Fermi National Accelerator Laboratory

FERMILAB-Conf-91/168-E

Top Physics at CDF

C. Campagnari and the CDF Collaboration

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

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

June 1991

* To be published in the proceedings of the *XXVth International Conference on High Energy Physics*, August 2-8, 1990, Kent Ridge, Singapore.

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

TOP PHYSICS AT CDF

FERMILAB CONF 91/168-E
CDF/PUB/HEAVYFLAVOR/PUBLIC/1312

Claudio Campagnari

CDF Collaboration [1]
University of Chicago, Enrico Fermi Institute
5640 S. Ellis Av., Chicago, Il 60637, USA

Abstract

We present here preliminary results of an extension of our already published search for the top quark. The search is based on a data sample collected during the 1988-1989 run of the Fermilab Tevatron Collider corresponding to an integrated luminosity of 4.4 pb^{-1}. We find no evidence for top quark production and we establish preliminary limits on the t-tbar production cross section as a function of the top mass (M_{top}) in p-pbar collisions at $\sqrt{s} = 1.8$ TeV. Using theoretical expectations for this cross-section, we translate these limits into a preliminary lower limit for M_{top} of 89 Gev/c^2 at the 95% confidence level (C.L.).

Introduction

The top quark, which is expected to exist in order to complete the generation structure of the Standard Model (SM), has yet to be observed. Searches for the top quark in e^+e^- collisions at TRISTAN, SLAC and LEP have yielded lower limits as high as 45.8 GeV/c^2 [2] on M_{top}. More stringent lower limits have been placed by experiments at p-pbar colliders. At CERN the UA1 and UA2 collaborations have established limits of 60 and 69 Gev/c^2 (95% C.L.) respectively [3,4], and at Fermilab the CDF experiment has reported M_{top}> 77 GeV/c^2 (95% C.L.) [5]. Upper limits on the top quark mass of about 200 GeV/c^2 have been inferred by requiring consistency of SM parameters with the measured W and Z masses, the Z decay widths and neutral current data [6].

Top Signatures

In p-pbar collisions at Tevatron energies ($\sqrt{s}$ = 1.8 TeV) the dominant top quark production process is QCD creation of t-tbar pairs. This is to be contrasted with the situation at the lower energy of the CERN SppS ($\sqrt{s}$ = 0.63 TeV), where the pair-production cross-section is much lower and the dominant mechanism becomes production of top quarks via decays of W-bosons ($W \to t\ b$).

The pair-produced top quarks are then expected to decay via the weak charged current into a b-quark and a real (or virtual, depending on M_{top}) W-boson, which then in turn can decay into leptons or light quarks :

$t \to (W)\ b$; $W \to e\nu,\ \mu\nu,\ \tau\nu,\ ud,\ cs$

The relative branching fraction for the different decay modes of the t-tbar pair are listed below (where q denotes a generic light quark) :

$W \to qq$ $W \to qq$	36
$W \to qq$ $W \to e\nu$ (e-jets channel)	12
$W \to qq$ $W \to \mu\nu$ (μ-jets channel)	12
$W \to qq$ $W \to \tau\nu$	12
$W \to e\nu$ $W \to \mu\nu$ (e-μ channel)	2
$W \to e\nu$ $W \to \tau\nu$	2
$W \to \mu\nu$ $W \to \tau\nu$	2
$W \to e\nu$ $W \to e\nu$ (e-e channel)	1
$W \to \mu\nu$ $W \to \mu\nu$ (μ-μ channel)	1
$W \to \tau\nu$ $W \to \tau\nu$	1

The totally hadronic decay mode is the most probable, however it is swamped by multi-jet QCD backgrounds. In practice the only modes accessible for study are those containing at least one electron or one muon.

Both the charged leptons and the neutrinos in top events tend to

To be published in the proceedings of the XXVth International Conference on High Energy Physics, Kent Ridge, Singapore, August 2-8, 1990.

have high transverse momentum (P_t), reflecting the fact that they are products of the decay of a heavy object. Another effect of the high top mass is that the leptons tend to be isolated in the detector, unlike high P_t leptons from semi-leptonic bottom or charm decays, where the boost of the decay prevents them from being separated from the other particles in the b- or c-jet. Therefore detectable top events are characterized by isolated, high P_t electrons or muons, high P_t neutrinos (which are "detected" by missing P_t techniques), and jets.

The best published CDF top mass limit of 77 GeV/c^2 [5] is based on an analysis of events with high P_t electrons, high missing P_t, and at least two jets. This would be the signature of t-tbar production with decay in the e-jets channel. The background to the top signal in this channel comes from production of W bosons in conjunction with jets and subsequent decays of the Ws into electrons. In that analysis we used the transverse mass distribution of the e-ν system to separate real and virtual W decays. This method fails for $M_{top} > M_W$, when real Ws are produced in the decay of top quarks. In the last year we have also published results of a search for top production in the e-μ channel [8]. This analysis, which led to a limit of $M_{top} > 72$ GeV/c^2, was statistics limited.

In this paper we report preliminary results on a natural extension of this search to the e-e and μ-μ channels and on a search in the e-jets and μ-jets channels, where we have attempted to reduce the W+jets background by tagging the b-quarks produced in top events through their semileptonic decays into muons.

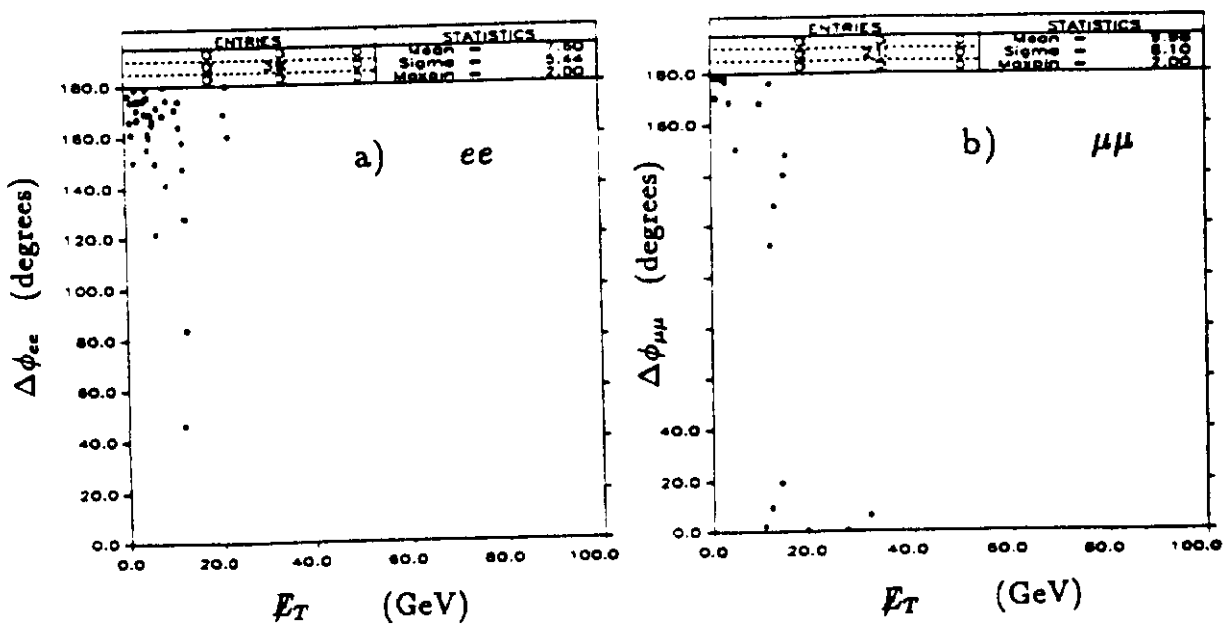

Figure 1(a-b) : Dilepton azimuthal separation vs. missing Transverse Energy after the Z-mass window cut for the e-e (a) and μ−μ data (b)

Search in the di-lepton channels

The top signature for these decay modes (e-e, e-μ and μ-μ)consists of a pair of high P_t leptons, missing P_t, and jets. We select events with isolated oppositely charged electrons or muons, with electron transverse energy (E_t) > 15 GeV and/or muon P_t > 15 GeV/c. The leptons are restricted to the central region ($|\eta| < 1$ for e's and $|\eta| < 1.2$ for μ's), where lepton detection is very well understood and the backgrounds are low. Note that although the central muon-chambers only cover the region $|\eta| < 0.6$, we can extend our muon acceptance for this analysis to $|\eta| < 1.2$ by tagging muons as isolated, high-P_t, minimum ionizing particles in the calorimeters.

For the e-e and $\mu-\mu$ final states we remove Z boson decays and other off-peak Drell-Yan events with the following requirements :

a) we reject events where the invariant mass of the pair is between 75 and 115 GeV/c^2
b) we require missing transverse energy (MET) > 20 GeV
c) we require the azimuthal separation between the two leptons ($\Delta\phi$) to be in the window $20° < \Delta\phi < 160°$

This last requirement rejects low transverse momentum Z and Drell-Yan events, for which $\Delta\phi$ is close to 180°, and also rejects a small background contamination from fake muons in jet events, where both μ-candidates belong to the same jet. Figures 1(a)-1(c) shows scatter plots of $\Delta\phi$ vs. MET for the e-e and $\mu-\mu$ data and for a t-tbar Monte Carlo after the mass cut has been applied.

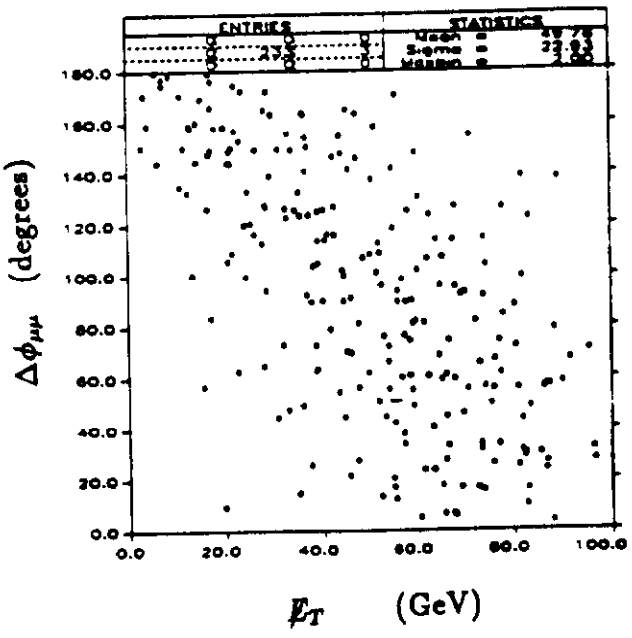

Figure 1(c): Same as Figure 1(b) but for a sample of Monte Carlo events in the $\mu-\mu$ channel (for M_{top}= 90 GeV/c^2)

No $\mu-\mu$ or e-e candidate events are found, while one e-μ candidate event survives all the cuts. This is the same event that was found in the e-μ analysis of Reference 8. It has an electron of E_t = 31.7 GeV, a muon of P_t = 42.5 GeV/c, with $\Delta\phi$ = 137°, a jet of E_t = 14 GeV [9], and an additional muon candidate in the forward detector with P_t = 10 GeV/c. The expected background in this channel is at the one event level, and comes mostly from $Z \rightarrow \tau\tau$ with subsequent decays of the taus into e-μ, although with leptons of such high transverse momenta the interpretation of this event as background from Z decays is unlikely. Other sources of background include WW and WZ production, from which we expect of order 0.3 events.

With only one event in the signal region, we place upper limits on σ(t-tbar) as a function of M_{top}. The acceptance of our analysis to t-tbar events is determined using the Isajet V6.22 Monte Carlo program [10] and a detector simulation. The expected number of t-tbar events is shown below, where we have used the central value of the theoretical calculation of σ(t-tbar) from Reference 7.

M_{top} (GeV/c^2)	σ	Exp. # of ev.
75	385 pb	10.2
80	285 pb	8.9
85	200 pb	6.6
90	153 pb	5.2

The 95% C.L. upper limit for σ(t-tbar) is then calculated by convoluting the Poisson probability for observing 1 event with the 20% uncertainty in the acceptance calculation. (This uncertainty is dominated by the 15% uncertainty on the luminosity measurement). In Figure 2 we show the cross-section-limit curve, together with theoretical expectations for σ(t-tbar). To set a limit on M_{top} we find the point at which the curve for the experimental limit crosses the lower (i.e. more pessimistic) bound of the theoretical prediction. We find M_{top} > 84 GeV/c^2 at the 95% C.L.

B-tagging through $b \rightarrow \mu$

The single lepton channels (e-jets and μ-jets) have higher branching ratios than the di-lepton channels. However in these channels one has to contend with serious backgrounds from W + jets production. As was argued in a previous section, the

earlier e-jets analysis [5], which was based on the transverse mass distribution of the e-ν system, breaks down as M_{top} becomes greater than M_W. We describe here a different method to distinguish between W+jets and top events.

A t-tbar event in the e-jets channel will result in one electron, missing energy, and up to four jets. In the earlier analysis we had selected events with one isolated electron of E_t > 20 GeV, missing-E_t > 20 GeV and 2 (or more) jets of E_t > 10 GeV (the "e-jets sample").

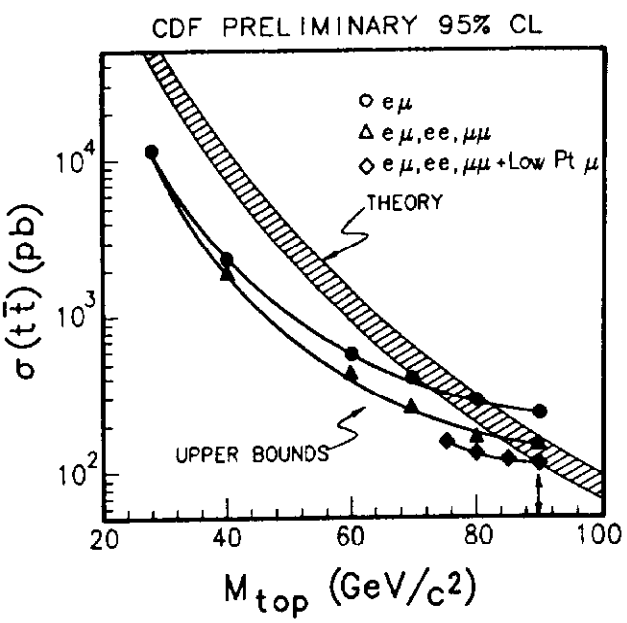

Figure 2 : This Figure shows the 95% C.L. upper limit for σ(t-tbar) as a function of M_{top} for the published e-μ analysis, for the combination of that analysis with the new e-e and μ−μ analyses and for the combination of all CDF analyses, together with theoretical expectations for σ(t-tbar).

For these selection criteria we would expect to find about 20 top events for M_{top}=90 GeV/c^2; we found 105 events, which we believe to be mostly W+jets events. In this mass region it is difficult to improve the signal to noise by requiring higher jet multiplicity because the kinematics of the decay for top masses near the W-mass are such that the b-quarks tend to have rather low momentum and are often not reconstructed as jets in the detector. Furthermore, the W-mass constraint on pairs of jets from the decay chain t→Wb, W→jet-jet, still results in a signal to noise only of order 1/2 for M_{top}=90 GeV/c^2 [11]. For these reasons we have attempted to separate top events from W-events by searching for muons from bottom decays in our e-jets sample.

The branching ratio for b → μ is only of order 10% , and to recover some of the loss in expected rate we have also searched in the equivalent "μ-jets" sample. This is a sample of 87 events, with isolated muons of P_t>20 GeV/c and with the same jet and missing energy requirements imposed on the e-jets sample. Again, we believe that this sample consists mostly of W+jets events.

We then searched in these 105+87=192 events for additional muons. Because muons from b-decays in top events are soft (see Figure 3), we impose no minimum requirement on the P_t of the muon candidate, beyond that of being energetic enough not to stop in the calorimeter before reaching the muon detector ($P_t \geq 1.6$ GeV/c). The only other requirement on the low-P_t μ candidates is of a rather loose match in φ between the track as measured in the tracking chamber and the hits in the μ chambers.

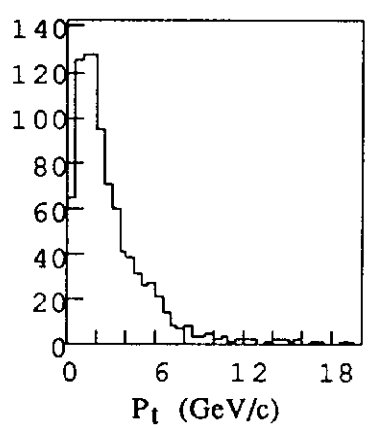

Figure 3: The Monte Carlo P_t spectrum of muons with $|\eta|$<0.6 from bottom decays in top event for M_{top}= 90 GeV/c^2 (arbitrary normalization)

We find 7 events with muon candidates, however all of these candidates are within one of the two highest P_t jets in the event. They are

likely to be either punch-through or decay in flights from hadrons in the jets. If we require a minimum separation $\Delta R = \sqrt{\Delta\phi^2+\Delta\eta^2} > 0.5$ between the μ candidate and the two jets, we are left with no events. Monte Carlo calculations show that this additional requirement is of order 70% efficient on top events. The expected number of detected t-tbar events is shown below, where we have once again used the cross section values from Reference 7.

M_{top} (GeV/c^2)	σ	Exp. # of ev.
75	385 pb	2.6
80	285 pb	2.3
85	200 pb	2.0
90	153 pb	1.6

The acceptance calculation was performed using Isajet V6.22 and the detector simulation. The momentum spectrum of leptons from B-meson decays was modelled using results from the CLEO experiment [12]. The largest uncertainties come from the luminosity normalization (15%), the Monte Carlo statistics (12%) and the $b \rightarrow \mu$ branching ratio (9%).

We then combine the result from the search in this channel with the result from the di-lepton search by adding the acceptances and yields from all the channels. The product of acceptance and branching fraction is a slowly varying function of the top mass and is 1% for M_{top} = 90 GeV/c^2; the yield is one event (the e-μ top candidate). To set a limit on M_{top}, we again convolute the Poisson statistics for one event with the uncertainties in the acceptance calculation, including correlations between uncertainties in the two analyses (e.g. the luminosity or the fragmentation assumptions). The results are shown in Figure 2. We find, using once again the lower value for the theoretical expectation for σ(t-tbar), that M_{top} > 89 GeV/c^2 at 95% C.L. (preliminary).

References

[1] CDF is a collaboration of physicists from the following institutions: Argonne National Laboratory, Brandeis University, University of Chicago, Fermi National Accelerator Laboratory, Laboratori Nazionali di Frascati dell' INFN, Harvard University, University of Illinois, National Laboratory for High Energy Physics (KEK), Lawrence Berkeley Laboratory, University of Pennsylvania, INFN Universita and Scuola Normale Superiore of Pisa, Purdue University, Rockefeller University, Rutgers University, Texas A&M University, University of Tsukuba, Tufts University and University of Wisconsin

[2] See F. Dydak, this conference

[3] C. Albajar et. al., submitted to Z. Phys. CERN-EP/90-57

[4] T. Akesson et al., Z. Phys. **C46**, 179 (1990)

[5] F. Abe et al., Phys. Rev. Lett. **64**, 142 (1990)

[6] W. Marciano and A. Sirlin, Phys. Rev. **D29**, 945 (1984); D. Bardin et al., Z. Phys. **C32**, 121 (1986); U. Amaldi et al., Phys. Rev. **D36**, 1385 (1987); P. Langacker Phys. Rev. Lett. **63**, 1920 (1989)

[7] G. Altarelli, M. Diemonz, G. Martinelli and P. Nason, Nucl. Phys. **B308**, 724 (1988)

[8] F. Abe et al., Phys. Rev. Lett. **64**, 147 (1990)

[9] A 14 GeV calorimeter cluster corresponds roughly to a parton E_t of 20 GeV; see F. Abe et al., Phys. Rev. Lett. **62**, 613 (1989)

[10] F. Paige and S.D. Protopopescu, BNL Report No. 38034, 1984 (unpublished)

[11] See for example P. Tipton, Proc. 9th Int. Conference on Physics in Collision, ed. J. Grunhaus, pg 267 (1989)

[12] S. Behrends et al., Phys. Rev. Lett. **59**, 407 (1987) ; See also Cornell Preprint CLNS 90/988