Measurement of the W boson polarisation in $t\bar{t}$ events at $\sqrt{S}$= 8 TeV in the lepton+jets channel with ATLAS

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Bundesministerium
für Bildung
und Forschung

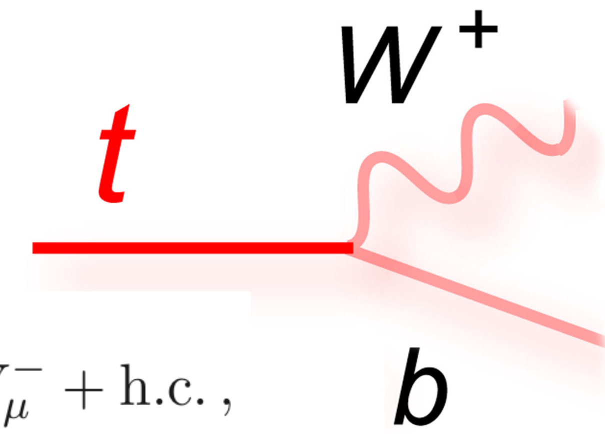
PHYSICS AT THE TERA SCALE
Helmholtz Alliance

FSP 103
ATLAS

ATLAS

Motivation

- Top quarks decay almost ~100% through $t \rightarrow Wb$
- The top quark decay vertex Lagrangian:

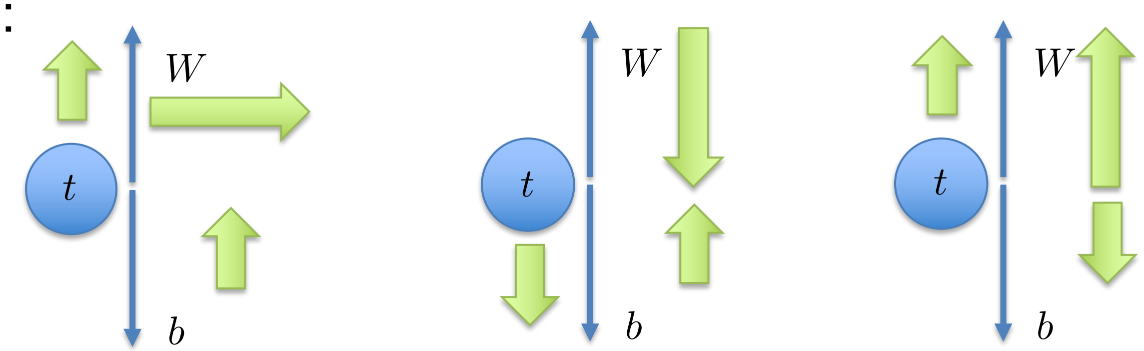


$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\left(V_{\rm L}P_{\rm L} + V_{\rm R}P_{\rm R}\right)t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(g_{\rm L}P_{\rm L} + g_{\rm R}P_{\rm R}\right)t\,W_{\mu}^{-} + {\rm h.c.}\,,$$

Anomalous couplings:

- No SM contribution at tree-level
- Any BSM contribution?
- Direct impact on the the W boson polarisation (from top quark decay)

- Measuring W boson polarisation with high precision provides:
  - Good test of the Standard Model prediction
  - Probe for new physics processes



F_0=0.687±0.005 **F_L=0.311±0.005** **F_R0=0.0017±0.0001**

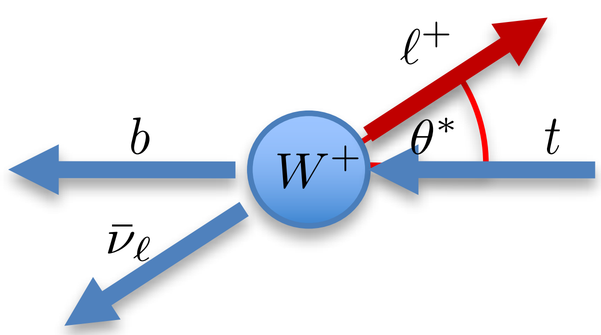
SM NNLO calculation: Phys. Rev. D81, 111503 (2010)

Physical Observable

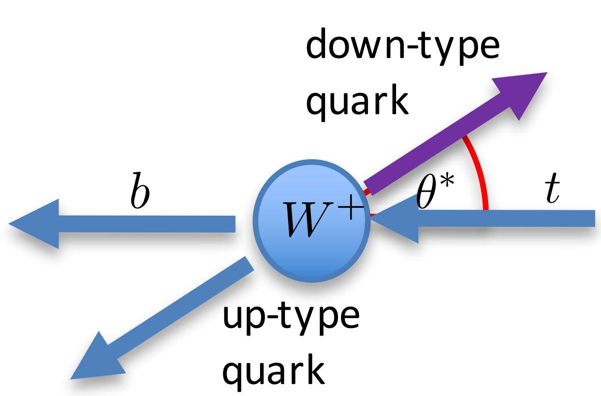
- The angular distributions of the **charged lepton** and the **down-type quark** in W rest frame

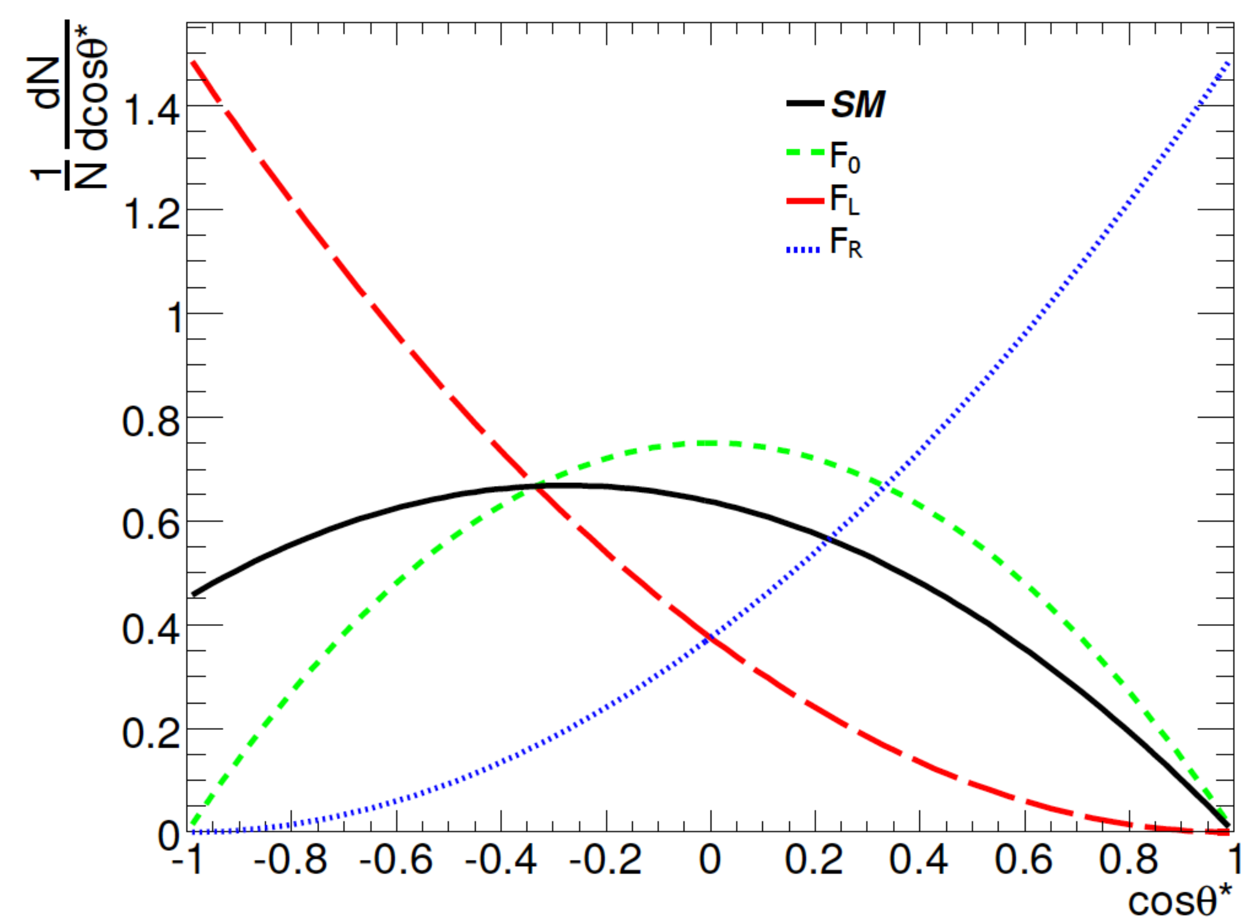
$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right)\,F_0 + \frac{3}{8}\,(1-\cos\theta^*)^2\,F_L + \frac{3}{8}\,(1+\cos\theta^*)^2\,F_R$$

Leptonic analyser



Hadronic analyser





Dataset + Object / Event Selection

- 20.2 fb^{-1} data from 8 TeV proton-proton collisions recorded by the ATLAS detector in 2012
- Monte Carlo simulations used for $t\bar{t}$ signal, *W*+jets, Z+jets, diboson, and single top
- Data-driven methods used to estimate fake lepton contribution and W+jets normalisation
  - W+jets categorised by heavy flavour content (*W*+light, *W*+c, *W*+bb/cc)

Object Selection

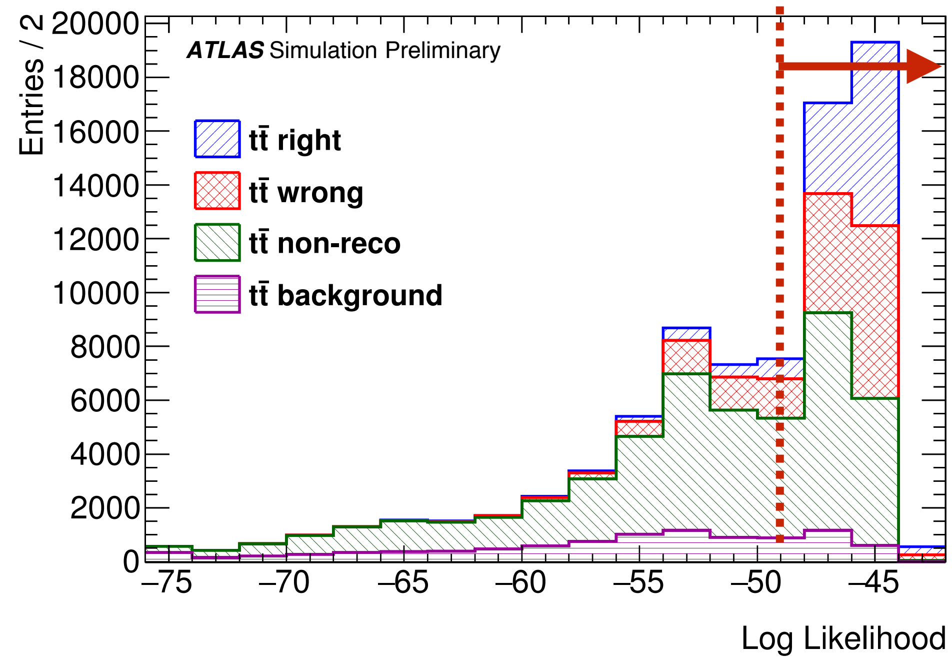
- **Lepton: p_T > 25 GeV & |η| < 2.5, isolated**
- **Jet: Anti-k_T R=0.4, p_T> 25 GeV & |η| < 2.5,**
  - **|JVF| > 0.5 (for p_T> 50 GeV)**
- **MET(1 excl. b-tag only):**
  - **MET ⩾ 20 GeV, MET+M_T^W ⩾ 60 GeV**

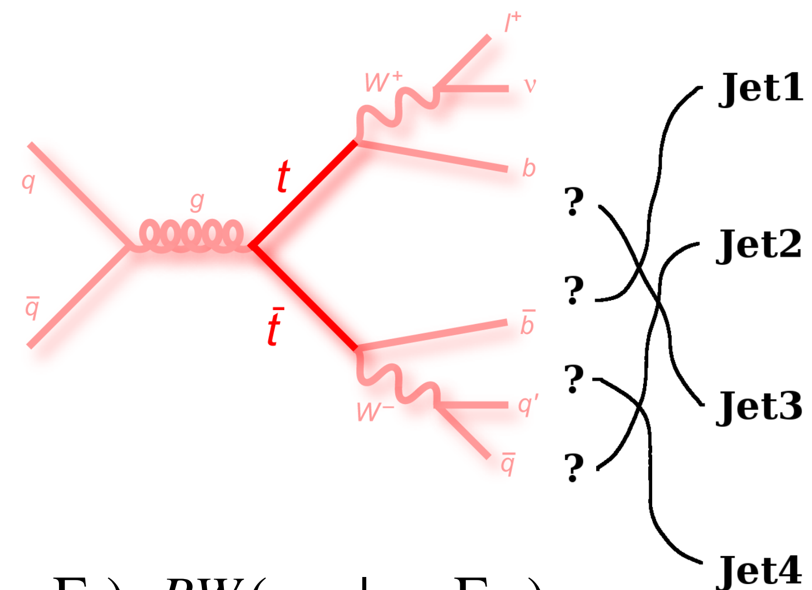
Event Selection

- **Lepton trigger**
- **⩾ 1 primary vertex with ⩾ 5 tracks**
- **Exactly one lepton**
- **⩾ 4 jets (1 or ⩾ 2 b-tagged)**
- **Reconstruction quality criteria**

Event Reconstruction (I)

- Events reconstruction via extended kinematic likelihood fit [1]
- Permute two highest b-tag weight jets + next 2/3 jets leading in p_T jets => 4!(5!)=24(120) permutations
- Evaluate each permutation using:
  - Breit-Wigners for invariant masses as constraints
  - Transfer functions *W* to map energies from reconstructed to parton level
- Require log likelihood > -48 to increase purity and maximise sensitivity (required for hadronic analyser)





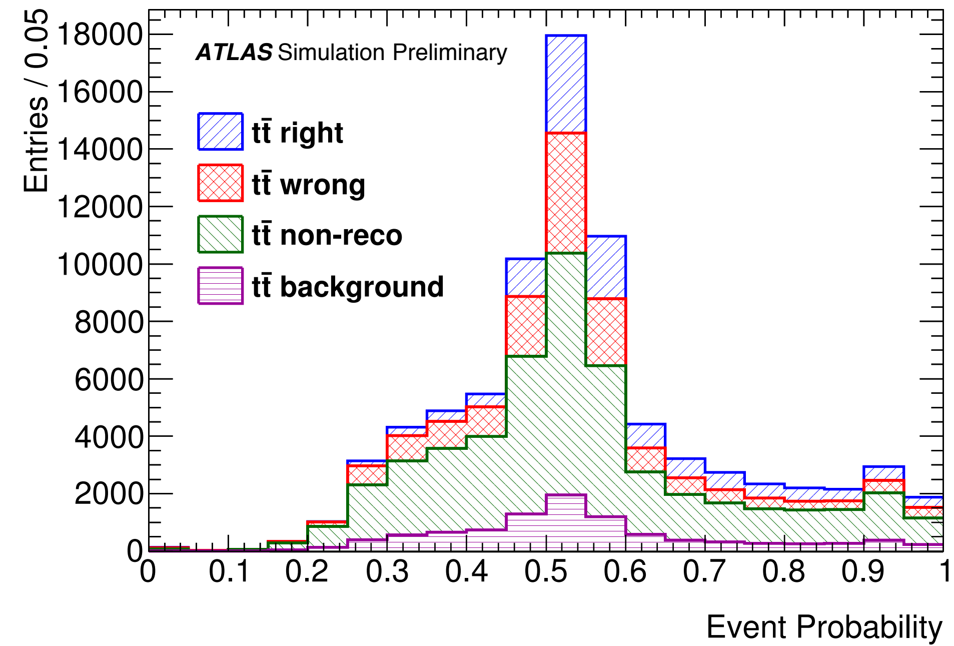
$$L = BW(m_{q1q2q3} \mid m_t \Gamma_t) \bullet BW(m_{q1q2} \mid m_W \Gamma_W) \bullet BW(m_{q4} \ell \upsilon \mid m_t \Gamma_t) \bullet BW(m_{\ell\upsilon} \mid m_W \Gamma_W)$$

$$\bullet \prod_{i=1}^{4} W_{jet}(E_i^{meas.} \mid E_i) \bullet W_{\ell}(E_x^{meas.} \mid E_{\ell}) \bullet W_{miss}(E_x^{miss} \mid p_x^{\upsilon}) \bullet W_{miss}(E_y^{miss} \mid p_y^{\upsilon})$$

[1]: NIM A 748 (2014) 18–25, [2]: TOPQ-2016-02

Event Reconstruction (II)

- Likelihood extended to a normalised event probability (adding b-tagging info.)
- up/down type jet separation
  - Use jet p_T dependent b-tag weight
  - Discrimination comes mainly from 50% $W \rightarrow cs$ decays
- Choose jet permutation with highest event probability p_i



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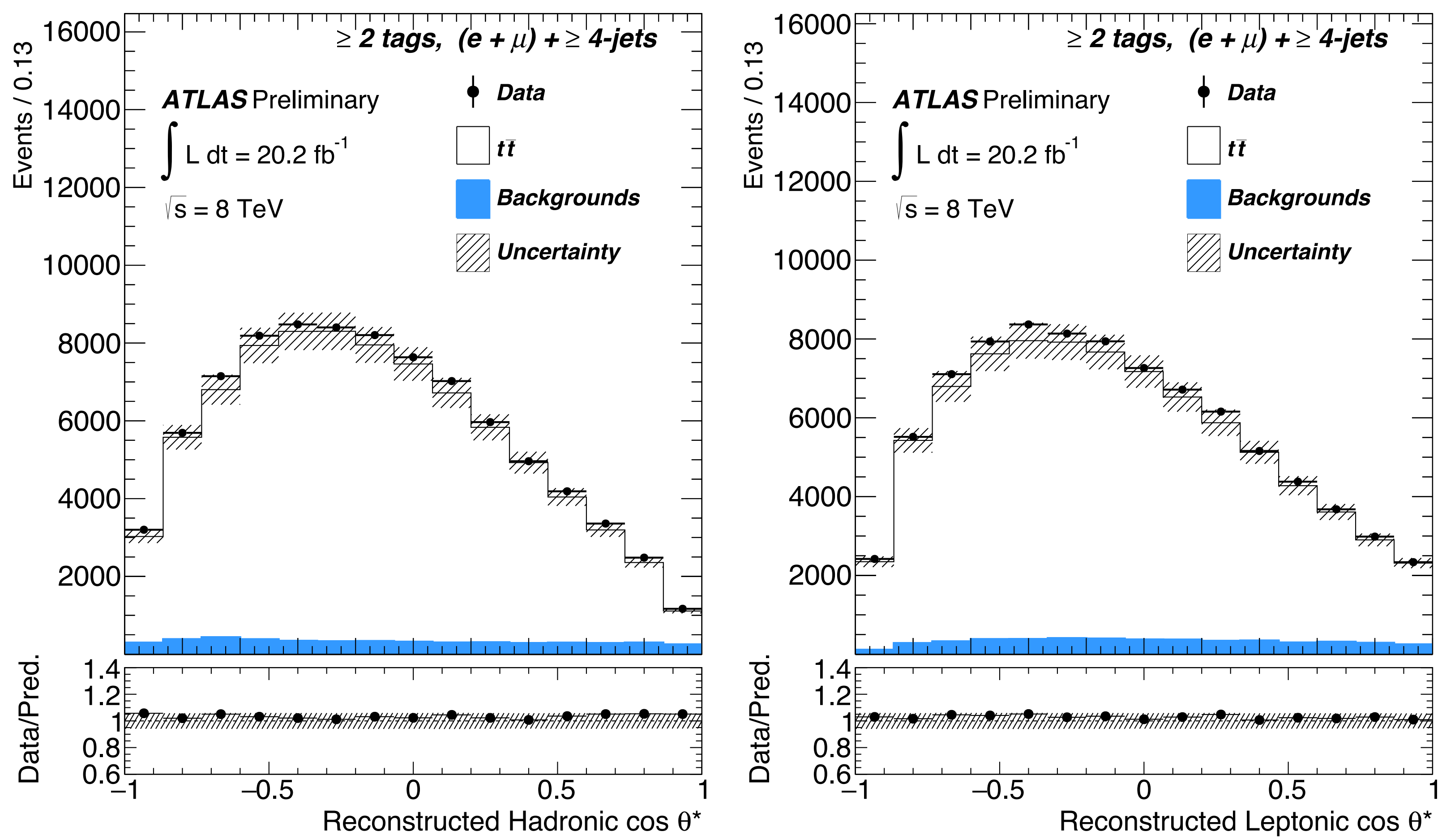


$$p_i = \frac{\mathcal{L}_i \prod_j \Delta p_{i,j}}{\sum_i \mathcal{L}_i \prod_j \Delta p_{i,j}}$$

[2]: TOPQ-2016-02

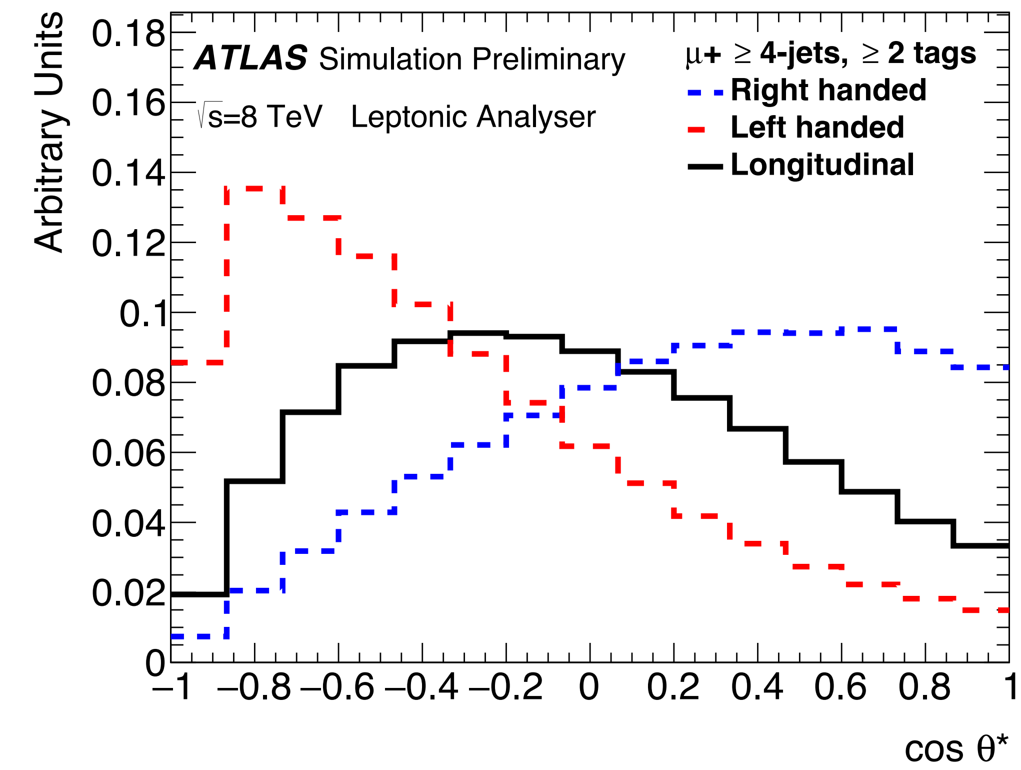
Template Fit Method

- Dedicated template for the difference polarisation states obtained by reweighing (3 sig. + 5 bkg. templates)
- Analytic reweighing function from fit to cos(θ*) truth distribution in full phase space (before selection)
- Fit parameters:
  - Yields of signal (n_0, n_L, n_R) and background (W+jets, QCD, Rem.bkg)
- A binned likelihood fit is performed

$$L = \prod_{k=1}^{N_{\rm bins}} {\rm Poisson}(n_{{\rm data},k}, n_{{\rm exp},k}) \prod_{j=1}^{N_{\rm bkg}} \frac{1}{\sqrt{2\pi}\sigma_{{\rm bkg},j}} e^{\frac{-(n_{{\rm bkg},j}-\hat{n}_{{\rm bkg},j})^2}{2\sigma^2_{{\rm bkg},j}}}$$

- Use normalisation uncertainties as Gaussian priors to constrain background normalisation (See backup slides)
- *W* boson polarisation extracted as

$$F_{\rm i} = \frac{N_i}{N_0+N_L+N_R}, \quad n_i = \epsilon_i^{\rm sel} N_i \quad \text{for i= 0, L, R.}$$



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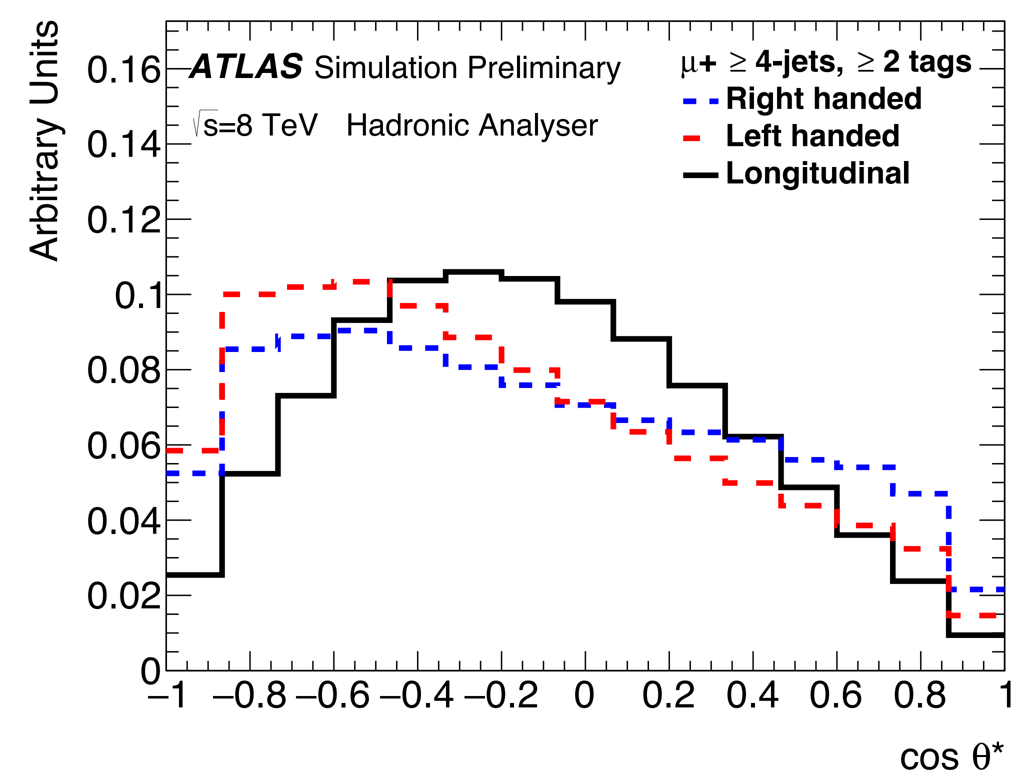


[2]: TOPQ-2016-02

Systematics Uncertainties

Dominant Uncertainties

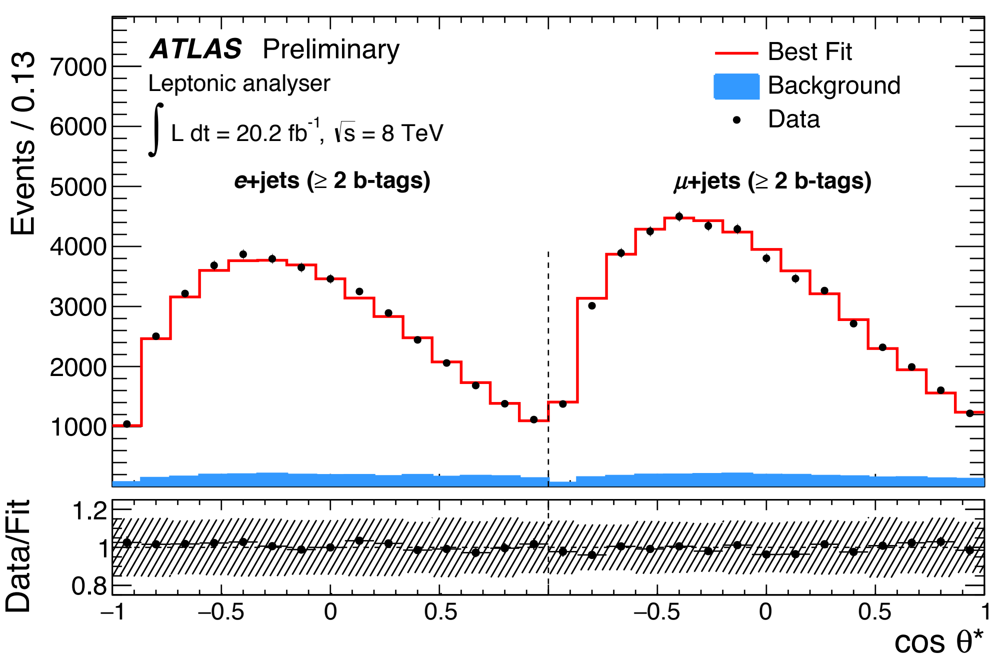
Systematic Uncertainty	Lepontic ≥ 2 b-tags			Hadronic 1 + ≥ 2 b-tags		
	F_0	F_L	F_R	F_0	F_L	F_R
Reconstructed Objects						
Jet Energy Scale	+0.006 -0.003	+0.003 -0.002	+0.004 -0.001	+0.007 -0.007	+0.012 -0.008	+0.014 -0.005
Jet Energy Resolution	+0.006 -0.006	+0.005 -0.002	+0.007 -0.007	+0.027 -0.031	+0.033 -0.041	+0.057 -0.071
***b* tagging**	+0.002 -0.002	+0.001 -0.001	+0.001 -0.001	+0.029 -0.031	+0.013 -0.014	+0.034 -0.035
Signal Modelling						
Showering & Hadronisation	±0.002	±0.002	±0.004	±0.015	±0.001	±0.014
ME Generator	±0.003	±0.003	±0.006	±0.016	±0.024	±0.040
ISR/FSR	±0.003	±0.006	±0.003	±0.018	±0.039	±0.057

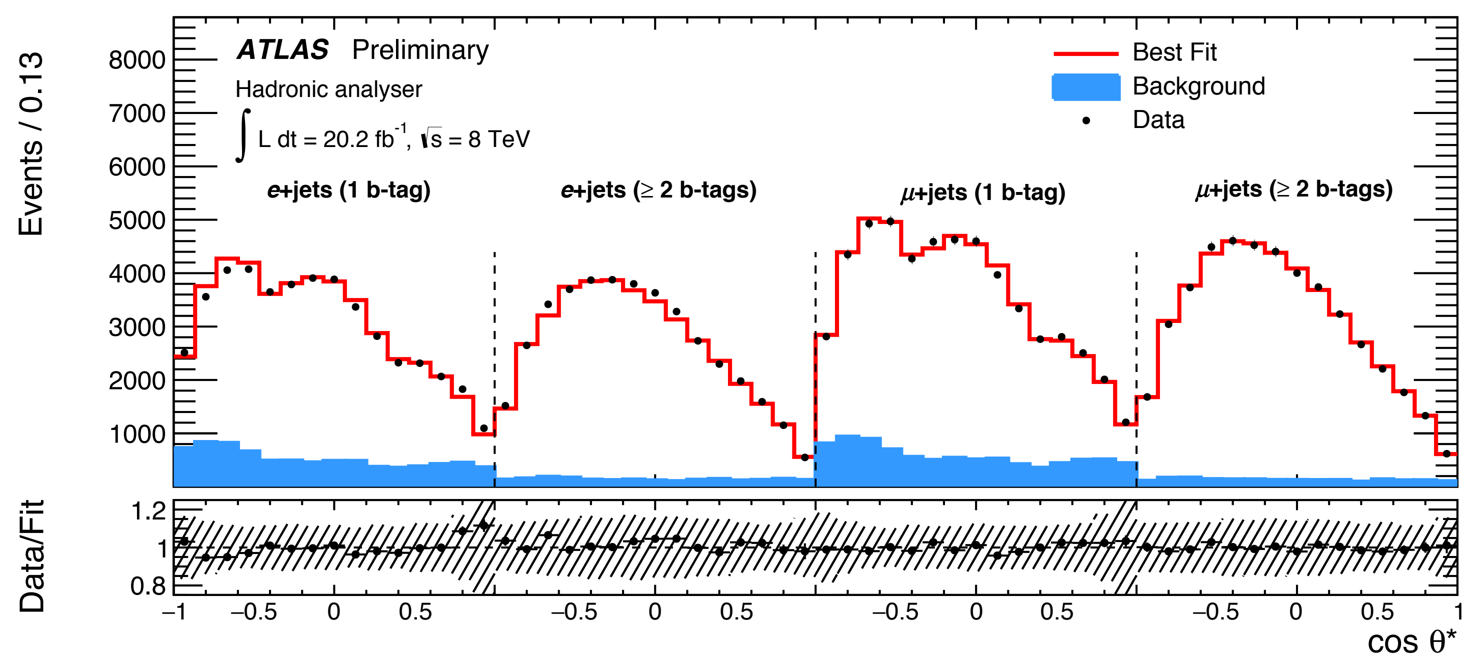
- Systematic uncertainties evaluated via ensemble tests
  - Generate 5000 sets of pseudo-data for each systematic variation
- Perform likelihood fit using nominal templates and systematically varied pseudo-data
- Background normalisation directly evaluated in the fit

Results

- Channels combined via performing a simultaneous fit on the extended templates (histograms)
- Possible combinations are studied (8 orthogonal channels)
- Best results obtained for each analysers:
  - Leptonic analyser: in ⩾2 b-tags **(most sensitive / best result)**
  - Hadronic analyser: in 1 b-tag + ⩾2 b-tags
- Most accurate measured *W* boson polarisation to date
- In good agreement with the Standard Model prediction

[2]





Leptonic analyser (≥2 *b*-tags)

$$F_0 = 0.709 \pm 0.012 \ \text{(stat. + bkg. norm.)} \ {}^{+0.015}_{-0.014} \ \text{(syst.)}$$
$$F_L = 0.299 \pm 0.008 \ \text{(stat. + bkg. norm.)} \ {}^{+0.013}_{-0.012} \ \text{(syst.)}$$
$$F_R = \text{-}0.008 \pm 0.006 \ \text{(stat. + bkg. norm.)} \pm 0.012 \ \text{(syst.)}$$

Hadronic analyser (1 *b*-tag + ≥2 *b*-tags)

$$F_0 = 0.659 \pm 0.010 \ \text{(stat. + bkg. norm.)} \ {}^{+0.052}_{-0.054} \ \text{(syst.)}$$
$$F_L = 0.281 \pm 0.021 \ \text{(stat. + bkg. norm.)} \ {}^{+0.063}_{-0.067} \ \text{(syst.)}$$
$$F_R = 0.061 \pm 0.022 \ \text{(stat. + bkg. norm.)} \ {}^{+0.101}_{-0.108} \ \text{(syst.)}$$

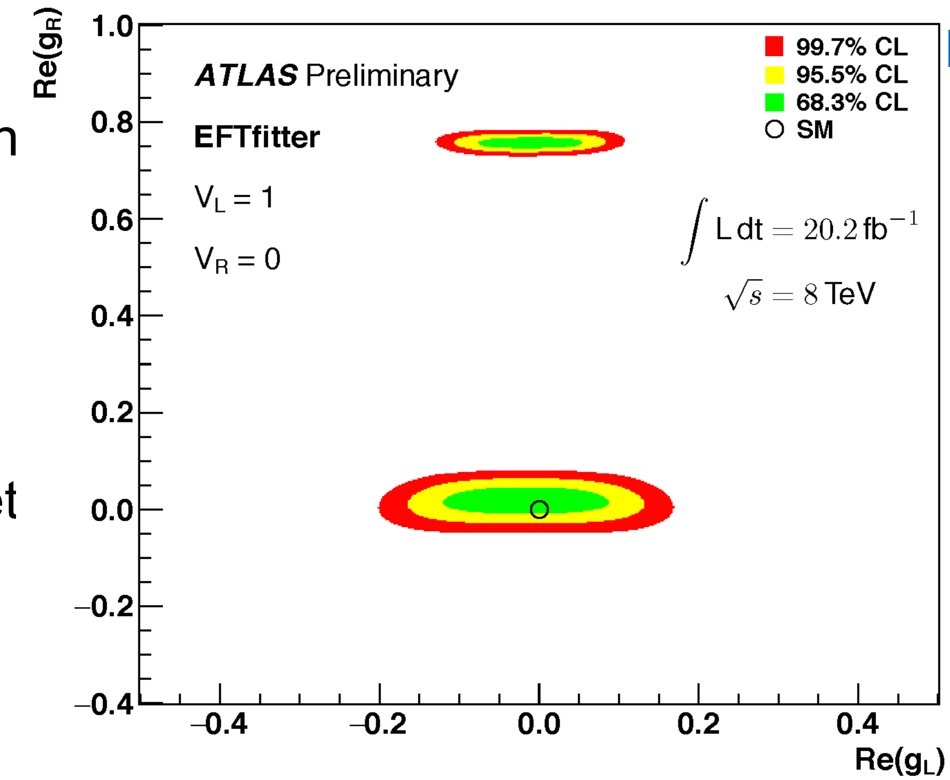
[2]: TOPQ-2016-02

EFT Limits

- Effect of anomalous couplings on helicity fractions modeled within effective theory framework
- All anomalous couplings assumed to be real
- Limits on couplings set using the EFTfitter framework [3]
- One-dimensional limits extracted while fixing others to zero (set to the SM expectation)

Coupling	95% CL limit
V_R	[-0.24, 0.31]
g_L	[-0.14, 0.11]
g_R	[-0.02, 0.06],[0.74, 0.78]

- Two-dimensional limits for $Re(g_L)/Re(g_R)$ and $Re(V_R)/Re(g_R)$ set



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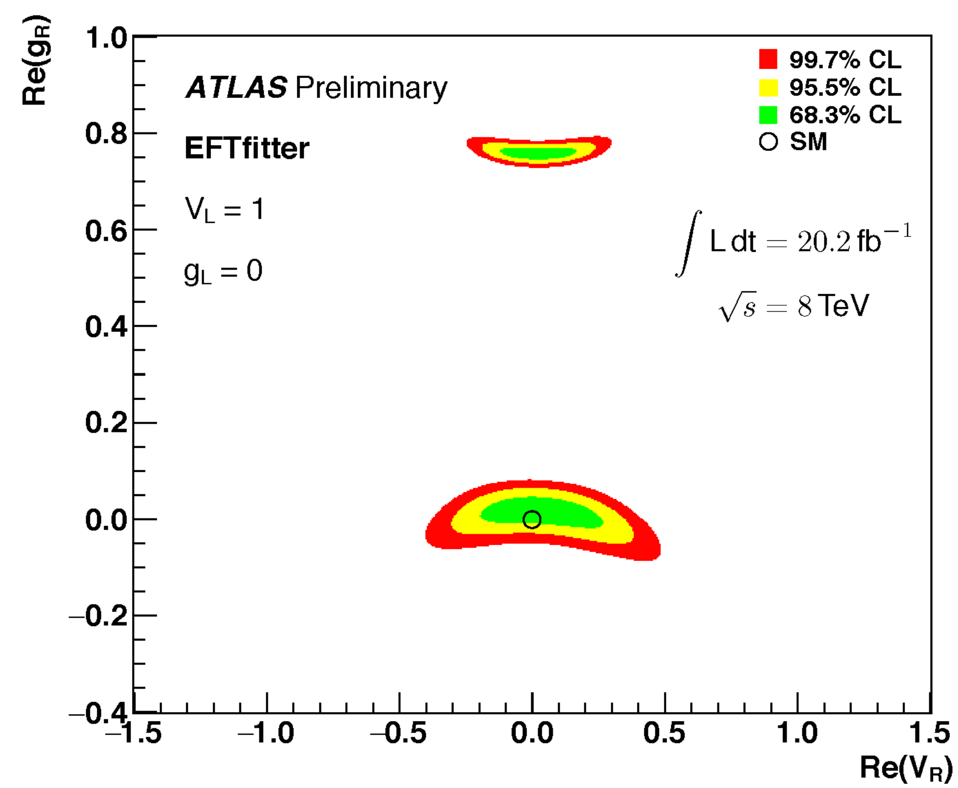

[2]: TOPQ-2016-02, [3]: Eur.Phys.J. C76 (2016) 8, 432

Summary

The Top Quark

- Has very special properties
- Top quark properties precision measurements:
  - Can open a window to BSM physics
  - Good probe for the Standard Model

W Boson Polarisation Measurement in top quark decay

- ATLAS has measured the *W* boson polarisation produced in $t\bar{t}$ lepton+jet decays at 8 TeV
- First direct measurement using hadronic analysers
- Most accurate measured *W* boson polarisation to date
- Limits placed on anomalous *Wtb* couplings
- Result is in good agreement with the Standard Model prediction
- To be submitted to EPJ C.

Backup

Comparison to other measurements

	7 TeV	8 TeV
CMS	**5 fb^{-1}** [JHEP 1310 (2013) 167] F_0 = 0.682 ± 0.030 (stat.) ± 0.06 (syst.) F_L = 0.310 ± 0.022 (stat.) ± 0.03 (syst.) F_R = 0.008 ± 0.012 (stat.) ± 0.04 (syst.)	**19.6 fb^{-1}** [CMS-TOP-13-008, sub. to PLB] F_0 = 0.681 ± 0.012 (stat.) ± 0.023 (syst.) F_L = 0.323 ± 0.008 (stat.) ± 0.014 (syst.) F_R = -0.004 ± 0.005 (stat.) ± 0.014 (syst.)
ATLAS	**1.4 fb^{-1}** [JHEP 1206 (2012) 088] F_0 = 0.67 ± 0.03 (stat.) ± 0.06 (syst.) F_L = 0.32 ± 0.02 (stat.) ± 0.03 (syst.) F_R = 0.01 ± 0.01 (stat.) ± 0.04 (syst.)	**This Analysis** F_0 = 0.709 ± 0.012 (stat.*) ± 0.015 (syst.) F_L = 0.299 ± 0.008 (stat.*) ± 0.013 (syst.) F_R = -0.008 ± 0.006 (stat.*) ± 0.012 (syst.)

* Including uncertainty from background normalisation

Bkg. normalisation uncertainties

- Background normalisation uncertainties used in Gaussian priors of the fit:

Background	Prior Width
W + light jets	5 %
W + c	25 %
W + cc/bb	7 %
Lepton fakes	30 %
Remaining background (Single top, Z+jets, WW/ZZ/WZ)	16 % / 17 % (≥ 2 b-tags, ≥1 b-tag)