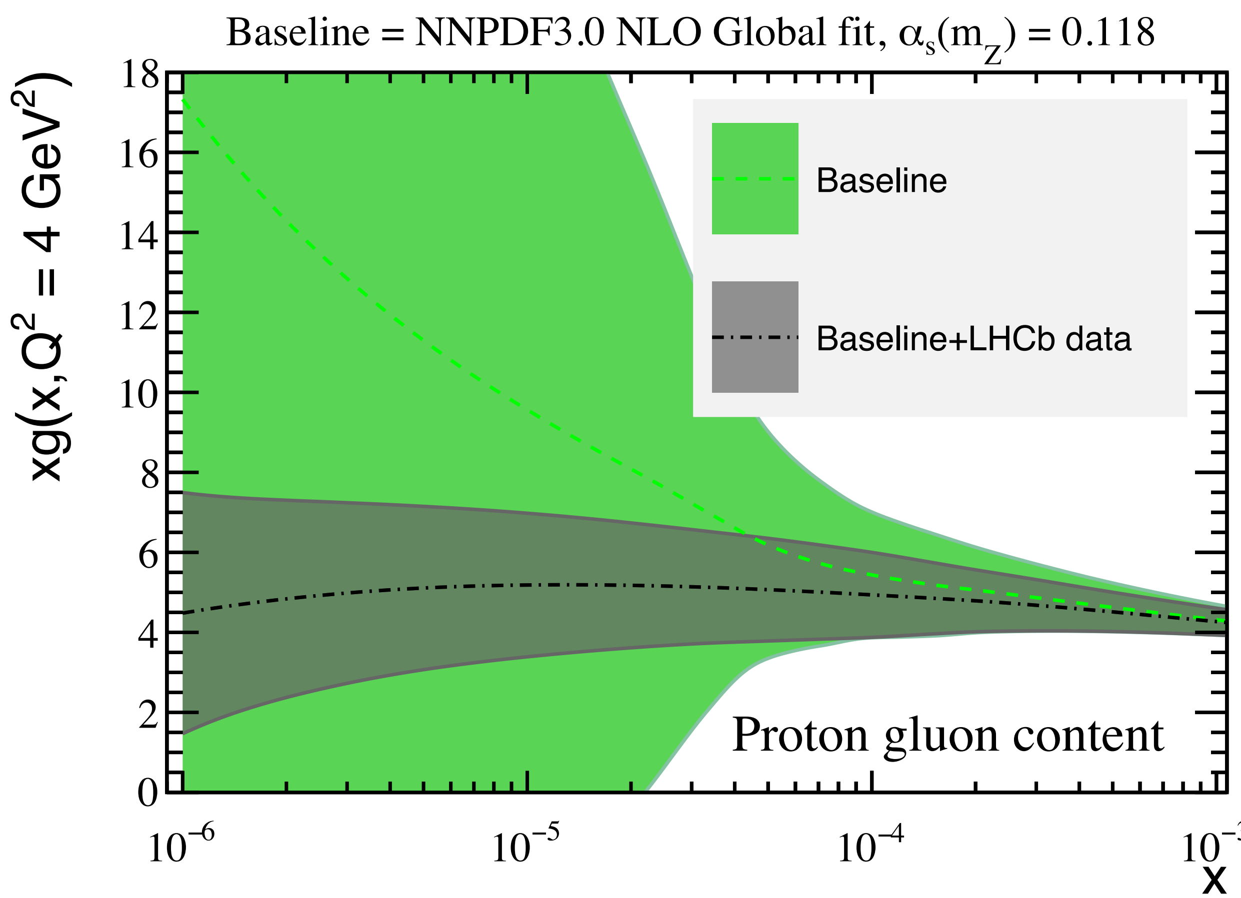
Forward heavy quark production (and the structure of the proton)

Rhorry Gauld

Phenomenology Seminar, Wednesday 18th April



ETH
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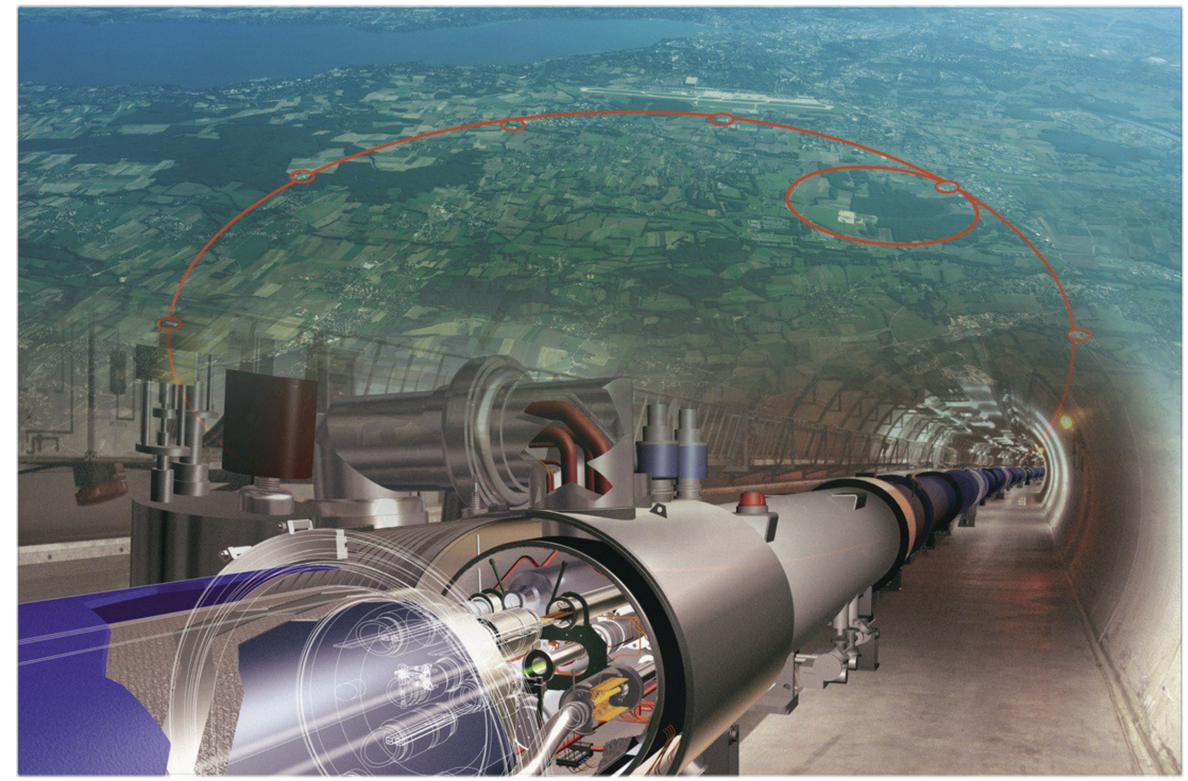
Swiss Federal Institute of Technology Zurich

MC@NNLO

Setting the scene

$$pp \to D/B + X$$

Heavy flavour c/b-quark hadrons



Summary of most relevant LHC measurements:

* pp > D+X, at 5 TeV LHCb Collaboration, JHEP**06**(2017) 147
* pp > D+X, at 7 TeV LHCb Collaboration, Nucl. Phys. **B871** (2013)
* pp > D+X, at 13 TeV LHCb Collaboration, JHEP**05**(2017) 074

JHEP**09**(2016) 013, JHEP**03**(2016) 159

(* pp > B+X, at 7, 13 TeV LHCb Collaboration, PRL 119(2017) 169901)

PRL **118**(2017) 052002

This seminar: discuss these data and their implications

Overview

Introduction

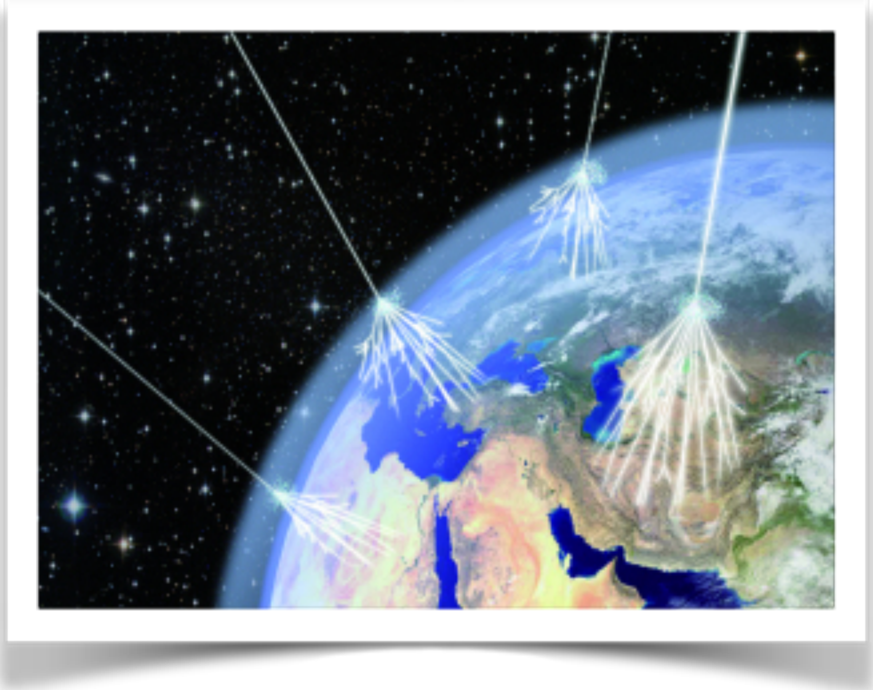
* heavy quark-pair production
* motivation to study forward D/B production

Studying the LHCb data

* Defining suitable observables
* Impact on our knowledge of proton structure

Applications beyond the LHC

Concluding remarks



Introduction

Introduction

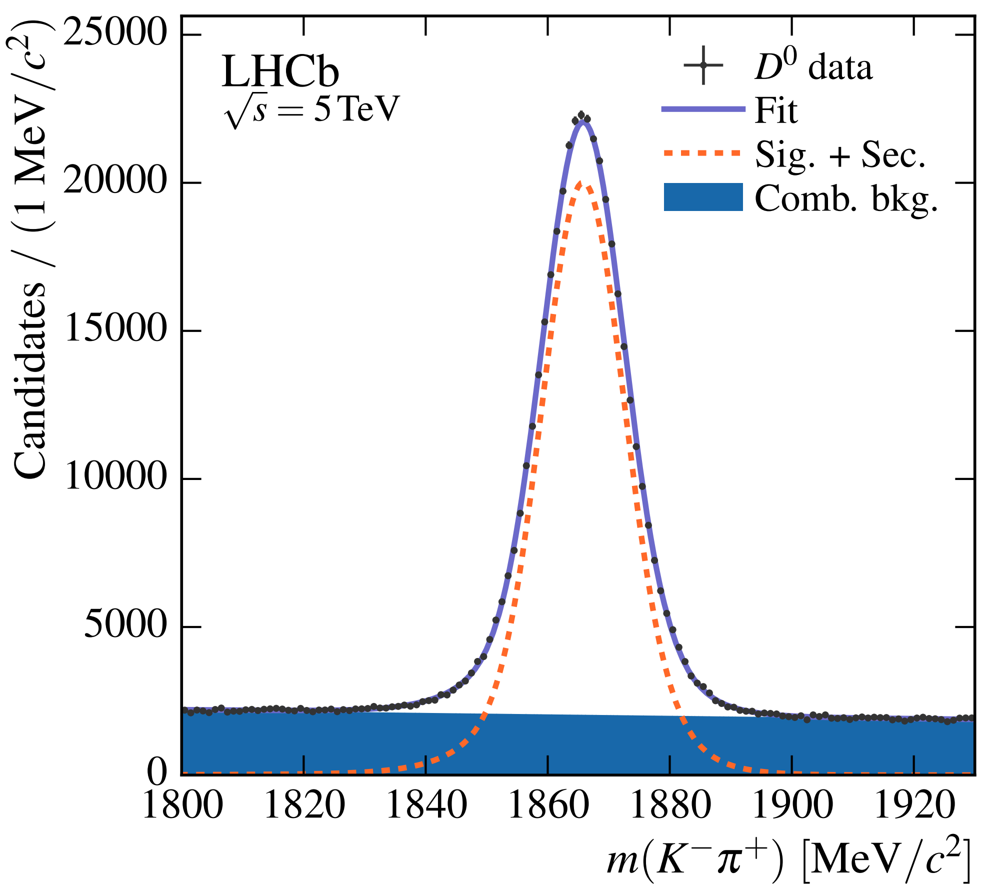
$$y = \frac{1}{2} \ln \left[\frac{E + p_z}{E - p_z} \right]$$

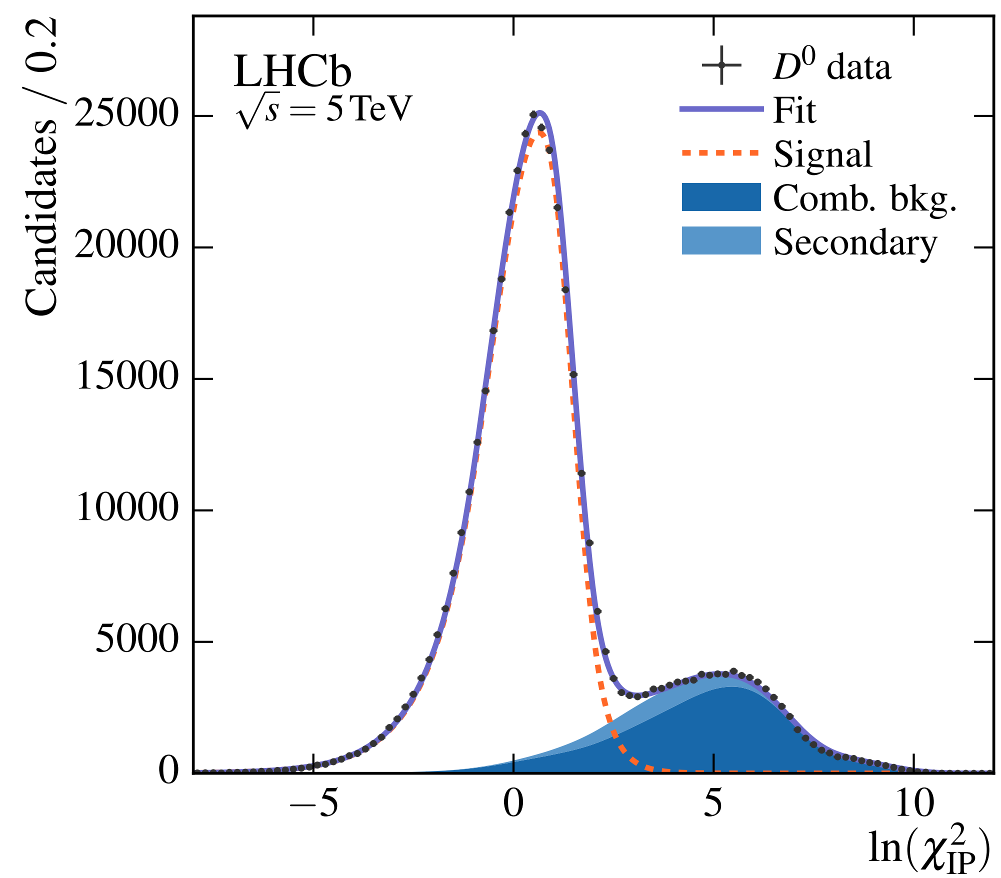
$$pp \rightarrow D^0 + X$$
$$D^0 \rightarrow K^- \pi^+$$

Exclusively reconstruct D-hadrons within experimental acceptance

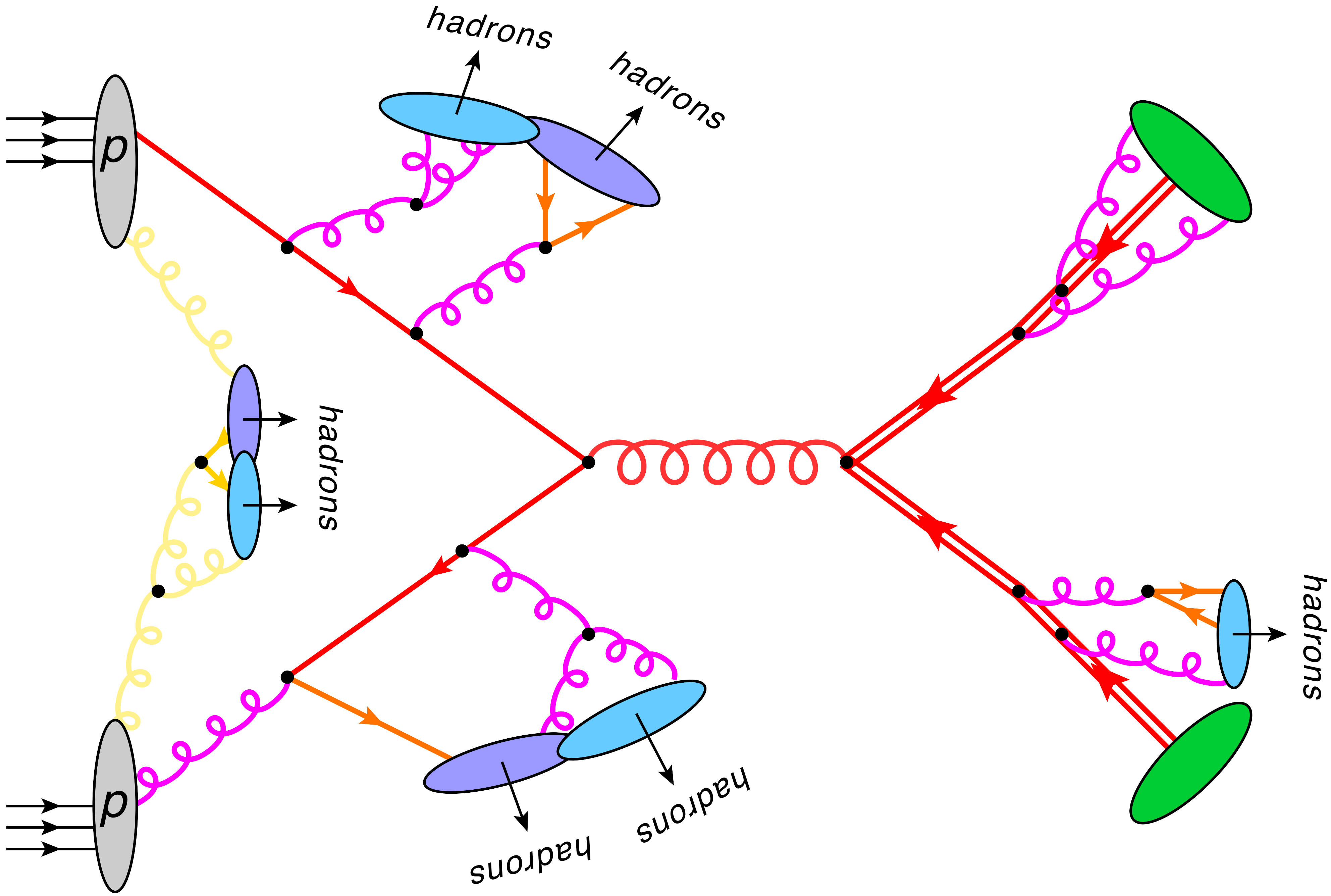
For example, LHCb fiducial region:

$$p_T^D < 8 \text{ GeV}$$
$$2.0 < y^D < 4.5$$





Heavy quark-pair production



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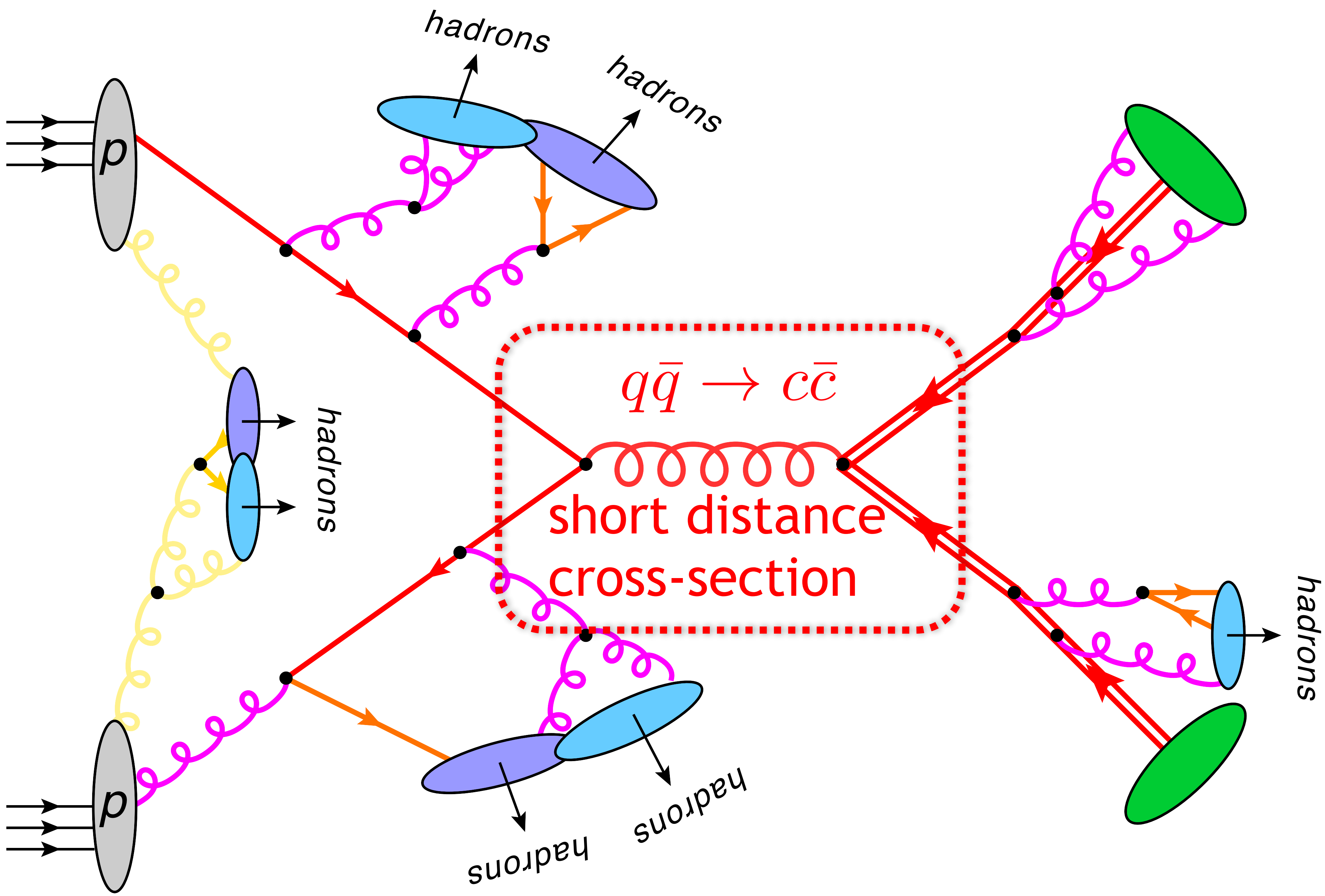
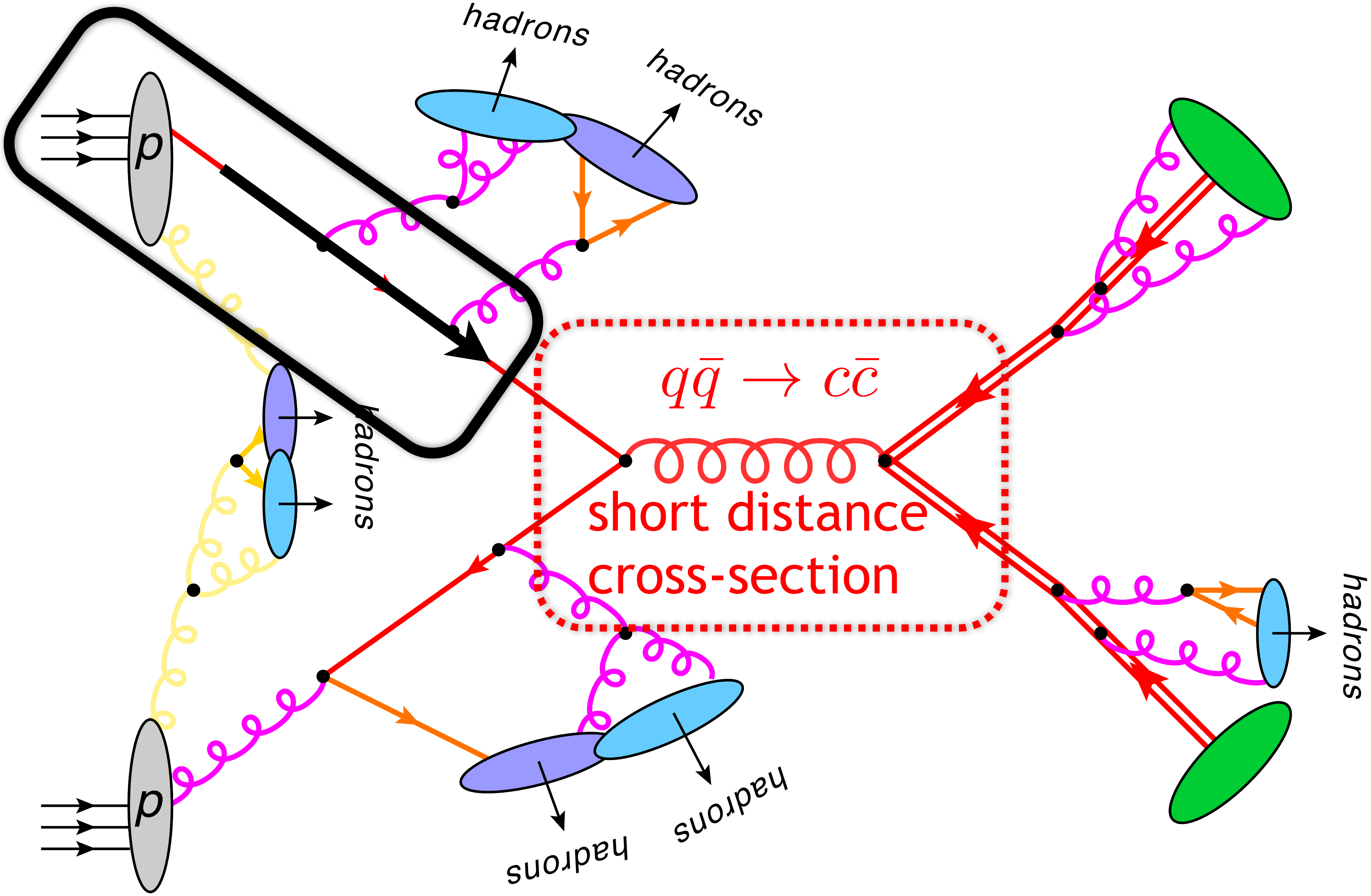
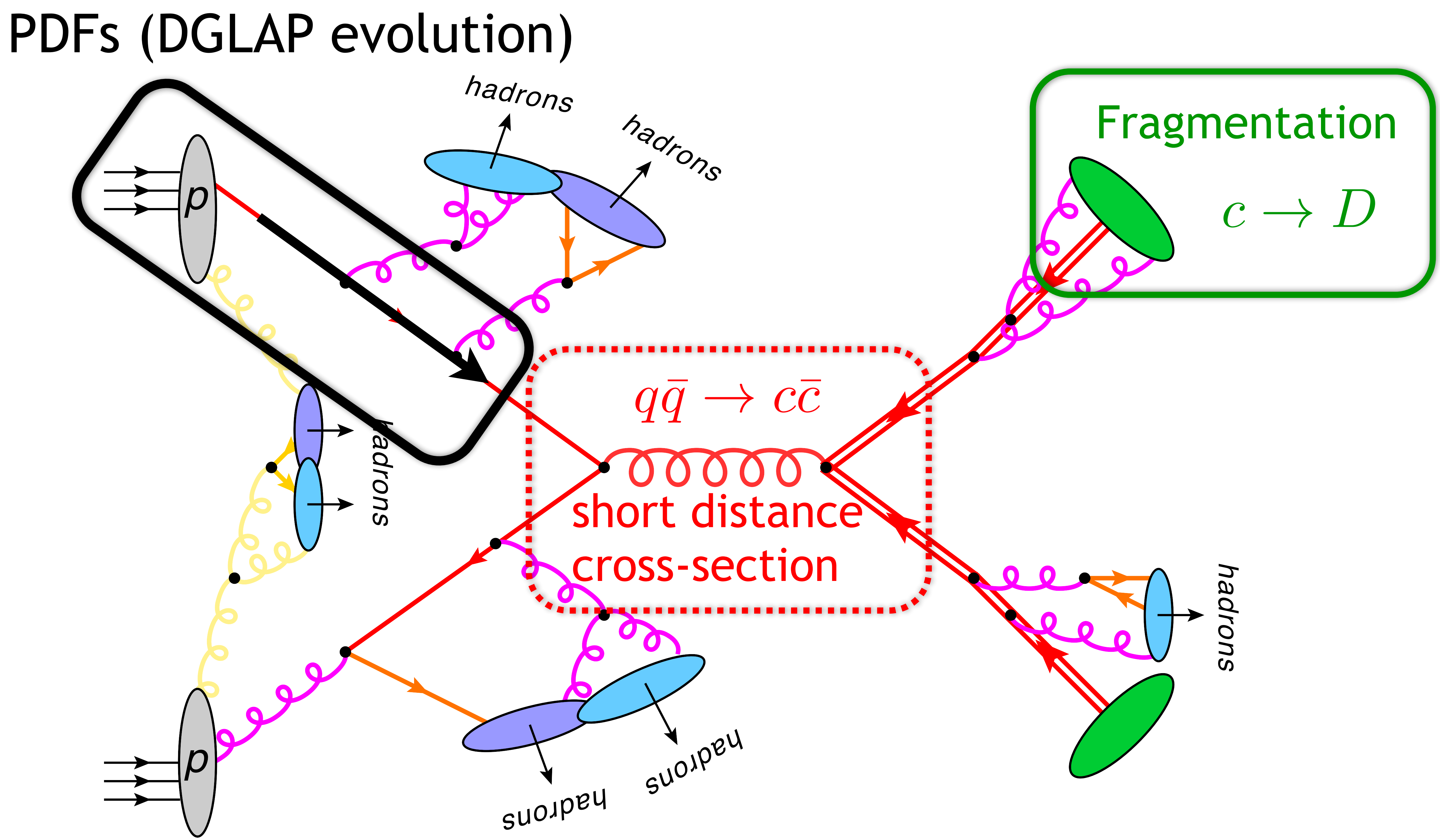


Heavy quark-pair production

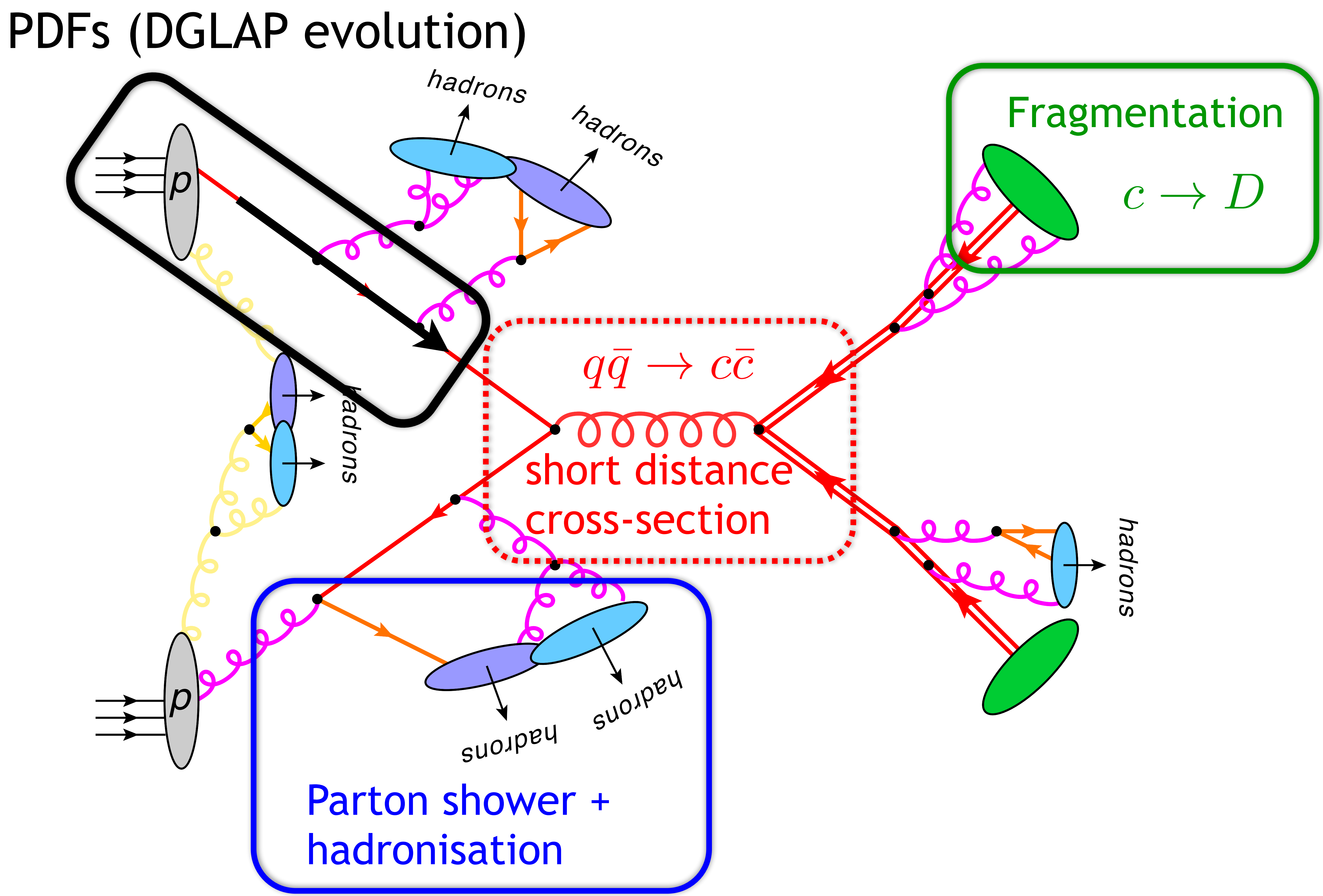
PDFs (DGLAP evolution)



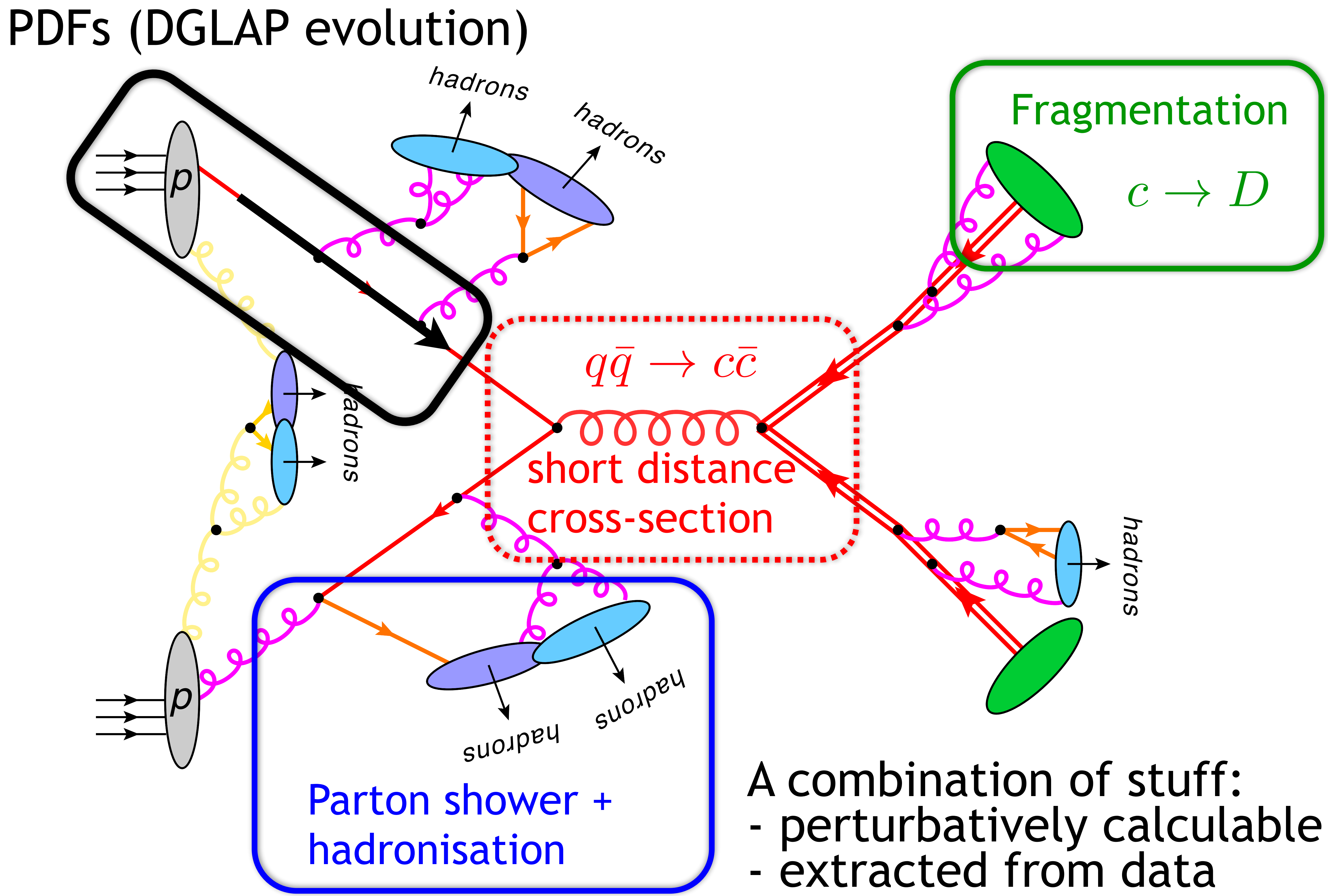
Heavy quark-pair production



Heavy quark-pair production



Heavy quark-pair production



A combination of stuff:
- perturbatively calculable
- extracted from data

Heavy quark-pair production

More formally, follows from factorisation theorems

$$\sigma^{p_A p_B \to c\bar{c}X} = \sum_{a,b} \int \mathrm{d}x_{a,b} f_{a/A}(x_a, \mu_F^2) f_{b/B}(x_b, \mu_F^2)\, \hat{\sigma}^{ab \to c\bar{c}X}\,(\hat{s}, m, \mu_F, \mu_R, \alpha_s(\mu_R))$$

$$+\mathcal{O}\left(\frac{\Lambda^2_{\mathrm{QCD}}}{\hat{s}}\right)$$

... neglected non-factoriseable corrections

PDFs: **n.p.** component extracted from data (evolved perturbatively)

Partonic cross section: computed perturbatively (Feynman diagrams)

$$\frac{\mathrm{d}\sigma^{ab \to DX}}{dz}(z, Q, m) = \int_z^1 \frac{\mathrm{d}\beta}{\beta} \frac{\mathrm{d}\sigma^{ab \to cX}}{d\beta}(\beta, Q, m) F^D_{\mathrm{n.p.}}\left(\frac{z}{\beta}\right)$$

Fragmentation function: **n.p.** component extracted from data

Heavy quark-pair production

- Process **dependent**
- Organising IR divergences

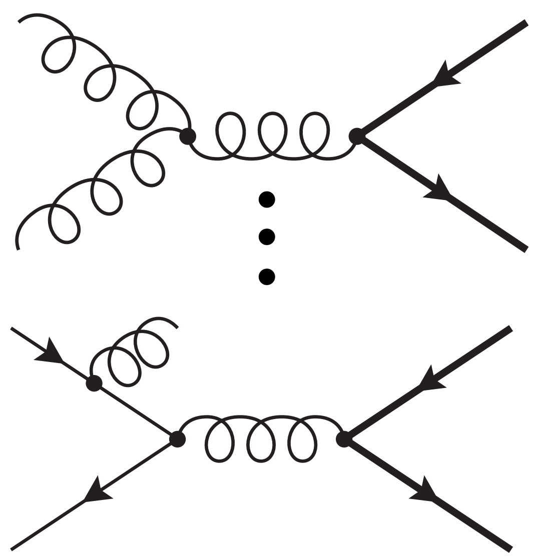
$$d\sigma_{ij\to Q\bar{Q}X} = \frac{1}{2s_{ij}}\overline{\sum}|\mathcal{M}_{ij\to Q\bar{Q}X}|^2 d\phi_n$$

NLO QCD

P. Nason, S. Dawson, R.K. Ellis, 1988
P. Nason, S. Dawson, R.K. Ellis, 1999 *
W. Beenakker, H. Kuif, W.L.van Neerven, J. Smith 1989 *

NNLO QCD

M. Czakon, P. Feilder, A. Mitov 2013
M. Czakon, P. Feilder, A. Mitov 2014 *
… + resummation, EW+QCD, NLO>>PS



$$F_i^D(z,\mu,m_h) = F_i^c(z,\mu,m_c)\otimes F^D_{\mathrm{n.p.}}(z)$$

z : normalised energy fraction

The first term = perturbative fragmentation function (PFF)
Has the job of resumming quasi-collinear logs: $\alpha_s^n \ln\left[m/Q\right]^k\ ,\ k\le n$

NLO B. Mele, P. Nason, Nucl. Phys. B **361** (1991) 626
NNLO K. Melnikov, A. Mitov PRD **70** (2004) 034027

In either case, n.p. piece extracted from precise D/B spectrum at LEP

* differential

Parton Distribution Functions (PDFs)

$$f_{i/A}(x, Q^2)$$
$$i = g,\, d\,,\bar{d}\,,u\,,\cdots$$

x : momentum fraction

Q^2 : parton virtuality

Global fits performed to a range of data (collisions involving a hadron)

The main examples being fixed-target, HERA, TeVatron, and LHC

Modern proton PDF fits:

ABMP PRD **96** (2017) 014011

CT PRD **93** (2015) 033006

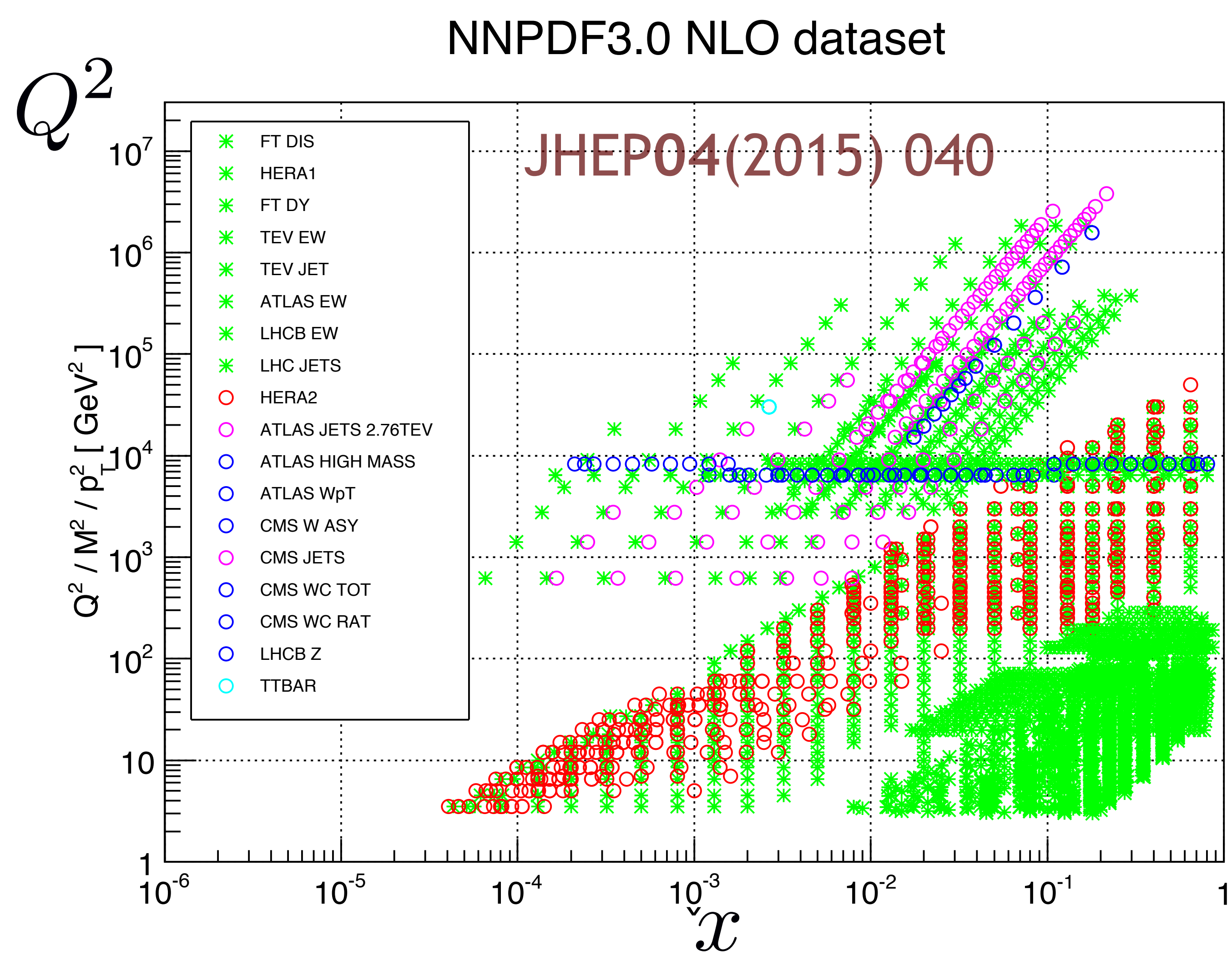
HERA EPJC **75** (2015) 580

MMHT EPJC **75** (2015) 204

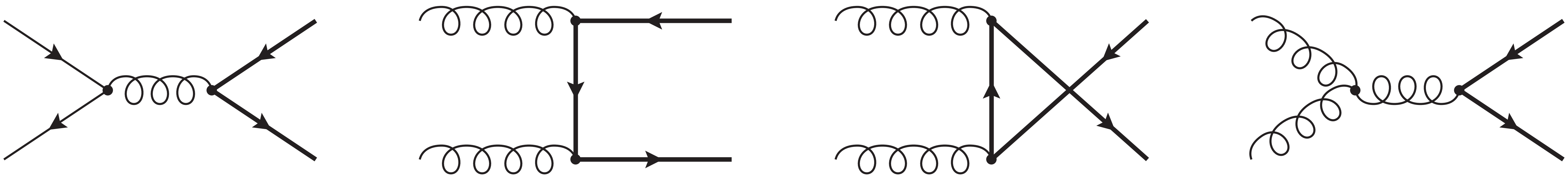
NNPDF JHEP **04** (2015) 040

More specialised: LUXQED, CJ

Nuclear: EPPS, nCTEQ, DSSZ…



Forward heavy quark production



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

dominant subprocess at LHC

$$p_1 = \sqrt{S}/2\,(x_1, 0, 0, x_1)$$

x_i : momentum fraction

y_j : rapidity

$\sqrt{S}$: hadronic COM

m_T : transverse mass

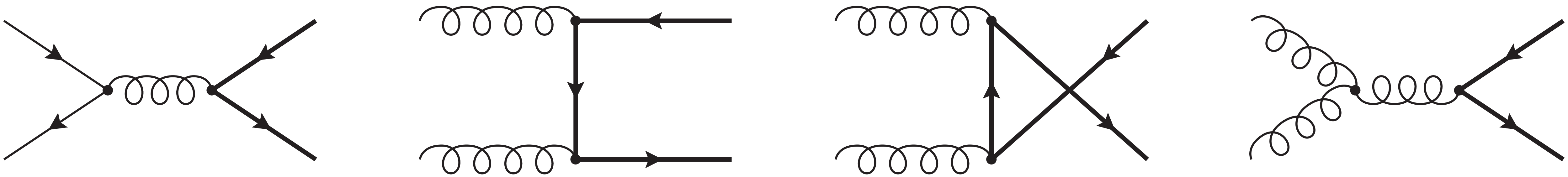
LO PDF sampling occurs at

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

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

Forward heavy quark production



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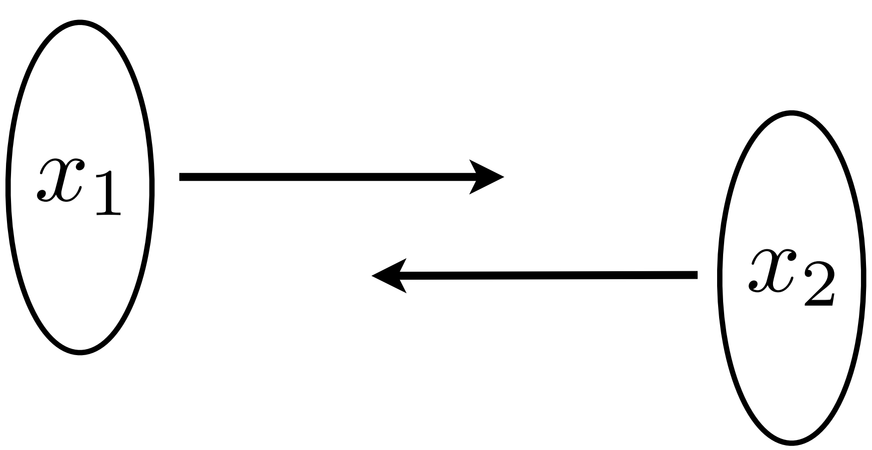
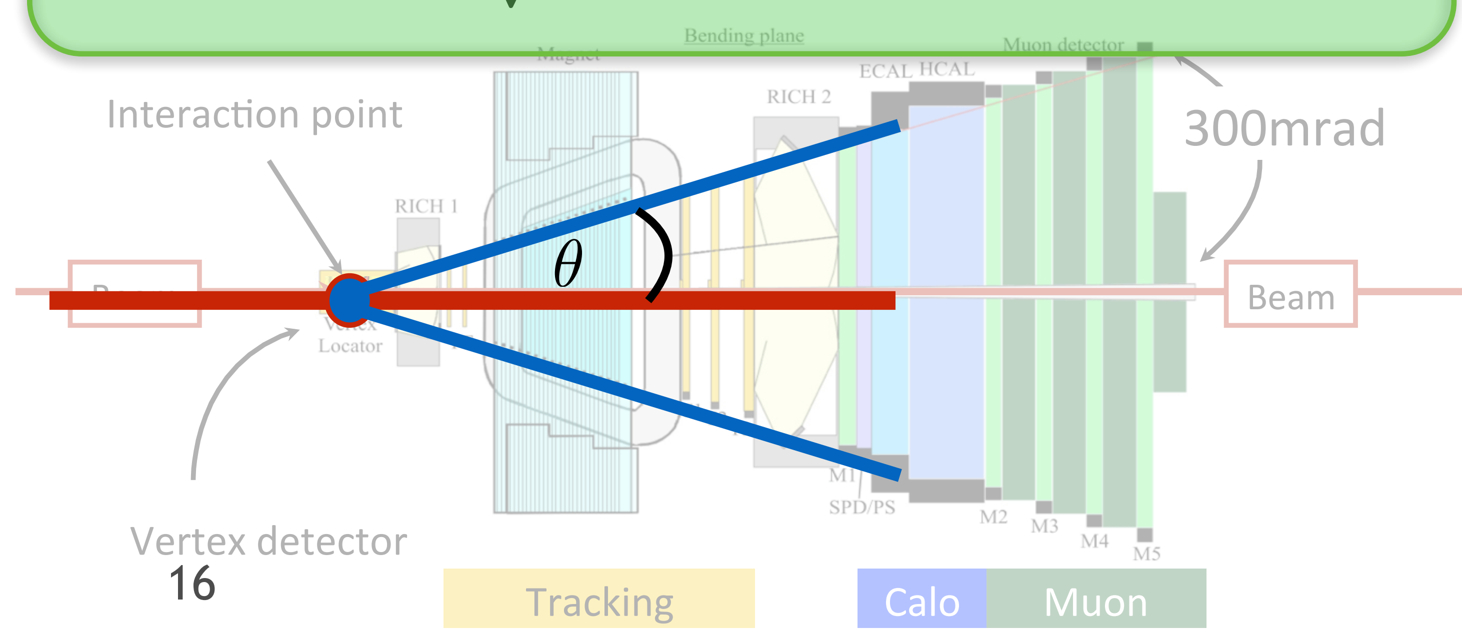
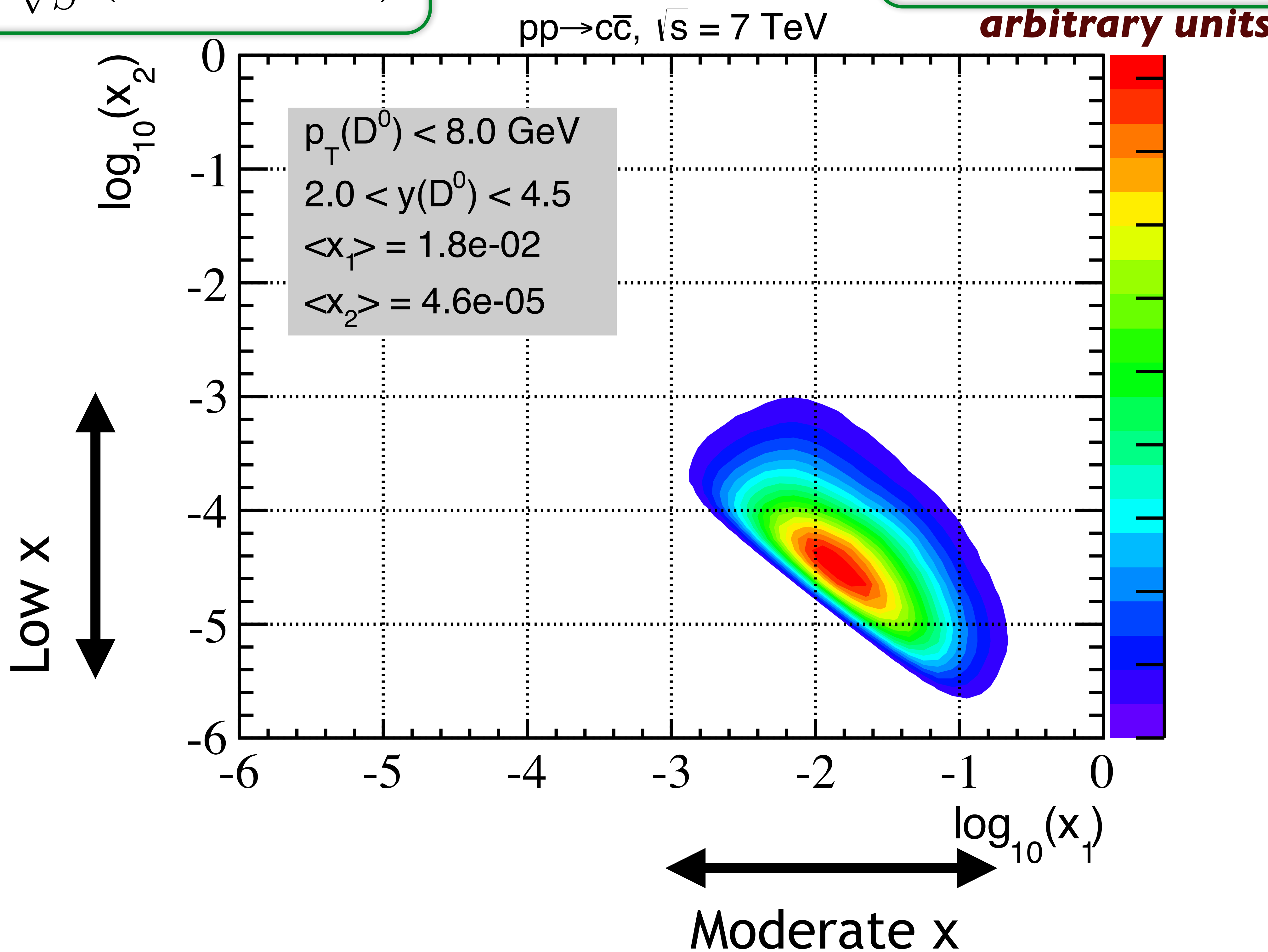




$$x_{1,(2)} = \frac{m_T}{\sqrt{S}} \left(e^{(-)y_3} + e^{(-)y_4} \right)$$

$$\sqrt{\hat{s}} = \sqrt{x_1\, x_2\, S} \geq 2m_c$$



Require a D hadron within LHCb acceptance at 7 TeV

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

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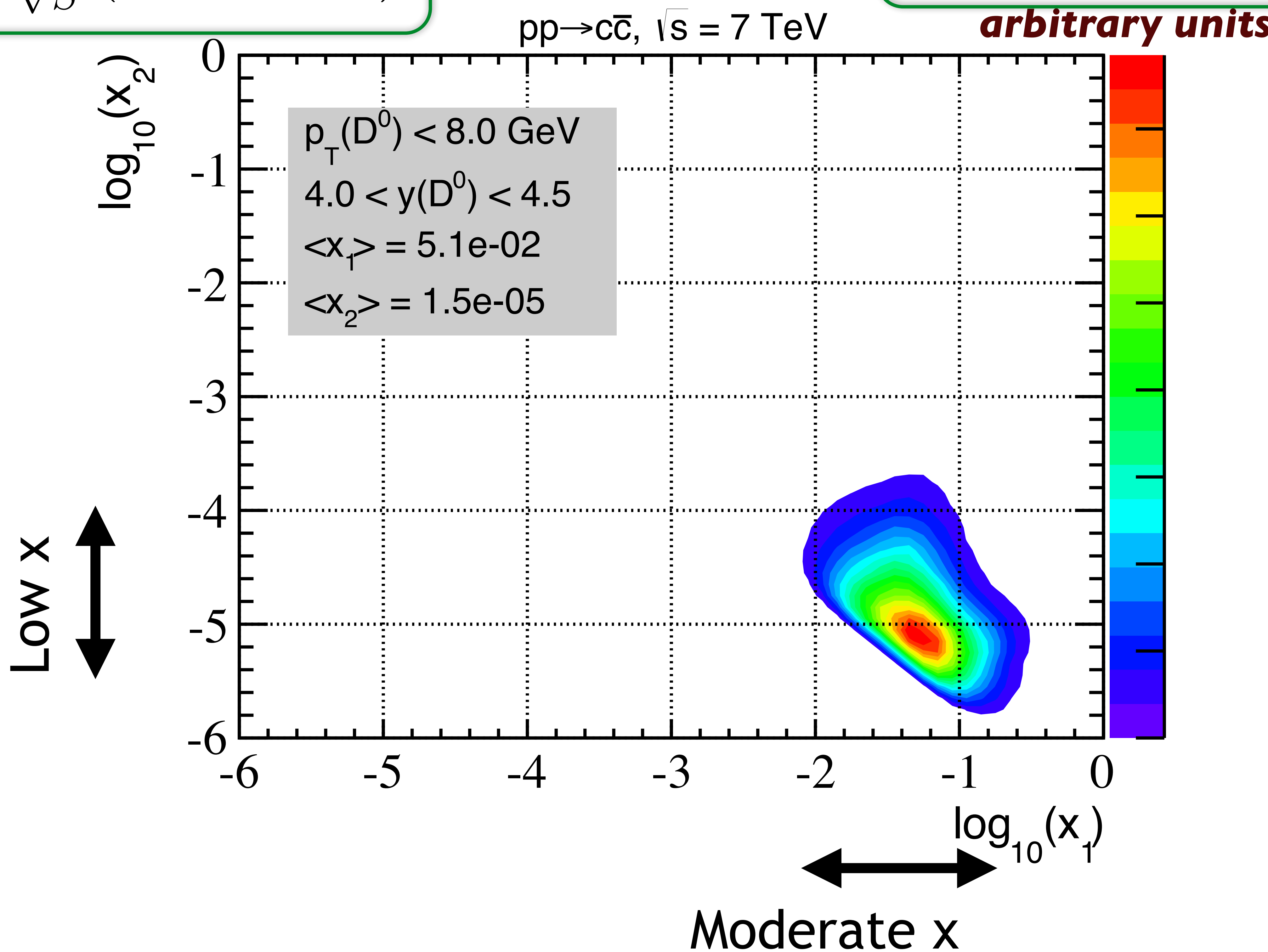

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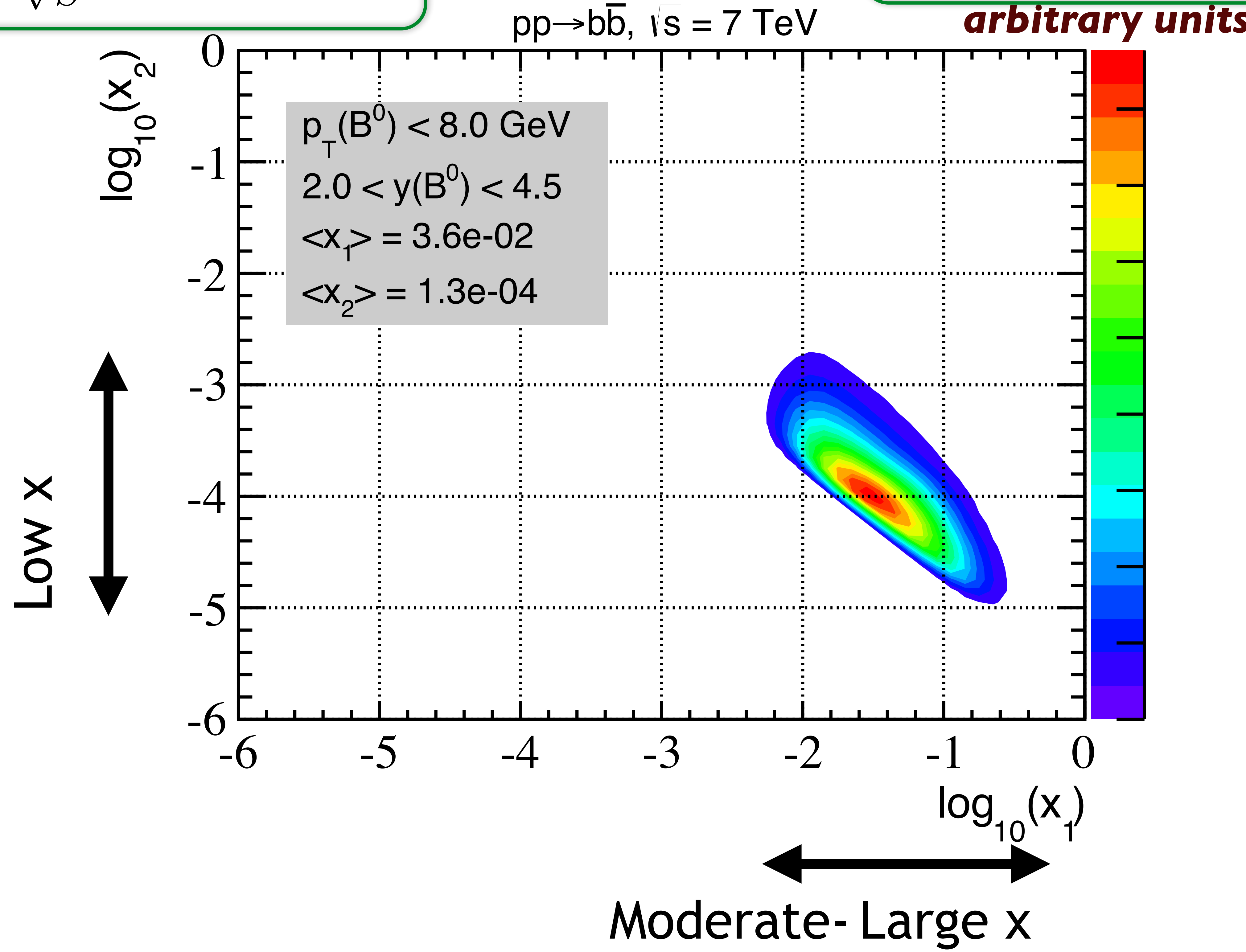
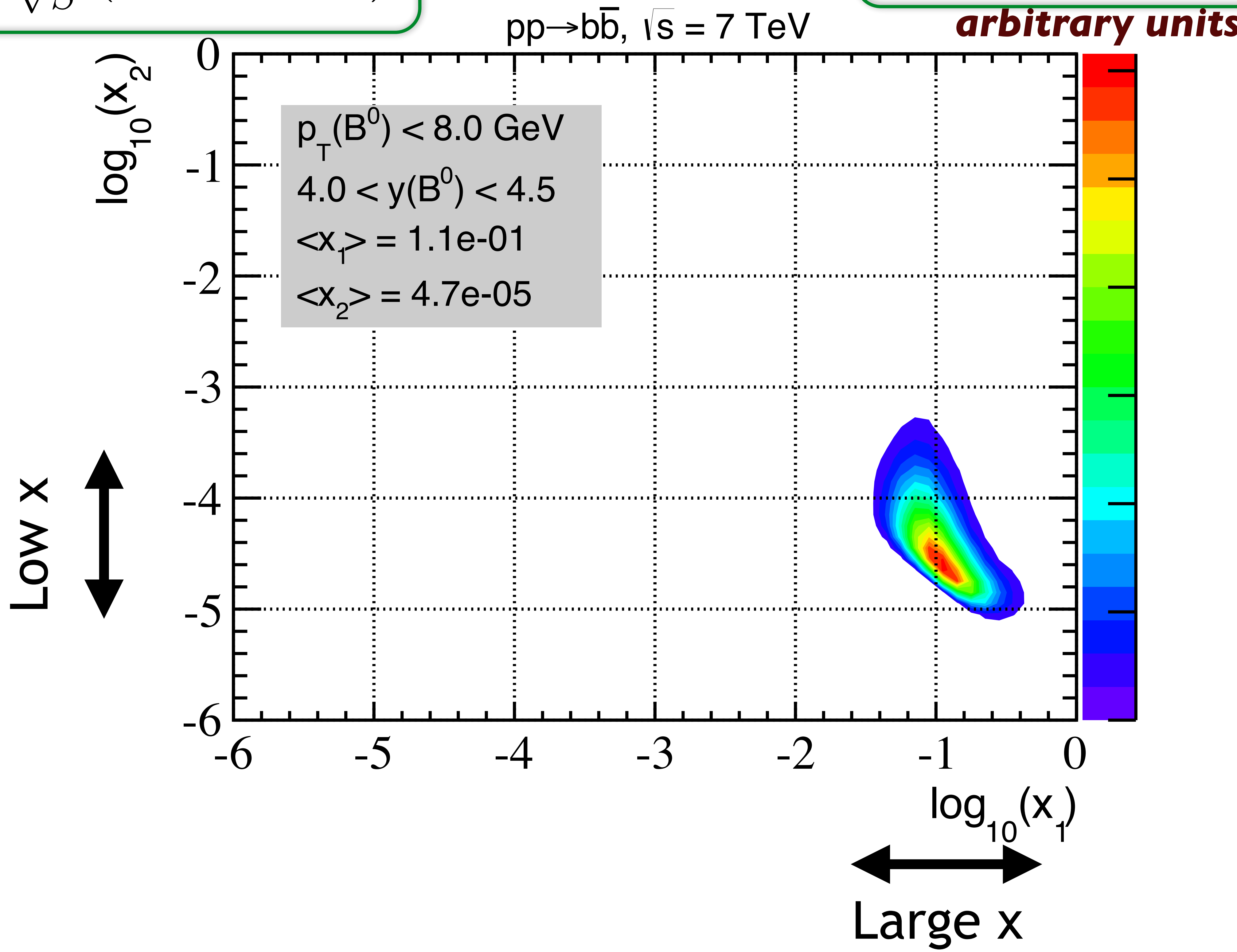


Require a B hadron within LHCb acceptance at 7 TeV

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

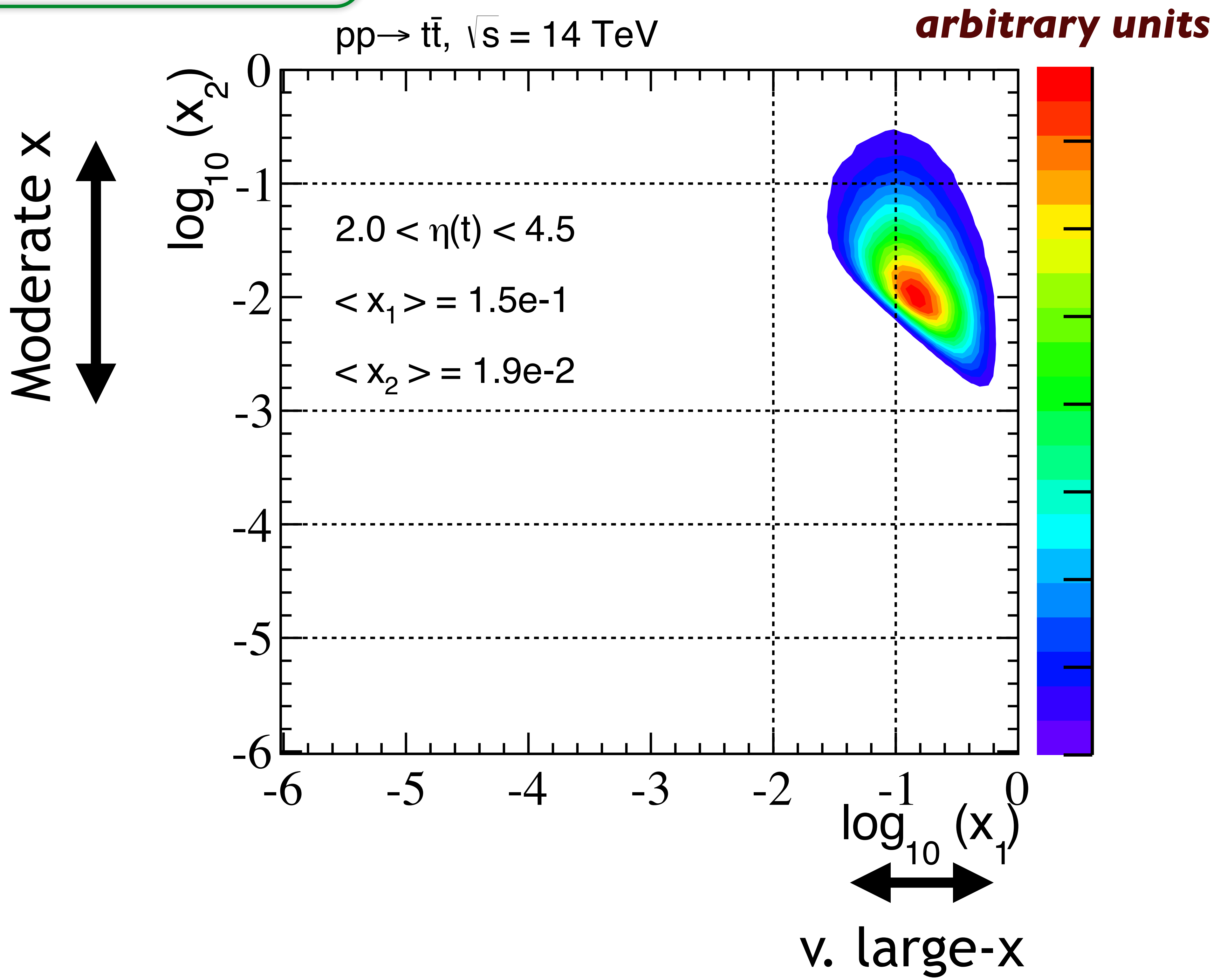
$$\sqrt{\hat{s}} = \sqrt{x_1 \, x_2 \, S} \geq 2m_b$$



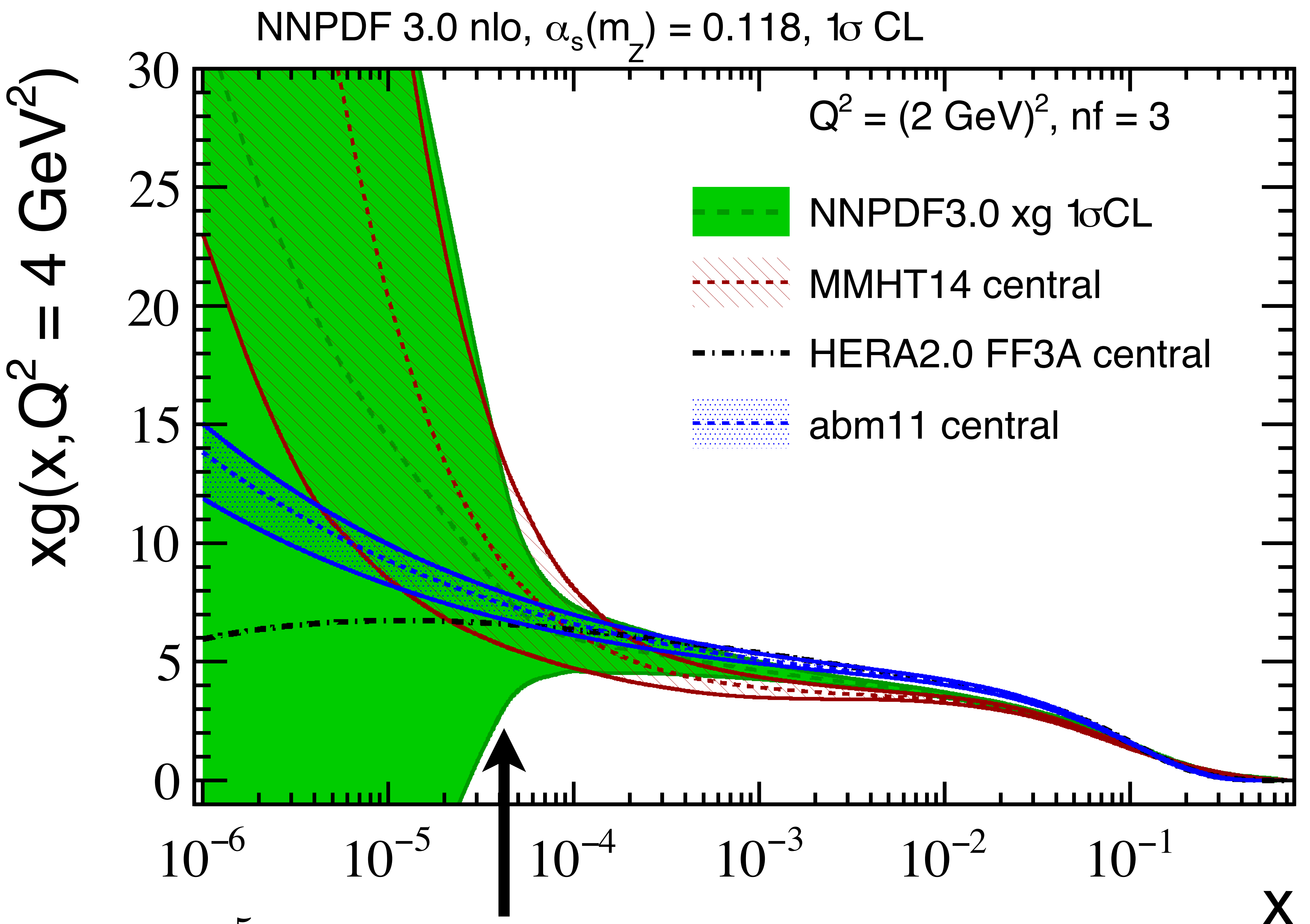
Require a B hadron within LHCb acceptance at 7 TeV

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

$$\sqrt{\hat{s}} = \sqrt{x_1\, x_2\, S} \geq 2m_t$$

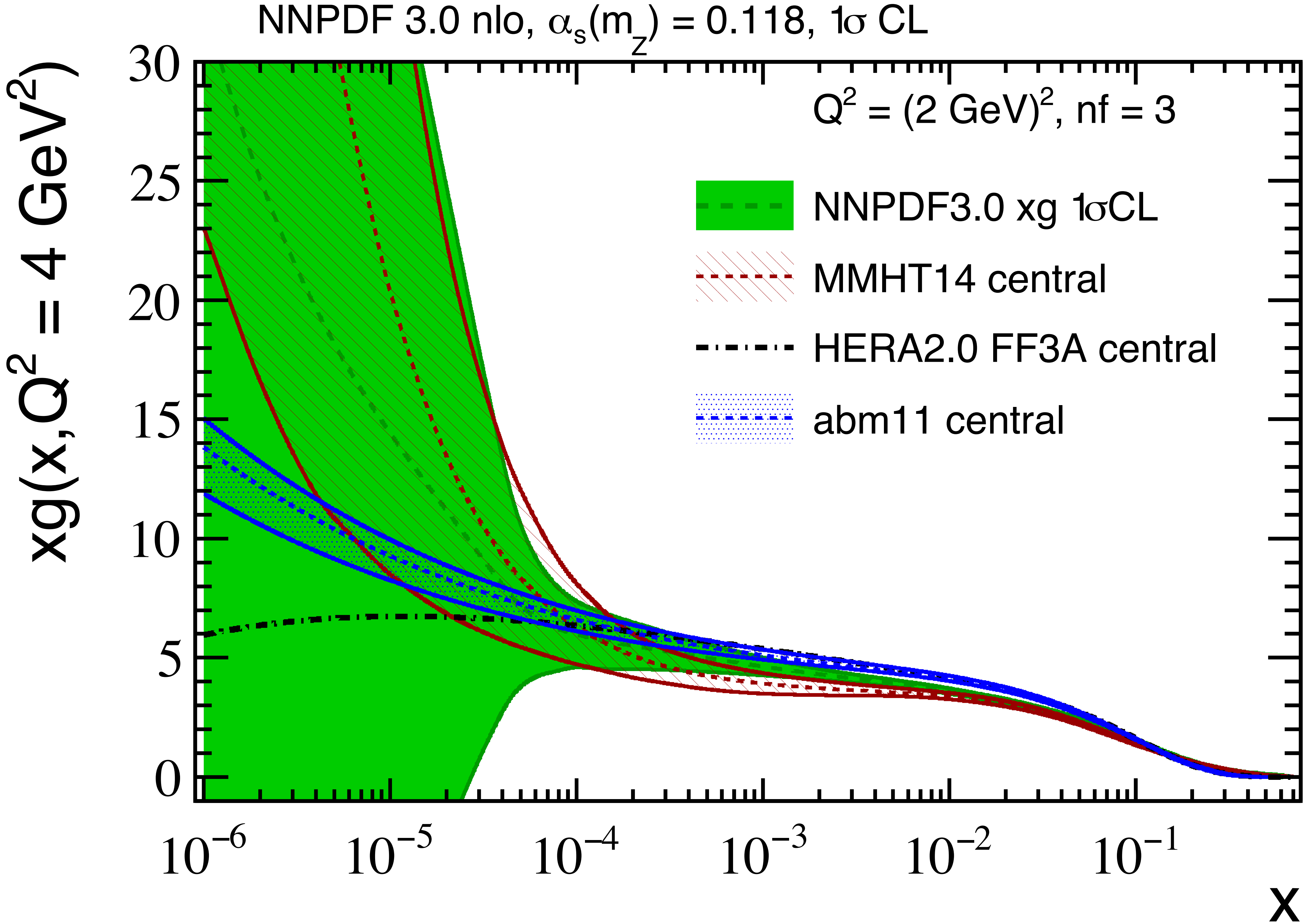


Require a top within LHCb acceptance at 14 TeV



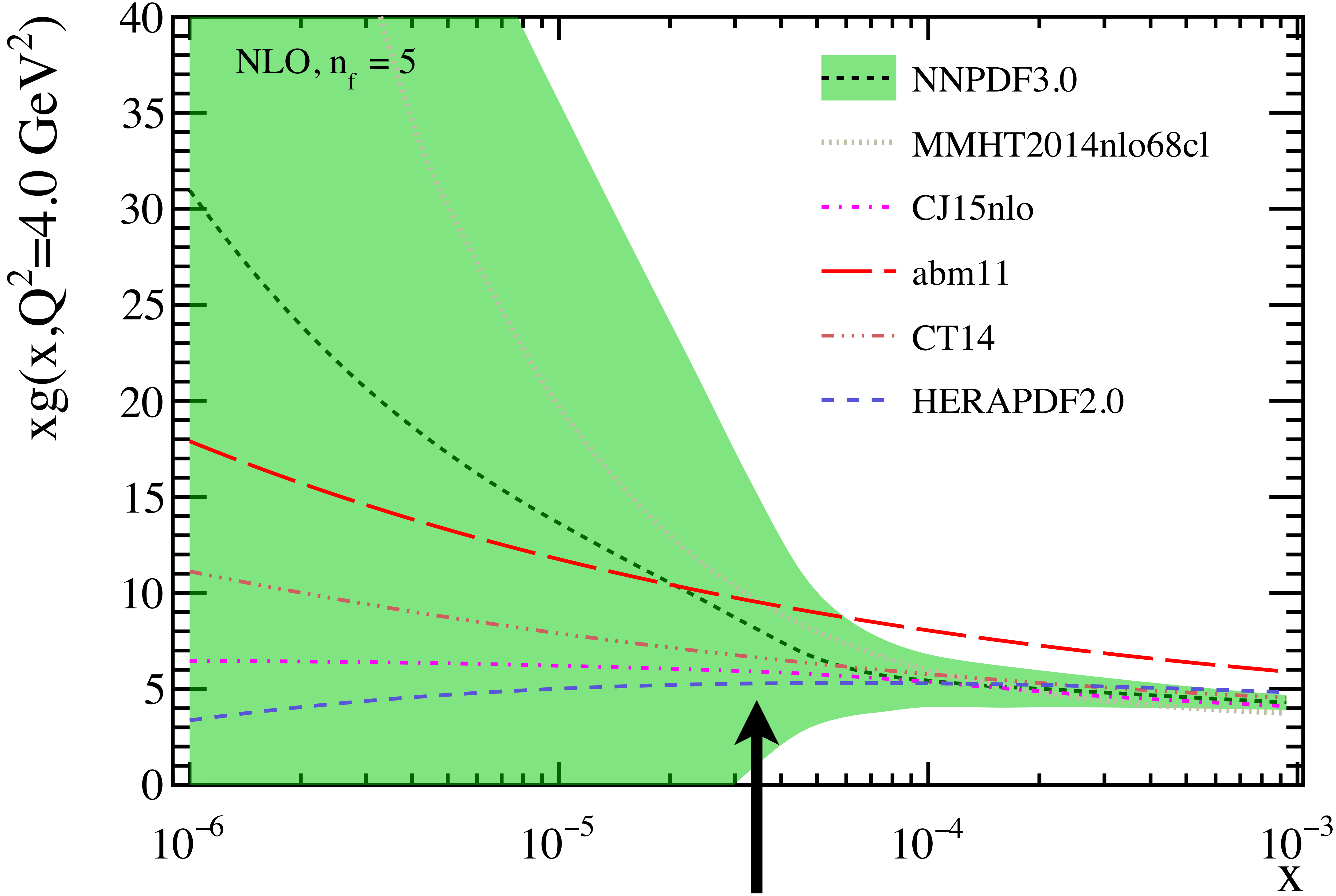
$x \geq 3 \cdot 10^{-5}$ PDF constraints from HERA charm data

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



MMHT14 gluon parameterisation (polynomial function in x):

$$xg(x, Q_0^2) = A_g(1-x)^{\eta_g} x^{\delta_g} \left(1 + \sum_{i=1}^{2} a_{g,i} T_i^{\mathrm{Ch}}(y(x))\right) + A_{g'}(1-x)^{\eta_{g'}} x^{\delta_{g'}}$$



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

Strategy

As a Baseline, use the NNPDF3.0 NLO Global PDF fit

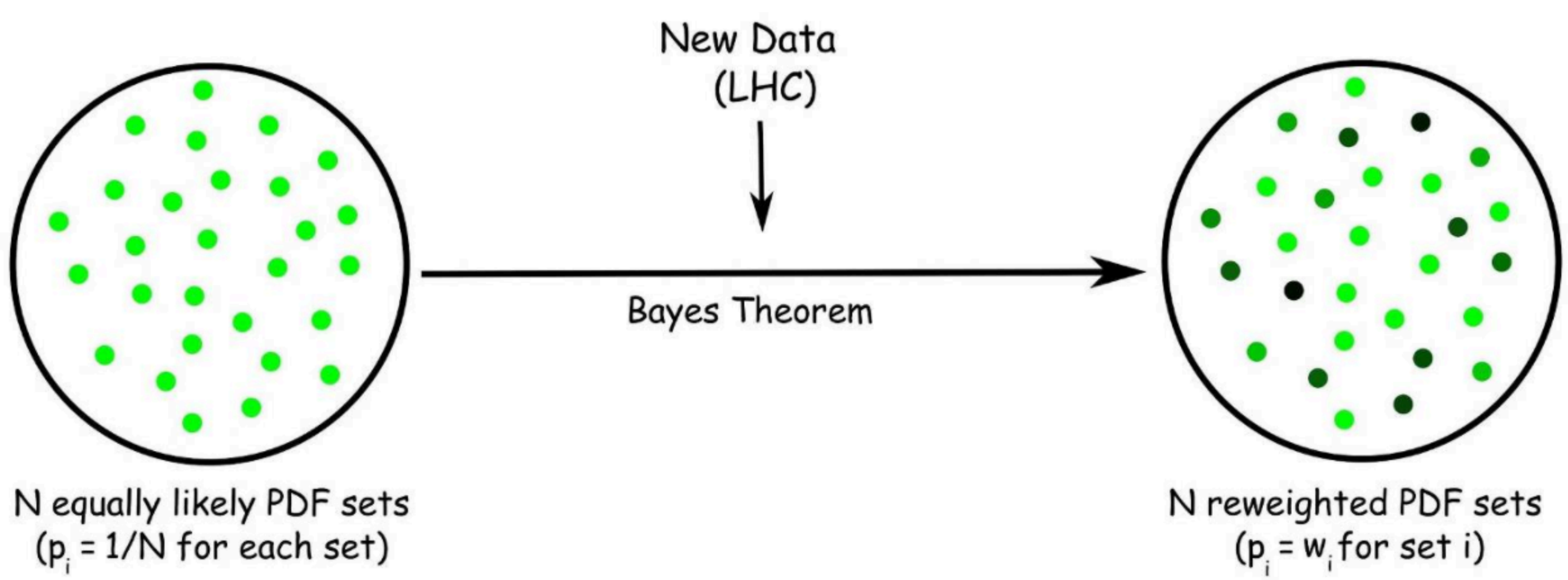
JHEP **04** (2015) 040

$$f_i(x, Q_0) = A_i x^{-\alpha_i} (1-x)^{\beta_i} \mathrm{NN}_i(x)$$

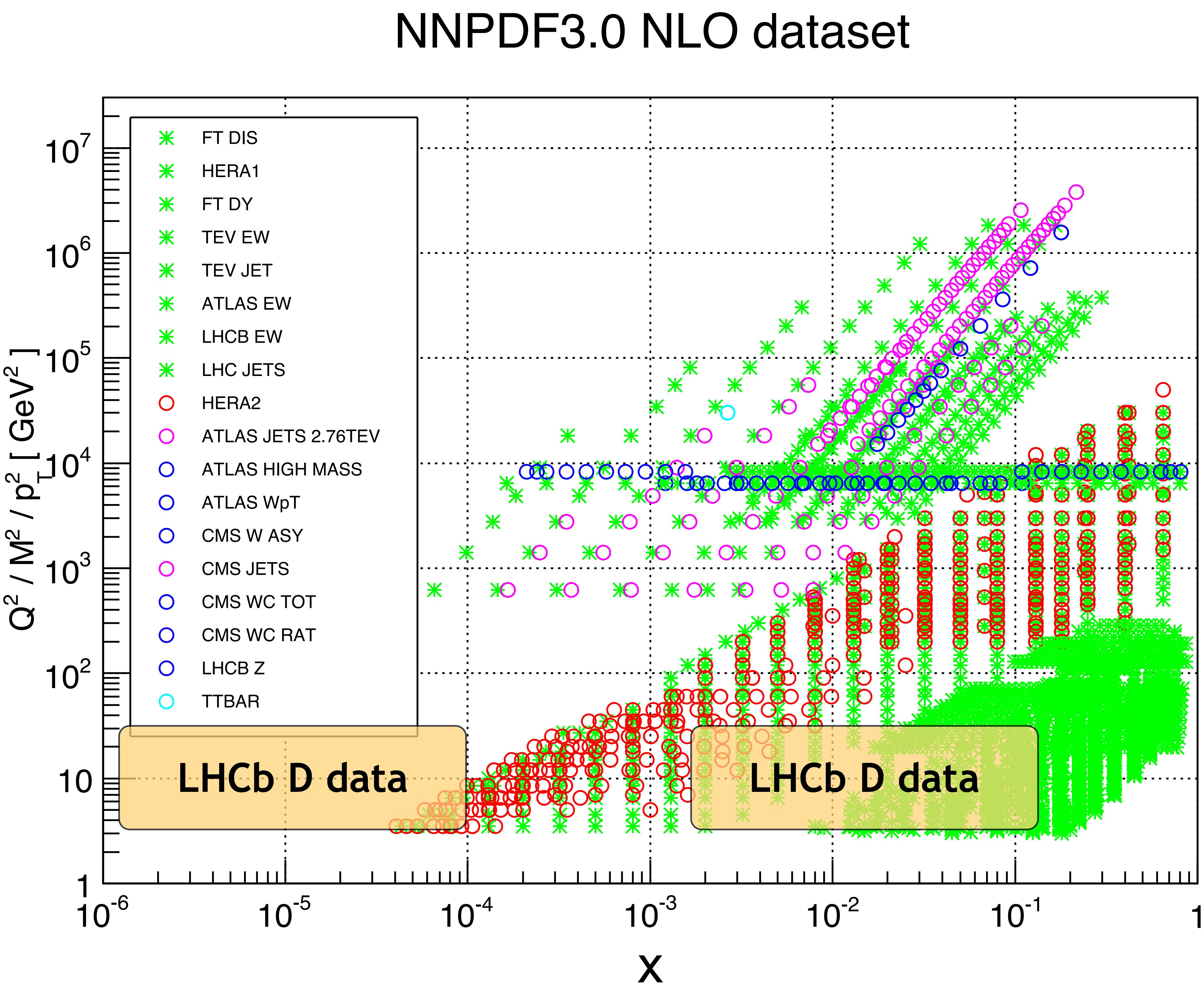
Pre-processing terms

Functional form parameterised by neural network

Extend the data set to include the LHCb D hadron data



See http://nnpdf.mi.infn.it/research/reweighting/



Kinematic coverage of Global Fit

Studying the LHCb data

Data:
* pp > D+X, at 5 TeV LHCb Collaboration, JHEP**06**(2017) 147
* pp > D+X, at 7 TeV LHCb Collaboration, Nucl. Phys. **B871** (2013)
* pp > D+X, at 13 TeV LHCb Collaboration, JHEP**05**(2017) 074

Theory baseline:
* NLO+Pythia8, achieved with POWHEG nf=3 scheme

What exactly is measured?

$$pp \to D + X$$

$\hookrightarrow D^0,\ D^+,\ D_s,\ D^{*+}\ (+c.c.)$

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_T^D\,\mathrm{d}y^D} = \frac{1}{\Delta p_T^D\,\Delta y^D} \cdot \frac{N_i(D \to f + c.c.)}{\epsilon_i(D \to f)\mathcal{B}(D \to f)\kappa\mathcal{L}_{\mathrm{int}}}$$

What exactly is measured?

$$pp \to D + X$$

$\to D^0,\ D^+,\ D_s,\ D^{*+}\ (+c.c.)$

Number of events

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_T^D\,\mathrm{d}y^D} = \frac{1}{\Delta p_T^D\,\Delta y^D} \cdot \frac{N_i(D \to f + c.c.)}{\epsilon_i(D \to f)\mathcal{B}(D \to f)\kappa\mathcal{L}_{\mathrm{int}}}$$

$\mathcal{L}_{\mathrm{int}} \to$ lumi

bins

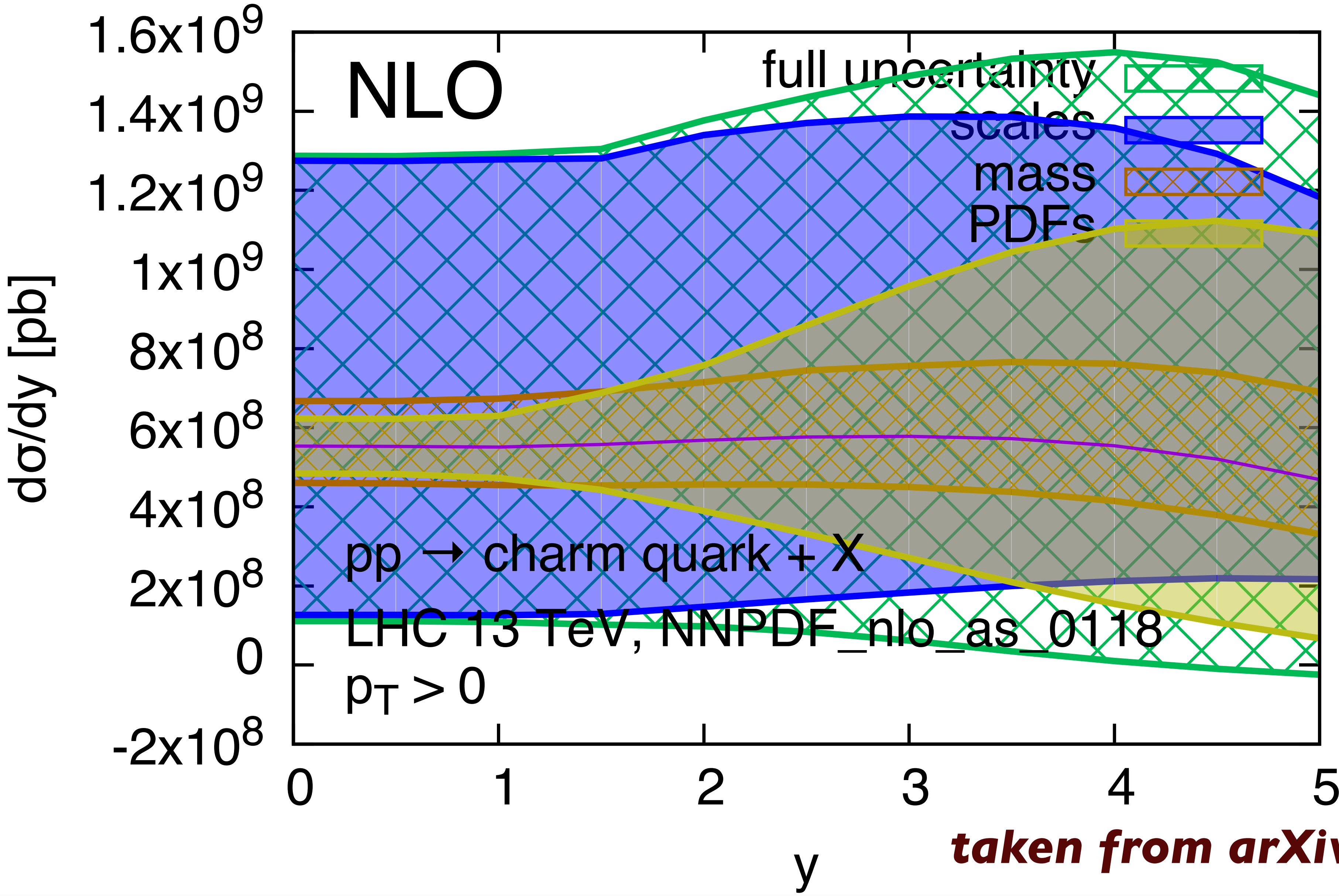
efficiency to measure f

branching fraction to f

hardware efficiency

- Measurements performed at 3 CoM Energies (5, 7, 13 TeV)
- 8 bins within $p_T^D < 8.0$ GeV, 5 bins within $2.0 < y^D < 4.5$ (40 total)

In total approximately 480 data points



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

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

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

CoM Energy

Measurements performed double differentially in p_T^D and y_D

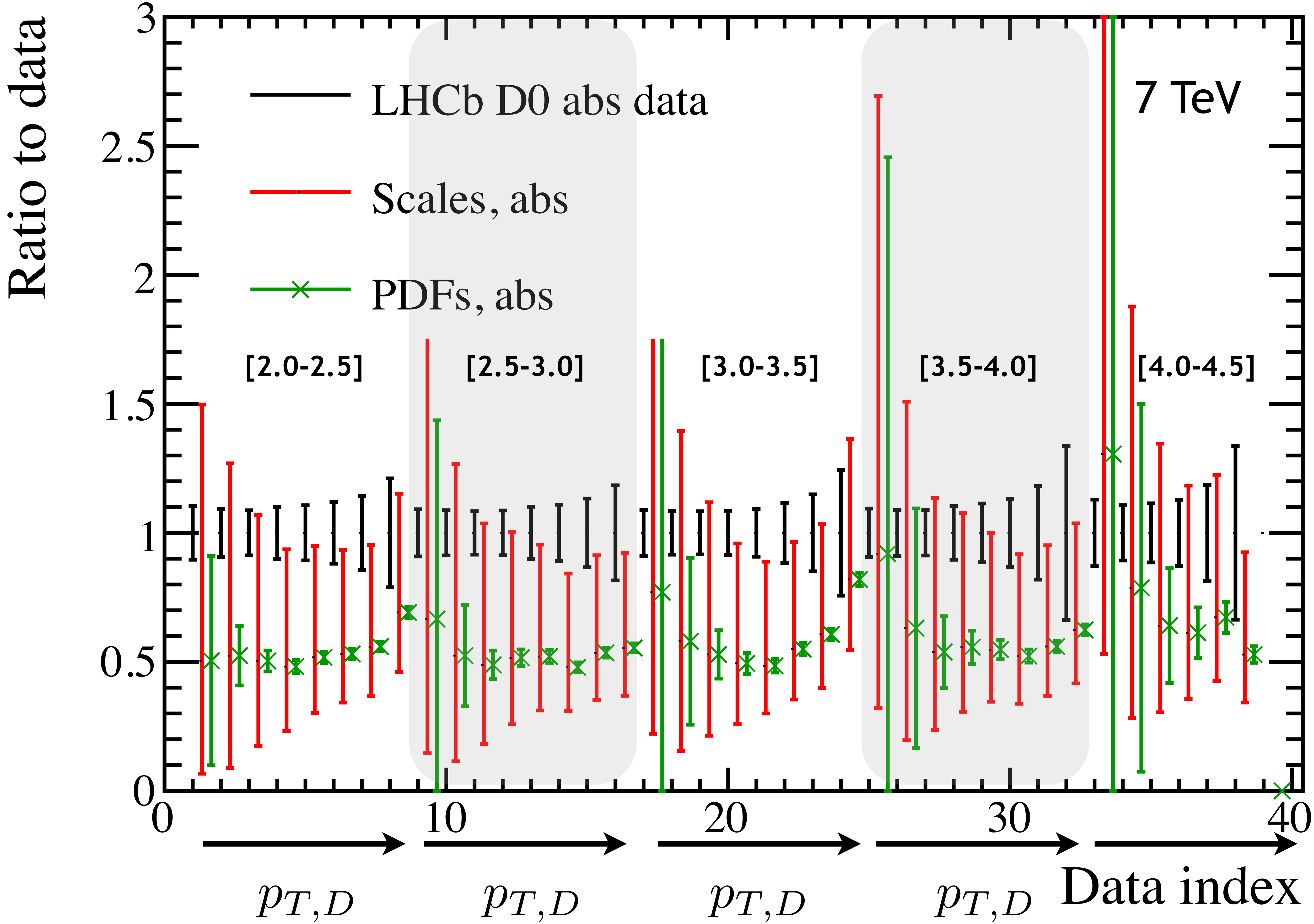
$$N_X^{ij} = \frac{d^2\sigma(\text{X TeV})}{dy_i^D d(p_T^D)_j} \Bigg/ \frac{d^2\sigma(\text{X TeV})}{dy_{\text{ref}}^D d(p_T^D)_j}$$

Measurements performed at multiple hadronic CoM values

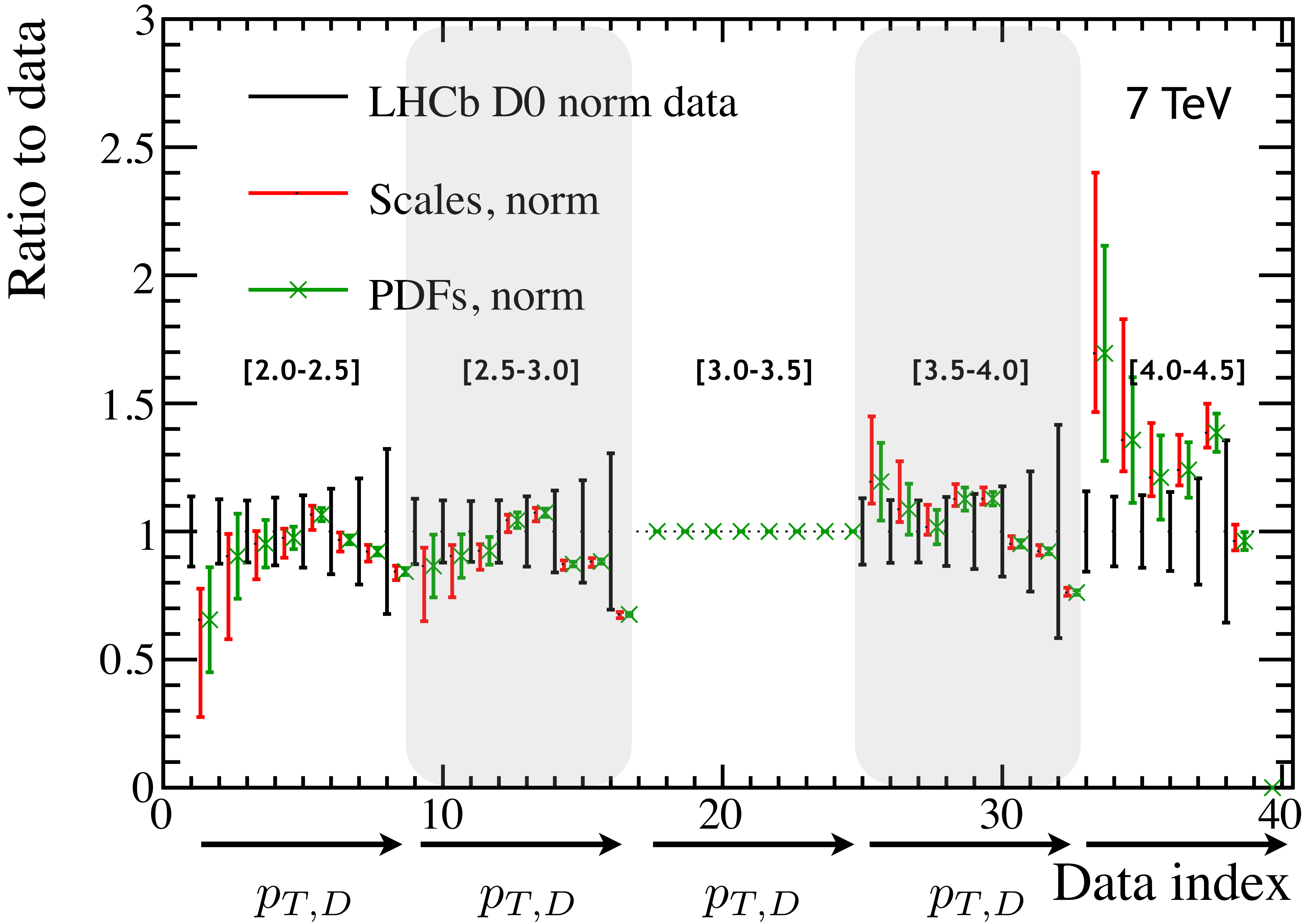
$$R_{13/X}^{ij} = \frac{d^2\sigma(13\ \text{TeV})}{dy_i^D d(p_T^D)_j} \Bigg/ \frac{d^2\sigma(\text{X TeV})}{dy_{\text{i}}^D d(p_T^D)_j}$$

pros: theoretical (and experimental) uncertainties highly correlated

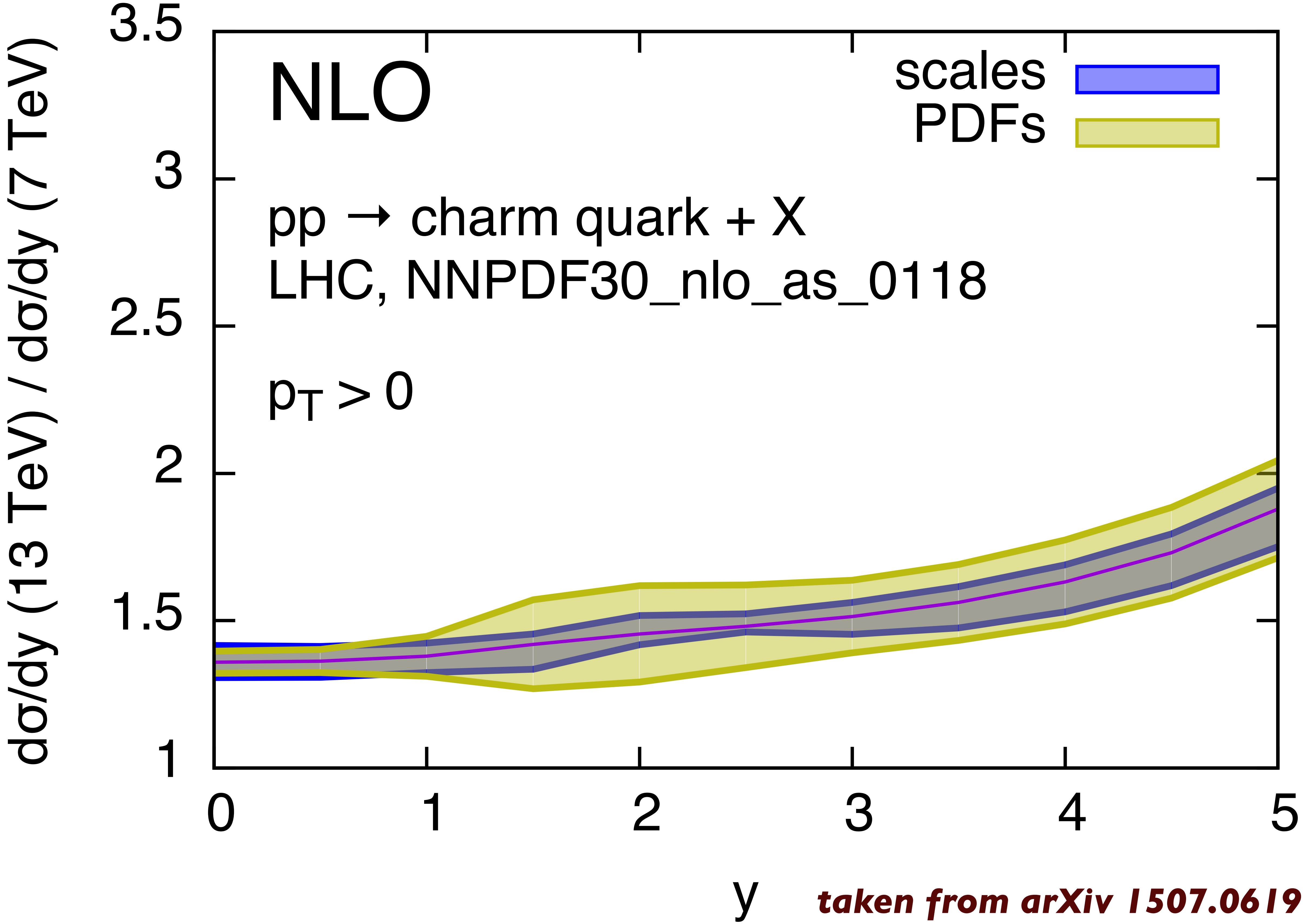
cons: PDF uncertainties **also** correlated (lose sensitivity to PDFs)



Absolute cross-section



Normalised cross-section



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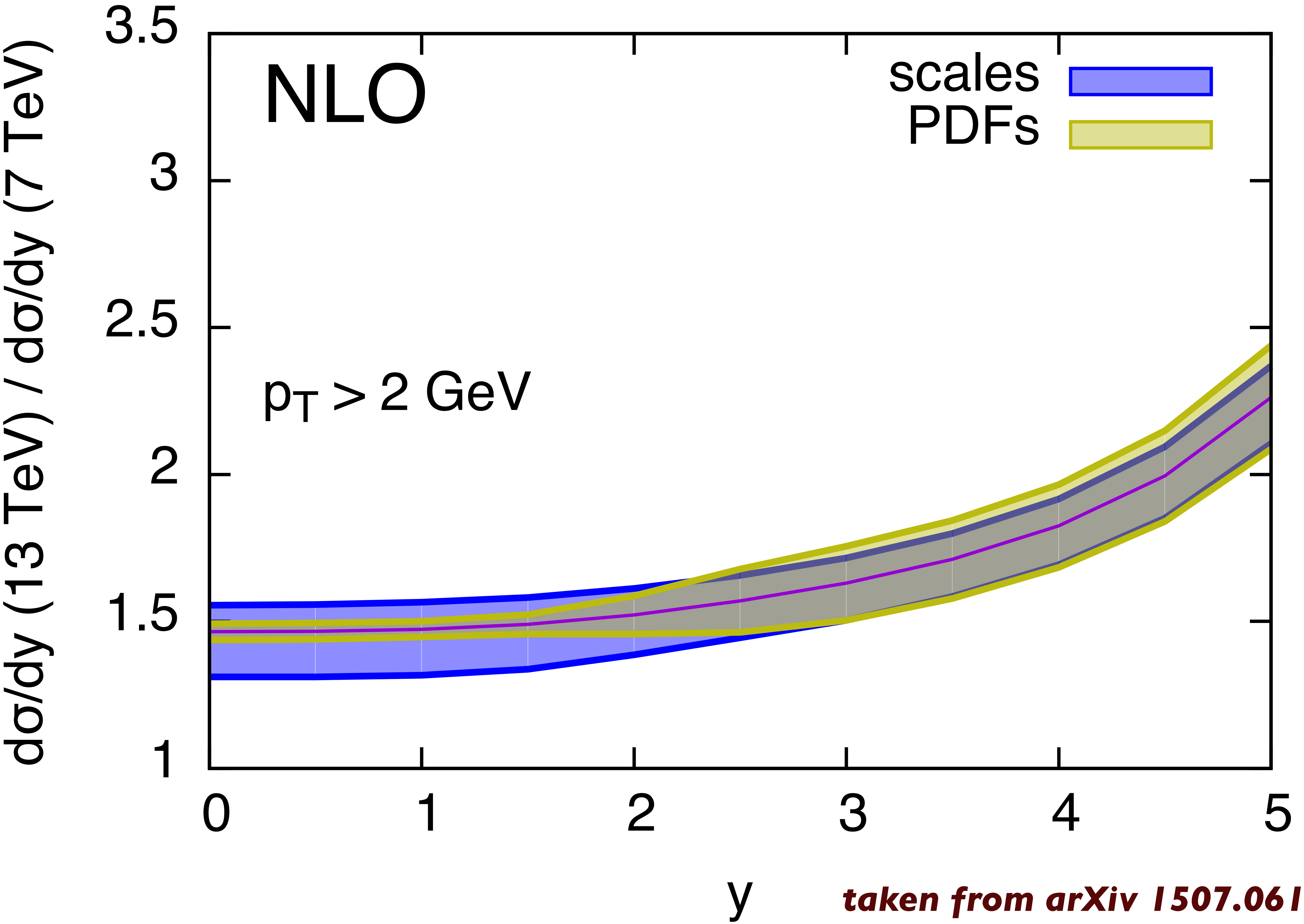
Ratio of cross-sections



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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 (reweighting or fits)

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
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Analyses of absolute D cross section data, arXiv:1705.08845
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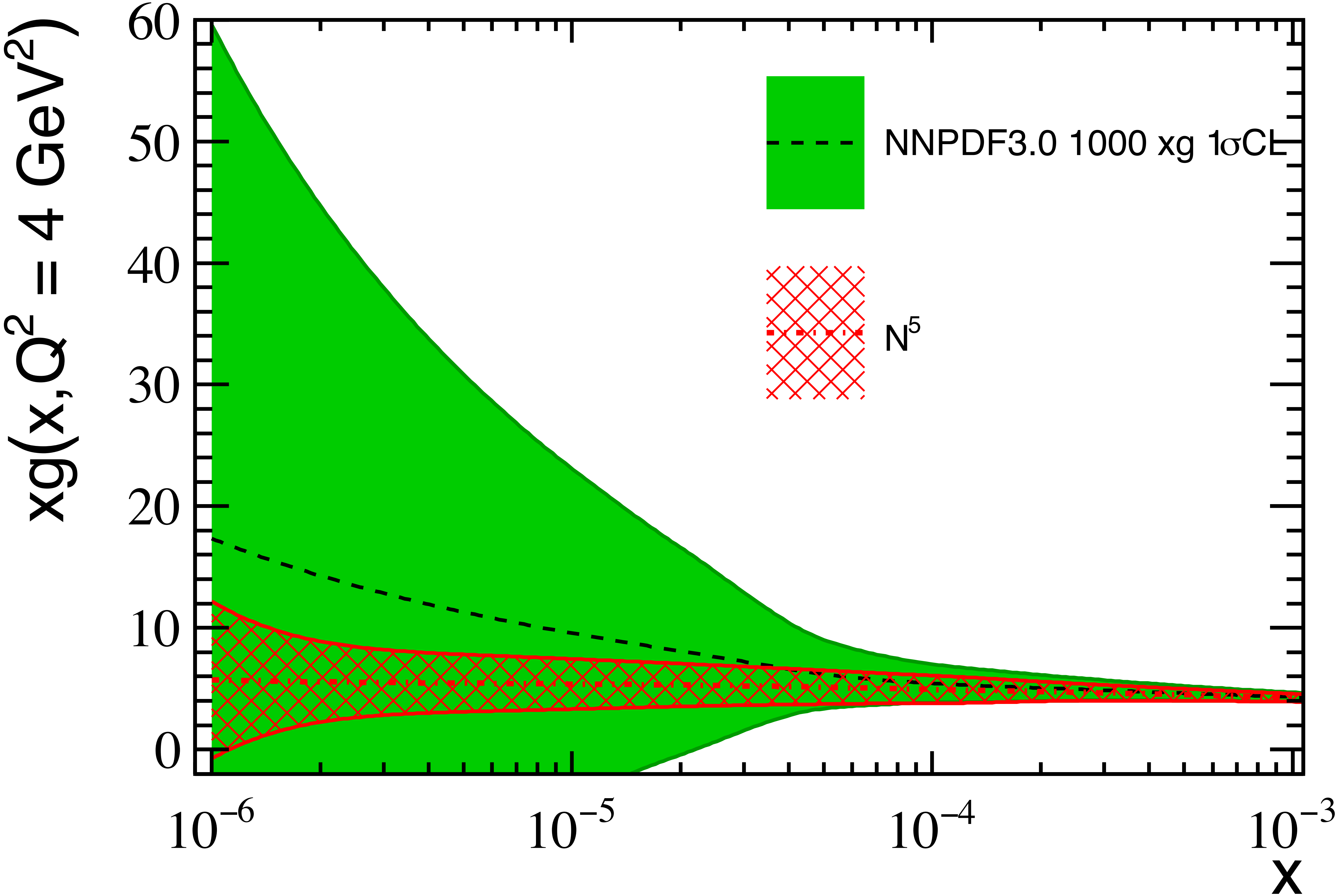
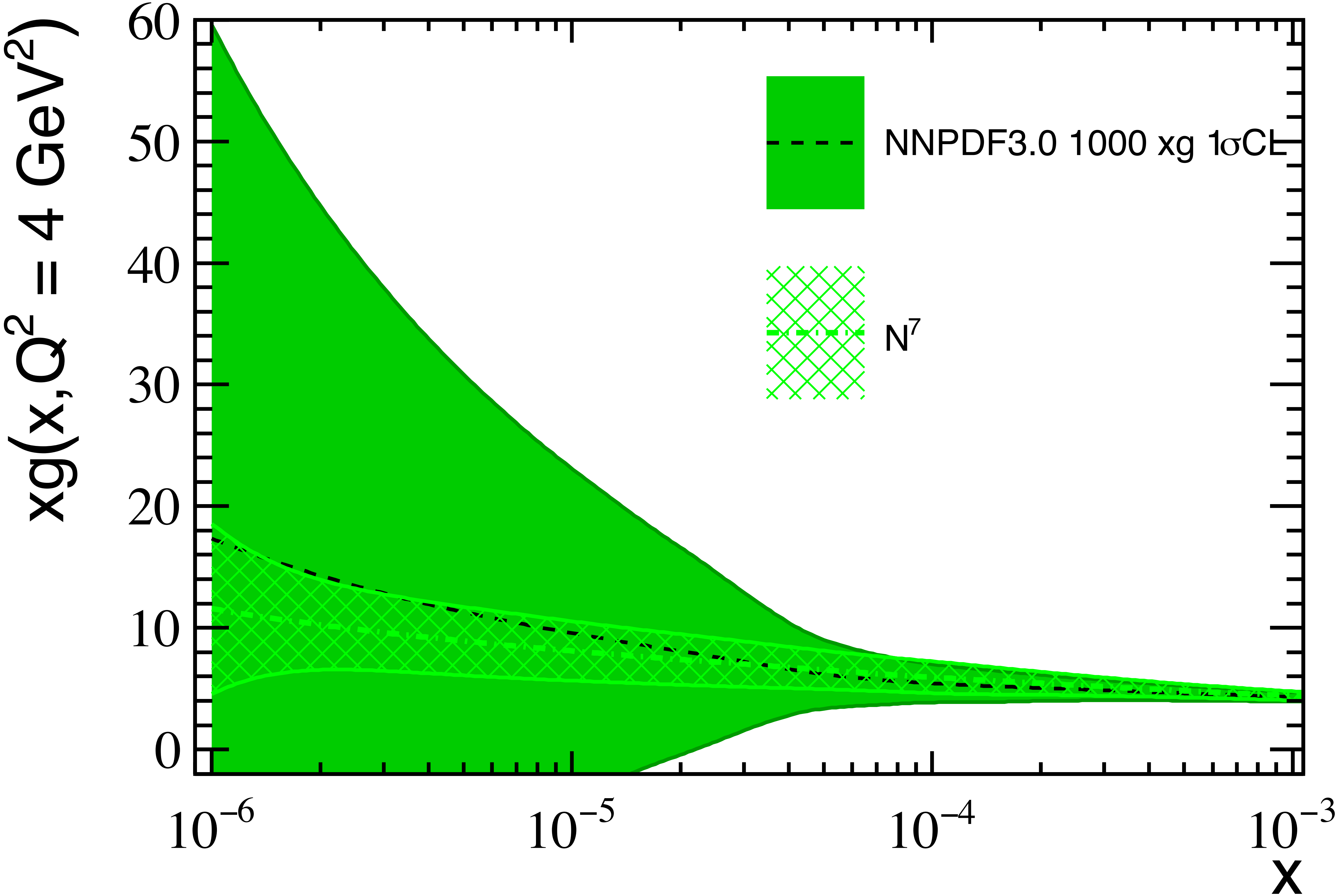
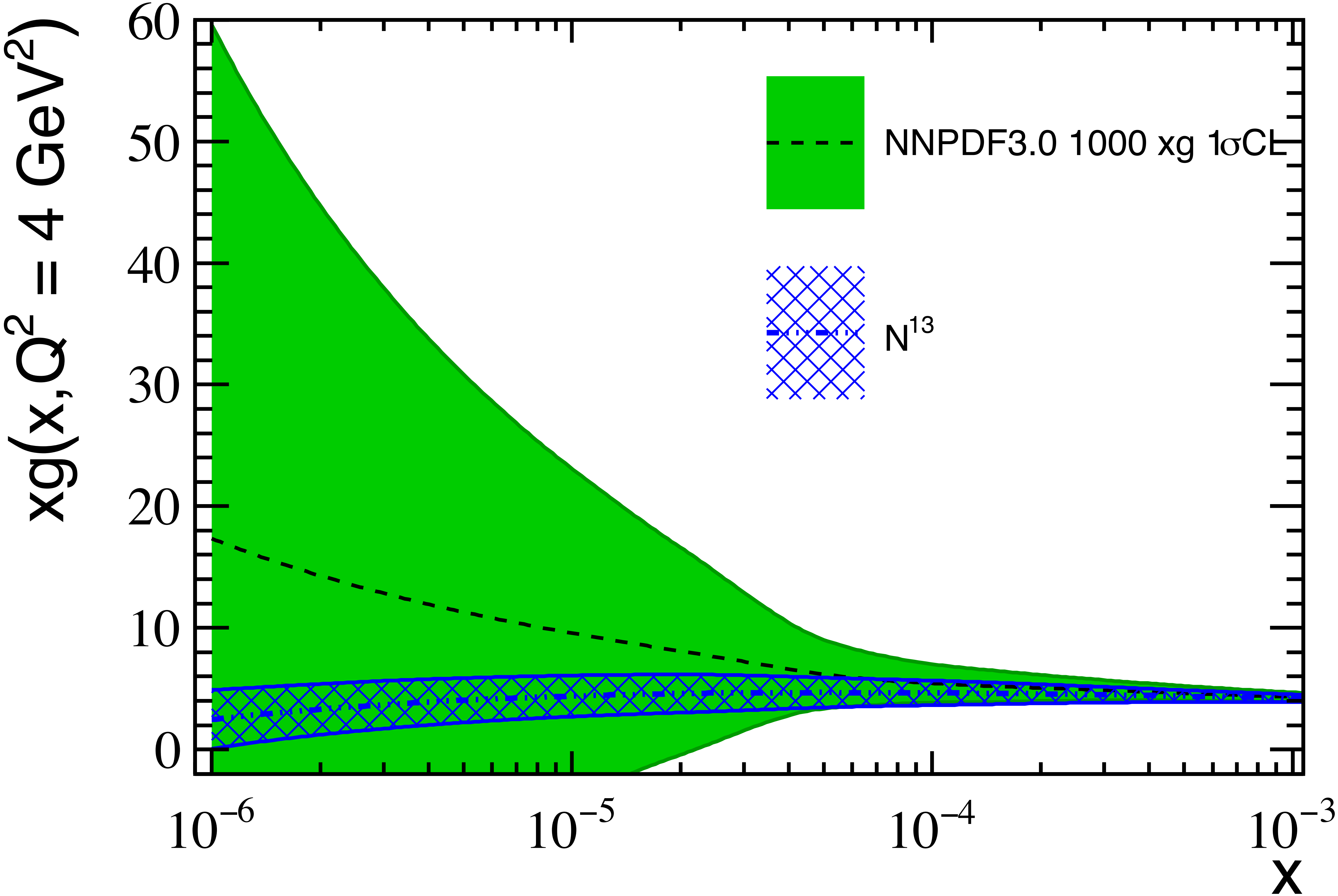


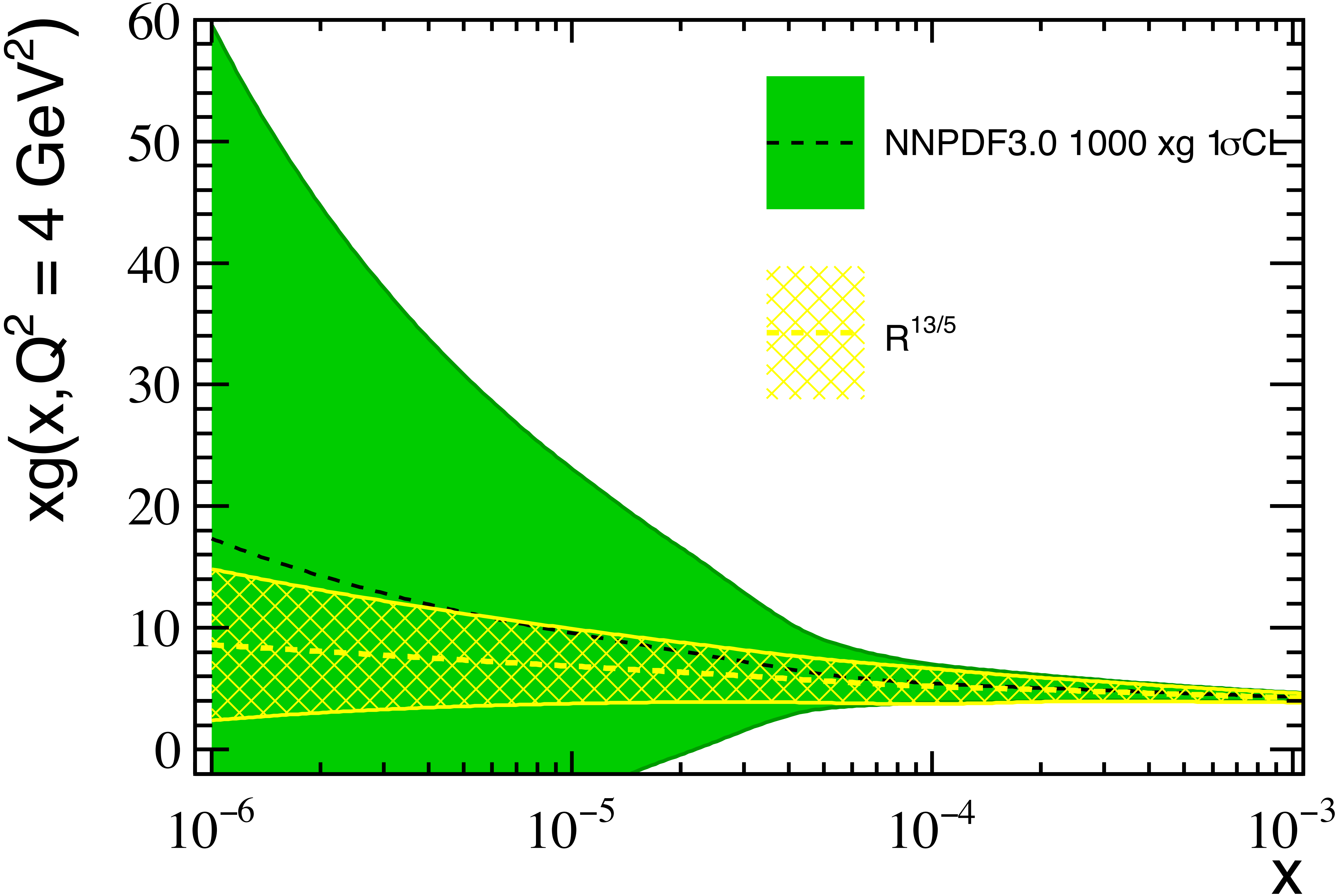
$xg(x, Q^2 = 4\ GeV^2)$
60
50
40
30
20
10
0
NNPDF3.0 1000 xg 1σCL
N^5
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x



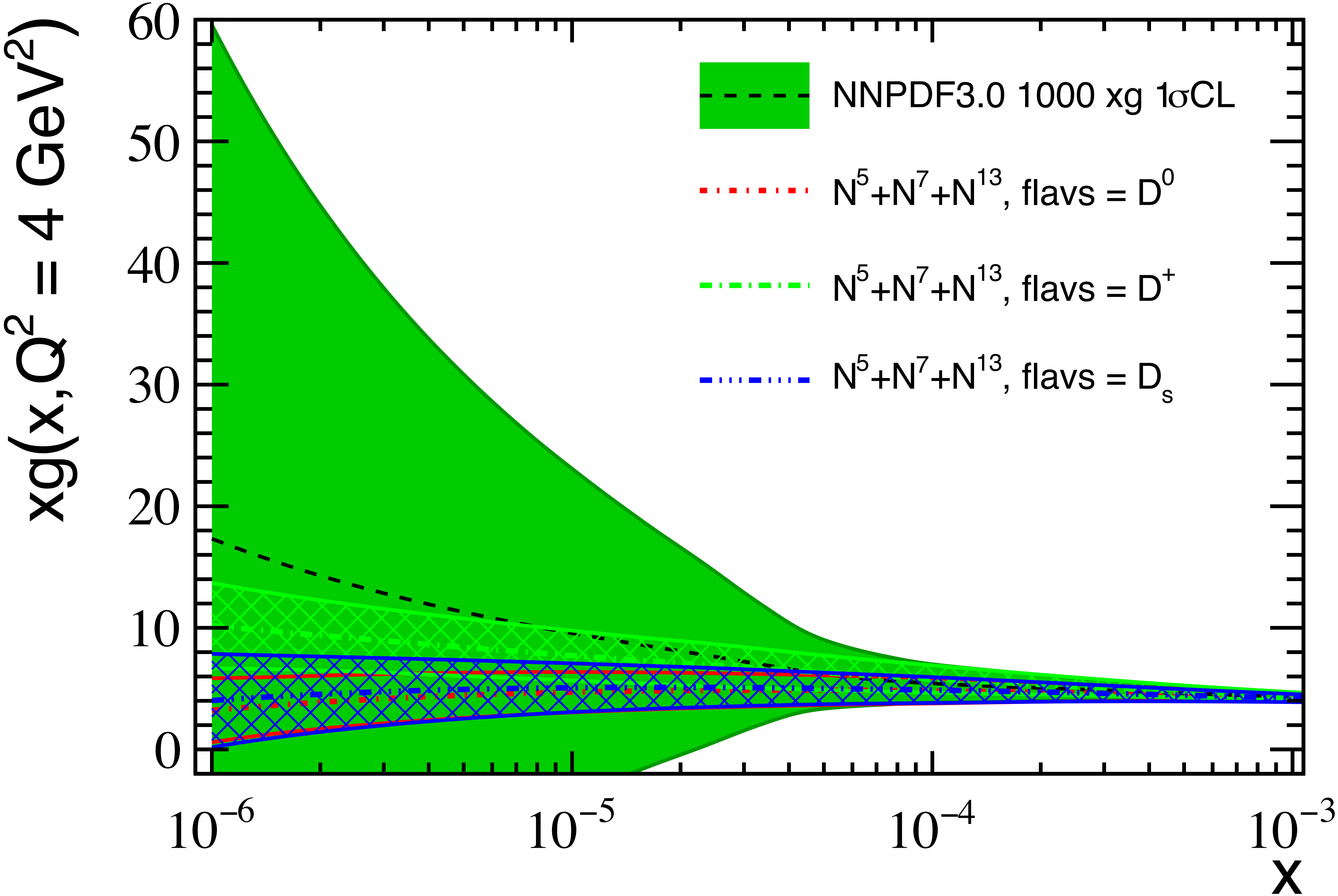
$xg(x,Q^2 = 4\ GeV^2)$
60
50
40
30
20
10
0
NNPDF3.0 1000 xg 1σCL
N^7
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x



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



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



$xg(x,Q^2 = 4\ GeV^2)$
60
50
40
30
20
10
0
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

Observable

Number of data points

$N_5(84)$	$N_7(79)$	$N_{13}(126)$	$R_{13/5}(107)$	$R_{13/7}(102)$
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

$$\chi^2/N_{\mathrm{dat}} = \sum_{i,j}(O_i - T_i)\sigma_{ij}^{-1}(O_j - T_j)$$

Theoretical uncertainties/cross checks

Choice of dynamical reference scale used in calculation

$$\mu_0 = \sqrt{p_{T,Q}^2 + m_Q^2}\,, \qquad \mu_0 = \sqrt{p_{T,Q}^2 + (2m_Q)^2}$$

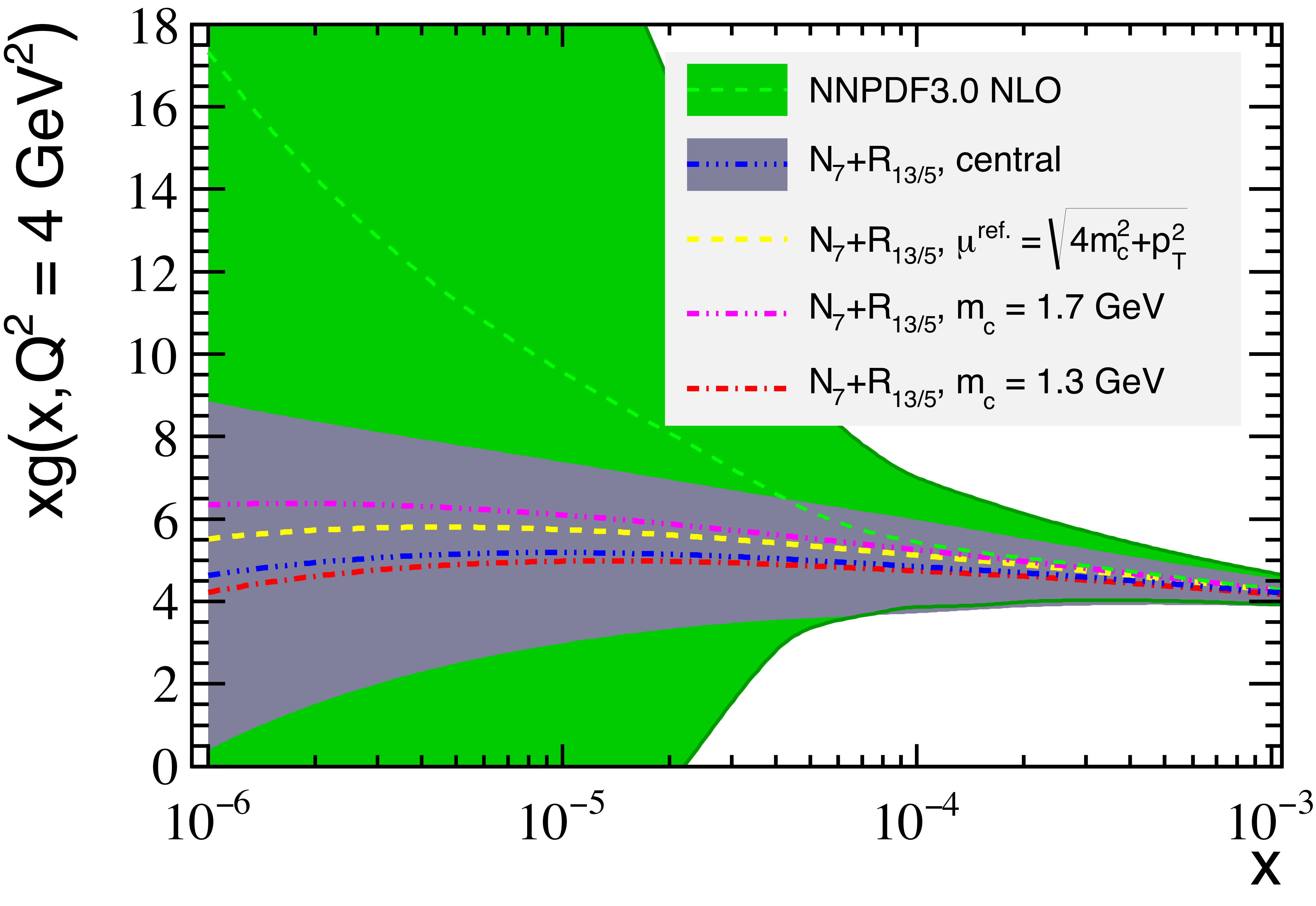
- Check impact of placing pT > 1, 2 GeV in analysis
- Change underlying parton shower tune (Monash, T4C, TA14)
- Fragmentation model/parameters (Peterson, Bowler)

Impact of varying charm quark pole mass in calculation*

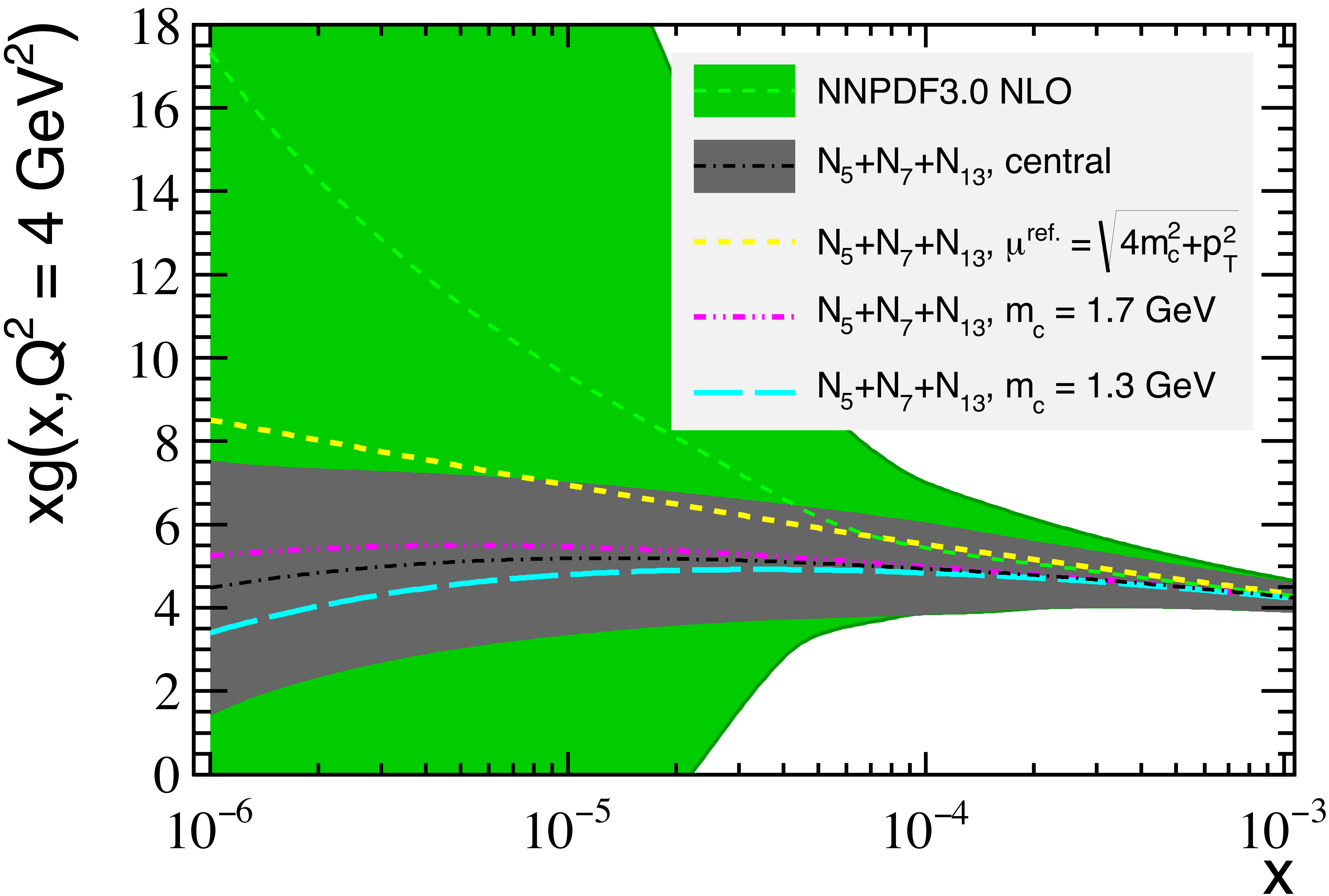
$$m_c^{\text{pole}} = (1.3,\, 1.5,\, 1.7)\ \text{GeV}$$

*Baseline is NNPDF3.0 with mc = 1.275 GeV, in a future global PDF better to correlate mc used throughout fit

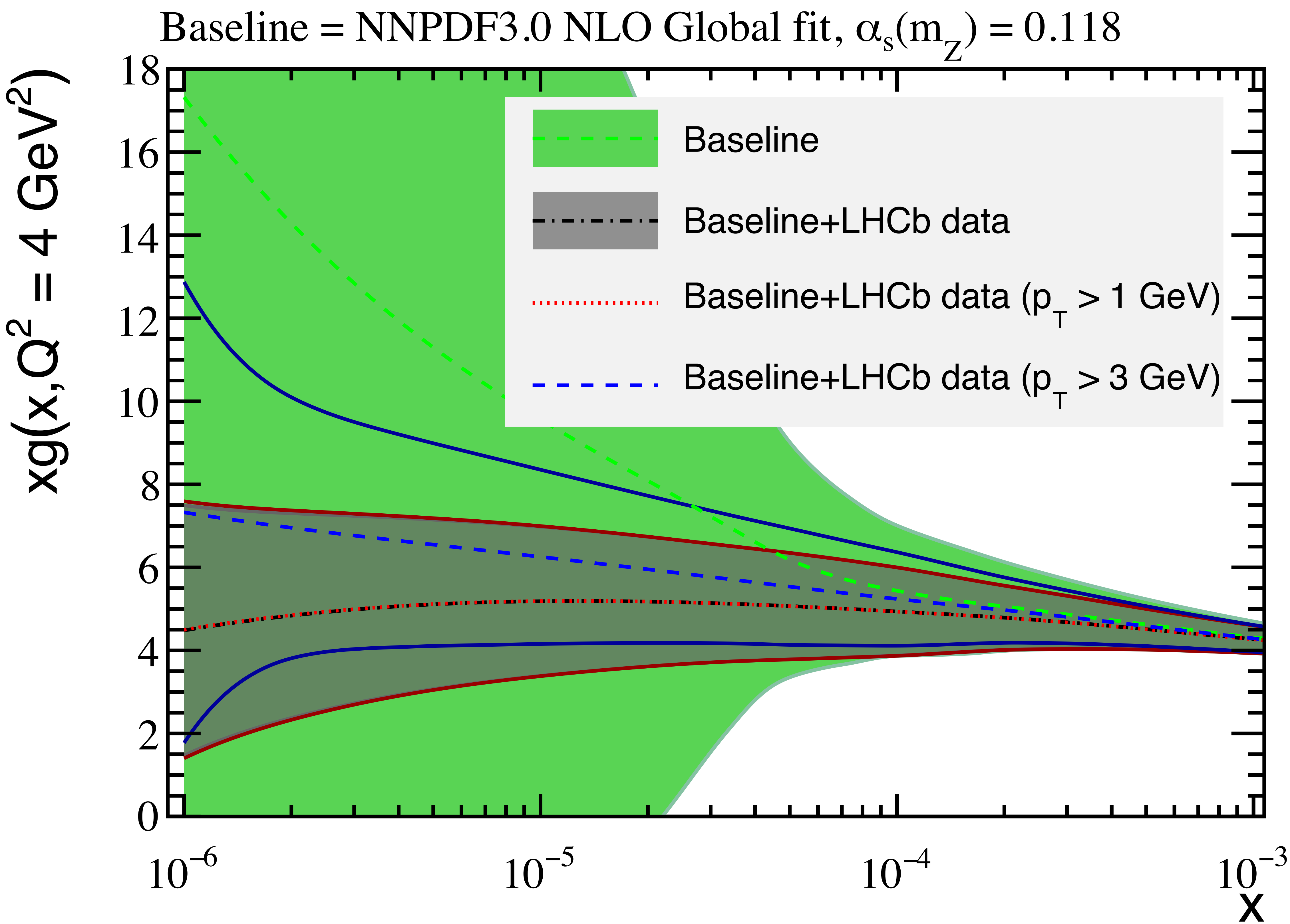
Additional theory checks



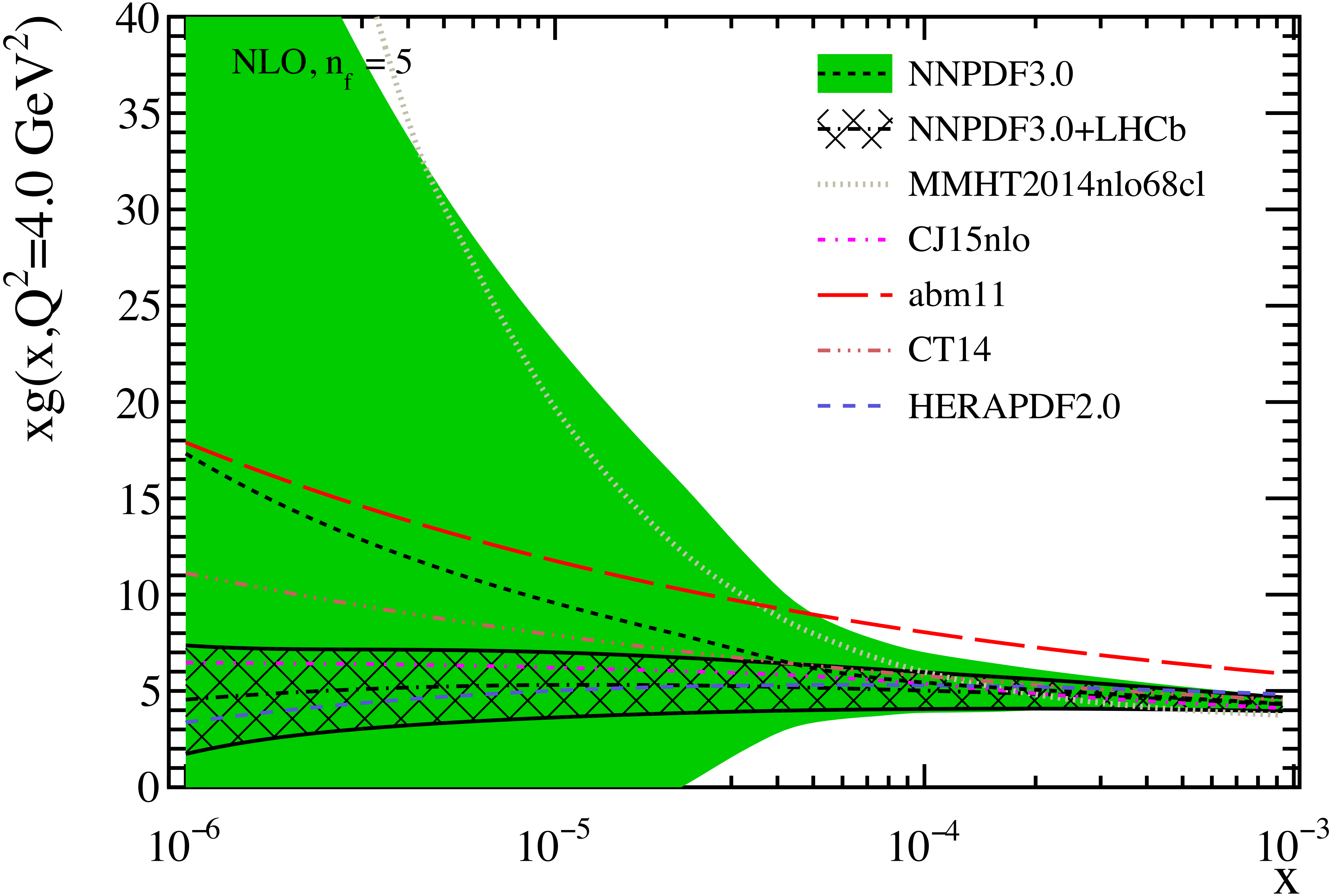
Additional theory checks



pT cut dependence



The results in context



Interim 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

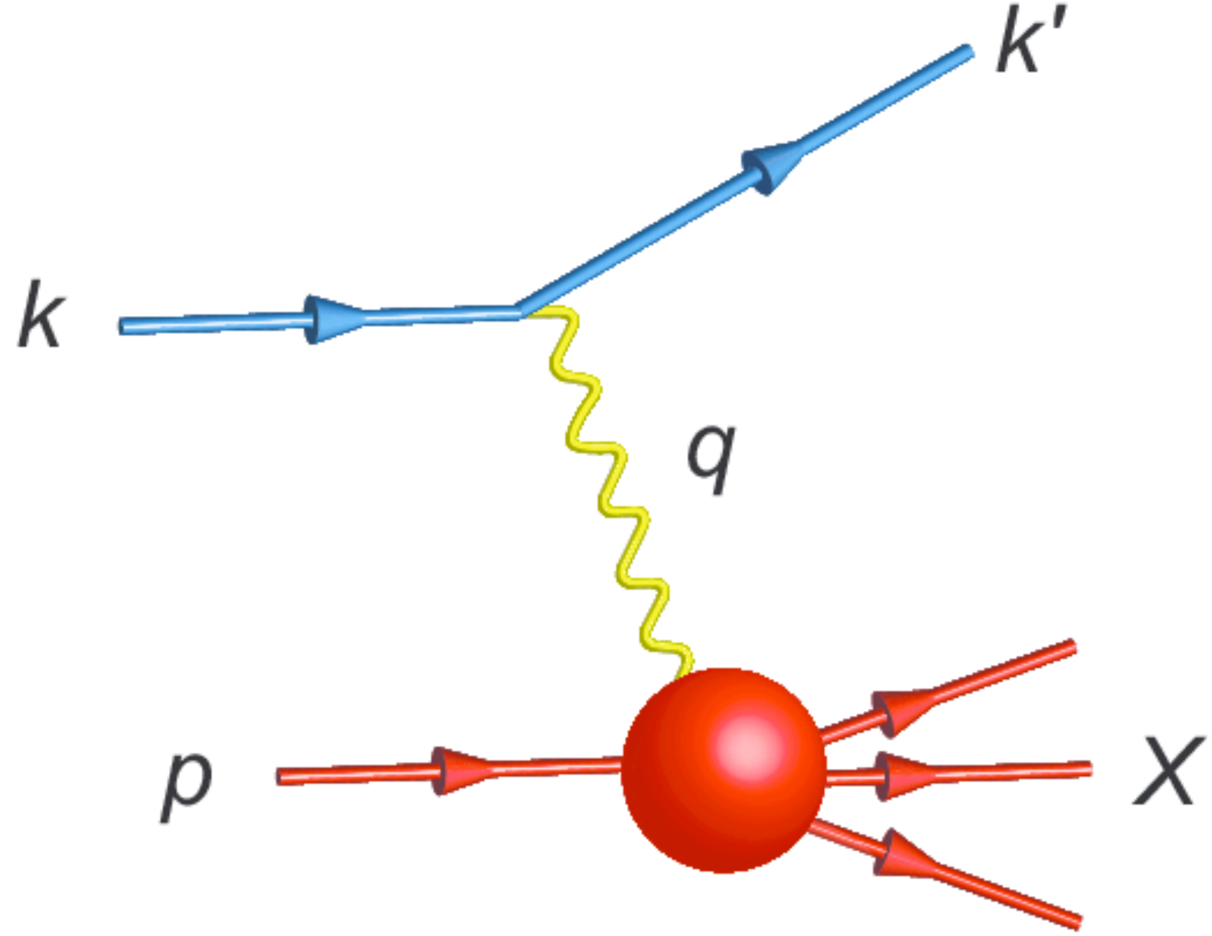
3 flavour PDFs
http://pcteserver.mi.infn.it/~nnpdf/NNPDF30LHCb/NNPDF30_nlo_as_0118_L13L7L5_nf3.tar.gz

Applications beyond the LHC

Applications I

Ultra High Energy (UHE) neutrino-nucleon cross section

$$\nu(k) + N(p) \to l(k') + X$$



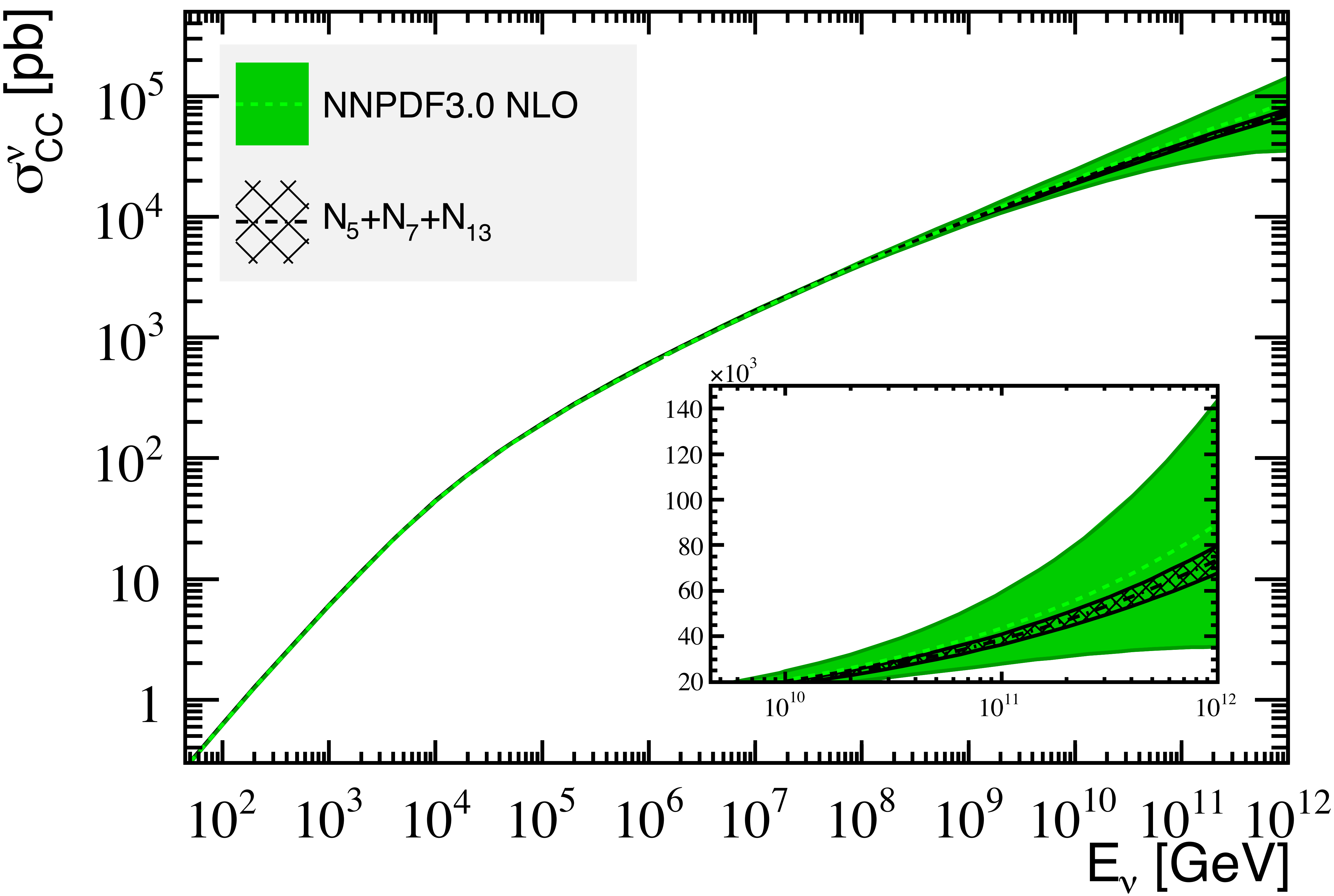
$$\frac{d^2\sigma(\nu(\bar{\nu})N)}{dx\,dQ^2} = \frac{G_F^2 M_W^4}{4\pi x (Q^2 + M_W^2)} \left(Y_+ F_2^{\nu(\bar{\nu})}(x,Q^2) \mp Y_- x F_3^{\nu(\bar{\nu})}(x,Q^2) - y^2 F_L^{\nu(\bar{\nu})}(x,Q^2) \right)$$

$$Y_\pm = 1 \pm (1-y)^2 \,, \quad y = 1 - \frac{E_l}{E_\nu}$$

→ DIS Structure Functions

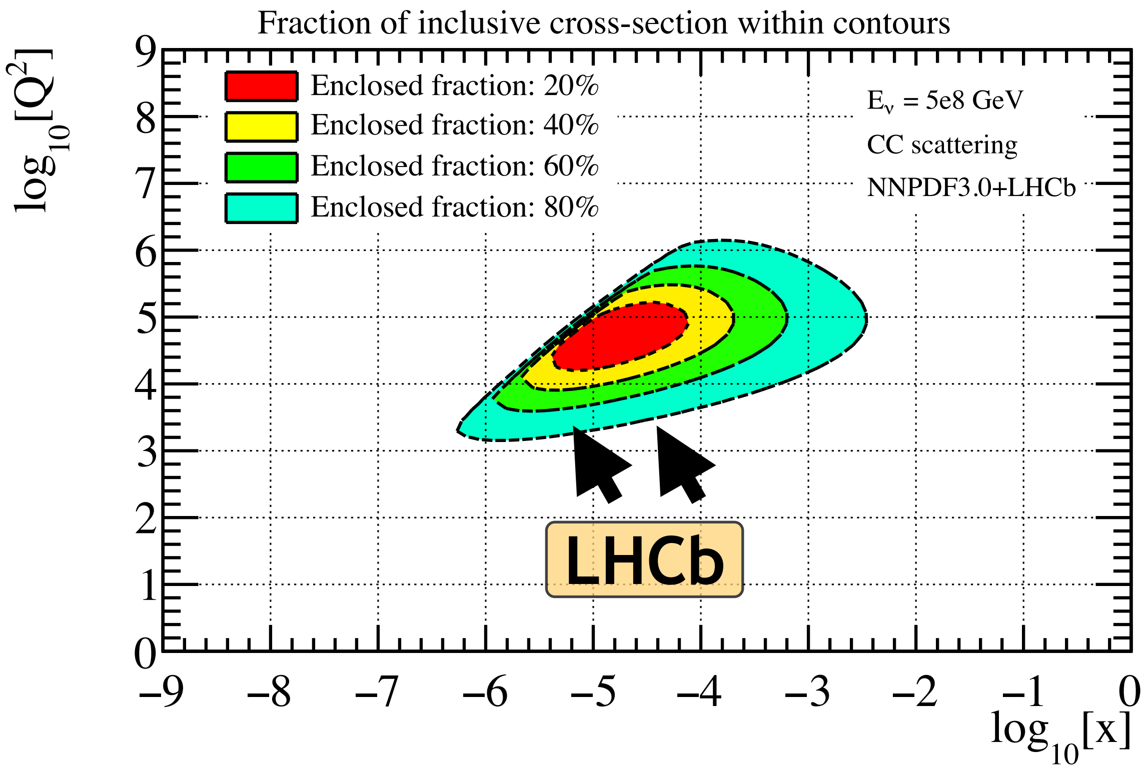
Applications I

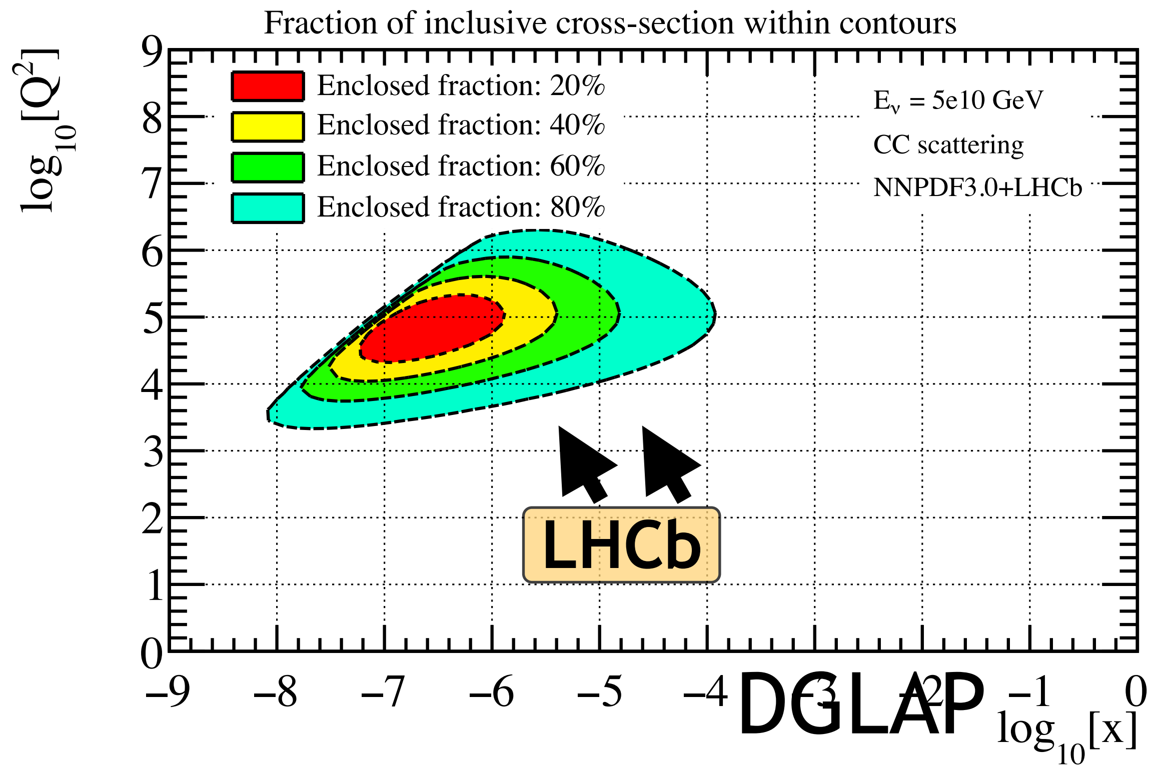
Ultra High Energy (UHE) neutrino-nucleon cross section



Applications I

Ultra High Energy (UHE) neutrino-nucleon cross section



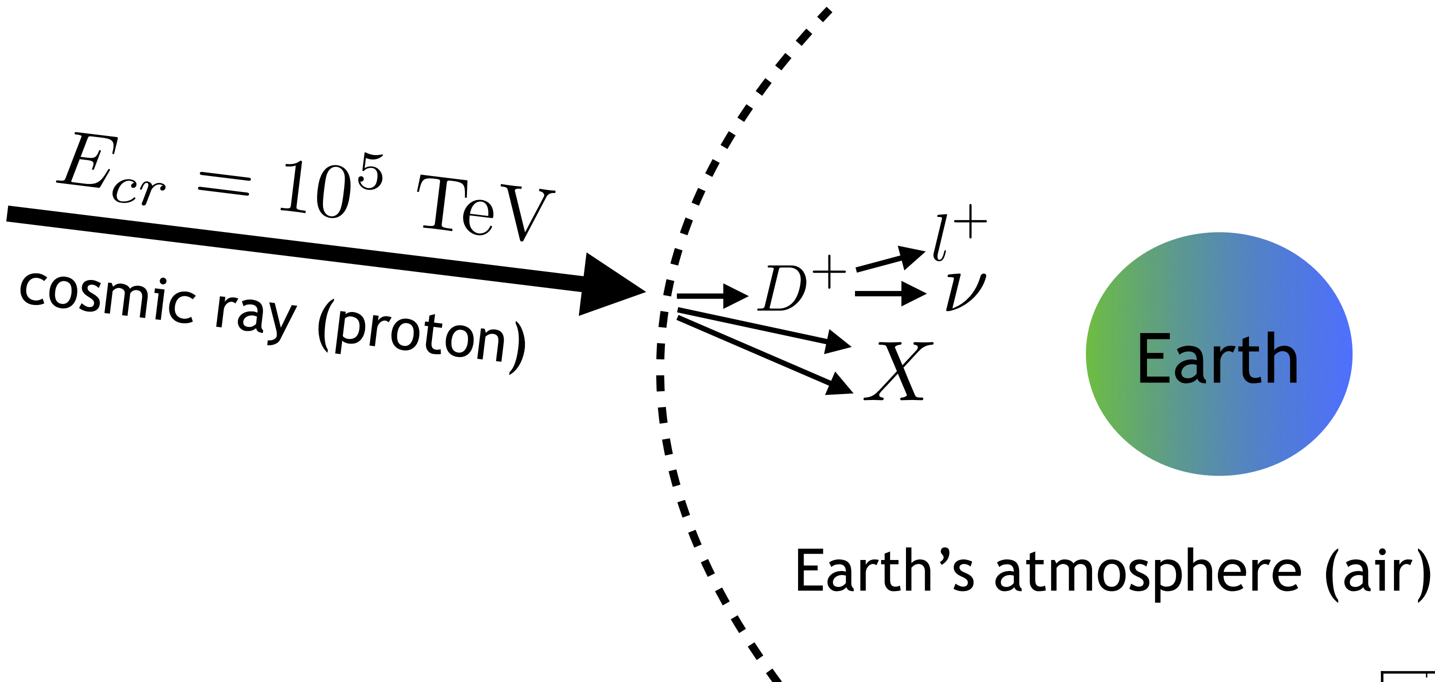


$E_\nu = 5 \times 10^8 \text{ GeV}$ $E_\nu = 5 \times 10^{10} \text{ GeV}$

RG, V. Bertone, J. Rojo, In preparation

Applications II

Atmospheric production of heavy quarks

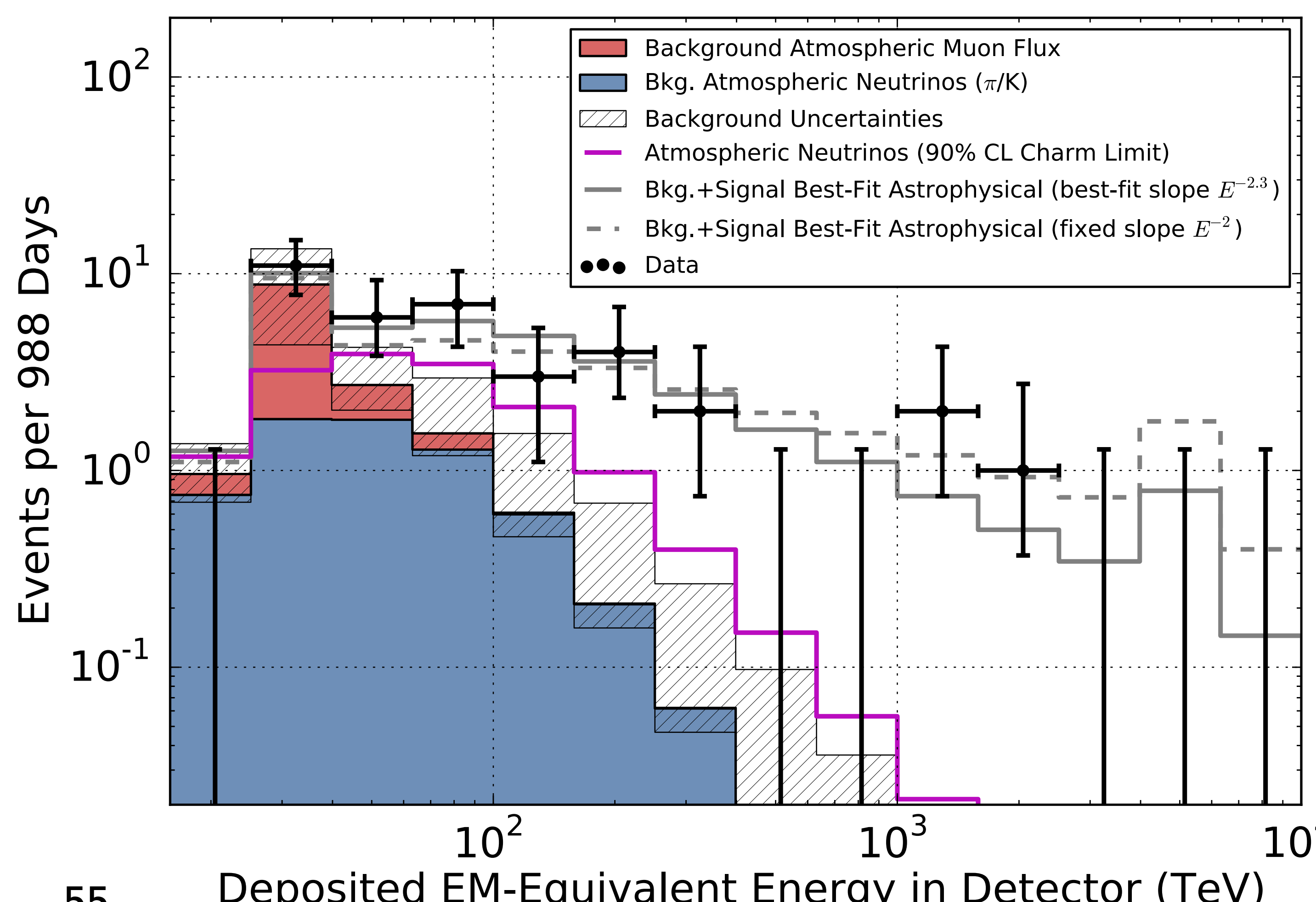


$$\sqrt{S} = \sqrt{2m_N E_{cr}} \approx 14 \text{ TeV}$$

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

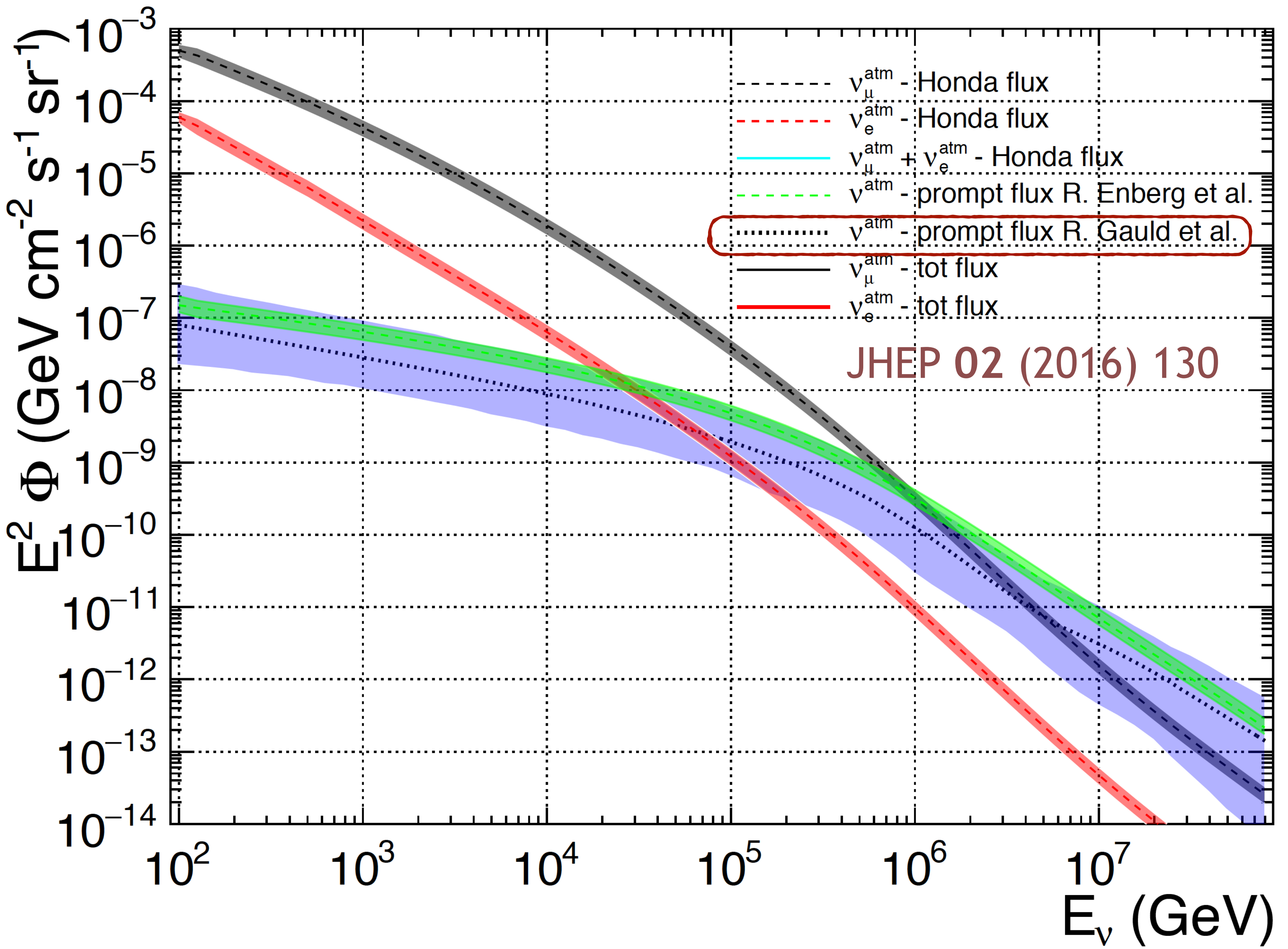
Dominant background for:

UHE astrophysical neutrino measurements (IceCube, …)



Applications II

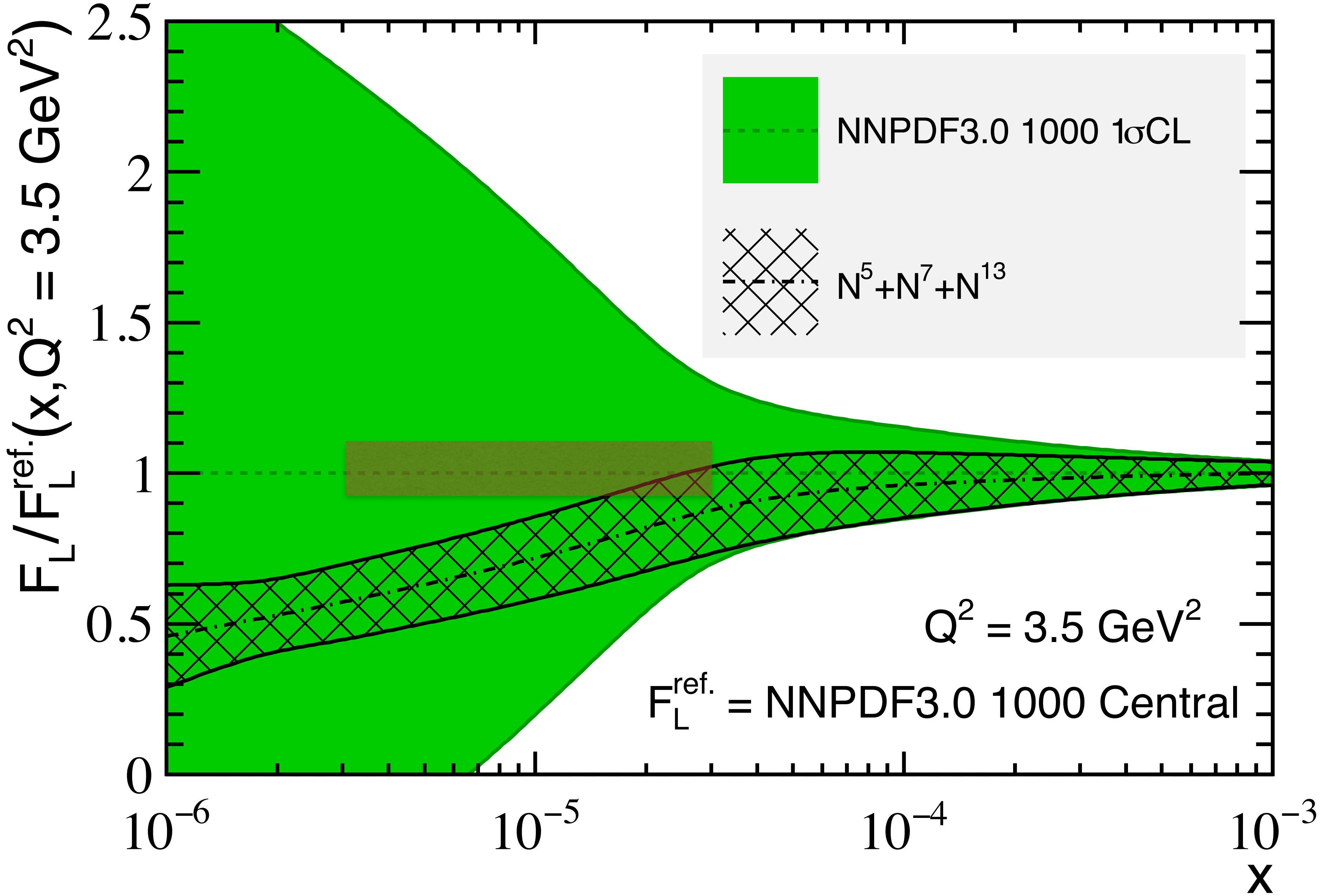
Atmospheric production of heavy quarks



From KM3NeT Letter of intent - arXiv:1601.07459

Applications III

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



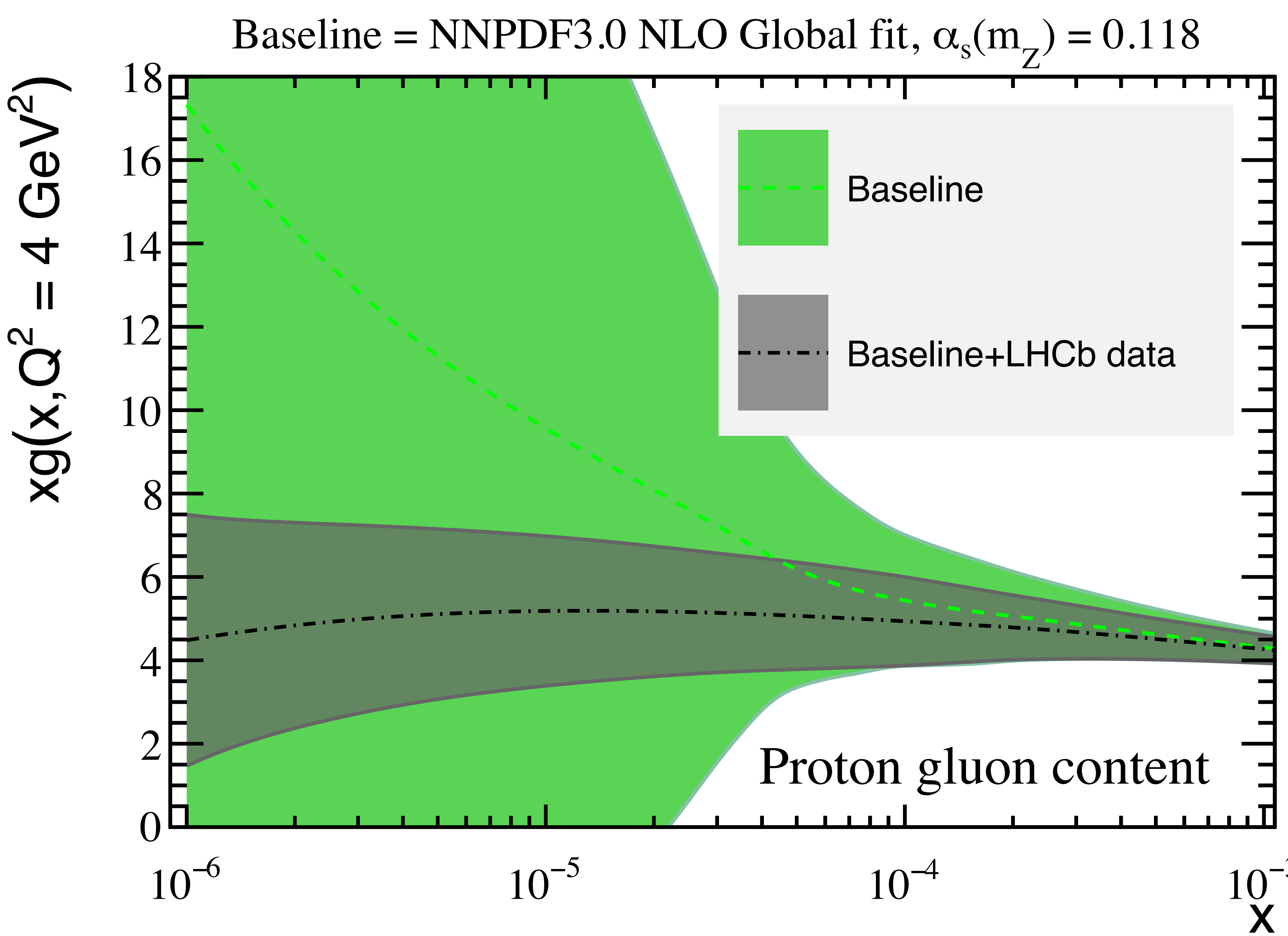
= Typical* precision of F_L that LHeC could probe

* Depends on beam energy, polarisation, ... etc.

Summary

- Precise measurements at LHC(b) providing unique information

- Many implications of the LHCb D-hadron measurements

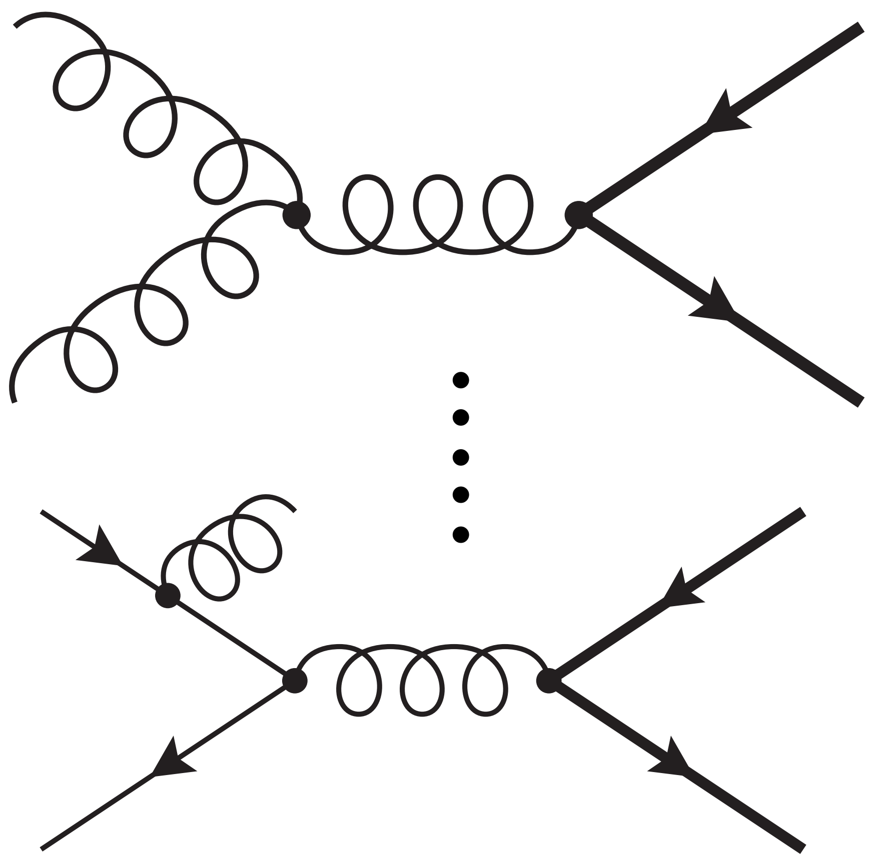


Back-up slides

Partonic cross-section

$$d\sigma_{ij\to Q\bar{Q}X} = \frac{1}{2s_{ij}}\overline{\sum}|\mathcal{M}_{ij\to Q\bar{Q}X}|^2 d\phi_n$$

- Process **dependent**
- Organisation of IR divergences



NLO QCD

P. Nason, S. Dawson, R. K. Ellis, 1988
P. Nason, S. Dawson, R. K. Ellis, 1989 *
W. Beenakker, H. Kuijf, W.L. van Neerven, J. Smith 1989 *

NLO QED/WEAK

Kuhn, Scharf, Uwer , 2005, 2006 *
W. Bernreuther, M. Fucker, Z. G. Si 2005 *
W. Hollik, M. Kollar, 2006 *

NLO QCD interfaced to PS

S. Frixione, P. Nason, B. R. Webber 2003
also with G. Ridolfi 2007

NNLO QCD

M. Czakon, P. Fiedler, A. Mitov, 2013
M. Czakon, P. Fiedler, A. Mitov, 2014 *

... + exhaustive list of resummation calcs.

* Denotes differential calculation

Fragmentation Functions (FFs)

$$F_i^D(z,\mu,m_h) = F_i^c(z,\mu,m_c) \otimes F_{\rm n.p.}^D(z)$$

z : normalised energy fraction

The first term = perturbative fragmentation function (PFF)
Has the job of resumming quasi-collinear logs: $\alpha_s^n \ln\left[m/Q\right]^k$, $k \leq n$

NLO B. Mele, P. Nason, Nucl. Phys. B **361** (1991) 626
NNLO K. Melnikov, A. Mitov PRD **70** (2004) 034027

In Parton Shower (PS), time-like evo. also resums collinear logs

Underlying hadronisation details depend on methodology:

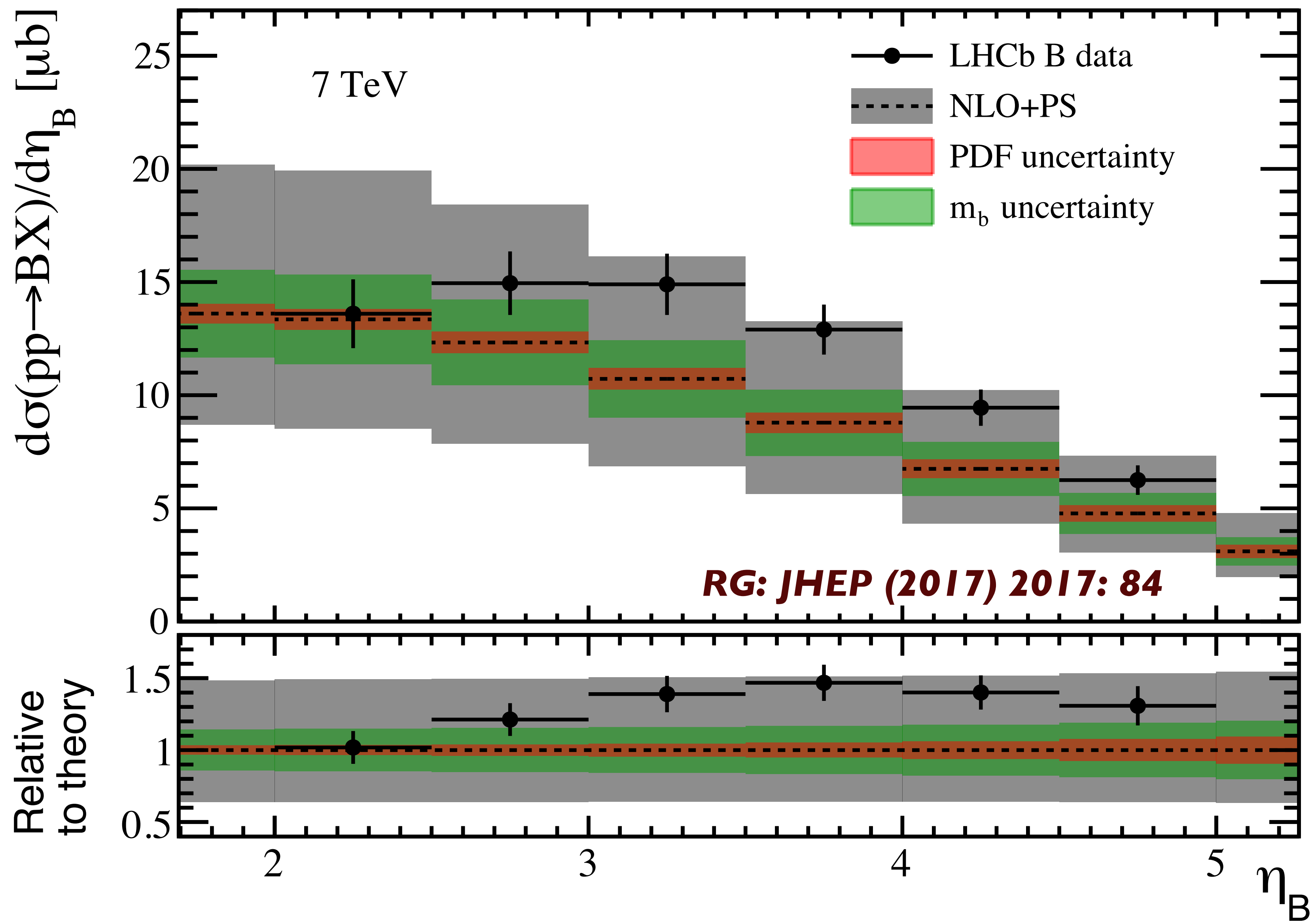
- String (Pythia) or Cluster model (Herwig, Sherpa, ..)

e.g. $$F_{\rm n.p.}^{Q,\rm peterson}(z) = \frac{N_H}{z}\left[1 - \frac{1}{z} - \frac{\epsilon_q}{1-z}\right]$$

In either case, n.p. piece extracted from precise D/B spectrum at LEP

B cross-section (absolute)

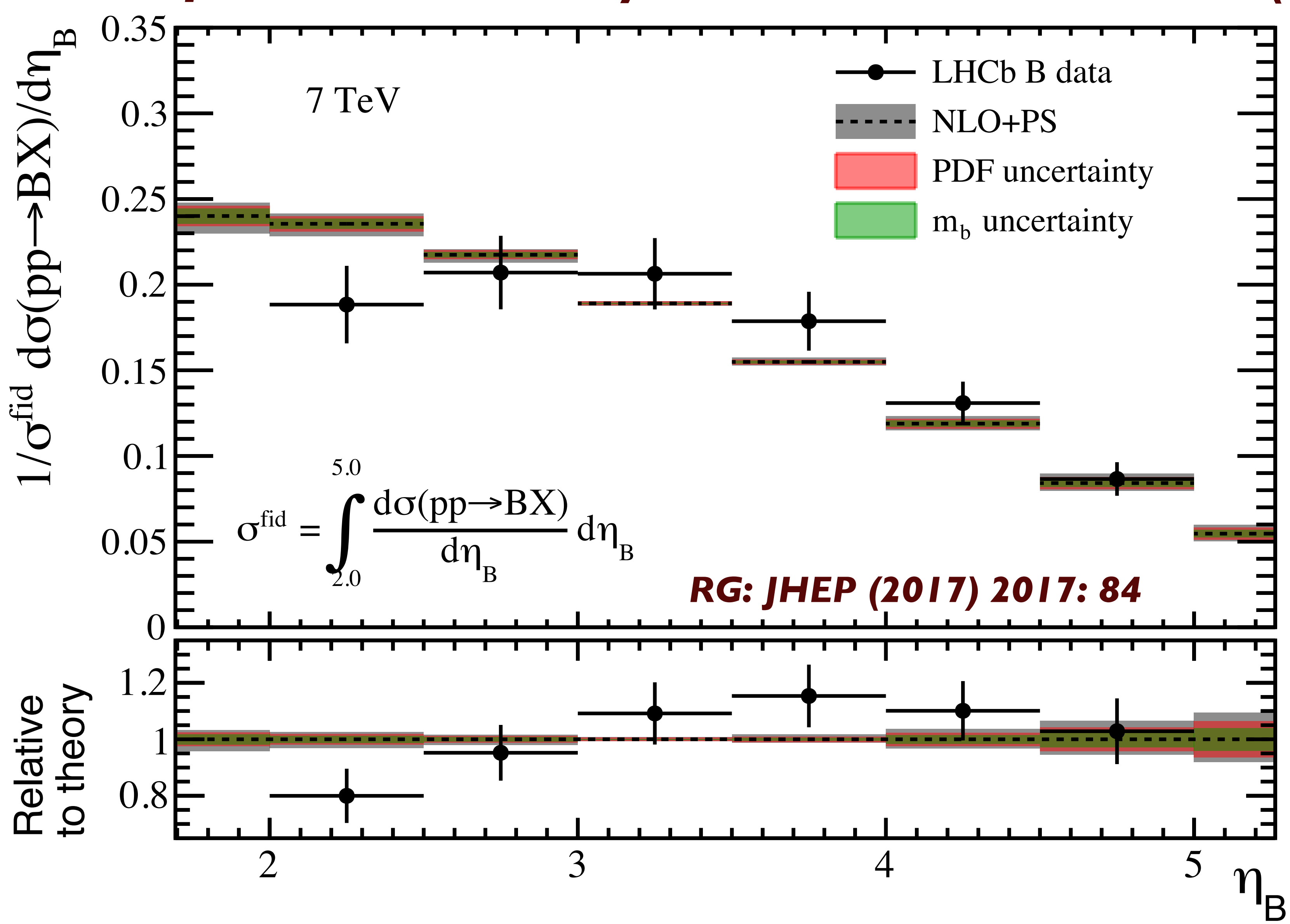
LHCb data from Erratum: Phys. Rev. Lett. 118, 052002 (2017)



1) Differential and fiducial rate measurements
   * Test of pQCD predictions, and baseline for other analyses

B cross-section (normalised)

LHCb data from Erratum: Phys. Rev. Lett. 118, 052002 (2017)

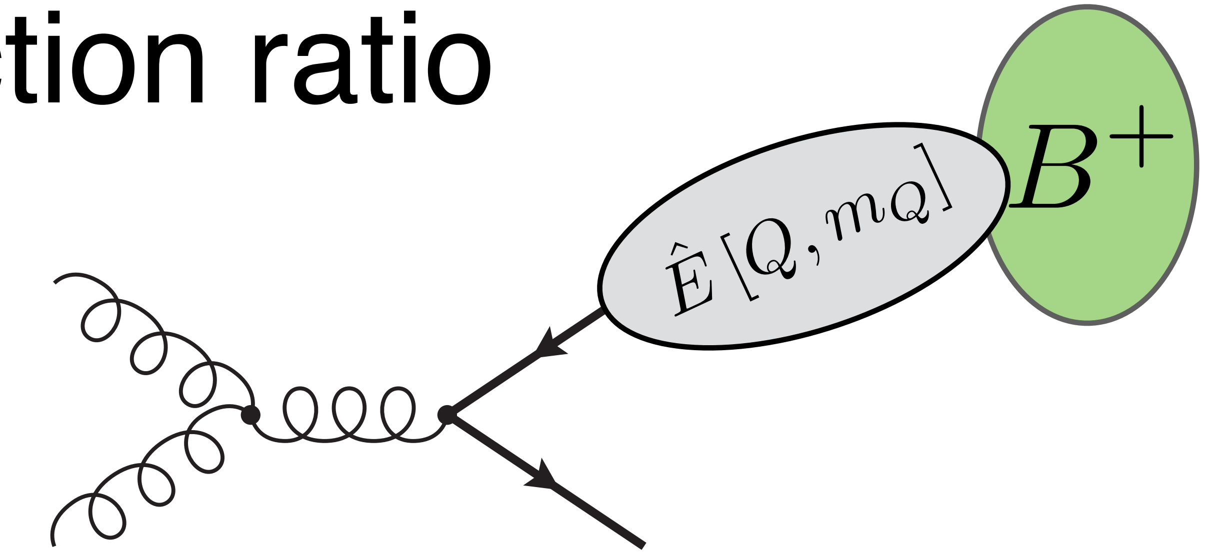


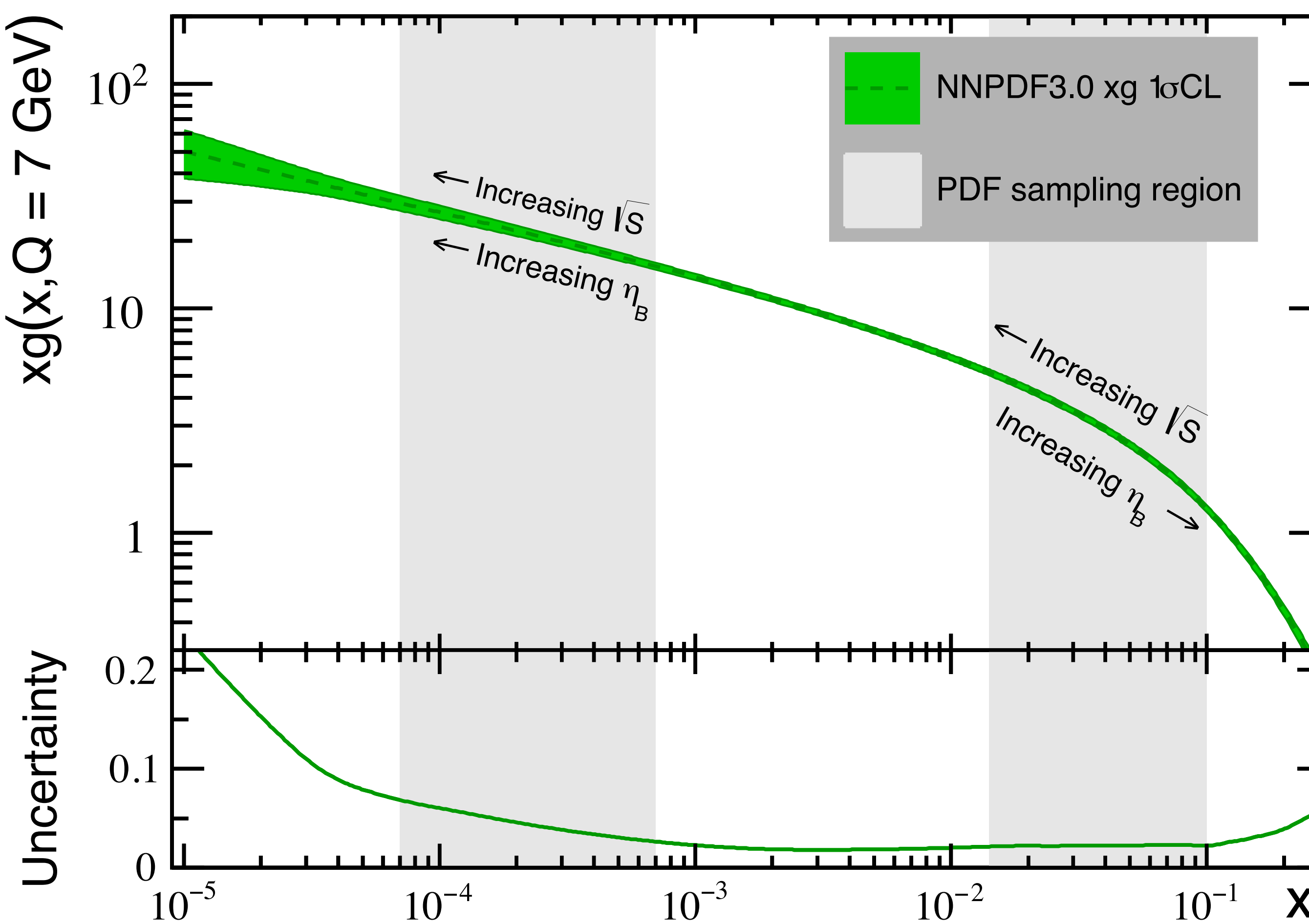
1) Differential and fiducial rate measurements
   * Test of pQCD predictions, and baseline for other analyses

2) Normalised cross-section measurement
   * Test of shape of pQCD predictions (generally more precise)

B cross-section ratio

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



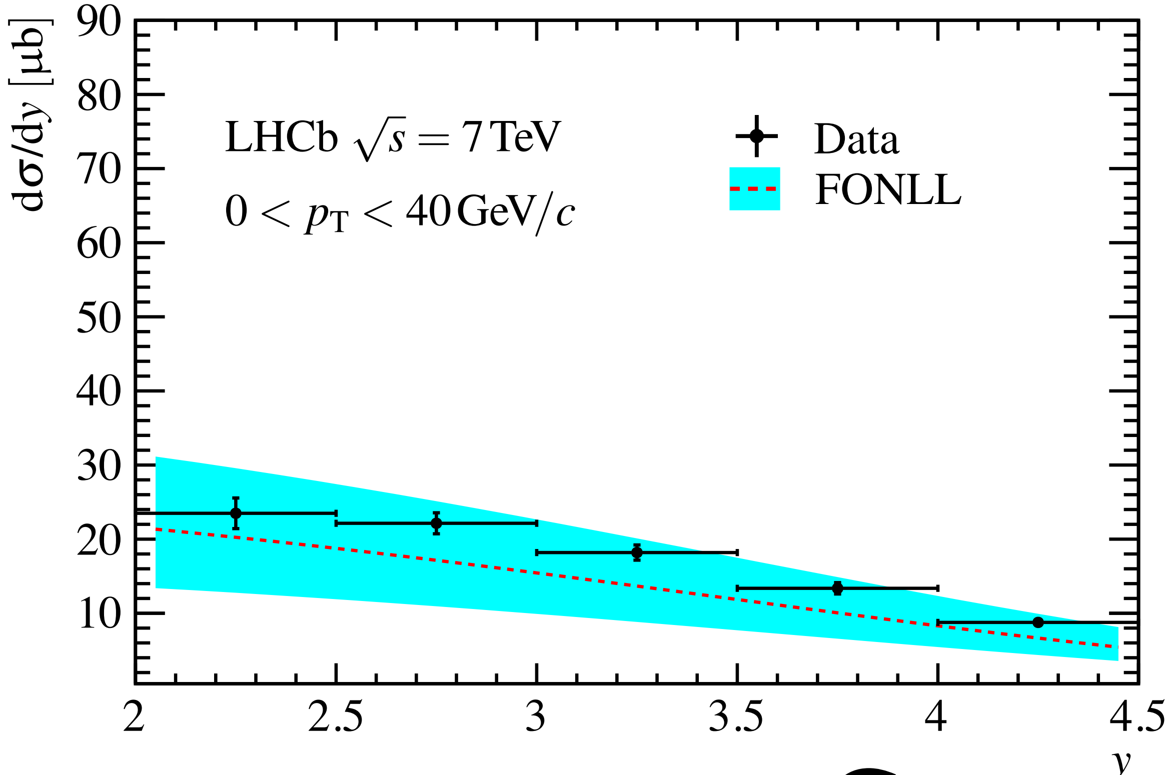


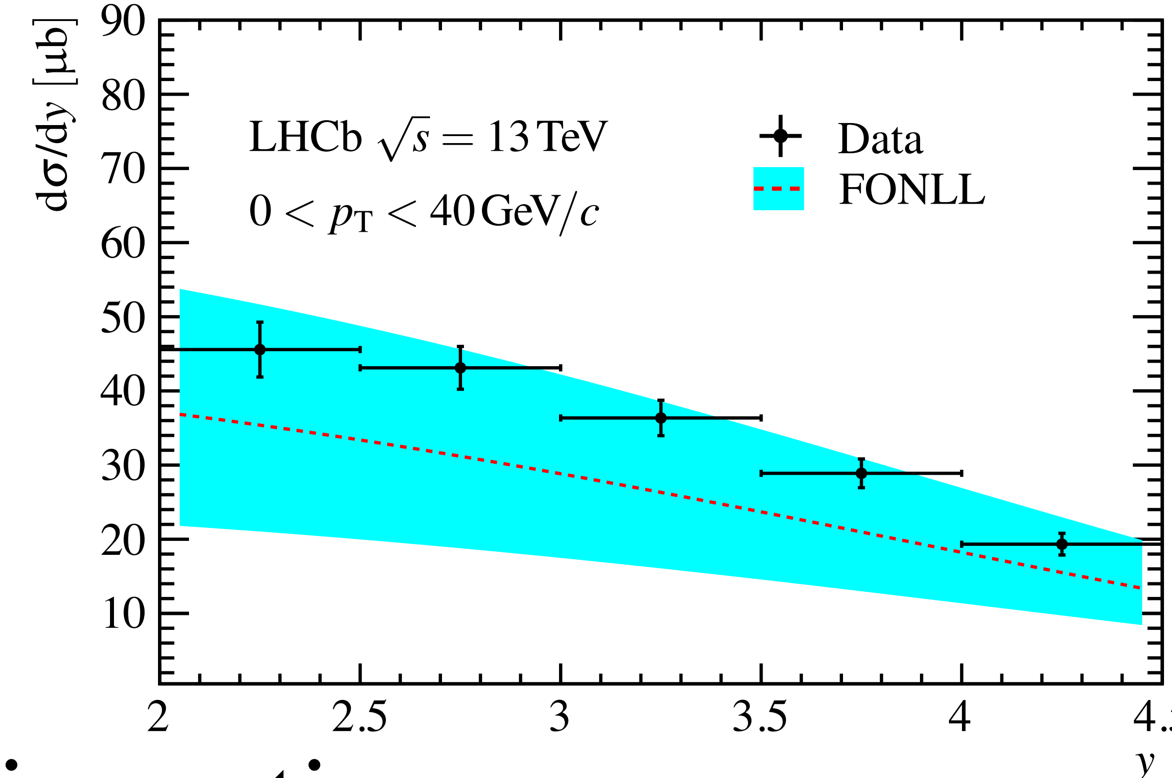
1) Tests the rate of growth of gluon PDF at both small and large-x
* See for example:

RG et al.: JHEP (2015) 2015: 9
Cacciari et al.: EPJC 75 (2015) no.12, 610
RG: JHEP (2017) 2017: 84

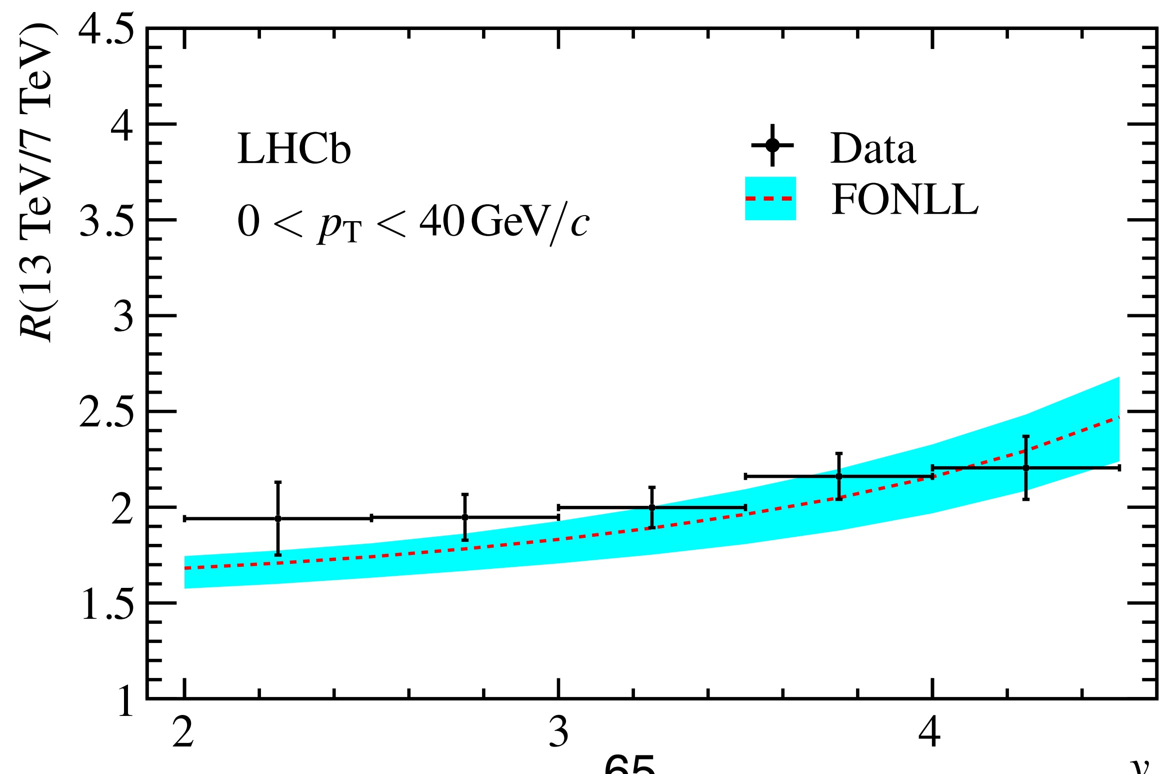
B cross-section: $B \to J/\psi K$ data

Absolute cross-section



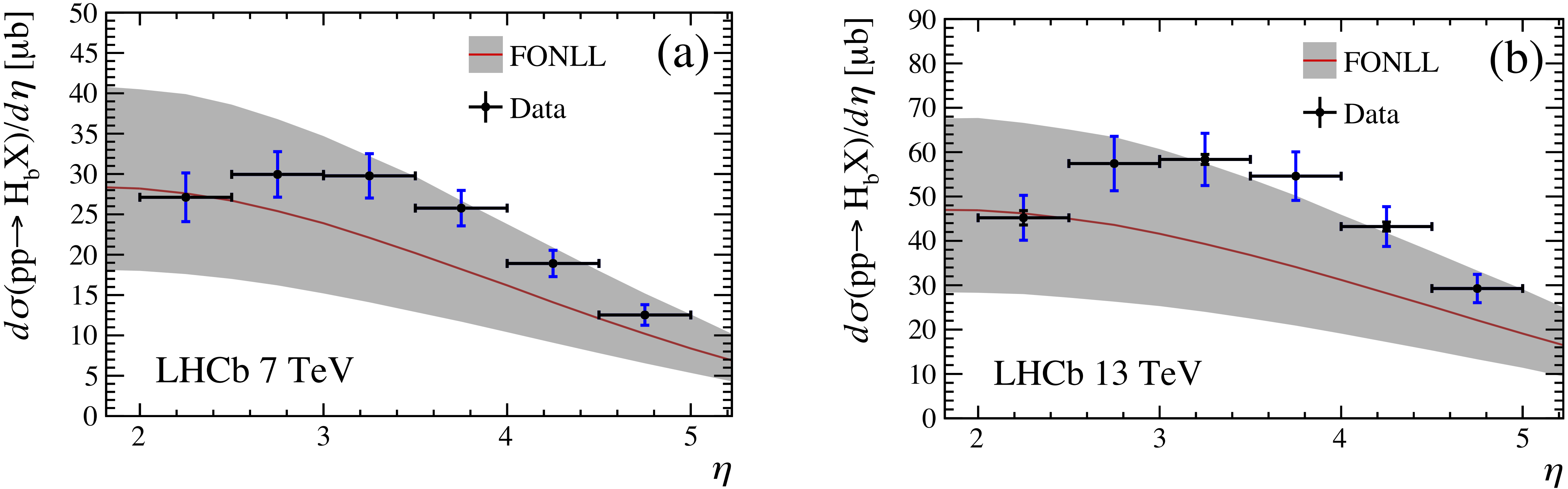


Cross-section ratio

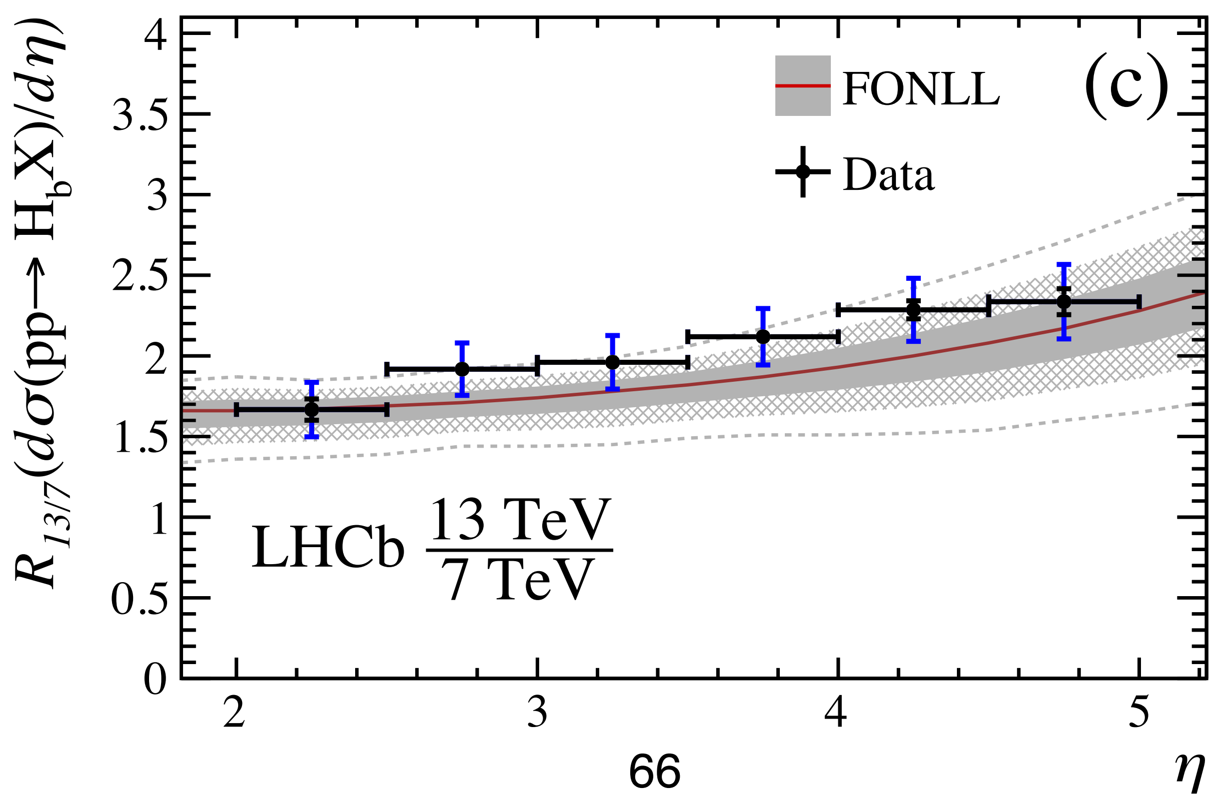


B cross-section: $B \to D\mu\nu$ data

Absolute cross-section

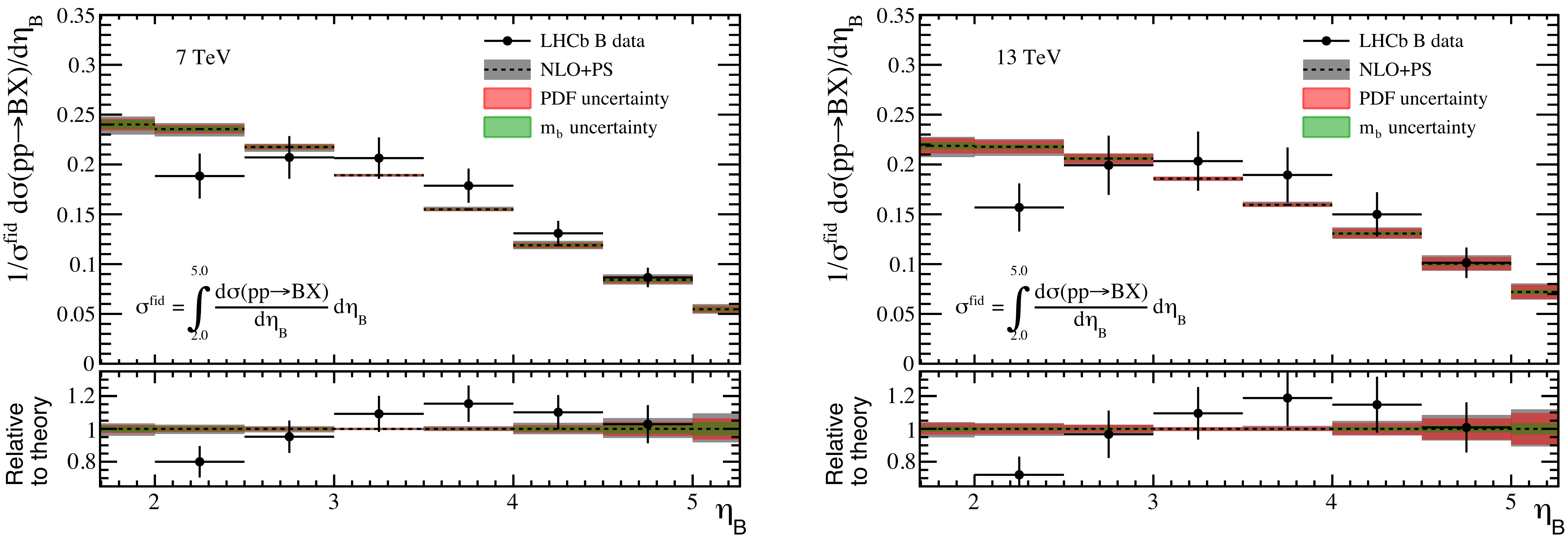


Cross-section ratio



B cross-section: $B \to D\mu\nu$ data

Normalised cross-section



1) Shape of normalised distributions not well described by pQCD

2) Large `dip' observed in the region of $\eta_B \in [2.0, 2.5]\,,\ P_{T,B} > 0\ \mathrm{GeV}$

3) Such behaviour **not** observed in B (->J/PsiK) or D-hadron rapidity distributions

Cross-checks

1) Please always provide systematic bin-by-bin correlations
 * Can then construct normalised distributions
 * Needed to test consistency of theory to data
 * … important when including data in PDF fit

See for example PROSA analysis (Maria V.'s talk)

2) Is it possible to clarify the consistency of these two B-hadron measurements?

Future studies

1) With large data samples, measurement of B hadron production at large-pT
 * Probes region of quasi-collinear gluon emission + sensitivity to large-x gluon

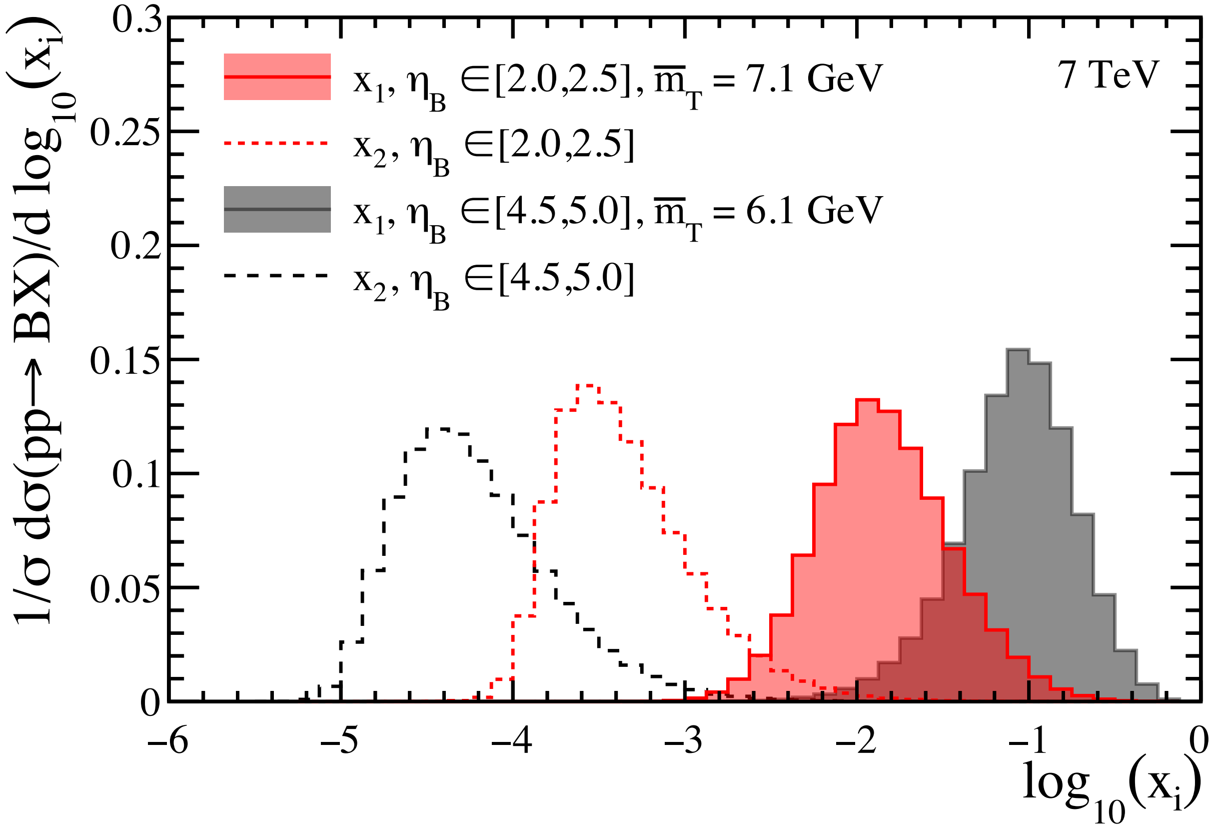
2) Are (can) the bin-by-bin cross correlations between different CoM be provided?
 * Would allow construction of `shifted CoM ratios', see RG JHEP (2017) 2017:84

$$\overline{R}_{13/7}\left[d\sigma(pp \to BX)/dy_B\right] = \frac{d\sigma_{13}(pp \to BX)}{dy'_B} \bigg/ \frac{d\sigma_7(pp \to BX)}{dy_B} \qquad y'_B = y_B + \ln\left[\frac{13\ \mathrm{TeV}}{7\ \mathrm{TeV}}\right]$$

PDF sampling in B production at LHCb

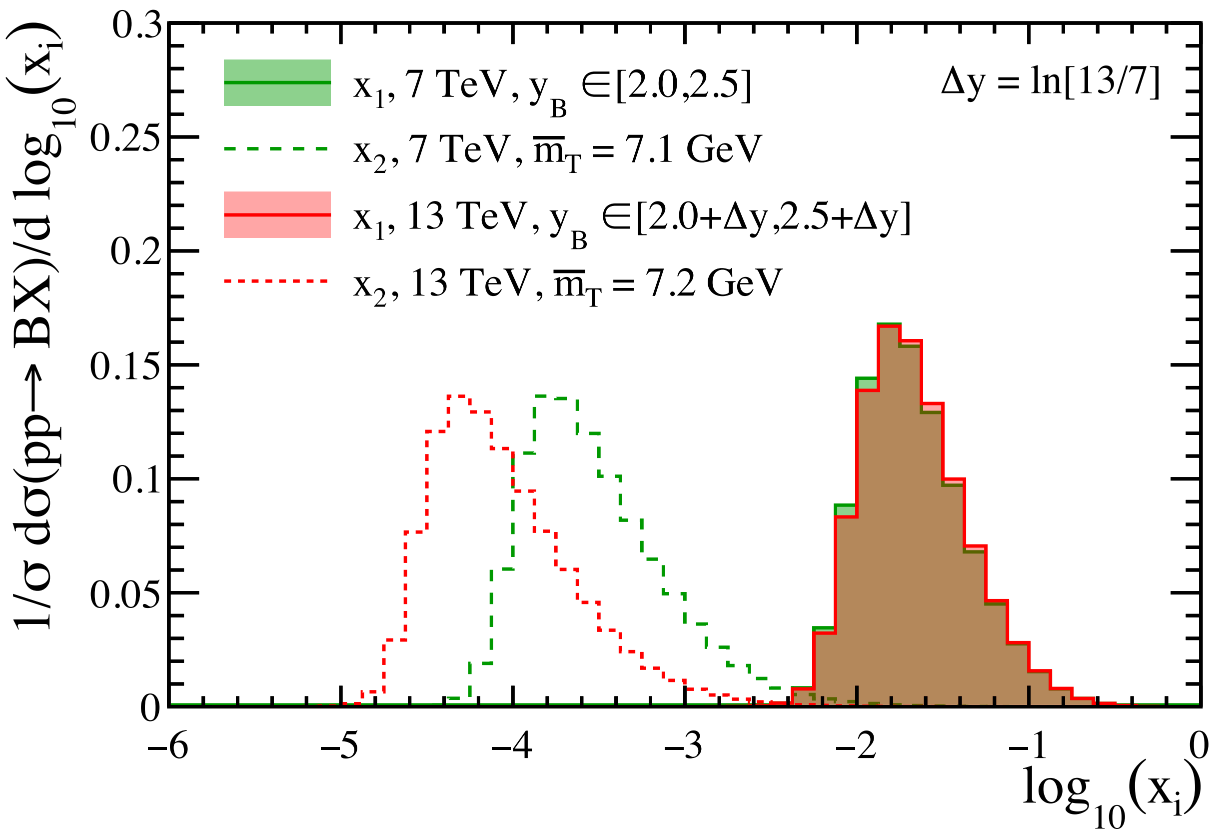
$$x_{1,(2)} = \frac{m_T}{\sqrt{S}} \left(e^{(-)y_3} + e^{(-)y_4} \right)$$

PDF sampling region:
- B hadron production at 7 TeV
- LHCb pseudorapidity bins



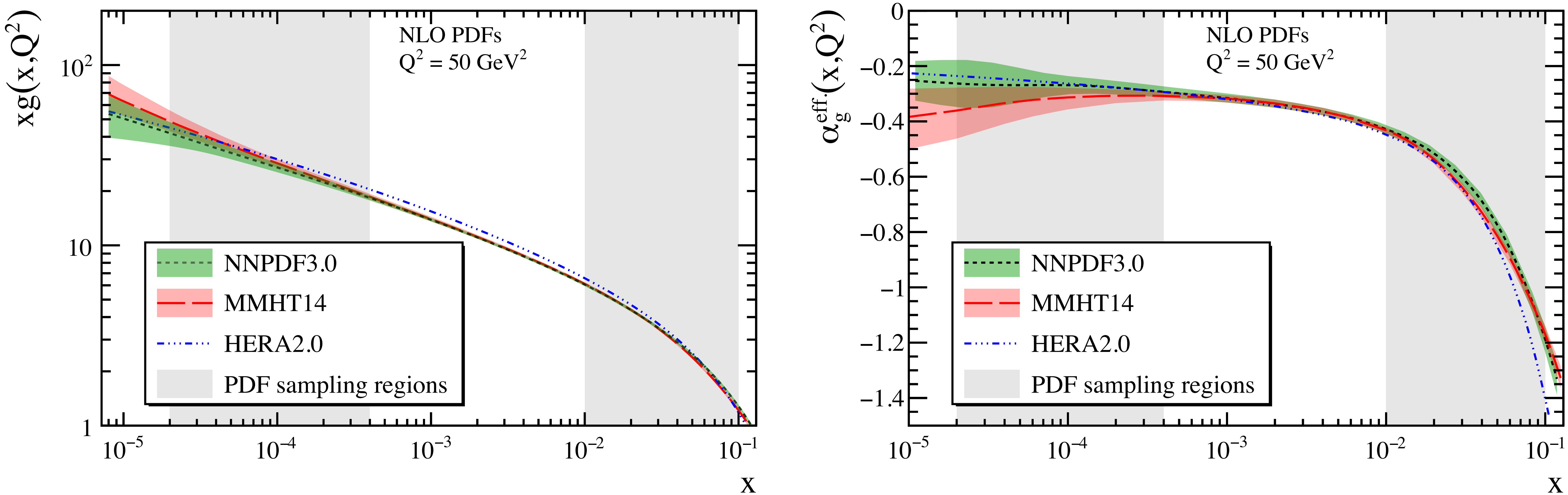
PDF sampling region:
- effect of aligning x-regions
- can align either low or high-x regions

$$y'_B = y_B + \ln\left[\frac{13\ \text{TeV}}{7\ \text{TeV}}\right]$$



Bunch of `useful’ plots below

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



What do normalised cross section and ratios probe?

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

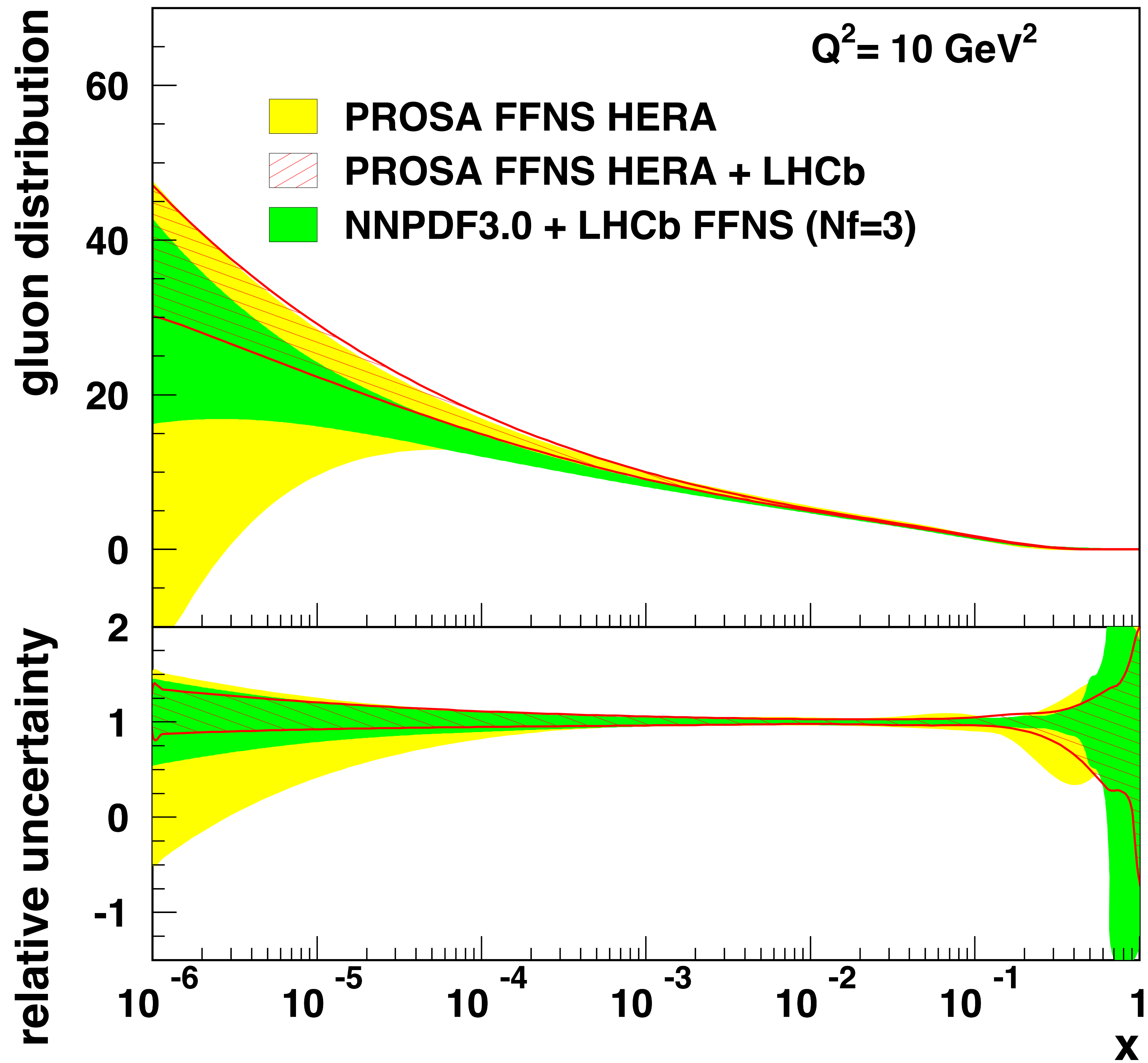
Gluon PDF extraction at 7 TeV

PROSA results:

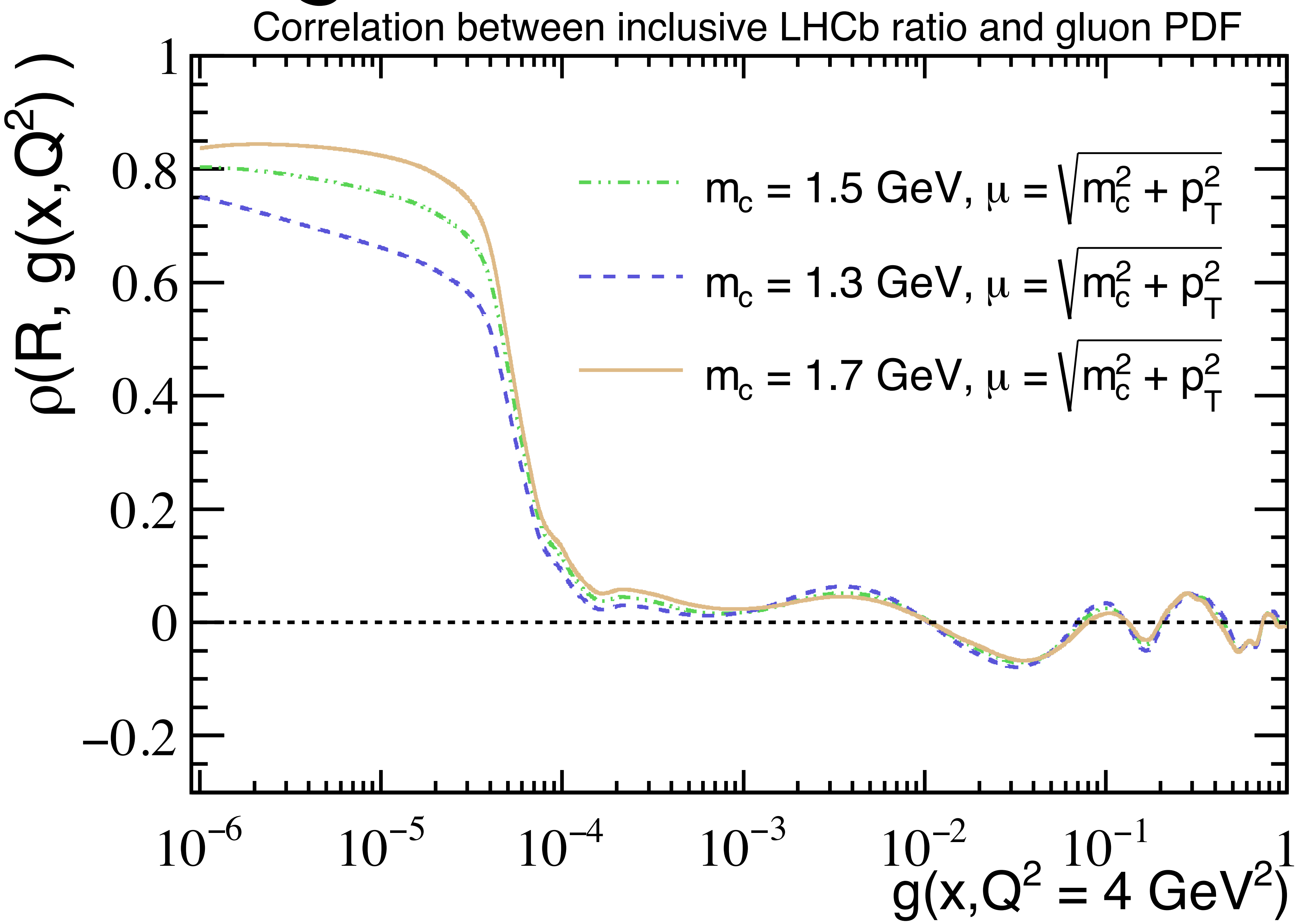
- HERA+LHCb Data PDF fit
- FFS, NF=3
- Normalise to 'middle' rapidity bin for each pT
- HERAfitter framework
- Also LHCb B data

GRRT results:

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

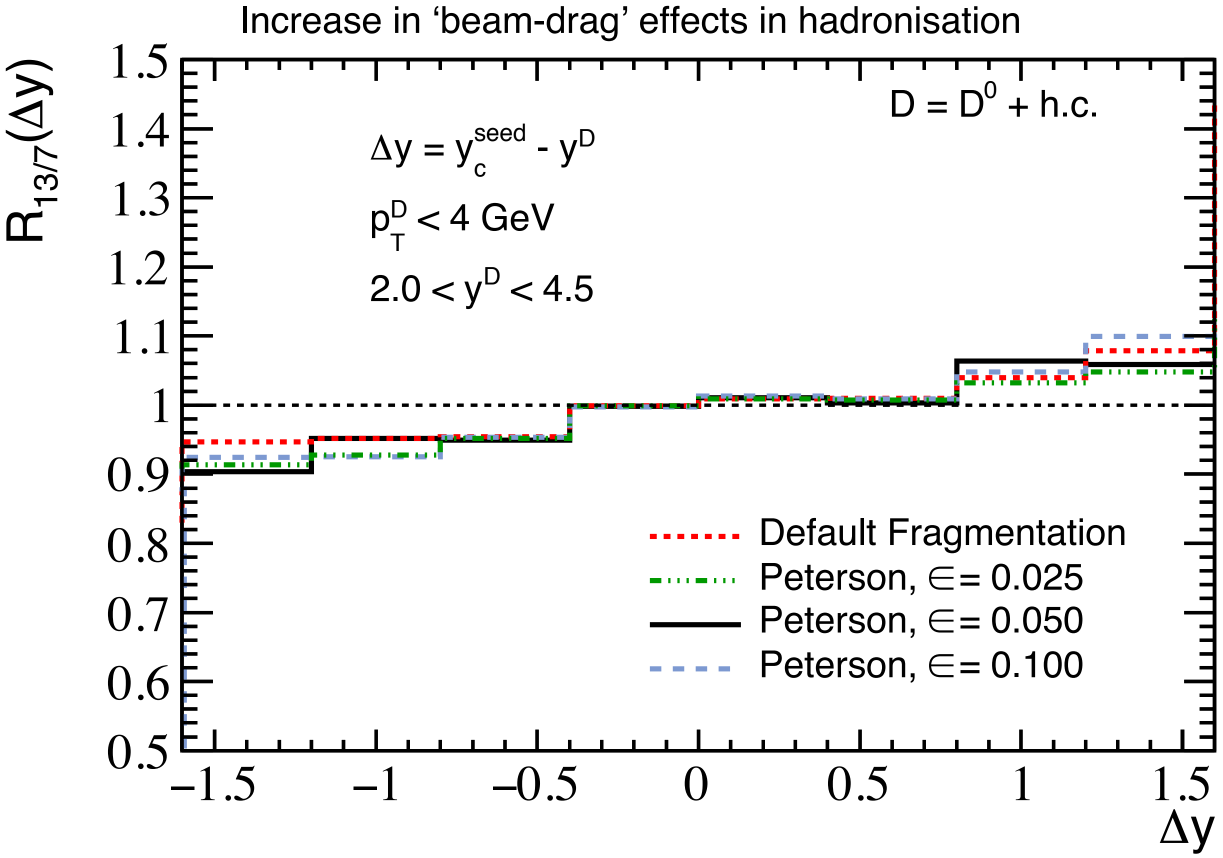


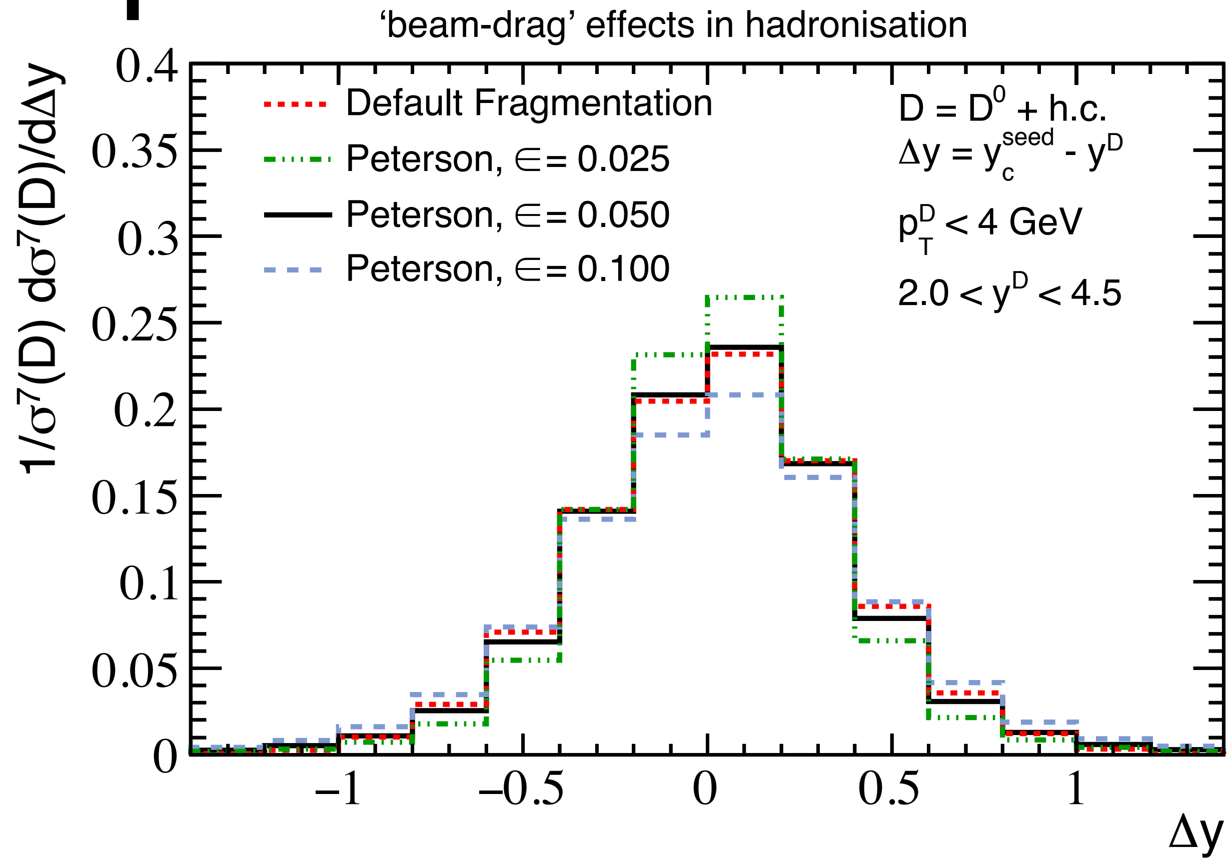
gPDF Correlations

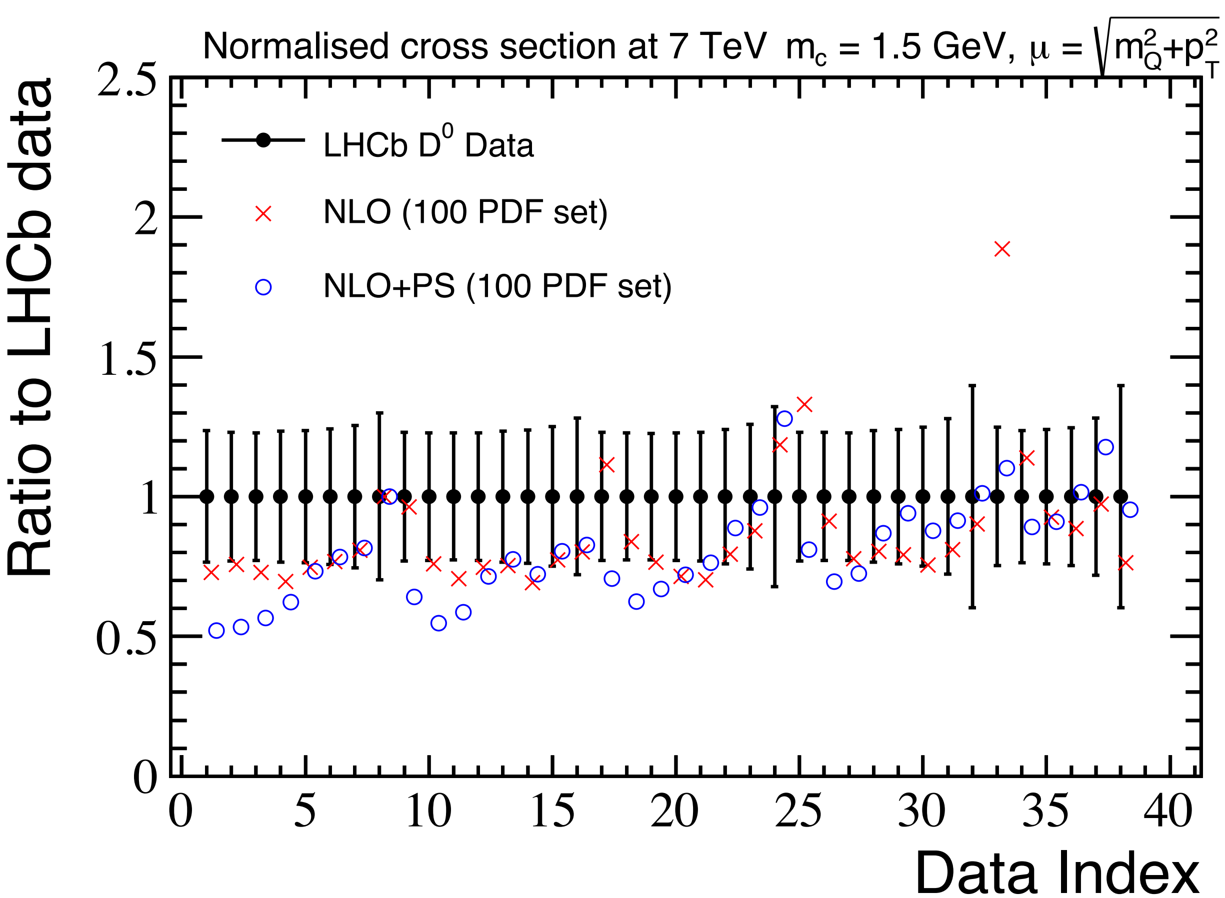


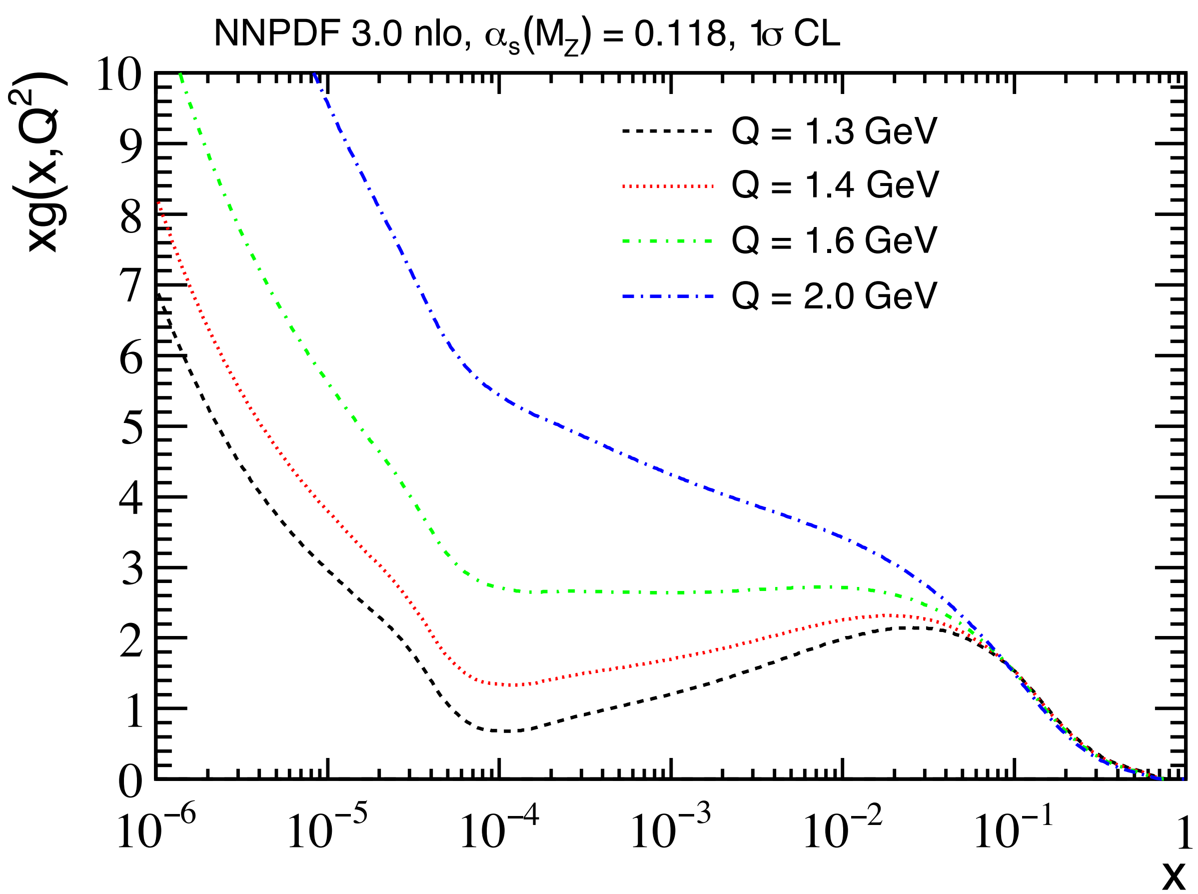
Gluon PDF correlation with inclusive LHCb 13/7 Charm ratio measurement

Useful plots

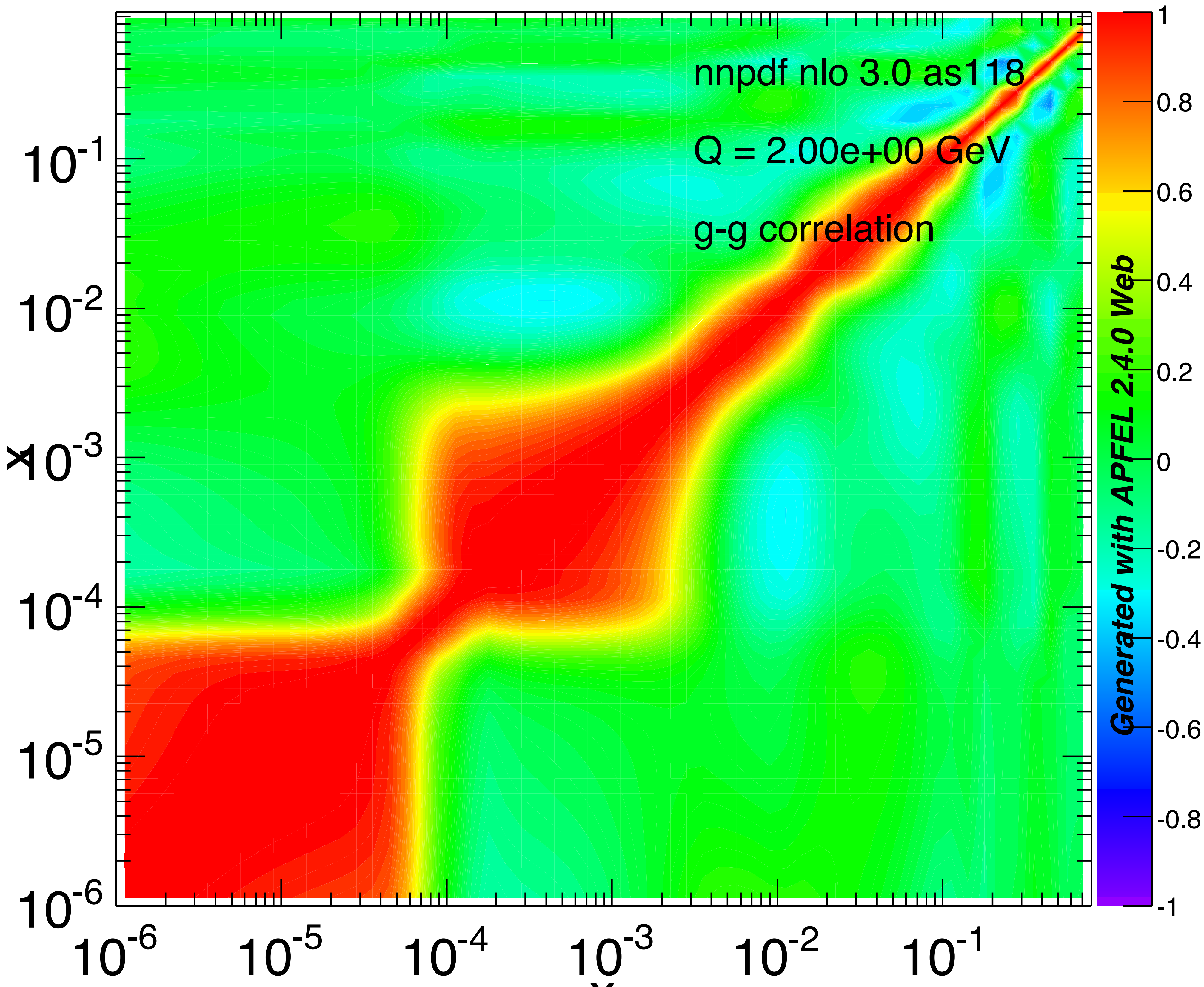




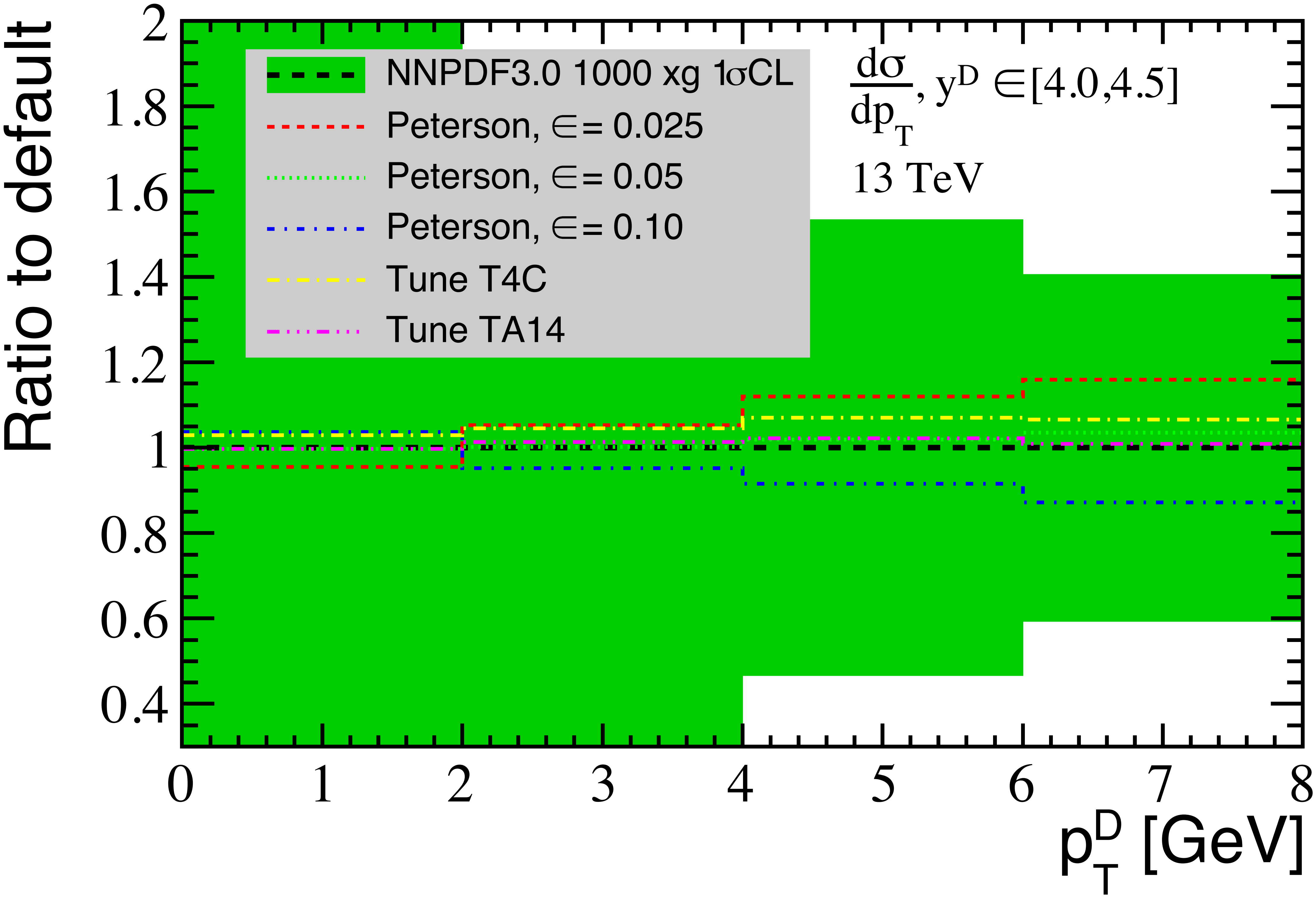




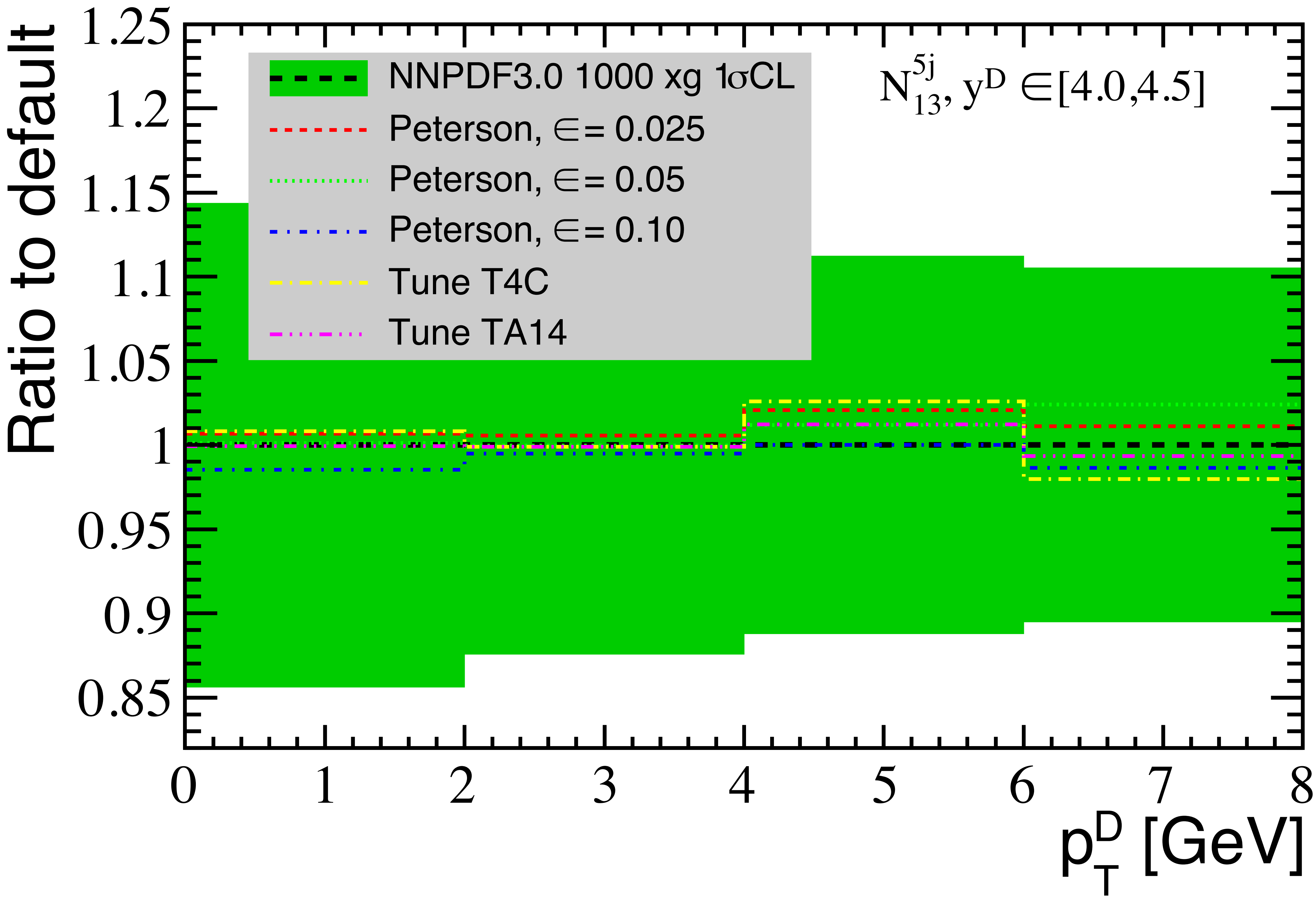
PDF correlation matrix



Impact of tune on cross-section

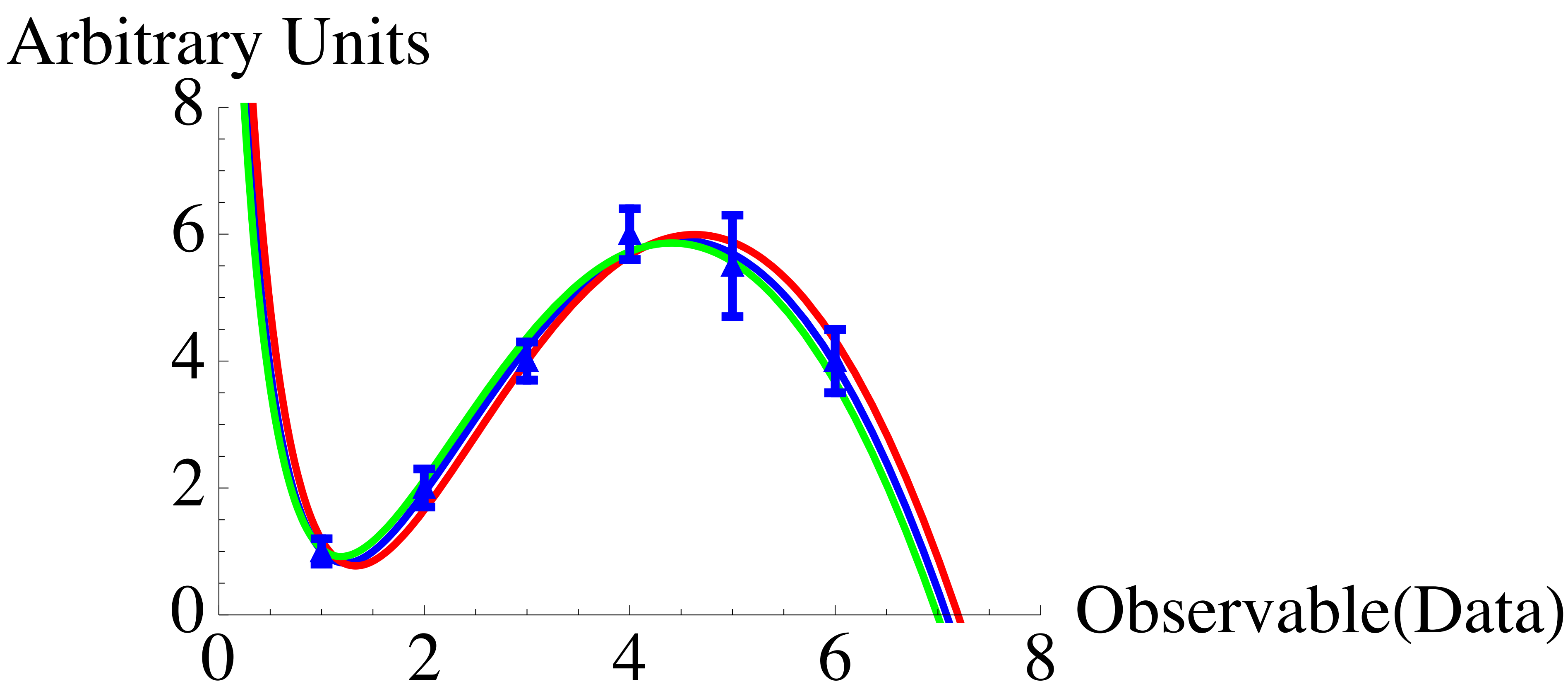


Impact of tune on normalised cross-section



Wish to determine the impact of new data

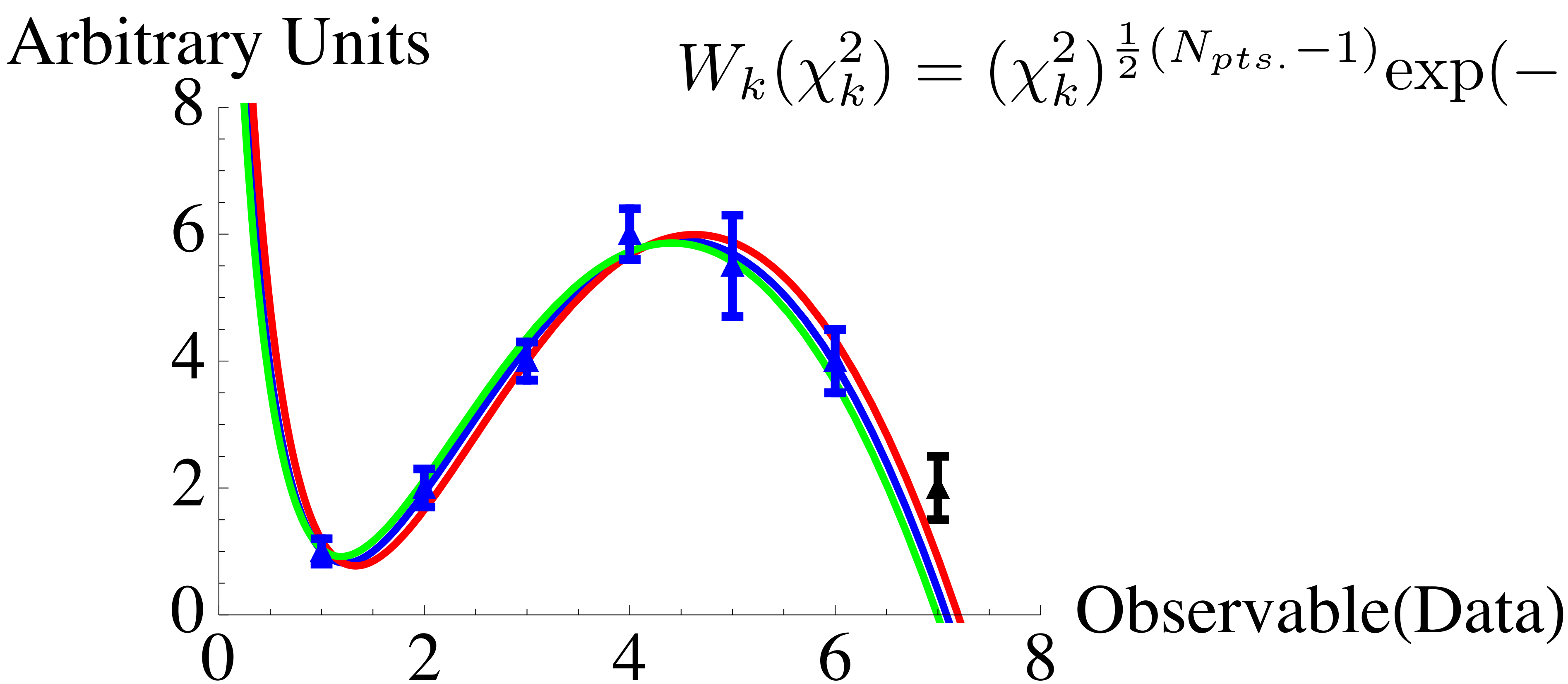
Use a reweighting technique of PDF replicas
see - arXiv:1012.0836, NNPDF collaboration



1. NNPDF provide replica ensemble of PDFs (from global fit)
2. These replicas are conditional on input data (and th. assumptions)

Wish to determine the impact of new data

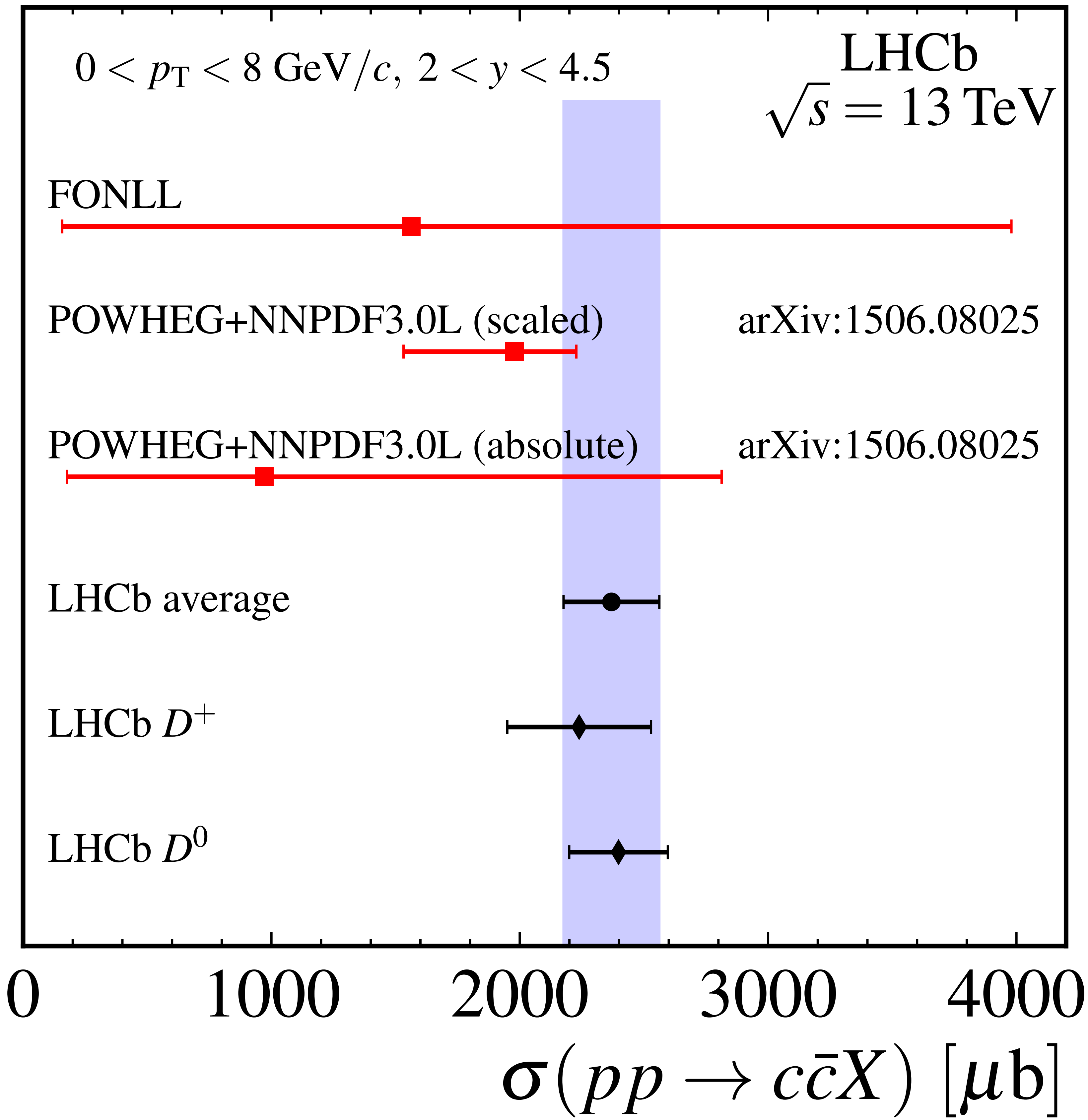
Use a reweighting technique of PDF replicas
see - arXiv:1012.0836, NNPDF collaboration



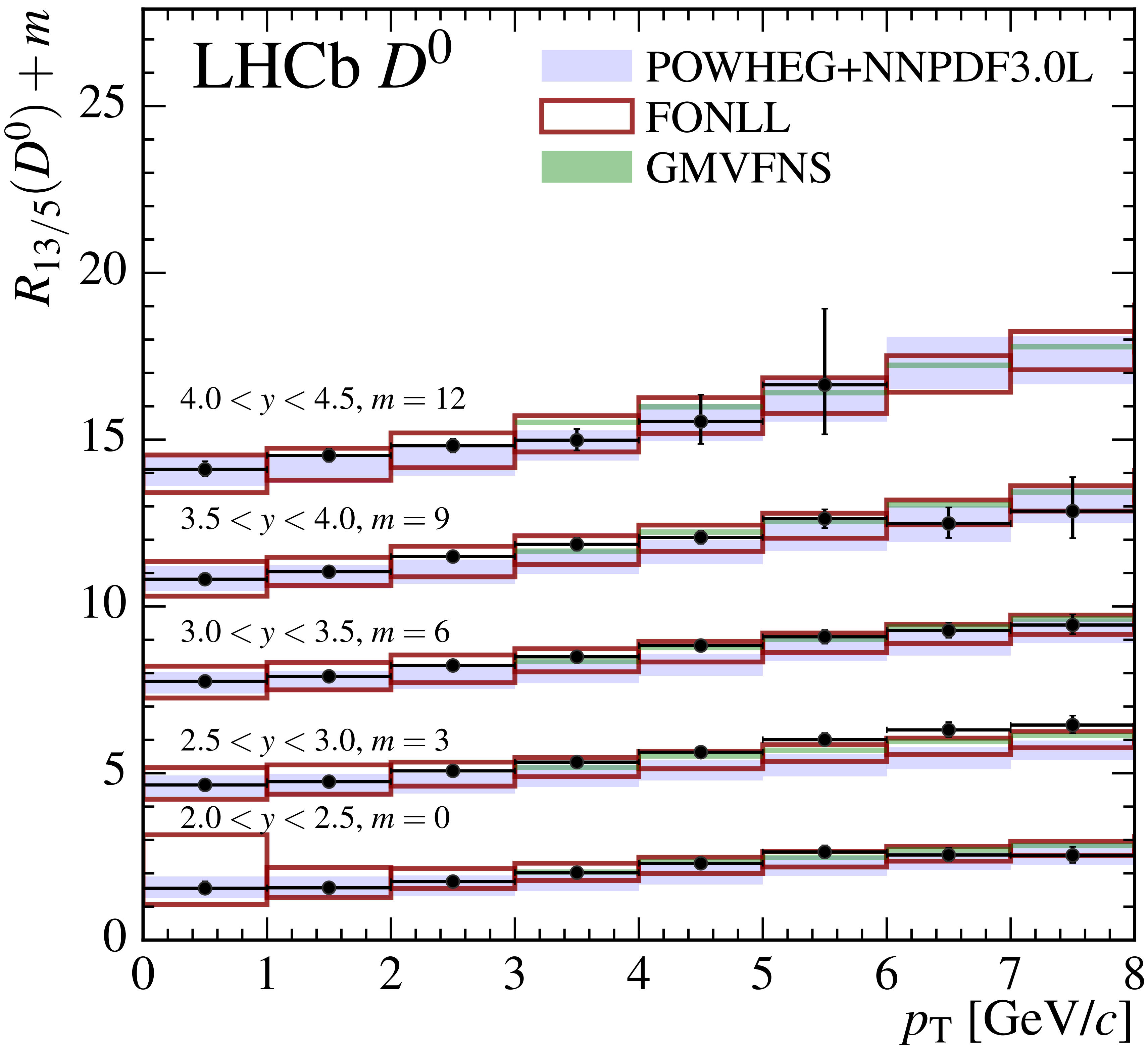
$$W_k(\chi^2_k) = (\chi^2_k)^{\frac{1}{2}(N_{pts.}-1)}\exp(-\frac{1}{2}\chi^2_k)$$

1. NNPDF provide replica ensemble of PDFs (from global fit)
2. These replicas are conditional on input data (and th. assumptions)
3. Construct weighted ensemble of PDFs, also conditional on new data

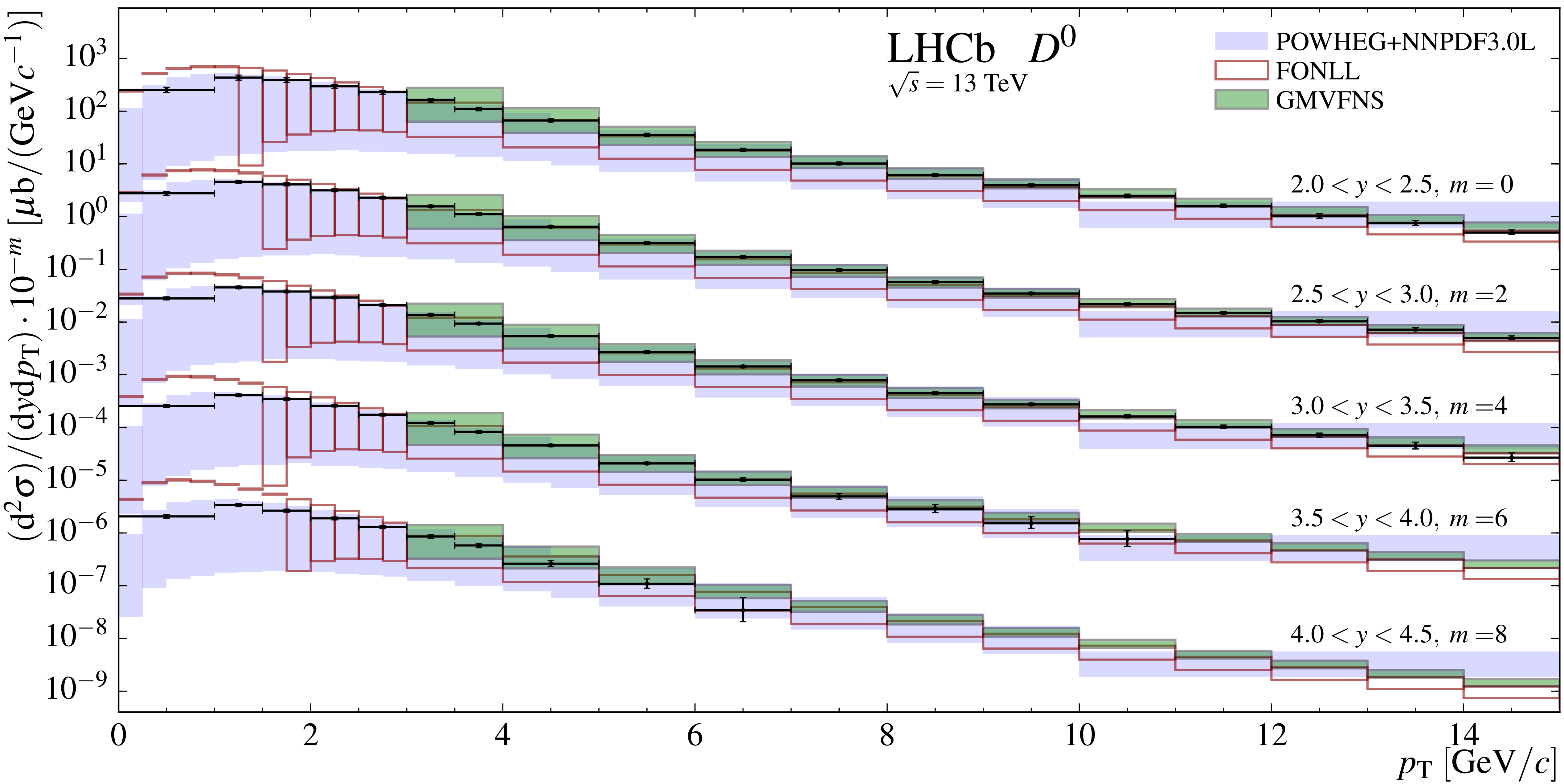
How do the data actually look?

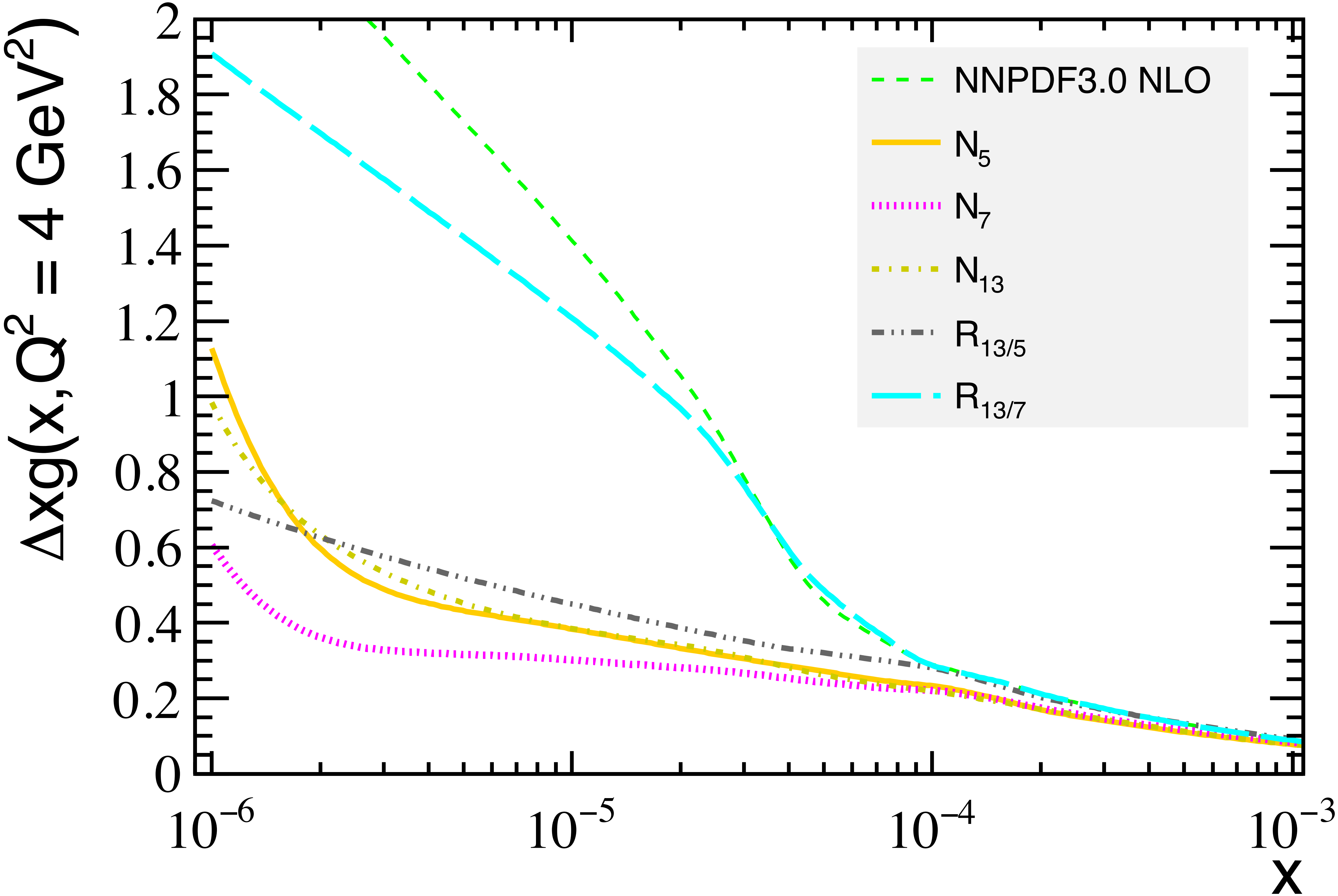


How do the data actually look?



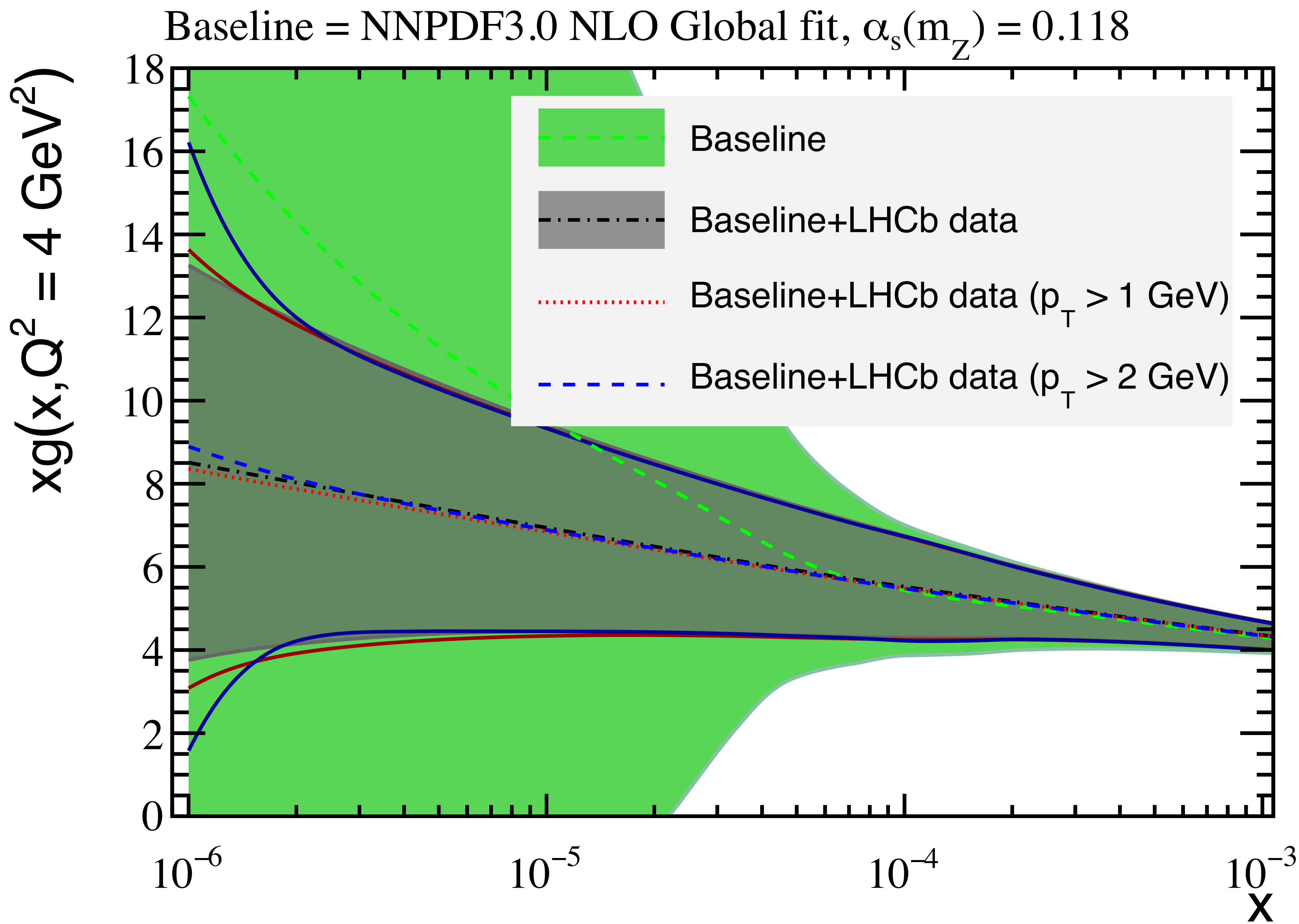
How do the data actually look?

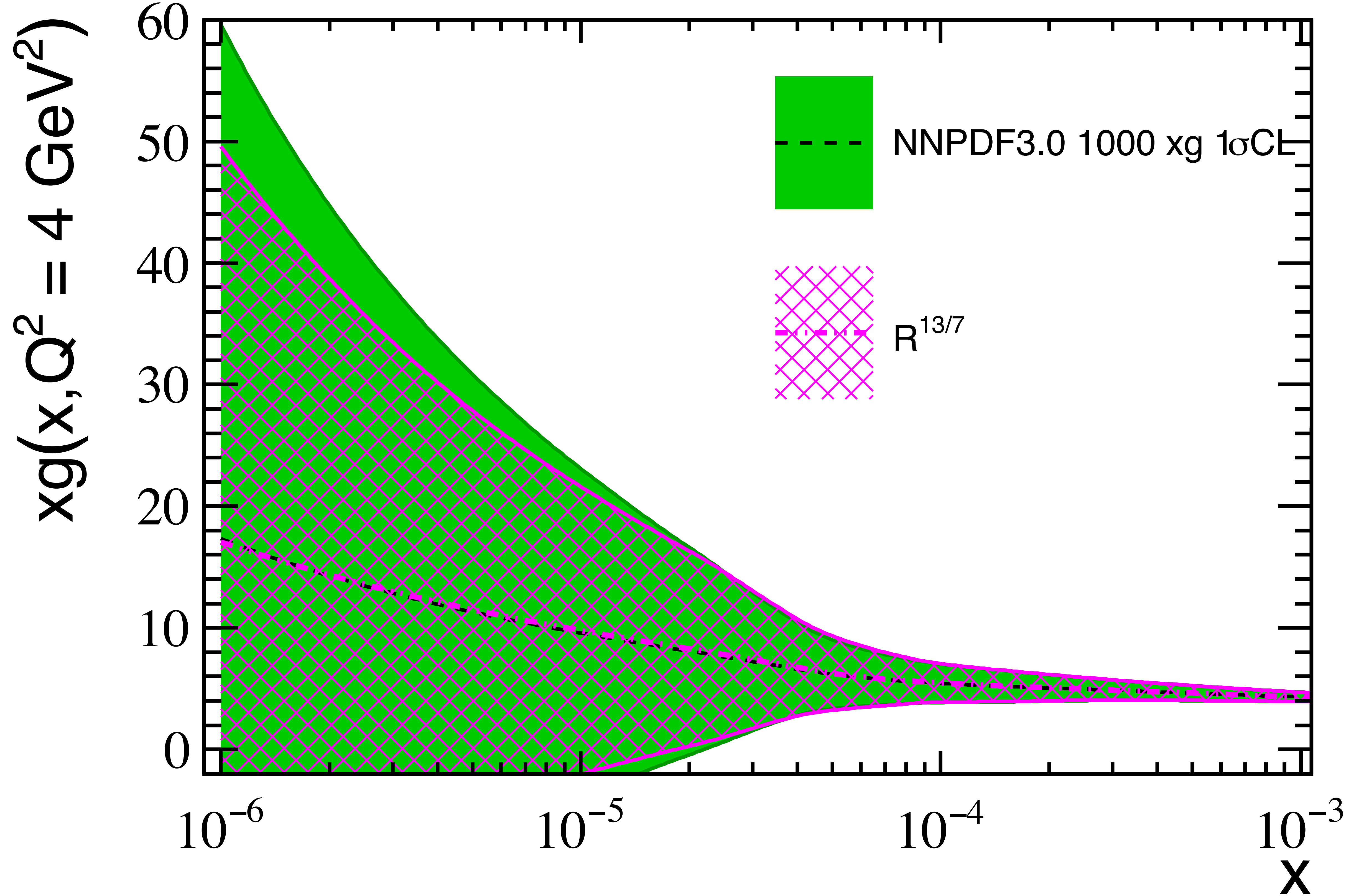




$\Delta xg(x,Q^2 = 4\ \mathrm{GeV}^2)$
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x
NNPDF3.0 NLO
N_5
N_7
N_{13}
$R_{13/5}$
$R_{13/7}$

pT dependence (mcen, up)





NNPDF3.0 1000 xg 1σCL
R^13/7
xg(x,Q^2 = 4 GeV^2)
x