Search for the Top Quark with CDF *

The CDF Collaboration

presented by

Angela Barbaro-Galtieri
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

January 22, 1991

SEARCH FOR THE TOP QUARK WITH CDF

The CDF Collaboration

Presented by Angela Barbaro-Galtieri

Lawrence Berkeley Laboratory, University of California

Talk given at the DPF Summer Study on High Energy Physics, Snowmass, Colorado, June 25-July 13, 1990

ABSTRACT

During the 1988-89 Tevatron Collider run the CDF detector has collected data for an integrated luminosity of 4.4 pb$^{-1}$. The sample has been used to search for the top quark in several topologies. Preliminary results show that a top mass below 89 GeV is excluded at the 95% confidence level, thus extending the limit of 77 GeV previously published by CDF.

1 Introduction

The Standard Model includes three lepton and three quark doublets as confirmed by recent measurements at SLC and LEP, which find [1] the number of neutrinos to be 3.1 ± 0.1. Apart from a lack of direct observation of the $v_\tau$, the top quark is the last missing block of the model. Experiments at Hadron Colliders have reported lower mass limits (95% C.L.) of 60 and 66 GeV at CERN (UA1 [2] and UA2 [3] collaborations respectively) and of 77 GeV at Fermilab by the CDF collaboration [4]. Recent fits to the Standard Model parameters, including radiative corrections to the $W$ and $Z$ mass, provide an upper limit of $m_t < 200$ GeV [5].

2 Top Signature

Top production at a hadron collider can take place through the electroweak process $pp \rightarrow W \rightarrow t\bar{b}$ or the hard scattering process $pp \rightarrow t\bar{t}$. For the first process to occur the top mass has to be below the $W$ mass, Figure 1 shows the total cross sections for the two processes [6] at $\sqrt{s} = 0.63$ and 1.8 TeV. At the Tevatron Collider the top production rate through the electroweak process is always lower than that from hard scattering, therefore it is not considered here. The hard scattering cross sections of Figure 1 are obtained by combining the higher order calculations of Nason et al [7], with the structure functions of Diemoz et al. [8], using the method of Altarelli et al [9]. Uncertainties due to choice of $Q^2$ scale and $\Lambda_{QCD}$ are shown by the bands.

The $t\rightarrow Wb$ decay of the top via the weak charged current into a bottom quark and a virtual (real for $m_{top} > m_W + m_t$) $W$, provides the signatures to be exploited for a top search. In the naive parton model the relative rates for the different top decay modes are

- $t \rightarrow b\bar{b} + 4$ jets (44.2%)
- $t \rightarrow b\bar{b} + 2$ jets + $\ell + \nu$ (14.8%)
- $t \rightarrow b\bar{b} + \ell_1\nu_1 + \ell_2\nu_2$ (3.25%) $\ell_1 \neq \ell_2$
- $t \rightarrow b\bar{b} + \ell_1\nu_1 + \ell_2\nu_2$ (1.25%) $\ell_1 = \ell_2$
The most copious channel is given by the multijet decay mode, but it suffers from severe backgrounds since the QCD multijet production is several orders of magnitude larger. A much cleaner signature consists of high PT leptons in the event. Leptons from top have large transverse momenta due to the large mass of the top and tend to be isolated, because of the large transverse momentum to the top line of flight. The number of jets in the event is determined by the kinematics and depends on the top mass, i.e., the b jet can have very low momentum and be hardly detected especially for top masses close to m_{top}, where there is a change from three-body to two-body kinematics.

Backgrounds to leptonic decays of top come from other physics processes and from lepton misidentification. Assuming that misidentification is reduced by proper requirement on the data (see later), there remain the physics backgrounds to take into account. The Drell-Yan process, W, Z production and bb pair production are sources of high PT leptons. These processes have to be understood in order to assess their contribution to the signal. For the lepton+jets final state the major background comes from bb and W+jets production. For the dilepton channels it comes from bb production and Drell-Yan: for ee from Z^0 \rightarrow \tau^+\tau^- for the ee and \mu\mu final states the Z mass region has to be removed altogether.

3 The CDF detector

The CDF detector [10] is a solenoidal detector with tracking and calorimetry covering almost the full solid angle, and with muon coverage over the central and forward region. We describe here briefly the parts relevant to this analysis.

Charged particle tracking is provided by the Vertex Time Projection Chamber (VTCP) and the Central Tracking Chamber (CTC). The VTPC is located just outside the beam pipe extending to a pseudorapidity \eta = 3.25. Outside the VTPC is a large drift chamber (CTC) that extends to \eta = 1.2 and to a radius of 1.38 m. Both tracking chambers are inside a 1.41 T solenoid which is 5 m. long. The CTC momentum resolution is \delta(P_T)/P_T = 0.0017P_T where P_T is in GeV/c.

The calorimetry used for the electron and muon analyses consists of the central electromagnetic (CEM), the central hadron(CHIA) and the wall hadron (WHA) calorimeters. These calorimeters are segmented in a projective geometry consisting of towers of 15° in azimuth by 0.1 unit of rapidity. The CEM is a lead-scintillator sampling calorimeter with a single layer strip chamber (CES) with cathode and wire readout, located at shower maximum. The hadron calorimeters are steel-scintillator sampling calorimeters. The rest of the calorimeters, plug and forward regions down to \eta = 4.2, consist of many layers of MWPC sandwiched with lead for the EM compartment and steel for the HAD compartment. Their segmentation is of 5° by 0.1 units of rapidity. Finally, outside the central calorimeters, are four layers of streamer chambers for muon identification in the region |\eta| < 0.65. For this analysis the muon coverage has been extended to |\eta|=1.2 by using CTC tracks that appear as minimum ionizing and that are isolated in the calorimeters.

The CDF trigger system has two levels of hardware triggers followed by a software (Level-3) trigger that utilizes a farm of processors running offline-like algorithms. Two of the many triggers are used for this analysis, a. the central “inclusive electron” trigger with P_T > 12 GeV/c and b. the central “inclusive muon” trigger with a 9 GeV/c P_T threshold.

The identification of electrons in the central region uses information from the tracking chambers, the central calorimeters and the strip chambers (CES). The electron/pion separation has been studied in the test beam and verified with data taken at the collider [11] using an unbiased sample of electrons. The efficiency was obtained from a Z \rightarrow e^+e^- and a W sample obtained from the missing E_T trigger, it was found to be (78 \pm 3)%.

Muon identification uses calorimeters, muon chambers as well as tracking chamber (CTC) information. Matching cuts in \eta are applied to the CTC track and the track segment found in the muon chambers. The calorimeter response in the tower where the muon track points to, must be consistent with minimum ionizing with the additional requirement of isolation for the region beyond the muon chambers coverage. The efficiency for the \mu selection was evaluated by using a sample of Z events and found to be (96 \pm 3)%.

4 Searches in the lepton+jets channels

These channels have the largest branching ratios, but also have large backgrounds from bb and W+jets events.

The inclusive electron spectrum measured by CDF is shown in Figure 2. The hadronic background is estimated to be (15 \pm 15)% Most electrons from photon conversion have been removed, the remaining contribution to the background is estimated to be (12 \pm 7)%. Top candidates are obtained by requiring an electron and two or more jets in the event. To remove bottom and W+jets background the following cuts are applied: a. E_T > 20 GeV in the |\eta| < 1. region; b. missing
Figure 2: The inclusive electron spectrum for both the 7 and the 12 GeV triggers. The lower set of points represents the spectrum obtained after W and Z subtraction.

$E_T > 20$ GeV where the energy was added in the $|\eta| < 3.6$ region; c. two or more jets with uncorrected energy $E_T^{\text{jet}} > 10$ GeV. After these selection criteria 104 events remain. The transverse mass distribution $M_T^W$ for these events is shown in Figure 3. A top signal would appear as a deviation from the distribution expected for W production. The requirement of > 2 jets reduces the W+jets rate considerably, retaining only the high $P_T$ W’s. From these data CDF published an upper limit $m_t > 77$ GeV [4].

For $m_t > m_W + m_b$ the transverse mass study method is no longer valid as top events become indistinguishable from W events. The second W decays into two jets, but a W peak in the two jet mass is difficult to detect because of large W+jets production as seen in Figure 4. At this time, this is due to lack of statistics more than to jet resolution. For $m_t = 90$ GeV the expected number of events is 20, with a signal/background ratio of about 1/2. In this mass region it is not possible to improve the s/b ratio by requiring more jets. Infact, close to the real W threshold, the kinematics is such that the $b$ jets are very soft and are not measurable. Very few of the 104 events have more than two jets.

To extend the sensitivity to higher top mass, this analysis has been applied to the $\mu$ sample where 87 additional events are found. The strategy for separating W+jets from top production is then to search for a low $P_T \mu$ from the $b$ quark. There is no minimum $P_T$ re-
Figure 5: The $\Delta R$ between the low energy $\mu$ and the closest of the two jets, for (a) the CDF data (preliminary), and (b) a top Monte Carlo with $m_t = 80$ GeV\cite{13}.

Figure 6: Electron transverse energy vs muon transverse momentum for the CDF $e\mu$ events\cite{14}.
Figure 7: Angle between the two electrons, $\Delta \phi$ vs missing $E_T$ for the di-electron sample.

at which the measured upper limit crosses the lowest calculated value of the cross section. The di-lepton channel sets a limit $m_t > 84$ GeV.

6 Summary and Conclusions

Combining the results from the di-lepton channels and the $\ell^+ + j$ + low $P_T$ muon channels the lowest curve shown in Figure 8 is obtained. Assuming that top decays exclusively via the charged current mode ($t \rightarrow W^+b$) the preliminary CDF result [13] thus is:

$$m_t > 89 \text{ GeV with 95\% C.L.}$$

7 References


