Top charge asymmetry in ATLAS

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CKM 2014
Wien, 11/09/14

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Outline

- Introduction: which asymmetries are we measuring?
- $t\bar{t}$ and lepton-based charge asymmetries
- Analyses based on different $t\bar{t}$ final state:

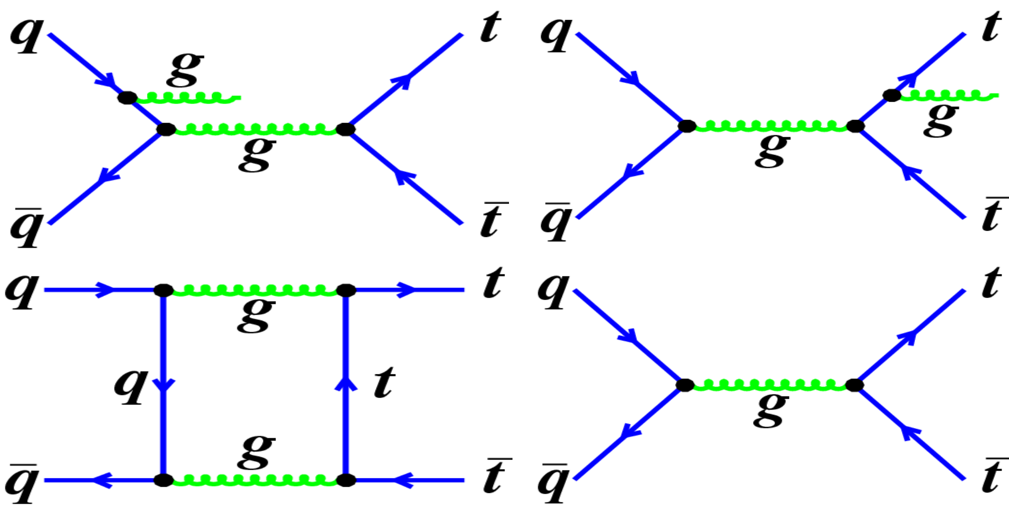
Single lepton channel ***Dilepton channel***

- Object selection, background estimation, $t\bar{t}$ system reconstruction
- Unfolding procedures: from reco to parton level
- Results:
  - Lepton and $t\bar{t}$-based inclusive and differential asymmetries
  - Results vs BSM models predictions

- Combination with CMS (single lepton channel only)
- Conclusions & future plans

Which asymmetry?

- $t\bar{t}$ forward-backward asymmetry is a tiny QCD NLO effect present in $q\bar{q}/qg$ production mechanisms, while gg-> $t\bar{t}$ is symmetric
- The diagrams below lead to asymmetry in the differential top/antitop rapidity distributions



Negative asymmetry

Positive asymmetry

Hadron colliders:
difficult to reconstruct the partons 4-vectors.
So, look at variables in the lab. frame.
In particular, the Tevatron choice is

$$\Delta y = y_t - y_{\bar{t}}$$

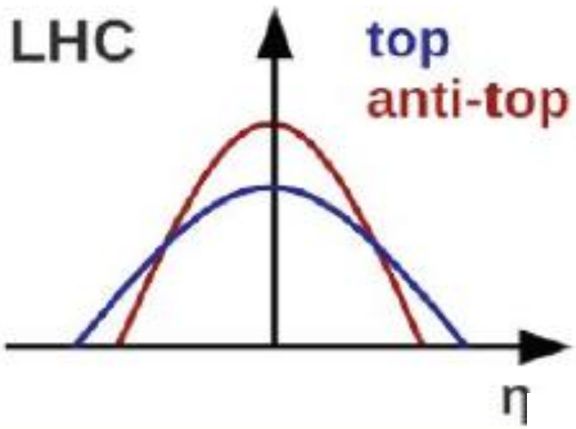
$$A^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

«Forward-backward» asymmetry

Which asymmetries @ LHC ?

- In pp collisions, impossible to distinguish the direction of the quark → Δy symmetric by definition. In addition only 20% of events come from $q\bar{q}$ / qg hard scattering. But still a small asymmetry exists in the $q\bar{q}$ events since valence quarks are more boosted than sea antiquarks.

Charge asymmetry variable: «Forward/backward-central» asymmetry



$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

Lepton-based asymmetry

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

- Advantages: Leptons are very precisely measured; polarization effects
- Drawbacks: Lower statistics in dilepton than in single lepton channel

Single lepton channel

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- Measurement in the single lepton channel with 4.7 fb^{-1}, $\sqrt{s}$ = 7 TeV
- Object selection:
  - Exactly one isolated electron (muon) with p_T> 25(20) GeV that fired the single lepton triggers.
  - At least 4 jets with p_T>25 , at least one of them tagged as a b-jet (b-tag working point corresponding to a 70% efficiency);
  - Additional kinematical cuts to reduce Multijet contribution:
    - MET > 30 GeV && M_T^W > 30 GeV (electron).
    - MET > 20 GeV && (MET+ M_T^W) > 60 GeV (muon)
- **Data driven multijet and W+jets background estimation**

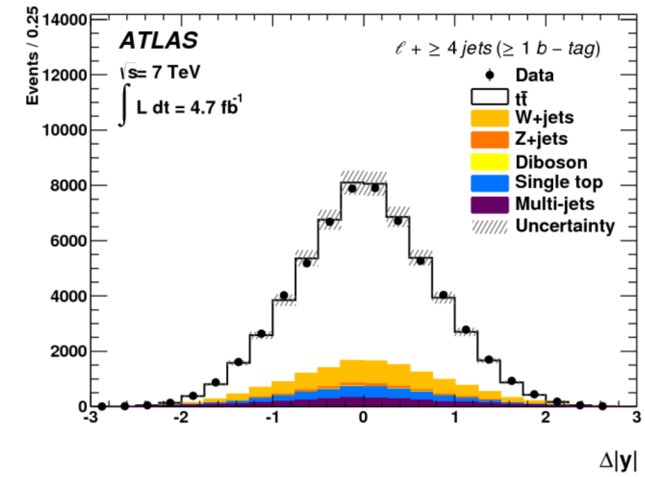
\- **Multijet:** Matrix Method for electron and muon channel. Fake rate estimation in the MET < 20 GeV region for electron or M_T^W < 20 GeV && (M_T^W +MET) < 60 GeV for muon channel.

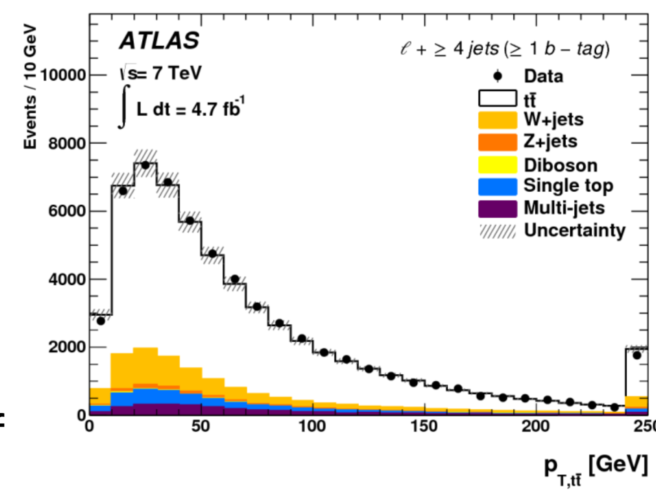
\- **W+jets:** normalisation estimated based on the **W^+/W^-** charge asymmetry and heavy-flavour components (Wbb/cc/c/light +jets) evaluated splitting data by lepton charge in a W+jets dominated sample (==2 jets, >=1 b-tag).

- **Other backgrounds:** Z+jets, Diboson, Single top taken from MC

Reconstruction of the $t\bar{t}$ final state

- Full top/antitop kinematics, is reconstructed using the Kinematic Likelihood fitter (KLFitter)
- Given p_T, η, ϕ of the lepton and jets (with b-tag/rejection probability) and the $\mathbf{P}_T^{\mathrm{MISS}}$ vector, it takes into account the resolution and reconstruction effects and chooses the permutation (using the 5 highest p_T jets in the event) that is more similar to the $t\bar{t}$ simulated kinematic.
- It maximises the likelihood using:
  - Breit-Wigner to parameterise measured vs fitted energies
  - Transfer functions to associate “reco” and “truth” quantities
  - b-tagging probability to identify the 2 b-jets
- The efficiency to reconstruct the correct sign of $\Delta|y|$ is **75%** for the tagged selection





Unfolding

Observed distrib. $\boldsymbol{O_i}$ $\boldsymbol{O_i = \sum_j M_{ij} T_j}$ Truth distrib. $\boldsymbol{T_j}$

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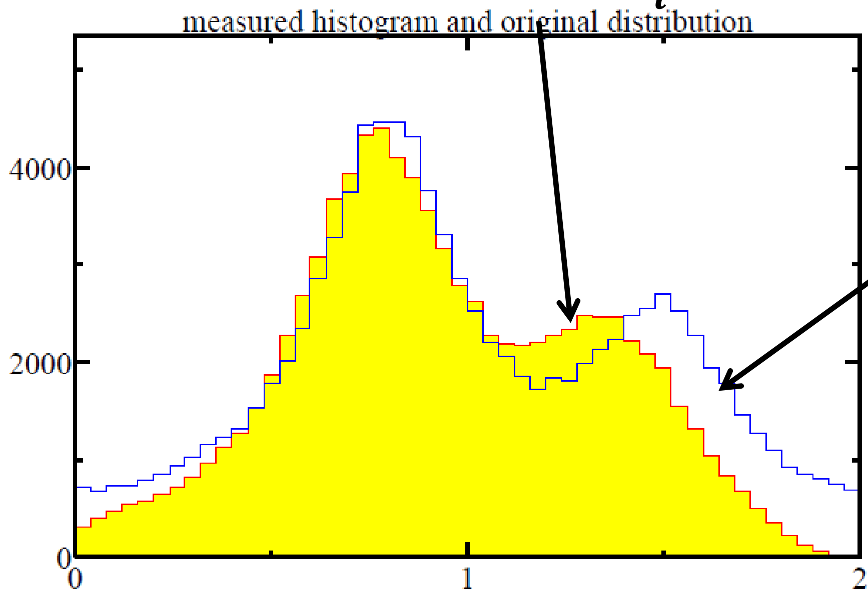

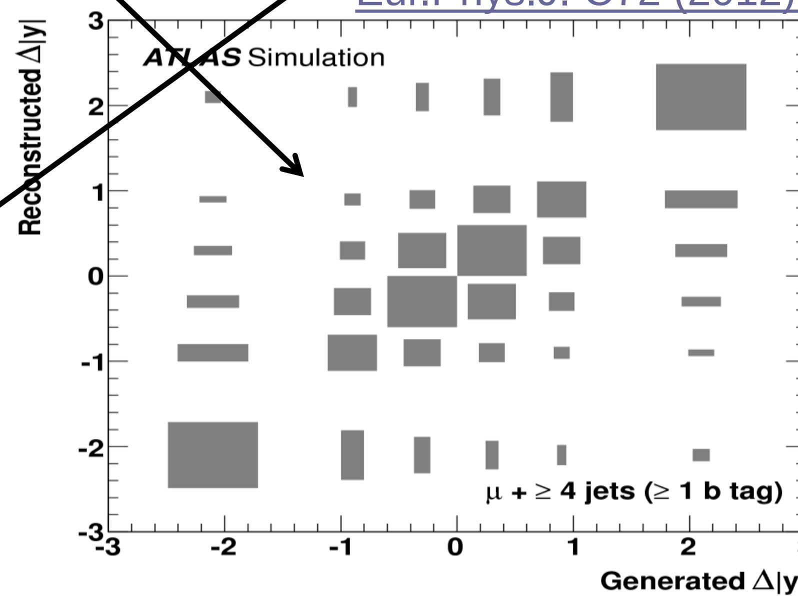

- The response matrix $\boldsymbol{M_{ij}}$ has to be inverted to get the truth spectrum $\boldsymbol{T_i}$
- The numerical inversion of $\boldsymbol{M_{ij}}$ would have no bias but is affected by large variance due to limited knowledge of the initial elements of $\boldsymbol{M_{ij}}$
- A regularisation function is used to correct the spectrum after the unfolding procedure is applied.
- This regularisation function reduces the variance but introduces a bias that needs to be evaluated.

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FBU unfolding

- The Fully Bayesian Unfolding (FBU) technique is used. It applies the Bayes' theorem to the solution of the unfolding problem.

$$p(\mathbf{T}|\mathbf{D},\mathcal{M}) \propto \mathcal{L}(\mathbf{D}|\mathbf{T},\mathcal{M}) \cdot \pi(\mathbf{T})$$

- Basic ingredients: $\Delta|y|$ distribution **D** is the data events after background subtraction, the response matrix M relating reconstructed **R** and truth **T** $\Delta|y|$ distributions and the prior π(**T**)
- The outcome is a posterior p(**T**|**D**, M) where $\mathscr{L}$(**D**|**T**,M) is the likelihood for data **D**, given the truth **T** and the response matrix **M**.
- The mean and the uncertainty of p(**T**|**D**, M) are respectively the values quoted for A_C and its uncertainty.
- The choice of the prior is arbitrary. The use of a flat prior corresponds to the numerical matrix inversion.
- To reduce the variance, a non flat prior is used for some measurements. This choice didn't introduce any bias in the A_C measurement

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Results

- Inclusive asymmetries after background subtraction and unfolding for combined electron and muon channels
- The results quoted for A_C are the mean and the uncertainty of the posterior **after** the marginalisation procedure that includes all the source of systematic uncertainties.
- The uncertainties include statistical and systematic components, but are dominated by the statistical component in all the measurements.

A_C	Data	Theory
Unfolded	0.006 ± 0.010	0.0123 ± 0.0005
Unfolded with $m_{t\bar{t}} > 600$ GeV	0.018 ± 0.022	$0.0175^{+0.0005}_{-0.0004}$
Unfolded with $\beta_{z,t\bar{t}} > 0.6$	0.011 ± 0.018	$0.020^{+0.006}_{-0.007}$

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Results (2)

Differential results compared with SM (black) and two axi-gluon models: with M=300 GeV (red) and M=7 TeV (blue)

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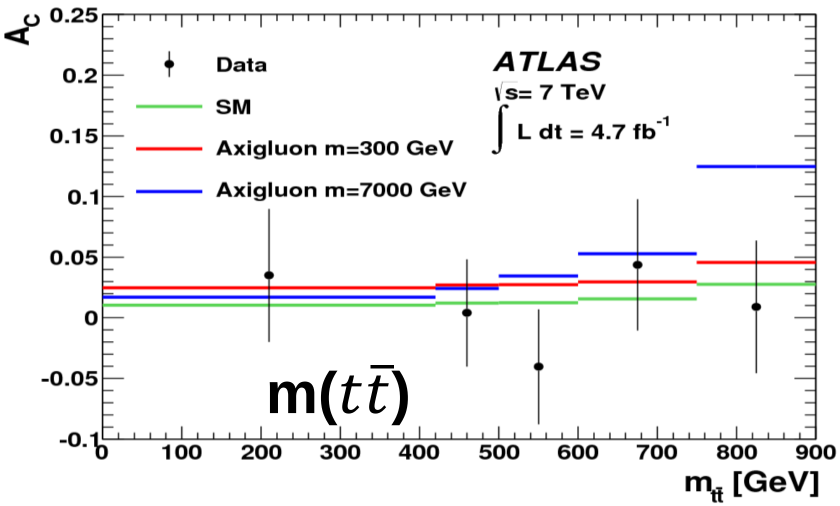

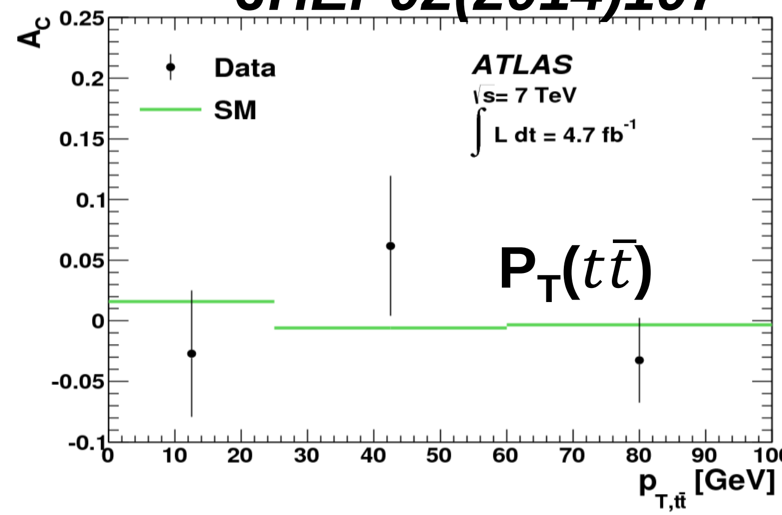

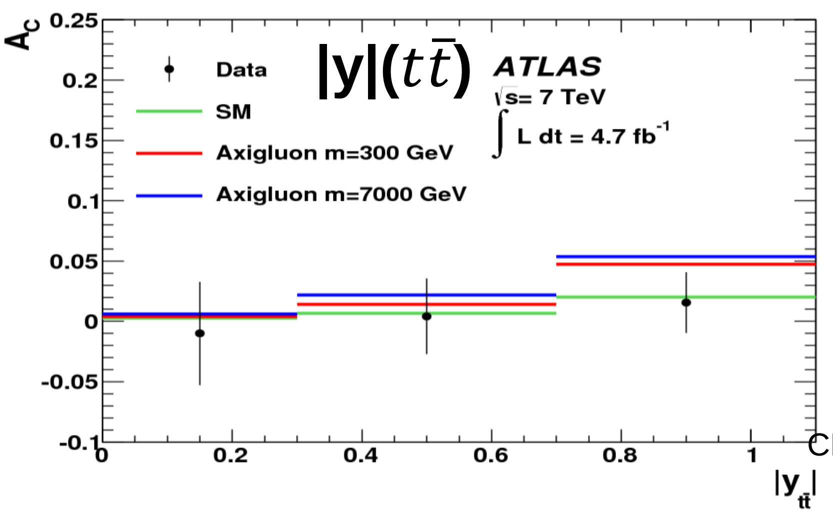

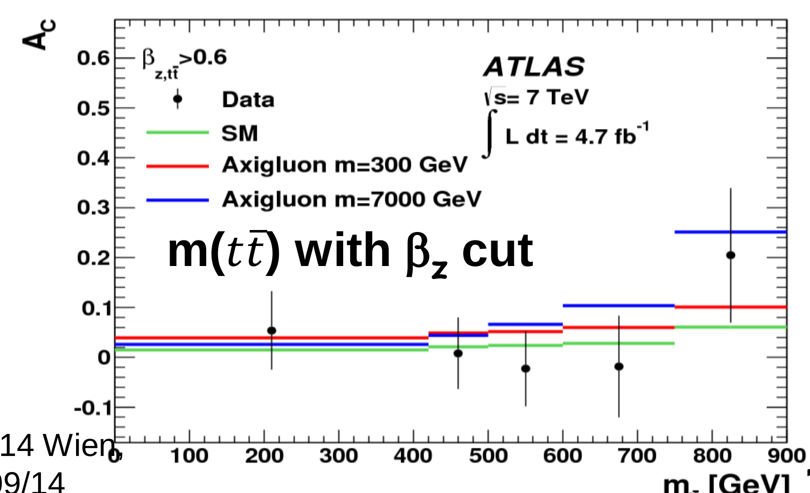

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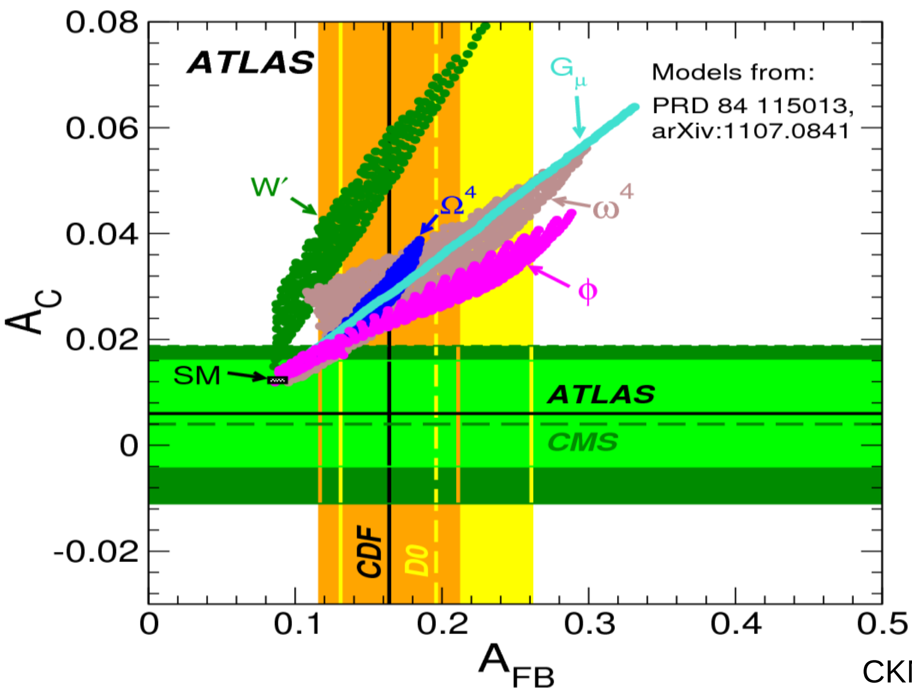
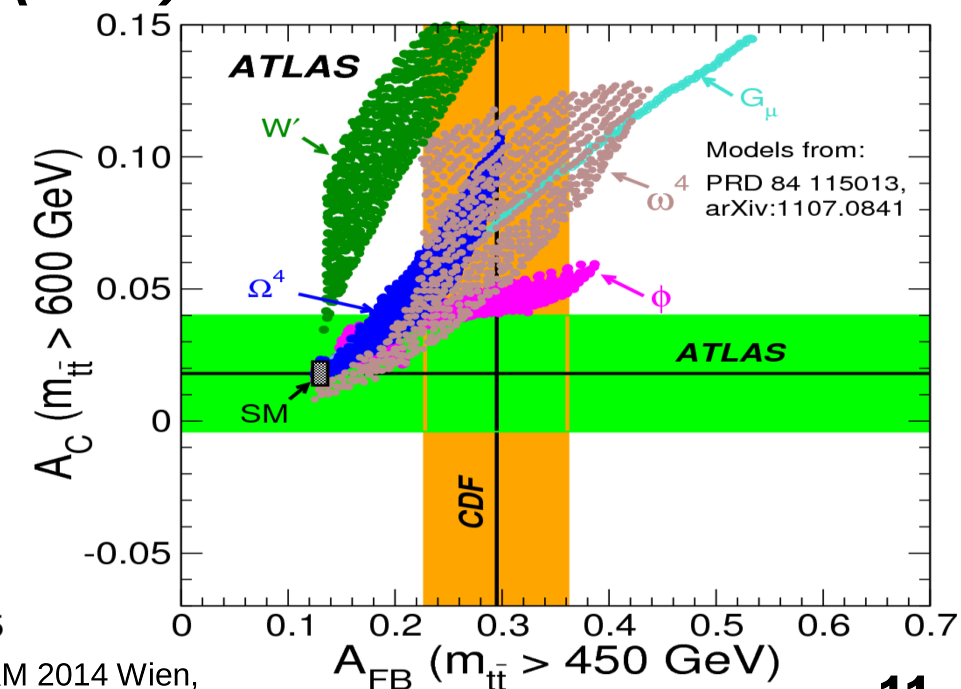
Comparisons & BSM models

1) Comparisons with other measurements:

- Inclusive A_C measurements compared with CDF, D0 and CMS (left)
- Inclusive A_C measurement with $m(t\bar{t})$ > 600 GeV compared with A_{FB} measurement for $m(t\bar{t})$ > 450 GeV from CDF (right)

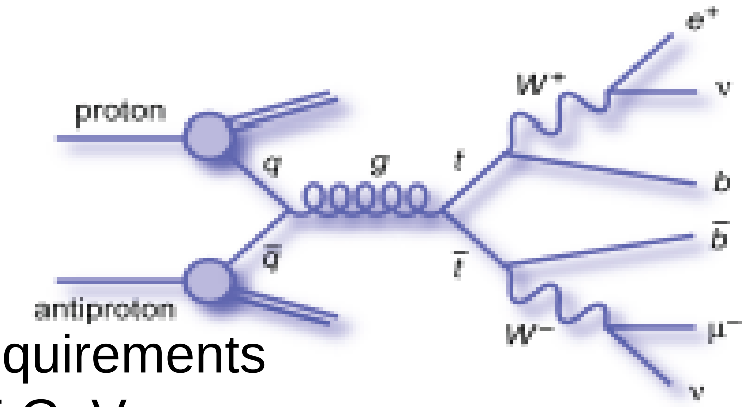
2) Various New Physics models (W', Ω^4, ϕ, G_μ, ω^4) generated with PROTOS to scan the mass-coupling parameter space. Some model (e.g. W') seems to be disfavoured. ***JHEP02(2014)107***





Dilepton channel

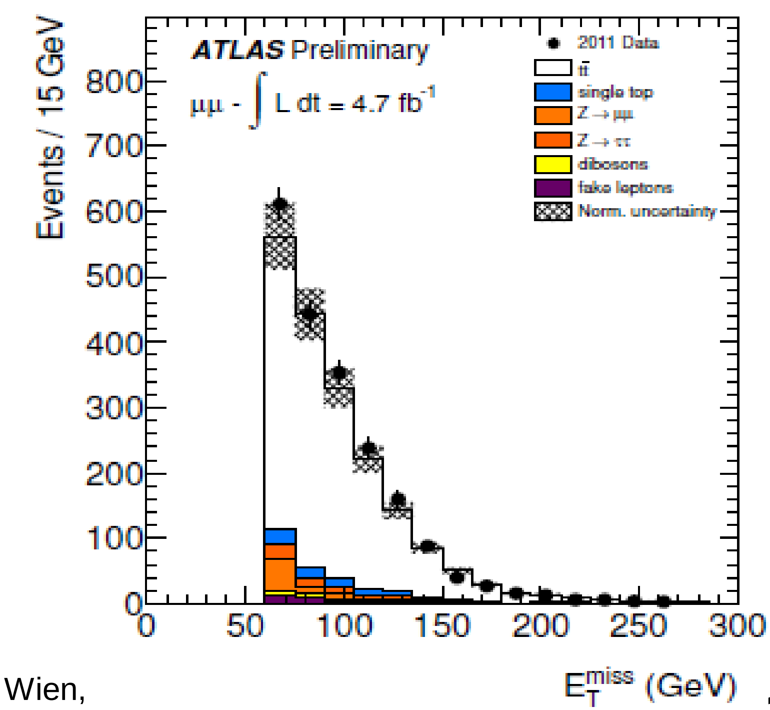
Event selection: 7 TeV, 4,7 fb^{-1}



- Exactly two leptons (ee, μμ, eμ)
- $E_T(e) > 25$ GeV; $p_T(\mu)>20$ GeV
- At least 2 jets with $p_T>25$ GeV, no b-jet requirements
- ee/μμ channels: MET>60 GeV + m(ll)>15 GeV
+ Z peak veto (± 10 GeV window)
- eμ channel: $H_T>130$ GeV
- Multijets/W+jets backgrounds estimated from data

ATLAS-CONF-2012-057

Channel	ee	$e\mu$	$\mu\mu$
$t\bar{t}$	590 ± 60	4400 ± 500	1640 ± 170
$Z \to ee/\mu\mu$	19 ± 7	-	83 ± 29
$Z \to \tau\tau$	19 ± 7	180 ± 60	67 ± 23
Single top	30 ± 2	230 ± 20	82 ± 7
Dibosons	9 ± 1	70 ± 4	23 ± 2
Multijets/W+jets	70 ± 36	250 ± 130	32 ± 17
Total	740 ± 70	5100 ± 500	1930 ± 170
Data	732	5305	2010



Reconstruction of the tt final state

- $t\bar{t}$ system difficult to reconstruct due to the presence of two neutrinos;
- The reconstruction method is based on computing a probability distribution using the $gg \rightarrow t\bar{t}$ LO Matrix Element (ME).
  - 22 unknowns (top/antitop, W±, neutrinos 4-momenta)
  - 16 measured quantities: leptons and jets 4-momenta
  - Fix m(top) and m(W) + 2 equations to relate $\overrightarrow{\mathbf{p}_T}(\nu)$ and $\overrightarrow{\mathbf{p}_T}(t\bar{t})$
  - Use transfer functions to take into account jet resolutions
  - Use MC for $\overrightarrow{\mathbf{p}_T}(t\bar{t})$ depending on the number of jets (2 or more)
- For each l-j combination a weight is computed proportional to the LO ME, PDF and transfer functions from partonic to reco quantities:

gluon momentum fraction

Reco quantity

Partonic quantity

$$\frac{(2\pi)^4}{\varepsilon_1\varepsilon_2 s} d\varepsilon_1 d\varepsilon_2 f_{PDF}(\varepsilon_1) f_{PDF}(\varepsilon_2) |\mathcal{M}(y)|^2 W(x,y) d\Phi_n$$

LO matrix element

- The combination with the highest weight is choosen.
- The right lepton-jet combination is found in 47% of the cases.

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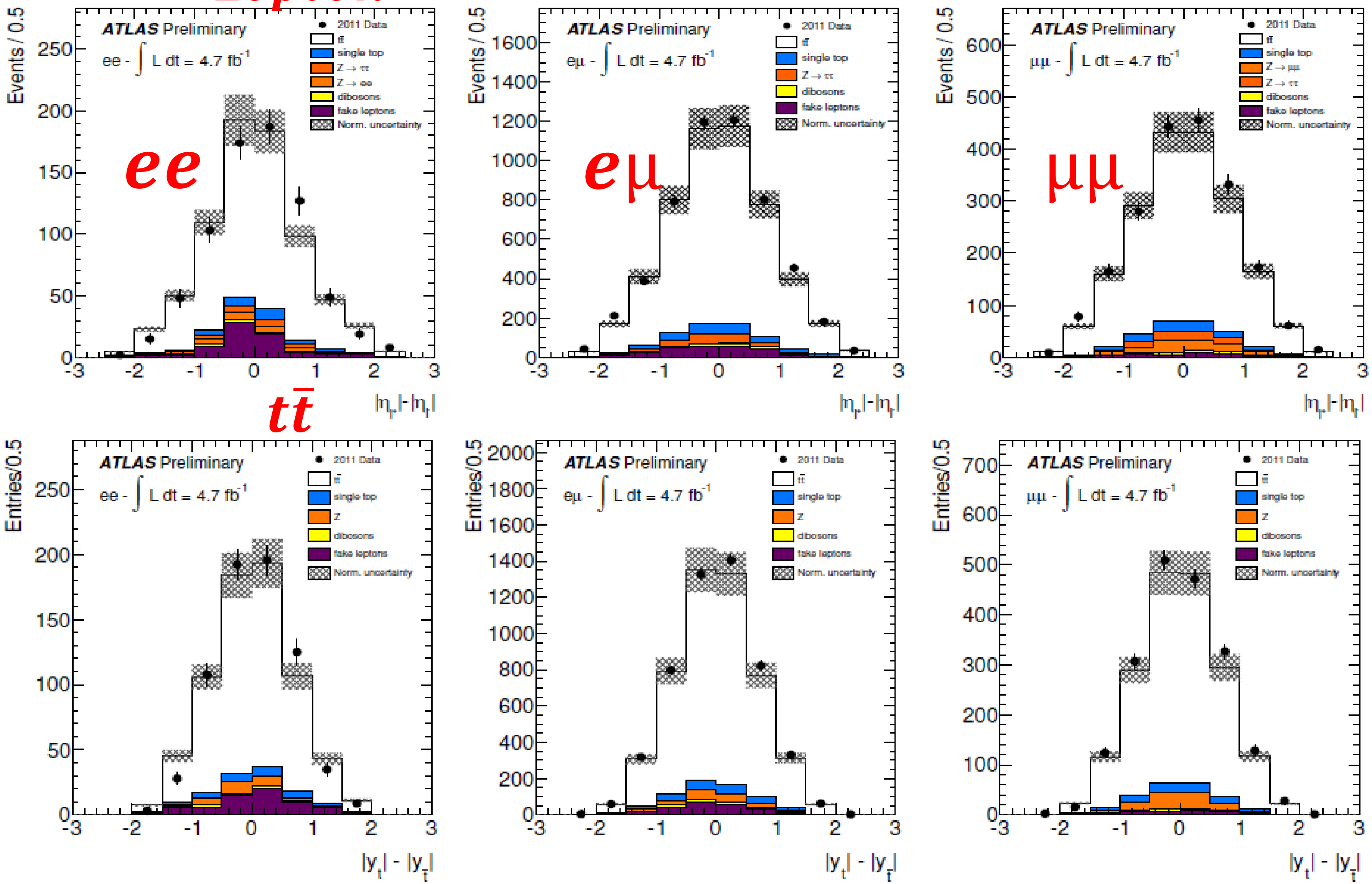
Some distribution

Δ|y| ($t\bar{t}$) and Δ|η| (leptons) distributions

ATLAS-CONF-2012-057

Lepton



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Calibration curves

- Correction is needed for resolution and acceptance effects going back to the parton level asymmetries
- Use MC@NLO $t\bar{t}$ sample to build a calibration curve, i.e. a function that for different parton level injected asymmetries, gives back the corresponding reconstructed asymmetry
- Different asymmetries (from -10% to 10%) obtained by artificially reweighting the original MC@NLO sample are injected at the truth level. The corresponding reco asymmetries are then computed and a fit with a straight line is finally performed.
- Measured asymmetries are rescaled by the **slope** and the **offset** obtained in the fit.
- Possible effects from new physics have been tested reweighting the original MC@NLO $t\bar{t}$ sample to describe the various Δ|y| and Δ|η| distributions at parton level for some new physics samples (axigluons with different asymmetries)

Results

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Final asymmetries after background subtraction and calibration

Main systematics: signal modelling (generator, ISR/FSR) and calibration procedure.

Lepton-based asymmetry

$A_C^{\ell\ell} = 0.091 \pm 0.041\,(\text{stat.}) \pm 0.029\,(\text{syst.})\quad (ee \text{ channel})$

$A_C^{\ell\ell} = 0.018 \pm 0.014\,(\text{stat.}) \pm 0.009\,(\text{syst.})\quad (e\mu \text{ channel})$

$A_C^{\ell\ell} = 0.026 \pm 0.023\,(\text{stat.}) \pm 0.009\,(\text{syst.})\quad (\mu\mu \text{ channel})$

$t\bar{t}$ asymmetry

$A_C^{t\bar{t}} = 0.079 \pm 0.087\,(\text{stat.}) \pm 0.028\,(\text{syst.})\quad (ee \text{ channel})$

$A_C^{t\bar{t}} = 0.078 \pm 0.029\,(\text{stat.}) \pm 0.017\,(\text{syst.})\quad (e\mu \text{ channel})$

$A_C^{t\bar{t}} = 0.000 \pm 0.046\,(\text{stat.}) \pm 0.021\,(\text{syst.})\quad (\mu\mu \text{ channel}).$

Combination

$A_C^{\ell\ell} = 0.023 \pm 0.012\,(\text{stat.}) \pm 0.008\,(\text{syst.})$

SM (MC@NLO): 0.004 ± 0.001

$A_C^{t\bar{t}} = 0.057 \pm 0.024\,(\text{stat.}) \pm 0.015\,(\text{syst.}).$

SM (MC@NLO): 0.006 ± 0.002

Combination of single lepton (1.04 fb^{-1}) & dilepton channel:

$$\boxed{A_C^{t\bar{t}} = 0.029 \pm 0.018\,(\text{stat.}) \pm 0.014\,(\text{syst.})}$$

No significant deviations from SM.

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ATLAS + CMS combination

- ATLAS & CMS A_C measurements using the full 7TeV dataset in the single lepton channel are combined
- Measurements after unfolding (even if the two experiments use different unfodling techniques) are used for combination
- Inputs to the combination: A_C central values, statistical and systematic uncertainties (broken into different sources) taking into account the correlations
- Since ATLAS applied a marginalisation procedure that forbids a decomposition between statistical and systematic uncertainties, the results **before** marginalisation are used for the combination
- BLUE (Best Linear Unbiased Estimator) method is used for the combination

ATLAS+CMS combination : systematic table

ATLAS-CONF-2014-012, CMS PAS TOP-14-006

		ATLAS	CMS	Comb.	Corr.
	A_C	0.006	0.004	0.005	0.058
Uncertainties	Statistical	0.010	0.010	0.007	0
	Detector response model	0.004	0.007	0.004	0
	Signal model	< 0.001	0.002	0.001	1
	W+jets model	0.002	0.004	0.003	0.5
	QCD model	< 0.001	0.001	0.000	0
	Pileup+MET	0.002	< 0.001	0.001	0
	PDF	0.001	0.002	0.001	1
	MC statistics	0.002	0.002	0.001	0
	Model dependence				
	Specific physics models	< 0.001	*	0.000	0
	General simplified models	*	0.007	0.002	0
	Systematic uncertainty	0.005	0.011	0.006	
	Total uncertainty	0.011	0.015	0.009	

- Changing the correlation coefficients has a negligible impact on the combined value and uncertainties
- Combination weights:
  ATLAS 65%
  CMS 35%
- Individual results improved by:
  - 40% for CMS
  - 18% for ATLAS
  - 10% for ATLAS after marginalisation

Combined value:

0.005 ± 0.007 (stat.) ± 0.006 (syst.)

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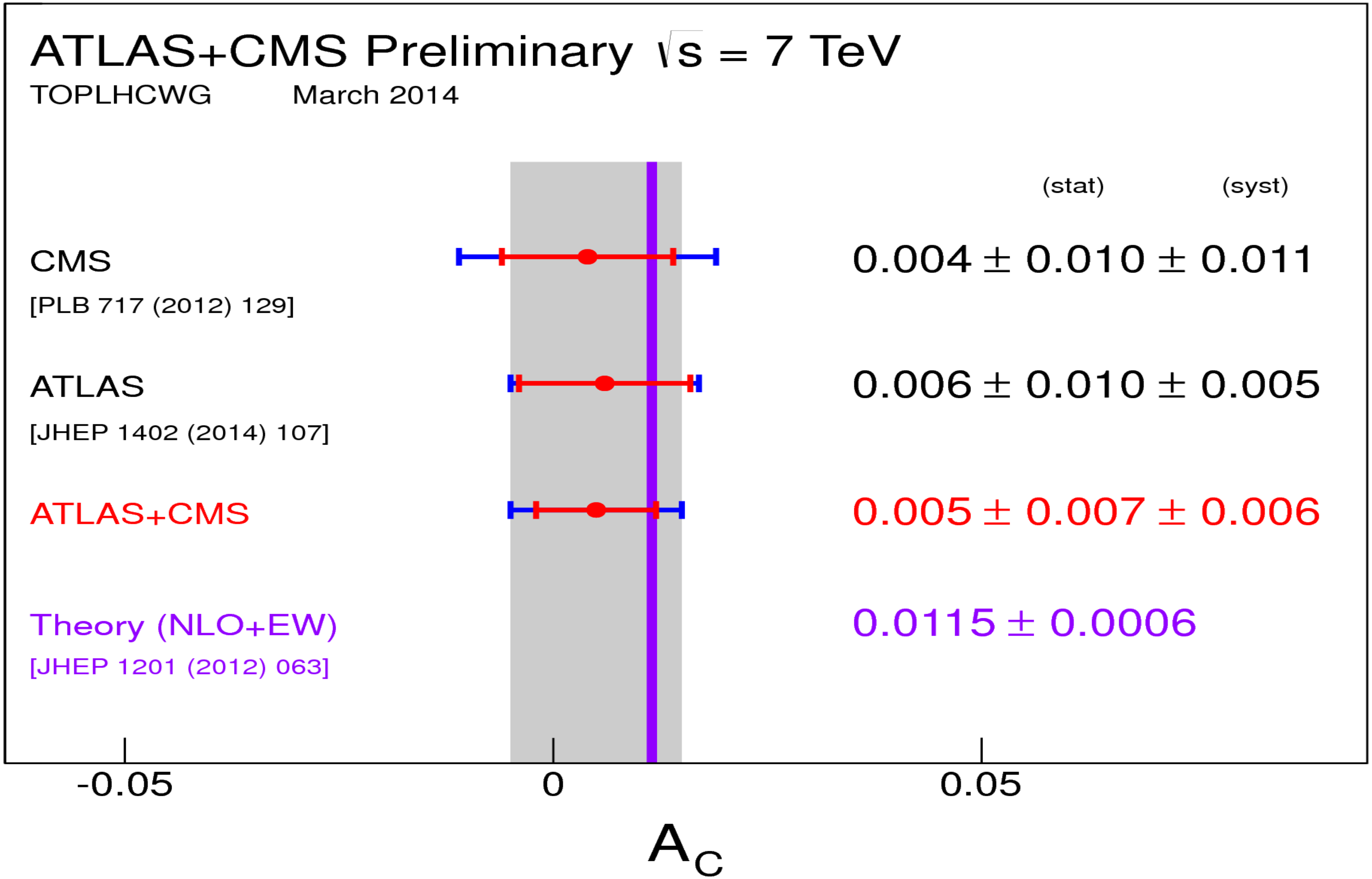
ATLAS + CMS combination results



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Conclusions & Plans

- The $t\bar{t}$-based charge asymmetry in the single lepton and dilepton channels and the lepton-based asymmetry in the dilepton channel have been measured by ATLAS experiment with the full 2011 statistics at $\sqrt{s}$ =7 TeV
- In the single-lepton channel, both inclusive and differential measurements have been performed
- A combination with CMS single lepton channel measurement has also been presented
- No significant excess w.r.t. SM expectations has been seen in all measurements
- 7 TeV measurement in dilepton channel is expected to be finalised for TOP2014, while single-lepton and dilepton measurements using full statistics at $\sqrt{s}$ =8 TeV are in progress

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Thanks for your attention!

BACKUP

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$t\bar{t}$ system quantities

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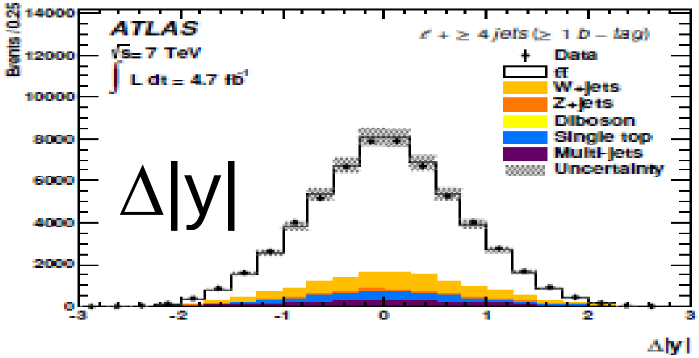

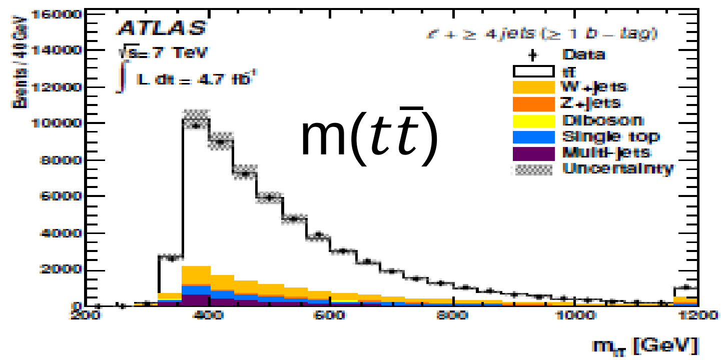

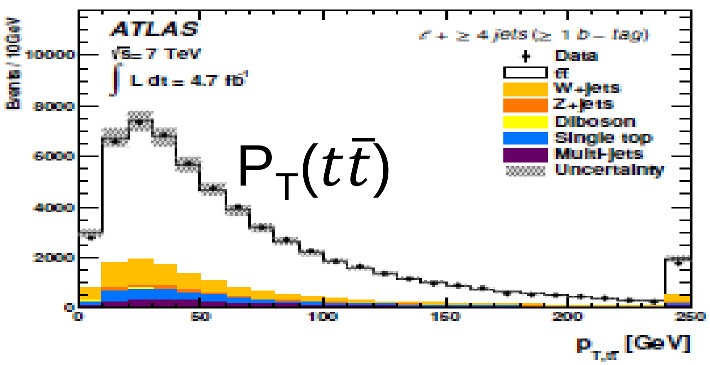

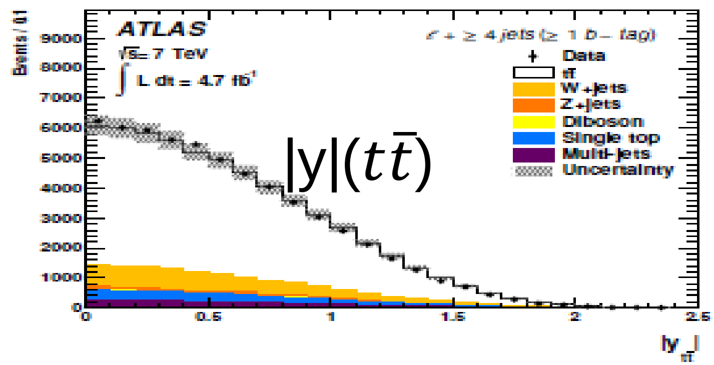

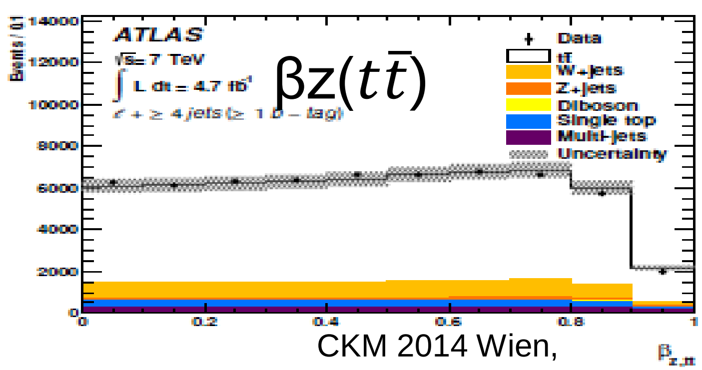

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Event yield

Channel	μ + jets pretag	μ + jets tagged	e + jets pretag	e + jets tagged
$t\bar{t}$	33000 ± 4000	28400 ± 3100	20100 ± 2200	17400 ± 1900
Single top	2460 ± 120	1970 ± 100	1530 ± 80	1220 ± 60
W+jets (data)	28000 ± 6000	4800 ± 1000	13000 ± 5000	2300 ± 900
Z+jets	3000 ± 1900	480 ± 230	3000 ± 1400	460 ± 220
Diboson	378 ± 19	76 ± 4	231 ± 12	47 ± 3
Multijets	5510 ± 1100	1800 ± 400	3800 ± 1900	800 ± 400
Total background	40000 ± 6000	9200 ± 1100	22000 ± 6000	4800 ± 1000
Signal + background	72000 ± 8000	37500 ± 3300	42000 ± 6000	22200 ± 2200
Observed	70845	37568	40972	21929

- QCD and W+jets data-driven with stat+syst. errors
- Agreement data/MC is quite good

FBU unfolding (2)

- A flat prior is used for the differential measurement as a function of m($t\bar{t}$) and |y|($t\bar{t}$)
- For the inclusive measurement and the differential one w.r.t $P_T(t\bar{t})$, the following prior, called "curvature prior", is used:

$$\pi(\mathbf{T}) \propto \begin{cases} e^{\alpha S(\mathbf{T})} & \text{in the integration space}, \forall t \in [1, N_t] \\ 0 & \text{otherwise} \end{cases}$$

where $\alpha=10^{-8}$ is the regularisation parameter and $S(\mathbf{T})=|C(\mathbf{T})-C(\tilde{\boldsymbol{T}})|$ is the difference between the curvature $C(\mathbf{T})$ of the Δ|y| spectrum in data and in the truth $C(\tilde{\boldsymbol{T}})$.

- The same procedure is applied for the differential measurements, translating the 2-D histogram in a 1-D histogram with consecutive sub-ranges of Δ|y| distributions for each differential bin.

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Systematic uncertainties

- For each systematic uncertainty, the posterior is recomputed varying coherently the background, the efficiencies or the response matrix.
- The final uncertainty (stat.+syst.) is obtained after a marginalisation procedure involving the various systematics.
- The marginalisation is performed integrating over the nuisance parameters θ described by a gaussian prior

$$p(\mathbf{T}|\mathbf{D}) \propto \int \mathcal{L}(\mathbf{D}|\mathbf{T},\theta)\cdot\pi(\mathbf{T})\,\mathrm{d}\theta$$

Source of systematic uncertainty	δA_C
Lepton reco/ID	< 0.001
Lepton energy scale and resolution	0.003
Jet energy scale and resolution	0.003
Missing transverse momentum and pile-up modelling	0.002
Multijet	< 0.001
b-tagging/mis-tag efficiency	< 0.001
Signal modelling	< 0.001
Parton shower/hadronisation	< 0.001
MC Statistics	0.002
PDF	0.001
W+jets normalisation and shape	0.002
Statistical uncertainty	0.010

- Shift in the mean of the posterior for the inclusive A_C measurement **before the marginalisation**.
- Statistical uncertainty dominates here and in all the measurements

Systematic uncertainties: Lepton asymm.

	ee	*eμ*	*μμ*
signal and background modeling			
signal generator	0.011	0.003	0.002
ISR and FSR	0.004	0.004	0.006
parton shower/fragmentation	0.001	0.004	0.003
PDF	<0.001	<0.001	<0.001
Z+jets	0.005	0.004	0.001
diboson	<0.001	<0.001	<0.001
single top	<0.001	<0.001	<0.001
multijet background	0.014	0.002	<0.001
Detector modeling			
jet efficiency and resolution	0.008	0.001	0.003
jet energy scale	0.006	0.001	0.002
muon efficiency and resolution	<0.001	0.001	0.002
electron efficiency and resolution	0.005	0.003	<0.001
calibration	0.019	0.002	0.004
luminosity	0.002	<0.001	<0.001
Total	0.029	0.009	0.009

- eμ and μμ channels show a lower overall systematic uncertainty w.r.t ee channel
- Dominat syst. in ee channel is the QCD data-driven estimate and the calibration (i.e. error propagation from fit parameters)
- If the syst affects the background → perform subtraction, recompute the asymmetry and calibrate
- If the syst affects the signal → redo the calibration curves

Systematic uncertainties: $t\bar{t}$ asymm.

	ee	$e\mu$	$\mu\mu$
Signal and background modeling			
signal generator	0.014	0.009	0.002
ISR and FSR	0.008	0.002	0.018
parton shower/fragmentation	0.001	0.001	0.001
PDF	0.001	<0.001	<0.001
Z+jets	0.001	0.006	0.002
diboson	<0.001	<0.001	<0.001
single top	<0.001	<0.001	<0.001
multijet background	0.012	0.010	0.001
Detector modeling			
jet efficiency and resolution	0.007	0.001	0.005
jet energy scale	0.003	0.002	0.006
muon efficiency and resolution	0.004	0.003	0.005
electron efficiency and resolution	0.013	0.006	0.002
calibration	0.004	0.001	0.002
luminosity	<0.001	0.001	<0.001
Total	0.028	0.017	0.021

- The three channels show similar overall systematic uncertainty
- Some fluctuation in some systematic (ISR/FSR, $t\bar{t}$ generator) especially in the ee channel is due to limited available statistics
- If the syst affects the background → perform subtraction, recompute the asymmetry and calibrate
- If the syst affects the signal → redo the calibration curves