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Search for the leptonic charge asymmetry of top-quark–antiquark pair production in association with a W boson with the ATLAS detector

Marcos Miralles López
on behalf of the ATLAS Collaboration

Instituto de Física Corpuscular (IFIC)
Universitat de València – CSIC, Valencia, SPAIN

A search for the leptonic charge asymmetry of top–antitop quark pair production in association with a W boson is presented. The search is performed using final states with exactly three charged light leptons (electrons or muons) and is based on $\sqrt{s} = 13$ TeV proton–proton collision data collected with the ATLAS detector at the Large Hadron Collider at CERN during the years 2015–2018, corresponding to an integrated luminosity of 139 fb^{-1}. A profile-likelihood fit to the event yields in multiple regions corresponding to positive and negative differences between the pseudorapidities of the charged leptons from top-quark and top-antiquark decays is used to extract the charge asymmetry. At reconstructed level, the asymmetry is found to be -0.123 ± 0.136 (stat.) ± 0.051 (syst.). An unfolding procedure is applied to convert the result at reconstructed level into a charge-asymmetry value in a fiducial volume at particle level with the result of -0.112 ± 0.170 (stat.) ± 0.055 (syst.). The Standard Model expectations for these two observables are calculated using Monte Carlo simulations with next-to-leading order plus parton shower precision in quantum chromodynamics and including next-to-leading order electroweak corrections. They are $-0.084\,^{+0.005}_{-0.003}$ (scale) ± 0.006 (MC stat.) and $-0.063\,^{+0.007}_{-0.004}$ (scale) ± 0.004 (MC stat.), respectively.

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1 Introduction

The production of a top-quark–antiquark ($t\bar{t}$) pair in association with a W boson, commonly referred to as $t\bar{t}W$, is a rare process in the Standard Model (SM) which can be produced at the Large Hadron Collider (LHC). State-of-the-art cross-section calculations for the $t\bar{t}W$ process are especially complex, as large corrections arise from higher powers of both the strong and weak couplings [1]. Thus, measurements of the $t\bar{t}W$ process represent a sensitive test of the predictions of quantum chromodynamics (QCD) and the electroweak (EW) sector of the SM, as well as their interplay.

These proceedings present a search for the leptonic charge asymmetry (A_c^ℓ) in $t\bar{t}W$ production using proton–proton (pp) collision data at $\sqrt{s} = 13$ TeV in the trilepton (3ℓ) channel with the full Run 2 dataset with the ATLAS detector [2], corresponding to an integrated luminosity of 139 fb^{-1}. The leptonic charge asymmetry is defined as,

$$A_c^\ell = \frac{N\left(\Delta_\eta^\ell > 0\right) - N\left(\Delta_\eta^\ell < 0\right)}{N\left(\Delta_\eta^\ell > 0\right) + N\left(\Delta_\eta^\ell < 0\right)}, \tag{1}$$

where $\Delta_\eta^\ell = |\eta_{\bar{\ell}}| - |\eta_\ell|$ is the difference between the absolute pseudorapidities of the leptons decaying from the top quarks ($|\eta_{\bar{\ell}}|$) and top antiquarks ($|\eta_\ell|$), respectively.

Refs. [3, 4] give a comparison of next-to-leading order QCD matrix elements matched to parton shower (PS) calculations of the leptonic charge asymmetries of $t\bar{t}$ and $t\bar{t}W$ production in the full phase space at $\sqrt{s} = 13$ TeV. The charge asymmetry for $t\bar{t}W$ is larger with respect to $t\bar{t}$ production at the expense of a smaller cross section of the process. In addition, the charge asymmetry is sensitive to BSM physics, such as axigluons [3] and Standard Model Effective Field Theory scenarios corresponding to four-fermion operators [5, 6].

2 Event Selection

Only events with exactly three charged light leptons (electrons or muons) are selected. The selected events are classified into four signal regions (SRs), depending on their jet and b-jet multiplicities, as well as their $E_{\mathrm{T}}^{\mathrm{miss.}}$. In addition, four control regions (CRs) are defined in order to constrain the dominant backgrounds. A series of specific event selections are used for each region to enrich the CRs and SRs with the target background or the signal yields, respectively.

In the $t\bar{t}W$ process, the leptonic charge asymmetry is manifested only in the leptons that originate from the top quark and top antiquark. Hence, as this search targets events with three leptons, a problem arises when selecting the two leptons used to compute the A_c^ℓ value. This problem is addressed using a Boosted Decision Tree (BDT) classifier algorithm that computes a discriminator value for each *even*[*] lepton in each event. The fraction of events in the $t\bar{t}W$ sample in which the even

[*]In the 3ℓ final state, the two leptons with equal charge are called the even leptons.

lepton with the highest BDT discriminator value originates from a top-quark or top-antiquark decay is estimated to be $\approx 71\%$, using the information from Monte Carlo (MC) simulations.

3 Results

To extract the leptonic charge asymmetry from the reconstructed leptons (detector level), a simultaneous fit to the numbers of observed events in the SRs and CRs is performed. The fit is based on the binned maximum profile-likelihood technique. The normalisation factors for the most relevant background processes in the SRs, namely $t\bar{t}Z$, non-prompt electrons/muons from HF decays and electrons from γ-conversions, are allowed to freely float in the fit. Each of the four SRs and the four CRs are separated into $\Delta\eta^-$ and $\Delta\eta^+$ regions. These are shown in Figures 1 and 2, respectively. For the $\Delta\eta^-$ ($\Delta\eta^+$) set of regions, a single factor $\mathcal{N}_{\Delta\eta^-}$ ($\mathcal{N}_{\Delta\eta^+}$) models the relative normalisations of the signal yields across the four SRs. Accordingly, the A_c^ℓ value is extracted as a function of these normalisation factors. Similarly, separate normalisation factors in the $\Delta\eta^-$ and $\Delta\eta^+$ sets of regions for the major background processes are allowed to float freely in the fit in order to avoid a bias from an assumption of SM asymmetries for these processes in data.

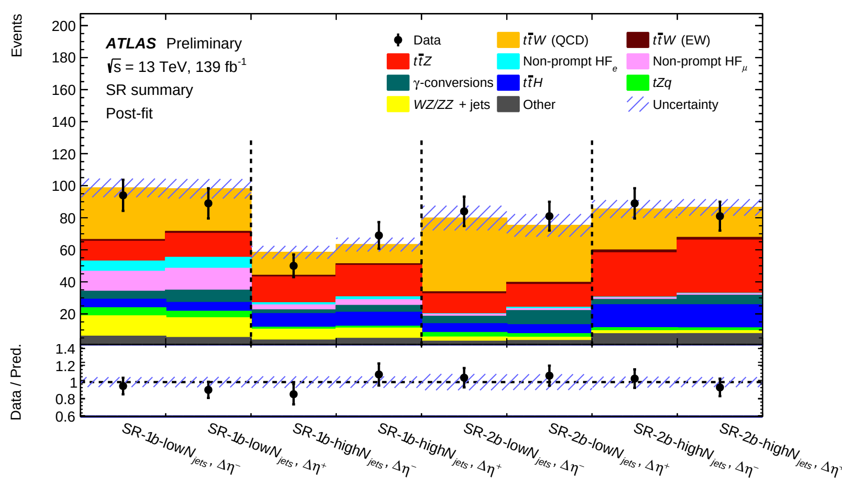

Figure 1: Comparison between data and the post-fit predictions for $\Delta\eta^\ell_{\mathrm{BDT}} \leq 0$ ($\Delta\eta^-$) and $\Delta\eta^\ell_{\mathrm{BDT}} > 0$ ($\Delta\eta^+$) in the four SRs. The error band includes the total uncertainties of the post-fit predictions. The ratio between the data and the total post-fit predictions is shown in the lower panel. Taken from Ref. [7].

The normalisation factors for the major background processes, $\mathcal{N}_{t\bar{t}Z}$, $\mathcal{N}^e_{\gamma\text{-conv}}$, $\mathcal{N}^e_{\mathrm{HF}}$ and $\mathcal{N}^\mu_{\mathrm{HF}}$ (all obtained separately for $\Delta\eta^-$ and $\Delta\eta^+$), together with $\mathcal{N}_{\Delta\eta^-}$ and the A_c^ℓ value for the $t\bar{t}W$ signal, are given in Figure 3. An uncertainty is added to account

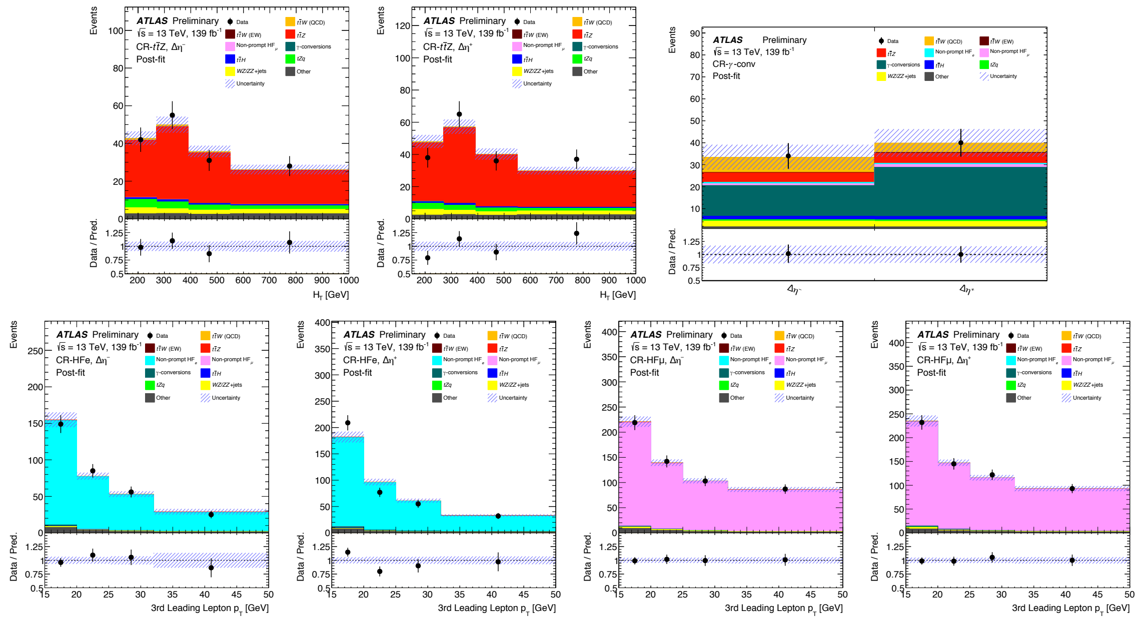

Figure 2: Comparison between data and the post-fit predictions for $\Delta\eta^{\ell}_{\mathrm{BDT}} \leq 0$ ($\Delta\eta^{-}$) and $\Delta\eta^{\ell}_{\mathrm{BDT}} > 0$ ($\Delta\eta^{+}$) in the CRs. The error band includes the total uncertainties of the post-fit predictions. The ratio between the data and the total post-fit predictions is shown in the lower panel. Taken from Ref. [7].

for the potential spurious impact of these background normalisation factors in the A^{ℓ}_{c} ($\Delta\eta^{\pm}$ dependency). The normalisation factor for the $t\bar{t}W$ process has been checked and found to be (within its uncertainty) compatible with the latest ATLAS and CMS $t\bar{t}W$ cross-section measurements [8, 9]. Tests in simulations have also been performed to validate that the extracted A^{ℓ}_{c} value is not biased by the absolute normalisation of the $t\bar{t}W$ process. The measured A^{ℓ}_{c} is compatible with the SM prediction and is limited by the available statistics. The largest systematic uncertainties originate from the $t\bar{t}W$ and $t\bar{t}Z$ modelling.

3.1 Unfolding procedure

To obtain the charge asymmetry at particle level (PL) in a specific fiducial volume, an unfolding procedure is performed. This allows for the correction of detector effects, as well as signal efficiency and acceptance effects. The unfolded value of A^{ℓ}_{c} is $-0.112 \pm 0.170\,(\mathrm{stat.}) \pm 0.055\,(\mathrm{syst.})$. An injection test is performed to verify that non-SM A^{ℓ}_{c} values can be recovered in the unfolding procedure. This is done by injecting the non-SM A^{ℓ}_{c} values into the particle level predictions, which are propagated to detector level and treated as pseudo-data in the fit. After the fit to real data, the observed A^{ℓ}_{c} is substituted into the relation to extract the bias. This bias is small and is added as an extra uncertainty to the unfolded A^{ℓ}_{c} value.

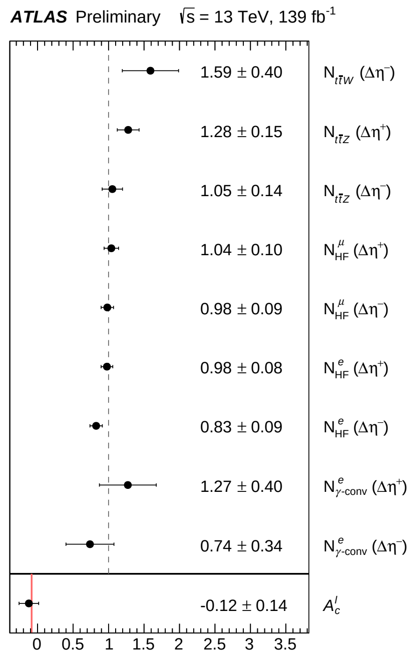

Figure 3: Normalisation factors for the major background processes, together with $\mathcal{N}_{\Delta\eta^-}$ for $t\bar{t}W$ and the A_c^ℓ value. The indicated uncertainties consider statistical as well as systematic uncertainties. The solid red vertical line in the last entry shows the SM expectation for A_c^ℓ, calculated using the $t\bar{t}W$ SHERPA [10] MC simulation. Taken from Ref. [7].

4 Summary

These proceedings present a search for the leptonic charge asymmetry in $t\bar{t}W$ production using pp collision data at $\sqrt{s} = 13$ TeV with the full Run 2 dataset collected by the ATLAS detector at the LHC. The charge asymmetry at reconstruction level is found to be

$$A_c^\ell(t\bar{t}W) = -0.123 \pm 0.136\,(\text{stat.}) \pm 0.051\,(\text{syst.}).$$

An unfolding procedure is used to obtain the charge asymmetry at particle level in a specific fiducial volume. The charge asymmetry at particle level yields

$$A_c^\ell(t\bar{t}W)^{\text{PL}} = -0.112 \pm 0.170\,(\text{stat.}) \pm 0.055\,(\text{syst.}).$$

Both are found to be compatible with the SM expectation calculated using the nominal $t\bar{t}W$ SHERPA MC generator. The most relevant systematic uncertainties affecting this search can be attributed to the $\Delta\eta^\pm$ dependency of the fit, as well as the modelling uncertainties of the $t\bar{t}W$ and $t\bar{t}Z$ MC processes in the 3ℓ channel. However, both the reconstructed and particle level results are severely limited by the statistical uncertainties of the data. These results are collected in Ref. [7].

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