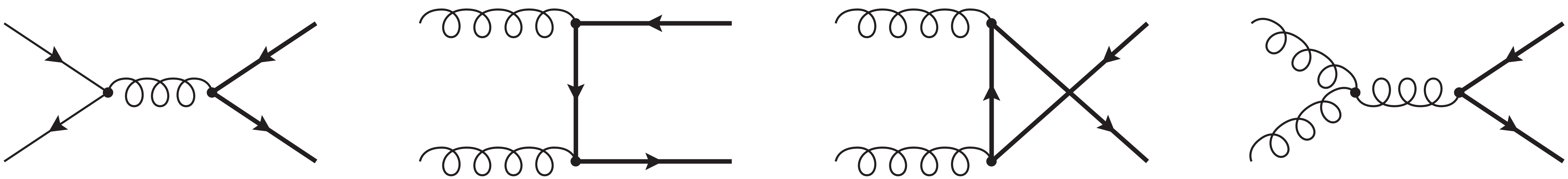
Top-quark (pair) asymmetry at LHCb

Rhorry Gauld

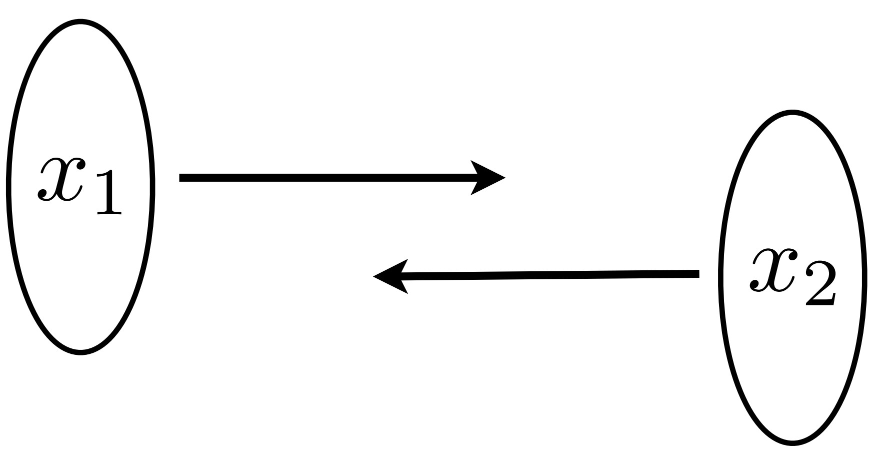
Contents

- Introduction and motivations
- Structure of asymmetry prediction
- Top quark asymmetry predictions at LHCb
  - see arXiv 1409.8631

Why study forward qqbar?



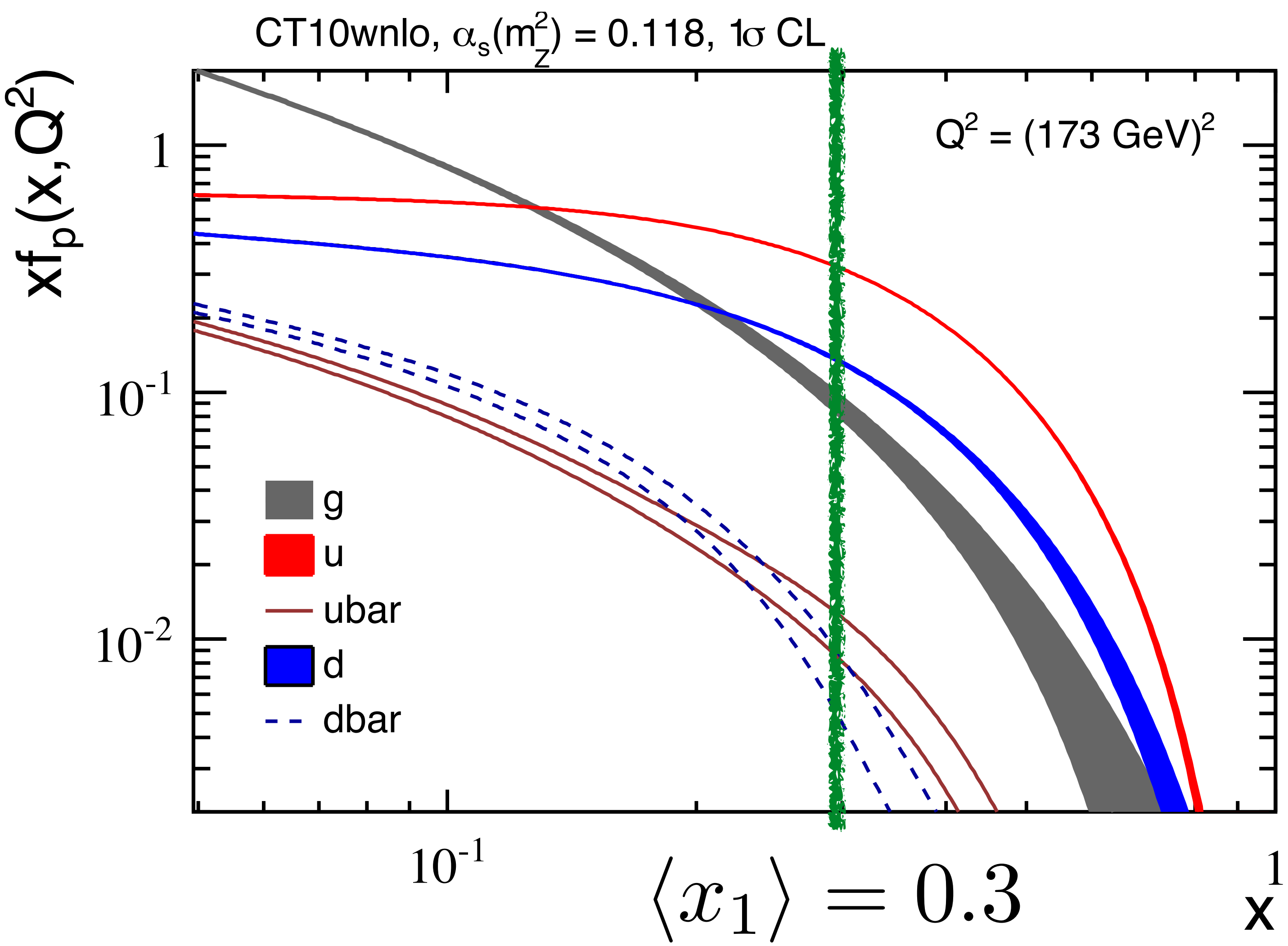
$$x_{1,(2)} = \frac{m_T}{\sqrt{\hat{s}}}\left(e^{(-)y_3} + e^{(-)y_4}\right)$$



Why study forward ttbar?

$$\hat{s} > 4m_t^2$$

$$m_t \simeq 173\ GeV$$

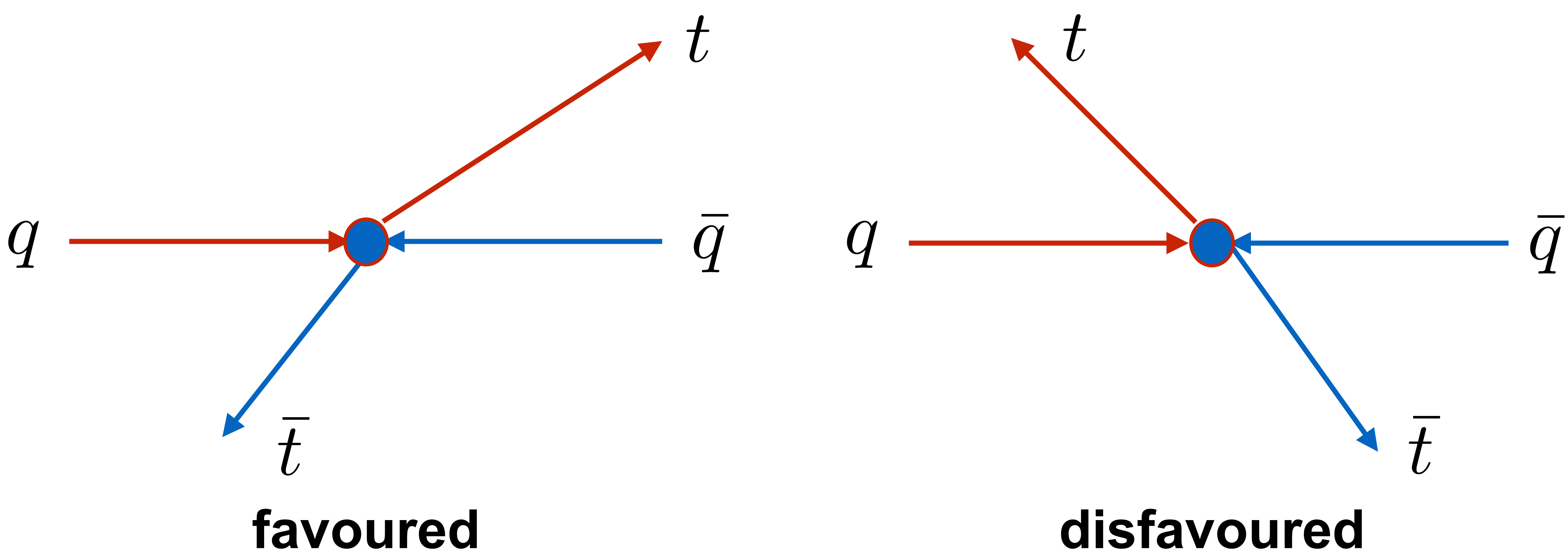


$$\langle x_1 \rangle = 0.3$$

Why is the LHCb phase space important for an asymmetry measurement?

Angular asymmetry in $f\bar{f} \rightarrow f'\bar{f}'$

Known for a long time in QCD and QED……



Nucl. Phys. B57 (1973) 381, F. A. Berends, K. Gaemer, and R. Gastmans,

Acta Phys. Polon. B14 (1983) 413, F. A. Berends, R. Kleiss, S. Jadach, and Z. Was,

Phys. Lett. B195(1987) 74 F. Halzen, P. Hoyer, and C. Kim

Nucl. Phys. B327 (1989) 49 P. Nason, S. Dawson, and R. K. Ellis

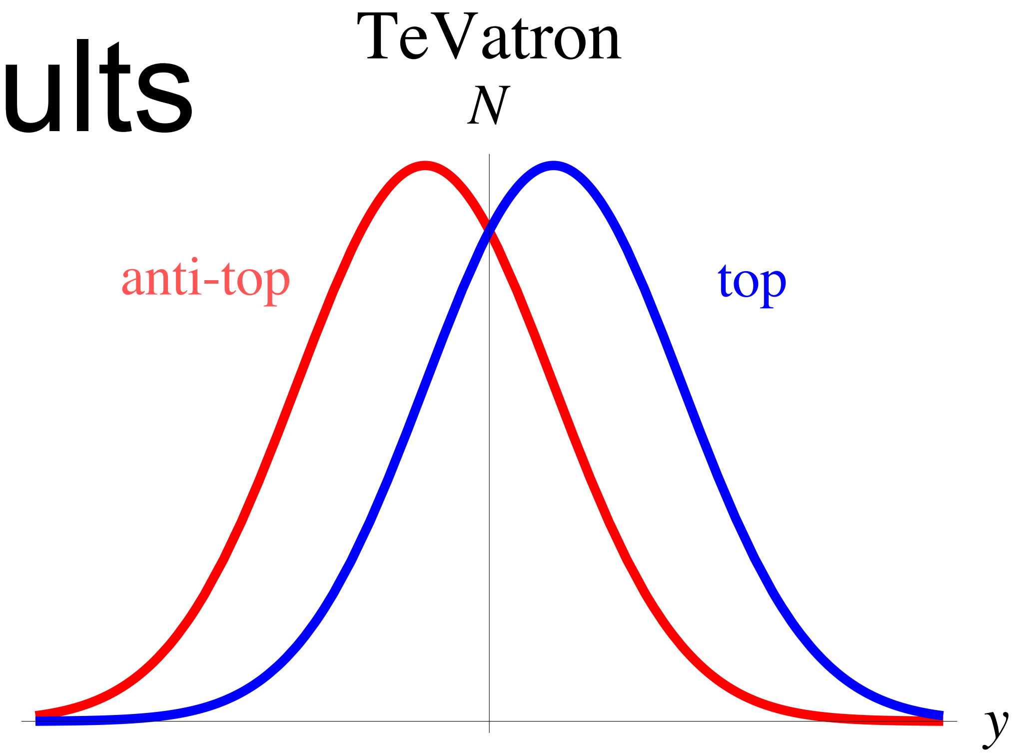
arXiv:hep-ph/9802268, arXiv:hep-ph/9807420 J.H.Kuhn, G. Rodrigo…. many more

Tevatron results

$$p\bar{p} \to t\bar{t}$$

$$A_{fb} = (N^+ - N^-)/N$$

$$\Delta y = y_t - y_{\bar{t}}$$



nnlo QCD + nlo ewk
Czakon,Fielder,Mitov

<u>Inclusive results</u> with **<u>all data</u>**

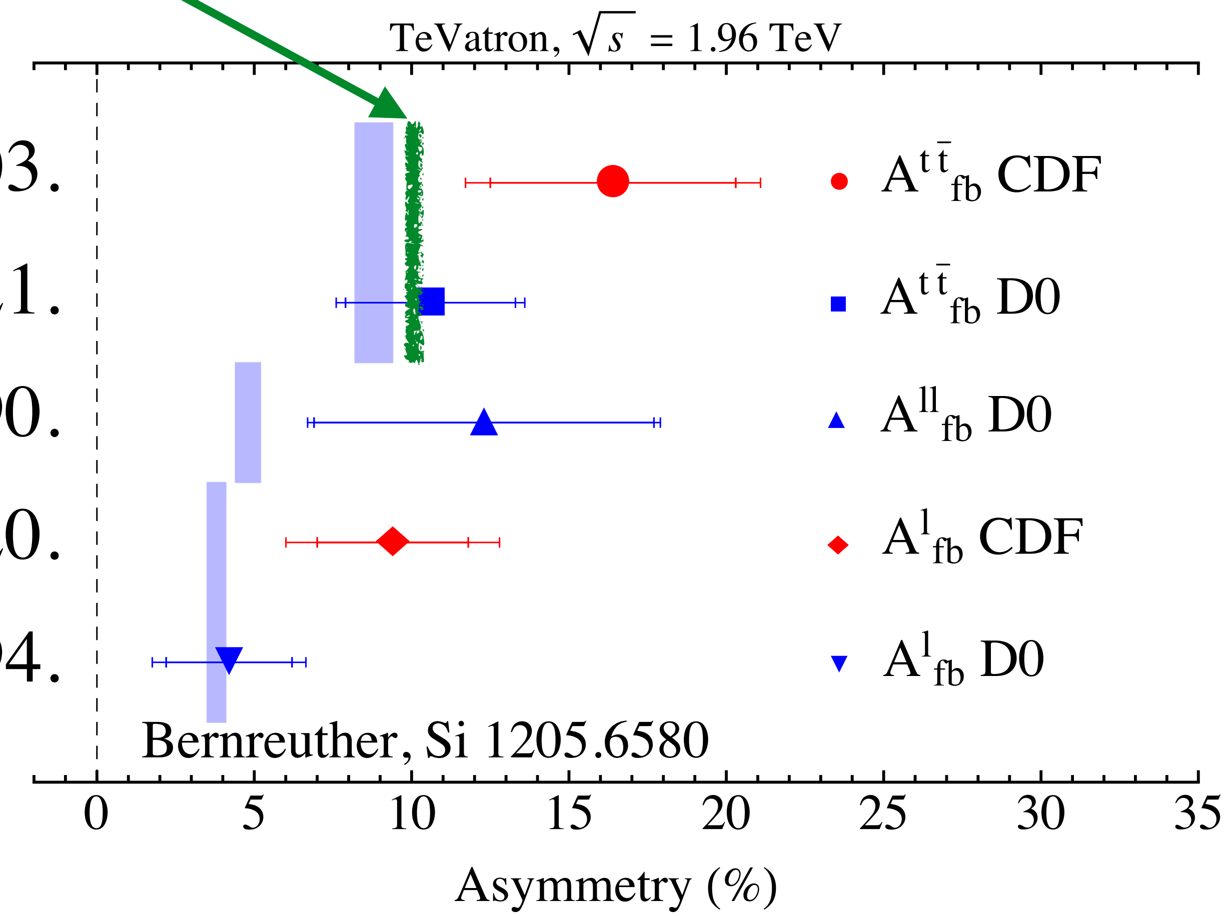
CDF Collaboration, arXiv:1211.1003.

D0 Collaboration, arXiv:1405.0421.

D0 Collaboration, 1308.6690.

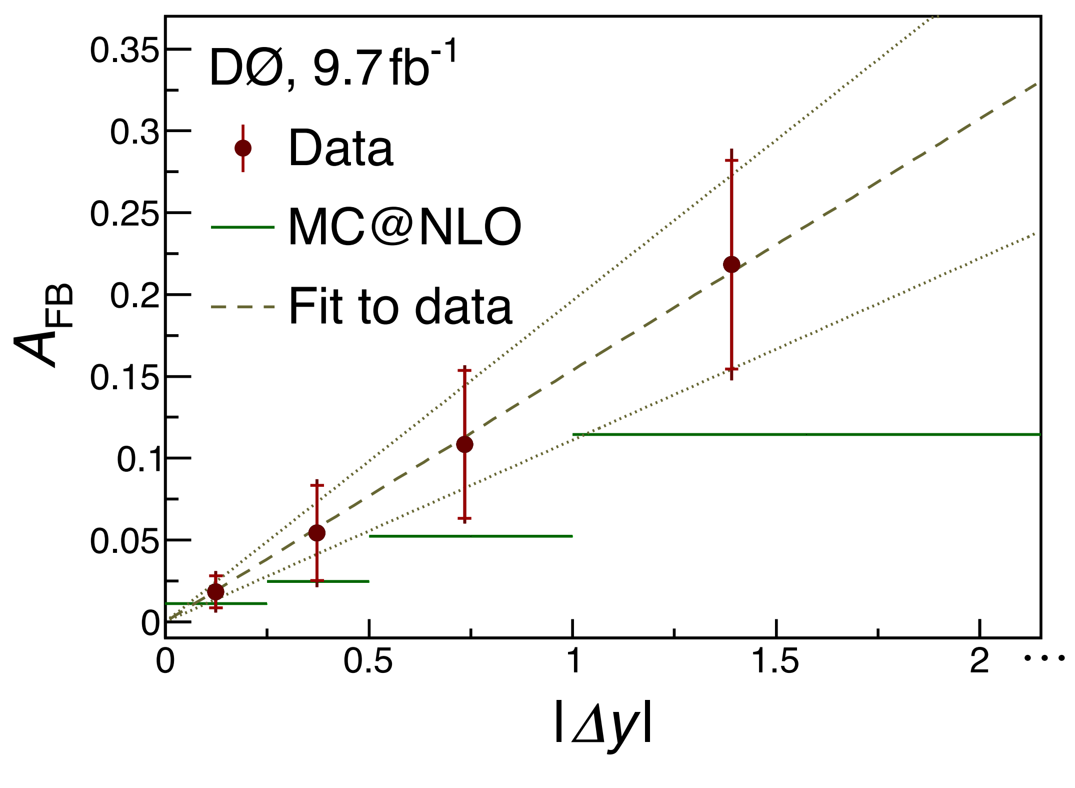
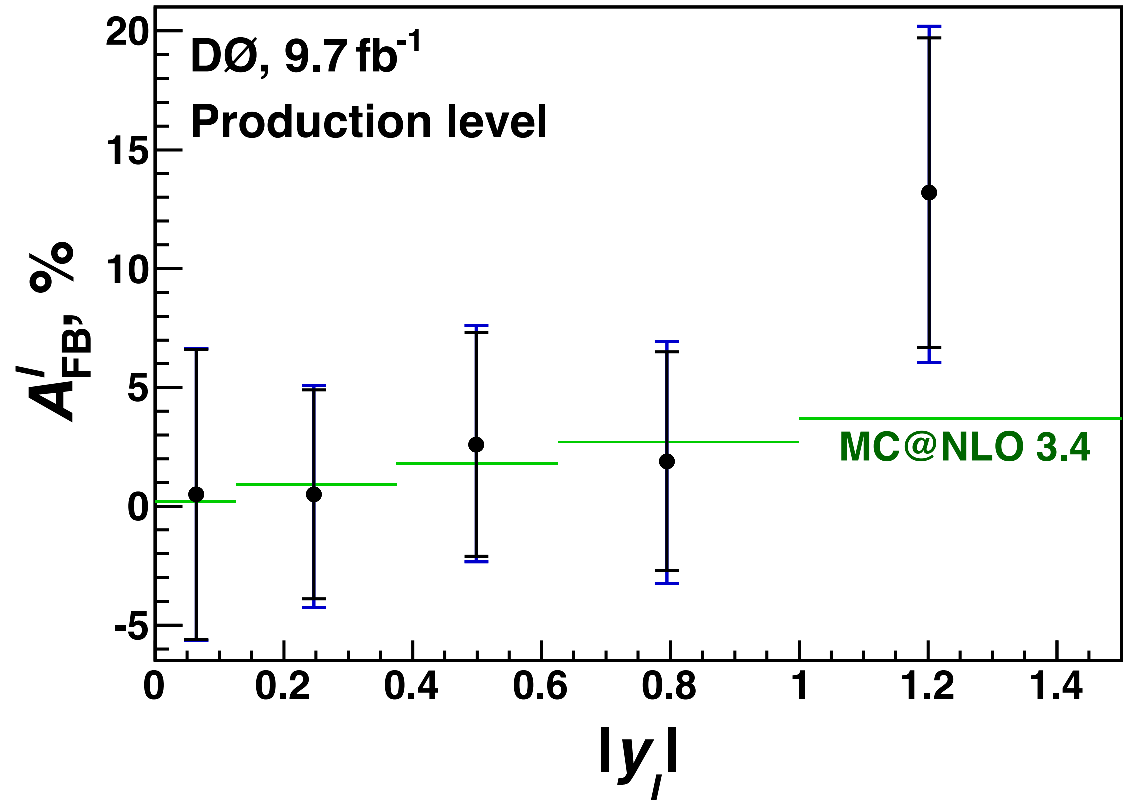
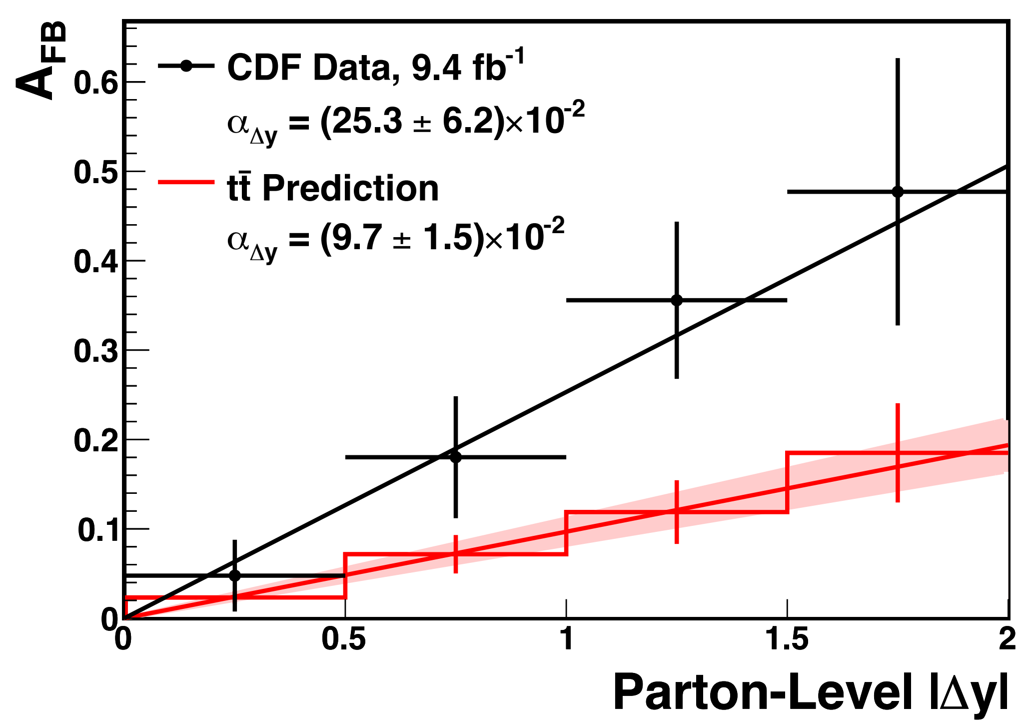
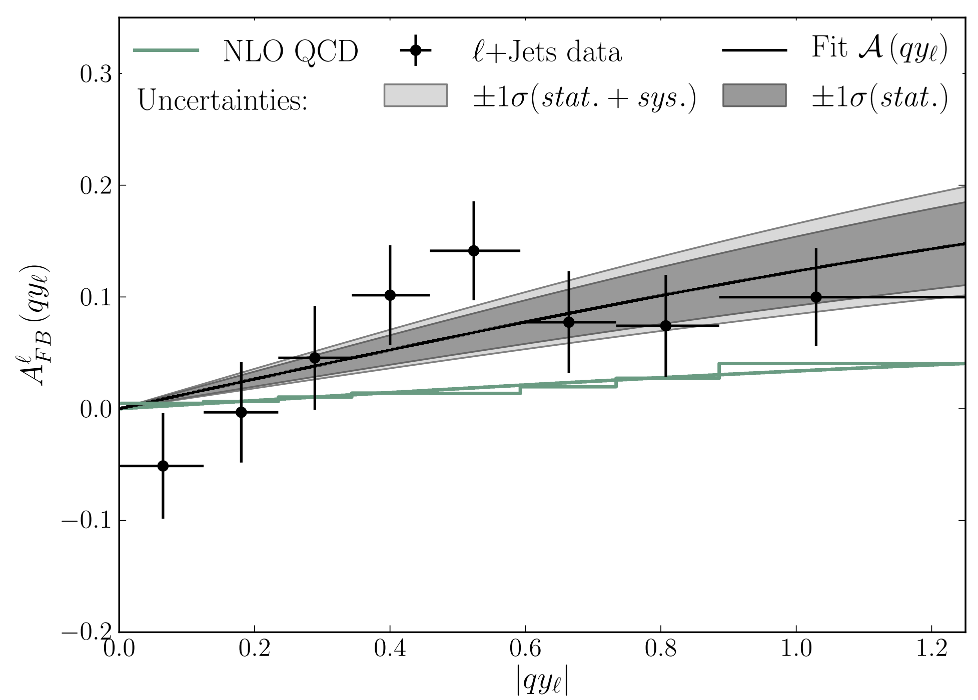
CDF Collaboration, arXiv:1308.1120.

D0 Collaboration, arXiv:1403.1294.



$$\chi^2/N_{\rm d.o.f.} \simeq 7.1/5 \simeq 1.3\sigma$$

Differentially?

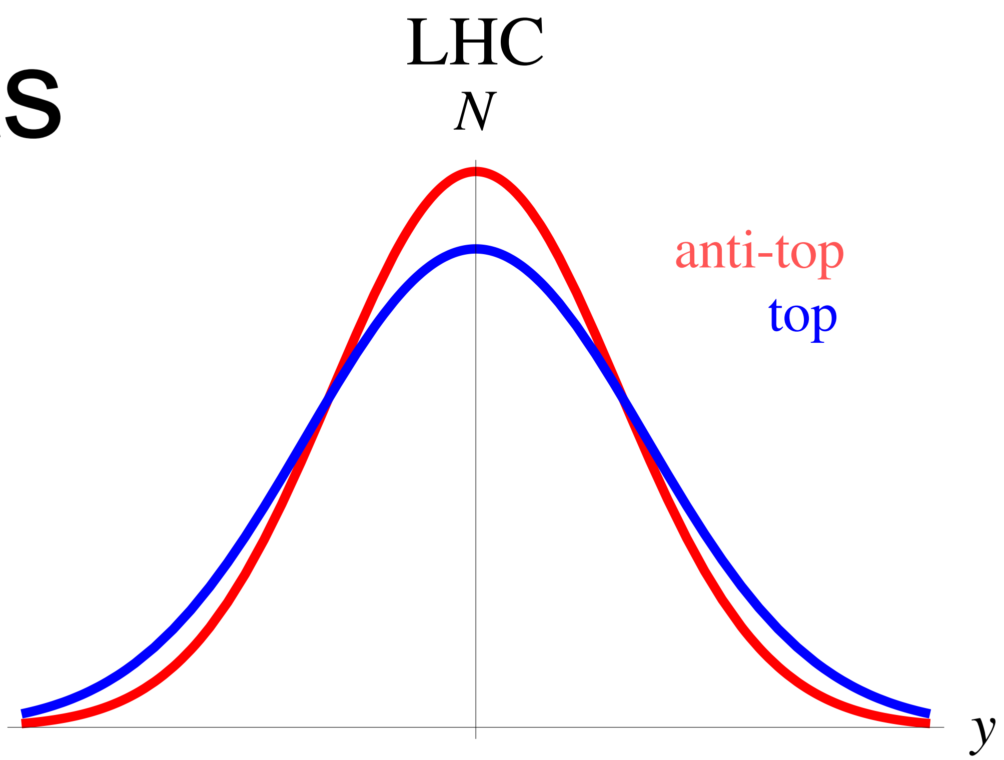
	Parton level	Lepton level
D0		
CDF		

LHC results

$$pp \to t\bar{t}$$

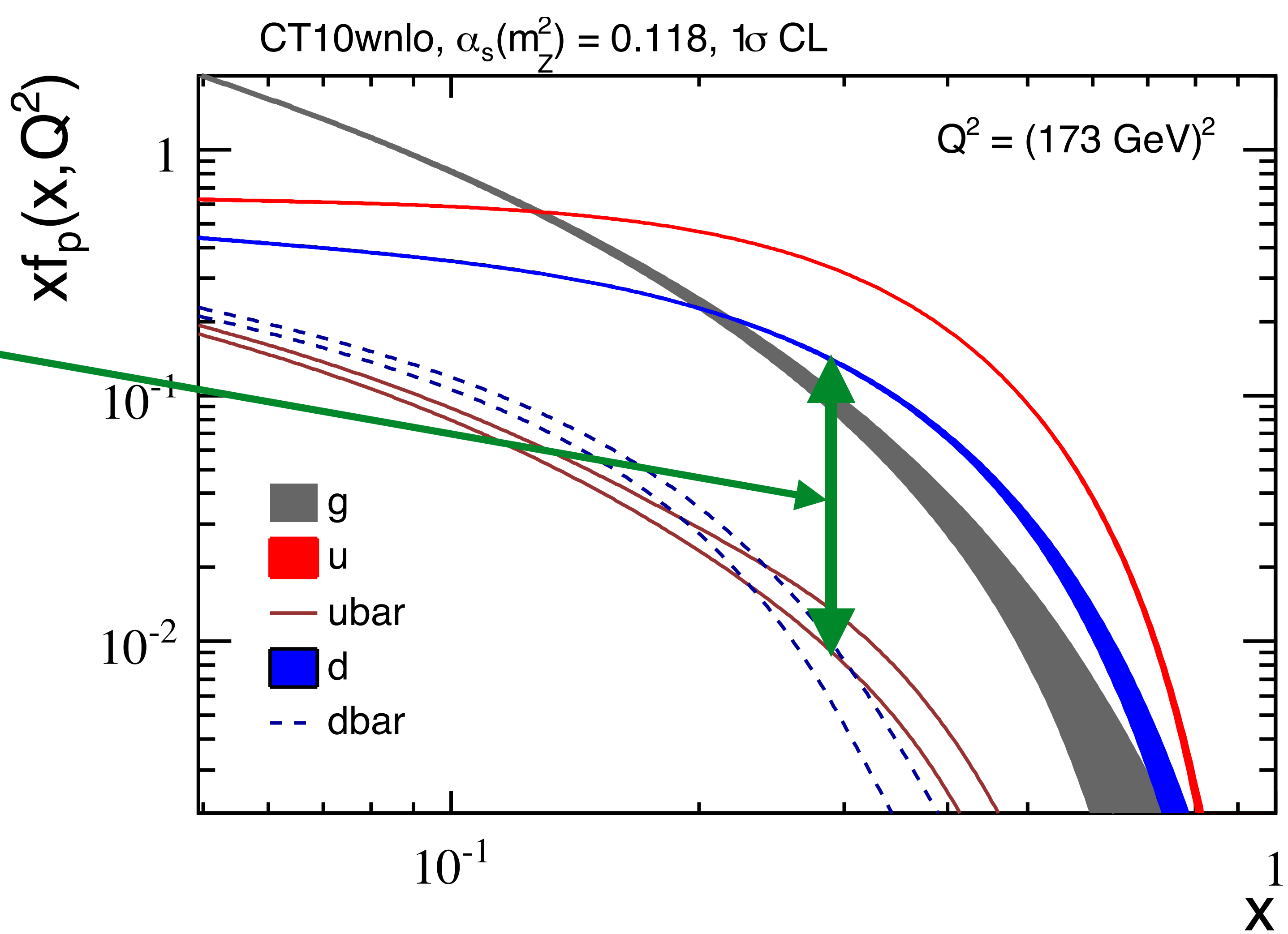
$$A_c = (N^+ - N^-)/N$$

$$\Delta y = |y_t| - |y_{\bar{t}}|$$

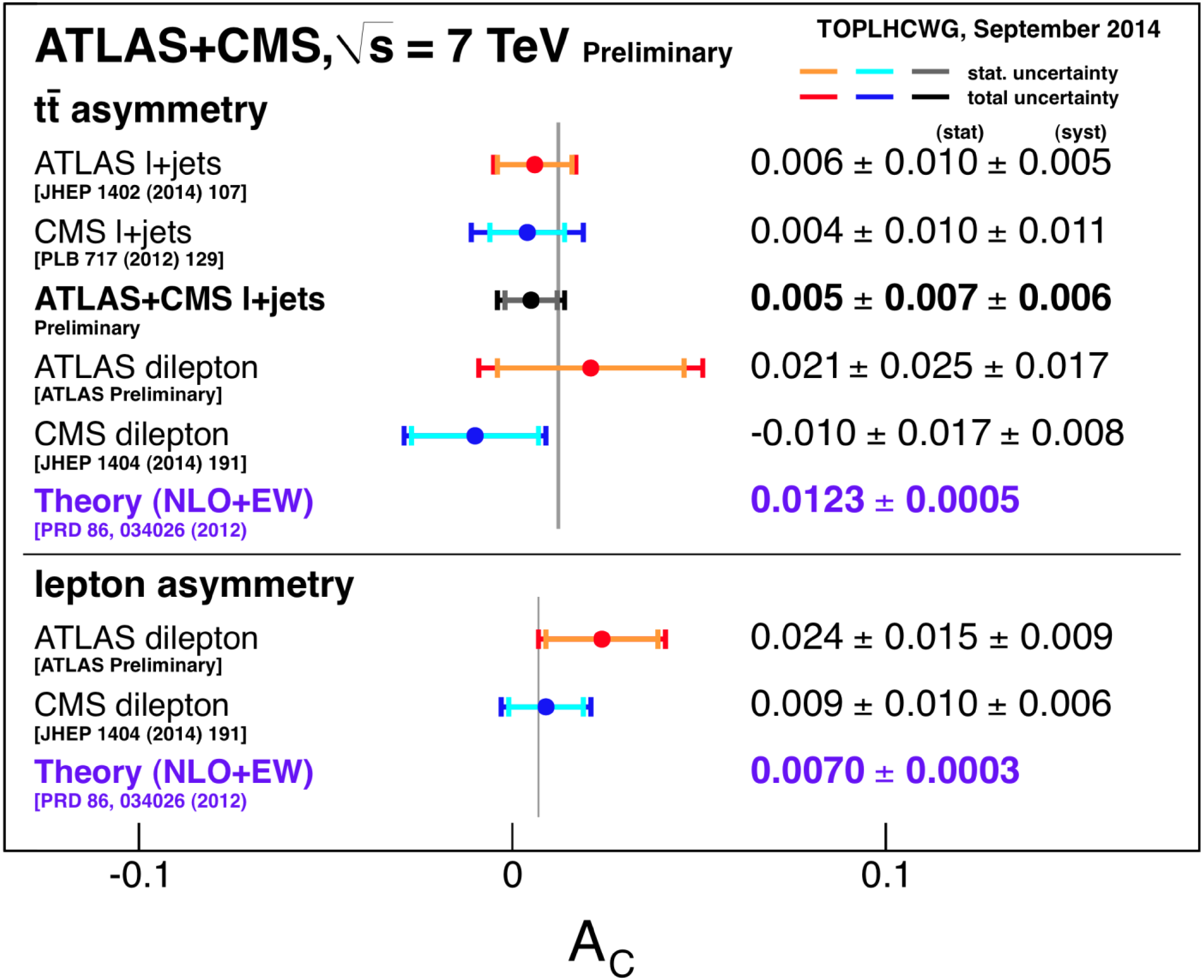


PDF asymmetry

$$f_q(x, Q^2) - f_{\bar{q}}(x, Q^2)$$



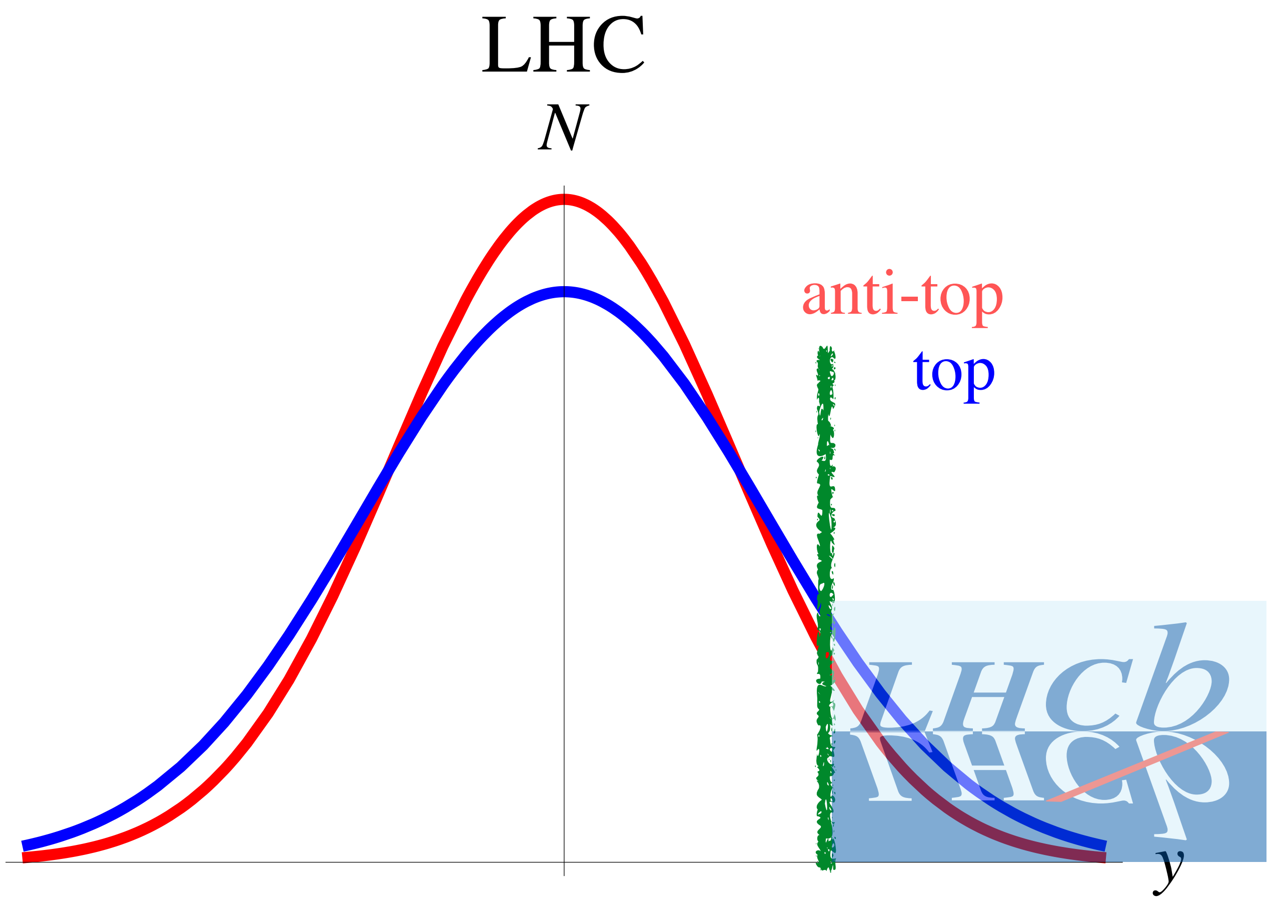
LHC results (R. Hawkings @top 2014)



What can LHCb provide?

1) Asymmetric cross section less diluted by symmetric gluon-fusion
2) PDF asymmetry $f_q(x,Q^2) - f_{\bar{q}}(x,Q^2)$ increases at high-x

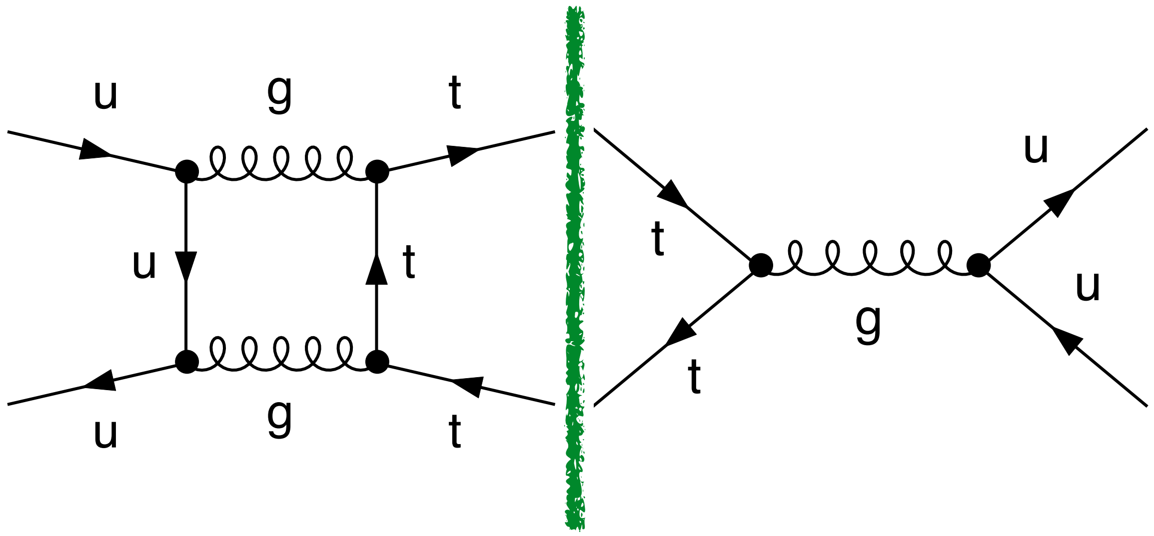
Proposal of A. Kagan, J. Kamenik, G. Perez, S. Stone 1103.3747

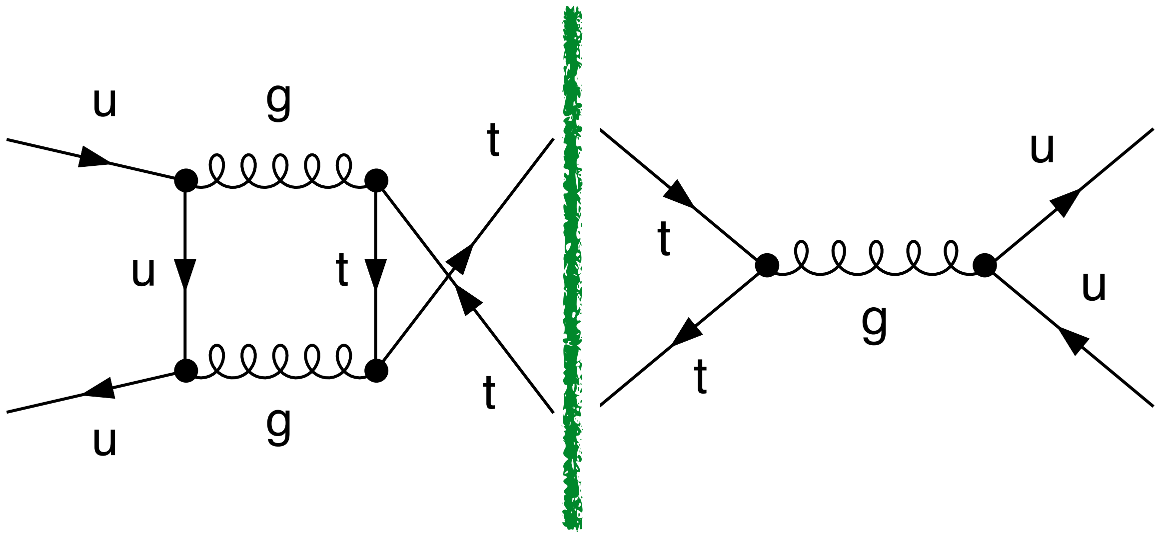


$$A = (N^t - N^{\bar{t}})/N$$

Asymmetry prediction for LHCb - the 1,2,3s

Main contribution - interference of NLO amplitudes!





$A(p_t, p_{\bar{t}})$ $\qquad$ $B(p_t, p_{\bar{t}})$

$$d\sigma_{\text{asym}}^{\text{virt}} = (A(p_t, p_{\bar{t}}) + B(p_t, p_{\bar{t}}) - A(p_{\bar{t}}, p_t) - B(p_{\bar{t}}, p_t))$$

1) Include relevant contributions for real+virt. (QCD,QED, weak, …)

2) At LHCb, one must also include top decay in the prediction!
(the tops are never fully reconstructed, use lepton direction)

3) Apply relevant analysis cuts

Asymmetry prediction for LHCb - the 1,2,3s

Main contribution - interference of NLO amplitudes!

$$A = \frac{\alpha_s^3 \sigma_a^{s(1)} + \alpha_s^2 \alpha_{e/w} \sigma_a^{e/w(1)} + \alpha_{e/w}^2 \sigma_a^{e/w(0)} + \cdots}{\alpha_s^2 \sigma_s^{s(0)} + \alpha_s^3 \sigma_s^{s(1)} + \cdots},$$

$$= \alpha_s \frac{\sigma_a^{s(1)}}{\sigma_s^{s(0)}} + \alpha_{e/w} \frac{\sigma_a^{e/w(1)}}{\sigma_s^{s(0)}} + \frac{\alpha_{e/w}^2}{\alpha_s^2} \frac{\sigma_a^{e/w(0)}}{\sigma_s^{s(0)}} + \cdots .$$

$\sigma_s^{s(0)}$ = symmetric LO cross section (coupling stripped)

$\sigma_a^{x(1)}$ = asymmetric NLO cross section (coupling stripped)

arXiv:hep-ph/9802268, arXiv:hep-ph/9807420, arXiv:1109.6830, J.H.Kuhn, G. Rodrigo

arXiv:1107.2606, W. Hollik and D. Pagani,

arXiv:1205.6580, W. Bernreuther and Z.-G. Si

arXiv:1302.6995, B. Grinstein, C. W. Murphy

arXiv:1409.8631, RG

Asymmetry prediction for LHCb - the 1,2,3s

Main contribution - interference of NLO amplitudes!

$$A = \frac{\alpha_s^3 \sigma_a^{s(1)} + \alpha_s^2 \alpha_{e/w} \sigma_a^{e/w(1)} + \alpha_{e/w}^2 \sigma_a^{e/w(0)} + \cdots}{\alpha_s^2 \sigma_s^{s(0)} + \alpha_s^3 \sigma_s^{s(1)} + \cdots},$$

$$= \alpha_s \frac{\sigma_a^{s(1)}}{\sigma_s^{s(0)}} + \alpha_{e/w} \frac{\sigma_a^{e/w(1)}}{\sigma_s^{s(0)}} + \frac{\alpha_{e/w}^2}{\alpha_s^2} \frac{\sigma_a^{e/w(0)}}{\sigma_s^{s(0)}} + \cdots.$$

1) Obtain QCD from MCFM, arXiv:1204.1513 J. Campbell, R. K. Ellis

2) Apply rescaling of couplings and colour factors

$$R_{q\bar{q}}^X(\mu) = \frac{36 Q_q^X Q_t^X \alpha_e}{5\alpha_s}, \quad R_{qg}^X(\mu) = \frac{24 Q_q^X Q_t^X \alpha_e}{5\alpha_s}.$$

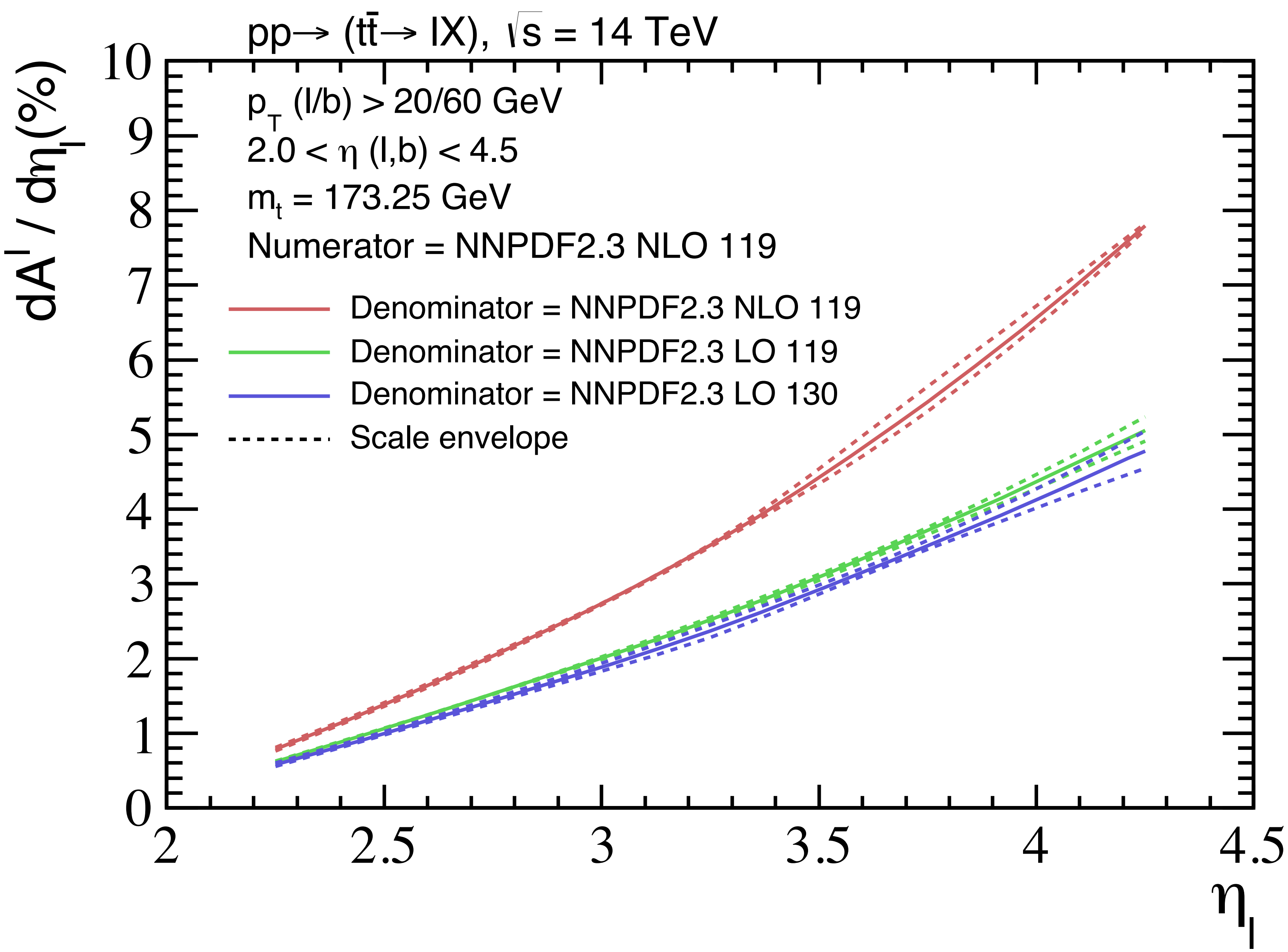
$$Q^w = (2\tau^3 - 4 s_w^2 Q^e)/4 s_w c_w$$

3) Its just LO…

Single-lepton asymmetry

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+b}/d\eta_l - d\sigma^{l^-b}/d\eta_l}{d\sigma^{l^+b}/d\eta_l + d\sigma^{l^-b}/d\eta_l} \right)$$

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



$$A^l = (1.4 - 2.0)\%$$

Backgrounds

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+b}/d\eta_l - d\sigma^{l^-b}/d\eta_l}{d\sigma^{l^+b}/d\eta_l + d\sigma^{l^-b}/d\eta_l} \right)$$

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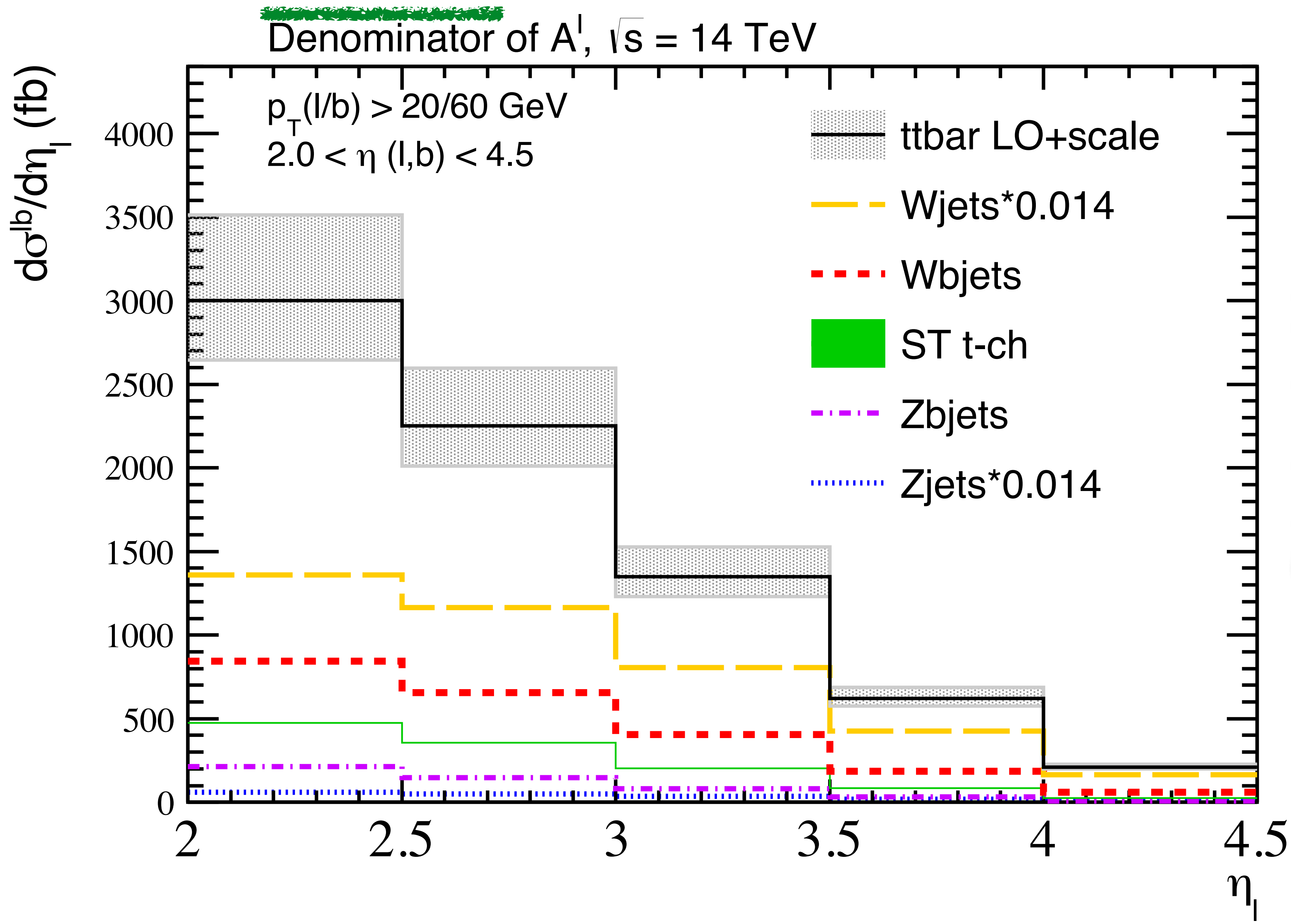

Fit backgrounds experimentally:

$l^{\pm}j, l^{\pm}bj, l^{\pm}bb$

control channels

Backgrounds

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l}{d\sigma^{l^+ b}/d\eta_l + d\sigma^{l^- b}/d\eta_l} \right)$$

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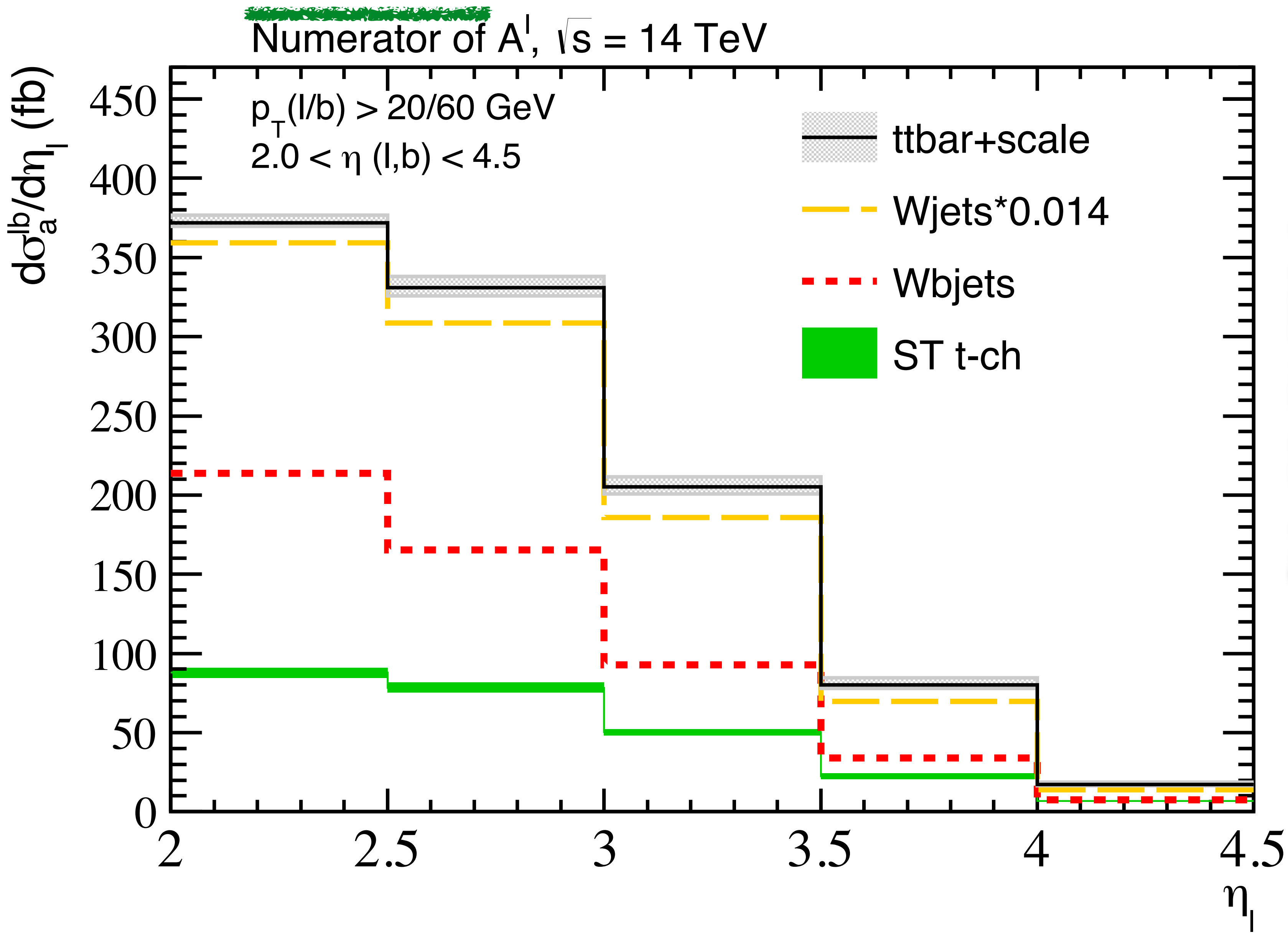


Fit backgrounds experimentally:

$l^{\pm}j, l^{\pm}bj, l^{\pm}bb$

control channels

Statistical feasibility

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l}{d\sigma^{l^+ b}/d\eta_l + d\sigma^{l^- b}/d\eta_l} \right)$$

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

If backgrounds can be controlled!

$$\sigma^{\text{LO}} \simeq 4.7 \text{ pb}$$

$$\int \mathcal{L} dt = 50 \text{ fb}^{-1}$$

Apply b-tagging efficiency 0.7
Apply lepton efficiency 0.75

$$N_{\text{events}} \simeq 1.2e5$$

$$A^l = (1.4 - 2.0) \pm 0.3\%$$

Final Remarks

- Systematics (exp. and theory) are a big task

  Top Quark LHC WG - next meeting 12-13th Jan' 2015
  https://indico.cern.ch/event/340357/

  Important to initiate exp. <-> theory dialogue for tops!

- Also, please submit data to the HepData project!

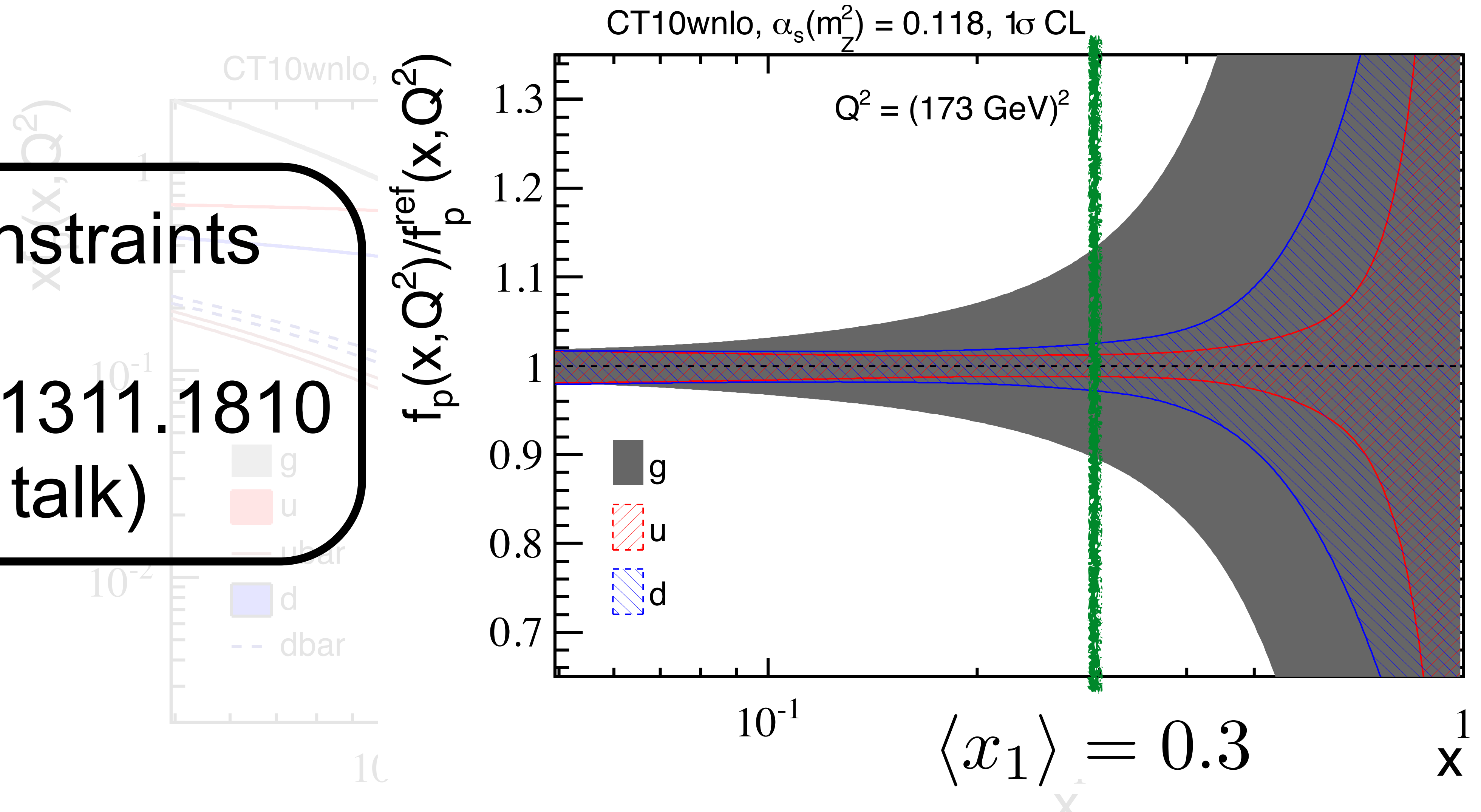
  http://hepdata.cedar.ac.uk

Thank you for your attention!

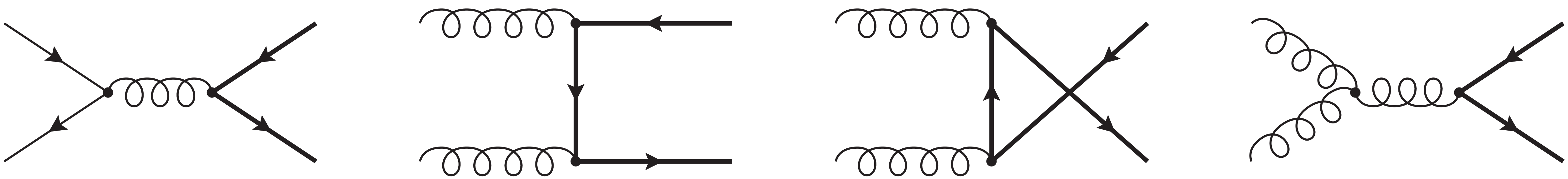
Why study forward ttbar?

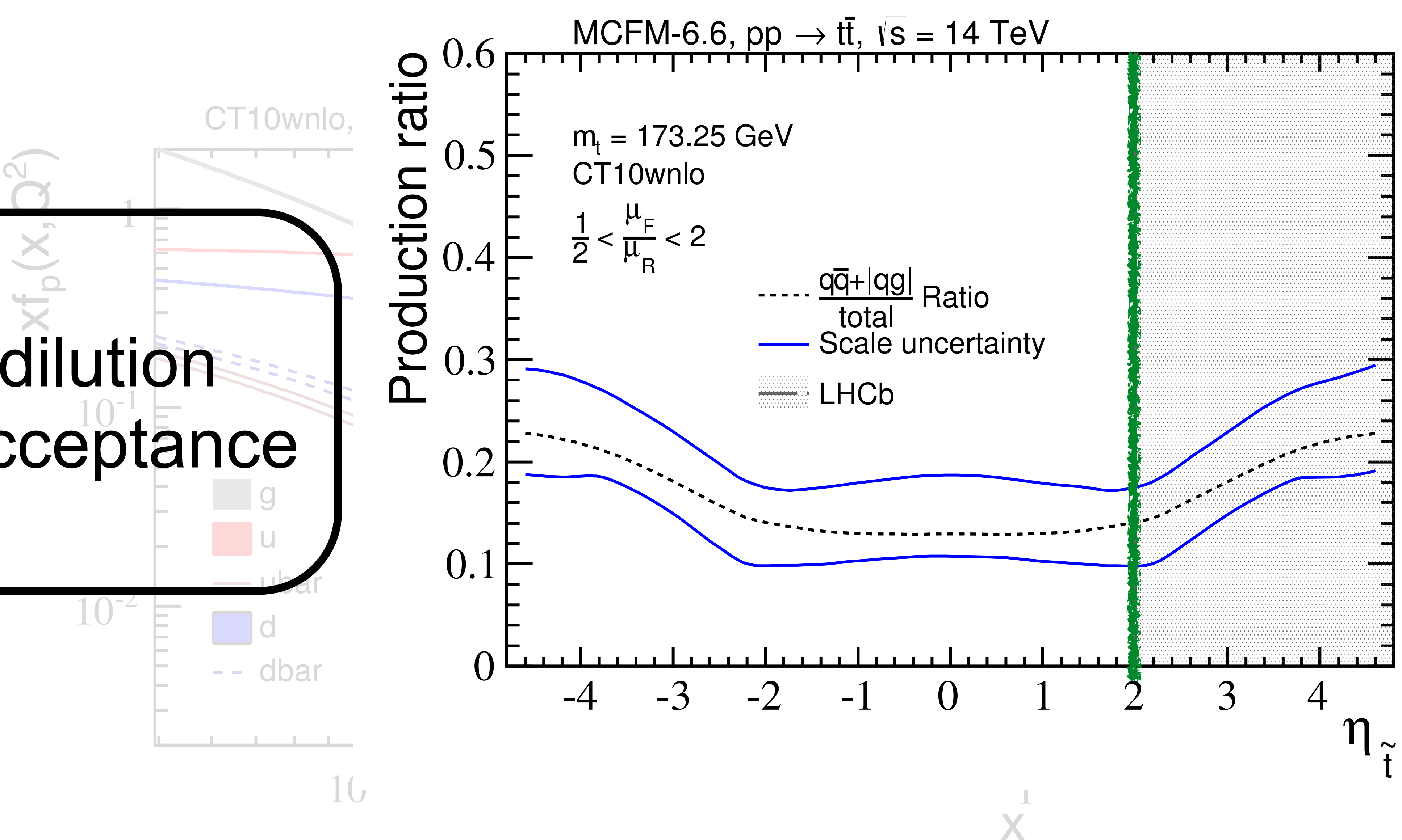
1) PDF constraints

See arXiv 1311.1810
(or Victors talk)



Why study forward ttbar?





2) less gg-dilution in LHCb acceptance

Single-lepton backups

N^l (fb)		$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$
$\mathcal{O}(\alpha_s^3)$	$u\bar{u}$	55.62	40.84	31.56
	$d\bar{d}$	23.15	16.99	13.05
	ug	1.79	1.02	0.65
	dg	0.72	0.45	0.26
$\mathcal{O}(\alpha_s^2\alpha_e)$		9.37	7.65	6.47
$\approx \mathcal{O}(\alpha_s^2\alpha_w)$		0.35	0.25	0.19
$\mathcal{O}(\alpha_{e/w}^2)$		0.81	0.78	0.77
Total		91.80	67.96	52.95

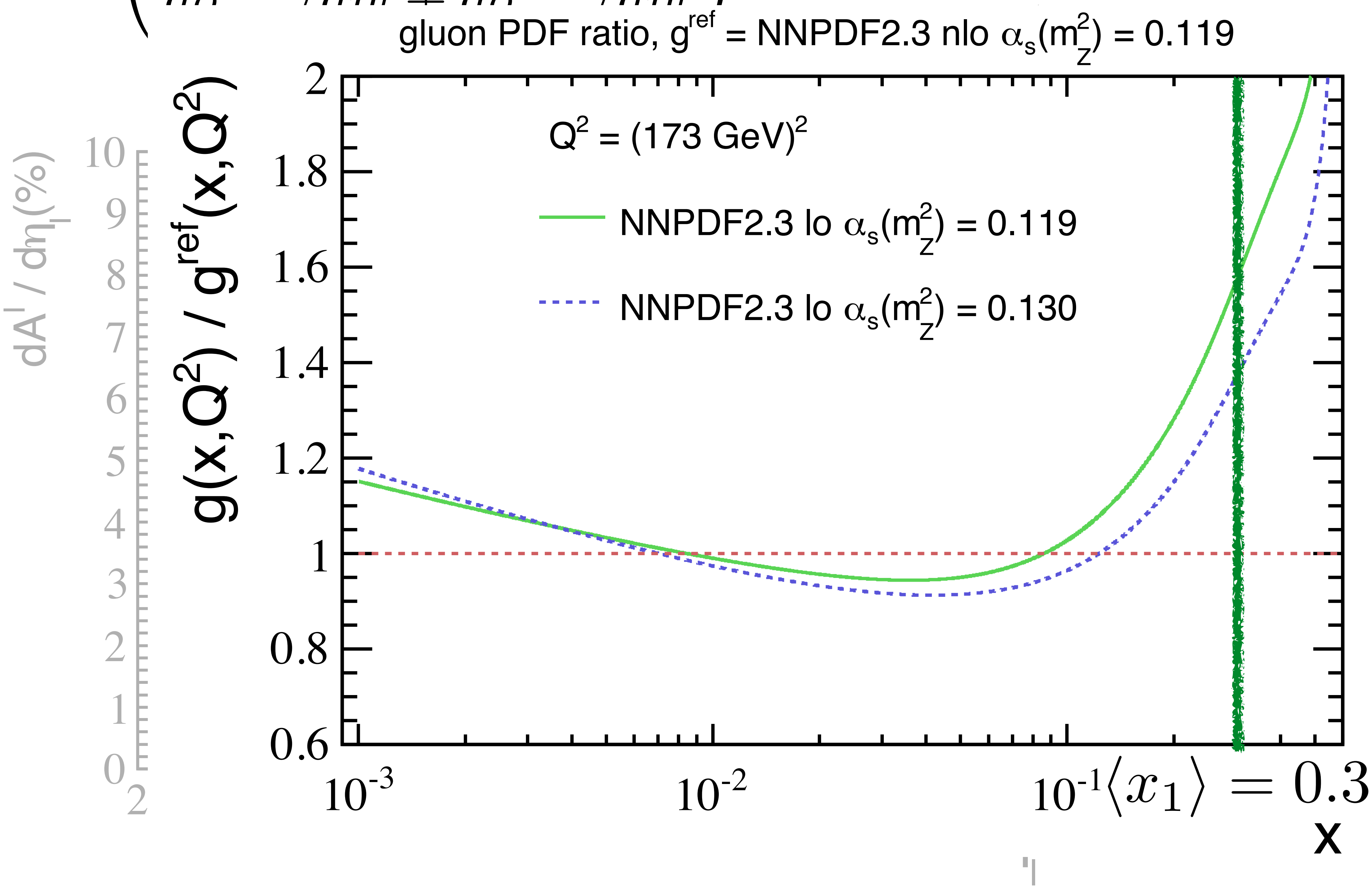
	D^l (fb), 14 TeV			
PDF	$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$	A^l (%)
NLO 119	4626	3512	2742	1.95 (3)
LO 119	6225	4663	3586	1.47 (1)
LO 130	6761	4961	3752	1.38 (3)

Single-lepton asymmetry

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l}{d\sigma^{l^+ b}/d\eta_l + d\sigma^{l^- b}/d\eta_l} \right)$$

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

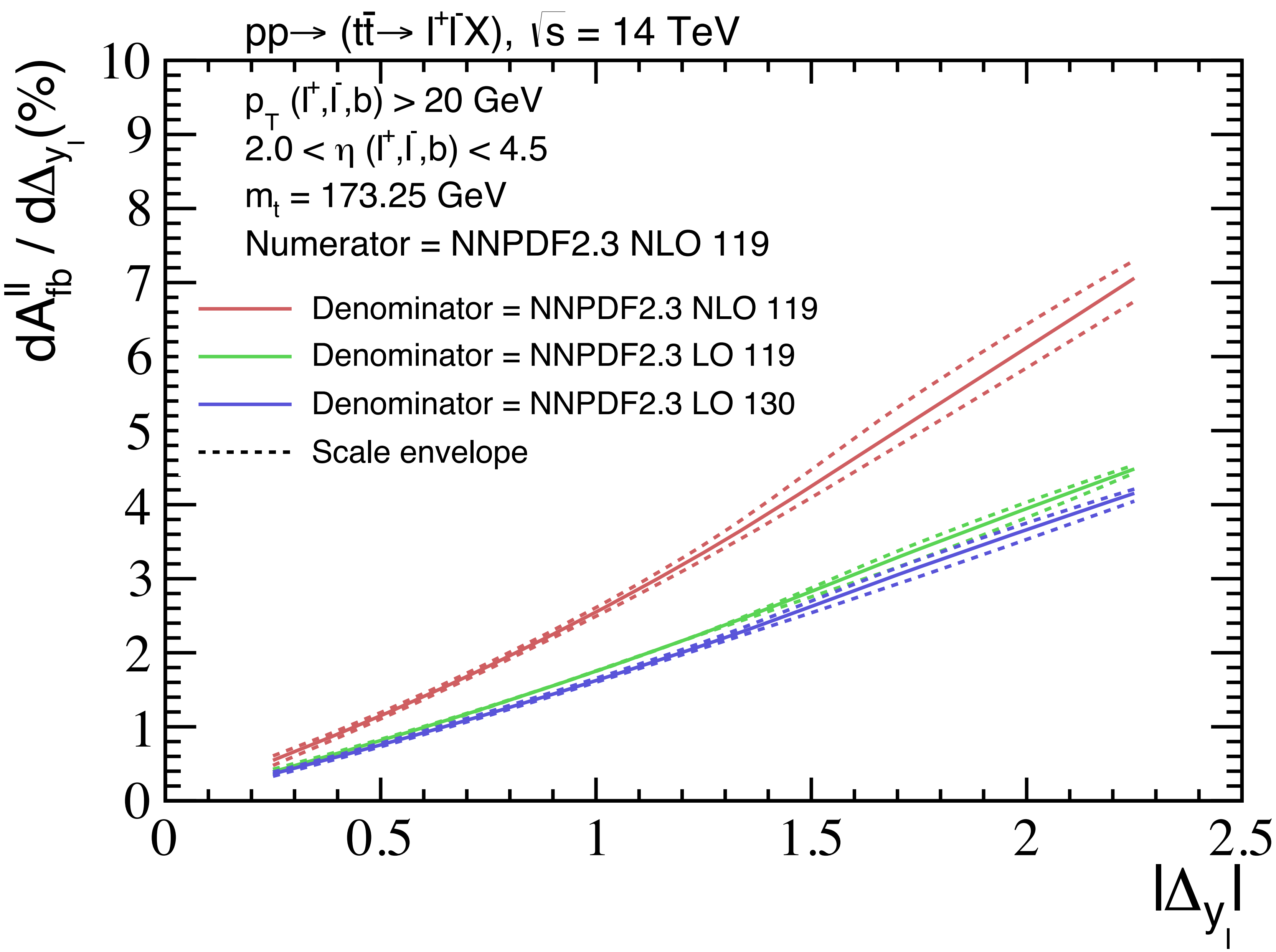
$$p_T(l/b) > 20/60 \text{ GeV}$$



Di-lepton asymmetry

$$A_{fb}^{ll} = \int d\Delta_y \frac{\left(d\sigma^{\mu e b}(\Delta_y > 0) - d\sigma^{\mu e b}(\Delta_y < 0)\right)/d\Delta_y}{d\sigma^{\mu e b}/d\Delta_y}$$

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



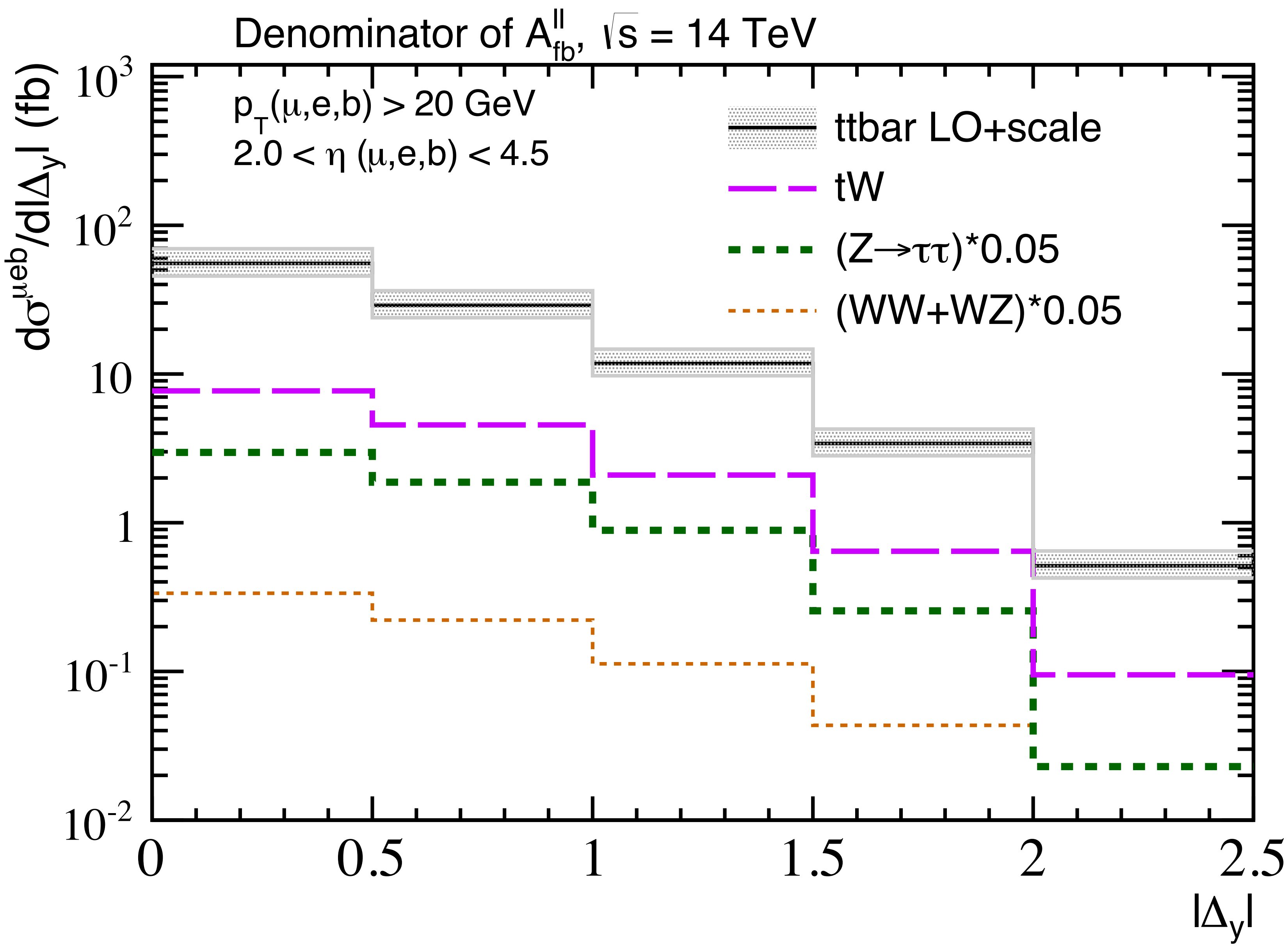
$$A_{fb}^{ll} = (0.9 - 1.4)\%$$

Di-lepton asymmetry

N_{fb}^{ll} (fb)		$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$
$\mathcal{O}(\alpha_s^3)$	$u\bar{u}$	0.977	0.709	0.536
	$d\bar{d}$	0.344	0.239	0.181
	ug	0.095	0.070	0.045
	dg	0.031	0.021	0.013
$\mathcal{O}(\alpha_s^2\alpha_e)$		0.179	0.146	0.120
$\approx \mathcal{O}(\alpha_s^2\alpha_w)$		0.009	0.007	0.006
$\mathcal{O}(\alpha_{e/w}^2)$		0.006	0.005	0.005
Total		1.642	1.198	0.907

	D_{fb}^{ll} (fb), 14 TeV			
PDF	$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$	A_{fb}^{ll} (%)
NLO 119	110.4	85.0	67.4	1.41 (8)
LO 119	160.7	120.7	93.3	0.99 (3)
LO 130	176.6	130.0	98.8	0.92 (1)

Di-lepton asymmetry

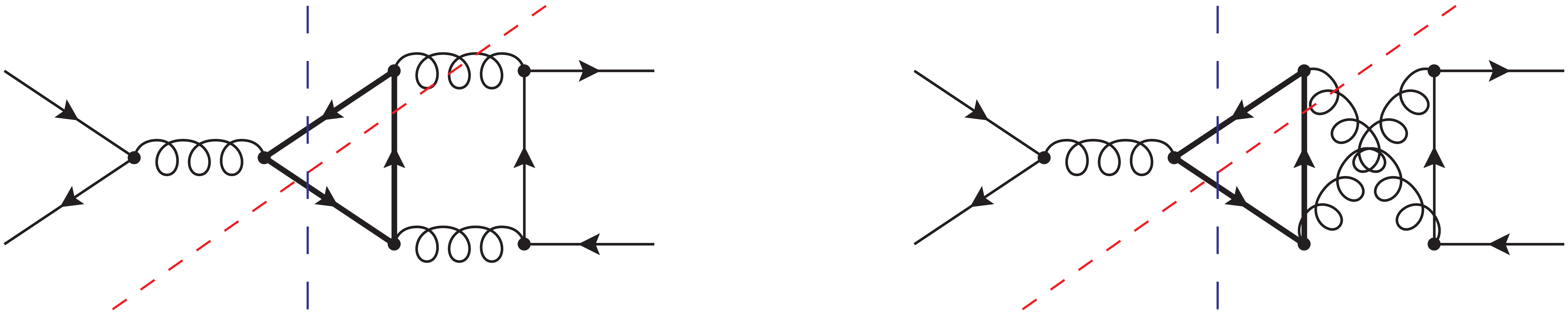


$$A^{ll}_{fb} = (0.9 - 1.4) \pm 1.6\%$$

stat. 50 fb-1

At the Tevatron

$$\sigma_{(a)s} = \frac{1}{2}\int_0^1 d\cos\theta \left(\frac{d\sigma^{pp\to t\bar{t}X}}{d\cos\theta} \underset{(-)}{+} \frac{d\sigma^{pp\to \bar{t}tX}}{d\cos\theta} \right)$$



$$\sigma_a^{s(1)} = \frac{1}{2}\int_0^1 d\cos\theta \Bigg(\left(\mathcal{C}_{\text{left}} \frac{d\sigma_{\text{left}}(p_3,p_4)}{d\cos\theta} + \mathcal{C}_{\text{right}} \frac{d\sigma_{\text{right}}(p_3,p_4)}{d\cos\theta} \right) - \left(\mathcal{C}_{\text{left}} \frac{d\sigma_{\text{left}}(p_4,p_3)}{d\cos\theta} + \mathcal{C}_{\text{right}} \frac{d\sigma_{\text{right}}(p_4,p_3)}{d\cos\theta} \right) \Bigg)$$

Single-lepton

- generate samples (**POWHEG**) and match to parton shower (**Pythia8176**)
- apply <u>realistic</u> cuts: **l pT > 20 GeV** and **b pT > 60 GeV**
- apply b-tagging efficiencies: 70% efficiency and 1% mis-tag (non b-jet)
- apply muon efficiencies: 75% (trigger, identification, reconstruction)
- apply muon isolation: dR (mu, j/b) > 0.5

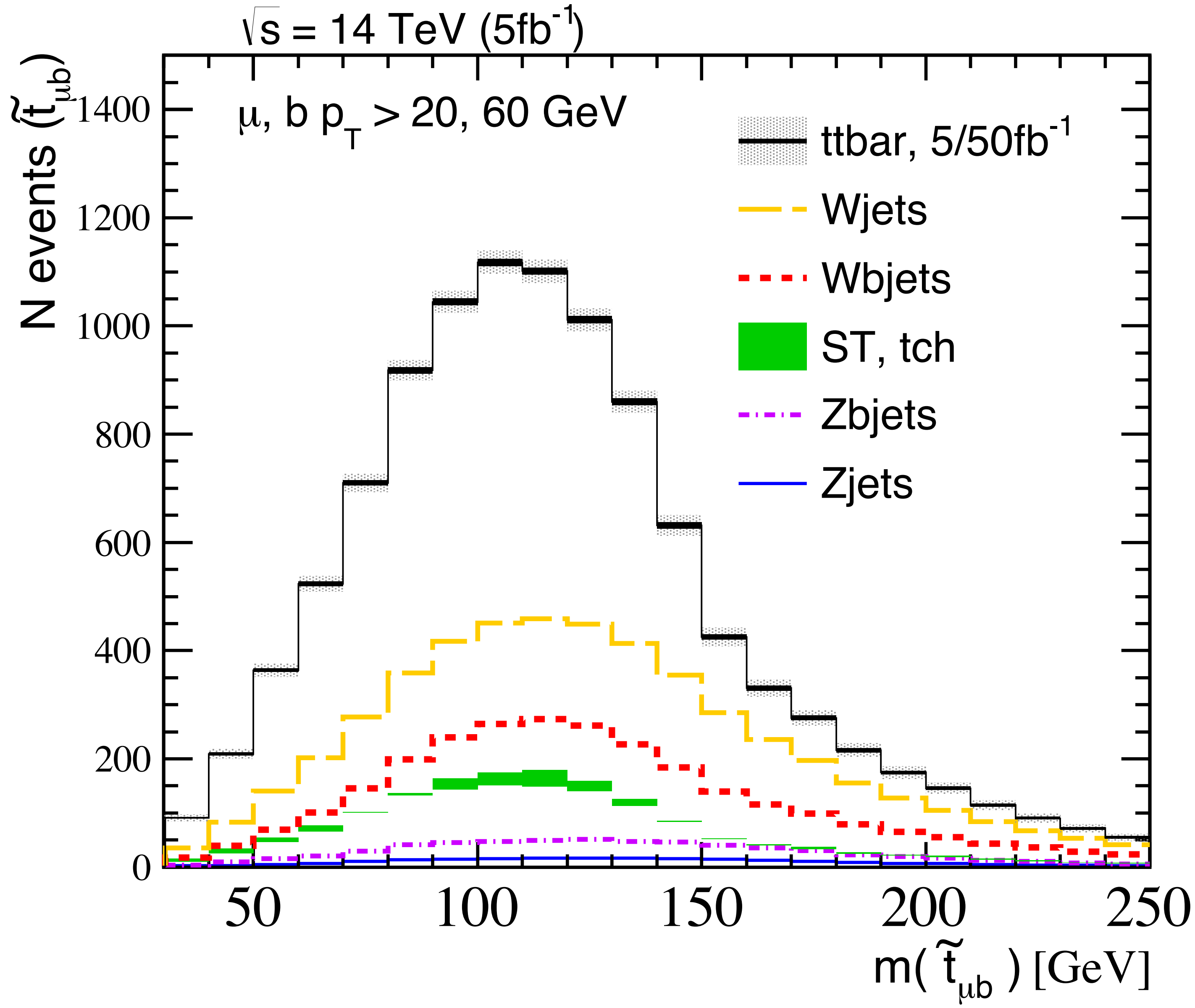
$$14\ TeV$$

$$l^{\pm}b$$

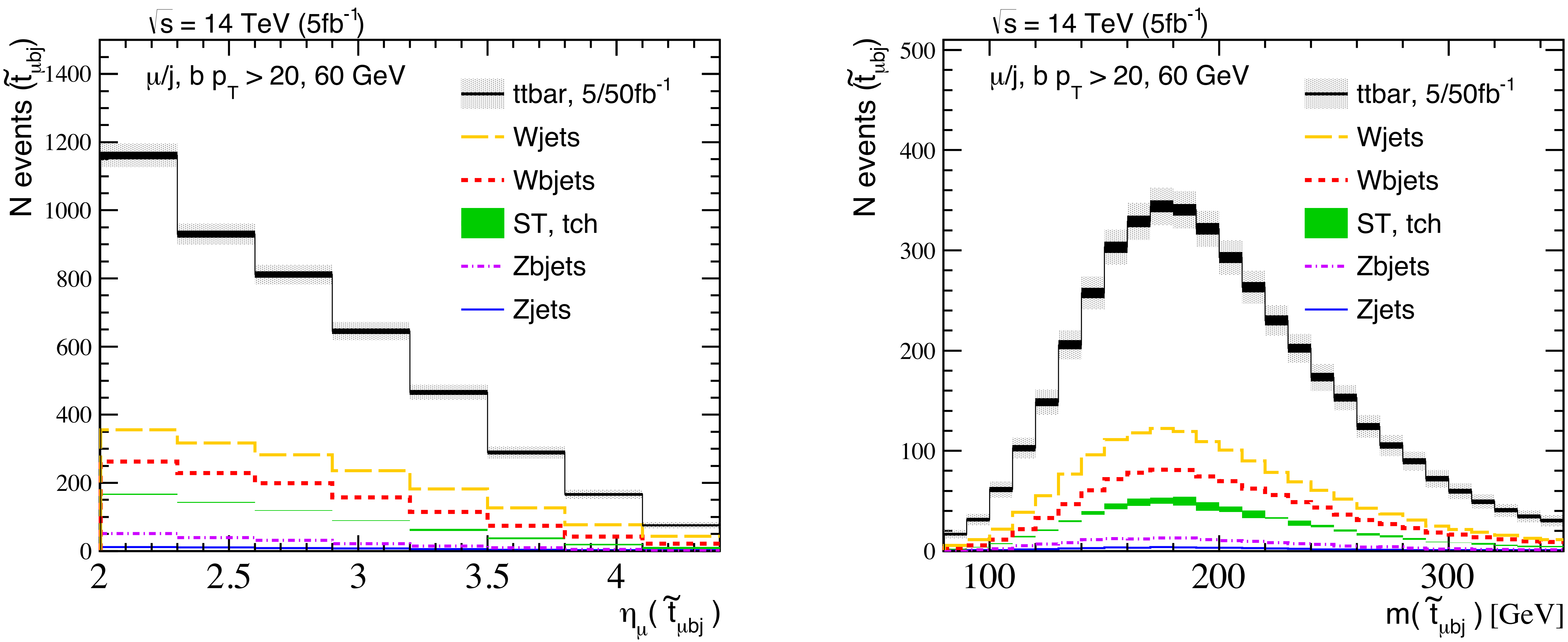
N events expected

2017 - 5 ifb

2030 - 50 ifb



Single-lepton 14 TeV (lbj)



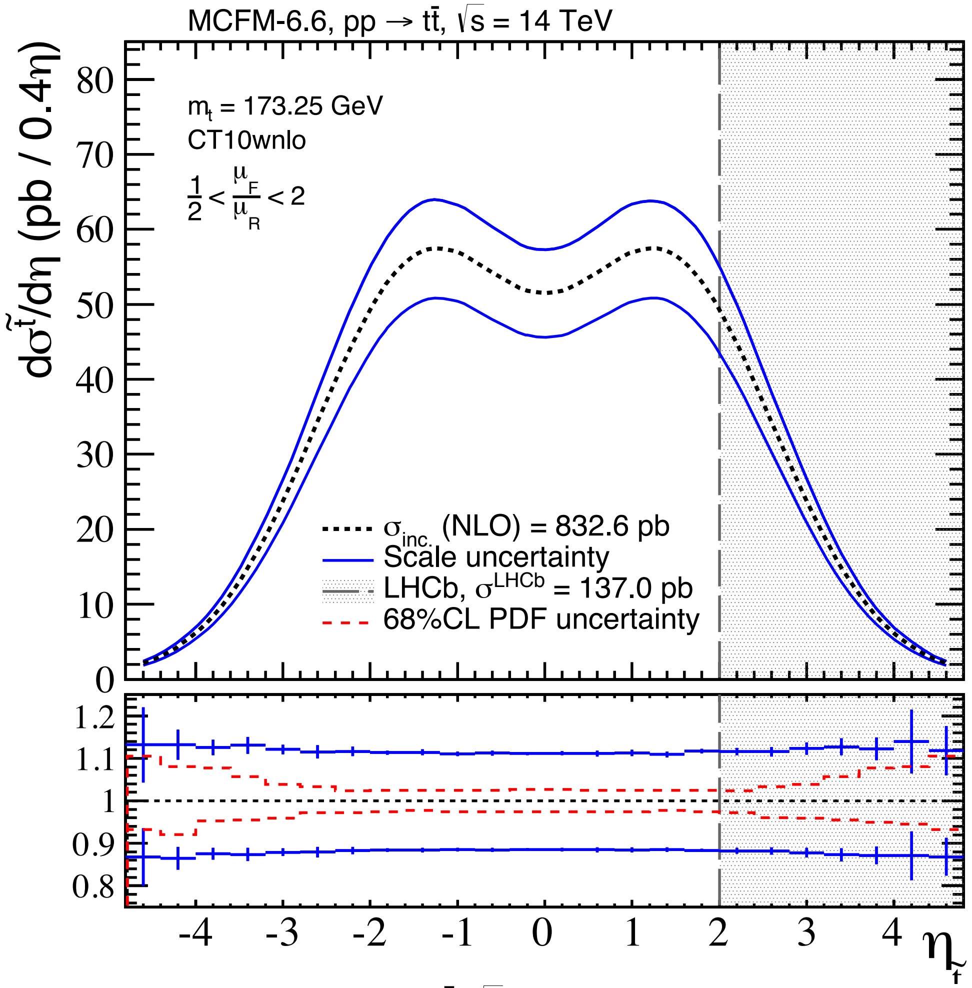
$$14\ TeV$$

$$l^{\pm}bj$$

Theoretical systematics for ttbar at LHCb

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

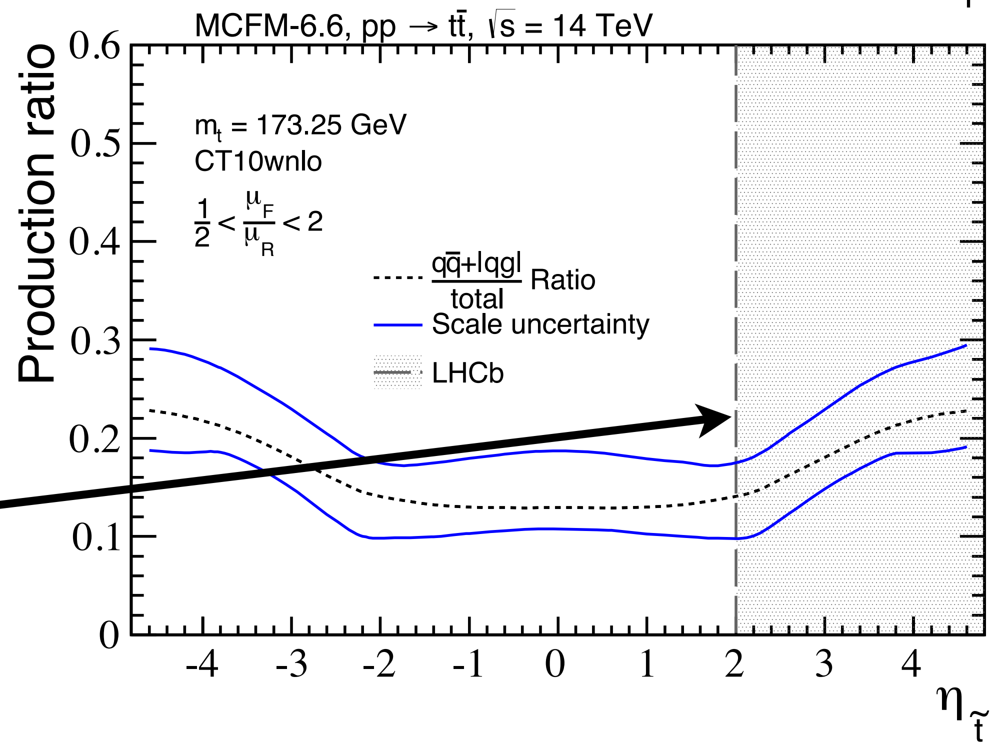
$$\sigma^{\rm LHCb} = \int_{\eta=2} \frac{d\sigma^{\tilde{t}}}{d\eta}$$



Production mechanism ratio:

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

LHCb probes unique region

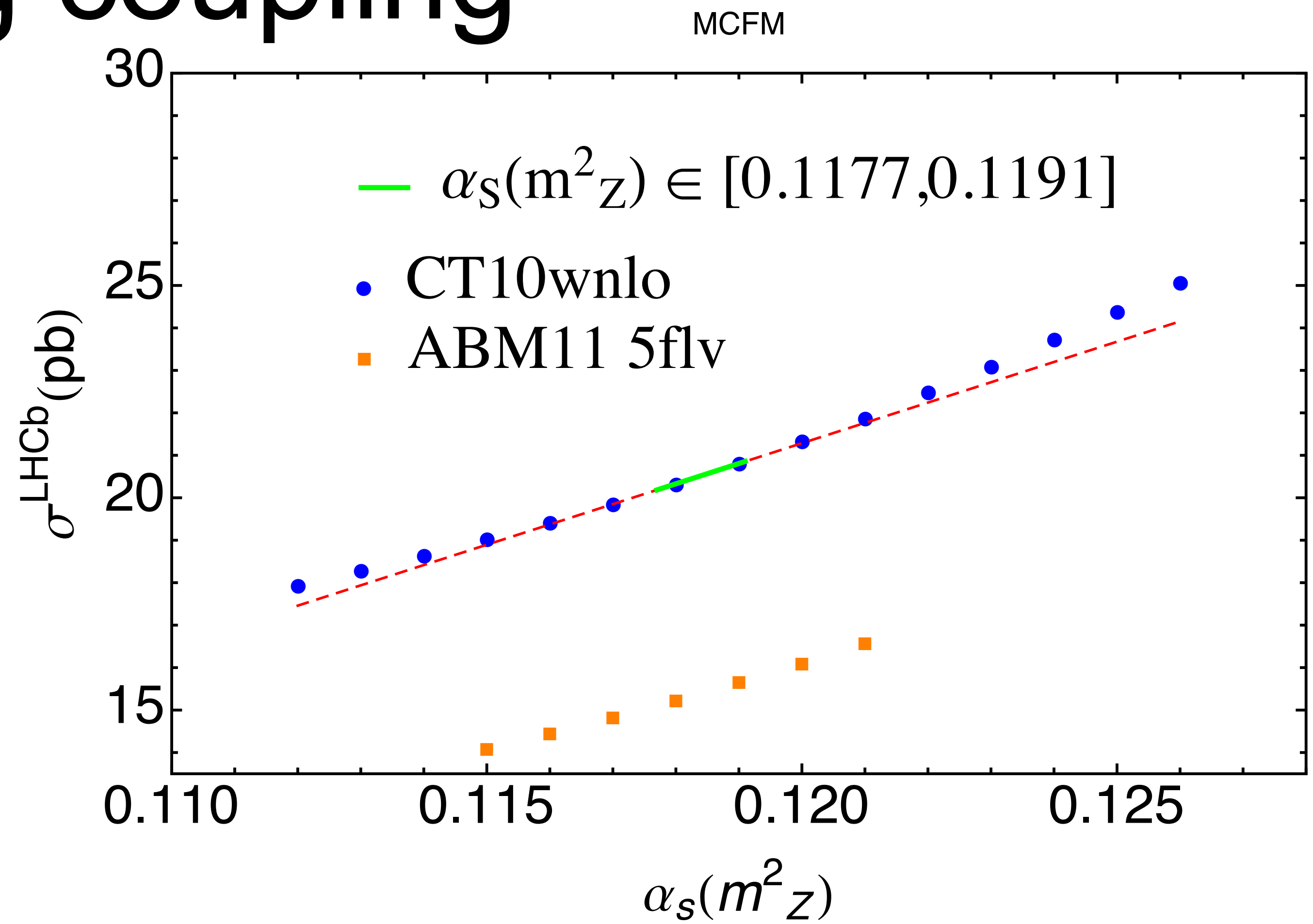


strong coupling

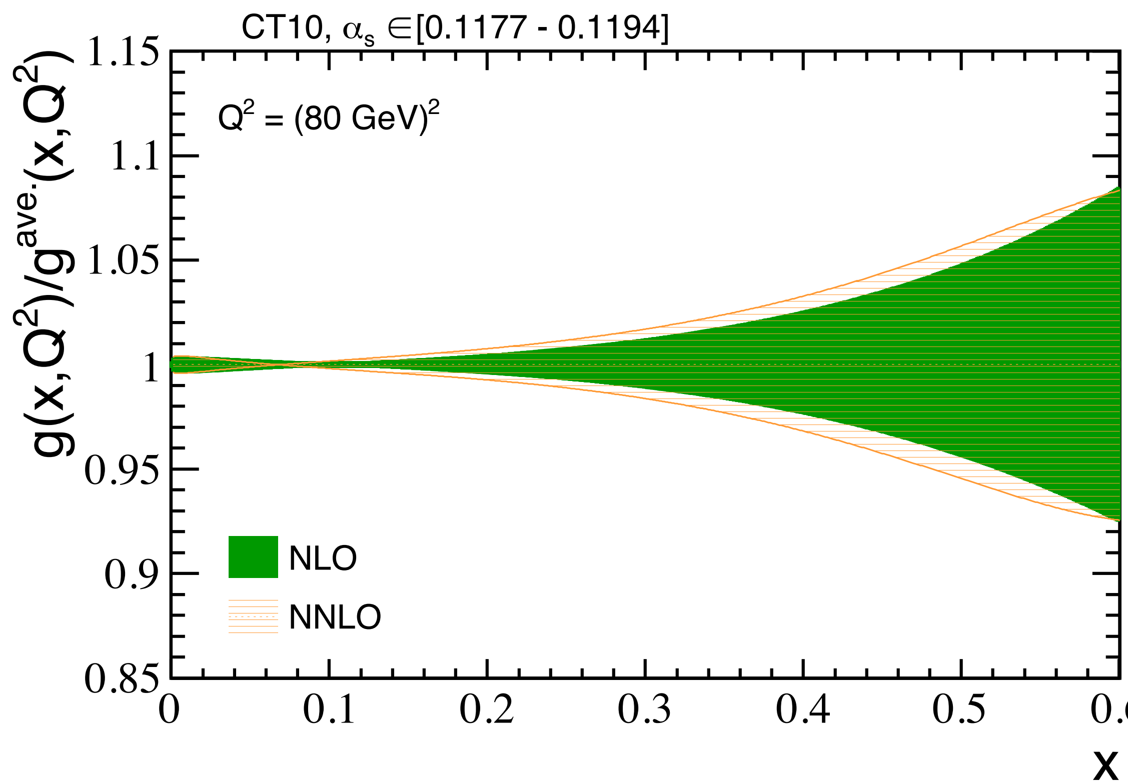
σ^{LHCb} vs. $\alpha_s(M_Z)$

Current PDG value

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



gluon PDF uncertainty for $\delta\alpha_s$

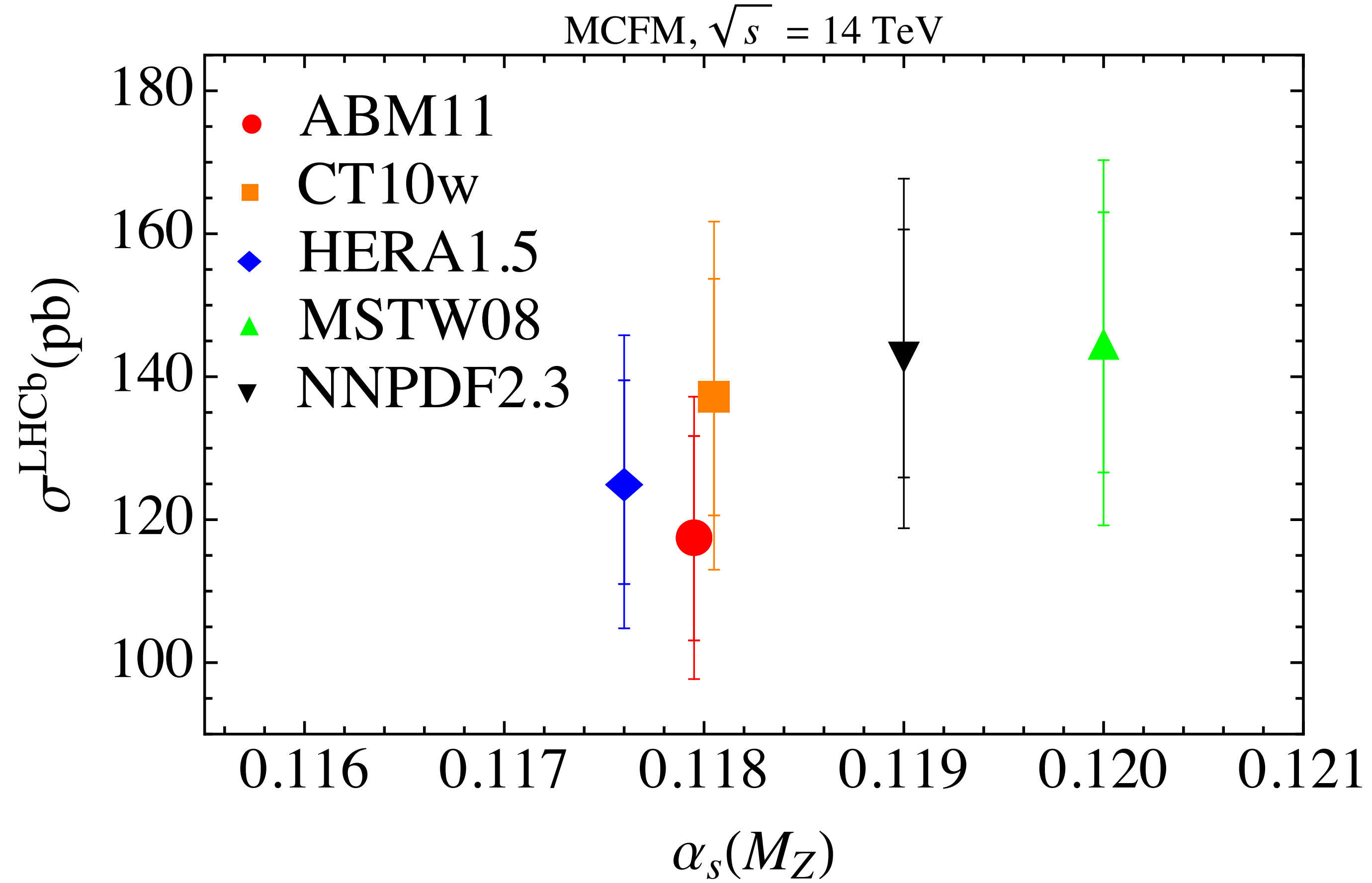


$$\delta\alpha_s \rightarrow \delta\sigma^{\mathrm{LHCb}} = 1.3\%$$

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 theory systematics (NLO)

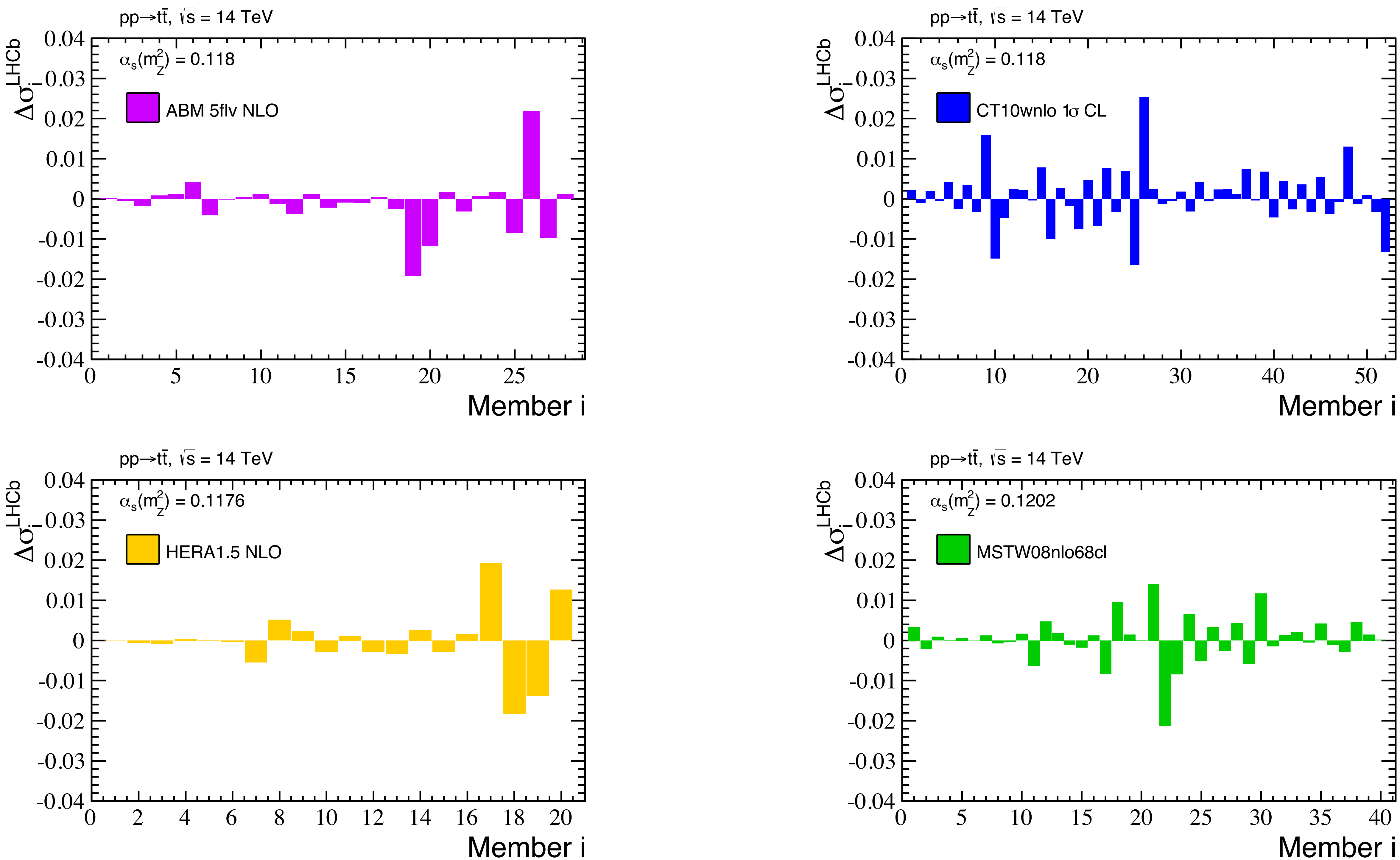
$$\delta_{\text{total}} = \delta_{\text{scale}} + (\delta^2_{\text{PDF}} + \delta^2_{\alpha_s} + \delta^2_{m_t})^{\frac{1}{2}}$$



$$\delta_X^{\text{ratio}} = \frac{\delta_X^{\text{LHCb}}}{\delta_X^{NLO}}$$

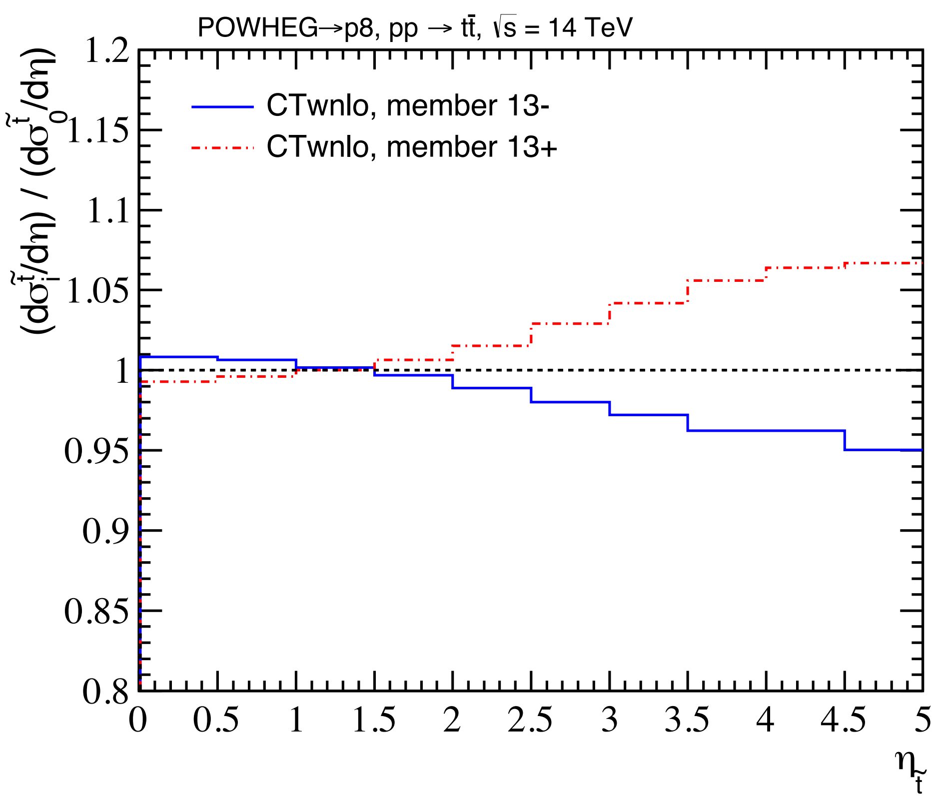
PDF	$\delta^{\text{ratio}}_{\text{scale}}$	$\delta^{\text{ratio}}_{\text{PDF}}$	$\delta^{\text{ratio}}_{\alpha_s}$	$\delta^{\text{ratio}}_{m_t}$	$\delta^{\text{ratio}}_{\text{total}}$
ABM	$^{+1.05}_{-1.00}$	$^{+1.40}_{-1.40}$	$^{+0.00}_{-0.00}$	$^{+1.05}_{-1.05}$	$^{+1.06}_{-1.02}$
CT10	$^{+1.05}_{-1.03}$	$^{+1.55}_{-1.40}$	$^{+1.20}_{-1.20}$	$^{+1.06}_{-1.05}$	$^{+1.09}_{-1.07}$
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	$^{+1.05}_{-1.03}$	$^{+1.45}_{-1.45}$	$^{+1.27}_{-1.27}$	$^{+1.07}_{-1.07}$	$^{+1.07}_{-1.06}$

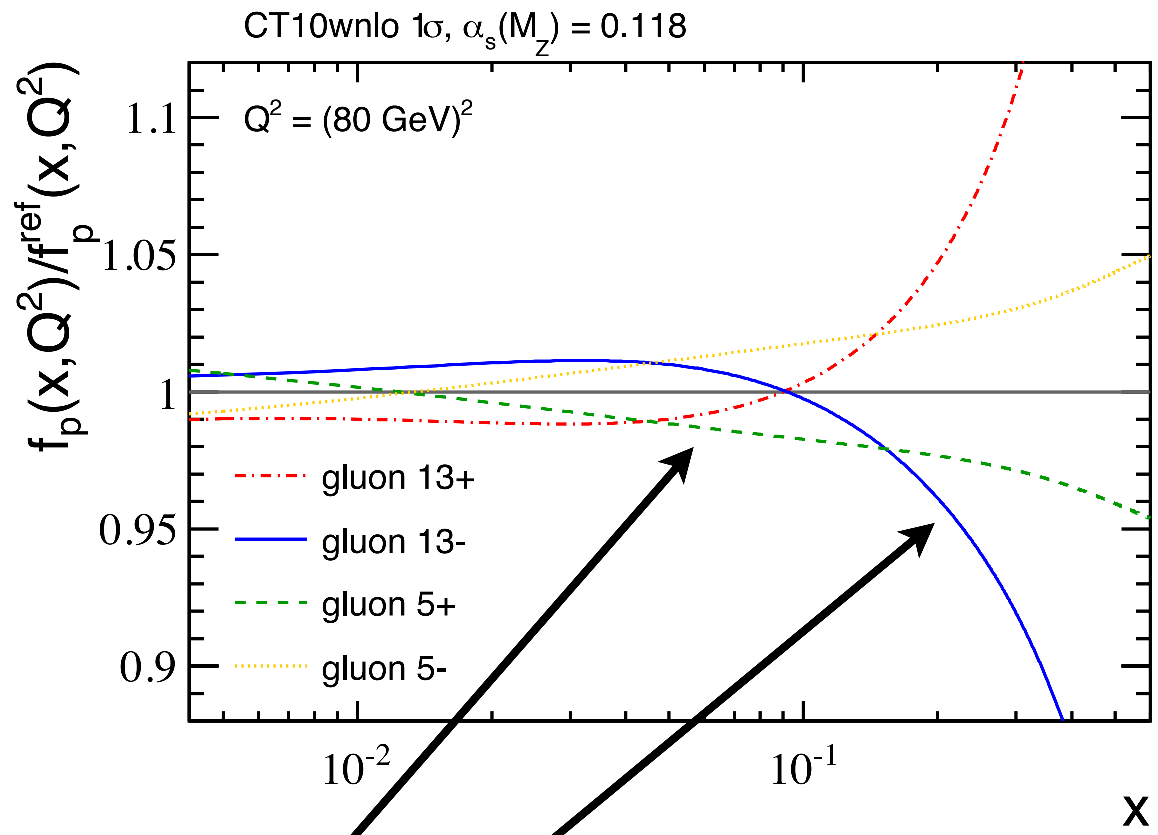
Summary of eigenvector sensitivity



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

Effect of LHCb analysis cuts

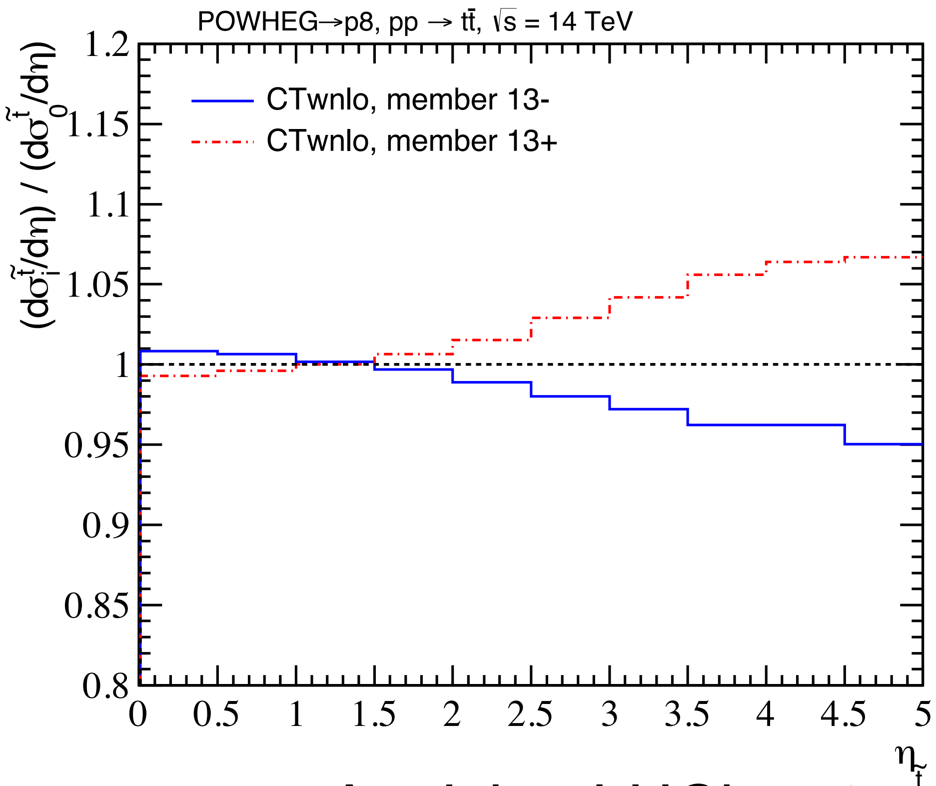




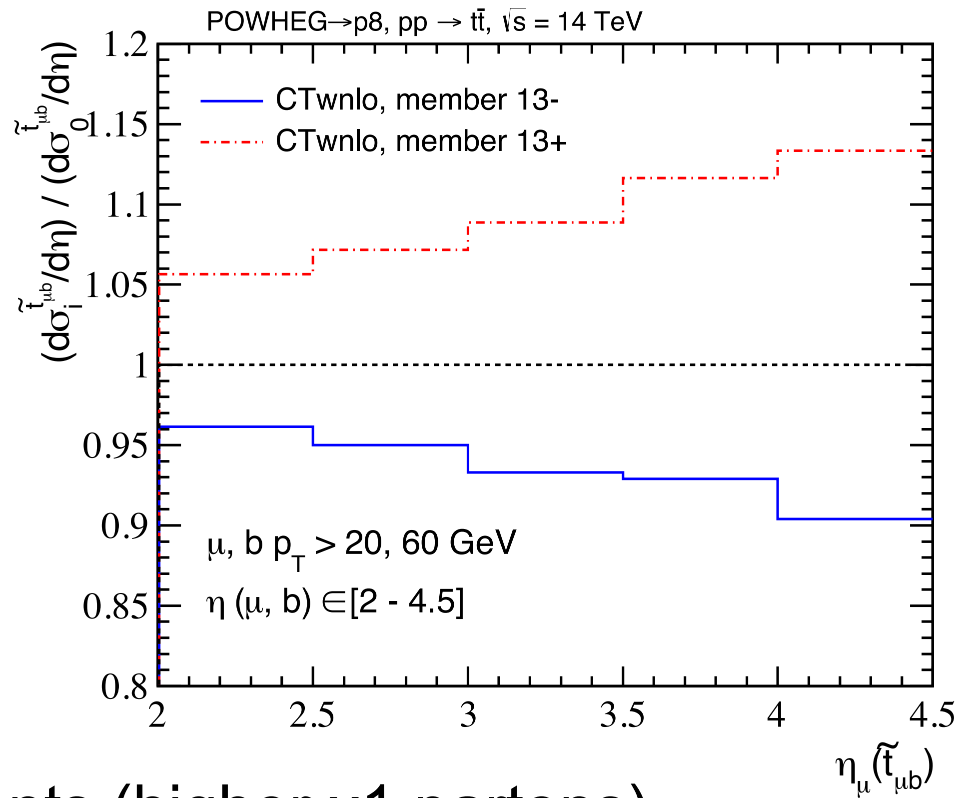
Central production, x < 0.1

Forward production, x > 0.1

Effect of LHCb analysis cuts

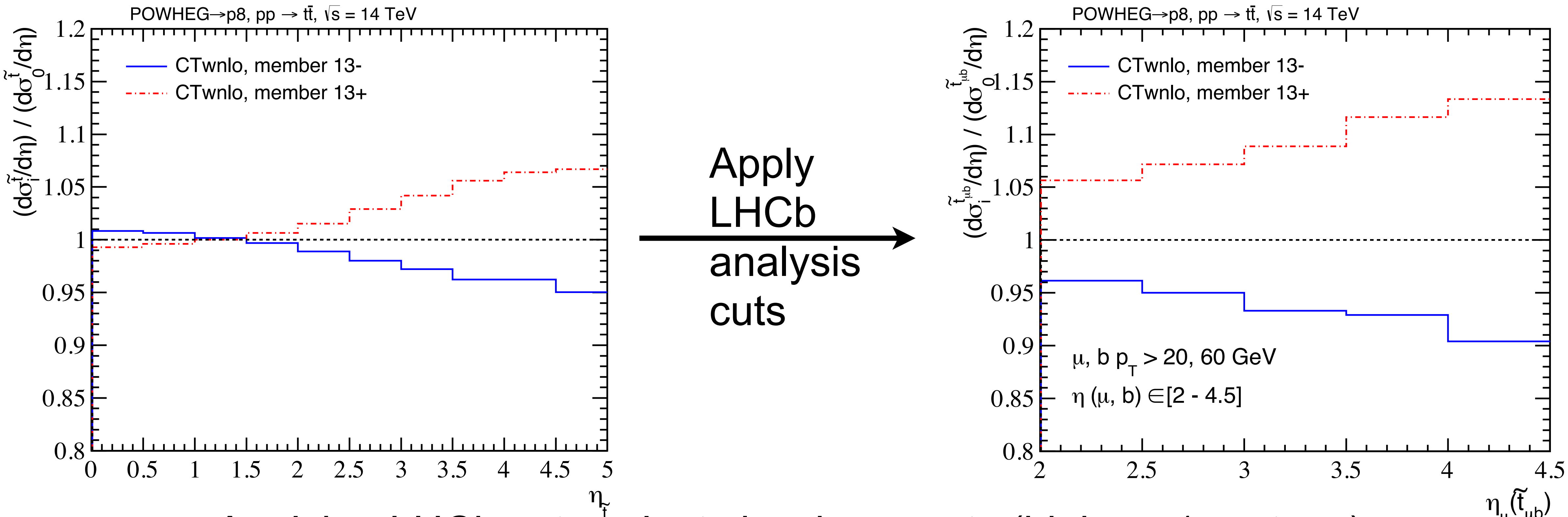


Apply LHCb analysis cuts

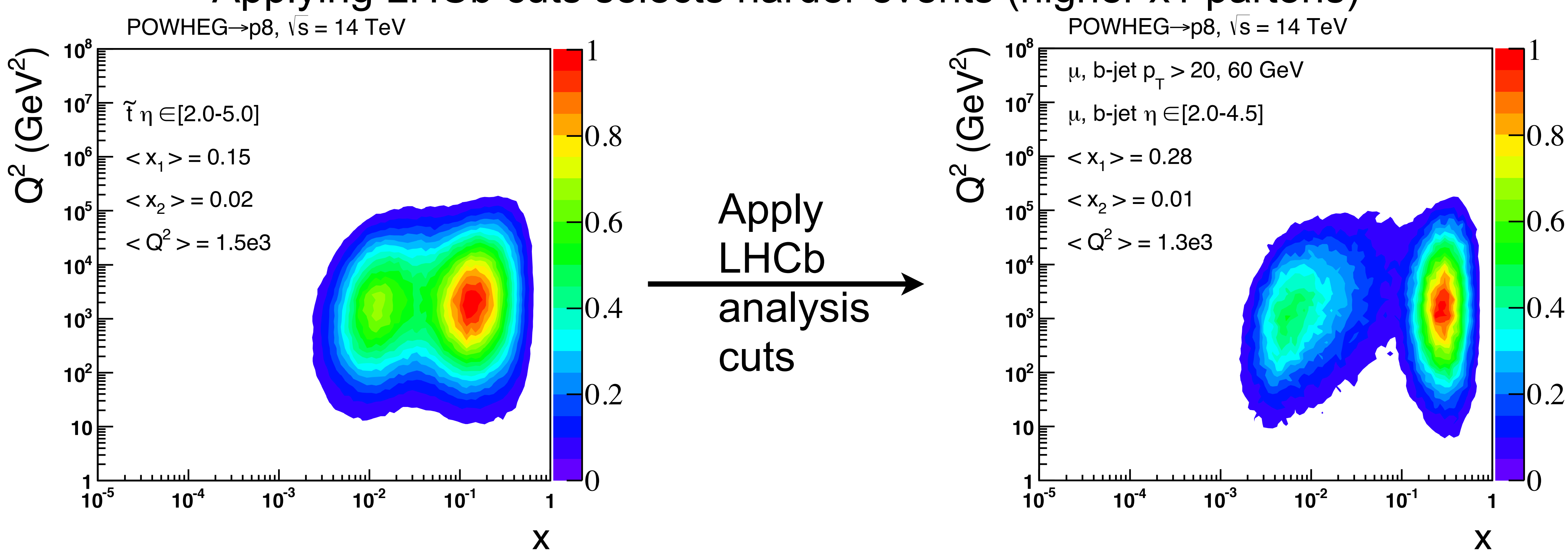


Applying LHCb cuts selects harder events (higher x1 partons)

A few more comments



Applying LHCb cuts selects harder events (higher x1 partons)



LHC 8TeV Asym Systematics

CMS-PAS-TOP 12 033
8TeV

Systematic uncertainty	shift in inclusive A_C	range of shifts in differential A_C
JES	0.001	0.001 – 0.005
JER	0.001	0.001 – 0.005
Pileup	0.001	0.000 – 0.003
b tagging	0.000	0.001 – 0.003
Lepton ID/sel. efficiency	0.002	0.001 – 0.003
Generator	0.003	0.001 – 0.015
Hadronization	0.000	0.000 – 0.016
p_T weighting	0.001	0.000 – 0.003
Q^2 scale	0.003	0.000 – 0.009
W+jets	0.002	0.001 – 0.007
Multijet	0.001	0.002 – 0.009
PDF	0.001	0.001 – 0.003
Unfolding	0.002	0.001 – 0.004
Total	0.006	0.007 – 0.022