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# Measurement of top quark charge asymmetry at the LHC using the ATLAS detector

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**Summary.** — Charge asymmetry in top quark pair production at the LHC can be an important window on new physics, as in some theories beyond the Standard Model this asymmetry is significantly enhanced with respect to Standard Model prediction. The measurement performed by the ATLAS Collaboration with 2011 pp collision data corresponding to an integrated luminosity of $0.70\,\mathrm{fb}^{-1}$ is presented. The analysis has been performed selecting signal events in the semileptonic channel. A kinematic likelihood has then been used to reconstruct the top quark pair event topology. After background subtraction, a Bayesian unfolding procedure has been applied to correct for acceptance and detector effects. The final result is shown as well as a comparison between measured and predicted asymmetry.

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## 1. – Introduction

The LHC is a promising machine to discover new physics in the top sector. Indeed in some Beyond Standard Model (BSM) theories top quark pairs can be produced by the exchange of undiscovered heavy particles. The presence of such particles might generate a sizable asymmetry in the rapidity distribution of top *versus* antitop quarks, called charge asymmetry.

Top quark charge asymmetry only occurs via asymmetric initial states in top quark pair production. The process $q\bar{q} \to t\bar{t}$ gives the main contribution to this asymmetry. The asymmetry comes from the fact that top quark is preferably emitted in the direction of the incoming quark and not in the one of the incoming antiquarks.

The LHC is a proton-proton machine, so the direction of the incoming quark is *a priori* unknown. Since quarks in the initial state will mainly be valence quarks, whereas antiquarks will always be sea quarks, the quark momentum fraction will more frequently be higher than the antiquark one. Top quarks, emitted preferentially in the incoming quark direction, will be more boosted than the antitop quarks and they will be therefore characterized by a broader rapidity $Y$. A sensible quantity to the asymmetry is consequently the difference between the absolute values of top and antitop rapidities: $\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$.

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Based on this observation, one observable to measure the charge asymmetry is

$$A_c = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)},$$

where $N(\Delta|Y| > 0)$ is the number of events in which $\Delta|Y|$ is positive, while $N(\Delta|Y| < 0)$ is the number of events in which $\Delta|Y|$ is negative.

Within Standard Model (SM) charge asymmetry appears only at NLO. The predicted value is therefore small: $\sim 0.6\%$ according to MC@NLO Monte Carlo [1]. The SM asymmetry is enhanced in some BSM models. Deviations of the measured value of the asymmetry from the one predicted by SM can be therefore a hint of new physics.

## 2. – Analysis description

The measurement has been performed using data collected by the ATLAS detector from March to June 2011 and corresponding to an integrated luminosity of $0.70\,\text{fb}^{-1}$ [2]. Events have been selected in the semileptonic channel with one $W$ decaying into a lepton (an electron or a muon) and a neutrino while the other one is decaying into quarks: $t\bar{t} \to WbWb \to l\nu bjjb$.

The crucial ingredients of the analysis are discussed in the following.

**2**˙1. *Event selection.* – Signal events are characterized by the presence of one energetic charged electron or muon, missing transverse momentum ($\not{E}_T$) due to the neutrino and four energetic jets, two of them coming from a $b$ quark.

Signal candidate events have been selected online using a single lepton trigger. Cleaning cuts have been then applied to reject non-collision backgrounds. Events have been selected offline asking for the presence of exactly one energetic and isolated electron or muon, significant $\not{E}_T$ and imposing a lower cut on lepton-$\not{E}_T$ transverse mass ($M_T$). The presence of at least four jets with $p_T > 25\,\text{GeV}$, one of which identified as a $b$-jet, has been finally required.

**2**˙2. *Background estimate.* – The dominant background processes to this channel come from the production of a $W$ boson in association with jets and from QCD multi-jets events. Since Monte Carlo predictions are not completely reliable, both their contributions have been estimated with the help of data-driven (DD) techniques as described below. Other backgrounds come from single top, $Z$+jets and diboson events, which have a minor impact and have been estimated using Monte Carlo.

QCD background has been estimated using the so-called matrix method. This technique is based on the selection of two categories of events, using loose and tight lepton identification requirements. The tight sample typically employs the final lepton selection criteria, while for the loose sample some identification requirements are dropped or relaxed. The number of background events has been obtained by solving this system of two equations:

$$N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}},$$

$$N^{\text{tight}} = \epsilon_{\text{real}} \cdot N^{\text{loose}}_{\text{real}} + \epsilon_{\text{fake}} \cdot N^{\text{loose}}_{\text{fake}},$$

where $N^{\text{loose}}$ ($N^{\text{tight}}$) is the number of selected events with one loose (tight) lepton, $N^{\text{loose}}_{\text{real}}$ and $N^{\text{loose}}_{\text{fake}}$ are the contributions to the loose sample coming from signal and background events respectively and $\epsilon_{\text{real}}(\epsilon_{\text{fake}})$ represents the probability for a real (fake) lepton that satisfies the loose criteria, to also satisfy the tight ones. Both probabilities have been determined from data: $\epsilon_{\text{real}}$ has been measured using events with a $Z$ boson decaying into leptons, while $\epsilon_{\text{fake}}$ has been measured in control regions at low $\not{E}_T$ and $M_T$ enriched with QCD events. This method has been applied in different bins of $\Delta|Y|$, in order to obtain the shape of the background.

As concerns the $W$+jets background, the shape has been taken from Monte Carlo, while data have been used to estimate its normalisation. The expected rate of $W$+jets background has been evaluated before the request of $b$-tagging using a DD technique. To obtain the final estimate, this result has been then multiplied by the tagging probability, extracted both from Monte Carlo predictions and measurements in control regions in data. The developed DD technique takes advantage from the fact that $W$ boson production is charge asymmetric in $pp$ collider, while all the other processes (including the signal) are to a good approximation charge symmetric. The ratio between $W^+$ and $W^-$ cross-sections $r \equiv \frac{\sigma(pp \to W^+)}{\sigma(pp \to W^-)}$ is moreover known theoretically with high precision.

The $W$+jets background has been therefore extracted from the following formula:

$$N_{W^+} + N_{W^-} = \left( \frac{r_{MC} + 1}{r_{MC} - 1} \right) (N_{W^+} - N_{W^-}),$$

where $r_{MC} \equiv \frac{\sigma(pp \to W^+)}{\sigma(pp \to W^-)}$ has been evaluated from Monte Carlo simulation and the difference between $N_{W^+}$ and $N_{W^-}$ has been measured in data as the difference between the total number of events with a positively charged lepton and the number of selected events with a negatively charged lepton.

**2**˙3. *Reconstruction of the top quark pair kinematics*. – The precise determination of top and antitop quarks kinematic variables is fundamental. Misreconstruction and resolution effects can indeed cause a dilution of the asymmetry.

Top and antitop quark directions are obtained from their decay products. The top (or antitop) quark which has decayed hadronically is reconstructed from three of the selected jets and the other one from the lepton, the remaining jet and $\not{E}_T$. A likelihood method is used to correctly assign the measured jets to the decay products. This algorithm takes as input the 4-momenta of the charged lepton and of the five hardest jets and the transverse momentum of $\not{E}_T$ in the selected event. The top quark and the $W$ boson masses and widths are fixed to their world average values in the likelihood computation. $b$-tagging information is also taken into account. A loop over all possible jets combination is performed and a probability is assigned to each of them. The most likely event topology is chosen and used for all further studies. The charge of the top quark (or antiquark) decaying leptonically is finally determined using the lepton charge.

The reconstructed $\Delta|Y|$ distributions for the electron (left) and the muon (right) channels are shown in fig. 1.

**2**˙4. *Unfolding procedure*. – The detector resolution and the applied event selection alter the $\Delta|Y|$ distribution. The measured asymmetry is therefore different with respect to the original one (*production level asymmetry*). In order to obtain a measurement comparable with theoretical predictions, an unfolding technique has been applied to the observed $\Delta|Y|$ distribution in data, after subtracting backgrounds, to obtain the production level asymmetry.

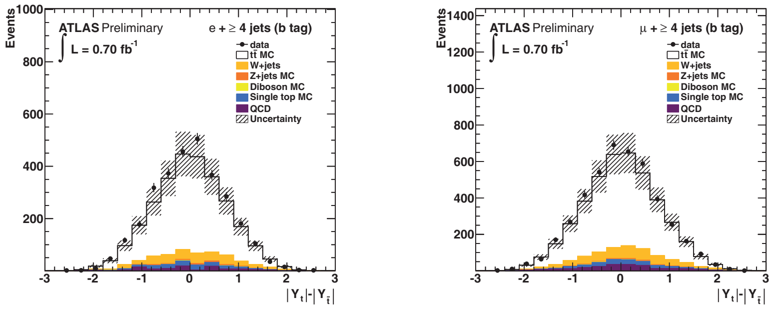


Fig. 1. – The measured $\Delta|Y|$ distribution for the electron (left) and muon channel (right) [2]. Data (points) and Monte Carlo estimates (solid lines) are shown.

The truth $\Delta|Y|$ distribution, $T_j$, is related to the reconstructed distribution $S_i$ as

$$S_i = \sum_j R_{ij} T_j,$$

where $R_{ij} = P$ (observed in bin $i$ | expected in bin $j$) is the response matrix obtained from Monte Carlo simulation.

In order to obtain the production level asymmetry from the measured distribution, the response matrix has been inverted using Bayes theorem iteratively.

## 3. – Results and conclusions

The asymmetry has been found to be:

$$A_c = -0.009 \pm 0.023(\text{stat.}) \pm 0.032(\text{syst.}) \qquad (\text{e} + \text{jets}),$$
$$A_c = -0.028 \pm 0.019(\text{stat.}) \pm 0.022(\text{syst.}) \qquad (\mu + \text{jets}).$$

The measurement is already limited by the systematic uncertainties. The main contributions come from the uncertainty on signal modelling, jet energy determination and background normalisation.

The combined asymmetry value has been found to be

$$A_c = -0.024 \pm 0.016(\text{stat.}) \pm 0.023(\text{syst.}).$$

The result is compatible with the prediction from MC@NLO ($A_c = 0.006$). No evidence for an enhancement from BSM physics has been observed at the moment.

Almost 7 times more data are now available. Measurements of the top charge asymmetry as a function of top-antitop kinematic variables can then be foreseen. Moreover work is ongoing to reduce the systematic uncertainties on the measurement.

REFERENCES

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[2] The ATLAS Collaboration, ATLAS-CONF-2011-106, `https://cdsweb.cern.ch/record/1372916`.