Parton Distributions and MC event generators

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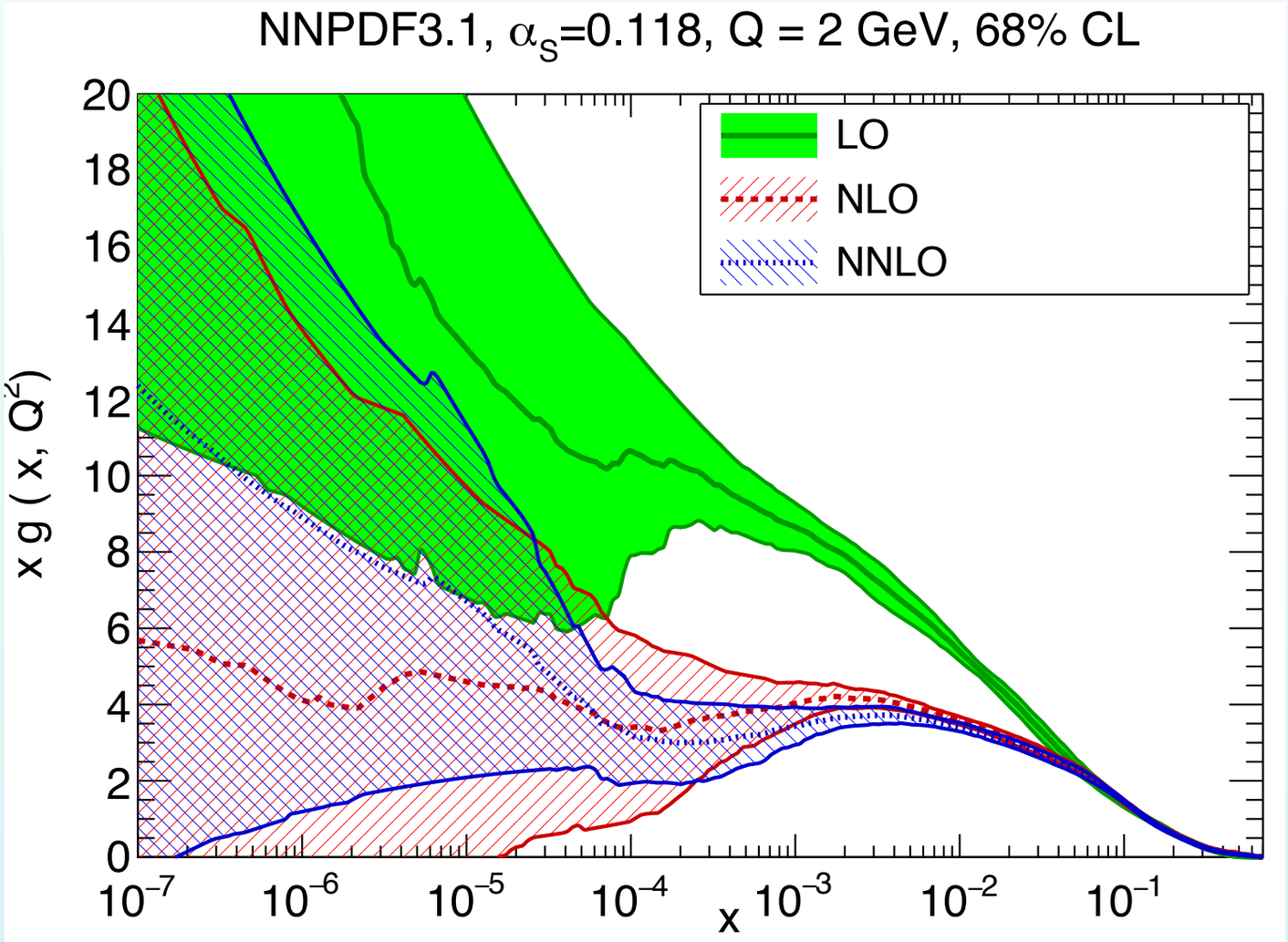
PDFs: perturbative convergence

- **Big differences in PDFs from LO to NLO**, in particular for small-x gluon (relevant for MC tunes)
- The **data/theory agreement** is very poor at LO for most types of processes
- Smaller variations when going from NLO and NNLO, **moderate χ^2 improvement**



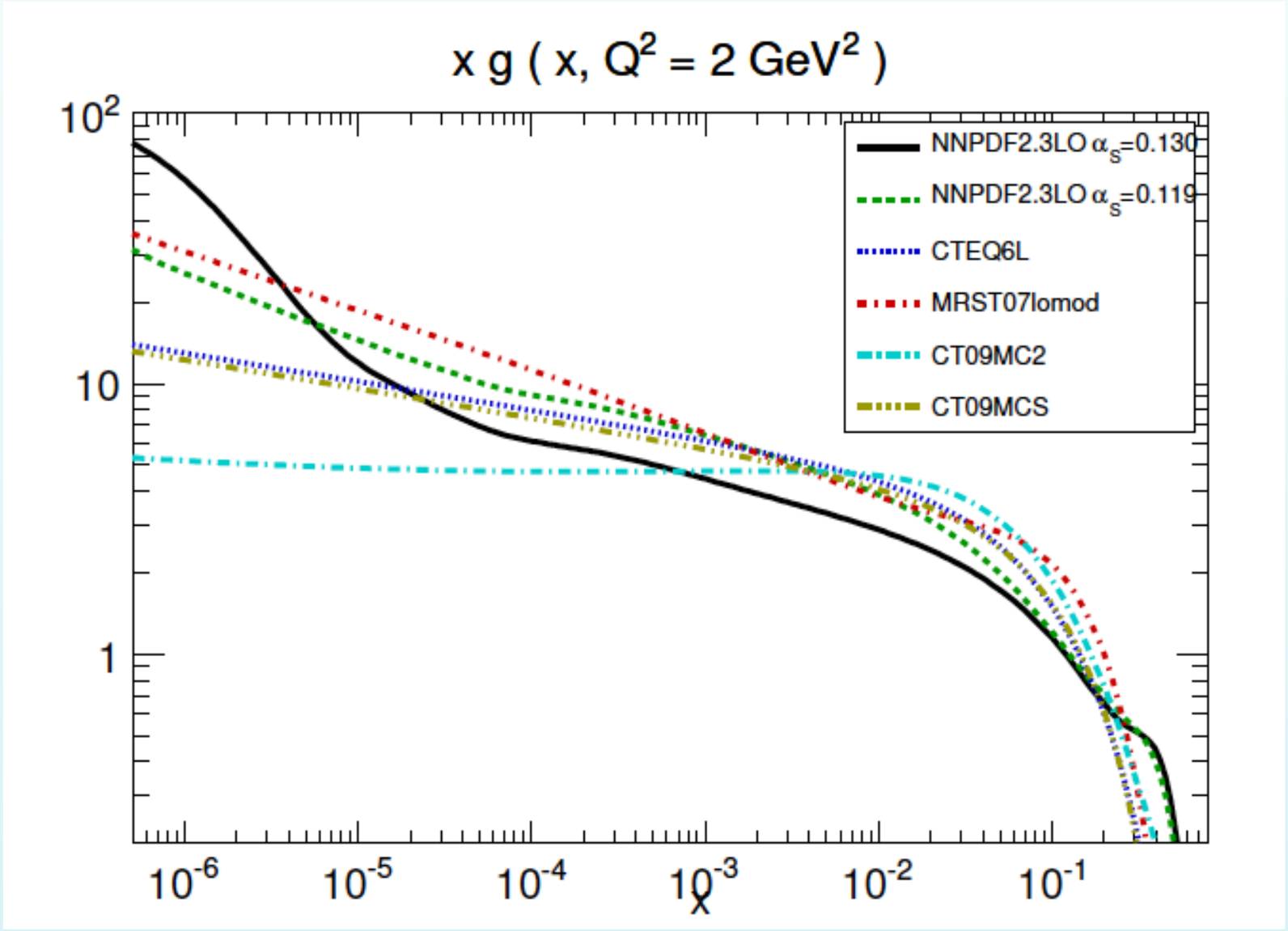
Dataset	NNPDF3.1 NNLO	NLO	LO
NMC	1.30	1.35	3.25
SLAC	0.75	1.17	3.35
BCDMS	1.21	1.17	2.20
CHORUS	1.11	1.06	1.16
NuTeV dimuon	0.82	0.87	4.75
HERA I+II inclusive	1.16	1.14	1.77
HERA $\sigma_c^{\rm NC}$	1.45	1.15	1.21
DY E886 σ^p	1.43	1.05	0.81
DY E605 σ^p	1.21	0.97	0.66
CDF Z rap	1.48	1.619	1.54
CDF Run II k_t jets	0.87	0.84	1.07
D0 Z rap	0.60	0.67	0.65
D0 $W \to e\nu$ asy	2.70	1.59	1.75
D0 $W \to \mu\nu$ asy	1.56	1.52	2.16
ATLAS total	**1.09**	**1.36**	**5.34**
CMS total	**1.06**	**1.20**	**2.13**
LHCb total	**1.47**	**1.62**	**5.16**
Total dataset	**1.148**	**1.168**	**2.238**

LO and LO* PDFs

- LO and LO* PDFs are effected by **large theoretical uncertainties** due to missing higher orders (not accounted for in the standard PDF uncertainties)

- Therefore, the **spread of LO PDFs from different groups** (and even among the same group) exhibits much larger differences than the corresponding NLO and NNLO PDFs

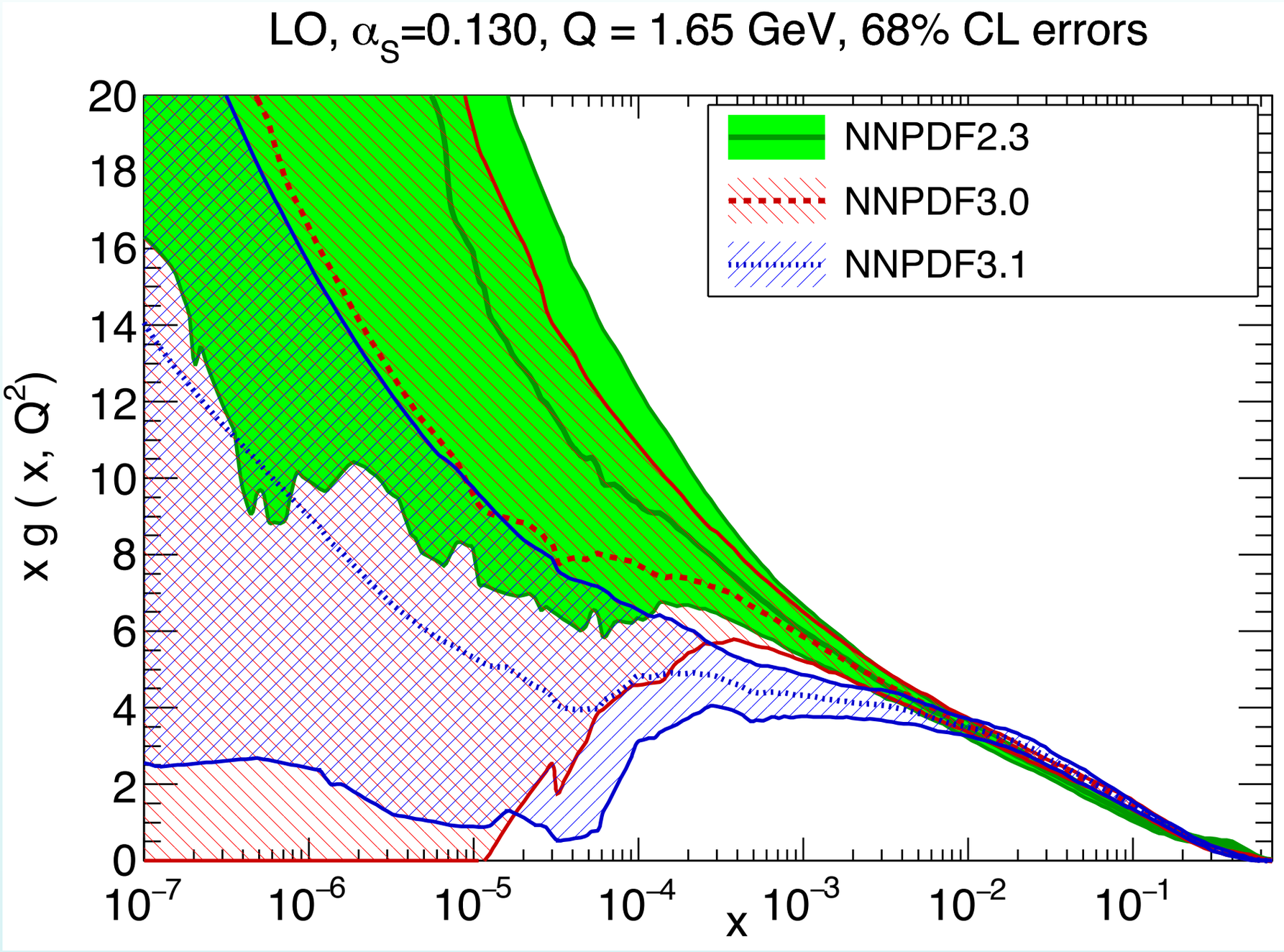
- Effect is specially visible in the **extrapolation regions**, such as small-x, where there is no data



LO NNPDFs

- At LO, PDFs are **positive-definite** since they admit a probabilistic interpretation

- In the NNPDF family, this feature is implemented by construction, using **ANNs with quadratic output**, as well as by enforcing the ***ForcePositive*** **option** in LHAPDF6



PDFs in MC generators

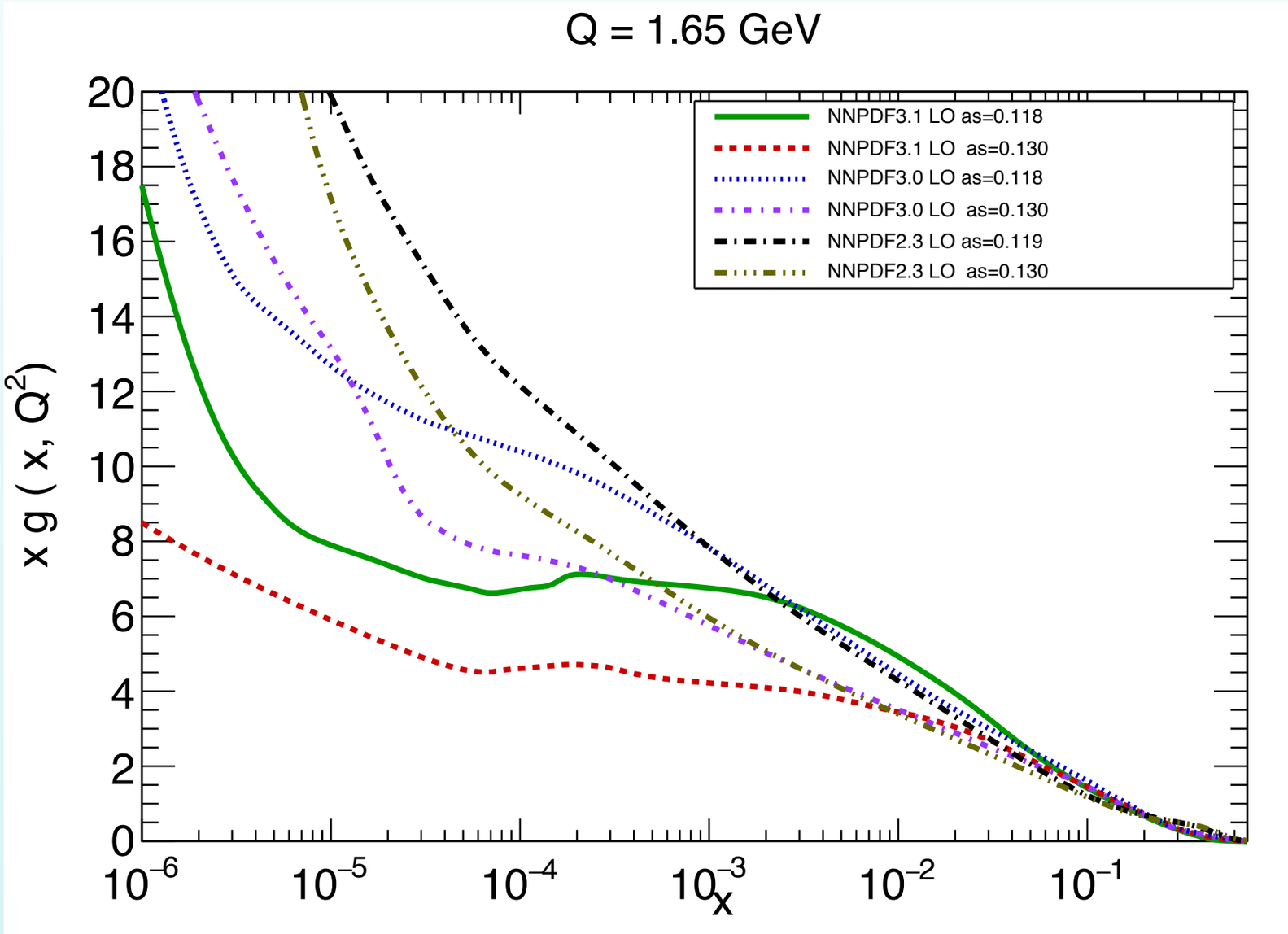
- PDFs enter MC generators in several places, such as
  - ☑ When evaluating the **hard partonic matrix element (ME)**
  - ☑ To compute **Initial State Radiation (ISR)** (backwards evolution from Q to Q_0)
  - ☑ As input to the **Underlying Event** (UE) and **Multiple Parton Interactions** (MPI) models
- Which perturbative order for the PDFs should be used in each case?
- In the case of NLO/NNLO MC event generators, no question that **NLO/NNLO PDFs must be used in the ME**, but less obvious what is optimal for ISR/UE/MPI
- Perhaps the most important rule here is to **always consistently used the same PDF for ISR/UE/MPI as the one used for the corresponding MC tune,** else all the soft and semi-hard QCD physics will not be reproduced correctly
- Different MC generators adopt different strategies:
  - ☑ In-house CMS and ATLAS tunes tend to be based on LO PDFs
  - ☑ **Pythia8** tunes are mostly based on LO PDFs (*i.e.* Monash 2013 is based on NNPDF2.3LO)
  - ☑ **Sherpa2** tunes are based on NNLO PDFs (*i.e.* latest tunes are based on NNPDF3.0NNLO)
  - ☑ **Herwig7** has presented tunes based on NLO PDFs (in particular MMHT2014NLO)

NNPDF LO sets

- Compared to NNPDF2.3LO, the NNPDF3.1 LO gluons are reduced at small-x

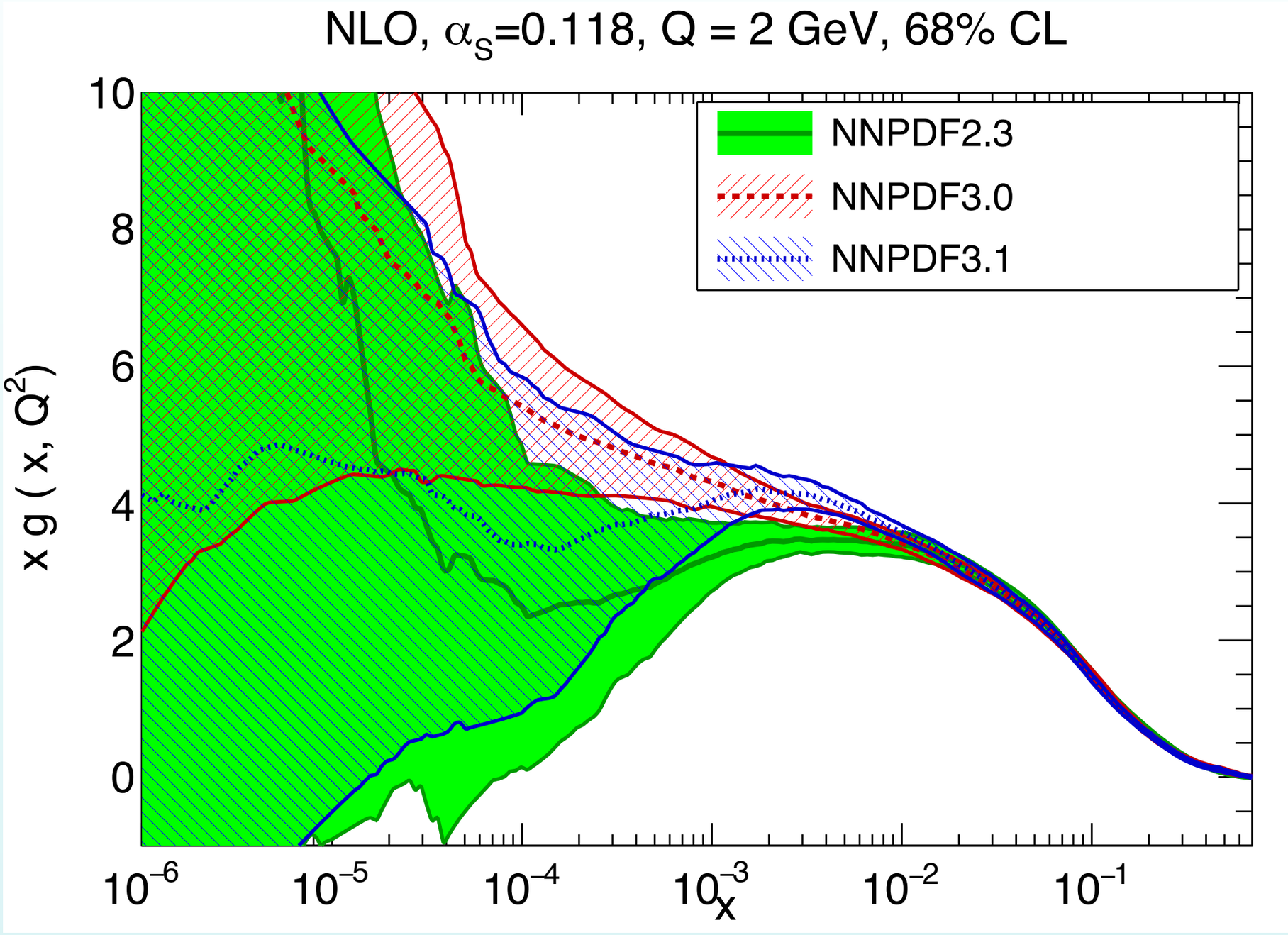
- This could be related to the significant amount of new data in NNPDF3.1 that **constraints the gluon in a wide *x* range**, from Z p_T and inclusive jets to differential top quark distributions

- Consequently, **new MC tunes** based on NNPDF3.1 LO need to be performed



NNPDF LO sets

- As expected, **perturbative convergence** of the NNPDF sets is much more stable at (N)NLO



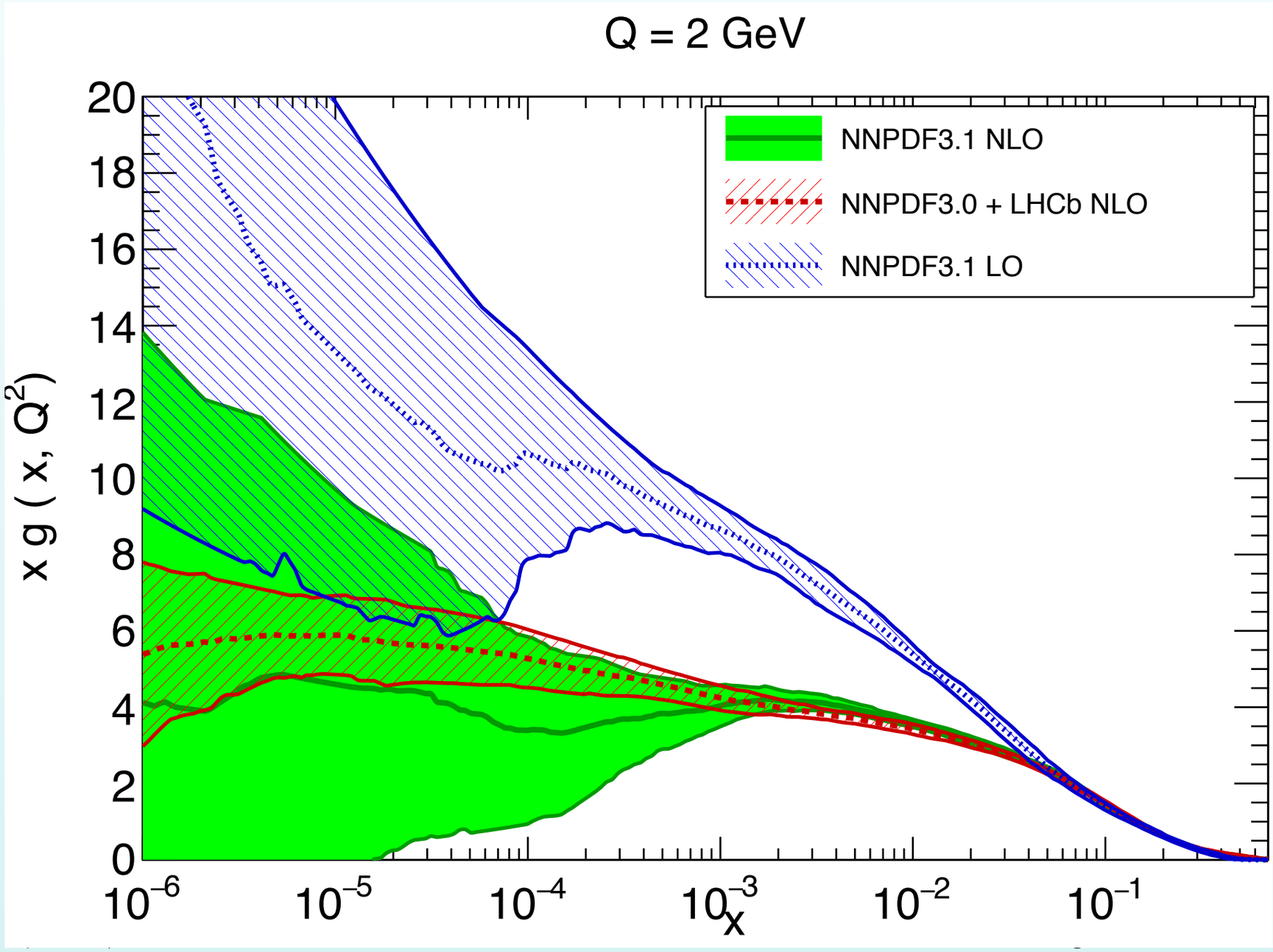
- **Tunes based on (N)NLO PDFs** should then be easier to update once new PDF sets are produced

Pinning down the small-x gluon

- PDF uncertainties at small-x are affected by large errors due to limited exp constraints

- Recently it has been shown how the constraints from **LHCb charm data (5+7+13 TeV)** allow to pin down the gluon with reasonably accuracy **down to $x=10^{-6}$**

- A **flat gluon at NLO and small-x** is suggested by LHCb data, consistent with the NNPDF3.1 results (which do not include the LHCb charm measurements). Can we use this info in MC tunes?



Some ideas (instead of a conclusion)

- In MC event generators, the perturbative order of the PDFs that enters the evaluation of the hard ME should always match the one in the ME. The higher the perturbative order, the smaller the residual theoretical uncertainties

- For the evaluation of ISR/UE/MPI, different options are possible, sometimes to be decided from practical reasons, *i.e.* which PDF set / perturbative order leads to better description of soft and semi-hard QCD data within a given tune

- Using different PDF sets and orders for the ME and ISR/UE/MPI evaluations is certainly consistent, since in the latter case the PDF needs to be understood as an essential ingredient of the MC tune. This option is available in most MC generators.

- Several other options towards improved PDFs for MC generators can (and should) be explored, aiming towards an improved description of soft QCD processes at the LHC Run II