Top quark mass measurements with CMS

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on behalf of the CMS collaboration

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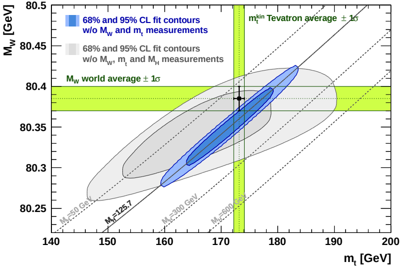
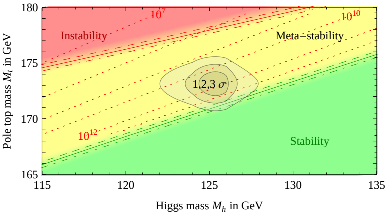
Why the top mass is important

- Precise top mass measurement is crucial for accurate tests of the SM
- The top sector is expected to be sensitive to new physics
- Also interesting in the Higgs era

The Electroweak Fit of the Standard Model (arxiv:1209.2716)



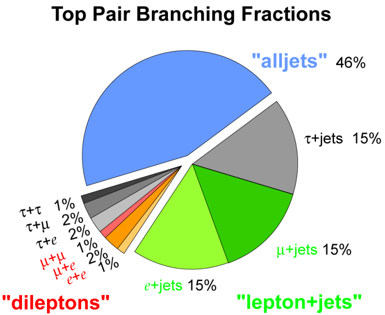
Vacuum stability in the Standard Model at NNLO (arxiv:1205.6497)



TTbar event decay channels

- Top decays most of the time to a b quark and a W boson

$$BR(t \to W^+ b) \simeq 1$$



- Dilepton channel : Low branching ratio and low background (DY)
- Lepton+Jets channel : Medium branching ratio and moderate background (W+Jets)
- Full hadron channel : High branching ratio and high background (QCD)

Dilepton channel

Analytical Matrix Weighting Technique

CMS-TOP-11-016, CERN-PH-EP-2012-222, arxiv:1209.2393, EPJC 72(2012) 2202

- 5fb^{-1} of 2011 data ($\sqrt{s} = 7\text{TeV}$) is used
- Events with two leptons and at least one b-tagged jet are selected

Processes	ee	eμ	$\mu\mu$
1 b-tagged jet			
$t\bar{t}$ signal	**598** $\pm$ 18	**2359** $\pm$ 71	**770** $\pm$ 23
$t\bar{t}$ background	10.6 $\pm$ 0.3	101.8 $\pm$ 3.1	15.7 $\pm$ 0.5
Single top	40.7 $\pm$ 1.2	172.2 $\pm$ 5.2	53.3 $\pm$ 1.6
Drell–Yan	107 $\pm$ 24	241 $\pm$ 27	143 $\pm$ 31
Dibosons	11.4 $\pm$ 0.3	39.7 $\pm$ 1.2	13.0 $\pm$ 0.4
Sum MC	767 $\pm$ 30	2914 $\pm$ 76	995 $\pm$ 39
Data	**817**	**2788**	**1032**
$\geq$ 2 b-tagged jets			
$t\bar{t}$ signal	**1057** $\pm$ 32	**4312** $\pm$ 129	**1393** $\pm$ 42
$t\bar{t}$ background	4.6 $\pm$ 0.3	37.6 $\pm$ 1.1	5.5 $\pm$ 0.5
Single top	36.8 $\pm$ 1.1	140.6 $\pm$ 4.2	48.2 $\pm$ 1.4
Drell–Yan	38 $\pm$ 11	38.9 $\pm$ 4.3	32 $\pm$ 12
Dibosons	2.9 $\pm$ 0.1	9.1 $\pm$ 0.3	2.5 $\pm$ 0.1
Sum MC	1139 $\pm$ 34	4539 $\pm$ 130	1481 $\pm$ 43
Data	**1151**	**4365**	**1474**

- For the DY background, the relative contribution is derived from data in the Z-boson mass window

Analytical Matrix Weighting Technique

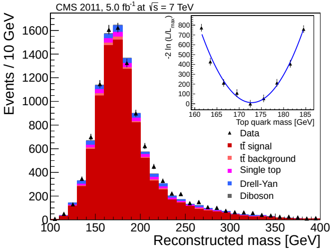
- The top-quark mass is varied between 100 and 400 GeV in 1 GeV steps
  - ν 's momenta are obtained by solving the kinematic equations
- Each solution is weighted according to top mass hypothesis and lepton momenta
- For each event, the mass hypothesis with maximum weight is chosen
  - 14% of events are discarded if weight is small or no solution
- For each value of m_t, a likelihood $\mathcal{L}$ is computed by comparing the reconstructed mass distribution in data with the simulation

Top Mass

$$m_t = 172.5 \pm 0.4(stat) \pm 1.5(syst)$$

Main Systematics

- JES : 1.0 GeV
- b-JES : 0.6 GeV



- The method is calibrated using pseudoexperiments

Mass from kinematic endpoints

CMS-TOP-11-027, CERN-PH-EP-2013-059, arxiv:1304.5783

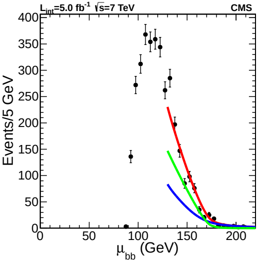
- $5\mathrm{fb}^{-1}$ of 2011 data ($\sqrt{s} = 7\mathrm{TeV}$) is used
- At least two b-tagged jets are required
- $M_{\mathrm{T2}\perp}$ for 3 subsystems are used :
  - $M^{221}_{\mathrm{T2}\perp} \equiv \mu_{bb}$: lower bound of m$_t$ for known m$_W$
  - $M^{210}_{\mathrm{T2}\perp} \equiv \mu_{ll}$: endpoint is the W boson mass at $m_\nu = 0$
  - $M^{220}_{\mathrm{T2}\perp} \equiv M_{bl}$: endpoint is $\sqrt{(m_t^2 - m_W^2)(m_W^2 - m_\nu^2)/m_W^2}$
- The masses of all final state particles can be extracted simultaneously

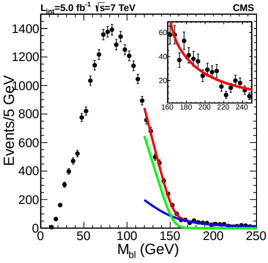
Top Mass (fixed m_W and m_ν)

$$173.9 \pm 0.9(stat)^{+1.6}_{-2.0}(syst)$$

Main Systematics

- JES : $^{+1.3}_{-1.8}\mathrm{GeV}$
- JER : $\pm 0.5\mathrm{GeV}$





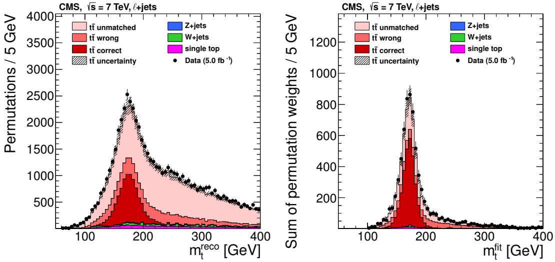
Lepton+Jets Channel

Lepton+Jets channel

CMS-TOP-11-015, CERN-PH-EP-2012-250, arxiv:1209.2319, JHEP12(2012)105

- 5fb^{-1} of 2011 data ($\sqrt{s} = 7\text{TeV}$) is used
- at least four jets and two b-tagged jets are required
  - $18k$ events are selected in data
  - 90% are $t\bar{t}$
- Ideogram method :
  - all permutations of jet assignments to top quark decays considered
  - m_W constraint on both W, equal mass of decaying heavy particle
  - permutations with low goodness-of-fit (gof) values are discarded
  - "gof" from kinematic fit is used to weight the permutations

before cut on "gof" →



← after cut on "gof"

l+jets channel, in-situ constraints

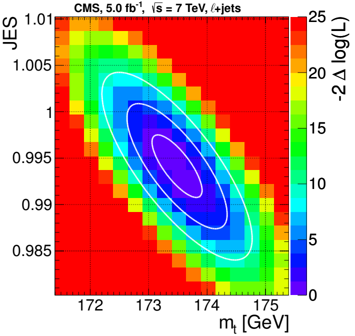
- Residual Jet energy scale and m_t fit simultaneously to reduce syst. uncertainty
- Nominal calibration validated in-situ
- Simulated pseudo-experiments used to scan possible JES/m_t points, correct possible bias

Top Mass

$$173.49 \pm 0.43(stat. + JES) \pm 0.98(syst.)$$
$$(JES = 0.994 \pm 0.003(stat.) \pm 0.008(syst.))$$

Main Systematics

- Color reconnection effects
- b-JES
- p_T and η dependent JES



Fully hadronic channel

Fully hadronic channel

CMS-TOP-11-017

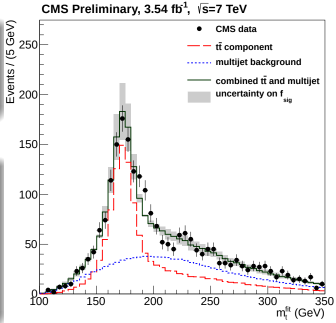
- 3.54fb^{-1} of 2011 data ($\sqrt{s} = 7\text{TeV}$) is used
- Apply a kinematic fit and choose permutation with lowest χ^2
  - $51\% t\bar{t}, 28\%$ correct permutation
- bkg modeled from data (event mixing from pre-selected sample)
- Similar ideogram method and calibration as in lepton+jets channel

Top Mass (Fixed JES)

$$m_t = 173.49 \pm 0.69(stat.) \pm 1.21(syst.)$$

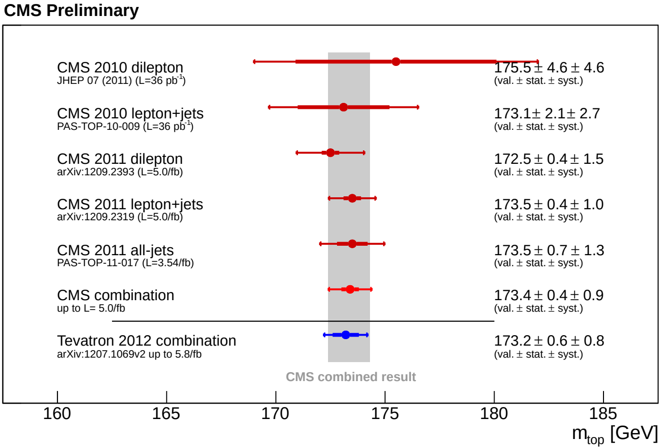
2D Fit results

$$m_t =$$
$$174.28 \pm 1.00(stat. + JES) \pm 1.23(syst.)$$
$$JES = 0.991 \pm 0.008(stat.) \pm 0.013(syst.)$$



Combination

CMS-TOP-11-018



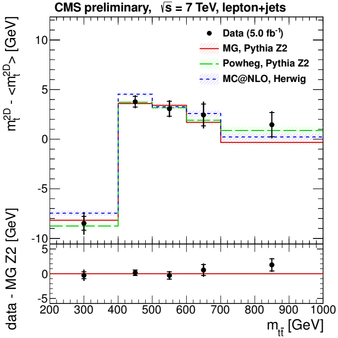
- Best Linear Unbiased Estimator method (BLUE) is used to combine the results
- The TEVATRON result is updated in March 2013 by 8.7fb^{-1} to $m_t = 173.2 \pm 0.87$

top-quark mass measurement and event kinematics

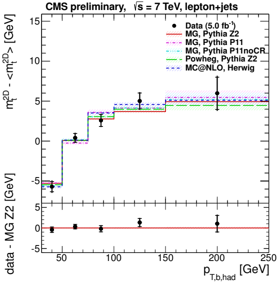
CMS-TOP-12-029 (February 2013)

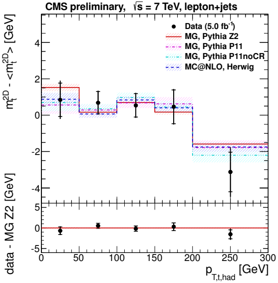
- 5fb^{-1} of 2011 data ($\sqrt{s} = 7\text{TeV}$) is used
- The same selection and method as l+jets analysis to measure the top mass (and JES simultaneously)
- Top mass vs. 12 different event kinematic variables is measured
- The variables are categorized according to their sensitivity to the sources of error

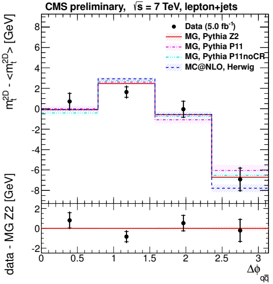
	Observable	m_t^{2D} χ^2	Ndf
Color Recon.	$\Delta R_{q\bar{q}}$	1.49	3
	$\Delta\phi_{q\bar{q}}$	2.89	3
	$p_{T,t,had}$	2.41	4
	$\lvert\eta_{t,had}\rvert$	3.17	3
ISR/FSR	H_T	2.24	4
	$m_{t\bar{t}}$	2.25	4
	$p_{t\bar{t}}$	2.18	4
	# Jets	1.56	2
b. quark kin.	$p_{T,b,had}$	2.17	4
	$\lvert\eta_{b,had}\rvert$	0.48	2
	$\Delta R_{b\bar{b}}$	8.01	3
	$\Delta\phi_{b\bar{b}}$	6.86	3



top-quark mass measurement and event kinematics







With the current precision, no mismodelling effect due to

- Colour reconnection
- ISR/FSR
- b-quark kinematics

top - antitop mass difference

CMS-TOP-12-031 (March 2013)

- 18.92fb^{-1} of 2012 data ($\sqrt{s} = 8\text{TeV}$) is used
- Test the CPT Invariance : $m_t = m_{\bar{t}}$?
- lepton+jets analysis (ideogram method) repeated for l^+ and l^- selections separately

Results

$$\Delta m_t = -272 \pm 196(stat.) \pm 122(syst.)\text{MeV}$$

Main Systematics

- b vs. $\bar{b}$ jet response
- background composition
- signal fraction
- b vs. $\bar{b}$ tagging efficiency

Summary

- CMS performs measurements of the top mass at high precision
- Combining all direct top mass measurements of the CMS experiment (except the kinematic endpoint result), the top mass is measured to be:

$$m_t = 173.36 \pm 0.38(stat.) \pm 0.91(syst.)GeV.$$

- The dependency of the top mass measurement on the event kinematics has been studied
- The measured difference of the top and anti-top mass is compatible with 0

Backup Slides

Mass from cross section

CMS-TOP-11-008

- 1.14fb^{-1} of 2011 data ($\sqrt{s} = 7\text{TeV}$) is used
- Direct mass measurements are well defined but affected by soft interactions, non-calculable in pQCD
- Beyond LO QCD predictions, the top mass depends on the renormalization scheme
- In current measurements, a quantity measured in data is compared to MC
  - mass measured corresponds to the mass definition in MC
- Extracting the top mass by comparing the measured inclusive $\sigma_{t\bar{t}}$ to fully inclusive calculations at high-order QCD provides an unambiguous definition of m$_t$

Mass from cross section (II)

- Parametrize measured and predicted $\sigma_{t\bar{t}}$ as a function of the top mass
- Extract top mass using joint-likelihood approach
- Uncertainties: Systematics on $\sigma_{t\bar{t}}$, PDF, α_s