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Measurement of the Top Quark Mass using the Neutrino Weighting Algorithm on Dilepton Events at CDF

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We measure the top quark mass using 19 $t\bar{t}$ candidate events in which both W bosons from top quarks decay into leptons ($e\nu, \mu\nu$, or $\tau\nu$). These "dilepton" events were collected by the Collider Detector at Fermilab in 197 pb^{-1} of Run II Tevatron data produced by $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. Only one of the two leptons is required to be identified as an electron or a muon candidate, while the other is just a well measured charged particle. We employ the Neutrino Weighting Algorithm to reconstruct the 19 events according to the $t\bar{t}$ decay hypothesis and we measure a top mass of $168.1^{+11.0}_{-9.8}(stat) \pm 8.6(syst)$ GeV/c^2.

Preliminary Results

I. INTRODUCTION

The top quark is about 35 times heavier than any other quark in the Standard Model (SM). Even though its mass is a free parameter in the model, it is linked with the mass of the W and Higgs bosons. Since the Higgs still eludes experimental observation, the measurement of the top quark mass, in conjunction with a precise W mass measurement, serves as a constraint to the Higgs mass, which in turn benefits Higgs search strategies. Once all three masses are accurately known, they will provide a stringent consistency check of the SM.

Top quarks were first observed by the CDF and D0 collaborations [1] in events produced at $p\bar{p}$ collisions at the Fermilab Tevatron collider. The main mechanism of producing top quarks at $p\bar{p}$ collisions of $\sqrt{s} = 1.96$ TeV is $p\bar{p} \to t\bar{t}$ production via quark-antiquark annihilation ($\sim 90\%$) or gluon-gluon fusion. According to the SM, each top quark decays almost 100% of the time to Wb, with the b quark hadronizing into a jet of particles. Each of the two W's can either decay to quarks or to a lepton-neutrino pair. The decay mode of the W's sets the characteristics of the $t\bar{t}$ event and, consequently, the event selection strategy.

In this article we present a measurement of the top quark mass using $t\bar{t}$ "dilepton" candidate events in which both W bosons from top quarks decay into leptons ($e\nu, \mu\nu$, or $\tau\nu$). Such a measurement is important in order to check consistency with top mass measurements obtained using events from other $t\bar{t}$ decay modes. Since all top mass measurements assume a sample composition of $t\bar{t}$ and SM background events, any discrepancy among the measured top masses could indicate the presence of non-SM events in our sample(s). We employ the Neutrino Weighting Algorithm (NWA) to reconstruct each dilepton event according to the $t\bar{t}$ decay hypothesis, with each event yielding a most probable top mass. We then use an unbinned likelihood method to find the top mass hypothesis which best explains the observed data values as a mixture of background and $t\bar{t}$ signal events. The NWA was the method used in Run I to obtain the final published results by CDF [2] and one of the two methods used by D0 [3]. It is therefore a natural baseline for Run II measurements.

II. DATA SAMPLE & EVENT SELECTION

We use two-lepton events collected by the Collider Detector at Fermilab in 197 pb^{-1} of Run II Tevatron data produced by $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The CDF detector is described in detail in Ref. [4].

The signature of $t\bar{t}$ decays in the dilepton channel is two jets from the b quarks, two leptons and missing energy from the unobserved neutrinos. We follow the "LTRK" event selection, which is one of the two selections used for the top cross section measurement in the dilepton decay channel [5]. This selection allows a greater signal acceptance, but also results in a worse background contamination. Because measurements of the top quark mass in the dilepton channel are statistically limited, we base our decision for using the LTRK selection on the fact that the expected (i.e., a-priori) statistical uncertainty for this selection is overall smaller than the uncertainty expected from the other (so-called "DIL" [5]) selection. The LTRK selection is described in detail in Ref. [5] and here we just mention the basic requirements.

The data are collected with an inclusive lepton trigger that requires events with an electron or muon with $E_T > 18$ GeV ($p_T > 18$ GeV/c for the muon) [6]. If the electron candidate is in $1.2 < |\eta| < 2.0$ (in the end-plug calorimeter region), it is required to have $E_T > 20$ GeV and the event have $\not\!\!E_T > 15$ GeV. From this inclusive lepton dataset we select events offline with an electron E_T (muon p_T) greater than 20 GeV. Such an electron (muon) is required to be "isolated', that is, to be no more than 10% extra energy (momentum) measured in a cone of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \leq 0.4$ around the lepton. We do not attempt to identify the other lepton as an electron or muon; we just require a well-measured isolated track with $p_T > 20$ GeV/c in $|\eta| < 1$. We also require candidate events to have $\not\!\!E_T > 25$ GeV and at least two jets with $E_T > 20$ GeV in $|\eta| < 2$. The extra jets could be produced from initial or final-state radiation. In this analysis we assume that the two highest E_T jets in the event are the b jets.

After all selection criteria are applied, we have 19 candidate $t\bar{t}$ events, out of which 6.9 ± 1.7 are expected to be background events [5]. The main sources of background to the $t\bar{t}$ dilepton topology are estimated to be: i) 4.2 ± 1.6 Drell-Yan events ($Z/\gamma \to \ell^+\ell^- X$, where $\ell = e, \mu$, or τ), ii) 1.5 ± 0.5 "fake" events, where a $W + jets$ event is selected due to a jet mimicking the signature of a lepton, and iii) 1.2 ± 0.3 diboson events (WW, WZ and ZZ).

III. METHOD FOR TOP MASS MEASUREMENT

A. Top mass reconstruction with the Neutrino Weighting Algorithm

The top mass measurement in the dilepton channel is an unconstrained problem because there is no one-to-one correspondence between observables and decay particles; the measured $\not\!\!E_T$ is due to two neutrinos. In order to solve the problem we have to make assumptions (the top mass being one of them) and find how well they fit the observations in the event at hand. Assuming each event is a $t\bar{t}$ dilepton decay, we obtain a distribution of probability vs. top mass hypothesis, by integrating out all other assumptions.

In the Neutrino Weighting Algorithm we assume we know: i) the top mass, ii) the W mass (we use 80.5 GeV/c^2), iii) the η's of the two neutrinos, and iv) the lepton-jet pair which originated from the top quark decay, e.g., $\ell^+ - jet_1$. Then, we apply energy-momentum conservation on the t-side and obtain up to two possible solutions for the 4-vector ($\boldsymbol{\nu}$) of the neutrino. We repeat on the $\bar{t}$-side and we end up with up to four possible pairs of neutrino-antineutrino solutions ($\boldsymbol{\nu}, \bar{\boldsymbol{\nu}}$). Each of the four solutions is assigned a probability (weight, w_i) that it describes the observed missing E_x and E_y within uncertainties σ_x and σ_y, respectively:

$$w_i = exp(-\frac{(\not\!\!E_x - P_x^{\nu} - P_x^{\bar{\nu}})^2}{2\sigma_x^2}) \cdot exp(-\frac{(\not\!\!E_y - P_y^{\nu} - P_y^{\bar{\nu}})^2}{2\sigma_y^2}) \quad (1)$$

We use $\sigma_x = \sigma_y = 15$ GeV, which is obtained by a $t\bar{t}$ Monte Carlo sample generated with $m_t = 175$ GeV/c^2 and, independently, by using the individual resolutions of the observed objects (electron/muon, track, jets and unclustered energy in the calorimeters).

Given the assumed top mass and the neutrino η values, any of the four solution pairs ($\boldsymbol{\nu}, \bar{\boldsymbol{\nu}}$) could have occurred in nature. So, we just add up the four weights:

$$w(m_t, \eta_\nu, \eta_{\bar{\nu}}, \ell - jet) = \sum_{i=1}^{4} w_i \quad (2)$$

Not knowing which are the true neutrino η's in our event, we repeat the above steps for many possible $(\eta_\nu, \eta_{\bar{\nu}})$ pairs. Monte Carlo $t\bar{t}$ simulations indicate that the neutrino and antineutrino η's are uncorrelated and distributed Gaussianly around 0 with a width of 1. We scan the neutrino η distributions from -3 to +3 in steps of 0.1 and each $(\eta_\nu, \eta_{\bar{\nu}})$ pair is assigned a probability of occurrence $P(\eta_\nu, \eta_{\bar{\nu}})$ derived from the aforementioned Gaussian. Then, each trial $(\eta_\nu, \eta_{\bar{\nu}})$ pair contributes to the event weight according to its weight (Eq. 2) and probability of occurrence, $P(\eta_\nu, \eta_{\bar{\nu}})$:

$$w(m_t, \ell - jet) = \sum_{\eta_\nu, \eta_{\bar{\nu}}} P(\eta_\nu, \eta_{\bar{\nu}}) \cdot w(m_t, \eta_\nu, \eta_{\bar{\nu}}, \ell - jet)$$

Since we do not distinguish b jets from $\bar{b}$ jets, the problem is solved with both possible lepton-jet pairings and the two resulting weights $w(m_t, \ell - jet)$ are added up. Thus, the final weight is only a function of the top mass, with all other unknowns integrated out:

$$W(m_t) = \sum_{\ell^+ - jet_1}^{\ell^+ - jet_2} w(m_t, \ell - jet)$$

We try top masses from 100 GeV/c^2 to 500 GeV/c^2 in 1 GeV/c^2 steps. Finally, the weight distribution from each event is normalized to one. For simplicity, we pick one indicative top mass from each event; we use the top mass which best explains the event as a $t\bar{t}$ dilepton decay.

B. Probability density functions for Signal and Background events.

We use fully simulated Monte Carlo events of $t\bar{t}$ signal and background processes to build "template" distributions of the top masses reconstructed as explained above. Parameterizing these templates we construct probability density functions (p.d.f's) for signal and background events to be used in the likelihood.

For the signal, we use $t\bar{t}$ dilepton events generated with "Tune A" PYTHIA version 6.203 [7] at top masses from 135 GeV/c^2 to 225 GeV/c^2 in 5 GeV/c^2 increments. The CTEQ5L [8] Structure Functions are used to model the

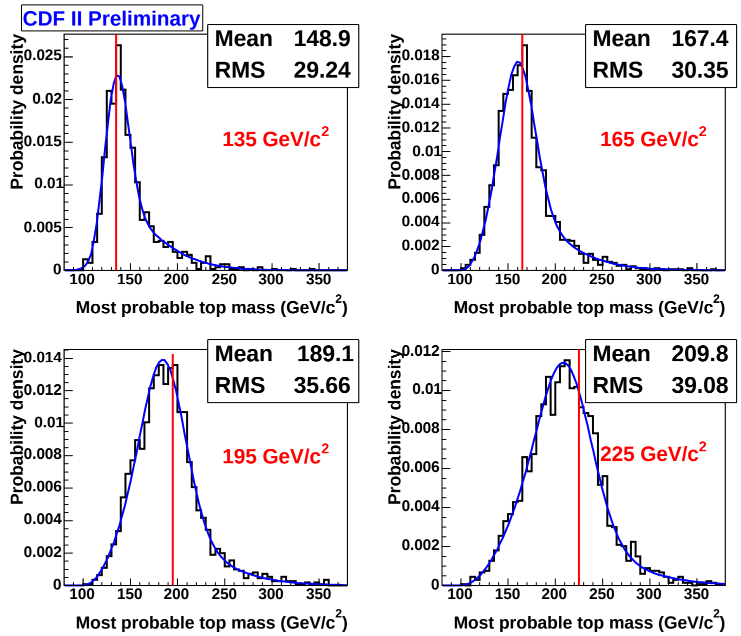

FIG. 1: Four signal templates (probability density per 5 GeV/c^2) as a function of the most probable reconstructed top mass, for generated top masses of 135, 165, 195 and 225 GeV/c^2. Overlaid are the parameterized fitting functions using Eq. 3. The vertical line indicates the generated top mass.

momentum distribution of the initial state partons. The obtained signal templates are parameterized as the sum of a Gaussian and the function which when integrated gives the Gamma function. We thus get the signal p.d.f, $P_s(m; m_{top})$, which represents the probability of reconstructing a top mass m when the true top mass is m_{top}:

$$\begin{aligned} P_s(m; m_{top}) = \alpha_5 \frac{\alpha_2^{1+\alpha_1}}{\Gamma(1+\alpha_1)} (m-\alpha_0)^{\alpha_1} \exp\left(-\alpha_2(m-\alpha_0)\right) \\ +(1-\alpha_5)\frac{1}{\alpha_4\sqrt{2\pi}} \exp\left(-\frac{(m-\alpha_3)^2}{2\alpha_4^2}\right) \end{aligned} \tag{3}$$

where each of the 6 parameters α_i are constrained to be linearly dependent on the generated top mass, such that we in fact perform a 12-parameter fit on all templates simultaneously; i.e., $\alpha_i = p_i + p_{i+6}(m_{top} - 175 \text{ GeV/c}^2)$. In Fig. 1 we see four of the signal templates with the parameterized fitting function.

For the background events, we create one representative background template by adding the individual templates from each background source according to their expected yields. In doing so, we also take into account the NWA acceptance; the inefficiency is introduced when none of the top masses tried explains the event as a $t\bar{t}$ dilepton decay. The weighted average NWA acceptance for background events is 96%, whereas the equivalent acceptance for signal is 99.8%. Therefore, after the event selection and top mass reconstruction, we expect 6.6 ± 1.7 background events in our data sample. We then obtain the background p.d.f, $P_b(m)$, by fitting the combined background template (see Fig. 2) to the functional form given in Eq. 3, but this time the parameters are made independent of m_{top}. The templates from the various background processes are reconstructed from fully simulated Monte Carlo samples created for the $t\bar{t}$ dilepton cross section measurement [5]: the Drell-Yan events from PYTHIA, the Diboson from PYTHIA and ALPGEN+HERWIG [9, 10], and the fakes from ALPGEN+HERWIG simulation of $W(\rightarrow e\nu) + 3$ partons.

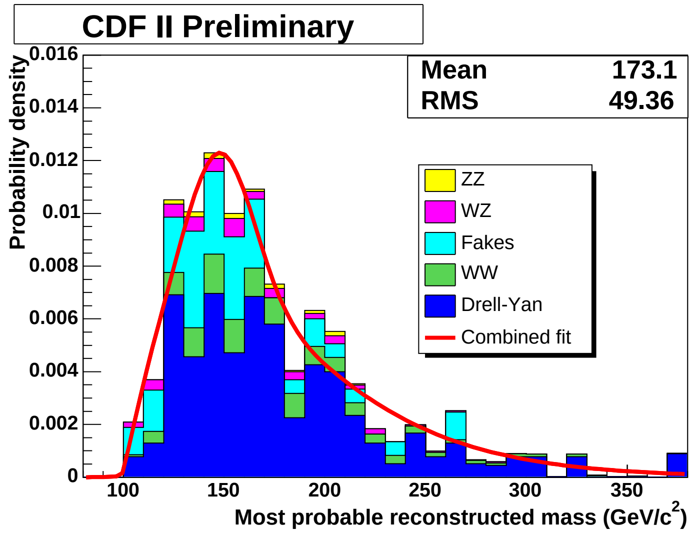

FIG. 2: The combined background template. Overlaid is the fitted probability density function.

C. The Likelihood function

We find the probability that our data are described as an admixture of background events and dilepton $t\bar{t}$ decays with top mass m_{top}, by employing the following likelihood function:

$$\mathcal{L}(m_{top}) = \mathcal{L}_{shape}(m_{top}) \times \mathcal{L}_{n_b} \times \mathcal{L}_{(n_s+n_b)}, \quad \text{with}$$
$$\mathcal{L}_{shape}(m_{top}) = \prod_{i=1}^{N} \frac{n_s P_s(m_i; m_{top}) + n_b P_b(m_i)}{n_s + n_b},$$
$$-\ln \mathcal{L}_{n_b} = \frac{(n_b - n_b^{exp})^2}{2\sigma_{n_b}^2}, \quad \text{and}$$
$$\mathcal{L}_{(n_s+n_b)} = \frac{e^{-(n_s+n_b)}(n_s+n_b)^N}{N!} \tag{4}$$

where, i) the term $\mathcal{L}_{shape}$ determines the relative abundance of signal and background events, n_s and n_b, respectively, by comparing the distribution of top masses m_i in the data with the signal and background p.d.f's, $P_s(m_i; m_{top})$ and $P_b(m_i)$, respectively; ii) the term $\mathcal{L}_{n_b}$ constrains (within uncertainty σ_{n_b}) the number of background events to the a-priori estimate of n_b^{exp} events; and, iii) the term $\mathcal{L}_{(n_s+n_b)}$ imposes that the total number of signal and background events $(n_s + n_b)$ be in agreement with the event count, N, in the data sample.

The top mass hypothesis which minimizes $-ln(\mathcal{L})$ is retained. At this stage, the best estimate of the statistical uncertainty is the difference between this mass and the mass at $-ln(\mathcal{L}_{max}) + 0.5$.

IV. TESTING THE PROCEDURE WITH PSEUDO-EXPERIMENTS

We use pseudo-experiments to check if the methodology described above returns the expected top mass. For each generated top mass from $150\,\mathrm{GeV/c^2}$ to $210\,\mathrm{GeV/c^2}$, we construct a set of 5000 pseudo-experiments. Each pseudo-experiment is made up of top masses drawn randomly from the signal and background templates (e.g., Figs. 1 and 2). The number of signal and background events in each pseudo-experiment is given by random Poisson values around the a-priori estimates of 11.5 signal and 6.6 background events. These event yields correspond to $(197 \pm 12)\ \mathrm{pb}^{-1}$ of Run II data (from Table I of Ref. [5] and the aforementioned 96% NWA efficiency for background events). Then, the likelihood function provides a "measured" top mass and a statistical uncertainty from each pseudo-experiment.

As seen in Figure 3, the output (measured) top mass traces the input (generated) top mass. Any residual differences between the output and input mass are much smaller than the statistical uncertainties, shown in Fig. 4. The mean and sigma of the pull distributions from each set of pseudo-experiments are shown in Figure 5 and we see that our

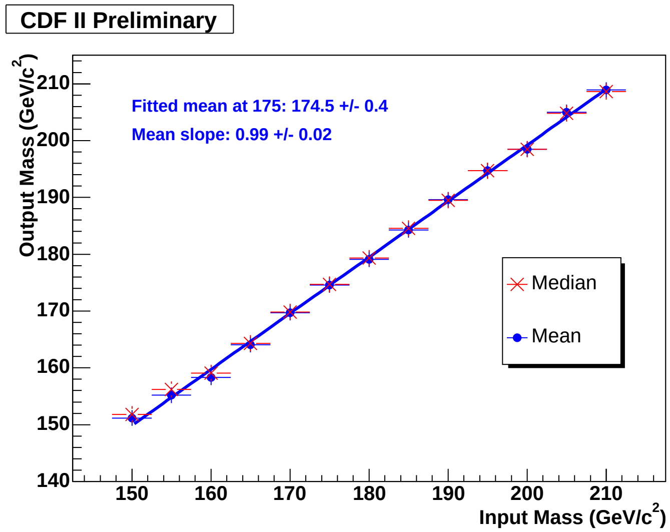

FIG. 3: The median and mean of the output (measured) top mass as a function of the input (generated) top mass. For each input top mass 5000 pseudo-experiments with (11.5 ± 1.5) signal and (6.6 ± 1.7) background events are constructed. The likelihood maximization gives a measured top mass from each pseudo-experiment.

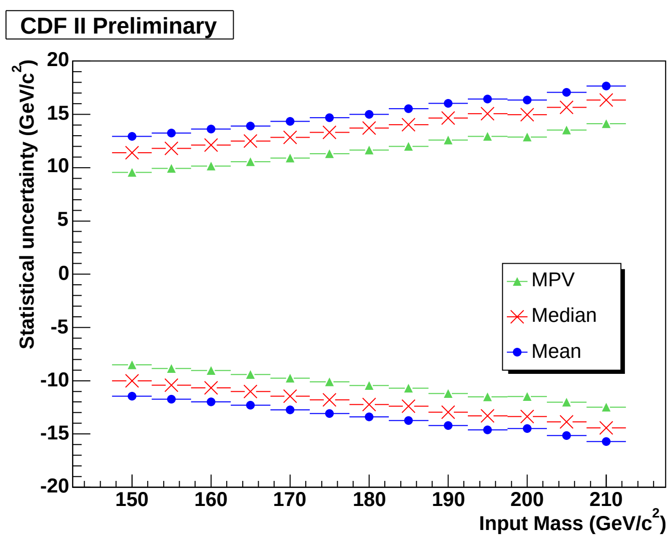

FIG. 4: The statistical uncertainty on the measured top mass in pseudo-experiments, as a function of the generated top mass. The $+1\sigma$ and -1σ uncertainties are shown separately. The distribution of statistical uncertainties in each set of pseudo-experiments resembles a Landau distribution. The most probable value (MPV), the median and the mean of these distributions are shown here.

method provides essentially unbiased measurement of the top mass. Nevertheless, the statistical uncertainty estimates we obtain have a small bias for some of the generated top masses (an unbiased estimate would always yield a sigma for the pull distributions equal to one). Therefore, for the final result we scale the uncertainties obtained from the likelihood fit on the data. The scale factor is found from pseudo-experiments, such that the "corrected $\pm 1\sigma$" interval encompasses 68% of the output top mass values.

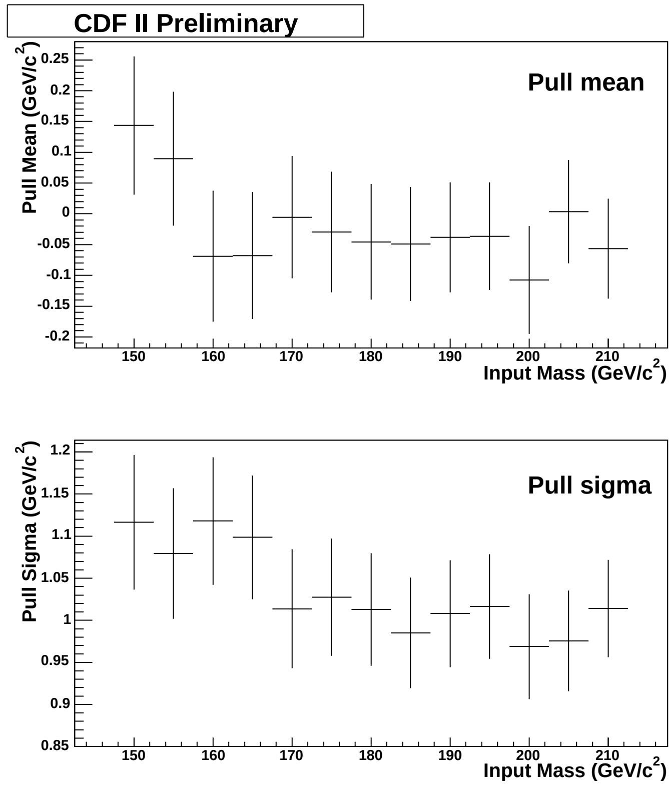

FIG. 5: Average and sigma of the pull distributions in pseudo-experiments. The uncertainties shown here account for background template statistics and are therefore correlated.

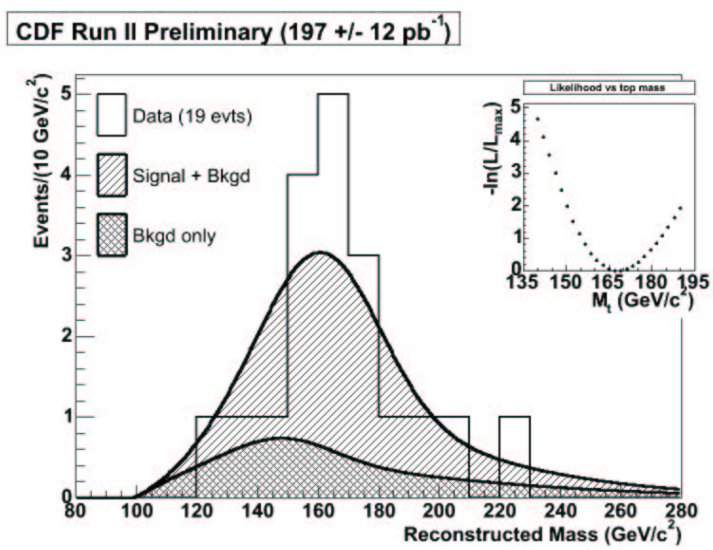

FIG. 6: Reconstructed top mass for the 19 data events (histogram). The normalized shapes of the background and signal plus background p.d.f's are shown as hatched curves. The shape of the likelihood function is shown in the inset.

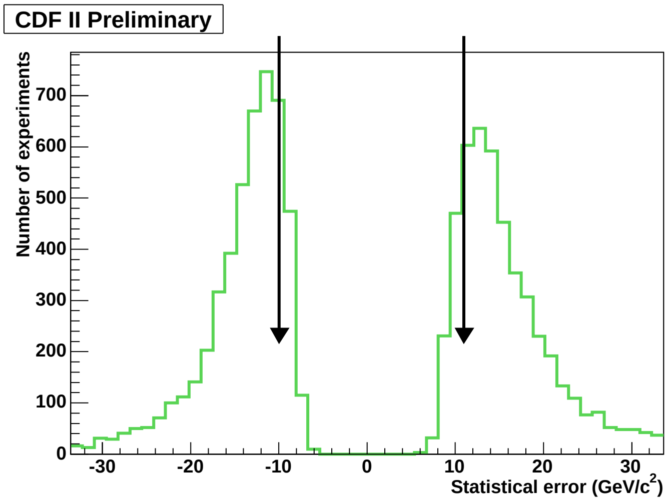

FIG. 7: The positive and negative statistical uncertainties for 5000 pseudo-experiments generated using the 170 GeV/c^2 signal template (histogram). The arrows indicate the values measured in the data.

V. RESULT ON DATA

We have 19 events satisfying the LTRK selection in 197 pb^{-1} of Run II data. Selecting from each event the most probable top mass and applying the procedure described in Sec. III, we measure a top mass of 168.1 GeV/c^2. Figure 6 shows the reconstructed top masses in the data, the normalized background shape, the normalized sum of the signal and background shapes, and, in the inset, the variation of $-ln(\mathcal{L})$ as a function of the top mass hypothesis. By taking the width at $-ln(\mathcal{L}_{max}) + 0.5$ we obtain a statistical uncertainty of $+10.2$ GeV/c^2 and -9.1 GeV/c^2. Since the expected average mass offset is consistent with zero (See Fig. 5), we do not correct the measured central value. However, the statistical uncertainty quoted above is underestimated; both set of pseudo-experiments drawn using the 165 and 170 GeV/c^2 signal templates (which bracket the measured value of 168.1 GeV/c^2) yield $\sigma_{pull} > 1$. As explained in the previous section, the uncertainty is then corrected by an appropriate scale factor. Using the 165 GeV/c^2 signal template we find a scale factor of 1.12, while using the 170 GeV/c^2 signal template we find 1.05. We then interpolate to 168 GeV/c^2 and get a scale factor of 1.08. Thus, we obtain $m_{top} = 168.1^{+11.0}_{-9.8}$ GeV/c^2. The statistical uncertainty measured in the data is consistent with the distribution of statistical uncertainties from 5000 pseudo-experiments using the 170 GeV/c^2 signal template (see Figure 7).

The fit found 14.1 ± 4.5 signal and 6.0 ± 1.7 background events. When we remove the Gaussian constraint on the background (i.e., the term $\mathcal{L}_{n_b}$ in Eq. 4), the fit converges on zero background events and the resulting top mass is 166.9 GeV/c^2.

VI. SYSTEMATIC UNCERTAINTIES

Apart from the uncertainty on the measured top mass due to the limited size of our data sample, there are several sources of systematic uncertainty, amounting to 8.6 GeV/c^2. We evaluate each uncertainty from pseudo-experiments drawn from "$\pm 1\sigma$ shifted" Monte Carlo samples, while we keep using the nominal p.d.f's in the likelihood function.

The largest systematic uncertainty (7.4 GeV/c^2) arises from the jet energy measurement, mainly due to uncertainties on i) the jet energy corrections as a function of the calorimeter region (function of η), ii) the absolute calibration of the hadronic calorimeters, and iii) the jet fragmentation model.

The rest of the uncertainties deal with the modeling of the signal and background events by the templates used. The largest of these uncertainties steams from the modeling of the background, even in the limit of infinite statistics. We conservatively state that the true background p.d.f could be anything between the two most different contributions: the Drell-Yan and the fakes, which also happen to be the two largest backgrounds. We draw pseudo-experiments using either the Drell-Yan or the fake background template as a model for the whole background shape, and we get a difference of 9.8 GeV/c^2 in the top mass measured in pseudo-experiments. The uniform probability assumed above yields a standard deviation of $9.8/\sqrt{12} = 2.8$ GeV/c^2. We performed a series of cross-checks to convince ourselves

CDF II Preliminary		
Systematic	Measure	Uncertainty (GeV/c^2)
Monte Carlo Generators	HERWIG - PYTHIA	-0.1 ± 0.6
We take		0.6
PDFs (Parton Distribution Functions)	MRST72 - CTEQ5L	-0.2 ± 0.6
	MRST75 - MRST72	0.4 ± 0.5
We take		0.8
ISR (Initial State Radiation)	"TuneB" - "TuneA" PYTHIA	0.2 ± 0.6
	"-1σ" ISR	0.5 ± 0.6
	"$+1\sigma$" ISR	2.5 ± 0.6
We take		2.5
FSR (Final State Radiation)	"-1σ" FSR	1.2 ± 0.6
	"$+1\sigma$" FSR	-1.3 ± 0.6
We take		1.3

TABLE I: Details on the systematic uncertainties on the measured top mass due to the modeling of the $t\bar{t}$ dilepton events.

that the 2.8 GeV/c^2 quoted here is indeed conservative.

The uncertainty due to the modeling of the $t\bar{t}$ signal (shown in Table I) is studied by: i) using two different Monte Carlo generators, HERWIG [10] and PYTHIA (we take $\sigma_{m_{top}} = 0.6$ GeV/c^2 = max{0.1, 0.6}); ii) using parton distribution functions from two different groups (CTEQ and MRST), where the two MRST sets employed are derived using different Λ_{QCD} values (we take $\sigma_{m_{top}} = 0.8$ GeV/c^2 = max{0.2,0.6} $\oplus$ max{0.4, 0.5}); iii) varying the initial and final state radiation in PYTHIA samples, by changing the QCD parameters for parton shower evolution according to comparisons between CDF Drell-Yan data and Monte Carlo (the maximum observed difference, 2.5 and 1.3 GeV/c^2, respectively, is taken as the systematic uncertainty on the top mass).

The finite statistics in the signal and background templates results in a systematic uncertainty on the p.d.f's used in the likelihood (Eq. 4), even if the modeling of the signal and background processes were correct. For each signal template we Poisson-fluctuate the number of events in each bin and create a new template. Then, we fit the probability density function (Eq. 3) to the "fluctuated template" and perform a set of 5000 pseudo-experiments, by drawing events from the nominal (non-fluctuated) template. We repeat 100 times and each time we get an average top mass measured from the pseudo-experiments. We use the root mean square of this distribution (0.3 GeV/c^2) as the systematic uncertainty due to the signal template statistics. Performing this test using events from the 175 GeV/c^2 signal template yields the same result. We repeat the same procedure for each bin of each background component and obtain a systematic uncertainty due to the limited background template statistics of 1.3 GeV/c^2.

The $\not{E}_T$ resolution is the last source of non-negligible systematic uncertainty we consider. Should our knowledge of the $\not{E}_T$ resolution not represent that of the data, the weights assigned to a certain configuration will change (see Eq. 1) and may cause a systematic error. We create two extra sets of signal ($m_t = 170$ GeV/c^2) and background templates; one set using $\sigma_{\not{E}_T} = 8\,$GeV in Eq. 1 when reconstructing the top mass in simulated events and the other set using $\sigma_{\not{E}_T} = 30\,$GeV. We perform pseudo-experiments by drawing events from the templates created using $\sigma_{\not{E}_T} = 8\,$GeV or $\sigma_{\not{E}_T} = 30\,$GeV, but the likelihood uses the nominal p.d.f's, obtained with $\sigma_{\not{E}_T} = 15\,$GeV. The $\sigma_{\not{E}_T} = 8\,$GeV value corresponds to the case where the jets are almost perfectly measured, whereas the 30 GeV value corresponds to the case where the two jets are about 250 GeV each and this should account for any unmodeled wide component to the $\not{E}_T$ resolution. Notice that the average p_T of b quarks in dilepton $t\bar{t}$ decays is about 70 GeV/c, with a root-mean-square of 26 GeV/c. Conservatively assuming that the true $\not{E}_T$ resolution can uniformly be anything between 8 and 30 GeV, we take the difference of the top masses measured in pseudo-experiments over $\sqrt{12}$ and obtain a systematic uncertainty of 0.3 GeV/c^2. The same result is obtained when performing this test using the 165 GeV/c^2 signal template.

In Table II we summarize the systematic uncertainties on the top mass measurement.

VII. CONCLUSION

Using the Neutrino Weighting Algorithm applied on the 19 "lepton+track" events collected by CDF in 197 pb^{-1} of the Run II data, we measure a top quark mass of $168.1^{+11.0}_{-9.8}(stat) \pm 8.6(syst)$ GeV/c^2.

CDF II Preliminary	
Systematic	Uncertainty (GeV/c^2)
Jet energy scale	7.4
Background shape	2.8
Signal template statistics	0.3
Background template statistics	1.3
Signal Monte Carlo generators	0.6
Parton Distribution Functions	0.8
Initial State Radiation	2.5
Final State Radiation	1.3
$\not\!\!E_T$ resolution	0.3
Total	8.6

TABLE II: Summary of the systematic uncertainties on the top mass measurement. The total uncertainty is obtained by adding the individual contributions in quadrature.

Acknowledgments

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