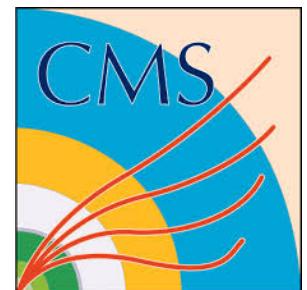


*Selected Topics from Top Mass:
Measurements in Fixed Schemes
and
Using Alternative Methods*

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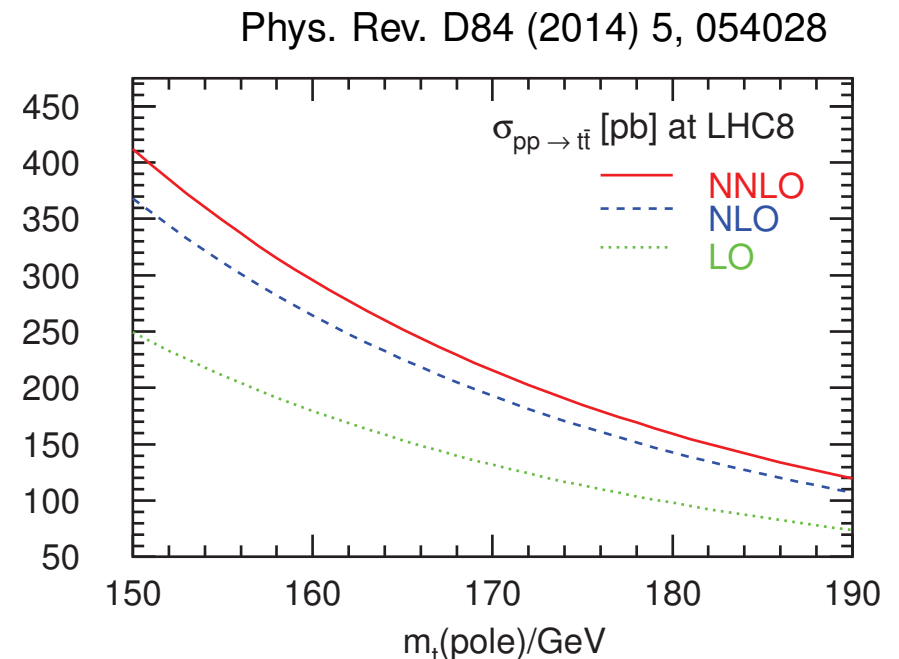
Introduction

- ▶ The top quark is the heaviest known elementary particle
- ▶ Precise measurements of the top quark mass, m_t , can provide inputs to test the self-consistency of the Standard Model (SM)
- ▶ The most precise m_t measurements have been performed from kinematical reconstruction of measured top quark decay products: e.g. jets, leptons, ...
- ▶ Reached precision of m_t measurements below $< 1 \text{ GeV}$
- ▶ These measurements don't have a direct link to an unambiguous Lagrangian m_t performed in a theoretically well-defined renormalization scheme in the SM
- ▶ Alternative interpretation of the top quark mass measurement can be done using alternative methods and also by using new observables
- ▶ Different m_t definitions:
 - The Monte Carlo (MC) m_t , m_t^{MC} (the parameter put into the MC generator program)
 - The pole mass, m_t^{pole} (the parameter that enters the top propagator)
 - The mass in a low-scale short distance scheme



Top Quark Mass Measurements

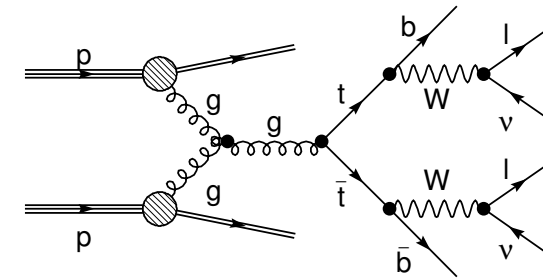
- ▶ Typical m_t^{MC} analyses reconstruct top quark candidates in data and MC often using kinematic fits and likelihood fits based on templates, in one (m_t) or more (JES, bJES) parameters
- ▶ “The uncertainty on the translation from the m_t^{MC} definition to a theoretically well defined short distance mass definition at low scale is currently estimated to be of the order of 1 GeV” S. Moch and al. (arxiv:1405.4781), A. H. Hoang and I. W. Stewart (Nucl. Phys. Proc. Suppl. 185 (2008):220-226)
- ▶ Cross-section based methods measure a theoretically well defined mass e.g. the m_t^{pole}
 - Large dependency on LO, NLO, NNLO $\sigma_{NNLO}/\sigma_{NLO} \sim 10\%$
 - Unfolding more difficult than folding
 - Cross-sections need absolute normalization
 - Not competitive precision:
 $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}} \sim 5\% \rightarrow \Delta m_t/m_t \sim 1\%$
- ▶ Usage of new observable help



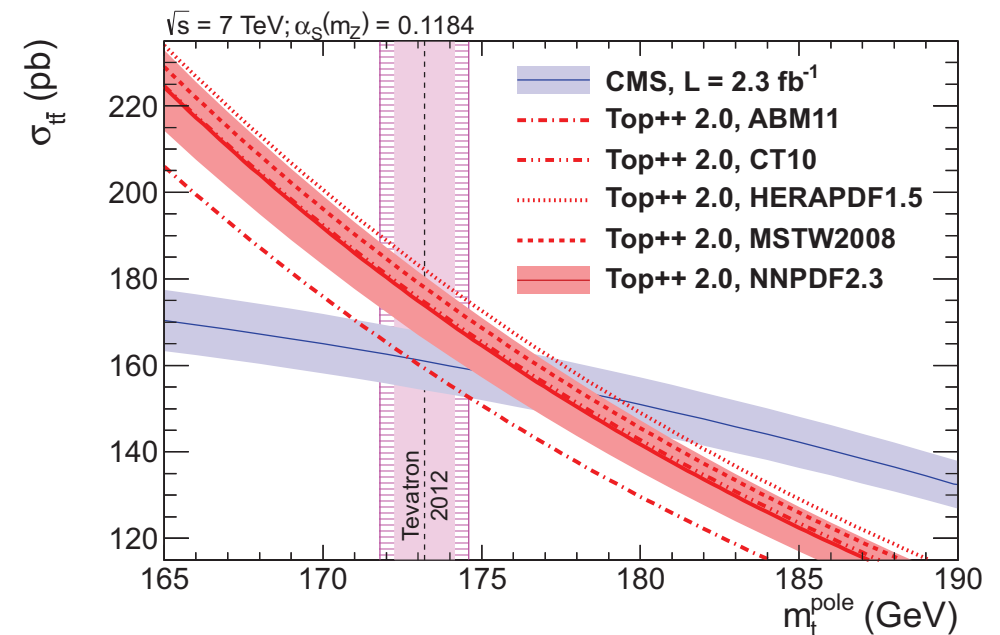
Pole Mass Measurements: Dilepton CMS 7 TeV

$$t\bar{t} \rightarrow W^+ b W^- \bar{b} \rightarrow \ell^\pm \ell^\pm \nu \bar{\nu} b \bar{b}$$

- ▶ m_t^{pole} measurement from total cross-section in the dilepton channel done by CMS @ 7 TeV
- ▶ Original cross-section measurement performed assuming $m_t = 172.5 \text{ GeV}$ and $\alpha_s(m_Z) = 0.1184$
- ▶ Plot shows predicted cross-section at NNLO+NNLL as function of m_t^{pole} using different PDF sets compared to results obtained by CMS assuming $m_t = m_t^{pole}$
- ▶ $\sigma_{t\bar{t}} = 161.9 \pm 6.7 \text{ pb}$

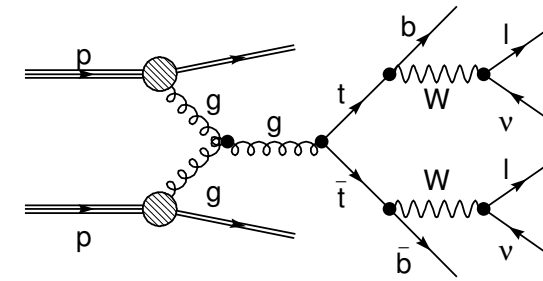


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Pole Mass Measurements: Dilepton CMS 7 TeV

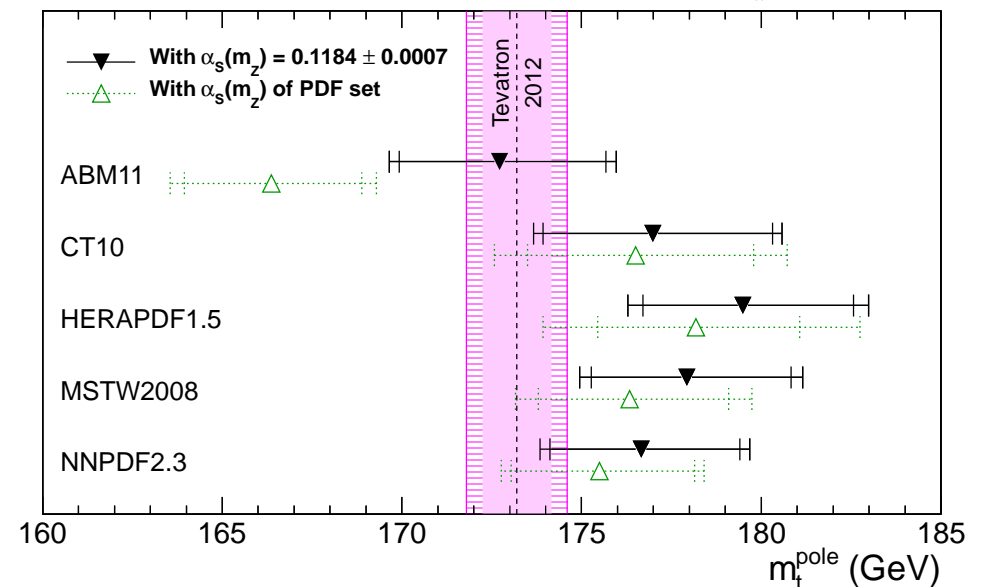
$$t\bar{t} \rightarrow W^+ b W^- \bar{b} \rightarrow l^\pm l^\pm \nu \bar{\nu} b \bar{b}$$



- ▶ The CMS analysis was turned around to measure the m_t^{pole} or α_s from the predicted $\sigma_{t\bar{t}}$ in NNLO+NNLL with different NNLO PDF sets
- ▶ Latest m_t average measurement is shown as vertical band. Inner (solid) area are the original uncertainty of the m_t average. Outer (hatched) area accounts for the differences between m_t and m_t^{pole}
- ▶ Results obtained using the PDF NNPDF2.3: $m_t^{pole} = 176.7^{+3.0}_{-2.8}$ GeV
- ▶ m_t^{pole} results complementary to m_t^{MC} measurements

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CMS, $\sqrt{s} = 7$ TeV, $L = 2.3 \text{ fb}^{-1}$; NNLO+NNLL for $\sigma_{t\bar{t}}$



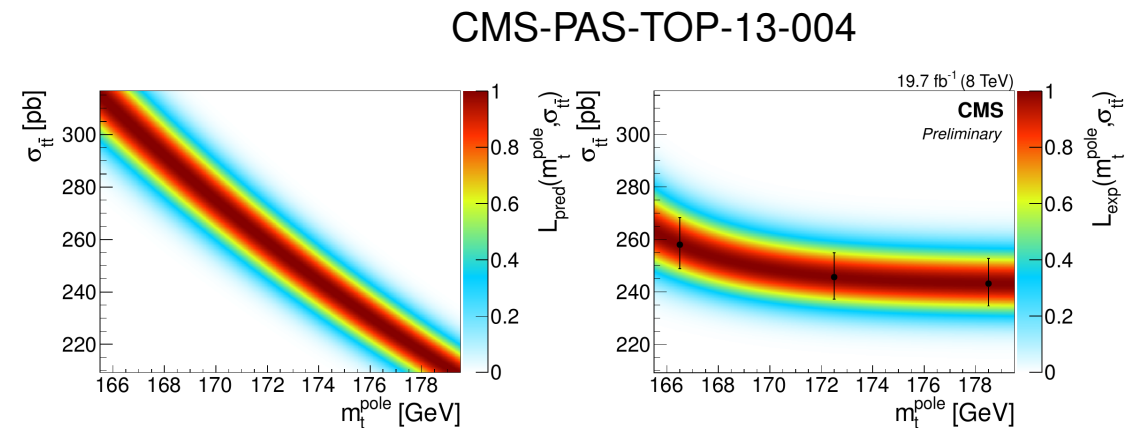
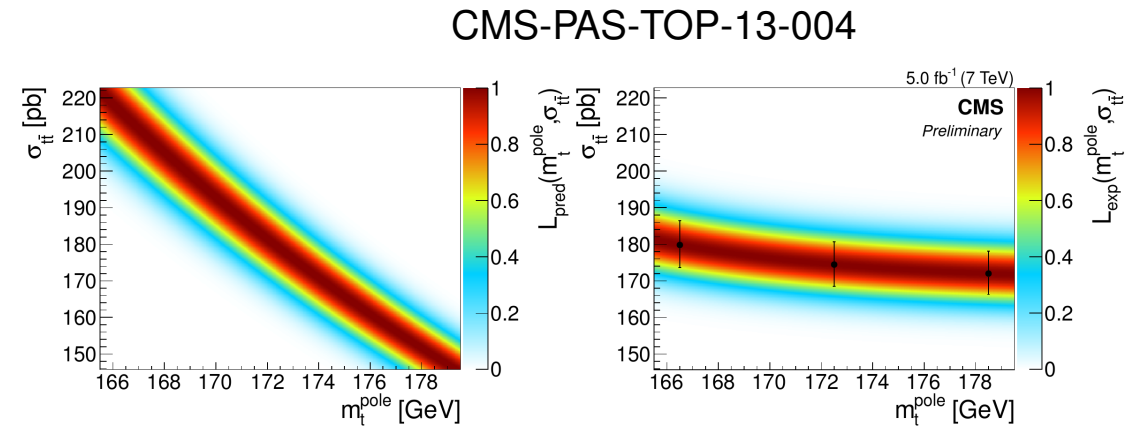
Pole Mass Measurements: Dilepton CMS 7 & 8 TeV

- ▶ Preliminary CMS m_t^{pole} results from inclusive $\sigma_{t\bar{t}}$ measurements at 7 and 8 TeV (full data samples)
- ▶ Left plots show predicted $\sigma_{t\bar{t}}$ in NNLO+NNLL using TOP++ 2.0 with $\alpha_s = 0.1184$ and PDF set NNPDF30
- ▶ Right plots show measured dependence of $\sigma_{t\bar{t}}$ on m_t^{pole} .
- ▶ Results:

$$m_t^{pole} = 173.6_{-1.8}^{+1.7} \text{ GeV (NNPDF30)}$$

$$m_t^{pole} = 173.9_{-1.9}^{+1.8} \text{ GeV (MMHT2014)}$$

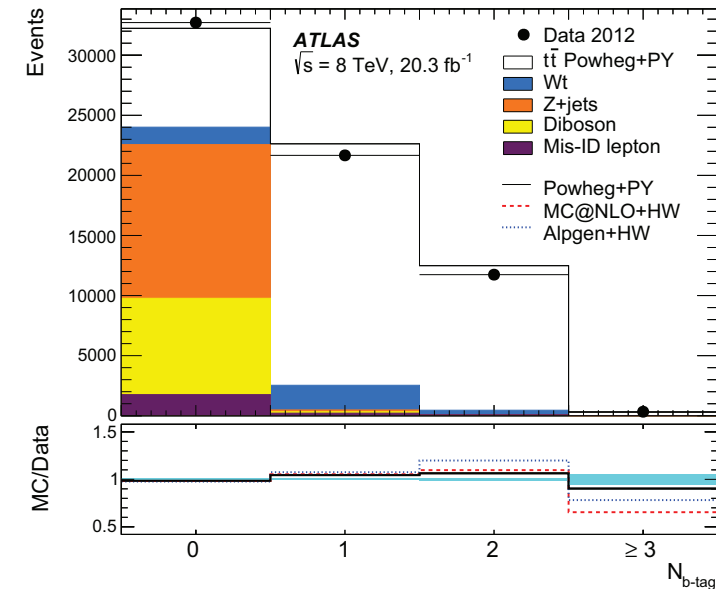
$$m_t^{pole} = 174.1_{-2.2}^{+2.1} \text{ GeV (CT14)}$$



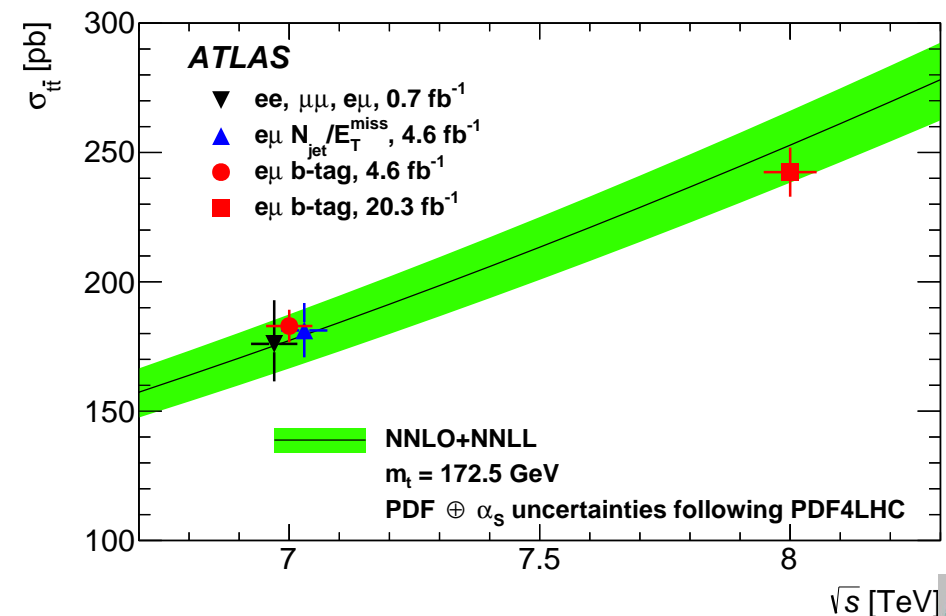
Pole Mass Measurements: Dilepton ATLAS 7 & 8 TeV

- ▶ m_t^{pole} measurement from total cross-section in the dilepton channel done by ATLAS @ 7 and 8 TeV
- ▶ Production $\sigma_{t\bar{t}}$ measurement performed using $t\bar{t}$ events with opposite-charge $e\mu$ pair in the final state and exactly one or two b-tagged jets
- ▶ Main background: Wt
- ▶ $\sigma_{t\bar{t}} = 182.9 \pm 7.1$ pb (7 TeV)
- ▶ $\sigma_{t\bar{t}} = 242.4 \pm 10.3$ pb (8 TeV)

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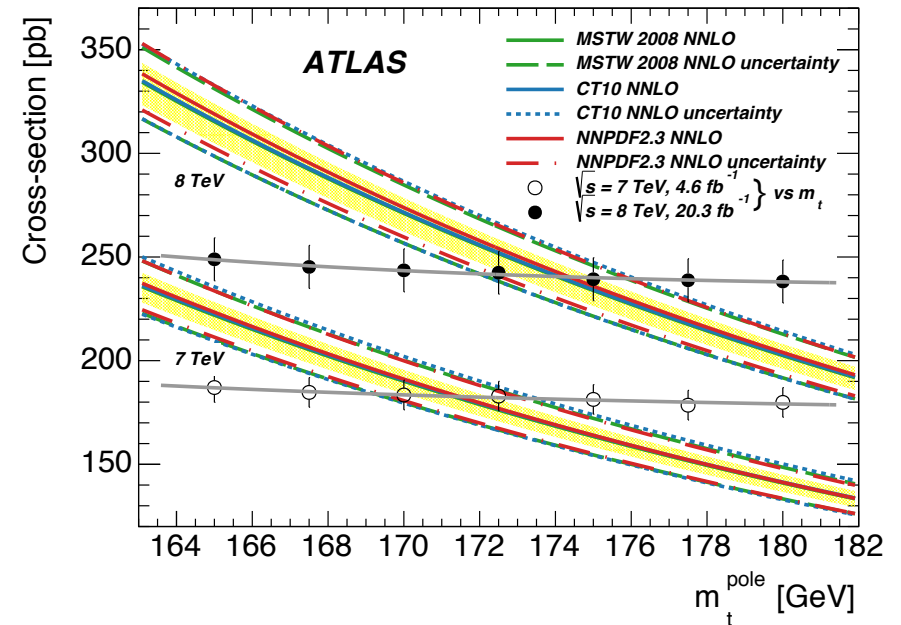
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Pole Mass Measurements: Dilepton ATLAS 7 & 8 TeV

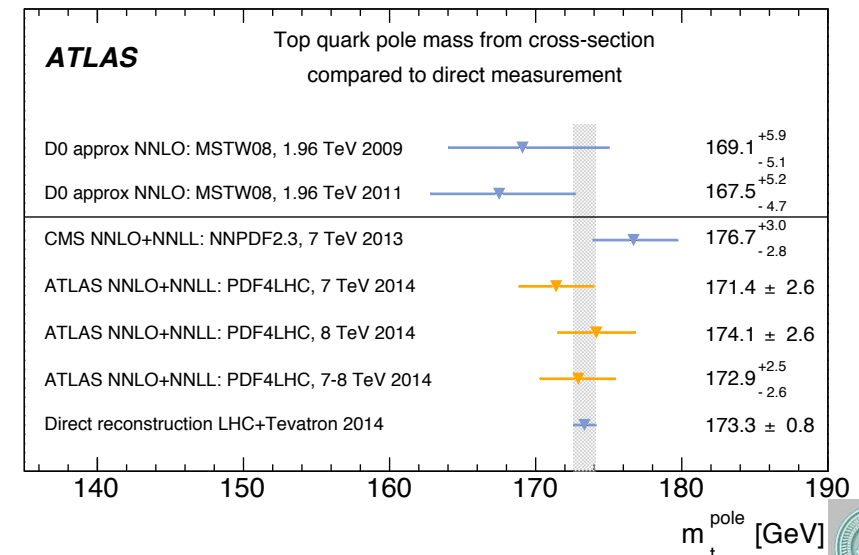
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- ▶ Extration of m_t^{pole} using a bayesian likelihood approach
- ▶ Assumed $m_t = 172.5$ GeV
- ▶ Used different PDF + α_s sets and relative uncertainties
- ▶ Results obtained using PDF4LHC show small dependency of $\sigma_{t\bar{t}}$ on the assumed value of m_t arising from variations in the acceptance and Wt background



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- ▶ $m_t^{pole} = 171.4 \pm 2.6$ GeV (7 TeV)
- ▶ $m_t^{pole} = 174.1 \pm 2.6$ GeV (8 TeV)
- ▶ From combined 7 and 8 TeV measurements, extracted $m_t^{pole} = 172.9^{+2.5}_{-2.6}$ GeV
- ▶ Results compatible with m_t extracted using different techniques



Top Mass Measurement: Dileptonic CMS 8 TeV

- ▶ Use the invariant mass of the b-quark and the lepton, m_{lb} , in dileptonic $t\bar{t}$ decays for the determination of m_t

- ▶
$$m_{lb} = \frac{m_t^2 - m_W^2}{2} (1 - \cos\theta_{lb})$$

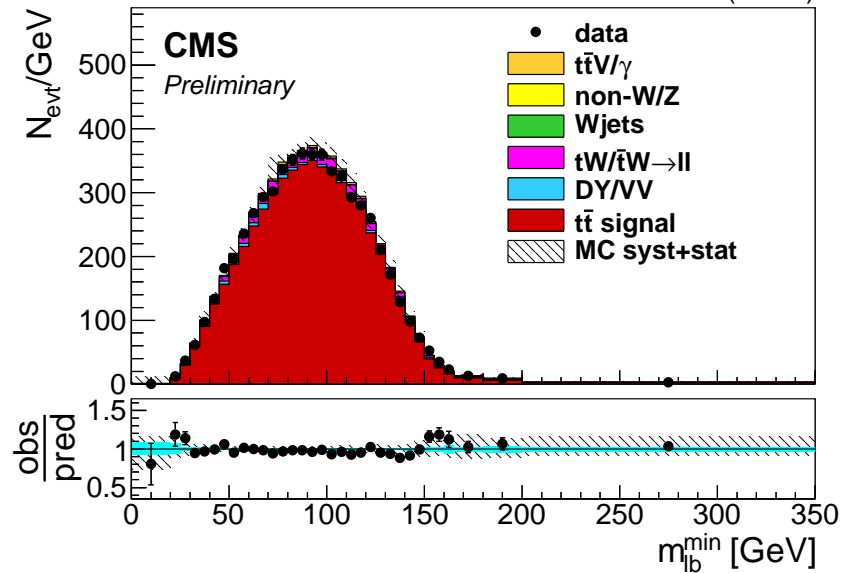
- ▶ Take permutation that minimizes m_{lb} using leptons (μ^\pm / e^\pm) and leading b-jet

- ▶ In this definition “ m_{lb}^{min} ” correct lb combination are found in 85% of the cases

- ▶ Require $p_T^\ell > 20$ GeV and $p_T^b > 30$ GeV, both in $|\eta| < 2.4$
- ▶ $m_t = 172.3 \pm 1.3$ GeV

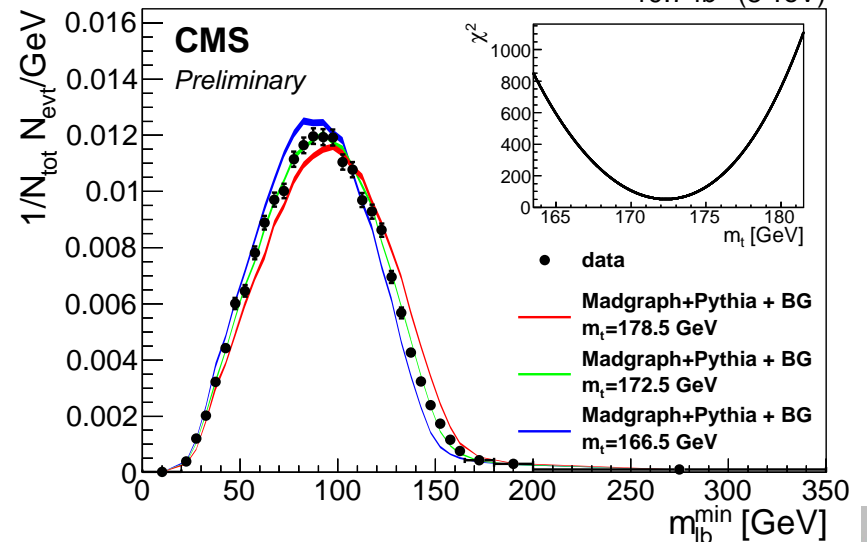
CMS-PAS-TOP-14-014

19.7 fb⁻¹ (8 TeV)



CMS-PAS-TOP-14-014

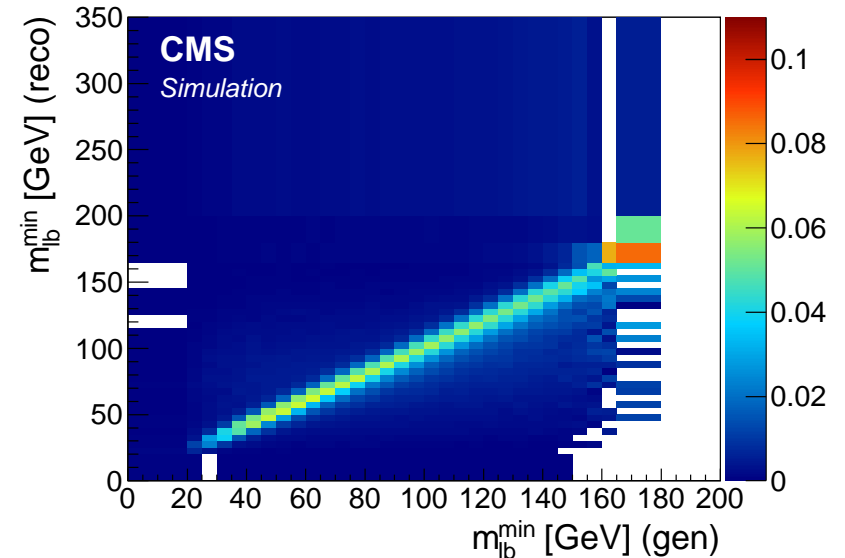
19.7 fb⁻¹ (8 TeV)



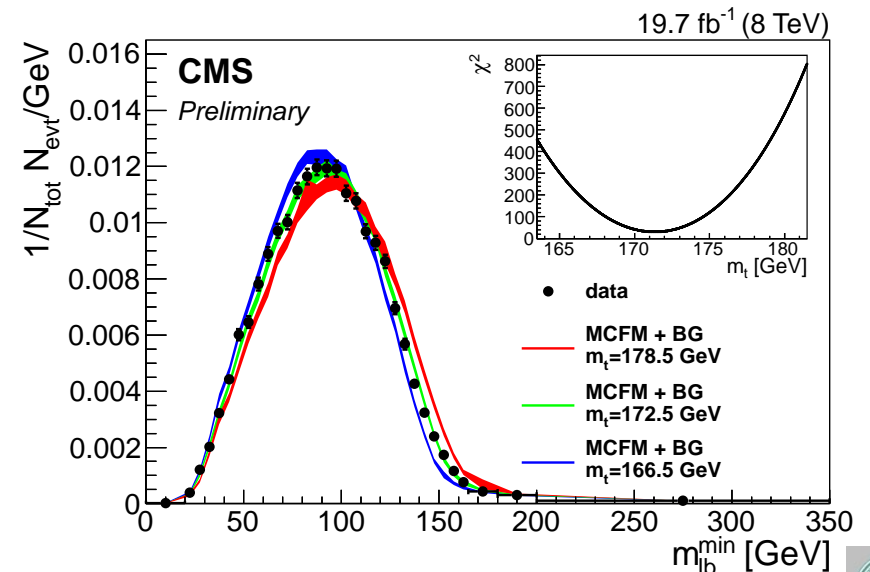
Pole Mass Measurements: Dileptonic CMS 8 TeV

- ▶ Use alternative technique such as Monte Carlo for Femtobarn processes, MCFM, to determine m_t here is equal to m_t^{pole}
- ▶ Take permutation that minimize m_{lb}
- ▶ Build detector response matrix to map generated m_{lb}^{gen} to reconstructed m_{lb}^{reco}
- ▶ MCFM doesn't implement the simulation of the final state at detector level \rightarrow folding needed
- ▶ Fold MCFM m_{lb} prediction of differential cross-section σ_{pred} with response matrix
- ▶ Fit the predicted MCFM (NLO) m_{lb} distribution for different values of m_t to the space of the data
- ▶ $m_t^{pole} = 171.4_{-1.1}^{+1.0}$ GeV (MCFM NLO prod.)
- ▶ $m_t^{pole} = 171.5_{-1.1}^{+1.1}$ GeV (MCFM LO prod.)

CMS-PAS-TOP-14-014



CMS-PAS-TOP-14-014



Pole Mass Measurements: $t\bar{t} + 1jet$ ATLAS

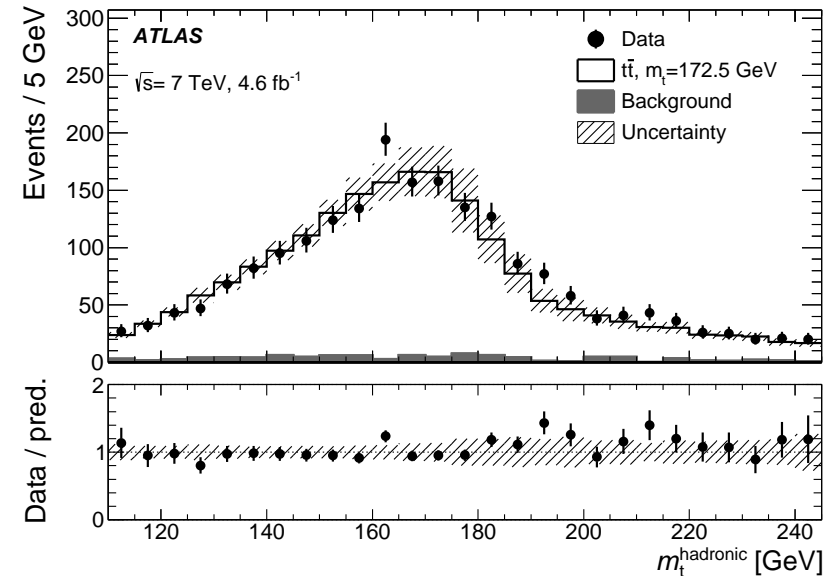
- ▶ m_t^{pole} extracted from comparing NLO prediction with the normalized differential cross-section in $t\bar{t} + 1jet$ events as function of invariant mass of the $t\bar{t} + 1jet$ system, ATLAS @ 7 TeV

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

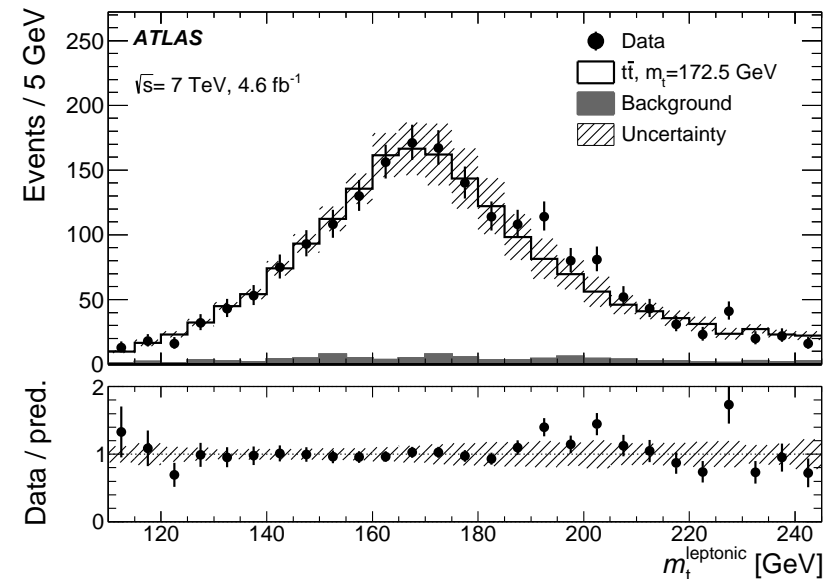
- ▶
$$\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1jet}}}, \text{ with } m_0 = 170 \text{ GeV}$$

- ▶ $\sigma_{t\bar{t}+1jet}$ enhanced in the phase-space region close to $t\bar{t} + 1jet$ prod. threshold
- ▶ Select semileptonic $t\bar{t}$ events with 2 b-tag jets
- ▶ Mass jets pair (m_{jj}) consistent with W boson: $0.9 < \alpha = m_W^{ref} / m_{jj} < 1.25$ ($m_W^{ref} = 80.4 \text{ GeV}$), and correct with α
- ▶ Further requirement $m_t^{lep} / m_t^{hadro} > 0.9$

arXiv:1507.01769v1



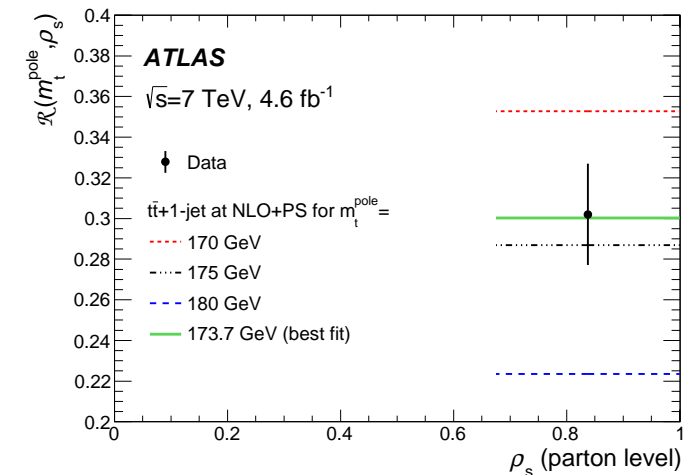
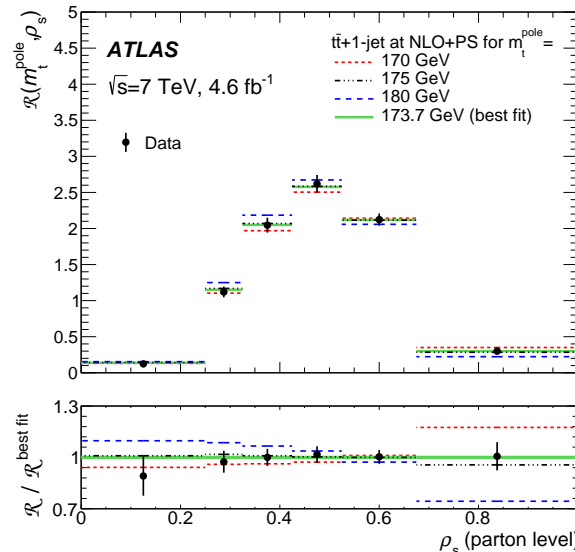
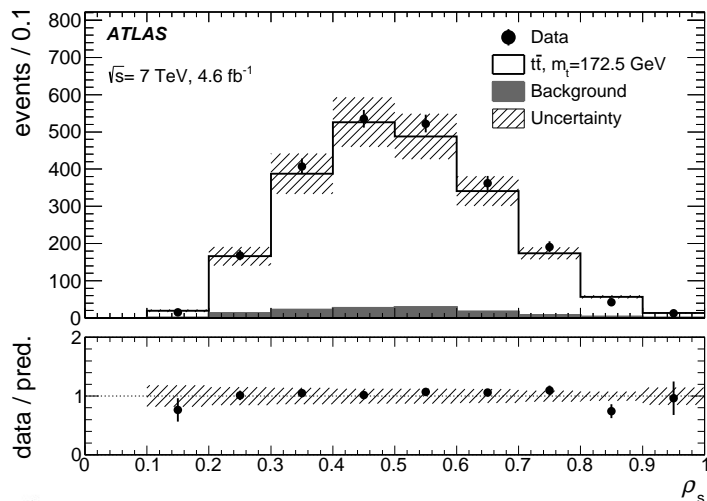
arXiv:1507.01769v1



Pole Mass Measurements: $t\bar{t} + 1jet$ ATLAS

- ▶ m_t^{pole} extracted by fitting the parameterized NLO+PS prediction to the measured distribution \mathcal{R} , after background subtraction
- ▶ m_t^{pole} obtained from χ^2 fit theory with regularized covariance matrix in unfolded $0.25 < \rho_s < 1$. Most sensitive bin $0.675 < \rho_s < 1$
- ▶ Prediction of $t\bar{t} + 1jet$ at NLO+PS using $m_t^{pole} = 170, 175, 180$ GeV is compared to the with m_t^{pole} extracted from best fit
- ▶ $m_t^{pole} = 173.7 \pm 1.5(stat.) \pm 1.4(sys.)_{-0.5}^{+1.0}(theory)$ GeV

arXiv:1507.01769v1



Conclusions

- ▶ Presented results of top quark pole mass measurements performed by the ATLAS and CMS experiments using Run1 data at LHC
- ▶ Top-quark pole mass values extracted from cross-section measurements
- ▶ Folding/Unfolding methods to pole mass sensitive distributions are improving in precisions
- ▶ So far achieved top quark pole mass measurements show no inconsistencies between the different measurement schemes
- ▶ We will continue looking at more interesting measurements to be done using Run2 data at LHC

