Measurement of the W helicity in top quark decays with the ATLAS detector using a template method

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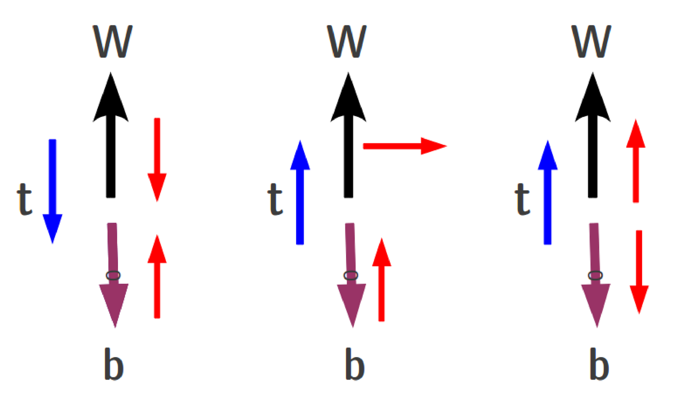
Abstract

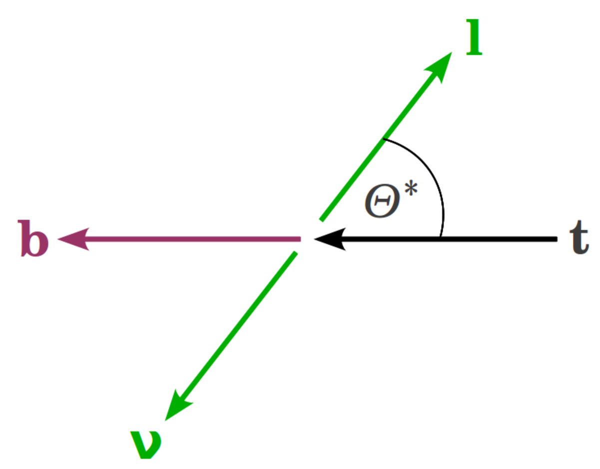
With the ATLAS experiment, the W-boson polarisation has been studied using lepton+jets events in a data set of 35 $^{-1}$ pb. The helicity fractions have been extracted via different methods. One of them is a template method that will be presented in the following. All results have been so far in good agreement with the Standard Model.

Introduction

The Wtb vertex structure can be studied using the W-polarisation in top quark decays. Since the top- and the b-quark are fermions, there are three possible helicity states for the W-boson: left-handed, right-handed and longitudinal.



$F_L \approx 0.3$ $F_0 \approx 0.7$ $F_R \approx 0$

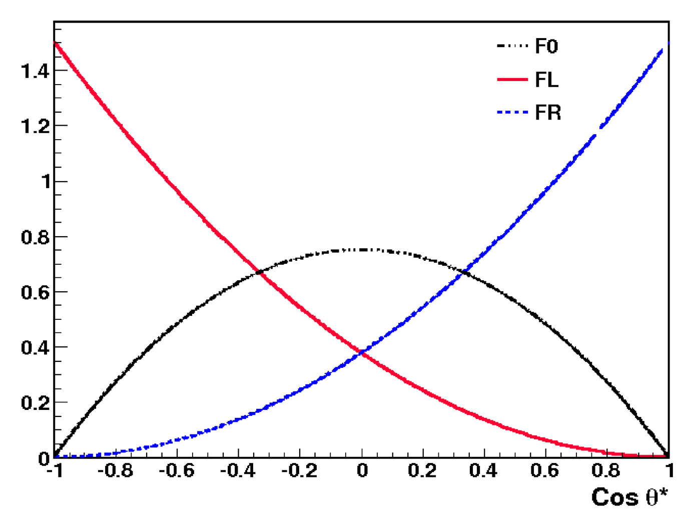


In the Standard Model, the Wtb vertex has a V-A structure:

$$-i\frac{g}{2\sqrt{2}}V_{tb}\gamma^{\mu}(1-\gamma^5)\,.$$

The right-handed contribution is suppressed.

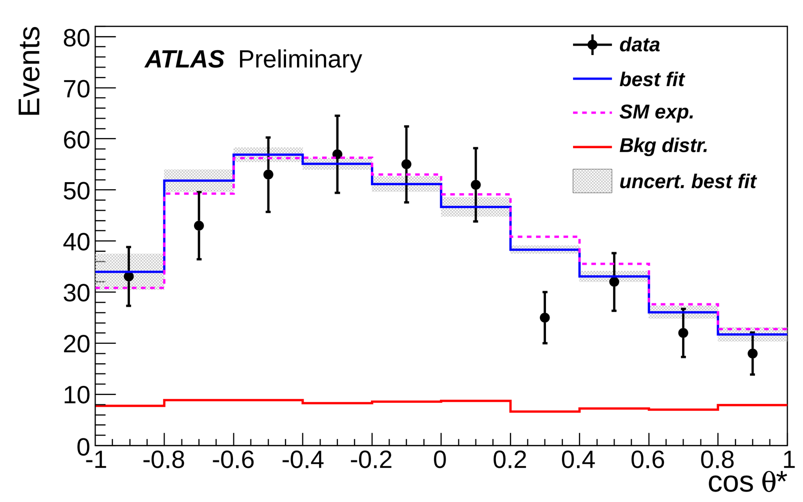
The helicity angle $\cos\theta^*$ is a good estimator to extract the W-helicity fractions and is defined here in the rest frame of the W-boson. The $\cos\theta^*$ distributions (right Fig.) have clearly different shapes for the three helicity states. The angular distribution yields:



$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1+\cos\theta^*)^2\,F_{\rm R} + \frac{3}{8}(1-\cos\theta^*)^2\,F_{\rm L} + \frac{3}{4}\sin^2\theta^*\,F_0$$

Results for template method

The events have been selected requiring one high-p_T lepton, missing transverse energy and at least four jets (at least one of them b-tagged). The data set for the two channels yield 246 events (μ+jets) and 156 events (e+jets). Systematic uncertainties have been estimated via ensemble tests with 2000 ensembles each. The ensembles (normalized to 35 $^{-1}$ pb) have been created assuming Possonian fluctuations in each bin. The difference of the mean values between the standard pseudo-experiment and the systematic varied one has been used as uncertainty. The uncertainties have been estimated in both channels separately and for the combined likelihood fit. The uncertainties are dominated by the statistical uncertainty, ISR/FSR and jet modeling, as well as the background modeling.



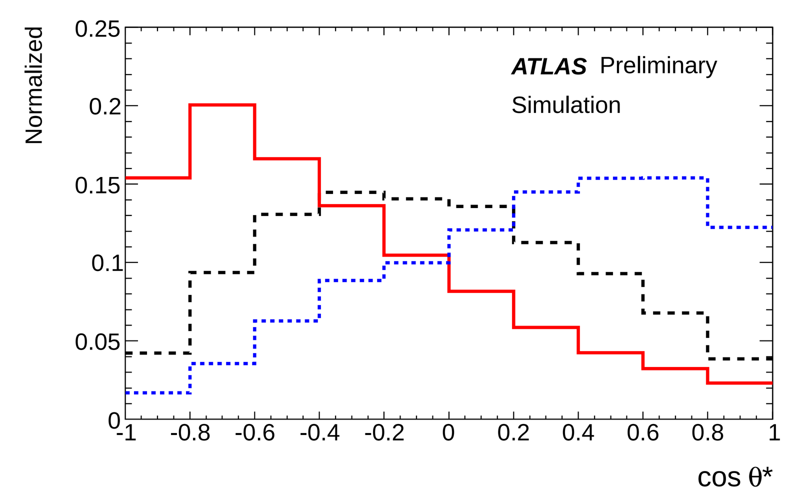
The figure on the left side [1] shows the best fit (solid blue line) compared to the Standard Model expectation (solid magenta line) and the overall uncertainty for the combination of the e+jets and μ+jets channel.

	e+jets	μ+jets	combined
F_0	0.60 ± 0.20	0.56 ± 0.18	0.59 ± 0.12
F_L	0.40 ± 0.20	0.44 ± 0.18	0.41 ± 0.12

All results [1] shown here are in good agreement with the Standard Model expectation.

The template method

The events are fully reconstructed using a kinematic likelihood fitter (KLFitter). The four highest p_T jets are used in the fit to calculate all possible jet-parton assignments (permutations). Non-gaussian transfer functions have been obtained from MC and are also applied in the fit. The reconstruction efficiency has been increased by constraining the top quark mass and by using b-tagging information. The jet-parton assignment with the highest probability is chosen for the reconstruction of the angular distribution. The reconstructed templates are shown below for the e+jets channel [1]:



The template samples are generated with Protos [2]. Pure left-handed, right-handed and longitudinal samples are obtained, which allow to create samples with every possible helicity final state.

A binned likelihood fit is performed. It is assumed that the right-handed contribution is negligible. Only the templates for F_0 and F_L and the background are taken into account. The background is constrained using a Gaussian distribution.

$$\mathcal{L}(F_0, F_{\rm L}, F_{\rm R}=0) = e^{\frac{-(n_{\rm bkg}-\bar{n}_{\rm bkg})^2}{2\sigma^2_{\rm bkg}}}\prod_{i=1}^{N_{bins}} P(n_i;\bar{n}_i(F_0,F_{\rm L},F_{\rm R}=0)).$$

Interpretation in effective field theory

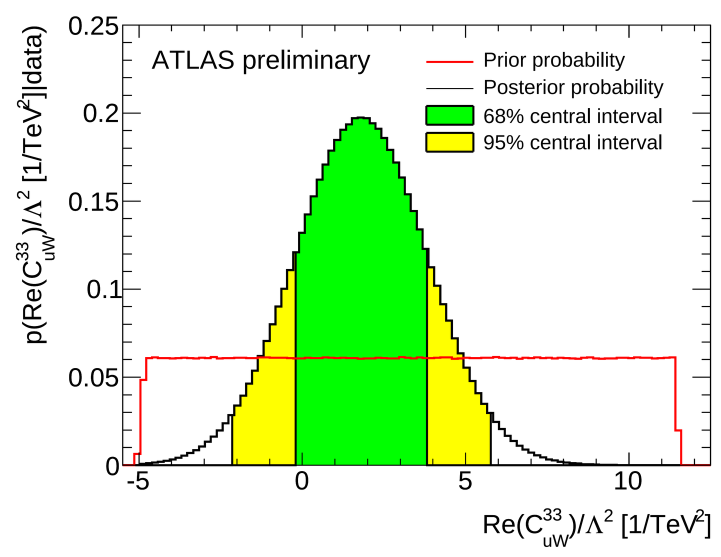
A significant deviation of measured quantities from Standard Model predictions could be a hint to new physics processes. These processes could be expressed by an effective model: $\mathcal{L}_{\rm eff} = \sum \frac{C_x}{\Lambda^2}O_x + \ldots$, where the O_x are dimension-six operators [3]. In the effective theory there is an operator altering the helicity fractions [4, 5].

$$F_{0,L} = \frac{m_t^2}{m_t^2+2m_W^2} \mp \frac{4\sqrt{2}{\rm Re}\,(C_{uW}^{33})v^2\,m_t m_W(m_t^2-m_W^2)}{\Lambda^2 V_{tb}\,(m_t^2+2m_W^2)^2}$$

The measurement presented can be used to set a limit on the corresponding coefficient C_{uW}^{33}:

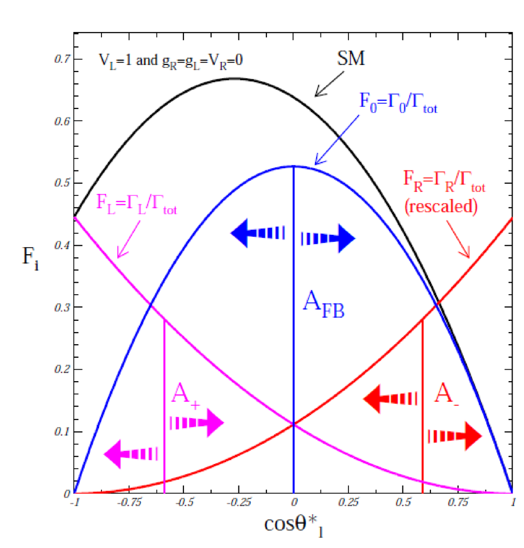
$$\frac{{\rm Re}\,(C_{uW}^{33})}{\Lambda^2} \in [-2.14, 5.77]\ {\rm TeV}^{-2} \quad \text{(at 95 \% C.L.)}.$$

The limits obtained are still consistent with zero and therefore consistent with the Standard Model assumptions.



Further approaches: Correction function method

Events are reconstructed using a χ^2 fit. The best jet-parton assignment is used for the calculation of $\cos\theta^*$. All background contributions are subtracted from data, afterwards the MC prediction is corrected by bin-wise correction factors.



Angular asymmetries are obtained with a counting experiment.

$$A_z = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}\,.$$

Using $A_{\rm FB}$, A_+ and A_- the helicity fractions are calculated:

$$F_{\rm L} = \frac{1}{1-\beta} - \frac{A_+ - \beta A_-}{3\beta(1-\beta^2)} \quad , F_0 = -\frac{1+\beta}{1-\beta} + \frac{A_+ - A_-}{3\beta(1-\beta)}$$

The fractions obtained are also in good agreement with the SM expectations [1]:

	e+jets	μ+jets	combined
F_0	0.64 ± 0.27	0.66 ± 0.19	0.65 ± 0.15
F_L	0.36 ± 0.17	0.36 ± 0.12	0.36 ± 0.10
F_R	0.00 ± 0.13	-0.02 $\pm$ 0.08	-0.01 $\pm$ 0.07

References

[1] "Measurement of the W-boson polarization in top quark decays in pp collision data at $\sqrt{s}$ = 7 TeV using the ATLAS detector", ATL-CONF-2011-037.

[2] J. A. Aguilar-Saavedra, "Single top quark production at LHC with anomalous Wtb couplings", Nucl. Phys. B 804 (2008) 160, arXiv:0803.3810 [hep-ph].

[3] W. Buchmüller and D. Wyler, "Effective Lagrangian Analysis Of New Interactions And Flavor Conservation", Nucl. Phys. B268 (1986) 621.

[4] J. A. Aguilar-Saavedra, "A minimal set of top anomalous couplings", Nucl. Phys. B812 (2009) 181204.

[5] C. Zhang and S. Willenbrock, Effective-Field-Theory Approach to Top-Quark Production and Decay, Phys. Rev. D83 (2011) 034006.