Global Analysis of Polarized PDFs

Nobuo Sato

In Collaboration with:

Wally Melnitchouk, Jacob Ethier, Alberto Accardi
(Pedro Jimenez-Delgado)

Outline

- Part I: Large x behavior of nucleon spin structure.
- Part II: Constraints from direct photon data at large x on PDFs.

Part I: Large x behavior of nucleon spin structure.

Motivations: "Large x behavior of nucleon spin structure"

- Valence PDFs at large $x \rightarrow$ direct connection with models of nucleon structure.
- Opportunity to study the behavior of $\Delta q/q$ ratios at $x \rightarrow 1$.
- Impact of finite Q^2 & nuclear corrections to parton distributions at high x (following CJ).
- Non trivial interplay between pQCD and the nuclear models at high x.

Motivations: "Large x behavior of nucleon spin structure"

- pQCD:

$$q^{\downarrow} \sim (1-x)^2 q^{\uparrow} \sim (1-x)^5$$

- Some of the consequences:

$$\Delta q/q \to 1 \qquad \text{(for all flavors)}$$
$$A_1 \to 1$$

- To test the above statements, a global analysis of spin PDFs (SPDFs) at large x region is needed.

The JAM global analysis of SPDF

- The bulk of the available data are the polarized inclusive DIS cross section asymmetries:

$$A_{||} = \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Downarrow}} = D(A_1 + \eta A_2)$$

$$A_{\perp} = \frac{\sigma^{\uparrow\Rightarrow} - \sigma^{\uparrow\Leftarrow}}{\sigma^{\uparrow\Rightarrow} + \sigma^{\uparrow\Leftarrow}} = d(A_2 - \xi A_1)$$

$$A_1 = \frac{(g_1 - \gamma^2 g_2)}{F_1} \quad A_2 = \gamma \frac{(g_1 + g_2)}{F_1}$$

- Theory predictions for polarized observables depends on unpolarized PDFs.

The JAM global analysis of SPDF

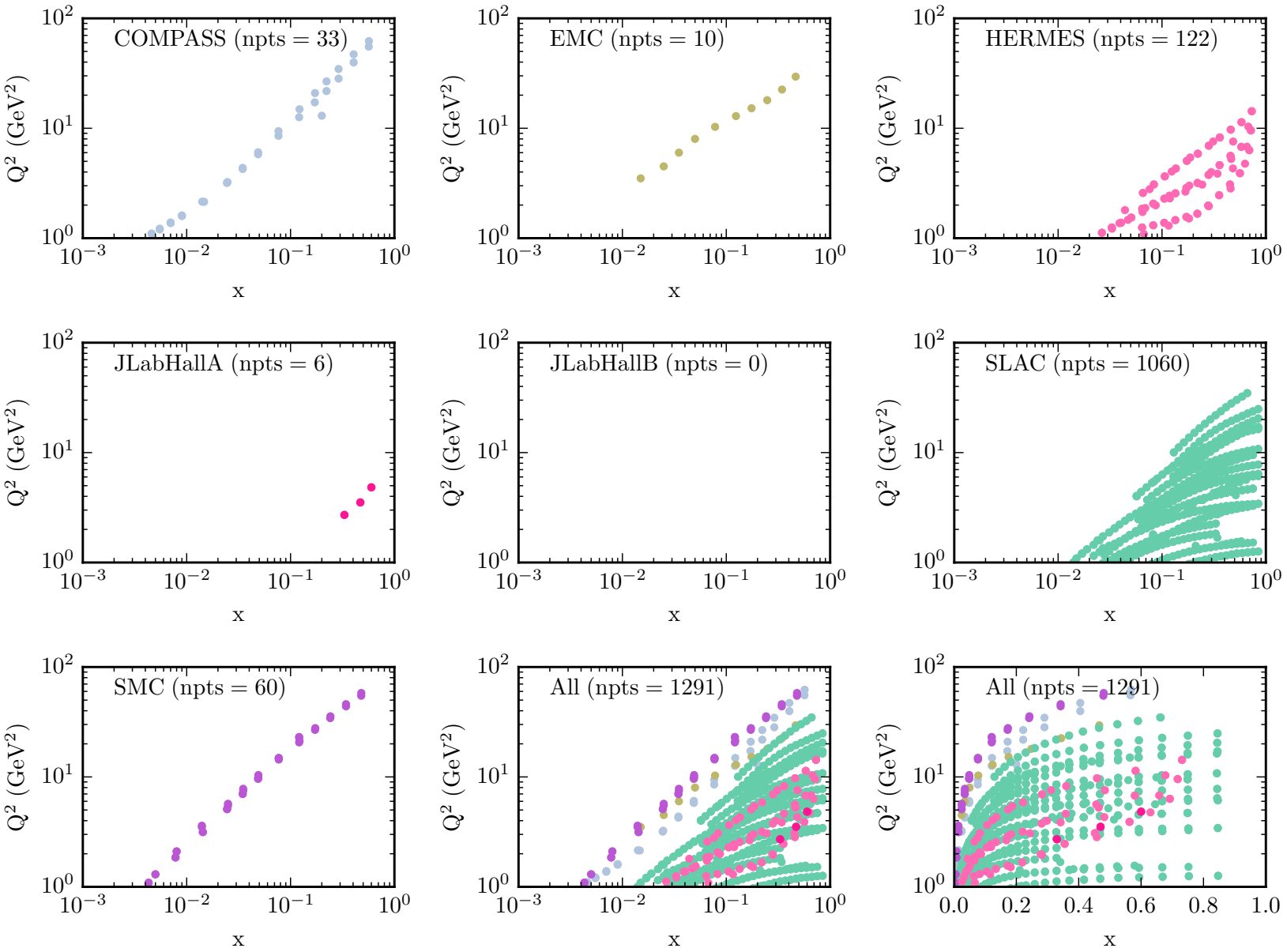
- To ensure that leading twist contribution dominates the scattering process, cuts on Q^2 and W^2 are imposed.

- Typically for unpolarized PDFs $Q^2 \geq 4\text{GeV}^2$ and $W^2 \geq 14\text{GeV}^2$.

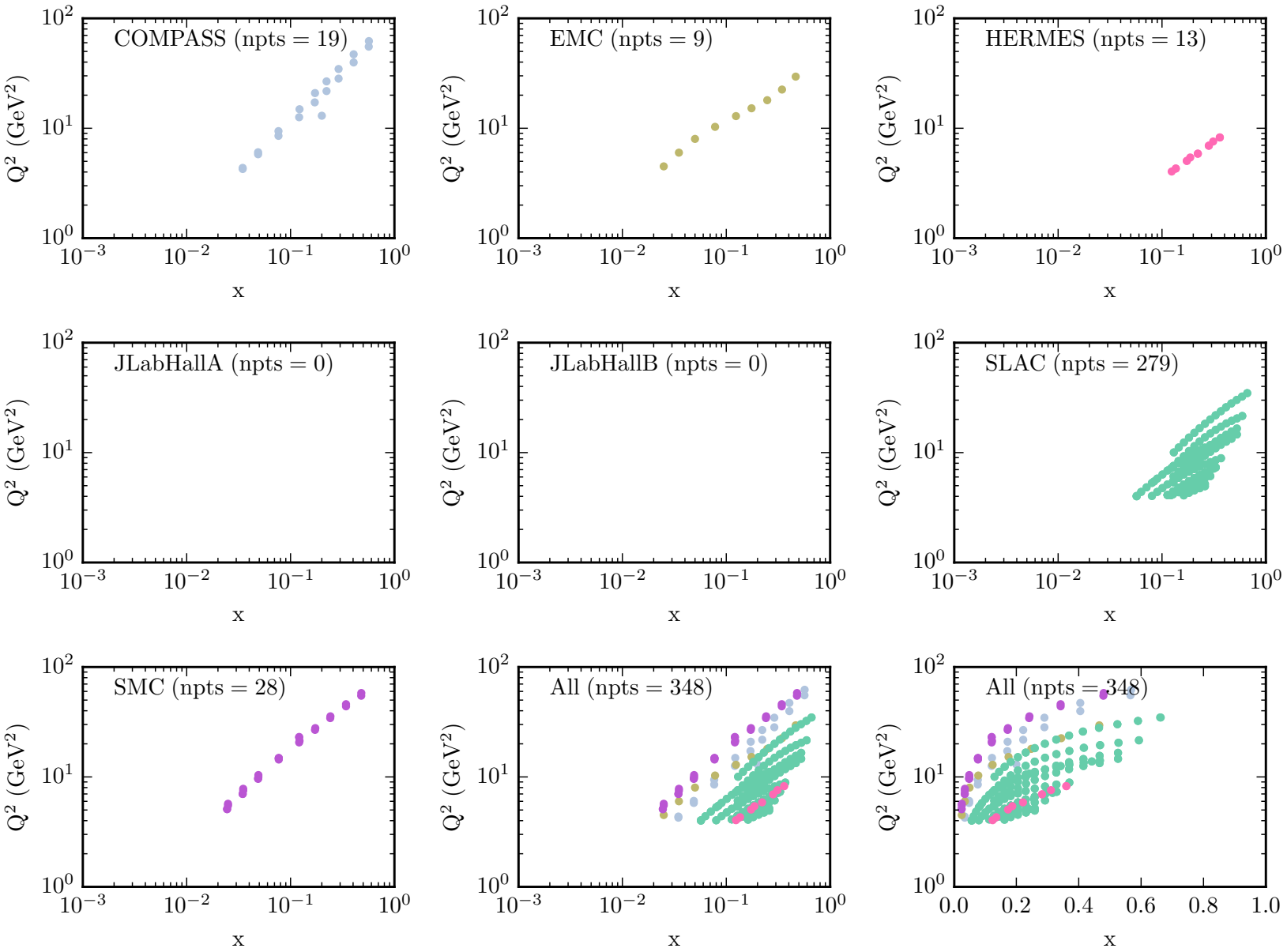
- These cuts are severe for global SPDF analysis.

$$W^2 = M_N^2 + Q^2(1/x - 1)$$

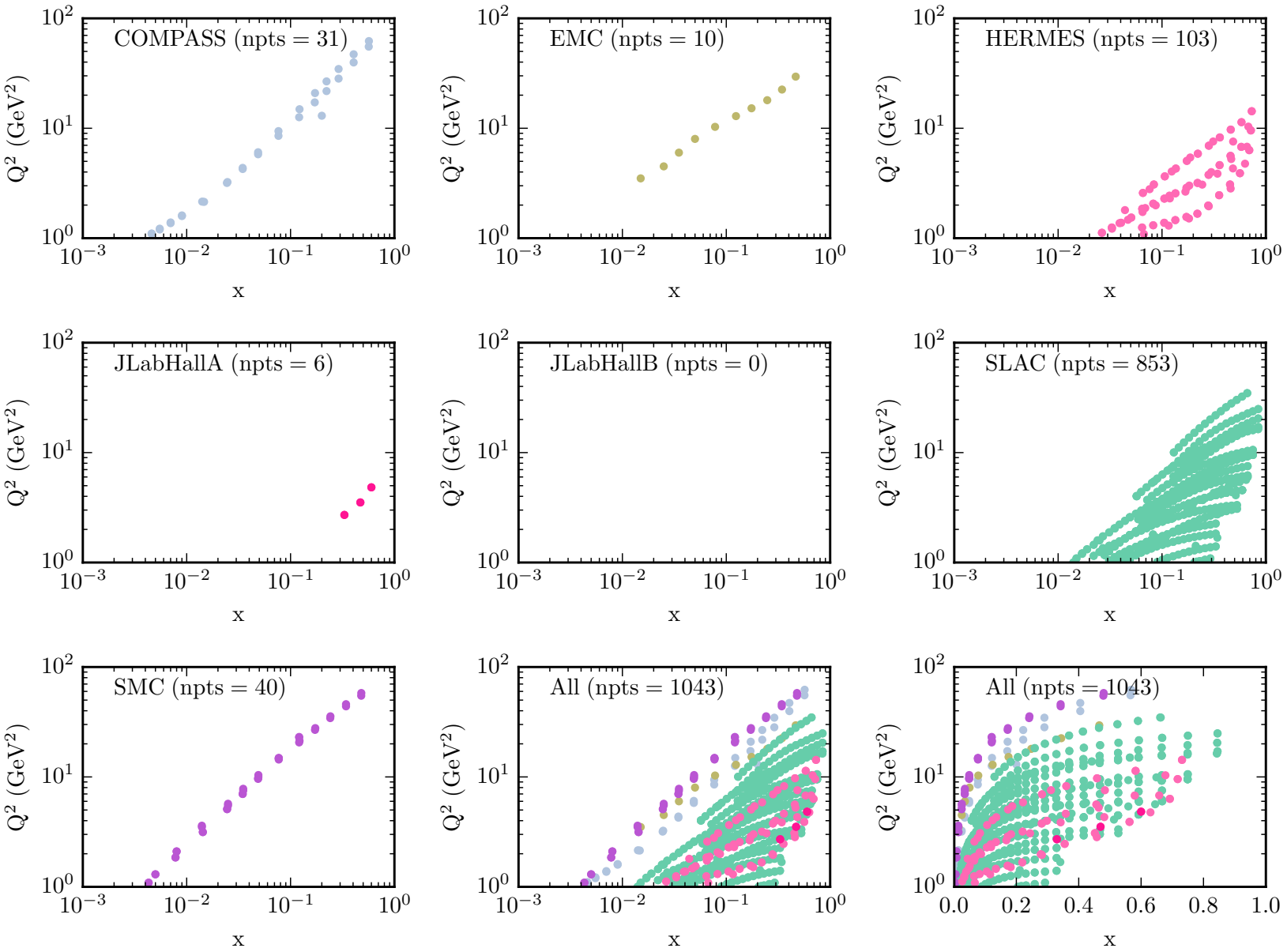
polarized DIS data WITHOUT CUTS



polarized DIS data WITH "TYPICAL" CUTS



polarized DIS data WITH JAM13 CUTS



The JAM13 global analysis of SPDF

- In order to maximally utilize the data, the JAM13 analysis sets the cuts to $Q^2 \geq 1\text{GeV}^2$ and $W^2 \geq 3.5\text{GeV}^2$.

The price:

- TM and HT corrections must be included.
- Asymmetries depend on unpolarized PDFs.
- A consistent analysis requires to fit unpolarized PDFs under the same conditions.

Higher twist corrections

- The leading twist τ (NLO) in Mellin-space

$$g_{1,\tau=2}^{(n)} = \frac{1}{2}\sum_q e_q^2(\Delta C_{qq}^{(n)}\Delta q^{(n)} + \Delta C_g^{(n)}\Delta g^{(n)})$$

$$g_{2,\tau=2}^{(n)} = -\frac{n-1}{n} g_{1,\tau=2}^{(n)}$$

Higher twist corrections

- Twist-3 part of g_2 (PRD 83,094023(2011))

$$g_2^{(\tau=3)} = t_0 \left[\log x + (1-x) + \frac{1}{2}(1-x)^2 \right] + \sum_{i=1}^{4} t_i (1-x)^{i+2}$$

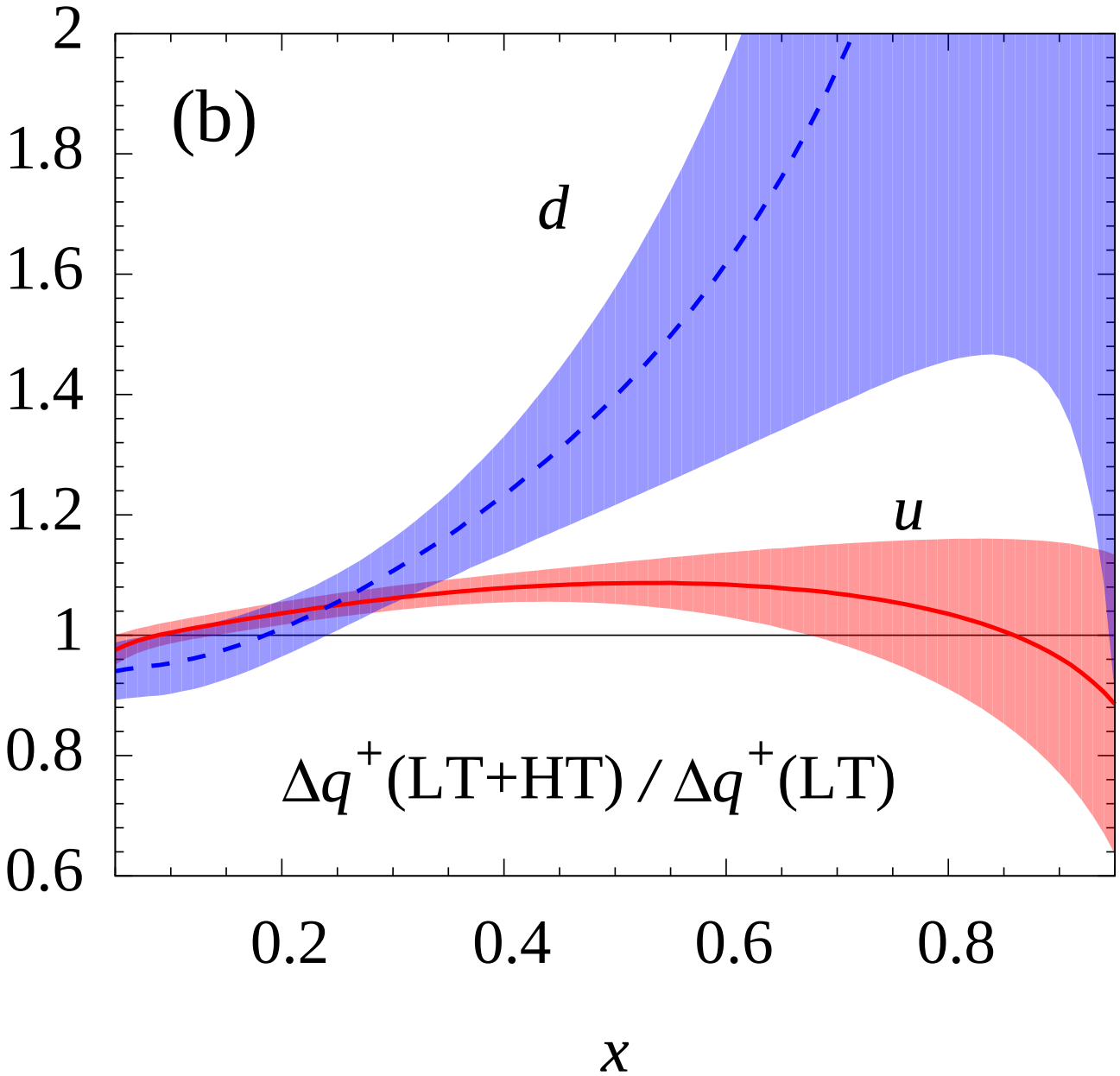
- Twist-3 part of g_1 (NPB,553(1999))

$$g_1^{(\tau=3)} = \gamma^2 \left[g_2^{(\tau=3)} - 2 \int_x^1 \frac{dy}{y} g_2^{(\tau=3)} \right]$$

- Twist-4 part of g_1 (spline parametrization)

$$g_1^{(\tau=4)} = \frac{h(x)}{Q^2}$$

Higher twist corrections



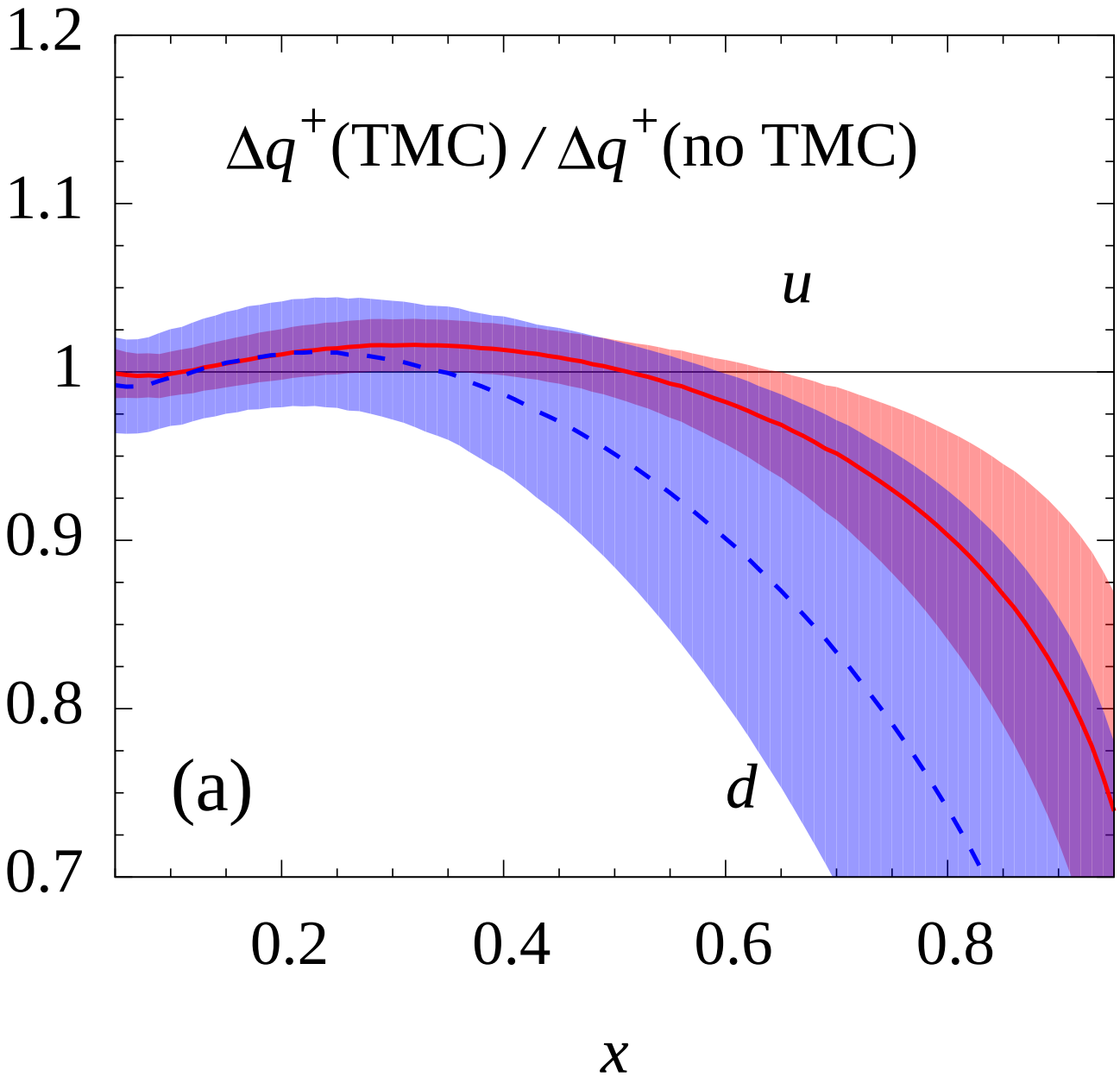
Target Mass corrections (twist-2)

- TM to g_1

$$g_1^{(n)} = n \sum_{j=0}^{\infty} \left(\frac{M^2}{Q^2}\right)^j \frac{(n+j)!}{j!(n-1)!(n+2j)^2} g_{1(0)}^{(n+2j)}$$

$$\simeq g_{1(0)}^{(n)} + \frac{M^2}{Q^2} \frac{n^2(n+1)}{(n+2)^2} g_{1(0)}^{(n+2)} + \mathcal{O}\left(\frac{M^4}{Q^4}\right)$$

Target Mass corrections (twist-2)



Nuclear corrections

- To achieve flavour separation (at least between Δu and Δd) polarized data with deuterium and ^{3}He are used.

- Ignoring nuclear binding and Fermi motion the "nuclear" structure functions are given by

$$g_i^A(x, Q^2) = P_{p/A}\, g_i^p(x, Q^2) + P_{n/A}\, g_i^n(x, Q^2)$$

- This is called *Effective Polarization Approximation* (EPA). (no dependence on x)

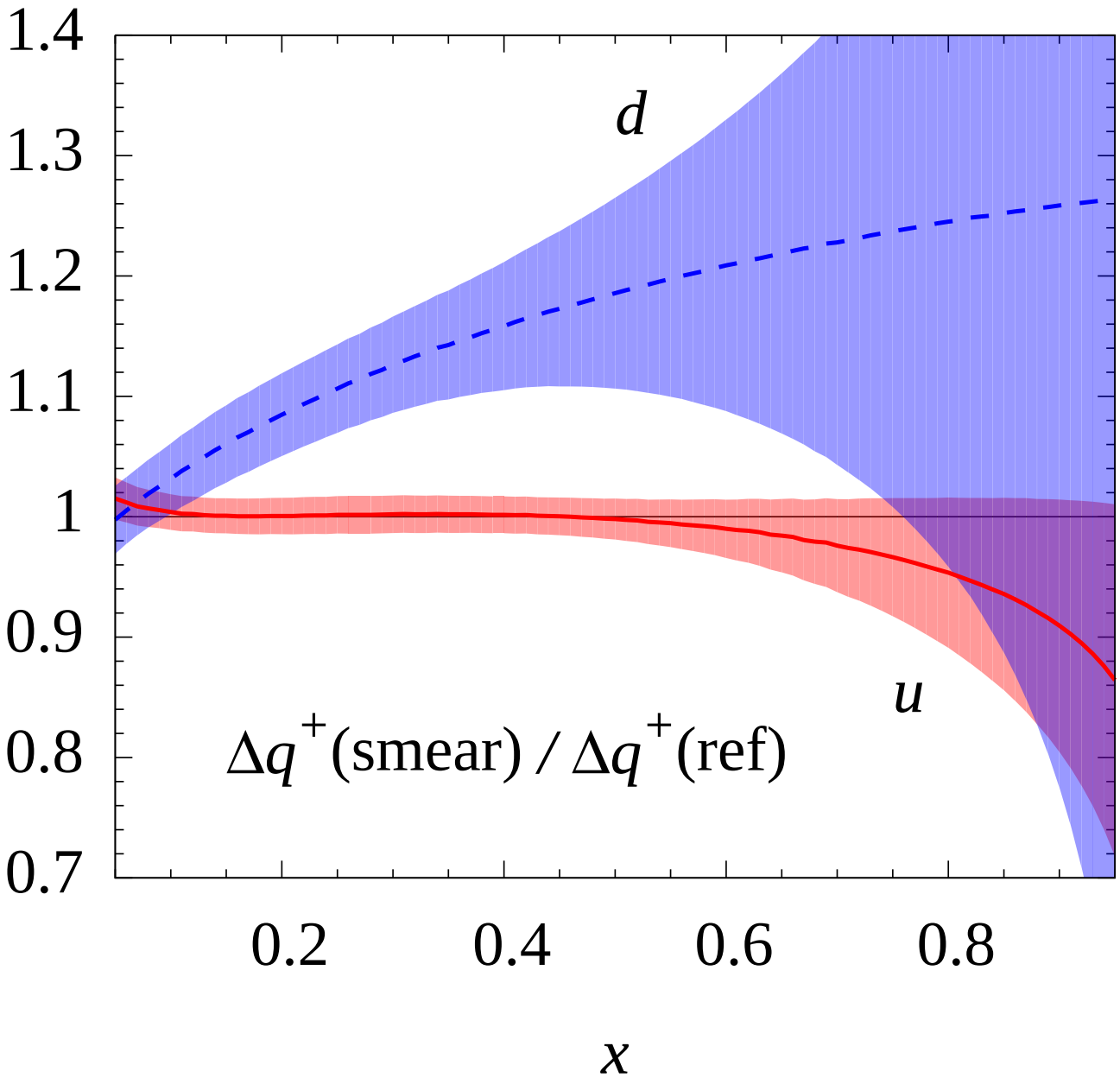
Nuclear corrections

- At large x the nuclear smearing plays an important role (PRC,88,5)

- Within the weak binding approximation the structure functions are written as

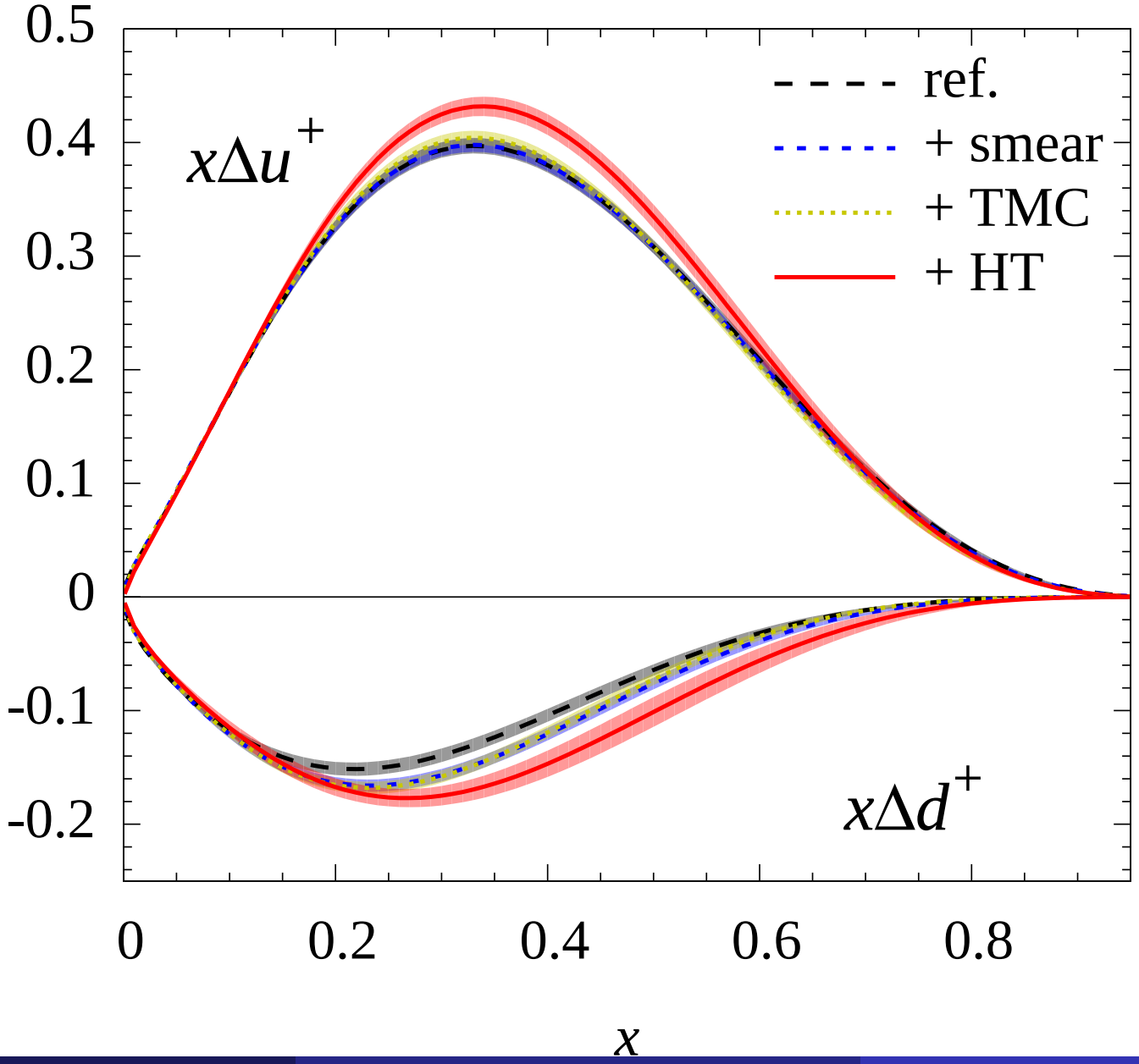
$$g_i^A(x, Q^2) = \sum_N \int \frac{dy}{y} f_{ij}^N(y, \gamma) g_j^N(x/y, Q^2) \quad i, j = 1, 2$$

Nuclear corrections



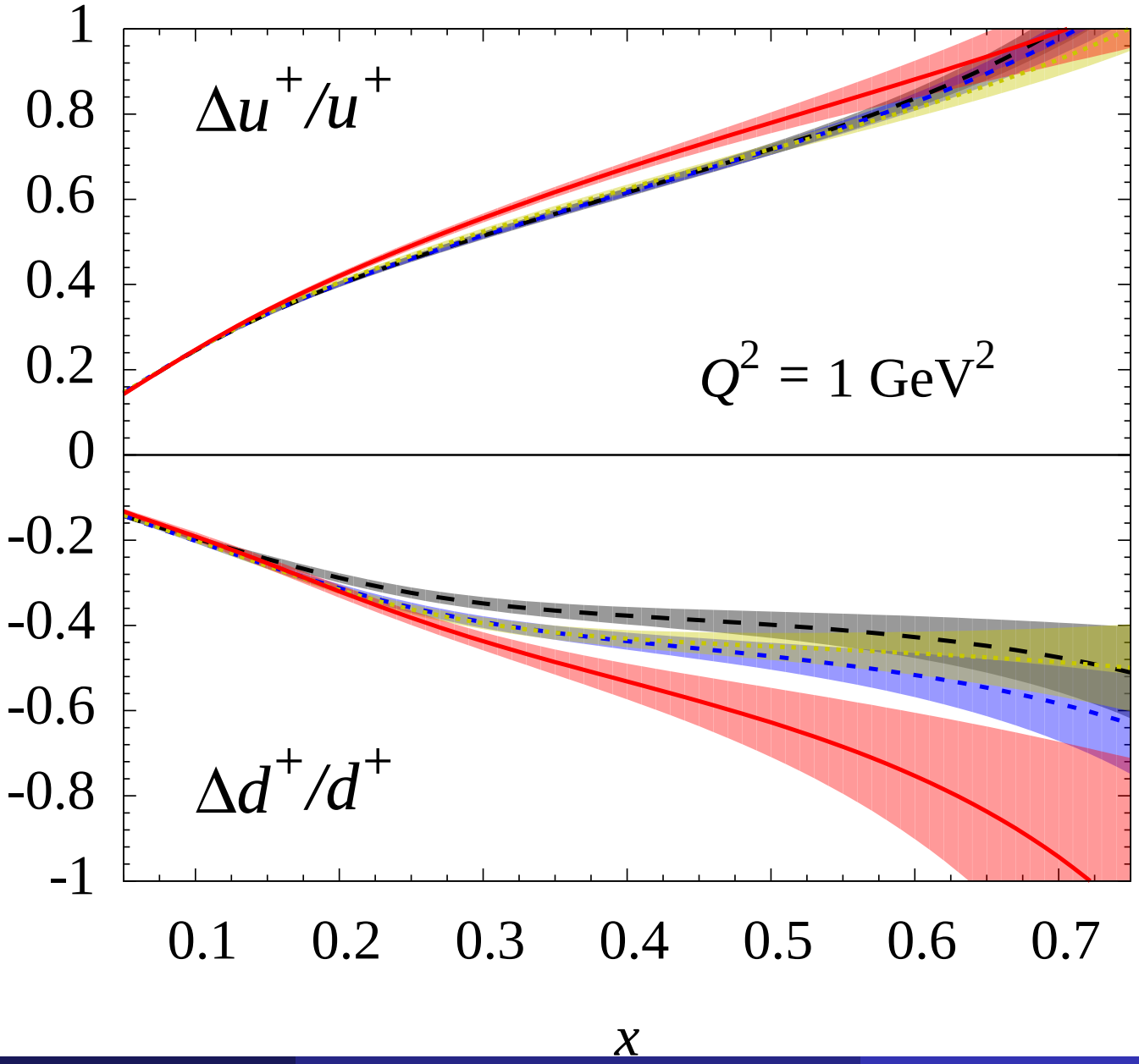
Combining all the effects...

The JAM13 distributions



The $\Delta q/q$ ratio ?

The JAM13 distributions



Other groups

	← expt →			← theory →			
	DIS	SIDIS	hadron collider	nuclear smearing	TMCs	HT g_1	HT g_2
DSSV 09*	✓	✓	✓				
AAC 09	✓		✓ π^0 (LO)				
BB 10	✓				✓	✓	~
LSS 10	✓	✓			✓	✓	
NNPDF 13*	✓		✓		✓		
JAM 13*	✓	(in 2014)	(in 2015)	✓	✓	✓	✓

Current Status

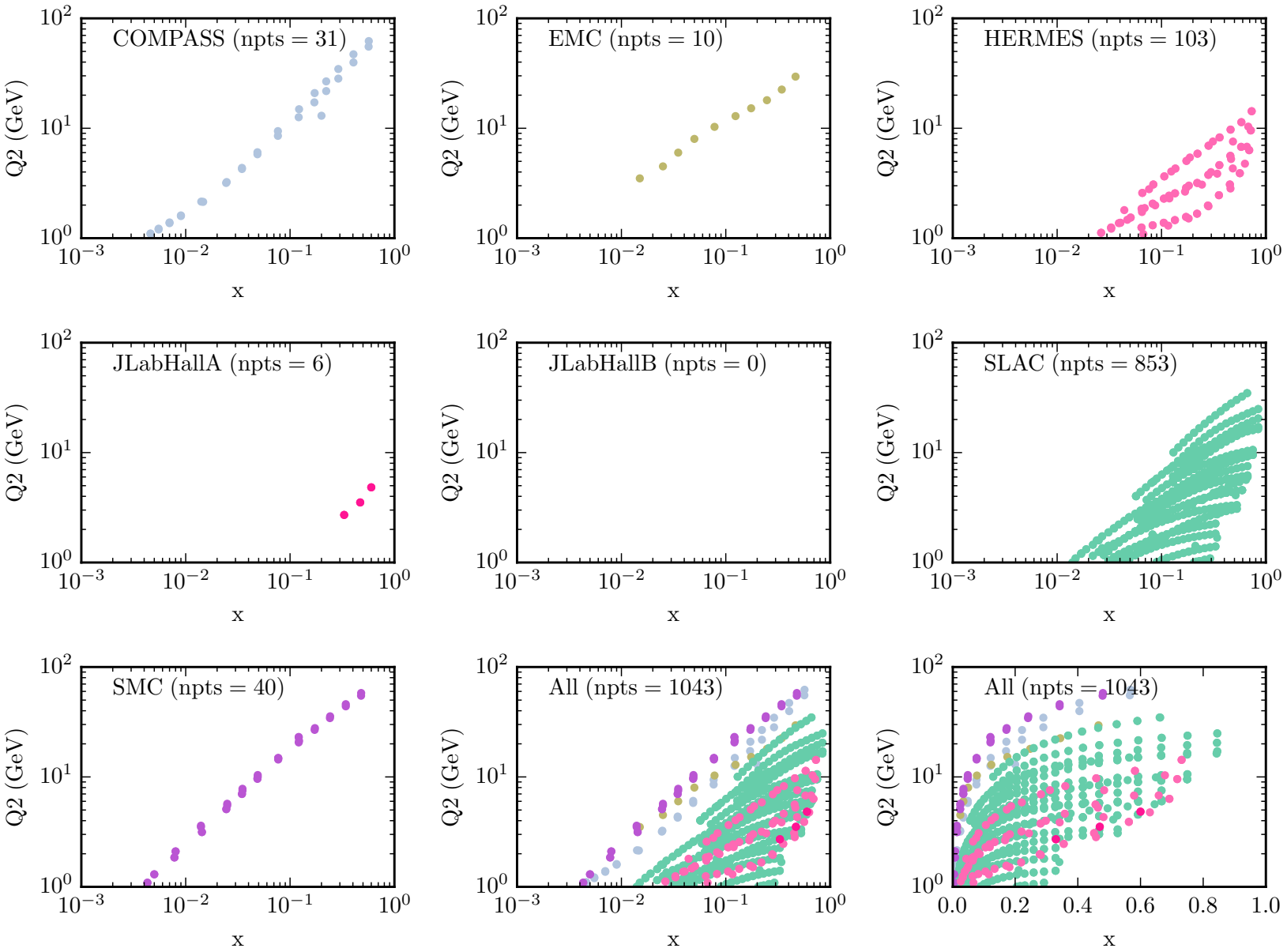
- Inclusion of new data sets from

HallA: d2n (DIS from ^{3}He)

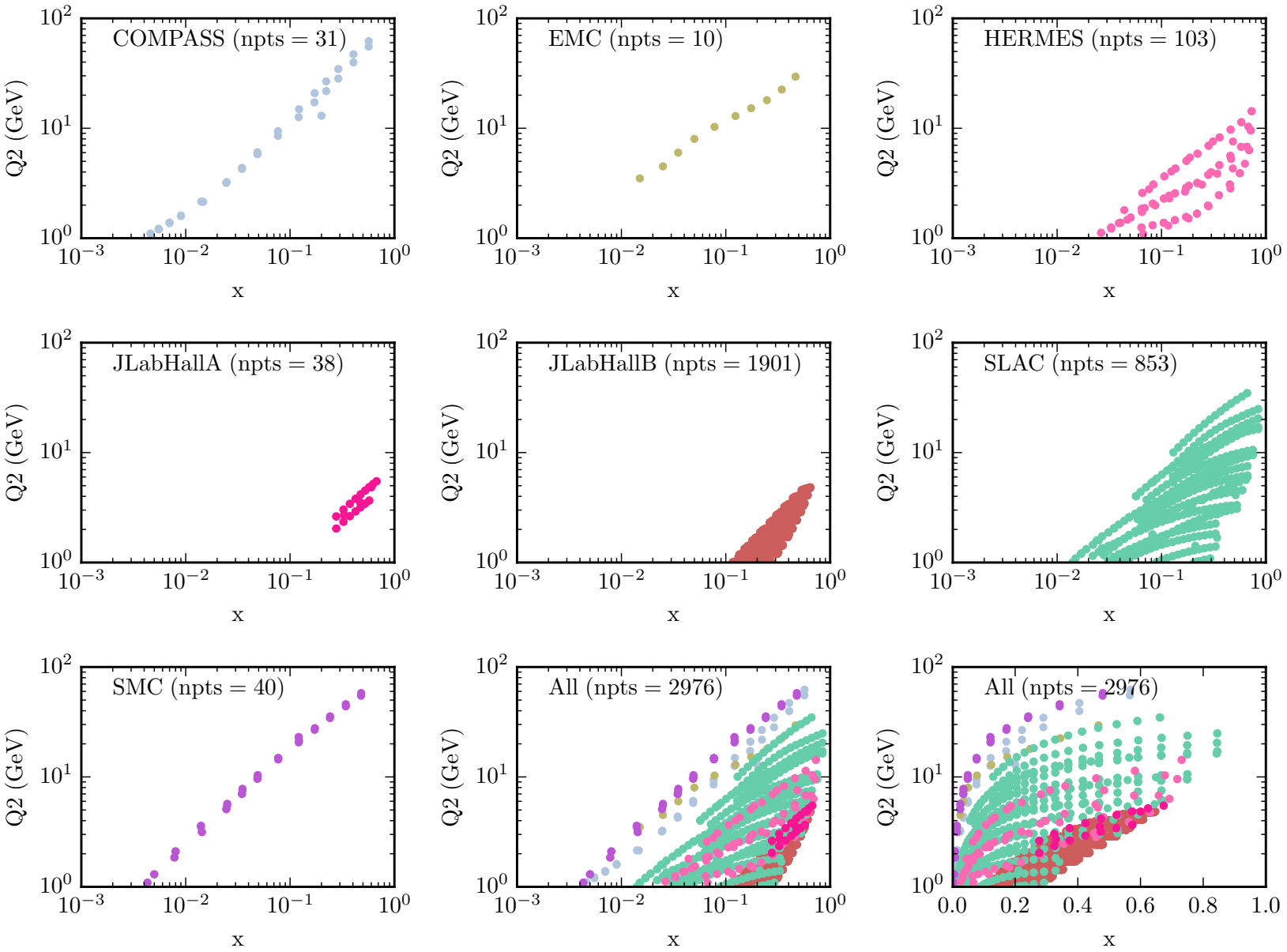
HallB: EG1-dvcs (DIS from p,d)

HallB: EG1b (DIS from p,d)

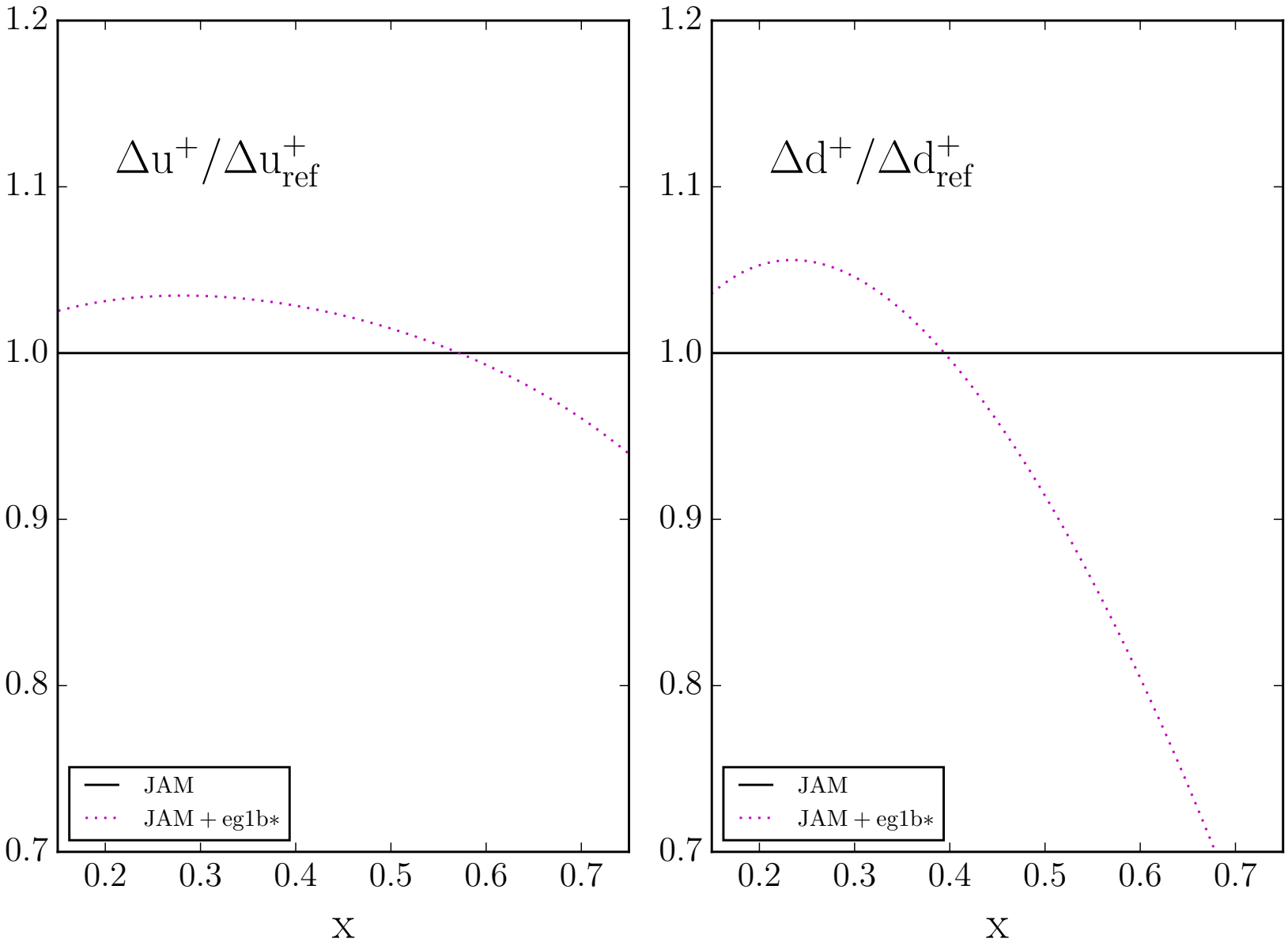
JAM 13 data


COMPASS (npts = 31)
EMC (npts = 10)
HERMES (npts = 103)
JLabHallA (npts = 6)
JLabHallB (npts = 0)
SLAC (npts = 853)
SMC (npts = 40)
All (npts = 1043)
All (npts = 1043)
Q2 (GeV)
x

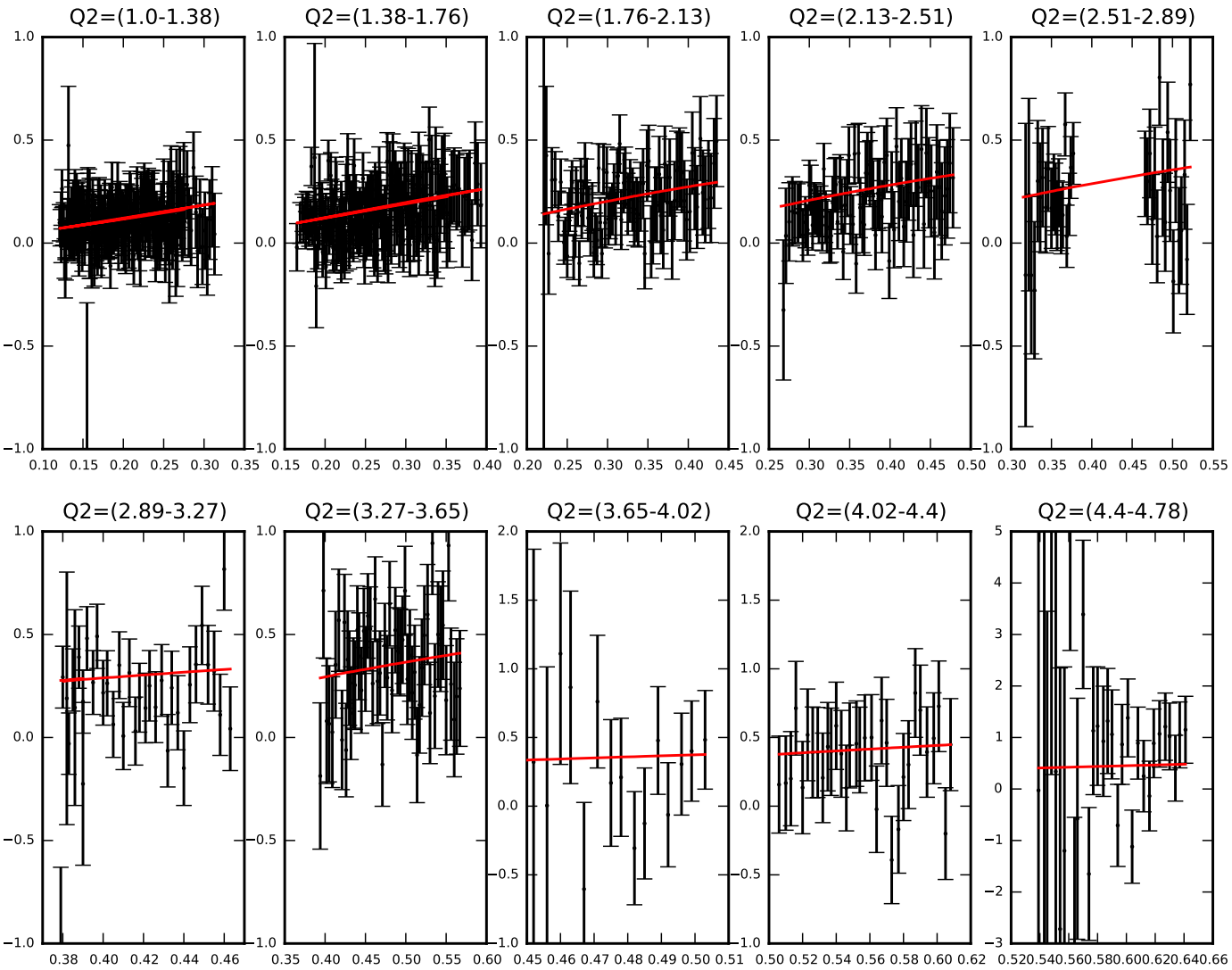
JAM 13 + new data sets



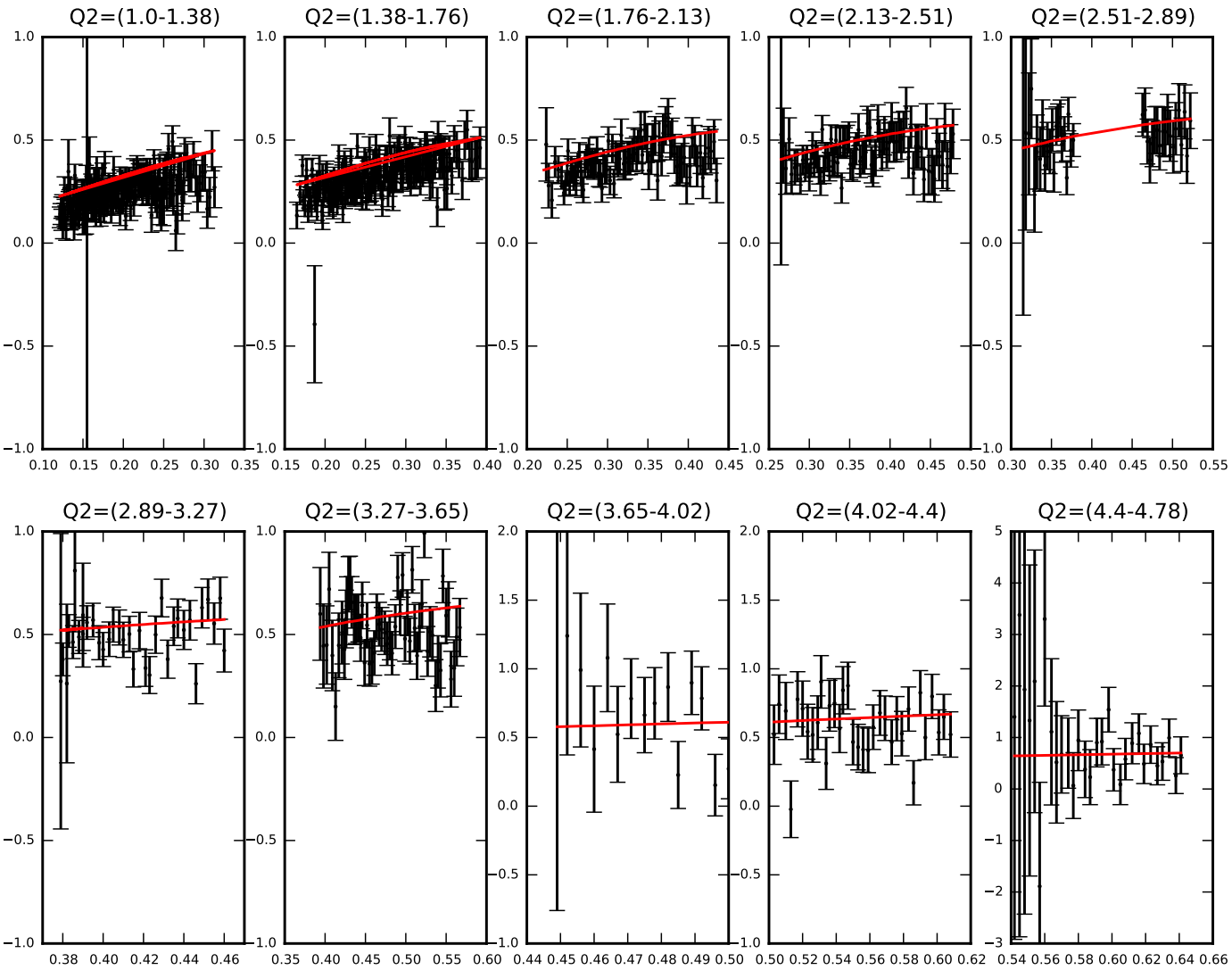
Preliminary results



Preliminary results: eg1b A1 d



Preliminary results:eg1b A1 p



Summary

- HTs are very important if we use data down to $Q^2 = 1$ GeV^2.
- There is no indication of an upturn in $\Delta d/d$ as indicated by pQCD.

TODO

- Inclusion of SIDIS data
- Inclusion polarized pp data: π^0,Jets
- Study the error correlation between PDFs and SPDFs (Impact of large x PDFs to SPDFs)

Part II: Constraints from direct photon data at large x on PDFs.

Motivations:

- PDFs at collider energies receives contributions from PDFs at large x and low Q^2 via DGLAP evolution equations.

- Production of a massive state in pp collisions at forward rapidities are sensitive to PDFs at small and large x $(x \simeq (m/\sqrt{s})\exp(\pm y))$.

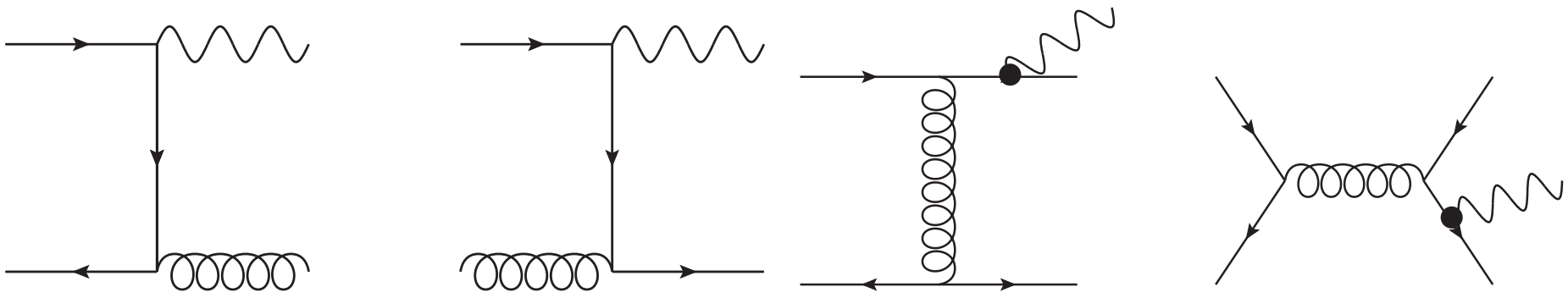
- In particular, gluon distribution is largely unconstrained for $x > 0.6$. Current constraint for the gluon comes from inclusive Jet data.

Motivations:

- The data of direct photon production has the potential to constrain large x gluons.
- Currently, direct photon data are largely excluded from global fits due to inconsistencies among the data and the theory at NLO in pQCD.
- Threshold resummation at NLO+NLL seems to alleviate the disagreement (Catani *et al*, de Florian,Vogelsang).

Direct photon production.

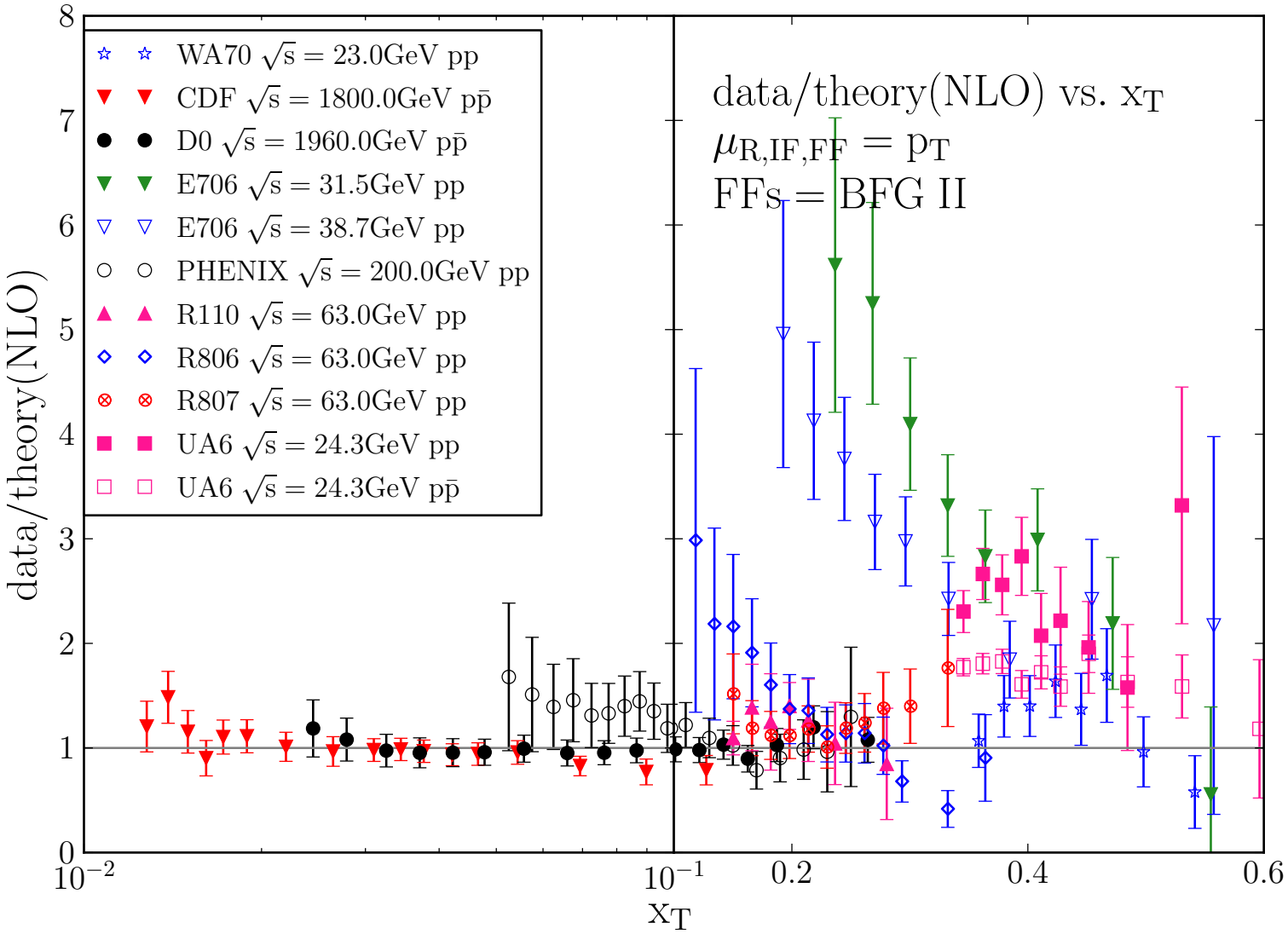
The *leading-order* (LO)



- In proton-proton collisions direct photon productions is dominated by qg scattering.

Do we understand direct photons?

Direct photon production.



Can we improve the theory predictions?

Direct photon production.

Rapidity integrated cross section

$$p_T^3 \frac{d\sigma}{dp_T}(x_T^2) =$$

$$\sum_{a,b,c} \int_{x_T^2}^{1} dx_a f_{a/A}(x_a, \mu_{IF}) \int_{x_T^2/x_a}^{1} dx_b f_{b/B}(x_b, \mu_{IF}) \int_{x_T/\sqrt{x_a x_b}}^{1} dz z^2 D_{\gamma/c}(z, \mu_F$$

$$\times \frac{\hat{x}_T^4 \hat{s}}{2} \frac{d\sigma_{a,b}^{(0)}}{d\hat{x}_T^2}(\hat{x}_T^2, \mu_R) \left[1 + \alpha_s(\mu_R)\{A' \ln^2(1 - \hat{x}_T^2) + B' \ln(1 - \hat{x}_T^2) + C' + \ldots\right]$$

- $x_T = 2p_T/\sqrt{S}$
- $\hat{x}_T = 2p_T/z\sqrt{x_a x_b S}$
- At large x_T the role of logs are more relevant.

Direct photon production.

$$p_T^3 \frac{d\sigma(x_T)}{dp_T} = \sum_{a,b,c} f_{a/A}(x_a, \mu_{IF}) * f_{b/B}(x_b, \mu_{IF}) * D_{\gamma/c}(z, \mu_{FF}) * \hat{\Sigma}(\hat{x}_T, ...)$$

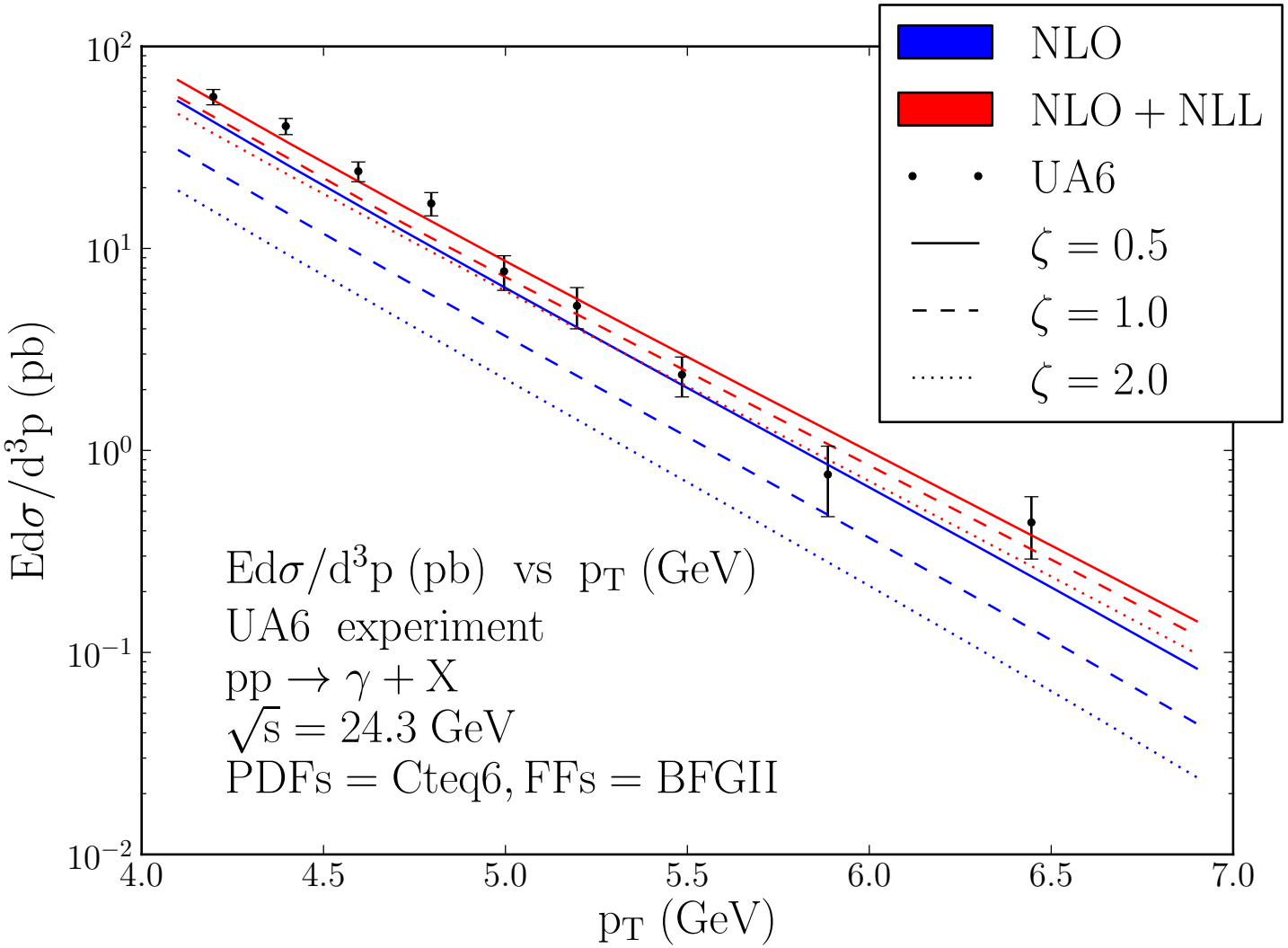
$\hat{\Sigma}(\hat{x}_T, ...) \supset$

1				LO
$\alpha_s L^2$	$\alpha_s L$	α_s		NLO
$\alpha_s^2 L^4$	$\alpha_s^2 L^3$	$\alpha_s^2 L^2$	$\alpha_s^2 L$	NNLO
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\alpha_s^n L^{2n}$	$\alpha_s^n L^{2n-1}$	$\alpha_s^n L^{2n-2}$	...	N^{n}LO
LL	NLL	NNLL	...	

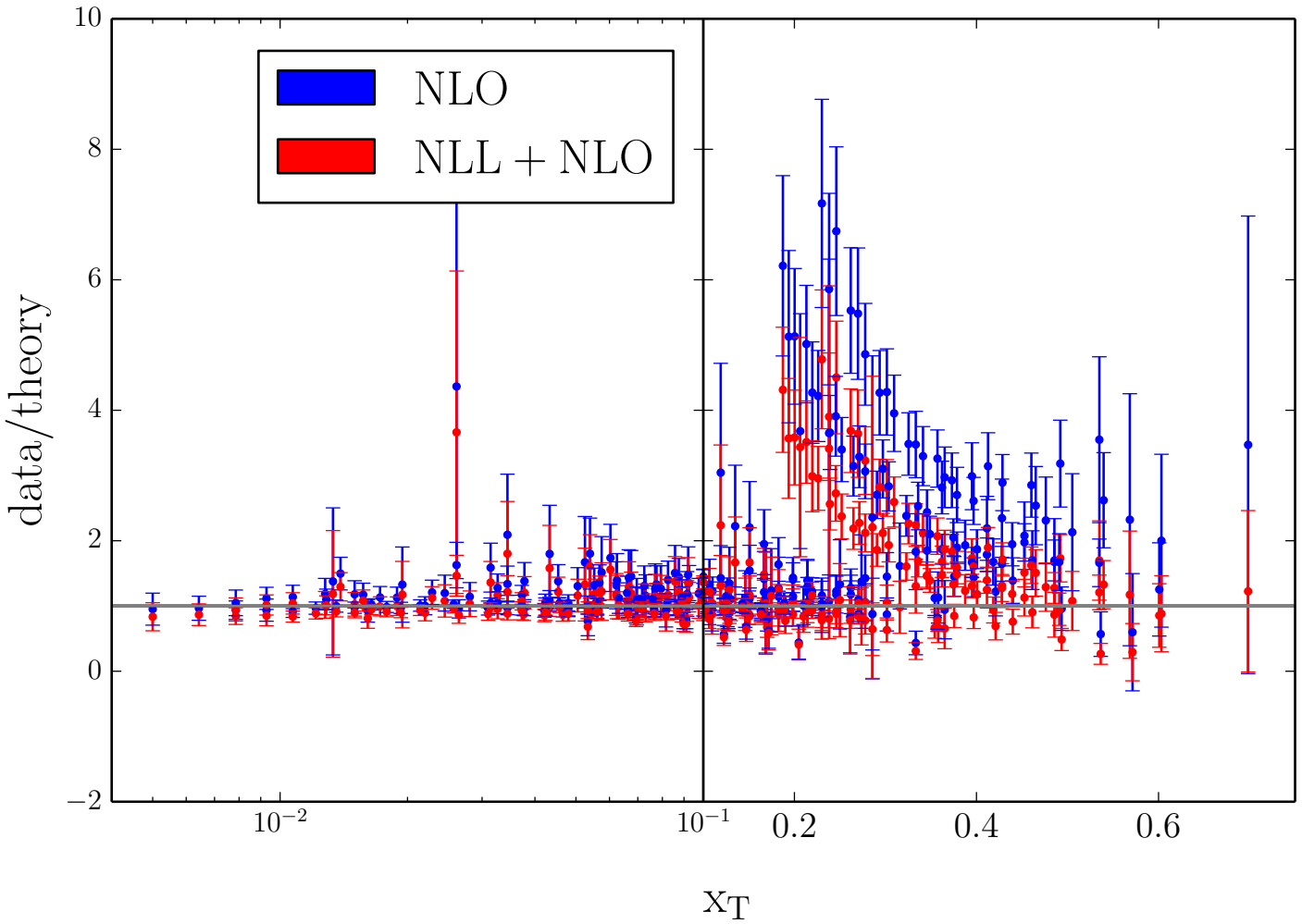
- It is possible to include "towers" of logs into the cross section$\rightarrow$ Threshold Resummation

Global analysis

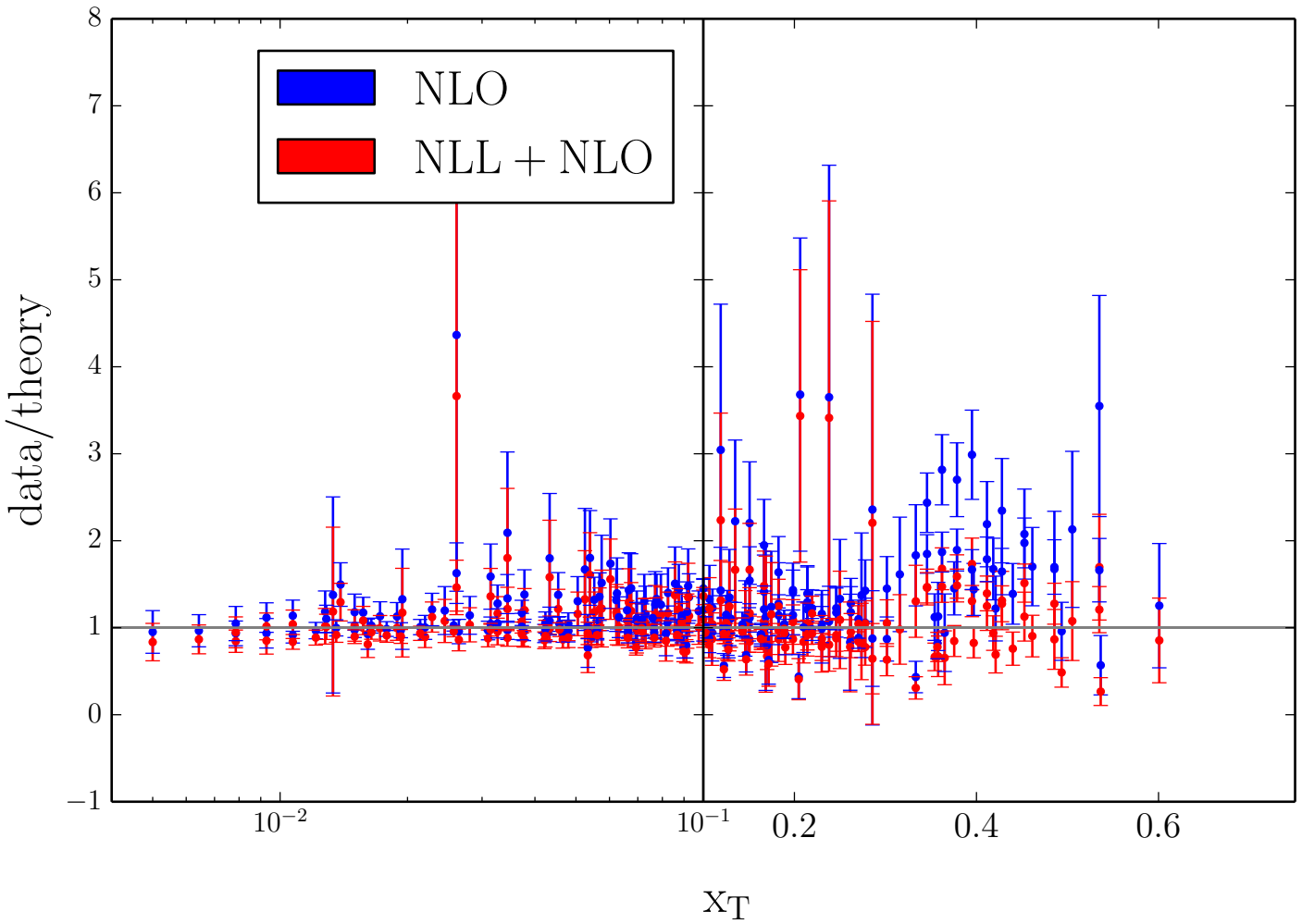
Example: UA6 experiment ($\sqrt{s} = 24.3$ GeV)



All the data sets



All the data sets without E706



Impact on PDFs: Bayesian Reweighting

The method:

- Construct replica PDFs (Monte Carlo sampling) from the uncertainty band of a gives PDF set
- Compute replica cross sections.
- Assign a weight to each replica PDF:

$$w_k \propto \exp\left(-\frac{1}{2}\sum_e \chi_e^2(k)\right)$$

Reweighting PDFs

The method:

- Get reweighted theoretical cross sections

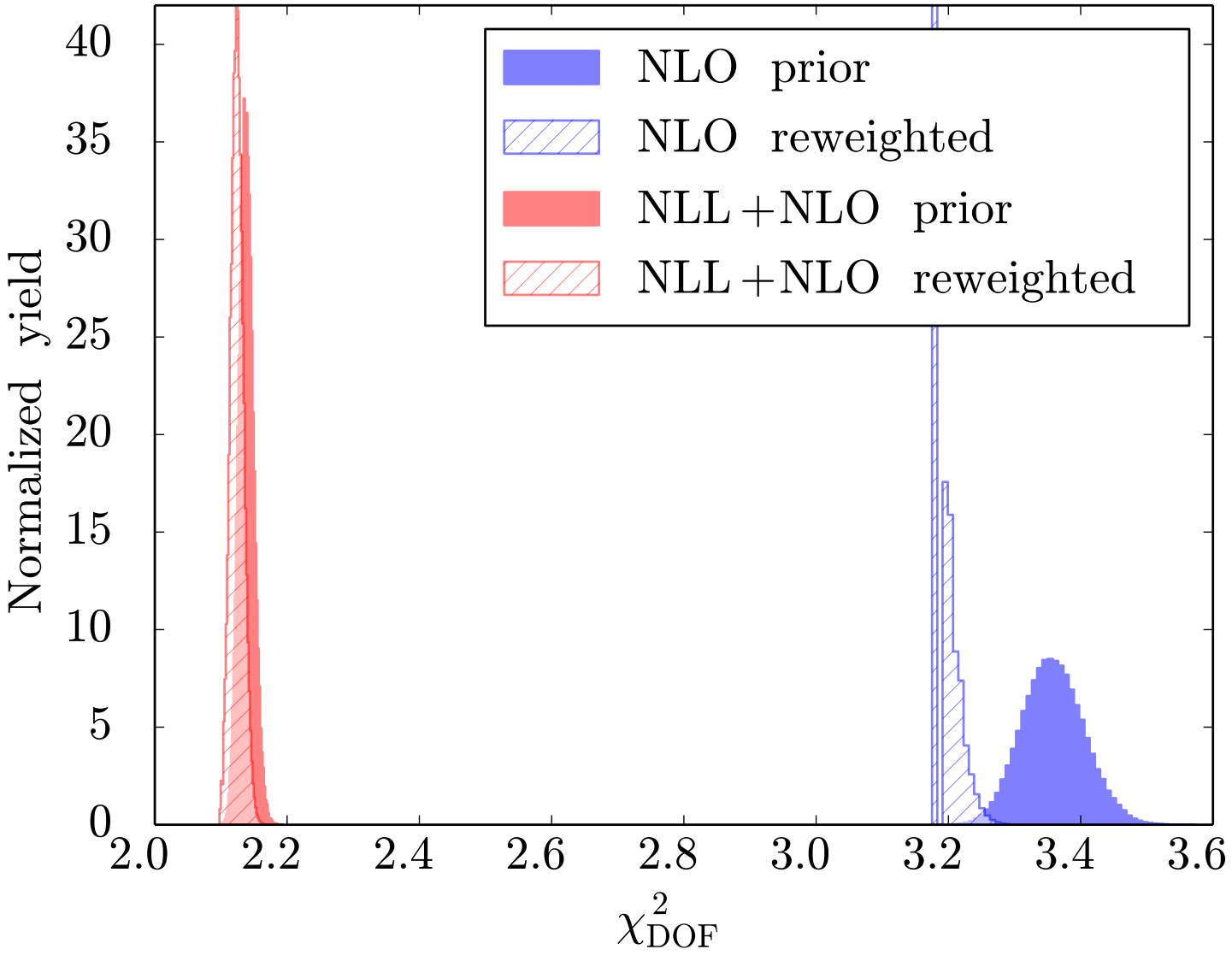
$$\mathsf{E}[\sigma] = \sum_k w_k \sigma_k$$
$$\mathsf{VAR}[\sigma] = \sum_k w_k (\sigma_k - \mathsf{E}[\sigma])^2$$

- Get reweighted PDFs

$$\mathsf{E}[f] = \sum_k w_k f_k$$
$$\mathsf{VAR}[f] = \sum_k w_k (f_k - \mathsf{E}[f])^2$$

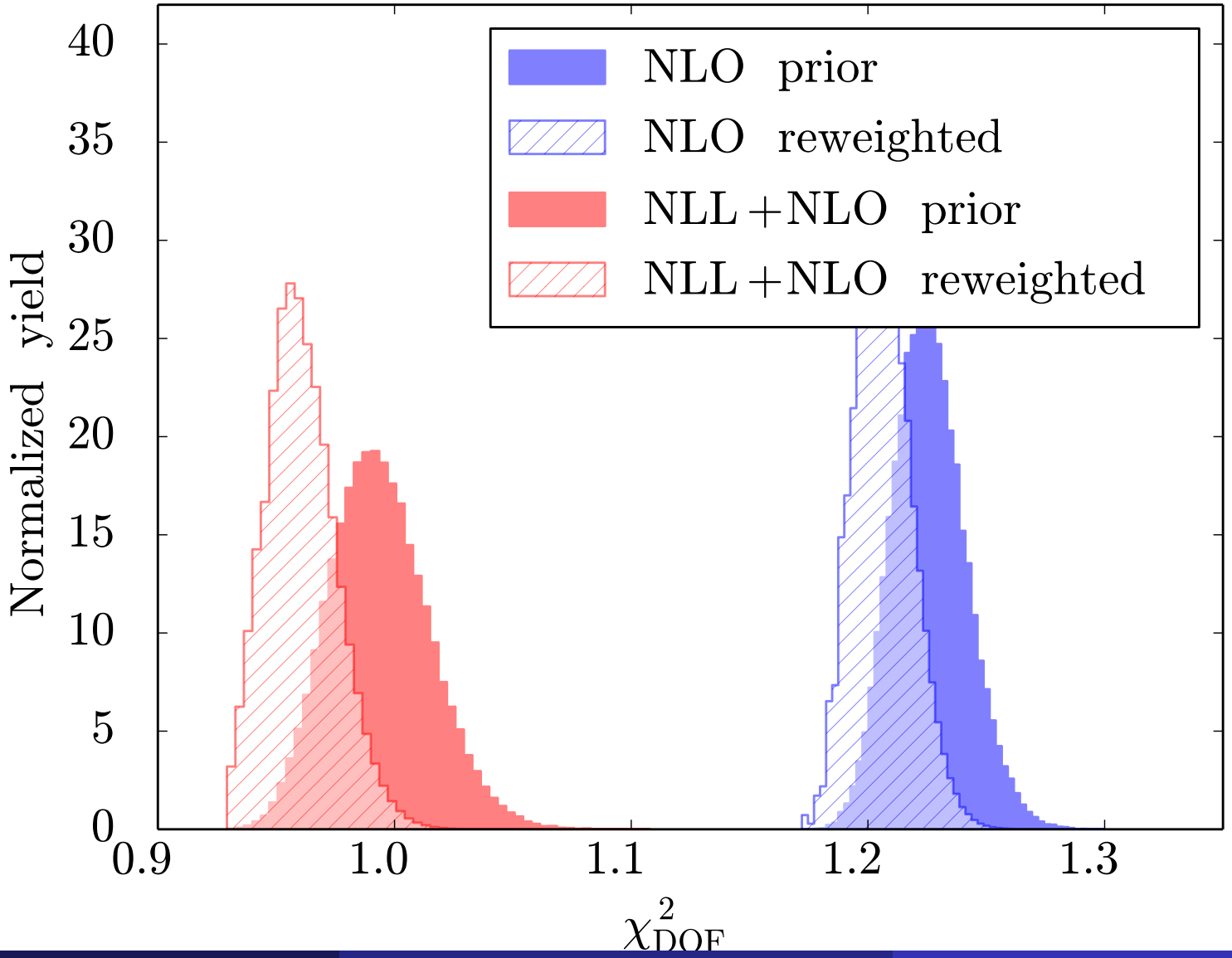
Reweighting PDFs

All the data sets

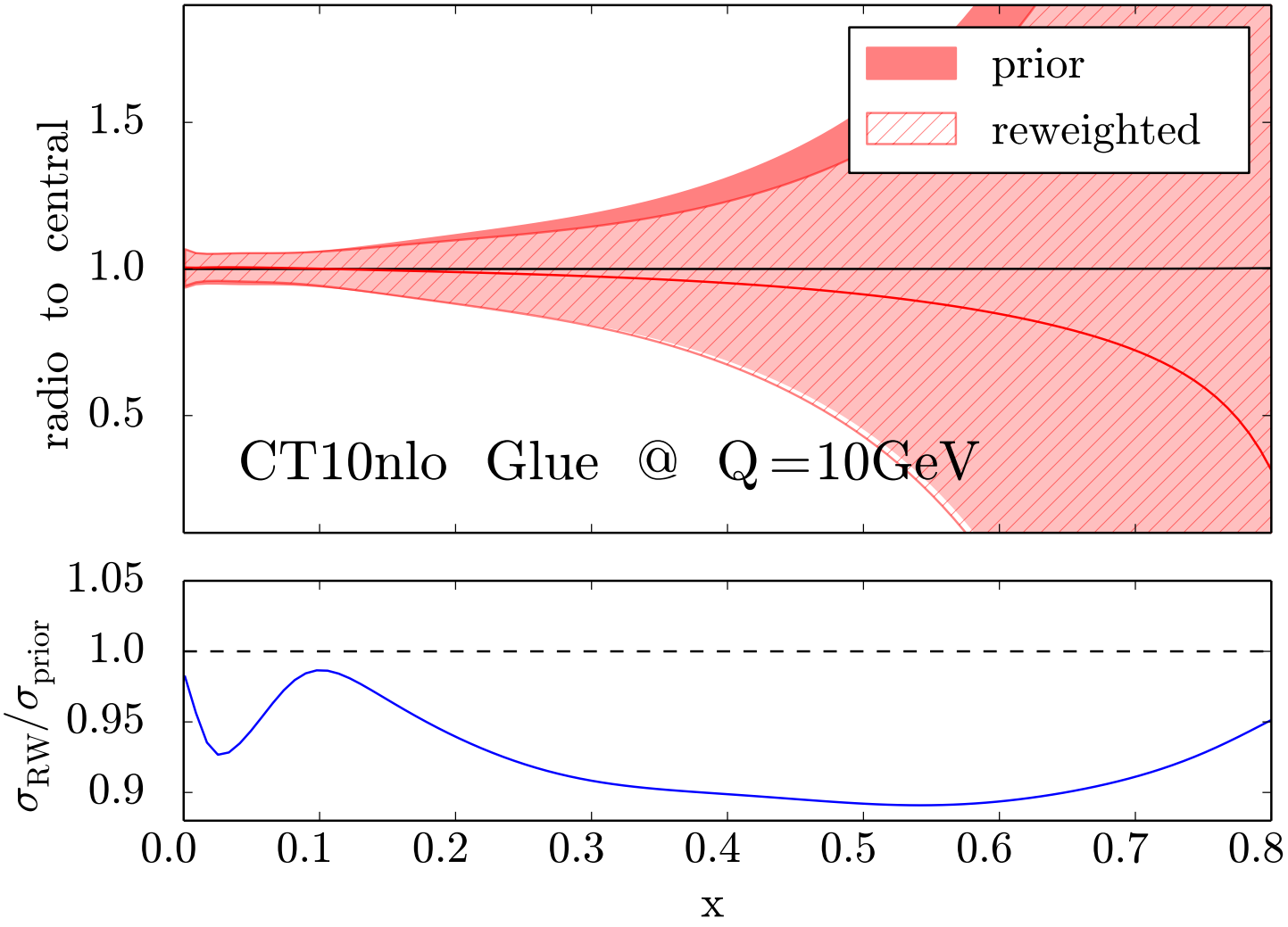


Reweighting PDFs

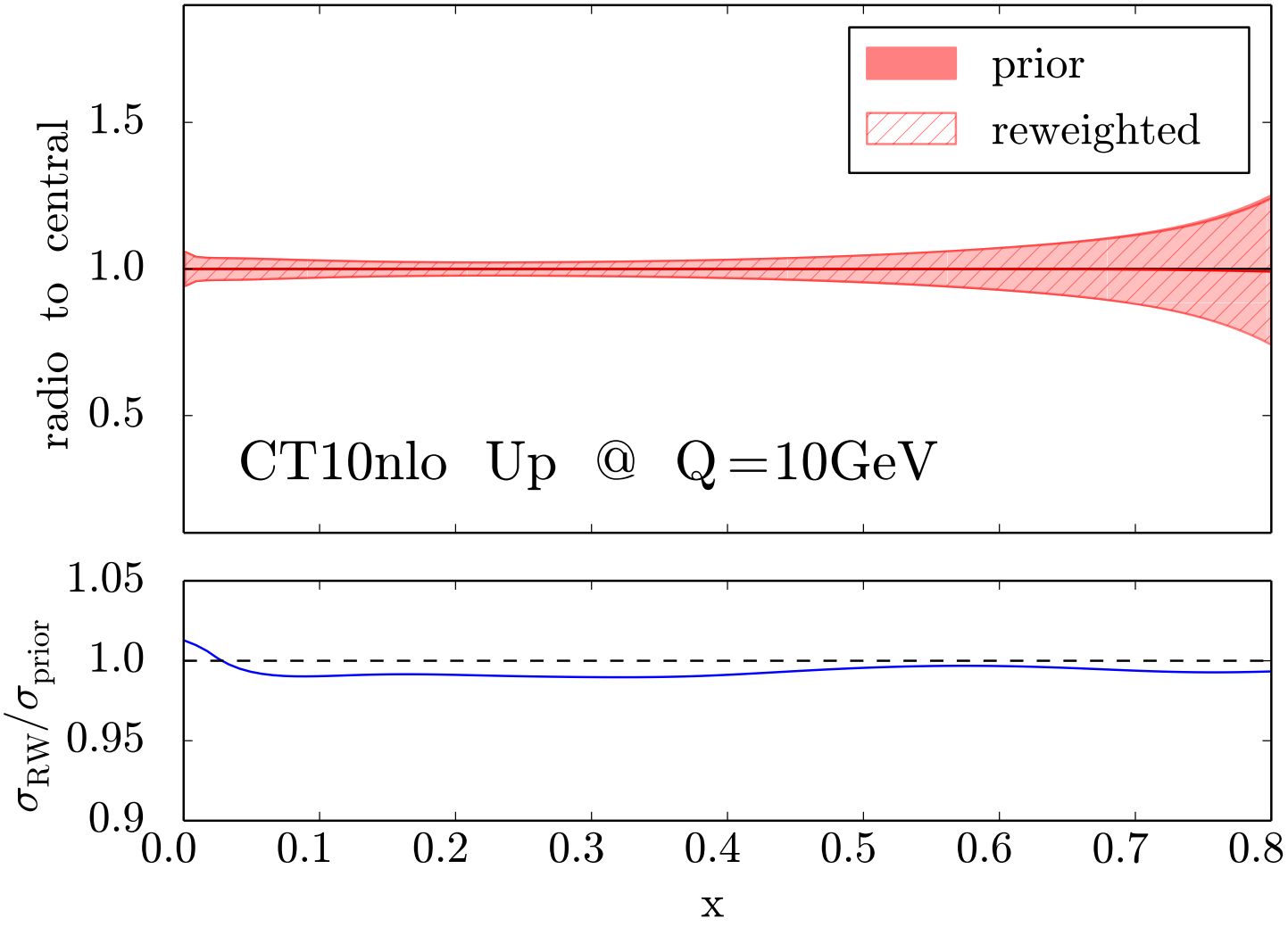
All the data sets excluding E706



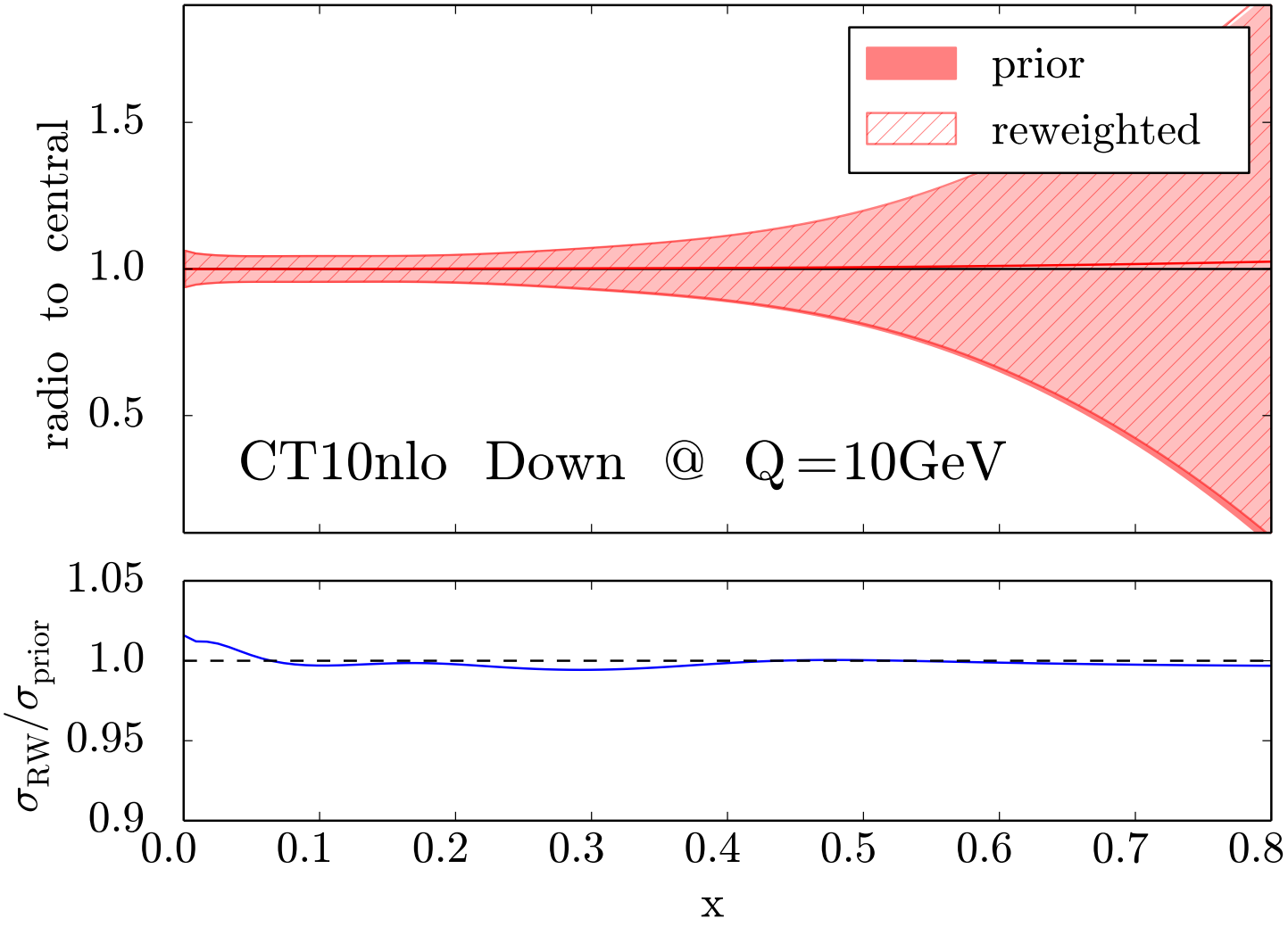
Reweighting PDFs



Reweighting PDFs



Reweighting PDFs



Summary

- Direct photon data contraints gluon PDFs at large x.
- Uncertanties on PDFs (gluon) at large x might have an impact on SPDF at large x.
- Threshold correction might have an impact on polarixed pp collistion. (To be implement in future JAM analysis)

END