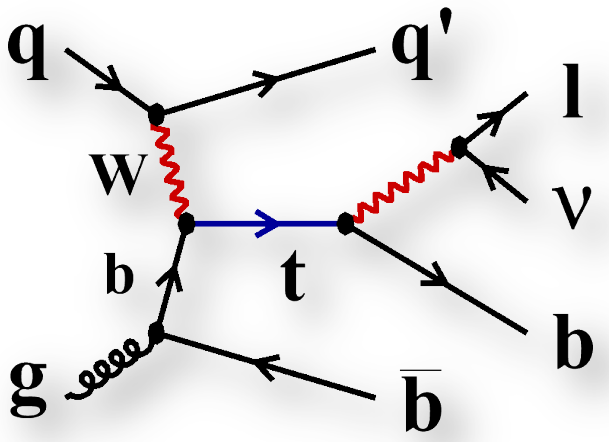
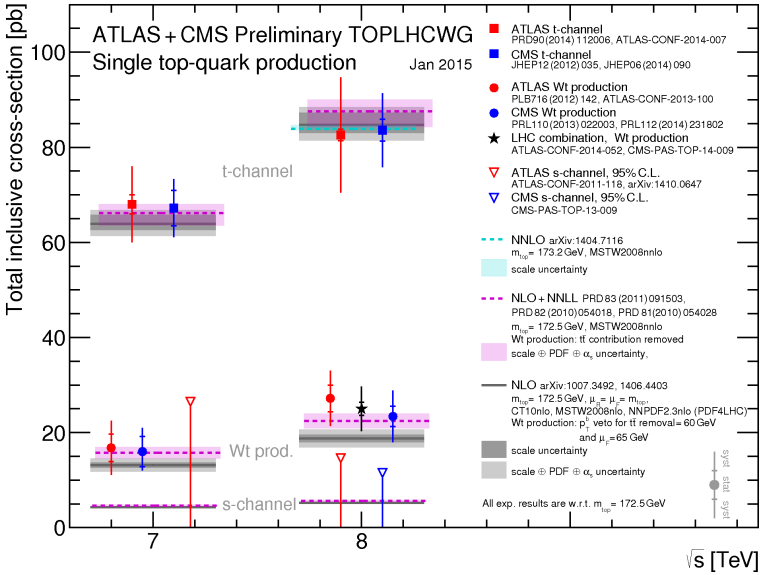
Overview on inclusive and differential single top-quark cross-sections and results on $|V_{tb}|$





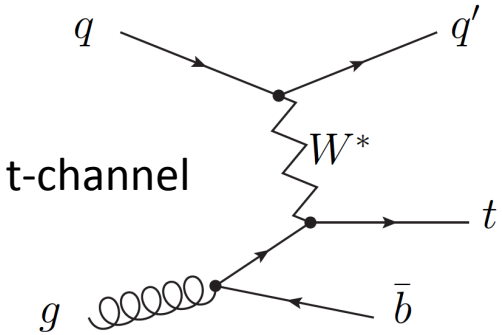
Kathrin Becker, University of Oxford
on behalf of the ATLAS and CMS collaborations

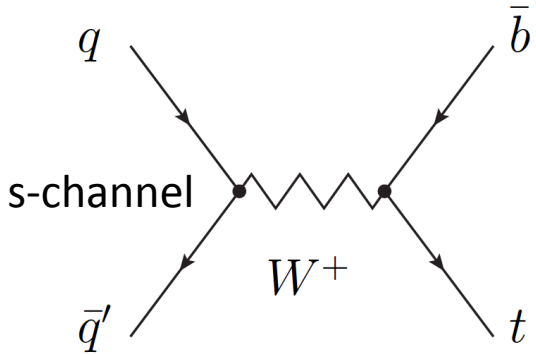
UNIVERSITY OF OXFORD

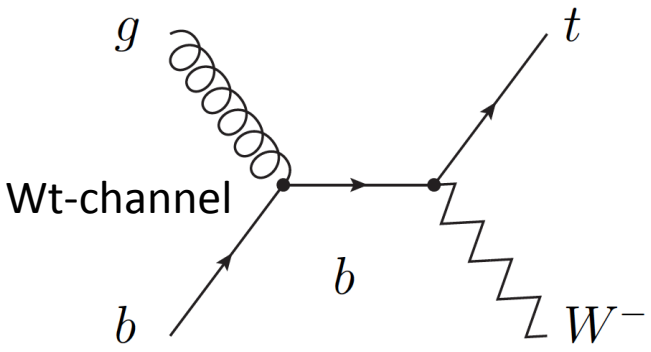
SM@LHC 2015, Florence, 22.04.2015

Single top-quark production

- Production via the weak interaction







$\sigma_{7\ TeV}$ = 64 pb (4.6% unc.)
$\sigma_{8\ TeV}$ = 85 pb (4.4% unc.)

PRD 86 (2012) 010001

$\sigma_{7\ TeV}$ = 4.6 pb (4.3% unc.)
$\sigma_{8\ TeV}$ = 5.6 pb (3.6% unc.)

PRD 82 (2010) 054018

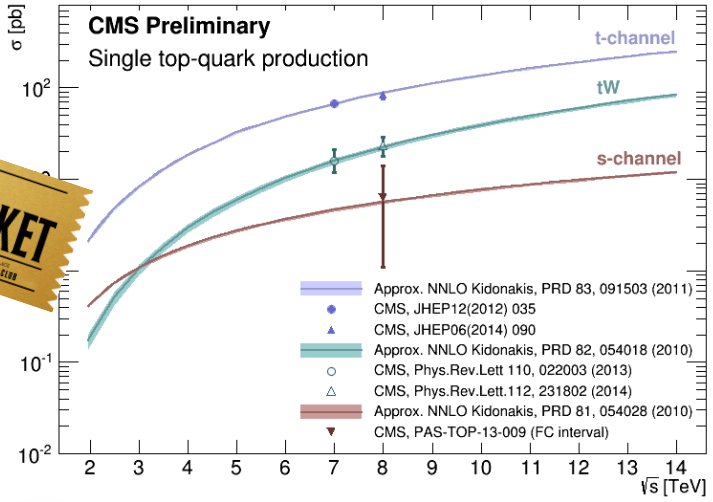
$\sigma_{7\ TeV}$ = 16 pb (7.0% unc.)
$\sigma_{8\ TeV}$ = 22 pb (6.7% unc.)

PRD 81 (2010) 054028

- Final state: Lepton + $E_{T,miss}$ + two to three jets (one or two b-tagged)
- In case of Wt production: Dilepton + $E_{T,miss}$ + one b-tagged jet
- Main backgrounds are W+jets production and top-quark pair production

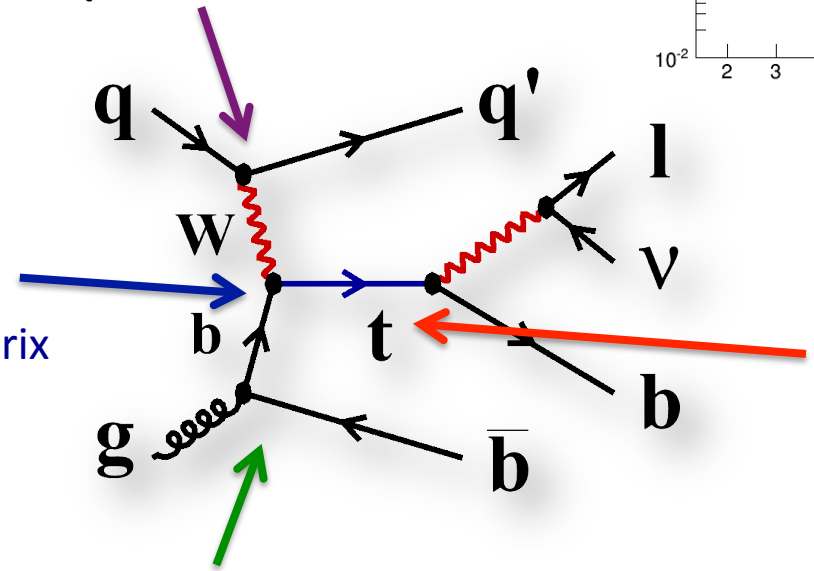
t-channel single top-quark production

- Single top quark production via t-channel: largest cross section @LHC
- Checks of the Standard Model:



Ratio of u- and d-quark PDF

Measure $R_t = \sigma_t(t)/\sigma_t(\bar{t})$



Direct measurement of $|V_{tb}|^2$ (α cross section)

Unitarity test of CKM matrix

Measurement of $\sigma_t(t+\bar{t})$, extract $|V_{tb}|$

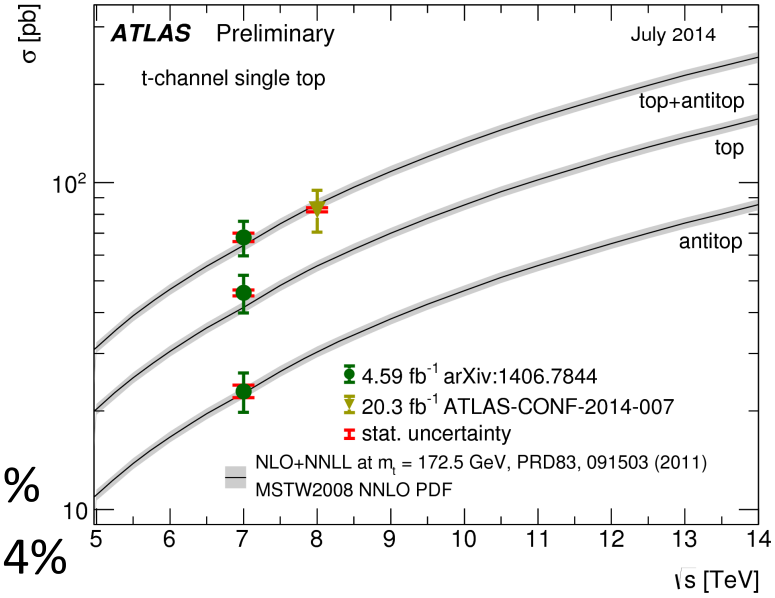
Top quark properties: Polarization, p_T, rapidity

Measure differential distributions

Test of the b-quark PDF

Cross-section measurements

ATLAS and CMS worked consistently in Run 1 on the t-channel single top-quark cross sections.



Latest results:

- CMS, 8 TeV, 19.7 fb^{-1}: **JHEP 06 (2014) 090**
  - $\sigma(tq) = 53.8 \pm 1.5$ (stat.) ± 4.4 (syst.) pb -> 9%
  - $\sigma(\bar{t}q) = 27.6 \pm 1.3$ (stat.) ± 3.7 (syst.) pb -> 14%
  - $\sigma(tq+\bar{t}q) = 83.6 \pm 2.2$ (stat.) ± 7.4 (syst.) pb -> 9%
- ATLAS, 7 TeV, 4.59 fb^{-1}: **PRD 90, 112006 (2014)**
  - $\sigma(tq) = 46 \pm 1$ (stat.) ± 6 (syst.) pb -> 12%
  - $\sigma(\bar{t}q) = 23 \pm 1$ (stat.) ± 3 (syst.) pb -> 16%
  - $\sigma(tq+\bar{t}q) = 68 \pm 2$ (stat.) ± 8 (syst.) pb -> 12%
- All results agree well with the SM prediction within the total uncertainty.

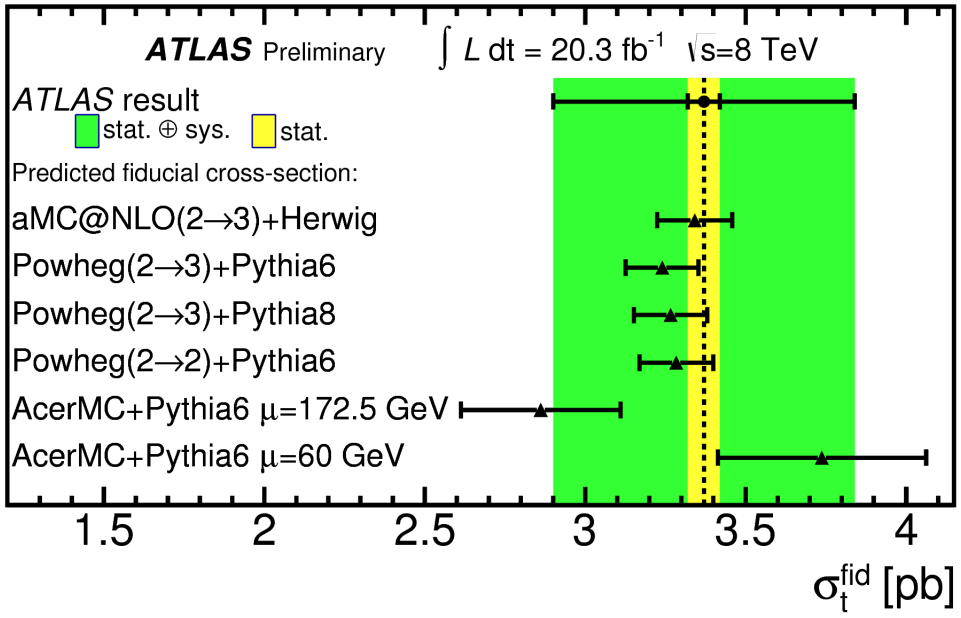
Dominant uncertainties:
- Jet energy scale (forward jets)
- Signal modeling

Fiducial cross section

- Fiducial cross section reduces the extrapolation uncertainties from the measured region to the inclusive region, which are determined from Monte Carlo
- Cross section measured within the detector acceptance
- Fiducial region defined as signal region, but using particle-level objects
- $\sigma_{fid}(tq+\bar{t}q) = 3.37 \pm 0.05\ (stat.) \pm 0.48\ (syst.)$ pb -> 14% uncertainty

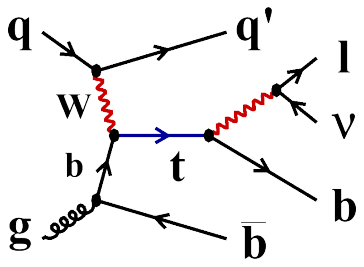
- Reduction on signal modeling uncertainty of about 3%
- Provides feedback to the generator community
- Fiducial cross section can be extrapolated to the inclusive cross section using the acceptance of the different generators and the BR(t->Wb)

ATLAS-CONF-2014-007



Top-quark to top-antiquark production

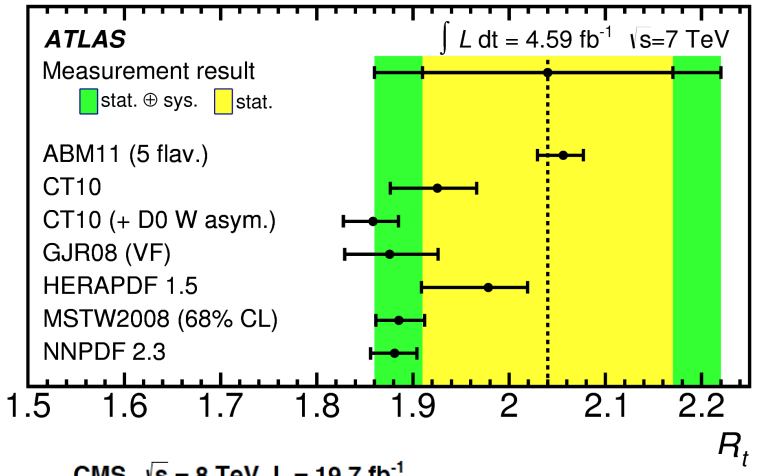
- Charge of the top quark corresponds to type of initial light quark

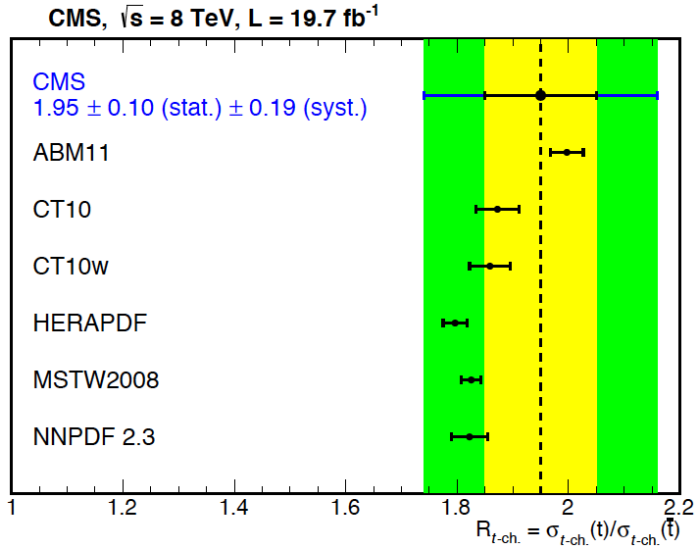


- $R_t = \sigma_t(t)/\sigma_t(\bar{t})$ sensitive to ratio of u- and d-quark PDFs
- Momentum fraction of light quarks in single top-quark events: $0.02 < x < 0.5$

Results on ratio R_t:

- $R_t = 2.04 \pm 0.13$ (stat.) ± 0.12 (syst.), 8.7%, ATLAS, 7 TeV, 4.59 fb^{-1} **PRD 90, 112006 (2014)**
- $R_t = 1.95 \pm 0.10$ (stat.) ± 0.19 (syst.), 10.9%, CMS, 8 TeV, 19.7 fb^{-1}: **JHEP 06 (2014) 090**
- Both results are comparable even though done at different energies
- Measurements can profit from more data





t-channel single top-quark production

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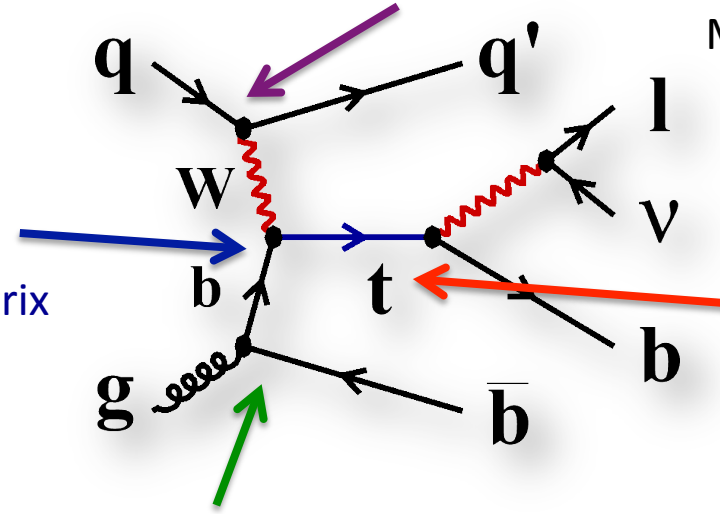
- Checks of the Standard Model:

Ratio of u- and d-quark PDF

Measure $R_t = \sigma_t(t)/\sigma_t(\bar{t})$



Direct measurement of $|V_{tb}|^2$ (α cross section)

Unitarity test of CKM matrix

Measurement of $\sigma_t(t+\bar{t})$, extract $|V_{tb}|$

Test of the b-quark PDF

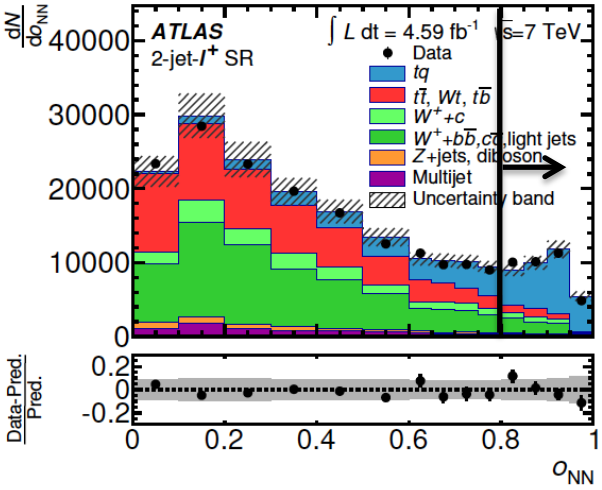
Top quark properties: Polarization, p_T, rapidity

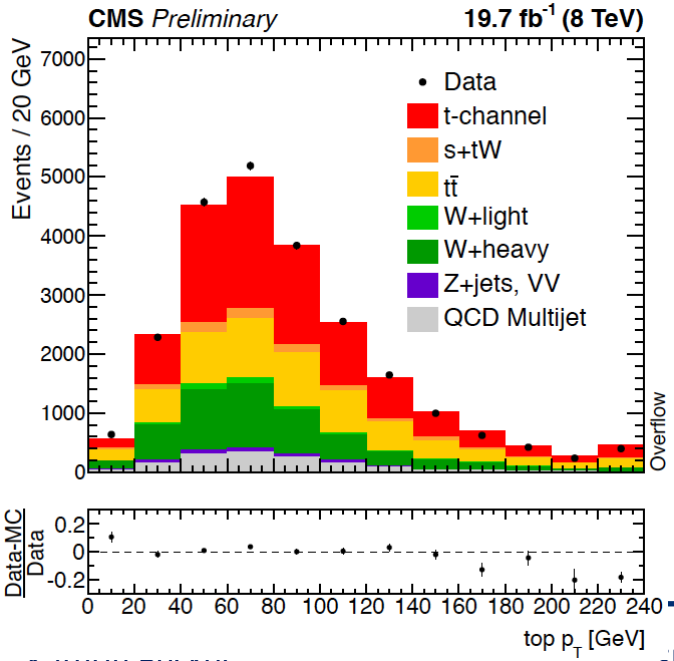
Measure differential distributions

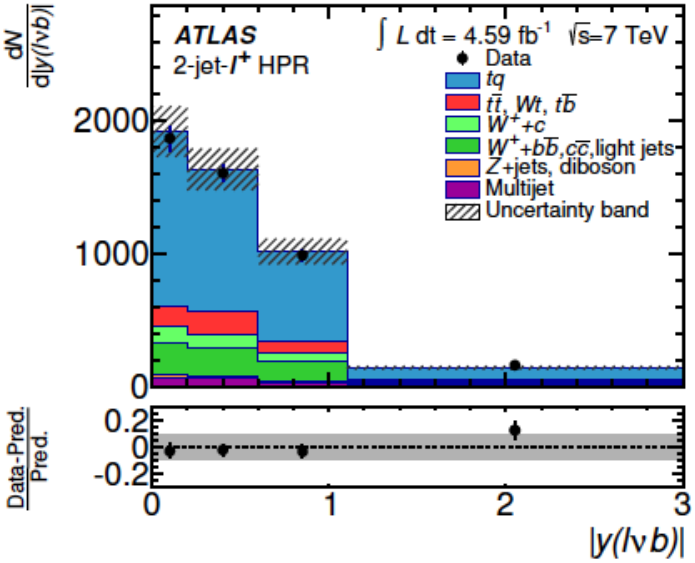
t-channel events in LHC Run 1:
7 TeV: ~5500 events (ATLAS, 4.6 fb^{-1})
8 TeV: ~10000 events (CMS, 19.7 fb^{-1})

Differential cross section

- Use a multivariate discriminant to define a high purity region
- Measure differential cross section as function of $p_T(t)$, $p_T(\bar{t})$, $|y(t)|$, and $|y(\bar{t})|$ (ATLAS) or $p_T(t+\bar{t})$ and $|y(t+\bar{t})|$ (CMS)
- So far, unfolded to parton-level top quark







Reconstructed distributions

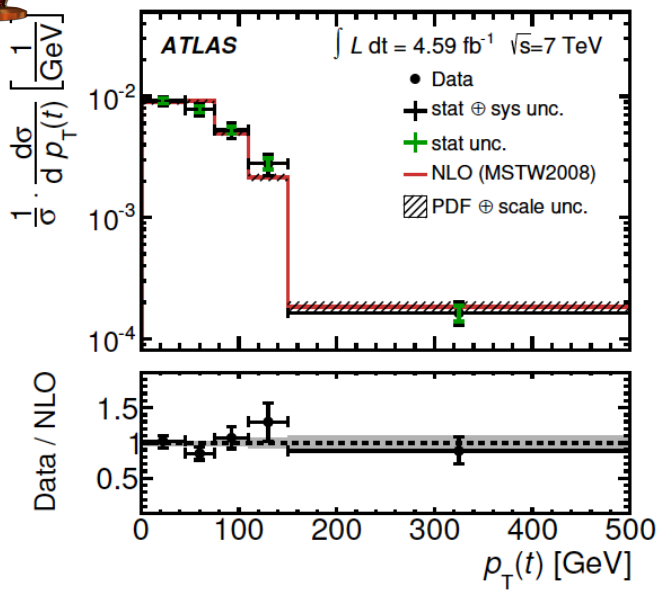
ATLAS, 7 TeV, 4.59 fb^{-1}
PRD 90, 112006 (2014)
CMS, 8 TeV, 19.7 fb^{-1}
CMS PAS TOP-14-004

Results on differential cross sections

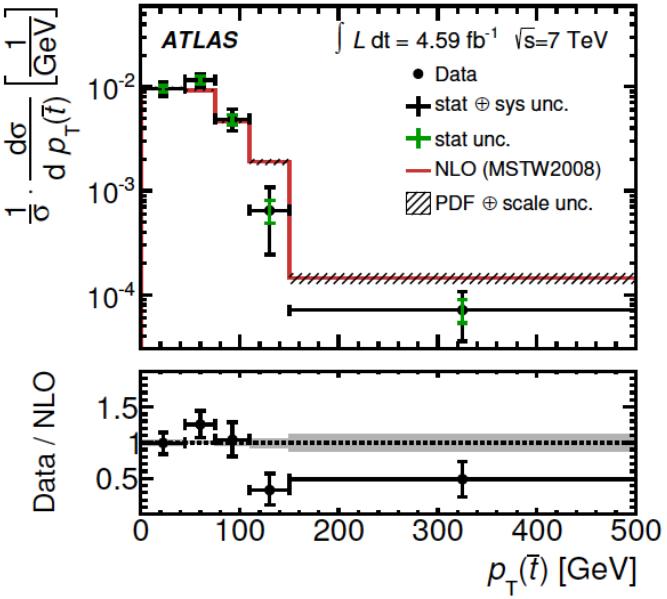
Top Quark

Top Antiquark

p_T



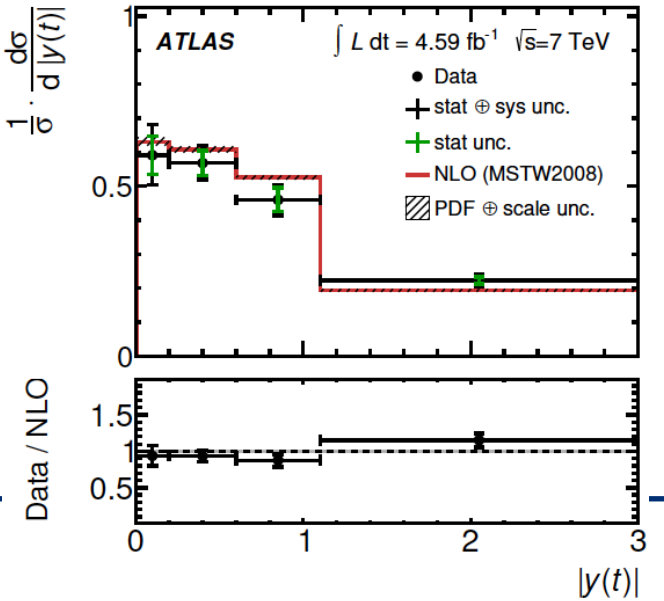
9-22%



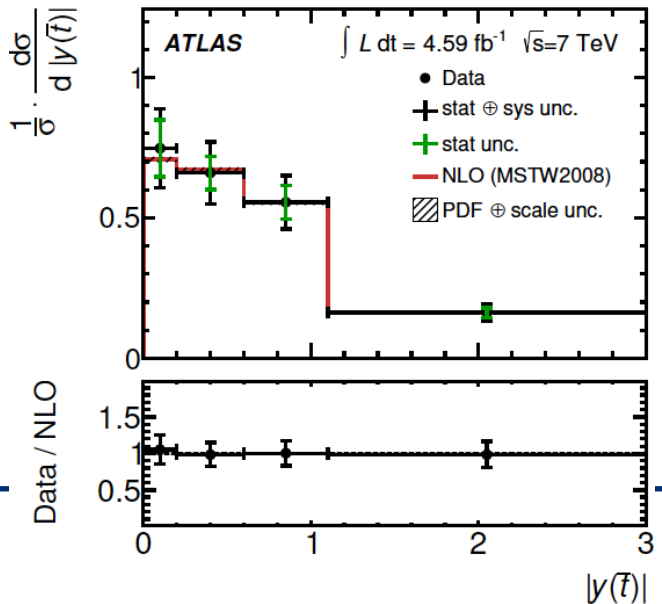
15-67%

ATLAS, 7 TeV, 4.59 fb^{-1} **PRD 90, 112006 (2014)**

|y|

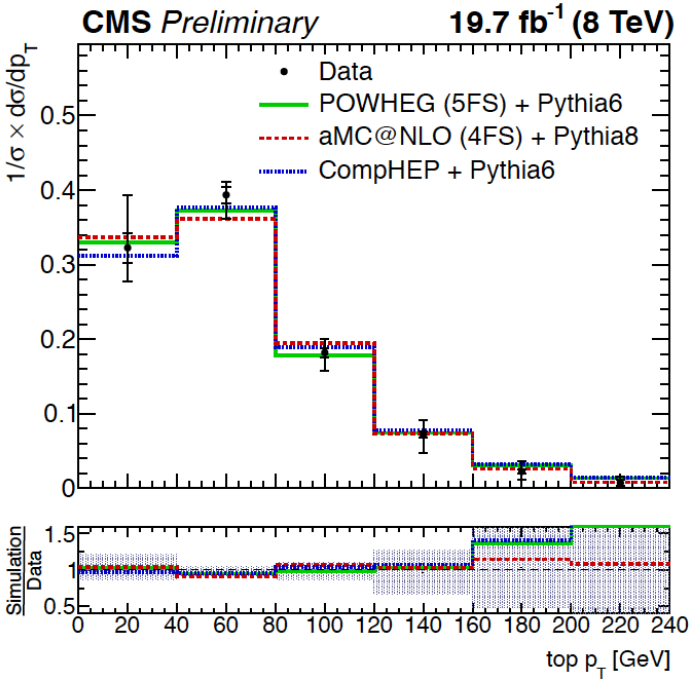


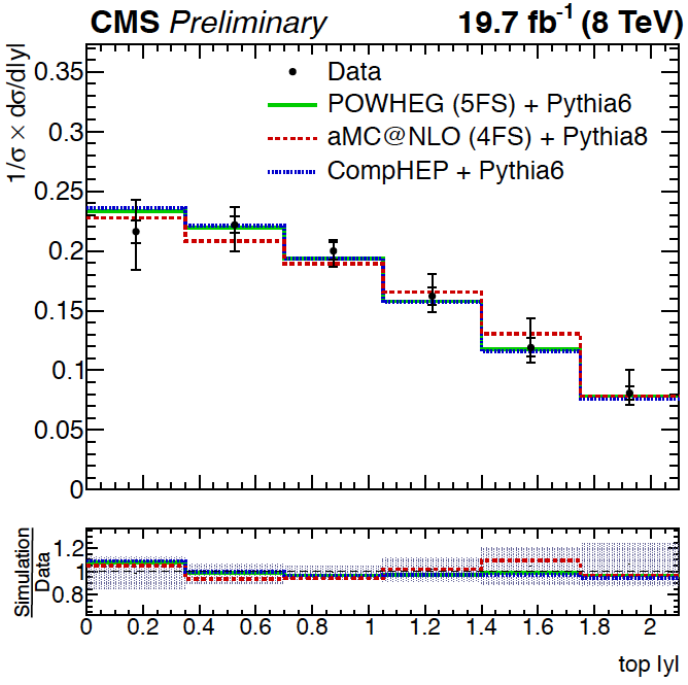
8.5-15%



17-19%

Results on differential cross sections



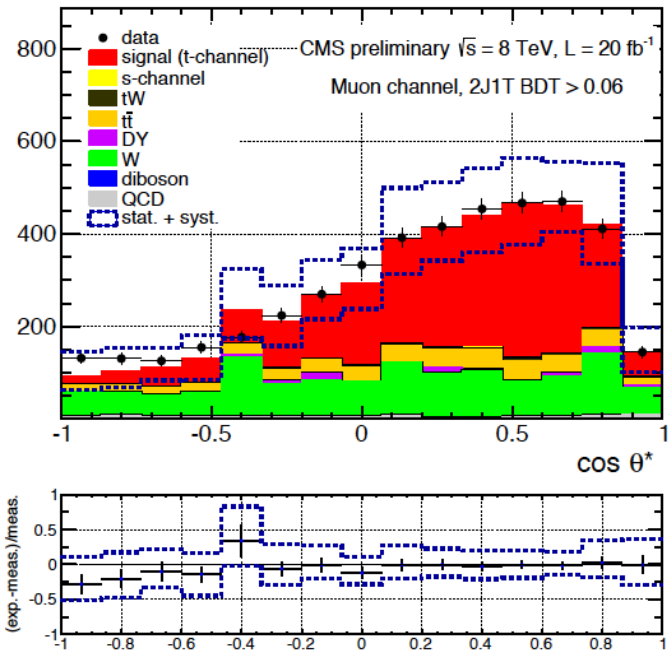


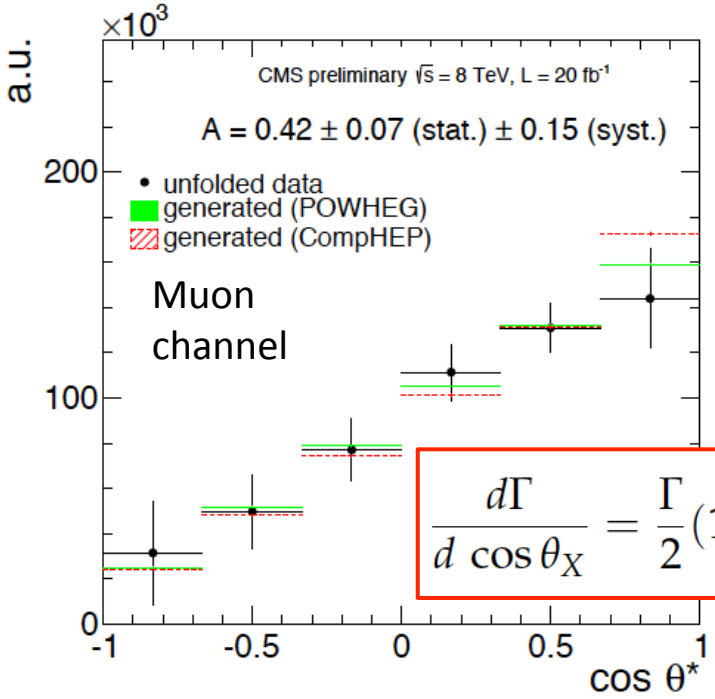
CMS, 8 TeV, 19.7 fb^{-1}

CMS PAS TOP-14-004

- All distributions from ATLAS and CMS agree well with SM predictions
- Measurements still limited by data statistics and background modelling -> precision at best around 10%

Polarization of the top quark





CMS, 8 TeV, 20 fb^{-1}

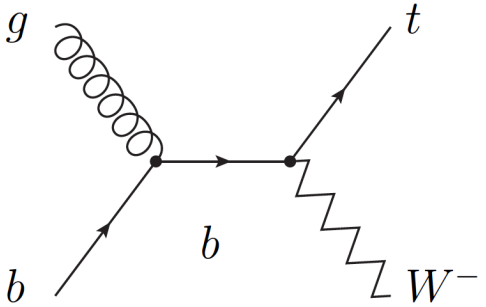
CMS PAS TOP-13-001

$$\frac{d\Gamma}{d\cos\theta_X} = \frac{\Gamma}{2}(1 + P_t \alpha_X \cos\theta_X)$$

- CMS measured also the top quark polarization in single top-quark events -> 100% polarized, V-A coupling structure
- cos θ*(lepton, untagged jet) is unfolded to access the top quark spin asymmetry. e+μ combined result: $A_l = 0.41 \pm 0.06$ (stat.) ± 0.16 (syst.) -> 41%
- Polarization: $P_t = 2 A_l/\alpha_l = 0.82 \pm 0.12$ (stat.) ± 0.32 (syst.) assuming that the spin analyzing power of the lepton α_l is 100%.
- Uncertainty is dominated by systematic uncertainties

Cross-section of W-associated single top-quark production

- Both, ATLAS and CMS measure Wt production in the dilepton final state with one additional b-tagged jet and in case of ATLAS a significant amount of $E_{T,miss}$
- Boosted Decision Trees are trained to separate the signal from the dominant $t\bar{t}$ background
- Important variables:
  - number of loose jets ($p_T(j) > 20$ GeV, $|\eta| < 4.9$)
  - vector sum of all transverse momenta in event p_T^{sys}

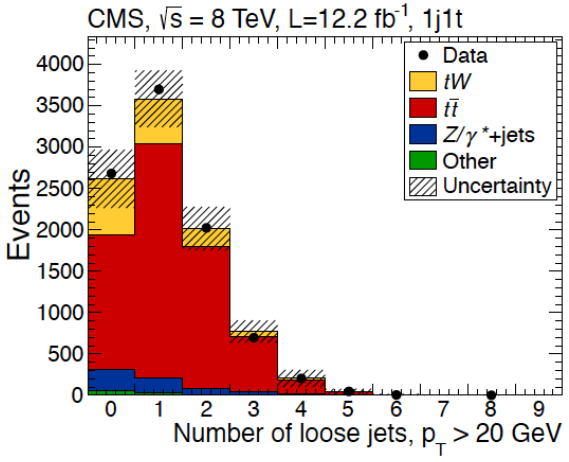


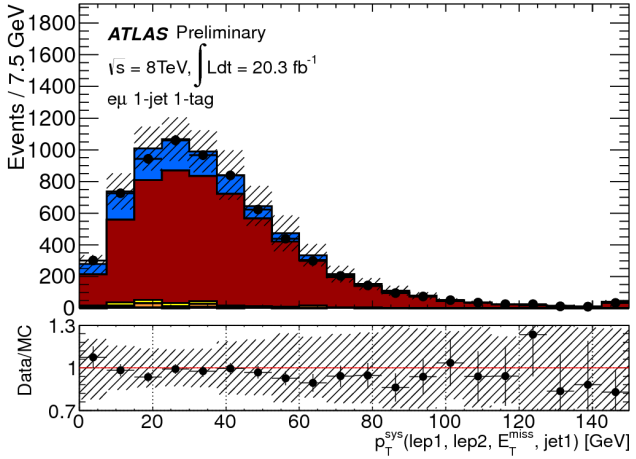
CMS, 8 TeV, 12.2 fb^{-1}

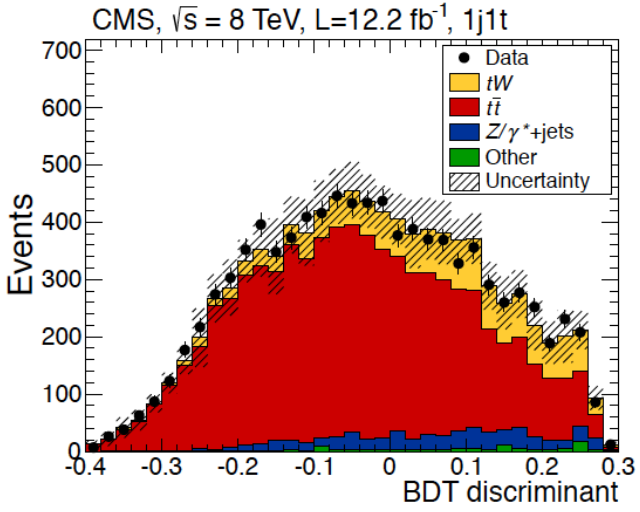
PRL 112 (2014) 231802

ATLAS, 8 TeV, 20.3 fb^{-1}

ATLAS-CONF-2013-100

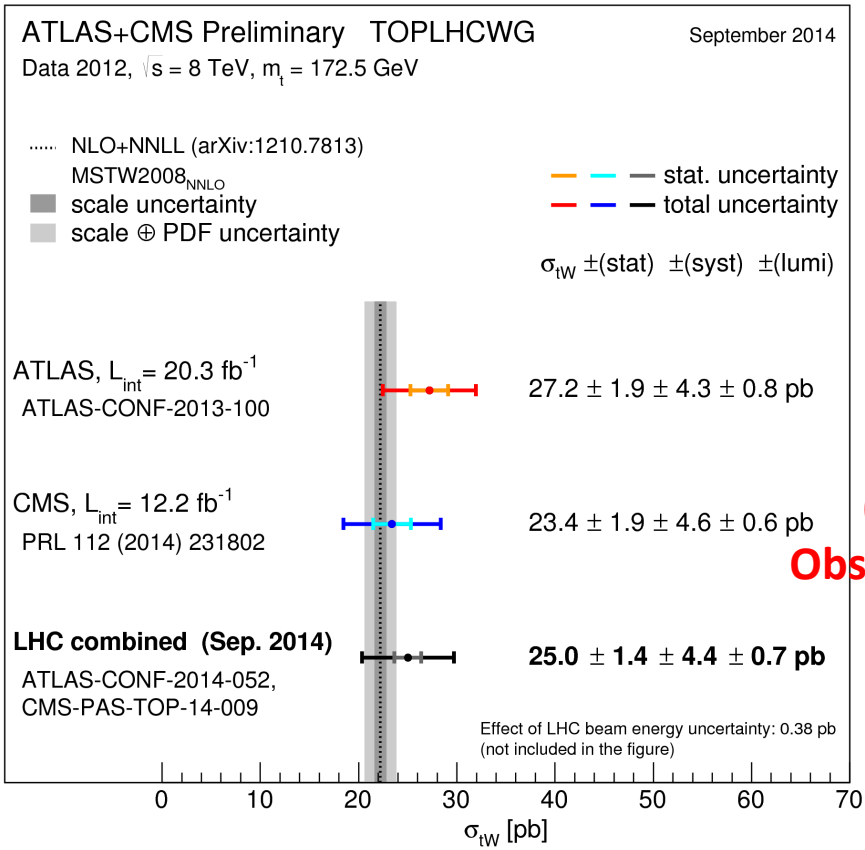






Cross-section of W-associated single top-quark production

- Uncertainty on inclusive cross section of 23% (21%) for CMS (ATLAS), dominated by systematic uncertainties
  -> $t\bar{t}$ and signal modeling



Extraction of $|V_{tb}|$

Assumptions for $|V_{tb}|$ extraction from the t-channel and Wt-channel cross sections:

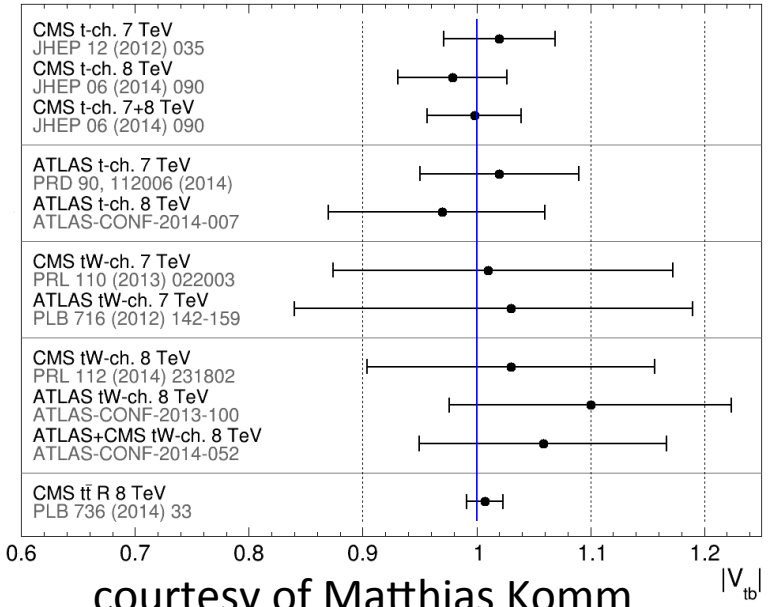
- $|V_{tb}| >> |V_{td}|, |V_{ts}|$
- BR(t->Wb) = 1
- Wtb interaction is a SM-like left-handed weak coupling

Determination of $|V_{tb}|$:

- $|V_{tb}|^2 = \sigma(tq+\bar{t}q)/\sigma_{theo}(tq+\bar{t}q)$
- CMS, 7 and 8 TeV combined, t-channel:
  $|V_{tb}| = 0.998 \pm 0.038$ (exp) ± 0.016 (theo) -> 4.1%
- ATLAS, 7 TeV, t-channel:
  $|V_{tb}| = 1.02 \pm 0.06$ (exp) ± 0.02 (theo) -> 6.2%

Limit:

- Flat prior between 0 and 1
- Assumption, that $|V_{tb}| \leq 1$
- CMS: $|V_{tb}| > 0.92$ at 95% C.L.
- ATLAS: $|V_{tb}| > 0.88$ at 95% C.L.



courtesy of Matthias Komm

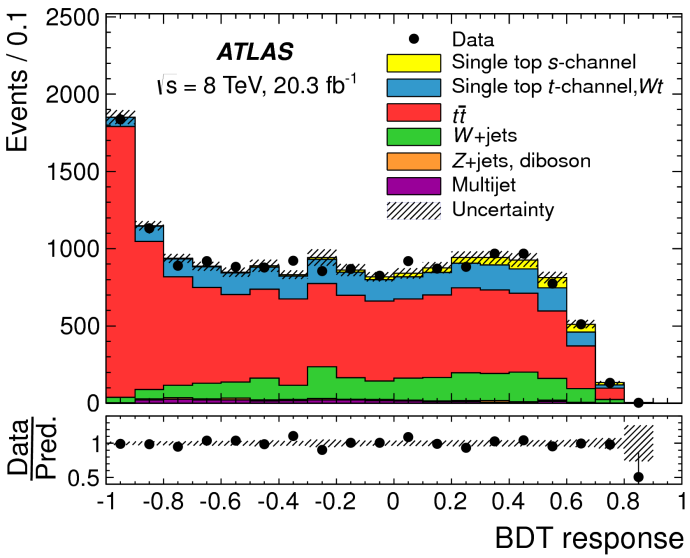
- Additional measurement of $|V_{tb}|$ in $t\bar{t}$ events via: $\mathcal{R}_b = \mathcal{B}(t \to Wb) / \mathcal{B}(t \to Wq)$
- Most precise value, **BUT** assumption of unitarity of the CKM matrix

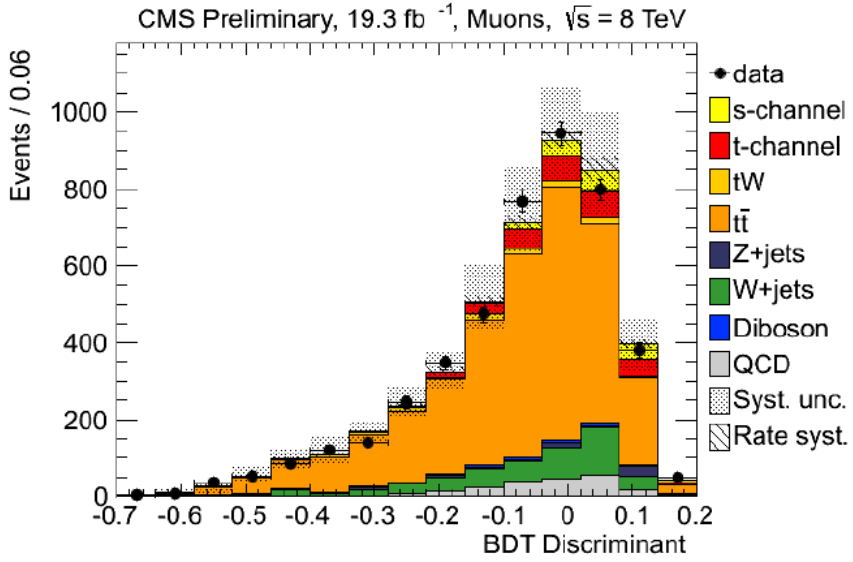
s-channel single top-quark production

- Due to the small cross section of s-channel single top-quark production, there has been no evidence of the production in LHC Run 1 for the time being
- Both ATLAS and CMS have performed a search with the full dataset at 8 TeV
- BDTs are trained to separate signal from background
- The observed (expected) significances are 0.7 (0.9) for CMS and 1.3 (1.4) for ATLAS
- Upper limits are set on the cross section of 11.5 pb (CMS) or 14.6 pb (ATLAS) at 95% C.L.

ATLAS, 8 TeV, 20.3 fb^{-1} **PLB 740 (2015) 118**

CMS, 8 TeV, 19.3 fb^{-1} **CMS PAS TOP-13-009**





Prospects for LHC Run 2

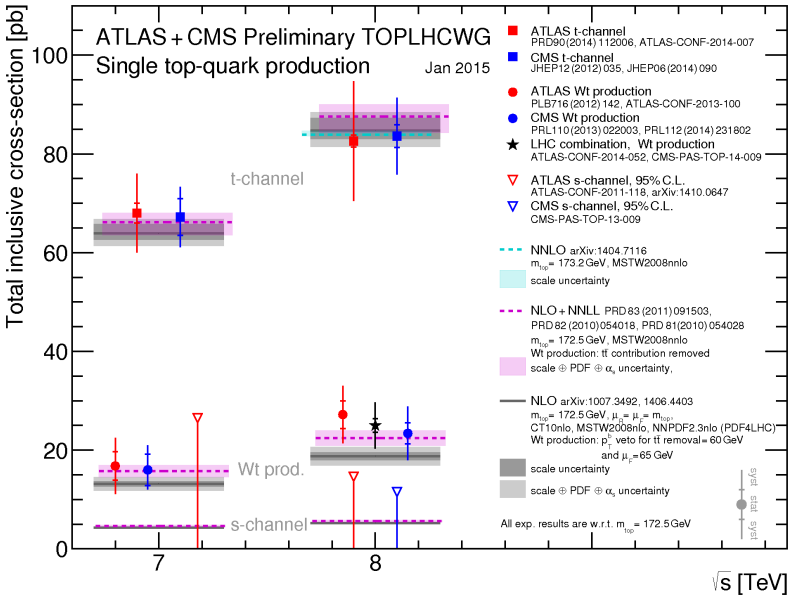
Cross section ratios of 13 TeV to 8 TeV:

	13/8 TeV
t-channel	2.6
Wt-channel	3.2
s-channel	2.0
$t\bar{t}$	3.3

- t-channel:
  - Measurements of top-quark properties will gain from improved statistics
    -> more bins
    -> smaller statistical uncertainty
  - Maybe possible to look at the spectator b-quark
- Wt-channel
  - Will still be challenging as $t\bar{t}$ background increases with the same fraction
  - BUT will profit from more statistics
- s-channel:
  - Evidence or observation with more luminosity?
    -> will remain tough

Conclusion

- Both ATLAS and CMS have performed extensive measurements of single top-quark production in Run 1
- In t-channel single top-quark production an uncertainty ~10% has been achieved for the inclusive cross section
- High statistics allow separate measurements of top-quark and top-antiquark production as well as differential measurements of top-quark properties
- First fiducial measurements have been performed
- Wt-channel single top-quark production has been observed for the first time
- Run 2 will see improvements of current as well as new exciting measurements



BACK - UP

Details on the fiducial region used in ATLAS-CONF-2014-007

- Stable particles = particles with a lifetime > 30 ps
- Particle-level leptons (e, μ and neutrinos):
  - reject leptons from hadronic decays
  - request a W boson decay
  - accept leptons from τ decays in W boson decay
  - e, μ are dressed with photons within a cone of $\Delta R < 0.1$
- E_T^{miss} is the vectorial of the selected neutrinos
- Particle-level jets:
  - reconstructed using Anti-k_t algorithm with the FASTJET package with a width of R=0.4
  - all stable particles are used for clustering except for the selected leptons
  - b-tagging is done by B-Hadron matching within a jet
- A lepton overlap removal is applied if $\Delta R(\text{jet,lepton})<0.4$ (as for reconstructed selection
- All cuts on the reconstructed phase space are also applied to the fiducial phase space

Details on the parton-level top-quark definitions in ATLAS and CMS

- Both, ATLAS and CMS, show measurements unfolded to a parton-level top quark for measurements of the top-quark properties
- 7 TeV ATLAS measurement uses Powheg+Pythia6 as generator, top quark is taken from the pythia particle record as the particle with abs(pdg_id)=6
- CMS does the same for their 8 TeV measurements

The future: pseudo-tops

- Both ATLAS and CMS plan to unfold to particle-level "pseudo-tops" in their future differential cross section measurements.
- Here, the decay products at particle-level are used to reconstruct the "pseudo-top"
- Both experiments have presented results for differential measurements of $t\bar{t}$ production unfolding to the "pseudo-top" -> see previous talk