



Summer Student Program 2017



Top quark polarization in t-channel single top-quark events with the ATLAS detector

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Abstract

This summary presents the measurement of the top-quark polarization in t-channel single top quarks with the ATLAS detector at the LHC. Monte Carlo simulated events are used. Selected events contain one lepton, large missing transverse momentum and exactly two jets, with one of them identified as b-jet. Selection cuts are used to identify the t-channel topology at reconstruction level. The polarization is measured, from an asymmetry in an angular distribution, at parton level by correcting the reconstructed angular distribution for detector effects. This project provides an overview on how a "standard" physics analysis is performed within ATLAS. The analysis is performed in ROOT. Simulation data is reconstructed to perform an unfolded measurement of a given property of a fundamental particle within the Standard Model. Finally results are compared with theoretical predictions.

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1. Introduction

The top quark is the heaviest known fundamental particle. Within the Standard Model (SM), the top quark decays predominantly through the electroweak interaction to an on-shell W boson and a b-quark. Due to its large mass [1], its lifetime $O(10^{-25} \text{ s})$ is smaller than its harmonization time-scale $O(10^{-24} \text{ s})$, allowing this quark to be studied as a free quark. Since the top-quark lifetime is also shorter than the depolarization timescale $O(10^{-21} \text{ s})$ [2] and the W boson is produced on-shell in the top-quark decay, the top-quark spin information is directly transferred to its decay products.

At hadron colliders, top quarks are produced predominantly in pairs ($t\bar{t}$) via the flavor-conserving strong interaction, while an alternative process produces single top quarks through the electroweak interaction. Although the $t\bar{t}$ production cross-section is larger than that of single top-quark production, top quarks are produced unpolarized because of parity conservation in quantum chromodynamics, contrary to what happens for single top quarks. At the Large Hadron Collider (LHC) [3], in proton-proton (pp) collision data, the t-channel is the dominant process for producing single top quarks used for the measurements.

My research project is to measure top-quark polarization from t-channel single top-quark events. Measurements are performed with the ATLAS detector [4] using simulation data at centre-of-mass energy of 8 TeV in pp collisions at the LHC. The ATLAS detector consists of a set of sub-detector systems, cylindrical in the central region and planar in the two endcap regions, that covers almost the full solid angle around the interaction point.

We use samples of simulated events for the top-quark polarization measurement. We write an analysis program in ROOT and analyze these data. The information about the generated MC events is stored in ROOT ntuples from which we construct the t-channel single top-quark particles from the available decay products. Then, the top-quark polarization is extracted from an asymmetry in an angular distribution measured with respect to a spin quantization axis. The asymmetry measurement is performed at parton level by correcting the reconstructed angular distribution for detector effects.

2. Detailed description of project

We consider single top-quark events as showed in a Fig:1. In the t-channel, a light-flavor quark q from one of the colliding protons interacts with a b-quark by exchanging a virtual W boson, producing a top quark t and a recoiling light-flavor quark q' , called the spectator quark. The decay product particles in the t-channel are a lepton, a neutrino, a bottom and the spectator quark.

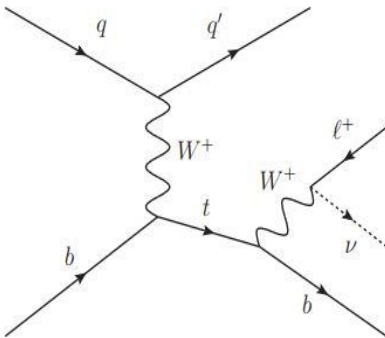


Fig:1: Feynman diagram for t-channel.

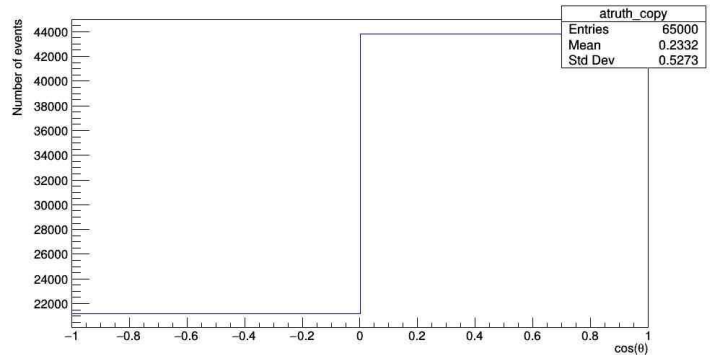


Fig:2: Truth $\cos(\theta)$ distribution in 2 bins.

For the first phase of my project we used standalone MC simulation produced with the leading-order Protos generator [5] to study the theoretical SM prediction; what we call the truth. The scheme of working is: we read the properties of final stable particles (transverse momentum p_t , Φ , pseudorapidity η and energy E) from the ROOT ntuples to construct their Lorentz vectors. From these vectors, W boson and top quark are reconstructed. For defining top-quark polarization we use equation (1) from Ref.[6], where Γ is total width, α spin analyzing power and P is degree of polarization. The angle θ in Eq. (1) is the angle between lepton and a spin quantization axis, in my case the spectator quark momentum direction.

$$\frac{1}{\Gamma} \frac{\partial \Gamma}{\partial \cos \theta} = \frac{1}{2} (1 + \alpha P \cos \theta) \quad (1)$$

$$P = \frac{N_{\downarrow} - N_{\uparrow}}{N_{\downarrow} + N_{\uparrow}} \quad (2)$$

$$P = \frac{1}{2} A_{FB} \alpha \quad (3)$$

In Eq. (2) $N_{\downarrow}$ and $N_{\uparrow}$ are number of top quarks with different direction of spin. Since at reconstruction level we cannot access to the spin information an asymmetry forward-backward, A_{FB} , defined by equation (3), is used to measure the top-quark polarization [6]. This asymmetry is measured from the distribution of $\cos(\theta)$. The $\cos(\theta)$ is in interval $[-1, 1]$, so we count number of events in interval $[-1, 0]$ and $[0, 1]$ separately [6].

To define the angle θ , first we need to create boost vector, which will transfer all the particles into the top-quark rest frame. Then we create boost vector for W boson, and this transfers lepton into the W rest frame. So we build the distribution for $\cos(\theta)$ term as shown in Fig 2.

According to Eq.(1) we create angle distribution with 2 bins and calculated how much events where polarized on one side or another. In first bin appeared 3249 ± 57 events and in second 6751 ± 82 . We calculate polarization at truth level which is $P = 0.716 \pm 0.067$.

For second phase we use the standalone MC simulation produced with Protos after being passed through the full simulation of the ATLAS detector. Here we make an object and event selection to identify the t-channel single top-quark topology at reconstruction level. The object selection is done according to next conditions: electrons are required to satisfy $p_t > 25$ GeV and $|\eta| < 2.47$. Muons are required to have $p_t > 25$ GeV and $|\eta| < 2.5$. Only events containing reconstructed jets with $p_t > 30$ GeV and $|\eta| < 4.5$ (for light-jets) or $|\eta| < 2.5$ (for b-jets) are considered. The p_t threshold is raised to 35 GeV for the jets in the calorimeter endcap–forward transition region, corresponding to $2.7 < |\eta| < 3.5$. The event selection requires exactly one electron or muon, large missing transverse momentum (larger than 30 GeV) and exactly two jets, with one of them identified as b-jet.

After this selection we construct Lorentz vectors for decay products. For neutrino we only have its transverse energy E_t since we assume it is the missing transverse momentum in the ntuple, so we reconstruct p_z from energy conservation. And after that we make the additional cuts to further select the t-channel topology [7] (though backgrounds are not considered in this project):

- The η of the spectator jet must satisfy $|\eta(\text{spect-jet})| > 2.0$, since the spectator jet tends to be produced in the forward region in the t-channel signature.
- The scalar sum of the p_t of all final-state objects (lepton, jets and missing transverse momentum), HT , must be larger than 195 GeV, since the HT distributions of the backgrounds peak at lower values (in particular for the W+jets contribution) than the t-channel signature.
- The mass of the top quark reconstructed from its decay products is required to be within 130–200 GeV, to reject background events from processes not involving top quarks.
- The absolute difference in η between the spectator jet and the b-jet, $|\Delta\eta(\text{spect-jet}, \text{b-jet})|$, must be larger than 1.5, to further reduce $t\bar{t}$ contributions.

Here we finish the event selection and create $\cos(\theta)$ distribution and asymmetry A_{FB} .

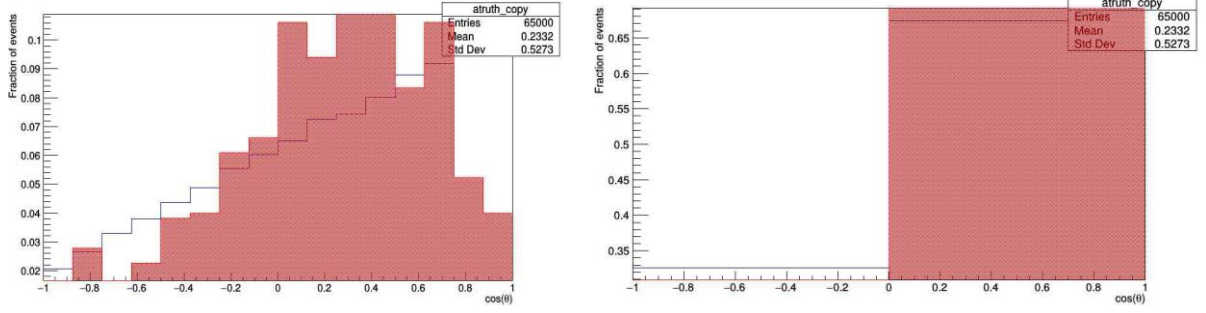


Fig:3: Distribution of $\cos(\theta)$ at truth (white) and at reconstruction (red). On the left 16 are used while on the right, just 2 bins are shown, to extract the asymmetry A_{FB} .

We can see that there is a difference between truth and reconstructed angular distributions Fig. 3.

The last part is to correct for detector effects by performing a simple unfolding. Because of some other effects like imperfect measurement or detector acceptance and inefficiencies the $\cos(\theta)$ distribution is distorted as well as resolution for effects due to the neutrino and the reconstruction of the top quark. All these effects lead to the migration of events between different bins in the $\cos(\theta)$ distribution. Therefore, we need to create the transfer T_{ij} that translates the migrations. The T_{ij} matrix is 2X2 matrix, with two bins for truth and two bins for reco. Then, the migration matrix M_{ij} is just a normalized transfer matrix Fig.5.

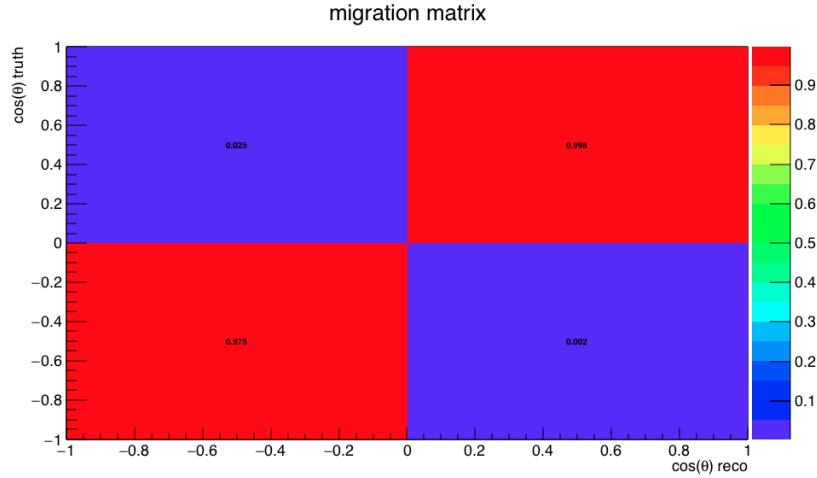


Fig:5: M_{ij} migration matrix. Truth and reconstructed $\cos(\theta)$ per event.

Migration matrix M_{ij} gives the probability for a value of the truth (bin j) physical quantity to be reconstructed at another value (bin i). In the end we define the asymmetry for reconstruction just as we did for truth. So according to results on one side 19455 ± 139.481 events are polarized, on another $399493 \pm 198,729$. We calculate the polarization at reconstruction level which is $P_{unfolding} = 0.68 \pm 0.16$. This is compatible with the polarization measured using truth events.

3. Conclusion

I have studied the top-quark polarization in t-channel single top-quark events. At the beginning I used standalone MC simulation to measure the theoretical prediction. For the second step I added the detector simulation on top of the standalone MC simulation of the t-channel events. For this simulation data I made event selections according to previous researches done by the ATLAS

Collaboration [7]. Then, I built the asymmetry for reconstruction just as for standalone MC prediction. Asymmetry provides the value of the top-quark polarization in single top-quark events.

References

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