Using the angular distribution of the charged lepton for W- helicity measurements at ATLAS

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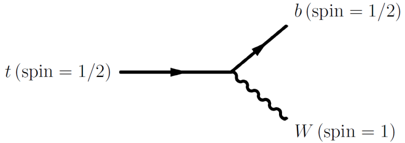
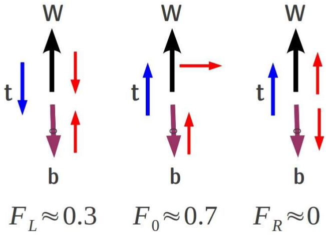
W-helicity in top-quark decays

Wtb vertex in the SM has a V-A structure:

$$-i\frac{g}{2\sqrt{2}}V_{tb}\gamma^{\mu}(1-\gamma^{5})\,.$$

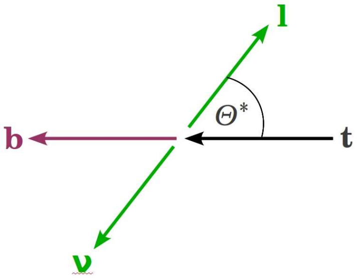




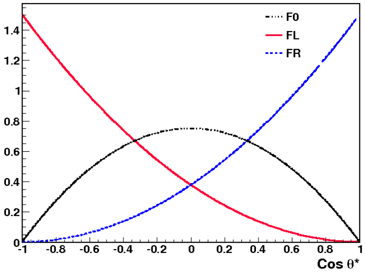
- three possible polarisation states
- right-handed contribution is suppressed in the SM
- significant deviation of the fractions from SM prediction would be a hint to new physics

How can we measure the fractions?

Rest frame of the W:

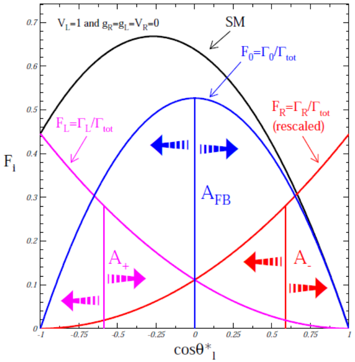


Angular distribution of charged lepton:



$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1+\cos\theta^*)^2 F_{\mathrm{R}} + \frac{3}{8}(1-\cos\theta^*)^2 F_{\mathrm{L}} + \frac{3}{4}\sin^2\theta^* F_0$$

Angular asymmetries



$$A_z = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$$

SM NNLO prediction:

- $z = \mp(2^{2/3} - 1)$ for $A_\pm$
- $A_+ = 0.537$
- $A_- = -0.841$

Dependent on fractions:

$$A_+ = 3\beta\left[F_0 + (1+\beta)F_\mathrm{R}\right]$$
$$A_- = -3\beta\left[F_0 + (1+\beta)F_\mathrm{L}\right]$$
$$\beta = 2^{2/3} - 1$$

Measurements presented today:

Angular asymmetries (0.7 fb^{-1})

- measure angular asymmetries
- set limits on anomalous couplings

Template method (0.7 fb^{-1}):

- measure all three W-helicity fractions (l+jets)
- measure the W-helicity fractions with F_R fixed to zero
  $\Rightarrow$ set limit on six-dimension operators

Template method (1.04 fb^{-1}):

- measure all three W-helicity fractions (l+jets)

Template method

Signal templates

- samples produced with PROTOS MC (LO)
- three templates from separate data sets:
  - $F_0 = 1$
  - $F_\mathrm{L} = 1$
  - $F_\mathrm{R} = 1$

Background templates

- W+jets (data-driven normalisation)
- multijet production (data-driven)
- Z+jets, Diboson and Single Top (simulation)

Template method

Fit parameter:

- reconstruct cos θ^* distribution
- perform a likelihood fit
- parameter: total number of events for templates **before** applying cuts:

$$\lambda_i = \sum_{h=-1,0,+1} \lambda_i^h \cdot \epsilon^h + \sum_{j=1}^{N_{\mathrm{bkg}}} \lambda_i^{\mathrm{bkg}j}$$

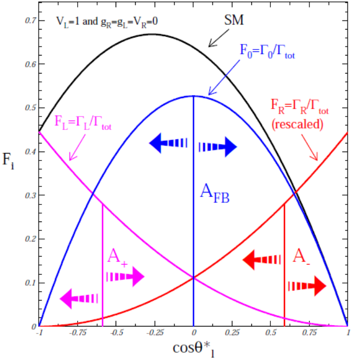
Background templates:

- three templates: W+jets, multijet, remaining bkg
- use Gaussian to constrain background contribution

$$L(\vec{\lambda}) = \prod_{i=1}^{n_{\mathrm{bins}}} \frac{\lambda_i^{n_i}}{n_i!} e^{-\lambda_i} \cdot \prod_{j=1}^{N_{\mathrm{bkg}}} \mathcal{N}(\lambda^{\mathrm{bkg}j}, \Delta^{\mathrm{bkg}j})$$

Angular asymmetries

- reconstruct distribution
- subtract background
- count events < or > z
- calculate asymmetry
  → calculate helicity fractions



Event selection

lepton+jets

- trigger has fired
- exactly one high p_T lepton (electron/muon)
- MET cut, transverse mass cut
- at least 4 good jets with $p_{\mathrm{T}} > 25$ GeV (1 btag)

dilepton

- e or μ trigger has fired
- exactly two good opposite-sign leptons
- at least two high p_T jets
- $E_{\mathrm{T}}^{\mathrm{miss}}(ee, \mu\mu) > 60$ GeV, $H_{\mathrm{T}}(e\mu) > 130$ GeV
- m(ee, $\mu\mu$) $>$ 15 GeV and |m(ee, $\mu\mu$) -91 GeV| $<$ 10 GeV

Event yield lepton+jets [1]

Process	Single electron channel	Single muon channel
$t\bar{t}$	2200 ± 400	3200 ± 500
Single top	120 ± 10	160 ± 10
QCD multijets	80 ± 80	200 ± 200
W+jets	300 ± 160	500 ± 250
Z+jets	30 ± 20	40 ± 20
Diboson	5 ± 1	8 ± 1
Total predicted	2800 ± 400	4100 ± 600
Data	3006	4313

Background estimate:

- fake lepton: matrix method for e+jets and μ+jets
- W-jets: use estimate from charge asymmetry group for the normalization

[1] see ATLAS-CONF-2011-122

Event yield dilepton [2]

Process	ee channel	$\mu\mu$ channel	$e\mu$ channel
$t\bar{t}$	80 ± 20	160 ± 20	540 ± 50
Single top	3 ± 1	7 ± 1	22 ± 3
Fake leptons	2 ± 1	0 ± 1	30 ± 20
Z ($\rightarrow ee/\mu\mu$) +jets	3 ± 3	4 ± 2	—
Z ($\rightarrow \tau\tau$) + jets	2 ± 1	5 ± 1	26 ± 5
Diboson	2 ± 1	4 ± 9	14 ± 2
Total predicted	90 ± 20	180 ± 20	630 ± 60
Data	103	175	643

Background estimate:

- fake lepton: estimate with matrix method

[2] see ATLAS-CONF-2011-122

Event reconstruction

Semileptonic channel:

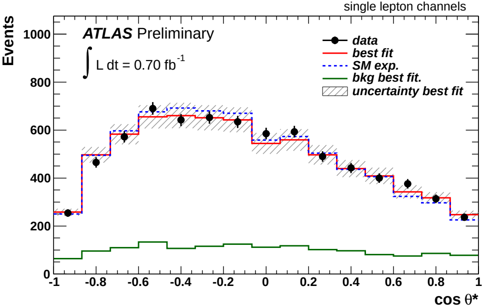
- Kinematic Likelihood fit (Template method)
- unfolding + χ^2-fit (Angular asymmetries)

Dileptonic channel:

→ get solution for two neutrinos:

$$
\begin{aligned}
p_x^{\nu_1} + p_x^{\nu_2} &= \not{E}_{\mathrm{x}}, \\
p_y^{\nu_1} + p_y^{\nu_2} &= \not{E}_{\mathrm{y}}, \\
(p_{\ell_1} + p_{v_1})^2 &= m_{\mathrm{W}}^2, \\
(p_{\ell_2} + p_{v_2})^2 &= m_{\mathrm{W}}^2, \\
(p_{W_1} + p_{j_1})^2 &= m_{\mathrm{t}}^2, \\
(p_{W2} + p_{j_2})^2 &= m_{\mathrm{t}}^2.
\end{aligned}
$$

Result with 0.7 fb^{-1} [3]



Result for the combined lepton+jets channel:

$$
\begin{aligned}
F_0 &= 0.57 \pm 0.07(\mathrm{stat.}) \pm 0.09(\mathrm{syst.}) \\
F_L &= 0.35 \pm 0.04(\mathrm{stat.}) \pm 0.04(\mathrm{syst.}) \\
F_R &= 0.09 \pm 0.04(\mathrm{stat.}) \pm 0.08(\mathrm{syst.})
\end{aligned}
$$

[3] see ATLAS-CONF-2011-122

Limit on effective operator

New physics processes can be modeled by effective Langrangian [4] :

$$\mathcal{L}_{\text{eff}} = \sum \frac{C_x}{\Lambda^2} O_x + \dots$$

One of the six-dimension operators (C_{uW}^{33}) can alter the helicity fractions:

$$F_0 = \frac{m_t^2}{m_t^2 + 2m_W^2} - \frac{4\sqrt{2}\mathrm{Re}\,(C_{uW}^{33})v^2}{\Lambda^2 V_{tb}} \frac{m_t m_W (m_t^2 - m_W^2)}{(m_t^2 + 2m_W^2)^2}$$

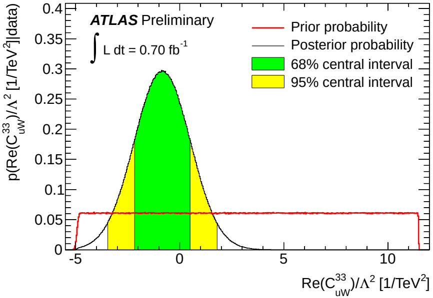
$$F_L = \frac{2m_W^2}{m_t^2 + 2m_W^2} + \frac{4\sqrt{2}\mathrm{Re}\,(C_{uW}^{33})v^2}{\Lambda^2 V_{tb}} \frac{m_t m_W (m_t^2 - m_W^2)}{(m_t^2 + 2m_W^2)^2}$$

$\rightarrow$ Assumption in model: $F_R = 0$

[4] C. Zhang and S. Willenbrock, Effective-Field-Theory Approach to Top-Quark Production and Decay, Phys. Rev. D83 (2011) 034006; J.A. Aguilar-Saavedra, A minimal set of top anomalous couplings, Nucl. Phys B812 (2009) 181.

Set limit on non-SM coupling (comb. with dilepton)[5]

2D fit: $F_0 = 0.75 \pm 0.08\,(\mathrm{stat.+syst.})$



$$\frac{\mathrm{Re}(C^{33}_{uW})}{\Lambda^2} \in [-3.45,\ 1.80]\ \mathrm{TeV}^{-2}$$

→ No deviation from SM predictions has been found

[5] see ATLAS-CONF-2011-122

Limits on anomalous couplings

Lagrangian for the Wtb vertex including anomalous couplings:

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_{\mathrm{L}}P_L + V_{\mathrm{R}}P_R\right)t\;W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(g_{\mathrm{L}}P_L + g_{\mathrm{R}}P_R\right)t\;W_{\mu}^{-} + \mathrm{h.c.}$$

$$V_{\mathrm{L}} = V_{tb} + C_{\phi q}^{(3,3+3)}\frac{v^2}{\Lambda^2} \qquad V_{\mathrm{R}} = \frac{1}{2}C_{\phi\phi}^{33*}\frac{v^2}{\Lambda^2}$$

$$g_{\mathrm{L}} = \sqrt{2}C_{dW}^{33*}\frac{v^2}{\Lambda^2} \qquad g_{\mathrm{R}} = \sqrt{2}C_{uW}^{33}\frac{v^2}{\Lambda^2}$$

Get two sets of limits:

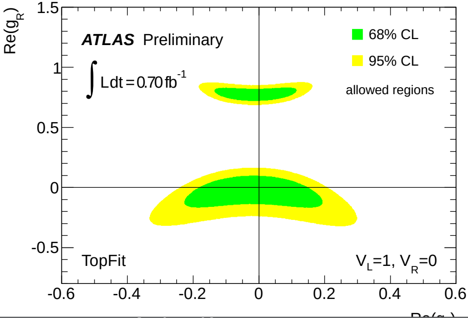
- make 2D limit assuming $V_{\mathrm{R}} = 0$ and $V_{\mathrm{L}} = 1$
- make 1D limits: only one non-zero coupling

Set limits on g_R and g_L:

- assumption: $V_R = 0$ and $V_L = 1$
- use measured angular asymmetries (lepton+jets & dilepton) [a]

$$A_+ = 0.54 \pm 0.02\ (\text{stat.}) \pm 0.04\ (\text{syst.})$$
$$A_- = -0.85 \pm 0.01\ (\text{stat.}) \pm 0.02\ (\text{syst.})$$

[a] see ATLAS-CONF-2011-122



Assuming only one non-vanishing coupling:

$$\text{Re}\, V_{\text{R}} \in [-0.34, 0.39] \rightarrow \frac{\text{Re}\,(C^{33}_{\phi\phi})}{\Lambda^2} \in [-11.2, 12.7]\ \text{TeV}^{-2}$$

$$\text{Re}\, g_{\text{L}} \in [-0.20, 0.16] \rightarrow \frac{\text{Re}\,(C^{33}_{dW})}{\Lambda^2} \in [-2.28, 1.90]\ \text{TeV}^{-2}$$

$$\text{Re}\, g_{\text{R}} \in [-0.19, 0.13] \rightarrow \frac{\text{Re}\,(C^{33}_{uW})}{\Lambda^2} \in [-2.27, 1.57]\ \text{TeV}^{-2}$$

Conclusion for angular asymmetries:[6]

- measurements are in agreement with SM expectations
- helicity fractions are compatible with template method

[6] see ATLAS-CONF-2011-122

Update for template method:
– 1.04 fb^{-1} –

- use new b-tagging algorithm
- use jet smearing
- use samples with higher statistics (esp. templates)

Event yields (ATLAS work in progress)

Process	Single electron channel	Single muon channel
$t\bar{t}$	4391 ± 1091	6518 ± 1435
Single top	257 ± 93	363 ± 105
QCD multijets	219 ± 219	499 ± 499
W+jets	907 ± 705	1386 ± 1002
Z+jets	117 ± 92	135 ± 93
Diboson	14 ± 12	22 ± 12
Total predicted	5905 ± 1324	8924 ± 1825
Data	5830	9121

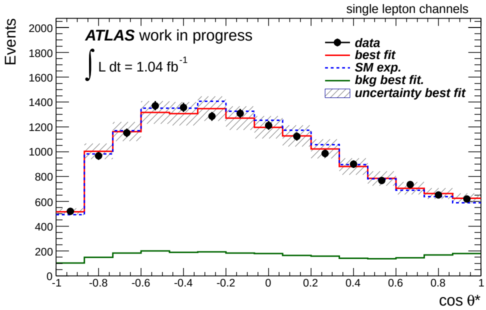
Background estimate:

- fake lepton e+jets: normalisation from matrix method, shape from fitting method
- fake lepton μ+jets: matrix method

Systematic uncertainties (ATLAS work in progress)

Source	Single lepton F_0	F_L	F_R
Signal and background modelling			
Signal modelling	0.036	0.018	0.017
ISR/FSR	0.050	0.020	0.029
PDF uncertainty	0.011	0.006	0.006
Top mass	0.004	0.008	0.004
QCD uncertainty	0.014	0.012	0.002
Wjets uncertainty	0.011	0.005	0.006
Bkg modelling	0.018	0.004	0.013
Detector modelling			
Lepton scale factors	0.003	0.002	0.001
Lepton reconstruction	0.015	0.006	0.009
Jet energy scale	0.026	0.010	0.017
Jet reconstruction	0.037	0.012	0.025
b-tagging uncertainty	0.014	0.005	0.010
Calorimeter readout	0.015	0.008	0.007
Machine unc.	0.011	0.006	0.005
Method	0.018	0.015	0.023
Statistical uncertainty	0.058	0.030	0.033
Systematic uncertainty	0.088	0.041	0.056
Total uncertainty	0.105	0.051	0.065

Combination for lepton+jets



Combined lepton+jets:

$$F_0 = 0.57 \pm 0.06\ (\text{stat.}) \pm 0.09\ (\text{syst.})$$
$$F_L = 0.37 \pm 0.03\ (\text{stat.}) \pm 0.04\ (\text{syst.})$$
$$F_R = 0.07 \pm 0.04\ (\text{stat.}) \pm 0.06\ (\text{syst.})$$

Conclusion

- performed analysis with 0.7 fb^{-1} of data (taken 2011)
- measured W-helicity fractions and angular asymmetries
- set limits on anomalous couplings
- no deviation from Standard Model prediction so far
- decreased uncertainty with 1.04 $^{-1}$ fb

Outlook

- update with 5 fb^{-1} and modify method

  $\rightarrow$ need to decrease systematics (ISR/FSR, jet uncertainties)

Backup

Systematics for W-helicity fractions

Source	Single lepton		
	F_0	F_{L}	F_{R}
Signal and background modeling			
Signal modeling	0.057	0.022	0.045
ISR/FSR	0.044	0.016	0.039
PDF	0.010	0.004	0.007
Top mass	0.002	0.010	0.009
Misidentified leptons	0.014	0.010	0.005
W+jets	0.012	0.005	0.008
Background modeling	0.000	0.000	0.000
Detector modeling			
Lepton reconstruction	0.018	0.008	0.015
Jet energy scale	0.006	0.003	0.008
Jet reconstruction	0.009	0.001	0.009
b-tagging uncertainty	0.035	0.014	0.027
Calorimeter readout	0.028	0.010	0.025
Luminosity and pileup	0.020	0.008	0.022
Method	0.020	0.009	0.014
Systematic uncertainty	0.093	0.039	0.073

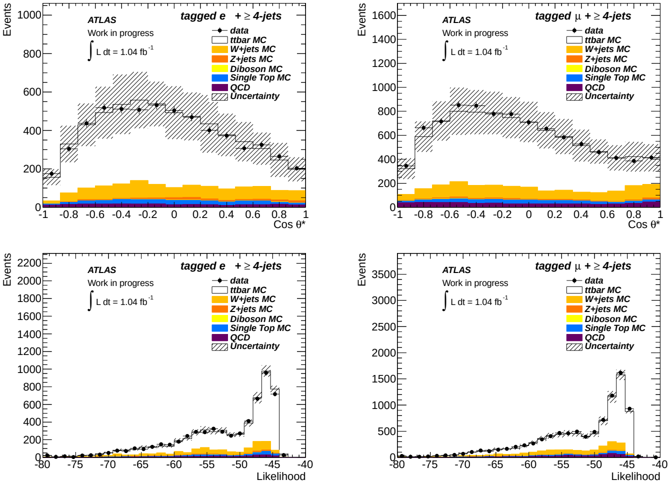
Systematics for angular asymmetries

Source	Single lepton		Dilepton		All channels	
	A_+	A_-	A_+	A_-	A_+	A_-
Signal and background modeling						
Signal modeling	0.028	0.012	0.029	0.012	0.024	0.011
ISR/FSR	0.026	0.009	0.025	0.016	0.023	0.006
PDF	0.004	0.004	0.008	0.013	0.005	0.005
Top mass	0.005	0.007	0.018	0.013	0.009	0.008
Misidentified leptons	0.018	0.003	0.016	0.003	0.016	0.003
W+jets	0.003	0.007	—	—	0.003	0.007
Background modeling	0.002	0.002	0.002	0.002	0.001	0.002
Detector modeling						
Lepton reconstruction	0.009	0.003	0.008	0.003	0.009	0.003
Jet energy scale	0.011	0.012	0.016	0.007	0.012	0.011
Jet reconstruction	0.003	0.002	0.005	0.002	0.003	0.001
b-tagging uncertainty	0.003	0.004	—	—	0.003	0.004
Calorimeter readout	0.003	0.003	0.004	0.003	0.001	0.002
Luminosity and pileup	0.003	0.004	0.002	0.002	0.001	0.003
Method	0.005	0.004	0.003	0.016	0.005	0.005
Systematic uncertainty	0.046	0.024	0.050	0.033	0.042	0.022

Event selection

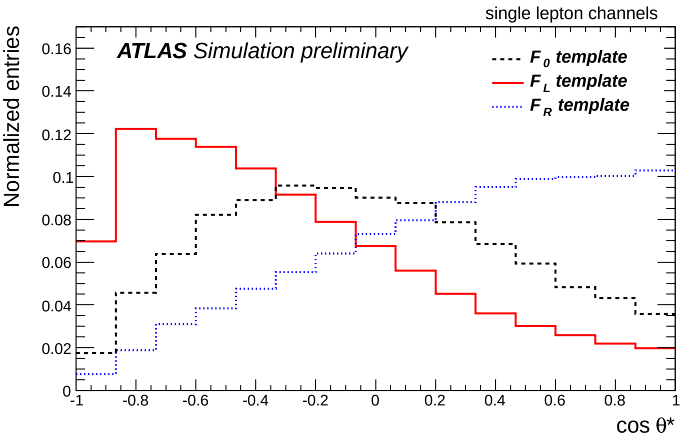
- trigger has fired (for μ+jets: only in data)
- good primary vertex with $\geq$ 5 tracks
- exactly one isolated electron/muon ($p_T > 25/20$ GeV)
- trigger matching
- e-μ overlap removal
- $E_{\mathrm{T}}^{\mathrm{miss}} > 35(20)$ GeV for e+jets(μ+jets)
- $m_{T,W} > 25$ GeV (e)
- $m_{T,W} + E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV (μ)
- at least 4 good jets with $p_{\mathrm{T}} > 25$ GeV (one b-tagged jet)

Control plots for 1.04 $^{-1}$ fb



→ uncertainty contains: statistics, JES, b-tag, ISR/FSR, signal modelling

Reconstructed template distributions



Event reconstruction (Template method l+jets)

- 12 possibilities to map jets with partons
- have to choose one for reconstruction
- with kinematic likelihood fitter: KLFitter
- transfer functions extracted from MC
- top mass is fixed
- most probable jet-parton mapping is used for $\cos\theta^*$

Angular asymmetry: Correction Function method

- unfolding of cos θ^* distribution to parton level
- "correction function": bin-by-bin unfolding (iterative procedure)
- subtract background from data
- Unfolding factor: $f_C = \frac{\text{generated signal}}{\text{reconstructed signal}}$

Systematic uncertainties I

Signal and bkg modelling:

- Signal modeling: Showering, MC Generators, Colour reconnection;
- Background modeling: HF, Wshape, QCDshape, Bkg normalization
- ISR/FSR, Top mass, PDF

Detector modelling:

- JES, Jet reconstruction (JRE, JER)
- Lepton SF, Lepton reconstruction (LES, LER)
- calorimeter readout
- machine uncertainties (Luminosity and Pileup)
- Method (Template statistics, event reconstruction)

BLUE weights for combination

Table: BLUE weights for the combination of the results from the lepton+jets channel obtained by the template method.

		F0	FL
	ej T	50.01	-4.80
F0	mj T	49.99	4.80
	ej T	0.04	35.30
FL	mj T	-0.04	64.70
	All [%]	100.00	100.00