Forward heavy quark production

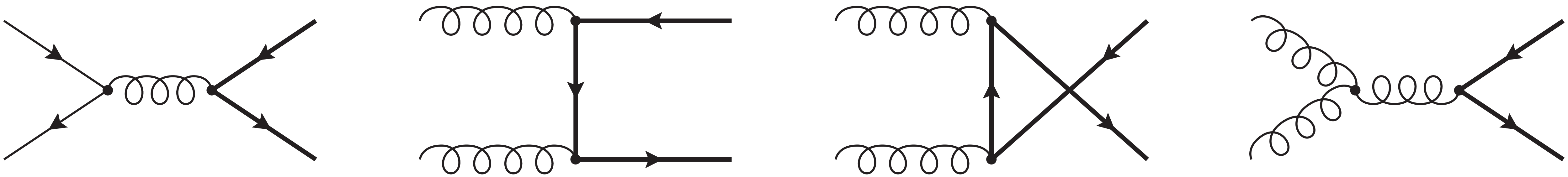
Rhorry Gauld

HF workshop - Durham Sept 2017

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

MC@NNLO

Heavy quark-pair production



$$g(p_1) + g(p_2) \to Q(p_3) + \bar{Q}(p_4) + X$$

dominant subprocess at LHC

x_i : momentum fraction

y_j : rapidity

$\sqrt{S}$: hadronic COM

m_T : transverse mass

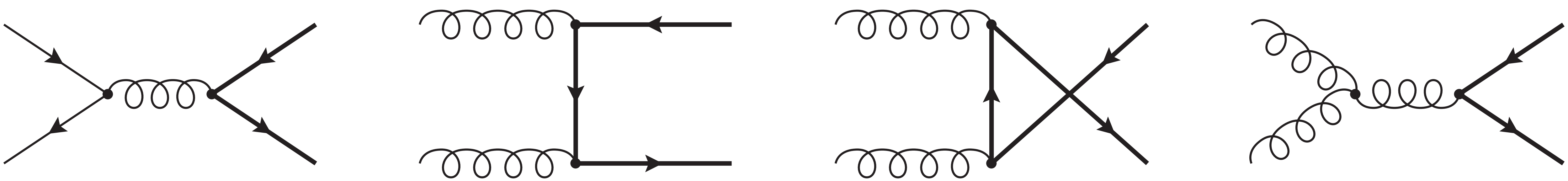
LO PDF sampling occurs at

$$x_{1,(2)} = \frac{m_T}{\sqrt{S}} \left(e^{(-)y_3} + e^{(-)y_4} \right)$$

LHCb detector provides unique information

1. Can reconstruct D/B hadrons from $p_T > 0$ $(m_T \sim m_Q)$
2. Forward LHCb acceptance extends kinematic sensitivity

Heavy quark-pair production



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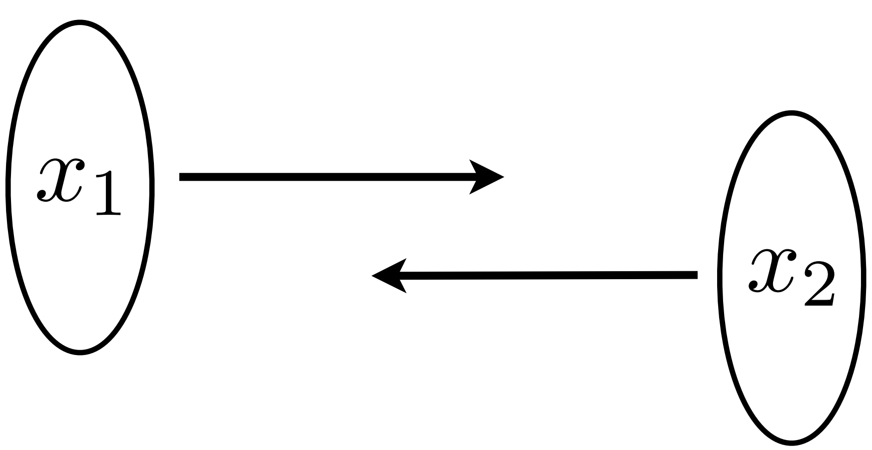

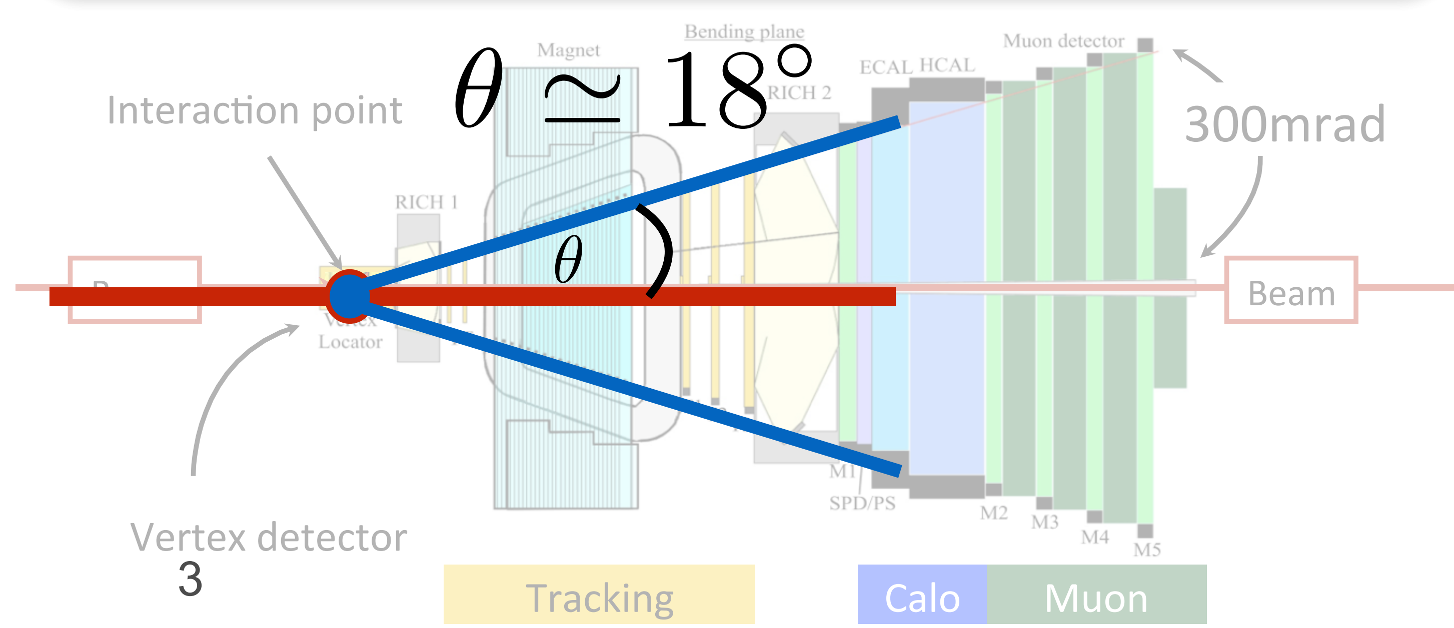

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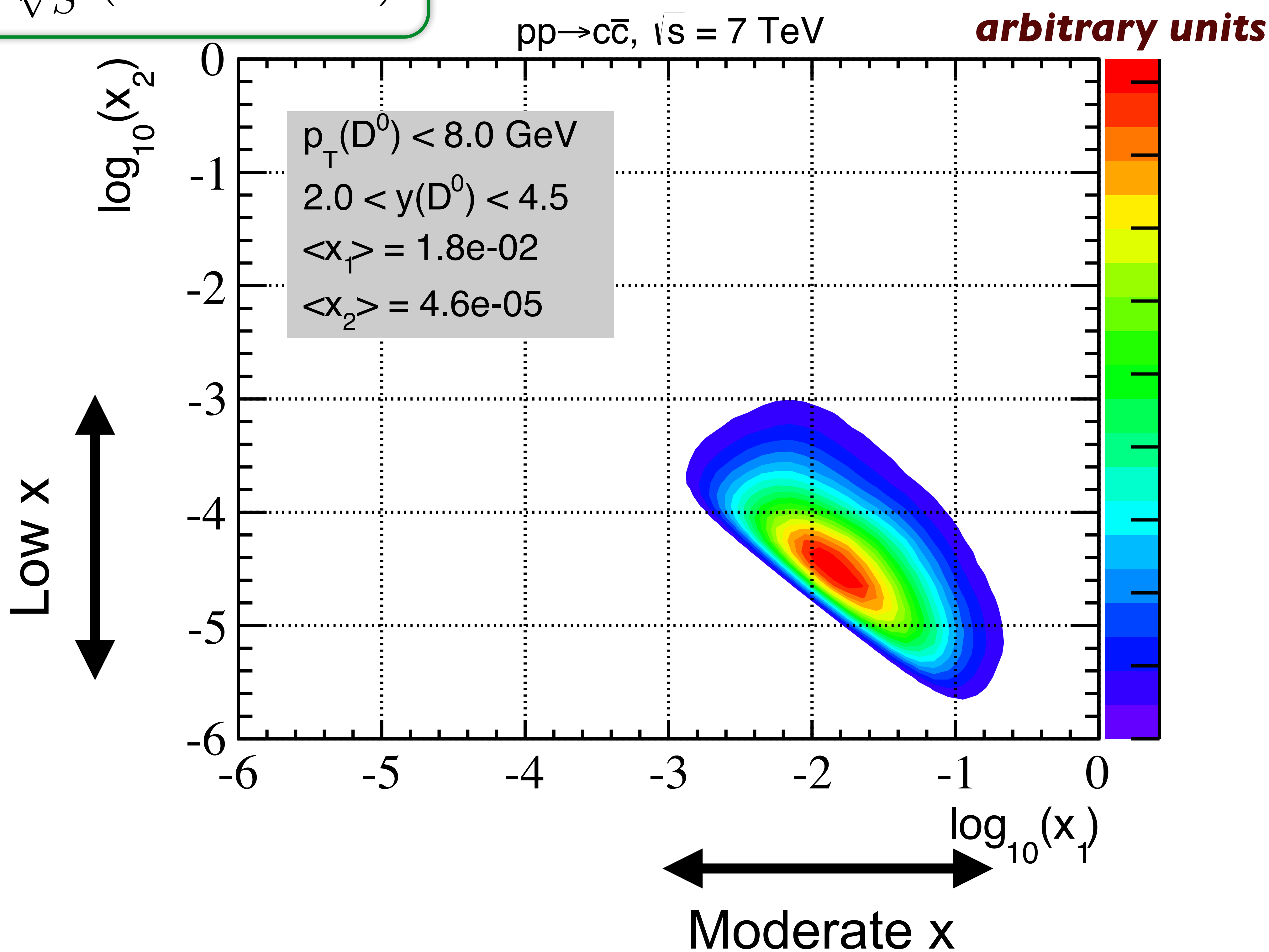
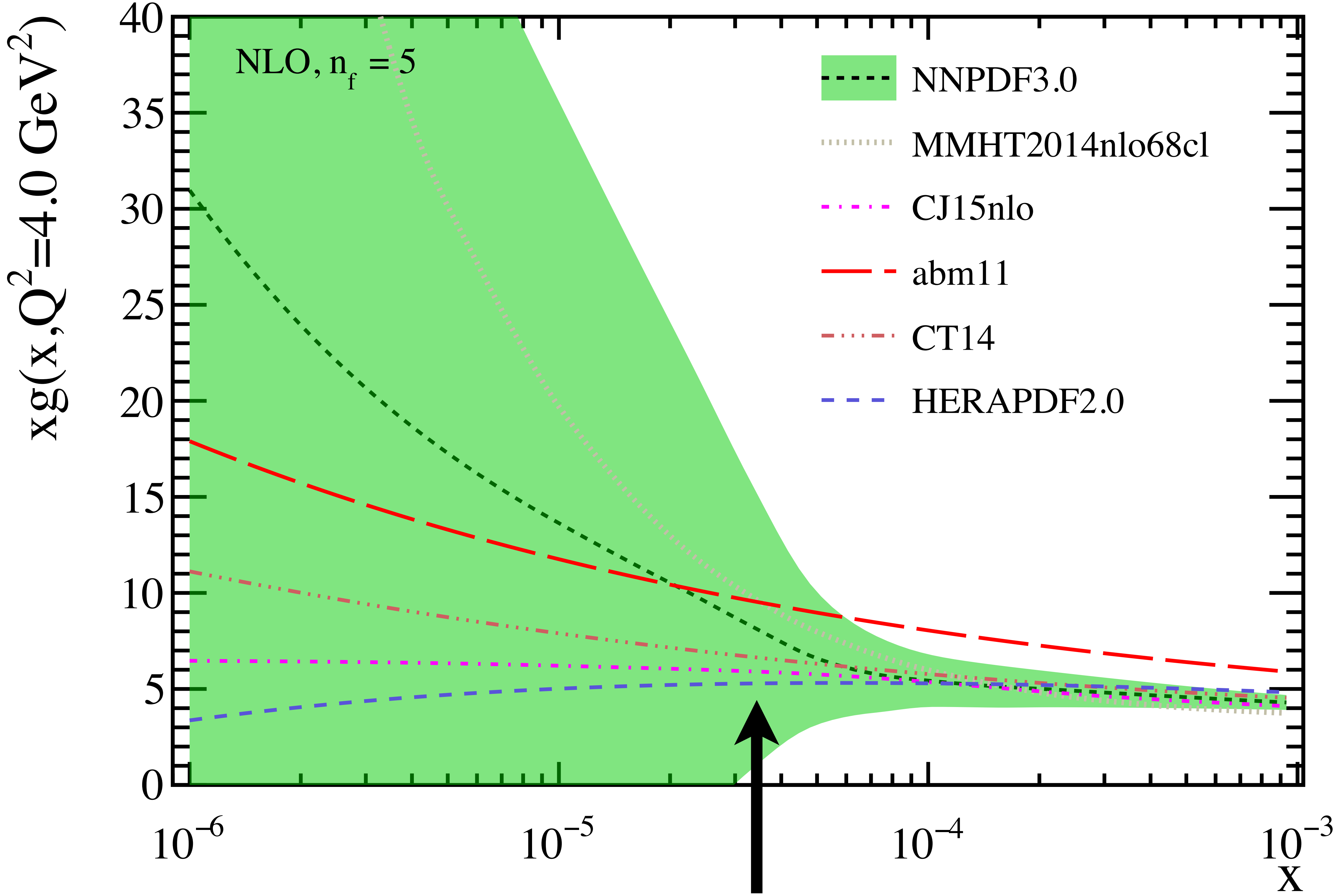


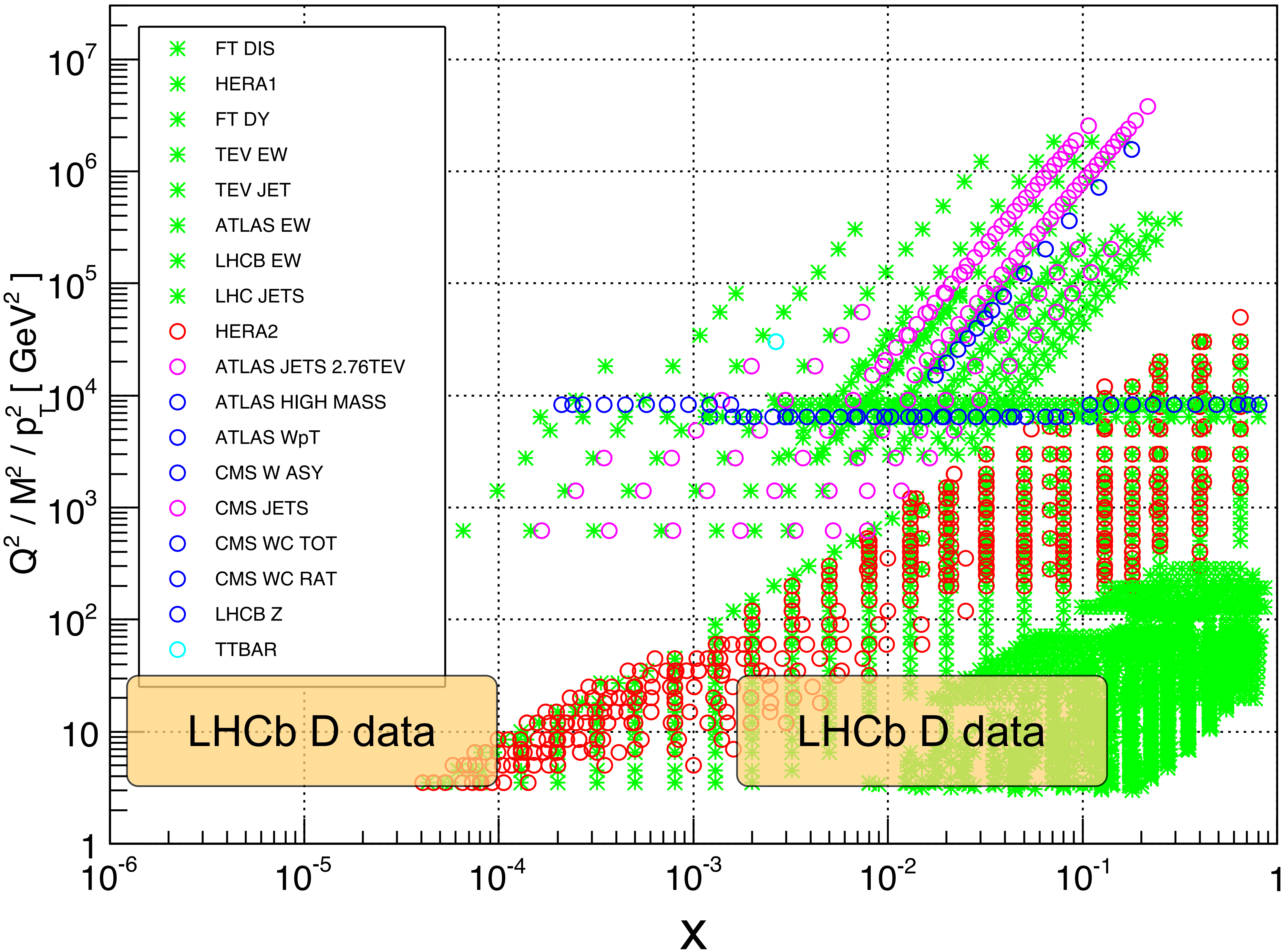
Require a D hadron within LHCb acceptance at 7 TeV



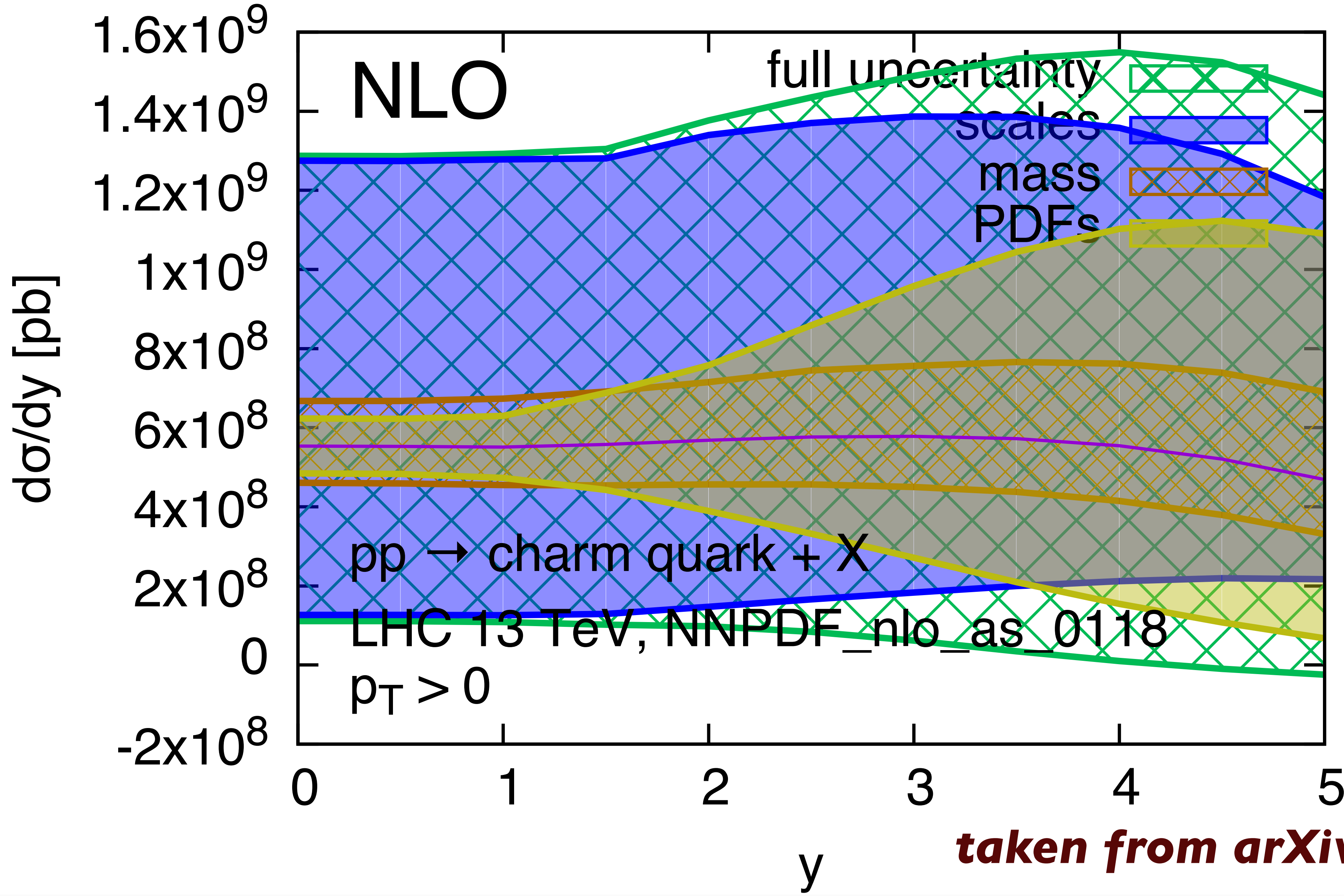
$x \geq 3 \cdot 10^{-5}$ PDF constraints from HERA charm data

$x \leq 3 \cdot 10^{-5}$ Shape/uncertainty determined by parameterisation of non-pert. gluon PDF

NNPDF3.0 NLO dataset



Kinematic coverage of Global Fit



taken from arXiv 1507.06197

$$\hat{\sigma}_{ij}(\beta, m, \mu_F) = \frac{\alpha_s^2(\mu_R)}{m_Q^2}\left(\sigma_{ij}^{(0)} + \alpha_s(\mu_R)\left[\sigma_{ij}^{(1)} + \overline{\sigma}_{ij}^{(1)}(\mu_F, \mu_R)\right] + ...\right)$$

Scale uncertainties at low energy scales overwhelming

$$\mu \sim \sqrt{m_Q^2 + p_{T,Q}^2} \sim 2.2\,\mathrm{GeV} \qquad \alpha_s(2.2\,\mathrm{GeV}) \sim 0.3$$

Measurements performed double differentially in p_T^D and y_D

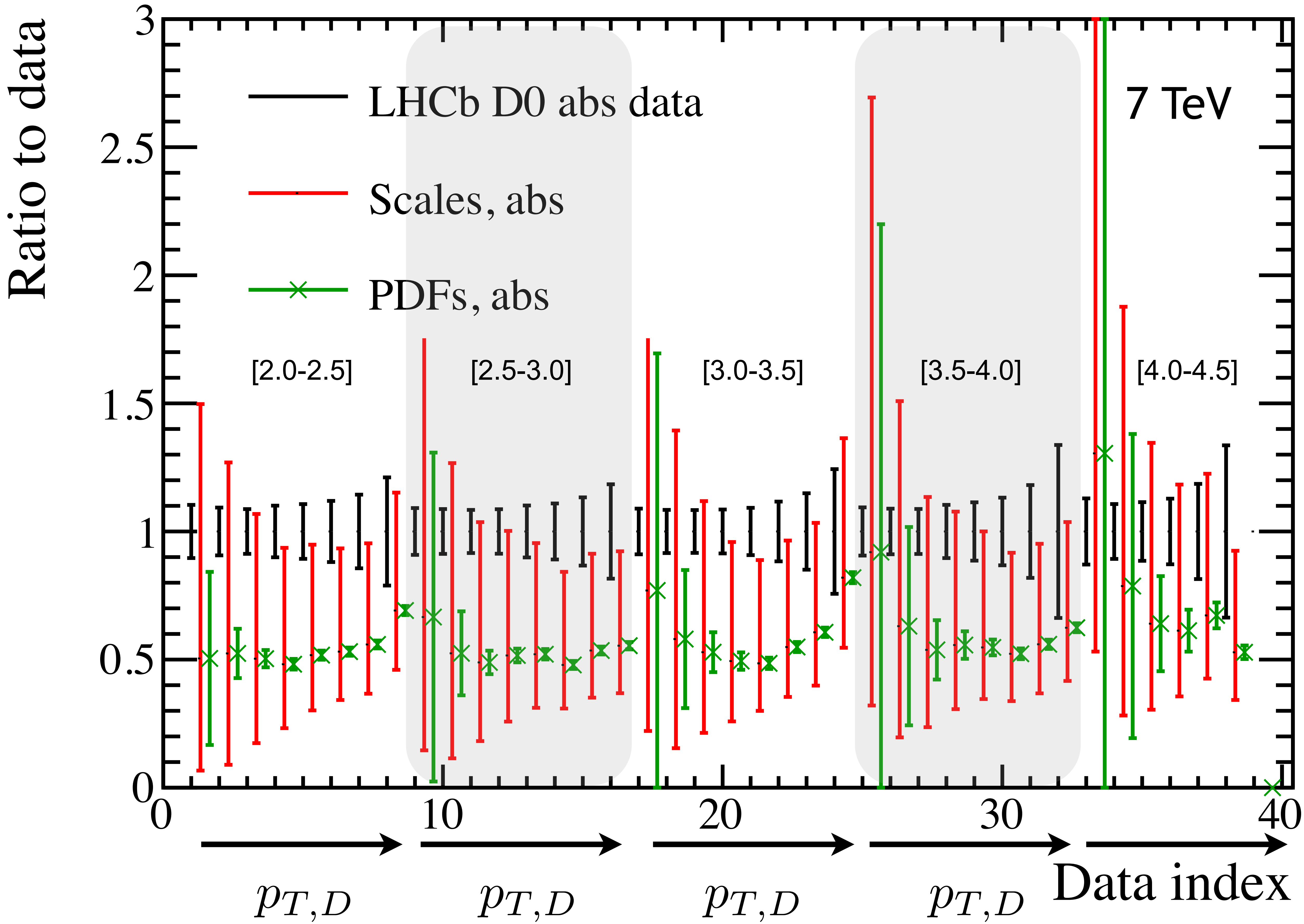
$$N_X^{ij} = \frac{d^2\sigma(\mathrm{X\ TeV})}{dy_i^D d(p_T^D)_j} \bigg/ \frac{d^2\sigma(\mathrm{X\ TeV})}{dy_{\mathrm{ref}}^D d(p_T^D)_j}$$

Measurements performed at multiple hadronic CoM values

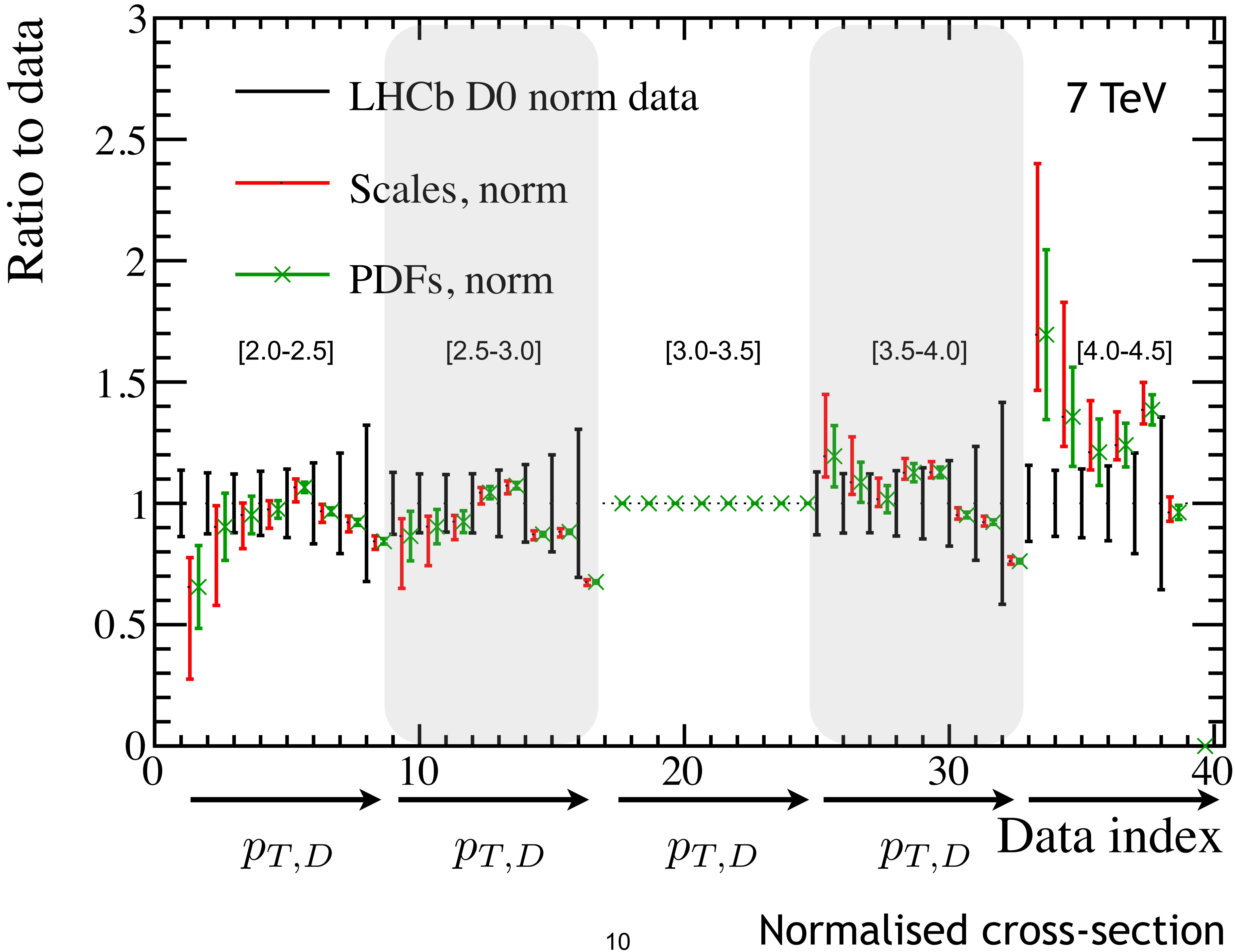
$$R_{13/X}^{ij} = \frac{d^2\sigma(13\ \mathrm{TeV})}{dy_i^D d(p_T^D)_j} \bigg/ \frac{d^2\sigma(\mathrm{X\ TeV})}{dy_{\mathrm{i}}^D d(p_T^D)_j}$$

pros: theoretical (and experimental) uncertainties highly correlated

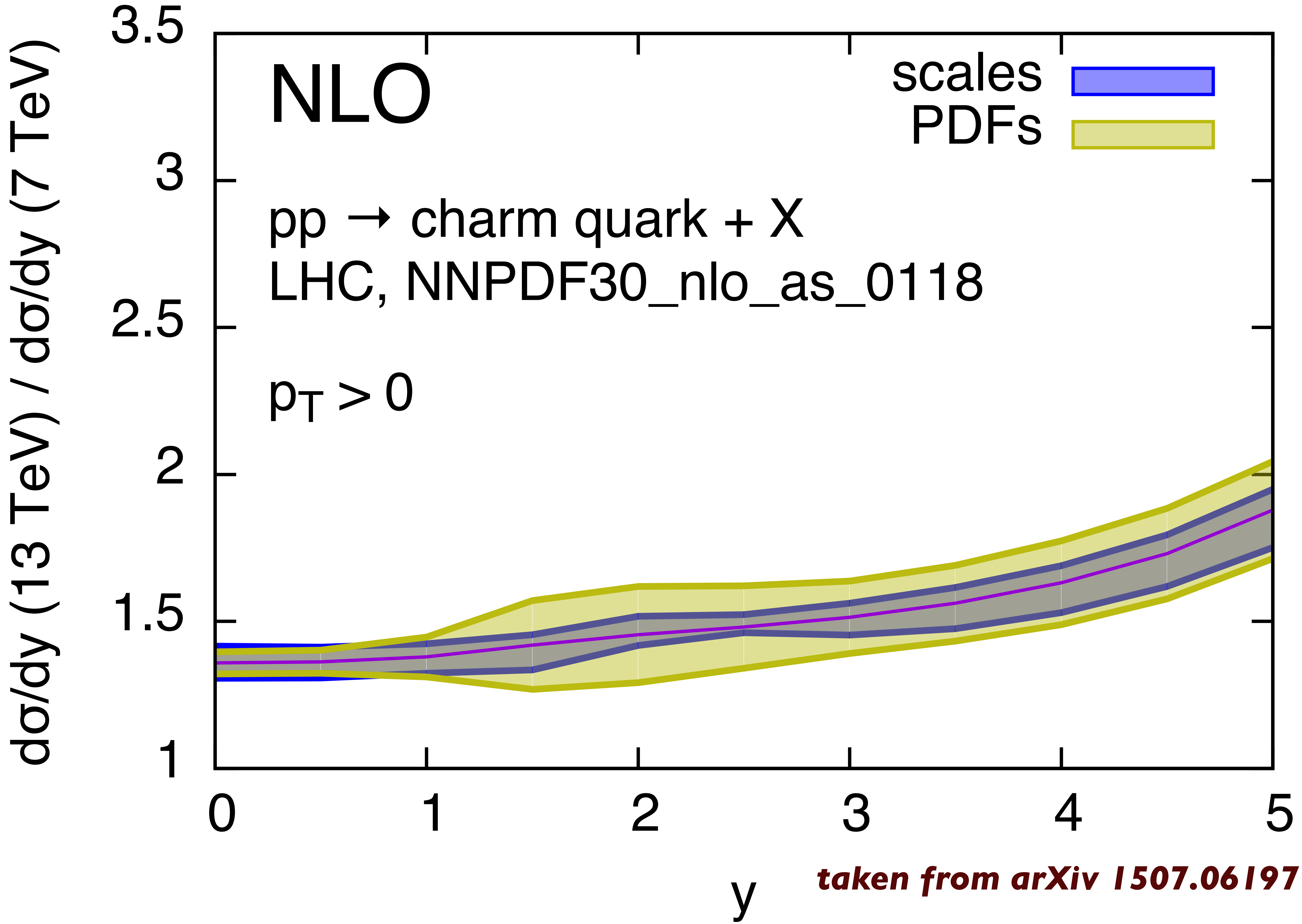
cons: PDF uncertainties **<u>also</u>** correlated (lose sensitivity to PDFs)



Absolute cross-section



Ratio to data
LHCb D0 norm data
Scales, norm
PDFs, norm
7 TeV
[2.0-2.5]
[2.5-3.0]
[3.0-3.5]
[3.5-4.0]
[4.0-4.5]
0
0.5
1
1.5
2
2.5
3
10
20
30
40
$p_{T,D}$
$p_{T,D}$
$p_{T,D}$
$p_{T,D}$
Data index
Normalised cross-section



taken from arXiv 1507.06197

Ratio of cross-sections

Summary of LHCb data

Prompt charm production at 13 TeV (and 13/7 ratio), arXiv:1510.01707
Erratum: September 2016
Erratum: May 2017

Prompt charm production at 5 TeV (and 13/5 ratio), arXiv:1610.02230
Erratum: May 2017

Prompt charm production at 7 TeV, arXiv:1302.2864

Prompt B production at 13 TeV (and 13/7 ratio), arXiv:1612.05150
Erratum: September 2017

Prompt B production at 7 TeV, arXiv:1306.3663

Summary of PDF analyses

NLO analysis, HERA + LHCb B/D 7 TeV data, arXiv:1503.04581
Prosa Collaboration

NNPDF3.0 NLO Global fit + LHCb D 7 TeV data, arXiv:1506.08025
RG, Rojo, Rottoli, Talbert

NNPDF3.0 NLO Global fit + LHCb D 13, 7, 5 TeV data, arXiv:1610.09373
RG, Rojo (updated May 2017)

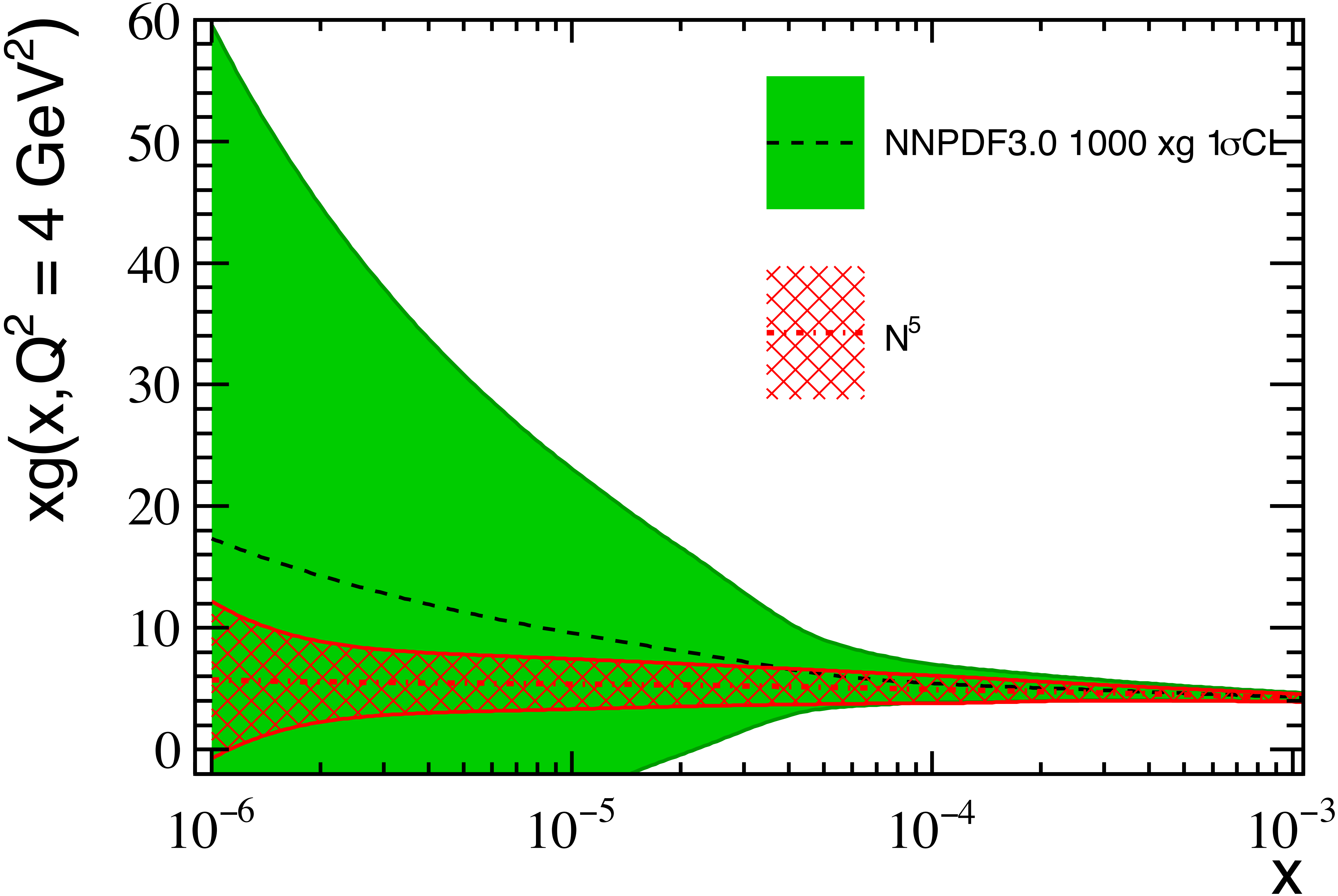
The LHCb B and D hadron data is wrong paper, arXiv:1703.03636
RG

Analyses of absolute D cross section data, arXiv:1705.08845
Martin, Oliviera, Ryskin

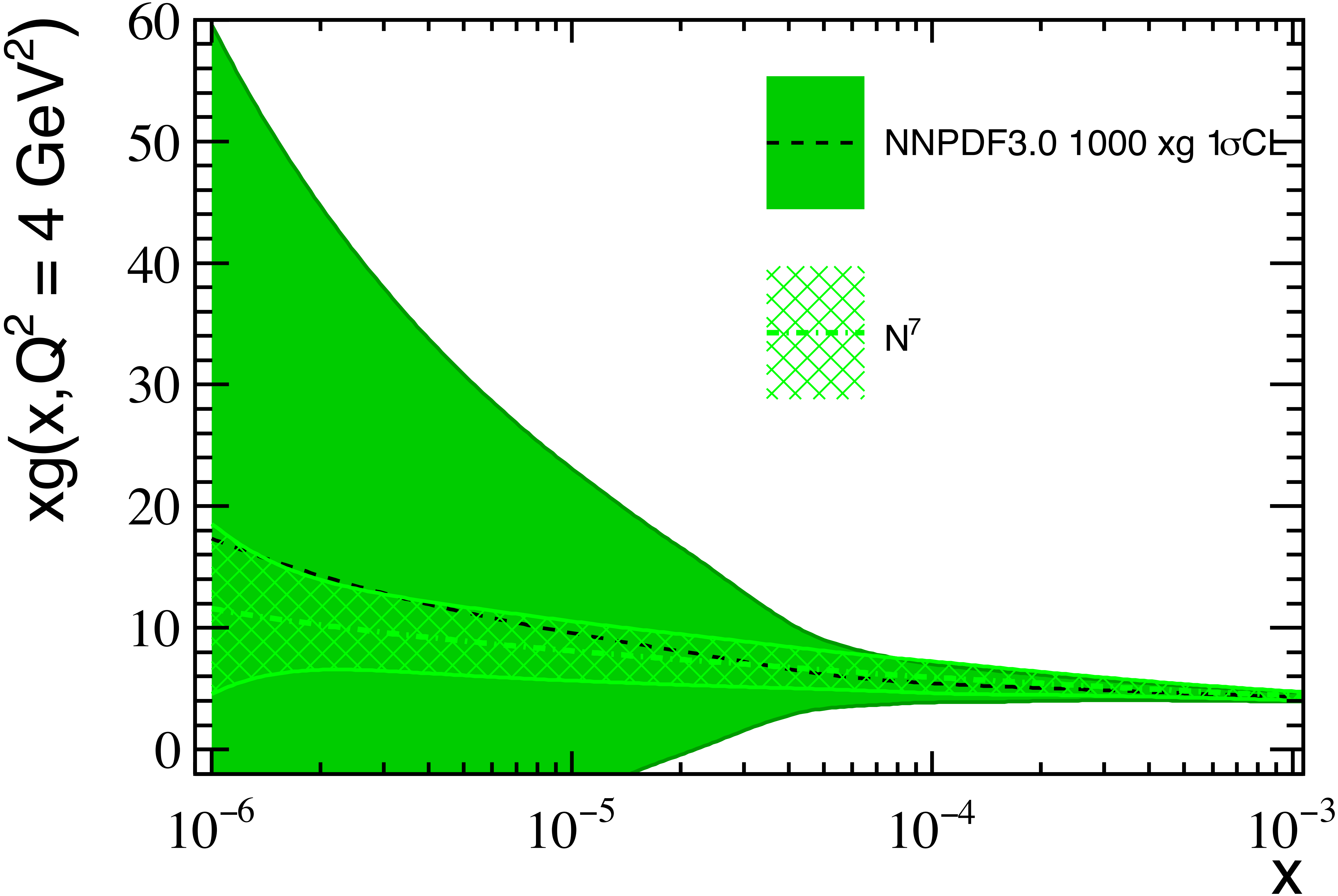
$N_5(84)$	$N_7(79)$	$N_{13}(126)$	$R_{13/5}(107)$	$R_{13/7}(102)$
1.97	1.21	2.36	1.36	0.80
0.86	0.72	1.14	1.35	0.81
1.31	**0.91**	1.58	1.36	0.82
0.74	0.66	**1.01**	1.38	0.80
1.08	0.81	1.27	**1.29**	0.80
1.53	0.99	1.73	1.30	**0.81**
1.07	0.81	1.34	1.35	**0.81**
0.82	**0.70**	1.07	**1.35**	0.81
0.84	**0.71**	**1.10**	1.36	0.81

TABLE I: The $\chi^2/N_{\rm dat}$ for the LHCb D meson measurements considered, N_5, N_7, N_{13}, $R_{13/7}$ and $R_{13/5}$, for various combinations of input to the PDF fit (highlighted in boldface).

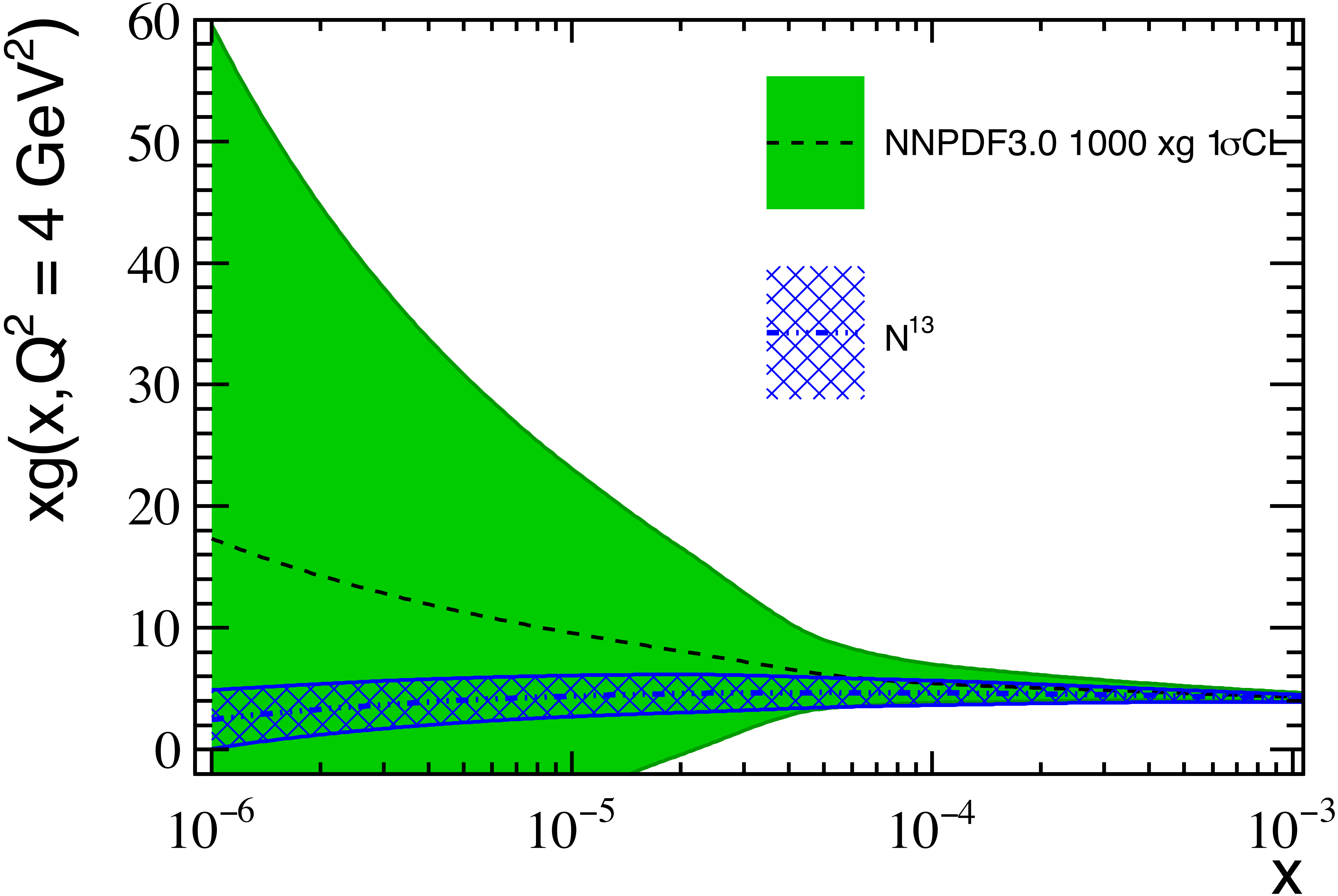
$2.0 < y_D < 4.5$ $\qquad$ $p_{T,D} < 8\,\mathrm{GeV}$

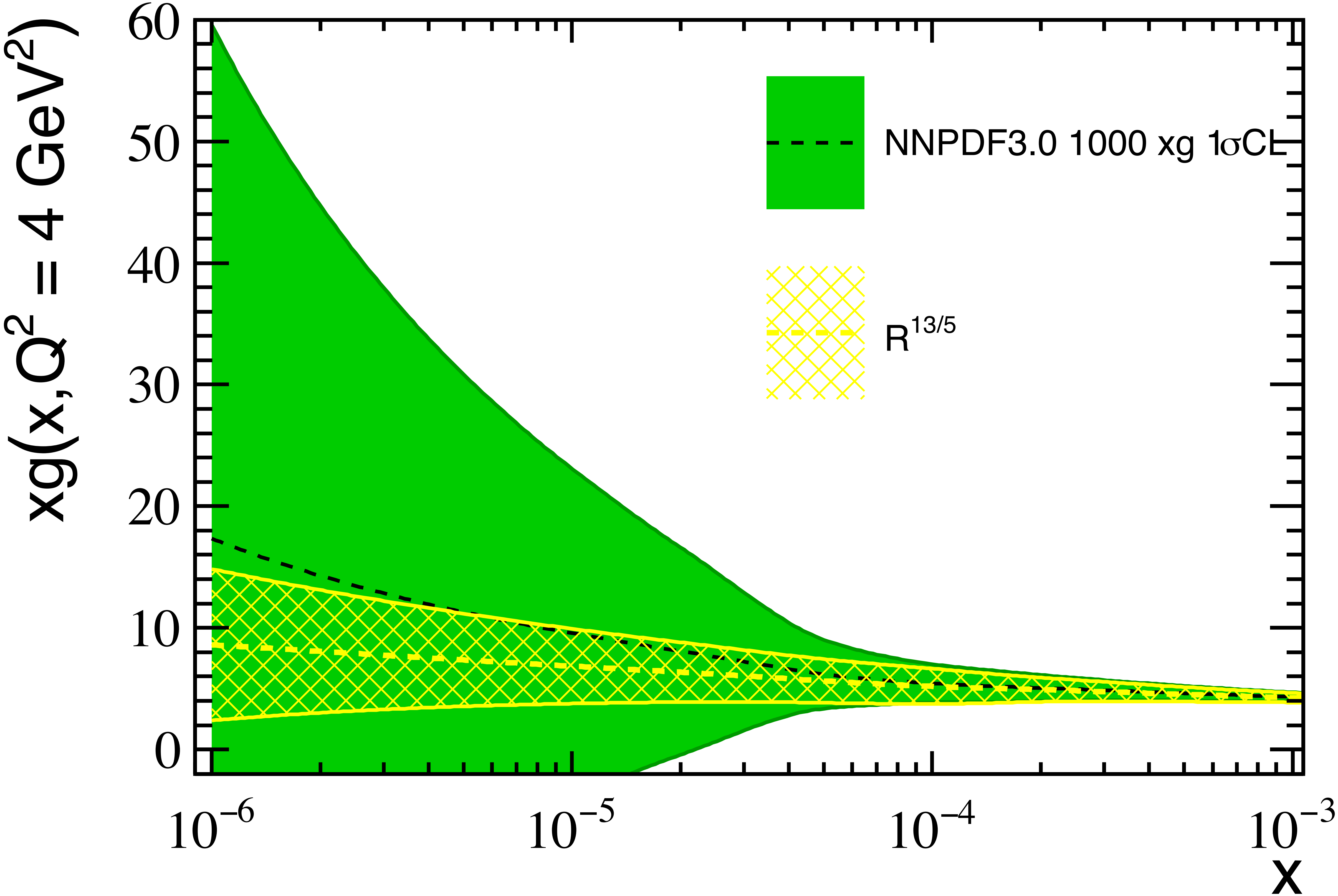


$xg(x, Q^2 = 4\ GeV^2)$
60
50
40
30
20
10
0
NNPDF3.0 1000 xg 1σCL
N^5
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x

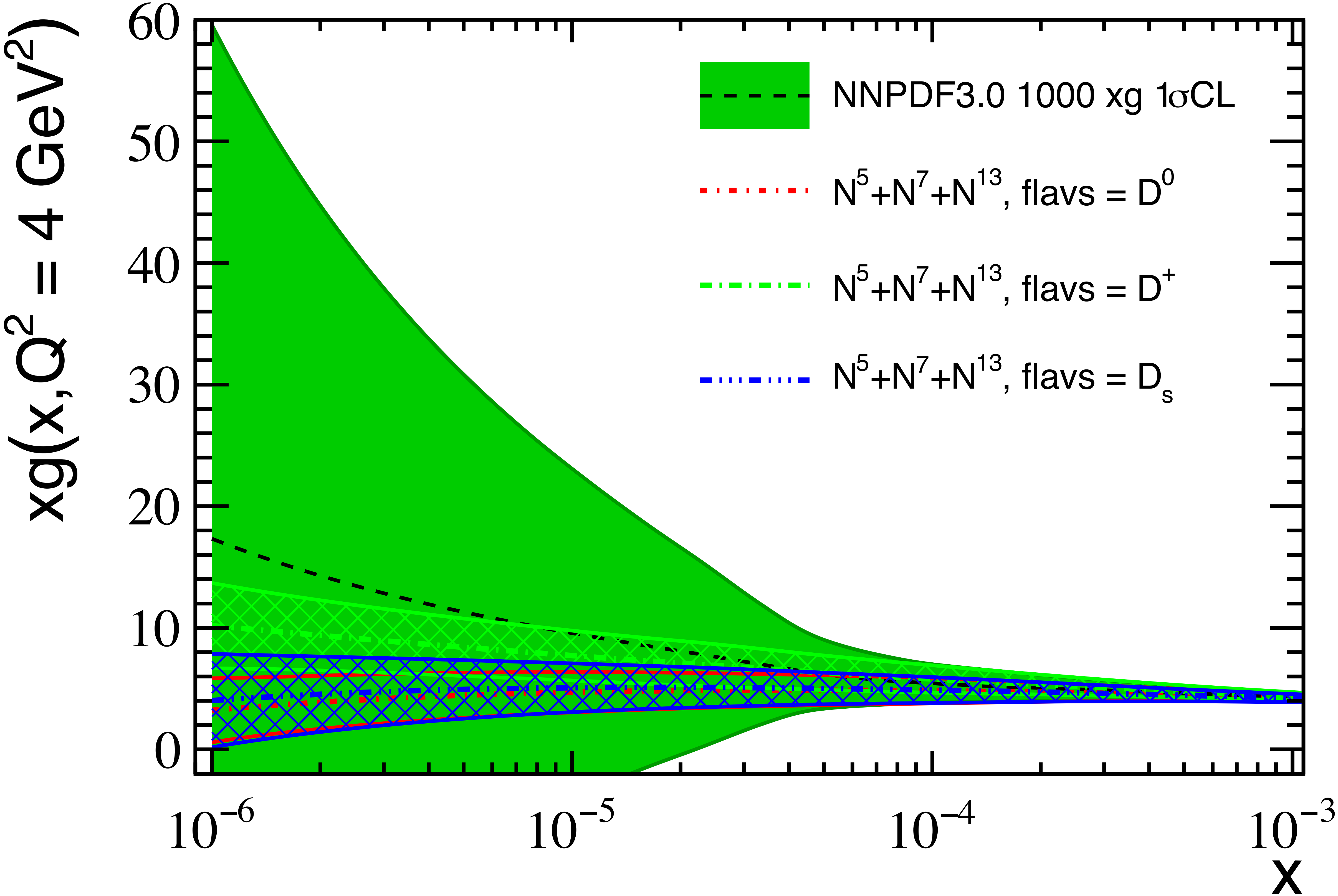


60
50
40
30
20
10
0
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x
$xg(x,Q^2 = 4\ GeV^2)$
NNPDF3.0 1000 xg 1σCL
N^7

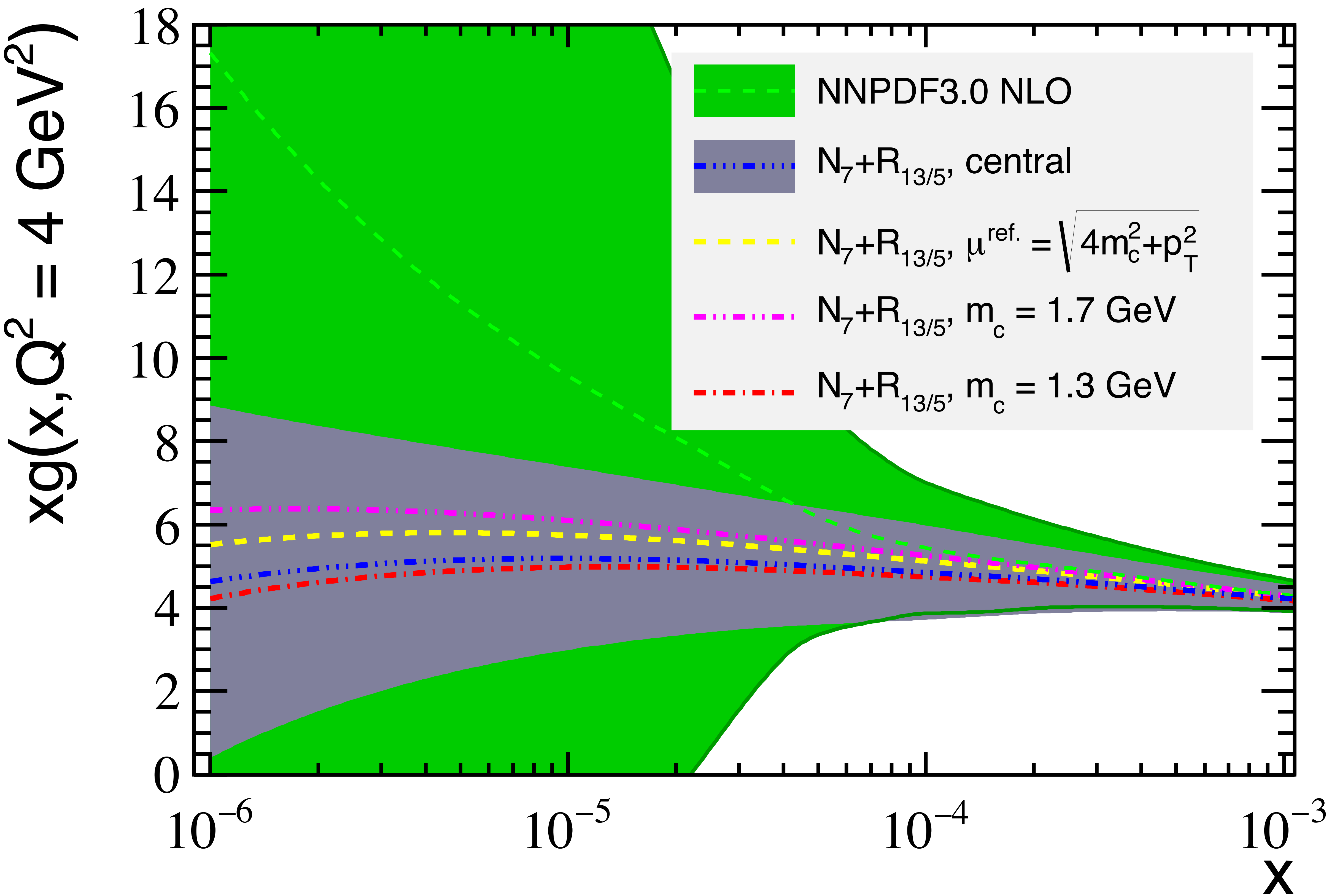

xg(x,Q^2 = 4 GeV^2)
60
50
40
30
20
10
0
NNPDF3.0 1000 xg 1σCL
N^13
10^-6
10^-5
10^-4
10^-3
x



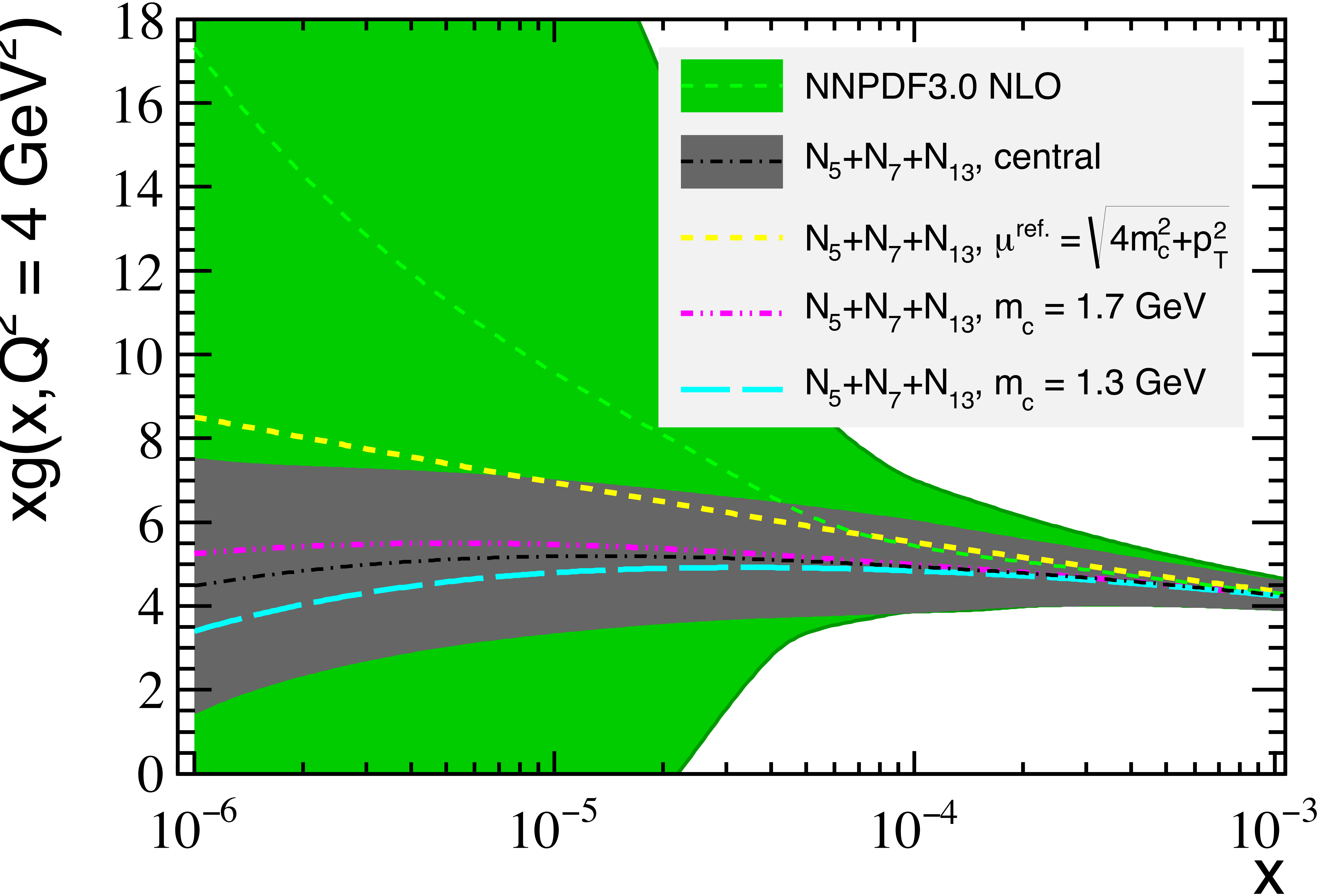
$xg(x,Q^2 = 4\ GeV^2)$
60
50
40
30
20
10
0
NNPDF3.0 1000 xg 1σCL
$R^{13/5}$
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x



NNPDF3.0 1000 xg 1σCL
N^5+N^7+N^13, flavs = D^0
N^5+N^7+N^13, flavs = D^+
N^5+N^7+N^13, flavs = D_s
xg(x, Q^2 = 4 GeV^2)
x
60
50
40
30
20
10
0
10^-6
10^-5
10^-4
10^-3



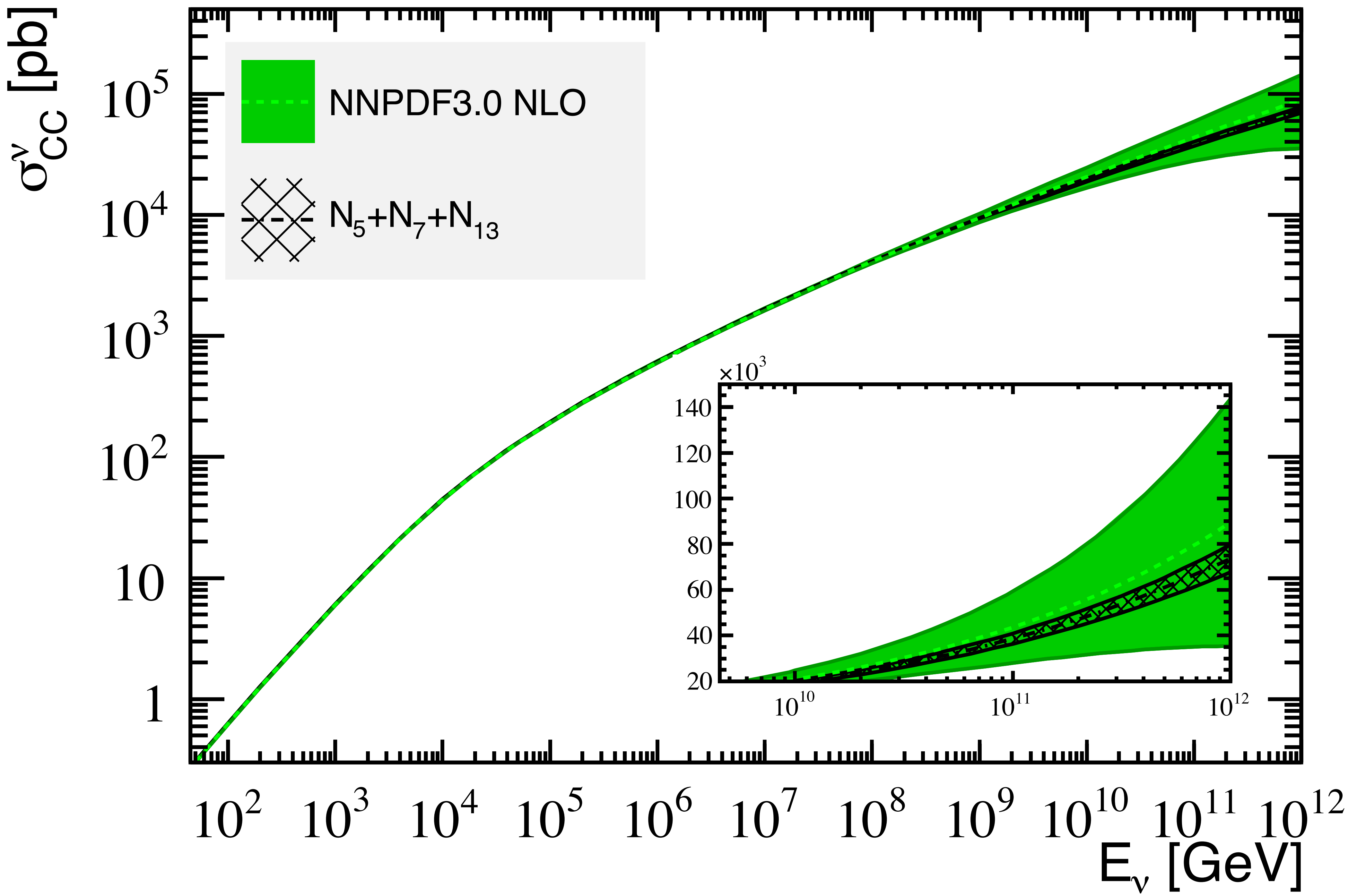
$xg(x, Q^2 = 4\ GeV^2)$
18
16
14
12
10
8
6
4
2
0
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x
NNPDF3.0 NLO
$N_7+R_{13/5}$, central
$N_7+R_{13/5}$, $\mu^{ref.} = \sqrt{4m_c^2+p_T^2}$
$N_7+R_{13/5}$, m_c = 1.7 GeV
$N_7+R_{13/5}$, m_c = 1.3 GeV



xg(x,Q² = 4 GeV²)
NNPDF3.0 NLO
N5+N7+N13, central
N5+N7+N13, μref. = √(4mc²+pT²)
N5+N7+N13, mc = 1.7 GeV
N5+N7+N13, mc = 1.3 GeV
0
2
4
6
8
10
12
14
16
18
10−6
10−5
10−4
10−3
x

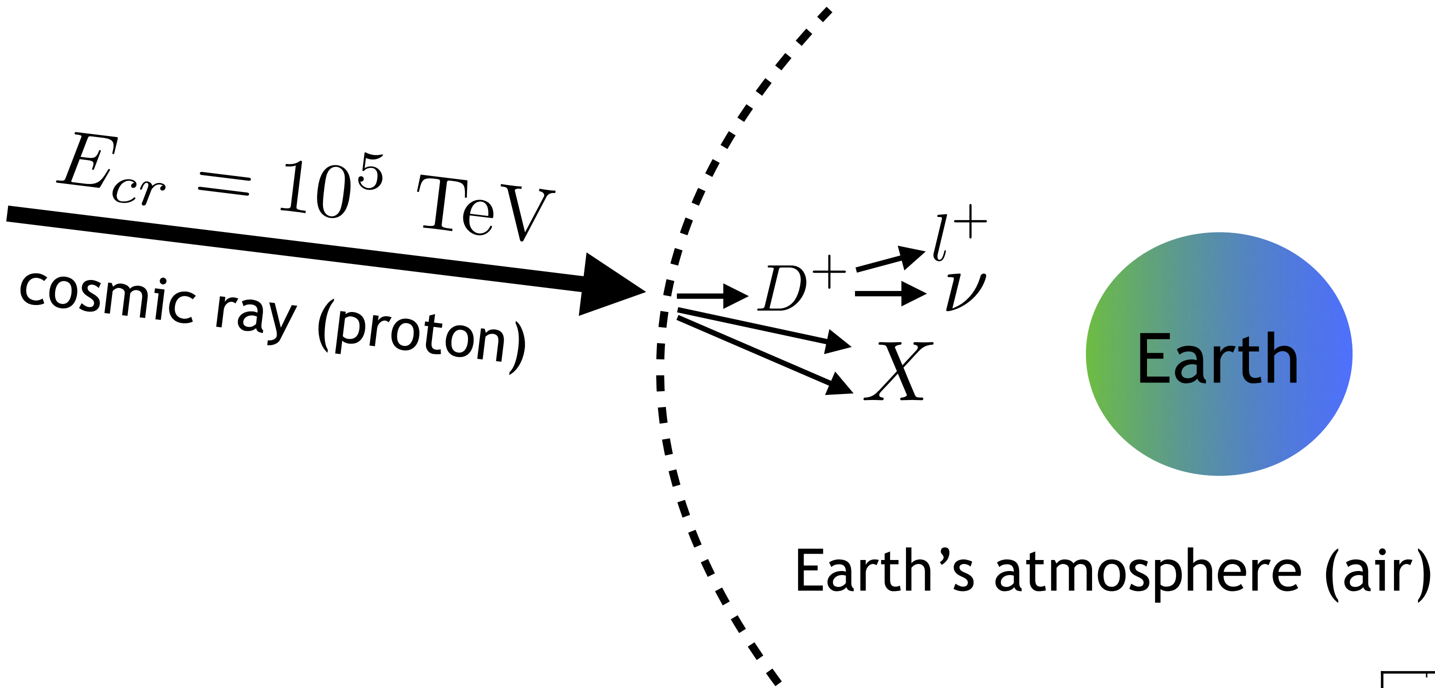
Applications I

Ultra High Energy (UHE) neutrino-nucleon cross section



Applications II

Atmospheric production of heavy quarks

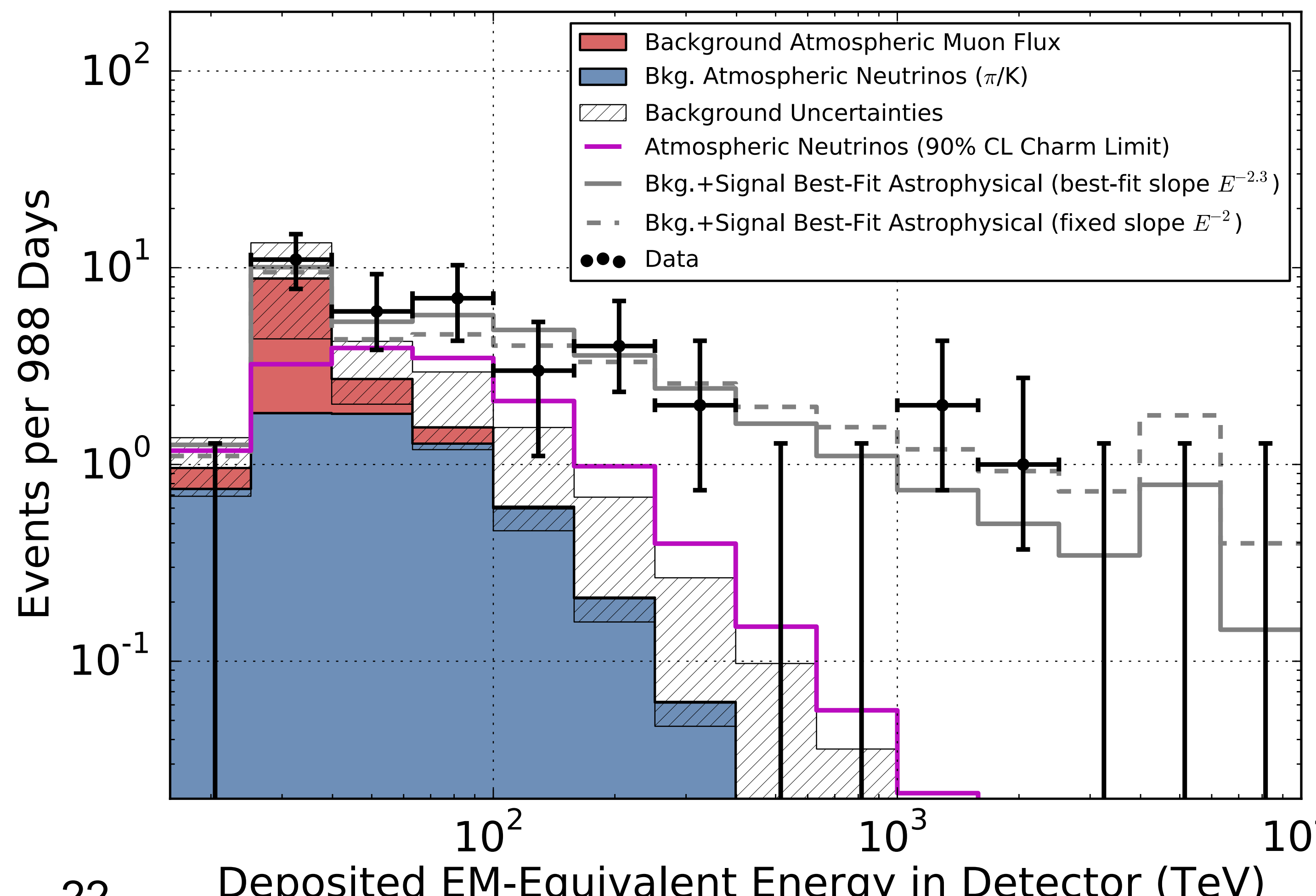


$$\sqrt{S} = \sqrt{2m_N E_{cr}} \approx 14 \text{ TeV}$$

At the LHC $\sqrt{S} = 13$ TeV

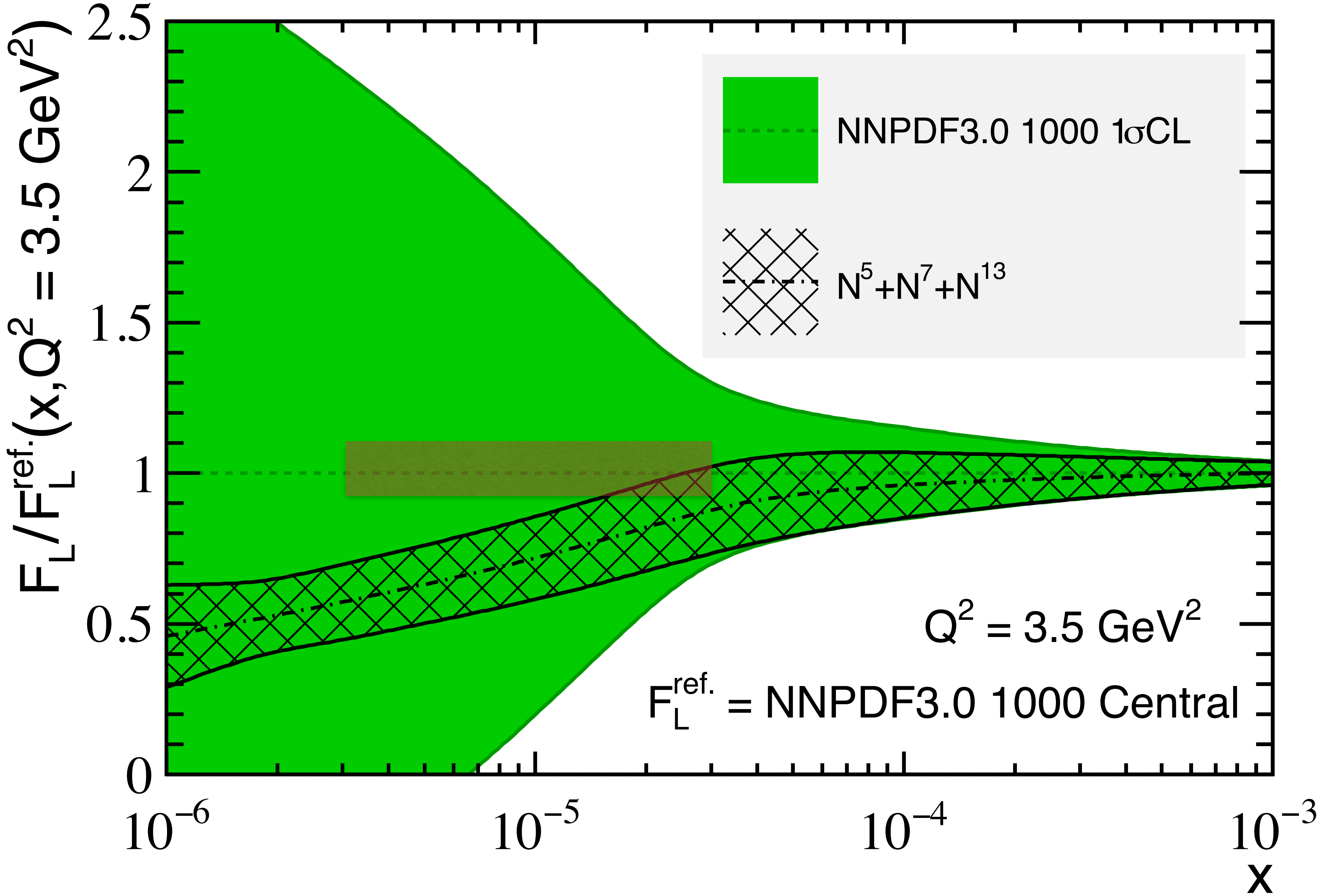
Dominant background for:

UHE astrophysical neutrino measurements (IceCube, …)



Applications III

LHeC, High energy pp collider, forward photons at the LHC, …



= Typical* precision of F_L that LHeC could probe

* Depends on beam energy, polarisation, … etc.

Summary

- Dust settling on the LHCb data now….

- Normalised cross section/ratio data lead to consistent results

- Low-x gluon PDF previously unknown

Disclaimer: Didn't discuss exclusive J/Psi - Jones et al. arXiv: 1610.02272

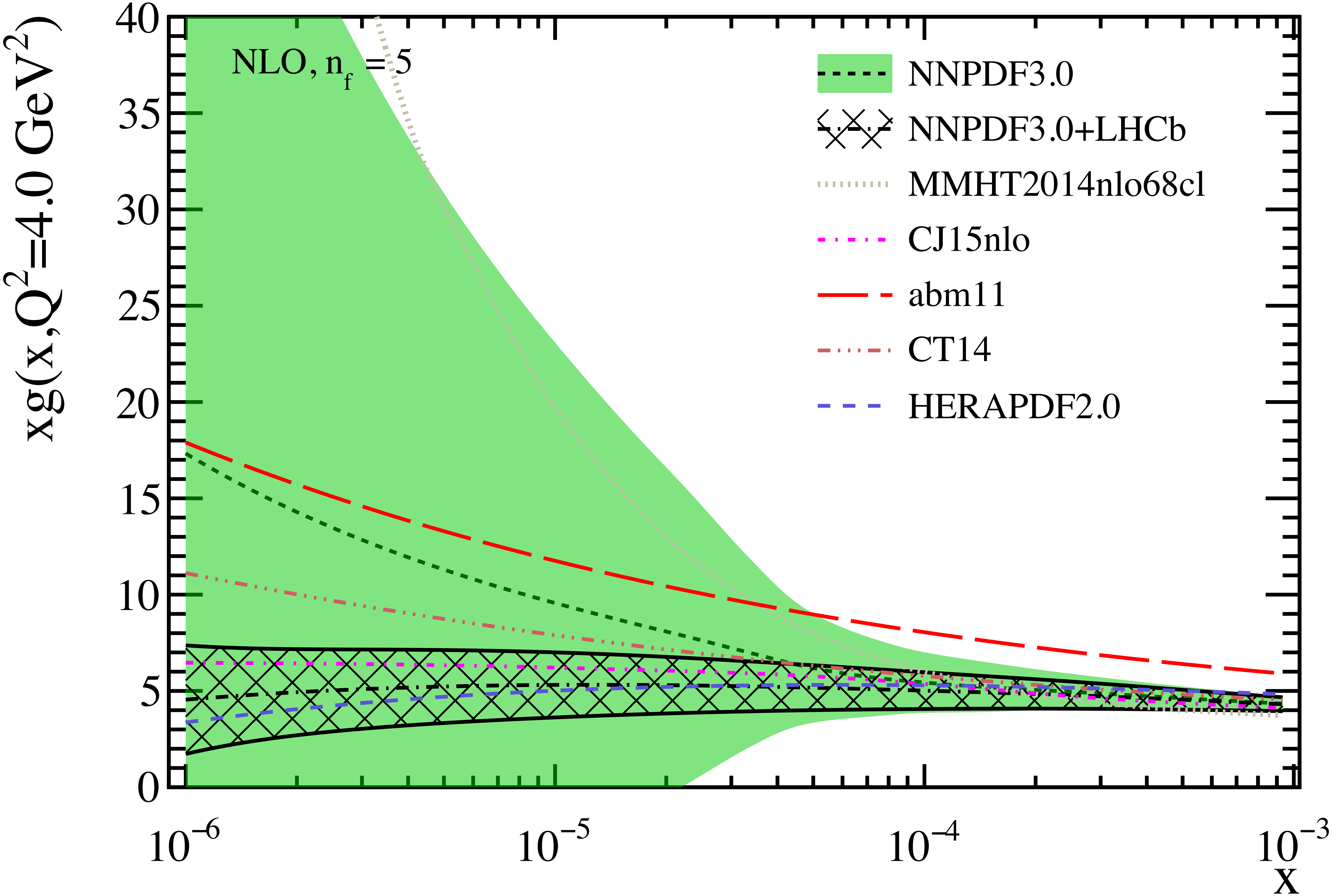
Our LHgrids (100 member replica set) are available here:

5 flavour PDFs

http://pcteserver.mi.infn.it/~nnpdf/NNPDF30LHCb/NNPDF30_nlo_as_0118_L13L7L5.tar.gz

3 flavour PDFs

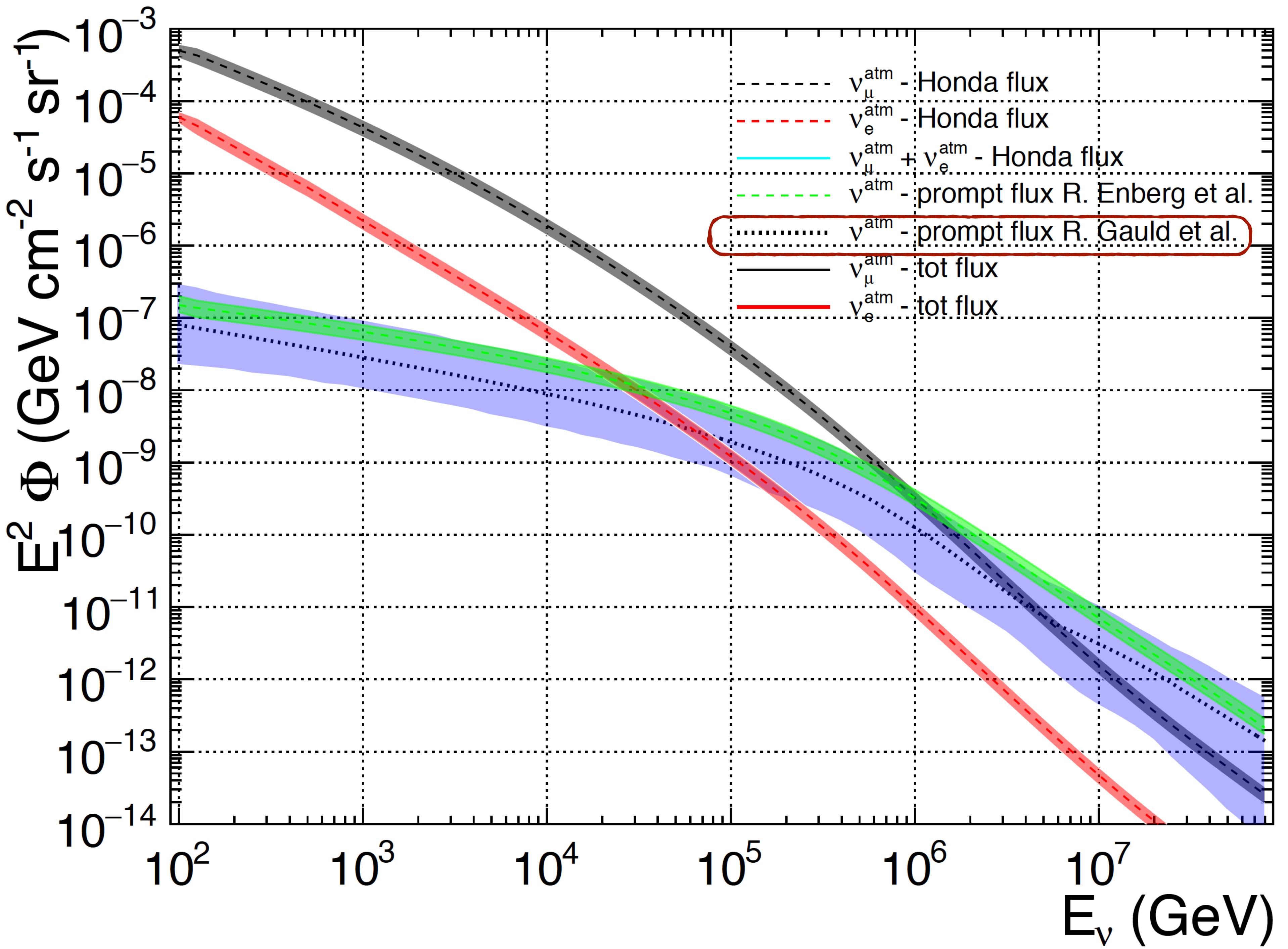
http://pcteserver.mi.infn.it/~nnpdf/NNPDF30LHCb/NNPDF30_nlo_as_0118_L13L7L5_nf3.tar.gz



NLO, n_f = 5
NNPDF3.0
NNPDF3.0+LHCb
MMHT2014nlo68cl
CJ15nlo
abm11
CT14
HERAPDF2.0
$xg(x,Q^2=4.0\ GeV^2)$
0
5
10
15
20
25
30
35
40
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x

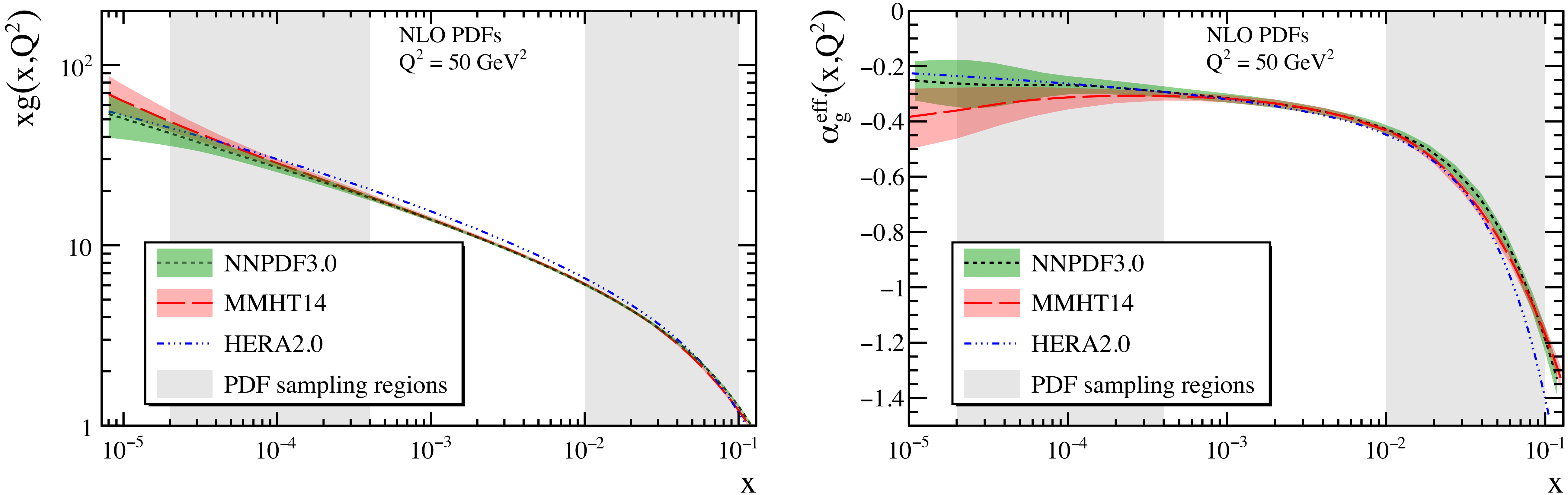
Bunch of `useful’ plots below

Neutrino flux from prompt charm



From KM3NeT Letter of intent - arXiv:1601.07459

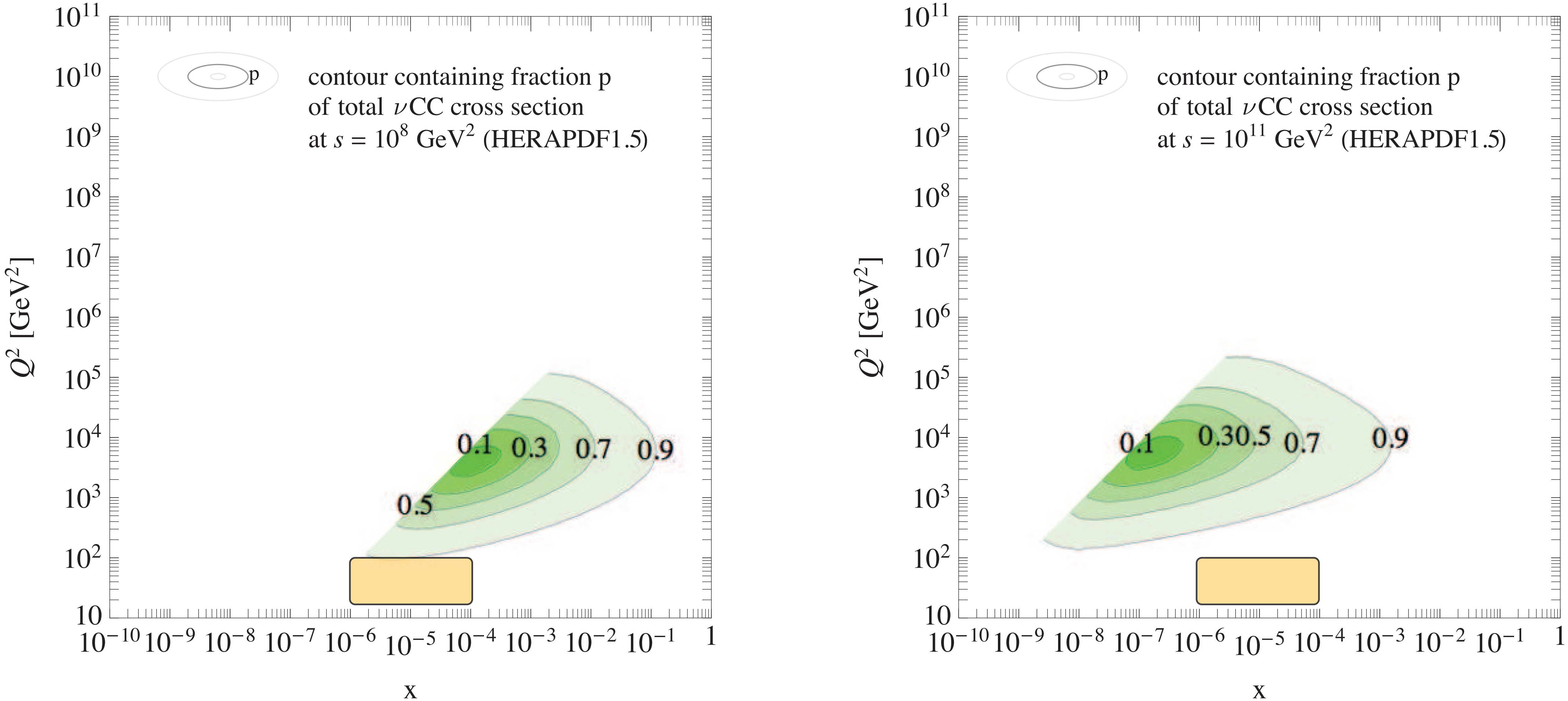
$$\alpha_{\mathrm{g}}^{\mathrm{eff.}}(x, Q^2) = \frac{\partial \ln \left[xg(x, Q^2) \right]}{\partial \ln x}$$



What do normalised cross section and ratios probe?

Essentially the rate of change of the gluon PDF within an x-range

UHE CC neutrino cross section



Taken from (Cooper-)Sarkar, Mertsch, arXiv:1106.3723

$$\frac{d^2\sigma(\nu(\bar{\nu})N)}{dx\ dQ^2} = \frac{G_F^2 M_W^4}{4\pi(Q^2+M_W^2)^2 x}\sigma_r(\nu(\bar{\nu})N)$$

$$\sigma_r(\nu N) = \left[Y_+ F_2^{\nu}(x,Q^2) - y^2 F_L^{\nu}(x,Q^2) + Y_- x F_3^{\nu}(x,Q^2)\right]$$

$$\sigma_r(\bar{\nu} N) = \left[Y_+ F_2^{\bar{\nu}}(x,Q^2) - y^2 F_L^{\bar{\nu}}(x,Q^2) - Y_- x F_3^{\bar{\nu}}(x,Q^2)\right]$$

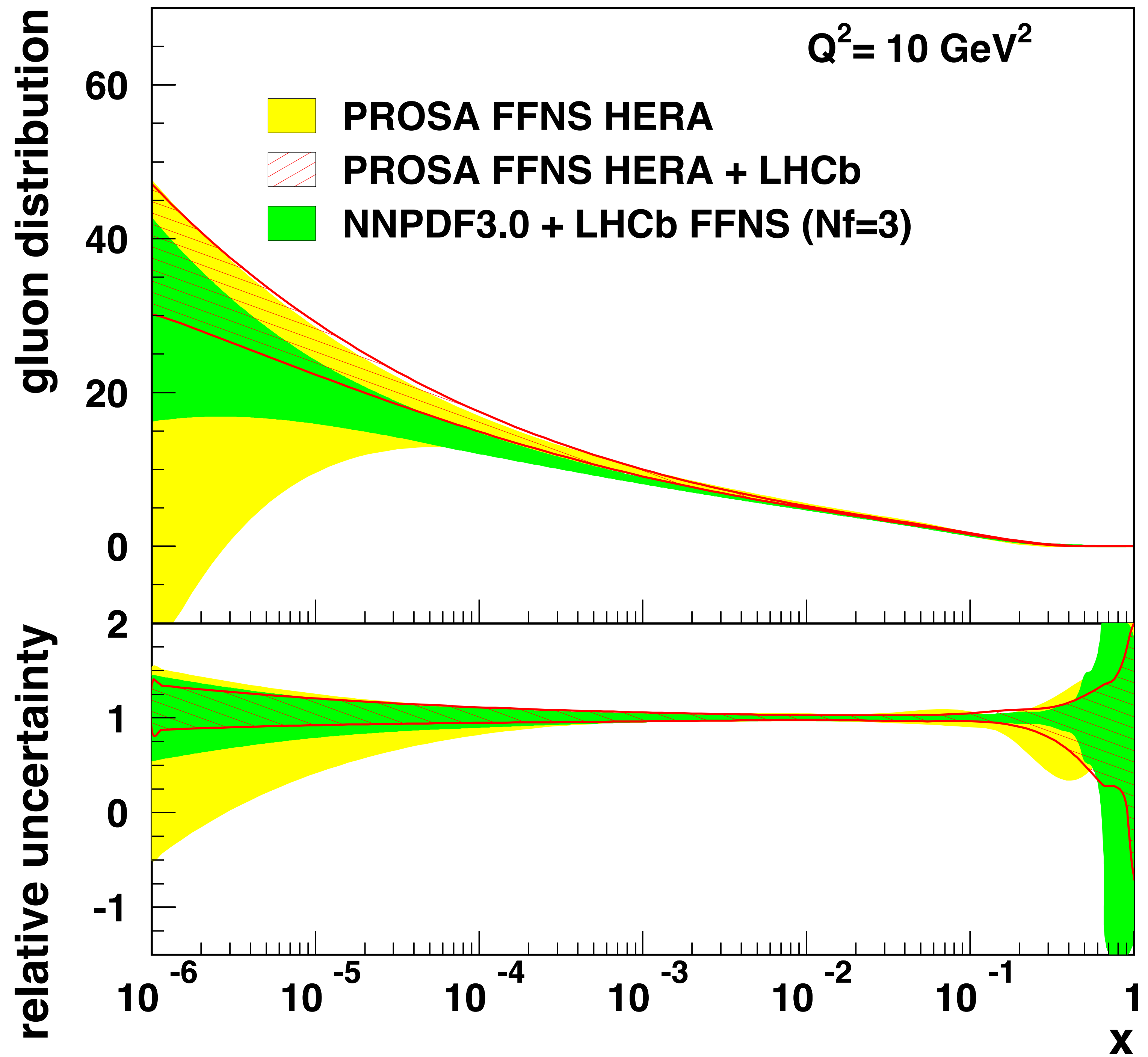
Gluon PDF extraction at 7 TeV

PROSA results:

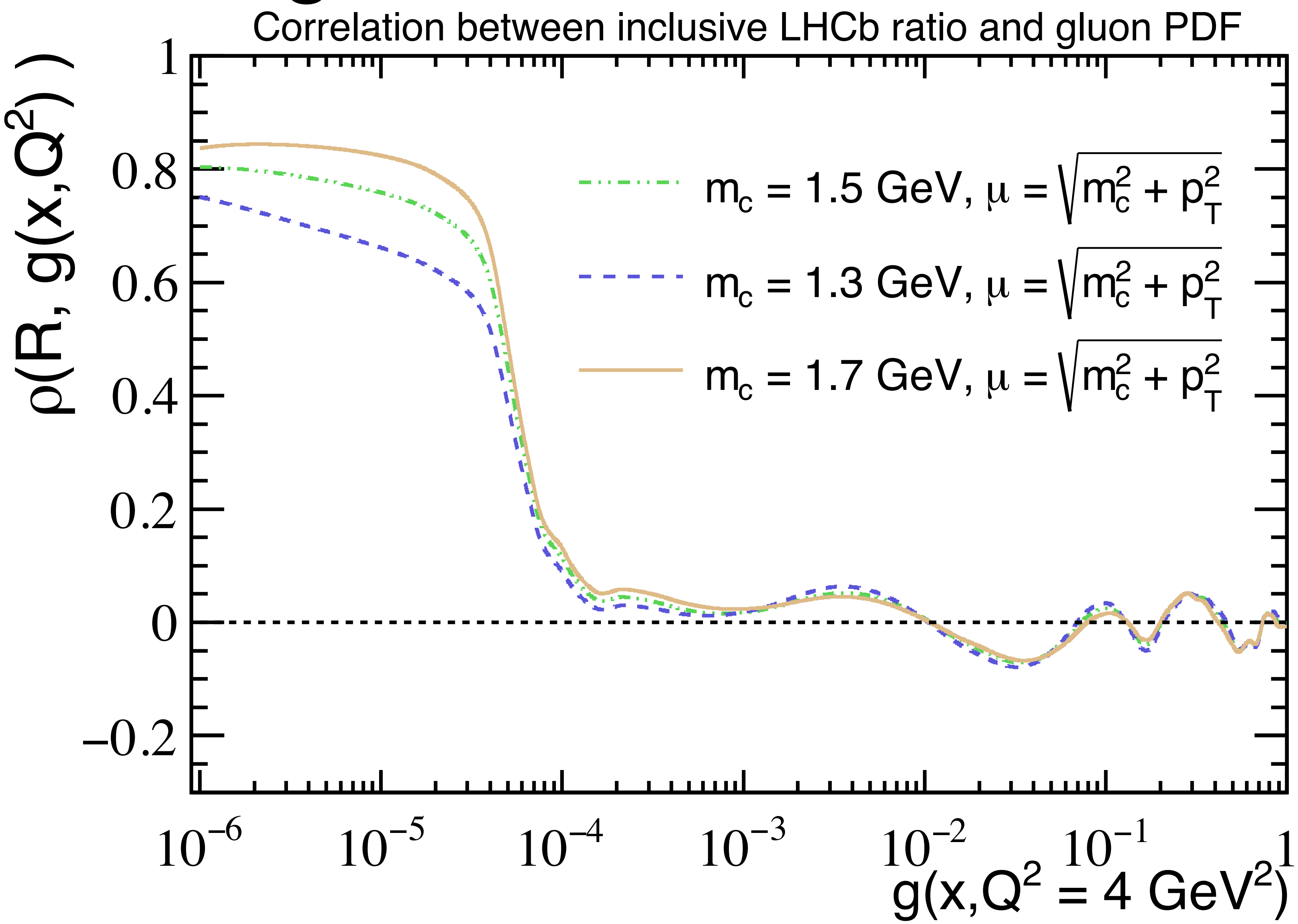
- HERA+LHCb Data PDF fit
- FFS, NF=3
- Normalise to 'middle' rapidity bin for each pT
- HERAfitter framework
- Also LHCb B data

GRRT results:

- NNPDF3.0 Global fit
- input set is VFNS
- Normalise to max pT / min rapidity bin
- Bayesian Reweighting

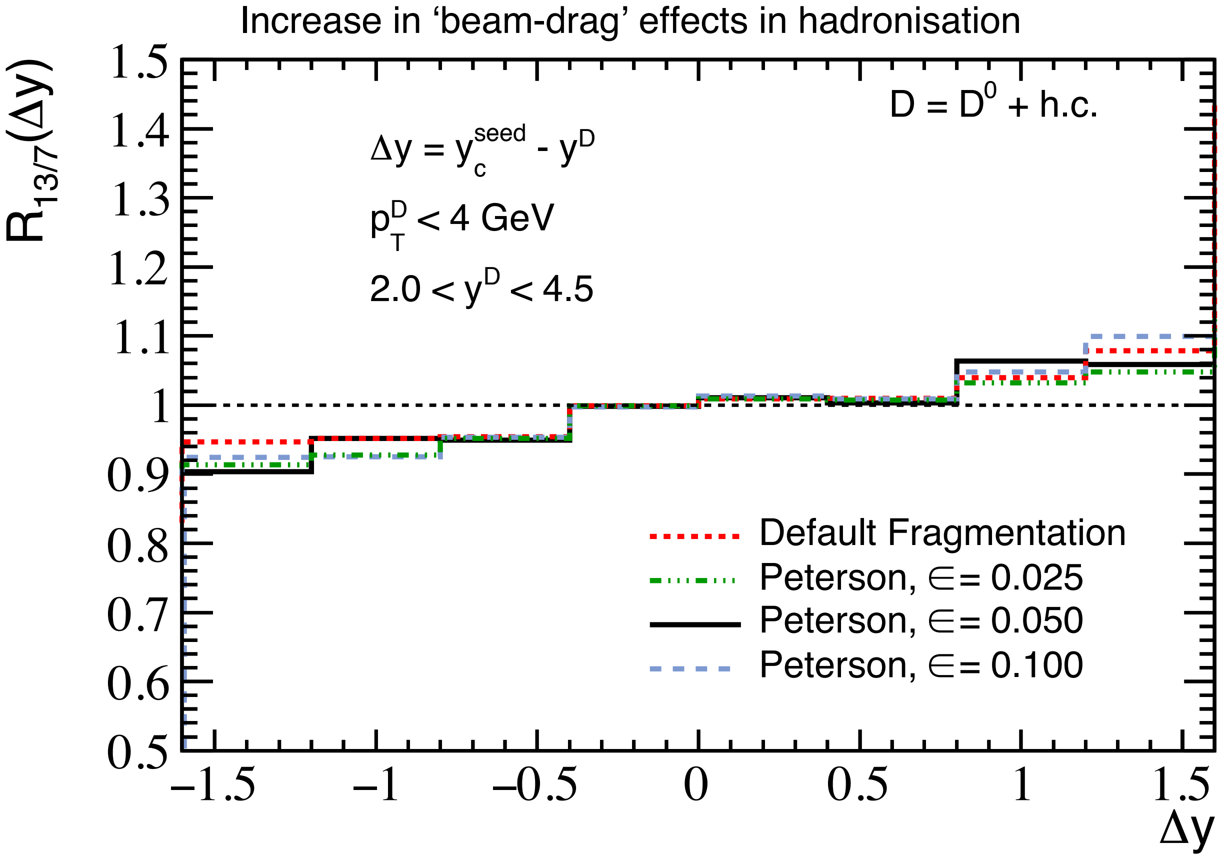


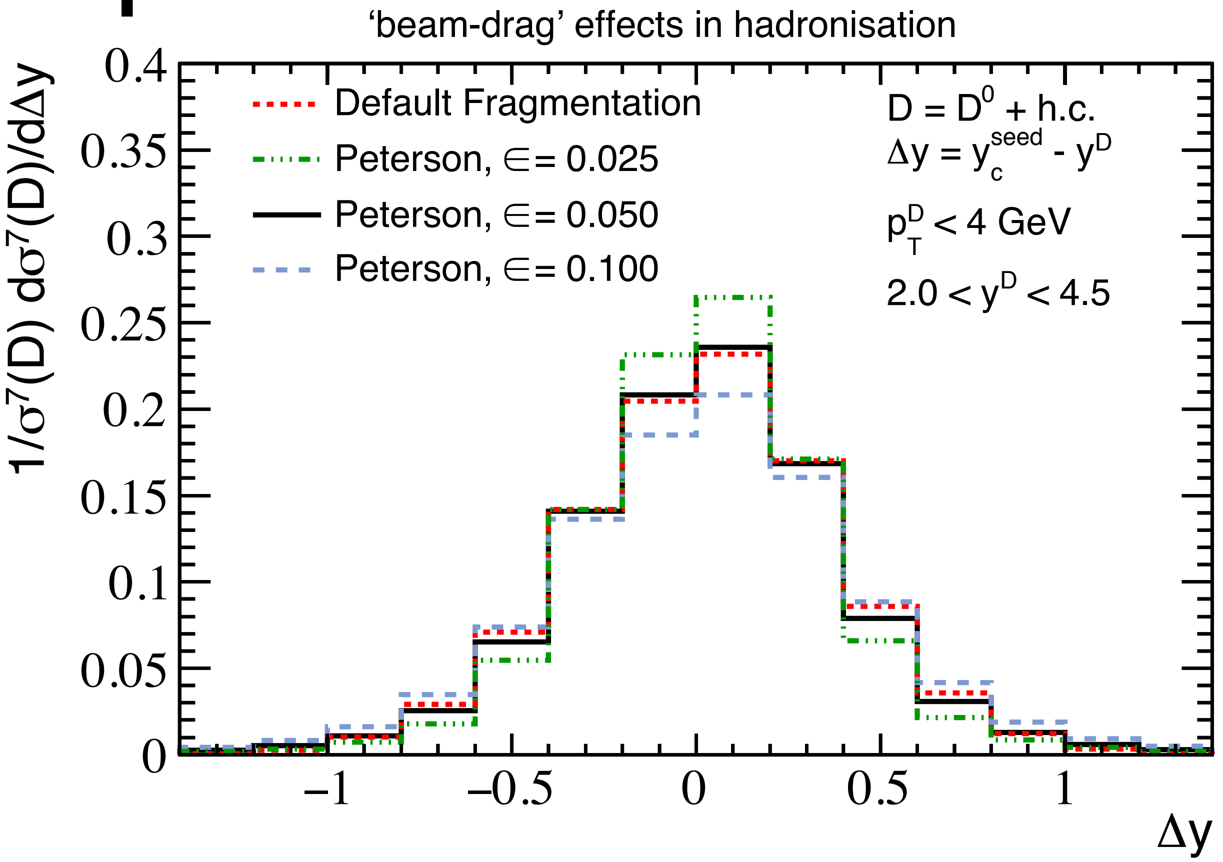
gPDF Correlations

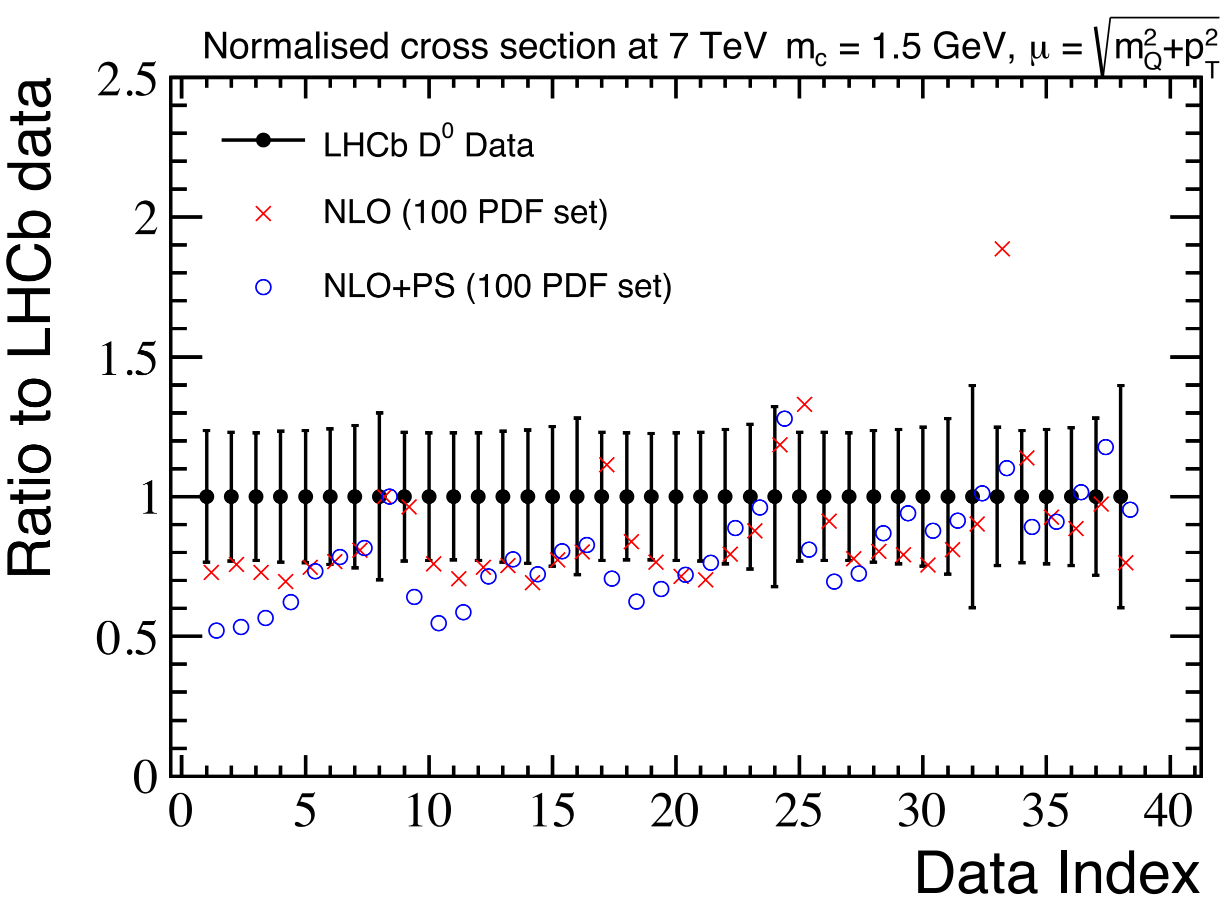


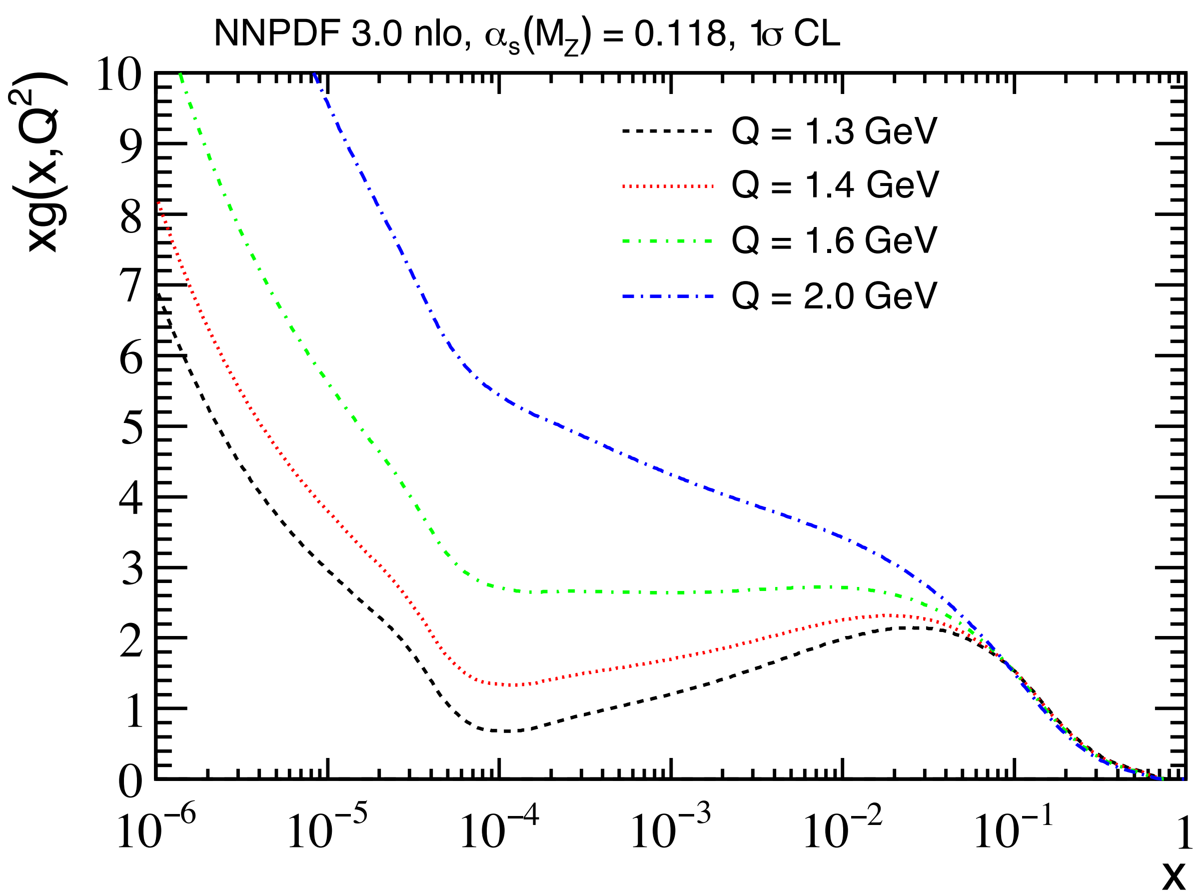
Gluon PDF correlation with inclusive LHCb
13/7 Charm ratio measurement

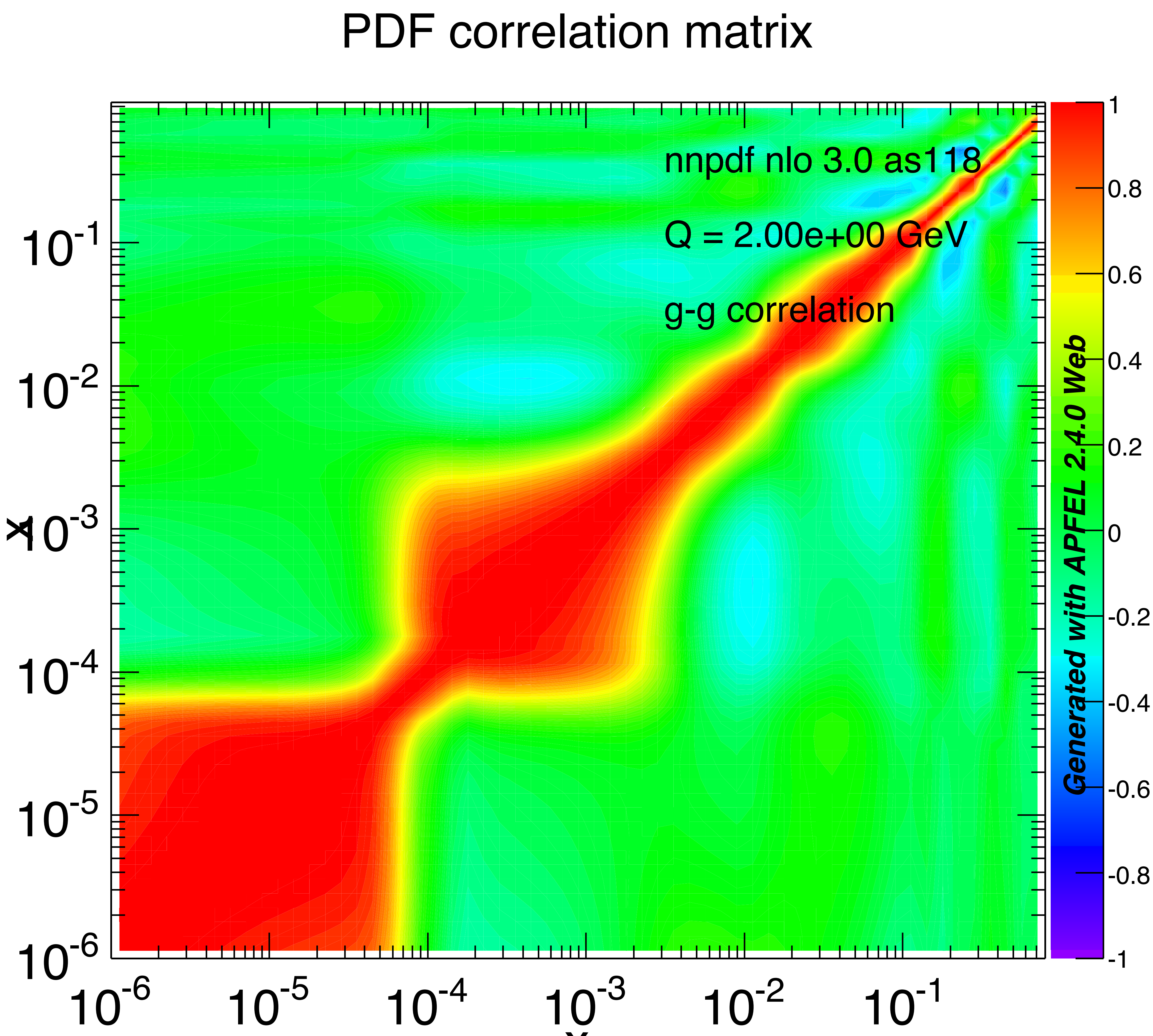
Useful plots

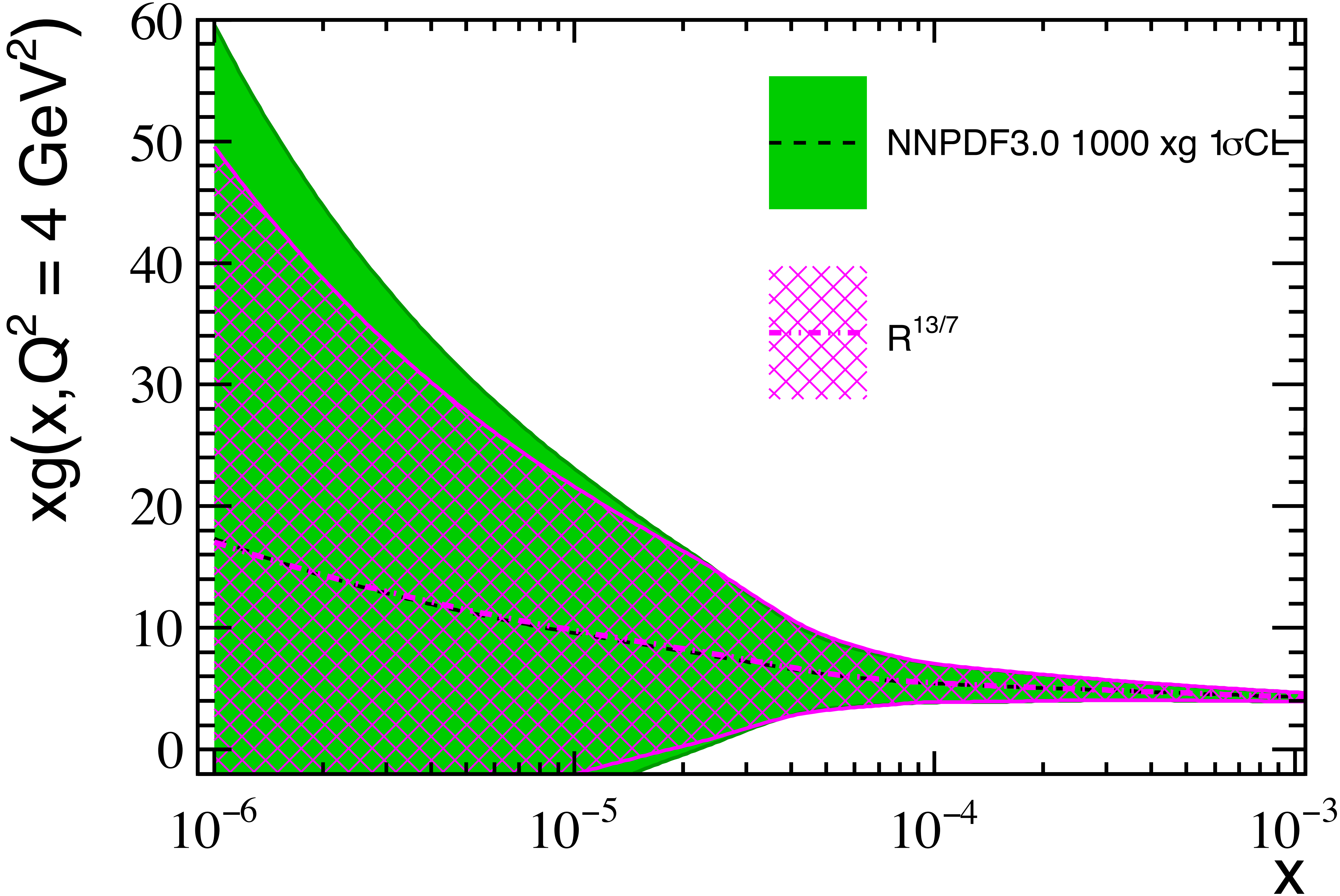









PDF correlation matrix
nnpdf nlo 3.0 as118
Q = 2.00e+00 GeV
g-g correlation
Generated with APFEL 2.4.0 Web
x
x
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1


xg(x,Q² = 4 GeV²)
60
50
40
30
20
10
0
10⁻⁶
10⁻⁵
10⁻⁴
10⁻³
x
NNPDF3.0 1000 xg 1σCL
R^13/7