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TOP DECAY PHYSICS AT CDF AND MEASUREMENT OF THE CKM ELEMENT V_{tb}

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1. Introduction

Now that the top quark's existence has been firmly established by the CDF and D0 experiments [1,2], we begin to measure its properties. Branching fractions are of particular interest in the case of the t quark, since they probe the couplings of the top quark to gauge bosons and other quarks, and because "the top quark is the only quark with reasonable mass" [3]. Because the top quark is the only quark with mass comparable to the electroweak scale, its decays, particularly non-standard decays, might shed some light on what makes the top quark different from lighter quarks, and the role it plays in electroweak symmetry breaking.

This paper describes some recent measurements on the decay of the top quark using the CDF detector, a general purpose detector designed to study $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV; it has been described in detail elsewhere [4,1]. The analyses presented use 100-110 pb^{-1} of data collected between 1992 and 1995 at the Fermilab TeVatron.

2. Measuring $BF(t \to W + b)/BF(t \to W + q)$ and V_{tb}

To investigate the coupling of the top quark to the bottom quark and the W boson, we measure the branching ratio $BF(t \to W + b)/BF(t \to W + q)(\equiv b)$. This ratio is given by the following ratio of CKM matrix elements:

$$b \equiv \frac{BF(t \to W + b)}{BF(t \to W + q)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

In the Standard Model with 3 Families, the denominator is simply 1, so $b = |V_{tb}|^2$. Unitarity constraints on the CKM matrix require $b > .997$; any measurement of a smaller value will indicate new physics, such as a fourth generation. It is perhaps intriguing to note that a tWb

coupling smaller than SM predictions would manifest itself as smaller radiative corrections to $BF(Z \rightarrow b + \bar{b})$, increasing the branching fraction of the Z^0 to bottom quarks.

In this analysis, we use $t\bar{t}$ events, which are assumed to decay to $W + q$. These events are then categorized according to the subsequent decays of the W's: *dilepton* events have both W's decaying to leptons; *lepton plus jets* events have one W decaying to leptons, and the other decaying to hadrons. The branching fraction is substantially larger for lepton plus jets events, which makes reconstructing top pairs in this channel appealing, but the QCD backgrounds are also larger. To reject these backgrounds, we take advantage of the fact in the Standard Model $BF(t \rightarrow W + b) \sim 100\%$, and have developed two methods of identifying or "tagging" jets containing b quarks. The Secondary Vertex (SVX) method identifies b jets via a secondary vertex in the jet from the decay of a (long lived) b hadron, and the Soft Lepton (SLT) method identifies them via the decays $b \rightarrow lX$ or $b \rightarrow c \rightarrow lX$. To be included in the lepton plus jets sample, an event must have at least one jet tagged by at least one algorithm. In this analysis, the event must have at least as many jets as expected from a pair of t quarks. We observe 8 dilepton events over a background of 1.9 ± 0.4. Three of these events have one jet tagged as containing a b hadron. We also observe 32 lepton plus jets events over a background of approximately 10. Six of these events have both jets identified as containing a b hadron.

For a pure $t\bar{t}$ sample and a single tagging algorithm, the ratio of tagged to untagged events (and also the ratio of the number events with both jets tagged to the number with only one tagged) is simply b times the tagging efficiency. The real situation becomes more complicated because there are two tagging algorithms, backgrounds to top, and built-in correlations between tagging one b and tagging the other, since the CDF's Silicon Vertex Detector is shorter than the full luminous region of the accelerator. To take all this information into account, we construct a likelihood estimator based on the number and distribution of the b tags, and we then find the value of b that maximizes this likelihood. The result of this procedure is:

$$b \equiv \frac{BF(t \rightarrow Wb)}{BF(t \rightarrow Wq)} = 0.94 \pm 0.27(\text{stat.}) \pm 0.13(\text{syst.})$$

with a 95% CL of $b > 0.34$. Systematics are dominated by the uncertainty in the tagging efficiencies, in turn dominated by the statistical uncertainties on its measurement.

Assuming a unitary CKM matrix, $|V_{tb}| = .97 \pm .15 \pm .07$. This is the first direct measurement of this value. Relaxing 3 generation unitarity softens the limit: $|V_{tb}| > 0.022(95\%)$.

A complementary analysis is underway which improves the top purity by imposing kinematic cuts, allowing the use of the untagged lepton plus jets events. Preliminary results are in agreement with the above.

3. Flavor Changing Neutral Current Decays

The Standard Model has no tZc or $t\gamma c$ vertices; the decays $t \rightarrow Z + c$ and $\gamma + c$ occur only at one or more loops. Thus, the branching fractions are expected to be tiny: $10^{-7} - 10^{-12}$. We expect to see no events in a sample this size; any signal would be indicative of physics beyond the Standard Model.

We search for $t \rightarrow q\gamma$ (where $q = c$ or u) by identifying a high E_T photon-jet combination with the top quark mass and some evidence of a second top in the event: either a lepton from the W decay, or three jets kinematically consistent with top, one of which is b-tagged, if the W decayed hadronically. One event is seen, with a 88 GeV photon, a 72 GeV muon, 24 GeV of missing transverse energy (indicative of a neutrino), and 3 jets. This event is kinematically consistent with the decay chain $t \rightarrow W^+b$, $W^+ \rightarrow \mu^+\nu$ and $\bar{t} \rightarrow W^-\gamma\bar{b}$, $W^- \rightarrow jj$. To set a limit on the top branching fraction, we make the conservative assumption that this is a signal event. One observed event implies a 95% confidence level limit of:

$$BF(t \rightarrow c + \gamma) + BF(t \rightarrow u + \gamma) < 2.9\%$$

Additionally, we search for the decay $t \rightarrow Z + q$, by requiring an identified $Z \rightarrow e^+e^-$ decay, plus four additional jets with $E_T > 20$ GeV. No events are seen, which translates to a limit (at 90% confidence level) of:

$$BF(t \rightarrow c + Z) + BF(t \rightarrow u + Z) < 90\%$$

The present data is insufficient to provide a 95% limit. The large difference in sensitivity between the two FCNC modes arises from the small branching fraction of the Z to electrons. This analysis is being extended to include decays of the Z to muons and hadrons.

4. Summary

CDF is beginning to explore the physics of top quark decays. There is no significant evidence for the nonstandard decays $t \rightarrow W + s$, $W + d$, $Z + c$, $Z + u$, $\gamma + u$ or $\gamma + c$.

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