Measurement of the top-quark mass

in lepton+jets final states

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December, 2012

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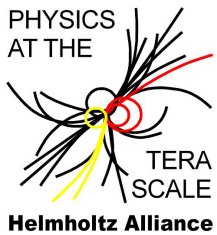
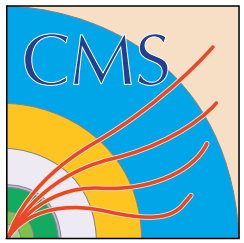
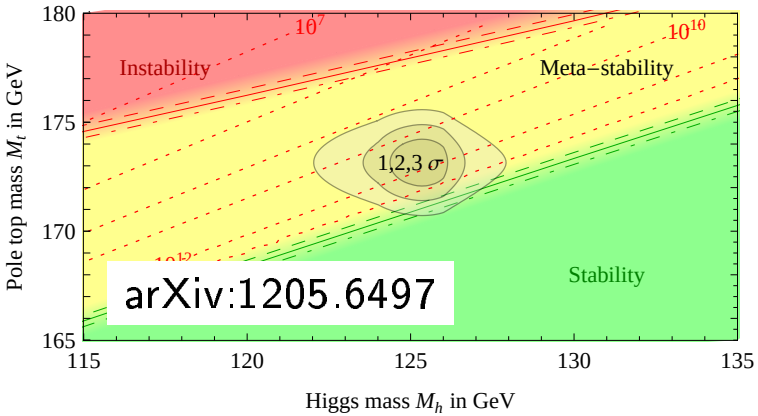


Helmholtz Alliance

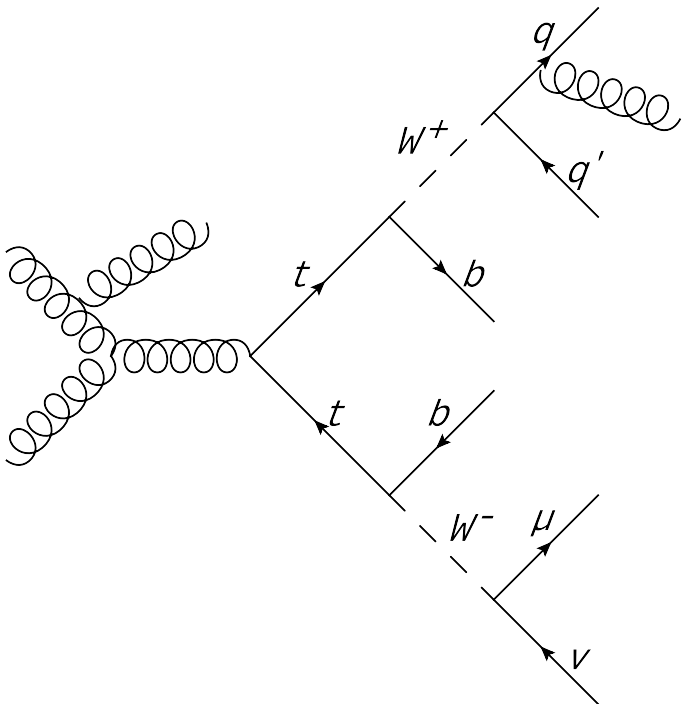


Measurement of the top-quark mass in ℓ+jets final states



Motivation

- m_t important parameter of SM
- Benchmark for detector performance (Tevatron precision: 1 GeV)



Challenges

- Combinatorial background
- More ISR/FSR at 7 TeV
- Uncertainty of jet energy scale (JES)

Analysis strategy

- Select high-purity $t\bar{t}$ sample
- Ideogram method with kinematic fit for measurement of m_t and JES

Event Selection

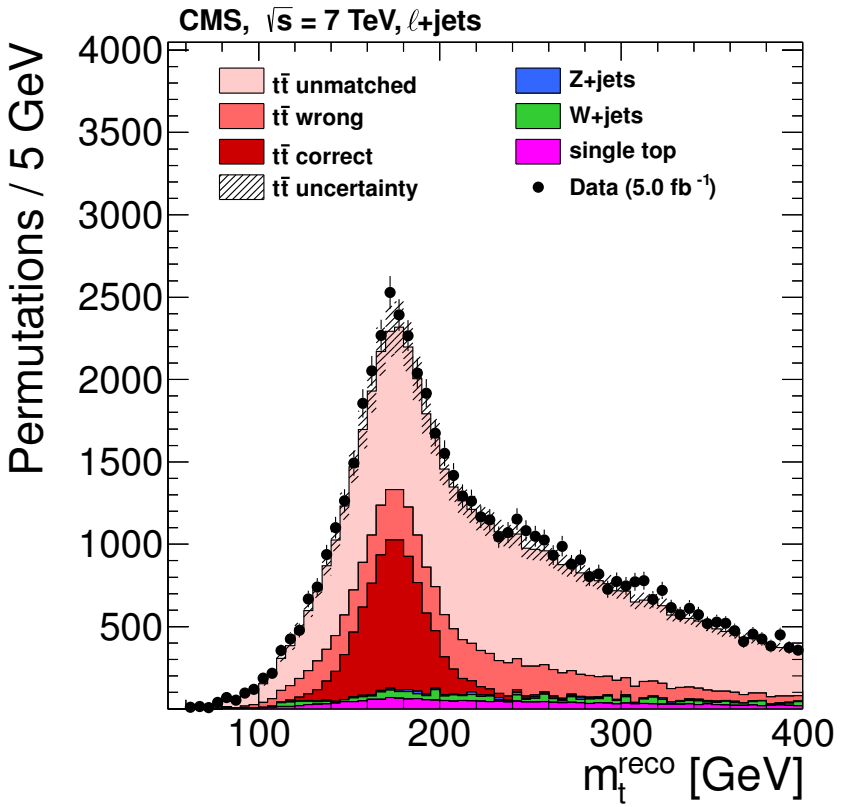
- Single isolated muon trigger or electron cross trigger
- Primary vertex selection, charged hadron subtraction
- Exactly 1 isolated muon or electron with $p_T > 30$ GeV, $|\eta| < 2.1$ (veto additional isolated e, μ)
- ≥ 4 anti-k_t jets with $p_T > 30$ GeV, $|\eta| < 2.4$, $R = 0.5$
- ≥ 2 b-tags among the 4 leading jets (*Combined Secondary Vertex Medium*)
- 17985 selected events in 5 fb^{-1} 2011 data

Event Reconstruction

- Need full event reconstruction for invariant masses
- Associate 4 leading jets to quarks from $t\bar{t}$ decay
- Take only permutations compatible with b-tag information

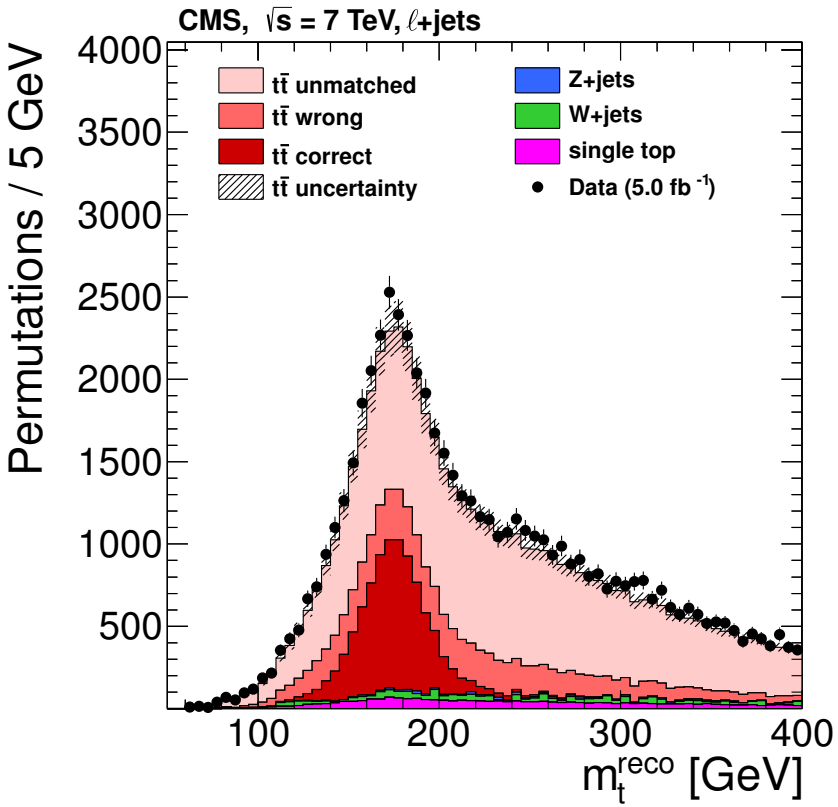
3 different types of $t\bar{t}$ permutations
found via jet-parton matching on MC

- *correct*, $f_{cp} = 13\%$
- *wrong*, $f_{wp} = 16\%$
  Flipped b-quarks, mistags
- *unmatched*, $f_{un} = 71\%$
  Matching (*unambiguousOnly*) failed due to ISR, FSR and selection



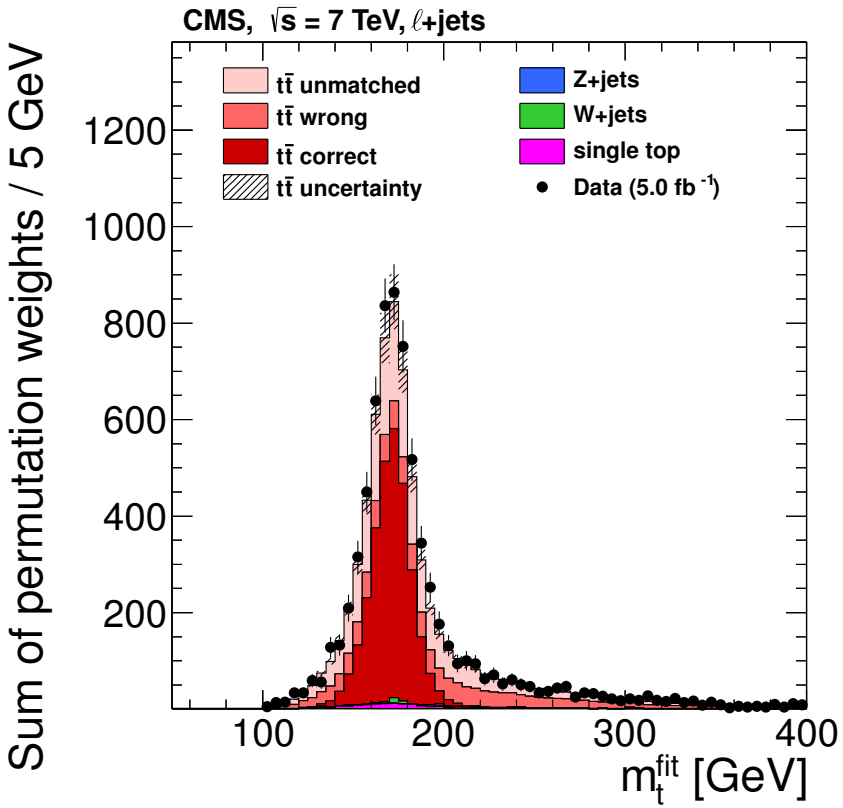
Kinematic Fit & Final Selection: Top-Mass Distribution

- Improve with constrained kinematic fit ($m_W = 80.4$ GeV, $m_t = m_{\bar{t}}$)
- Weight each permutation by $P_{\text{fit}} = \exp\left(-\frac{1}{2}\chi^2\right)$, cut $P_{\text{fit}} > 0.2$



Fit

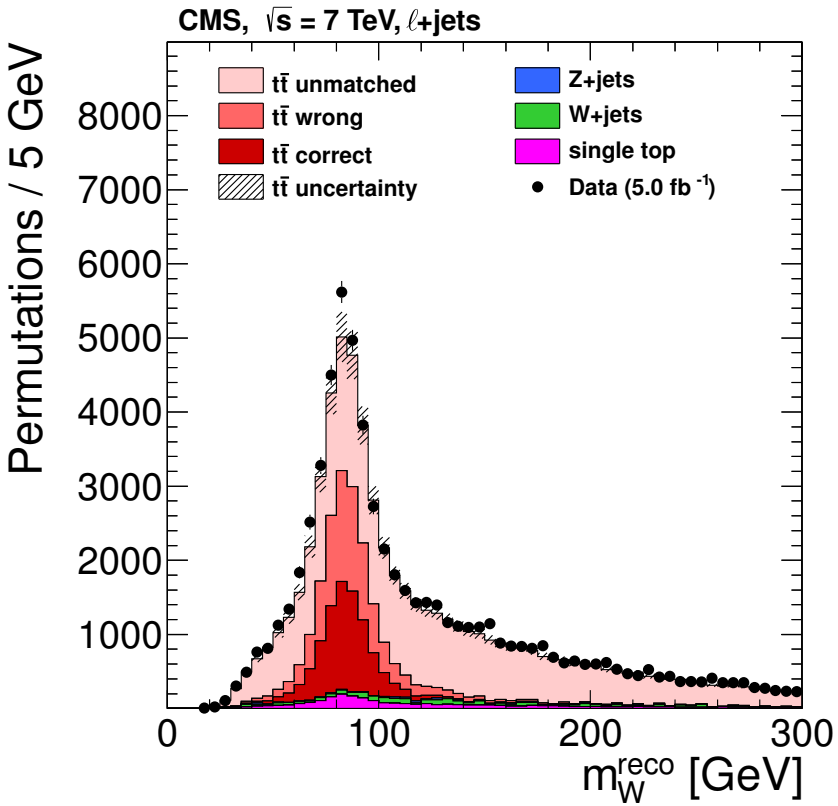
Cut



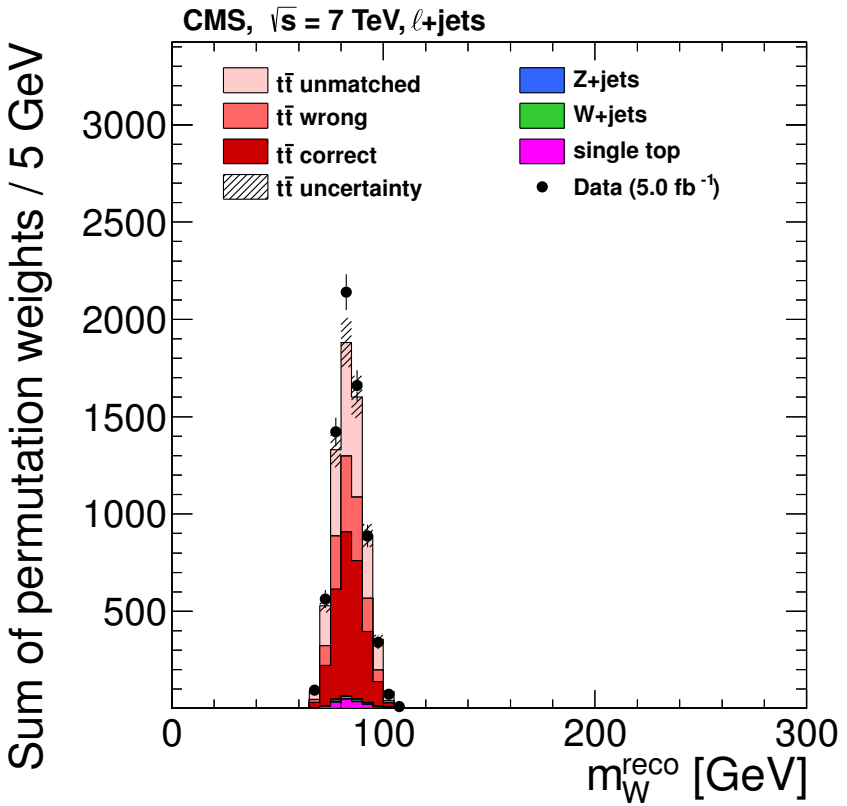
- Fraction of correct $t\bar{t}$ permutations enhanced: $f_{cp} = 13\% \rightarrow 44\%$

Kinematic Fit & Final Selection: W-Mass Distribution

- Weight each permutation by $P_{\text{fit}} = \exp\left(-\frac{1}{2}\chi^2\right)$, cut $P_{\text{fit}} > 0.2$



Cut

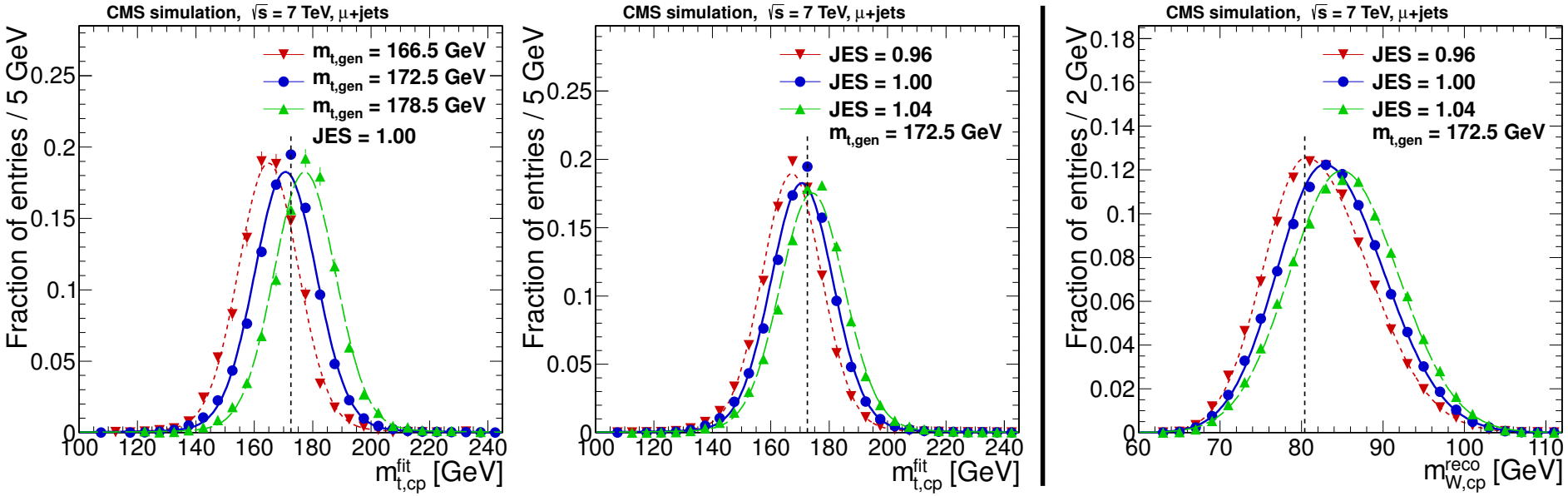


- Treatment of non-$t\bar{t}$ background (4%) $\rightarrow$ systematics
- 5192 selected events in 5 fb^{-1} 2011 data

Ideogram Method: Probability Densities

- Simulated m_t^{fit}, m_W^{reco} distributions, 9×3 m_t-JES points

Example: *correct permutations*



- Fit with analytical expressions
- Parametrize linearly in m_t, JES, $m_t \times$ JES
  $\rightarrow P_{cp}\left(m_t^{\mathrm{fit}} | m_t, \mathrm{JES}\right), P_{cp}\left(m_W^{\mathrm{reco}} | m_t, \mathrm{JES}\right)$

Ideogram Method: Overview

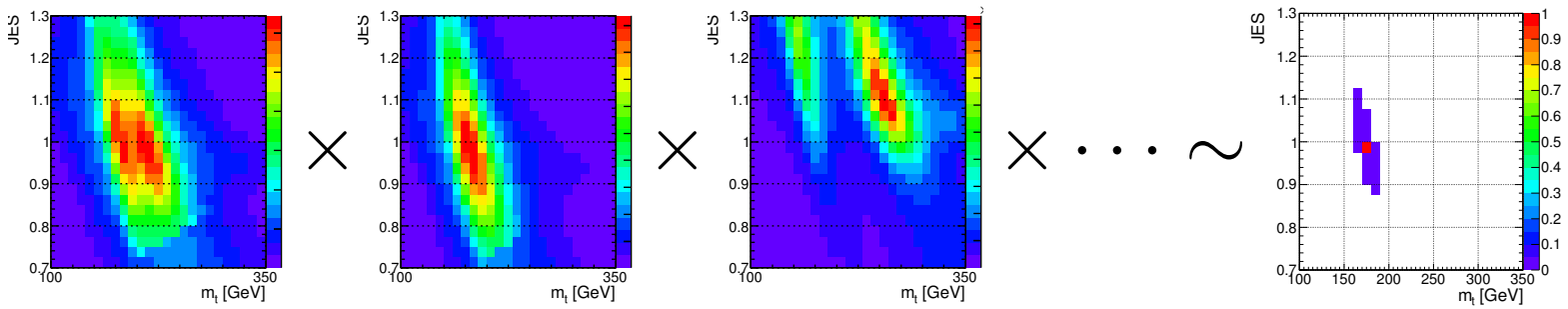
- Calculate likelihood for event with n permutations ("ideogram"), j representing *correct*, *wrong* and *unmatched* permutation case

$$\mathcal{L}\left(\text{event}|m_t, \text{JES}\right) = \sum_{i=0}^{n} P_{gof}\left(i\right) P\left(m_{t,i}^{fit}, m_{W,i}^{reco}|m_t, \text{JES}\right),$$

$$P\left(m_{t,i}^{fit}, m_{W,i}^{reco}|m_t, \text{JES}\right) = \sum_{j} f_j P_j\left(m_{t,i}^{fit}|m_t, \text{JES}\right) \cdot P_j\left(m_{W,i}^{reco}|m_t, \text{JES}\right)$$

- Most likely m_t and JES given data sample (Maximum Likelihood)

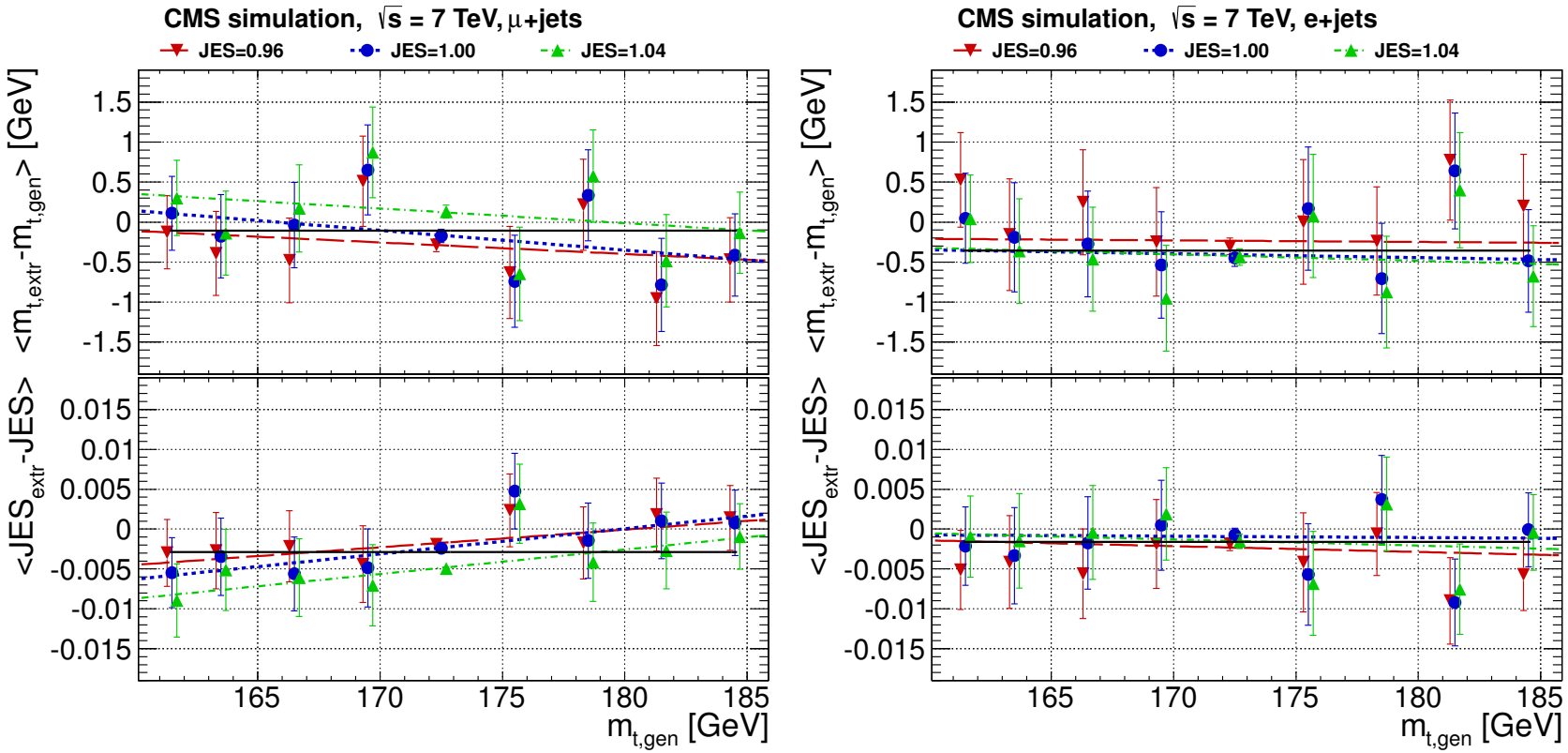
$$\mathcal{L}\left(m_t, \text{JES}|\text{sample}\right) \sim \prod_{\text{events}} \mathcal{L}\left(\text{event}|m_t, \text{JES}\right)^{w_{\text{event}}}$$



Validation and Calibration: Biases

- 10000 pseudo-experiments for every generated m_t-JES combination
- Each pseudo-experiment corresponds to 5.0 fb^{-1}

Difference of extracted and generated values



- Extraction of m_t works out-of-the-box, for arbitrary JES
- Check statistical uncertainty with pull distributions, correct $\mathcal{L}$

Systematic Uncertainties

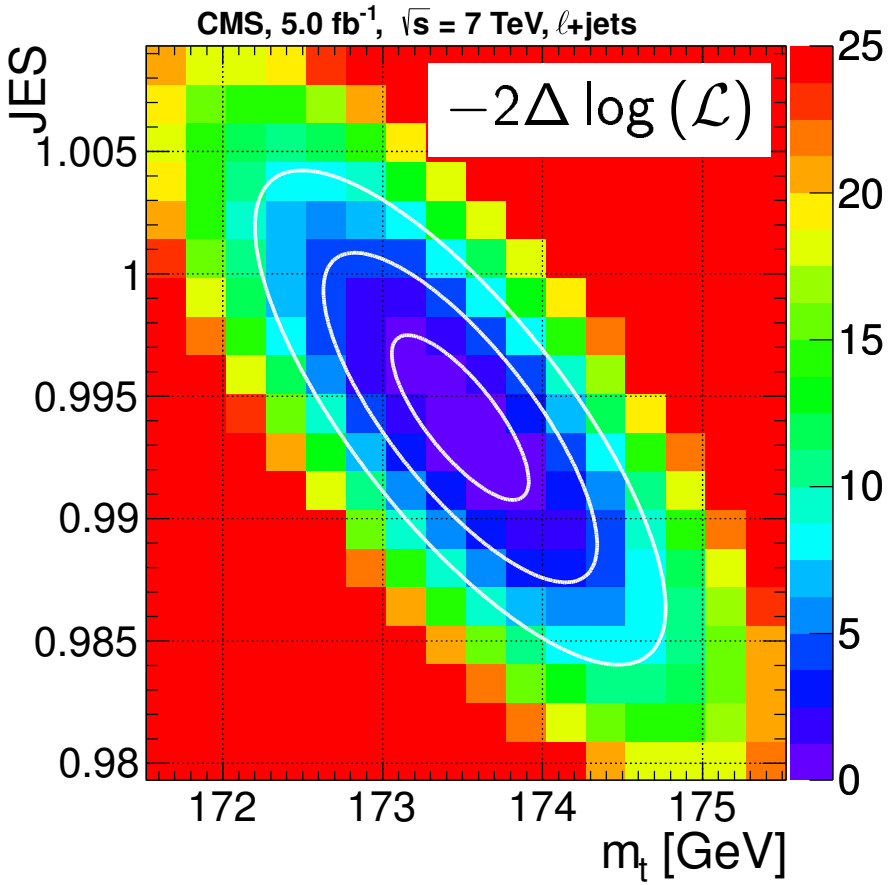
Source	Description	$\delta^{\ell}_{m_t}$	$\delta^{\ell}_{\mathrm{JES}}$
Fit calibration	Propagate statistical uncertainty	0.06	0.001
b-JES	Scale b-jet energies $\pm\sigma_{\mathrm{flavor}}$	0.61	0.000
p_T- and η-dependent JES	Scale all jet energies $\pm\sigma$	0.28	0.001
Lepton energy scale	Scale all lepton energies $\pm\sigma$	0.02	0.000
Missing transverse momentum	Scale unclustered energy $\pm 10\%$	0.06	0.000
Jet energy resolution	Scale jet energy resolution $\pm\sigma$	0.23	0.004
b-tagging	Shift b-tag working point	0.12	0.001
Pileup	Number of pile-up events $\pm 5\%$	0.07	0.001
Non-$t\bar{t}$ background	Add 8% background events	0.13	0.001
PDF	Uncertainty on CTEQ 6.6 PDF	0.07	0.001
μ_R, μ_F	Vary by factors of 0.5 and 2	0.24	0.004
ME-PS matching threshold	Vary by factors of 0.5 and 2	0.18	0.001
Underlying event	Pythia P11, P11mpiHi, P11TeV	0.15	0.002
Color reconnection effects	Pythia P11 and P11noCR	0.54	0.004
Total		**0.98**	**0.008**

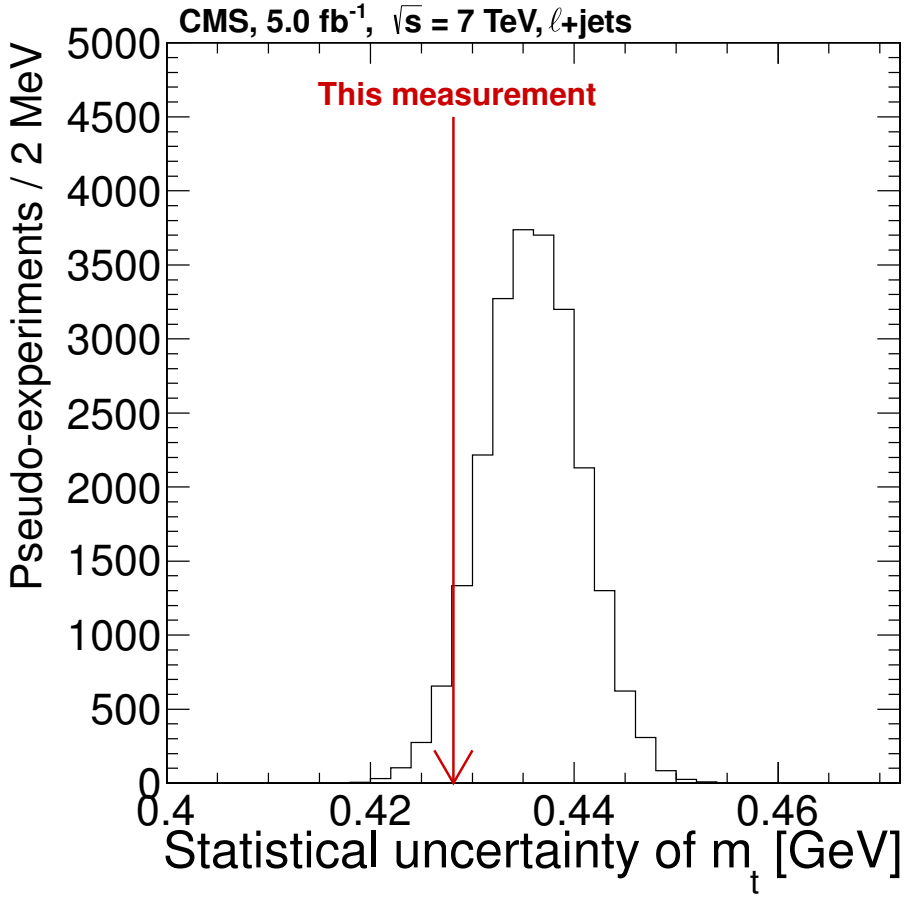
- b-JES and CR lead to different shifts in m_t^{fit} and m_W^{reco}

Result on Data

Result with 5174 selected events in ℓ+jets channel:

$$m_t = 173.49 \pm 0.43\ (\text{stat+JES}) \pm 0.98\ (\text{syst})\ \text{GeV}$$
$$\text{JES} = 0.994 \pm 0.003\ (\text{stat}) \pm 0.008\ (\text{syst})$$





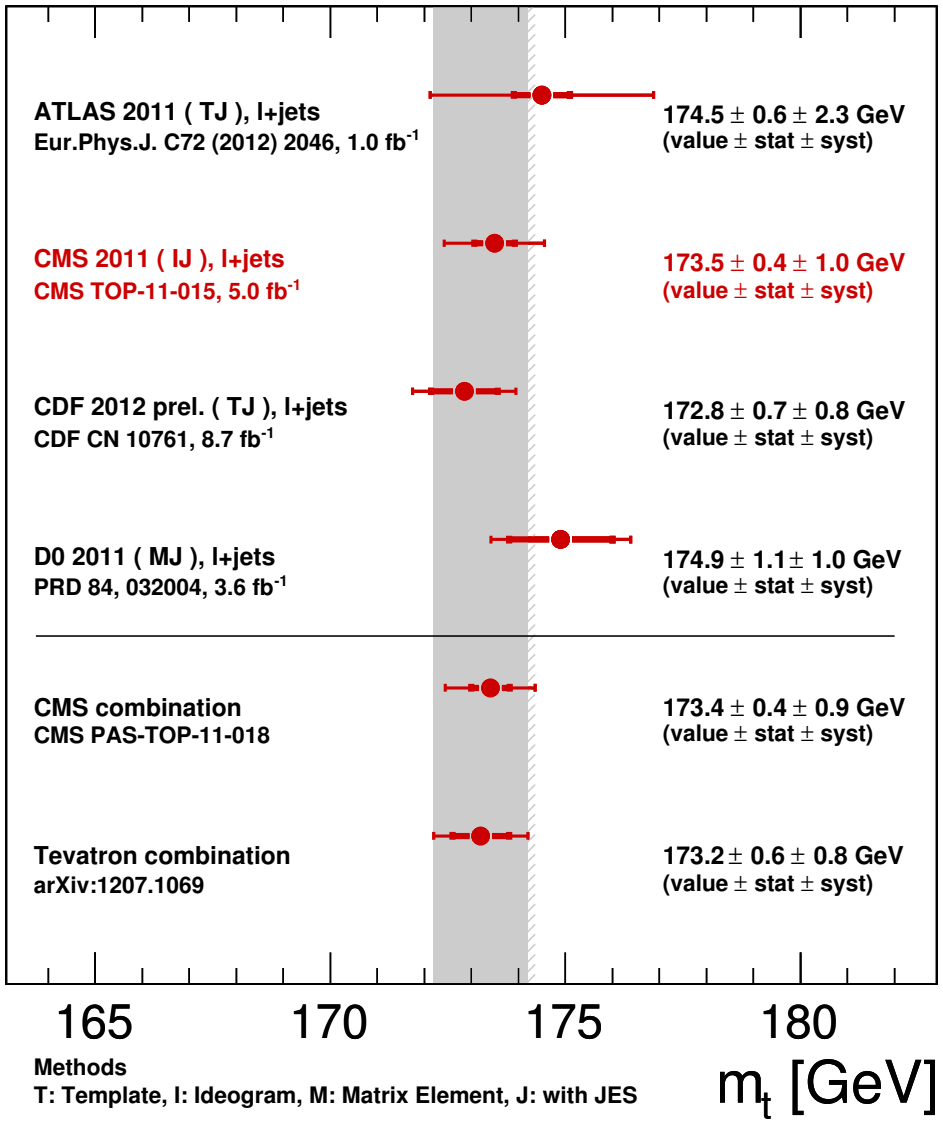
Summary & Outlook

Summary

- Simultaneous measurement of top-quark mass and JES
- Result using 5 fb^{-1} data: $m_t = 173.49 \pm 1.07$ GeV
- Public result accepted by JHEP, CMS-TOP-11-015, arXiv:1209.2319

Outlook

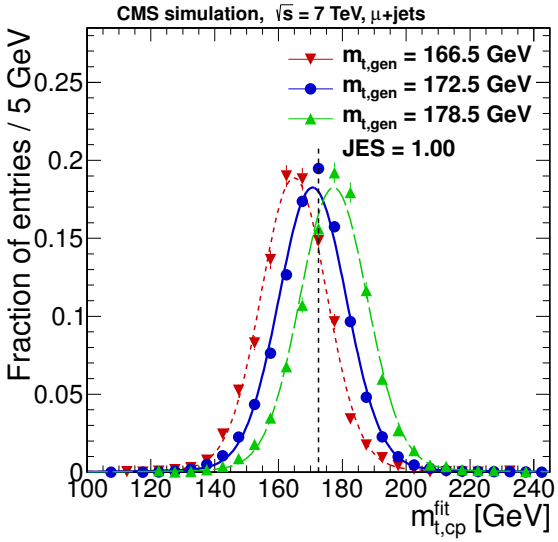
- Differential measurement to constrain modeling
- Improved jet energy measurement using color flow observables

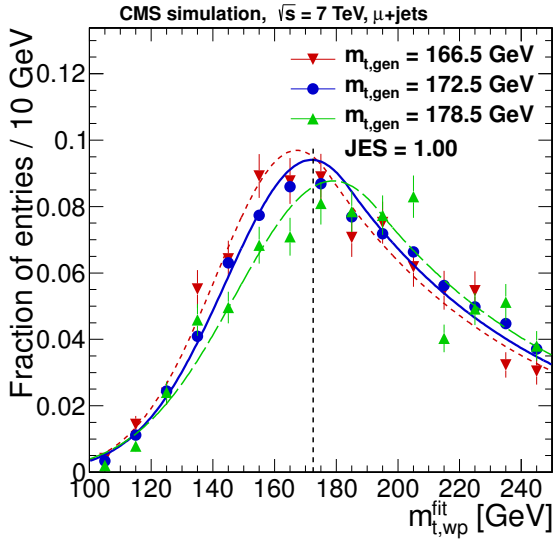


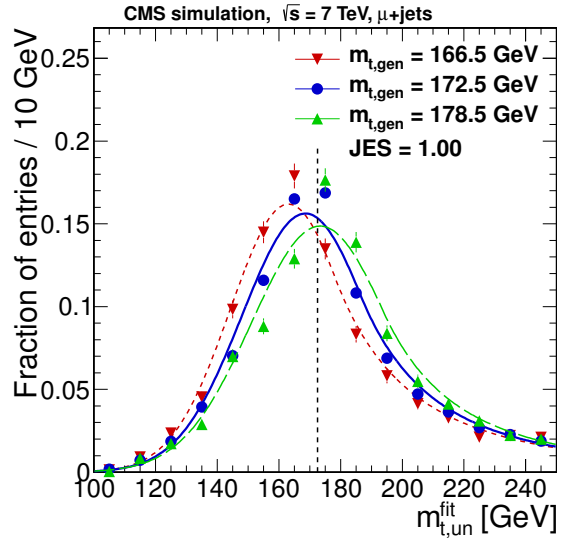
Backup

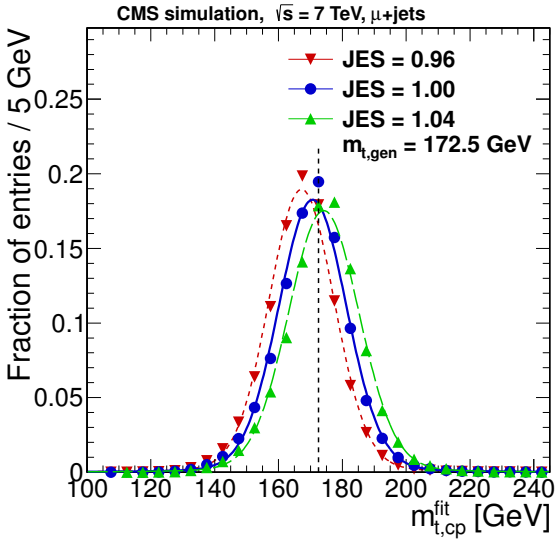
The Ideogram Method: m_t^{fit} Distributions

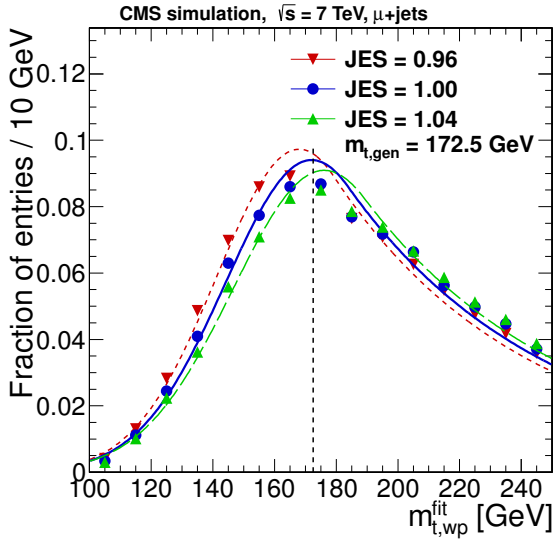
correct (BW⊗G) wrong (CB) unmatched (CB)

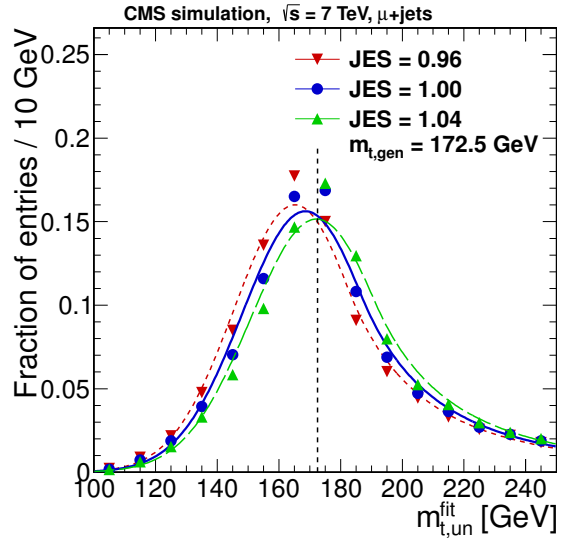






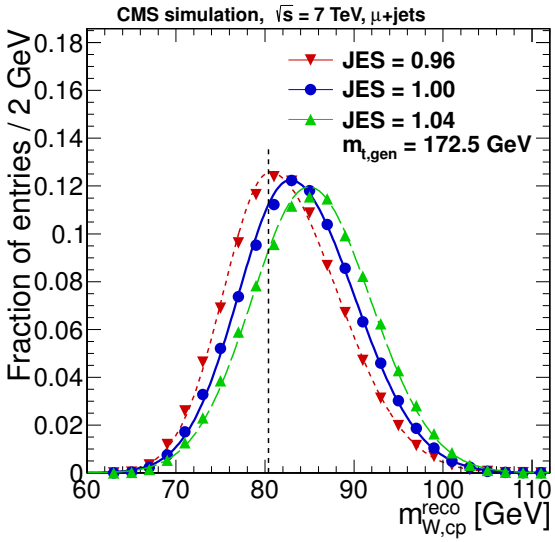


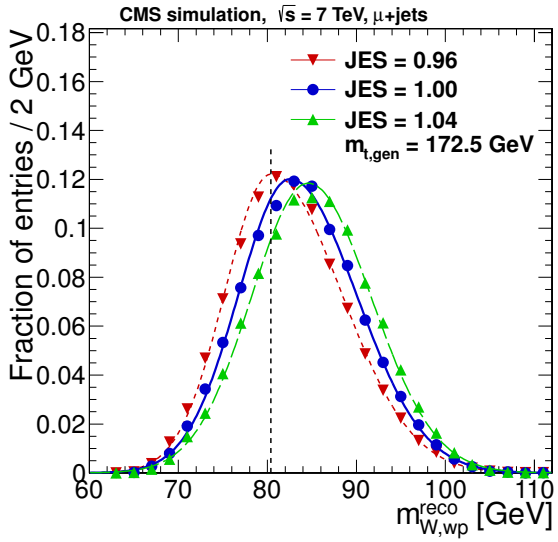


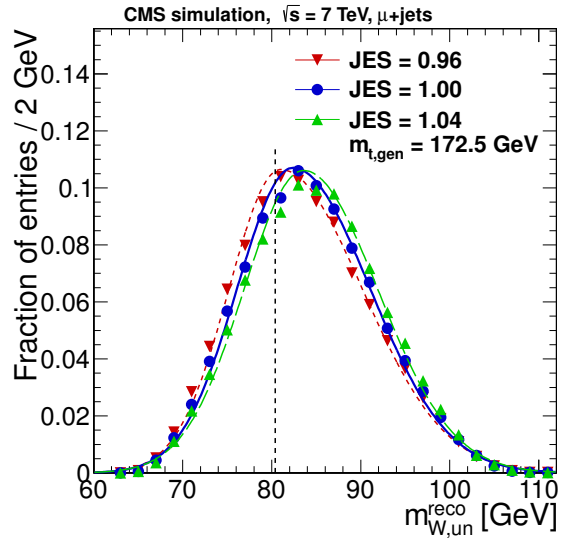


The Ideogram Method: m_W^{reco} Distributions

correct (AG) | wrong (AG) | unmatched (AG)

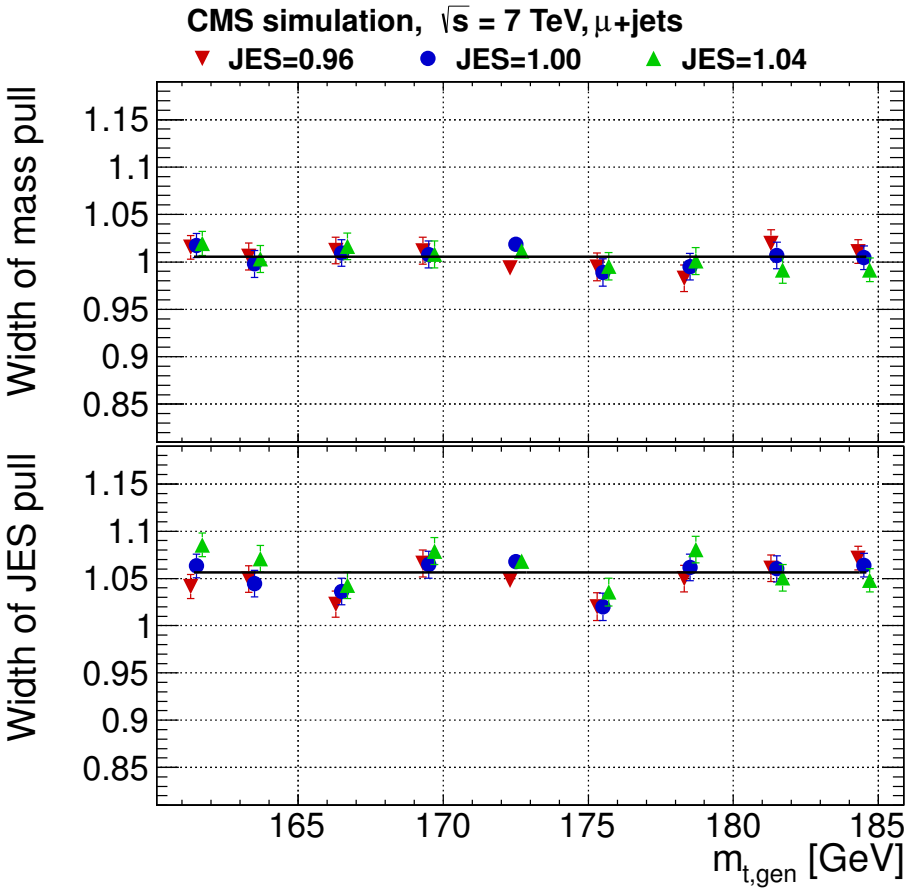


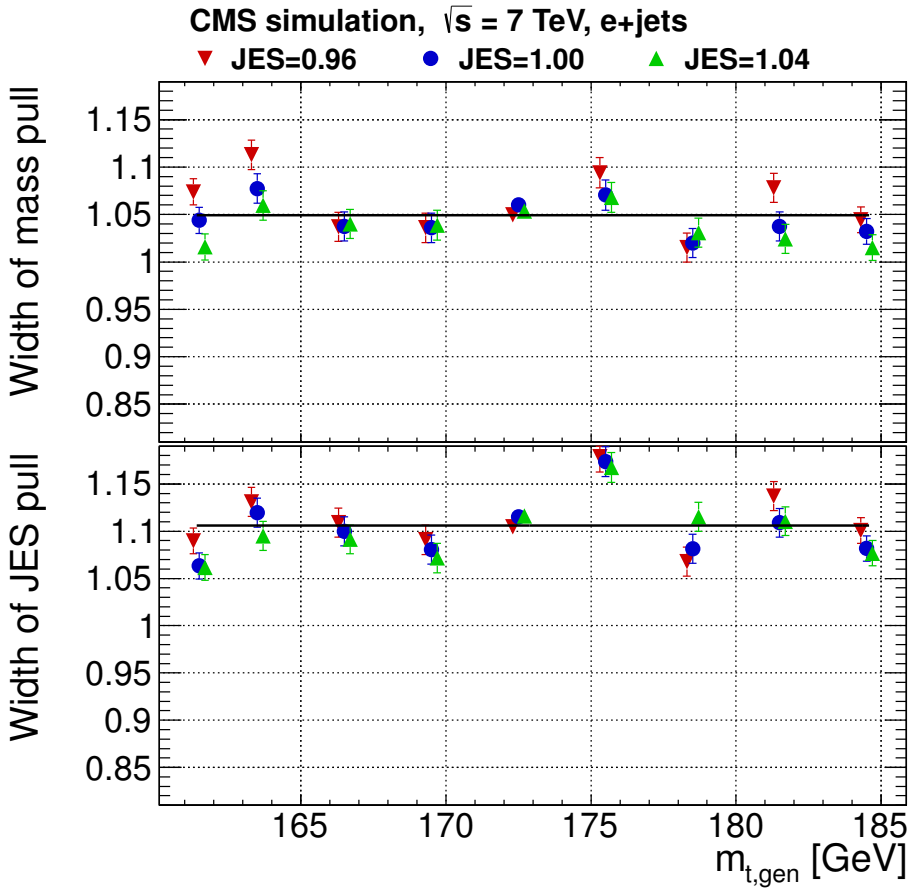




Validation & Calibration: Statistical Uncertainty

- Investigate pull distributions of calibrated pseudo-experiments, $\text{pull} = (\text{meas} - \text{gen}) / \sigma(\text{meas})$





- Pull width above unity, correct $\mathcal{L}$ accordingly

Results in Single Channels

Lepton+jets (5192 events)

$$\begin{aligned} m_t &= 173.49 \pm 0.43\ (\text{stat+JES}) \pm 0.98\ (\text{syst})\ \text{GeV} \\ \text{JES} &= 0.994 \pm 0.003\ (\text{stat}) \pm 0.008\ (\text{syst}) \end{aligned}$$

Muon+jets (2906 events)

$$\begin{aligned} m_t &= 173.22 \pm 0.56\ (\text{stat+JES}) \pm 1.06\ (\text{syst})\ \text{GeV} \\ \text{JES} &= 0.999 \pm 0.005\ (\text{stat}) \pm 0.008\ (\text{syst}) \end{aligned}$$

Electron+jets (2268 events)

$$\begin{aligned} m_t &= 173.72 \pm 0.66\ (\text{stat+JES}) \pm 1.00\ (\text{syst})\ \text{GeV} \\ \text{JES} &= 0.989 \pm 0.005\ (\text{stat}) \pm 0.007\ (\text{syst}) \end{aligned}$$