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Inclusive and differential measurements of the $t\bar{t}$ charge asymmetry at 8 TeV with the CMS experiment

PoS(TOP2015)064

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The $t\bar{t}$ charge asymmetry is measured in proton-proton collisions at a centre-of-mass energy of 8 TeV. The data, collected with the CMS experiment at the LHC, correspond to an integrated luminosity of $19.7\,\mathrm{fb}^{-1}$. Selected events contain an electron or a muon and four or more jets, where at least one jet is identified as originating from b-quark hadronization. The $t\bar{t}$ charge asymmetry is measured inclusively and differentially as a function of rapidity, transverse momentum, and invariant mass of the $t\bar{t}$ system. For the first time at the LHC, the measurements are also performed in a reduced fiducial phase space of top quark pair production.

8th International Workshop on Top Quark Physics
14-18 September, 2015
Ischia, Italy

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Hundreds of thousands of top quark-antiquark pairs ($\mathrm{t\bar{t}}$) have been produced during the LHC run at a centre-of-mass energy of 8 TeV. The large data samples collected with the ATLAS and CMS [1] detectors enable precision measurements of properties of the heaviest elementary particle known so far. One interesting property of the production of $\mathrm{t\bar{t}}$ pairs is the so-called "charge asymmetry" - a difference in angular distributions between top quark and antiquark. In the Standard Model (SM) this difference is caused by interference effects between the different possibilities to create a $\mathrm{t\bar{t}}$ pair from the annihilation of an initial $\mathrm{q\bar{q}}$ pair. An observable that is commonly used to measure this effect is the difference in the absolute rapidity between top quark and antiquark, $\Delta|y| = |y_{\mathrm{t}}| - |y_{\mathrm{\bar{t}}}|$. With this observable the charge asymmetry is defined as

$$A_C = \frac{N^{\Delta|y|>0} - N^{\Delta|y|<0}}{N^{\Delta|y|>0} + N^{\Delta|y|<0}}. \tag{1}$$

The CMS collaboration has measured the $\mathrm{t\bar{t}}$ charge asymmetry based on a data set corresponding to an integrated luminosity of 19.7 TeV of proton proton collisions at 8 TeV [2]. Events with a lepton+jets signature are selected, requiring the presence of exactly one highly energetic electron or muon, well isolated from other energy deposits in the calorimeter, and at least four jets. One of these jets has to be identified as b jet by the Combined Secondary Vertex tagger [3]. The amounts of remaining background contributions are estimated by fitting the distributions of two discriminating variables, the transverse mass of the W boson ($m_{\mathrm{T}}^{\mathrm{W}}$) and the invariant mass of the three-jet combination that yields the largest transverse momentum (m_3). While $m_{\mathrm{T}}^{\mathrm{W}}$ distinguishes between events with and without real W bosons, m_3 can be used to discriminate between events with and without top quarks. A signal fraction of about 80% is estimated, with the largest background contribution coming from W+jets production.

The four-vectors of top quarks and antiquarks are reconstructed from the decay products observed in the detector. The leptonically decaying W boson is reconstructed from the charged lepton and the missing transverse momentum vector, constraining the mass of the reconstructed object to the known mass of the W boson. The assignment of the reconstructed jets to the final-state quarks in the $\mathrm{t\bar{t}}$ decay chain (two b quarks from the two top quark decays and two light quarks from the decay of the second W boson) is done based on the b-tagging information of the jets and the invariant masses of the reconstructed top quarks and of the reconstructed hadronically decaying W boson.

The resulting $\Delta|y|$ distribution has to be corrected for background contamination and for distorting effects due to the resolution of the reconstruction and the efficiency of the event selection. This is done using a regularized matrix inversion unfolding method as implemented in TUnfold [4]. For the differential measurements not only the $\Delta|y|$ distribution but also that of the given kinematic variable (rapidity $|y_{\mathrm{t\bar{t}}}|$, transverse momentum $p_{\mathrm{T}}^{\mathrm{t\bar{t}}}$, or mass $m_{\mathrm{t\bar{t}}}$ of the $\mathrm{t\bar{t}}$ system) are unfolded. While the correction for background contamination and reconstruction effects operates only on the selected events, the correction for possible non-flatness of the event selection efficiency includes an extrapolation into a phase-space defined based on parton level objects. In this analysis two different approaches are realized. In the first approach the distributions are extrapolated from the phase space representing the selected data sample to the full phase space of $\mathrm{t\bar{t}}$ production. This procedure enables direct comparisons of the corrected results with theory predictions. However, the extrapolation relies solely on information from simulated events; to reduce the dependence on

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	Asymmetry (A_C)
Reconstructed	0.0036 ± 0.0017 (stat.)
Background-subtracted	0.0008 ± 0.0023 (stat.)
Corrected for migration effects	-0.0042 ± 0.0072 (stat.)
Fiducial phase space	-0.0035 ± 0.0072 (stat.) ± 0.0031 (syst.)
Theoretical prediction [Bernreuther, Si] [5]	0.0101 ± 0.0010
Full phase space	0.0010 ± 0.0068 (stat.) ± 0.0037 (syst.)
Theoretical prediction [Kühn, Rodrigo] [6]	0.0102 ± 0.0005
Theoretical prediction [Bernreuther, Si] [5]	0.0111 ± 0.0004

Table 1: The measured inclusive asymmetry at the different stages of the analysis and the corresponding theoretical predictions from the SM.

the simulation of phase space regions that are not within the reach of the detector, a fiducial measurement is performed in addition. In this measurement the extrapolation is performed into a phase space, defined using generator-level selection criteria that mimic the reconstruction-level criteria applied during the nominal selection. The results of the fiducial measurement can be compared with theory calculations in which the same requirements on the final state partons are applied.

The unfolding procedure is tested in pseudo experiments with different input values for the charge asymmetry, and no bias is found. Several sources of systematic uncertainties are evaluated. The largest contributions to the overall uncertainty come from the uncertainty on the jet energy scale, the uncertainty due to the unfolding method, the modelling of the QCD-multijet background, and the modelling of the hadronization in the event generation. The total systematic uncertainties for the inclusive measurements amount to $\Delta A_C = 0.0037$ for the extrapolation to the full phase space and $\Delta A_C = 0.0031$ for the fiducial measurement. The systematic uncertainties of the differential measurements vary between the bins and kinematic variables and lie in the range from $\Delta A_C = 0.0041$ to $\Delta A_C = 0.0120$.

The results of the inclusive measurement at the different stages of the analysis are summarized in Table 1. Within statistical and systematic uncertainties all results are compatible with the theoretical predictions from the SM. The asymmetry values (unfolded to the full phase space) as a function of $|y_{\mathrm{t\bar{t}}}|$, $p_{\mathrm{T}}^{\mathrm{t\bar{t}}}$, and $m_{\mathrm{t\bar{t}}}$ can be found in Fig. 1. Again no significant deviations from the SM predictions are observed. The differential asymmetry distributions unfolded to the fiducial phase space (not shown in this article) also are in agreement with SM predictions.

The presented analysis exploits the full CMS-dataset collected at 8 TeV and provides for the first time at the LHC inclusive and differential measurements of the $\mathrm{t\bar{t}}$ charge asymmetry in a fiducial volume. All measured asymmetries agree within the estimated uncertainties with SM predictions and deviate from these if at all towards lower values, while most beyond-the-SM scenarios predict larger A_C values. The results of this analysis do not give any indication of effects from physics beyond-the-SM.

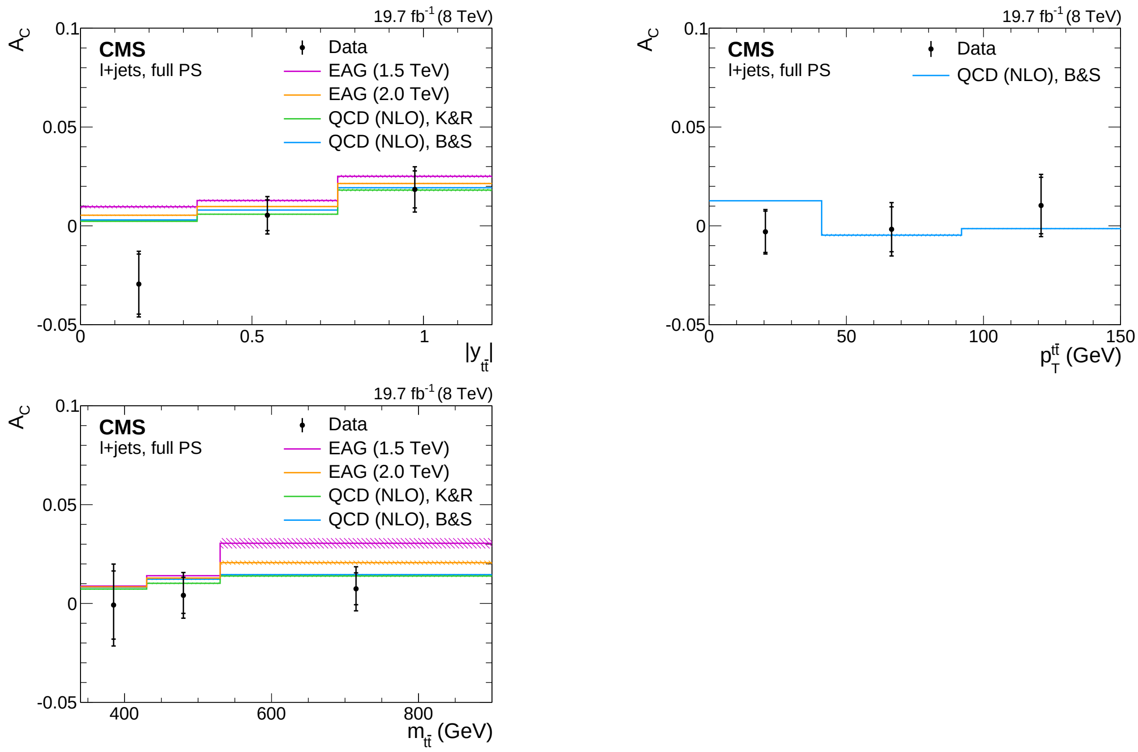

Figure 1: Distributions of the corrected asymmetry as a function of $|y_{t\bar{t}}|$ (upper left), $p_T^{t\bar{t}}$ (upper right), and $m_{t\bar{t}}$ (bottom row). The measured values are compared to SM-NLO calculations by Kühn and Rodrigo (K&R) [6] and Bernreuther and Si (B&S) [5], as well as to the predictions of a model featuring an effective axial-vector coupling of the gluon (EAG) [7, 8]. The inner (outer) bars indicate the statistical (total) uncertainty.

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