Single-top cross-section and properties measurements in ATLAS

LHCP 2016 - Lund

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On behalf of
The ATLAS Collaboration

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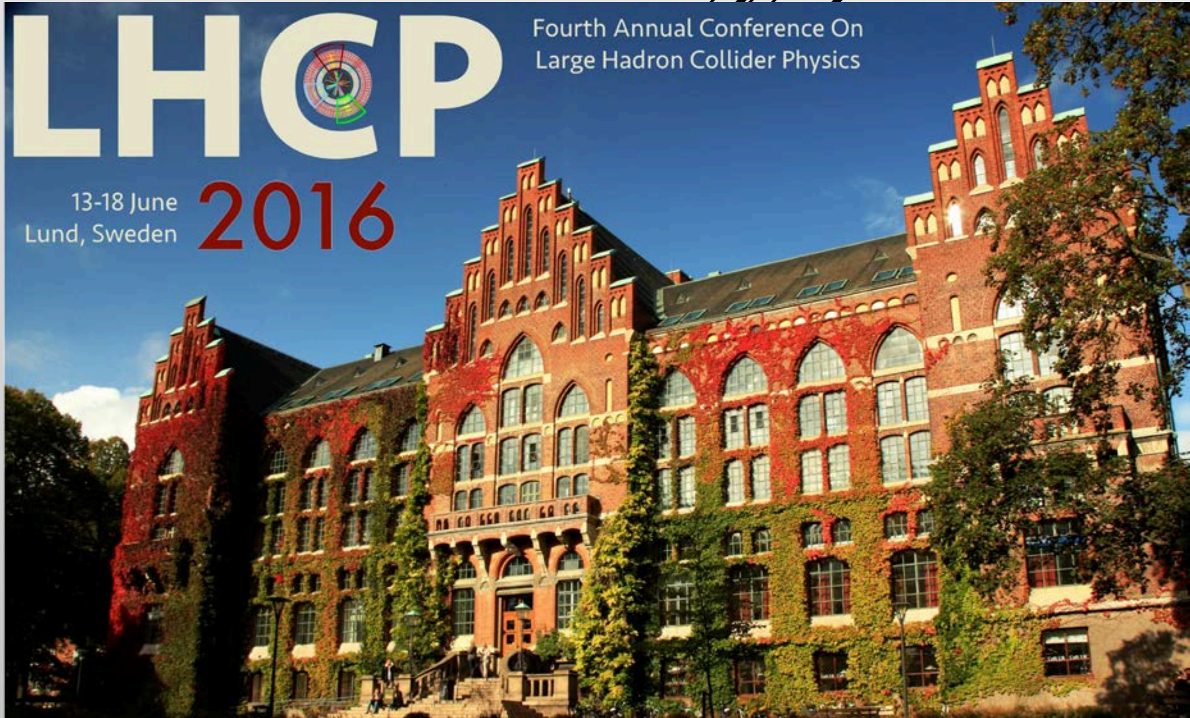
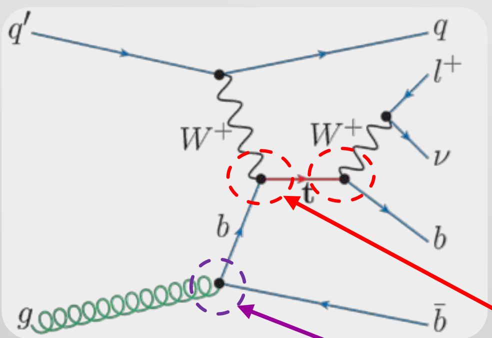


Single Top-Quarks

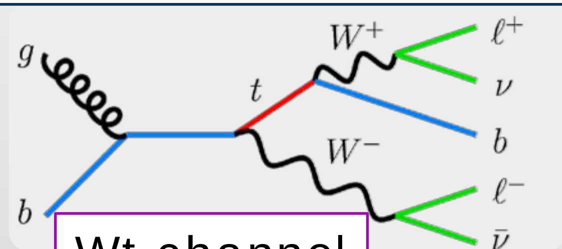
Production via three distinct channels

- Single top-quarks are produced via the weak interaction
- t-channel production is the dominant mode, the associated Wt and s-channel contibute about 1/3 of the combined cross-section



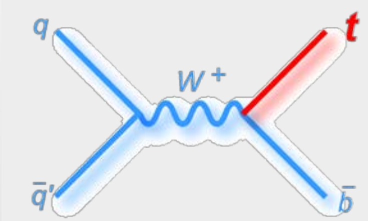
t-channel

7 TeV: $\sigma^{NLO}_{t-ch.} = 63.9^{+2.9}_{-2.5}$ pb
8 TeV: $\sigma^{NLO}_{t-ch.} = 84.7^{+3.8}_{-3.2}$ pb
13 TeV: $\sigma^{NLO}_{t-ch.} = 217^{+9.0}_{-7.7}$ pb
arXiv:1406.4403



Wt-channel

8 TeV: $\sigma^{NLO+NNLL}_{Wt-ch.} = 22.4 \pm 1.5$ pb
PRD83(2011) 091503



s-channel

8 TeV: $\sigma^{NLO}_{s-ch.} = 5.2^{+3.8}_{-3.2}$ pb
arXiv:1406.4403

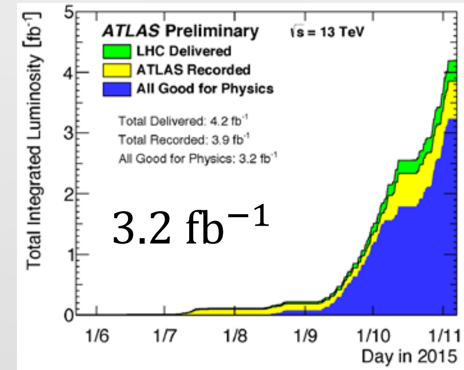
Intriguing features

- Sensitive to the CKM matrix element $|V_{tb}|$
- Probe W-t-b vertex
- Treatment of *b*-Quarks in the initial state in MC generators / calculations
  - 4-,5-flavour-schemes
- σ_t sensitive to PDFs, *b*-quark PDF, ratio of *u*- to *d*-quark PDF

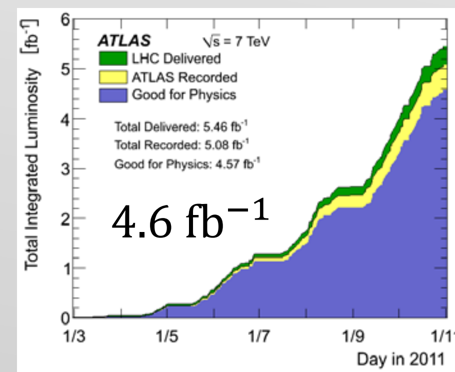
Outline

- t-channel cross-section
- Anomalous couplings
- FCNC
- Wt cross-section
- s-channel cross-section
- Summary&Prospects

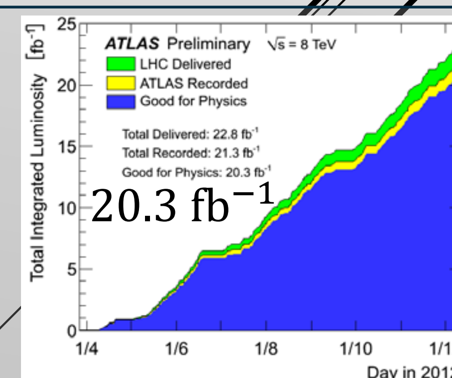
13 TeV



7 TeV



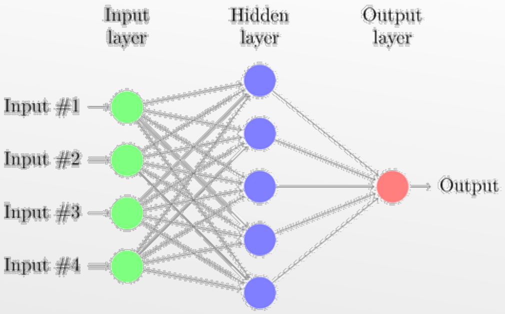
8 TeV

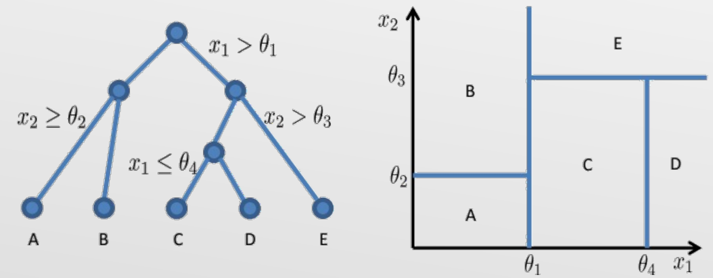


Multivariate Techniques

Multiy Variate Analysis(MVA)

- Almost all presented single-top quark analysis employ MVAs to increase sensitivity
- Reduce systematic dependence by averaging
- Three distinct MVA methods are used:
  Artificial Neural Networks(**NN**)
  Boosted Decision Trees(**BDT**)
  Matrix Element Method(**MEM**)





NN

- Several discriminating observables are linearly combined a single discriminant

BDT

- Consecutive cuts on several discriminating observables are optimized iteratively, a single discriminant is obtained

MEM

- An event-by-event calculation yields a probability to originate from a given process
- Likelihood ratios are used to derive discriminant distributions

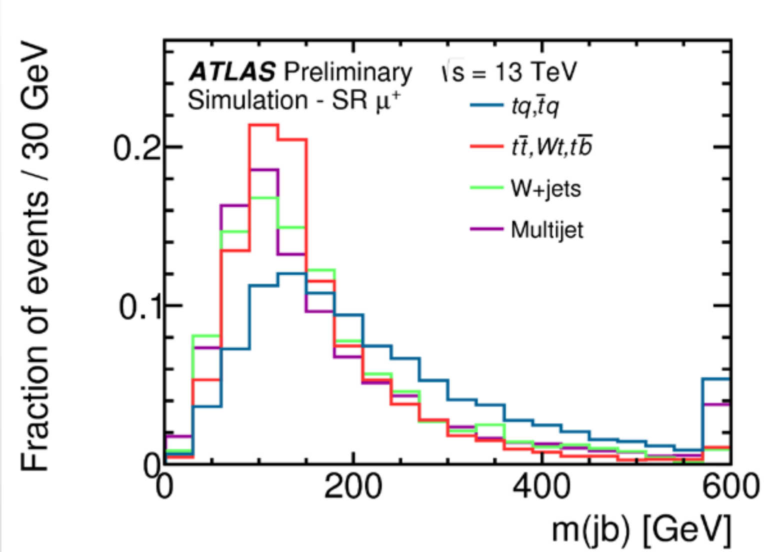
$$\mathcal{P}(\mathbf{x}|H) = \frac{1}{\sigma\epsilon} \sum_{p \in \{\text{perms}\}} \int dx_1 dx_2 \sum_{i,j} f_i(x_1) f_j(x_2) \cdot \int d\mathbf{y} \frac{\|\mathcal{M}^H_{i,j}(\mathbf{y})\|^2}{2x_1x_2s} \cdot W_p(\mathbf{x},\mathbf{y})$$

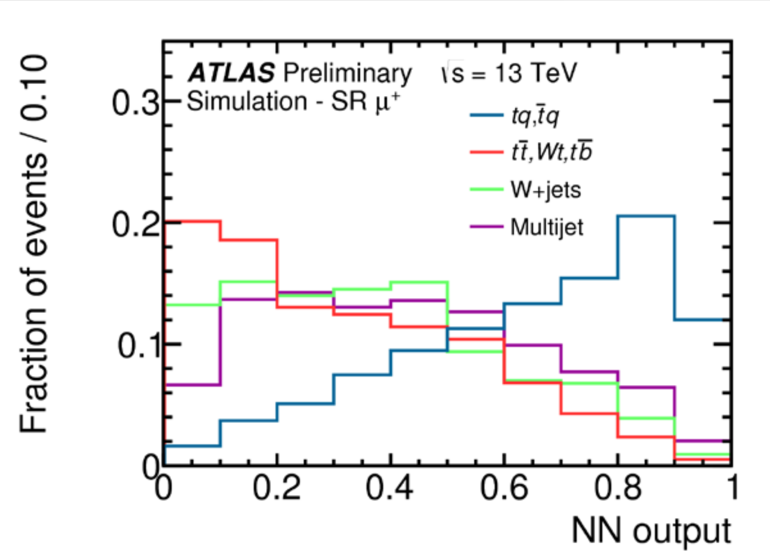
t-channel cross-section

13 TeV

Strategy I

- μ + 2 jets
- High $E_T^{miss}/m_T(\ell\ E_T^{miss})$
- ML fit to NN based discriminant





Strategy II

- NN uses 10 well modelled observables to yield good signal/background separation
- Measure $\sigma(tq)$ and $\sigma(\bar{t}q)$ separately, using the μ charge

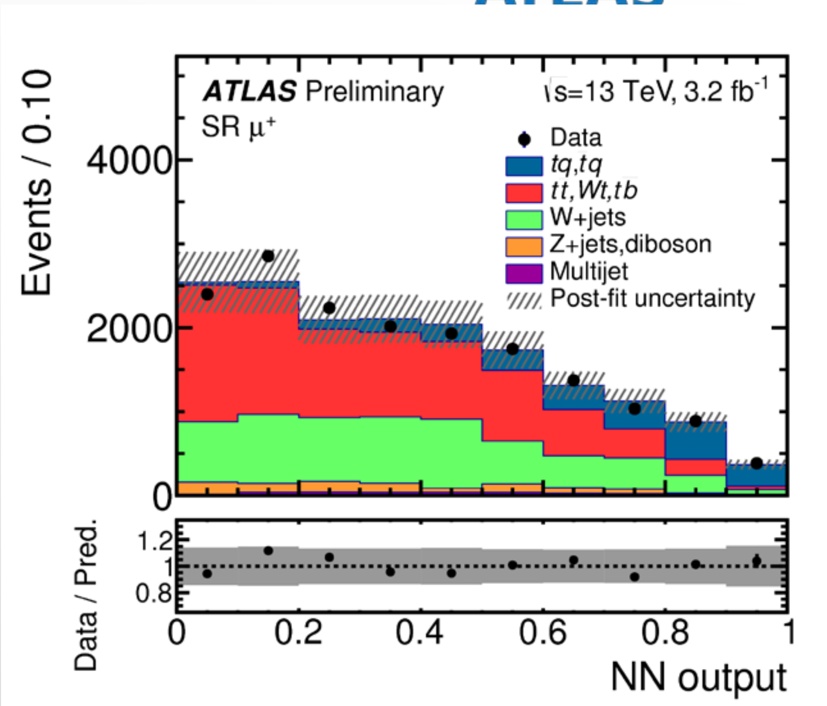
ATLAS-CONF-2015-079

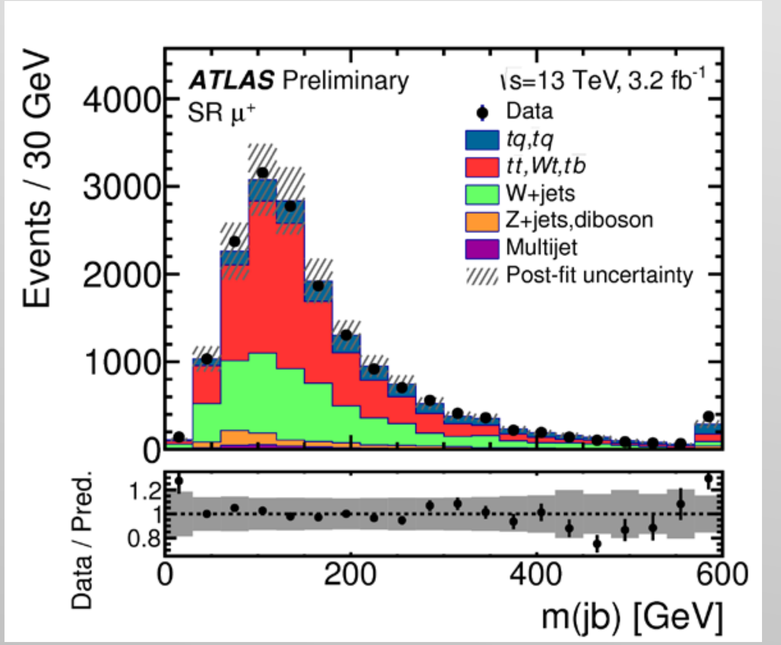
t-channel cross-section

13 TeV

Uncertainties

- Statistical analysis based on pseudo experiments
- Systematic uncertainties are dominated by: signal generator choice, b-tagging, Data/MC statistics
- Total uncertainty 19%(top)/25%(antitop)





Results

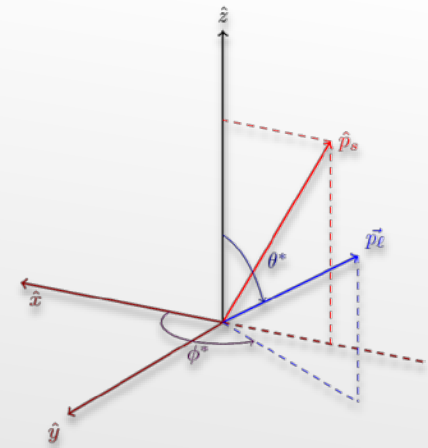
- $\sigma(tq) = 133 \pm 25$ pb
- $\sigma(\bar{t}q) = 96 \pm 24$ pb
- $\sigma(tq + \bar{t}q) = 229 \pm 48$ pb
- $|f_{LV} \cdot V_{tb}| = 1.03 \pm 0.11$
- $|V_{tb}| > 0.78@95\%\text{C. L.}$

ATLAS-CONF-2015-079

Anomalous couplings

Theory

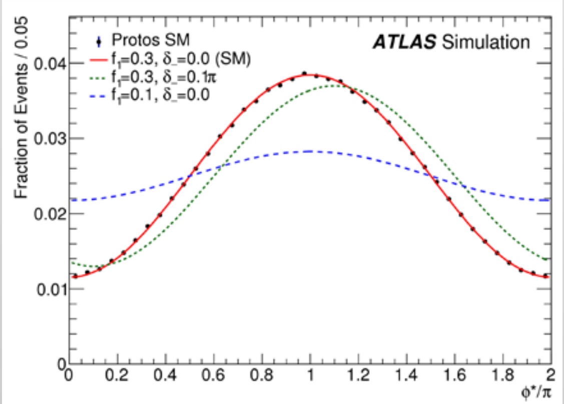
- Anomalous couplings of the W-t-b vertex are sensitive to new physics
- The general effective Lagrangian introduces the vector couplings(V_L, V_R) and tensor couplings (g_L, g_R)
- If the anomalous couplings are non-zero: evidence of new physics
- If the anomalous couplings are complex: implication of CP violation



$$L_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + h.c.$$

Strategy

- Complete description of top-quark decay via a double differential decay rate, expressed as a series in spherical harmonics
- f_1: fraction of transversely polarized W bosons decays
- δ_-: phase between amplitudes for longitudinally polarised and transversally polarized W bosons recoiling against left handed b-quarks

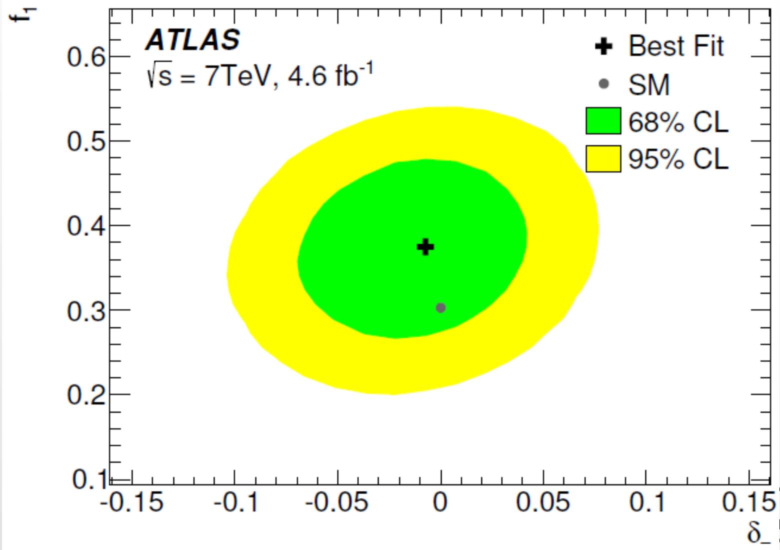


JHEP 1604 (2016) 023

Anomalous couplings

Uncertainties

- Determined by MC samples with parameter variations
- Extract covariance matrices and correlations
- Dominating: statistics, jet energy scale, signal generator



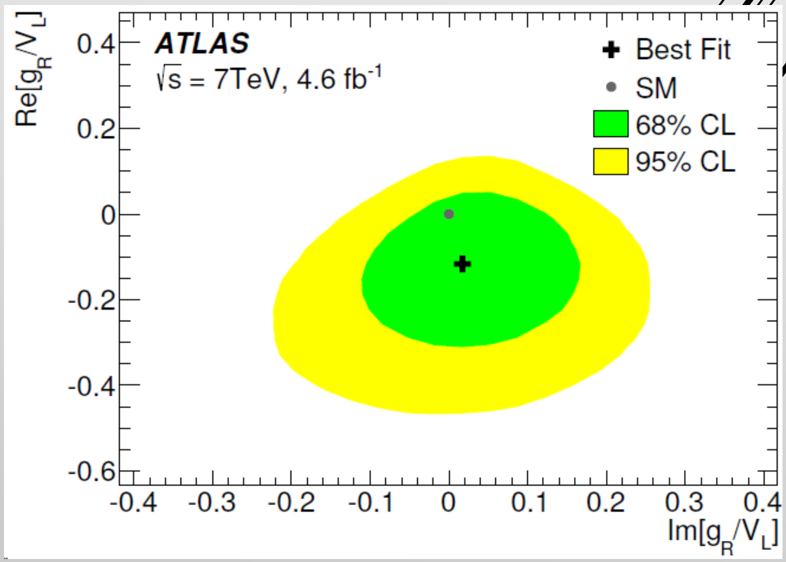
Results

- $\mathrm{Re}\left[\frac{g_R}{V_L}\right] = -0.13 \pm 0.07(stat.) \pm 0.10(syst.)$

$$\Rightarrow Re\left[\frac{g_R}{V_L}\right] \in [-0.36, 0.10]$$

- $\mathrm{Im}\left[\frac{g_R}{V_L}\right] = 0.03 \pm 0.06(stat.) \pm 0.07(syst.)$

$$\Rightarrow Im\left[\frac{g_R}{V_L}\right] \in [-0.17, 0.23]$$



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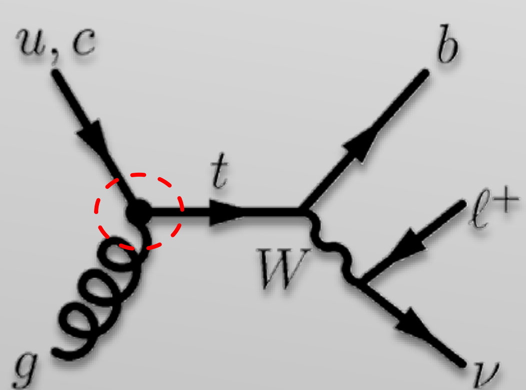
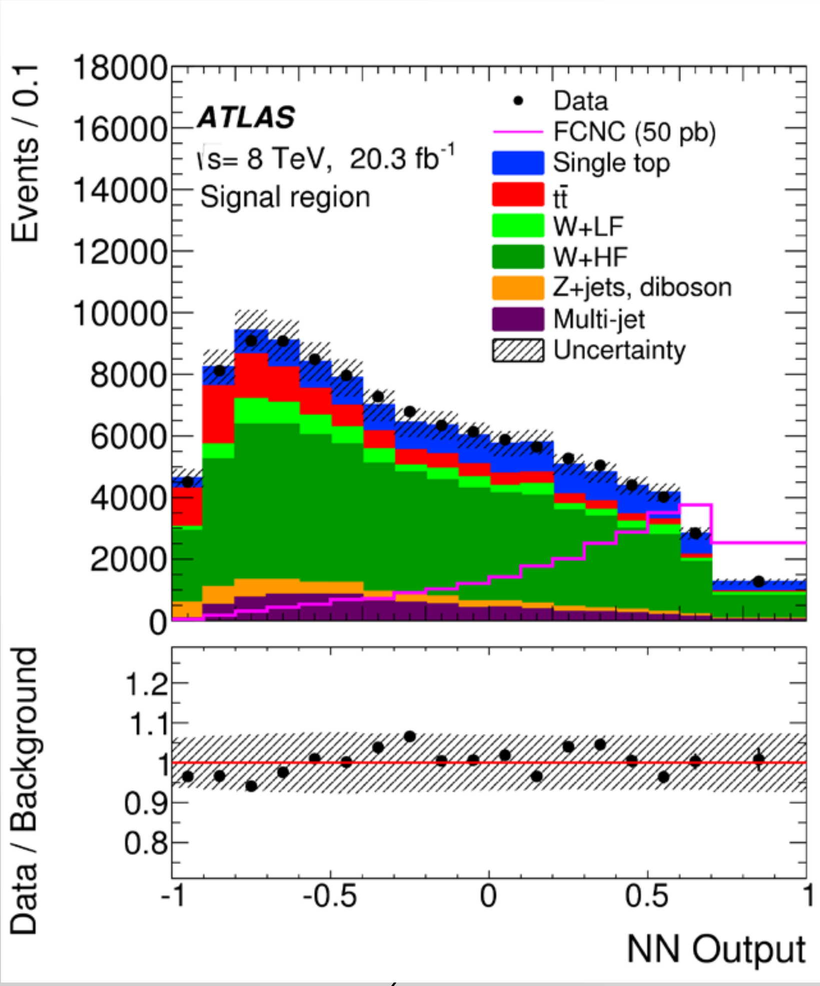
Search for FCNC

Strategy

- Search for anomalous single-top quark production
- 1 charged lepton, $E_{\mathrm{T}}^{\mathrm{miss}}$ and one b-tagged jet
- Construct NN discriminant using 13 well-modelled observables





Eur.Phys.J.C76(2016)55

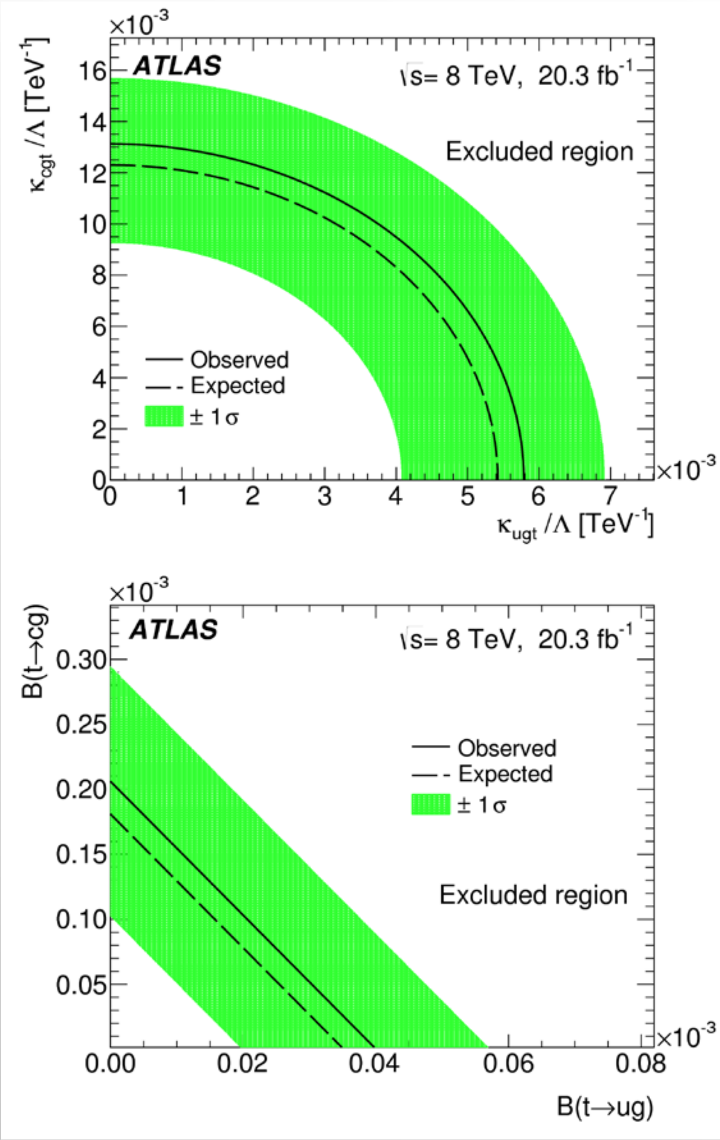
Search for FCNC

Uncertainties

- Evaluate systematic uncertainties using pseudo experiments
- Dominant:
  jet energy scale/resolution, flavour tagging and PDFs

Results

- No signal is observed hence upper limits are derived
- $\sigma_{qg\to t} \times \mathfrak{B}(t \to Wb) < 3.4\ \mathrm{pb}$
- $\mathfrak{B}(t \to ug) < 4.0 \times 10^{-5}$
- $\mathfrak{B}(t \to cg) < 20 \times 10^{-5}$



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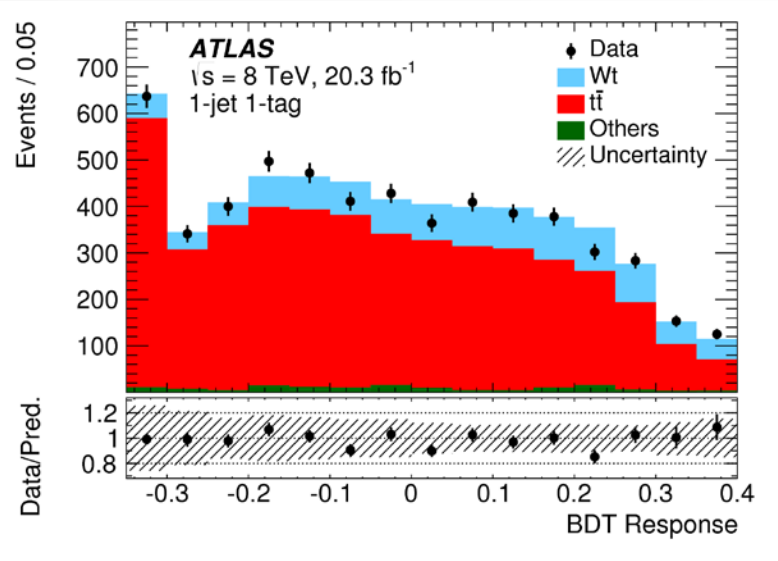
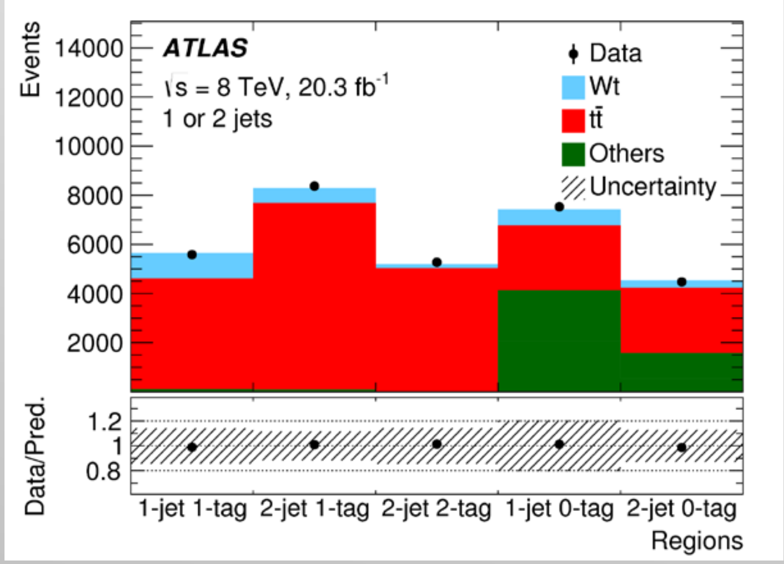
Wt-channel measurement

8 TeV

Strategy

- Di-lepton (op. charge) +1 b-jet
- Main background: $t\bar{t}$
- ML fit to BDT based discriminant





Strategy II

- Different selection regions are used to constrain signal and background
- Jet and *b*-tag multiplicities separate the regions

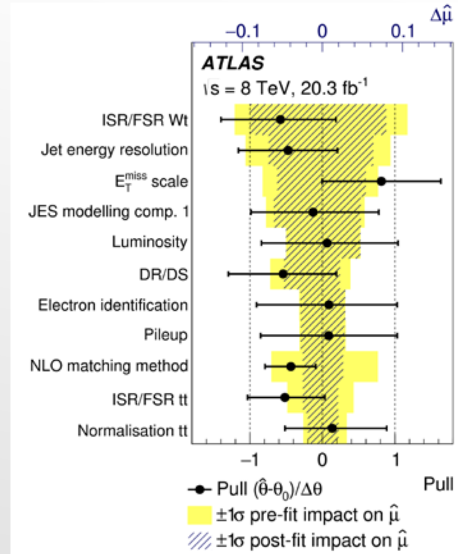
JHEP01(2016)064

Wt-channel measurement

8 TeV

Uncertainty

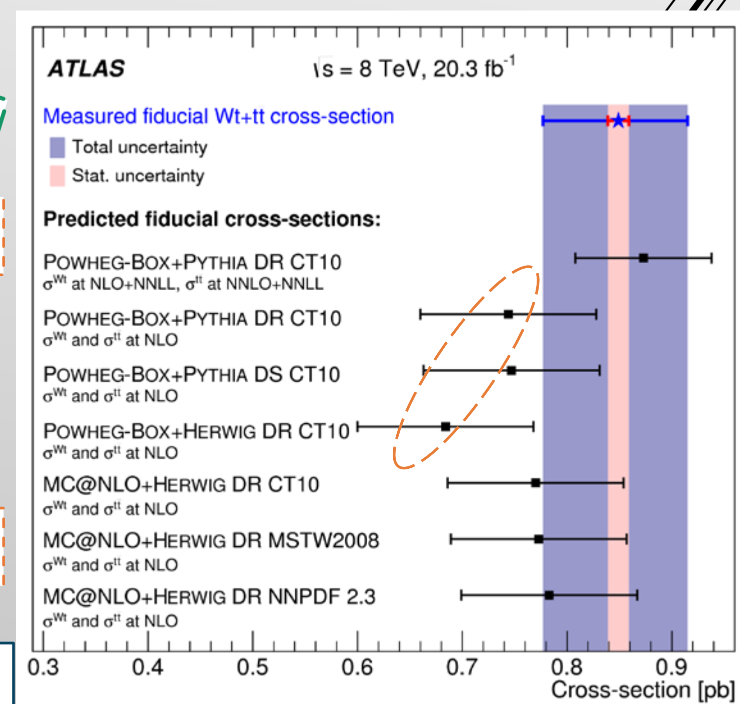
- Dominating systematics are: signal scale-variation, jet energy-resolution and E_T^{miss} scale



Results

Observation!

- $\sigma_{tot}(Wt) = 23.0 \pm 1.3(\text{stat.})^{+3.2}_{-3.5}(\text{syst.}) \pm 1.1(\text{lumi})\text{pb}$ 16%
- Observed significance: 7.7σ
- $|V_{tb} \cdot f_{LV}| = 1.01 \pm 0.1$
- $\sigma_{fid}(Wt) = 0.85 \pm 0.01(\text{stat.})^{+0.06}_{-0.07}(\text{syst.}) \pm 0.03(\text{lumi})\text{pb}$ 8%



JHEP01(2016)064

s-channel measurement

8 TeV

Strategy

- Charged lepton + 2 b-jets
- High $E_T^{miss}/m_T(\ell\ E_T^{miss})$
- ML fit to MEM based discriminant

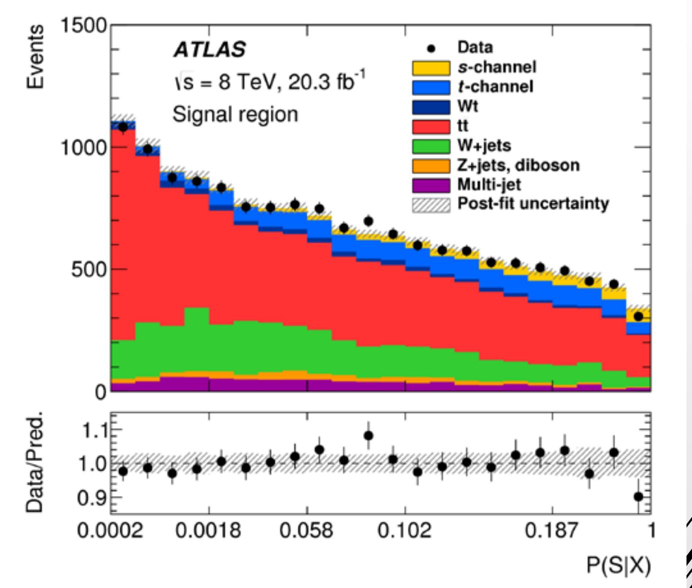
Uncertainties

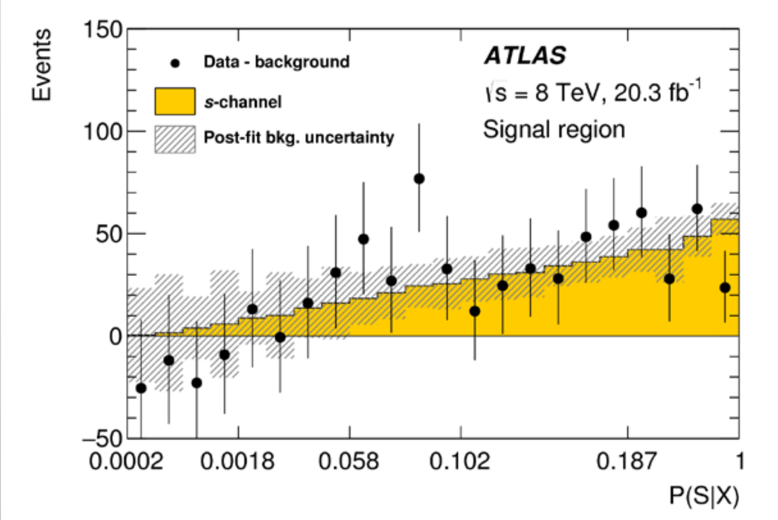
- Fully propagated MEM calculation
- Dominant: JES, generator, b-tagging

Results

- $\sigma_{s-ch.} = 4.8^{+1.8}_{-1.6}$pb 37%
- Expected significance: 3.9σ
- Observed significance: 3.2σ

Evidence!



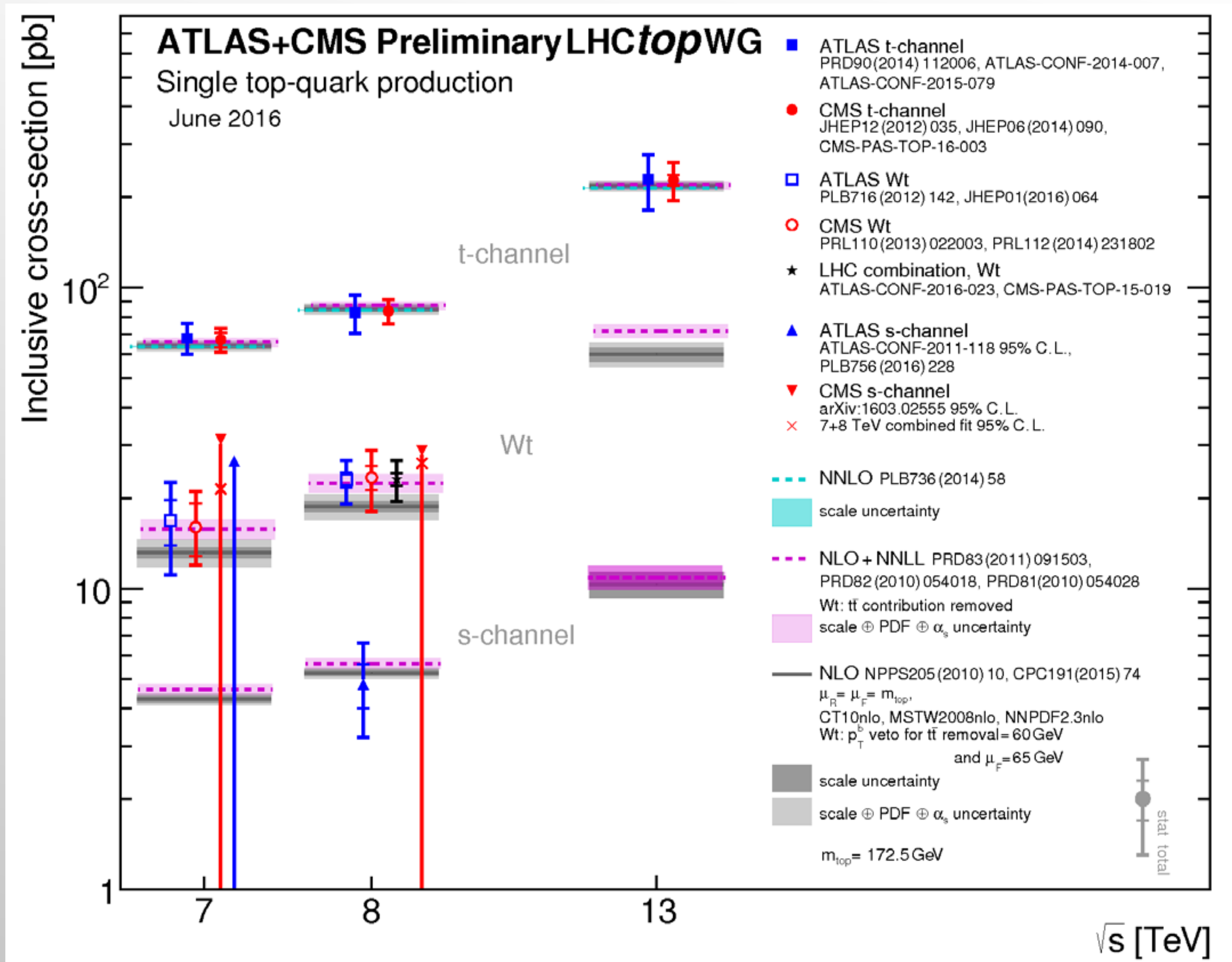


PLB(2016), pp. 228-246

Single top-quark cross-sections

Remarks

- Many measurements have been performed
- Excellent agreement with the SM prediction



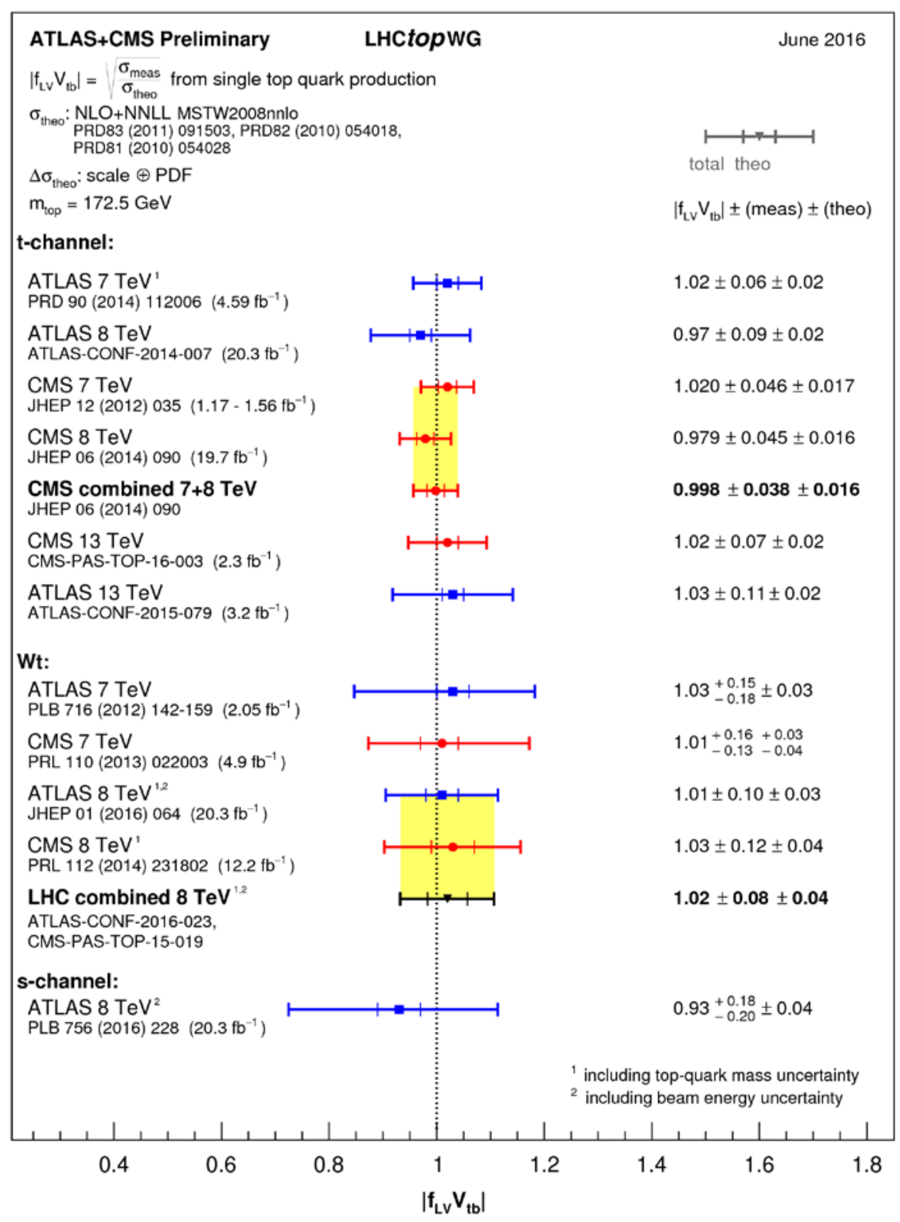
V_{tb} measurements

Measurements

- The SM predicts $f_{LV} = 1$, and $V_{tb} \approx 1$
- Measurements in single-top processes do not constrain the number of quark generations
- Currently best constraint on $|f_{LV} \cdot V_{tb}|$ by CMS 7+8 TeV with 4% uncertainty

Assumptions

- $|V_{tb}| \gg |V_{ts}|, |V_{td}|$
- Wtb interaction involves a SM-like left-handed weak-coupling



Prospects

- Run-1 analyses are being finalised
- Outstanding LHC performance will provide a large 13 TeV dataset for 2016 ($2\ \mathrm{fb}^{-1}$ two weeks ago alone!)
- Many interesting 8 TeV analysis can be improved at 13 TeV

Thank you for your attention

t-channel cross-section

Source	$\Delta\sigma_{tq}/\sigma_{tq}$ [%]	$\Delta\sigma_{\bar{t}q}/\sigma_{\bar{t}q}$ [%]
Data statistics	$\pm$ 4.6	$\pm$ 5.0
MC statistics	$\pm$ 6.3	$\pm$ 6.5
Multijet normalisation	$\pm$ 0.8	$\pm$ 2.4
Other background normalisation	$\pm$ 1.4	$\pm$ 0.5
Muon uncertainties	$\pm$ 1.6	$\pm$ 1.6
JES	$\pm$ 5.5	$\pm$ 1.6
Jet energy resolution	$\pm$ 4.3	$\pm$ 3.1
$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	$\pm$ 4.2	$\pm$ 4.5
b-tagging efficiency	$\pm$ 7.1	$\pm$ 7.5
c-tagging efficiency	< 0.5	< 0.5
Light-jet tagging efficiency	< 0.5	< 0.5
Pile-up reweighting	$\pm$ 1.2	$\pm$ 3.2
W+jets modelling	$\pm$ 2.3	$\pm$ 1.0
$t\bar{t}$,Wt and s-channel shower generator	< 0.5	$\pm$ 2.3
$t\bar{t}$,Wt and s-channel NLO matching	$\pm$ 2.7	$\pm$ 7.0
$t\bar{t}$,Wt and s-channel scale	$\pm$ 2.6	$\pm$ 0.9
t-channel scale	$\pm$ 5.9	$\pm$ 7.7
t-channel generator	$\pm$ 11.0	$\pm$ 15.0
PDF	< 0.5	$\pm$ 1.0
Luminosity	$\pm$ 5.0	$\pm$ 5.0
Total systematic uncertainty	$\pm$ 18.4	$\pm$ 24.4
Total uncertainty	$\pm$ 19.0	$\pm$ 25.0

FCNC

Source	Expected 95 % CL upper limit [pb]	Change in the upper limit [%]
Normalisation & MC statistics	1.5	-
Multi-jets normalisation and modelling	1.8	25
Luminosity	1.5	5
Lepton identification	1.5	3
Electron energy scale	1.6	8
Electron energy resolution	1.5	4
Muon momentum scale	1.5	1
Muon momentum resolution	1.5	5
Jet energy scale	1.6	8
Jet energy resolution	1.9	32
Jet reconstruction efficiency	1.5	4
Jet vertex fraction scale	1.5	3
b-tagging efficiency	1.5	3
c-tagging efficiency	1.5	4
Mistag acceptance	1.5	2
$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	1.9	34
PDF	1.5	5
Scale variations	1.5	2
MC generator (NLO subtraction method)	1.6	8
Parton shower modelling	1.5	5
All systematic uncertainties	2.9	-