Measurement of the Helicity of W Bosons Produced in Top-Quark Decay at CDF II

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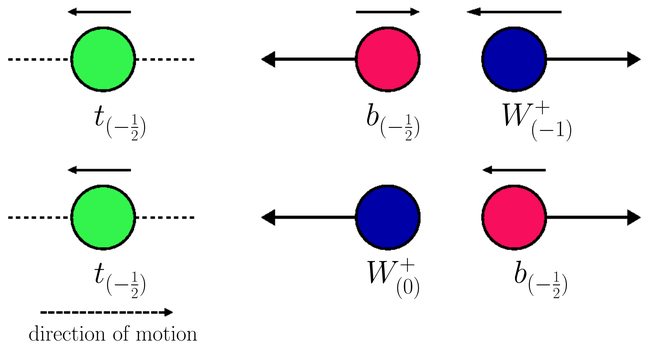
11th August 2003

Introduction

We test the $V-A$ structure of the weak interaction at high energy by measuring the helicity of W bosons in the decay $t \to Wb$. In the Standard Model (SM), W bosons couple only to left-handed fermions and right-handed anti-fermions. Angular momentum conservation then requires the weak decay of a left-handed top quark to proceed through either a left-handed (negative-helicity) or longitudinal (zero-helicity) W^+.

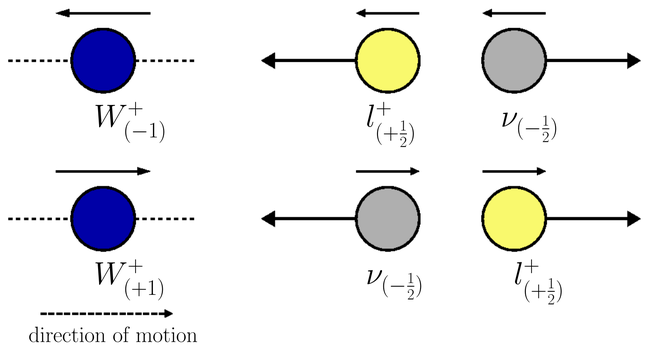


Top-quark decay to longitudinal W bosons is enhanced relative to the left-handed mode as a consequence of the large coupling of the top to the Higgs sector. The SM prediction for the fraction of longitudinal W's produced in top decay is

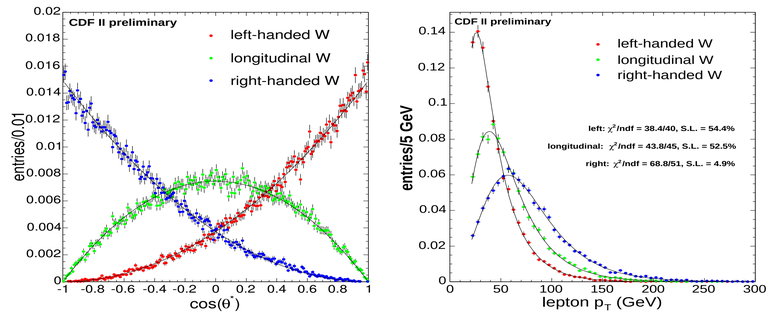
$$F_0 = \frac{\Gamma(t \to W_{(0)}b)}{\Gamma(t \to W_{(0)}b) + \Gamma(t \to W_{(\pm)}b)} = \frac{\frac{1}{2}(\frac{m_t}{M_W})^2}{1 + \frac{1}{2}(\frac{m_t}{M_W})^2}.$$

For $m_t = 175$ GeV, the SM prediction is $F_0 = 0.703$.

To measure the W helicity content of our $t\bar{t}$ sample, we use the distribution of lepton p_T from the W decay. Angular momentum conservation favors a final state in which the charged lepton is thrown backward relative to the W's direction of motion in a left-handed W^+ decay, and forward in a right-handed decay.



In the lab frame the charged leptons from left-handed W decays will have a softer p_T distribution, on average, than the leptons from right-handed decays. In the case of a longitudinally polarized W, the leptons are preferentially emitted transverse to the W direction; they have average laboratory p_T's in between those from left- and right-handed decays.



Right are the charged-lepton p_T spectra for top-quark decay to W's with $h = -1, 0, +1$. Left are the distributions of $cos(\theta^*)$. $cos(\theta^*)$ is defined as the angle, in the W rest frame, between the charged-lepton momentum and the top-quark momentum.

In Run I, CDF measured with this technique $F_0 = 0.91 \pm 0.37(\text{stat}) \pm 0.13(\text{syst})$, a value consistent with the SM prediction. In Run I CDF also measured F_+, the fraction of right-handed W's produced in top decay, $F_+ = 0.11 \pm 0.15(\text{stat})$. This Run I measurement of F_+ is consistent with the SM prediction $F_+ \simeq 0$.

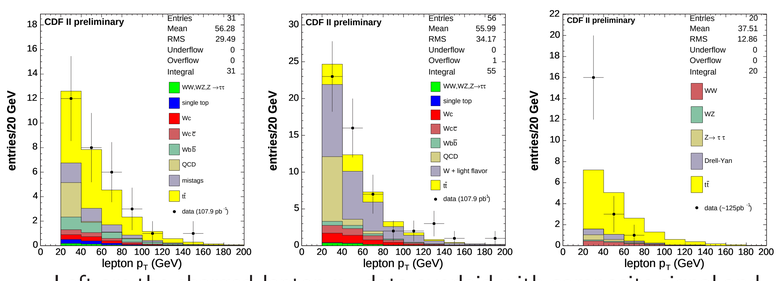
Measurement Strategy

We employ an unbinned maximum-likelihood fit to extract from the data the fraction of longitudinal W's produced in top decay. We construct a likelihood function which is composed of template functions representing the lepton p_T spectra of the background and signal components.

$$\mathcal{L} = \prod_{s=1}^{N} \left\{ \mathcal{P}_s^{(\text{bg})}(\beta_s) \left\{ \prod_{i=1}^{N_s} \mathcal{P}_s(x_{i,s}; F_0, \beta_s) \right\} \right\}$$

$$\mathcal{P}_s(x_{i,s}; F_0, \beta_s) = \beta_s T_s^{(\text{bg})}(x_{i,s}) + (1-\beta_s)[(1-F_0^{\text{obs}})T_s^{(-)}(x_{i,s}) + F_0^{\text{obs}}\, T_s^{(0)}(x_{i,s})],$$

$$F_0^{\text{obs}} = (1 + \frac{A_-}{A_0}(\frac{1}{F_0} - 1))^{-1}$$

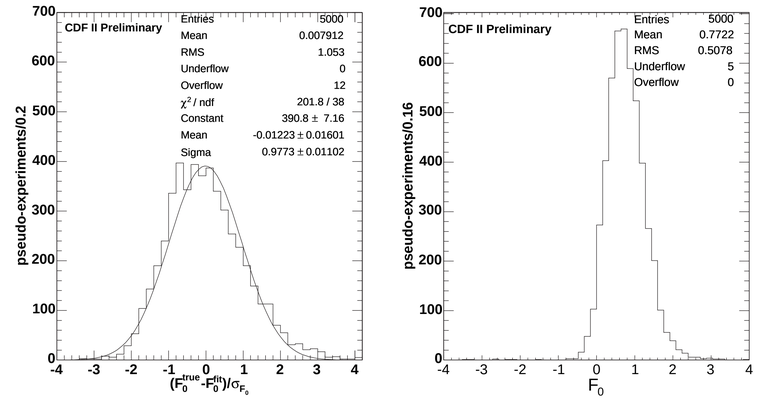


Left are the charged-lepton p_T data overlaid with composite signal and background models for the lepton + jets + b-tag sample; center, the no-tag sample; right, the dilepton sample.

The signal templates are drawn from Monte Carlo samples generated with `HERWIG 6.5x`, where the helicity of one of the $W's$ in $t\bar{t}$ decay is fixed. The background templates are adapted from the backround estimates of the b-tag and dilepton $t\bar{t}$ cross-section measuements. All templates are parameterized by a smooth function.

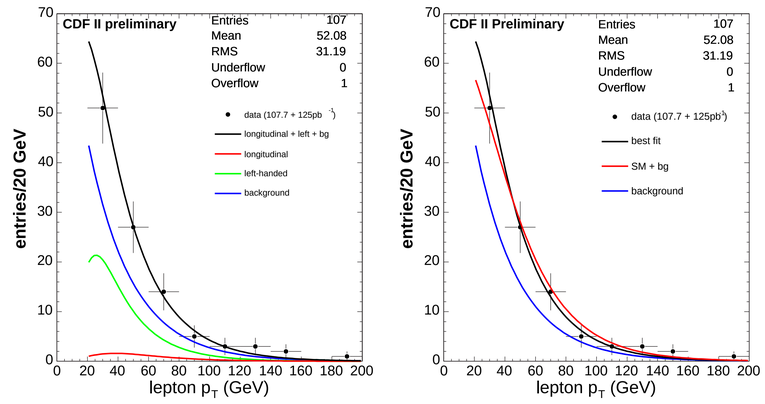
Sensitivity

To estimate our sensitivity given $125\ \text{pb}^{-1}$ of data in the dilepton channel and $107.9\ \text{pb}^{-1}$ of data in the lepton + jets channels we perform pseudo-experiments. Assuming Standard Model tWb coupling and the background shape and normalization estimates from the cross-section measurements, we expect a statistical uncertainty of ~ 0.47 on F_0.



Results

We fit the lepton p_T spectra of the b-tag, no-tag and dilepton samples to extract F_0. Shown are histograms of lepton p_T for all samples plotted against the best-fit and the fit components, as well as the Standard Model expectation.



We also fit to the b-tag and no-tag samples only. Shown are the result of that fit plotted against the best-fit and the fit components, as well as the Standard Model expectation.