

Top quark properties at ATLAS

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Why study the top quark properties?

- Top decays before hadronization

- $\Lambda_{\text{QCD}}^{-1} = (100 \text{ MeV})^{-1} \sim 10^{-23} \text{ s}$
- $\Gamma_t^{SM} = 1.42 \text{ GeV}$
 $\tau_t \sim 10^{-25} \text{ s} \ll 10^{-23} \text{ s}$

- Top decays (almost exclusively) through $t \rightarrow bW$:

$$BR(t \rightarrow sW) \leq 0.18\%, BR(t \rightarrow dW) \leq 0.02\%$$

- among the different top couplings to the gauge and Higgs bosons, the Wtb vertex deserves a special attention
- rare decays via flavour changing neutral currents (FCNC) are an important probe for physics beyond the SM

- Large mass of the t -quark ($m_t = 173.2 \pm 0.9 \text{ GeV}$, arXiv:1107.5255)

- $\lambda_t = \sqrt{2}m_t/v \sim 1$ ↗ special role in EWSB?
- top quark as a probe for new physics

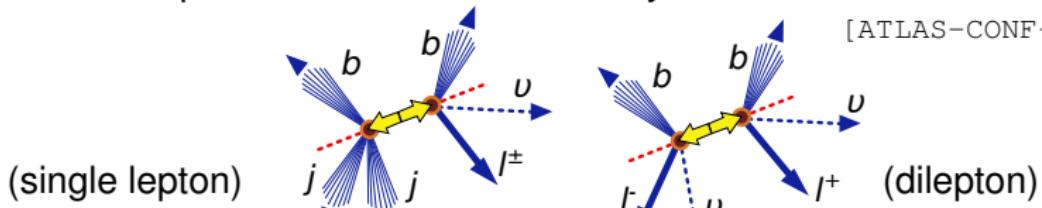
Quarks	I	II	III	
Leptons	u	c	t	γ
	d	s	b	g
	ν_e	ν_μ	ν_τ	Z
	e	μ	τ	W

Three Generations of Matter



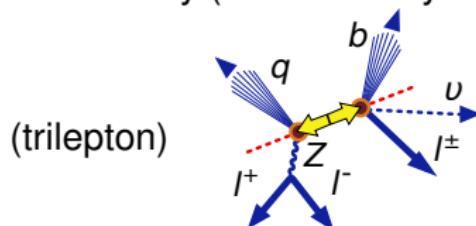
- **$t\bar{t}$ production**

- W polarisation in $t \rightarrow bW$ decay and Wtb vertex structure



[ATLAS-CONF-2011-122]

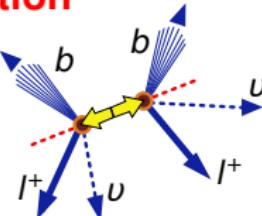
- $t \rightarrow qZ$ FCNC decay (other t decays via SM, $t \rightarrow bW$)



[ATLAS-CONF-2011-154]

- **same-sign $t\bar{t}$ production**

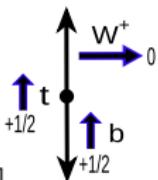
(same-sign dilepton)



[arXiv:1202.5520]

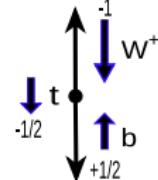
Nuno Castro - Top Quark Properties at ATLAS

W polarisation in $t \rightarrow bW$ decays

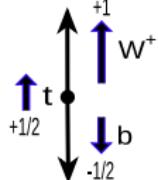


[PRD81 (2010) 111503]

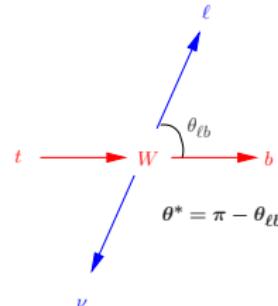
longitudinal W
SM (NNLO): $F_0 = 0.687$



left-handed W
 $F_L = 0.311$

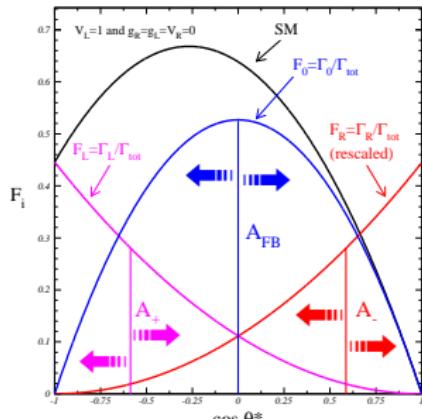


right-handed W
 $F_R = 0.0017$



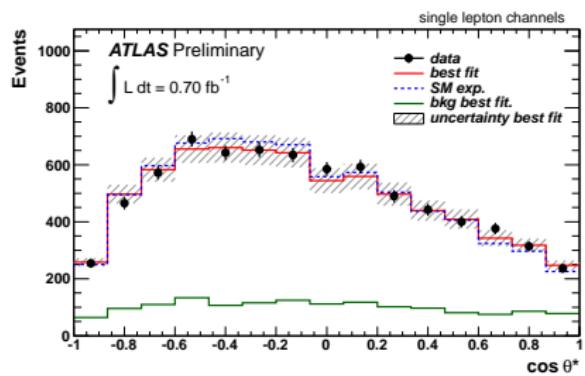
$$\frac{1}{N} \frac{dN}{d \cos \theta^*} = \frac{3}{2} \left[F_0 \left(\frac{\sin \theta^*}{\sqrt{2}} \right)^2 + F_L \left(\frac{1 - \cos \theta^*}{2} \right)^2 + F_R \left(\frac{1 + \cos \theta^*}{2} \right)^2 \right]$$

- ☛ fit of the $\cos \theta^*$ using templates
- ☛ evaluation of angular asymmetries
- ☛ BSM structure of the Wtb vertex changes W helicity fractions and angular asymmetries



W polarisation in $t \rightarrow bW$ decays

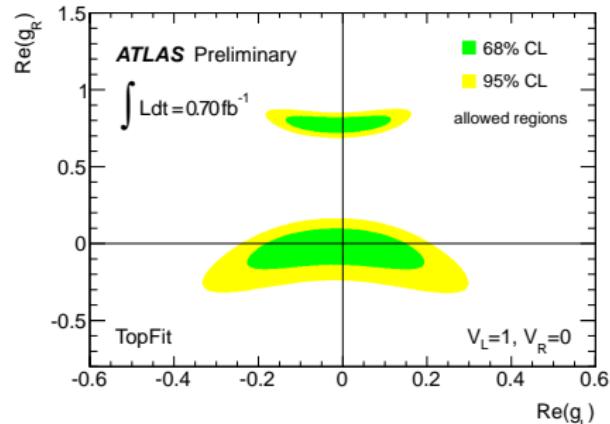
⌚ $\ell + \text{jets}$ and dilepton channels



Effective Wtb vertex from dim-6 operators

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

$V_L \equiv V_{tb} \sim 1$ (within SM)
 $V_R, g_R, g_L \Rightarrow$ anomalous couplings

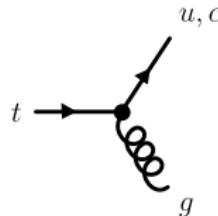
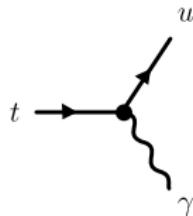
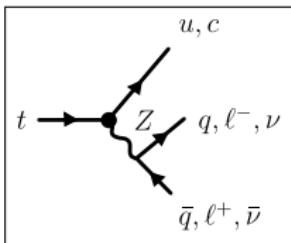


	templates $\ell + \text{jets}$	templates dilepton	asymmetries all
F_0	0.57 ± 0.11	0.75 ± 0.08	0.70 ± 0.10
F_L	0.35 ± 0.06	0.25 ± 0.08	0.31 ± 0.07
F_R	0.09 ± 0.09	fixed to 0	-0.01 ± 0.04

$$\begin{aligned} A_+ &= 0.54 \pm 0.04 \\ A_- &= -0.85 \pm 0.02 \end{aligned}$$



Search for FCNC



Theoretical predictions for the BR of FCNC top quark decays

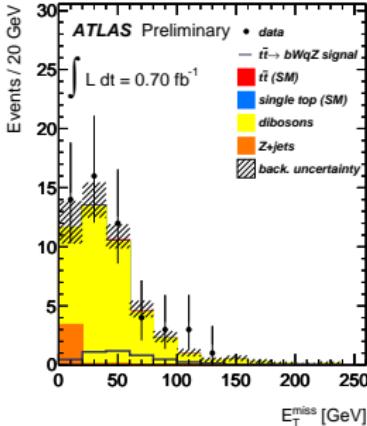
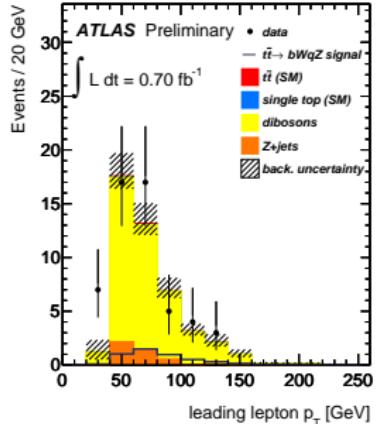
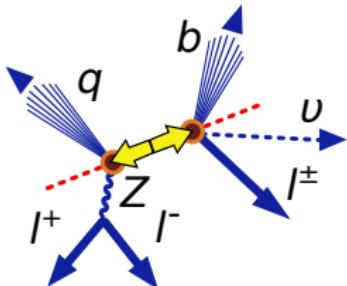
Process	SM	QS	2HDM	FC 2HDM	MSSM	R SUSY	TC2	RS
$t \rightarrow u\gamma$	3.7×10^{-16}	7.5×10^{-9}	—	—	2×10^{-6}	1×10^{-6}	—	$\sim 10^{-11}$
$t \rightarrow uZ$	8×10^{-17}	1.1×10^{-4}	—	—	2×10^{-6}	3×10^{-5}	—	$\sim 10^{-9}$
$t \rightarrow ug$	3.7×10^{-14}	1.5×10^{-7}	—	—	8×10^{-5}	2×10^{-4}	—	$\sim 10^{-11}$
$t \rightarrow c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}	$\sim 10^{-6}$	$\sim 10^{-9}$
$t \rightarrow cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}	$\sim 10^{-4}$	$\sim 10^{-5}$
$t \rightarrow cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}	$\sim 10^{-4}$	$\sim 10^{-9}$

- In the SM flavour changing neutral currents (FCNC) are forbidden at tree level and **much smaller** than the dominant decay mode ($t \rightarrow bW$) at one loop level
- BSM models predict **higher BR** for top FCNC decays
 - powerful probe for new physics



Search for FCNC $t \rightarrow qZ$ decays

- $t\bar{t} \rightarrow bWqZ \rightarrow bl\nu qll$ topology



👉 No evidence for signal found

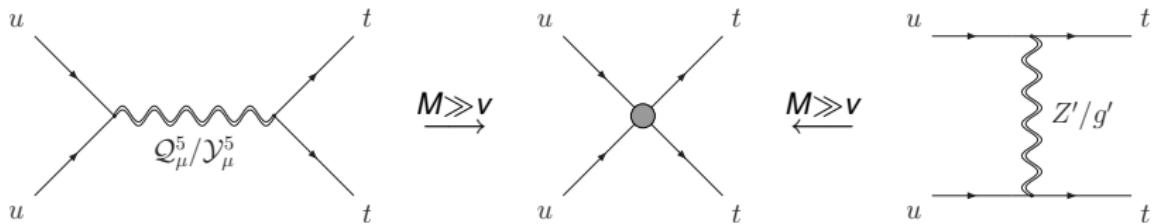
👉 95% CL limits on $BR(t \rightarrow qZ)$:

	observed	(-1σ)	expected	($+1\sigma$)
stat. only	1.06%	0.78%	1.22%	1.94%
syst. + syst.	1.13%	0.83%	1.30%	2.09%



Search for same-sign tt production

- Production of same-sign top pairs at LHC:



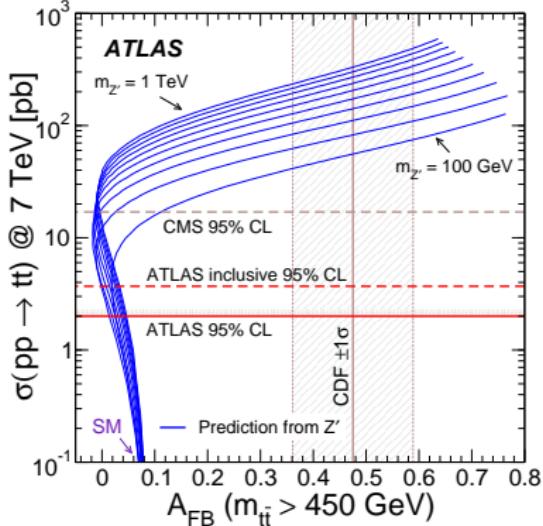
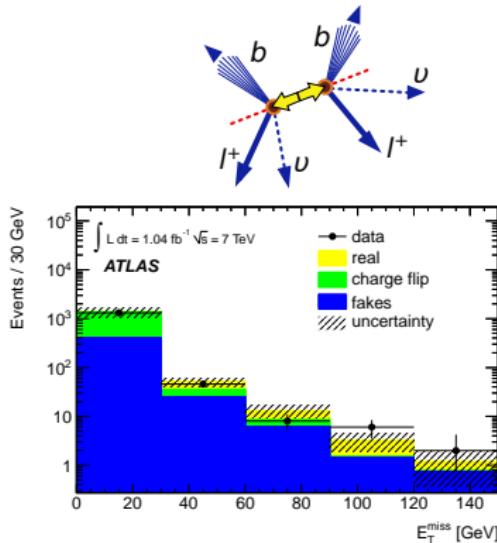
- s-channel: new colour-triplet (\mathcal{Q}_μ^5) or sextet (\mathcal{Y}_μ^5) [$Q = 4/3e$]
- t-channel: new colour singlet (Z') or octet (g') [$Q = 0$]
- For resonance masses \gg EWSB scale:
 - ⌚ gauge-invariant effective four-fermion interaction

$$\begin{aligned}\mathcal{L}_{4F} = & \frac{1}{2} \frac{C_{LL}}{\Lambda^2} (\bar{u}_L \gamma^\mu t_L) (\bar{u}_L \gamma_\mu t_L) + \frac{1}{2} \frac{C_{RR}}{\Lambda^2} (\bar{u}_R \gamma^\mu t_R) (\bar{u}_R \gamma_\mu t_R) \\ & - \frac{1}{2} \frac{C_{LR}}{\Lambda^2} (\bar{u}_L \gamma^\mu t_L) (\bar{u}_R \gamma_\mu t_R) - \frac{1}{2} \frac{C'_{LR}}{\Lambda^2} (\bar{u}_{La} \gamma^\mu t_{Lb}) (\bar{u}_{Rb} \gamma_\mu t_{Ra}) + \text{h.c.}\end{aligned}$$



Search for same-sign $t\bar{t}$ production

- same-sign dilepton ($\ell^+ \ell^+$) topology

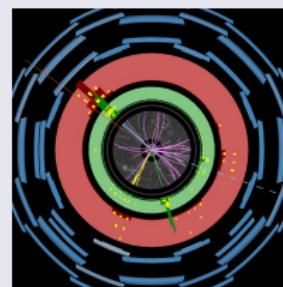


Chirality config.	Median expected limit, σ	68% range limit, σ	Observed limit, σ	Observed limit, C
LL	$\sigma < 1.8 \text{ pb}$	1.1-3.2 pb	$\sigma < 1.7 \text{ pb}$	$C_{LL}/\Lambda^2 < 0.35 \text{ TeV}^{-2}$
LR	$\sigma < 1.7 \text{ pb}$	1.0-3.0 pb	$\sigma < 1.7 \text{ pb}$	$C_{RL}/\Lambda^2, C'_{LR}/\Lambda^2 < 0.98 \text{ TeV}^{-2}$
RR	$\sigma < 1.7 \text{ pb}$	1.0-3.0 pb	$\sigma < 1.7 \text{ pb}$	$C_{RR}/\Lambda^2 < 0.35 \text{ TeV}^{-2}$



Summary

- LIP team very active in the ATLAS top working group
- Top quark physics entered the precision measurements era
- ATLAS/LIP team expertise in top quark physics used to open a new research line in new physics searches
 - Searches for new heavy quarks
 - $t\bar{t}t\bar{t}$ production
 - (...)





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