Top Quark Properties at LHC with ATLAS and CMS experiments

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On behalf of the ATLAS and CMS Collaborations

Heavy Quarks and Leptons 2012

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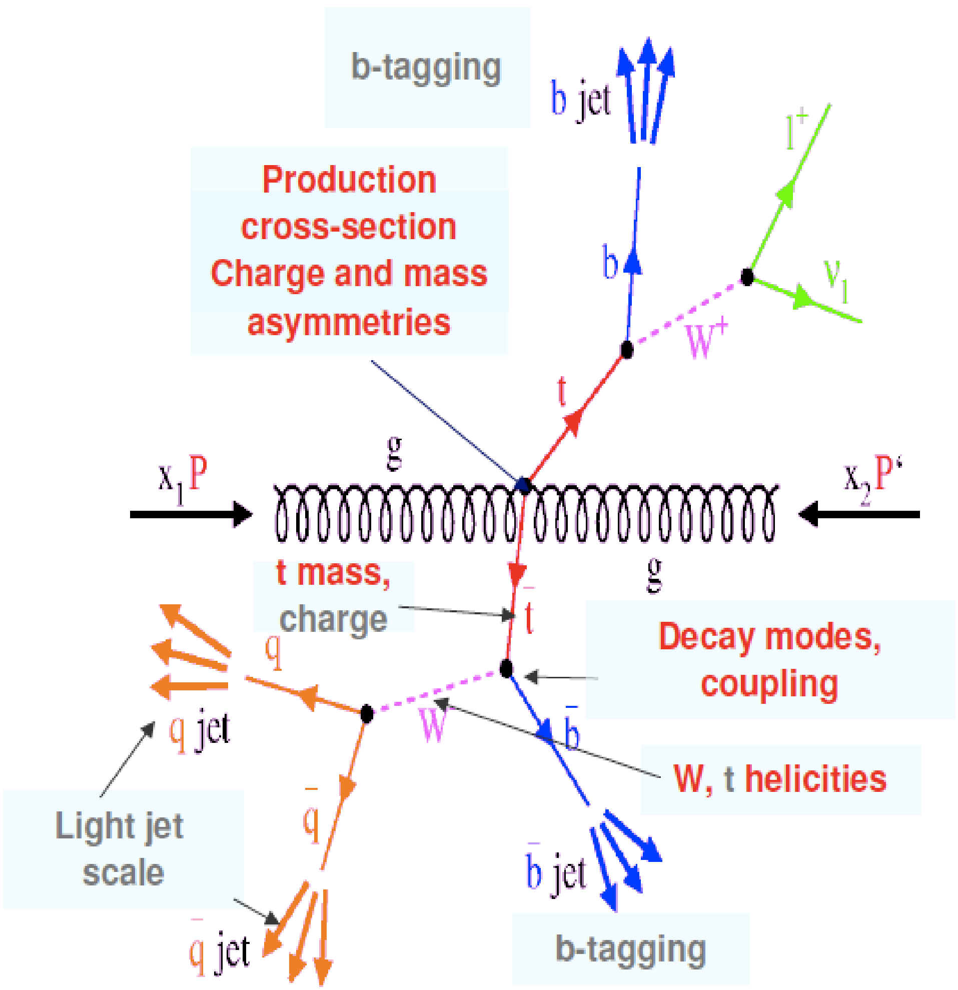
Top Quark Properties Outline

The top physics results in ATLAS and CMS presented in this talk:



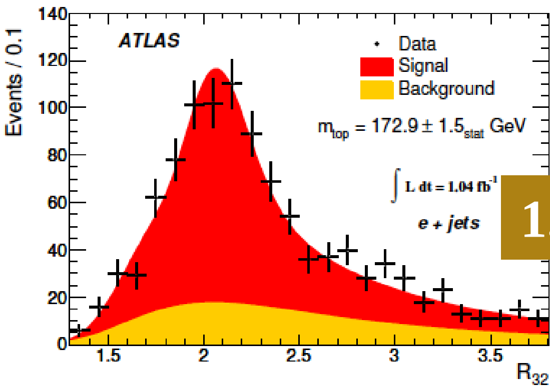
- **Top Quark Mass**
- **Top Quark Mass difference**
- **Top Quark Charge**
- **Branching Ratio**
- **FCNC**
- **W-Boson Polarization**
- **Charge Asymmetry**
- **Spin Correlation**

Top Quark Mass: lepton+jets

ATLAS Templates methods have been used to determine m_{top} in μ/e+jets

1D template:

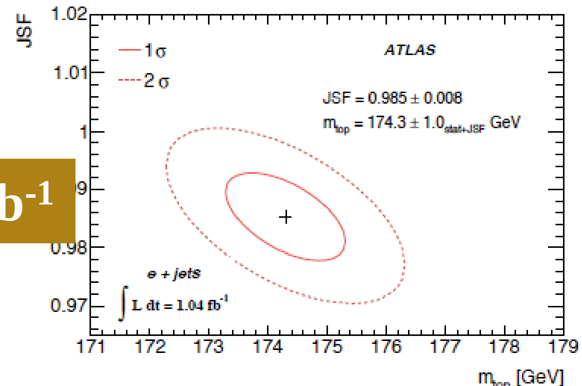
Based on the variable $R_{32} = m_{top}/m_W$



1.0 fb^{-1}

2D template:

Determine m_{top} and a global jet energy scale factor (JSF) simultaneously

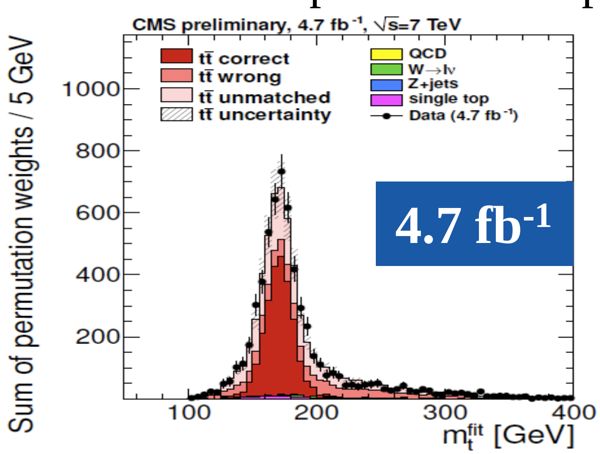


m_{top}^{l+jets} = (174.5 ± 0.6$_{stat}$ ± 2.3$_{syst}$)GeV

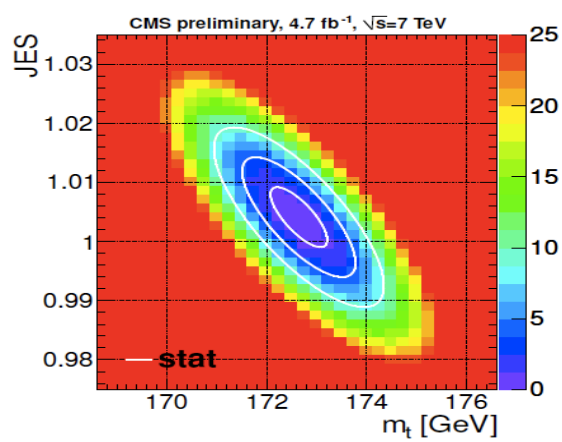
2D result

CMS Kinematic fit + **Ideogram method** is used to determine m_{top} in μ+jets

Kinematic fit exploits the compatibility with $t\bar{t}$ hypothesis



4.7 fb^{-1}



$m_{top}^{\mu+jets}$ = (172.64 ± 0.57$_{stat+JES}$ ± 1.18$_{syst}$)GeV

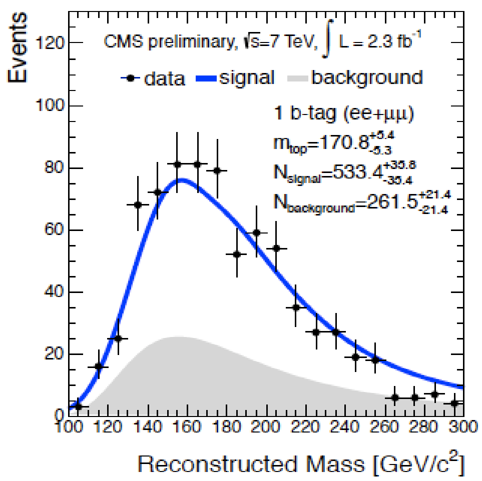
Top Quark Mass: dilepton

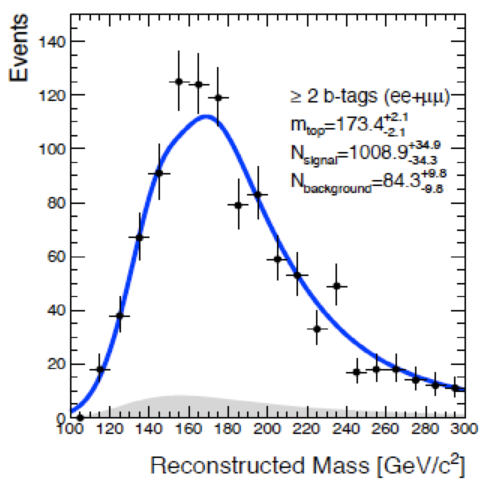
2.3 fb^{-1}

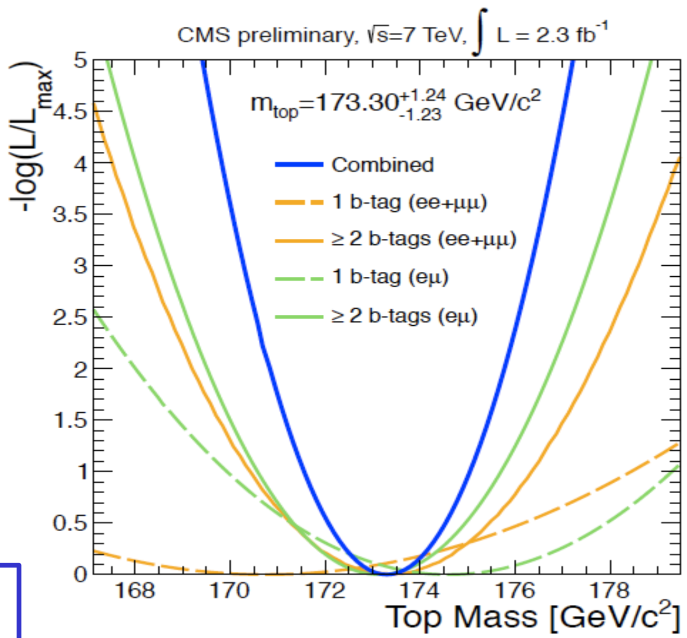
KINb method (kinematic equation describing $t\bar{t}$ system):

- Solved many times per event, for all lepton+jets combination
- jet p_T, E_T^{miss} and p_z^{tt} are varied independently according to their resolutions
- Most probable combination is chosen

Unbined likelihood fit of the m_{KINb} using templates at different masses







$$m_{top} = (173.3 \pm 1.2_{stat} \pm 2.5_{syst})\,\text{GeV}$$

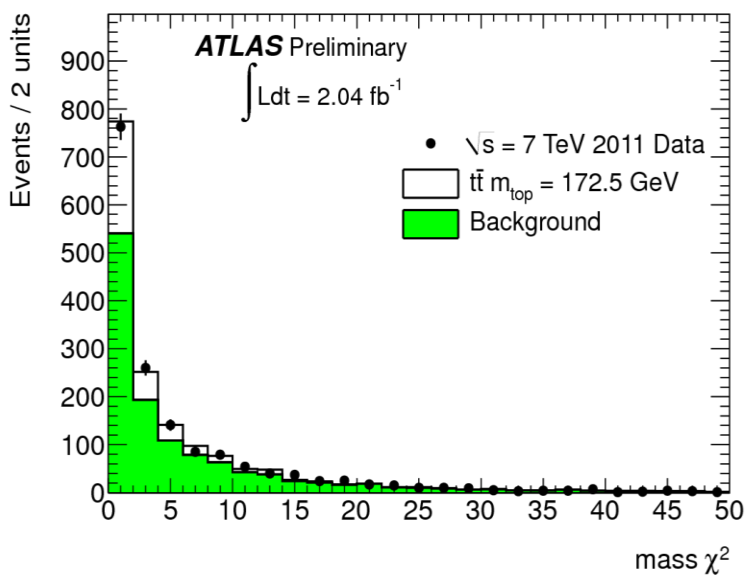
Measurement dominated by Jet Energy Scale (JES) and flavor-JES

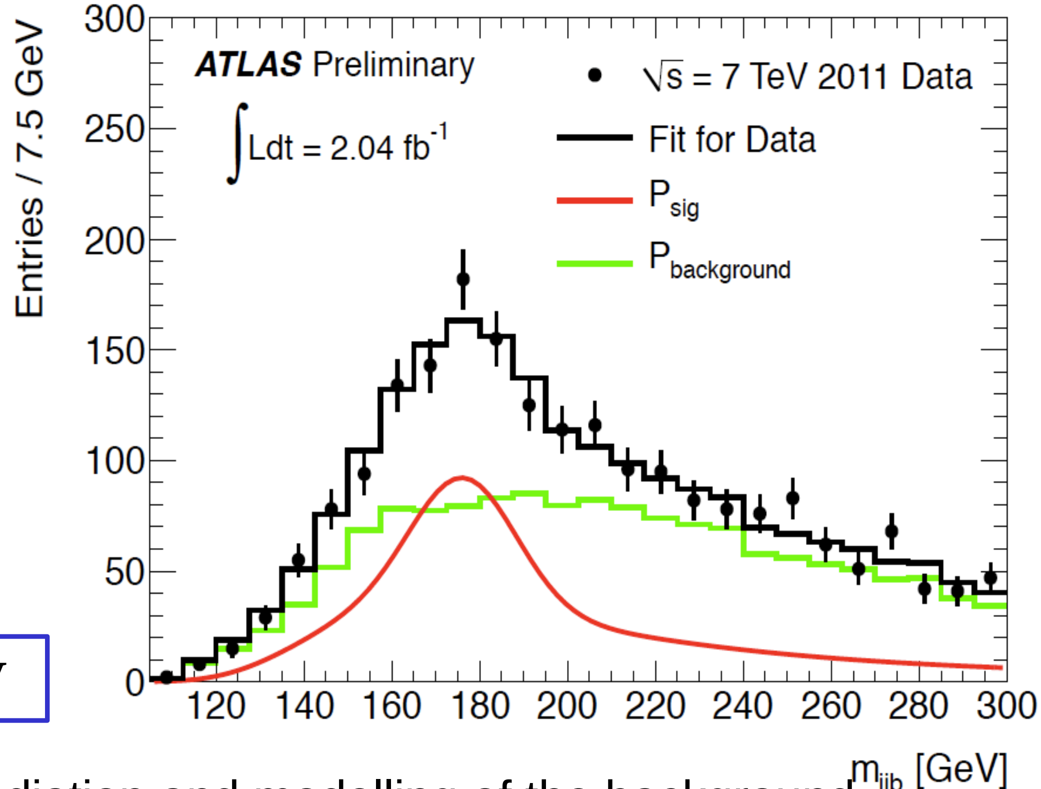
Top Quark Mass: full hadronic

ATLAS-CONF-2011-030

2.0 fb^{-1}

- m_{top} extracted with a template method
- Jet assignment done by a minimal χ^2 finding
  - More than 6 jets involved in the analysis (2 b-tagged jets)
  - Lower χ^2 is kept ($\chi^2<8$)
- Main background: Multi-jet sample, estimated by data-driven method



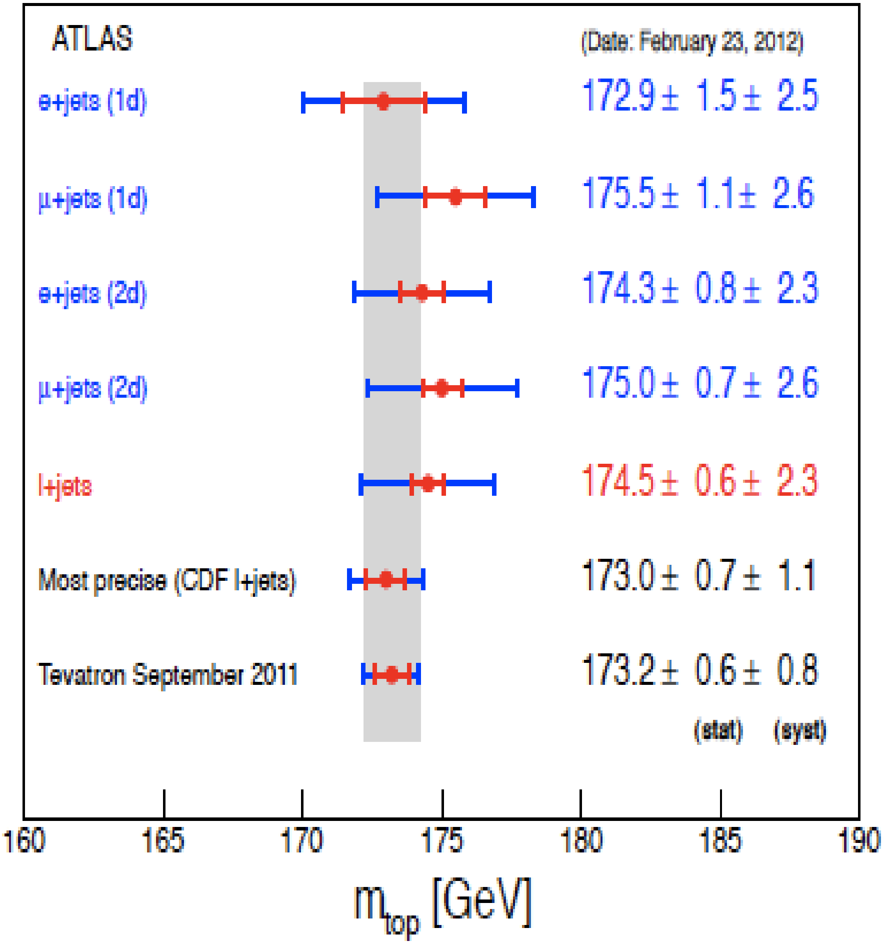


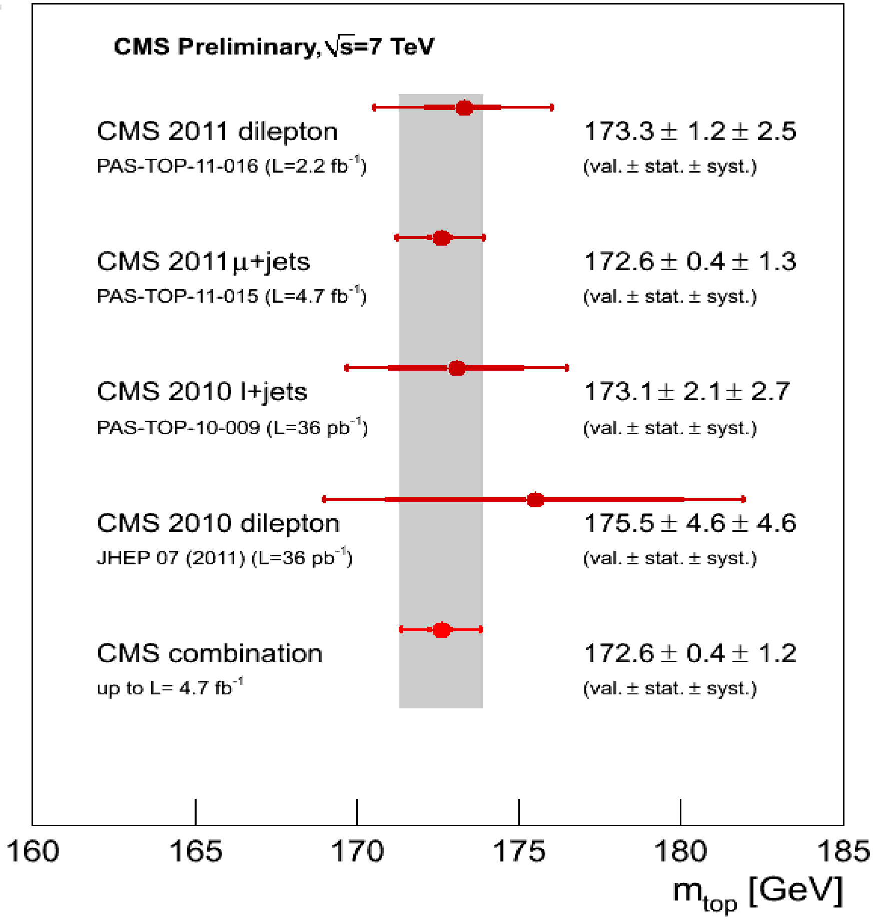
m_{top}= (174.9 ± 2.1$_{stat}$ ± 3.8$_{syst}$)GeV

Dominating uncertainties are JES, radiation and modelling of the background

Top Quark Mass: Combination

LHC combination is ongoing …





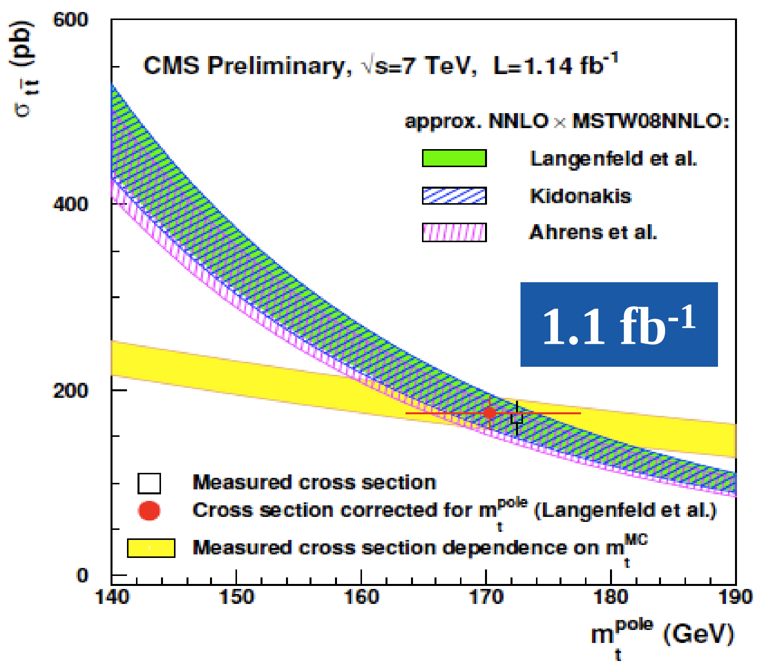
The ATLAS hadronic top mass measurement has not been included yet

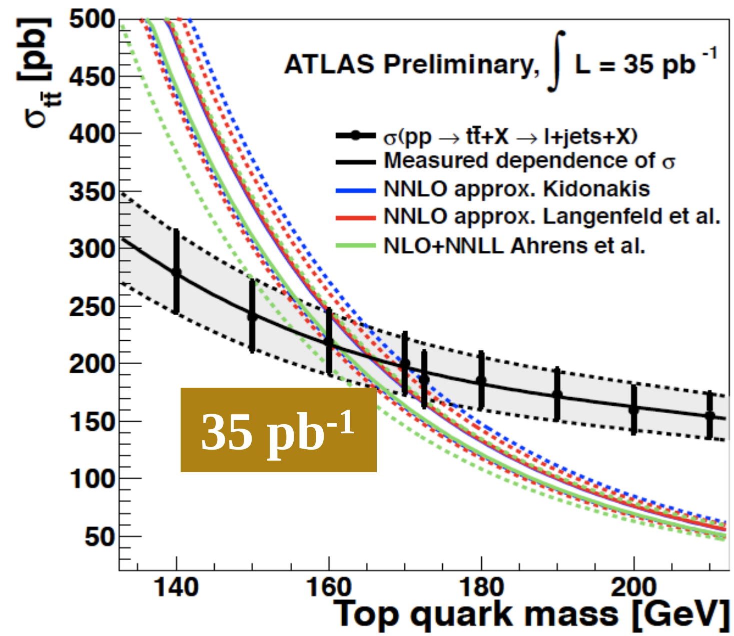
Top Quark Mass from Cross Section

CMS-PAS-TOP-11-008
ATLAS-CONF-2011-054

- Extraction of the m^{top}_{pole} from the measurement of $\sigma_{t\bar{t}}$
- Different theoretical approaches to calculate $\sigma_{t\bar{t}}$ with higher NLO corrections

$$L(m_t) = \int f_{\exp}(\sigma_{t\bar{t}}|m_t) f_{\text{th}}(\sigma_{t\bar{t}}|m_t) d\sigma_{t\bar{t}}. \Rightarrow \mathbf{m^{top}_{pole}}$$ (*well defined top mass independent of MC*)





m_{top}^{pole}= 170.3 $^{+7.3}_{6.7}$ GeV *NNLO-Langenfeld*	m_{top}^{pole}= 166.4 $^{+7.8}_{-7.3}$ GeV *NNLO-Langenfeld*
m_{top}^{pole}= 170.0 $^{+7.6}_{-7.1}$ GeV *NNLO-Kidonakis*	m_{top}^{pole}= 166.2 $^{+7.8}_{-7.4}$ GeV *NNLO-Kidonakis*
m_{top}^{pole}= 167.6 $^{+7.6}_{-7.1}$ GeV *NNLL-Ahrens*	m_{top}^{pole}= 162.2 $^{+8}_{-7}$ GeV *NNLL-Ahrens*

Top Quark Mass difference

CMS: arXiv.1204.2807
Submitted to JHEP

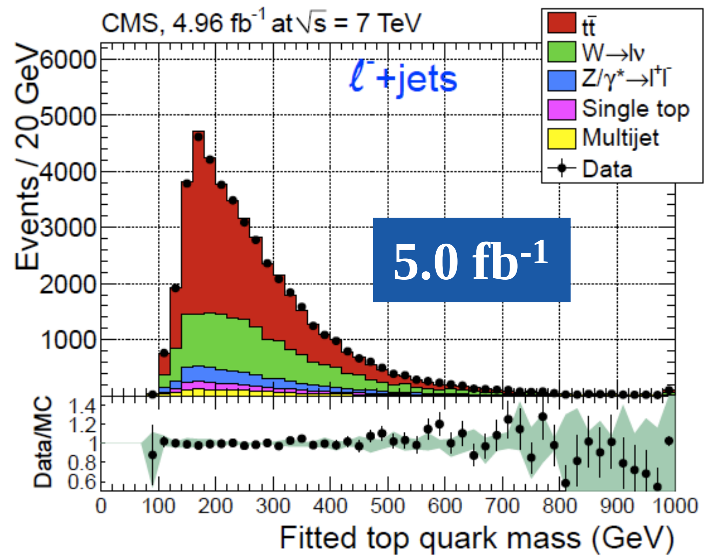
$$m_{top} = m_{anti\text{-}top}?$$

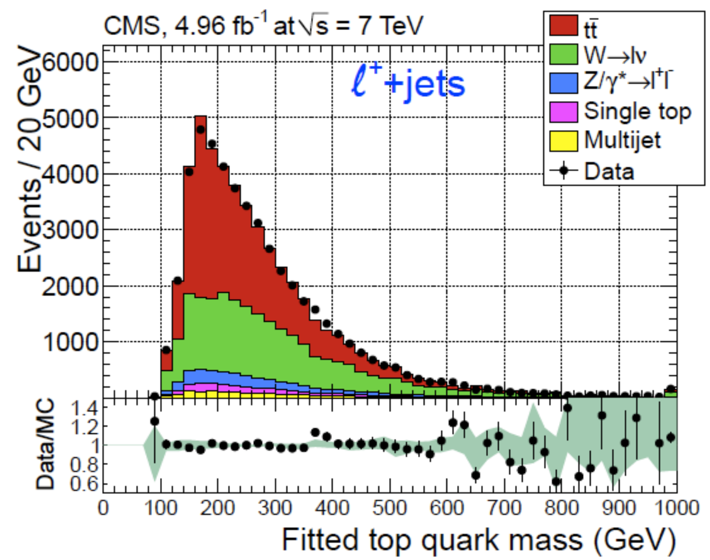
- Sample divided in l^++*jets* and l^-+*jets*
- Top mass is reconstructed using hadronic side
- Kinematic fit to perform jet association:
- Final measurement from ideogram method:
  - Likelihood for l^+ l^- separately

$$\Delta m_{top} = (-0.44 \pm 0.46_{stat} \pm 0.27_{syst})\,\mathrm{GeV}$$

Many of the main systematic uncertainties for m_{top} are cancelled in this analysis

In agreement with the consequence of CPT invariance





Top Quark Charge

CMS-PAS-TOP-11-031
ATLAS-CONF-2011-141

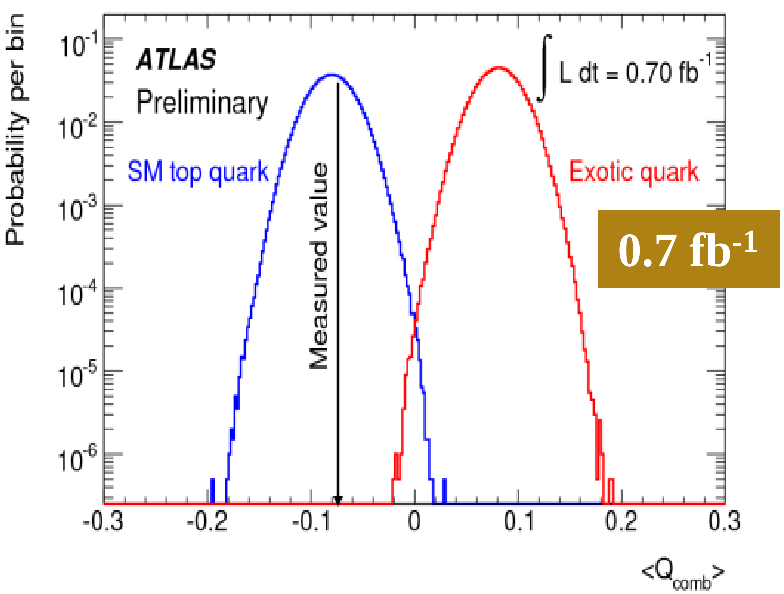
- Top quark charge Q = +2/3 by SM prediction and Q = -4/3 in Exotic scenario
- The measurement of top quark charge is based on its decay products:

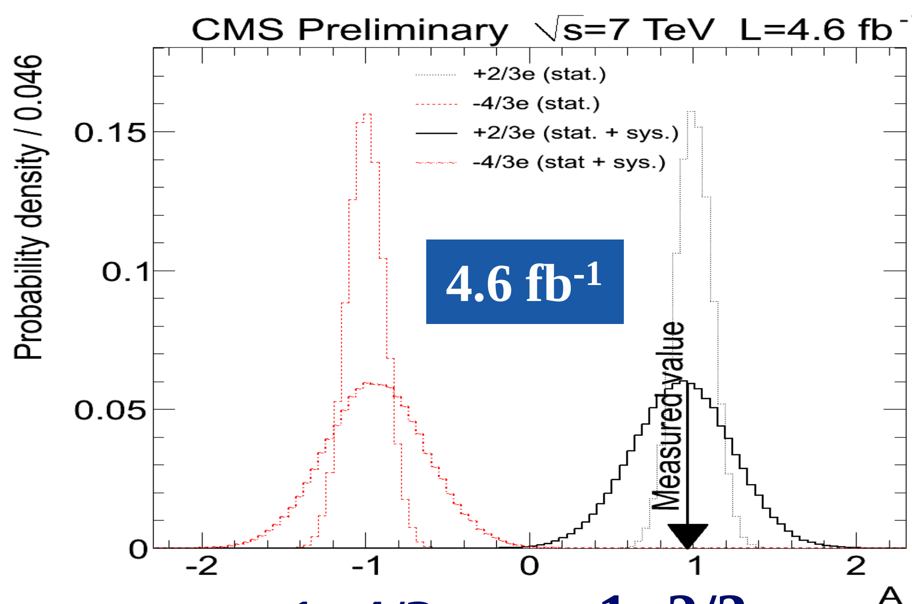
W : Charge determined with lepton charge

b-jet : Charge is not directly measured: { **Tracks charge weighting technique**, **Semi-leptonic b hadron decay** }

$$<Q_{comb}> = <Q_{bjet} \cdot Q_{lep}>$$

$$A = \frac{1}{D_S}\frac{N_{SM} - N_{XM} - <N_{BG}> D_B}{N_{SM} + N_{XM} - <N_{BG}>}$$





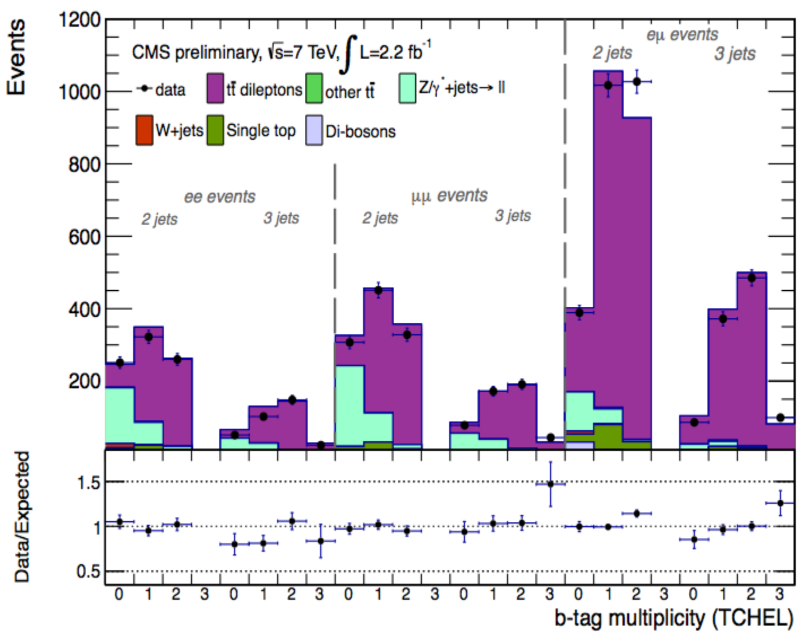
-1: 4/3e **1: 2/3e**

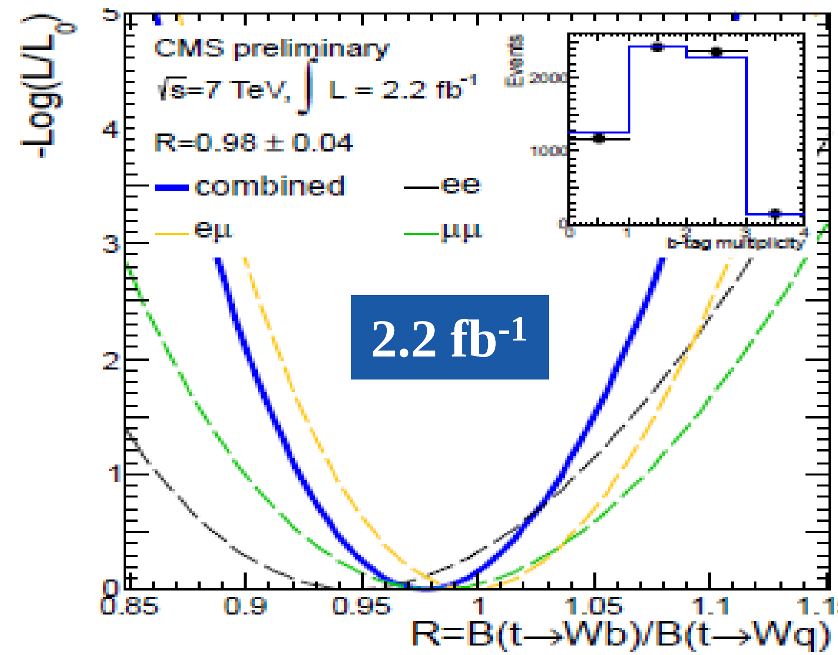
Exotic scenario is excluded with more than 5σ

Measurement of $R_b \equiv Br(t\rightarrow wb)/Br(t\rightarrow wq)$

CMS-PAS-TOP-11-029

- Standard model predicts nearly all tops decay to Wb as $V_{tb}\approx 0.999$.
- Can also measure this by measuring rate of tagged b jets in ttbar events
  - Measure rate of 2,3 jet events with 0,1,2,3 tagged b-jets
  - Fit model with R_b as free parameter to data
  - Understanding of b-tagging efficiency leading source of systematic uncertainty





R_b=0.98 ± 0.04 (stat.+syst)→ R_b>85% at 95% C.L. (if $R_b \leq 1$)

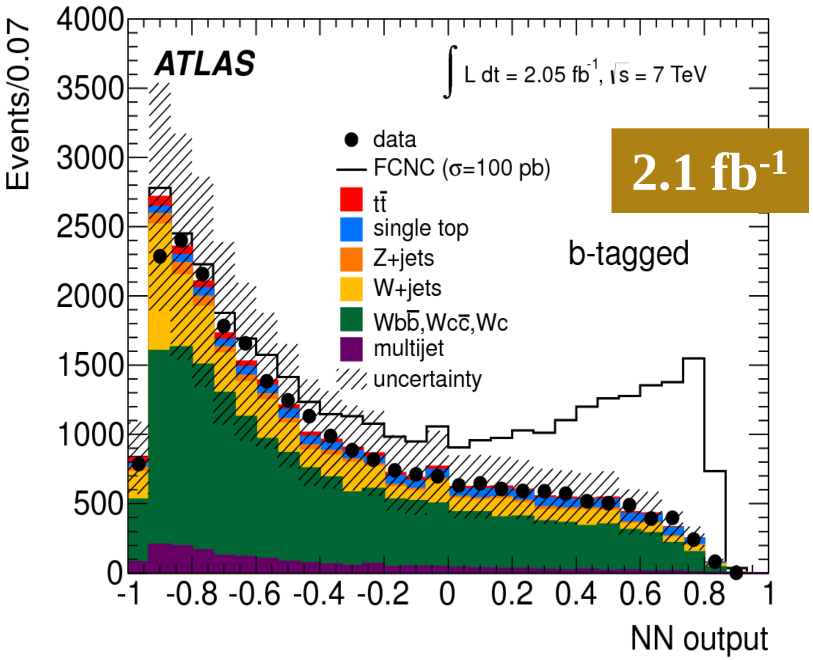
Consistent with SM prediction

FCNC In Single Top

ATLAS: PLB 712 (2012) 351-369

- Standard model prohibits flavor changing neutral currents.
- Test this by looking for processes with *tug* and *tcg* couplings in single top
- Use 10 variable Neural Network discriminant

Variable	Significance (σ)
p_T^W	57
$\Delta R(b\text{-jet,lep})$	28
Lepton charge	22
m_{top}	20
$m_{b\text{-jet}}$	15
$\eta_{b\text{-jet}}$	12
$\Delta\phi(W,b\text{-jet})$	11
p_T^{lep}	12
$p_T^{b\text{-jet}}$	6.5
$\cos\theta^*$	5.7
$\Delta R(W,b\text{-jet})$	5.0



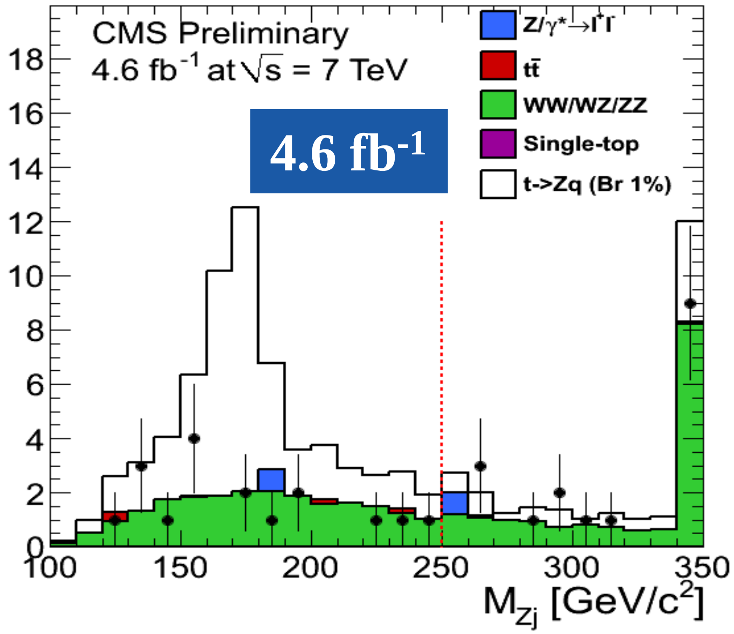
BR(t → ug) < 5.7×10^{-5}
BR(t → cg) < 2.7×10^{-4}

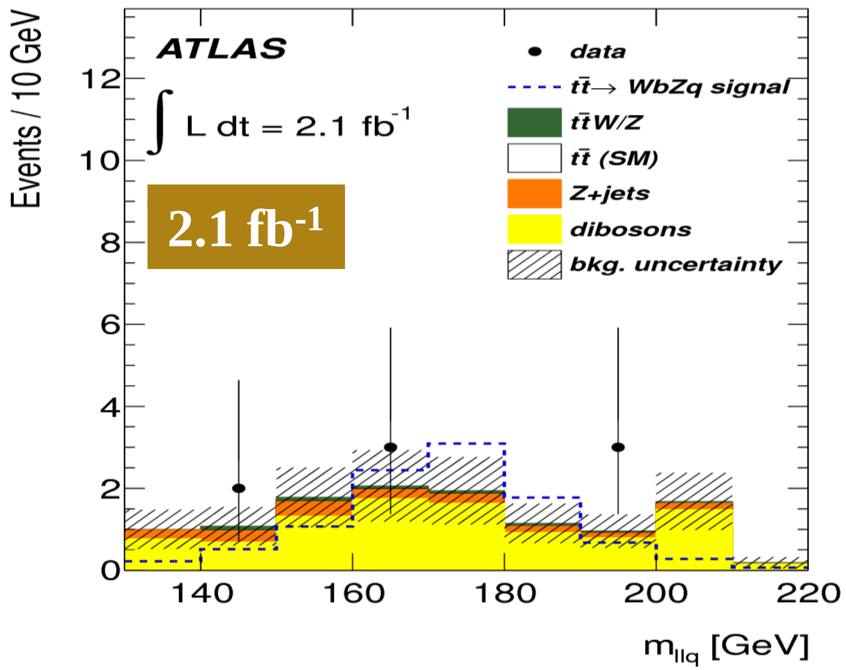
At 95% C.L.

FCNC In $t\bar{t}$

CMS-PAS-TOP-11-028
ATLAS : arXiv:1206.0257, submitted to JHEP

- **look for FCNC coupling tqZ in $t\bar{t}$ decays**
  - One t-->wb and another t-->Zq
  - Three lepton final state with small background (mainly diboson)





At 95% C.L.

BR(t→Zq) < 0.34%	**BR(t→Zq) < 0.73%**

W boson polarization

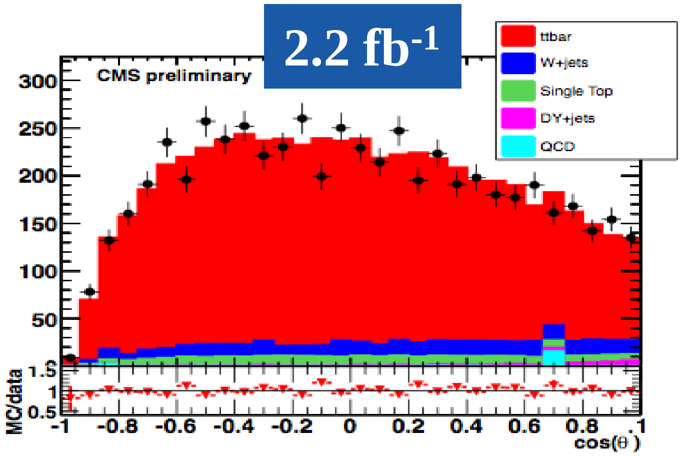
ATLAS: arXiv:1205.2484, submitted JHEP
CMS-PAS-TOP-11-020

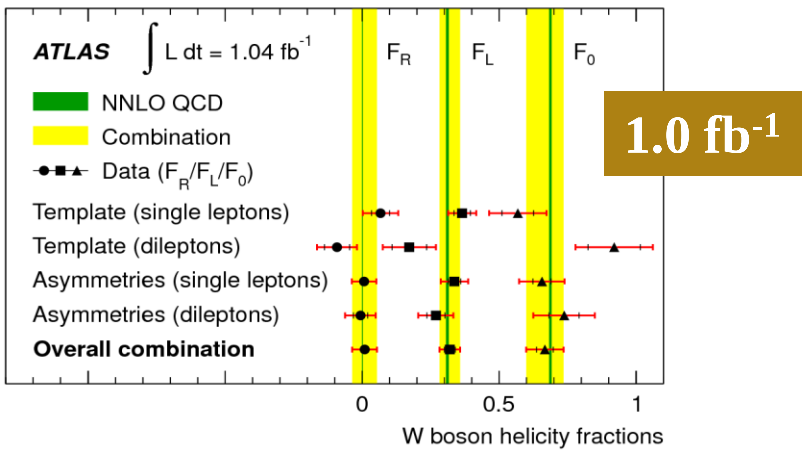
- Investigate V-A structure of Wtb vertex by examining polarization of W from top decay
- Polarization of W by NNLO calculation of SM :

  $\mathbf{F_0}$ = (68.5±0.5)%, $\mathbf{F_L}$ = (31.1±0.5)%, $\mathbf{F_R}$ = (0.17±0.01)%

Measure opening angle cos(θ*) between l and b in W rest-frame

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right) F_0 + \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_L + \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_R\,.$$





$$F_0 = 0.567 \pm 0.074(stat.) \pm 0.047(syst.)$$
$$F_L = 0.393 \pm 0.045(stat.) \pm 0.029(syst.)$$
$$F_R = 0.040 \pm 0.035(stat.) \pm 0.044(syst.)$$

$$F_0 = 0.67 \pm 0.03(stat.) \pm 0.06(syst.)$$
$$F_L = 0.32 \pm 0.02(stat.) \pm 0.03(syst.)$$
$$F_R = 0.01 \pm 0.01(stat.) \pm 0.04(syst.)$$

Good agreement with SM prediction

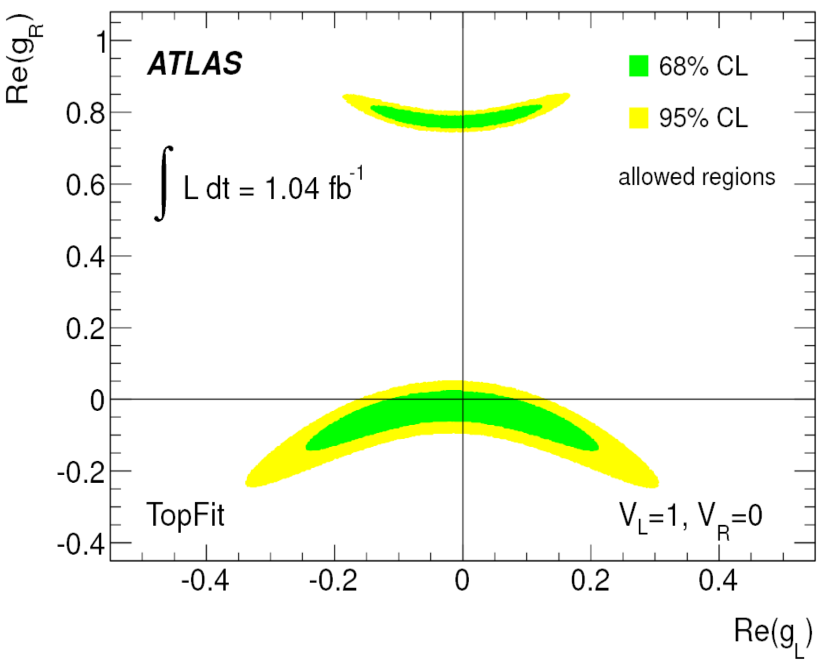
W boson polarization : Anomalous WTB

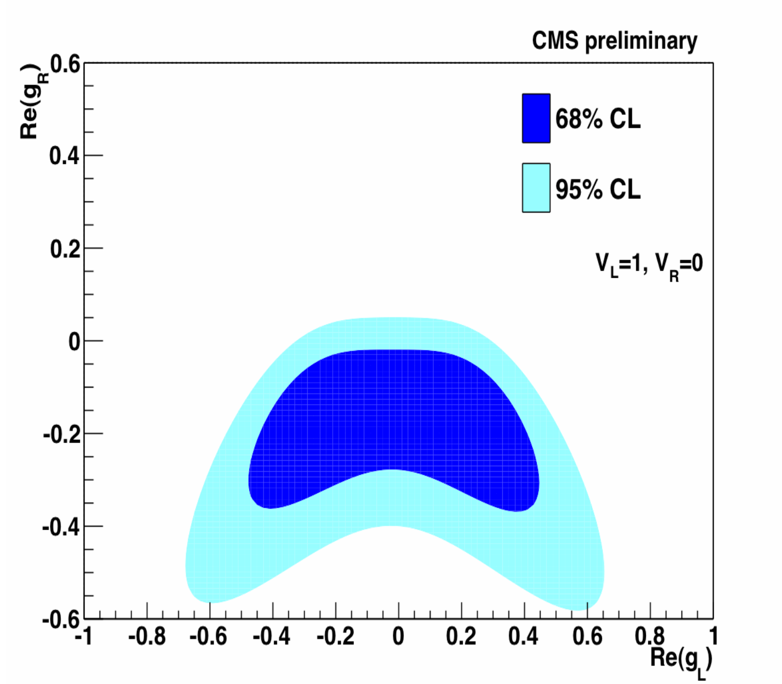
Constraints on possible new physics

New physics can be parameterized in terms of an effective Lagrangian

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-} + \text{h.c.}$$

Allowed region in g_R vs g_L (assuming V_L=1 and V_R=0)



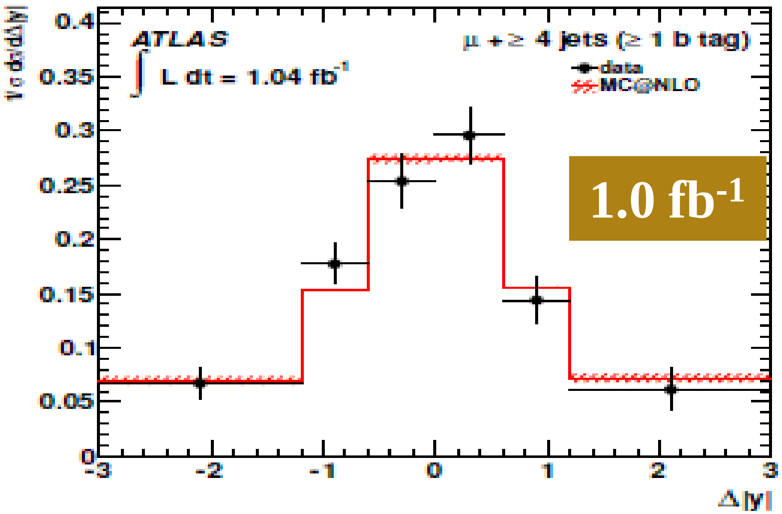


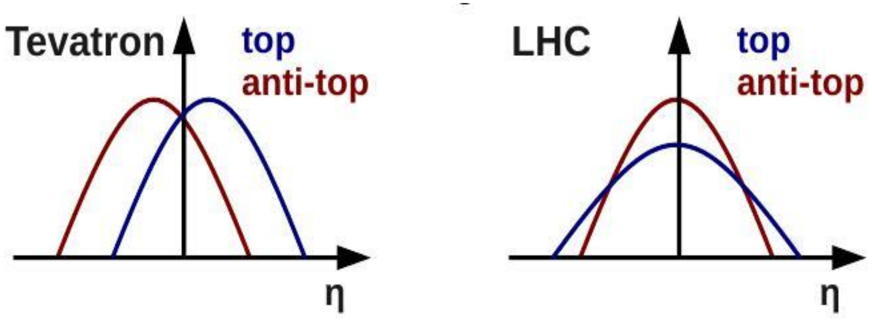
Improve previously obtained limits

Charge Asymmetry : l+jets

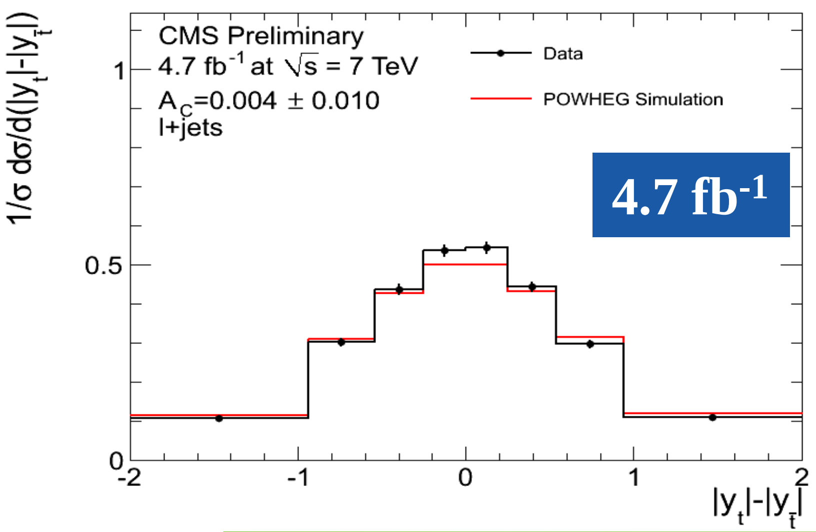
ATLAS: arXiv:1203.4211, submitted EJPC
CMS: CMS-PAS-TOP-11-030

- Expect small asymmetry between top and anti-top in SM





- Observable : $\Delta|y| = |y_t| - |y_{\bar{t}}|$
- Subtract background and apply unfolding procedure to obtain truth-level distribution



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

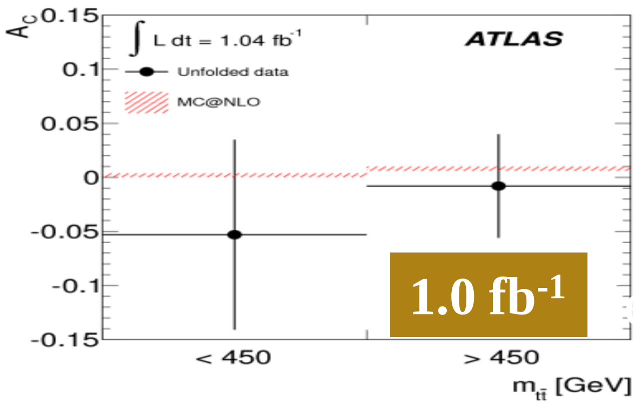
CMS $A_c = 0.004 \pm 0.010(stat.) \pm 0.012(syst.)$

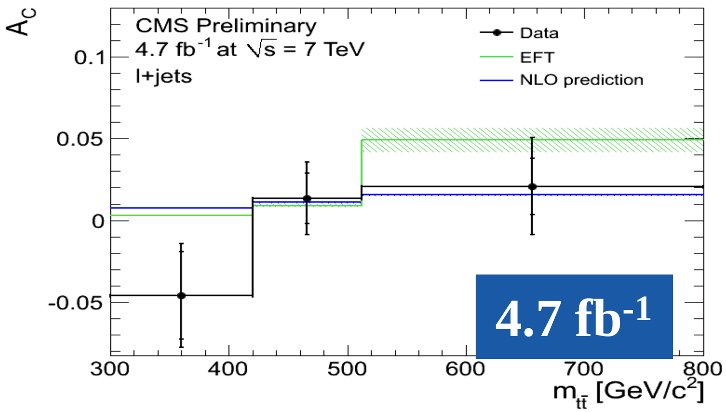
ATLAS $A_c = -0.018 \pm 0.028(stat.) \pm 0.023(syst.)$

Consistent with SM prediction

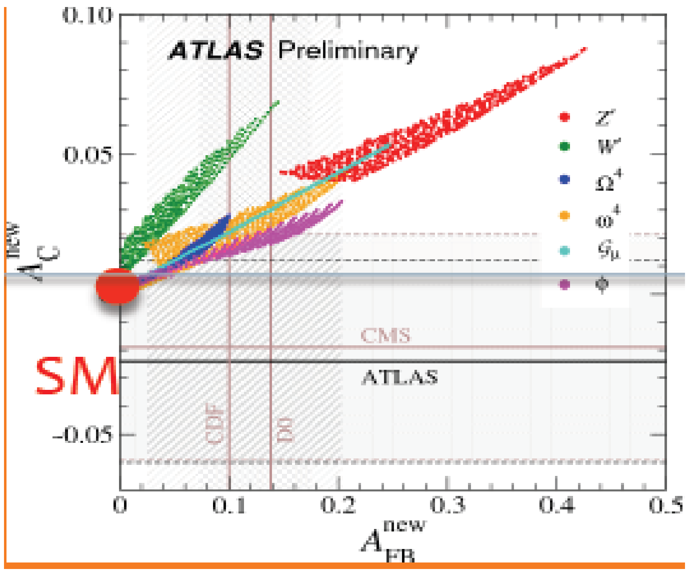
Differential Charge Asymmetry : l+jets

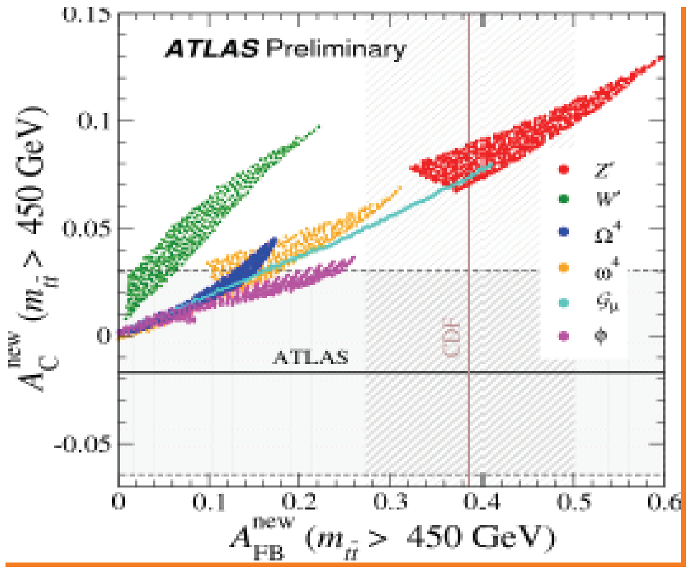
- Investigate Tevatron (CDF) excess for $M_{t\bar{t}}$ > 450 GeV





no significant dependence on the $t\bar{t}$ invariant mass (rapidity and Pt, see backup)

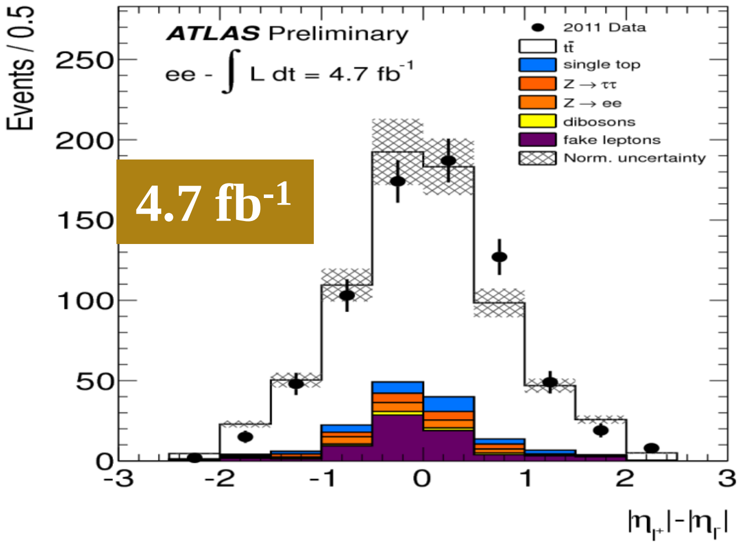


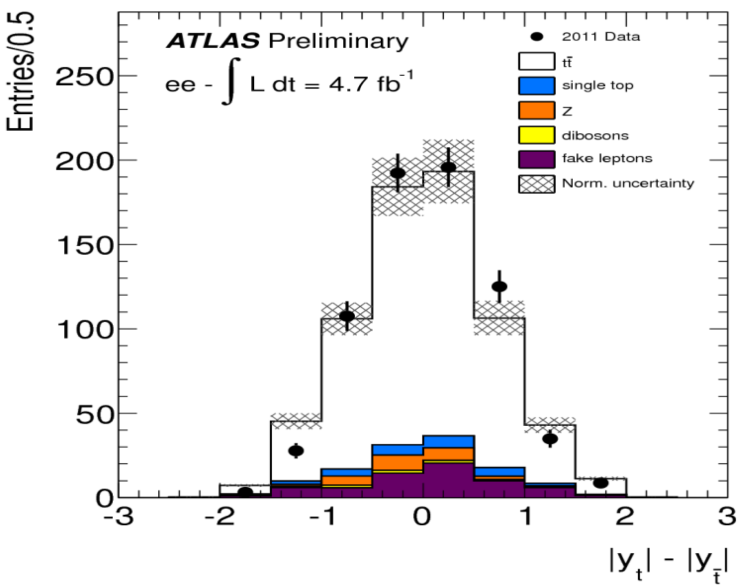


Disfavor models with flavor changing Z' and W'

Charge Asymmetry : dilepton

ATLAS-CONF-2012-057





- **The charge asymmetry from $t\bar{t}$ *is transmitted to the* leptons**
- **It is possible to also measure a purely leptonic based asymmetry**
- **Rapidity difference between l^+ and l^-**

SM (MC@NLO)

$$A_C^{\ell\ell} = 0.004 \pm 0.001 \text{ and } A_C^{t\bar{t}} = 0.006 \pm 0.002$$

Measurement :

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

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

Combined ATLAS dilepton and l+jets :

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

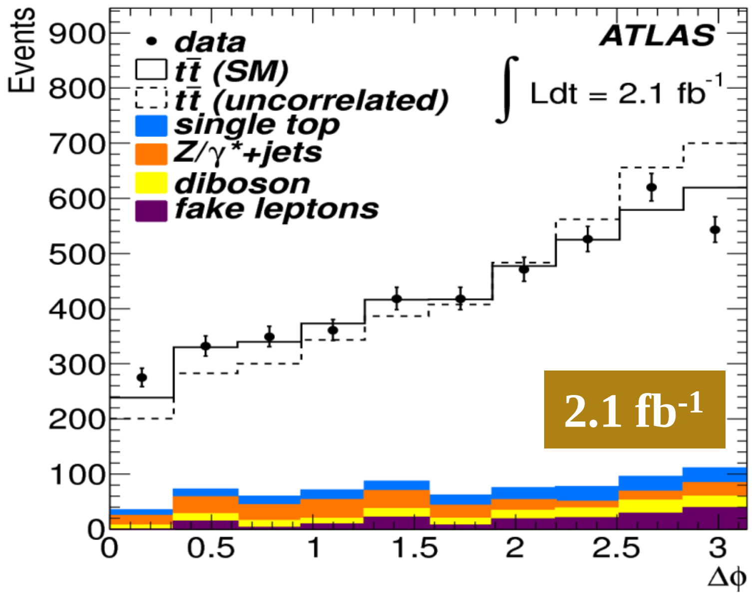
Consistent with SM prediction

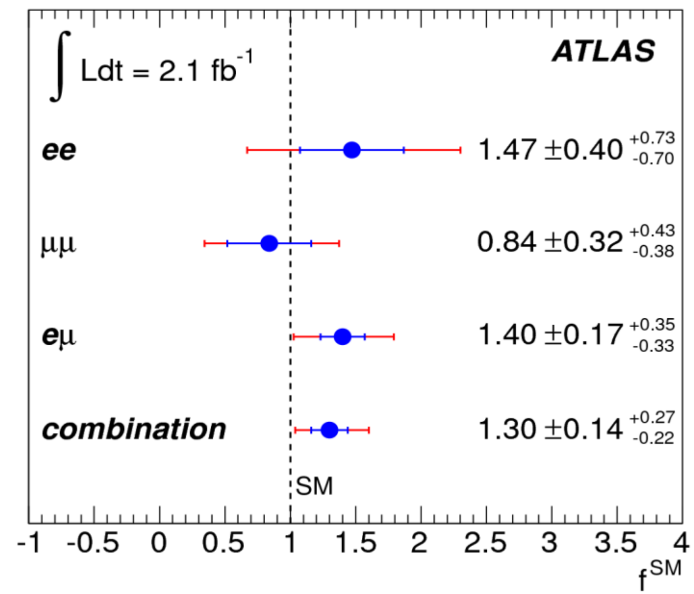
Spin Correlations

ATLAS: PRL. 108,212001(2012)

- Spins of t and $\bar{t}$ are predicted to be correlated in SM.
- Top decay before hadronization allows to measure top spin from its decay products.
- By dilepton channel, Δφ between 2 leptons in the lab frame.

$$f_{SM} F_{SM-spincorr}(\Delta\phi) + (1 - f_{SM}) F_{no-spincorr}(\Delta\phi)$$





Zero spin correlation hypothesis excluded at 5.1σ

Fit result recast as asymmetry

$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}.$$

$$A_{helicity} = 0.40 \pm 0.04(stat.) \pm^{0.08}_{0.07} (syst.)$$

$$A^{SM}_{helicity} = 0.31$$

Summary

- **LHC is working really well as a top factory!**

  -- **thousands of top quarks have been produced**

- **Rich program of top properties measurements now underway. Already several LHC measurement now worlds best.**

  -- **Observation of spin correlations, W polarization…**

- **All measurements are consistent with SM (so far).**

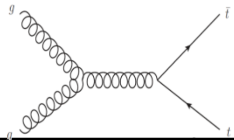
- **Systematic uncertainties dominate most measurements now.**

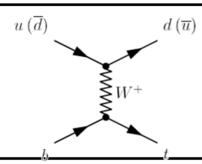
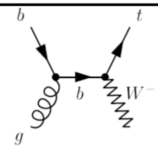
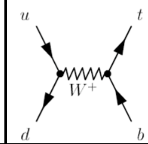
  -- **Will improve with better understanding of detector and top modeling**

Thank you very much!

Top quark Physics with ATLAS & CMS

Top quark decays take place almost exclusively: **t** $\Longrightarrow$ **W+b**

tt			
Channel	All Hadronic (quark:45%) (τ^{had}:12.3)	Single lepton (l=e or μ → ~30%) (l= τ^{lep} →6%)	Dilepton (ee,μμ,eμ →~4.5%) ($e\tau^{lep}$,$\mu\tau^{lep}$,$\tau^{lep}\tau^{lep}$ →~1.9%)
Products	6 jets	l+E_T^{miss}+4jets l=(e,μ)	2l+E_T^{miss}+2jet l=(e,μ,τ)
Background			

Single top			
Channel	t-channel	Wt production	s-channel
Products	l+E_T^{miss}+2jets	2l+E_t^{miss}+1jets	l+E_t^{miss}+2jet
Background			

Top Quark Mass : systematic uncertainties

ATLAS: arXiv.1203.5755
Submitted to EPJC

1.0 fb^{-1}

	1d-analysis		2d-analysis		Combinations	
	e+jets	μ+jets	e+jets	μ+jets	1d	2d
Measured value of m_{top}	172.93	175.54	174.30	175.01	174.35	174.53
Data statistics	1.46	1.13	0.83	0.74	0.91	0.61
Jet energy scale factor	na	na	0.59	0.51	na	0.43
Method calibration	0.07	< 0.05	0.10	< 0.05	< 0.05	0.07
Signal MC generator	0.81	0.69	0.39	0.22	0.74	0.33
Hadronisation	0.33	0.52	0.20	0.06	0.43	0.15
Pileup	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Underlying event	0.06	0.10	0.42	0.96	0.08	0.59
Colour reconnection	0.47	0.74	0.32	1.04	0.62	0.55
ISR and FSR (signal only)	1.45	1.40	1.04	0.95	1.42	1.01
Proton PDF	0.22	0.09	0.10	0.10	0.15	0.10
W+jets background normalisation	0.16	0.19	0.34	0.44	0.18	0.37
W+jets background shape	0.11	0.18	0.07	0.22	0.15	0.12
QCD multijet background normalisation	0.07	< 0.05	0.25	0.33	< 0.05	0.20
QCD multijet background shape	0.14	0.12	0.38	0.30	0.09	0.27
Jet energy scale	1.21	1.25	0.63	0.71	1.23	0.66
b-jet energy scale	1.09	1.21	1.61	1.53	1.16	1.58
b-tagging efficiency and mistag rate	0.21	0.13	0.31	0.26	0.17	0.29
Jet energy resolution	0.34	0.38	0.07	0.07	0.36	0.07
Jet reconstruction efficiency	0.08	0.11	< 0.05	< 0.05	0.10	< 0.05
Missing transverse momentum	< 0.05	< 0.05	0.12	0.16	< 0.05	0.13
Total systematic uncertainty	2.46	2.56	2.31	2.57	2.50	2.31
Total uncertainty	2.86	2.80	2.46	2.68	2.66	2.39

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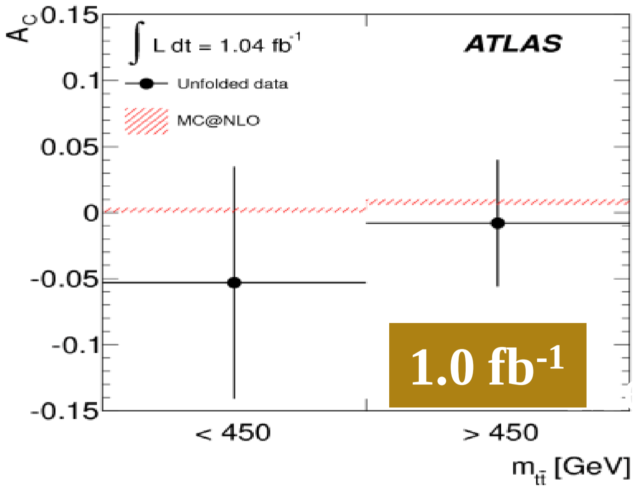
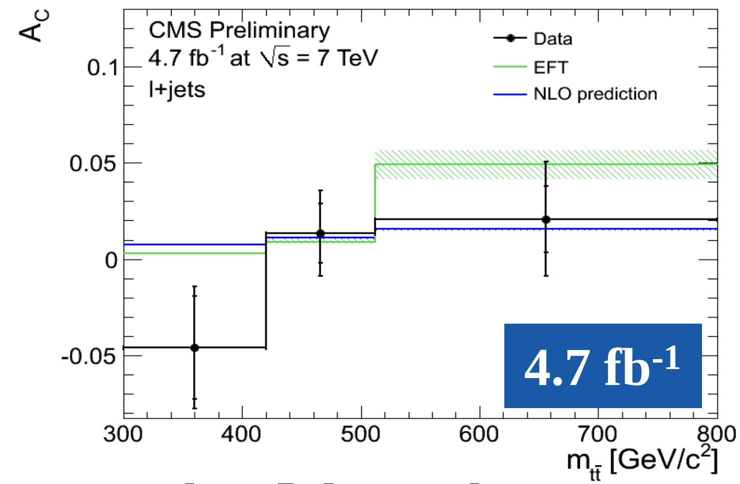
4.7 fb^{-1}

	δ_{m_t} (GeV)	δ_{JES}
Calibration	0.15	0.001
b-tagging	0.17	0.002
b-JES	0.66	0.000
p_T- and η-dependent JES	0.23	0.003
Jet energy resolution	0.21	0.003
Missing transverse energy	0.08	0.001
Factorization scale	0.76	0.007
ME-PS matching threshold	0.25	0.007
Non-$t\bar{t}$ background	0.09	0.001
Pile-up	0.38	0.005
PDF	0.05	0.001
Total	1.18	0.012

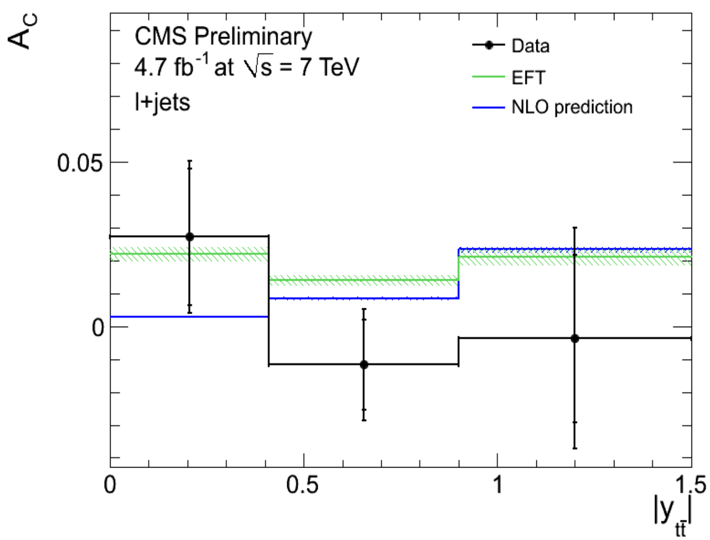
Differential Charge Asymmetry : l+jets

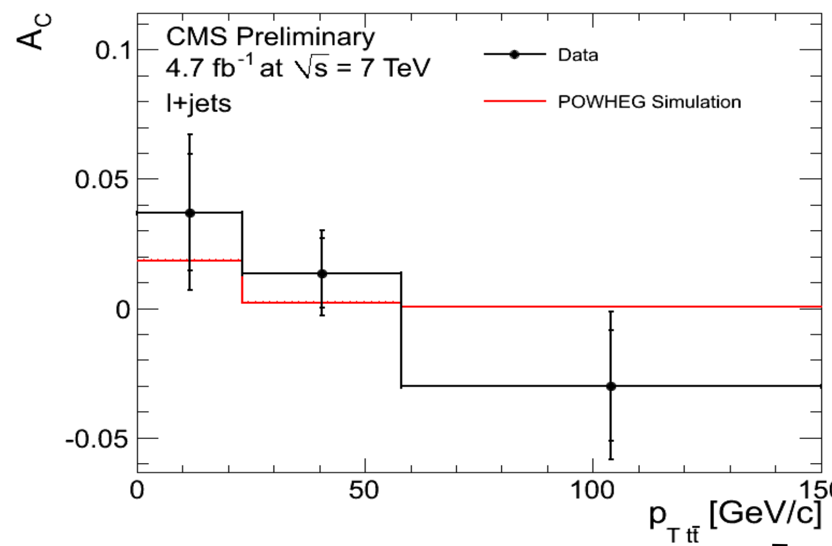
ATLAS: arXiv:1203.4211, submitted EJPC
CMS: CMS-PAS-TOP-11-030





no significant dependence on the $t\bar{t}$ invariant mass





no significant dependence on the rapidity and Pt of $t\bar{t}$