Top Mass & JES Measurement

in the μ+Jets Channel at CMS using the Ideogram Method

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PHYSICS AT THE TERA SCALE
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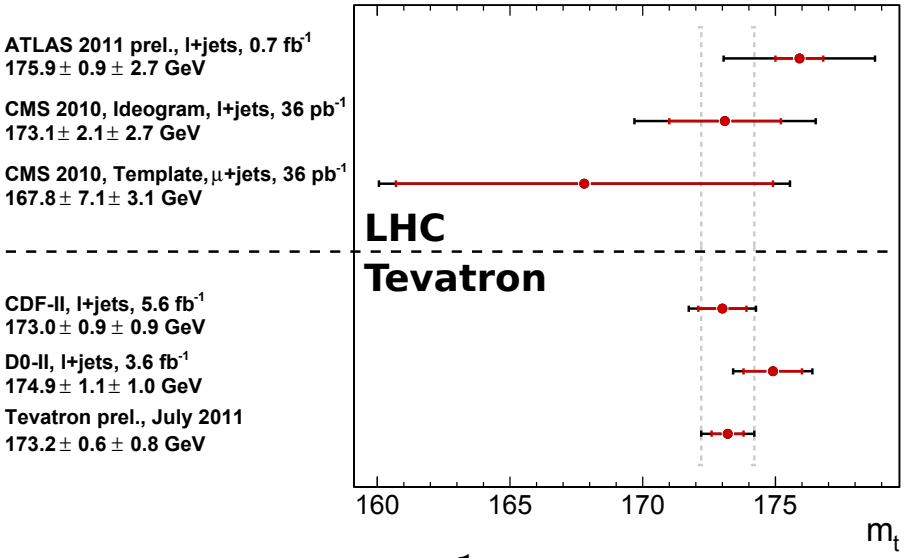
CMS

Measuring the Top Quark Mass in the μ+Jets Channel



CMS 2010, 36 pb^{-1}

Source	Ideogram analysis δm_t (GeV)	Cross-check δJES	Cross-check δm_t
JES (overall data/MC)	+2.4-2.1	-	-
JES p_T and η dependence	-	0.004	0.3
light vs b-jet scale	-	0.002	2.6
JER (10% effect)	0.07	0.005	0.2
MET (10% effect)	0.4	-	-
Factorization scale	1.1	0.001	0.9
ME-PS matching threshold	0.4	0.003	0.2
ISR/FSR	0.2	0.008	0.4
Underlying event	0.2	0.001	0.7
Pile-up effect	0.1	0.005	0.2
PDF	0.1	0.002	0.2
Background	0.5	0.007	0.9
B-tagging	0.05	0.003	0.2
Fit calibration statistics	0.1	0.004	0.1
Total systematic uncertainty	+2.8- 2.5	0.015	3.1

Goals

- Competitive precision $\mathcal{O}$ (1 GeV)
- Benchmark for detector performance

Challenges

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

Ansatz

- Select high-purity $t\bar{t}$ sample
- Combine methods used in 2010: 2D ideogram method with kinematic fit for measuring m_t and JES

Collision Data & Simulation

LHC Collision data

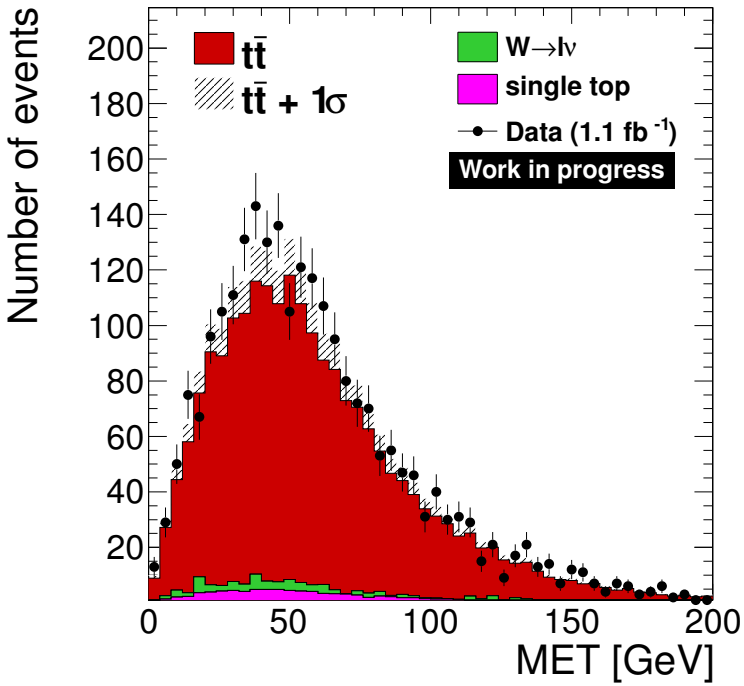
- 1.1 fb^{-1} pp collisions at $\sqrt{s} = 7$ TeV

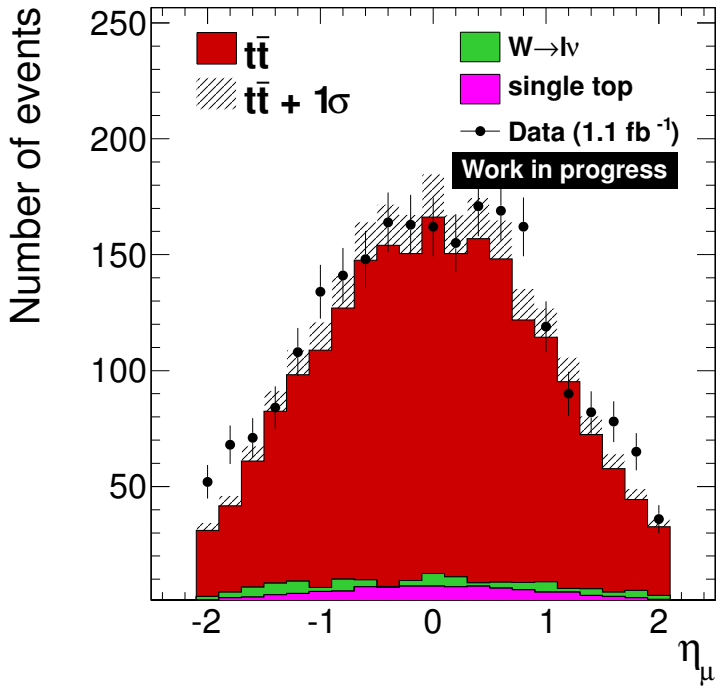
Simulation (CMS MC production)

- $t\bar{t}$ signal sample (Madgraph + Pythia)
  - 161.5 GeV $\leq m_{t,\text{gen}} \leq$ 184.5 GeV (9 points)
  - $0.96 \leq \text{JES}_{\text{gen}} \leq 1.04$ (3 points)
- Background samples
  - W+jets (Madgraph + Pythia)
  - Single top, s-, t-, tW-channel (POWHEG)

Event Selection

- Single isolated muon trigger ($p_T > 17$ GeV), select primary vertex
- Exactly 1 isolated muon with $p_T > 20, |\eta| < 2.1$ (veto additional e, μ)
- ≥ 4 particle flow jets (anti-k_t, $R = 0.5$) with $p_T > 30, |\eta| < 2.4$
- ≥ 2 jets with b-tag (*secondary vertex algorithm*)





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

Event Reconstruction

- Need full event reconstruction for invariant masses
- Associate muon, MET and 4 leading jets to $t\bar{t}$ partons
- Take only permutations compatible with b-tag information

Different types of permutations found via jet-parton matching on MC

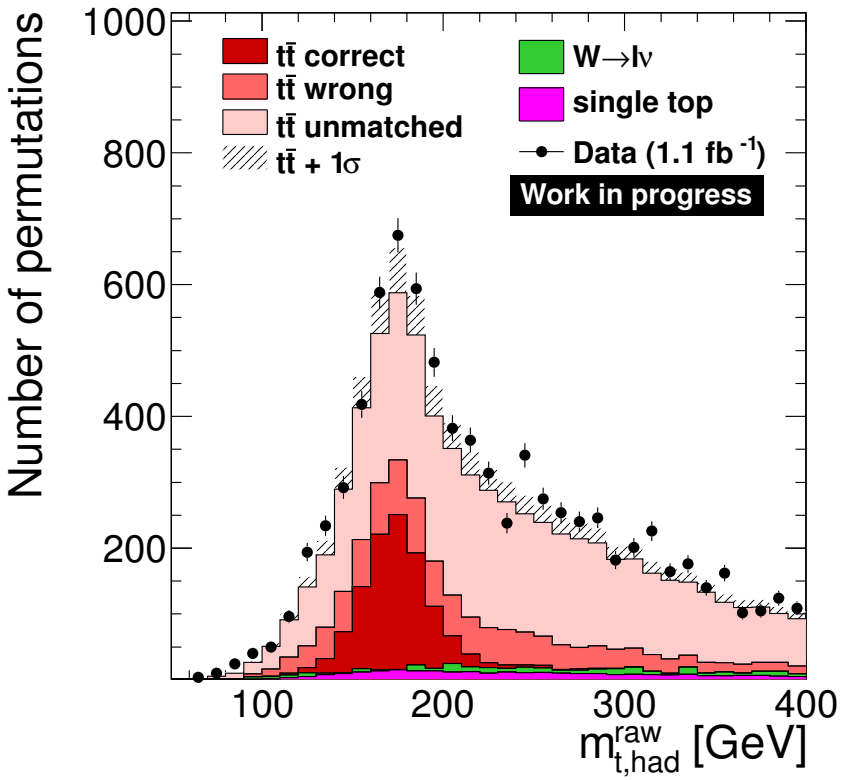
- 15% *correct*
- 19% *wrong*: Flipped b-quarks, mistags
- 66% *unmatched*: Matching failed due to ISR/FSR/selection

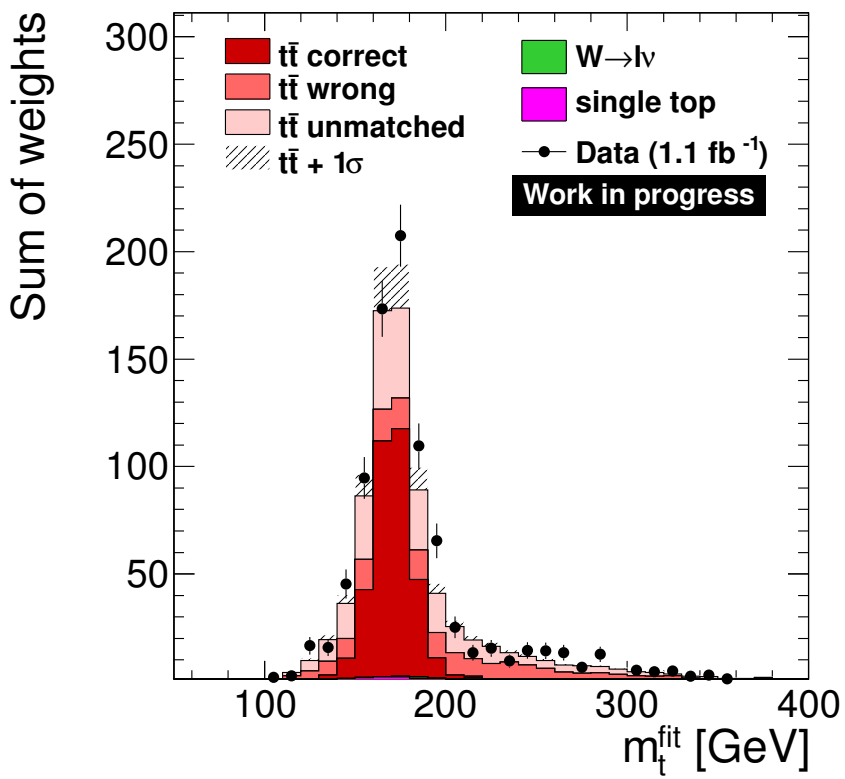
Improve with kinematic fit

- Minimize $\chi^2 = \left(\mathbf{x}^{fit} - \mathbf{x}^{raw}\right)^T G \left(\mathbf{x}^{fit} - \mathbf{x}^{raw}\right)$
- Constraints: $m_{W,\text{had}} = m_{W,\text{lep}} = 80.4$ GeV, $m_t = m_{\bar{t}}$

Final Selection & Top Mass Distribution

- Weight each permutation by P_{fit} and cut $P_{\text{fit}} > 0.2$





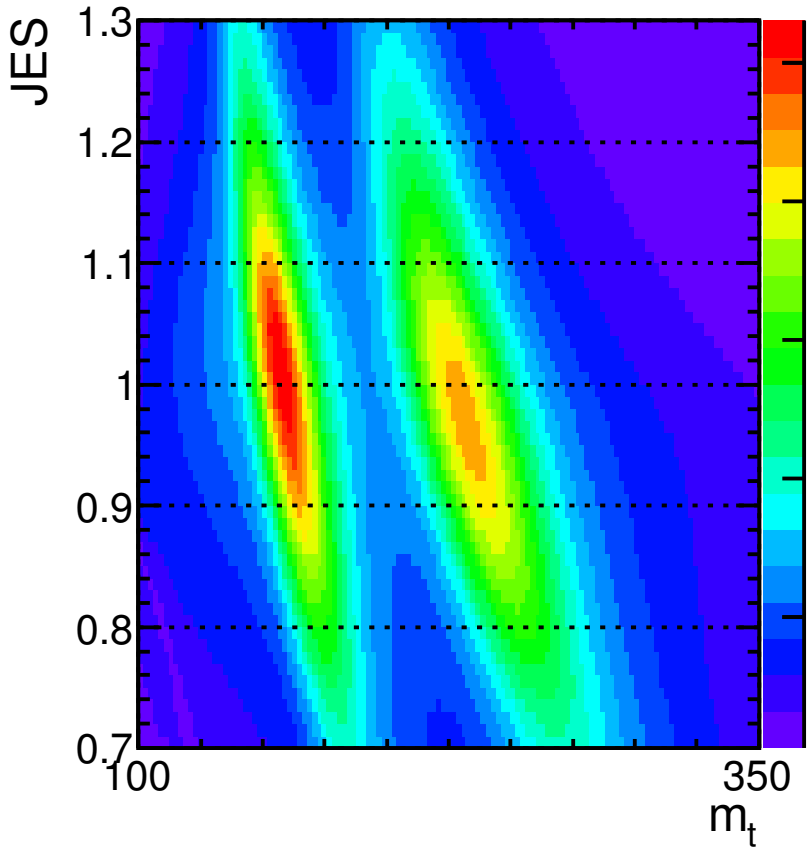
- Fraction of correct $t\bar{t}$ permutations enhanced: **15% ⇒ 44%**
- Non-$t\bar{t}$ background (W+jets, single top) negligible!

The Ideogram Method

- Probability for permutation i with observables $\mathbf{x}_i = \left(m_{t,i}^{fit}, m_{W,i}^{raw}\right)$

$$P\left(\mathbf{x}_i | m_t, \mathrm{JES}\right) = \sum_{j \in \{cp,wp,un\}} f_j P_j\left(m_{t,i}^{fit} | m_t, \mathrm{JES}\right) \cdot P_j\left(m_{W,i}^{raw} | m_t, \mathrm{JES}\right)$$

- Get probability densities P_j from simulation



Ideogram = Event Likelihood

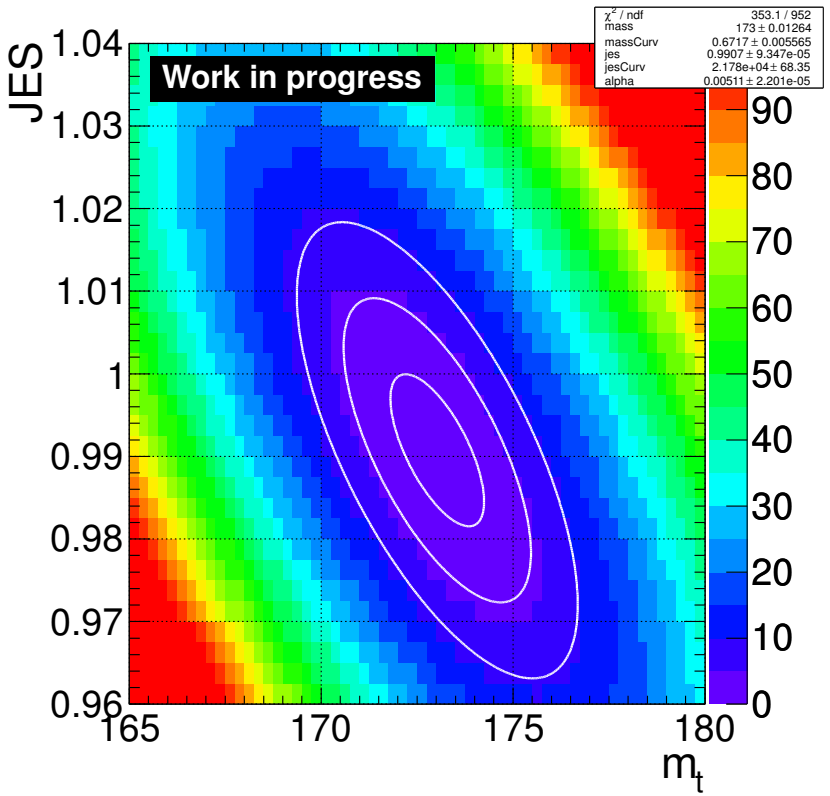
$$\mathcal{L}\left(m_t, \mathrm{JES} | \mathrm{event}\right) = \sum_i P_{\mathrm{fit}}\left(i\right) P\left(\mathbf{x}_i | m_t, \mathrm{JES}\right)$$

- Full (anti-)correlation of m_t and JES incorporated in likelihood
- Example:
  2 different b-quark assignments

The Ideogram Method

$$\mathcal{L}\left(m_t, \mathrm{JES}|\mathrm{sample}\right) = \prod_{\mathrm{events}} \left(\sum_i P_{\mathrm{fit}}\left(i\right) P\left(\mathbf{x}_i|m_t, \mathrm{JES}\right) \right)^{\sum_i P_{\mathrm{fit}}(i)}$$

- Minimize $-2\ln\left\{\mathcal{L}\left(m_t, \mathrm{JES}|\mathrm{sample}\right)/\mathcal{L}_{\mathrm{max}}\right\}$



Example: Pseudo-experiment corresponding to 1.1 fb^{-1}

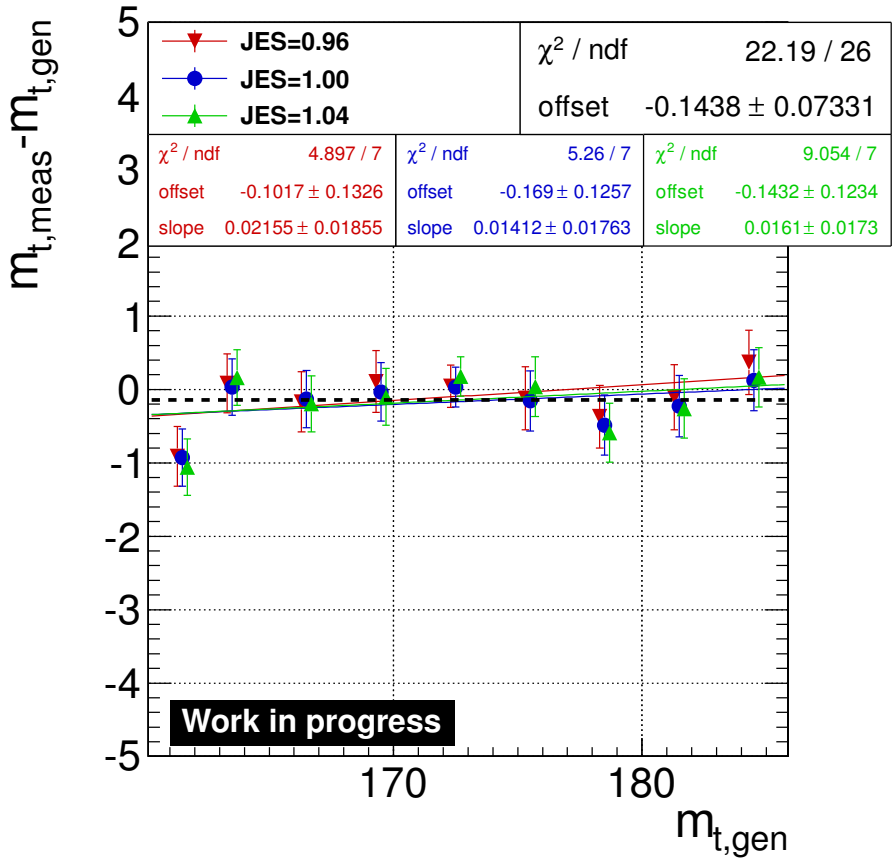
$$m_{t,\mathrm{gen}} = 172.5 \text{ GeV}$$
$$\mathrm{JES}_{\mathrm{gen}} = 1.000$$

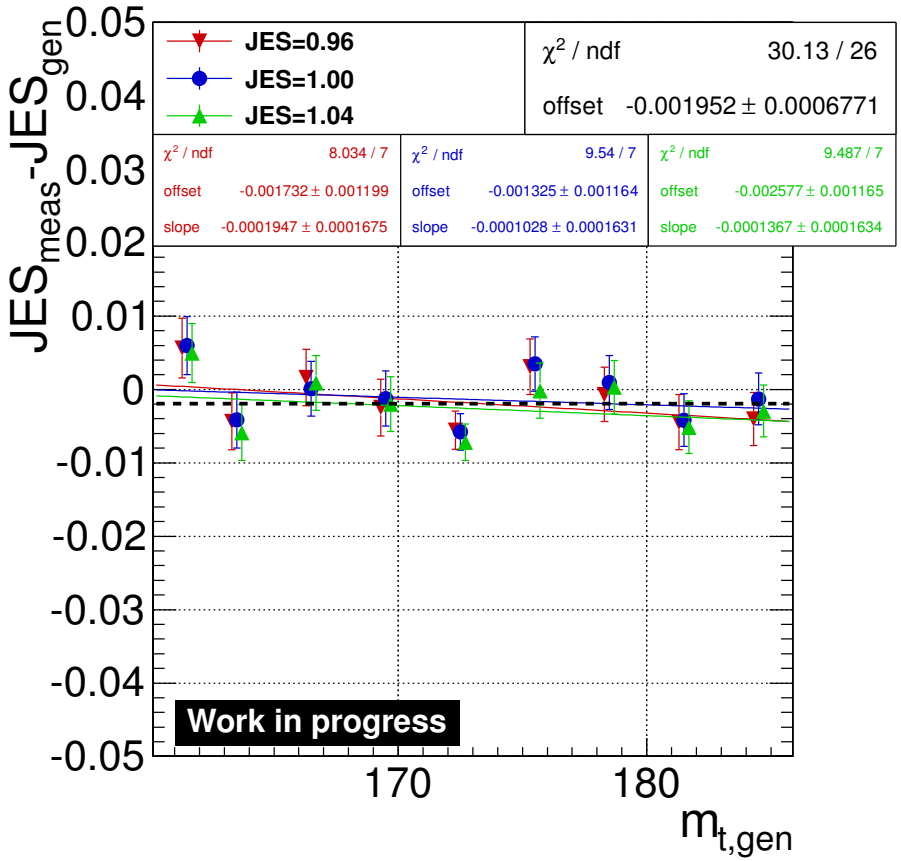
Fit likelihood with paraboloid

$$m_t = 173.0 \pm 1.2 \text{ (stat) GeV}$$
$$\mathrm{JES} = 0.991 \pm 0.009 \text{ (stat)}$$

Validation & Calibration

- Run on full $t\bar{t}$ sample ($10 - 23$ fb^{-1}), 9 $m_{t,\mathrm{gen}}$, 3 JES$_{\mathrm{gen}}$





- Good performance out of the box, small mass and JES bias
- Statistical uncertainty checked with pseudo-experiments

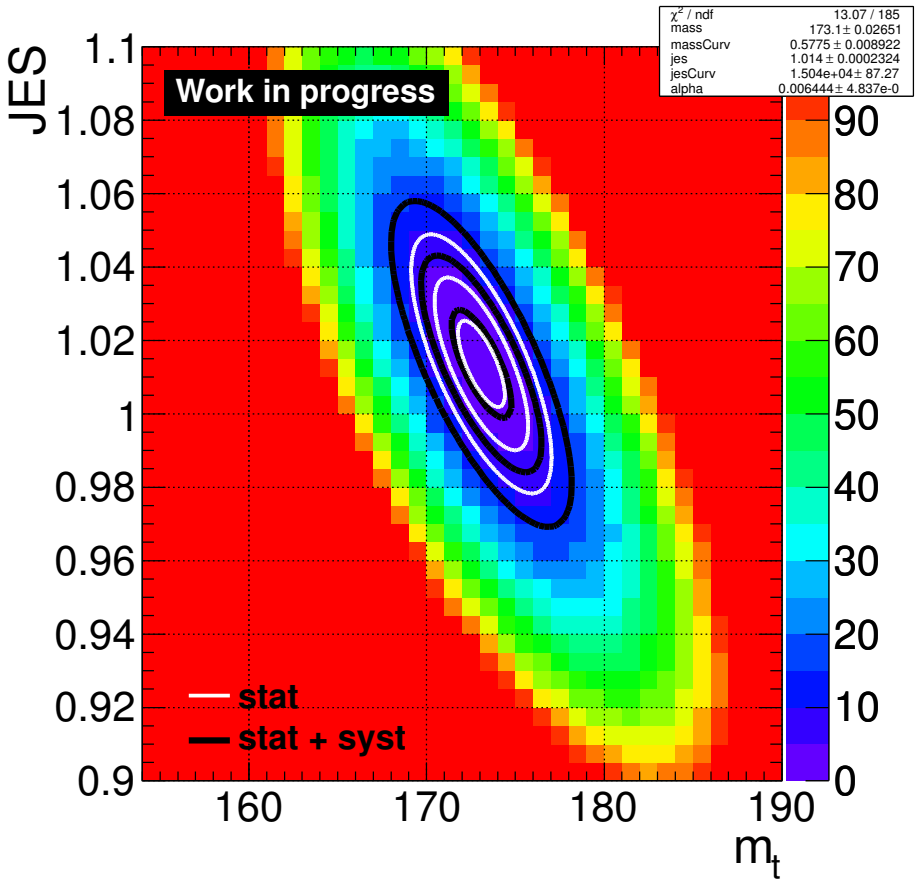
Systematic Uncertainties

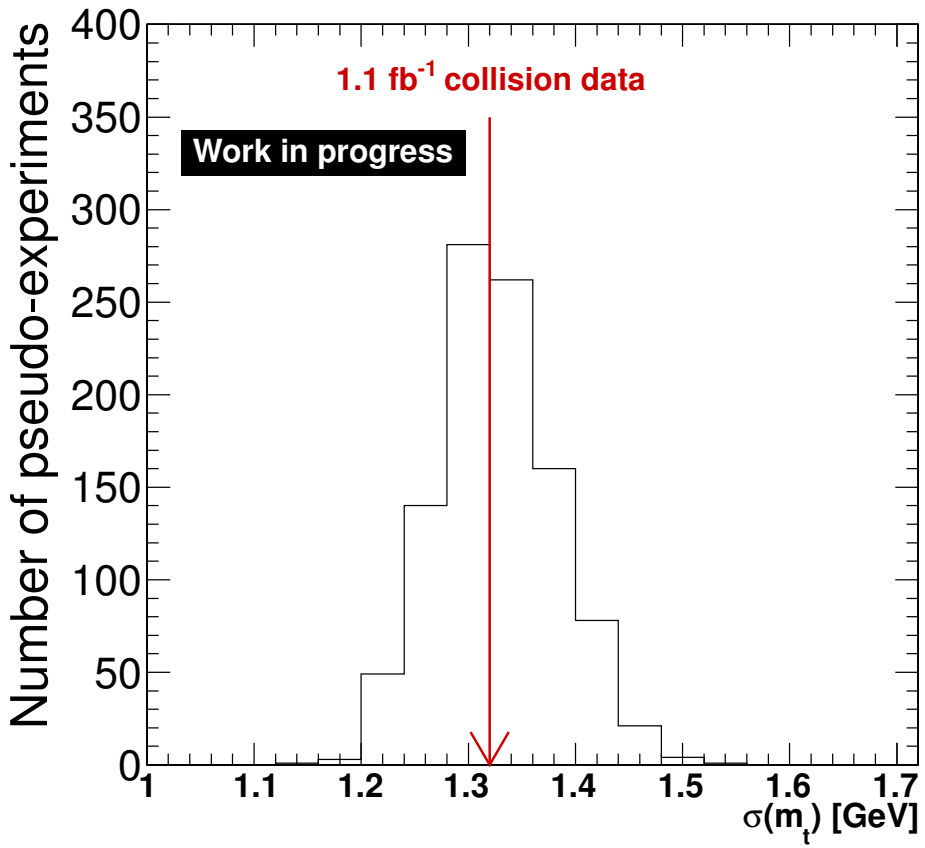
	δ_{m_t} (GeV)	δ_{JES}
Fit calibration	0.13	0.001
Muon trigger	0.05	0.001
b-tagging	0.07	0.002
b-JES	0.58	0.000
p_T and η dependent JES	0.16	0.002
Jet energy resolution	0.27	0.004
Factorization scale	0.28	0.006
ME-PS matching threshold	0.45	0.002
Pythia Tune (PS+UE)	0.62	0.005
Non-$t\bar{t}$ background	0.10	0.001
Pile up	0.05	0.001
PDF	0.05	0.001
Systematic	1.07	0.010

Result on Data

Result with 670 selected events in μ+jets channel, 1.1 fb^{-1}

$$m_t = 173.1 \pm 1.3\ (\text{stat+JES}) \pm 1.1\ (\text{syst})\ \text{GeV}$$
$$\text{JES} = 1.014 \pm 0.012\ (\text{stat}) \pm 0.010\ (\text{syst})$$





Top Quark Mass Results

ATLAS 2011 prel., l+jets, 0.7 fb^{-1}
175.9 ± 0.9 ± 2.7 GeV

CMS 2010, Ideogram, l+jets, 36 pb^{-1}
173.1 ± 2.1 ± 2.7 GeV

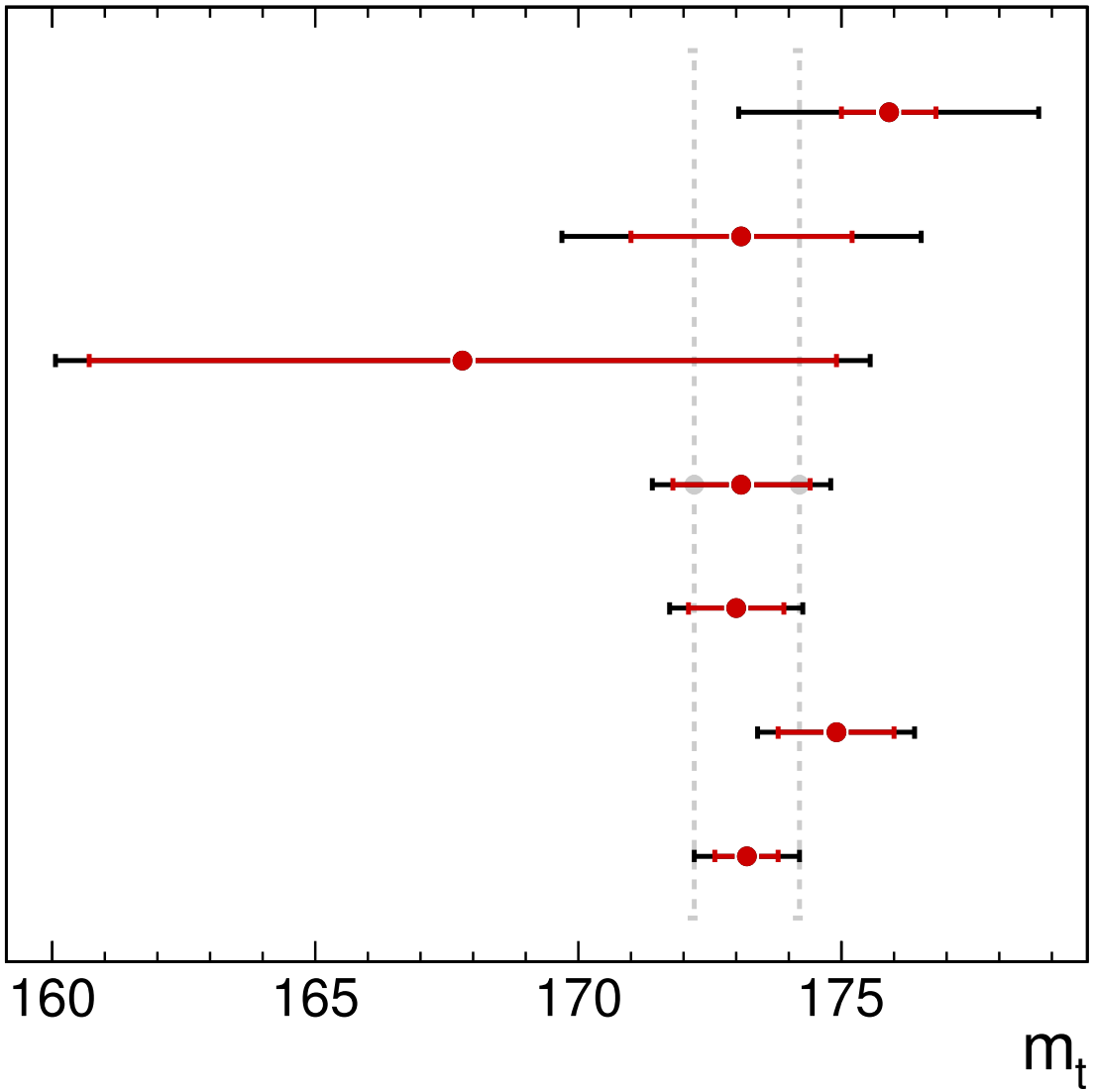
CMS 2010, Template, μ+jets, 36 pb^{-1}
167.8 ± 7.1 ± 3.1 GeV

This analysis, μ+jets, 1.1 fb^{-1}
173.1 ± 1.3 ± 1.1 GeV

CDF-II, l+jets, 5.6 fb^{-1}
173.0 ± 0.9 ± 0.9 GeV

D0-II, l+jets, 3.6 fb^{-1}
174.9 ± 1.1 ± 1.0 GeV

Tevatron prel., July 2011
173.2 ± 0.6 ± 0.8 GeV



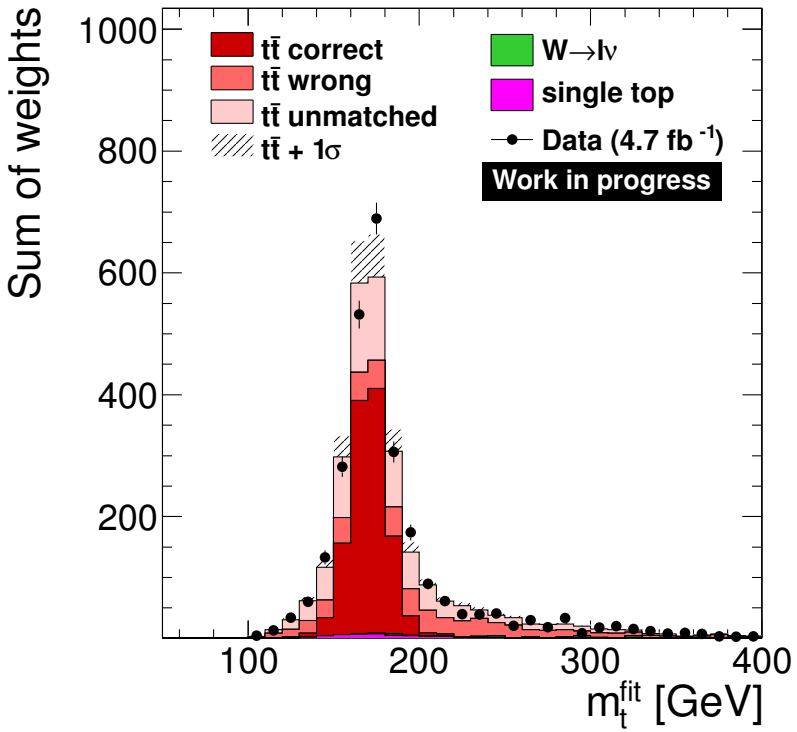
Summary and Plans

Summary

- Simultaneous measurement of top quark mass and JES
- Result: $m_t = 173.1 \pm 1.7$ GeV
- Improvement of 2010 uncertainty by a factor 2
  - JES stat uncertainty 1.2%, was 2.5% (36 pb^{-1}, γ+jet)
  - Anti-correlation reduces impact of systematics on m_t

Plans

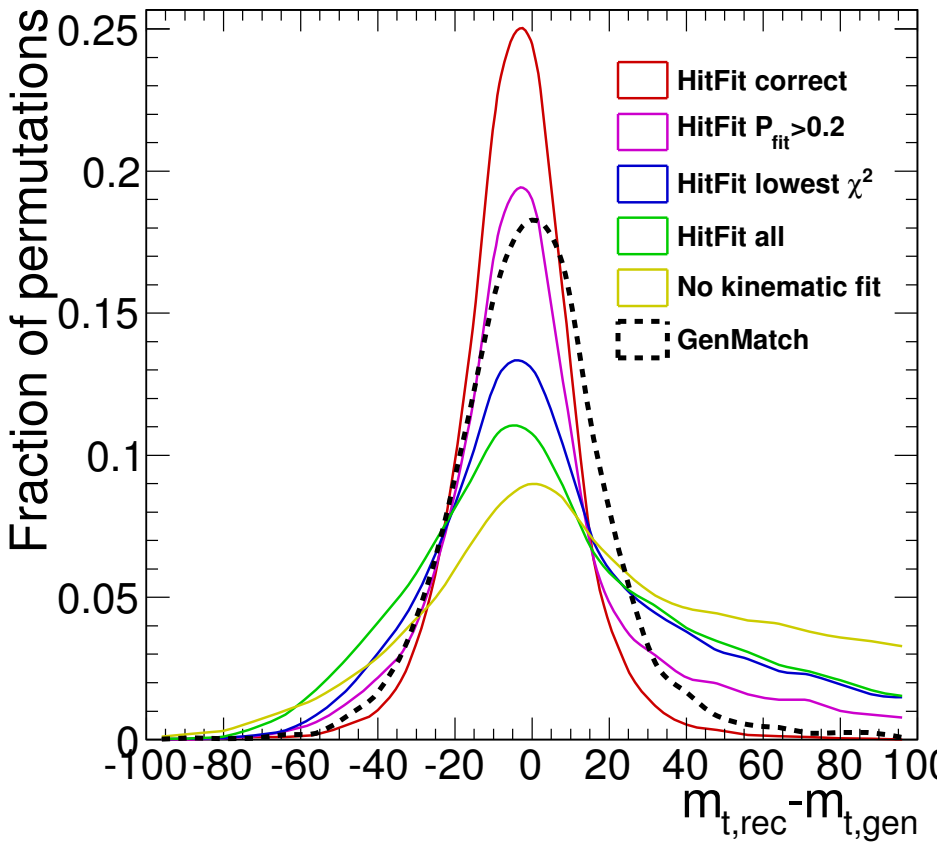
1. Study and reduce theory/modeling uncertainties
2. Measurement with full 2011 dataset

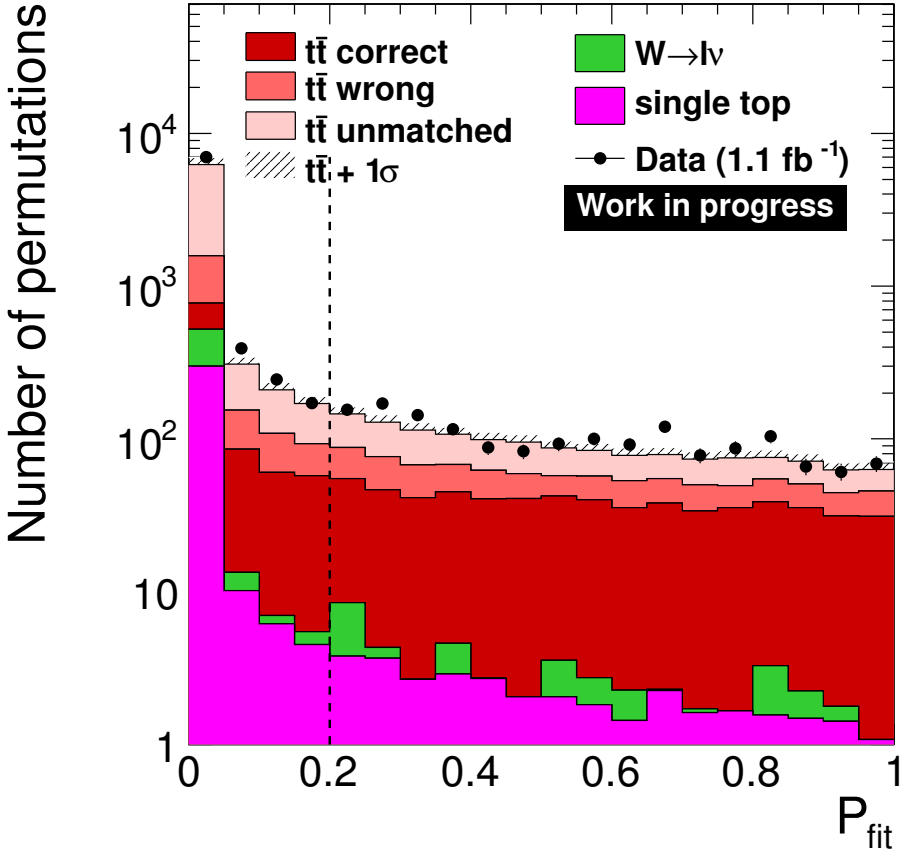


Backup

Event Reconstruction: Kinematic Fit

- Kinematic fit minimizes $\chi^2 = (\mathbf{x} - \mathbf{x}^m)^T \, G \, (\mathbf{x} - \mathbf{x}^m)$
- Constraints: $m_{W,\text{had}} = m_{W,\text{lep}} = 80.4$ GeV, $m_t = m_{\bar{t}}$





The Ideogram Method

- Simultaneous measurement of top mass (m_t^{fit}) and JES (m_W^{raw})
- Probability for permutation with observables $\mathbf{x}_i$

$$P\left(\mathbf{x}_i|m_t, \mathrm{JES}\right) = \sum_{j\in\{cp,wp,un\}} f_j P_j\left(m_{t,i}^{fit}|m_t, \mathrm{JES}\right) \cdot P_j\left(m_{W,i}^{raw}|m_t, \mathrm{JES}\right)$$

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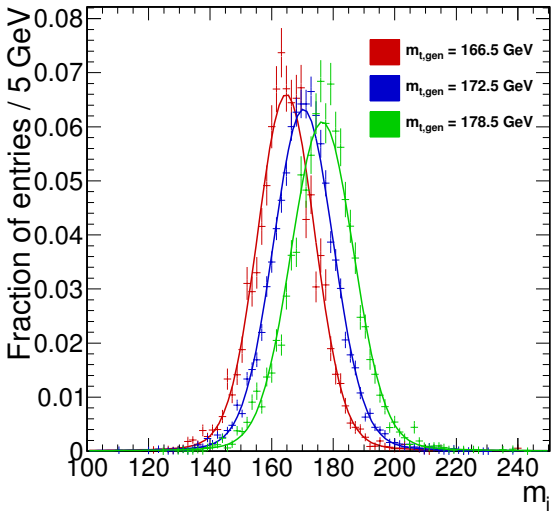
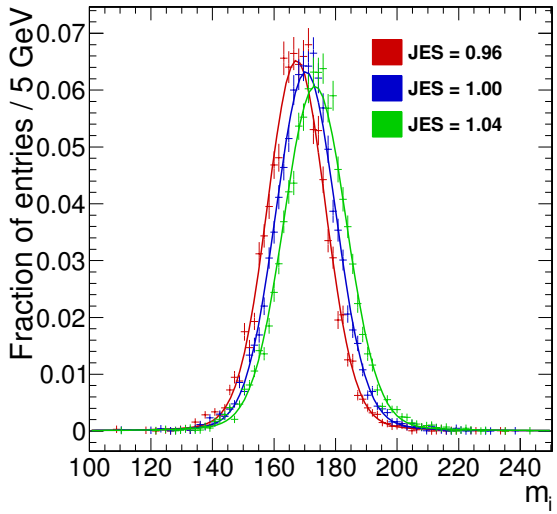
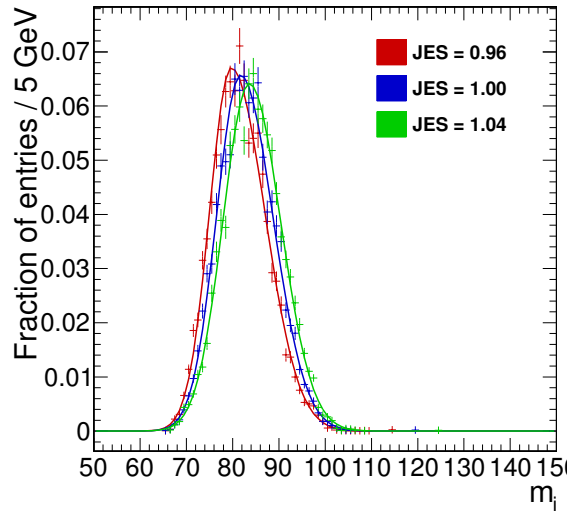


$P_{cp}\left(m_{t,i}^{fit}|m_t\right)$

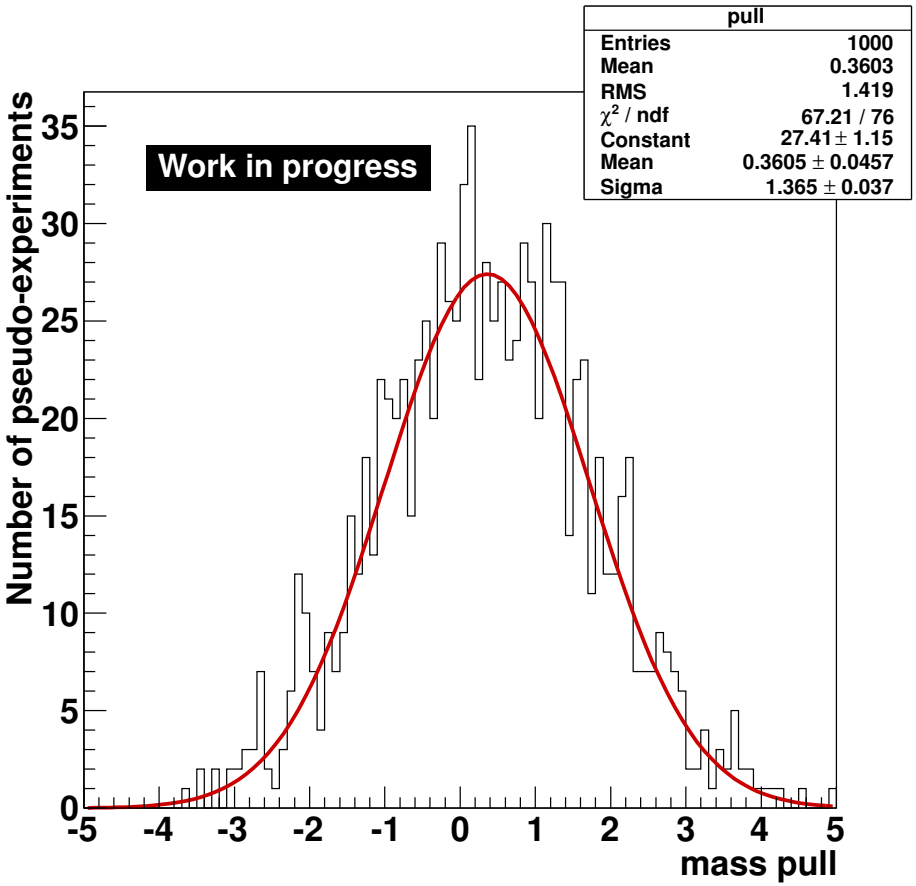


$P_{cp}\left(m_{t,i}^{fit}|\mathrm{JES}\right)$



$P_{cp}\left(m_{W,i}^{raw}|\mathrm{JES}\right)$

Validation & Calibration: Statistical Uncertainty



- 1000 pseudo-experiments, each corresponding to 1.1 fb^{-1}

$$\text{mass pull} = \frac{m_{t,\text{meas}} - m_{t,\text{gen}}}{\sigma\left(m_{t,\text{meas}}\right)}$$

- Should follow Normal Distribution
- Pull width above unity
  $\Rightarrow$ uncertainty underestimated
- Correct likelihood accordingly

Systematic Uncertainties: Jet Energy Scale

- Global JES measured
- Flavor uncertainty:
  Transition from uds to gluon dominated sample
- Response of b-jets between uds and gluon
- B-JES uncertainty covered by flavor uncertainty
- CMS Paper JME-10-011