CDF note 7937

Combined Top Quark Mass Measurement in the Dilepton Channel at CDF

The CDF Collaboration
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We present a measurement of the top mass in dilepton events from a combination of four measurements. In 340-360 pb^{-1} of integrated luminosity, we find

$$M_t = 168.2 \pm 5.3_{stat} \pm 3.3_{syst} \mathrm{GeV}/c^2.$$

A combination of the three measurements which use template methods yields

$$M_t = 170.3 \pm 6.1_{stat} \pm 3.7_{syst} \mathrm{GeV}/c^2.$$

Combining all Run1 and Run2 results gives

$$M_t = 168.1 \pm 4.7_{stat} \pm 3.5_{syst} \mathrm{GeV}/c^2.$$

I. INTRODUCTION

The mass of the top quark is a free parameter of the Standard Model; it is of great interest due to its exceedingly large value and the constraints it places on the mass of the Higgs boson. At the Tevatron, top quarks are primarily produced in pairs and decay to a W boson and b quark nearly 100% of the time. Of these decays, the "dilepton" channel, which includes events where both W bosons decay to an electron or muon, has small statistics but little background contamination. The measurement of the mass in this channel is an important and direct confirmation that events in excess over background are due to the top quark as described by the Standard Model. If the measurement is consistent with that in other channels, it can be combined to yield greater precision; a significant discrepancy from measurements in other channels could indicate contributions to the sample from new sources.

CDF has measured the top quark mass in dilepton events using a matrix-element method[1]

$$M_{top} = 165.2 \pm 6.1(\text{stat.}) \pm 3.4(\text{syst.})\ \text{GeV}/c^2$$

and three template methods, ν_η[2], P_z[3] and ν_ϕ[4]. A first method integrates over the unmeasured η of the neutrinos from W decay; the result is

$$M_{top}^{(\eta\ of\ \nu)} = 170.8^{+7.0}_{-6.7}(\text{stat.}) \pm 3.7(\text{syst.})\ \text{GeV}/c^2.$$

A second template technique integrates over the unconstrained P_z of the $t\bar{t}$ system, giving

$$M_{top}^{(P_z\ of\ t\bar{t})} = 169.9^{+7.7}_{-7.2}(\text{stat.}) \pm 4.0(\text{syst.})\ \text{GeV}/c^2.$$

A final template approach samples possible solutions for the unmeasured ϕ of the neutrinos; it gives

$$M_{top}^{(\phi\ of\ \nu)} = 169.7^{+8.9}_{-9.0}(\text{stat.}) \pm 4.0(\text{syst.})\ \text{GeV}/c^2.$$

We study the statistical and systematic correlation between the measurements and present a combination with $\approx 15\%$ greater precision than that from the single most precise measurement.

To combine several correlated measurements of a single quantity, we use an implementation of the BLUE[5] method. This requires treating the sources of uncertainty as Gaussian and evaluating the global matrix of correlations. Section 2 discusses the statistical correlations, Section 3 describes the systematic correlations and Section 4 gives the results. In Section 5, we combine the Run2 result with the Run 1 measurement.

II. STATISTICAL CORRELATION

To measure the statistical correlation between the methods, we study the measured mass in pseudo-experiments which model the expected data samples. Three of the methods (ME,ν_ϕ and P_z) use a selection which requires two identified leptons (DIL)[6] and one, ν_η, uses a looser selection which requires an identified lepton and an isolated track (LTRK)[7]. The pseudo-experiments must model the typical signal and background composition of each selection as well as the overlap between the two.

A. Pseudo-experiment Construction

We form pseudo-experiments which model the expected events before any selection is applied; each pseudo-experiment corresponds to 350 pb^{-}1. Candidates for each selection are then identified from this pool. Assuming $N_{DIL} = \epsilon_{DIL}\sigma \int dtL$ and $N_{LTRK} = \epsilon_{LTRK}\sigma \int dtL$, the number of signal events in each pseudo-experiment should correspond to the expected number of signal events. There is significant overlap in the selection of $t\bar{t}$ events.

The same prescription cannot in general be applied to include background events in these psuedo-experiments, as the expected contribution of $Z \rightarrow ll$ to the collected sample is estimated to be larger than the simple prediction from simulated events, breaking the relation $N = \epsilon\sigma \int dtL$. In addition, the statistics of the background samples represent considerably smaller integrated luminosity. For backgrounds other than fake leptons, we model the contributions of background to the DIL pseudo-experiment by selecting $< N_{DIL} >$ events from the pool of events accepted by DIL.

M_t	ME	ν_η	ν_ϕ	P_z
165	1.000			
	0.206	1.000		
	0.471	0.262	1.000	
	0.308	0.154	0.372	1.000
170	1.000			
	0.116	1.000		
	0.429	0.253	1.000	
	0.398	0.138	0.347	1.000
175	1.000			
	0.158	1.000		
	0.499	0.245	1.000	
	0.371	0.184	0.377	1.000

TABLE I: Statistical correlation between methods at varying masses.

The contribution to the LTRK pseudo-experiment is constructed as the union of those events in the DIL psuedo-experiment which pass the LTRK selection, and $< N_{LTRK} - N_{LTRK \cap DIL} >$ from the pool of events accepted only by LTRK. $N_{LTRK \cap DIL}$ is the number of events expected in common, which is estimated from the number events selected in common in simulated events. Fake backgrounds are assumed to be uncorrelated; studies in simulated events suggest that there is very little overlap in the category of fake events which would provide a contribution to both samples.

B. Correlation Coefficient

We measure the pair-wise linear correlation coefficient ρ,

$$\rho_{xy} = \frac{N\sum xy - \sum x \sum y}{\sqrt{(N\sum x^2 - (\sum x)^2)}\sqrt{(N\sum y^2 - (\sum y)^2)}}$$

between the residuals $M_t^{res} = M_t^{meas} - M_t^{true}$.

C. Statistical Correlation between Methods

In pseudo-experiments as constructed as described in Section 2.1, we measure the statistical correlation between the four Run2 methods. Table 1 compiles the correlations between measurement residuals in samples with $M_t = 165, 170, 175$ GeV.

D. Iterative Combination

The method of combination described in Ref [5] assumes that there is no correlation between the measured statistical error and the measured quantity. The measurement of the top quark mass yields an average error which is a fixed fraction of the mass; thus, larger measurements will on average have larger errors. The combination will therefore tend to be biased towards smaller values of mass. To remove this bias, we perform an iterative procedure in which the errors of the measurements are extrapolated from their values at the individual measured masses to the combined mass.

III. SYSTEMATIC CORRELATION

The systematic uncertainty in each measurement are categorized following the definitions constructed to aid combination of CDF and DZero's mass measurements[8]. We assume that each category is either 0% or 100% correlated. Table 9 gives the size of the uncertainty in each channel for each measurement, and indicates the assumption regarding the correlations.

Source	ME	ν_η	P_z	ν_ϕ	Correlation
iJES					1.0
aJES					1.0
bJES	0.5	0.6	0.6	0.7	1.0
cJES	2.2	1.0	2.3	2.3	1.0
dJES	0.0	0.0	0.0	0.0	1.0
rJES	1.4	2.4	2.2	2.6	1.0
Signal	0.9	1.1	0.8	0.9	1.0
MC	0.8	0.5	0.6	0.7	1.0
UN/MI					1.0
BG	0.8	1.9	1.6	1.5	1.0
Fit	1.3	1.3	1.3	0.0	0.0
Total	3.4	3.7	4.0	4.0	

TABLE II: Correlations between systematic uncertainties.

Method	Total Corr Matrix				Weight	Pull
ME	1.00				44%	-0.7
ν_η	0.25	1.00			40%	0.5
ν_ϕ	0.52	0.37	1.00		-1%	0.2
P_z	0.49	0.29	0.46	1.00	17%	0.2

TABLE III: Total correlation matrix, weight and pull of each method in the combined Run2 result.

IV. RUN2 RESULTS

The combined Run2 result is:

$$M_t = 168.2 \pm 5.3_{stat} \pm 3.3_{syst}.\mathrm{GeV}/c^2$$

The weights and pulls of each measurement can be found in Table 10. The systematic error is broken down by category in Table 11.

Combining just the template results gives a measurement of

$$M_t^{template} = 170.3 \pm 6.1_{stat} \pm 3.7_{syst}.\mathrm{GeV}/c^2$$

The weights and pulls of each template measurement can be found in Table IV. The systematic error is broken down by category in Table 12.

V. RUN1+RUN2 RESULTS

We combine the four Run2 measurements with the CDF Run1 dilepton mass measurement [9]. The statistical uncertainty is uncorrelated, and we follow the breakdown of the systematic error and uncertainty from [8]. Specifically, we assume 100% correlation between Run1 and Run2 in b-jet energy scale (bJES), fragmentation, out-of-cone corrections

Method	Total Corr Matrix			Weight	Pull
ν_η	1.00			51%	0.1
ν_ϕ	0.37	1.00		13%	-0.1
P_z	0.29	0.46	1.00	36%	-0.1

TABLE IV: Total correlation matrix, weight and pull of each method in the combined template result.

Source	Template Comb.	Run2 Comb.	Run1+Run2 Comb.
iJES	0.0	0.0	0.0
aJES	0.0	0.0	0.0
bJES	0.6	0.6	0.6
cJES	1.7	1.8	1.9
dJES	0.0	0.0	0.1
rJES	2.3	1.9	2.0
Signal	1.0	0.9	1.3
MC	0.6	0.7	0.6
UN/MI	0.0	0.0	0.0
BG	1.7	1.3	1.2
Fit	0.8	0.8	0.6
Total	3.7	3.3	3.5

TABLE V: Final systematic errors for the Run2 result and the template combination by category.

Method	Total	Corr Matrix	Weight	Pull
Run 2	1.0		82%	0.07
Run 1	0.20	1.0	18%	-0.07

TABLE VI: Total correlation matrix, weight and pull in the combined Run1+Run2 result.

(cJES), calorimeter response, relative corrections and multiple interactions (rJES), signal modelling, background modelling, and generator uncertainty; we assume 0% correlation between Run1 and Run2 in calibration samples (dJES) and in method if fit.

The combined result for Run1+Run2 is

$$M_t = 168.1 \pm 4.7 stat \pm 3.5_{syst}.\mathrm{GeV}/c^2$$

The weights and pulls of each measurement can be found in Table V. The systematic error is broken down by category in Table IV.

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[2] S. Sabik *et. al.*, Measurement of the Top Quark Mass using the Neutrino Weighting Algorithm on Dilepton Events at CDF, CDFNote 7303

[3] T. Maki *et. al.* Top Quark Mass from a Full Kinematic Analysis using P_z of $t\bar{t}$ in Gen5, CDFNote 7797

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[5] A. Valassi, Nucl.Instrum.Meth.A500:391-405,2003

[6] A Measurement of the tt cross-section using dileptons, CDFNote 6830

[7] C. Mills *et. all.* A Measurement of the Top Dilepton Cross-section Using The Tight Lepton and Isolated Track Sample, CDFNote 7679

[8] Combination of CDF and D0 results on the top quark mass, CDFNote 7727, hep-ex/0507091.

[9] F. Abe *et. al.*, The CDF Collaboration, Phys. Rev. Lett. **82**, 271 (1999)