Eur Phys J C **33**, s01, s677–s679 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2004-03-1617-4

EPJ C direct
electronic only

Top quark mass measurement at CDF Run-II

Takasumi Maruyama, for the CDF collaboration

Enrico Fermi Institute, University of Chicago, 5640 Ellis Ave., Chicago, IL, 60637-1433

Received: 28 October 2003 / Accepted: 14 January 2004 /
Published Online: 3 February 2004 –

Abstract. CDF has resumed the top quark mass measurement with upgraded detectors at the upgraded Tevatron complex. High statistics should allow us to determine the top mass with an uncertainty of a few GeV/c^2 by the end of Run-II. The current measured value, using an integrated luminosity of $\sim$108pb^{-1}, is $177.5^{+12.7}_{-9.4}(stat.) \pm 7.1(syst.)\ GeV/c^2$ (lepton + jets with one b-jet tagged mode: the current best mode), which is consistent with Run-I measurements.

PACS. 14.65.Ha Top quark mass measurement

1 Introduction

The top quark was first seen by the CDF experiment at the Tevatron in 1994 [1]. It is surprising that this quark has such a large mass, $\sim$175 GeV/c^2 [2], and a Yukawa coupling constant $\sim$1.

The top quark mass measurement is one of the most fascinating and important physics topics at CDF Run-II. It provides a constraint of the Higgs boson mass as well as the measurement of a basic standard model parameter. CDF Run-II aims to determine the top mass with a few GeV/c^2 accuracy. Together with precision knowledge of the W boson mass ($30 \sim 40$ MeV/c^2 accuracy), this provides a $\sim 30-40\%$ constraint on the Higgs mass (M_H). To achieve this goal, CDF has improved its silicon detector to increase the b-quark tagging efficiency, which is very crucial for identifying top quark decays. Lepton acceptance was also increased by the detector upgrade.

This article describes the top quark mass measurement: selection of the top quark signal (Sect. 2), the method for determining the top quark mass (Sect. 3), and current results (Sect. 4).

2 Selection of top quark events

Since the top quark decays to a W boson and a b quark with $\sim$100% branching ratio, there are only a small number of final states to be considered. For simplicity, we only describe the most important $t\bar{t}$ decay channel, $t\bar{t} \rightarrow WbW\bar{b} \rightarrow l\nu bjj\bar{b}$. This channel provided the best top quark mass measurement among all decay modes in Run-I, and has given the earliest result in Run-II.

The event selection criteria are as follows:

(1) The event passes the high-P_T electron or muon trigger,
(2) Lepton $E_T > 20$ GeV and $\not{E}_T > 20$ GeV, then either
(3) Three jets with $E_T > 15$ GeV and $|\eta| < 2.0$, and another jet with $E_T > 8$ GeV and $|\eta| < 2.0$, with at least 1 jet tagged as a b-jet based on finding a secondary vertex.
or
(4) All four jets satisfy a tight requirement ($E_T > 15$GeV and $|\eta| < 2.0$), but there is no tag requirement (pretagged sample).

(Here E_T is transverse energy, P_T is transverse momentum, $\not{E}_T$ is missing transverse energy, and η is pseudorapidity.)

After these cuts, the background fraction is already small ($\sim$ 15 %) for b-jet tagged events, while the pretagged sample still contains $\sim$50% background. The main background comes from W boson plus heavy quarks (i.e. $Wb\bar{b}$) in the former case, while W boson + light quarks is the main background in the latter case.

3 Determination of the top quark mass

There are two steps in measuring the top quark mass. The first is to use a constrained fit to determine the top quark mass on an event-by-event basis. The other is to measure the background fraction and extract an ensemble top mass using a log-likelihood method. The following two subsections describe these steps.

3.1 Constrained fit for event kinematics

The $t\bar{t}$ events have the decay chain mentioned above, namely $p\bar{p} \rightarrow t\bar{t}X \rightarrow WbW\bar{b}X \rightarrow l\nu bjj\bar{b}X$. There are five decay vertices in this chain, corresponding to 20 kinematic equations (energy and momenta conservation at each vertex) for the 21 unknowns (the 4-momenta of the t, $\bar{t}$, and

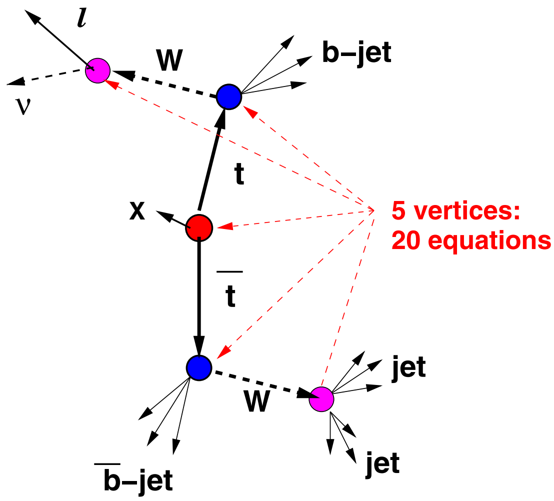

Fig. 1. The schematic view of a top quark and top antiquark decay. There are five vertices and 20 kinematic equations

the two W's, the 3-momentum of the ν, and the energy and z momentum of X) (Fig. 1). Adding the W boson mass (80.423 GeV/c^2 : [3]) constraints, $M_{l\nu} = M_{jj} = M_W$, and the top quark mass constraint, $M_t = M_{\bar{t}}$, provides a two parameter overconstrained χ^2 fit.

Another issue is choosing among the multiple solutions. The four observed jets must be assigned to the final state quarks. For pre-b-tagged events , any of the four jets can be assigned to the b quark, with one of the remaining three assigned to the $\bar{b}$ quark. That gives 12 combinations. In addition, there is a quadratic ambiguity when solving for the z momentum of the ν, giving a total of 24 possible solutions. Even in b-tagged events, there still are 12 combinations. The combination with the best fit χ^2 is chosen for the jet assignments and the z component of the ν momentum.

3.2 Likelihood fit to deduce the top mass and background fraction

The final step in determining the top quark mass is a likelihood fit of the individual event masses to the sum of signal and background templates, with the fit parameter being the background fraction. A fit is carried out at each top mass, and the minimum of the negative-log-likelihood determines the final reported top mass.

4 Results

In this paper, we show three top quark mass measurement results. One uses b-tagged events, the second one uses events without a b-tag requirement, and the third uses events that have two leptons (ee, eμ or $\mu\mu$) in the event. This latter final state is not discussed in detail here; only the number of events and the extracted mass are presented.

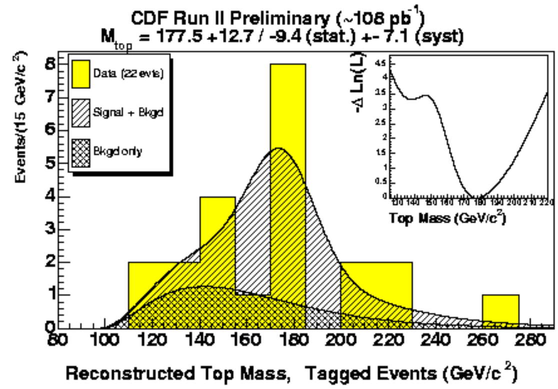

Fig. 2. The reconstructed top quark mass from the constrained fit described in Sect. 3.1. There are 22 events containing a b-tagged jet. This figure also shows the mass distribution from the log-likelihood fit for the best fit top mass. The *top-right* figure shows the -$\Delta Ln(L)$ as a function of top mass

4.1 Results from b-tagged events

Currently, an integrated luminosity of 108pb^{-1} is available in this analysis mode. Twenty-two candidates are found. Figure 2 shows the reconstructed mass using the constrained χ^2 fit mentioned in Sect. 3.1. The histogram shows the b-tagged data. The best fit curve from the log-likelihood fit is also shown. One can see the templates for the signal and background scaled to the fit fractions. The best fit mass from this dataset is
$177.5^{+12.7}_{-9.4}(stat.)\pm$ 7.1 (syst.) GeV/c^2

4.2 Results from the pre-b-tag sample

In this mode, we use 72pb^{-1} of integrated luminosity. Thirty-three events are reconstructed as $t\bar{t}$ and fitted as a superposition of the top and W+jets background. The result of this fit is shown in Fig. 3. One sees that this sample has a much larger background fraction than the b-tagged sample.

The best fit mass from this sample is
171.2±13.4($stat.$)± 9.9 (syst.) GeV/c^2

4.3 Results from the di-lepton mode

There are 6 di-lepton events corresponding to a 125.8pb^{-1} integrated luminosity. This mode has very small background but also small statistics due to the additional $W \to l\nu$ branching ratio. The analysis using this sample gives:
$175.0^{+17.4}_{-16.9}(stat.)\pm$ 8.4 (syst.) GeV/c^2 .

Table 1 summarizes these results.

5 Perspectives for reducing systematic uncertainties

To achieve the aimed accuracy for the top mass in Run-II, there are lots of things to do. To see what are the key

Table 1. Summary of top quark mass measurements at CDF run-II.

sample	best fit value
b-tagged	$177.5^{+12.7}_{-9.4}(stat.)\pm$ 7.1 (syst.) GeV/c^2
pre-b-tag	$171.2\pm13.4(stat.)\pm$ 9.9 (syst.) GeV/c^2
di-lepton	$175.0^{+17.4}_{-16.9}(stat.)\pm$ 8.4 (syst.) GeV/c^2

Table 2. Current uncertainties for the top quark mass measurement using the b-tagged sample

source	size
statistical	$^{+12.7}_{-9.4}$ GeV/c^2
jet scale	6.2 GeV/c^2
MC modeling	1.0 GeV/c^2
generator	0.6 GeV/c^2
initial state radiation	1.3 GeV/c^2
final state radiation	2.2 GeV/c^2
parton distribution functions	2.0 GeV/c^2
background	0.5 GeV/c^2
b-tagging	0.1 GeV/c^2

issues, we show the current uncertainties for the b-tagged sample in Table 2.

The statistical error will be reduced by combining all the independent analysis modes as well as using the full Run-II luminosity (>2.0 fb^{-1}), more than a factor of 20 beyond the integrated luminosity used here. Among the systematic uncertainties, the most significant one comes from the jet energy scale uncertainty. To reduce this, a lot of effort is under way to better understand the detector response, to maintain the detector, to calibrate the jet energy scale in new ways and so forth. Studying $Z \to b\bar{b}$ events and the reconstructed dijet W boson mass in top events are expected to be quite useful for improving the jet energy calibration.

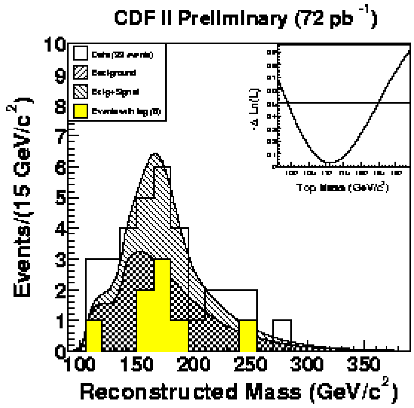

Fig. 3. The reconstructed top quark mass using 33 pre-b-tagged events. The *shaded histogram* shows the b-tagged events within this sample. Signal and background templates for the fit are also shown. The *top-right* figure shows -$\Delta Ln(L)$ as a function of top mass

6 Summary

CDF has resumed measuring the top quark mass with the upgraded Run-II detector and Tevatron. We find $177.5^{+12.7}_{-9.4}(stat.) \pm 7.1(syst.)$ GeV/c^2 for the top quark mass employing $\sim$108pb^{-1} integrated luminosity (lepton + jets decay with one b-jet tagged mode). This value is clearly consistent with the Run-I measurement.

The goal of CDF in Run-II is to reduce the uncertainty for this measurement to a few GeV/c^2 . To achieve this, there are many things to do, especially reducing the uncertainty in the jet energy measurement. With these improvements, CDF will provide an important top quark mass measurement by the end of the Run-II.

References

1. F. Abe et al: Phys. Rev. Lett. **73**, 225 (1994)
2. L. Demortier et al (The Top Averaging Group for the CDF and D0 Collaborations): FERMILAB-TM-2084 (1999)
3. Review of Particle Properties: Phys. Rev. D **66**, 1 (2002)