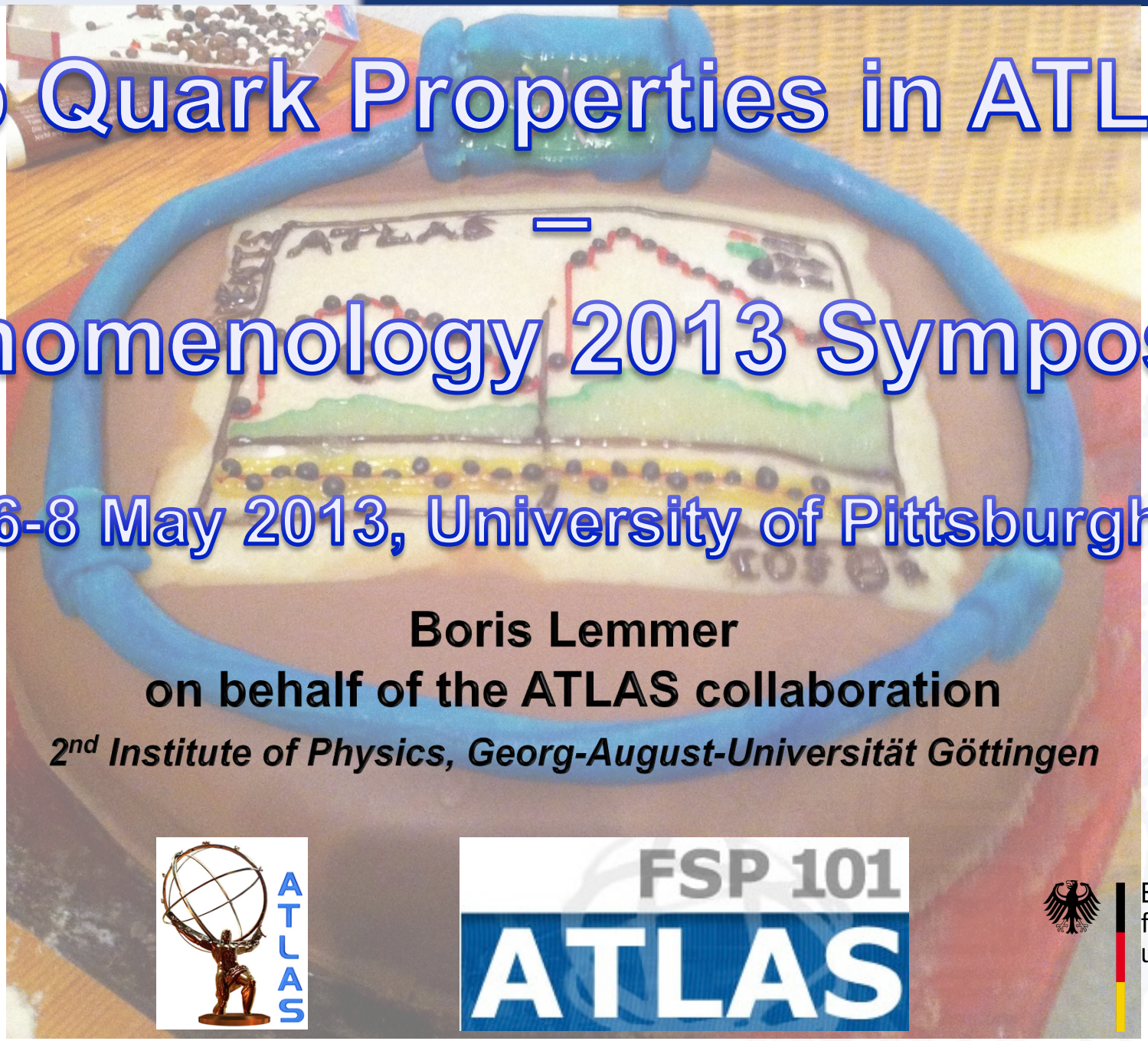


Top Quark Properties in ATLAS
–
Phenomenology 2013 Symposium

6-8 May 2013, University of Pittsburgh

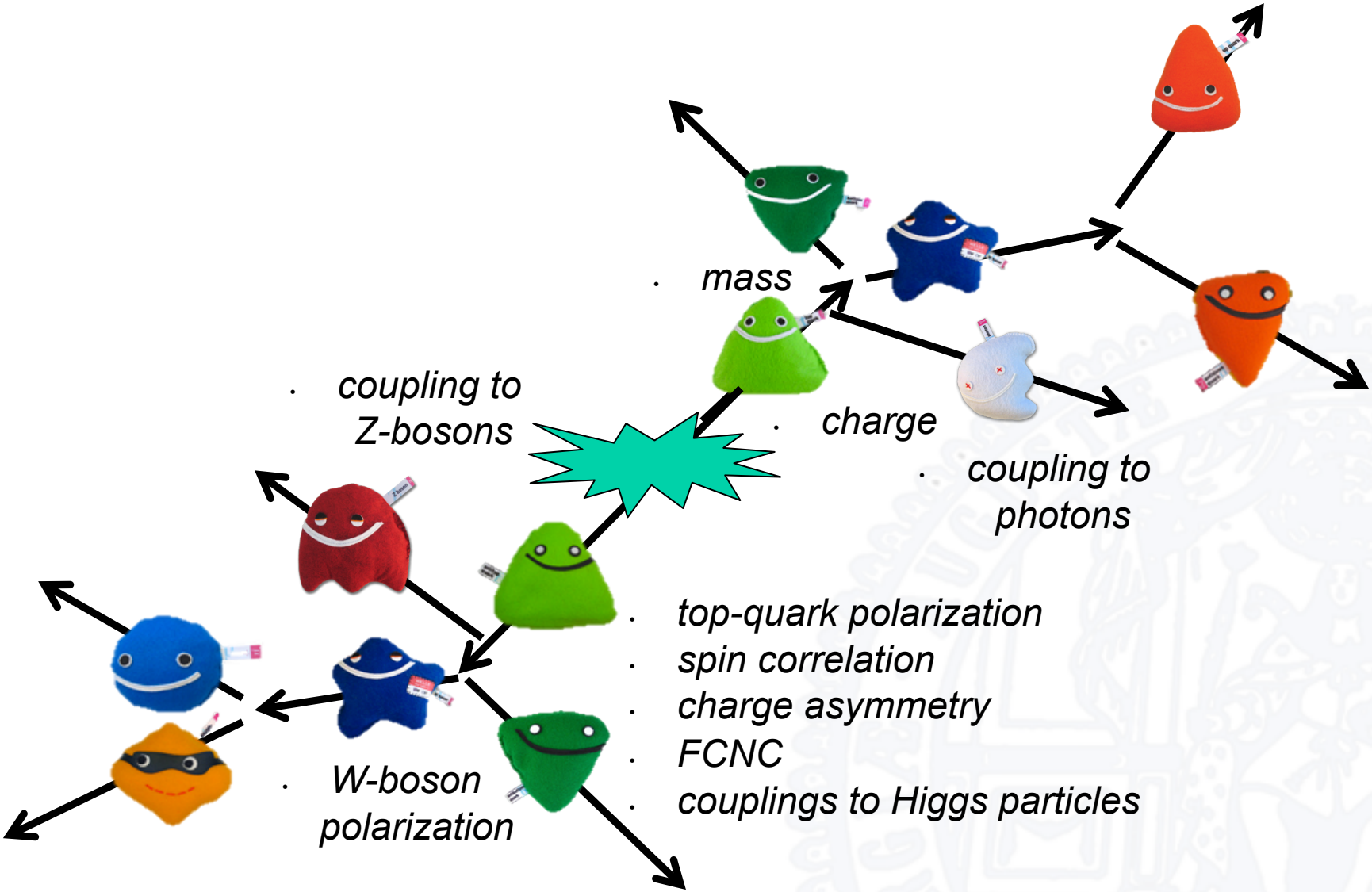
Boris Lemmer
on behalf of the ATLAS collaboration
2nd Institute of Physics, Georg-August-Universität Göttingen

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

FSP 101 ATLAS

Bundesministerium für Bildung und Forschung

The Top Quark: An Interesting Friend



Top Mass

Top Mass

- Fundamental parameter of SM without prediction
- Lepton+jets [1]
  - 1D fit: $R_{32} = \frac{m_{\mathrm{top}}^{\mathrm{reco}}}{m_{\mathrm{W}}^{\mathrm{reco}}}$
  - 2D fit: m_{top} vs. jet energy scale factor (JSF)
- Dilepton [2]
  - m_{T2} variable in eμ channel
- Fully hadronic [3]
  - Template fit: m_{jjb}

Results

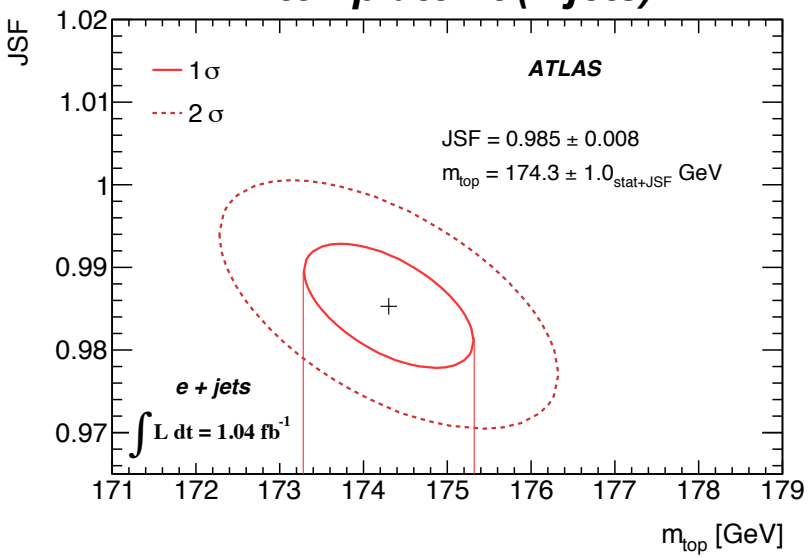
- Best single result: 2D template fit for l+jets channel
- LHC combination (ATLAS: l+jets and full hadronic):

m_{top} = 173.3 ± 0.5 (stat.) ± 1.3 (syst.)		
ATLAS-CONF-2012-095	full had.and l+jets	≤ 4.9 fb^{-1} @ 7 TeV

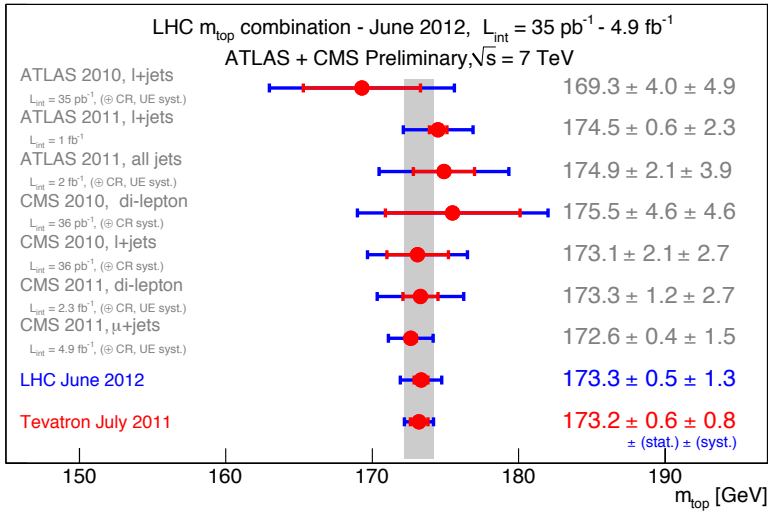
Main Systematics (2D, l+jets)

- bJES (1.58 GeV)
- ISR/FSR (1.01 GeV)
- JES (0.66 GeV)

2D template fit (l+jets)



LHC Combination



[1] Eur. Phys. J. C (2012) 72:2046
[2] ATLAS-CONF-2012-082
[3] ATLAS-CONF-2012-030

Top Charge

Top Charge

- No direct measurement so far
- Instead: Exclusion of possible alternative: -4/3 *e*
- Lepton+jets channel combination:
  - Weighted jet charge method

$$Q_{\text{b-jet}} = \frac{\sum_i q_i \left|\vec{j}\cdot\vec{p}_i\right|^{\kappa}}{\sum_i \left|\vec{j}\cdot\vec{p}_i\right|^{\kappa}} \qquad Q_{\text{comb.}} = Q_{\text{b-jet}} \cdot Q_{\text{lepton}}$$

q_i : track charge
$\vec{j}$: jet axis
$\vec{p}_i$: track momentum
κ : separation tuning factor

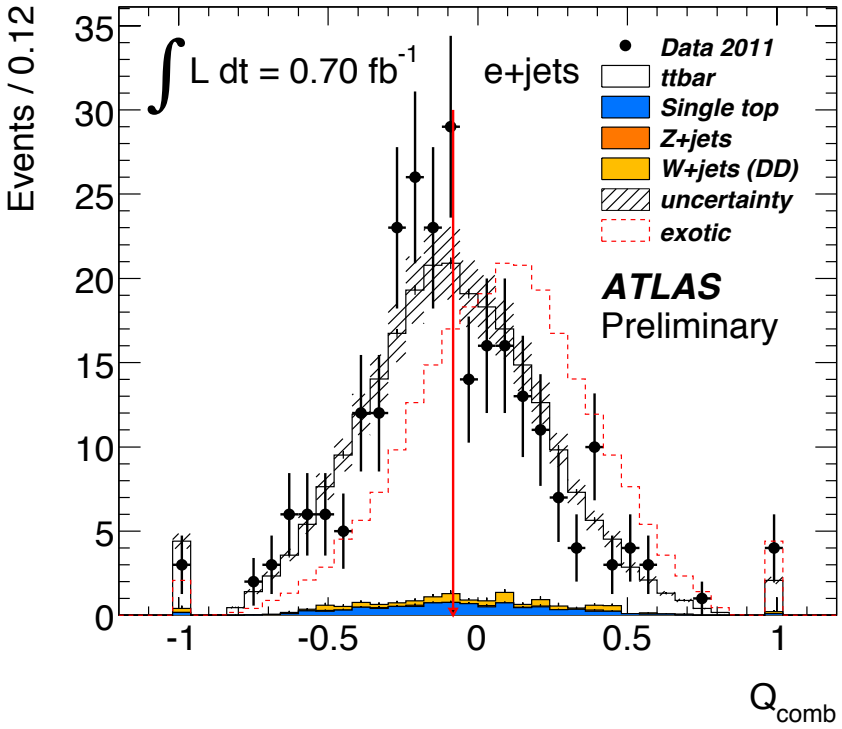
  - Soft muon method

Result

Exotic charge of -4/3 *e* excluded by > 5 σ

ATLAS-CONF-2011-141	l+jets	0.7 fb^{-1} @ 7 TeV

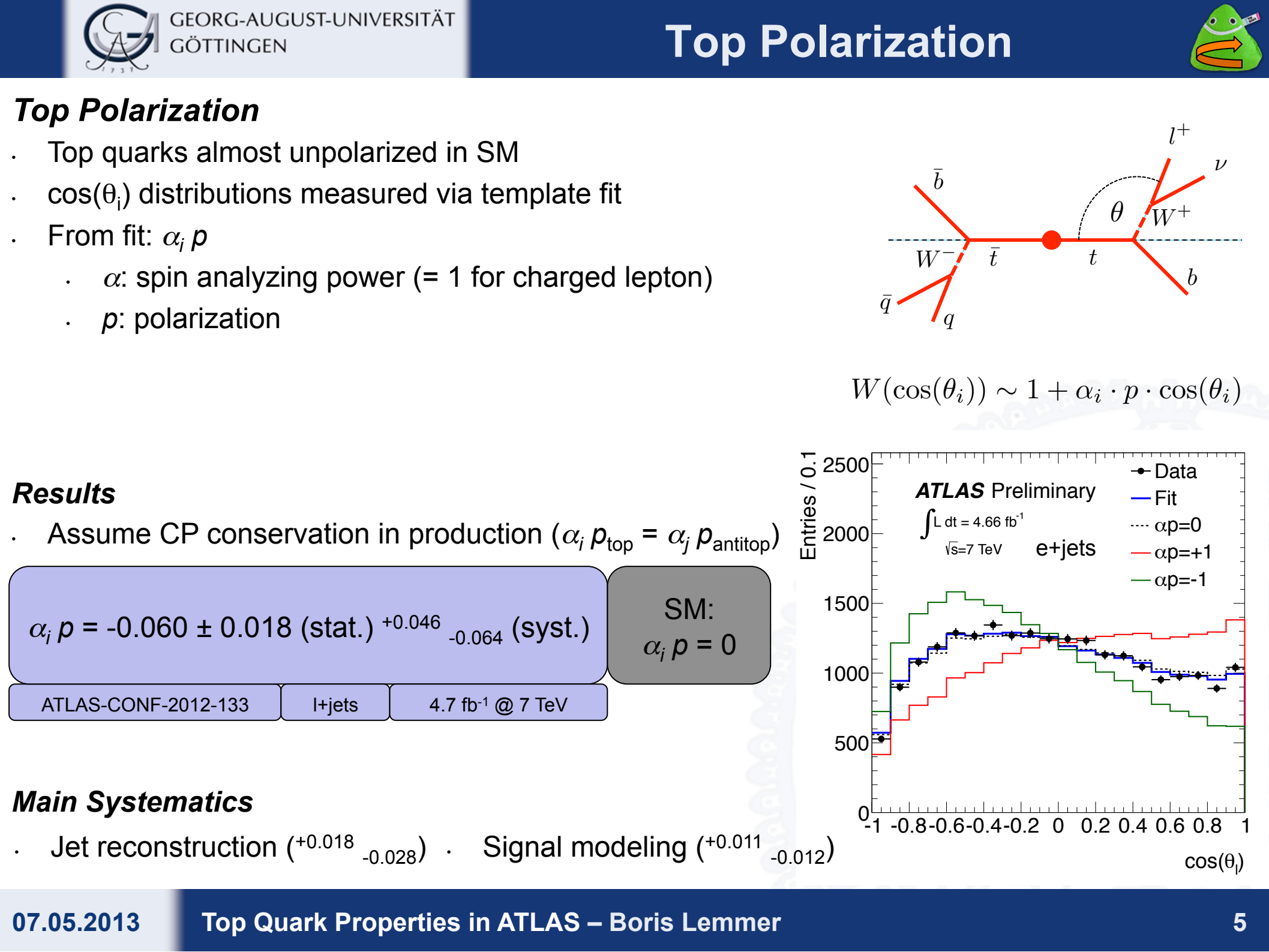
Weighted b-jet charge



Main Systematics (<Q_{comb}> [%])

- ISR/FSR (13.8)
- Jet/E_t^{miss} reconstruction (7.2)

Top Polarization



Top Polarization

- Top quarks almost unpolarized in SM
- cos(θ_i) distributions measured via template fit
- From fit: $\alpha_i\, p$
  - α: spin analyzing power (= 1 for charged lepton)
  - p: polarization

$$W(\cos(\theta_i)) \sim 1 + \alpha_i \cdot p \cdot \cos(\theta_i)$$

Results

- Assume CP conservation in production ($\alpha_i\, p_{top} = \alpha_j\, p_{antitop}$)

$\alpha_i\, p = -0.060 \pm 0.018\,(stat.)\,{}^{+0.046}_{-0.064}\,(syst.)$	SM: $\alpha_i\, p = 0$

ATLAS-CONF-2012-133	l+jets	4.7 fb^{-1} @ 7 TeV

Main Systematics

- Jet reconstruction ($^{+0.018}_{-0.028}$)
- Signal modeling ($^{+0.011}_{-0.012}$)

Top Spin Correlation

Top Spin Correlation

- SM description of production and decay predicts spin correlation A
- Azimuthal angle $\Delta\phi_{lab}$(analyzer$_1$, analyzer$_2$)
  [Mahlon and Parke, Phys. Rev. D 81, 074024 (2010)]
- Dilepton channel $\Delta\phi_{lab}$(lepton$_1$, lepton$_2$) :
  α_{lep}= ± 1, no full reconstruction needed
- Template fit: SM correlation, uncorrelated $t\bar{t}$ pairs

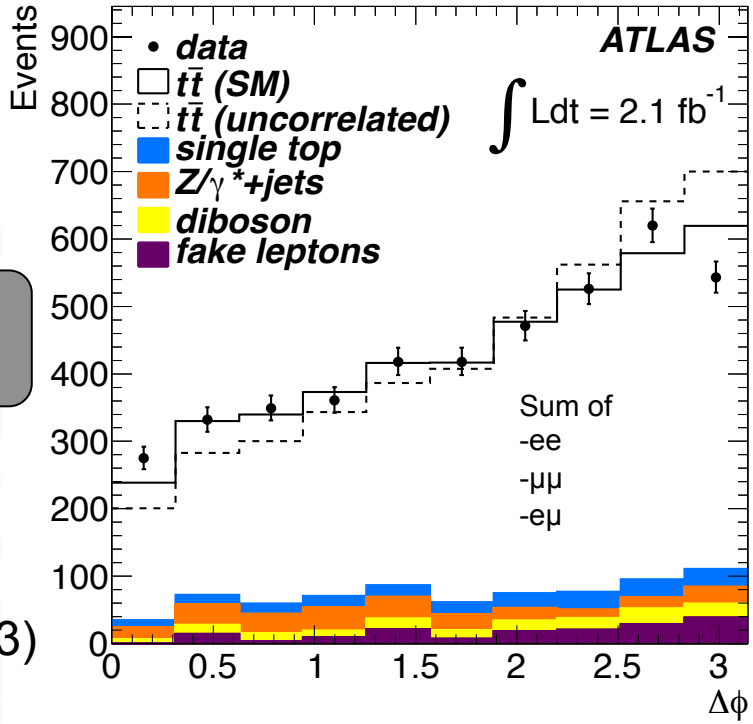
$$A = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}} = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

Results

- First observation (5 σ exclusion of no spin hypothesis)

A_{hel} = 0.40 ± 0.04 (stat.) $^{+0.08}_{-0.07}$ (syst.)			SM (NLO)*: A_{hel} = 0.31
PRL 108, 212001 (2012)	dilepton	2.1 fb^{-1} @ 7 TeV	

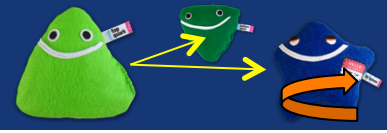
[* Bernreuther and Zi, Nucl. Phys. B837, 90 (2010)]



Main Systematics (A_{hel})

- Jet reconstruction (0.04)
- Fake lepton estimate ($^{+0.05}_{-0.02}$)
- Template statistics (0.03)
- Signal modeling (0.02)

W-Boson Polarization



W-Boson Polarization

- Probes *Wtb* vertex for anomalous couplings
- Two analyses combined:
  - Helicity fraction template fit

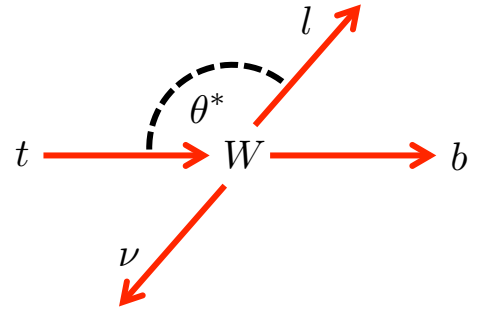
$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right)F_0 + \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_L + \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_R$$

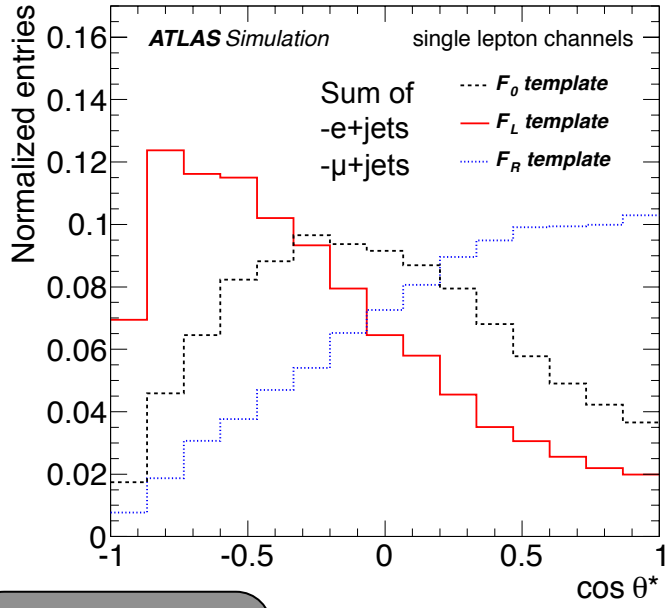
  - Angular asymmetries

$$A_{\pm} = \frac{N\left(\cos\theta^* > z\right) - N\left(\cos\theta^* < z\right)}{N\left(\cos\theta^* > z\right) + N\left(\cos\theta^* < z\right)}$$

- New: LHC combination (ATLAS-CONF-2013-033)

F_i: fractions of longitudinally polarized (F_0), left- (F_L) and right-handed (F_R) W-bosons





Results

- ATLAS combination
- Anomalous couplings compatible with 0

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

JHEP 06 (2012) 088	dilepton and l+jets	1.0 fb^{-1} @ 7 TeV

NNLO pQCD*:
$F_0 = 0.687$
$F_L = 0.311$
$F_R = 0.002$

[* A. Czarnecki, J.G. Korner and J.H. Piclum, Phys. Rev. D 81 (2010) 111503]

Main Systematics (F_0)

- JES (0.026)
- Fake lepton estimate (0.020)
- m_{top} (0.016)
- ISR/FSR (0.015)

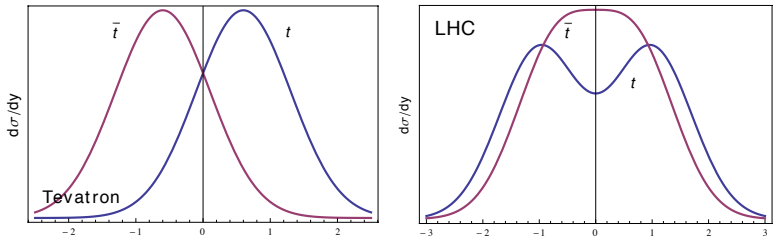
Charge Asymmetry

Top Charge Asymmetry

- SM: small asymmetry in |y| at LHC
- BSM physics in differential measurements
- |y| reconstructed, unfolded, binned in $m_{t\bar{t}}$
- Also: lepton asymmetries (no reconstruction)

$$A_C^{t\bar{t}} = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)} \qquad A_C^{ll'} = \frac{N(\Delta|\eta|>0) - N(\Delta|\eta|<0)}{N(\Delta|\eta|>0) + N(\Delta|\eta|<0)}$$

$$\Delta|y| \equiv |y_t| - |y_{\bar{t}}| \qquad \Delta|\eta| \equiv |\eta_{l^+}| - |\eta_{l^-}|$$



From: German Rodrigo (arXiv:1207.0331)

Results

- Consistent with SM, no support for Z‘

$$A_C^{t\bar{t}} = -0.019 \pm 0.028\ (\text{stat.}) \pm 0.024\ (\text{syst.})$$

SM (MC@NLO): $A_C^{tt} = 0.006 \pm 0.002$

Eur. Phys. J. C (2012) 72:2039	l+jets	1.0 fb^{-1} @ 7 TeV

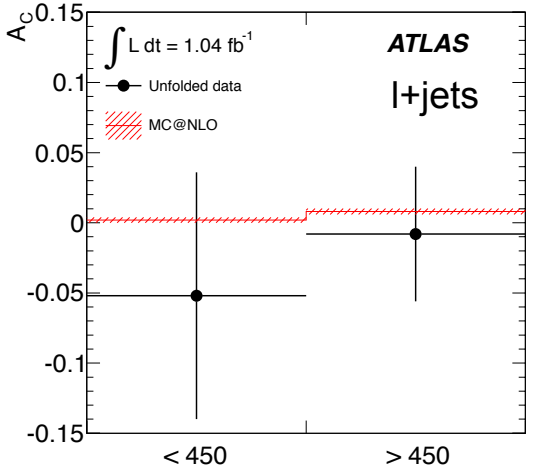
$$A_C^{ll'} = 0.023 \pm 0.012\ (\text{stat.}) \pm 0.008\ (\text{syst.})$$

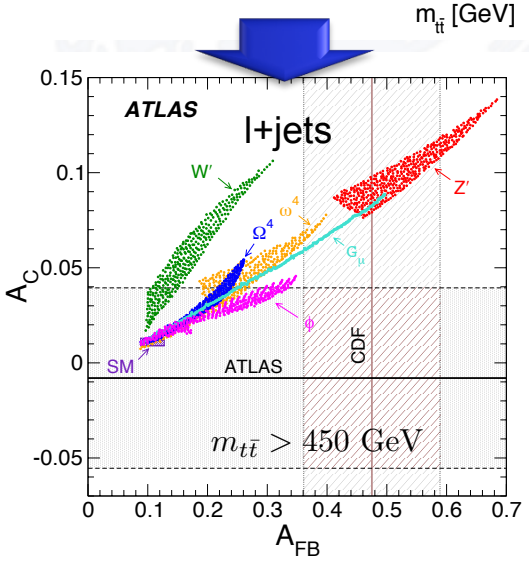
$$A_C^{t\bar{t}}(\text{comb.}^*) = 0.029 \pm 0.018\ (\text{stat.}) \pm 0.014\ (\text{syst.})$$

* combination: $A_C^{t\bar{t}}$ (l+jets) and $A_C^{t\bar{t}}$ (dilepton)

SM (MC@NLO): $A_C^{ll'} = 0.004 \pm 0.001$, $A_C^{tt} = 0.006 \pm 0.002$

ATLAS-CONF-2012-057	dilepton	4.7 fb^{-1} @ 7 TeV





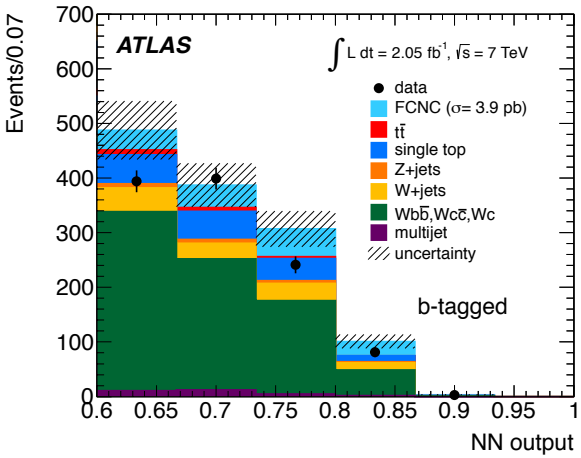
Main Systematics (e+jets)

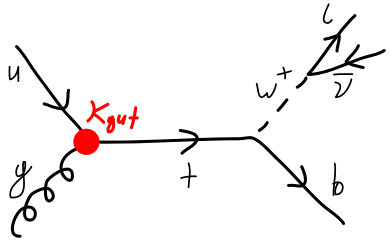
- JES (0.012)
- Parton shower (0.010)
- $t\bar{t}$ modeling (0.011)
- ISR/FSR (0.010)

FCNC With Tops

FCNC in Single Top Production

- SM: $\mathrm{BR}(t \to qg) \approx 10^{-13}$
- BSM physics with BR up to 10^{-3}
- Check single top production with NN output
- Set upper limits on coupling strengths





Result

$$\sigma_{qg \to t} \cdot \mathrm{BR}(t \to Wb) < 3.9 \text{ pb } @\ 95\ \%\ \mathrm{CL}$$

$$\mathrm{BR}(t \to ug) < 5.7 \cdot 10^{-5} (1)$$

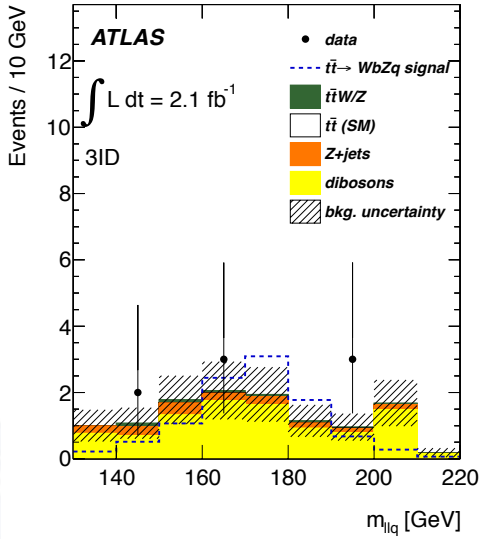
$$\mathrm{BR}(t \to cg) < 2.7 \cdot 10^{-4} (2)$$

$^1\text{for } \mathrm{BR}(t \to cg) = 0 \quad ^2\text{for } \mathrm{BR}(t \to ug) = 0$

Phys. Lett. B712 (2012) 351-369	2.1 fb^{-1} @ 7 TeV

FCNC in $t\bar{t} \to WbZq \to l^+l^-l'\nu qb$

- SM: $\mathrm{BR}(t \to qZ) \approx 10^{-14}$
- BSM physics with BR up to $2 \cdot 10^{-4}$
- Selection with either 3 leptons or 2 leptons and 1 track lepton (22% higher acc.)



Result

- Combination of both lepton selections

$$\mathrm{BR}(t \to Zq) < 7.3 \cdot 10^{-3} \ @\ 95\ \%\ \mathrm{CL}$$

$$(\text{for } \mathrm{BR}(t \to Wb) + \mathrm{BR}(t \to Zq) = 1)$$

JHEP09(2012)139	2.1 fb^{-1} @ 7 TeV

$t\bar{t}$ + Bosons

$t\bar{t}Z$ Production

- Test EW coupling
- Trilepton selection (2 from Z, 1 from $t\bar{t}$)
  $\epsilon = 0.13\ \% \rightarrow 1$ candidate event
  exp.: 0.85 (signal) + 0.28 (BG) + 0 (fake lepton BG)

Result

$\sigma_{t\bar{t}Z} < 0.71$ pb @ 95 % CL

ATLAS-CONF-2012-126	trilepton	4.7 fb^{-1} @ 7 TeV

SM (NLO)*: $\sigma_{t\bar{t}Z} = 0.14$ pb

[* M. V. Garzelli et al., Phys. Rev. D 85 (2012) 074022]

$t\bar{t}\gamma$ Production

- Access top charge and EM coupling
- Template fit of photon isolation variable
- Fiducial cross section for $p_{T\gamma} > 8$ GeV

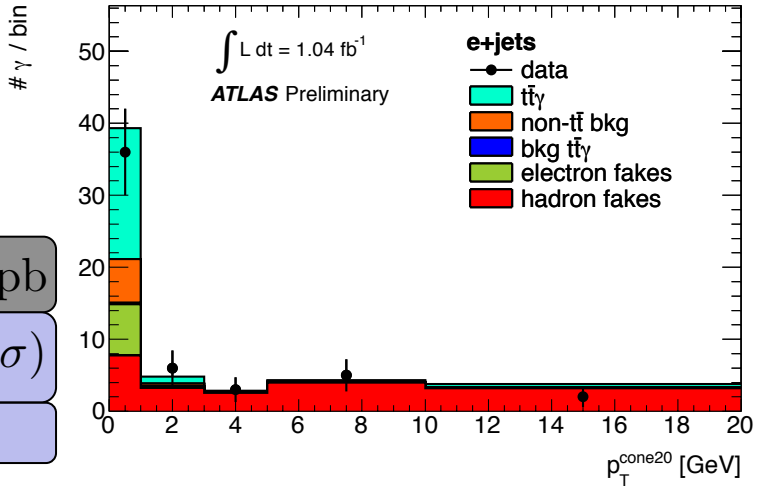
Result

SM (NLO)*: $\sigma^{\text{fid.}}_{t\bar{t}\gamma} \cdot \text{BR}(\text{dilep, l+jets}) = 2.1 \pm 0.4$ pb

$\sigma^{\text{fid.}}_{t\bar{t}\gamma} \cdot \text{BR} = 2.0 \pm 0.5\ (\text{stat.}) \pm 0.7\ (\text{syst.}) \pm 0.8\ (\text{lumi.})$ pb (2.7σ)

ATLAS-CONF-2011-153	l+jets	1.0 fb^{-1} @ 7 TeV

[* K. Melnikov, M. Schulze, and A. Scharf, Phys. Rev. D83 (2011) 07]



$t\bar{t}H$ Production

- Access to Yukawa coupling of top
- Search for $t\bar{t}(\rightarrow \text{l+jets}) + H(\rightarrow b\bar{b})$
- 9 channels in [n_{jets}]x[$n_{\text{b-tags}}$]
- Discriminants: $m_{b\bar{b}}$ and H_T^{had}
- Nuisance parameter fit to constrain backgr.

See also talks given by:
Xin Chen (LHC Higgs boson results involving fermions)
Rosemarie Zoe Aben (Search for a Higgs boson in fermion modes using the ATLAS detector)

Result

$\sigma_{m_H=125\ \text{GeV}}/\sigma_{SM} < 13.1\ (\text{exp.: } 10.5)$ @ 95 % CL

ATLAS-CONF-2012-135	l+jets / $b\bar{b}$	4.7 fb^{-1} @ 7 TeV

Summary

- **The Top Quark ...**
  - ... is the most massive elementary particle known with resulting very special properties
  - ... is a good probe for the Standard Model and the Higgs boson
  - ... is expected to open the gate to BSM physics
  - ... tests your detector performance in many ways

- **Measurements at 7 TeV ...**
  - ... are based on a solid dataset with high statistics
  - ... are mostly (except charge asymmetry) limited by systematic uncertainties
  - ... validated the Standard Model in many ways (e.g. first observation of spin correlation)
  - ... will still follow. Stay tuned!

- **Measurements at 8 TeV and analyses with the upgraded LHC ...**
  - ... will soon start a new era of high precision top quark analyses

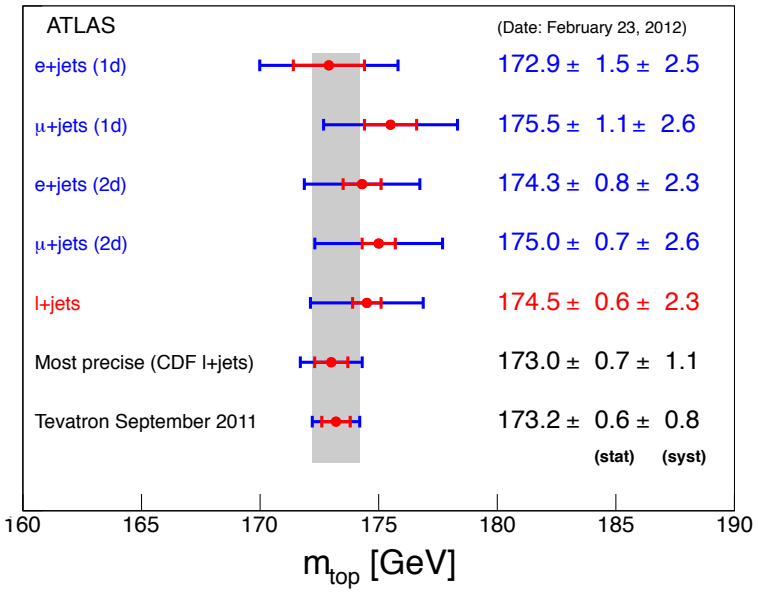
Backup

Top Mass (Backup)

$$m_{T2}(m_{\text{invis}}) = \min_{\vec{p}_T^{(1)},\,\vec{p}_T^{(2)}} \left\{ \max\left[m_T(m_{\text{invis}}, \vec{p}_T^{(1)}), m_T(m_{\text{invis}}, \vec{p}_T^{(2)}) \right] \right\} \quad m_T(m_{\text{invis}}, \vec{p}_T^{(i)}) = \sqrt{m_{\text{vis}}^2 + m_{\text{invis}}^2 + 2(E_T^{\text{vis}} E_T^{\text{invis}} - \vec{p}_T^{\text{vis}} \cdot \vec{p}_T^{(i)})}$$

ATLAS Combination

Eur. Phys. J. C (2012) 72:2046



LHC Combination / ATLAS-CONF-2012-095

Uncertainty Categories			Size [GeV]							Correlation	
			ATLAS			CMS					
Tevatron	ATLAS	CMS	2010 l+jets	2011 l+jets	2011 all jets	2010 di-l	2010 l+jets	2011 di-l	2011 μ+jets	ρ_{exp}	ρ_{LHC}
Statistics			4.0	0.6	2.1	4.6	2.1	1.2	0.4	0	0
iJES	Jet Scale Factor	Jet Scale Factor		0.4					0.4	0	0
aJES											
bJES	JES_{b-jet}	JES_{b-jet}	2.5	1.6	1.4	0.9	0.9	1.1	0.7	1	0.5
cJES											
dJES	$JES_{light-jet}$	$JES_{light-jet}$	2.1	0.7	2.1	2.1	2.1	2.0	0.2	1	0
rJES		residual-JES				3.3				0	0
LepPt		Lepton p_T Scale				0.3		0.2		1	0
MC	MC Generator	MC Generator	0.7	0.3	0.5	0.4		0.1			
	Hadronisation		0.7	0.2	(*)						
	Sum	Sum	1.0	0.4	0.5	0.4		0.1		1	0.5
Rad	ISR/FSR	ISR/FSR	2.5	1.0	1.7	0.2	0.2				
		Q-Scale				0.6	1.1	0.4	0.8		
		Jet-Parton Scale				0.7	0.4	0.7	0.3		
	Sum	Sum	2.5	1.0	1.7	0.9	1.2	0.8	0.8	1	0.5
CR	Colour Recon.		*0.6*	0.6	*0.6*	*0.5*	*0.5*	0.5	0.5	1	1
PDF	Proton PDF	Proton PDF	0.5	0.1	0.6	0.5	0.1	0.4	0.1	1	1
DetMod	Jet Energy Res.	Jet Energy Res.	0.9	0.1	0.3	0.5	0.1	0.3	0.2		
	Jet Rec. Eff.		0.5	< 0.05	0.2						
	b-tagging	b-tagging	0.5	0.3	0.3	0.4	0.1	0.5	0.2		
	E_T^{miss}	E_T^{miss}		0.1		0.1	0.4	0.4	0.1		
	Sum	Sum	1.2	0.3	0.5	0.7	0.4	0.7	0.3	1	0
UE	Underlying Event	Underlying Event	*0.6*	0.6	*0.6*	1.4	0.2	*0.6*	*0.6*	1	0
BGMC	W+jet Norm.		1.6								
	W+jet Shape		0.8	0.1							
		background				0.1	0.2		0.1		
	Sum	Sum	1.8	0.1		0.1	0.2		0.1	1	1
BGData	W+jet Norm.			0.4							
	QCD Norm.	QCD Norm.	0.5	0.2			0.4	0.4			
	QCD Shape		0.4	0.3	1.9						
	Sum	Sum	0.6	0.5	1.9		0.4	0.4		0	0
Method	Method Calib.	Method Calib.	0.4	0.1	1.0	0.3	0.1	0.4	0.2	0	0
MHI	Pile-up	Pile-up	0.7	< 0.05		1.0	0.1	0.2	0.4	1	1

Top Charge

- Soft muon method
  - Select b-jets with non-isolated muon
  - Reconstruction via kinematic likelihood fit
  - Combine muon charge (b-jet charge) with charge of lepton from same top

ATLAS-CONF-2011-141

Source	$< Q_{comb} >$ (%)		$< Q_{comb}^{soft} >$ (%)	
	e + jets	μ + jets	e + jets	μ + jets
ISR/FSR	13.8	11.0	15	24
Other tt modeling uncertainties	2.1	1.6	7	10
W+jets uncertainties	1.2	1.9	1.8	5.5
QCD uncertainties	0.4	1.6	4.0	1.0
Other SM background modeling uncertainties	2.0	1.0	< 1	1.6
Jet/$E_{\mathrm{T}}^{\mathrm{miss}}$ systematics	7.2	7.6	5	7.5
Lepton systematics	2.9	4.1	2	1.5
b-tagging systematics	1.1	< 1	1	< 1
Total uncertainty (%)	16.2	14.4	18	27

Table 3: Systematic uncertainties for $< Q_{comb} >$ and $< Q_{comb}^{soft} >$ in percent. The total uncertainty was calculated by adding the individual ones in quadrature. The estimation of some of the systematic uncertainties suffers from a small number of simulated events. The statistical error is in these cases conservatively included in the systematic effect estimation.

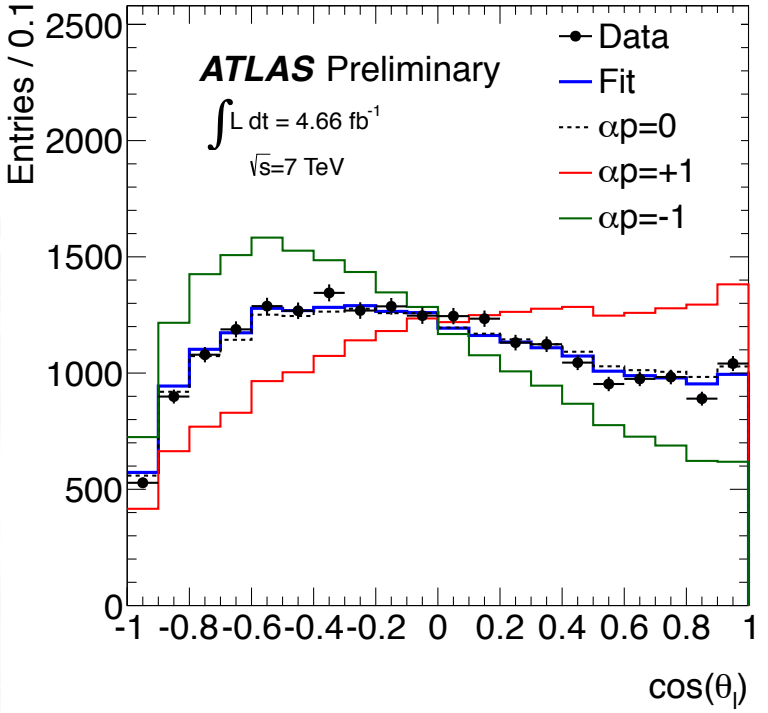
Top Polarization (Backup)

ATLAS-CONF-2012-133

Source	Δf	
Lepton reconstruction	+0.002	-0.003
Jet reconstruction	+0.018	-0.028
$E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction	+0.001	-0.003
Signal modelling	+0.011	-0.012
W+jets shape	+0.004	-0.004
Fake lepton shape	+0.004	-0.005
Monte Carlo background cross section	+0.002	-0.002
Template statistical uncertainty	+0.004	-0.004
Total systematic	+0.023	-0.032

$$\frac{1}{2}f(1+\cos\theta_l)+\frac{1}{2}(1-f)(1-\cos\theta_l)=\frac{1}{2}(1+\alpha_l p\cos\theta)$$

$$\alpha_l p = 2f-1$$



Top Spin Correlation (Back.)

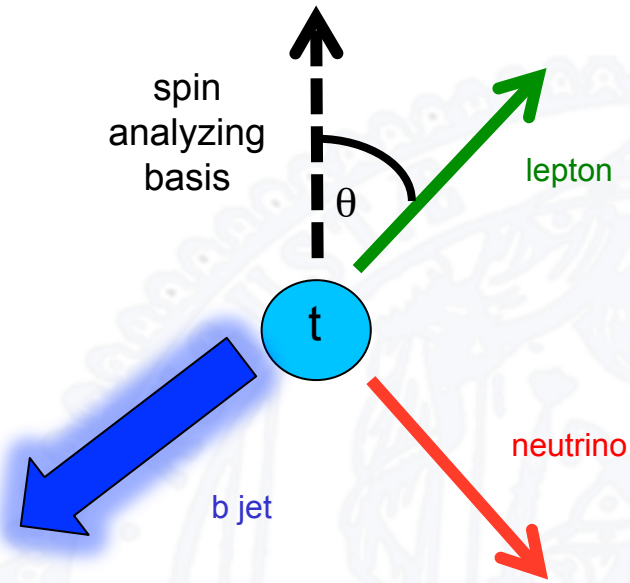
	b quark	W+	l+	d/s quark	u/c quark
α_i (LO)	-0.41	0.411	1	1	-0.31
α_i (NLO)	-0.39	0.390	0.998	0.93	-0.31

[A. Brandenburg, Z.-G. Si, and P. Uwer, Phys. Lett. B539 (2002) 235]

$$A = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}} = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}\left(1 - \alpha_i \alpha_j A \cos(\theta_1)\cos(\theta_2)\right)$$

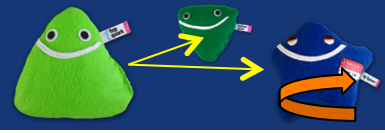
Uncertainty source	Δf^{SM}
Data statistics	± 0.14
MC simulation template statistics	± 0.09
Luminosity	± 0.01
Lepton	± 0.01
Jet energy scale, resolution and efficiency	± 0.12
NLO generator	± 0.08
Parton shower and fragmentation	± 0.08
ISR/FSR	± 0.07
PDF uncertainty	± 0.07
Top quark mass	± 0.01
Fake leptons	$+0.16/-0.07$
Calorimeter readout	± 0.01
All systematics	$+0.27/-0.22$
Statistical + systematic	$+0.30/-0.26$



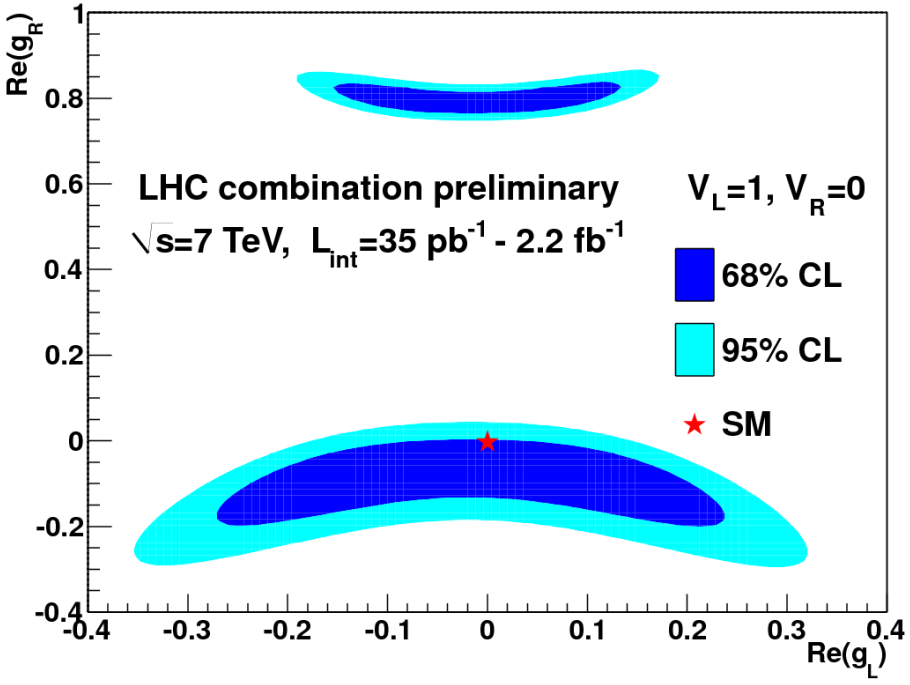
$$N = f_{SM} N_{SM} + (1 - f_{SM}) N_{uncorr}$$

$$A_{basis}^{measured} = A_{basis}^{SM} \cdot f_{SM}$$

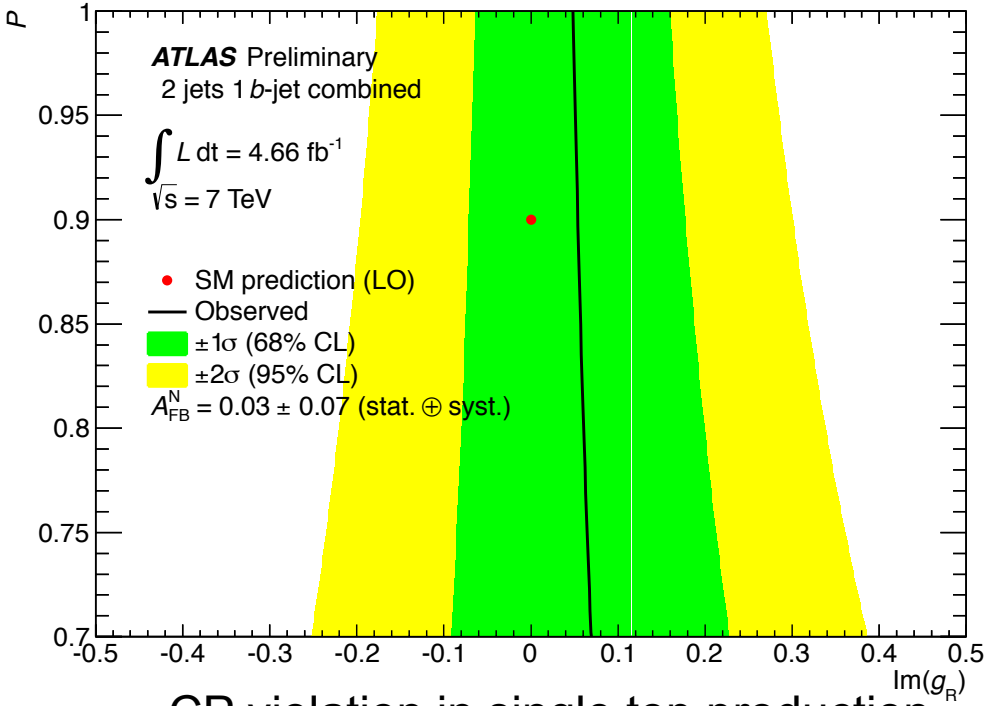
W Polarization (Back.)



ATLAS-CONF-2013-033



ATLAS-CONF-2013-032



CP violation in single top production

Results

- ATLAS + CMS combination

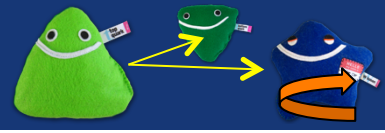
$F_0 = 0.626 \pm 0.034\ (stat.) \pm 0.048\ (syst.)$
$F_L = 0.359 \pm 0.021\ (stat.) \pm 0.028\ (syst.)$
$F_R = 0.015 \pm 0.034\ (stat.+syst)$
$Re(g_R) = -0.10 \pm 0.06\ (stat.)\ ^{+0.07}_{-0.08}\ (syst.)$
$Re(C^{33}_{uW})/\Lambda^2 = -1.1 \pm 0.6\ (stat.)\ ^{+0.9}_{-1.0}\ (syst.)\ TeV^{-2}$

ATLAS-CONF-2013-033	dilepton and l+jets	< 2.2 fb^{-1} @ 7 TeV

NNLO pQCD*:
$F_0 = 0.687$
$F_L = 0.311$
$F_R = 0.002$

[* A. Czarnecki, J.G. Korner and J.H. Piclum, Phys. Rev. D 81 (2010) 111503]

W Polarization (Back.)



ATLAS-CONF-2013-033

Category	ATLAS 2011 (single lepton)				ATLAS 2011 (dilepton)			
	F_0	F_L	$\rho_{\text{ATLAS}}(F_0, F_L)$	F_R	F_0	F_L	$\rho_{\text{ATLAS}}(F_0, F_L)$	F_R
Detector modeling								
Detector model	0.032	0.019	-0.778	0.021	0.012	0.005	-0.887	0.008
Jet energy scale	0.027	0.014	-0.310	0.026	0.056	0.036	-0.485	0.050
Luminosity and pile-up	0.012	0.005	-0.862	0.008	0.002	0.001	-0.940	0.001
Signal and background modeling								
Monte Carlo	0.019	0.014	-0.915	0.008	0.023	0.015	-0.917	0.011
Radiation	0.030	0.019	-0.579	0.025	0.028	0.014	-0.854	0.017
Top-quark mass	0.027	0.014	-0.090	0.029	0.028	0.016	-0.436	0.025
PDF	0.009	0.005	-0.875	0.005	0.028	0.015	-0.875	0.017
Background (MC QCD)	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Background (MC W + jets)	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Background (MC other)	0.008	0.005	-0.891	0.004	0.006	0.004	-0.913	0.003
Background (data-driven)	0.027	0.017	-0.929	0.013	0.018	0.011	-0.997	0.007
Method-specific uncertainties								
Method	0.015	0.011	-0.779	0.009	0.032	0.016	-0.945	0.018
Total uncertainties								
Total systematic uncertainty	0.071	0.042	-0.627	0.055	0.087	0.051	-0.664	0.065
Statistical uncertainty	0.030	0.020	-0.910	0.014	0.050	0.031	-0.913	0.026
Total uncertainty	0.076	0.046	-0.673	0.057	0.100	0.059	-0.729	0.070

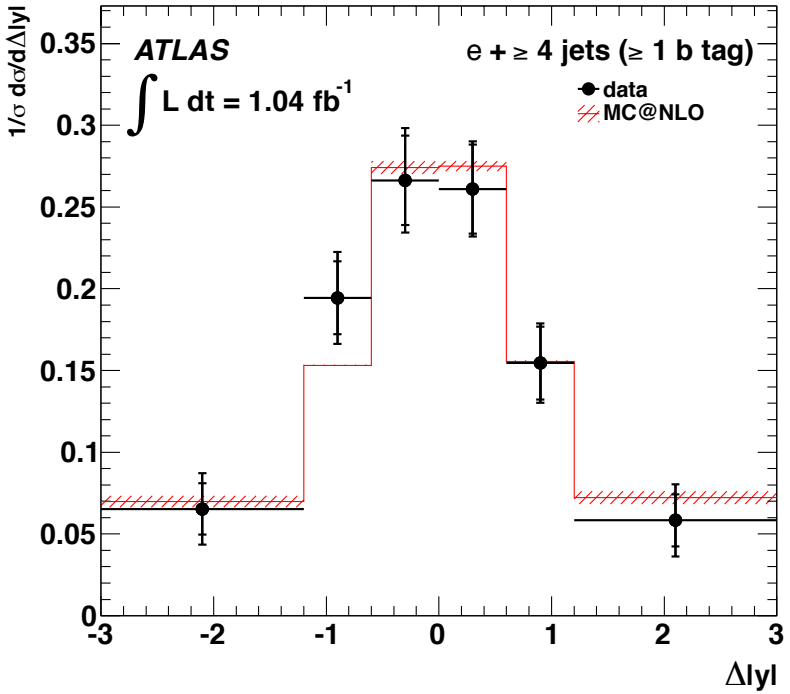
Category	CMS 2011 (single lepton)			
	F_0	F_L	$\rho_{\text{CMS}}(F_0, F_L)$	F_R
Detector modeling				
Detector model	0.020	0.015	-0.95	0.007
Jet energy scale	0.018	0.011	-0.99	0.007
Luminosity and pile-up	–	–	–	–
Signal and background modeling				
Monte Carlo	–	–	–	–
Radiation	0.026	0.008	+0.21	0.028
Top-quark mass	0.009	0.010	-0.87	0.005
PDF	0.001	0.001	-1.00	$< 10^{-4}$
Background (MC QCD)	0.007	0.002	-1.00	0.005
Background (MC W + jets)	0.020	0.006	+1.00	0.026
Background (MC other)	0.019	0.007	-0.59	0.015
Background (data-driven)	–	–	–	–
Method-specific uncertainties				
Method	–	–	–	–
Total uncertainties				
Total systematic uncertainty	0.048	0.024	-0.43	0.043
Statistical uncertainty	0.074	0.045	-0.94	0.035
Total uncertainty	0.088	0.051	-0.81	0.056

Charge Asym. (Backup)

- SM pred. for LHC: $A_C(\Delta|y|) = 1.15\ \%$ [JHEP 1201 (2012) 063]

Eur. Phys. J. C (2012) 72:2039

Source of systematic uncertainty on A_C	Electron channel	Muon channel
Detector modelling		
Jet energy scale	0.012	0.006
Jet efficiency and resolution	0.001	0.007
Muon efficiency and resolution	<0.001	0.001
Electron efficiency and resolution	0.003	0.001
b-Tag scale factors	0.004	0.002
Calorimeter readout	0.001	0.004
Charge mis-ID	<0.001	<0.001
b-Tag charge	0.001	0.001
Signal and background modelling		
Parton shower/fragmentation	0.010	0.010
Top mass	0.007	0.007
$t\bar{t}$ modelling	0.011	0.011
ISR and FSR	0.010	0.010
PDF	<0.001	<0.001
W + jets normalisation and shape	0.008	0.005
Z + jets normalisation and shape	0.005	0.001
Multijet background	0.011	0.001
Single top	<0.001	<0.001
Diboson	<0.001	<0.001
MC statistics	0.006	0.005
Unfolding convergence	0.005	0.007
Unfolding bias	0.004	<0.001
Luminosity	0.001	0.001
Total systematic uncertainty	0.028	0.024



Charge Asym. (Backup)

ATLAS-CONF-2012-057

	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

Lepton asymmetry uncertainties

	ee	*eμ*	*μμ*
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

$t\bar{t}$ asymmetry uncertainties

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

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

$$A_C^{t\bar{t}} = -0.019 \pm 0.028\ (\text{stat.}) \pm 0.024\ (\text{syst.})$$

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

FCNC (Backup)

FCNC in Single Top Production

- Check single top production with NN output
  - Most powerful variables:
    - $p_{T,W}$
    - ΔR(b-jet,lepton)
    - Lepton charge
- Set upper limits on coupling strenghts

Result

$$\sigma < 3.9 \text{ pb @ 95 \% CL}$$
$$\text{BR}(t \to ug) < 5.7 \cdot 10^{-5}$$
$$\text{BR}(t \to cg) < 2.7 \cdot 10^{-4}$$
$$\kappa_{ugt}/\Lambda < 6.9 \cdot 10^{-3} \text{ TeV}^{-1}$$
$$\kappa_{cgt}/\Lambda < 1.6 \cdot 10^{-2} \text{ TeV}^{-1}$$

Phys. Lett. B712 (2012) 351-369 | 2.1 fb^{-1} @ 7 TeV

FCNC in $t\bar{t} \to WbZq \to l^+l^-l'\nu qb$

- χ^2 fit to event topology

JHEP09(2012)139

	3ID		2ID+TL	
Source	Background	Signal	Background	Signal
Luminosity	4%	4%	<1%	4%
Electron trigger	4%	1%	<1%	<1%
Electron reconstruction modelling	10%	3%	<1%	2%
Muon trigger	3%	1%	<1%	<1%
Muon reconstruction modelling	7%	1%	<1%	1%
TL reconstruction modelling	—	—	2%	1%
Jet energy scale	11%	1%	1%	1%
Jet reconstruction efficiency	5%	2%	<1%	<1%
Jet energy resolution	1%	3%	1%	4%
E_T^{miss} modelling	4%	1%	<1%	<1%
LAr readout problem	3%	1%	<1%	1%
Pile-up	4%	<1%	<1%	<1%
b-tagging	—	—	1%	6%
Top quark mass	<1%	2%	—	3%
$\sigma_{t\bar{t}}$	<1%	8%	—	8%
ISR/FSR	<1%	3%	—	6%
PDFs	—	3%	—	3%
ZZ and WZ shape	33%	—	5%	—
ZZ and WZ cross section	4%	—	<1%	—
ZZ and WZ heavy-flavour content	—	—	<1%	—
Fake leptons	1%	—	17%	—
Total	38%	12%	18%	15%

$t\bar{t}$ + Bosons (Backup)

$t\bar{t}Z$ Production

Systematic uncertainty	Background	Signal
Luminosity	4%	4%
b-tagging	5%	5%
e trigger efficiency	2%	<1%
e reco. and identification efficiency	5%	5%
e energy scale	<1%	<1%
e energy resolution	<1%	<1%
μ trigger efficiency	2%	<1%
μ reco. efficiency	2%	2%
μ momentum scale	<1%	<1%
μ momentum resolution	<1%	<1%
Jet energy scale	5%	7%
Jet reco efficiency	<1%	<1%
$E_{\mathrm{T}}^{\mathrm{miss}}$ unassociated cells and soft jet	1%	<1%
$E_{\mathrm{T}}^{\mathrm{miss}}$ pileup	1%	<1%
Jet vertex fraction	5%	6%
Renormalisation & factorisation scale	-	10%
ISR/FSR	-	6%
MC driven background normalisation	50%	-
Total	51%	17%

	SR
$t\bar{t}Z$	0.85 ± 0.04
WZ+jets	0.06 ± 0.04
ZZ+jets	0.014 ± 0.014
$t\bar{t}W$	0.011 ± 0.008
$(t\bar{b}Z + \bar{t}bZ) + X(= jj, l\nu)$	0.125 ± 0.013
$WZbbjj$	0.065 ± 0.016
MC Total	1.13 ± 0.06
Fake lepton background	$0.0^{+1.6}_{-0.0}$
Observed	1

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$t\bar{t}\gamma$ Production

Description	Uncertainty on the cross section [pb]
Modelling	± 0.18
Initial and final state radiation	± 0.31
Electron related	± 0.05
Muon related	± 0.08
Jet energy scale	± 0.24
Jet energy scale (pile-up uncertainty)	± 0.28
b-jet energy scale	± 0.06
Jet reconstruction and resolution	± 0.06
$E_{\mathrm{T}}^{\mathrm{miss}}$ related	± 0.03
b-tagging performance	± 0.18
Treatment of dead region in LAr calorimeter read-out	± 0.05
Luminosity	± 0.08
Photon identification efficiency	± 0.33
Photon energy scale	± 0.02
Photon resolution	± 0.01
$t\bar{t}\gamma$ background yield	± 0.03
non-$t\bar{t}$ background yield	± 0.11
Electron to photon extrapolation	± 0.22
Fraction of converted prompt photons	± 0.03
Fraction of converted hadron fakes	± 0.16
Reweighting of the background templates (p_{T})	± 0.11
Reweighting of the background templates (η)	± 0.06
Pile-up dependence of the signal templates	± 0.01
Pile-up dependence of the background templates	± 0.05
Sum	± 0.7

ATLAS-CONF-2010-153

$t\bar{t}H$ Production

m_H (GeV)	observed	-2 s.d.	-1 s.d.	median	+1 s.d.	+2 s.d.	stat only
110	7.0	3.2	4.3	6.0	8.5	11.8	3.5
115	8.7	3.7	5.0	6.9	9.7	13.6	4.0
120	10.4	4.6	6.2	8.5	12.0	16.7	4.9
125	13.1	5.7	7.6	10.5	14.7	20.6	6.1
130	16.4	7.0	9.4	13.0	18.3	25.5	7.8
140	33.0	12.5	16.7	23.2	32.7	45.5	14.2

ATLAS-CONF-2012-135