Measurement of the longitudinal polarization of the top quark in top-antitop events with the ATLAS experiment.

1. Why should we measure top polarization?

- In the SM, parity conservation in the strong production of top–antitop quark pairs renders un–polarized top quarks.
- SM parity–violating weak interactions generate a small contribution to the polarization [arXiv:1305.2066].
- The anomalous forward–backward asymmetry (A_{FB}) results from the Tevatron have motivated theorists to explain the result using BSM models, such as axi–gluons, that produce non–zero longitudinal polarization of top quarks.

Top polarization can be used as a check for the SM and as way to probe the existence of BSM physics.

2. Extract polarization through the top's decay products

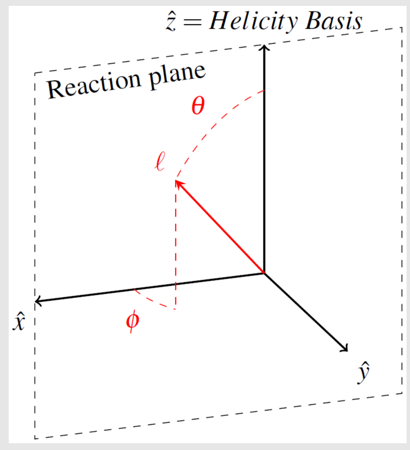
- Due to the top quark's short lifetime, it decays before hadronization can occur, preserving its spin information.
- The spin information can be accessed through the angular distributions of its decay products.

$$W(\cos\theta_i) = \frac{1}{2}(1+\alpha_i P\cos\theta_i)$$

P : polarization
α_i : spin – analyzing power of final – state decay product , i
θ_i : polar angle of final – state decay product , i , w.r.t. a given quantization axis

α_i	Particle Type
1.0	Charged Lepton
1.0	Down Type Quark
-0.4	b Quark
-0.3	Neutrino
-0.3	Up Type Quark

- The helicity basis is used, in which the quantization axis is chosen as the parent top quark's momentum direction in the top–antitop center–of–mass frame.
- Utilize the charged lepton in the single lepton channel to perform analysis. This result is combined with the dilepton channel measurement.

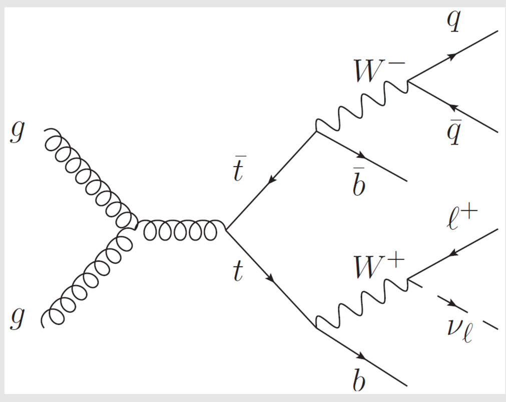


Analyze the angular distribution of the top quark's decay products to extract its polarization, relying upon the full reconstruction of the top–antitop decay and a template fit to the data. The 4.7 fb⁻¹ data set of proton–proton collisions at 7 TeV collected by the ATLAS experiment is used for the analysis.

3. Single lepton event selection

- Exactly one high–p_T isolated electron or muon
- At least four jets, with at least one *b*–tagged
- Large missing transverse energy from the neutrino
- Large transverse mass of the leptonically decaying *W*–boson, defined as:

$$m_T = \sqrt{2p_T^\ell E_T^{miss}[1-\cos(\phi^\ell - \phi(E_T^{miss}))]}$$



4. Signal and background estimation

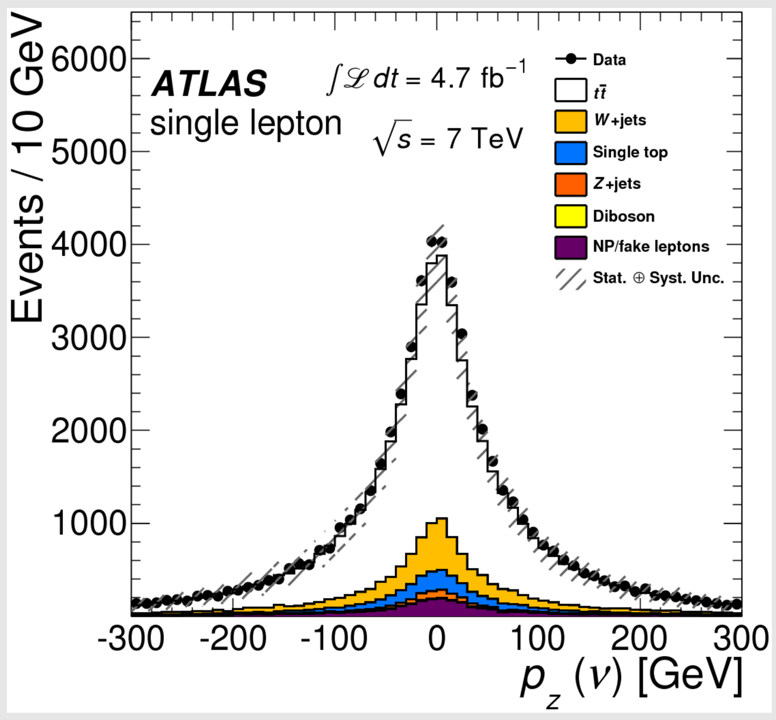
- Monte Carlo simulated samples are used to predict most of the SM signal and background contributions.
- The top–antitop signal, diboson, and single top processes are estimated using NLO generators. Meanwhile, the *Z*+jets background is estimated using a LO plus extra legs generator.
- The *W*+jets background is estimated using a LO plus extra legs generator and is normalized to agree with the lepton charge asymmetry measurement using ATLAS data [arXiv:1203.4211].
- Non-prompt(NP)/fake leptons (primarily from QCD multi-jet events) are estimated using a data driven matrix method based on the ratio of jets passing loose lepton selection to those passing tight lepton selection.

Source	e+jets	μ+jets
$t\bar{t}$	16200	26500
Background	5100	9400
Total	21300	35900
Uncertainty	±1300	±1700
Data	21956	37919

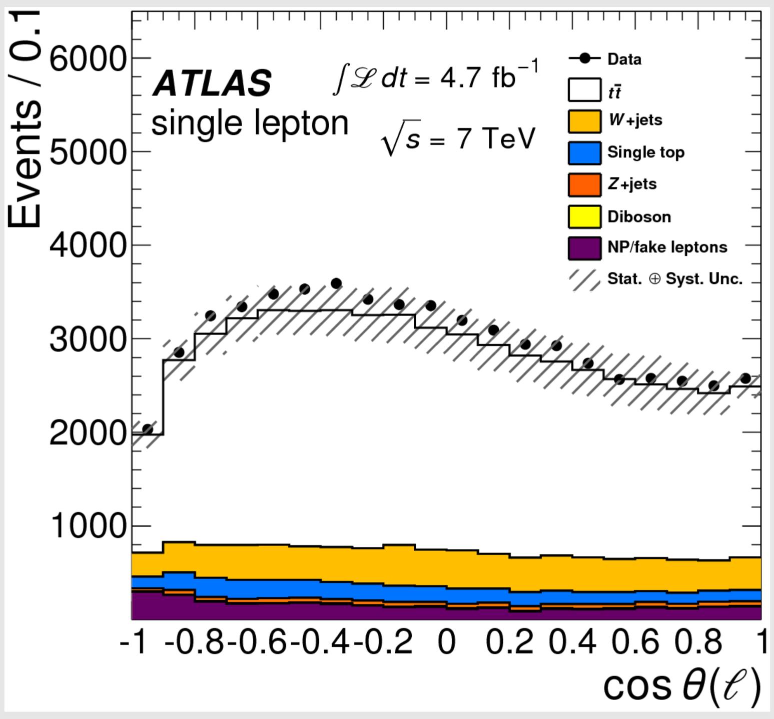
5. Top-antitop reconstruction

- In order to calculate cos(θ) of the charged lepton, a full reconstruction of the top and antitop's 4–momentum is required.
- A kinematic likelihood fit, which utilizes *b*–tagging information, is employed to determine the longitudinal momentum of the neutrino and to assign the selected jets to the top (antitop) decay.

Neutrino longitudinal momentum



Charged lepton polar angle



6. Reweighting the Monte Carlo

- The Monte Carlo available for this analysis lacks polarized top quarks. Therefore, the signal Monte Carlo is reweighted to induce polarization of the top quarks. Each Monte Carlo signal event is reweighted based on the double differential cross section (where 1 and 2 refer to a decay product from the top and antitop respectively):

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1+\alpha_1 P_1 \cos\theta_1 + \alpha_2 P_2 \cos\theta_2 - C\cos\theta_1\cos\theta_2)$$

C = anti – correlation factor , representing the spin correlation of the top – antitop pair

- Each Monte Carlo signal event is reweighted using its truth information. After applying the weight, the parton level distributions of the top (antitop) decay products follow the relationship:

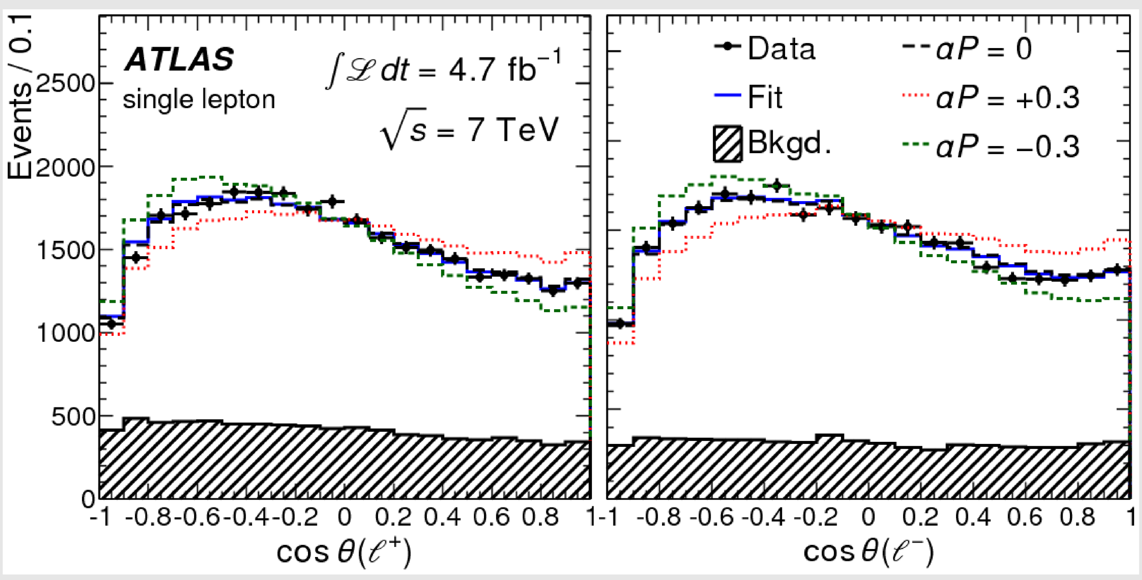
$$W(\cos\theta_i) \propto 1 + \alpha_i P \cos\theta_i$$

The value of C is taken from Monte Carlo and is valued at 0.307 with the value of $\alpha_i P$ chosen as ± 0.3 to ensure a positive cross section.

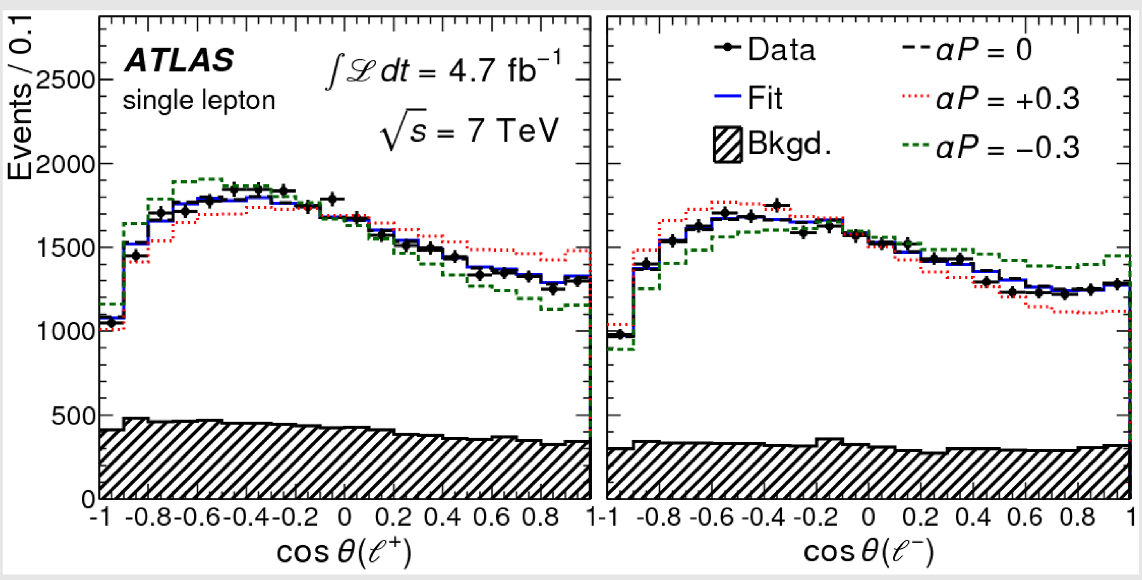
7. Template production and fit

- Two scenarios for top quark polarization are considered: CP conserving (CPC) and CP violating (CPV). For the CPC case, $\alpha_1 P = \alpha_2 P$, and in the CPV case, $\alpha_1 P = -\alpha_2 P$.
- Templates of the reconstructed cos(θ) for the charged lepton are created for the CPC and CPV scenarios, each requiring two sets of templates: a positive and a negative template. The positive and negative templates are then fit to the data using a binned maximum likelihood fit to extract the top quark's polarization.
- The fit is performed for all considered channels using charge separated templates. The single lepton result is obtained by multiplying the electron and muon likelihoods together. The single lepton likelihood is multiplied by the dilepton likelihood to obtain the combined result. The top–antitop cross section is simultaneously fit to reduce the normalization uncertainty.
- The product of the spin–analyzing power and the polarization is quoted as the result.

CP Conserving Fit and templates



CP Violating Fit and templates



- Templates are created for each source of systematic uncertainty. The systematic uncertainty for the up and down variations is quoted as the mean of the distribution of differences between the central fit value and the systematic template fit to 1,000 pseudo–datasets.
- The sources of uncertainty that do not depend on the charge of the lepton dramatically reduce the uncertainty in the CPV scenario. This is due to the fit parameters being pushed in opposing directions for the oppositely charged templates. The tension created in the fit leads to the reduced uncertainty.

8. Results

Single Lepton Results

Channel	$\alpha_\ell P_{CPC}$	$\alpha_\ell P_{CPV}$
e+jets	$-0.031 \pm 0.028^{+0.043}_{-0.040}$	$0.001 \pm 0.031^{+0.019}_{-0.019}$
μ+jets	$-0.033 \pm 0.021^{+0.039}_{-0.039}$	$0.036 \pm 0.023^{+0.018}_{-0.017}$
ℓ+jets	$-0.034 \pm 0.017^{+0.038}_{-0.037}$	$0.023 \pm 0.019^{+0.012}_{-0.011}$

Combined Results (single lepton and dilepton)

$$\alpha_\ell P_{CPC} = -0.035 \pm 0.014^{+0.037}_{-0.037} \qquad \alpha_\ell P_{CPV} = 0.020 \pm 0.016^{+0.013}_{-0.017}$$

Source	$\Delta\alpha_\ell P_{CPC}$		$\Delta\alpha_\ell P_{CPV}$	
Jet reconstruction	+0.031	−0.031	+0.009	−0.005
Lepton reconstruction	+0.006	−0.007	+0.002	−0.001
E_T^{miss} reconstruction	+0.008	−0.007	+0.004	−0.001
$t\bar{t}$ modeling	+0.015	−0.016	+0.005	−0.013
Background modeling	+0.011	−0.010	+0.005	−0.007
Template statistics	+0.005	−0.005	+0.006	−0.006
Total systematic uncertainty	+0.037	−0.037	+0.013	−0.017

- Jet reconstruction: The largest components of this uncertainty come from the jet energy scale uncertainties.
- Signal modeling: The largest components of this uncertainty come from the *b*–tagging efficiency and the top mass uncertainty, which is determined by repeating the fitting procedure for 7 Monte Carlo samples with different values of the top mass and then interpolating the change in the result corresponding to a variation in the top mass of ± 1.4 GeV.
- Background modeling: The largest component of this uncertainty comes from the uncertainty on the NP/fakes background estimation.

Conclusion:

The top quark longitudinal polarization in the CP conserving scenario has been measured and is found to be in agreement with the Standard Model. The data does not support a CP violating mechanism for top quark longitudinal polarization. The paper for this analysis has been submitted to the Physics Review Letters and may be found on the arxiv: arxiv:1307.6511 [hep-ex]

For more information regarding the dilepton measurement, consult Ralph Schäfer's poster.

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