LHC top WG

Single Top and Vtb : brief update on combination

Tuesday, November 22

LHC Top WG meeting

N. Jafari, R. Schwienhorst and C. Escobar

UCL Université catholique de Louvain

MICHIGAN STATE UNIVERSITY

University of Pittsburgh

Outline

- Recently public results since last LHC top WG meeting:
  - ATLAS and CMS *t*-channel cross-section at 13 TeV.
  - ATLAS *Wt* cross-section at 13 TeV.
  - ATLAS *t*-channel cross-section at 8 TeV.
  - CMS search for SM and FCNC *tZ(q)* process at 8 TeV.
- Run-I single top legacy paper: V_{tb} combination.
- Updated two single top summary plots.

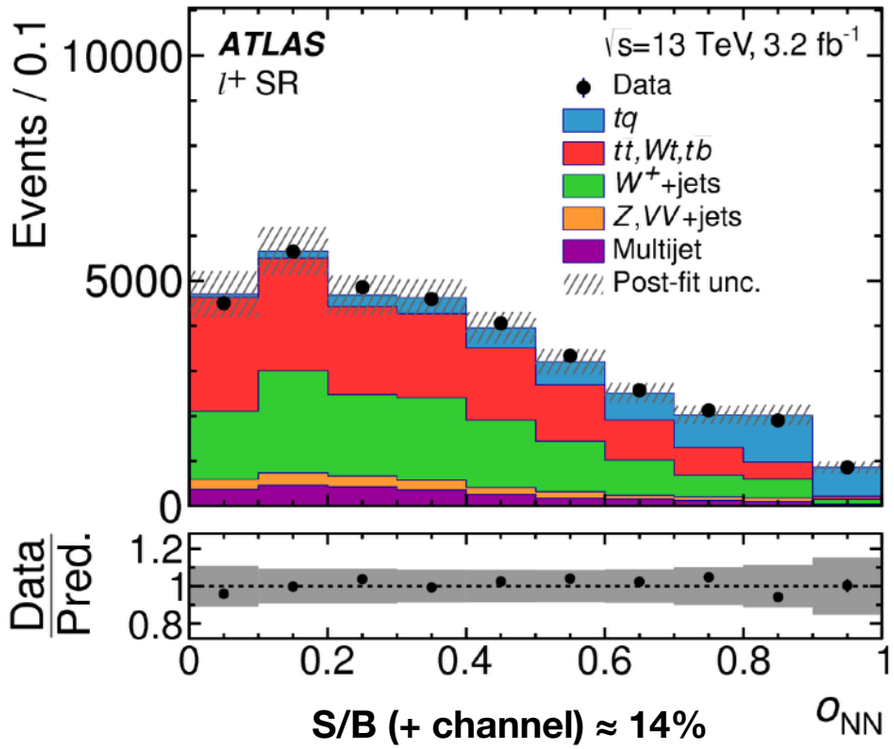
Recently public results since last *LHCtopWG* meeting

ATLAS *t*-channel cross-section at 13 TeV

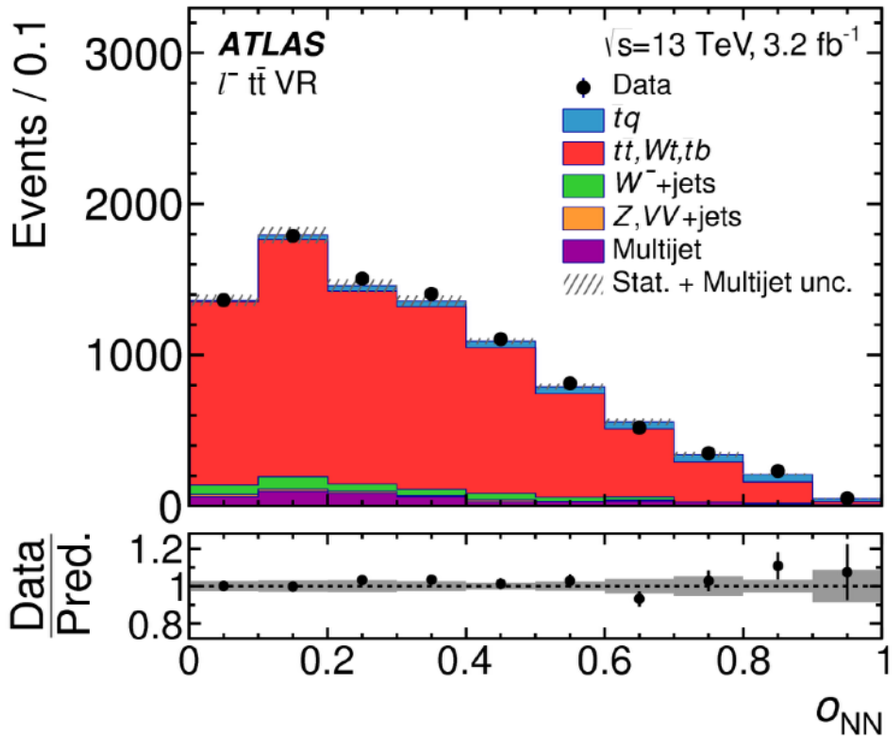
arXiv:1609.03920

- *t*-channel production at 13 TeV (3.2 fb^{-1}).
- Inclusive cross-section measurement independently for top quark and top antiquark.
- Additionally separated into positive and negative lepton charge.
- Events are separated into SRs and VRs based on the number of jets and b-tagged jets.
- Use NN in order to separate *t*-channel from background.
- Signal extraction: maximum likelihood fit.

SR



VR



S/B (+ channel) ≈ 14%

S/B (- channel) ≈ 10%

Good data/MC agreement

Measured cross section:

σ_{tq} =156 ± 5 (stat.) ± 27 (syst.) ± 3 (lumi.) pb (total unc.:18%)

$\sigma_{\bar{t}q}$ = 91 ± 4 (stat.) ± 18 (syst.) ± 2 (lumi.) pb (total unc.: 21%)

$\sigma_{tq+\bar{t}q}$ = 247 ± 6 (stat.) ± 45 (syst.) ± 5 (lumi.) pb (total unc.: 19%)

σ_{tq} =136.0 ± 5.4 pb

$\sigma_{\bar{t}q}$ = 81.0 ± 4.1 pb

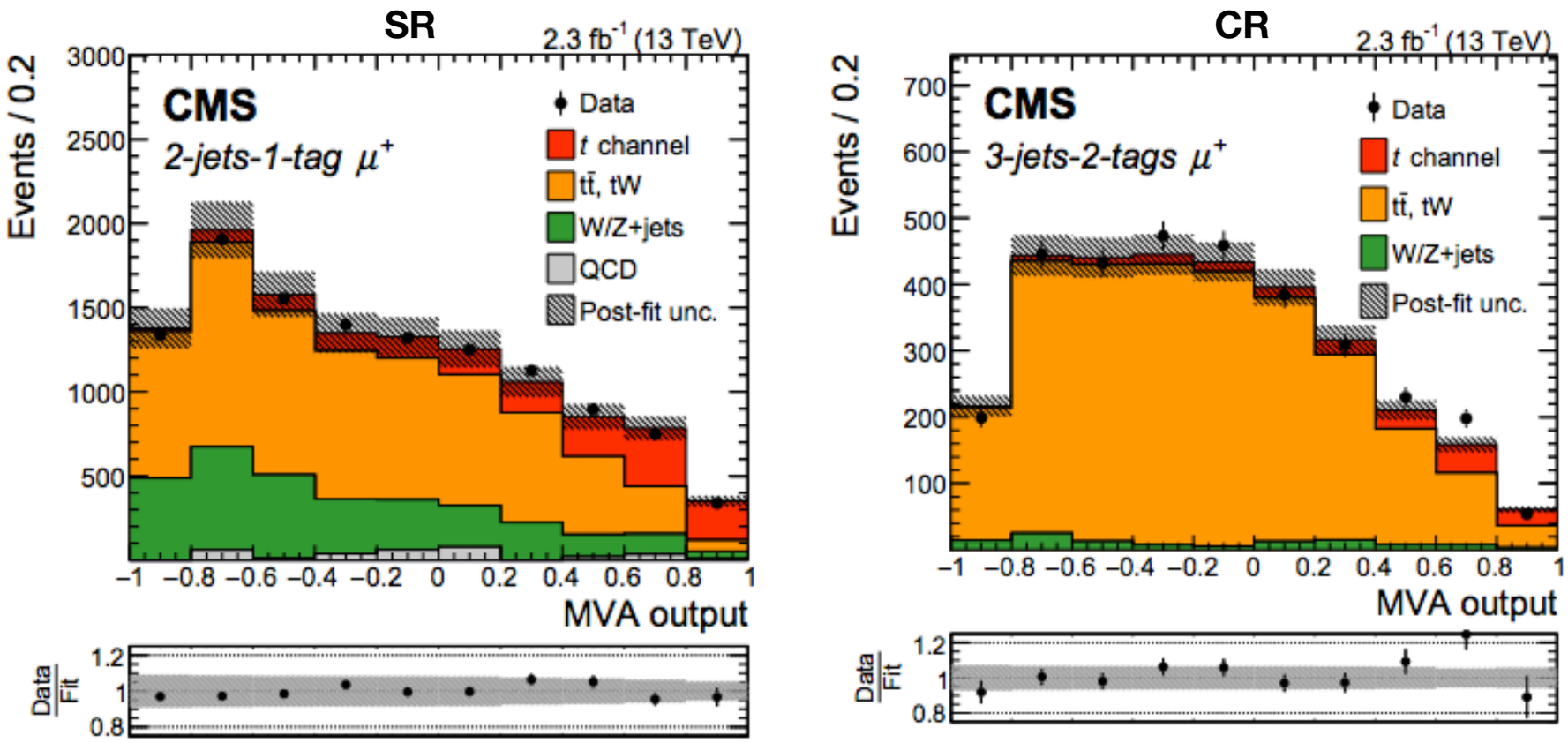
$\sigma_{tq+\bar{t}q}$ = 217.0 ± 9.1 pb

Calculated @ SM NLO by Hathor

CMS *t*-channel cross-section at 13 TeV

arXiv:1610.00678

- *t*-channel production at 13 TeV (3.2 fb^{-1}).
- Inclusive cross-section measurement (μ+jets channel).
- Events are separated into SRs and VRs based on the number of jets and b-tagged jets.
- Use NN in order to separate *t*-channel from background.
- Signal extraction: simultaneous fit in 3 regions: SR and two $t\bar{t}$ CRs.



Measured cross section:

σ_{tq} = 150 ± 8 (stat.) ± 20 (syst.) ± 4 (lumi.) pb (total unc.:15%)

$\sigma_{\bar{t}q}$ = 82 ± 10 (stat.) ± 12 (syst.) ± 2 (lumi.) pb (total unc.:20%)

$\sigma_{tq+\bar{t}q}$ = 232 ± 13 (stat.) ± 28 (syst.) ± 6 (lumi.) pb (total unc.:13%)

σ_{tq} =136.0 ± 5.4 pb

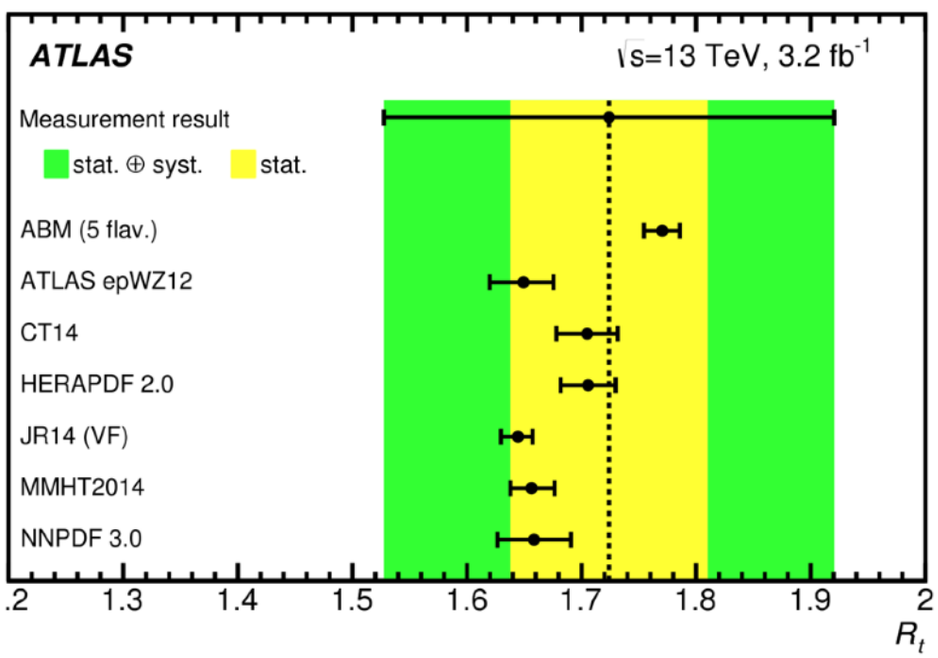
$\sigma_{\bar{t}q}$ = 81.0 ± 4.1 pb

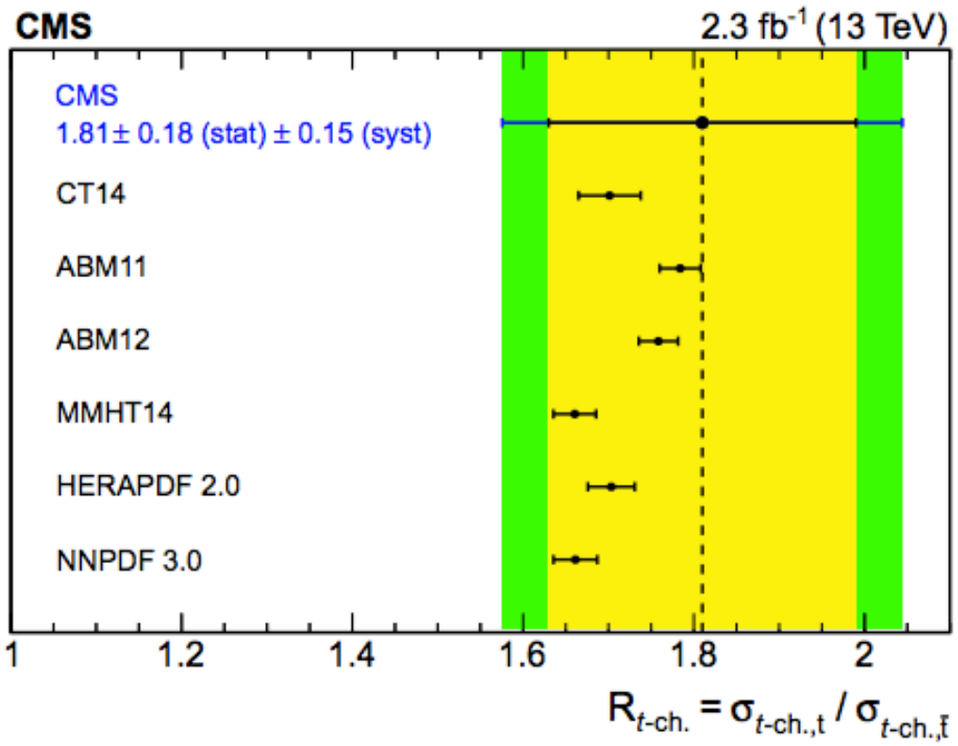
$\sigma_{tq+\bar{t}q}$ = 217.0 ± 9.1 pb

Calculated @ SM NLO by Hathor

ATLAS/CMS *t*-channel cross-section at 13 TeV

- Cross-section ratio.
- The charge of the top quark is connected to the type of the incoming light-flavour quark
  - top-quark/top-antiquark production is sensitive to d/u-quark ratio : $R_t = \sigma_{tq} / \sigma_{\bar{t}q}$.





arXiv:1609.03920

Measured ratio:

R_t = 1.72 ± 0.09 (stat.) ± 0.18 (syst.)

Total unc.: 12%

arXiv:1610.00678

Measured ratio:

R_t = 1.81 ± 0.18 (stat.) ± 0.15 (syst.)

Total unc.: 13%

ATLAS/CMS *t*-channel cross-section at 13 TeV

ATLAS EXPERIMENT arXiv:1609.03920

Source	$\frac{\Delta\sigma(tq)}{\sigma(tq)}$ [%]	$\frac{\Delta\sigma(\bar{t}q)}{\sigma(\bar{t}q)}$ [%]	$\frac{\Delta R_t}{R_t}$ [%]
Data statistics	± 2.9	± 4.1	± 5.0
Monte Carlo statistics	± 2.8	± 4.2	± 5.1
Reconstruction efficiency and calibration uncertainties			
Muon uncertainties	± 0.8	± 0.9	± 1.0
Electron uncertainties	< 0.5	± 0.5	± 0.7
JES	± 3.4	± 4.1	± 1.2
Jet energy resolution	± 3.9	± 3.1	± 1.1
$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	± 0.9	± 1.2	< 0.5
b-tagging efficiency	± 7.0	± 6.9	< 0.5
c-tagging efficiency	< 0.5	± 0.5	± 0.6
Light-jet tagging efficiency	< 0.5	< 0.5	< 0.5
Pile-up reweighting	± 1.5	± 2.2	± 3.8
Monte Carlo generators			
tq parton shower generator	± 13.0	± 14.3	± 1.9
tq NLO matching	± 2.1	± 0.7	± 2.8
tq radiation	± 3.7	± 3.4	± 3.7
$t\bar{t}$, Wt, $t\bar{b}+\bar{t}b$ parton shower generator	± 3.2	± 4.4	± 1.2
$t\bar{t}$, Wt, $t\bar{b}+\bar{t}b$ NLO matching	± 4.4	± 8.6	± 4.6
$t\bar{t}$, Wt, $t\bar{b}+\bar{t}b$ radiation	< 0.5	± 1.1	± 0.7
PDF	± 0.6	± 0.9	< 0.5
Background normalisation			
Multijet normalisation	± 0.3	± 2.0	± 1.8
Other background normalisation	± 0.4	± 0.5	< 0.5
Luminosity	± 2.1	± 2.1	< 0.5
Total systematic uncertainty	± 17.5	± 20.0	± 10.2
Total uncertainty	± 17.8	± 20.4	± 11.4

CMS arXiv:1610.00678

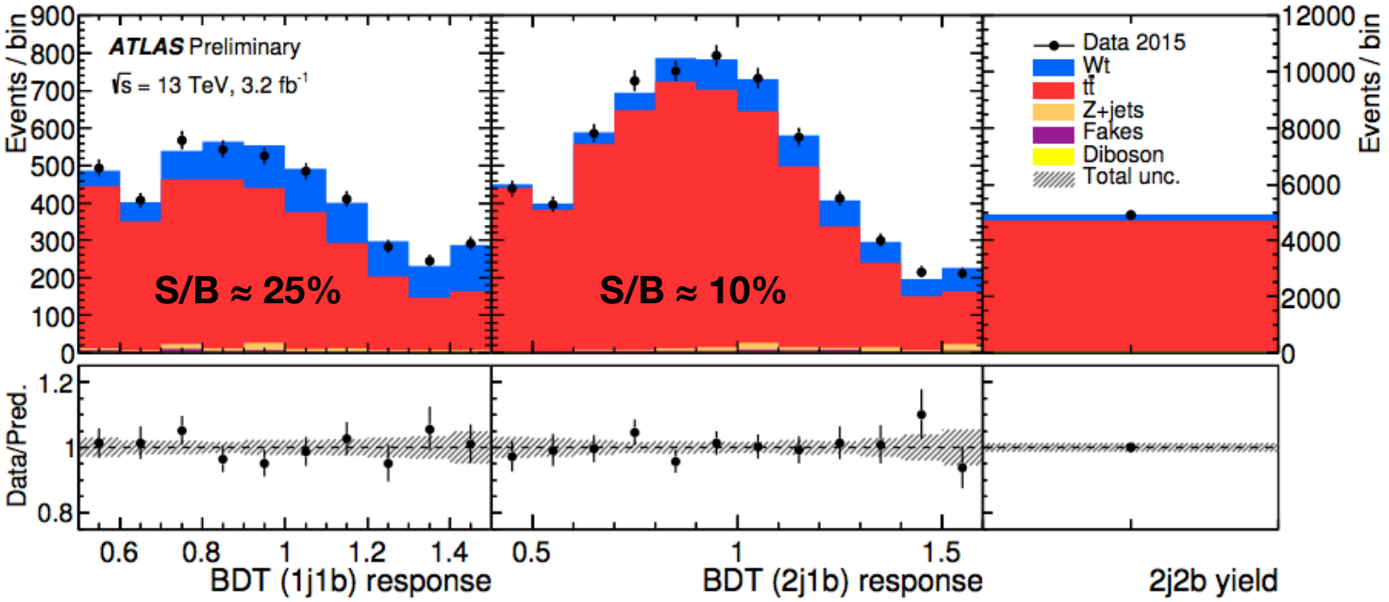
Uncertainty source	$\Delta\sigma_{t\text{-ch.},t}/\sigma^{\mathrm{obs}}_{t\text{-ch.},t}$	$\Delta\sigma_{t\text{-ch.},\bar{t}}/\sigma^{\mathrm{obs}}_{t\text{-ch.},\bar{t}}$	$\Delta R_{t\text{-ch.}}/R_{t\text{-ch.}}$
Statistical uncert.	±5.3%	±11.5%	±9.7%
Profiled exp. uncert.	±5.7%	±4.9%	±3.3%
Total fit uncert.	±7.8%	±12.5%	±10.3%
Integrated luminosity	±2.7%	±2.7%	-
Signal modelling	±8.2%	±8.5%	±5.3%
$t\bar{t}$ modelling	±4.3%	±4.5%	±4.0%
W+jets modelling	−1.6/+2.3%	−2.5/+2.3%	−1.7/+2.0%
$\mu_{\mathrm{R}}/\mu_{\mathrm{F}}$ scale *t*-channel	−5.7/+5.2%	−7.2/+5.1%	−0.7/+1.2%
$\mu_{\mathrm{R}}/\mu_{\mathrm{F}}$ scale $t\bar{t}$	−3.5/+4.1%	−4.7/+3.1%	−1.1/+1.0%
$\mu_{\mathrm{R}}/\mu_{\mathrm{F}}$ scale tW	−0.6/+0.8%	−1.1/+0.7%	−0.2/+0.1%
$\mu_{\mathrm{R}}/\mu_{\mathrm{F}}$ scale W+jets	−3.5/+3.0%	−4.9/+3.8%	−1.2/+0.9%
PDF uncert.	−2.1/+1.6%	−1.8/+2.1%	−2.2/+2.5%
Top quark p_{T} modelling	±0.2%	±0.2%	±0.1%
Total theory uncert.	−12.2/+12.1%	−13.6/+12.9%	±7.5%
Total uncert.	±14.7%	−18.7/+18.2%	±12.7%

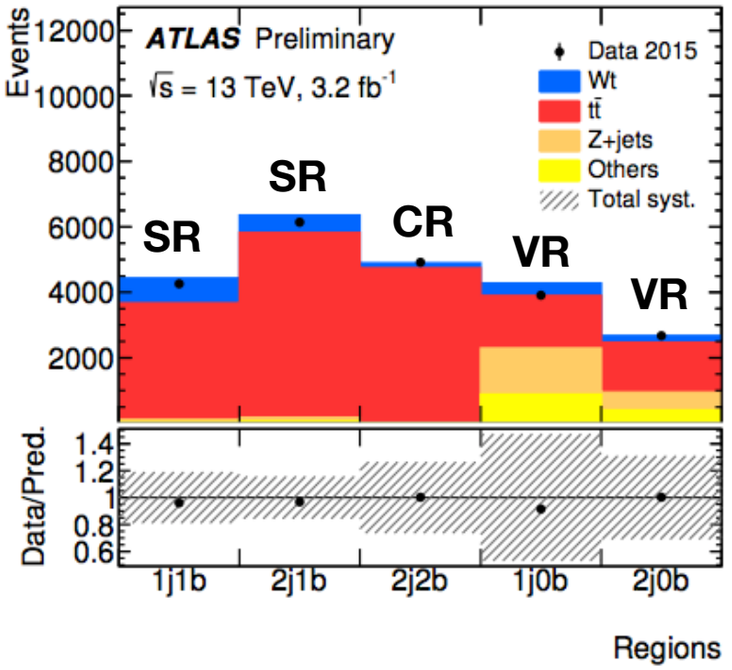
t-channel inclusive measurements at 13 TeV could be combined using BLUE once the papers are ready.

ATLAS *Wt* cross-section at 13 TeV

ATLAS-CONF-2016-065

- *Wt* associated production (di-lepton channel) at 13 TeV (3.2 fb^{-1}).
- Events are separated into SR and CR based on the number of jets and b-tagged jets.
- Use BDTs in two signal regions in order to separate *Wt* and $t\bar{t}$.
- Signal extraction: Profile maximum likelihood fit:





- **Measured cross section:**

  σ_{Wt} = 94 ± 10 (stat.) $^{+28}_{-23}$ (syst.)

  SM: σ_{Wt} = 71.1 ± 3.9 pb ; Calculated @ NLO

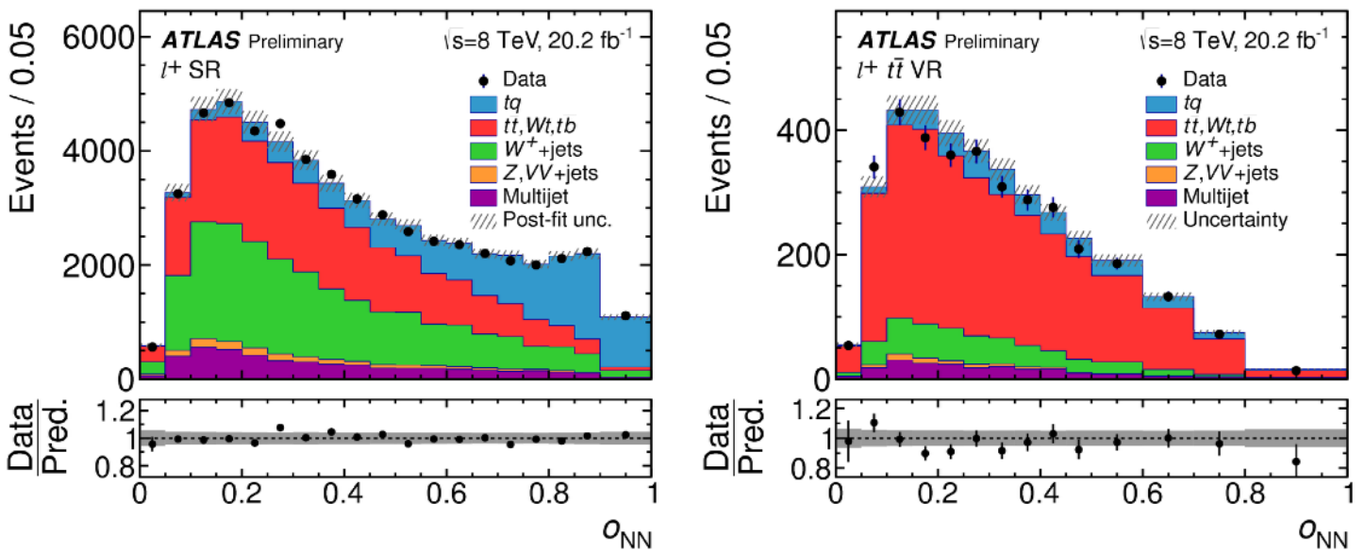
  Significance: 4.5 σ

Source	$\Delta\sigma_{Wt}/\sigma_{Wt}$ [%]
Luminosity	2.3
Lepton efficiency, energy scale and resolution	1.3
$E_{\mathrm{T}}^{\mathrm{miss}}$ soft terms	5.3
Jet energy scale	21
Jet energy resolution	8.6
b-tagging	4.3
NLO matrix element generator	18
Parton shower and hadronisation	7.1
Initial-/final-state radiation	6.4
Diagram removal/subtraction	5.3
Parton distribution function	2.7
Non-$t\bar{t}$ background normalisation	3.7
Total systematic uncertainty	30
Data statistics	10
Total uncertainty	31

ATLAS *t*-channel cross-section at 8 TeV

Paper in preparation

- *t*-channel production at 8 TeV (20.2 fb^{-1}).
- Inclusive, fiducial and differential cross-section measurement independently for tq and $\bar{t}q$.
- Additionally separated into positive and negative lepton charge.
- Events are separated into SRs and VRs based on the number of jets and b-tagged jets.
- Measurement is done in a fiducial phase space close to the experimental one.
- Use NN in order to separate *t*-channel from background (NN without $|\eta_j|$ for differential).
  - Minimal number of input variables, while keeping sensitivity.
- Signal extraction: maximum likelihood fit.



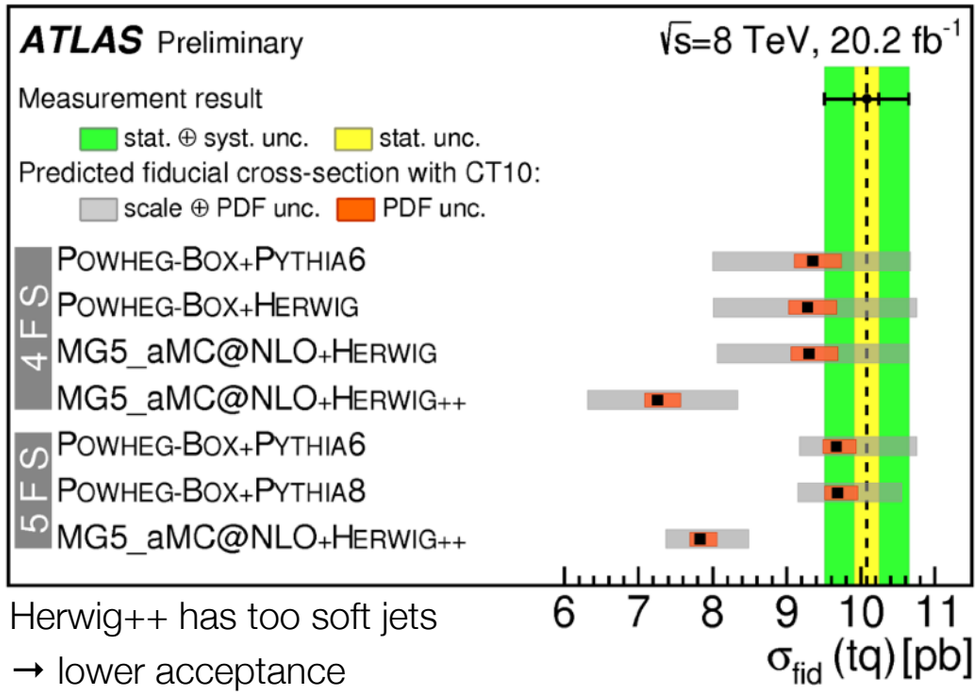
Good data/MC agreement

Several uncertainties are reduced for the fiducial cross-section wrt the total cross-section

V_{tb} precision: ~4%

Source	$\Delta\sigma_{\text{fid}}(tq) / \sigma_{\text{fid}}(tq)$ [%]	$\Delta\sigma_{\text{fid}}(\bar{t}q) / \sigma_{\text{fid}}(\bar{t}q)$ [%]
Data statistics	± 1.7	± 2.5
Monte Carlo statistics	± 1.0	± 1.4
Background normalisation	< 0.5	< 0.5
Background modelling	± 1.0	± 1.6
Lepton reconstruction	± 2.1	± 2.5
Jet reconstruction	± 1.2	± 1.5
Jet energy scale	± 3.1	± 3.6
Flavour tagging	± 1.5	± 1.8
$E_{\text{T}}^{\text{miss}}$ modelling	± 1.1	± 1.6
$b/\bar{b}$ tagging efficiency	± 0.9	± 0.9
PDF	± 1.3	± 2.2
tq ($\bar{t}q$) NLO matching	± 0.5	< 0.5
tq ($\bar{t}q$) parton shower	± 1.1	± 0.8
tq ($\bar{t}q$) scale variations	± 2.0	± 1.7
$t\bar{t}$ NLO matching	± 2.1	± 4.3
$t\bar{t}$ parton shower	± 0.8	± 2.5
$t\bar{t}$ scale variations	< 0.5	< 0.5
Luminosity	± 1.9	± 1.9
Total systematic	± 5.6	± 7.3
Total (stat. + syst.)	± 5.8	± 7.8

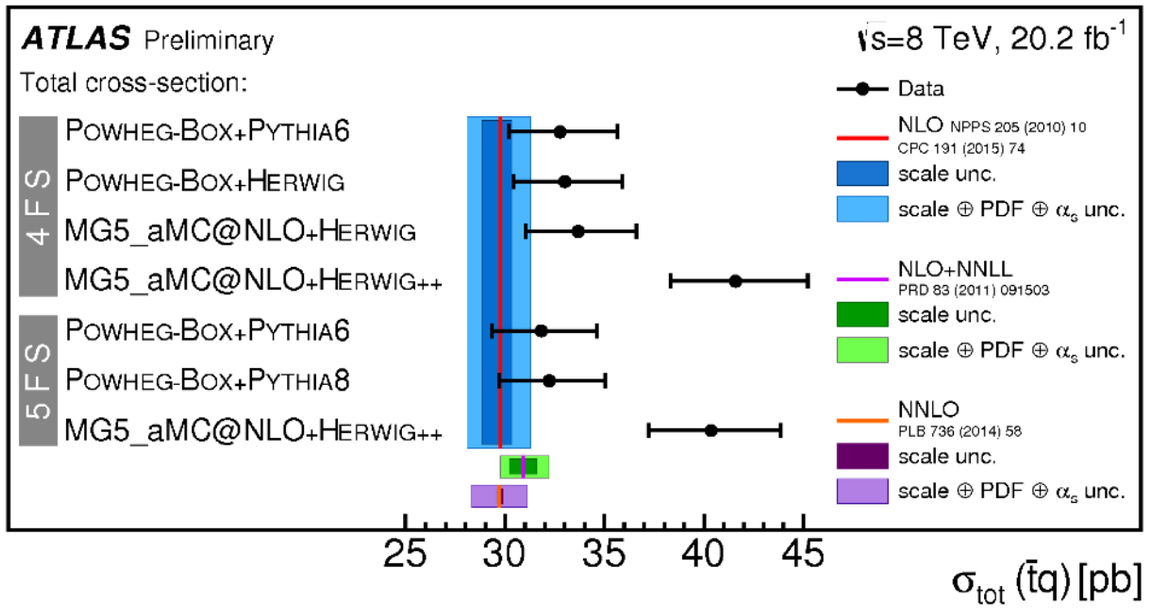
Fiducial



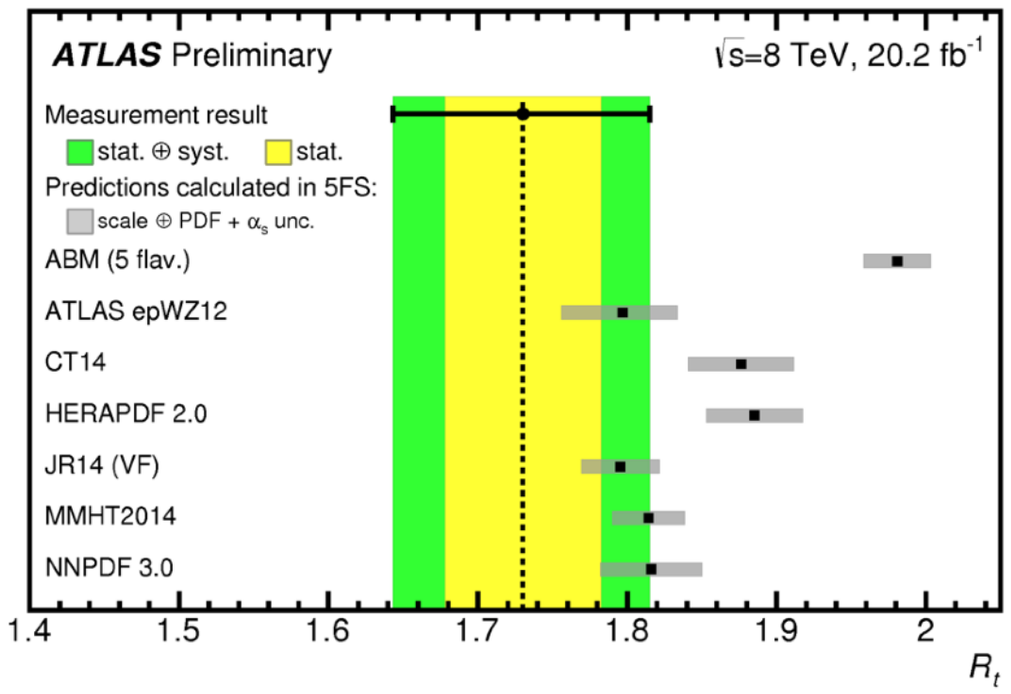
Herwig++ has too soft jets

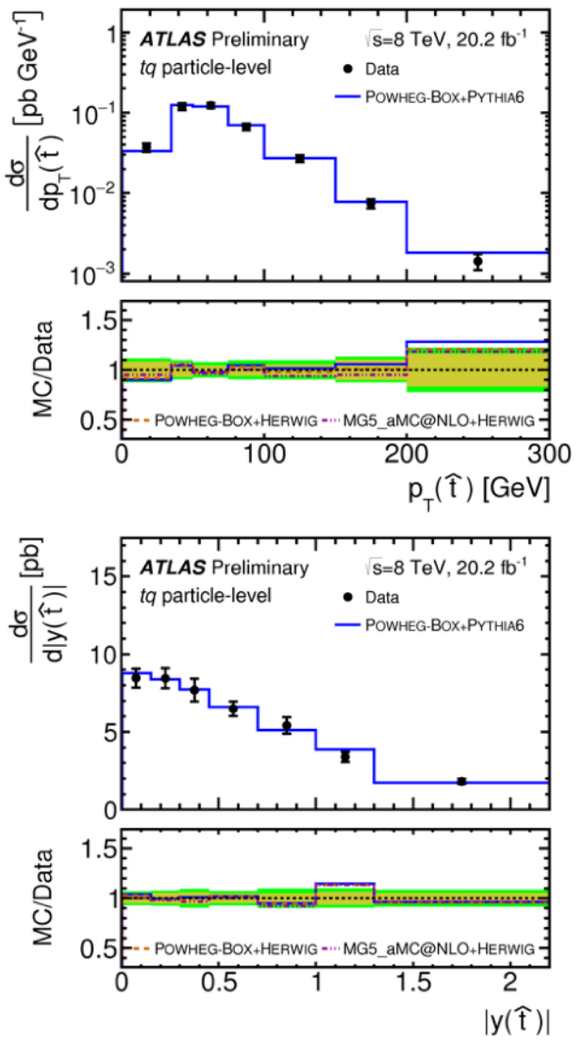
→ lower acceptance

Inclusive (extrapolated)

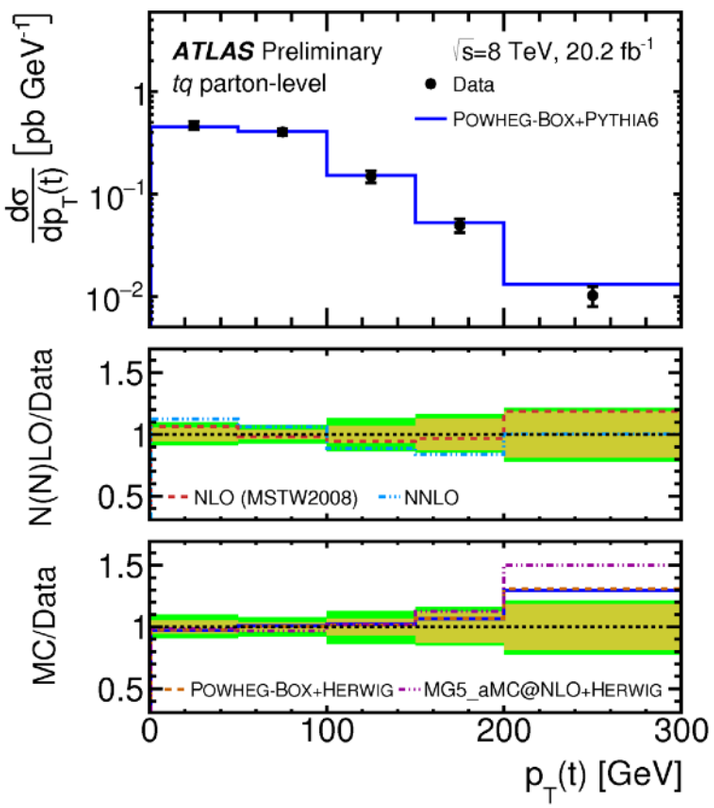


Ratio





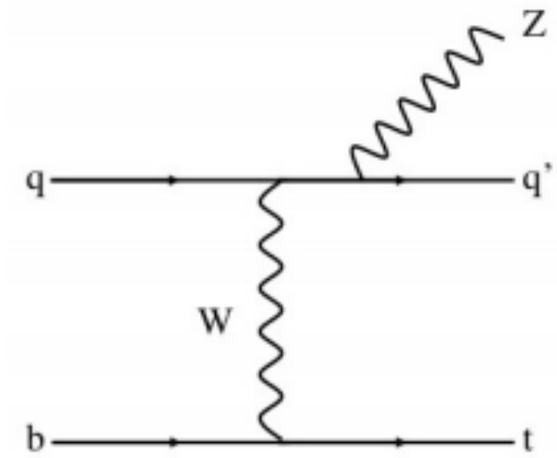
Differential at parton and particle level

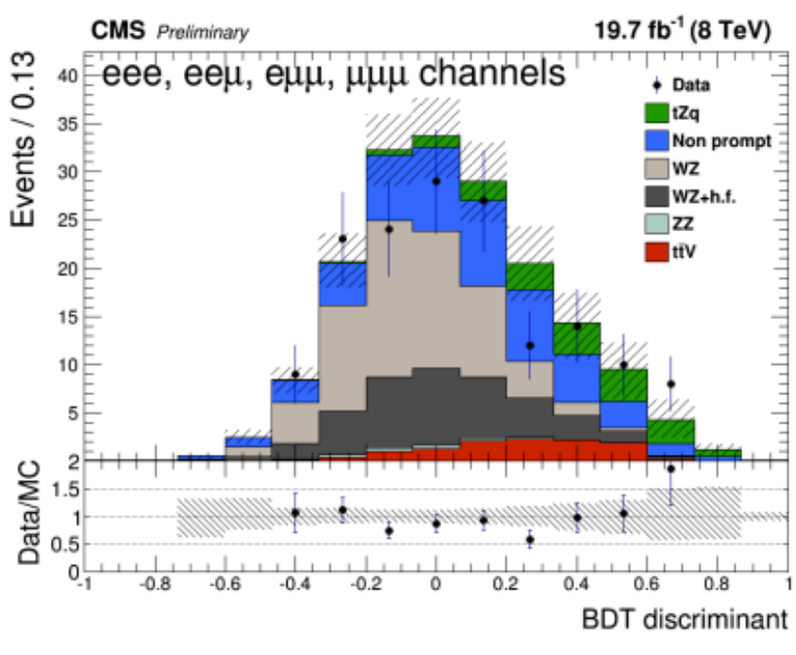


CMS search for SM and FCNC *tZ(q)* process at 8 TeV

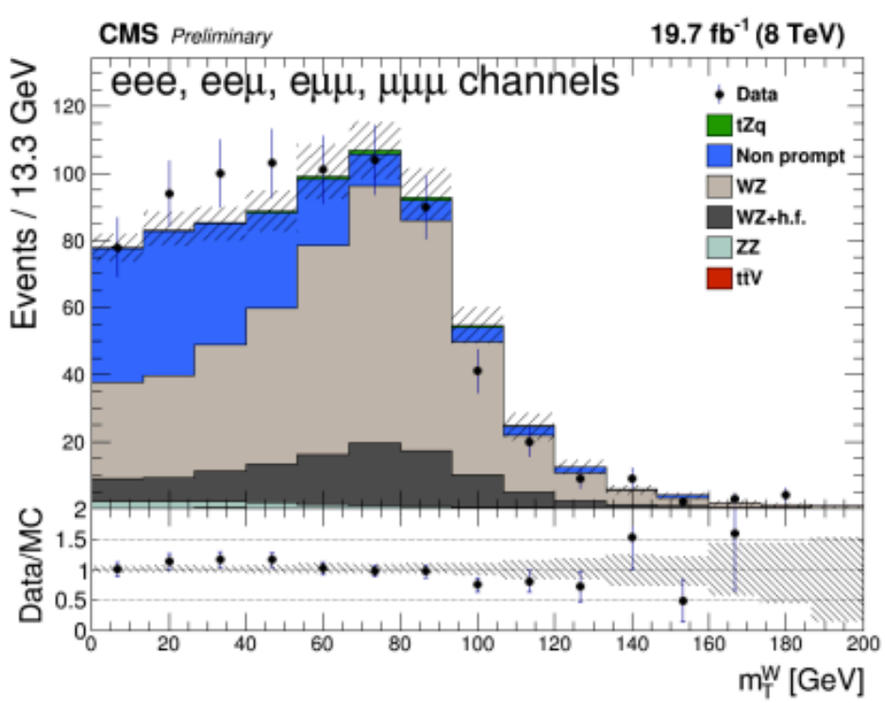
TOP-12-039

- Search for *tZ(q)* process at 8 TeV (19.7 fb^{-1}).
- *tZ*+$\bar{t}$*Z* have a cross section at the same level as *ttZ*.
- 2 lepton compatible with *Z* boson and 1 lepton from *W* boson.
- Fake leptons: data driven template.
- Use BDT in order to separate *tZ(q)* from *t*$\bar{t}$*Z* and *WZ*.
- Signal extraction for SM:
  - Simultaneous fit on BDT in the SR and $m_T(W)$ distributions in the CR.





SR



CR

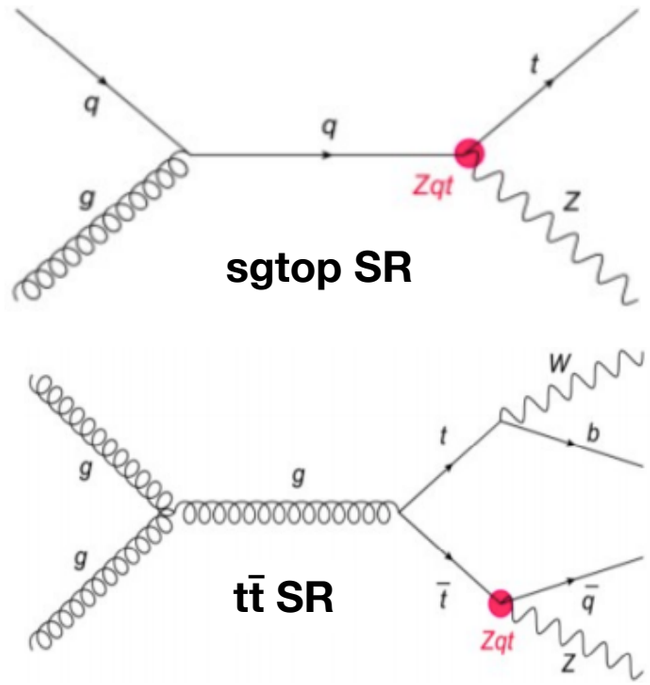
- Measured upper limit at 95% CL.: 21 fb.
- Measured cross section: $\sigma_{tZ(q)} = 10^{+8}_{-7}$ **fb.**
- Observed(expected) significances: 2.4 (1.8)σ.

- **SM: $\sigma_{tZ(q)} = 8.2^{+0.59}_{-0.03}$ (scale) fb.**

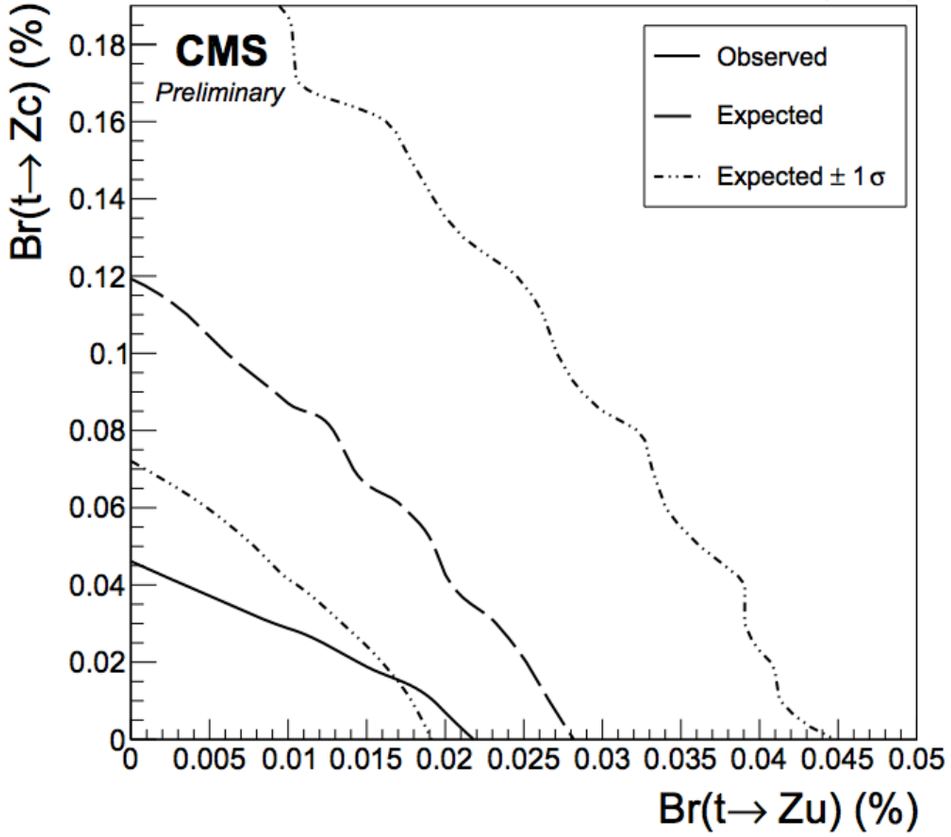
CMS search for SM and FCNC *tZ(q)* process at 8 TeV

TOP-12-039

- Search for *tZ(q)* process at 8 TeV (19.7 fb^{-1}).
- *tZ*+$\bar{t}Z$ have a cross section at the same level as *ttZ*.
- 2 lepton compatible with *Z* boson and 1 lepton from *W* boson.
- Fake leptons: data driven template.
- Use BDT in order to separate *FCNC* from SM backgrounds, excluding fakes.
- Signal extraction for FCNC:
  - Simultaneous fit on single top and $t\bar{t}$ BDT in the SR and $m_T(W)$ distributions in the CR.



- Combined limit for *tZc* and *tZu* couplings:



- Independent limit for *tZc* and *tZu* couplings:
  - **BR(*t*→*Zu*) < 0.022% at 95 CL.**
  - **BR(*t*→*Zc*) < 0.049% at 95 CL.**
- No presence of FCNC production of *tZ(q)* is observed.

Check Eric's slides (tomorrow) for more FCNC details!

Ongoing combinations within the *LHCtopWG*

Run-I single top legacy paper: V_{tb} combination

- Planning the V_{tb} combination using all Run-I legacy measurements.
- Single top-quark production cross-sections are proportional to $|Vtb|^2$.

- **Strategy:**
  - Combine the cross-sections (per channel and per sqrt(s)).
  - Then, extract value for $|f_L V_{tb}|^2$ by dividing experimental measurement by theory prediction.
  - Combine values for $|f_L V_{tb}|^2$ and then take square root.
- Assumptions:
  - Assume V_{ts} and V_{td} are negligible either in top production and decay.
  - Assume coupling is left-handed vector coupling (i.e. SM-like kinematics).
  - No assumptions about CKM unitarity.
    - Sensitivity to new physics.
      - Top could be mixing with top partner or other NP particles.

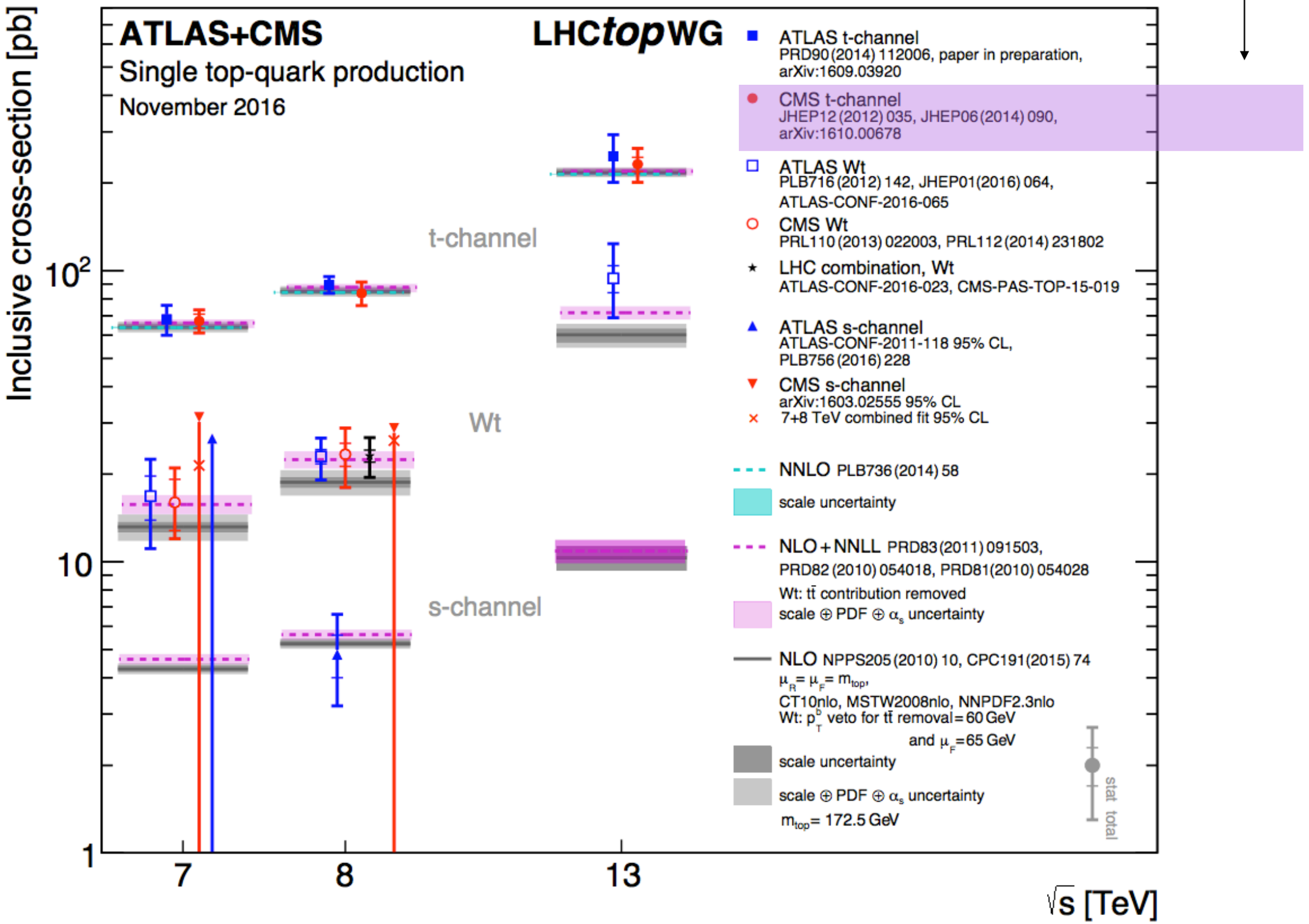
- **Paper draft on going**
  - Includes all published single top measurements at 7 and 8 TeV (Run-I).
  - Theory predictions:
    - Hathor (NLO) for *t*-channel and *s*-channel.
      - Also considers NNLO calculation for t-channels.
    - Kidonakis (NLO+NNLL) for *Wt*.
  - Considers theory uncertainties and their correlations.

Updating summary plots for the LHCtopWG

Coming soon: updated summary plot

Updates:

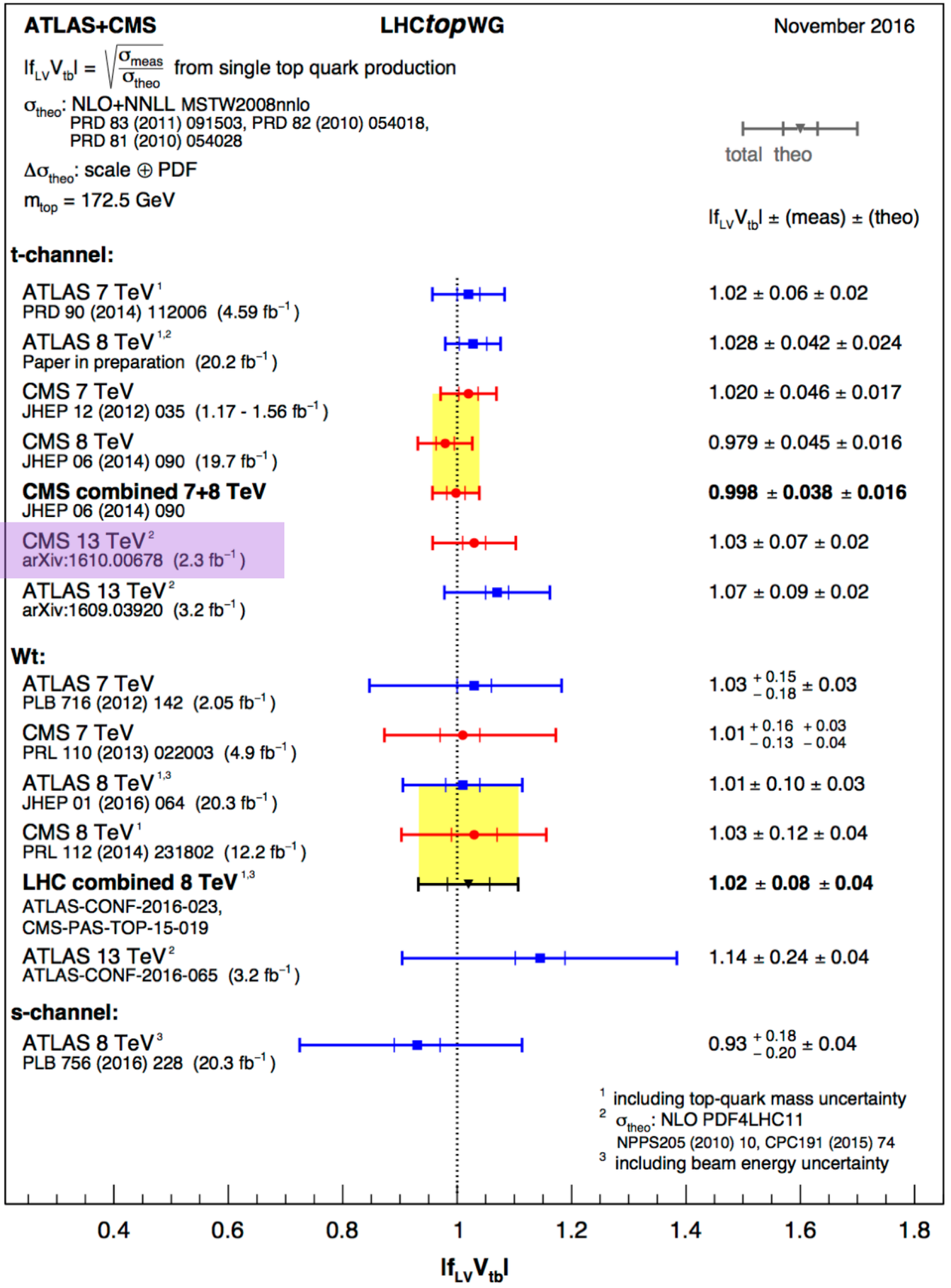
- Add arXiv number (i.e. arXiv:1610.00678) of CMS *t*-channel at 13 TeV.



Coming soon: updated summary plot

Updates:

- Add arXiv number (i.e. arXiv:1610.00678) of CMS *t*-channel at 13 TeV.
- Cosmetics in some reference citations.



Conclusions

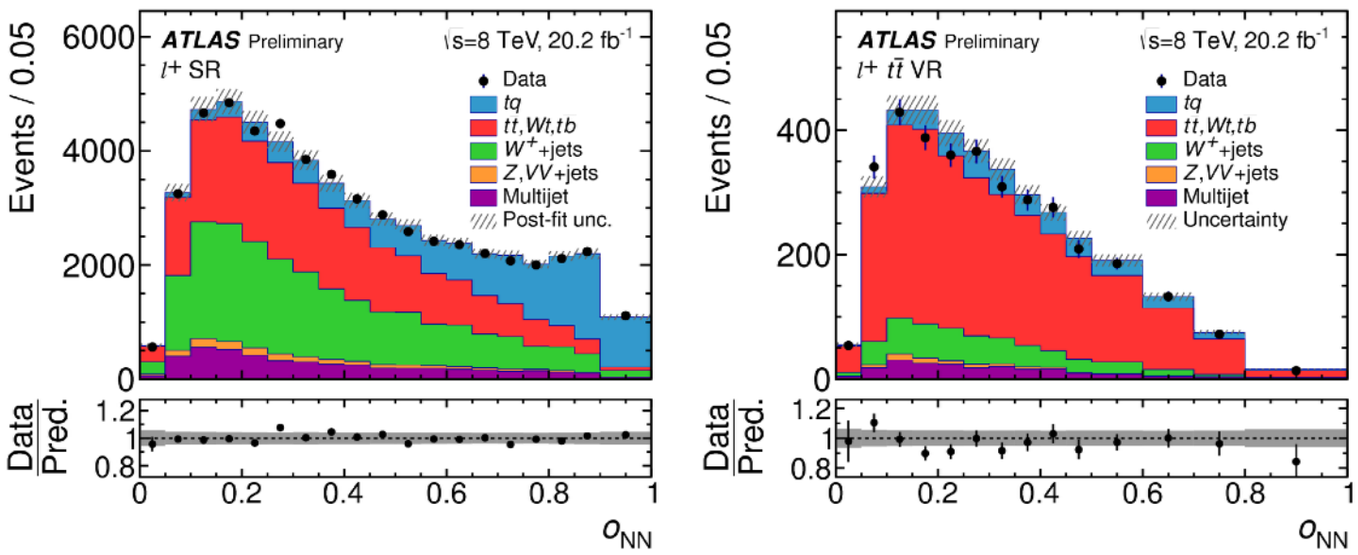
- New public results are available from ATLAS and CMS:
  - Cross section measurements for the *t*- and *Wt* channels at 13 TeV.
  - Cross section measurements for the *t*-channel at 8 TeV.
  - Search for SM and FCNC *tZ(q)* process at 8 TeV.

- On going V_{tb} combination using all Run-I legacy measurements.
  - Additionally, combination of the cross-sections per channel and per sqrt(s).

- Two summary plots will be updated, including the arXiv number of CMS *t*-channel at 13 TeV.

BACKUP

- *t*-channel production at 8 TeV (20.2 fb^{-1}).
- Inclusive and fiducial cross-section measurement independently for top quark and top antiquark.
- Additionally separated into positive and negative lepton charge.
- Events are separated into SRs and VRs based on the number of jets and b-tagged jets.
- Measurement is done in a fiducial phase space close to the experimental one.
- Use NN in order to separate *t*-channel from background.
  - Minimal number of input variables, while keeping sensitivity.
- Signal extraction: maximum likelihood fit.



Good data/MC agreement

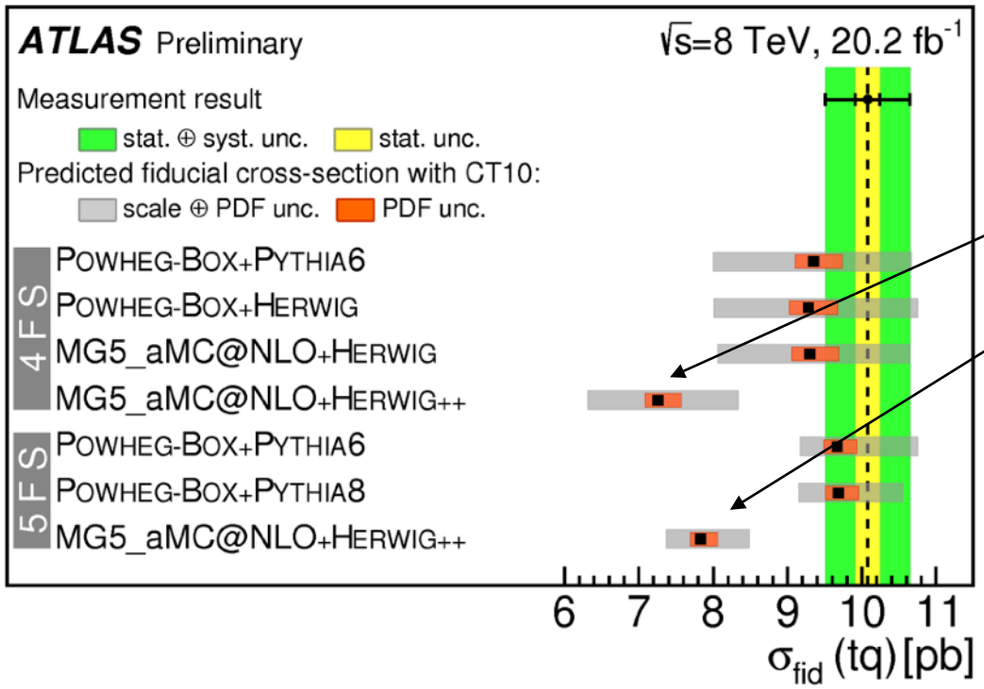
Several uncertainties are reduced for the fiducial cross-section wrt the total cross-section

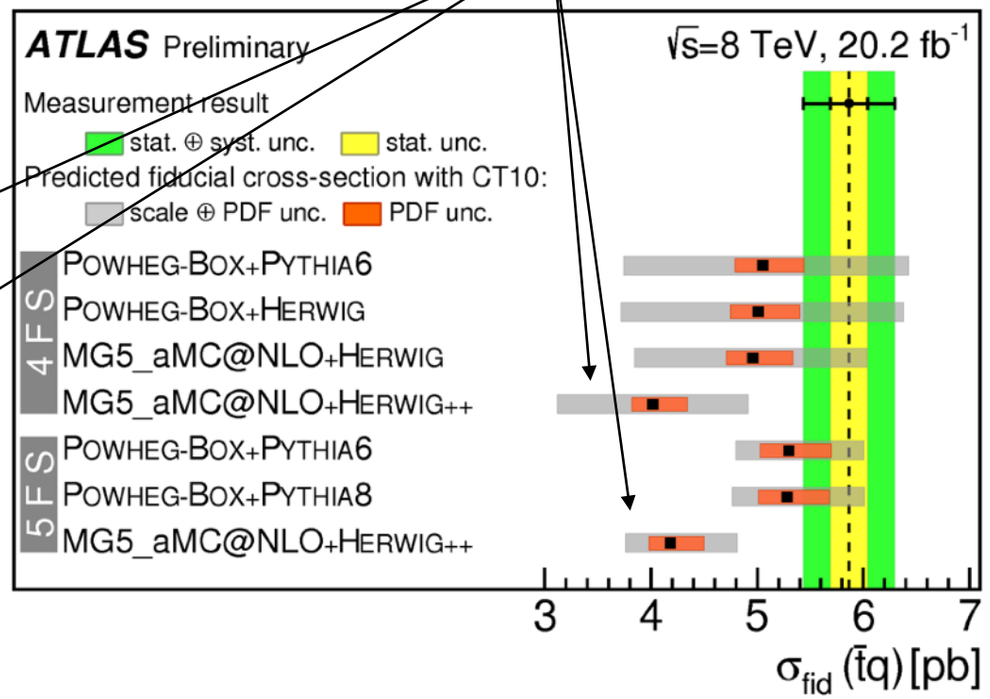
V_{tb} precision: ~4%

Source	$\Delta\sigma_{\text{fid}}(tq) / \sigma_{\text{fid}}(tq)$ [%]	$\Delta\sigma_{\text{fid}}(\bar{t}q) / \sigma_{\text{fid}}(\bar{t}q)$ [%]
Data statistics	± 1.7	± 2.5
Monte Carlo statistics	± 1.0	± 1.4
Background normalisation	< 0.5	< 0.5
Background modelling	± 1.0	± 1.6
Lepton reconstruction	± 2.1	± 2.5
Jet reconstruction	± 1.2	± 1.5
Jet energy scale	± 3.1	± 3.6
Flavour tagging	± 1.5	± 1.8
$E_{\text{T}}^{\text{miss}}$ modelling	± 1.1	± 1.6
$b/\bar{b}$ tagging efficiency	± 0.9	± 0.9
PDF	± 1.3	± 2.2
tq ($\bar{t}q$) NLO matching	± 0.5	< 0.5
tq ($\bar{t}q$) parton shower	± 1.1	± 0.8
tq ($\bar{t}q$) scale variations	± 2.0	± 1.7
$t\bar{t}$ NLO matching	± 2.1	± 4.3
$t\bar{t}$ parton shower	± 0.8	± 2.5
$t\bar{t}$ scale variations	< 0.5	< 0.5
Luminosity	± 1.9	± 1.9
Total systematic	± 5.6	± 7.3
Total (stat. + syst.)	± 5.8	± 7.8

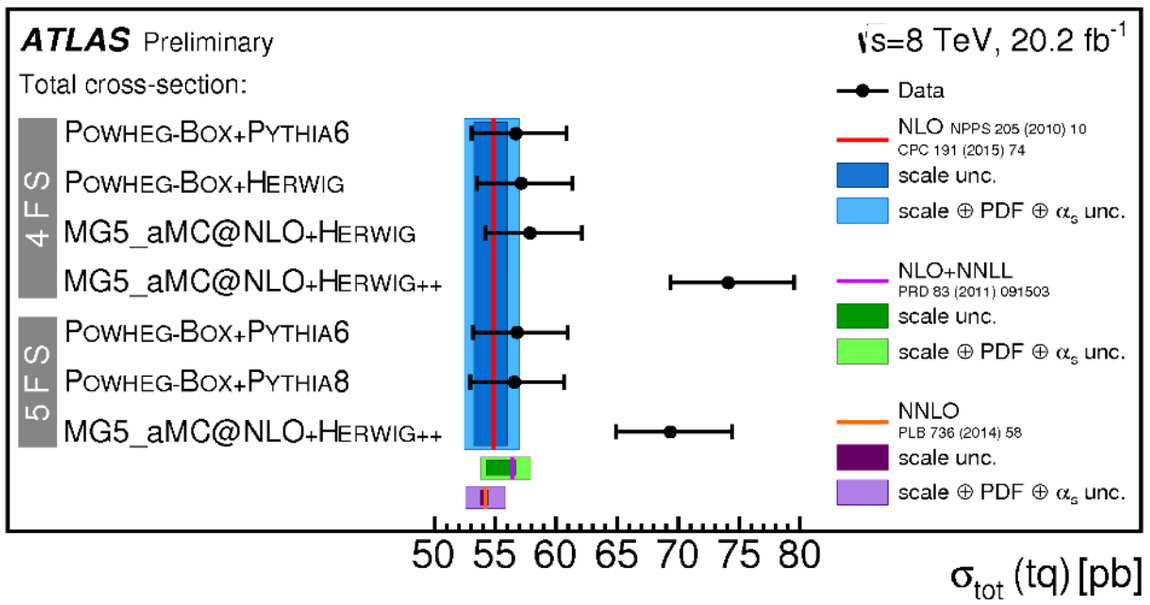
- Comparison with different MC generators.

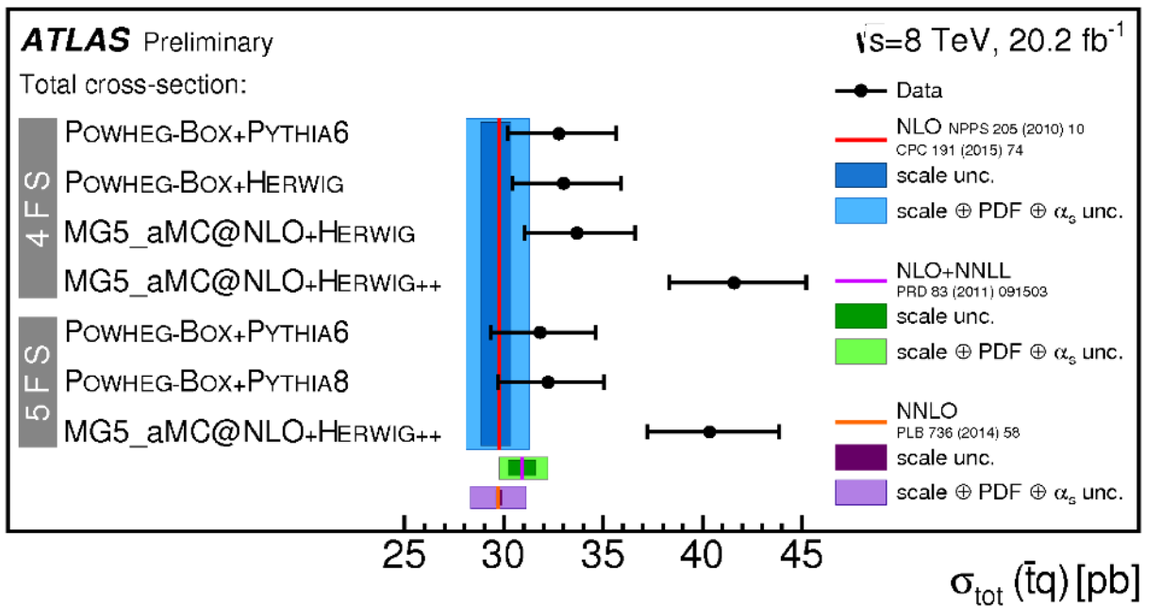
Herwig++ has too soft jets → lower acceptance



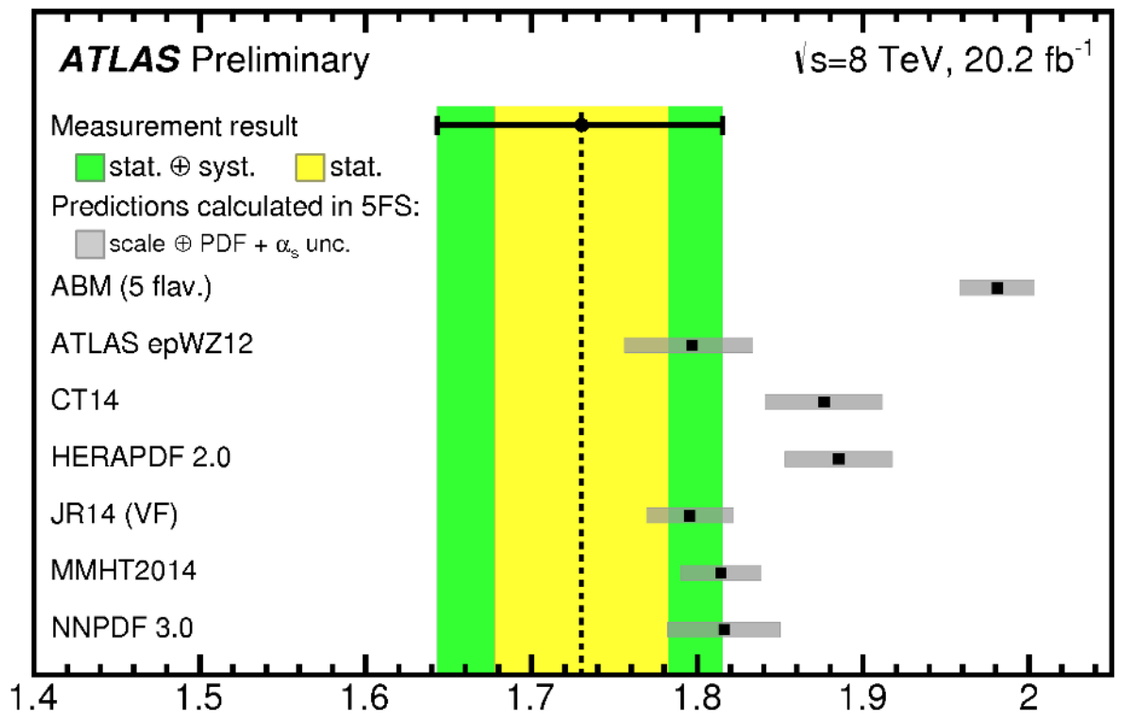


- Extrapolated cross-section





- Cross-section ratio

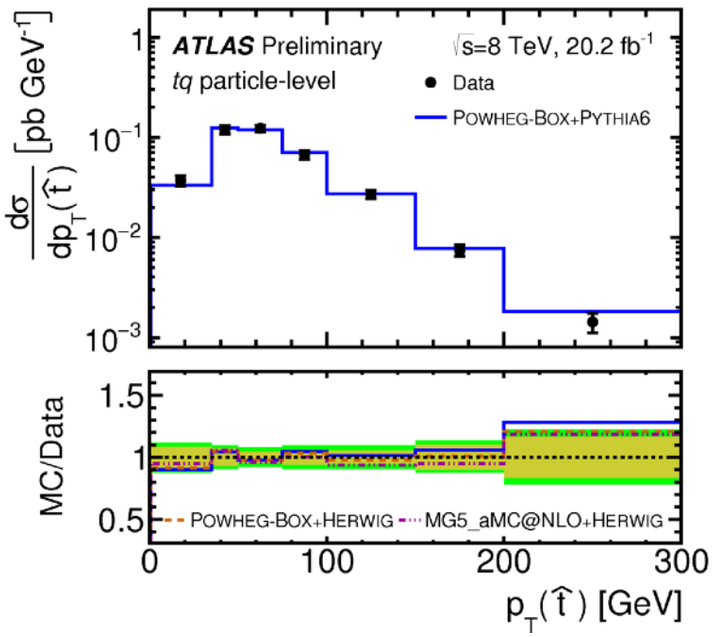


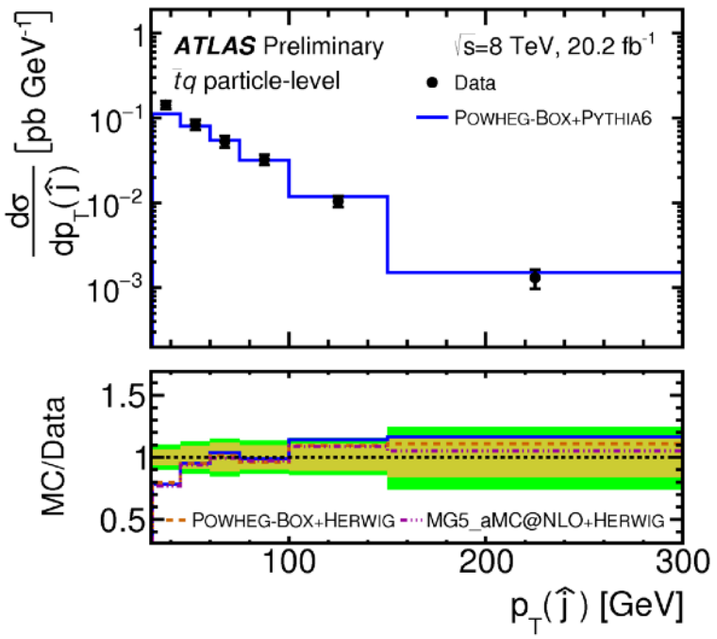
Source	$\Delta R_t / R_t$ [%]
Data statistics	± 3.0
Monte Carlo statistics	± 1.8
Background modelling	± 0.7
Jet reconstruction	± 0.5
$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	± 0.6
tq ($\bar{t}q$) NLO matching	−0.5/ + 0.9
$t\bar{t}$ NLO matching	± 2.3
$t\bar{t}$ parton shower	± 1.7
PDF	± 0.7
Total systematic	± 3.8
Total (stat. + syst.)	± 4.9

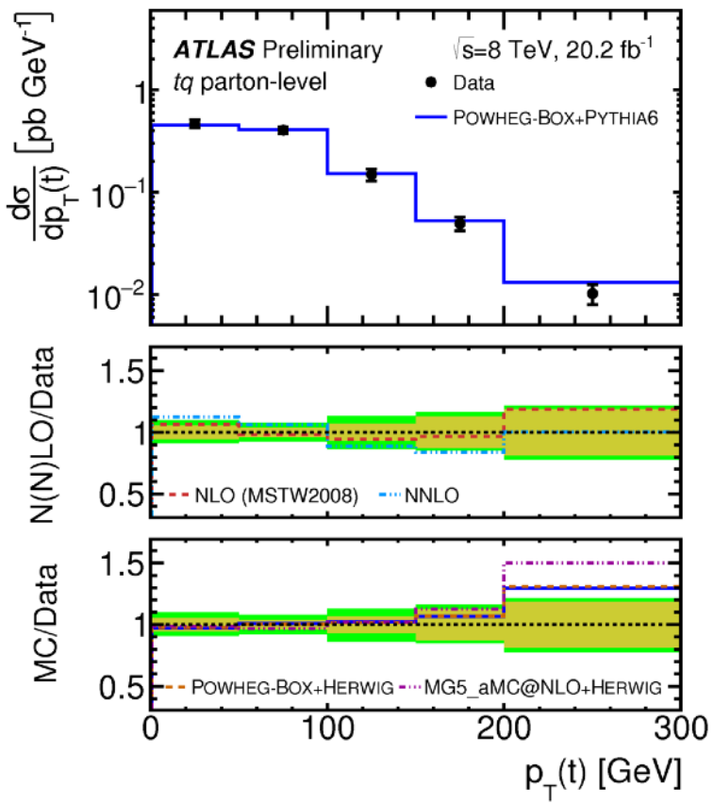
Using the extrapolated cross-section:

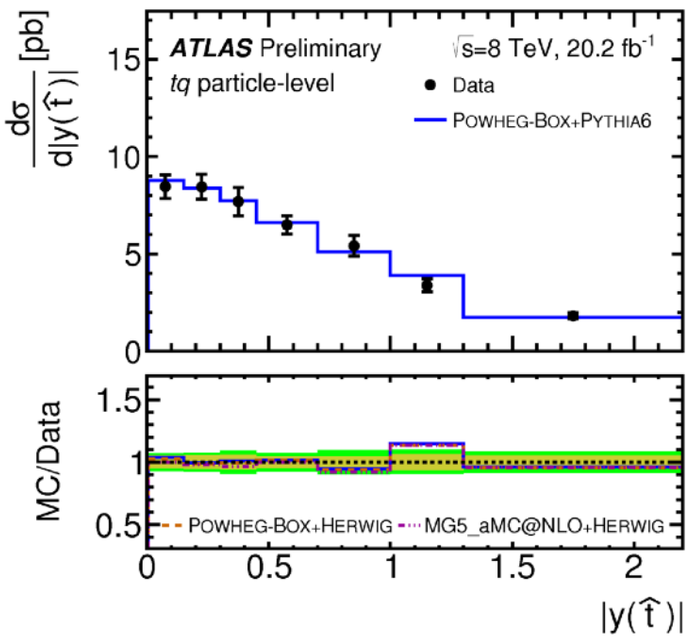
R_t = 1.73 ± 0.05 (stat.) ± 0.07 (syst.)

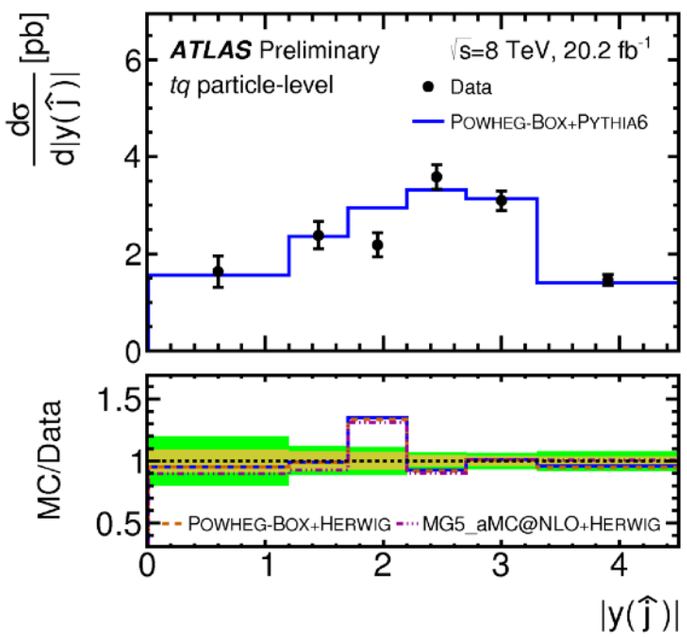
- Differential cross-sections at parton and particle level.
  - Use NN without $|\eta_j|$.

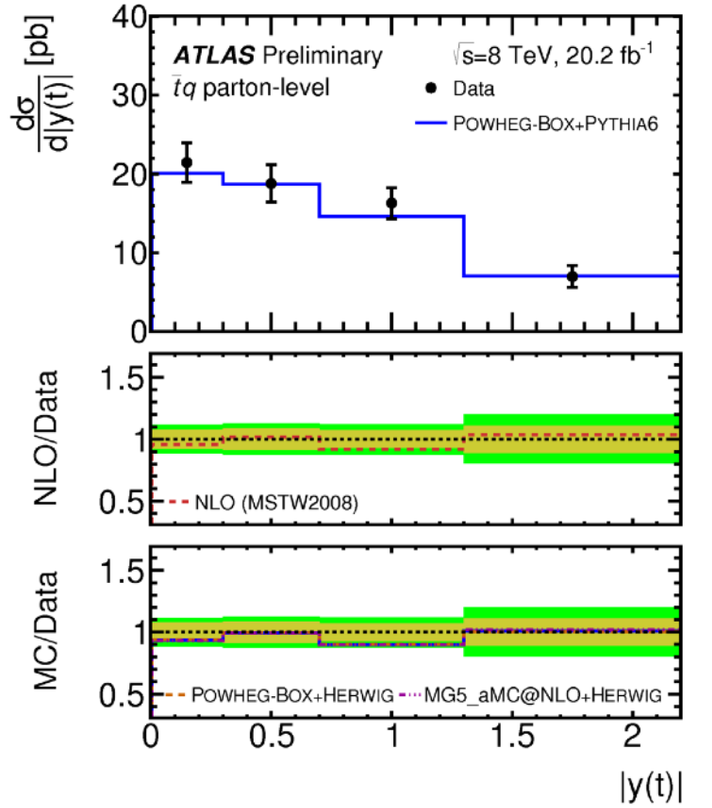












- Measurements to improve the MC!