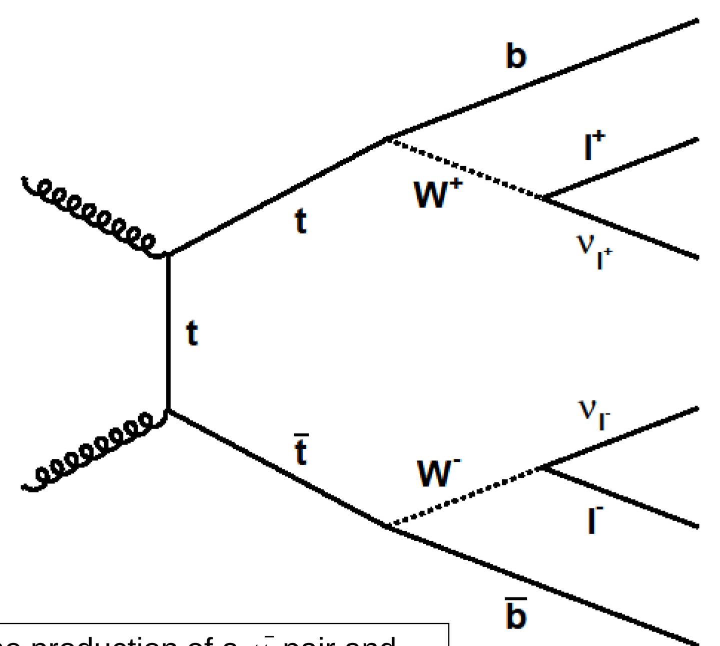
Measurement of the Top Mass in pp Collisions at √s = 7 TeV

Aram Avetisyan on behalf of the CMS Collaboration

The top quark is an important parameter of the Standard Model. Because it is the heaviest known elementary particle, its mass affects predictions of Standard Model observables and serves as an important input to electroweak fits. Thus, it can be used to constrain predictions of the properties of hypothetical particles, including the Higgs boson. In this analysis, we measure the mass of the top quark in the dilepton channel using two methods: an analytical matrix weighting technique (AMWT) and a full kinematic analysis (KINb).



The production of a $t\bar{t}$ pair and its decay in the dilepton channel.

At the LHC, most top quarks are pair-produced by gluon-gluon fusion. Unlike all other quarks, the top quark does not form color singlets and decays promptly via t→Wb.

We consider the dilepton channel to be decays wherein each of the two W bosons decays into an electron or a muon and a neutrino. Because the τ lepton appears as a jet in our detector when it decays into hadrons, we include it in the dilepton channel only when it decays leptonically.

The dilepton channel has the smallest branching fraction of all $t\bar{t}$ decays, but it is the least contaminated by background. Because it has the fewest hadrons, it is also the least sensitive to the calibration of the jet energy scale. The dominant Standard Model backgrounds for this channel are Z^0+Jets, single top in the tW channel and semi-leptonic $t\bar{t}$ decays where one of the bottom quarks decays into a lepton.

Event Selection

Two Leptons (electrons or muons)

- Prompt, isolated leptons with quality cuts
- $p_T > 20$ GeV/c
- $|\eta| < 2.5$ for electrons / 2.4 for muons
- Dilepton invariant mass M(ll) > 12 GeV/c^2 to exclude quarkonia
- Exclude 76 GeV/c^2 < M(ll) < 116 GeV/c^2 for ee and μμ to reduce Z^0+Jets
- Transverse distance from beamspot < 0.4mm for electrons / 0.2mm for muons

Two Jets (particle flow reconstruction algorithm)

- $p_T > 30$ GeV/c
- $|\eta| < 2.5$
- b-tag driven selection: rank the jets in order of p_T, but give priority to b-tagged ones if there are any
- b-tagging algorithm: track counting

Missing Transverse Energy (MET)

- MET > 30 GeV for ee and μμ
- MET > 20 GeV for eμ

Event Yields

Selection cut	Data	Total expected	$t\bar{t}$ signal	Total background
pre-tagged sample				
≥2 isolated leptons	27257	28934 ± 49	158.8 ± 0.9	28775 ± 49
opposite sign	26779	28545 ± 42	157.3 ± 0.9	28388 ± 42
Z/quarkonia-veto	2878	2873 ± 27	139.3 ± 0.8	2734 ± 27
≥2 jets	204	193 ± 2	103.1 ± 0.7	90 ± 2
$\not{E}_T$	102	$108.5 \pm 0.9\,^{+3}_{-2}$	$92.1 \pm 0.7\,^{+2}_{-1}$	$16.3 \pm 0.7\,^{+1}_{-1}$
b-tagged sample				
= 0 b-tag	19	$15.9 \pm 0.6\,^{+13}_{-8}$	$6.9 \pm 0.2\,^{+7}_{-3}$	$9.0 \pm 0.6\,^{+6}_{-5}$
= 1 b-tag	35	$40.9 \pm 0.5\,^{+17}_{-14}$	$35.7 \pm 0.4\,^{+9}_{-8}$	$5.1 \pm 0.4\,^{+8}_{-6}$
≥ 2 b-tags	48	$51.7 \pm 0.5\,^{+14}_{-16}$	$49.5 \pm 0.5\,^{+11}_{-15}$	$2.2 \pm 0.2\,^{+3}_{-1}$

Total number of events after each selection cut. The quoted uncertainties are statistical except for the last four rows which contain uncertainties for jet energy scale variation. In the last three rows, the b/mis-tagging efficiency variation is also included.

Event Reconstruction

Two neutrinos → six unknown variables

Five constraints:
- Transverse momentum conservation (2)
- Invariant mass of (lepton + neutrino) = M_W (2)
- Top and anti-top have the same mass, m_t (1)

} Under-constrained system

Analytical Matrix Weighting Technique

- Solve analytically using hypothetical values of the top mass as the missing constraint
- Smear the jets and MET many times to account for jet energy resolution
- Iterate over m_t from 100 to 700 GeV/c^2
- For every mass and every jet smearing, there are 0, 2 or 4 solutions for each of the two pairs of lepton-jet assignments
- Assign a weight to each solution based on CTEQ6.1 PDF and kinematics of the decay:

$$W = f(x)f(\bar{x})p(E^*|m_{top})p(\bar{E}^*|m_{top})$$

- Sum weights of all solutions for a given m_t
- The mass estimator for each event is the m_t with the highest total weight

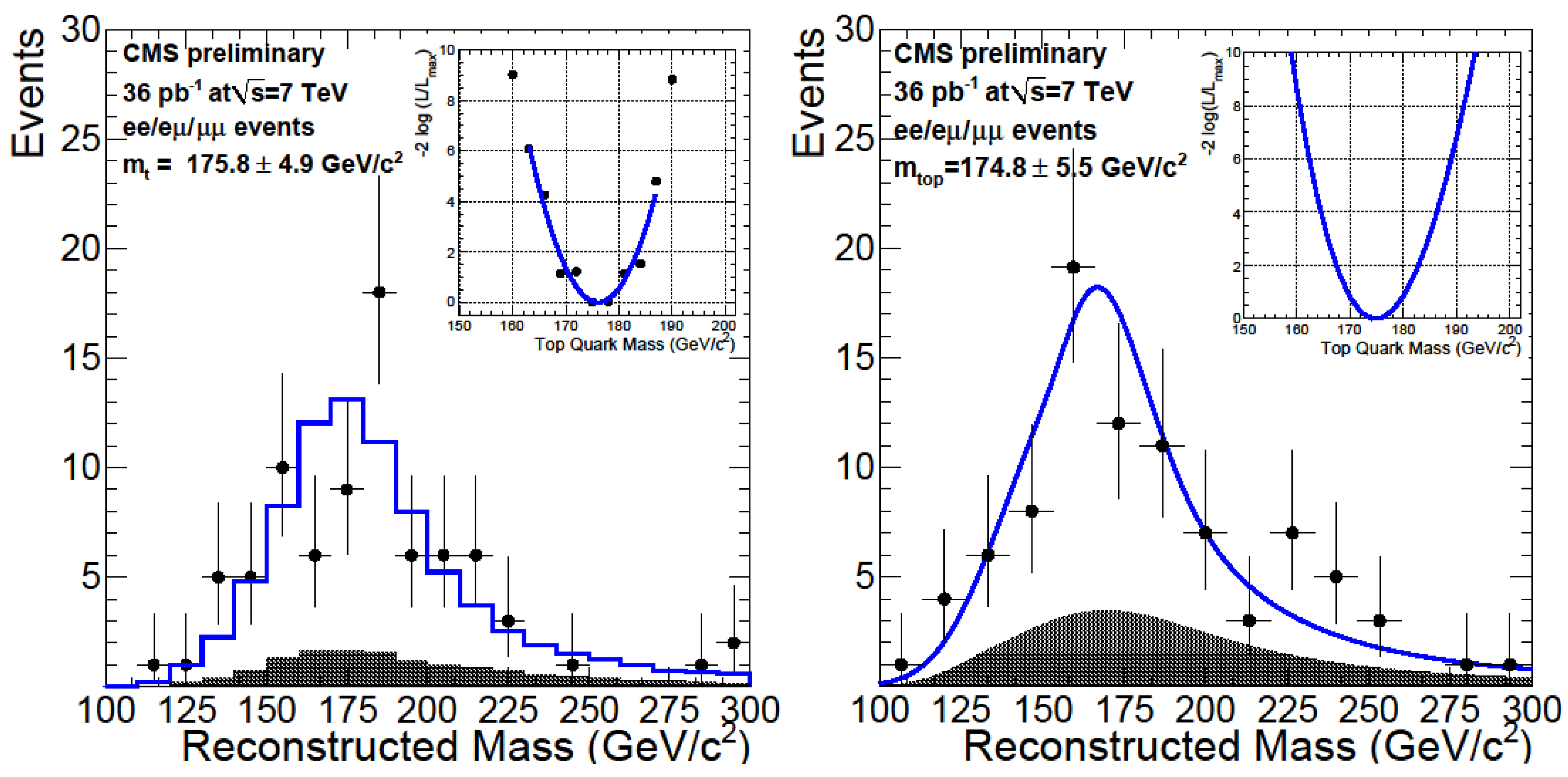
Full Kinematic Analysis

- Solve numerically using the longitudinal balance of the $t\bar{t}$ system $p_z(tt)$
- $p_z(tt)$ is drawn from simulation 10^4 times for each jet-lepton assignment
- Smear the jets and MET many times to account for jet energy resolution
- Accept solutions if the two decay legs agree to within $\Delta m_t < 3$ GeV/c^2
- The jet-lepton combination with the largest number of solutions is chosen
- Construct distribution of the number of solutions as a function of m_t
- The mass estimator for each event is the result of a Gaussian fit around the peak of the distribution

Template Fit

- Top mass is measured by a maximum likelihood fit of the mass distribution to simulated templates
  - KINb parameterizes the templates using a Gaussian+Landau function
- Signal templates of masses from 151 to 199 GeV/c^2 in intervals of 3 GeV
- Templates are restricted to a range of 100 to 300 GeV/c^2 to avoid fluctuations in the tails
- Samples are split into different templates for each b-tagging multiplicity (0, 1 or 2 b-tagged jets in the event)
- Concurrent fit of the three b-tagging multiplicities
- The single top and non-dilepton $t\bar{t}$ backgrounds are taken from simulation. The Z^0+Jets background is estimated from data using events in the Z^0 peak.
  - AMWT fixes the background to the expected value in the fit
- Minimum of -ln(likelihood) gives estimate of top mass
  - AMWT fits a quadratic polynomial over a range of 12 GeV/c^2 around the lowest point

Results of the Fit



Reconstructed mass distribution for the AMWT (left) and KINb (right) methods. Also shown is the total background plus signal model, and the background-only shape (shaded). The inset shows the likelihood as a function of m_t.

Systematic Uncertainties

Systematic uncertainties are estimated using pseudo-experiments. The dominant source of uncertainty is the jet energy scale for which we assign an uncertainty to all jets and then an additional uncertainty specific to b-jets. Sources of systematic uncertainty are listed in the table below:

Source	KINb	AMWT	Correlation factor	Combination
jet energy scale	+3.1/−3.7	3.0	1	3.1
b-jet energy scale	+2.2/−2.5	2.5	1	2.5
Underlying event	1.2	1.5	1	1.3
Pileup	0.9	1.1	1	1.0
Jet-parton matching	0.7	0.7	1	0.7
Factorization scale	0.7	0.6	1	0.6
Fit calibration	0.5	0.1	0	0.2
MC generator	0.9	0.2	1	0.5
Parton density functions	0.4	0.6	1	0.5
b-tagging	0.3	0.5	1	0.4

AMWT Result: $m_t = 175.8 \pm 4.9\,(\text{stat}) \pm 4.5\,(\text{syst})$ GeV/c^2

KINb Result: $m_t = 174.8 \pm 5.5\,(\text{stat})\,^{+4.5}_{-5.0}\,(\text{syst})$ GeV/c^2

Combination

The results of the AMWT and KINb methods were combined with the Best Linear Unbiased Estimate (BLUE) method. The statistical correlation between the two methods is determined to be 0.57 from pseudo-experiments. Systematic uncertainties common to the two methods are assumed to be 100% correlated. Pseudo-experiments are also used to determine that the result is practically unbiased: the residual bias of 0.1 ± 0.1 GeV/c^2 is corrected for in the final result.

CMS Dilepton Top Mass From 2010 Data:
$m_t = 175.5 \pm 4.6\,(\text{stat}) \pm 4.6\,(\text{syst})$ GeV/c^2

Reference: CMS Collaboration, "First measurement of the top quark mass in the dilepton channel in pp collisions at sqrt(s) = 7 TeV", **CMS-PAS-TOP-10-006**