

Top quark mass measurements in ATLAS

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DIS 2017

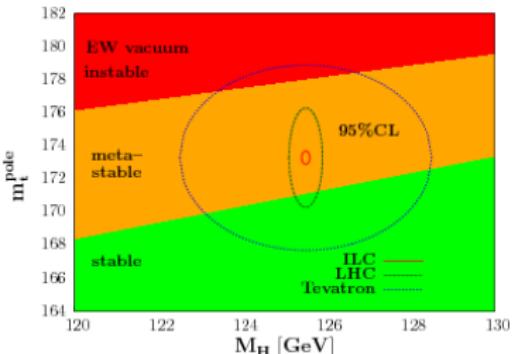
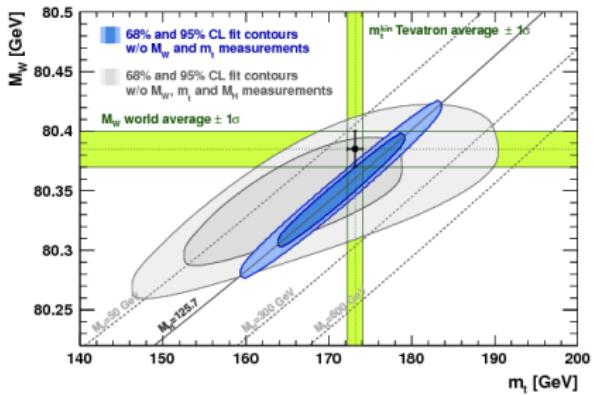
Birmingham, 4th April 2017



Introduction

Motivations:

- EW precision calculations depends on m_t
- EW vacuum stability involve m_t
- m_t is large → connection with high energy theories
- Unique opportunity to study a (almost) bare quark



Phys.Lett. B716 (2012) 214-219



Mass measurements: methods

Confinement → quark masses are not observables → what is m_t ?

- top decay products invariant mass → m_t^{gen}
- theory parameter in the Lagrangian → m_t^{pole} (in pole mass scheme)

$$\left| m_t^{\text{gen}} - m_t^{\text{pole}} \right| \leq 1 \text{ GeV} \quad [\text{Nucl.Phys.Proc.Suppl. } 185 \text{ (2008) } 220-226]$$

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m_t^{gen} → Direct measurements

- Choose *detector-level* observables (\mathcal{O}_i) which depend on the top quark mass.
- Generate MC with varied m_t^{gen} values.
- From MC, parametrise $\mathcal{O}_i(m_t^{\text{gen}})$.
- Take value of m_t^{gen} which best describes data.

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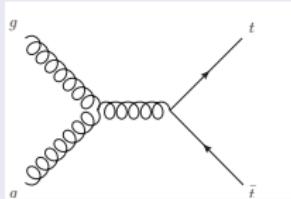
m_t^{pole} → Cross section measurements

- Take at least a NLO calculation (fix scheme)
- Obtain $\sigma_{t\bar{t}+X}(m_t^{\text{pole}})$ (differential also)
- Compare measured $\sigma_{t\bar{t}+X}^{\text{exp}}$ with theory
- Choose value of m_t^{pole} which best match $\sigma_{t\bar{t}+X}^{\text{exp}}$.
- m_t^{pole} well-defined theoretically.

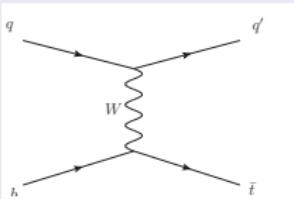
Mass measurements: topologies

Top quark mass measurements in ATLAS performed for a variety of topologies.

Top quark production modes

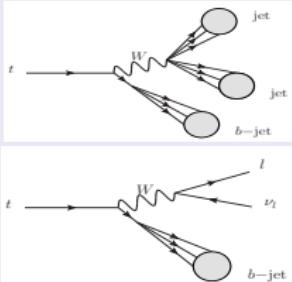


Strong interaction ($t\bar{t}$)



Weak interaction (single- t)

Top quark decays



Hadronic
Leptonic

Simplified event selection:

$t\bar{t}$ all-hadronic

- 6 jets (2 b -jets)
- no leptons
- no E_T^{miss}

$t\bar{t}$ semileptonic

- 4 jets (2 b -jets)
- 1 lepton
- $E_T^{\text{miss}} > 30 \text{ GeV}$

$t\bar{t}$ dileptonic

- 2 b -jets
- 2 leptons
- $E_T^{\text{miss}} > 60 \text{ GeV}$

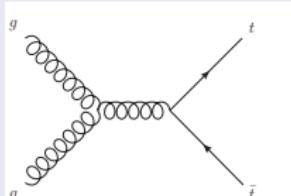
single- t (t leptonic)

- 2 jets (1 b -jet)
- 1 lepton
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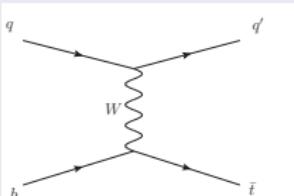
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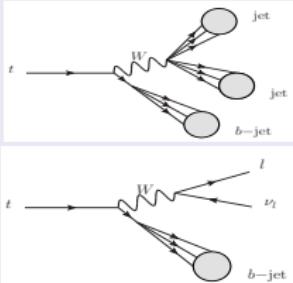


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Leptonic Hadronic

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Advantages of combination



- reduce fluctuations (from method/decay channel)
- **reduce error!**

Main challenges:

- Big multijet background (data driven estimated).
- High combinatoric background.

Event selection details:

- 6 jets with “high” p_T .
- control/signal regions from $N_{b\text{-jets}}$ and $\Delta\phi(b, W^{\text{reco}})$.

Observable $R_{3/2} = \frac{m_{jj}}{m_{jj}}$:

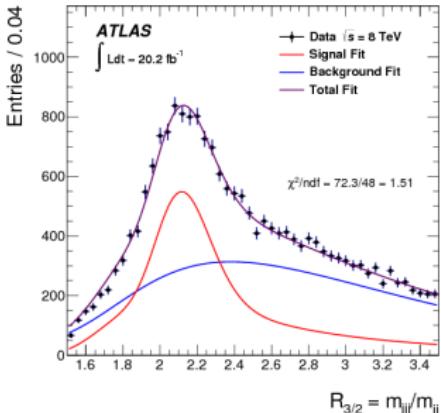
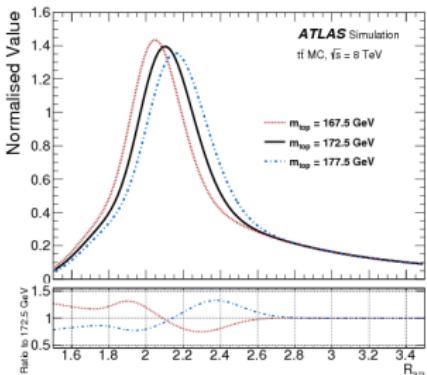
- m_{jj} invariant mass of top, m_{jj} invariant mass of W.
- two values for each event.
- $R_{3/2}$ reduce JES uncertainty.

Result:

$$m_t^{\text{gen}} = 173.72 \pm 0.55(\text{stat}) \pm 1.01(\text{syst}) \text{ GeV}$$

main uncertainties :

- JES (0.60 GeV) and bJES (0.34 GeV)
- hadronisation modelling (0.64 GeV)



Main challenges:

- Two $\nu \rightarrow$ can't reconstruct invariant mass

Event selection details:

- 2 oppositely charged leptons, $\geq 2 b$ -tagged jets
- Main backgrounds: low mass resonances, $Z+jets$, QCD.
- $p_{T,lb} > 120$ GeV minimises total uncertainty
- $30\text{GeV} < m_{lb}^{\text{reco}} < 170$ GeV increase purity and truth-matching efficiency

Observable m_{lb}^{reco} :

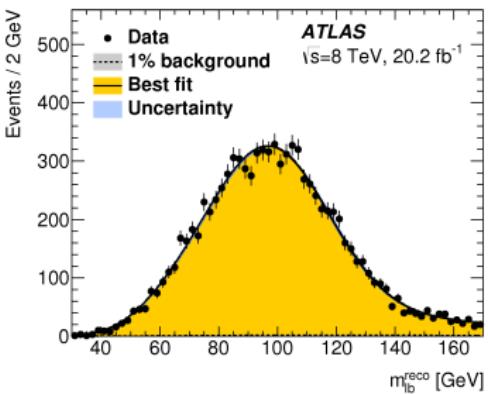
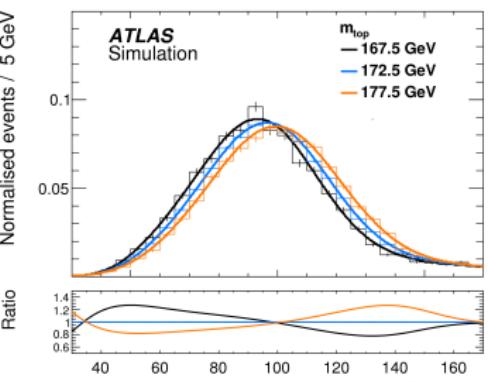
- No E_T^{miss} in observable definition \rightarrow good resolution

Result:

$$m_t^{\text{gen}} = 172.99 \pm 0.41(\text{stat}) \pm 0.74(\text{syst}) \text{ GeV}$$

main uncertainties:

- JES (0.54 GeV) and bJES (0.30 GeV)
- hadronisation and ISR/FSR modelling (0.22 GeV)
- Combination with 7TeV $/+jets$ and dilep measurements reduce error by 15%



Main challenges:

- Reduce dominant JES and bJES systematics.

Event selection and system reco details

- 1 lep, ≥ 4 jets, ≥ 1 b -jet, E_T^{miss} .
- Match reco objects to truth tops decay products, kinematical fit.

3D template fit, observables:

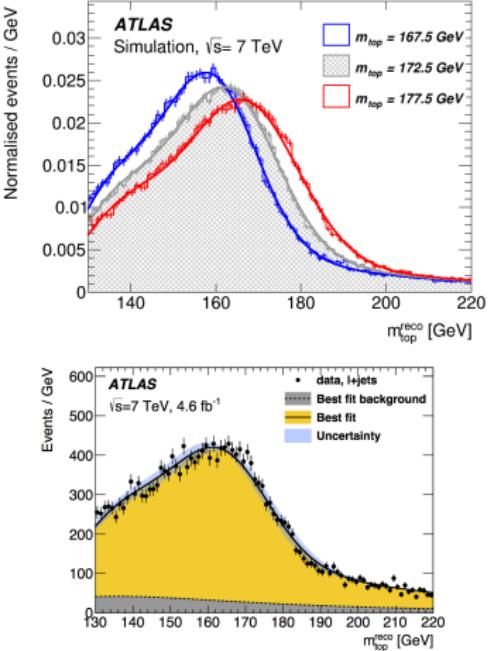
- $m_t^{\text{reco}} \rightarrow$ sensitive to m_t , JES and bJES
- $m_W^{\text{reco}} \rightarrow$ sensitive to JES
- $\frac{p_T^{\text{had}} + p_T^{\text{lep}}}{p_T^{j_1} + p_T^{j_2}} \rightarrow$ sensitive to bJES

Result:

$$m_t^{\text{gen}} = 172.33 \pm 0.75(\text{stat}) \pm 1.02(\text{syst}) \text{ GeV}$$

main uncertainties:

- JES (0.57 GeV) and bJES (0.67 GeV, stat)



Cross section methods: $\sigma_{t\bar{t}}$, 7 and 8 TeV Eur. Phys. J. C76 642



Main challenges:

- Measure m_t^{pole} from NNLO calculation.
- Need to correct for detector/reconstruction efficiency

Event selection:

- Opposite sign $e\mu$ pair, exactly one and two b -jets
- Two signal regions: (N1, 1 b -jet) ; (N2, 2 b -jets)
- Same sign $e\mu$ pair to estimate backgrounds

Observables:

$$N_1 = \mathcal{L} \sigma_{t\bar{t}} \epsilon_{\text{sel}} 2 \epsilon_{b\text{-tag}} (1 - C_{b\text{-tag}} \epsilon_{b\text{-tag}}) + N_1^{\text{bkg}}$$

$$N_2 = \mathcal{L} \sigma_{t\bar{t}} \epsilon_{\text{sel}} C_{b\text{-tag}} \epsilon_{2b\text{-tags}} + N_2^{\text{bkg}}$$

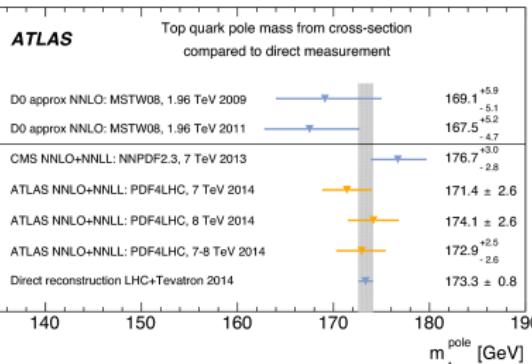
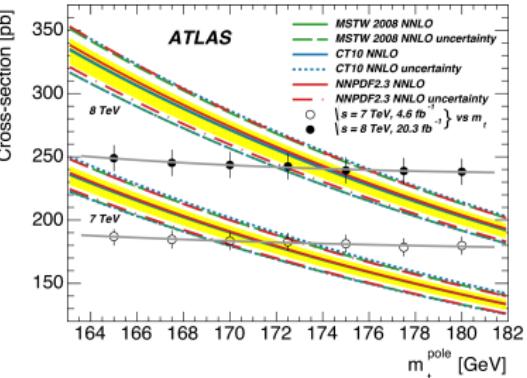
$\sigma_{t\bar{t}}$ depends on m_t^{pole} !

Result (7+8 TeV):

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

main uncertainties:

- PDF+ α_s (1.8 GeV)



Cross section methods: $t\bar{t} + 1\text{jet}$ at 7 TeV JHEP 10 (2015) 12

Main challenges:

- Big uncertainties (less stat than $t\bar{t}$).
- Correct data to parton level.
- $t\bar{t} + 1\text{jet}$ @NLO+PS, jet radiation depends on m_t .

Event selection:

- Standard $t\bar{t}$ semileptonic selection
- At least one additional jet is required.

Observable: $\mathcal{R} = \frac{1}{\sigma_{t\bar{t}+1\text{jet}}} \frac{d\sigma_{t\bar{t}+1\text{jet}}}{d\rho_s}$, $\rho_s \propto s_{t\bar{t}+1\text{jet}}^{-1/2}$

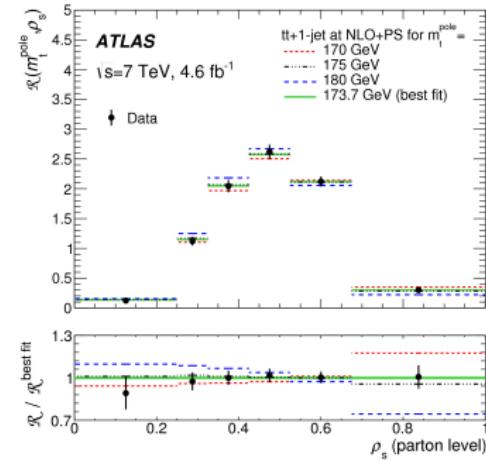
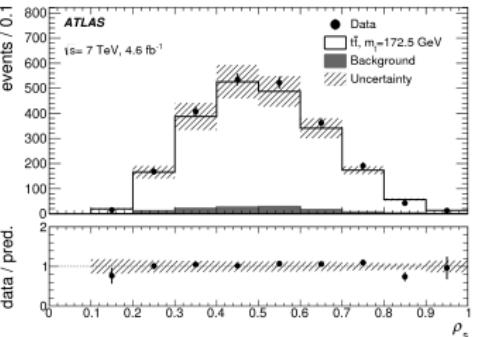
- Strong dependence on m_t^{pole} for $\rho_s \geq 0.7$
- Differential and normalised
- Fixed renormalisation scheme (pole mass)

Result:

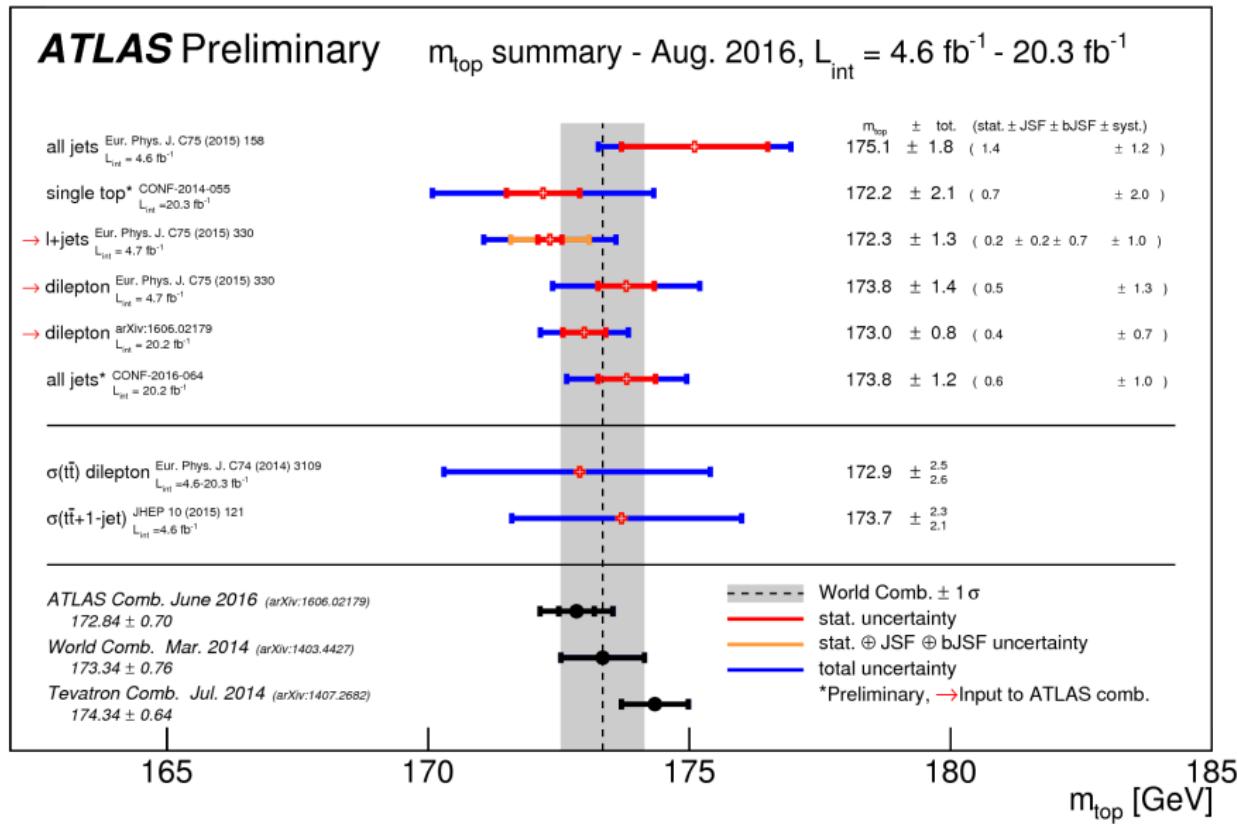
$$m_t^{\text{pole}} = 173.71 \pm 1.50(\text{stat}) \pm 1.44(\text{syst})^{+0.95}_{-0.49} \text{ (theo) GeV}$$

main uncertainties:

- statistical (1.5 GeV), JES+bJES (0.94 GeV)
- ISR/FSR modelling (0.72 GeV)



Latest ATLAS combination



Summary

- m_t is a fundamental parameter of the Standard Model.
- m_t determination is of great importance for the incoming precision physics era.
- Top quarks not directly observable → need well defined m_t definitions.
- Measurements performed with ATLAS scan a variety of channels and methods.
- 8 TeV measurements are completed (...to be public soon).
- For m_t^{gen} measurements, combination is the key (goal is $\approx 0.5\text{GeV}$, less at 13 TeV).
- m_t^{pole} measurements start getting high precision.
- 13 TeV efforts started:
 - More alternative methods
 - Reduce systematics

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Thanks for your attention!

Back-up



Main challenges:

- First time measurement in ATLAS.
- Large $W+jets$ background.

Event selection:

- Top leptonic decay: one b -jet, lepton and E_T^{miss} .
- One light jet (not from top).
- Control region with relaxed b -tag \rightarrow more $W+jets$
- Neural network (NN) increase $\frac{S}{B}$ ($\approx 0.15 \rightarrow \approx 0.9$)

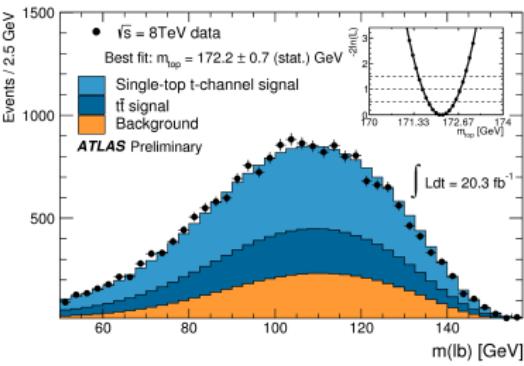
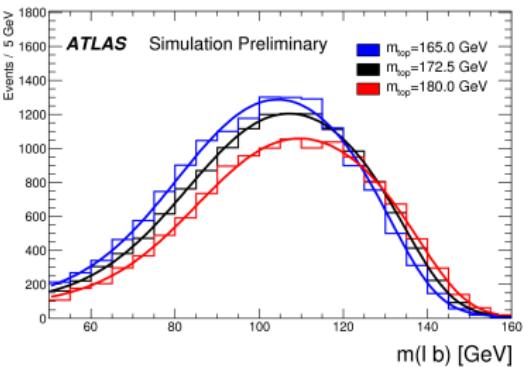
Observable m_{lb}^{reco} :

- Same of standard $t\bar{t}$ semilep. measurement

$$m_t^{\text{gen}} = 172.2 \pm 0.7(\text{stat}) \pm 2.0(\text{syst}) \text{ GeV}$$

main uncertainties:

- JES (1.5GeV)
- statistical and hadronisation modelling (0.7GeV)



Direct measurements summary (with CMS)

