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(On behalf of the CDF Collaboration)

TOP QUARK MASS MEASUREMENT IN NON-TAGGED LEPTON + JETS EVENTS AT CDF

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INTRODUCTION

The precise measurement of the top quark mass is one of the main goals in the CDF-II physics program [1]. Because it is so heavy, the top quark provides an unusually sensitive tool for investigating the Higgs field and may possibly have a special role in electroweak symmetry breaking.

At the Tevatron, top quarks are produced primarily as top pairs ($t\bar{t}$) from quark–antiquark annihilations ($\sim 90\%$) or gluon–gluon fusion. According to the Standard Model (SM), both top quarks almost exclusively decay as $t \to Wb$, with following decay of W into lepton–neutrino ($l\nu$) or quark pairs. For our measurement we use the «*lepton + jet*» channel of $t\bar{t}$ candidates, when one of two Ws decays into $l\nu$ while the other decays into a quark pair, producing jets.

We report on the first attempt in Run 2 to measure the top quark mass in non-tagged lepton + jets events. The motivation of this work is to measure the top mass in a data sample not used in other mass measurements at CDF, and thus provide additional information to a combined measurement. Our non-tagged sample was obtained from the pre-tagged sample after removing the b-tagged events. Since tagging was not available in 31.9 pb^{-1} of data, there is a $\sim 16\%$ contribution of pre-tagged data in our sample.

1. EVENT SELECTION

The sample used in this analysis includes data collected from March 2002 to September 2003 and corresponds to a total integrated luminosity of 193.5 pb^{-1}.

We are requesting 4 rather than 3 jets of equally large E_T. We note that in the «optimized» Run 1 analysis [2] these cuts were used in order to define a top-enriched sample after removing the b-tagged events. Due to the increased tagging efficiency in Run 2, we have a signal to background ratio in non-tagged samples (~ 0.3) smaller than in Run 1. In order to increase this ratio we optimized the cut on jet transverse energy and made it harder.

In the event selection we require a single isolated lepton (electron or muon) with $E_T > 20$ GeV, 4 (or more) tight jets ($E_T > 21$ GeV and $|\eta| < 2.0$), and missing transverse energy $\not{E}_T > 20$ GeV. Cosmic ray, conversion or Z events are eliminated.

39 $t\bar{t}$-candidate events were selected by these cuts after removing b-tagged events.

2. TEMPLATE METHOD

The kinematics of the lepton + jet decay channel:

$$p\overline{p} \to t\overline{t} + X \to l\nu q\overline{q}'b\overline{b} + X \tag{1}$$

are over-constrained by the number of measured quantities and the number of applicable energy-momentum conservation equations at production and decay. This allows to completely reconstruct the particles in the decay chain and hence an event-by-event top mass determination. We produce the expected invariant mass distributions for the $t\overline{t}$ candidates from the Monte-Carlo simulated signal (for different top quark masses) and background events, called top mass templates. Then a likelihood procedure is used to extract the top mass from the reconstructed-mass distributions of the data samples and of the $t\overline{t}$ signal and background models, along with the constraint on the signal fractions.

The details of the method are described in [2].

2.1. Event Reconstruction. The events were reconstructed as $t\overline{t}$ with MINUIT. Since we have no b-jet information, each event provides 24 solutions. 12 combinations correspond to different assignments of jets to primary quarks. For each of these there are two solutions for sign of the longitudinal momentum of the neutrino. Energy-momentum conservation at production and decay of tops and Ws, the constraint $m_t = m_{\overline{t}}$, the assumed theoretical value of the top width Γ_t, the measured values of W mass M_W and width Γ_W provide 20 equations with 18 unknowns. A 2-C fit to determine the top mass and the longitudinal momentum of the neutrino can be performed. The chosen top mass was the one returned by the combination with the minimum χ^2.

The χ^2 to be minimized as follows:

$$\chi^2 = \sum_{l,\,\text{jets}} \frac{(P_T - \widetilde{P_T})^2}{\sigma^2_{P_T}} + \sum_{j=x,y} \frac{(UE_j - \widetilde{UE_j})^2}{\sigma^2_{UE_j}} + \\ + \frac{(M_{l\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{q\overline{q}'} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bl\nu} - m_t)^2}{\Gamma_t^2} + \frac{(M_{q\overline{q}'\overline{b}} - m_t)^2}{\Gamma_t^2}, \tag{2}$$

where the sum in the first term runs over the primary lepton and over all jets with observed $E_T \geqslant 8$ GeV and $|\eta| \leqslant 2.0$, and the second sum runs over the transverse components of the unclustered energy. The hatted variables $\widetilde{P_T}$ and $\widetilde{UE}$ refer to the output of the minimization procedure, whereas P_T and UE represent measured values, corrected for known detector and physics effects. m_t is the fit parameter giving the reconstructed top mass for the combination being considered.

Only combinations which could be fitted as $t\overline{t}$ with $\chi^2_{\min} < \chi^2_{\text{limit}}$ are accepted. Events with no combination satisfying this criterion were rejected. Run 1 limit for the χ^2 cut was set 10. For the sake of compatibility with the other top mass measurements at CDF, we applied $\chi^2 < 9$ cut.

2.2. Top Mass Templates for Signal and Background. To derive the signal templates we used the Herwig [3] Monte-Carlo samples with input top mass at 5 GeV/c^2 intervals from 150 to 210 GeV/c^2.

The top signal template is parametrized as a sum of a gamma function and of a Gaussian comprising 6 parameters that depend linearly on the top mass. These

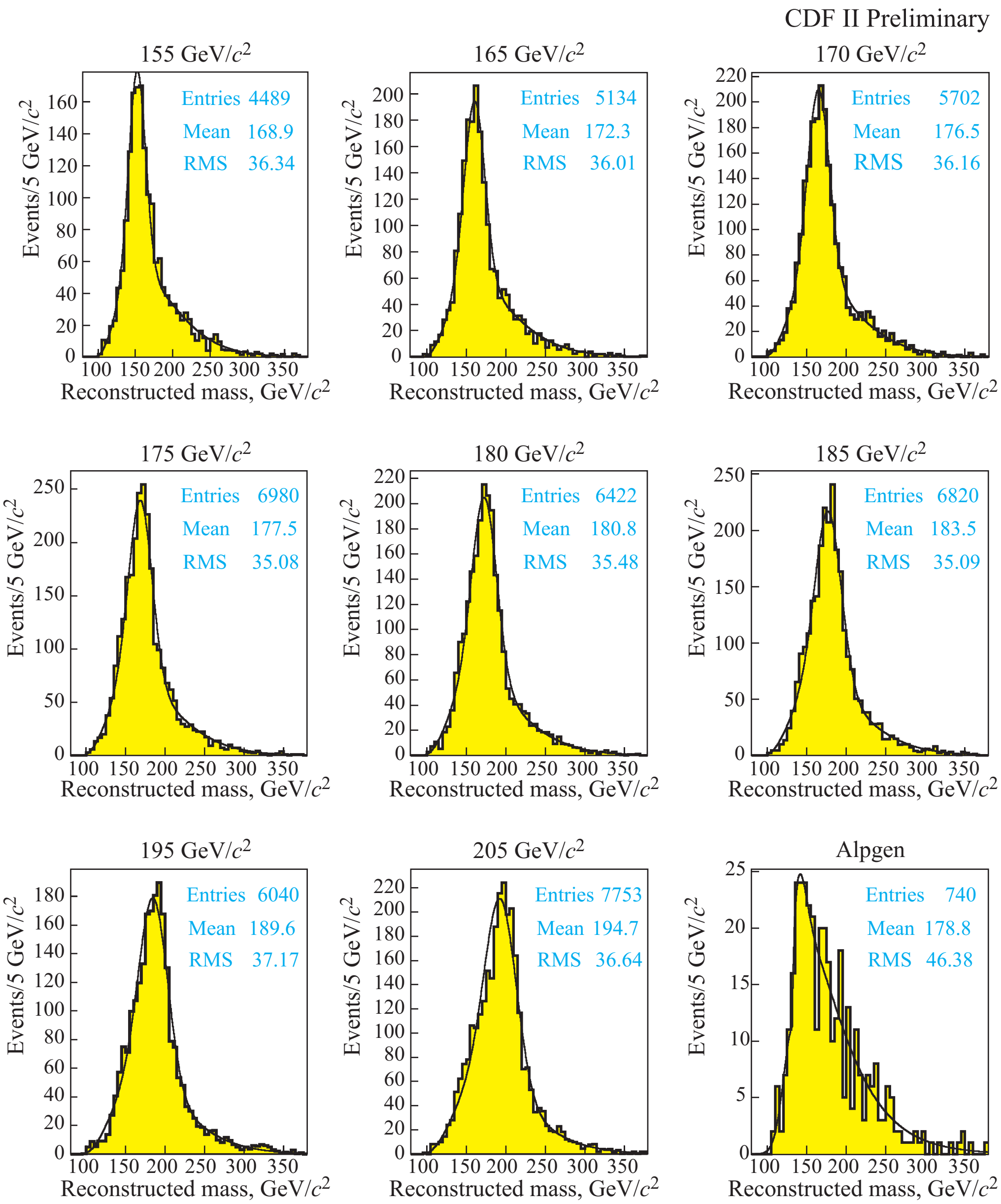

Fig. 1. Herwig simulated signal distributions and Alpgen generated background distribution compared to the fitted templates (continuous curves) for the selected Monte-Carlo samples

parameters are found by fitting the distributions of top masses determined on simulated events for a representative set of mass values:

$$f_s(m_t|M_{\rm top}) = \frac{(1-p_6)}{\sqrt{2\pi}\,p_5}\,{\rm e}^{-0.5(\frac{m_t-p_4}{p_5})^2} + \frac{p_6 p_3^{(1+p_2)}}{\Gamma(1+p_2)}(m_t-p_1)^{p_2}\,{\rm e}^{-p_3(m_t-p_1)}. \quad (3)$$

The parameters of the Gaussian and gamma distributions are themselves linear functions of the input top mass $M_{\rm top}$:

$$p_k = \alpha_k + \alpha_{k+6} M_{\rm top}. \quad (4)$$

The mass shift of the top templates with respect to the input mass and the mass dependence on their shape are fitted to determine the 12 α_k parameters.

Our final templates are built as a composition of non-tagged and pre-tagged templates in proportion of their presense in our data sample (161.6 $\rm pb^{-1}$ of non-tagged and 31.9 $\rm pb^{-1}$ of pre-tagged samples).

The background template is parametrized with the same functions as the signal, but with $M_{\rm top}$-independent parameters. To simulate the background we used Alpgen $W+3$ parton samples. The fitted templates are compared to the parent distributions in Fig. 1.

2.3. Likelihood Method. We perform an unbinned fit to the likelihood function:

$$L = L_{\rm shape} \times L_{\rm signal} \times L_{\rm param},$$

where

$$L_{\rm shape} = \prod_{n=1}^{N} (x_s f_s(m_t, \alpha_K, M_{\rm top}) + (1-x_s) f_b(m_t, \beta_K)), \quad (5)$$

$$L_{\rm signal} = \exp\left\{-0.5\left[\frac{(N_s - N_s^{\rm pred})^2}{\Delta N_s^2}\right]\right\}, \quad (6)$$

and

$$L_{\rm param} = \exp\{-0.5[(\alpha-\alpha_0)^T U^{-1}(\alpha-\alpha^0) + (\beta-\beta_0)^T V^{-1}(\beta-\beta_0)]\}. \quad (7)$$

The likelihood $L_{\rm shape}$ is the joint probability density for a sample of N reconstructed mass m_t to come from a parent distribution with a signal fraction x_s. The signal fraction is constrained by the signal likelihood $L_{\rm signal}$. Because of the finite statistics of the Monte-Carlo sample, we constrain the shapes of the signal and background templates to agree with input parameter values using the likelihood $L_{\rm param}$. With these constraints, the likelihood is maximized with respect to the true top mass, $M_{\rm top}$.

We checked whether our likelihood fit was able to return the correct mass by performing a number of pseudo-experiments for different input top mass values. Events were drawn from the Monte-Carlo signal and background templates. The output $m_{\rm top}$ vs. input $M_{\rm top}$ is shown in Fig. 2. A linear fit has a slope of 0.98 ± 0.2. The mean and width of the pull distributions are shown in Fig. 3.

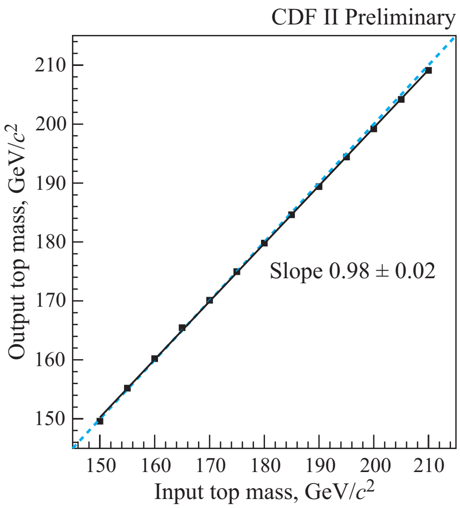

Fig. 2. Top mass returned by pseudo-experiments (medians) as a function of input mass. The dotted line has a slope of exactly 1.0

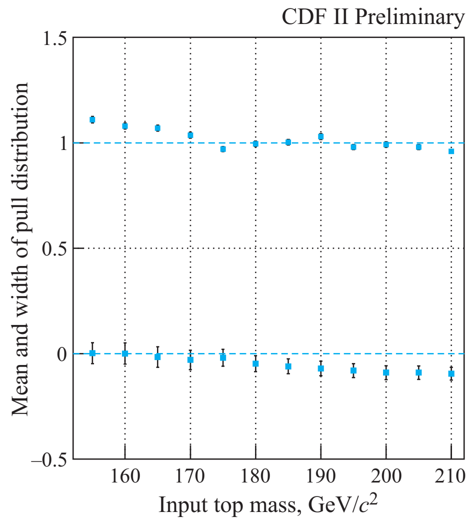

Fig. 3. Average pull and width of pull distributions as determined from pseudo-experiments, as a function of input top mass

3. SYSTEMATIC UNCERTAINTIES

We have considered the following sources of systematic uncertainties on the fitted mass value: a) jet energy scale, b) amount of initial and final state radiation, c) shape of the background template, d) parton distribution functions, and e) approximations made by Monte-Carlo generators. We have estimated each systematic uncertainty by performing a series of pseudo-experiments (PE) with $\pm 1\sigma$ systematic Monte-Carlo samples. The reconstructed mass distribution from each PE was fitted with the same likelihood procedure as for the data. The obtained mass value was entered into an ensamble of results of simulated experiments. The systematic uncertainty assigned to our measurement is the difference in the medians of the results for the nominal and shifted ensembles.

The largest contribution to the systematic error comes from the uncertainty in the jet energy measurement, which includes jet energy corrections for different calorimeter response (as a function of η), the absolute hadron energy scale, and jet fragmentation. The initial and final state radiation (ISR and FSR) uncertainties are estimated using the Pythia [5] Monte-Carlo samples, in which QCD parameters for parton shower evolution are varied based on the CDF studies of Drell–Yan data. For the parton distribution functions (PDF) we considered two different PDFs (CTEQ and MRST), two sets of MRST for different Λ_{QCD} values, and 20 pairs of CTEQ6M uncertainty sets. In addition, we have estimated the systematic uncertainty due to the background shape (Alpgen generated samples with different Q^2, Alpgen $W + 3p$ and $W + 4p$ samples), different Monte-Carlo generators (Pythia and Herwig [3]).

The systematic uncertainties are summarized in the Table. The total systematic uncertainty is estimated to be 8.4 GeV/c^2.

Table. **Systematic uncertainties as determined with the pseudo-experiments**

CDF II Preliminary

Source of systematics	Uncertainty, GeV/c^2
Jet energy measurement	8.4
Initial state radiation	0.4
Final state radiation	1.0
Background shape	1.0
Parton distribution functions	0.5
Monte-Carlo generators	0.5
Total	**8.5**

4. RESULT

The two-component signal-constrained fit ($N_{\text{sig}} = 15.5 \pm 3.2$) to the non-tagged lepton + 4(or more) jet sample returns: $m_t = 179.1 \pm^{10.5}_{9.5}$ (stat.) $\pm$ 8.5 (syst.) GeV/c^2, with 16 ± 3 signal events and 23 ± 7 background events.

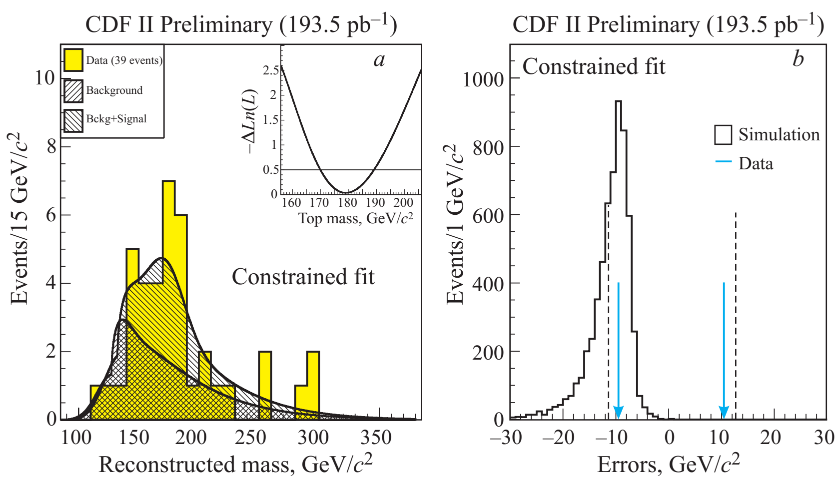

Fig. 4. *a*) Two-component constrained fit to the non-tagged lepton + 4 jet sample. The dark-shaded area corresponds to the background returned by the fit and the light-shaded area is the sum of background and signal events. The insert shows the mass-dependent negative log-likelihood used in the fit. *b*) Error distribution returned by the PEs. The blue arrows indicate the errors returned by the fit to the data

The left plot in Fig. 4 shows the fitted mass distribution. The insert shows the mass dependence of the negative log-likelihood function. The right plot is the error distribution returned by MINOS for Monte-Carlo simulated experiments with the same statistics, where the arrows indicate the present result.

We also performed a fit when the number of the signal events was unconstrained. The result is shown in Fig. 5. This fit returns $m_t = 177.5 \pm ^{9.1}_{7.7}$ (stat.) ± 8.5 (syst.) GeV/c^2, with 26 ± 13 signal events and 13 ± 12 background events.

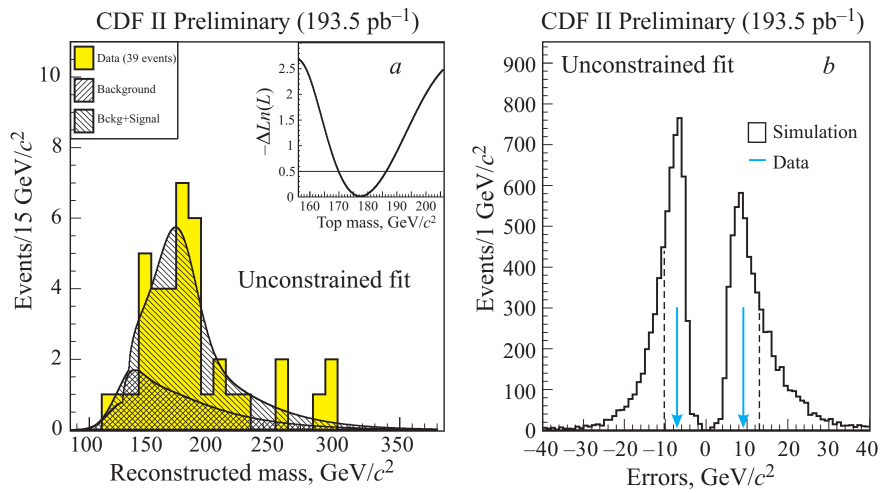

Fig. 5. *a*) Two-component unconstrained fit to the non-tagged lepton + 4 jet sample. The dark-shaded area corresponds to the background returned by the fit and the light-shaded area is the sum of background and signal events. The insert shows the mass-dependent negative log-likelihood used in the fit. *b*) Error distribution returned by the PEs. The blue arrows indicate the errors returned by the fit to the data

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Беллеттини Дж. и др. (по поручению коллаборации CDF) E1-2005-17

Измерение массы топ-кварка в немеченых событиях
типа «лептон + струи» на CDF

Впервые на CDF-II была измерена масса топ-кварка в немеченом наборе событий типа «лептон + 4 струи» в протон-антипротонных взаимодействиях при $\sqrt{s} = 1{,}96$ ТэВ. Интегральная светимость данных составила 193,5 пб$^{-1}$. Для улучшения качества отбора событий был применен порог $E_T > 21$ ГэВ для поперечной энергии струй. 39 событий были отобраны в рамках $t\bar{t}$-гипотезы и отфильтрованы как суперпозиция сигнальных и фоновых ($W+$струи)-событий. В результате при фиксации числа сигнальных событий на уровне $15{,}5 \pm 3{,}2$ получена масса топ-кварка $M_{\rm top} = 179{,}1\pm^{10{,}5}_{9{,}5}$ (стат.) $\pm 8{,}5$ (сист.) ГэВ/c^2. А при свободном параметре сигнал/фон масса топ-кварка составила $M_{\rm top} = 177{,}5\pm^{9{,}1}_{7{,}7}$ (стат.) $\pm 8{,}5$ (сист.) ГэВ/c^2.

Сообщение Объединенного института ядерных исследований. Дубна, 2005

Bellettini G. et al. (On behalf of the CDF Collaboration) E1-2005-17

Top Quark Mass Measurement
in Non-Tagged Lepton + Jets Events at CDF

We report on the first CDF-II measurement of the top quark mass in non-tagged sample of lepton + 4 jet events from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The integrated luminosity of the data sample is 193.5 pb^{-1}. To improve the sample purity a cut at $E_T > 21$ GeV was applied on transverse energy of the jets. 39 events were reconstructed as $t\bar{t}$ and fitted as a superposition of top and $W+$jet events. The signal-constrained fit imposing a signal of 15.5 ± 3.2 events returned a mass $M_{\rm top} = 179.1\pm^{10.5}_{9.5}$ (stat.) ± 8.5 (syst.) GeV/c^2. The unconstrained fit returned $M_{\rm top} = 177.5\pm^{9.1}_{7.7}$ (stat.) ± 8.5 (syst.) GeV/c^2.

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