Top Quark Mass in μ+Jets

LHC Physics Discussions

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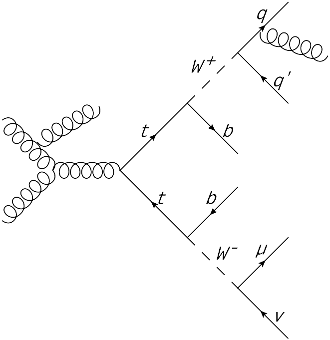
Measuring the Top Quark Mass in the μ+Jets Channel



Motivation

- m_t important parameter of SM
- Benchmark for detector (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

Collision Data & Simulation

Collision Data

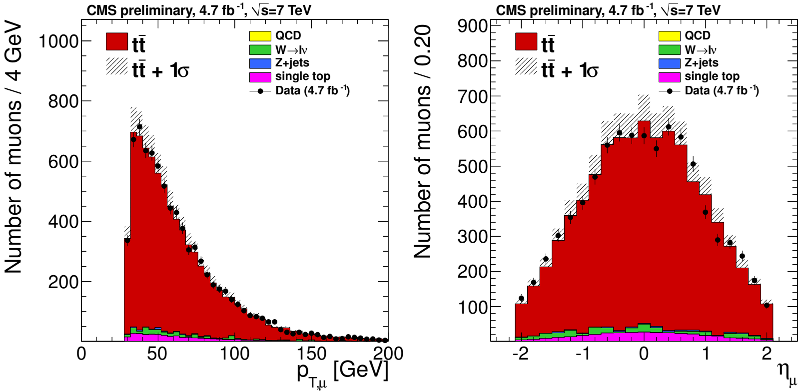
- 4.7 fb^{-1} pp collisions at $\sqrt{s} = 7$ TeV

Simulation

- $t\bar{t}$ signal sample (Madgraph + Pythia)
  - 9 different top masses: 161.5 GeV$, ..., 172.5$ GeV$, ..., 184.5$ GeV
  - 3 different JES: $0.96, 1.00, 1.04$
- Background samples
  - QCD, W+jets, Z+jets (Madgraph + Pythia)
  - Single top, s-, t-, tW-channel (Powheg)

Event Selection

- Single isolated muon trigger ($p_T > 17/24$ GeV)
- Exactly 1 isolated muon with $p_T > 30$ GeV, $|\eta| < 2.1$
- ≥ 4 AK5PF jets with $p_T > 30$ GeV, $|\eta| < 2.4$
- ≥ 2 leading jets with b-tag



- Estimated composition: 92% $t\bar{t}$, 3% W+jets, 4% single top, 1% other

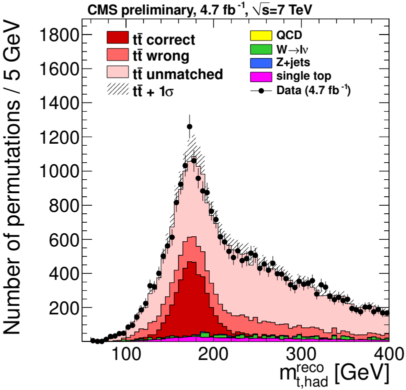
Event Reconstruction

- 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 permutations

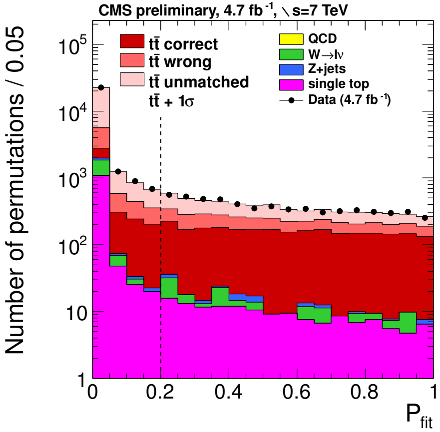
found via jet-parton matching on MC

- *correct*, $f_{cp} = 15\%$
- *wrong*, $f_{wp} = 19\%$
  Flipped b-quarks, mistags
- *unmatched*, $f_{un} = 66\%$
  Matching (*unambiguousOnly*) failed due to ISR, FSR and selection



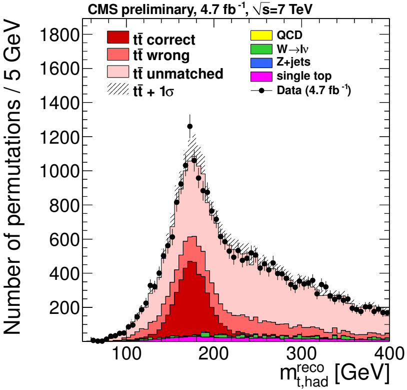
Kinematic Fit & Final Selection

- Enhance f_{cp} with kinematic fit
- Minimize
  $\chi^2 = (\mathbf{x}^{fit} - \mathbf{x}^{reco})^T G (\mathbf{x}^{fit} - \mathbf{x}^{reco})$
- Constraints:
  $m_W = 80.4$ GeV, $m_t = m_{\bar{t}}$
- Weight each permutation by
  $P_{\text{fit}} = \exp\left(-\frac{1}{2}\chi^2\right)$
- Cut $P_{\text{fit}} > 0.2$



- Fraction of correct $t\bar{t}$ permutations enhanced: $f_{cp} = 15\% \rightarrow 44\%$
- Non-$t\bar{t}$ background $\rightarrow$ systematics

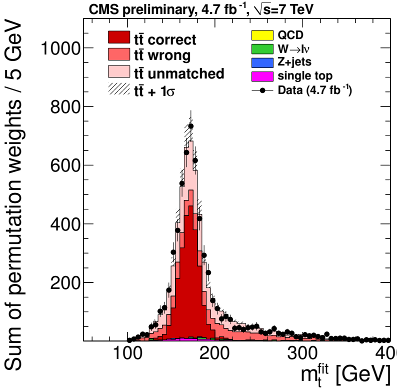
Top Quark Mass Distribution



Fit

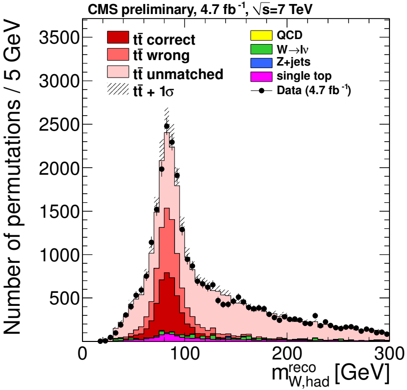
$\Longrightarrow$

Cut

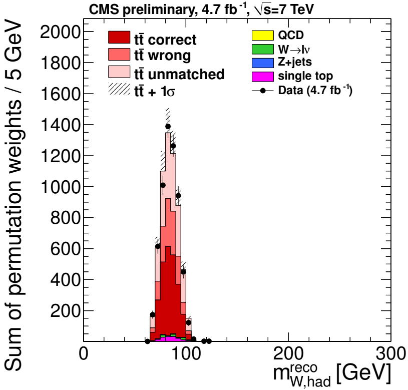


- Kinematic fit improves top mass resolution
- High-mass tail suppressed by $P_{\text{fit}} > 0.2$

W Boson Mass Distribution



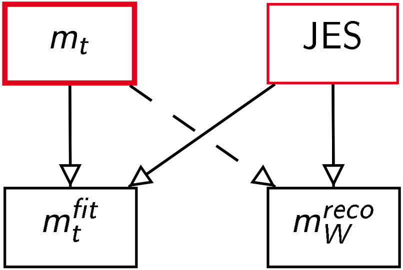
⇒ Cut



- Cut keeps only solutions where m_W^{reco} around 80 GeV

The Ideogram Method: Observables

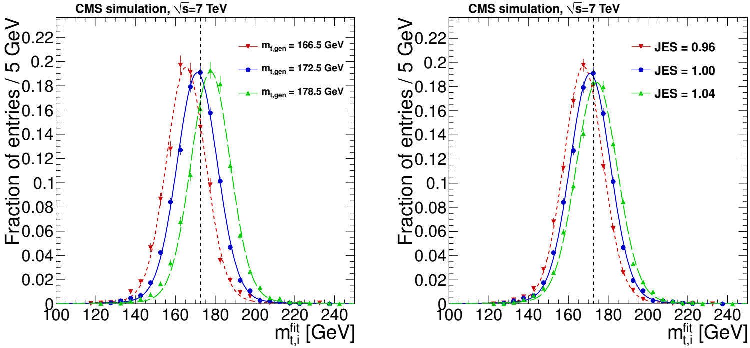
- Construct event-by-event likelihood for measuring m_t and JES



- Need probability densities of observables given m_t and JES
- Correct permutations more sensitive than wrong/unmatched ones
  $\Rightarrow$ 2D parametrization for each permutation case separately

The Ideogram Method: Probability Densities

- Fit m_t^{fit} distribution of *correct permutations (cp)* with Voigtian (BW $\otimes$ G) for 9×3 m_t-JES points



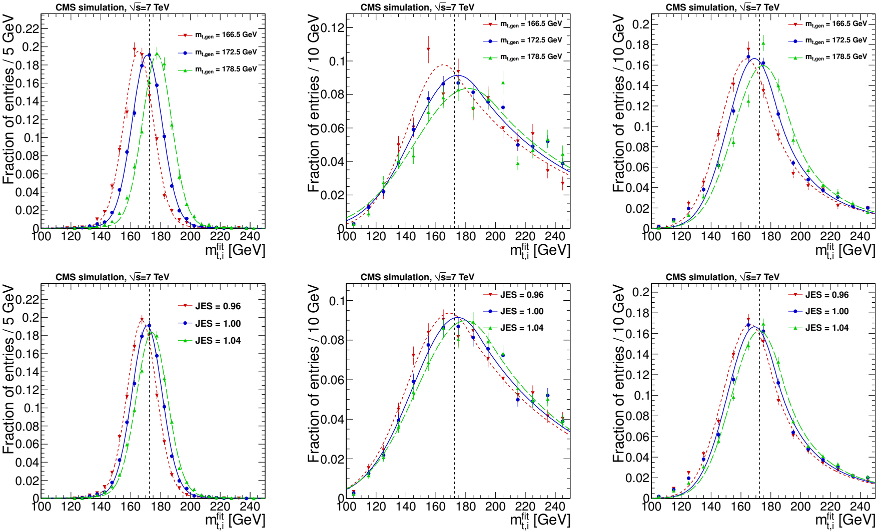
- Parametrize fitted distributions

$$\mu\left(m_t, \text{JES}\right) = q_1 + q_2 \times \text{JES} + q_3 \times m_t + q_4 \times m_t \times \text{JES}$$
$$\sigma_{res}\left(m_t, \text{JES}\right) = q_5 + q_6 \times \text{JES} + q_7 \times m_t + q_8 \times m_t \times \text{JES}$$

- $P_{cp}\left(m_t^{fit} | m_t, \text{JES}\right) = \text{V}\left(m_t^{fit}; \mu\left(m_t, \text{JES}\right), \sigma\left(m_t, \text{JES}\right), \Gamma_t = 2\text{ GeV}\right)$

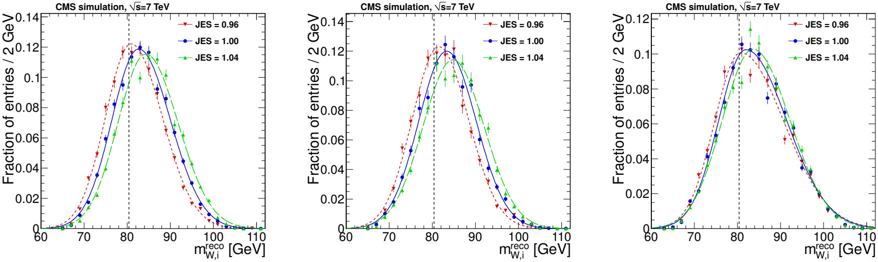
The Ideogram Method: m_t^{fit} Distributions

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



The Ideogram Method: m_W^{reco} Distributions

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



The Ideogram Method: Overview

- Probability for single permutation

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

$j \in \{cp, wp, un\}$, f_j, P_j from simulation

- Likelihood for event with n permutations

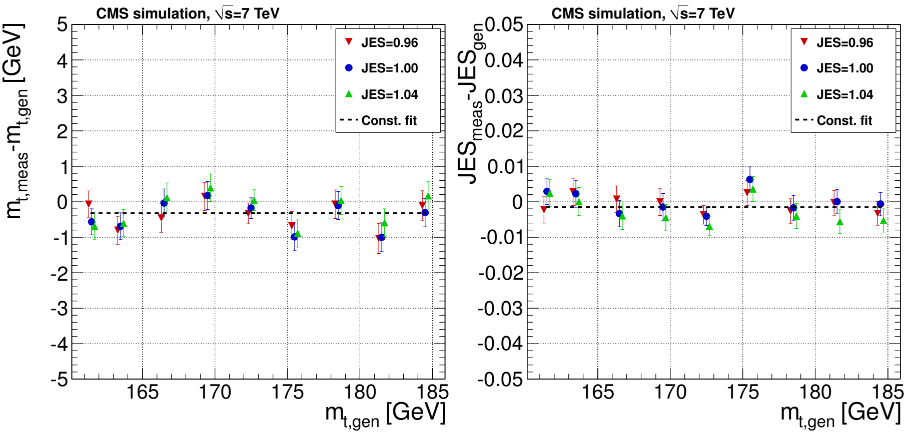
$$\mathcal{L}\left(\mathrm{event} | m_t, \mathrm{JES}\right) = \sum_{i=0}^{n} P_{fit}\left(i\right) P\left(m_{t,i}^{fit}, m_{W,i}^{reco} | m_t, \mathrm{JES}\right),$$

- Every event is assigned a weight $w_{event} = \sum_i P_{fit}\left(i\right)$, sum of event weights normalized to number of events
- Most likely m_t and JES given data sample (Maximum Likelihood)

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

Validation and Calibration: Biases

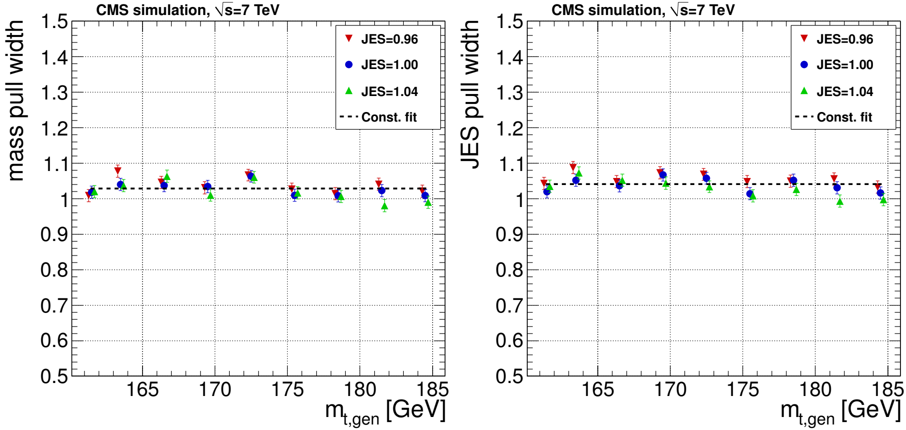
- 10000 pseudo-experiments for every generated m_t-JES combination
- Each pseudo-experiment corresponds to 4.7 fb^{-1}



- Good performance out of the box, small mass and JES bias
- Apply offset correction to $\mathcal{L}$

Validation & Calibration: Statistical Uncertainty

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



- Pull width above unity $\Rightarrow$ uncertainty slightly underestimated
- Correct $\mathcal{L}$ accordingly

Systematic Uncertainties

	δ_{m_t} (GeV)	δ_{JES}
Calibration	0.15	0.001
b-tagging	0.17	0.002
b-JES[1]	0.66	0.000
JES p_T/η	0.23	0.003
Jet energy resolution	0.21	0.003
Missing transverse energy	0.08	0.001
Q^2 scale	0.76	0.007
ME-PS matching threshold	0.25	0.007
Non-$t\bar{t}$ background	0.09	0.001
Pile up	0.38	0.005
PDF	0.05	0.001
Total[2]	1.18	0.012

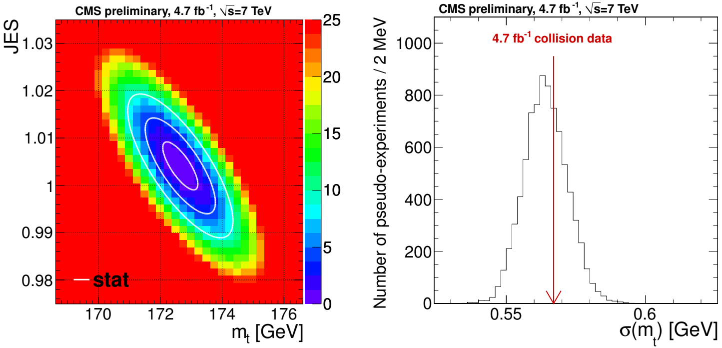
[1] Compare to JES uncertainty without simultaneous measurement: 1.2 GeV

[2] Without non-perturbative QCD uncertainties

Result on Data

Result with 2391 selected events in μ+jets channel, 4.7 fb^{-1}

$$m_t = 172.64 \pm 0.57\ (\text{stat+JES}) \pm 1.18\ (\text{syst})\ \text{GeV}$$
$$\text{JES} = 1.004 \pm 0.005\ (\text{stat}) \pm 0.012\ (\text{syst})$$



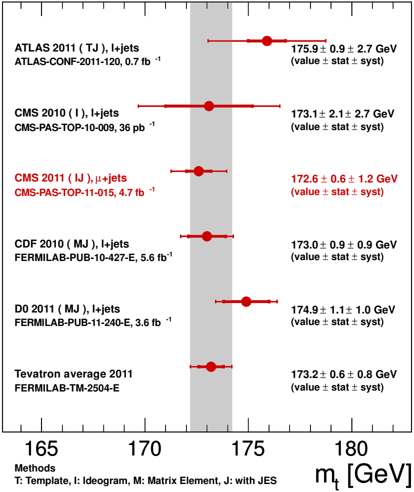
- Additional JES measurement consistent with JES from γ/Z+jets

Summary

- Simultaneous measurement of top quark mass and JES
  $\Rightarrow$ Reduced systematic JES uncertainties
- Result with 4.7 fb^{-1} data[3]:

$$m_t = 172.6 \pm 1.3 \text{ GeV},$$
$$\text{JES} = 1.004 \pm 0.013$$

- Documentation:
  CMS PAS-TOP-11-015



[3] Without non-perturbative QCD uncertainties

Backup

Systematic Uncertainties: b-JES