Measurements of the $t\bar{t}$ charge asymmetry using the dilepton decay channel in pp collisions at $\sqrt{s} = 7$ TeV with CMS [1]

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Introduction

Charge asymmetry: Difference in rapidity distribution of t and $\bar{t}$

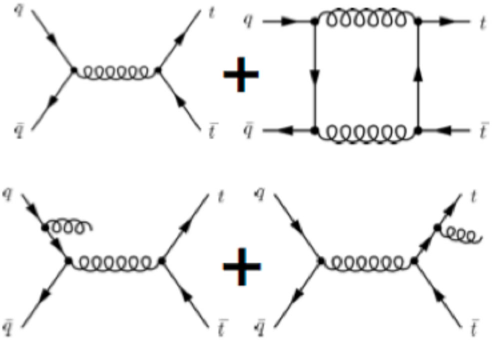
Small positive charge asymmetry is predicted by NLO QCD-processes

Charge asymmetry could be enhanced by new physics
(axigluon, t-channel W' or Z' exchange)

Measurements at Tevatron indicated a disagreement with the Standard model especially at high invariant masses.

Charge asymmetry

Interference between even and odd terms results in asymmetric interference terms



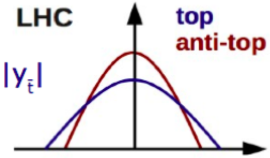
Interference between tree level (top left) and box (top right) diagrams: positive asymmetry
Interference between initial state radiation (bottom left) and final state radiation (bottom right): negative asymmetry

Charge asymmetry measurement at LHC

Proton-proton collision $\rightarrow$ forward-backward symmetric by setup

But:
quarks are (mainly) valence quarks, antiquarks are only sea quarks
valence quarks carry more momentum

$\rightarrow$ on average the top quark will carry more momentum than the anti-top quark which results in a broader rapidity distribution for the top quark



Definition Observables

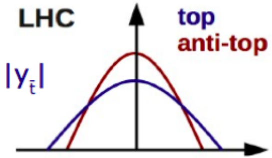
$\Delta|y_t| = |y_t| - |y_{\bar{t}}|$ is suitable to measure charge asymmetry

Charge asymmetry can now be defined as:

$$A_C = \frac{N(\Delta|y_t| > 0) - N(\Delta|y_t| < 0)}{N(\Delta|y_t| > 0) + N(\Delta|y_t| < 0)}$$

Analogically for the leptons:

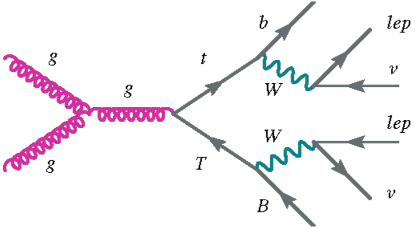
$$A_C^{lep} = \frac{N(\Delta|\eta_\ell| > 0) - N(\Delta|\eta_\ell| < 0)}{N(\Delta|\eta_\ell| > 0) + N(\Delta|\eta_\ell| < 0)}$$



Event selection

Lepton Triggers:

- at least two high p_T, isolated leptons
- $\ell_1 : p_T > 17 GeV$
  $\ell_2 : p_T > 8 GeV$
- relative isolation > 0.15



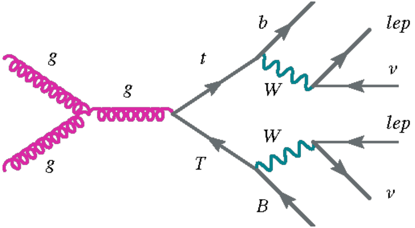
Cuts on Lepton Candidates:

- $p_T > 20 GeV$ (both leptons)
- $|\eta| < 2.5$ (e); $|\eta| < 2.4$ (mu)
- opposite charge
- originate from same vertex
- to reduce Drell-Yan background, reject:
  - invariant mass between 76 and 106 GeV (Z-mass-window)
  - invariant mass below 20 GeV

Event selection

Cuts on Jet candidates:

- $p_T > 30 GeV$
- $|\eta| < 2.5$
- seperated by $\Delta R > 0.4$ from the lepton candidates
- at least one jet b-tagged



Cuts on missing energy:

- $E_T^{miss} > 40 GeV$ for same flavor leptons
- No E_T^{miss} requirement otherwise

Background

Sample	$e\ e$	$\mu\ \mu$	$e\ \mu$	All
t$\bar{t}$ (non-dileptonic)	38.3 ± 1.6	4.02 ± 0.45	91.7 ± 2.4	134.0 ± 2.9
W+ jets	< 2.0	4.7 ± 3.3	11.1 ± 5.1	15.8 ± 6.1
Drell-Yan	30.2 ± 4.4	29.6 ± 4.1	35.0 ± 4.5	94.8 ± 7.5
Diboson	8.27 ± 0.44	10.20 ± 0.47	27.90 ± 0.81	46.4 ± 1.0
Single top-quark	72.5 ± 2.1	86.8 ± 2.2	289.4 ± 4.2	448.7 ± 5.2
Total (background)	149.3 ± 5.5	135.3 ± 5.8	455.1 ± 8.4	740 ± 11
Data	1631	1964	6229	9824

Notes:

- $e\ \mu$ channel has more events (no cut on E_T^{miss})
- biggest background from non dileptonic channel of $t\bar{t}$
- Drell-Yan background successfully reduced by cuts

Reconstruction

To measure A_C, the entire $t\bar{t}$-event needs to be reconstructed.

Two ways to combine leptons and b-jets

By fixing m_t to 172.5 GeV, solutions the neutrino belonging to each lepton-jet-pair lie on a plane in p_x,p_y direction.
$\rightarrow$ solutions for the system are the intersections of the two ellipses (max 4).

Solutions are weighted by their probability (AMWT) and the one with the largest weight is taken

No solution for 14% of the events $\rightarrow$ treated as additional cut

Unfolding

Goal: Get corrected $\Delta|y_t|$ and $\Delta|\eta_\ell|$ distributions at parton level

Binning was chosen to minimise bin-to-bin statistical fluctuations:

$\Delta\|y_t\|$	$[-\infty, -0.7]$	$[-0.7, -0.3]$	$[-0.3, 0.0]$	$[0.0, 0.3]$	$[0.3, 0.7]$	$[0.7, \infty]$
$\Delta\|\eta_\ell\|$	$[-\infty, -0.8]$	$[-0.8, -0.4]$	$[-0.4, 0.0]$	$[0.0, 0.4]$	$[0.4, 0.8]$	$[0.8, \infty]$

Relation between background-subtracted distribution $\vec{b}$ and parton level distribution $\vec{x}$

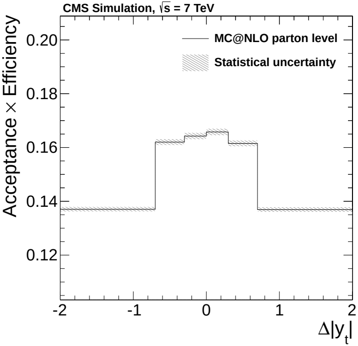
$$\vec{b} = SA\vec{x}$$

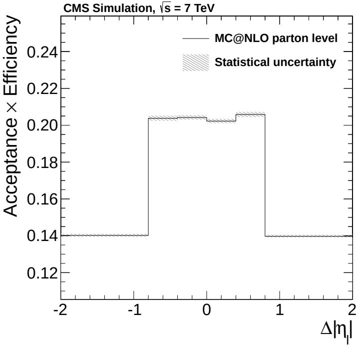
- A Diagonal (no bin-to-bin migration) matrix describing fraction of produced events to be selected in measured bins
- S Smearing matrix describing migration of events between bins

A and S matrices were obtained by simulation at NLO

Unfolding

A matrices for $\Delta|y_t|$ and $\Delta|\eta_\ell|$ distributions

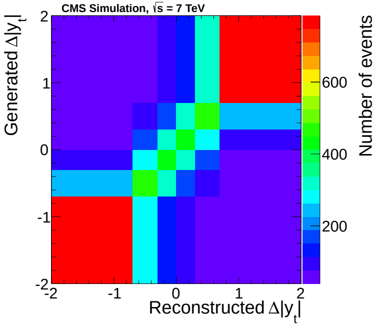


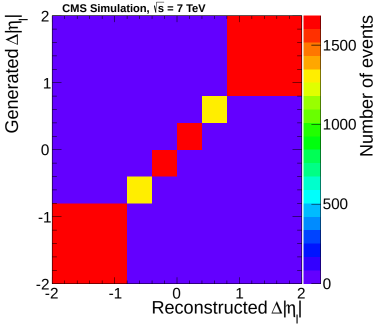


A matrices are determined by event selection criteria, detector acceptance and trigger efficiency

Unfolding

S matrices for $\Delta|y_t|$ and $\Delta|\eta_\ell|$ distributions





- largest number of events lies on diagonal - little migration between far-apart bins (left)
- good angular resolution - nearly diagonal smearing matrix (right)

Systematic Uncertainties

Main sources of uncertainties

1. Jet-energy-scale
   - affects $t\bar{t}$ reconstruction and event selection
2. factorisation and renormalization scale
3. unfolding - significant for A_C
   - obtained by performing linearity test of unfolding procedure
   - reweight simulated events by linear function $w = 1 + K\Delta|y_t|$ and vary K

Factorization and renormalization scales cause highest systematic error for A_C^{lep} while unfolding procedure is the source of most significant error for A_C. Unfolding for A_C^{lep} does not cause significant systematic uncertainty since smearing matrix is close to diagonal.

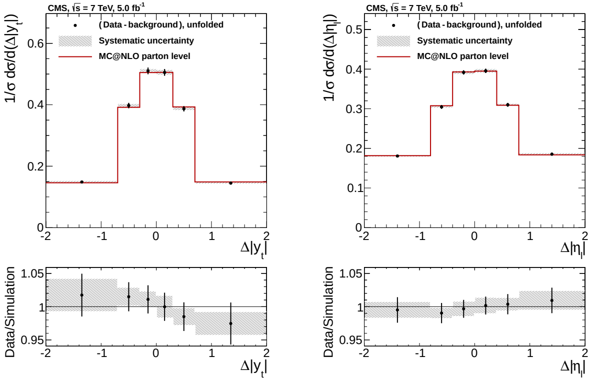
Systematic Uncertainties

Systematic uncertainties in the unfolded values of A_{C} and $A_{\mathrm{C}}^{\mathrm{lep}}$ from the sources listed.

Variable	A_{C}	$A_{\mathrm{C}}^{\mathrm{lep}}$
Experimental uncertainties		
Jet energy scale	0.003	0.001
Lepton energy scale	<0.001	<0.001
Background	0.001	0.001
Jet energy resolution	<0.001	<0.001
Pileup	<0.001	0.001
Scale factor for b tagging	<0.001	<0.001
Lepton selection	<0.001	<0.001
$t\bar{t}$ modelling uncertainties		
Fact. and renorm. scales	0.004	0.005
Top-quark mass	0.001	0.001
Parton distribution functions	<0.001	<0.001
τ-lepton decay	<0.001	<0.001
Top-quark p_T reweighting	0.001	<0.001
Unfolding	0.006	0.001
Total systematic uncertainty	0.008	0.006

Results

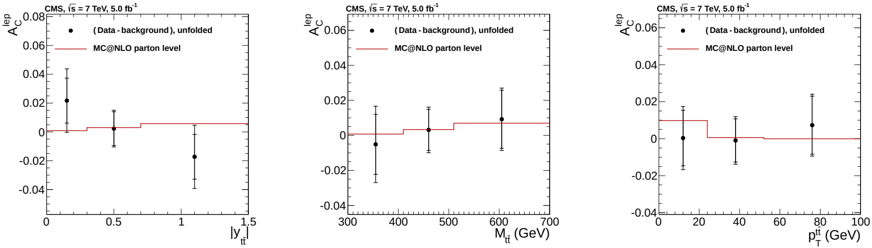
Measured values are consistent with SM



Variable	Data (unfolded)	MC@NLO prediction	NLO theory
A_C	$-0.010 \pm 0.017 \pm 0.008$	0.004 ± 0.001	0.0123 ± 0.0005
A_C^{lep}	$0.009 \pm 0.010 \pm 0.006$	0.004 ± 0.001	0.0070 ± 0.0003

Results

Dependence of A_C^{lep} on $M_{t\bar{t}}$, $|y_{t\bar{t}}|$ and $p_T^{t\bar{t}}$ was obtained by performing unfolding procedure on 2D-distribution - two bins in $\Delta|\eta_\ell|$ ($\Delta|\eta_\ell| > 0$ and $\Delta|\eta_\ell| < 0$) and three bins in $M_{t\bar{t}}$, $|y_{t\bar{t}}|$ or $p_T^{t\bar{t}}$



Differential A_C values were not measured, since large migration of events between positive and negative bin resulted in biased response if two bins in $|\Delta_t|$ were used in unfolding

Conclusions

- First measurement of asymmetry of $|y|$ and $|\eta|$ distribution in dilepton final state given in terms of A_C and A_C^{lep}
- Functional dependence of asymmetry on $M_{t\bar{t}}$ is now in perfect agreement with theory in contrast to previous measurements
- All measurements are in agreement in with Standard model