Top Quark Physics at Hadron Colliders (focussing on the forward region)

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thanks to Ulrich Haisch

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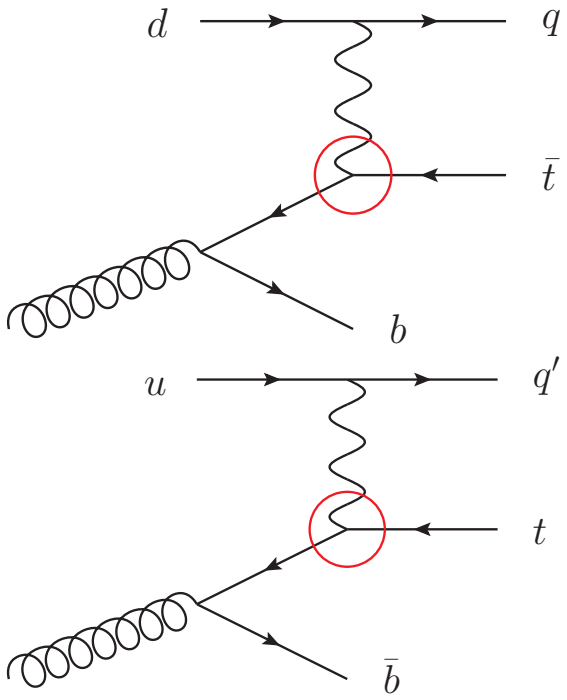
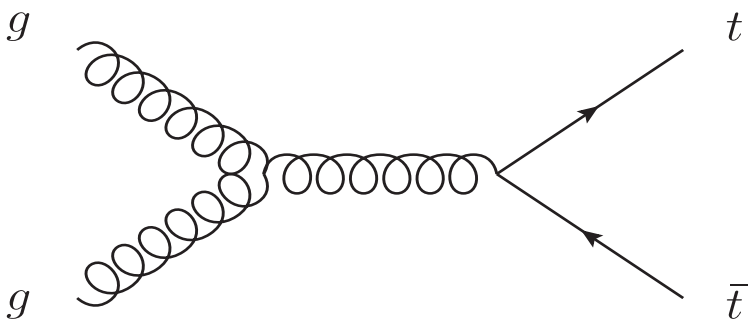
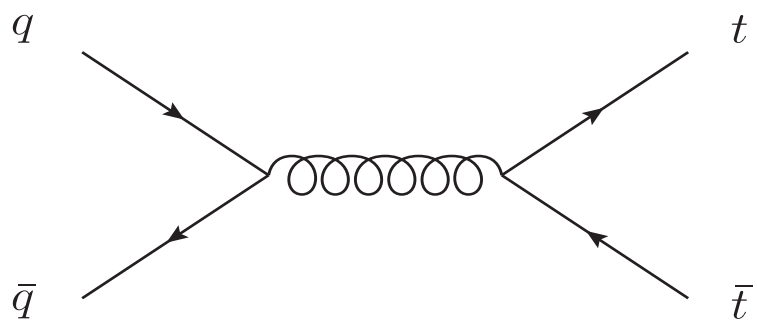
Why Study Top Quarks?

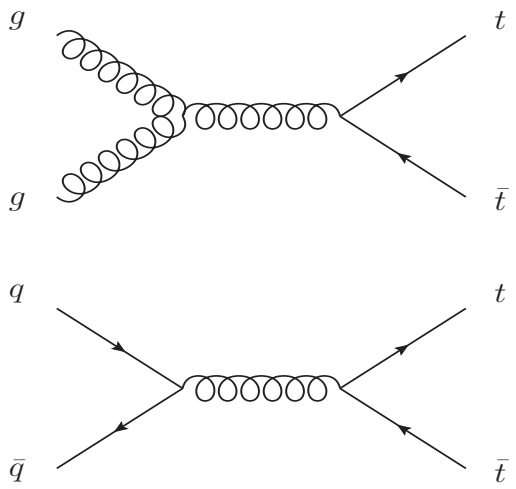
- $m_t \approx 173 GeV$ (important for loops)
- $\Gamma_t \approx G_F m_t^3 \approx 10 GeV$ (unstable)
- $\Gamma_t \gg \Lambda_{QCD}$ (weak decays, spin info.)
- $V_{tb} \cong 1$?, no top mesons
- PDF information of high-x gluons
- Test of perturbative QCD







$t\bar{t}$ pair production at Hadron Colliders



Contribution to $\sigma_{inc.}$ (pb)

TeV2 ($p\bar{p}$)	LHC7	LHC14
1(14%)	130(81%)	820(91%)

TeV2 ($p\bar{p}$)	LHC7	LHC14
6(86%)	30(19%)	80(9%)

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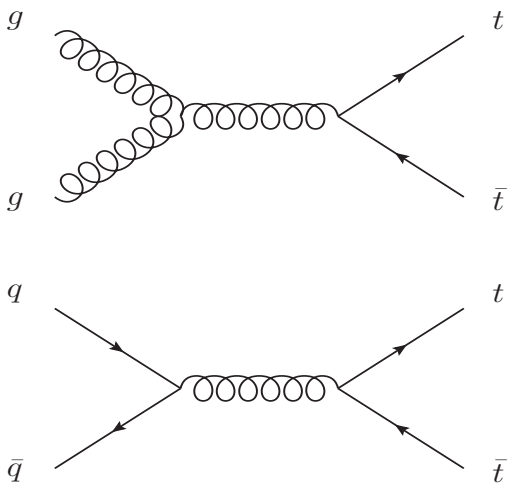

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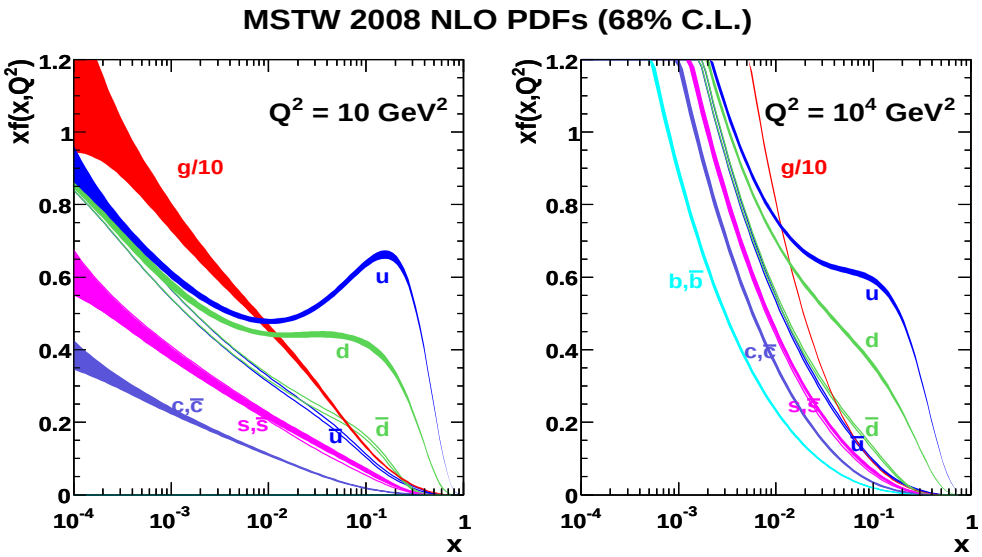
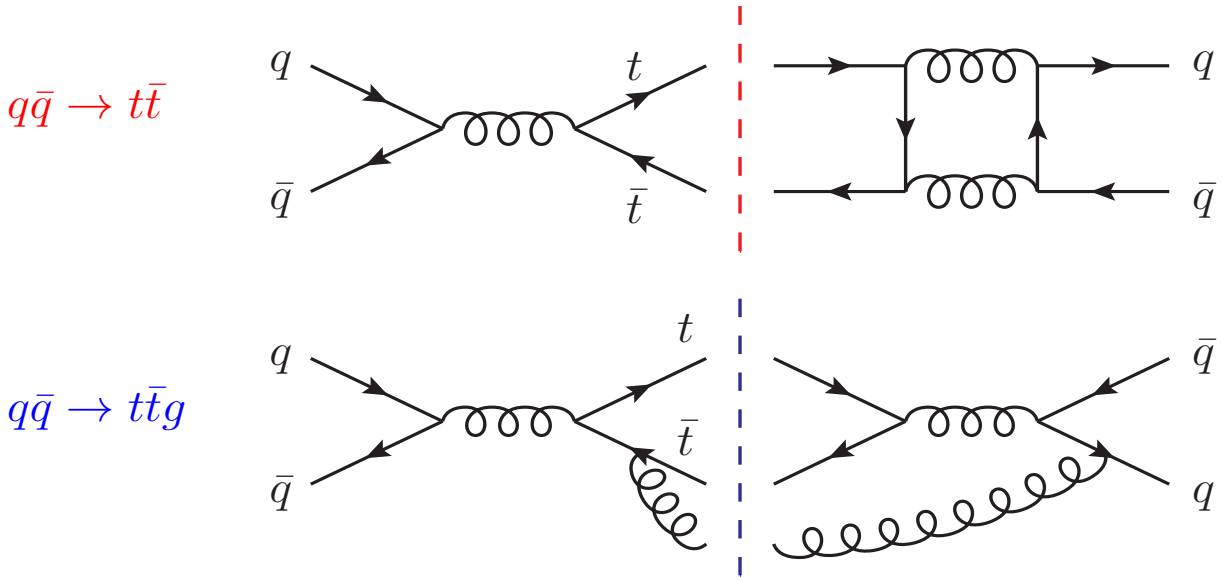


Working point - $m_t \approx 173 GeV$

@1TeV - x = 0.2
@3.5TeV - x = 0.05
@7TeV - x = 0.025

$t\bar{t}$ asymmetry @NLO

Why is there an asymmetry at all? $g \to q\bar{q}$ vector coupling

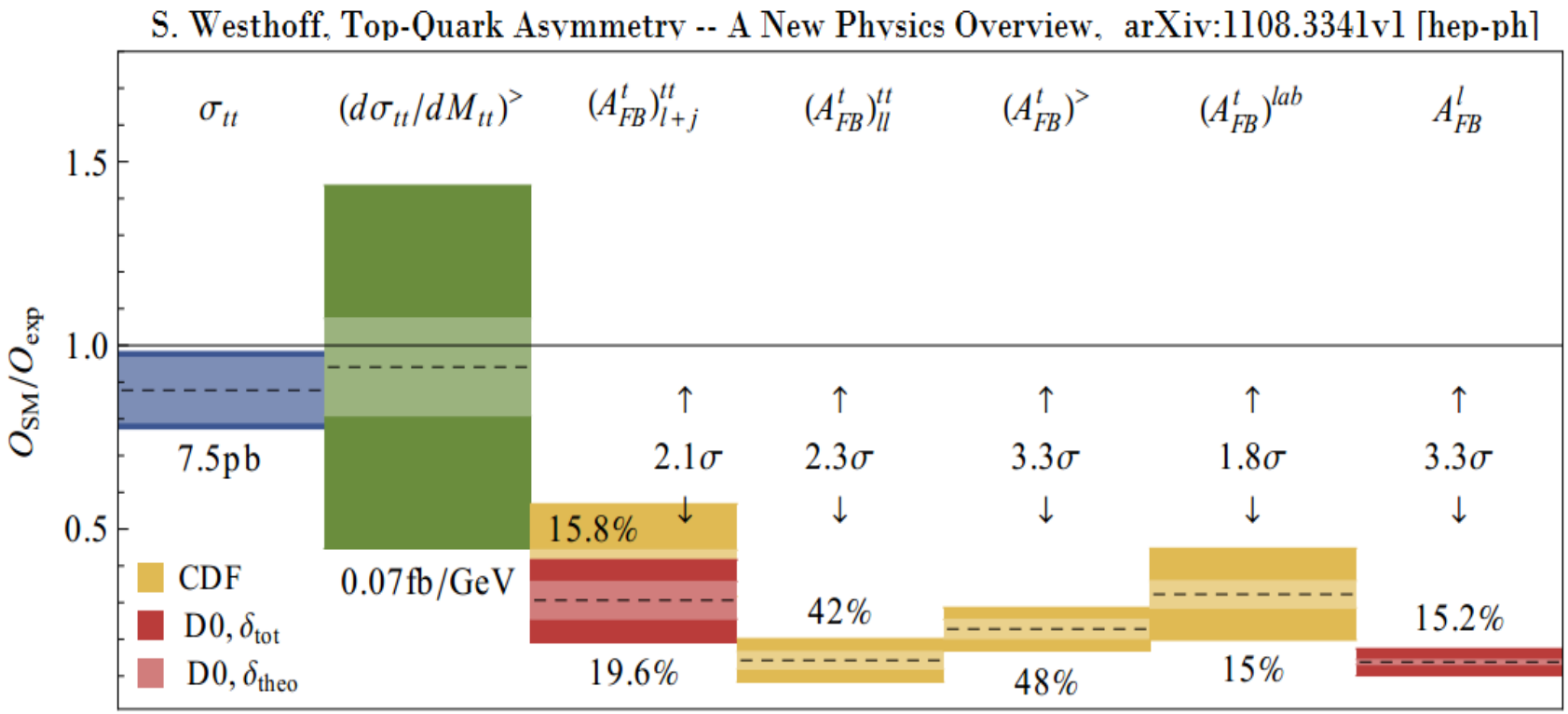


Blue (Real), Red (Virtual). Asymmetric under $\mathcal{C}(t\bar{t})$

- Results in a 'colour charge repulsion', q $\Rightarrow$ t
- Forward-backward asymmetry at TeVatron
- Charge asymmetry at LHC (symmetric initial state)

TeVatron Results

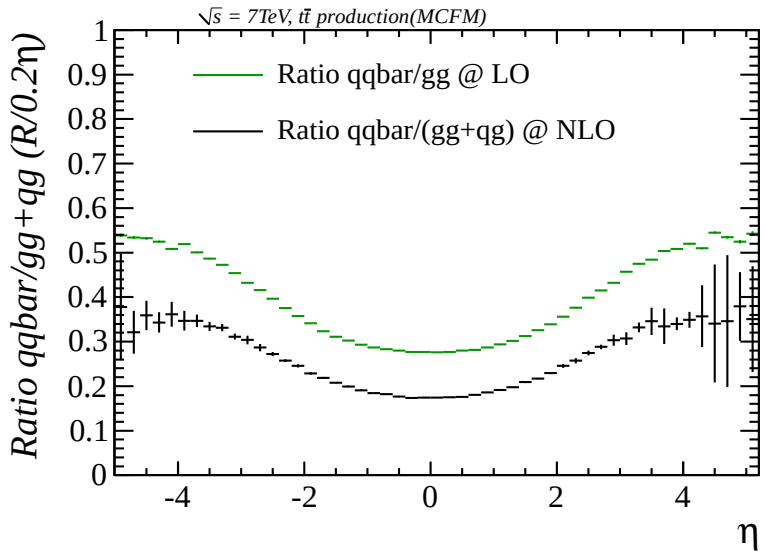
SM Asymmetry predicition @NLO (with EW) $\approx 6\%$[1]



- Inclusive cross-section consistent with SM
- Invariant mass distribution consistent with SM

Asymmetry at the LHC?

- Symmetric initial state
- Production mechanisms η dependent
- $\Uparrow$Asymmetry with $\Uparrow \eta$
- $\Downarrow$Events with $\Uparrow \eta$



Propose an indirect measurement

$$A_\eta^t = \left(\frac{N^{l^+} - N^{l^-}}{N^{l^+} + N^{l^-}} \right)_{\eta \in 2-5}$$

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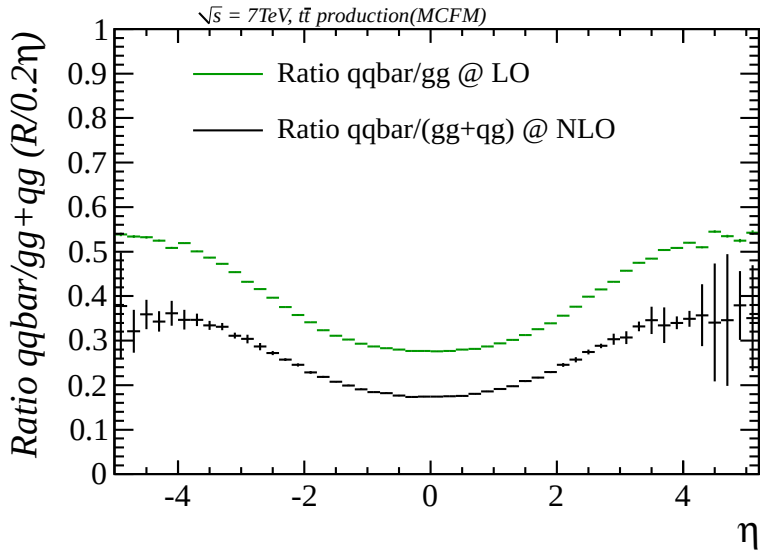
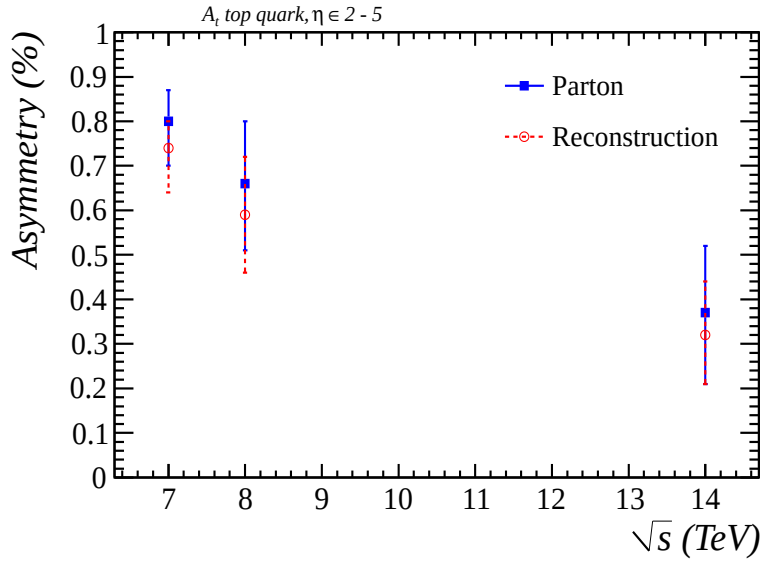




Case Study, lb at 7TeV

Backgrounds generated in MadGraph. Scaled to match results/NLO
Differentiate between l^- / l^+ backgrounds. $\frac{\partial\sigma}{\partial\eta}$(pb), $\eta \in$ 2-5

Channel	$l^{\pm}/j,b\ \ p_T > 20/30 GeV$	$l^{\pm}/j,b\ \ p_T > 20/50 GeV$
l^-b/l^+b	0.42 / 0.44	0.30 / 0.36
W^-j/W^+j	86 / 151	24 / 46
W^-b/W^+b	0.23 / 0.37	0.05 / 0.08
$\bar{t}/t$	0.11 / 0.41	0.10 / 0.34
$tW(l^-/l^+)$	0.03 / 0.03	0.03 / 0.03
Zj	8.1 / 8.1	2.7 / 2.7
Zb	0.15 / 0.15	0.04 / 0.04

- Very asymmetric backgrounds. A_η^t measurement unlikely
- Single top measurement possible!

References

[1] J.H. Kuhn, G. Rodrigo, arXiv:hep-ph/9807420v1 [hep-ph]

S. Westhoff, arXiv:1108.3341v1 [hep-ph]

A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, MSTW, arXiv:0901.0002v3 [hep-ph]

S. Frixione, P. Nason and G. Ridolfi, *Heavy-quark pair production*, arXiv:0707.3088v3 [hep-ph]

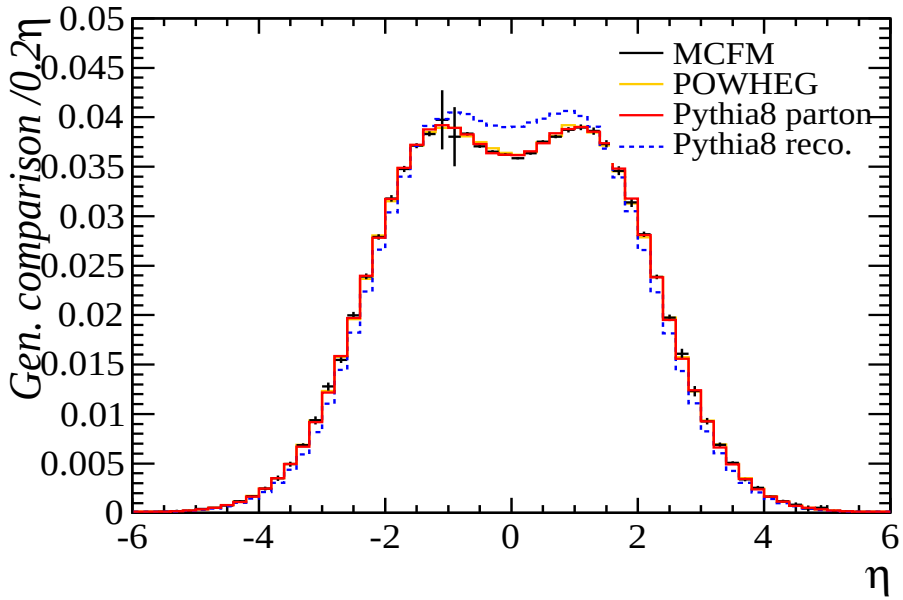
J. M. Campbell, R. K. Ellis, *MCFM for the Tevatron and the LHC*, arXiv:1007.3492v1 [hep-ph]

J. Alwall et al., MG5, *MadGraph 5:Going Beyond*, arXiv:1106.0522v1 [hep-ph]

T. Sjostrand, S. Mrenna, P. Skands, *PYTHIA 8.1*, arXiv:0710.3820v1 [hep-ph]

Event generation

$qg \to t\bar{t}$ production and $q\bar{q} \to t\bar{t}$ asymmetry are present at NLO
At 7TeV, Pythia8 (LO) $\sigma_{t\bar{t}} = 94pb$ vs. ATLAS/CMS $\sigma_{t\bar{t}} \approx 160pb$



- PYTHIA8(CTEQ6l) vs. POWHEG, MCFM (MSTWNLO0868cl)
- PYTHIA8 $q\bar{q}$,$gg \to gg + qg$ scaled separately to MCFM result
- Discrepancy due to parton shower effects

Decay Channels

Forward detector has limited acceptance (LHCb)
$\Rightarrow$ Full reconstruction difficult

$$t\bar{t} \rightarrow W^+ b W^- \bar{b}$$

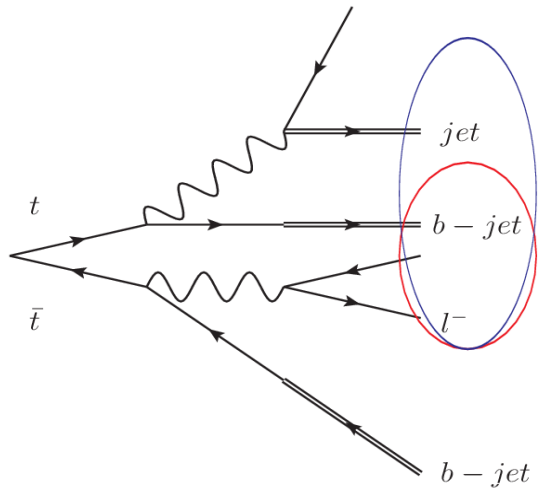
1. Tag 1 charged lepton + x jets + y b-jets (y$\geq$1)
2. Tag 2 oppositely charged leptons

e.g. $l^- b$ or $l^- bj$

jets required to reduce backgrounds

jet charge not required

lepton charge $\rightarrow$ top charge

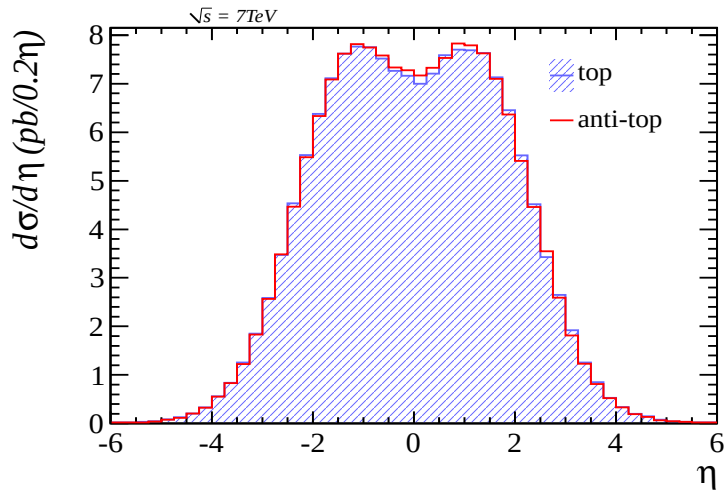


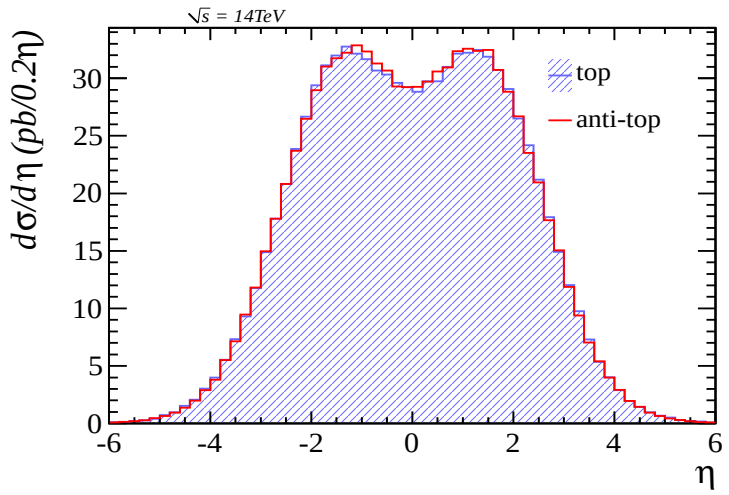
Results $t\bar{t}$ ($\eta \in 2-5$)

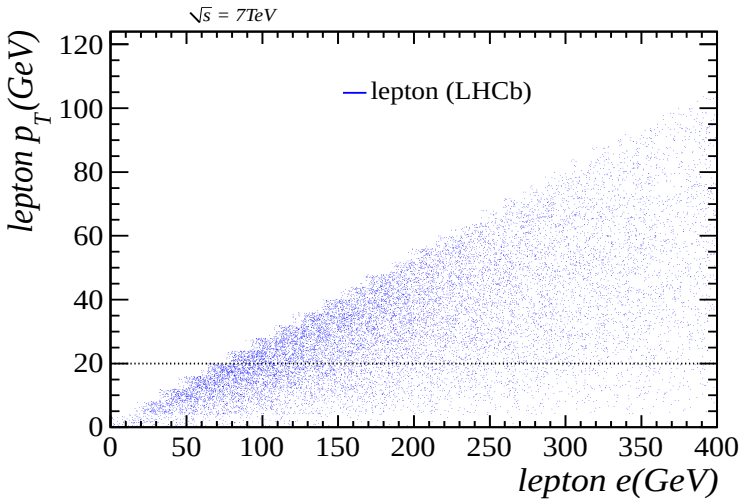
Number of events expected in $1(fb)^{-1}$ before cuts / detector effects

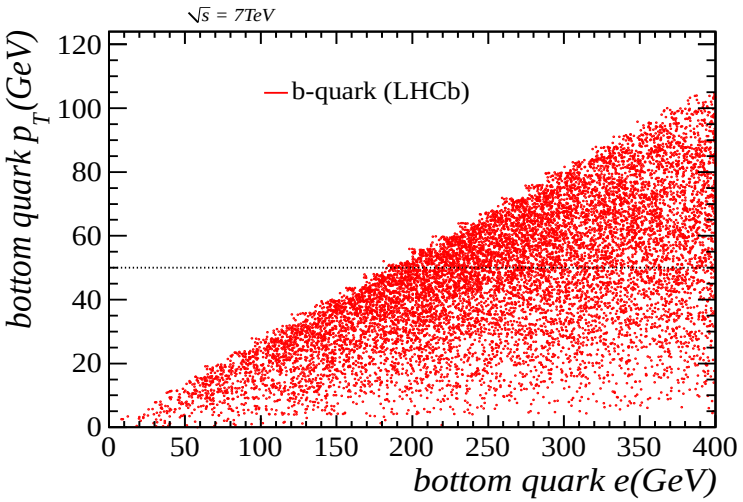
Channel	7TeV	8TeV	14 TeV
lb	1398±277	2503±357	18643±2437
lbj	340±87	729±102	8092±1007
$lbjj$	48±15	121±20	2036±249
lbb	138±24	285±35	3139±377
$lbbj$	44±13	111±13	1852±217
$lbbjj$	7±3	20±3	515±65
l^+l^-	56±11	100±12	761±65
l^+l^-b	24±8	52±9	535±64

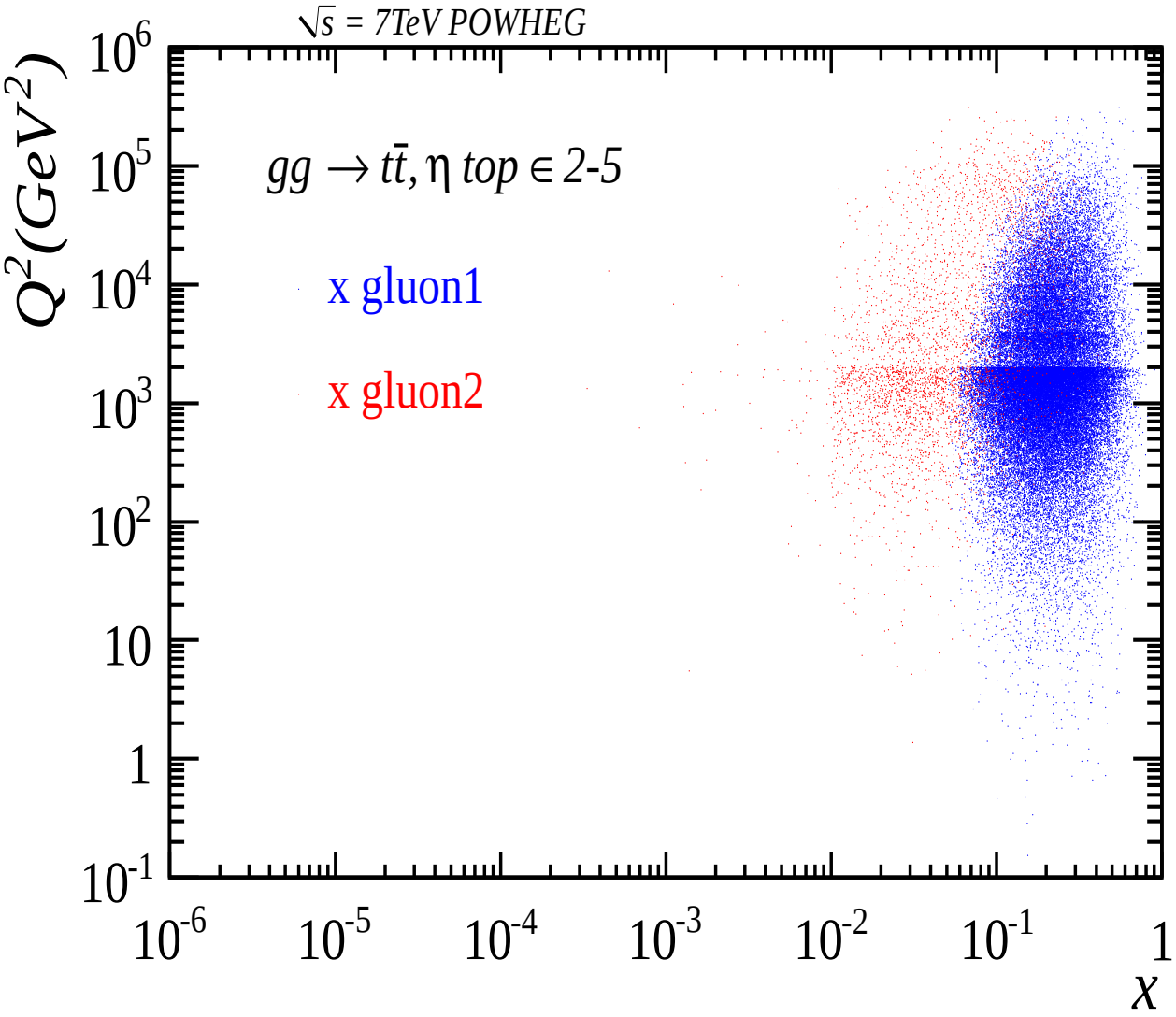
Uncertainty; systematic due to scale, PDF and stat. for $1(fb)^{-1}$
Corresponds to $\sigma_{t\bar{t}} \approx 160, 220, 900$pb for 7, 8, 14 TeV respectively


√s = 7TeV
dσ/dη (pb/0.2η)
top
anti-top
η


√s = 14TeV
dσ/dη (pb/0.2η)
top
anti-top
η

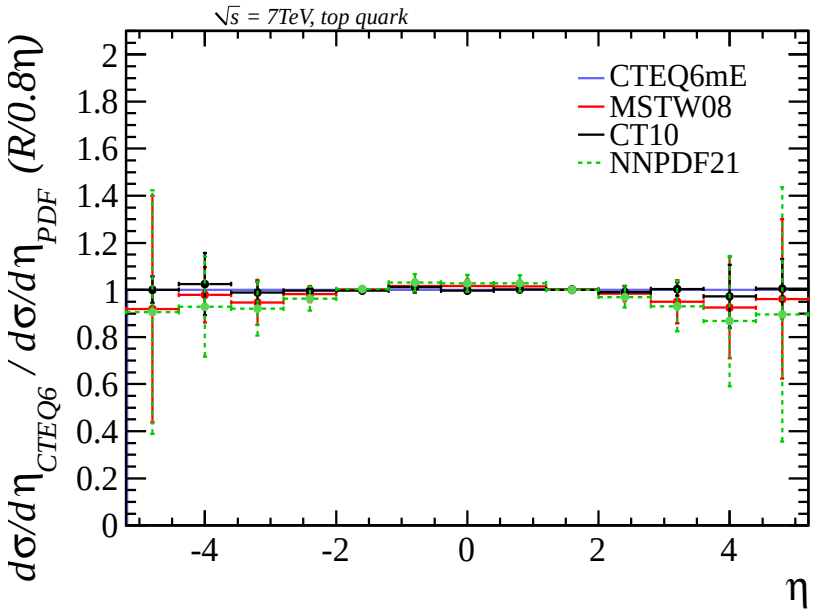

√s = 7TeV
lepton (LHCb)
lepton p_T(GeV)
lepton e(GeV)

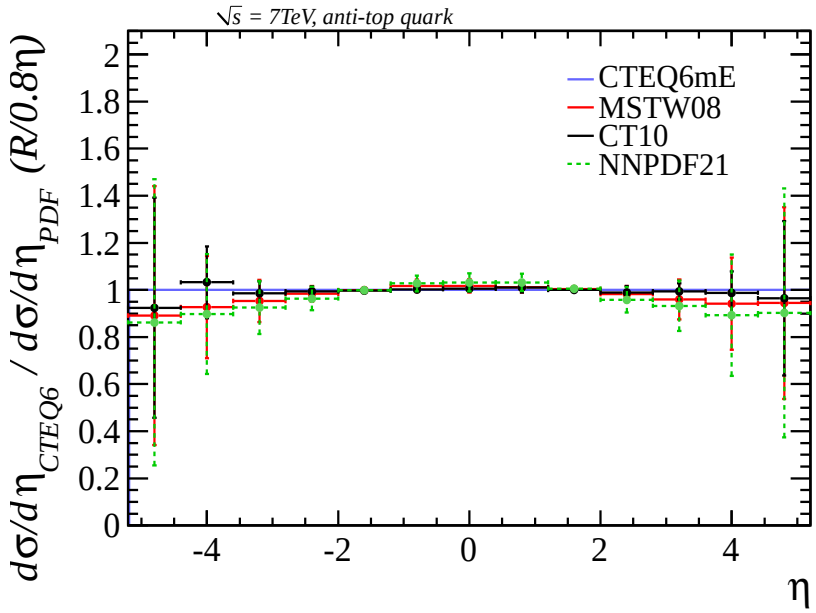

√s = 7TeV
b-quark (LHCb)
bottom quark p_T(GeV)
bottom quark e(GeV)


$\sqrt{s}$ = 7TeV POWHEG
$gg \to t\bar{t}, \eta\ top \in$ 2-5
x gluon1
x gluon2
$Q^2(GeV^2)$
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

PDF Variation

POWHEG used to generate events and compare PDF, Scale variation

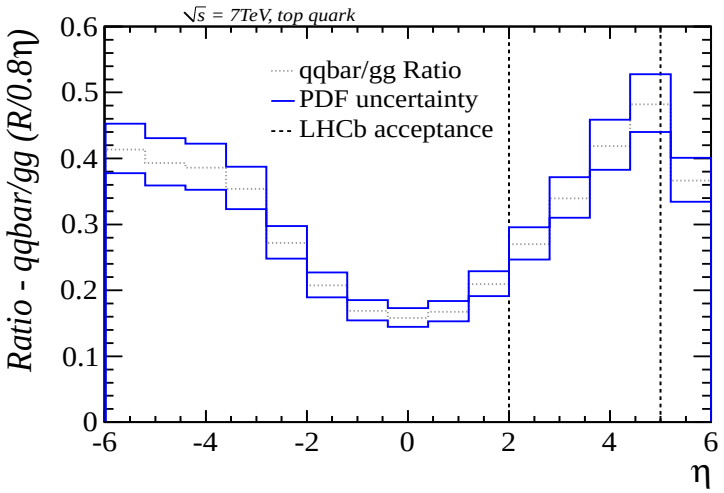


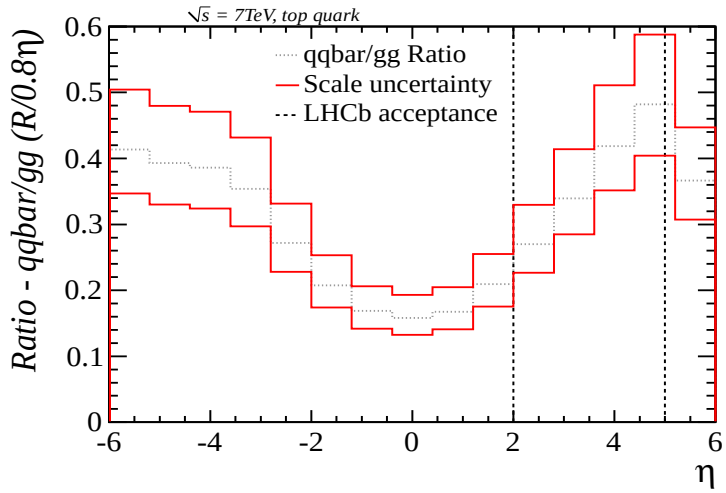


- CT10, NNPDF2.1, MSTW08 NLO PDF sets used
- PDF uncertainty $\approx 6\%$
- Largest PDF uncertainty on gg process (next section)

Production ratio

Asymmetry signal therfore related to ratio; $\frac{q\bar{q}}{gg+qg}$

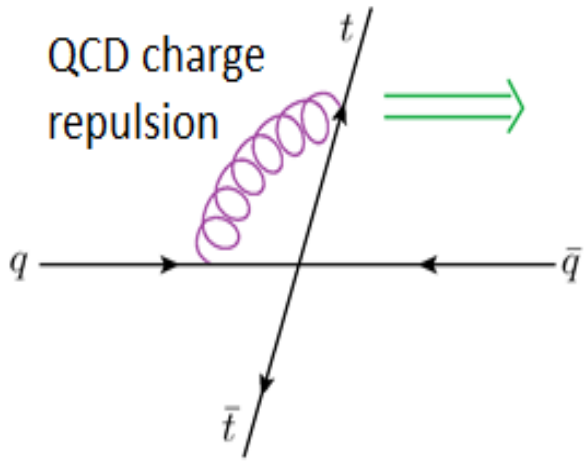




PDF uncertainty from using central CT10, NN2.1 and MSTW08
Scale uncertainty from independently varying μ_F, μ_R by $2^{\pm 1}$
PDF error coming from $gg + qg$ contribution (high-x gluon)
Scale uncertainty from $gg + qg$ contribution (not converged at NLO)

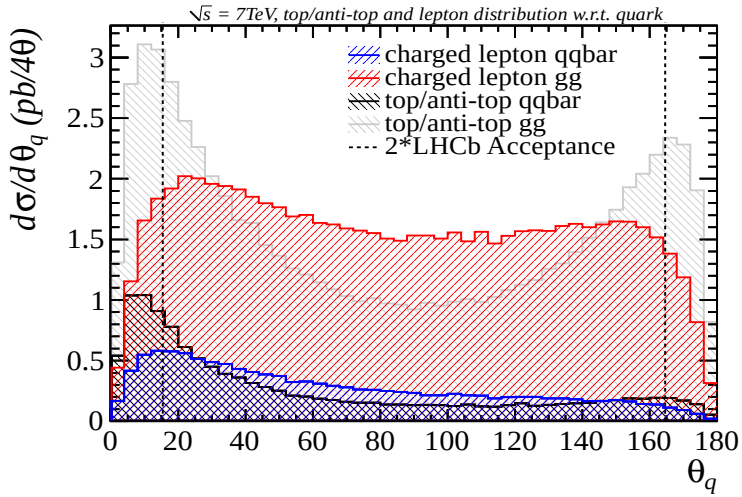
Dilution($q\bar{q}$)

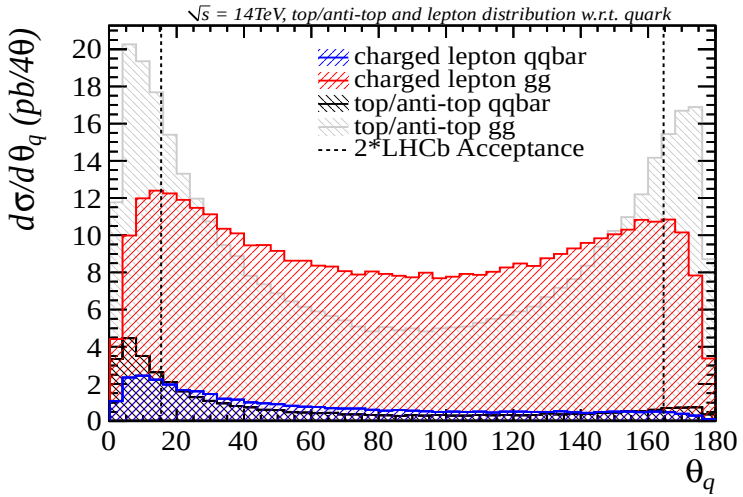
Charge asymmetry repulses t from q direction
At a proton collider; generally $P_z(q) > P_z(\bar{q})$



$$D = \frac{N_f - N_b}{N_f + N_b}$$

N_f - forward w.r.t. quark direction





$D_t = 0.73$ at 7TeV. $D_t = 0.70$ at 14TeV (Bjorken Scaling)
Also, symmetric contribution (stacked) from gg increases with $\sqrt{s}$