Top Quark Properties Measurements with the ATLAS Experiment

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XV Mexican Workshop on Particles and Fields
Mazatlán, México

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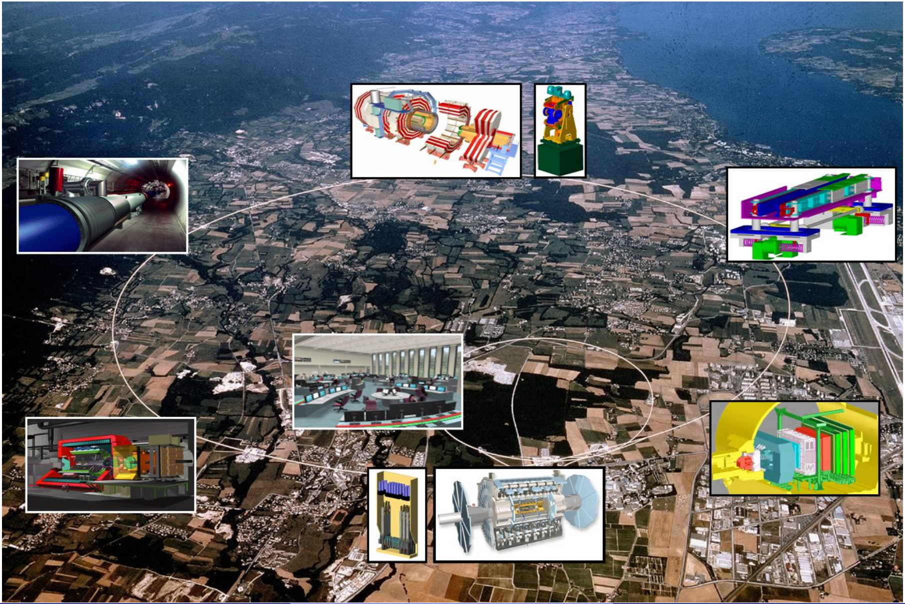
Overview

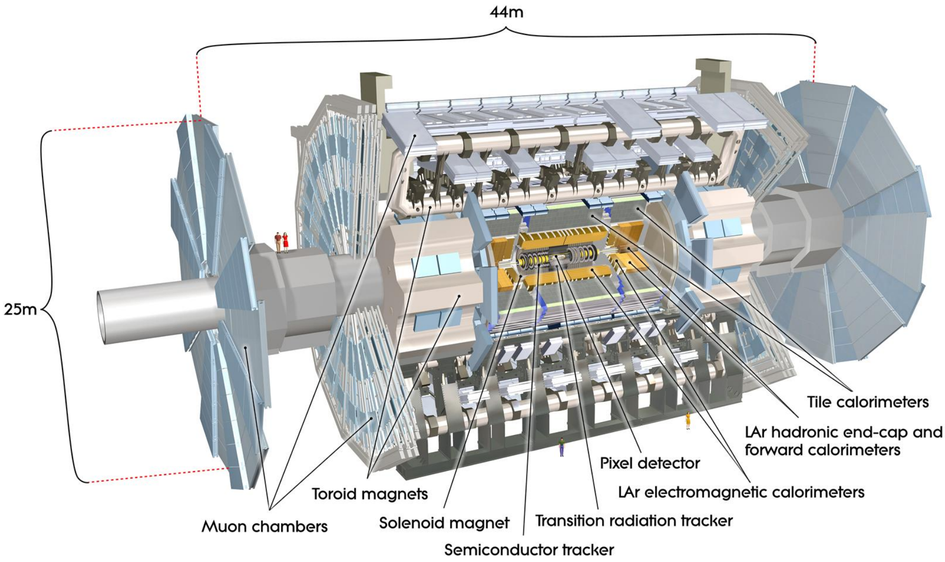
Some sources of useful information

- European Physical Society HEP 2015 Conference Indico Website
  ▸ Timetable and talks here
- TOP2015 8th International Workshop on Top Quark Physics
  ▸ Timetable and talks here
- 50th Rencontres de Moriond EW 2015
  ▸ Timetable and talks here
- 37th International Conference on High Energy Physics
  ▸ Timetable and talks here
- ATLAS Experiment Public Results
  ▸ Summary plots and publications here

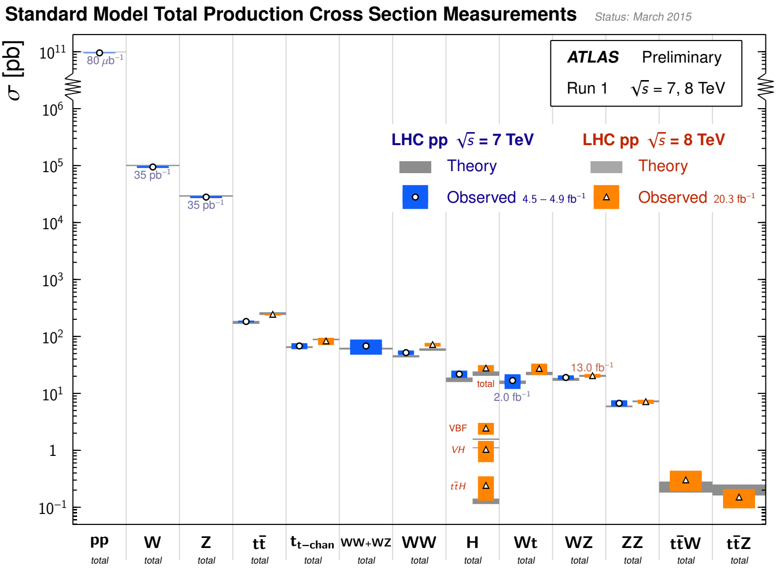
Main Experiments Incorporated to the LHC



The ATLAS Detector - Run-I at $\sqrt{s} = 7$ TeV, 8 TeV successfully completed



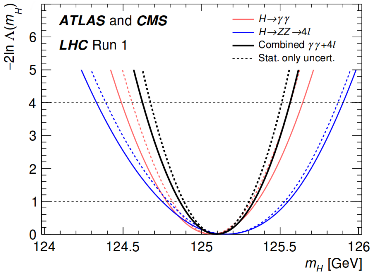
Recent Results From ATLAS - Confirming predictive power of the SM



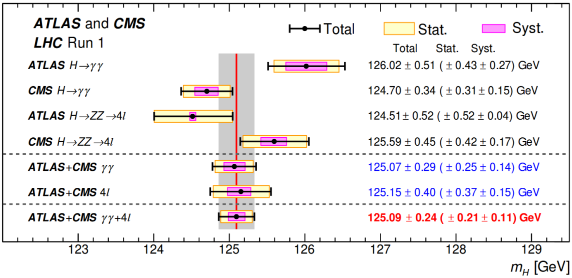
Measurement of the Higgs Mass - arXiv:1503.07589 [hep-ex]

- The $H \to \gamma\gamma$ and $H \to 4\ell$ channels are analyzed by fitting the peaks of reconstructed Higgs-boson invariant mass
- With m_H known all the properties of the SM Higgs boson, such as its production cross section and partial decay width, can be predicted
- Measured masses from the two channels and both experiments are combined, giving a value equal to $m_H = 125.09 \pm 0.21\ (\text{stat.}) \pm 0.11\ (\text{syst.})$ GeV

Likelihood scan for m_H measurement



Combination of ATLAS and CMS Run-I measurements



Lower Limits for Supersymmetry

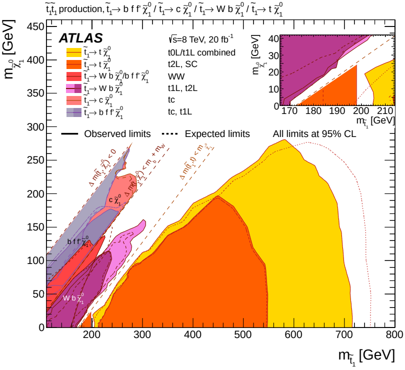
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

- The ATLAS collaboration has performed a wide range of direct searches for supersymmetry during Run-I of the LHC

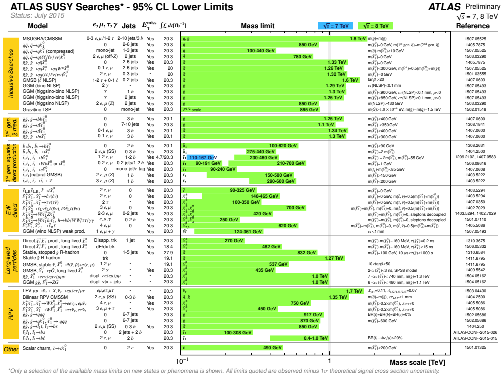
  → No significant excess of events over the SM expectation is observed

- Exclusion limits at 95% confidence level have been set for the masses of supersymmetric particles: squarks, gluinos, electroweakinos, sleptons and heavy neutral higgs bosons

Excluded limits for neutralino and s-top



Excluded Mass Ranges for SUSY Particles



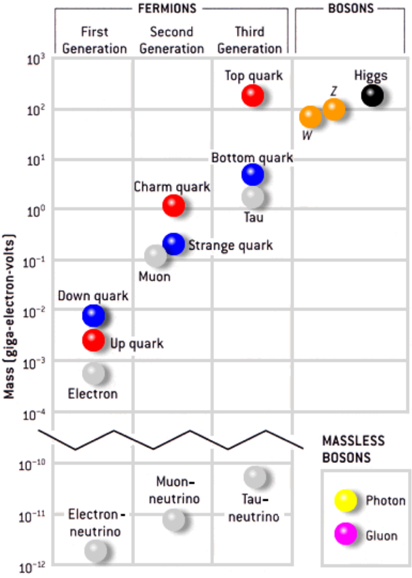
Why is the top quark so important?

- The top quark is the heaviest known fundamental particle, $m_{top} \sim 172.5$ GeV

  → Precise measurements of m_{top} provide critical input to fits of global electroweak parameters, that help assess the consistency of the SM

- Higgs-boson mass m_H (~ 125 GeV), W-boson mass m_W (~ 80 GeV), and the top quark mass (m_{top}) can be used to directly test the consistency of the SM

- Measurements of the top quark properties play an important role in testing the Standard Model (SM), of particle physics and its possible extensions



Events with top quark $t\bar{t}$ pairs: ℓ + jets, dilepton and all-hadronic channels

- At the LHC, top quarks are produced mainly in pairs via the strong interaction and are predicted to decay via the electroweak interaction into a W-boson and a bottom quark with nearly 100% branching fraction

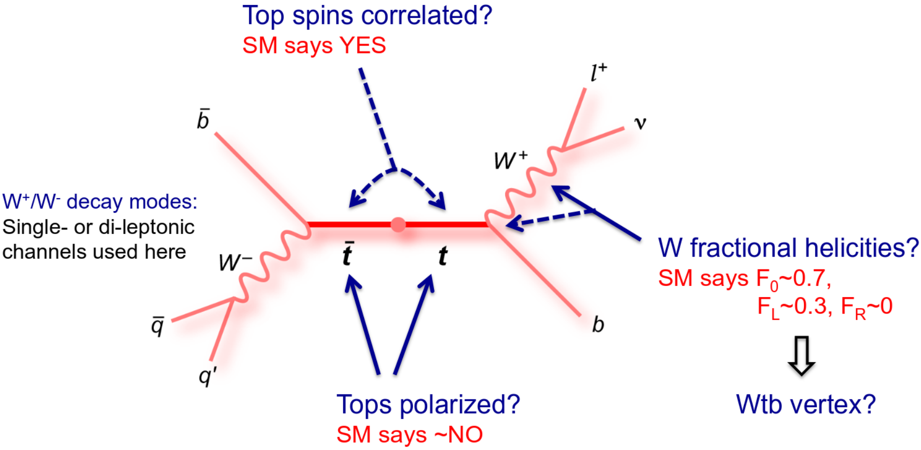


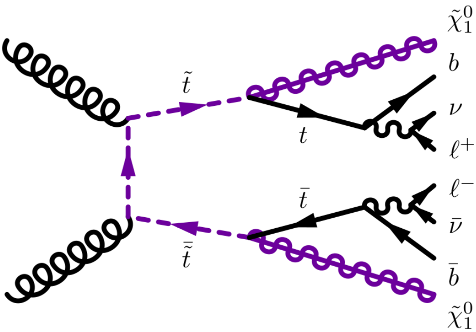
Diagram illustrating an ℓ + jets event / Image by T. Wengler, TOP2012

Measurement of the spin correlation in $t\bar{t}$ decays

Measurement of the Spin Correlation - arXiv:1412.4742 [hep-ex]

- Correlation between the top and antitop quarks spins is extracted from dilepton $t\bar{t}$ events using full data from proton-proton collisions recorded at $\sqrt{s} = 8$ TeV
- The degree of spin correlation is defined as $A_{helicity} = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}}$
- A binned log-likelihood fit is used to extract the spin correlation from the $\Delta\phi$ distribution in data $\rightarrow$ $f_{SM} = 1.20 \pm 0.05$ (stat.) ± 0.13 (syst.) GeV

Signal Diagram



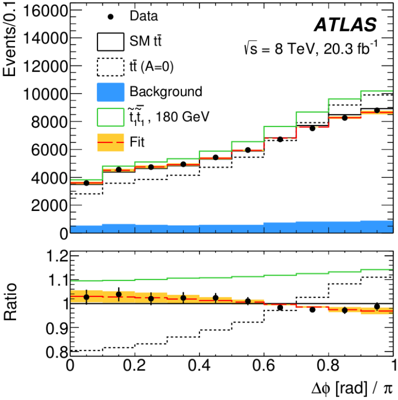
Event Selection Yields

Process	Yield
$t\bar{t}$	$54000 \, ^{+\,3400}_{-\,3600}$
Z/γ^*+jets	2800 ± 300
tV (single top)	2600 ± 180
$t\bar{t}V$	80 ± 11
WW, WZ, ZZ	180 ± 65
Fake leptons	780 ± 780
Total non-$t\bar{t}$	6400 ± 860
Expected	$60000 \, ^{+\,3500}_{-\,3700}$
Observed	60424
$\tilde{t}_1\bar{\tilde{t}}_1$	7100 ± 1100
($m_{\tilde{t}_1} = 180$ GeV, $m_{\tilde{\chi}_1^0} = 1$ GeV)	

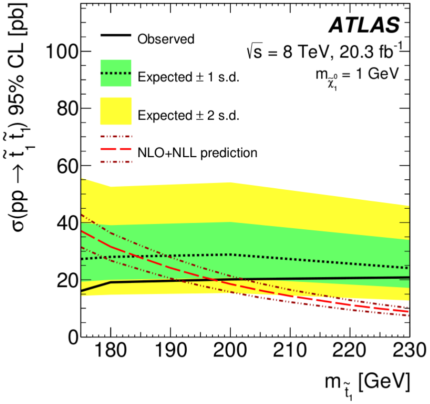
Measurement of the Spin Correlation - arXiv:1412.4742 [hep-ex]

- A search is performed for top squarks decaying predominantly to top quarks and light neutralinos
- Top squarks with masses between the top quark mass ($\sim$ 172.5 GeV) and 191 GeV are excluded at 95 % C.L.

Selected data events with MC templates



Lower limit on stop mass at 95 % C.L.



Measurement of charge asymmetry in $t\bar{t}$ decays

Measurement of Charge Asymmetry - arXiv:1509.02358 [hep-ex]

- Measurement of the $t\bar{t}$ production charge asymmetry

  → ℓ + jets channel
  → A likelihood fit is used to reconstruct the $t\bar{t}$ system

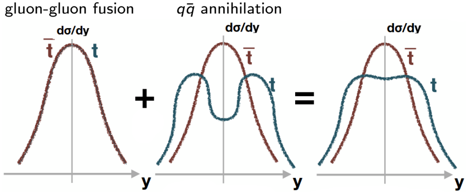
- Rapidity → $y = \frac{1}{2} ln\left(\frac{E+p_z}{E-p_z}\right)$

- $\Delta|y| = |y_{top}| - |y_{antitop}|$

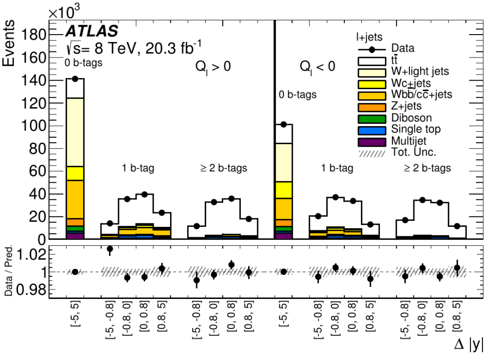
  difference between the absolute value of the top quark rapidity $|y_t|$ and the absolute value of the top antiquark rapidity $|y_{\bar{t}}|$

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

- A bayesian unfolding procedure is used to obtain asymmetry at parton level



Δ|y| Distributions



Measurement of Charge Asymmetry - arXiv:1509.02358 [hep-ex]

- The precision of the measurement is limited by the statistical uncertainty

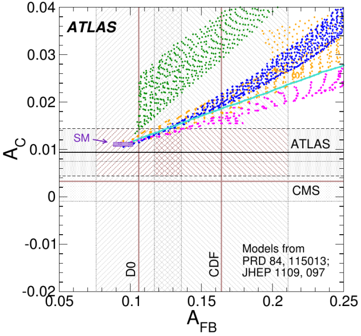
  → For differential measurements it is not possible to distinguish between the SM and Beyond the SM (BSM) models at this level of precision

- ATLAS and CMS measurements on A_C are compared with the $t\bar{t}$ forward-backward asymmetry A_{FB} measured by the Tevatron by CDF and D0 experiments

  → so far the measured values for both asymmetries by four different experiments agree with the SM predictions

		stat	syst	
Ac =	0.0010	± 0.0068	± 0.0037	CMS
				Submitted to Phys.Lett. B arxiv:1507.03119
Ac =	0.009		± 0.005 stat+syst	ATLAS
				Submitted to EPJC arxiv:1509.02358
Ac =	0.0101		± 0.0005	NNLO
				Kuhn, Rodrigo

SM Prediction & Measurements



Measurement of the color flow in $t\bar{t}$ decays

Measurement of Color Flow in $t\bar{t}$ events - arXiv:1506.05629 [hep-ex]

- The distribution and orientation of energy inside jets is predicted to be an experimental handle on color connections between hard-scatter quarks and gluons initiating jets

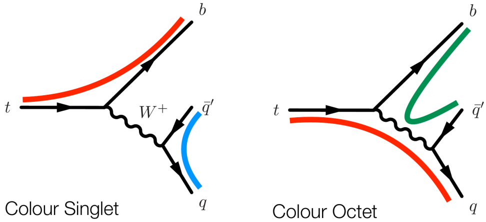
  Previous studies by D0 experiment
  $\rightarrow$ arXiv:1101.0648 [hep-ex]

- Jet coordinates (y_J, ϕ_J)
  $\rightarrow$ Jet component i,
  position $\vec{r}_i = (\Delta y_i, \Delta\phi_i)$

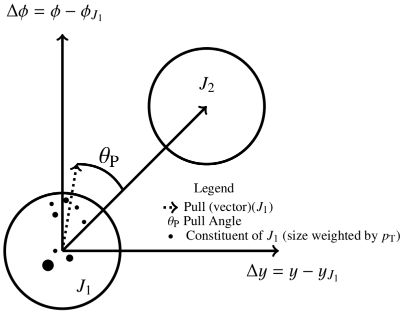
- Pull vector $\rightarrow \vec{v}_p^J = \sum_{i \in J} \frac{p_T^i |r_i|}{p_T^J} \vec{r}_i$

- Pull angle $\theta_p(J_1, J_2)$ is expected to be sensitive to color connections between the jets $\rightarrow$ If two jets originate from color connected quarks $\theta_p \sim 0$

Color Flow Models



Pull Angle

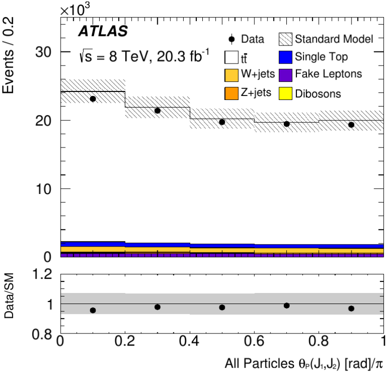


Measurement of Color Flow in $t\bar{t}$ events - arXiv:1506.05629 [hep-ex]

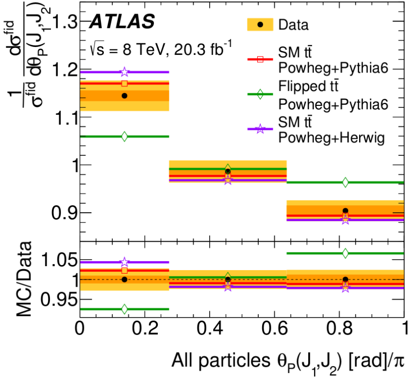
- A similar unfolding technique is used as with charge asymmetry measurements
- Comparison with models with simulated W-bosons that are color charged (color octet W-boson) or color neutral

  → $\Delta\chi^2$ test statistic is used for comparison with the SM and flipped models
  → Data differ from flipped model by 2.3σ and 3.3σ with just charged particles

Pull Angle Distribution (ℓ + jets channel)



Pull Angle Distribution (ℓ + jets channel)



Measurement of the W-boson polarization in $t\bar{t}$ decays

W-boson polarization in $t\bar{t}$ events - arXiv:1205.2484 [hep-ex]

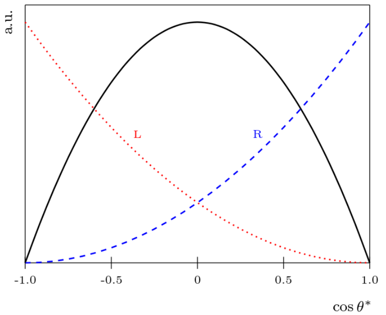
- Polarisation fractions are predicted at next-to-next-to-leading-order (NNLO), QCD calculations are predicted to be:

$$F_o = 0.687 \pm 0.005,\ F_L = 0.311 \pm 0.005 \text{ and } F_R = 0.0017 \pm 0.0001$$

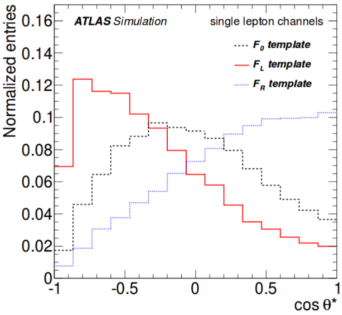
- These fractions are measured using the distribution of the angular variable $cos\theta^*$, where θ^* is the angle between the direction of momentum of lepton and the corresponding b-quark

$$\frac{1}{N}\frac{dN}{dcos\,\theta^*} = \frac{3}{4}sin^2\theta^* F_0 + \frac{3}{8}(1 - cos\,\theta^*)^2 F_L + \frac{3}{8}(1 + cos\,\theta^*)^2 F_R$$

Analytical Templates



Detector Level Templates

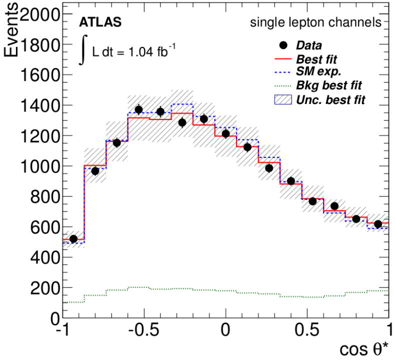


W-boson polarization in $t\bar{t}$ events - arXiv:1205.2484 [hep-ex]

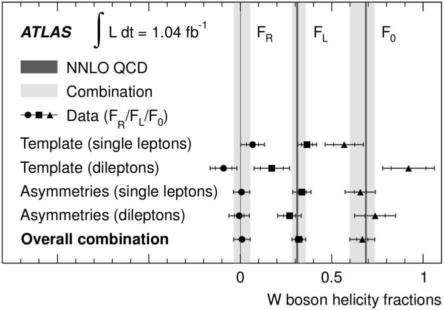
- Previous measurements performed by CDF and D0 collaborations are in agreement with the SM predictions
- In the presence of anomalous Wtb couplings the helicity fractions and angular asymmetries depart from their SM values
- The measured values are:

$$F_0 = 0.67 \pm 0.07,\ F_L = 0.32 \pm 0.04 \text{ and } F_R = 0.01 \pm 0.05$$

Fit with data



Overall Combination

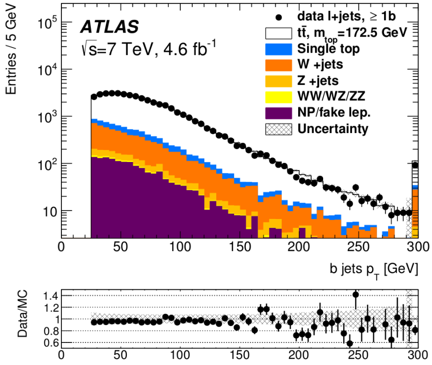


Measurement of the top quark mass in $t\bar{t}$ decays

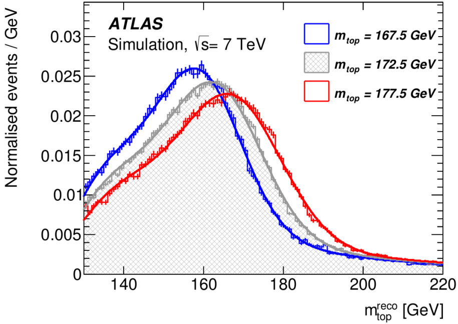
Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

- Single lepton (ℓ + jets) or two leptons (dilepton) channels → Events with one or two isolated charged leptons with relatively high p_T and E_T^{miss} accounting for neutrinos. Also at least two b-jets are required
- Template method → Monte Carlo (MC) simulated template distributions are re-constructed for a chosen observable sensitive to m_{top}

ℓ + Jets Channel (Selected Events)



m_{top}^{reco} Variable / m_{top} Parameter

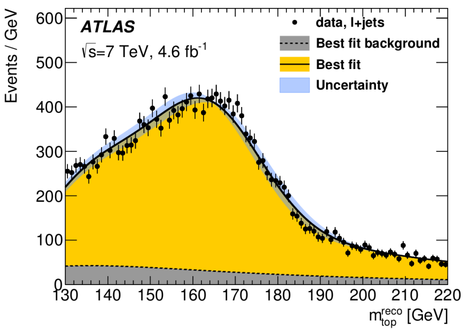


Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

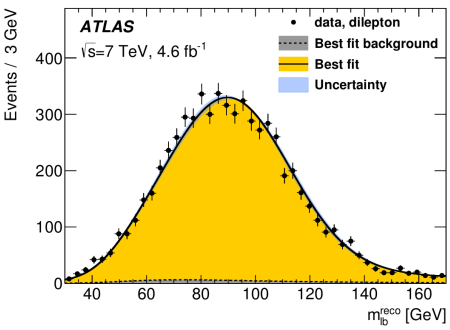
- For the ℓ + jets channel, the additional parameters JSF and bJSF are also fitted to data → through the observables m_W^{reco} and R_{bq}^{reco} respectively, sensitive to them
- Signal and background shapes are parametrised and a binned likelihood distribution is built to extract the parameters

→ A tridimensional fit is performed for the ℓ + jets channel (m_{top}, JSF, bJSF)
→ A one dimentional fit is performed for the dilepton channel (m_{top})

Fit with Data / ℓ + Jets Channel



Fit with Data / Dilepton Channel



Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

- The measured values for parameters for $\ell +$ jets and dilepton analyses are:

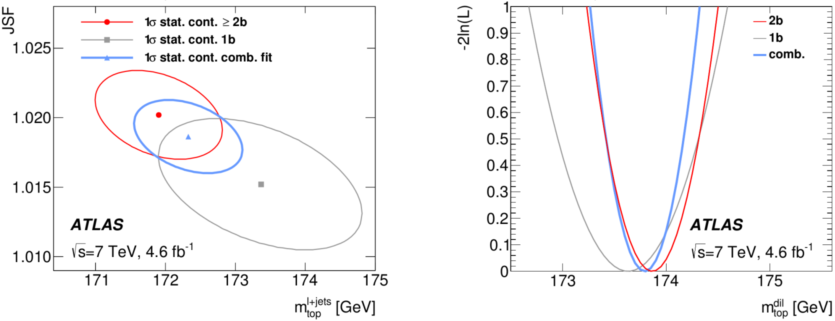
$$m_{top}^{\ell+jets} = 172.33 \pm 0.75\ (stat) \pm 1.02\ (syst)\ GeV,$$
$$JSF = 1.019 \pm 0.003\ (stat) \pm 0.027\ (syst),$$
$$bJSF = 1.003 \pm 0.008\ (stat) \pm 0.023\ (syst),$$
$$m_{top}^{dil} = 173.79 \pm 0.54\ (stat) \pm 1.30\ (syst)\ GeV$$

- Overall combination: ATLAS best combination from a single analysis

$$m_{top}^{comb} = 172.99 \pm 0.48\ \text{(stat)} \pm 0.78\ \text{(syst) GeV} = 172.99 \pm 0.91\ \text{GeV}$$

JSF / $m_{top}^{\ell+jets}$ 2D Likelihood Scan

$m_{top}^{dilepton}$ 1D Likelihood Scan

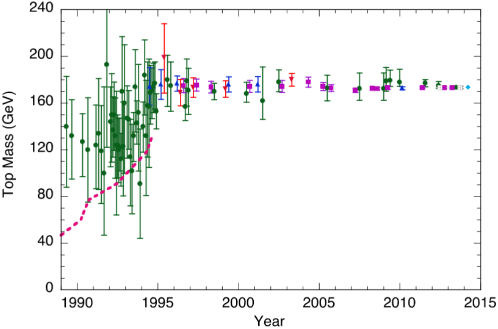


Evolution of Top Quark Mass Measurements

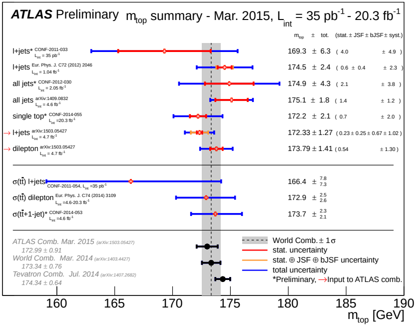
- Tevatron + LHC (world) combination arXiv:1403.4427 [hep-ex] Mar/2014
  $\rightarrow m_{top} = 173.34 \pm 0.27\ (\text{stat}) \pm 0.71\ (\text{syst})$ GeV
- Recent Tevatron overall combination arXiv:1407.2682 [hep-ex] Jul/2015
  $\rightarrow m_{top} = 174.34 \pm 0.37\ (\text{stat}) \pm 0.52\ (\text{syst})$ GeV
- CMS overall combination arXiv:1509.04044 [hep-ex] Sep/2015
  $\rightarrow m_{top} = 172.44 \pm 0.13\ (\text{stat}) \pm 0.47\ (\text{syst})$ GeV

Level of precision reached $\sim$ 0.3 %

Evolution of Uncertainty (Figure by Chris Quigg)



Recent m_{top} Measurements and Combinations



Measurement of the top quark width in $t\bar{t}$ decays

Measurement of the Top Quark Width - arXiv:1308.4050 [hep-ex]

- The CDF collaboration reported the first result using a direct approach, using the same analysis technique as the ATLAS collaboration $\rightarrow$ $\Gamma_{top}^{SM} \sim 1.33$ GeV

  $\rightarrow$ It took $\sim$ 10 years for CDF to produce optimized result

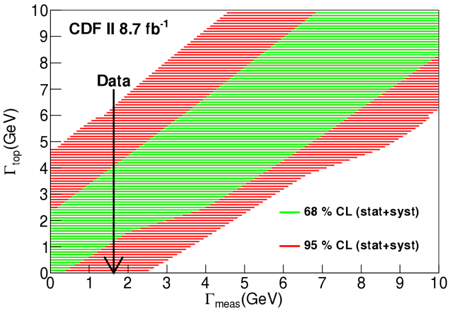
  $1.10 < \Gamma_{top} < 4.05$ GeV at 68 % confidence level and

  $\Gamma_{top} < 6.38$ GeV at 95 % confidence level

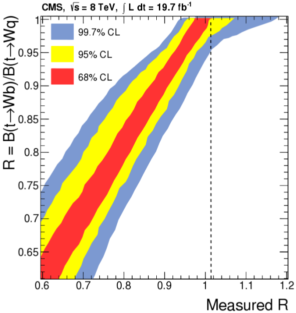
- The CMS collaboration following the DØ collaboration indirect approach has measured Γ_{top}, arXiv:1404.2292 [hep-ex]

  $\rightarrow$ $\Gamma_{top} = 1.36 \pm 0.02$ (stat) $^{+0.14}_{-0.11}$ (syst)

CDF Direct Measurement



CMS Indirect Measurement

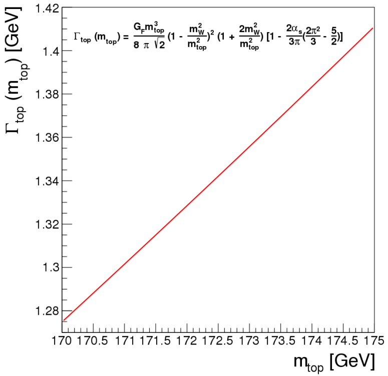


Measurement of the Top Quark Width

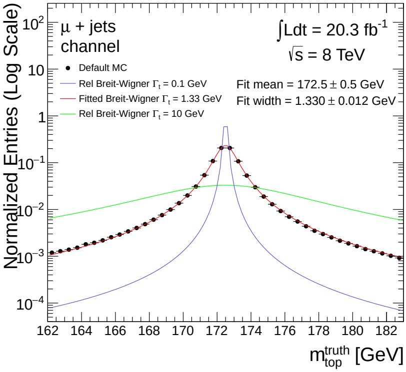
$$\Gamma_{top}(m_{top}) = \frac{G_F m_{top}^3}{8\pi\sqrt{2}}\left(1 - \frac{m_W^2}{m_{top}^2}\right)^2\left(1 - \frac{2m_W^2}{m_{top}^2}\right)\left[1 - \frac{2\alpha_s}{3\pi}\left(\frac{2\pi^2}{3} - \frac{5}{2}\right)\right] \quad \text{SM Dependence} \tag{1}$$

$$f(m) = \frac{k}{(m^2 - m_{top}^2)^2 + m_{top}^2\Gamma^2}, \qquad k = \frac{2\sqrt{2}m_{top}\Gamma\gamma}{\pi\sqrt{m_{top}^2 + \gamma}}, \qquad \gamma = \sqrt{m_{top}^2(m_{top}^2 + \Gamma^2)} \quad \text{Mass Resonance} \tag{2}$$

Standard Model $\Gamma_{top}(m_{top})$ dependence



Templates at Truth Level



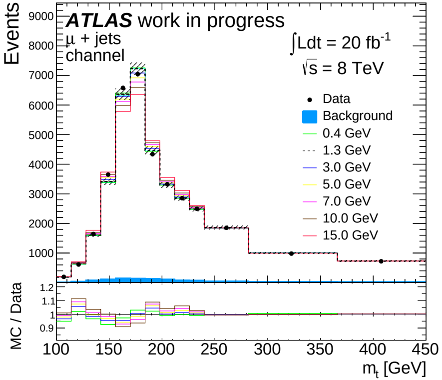
Measurement of the Top Quark Width with ATLAS - To be published

- ATLAS has performed its first measurement of Γ_{top} using a direct approach in the ℓ + jets channel
- The m_t observable is reconstruted with χ^2 and KL-Fitter techniques. A template method is used to measure the parameter Γ_{top} from data

Selected Events

Process	μ + jets channel	e + jets channel
Single top	$2048\ ^{+129}_{-168}$	$1217\ ^{+97}_{-79}$
W + jets	$298\ ^{+17}_{-41}$	$482\ ^{+77}_{-37}$
Z + jets	$113\ ^{+20}_{-13}$	$109\ ^{+31}_{-18}$
Diboson	$21\ ^{+2}_{-2}$	$16\ ^{+1}_{-1}$
QCD Multijet	$969\ ^{+292}_{-290}$	$1313\ ^{+393}_{-392}$
$t\bar{t}$	$45732\ ^{+2600}_{-2800}$	$26359\ ^{+1600}_{-1700}$
Total prediction	$49180\ ^{+2600}_{-2800}$	$29500\ ^{+1600}_{-1800}$
$t\bar{t}$ Significance	0.93	0.89
Data	48502	30345

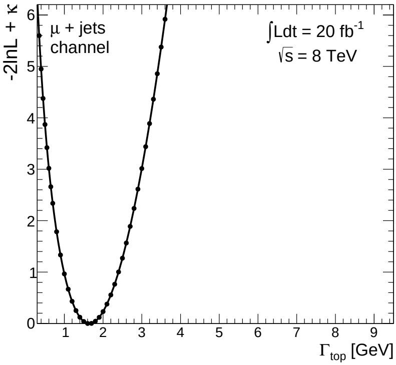
Observable (m_t) Distribution



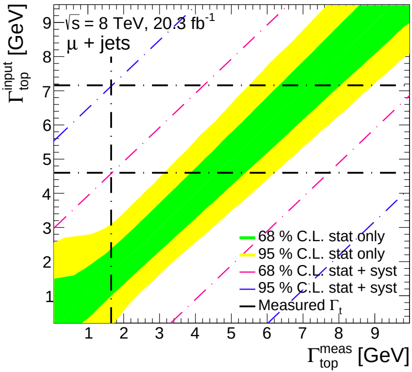
Measurement of the Top Quark Width with ATLAS - To be published

- A binned likelihood profile is build to measure Γ_{top} from data. Pseudo-experiments are performed to evaluate statistical and systematic uncertainties
- From the obtained uncertainties confidence belt and the measured Γ_{top}, the upper limits for Γ_{top} are: $\Gamma_{top} < 4.60$ GeV at 68 % confidence level and $\Gamma_{top} < 7.16$ GeV at 95 % confidence level

Likelihood Profile with Data



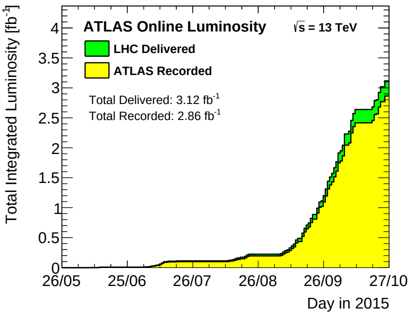
Confidence Intervals and Measurement

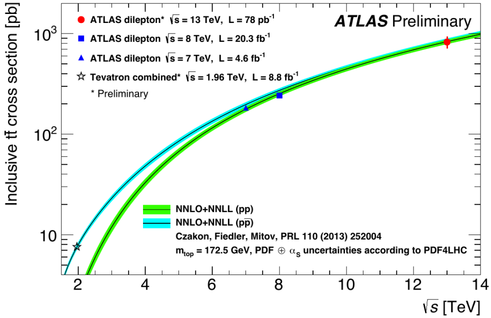


Run-II will be era for precision measurements in top and higgs physics

- ATLAS went through important upgrades during LS1, before the start of Run-II in all areas: detector, online, offline and computing
- For proton-proton collisions at $\sqrt{s} = 13$ TeV the $t\bar{t}$ events cross-section is expected to increase by a factor ~ 3.3 with respect production at $\sqrt{s} = 8$ TeV

  → Number of events used for analyses will be substantially larger than in Run-I
  → Sources of systematic uncertainties are well understood so much more precise measurements will be achieved during Run-II





Outlook

- The ATLAS collaboration has experienced a productive period during LHC Run-I
  - $\rightarrow$ Focusing on the understanding of sources of systematic uncertainties (main limitation for most measurements)
  - $\rightarrow$ Several top properties have been measured, obtaining comparable results with the measuremets from Tevatron experiments
  - $\rightarrow$ Higher precision for all measurements is expected during Run-II

- The collaboration is already fully engaged with analyses with data from collisions at $\sqrt{s} = 13$ TeV (highest collider energies ever reached)

  $\rightarrow$ Data collection is ongoing, MC calibration and pileup studies are in progress and some preliminary measurements have already been performed

- During Run-II searches for new physics will be attempted exhaustively

See additional slides with more plots & complementary information

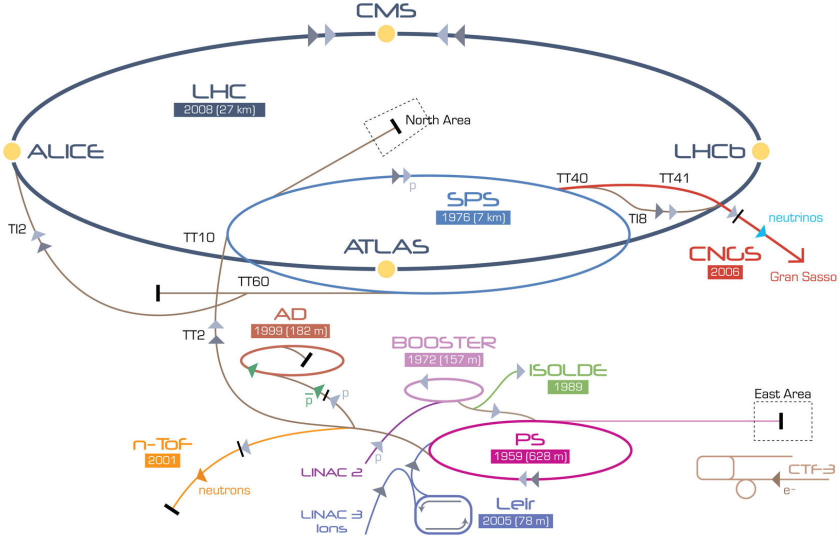
Backup

CERN's Large Hadron Collider (LHC)

- The LHC extends to both sides of the border between France and Switzerland

Acceleration complex at CERN

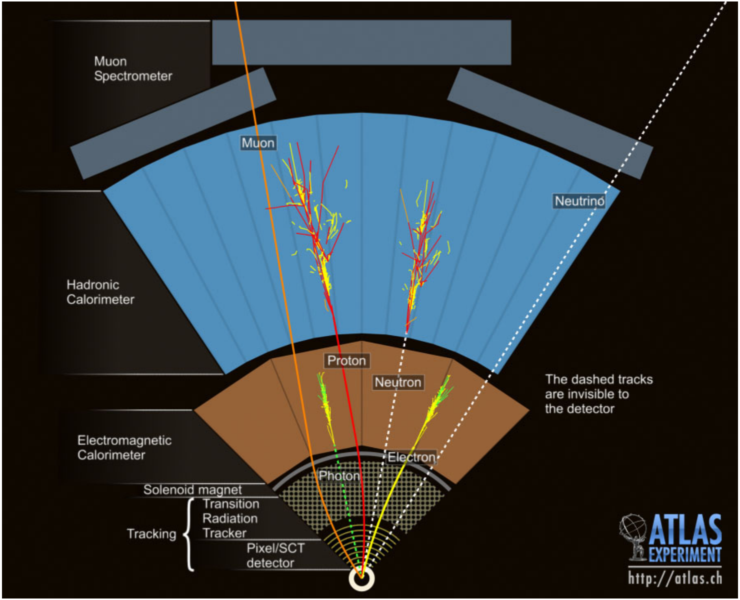
- Proton bunches are produced, split and accelerated sequentially through different accelerators before injection into the LHC



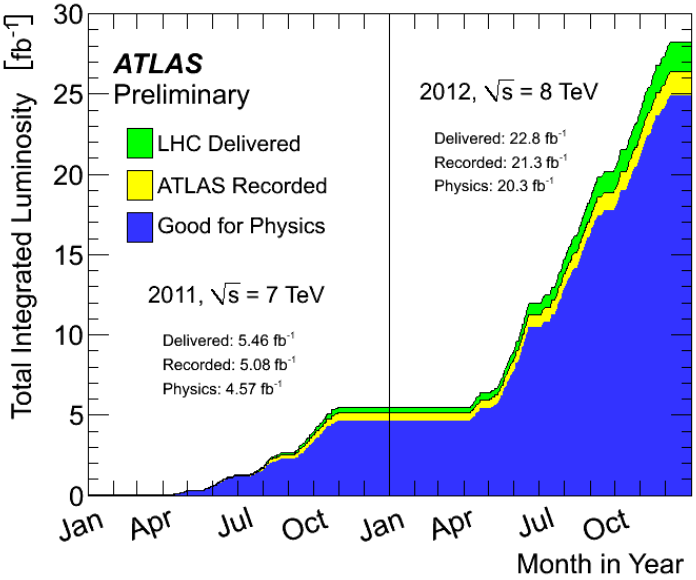
Main Experiments Incorporated to the LHC

- CMS $\rightarrow$ Is a multi-purpose detector with similar aims as ATLAS, with a large superconducting solenoid that produces a magnetic field ~ 4 T. The measurements from ATLAS and CMS can be combined in most cases
- ALICE $\rightarrow$ Used to analyze particles from lead nucleus-nucleus, Pb-Pb, head-on collisions. These generate very dense matter states such as the quark gluon plasma
- LHCb $\rightarrow$ It's main purpose is the identification of small asymmetries between matter and antimatter from interactions that involve B-meson particles, made up with a b-quark
- TOTEM $\rightarrow$ These detectors attempt to measure the cross section of proton - proton interactions, the luminosity of the LHC and to perform difractive studies that are not accesible in other detectors
- LHCf $\rightarrow$ Studies particles from proton - proton collisions produced at very small angles in order to calibrate large scale cosmic ray experiments

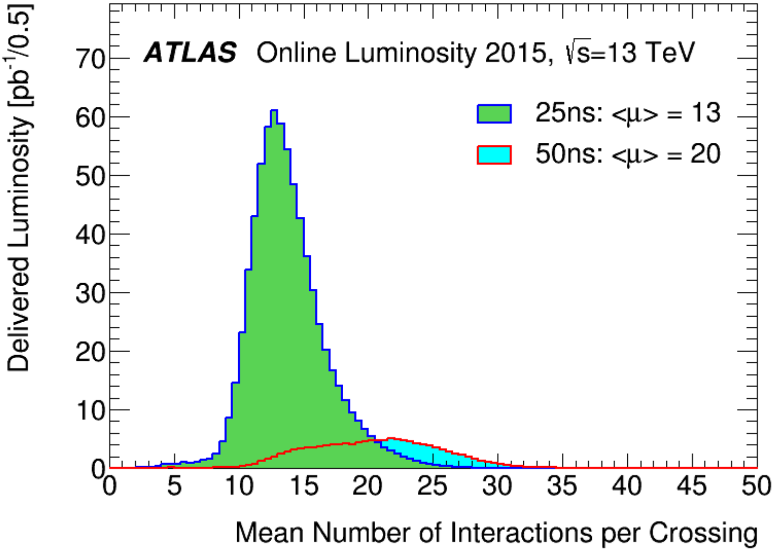
The ATLAS Detector



Available Data Recorded by the ATLAS Detector



Available Data Recorded by the ATLAS Detector



Measurement of Charge Asymmetry - arXiv:1509.02358 [hep-ex]

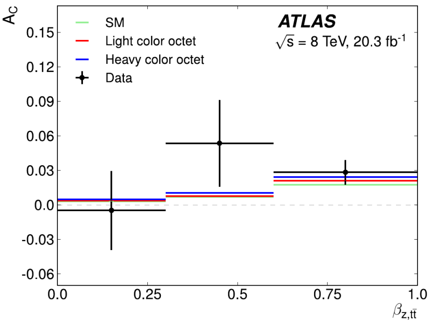
- Selection Requirements

ATLAS	CMS
1 isolated lepton p_T > 25 GeV (e), 25 GeV (μ) $\|\eta\|$ < 2.5	1 isolated lepton p_T > 30 GeV (e), 26 GeV (μ) $\|\eta\|$ < 2.5 (e), 2.1 (μ)
≥ 4 jets with p_T > 25 GeV and $\|\eta\|$ < 2.5	≥ 4 jets with p_T > 20 GeV and $\|\eta\|$ < 2.5
Signal Regions: 0,1, 2+ b-tag jets Efficiency: 70% b-jet, < 1% light jets	≥ 1 b-tagged jet Efficiencies: 65% b-jet, ~1.5% light jets
$E_T^{miss} + m_T^W$ > 60 GeV for 0,1 b-tags E_T^{miss} > 40 (20) GeV for 0 (1) b-tags	m_T^W used in fit to constrain QCD background
S/B ~ 3.5 ~ 60% Background is W+Jets	S/B ~ 4 ~ 60% Background is W+Jets

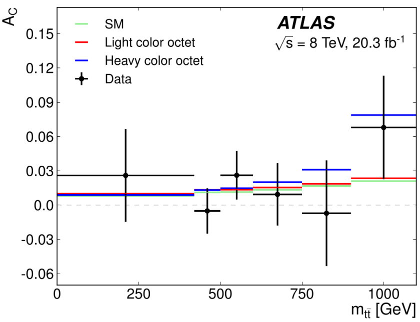
Measurement of Charge Asymmetry - arXiv:1509.02358 [hep-ex]

- For differential measurements it is not possible to distinguish between the SM and Beyond the SM (BSM) models at this level of precision
- Differential measurements are performed as a function of the variables $m_{t\bar{t}}$, $\beta_{z,t\bar{t}}$ and $p_{T,t\bar{t}}$

$\Delta|y|$ Distributions



Measured A_c



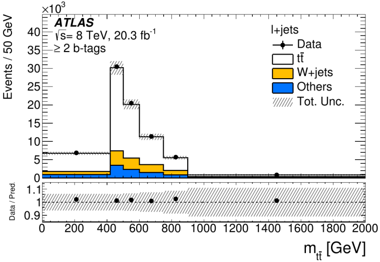
Measurement of Charge Asymmetry - arXiv:1509.02358 [hep-ex]

- A measurement of the $t\bar{t}$ production charge asymmetry in the $\ell + $ jets channel
  $\rightarrow$ from proton-proton collisions at centre-of-mass energy $\sqrt{s} = 8$ TeV
- A likelihood fit is used to reconstruct the $t\bar{t}$ system

Selected events

Channel	ℓ + jets 0-tag	ℓ + jets 1-tag	ℓ + jets 2-tag
Single top	3400 ± 400	12100 ± 1300	8700 ± 900
W+jets	173000 ± 9000	45000 ± 4000	8600 ± 700
Z+jets	13000 ± 6000	3900 ± 2000	1900 ± 900
Diboson	8000 ± 4000	2000 ± 900	400 ± 200
Multijets	10800 ± 3500	6300 ± 2000	2200 ± 700
Total background	208500 ± 1300	69600 ± 2600	21800 ± 1300
$t\bar{t}$	33900 ± 1200	146900 ± 2700	171600 ± 1500
Total expected	242400 ± 600	216500 ± 500	193400 ± 400
Observed	242420	216465	193418

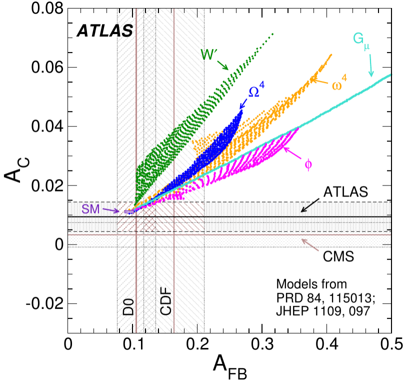
Reconstructed $t\bar{t}$ invariant mass



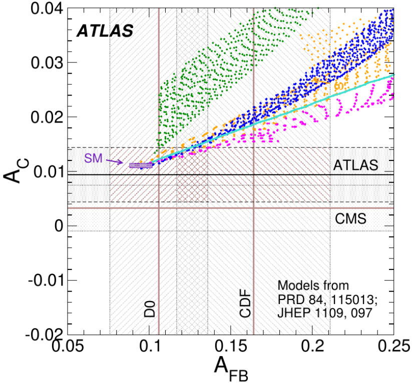
Measurement of Charge Asymmetry - arXiv:1509.02358 [hep-ex]

- ATLAS and CMS measurements on A_C are compared with the $t\bar{t}$ forward-backward asymmetry A_{FB} measured by the Tevatron by CDF and D0 experiments
- Several BSM models predic a especific relationship between these two asymmetries,
  $\rightarrow$ so far the measured values for both asymmetries by four different experiments agree with the SM predictions

$\Delta|y|$ Distributions

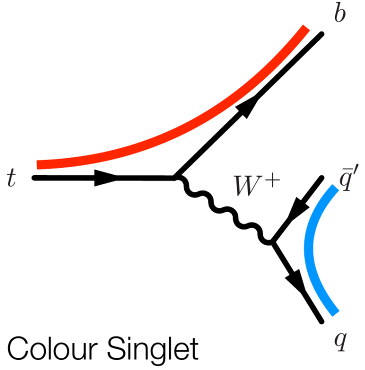


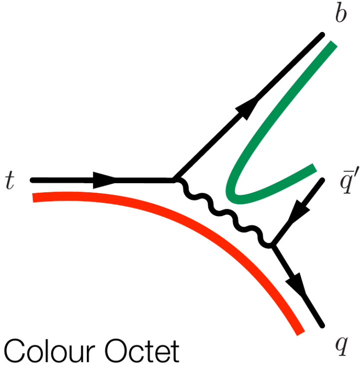
Measured A_c



Measurement of Color Flow in $t\bar{t}$ events - arXiv:1506.05629 [hep-ex]

- The distribution and orientation of energy inside jets is predicted to be an experimental handle on color connections between hard-scatter quarks and gluons initiating jets → previous studies by D0 experiment
- Strength and direction of the strong force depends on the colour charge of the particles involved

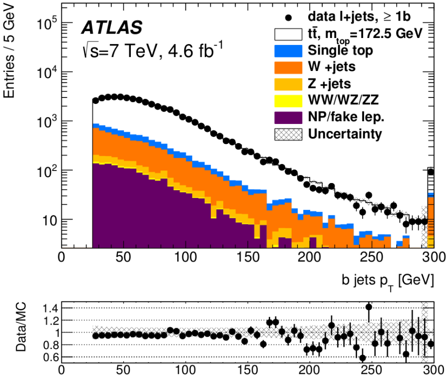




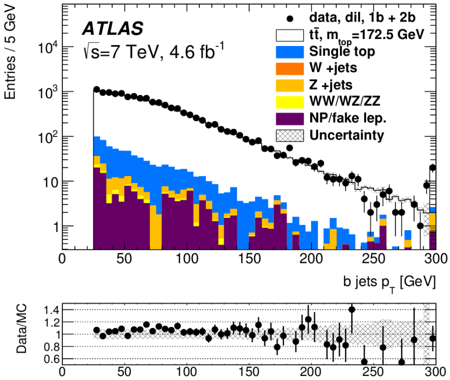
Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

- Single lepton (ℓ + jets) or two leptons (dilepton) channels → Events with one or two isolated charged leptons with relatively high p_T and E_T^{miss} accounting for neutrinos. Also at least two b-jets are required

ℓ + Jets Channel



Dilepton Channel

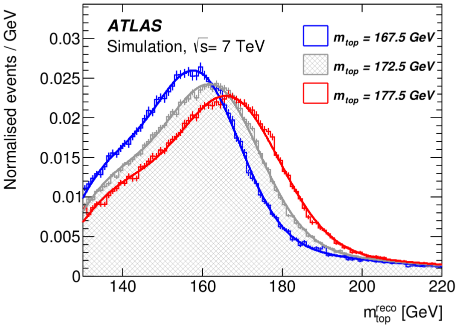


Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

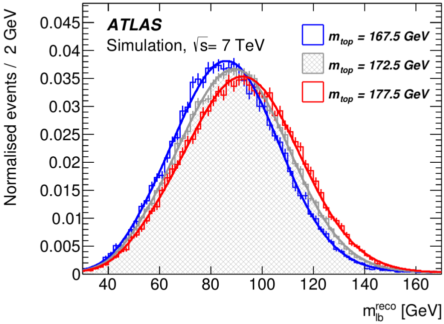
- Template method is used for all channels to extract m_{top}

  → Monte Carlo (MC) simulated template distributions are constructed for a chosen observable sensitive to m_{top}
- The KL-Fitter algorithm is used to reconstruct the $t\bar{t}$ event topology for the ℓ + jets channel → from where the m_{top}^{reco} observable is extracted
- For the dilepton channel the m_{top}-sensitive m_{lb}^{reco} is obtained using event leptons and b-jets

m_{top}^{reco} Variable / m_{top} Parameter



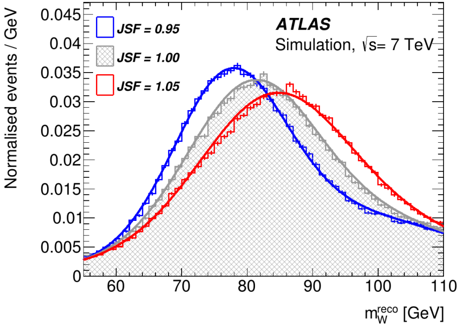
$m_{\ell b}^{reco}$ Variable / m_{top} Parameter



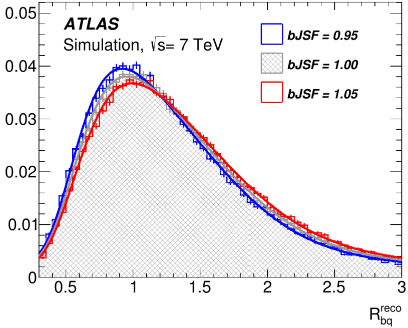
Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

- For the ℓ + jets channel, the additional parameters JSF and bJSF are also fitted to data
  - → Modelling of the MC with data improves
  - → Additional fits reduce the size of the systematic uncertainty
- To measure these parameters, the observables m_W^{reco} and R_{bq}^{reco} sensitive to them are constructed

m_W^{reco} Variable / JSF Parameter



R_{bq}^{reco} Variable / bJSF Parameter

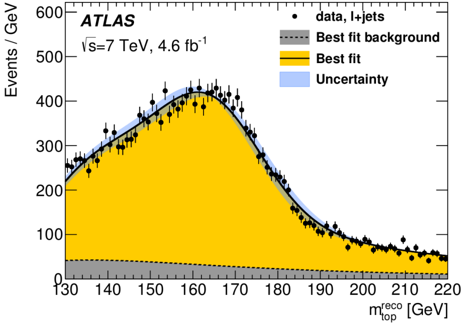


Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

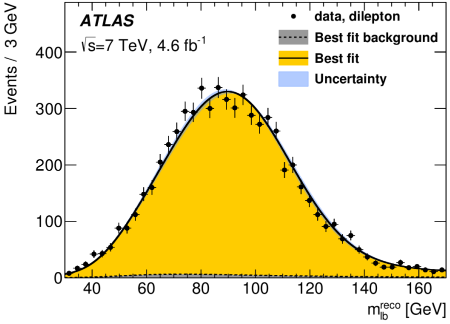
- For ℓ + jets and dilepton channels events with 1 or more b-tagged jets from muon or electron sub-channels were combined → statistical uncertainty is reduced
- Signal and background shapes are parametrised and then fitted to data. Parameters are extracted from the maximisation of a likelihood expression

  → A tridimensional fit is performed for the ℓ + jets channel (m_{top}, JSF, bJSF)
  → A one dimentional fit is performed for the dilepton channel (m_{top})

Fit with Data / ℓ + Jets Channel



Fit with Data / Dilepton Channel

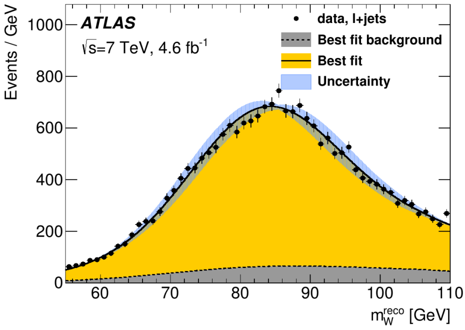


Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

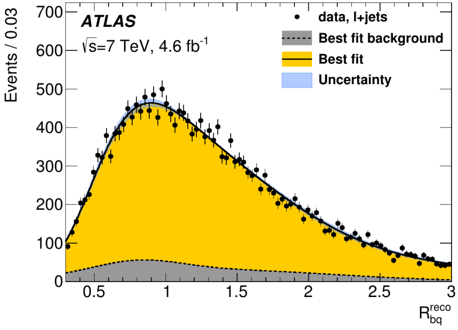
- The measured values for parameters for $\ell +$ jets and dilepton analyses are:

$$m_{top}^{\ell+jets} = 172.33 \pm 0.75\ (stat) \pm 1.02\ (syst)\ GeV,$$
$$JSF = 1.019 \pm 0.003\ (stat) \pm 0.027\ (syst),$$
$$bJSF = 1.003 \pm 0.008\ (stat) \pm 0.023\ (syst),$$
$$m_{top}^{dil} = 173.79 \pm 0.54\ (stat) \pm 1.30\ (syst)\ GeV$$

Fit with Data / ℓ + Jets Channel / m_W^{reco}



Fit with Data / ℓ + Jets Channel / R_{qb}^{reco}

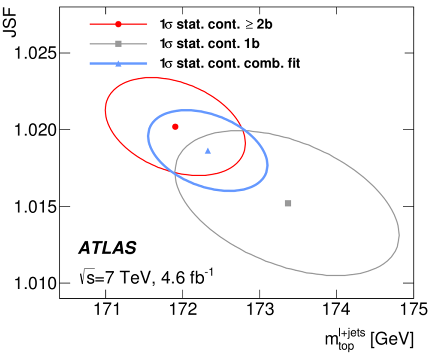


Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

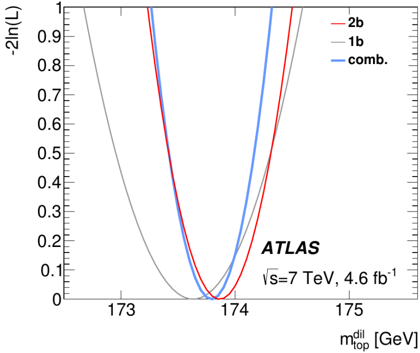
- The three dimensional ℓ + jets analysis in general decreases sizes of uncertainties and makes the two channels (ℓ + jets and dilepton) less correlated
- After the combination m_{top} results from both channels, the final obtained result is:

$$m_{top}^{comb} = 172.99 \pm 0.48\ (\text{stat}) \pm 0.78\ (\text{syst})\ \text{GeV} = 172.99 \pm 0.91\ \text{GeV}$$

JSF / $m_{top}^{\ell+jets}$ 2D Likelihood Scan



$m_{top}^{dilepton}$ 1D Likelihood Scan



Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

ℓ+jets final state			
Process	One b-tagged jet	At least two b-tagged jets	Sum
$t\bar{t}$ signal	9890 ± 630	8210 ± 560	18100 ± 1100
Single top quark (signal)	756 ± 41	296 ± 19	1052 ± 57
W+jets (data)	2250 ± 680	153 ± 49	2400 ± 730
Z+jets	284 ± 87	18.5 ± 6.1	303 ± 93
$WW/WZ/ZZ$	43.5 ± 2.3	4.65 ± 0.48	48.2 ± 2.6
NP/fake leptons (data)	700 ± 350	80 ± 41	780 ± 390
Signal+background	13920 ± 1000	8760 ± 560	22700 ± 1400
Data	12979	8784	21763
Exp. Bkg. frac.	0.25 ± 0.02	0.03 ± 0.00	0.16 ± 0.01
Data/MC	0.93 ± 0.07	1.00 ± 0.07	0.96 ± 0.06

Dilepton final state			
Process	One b-tagged jet	Two b-tagged jets	Sum
$t\bar{t}$ signal	2840 ± 180	2950 ± 210	5790 ± 360
Single top quark (signal)	181 ± 10	82.5 ± 5.7	264 ± 15
Z+jets	34 ± 11	4.1 ± 1.5	38 ± 12
$WW/WZ/ZZ$	7.01 ± 0.63	0.61 ± 0.15	7.62 ± 0.67
NP/fake leptons (data)	52 ± 28	2.6 ± 8.4	55 ± 30
Signal+background	3110 ± 180	3040 ± 210	6150 ± 360
Data	3227	3249	6476
Exp. Bkg. frac.	0.03 ± 0.00	0.00 ± 0.00	0.02 ± 0.00
Data/MC	1.04 ± 0.06	1.07 ± 0.07	1.05 ± 0.06

Measurement of the Top Quark Mass - arXiv:1503.05427 [hep-ex]

	$t\bar{t} \to$ lepton+jets			$t\bar{t} \to$ dilepton	Combination	
	$m_{\mathrm{top}}^{\ell+\mathrm{jets}}$ [GeV]	JSF	bJSF	$m_{\mathrm{top}}^{\mathrm{dil}}$ [GeV]	$m_{\mathrm{top}}^{\mathrm{comb}}$ [GeV]	ρ
Results	172.33	1.019	1.003	173.79	172.99	
Statistics	0.75	0.003	0.008	0.54	0.48	0
– *Stat. comp. (m_{top})*	*0.23*	*n/a*	*n/a*	*0.54*		
– *Stat. comp. (JSF)*	*0.25*	*0.003*	*n/a*	*n/a*		
– *Stat. comp. (bJSF)*	*0.67*	*0.000*	*0.008*	*n/a*		
Method	0.11 ± 0.10	0.001	0.001	0.09 ± 0.07	0.07	0
Signal MC	0.22 ± 0.21	0.004	0.002	0.26 ± 0.16	0.24	+1.00
Hadronisation	0.18 ± 0.12	0.007	0.013	0.53 ± 0.09	0.34	+1.00
ISR/FSR	0.32 ± 0.06	0.017	0.007	0.47 ± 0.05	0.04	−1.00
Underlying event	0.15 ± 0.07	0.001	0.003	0.05 ± 0.05	0.06	−1.00
Colour reconnection	0.11 ± 0.07	0.001	0.002	0.14 ± 0.05	0.01	−1.00
PDF	0.25 ± 0.00	0.001	0.002	0.11 ± 0.00	0.17	+0.57
W/Z+jets norm	0.02 ± 0.00	0.000	0.000	0.01 ± 0.00	0.02	+1.00
W/Z+jets shape	0.29 ± 0.00	0.000	0.004	0.00 ± 0.00	0.16	0
NP/fake-lepton norm.	0.10 ± 0.00	0.000	0.001	0.04 ± 0.00	0.07	+1.00
NP/fake-lepton shape	0.05 ± 0.00	0.000	0.001	0.01 ± 0.00	0.03	+0.23
Jet energy scale	0.58 ± 0.11	0.018	0.009	0.75 ± 0.08	0.41	−0.23
b-jet energy scale	0.06 ± 0.03	0.000	0.010	0.68 ± 0.02	0.34	+1.00
Jet resolution	0.22 ± 0.11	0.007	0.001	0.19 ± 0.04	0.03	−1.00
Jet efficiency	0.12 ± 0.00	0.000	0.002	0.07 ± 0.00	0.10	+1.00
Jet vertex fraction	0.01 ± 0.00	0.000	0.000	0.00 ± 0.00	0.00	−1.00
b-tagging	0.50 ± 0.00	0.001	0.007	0.07 ± 0.00	0.25	−0.77
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.15 ± 0.04	0.000	0.001	0.04 ± 0.03	0.08	−0.15
Leptons	0.04 ± 0.00	0.001	0.001	0.13 ± 0.00	0.05	−0.34
Pile-up	0.02 ± 0.01	0.000	0.000	0.01 ± 0.00	0.01	0
Total	1.27 ± 0.33	0.027	0.024	1.41 ± 0.24	0.91	−0.07

Measurement of the Top Quark Width - arXiv:1308.4050 [hep-ex]

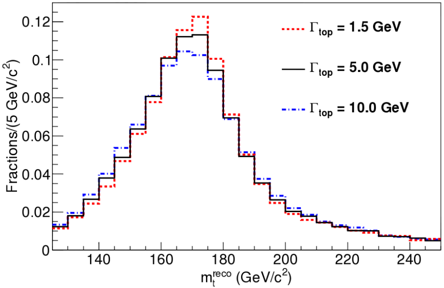
- The CDF collaboration reported the first result using a direct approach, using the same analysis technique as the ATLAS collaboration

  $\rightarrow$ It took $\sim$ 10 years for the CDF collaboration to produce their optimized result on top quark width Γ_{top}

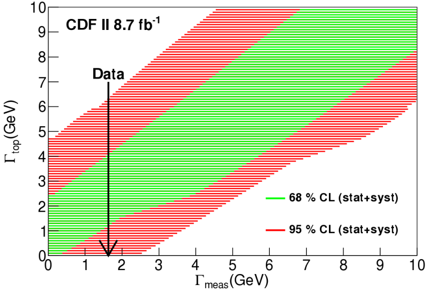
- The m_t^{reco} observable is reconstructed using a χ^2 technique, producing templates with different values Γ_{top} (0, 10) GeV

  $\rightarrow$ The CDF result can be summarized as $1.10 < \Gamma_{top} < 4.05$ GeV at 68 % confidence level and $\Gamma_{top} < 6.38$ GeV at 95 % confidence level

Reconstructed Γ_{top} templates



Confidence Intervals and Measurement



Indirect Measurement of the Top Quark Width - arXiv:1404.2292 [hep-ex]

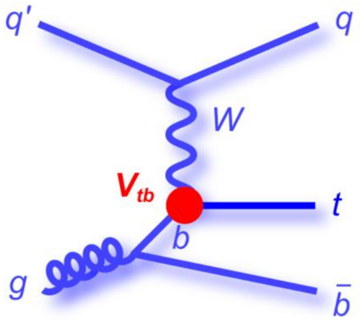
$$R = \frac{B(t \to W + b)}{B(t \to W + q)} \quad (3)$$

$$\Gamma_{top} = \frac{\sigma_{t-channel}}{B(t \to W + b)} \times \frac{\Gamma_{th}(t \to W + b)}{\sigma^{theory}_{t-channel}} \quad (4)$$

- The CMS collaboration following the DØ collaboration indirect approach has measured Γ_{top}

  → The result from CMS is Γ_{top} 1.36 ± 0.02 (stat) $^{+0.14}_{-0.11}$ (syst)

Single Top Channel



Confidence Intervals and Measurement