Search for new interactions on the top quark sector

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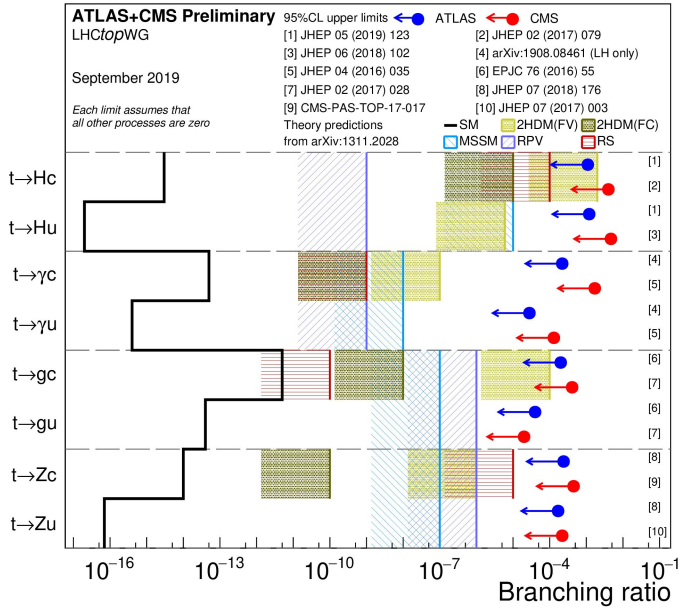
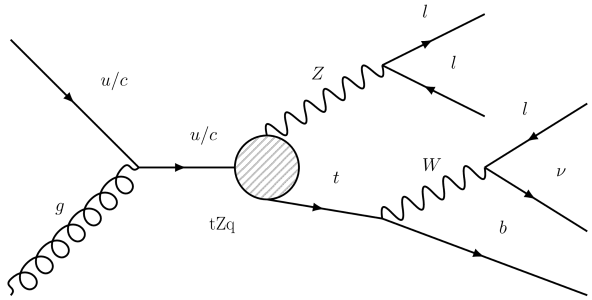
Reminders on FCNC

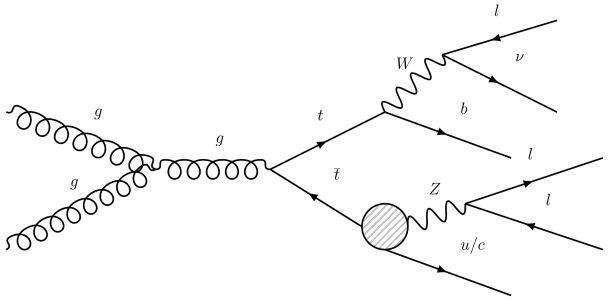
- Fermion changing its **flavor** without changing its charge
- **Forbidden** at tree level and heavily suppressed at **loop level** by GIM mechanism in SM
- Several **BSM models** lead to FCNC contributions, often at tree level
- Top quark decays via FCNC presents a powerful probe of new physics



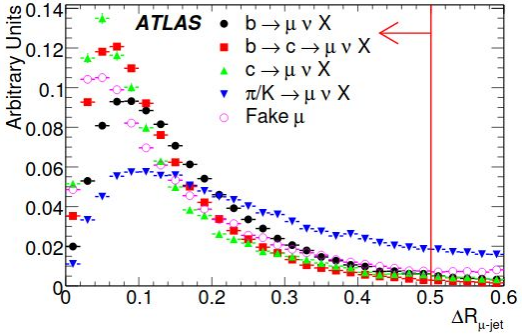
Reminders on FCNC

- FCNC processes possible in two modes
  - In **production**: **t+X** with X = H, Z, g, γ
  - In **decay**: **ttbar (t → qX)** with q = u, c
  - **Interference effects** should be estimated - Work done for tZq and tγq anomalous couplings with Nuno Castro and Maura Barros in collaboration with TU Dortmund: **published in the EPJ+ in March**





Search strategy
FCNC *tZq*



- Analysis with **full** Run-2 ATLAS dataset (140 fb^{-1})
  - Combining **production and decay** modes
  - Collaboration with **Berlin, Tbilisi** and **Roma**
- In **production**: single-top production ⇒ Particularly sensitive to **tZu** coupling
- In **decay**: ttbar decay *($t \rightarrow q\,Z$, $q=u,c$)* (including Soft Muon Tagging as charm-quark tagger)

- **Trileptonic** topology: $l^+ l^- + l$ + b-jets + E_T^{Miss}
- **Main backgrounds:** ttbar, ttbar+Z and diboson (WZ and ZZ) processes
- Split into two dedicated analyses with only **tZu** or **tZc** anomalous coupling

Signal regions
FCNC *tZq*

- For the ***utZ*** **coupling:**
  - **Two signal regions** are defined focusing on the different channels
  - Shape differences between **left- and right-handed couplings** considered
- For the ***ctZ*** **coupling:**
  - Three signal regions with one dedicated to the charm-tagger with soft muon tagging
- **Main differences between production and decay** signal regions are:
  - Multiplicity of *b*-tagged jet
  - Reconstruction of two top-quarks for the decay case and only a top-quark and a more boosted Z boson (in comparison with decay) for the production case

Control regions
FCNC *tZq*

- Control regions targeting ttbar and ttbar+Z processes: **region focused on ttbar processes** to determine the normalization from data
- **Inverse cuts on the mass of the top quark** candidates allows **side-band control regions** with the decay and production signal regions:

Common selections				
Exactly 3 leptons with $\|\eta\| < 2.5$ and $p_T(\ell_1) > 27$ GeV, $p_T(\ell_2) > 15$ GeV, $p_T(\ell_3) > 15$ GeV				
$t\bar{t}$ CR	$t\bar{t}Z$ CR	Side-band CR1 tZu	Side-band CR1 tZc	Side-band CR2
≥ 1 OS pair, no OSSF	≥ 1 OSSF pair with $\|m_{\ell\ell} - 91.2\,\text{GeV}\| < 15$ GeV	≥ 1 OSSF pair with $\|m_{\ell\ell} - 91.2\,\text{GeV}\| < 15$ GeV	≥ 1 OSSF pair with $\|m_{\ell\ell} - 91.2\,\text{GeV}\| < 15$ GeV	≥ 1 OSSF pair with $\|m_{\ell\ell} - 91.2\,\text{GeV}\| < 15$ GeV
–	$m_T(\ell_W, \nu) > 30$ GeV	$m_T(\ell_W, \nu) > 40$ GeV	$m_T(\ell_W, \nu) > 40$ GeV	$m_T(\ell_W, \nu) > 40$ GeV
≥ 1 jet with $\|\eta\| < 2.5$	≥ 4 jet with $\|\eta\| < 2.5$	≥ 2 jet with $\|\eta\| < 2.5$	≥ 2 jet with $\|\eta\| < 2.5$	$= 1$ jet with $\|\eta\| < 2.5$
$= 1$ b-jet	$= 2$ b-jet	$= 1$ b-jet	$= 1$ b-jet	$= 1$ b-jet
–	–	–	$= 0$ SMT anti-b-tagged jet	–
–	–	$\|m_t^{\text{FCNC}} - 172.5\,\text{GeV}\| > 2\sigma^{FCNC}$	$\|m_t^{\text{FCNC}} - 172.5\,\text{GeV}\| > 2\sigma^{FCNC}$	–
–	–	$\|m_t^{\text{SM}} - 172.5\,\text{GeV}\| > 2\sigma^{SM}$	$\|m_t^{\text{SM}} - 172.5\,\text{GeV}\| > 2\sigma^{SM}$	$\|m_t^{\text{SM}} - 172.5\,\text{GeV}\| > 2\sigma^{SM}$

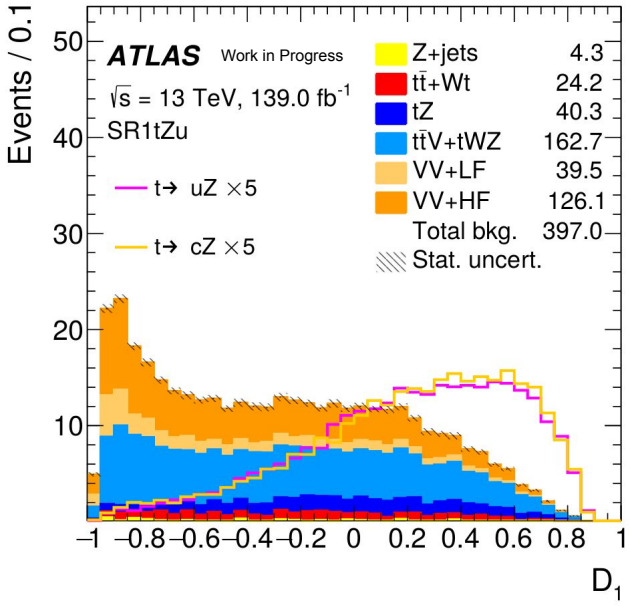
Signal and background discrimination
FCNC *tZq*

- **Boosted Decision Trees with Gradient boosting (BDTG)** method from the TMVA tool used to discriminate signal from background
- Different **variables** considered for each **signal region**:

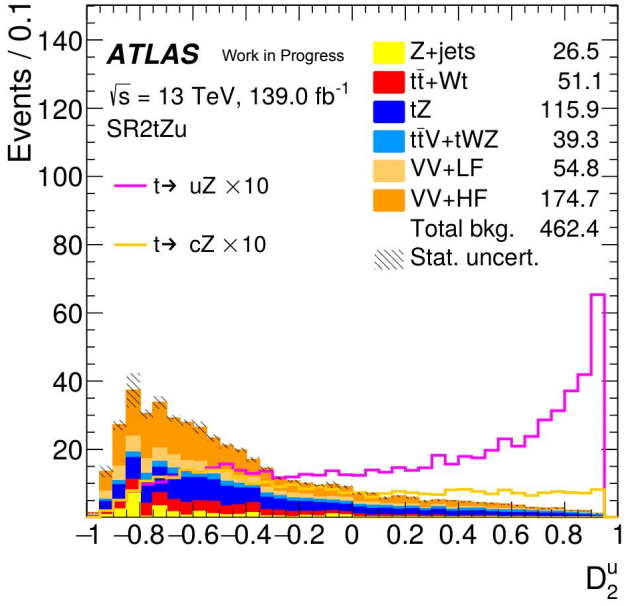
Decay signal region	Production signal region	Decay SMT signal region
M (SM), M(FCNC top quark)	M (SM top quark), M (W boson)	M (SM), M(FCNC top quark)
pT (u/c-quark), pT (b-quark)	pT(Z boson), pT (W boson), pT (b-quark)	pT (u/c-quark), pT (b-quark)
ΔR (SM, FCNC top quark), ΔR (u/c-quark, Z boson)	ΔR (Z boson, b-quark)	ΔR (SM, FCNC top quark), ΔR (u/c-quark, Z boson)

Multivariate discriminant

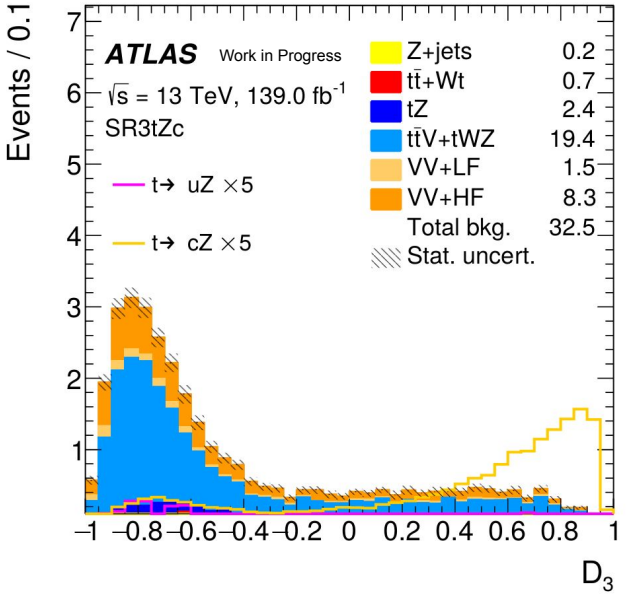
FCNC *tZq*



SR1 Decay



SR2 Production



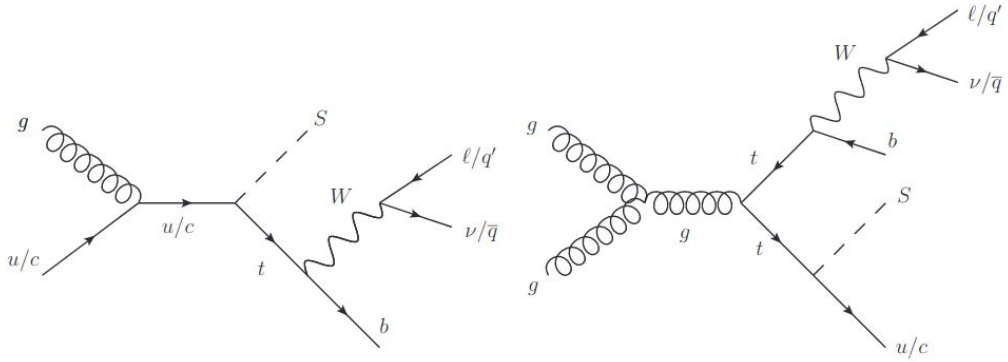
SR3 Decay with *c*-tag

Expected Limits
FCNC *tZq*

- **Profile likelihood** with a signal strength ***μ*** and nuisance parameters for systematic uncertainties (as luminosity, pileup reweighting, Monte Carlo statistics, generators)
- **Normalization uncertainty** for main backgrounds as ttbar, diboson and tZj
- **Experimental limits** on branching ratio of $t \rightarrow q\,Z$ with q=u,c obtained using the **BDTG score** from each signal region and **leading lepton pT** from control regions
- Comparison between previous and current **expected limits** shows a significant improvement using the **full run-2 dataset**:

Limits	-1σ	Expected	+1σ
BR $(t \rightarrow uZ)$	3.4×10^{-5}	4.9×10^{-5}	7.1×10^{-5}
BR $(t \rightarrow uZ)$ - 36 fb^{-1}	1.7×10^{-4}	2.4×10^{-4}	3.4×10^{-4}
BR $(t \rightarrow cZ)$	8.2×10^{-5}	11.7×10^{-5}	16.8×10^{-5}
BR $(t \rightarrow cZ)$ - 36 fb^{-1}	2.2×10^{-4}	3.2×10^{-4}	4.6×10^{-5}

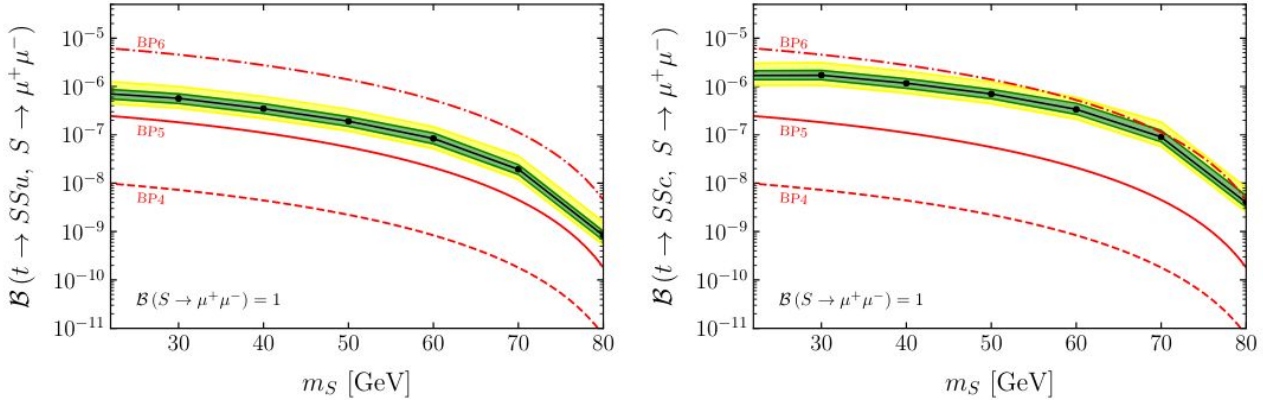
Phenomenology
New scalar *S* particle



- **Phenomenological study** on top decays with new scalar S in collaboration with Maria Ramos and Mikael Chala: see [arXiv:**2005.09594**]
  - Assuming the **top-quark with decays to a new scalar S and a light-quark** (up or charm)
  - Considering **different masses** for the new particle (from 20 to 150 GeV)
  - Focusing on three **decays** of the scalar particle: 1) $t \to Sq$, $S \to \mu^+ \mu^-$, 2) $t \to Sq$, $S \to \tau^+ \tau^-$ and 3) $t \to SSq$, $S \to \mu^+ \mu^-$ with **leptonic or hadronic** decays of the top quark considered for different cases

Phenomenology
New scalar *S* particle

- **Limits on the branching ratios** assuming a centre-of-mass energy of 13 TeV and a luminosity of 150 fb^{-1}
- For $t \to SSq$, $S \to \mu^+ \mu^-$ case: BR > 5 (25)×10^{-10} in the up (charm) channel for m(*S*) = 80 GeV



Conclusions
& Next Steps

- First **analysis** focusing on *tZq* anomalous coupling with **both production and decay modes** exploiting from the Run-2 dataset collected by the ATLAS detector
  - Event selection defined and full machinery in place
  - Currently at the approval process within the collaboration
  - Seeking a publication during late Summer
- Phenomenological study considering a **new particle with top quark decays via FCNC** processes with distinct final states
- PhD thesis close to be finished and aiming for the defense at the end of the year

Thanks