Top Quark Mass Measurements in ATLAS

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Top Quark Physics Day
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Top Quark Mass Measurements in ATLAS

This talk:

ℓ+jets channel

$\sqrt{s}$ = 7 TeV, L = 4.6 fb^{-1}:

- 3-d template: ATLAS-CONF-2013-046
- Δm_t: Physics Letters B 728 (2014)

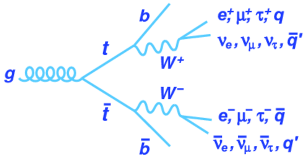
dilepton channel

$\sqrt{s}$ = 7 TeV, L = 4.6 fb^{-1}:

- 1-d template: ATLAS-CONF-2013-077

$\sqrt{s}$ = 7/8 TeV, L = 4.6/20.3 fb^{-1}:

- m$_t$ from $t\bar{t}$ x-Section: arXiv:1406.5375



all-hadronic channel

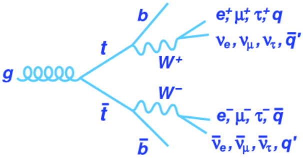
$\sqrt{s}$ = 7 TeV, L = 2.04 fb^{-1}:

- 1-d template: ATLAS-CONF-2012-030

Event Selection

ℓ+jets channel*:
[ATLAS-CONF-2013-046]

- single lepton trigger
- $==1$ lepton, E_T^{miss}
- ≥ 4 jets ($p_T > 25$ GeV)
- ≥ 1 b-tagged jets



dilepton channel*:
[ATLAS-CONF-2013-077]

- single lepton trigger
- $==2$ opposite sign leptons, E_T^{miss}
- ≥ 2 jets ($p_T > 25$ GeV)
- $==2$ b-tagged jets

all-hadronic channel:
[ATLAS-CONF-2012-030]

- multijet trigger
- $==0$ leptons
- ≥ 6 jets ($p_T > 55/30$ GeV), $E_T^{miss}/\sqrt{H_T}\,[\mathrm{GeV}^{-0.5}] < 3$
- $==2$ b-tagged jets ($\Delta R_{b\bar{b}} > 1.2$)

$\Rightarrow$ select orthogonal datasets $\leftrightarrow$ combination
$\Rightarrow$ b-tagging to increase signal purity (+ reduce combinatorial background $\leftrightarrow$ $t\bar{t}$ reconstruction)

* excluding τ's

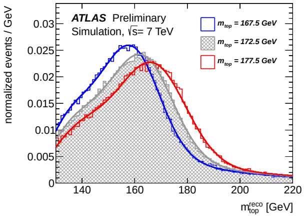
Top Quark Mass Measurement Techniques in ATLAS

- template method widely used in ATLAS

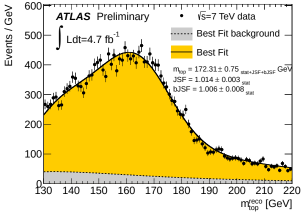
observable sensitive to top quark mass:

  - typically relies on reconstruction of $t\bar{t}$-decay (m_{bjj}, $m_{\ell b}$,..)
  - parameterize observable as a function of m_t
  - (+ use further observables to constrain JES uncertainty,...)

ATLAS-CONF-2013-046



ATLAS-CONF-2013-046



  - perform likelihood fit to measure top quark mass in data

$\Rightarrow m_t^{measured} = m_t^{MC}$ due to MC based mass calibration

- exploit top mass dependence of $\sigma_{t\bar{t}}$

  $\Rightarrow$ theoretical calculations use pole mass $\leftrightarrow m_t^{measured} = m_t^{pole}$

Systematic Uncertainties: Monte-Carlo Modelling

Nominal: POWHEG + PYTHIA

- Generator:
  POWHEG $\leftrightarrow$ MC@NLO
- Hadronisation:
  PYTHIA $\leftrightarrow$ HERWIG
- ISR/FSR:
  variation of PYTHIA parameters controlling the parton shower strength, constrained by Eur.Phys.J. C72 (2012) 2043
- Underlying Event:
  PERUGIA 2011 $\leftrightarrow$ PERUGIA 2011 MPIHI
- Colour Reconnection:
  PERUGIA 2011 $\leftrightarrow$ PERUGIA 2011 NOCR

$\Rightarrow$ hadronisation and ISR/FSR typically among dominant sources of MC modelling uncertainties

$\Rightarrow$ sensitivity also depends on estimator/technique

Systematic Uncertainties: Detector Modelling

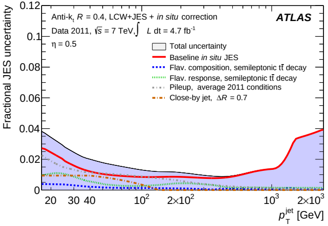
- uncertainties on (b)-jet energy scale typically dominant:
  - basline in-situ JES: 1-3% for jets with $20 < p_{\mathrm{T}} < 500$ GeV in the central region
  - additional uncertainty dependent on event topology (light quark/gluon jet composition), pile-up conditions
  - b-JES: 0.7-1.8%

$\Rightarrow$ impact on m_{jjj}: 1-2 GeV (JES), 0.5-1 GeV (bJES)

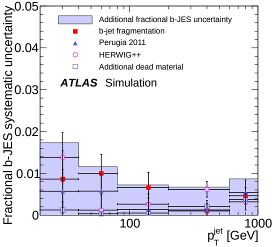
$\Rightarrow$ constrain JES uncertainty: simultaneous measurement of (b-)jet energy scale factor

- b-tagging: can impact estimators reconstructed based on b-tagging info

arXiv:1406.0076



arXiv:1406.0076



$t\bar{t} \to \ell$+jets: $\sqrt{s} = 7$ TeV (L = 4.6 fb^{-1})

3d Template Method (ATLAS-CONF-2013-046):

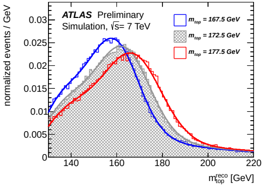
⇒ simultaneous determination of $\mathbf{m}_t$ and global jet energy scale factor (**JSF**) / b-jet scale factor (**bJSF**)

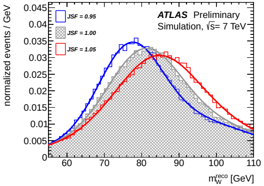
$$m_t^{\text{reco}} \leftrightarrow m_t$$

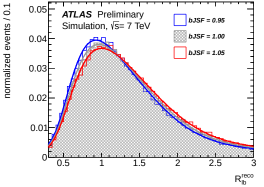
$$m_W^{\text{reco}} \leftrightarrow \text{JSF}$$

$$\left.\begin{array}{l} R_{\text{lb}}^{\text{reco,1b}} = \dfrac{p_{\text{T}}^{b_{\text{tag}}}}{(p_{\text{T}}^{W_{\text{jet}_1}} + p_{\text{T}}^{W_{\text{jet}_2}})/2} \\ R_{\text{lb}}^{\text{reco,2b}} = \dfrac{p_{\text{T}}^{b_{\text{had}}} + p_{\text{T}}^{b_{\text{lep}}}}{p_{\text{T}}^{W_{\text{jet}_1}} + p_{\text{T}}^{W_{\text{jet}_2}}} \end{array}\right\} \leftrightarrow \text{bJSF}$$

kinematic likelihood fit to assign jets to the W boson ($W_{\text{jet}_{1/2}}$) and b-quarks ($b_{\text{had/lep}}$)

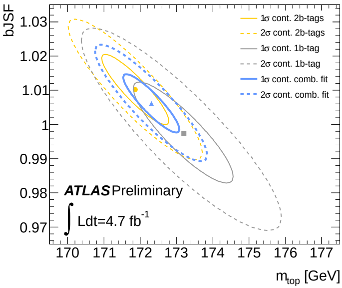






$t\bar{t} \to \ell$+jets: $\sqrt{s} = 7$ TeV ($L = 4.6$ fb^{-1})

ATLAS-CONF-2013-046



- b-tag efficiency, JES and I/FSR dominant sources of systematic uncertainty
- bJES unc. reduced thanks to $R_{\mathrm{lb}}^{\mathrm{reco}}$ variable ($\leftrightarrow$ 2d analysis: 0.92 GeV)

Method calibration	0.13
Signal MC generator	0.19
Hadronisation	0.27
Underlying event	0.12
Colour reconnection	0.32
ISR and FSR (signal only)	0.45
Proton PDF	0.17
single top normalisation	0.00
W+jets background	0.03
QCD multijet background	0.10
Jet energy scale	0.79
b-jet energy scale	0.08
Jet energy resolution	0.22
Jet reconstruction efficiency	0.05
b-tag efficiency and mistag rate	0.81
Lepton energy scale	0.04
Missing transverse momentum	0.03
Pile-up	0.03

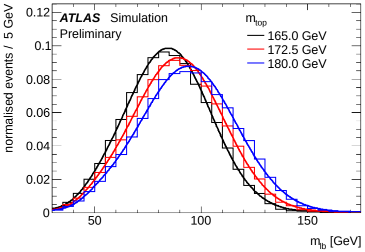
$$m_t = 172.31 \pm 0.23\ (\text{stat}) \pm 0.27\ (\text{JSF}) \pm 0.67\ (\text{bJSF}) \pm 1.35\ (\text{syst})\ \text{GeV}$$
$$m_t = 172.31 \pm 0.75\ (\text{stat+JSF+bJSF}) \pm 1.35\ (\text{syst})\ \text{GeV}$$

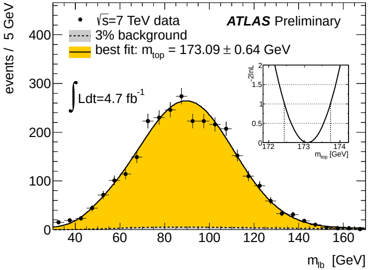
- 1-d template method
- m_{lb} estimator: average invariant mass of lepton + b-jet system (choose permutation which gives lowest average m_{lb})
- dominant sources of systematic uncertainty:

Hadronisation	0.44
Underlying event	0.42
Colour reconnection	0.29
ISR/FSR	0.37
Jet energy scale	0.89
bjet energy scale	0.71
b-tag efficiency and mistag rate	0.46
...	...

$m_t = 173.09 \pm 0.64$ (stat) ± 1.50 (syst) GeV

ATLAS-CONF-2013-077





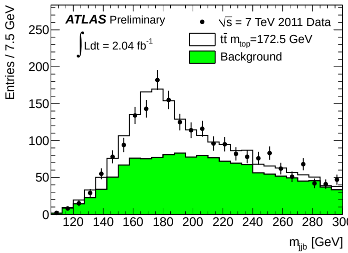
$t\bar{t} \rightarrow$ jets: $\sqrt{s} = 7$ TeV (L $= 2.04$ fb^{-1})

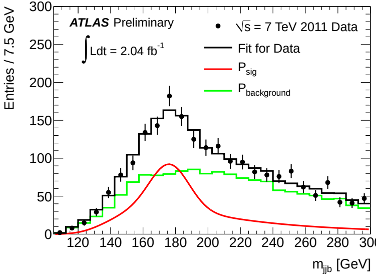
ATLAS-CONF-2012-030

- 1-d template method
- m_{jjb} estimator: $t\bar{t}$ reconstruction via χ^2-fit
- multijet background from data via event mixing
- dominant sources of systematic uncertainty:

ISR/FSR	1.7
Jet energy scale	2.1
bjet energy scale	1.4
Background modelling	1.9
...	...

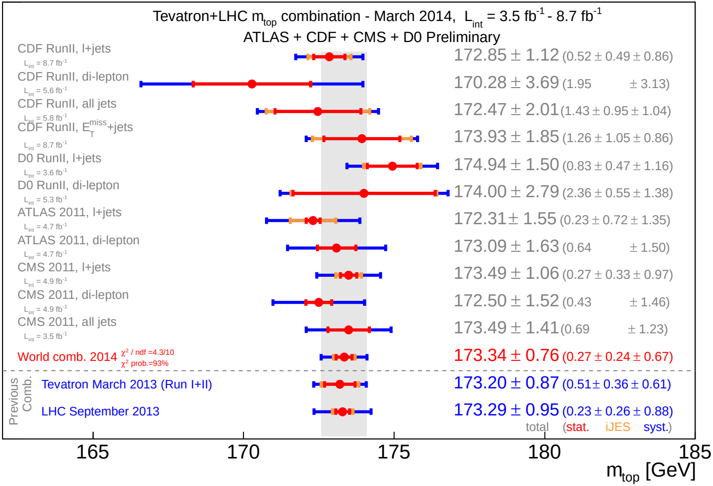
$m_t = 174.9 \pm 2.1$ (stat) ± 3.8 (syst) GeV





m_t World Combination

ATLAS-CONF-2014-008, CDF Note 11071, CMS PAS TOP-13-014, D0 Note 6416



⇒ first combination of LHC and Tevatron results, 0.43% overall precision

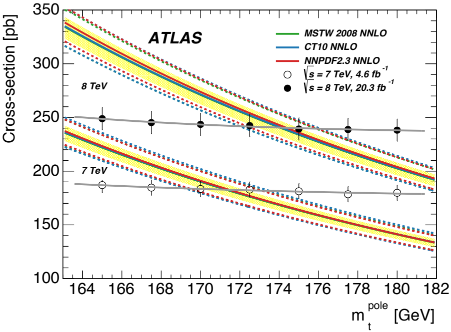
m_t from $t\bar{t}$ x-Section: $\sqrt{s} = 7/8$ TeV ($L = 4.6/20.3\ \text{fb}^{-1}$)

exploit theoretical dependence of $\sigma_{t\bar{t}}$ on m_t^{pole}

$\Rightarrow$ well defined renormalization scheme

arXiv:1406.5375

- using opposite sign $e\mu$ events
- small exp. dependence on m_t
- m_t^{pole} extracted via likelihood maximization



Theoretical uncertainties:

- including PDF / α_s / QCD scales uncertainties
- slightly larger compared to exp. uncertainties from $\sigma_{t\bar{t}}$ measurement

$\rightarrow$ see talk by L. Mijovic

$$m_t^{\text{pole}} = 171.4 \pm 2.6\,\text{GeV}\ (\sqrt{s} = 7\,\text{TeV})$$

$$m_t^{\text{pole}} = 174.1 \pm 2.6\,\text{GeV}\ (\sqrt{s} = 8\,\text{TeV})$$

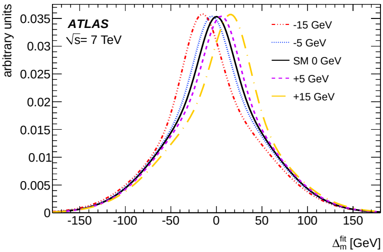
$$m_t^{\text{pole}} = 172.9^{+2.5}_{-2.6}\,\text{GeV}\ (\sqrt{s} = 7/8\,\text{TeV})$$

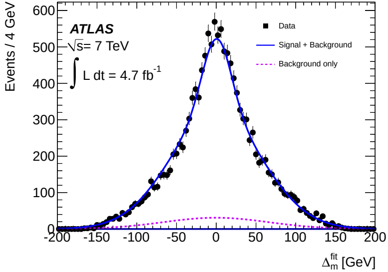
Δm_t: $\sqrt{s} = 7$ TeV (L $= 4.6$ fb^{-1})

Physics Letters B 728 (2014)

- check for equal particle and anti-particle masses in ℓ+jets events $\leftrightarrow$ CPT invariance
- estimator:
  $\Delta m_t = q_\ell \times (m^{\text{fit}}_{b\ell\nu} - m^{\text{fit}}_{bjj})$
  $m^{\text{fit}}_{b\ell\nu}$, m^{fit}_{bjj}: masses from kinematic fit
  q_ℓ: lepton charge
- systematic uncertainty dominated by b/b^- decay uncertainties (0.34 GeV)

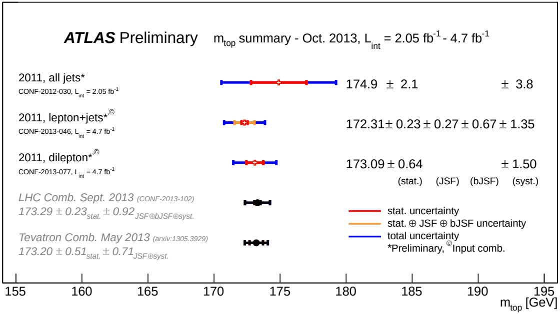
$$\Delta m_t = 0.67 \pm 0.61 \text{ (stat) } \pm 0.41 \text{ (syst) GeV}$$





Summary of ATLAS Top Quark Mass Measurements

- latest m_t measurements performed in different $t\bar{t}$ decay channels ($\sqrt{s}$=7 TeV):



- m_t^{pole} extraction from $\sigma_{t\bar{t}}$ ($\sqrt{s} = 7/8\,\text{TeV}$):

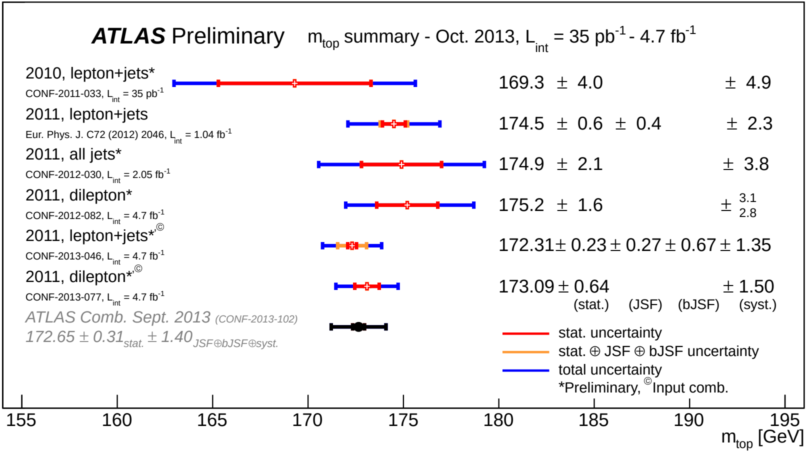
$$m_t^{\text{pole}} = 172.9^{+2.5}_{-2.6}\,\text{GeV} \text{ (arXiv:1406.5375)}$$

- check for CPT invariance:

$$\Delta m_t = 0.67 \pm 0.61 \text{ (stat) } \pm 0.41 \text{ (syst) GeV (Physics Letters B 728 (2014))}$$

Backup Slides...

ATLAS Top Quark Mass Measurements



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP