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CDF

Top Mass Measurement at CDF

J. Lys
For the CDF Collaboration
Lawrence Berkeley National Laboratory
Berkeley, California 94720

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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TOP MASS MEASUREMENTS AT CDF

J. LYS

Lawrence Berkeley National Laboratory, Berkeley, Ca 94720

(For the CDF Collaboration)

We report on measurements of the top quark mass by the CDF experiment at the Fermilab Tevatron collider. The top quark is produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The analyses use an integrated luminosity of 110 pb^{-1}. Results are presented from three decay channels, (i) one lepton plus jets, (ii) dilepton, (iii) all hadronic. The smallest error on the mass comes from (i), with a preliminary top mass value of 175.6 ± 4.4 (stat.) ± 4.8 (syst.) GeV. Results from the other channels are consistent with this value.

1 Introduction

In $p\bar{p}$ collisions the Standard Model predicts that high-mass top quarks will be produced predominantly in pairs. That is, as $p\bar{p} \rightarrow t\bar{t}$ + X. The model also predicts that the top quark will decay almost exclusively into a W boson plus a b quark. Therefore top quark events are classified according to the decay modes (hadronic or leptonic) of the two W bosons: (i) lepton plus jets, one leptonic and one hadronic W decay; (ii) dilepton, two leptonic W decays; (iii) all hadronic, two hadronic W decays. The expected percentages in the three channels are 30%, 5%, and 44% respectively, if tau-lepton decays are excluded. Events where one or both decays of the W includes a tau-lepton can contribute to all of these channels.

CDF has made top mass measurements for events in each of these three channels. The events come from 110 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron Collider.

2 Lepton plus jets analysis

2.1 Event selection

The event selection here requires (i) an isolated, high transverse momentum ($P_T > 20$ GeV/c) electron or muon, (ii) a large missing transverse energy ($\not\!\!E_T > 20$ GeV), (iii) at least 3 jets with uncorrected transverse energy $E_T > 15$ GeV and pseudo rapidity magnitude $|\eta| < 2.0$, (iv) at least 4 jets with uncorrected $E_T > 8$ GeV and $|\eta| < 2.4$. A total of 163 events pass these cuts.

2.2 Kinematic fit

To extract a top mass, a kinematic fitting method is used [1]. The fit considers 5 vertices, the production vertex, two top decay vertices, and two W decay vertices. The 4 jets with the highest E_T values in an event are assigned to the two b quarks from top decay and the two quarks from hadronic W decay, initially with all possible permutations. Jet directions and corrected jet energies, with errors, are assigned to the quark-level entities, together with masses of 5.0 (b-quarks) or 0.5 GeV. The masses of the two top quarks in an event are required to be equal. The net result is a 2-constraint fit. In general there are two solutions per jet assignment permutation, corresponding to two solutions for the neutrino longitudinal momentum. Therefore, with all possible permutations there may be 24 fit solutions for a given event.

The number of solutions may be reduced by tagging b jets. A jet is tagged as a b-jet if there is evidence that the jet contains a b-hadron decay. Two types of tagging [1] are used, (a) SVX, making use of the silicon vertex detector to find tracks that originate from a vertex downstream from the event's primary vertex; (b) SLT, observing a soft lepton that is consistent with coming from a semileptonic decay of a b-hadron or a daughter charm hadron. Then, only those permutations that have a tagged jet assigned as a b jet need be considered.

Kinematic fits are required to have $\chi^2 < 10$. Of the 163 events passing the cuts, 153 have at least one passing kinematic fit. Of these 153 events, 34 events have one or two b-tags.

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2.3 *Monte Carlo simulation*

A Monte Carlo simulation of the kinematic fitting is necessary for several reasons. Firstly, there is experimental smearing, predominantly in the jet energy. Secondly, there is the need to relate the jet energies to parton energies. Thirdly, one (or more) of the four highest E_T jets may not be directly related to the partons in the decay chain (and in particular could come from hard gluon radiation from initital or final state partons). Fourthly, the fit solution with the lowest χ^2 may not have the correct jet assignment or correct neutrino longitudinal momentum solution.

The Monte Carlo programs used are HERWIG [2] for top production and decay, and VECBOS[3] for background processes, together with the standard CDF detector simulation, which includes modelling of the b tagging.

The distributions of many kinematic variables of the observed events have been compared with the predictions from HERWIG plus VECBOS events in the expected ratios. Generally good agreement is observed.

2.4 *Background estimate*

The estimate of the background (i.e., non-top) fraction of the event samples comes from the observed numbers of b-tags of different types and the estimated tagging efficiencies for top and non-top events. Then background fraction estimates are approx. 66% of the 153-event sample, and approx. 20% of the 34-event tagged sample.

2.5 *Likelihood Fit*

The top mass estimate uses a likelihood fit to the M_t distribution. Here, M_t is the top mass estimate from the kinematic fit (i.e., the reconstructed mass), one M_t value per event. The M_t value is taken from the lowest chisquare solution that has jet assignments consistent with observed b-tags.

The predicted distributions for the likelihood fit come from Monte Carlo events, at several M_{top} values, run through the same kinematic fitting as the data. Finite Monte Carlo statistics give a statistical error to the likelihood at each M_{top} value. A quadratic fit is made to a limited portion of the negative-log- likelihood versus M_{top} plot. The true M_{top} estimate is given by the minimum of the quadratic, and the statistical error by where

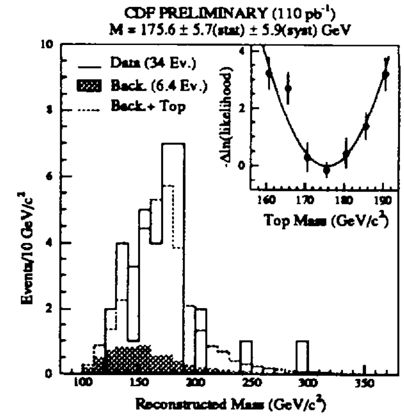

Figure 1: Lepton plus jets with ≥ 1 tag, observed (solid) and predicted (dashed) reconstructed mass, and likelihood fit.

the quadratic has increased by 0.5 units from the minimum.

2.6 *Tagged event results*

Results for the 34-event sample with b tags are shown in Fig. 1. The histograms show the observed M_t distribution and that predicted for top events (M_{top} = 175 GeV) plus background events. The likelihood fit gives M_{top} = 175.6 $\pm$ 5.7 GeV (stat.error). The estimated systematic error is $\pm$ 5.9 GeV. Compared to what was presented earlier [4] the systematic errors have been reevaluated. The leading systematic error sources are soft gluon plus jet energy scale uncertainties ($\pm$ 3.8 GeV), hard gluon uncertainties ($\pm$ 3.6 GeV), and kinematic and likelihood fitting method uncertainties ($\pm$ 2.0 GeV).

2.7 *Optimized tagged plus no-tagged samples*

Monte Carlo studies indicate a reduced error if the tagged events are subdivided into different tagging classes and a subset of the no-tagged events is added. Therefore, the following four exclusive subsamples were used: (i) events with just one SVX tag (15 events), (ii) events with two SVX tags (5 events), (iii) events with a SLT tag(s) but no SVX tag (14 events), (iv) events with no tag and with all four leading jets having $E_T > 15$ GeV (48 events). The first three subsamples comprise the 34-event tagged sample considered above.

For each subsample, an expected background fraction was estimated, and predicted M_t (re-

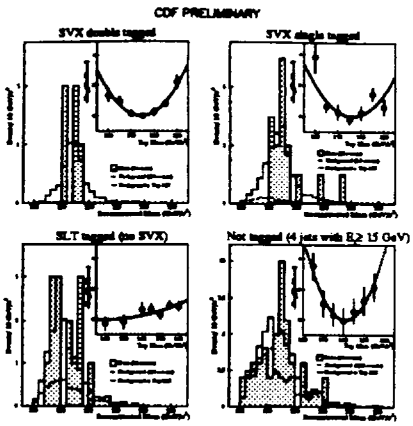

Figure 2: Lepton plus jets optimized subsamples, observed (shaded) and predicted (unshaded) reconstructed masses, and likelihood fits.

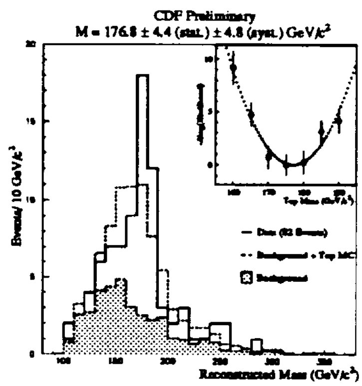

Figure 3: Lepton plus jets optimized subsamples, combined observed (solid) and predicted (dashed) reconstructed mass, and product likelihood.

constructed mass) distributions for both top and background events were obtained from Monte Carlo events at several M_{top} values. Then a likelihood fit was made for each subsample, shown in Fig. 2.

At a given top mass value, the likelihood values from the four subsamples are essentially independent, so a combined result is obtained by taking the product of the four values. The sums of the M_t distributions, and the likelihood product versus top mass plot, are shown in Fig. 3. From the likelihood product plot the top mass estimate is 176.8 ± 4.4 (stat) GeV.

Pseudo-experiments were used to check this procedure. For each pseudo-experiment, Monte

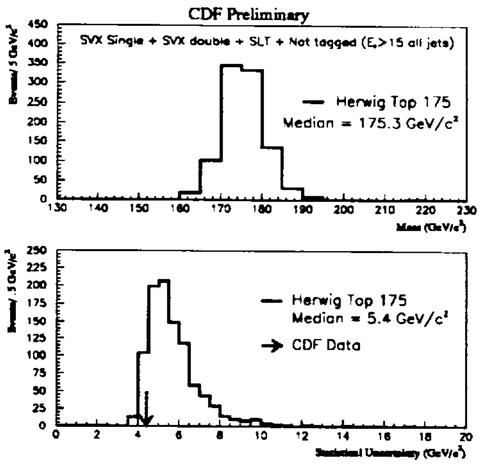

Figure 4: Lepton plus jets optimized subsamples, top mass values and statistical errors from 1000 Monte Carlo experiments.

Carlo events were used, with the same number of events in each subsample as observed in the data and with the appropriate background fraction in each subsample. Then the same likelihood fit as used on the data was applied. Results are in Fig. 4. The median top mass estimate of 175.3 GeV agrees with the input Monte Carlo value of 175 GeV. The median statistical error of 5.4 GeV is somewhat larger than the value from the data of 4.4 GeV, but a value smaller than 4.4 GeV occurs in nearly 10% of the pseudo-experiments.

The total systematic error is ± 4.8 GeV. The largest contribution (± 3.6 GeV) comes from soft gluon plus jet E_T scale uncertainties, that is, from uncertainty in estimating the true jet energy from the observed energy in a cone of radius 0.4 (in $\eta-\phi$ space). The hard gluon effects systematic error (± 2.2 GeV) reflects uncertainty in how often one of the four leading jets is associated with a hard gluon rather than directly with a parton in top decay. All other contributions are $\leq$ 1.5 GeV.

3 Dilepton events

The event selection requires (i) two central, oppositely-charged leptons (electron or muon) with transverse energy E_T > 20 GeV, (ii) large missing transverse energy ($\not{E}_T$ > 25 GeV), (iii) at least two jets with E_T > 10 GeV, (iv) the sum of the E_T's of the leptons and the jets plus the $\not{E}_T$ > 170 GeV, (v) the two-lepton invariant mass not in the Z region. If $\not{E}_T$ < 50 GeV there is a cut on the angular separation between the $\not{E}_T$ direction and the closest jet or lepton. A total of 8 events pass these cuts. The expected background (i.e., non-top) contribution is $\sim$ 1 event.

The two neutrinos present preclude straightforward kinematic fitting in this channel. Instead, the observed distribution in a kinematic variable whose distribution is dependent on the top mass can be compared to the predicted distribution as a function of top mass.

Earlier[4] a result using the lepton (electron or muon) energy distribution was shown. A second analysis has used the invariant mass-squared of a lepton plus a jet. For each event the average value of the pairing that gives the smaller value is chosen. Comparison to predicted distributions leads to an M_{top} estimate of 162 $\pm$21 (stat) $^{+7.1}_{-7.6}$ (syst.) GeV.

4 All hadronic events

Events here are required to have at least 6 jets with $E_T > 15$ GeV and $|\eta| < 2.0$, and no more than 8 such jets. The minimum jet-jet separation in $\eta - \phi$ space must be > 0.5. The total transverse energy must be > 200 GeV and $> 0.75 \sqrt{s}$. There is also a transverse energy-dependent cut on aplanarity. Finally, events must have at least one jet with an SVX tag. The final event sample contains 142 events. The calculated number of background (i.e., non-top) events in the sample is 113 events with an error of 6.5%.

A kinematic fit is performed, using the 6 leading jets of each event. The fit has each top parton decaying to a W plus a b parton, and each W decaying to two jets, and has 3 constraints. After requiring the tagged jet to be assigned as a b jet, there are 30 possible jet assignments, and so 30 possible solutions. The solution with lowest χ^2 value is chosen, and that value is required to be $<$ 10.

The predicted background mass distribution is taken to be given by no-tag events that otherwise pass the selection cuts. These events are run through the same kinematic fit as the tagged sample. The predicted mass distribution for top events is obtained from HERWIG Monte Carlo events. A likelihood fit, with the background contribution constrained to the calculated fraction, gives a top mass estimate of 187 $\pm$8 (stat.) GeV. The systematic error is $^{+13}_{-12}$ GeV, with largest contributions coming from the jet energy scale and hard gluon uncertainties.

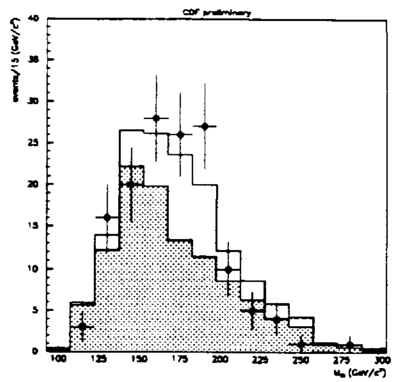

Figure 5: All hadronic channel, observed (solid circles), background (shaded), and predicted top (185 GeV) plus background reconstructed mass.

The best fit top mass distribution is shown in Fig. 5 , together with the predicted mass distributions from background events and background plus top events with $M_{top} = 185$ GeV.

5 Conclusion

The CDF experiment has measured the top quark mass in each of three topologies.

The most accurate measurement comes from the lepton plus jets topology, using 34 tagged and 48 no-tag events. The result is 176.8 $\pm$4.4 (stat.) $\pm$4.8 (syst.) GeV.

The dilepton topology result, from the lepton-plus-jet effective mass, is 162 $\pm$21 $\pm$7 GeV.

The all-hadron topology kinematic fitting result is 187 $\pm$8 $\pm$12 GeV.

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