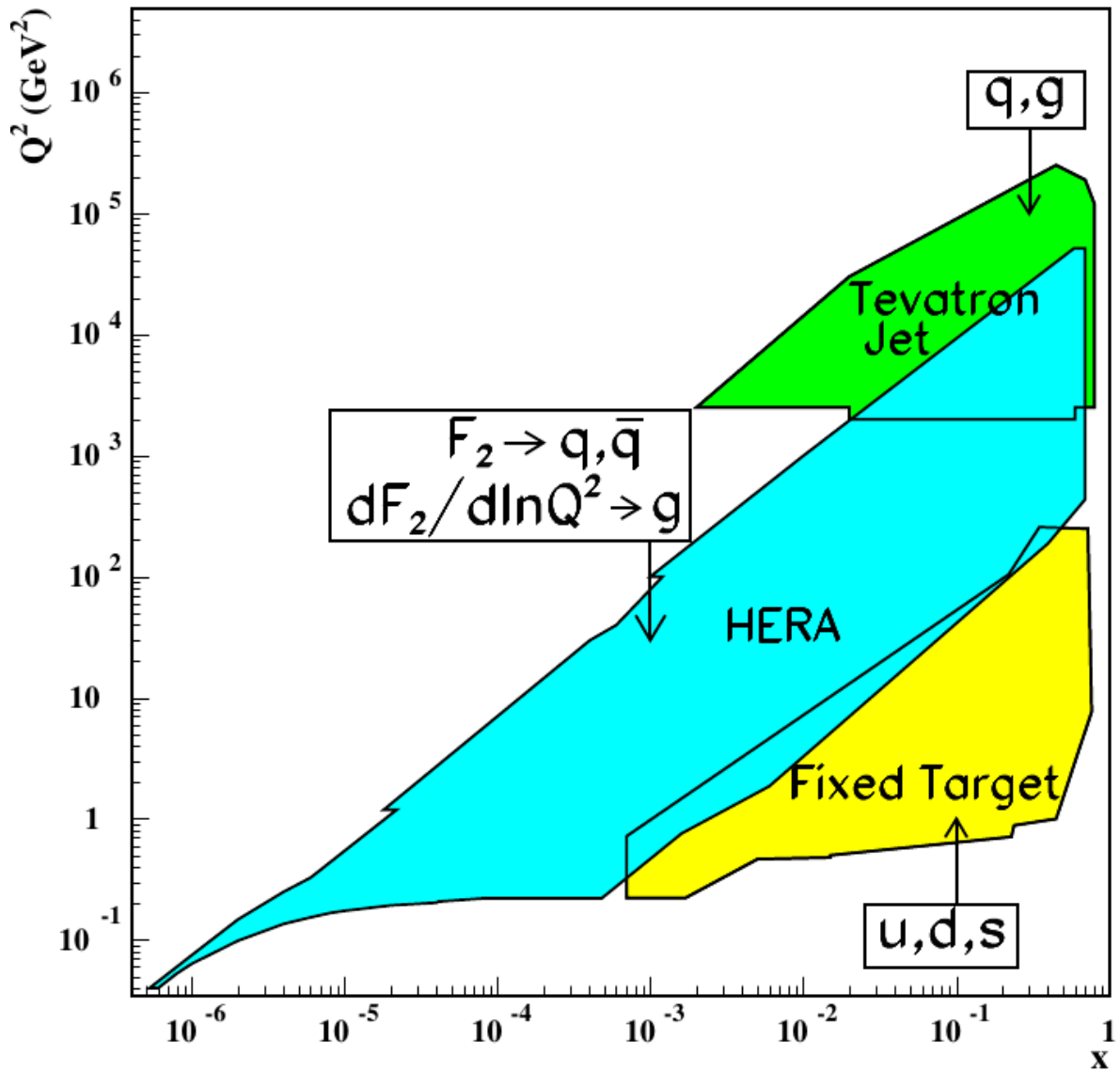
Inclusive DIS structure functions (FT and HERA)

Drell-Yan (or CC DIS) needed for $\bar{d} \neq \bar{u}$

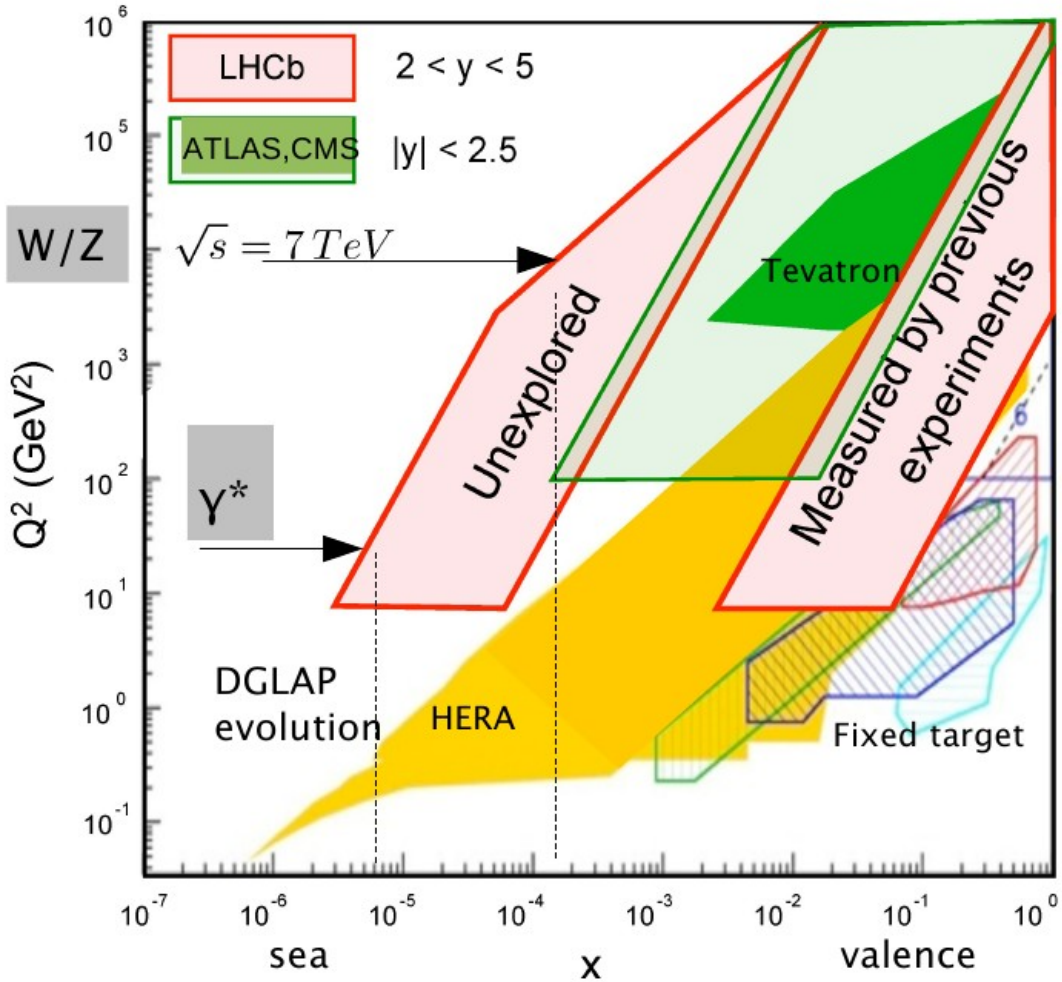
Neutrino dimuon data sensitive to strangeness

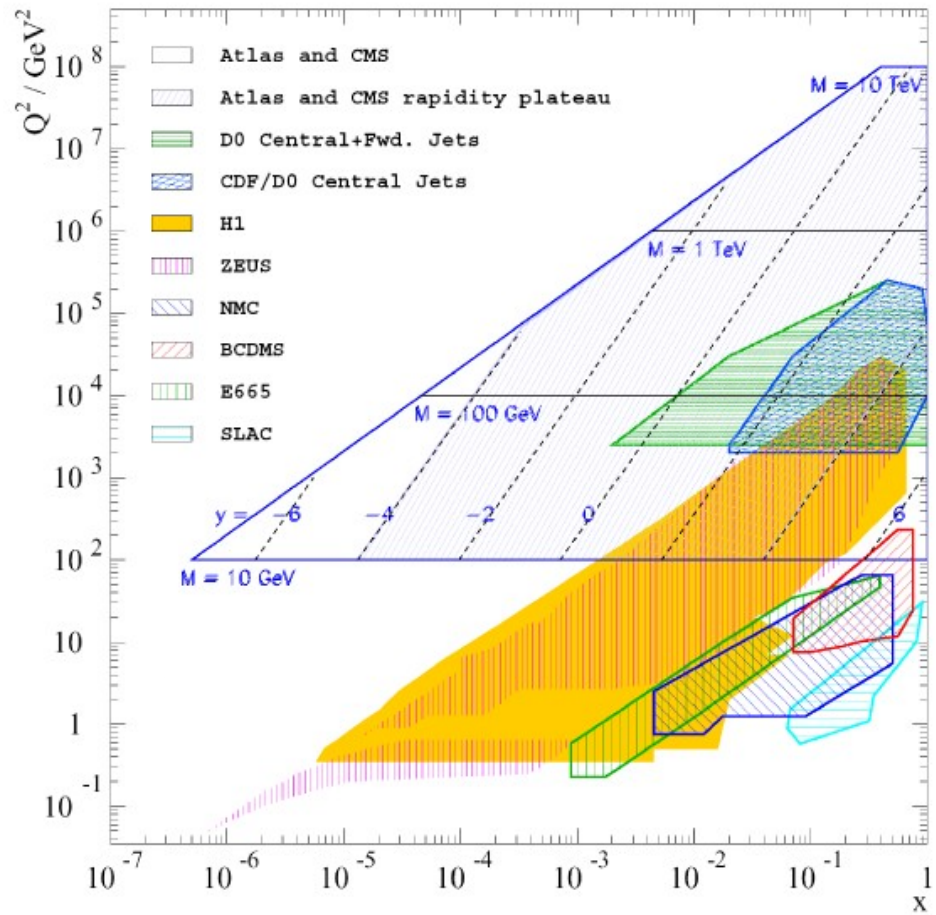
W/Z production (Tevatron) provides additional (redundant) information

Gluon only enters (at LO) in jet production (large-*x*) and semi-inclusive heavy-quark production in DIS (small-*x*)



Data for unpolarized distributions





We will go from predicting LHC measurements to using them for constraining the parton distributions (some groups have already started)

Current global PDF groups

ABM: Careful treatment of experimental correlations, nuclear and power corrections in DIS, FFNS

MSTW: negative input gluons at small-*x*, rather "large" $\alpha_s(M_Z^2)$, GMVNS

HERAPDF: Only HERA data, less negative gluons, GMVFS

NNPDF: neural-network parametrization, Monte Carlo approach for error propagation, GMVFNS

CTEQ-TEA: parametrization with exponentials, substantially inflated uncertainties, GMVFNS

JR [with E. Reya]: detailed study of input scale dependence, dynamical (and "standard") versions, FFNS

(there are more groups focused on particular aspects, e.g. CTEQ-JLab)

Polarized data and groups

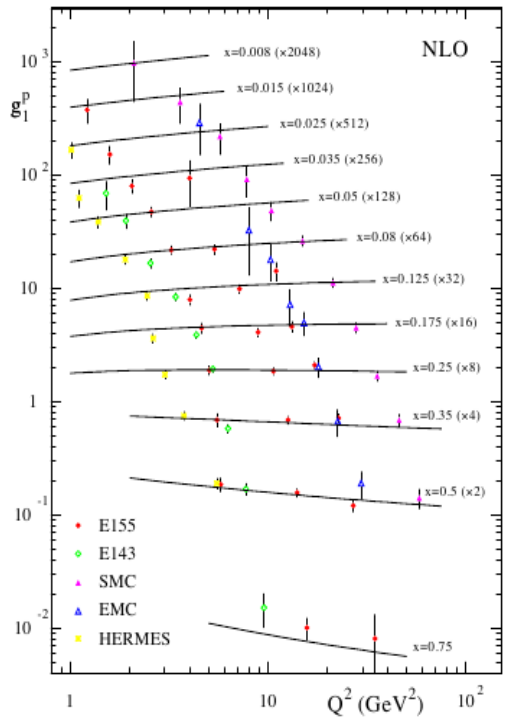
Mainly DIS structure functions

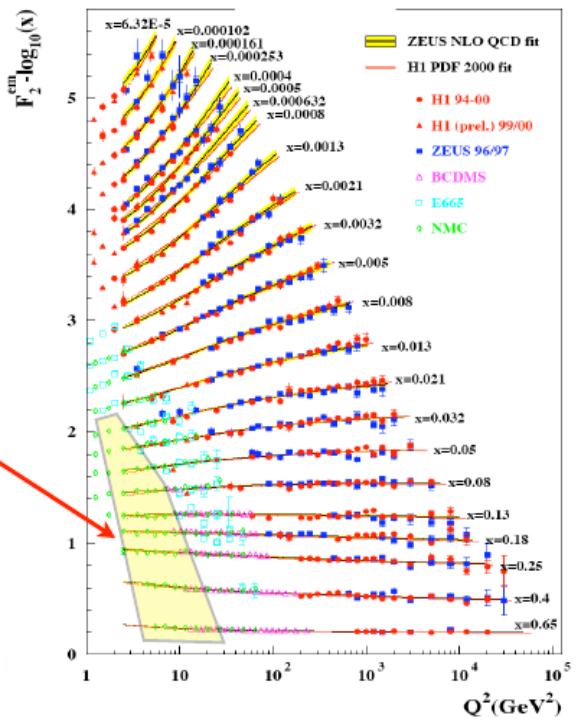
Kinematic coverage greatly reduced (compared to unpolarized)

One can use SIDIS (less "clean")

DSSV/AAC use *pp* data (RHIC) as well

State-of-the-art is NLO





[D. de Florian]

<u>Main current groups:</u>

DSSV: de Florian, Sassot, Stratmann, Vogelsang

LSS: Leader, Sidorov, Stavenov

BB: Blümlein, Bötcher

AAC: Asymmetry Analysis Collaboration

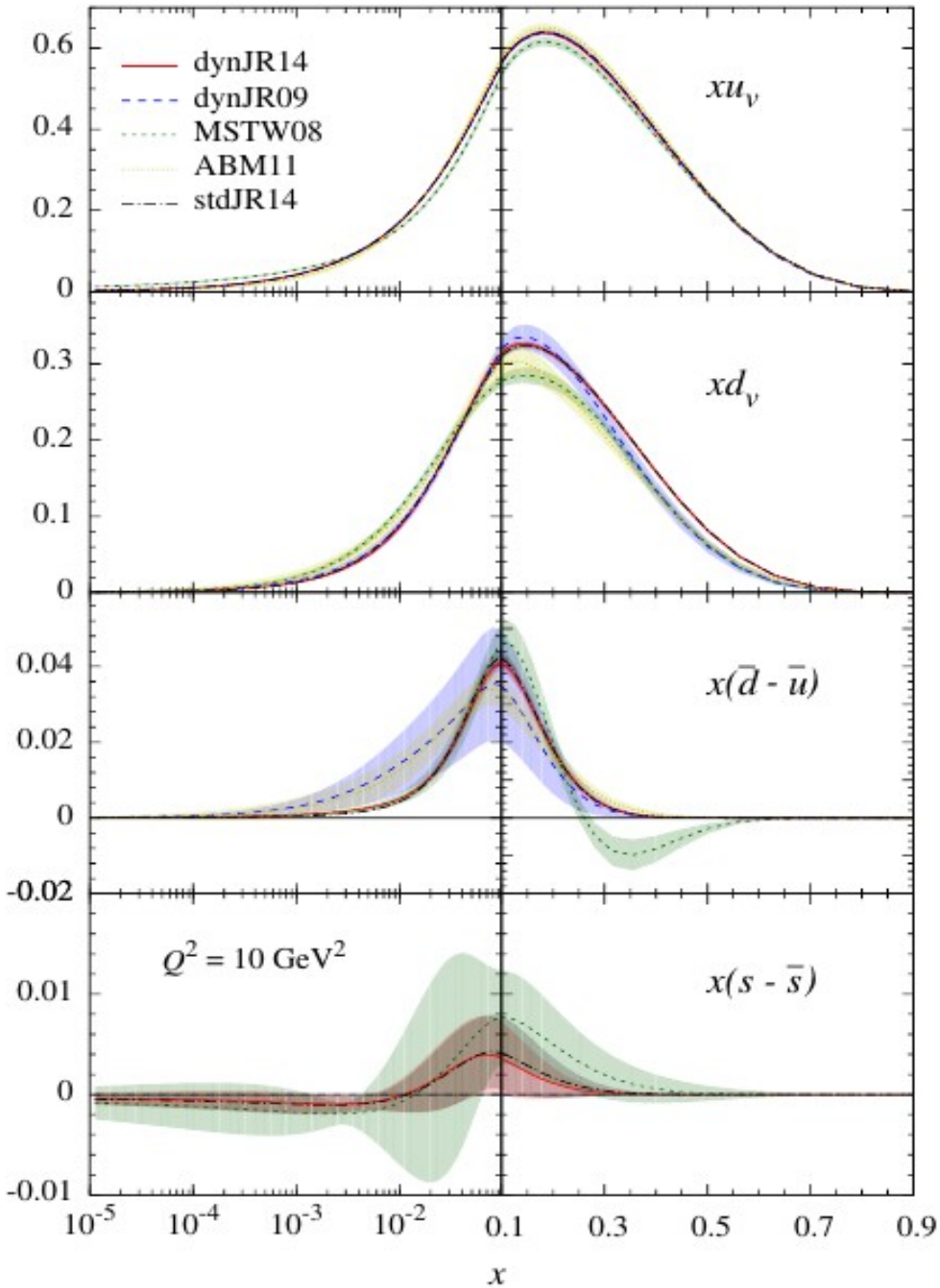
NNPDF: Neural Network Collaboration

JAM: Jefferson Lab Angular Momentum Collaboration

Our determinations of unpolarized PDFs and the strong coupling: JR

PJD, E. Reya, arXiv:1403.1852 [hep-ph]

Introduction: non-singlet sector



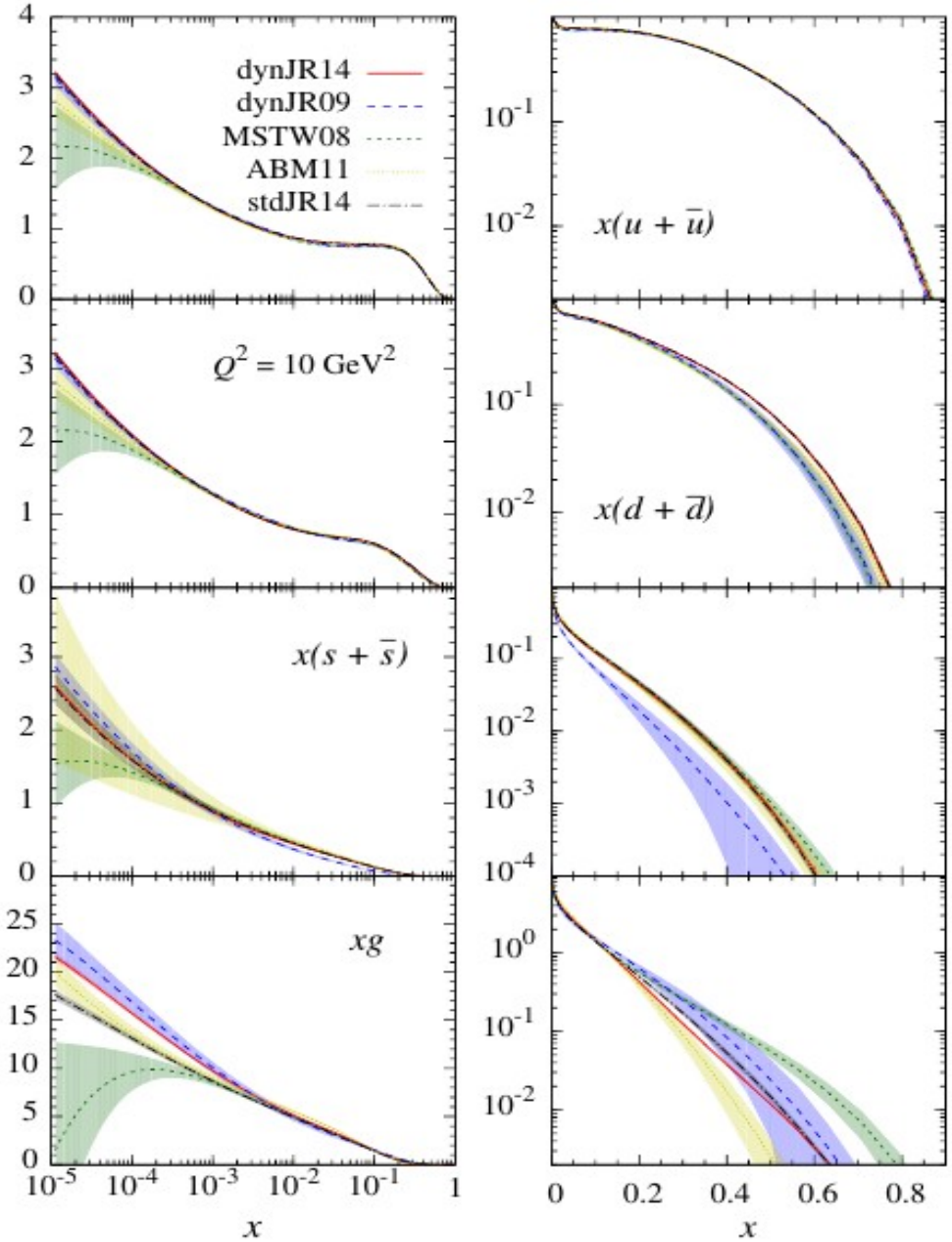
u-valence rather well determined

larger differences for d-valence, but also quite stable

much smaller but can be determined using Drell-Yan σ^{pd}/σ^{pp} ratios

far less relevant except for $\nu, \bar{\nu}$ differences in dimuon production

Introduction: singlet sector



sea distributions at small x determined by the gluon via RGE evolution

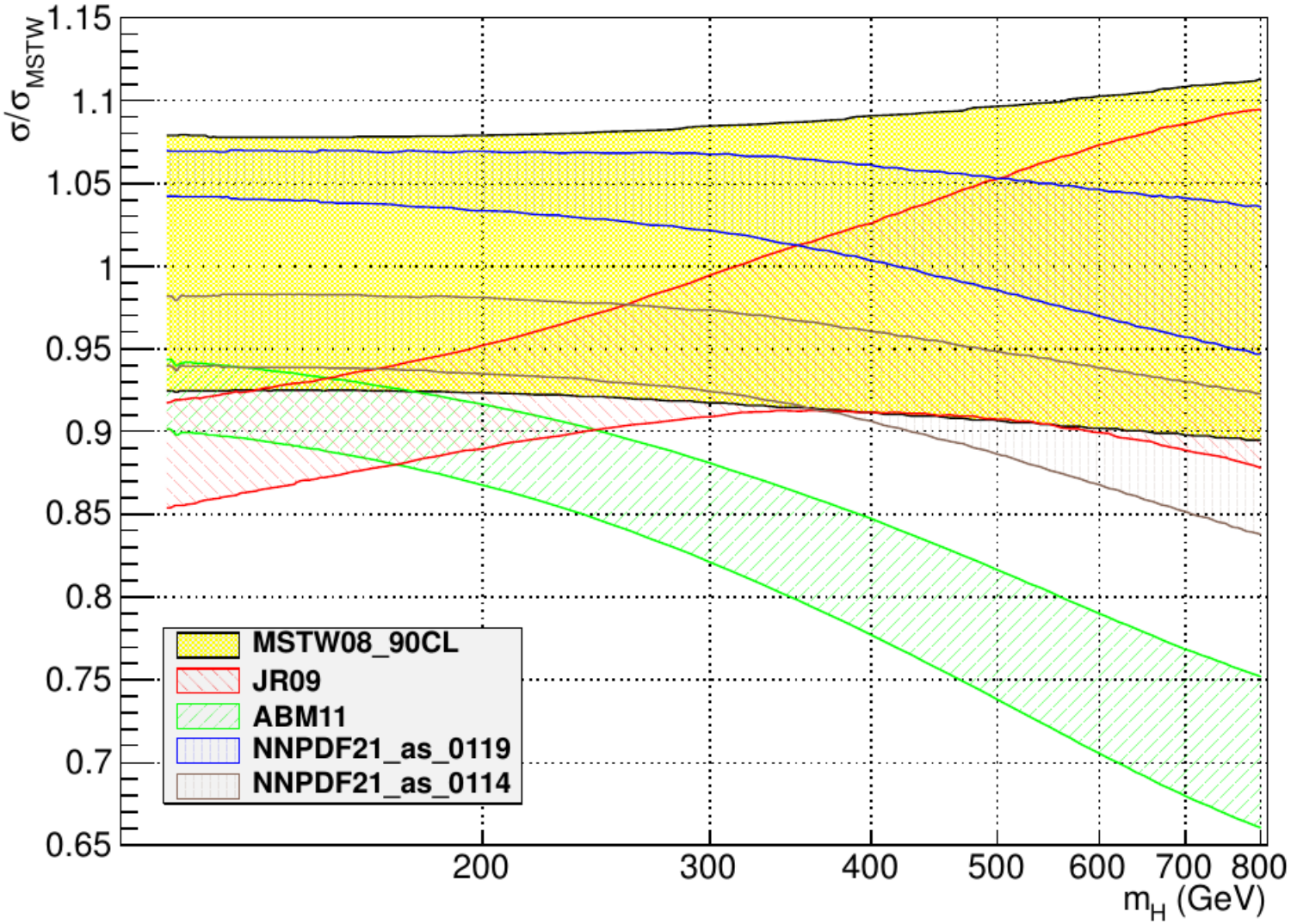
d/u ratio at large x sensitive to nuclear corrections and parametrizations

strange-quark well determined from dimuon (now also LHC) data

largest and most relevant differences in the gluons and α_s values

Propagation to Higgs cross-section

[Anastasiou et al. 2012]



Constraints on the gluon

Gluon only enters directly (at LO) in:

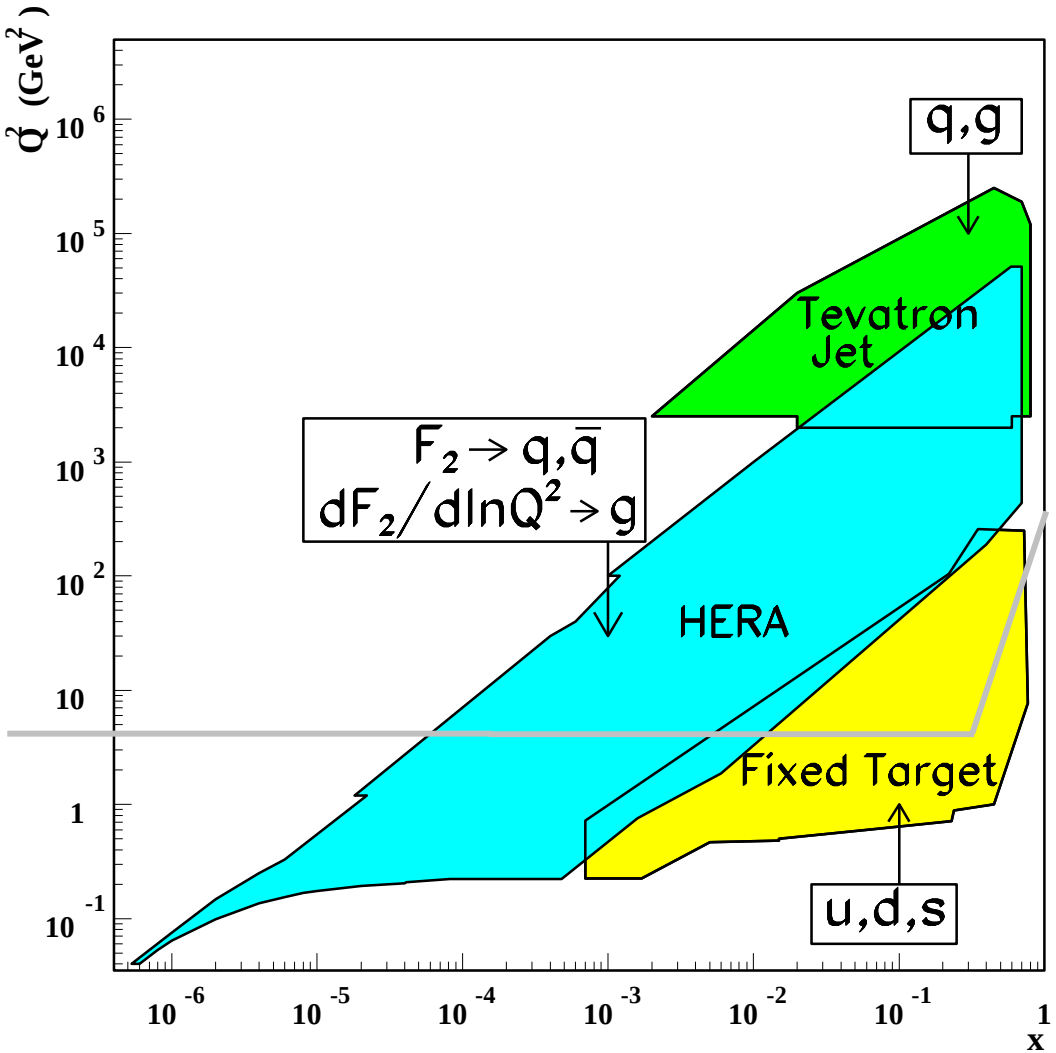
- F_L (both small and large x)
- HQ electroproduction (small x)
- jet production (medium to large x)

But constrained via scaling violations in the small x region

Momentum sum rule correlates small and large x

DIS data often excluded from fits:

$$Q^2 \gtrsim 4\ \mathrm{GeV}^2,\ W^2 \gtrsim 10\ \mathrm{GeV}^2$$



[Particle Data Group]

Moderate cuts lead to larger α_s, thus softer small-x gluons

Jet data also moderately increase α_s; should not be used beyond NLO

(NNLO corrections are large)

Updating JR09: data selection

- Switched to HERA combined neutral-current DIS σ_r, σ_r^c

  and included charged-current

- F_2 replaced for cross-section for SLAC, BCDMS and NMC [ABM 2010]

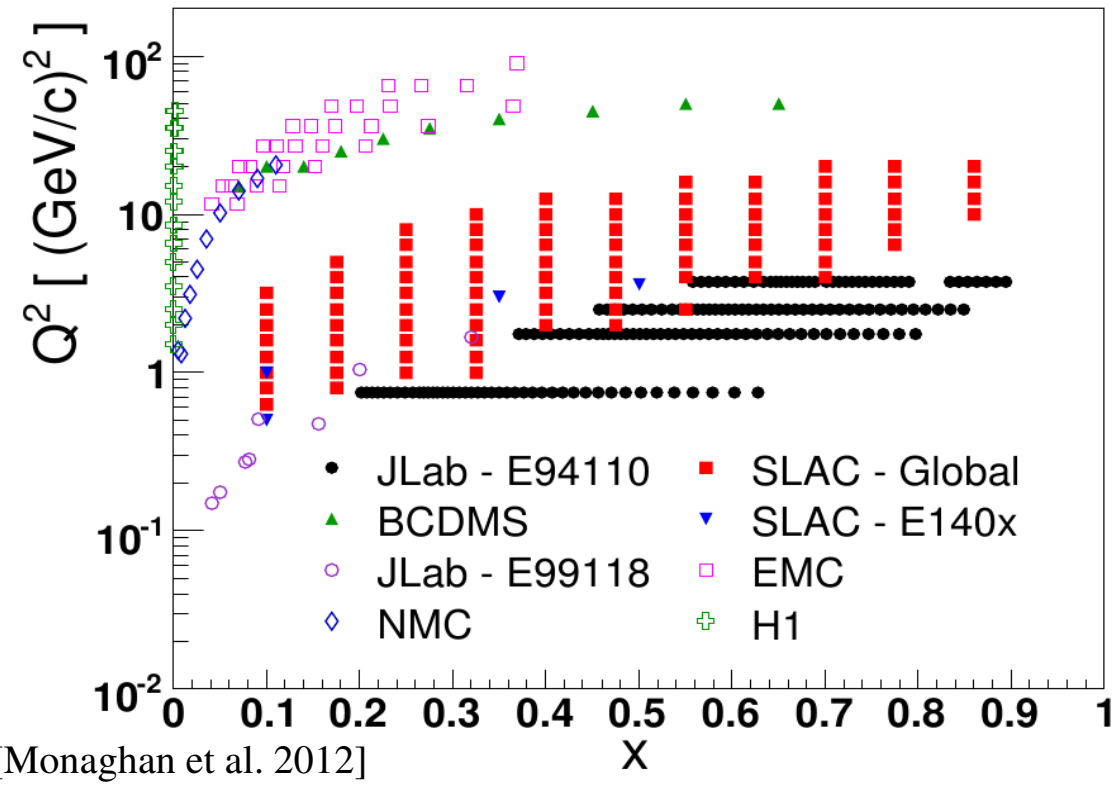
- From 30 points on *p/n* ratios to an equal-footing treatment of fixed-target data

- Dimuon data included in nominal fits

- JLab proton and deuteron data included (need lower *W* cuts)

$$Q^2 \geq 2\mathrm{GeV}^2, W^2 \geq 3.5\mathrm{GeV}^2$$

- Inclusion of Rosenbluth separated (F_2, F_L) data from H1, and from BCDMS, SLAC and JLab

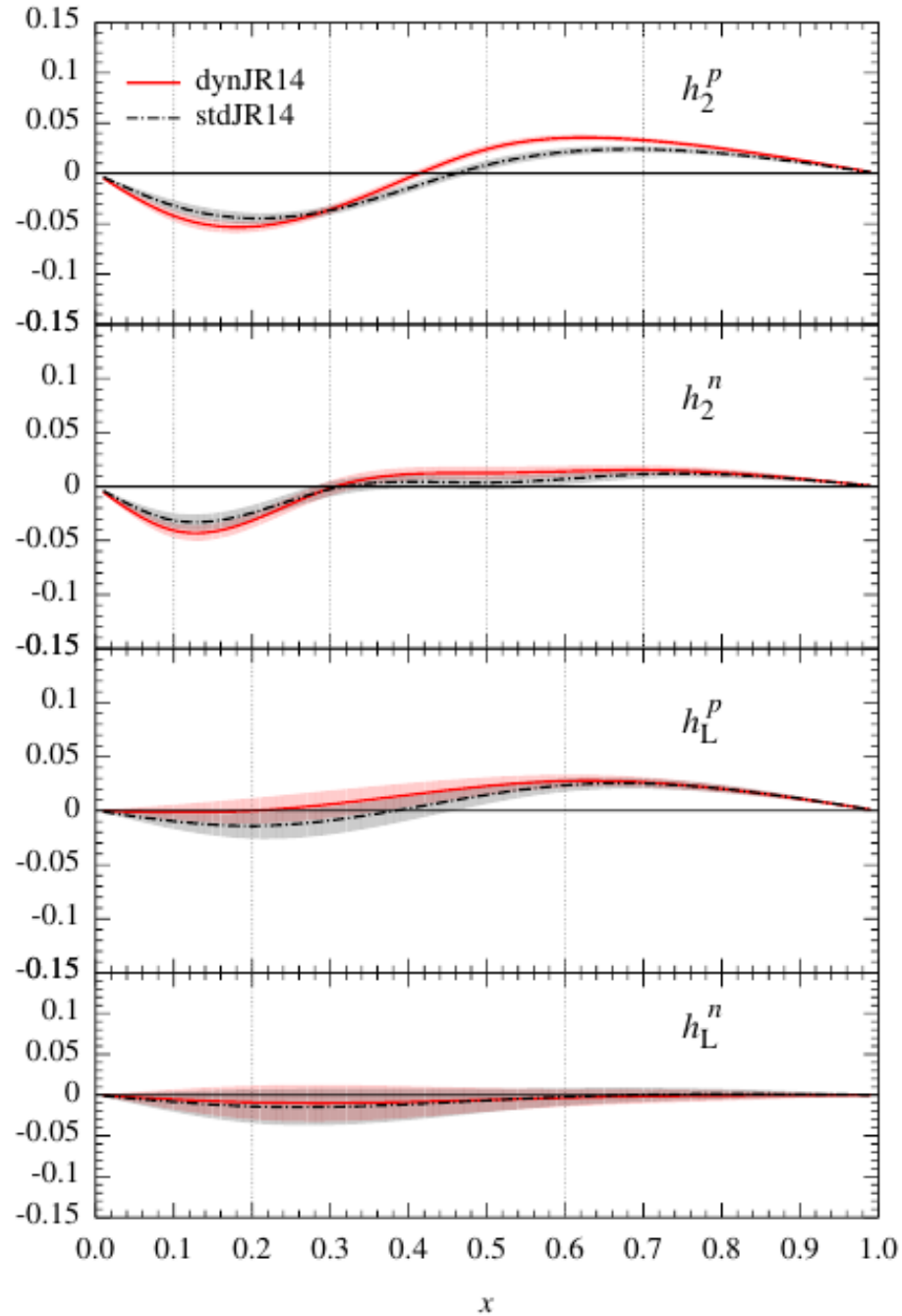


[Monaghan et al. 2012]

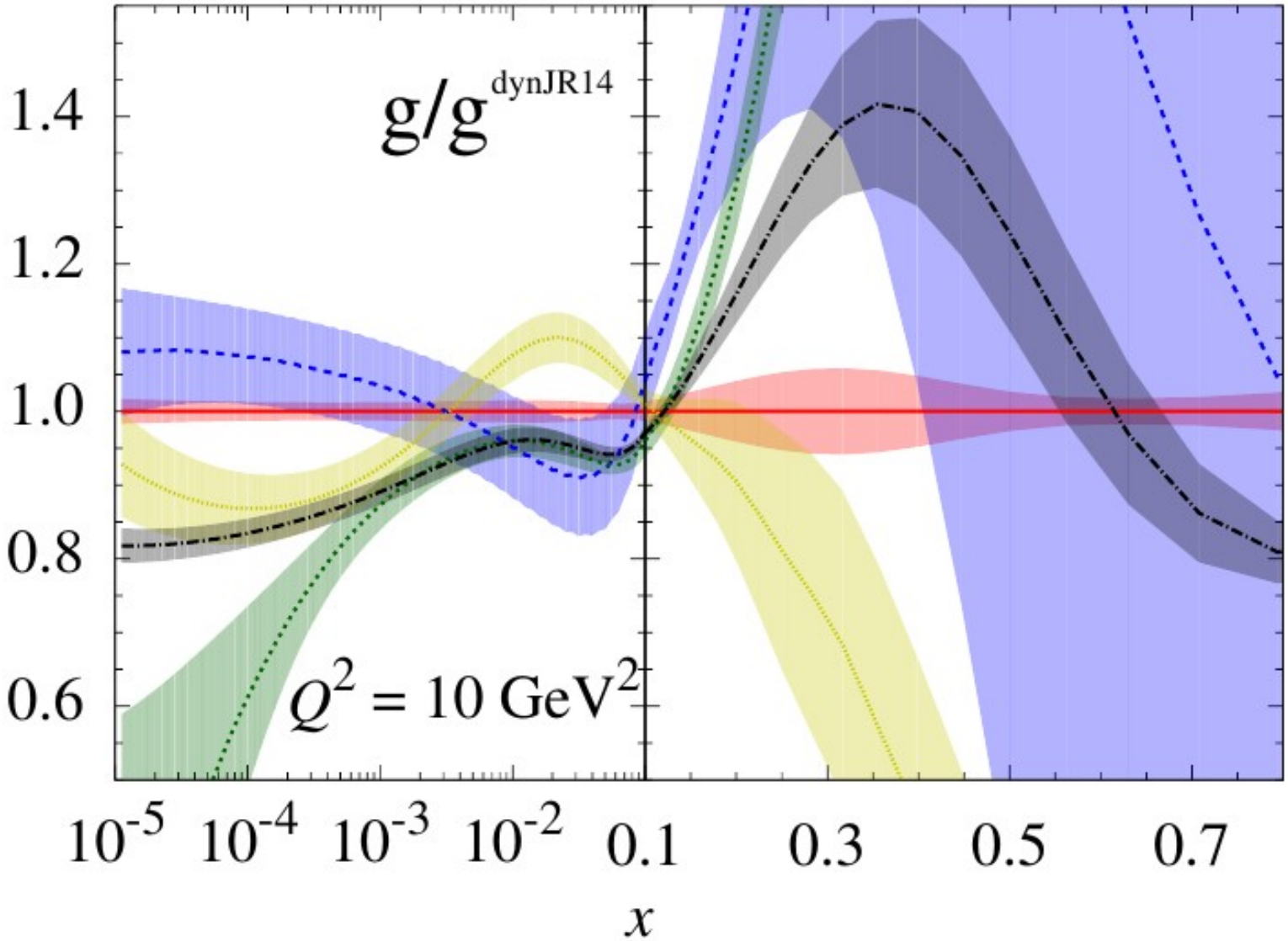
Updating JR09: calculations

- Experimental correlations properly treated (also multiplicative errors)
- Switched to $\overline{\mathrm{MS}}$ scheme for heavy quark masses [ABM 2010]
- NNLOapp for heavy quark structure functions [ABM 2010]
- Target mass corrections used also for F_L (in addition to F_2)
- Nuclear corrections for deuteron data [CJ 2012]
- Determination of higher-twist contributions to structure functions

$$F_{2,L}^{p,n}(x,Q^2) + \frac{h_{2,L}^{p,n}(x)}{Q^2}$$



Status of gluon distributions



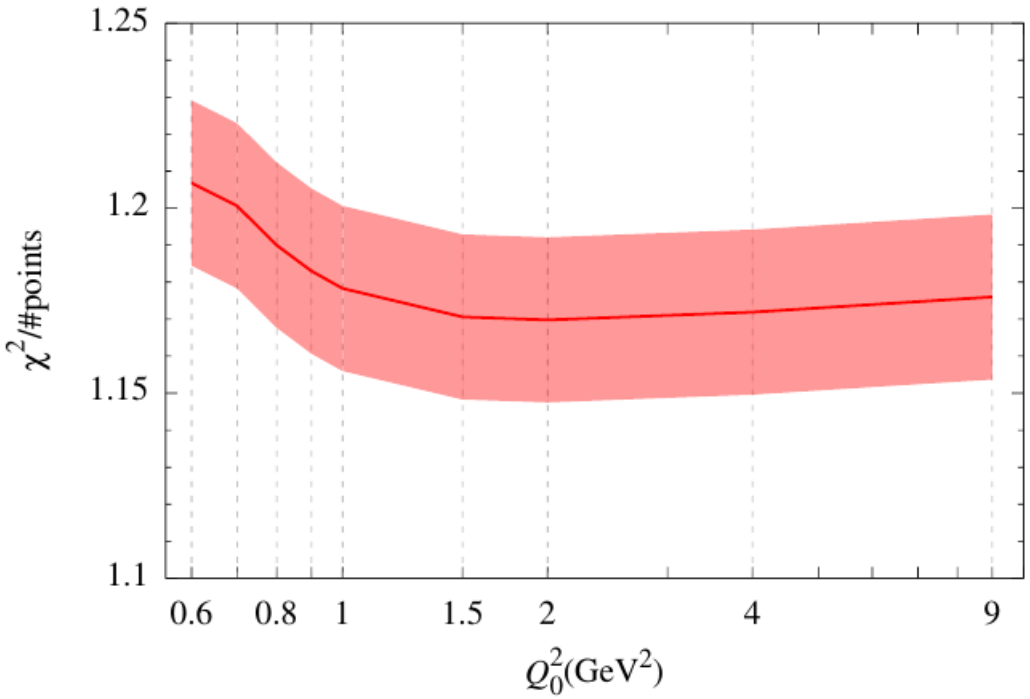
Reduced experimental uncertainties due to new constraints

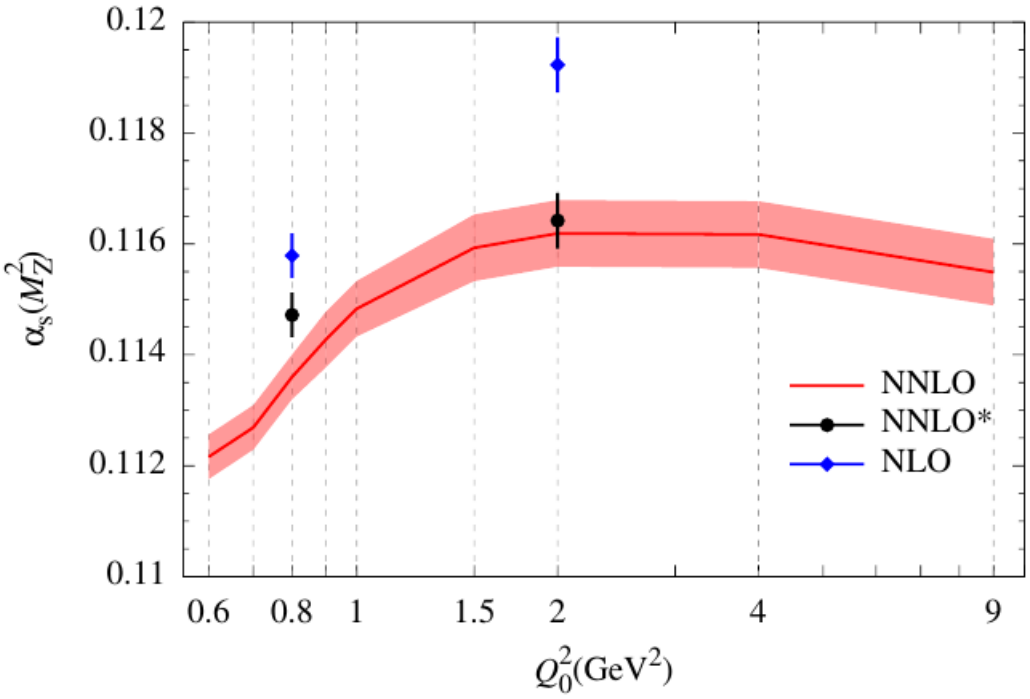
Systematic (*procedural*) uncertainties become dominant

The role of the input scale in PDF analysis

[PJD 2012]

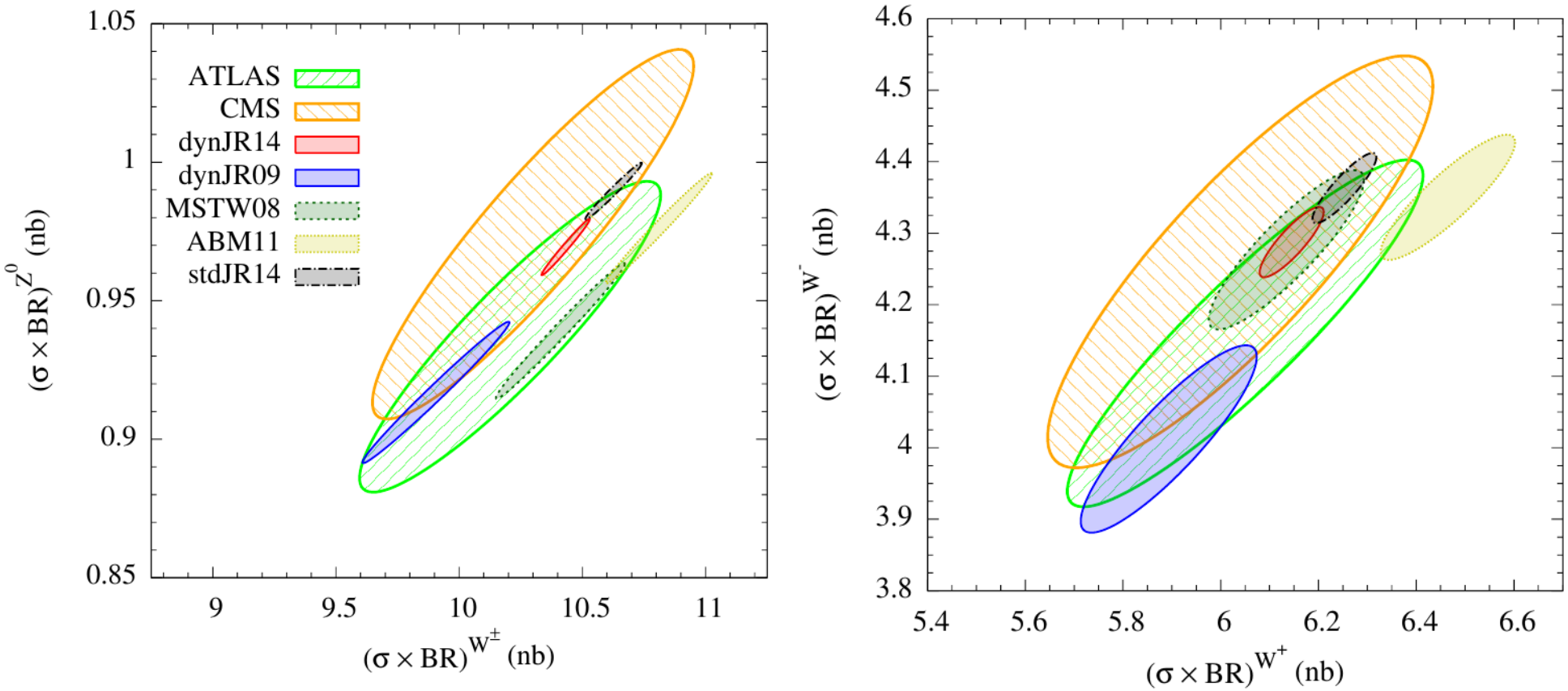
Any dependence is due to shortcomings of the estimation: *procedural bias*
(e.g. parametrization bias, backwards evolution to low scales, … rather general)





These variations can be used to estimate the procedural uncertainty
(devise a measure: e.g. in JR half the difference between dynamical and standard)

Benchmark cross-sections and other predictions



PDFs, details of the fits (correlations, eigenvectors, etc.), predictions for structure functions, LHC cross-sections, etc., available:

`http://users.hepforge.org/~pjimenezdelgado`

...and polarized PDFs: JAM

The JAM collaboration

www.jlab.org/jam

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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.

12000 Jefferson Avenue, Newport News, VA 23606
Phone: (757) 269 5854 Fax: (757) 269 7002

contact Wally Melnitchouk
updated March 21, 2013

Parallel effort to our unpolarized PDFs: CJ and JR

The JAM collaboration

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Collaboration

The JAM Collaboration consists of the following members:

Theory

- Pedro Jimenez-Delgado (*Jefferson Lab*)
- Alberto Accardi (*Hampton University*)
- Wally Melnitchouk (*Jefferson Lab*)

Database Working Group

- Peter Bosted (*Jefferson Lab / College of William and Mary*)
- Jian-ping Chen (*Jefferson Lab*)
- Keith Griffioen (*College of William and Mary*)
- Sebastian Kuhn (*Old Dominion University*)
- Wally Melnitchouk (*Jefferson Lab*)
- Oscar Rondon (*University of Virginia*)
- Brad Sawatzky (*Jefferson Lab*)

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contact Wally Melnitchouk
updated March 21, 2013

to start with, open to further contributions

The JAM database

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

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  - All data
  - proton
  - deuteron
  - 3He

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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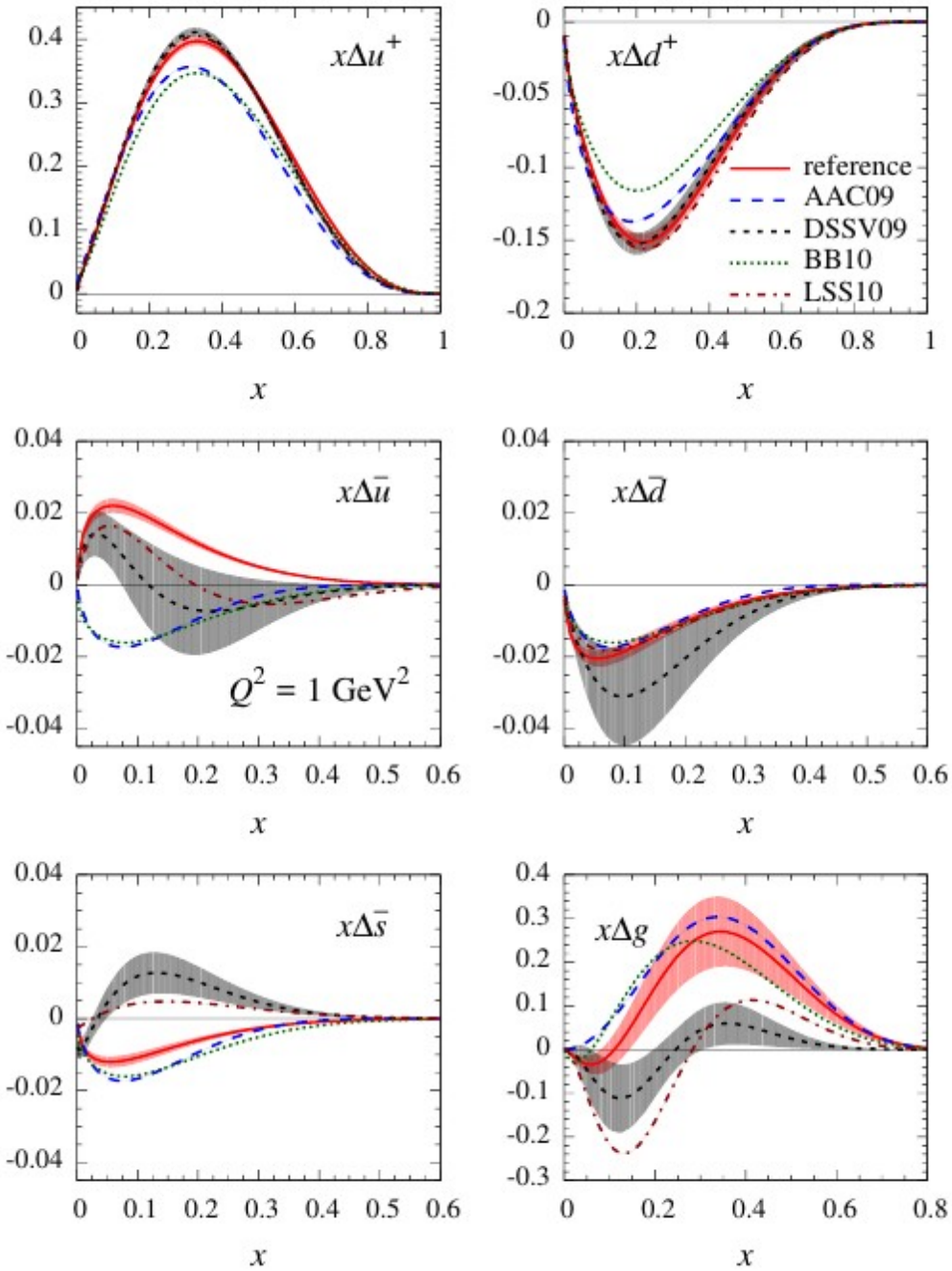
Data and theory comparison with other groups

	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 concentrated on improvements in the theoretical description of DIS

Long-term objective is to tick all the boxes (include SIDIS and RHIC data)

Current status of polarized PDFs



Worse known than the unpolarized

$\Delta u^+ = \Delta u + \Delta\bar{u}$ and

$\Delta d^+ = \Delta d + \Delta\bar{d}$ better known

Sea distributions $\Delta\bar{u},\ \Delta\bar{d},\ \Delta\bar{s}$

do not enter in DIS asymmetries

Δg less known, determined mainly from RHIC data (also COMPASS)

Data considered at this (first) stage

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

experiment	reference	observable	target	$N_{\rm data}$	$\chi^2(\mathrm{LT})/N_{\rm dat}$	$\chi^2(\mathrm{JAM})/N_{\rm dat}$
EMC	[1]	A_1	p	10	0.42	0.39
SMC	[29]	A_1	p	12	0.36	0.36
	[29]	A_1	d	12	1.59	1.66
	[30]	A_1	p	8	1.37	1.35
	[30]	A_1	d	8	0.54	0.56
COMPASS	[31]	A_1	p	15	0.95	0.97
	[32]	A_1	d	15	0.57	0.51
SLAC E80/E130	[33]	$A_\parallel$	p	23	0.52	0.54
SLAC E142	[34]	A_1	^{3}He	8	0.58	0.70
	[34]	A_2	^{3}He	8	0.70	0.70
SLAC E143	[35]	$A_\parallel$	p	85	0.85	0.81
	[35]	$A_\perp$	p	48	0.95	0.91
	[35]	$A_\parallel$	d	85	1.05	0.85
	[35]	$A_\perp$	d	48	0.92	0.91
SLAC E154	[36]	$A_\parallel$	^{3}He	18	0.43	0.42
	[36]	$A_\perp$	^{3}He	18	1.00	1.00
SLAC E155	[37]	$A_\parallel$	p	73	1.00	0.92
	[37, 38]	$A_\perp$	p	66	1.00	0.96
	[39]	$A_\parallel$	d	73	0.98	0.97
	[38, 39]	$A_\perp$	d	66	1.51	1.49
SLAC E155x	[40]	$\tilde{A}_\perp$	p	117	2.17	1.64
	[40]	$\tilde{A}_\perp$	d	117	0.90	0.84
HERMES	[41]	$A_\parallel$	p	37	0.38	0.39
	[41]	$A_\parallel$	d	37	0.86	0.85
	[42]	A_1	"n"	9	0.29	0.30
	[43]	A_2	p	20	1.07	1.16
JLab E99-117	[44]	$A_\parallel$	^{3}He	3	0.62	0.06
	[44]	$A_\perp$	^{3}He	3	1.08	0.87
COMPASS	[48]	$\Delta g/g$	p	1	5.27	2.71
total				1043	1.07	0.98
JLab E97-103*	[45]	$A_\parallel$	^{3}He	2	—	—
	[45]	$A_\perp$	^{3}He	2	—	—
JLab EG1b*	[47]	A_1	p	766	—	—
(prelim.)	[47]	A_1	d	767	—	—

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 NLO)

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

Underlying QCD description

Asymmetries from (un)polarized structure functions:

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

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

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

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

Calculations and RGE evolution implemented in the space of complex Mellin *moments* (truncated solutions)

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

Parametrization

Only *two* independent combinations of quark distributions contribute:

$$x\Delta u^+(x,Q_0^2) = N_u\, x^{a_u}(1-x)^{b_u}(1+A_u\sqrt{x}+B_u\, x) \qquad \Delta q^+ \equiv \Delta q + \Delta\bar{q}$$

$$x\Delta d^+(x,Q_0^2) = N_d\, x^{a_d}(1-x)^{b_d}(1+A_d\sqrt{x}+B_d\, x) \qquad Q_0^2 = 1\ \mathrm{GeV}^2$$

Constrains from hyperon decays relate N_u and N_d, and fix N_s :

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

The *x*-dependence of the sea has been fixed by counting rule and imposing:

$$\lim_{x\to 0} \Delta\bar{q}(x,Q_0^2) = \frac{1}{2}\lim_{x\to 0}\Delta q^+(x,Q_0^2) \qquad \frac{1}{2}\left(\left|\frac{\Delta\bar{q}^{(2)}}{\Delta\bar{s}^{(2)}}\right| + \left|\frac{\Delta\bar{s}^{(2)}}{\Delta\bar{q}^{(2)}}\right|\right) = 1 \pm 0.25$$

For the gluon we leave N_g and B_g as free parameters

Nominally 13 (LT) + 14 (HT) = 27 parameters to be determined

Statistical estimation

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*

Iterative procedure for multiplicative correlated errors [PJD 2012]

Unfortunately most experiments do not provide all this information

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

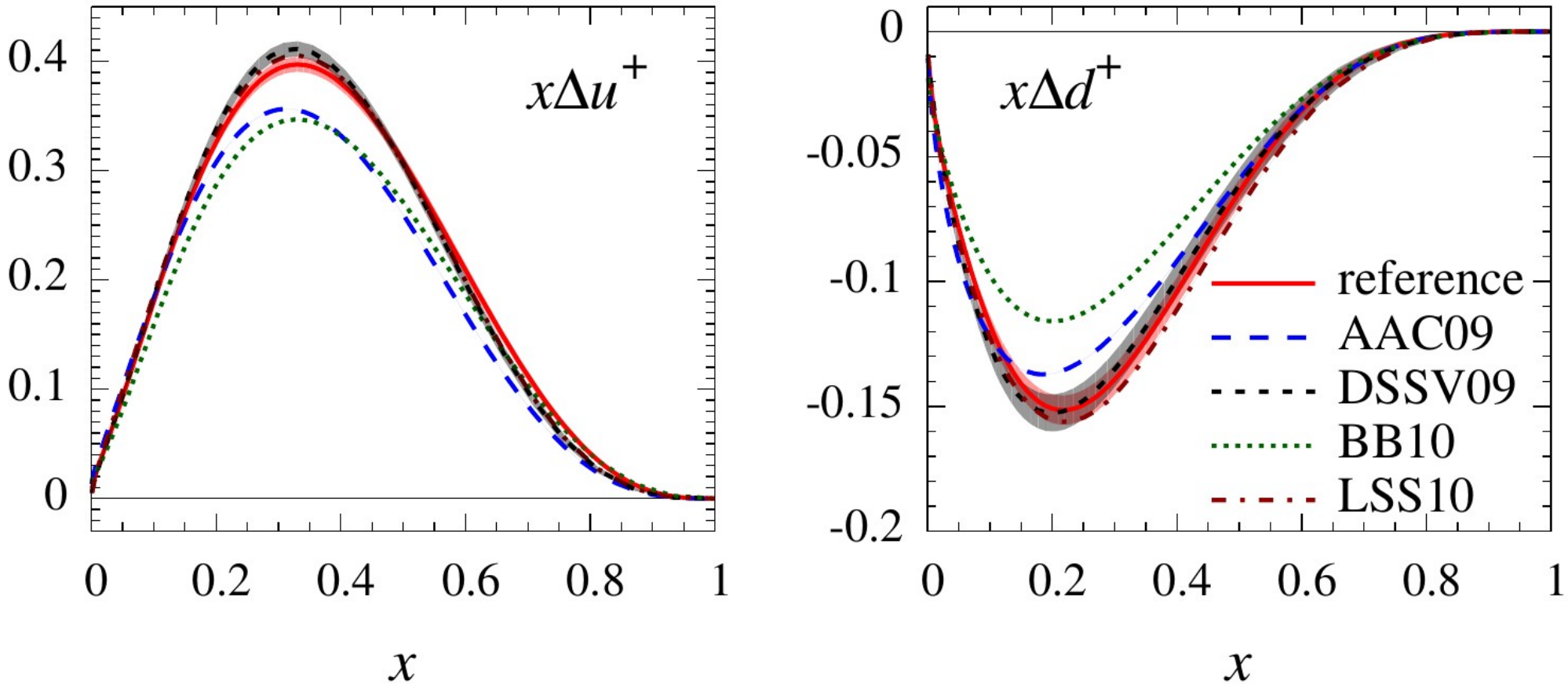
"Vicinity" of the minimum (tolerance) characterized by:

$$\Delta\chi^2 = \chi^2(p) - \chi^2(p^0) \leq T^2 = 1$$

Simple fit without further corrections: reference

Nuclear targets treated with the "effective polarization" approximation:

$$g_1^d = (1 - \tfrac{3}{2} w_d)(g_1^p + g_1^n) \qquad g_1^{\mathrm{He3}} = P_n\, g_1^n + P_p\, g_1^p$$



More similar to DSSV, LSS than to others

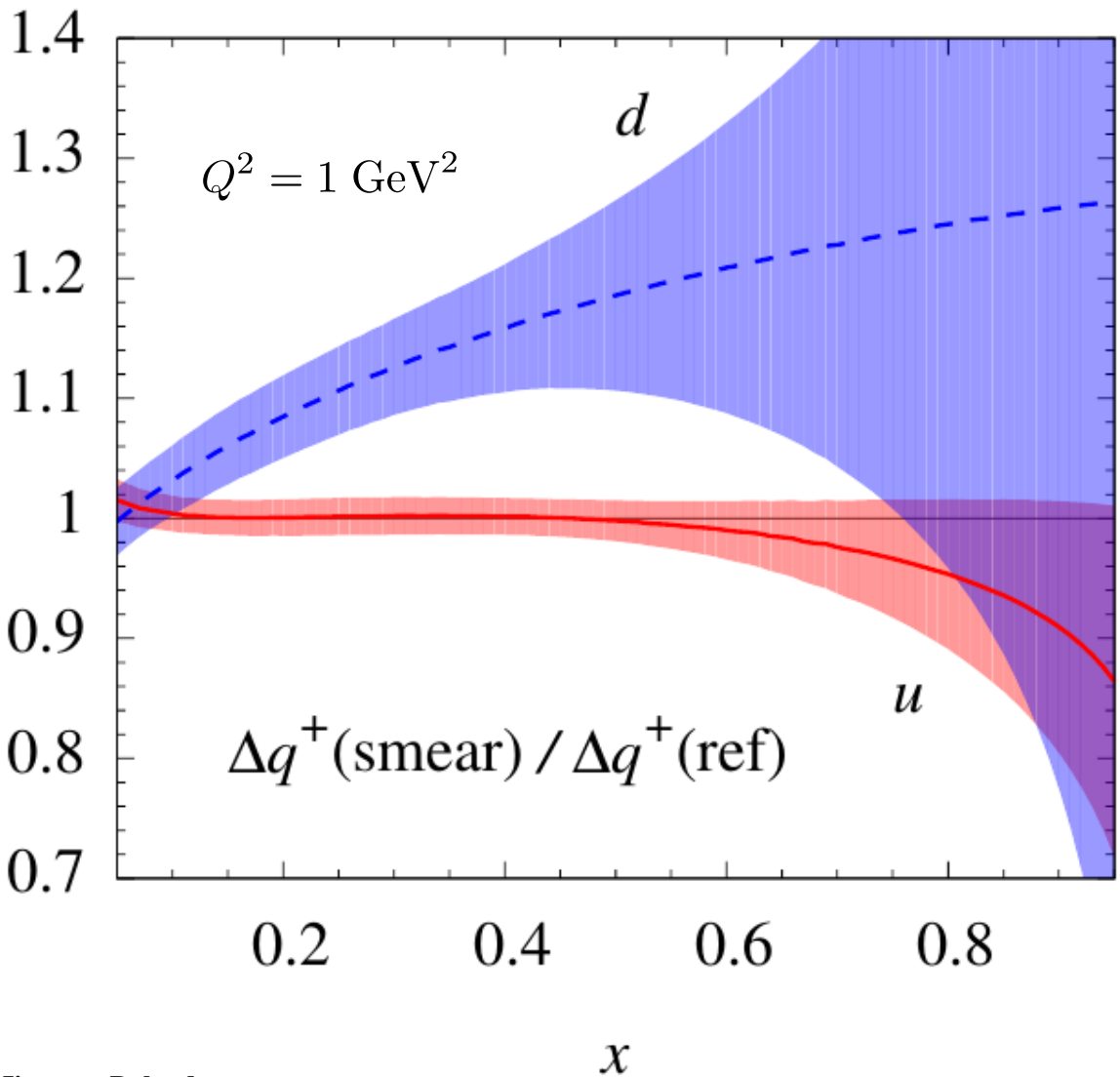
Baseline for assessing the impact of additional corrections

Improved description of nuclear targets

Improved by using "smearing functions" derived from nuclear wave functions:

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

[Kulagin, Petti 06]



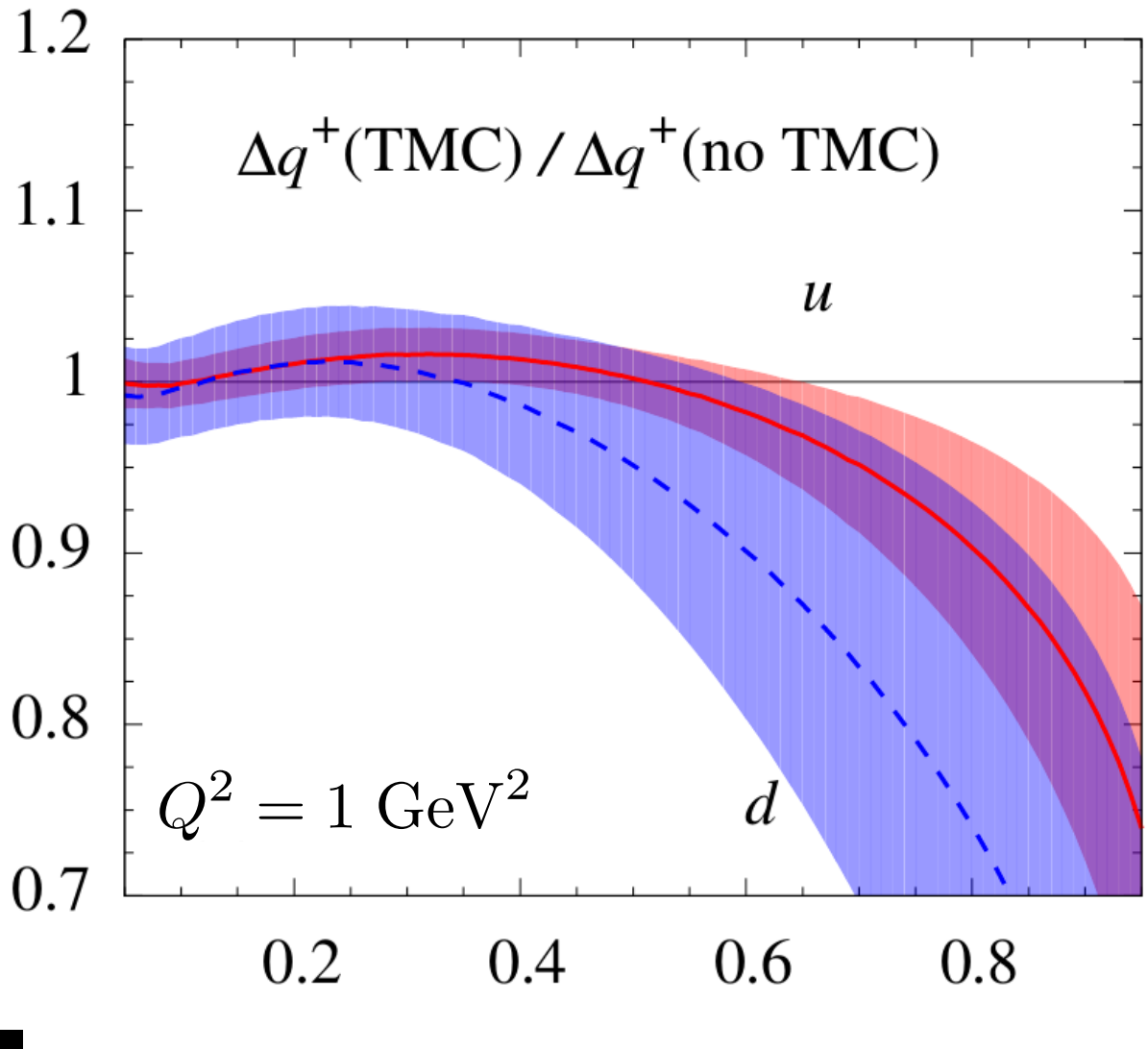
Most relevant for Δd in the medium- and large-x region

Target-mass corrections

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

$$g_1^{\mathrm{TMC}}(n) = g_1(n) + \frac{M^2}{Q^2}\frac{n^2(n+1)}{(n+2)^2}g_1(n+2) + \frac{M^4}{Q^4}\ldots + \mathcal{O}(\frac{M^8}{Q^8})$$

[Bluemlein, Tkabladze 99]



Note that the Wandzura-Wilzceck relation holds also after TMCs

Relevant for both Δu and Δd in the large-x region

Both TMC and nuclear corrections *should* be included in global fits

Higher twist contributions

We consider also corrections from higher twist contributions:

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

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

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

[Bluemlein, Tkabladze 99]

With a phenomenological parametrization :

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

[Braun *et al.* 09]

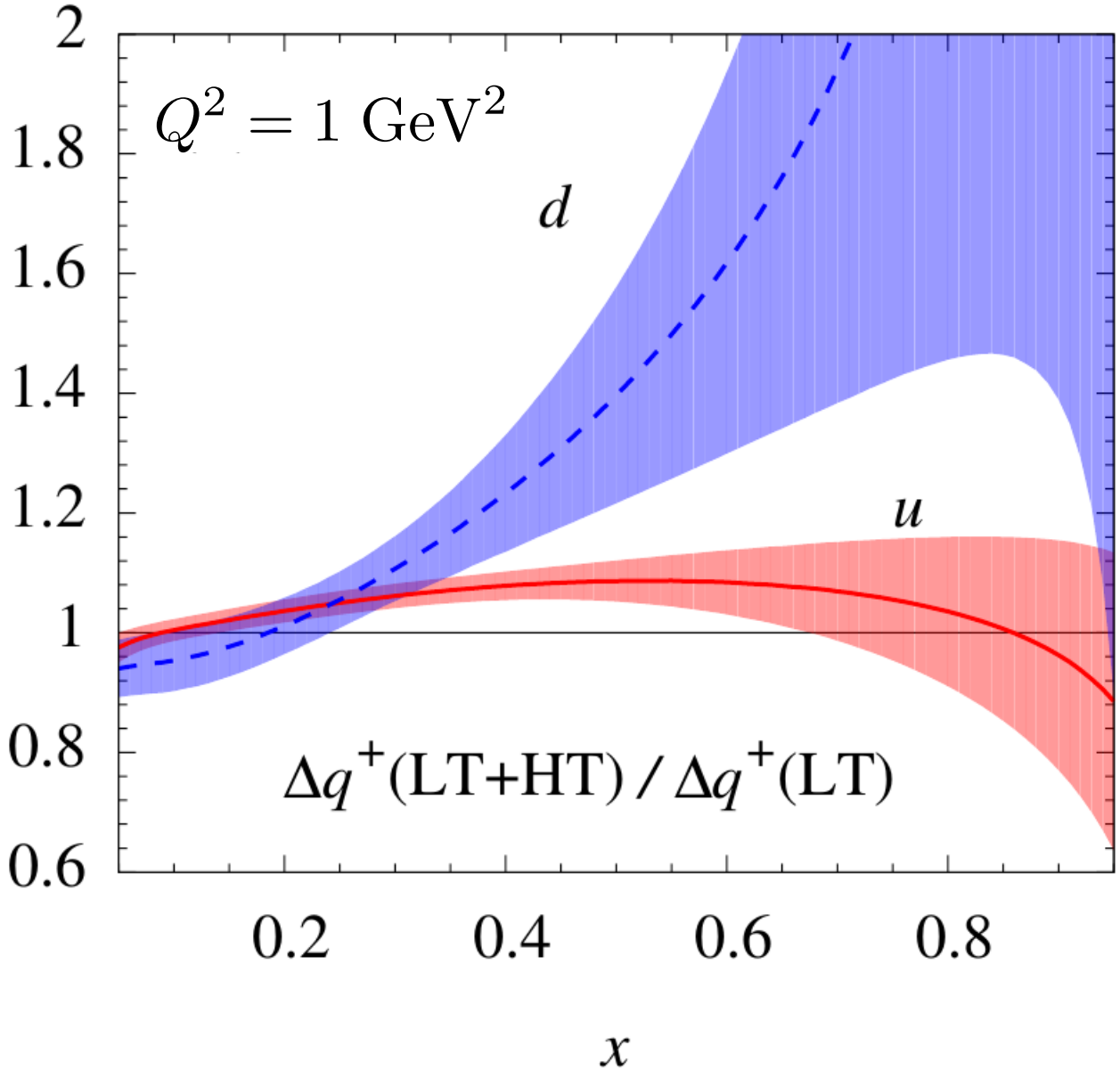
And a splines approximation for: $g_1^{\tau=4} = \dfrac{h(x)}{Q^2}$

$$\int_0^1 dx\, g_2^{\tau=3} = 0$$

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

Higher twist contributions

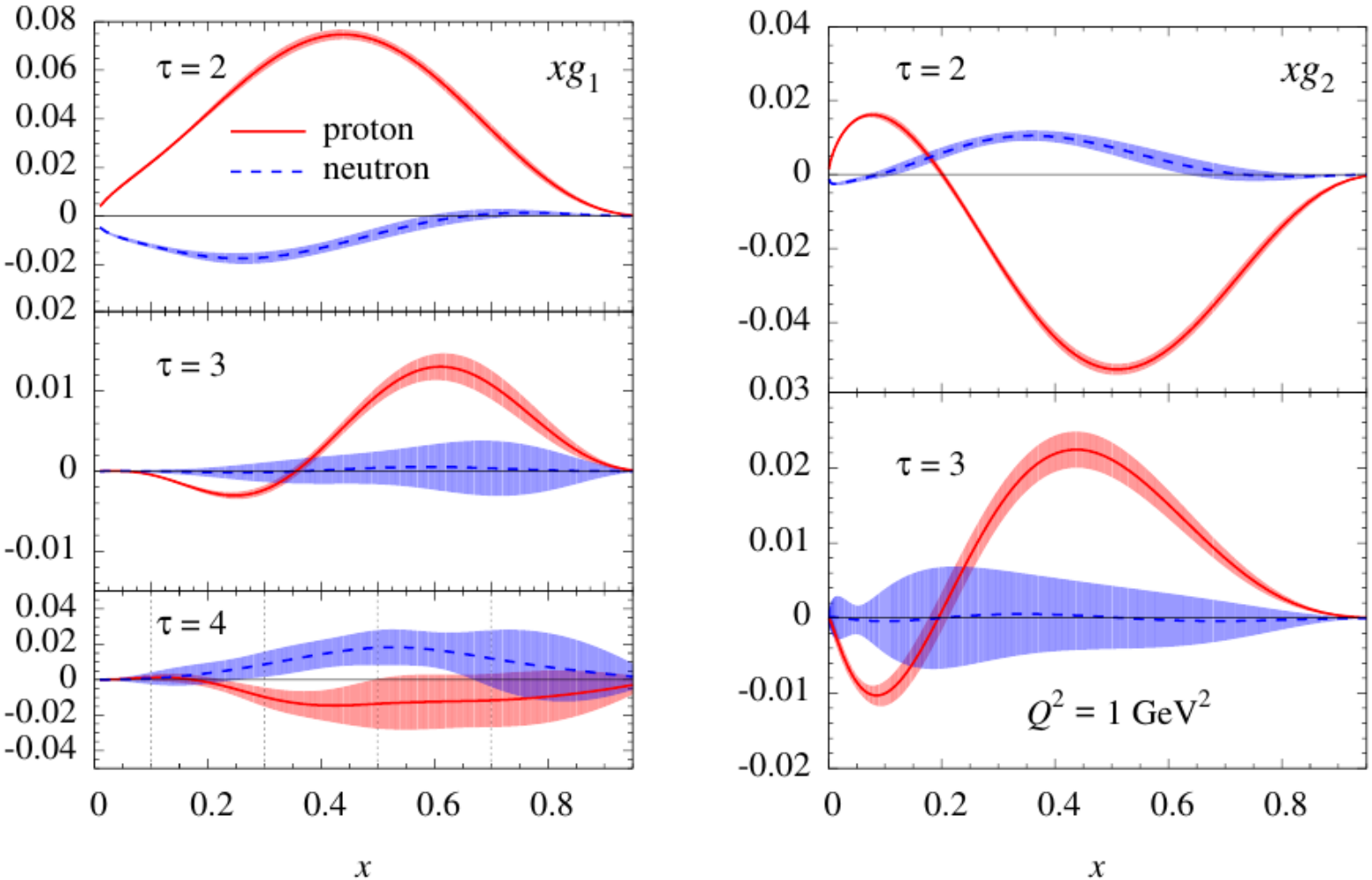
Considerable improvement of χ^2 for some sets (globally $1.07 \to 0.98$, 3σ)



Very large changes in Δd

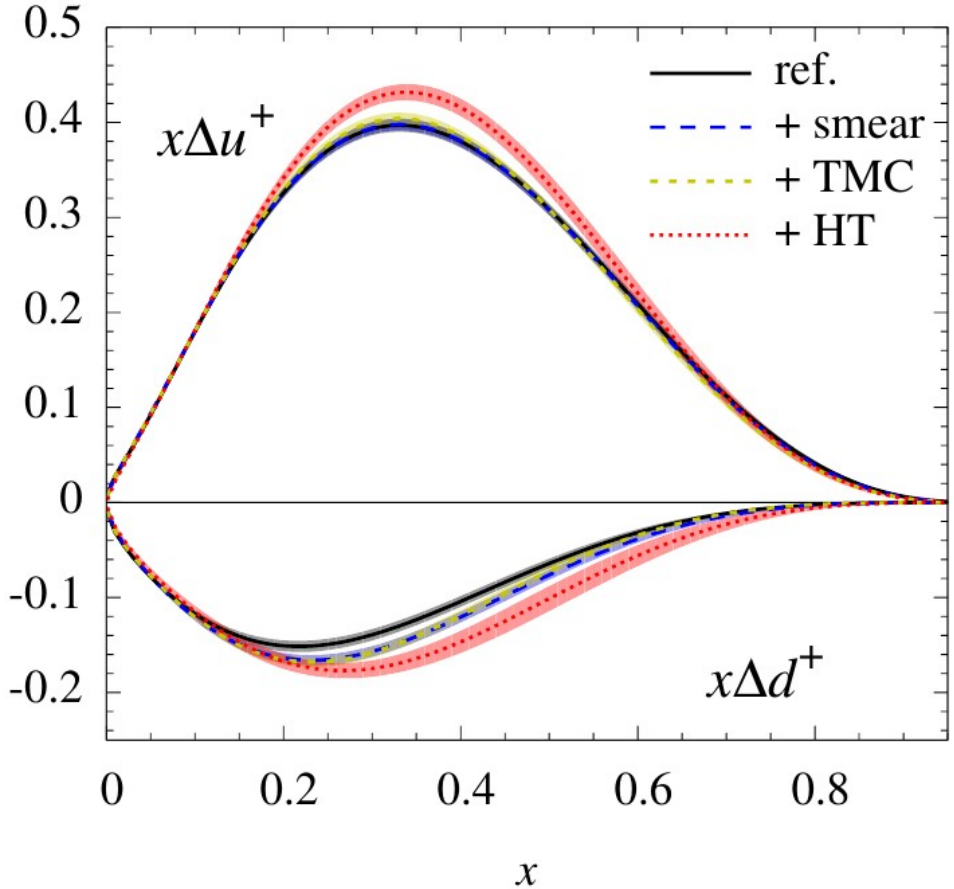
Higher twist contributions

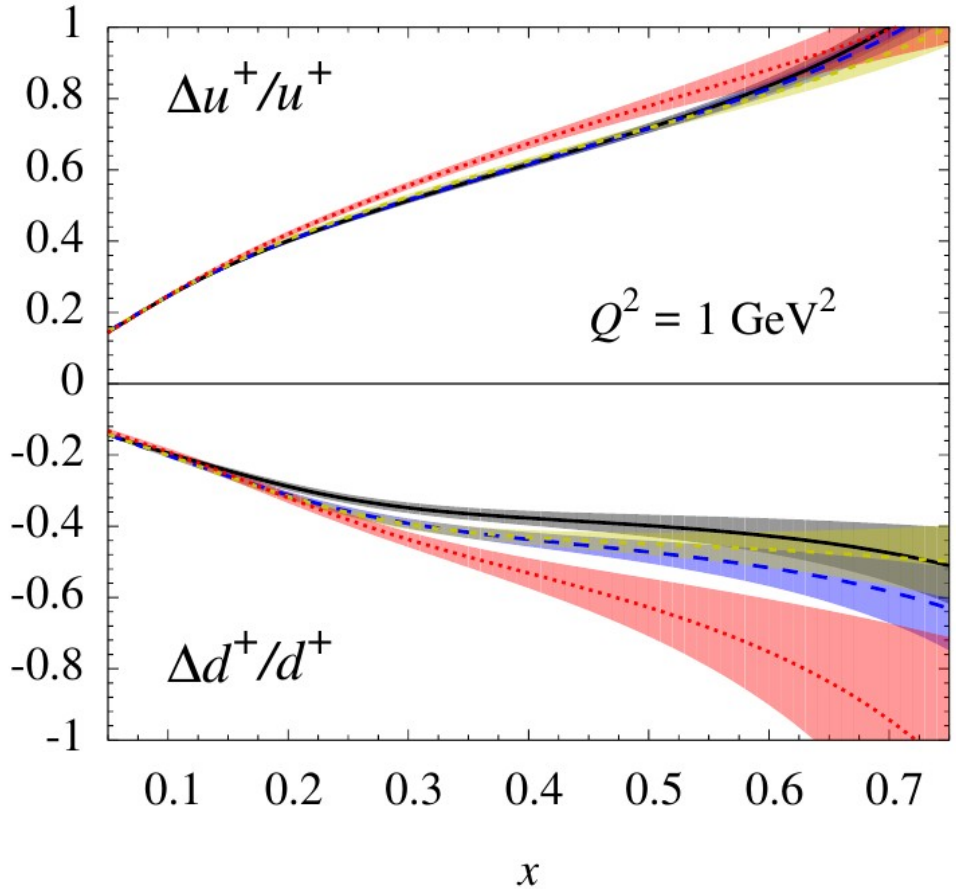
It is possible to determine *simultaneously* higher-twist contributions for g_1 and g_2



Qualitative agreement with previous (separated) determinations

Including all these corrections

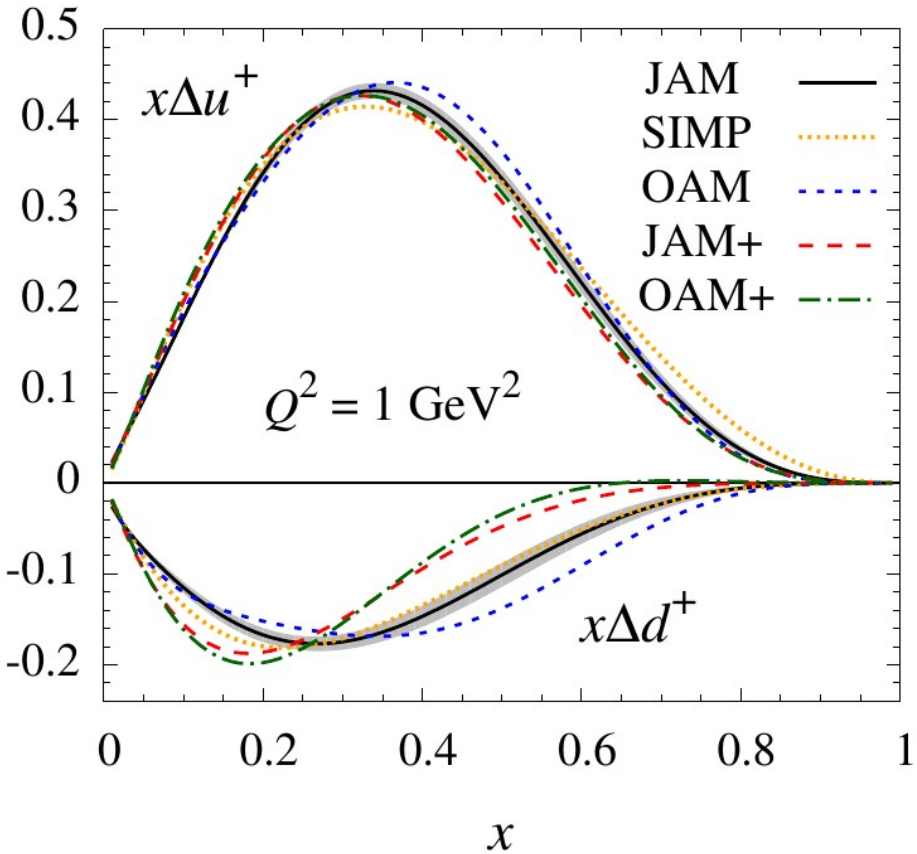


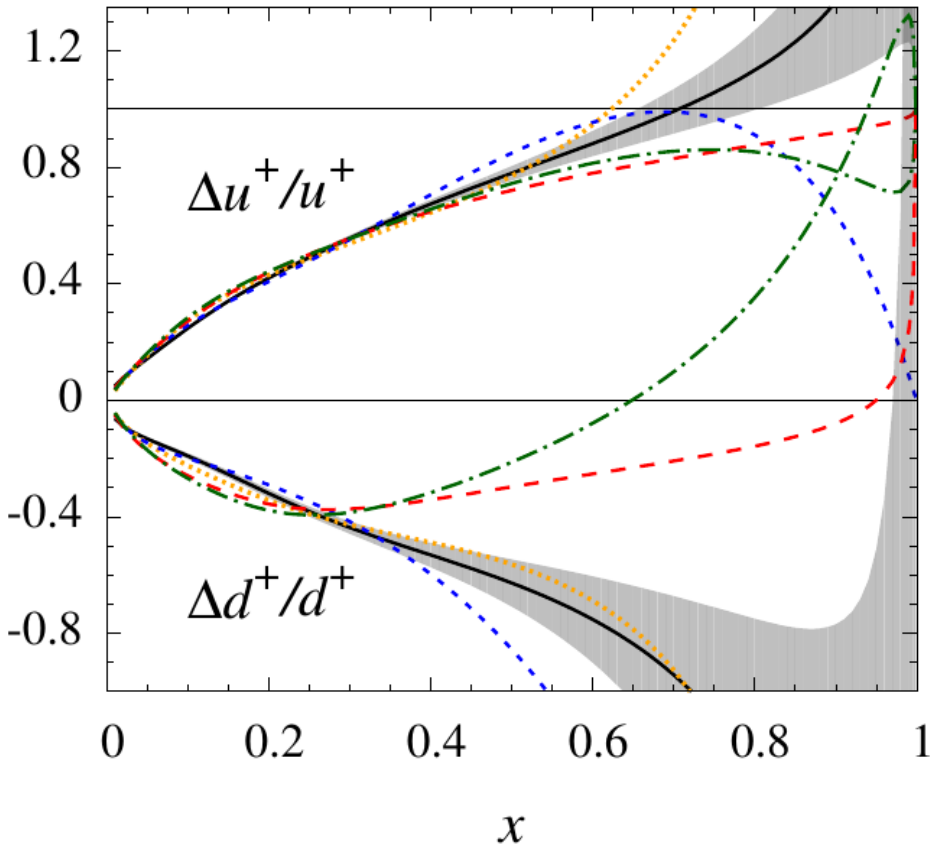


This corrections are *manifestly important* for PDF extractions

PJD, A. Accardi, W. Melnitchouk, PRD89 (2014) 034025

Constraints at large x



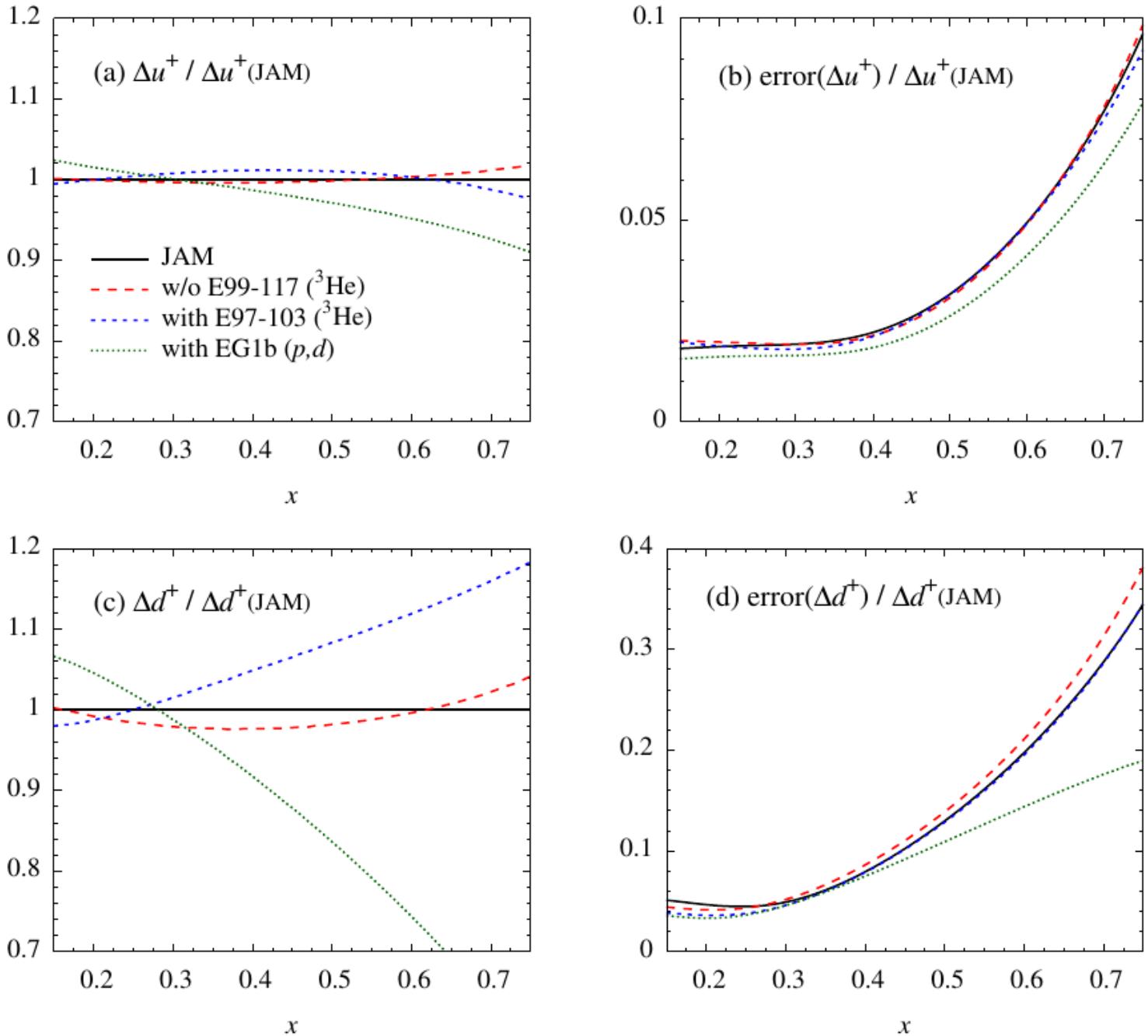


Current data can be accommodated by a range of large-x behaviors

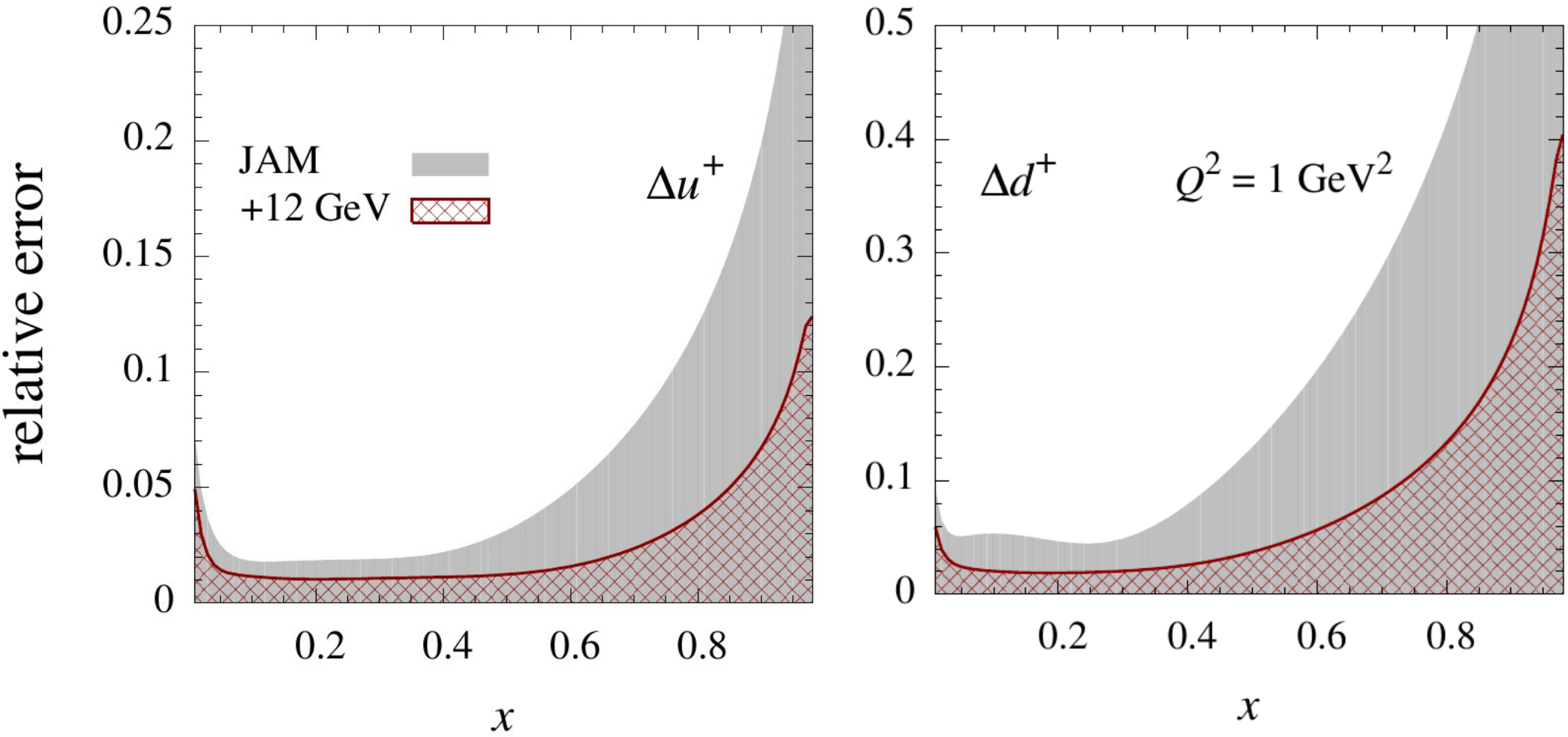
Systematic uncertainties should be considered, and more data needed!

PJD, H. Avakian, W. Melnitchouk, arXiv:1403.3355 [hep-ph]

Impact of JLab data



Impact of JLab 12 data

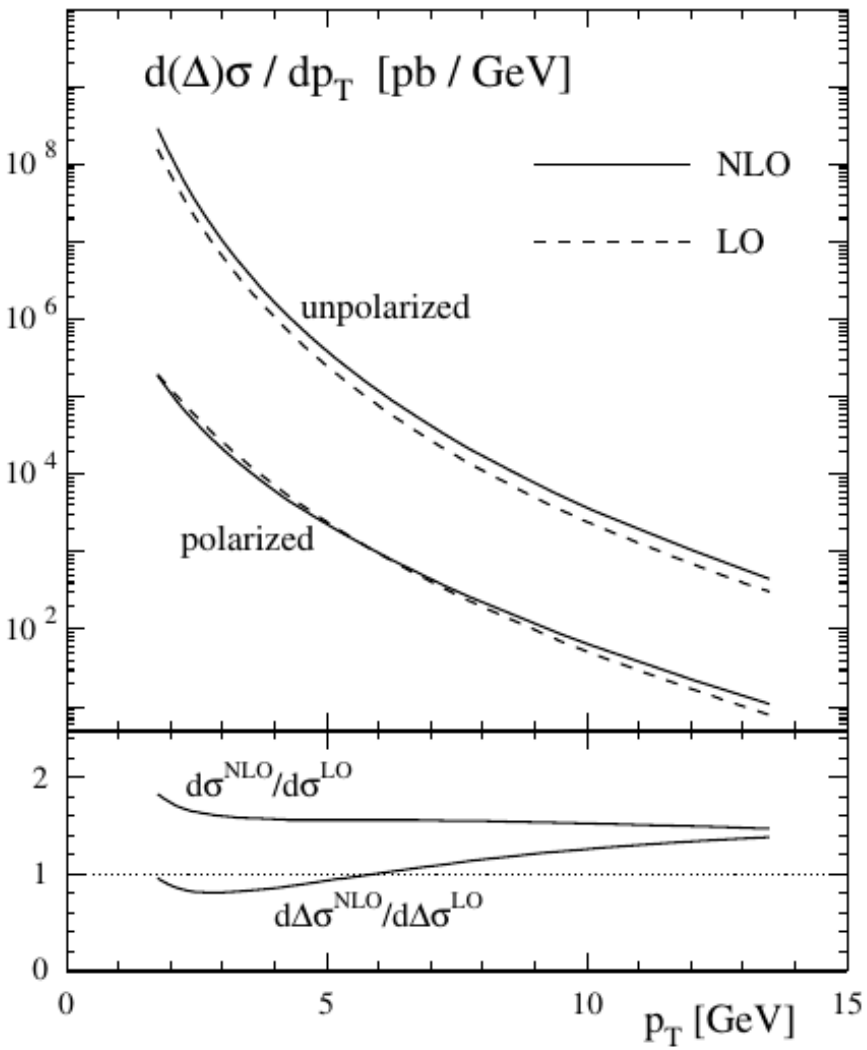


70% reduction of experimental uncertainty for $0.6 \leq x \leq 0.8$

PJD, H. Avakian, W. Melnitchouk, arXiv:1403.3355 [hep-ph]

Moving forwards: including RHIC data

High p_T pion production at RHIC: $pp \to \pi^0 X$



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

We use scaled LO (K-factors):

$$d\Delta\sigma^{NLO} = 1 \times d\Delta\sigma^{LO}$$

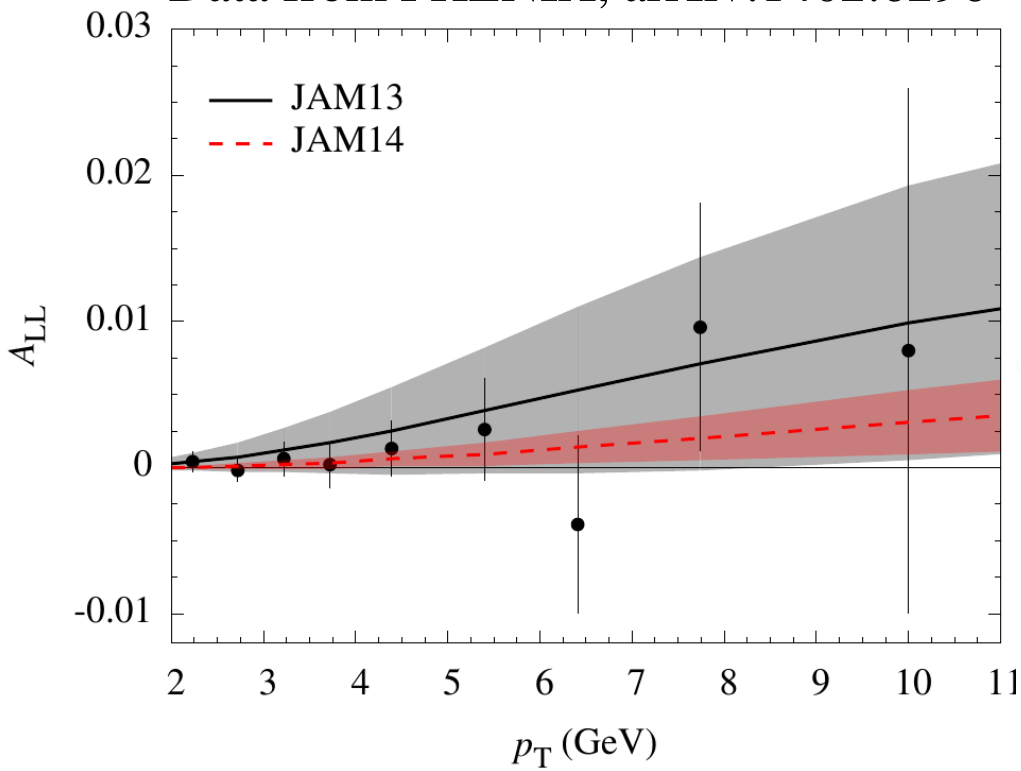
$$d\sigma^{NLO} = 1.5 \times d\sigma^{LO}$$

One should use the full calculation, however experimental errors are large

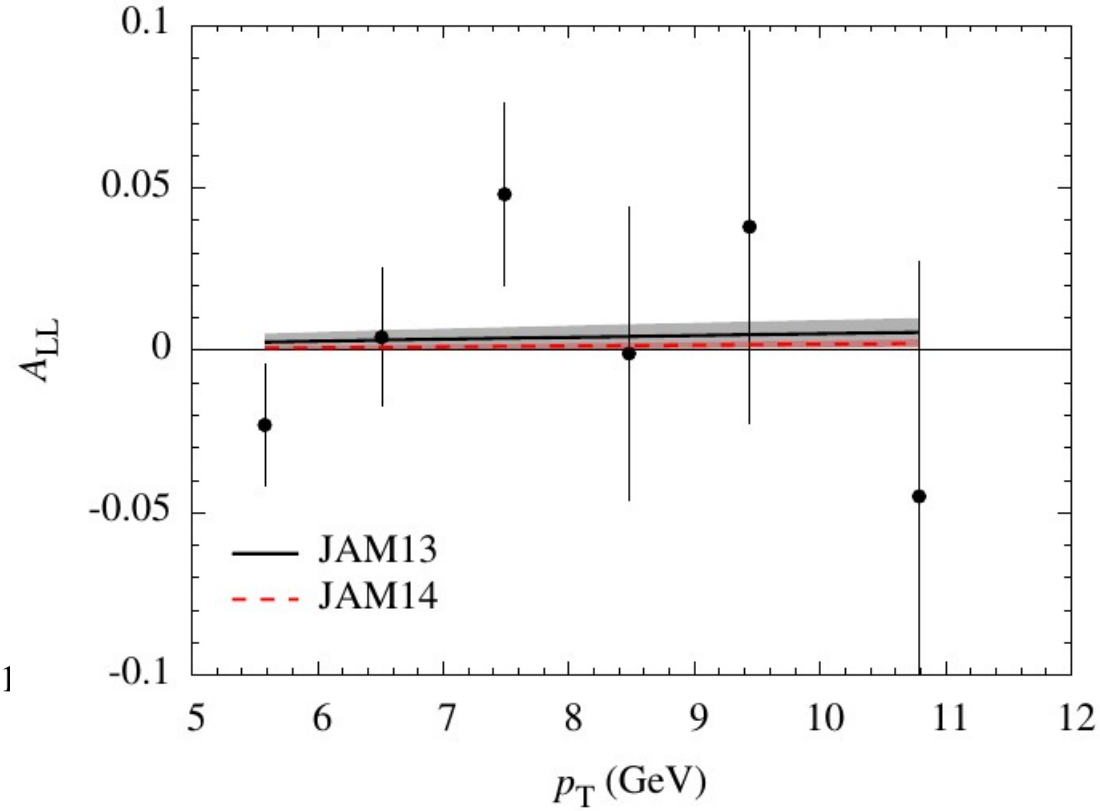
[B. Jäger *et al.*, PRD67 (2003) 054005]

Moving forwards: including RHIC data

Data from PHENIX, arXiv:1402.6296



Data from STAR, PRD89(2014)012001



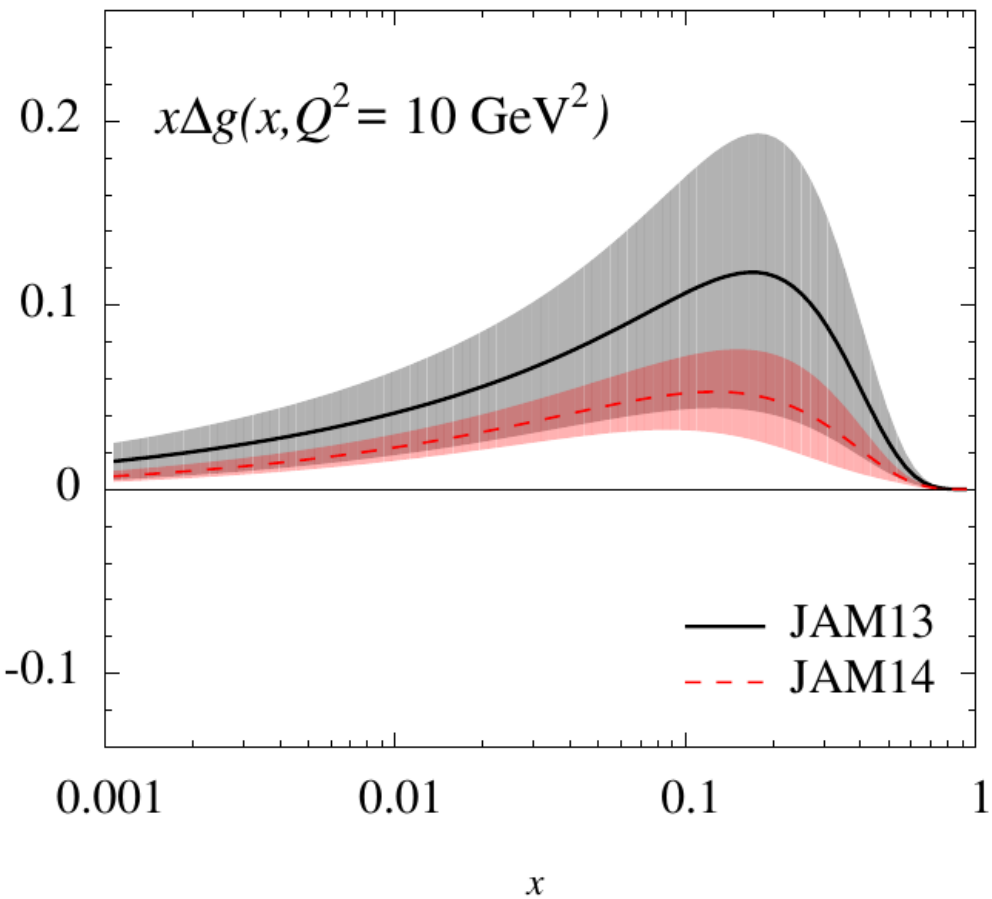
Already "well described" by JAM because of relatively large errors

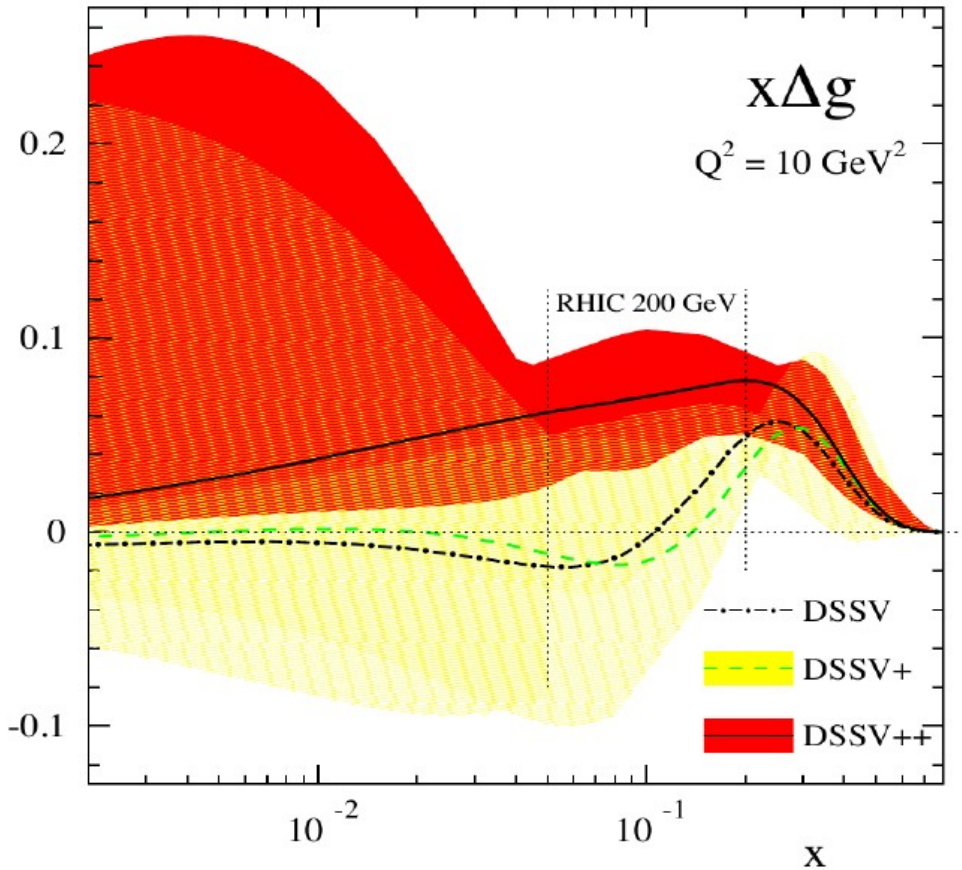
Data do not affect quark distributions or DIS asymmetries,
but do constrain Δg at small x

Preliminary!!

PJD, M. Hirai, S. Kumano, W. Melnitchouk

Effect on the polarized gluon distribution





$$\int_{0.05}^{0.2} \Delta g(x, Q^2 = 10\,\mathrm{GeV}^2)\,dx = 0.10^{+0.06}_{-0.07}$$ [DSSV]

Quite comparable with DSSV++ , except for small-x error band (?!)

$$\int_{0.05}^{0.2} dx\ \Delta g(x, Q^2 = 10^2) = 0.15 \pm 0.09 \rightarrow 0.07 \pm 0.03$$

JAM13 JAM14

Preliminary!!

Summary and outlook

Last update JR14 of our unpolarized distributions has recently been presented

Results not very different from JR09 although with several improvements

A *procedural bias* which is usually disregarded in PDF analysis can be estimated from input-scale variations and is *not* always *small*

Next natural step: inclusion of LHC data

First JAM results on the determination of polarized parton distributions:

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

Dedicated studies of large-x region and impact of JLab data

Other developments in progress or planned: RHIC, SIDIS, EIC …