Measurement of the charge asymmetry in top quark pair production in pp collisions at $\sqrt{s}$ = 7 TeV using the ATLAS detector

Rachik Soualah (rsoualah@cern.ch, INFN Udine) on behalf of the ATLAS collaboration
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Introduction

- The ttbar production at high energy interactions of pp collisions is described by perturbative QCD.
- At the LHC with 7 TeV pp collisions the dominant mechanism for the ttbar production is the *gg* fusion process (~85 %) which is charge symmetric.
- The ttbar production via *qqbar* or *qg* (~15 %) is charge asymmetric and small in most of the phase space.
- The "q" are valence quarks which are mostly boosted than the sea "qbar" quarks
  ➔ Excess of boosted top quarks along the beam axis

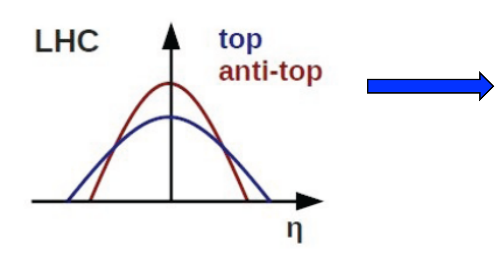
- Top and antitop quarks have identical angular distributions at LO.
- At NLO a charge asymmetry arises due to:
- Interference of Initial State Radiation (ISR) with Final State Radiation(FSR)
- Interference of between the Born and the box diagrams.

➔ **Charge asymmetry** : Top quarks preferentially emitted in the direction of the initial quarks in the ttbar rest frame, the boost into the laboratory frame drives the top mainly in the forward directions, while antitops are kept more in the central region.

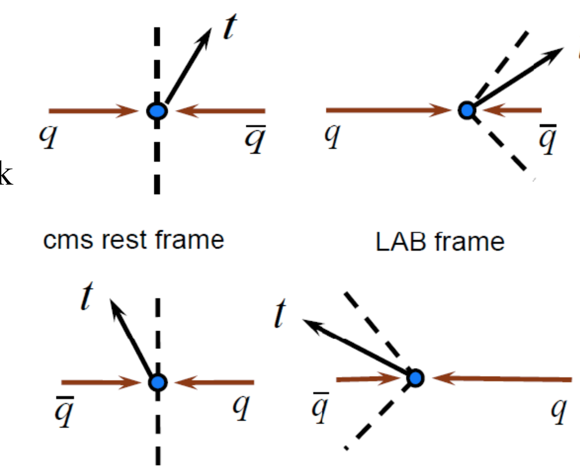
Which asymmetry ?

pp ⟶ ttbar is symmetric (mostly gg ⟶ttbar) ➡ no FB asymmetry

BUT it is possible to look at variables in appropriate kinematic regions.



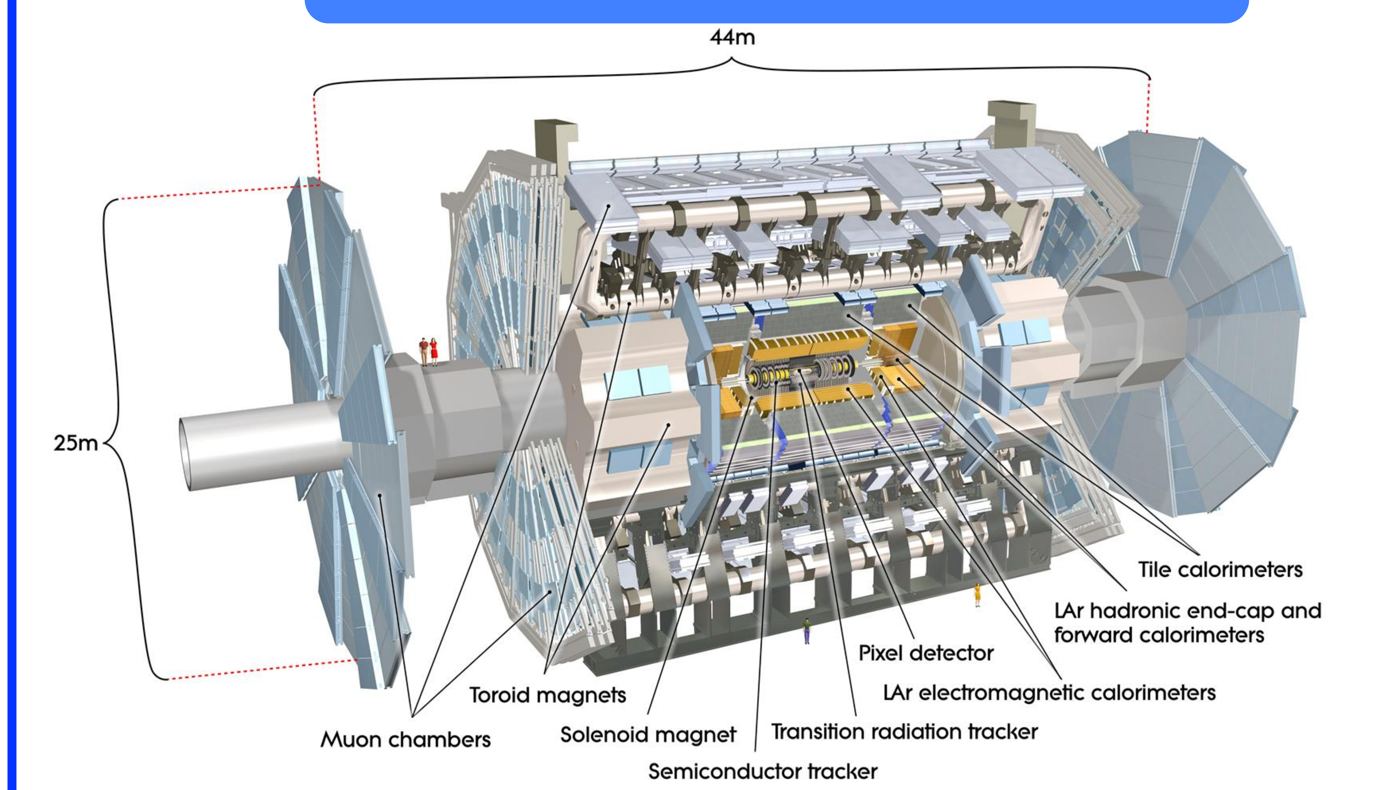
➡ Need to study $\Delta|Y| \equiv |Y_t| - |Y_{\bar{t}}|$



However the direction of the quark is not easy to distinguish,

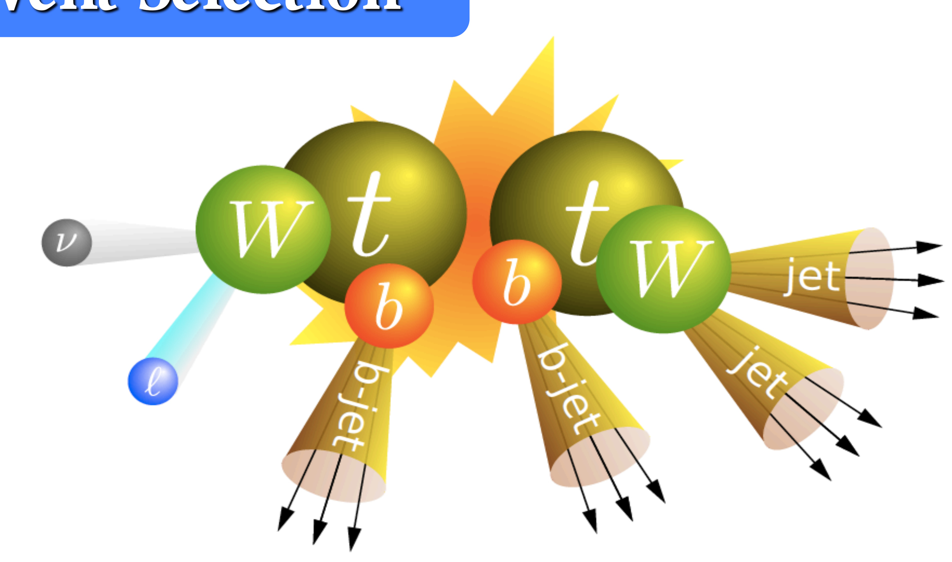
$$A_C = \frac{N(\Delta|Y|>0) - N(\Delta|Y|<0)}{N(\Delta|Y|>0) + N(\Delta|Y|<0)}$$

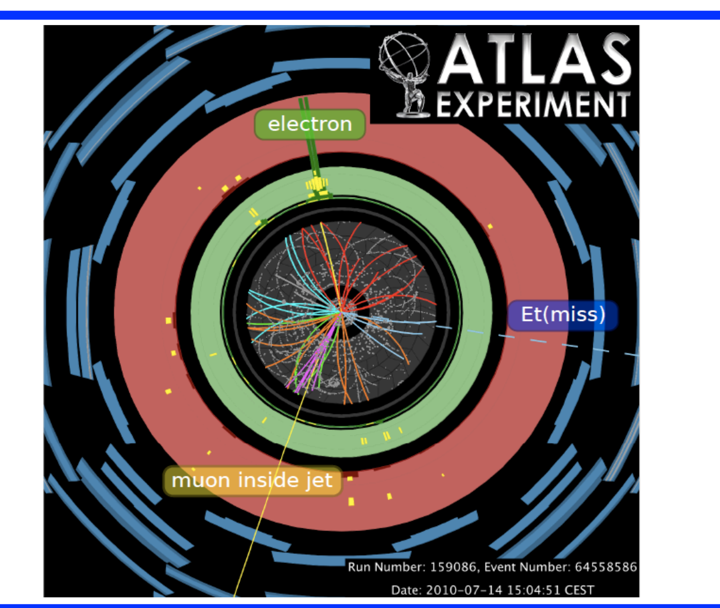
ATLAS detector



Event Selection

- The ttbar charge asymmetry measurement is presented using data corresponding to an integrated luminosity of 0.7 fb^{-1} . Event selection criteria has been performed for the **semileptonic** channel .
- Single lepton (e or mu) trigger.
- At least one primary vertex with at least 5 associated tracks.
- Exactly one lepton (e or mu) with pt > 25 GeV for electrons and pt >20 GeV for muons, either matched to the trigger.
- E_T^{miss}>20 GeV, E_T^{miss}+ M_T > 60 GeV (muon channel)
- E_t^{miss}>35 GeV and M_T > 25 GeV (electron channel)
  ➔ to suppress the higher QCD multi-jet background where $M_T = \sqrt{2 p_T^l p_T^\nu (1-\cos(\phi^l - \phi^\nu))}$
- Each event is required to have at least 4 jets with pt>25 GeV and |η| < 2.5
- At least one of these jets is required to be b-tagged (SV0)





Background determination

1- QCD multi-jets background (due to non-prompt (fake) leptons):

➔ Using the Matrix Method: low MET for electron or M_T region for muon

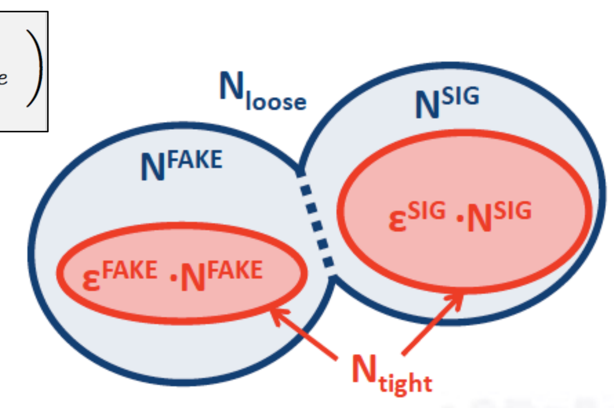
Basic principal:

Relies on two regions in the event space defined by "tight" and "loose" requirement on the objects, and measuring the efficiencies of "real" and "fake" loose leptons to be selected as tight leptons.

$$\left.\begin{array}{l} N_{loose} = N^{sig} + N^{fake} \\ N_{tight} = \epsilon^{sig} N^{sig} + \epsilon^{fake} N^{fake} \end{array}\right\} \Longrightarrow \begin{pmatrix} N_{loose} \\ N_{tight} \end{pmatrix} = \begin{bmatrix} 1 & 1 \\ \epsilon^{sig} & \epsilon^{fake} \end{bmatrix} \times \begin{pmatrix} N^{sig} \\ N^{fake} \end{pmatrix}$$

where

$$\epsilon^{sig} = \frac{N^{sig}_{tight}}{N^{sig}_{loose}} \quad ; \quad \epsilon^{fake} = \frac{N^{fake}_{tight}}{N^{fake}_{loose}}$$



- **The loose data samples:**
  - **Electrons:** It is defined by removing the isolation requirement in the default electron selection.
  - **Muons:** It is defined by removing the isolation requirement in the default muon selection.

- **The fake lepton efficiencies:**
  - **Electrons:** It is determined using a low E_T^{miss} control region (5 GeV < E_T^{miss} <20 GeV).
  - **Muons:** It is determined using low M_T (M_T < 20 GeV) with an additional cut (E_t^{miss}+M_T < 60 GeV).

By solving the matrix, N^{FAKE} is our estimation to the QCD contamination in the signal region.

2- W+jets background:

- A W charge asymmetry is expected where we get the shape from the MC.
- Normalization factor determined from data based on the charge asymmetry for each jet multiplicity bin using the well known ratio $r_{MC} = W^+/W^-$ from the simulation.
- To exploit the total W+jets rate from data, we use the formula:

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

D^+ and D^- are numbers of events in data after ttbar selection (The W charge is determined from the lepton charge)

- The number of the estimated W+jets events with at least one b-tagged jet is estimated as:

$$W_{tagged} = W_{pretag} \cdot f_{tagged}$$

where $W_{pretag} = N_{W^+} + N_{W^-}$ and f_{tagged} = tag/pretag in the 4[th] jet bin from MC.

3- Small backgrounds: Z+jets, Di-bosons, single top

➔ shape from MC, normalization from theoretical calculation.

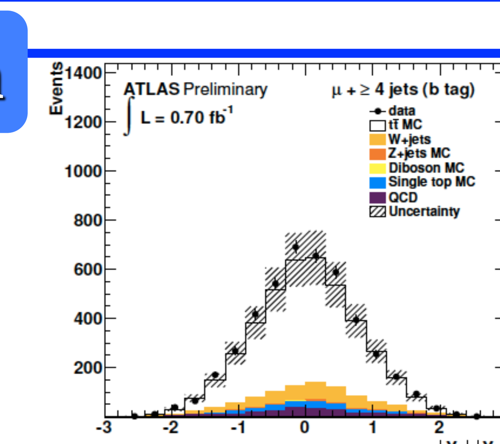
Event yield

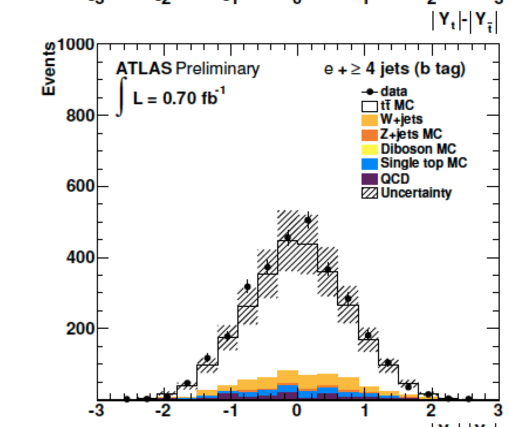
- Requiring at least 4 jets, we see a good agreement between expectation and data.
- The number of events in the electron channel is significantly lower than the muon channel due to the higher p_T cut and the more stringent E_t^{miss} cut.
- In both electron and muon channel, the W+jets is the main background.

Channel	μ + jets pretag	μ + jets tagged	e + jets pretag	e + jets tagged
$t\bar{t}$	4784 ± 5	3247 ± 4	3293 ± 4	2218 ± 4
Single top	306 ± 2	171 ± 2	219 ± 2	124 ± 2
Z+jets	632 ± 7	43 ± 2	535 ± 7	35 ± 1
Diboson	90 ± 2	8 ± 1	56 ± 1	5 ± 0
W+jets	5741 ± 915	494 ± 234	3436 ± 628	309 ± 144
QCD	1103 ± 552	227 ± 227	665 ± 332	84 ± 84
Total background	7871 ± 1068	943 ± 326	4910 ± 711	557 ± 167
Signal + background	12655 ± 1068	4189 ± 326	8203 ± 711	2775 ± 167
Observed	12705	4392	8193	2997

The ttbar topology reconstruction

- Full kinematic reconstruction of ttbar events performed via Likelihood maximization method to built the asymmetry observable ($|Y_t|-|Y_{tbar}|$).
- In each event the Likelihood takes as inputs:
  - (E,η, ϕ) of the 4 or 5 jets with largest pt.
  - The measured energy of the lepton.
  - The missing transverse energy (E_T^{miss}).
  - Fixed top mass (172.5 GeV)
- Likelihood defined from Breit-Wigner parametrisations of measured vs partonic jet energies.
- The association of the reconstructed and the parton level quantities is done via transfer functions which take into account the resolution effects.
- The b-tagged jet probability is taken into account in the Likelihood.
- The correct reconstruction efficiencies in which the jets can be matched to parton level quarks of the final state was found to be:
  74 % with b-tagging and 64 % without b-tagging



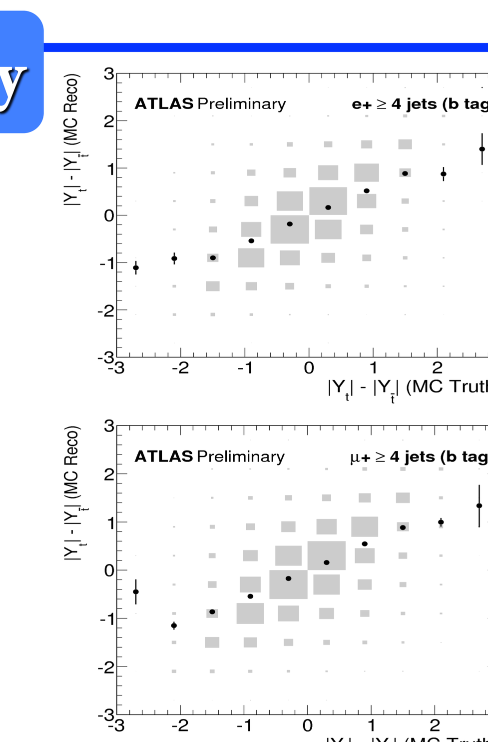


Unfolding the top charge asymmetry

- Unfolding is used to estimate the truth asymmetry, i.e., moving form the reconstructed asymmetry to the truth asymmetry that would be measured with an ideal detector and infinite event statistics.
- **Basic principle:** Truth distribution (**T_j**), reconstructed distribution (**S_j**) and response Matrix (**R_{ij}**) defined as:

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

- To get **T_j** ➔ invert **R_{ij}** ➔ used method is Bayesian iterative unfolding.
- The iterative unfolding uses a regularisation parameter to prevent the statistical fluctuations using a small number of iterations.
- The response matrix from MC@NLO was obtained using RooUnfold framework.

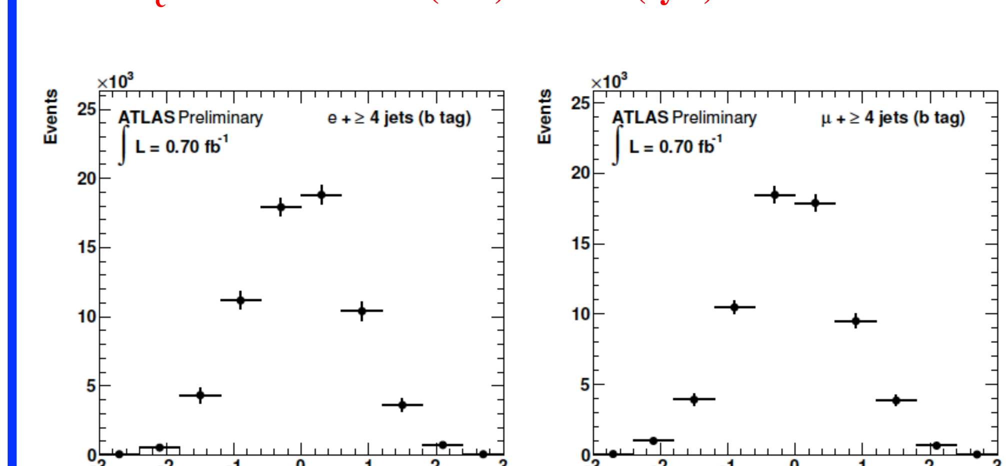


A_C results

Asymmetry	Detector unfolded	Det. + accept unfolded
A_c (el b-tag)	-0.012±0.026 (stat)±0.030 (syst)	-0.009±0.023 (stat)±0.032 (syst)
A_c (mu b-tag)	-0.030±0.021 (stat)±0.020 (syst)	-0.028±0.019 (stat)±0.022 (syst)

The combination of the two channels (e: 25 % & mu: 75 %) using BLUE estimator (systematics are taken into account):

A_c = -0.024 ± 0.016 (stat) ± 0.023 (syst)



- **Both results in the electron and muon channel are compatible with the SM predictions (from MC@NLO) of A_c= 0.006.**
- **Further studies are ongoing to enhance the sensitivity of the ttbar charge asymmetry.**

Systematic uncertaitnites

	Electron channel	Muon channel
Source of systematic uncertainty	ΔA_C	
Signal and background modelling		
$t\bar{t}$ generator	0.0243	0.0100
Parton shower/fragmentation	0.0108	0.0079
ISR/FSR	0.0074	0.0074
PDF uncertainty	0.0008	0.0008
Top mass	0.0059	0.0059
QCD normalisation	0.0062	0.0059
W+jets normalisation	0.0054	0.0097
W+jets shape	0.0043	0.0043
Z+jets normalisation	0.0002	0.0002
Z+jets shape	0.0010	0.0010
Single Top normalisation	0.0002	0.0002
Diboson normalisation	0.00001	0.00001
MC sample sizes	0.0043	0.0029
Detector modelling		
Muon efficiencies	(n.a.)	0.0002
Muon momentum scale and resolution	0.0004	0.0004
Electron efficiencies	0.0004	(n.a.)
Electron energy scale and resolution	0.0004	0.0004
Lepton charge misidentification	0.0002	0.0002
Jet energy scale	0.0041	0.0046
Jet energy resolution	0.0105	0.0040
Jet reconstruction efficiency	0.0003	0.0003
b-tagging scale factors	0.0038	0.0038
Charge asymmetry in *b*-tagging efficiency	0.0007	0.0007
Calorimeter readout	0.0015	0.0029
Combined uncertainty	0.032	0.022