CMS Measurements of the Top-Quark Mass

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on behalf of the CMS Collaboration

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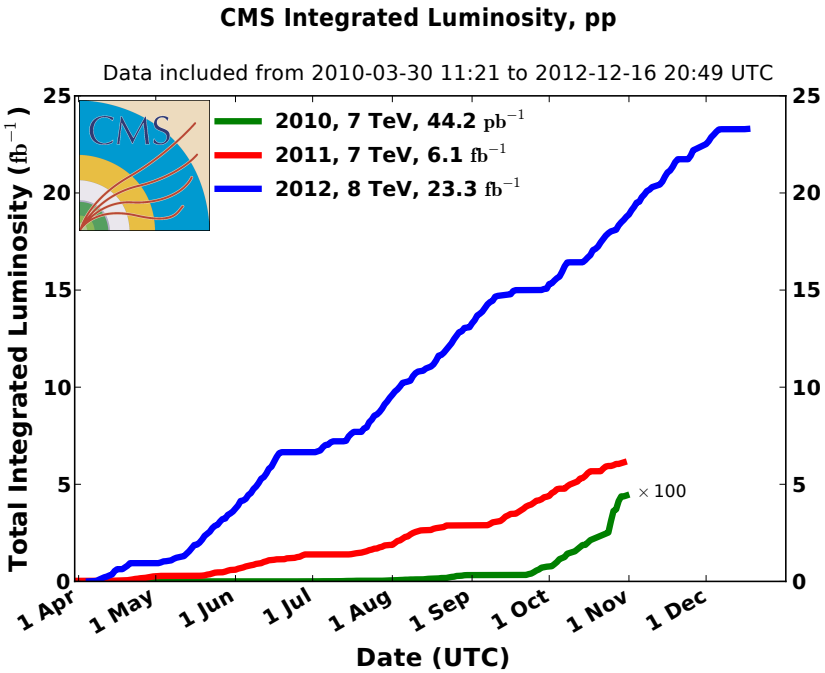
Contents

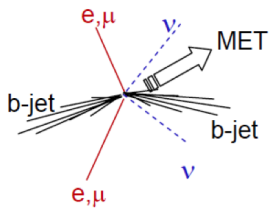
Measurements of the top-quark mass using "standard" methods:

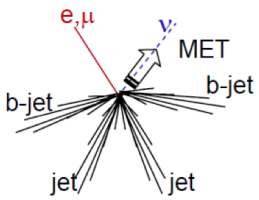
- Measurement of the top-quark mass in $t\bar{t}$ events with dilepton final states in pp collisions at $\sqrt{s} = 7$ TeV
  CMS Collaboration, Eur. Phys. J. C **72**, 2202 (2012);
  http://arxiv.org/abs/1209.2393
- Measurement of the top-quark mass in $t\bar{t}$ events with lepton+jets final states in pp collisions at $\sqrt{s} = 7$ TeV
  CMS Collaboration, JHEP **12**, 105 (2012);
  http://arxiv.org/abs/1209.2319
- New Measurement of the top-quark mass in all-jets $t\bar{t}$ events in pp collisions at $\sqrt{s} = 7$ TeV
  Submitted to EPJC; includes new combination;
  http://arxiv.org/abs/1307.4617

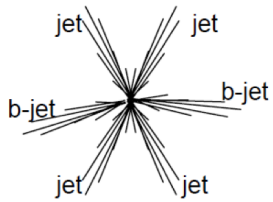
There is a second talk on alternative measurement approaches by Stijn Blyweert.

Top Quarks at CMS



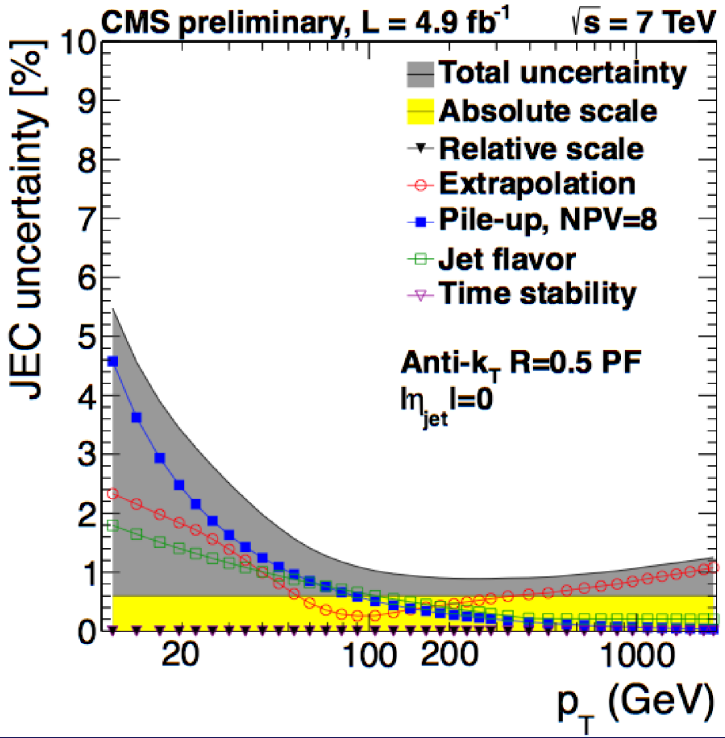




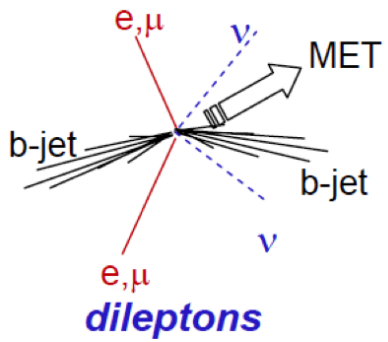


jets in final state: jet energy scale (JES) crucial for top quark mass measurement!

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



Top Mass Measurement in Dilepton Channel



selection:

- 2 isolated e,μ with $p_T > 20$ GeV,$|\eta| < 2.4$
- $\geq$ 2 jets with $p_T > 30$ GeV,$|\eta| < 2.4$
- $\geq$ 1 b-tagged jet
- $\not{E}_T > 40$ GeV and $m_{ee,\mu\mu}$ cut for ee and $\mu\mu$

After preselection: 11627 events, 90% $t\bar{t}$ signal

Analytical Matrix Weighting Technique:

scan different m_t hypotheses

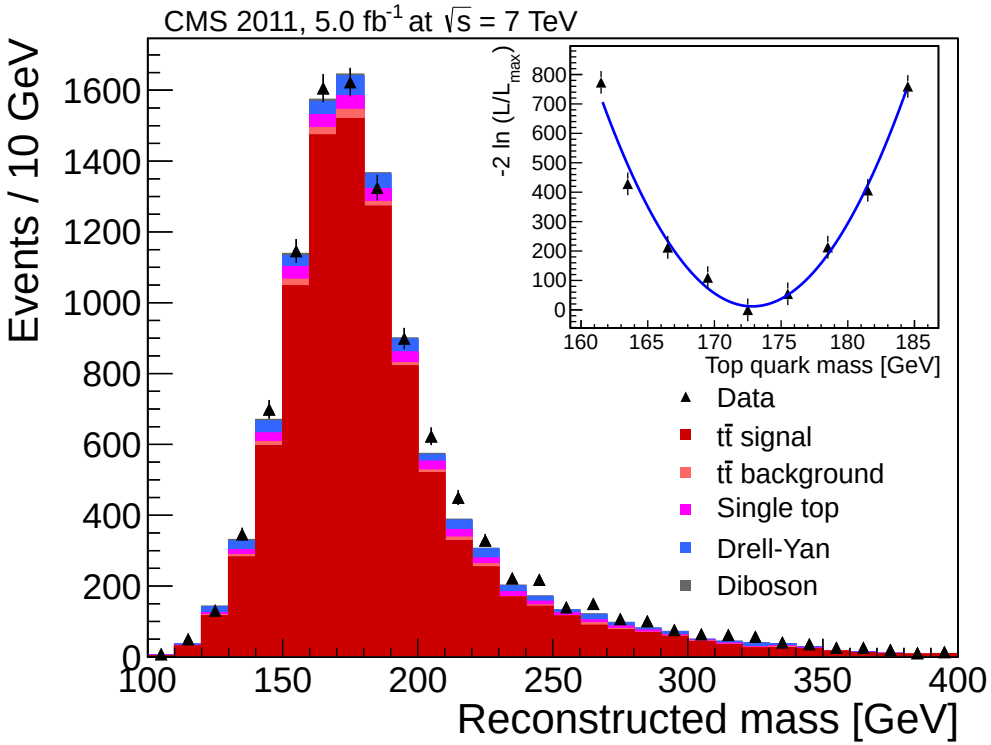
- smear jets (1000 times)
- solve kin. equations of $t\bar{t}$ system
- sum weights $w = \{\sum f(x_1)f(x_2)\}p(E^*_{\ell^+|m_t})p(E^*_{\ell^-|m_t})$

hypothesis with maximum weight $\rightarrow$ reconstructed mass

Result on Data

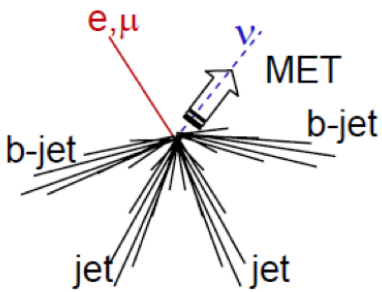
Result with 9934 selected events in dilepton channel, 5.0 fb^{-1}

$$m_t = 172.5 \pm 0.4\ (\text{stat.}) \pm 1.5\ (\text{syst.})\ \text{GeV}$$



Source	δ_{m_t} (GeV)
Fit calibration	± 0.40
Jet energy scale	$^{+0.90}_{-0.97}$
b-JES	$^{+0.76}_{-0.66}$
Lepton energy scale	± 0.14
Unclustered $\not\!\!E_T$	± 0.12
Jet energy resolution	± 0.14
b tagging	± 0.09
Pileup	± 0.11
Background normalization	± 0.05
Parton distribution functions	± 0.09
μ_R and μ_F scales	± 0.55
ME-PS matching threshold	± 0.19
Underlying event	± 0.26
Color reconnection effects	± 0.13
Monte Carlo generator	± 0.04
Total	± 1.48

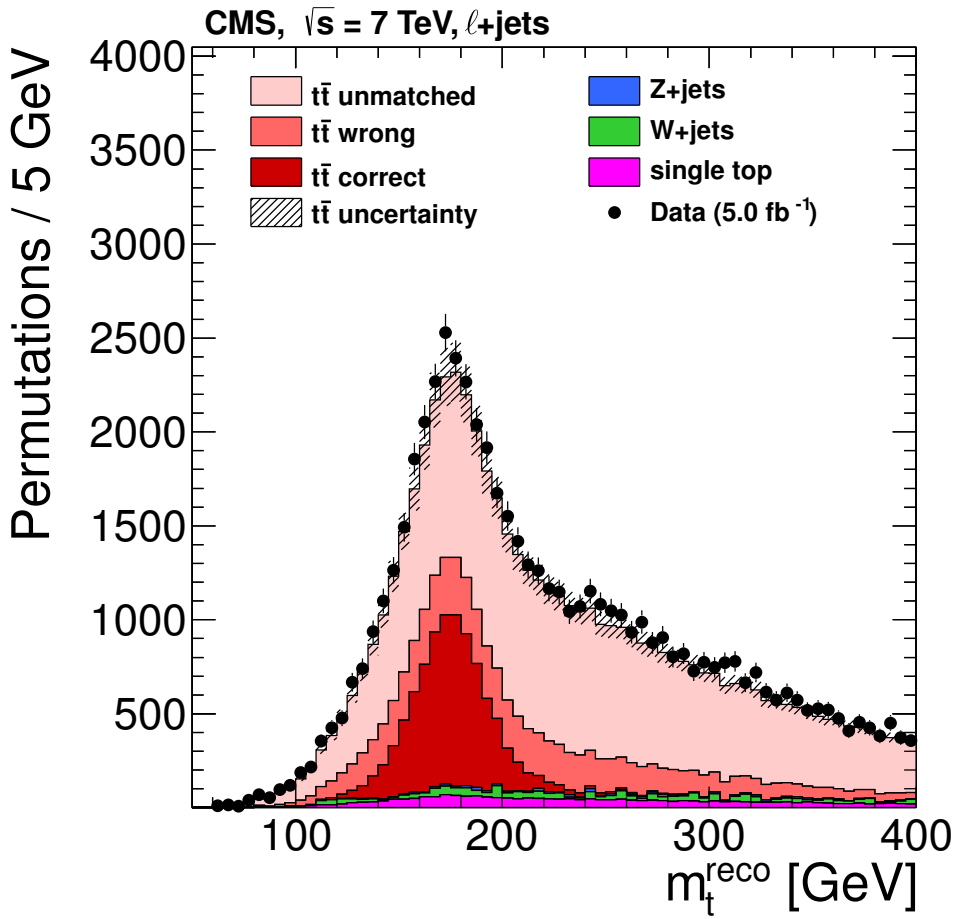
Top Mass Measurement in ℓ+jets Channel



lepton + jets

selection:

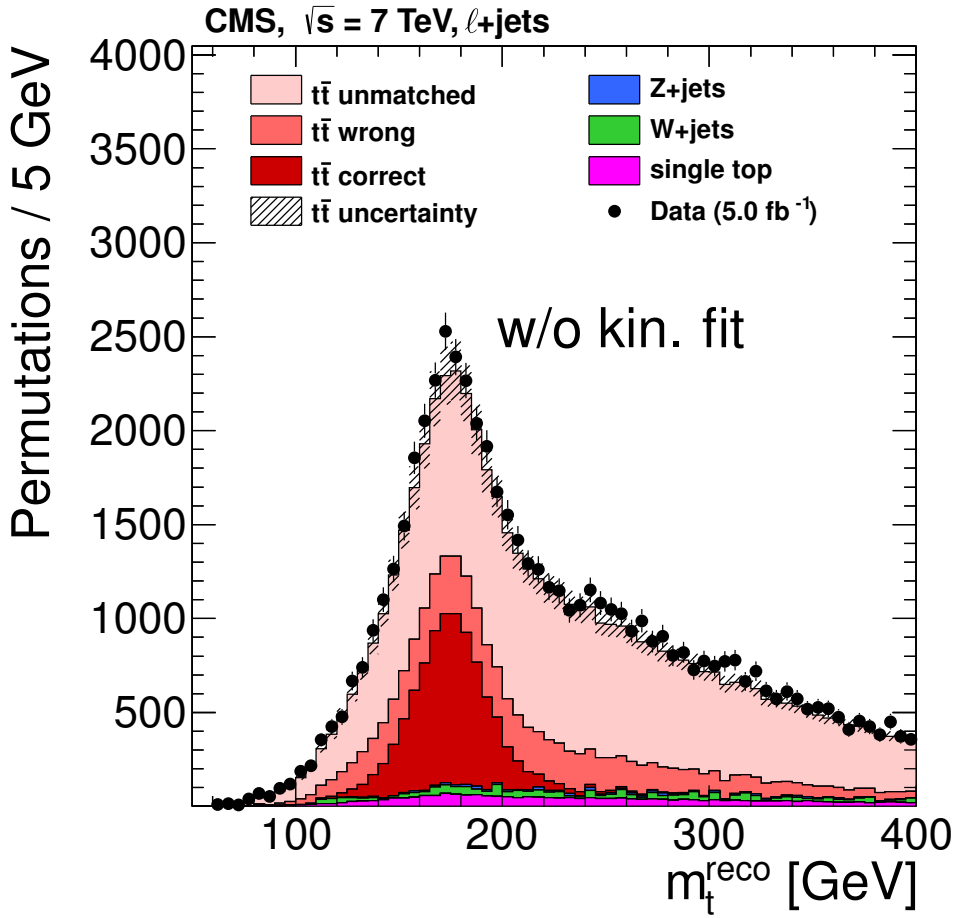
- exactly 1 isolated e,μ with $p_T > 30$ GeV,$|\eta| < 2.1$ (veto additional e, μ)
- $\geq$ 4 jets with $p_T > 30$ GeV,$|\eta| < 2.4$
- $\geq$ 2 jets with b-tag



Estimated composition: 90% $t\bar{t}$, 3% W+jets, 4% single top, 3% other

Kinematic Fit

- split in 3 permutation classes:
  - correct
  - wrong
    flipped *b*-quarks, mistags
  - unmatched
    no unambiguous match
- kinematic fit:
  - two untagged jets: $m_{jj} = 80.4$ GeV
  - lepton and neutrino ($\not\!\!E_T$) $m_{\ell\nu} = 80.4$ GeV
  - combine with two *b*-tagged jets: $m_{Pjjb_1} = m_{\ell\nu b_2}$



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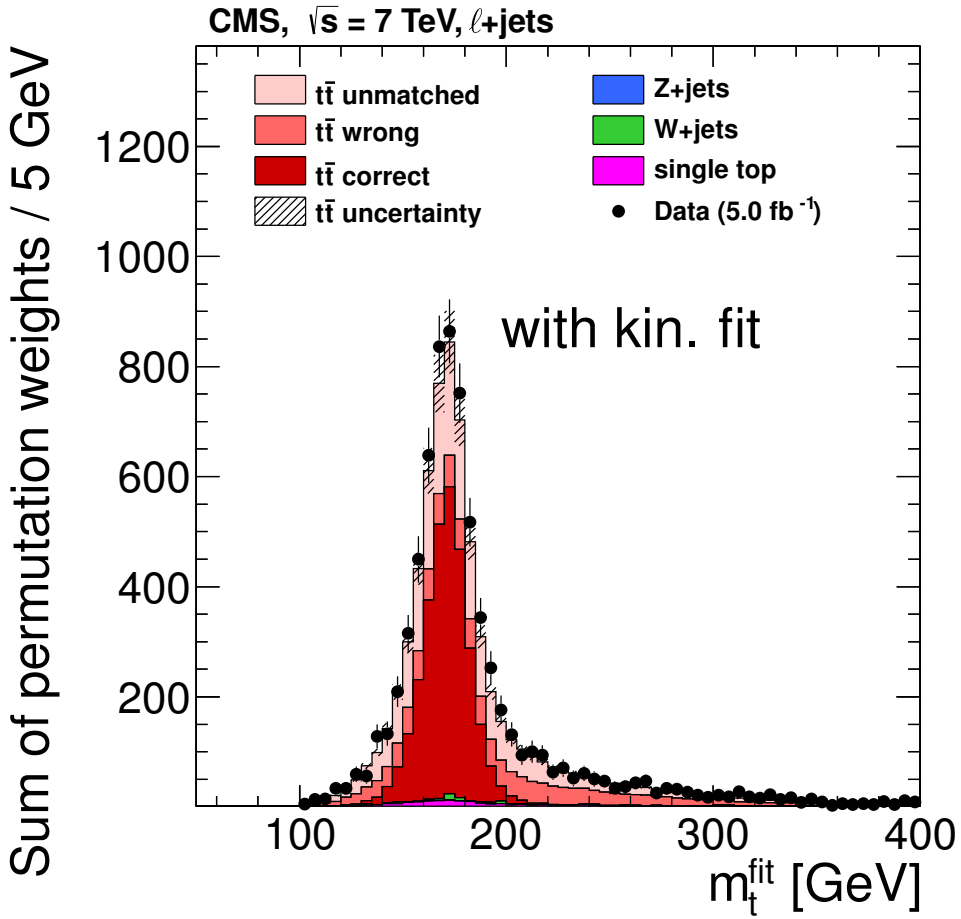
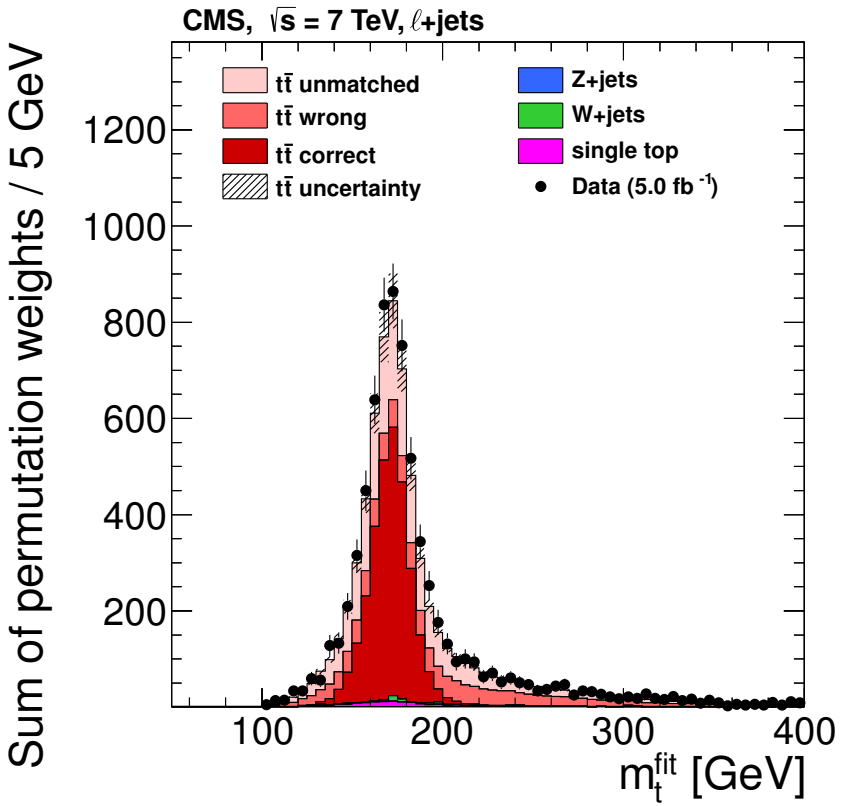


$P_{gof} > 0.2$ & weight permutations by P_{gof}:

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

Ideogram Method

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



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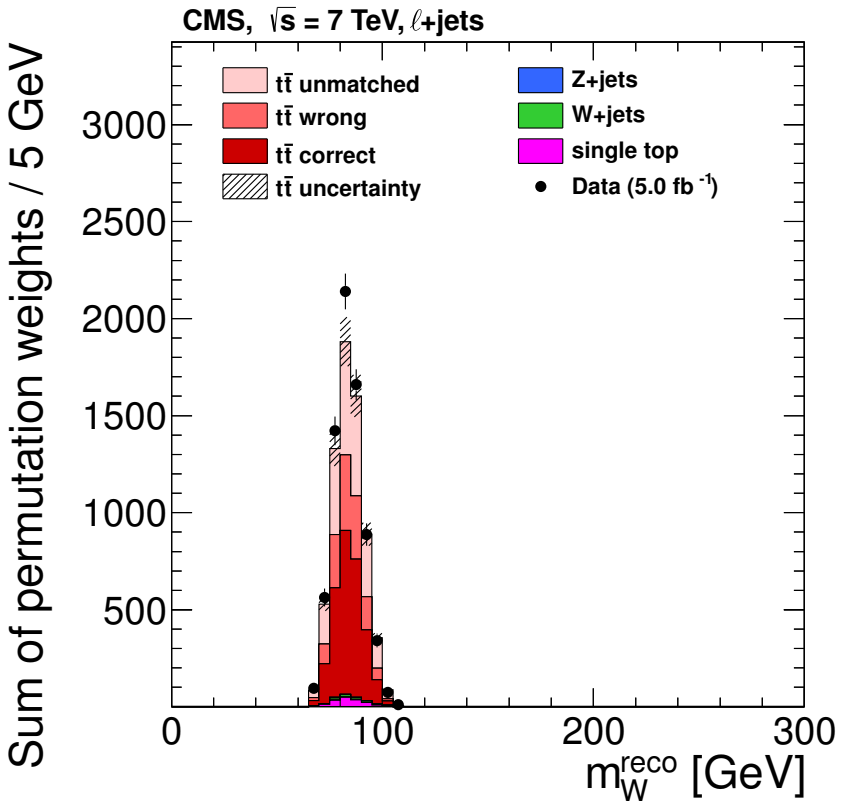

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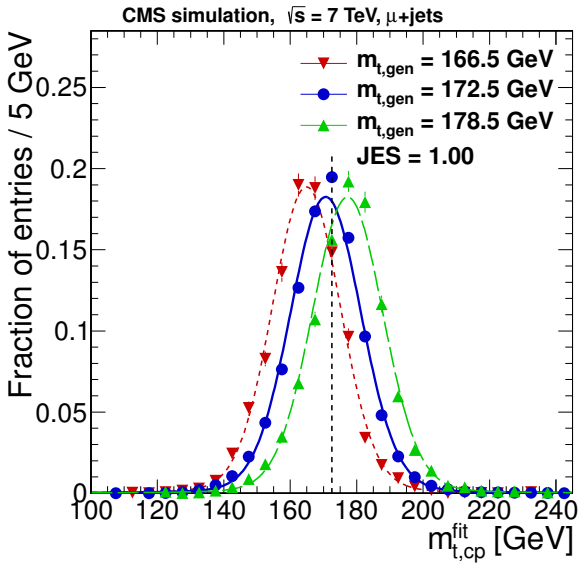
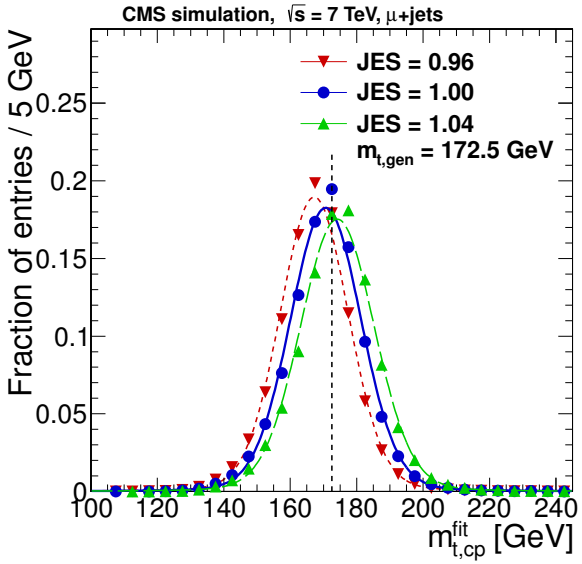
- use all allowed permutations i per event
- $P_i = \sum_j f_j P_j \left(m_{t,i}^{\text{fit}} | m_{\text{t}}, \text{JES} \right) \cdot P_j \left(m_{W,i}^{\text{reco}} | m_{\text{t}}, \text{JES} \right)$





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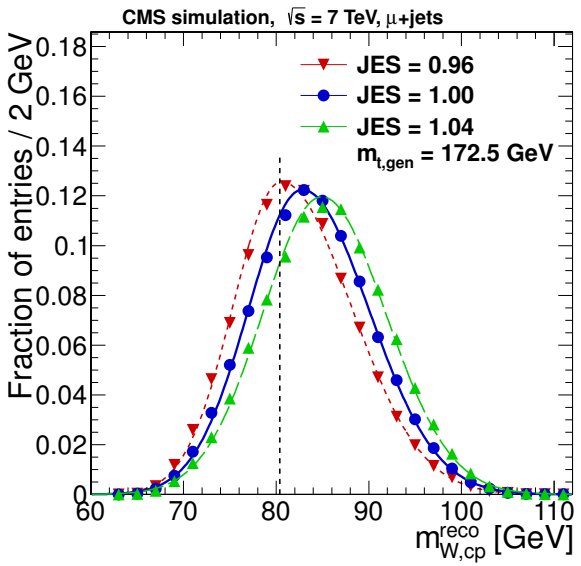
- use all allowed permutations i per event
- $P_i = \sum_j f_j P_j\left(m_{t,i}^{\text{fit}}|m_{\text{t}}, \text{JES}\right) \cdot P_j\left(m_{W,i}^{\text{reco}}|m_{\text{t}}, \text{JES}\right)$

no dependence on $m_{\text{t,gen}}$



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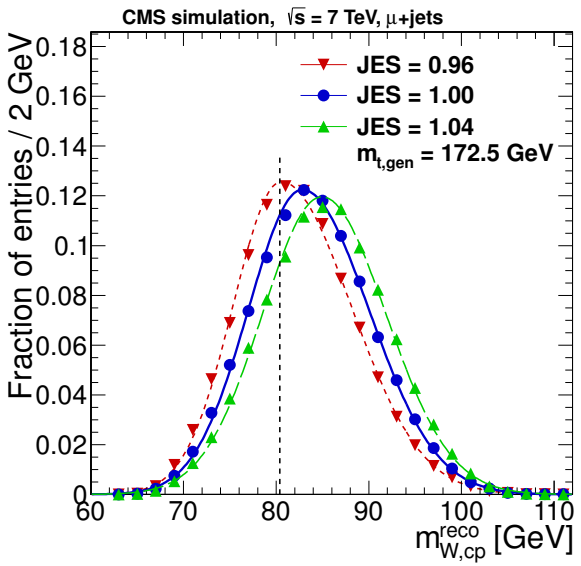
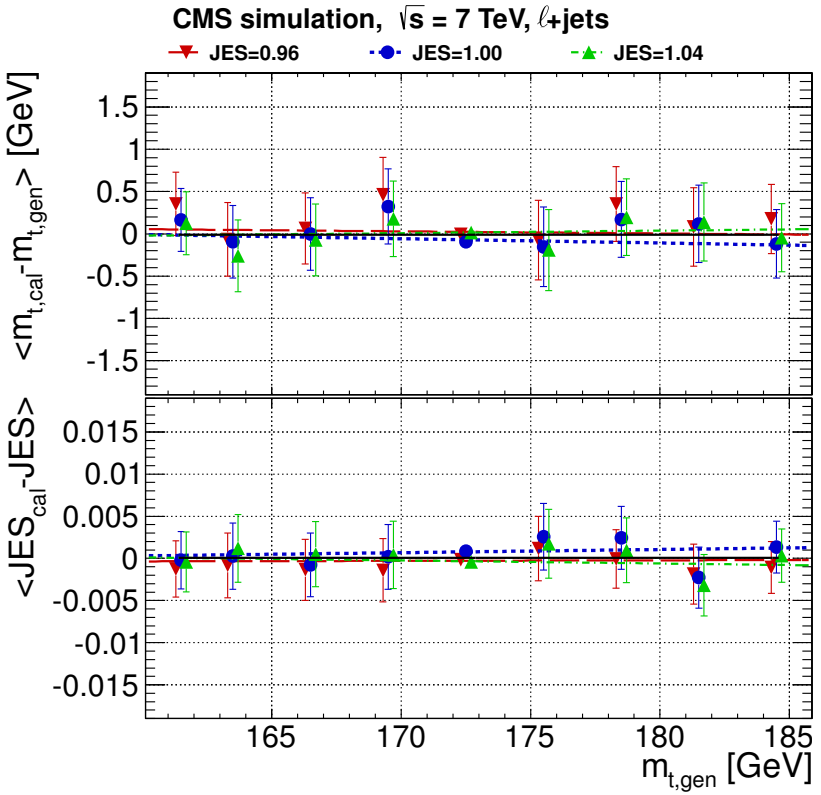
- $P_i = \sum_j f_j P_j\left(m_{t,i}^{\text{fit}}|m_{\text{t}}, \text{JES}\right) \cdot P_j\left(m_{W,i}^{\text{reco}}|m_{\text{t}}, \text{JES}\right)$
- final ideogram: combine P_i and weight event by sum of fit probabilities

no dependence on $m_{\text{t,gen}}$



Ideogram Method

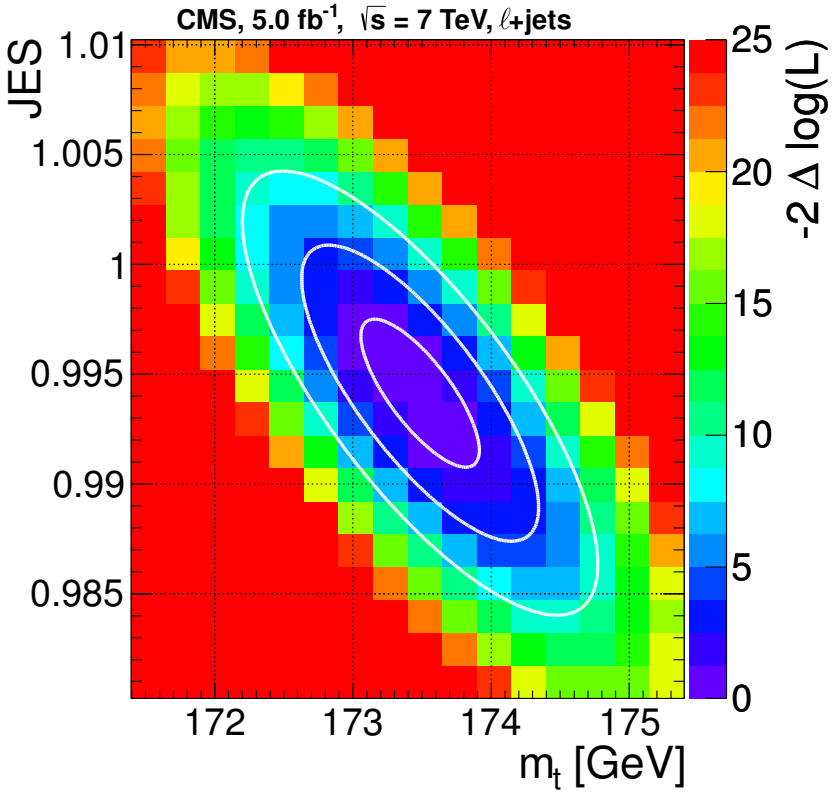
- simultaneous measurement of the top quark mass and jet energy scale (JES)
- ideogram: $P(\text{event}|m_{\text{t}}, \text{JES})$
- input: $m_{t,i}^{\text{fit}}$ and $m_{W,i}^{\text{reco}}$
- use all allowed permutations i per event
- $P_i = \sum_j f_j P_j\left(m_{t,i}^{\text{fit}}|m_{\text{t}}, \text{JES}\right)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

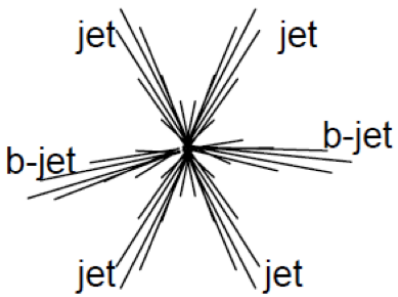
Result with 5174 selected events in ℓ+jets channel, 5.0 fb^{-1}

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



	δ_{m_t} (GeV)	δ_{JES}
Fit calibration	0.06	0.001
Jet energy scale	0.28	0.001
b-JES	**0.61**	0.000
Lepton energy scale	0.02	0.000
Unclustered $\not\!\!E_T$	0.06	0.000
Jet energy resolution	0.23	0.004
b tagging	0.12	0.001
Pileup	0.07	0.001
Non-$t\bar{t}$ background	0.13	0.001
Parton distribution functions	0.07	0.001
μ_R and μ_F scales	0.24	0.004
ME-PS matching threshold	0.18	0.001
Underlying event	0.15	0.002
Color reconnection effects	**0.54**	0.004
Total	0.98	0.008

Top Mass Measurement in all-jets Channel



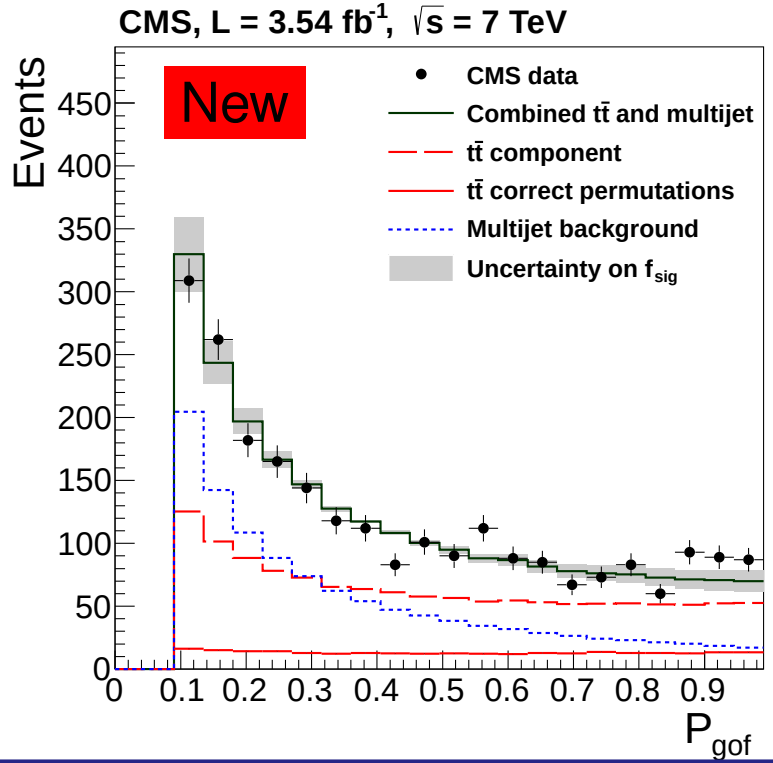
all hadronic

selection with p_T-ordered jets:

- six jets with $|\eta| < 2.4$ and $p_{T,4} > 60$ GeV, $p_{T,5} > 50$ GeV, $p_{T,6} > 40$ GeV
- ≥ 2 jets with b-tag

kinematic fit:

- 2×2 untagged jets: $m_{\mathrm{jj}} = 80.4$ GeV
- combine with two b-jets: $m_{\mathrm{jjb}} = m_{jj\bar{\mathrm{b}}}$



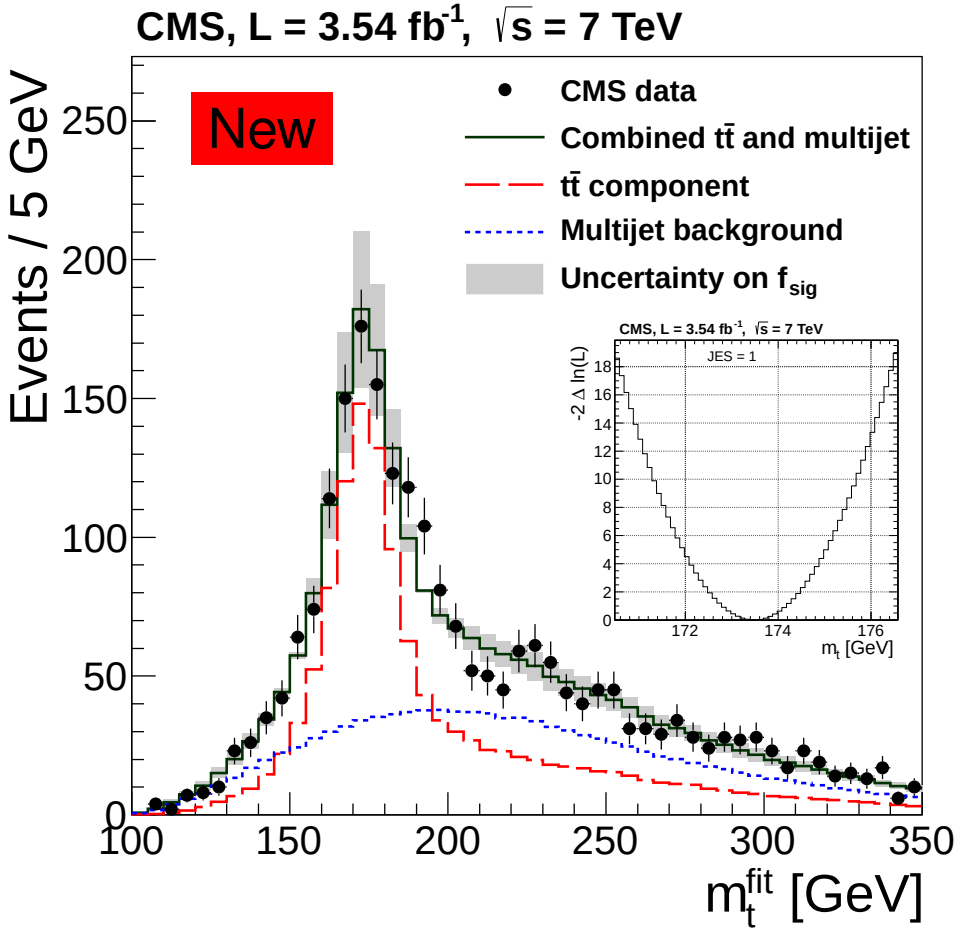
$P_{\mathrm{gof}} > 0.09$ and $\Delta R_{\mathrm{b\bar{b}}} > 1.5$: $f_{\mathrm{sig}} = 51\%$

background modeled by mixing jets from selected data events

Result on Data

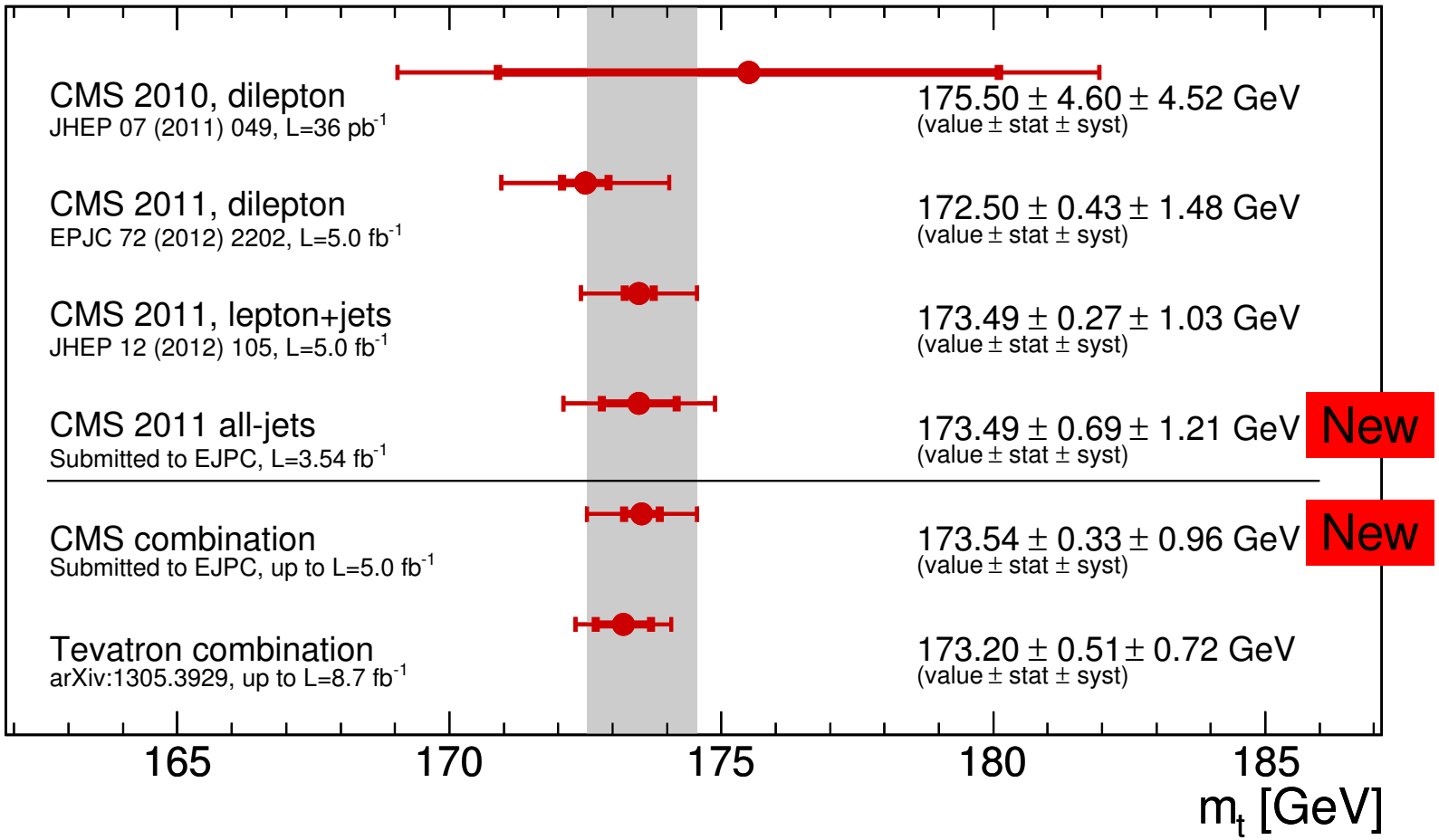
Result with 2418 selected events using an ideogram method similar to ℓ+jets, 3.54 fb^{-1}

$$m_t = 173.49 \pm 0.69\ (\text{stat.}) \pm 1.21\ (\text{syst.})\ \text{GeV}$$



	δ_{m_t} (GeV)
Fit calibration	0.13
Jet energy scale	**0.97**
b-JES	**0.49**
Jet energy resolution	0.15
b tagging	0.06
Trigger	0.24
Pileup	0.06
Multijet background	0.13
Parton distribution functions	0.06
μ_R and μ_F scales	0.22
ME-PS matching threshold	0.24
Underlying event	0.20
Color reconnection effects	0.15
Total	1.21

Combination

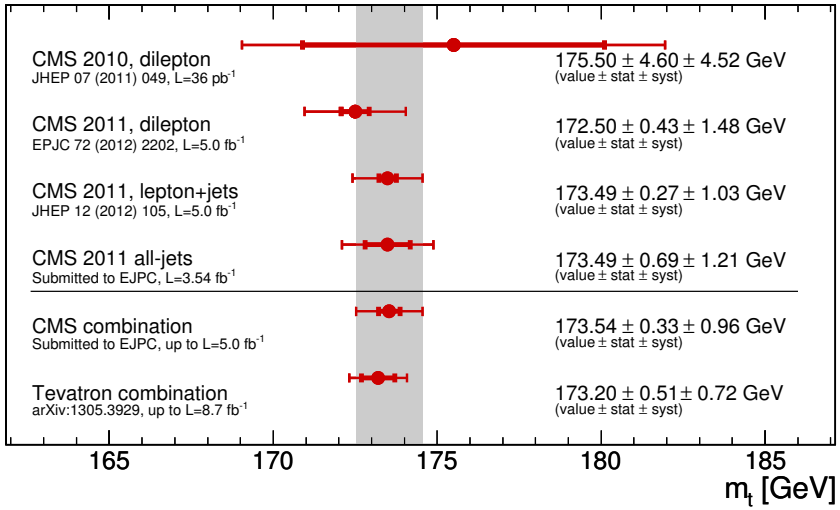


Published mass measurements with the 2011 data in all three decay channels.

Summary

top-quark mass measurements:

- in dilepton channel with 5.0 fb^{-1}
  - Analytical Matrix Weighting Technique
  - unbinned likelihood for m_t
- in lepton+jets channel with 5.0 fb^{-1}
  - good mass resolution due to kinematic fit
  - 2D ideogram for m_t and JES
- in all-jets channel with 3.5 fb^{-1}
  - large multijet background before final selection
  - after kinematic fit: 51% signal
  - 1D ideogram for m_t



Each measurement is the most precise measurement in the respective channel!

Measurements limited by systematic uncertainties → investigate alternative approaches, constrain MC with data