Measurement of the top polarization in the lepton+jets decay channel with the D0 detector

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1 Introduction

Top quark and its properties play an important role in the Standard Model (SM) and may probe for the new physics. The recent results for the top forward-backward asymmetry from the Tevatron [1, 2] showed tension between the SM and measurements. Various models can address that tension with regards to the top polarization and the spin correlation of the top-antitop pairs. The SM predicts top quark pairs produced unpolarized at the Tevatron, while various models beyond Standard Model (BSM) expect non-zero polarization of the top pairs. As the matter of fact, the polarization quantity itself is distinctive for different models and thus the experimental result of the top polarization can confirm the SM calculation or various models BSM.

This on-going measurement of the top quark polarization uses lepton+jets decay channel of the top quark pair produced at the Tevatron collider in proton-antiproton collisions. The study analyzes data detected by the DØ detector with integrated luminosity of 9.7 fb^{-1}. Top quark polarization can play important role in confirmation of the Standard Model theory or in understanding BSM models as it supplements the measurements of forward-backward asymmetry. The polarization is studied by angular distribution of the lepton in beam basis and helicity basis, furthermore, the transverse part of the polarization is studied.

2 Method

Top polarization $P_{\hat{n}}$ can be measured in the top rest frame by the angular distribution of the top decay products with respect to a chosen axis $\hat{n}$ [3, 4]:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{i,\hat{n}}} = \frac{1}{2}(1 + P_{\hat{n}}\kappa_i \cos\theta_{i,\hat{n}}), \tag{1}$$

where i is the decay product (that is lepton, quark, neutrino) and κ_i its spin analyzing power, that equals 1 for lepton, -0.4 for b-quark, and -0.3 for neutrino. As one can see, the lepton is the most sensitive product of the top quark decay to its polarization. Thus, this measurement is focused on the polarization information that is carried by the lepton[1],

[1] In this article, by lepton are denoted only electron and muon.

which is detected and reconstructed by the DØ detector with a high accuracy. The down-type quark has also analyzng power close to 1 [5], however its identification is complicated.

The polarization is measured with respect to following axes:

- **beam** axis is given by the direction of the proton (antiproton) beam and is optimal for the Tevatron energy.
- **helicity** axis is given by the direction of the parent top quark in $t\bar{t}$ rest frame. This is preferred by the LHC energies, but can be measured at the Tevatron.

The axes and the respective polarization angles using lepton as the analyzing particle are shown in Figure 1. One can define the net polarization using cosines of the polarization angles as

$$P_{\hat{n}} = \frac{N(\cos\theta_{l,\hat{n}} > 0) - N(\cos\theta_{l,\hat{n}} < 0)}{N(\cos\theta_{l,\hat{n}} > 0) + N(\cos\theta_{l,\hat{n}} < 0)}. \qquad (2)$$

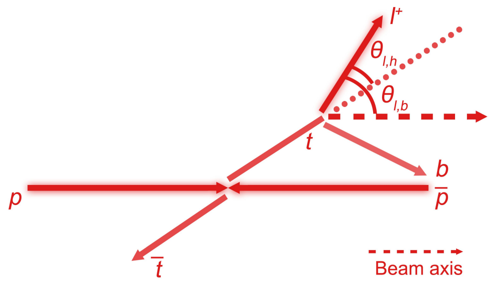

Figure 1: Visualization of the helicity ($\theta_{i,\hat{h}}$) and beam ($\theta_{i,\hat{b}}$) polarization angles using lepton as the analyzing particle in the top quark decay topology at the Tevatron.

To extract the polarization value from data, a fit using templates for polarized top quarks is performed. The polarized samples are produced by reweighing signal Monte Carlo sample with weight derived from Eq. 1, $(1 + \cos\theta_{l,\hat{n}})$ for positive and $(1 - \cos\theta_{l,\hat{n}})$ for negative polarization of the top quarks. The polarization is expected to be close to zero in the SM and a very small polarization is generated by the electro-weak interaction.

The bases mentioned above are longitudinal, but one can also study polarization **transverse**, perpendicular component to the production plane [6, 7]. Such polarization is allowed to be non-zero in the SM and has different values for various BSM models. Measurement of transverse polarization of the top quarks has never been performed.

3 Selection and samples

The measurement is performed with an integrated luminosity of 9.7 fb^{-1} of proton-antiproton collisions at the center-of-mass energy of 1.96 TeV, recorded during Run II by the DØ detector [8] at the Tevatron collider. The events in the l+jets channel have exactly one isolated lepton with $p_T > 20$ GeV and $|\eta| < 1.1$ in case of electron, or $|\eta| < 1.5$ in case of muon. Events are required to have four or more jets identified by cone algorithm, each jet with transverse momentum of $p_T > 25$ GeV and $|\eta| < 2.5$. The leading jet has to satisfy $p_T > 40$ GeV criterium and at least one of the jets is required to be tagged as b-quark jet by multivariate tagging algorithm. The top quark pair decay topology in l+jets channel contains undetected neutrino, therefore additional selection criteria on the imbalance in the transverse momentum, $\not{E}_T > 20$ GeV, is applied. Additional quality cuts are applied to encrease signal-to-background ratio in selection of the $t\bar{t}$ events. Details about selection requirements, particle reconstruction, and identification are described in [9, 10].

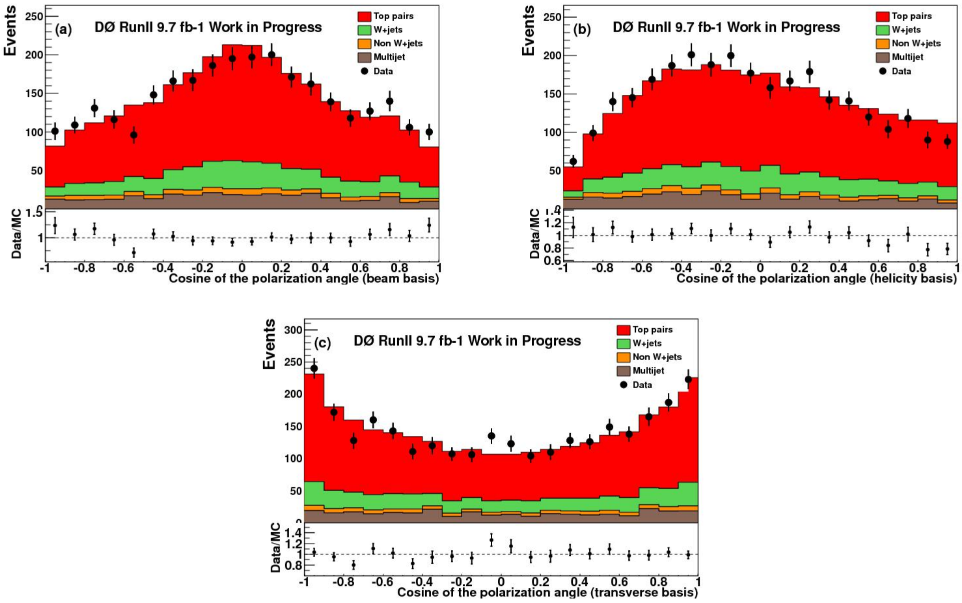

Figure 2: Distributions of the cosines of the polarization angles with respect to the beam axis (a), to the helicity axis (b), and to the transverse component (c). The signal is modeled by leading order generator ALPGEN, the background samples are described in Sec. 3

Both data-driven techniques and Monte Carlo (MC) simulations are used to estimate the sample composition of the data. Each MC sample is processed through full simulation of the DØ detector based on GEANT. Signal $t\bar{t}$ events are simulated using various MC generators, a next-to-leading generator MC@NLO combined with HERWIG showering and a leading order generator ALPGEN combined with PYTHIA. The dominant background is W+jets, followed by multijet (MJ) contribution, where jets are misidentified as leptons, and small contributions from single top quark, Z+jets, and diboson are also calculated. Background samples are simulated using ALPGEN (W+jets, Z+jets), PYTHIA (diboson), COMPHEP (singletop), or from control samples from DØ data (MJ). The measurements uses various axigluon models for comparison, generated with MADGRAPH+PYTHIA. For direct comparison a $t\bar{t}$ signal with zero polarization was also generated using the same MC generators.

4 Results

To study angular distributions with the respective axes mentioned in Sec. 2, one needs entire information about kinematic of the top quark decay to reconstruct the top quark kinematic parameters. For this purpose, kinematic reconstruction is utilized to handle the assignments and combinatorics. The kinematic fit is constrained with the mass of the top quark and the mass of the W boson, and only the assignment with the lowest χ^2 is kept right now.

Cosines of the polarization angles are then evaluated as shown on the control plots for the beam axis (a), helicity axis (b), and transverse component of the polarization (c) (Fig. 2).

Being "work in progress", this paper is able to report only MC results for the top quark polarization. Table 1 summarizes net polarizations for different MC simulations of $t\bar{t}$ signal after selection in comparison with axigluon models. Uncertainties are from MC statistics. For the first two SM MC generators, the dependency of the polarization on $M_{t\bar{t}}$ is shown. In case of data, the net polarization will be measured after the background subtraction.

	beam axis		helicity axis		transverse axis	
	$M_{t\bar{t}} < 450$	$M_{t\bar{t}} > 450$	$M_{t\bar{t}} < 450$	$M_{t\bar{t}} > 450$	$M_{t\bar{t}} < 450$	$M_{t\bar{t}} > 450$
SM ALPGEN	-0.001(3)		-0.024(3)		-0.005(3)	
	0.002(3)	-0.005(4)	0.004(3)	-0.068(4)	-0.004(3)	-0.007(4)
SM MC@NLO	-0.008(1)		-0.043(1)		0.002(1)	
	-0.001(2)	-0.018(2)	- 0.008(2)	- 0.096(2)	0.003(2)	0.001(2)
SM MADGRAPH	-0.007(11)		-0.020(11)		-0.015(11)	
200 GeV axigluon$_L$	-0.083(11)		-0.080(11)		-0.011(11)	
200 GeV axigluon$_R$	0.065(11)		0.013(11)		0.013(11)	
2000 GeV axigluon$_L$	-0.068(11)		-0.092(11)		-0.003(11)	
2000 GeV axigluon$_R$	0.041(11)		-0.011(11)		0.014(11)	

Table 1: Summary of Monte Carlo predictions of the net polarization after selection. The SM signal is modeled using ALPGEN, MC@NLO, and MADGRAPH, axigluon models are simulated with MADGRAPH. Uncertainties are statistical.

Template fit with weighted MC samples (+1 and -1 polarized signal templates) will be used to measure the polarization in data.

5 Conclusion

The described measurement is an on-going study of the top polarization using the full Run II dataset from the DØ detector. The motivation is to provide result that will help to resolve whether there is new physics associated with the top quark or the SM holds true. This measurement is the first attempt to measure transverse part of the top quark polarization.

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