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Search for the Top Quark at CDF

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ABSTRACT

We review prospects for top discovery in the current 1992 CDF run, focusing on the inclusive electron and muon channels. In the standard model, $\sim 37\%$ of $t\bar{t}$ events contain a high P_T electron or muon. In particular, b tagging through soft leptons and secondary vertices are discussed. Expected signal to background and prospects for the current CDF 1992 run are given.

1. Introduction

1.1. Standard Model Top

At the Tevatron, Standard Model top quarks are expected to be pair produced in $p\bar{p} \to t\bar{t}$ through quark annihilation and gluon fusion. Total cross sections fall with increasing top mass, from $100pb$ at $m(t) < 100GeV/c^2$ to $1pb$ above $200GeV/c^2$.[1]

Standard Model top quark decays proceed through $t \to W^+b$. The final state signatures follow from the W branching ratios. The dominant mode is $t\bar{t} \to 6$ jets. However, this mode suffers from large backgrounds and will not be covered in this review. Considering only electrons and muons, approximately 37% of $t\bar{t}$ events contain at least one lepton and 5% contain at least two leptons from $W \to l\nu$. These high P_T inclusive lepton samples provide the most promising channels in which to search for the top.

1.2. Current CDF Top Limits

In previous CDF runs, several analyses using inclusive lepton channels were used. For the 1988-89 run, final states with ee, $\mu\mu$, and $e\mu$ were looked for. In addition, CDF has searched for a low-transverse-momentum muon as a tag of the b quark in events with a high P_T electron or muon and at least 2 jets. From a $4.1pb^{-1}$ data sample, a lower limit of $m(t) > 91GeV/c^2$ was set at the 95% confidence level.[2]

Additional constraints on the top mass can be placed from electroweak measurements. Using measurements of the W mass and assuming a Higgs mass of less than $1000GeV/c^2$, an upper limit on m_{top} of approximately $225GeV/c^2$ is obtained at 95% C.L. This implies that the relevant mass range for future Standard Model top searches is 91 to $\sim 225GeV/c^2$.

2. CDF Detector for 1992

Between the 88-89 and 1992 runs, numerous upgrades have been made to the

CDF detector. Of particular interest are the upgraded muon system and the addition of a silicon tracking detector around the beampipe. Many other improvements were also made, including upgrades to the lepton triggers and improved electron systems.

The upgraded muon system consists of two parts. The Central Muon upgrade (CMP) adds a steel wall of over 2 hadronic absorption lengths and additional layers of muon chambers outside the previous Central Muon system (CMU). This increases the total number of absorption lengths to over 8 in the region $|\eta| < 0.4$. The Central Muon extension (CMX) provides muon identification in the region $0.63 < |\eta| < 0.9$.

The Silicon Vertex detector (SVX) consists of two barrels in the region $|z| < 26cm$.[3] There are four layers of single-sided silicon wafers per barrel, providing precision $r\phi$ tracking information. The layers are arranged from $r = 3$ to $8cm$. This covers a region out to $|\eta| < 1.9$ at the outermost layer. The impact parameter resolution of the device is better than $40\mu m$ for tracks with $P_T > 1GeV/c$. Using preliminary alignment constants, we obtain an impact parameter resolution of $\sim 13\mu m$ for tracks with $P_T > 10GeV/c$.

3. b Tagging

The high P_T lepton + jets channel, with its relatively high branching ratio, provides a good way to select $t\bar{t}$ events. However, W+jets background may prove troublesome for higher mass top. To reduce this background, b tagging can be used. For the 1992 CDF run, two methods of b tagging are being developed. The first utilizes the tracking information from the SVX, and tags the b through displaced tracks. The second is an extension of the soft lepton analysis used in the 88-89 run.

3.1. b Tagging with the SVX

With its precision tracking information, the SVX can be used to tag the decay products of long-lived particles, in particular b-flavored hadrons. These decay products can be tagged by their impact parameter (d) relative to the primary event vertex. We also use impact parameter significance (S_d), which is the impact parameter d divided by σ_d, the total error in d.

The S_d distribution for tracks which are daughters of b-flavored hadrons falls slowly with increasing S_d. In contrast, S_d is sharply peaked towards 0 for tracks which are not from b. The distributions from top MC with $m_{top} = 120GeV/c^2$ are shown in figure 1.

Displaced tracks are selected by requiring a minimum d and/or S_d for each track. Minimum requirements on P_T are also made to reject very low momentum tracks which typically have poorer tracking resolution. Displaced tracks in an event are then grouped into candidate b jets by vertexing the tracks or by looking for correlations in $\eta\phi$ space. CDF has developed several such methods for b tagging. Since this is still a new device and a new type of analysis, these SVX b tagging algorithms are still under study. Three representative methods will be summarized here.

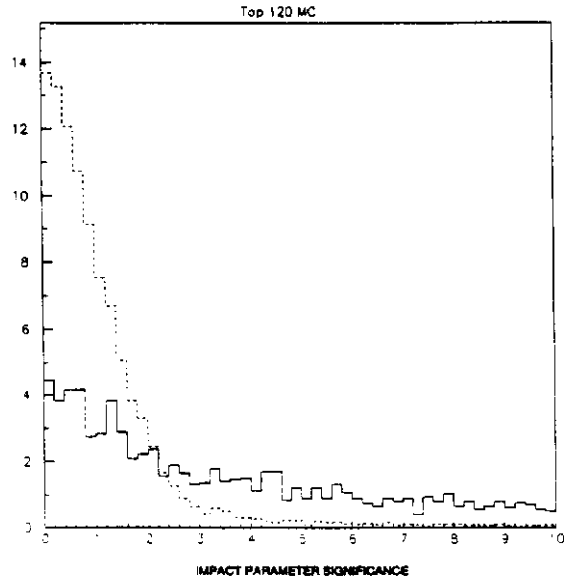

Figure 1: Impact Parameter Significance S_d for $m_{top} = 120GeV/c^2$ Monte Carlo. Solid line is for tracks from b-flavored hadrons. Dashed line is for all other tracks. Distributions are normalised to equal area.

∘ *$d\phi$ Clustering:* This method relies on the fact that tracks from a secondary vertex form a sinusoid in $d\phi$ space, where d is the signed impact parameter, and ϕ is the usual azimuthal angle in the transverse plane. This follows from simple geometric arguments. For forward boosted decays, we can approximate the relevant portion of the sinusoid with a straight line. Secondary vertices are then found by linking displaced tracks to straight lines in $d\phi$ space. Those with at least three tracks are tagged as b jet candidates.

∘ *Jet Vertexing:* In this method, displaced tracks are assigned to jets if the track is within 25° of the jet axis. The displaced tracks in a given jet are then vertex constrained. Tracks which contribute more than 20 to the total χ^2 of the fit are discarded. The vertexing is then iterated. Jets with at least 2 surviving tracks are tagged as b jet candidates.

∘ *Cone Tagging:* Cone tagging selects displaced tracks with some minimum P_T and S_d. A upper cut on d is also made, to reject very long-lived particles, such as K's. Displaced tracks within a cone of 0.4 are clustered together. Cones with at least three tracks are tagged as b jet candidates.

The event efficiencies for these b tagging methods rise with increasing top mass. For $m_{top} = 120GeV/c^2$, efficiencies of about 23% are obtained. For $m_{top} = 160GeV/c^2$, the efficiency rises to $\sim 33\%$. The expected background acceptance from W+jets is $\sim 0.7\%$ per event, where we have not included b tags due to real c and b quarks in W+jets events. These efficiencies include SVX acceptance, but do not include any

kinematic or high P_T lepton cuts.

3.2. Kinematic Cuts

In addition to selecting a high P_T lepton and b tagging, kinematic cuts are needed to suppress the W+jets background. In particular, kinematic cuts should be extremely useful in reducing the $Wb\bar{b}$ background in the b tags.[4] We have studied many different variables, including jet counting, energy variables, such as ΣE_T and $\hat{s}$, and shape variables, such as sphericity and aplanarity. We find that jet counting seems to be as effective as any of the other methods, and has the advantage of being the simplest.

3.3. b Tagging with Soft Leptons

Another method of b tagging is to look for soft leptons from the processes $b \to l\nu X$ and $b \to cX \to l\nu X$. In every $t\bar{t}$ event, there will be two b and two c quarks. Using $Br(b \to lX) \sim 20\%$ and $Br(c \to lX) \sim 20\%$, where $l = e, \mu$, this means $\sim 57\%$ of all $t\bar{t}$ events will have at least one electron or muon from b or c. These leptons will have low P_T, with the spectrum peaked towards 0. CDF hopes to efficiently tag electrons and muons down to $P_T \sim 2GeV/c$. Preliminary results give a low P_T lepton tag efficiency of $\sim 26\%$ per event for $m_{top} \geq 120GeV/c^2$. The fake tag rate is on the order of 10^{-2} per track.

3.4. b Tag Observed Cross Sections

To illustrate the potential of these b tagging analyses, we use the following sets of cuts:

- an electron or muon with $P_T > 20GeV/c$
- $\not{E}_T > 20GeV$
- SVX or soft lepton tag:
  SVX tag: at least two jets with $E_T > 15GeV$, at least one additional jet with $E_T > 10GeV$, and an SVX b tag.
  Soft lepton tag: at least two jets with $E_T > 20GeV$, at least one additional jet with $E_T > 10GeV$, and an additional e or μ with $P_T > 2GeV/c$.

In a data sample of $25pb^{-1}$, the number of expected events using the SVX tag is ~ 13 for $m_{top} = 120GeV$, falling to ~ 5 events for $m_{top} = 160GeV$. The background from W+jets is ~ 2 events, which includes tags due to real c and b in the W+jets events. The expected number of top events using the soft lepton tag is comparable to that given by the SVX tag. However, the expected background for this mode is ~ 4 events. The expected observed cross sections for top and background are shown in figure 2.

4. Dilepton Analysis

The high P_T ee, $\mu\mu$, and $e\mu$ dilepton channels have a total branching fraction of only $\sim 5\%$, but has the advantage of low background rates. Based on the 88-89

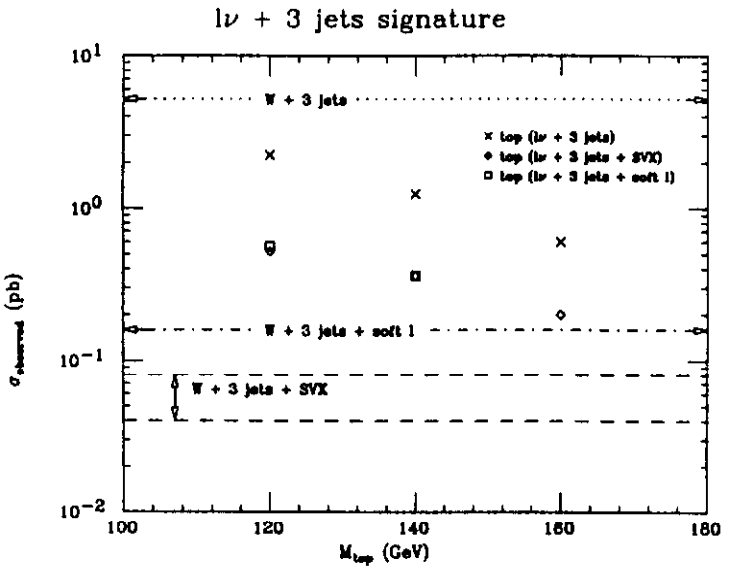

Figure 2: Expected observed cross sections for $t\bar{t}$ and W+jets using the high P_T lepton + 3 jets signature. The crosses are for top, before a b tag is applied. This should be compared to the dotted line for W+jets background. The diamonds are for top, after requiring an SVX b tag. The area bounded by the dashed lines is for W+jets+SVX. The squares are for top, after requiring a soft lepton b tag. The dot-dashed line is for W+jets+soft lepton.

analysis, we would expect about 64 top events for $m_{top} = 90GeV$ in $25pb^{-1}$. A data sample of this size will allow CDF to look for top up to $\sim 130GeV/c^2$ in the dilepton channels.[5] This is a conservative estimate, since CDF has a number of upgrades for the 1992 run, and the top selection efficiencies should rise slightly with increasing top mass. In addition, we can reduce the background to the dilepton analysis even further with kinematic cuts and/or b tagging.

5. Summary

CDF is working on a number of top search algorithms using dileptons and lepton + b tag. The SVX provides a powerful new selection method for tagging b jets, which complements the soft lepton tag algorithm. With $25pb^{-1}$ of data, these methods, and combinations these methods, will allow CDF to search for top up to masses of approximately 150 to $160GeV/c^2$.

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3. O. Schneider, contribution to these proceedings.
4. M. Mangano, contribution to these proceedings.
5. L. Song, contribution to these proceedings.