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A Top Mass Measurement in Dilepton Channels with m_{T2}

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Abstract

We report a measurement of the mass of the top quark with 3.4 fb^{-1} of data using the template method in Dilepton channel. Both two-dimensional and one-dimentional probability density functions(PDF) in this channel are derived using the Kernel Density Estimation. With the variable m_{T2} and and extracted top quark mass from the neutrino weighting algorithm the top quark mass is measured to be $\mathrm{M_{top}}$=169.3 ± 2.7 (stat.) ± 3.2 (syst.) GeV/c^2 = 169.3 ± 4.2 GeV/c^2 in the Dilepton channel with two-dimentional PDF(M_t^{NWA} and m_{T2}); with the m_{T2} variable alone(one-dimentional PDF), the measurement is $\mathrm{M_{top}}$=168.0 $^{+4.8}_{-4.0}$ (stat.) ± 2.9 (syst.) GeV/c^2 = 168.0 $^{+5.6}_{-5.0}$ GeV/c^2.

1 Introduction

We present the measurement of top quark mass in Dilepton channel with 3.4 fb^{-1} of data using the template method. We introduced a variable m_{T2} in CDF note9661 [1], and we mainly study the power of m_{T2} in this paper by comparing some results involved with m_{T2} with that without it. The method of current analysis is similar to our earlier analysis with 2.7 fb^{-1} [2]; the event selection here is the same as what was used in CDF note9549 [2] except we have requirement for m_{T2} here. Detail about the definition of m_{T2} in our analysis can be found in CDF note [1], so is the validation of data with 3.4 fb^{-1}. We won't be too specific about the method we use in this note since it can be found in CDF note9661 [1]. Instead, we directly jump to study of statistical power of m_{T2} by running a few pseudo experiments. Further, by calculating the systematic uncertainties we are able to compare the strength of m_{T2} with others in measurement top quark mass. Finally, the top quark mass measured using data with be shown.

2 Bias checks

In order to study the statistical power of m_{T2} and other variables, we first study the bias check for each of them, as a result of which we run checks with various $\mathrm{M_{top}}$values to investigate possible biases in our method. For each point, the background pseudodata is drawn with JES having the same value as the signal pseudodata. The number of background events is obtained by applying the boundary cut. The number of signal events is obtained using the theoretical cross section at $\mathrm{M_{top}}$=175 GeV/c^2, σ = 6.7 pb. Uncertainties are given by results from the bootstrap method, described in Ref. [7]. We present fit results using $\Delta_{\mathrm{JES}} = 0$ only.

Five kinds of measurement of top quark mass are done in this analysis: $M_t^{NWA}+m_{T2}$ and $M_t^{NWA}+H_T$; $\mathrm{M_{top}}$ only, H_T only and m_{T2} only. Thus we have five bias checks repectively. as shown in Fig. 1 and Fig. 2. These plots tell us how much we should correct the results of top mass if needed.For Dilepton measurement with $M_t^{NWA}+m_{T2}$, $M_t^{NWA}+H_T$, $\mathrm{M_{top}}$ only and H_T only, the ratios of bias to their corresponding errors are less than three sigma, so the top mass results of these measurements are not corrected. But for the Dilepton channel with m_{T2} only, we have an average bias of -0.26 ± 0.10 GeV/c^2 and we apply this correction to the Dilepton mass measurement with m_{T2} only. The pull widths are shown in Fig. 3. They are defined as the RMS of the pull distributions, which use asymmetric uncertainties. We correct the statistical uncertainty of the top mass measurement by the average pull width. Figures 5 and 7 show the expected statistical uncertainties estimated by pseudo experiments.

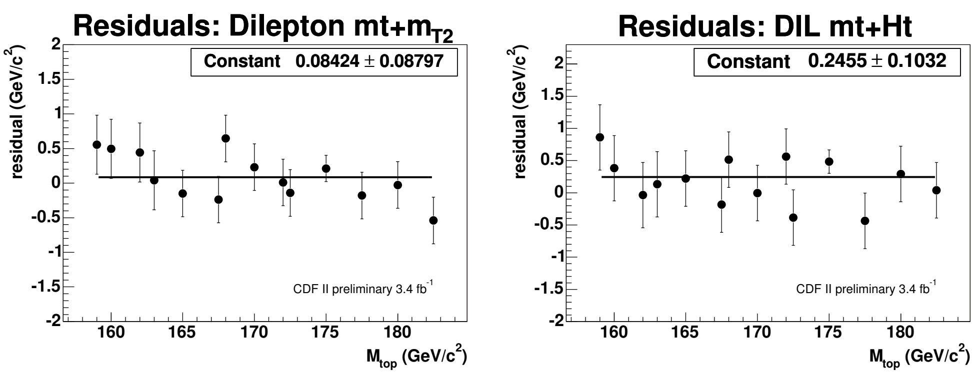

Figure 1: Bias in the fitted top quark mass for Dilepton using $M_t^{NWA}+m_{T2}$ fit (left) and Dilepton using $M_t^{NWA}+H_T$ (right) . Lines represents fit to constants using JES = 0.

From the results of bias check for all five measurements, we are able to directly compare the statistical powers of variables and combinations of them. As shown in Fig. 9(done by Pseudo Experiments), we conclude that m_{T2} has a better statistical power than that of H_T.

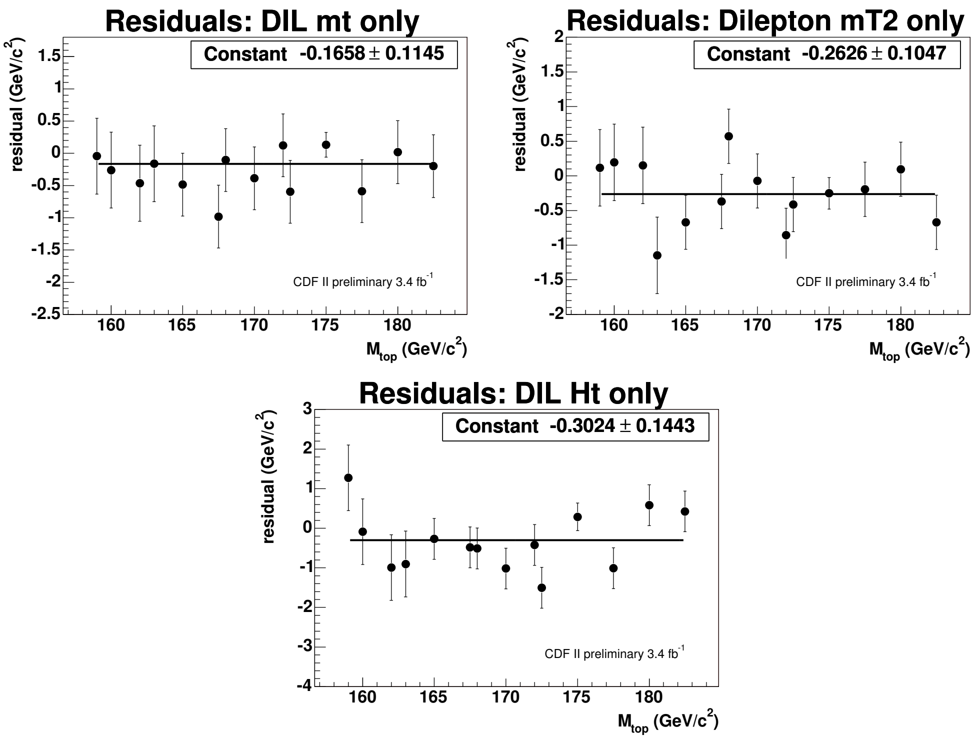

Figure 2: Bias in the fitted top quark mass for Dilepton only using M_t^{NWA} fit (top left), Dilepton only using m_{T2} fit (top right) and Dilepton only using H_T fit (bottom). Lines represents fit to constants using JES = 0.

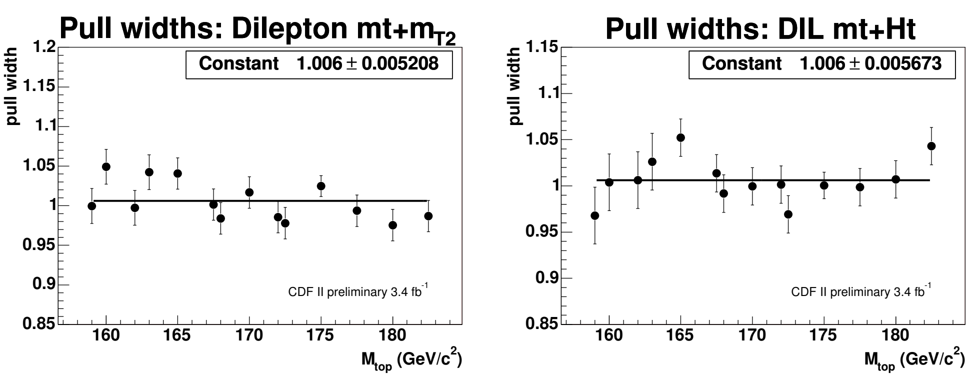

Figure 3: Width of the pull distribution for fitted top quark mass for Dilepton using $M_t^{NWA} + m_{T2}$ fit (left) and Dilepton using $M_t^{NWA} + H_T$ fit (right) . Lines represents fit to constants using JES = 0.

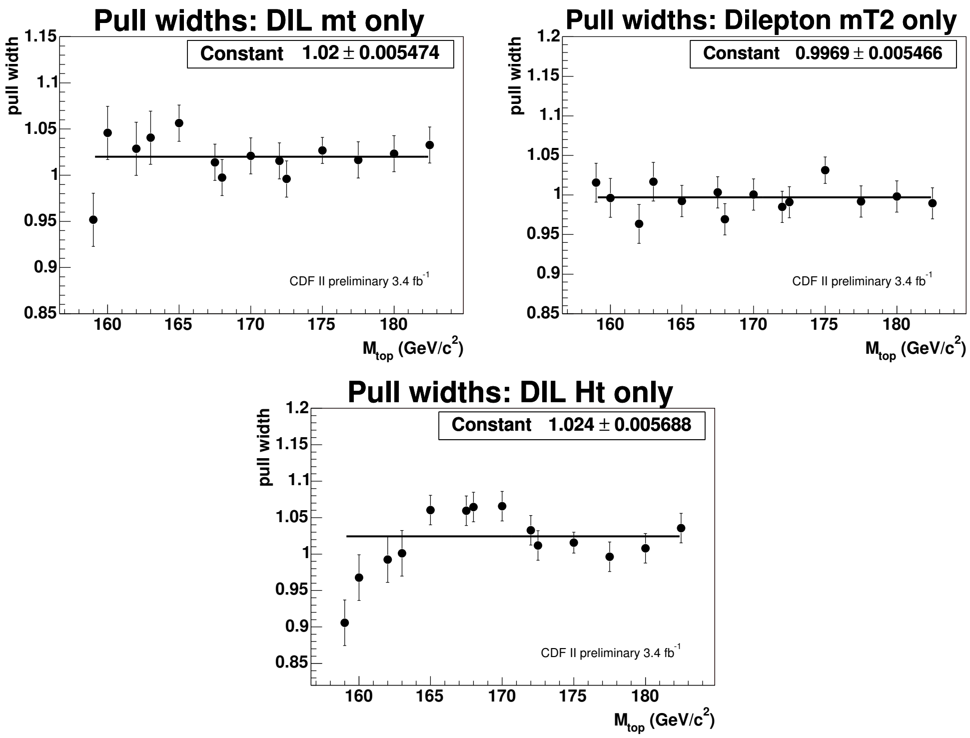

Figure 4: Width of the pull distribution for fitted top quark mass for Dilepton only using M_t^{NWA} fit (top left), Dilepton only using m_{T2} fit (top right) and Dilepton only fit using H_T (bottom). Lines represents fit to constants using JES = 0.

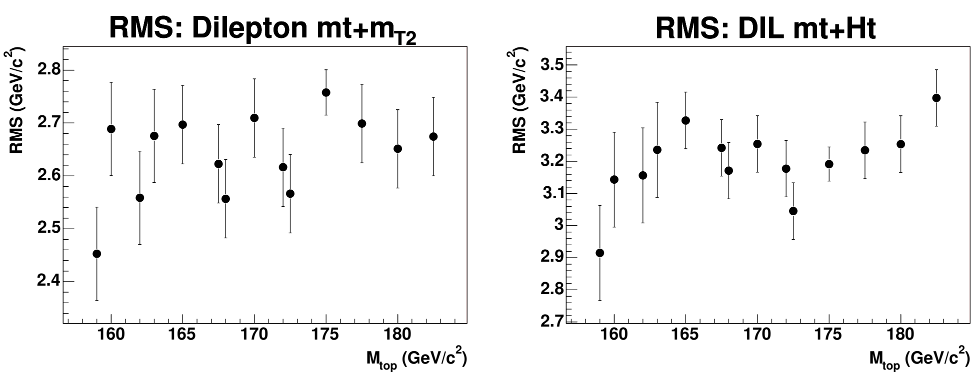

Figure 5: Expected statistical uncertainties (RMS) in the top quark mass measurement for Dilepton using $M_t^{NWA} + m_{T2}$ fit (left) and Dilepton using $M_t^{NWA} + H_T$ fit (right) .

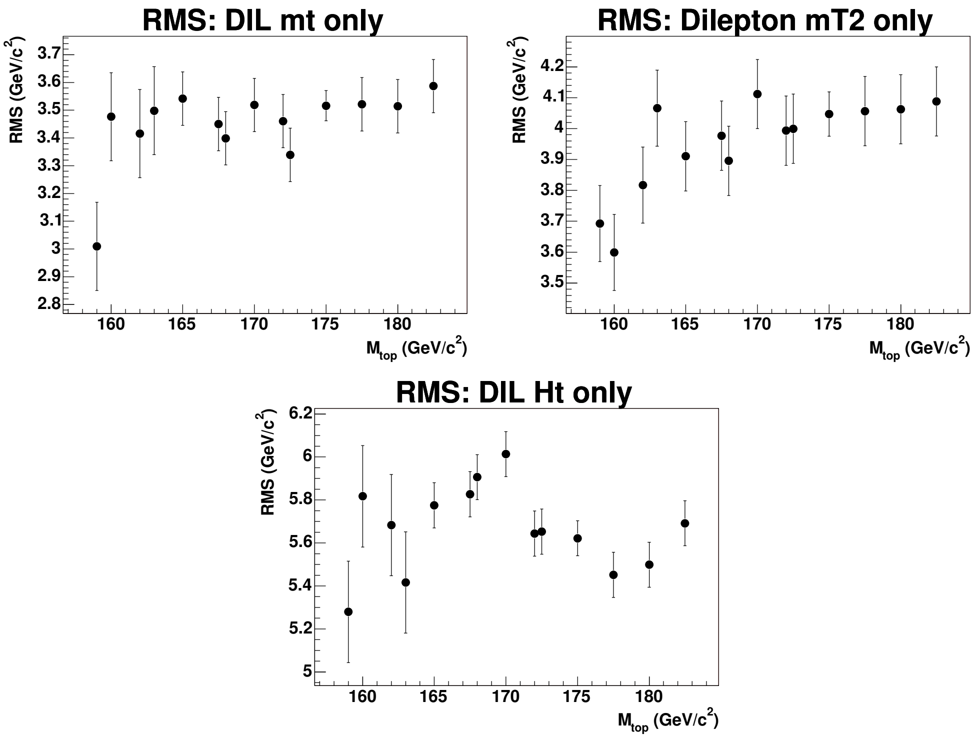

Figure 6: Expected statistical uncertainties (RMS) in the top quark mass measurement for Dilepton only using M_t^{NWA} fit (top left), Dilepton only using m_{T2} fit (top right) and Dilepton only fit using H_T (bottom).

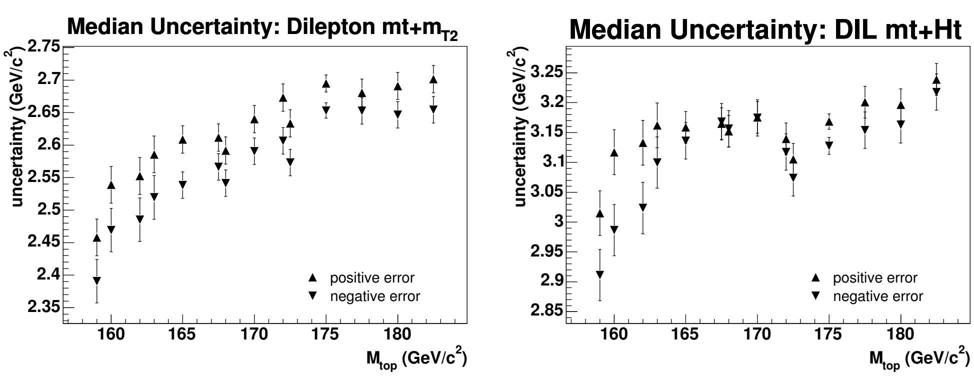

Figure 7: Expected statistical uncertainties (median asymmetric errors) in the top quark mass measurement for Dilepton using M_t^{NWA}+m_{T2} fit (left) and Dilepton using M_t^{NWA}+H_T fit (right) .

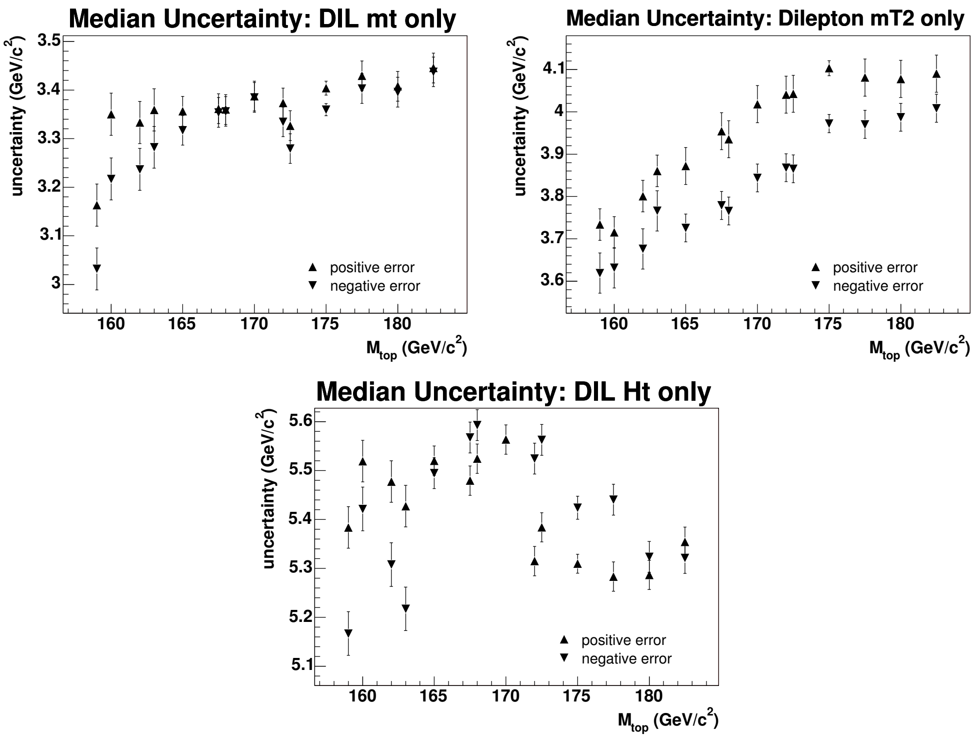

Figure 8: Expected statistical uncertainties (median asymmetric errors) in the top quark mass measurement for Dilepton only using M_t^{NWA} fit (top left), Dilepton only using m_{T2} fit (top right) and Dilepton only fit using H_T (bottom).

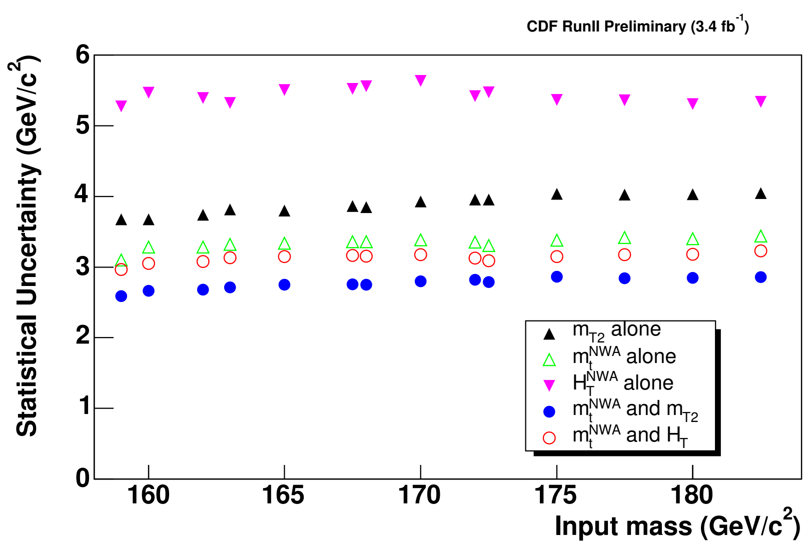

Figure 9: Comparison of expected statistical uncertainties in the top quark mass measurement for Dilepton channel.

Table 1: Summary of Jet Energy Scale systematic uncertainties. All numbers have units of GeV/c^2.

Sample	DIL (M_t^{NWA}+ H_T) M_{top}	DIL (M_t^{NWA}+ m_{T2})M_{top}	DIL(M_t^{NWA}) M_{top}	DIL (H_T) Δ_{JES}	DIL (m_{T2}) M_{top}
Pythia M_{top}=175 (ttkt75)	175.48	175.21	175.13	175.29	174.75
ttkt75 +L1	176.16	175.81	175.80	175.99	175.18
ttkt75 -L1	174.86	174.45	174.45	174.58	174.03
ttkt75 +L5	177.67	177.16	177.32	177.64	176.62
ttkt75 -L5	173.23	173.04	172.78	172.90	172.72
ttkt75 +L7	178.01	177.27	177.69	178.13	176.17
ttkt75 -L7	173.10	173.11	172.65	172.66	173.33
ttkt75 +L4	175.57	175.19	175.18	175.44	174.71
ttkt75 -L4	175.45	175.08	175.07	175.35	174.70
ttkt75 +L6	175.73	175.46	175.33	175.61	174.95
ttkt75 -L6	175.06	174.84	174.64	175.02	174.50
ttkt75 +L8	175.97	175.53	175.59	175.86	174.93
ttkt75 -L8	174.97	174.74	174.54	174.88	174.35

3 Systematic Uncertainties

We examine a variety of effects that could systematically shift our measurement.

Jet Energy Scale: To evaluate the jet energy systematic we construct signal and background samples where we have shifted all the jets in the sample by one σ_{Li} up or down, where σ_{Li} corresponds to systematic uncertainty due to particular jet energy scale effect. The shifts to jet energies are performed before the selection to properly model the effects on the shapes due to events entering and leaving the samples. We construct such samples for all the jet correction level uncertainties. We run pseudoexperiment drawing signal and background pseudodata from the shifted samples. The half difference between mean fitted masses resulting from positive and negative shifts are taken as jet energy systematic due to effect described by a particular jet correction level. Table 1 summarizes the results.

The total residual JES uncertainty is 3.04 GeV/c^2 in the Dilepton using $M_t^{NWA} + m_{T2}$ fit, 3.43 GeV/c^2 in the Dilepton using $M_t^{NWA} + H_T$ fit, 3.51 GeV/c^2 in Dilepton only using M_t^{NWA} fit, 2.58 GeV/c^2 in Dilepton only using m_{T2} fit and 3.73 GeV/c^2 in Dilepton only using H_T fit.

b-jet Energy Scale: We vary the energy of b jets, which have different fragmentation than light quark jets, as well as semi-leptonic decays and different color flow, resulting in a b-JES

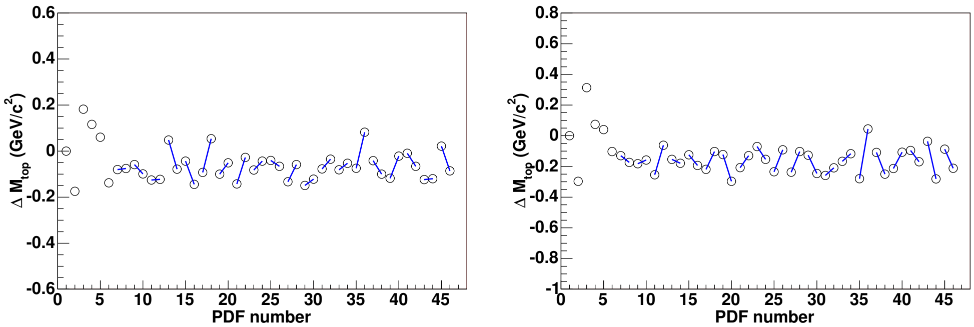

Figure 10: Results from reweighting ttkt75 for PDF systematics for Dilepton using $M_t^{NWA}+m_{T2}$ fit (left) and Dilepton using $M_t^{NWA}+H_T$ fit (right) .

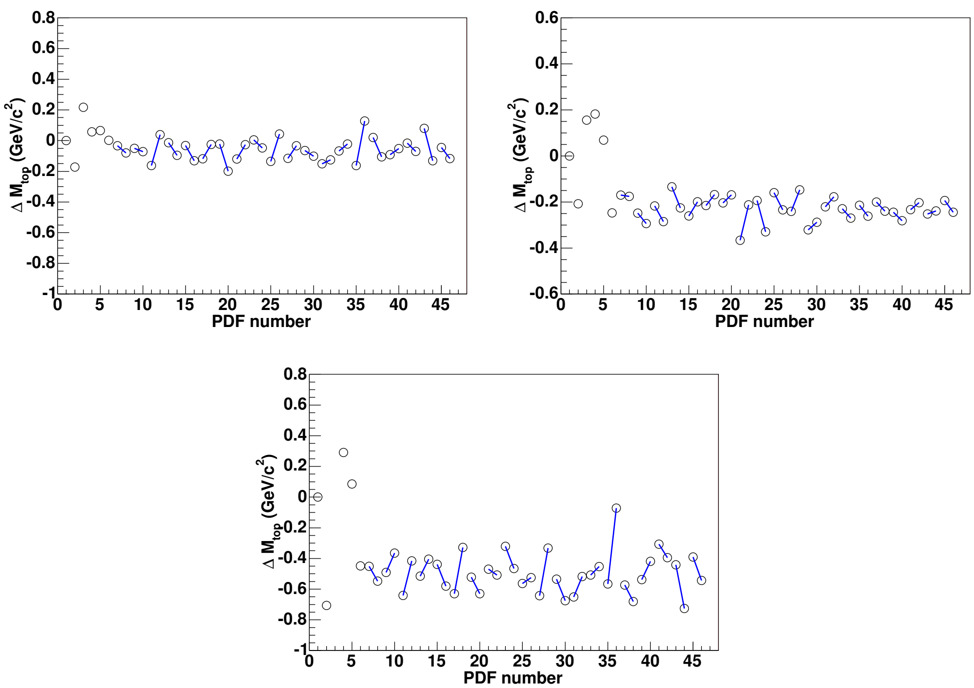

Figure 11: Results from reweighting ttkt75 for PDF systematics for Dilepton only using M_t^{NWA} fit (top left), Dilepton only using m_{T2} fit (top right) and Dilepton only fit using H_T (bottom).

systematic.

Initial and Final State Radiation: Effects due to uncertain modeling of initial-state radiation (ISR) and final-state radiation (FSR) are studied by extrapolating uncertainties in the p_T of Drell-Yan events to the $t\bar{t}$ mass region, resulting in radition (ISR and FSR) systematics.

Generators: Comparing pseudoexperiments generated with HERWIG and PYTHIA gives an estimate of the generator systematic. We compare HERWIG (otop1s) and PYTHIA with input values of $\mathrm{M_{top}} = 175.0$ GeV/c^2. The differences are 0.46 GeV/c^2 in the Dilepton using $M_t^{NWA} + m_{T2}$ fit, 1.27 GeV/c^2 in the Dilepton using $M_t^{NWA} + H_T$ fit, 0.99 GeV/c^2 in Dilepton only using M_t^{NWA} fit, 0.31 GeV/c^2 in Dilepton only using m_{T2} fit and 2.63 GeV/c^2 in Dilepton only using H_T fit.

Parton Distribution Functions: We evaluate PDF (parton distribution functions) systematics by reweighting the ttkt75 sample again. We compare different groups (CTEQ5L vs MRST72) and take the absolute difference as a systematics. We also compare Λ_{QCD} (MRST72 vs MRST75) and again take the absolute difference as a systematic. Finally, we compare the 20 +/- eigenvectors from CTEQ6M, taking half of the difference between the +1 σ and -1σ shifts for each eigenvector pair. For the DIL measurement using $M_t^{NWA} + m_{T2}$, we found systematic of 0.17 GeV/c^2 for different groups, 0.36 GeV/c^2 for different QCD scales and 0.27 GeV/c^2 for the different eigenvectors, giving a total PDF systematic of 0.48 GeV/c^2. For the DIL measurement using $M_t^{NWA} + H_T$, we found systematic of 0.30 GeV/c^2 for different groups, 0.61 GeV/c^2 for different QCD scales and 0.36 GeV/c^2 for the different eigenvectors, giving a total PDF systematic of 0.77 GeV/c^2. For the Dilepton only using m_{T2} measurement, we find systematics of 0.21 GeV/c^2 for the groups, 0.36 GeV/c^2 for the QCD scales, and 0.22 GeV/c^2 for the different eigenvectors, resulting in a combined systematic of 0.47 GeV/c^2. For the DIL measurement only using M_t^{NWA}, we found systematic of 0.17 GeV/c^2 for different groups, 0.38 GeV/c^2 for different QCD scales and 0.35 GeV/c^2 for the different eigenvectors, giving a total PDF systematic of 0.55 GeV/c^2. For the DIL measurement using H_T, we found systematic of 0.71 GeV/c^2 for different groups, 1.51 GeV/c^2 for different QCD scales and 0.57 GeV/c^2 for the different eigenvectors, giving a total PDF systematic of 1.76 GeV/c^2.

Summary plots for the PDF studies are shown in Figure 10 and Figure 11.

Gluon fusion (gg): We test the effect of reweighting MC to increase the fraction of $t\bar{t}$ events initiated by gg (versus qq) from the 6% in the leading order MC to 20%.

Lepton Energy Scales: Systematics due to lepton energy scales are estimated by propagating 1% shifts on electron and muon energy scales.

Background: Background composition systematics are obtained by varying the fraction of the different types of backgounds in pseudoexperiments. For Dilepton backgrounds varying the composition of the Drell-Yan sample between low and high jet multiplicities gives one systematic effect. We also shift the fake model in ways expected to maximally correlate with the reconstructed mass.

Monte Carlo Statistics: We quote the uncertainty on our bias checks as a systematic due to limited statistics of the signal Monte Carlo samples, yielding 0.09 GeV/c^2 in the Dilepton using $M_t^{NWA} + m_{T2}$ fit, 0.1 GeV/c^2 in the Dilepton using $M_t^{NWA} + H_T$ fit, 0.11 GeV/c^2 in Dilepton only using M_t^{NWA} fit, 0.10 GeV/c^2 in Dilepton only using m_{T2} fit and 0.14 GeV/c^2 in Dilepton only using H_T fit. For the background MC statictics, we use the bootstrap method where only the background samples are bootstrapped. We have 0.31 GeV/c^2 in the Dilepton using $M_t^{NWA} + m_{T2}$ fit, 0.32 GeV/c^2 in the Dilepton using $M_t^{NWA} + H_T$ fit, 0.33 GeV/c^2 in Dilepton only using M_t^{NWA} fit, 0.31 GeV/c^2 in Dilepton only using m_{T2} fit and 0.5 GeV/c^2 in Dilepton only using H_T fit.

Multiple Hadron Interactions: We estimate corrections and systematic uncertainties due to the difference in the instantaneous luminosity distribution between Monte Carlo samples and data. The estimation is done by studying the dependence of the fitted top quark mass on the number of z vertices (N_z) in the Monte Carlo events. We group ttop75 Monte Carlo events based on N_z and extract the top quark mass as a function of N_z. As shown in Fig. 12 and Fig. 13, there is a sizable N_z dependence in all the five fits. The difference in $< N_z >$ between data and ttop75 MC sample corresponds to a mass difference, which we will subtract from our final fits. Systematic uncertainties come from the ttop75 MC statistical uncertainty and they are 0.34 GeV/c^2, 0.29 GeV/c^2, 0.27 GeV/c^2, 0.18 GeV/c^2 and 0.28 GeV/c^2 for Dilepton using $M_t^{NWA} + m_{T2}$ fit, Dilepton using $M_t^{NWA} + H_T$ fit, Dilepton only using M_t^{NWA} fit, Dilepton only using m_{T2} fit and the Dilepton fit using H_T.

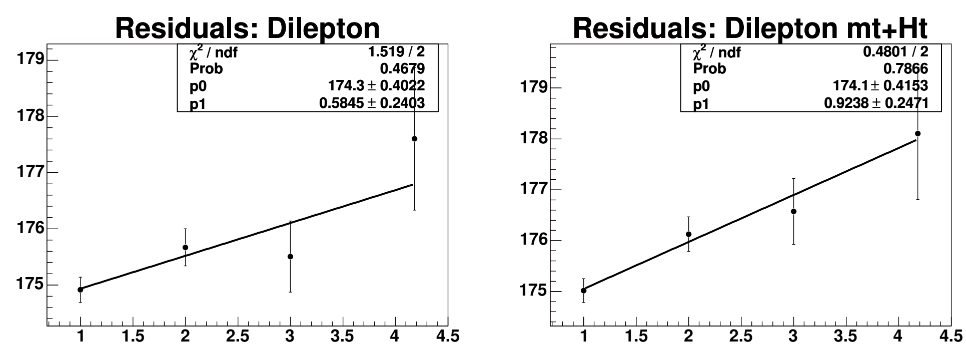

Figure 12: Dependence of the fitted top mass on the number of z vertices for Dilepton using $M_t^{NWA} + m_{T2}$ fit (left) and Dilepton using $M_t^{NWA} + H_T$ fit (right) .

Color Reconnection: We accounted the color reconnection effect by comparison between tune Apro (otop45) and tune ACRpro (otop46) where tune Apro is similar tune with nominal sample using Pythia v6.4.19 instead of v6.2.16 and tune ACRpro is including color reconnection. Because of limited statistics of samples, estimated statistical errors are higher than the difference between two samples for all of measurement. Therefore we accounted its errors as systematics. We have 0.38 GeV/c^2, 0.57 GeV/c^2, 0.60 GeV/c^2, 0.68 GeV/c^2 and 2.54 GeV/c^2 for Dilepton using $M_t^{NWA} + m_{T2}$ fit, Dilepton using $M_t^{NWA} + H_T$ fit, Dilepton only using M_t^{NWA} fit, Dilepton only using m_{T2} fit and the Dilepton fit using H_T.

Table 2 summarizes the systematic uncertainties.

Knowing the systematics, we can now compare the total uncertainties of the five measurement of top mass(from Pseudo Experiments, not from data). Fig. 14 compares the total uncertainties of each kind of measurement, which tells us that replacing H_T with m_{T2} in either one-dimential PDF or two-dimentional PDF gives improvement of top quark mass measurement.

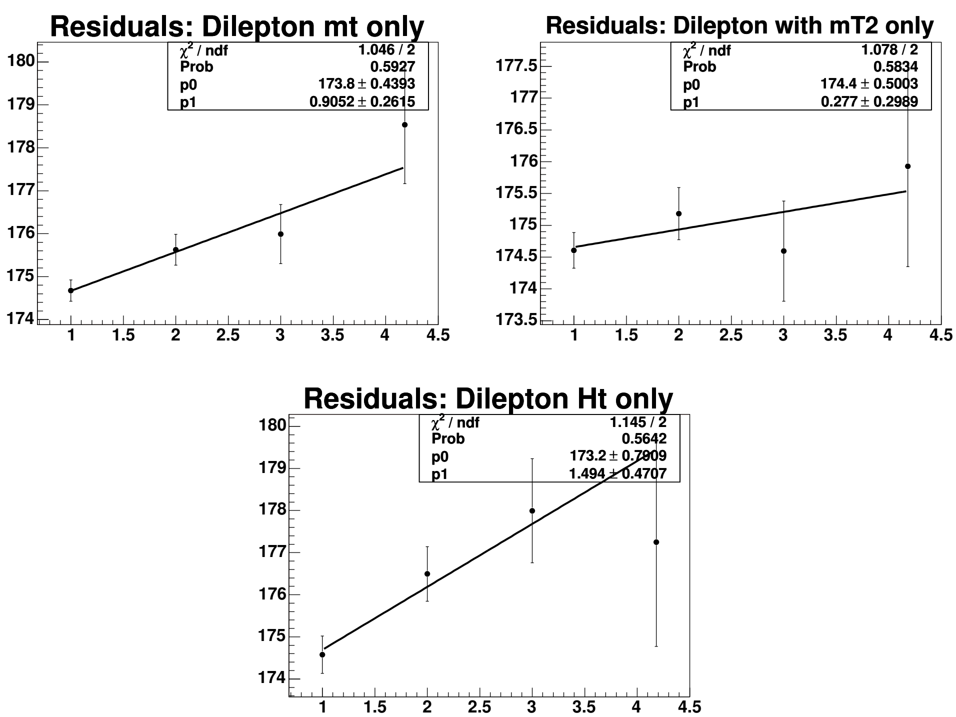

Figure 13: Dependence of the fitted top mass on the number of z vertices for Dilepton only using M_t^{NWA} fit (top left), Dilepton only using m_{T2} fit (top right) and Dilepton only fit using H_T (bottom).

Table 2: Summary of systematic uncertainties. All numbers have units of GeV/c^2.

Systematic (GeV/c^2)	m_{T2}	M_t^{NWA}	H_T	$M_t^{NWA} + m_{T2}$	$M_t^{NWA} + H_T$
Residual JES	2.58	3.51	3.73	3.04	3.43
Generator	0.31	0.99	2.62	0.46	1.27
Parton distribution functions	0.47	0.55	1.76	0.48	0.77
b jet energy	0.21	0.27	0.24	0.21	0.26
Background shape	0.36	0.25	0.69	0.12	0.30
Gluon fusion fraction	0.32	0.01	0.31	0.01	0.11
Initial and final state radiation	0.57	0.21	0.59	0.34	0.20
MC statistics	0.33	0.35	0.52	0.34	0.34
Lepton energy	0.56	0.28	0.69	0.28	0.16
Multiple Hardron Interaction	0.17	0.27	0.28	0.34	0.29
Color Reconection	0.68	0.60	2.54	0.55	0.57
Combined	2.92	3.80	5.67	3.24	3.83

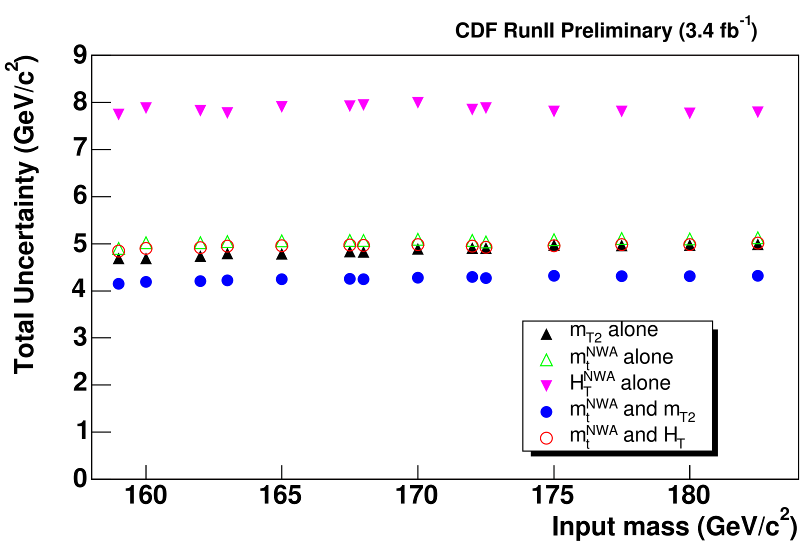

Figure 14: Comparison of total uncertainties in the top quark mass measurement for Dilepton channel–including systematics).

4 Fit Results

The likelihood profiles for all five Dilepton measurements are shown in Fig.s 15, 16,17, 18 and 19. The fitted results with statistical uncertainties are

$$\mathrm{M_{top}} = 169.34^{+2.67}_{-2.72}\ \mathrm{GeV}/c^2\ \text{(Dilepton channel using } M_t^{NWA} \text{ and } m_{T2})$$

$$\mathrm{M_{top}} = 169.91^{+2.76}_{-2.87}\ \mathrm{GeV}/c^2\ \text{(Dilepton channel using } M_t^{NWA} \text{ and } H_T)$$

$$\mathrm{M_{top}} = 169.31^{+3.21}_{-3.12}\ \mathrm{GeV}/c^2\ \text{(Dilepton channel with } M_t^{NWA} \text{ only)}$$

$$\mathrm{M_{top}} = 168.03^{+4.77}_{-4.03}\ \mathrm{GeV}/c^2\ \text{(Dilepton channel with } m_{T2} \text{ only)}$$

$$\mathrm{M_{top}} = 170.48^{+4.95}_{-6.42}\ \mathrm{GeV}/c^2\ \text{(Dilepton channel with } H_T \text{ only)}$$

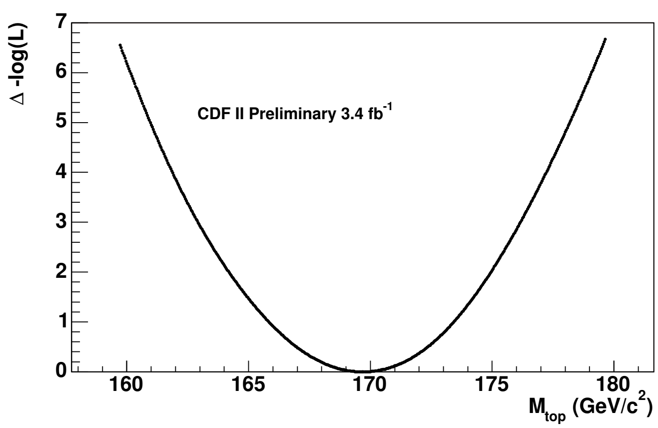

Figure 15: Likelihood profile for the Dilepton fit using M_t^{NWA} and m_{T2}.

We examine the p-value of our fits by comparing the measured symmetrized uncertainties with those expected from pseudoexperiments. Results are shown in Fig. 20. We use Pseudoexperiments with $\mathrm{M_{top}}$= 170 GeV/c^2 and $\Delta_{\mathrm{JES}} = 0\ \sigma_{\mathrm{C}}$.

Figure 21 show the one-dimentiona data templates with best fit 1d shapes overlaid on top for the three variables used in Dilepton channel.

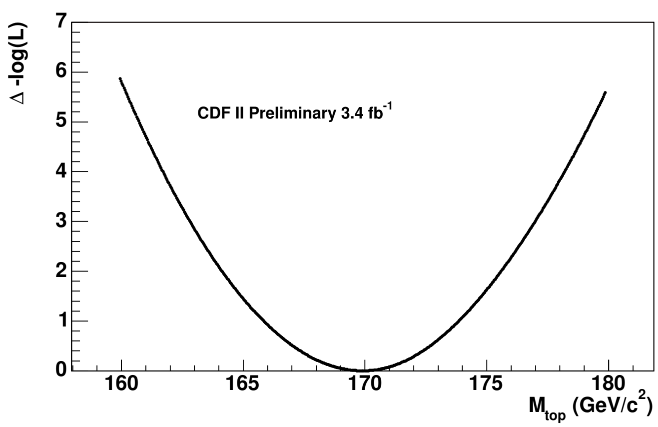

Figure 16: Likelihood profile for the Dilepton fit using M_t^{NWA} and H_T.

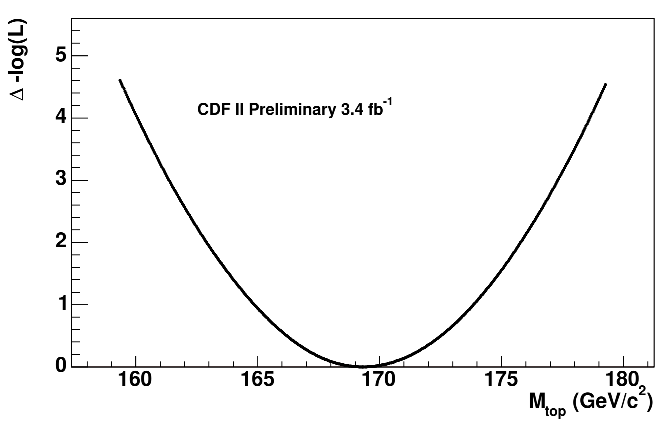

Figure 17: Likelihood profile for the Dilepton fit using M_t^{NWA} only.

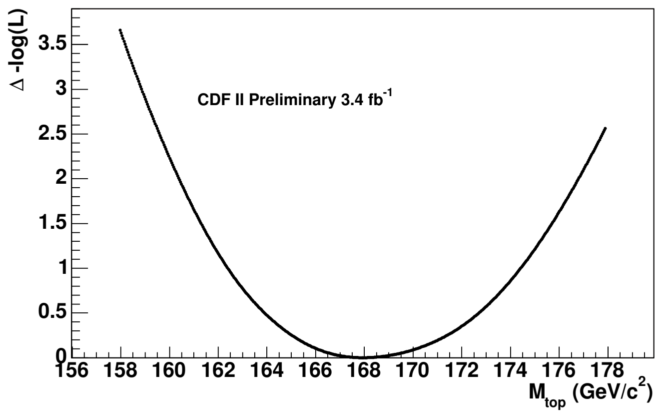

Figure 18: Likelihood profile for the Dilepton fit using m_{T2} only.

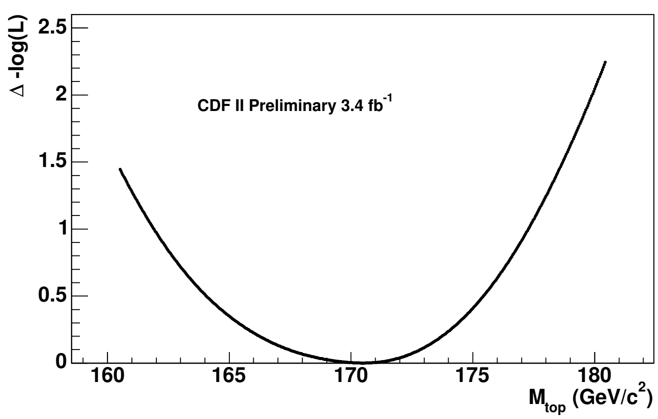

Figure 19: Likelihood profile for the Dilepton fit using H_T only.

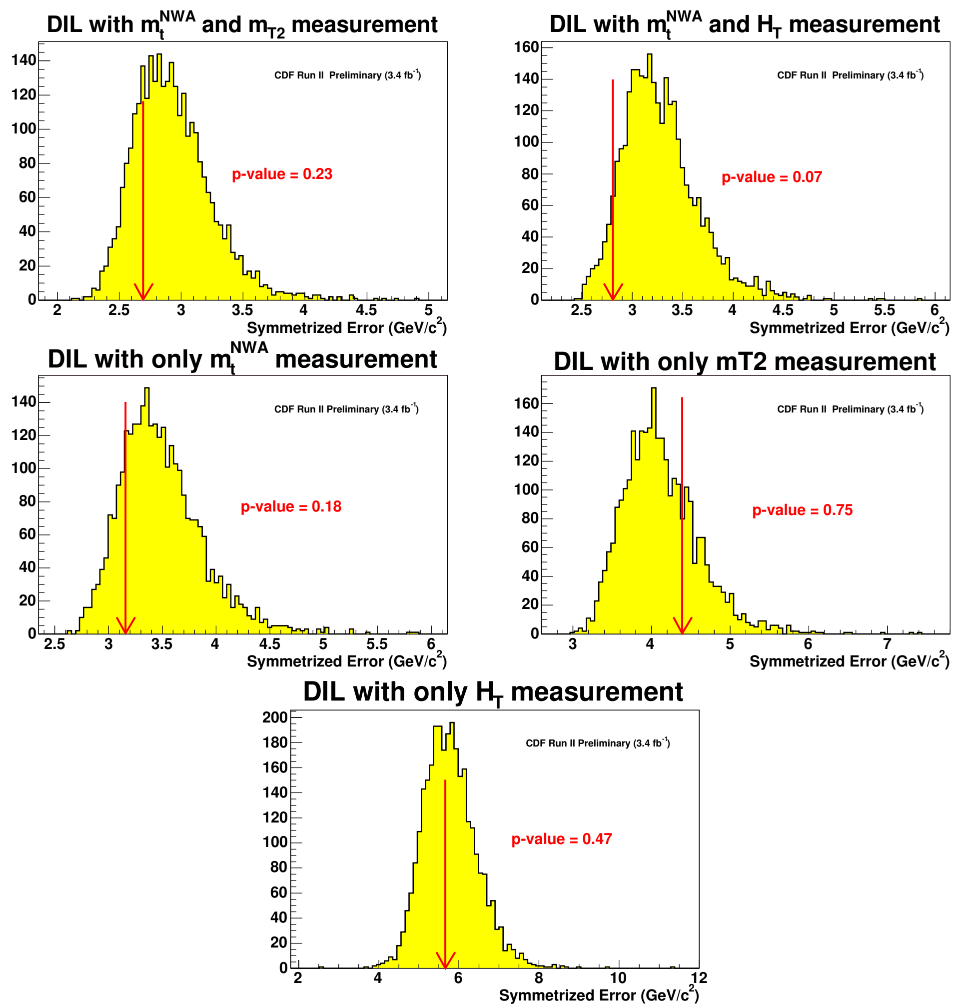

Figure 20: Expected errors and probability to get values equal to or smaller than the measured errors for the $M_t^{NWA} + m_{T2}$ fit (top left), $M_t^{NWA} + H_T$ fit(top right), M_t^{NWA} only fit (middle left), m_{T2} only fit (middle right) and H_T fit (bottom) .

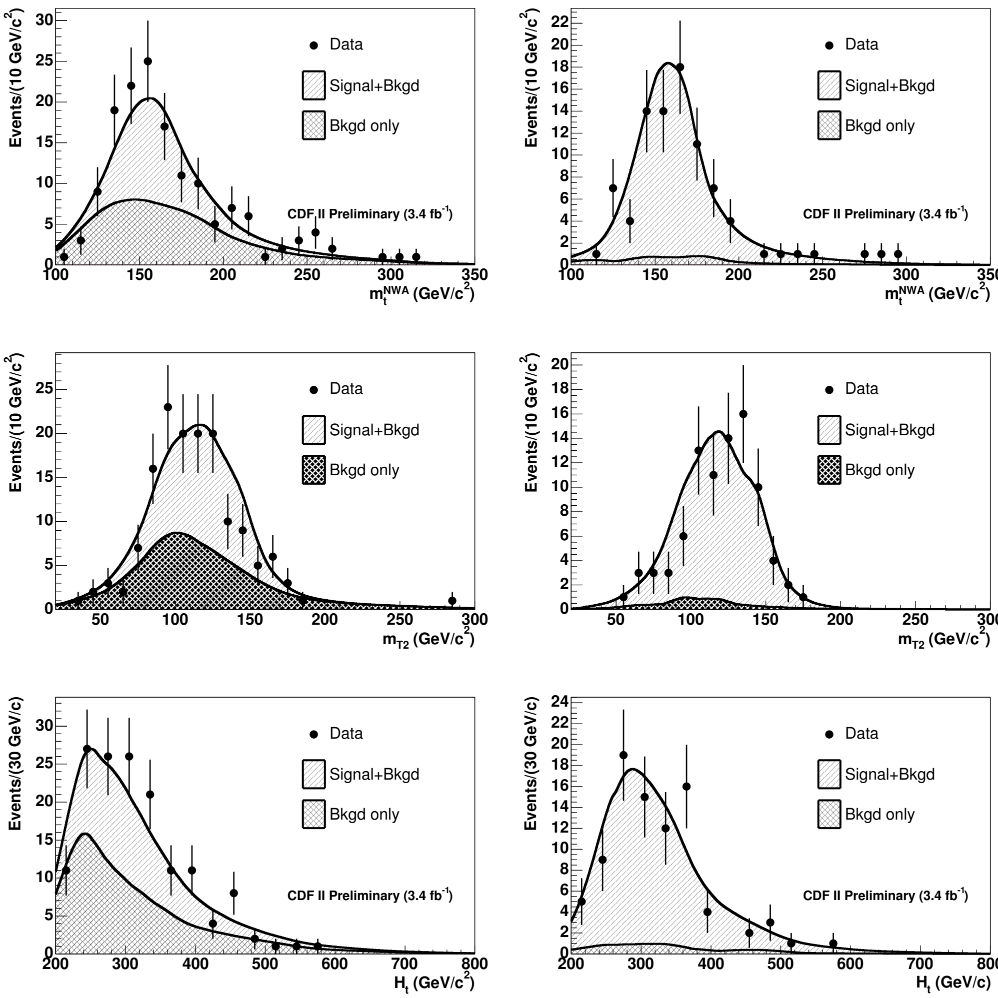

Figure 21: One-dimensional 0tag(left column) and tagged(right column) Dilepton data templates with PDFs from M_{top}= 169.0 GeV/c^2 and full background models overlaid.

5 Conclusions

We present the measurements of the top quark mass using data of 3.4 fb^{-1} by introducing a new variable m_{T2}. Five measurements are done with different or different combination of variables, in order to show that the new variable m_{T2} does excel H_T– in terms of both statistical and systematic uncertainties. The following summarize the five measurements of top quark mass. Here the mass measurement results are corrected by the top mass shift that comes from the difference in the instantaneous luminosity distribution between the Monte Carlo sample and data. The statistical uncertainties are scaled up by the pull width for all the measurements.

The top quark mass measurements are:

$$\begin{aligned} \mathrm{M_{top}} &= 169.3 \pm 2.7 \text{ (stat.)} \pm 3.2 \text{ (syst.) GeV}/c^2 \\ &= 169.3 \pm 4.2 \text{ GeV}/c^2 \text{ (Dilepton Channel using } M_t^{NWA} \text{ and } m_{T2}) \end{aligned}$$

$$\begin{aligned} \mathrm{M_{top}} &= 169.4\ ^{+2.8}_{-2.9} \text{ (stat.)} \pm 3.8 \text{ (syst.) GeV}/c^2 \\ &= 169.4\ ^{+4.7}_{-4.8} \text{ GeV}/c^2 \text{ (Dilepton Channel using } M_t^{NWA} \text{ and } H_T) \end{aligned}$$

$$\begin{aligned} \mathrm{M_{top}} &= 168.8\ ^{+3.3}_{-3.2} \text{ (stat.)} \pm 3.8 \text{ (syst.) GeV}/c^2 \\ &= 168.8 \pm 5.0 \text{ GeV}/c^2 \text{ (Dilepton Channel with } M_t^{NWA} \text{ alone)} \end{aligned}$$

$$\begin{aligned} \mathrm{M_{top}} &= 168.0\ ^{+4.8}_{-4.0} \text{ (stat.)} \pm 2.9 \text{ (syst.) GeV}/c^2 \\ &= 168.0\ ^{+5.6}_{-5.0} \text{ GeV}/c^2 \text{ (Dilepton Channel with } m_{T2} \text{ alone)} \end{aligned}$$

$$\begin{aligned} \mathrm{M_{top}} &= 169.6\ ^{+5.1}_{-6.6} \text{ (stat.)} \pm 5.7 \text{ (syst.) GeV}/c^2 \\ &= 169.6 \pm 7.6 \text{ GeV}/c^2 \text{ (Dilepton Channel with } H_T \text{ alone)} \end{aligned}$$

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