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Measurement of the W helicity in $t\bar{t}$ decays at $\sqrt{s} = 1.96$ TeV in the Lepton+jets Final States

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Two measurements of the W-helicity in $t\bar{t}$ decays at $\sqrt{s} = 1.96$ TeV have been carried out using data collected by the DØ detector. Semileptonic $t\bar{t}$ events in the electron and muon channel were used. In these events the distribution of the angle between the lepton and the direction of the top measured in the rest frame of the intermediate W boson is sensitive to the helicities of the W. The two analyses differ in the usage of lifetime tag information in the event selection. With an integrated luminosity of 168.7 pb^{-1} and 158.4 pb^{-1} in the e+jets and μ+jets channels respectively, an upper limit on the fraction f_+ of positive helicity W's of $f_+ < 0.244$ is set by both analyses at 90% confidence level.

1. Introduction

In the Standard Model the decay of the top quark is described by the V−A charged current interaction. The distribution of the down-type decay products (charged lepton or d,s quark) in the rest frame of the W can be described by using the helicity fractions $f_i (i = 0, -, +)$:

$$\omega(\theta) = f_0 \frac{3}{4}(1 - \cos^2\theta) + f_- \frac{3}{8}(1 - \cos\theta)^2 + f_+ \frac{3}{8}(1 + \cos\theta)^2 \quad (1)$$

where θ refers to the decay angle of the down-type particle with respect to the top quark direction in the W rest frame. The helicity fractions f_i depend on m_t, M_W and m_b and correspond to the branching fractions of $t \to bW$, with W in longitudinal, left-handed, and right-handed helicity states, respectively.

In the Standard Model the fraction of longitudinal polarized W's is predicted to be $f_0 \approx 0.7$ and f_+ is suppressed by chiral factors of order m_b^2/m_t^2.

In scenarios where the top has also a V+A charged current interaction the fraction of longitudinally polarized W's is unchanged, while the fraction of left handed W's is reduced in favor of right handed W's. A measurement of the W helicity can therefore probe the underlying weak interaction of the top decay. A next to leading order (NLO) calculation already shows that a value of $f_+ \geq 0.01$ must originate from non-SM physics [1]. In these analyses the parameter f_0 is fixed to this predicted value. The parameters f_0 and f_+ have already been measured by

CDF and DØ in Run I of the Tevatron. CDF measured $f_0 = 0.91 \pm 0.37 \pm 0.13$ and $f_+ = 0.11 \pm 0.15$ [2] and DØ measured $f_0 = 0.56 \pm 0.31$ [3].

2. Event selection and reconstruction

The data sample for both analyses consists of 169 pb^{-1} in the e+jets and 158 pb^{-1} in the μ+jets channel from the Run II of the Tevatron. The event preselection requires an isolated lepton (e or μ) with $p_T > 20$ GeV, no second lepton with $p_T > 15$ GeV in the event, high missing energy and at least four jets with $p_T > 15$ GeV.

The top and W momenta are reconstructed with a kinematic fit, which is performed by minimizing the function $\chi^2 = (\vec{x} - \vec{x}_M)G(\vec{x} - \vec{x}_M)^T$, where $\vec{x}_M$ is a vector of measured variables, $\vec{x}$ is a vector of fitted variables and G is the inverse error matrix of the measured quantities. The minimization is subject to the following constraints: two jets must form the invariant mass of the W, the lepton and the missing transverse energy must form the invariant mass of the W and the masses of the two reconstructed top quarks must be 175 GeV. Events that fail this fit are rejected. The analysis which makes use of b−tag information requires that at least one of the jets is tagged as a b-jet, i.e. the explicitly reconstructed secondary vertex must be displaced by at least seven standard deviations from the primary vertex.

To discriminate between W multijet production and $t\bar{t}$ pair production, a likelihood discriminant L is built. Its six input variables make use of the special event topology of $t\bar{t}$ events: the $t\bar{t}$ events tend to be more spherical due to the high mass of the top quark and are more energetic. The likelihood discriminant is built separately for both analyses and a cut which optimizes the statistical significance of the final result is applied to select the final sample.

Finally the composition of the event sample is calculated. The multijet QCD background is determined from data using the difference in the lepton identification efficiency compared to W multijet and $t\bar{t}$ production. The number of $t\bar{t}$ events is extracted using the cut efficiency of the likelihood discriminant determined on MC (topological analysis) or by performing a fit to the discriminant (b−tag analysis). Table 1 shows the predicted composition of the final sample for both analyses.

Table 1. Predicted sample composition after all cuts for each analysis.

Channel	topological analysis			b−tag analysis		
	$t\bar{t}$	W+jets	QCD	$t\bar{t}$	W+jets	QCD
μ+jets	11.3 ± 1.3	17.6 ± 1.2	2.1 ± 0.5	9.6 ± 2.7	2.0 ± 1.4	0.7 ± 0.4
e+jets	25.9 ± 1.5	20.3 ± 1.5	2.7 ± 0.5	14.2 ± 3.4	6.6 ± 1.8	0.6 ± 0.3

3. Measurement of the W helicity

The measurement of f_+ is done by comparing the observed $\cos\theta$ distribution with templates. The templates for the QCD multijet production are taken from data

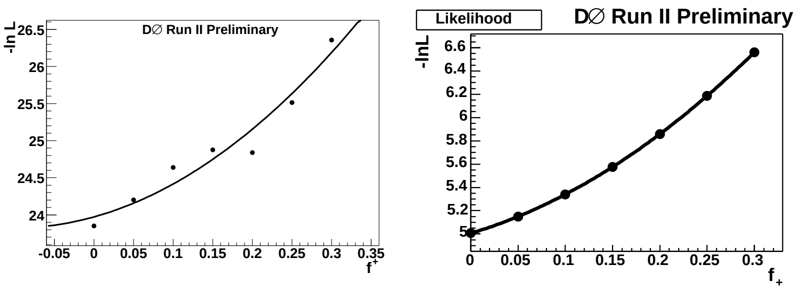

Fig. 1. Result of the maximum likelihood fit for the topological analysis (left) and the b−tag analysis (right). Electron and Muon channels are combined.

while the W multijet templates are taken from Monte Carlo. The $t\bar{t}$ signal templates are generated with values of f_+ ranging from $f_+ = 0$ to $f_+ = 0.3$.

A binned maximum likelihood fit is then performed to extract f_+. The topological analysis finds $f_+ = -0.11 \pm 0.19$ and the b−tag analysis observes $f_+ = -0.13 \pm 0.23$. These results include statistical errors only.

Since in the assumed model f_+ must lie between 0.0 and 0.3, a Bayesian technique is used to determine a 90% confidence limit. The prior is flat inside the physically allowed region and zero outside. Systematic uncertainties are taken into account by convoluting a Gaussian function with a width given by the total systematic uncertainty, 0.15 in the topological analysis and 0.11 in the b−tag analysis, with the likelihood. The dominant systematic uncertainties arise from the uncertainty on the Jet Energy Scale and on the top mass. Both analyses observe an identical upper limit of $f_+ < 0.244$ (90% C.L.).

4. Summary

Two measurements of the fraction f_+ of W's with positive helicity from the top decay, in the ℓ+jets channel using Run II data have been presented. After selection and, in case of the b−tag analysis, application of a Secondary Vertex tag, a kinematic fit to the $t\bar{t}$ hypothesis is performed and an event discriminant between signal and background is built. A Bayesian limit calculation is performed separately for each analysis yielding the same upper limit on f_+ with 90% confidence:

$$f_+ < 0.244 \ \text{(90\% C.L.)}$$

References

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