Top quark physics in ATLAS

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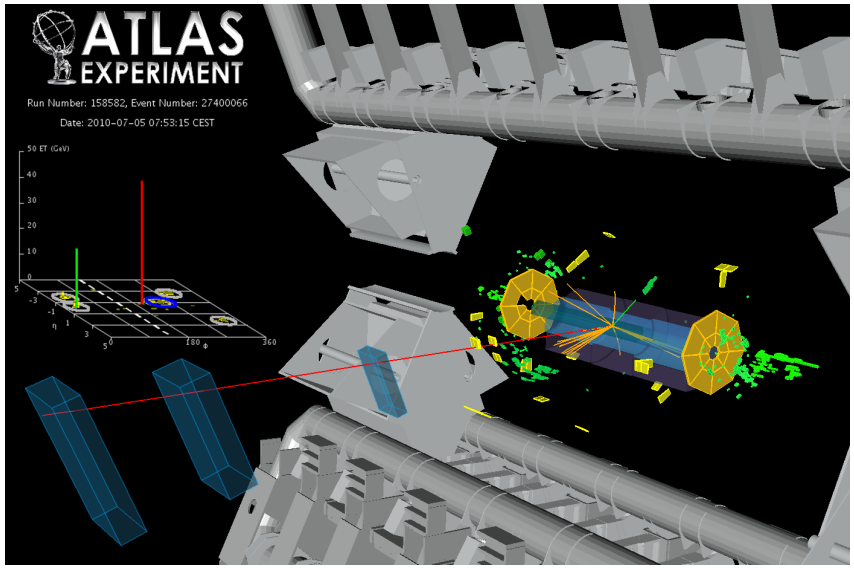
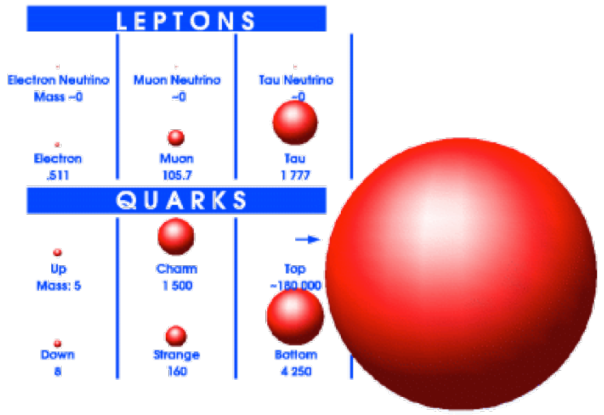
on behalf of the ATLAS collaboration
LHC days in Split 2014

Overview

- **Try to highlight a few (recent) analyses at ATLAS**
  - pair production cross section
  - single top production
  - top mass
  - top properties



- **top quark analyses entered the era of precision measurements**
- **challenge theory and provide (ttbar) or have the prospect to provide (single top) useful inputs to theory and MC generators**



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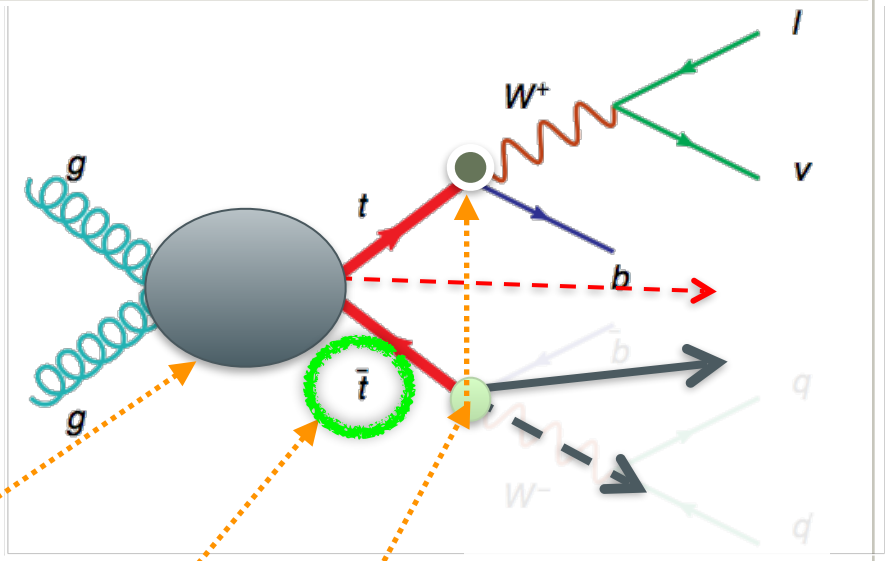
Top quark physics

- **Heaviest particle in SM**
  - Yukawa coupling close to one, special role in EWSB?
- **Short life time of 10^{-25}s, decay before hadronisation, spin information not diluted**
- **LHC is a top factory**
  - ~6.4M top quark pairs, 3M single tops
- **Rich phenomenology**
  - Production (top pair or single)
    - strong production mode, challenge QCD calculation, input to QCD phenomenology
    - weak production mode, EW consistency test
    - anomalous couplings
    - charge asymmetry, colour reconnection
  - Top properties
    - mass, **width**, **spin**, charge, mass difference top/anti-top
    - spin correlation, polarisation



  - Top decay
    - electroweak decay, EW consistency test
    - W helicity, Wtb coupling, V_{tb}, anomalous coupling
    - new or rare decays, **BR**
    - top as a calibration tool (b-tagging, $\mathbf{E_T^{Miss}}$)
- **Searches with top**
- **Top quark production is a major background Higgs and searches**

in **bold: what has not been explicitly measured at ATLAS, yet*

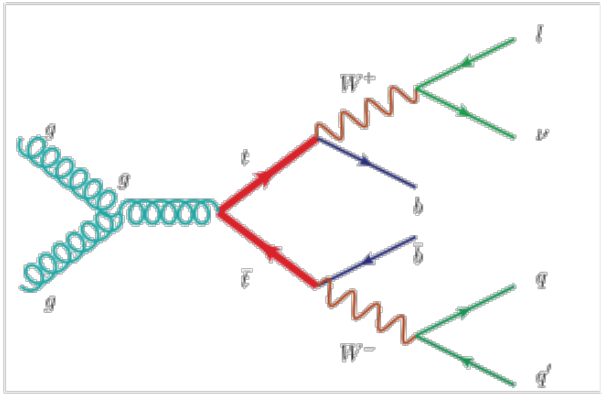
Top quark production

- **SM top production @LHC**
  - strong pair **production** via gg fusion

    ttbar cross sections **@NNLO+NNLL** m_t=172.5GeV:

    7TeV $177.3^{+10.1}_{-10.8}$ pb

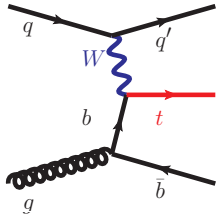
    8TeV $252.9^{+13.3}_{-14.5}$ pb



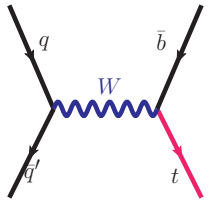
  - electroweak single top **production**

    single top cross sections

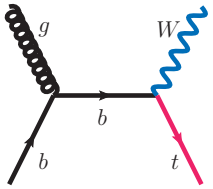
	t-channel	s-channel	Wt-channel	
7TeV	64.6 ± 2.4 pb	15.7 ± 1.1 pb	4.6 ± 0.2 pb	NLO+NLL
8TeV	87.8 ± 3.4 pb	22.4 ± 1.5 pb	5.6 ± 0.2 pb	m_t=172.5GeV



t-channel



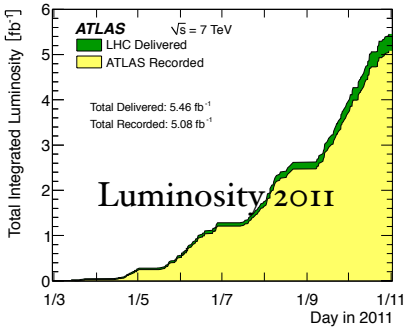
s-channel

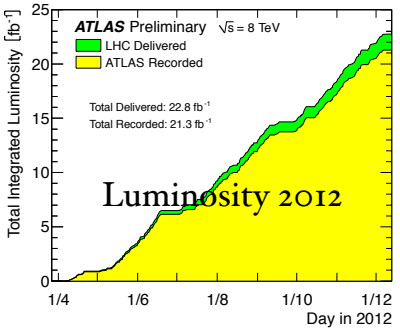


Wt-channel

t-channel now available @NNLO: σ(8TeV)= $83.9^{+0.8}_{-0.3}$ pb (m_t=173.2GeV) arXiv:1404.7116

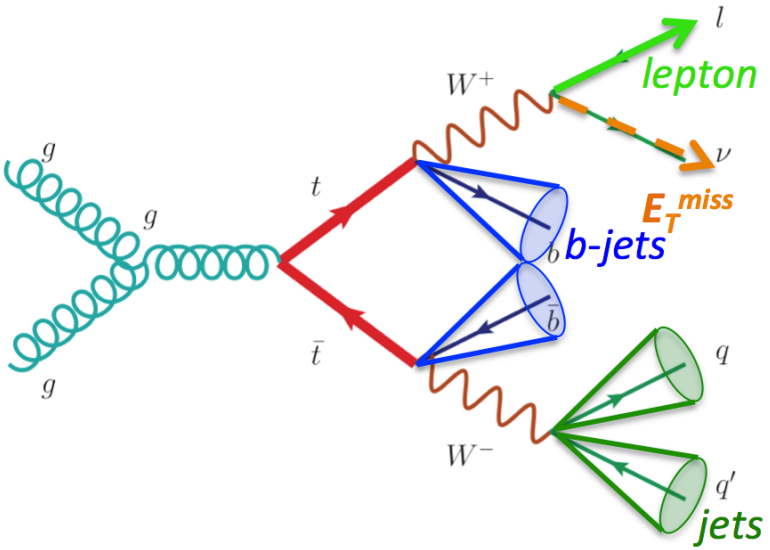
- **Data collected in ATLAS**
  - full 2011 7TeV dataset 4.6fb^{-1}
  - full 2012 8TeV dataset 20.3fb^{-1}





Top quark decay

- **Decay** of top quark
  - Decay mode in SM **BR~100% to Wb**
  - Classify according to **W decay modes**: all-hadronic (46%), single lepton (43%), dilepton (11%)
- **Selection of events**
  - **Dilepton selection:** exactly two isolated OS leptons, in ee,μμ events veto against Z+jet events (invariant mass, E_T^{Miss})
  - **Single lepton selection:** exactly one isolated lepton, cuts against W+jets and multi-jet production by E_T^{Miss} or $M_T(W)$, often dilepton veto with softer lepton p_T
  - important for selection: **b-tagging of jets,** typically @70% efficiency



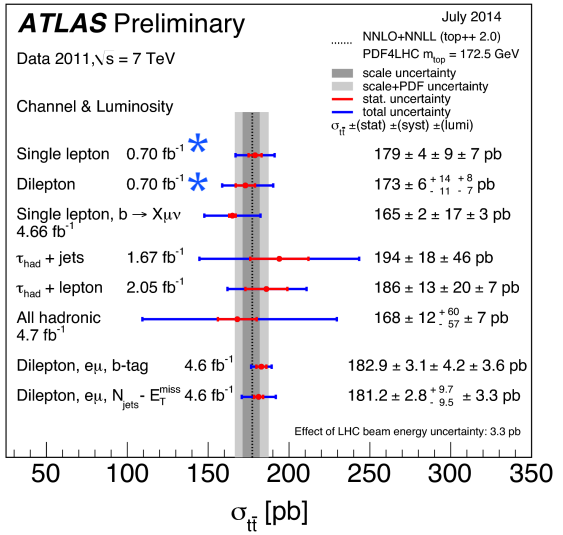
- **Typical background for top selection**
  - **single lepton:** W+jets, especially in association with heavy flavour, multi jet production
  - **dilepton:** Z+jets, diboson
  - **single top:** top pair production

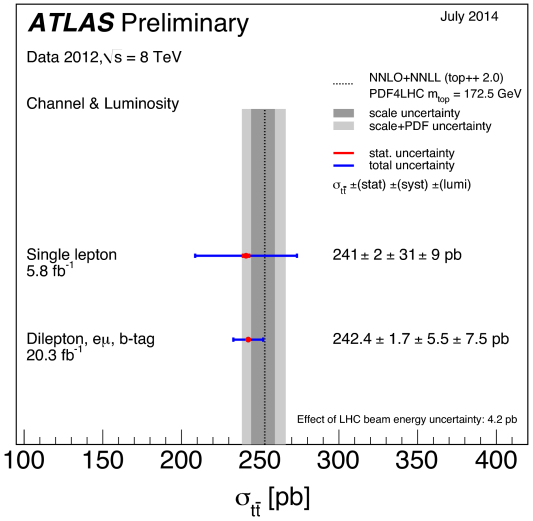
Top pair cross section measurements

Ttbar cross section measurements

*new results

- **Inclusive measurements in many final states**
  - Most precise measurements at both CME in the **dilepton** and **single lepton** final state (*arxiv:1406.5375, ATLAS-CONF-2012-149, Phys.Lett. B711 (2012) 244-263*)
  - All-hadronic final states and final states with tau leptons (*ATLAS-CONF-2012-031, Eur. Phys. J. C, 73 3 (2013) 2328, Phys.Lett. B 717 (2012) 89-108*)
  - **Combination @7TeV and @8TeV** with the most precise measurements within ATLAS(*) and with CMS (*ATLAS-CONF-2012-134, ATLAS-CONF-2014-054*)
  - Simultaneous measurement ttbar/Z/WW cross section (*arxiv:1407.0573*)
  - Top quark pole mass from theoretical dependence of total cross section
  - All measurements within the SM expectation, even challenge theory calculation



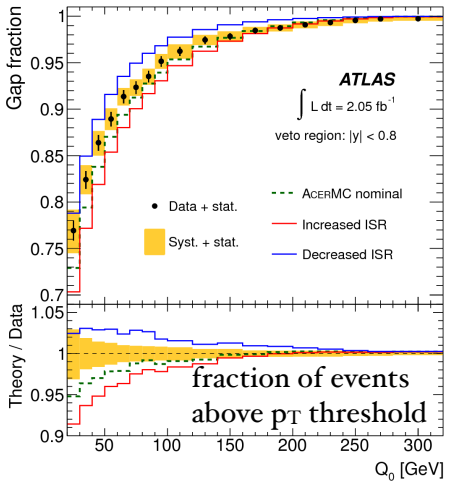


Ttbar cross section measurements

*new results

- **Differential measurements**
  - of top and ttbar kinematics, folded back to parton level and particle level (pseudo top) @7TeV and boosted ttbar production @8TeV, **compare MC models/PDF choices, valuable input to theory**
    (arxiv:1407.0891, arxiv:1407.0371, ATLAS-CONF-2014-059, ATLAS-CONF-2014-057)
- **Associated production**
  - with additional **jets**, with **heavy-flavour jets**, important for testing MC modelling
    (arxiv:1407.0891, Eur.Phys.J. C72 (2012) 2043, Phys.Rev. D 89, 072012 (2014))
  - evidence for **production with additional W/Z** @8TeV and near-evidence with **additional photons** @7TeV, important for EW couplings
    (ATLAS-CONF-2014-038, ATLAS-CONF-2011-153)

Eur.Phys.J. C72 (2012) 2043



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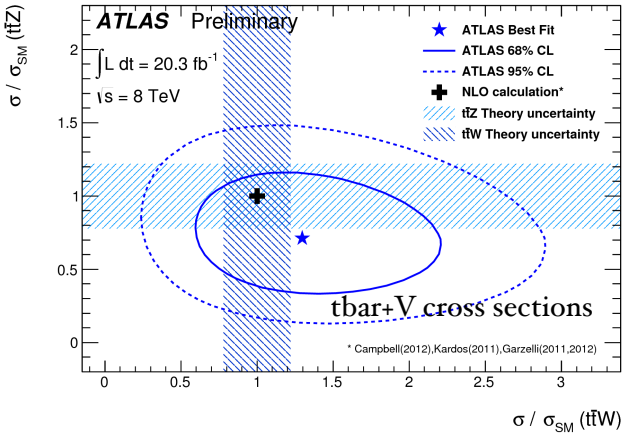


Combination of eμ channel 8TeV

(arxiv:1406.5375, ATLAS-CONF-2014-054)

new result

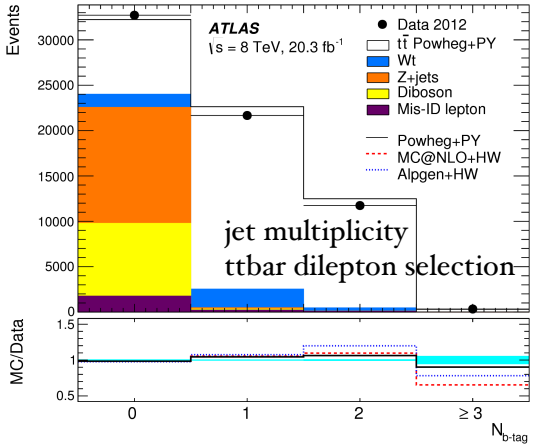
- **Using ATLAS measurement on full 8TeV dataset**
  - dilepton eμ selection with **≥1 jet, ≥1 b-tagged jets**
  - **Simultaneous** measurement of σ(ttbar) and (inclusive) efficiency for reconstruction and tagging b-jets by counting 1-tag and 2-tag events
    - Single most precise **cross section** result (4.3%):

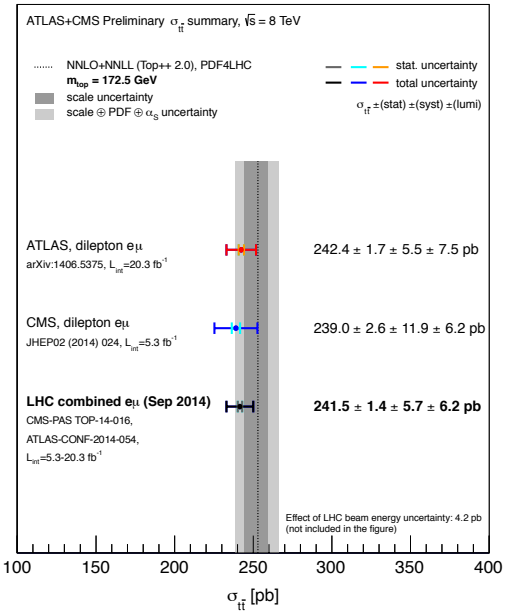
$$\sigma_{t\bar{t}} = 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2\,\text{pb}$$ (stat/syst/lumi/beam energy)

    - Also cross section within fiducial volume defined at particle level, derives top mass and sets limits on SUSY stop mass
    - Largest systematics: ttbar modelling and PDF uncertainties

- **Combination with CMS using BLUE with 3.5% uncertainty (<theory uncertainty)**

$$\sigma_{t\bar{t}} = 241.4 \pm 1.4 \pm 5.7 \pm 6.2\,\text{pb}\ @m_t = 172.5\,\text{GeV}$$
(stat/syst/lumi)

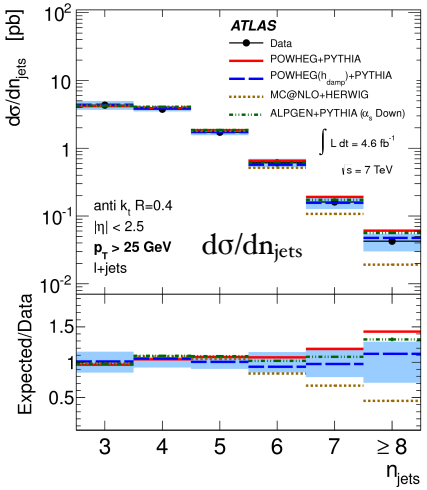


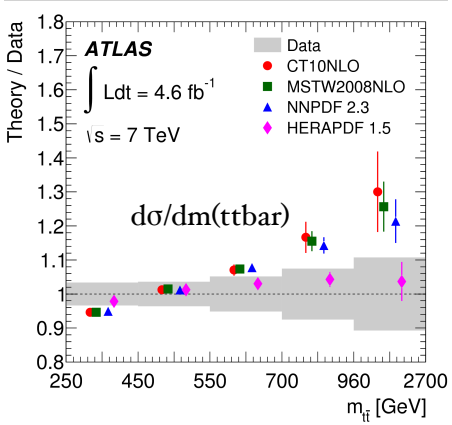


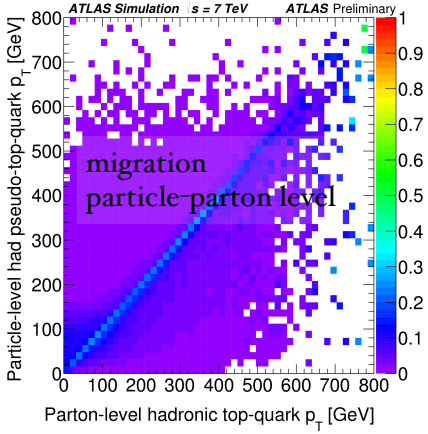
Differential cross sections 7TeV

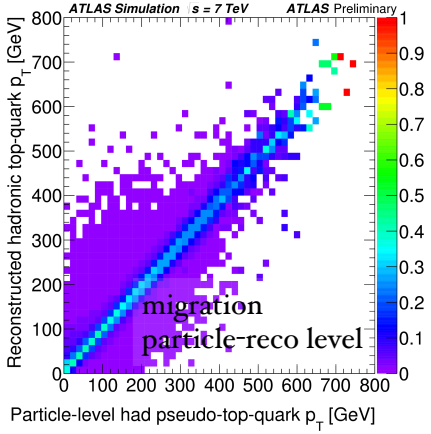
(arxiv:1407.0891, arxiv:1407.0371, ATLAS-CONF-2014-059)

- **as function of jet multiplicity and jet p_T, p_T(top), p_T(ttbar), m(ttbar), |y(ttbar)|, full dataset 7TeV**
  - Sensitive to higher-order pQCD effects, test theoretical calculations and modelling in MC, provide inputs for pQCD calculation at top mass scale
- differential cross section within **fiducial volume** defined at **particle level** and **unfolded to parton level**
  - **Powheg+Pythia** consistent with data, improve by limiting hard radiation
  - **HERAPDF fits better to data**
- **new approach:** differential cross section within fiducial volume defined at particle level and **unfolded to particle level**
  - avoid large extrapolations and minimise model-dependent corrections
  - need **pseudo-top quark definition** using reconstructed from data/stable particles in MC







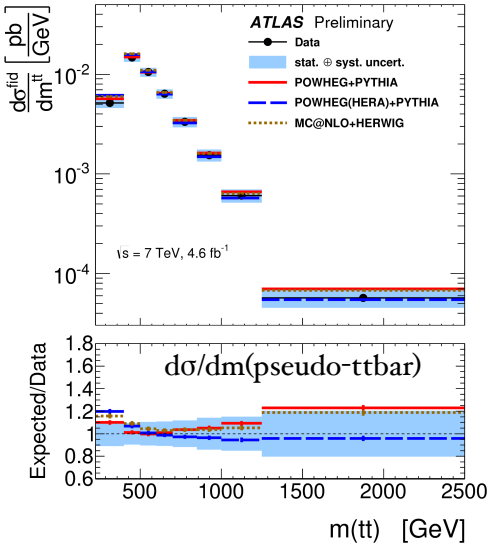


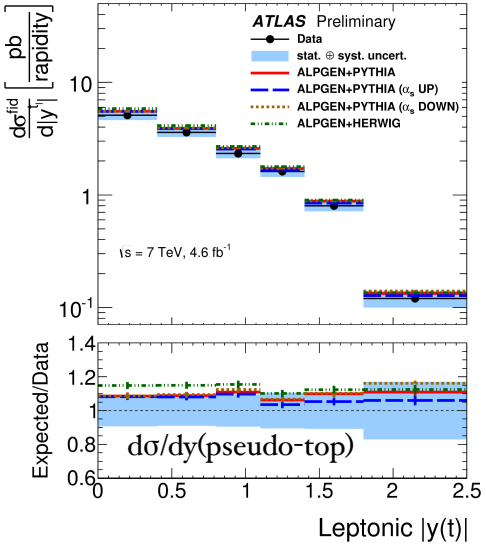
Differential cross sections 7TeV

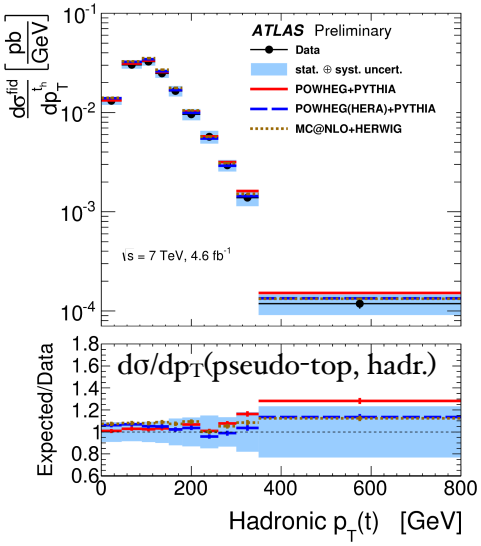
(arxiv:1407.0891, arxiv:1407.0371, ATLAS-CONF-2014-059)

new result

- **Pseudo-top quark definition**
  - **from reconstructed objects:** reconstruction of top pairs using kinematic constraints
  - **from stable particle:** $\tau > 0.3 \times 10^{-10}$ s, match reconstructed object within observed kinematic range, kinematic sum of decay products
  - E_T^{Miss}, leptons, jets based on exclusive particles: neutrinos from W decay, leptons with nearby photons, anti-kt R=0.4 based on remaining particles
  - **event selection:** exactly one lepton, four or more jets, two b-tagged, angular separation of leptons and jets
- **Bayesian unfolding of reconstructed pseudo-top distributions to particle level distributions (p_T, y, leptonic, hadronic top, ttbar, m(ttbar)) within fiducial region**
  - comparison with different MC generators, PDFs, showering scheme and Alpgen model with different shower parameters
  - Good modelling with Powheg+Pythia
  - Systematically limited by b-tagging, JES and ISR/FSR modelling





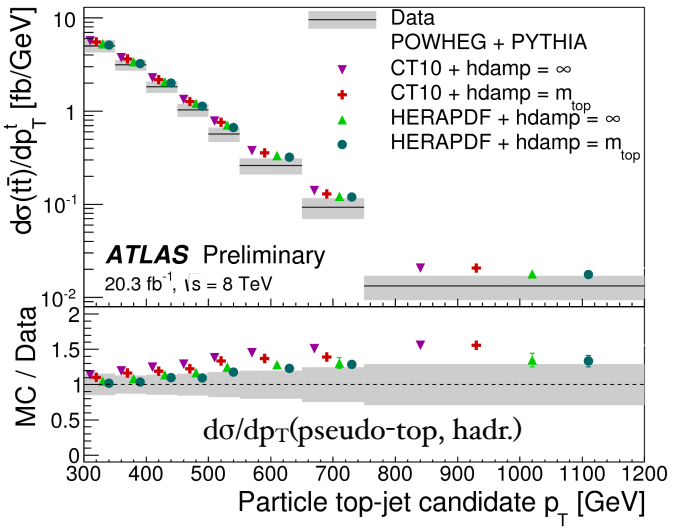


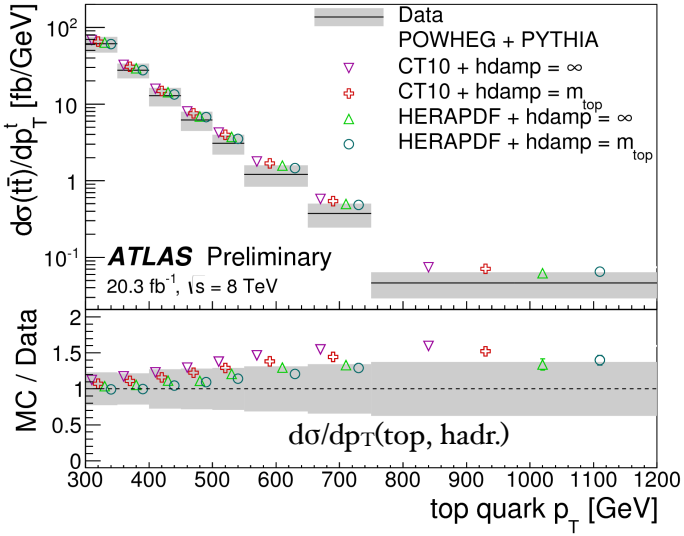
Differential cross section boosted top 8TeV

(ATLAS-CONF-2014-057)

new result

- **differential cross section as a function of hadronically decaying top pT of top quarks pT>300GeV using full 8TeV dataset**
  - extend range of differential measurements to high pT range using boosted topologies: collimated decay products
  - Selection based on single lepton decay mode, target hadronically decaying top quark
- **Reconstruction and selection of hadronically decaying top quark**
  - Using anti-kt jet with R=1.0, jet mass > 100 GeV, apply jet trimming and jet substructure cuts on kt-splitting scale $\sqrt{d_{12}}$
  - isolated leptons, large ETMiss
  - spatial separation between lepton and large-R jet, but nearby small-R jet identified as b-jet
- **SVD unfolding of reconstructed p_T distribution to particle and parton level and comparison with different generators**
  - over-estimation of all MCs at particle and on parton level, especially for high top p_T
  - better agreement for Powheg+Pythia
  - largest uncertainties from large-R JES



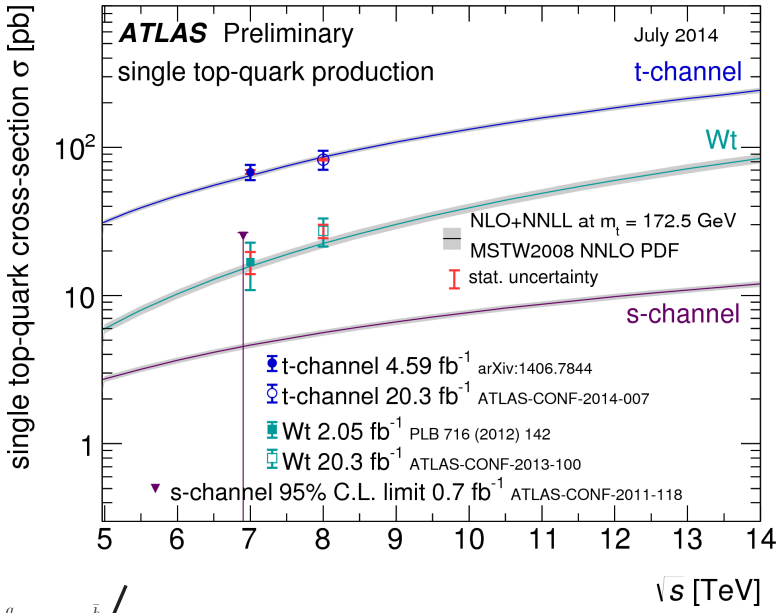


Single top cross section measurements

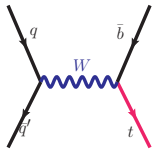
Single top cross section

*new results

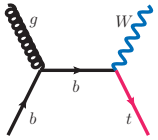
- **Inclusive measurements of all single top channels**
  - Unlike Tevatron
    - t-channel easy to observe, Wt-channel accessible, s-channel smallest cross section@LHC
    - smaller backgrounds



- **s-channel** limit (@7TeV) at ~5xSM *(ATLAS-CONF-2011-118)*

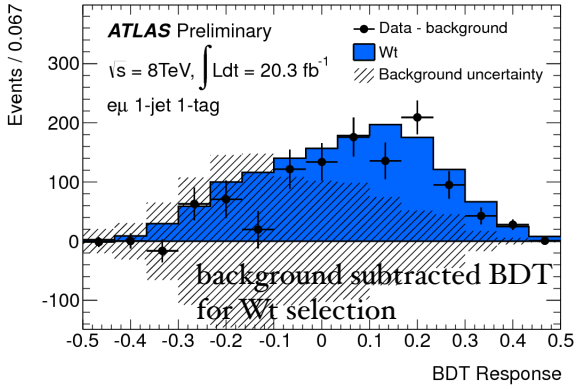


- **Wt-channel** evidence (@8TeV), near-observation at 4.2σ *(ATLAS-CONF-2013-100)*



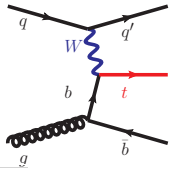
  - **combination** with CMS *(ATLAS-CONF-2014-052)*

ATLAS-CONF-2013-100



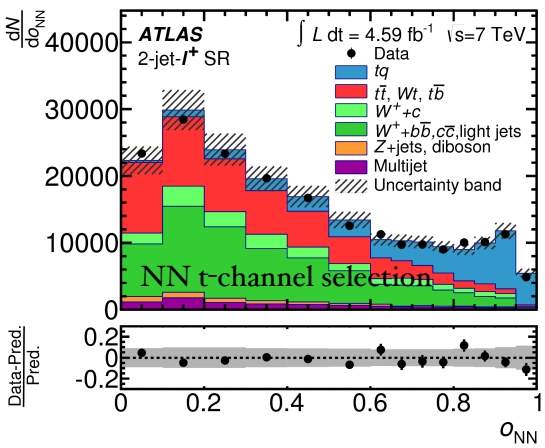
Single top cross section

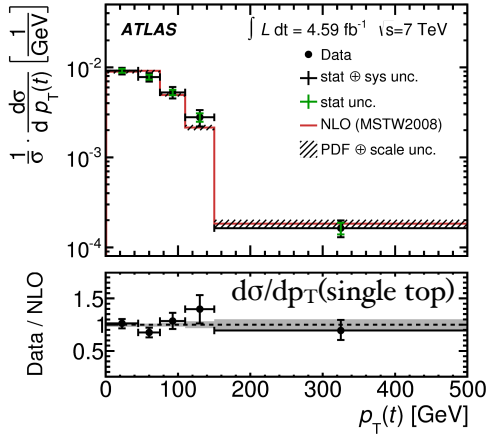
- **t-channel** well established with high purity
  (arxiv:1406.7844, ATLAS-CONF-2014-007)



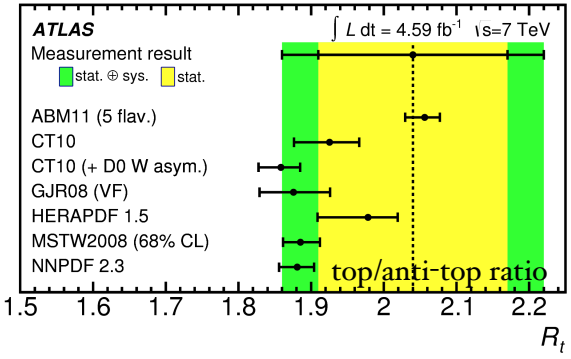
  - **Differential** (@7TeV) measurement in p_T (top/anti-top) and y(top/anti-top)
  - split in top and anti-top cross section for **ratio measurements**
  - **Fiducial** (@8TeV) cross section with extrapolation to different MC
  - **combination** with CMS *(ATLAS-CONF-2013-098)*

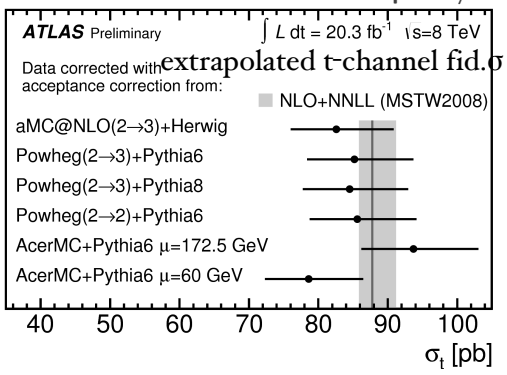
arxiv:1406.7844





ATLAS-CONF-2014-007





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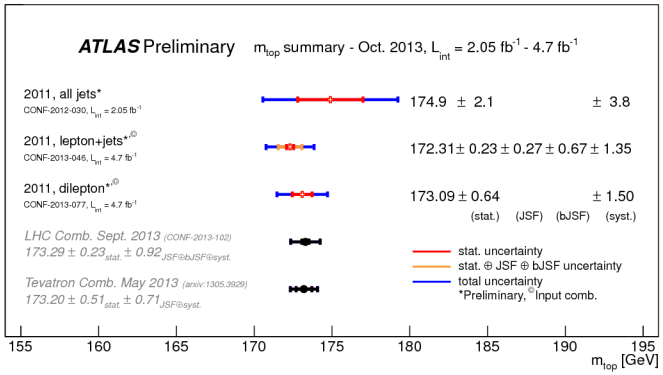
Top mass

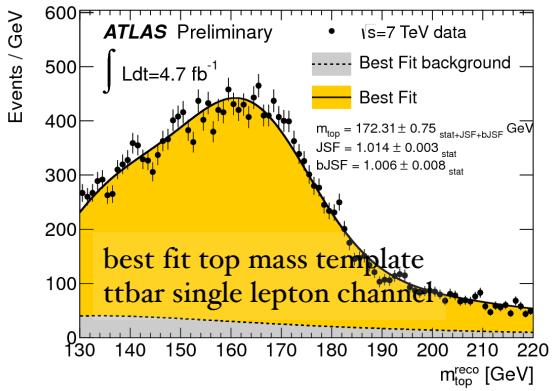
Top mass measurements

*new results

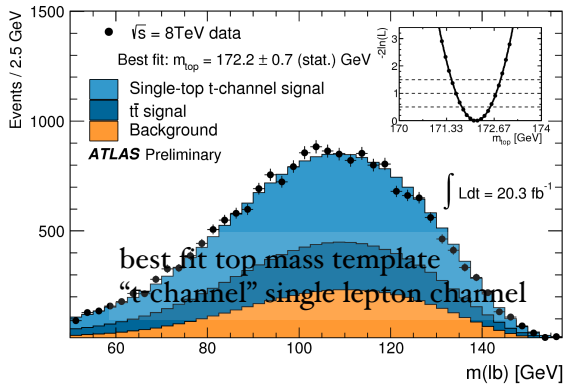
- **Top mass measurements**
  - Measurements with template methods or indirect measurements (dilepton) *(ATLAS-CONF-2013-046, ATLAS-CONF-2013-077, ATLAS-CONF-2012-082, arxiv:1409.0832)*
  - Measurements in single top enhanced events *(ATLAS-CONF-2014-055)*
  - Combinations within ATLAS and with CMS yield total uncertainties <1 GeV *(ATLAS-CONF-2013-102)*
  - World (LHC + Tevatron) combination with <0.5% uncertainty *(ATLAS-CONF-2014-008)*
  - Results at the moment only @7TeV
  - top quark pole mass from ttbar+1jet events (ATLAS-CONF-2014-053)
  - Mass difference between top and anti-top *(PhysLett B 728C (2014))*



ATLAS-CONF-2013-046



ATLAS-CONF-2014-055



top-quark pole mass using ttbar+1jet 7TeV

(ATLAS-CONF-2014-053)

new result

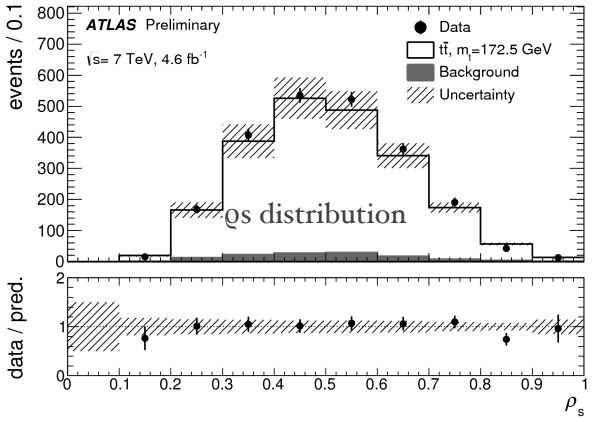
- **indirect pole mass measurement from differential ttbar cross section using full 7TeV dataset**
  - extraction based on sensitivity of gluon radiation on the top quark pole mass
  - normalized cross section as a function of inverse of invariant mass of ttbar+1jet system ϱ_s provides calculated in the top pole-mass scheme@NLO+PS
- **Kinematic reconstruction of single lepton events**
  - identify leptonically decaying W, mass and kinematic constraints on pairs of jets for hadronically decaying W
  - pairing with b-tag to minimise difference between top candidates
  - pT>50GeV requirement on the additional jet
- **Unfold rho_s using SVD to parton level and compare to NLO+PS theory calculation**
  - χ^2 minimisation fit to determine the best fit top pole mass

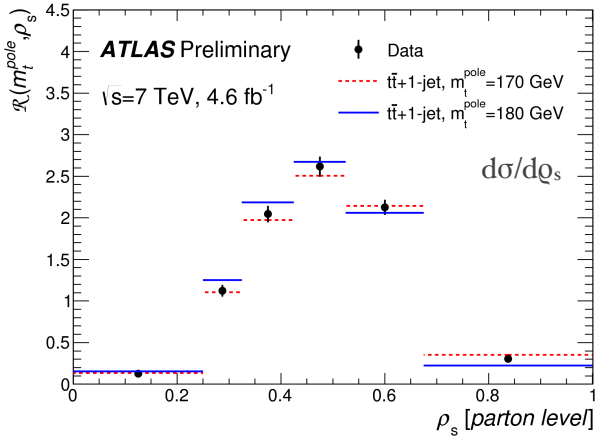
$$m_t^{\text{pole}} = 173.7\ ^{+2.3}_{-2.1}\ \text{GeV}$$

  - largest systematic from theory: missing higher orders, PDF and α_s
  - largest systematic from experiment: JES and ISR/FSR
  - in the future analysis will use calculation in $\overline{MS}$ mass scheme

$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{\text{pole}}, \rho_s),$$

$$\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}j}}},$$





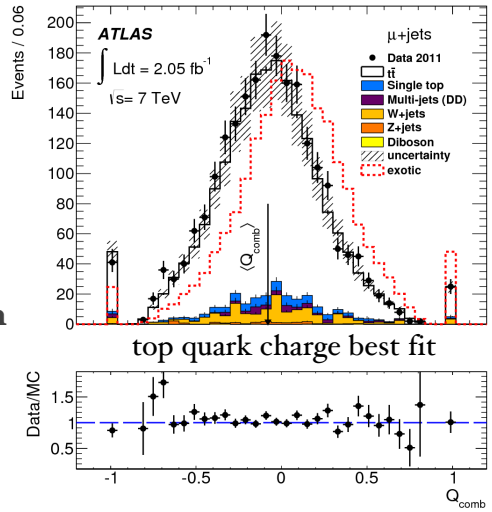
Top properties

Top properties

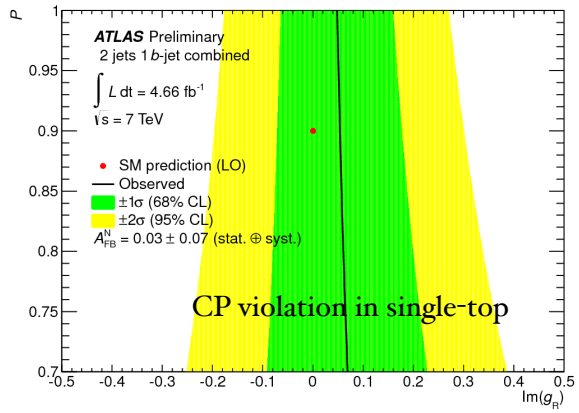
***new results**

- **Top charge**
  (JHEP11(2013)031)
- **W polarisation in top quark decays**
  (JHEP 1206 (2012) 088)
  - Combination with CMS
    (ATLAS-CONF-2013-033)
- **FCNC searches in decay to Zq or in single top production**
  (JHEP 1209 (2012) 139, ATLAS-CONF-2013-063)
- **Search for CP violation in single top**
  (ATLAS-CONF-2013-032)
- **Top charge asymmetry in single and dilepton final states**
  (JHEP02(2014)107, CERN-PH-EP-2014-233)
  - Combination with CMS
    (ATLAS-CONF-2014-012)
- **Top polarisation**
  (Phys. Rev. Lett 111, 232002 (2013))
- **Top spin correlation@7 TeV and @8TeV, also setting stop mass limits**
  (arxiv:1407.4314, ATLAS-CONF-2014-056)

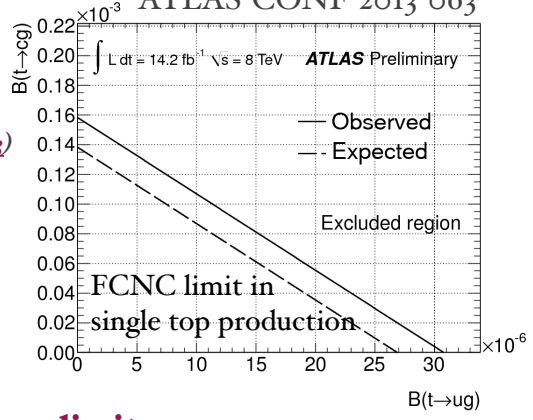
JHEP11(2013)031



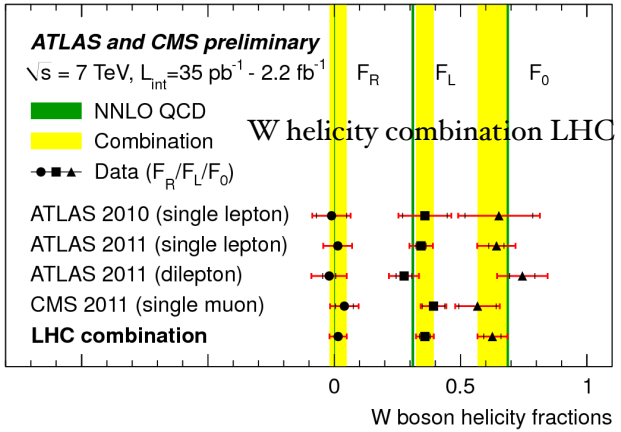
ATLAS-CONF-2013-032



ATLAS-CONF-2013-063



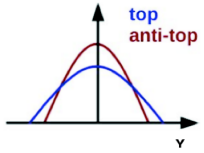
ATLAS-CONF-2013-033

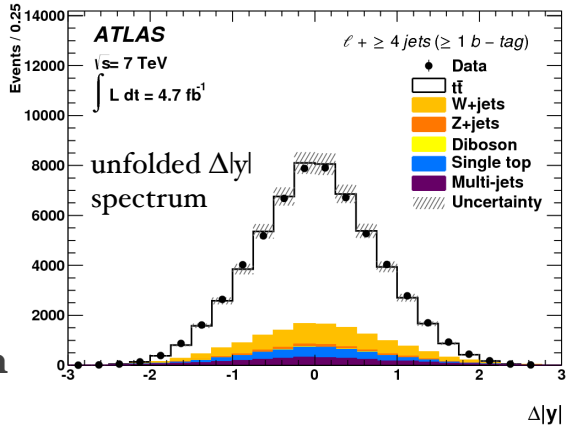


ttbar charge asymmetry 7TeV

(JHEP02(2014)107)

- **charge asymmetry A_C using full 7TeV dataset**
  - **Asymmetry from qqbar, qg production** with small excess of centrally produced anti-tops,
  - unlike Tevatron which observed an excess in the forward-backward asymmetry A_{FB}



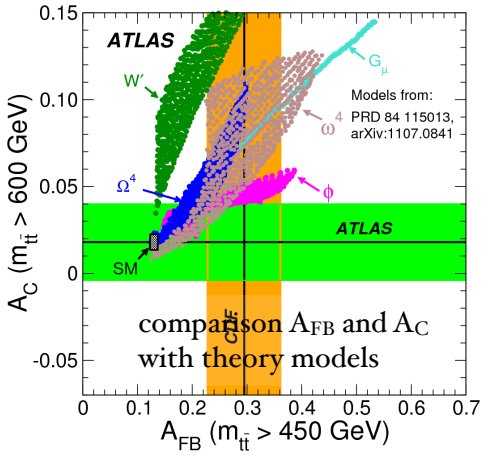


- Reconstruction of ttbar system with a **kinematic fit**, **Bayesian unfolding** of Δ|y| spectrum to parton level
  - single lepton selection with at least four jets and one b-tag
  - **inclusive and differential A_C** in |y(ttbar)| and m(ttbar), also for $\beta_{z,ttbar}$>0.6 enhancement predicted in certain models

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

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

  - Largest systematic uncertainty: data statistics



- Compare with model predictions, including A_{FB}
  - Different from A_{FB} (excess) measured at the Tevatron, tensions in specific models between A_C and A_{FB} measurements

ttbar charge asymmetry 7 TeV

(CERN-PH-EP-2014-233)

new result

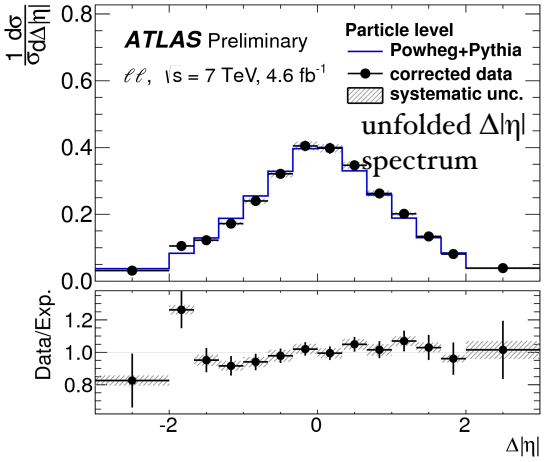
$$A_C^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)}$$

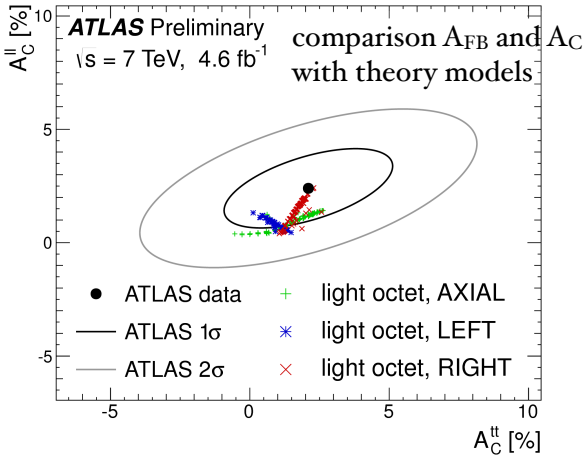
- **charge asymmetry A_C in dilepton events using full 7TeV dataset**
  - can determine lepton-based charge asymmetry (higher experimental precision) or asymmetry of top quarks after kinematic reconstruction of events (larger asymmetry)
- Reconstruction of ttbar system with a **kinematic fit with neutrino weighting**, **Bayesian unfolding** to parton level of $\Delta|y|$ and bin-by-bin correction for $\Delta|\eta|$ spectrum

$$A_C^{\ell\ell} = 0.024 \pm 0.015\ (\text{stat.}) \pm 0.009\ (\text{syst.})$$

$$A_C^{t\bar{t}} = 0.021 \pm 0.025\ (\text{stat.}) \pm 0.017\ (\text{syst.})$$

- Largest systematic uncertainty: data statistics
- Compare with SM predictions and with benchmark BSM models that could explain Tevatron A_{FB} for A_C^{ll} and A_C^{ttbar}

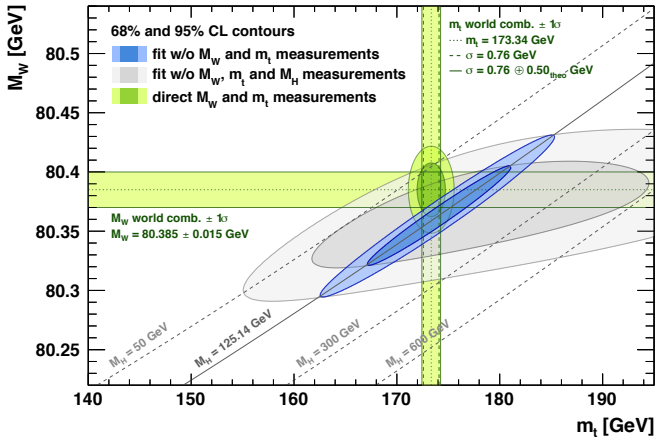




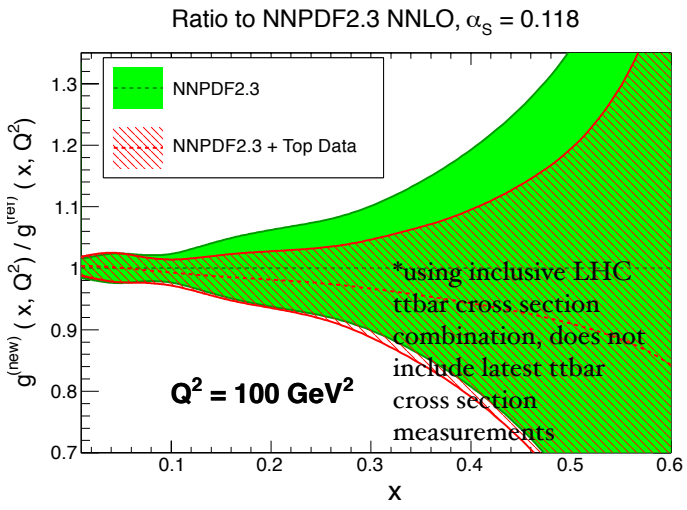
Summary

- **Top quark physics at ATLAS covers a large fraction of the rich phenomenology**
- **Measurement of top quark properties**
  - Interesting property measurements make mostly use of full 7TeV dataset
  - **Top mass precision reached <1% ATLAS alone, <0.5% in combination**
  - So far all properties are **compatible with the SM**
- **Inclusive top pair cross section measurements have reached theory precision**
  - **Differential/Fiducial cross sections** helped to **understand and tune MC modelling,** will help theory
  - **Single top production** will follow the top pair measurements in that respect
- **More results to come with full 8 TeV dataset**

arXiv:1407.3792



arXiv:1303.7215



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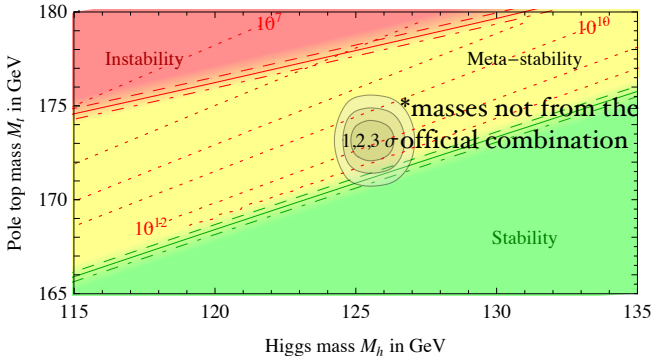
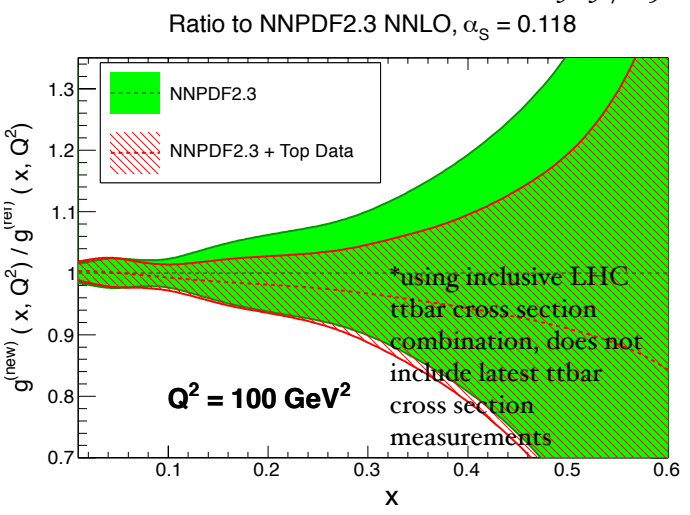
arXiv:1205.6497



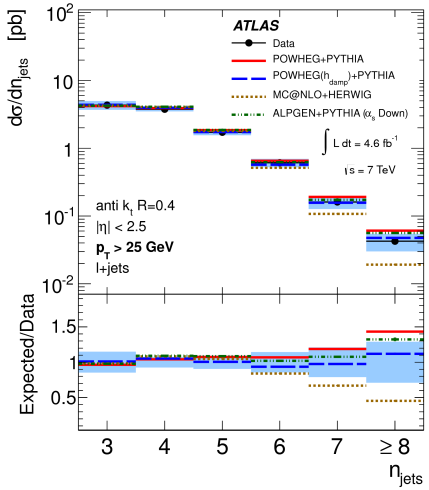
arXiv:1303.7215

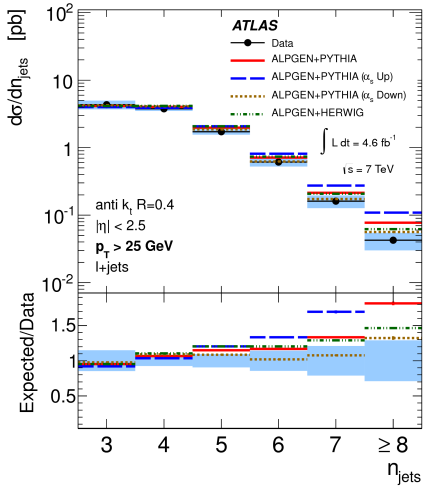


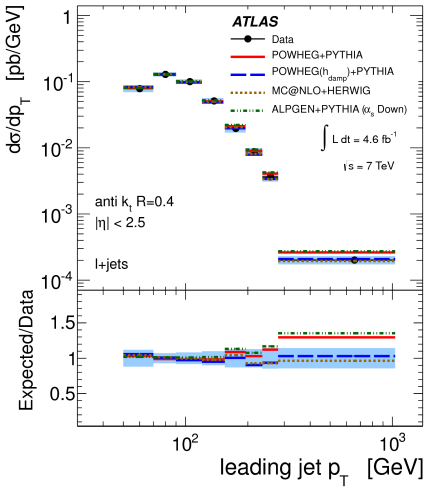
Backup

Differential cross section 7TeV *(arxiv:1407.0891)*

- **as function of jet multiplicity and jet p_T, full 7TeV dataset**
  - Sensitive to higher-order perturbative QCD effects, **test different theoretical calculations and modelling in MC**
- **differential** cross section within **fiducial volume** defined at **particle level**
  - single lepton selection, at least three jets, pT>50, 35, 25GeV, at least one b-tag
- Jet multiplicities with different jet p_T thresholds (25, 40, 60, 80GeV) and jet p_T up to the 5th-leading jet
  - **MC@NLO+Herwig** disfavoured at high jet multiplicities and high jet p_T
  - **Powheg+Pythia** consistent with data, improve by limiting hard radiation
  - **Alpgen+Pythia/Herwig** softer parton shower preferred at low jet p_T

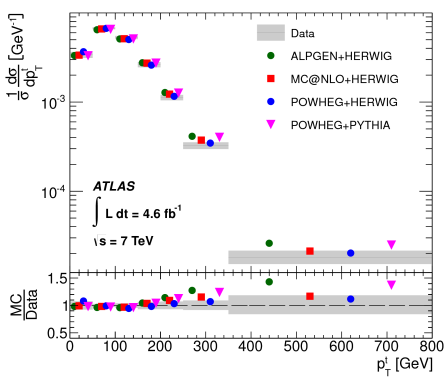


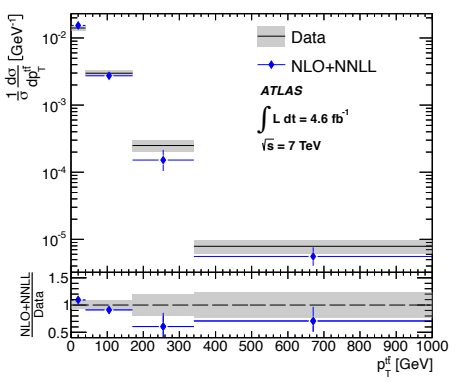


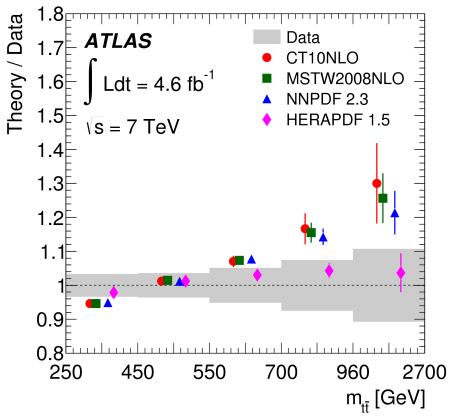


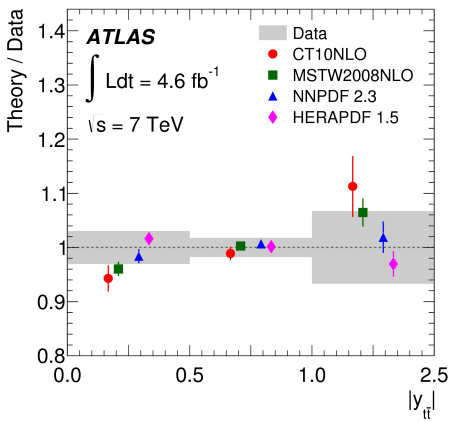
Differential cross section 7TeV *(arxiv:1407.0371)*

- **as a function of p_T(top), p_T(ttbar), m(ttbar), |y(ttbar)|, full dataset 7TeV**
  - test different **theoretical calculations** and **modelling in MC**
- kinematic reconstruction of full ttbar with kinematic likelihood fit to match object on parton level
  - single lepton selection, at least four jets, at least one b-tag
  - **unfolding of data with SVD method**
- Compare unfolded distributions with
  - different **MC generators**, with different **PDF sets** and **different theory calculation** (NLO/NLO+NLL)









- **Data in pT(top) is softer** than MC and NLO/NLO+NLL calculation, **m(ttbar) softer** in data than NLO/NLO+NLL calculation, **HERAPDF fits better to data**
- largest systematics: pT(top), m(ttbar): JES, signal generator choice, b-tagging efficiency; pT(ttbar), y(ttbar): fragmentation, jet energy resolution, only pT(ttbar): ISR/FSR

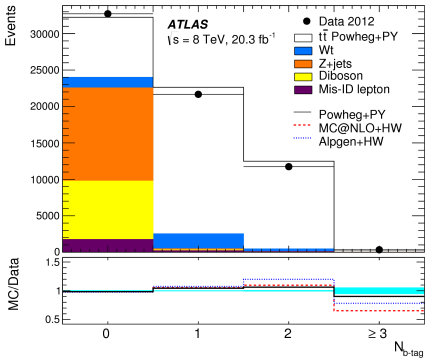
Dilepton channel 7TeV and 8TeV *(arxiv:1406.5375)*

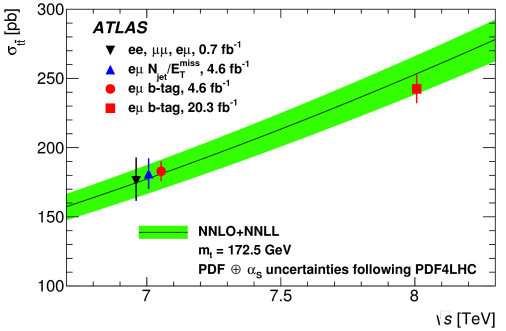
- **Using full 7TeV ($4.6fb^{-1}$) and full 8TeV ($20.3fb^{-1}$) dataset**
  - dilepton eμ selection with **≥1 jet, ≥1 b-tagged jets**
- **Simultaneous** measurement of σ(ttbar) and (inclusive) efficiency for reconstruction and tagging b-jets by counting 1-tag and 2-tag events
  - **Cross section** result, **ratio** $\sigma(8TeV)/\sigma(7TeV)$ (stat/syst/lumi/beam energy):

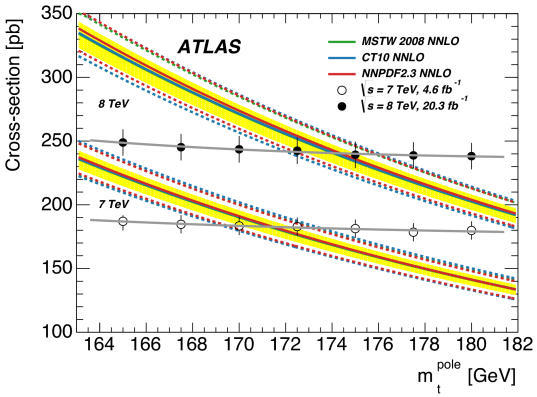
$$\sigma_{t\bar{t}} = 182.9 \pm 3.1 \pm 4.2 \pm 3.6 \pm 3.3\,\text{pb}\ (\sqrt{s} = 7\,\text{TeV})$$
$$\sigma_{t\bar{t}} = 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2\,\text{pb}\ (\sqrt{s} = 8\,\text{TeV})$$
$$R_{t\bar{t}} = 1.326 \pm 0.024 \pm 0.015 \pm 0.049 \pm 0.001$$

  - Largest systematics: ttbar modelling and PDF uncertainties
  - **Fiducial cross section** with different lepton p_T and η cuts reduce PDF systematics, background modelling becomes important
- **Pole mass from cross section** using experimental and theoretical dependence

$$m_t^{\text{pole}} = 172.9^{+2.5}_{-2.6}\ \text{GeV}$$





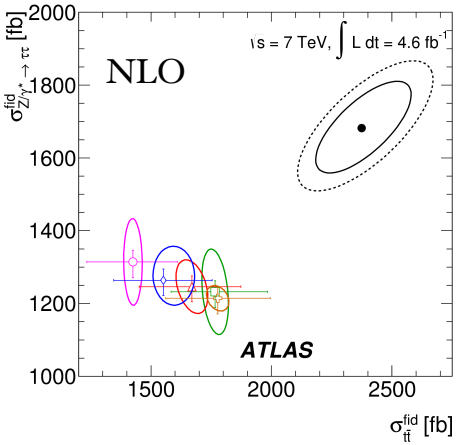


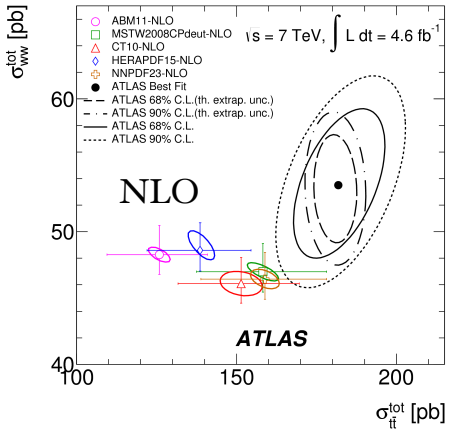
Simultaneous cross section ttbar/Z/WW *(arxiv:1407.0573)*

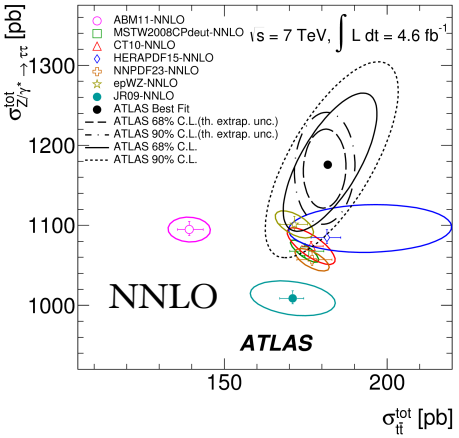
- **Simultaneous cross section measurement full dataset @7TeV in E_T^{Miss}-N_{jets} parameter space**
  - **broader test of SM**, take correlation of **PDFs** to each process into account
- **binned maximum likelihood fit** to templates, **fiducial volume** defined at **particle level**
  - dilepton eμ selection with no jets or at least one jet
  - Inclusive cross sections **comparable with dedicated measurements:**

$$\sigma(t\bar{t}) = 181.2 \pm 2.8^{+9.7}_{-9.5} \pm 3.3 \pm 3.3\,\text{pb}$$
$$\sigma(W^+W^-) = 53.3 \pm 2.7^{+7.3}_{-8.0} \pm 1.0 \pm 0.5\,\text{pb}$$
$$\sigma(Z/\gamma^* \to \tau\tau) = 1174 \pm 24^{+72}_{-87} \pm 21 \pm 9\,\text{pb}$$

(stat/syst/lumi/beam energy)



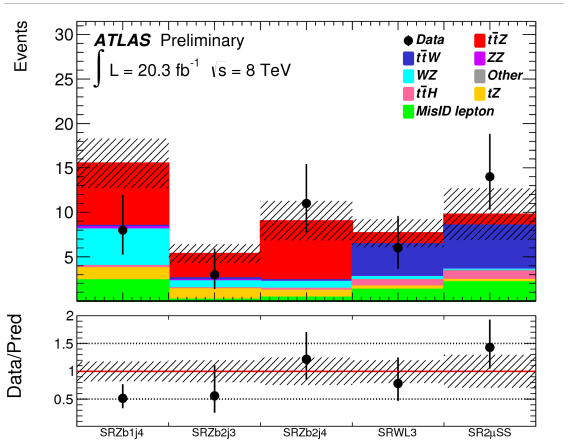


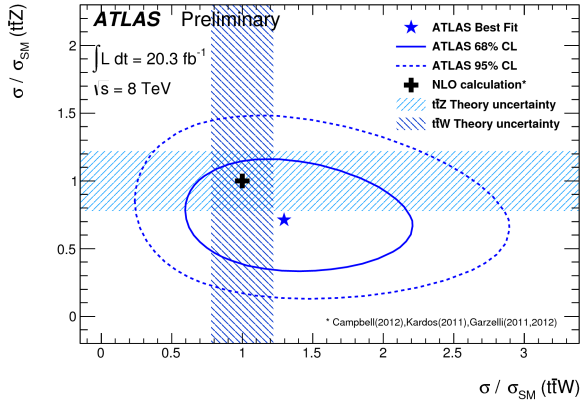


- Comparison of cross sections with **theory calculations@NLO/NNLO** using different PDFs
  - NLO significantly underestimates data, while comparison with **NNLO** calculations are **more compatible with data**
  - Largest systematics: mostly MC modelling and electron efficiencies

Associated V and ttbar production *(ATLAS-CONF-2014-038)*

- **Associated V-production**
  - probe top quark coupling to gauge bosons
- cut and count analysis
  - **same sign dimuon** (SR2μSS) with 2 b-tagged jets
  - **trilepton**, 3lZ (one pair OS,invariant mass near Z, SRZb***njm***) and 3lZveto (other, not all same sign, SRWL3)
- Multivariate analysis with NN
  - two **OS dilepton** channel, within Z mass window or outside
- Simultaneous fit to each channel/NN output distributions
  - largest systematics: data statistics, then detector systematics (ttW) or background (ttZ)



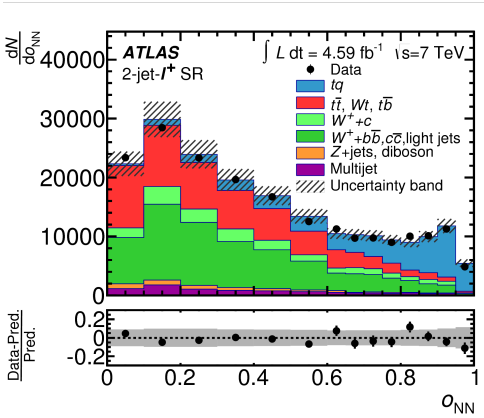


	Summary of combined simultaneous fit results		
Process	Measured cross-sections	Observed σ	Expected σ
$t\bar{t}Z$	150^{+58}_{-54}(total) = 150^{+55}_{-50}(stat.) ± 21(syst.) fb	3.1	3.7
$t\bar{t}W$	300^{+140}_{-110}(total) = 300^{+120}_{-100}(stat.)$^{+70}_{-40}$(syst.) fb	3.1	2.3

Process	Signal Strength	Observed σ	Expected σ
$t\bar{t}V$	$0.89^{+0.23}_{-0.22}$	4.9	4.9
$t\bar{t}W$	$1.25^{+0.57}_{-0.48}$	3.1	2.4
$t\bar{t}Z$	$0.73^{+0.29}_{-0.26}$	3.2	3.8

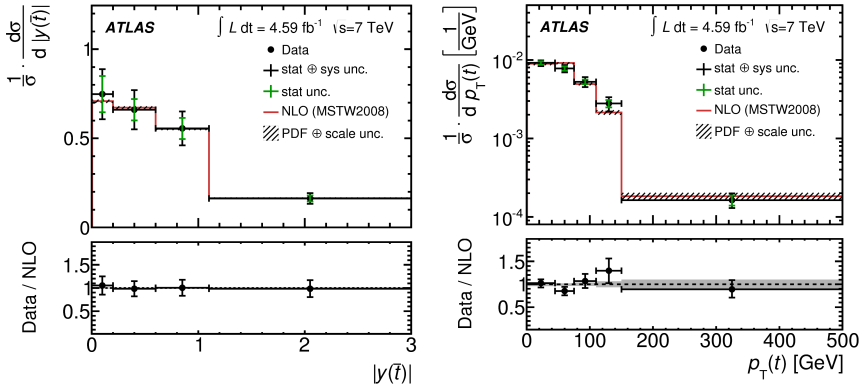
t-channel cross section (*arxiv:1406.7844*)

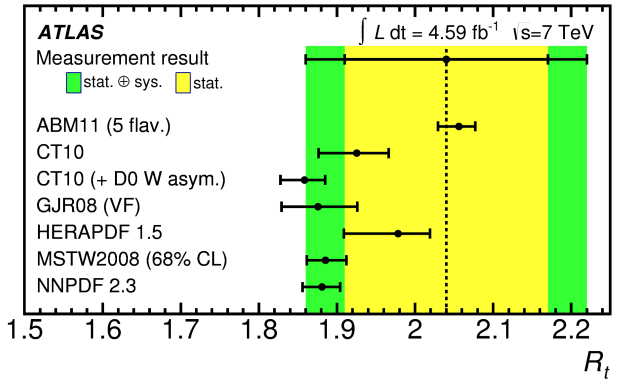
- **Inclusive cross section, cross section ratio top/anti-top, differential cross section using full 7TeV dataset**
  - single lepton selection with two or three central and **forward** jets and one b-tag
- Using **neural network to separate signal,** binned likelihood fit to extract cross sections
  - Separate neural networks for events with positively or negatively charged lepton and for each jet multiplicity
  - **Cross section ratio** has sensitivity to different PDFs
- Enhance signal by cut on NN for **differential cross section** in pT(top/anti-top), y(top/anti-top) using Bayesian unfolding to parton level
- Largest systematics: σ(t-channel): JES and b-tagging efficiencies; ratio: MC stat, PDF; differential: data stat., signal and bkg modelling



$$\sigma(tq) = 46 \pm 1\,(\text{stat.}) \pm 6\,(\text{syst.})\,\text{pb}$$
$$\sigma(\bar{t}q) = 23 \pm 1\,(\text{stat.}) \pm 3\,(\text{syst.})\,\text{pb}$$
$$R_t = 2.04 \pm 0.13\,(\text{stat.}) \pm 0.12\,(\text{syst.})$$

$$|V_{tb}| = 1.02 \pm 0.01\,(\text{stat.}) \pm 0.06\,(\text{syst.}) \pm 0.02\,(\text{theo.})\,^{+0.01}_{-0.00}\,(m_t)$$
$$= 1.02 \pm 0.07.$$

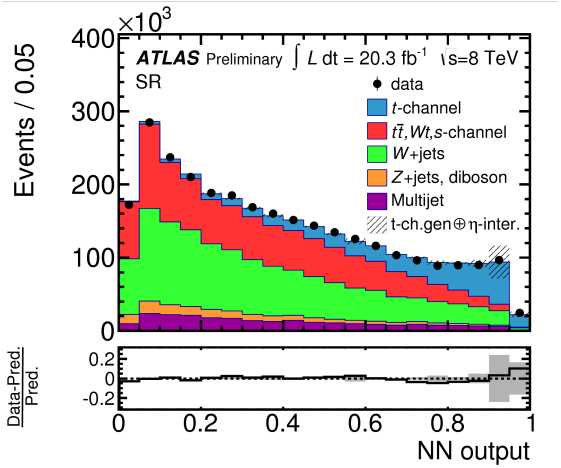




t-channel cross section *(ATLAS-CONF-2014-007)*

- **Fiducial cross section using full 8TeV dataset**
  - single lepton selection with two central and **forward** jets and one b-tag
- Using **neural network** to separate signal, binned likelihood fit to extract fiducial cross sections
  - **Fiducial cross** section less dependent on theory extrapolation uncertainties, separate theoretical and experimental uncertainties
  - Fiducial volume defined on **particle level:**

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



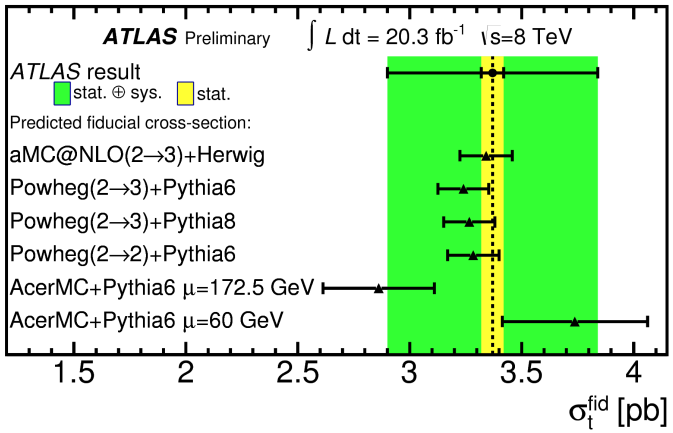
- Inclusive cross section obtained using a **particular choice of generator:**

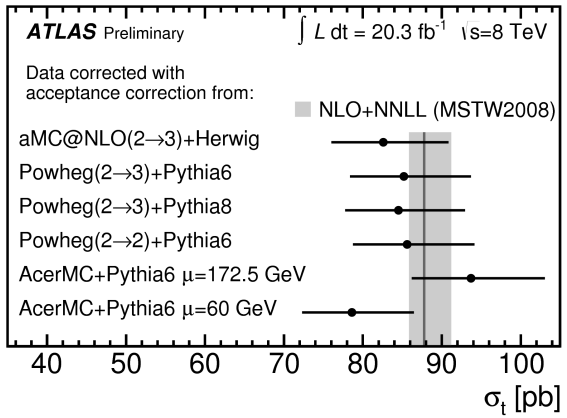
$$\sigma_t = 82.6 \pm 1.2\,(\text{stat.}) \pm 11.4\,(\text{syst.}) \pm 3.1\,(\text{PDF}) \pm 2.3\,(\text{lumi.})\ \text{pb}\quad (\text{aMC@NLO})$$

$$|V_{tb}| = 0.97 \pm 0.01\,(\text{stat.})^{+0.06}_{-0.07}\,(\text{syst.}) \pm 0.06\,(\text{gen.} + \text{PDF})^{+0.02}_{-0.01}\,(\text{theor.}) \pm 0.01\,(\text{lumi.})$$

$$|V_{tb}| > 0.78 \text{ at } 95\%\ \text{CL}$$

- Largest uncertainties: JES, t-channel generator, b-tagging efficiency





Wt cross section *(ATLAS-CONF-2013-100)*

- **Cross section measurement using 8TeV full dataset**
  - Dilepton eμ selection, one or two central jets, at least one b-tag
- Signal separation **against top pairs** using **BDT**, cross section determined with binned likelihood fit

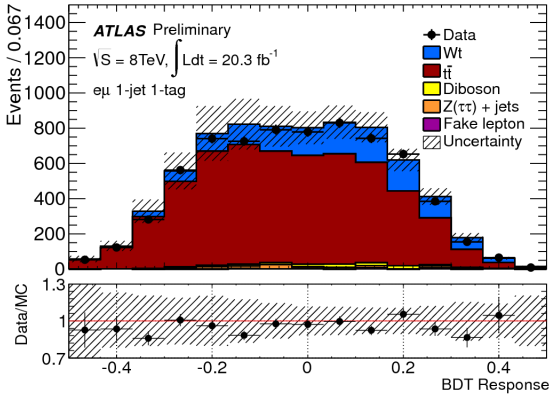
$$\sigma(pp \to \mathrm{Wt} + \mathrm{X}) = 27.2 \pm 2.8\ (\mathrm{stat}) \pm 5.4\ (\mathrm{syst})\ \mathrm{pb}$$

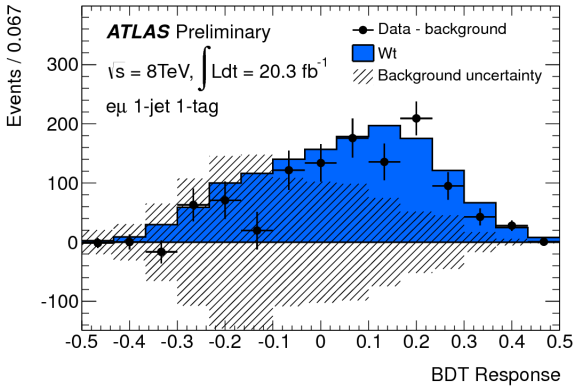
  - **Significance 4.2σ**

$$|V_{tb} \cdot f| = 1.10 \pm 0.12\ (\mathrm{exp}) \pm 0.03\ (\mathrm{theory})$$

$$|V_{tb}| > 0.72 \text{ at } 95\%\ \mathrm{CL}$$

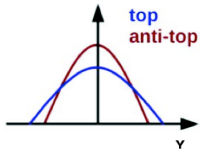
  - Largest systematics: JES and b-tagging



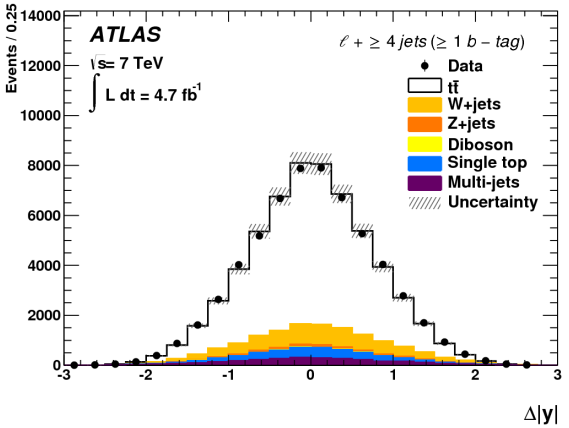


ttbar charge asymmetry (JHEP02(2014)107)

- **charge asymmetry A_C using full 7TeV dataset**
  - **Asymmetry from qqbar, qg production** with small excess of centrally produced anti-tops



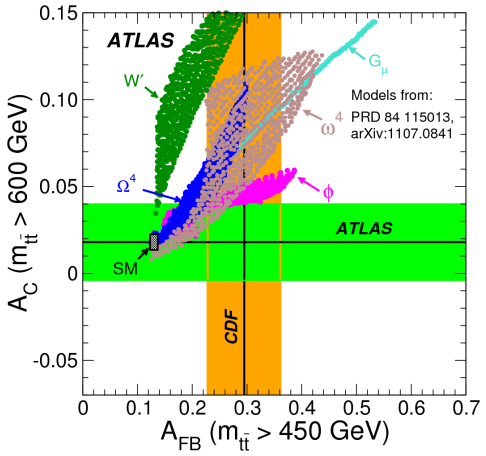
- Reconstruction of ttbar system with a **kinematic fit**, **Bayesian unfolding** of Δ|y| spectrum to parton level
  - single lepton selection with at least four jets and one b-tag
  - **inclusive and differential A_C** in |y(ttbar)| and m(ttbar), also for $\beta_{z,ttbar}$>0.6 enhancement predicted in certain models



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

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

  - Largest systematic uncertainty: data statistics



- Compare with model predictions, including A_{FB}
  - Different from A_{FB} (excess) measured at the Tevatron, tensions in specific models between A_C and A_{FB} measurements

Top spin correlation *(arxiv:1407.4314)*

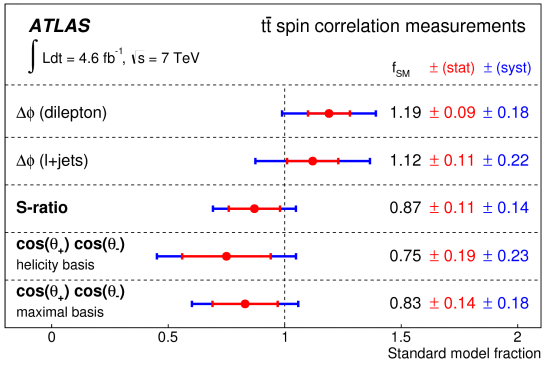
- **Spin correlation A full 7TeV dataset**

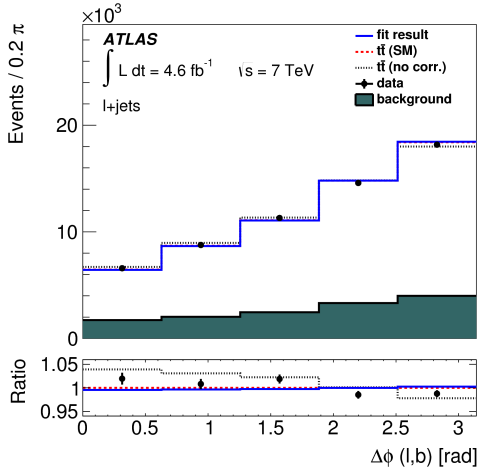
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos(\theta_+)\,d\cos(\theta_-)} = \frac{1}{4}\left(1 + A\,\alpha_+\alpha_-\cos(\theta_+)\cos(\theta_-)\right) \qquad A = \frac{N_{\text{like}} - N_{\text{unlike}}}{N_{\text{like}} + N_{\text{unlike}}}$$

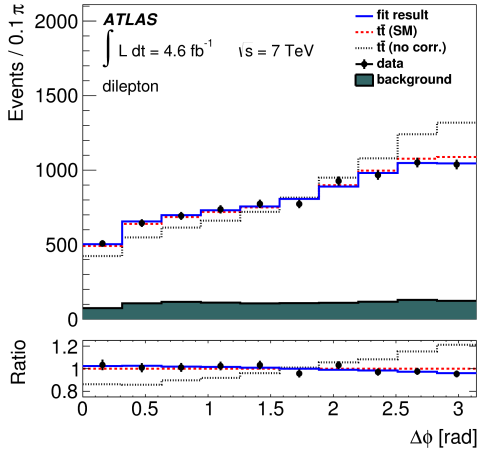
  - New physics can alter the spin correlation

- **Kinematic reconstruction** with neutrino weighting (dilepton), **kinematic likelihood fitter** (single lepton)
  - single lepton with at least four jets and dilepton selection with at least two jets
  - down-type quark identified by b-tag weight and jet pT
  - Variables **dilepton**: $\Delta\varphi$(leptons), S-ratio and angular correlations (=direct determination of A), **single lepton**: $\Delta\varphi$(lepton, b quark or d quark from W)

- **Binnend likelihood fit** to fraction f of templates with and without spin correlation
  - **5σ observation** of spin correlation
  - Largest systematic uncertainties: mostly data statistics and signal modelling







$$A^{\text{measured}}_{\text{basis}} = f_{\text{SM}}\,A^{\text{SM}}_{\text{basis}}$$

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Top polarisation *(Phys. Rev. Lett 111, 232002 (2013))*

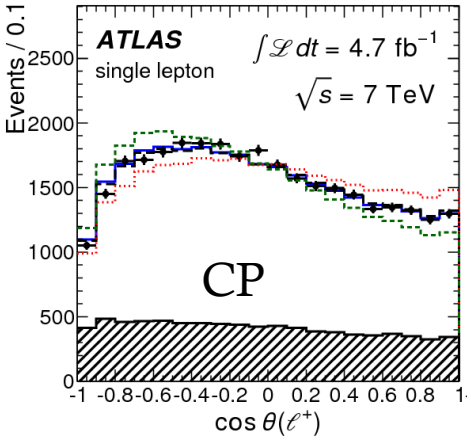
- **Polarisation $\alpha_1 P$ using full 7TeV dataset**
  - **neglibigle polarisation in SM** from EW interaction (spin correlation C set to SM value)

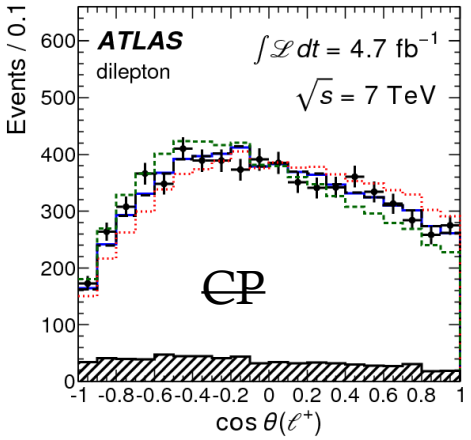
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 + \alpha_1 P_1 \cos\theta_1 + \alpha_2 P_2 \cos\theta_2 - C\cos\theta_1\cos\theta_2)$$

- **Kinematic reconstruction** with neutrino weighting (dilepton), **kinematic likelihood fitter** (single lepton)
  - single lepton with at least four jets and dilepton selection with at least two jets
- **template fit** to reweighed cosθ distribution(s) using SM
  - CP **conserving** ($\alpha_1 P_1 = \alpha_2 P_2$) and CP **violating** ($\alpha_1 P_1 = -\alpha_2 P_2$) scenarios

$\alpha_\ell P_{\mathrm{CPC}}$	$\alpha_\ell P_{\mathrm{CPV}}$
$-0.035 \pm 0.014^{+0.037}_{-0.037}$	$0.020 \pm 0.016^{+0.013}_{-0.017}$

  - Largest systematics: jet reconstruction, ttbar and bkg modelling



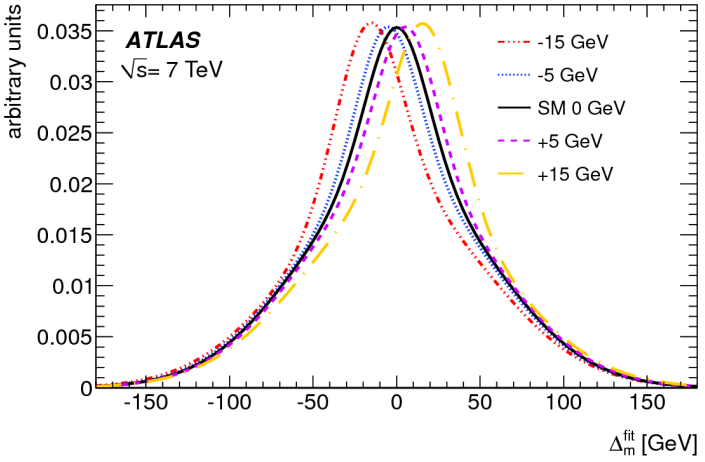


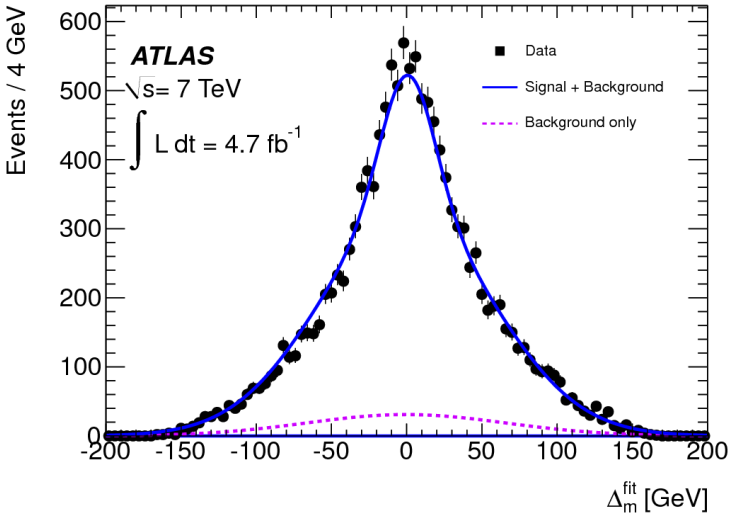
Top mass difference *(PhysLett B 728C (2014))*

- **Top/Anti-top mass difference using full 7TeV dataset**
  - Testing **CTP** invariance
- **Kinematic fit** to ttbar events with Δm_{fit}(top) as free parameter
  - single lepton selection with four or more jets, kinematic cuts against multi-jet background
  - **unbinned likelihood fit to templates** of Δm_{fit}(top) from samples with different Δm(top)

$$\Delta m \equiv m_t - m_{\bar{t}} = 0.67 \pm 0.61(\text{stat}) \pm 0.41(\text{syst})\ \text{GeV},$$

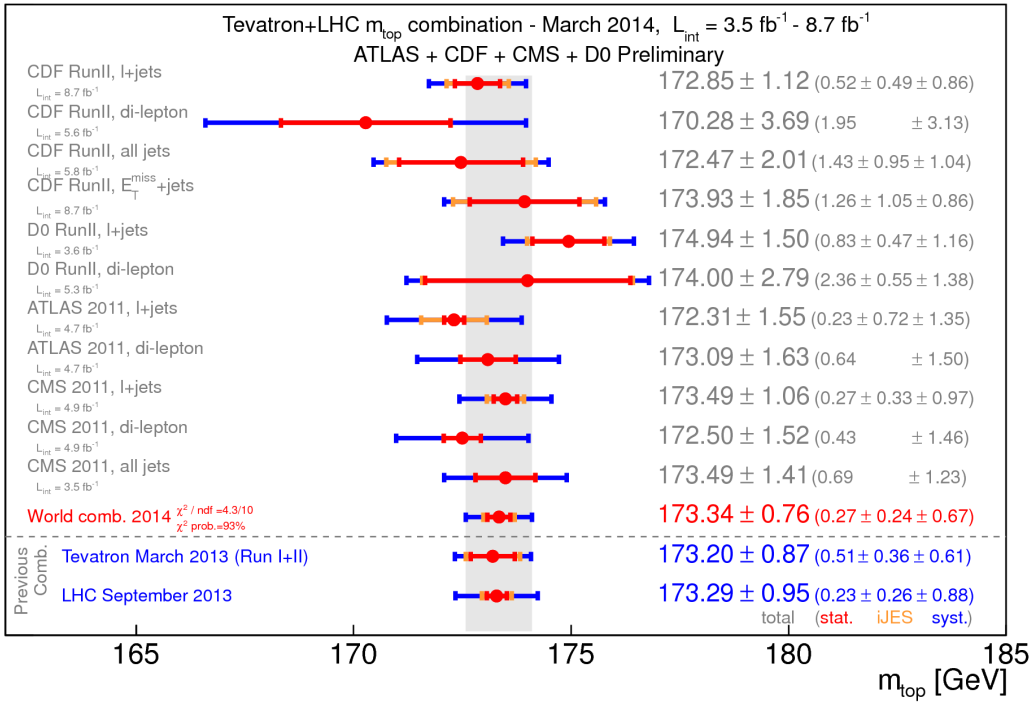
  - result limited by statistics, largest systematics from fragmentation and B hadrons decay

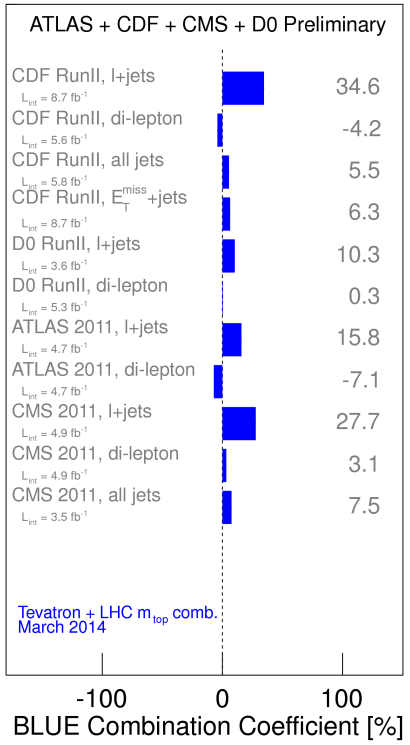




World top mass combination *(ATLAS-CONF-2014-008)*

- **Top mass combination using results from ATLAS, CDF, CMS and DO**
  - Uncertainty from LHC < 1GeV (only with 7TeV data)
  - Uncertainty on the combined top mass <0.5%



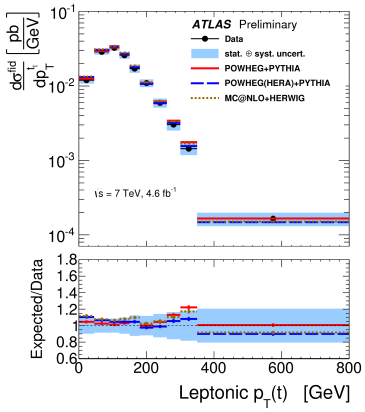


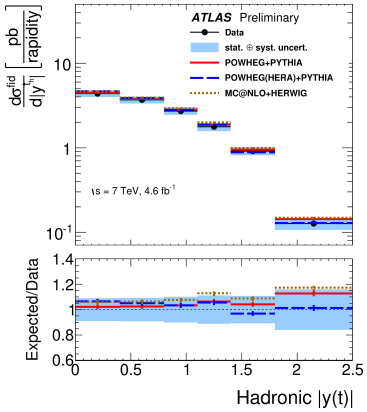
$$m_{\text{top}} = 173.34 \pm 0.27\ (\text{stat}) \pm 0.71\ (\text{syst})\ \text{GeV}.$$

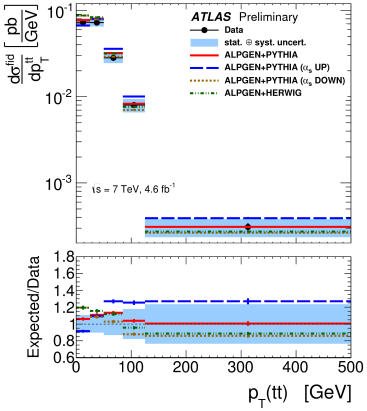
Pseudo-top differential cross section 7TeV

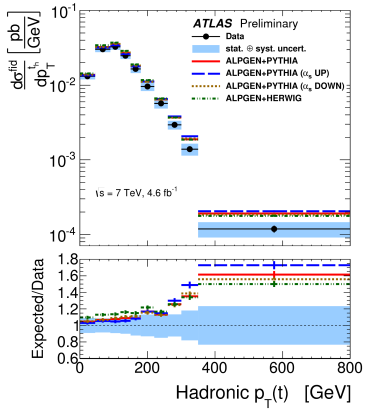
(ATLAS-CONF-2014-059)

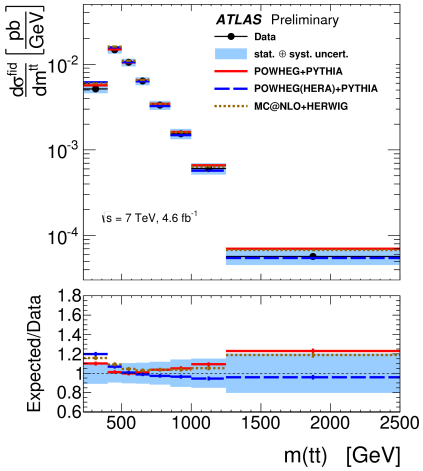
- **differential cross section measurement using top-quark-proxy observables with full 7TeV dataset**









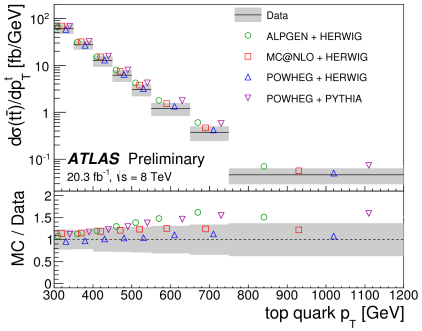


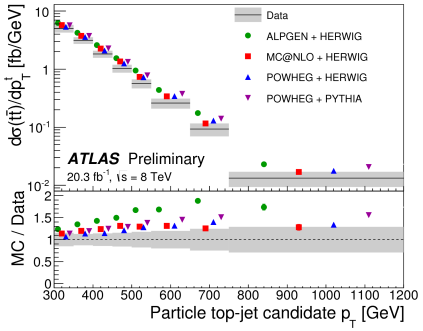
- **Bayesian unfolding of reconstructed pseudo-top distributions to particle level distributions within fiducial region**
  - comparison with different MC generators (NLO and multi-leg), PDFs, showering scheme and Alpgen model with different shower parameters
  - Alpgen generally predict excesses of events in the fiducial region, higher α_s variations disfavoured
  - good modelling with Powheg+Pythia except for m(ttbar)
  - Systematically limited by b-tagging, JES and ISR/FSR modelling

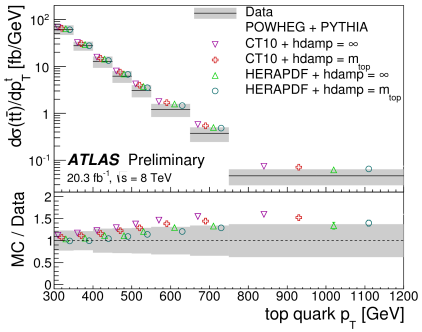
Differential cross section boosted top 8TeV

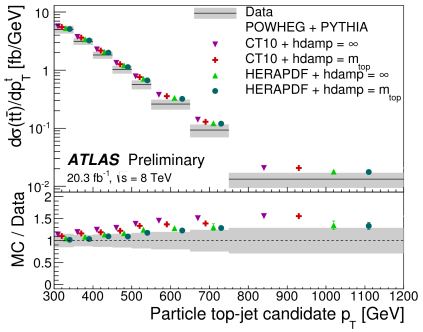
(ATLAS-CONF-2014-057)

- **differential cross section as a function of hadronically decaying top pT of top quarks pT>300GeV using full 8TeV dataset**
  - extend range of differential measurements to high pT range
  - identify high pT tops with collimated decay products using algorithm for such boosted objects that appear as a single jet with large radius R
  - Selection based on single lepton decay mode, target hadronically decaying top quark
- **Reconstruction and selection of hadronically decaying top quark**
  - Using anti-kt jet with R=1.0, jet mass > 100 GeV, apply jet trimming and jet substructure cuts on kt-splitting scale $\sqrt{d_{12}}$
  - isolated leptons, large ETMiss
  - spatial separation between lepton and large-R jet, but nearby small-R jet identified as b-jet
- **SVD unfolding of reconstructed p_T distribution to particle and parton level**
  - Measurement in fiducial region defined on particle level









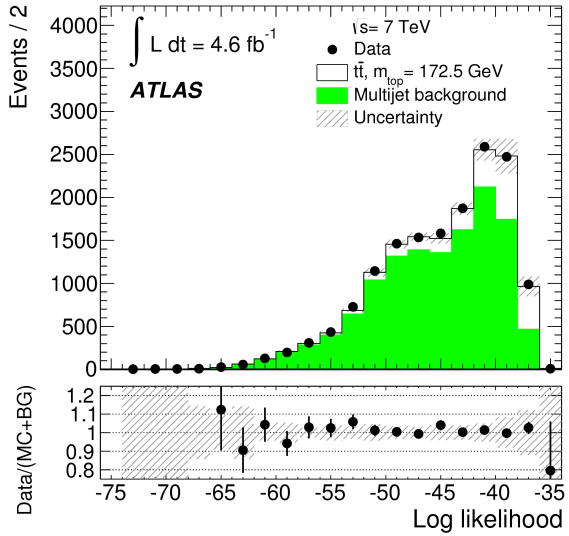
- **Comparison with different generators, also Powheg+Pythia w/ w/o EW corrections**
  - over-estimation of all MCs at particle and on parton level, especially for high top p_T
  - better agreement for particle level, slightly better agreement for Powheg+Pythia with EW corrections
  - largest uncertainties from large-R JES

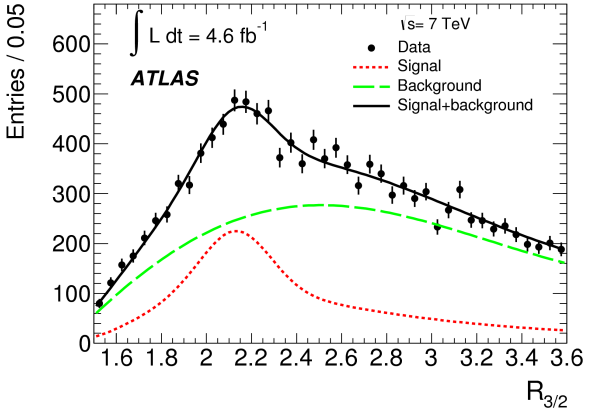
top mass all-hadronic channel 7TeV *(arxiv:1409.0832)*

- **mass measurement using full 7TeV dataset for the final state with the largest BR**
  - event selection requiring at least 6 central jets p_T> 30GeV after selection of events using jet based triggers, reject leptonic events
  - harder p_T>55GeV cut on 5 jets, pair-wise large distance ΔR>0.6
  - 2 b-tagged jets among the four leading jets
  - Small missing transverse momentum significance, larger centrality C>0.6
- **Reconstruction of the event using a kinematic fit, only require equality of top and anti-top mass**
  - select events with good fit (LL>-45)
- **Mass determination by binned maximum likelihood fit to templates of ratio between measured W and measure top mass $R_{3/2}$**

$$m_t = 175.1 \pm 1.4\ (\text{stat.}) \pm 1.2\ (\text{syst.})\ \text{GeV}$$

  - largest systematics residual uncertainties from JES, especially for b-quark jets, hadronisation modelling





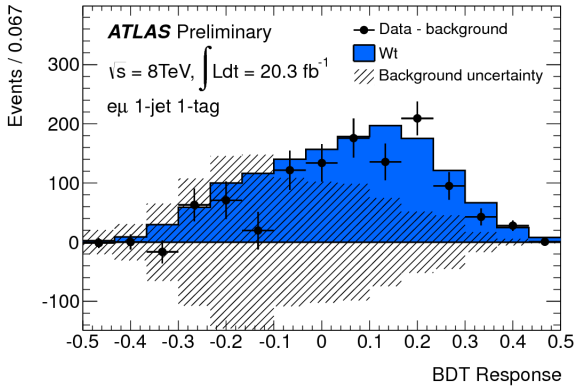
Combination of Wt cross section 8TeV

(ATLAS-CONF-2014-052)

- **Using ATLAS measurement on full 8 TeV dataset**
  - Dilepton eμ selection, one or two central jets, at least one b-tag
- Signal separation **against top pairs** using **BDT**, cross section determined with binned likelihood fit

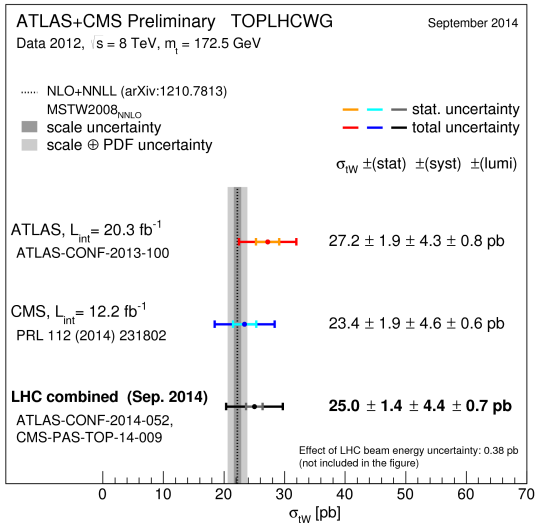
$$\sigma_{Wt} = 27.2 \pm 2.8\,(\text{stat}) \pm 5.4\,(\text{syst})\,\text{pb} = 27.2 \pm 5.8\,\text{pb}$$

  - **Significance 4.2σ**
  - Largest systematics: JES and b-tagging



- **Using CMS measurement on 12.2fb^{-1} 8TeV dataset**
  - all dilepton channels using events with 1-jet and one b-tag, 2-jet and on b-tag and 2-jet and two b-tags
- **Combination using iterative BLUE method with 19% uncertainty**

$$\sigma_{tW} = 25.0 \pm 1.4\,(\text{stat.}) \pm 4.4\,(\text{syst.}) \pm 0.7\,(\text{lumi.})\,\text{pb} = 25.0 \pm 4.7\,\text{pb}$$



top mass in single top enhanced events 8TeV

(ATLAS-CONF-2014-055)

- **measurement in events complementary to ttbar events using full 8 TeV dataset**
  - event selection requiring one lepton, 2 jets, including forward jets for t-channel selection, exactly 1-btag
  - Using event kinematics as input to NN for signal purification, select events with NN>0.75
- **Binned maximum likelihood fit to m(lb) templates**
  - overall normalisation, background fraction and top mass as parameters
  - mass templates from ttbar and single top MCs at different masses

$$m_{\text{top}} = 172.2 \pm 0.7\,(\text{stat.}) \pm 1.9\,(\text{syst.})\ \text{GeV}$$

  - largest uncertainty: JES and modelling of t-channel process