Testing V-A in Top Decay at CDF at $\sqrt{s}$ = 1.8 TeV

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Abstract. The structure of the tbW vertex can be probed by measuring the polarization of the W in $t \rightarrow W + b \rightarrow l + \nu + b$. The invariant mass of the the lepton and b quark measures the W decay angle which in turn allows a comparison with polarizations expected from a V-A and V+A tbW vertex. We measure the fraction by rate of Ws produced with a V+A coupling in lieu of the Standard Model V-A to be $f_{V+A} = -0.21^{+0.42}_{-0.24}$ (stat) $\pm$ 0.21 (sys). We assign a limit of $f_{V+A} < 0.80$ @ 95% CL. By combining this result with a complementary observable in the same data, we assign a limit of f_{V+A} < 0.61 @ 95% CL. From this CDF Run I preliminary result, we find no evidence for a non-standard Model tbW vertex.

INTRODUCTION

The heavy top quark mass has led to speculation that the top quark may have a unique relationship with the electroweak force which might modify the V-A structure of the decay of the top to a W boson and b quark. This could in turn lead to non-standard model W polarization evident from the study of angular distributions of leptons from W decay [1]. This analysis exploits the relationship between these angular distributions and the invariant mass of $l-b$ combinations from the top decay $t \rightarrow W + b \rightarrow l + \nu\ + b$ to fit for a non-standard model V+A contribution. To analyze the polarization of the W, it is necessary to know the weak isospin of the W decay products, therefore we use the leptonic decay of the W rather than the hadronic decay since quark jets cannot be distinguished from anti-quark jets. Scenarios introducing a V+A contribution include mirror fermions having a right-handed weak interaction either mixing with the top, or faking the top if having similar mass [2].

The spin-one W has three possible helicities for the W^+: -1 (left-handed), 0 (longitudinal), and +1 (right-handed). V-A theory predicts the probability of each W helicity distribution in top decay. Because $M_t > M_W$, a significant number of Ws will be longitudinally polarized with rate, F_0 = 0.70 for M_t = 174.3 GeV and M_W = 80.4 GeV [1] . Leptons from the decay of longitudinally polarized Ws have a symmetric angular distribution of the form $1-(cos\psi_l^\star)^2$, where $cos\psi_l^\star$ is defined as the angle between the lepton in the W rest frame and the boost vector from the top to the W rest frame. Maximal parity violation in the Standard Model V-A weak theory predicts that the remaining W helicity rate is left-handed, creating an asymmetric angular distribution of the form $(1-cos\psi_l^\star)^2$ [1]. Since the angle $\psi_l^\star$ can be related to the $l-b$ invariant mass combination by Equation 1,

$$M_{lb}^2 = \frac{1}{2}(M_T^2 - M_W^2)(1 + cos\psi_l^\star) \quad (1)$$

the distribution of M_{lb}^2 in $t\bar{t}$ data can be studied to determine the polarization of the non-longitudinal Ws. M_{lb}^2 is a good choice because no information about the top or W rest frames are required, and so the neutrino momentum need not be reconstructed. In a V+A theory, M_{lb}^2 would be larger on average than for a V-A theory.

DATA SAMPLES

The $t\bar{t}$ data samples are obtained from $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV in the CDF detector [3]. Three sub-samples of $t\bar{t}$ data are chosen for their low background and high efficiency for b jet identification. The samples and backgrounds are defined in detail elsewhere [4]. Each sample is classified by the number of leptons and identified b jets in the final state.

The dilepton sample is composed of $t\bar{t}$ in which both Ws decay to an electron or muon, and are distinguished by a signal of $\not{E}_T > 25GeV$ from the combination of $W \to l\nu$ decays, two opposite sign and flavor leptons with $P_T > 20GeV$ in the central region $|\eta| < 1.0$, and two jets with $E_T > 10GeV$ and $|\eta| < 2.0$. This sample is consistent with previous CDF analyses, but here only the $e + \mu + jets$ channel is used to eliminate Drell Yan production which is the dominant source of background in the dilepton sample. Initial and final state radiation can result in extra jets, so the b jets are chosen to be the two highest E_T jets. There are four M_{lb} pairings in each dilepton event.

Two lepton+jets samples are defined where only one W decays into an electron or muon, the other decaying into two jets. The lepton is required to have $P_T > 20GeV$, in the central region $|\eta| < 1.0$. Four jets are required, three with $E_T > 15GeV$, $|\eta| < 2.0$, and the fourth having $E_T > 8GeV$ and $|\eta| < 2.4$. One of these samples is required to have a jet "b-tagged" with a displaced vertex using the silicon vertex detector [4], reducing background greatly, and decreasing the number of M_{lb} pairings from at least four to only one per event. This sample is referred to as the "single-tagged" sample. The other lepton+jets sample is known as "double-tagged" and is required to have two b tags, further reducing background and providing two M_{lb} pairings. The b-tagging algorithm does not assign a charge to the b-jet, therefore half of all pairings incorrectly match leptons with b jets from the other top decay.

In the actual data, 7 events were found in the dilepton $e\mu$ sample with an expected background of 0.76 ± 0.21 events, for the single-tagged sample 15 events were found with a background 2.0 ± 0.7, and in the double-tagged sample there were 5 events with a 0.2 ± 0.2 background. Interesting to note is that since right-handed leptons have higher P_T, an increase in events passing the lepton P_T trigger requirement could also indicate a V+A theory. The actual number of events found is not used in this analysis, only the shape of the M_{lb}^2 distributions. When two pairings of the lepton are possible, the two variables are used simultaneously in the fit. While correct pairings are limited kinematically by $1/2(M_t^2 - M_W^2)$, incorrect pairings may have significantly higher mass.

METHOD

The M^2 data shape is fit to be a linear combination of V-A $t\bar{t}$, V+A $t\bar{t}$ [5], and background using a log likelihood method. Each data sample: dilepton, single-tagged, and double-tagged, is fit individually, and a combined log likelihood is used to determine f_{V+A} for the total data sample. f_{V+A} is not constrained to be in the physical region in the fit. Background is allowed to fluctuate within its uncertainties. The background and V-A $t\bar{t}$ samples are weighted by the relative efficiency for the events to pass the lepton P_T requirements as compared to the V+A sample which has a harder lepton P_T distribution. The likelihood fit technique is evaluated using Monte Carlo experiments and determined to be consistent with Gaussian central value and errors by including a 4% scale factor to the error of the fit.

Since this analysis fits to V-A and V+A rates, it does not take into account the interference effects resulting from left and right-handed W polarizations being involved in the decay. For f_{V+A} = 0.5, the interference is maximal and the matrix element fails to account for $m_b/E_b \sim 10\%$ of the decays. The actual uncertainty introduced in the fit is expected to be less than 10% in this case[6]. There is no interference in the case of all V-A or all V+A. This error is not significant compared to statistical and systematic uncertainties.

The largest systematic uncertainties are the top mass and jet energy scale. The top mass enters into the definition of M_{lb}^2, resulting in a shift of f_{V+A} of +0.21 for a top mass shift of 5 GeV. The jet energy scale uncertainty [4] results in a shift of +0.14 for a shift of the jet energy scale upwards within its uncertainty. Since the top mass has a large uncertainty due to the CDF jet energy scale [4], these systematics are highly correlated. Accounting for their correlations results in a top mass systematic shift of 0.19, independent of jet energy scale, and a jet energy scale systematic shift of 0.04, independent of top mass. The total systematic uncertainties amount to a shift in f_{V+A} of 0.21, and are listed in Table 1.

RESULTS

The results of the likelihood fit are $f_{V+A} = -0.21^{+0.42}_{-0.24}$ (stat) $\pm$ 0.21 (sys) for the combined data sample found in 109 pb^{-1}. The individual fits are shown in figure 1. Constructing a Neyman confidence band [7], we find an upper limit of $f_{V+A} <$ 0.80 @ 95% CL. The result is combined with a previous CDF analysis using the lepton P_T [8] to discriminate between left-handed and right-handed Ws for a fixed longitudinal component, and determined to be $f_{V+A} < 0.61$ @ 95%. The combined result is inconsistent with a pure V+A theory at the 2.67 σ level. All results are preliminary. For a data sample of 2 fb^{-1} expected in the first part of Run II, this analysis technique is expected to result in total systematic and statistical uncertainties of 0.14 in f_{V+A}.

TABLE 1. Summary of systematic uncertainties in terms of shift in measurement of V+A fraction.

Systematic Uncertainties	
Top mass Uncertainty	0.19 *(0.21 w/out jet energy correlation)*
Jet energy Scale	0.04 *(0.14 w/out top mass correlation)*
Background shape uncertainty	0.05
Background normalization	0.05
ISR Gluon radiation	0.04
FSR Gluon radiation	0.03
B tagging efficiency	0.03
Parton distribution Functions	0.02
Monte Carlo Statistics	0.01
Relative acceptance uncertainty	0.005
Total systematic	0.21

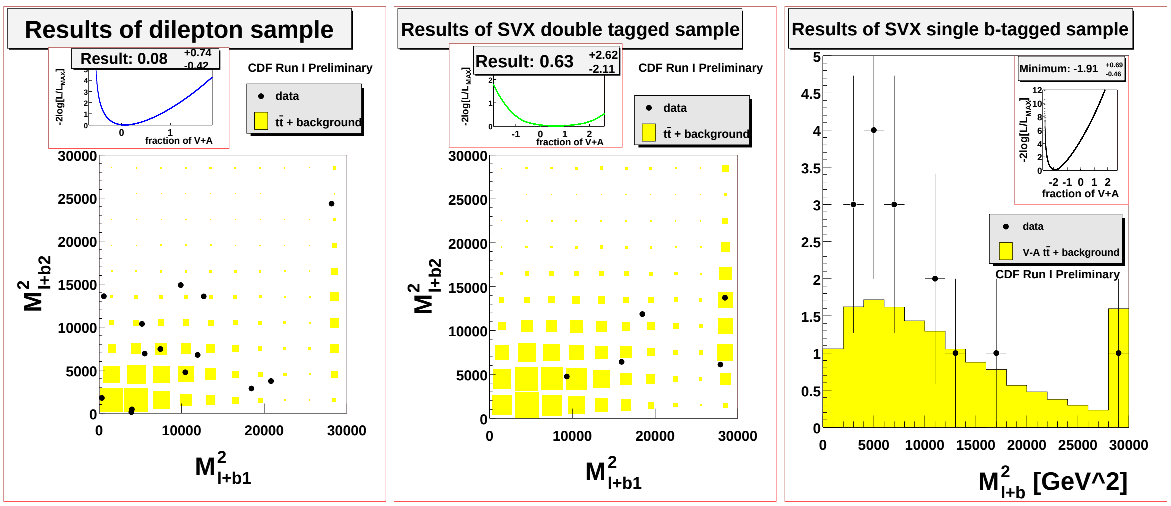

FIGURE 1. Data and Standard Model Monte Carlo distributions for each sample with $-2\log\mathscr{L}$ as a function of f_{V+A}.

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