Top quark physics in ATLAS

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Outline

- Introduction:
  - Why is the top interesting?
  - Top production at LHC.
- Top Production Measurements:
  - Top quark pair.
    - Inclusive cross-section measurements.
    - Differential measurements.
  - Single Top.
    - Cross-section measurements.
    - $|V_{tb}|$ determination.
- Top properties:
  - Top quark mass measurements.
  - Charge, polarization & spin correlation.
- Searches for new physics:
  - FCNC, Heavy Top-Like quarks, W', $t\bar{t}$ resonances.

Why is the top quark so interesting?

Top physics is one of the main pillars of the physics program at the LHC:

- ✓ Direct probe of the Standard Model:
  - Measurements of the **top-pair production cross-section** provide:
    - Test of perturbative Quantum Chromodynamics (QCD) calculations
    - Test of the SM description of the top quark decay
  - Measurements of the **single top production** provide a test of SM predictions:
    - Production cross-section and direct determination of the quark mixing matrix element $|V_{tb}|$
      $\rightarrow$ Test of unitarity of the CKM matrix
    - Probe of the b-quark structure function
  - **Top-quark mass** measurements:
    - Largest mass in SM $\rightarrow$ Largest coupling to SM Higgs.
    - Allows for Self-Consistency checks of SM Higgs.

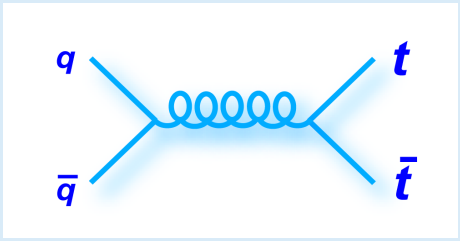
- ✓ Any observed deviation from the SM predictions would give hints to different models of **new physics**
  - Several scenarios with direct/indirect coupling to new physics
    - Excited quarks, charged Higgs, charged W-like bosons, composite models

- ✓ Top events are significant **background** in searches to Higgs and several expected beyond the SM (BSM) processes

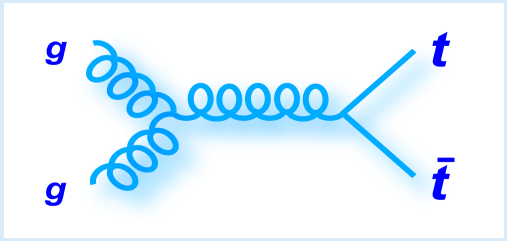
Top quark production at LHC

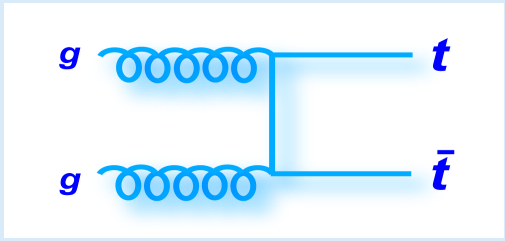
Top-pair production via strong interaction

15% $q - \bar{q}$ **annihilation**



Main mode (85%): gluon fusion



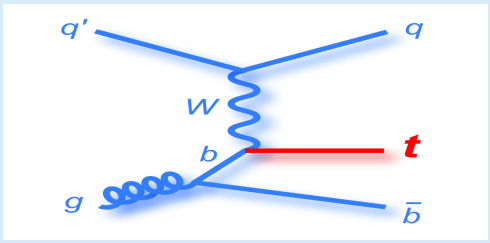


NNLO + NNLL accuracy with $m_t = 172.5$ GeV

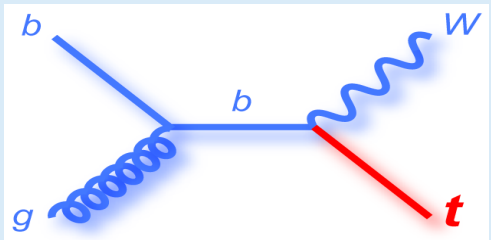
$\sqrt{s}$	$\sigma\ (t\bar{t})$
7 TeV	$177.3^{+10.1}_{-10.8}$ pb
8 TeV	$252.9^{+13.3}_{-14.5}$ pb

Single top production via electroweak interaction

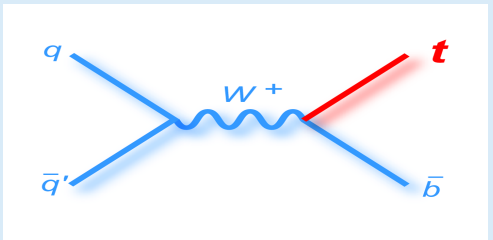
t-**channel**



Wt **channel**



s-**channel**



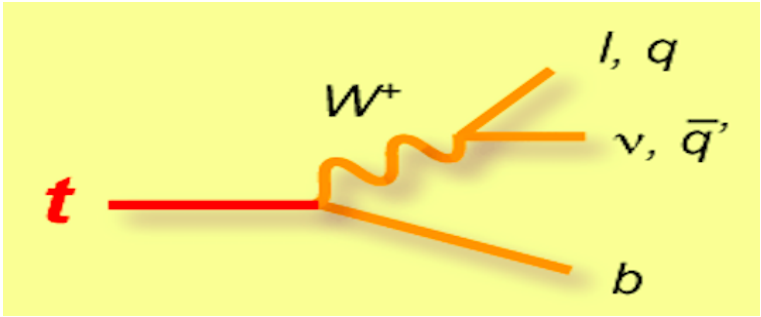
Approx. NNLO

$\sqrt{s}$	σ (*t*-channel)	σ (*Wt*)	σ (*s*-channel)
7 TeV	64.6 ± 2.4 pb	15.7 ± 1.1 pb	4.6 ± 0.2 pb
8 TeV	87.8 ± 3.4 pb	22.4 ± 1.5 pb	5.6 ± 0.2 pb

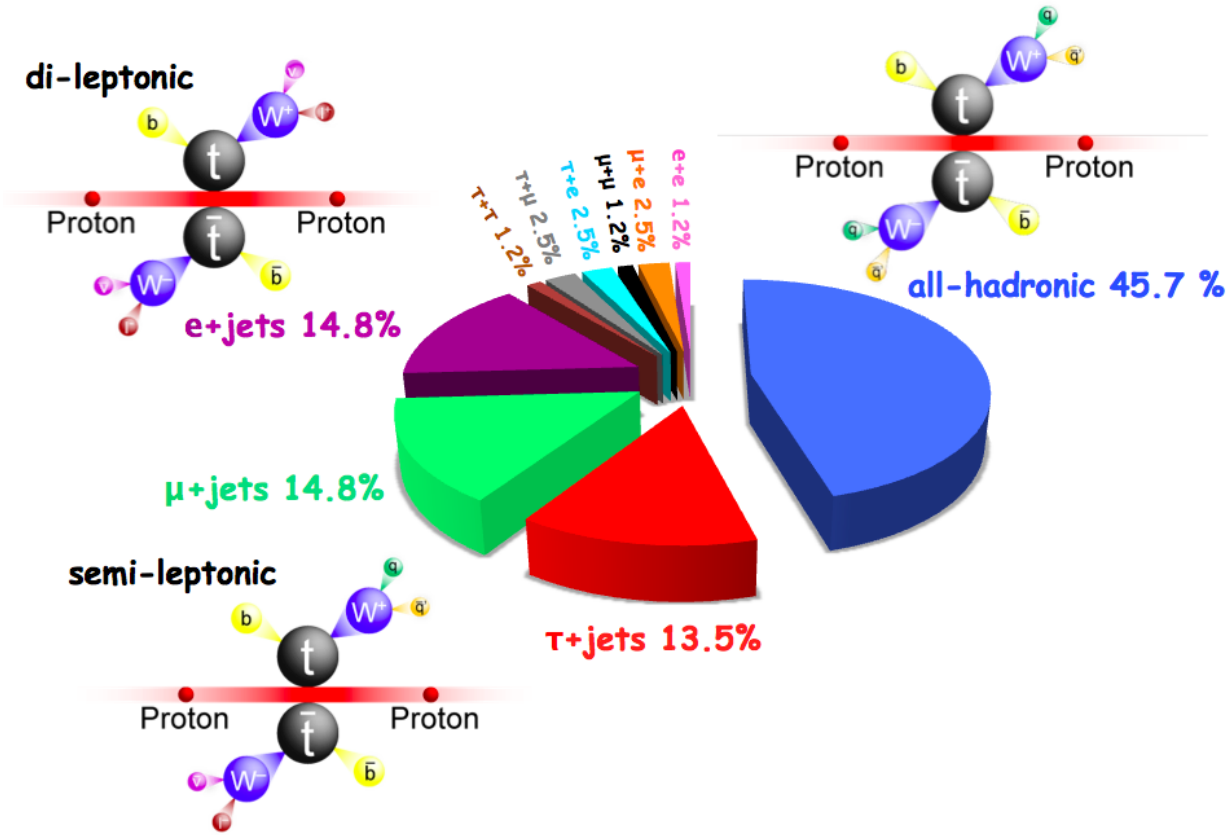
Top quark decay in SM

In the SM, top quarks decay nearly 100% into a *W* and a *b* quark

- W decays either to quarks or leptons
- Classified according to W boson decay

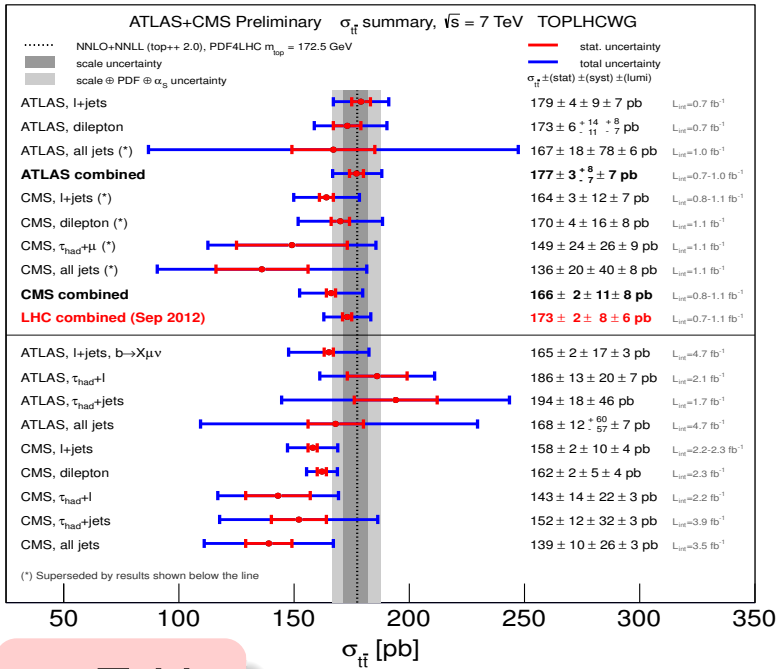


Top-pair Branching Ratios

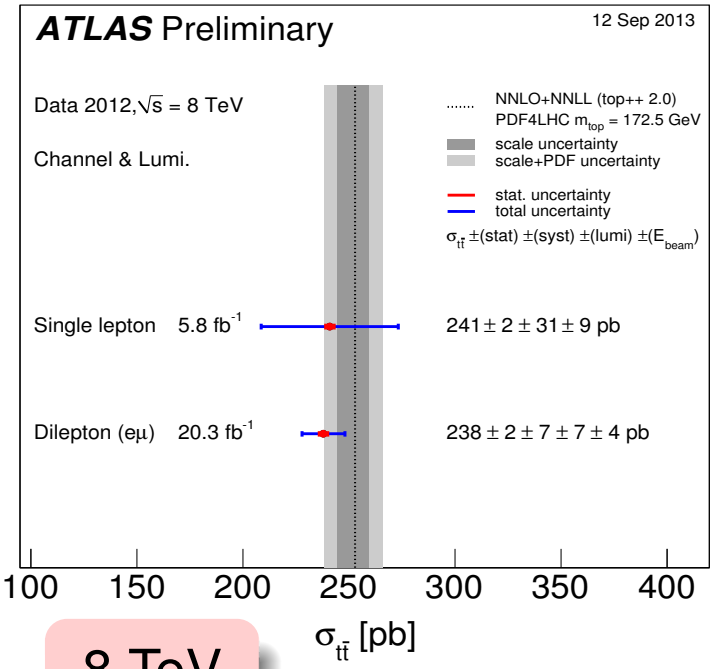


Inclusive top-pair cross-section summary

Top-pair cross-section measurements compared to the corresponding theoretical expectation.



7 TeV



8 TeV

- Broad range of measurements from ATLAS & CMS
- Results consistent with standard model at 7 TeV
- LHC combination: $\sigma_{t\bar{t}} = 173 \pm 8\,(\text{stat.}) \pm 6\,(\text{syst.})\,\text{pb}$

- First measurements in Single lepton & Dilepton channels

Following slides cover NEWEST measurements

For more results:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

Semilepton channel @ 8 TeV

ATLAS-CONF-2012-149
@ 5.8 fb^{-1}

- **Lepton (e, μ) + jets selection**:
  - One isolated e or μ with $p_T > 40$ GeV, $|\eta| < 2.5$
  - ≥ 3 jets with $p_T > 25$ GeV, $|\eta| < 2.5$ with ≥ 1 b-tagged
  - e+jets: $E_T^{miss} > 30$ GeV, $m_T(W) > 30$ GeV
  - μ+jets: $E_T^{miss} > 20$ GeV, $m_T(W) + E_T^{miss} > 60$ GeV
- **Main backgrounds:**
  - vector boson production ($Z/\gamma*$+jets, W+jets), single top and diboson (ZZ,WZ,WW) $\rightarrow$ MC
  - multijet is estimated $\rightarrow$ data-driven Matrix Method.
- **Analysis:**
  - Number of $t\bar{t}$ events ($N_{t\bar{t}}$) is extracted using a likelihood discriminant template fit.
  - Discriminant variables using in the fit: $\eta_{e,\mu}$ and aplanarity (A') $\rightarrow$ Designed to be not so sensitive to jet energy scale.
- **Results: $t\bar{t}$ production cross section**

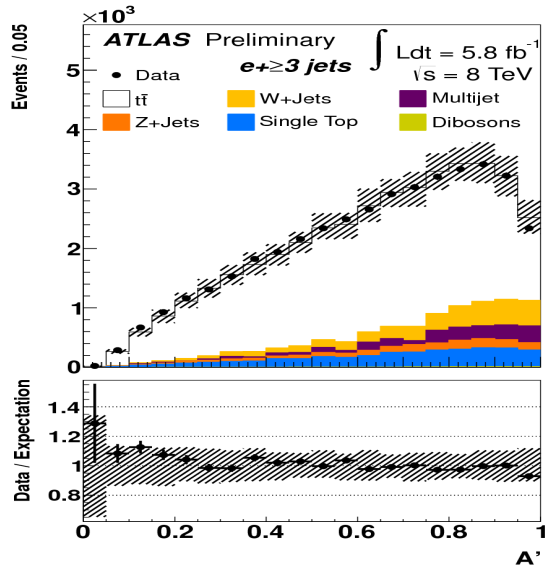
$$\sigma_{t\bar{t}} = \frac{N_{t\bar{t}}}{\mathcal{L} \times BR \times \varepsilon_{sig}}$$

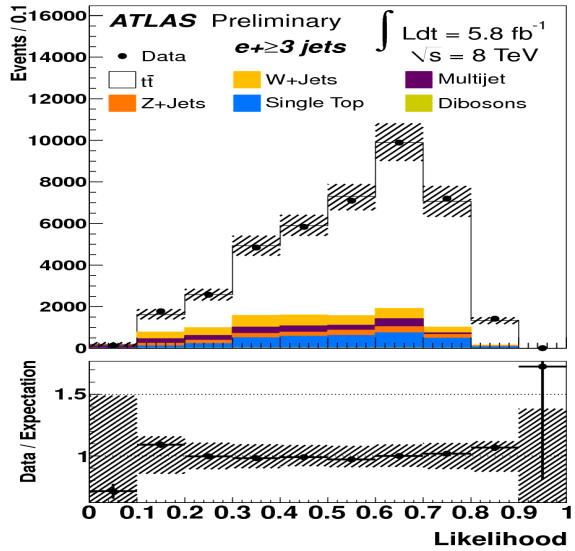
$\mathcal{L}$: integrated luminosity, BR: branching ratio,

ε_{sig} product of signal acceptance and efficiency

$$\sigma_{t\bar{t}} = 241 \pm 2\,(\text{stat.}) \pm 31\,(\text{syst.}) \pm 9\,(\text{lumi.})\ \text{pb}$$

- **Main systematic sources:**
  - Signal modelling (11%) and jet uncertainties ($5-6$%)





Dilepton channel @ 8 TeV

- **Selection → very pure signal selection**:
  - 1 $e\mu$ pair with opposite sign each isolated, 1 or 2 b-tagged jets
  - For all objects: $p_T > 25$ GeV, $|\eta| < 2.5$
- **Main backgrounds all modelled with MC:**
  - Two real leptons:
    single top Wt ; $Z \to \tau\tau$+jets & diboson (ZZ,WZ,WW)
  - One real lepton and one fake lepton:
    Z+jets & single top t-channel
- **Analysis:**
  - $t\bar{t}$ events in 1 b-tag (N_1) & 2 b-tag (N_2) signal region
    → with maximum likelihood fit.
  - Simultaneous estimation of $\sigma_{t\bar{t}}$ & b-tag jets identification and reconstruction efficiency (ϵ_b)
    → reduces jets and modelling uncertainties

$$N_1 = \mathcal{L}\,\sigma_{t\bar{t}}\,\epsilon_{e\mu} 2\epsilon_b(1 - C_b\epsilon_b) + N_1^{bkg}$$

$$N_2 = \mathcal{L}\,\sigma_{t\bar{t}}\,\epsilon_{e\mu} C_b\epsilon_b^2 + N_2^{bkg}$$

$\epsilon_{e\mu}$: efficiency to pass $e\mu$ preselection

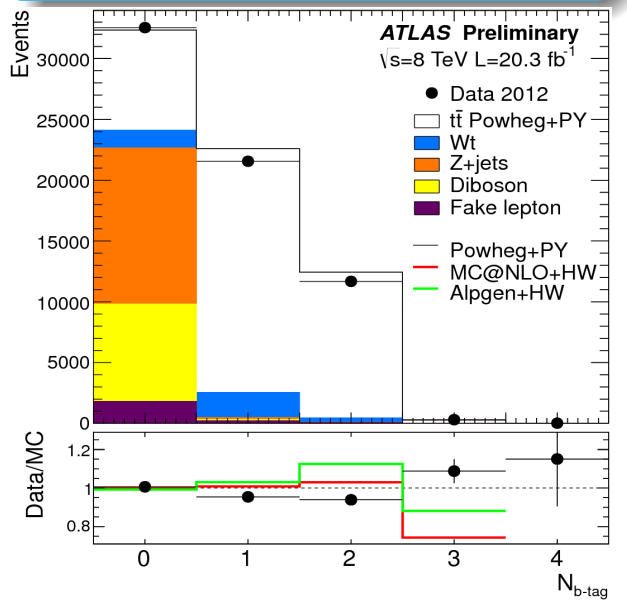
C_b: correlations between 2 b-tagged jets

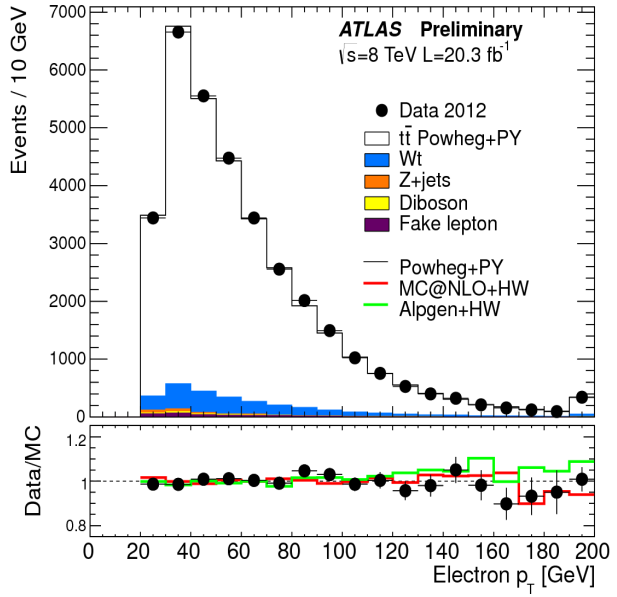
$$\sigma_{t\bar{t}} = 237.7 \pm 1.7\,(\text{stat.}) \pm 7.4\,(\text{syst.}) \pm 7.4\,(\text{lumi.}) \pm 4.0\,(\text{beam energy})\ \text{pb}$$

Precision of $\sim 4.8\%$

- **Main systematic sources:**
  - Luminosity (3.1%), beam energy (1.7%), signal modelling (1.5%) and electron ID (1.4%)

ATLAS-CONF-2013-097
@ 20.3 fb^{-1}





Differential top quark pair cross section @ 7 TeV

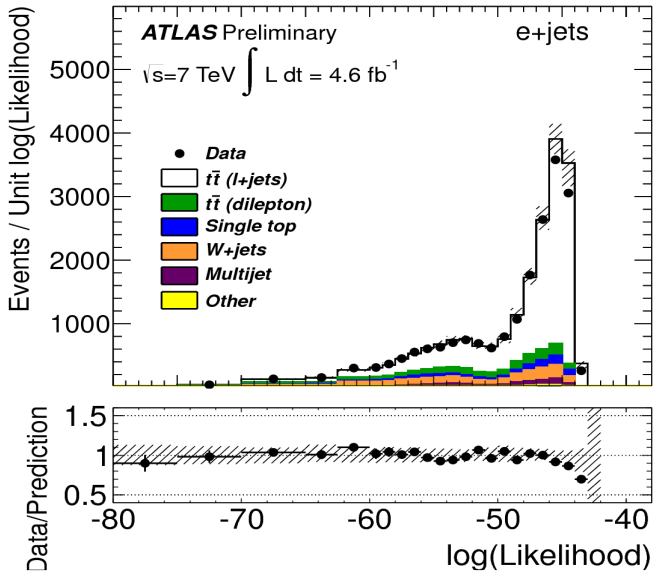
ATLAS-CONF-2013-099
@ 4.6 fb^{-1}

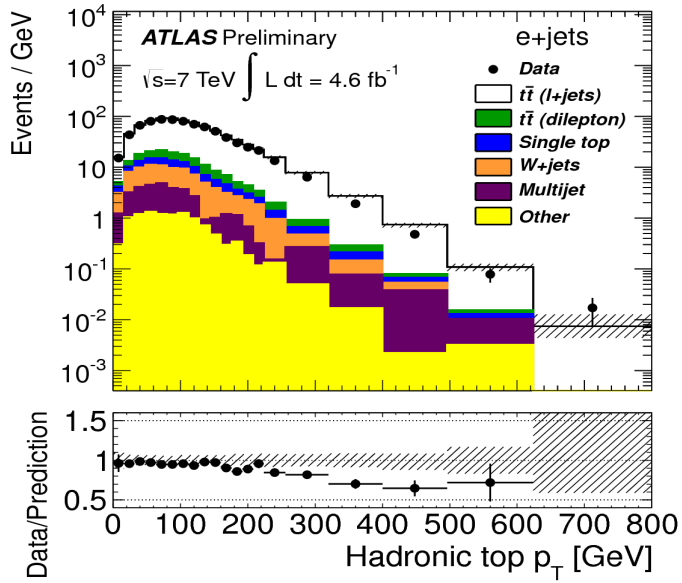
- **Lepton + jets selection**
- **Method:**
  - $d\sigma_{t\bar{t}}/dX$ measurement in bins of p_T^t, $m_{t\bar{t}}$, $y_{t\bar{t}}$ and p_T^{tt}
  - $t\bar{t}$ kinematics reconstructed using a maximum likelihood fitter to the reconstructed objects $\rightarrow$ lepton, jets & E_T^{miss}
    - Likelihood function includes Breit-Wigner functions taking advantage of:
      $\rightarrow$ W boson and top quark masses
      $\rightarrow$ transfer functions relating the measured lepton and jet energies to the corresponding parton level energies
- Differential cross-section **determination:**
  - Reconstructed variables are unfolded used regularised unfolding (SVD) after background subtraction
    - To correct for detector effects and acceptance

$$\frac{d\sigma}{dX_j} = \frac{1}{\Delta X_j} \cdot \frac{\sum_i \mathcal{M}_{ji}^{-1}[D_i - B_i]}{BR \cdot \mathcal{L} \cdot \epsilon_j}$$

$\mathcal{M}$: migration matrix derived from simulation, ϵ: efficiency

- Differential cross-sections are **normalised**
  - systematics not related to the shape cancel in the ratio
- Main **systematics**:
  - Jet energy scale ($\sim$ 3%), signal modelling ($\sim$ 2%), b-tagging efficiency ($\sim$ 2%)



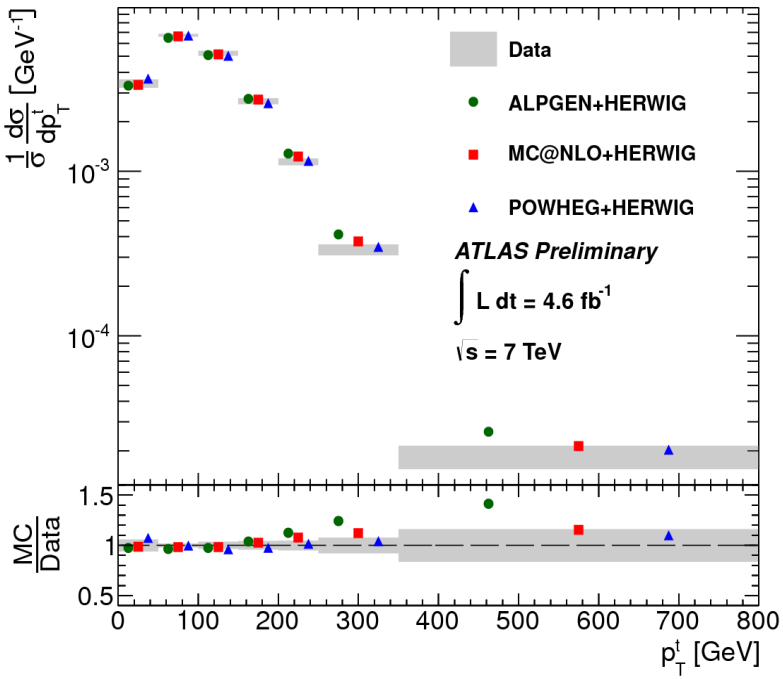


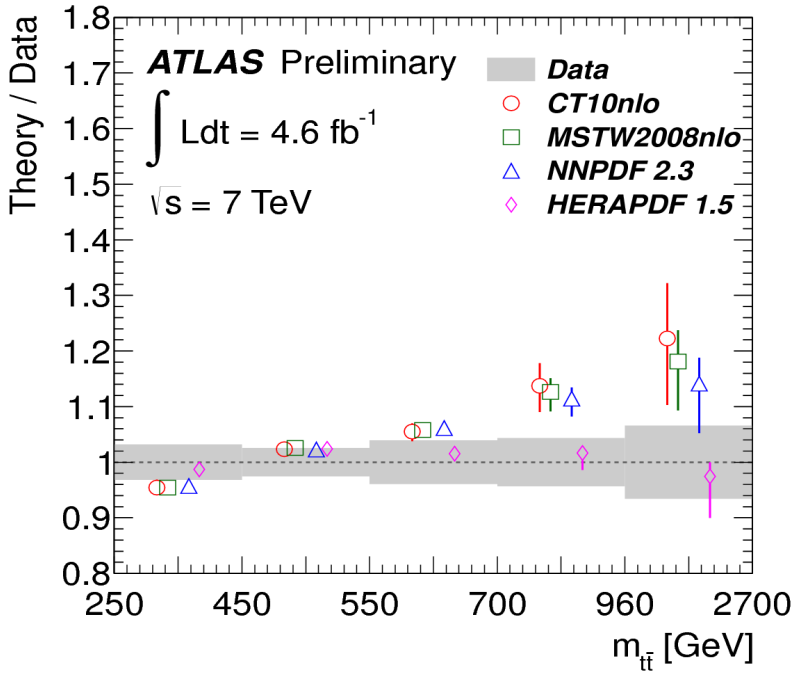
$d\sigma_{tt}/dX$ @ 7 TeV: Results

- **The unfolded distributions are compared to various MC generators, theoretical predictions & PDF sets.**

Data is softer than prediction
Best data description by POWHEG+HERWIG

HERAPDF gives the best data description
deviation at high m_{tt}



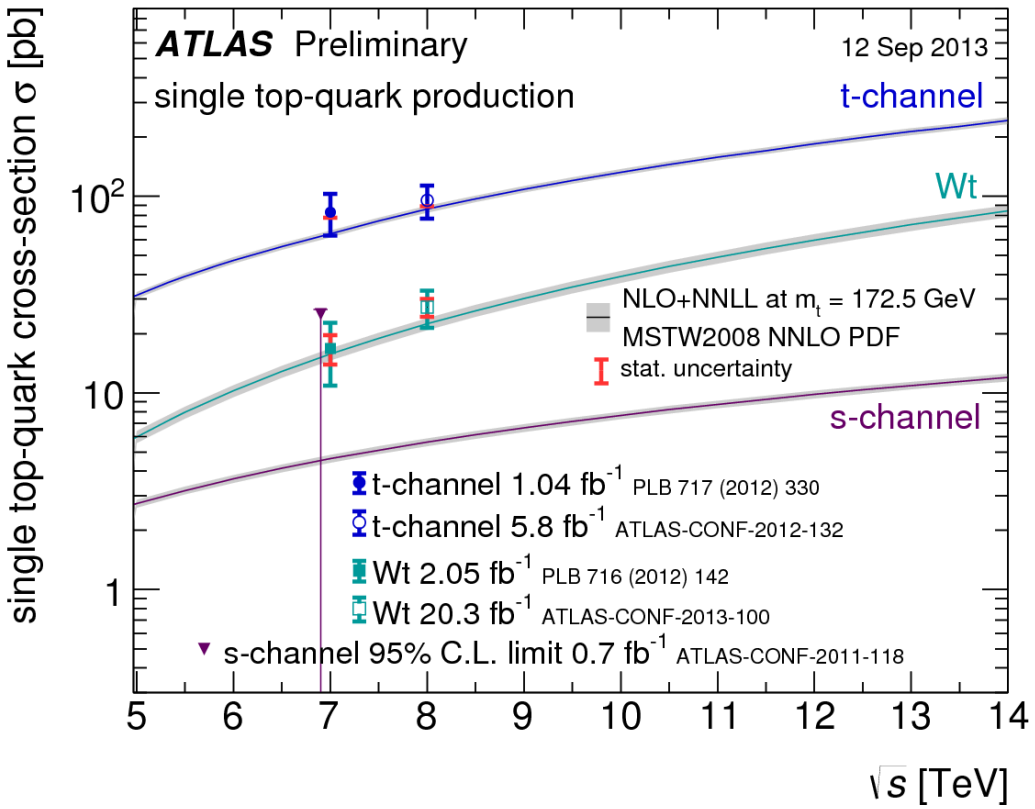


Improved understanding/tuning of generators and QCD predictions.

- Results can be used by PDF groups to improve their predictions and by many BSM searches re-weight the top-quark pT in simulation.

Single top quark production summary

Single top-quark cross-section measurements compared to the corresponding theoretical expectation



- Results in all channels in the single top quark sector at 7 and 8 TeV

Present here the LATEST results at 8 TeV

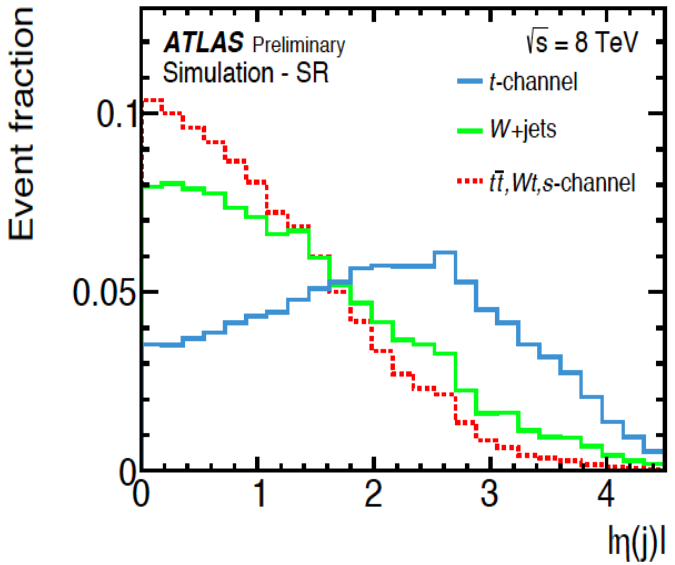
For more results:

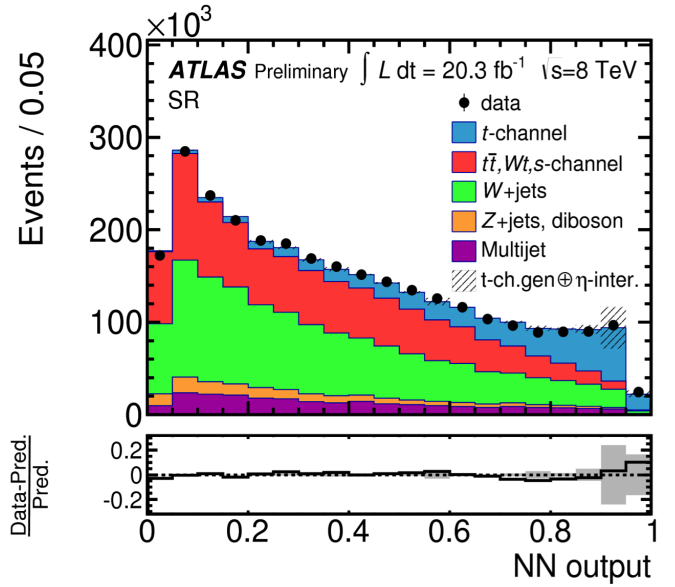
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

t-channel @ 8 TeV: analysis strategy

ATLAS-CONF-2014-007
@ 20.3 fb^{-1}

- **Selection**:
  - Require exactly one isolated lepton (e/μ) with $p_T > 25$ GeV
  - 2 jets with $|\eta| < 4.5$ and $p_T > 30$ GeV & exactly 1 b-tagged jet
  - $E_T^{miss} > 30$ GeV, $m_T(W) > 50$ GeV
- Main **backgrounds**:
  - W+jets, top pairs derived using theoretical cross-sections.
  - multijet determined from data with a template fit to E_T^{miss}.
- **Analysis**:
  - For signal/background discrimination combine several kinematic variables into one discriminant by using a Neural Network (NN) technique.
  - Three kinematic regions are defined:
    - Signal region (SR) with 1 b-tag jet.
    - W-boson control region (W CR) with 1 b-tag jet with a less stringent btagging requirement.
    - $t\bar{t}$ control region ($t\bar{t}$ CR) with 2 b-tag jets.
  - 14 highest-ranking variables are chosen in the signal & control regions.





t-channel @ 8 TeV: results

- The fiducial *t*-channel cross-section within detector acceptance is measured from the maximum likelihood fit to the NN output distributions:

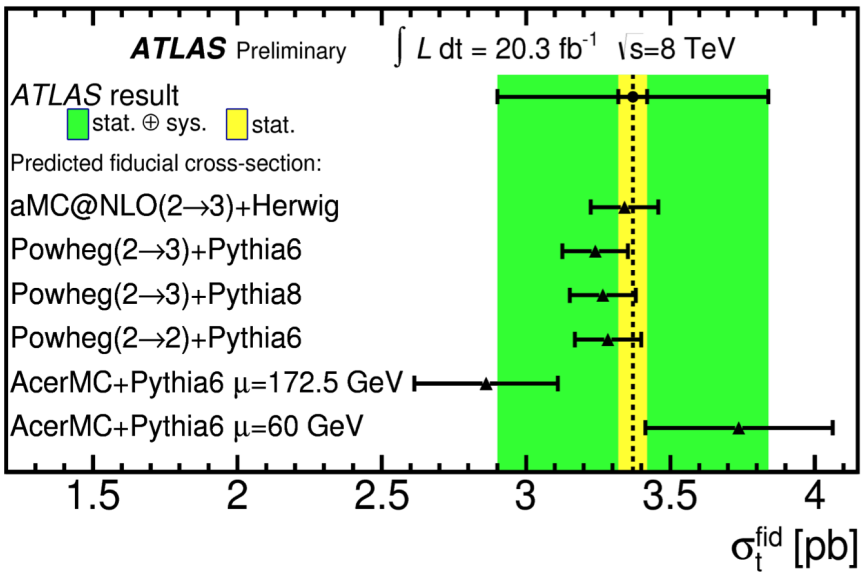
$$\sigma_{fid} = 3.37 \pm 0.05\ (\text{stat.}) \pm 0.47\ (\text{syst.}) \pm 0.09\ (\text{lumi})\ \text{pb}\ (17\%\ \text{syst.})$$

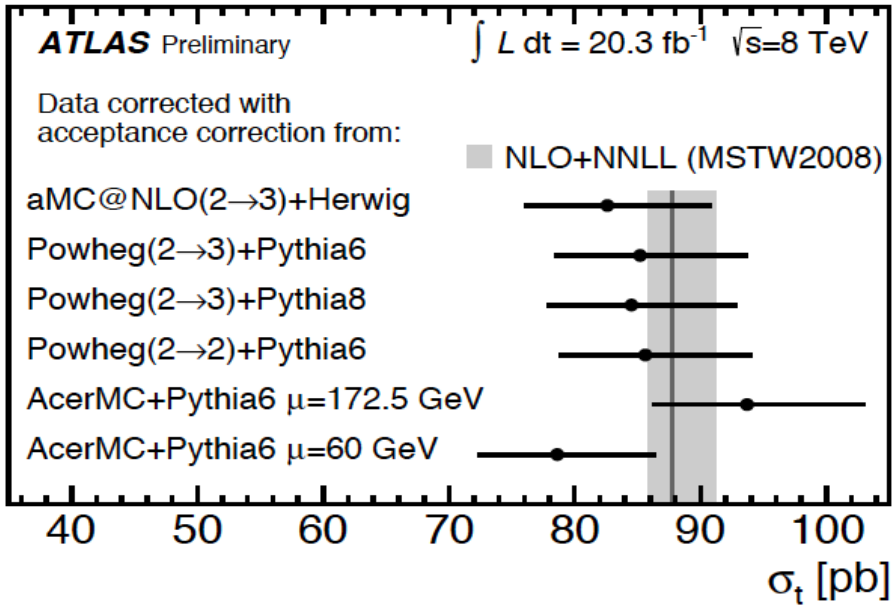
- The *t*-channel cross-section is determined by extrapolation to the entire phase space using several generator assumptions :

$$\sigma = \frac{1}{\epsilon_{fid}} \cdot \sigma_{fid}, \text{ with } \epsilon_{fid} \text{ is the selection efficiency of the particle-level selection.}$$

$$\sigma_{t-channel} = 82.6 \pm 1.2\ (\text{stat.}) \pm 11.4\ (\text{syst.}) \pm 3.1\ (\text{PDF}) \pm 2.3\ (\text{lumi.})\ \text{pb}$$

Precision of $\sim$ 22%



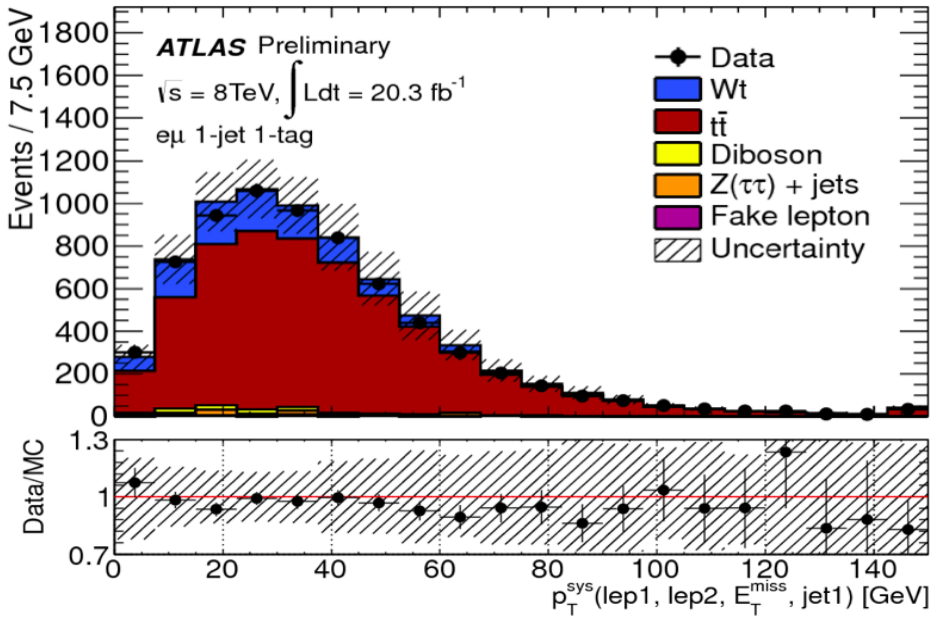


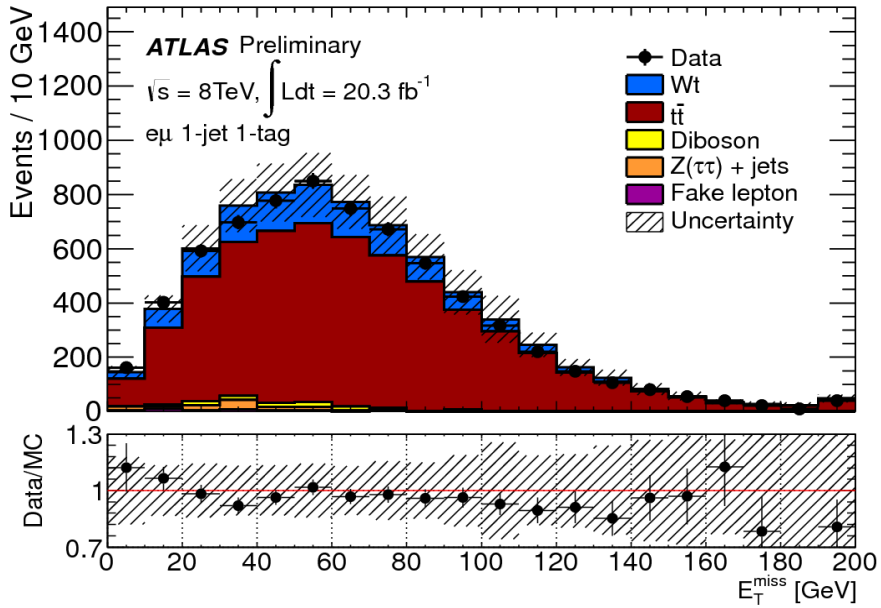
- Main systematics: Jet energy scale (7.9%) and *t*-channel generator (7.9%).

Wt channel @ 8 TeV: analysis strategy

ATLAS-CONF-2012-100 @ 20.3 fb^{-1}

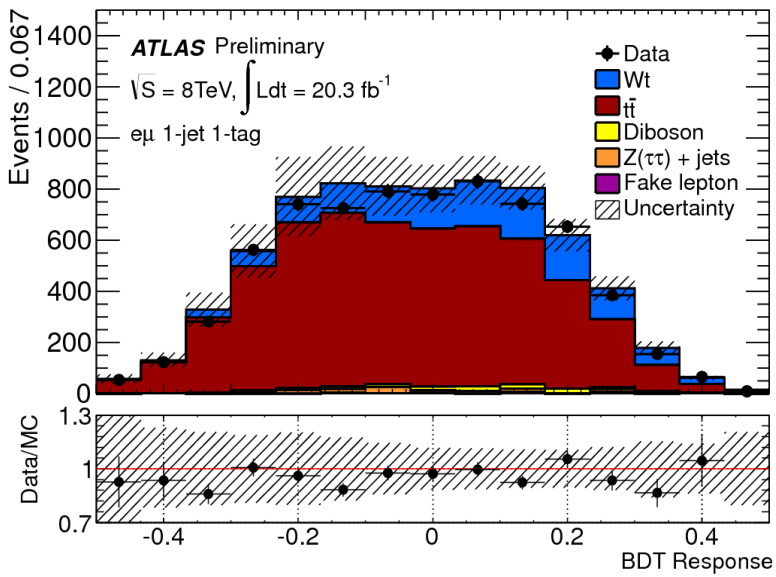
- **Selection**:
  - Require two opposite sign leptons (only $e\mu$) with $p_T > 25$ GeV
  - One or two central jets with $p_T > 30$ GeV and at least one *b*-tagged jet
- The main **background** is the top pair production
- **Analysis**:
  - To separate the *Wt* signal from the large $t\bar{t}$ background a multivariate method (BDT) is used
  - 19 highest-ranking variables are chosen in the signal region (exactly 1 *b*-tag) and 20 for the control region (at least 1 *b*-tag)



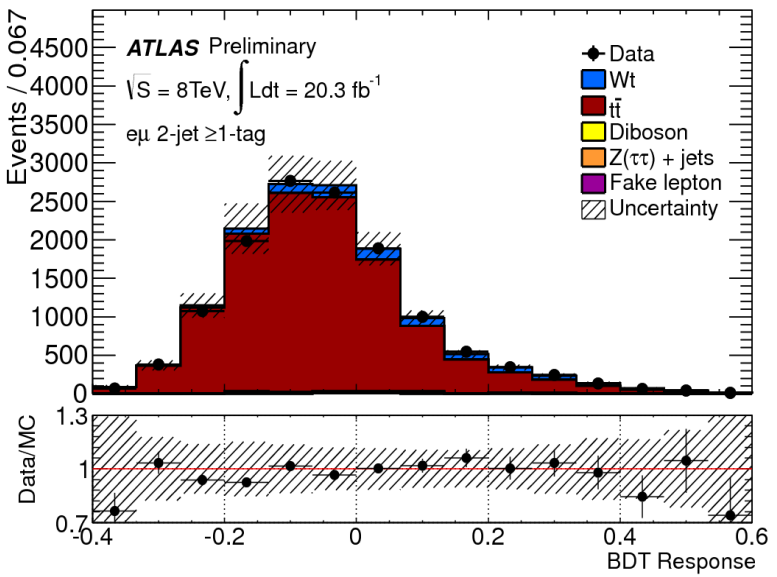


Wt channel @ 8 TeV: cross-section

1-jet signal region; $S/B \sim 0.16$; 80% top-pair



2-jet control region; $S/B \sim 0.05$; 90% top-pair



- The *Wt* cross-section is measured from a maximum likelihood fit to BDT classifier.
  - The 2-jets control region constrains the $t\bar{t}$ background uncertainties
  - The impact of systematic uncertainties is evaluated using ensembles of pseudo-experiments
    - A few systematics are profiled in the fit to data: *b*-tag, JES, E_T^{miss} scale

$\sigma_{Wt} = 27.2 \pm 2.8\,(\text{stat.}) \pm 5.4\,(\text{syst.})$ pb
Precision of $\sim 30\%$
Significance: 4.2σ (4.0σ exp.)

Consistent with SM expectation at 8 TeV:
$\sigma_{Wt} = 22.2 \pm 0.6 \pm 1.4$ pb

- Main **Systematics**: generator & PS modelling ($\sim 8\%$), *b*-tagging ($\sim 9\%$) and JES

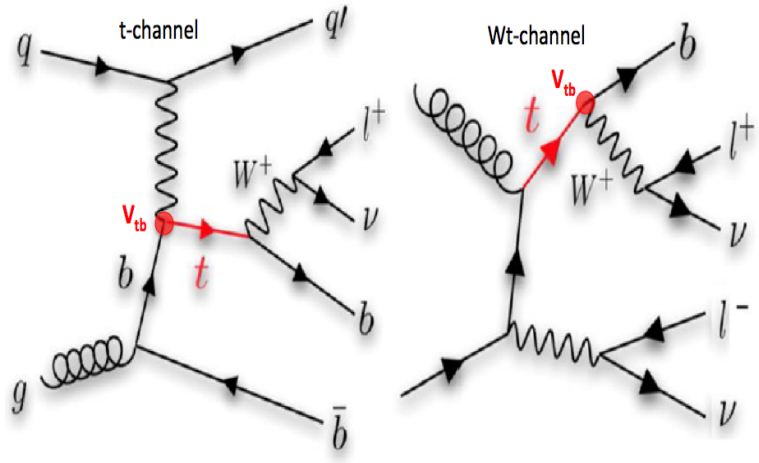
$|V_{tb}|$ measurements: t & Wt channel

- Direct determination of the quark mixing matrix element $|V_{tb}|$:
  - Opportunity to test the unitarity of the CKM matrix.
  - Deviations from the SM are potentially sensitive to new physics.

- Measure of $|V_{tb}|$ assuming left-handed SM-like Wtb coupling and $|V_{tb}| >> |V_{ts}|, |V_{td}|$:

$$|V_{tb} \cdot f|^2 = \frac{\sigma^{obs.}}{\sigma^{theory}}$$

  with $f = 1$ in SM
- Independent of N_{quark} generations or CKM unitarity



- Summary of the $|V_{tb}|$ measurements in the t-channel and Wt:

$\sqrt{s}$	$\lvert V_{tb}\rvert$ (t-channel)	$\lvert V_{tb}\rvert$ (Wt)
7 TeV	$1.13^{+0.14}_{-0.13}$ (11.9%)	$1.03^{+0.16}_{-0.19}$ (17.0%)
8 TeV	$0.97^{+0.09}_{-0.10}$ (9.8%)	1.10 ± 0.12 (11.2%)

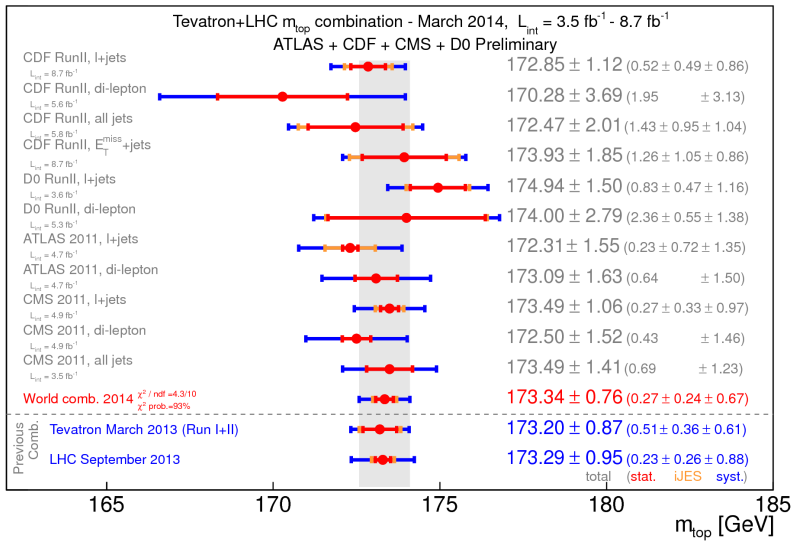
Top properties measurements

✓ Covered in this talk

- **Mass**
  - Lepton+jets with 4.7 fb^{-1}
    $\rightarrow$ 3D Template Method
    (ATLAS-CONF-2013-046)
    - Top/Anti-top quark mass difference
      (Phys. Lett. B, Vol 728, p.363-379)
  - Dileptonic with 4.7 fb^{-1}
    $\rightarrow$ Template method
    (ATLAS-CONF-2013-077)

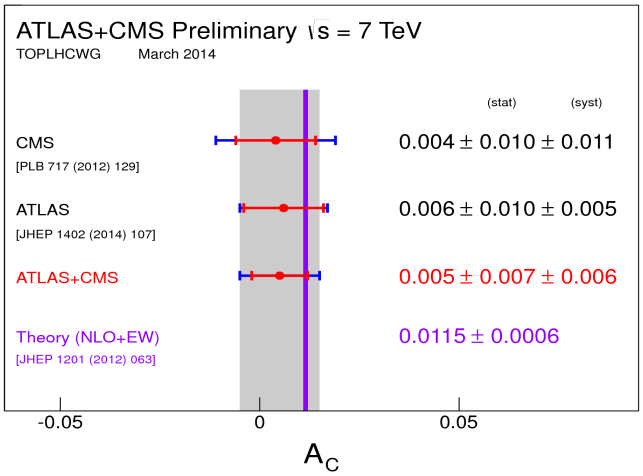
First world mass combination: LHC and Tevatron

(ATLAS-CONF-2013-102)



Word combination 2014: 173.34 $\pm$ 0.76 GeV

Charge asymmetry combination: ATLAS & CMS (ATLAS-CONF-2014-012)



- **Electric charge** (JHEP11 (2013) 031)
- **Polarization** (Phys.Rev.Lett 111, 232002 (2013))
- **Spin correlation** (ATLAS-CONF-2013-101)
- **Charge asymmetry** (JHEP02 (2014) 107)

Top quark mass: Lepton + jets @ 7 TeV

- **Lepton (e/μ) + jets selection**:
  - $\geq$ 4*jets* and at least one *b*-tagged jets
- **Strategy:**
  - 3 observables reconstruct from selected events: m_{top}^{reco} ($\rightarrow$ likelihood fit), m_W^{reco} ($\rightarrow$ jet permutation) & R_{lb}^{reco}

$$R_{lb}^{reco} = \begin{cases} \dfrac{p_T^{b_{had}} + p_T^{b_{lep}}}{p_T^{W_{jet_1}} + p_T^{W_{jet_2}}} & \text{if } \geq 2\ b\text{-tagged;} \\ \dfrac{p_T^{b_{tag}}}{(p_T^{W_{jet_1}} + p_T^{W_{jet_2}})/2} & \text{if } 1\ b\text{-tag.} \end{cases}$$

  - Templates for m_t[165.5, 177.5] in 3D: $m_{top} \otimes JSF \otimes b - JSF$
    - Designed to minimise the effect of *b*-JSF
- **Results**: Maximum likelihood fit to final distributions:

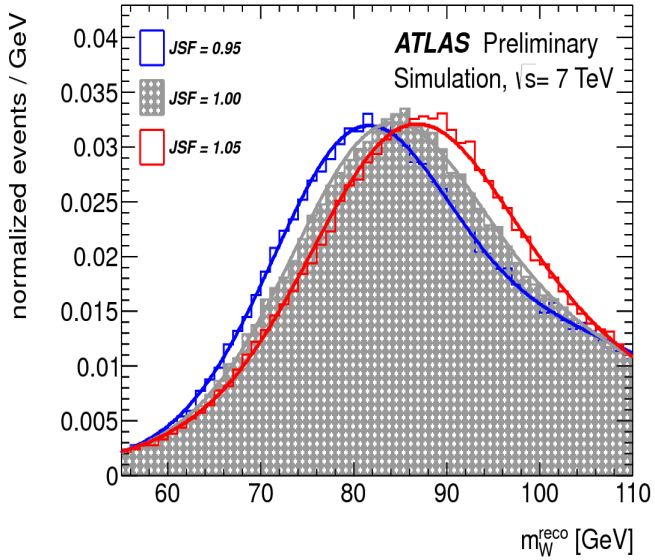
$$m_{top} = 172.31 \pm 0.75\,(\text{stat.} + \text{JSF} + \text{bJSF}) \pm 1.35\,(\text{syst.})\text{GeV}$$

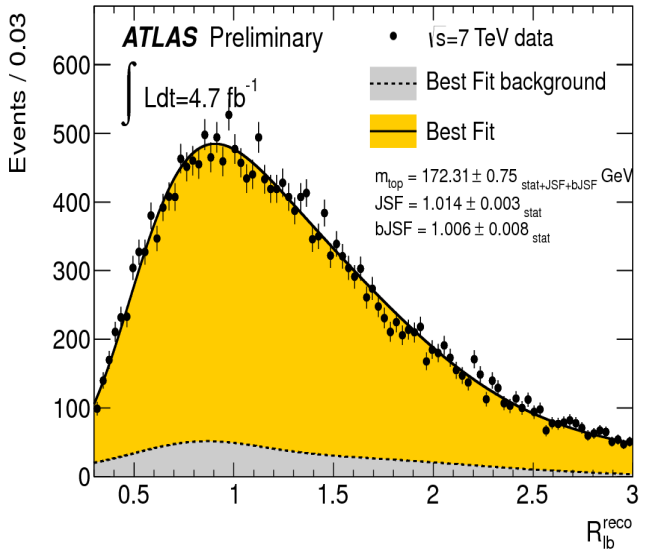
Precision of $< 1\%$

- **Main systematic sources:**
  - b-tagging efficiency (0.8%), *b*-JSF (0.7%) & JSF (0.5%)

JSF $\rightarrow$ Jet energy scale

ATLAS-CONF-2013-046
@ 4.7 fb^{-1}





Mass difference between t & $\bar{t}$ @ 7 TeV

Physics Letters B 728C (2014)
@ 4.7 fb^{-1}

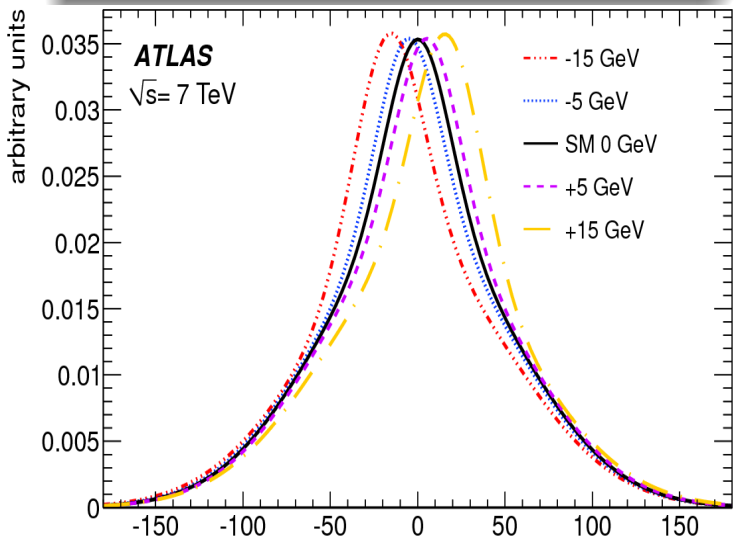
- **Lepton (e/μ) + jets selection**:
  - $\geq$ 4*jets* and at least two *b*-tagged jets
- **Strategy:**
  - Kinematic fit to measure $m(l\nu b) - m(jjb)$ on per-event basis
  - 15 simulated templates with $\Delta m = [-15, 15]$ GeV
- **Results**: An unbinned extended maximum likelihood fit to Δ_m^{fit} to extract Δm

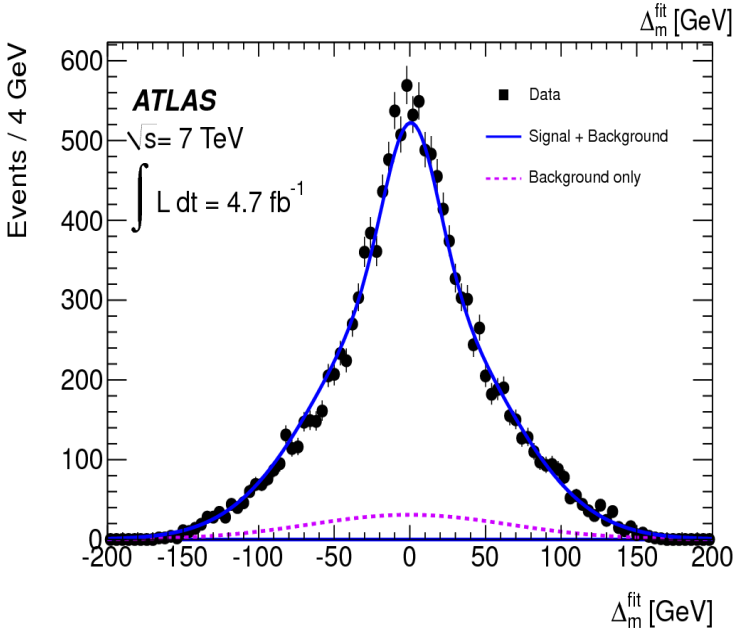
$$\Delta_m^{fit} = q_l \times (m_{bl\nu}^{fit} - m_{bjj}^{fit})$$

q_l: e/μ charge from leptonic top quark decay

$\Delta m_{top} = 0.67 \pm 0.61\ (\text{stat.}) \pm 0.41\ (\text{syst.})$GeV
consistent with SM predictions and CPT invariance.

- **Main systematic sources:**
  - Chose of *b* fragmentation model
    $\rightarrow$ *b* & $\bar{b}$ decay uncertainties (0.34%)





Top pair spin correlations @ 7 TeV

- **Dileptonic selection**
- **Strategy:**
  - Study observables sensitive to sources of new physics:
    1. $\Delta\phi$: Azimuthal angular separation between the two leptons in lab frame
    2. $S - ratio$: Ratio of matrix elements (correlated vs. uncorrelated spin)

$$S = \frac{(|\mathcal{M}|^2_{RR} + |\mathcal{M}|^2_{LL})_{corr}}{(|\mathcal{M}|^2_{RR} + |\mathcal{M}|^2_{LL})_{uncorr}}$$

  3-4. $cos(\theta_{\pm})$: Cosine of θ of the charged lepton & top spin quantization axis in the helicity and maximal basis

- **Results:**
  - Extraction of spin correlation strength (f_{SM}) by a binned maximum likelihood fit for the 4 observables

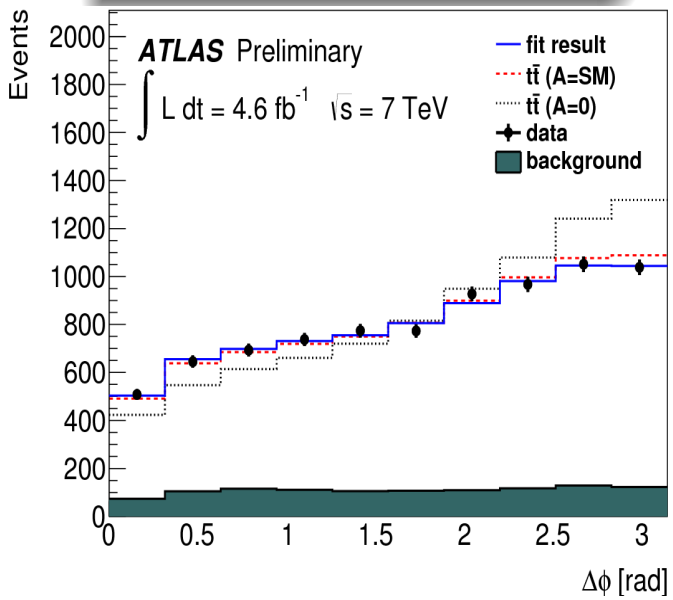
$$f_{SM} = N_{A=SM}/N_{A=SM} + N_{A=0}$$

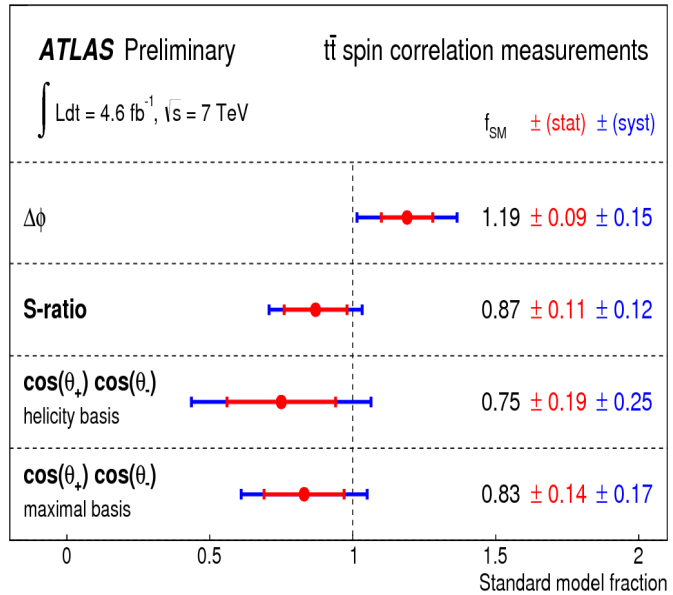
  - Extraction of $A^{measured}_{basis} = f_{SM} A^{SM}_{basis}$

Basis	$\Delta\phi$	S-ratio	$\cos(\theta_+)\cos(\theta_-)_{\text{helicity}}$	$\cos(\theta_+)\cos(\theta_-)_{\text{maximal}}$
$A^{\text{measured}}_{\text{helicity}}$	$0.37 \pm 0.03 \pm 0.05$	$0.27 \pm 0.03 \pm 0.04$	$0.23 \pm 0.06 \pm 0.10$	—
$A^{\text{measured}}_{\text{maximal}}$	$0.52 \pm 0.04 \pm 0.07$	$0.38 \pm 0.05 \pm 0.06$	—	$0.36 \pm 0.06 \pm 0.09$

- **Main systematic:** Signal modeling and Jet energy scale

ATLAS-CONF-2013-101
@ 4.6 fb^{-1}





Charge asymmetry @ 7 TeV

JHEP02(2014)107
@ 4.7 fb^{-1}

- **Semileptonic selection**
  - ≥ 4 high p_T jets & $\geq$ b-tagged
- **Strategy:**
  - Top pair production has a small asymmetry (NLO process) under charge conjugation in SM

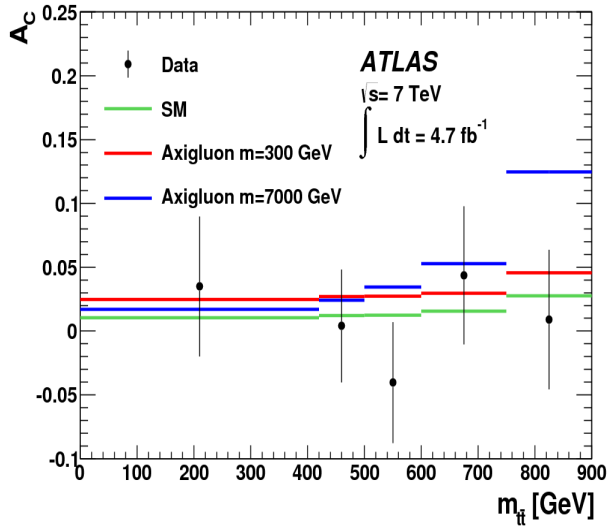
$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

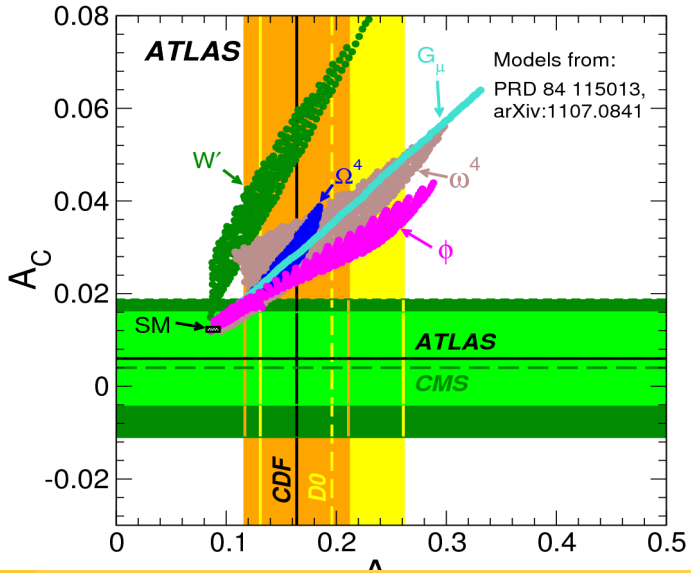
  - Differential measurements in p_T, mass & rapidity of $t\bar{t}$ pairs
- **Results:**

A_C	Data	Theory
Unfolded	0.006±0.010	0.0123±0.0005
Unfolded with $m_{t\bar{t}} > 600\,\text{GeV}$	0.018±0.022	$0.0175^{+0.0005}_{-0.0004}$
Unfolded with $\beta_{z,t\bar{t}} > 0.6$	0.011±0.018	$0.020^{+0.006}_{-0.007}$

In agreement with SM expectations

  - A_C & forward-backward asymmetry (A_{FB}) set constraints on several BSM predictions



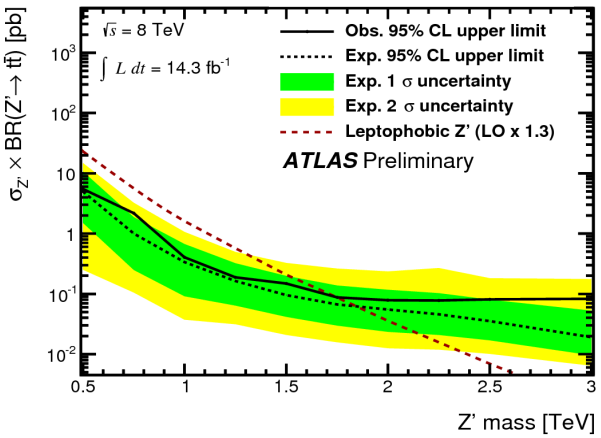


Searches for new physics in ATLAS

✓ Covered in this talk

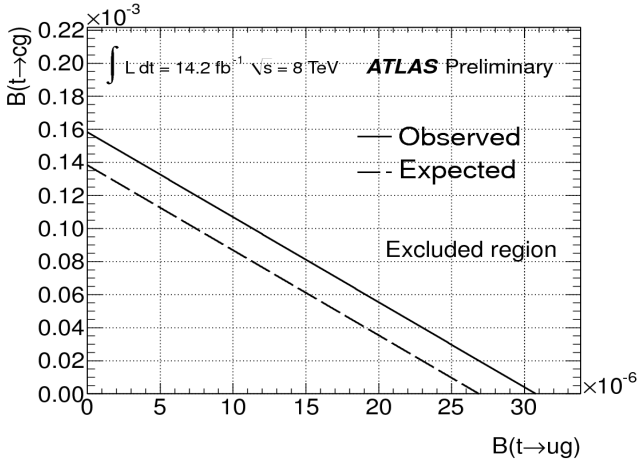
$t\bar{t}$ resonances @ 8 TeV: ATLAS-CONF-2013-052

Upper cross-section limits $\longrightarrow$ Z' bosons/G_{KK}/g_{KK}



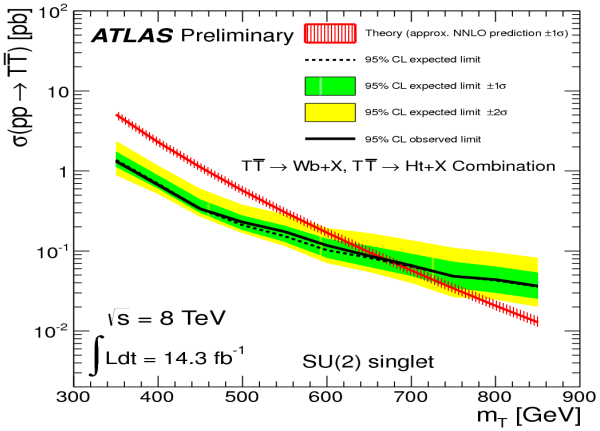
FCNC @ 8 TeV: ATLAS-CONF-2013-063

Upper limits in BR ($t \longrightarrow cg$, $t \longrightarrow ug$)



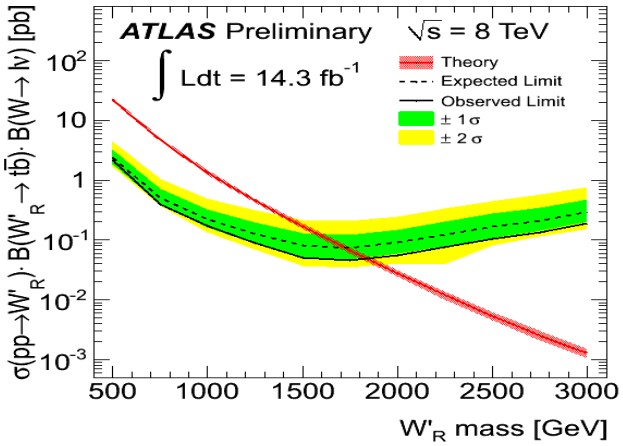
Heavy t-like quarks @ 8 TeV: ATLAS-CONF-2013-060

Upper cross-section limits $\longrightarrow$ vector-like $T\bar{T}$ quark



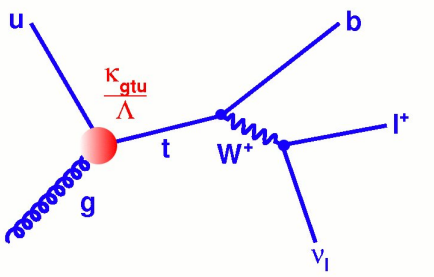
Heavy boson (W') @ 8 TeV:ATLAS-CONF-2013-050

Limits on the cross-section for a right-handed W'



FCNCs in single top production @ 8 TeV

ATLAS-CONF-2013-063
@ 14.2 fb^{-1}



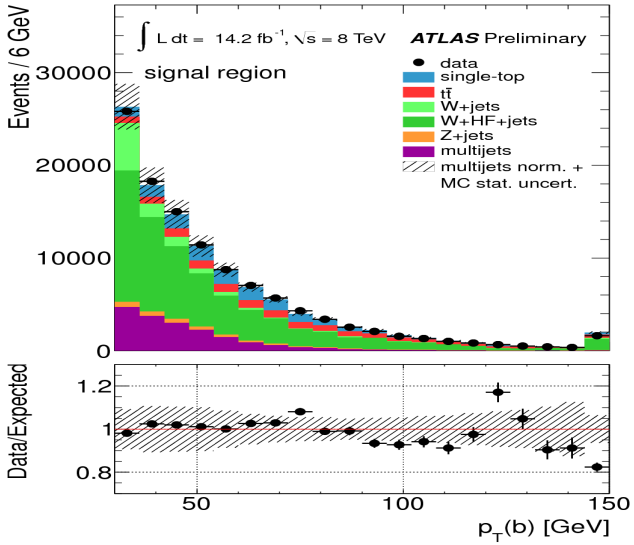
- **Motivations**:
  - FCNC highly suppressed by SM
    $\rightarrow$ enhanced in many BSM scenarios
  - $qg \rightarrow t \rightarrow l\nu b$ single top production has a good sensitivity

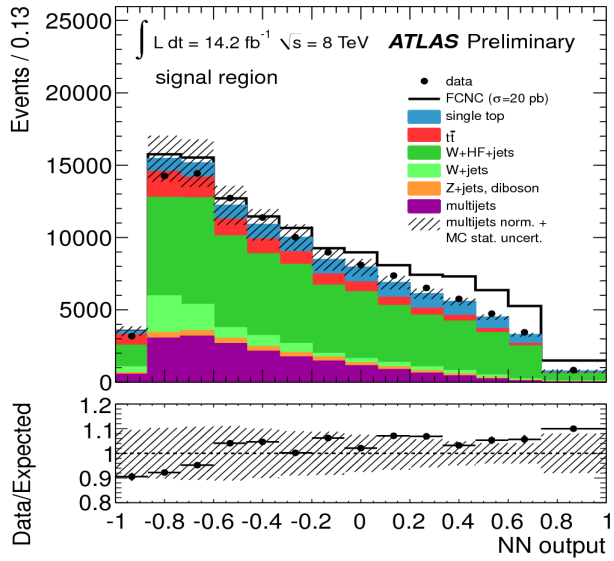
- **Strategy**:
  - Similar to t-channel cross-section analysis @ 8 TeV
    $\rightarrow$ exploits differences in kinematics
  - NN classifier employed to separate S/B
  - Binned likelihood fit to the NN output distribution to extract FCNC contribution

- **Results**:
  - No FCNC signal is observed $\rightarrow$ Limits:

- Observed @ 95% CL: $\sigma_{gg\rightarrow t} \times B(t \rightarrow Wb) < 2.5$ pb

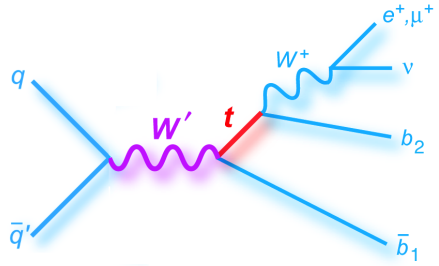
- Upper Limits:
  $B(t \rightarrow cg) < 1.6 \cdot 10^{-4}$
  $B(t \rightarrow ug) < 3.1 \cdot 10^{-5}$





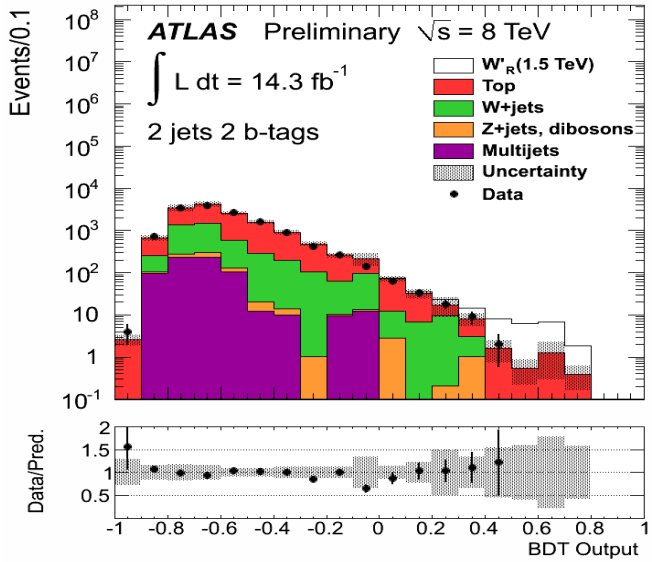
Search for W' boson @ 8 TeV

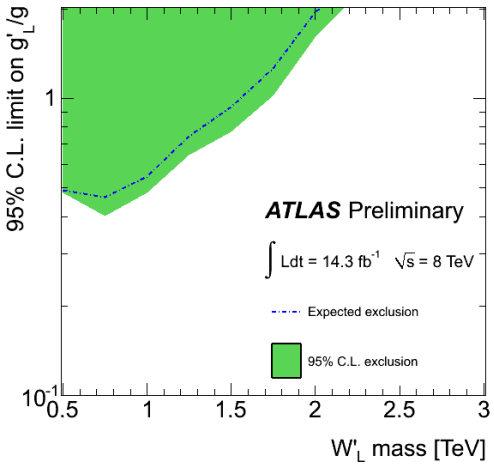
- **Motivations**:
  - Predicted by many BSM theories
  - $W' \rightarrow tb \rightarrow$ allows models with leptophobic W'

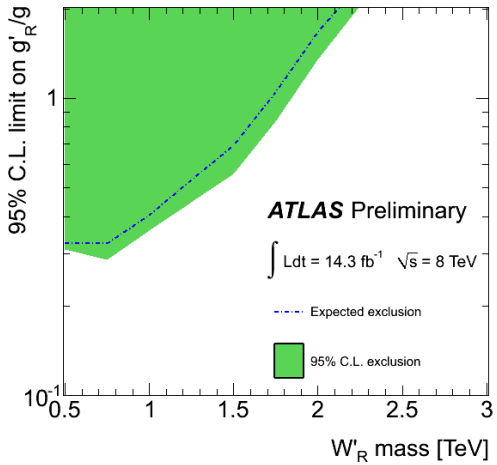


- **Selection**: Semileptonic $\rightarrow$ very clean signature
- **Strategy**:
  - Signal discrimination with two BDTs for 2- and 3-jet events
    - Most discriminating variables: m_{tb}, $p_T^{top,reco}$, $\Delta R(l, b_2)$
  - $W'_{R/L}$ mass from $0.5 - 3.0$ TeV considered
    - Simultaneous fit of 2-jet BDT output distribution for each mass value

ATLAS-CONF-2013-050
@ 14.2 fb^{-1}







- Excluded @ 95% CL:
  - Left-handed: $m_{W'} < 1.74$ TeV
  - Right-handed: $m_{W'} < 1.84$ TeV
- Limits on $\sigma(W' \rightarrow t\bar{b}) \times BR$
- Limits on $W' - t - b$ couplings vs. $m_{W'}$

Conclusions

- The LHC has opened a new era for high precision measurements of top quarks.
  - In 2012, $\sim$ 2 top pairs & $\sim$ 1 single top per second!
- Many precision Top Quark Measurements on ATLAS
  - $t\bar{t}$ production cross-section with a precision better than 5%
  - Top measurements now precise enough to constrain MC model parameters (scale, PDF, non-perturbative models, ...)
  - Top quark mass with a precision better than 1%
- Searches for new physics involved top quarks have started!
- Several more 8 TeV analyses in the pipeline!
- Many more ATLAS top results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
- Next LHC phases will push the energy frontier upward & higher luminosity will enlarge the statistics
  - Top physics might be the first place to find new physics

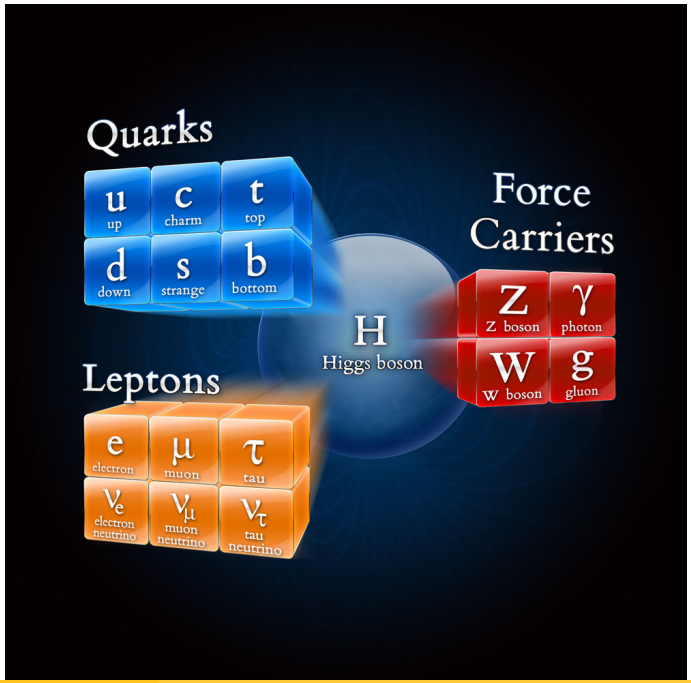
BACKUP

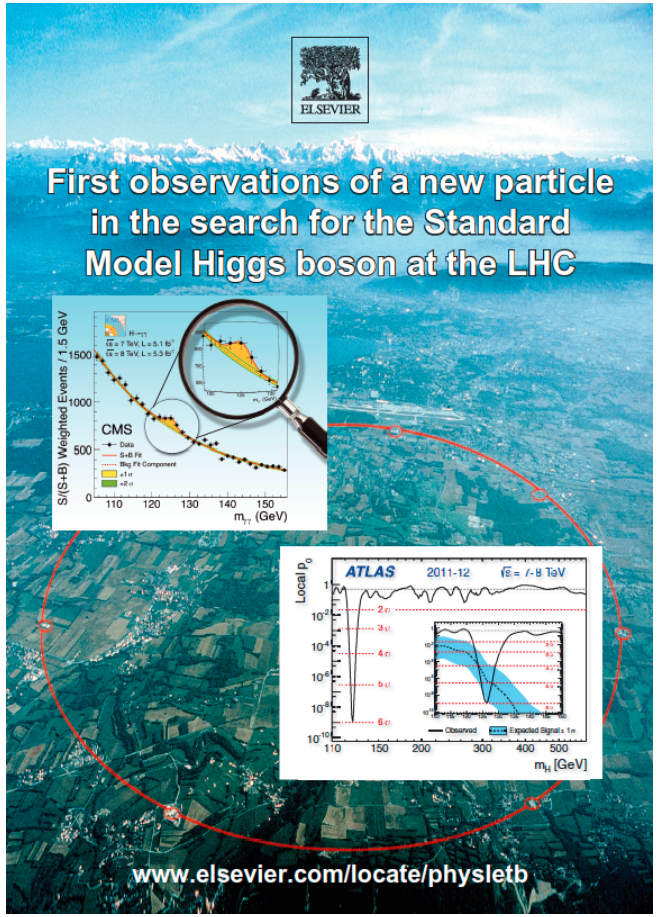
Setting the scene: Top in the Standard Model

The SM top quark:

- Spin $1/2$ fermion, charge $+2/3$.
- Weak-isospin partner of the bottom quark
- Most massive constituent of matter

  $m_t = 173.29 \pm 0.23(stat.) \pm 0.92(syst.)\ \mathrm{GeV}/c^2$ (CONF-2013-102)
  - $\sim$ 40 times heavier than bottom quark
- Short lifetime: $\tau \sim 4 \times 10^{-25}$ s
  - Decays faster than hadronisation
  - Spin information passed to decay products
- Large Yukawa coupling in SM: $Y_t > 0.9$.





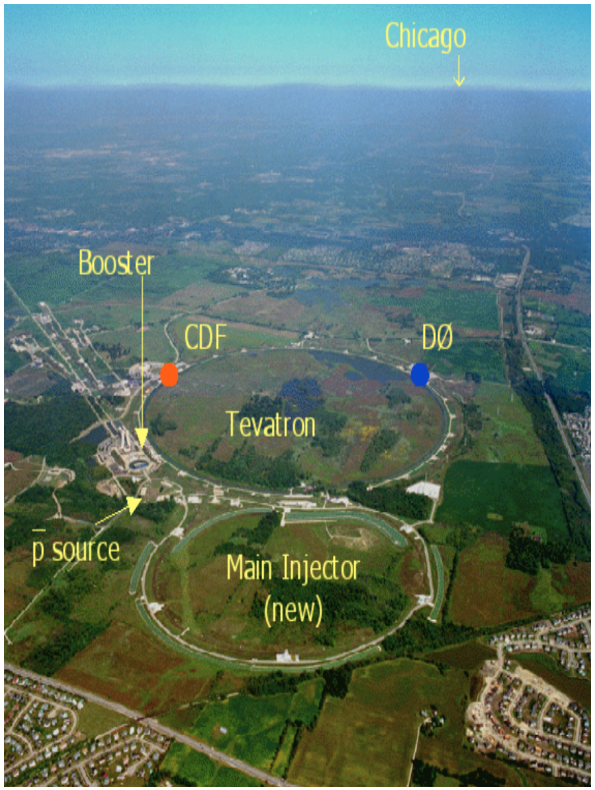
The Higgs boson:

- The last piece for the Standard Model puzzle was discovered at the LHC (CERN) on July 2012.
- $m_{higgs} \sim 126$ GeV

Top discovery

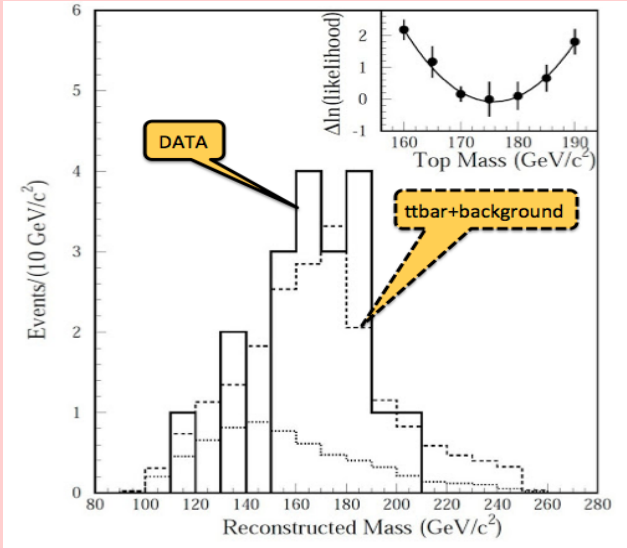
The top quark was discovered in 1995 by the CDF and D0 collaborations at the Tevatron proton-antiproton collider at Fermilab.

TEVATRON



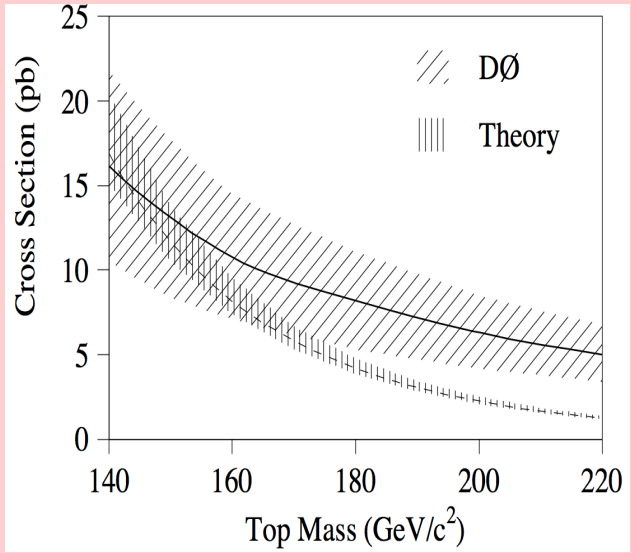
Centre of mass energy: 1.96 TeV

CDF, PRL 74 2626 (1995)



→ 19 selected events
→ exp. background 6.9 events
→ 4.8 s.d. significance
→ $m_{top} = 176 \pm 8(stat.) \pm 10(syst.)\ \mathrm{GeV/c^2}$
→ $\sigma_{t\bar{t}} = 6.8^{+3.6}_{-2.4}\ \mathrm{pb}$

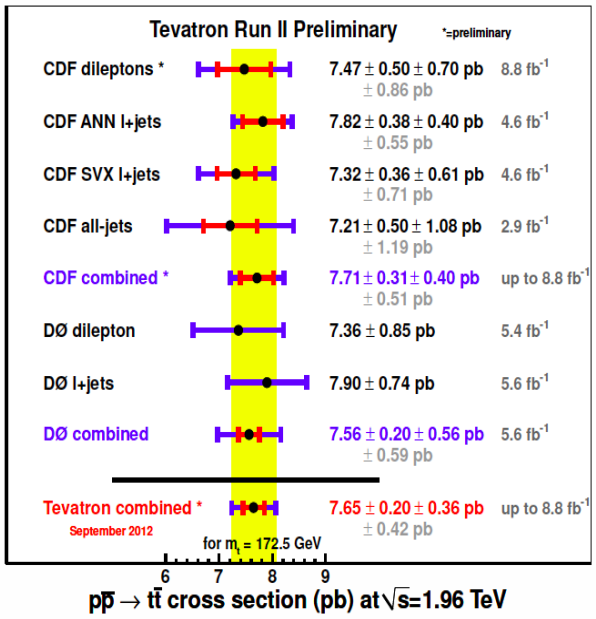
D0, PRL 74 2632 (1995)



→ 17 selected events
→ exp. background 3.8 events
→ 4.6 s.d. significance
→ $m_{top} = 199^{+19}_{-21}(stat.) \pm 22(syst.)\ \mathrm{GeV/c^2}$
→ $\sigma_{t\bar{t}} = 6.4 \pm 2.2\ \mathrm{pb}$

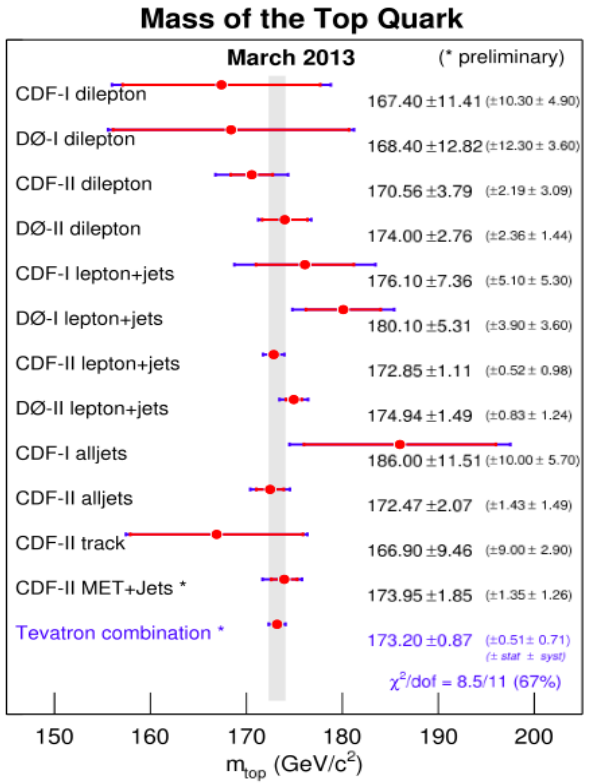
The top physics legacy of the Tevatron (1)

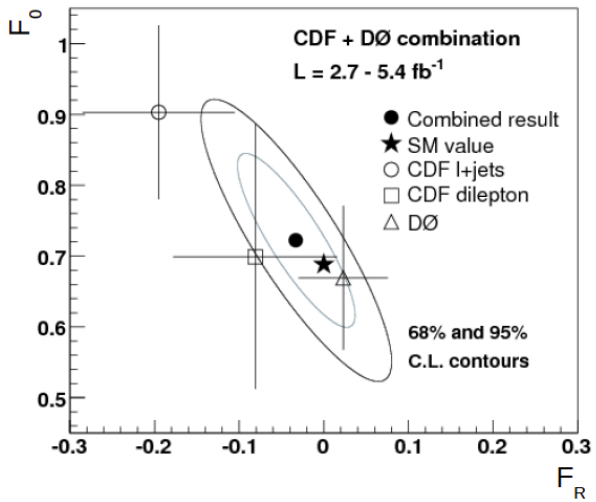
- Top quark is mainly produced in top-antitop ($t\bar{t}$) pairs



Phys. Rev. D 85 (2012) 071106

Top pair cross section ($\sigma_{t\bar{t}} = 7.50 \pm 0.48$ pb(6%)) and top mass ($m_t = 172.9 \pm 0.9$ GeV (0.5%)) have been determined in all possible channels at Tevatron





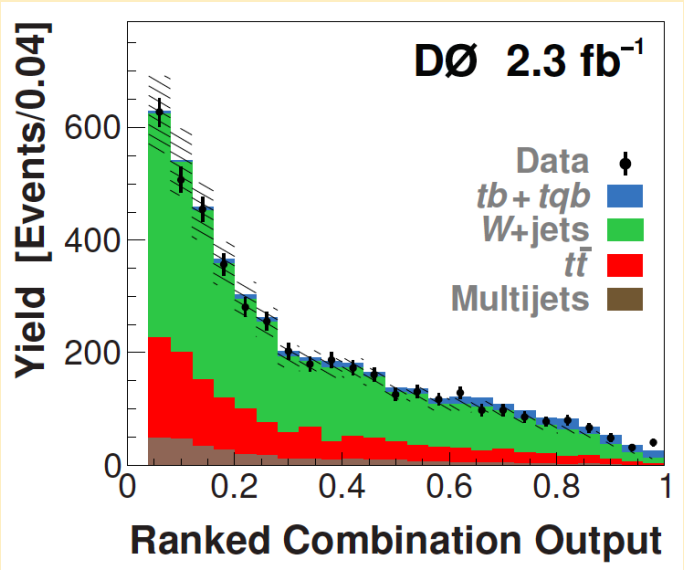
SM predictions: $F_0 \sim 69\%$; $F_R \sim 0\%$; $F_L \sim 31\%$

- With thousands of $t\bar{t}$ collected by D0 and CDF, many properties of the top have been studied (spin correlation, charge asymmetry, charge, width, W helicity in top decay).
  - Almost all measurements consistent with Standard Model expectations within uncertainties
  - The measurement of forward-backward asymmetry show more than 3σ deviation from the SM

The top physics legacy of the Tevatron (2)

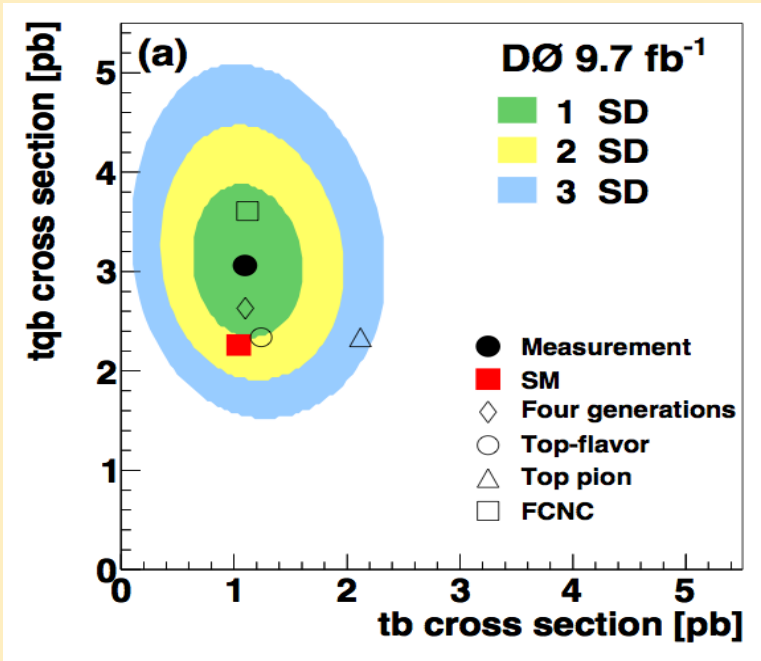
- Single top quarks can be produced by electroweak interaction via three channels: t-channel, s-channel and Wt-channel.

D0 and CDF made first observation in 2009



Expected 223 single top events from 4519 b-tagged selected events

Sensitivity to some models of BSM physics that will change the $s-$ or $t-$ channel cross section

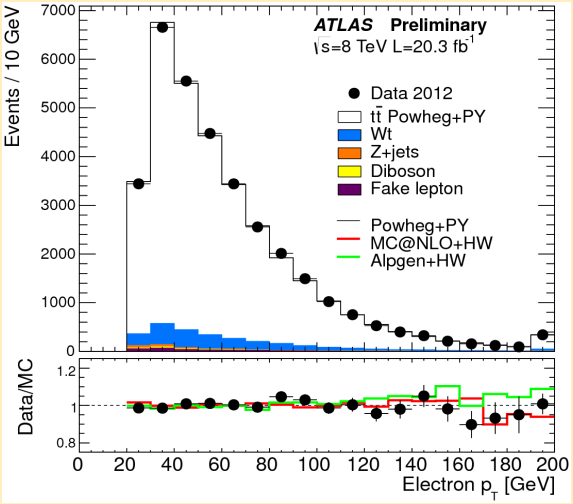


- Since they are looking for a small signal in a very large background ($S/B \sim 0.05$), these analyses introduced the use of Multivariate Techniques: Neural Network (NN), Boosted Decision Trees (BDT).
- The first evidence of the s-channel single top production at D0 was published in 2013

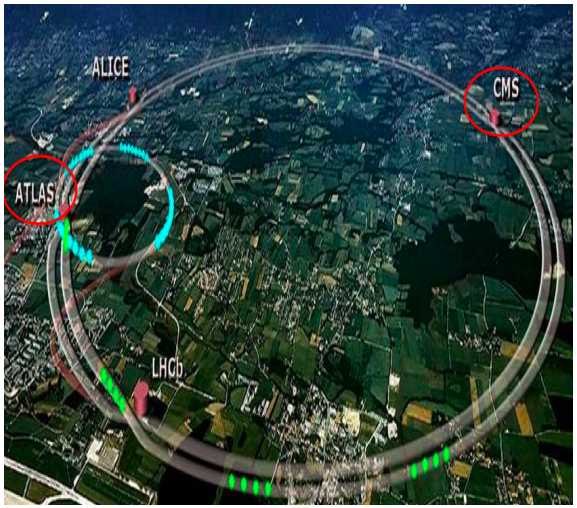
Top quark physics at the LHC

- LHC have opened a new era for high precision measurements top quarks.

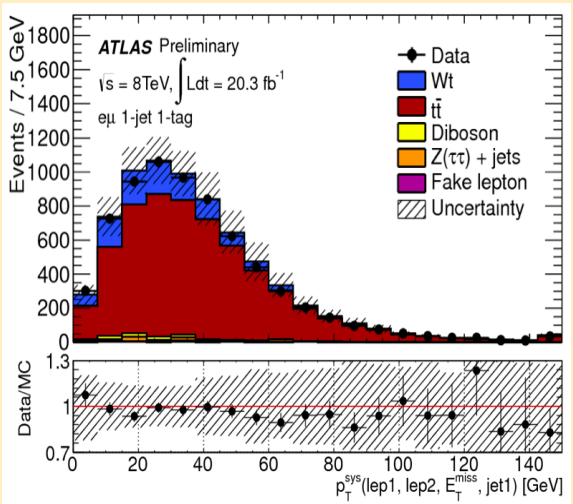
Top pair production:



21559 events observed, 2640 expected to be background ($S/B \sim 7$)



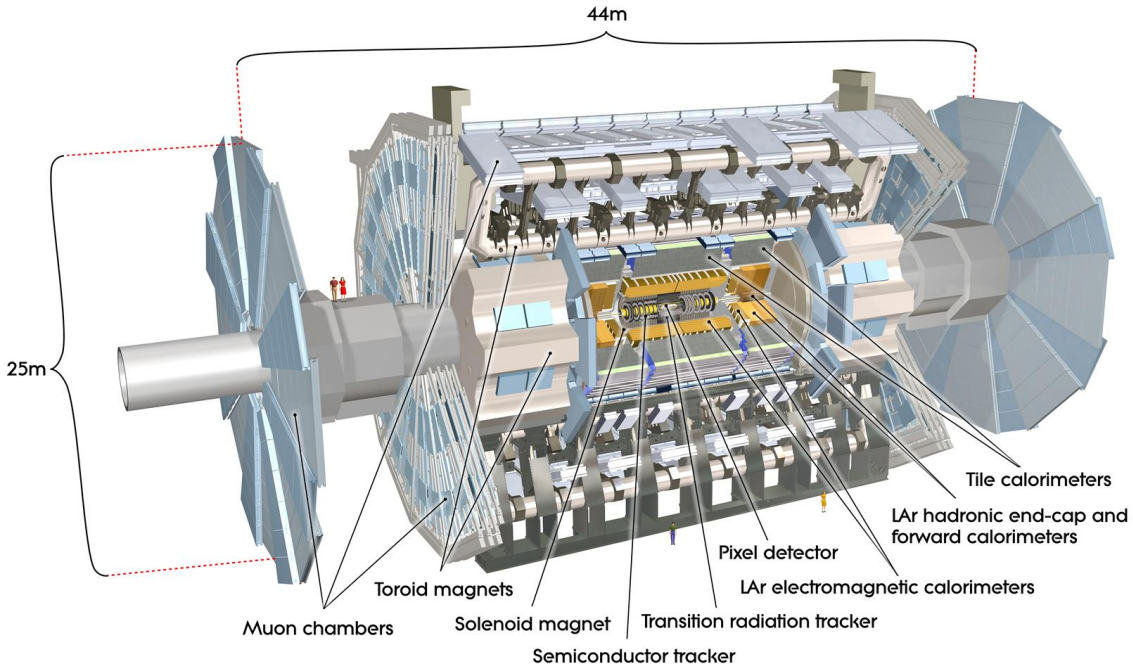
Single top production:



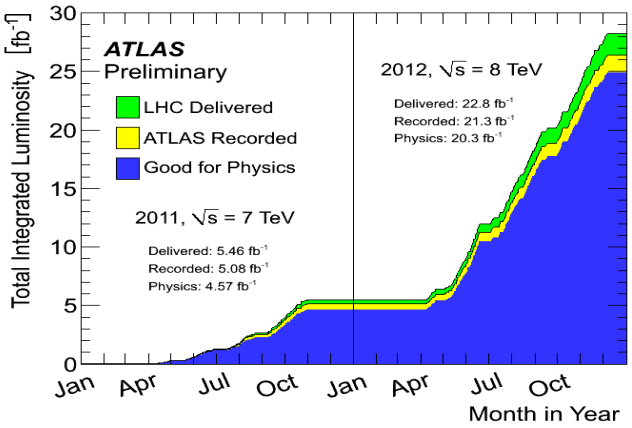
13159 events observed, 1140 expected to be *Wt* ($S/B \sim 0.1$)

- LHC top physic program complementary to Tevatron:
  - Same production mechanism but at different rates
  - Higher centre-of-mass energy
  - Large top quark samples available at 7 (2011) and 8 TeV (2012):
    - More than 10$\times$ top quarks produced than at Tevatron with $\sim 5\ \mathrm{fb}^{-1}$ (2011)

The ATLAS detector



Results presented based on:
4.7 fb^{-1}(2011) to 20.3 fb^{-1}(2012)



- High detector operation and data quality efficiency:
  - Detectors, trigger & DAQ systems working very well.
  - Average fraction of operational channels close to 100% for all subsystems.
- Pileup challenge:
  - Reach higher values of pile-up without degrading performance.
  - Twice more pileup in 2012 than in 2011.