

# Measurements of the top quark mass with the CMS experiment

Hartmut Stadie  
Universität Hamburg  
on behalf of the CMS collaboration

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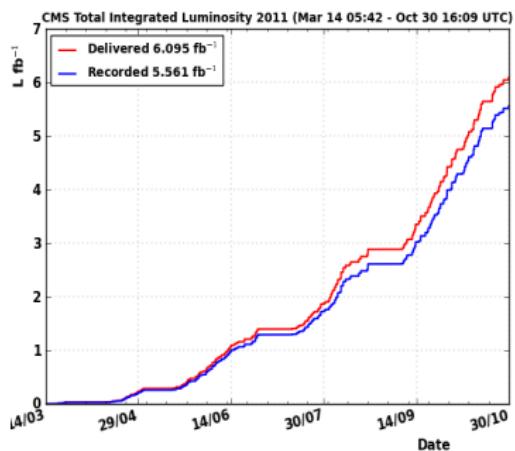


Federal Ministry  
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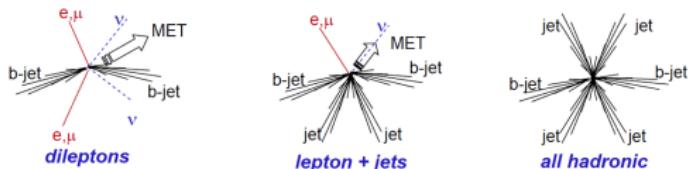
# Contents

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CMS-PAS-TOP-11-015
- Determination of the top quark mass from the  $t\bar{t}$  cross section at  $\sqrt{s} = 7 \text{ TeV}$   
CMS-PAS-TOP-11-008

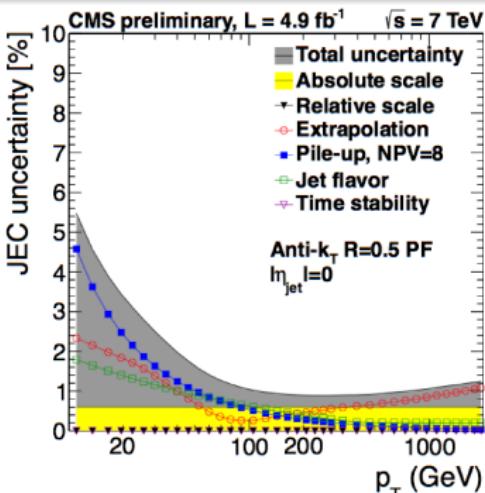
# Top Quarks at CMS



Number of produced top events in 2011:  
 $N_{t\bar{t}} = L \cdot \sigma \sim 800k$



jets in final state: jet energy scale (JES)  
 crucial for top quark mass measurement!



# Top Mass Measurement in Dilepton Channel

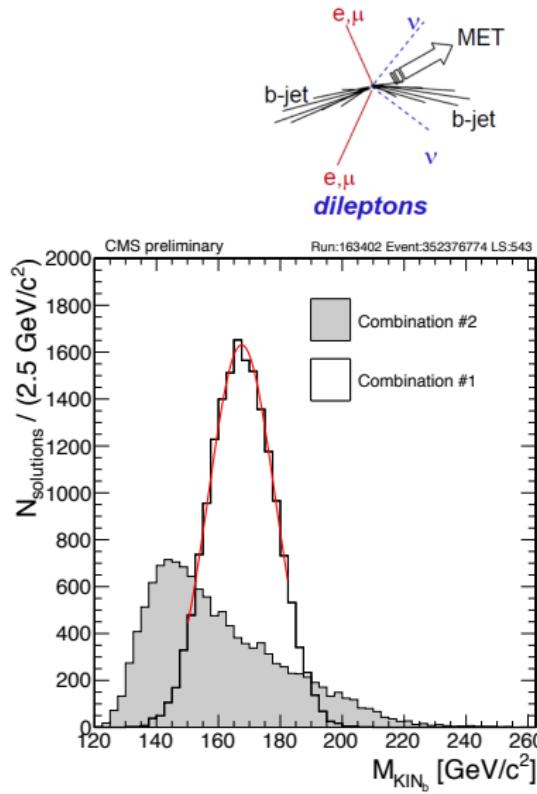
## Selection:

- 2  $e, \mu$  with  $p_T > 20 \text{ GeV}, |\eta| < 2.4$
- 2 jets with  $p_T > 30 \text{ GeV}, |\eta| < 2.4$
- 1  $b$ -tagged jet
- $E_T^{\text{miss}} > 30 \text{ GeV}$
- cut against Z events

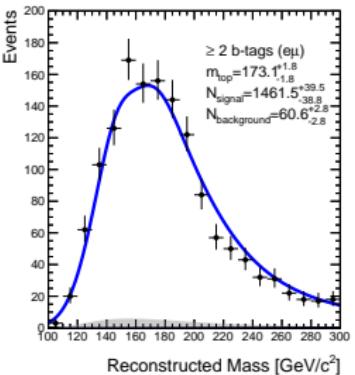
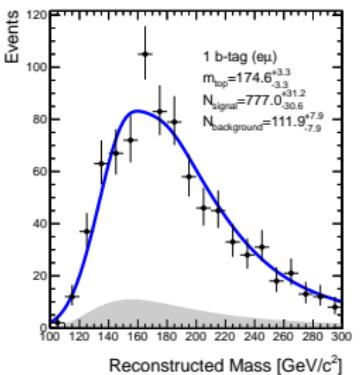
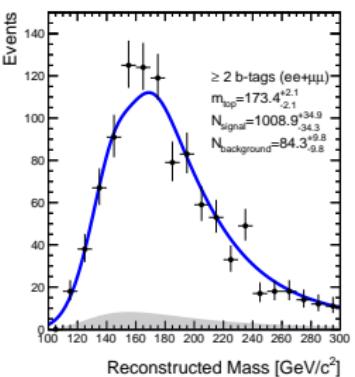
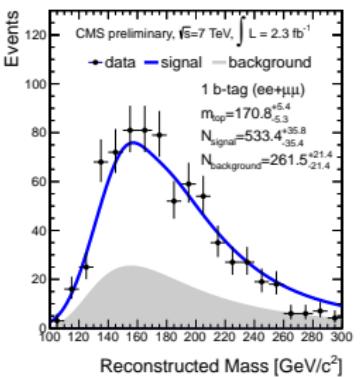
## KINb method:

solve kin. equations of  $t\bar{t}$  system

- vary jet  $p_T$ ,  $E_T^{\text{miss}}$  dir, and  $p_z^{t\bar{t}}$
- use  $p_z^{t\bar{t}}$  shape from simulation
- accept solutions with lowest  $m_{t\bar{t}}$  and similar  $m_t$



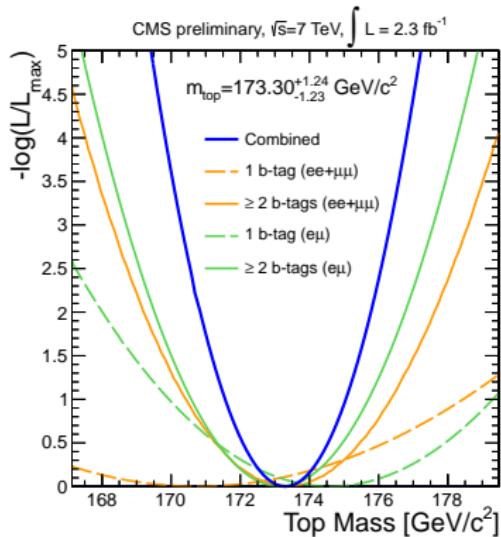
# Reconstructed Masses



# Result on Data

Result with 4312 selected events in dilepton channel,  $2.3 \text{ fb}^{-1}$

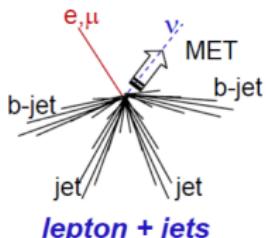
$$m_t = 173.3 \pm 1.2 \text{ (stat)} \pm 2.5 \text{ (syst) GeV}$$



Source	$\Delta m_{\text{top}} (\text{GeV}/c^2)$
JES	$+1.90$
flavor-JES	$-2.00$
JER	$+1.08$
LES	$-1.13$
Unclustered $E_T^{\text{miss}}$	$\pm 0.30$
Fit calibration	$\pm 0.12$
DY normalization	$\pm 0.18$
Factorization scale	$\pm 0.43$
Jet parton matching scale	$\pm 0.40$
Pile-up	$\pm 0.65$
b-tagging uncertainty	$\pm 0.19$
mis-tagging uncertainty	$\pm 0.30$
MC generator	$\pm 0.43$
PDF	$\pm 0.14$
<b>Total</b>	$+2.52$ $-2.63$

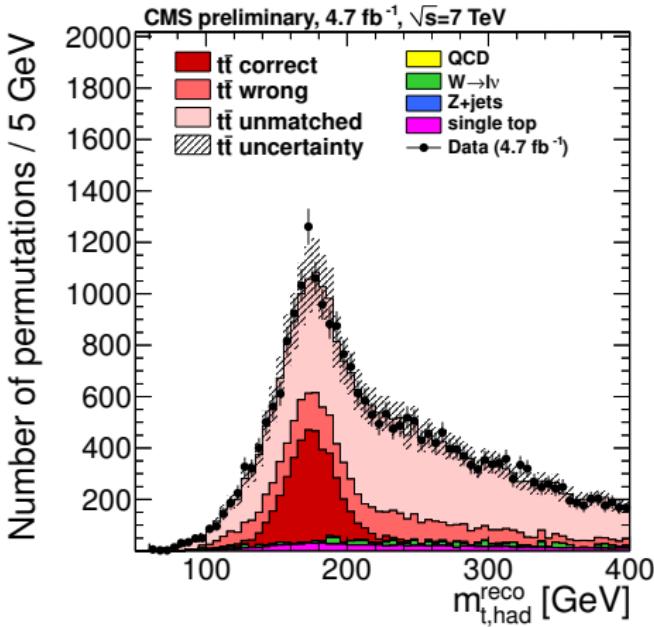
(UE tune and CR uncertainties not included in this preliminary result.  
studies ongoing; expected size  $\lesssim 0.5 \text{ GeV}$  each)

# Top Mass Measurement in $\mu + \text{jets}$ Channel



select very clean sample of  $t\bar{t}$  events:

- exactly 1 isolated muon with  $p_T > 30 \text{ GeV}, |\eta| < 2.1$  (veto additional  $e, \mu$ )
- $\geq 4$  jets with  $p_T > 30 \text{ GeV}, |\eta| < 2.4$
- $\geq 2$  jets with b-tag based on secondary vertices

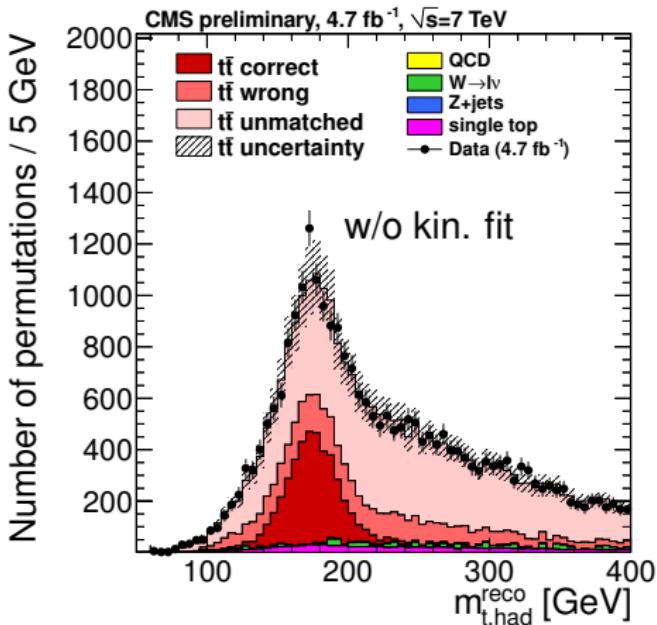


Estimated composition: 92%  $t\bar{t}$ , 3%  $W+\text{jets}$ , 4% single top, 1% other

# Kinematic Fit

- split in 3 permutation classes:
  - correct
  - wrong

flipped b-quarks, mistags
- unmatched  
no unambiguous match
- kinematic fit:
  - two untagged jets:  
 $m_{jj} = 80.4 \text{ GeV}$
  - muon and neutrino (MET)  
 $m_{\mu\nu} = 80.4 \text{ GeV}$
  - combine with two  $b$ -tagged jets:  
 $m_{jjb_1} = m_{\mu\nu b_2}$



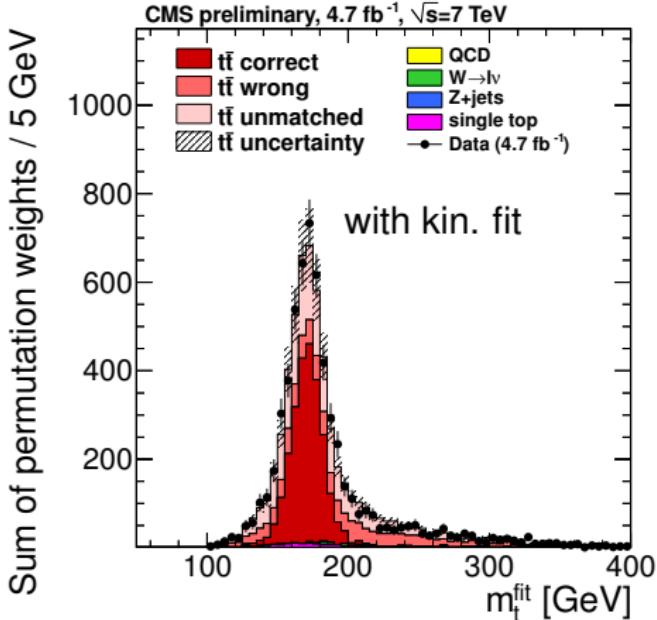
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- split in 3 permutation classes:

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- wrong
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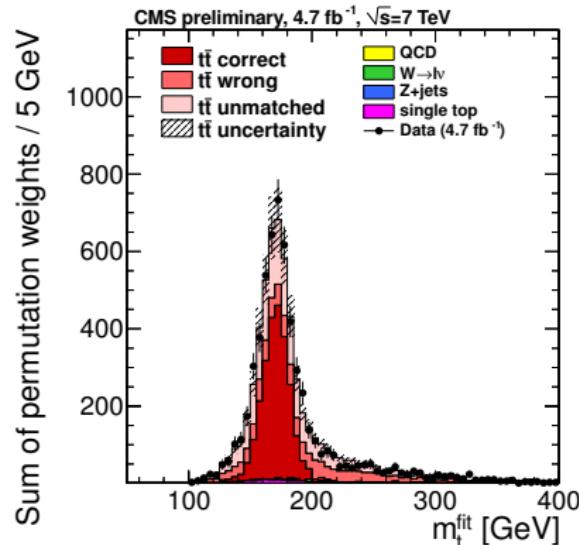


$P_{\text{fit}} > 0.2$  & weight permutations by  $P_{\text{fit}}$

$$f_{cp} = 13\% \rightarrow 44\%$$

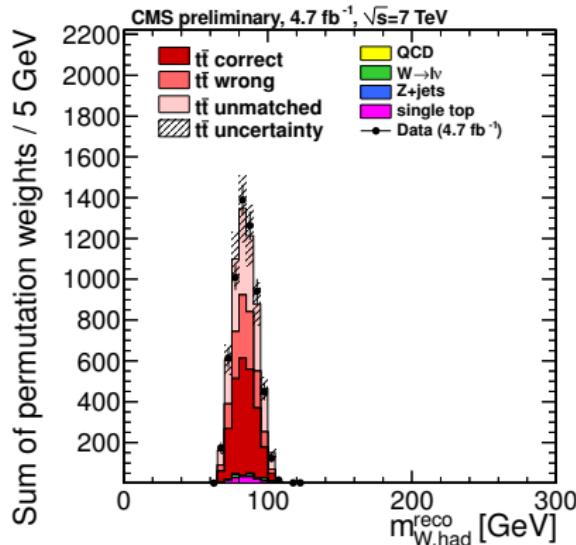
# Ideogram Method

- simultaneous measurement of the top quark mass and jet energy scale (JES)
- ideogram:  $P(\text{event} | m_t, \text{JES})$
- input:  $m_{t,i}^{\text{fit}}$  and  $m_{W,i}^{\text{reco}}$
- use all allowed permutations  $i$  per event



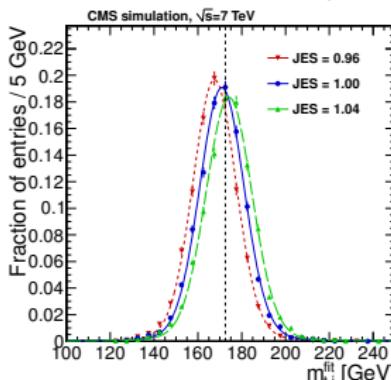
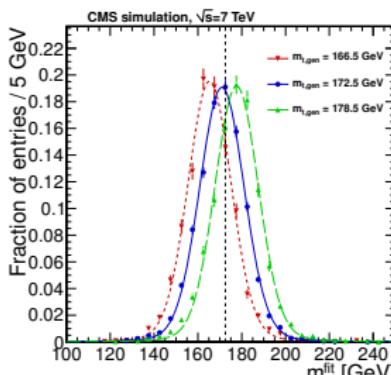
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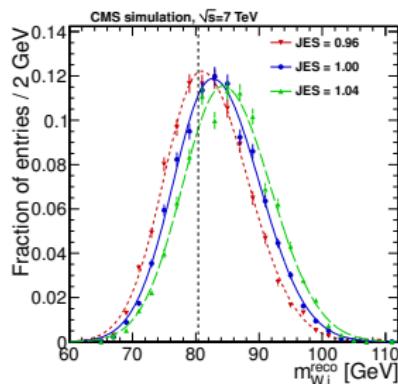
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- use all allowed permutations  $i$  per event
- $P_i = \sum_j f_j P_j(m_{t,i}^{\text{fit}} | m_t, \text{JES}) \cdot P_j(m_{W,i}^{\text{reco}} | m_t, \text{JES})$



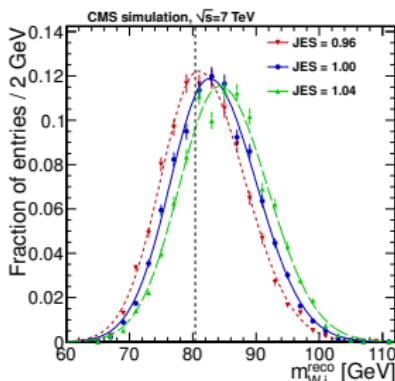
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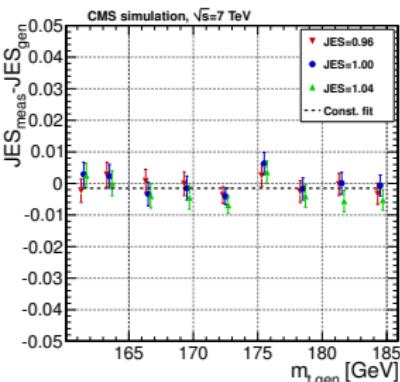
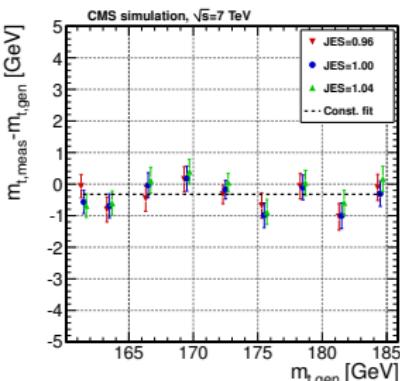
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- final ideogram: combine  $P_i$  and weight event by sum of fit probabilities



# Ideogram Method

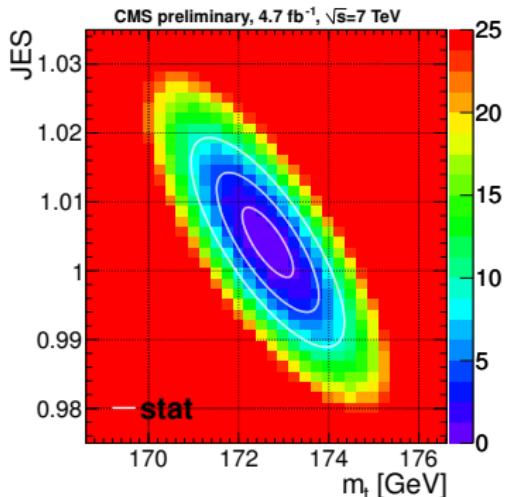
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- use all allowed permutations  $i$  per event
- $P_i = \sum_j f_j P_j(m_{t,i}^{\text{fit}} | m_t, \text{JES}) \cdot P_j(m_{W,i}^{\text{reco}} | m_t, \text{JES})$
- final ideogram: combine  $P_i$  and weight event by sum of fit probabilities
- combine all ideograms and extract  $m_t$  and JES after calibration



# Result on Data

Result with 2391 selected events in  $\mu$ +jets channel,  $5.0 \text{ fb}^{-1}$

$$\begin{aligned} m_t &= 172.6 \pm 0.7 \text{ (stat+JES)} \pm 1.2 \text{ (syst) GeV} \\ \text{JES} &= 1.005 \pm 0.006 \text{ (stat)} \pm 0.012 \text{ (syst)} \end{aligned}$$



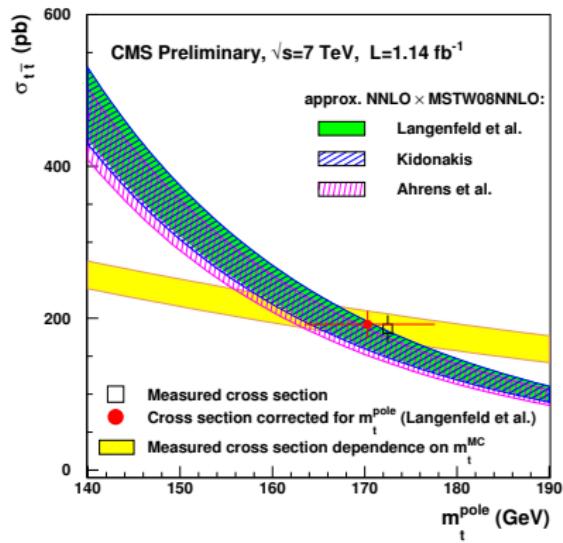
	$\delta m_t$ (GeV)	$\delta_{\text{JES}}$
Calibration	0.15	0.001
b-tagging	0.17	0.002
JES	$\Theta(1.2)$	
b-JES	0.66	0.000
$p_T$ and $\eta$ dependent JES	0.23	0.003
Jet energy resolution	0.21	0.003
Missing transverse energy	0.08	0.001
$Q^2$ scale	0.76	0.007
ME-PS matching threshold	0.25	0.007
Non- $t\bar{t}$ background	0.09	0.001
Pile up	0.38	0.005
PDF	0.05	0.001
Total	1.18	0.012

(UE tune and CR uncertainties not included in this preliminary result.  
studies ongoing; expected size  $\lesssim 0.5 \text{ GeV}$  each)

# Top Mass Measurement from the $t\bar{t}$ Cross Section

use measured  $t\bar{t}$  cross section in dilepton channel with  $1.1 \text{ fb}^{-1}$ :

- parametrize dependence of measured cross section on top mass
- parametrize dependence of predicted cross section on top mass
- extract top mass using joint-likelihood approach



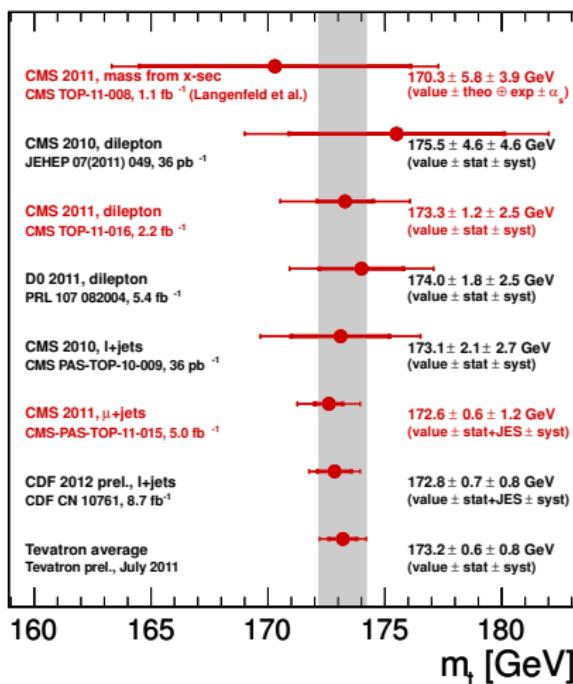
pole mass and  $\overline{MS}$  mass:

Approx. NNLO $\times$ MSTW08NNLO	$m_t^{\text{pole}} / \text{GeV}$	$m_t^{\overline{\text{MS}}} / \text{GeV}$
Langenfeld et al. [7]	$170.3^{+7.3}_{-6.7}$	$163.1^{+6.8}_{-6.1}$
Kidonakis [8]	$170.0^{+7.6}_{-7.1}$	-
Ahrens et al. [9]	$167.6^{+7.6}_{-7.1}$	$159.8^{+7.3}_{-6.8}$

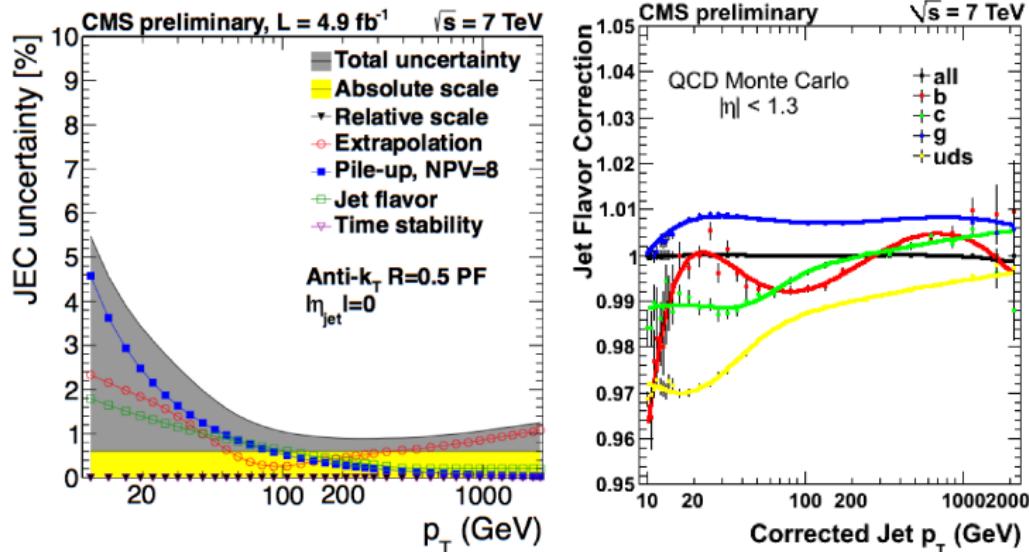
# Summary

top quark mass measurements:

- indirectly from  $t\bar{t}$  cross section in the dilepton channel with  $1.1 \text{ fb}^{-1}$   
CMS-PAS-TOP-11-008
- in dilepton channel with  $2.3 \text{ fb}^{-1}$   
CMS-PAS-TOP-11-016
  - exploit full kinematic analysis
  - unbinned likelihood for  $m_t$
- in muon+jets channel with  $5.0 \text{ fb}^{-1}$   
CMS-PAS-TOP-11-015
  - good mass resolution due to kinematic fit
  - 2D ideogram for  $m_t$  and JES



# Uncertainty of Jet Energy Corrections



- uncertainty on jet energy corrections: 1.5 – 5%

# Data Samples

## Collisions Data:

- $5.0 \text{ fb}^{-1}$  pp collisions at  $\sqrt{s} = 7 \text{ TeV}$
- single muon primary data set

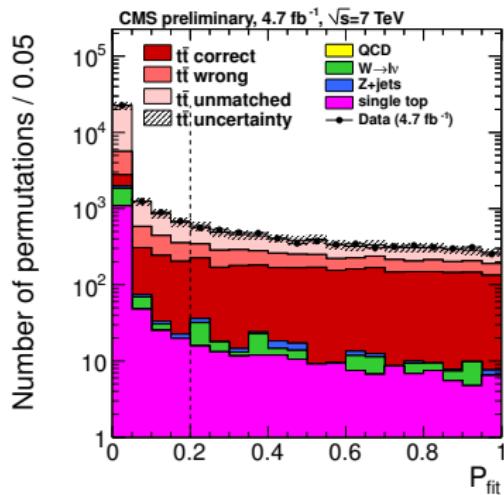
## Simulated Samples:

all simulated with *GEANT4*:

- $t\bar{t}$  signal sample (*Madgraph + Pythia*)
  - $161.5 \text{ GeV} \leq m_{t,\text{gen}} \leq 184.5 \text{ GeV}$
  - $0.96 \leq \text{JES}_{\text{gen}} \leq 1.04$
- background samples
  - QCD, W+jets, Z+jets (*Madgraph + Pythia*)
  - Single top,  $s$ -,  $t$ -,  $tW$ -channel (*Powheg*)
- corrections to match data distributions
  - pile-up (PU) reweighting, scale factors for b-tag/trigger efficiencies
  - jet energy resolution up by 7-20%

# Kinematic Fit & Final Selection

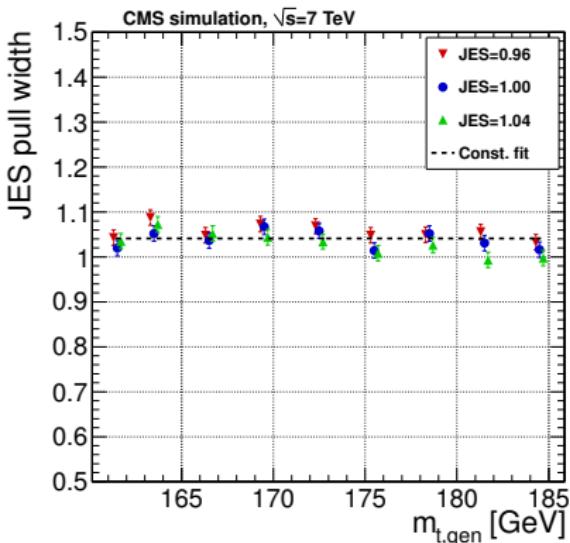
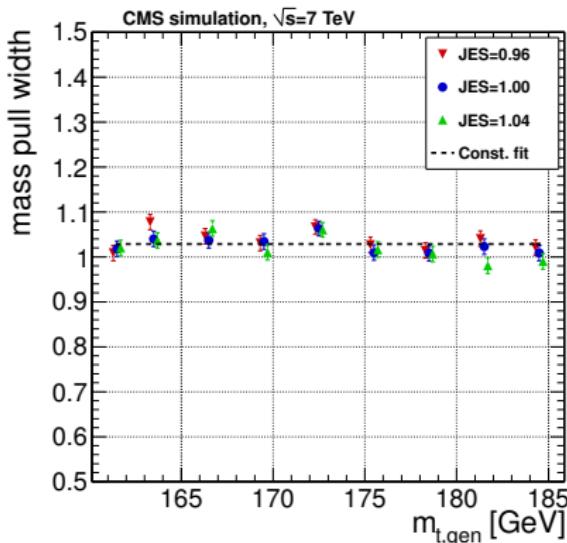
- Improve with constrained kinematic fit ( $m_W = 80.4 \text{ GeV}$ ,  $m_t = m_{\bar{t}}$ )
- Weight each permutation by  $P_{\text{fit}} = \exp(-\frac{1}{2}\chi^2)$ , cut  $P_{\text{fit}} > 0.2$



- Fraction of correct  $t\bar{t}$  permutations enhanced:  $f_{cp} = 13\% \rightarrow 44\%$
- No QCD left, treatment of non- $t\bar{t}$  background (4%)  $\rightarrow$  systematics

# 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

# Evaluation of Systematic Uncertainties

b-tagging: Vary tagger working point to reflect  $b$ -tag efficiency  
 $\pm 4\%$

b-JES: Scale jet energies  $\pm 1\sigma_{\text{flavor}}$

JES( $p_T, \eta$ ): Scale jet energies  $\pm 1\sigma_{\text{overall}}$  ( $\hat{\equiv} \pm 1.6\%$  global scale)

JER: Scale jet energy resolution by 7 to 20% depending on  $\eta$

$Q^2$  scale: Vary  $Q^2$  scale by factors of 0.25 and 4

ME-PS matching threshold: Vary matching threshold by factors of 0.5 and 2

Background: Add  $4 \times$  single top

Pile up: Vary average number of expected pile-up events of 8.8 by  $\pm 7\%$

PDF: reweight signal with 44 modified PDFs