CDF note 8959

Measurement of the top quark mass from the lepton transverse momentum in the $t\bar{t} \rightarrow$ dilepton channel at the Tevatron

The CDF Collaboration
URL http://www-cdf.fnal.gov

(Dated: August 13, 2007)

A new measurement of the top quark mass at 1.8 fb^{-1} integrated luminosity, using leptons' P_T in the dilepton channel is presented. A top quark mass of m_{top}=156$\pm$20$_{(stat)}$$\pm$4.6$_{(syst)}$GeV/$c^2$ is obtained with the Likelihood method and of 149$\pm$21$_{(stat)}$$\pm$5(syst)GeV/$c^2$ is obtained with the Straight Line method.

Preliminary Results for Summer 2007 Conferences

I. INTRODUCTION

This note presents a measurement of the top quark mass in the dilepton channel using 1.8fb^{-1} of data. The results presented are obtained using data collected by the CDF detector in $\bar{p}p$ collisions at $\sqrt{s} = 1.96$ TeV with the CDF detector at the Fermilab Tevatron. The CDF detector is described in detail in [1]. The top quark mass is measured using only the lepton's P_T information as proposed in [2]

The leptons' P_T is a variable that can be measured very well in the tracker and the calorimeter and can be accurately calibrated against Z→ dilepton decays. Jets have a minimal involvement in this analysis, i.e. only in the criteria used for the event selection. Therefore the top quark mass as extracted through this method, is not sensitive to JES uncertainty. The P_T is a simple variable that is common for the dilepton (DIL) and the Lepton+Jets (LJ) channels, a fact that gives the opportunity to combine results but also compare the two channels. A similar measurement has been presented and approved by the CDF for the Lepton+jets channel using 340pb^{-1} of data [3].

The measurement is based on the identification of both leptons in the decay chain $t\bar{t} \rightarrow (W^+b)(W^-\bar{b}) \rightarrow (l^+\bar{v}_l b)(l^- v_l \bar{b})$. Therefore it selects decays with two high transverse energy leptons, high missing transverse energy ($\not{E}_T$) and at least two jets in the final state. The excess of events selected in the data over the background expectation from the other known Standard Model sources is taken as a measurement of the production of $t\bar{t}$ events.

II. DATA SAMPLE & EVENT SELECTION

This analysis is based on an integrated luminosity of 1.8 fb^{-1} collected with the CDFII detector between December 2004 and March 2007. The data are collected with an inclusive lepton trigger that requires an electron or muon with E_T >18 GeV (P_T >18 GeV/c for the muon). From this inclusive lepton dataset, events with an offline reconstructed isolated electron of E_T, or muon with P_T, greater than 20 GeV are selected. A second electron of E_T, of muon of P_T, greater than 20 GeV is also required using looser identification cuts and no requirement on isolation. Events with more than two leptons in the final state are rejected.

This "dilepton" dataset is cleaned of other known Standard Model decays with two leptons in the final states by requiring $\not{E}_T$ >25 GeV (or >50 GeV if any lepton or jet is closer than 20^o from the missing E_T direction) and high missing E_T significance for ee and $\mu\mu$ events with dilepton invariant mass in the Z peak region [4].

At this point of the selection, events reconstructed with 0 or 1 jets of E_T >15 GeV are used as a control sample for the background estimation. The $t\bar{t}$ candidate region is obtained by requiring at least 2 jets with E_T >15 GeV, summed transverse energy H_T >200 GeV and the two leptons to be of opposite charge.

III. BACKGROUNDS

The sources of background processes considered for this selection are diboson (WW, WZ and ZZ) events, $W\gamma$ events in which the photon is misidentified as lepton, $q\bar{q} \rightarrow Z/\gamma^*$ and QCD production of W boson with multiple jets in which one jet is misidentified as lepton.

The two dominant sources of background dilepton events come from $Z/\gamma^* \rightarrow ee/\mu\mu$ with fake $\not{E}_T$ and from W+jets with a fake lepton. They are estimated using data-based methods. The diboson and $Z/\gamma^* \rightarrow \tau\tau$ decays are simulated with PYTHIA. The background from fake lepton source is calculated by using a large sample of generic jets triggered by the presence of at least one jet with E_T >50 GeV. This sample was used to calculate the probability, or fake rate, that a generic electron-like or muon-like object passes all of the identification cuts used to select a high E_T electron, or P_T muon.

IV. METHODS

This analysis has been based upon the observation that the leptons' transverse momentum (P_T) is sensitive to the top mass [2], [3]. Figures 1 and 2 show that the dependence of the mean P_T of the leptons to the mass is linear.

$$P_T = \kappa + \lambda M_{top} \tag{1}$$

In Figure 1 the mean P_T is derived from the P_T distributions of the mass signal templates generated for different input top masses. In Figure 2 each signal template has been combined to the total background template taking into account that the purity of the total sample, as calculated for Mtop = 175 GeV, is for $\rho \equiv \frac{\text{signal}}{\text{signal+background}} = 0.70$.

Taking the extreme case that only signal exists the sensitivity $\frac{d\langle P_T\rangle}{dM_{top}}$ is $\lambda_S = 13.5 \pm 0.4\%$. Including the background, as seen from Figure 2, the sensitivity is reduced to $\lambda_B = 9.4 \pm 0.3\%$. This decrease of the slope is expected since the background contaminates the Monte Carlo samples with events involving no top quarks and thus carrying no M_{top} information. This can be seen by decomposing the $\langle P_T\rangle$ into a 'signal' $\langle P_T\rangle_S$ and a 'background' $\langle P_T\rangle_B$ part:

$$< P_T >= \rho\langle P_T\rangle_S + (1-\rho)\langle P_T\rangle_B \quad (2)$$

where ρ is the purity of the sample as defined above. Using Equation 1 and the κ_S and λ_S values we can predict that the $\lambda_B = \rho \times \lambda_S = 9.4 \pm 0.4\%$, i.e consistent to the measured value.

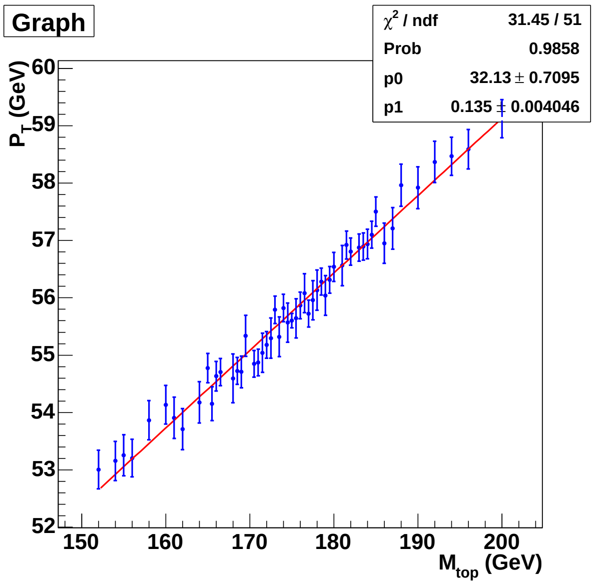

FIG. 1: Mean P_T vs Top Mass from signal only P_T distributions

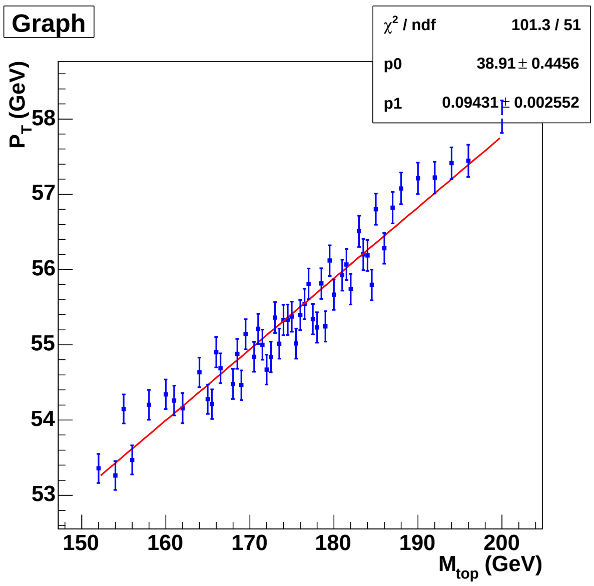

FIG. 2: Mean P_T vs Top Mass from signal and background P_T distributions

Going to a deeper level, we model the leptons' P_T distribution with an analytical function to examine how this function depends on the top mass. We found that such a function can be the product of a Gamma times a Fermi function as seen in Equation 3:

$$F(P_T) = \frac{1}{\Gamma(p+1, c/q)} \left(\frac{P_T}{q}\right)^p e^{-\frac{P_T}{q}} \times \frac{1}{1+e^{c-P_T/b}} \tag{3}$$

This function models successfully the shape of both the signal and the background P_T distributions. It has two free parameters p, q, where p is related to the expected rate of leptons with the average P_T and q can be interpreted as the expected average P_T per lepton. For the signal the p, q are mass dependent (see Eq. 4, 5) but for the background they are constant. The Fermi function models the leptons' P_T cut, setting c=20GeV/c and b=0.1GeV/c. The p and q are parametrized as in the following equations

$$p = \alpha_1 + \alpha_2 M_{top} \tag{4}$$

$$q = \alpha_3 + \alpha_4 M_{top} \tag{5}$$

From the above discussion it follows that we can establish two methods for measuring the top mass, both directly dependent to the top mass. For the first method we model the full shape of the signal and background P_T distributions using the Gamma x Fermi function and employ likelihood minimization method for the estimation of the top mass. This method, from now on will be denoted as Likelihood (LH). The second method directly exploits the fact that the mean P_T of the leptons is linearly dependent to the top mass as shown in Figure 2. This method, from now on will be called Straight Line method (SL).

V. SYSTEMATIC UNCERTAINTIES

The anticipated sources contributing to the systematic uncertainty can be grouped to three main categories. The first group contains the uncertainties to the top mass related to the signal. The second group involves the uncertainties related to the background. The third one deals with the leptons' P_T scale uncertainty. Table I summarizes the uncertainties for the LH and SL methods.

Source of systematic	error-LH (GeV)	error-SL (GeV)
Signal	2.84±2.5	3.1±1.7
Background scale	0.2±0.0	0.8±1.2
Background shape	3.2±0.0	3.4±0.0
P_T linearity	1.7±0.2	1.7±0.2
Total	4.6±2.5	5.0±2.1

TABLE I: Systematic errors

VI. RESULTS

The dilepton selection on the 1.8fb^{-1} data gives 125 dilepton events. The 250 leptons of this dataset have a mean P_T=52.96±1.97 GeV. Figure 3 illustrates the mean P_T of the data in comparison with the Standard Model signal+background expectation.

Table II presents the results of the fit to the 2fb^{-1} data using the Likelihood Method (LH). Figure 4 illustrates the fit to the data (blue line). The red line is the fit to the signal and the black line the fit to the background.

The LH method gives $M_{top} = 156^{+22}_{-19}{}_{(stat)} \pm 4.6_{(syst)} GeV/c^2$.

Using the standard Equation 2, the Straight Line method estimates that
M_{top}=149±21$_{(stat)}$ ± 5$_{(syst)}$ GeV/c^2.

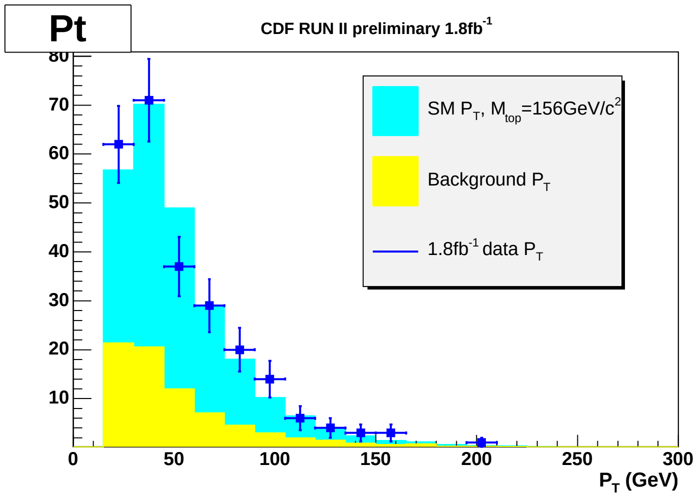

FIG. 3: Fit to the 1.8fb^{-1} data. The MC top signal is for a top mass of 156 GeV

n_{s1} (leptons)	n_{bg1} (leptons)	n_{s2} (leptons)	n_{bg2} (leptons)	M_{top} (GeV)
174.94	76.12	171±21	78 ±14	$156\ ^{+22}_{-19}$

TABLE II: We denote with n_{s1}, n_{bg1} the starting number of signal and background leptons and with n_{s2}, n_{bg2} the number of leptons estimated by the fit. The M_{top} is estimated by the likelihood minimization procedure. The quoted errors are statistical.

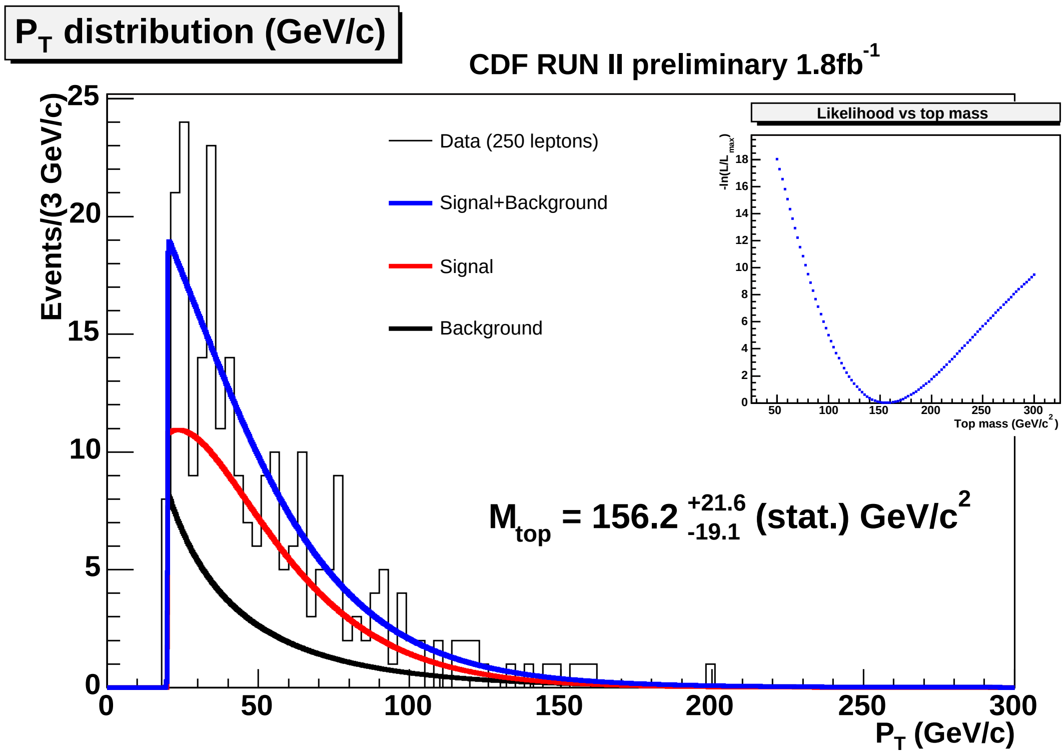

FIG. 4: Fit to the 1.8fb^{-1} data

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium fuer Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-20002, Probe for New Physics.

This work has been partly supported by the Greek General Secretariat for Research and Technology, by the EEC RTN contract HPRN-CT-2002-00292, by the INTAS-CERN grant 32-52-6447, by the Special Account for Research Grants of the National and Kapodistrian University of Athens, and by the EPEAEK II program (Operational Program for Education and Initial Training) in the framework of the projects "Hrakleitos" and "Pythagoras".

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