

Top-quark properties from ATLAS



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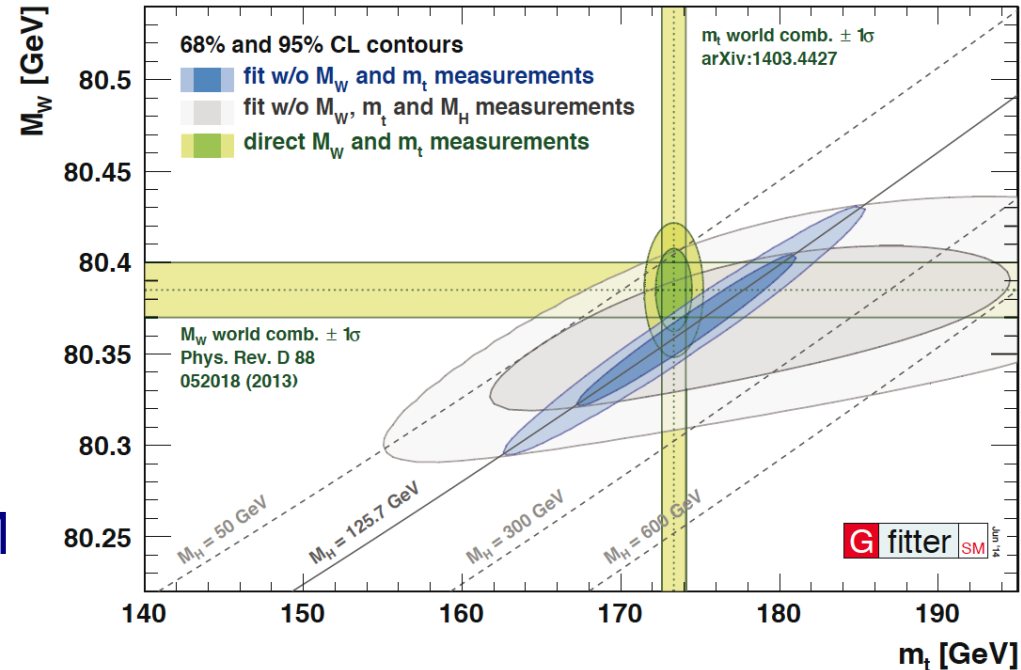
[On the beach at Valencia. J. Sorolla]

7 Sorolla B

- Introduction: the top quark in the SM
- Production & decay
- The top-quark mass
- Top vs antitop: mass difference
- Spin correlation
- Charge asymmetry
- Summary

The top quark in the SM

- Top-quark mass is a fundamental parameter of the SM
- Relation between top-quark, W and BEH-boson masses is predicted by the SM → consistency check of the SM
- Mass is another parameter of the SM Lagrangian that can be renormalized and defined using different schemes:
 - Pole mass and running mass
 - MC mass

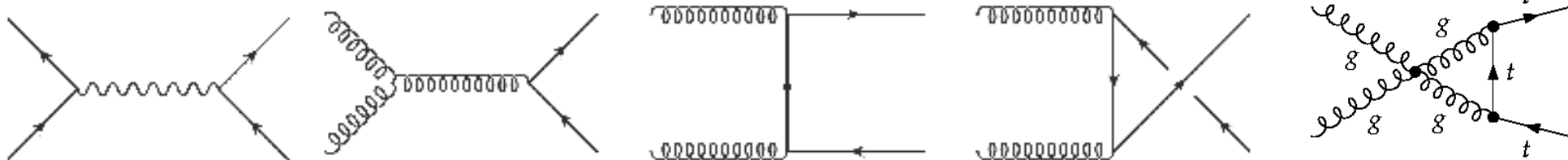


$$m_t = m(\mu) \left(1 + \frac{\alpha_s(\mu)}{\pi} \left[\frac{4}{3} + \ln \left(\frac{\mu^2}{m(\mu)^2} \right) \right] + \dots \right)$$

- It has a very short lifetime ($\sim 10^{-25}$ s), therefore we have access to the bare quark before hadronization. This is a unique feature of the top-quark.
 - Ability to study the top-quark polarization and the spin correlations

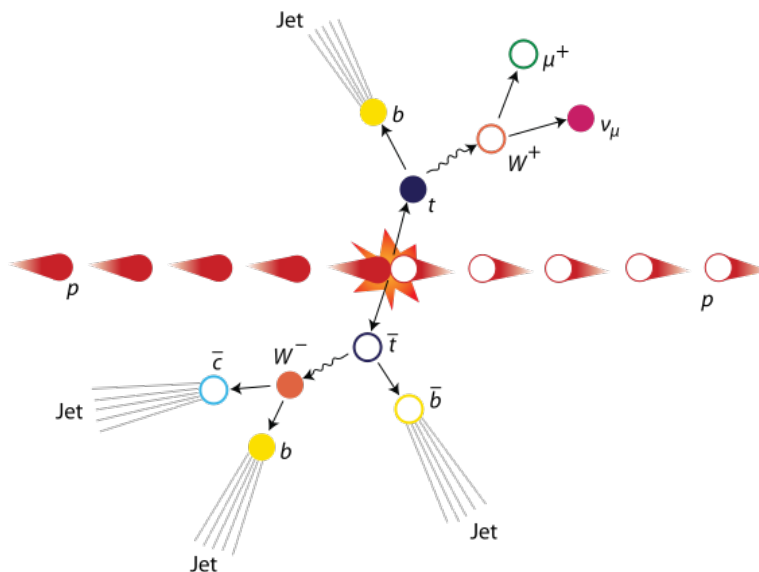
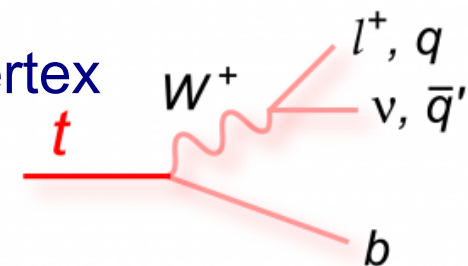
Production and decay

- At LHC energies main production is via gluon-gluon interactions
 - Cross section: $\sigma(7 \text{ TeV}) \sim 180 \text{ pb}$ & $\sigma(8 \text{ TeV}) \sim 240 \text{ pb}$



- The top quark decays almost exclusively via the $t \rightarrow Wb$ vertex

- The W may decay into quarks or leptons
 - W leptonic decays give neutrinos in the final state
 - W hadronic decays produce jets
- Many possible final states



Top Pair Decay Channels

$c\bar{s}$	electron+jets	muon+jets	tau+jets	all-hadronic	
$u\bar{d}$					
τ^-					
μ^-	$e\mu$	$\mu\mu$	$\mu\tau$	muon+jets	
e^-	$e\bar{e}$	$e\mu$	$e\tau$	electron+jets	
W decay	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$

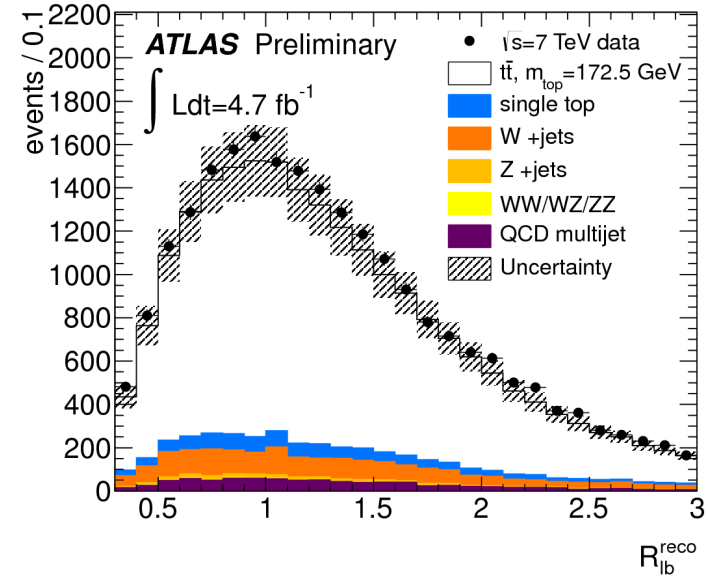
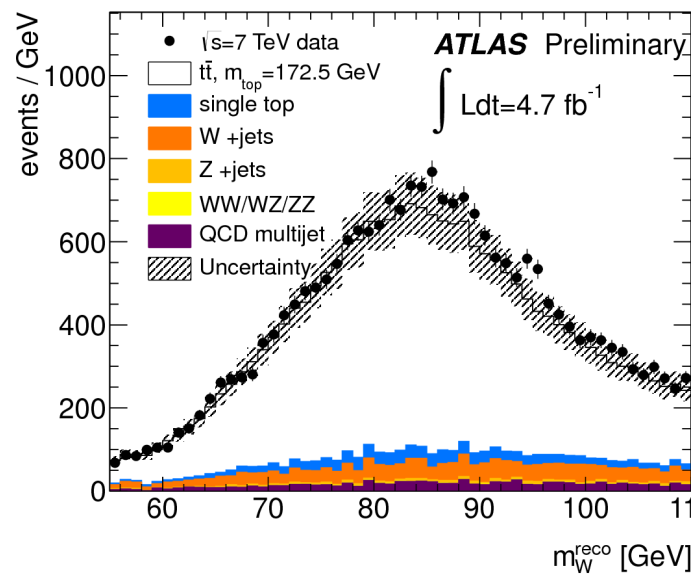
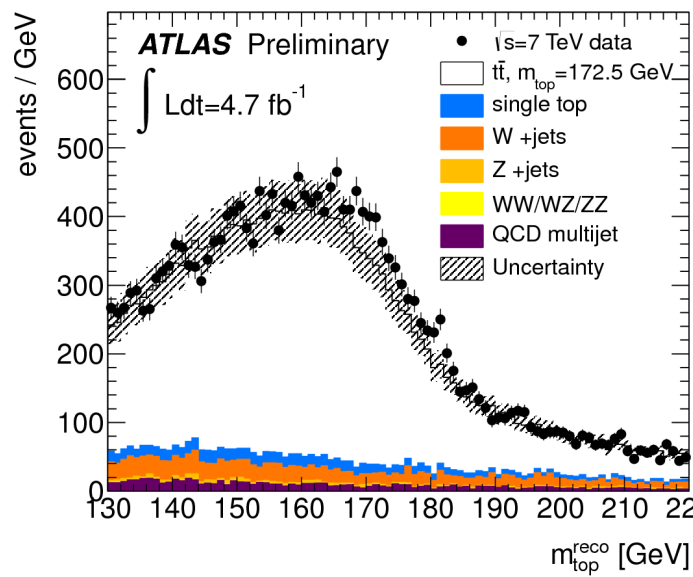
- Template methods are extensively used in ATLAS m_t analyses
 - MC: parametrize the distribution of a m_t sensitive observable
 - This analysis provides the top-quark mass as in MC
 - Real data: use that parametrization to obtain a m_t value that best fits the observable distribution in data
- Lepton + jets channel: 3D template fit
 - m_t sensitive observable: top-quark mass from an event kinematic fit
 - Include m_W to control/detect/avoid possible (small) differences in the jet energy scale factor (JSF) between real data and MC
 - Include an observable to control/detect/avoid possible (small) differences in the **b-jet** energy scale factor (bJSF) between real data and MC

$$R_{lb}^{reco,2b} = \frac{p_T^{bhad} + p_T^{blep}}{p_T^{Wjet1} + p_T^{Wjet2}} \quad R_{lb}^{reco,1b} = \frac{p_T^{bjet}}{(p_T^{Wjet1} + p_T^{Wjet2})/2}$$

observable	dependency		
	m_t	JSF	bJSF
m_t^{reco}	✓	✓	✓
m_W^{reco}		✓	
R_{lb}^{reco}	mild		✓

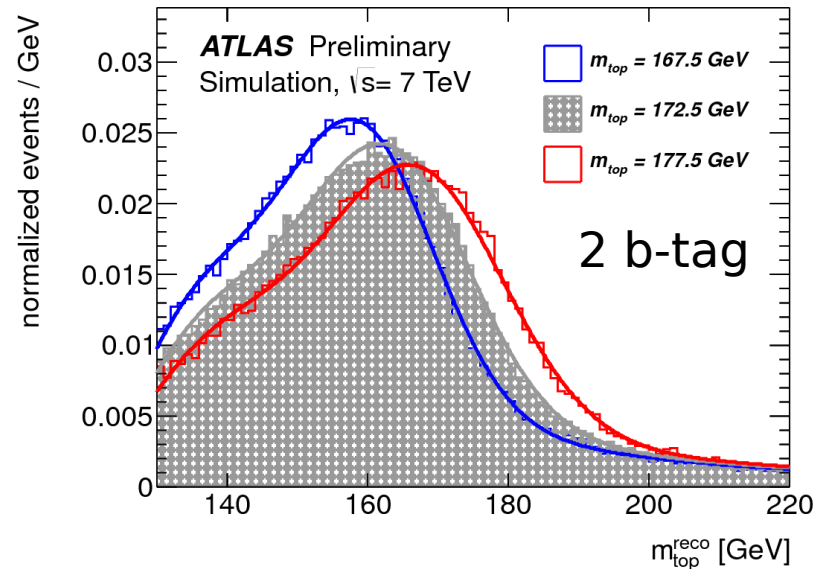
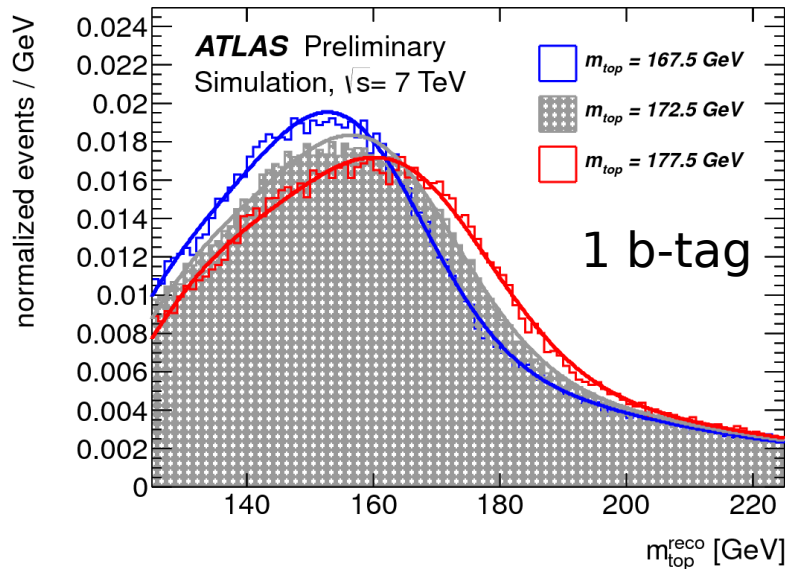
Top-quark mass: 3D template in lepton+jets

- Distributions of the 3 observables (1 & 2 b-tagged jets) (ATL-CONF-2013-046)



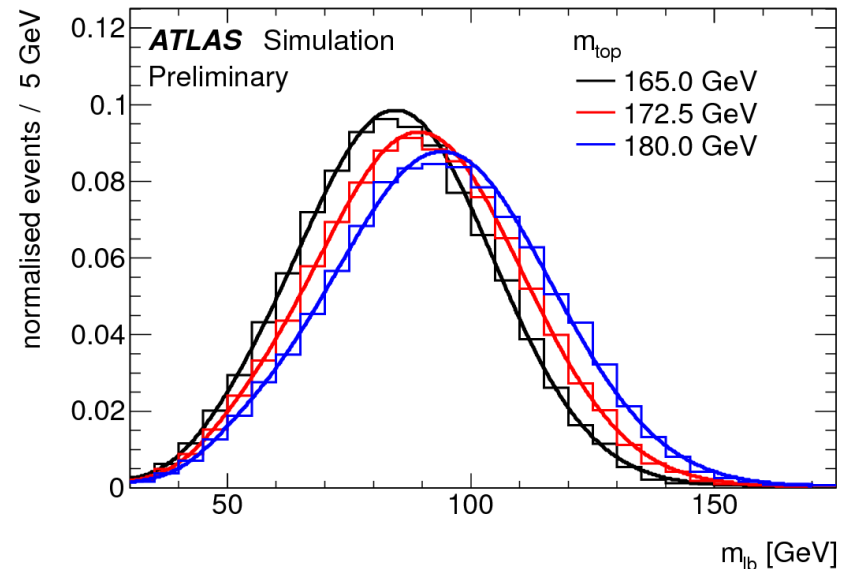
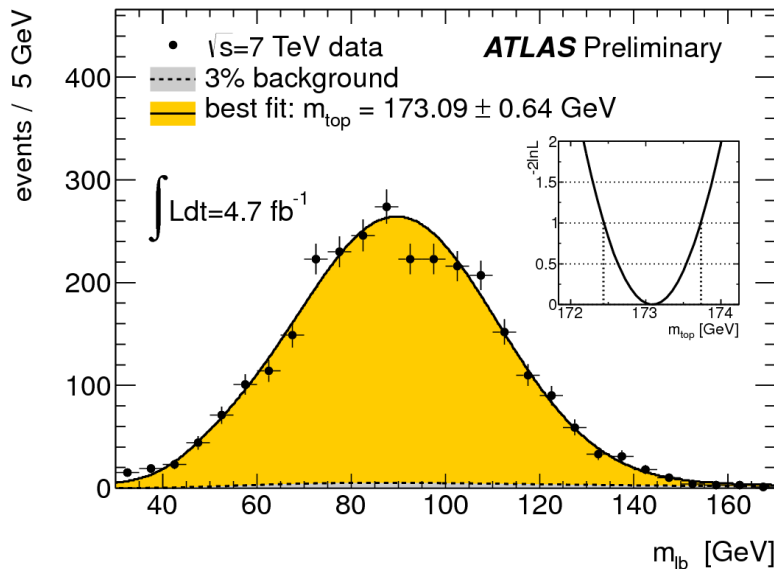
- Mass templates:

$$M_t = 172.31 \pm 0.75 \text{ (stat.+JSF+bJSF)} \pm 1.35 \text{ (syst.) GeV}$$



Top-quark mass: dilepton channel

- Using an 1D template method (ATL-CONF-2013-077)
 - Small background ($\sim 3\%$), the bulk of comes from single top (Wt channel)
 - Average m_{lb} (for the lepton + b-jet combination)



- Main systematic uncertainties: jet energy scale and b-jet energy scale

$$m_t = 173.09 \pm 0.64 \text{ (stat.)} \pm 1.50 \text{ (syst.) GeV}$$

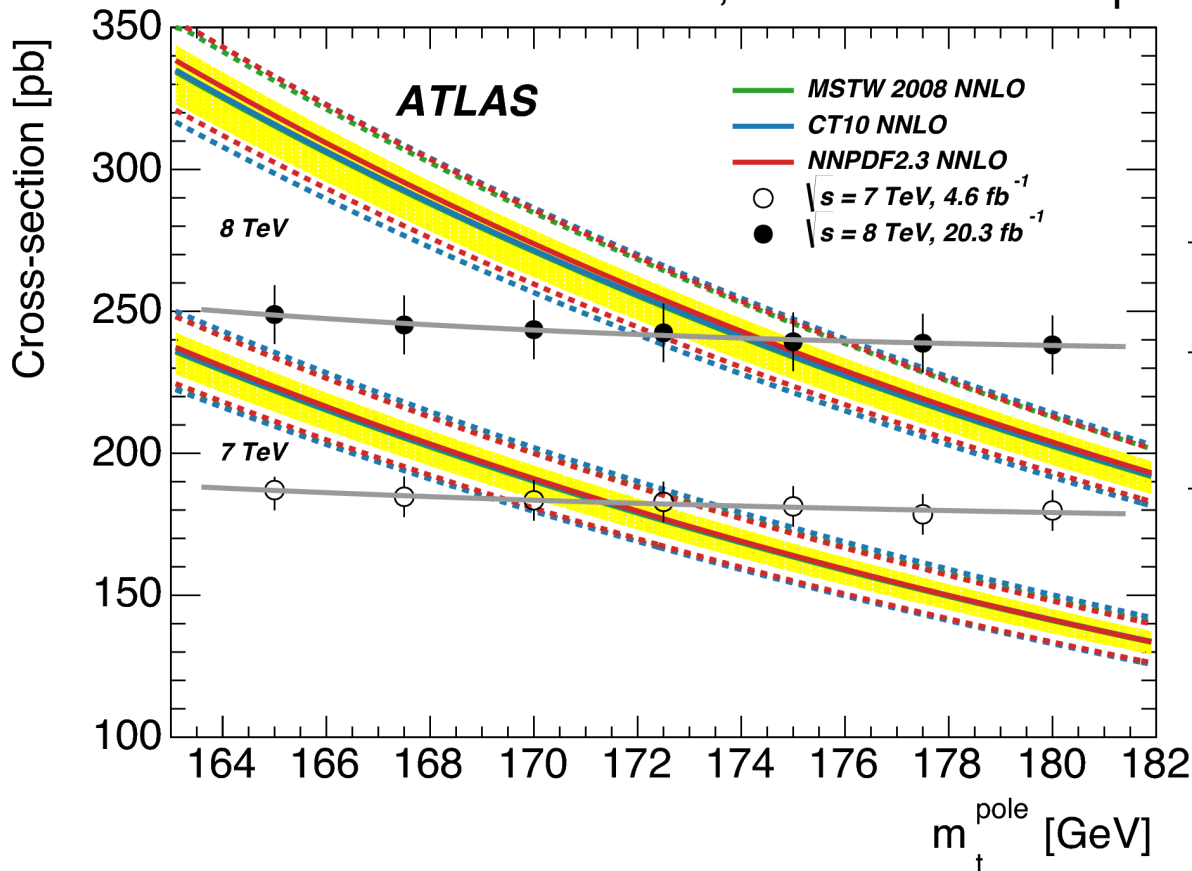
- All hadronic channel (ATL-CONF-2012-030)

- Warning: only 2 fb^{-1} used

$$m_t = 174.9 \pm 2.1 \text{ (stat.)} \pm 3.8 \text{ (syst.) GeV}$$

Top-mass from cross section

- The cross section depends on the top-quark mass
- Use full NNLO cross section calculations at 7 and 8 TeV (arXiv:1406.5375)
 - These calculations are performed with the pole mass scheme
 - Therefore, one measures explicitly the m_t^{pole}



PDF	m_t^{pole} (GeV) from $\sigma_{t\bar{t}}$	
	$\sqrt{s} = 7 \text{ TeV}$	$\sqrt{s} = 8 \text{ TeV}$
CT10 NNLO	171.4 ± 2.6	174.1 ± 2.6
MSTW 68% NNLO	171.2 ± 2.4	174.0 ± 2.5
NNPDF2.3 5f FFN	$171.3^{+2.2}_{-2.3}$	174.2 ± 2.4

$$m_t^{\text{pole}} = 172.9^{+2.5}_{-2.6} \text{ GeV}$$

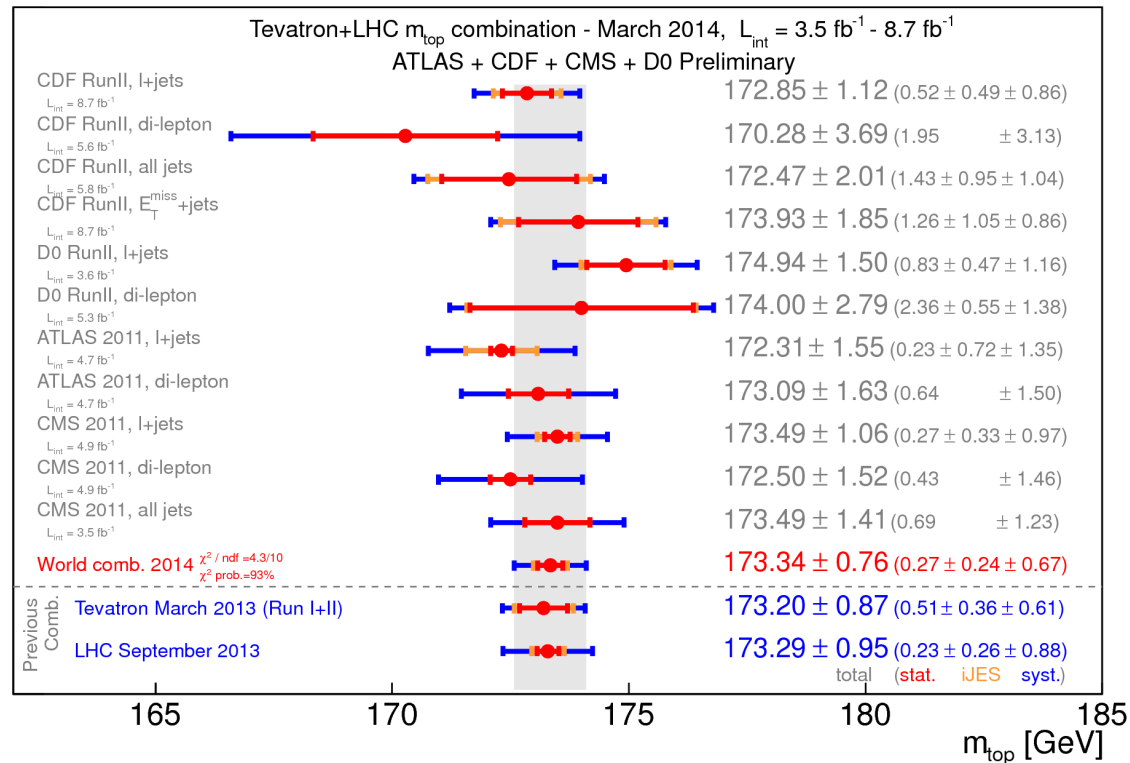
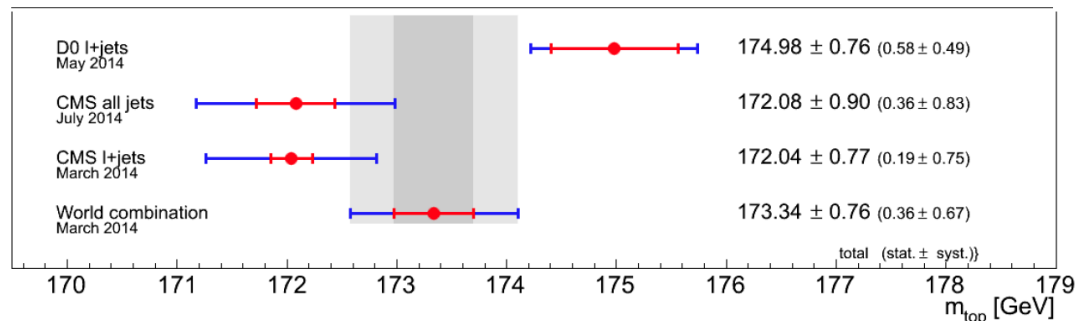
- New calculations of the top-quark pole mass in $t\bar{t}g$ events
 - “A new observable to measure the top-quark mass at hadron colliders”

Top-quark mass: summary

- The first combination of LHC & Tevatron results has been performed for the world top-quark mass
 - ATLAS-CONF-2014-008
- Best Linear Unbiased Estimate
 - BLUE
- Since then:
 - New CMS results (8 TeV)
 - New D0 measurement
 - New ATLAS result

- from Xsec at (7 and 8 TeV)

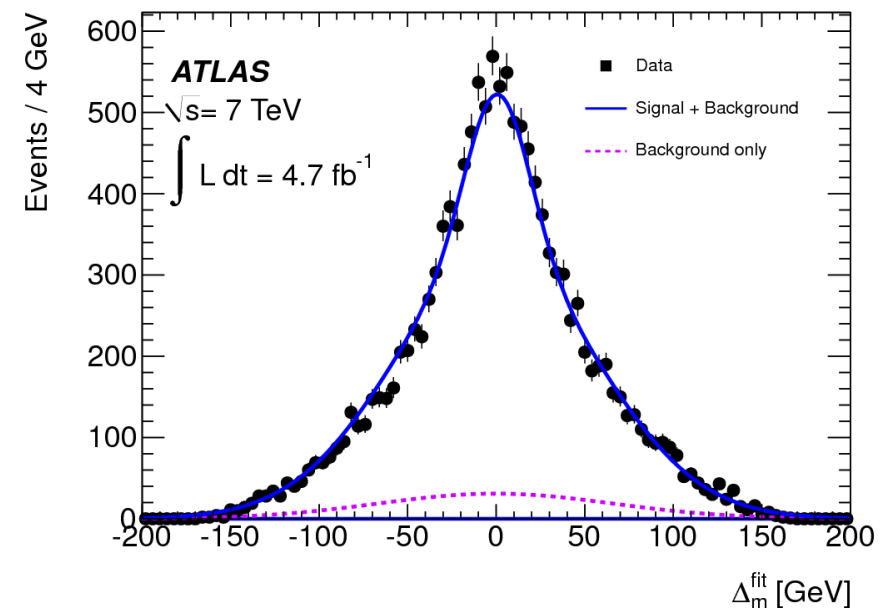
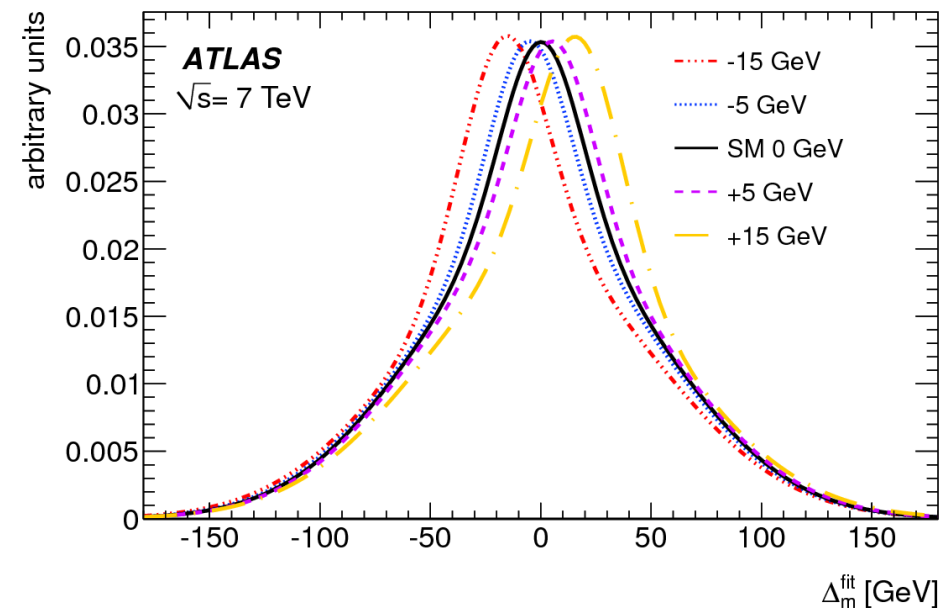
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Top-antitop: mass difference

- Analysis performed in the lepton+jets channel with two b-tagged jets
 - Perform a kinematic fit of the event with
 - M_W (80.42 GeV) constrained for the hadronic part
 - Allowing different masses for the hadronic and leptonic parts of the event
 - Keep the average top-quark mass (172.5 GeV)
 - The charge of the lepton serves to identify the top and antitop with

$$\Delta_m^{fit} = q_l \times (m_{bl\nu}^{fit} - m_{bjj}^{fit})$$



$$\Delta m_{top} = 0.67 \pm 0.61 \text{ (stat.)} \pm 0.41 \text{ (syst.) GeV}$$

- Although top quarks are produced essentially unpolarized, the correlation of the t and \bar{t} spin is predicted to be not null (sensitive to new physics)
- The products of the top quark decay carry information about its spin

$$\frac{1}{\sigma} \frac{d^2 \sigma}{d \cos \theta_1 d \cos \theta_2} = \frac{1}{4} (1 - C \cos \theta_1 \cos \theta_2)$$

$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)} \quad C = -A \alpha_1 \alpha_2$$

$\alpha_i \rightarrow$ spin analyzing power
 $C \rightarrow$ spin correlation
 $\cos \theta_i$ in the spin (helicity) analysis basis

	b	lepton	d	u
(LO) $\alpha_{i/j}$	-0.41	1.00	1.00	-0.31
(NLO) $\alpha_{i/j}$	-0.39	0.998	0.93	-0.31

- Analysis performed with 4 observables:
 - $\Delta\phi$ between the two leptons (dilepton) or lepton – jet (W in lepton+jets)
 - The “S-ratio” of matrix elements from the fusion of helicity-like gluons
 - Also requires the full reconstruction of the top and antitop.

$$\begin{aligned}
 S &= \frac{(|\mathcal{M}|_{RR}^2 + |\mathcal{M}|_{LL}^2)_{\text{corr}}}{(|\mathcal{M}|_{RR}^2 + |\mathcal{M}|_{LL}^2)_{\text{uncorr}}} \\
 &= \frac{m_t^2 \{ (t \cdot l^+) (t \cdot l^-) + (\bar{t} \cdot l^+) (\bar{t} \cdot l^-) - m_t^2 (l^+ \cdot l^-) \}}{(t \cdot l^+) (\bar{t} \cdot l^-) (t \cdot \bar{t})}
 \end{aligned}$$

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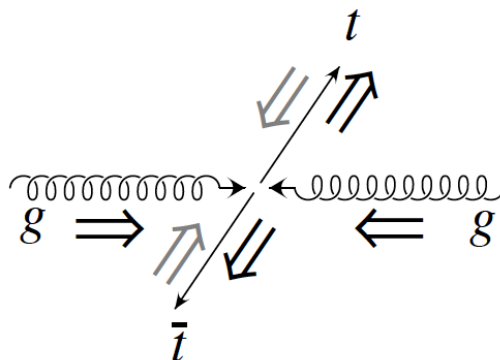
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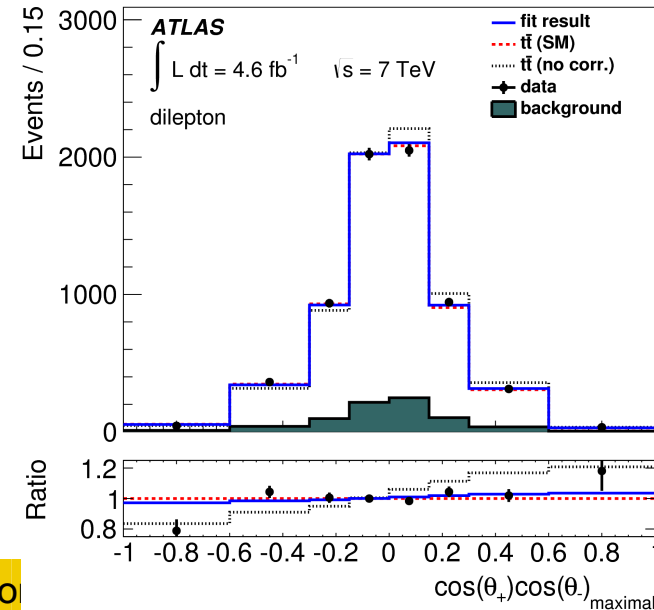
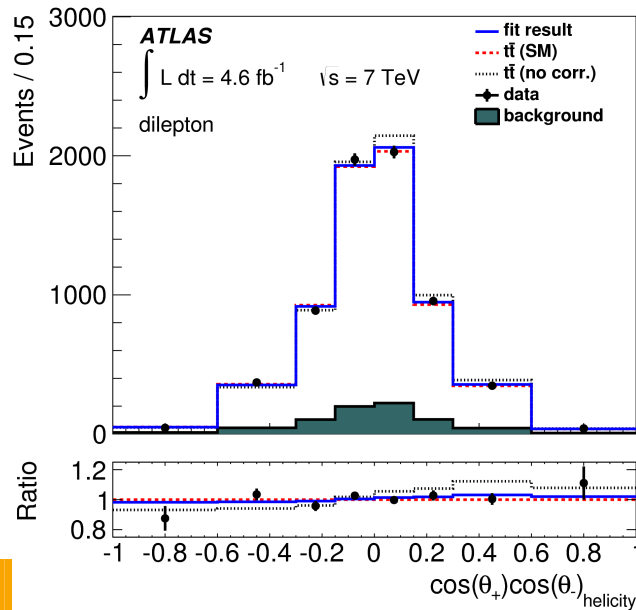
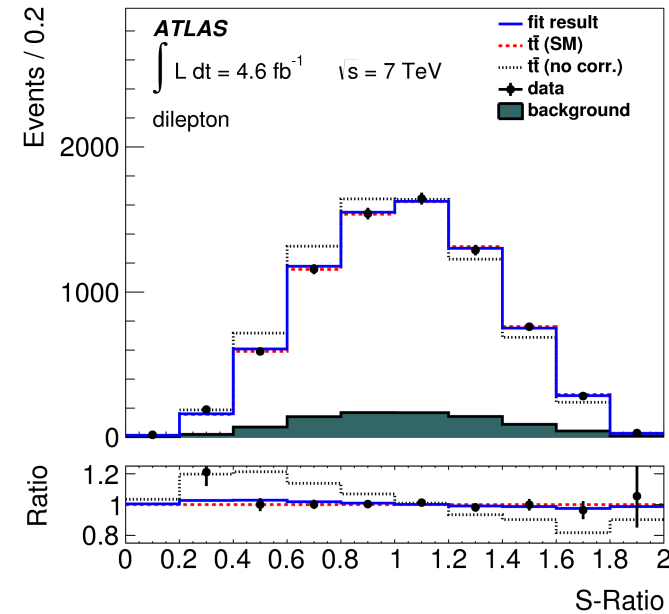
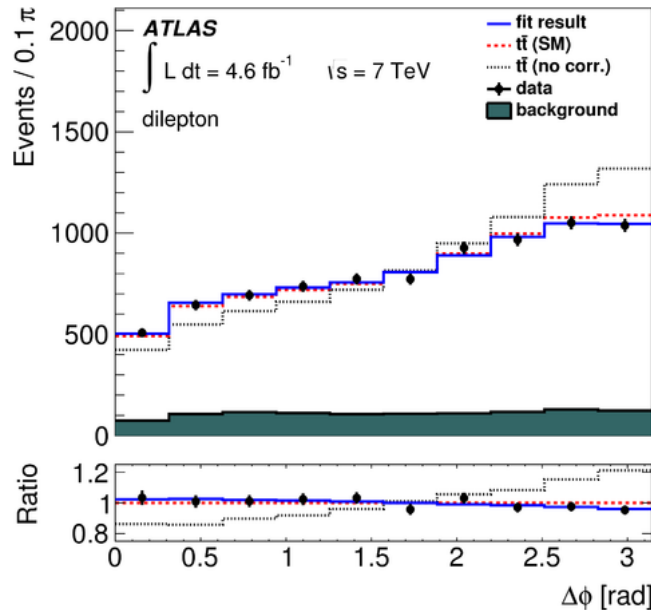
- Analysis performed with 4 observables:
 - The $\cos \theta_1 \cos \theta_2$ as computed in the direction of the top-antitop rest frame as spin quantization axis
 - The $\cos \theta_1 \cos \theta_2$ as computed in the maximal spin correlation (gluon fusion) basis



$t\bar{t}$ spin correlation

- Use templates generated with MC@NLO with and without spin correlation
 - The template fit determines the equivalent fraction of events in data with a spin correlation like in the SM

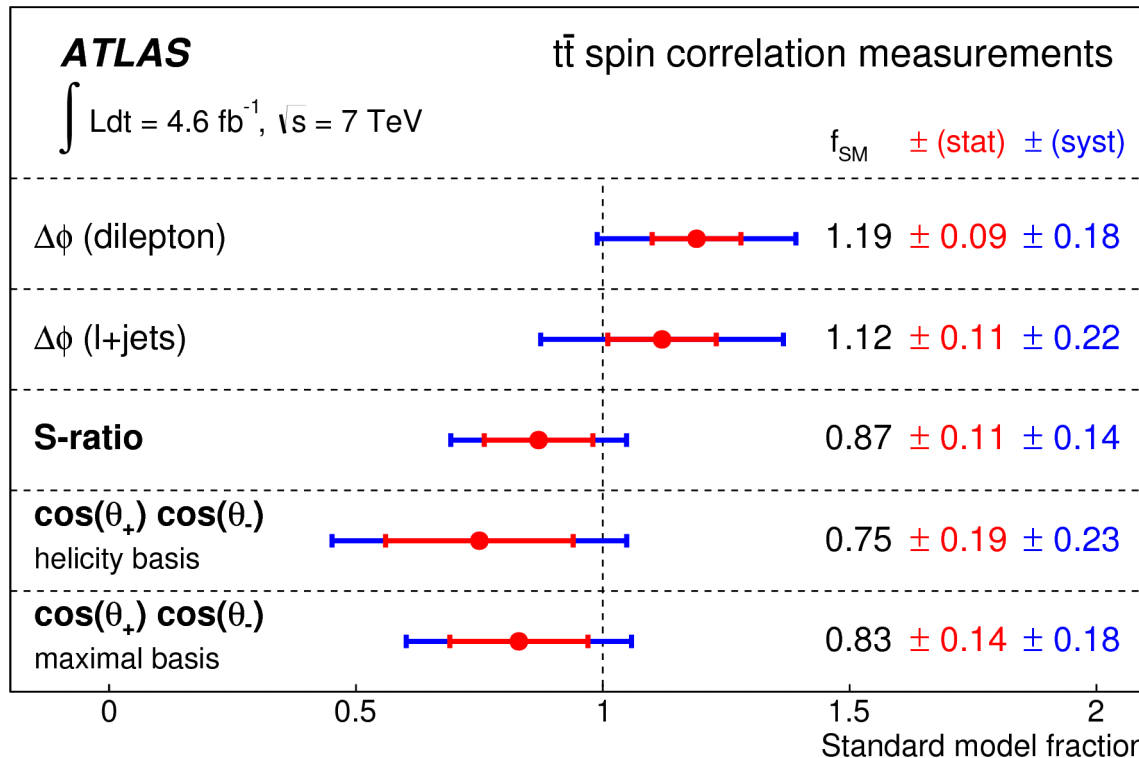
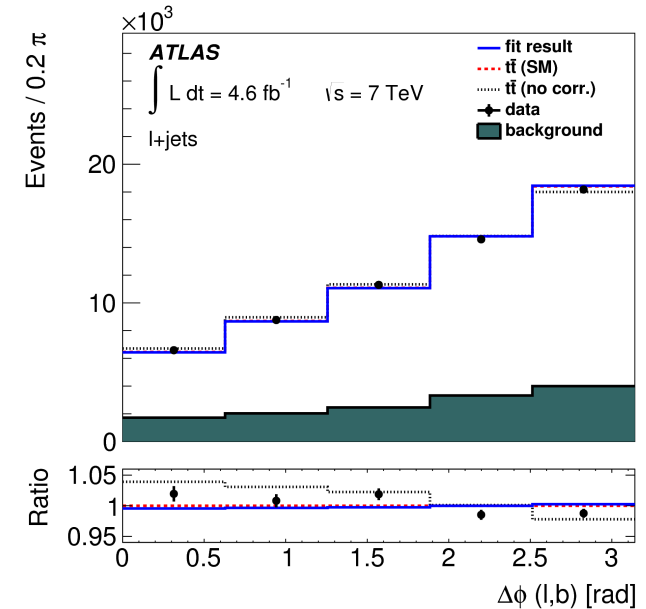
Dilepton channel



$t\bar{t}$ spin correlation

- Use templates generated with MC@NLO with and without spin correlation
 - The template fit determines the equivalent fraction of events in data with a spin correlation like in the SM

lepton+jets channel \rightarrow



\leftarrow Spin correlations summary

Charge asymmetry

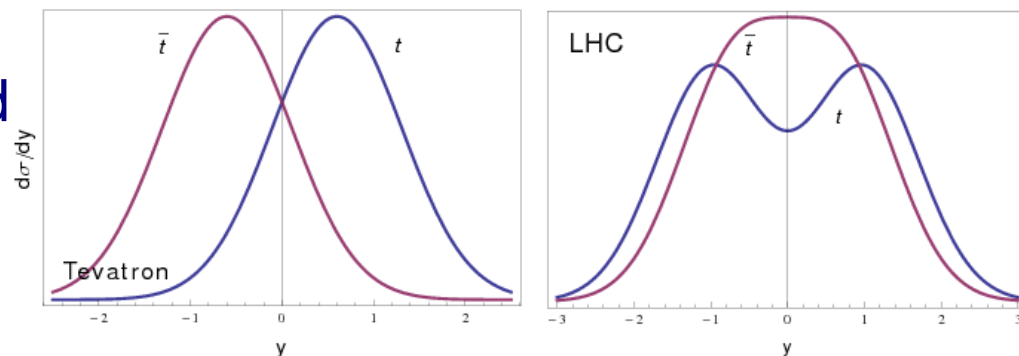
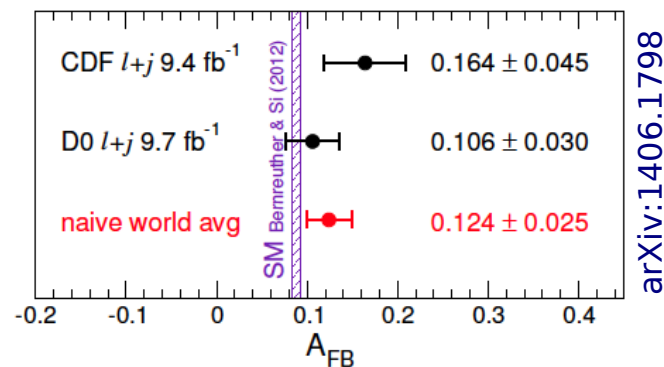
- Charge asymmetry studies in the $t\bar{t}$ events represent an important test of QCD at high energy and it is sensitive to BSM physics
- At LO the $gg \rightarrow t\bar{t}$ production is symmetric under the t and \bar{t} exchange
- However at NLO an asymmetry is introduced due to the interference between ISR and FSR
- Also $q\bar{q} \rightarrow t\bar{t}$ production is charge asymmetric due to interference terms
- CDF and D0 used to report A_{FB} measurements above the SM prediction

– Recent D0 results: new scenario

$$A_{FB} = \frac{N(\Delta y_{t\bar{t}} > 0) - N(\Delta y_{t\bar{t}} < 0)}{N(\Delta y_{t\bar{t}} > 0) + N(\Delta y_{t\bar{t}} < 0)}$$

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

- At Tevatron t are forward, \bar{t} backward
- At LHC \bar{t} are more central than t

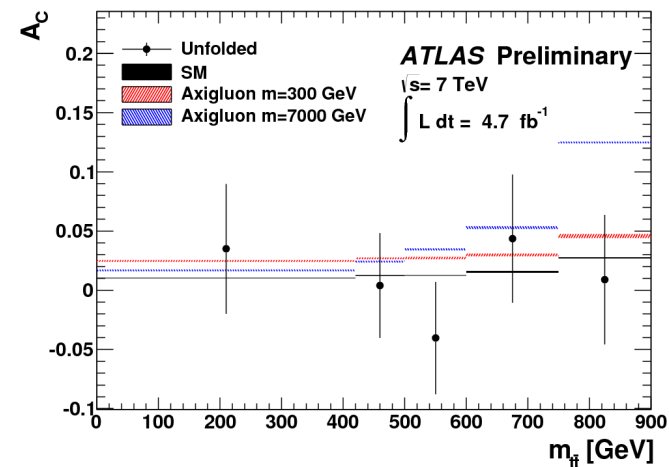
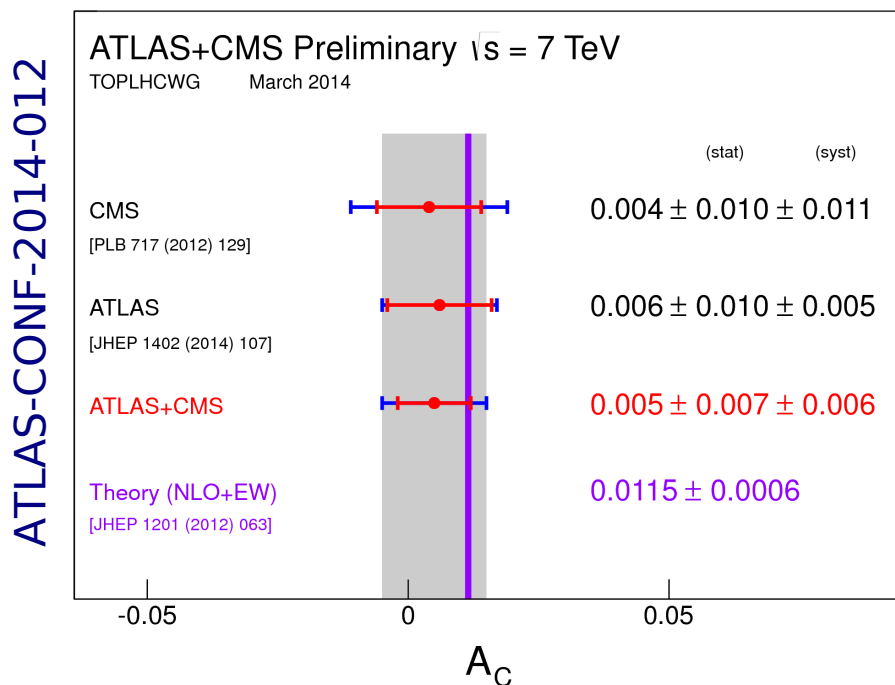
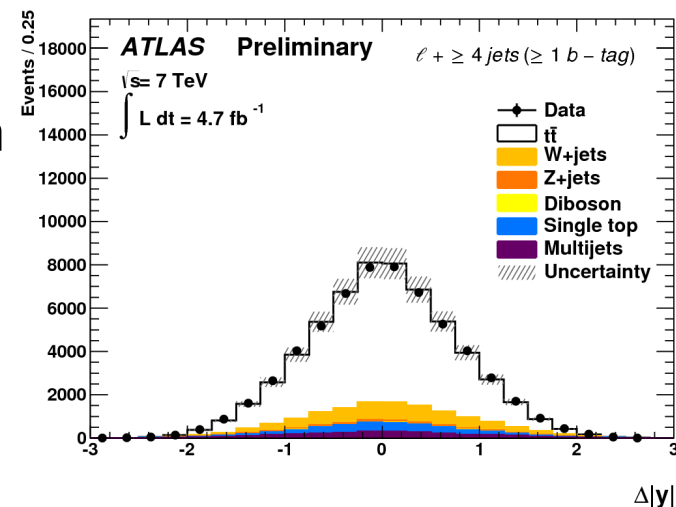


Charge asymmetry

- Charge asymmetry definition for LHC
 - Rapidity difference
- SM prediction @ NLO+EW: $A_C = 0.0115(6)$
- ATLAS analysis in lepton+jets topology
 - Full statistics at 7 TeV
 - Likelihood fit of the kinematics of the $t\bar{t}$ system
 - ATLAS-CONF-2013-078
- Combination with CMS

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

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



Summary and outlook



- The top-quark physics at LHC has entered in the precision era
- This talk presented
 - Top-quark mass
 - MC mass from template methods and pole mass from cross section
 - m_t world average (CDF + D0 + ATLAS + CMS)
 - top-antitop mass difference
 - Spin correlation
 - Charge asymmetry
- All measurements compatible with the SM
- In many analysis, precision is limited by systematic uncertainties
- Currently ATLAS is analyzing the full 8 TeV data set
- More results from ATLAS at this conference:
 - Top quark production in ATLAS (M. Hirose)
- ATLAS top-quark public results:
 - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults#List_of_preliminary_results

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Thank you!

Detector performance for top physics

- Reconstruction of the final state objects must be efficient and accurate
 - Electrons: EM calorimeter & tracking at the Inner Detector
 - Muons: track segments in Muon System and Inner Detector
 - Jets: calorimeters (EM & hadronic)
 - B-tagging: tracking in dense environments (jets)
 - Trigger: based on the e , μ , jets and missing E_T signatures.

ttbar			
Channel	Full Hadronic (45%)	Semi-leptonic (30%)	Di-leptonic (11%)
Products	6 jets	l+MET+4jets l=(e,μ)	2l+MET+2jet l=(e,μ,τ)
Background			

<p>↳</p> <p>Multijets W+jets</p>	<p>W+jets Multijets Single top Z+jets WW,ZZ</p>	<p>Z+jets Single top WW,ZZ Fake leptons</p>
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