NNPDF2.1 @ NNLO/LO

Luigi Del Debbio - NNPDF Collaboration
University of Edinburgh

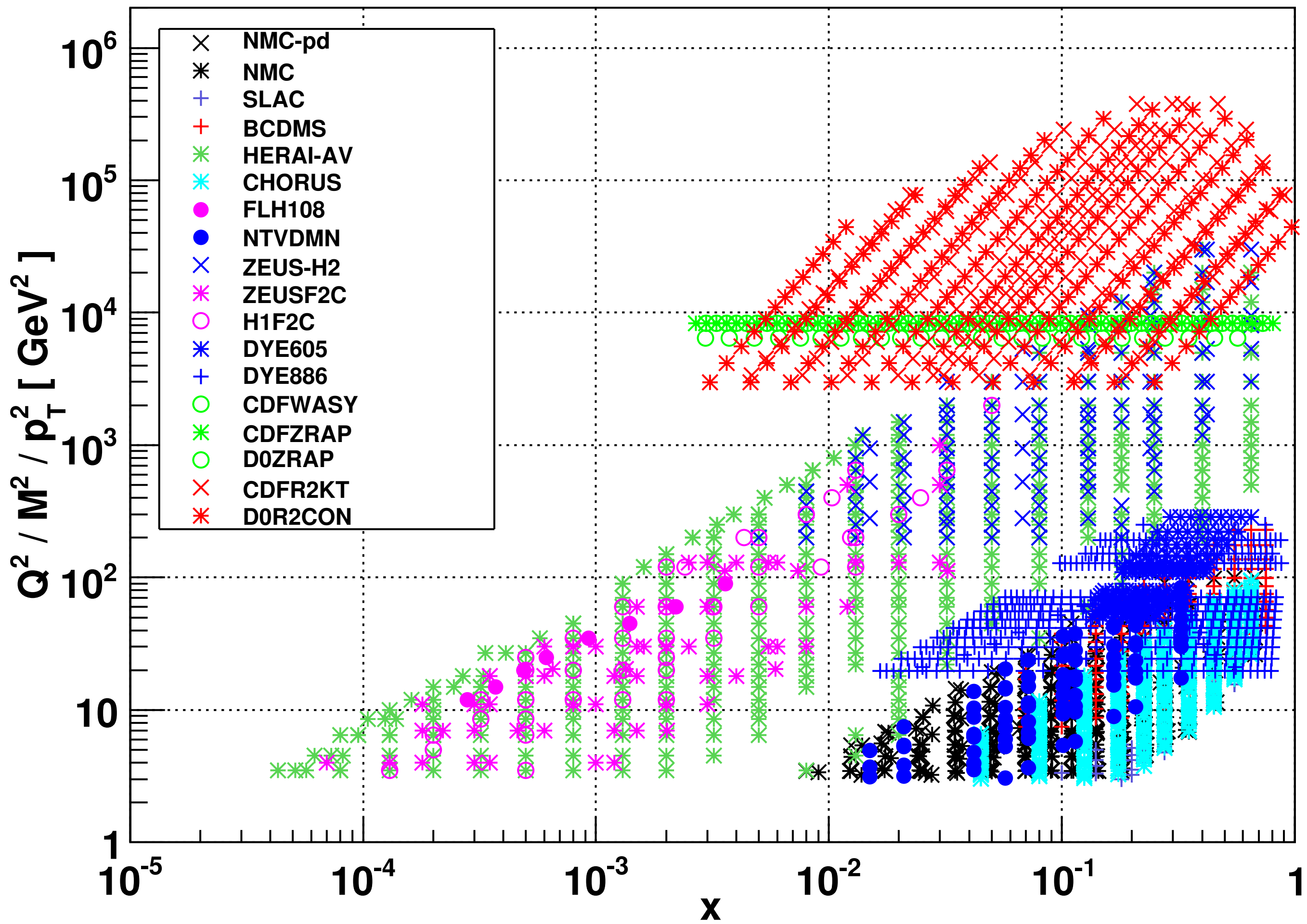
From NLO to NNLO/LO global fits

- **Datasets**: DIS, Drell-Yan, vector boson production, jet data
- **Implementation**: FONLL-C, K factors
- **Results**: MC ensemble of PDF - probability distribution for the PDFs
- **Comparison** with other determinations
- **Phenomenological implications**
- **Outlook**

Datasets

- Global fit - same cuts at LO and NLO, relax cuts on F2c @ NNLO

NNPDF2.1 dataset

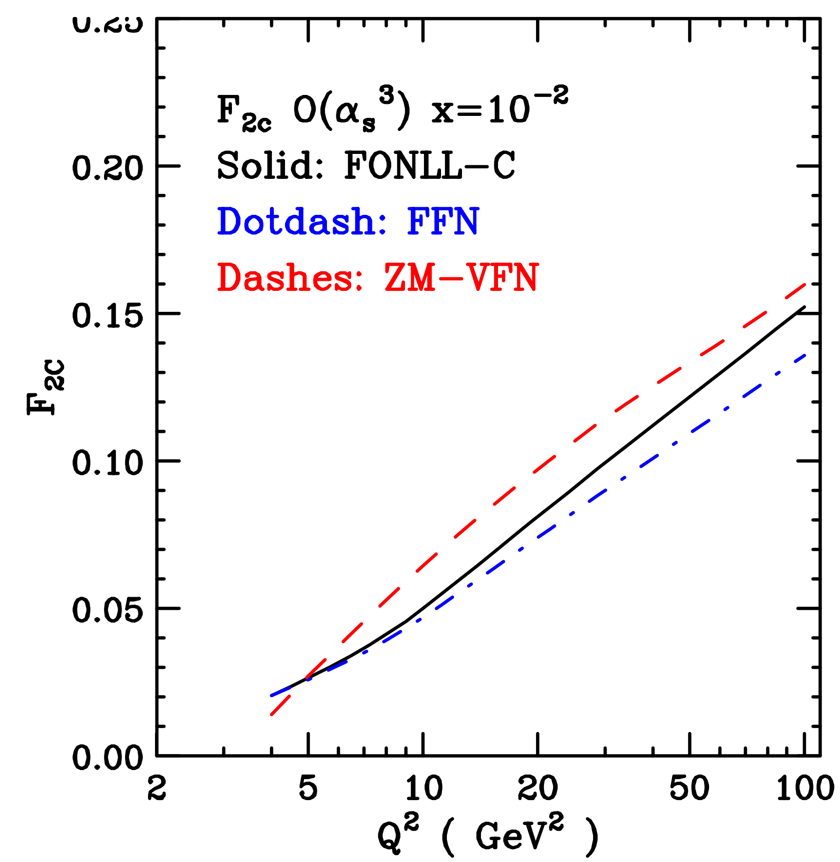


3507 data points @ NNLO
3415 data points @ NLO

OBS	***Data set***
Deep Inelastic Scattering	
F_2^d/F_2^p	NMC-pd
F_2^p	NMC, SLAC, BCDMS
F_2^d	SLAC, BCDMS
$\sigma_{NC}^{\pm}$	HERA-I, ZEUS (HERA-II)
$\sigma_{CC}^{\pm}$	HERA-I, ZEUS (HERA-II)
F_L	H1
$\sigma_\nu, \sigma_{\bar{\nu}}$	CHORUS
dimuon prod.	NuTeV
F_2^c	ZEUS, H1
Drell-Yan & Vector Boson prod.	
$d\sigma^{\mathrm{DY}}/dM^2dy$	E605
$d\sigma^{\mathrm{DY}}/dM^2dx_F$	E866
W asymm.	CDF
Z rap. distr.	D0/CDF
Inclusive jet prod.	
Incl. $\sigma^{(\mathrm{jet})}$	CDF (k_T) - Run II
Incl. $\sigma^{(\mathrm{jet})}$	D0 (cone) - Run II

NNLO implementation - Quark masses

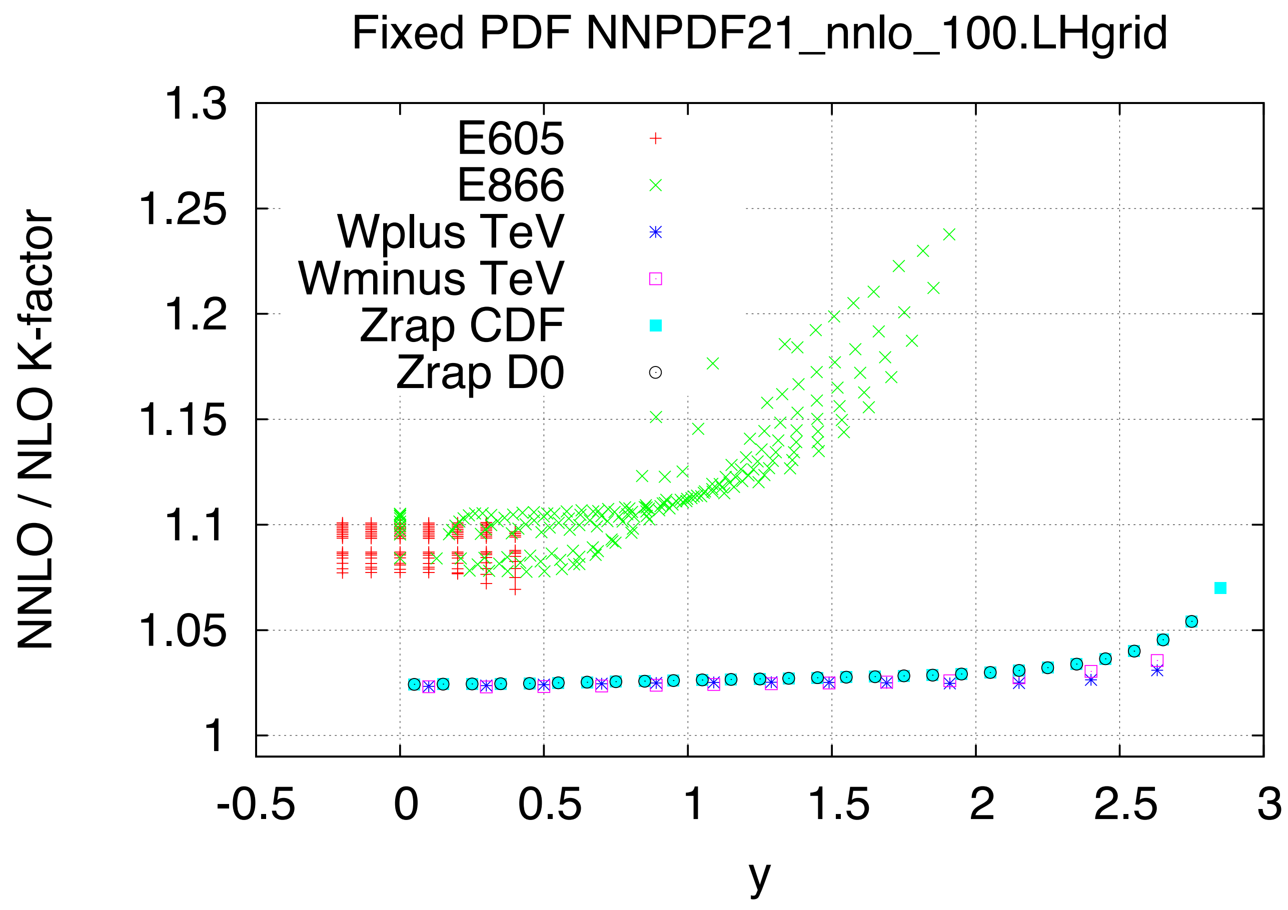
- quark masses: GM-VFN scheme introduced in NNPDF2.1
  - FONLL method [M Cacciari et al, 1998]; extended to DIS [S Forte et al, 2010]
  - NLO fit used FONLL-A scheme
  - FONLL-C: NNLO massless evolution + $\mathcal{O}(\alpha_s^2)$ massive coefficient functions
  - Quark masses: $$m_c = 1.41\ \mathrm{GeV}$$ $$m_b = 4.75\ \mathrm{GeV}$$



NNLO implementation - hadronic data

- **Full NLO** implementation in *FastKernel* for DY, W/Z production

- NNLO evolution, NLO partonic cross-section + K-factor (NNLO/NLO)



- inclusive jets: approximated NNLO in FastNLO

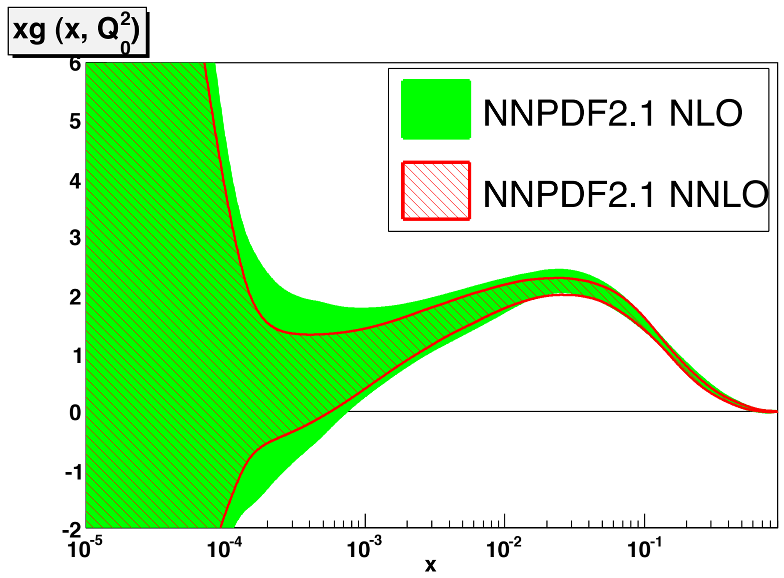
Results @ NNLO

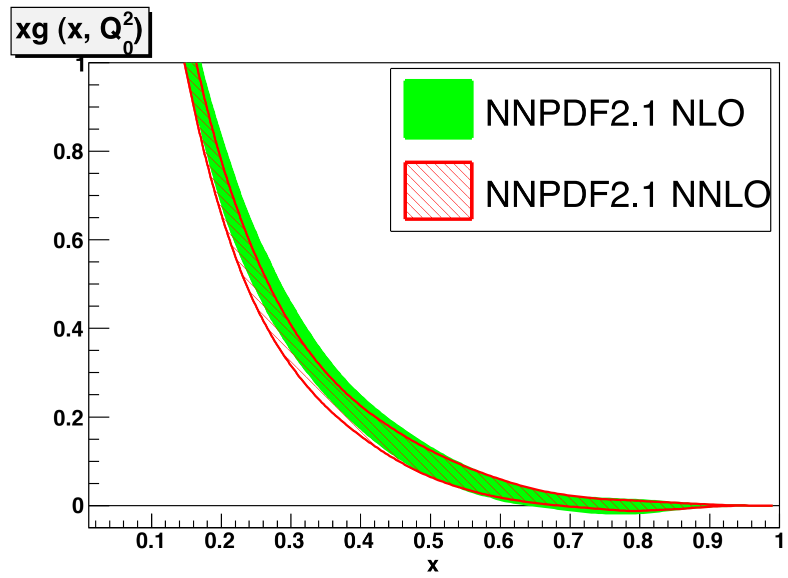
- Statistical features

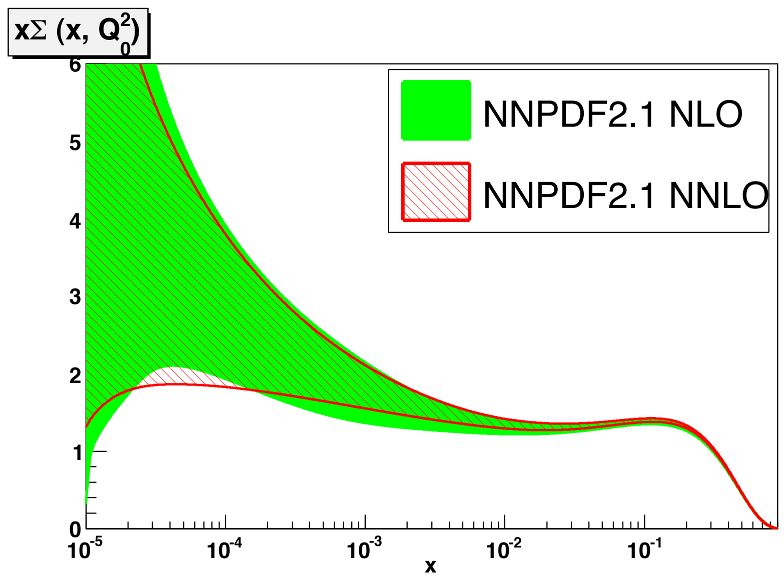
Experiment	χ^2	χ^2_{nlo}	$\langle\sigma^{(\mathrm{exp})}\rangle_{\mathrm{dat}}(\%)$	$\langle\sigma^{(\mathrm{net})}\rangle_{\mathrm{dat}}(\%)$
TOT	1.16	1.16	11.9	3.2
NMC-pd	0.93	0.97	1.8	0.5
NMC	1.63	1.73	5.0	1.8
SLAC	1.01	1.27	4.4	1.8
BCDMS	1.32	1.24	5.7	2.6
HERAI-AV	1.10	1.07	7.6	1.3
CHORUS	1.12	1.15	15.0	3.5
FLH108	1.26	1.37	72.1	4.8
NTVDMN	0.49	0.47	21.0	14.0
ZEUS-H2	1.31	1.29	14.0	1.3
ZEUSF2C	0.88	0.78	23.0	3.7
H1F2C	1.46	1.50	18.0	3.5
DYE605	0.81	0.84	25.0	7.2
DYE866	1.32	1.27	21.0	8.7
CDFWASY	1.65	1.86	6.0	4.3
CDFZRAP	2.12	1.65	12.0	3.6
D0ZRAP	0.67	0.60	10.0	3.0
CDFR2KT	0.74	0.97	23.0	4.8
D0R2CON	0.82	0.84	17.0	5.5

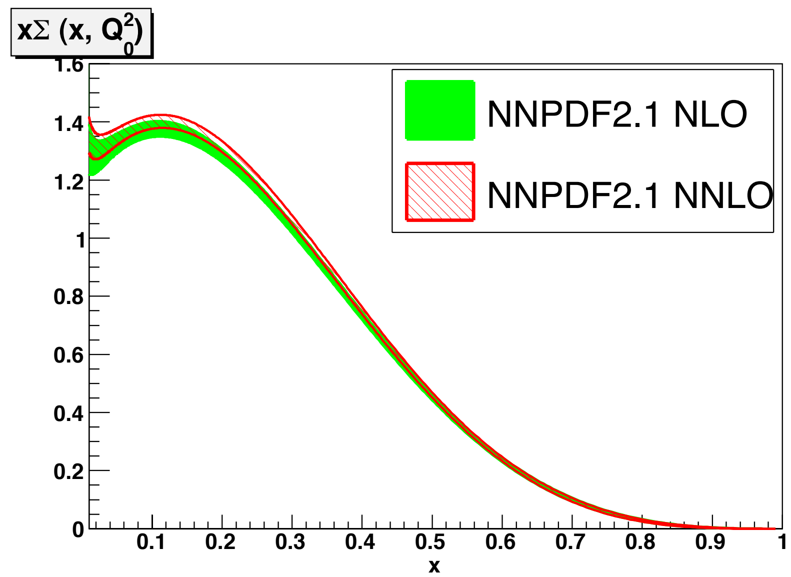
Results @ NNLO

- Singlet sector



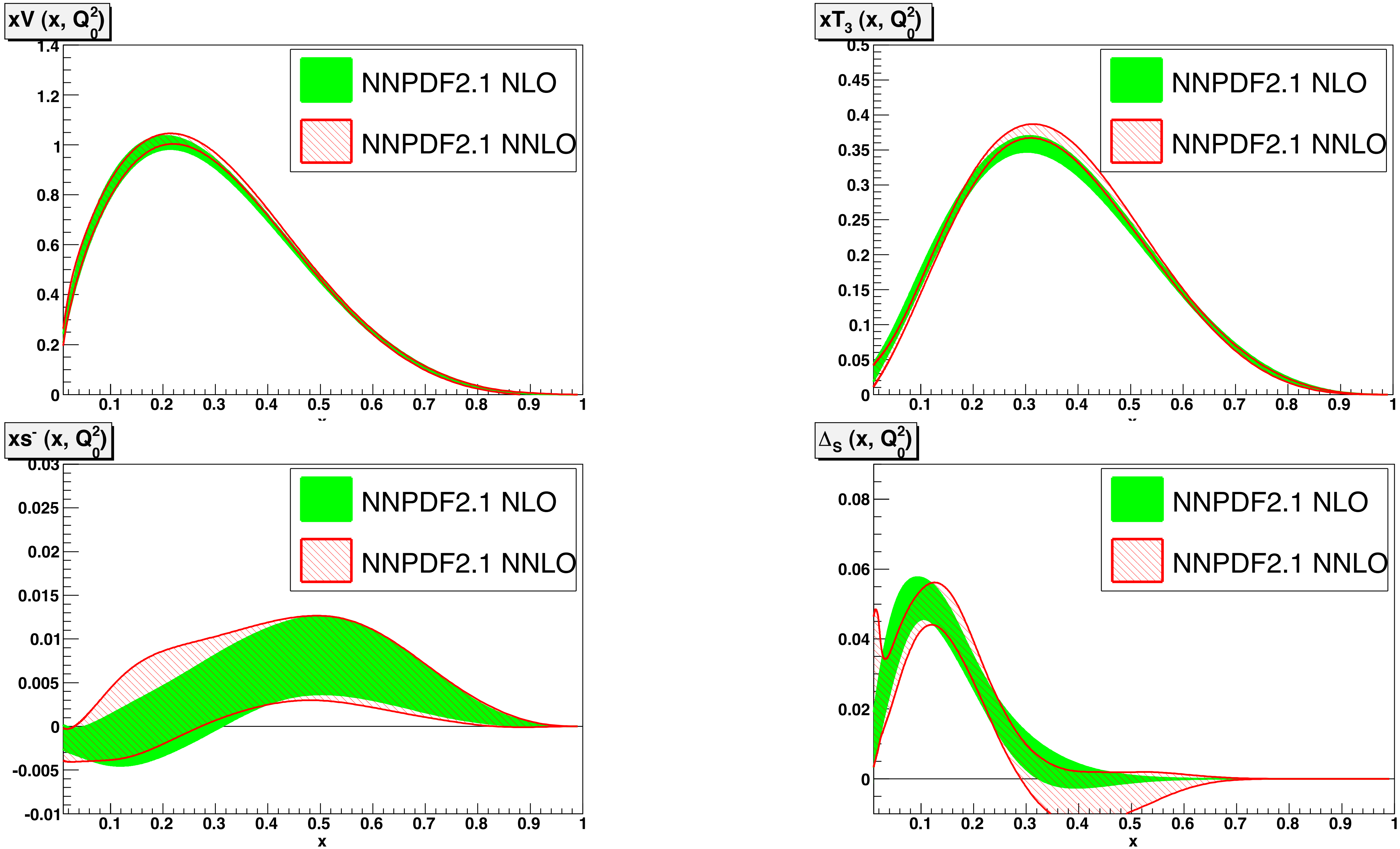






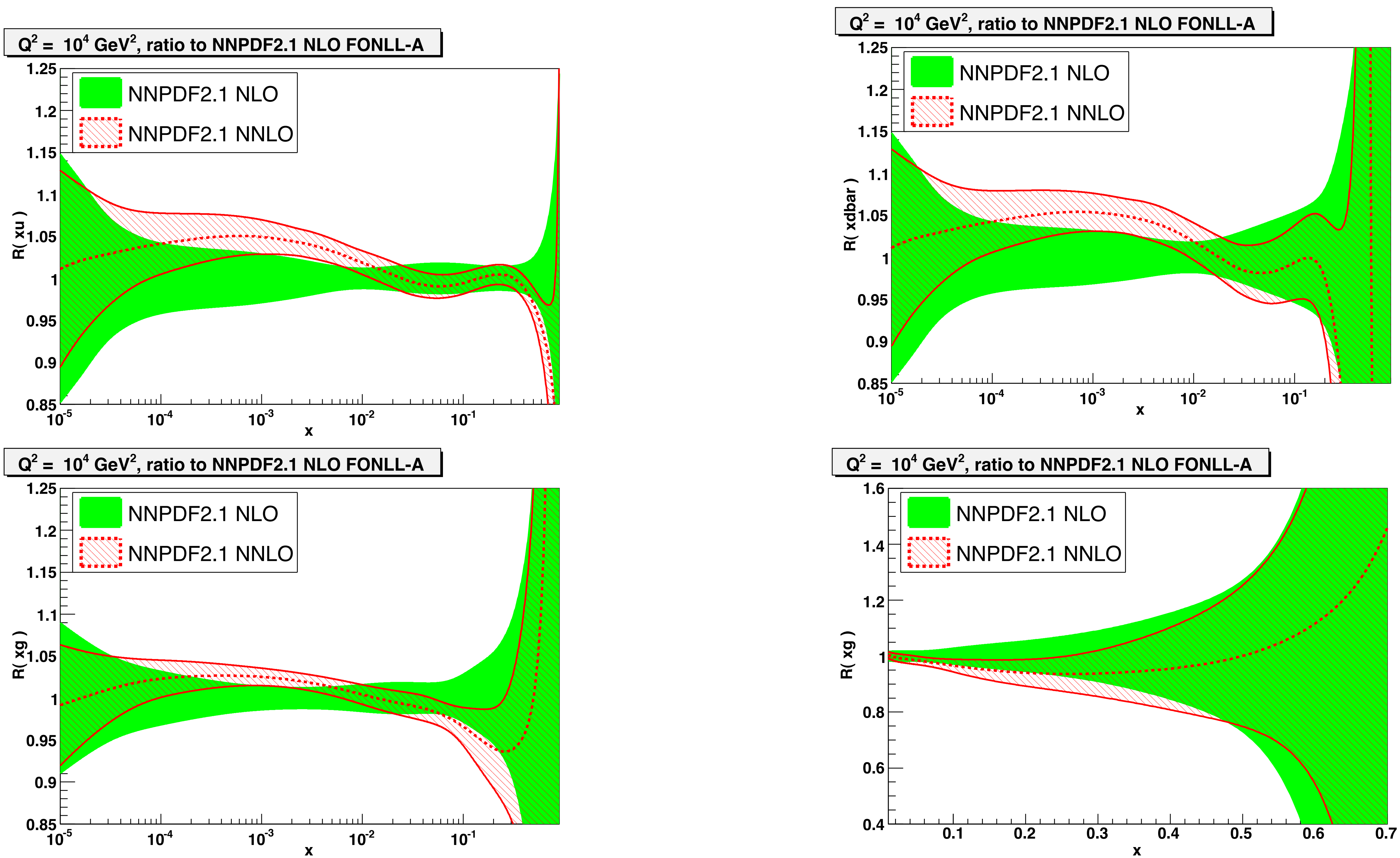
Results @ NNLO

- Non-singlet sector



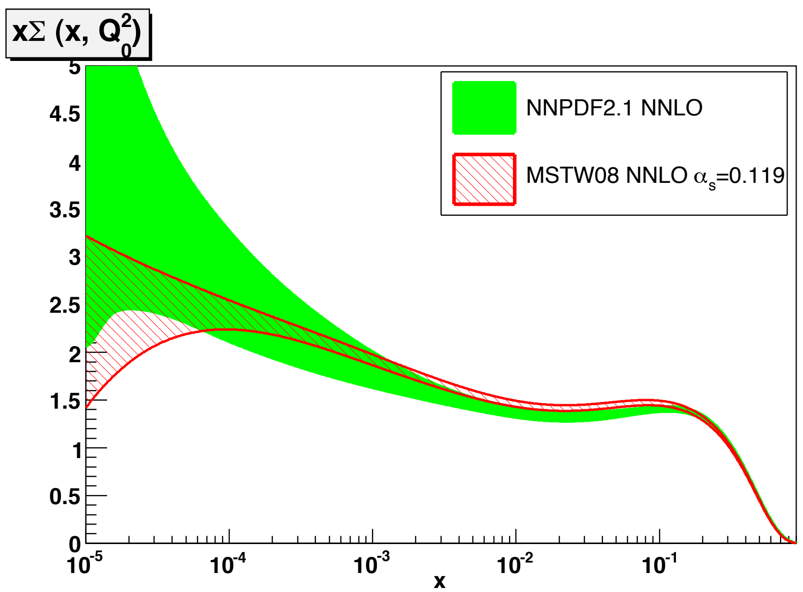
NNLO @ hard scale

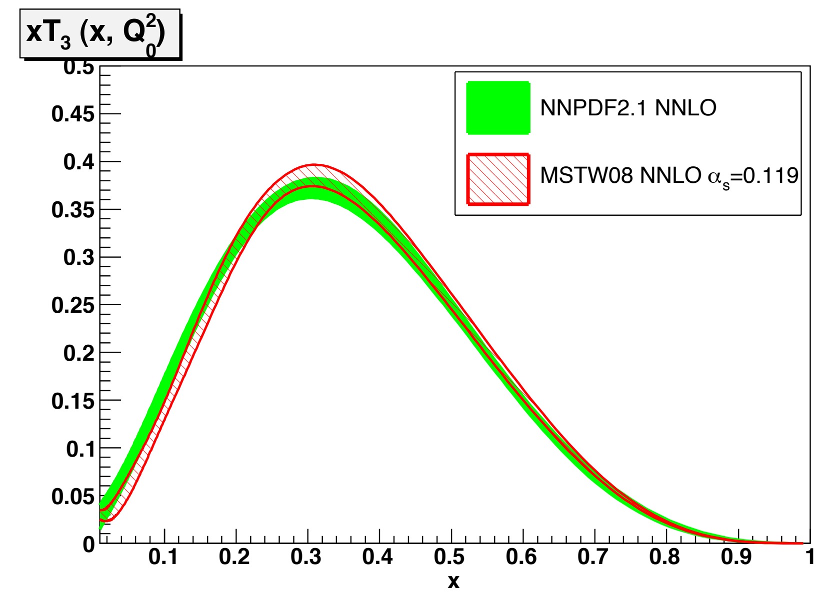
- PDFs at $Q^2 = (100\ \mathrm{GeV})^2$

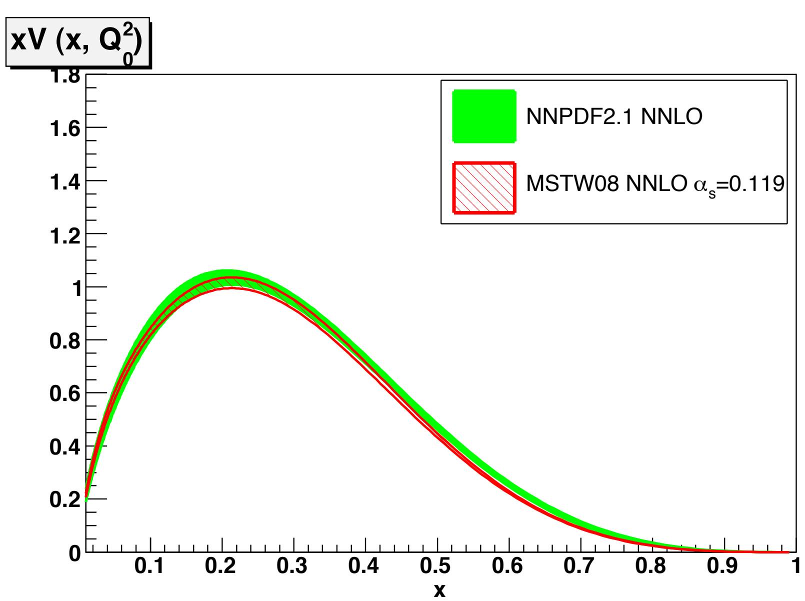


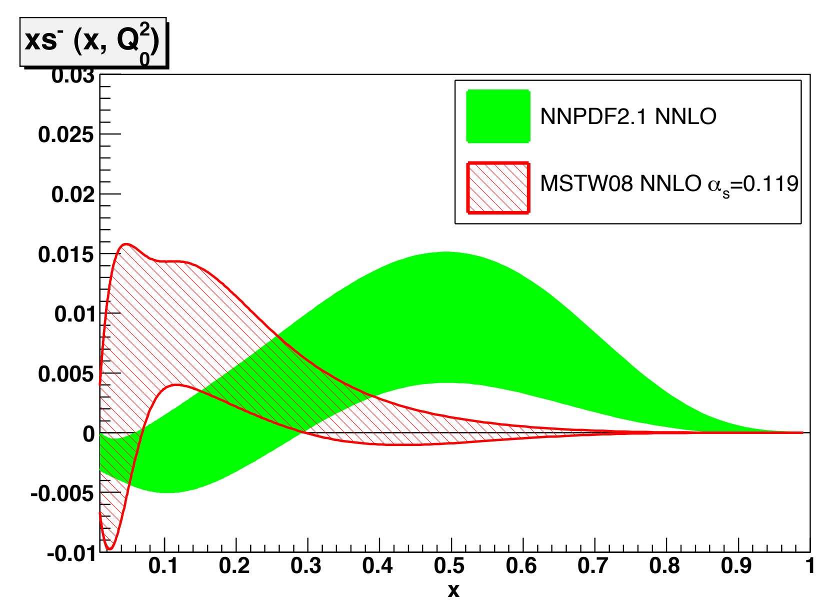
Comparison with other NNLO fits

- MSTW08 $\alpha_s = 0.119$









Comparison with other NNLO fits

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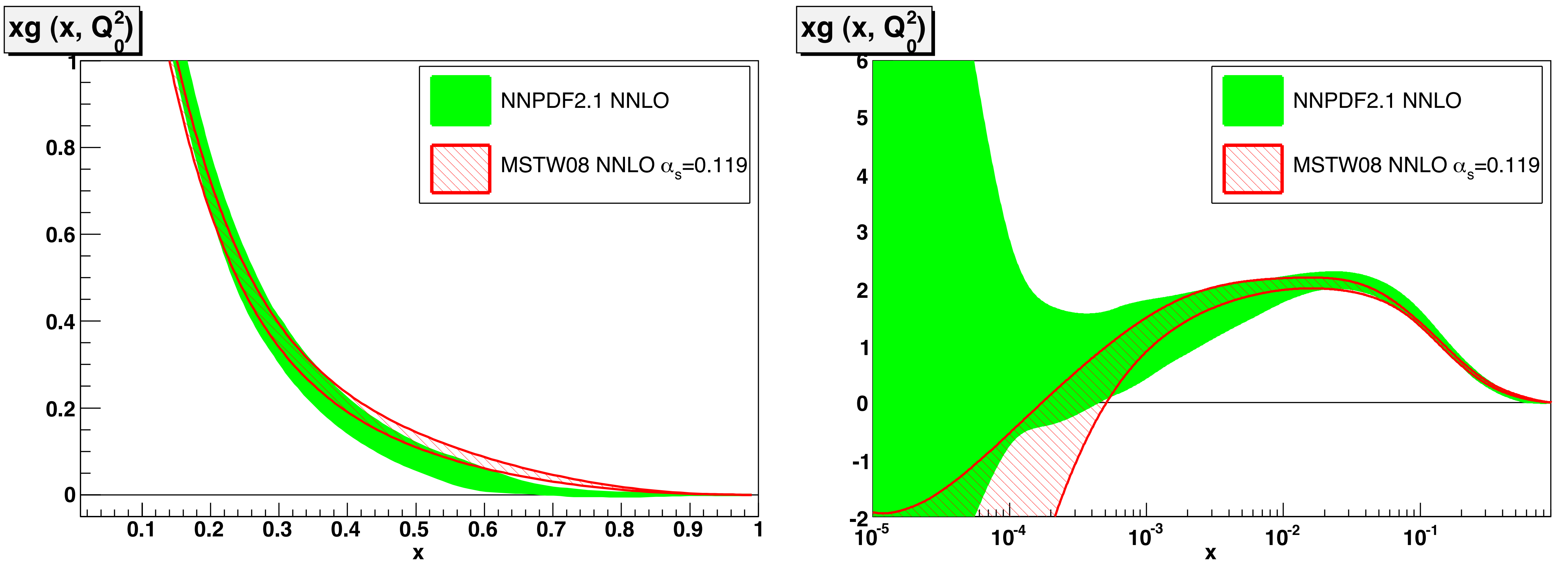


LO implementation

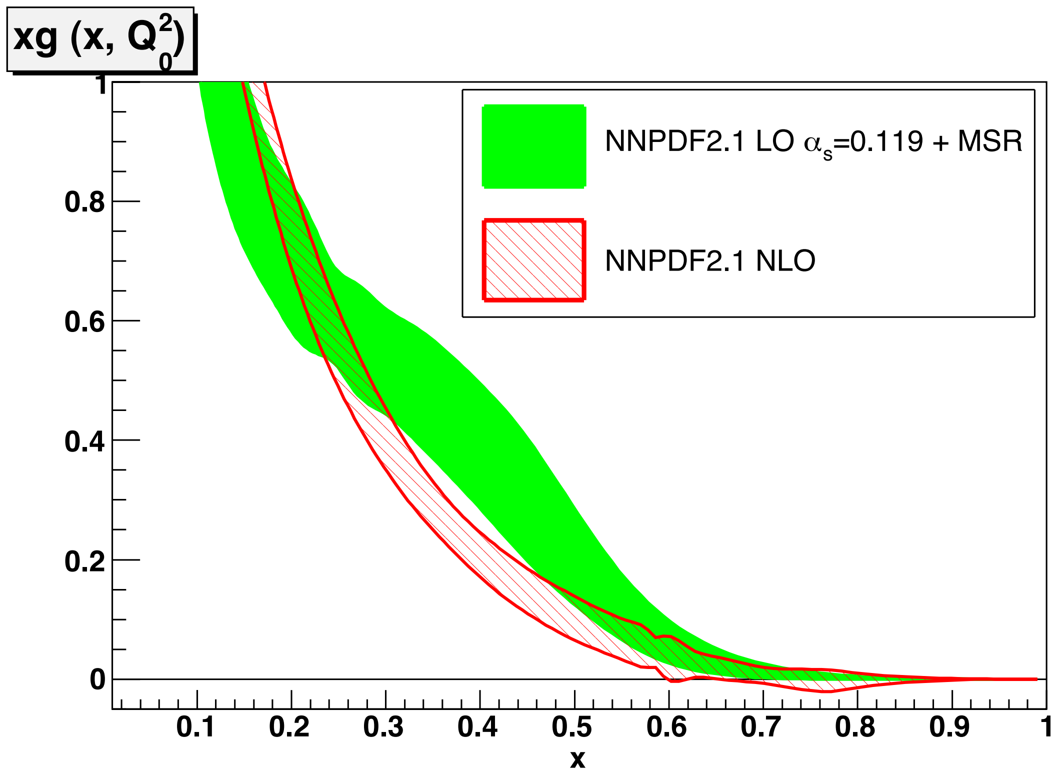
- four different sets of LO fits - LO running

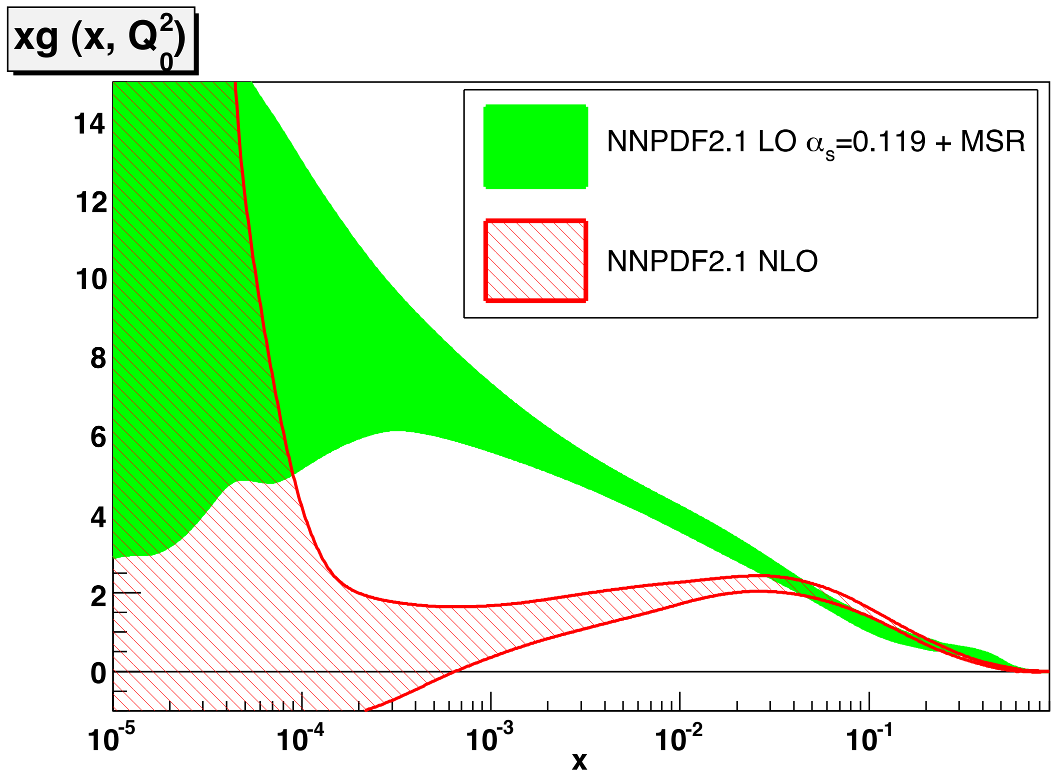
	NLO	LO α_s =0.119	LO* α_s =0.119	LO α_s =0.130	LO* α_s =0.130
Total χ^2	1.16	1.74	1.76	1.68	1.74
Total $\langle\chi^2\rangle$	1.25 ± 0.07	1.95 ± 0.21	1.89 ± 0.22	1.95 ± 0.19	1.94 ± 0.18
NMC-pd	0.97	1.43	1.13	1.18	1.12
NMC	1.72	2.05	1.68	1.74	1.72
SLACK	1.29	3.77	3.00	2.91	2.70
BEDIMS	1.24	1.87	1.82	1.76	1.75
HERAI-AV	1.07	1.70	1.55	1.58	1.59
CHORUS	1.15	1.51	1.67	1.53	1.67
NTVDMN	0.45	0.69	0.71	0.71	0.78
ZEUS-H2	1.29	1.51	1.42	1.43	1.44
ZEUSF2C	0.78	1.75	1.26	1.56	1.34
H1F2C	1.51	1.77	2.00	1.81	2.02
DYE605	0.85	1.86	2.02	1.70	1.83
DYE886	1.26	1.99	2.52	2.59	3.11
CDFWASY	1.83	1.80	2.50	2.16	2.29
CDFZRAP	1.64	2.88	3.89	2.08	2.58
D0ZRAP	0.59	1.07	1.29	0.87	1.02
CDFR2KT	0.96	2.60	3.22	2.45	2.76
D0R2CON	0.83	1.18	1.56	1.17	1.35
$[M]$	1	1	1.16 ± 0.03	1	1.09 ± 0.03

No improvement from NLO running; better fit if we release positivity constraint

Results @ LO

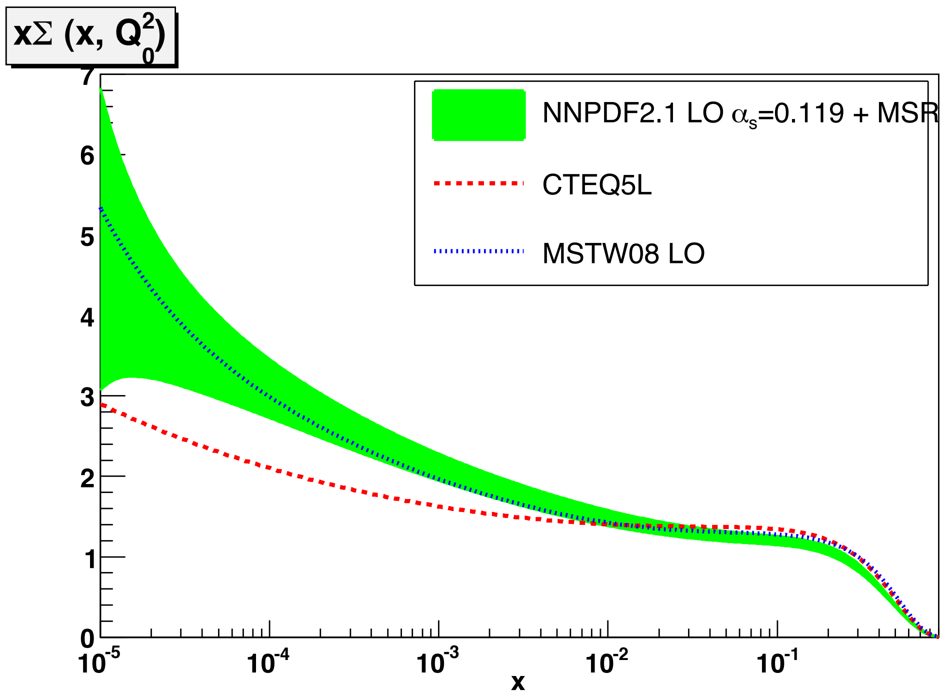
- large theoretical uncertainty due to the lack of higher order terms
- largest shift for gluon, sizeable differences for singlet and valence
- dependence on the coupling/MSR: *comparable* to the statistical uncertainty

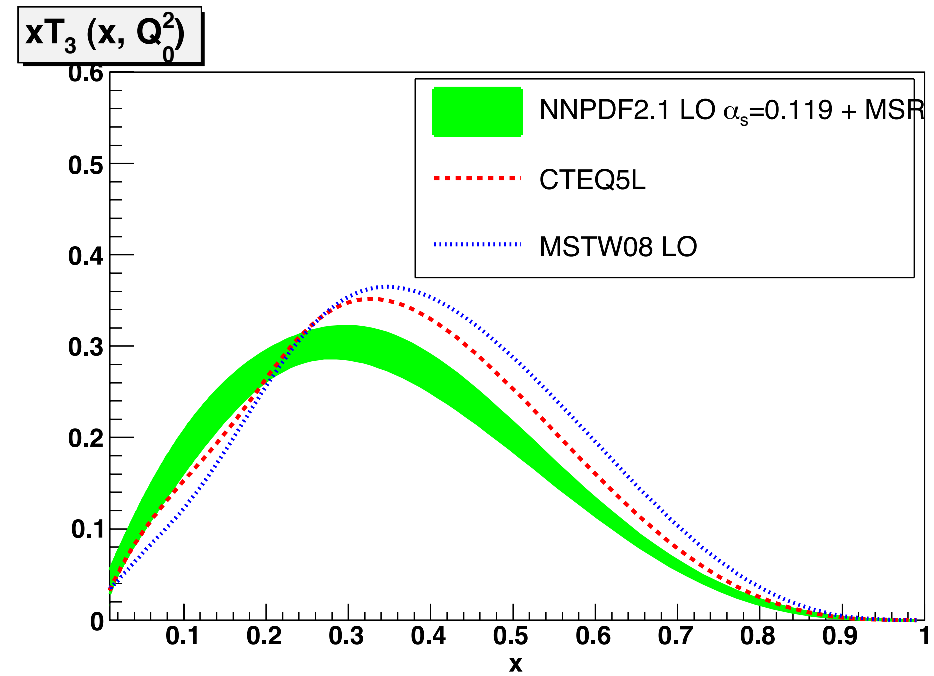


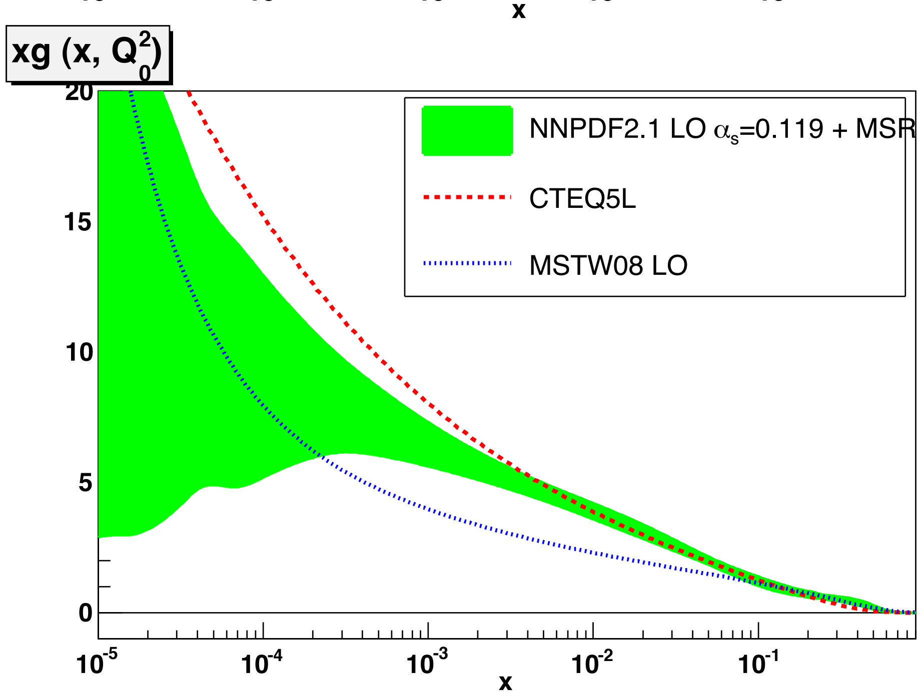


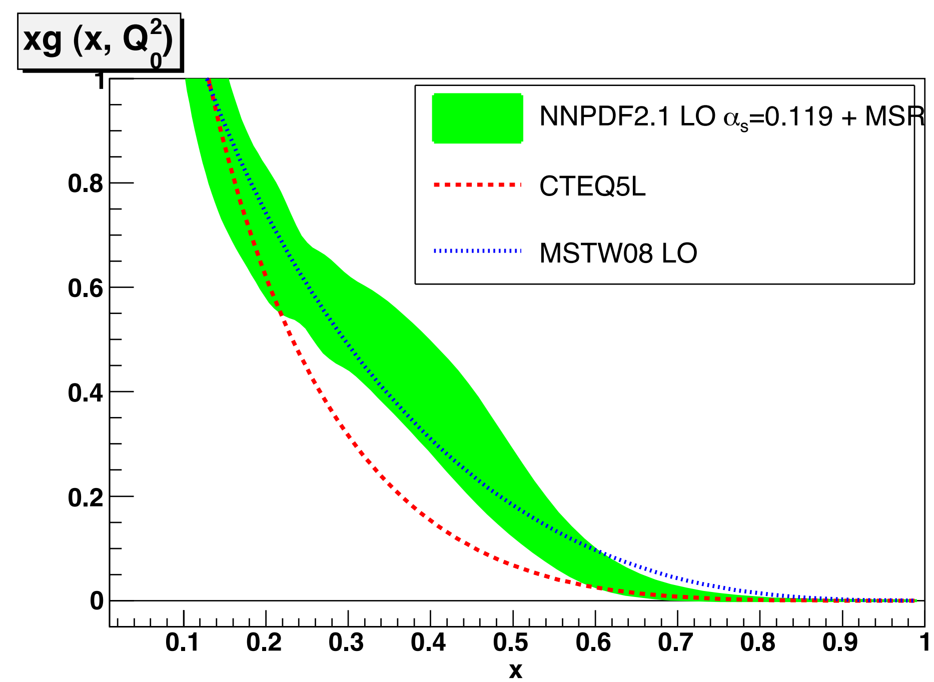
Comparison with other LO fits

- Largest differences for the gluon distribution at small and large x



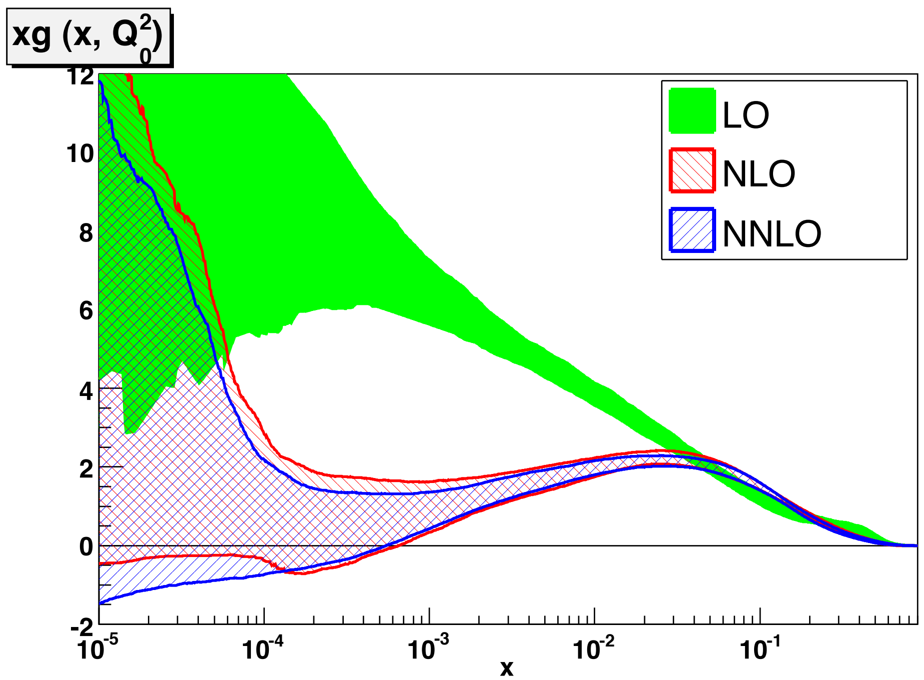


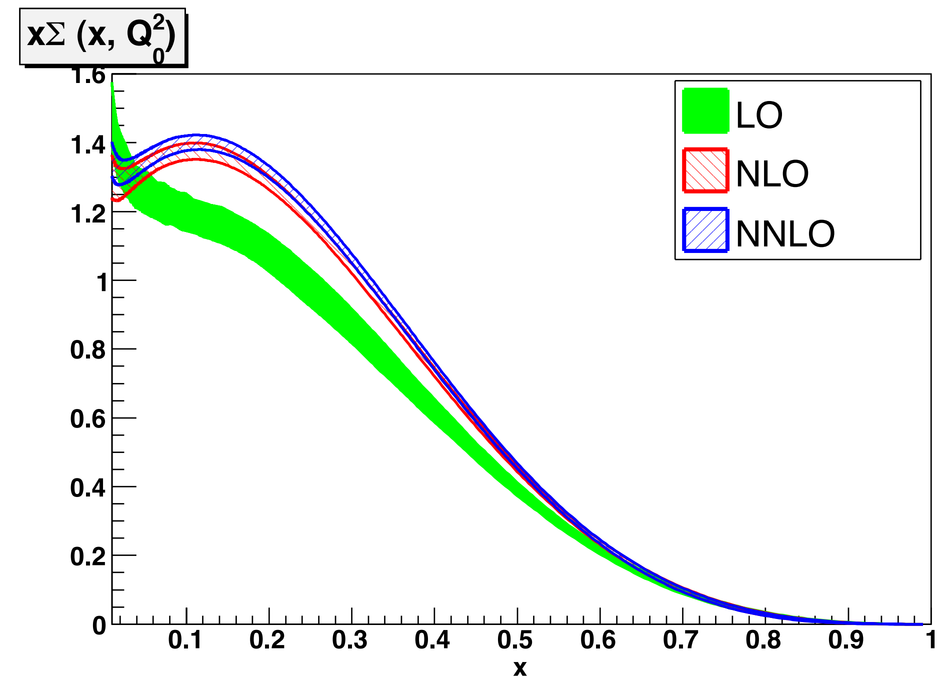


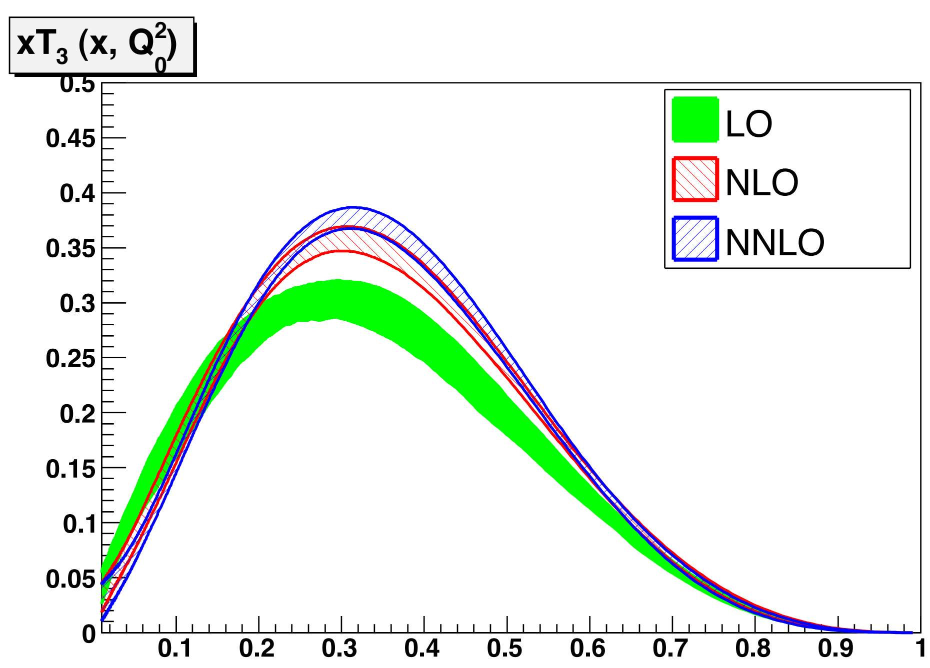


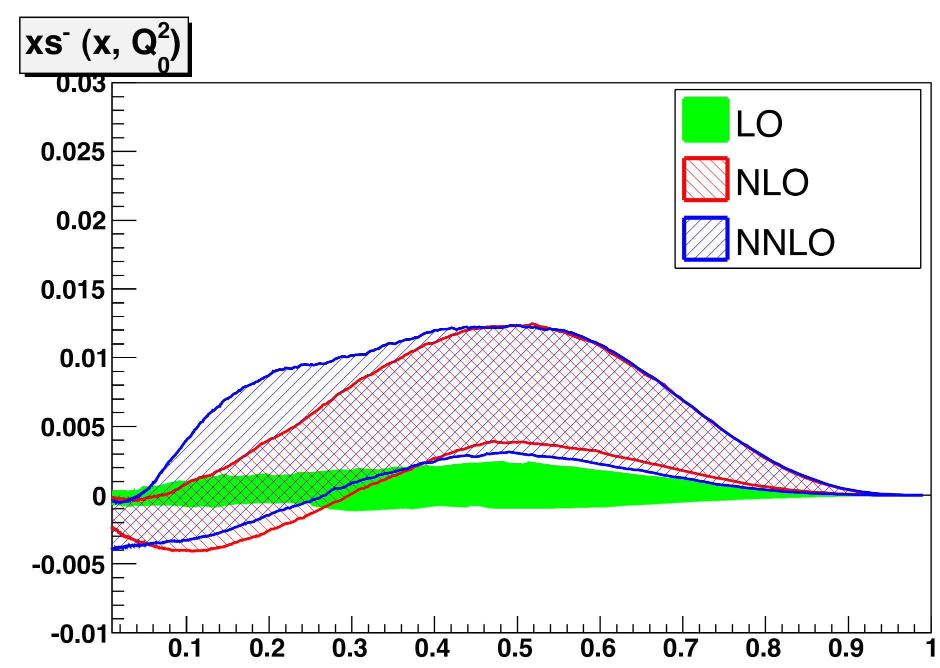
Perturbative stability

- Compare the PDFs obtained at different orders in PT



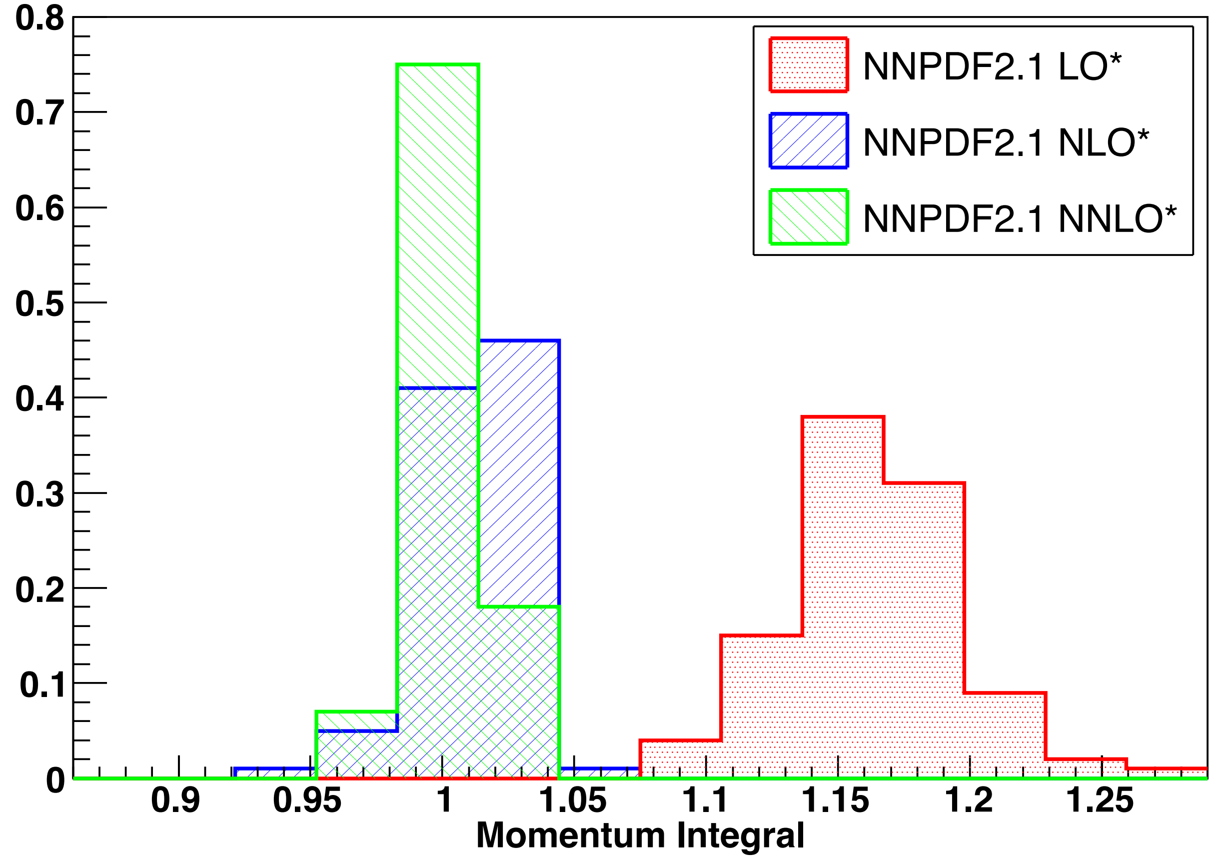






Momentum of partons

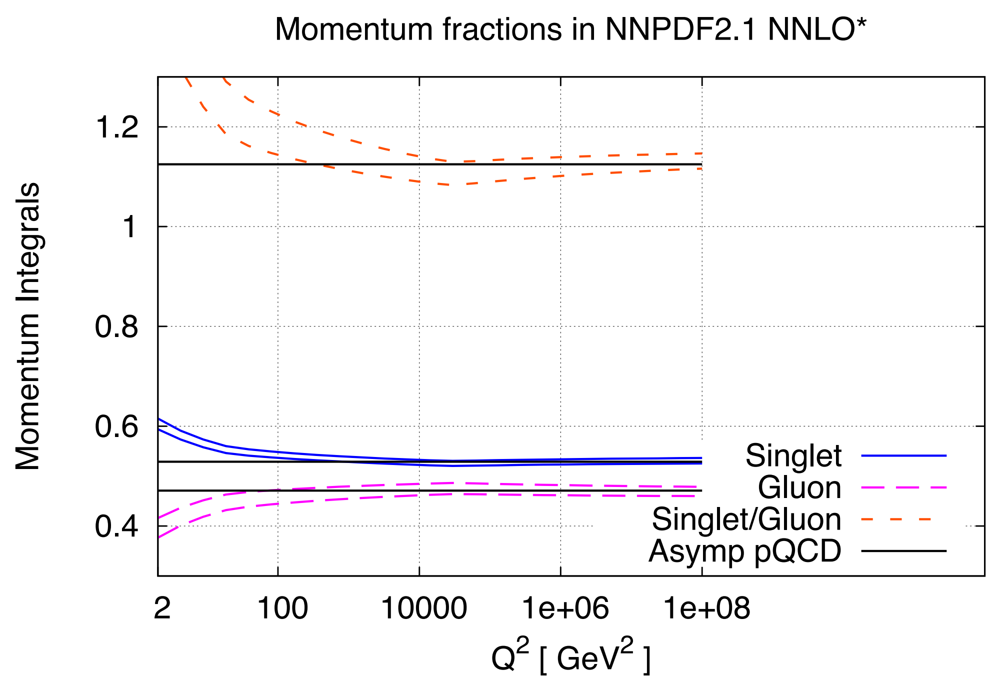
- Momentum fraction $[q](Q^2) = \int dx\, xq(x, Q^2)$
- Total momentum $[M] = [\Sigma] + [g] = 1$

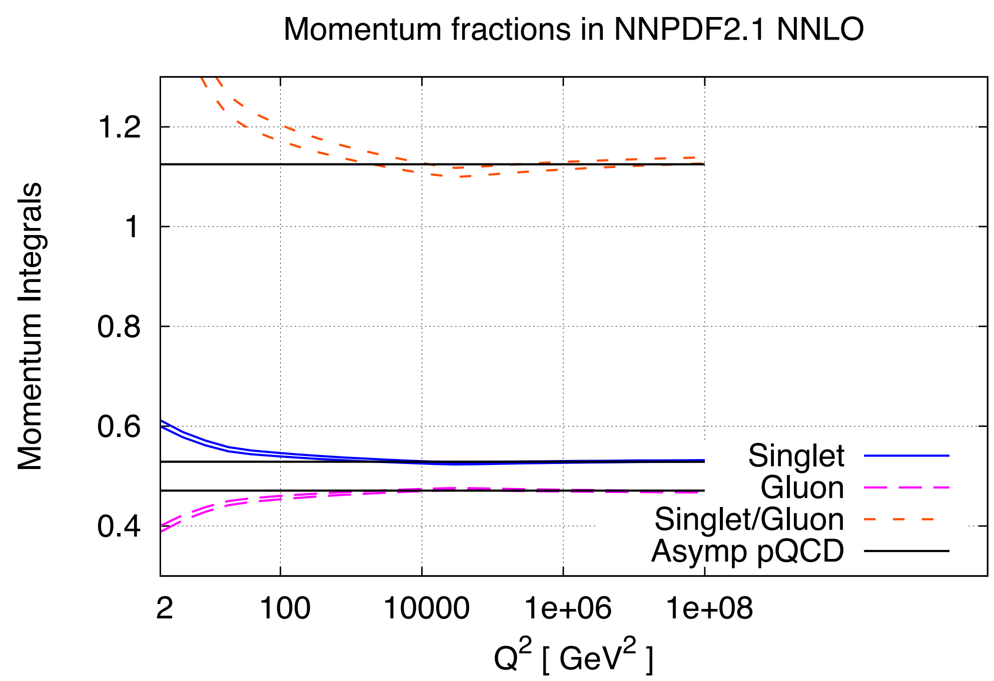


Momentum of partons

- perturbative prediction

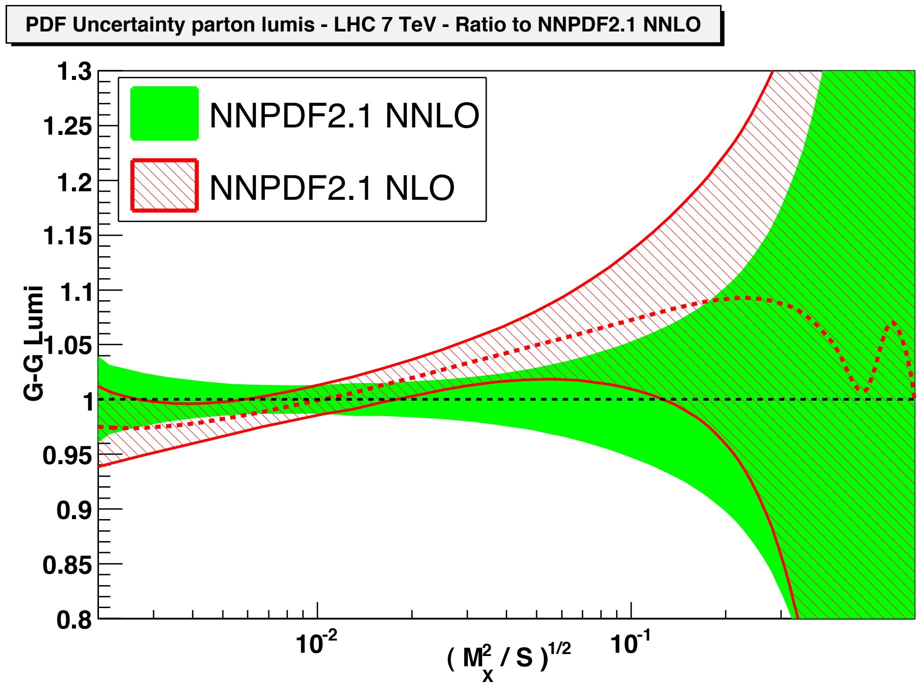
$$\lim_{Q^2\to\infty}[\Sigma](Q^2) = \frac{3n_f}{16+3n_f} \approx 0.5294; \qquad \lim_{Q^2\to\infty}[g](Q^2) = \frac{16}{16+3n_f} \approx 0.4706$$

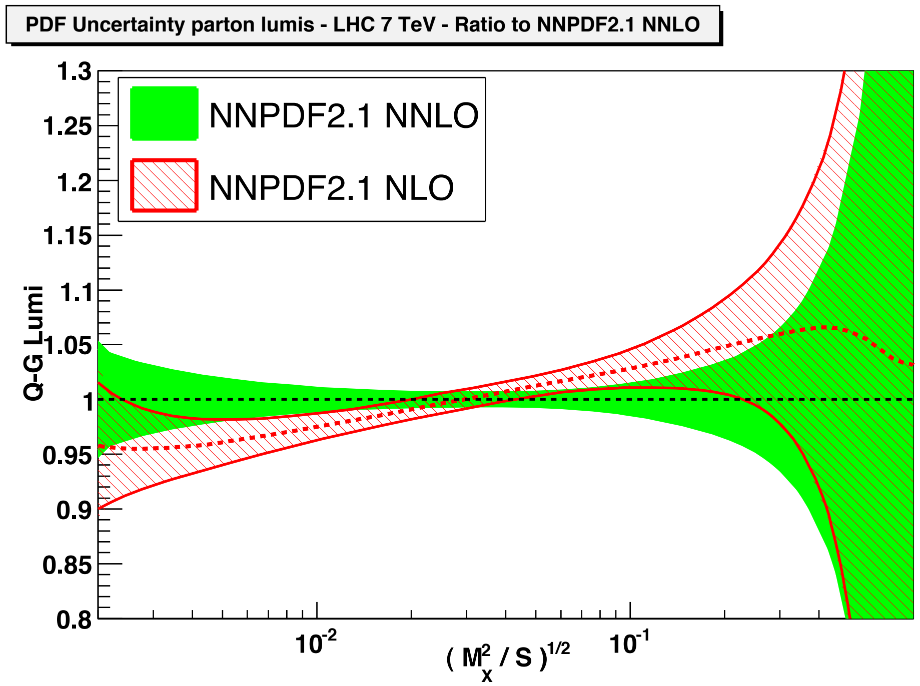


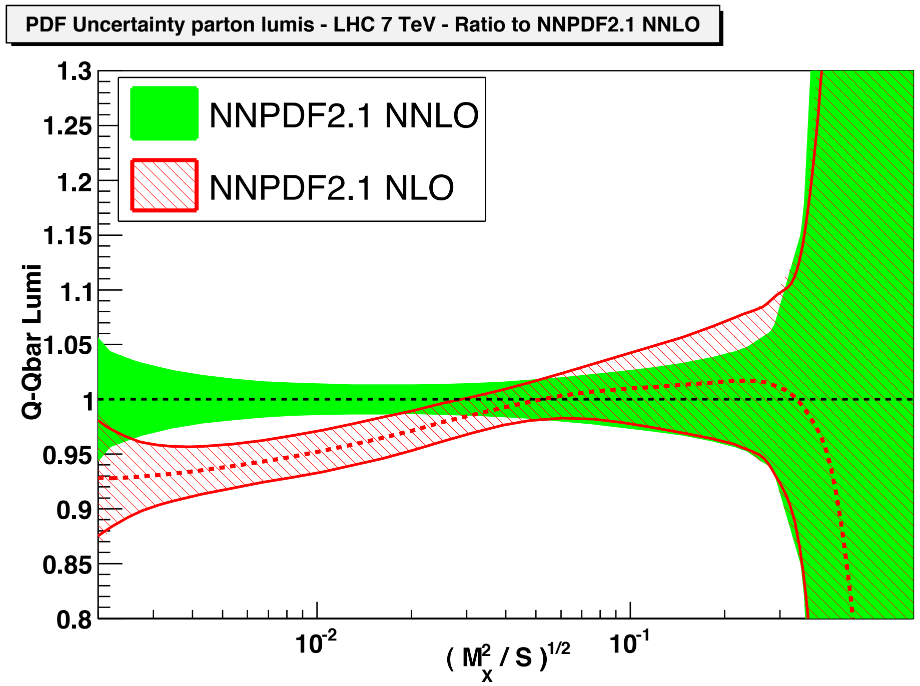


Phenomenolgical implications

- parton luminosities

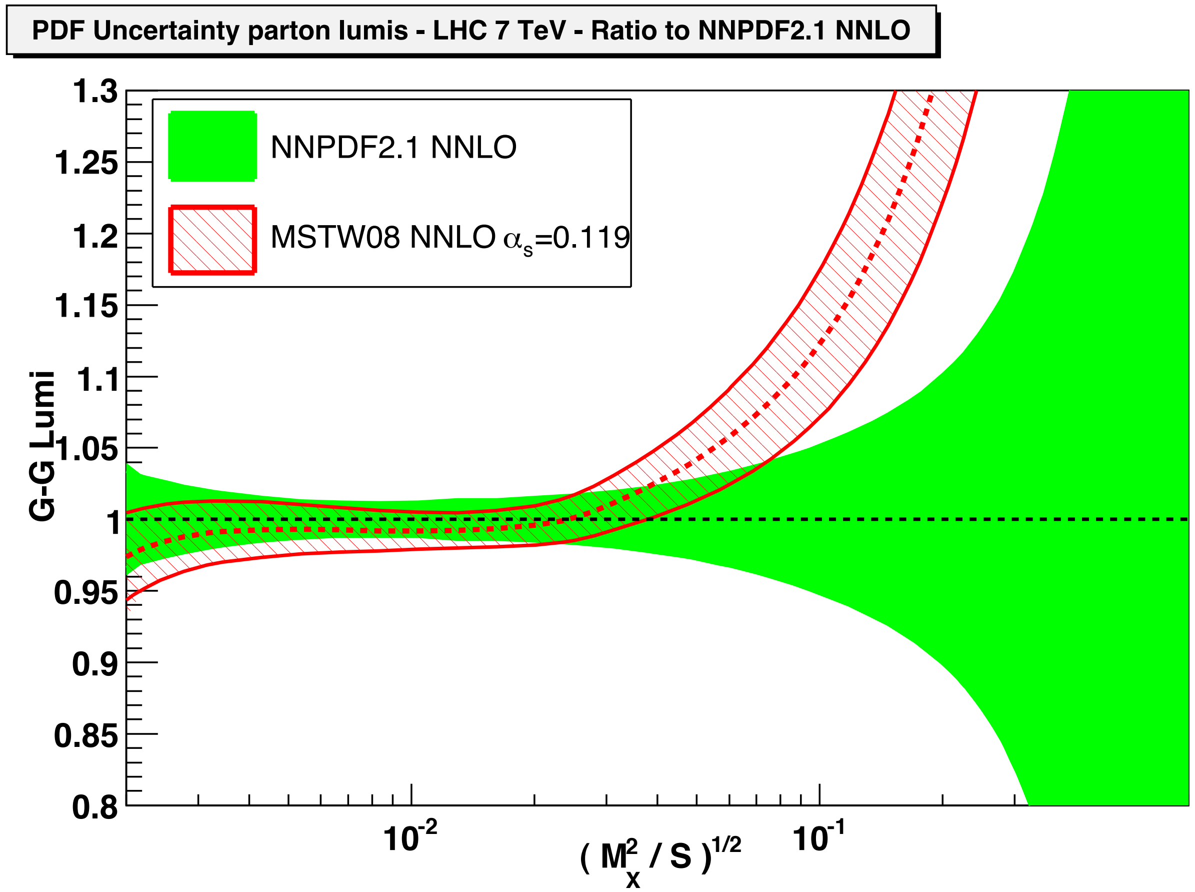


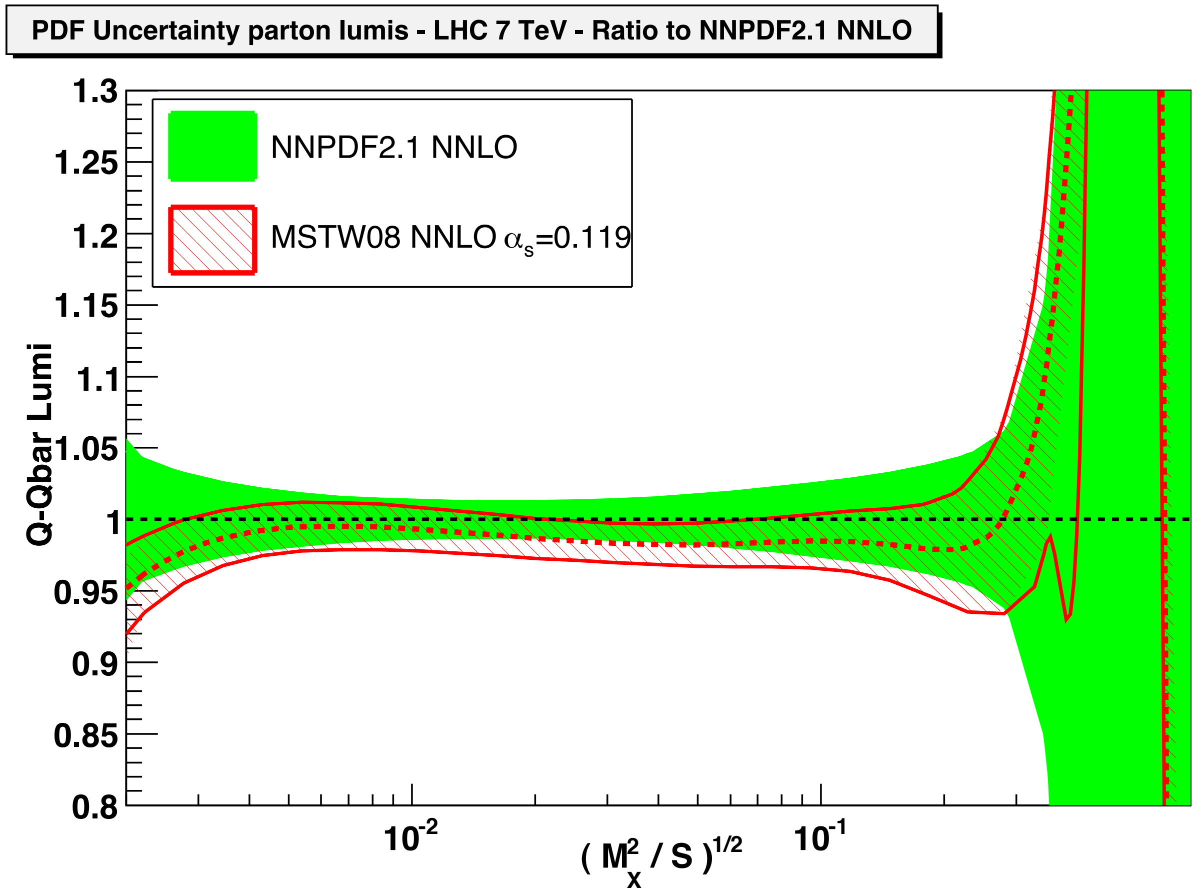




Phenomenological implications

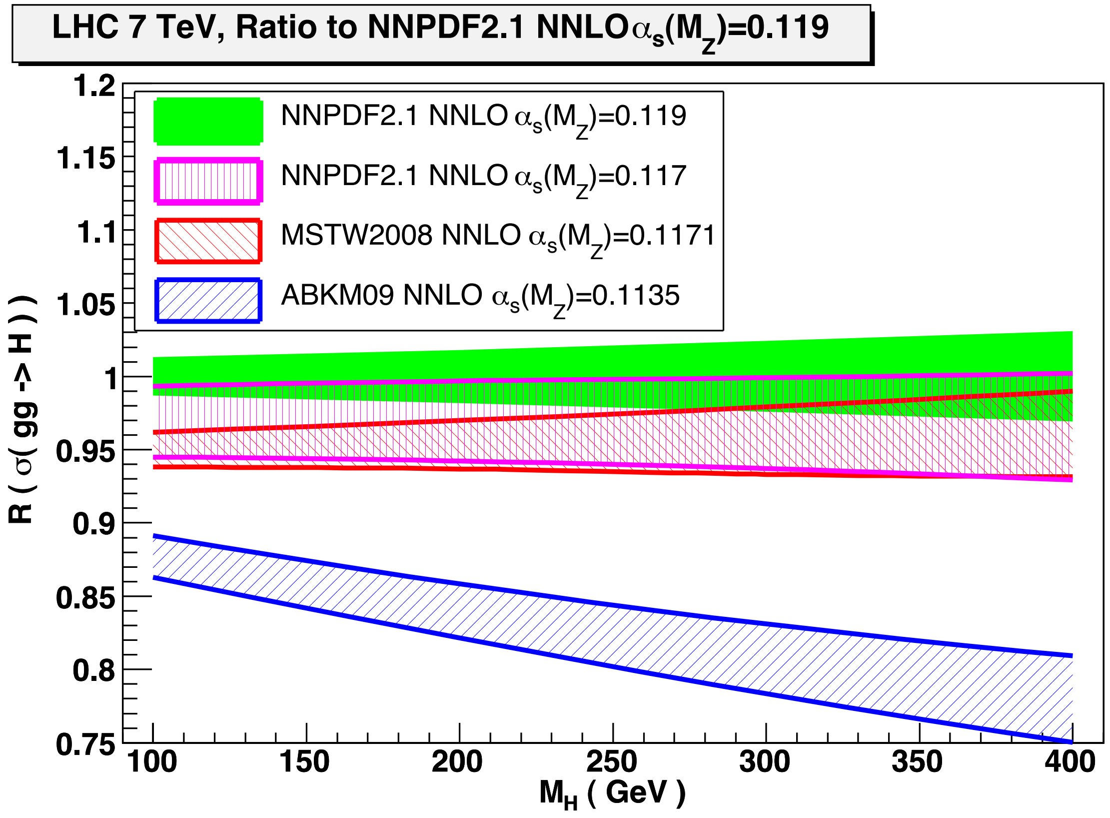
- parton luminosities comparison with MSTW08

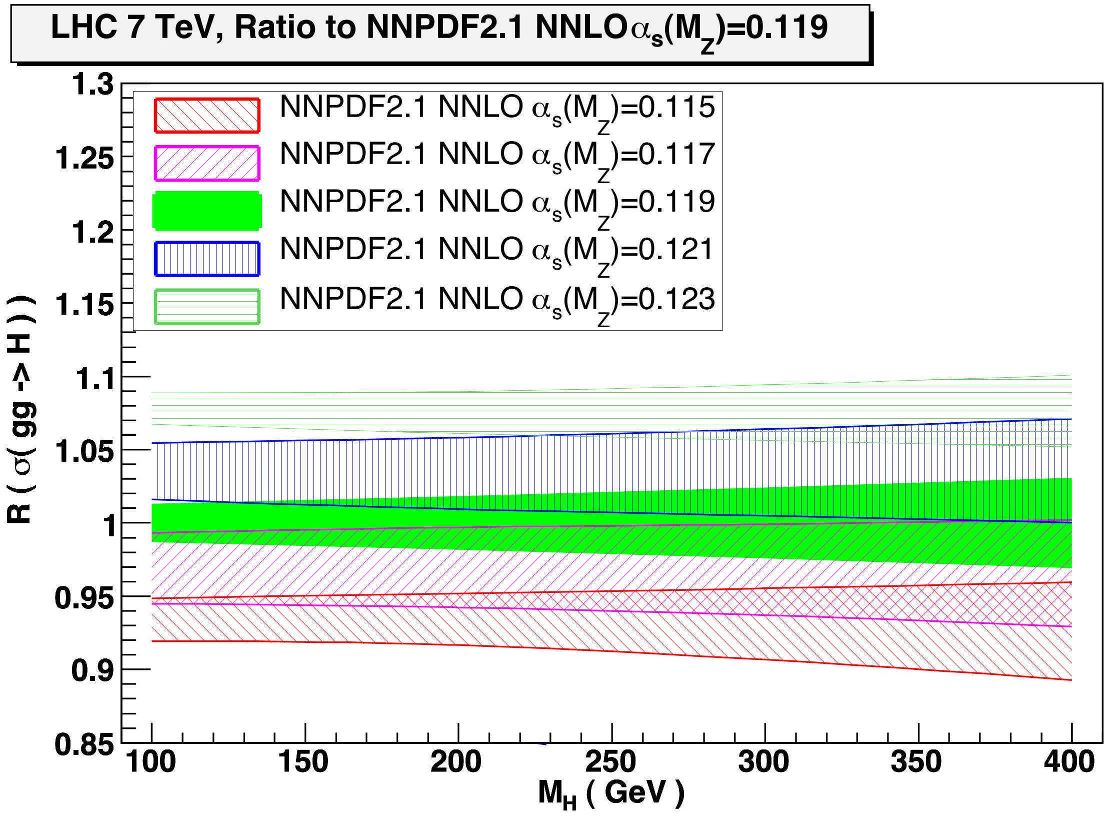




Phenomenological implications

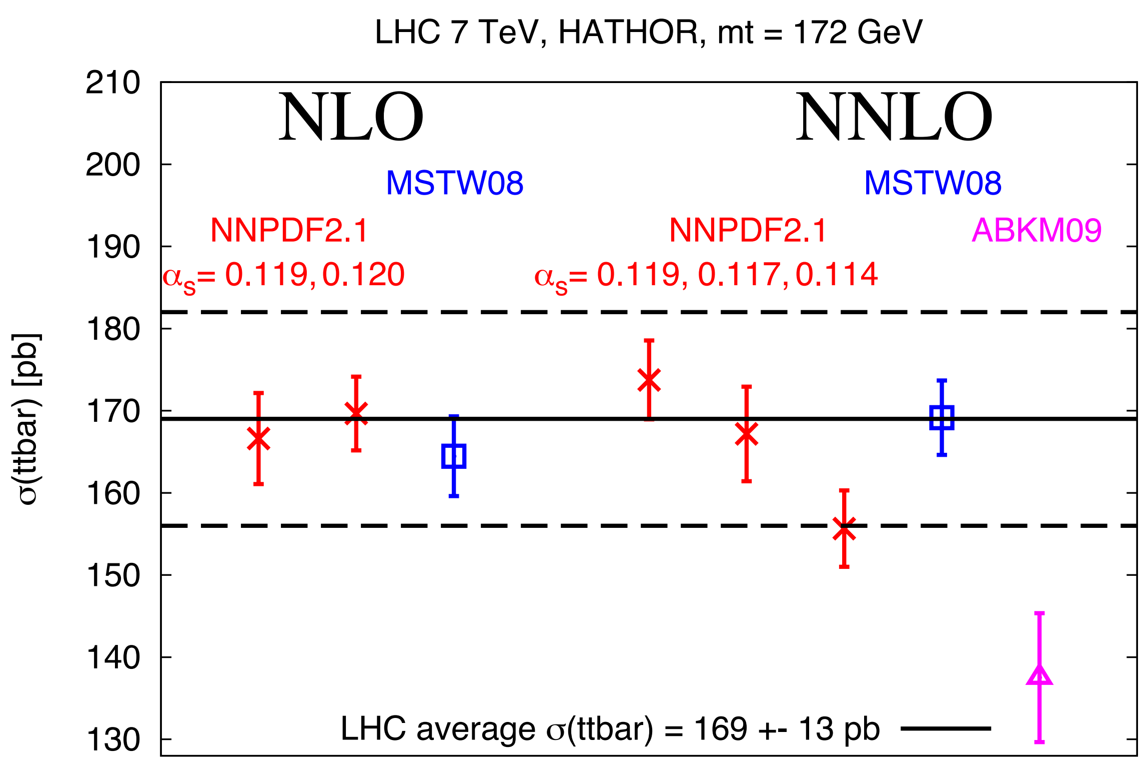
- Higgs production via gluon fusion

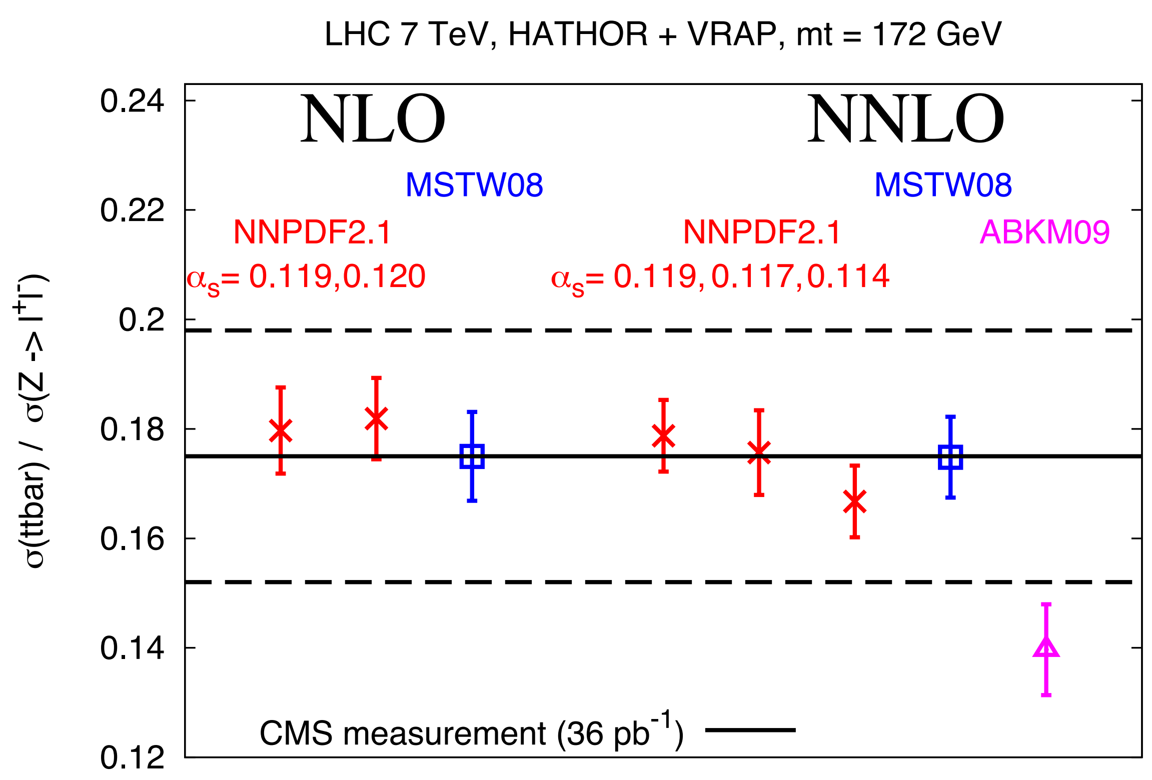




Phenomenological implications

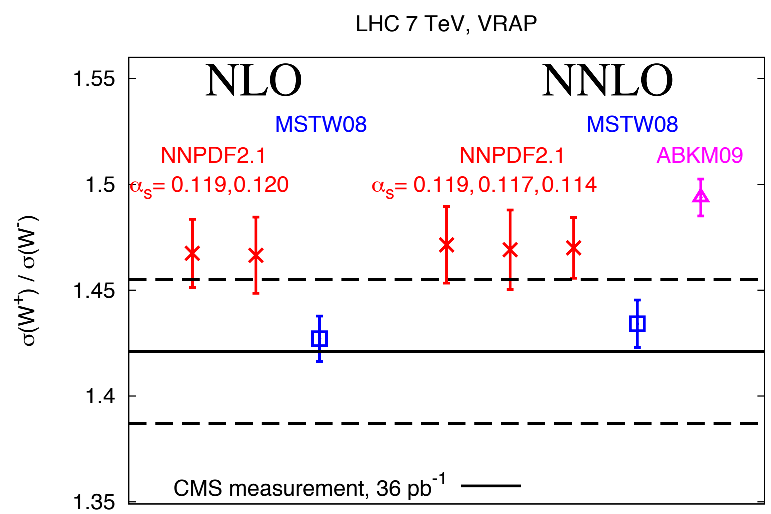
- ttbar production

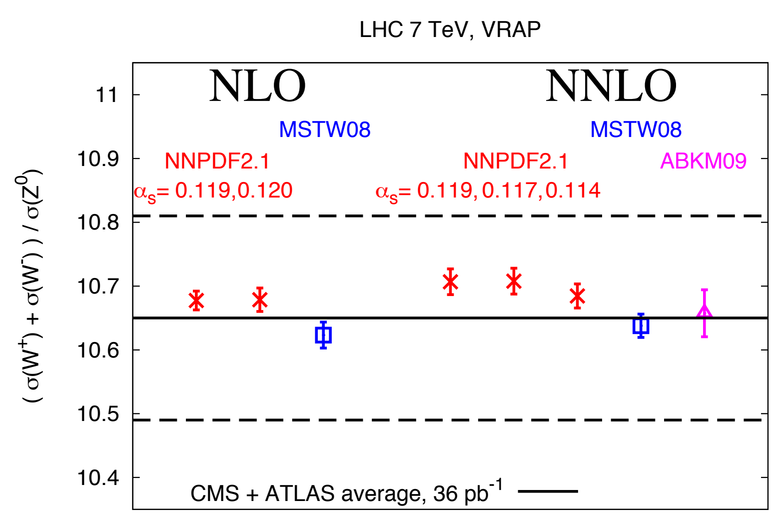


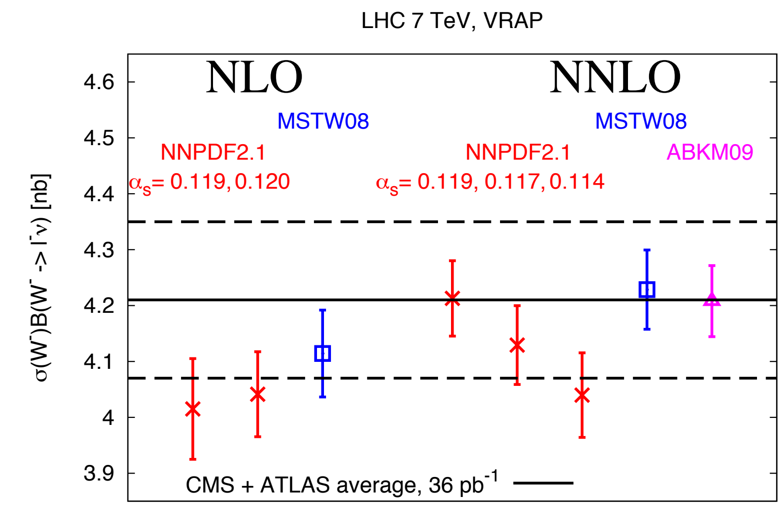


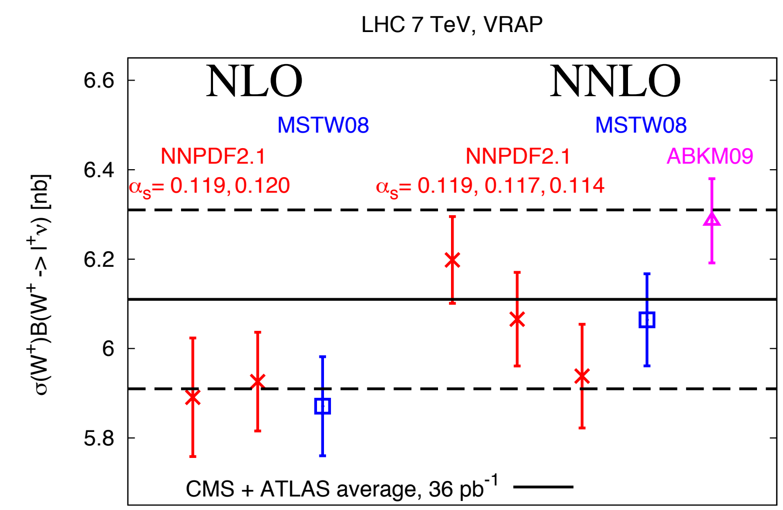
Phenomenological implications

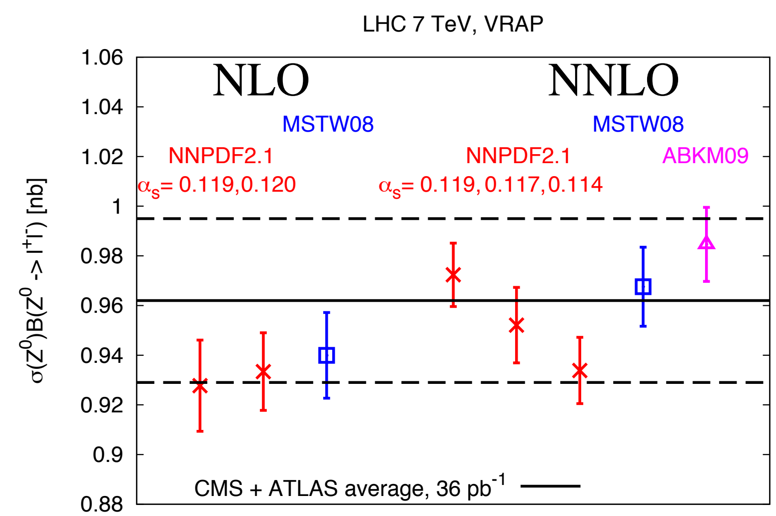
- vector boson production











Outlook

- NNLO/LO **global** fits (DIS, DY, vector boson, inclusive jets)
- NNLO fits compatible with NLO within statistical errors
- **consistent** picture @ NNLO GM-VFN (momentum sum rule, standard candles)
- flexible parametrization, unchanged since NNPDF1.2
- MC treatment of statistical fluctuations, statistically meaningful errors
- new data: reweighting the MC ensemble (cfr R Ball, Thurs)
- address theoretical uncertainties

Extras

- backup slides with detailed information

MC ensemble of PDFs

- output of our fits: set of replicas
- central value:

$$\mathcal{F} = \langle \mathcal{F} \rangle_{\rm rep} = \frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} \mathcal{F}[q^{(k)}]$$

- variance:

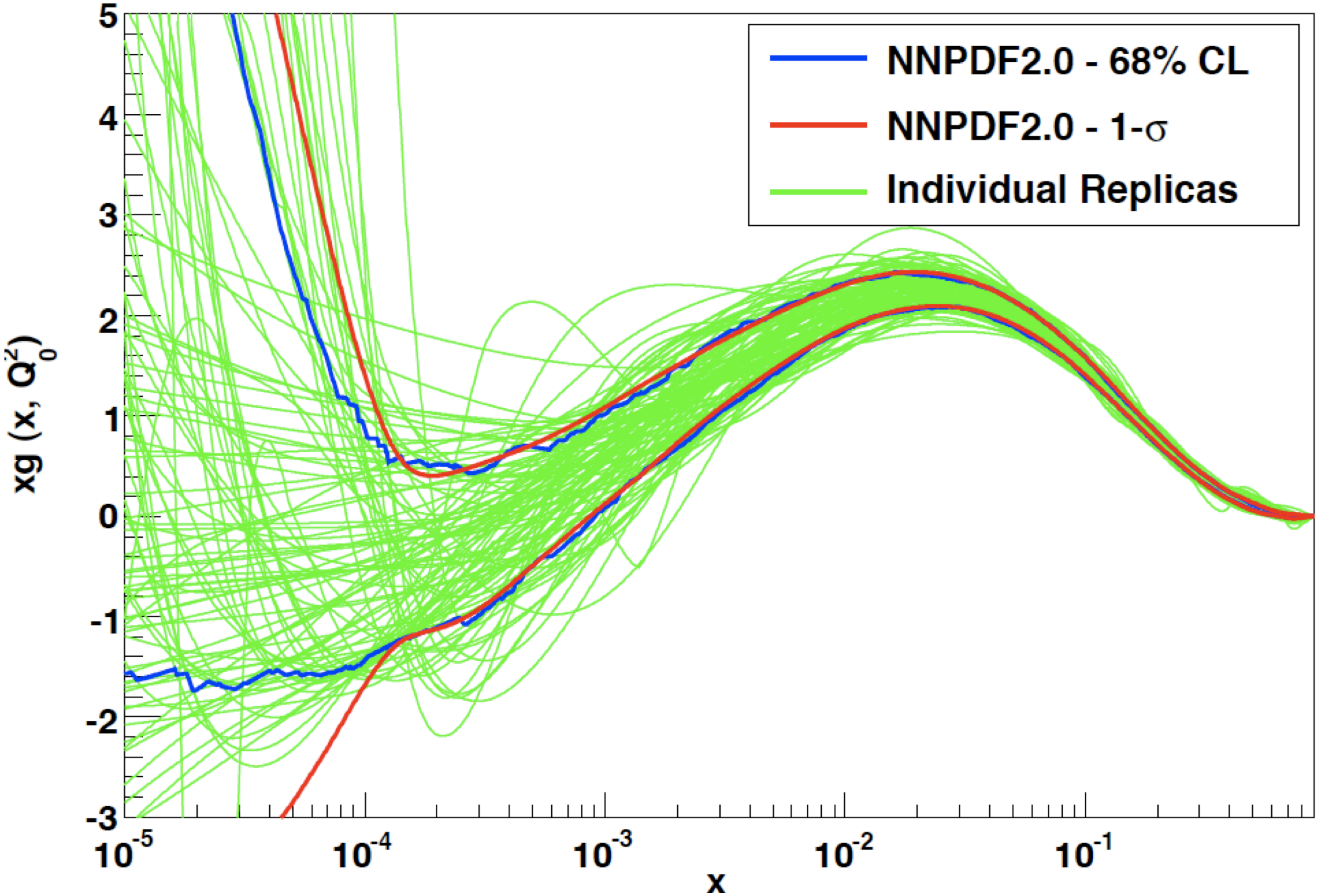
$$\sigma^2_{\mathcal{F}} = \frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} \left(\mathcal{F}[\{q^{(k)}\}] - \mathcal{F} \right)^2$$

- correlation:

$$\rho = \frac{\langle \mathcal{F}\ \mathcal{G} \rangle_{\rm rep} - \langle \mathcal{F} \rangle_{\rm rep}\ \langle \mathcal{G} \rangle_{\rm rep}}{\sigma_{\mathcal{F}}\ \sigma_{\mathcal{G}}}$$

Confidence level intervals

- Given the MC sample, we can compute the variance of the sample, or the central 68% percentile.



FONLL

- DIS structure function in the FONLL scheme:

$$F^{\mathrm{FONLL}}(x,Q^2) = \theta(Q^2-m^2)\left(1-\frac{m^2}{Q^2}\right)F^{(d)}(x,Q^2) + F^{(n_l)}(x,Q^2)$$

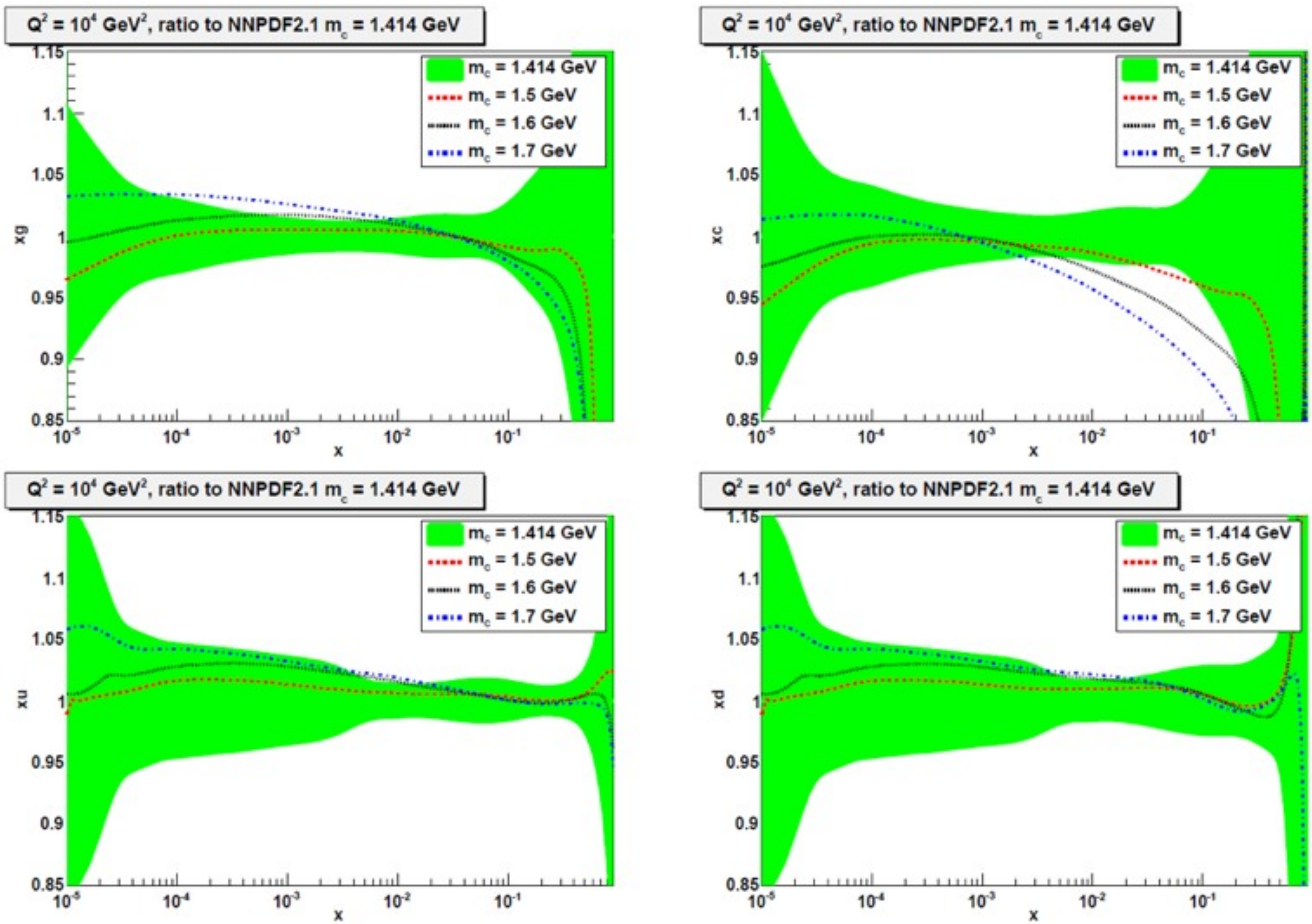
$$F^{(d)}(x,Q^2) = F^{(n_l+1)}(x,Q^2) - F^{(n_l,0)}(x,Q^2)$$

$$F^{(n_l,0)}(x,Q^2) = x\int_x^1 \frac{dy}{y}\sum_i B_i^{(0)}\left(\frac{x}{y},\frac{Q^2}{m^2},\alpha_s^{(n_l+1)}(Q^2)\right) f_i^{(n_l+1)}(y,Q^2)$$

$$\lim_{m\to 0}\left[B_i\left(z,\frac{Q^2}{m^2}\right) - B_i^{(0)}\left(z,\frac{Q^2}{m^2}\right)\right] = 0$$

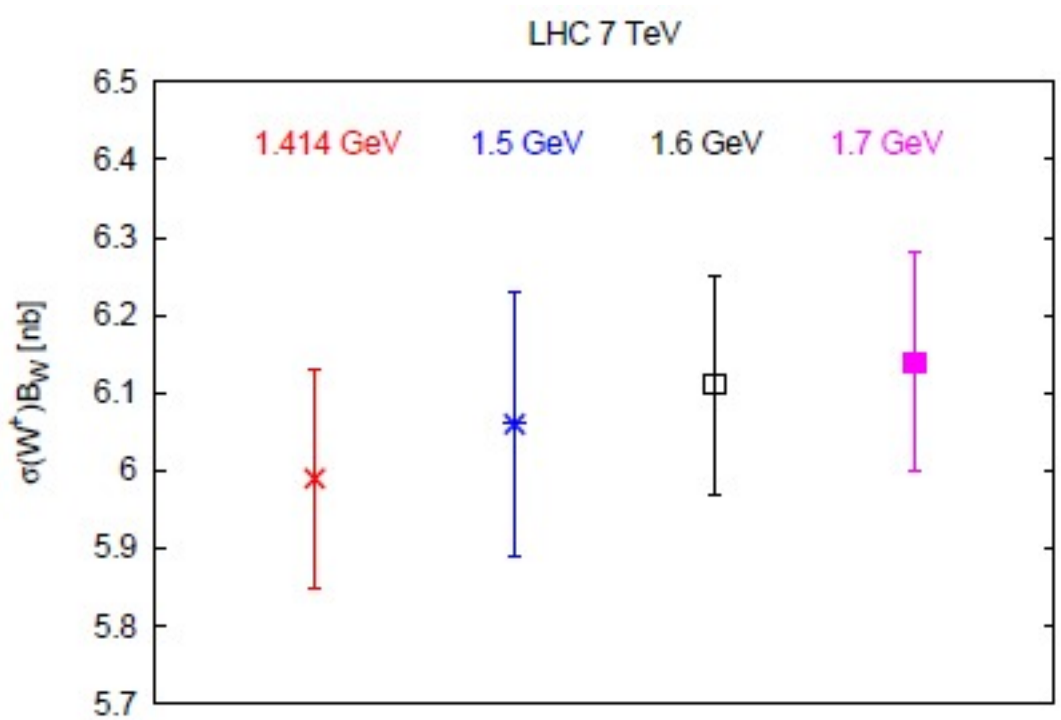
Dependence on the HQ mass

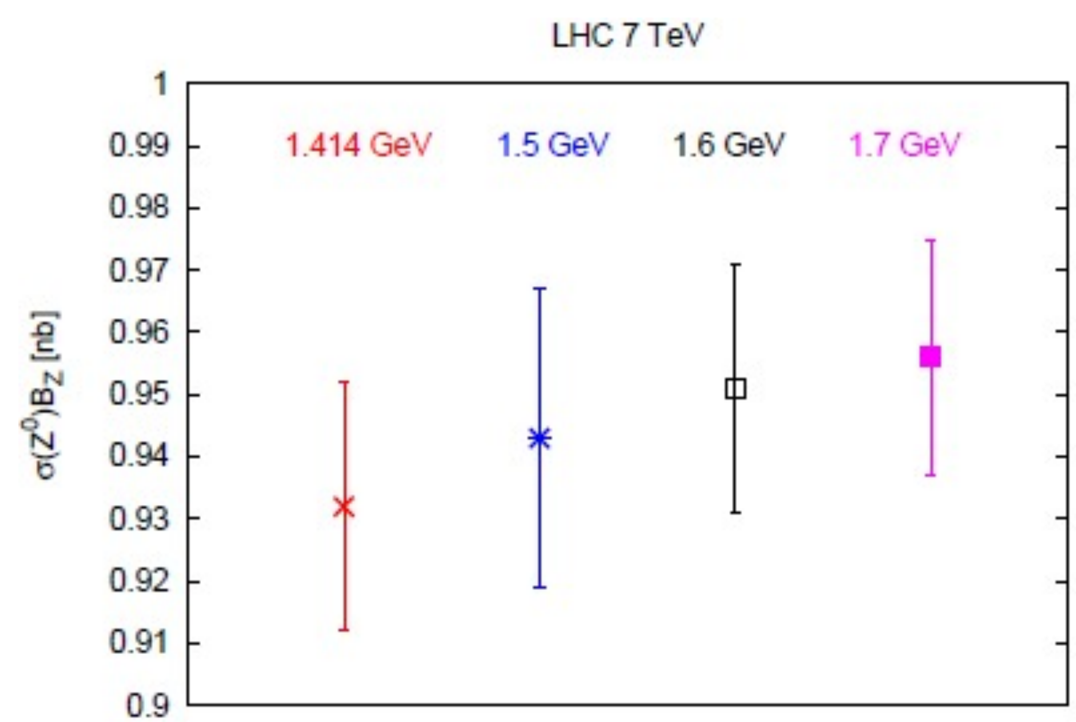
- F Cerruti @ Moriond 2011



Dependence on the HQ mass

- vector boson production





Charm mass dependence is within the statistical errors

Parametrization

- NN and parameter count

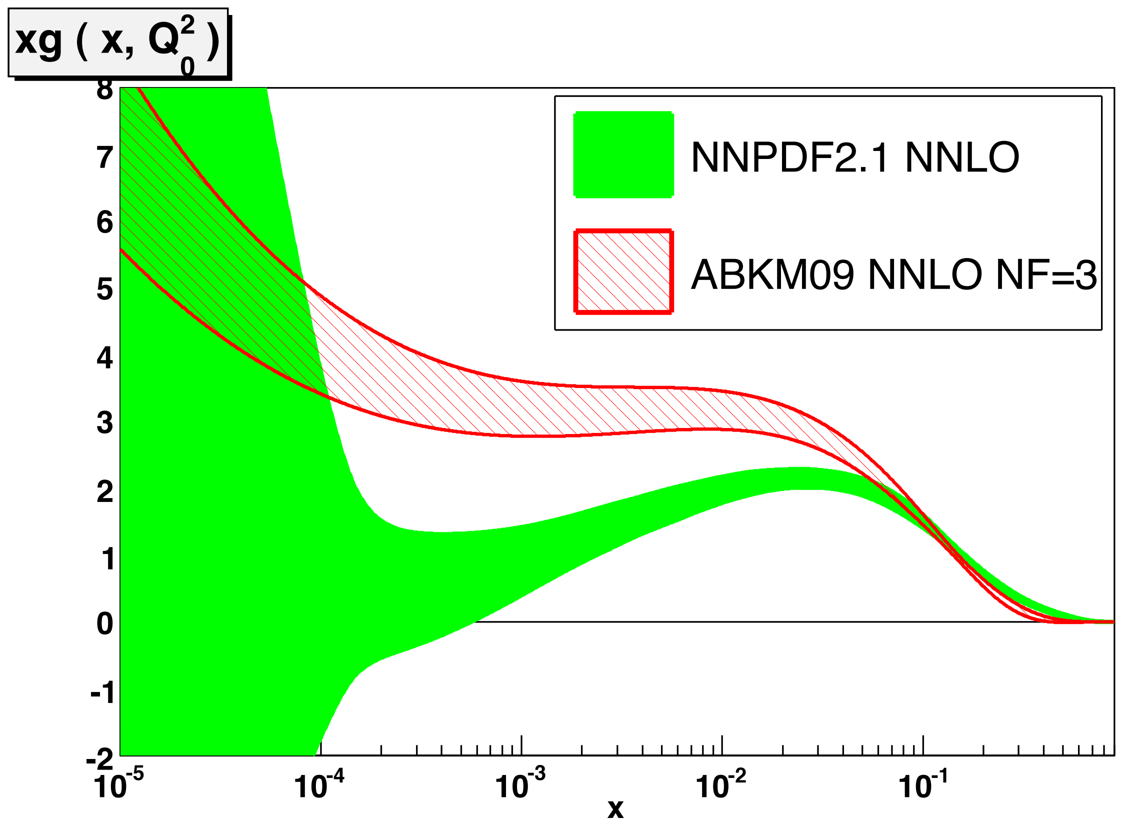
- no change in the parametrization since 1.2

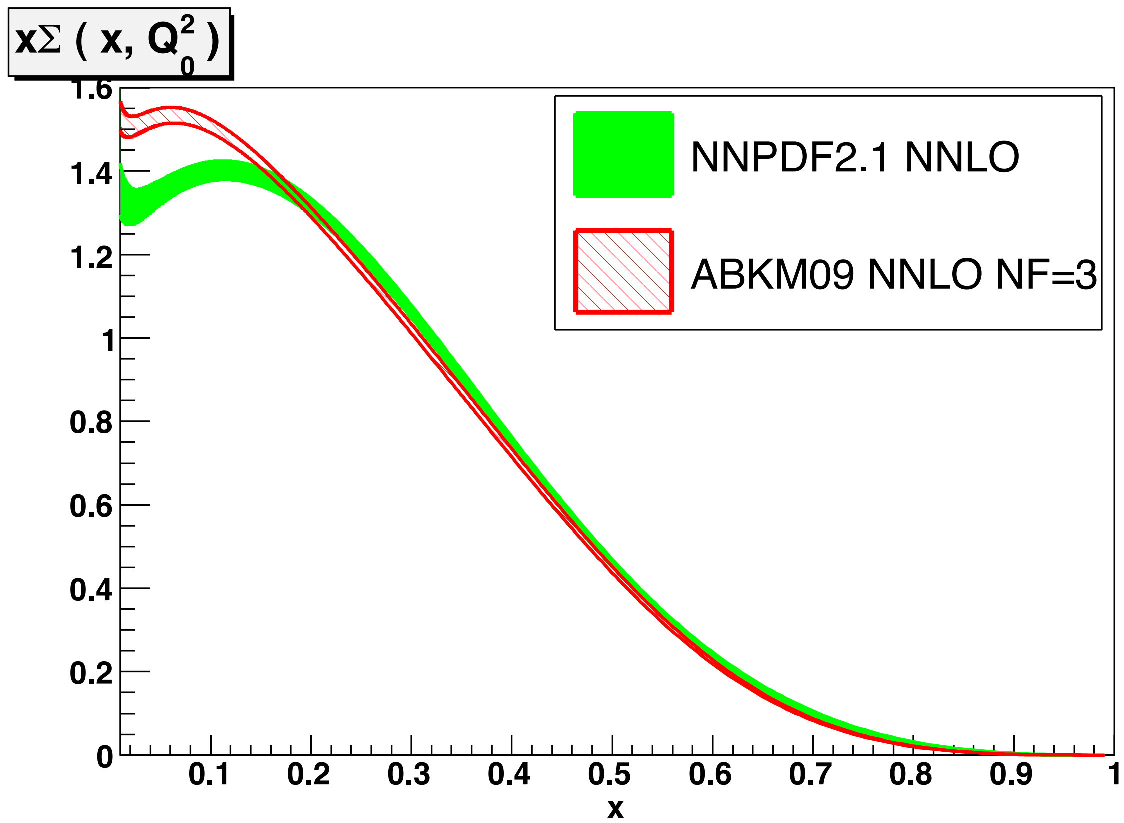
Parton Distributions Combination		**NN architechture**
Singlet $(\Sigma(x))$	$\Longrightarrow$	2-5-3-1 (37 pars)
Gluon $(g(x))$	$\Longrightarrow$	2-5-3-1 (37 pars)
Total valence $(V(x) \equiv u_V(x) + d_V(x))$	$\Longrightarrow$	2-5-3-1 (37 pars)
Non-singlet triplet $(T_3(x))$	$\Longrightarrow$	2-5-3-1 (37 pars)
Sea asymmetry $(\Delta_S(x) \equiv \bar{d}(x) - \bar{u}(x))$	$\Longrightarrow$	2-5-3-1 (37 pars)
Total Strangeness $(s^+(x) \equiv (s(x) + \bar{s}(x))/2)$	$\Longrightarrow$	2-5-3-1 (37 pars)
Strange valence $(s^-(x) \equiv (s(x) - \bar{s}(x))/2)$	$\Longrightarrow$	2-5-3-1 (37 pars)

Total **259** params

Comparison with other NNLO fits

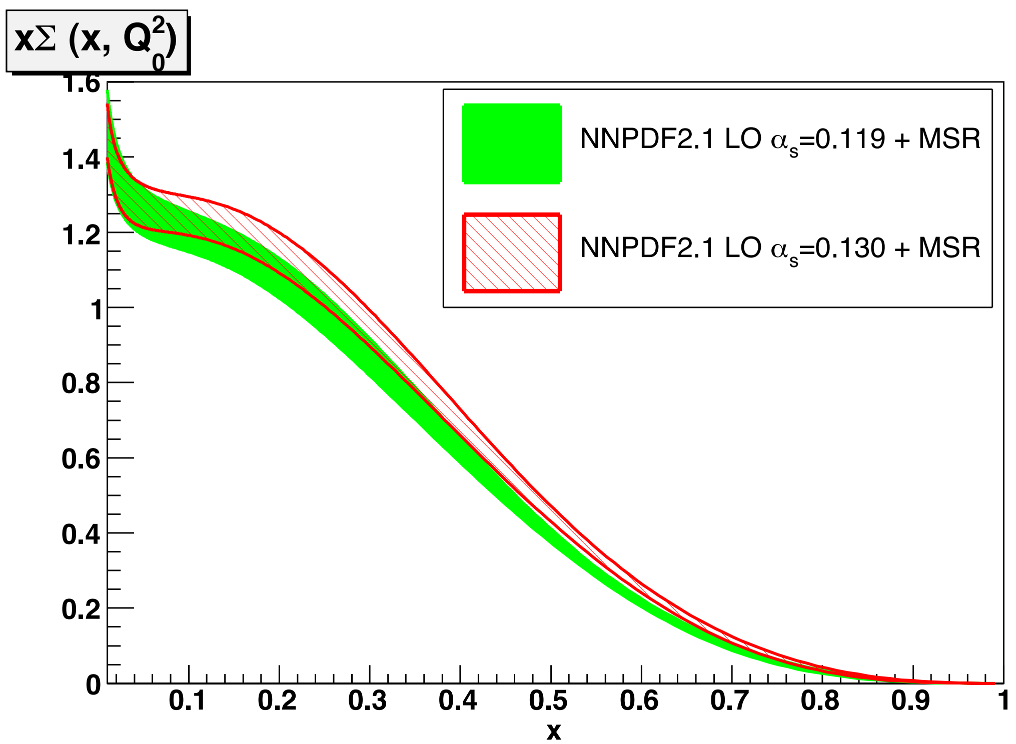
- ABKM09 $n_f = 3, \alpha_s = 0.1135 \pm 0.0014$

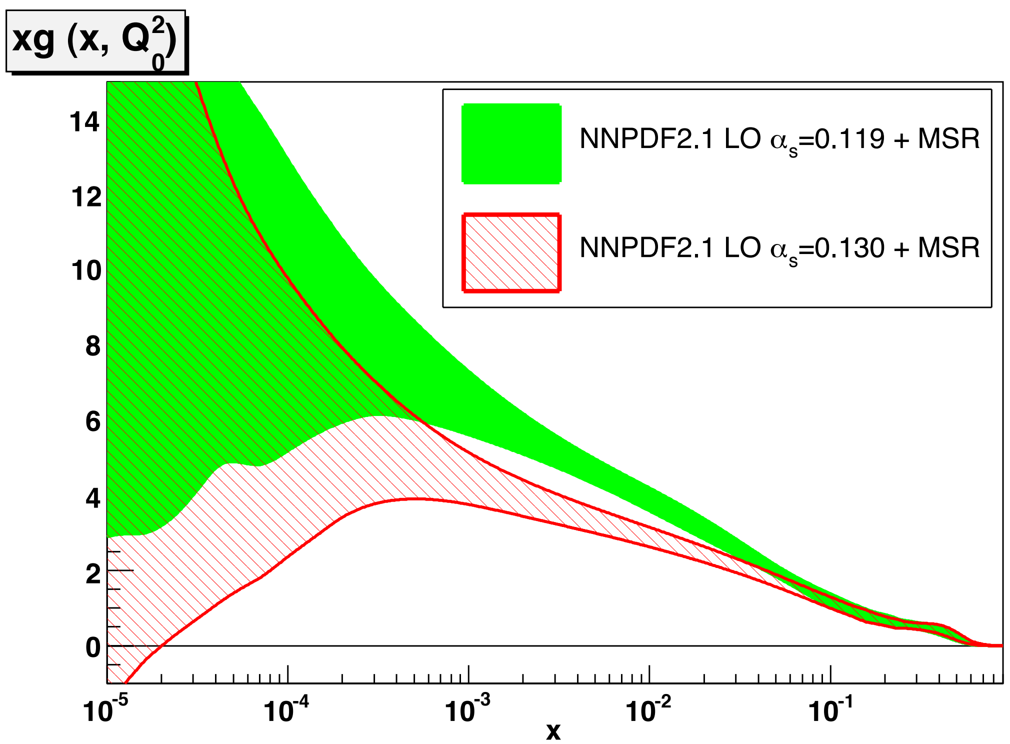




Distance between LO fits

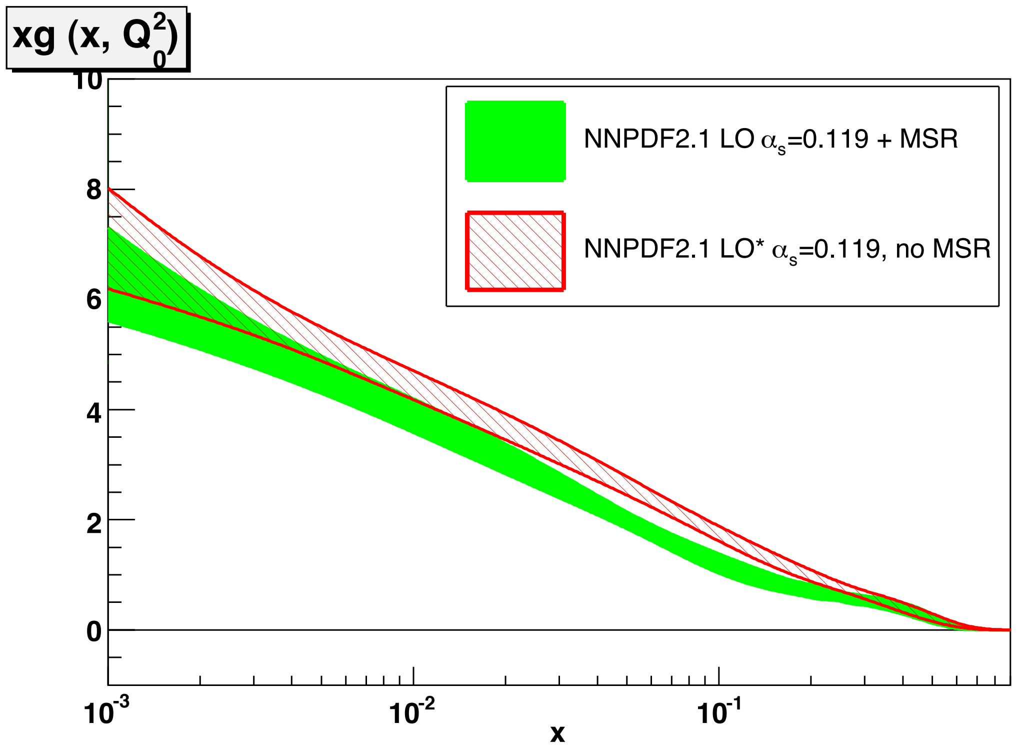
- Different values of α_s

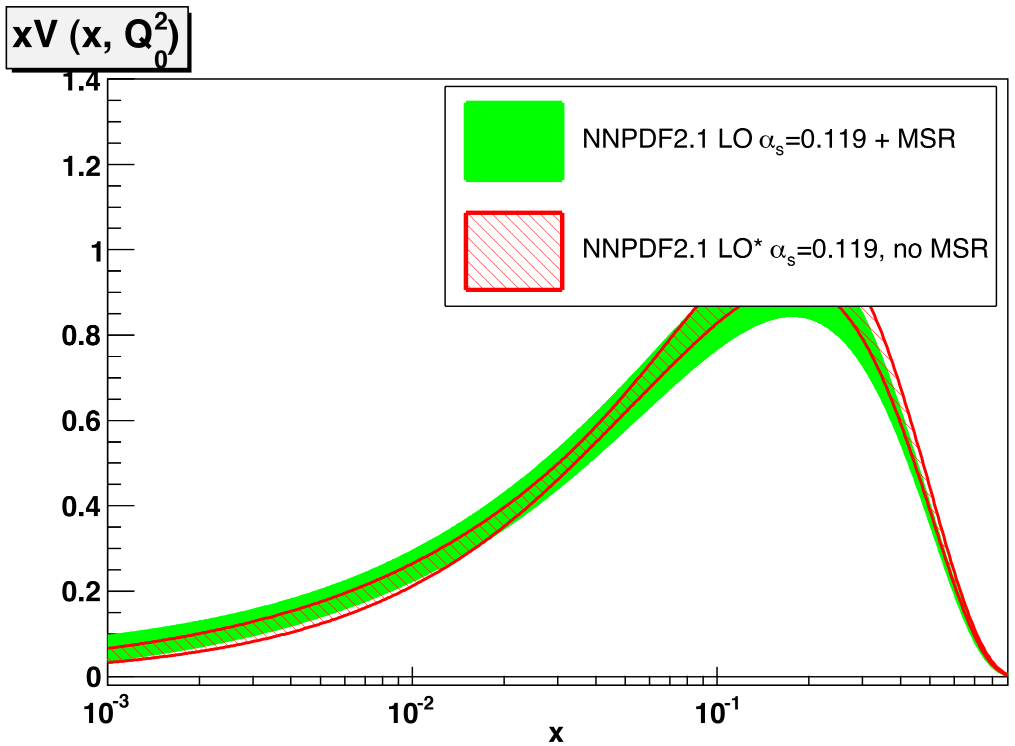




Distance between LO fits

- fits w and w/out momentum sum rule





Parton luminosities

- Definition:

$$\sigma = \sum_{i,j} \int dx_1 dx_2 \, f_i(x_1, \mu^2) f_j(x_2, \mu^2) \, \hat{\sigma}_{ij}$$

$$= \sum_{i,j} \int \frac{d\hat{s}}{\hat{s}} dy \, \frac{dL_{ij}}{d\hat{s} dy} \, \hat{s}\hat{\sigma}_{ij}$$

$$\tau = x_1 x_2 = \hat{s}/s, \quad y = \frac{1}{2} \log(x_1/x_2), \quad \hat{s} = M_X^2$$

$$\frac{dL_{ij}}{d\hat{s}} = \int dy \, \frac{1}{s} f_i(x_1, M_X^2) f_j(x_2, M_X^2)$$

$$= \int_\tau^1 \frac{dx_1}{x_1} \, f_i(x_1, M_X^2) f_j(\frac{\tau}{x_2}, M_X^2)$$

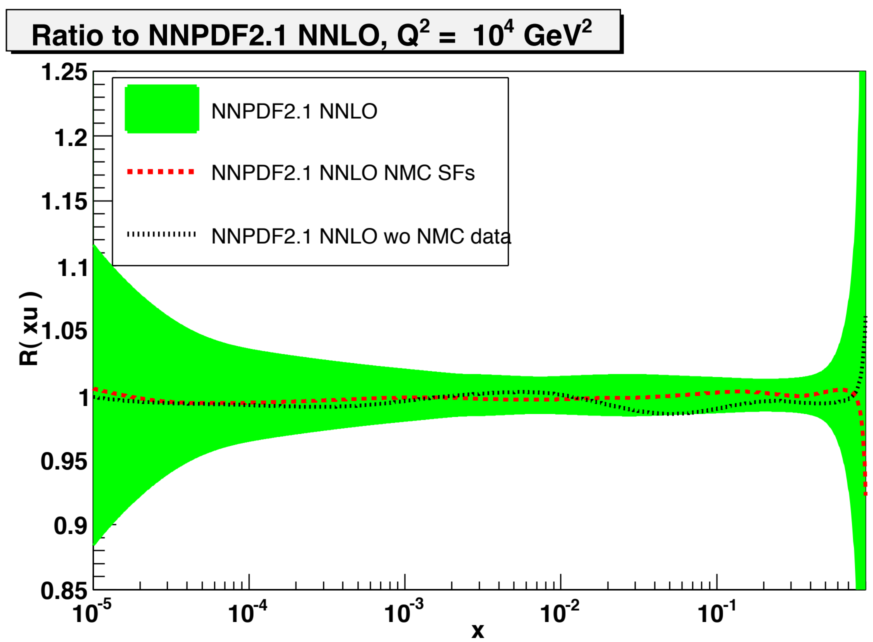
NMC cross section

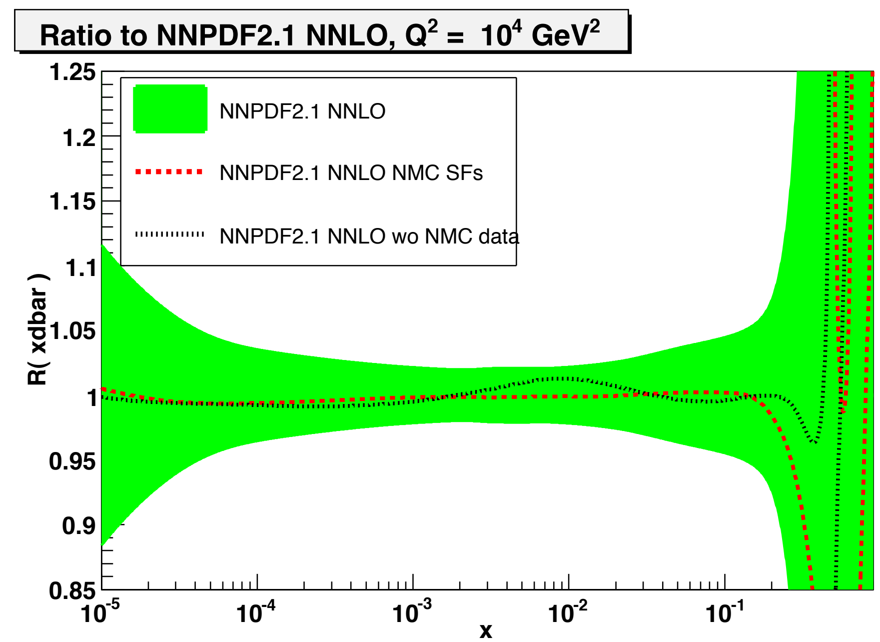
- Statistical features

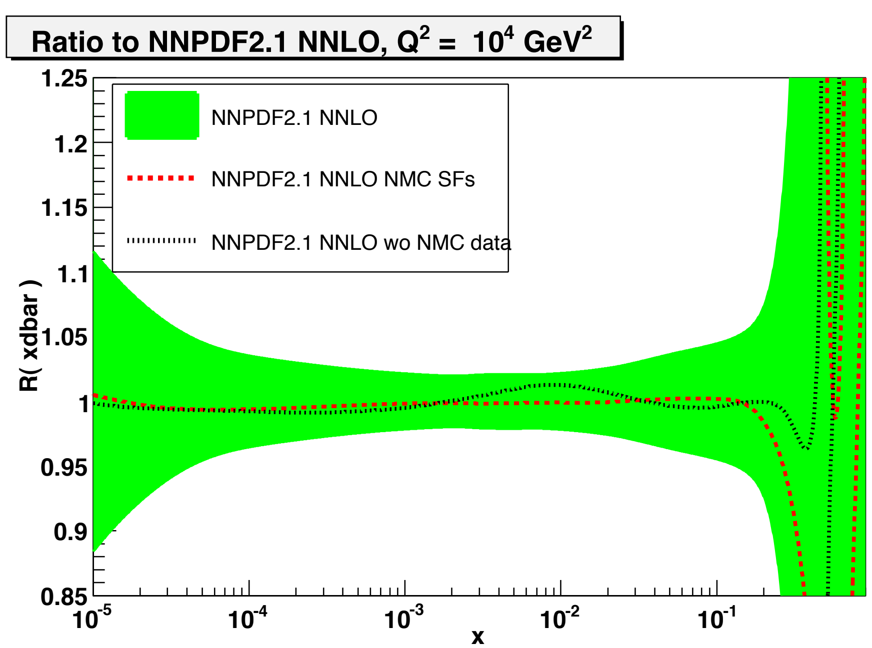
	NNPDF2.1 NLO			NNPDF2.1 NNLO		
	str. fctn.	xsec.	noNMC	str. fctn.	xsec.	noNMC
Total	1.16	1.14	1.09	1.16	1.16	1.12
NMC-pd	0.97	0.98	-	0.93	0.93	-
NMCp	*1.73*	*1.67*	-	*1.69*	*1.63*	-
SLAC	1.27	1.27	1.28	1.05	1.01	1.00
BCDMS	1.24	1.23	1.18	1.29	1.32	1.27
HERAI-AV	1.07	1.05	1.07	1.12	1.10	1.08
CHORUS	1.15	1.11	1.07	1.12	1.12	1.12
FLH108	1.37	1.34	1.38	1.27	1.26	1.29
NTVDMN	0.47	0.51	0.42	0.50	0.49	0.50
ZEUS-H2	1.29	1.23	1.24	1.32	1.31	1.30
ZEUSF2C	0.78	0.74	0.72	0.88	0.88	0.89
H1F2C	1.51	1.48	1.49	1.47	1.56	1.52
DYE605	0.85	0.93	0.88	0.81	0.81	0.81
DYE866	1.27	1.40	1.34	1.31	1.32	1.34
CDFWASY	1.85	1.87	1.60	1.55	1.65	1.41
CDFZRAP	1.62	1.76	1.64	2.16	2.12	2.18
D0ZRAP	0.60	0.57	0.56	0.67	0.67	0.67
CDFR2KT	0.97	0.73	0.81	0.79	0.74	0.80
D0R2CON	0.84	0.90	0.96	0.84	0.82	0.84

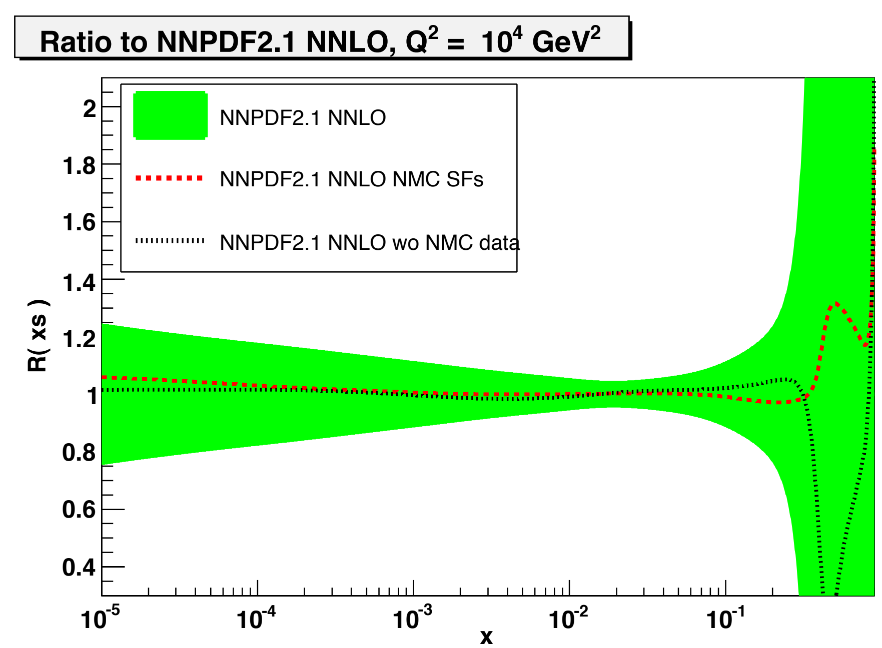
NMC cross section

- PDFs at ew scale









NMC cross section

- Higgs production