EFT Experimental Inputs

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HL/HE-LHC WG1 Meeting – Top Physics

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Cofinanciado por:

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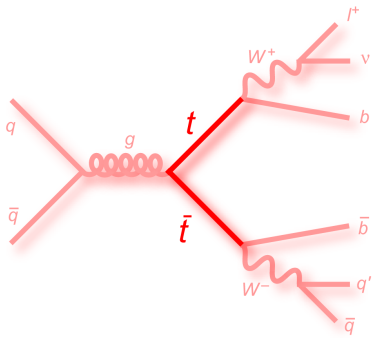
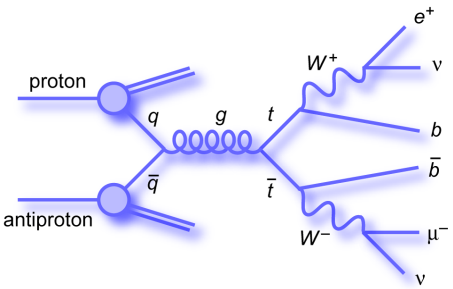
Outline

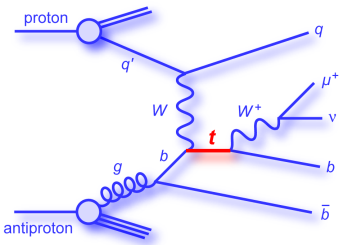
Main objective: extend the studies already performed at the LHC on top quark Anomalous Couplings/EFT in $t \to Wb$ decays to HL-LHC/HE-LHC

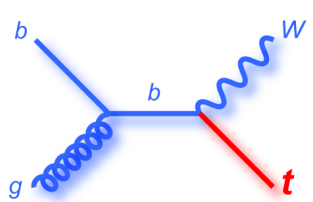
Several processes under study to probe the *Wtb* vertex[1]:

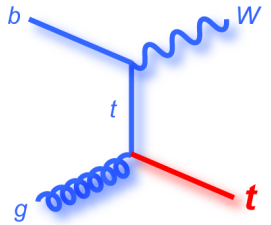
- Top quark pair production ($t\bar{t}$)
  - (i) semileptonic channel
  - (ii) dileptonic decays
- single top quark physics
  - (i) *t*-channel (single lepton)
  - (ii) *Wt*-channel (dileptonic decay)
- EFT/anomalous couplings studied associated to the *Wtb* vertex







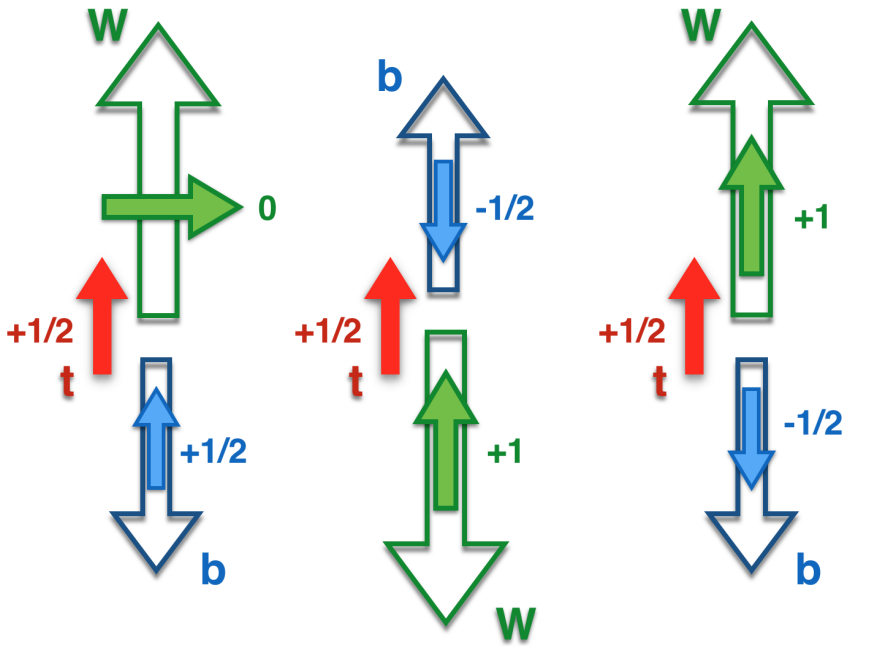




[1] JHEP**1206**(2012)088, EPJC**77**(2017)264, JHEP**04**(2017)124, JHEP**04**(2016)023, JHEP**12**(2017)017, PLB**717**(2012)330, PRD**90**(2014)112006, PLB**716**(2012)142, PLB**756**(2016)228, EPJC**77**(2017)531, JHEP**01**(2016)064, JHEP**04**(2017)086, JHEP**01**(2018)63, EPJC**78**(2018)186

Top quark pair production ($t\bar{t}$)

☞ Observable(s): angular distribution(s) $\cos\theta^*_\ell$ [F_0, F_L, F_R]



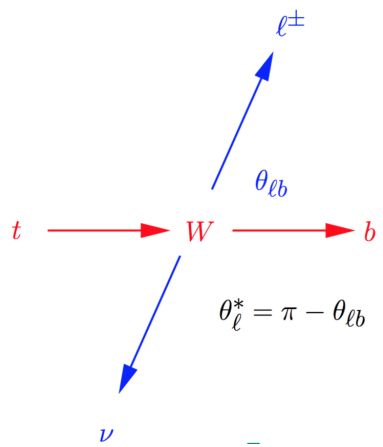
F_0
W Longitudinal fraction

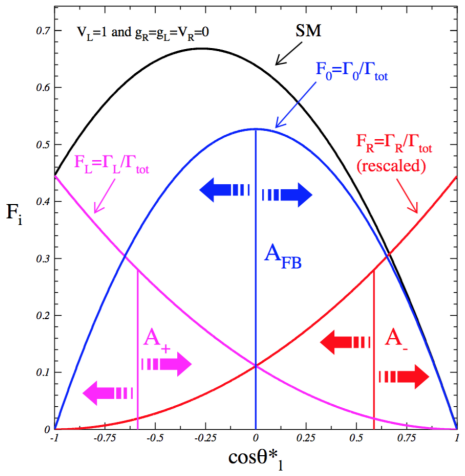
F_L
W Left-Handed fraction

F_R
W Right-Handed fraction

$$F_0^{SM} = 0.687 \pm 0.005$$
$$F_L^{SM} = 0.311 \pm 0.005$$
$$F_R^{SM} = 0.0017 \pm 0.0001$$

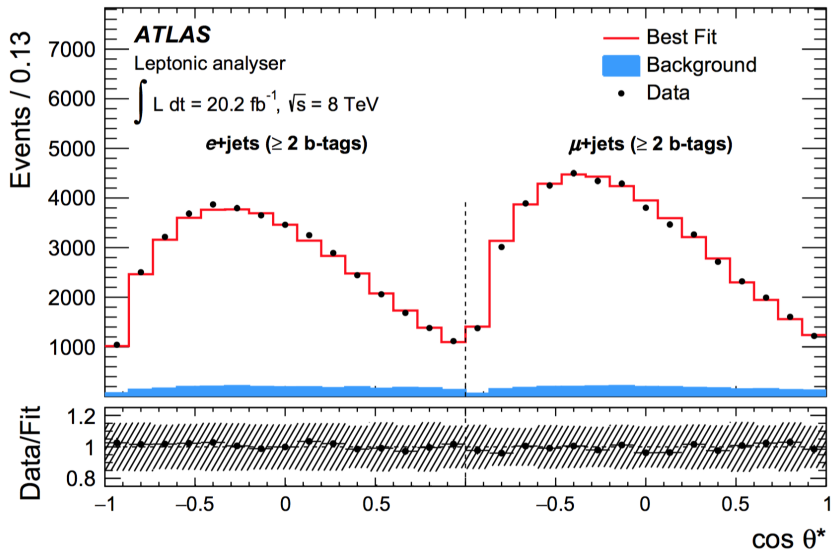
@ NNLO QCD calculation, PRD**81**(2010)111503
($F_0 + F_L + F_R = 1$)



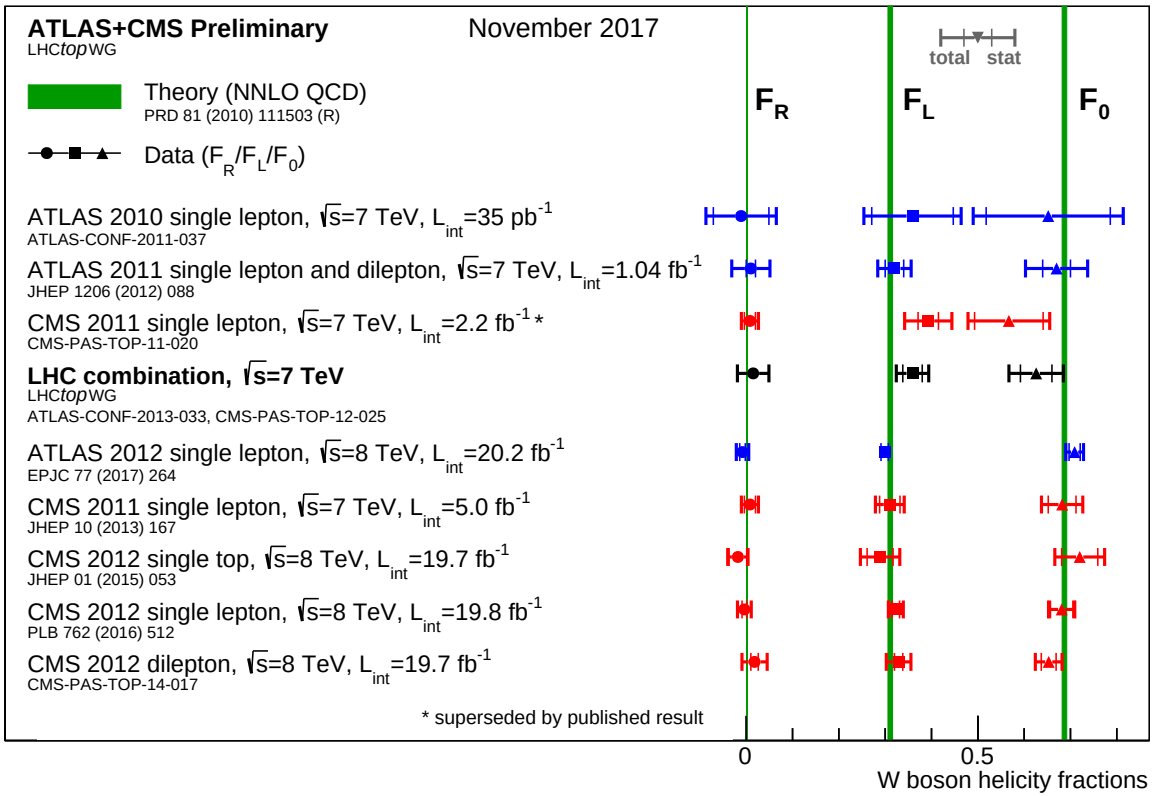


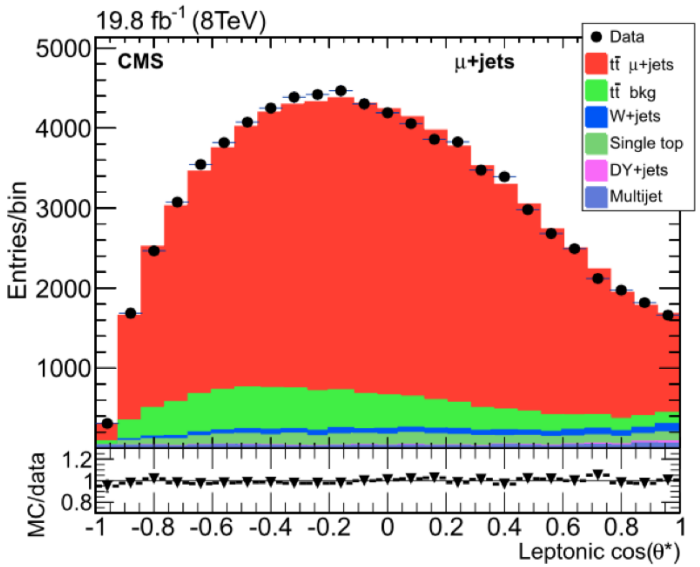
$$\frac{1}{N}\frac{dN}{d\cos\theta^*_\ell} = \frac{3}{2}\left[F_0\left(\frac{\sin\theta^*_\ell}{\sqrt{2}}\right)^2 + F_L\left(\frac{1-\cos\theta^*_\ell}{2}\right)^2 + F_R\left(\frac{1+\cos\theta^*_\ell}{2}\right)^2\right]$$

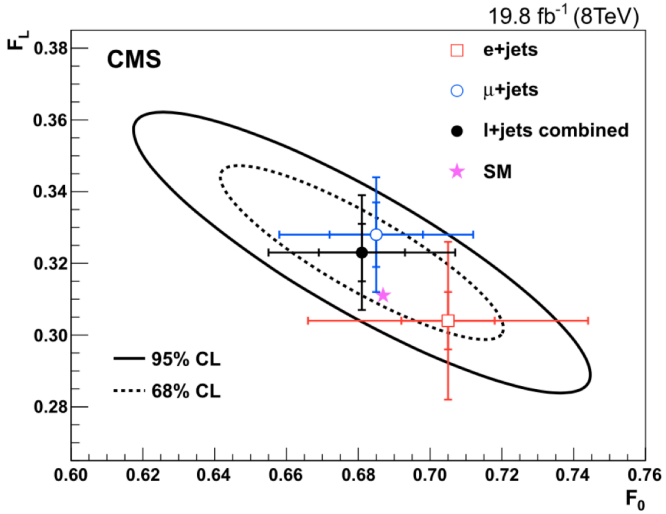
EPJC**77**(2017)264



Summary of W-boson helicity meas. @ LHC







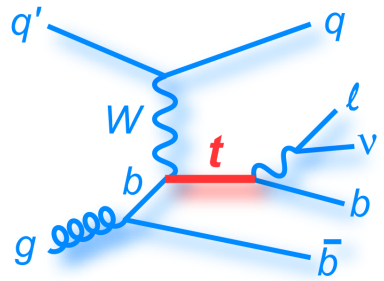
$\Delta F_0/F_0 \sim 2.7\%$ (3.7× theo. unc.)

$\Delta F_L/F_L \sim 5\%$ (3.1× theo. unc.)

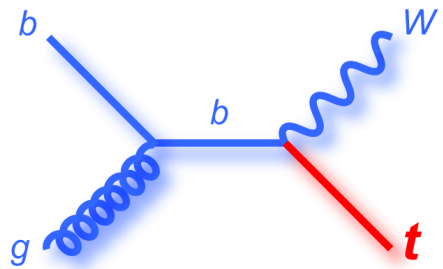
F_R=-0.008±0.014

Single top quark production

- Processes currently under study:

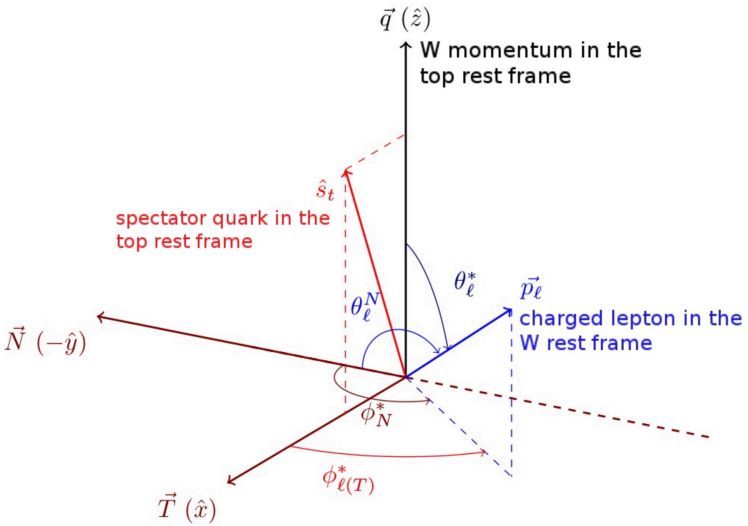


t-channel



(*Wt*-prod.)

☞ Observables: 2D angular distributions in *t*-channel production as a function of 6 spin observabels $< S_{1,2,3} >$, $< T_0 >$, $< A_{1,2} >$ [PRD **93** (2016) 011301]



1) Double-differential distribution:

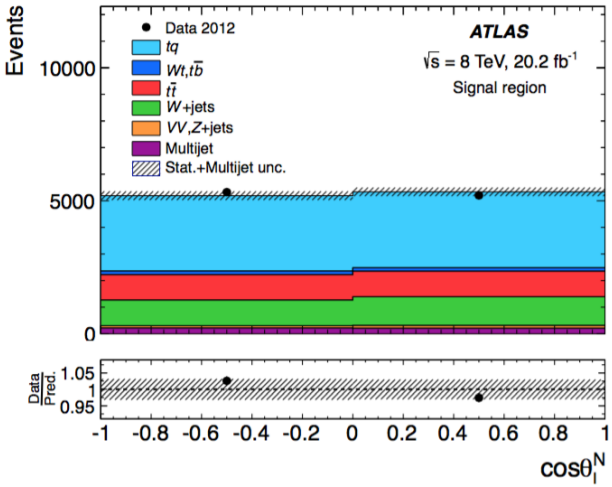
$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta^*_\ell)d\phi^*_\ell} = \frac{3}{8\pi}\left\{\frac{2}{3}+\frac{1}{\sqrt{6}}\langle T_0\rangle\left(3\cos^2\theta^*_\ell-1\right)+\langle S_3\rangle\cos\theta^*_\ell + \langle S_1\rangle\cos\phi^*_\ell\sin\theta^*_\ell + \langle S_2\rangle\sin\phi^*_\ell\sin\theta^*_\ell - \langle A_1\rangle\cos\phi^*_\ell\sin 2\theta^*_\ell - \langle A_2\rangle\sin\phi^*_\ell\sin 2\theta^*_\ell\right\}.$$

2) A_{FB} and A_{EC} Asymmetries:

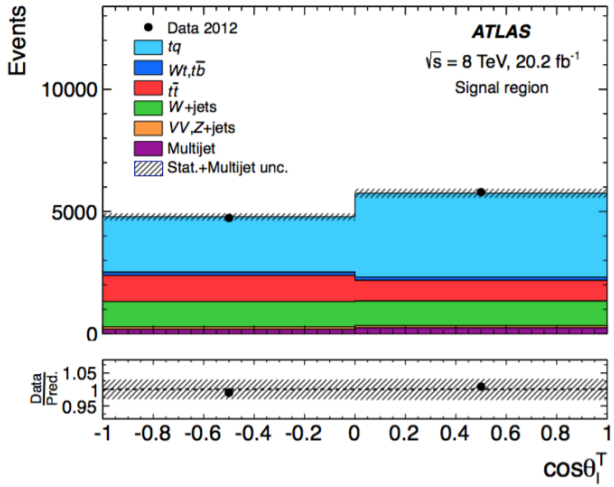
$$A_{\rm FB} = \frac{N(\cos\theta>0)-N(\cos\theta<0)}{N(\cos\theta>0)+N(\cos\theta<0)} \qquad A_{\rm EC} = \frac{N(|\cos\theta|>\frac{1}{2})-N(|\cos\theta|<\frac{1}{2})}{N(|\cos\theta|>\frac{1}{2})+N(|\cos\theta|<\frac{1}{2})}$$

Single top quark production

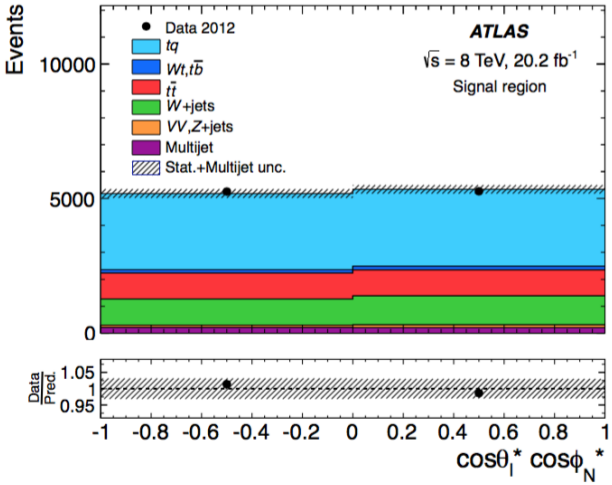
- Angular observables distributions in signal region [JHEP**04**(2017)124]:



(a)



(b)



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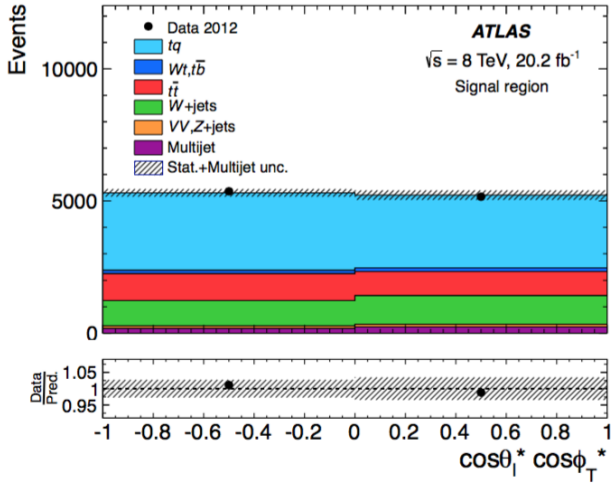


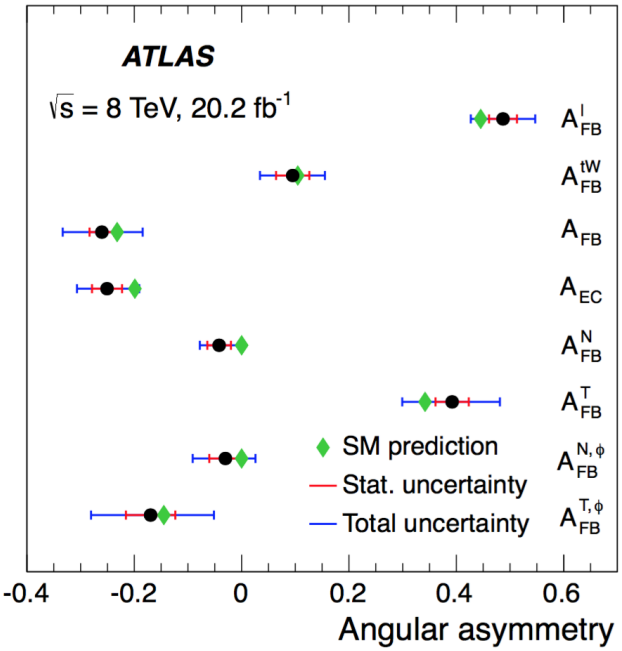
(d)

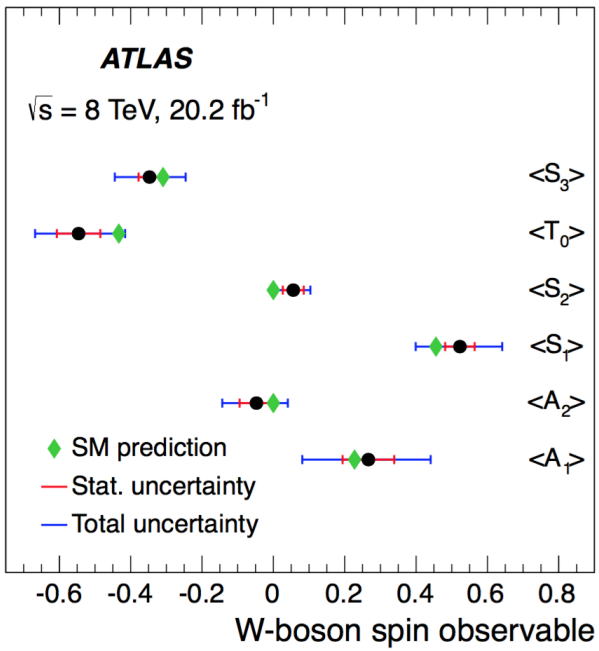
Single top quark production

- Asymmetries with associated angular distributions [JHEP**04**(2017)124]:

Asymmetry	Angular observable	Polarisation observable	SM prediction
A_{FB}^{ℓ}	$\cos\theta_{\ell}$	$\frac{1}{2}\alpha_{\ell}P$	0.45
A_{FB}^{tW}	$\cos\theta_{W}\cos\theta_{\ell}^{*}$	$\frac{3}{8}P\,(F_{\mathrm{R}}+F_{\mathrm{L}})$	0.10
A_{FB}	$\cos\theta_{\ell}^{*}$	$\frac{3}{4}\langle S_3\rangle = \frac{3}{4}\,(F_{\mathrm{R}}-F_{\mathrm{L}})$	−0.23
A_{EC}	$\cos\theta_{\ell}^{*}$	$\frac{3}{8}\sqrt{\frac{3}{2}}\langle T_0\rangle = \frac{3}{16}\,(1-3F_0)$	−0.20
A_{FB}^{T}	$\cos\theta_{\ell}^{T}$	$\frac{3}{4}\langle S_1\rangle$	0.34
A_{FB}^{N}	$\cos\theta_{\ell}^{N}$	$-\frac{3}{4}\langle S_2\rangle$	0
$A_{\mathrm{FB}}^{T,\phi}$	$\cos\theta_{\ell}^{*}\cos\phi_{T}^{*}$	$-\frac{2}{\pi}\langle A_1\rangle$	−0.14
$A_{\mathrm{FB}}^{N,\phi}$	$\cos\theta_{\ell}^{*}\cos\phi_{N}^{*}$	$\frac{2}{\pi}\langle A_2\rangle$	0

$$A_{\mathrm{FB}}^{\ell} = 0.49 \pm 0.03\ (\mathrm{stat.}) \pm 0.05\ (\mathrm{syst.}) = 0.49 \pm 0.06\,,$$
$$A_{\mathrm{FB}}^{tW} = 0.10 \pm 0.03\ (\mathrm{stat.}) \pm 0.05\ (\mathrm{syst.}) = 0.10 \pm 0.06\,,$$
$$A_{\mathrm{FB}} = -0.26 \pm 0.02\ (\mathrm{stat.}) \pm 0.07\ (\mathrm{syst.}) = -0.26 \pm 0.08\,,$$
$$A_{\mathrm{EC}} = -0.25 \pm 0.03\ (\mathrm{stat.}) \pm 0.05\ (\mathrm{syst.}) = -0.25 \pm 0.06\,,$$
$$A_{\mathrm{FB}}^{T} = 0.39 \pm 0.03\ (\mathrm{stat.}) \pm 0.09\ (\mathrm{syst.}) = 0.39 \pm 0.09\,,$$
$$A_{\mathrm{FB}}^{N,\phi} = -0.03 \pm 0.03\ (\mathrm{stat.}) \pm 0.05\ (\mathrm{syst.}) = -0.03 \pm 0.06\,,$$
$$A_{\mathrm{FB}}^{T,\phi} = -0.17 \pm 0.05\ (\mathrm{stat.})^{+0.11}_{-0.10}\ (\mathrm{syst.}) = -0.17^{+0.12}_{-0.11}\,.$$





Spin Measurements:

$< S_3 >= -0.35 \pm 0.10$

$< T_0 >= -0.55 \pm 0.13$

$< S_2 >= +0.06 \pm 0.05$

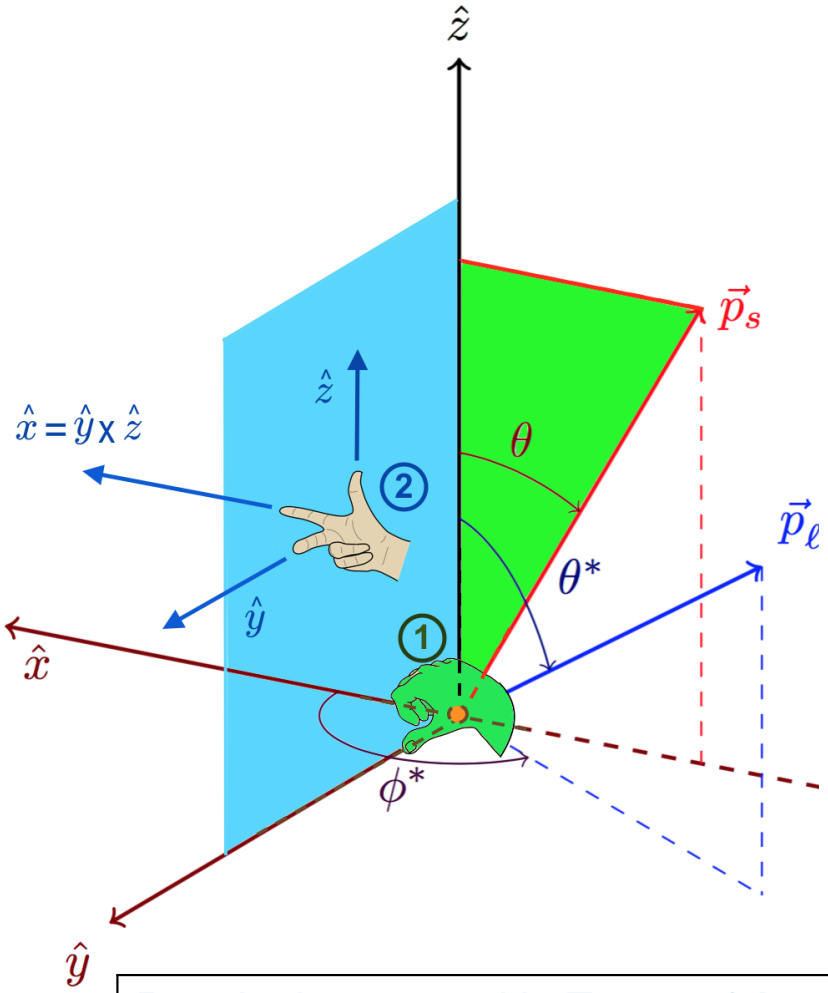
$< S_1 >= +0.52 \pm 0.12$

$< A_2 >= -0.05 \pm 0.10$

$< A_1 >= +0.27\ ^{+0.17}_{-0.19}$

- Triple-differential (3D) decay rates of polarised top quarks

  ☞ define specific coordinate system (in t centre-of-mass):



1) System Definition (in t-system):

$\hat{z} = \hat{p}^*_W = \vec{p}^*_W/|\vec{p}^*_W|$, $\vec{p}^*_s$=spectator quark mom.

$\hat{y} = \hat{p}^*_s \times \hat{p}^*_W$, $\quad \hat{x} = \hat{y} \times \hat{p}^*_W$

2) Triple-differential distribution:

$$\begin{aligned}
\varrho(\theta,\theta^*,\phi^*;P) = \frac{1}{N}\frac{\mathrm{d}^3N}{\mathrm{d}(\cos\theta)\mathrm{d}\Omega^*} &= \frac{1}{8\pi}\left\{\frac{3}{4}\left|A_{1,\frac{1}{2}}\right|^2(1+P\cos\theta)(1+\cos\theta^*)^2\right. \\
&+ \frac{3}{4}\left|A_{-1,-\frac{1}{2}}\right|^2(1-P\cos\theta)(1-\cos\theta^*)^2 \\
&+ \frac{3}{2}\left(\left|A_{0,\frac{1}{2}}\right|^2(1-P\cos\theta)+\left|A_{0,-\frac{1}{2}}\right|^2(1+P\cos\theta)\right)\sin^2\theta^* \\
&- \frac{3\sqrt{2}}{2}P\sin\theta\sin\theta^*(1+\cos\theta^*)\,\mathrm{Re}\left[e^{i\phi^*}A_{1,\frac{1}{2}}A^*_{0,\frac{1}{2}}\right] \\
&\left.- \frac{3\sqrt{2}}{2}P\sin\theta\sin\theta^*(1-\cos\theta^*)\,\mathrm{Re}\left[e^{-i\phi^*}A_{-1,-\frac{1}{2}}A^*_{0,-\frac{1}{2}}\right]\right\} \\
&= \sum_{k=0}^{1}\sum_{l=0}^{2}\sum_{m=-k}^{k} a_{k,l,m}M^m_{k,l}(\theta,\theta^*,\phi^*),
\end{aligned}$$

A_{λ_W,λ_b} = helicity amplitudes $\qquad M^m_{k,l}(\theta,\theta^*,\phi^*) = \sqrt{2\pi}Y^m_k(\theta,0)Y^m_l(\theta^*,\phi^*)$

Results Interpreted in Terms of Anomalous Couplings (V_R, g_L, g_R)

☞ **next slide**

Anomalous couplings/EFT parameters in global fits

General Wtb vertex

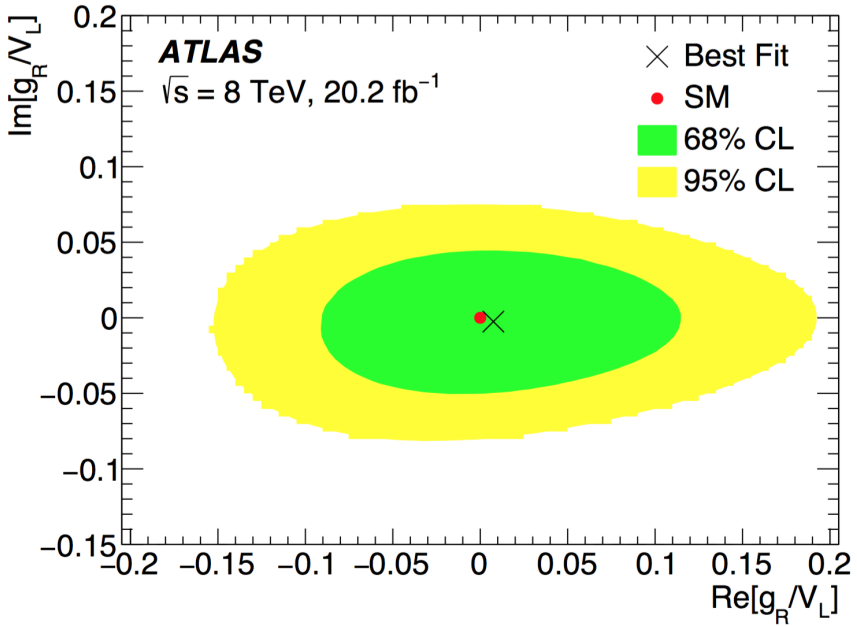
Eur.Phys.J. C50 (2007) 519-533

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

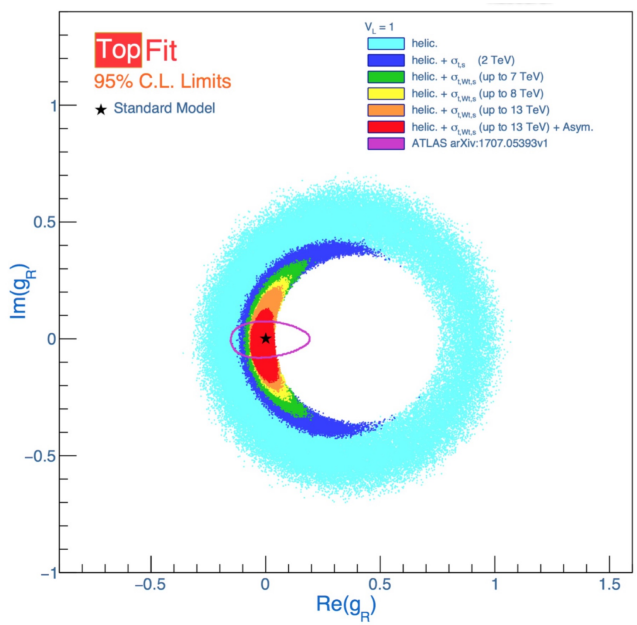
vector (V_R) and tensor like couplings (g_L, g_R) zero @ tree level in SM

☞ EFT parameters: anomalous couplings described by effective operators $\mathcal{O}_{uW}$,$\mathcal{O}_{dW}$, $\mathcal{O}_{\phi q}^{(3)}$ and $\mathcal{O}_{\phi ud}$ i.e., constraints on anomalous couplings equivalent to constraints on EFT parameters (a more integrating framework) [arXiv:1802.07237]

JHEP 12 (2017) 017



PRD 97 (2018) 1, 013007 (TopFit)



Fits Using:

σ, W_{hel}, A_{FB} @ 7,8,13 TeV

Current Status and Writeup

Contribution to the HL-LHC/HE-LHC Physics Case:

1) several analysis under way ($t\bar{t}$, t-channel and Wt-channel)
2) not yet approved ATLAS public plots
3) full kinematical reconstruction
4) angular distributions identified (progressively including more) in $t\bar{t}$ and single top
5) interpretation in terms of BSM couplings
6) HL-LHC under control, HE-LHC progressively available Monte Carlo samples

Write-up (proposal):

- Introduction

  Complementary introduction to $ttX(X = \gamma, Z)$ including the specific case of the Wtb vertex and interpretation of measurements within EFT (common underlying framework)

  ☞ 1/2 - 1 page

Current Status and Writeup

- Physics channels and analysis
  1) $t\bar{t}$: semileptonic + dileptonic
  2) Single top: t-channel and Wt-channel (semi.+dileptonic)

  ☞ Plots: 1 per analysis (angular observable)
  (material can go to public notes to simplify things)

  ☞ Tables: 1, including all analysis

  ☞ Pages: 1-2

- Results
  - Main: 95% CL limits on couplings, under the SM assumption

    ☞ Plots: 2 (with all contributions)

    ☞ Pages: 1

☞ Total Pages $\geq$ 2+1/2 (with 1/2 common to $t\bar{t}X$)

Conclusions

- On-going work from ATLAS for $t\bar{t}$ and single top quark observables for HL-LHC as well as HE-LHC
- For HL-LHC essentially all SM simulations are available (progressively available for HE-LHC)
- **The timescale:**
  - June 2018, first distributions looked at, for several channels in ATLAS (still not yet public approved plots)
  - July 2018, set of relevant distributions (after reconstruction) followed by fits
  - September 2018 for the Yellow Report and TOP2018
- **The deliverables:**
  Progressively understand how observables change sensitivity to anomalous couplings/EFT parameters
- **Results from CMS and Theoretical Interpretation:**

  Given the proposed underlying anomalous couplings/EFT approach, contacts with CMS and theorists well come to set up the best approach (it doesnt have to be exhaustive, we can start with few observables and go from there)