Constraining the gluon PDF

Rhorry Gauld

Parton Distributions for the LHC
Benasque - February 2015

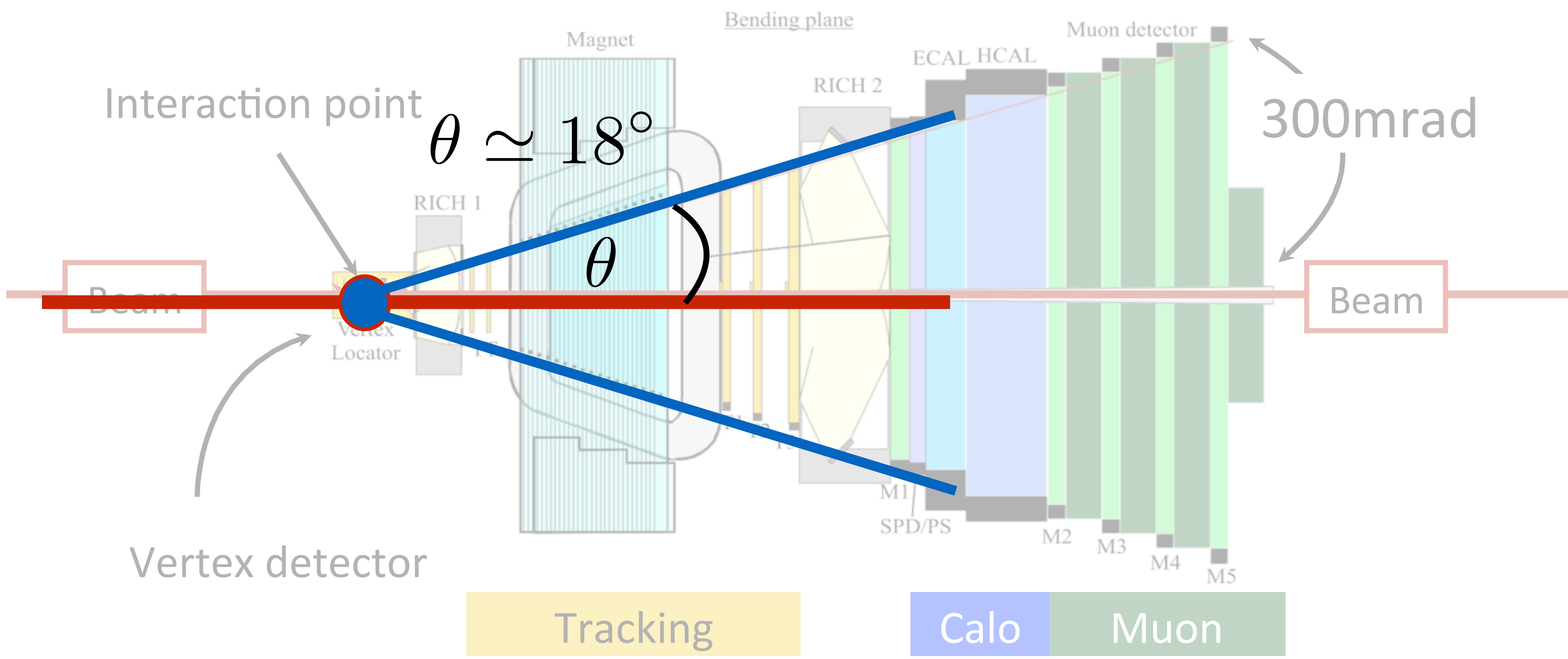
Science & Technology Facilities Council
Durham University

Overview

- Heavy quark pair physics
  - charm measurements
  - top measurements

- Electroweak + jets
  - Prospects for W+jets measurements

The LHCb detector and data



LHCb - forward acceptance: $\eta \in [2.0, 4.5]$

Data (ifb)	7 TeV	8 TeV	13 TeV	14 TeV (2030)
ATLAS/CMS	5	20	100	3000?
LHCb	**1**	**2**	**~5**	**~50**

Heavy quark pair production $pp \to Q_3\bar{Q}_4 + X$

Charm and Bottom production predictions:

FONLL - Fixed-Order + Resummation (Cacciari, Greco, Nason arxiv:9803400)

Web implementation:http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html

Cacciari, Frixione, Houdeau, Mangano, Nason and Ridolfi arxiv:1205.6344

GMVFNS - Generalised-Mass Variable-Flavour-Number-Scheme
Kniehl. Kramer, Schienbein, Spiesberger hep-ph: arxiv:0901.4130 and refs. therein

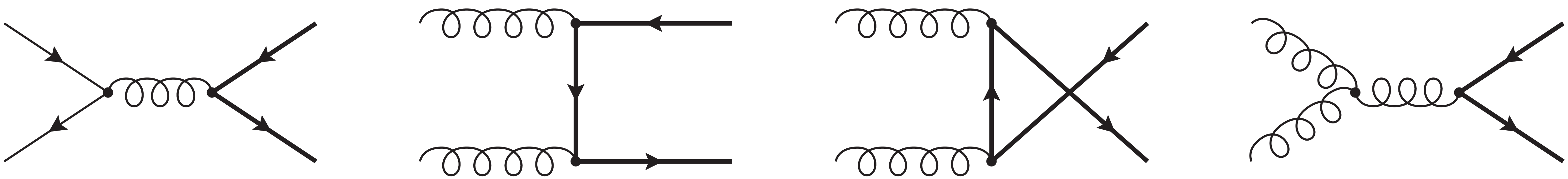
NLO Interfaced to PS (S. Frixione, P. Nason, B. R. Webber, G. Ridolfi)

$$d\hat{\sigma}_D = d\hat{\sigma}_Q \otimes D^{\mathrm{NP}}_{Q\to D}$$

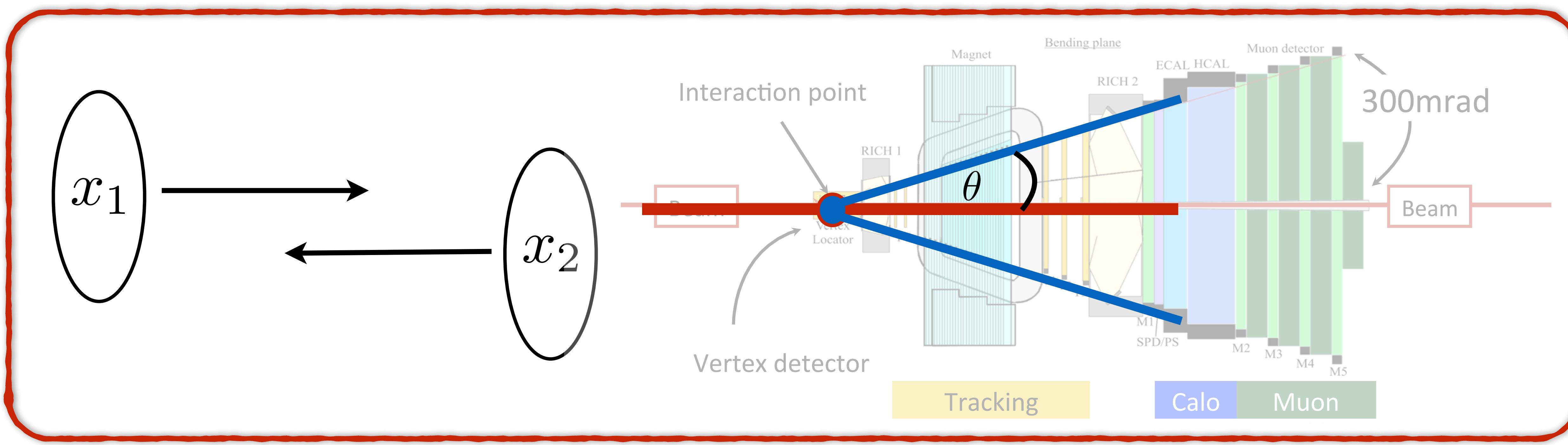
Top production predictions:

NLO - Nason, Dawson, Ellis, Nucl.Phys.B303 (1988) 607, Nucl.Phys B327 (1989) 49-92
NLO (prod / decay) - Melnikov, Schulze arxiv:0907.3090 Capmbell, Ellis arxiv 1204.1513
NNLO - Czakon, Fielder, Mitov, arxiv:1303.6254, arxiv: 1411.3007
~NNLO+(Decay) - Broggio, Papanastasiou, Signer, arxiv: 1407.2532 references therein

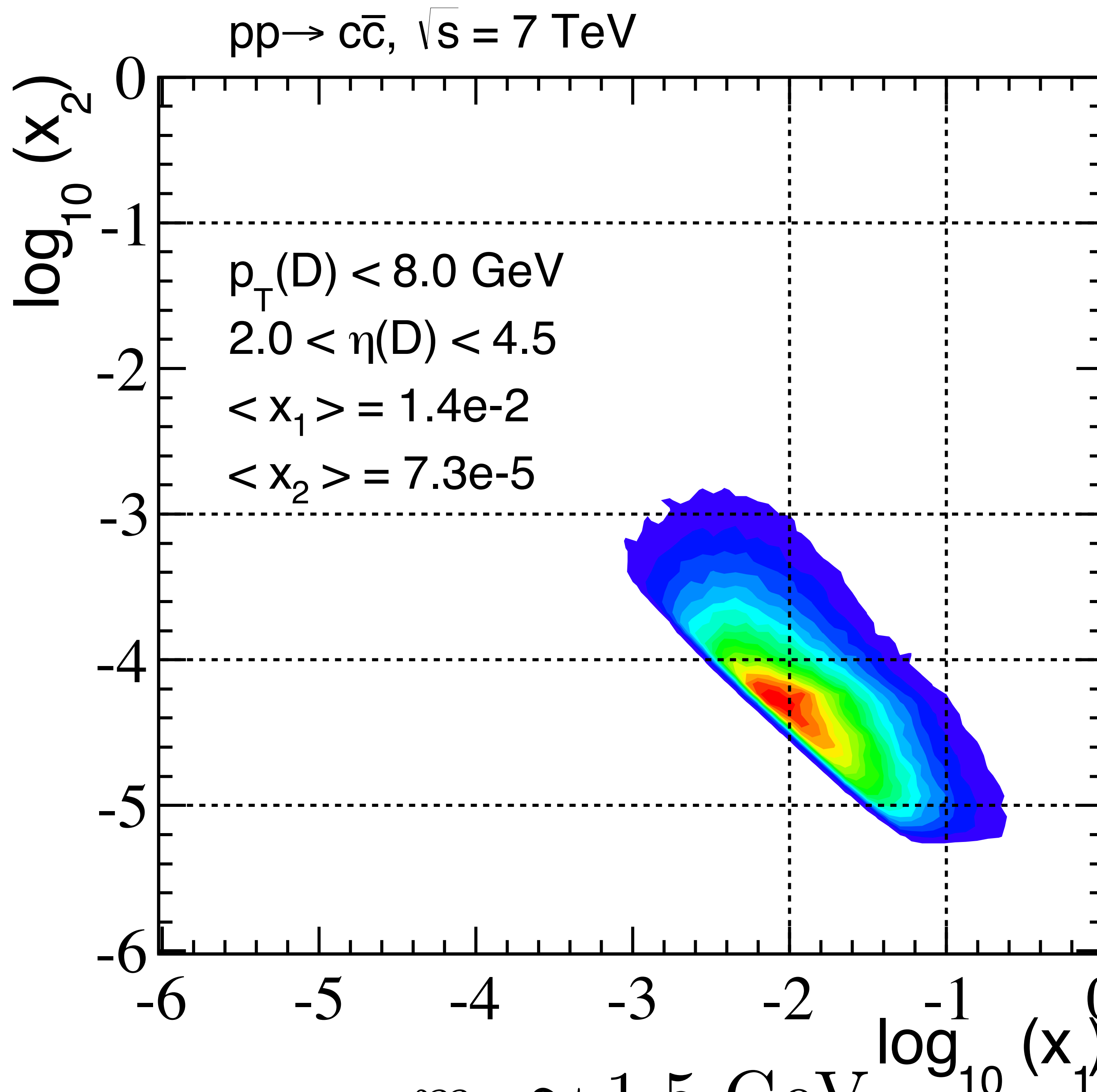
Why study forward $pp \to Q_3\bar{Q}_4 + X$?



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



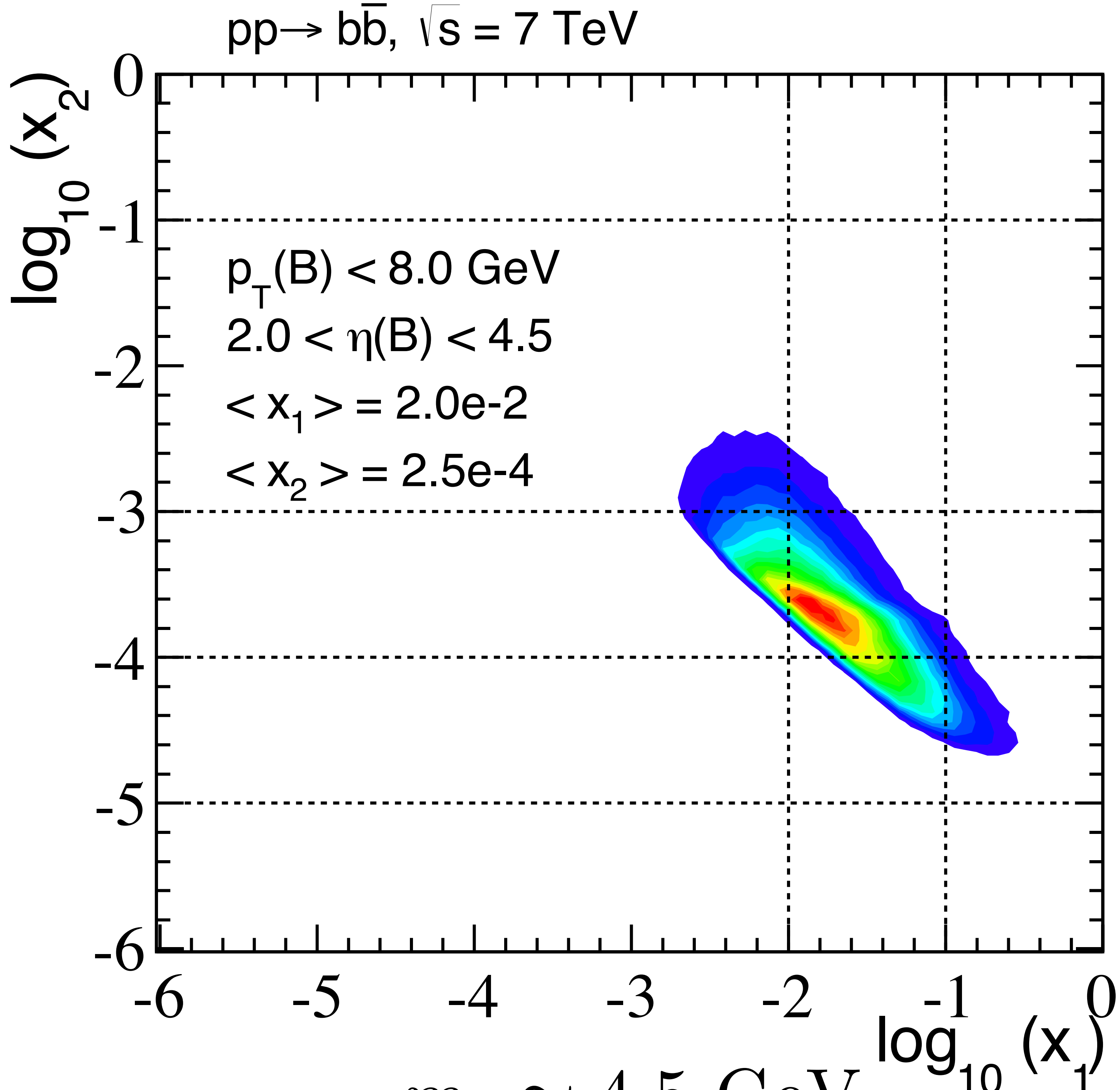
$$pp \to c\bar{c}$$



$m_c \simeq 1.5$ GeV

LHCb measurement arXiv: 1302.2864

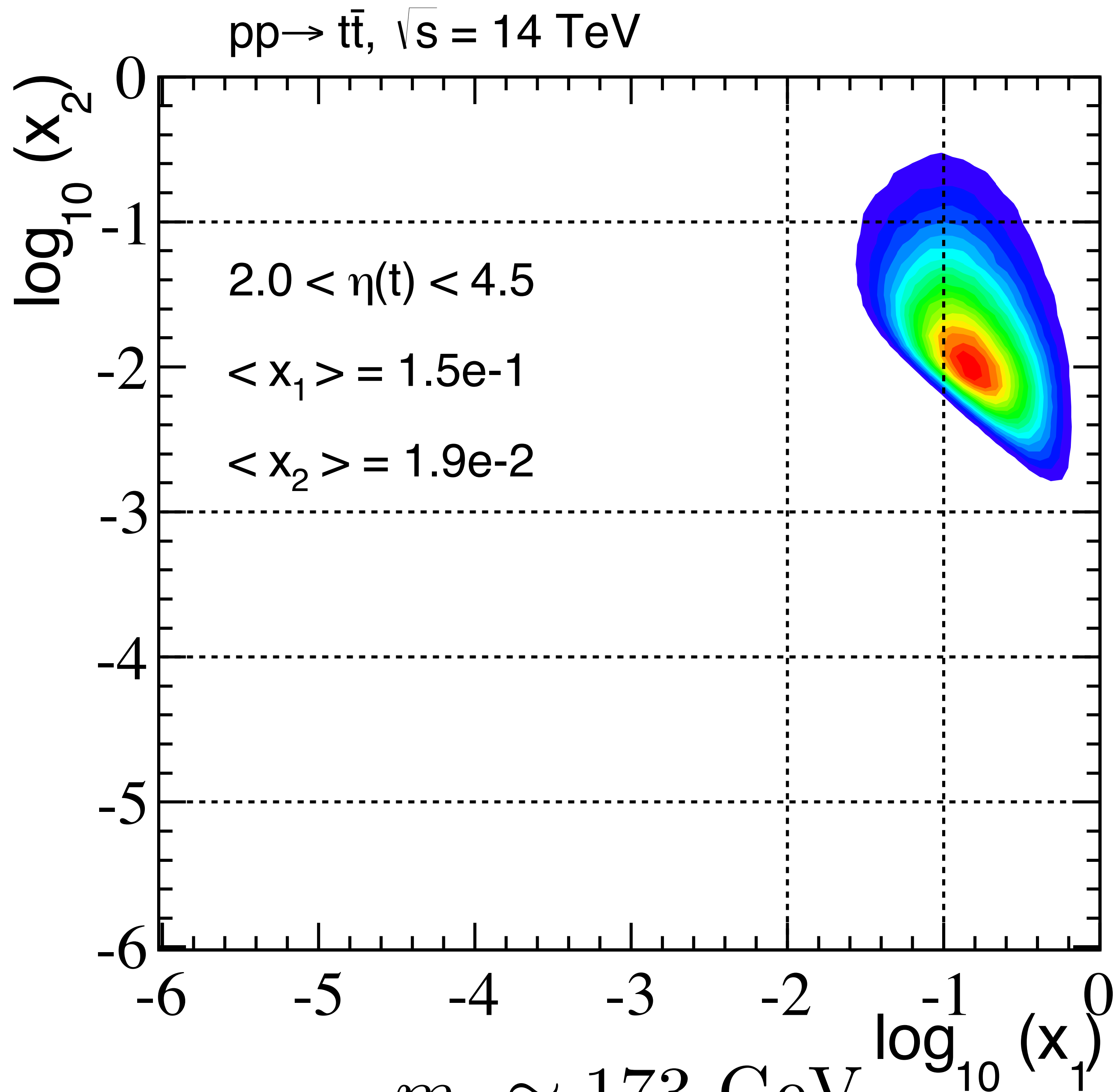
$pp \to b\bar{b}$



$m_b \simeq 4.5$ GeV

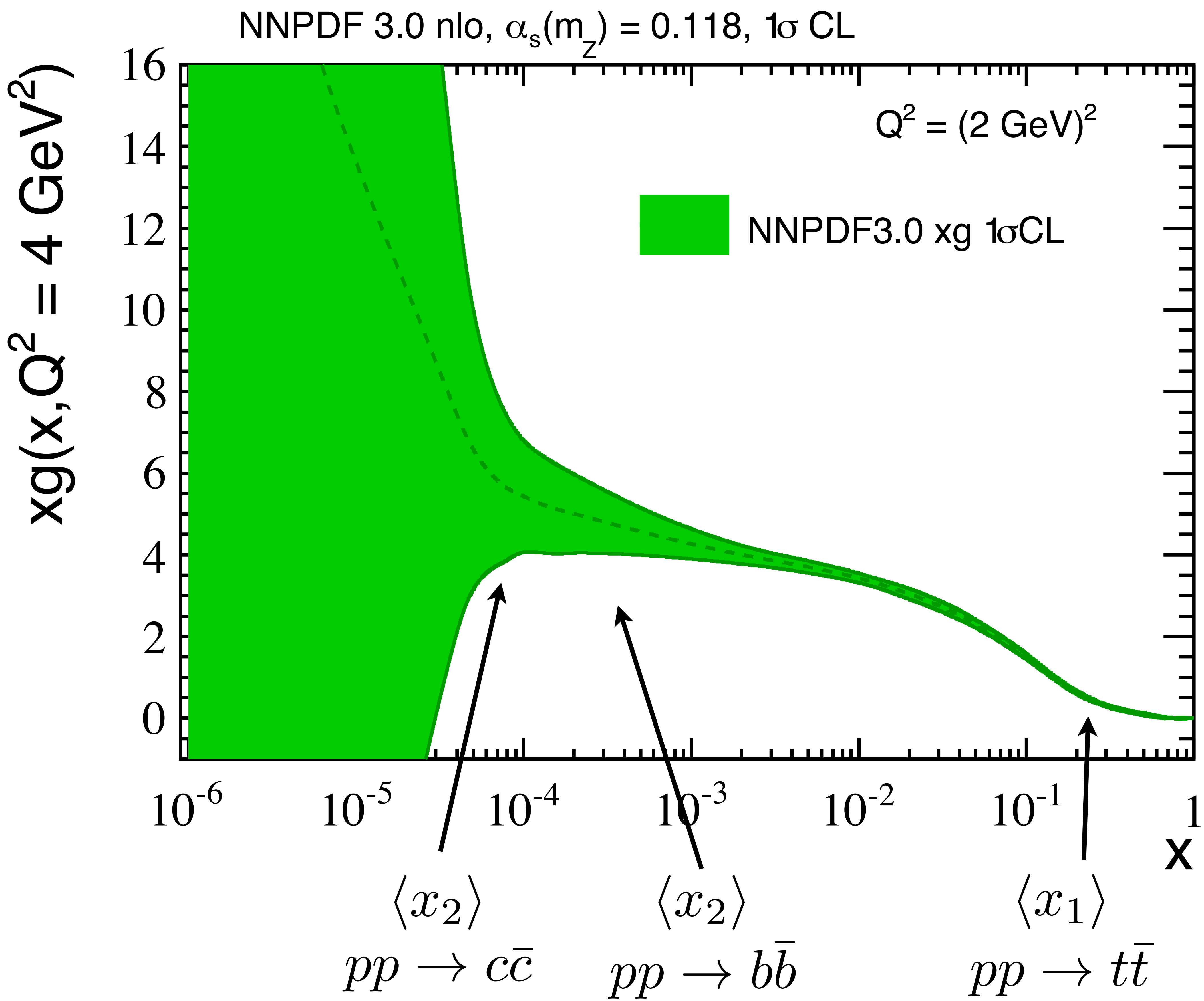
LHCb measurement arXiv: 1306.3663

$pp \to t\bar{t}$

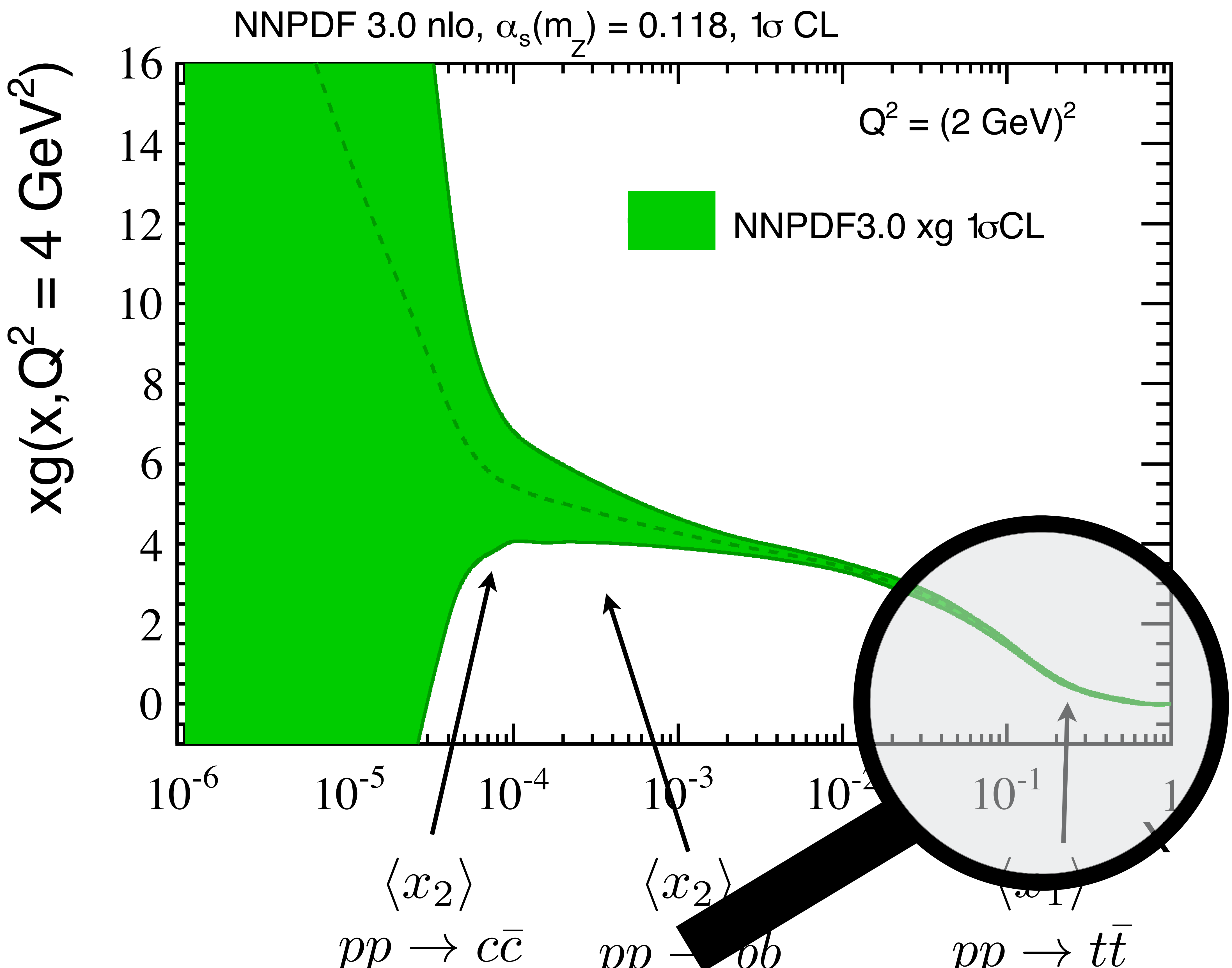


$m_t \simeq 173 \text{ GeV}$

LHCb measurement arXiv: 15??.????



NNPDF 3.0 nlo, $\alpha_s(m_Z)$ = 0.118, 1σ CL
$xg(x,Q^2 = 4\ GeV^2)$
$Q^2 = (2\ GeV)^2$
NNPDF3.0 xg 1σCL
16
14
12
10
8
6
4
2
0
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x
$\langle x_2 \rangle$
$pp \to c\bar{c}$
$\langle x_2 \rangle$
$pp \to b\bar{b}$
$\langle x_1 \rangle$
$pp \to t\bar{t}$



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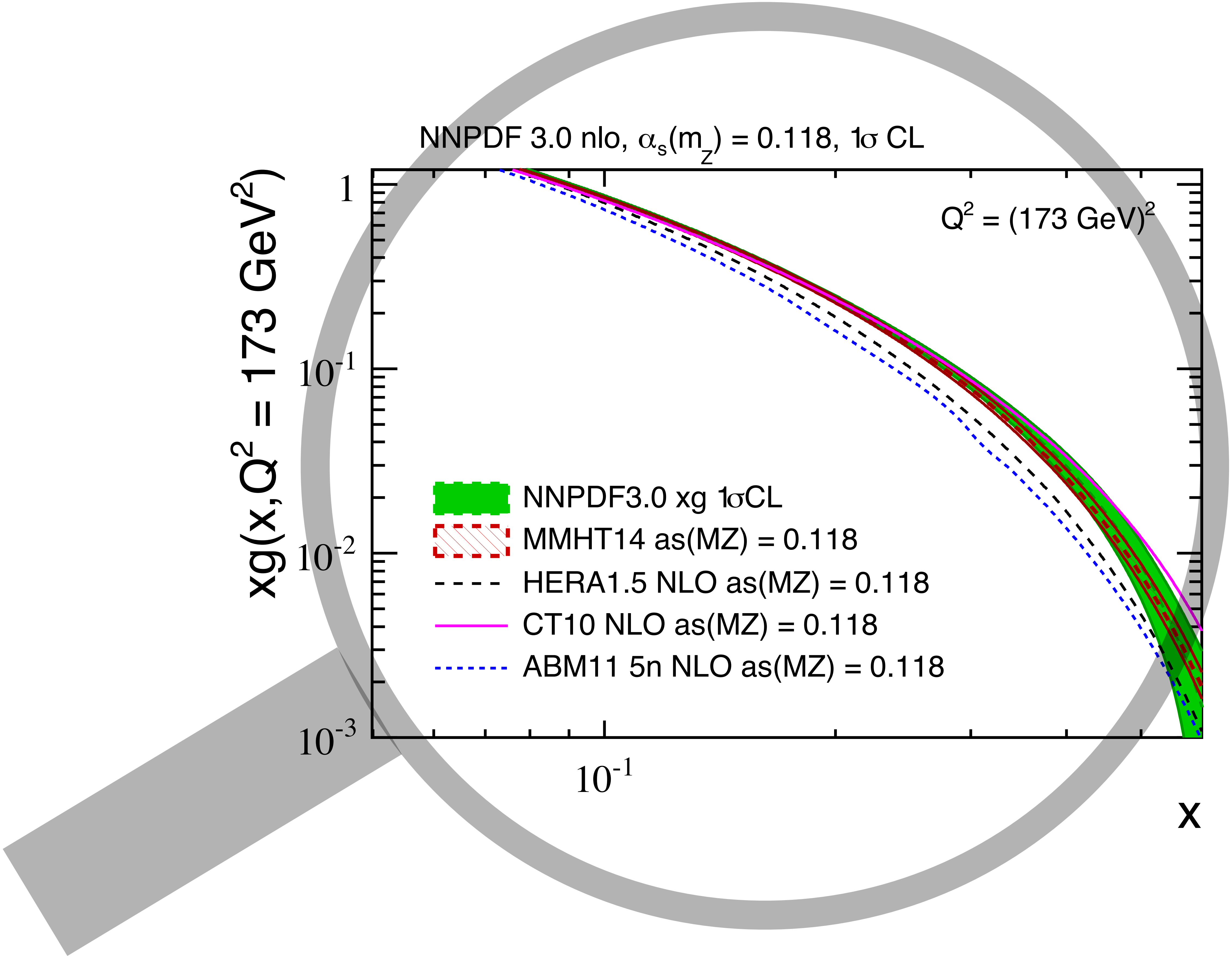
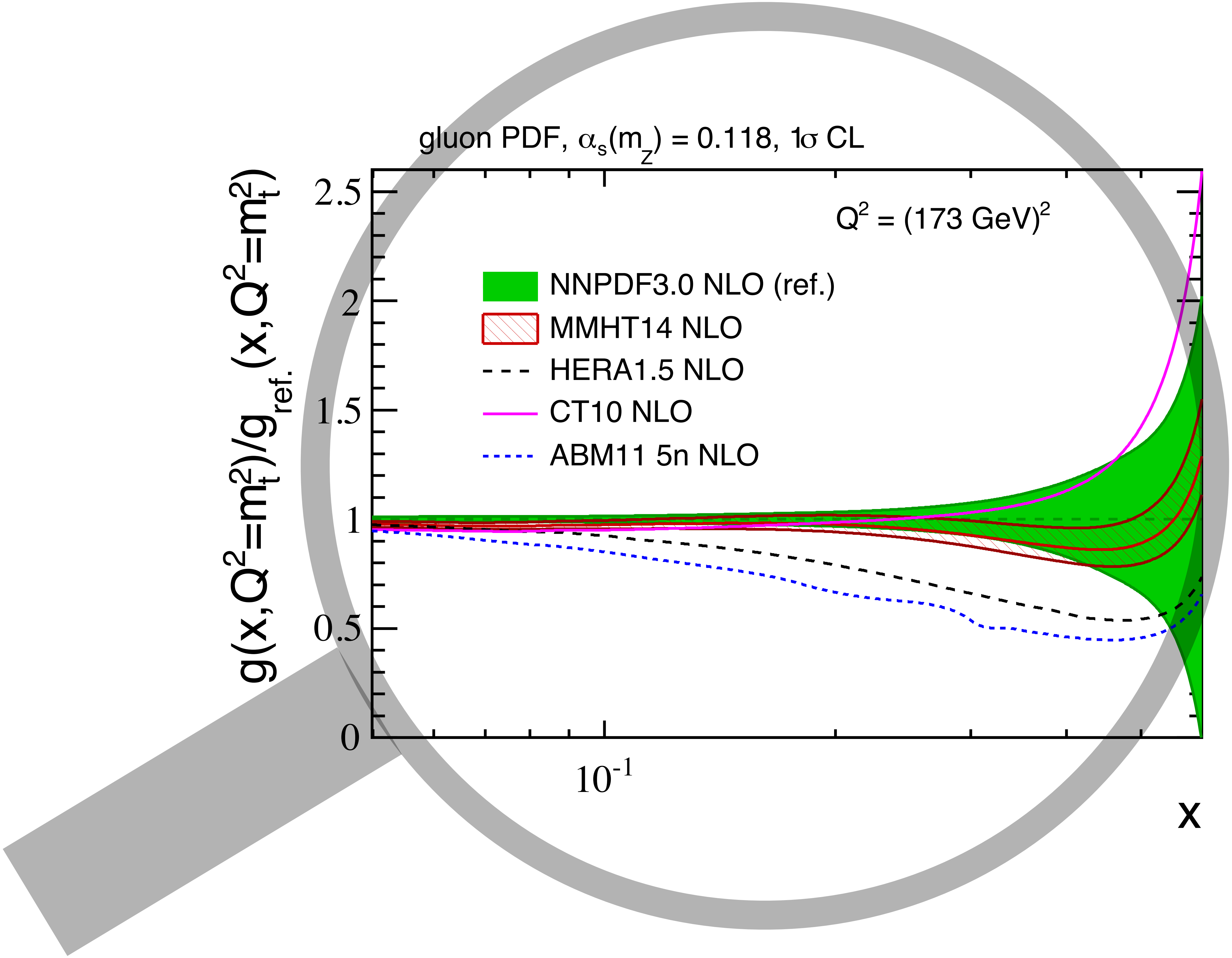
16
14
12
10
8
6
4
2
0
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-1}
x
$\langle x_2 \rangle$
$pp \to c\bar{c}$
$\langle x_2 \rangle$
pp
$pp \to t\bar{t}$


NNPDF 3.0 nlo, $\alpha_s(m_Z)$ = 0.118, 1σ CL
$xg(x,Q^2 = 173\ GeV^2)$
$Q^2 = (173\ GeV)^2$
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
x
NNPDF3.0 xg 1σCL
MMHT14 as(MZ) = 0.118
HERA1.5 NLO as(MZ) = 0.118
CT10 NLO as(MZ) = 0.118
ABM11 5n NLO as(MZ) = 0.118

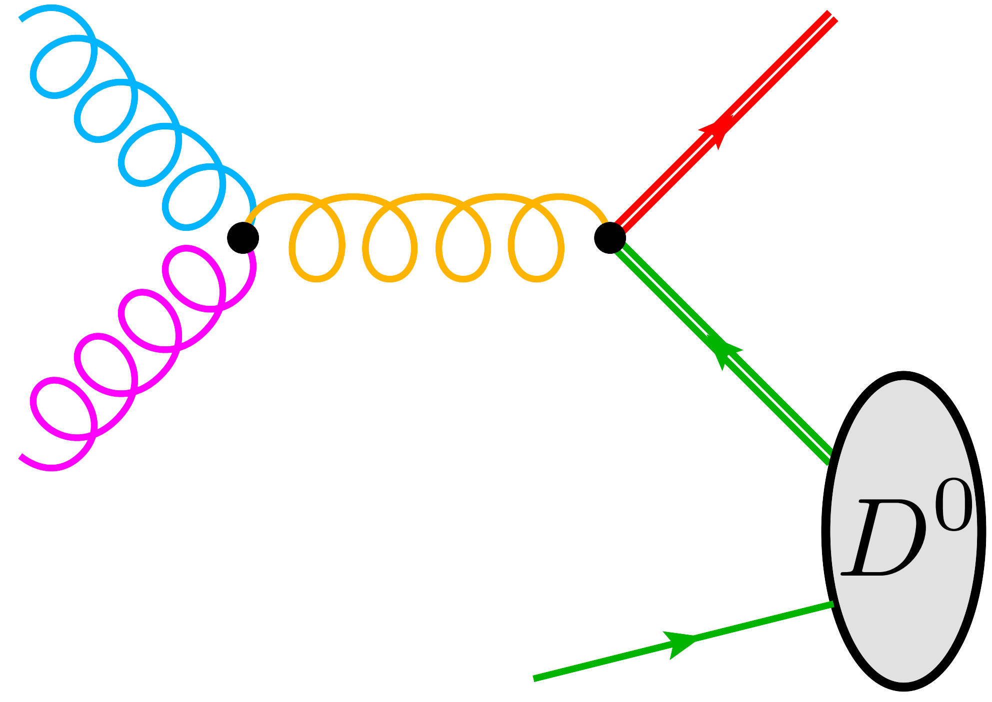


gluon PDF, $\alpha_s(m_Z)$ = 0.118, 1σ CL
$g(x,Q^2=m_t^2)/g_{ref.}(x,Q^2=m_t^2)$
Q^2 = (173 GeV)^2
NNPDF3.0 NLO (ref.)
MMHT14 NLO
HERA1.5 NLO
CT10 NLO
ABM11 5n NLO
2.5
2
1.5
1
0.5
0
10^{-1}
x

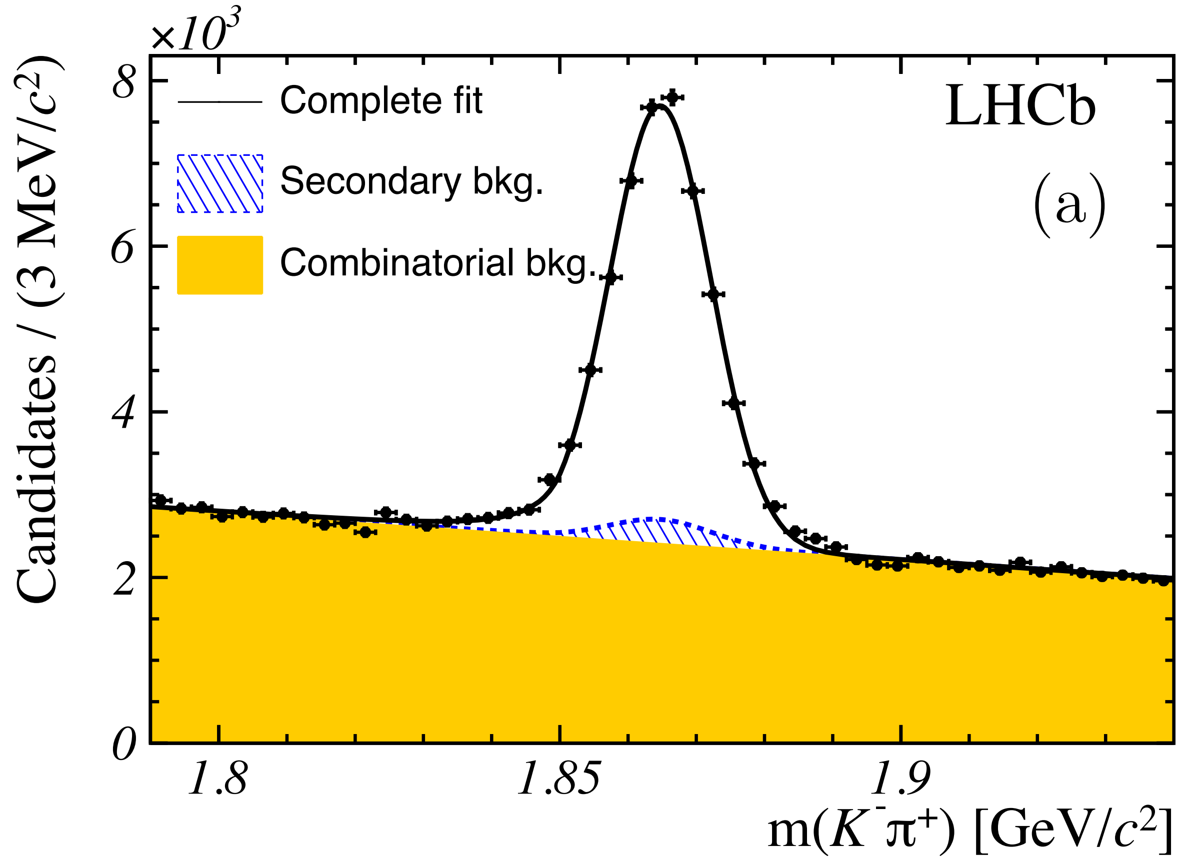
Cross-section measurements

D measurement (arXiv: 1302.2864)

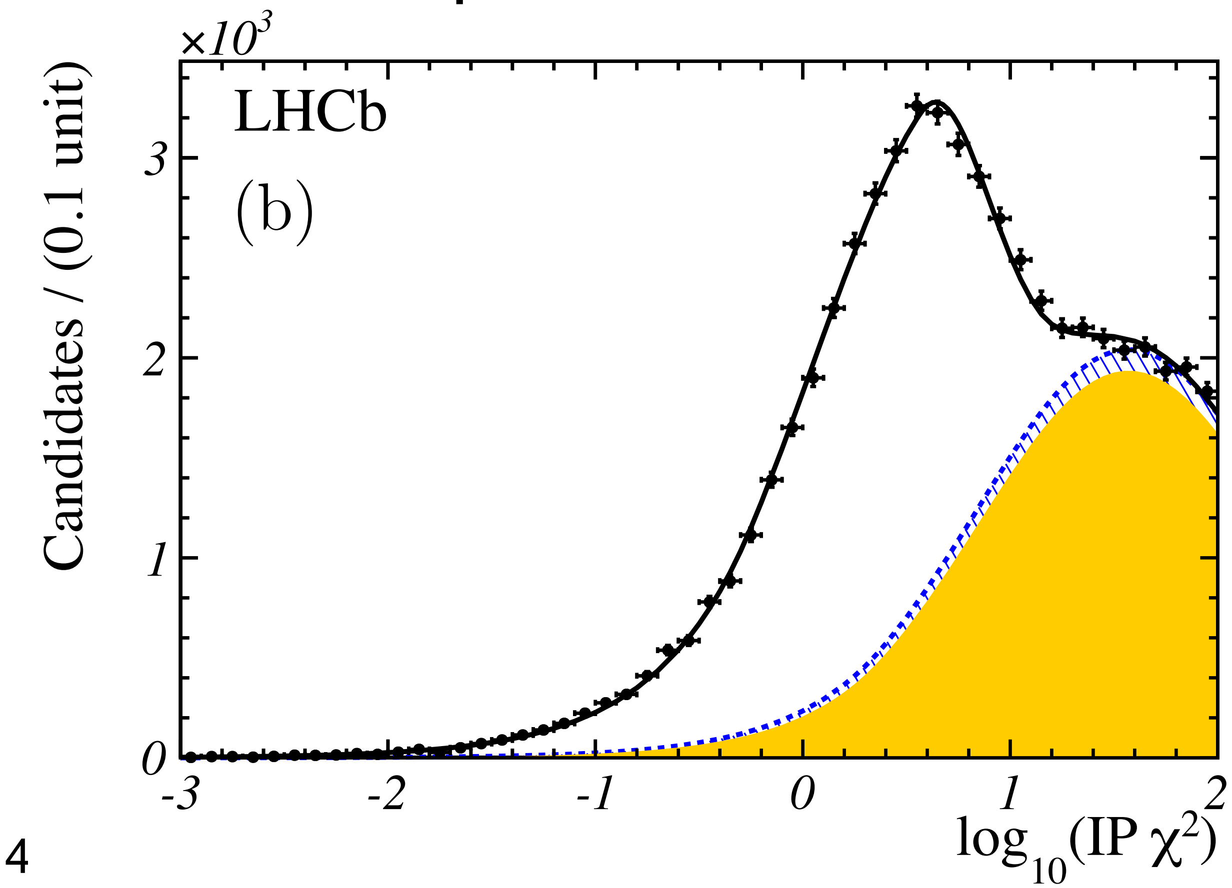
$$pp \rightarrow D + X$$
$$2.0 < y_D < 4.5$$
$$Dp_T < 8.0GeV$$



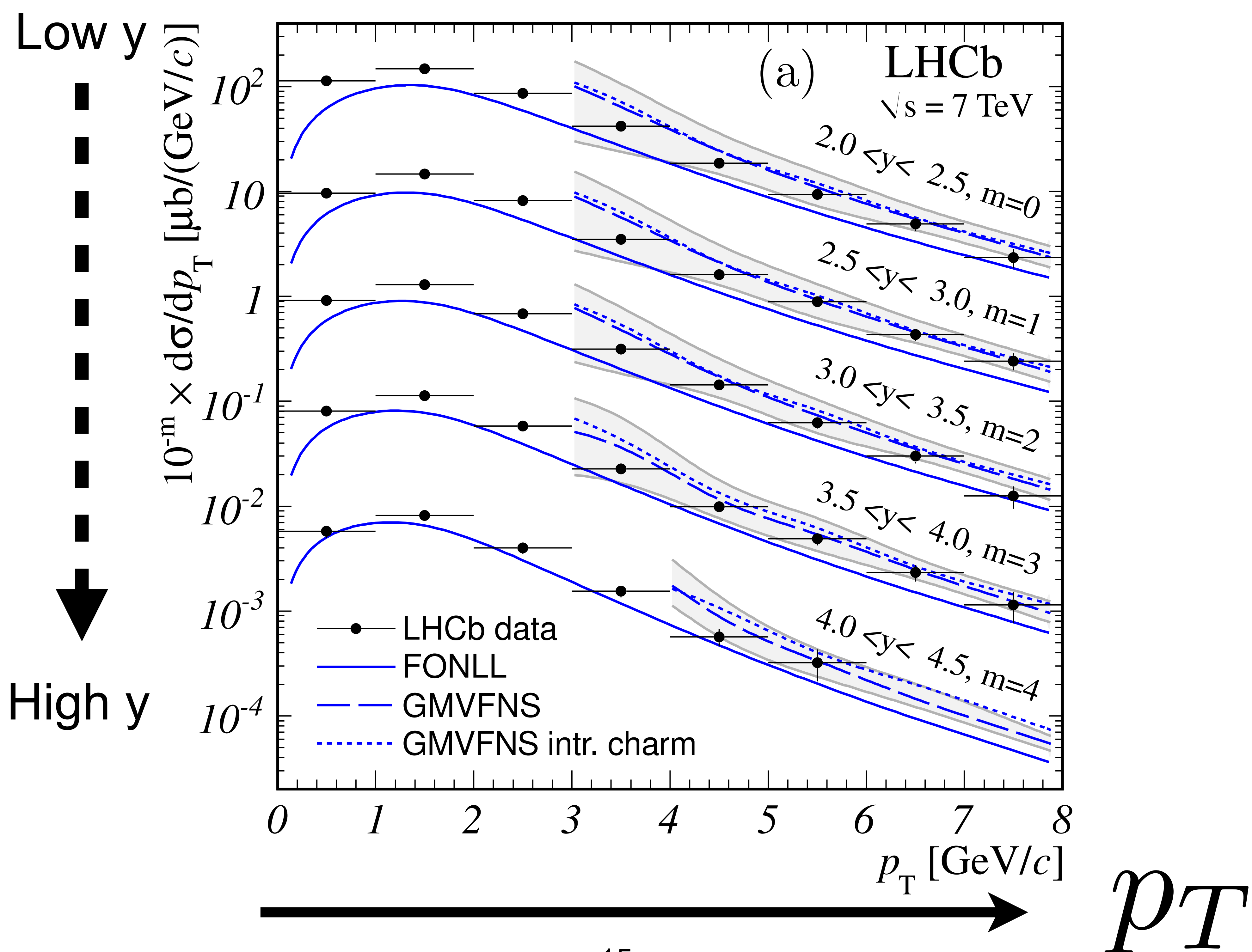
Mass requirement



Displaced vertex



D measurement (arXiv: 1302.2864)

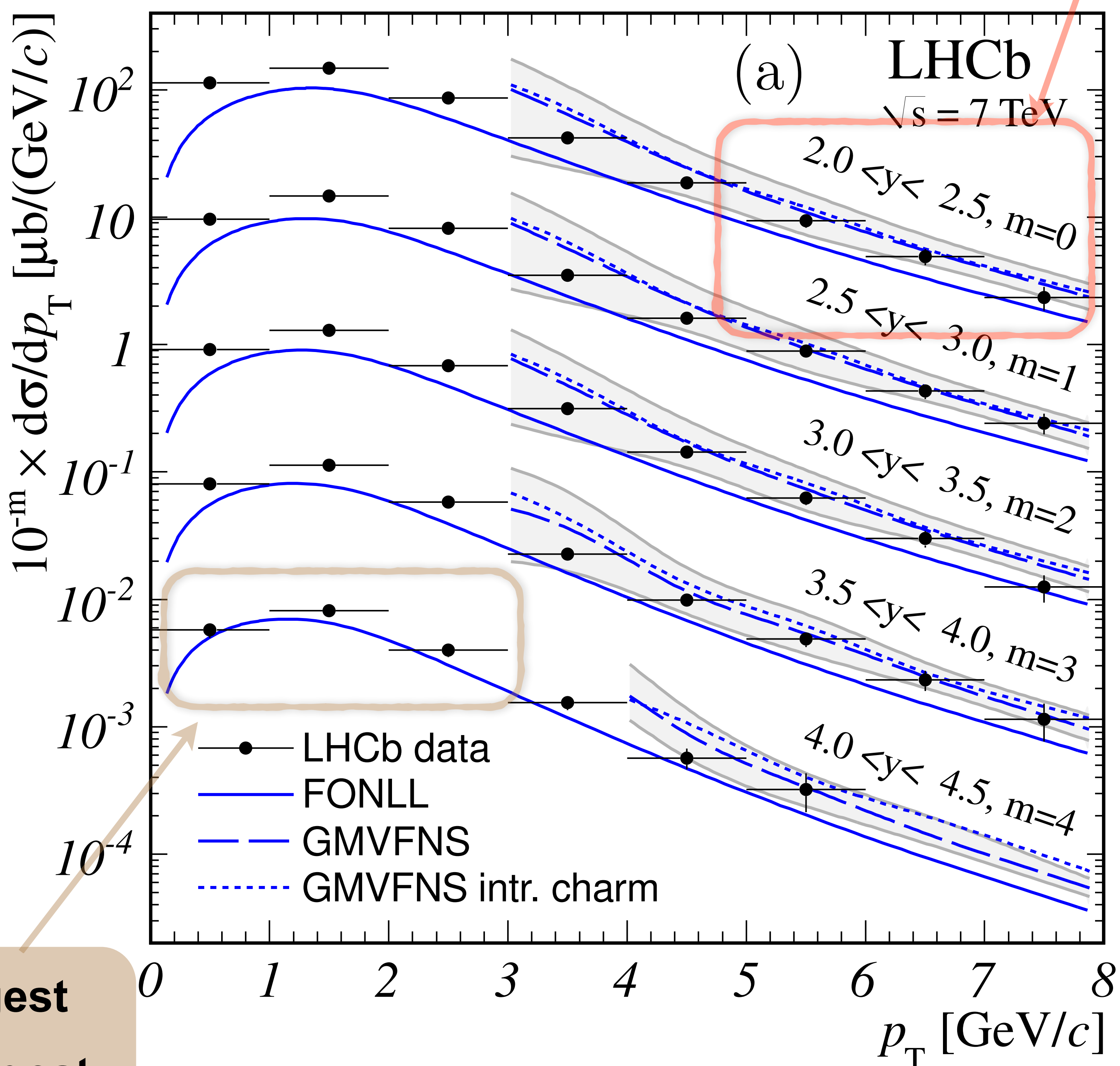


D measurement (arXiv: 1302.2864)

PDF Uncertainties **smallest**

Scale Uncertainties **smallest**

Low y



High y

PDF Uncertainties **largest**

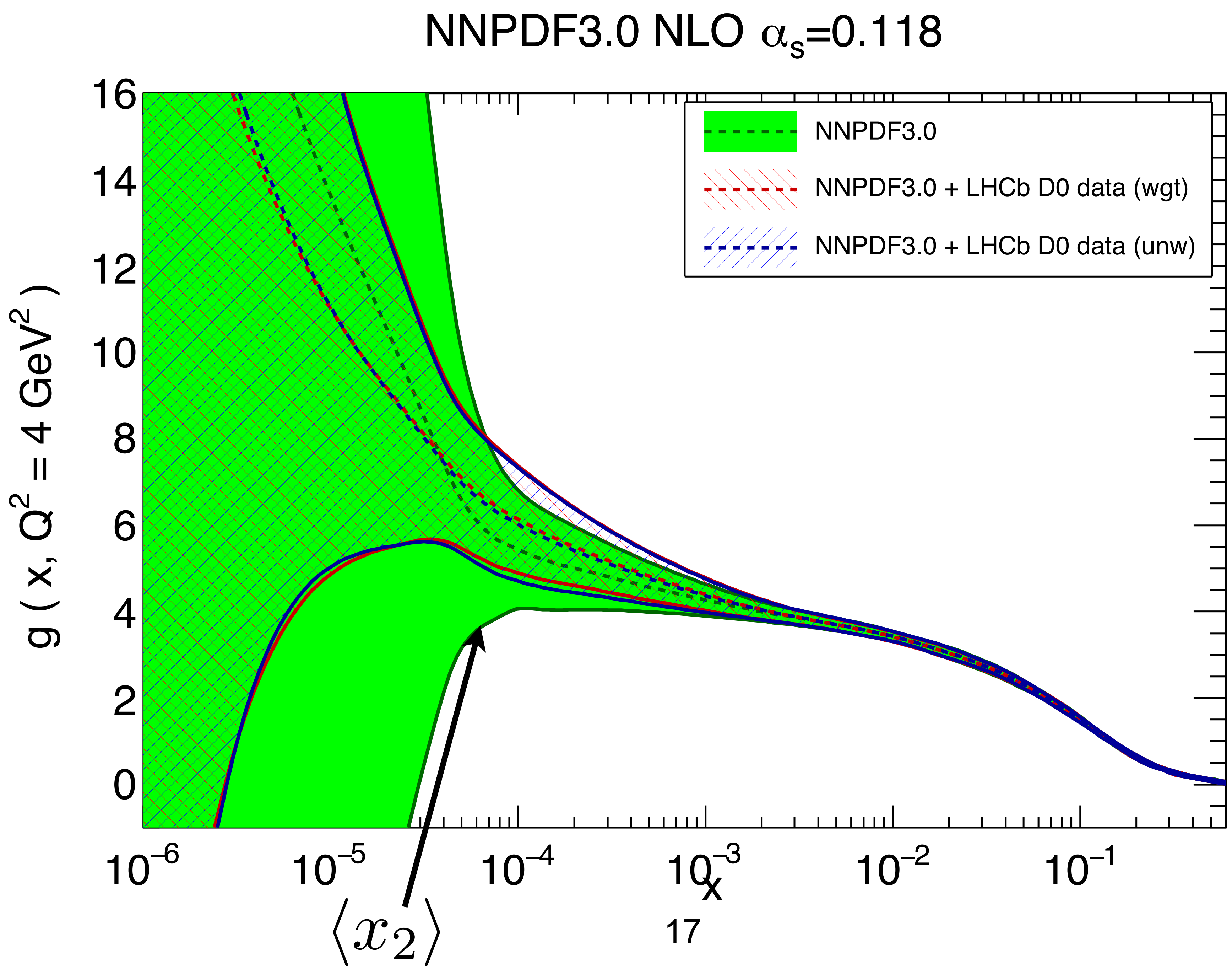
Scale Uncertainties **largest**

p_T

Preliminary results, reweighting NNPDF3.0

Work in progress with J. Rojo, L. Rottoli, S. Sarkar, J. Talbert

1) Normalise LHCb differential charm data to **high-pt**, **low-y** bin
2) Reweight the 100 replicas based on compatibility with LHCb data (here we use the FONLL predictions obtained from public web interface)



Results from PROSA

see - Oleksandr Zenaiev at QCD@LHC2014
(https://indico.desy.de/conferenceDisplay.py?confId=9319)

Using HERAFitter - Open Source QCD Fit Project

- Platform: HERAFitter [www.herafitter.org] HERAFitter
- Input data:
  - HERA-I $e^{\pm}p$ inclusive data ($\sim$ %) [JHEP01 (2010) 109]
  - Combined HERA charm data ($\sim$ 5-10%) [EPJ C73 (2013) 2311]
  - ZEUS beauty vertex data ($\sim$ 10-25%) [arXiv:1405.6915]
  - LHCb charm data ($\sim$ 5-20%) [NPB871 (2013) 1]
  - LHCb beauty data ($\sim$ 5-35%) [JHEP08 (2013) 117]
- Theoretical predictions (FFNS scheme)
  - NLO QCD predictions for $pp \to$ HQ by M. Mangano, P. Nason and G. Ridolfi [MNR] [NPB327 (1989) 49]
  - HQ frag. functions: c as meas. at HERA [EPJ C59 (2009) 589, JHEP04 (2009) 082], b as meas. at LEP [NPB565 (2000) 245]
  - HQ frag. fractions: comb. of LEP and HERA meas. [arXiv:1112.3757]
  - NLO QCD predictions for HERA data: FFNS ABM scheme
  - pole HQ masses m_c, m_b left free in the fit
  - $\alpha_s^{n_f=3}(M_Z) = 0.1059 \pm 0.0005$ (equivalent to PDG $\alpha_s^{n_f=5}(M_Z) = 0.1185 \pm 0.0006$)
  - DGLAP NLO PDF evolution

1) PDF Fit using hera data

2) Study the impact of LHCb data
   - Fiducial diff. cross section
   - Normalised diff. cross section

Results from PROSA

see - Oleksandr Zenaiev at QCD@LHC2014
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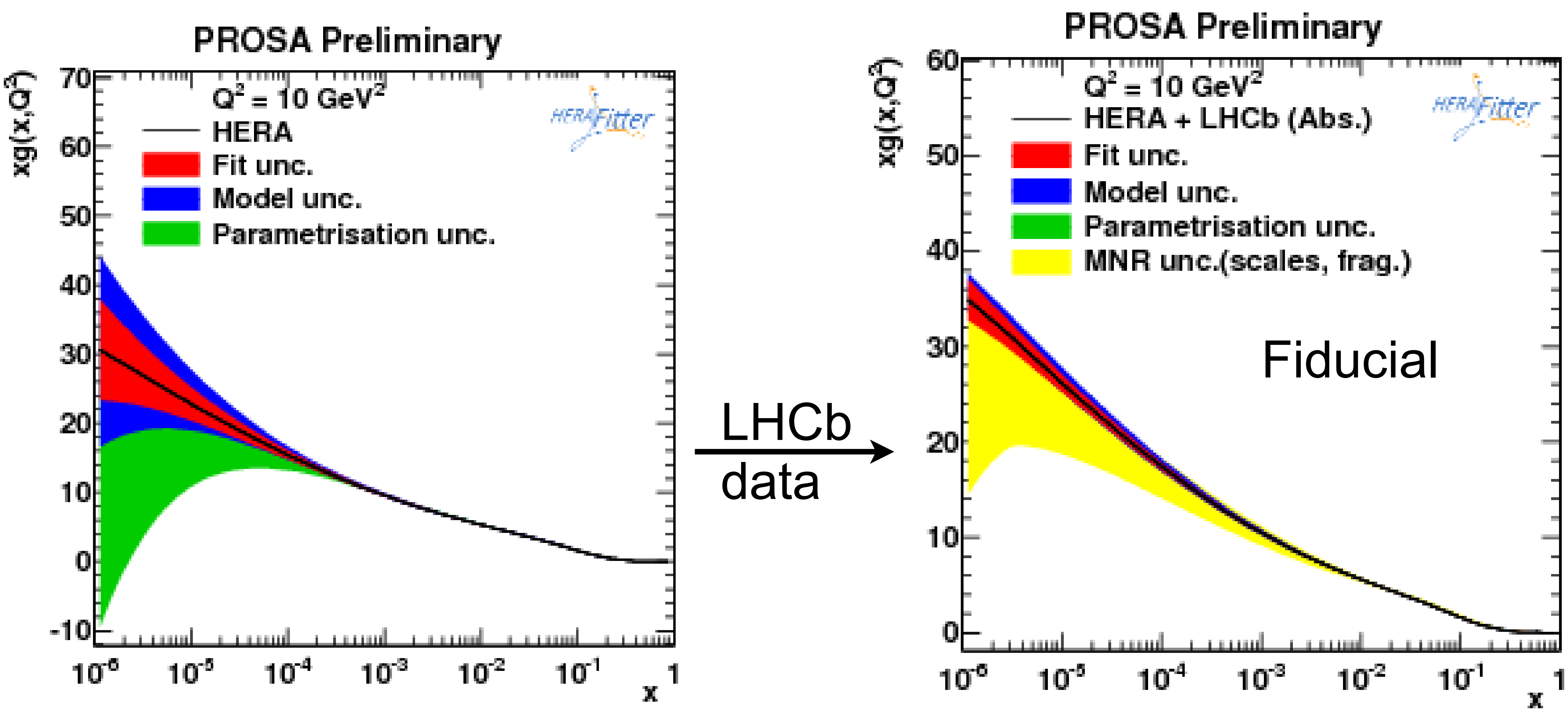
Using HERAFitter - Open Source QCD Fit Project



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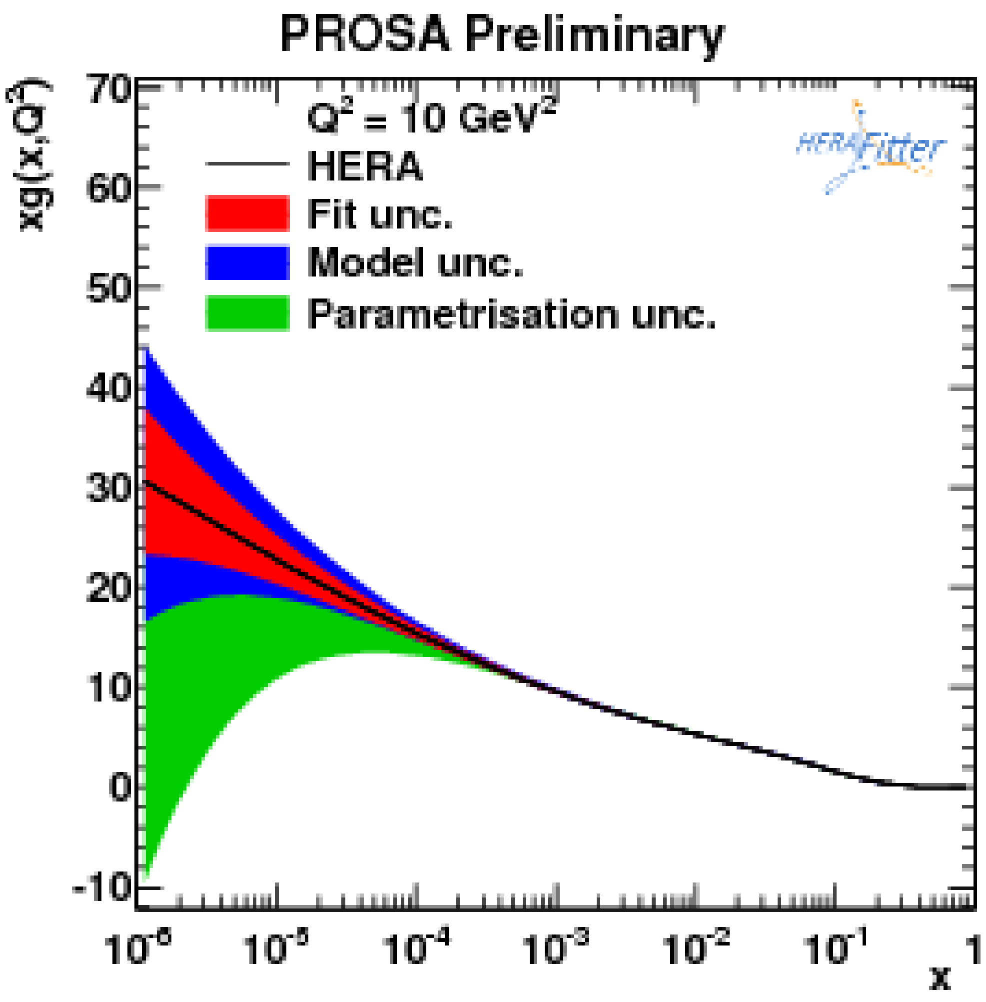
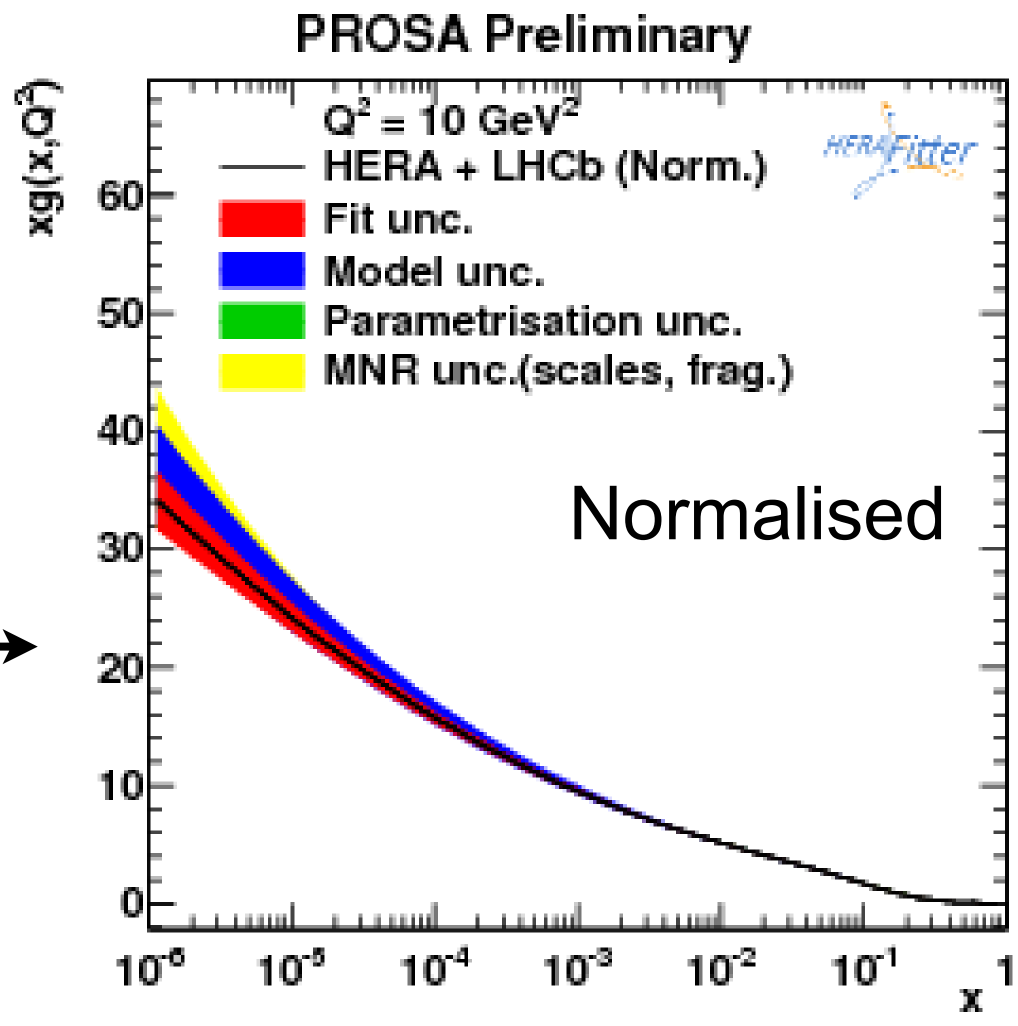
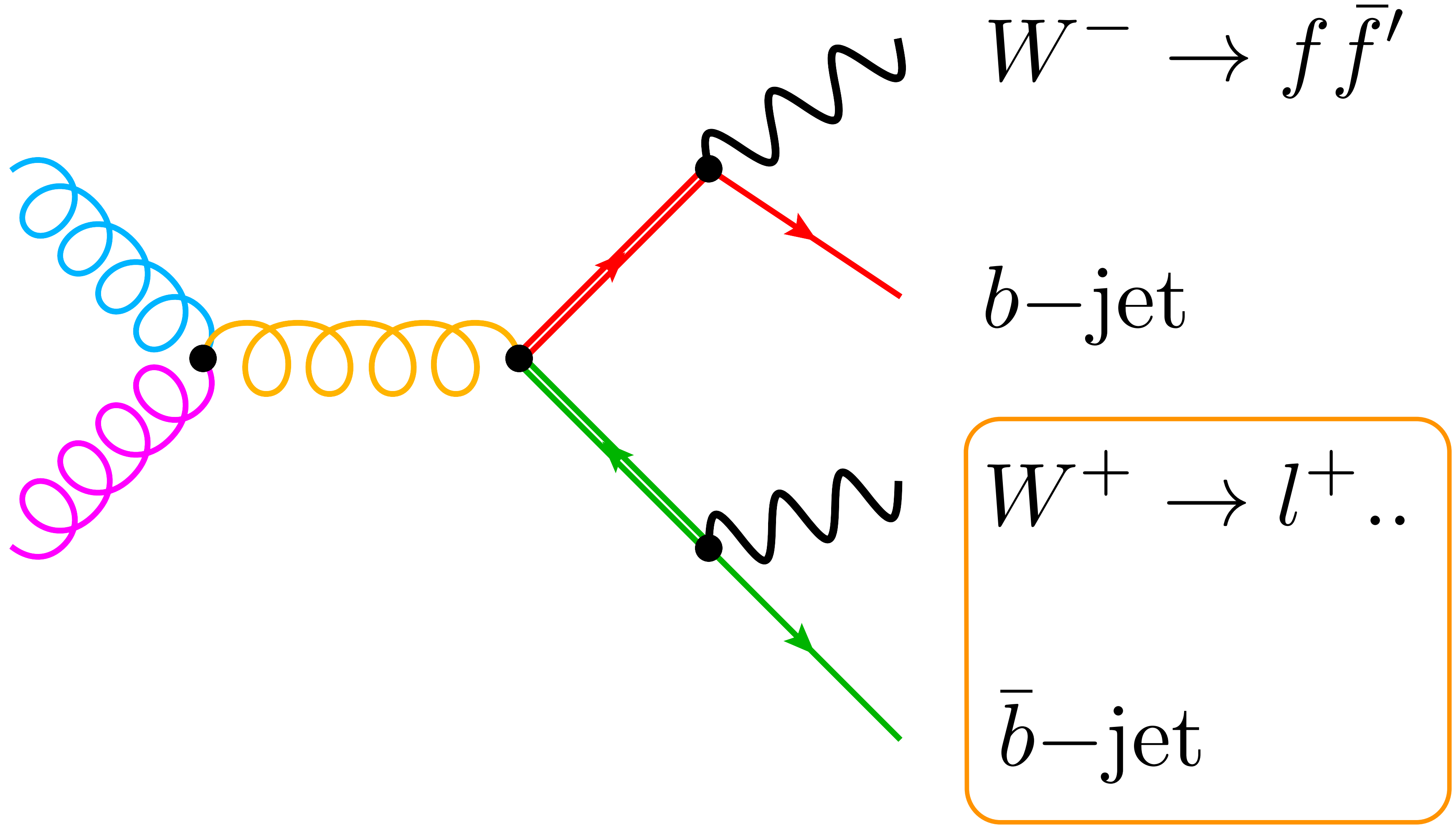


LHCb data →



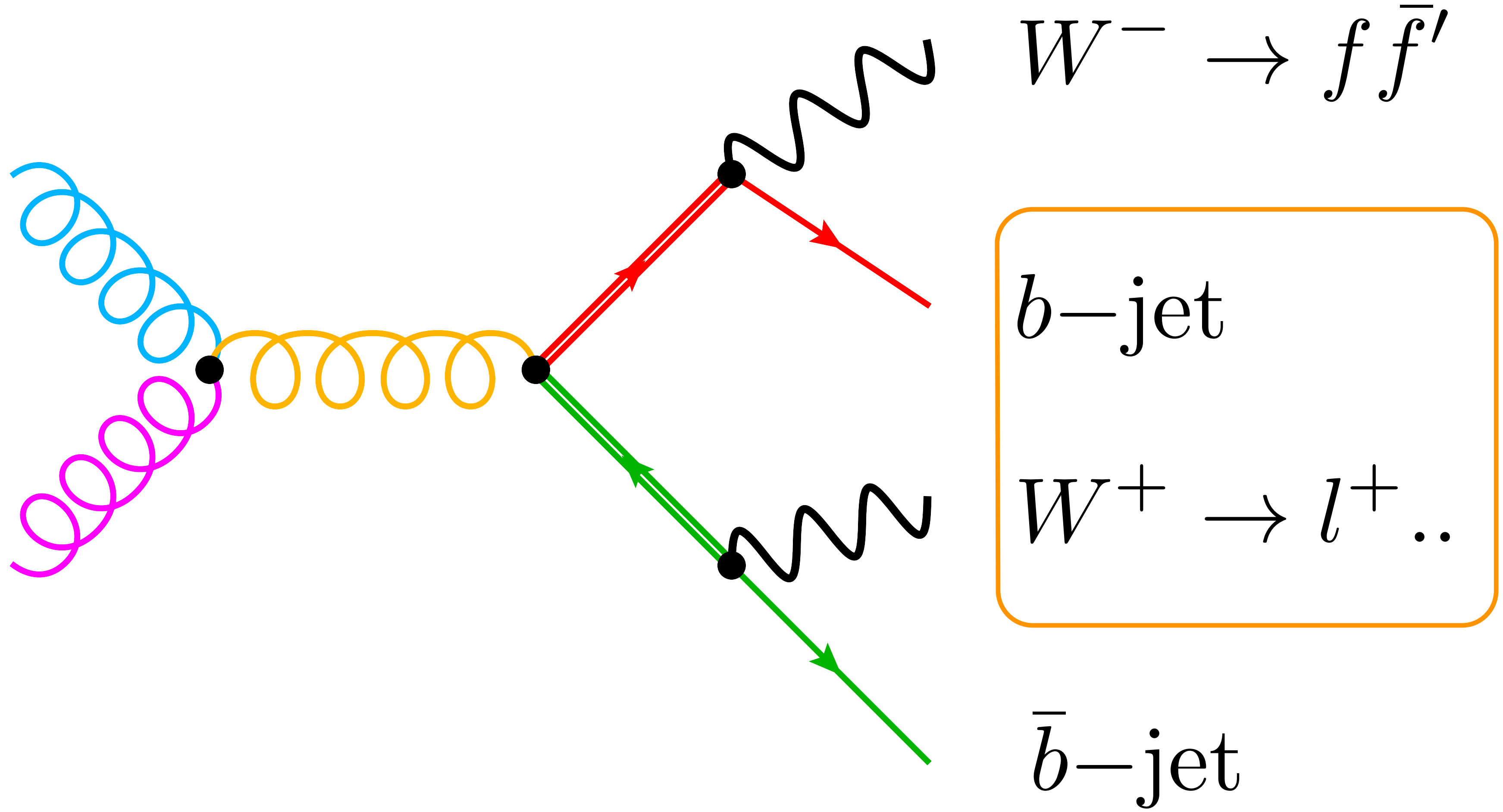
LHC~~b~~t (arXiv: 15xx.xxxx?)



Original proposal (in context of ttbar asymmetry):
Kagan, Kamenik, Perez, Stone arXiv: 1103.3747

RG arXiv: 1311.1810 (cross section and PDF constraints)

LHC~~b~~t (arXiv: 15xx.xxxx?)



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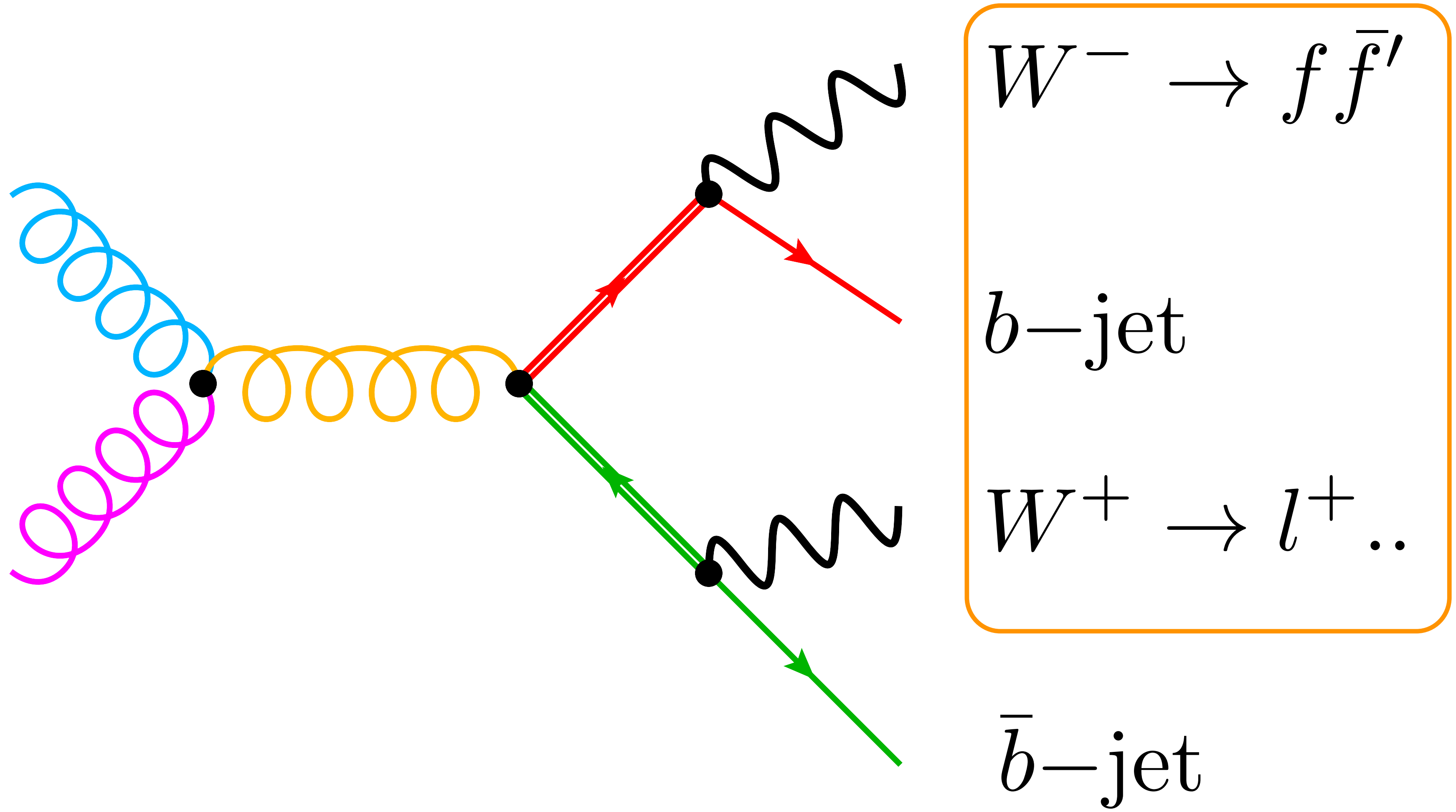


Original proposal (in context of ttbar asymmetry):
Kagan, Kamenik, Perez, Stone arXiv: 1103.3747

RG arXiv: 1311.1810 (cross section and PDF constraints)

Statistical feasibility of top measurements

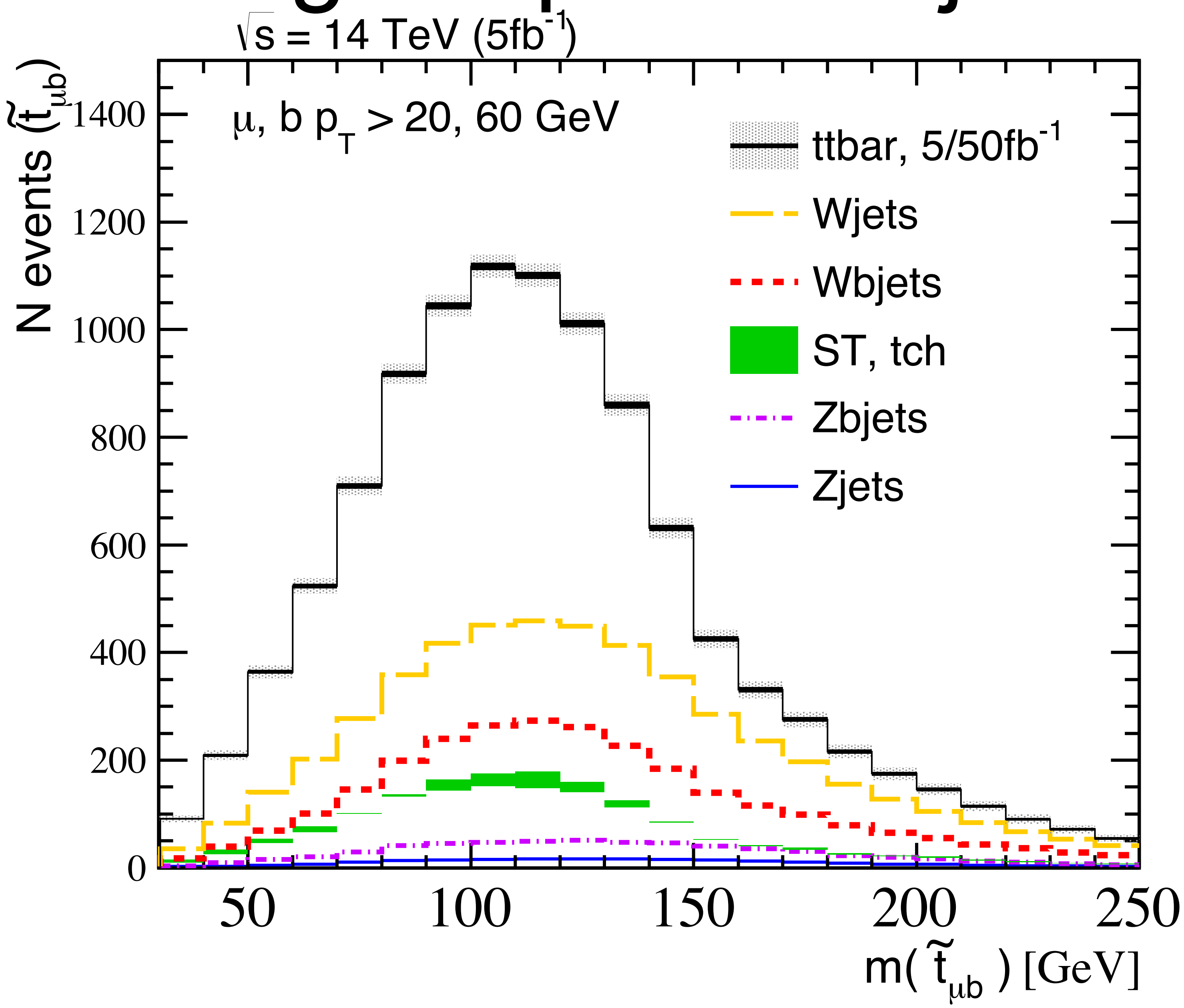
Set-up

- Signal and background generated with NLO (**POWHEG**) interfaced to PS (**P8**)
- Cluster jets with anti-kt algorithm using R = 0.5 distance parameter
- Truth match parton level b-quarks to jets within dR < 0.5 (b)
- Apply experimental trigger efficiencies (0.75 for high pT muons arxiv: 1204.1620)
- b-tagging assumptions:
    - mis-tag rate 1% (accidentaly think a light-jet is a b-jet)
    - efficiency 70% (how often you correctly tag a b-jet)

$$t\bar{t} \to XYZ$$

Acceptance
Kinematics
Isolation

Single lepton + b-jet

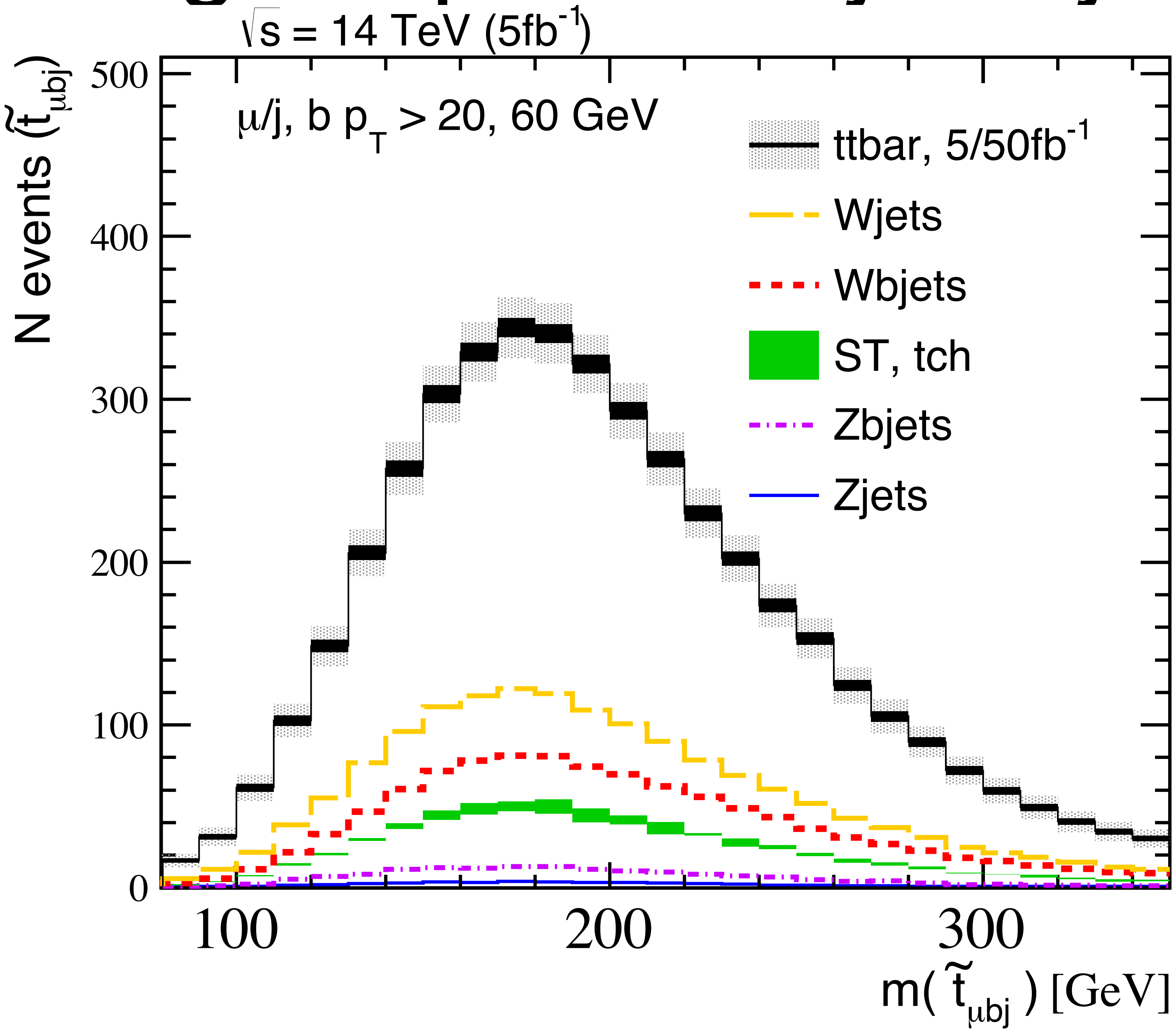


$$t\bar{t} \rightarrow l^{\pm} b X$$

14 TeV

$$2.0 < \eta(l, b) < 4.5$$
$$p_T(l/b) > 20/60 \text{ GeV}$$
$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$

Single lepton + b-jet + jet



$$t\bar{t} \to l^{\pm} b j X$$

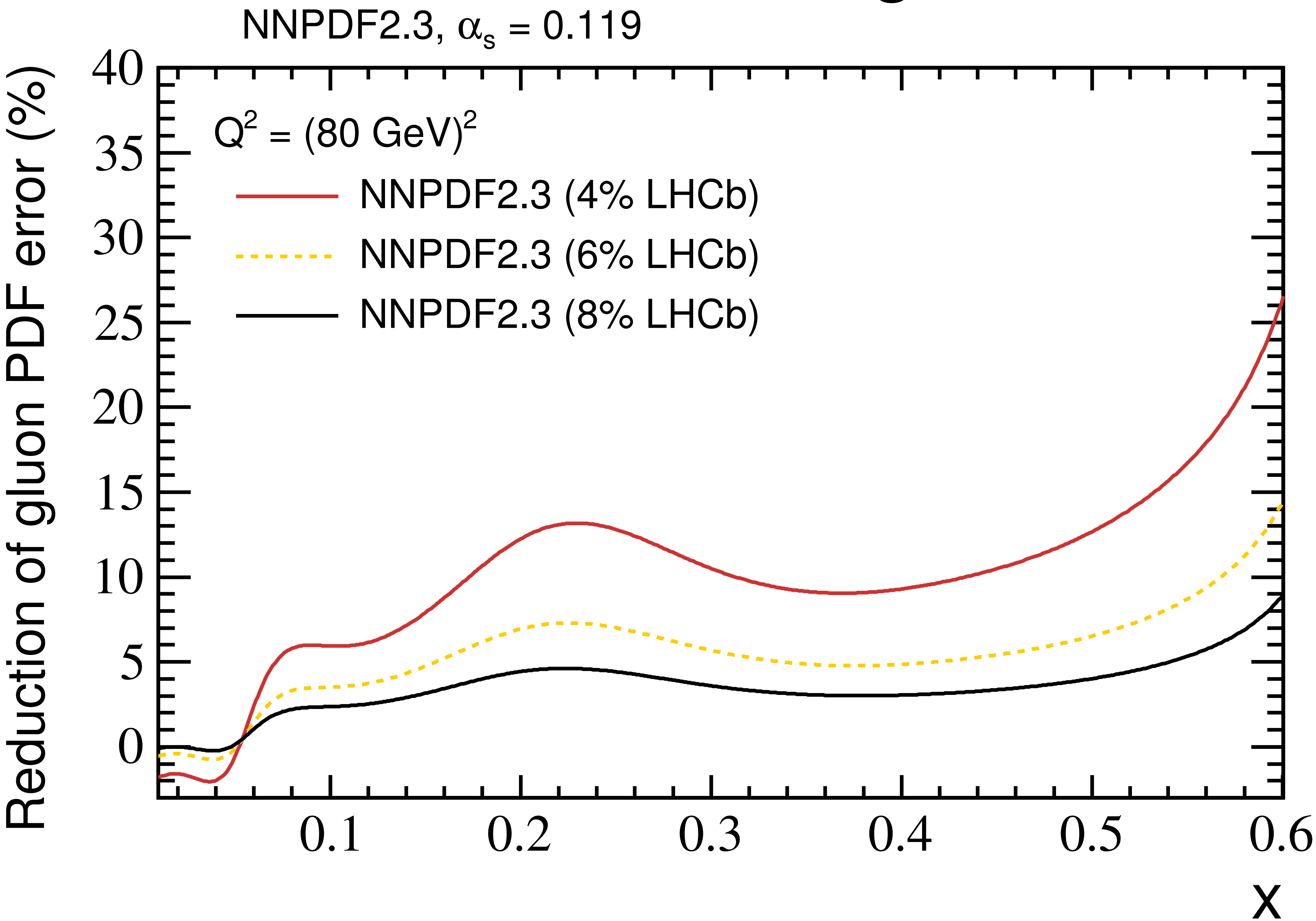
14 TeV

$$2.0 < \eta(l, b) < 4.5$$

$$p_T(l, j/b) > 20/60 \text{ GeV}$$

$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$

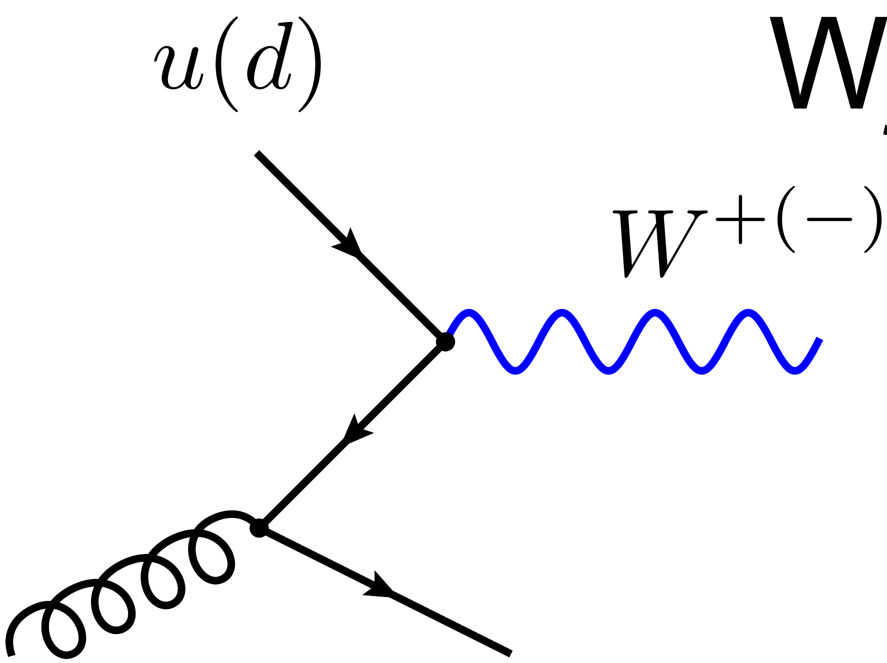
As a constraint on the gluon PDF

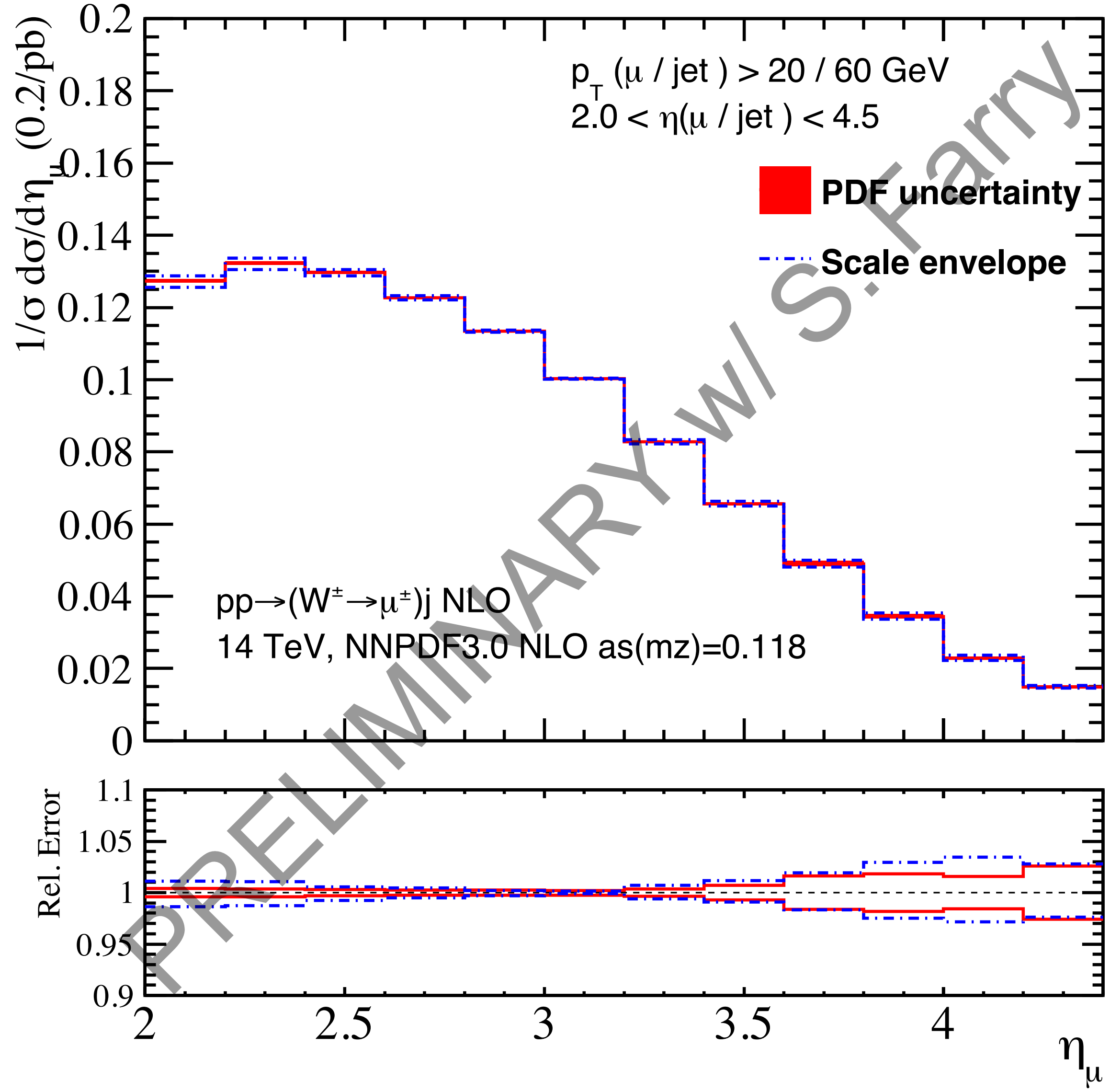


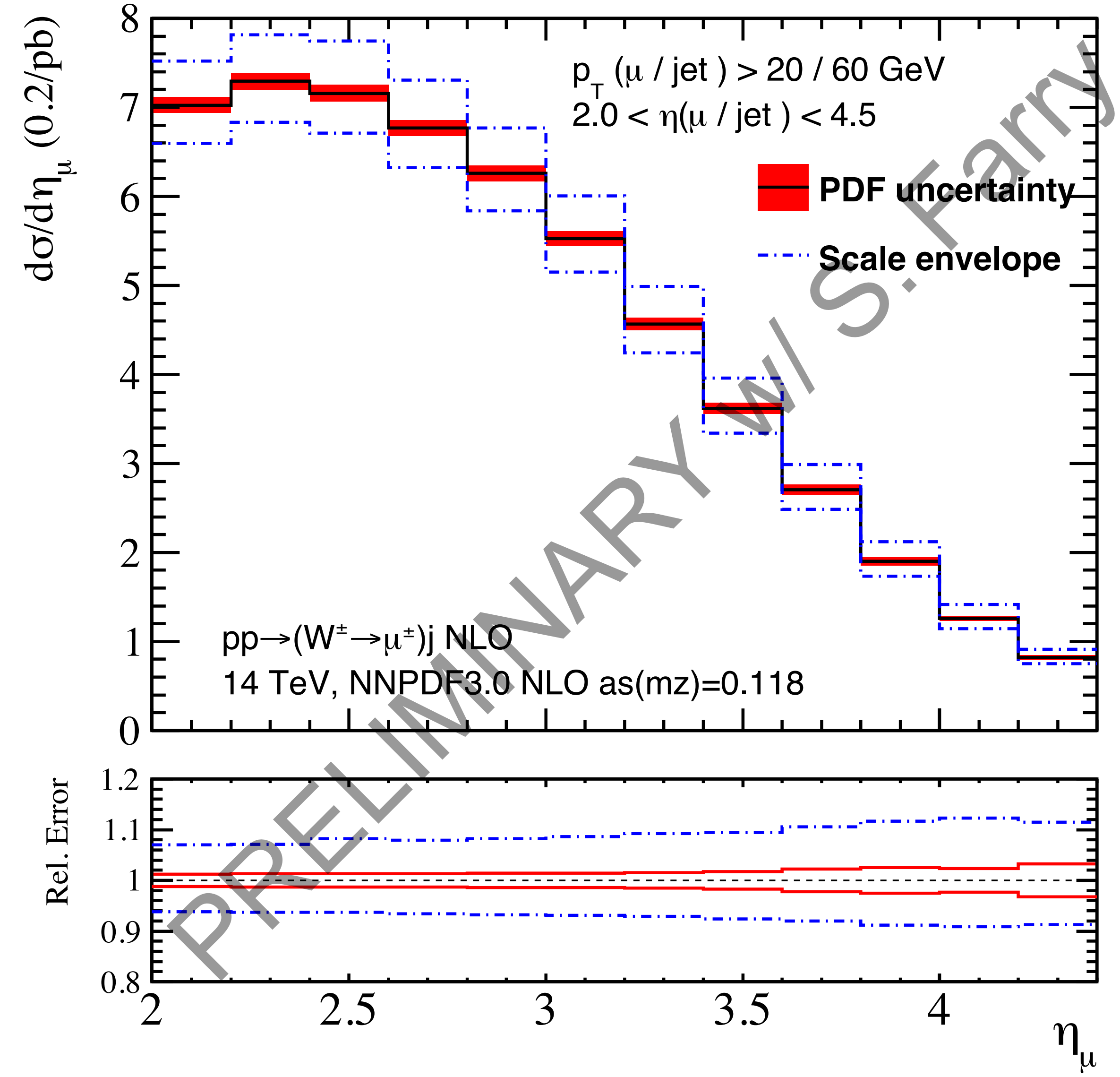
Estimated improvement in gluon PDF with LHCb data

Very **conservative** (doesn't include kinematic cuts)

Wjets at LHCb?



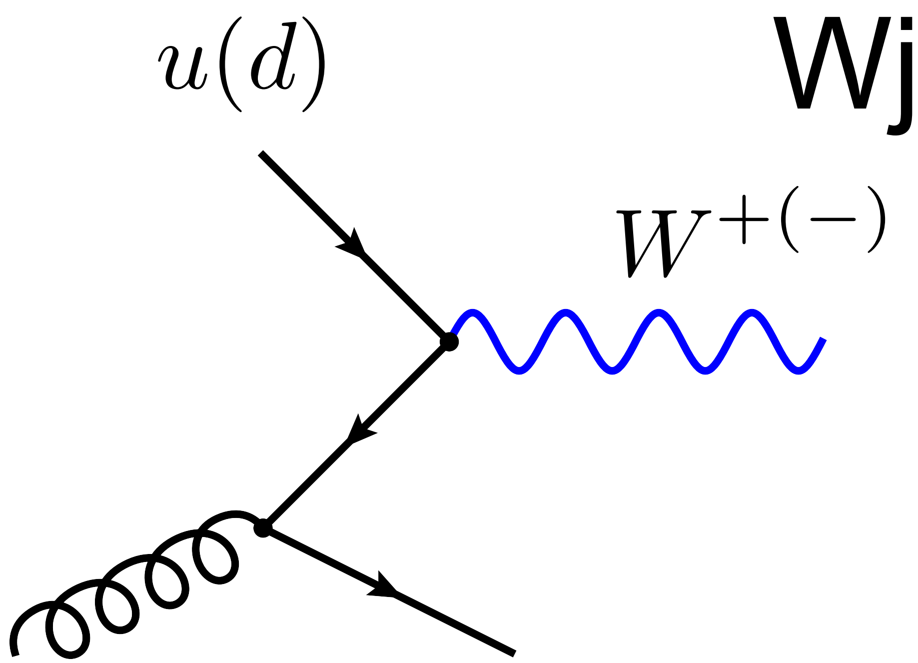


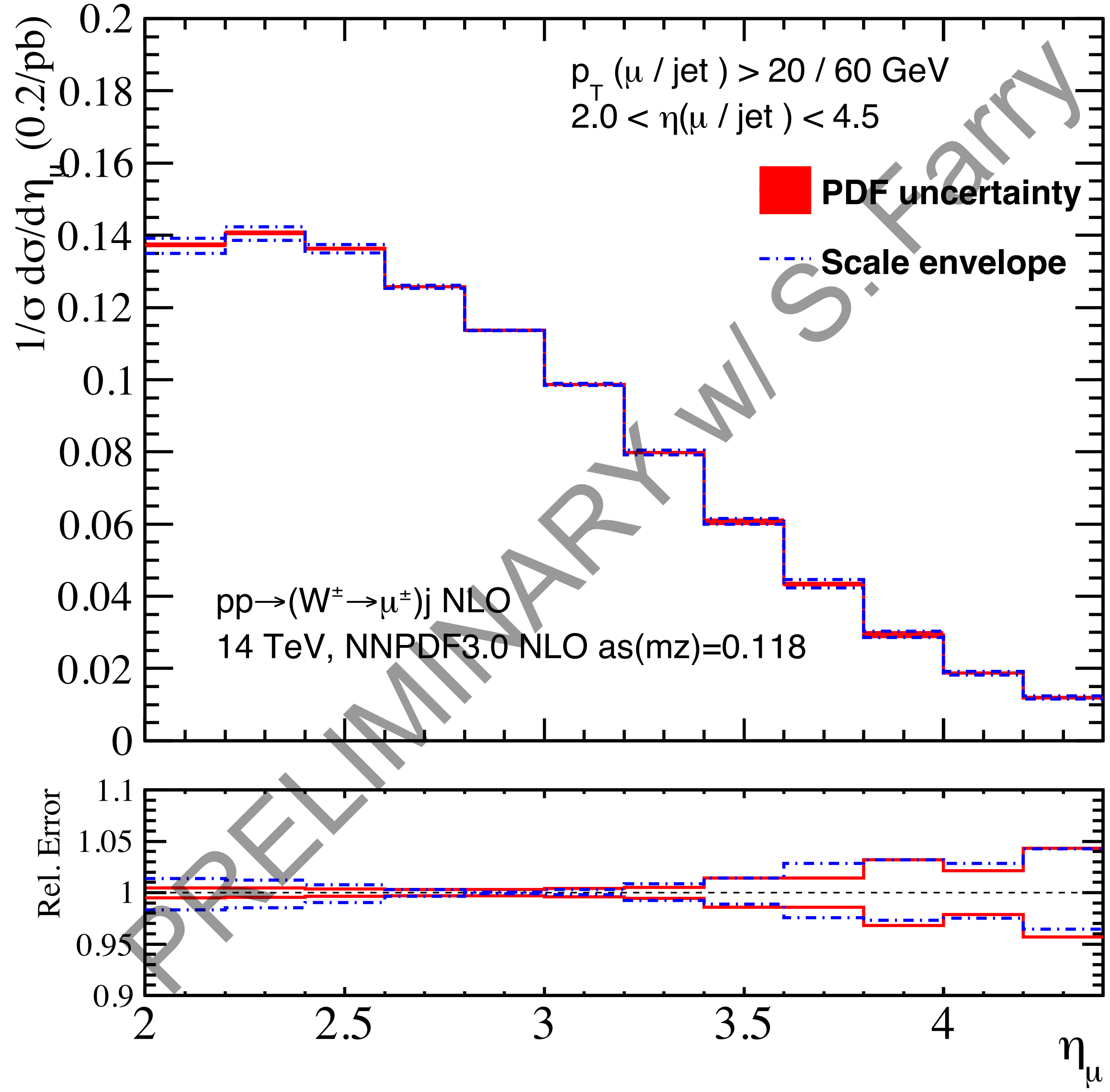


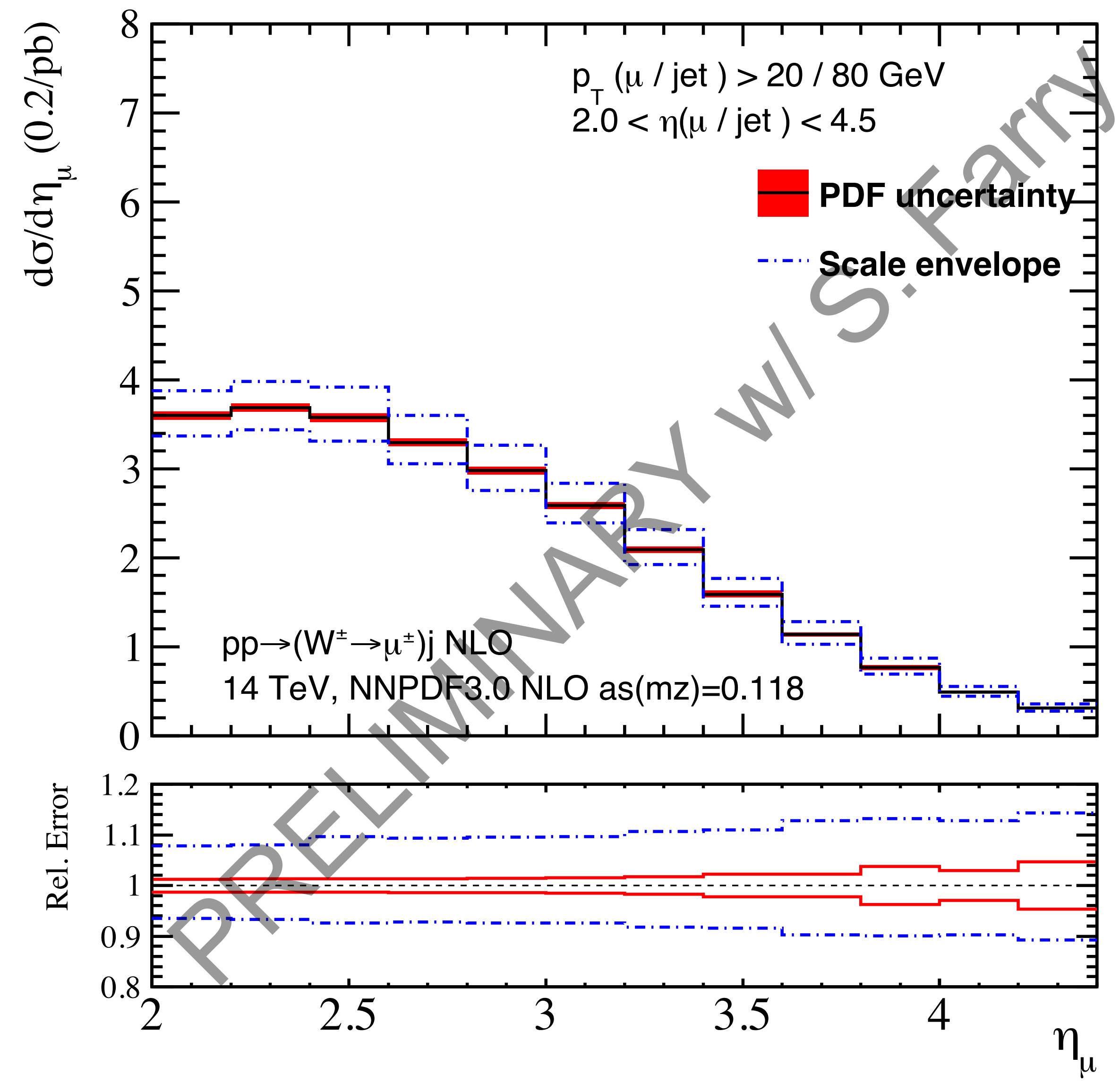
$$2.0 < \eta(\mu^{\pm}, j) < 4.5$$

$$p_T(\mu^{\pm}/j) > 20/60\text{GeV}$$

Wjets at LHCb?



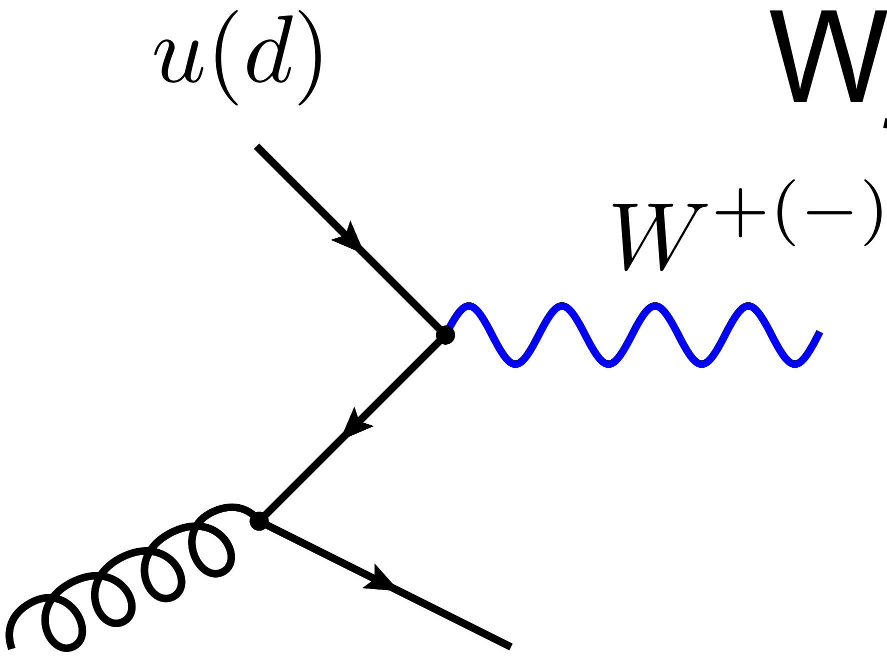


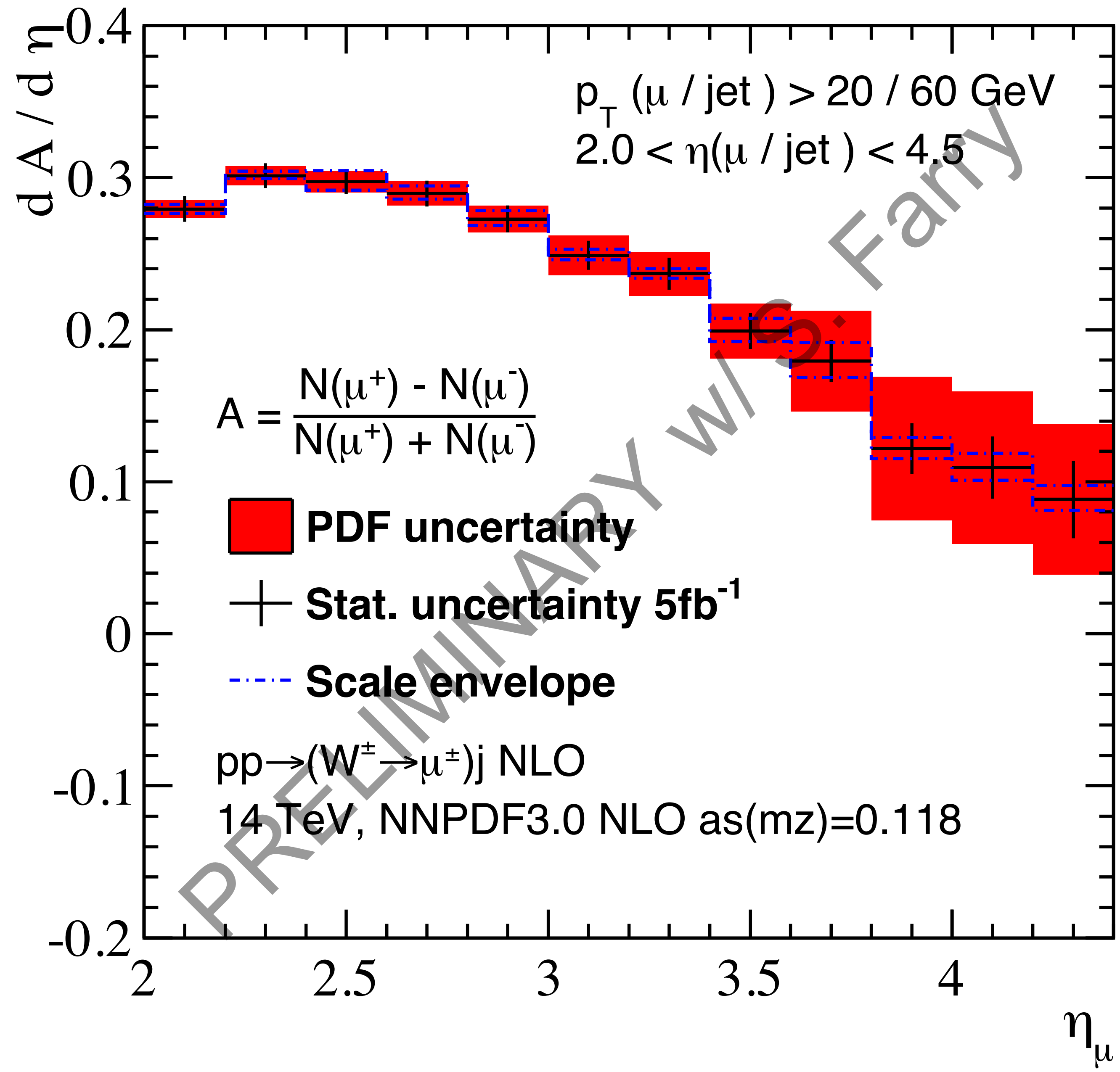


$$2.0 < \eta(\mu^{\pm}, j) < 4.5$$

$$p_T(\mu^{\pm}/j) > 20/80\text{GeV}$$

Wjets at LHCb?





Lepton asymmetry (w/ jets)

$$A = \frac{N(\mu^+ j) - N(\mu^+ j)}{N(\mu^+ j) + N(\mu^+ j)}$$

Jet handle! - probe higher-x

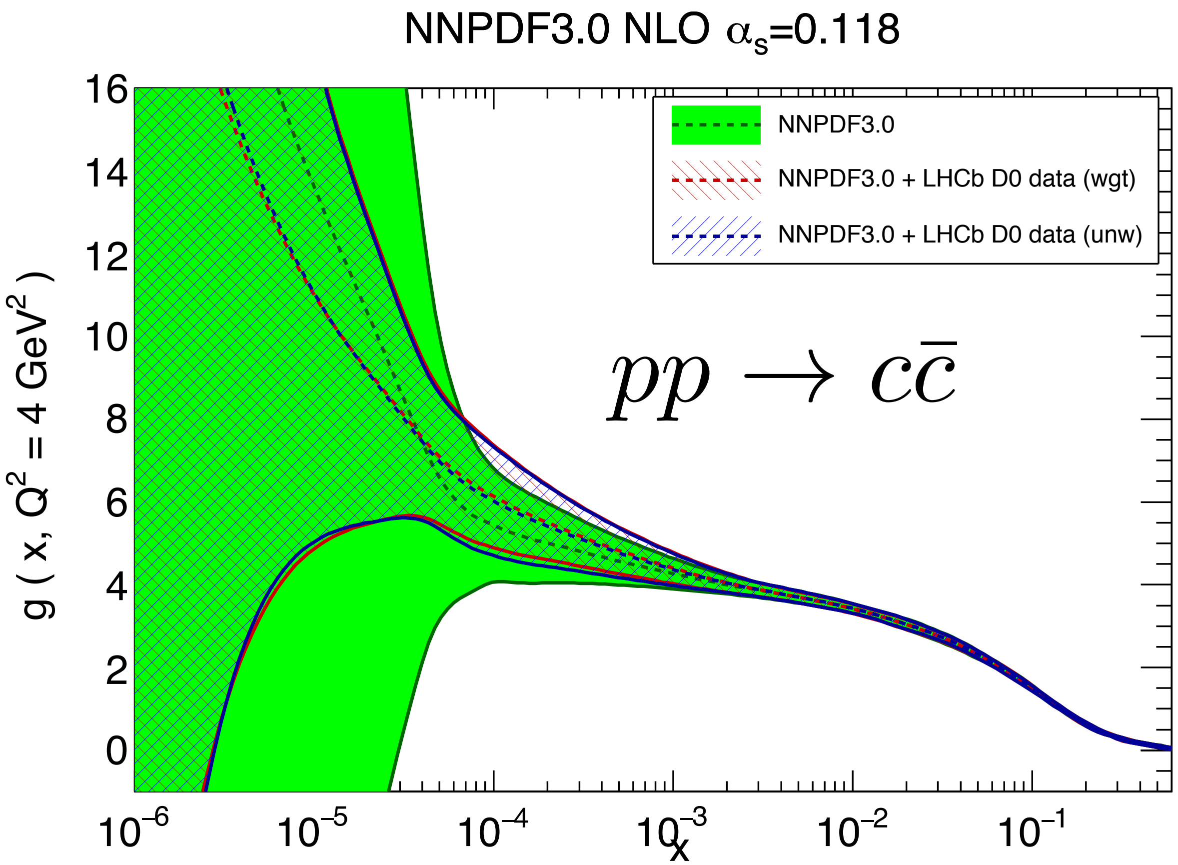
Sensitive d-PDF uncertainties

$$\langle x_1 \rangle = 0.4$$

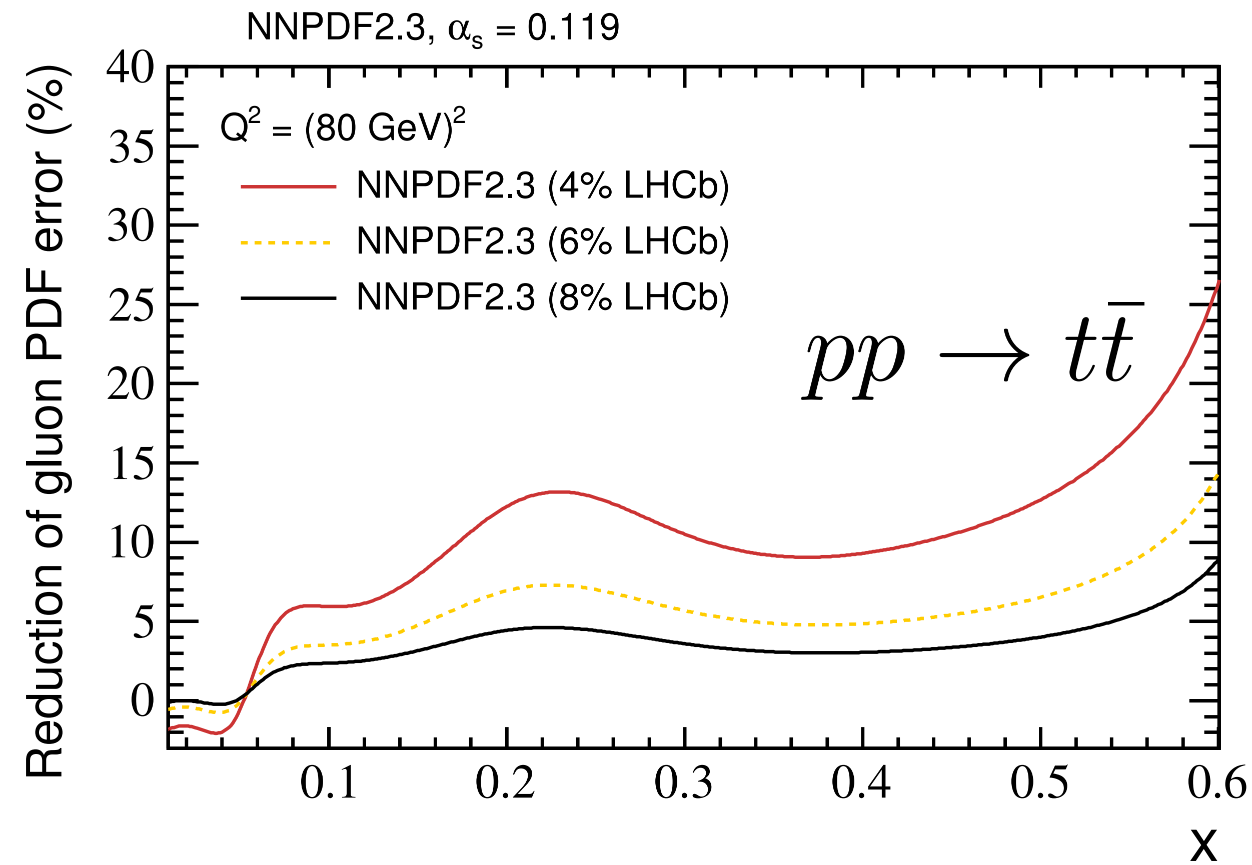
$$2.0 < \eta(\mu^\pm, j) < 4.5$$

$$p_T(\mu^\pm / j) > 20/60\text{GeV}$$

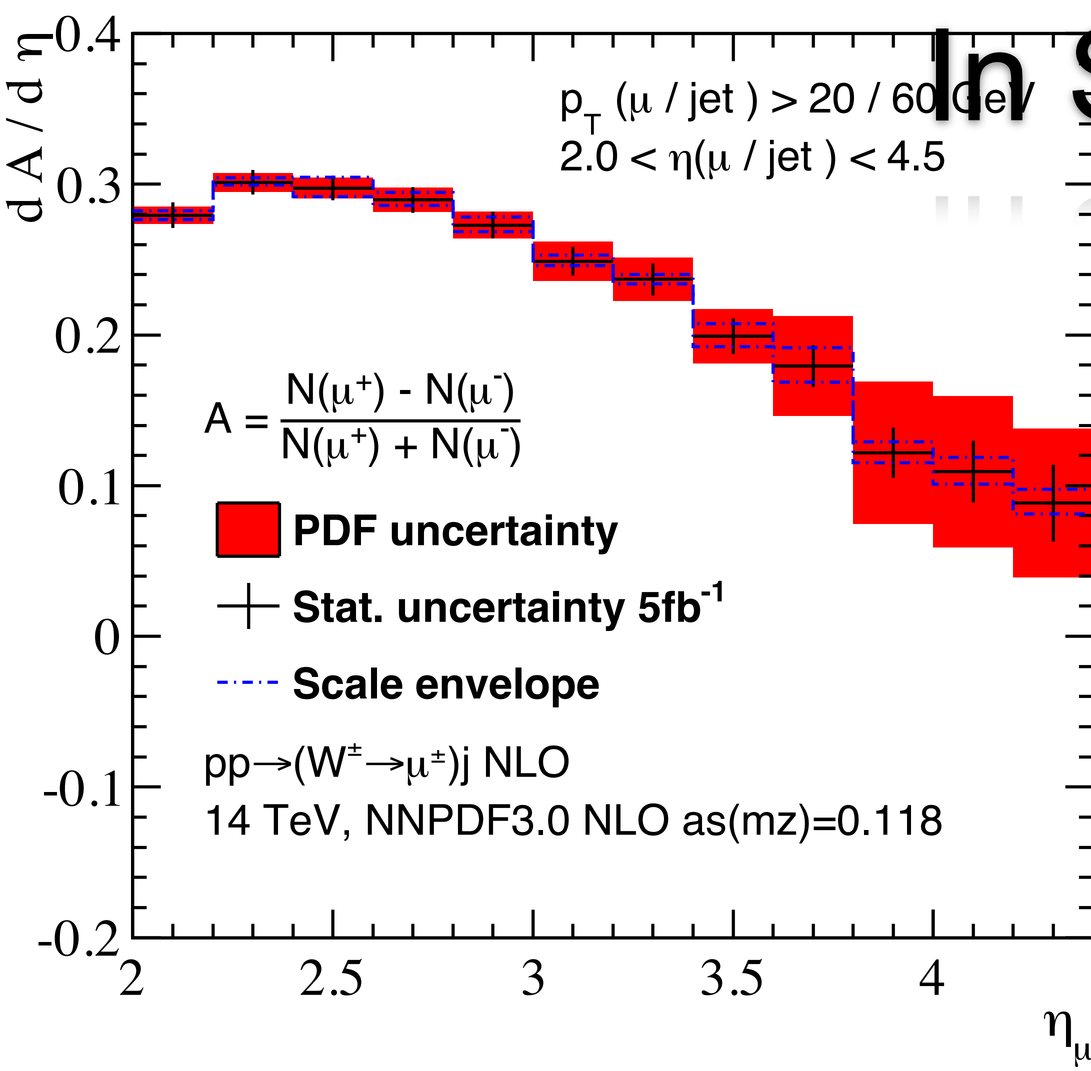
In Summary…



NNPDF3.0 NLO α_s=0.118
NNPDF3.0
NNPDF3.0 + LHCb D0 data (wgt)
NNPDF3.0 + LHCb D0 data (unw)
$pp \to c\bar{c}$
g (x, Q^2 = 4 GeV^2)
x



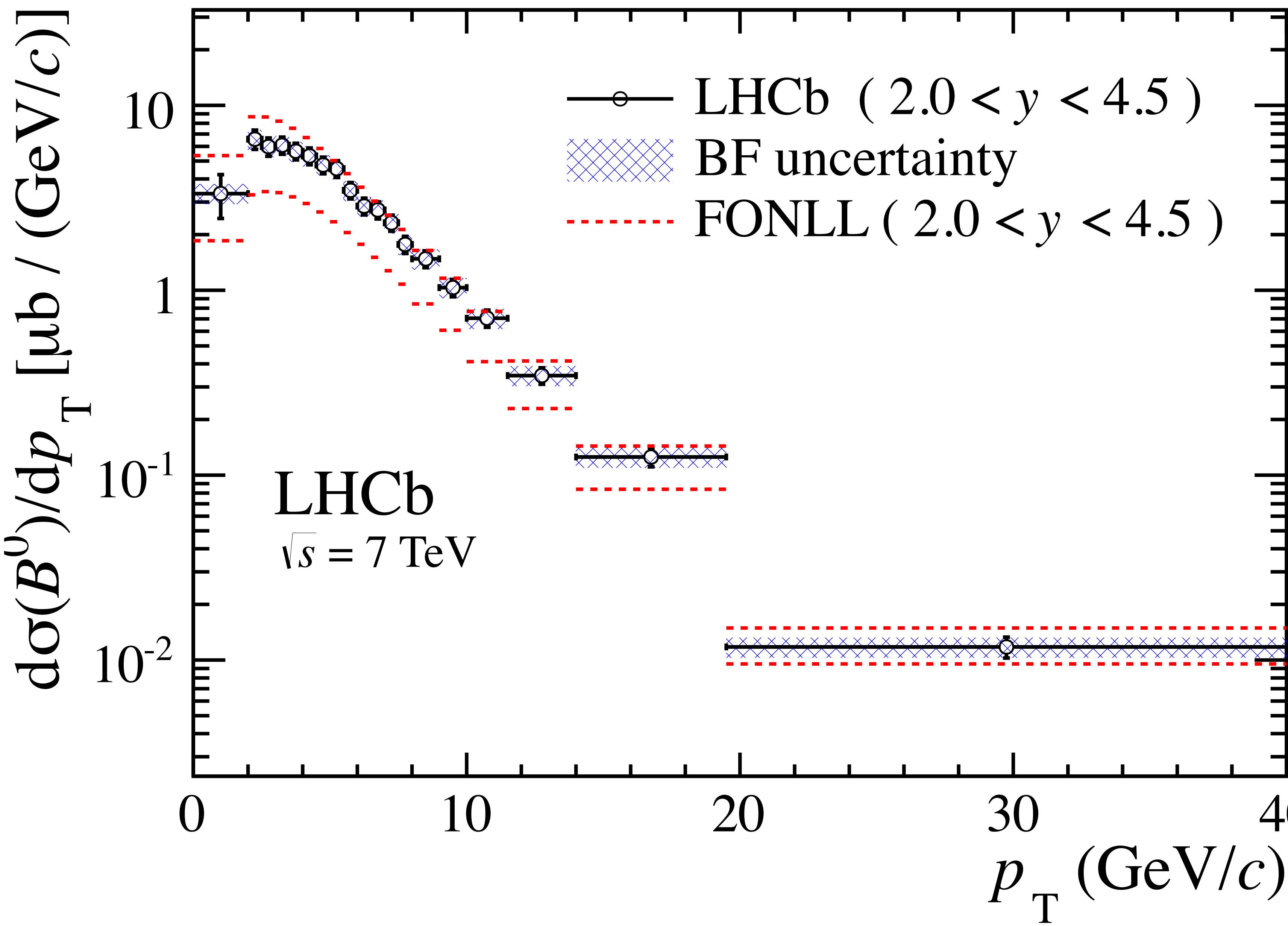
NNPDF2.3, α_s = 0.119
Q^2 = (80 GeV)^2
NNPDF2.3 (4% LHCb)
NNPDF2.3 (6% LHCb)
NNPDF2.3 (8% LHCb)
$pp \to t\bar{t}$
Reduction of gluon PDF error (%)
x



p$_T$ (μ / jet) > 20 / 60 GeV
2.0 < η(μ / jet) < 4.5
A = $\frac{N(\mu^+) - N(\mu^-)}{N(\mu^+) + N(\mu^-)}$
PDF uncertainty
Stat. uncertainty 5fb^{-1}
Scale envelope
pp→(W$^\pm$→μ$^\pm$)j NLO
14 TeV, NNPDF3.0 NLO as(mz)=0.118
d A / d η
η$_\mu$

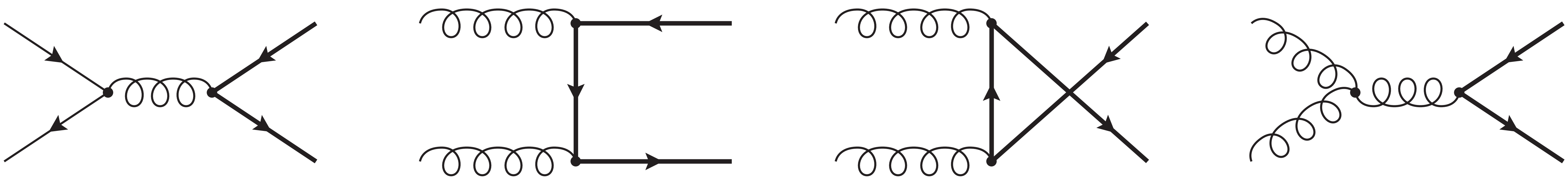
Thanks for listening

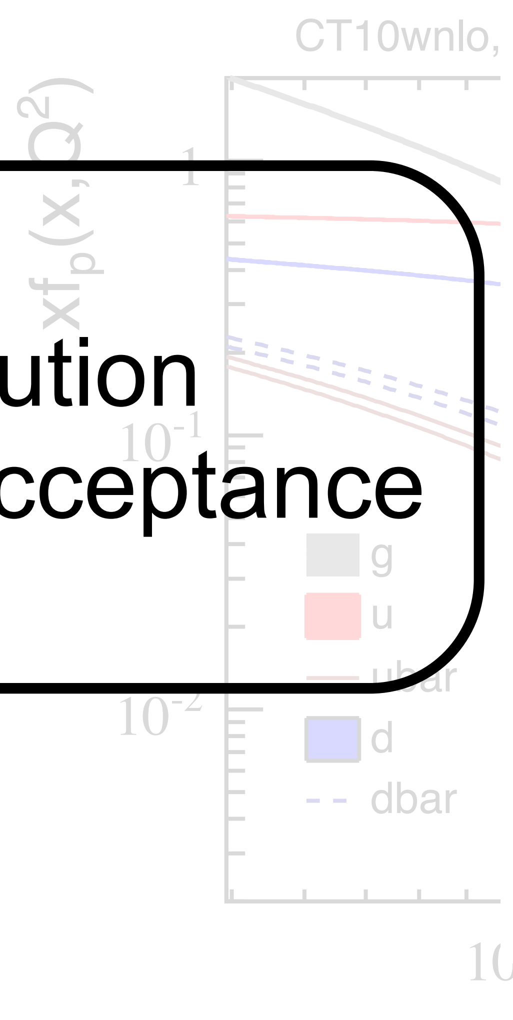
B measurement (arXiv: 1306.3663)



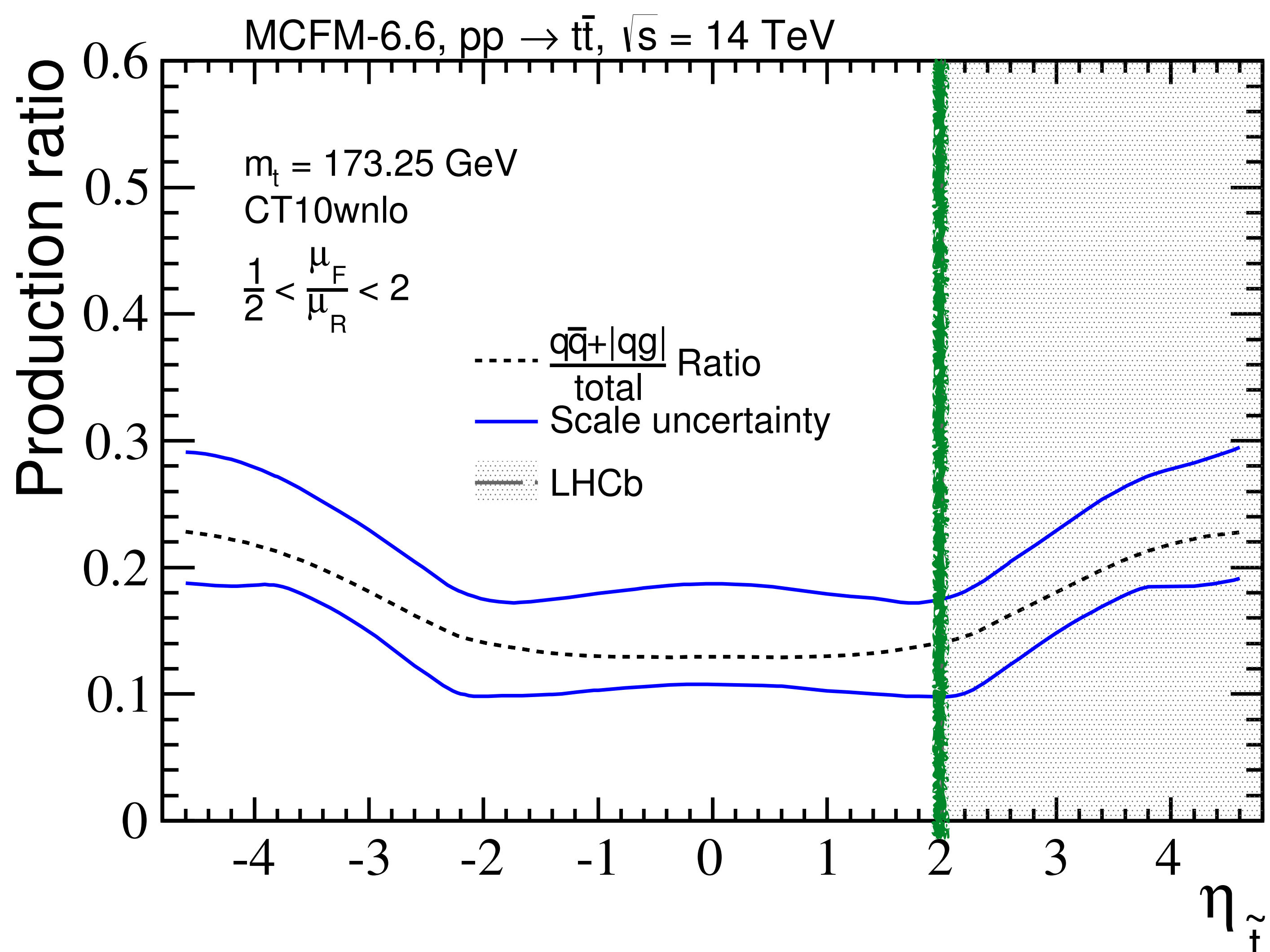
Theory + Data in agreement - within large theoretical uncertainties (scale)

Enriched qX->t+Y sample at LHCb

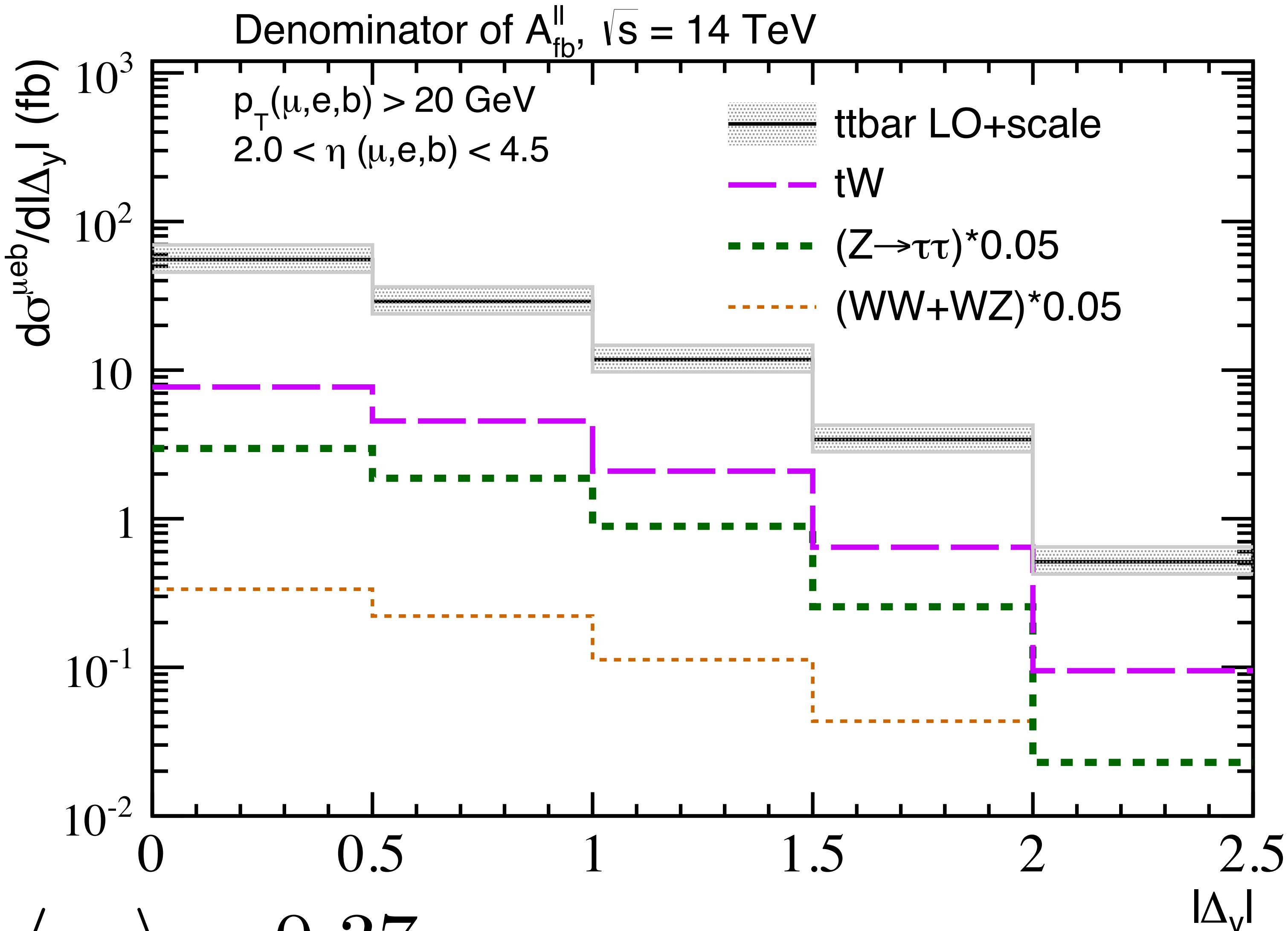




less gg-dilution
in LHCb acceptance



Dilepton + b-jet



$$\langle x_1 \rangle = 0.37$$

$$\delta\sigma_{\rm stat}(1\text{year}) = 6\%$$

$$t\bar{t} \to \mu^{\pm} e^{\mp} bX$$

14 TeV

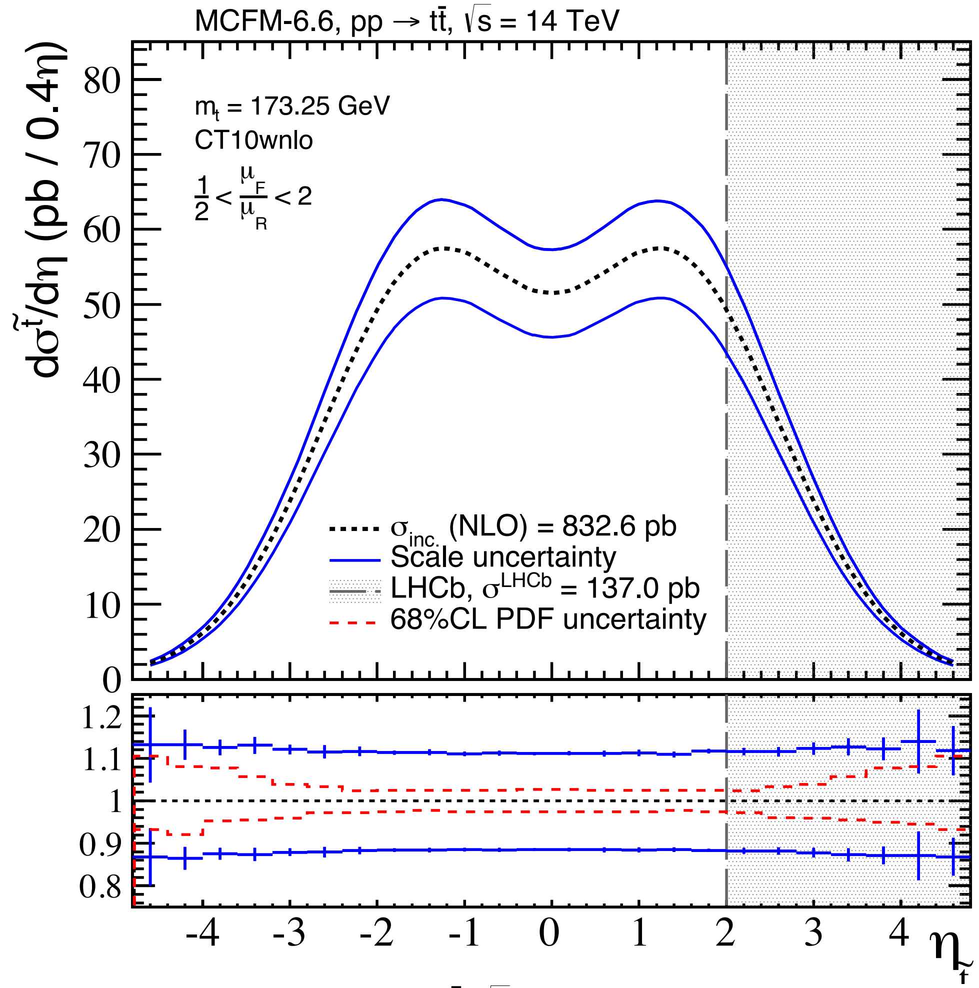
$$2.0 < \eta(l,b) < 4.5$$

$$p_T(l,b) > 20\ \text{GeV}$$

$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$

Parton level theoretical systematics

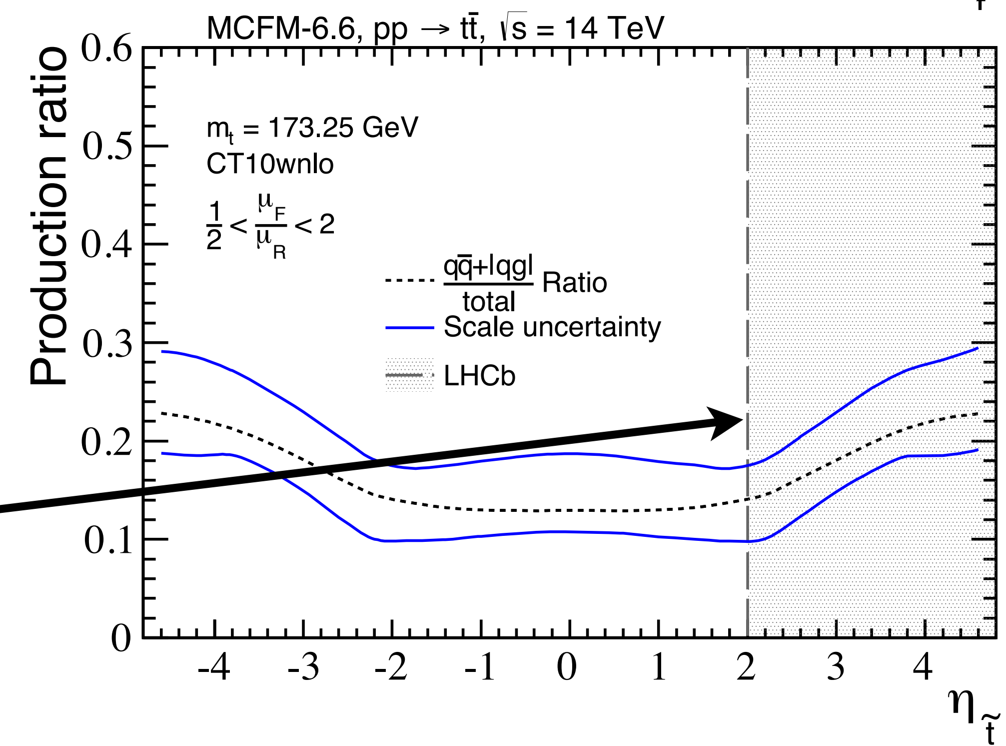
$$\frac{d\sigma^{\tilde{t}}}{dX} = \frac{1}{2}\left(\frac{d\sigma^{t}}{dX} + \frac{d\sigma^{\bar{t}}}{dX}\right)$$



Production mechanism ratio:

$$\frac{q\bar{q} + |qg|}{total}$$

LHCb probes unique region



Theoretical systematics for forward ttbar?

$$\sigma = \sum_{i,j} \int dx_i dx_j f_i(x_i, \mu_F^2) f_j(x_j, \mu_F^2) \frac{d\hat{\sigma}\left(m, \mu_F^2, \alpha_s(\mu_R), \mu_R^2\right)}{d\eta} d\eta$$

$$\frac{d\hat{\sigma}^{\text{LHCb}}}{d\eta} = \frac{1}{2}\left[\frac{d\hat{\sigma}}{d\eta_t} + \frac{d\hat{\sigma}}{d\eta_{\bar{t}}}\right]_{\eta\in[2,5]}$$

$$\frac{1}{2} < \frac{\mu_F}{\mu_R} < 2$$

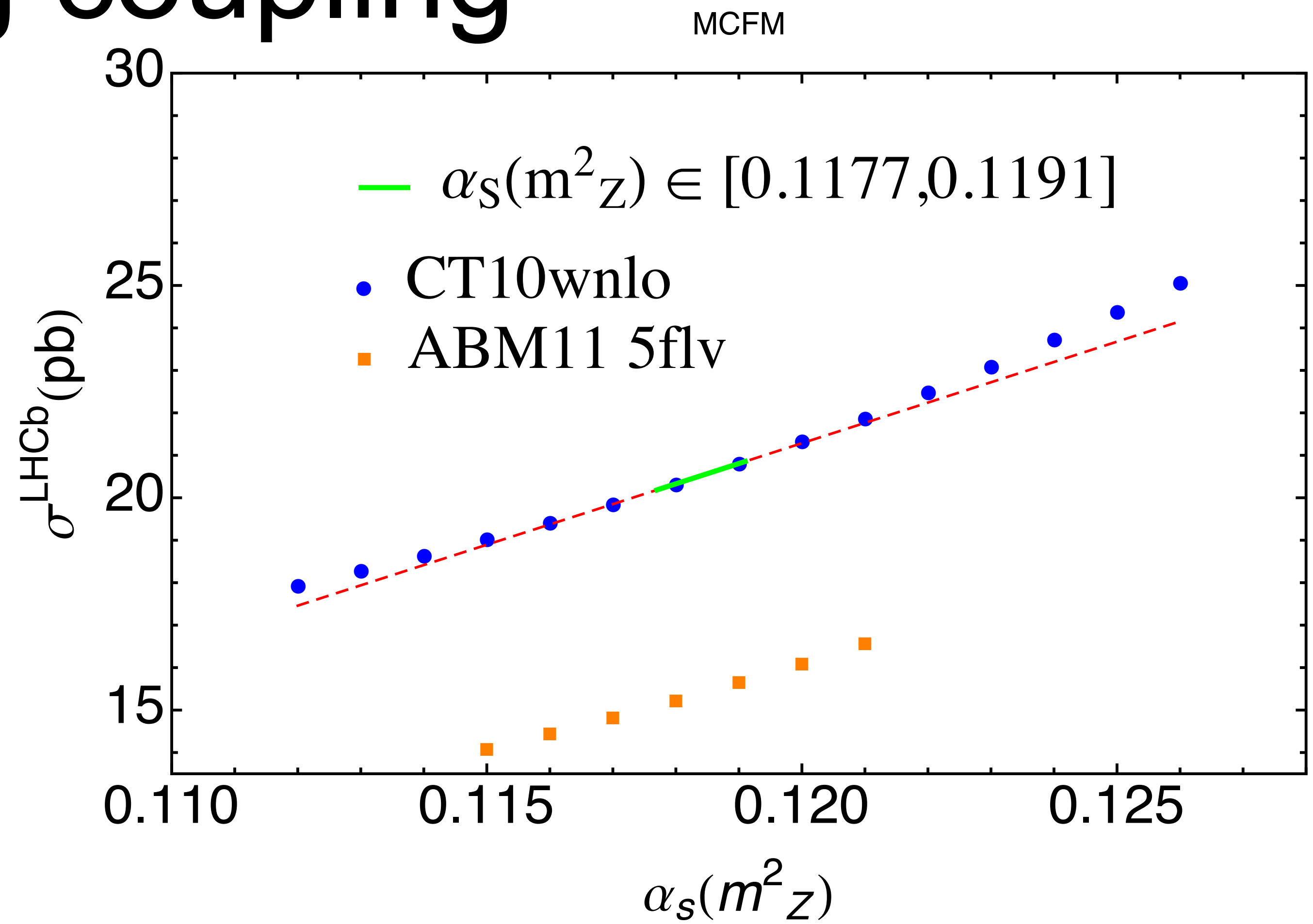
$$\delta\text{PDF} = 1\sigma\text{CL}$$

$$\alpha_s(M_Z) = 0.1184 \pm 0.0007$$

$$\delta m_t = 1.5 \text{ GeV}$$

Strong coupling

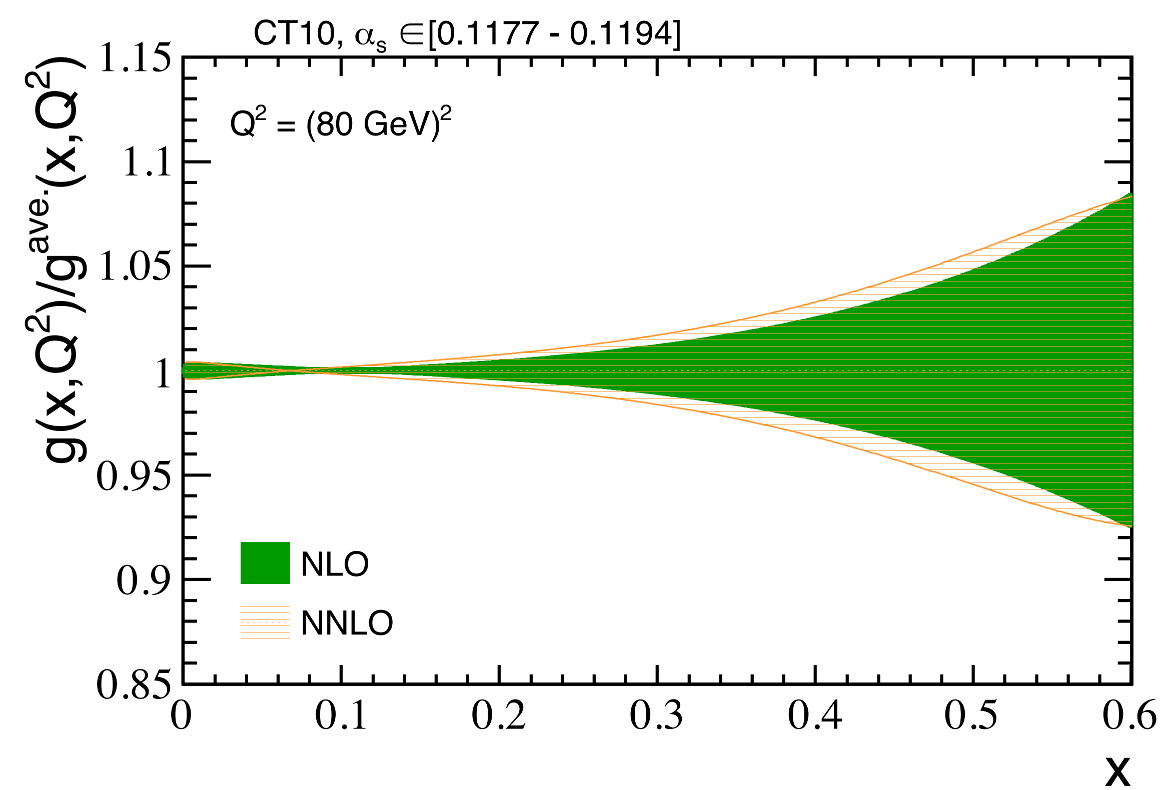
σ^{LHCb} vs. $\alpha_s(M_Z)$



Current PDG value

$$\alpha_s(M_Z) = 0.1184 \pm 0.0007$$

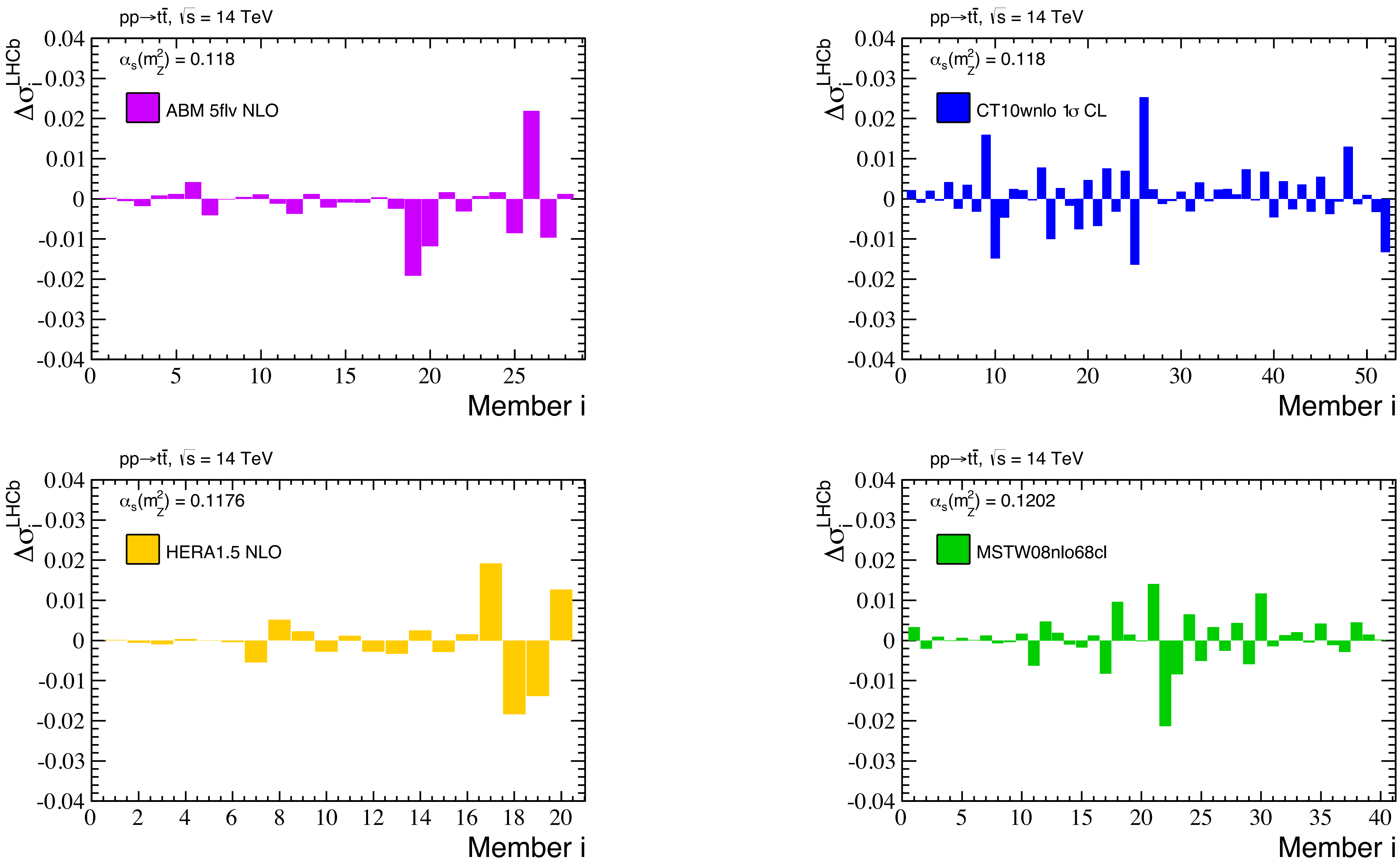
gluon PDF uncertainty for $\delta\alpha_s$



$$\delta\alpha_s \to \delta\sigma^{\rm LHCb} = 1.3\%$$

Order	PDF	σ(pb)	δ_{scale} (pb)	δ_{PDF} (pb)	δ_{α_s} (pb)	δ_{m_t} (pb)	δ_{total} (pb)
NNLO*(inc.)	ABM	832.0	+18.7 (+2.2%) −27.4 (−3.3%)	+25.1 (+3.0%) −25.1 (−3.0%)	+0.0 (+0.0%) −0.0 (−0.0%)	+34.9 (+4.2%) −33.7 (−4.1%)	+61.7 (+7.4%) −69.7 (−8.4%)
NLO(inc.)	ABM	771.9	+91.0 (+11.8%) −92.4 (−12.0%)	+9.4 (+1.2%) −9.4 (−1.2%)	+0.0 (+0.0%) −0.0 (−0.0%)	+32.3 (+4.2%) −31.9 (−4.1%)	+124.7 (+16.1%) −125.7 (−16.3%)
NLO(LHCb)	ABM	117.2	+14.5 (+12.3%) −14.1 (−12.0%)	+2.0 (+1.7%) −2.0 (−1.7%)	+0.0 (+0.0%) −0.0 (−0.0%)	+5.2 (+4.4%) −5.1 (−4.3%)	+20.0 (+17.1%) −19.5 (−16.7%)
NNLO*(inc.)	CT10	952.8	+23.3 (+2.4%) −34.5 (−3.6%)	+22.4 (+2.3%) −19.9 (−2.1%)	+14.0 (+1.5%) −14.0 (−1.5%)	+39.2 (+4.1%) −37.8 (−4.0%)	+70.6 (+7.4%) −79.5 (−8.3%)
NLO(inc.)	CT10	832.6	+97.0 (+11.7%) −96.7 (−11.6%)	+19.6 (+2.4%) −20.2 (−2.4%)	+9.2 (+1.1%) −9.2 (−1.1%)	+34.0 (+4.1%) −33.3 (−4.0%)	+137.4 (+16.5%) −136.6 (−16.4%)
NLO(LHCb)	CT10	137.0	+16.7 (+12.2%) −16.4 (−12.0%)	+5.0 (+3.6%) −4.6 (−3.4%)	+1.8 (+1.3%) −1.8 (−1.3%)	+5.9 (+4.3%) −5.8 (−4.2%)	+24.7 (+18.0%) −24.0 (−17.5%)
NNLO*(inc.)	HERA	970.5	+22.1 (+2.3%) −22.0 (−2.3%)	+15.7 (+1.6%) −25.7 (−2.6%)	+12.8 (+1.3%) −12.8 (−1.3%)	+39.6 (+4.1%) −38.4 (−4.0%)	+66.6 (+6.9%) −70.0 (−7.2%)
NLO(inc.)	HERA	804.2	+91.9 (+11.4%) −87.6 (−10.9%)	+16.1 (+2.0%) −21.9 (−2.7%)	+5.3 (+0.7%) −5.3 (−0.7%)	+33.4 (+4.1%) −32.4 (−4.0%)	+129.3 (+16.1%) −127.1 (−15.8%)
NLO(LHCb)	HERA	124.7	+14.8 (+11.8%) −13.7 (−11.0%)	+3.0 (+2.4%) −3.0 (−2.4%)	+1.1 (+0.9%) −1.1 (−0.9%)	+5.5 (+4.4%) −5.3 (−4.3%)	+21.1 (+16.9%) −19.9 (−15.9%)
NNLO*(inc.)	MSTW	953.6	+22.7 (+2.4%) −33.9 (−3.6%)	+16.2 (+1.7%) −17.8 (−1.9%)	+12.8 (+1.3%) −12.8 (−1.3%)	+39.1 (+4.1%) −37.9 (−4.0%)	+66.9 (+7.0%) −77.7 (−8.1%)
NLO(inc.)	MSTW	885.6	+107.2 (+12.1%) −105.7 (−11.9%)	+16.0 (+1.8%) −19.4 (−2.2%)	+10.1 (+1.1%) −10.1 (−1.1%)	+36.2 (+4.1%) −35.3 (−4.0%)	+148.1 (+16.7%) −147.3 (−16.6%)
NLO(LHCb)	MSTW	144.4	+18.6 (+12.8%) −17.8 (−12.3%)	+3.5 (+2.4%) −3.9 (−2.7%)	+1.9 (+1.3%) −1.9 (−1.3%)	+6.2 (+4.3%) −6.1 (−4.2%)	+25.9 (+18.0%) −25.2 (−17.5%)
NNLO*(inc.)	NNPDF	977.5	+23.6 (+2.4%) −35.4 (−3.6%)	+16.4 (+1.7%) −16.4 (−1.7%)	+12.2 (+1.3%) −12.2 (−1.3%)	+40.4 (+4.1%) −39.1 (−4.0%)	+68.9 (+7.0%) −80.0 (−8.1%)
NLO(inc.)	NNPDF	894.5	+107.6 (+12.0%) −101.0 (−11.3%)	+12.8 (+1.4%) −12.8 (−1.4%)	+9.9 (+1.1%) −9.9 (−1.1%)	+36.6 (+4.1%) −35.8 (−4.0%)	+147.6 (+16.5%) −140.3 (−15.7%)
NLO(LHCb)	NNPDF	142.5	+18.1 (+12.7%) −16.6 (−11.7%)	+3.0 (+2.1%) −3.0 (−2.1%)	+2.0 (+1.4%) −2.0 (−1.4%)	+6.2 (+4.4%) −6.1 (−4.3%)	+25.2 (+17.7%) −23.7 (−16.6%)

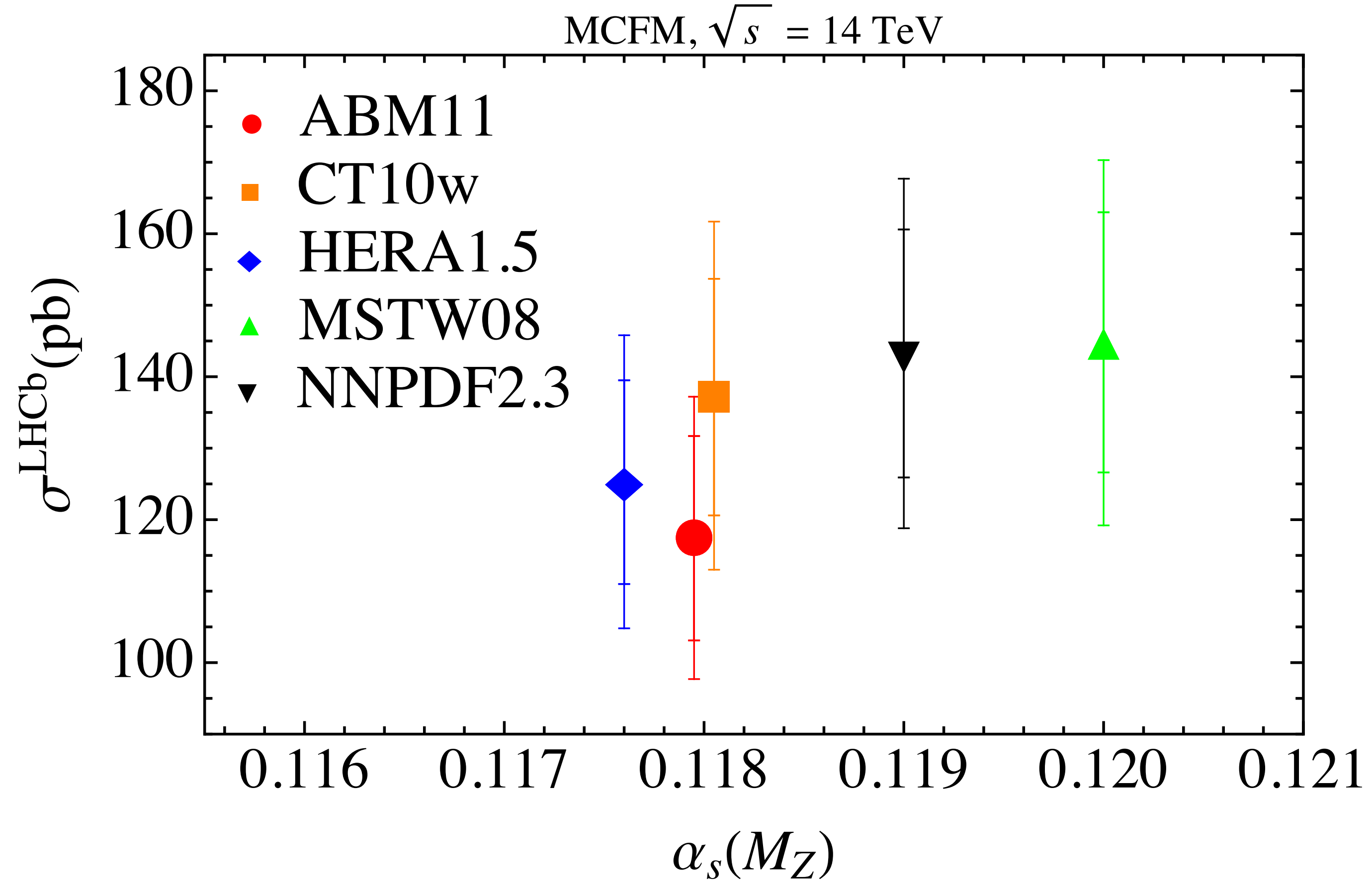
Summary of eigenvector sensitivity



$$\Delta X_j^{\pm} = \frac{X(\mathcal{S}_j^{\pm}) - X(\mathcal{S}_0)}{X(\mathcal{S}_0)}$$

Summary of theory systematics (NLO)

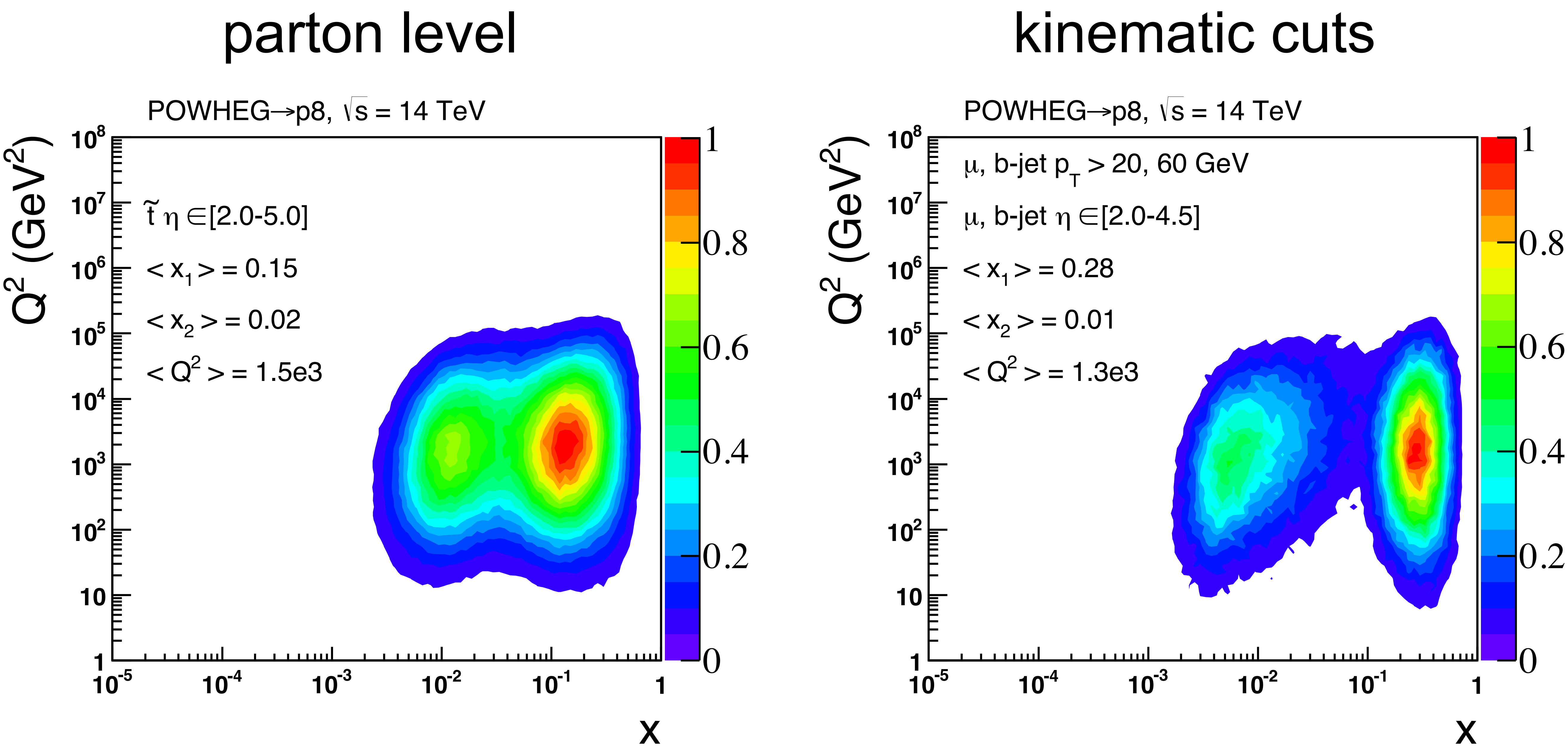
$$\delta_{\text{total}} = \delta_{\text{scale}} + (\delta^2_{\text{PDF}} + \delta^2_{\alpha_s} + \delta^2_{m_t})^{\frac{1}{2}}$$



$$\delta^{\text{ratio}}_X = \frac{\delta^{\text{LHCb}}_X}{\delta^{NLO}_X}$$

PDF	$\delta^{\text{ratio}}_{\text{scale}}$	$\delta^{\text{ratio}}_{\text{PDF}}$	$\delta^{\text{ratio}}_{\alpha_s}$	$\delta^{\text{ratio}}_{m_t}$	$\delta^{\text{ratio}}_{\text{total}}$
ABM	$^{+1.05}_{-1.00}$	$^{+1.40}_{-1.40}$	$^{+0.00}_{-0.00}$	$^{+1.05}_{-1.05}$	$^{+1.06}_{-1.02}$
CT10	$^{+1.05}_{-1.03}$	$^{+1.55}_{-1.40}$	$^{+1.20}_{-1.20}$	$^{+1.06}_{-1.05}$	$^{+1.09}_{-1.07}$
HERA	$^{+1.04}_{-1.01}$	$^{+1.19}_{-0.90}$	$^{+1.33}_{-1.33}$	$^{+1.07}_{-1.06}$	$^{+1.05}_{-1.01}$
MSTW	$^{+1.06}_{-1.03}$	$^{+1.35}_{-1.23}$	$^{+1.13}_{-1.13}$	$^{+1.05}_{-1.06}$	$^{+1.07}_{-1.05}$
NNPDF	$^{+1.05}_{-1.03}$	$^{+1.45}_{-1.45}$	$^{+1.27}_{-1.27}$	$^{+1.07}_{-1.07}$	$^{+1.07}_{-1.06}$

Impact of acceptance cuts (NLO)



Constraining the gluon PDF

Perform a bayesian reweighting based on statistical inference.
arXiv:1012.0836 NNPDF collaboration
arXiv:1205.4024 G. Watt, R. S. Thorne, applied technique to MSTW hessian set

I apply the technique to CT10w and NNPDF2.3 NLO sets

Recipe for Hessian reweighting

1) Calculate observables from eigenvector set

$$\{X_0(\mathcal{S}_0), X_1^-(\mathcal{S}_1^-), X_1^+(\mathcal{S}_1^+), ...X_N^-(\mathcal{S}_N^-), X_N^+(\mathcal{S}_N^+)\}$$

2) Generate random observables from these (storing random numbers)

$$X(\mathcal{S}_k) = X(\mathcal{S}_0) + \sum_{j=1}^{N}[X(\mathcal{S}_j^{\pm}) - X(\mathcal{S}_0)]|R_{kj}|$$

3) Apply a reweighting based on a 'measured' observable (e.g. cross-section)

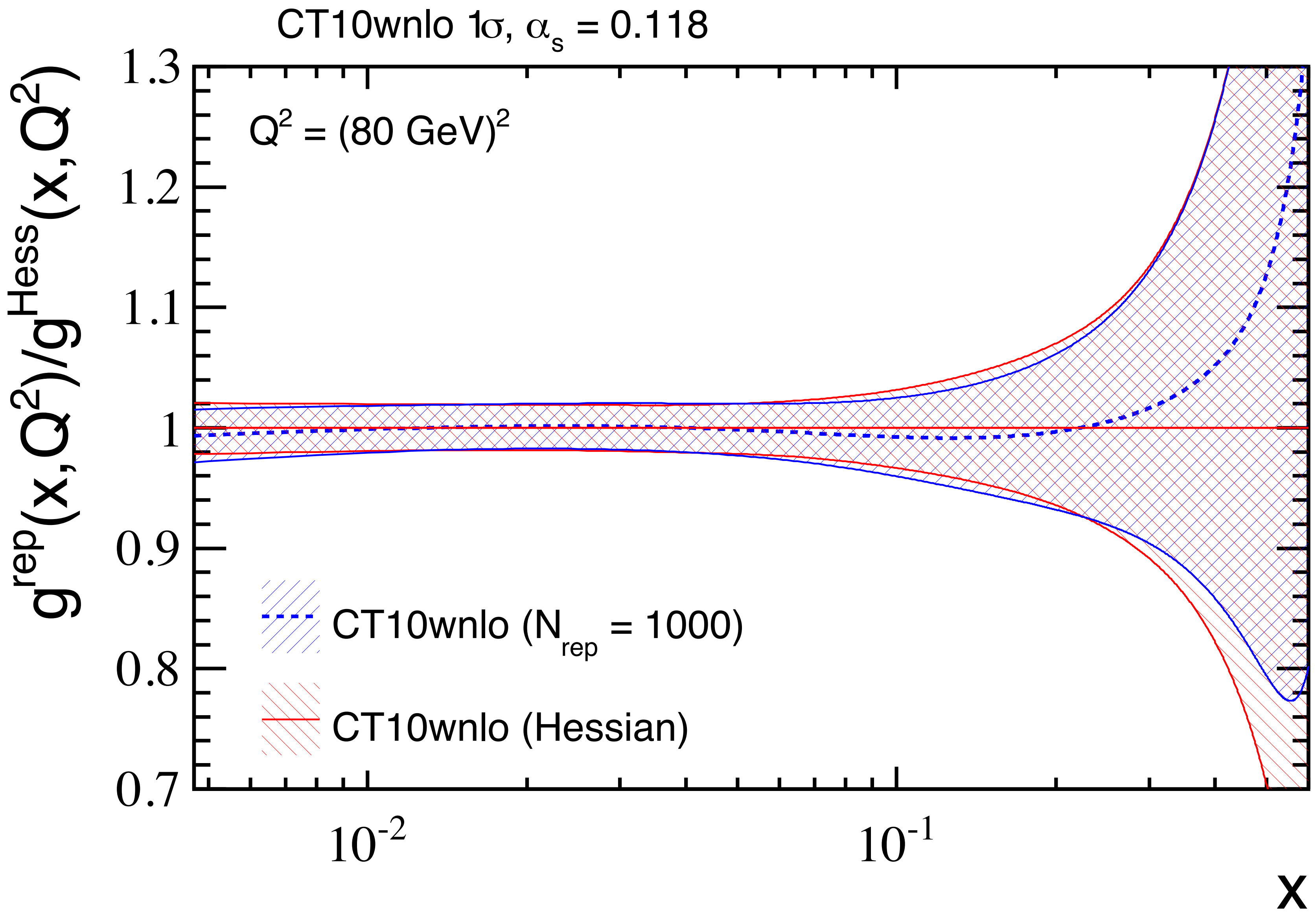
$$W_k(\chi_k^2) = (\chi_k^2)^{\frac{1}{2}(N_{pts.}-1)}\exp(-\frac{1}{2}\chi_k^2)$$

4) Apply these weights to the other observables (gluon PDF, ttbar asymmetry etc.)

Follow the recipe - steps 1, 2

1) Choose observable as evolved gluon PDF, $g^{\mathrm{Hess}}(x, [Q = 80\ \mathrm{GeV}]^2)$

2) Generate 1000 Replicas and compare, $g^{\mathrm{rep}}(x, [Q = 80\ \mathrm{GeV}]^2)$



Follow the recipe - steps 3, 4

3) Pick some pseudo LHCb cross-section data, $\bar{X}_0 = \frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} X_0(\mathcal{S}_0)[1 + R_{k0}]$

4) Apply weights found using pseudodata to reweight evolved gluon PDF