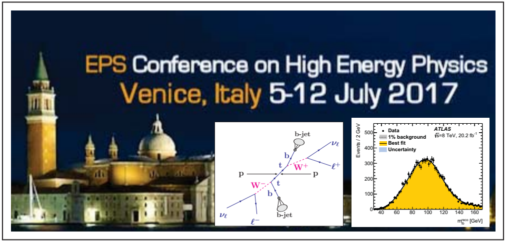
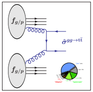
Measurements of the top quark mass with the ATLAS detector



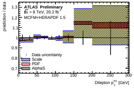
EPS 2017 Conference
Venice, July 7, 2017

Richard Nisius (MPP München)
for the ATLAS Collaboration

The plan of this presentation

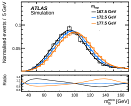


~~Introduction~~



Indirect determination of $m_{\mathrm{top}}^{\mathrm{pole}}$

— **Lepton differential distributions,** ATLAS-CONF-2017-044

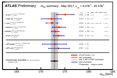


Direct measurements of m_{top}

— **All-jets channel,** arXiv:1702.07546

— **Lepton + jets channel,** Eur. Phys. J. C75 (2015) 330

— **Dilepton channel,** Phys. Lett. B761 (2016) 350



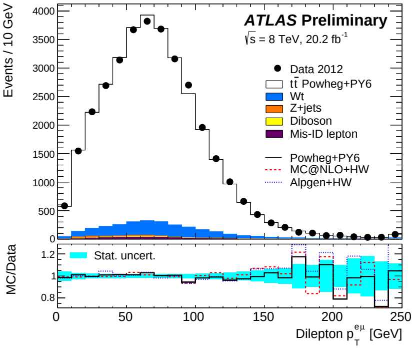
Combination of direct measurements

Conclusions

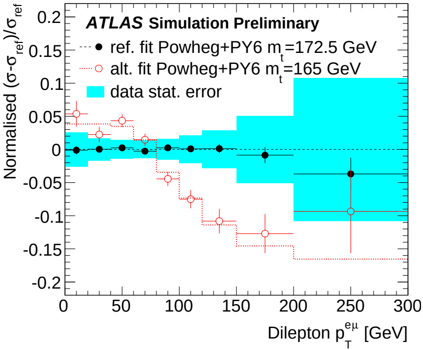
Note: - I cannot discuss in detail all displayed content, however, the main result figures have hyperlinks to the web page of the corresponding document.

The lepton differential cross-sections from 8 TeV data

An example compared to simulation



The sensitivity of $p_T^{e\mu}$ to m_{top}

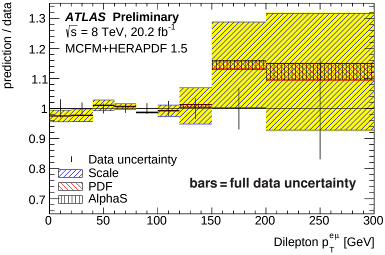


- Measure a number of lepton differential distributions in $t\bar{t} \to e\mu + X$ events.
- Correct to stable particle level (using Powheg+Pythia6+CT10), subtract the background and convert into normalised lepton differential cross-sections $\frac{1}{\sigma_x}\frac{d\sigma_x}{dx}$.
- Clear sensitivity to m_{top} for $x = p_T^\ell, p_T^{e\mu}, m^{e\mu}, p_T^e{+}p_T^\mu, E^e{+}E^\mu$, but not for $|\eta^\ell|, |y^{e\mu}|, \Delta\Phi^{e\mu}$.

The lepton differential cross-sections can be used to determine m_{top} or m_{top}^{pole}.

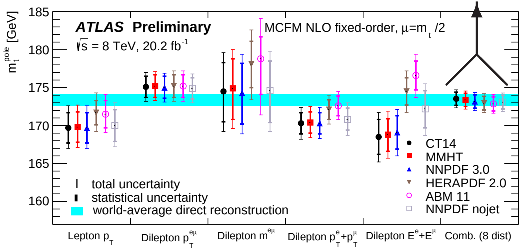
The m_{top}^{pole} mass from lepton differential cross-sections

Comparison to a fixed order prediction



The fitted m_{top}^{pole} values

$\frac{\chi^2}{Ndf} = \frac{64-71}{68}$



— **Within the sizeable uncertainties, the fixed order prediction describes the data.**

— **The results in m_{top}^{pole} are from fits to individual distributions, or to all distributions (including $|\eta^{\ell}|$, $|y^{e\mu}|$, $\Delta\Phi^{e\mu}$) while constraining the syst. uncertainties with nuisance parameters.**

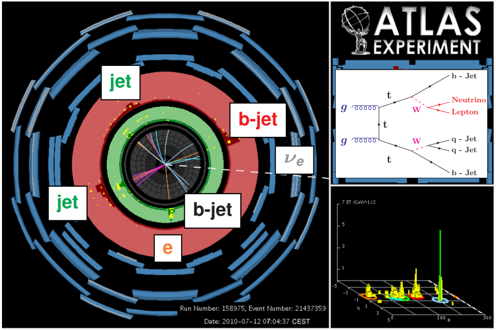
— **The spread in the individual results is about 6 GeV. The combined result is:**

$m_{top}^{pole} = 173.2 \pm 0.9\,(\text{stat.}) \pm 0.8\,(\text{syst.}) \pm 1.2\,(\text{theo.})\,\text{GeV} = 173.2 \pm 1.6\,\text{GeV}$. **The theo. uncertainty is from PDF (0.3 GeV) and fixed vs. dynamic (e.g. $\frac{E_T}{2}$) scale variations (1.1. GeV).**

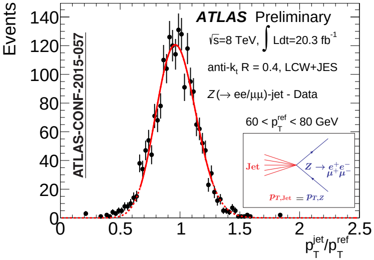
The first measurement of m_{top}^{pole} using this method results in an uncertainty of 1.6 GeV.

The uncertainty in the jet energy scale (JES)

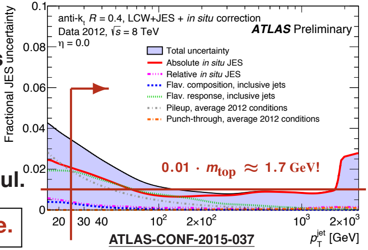
$t\bar{t} \to (b\, e\, \nu)\,(b\, q\, q),\;\; M(qq) = m_{\mathrm{W}},\;\; M(bqq) = m_{\mathrm{top}}$



Calibration via p_{T} - balance



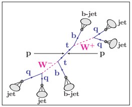
JES uncertainty versus Jet - p_{T}



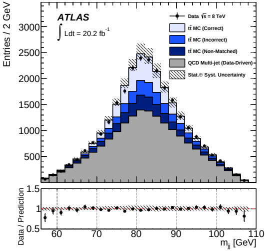
- Precise calibrations of the energy scale of inclusive jets (JES) and the relative *b*-to-light-jet energy scale (bJES) are vital for precise measurements of m_{top}.
- For high precision in m_{top} the possibility of in-situ calibrations of the mean JES and bJES are extremely helpful.

A small JES-induced uncertainty in m_{top} is indispensible.

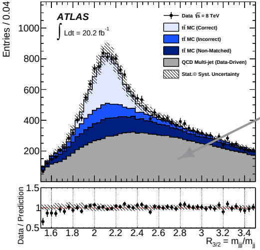
Measurement in the all-jets channel from 8 TeV data



The m_{jj} distribution

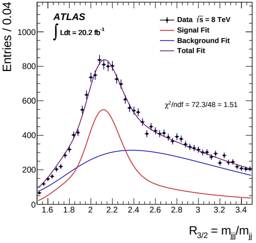


The R_{32} distribution



Some analysis details

- The number of b-tagged jets amongst the six leading jets and $\langle\Delta\Phi(b, W)\rangle$ in the signal and three control regions are used to determine the shape of the background distributions from data.
- Chosing the $R_{32} = \frac{m_{jjj}}{m_{jj}} = \frac{m_{bqq}}{m_{qq}}$ distribution (with an ATLAS Exp. expected *'peak'* at $\frac{172.84}{80.37} = 2.15$) stabilises m_{top} against a global JES uncertainty.



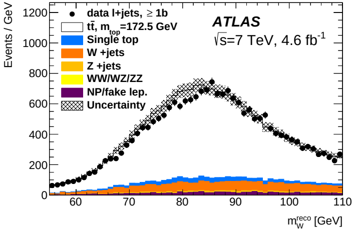
The result from the fit to data

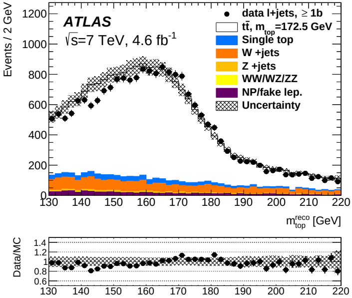
- $m_{top} = 173.72 \pm 0.55$ (stat) ± 1.01 (syst) GeV
- Most important systematic uncertainties: JES (0.60 GeV) bJES (0.34 GeV) and hadronisation (0.64 GeV).
- The summary so far:

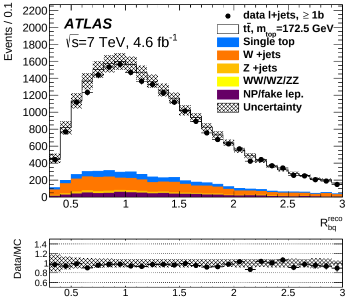
Channel ($\sqrt{s}$)	Stat	Model	Background	Experimental
All-jets (8)	0.55	0.70 ± 0.16	0.19	0.71 ± 0.04

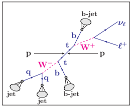
An about 40% improvement compared to the 7 TeV analysis.

Three-dimensional lepton + jets analysis from 7 TeV data









The analysis idea

— (b)JSF = (b)Jet Scale Factor to obtain scaled jets

$$p_t'(q) = \mathrm{JSF} \cdot p_t(q)$$
$$p_t'(b) = \mathrm{JSF} \cdot \mathrm{bJSF} \cdot p_t(b)$$

— Additional dimensions

2. $m_W^{reco} = 2E_1 E_2 (1 - cos\theta_{12}) \propto \mathrm{JSF}^2$

3. $R_{bq}^{reco} = \frac{\sum p_t(b)}{\sum p_t(q)} \propto \frac{\mathrm{bJSF} \cdot \mathrm{JSF}}{\mathrm{JSF}} = \mathrm{bJSF}$

1. m_{top}^{reco} = f(m_{top}, JSF, bJSF).
2. m_W^{reco} = f(JSF).
3. R_{bq}^{reco} = f(bJSF) with a weak m_{top} dependence.

— The 2D (m_{top}^{reco}, m_W^{reco}) or 3D (+R_{bq}^{reco}) template fit reduces the JES and bJES induced uncertainties in m_{top}.

— Since the JSF and bJSF are global, but JES and bJES are f(p_t, η), residual uncertainties remain.

This is the first 3D m_{top} analysis worldwide.

The list of systematic uncertainties

		$t\bar{t} \to$ lepton+jets		
		$m_{\mathrm{top}}^{\ell+\mathrm{jets}}$ [GeV]	JSF	bJSF
	Results	172.33	1.019	1.003
Statistics	Statistics	0.75	0.003	0.008
	– Stat. comp. (m_{top})	*0.23*	*n/a*	*n/a*
	– Stat. comp. (JSF)	*0.25*	*0.003*	*n/a*
	– Stat. comp. (bJSF)	*0.67*	*0.000*	*0.008*
	Method	0.11 ± 0.10	0.001	0.001
Model	Signal MC	0.22 ± 0.21	0.004	0.002
	Hadronisation	0.18 ± 0.12	0.007	0.013
	ISR/FSR	0.32 ± 0.06	0.017	0.007
	Underlying event	0.15 ± 0.07	0.001	0.003
	Colour reconnection	0.11 ± 0.07	0.001	0.002
	PDF	0.25 ± 0.00	0.001	0.002
Backgr.	W/Z+jets norm	0.02 ± 0.00	0.000	0.000
	W/Z+jets shape	0.29 ± 0.00	0.000	0.004
	NP/fake-lepton norm.	0.10 ± 0.00	0.000	0.001
	NP/fake-lepton shape	0.05 ± 0.00	0.000	0.001
Experimental	Jet energy scale	0.58 ± 0.11	0.018	0.009
	b-Jet energy scale	0.06 ± 0.03	0.000	0.010
	Jet resolution	0.22 ± 0.11	0.007	0.001
	Jet efficiency	0.12 ± 0.00	0.000	0.002
	Jet vertex fraction	0.01 ± 0.00	0.000	0.000
	b-Tagging	0.50 ± 0.00	0.001	0.007
	$E_{\mathrm{T}}^{\mathrm{miss}}$	0.15 ± 0.04	0.000	0.001
	Leptons	0.04 ± 0.00	0.001	0.001
	Pile-up	0.02 ± 0.01	0.000	0.000
	Total	1.27 ± 0.33	0.027	0.024

— **The third dimensions reduces the bJES induced uncertainty in m_{top} from 0.88 to $\sqrt{0.67^2 + 0.06^2} = 0.67$, but now it is mostly statistical.**

— **As a side effect a number of MC modelling uncertainties are reduced as well. This is because a different bJSF better accounts for the MC differences than a different m_{top}.**

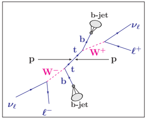
— **The uncertainty in m_{top} is back to being dominated by the JES induced uncertainty.**

— **The summary so far:**

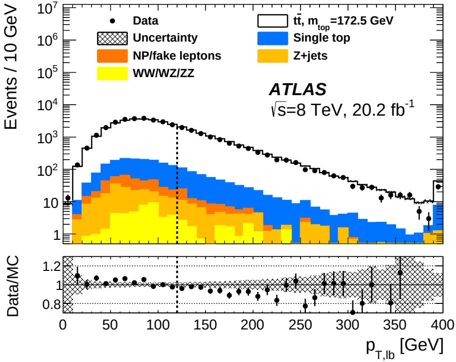
Channel ($\sqrt{s}$)	Stat	Model	Background	Experimental
All jets (8)	0.55	0.70 ± 0.16	0.19	0.71 ± 0.04
Lepton + jets (7)	0.75	0.53 ± 0.11	0.31 ± 0.00	0.82 ± 0.08

In this channel, the bJES induced uncertainty has finally lost its fright.

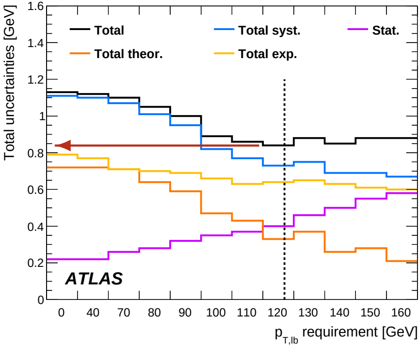
Optimisation in the dilepton channel from 8 TeV data



The $p_{T,\ell b}$ distribution



Uncertainty vs. $p_{T,\ell b}$



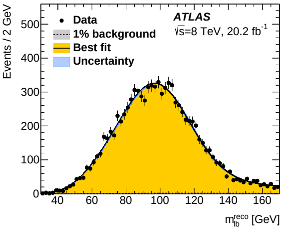
- The variable $p_{T,\ell b}$ denotes the mean p_T of the two lepton–b-jet pairs.
- The data-to-MC difference in $p_{T,\ell b}$ is covered by the hadronisation uncertainty (backup).
- Using $p_{T,\ell b} > 120$ GeV results in the smallest total uncertainty $\Rightarrow$ final selection.

The optimisation significantly reduces the total uncertainty.

The result from 8 TeV data

	$\sqrt{s}=7$ TeV		$\sqrt{s}=8$ TeV
	$m_{top}^{\ell+jets}$ [GeV]	m_{top}^{dil} [GeV]	m_{top}^{dil} [GeV]
Results	172.33	173.79	172.99
Statistics	0.75	0.54	0.41
Method	0.11 ± 0.10	0.09 ± 0.07	0.05 ± 0.07
Signal Monte Carlo generator	0.22 ± 0.21	0.26 ± 0.16	0.09 ± 0.15
Hadronisation	0.18 ± 0.12	0.53 ± 0.09	0.22 ± 0.09
Initial- and final-state QCD radiation	0.32 ± 0.06	0.47 ± 0.05	0.23 ± 0.07
Underlying event	0.15 ± 0.07	0.05 ± 0.05	0.10 ± 0.14
Colour reconnection	0.11 ± 0.07	0.14 ± 0.05	0.03 ± 0.14
Parton distribution function	0.25 ± 0.00	0.11 ± 0.00	0.05 ± 0.00
Background normalisation	0.10 ± 0.00	0.04 ± 0.00	0.03 ± 0.00
W/Z+jets shape	0.29 ± 0.00	0.00 ± 0.00	0
Fake leptons shape	0.05 ± 0.00	0.01 ± 0.00	0.08 ± 0.00
Jet energy scale	0.58 ± 0.11	0.75 ± 0.08	0.54 ± 0.04
Relative b-to-light-jet energy scale	0.06 ± 0.03	0.68 ± 0.02	0.30 ± 0.01
Jet energy resolution	0.22 ± 0.11	0.19 ± 0.04	0.09 ± 0.05
Jet reconstruction efficiency	0.12 ± 0.00	0.07 ± 0.00	0.01 ± 0.00
Jet vertex fraction	0.01 ± 0.00	0.00 ± 0.00	0.02 ± 0.00
b-tagging	0.50 ± 0.00	0.07 ± 0.00	0.03 ± 0.02
Leptons	0.04 ± 0.00	0.13 ± 0.00	0.14 ± 0.01
E_T^{miss}	0.15 ± 0.04	0.04 ± 0.03	0.01 ± 0.01
Pile-up	0.02 ± 0.01	0.01 ± 0.00	0.05 ± 0.01
Total systematic uncertainty	1.03 ± 0.31	1.31 ± 0.23	0.74 ± 0.29
Total	1.27 ± 0.33	1.41 ± 0.24	0.84 ± 0.29

Look at these lines on next slide



- **Largest experimental uncertainties stem from the jet energy scales.**
- **Largest modelling uncertainties are due to Hadronisation and ISR/FSR.**
- **The correlations of the estimators for all sources of systematic uncertainty are evaluated rather than assigned (as is commonly done).**

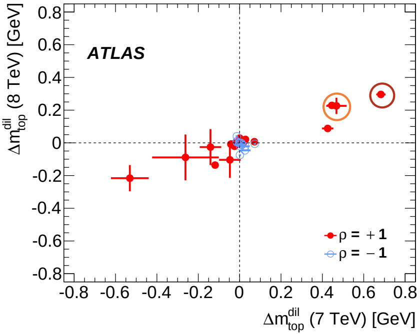
— **The summary:**

Channel ($\sqrt{s}$)	Value	Stat	Model	Background	Experimental	Total
All-jets (8)	173.72	0.55	0.70 ± 0.16	0.19	0.71 ± 0.04	1.15 (0.66 %)
Lepton + jets (7)	172.33	0.75	0.53 ± 0.11	0.31 ± 0.00	0.82 ± 0.08	1.27 (0.74 %)
Dilepton (8)	172.99	0.41	0.35 ± 0.09	0.08 ± 0.01	0.64 ± 0.04	0.85 (0.49 %)

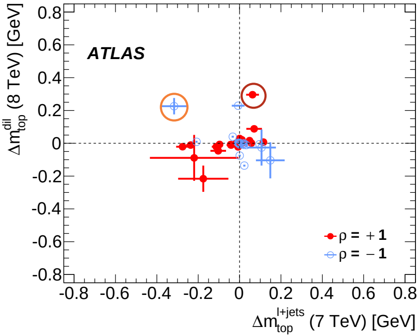
This is the most precise ATLAS measurement and the most precise result in this channel.

The correlations of the estimators for individual sources

Dilepton 7 vs. dilepton 8 TeV



Lepton + jets, 7 vs. dilepton 8 TeV



– **Δm = shift in mass from pairs of samples using 500 pseudo-experiments of the data size.**

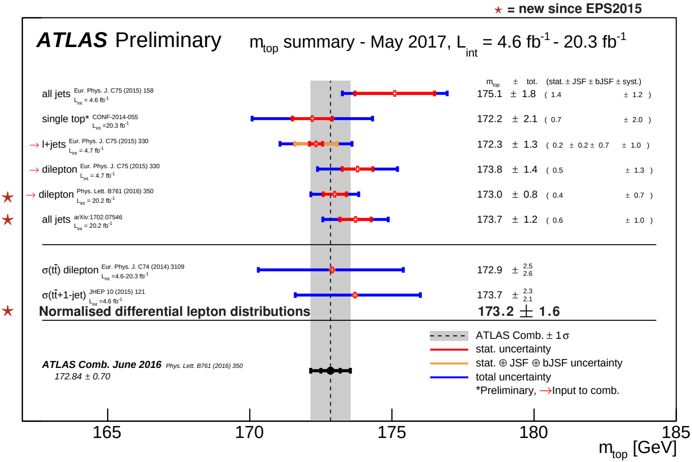
– **Each point corresponds to a single (sub-) component, with $\rho = +1$ or $\rho = -1$.**

bJES: 0.30 $\pm$ 0.01 (dil, 8), 0.68 $\pm$ 0.02 (dil, 7, $\rho = +1$), 0.06 $\pm$ 0.03 (ℓ+jets, 7, $\rho = +1$).

ISR/FSR: 0.23 $\pm$ 0.07 (dil, 8), 0.47 $\pm$ 0.05 (dil, 7, $\rho = +1$), 0.32 $\pm$ 0.06 (ℓ+jets, 7, $\rho = -1$).

By construction, the correlations to the three-dimensional lepton + jets analysis are small.

The ATLAS measurements of m_{top} and m_{top}^{pole}



– **The combination of three ATLAS measurements results in:**

$$m_{top} = 172.84 \pm 0.34\ (\mathrm{stat}) \pm 0.61\ (\mathrm{syst})\ \mathrm{GeV} = 172.84 \pm 0.70\ \mathrm{GeV}\ (0.40\%).$$

The direct measurements are superior in determining m_{top}.

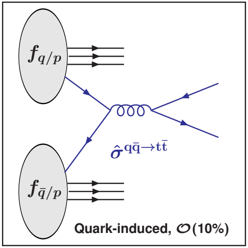
Conclusions

- ATLAS has performed various $m_{\mathrm{top}}^{\mathrm{pole}}$ measurements based on novel methods, e.g. by using $\mathrm{t\bar{t}}$ + 1-jet events and differential distributions of leptonic variables .
- Compared to direct measurements of m_{top}, these $m_{\mathrm{top}}^{\mathrm{pole}}$ determinations are performed in a well-defined renormalisation scheme, but suffer from larger uncertainties.
- The top quark m_{top} mass was directly measured in all $\mathrm{t\bar{t}}$ decay channels.
- The dilepton result: $m_{\mathrm{top}} = 172.99 \pm 0.41\ (\mathrm{stat}) \pm 0.74\ (\mathrm{syst})\ \mathrm{GeV} = 172.99 \pm 0.84$ GeV, is the most precise ATLAS measurement and the most precise in this channel to date.
- The largest experimental uncertainties stem from the calibration of the jet energy scales.
- The largest modelling uncertainties are due to Hadronisation and ISR/FSR radiation.
- For the combination of this result with other measurements the correlations of the estimators for all sources of systematic uncertainty are evaluated rather than assigned.
- The result is: $m_{\mathrm{top}} = 172.84 \pm 0.34\ (\mathrm{stat}) \pm 0.61\ (\mathrm{syst})\ \mathrm{GeV} = 172.84 \pm 0.70$ GeV.

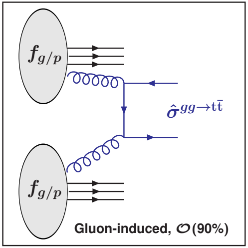
Backup - Transparencies

Production and decay of top-quark pairs

Production processes

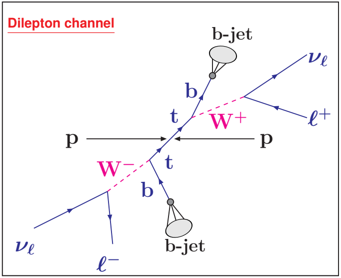


Quark-induced, $\mathcal{O}(10\%)$

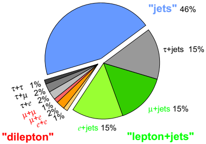


Gluon-induced, $\mathcal{O}(90\%)$

Decay channels ($V_{tb} \approx 1$)



– For $m_{\text{top}} = 172.5$ GeV and $\sqrt{s} = 8$ TeV, the cross-section is $\sigma(t\bar{t}) = 253^{+13}_{-15}$ pb, resulting in 250k events per 1/fb.



All-jets: highest rate $\mathcal{O}(46\%)$, but largest background.

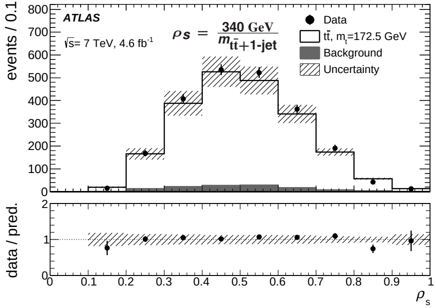
Lepton + jets: medium rate $\mathcal{O}(30\%)$, lepton 'tag', good compromise.

Dilepton: lowest rate $\mathcal{O}(4\%)$, high purity, incomplete kinematics.

The LHC is a top quark factory. In all channels, the systematic uncertainties matter most.

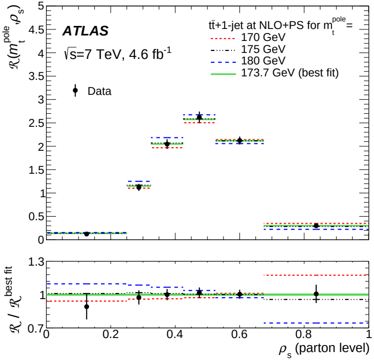
m_{top}^{pole} from the normalised differential $t\bar{t}$ + 1-jet cross-section

The data distribution



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

The unfolded distribution



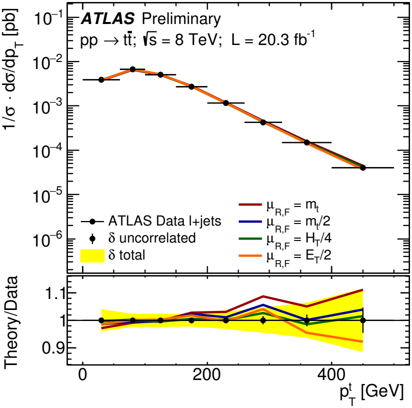
Largest sensitivity is close to threshold

- **Measure distribution of $t\bar{t}$ + 1-jet events in the lepton + jets channel in 7 TeV data.**
- **Unfold to parton level and compare $\mathcal{R}$ to the NLO+PS prediction as a function of m_{top}^{pole}.**
- **Perform χ^2 minimisation to get m_{top}^{pole} that best describes the data.**
- **Result: $m_{top}^{pole} = 173.7 \pm 1.5\,(\text{stat.}) \pm 1.4\,(\text{syst.})^{+1.0}_{-0.5}\,(\text{theo.})\ \text{GeV} = 173.7^{+2.3}_{-2.1}\ \text{GeV}$**

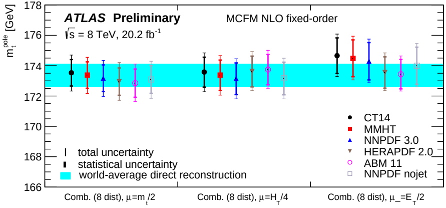
The first measurement of m_{top}^{pole} using this mehod, still with about 2.2 GeV uncertainty.

m_{top}^{pole} mass from lepton differential cross-sections - additional info

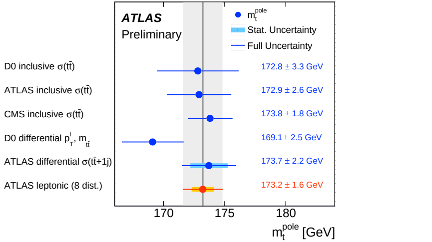
The top quark p_T spectrum



m_{top}^{pole} for different scale choices

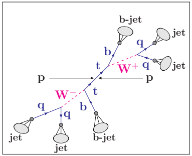


Comparison of measurements of m_{top}^{pole}



The largest theoretical uncertainty stems from the choice of the QCD scale.

Measurement in the all-jets channel from 8 TeV data



Numbers of events retained in the selection

Cut	Data (Event yields (thousands))	$t\bar{t}$ all-hadronic (MC) (Event yields (thousands))
Initial	850450	2338 ± 1
$N_{\mathrm{PV}_{>4\,\mathrm{tracks}}}$ & no isolated e/μ	33476	308.7 ± 0.6
Trigger: 5 jets with $p_{\mathrm{T}} > 55\,\mathrm{GeV}$ & ≥ 6 good jets	16110	241.4 ± 0.5
No 2 good jets (j_i, j_k) within $\Delta R(j_i, j_k) < 0.6$	7646	142.9 ± 0.4
≥ 5 good jets with $p_{\mathrm{T}} > 60\,\mathrm{GeV}$	3303	51.4 ± 0.2
$E_{\mathrm{T}}^{\mathrm{miss}} < 60\,\mathrm{GeV}$	3021	46.3 ± 0.2
$\Delta\phi(b_i, b_j) > 1.5$	1737	30.9 ± 0.2
$\chi^2 < 11$	645.8	22.3 ± 0.1
$N_{b_{\mathrm{tag}}} \geq 2$	21.9	6.61 ± 0.08
$\langle\Delta\phi(b, W)\rangle < 2$	12.9	4.40 ± 0.07

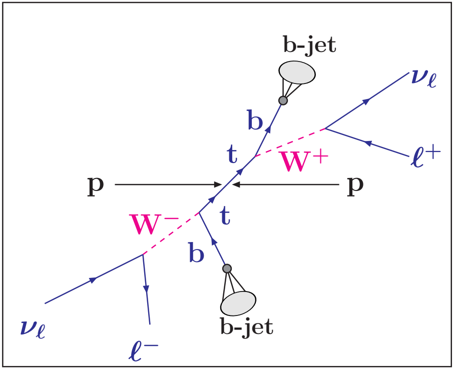
The list of uncertainties

Source of uncertainty	Δm_{top} [GeV]
Monte Carlo generator	0.18 ± 0.21
Hadronisation modelling	0.64 ± 0.15
Parton distribution functions	0.04 ± 0.00
Initial/final-state radiation	0.10 ± 0.28
Underlying event	0.13 ± 0.16
Colour reconnection	0.12 ± 0.16
Bias in template method	0.06
Signal and bkgd parameterisation	0.09
Non all-hadronic $t\bar{t}$ contribution	0.06
ABCD method *vs.* ABCDEF method	0.16
Trigger efficiency	0.08 ± 0.01
Lepton/$E_{\mathrm{T}}^{\mathrm{miss}}$ calibration	0.02 ± 0.01
Overall flavour-tagging	0.10 ± 0.00
Jet energy scale (JES)	0.60 ± 0.05
b-jet energy scale (bJES)	0.34 ± 0.02
Jet energy resolution	0.10 ± 0.04
Jet vertex fraction	0.03 ± 0.01
Total systematic uncertainty	1.01
Total statistical uncertainty	0.55
Total uncertainty	1.15

– **Results:** **7 TeV:** $m_{\mathrm{top}} = 175.1 \pm 1.4\,(\mathrm{stat}) \pm 1.2\,(\mathrm{syst})\,\mathrm{GeV} = 175.1 \pm 1.8\,\mathrm{GeV}.$
8 TeV: $m_{\mathrm{top}} = 173.72 \pm 0.55\,(\mathrm{stat}) \pm 1.01\,(\mathrm{syst})\,\mathrm{GeV} = 173.72 \pm 1.16\,\mathrm{GeV}.$

An about 40% improvement compared to the 7 TeV analysis.

The dilepton channel from 8 TeV data



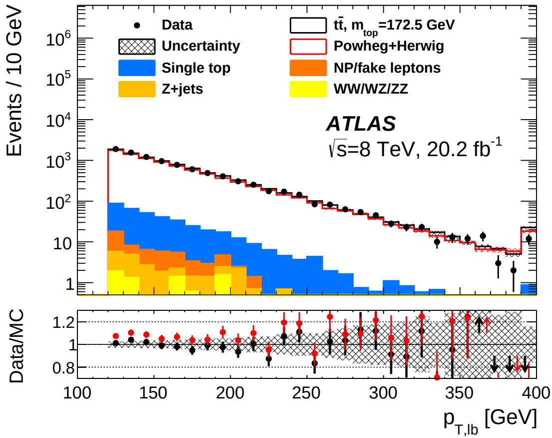
Pre-selection of events in 8 TeV data

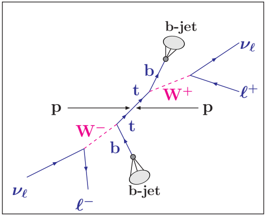
- Use $W^+W^- \to \ell^+\ell^-\nu\bar{\nu}$ with $\ell = e, \mu$.
- Quality requirements $\Rightarrow$ $20.2 \pm 0.4\ \mathrm{fb}^{-1}$.
- Trigger, good primary vertex $\geq$ 5 tracks.
- Electrons: $E_\mathrm{T} > 25$ GeV, $|\eta| < 2.47$.
- Muons: $p_\mathrm{t} > 25$ GeV, $|\eta| < 2.5$.
- ee, $\mu\mu$ channel: $E_\mathrm{T}^\mathrm{miss} > 60$ GeV
  $m_{\ell\ell} > 15$ GeV, $|m_{\ell\ell} - M_{Z^0}| > 10$ GeV.
- $e\mu$ channel: $H_\mathrm{T} > 130$ GeV.
- At least two jets with $p_\mathrm{t} > 25$ GeV
  and $|\eta^\mathrm{jet}| < 2.5$.
- At least one b-tagged jet ($\epsilon_b = 70\%$).

- Single top quark production is treated as signal rendering an m_top independent background.

The pre-selection yields about 36k events with 1% background.

The hadronisation uncertainty in 8 TeV data



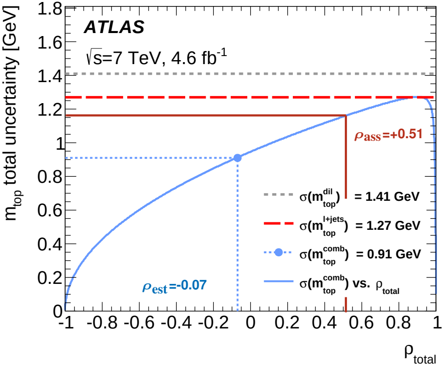


— **The difference between** POWHEG+PYTHIA **and** POWHEG+HERWIG **results in an hadronisation induced uncertainty in** m_{top} **of** 0.22 ± 0.09 GeV.

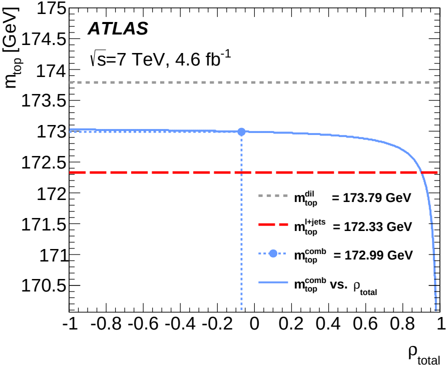
For this distribution, the data description is better for the POWHEG+HERWIG **event sample.**

Combination - dilepton and lepton + jets at 7 TeV

The uncertainty in m_{top}



The combined value of m_{top}



(1) $m_{top} = 172.91 \pm 0.50\,(\mathrm{stat}) \pm 1.05\,(\mathrm{syst})$ GeV (assigned $\rho_{ass,i}$ from world combination).

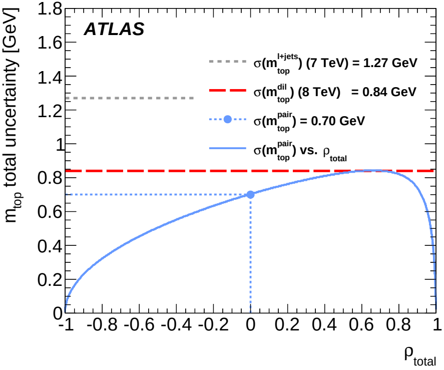
(2) $m_{top} = 172.99 \pm 0.48\,(\mathrm{stat}) \pm 0.78\,(\mathrm{syst})$ GeV, (estimated $\rho_{est,i}$).

$\Rightarrow \frac{\sigma_2}{\sigma_1} = \frac{0.91}{1.16} = 0.78$, i.e. a very significant improvement due to the estimated correlations.

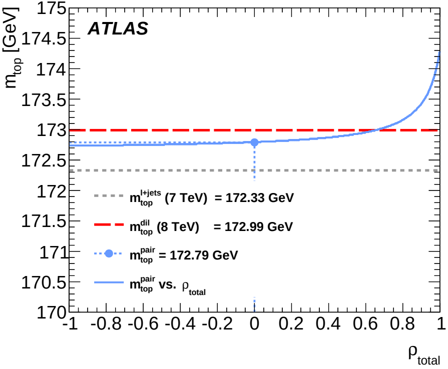
The use of the three-dimensional versus the one-dimensional fit is paying off.

Combination - dilepton at 8 TeV with lepton + jets at 7 TeV

The uncertainty in m_{top}



The combined value of m_{top}



— **Large improvement with respect to the more precise result, because the correlation is low, $\rho = 0.00 \ll \frac{0.84}{1.27} = 0.66 \Leftrightarrow$ the point of no improvement.**

The use of the three-dimensional versus the one-dimensional fit is paying off.

The various combinations

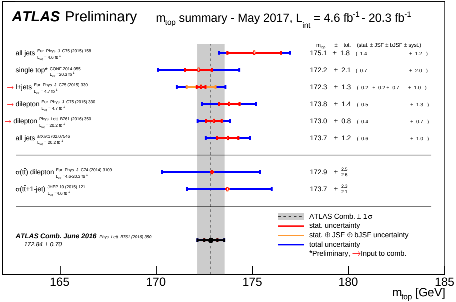
	$\sqrt{s}=7$ TeV		$\sqrt{s}=8$ TeV	Correlations			Combinations		
	$m_{top}^{\ell+jets}$ [GeV]	m_{top}^{dil} [GeV]	m_{top}^{dil} [GeV]	ρ_{01}	ρ_{02}	ρ_{12}	$m_{top}^{7\ TeV}$ [GeV]	m_{top}^{dil} [GeV]	m_{top}^{all} [GeV]
Results	172.33	173.79	172.99				172.99	173.04	172.84
Statistics	0.75	0.54	0.41	0	0	0	0.48	0.38	0.34
Method	0.11 ± 0.10	0.09 ± 0.07	0.05 ± 0.07	0	0	0	0.07	0.05	0.05
Signal Monte Carlo generator	0.22 ± 0.21	0.26 ± 0.16	0.09 ± 0.15	+1.00	+1.00	+1.00	0.24	0.10	0.14
Hadronisation	0.18 ± 0.12	0.53 ± 0.09	0.22 ± 0.09	+1.00	+1.00	+1.00	0.34	0.24	0.23
Initial- and final-state QCD radiation	0.32 ± 0.06	0.47 ± 0.05	0.23 ± 0.07	−1.00	−1.00	+1.00	0.04	0.24	0.08
Underlying event	0.15 ± 0.07	0.05 ± 0.05	0.10 ± 0.14	−1.00	−1.00	+1.00	0.06	0.10	0.02
Colour reconnection	0.11 ± 0.07	0.14 ± 0.05	0.03 ± 0.14	−1.00	−1.00	+1.00	0.01	0.03	0.01
Parton distribution function	0.25 ± 0.00	0.11 ± 0.00	0.05 ± 0.00	+0.57	−0.29	+0.03	0.17	0.04	0.08
Background normalisation	0.10 ± 0.00	0.04 ± 0.00	0.03 ± 0.00	+1.00	+0.23	+0.23	0.07	0.03	0.04
W/Z+jets shape	0.29 ± 0.00	0.00 ± 0.00	0	0			0.16	0.00	0.09
Fake leptons shape	0.05 ± 0.00	0.01 ± 0.00	0.08 ± 0.00	+0.23	+0.20	−0.08	0.03	0.07	0.05
Jet energy scale	0.58 ± 0.11	0.75 ± 0.08	0.54 ± 0.04	−0.23	+0.06	+0.35	0.41	0.52	0.41
Relative b-to-light-jet energy scale	0.06 ± 0.03	0.68 ± 0.02	0.30 ± 0.01	+1.00	+1.00	+1.00	0.34	0.32	0.25
Jet energy resolution	0.22 ± 0.11	0.19 ± 0.04	0.09 ± 0.05	−1.00	0	0	0.03	0.08	0.08
Jet reconstruction efficiency	0.12 ± 0.00	0.07 ± 0.00	0.01 ± 0.00	+1.00	+1.00	+1.00	0.10	0.01	0.04
Jet vertex fraction	0.01 ± 0.00	0.00 ± 0.00	0.02 ± 0.00	−1.00	+1.00	−1.00	0.00	0.02	0.02
b-tagging	0.50 ± 0.00	0.07 ± 0.00	0.03 ± 0.02	−0.77	0	0	0.25	0.03	0.15
Leptons	0.04 ± 0.00	0.13 ± 0.00	0.14 ± 0.01	−0.34	−0.52	+0.96	0.05	0.14	0.09
E_T^{miss}	0.15 ± 0.04	0.04 ± 0.03	0.01 ± 0.01	−0.15	+0.25	−0.24	0.08	0.01	0.05
Pile-up	0.02 ± 0.01	0.01 ± 0.00	0.05 ± 0.01	0	0	0	0.01	0.05	0.03
Total systematic uncertainty	1.03 ± 0.31	1.31 ± 0.23	0.74 ± 0.29				0.77	0.74	0.61
Total	1.27 ± 0.33	1.41 ± 0.24	0.84 ± 0.29	−0.07	0.00	0.51	0.91	0.84	0.70

– **The combined result:** $m_{top} = 172.84 \pm 0.34\ (stat) \pm 0.61\ (syst)$ GeV $= 172.84 \pm 0.70$ GeV.

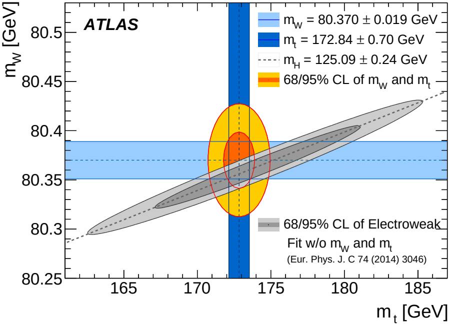
This combination of only three results has a precision of 0.4%.

Precision measurements and the Standard Model

The m_{top} combination



Consistency of the Standard Model



– **The combination of three ATLAS measurements results in:**

$$m_{top} = 172.84 \pm 0.34\,(\mathrm{stat}) \pm 0.61\,(\mathrm{syst})\ \mathrm{GeV} = 172.84 \pm 0.70\ \mathrm{GeV}\ (0.4\%).$$

– **The good description of the precise measurements of m_W with $\sigma(m_W) = 0.02\%$, m_{top} with $\sigma(m_{top}) = 0.4\%$ and M_H with $\sigma(M_H) = 0.2\%$ (from LHC) is another success of the SM.**

The Standard Model has successfully passed another precisions test.