Probing the Flavor Changing Interactions of the Top Quark at the LHC

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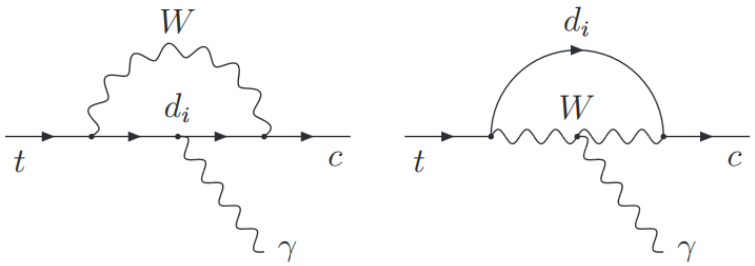
23-25 May 2016 @ Subatech

Motivations & goals

- FCNC top couplings are highly suppressed in the SM due to GIM (Glashow-Iliopoulos-Maiani) mechanism

→Promising signatures of New Physics

Standard Model (branching ratio)			
$t \to uZ$	8×10^{-17}	$t \to cZ$	1×10^{-14}
$t \to u\gamma$	3.7×10^{-16}	$t \to c\gamma$	4.6×10^{-14}
$t \to ug$	3.7×10^{-14}	$t \to cg$	4.6×10^{-12}
$t \to uH$	2×10^{-17}	$t \to cH$	3×10^{-15}



arXiv:0409342[hep-ph]

- **Our phenomenological project**
  - EFT-based research
  - gathering theorists & experimentalists
- **Goals:**
  - Reviewing expectations at **13 TeV** in FCNC results (single top + ttbar)
  - Providing guidelines for the CMS analyses (promising observables, relevance of a MVA, …)

LO model

Effective model for anomalous couplings between top & boson:

$$\mathcal{L}_{\text{eff}} = \sum \frac{C_x}{\Lambda^2}\mathcal{O}_{6,x} + \sum \frac{C_x}{\Lambda^4}\mathcal{O}_{8,x} + \sum \frac{C_x}{\Lambda^6}\mathcal{O}_{10,x} + \dots$$

Higher order are neglected

Wilson coefficients

Energy scale of new physics

Dimension-6 gauge invariant operators

Combining them to obtain Lorentz structure
[Aguilar-Saavedra arXiv:0803.3810, 0811.3842, 0904.2387]

Lagrangian piece corresponding to FCNC couplings:

$$\begin{aligned}\mathcal{L}_{FCNC} = \sum_{q=u,c} \Bigg[& \frac{\sqrt{2}}{2} g_s \frac{\kappa_{gqt}}{\Lambda} \cdot \bar{t}\sigma^{\mu\nu}\left(f^L_{gq}P_L + f^R_{gq}P_R\right) q G^a_{\mu\nu} \\ + & \frac{\sqrt{2}}{2} e \frac{\kappa_{\gamma qt}}{\Lambda} \cdot \bar{t}\sigma^{\mu\nu}\left(f^L_{\gamma q}P_L + f^R_{\gamma q}P_R\right) q A_{\mu\nu} \\ + & \frac{1}{\sqrt{2}} \eta_{hqt} \cdot \bar{t}\left(f^L_{hq}P_L + f^R_{hq}P_R\right) q H \\ + & \frac{\sqrt{2}}{4}\frac{g}{\cos\theta_W}\frac{\kappa_{zqt}}{\Lambda} \cdot \bar{t}\sigma^{\mu\nu}\left(f^L_{zq}P_L + f^R_{zq}P_R\right) q Z_{\mu\nu} \\ + & \frac{1}{4}\frac{g}{\cos\theta_W}\zeta_{zqt} \cdot \bar{t}\gamma^{\mu}\left(\tilde{f}^L_{zq}P_L + \tilde{f}^R_{zq}P_R\right) q Z_{\mu} \Bigg] + h.c\end{aligned}$$

with $\sigma^{\mu\nu} = \frac{i}{2}[\gamma^\mu, \gamma^\nu]$

Couplings

Links between couplings and Wilson coefficients

$$\kappa_{gqt} f^L_{gq} = \frac{v}{g_s \Lambda} \left[\bar{c}_{uG}\right]^*_{i3} \,, \qquad \kappa_{gqt} f^R_{gq} = \frac{v}{g_s \Lambda} \left[\bar{c}_{uG}\right]_{3i} \,,$$

$$\kappa_{\gamma qt} f^L_{\gamma q} = \frac{v}{e \Lambda} \left[c_W \bar{c}_{uB} - s_W \bar{c}_{uW}\right]^*_{i3} \,, \qquad \kappa_{\gamma qt} f^R_{\gamma q} = \frac{v}{e \Lambda} \left[s_W \bar{c}_{uB} - c_W \bar{c}_{uW}\right]_{3i} \,,$$

$$\kappa_{zqt} f^L_{zq} = -\frac{2 c_W v}{g \Lambda} \left[s_W \bar{c}_{uB} + c_W \bar{c}_{uW}\right]^*_{i3} \,, \qquad \kappa_{zqt} f^R_{zq} = -\frac{2 c_W v}{g \Lambda} \left[c_W \bar{c}_{uB} + s_W \bar{c}_{uW}\right]_{3i}$$

$$\zeta_{zqt} \tilde{f}^L_{zq} = -\frac{2 v^2}{\Lambda^2} \left[\left(\bar{c}^{(1)}_{hq} - \bar{c}^{(3)}_{hq}\right)_{i3} + \left(\bar{c}^{(1)}_{hq} - \bar{c}^{(3)}_{hq}\right)^*_{3i}\right] \,, \qquad \zeta_{zqt} \tilde{f}^R_{zq} = -\frac{2 v^2}{\Lambda^2} \left[\left(\bar{c}_{hu}\right)_{i3} + \left(\bar{c}_{hu}\right)^*_{3i}\right] \,,$$

$$\eta_{hqt} \hat{f}^L_{hq} = \frac{3 v^2}{2 \Lambda^2} \left[\bar{c}_{uh}\right]^*_{3i} \,, \qquad \eta_{hqt} \hat{f}^R_{hq} = \frac{3 v^2}{2 \Lambda^2} \left[\bar{c}_{uh}\right]_{i3} \,,$$

Conventions

$$\sqrt{\left|f^L_{xq}\right|^2 + \left|f^R_{xq}\right|^2} = 1$$

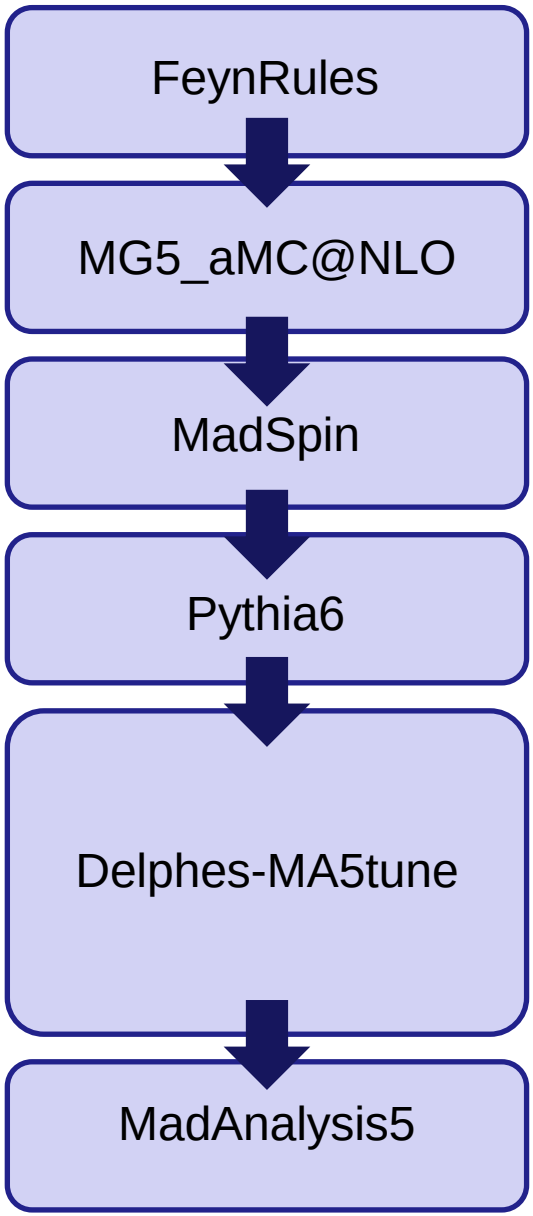
$$\sqrt{\left|\tilde{f}^L_{xq}\right|^2 + \left|\tilde{f}^R_{xq}\right|^2} = 1$$

$\frac{\kappa_{xqt}}{\Lambda}$, ζ_{xqt}, and η_{xqt} are real and positive

Simplifying assumptions

$$f^R = 1, \qquad f^L = 0$$

Framework



SM & BSM model description

Only LO generation + ME/PS merging
(MLM kt-cone scheme)

Top-quark & V decay

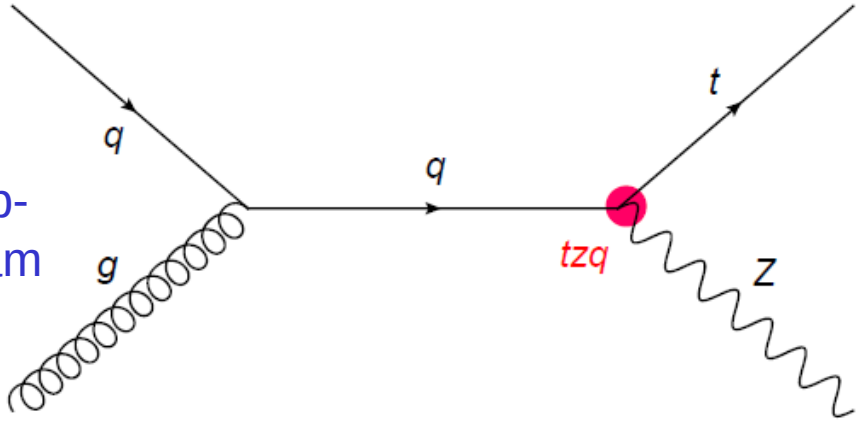
- Public TuneZ2
- Higgs decay

- **Delphes limitation:** no trigger, no fake lepton
- **MadAnalysis5 tune:**
  - Isolation @ analysis level: relative tracker+calo isolation I_{rel}
  - CMS b-tagging benchmarks (CSV L,M,T)
- **Private improvement:**
  - Basic implementation of fake electron
  - Misidentification of electron electric charge

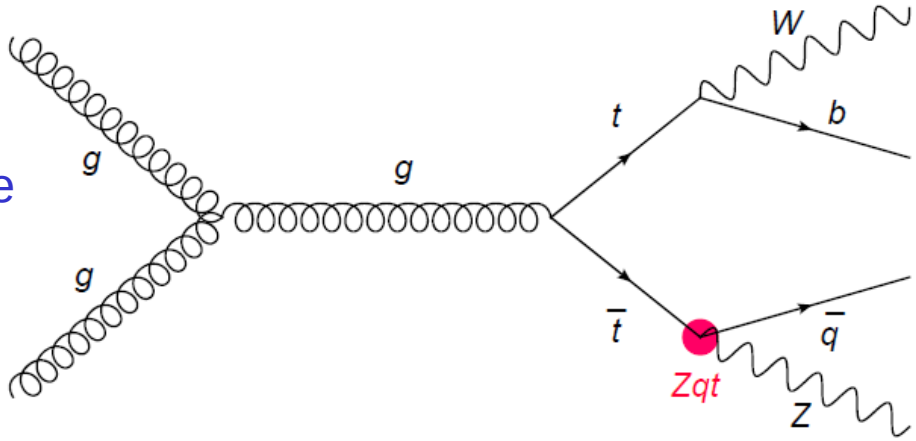
Generation @ LO

Signal (ex:Zqt coupling)

Single-top-like diagram



TTbar-like diagram



K-factor extracted from literature

Background

- V + jets
- H + jets
- VV + jets
- VH + jets

with V=W,Z,γ

- T + jets
- TV + jets
- TH + jets
- TT + jets
- TTV + jets
- TTH + jets
- TTVV + jets

No multijet!!!!!!!!

K-factor for background are mainly computed with MG_aMC@NLO

Analyses performed

single top
p p > t (+0,1 jet)

Considered decay: t > b l v

→ κ_{gqt}/Λ

single top
p p > tγ

Considered decay: t > b l v

→ $\kappa_{\gamma qt}/\Lambda$

single top
p p > tZ

ttbar
p p > tt where t > Zq

Considered decays: t > b l v & Z > l+ l-

→ κ_{Zqt}/Λ

→ ζ_{Zqt}

single top
p p > th

ttbar
p p > tt where t > hq

Considered decays: t > b l v &

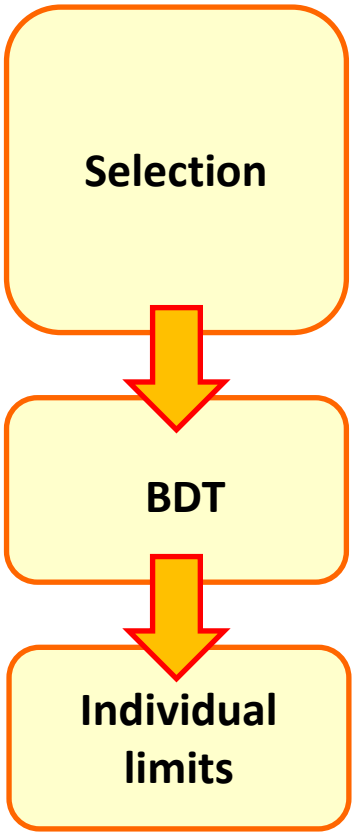
h > γγ
h > WW* > lvlv
h > bb

→ κ_{hqt}

Strategy

Step 1

One selection per process & one activated coupling



- Integrated luminosity = **100 fb^{-1}** (5 times the 8TeV LHC L^{int})
- Figure of merit (FOM) = $S/\sqrt{S+B}$
- Looking for all discriminant observables
- Optimizing individually each cut

- **TMVA** framework is used.
- Finding minimum set of observables (overtraining is checked).
- Estimating the possible gain of MVA wrt cut-and-count analysis.

- Limits computed for L=100fb^{-1} @ 2σ, 3σ and 5σ.
- Limits expressed in terms of BR (anomalous top decay)
- 2D plots u-quark vs c-quark

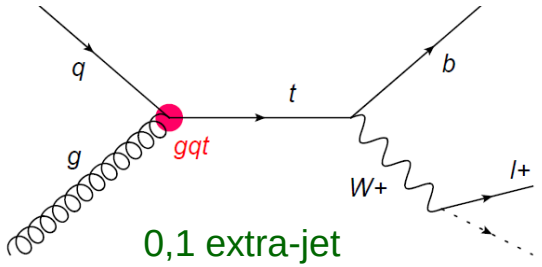
Step 2

Combination

- Combination between single top & ttbar
- Combination between different channels

Probing gqt coupling

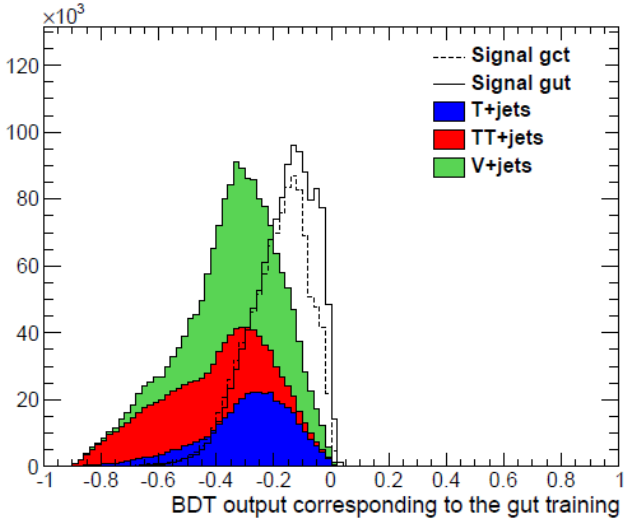
Selection



- 1 lepton p_T>30 GeV (no more with p_T>20 GeV), |η|<2.5, I_{rel}<0.2
- 1 or 2 jets: $p_T(j_1)$>30 GeV, $p_T(j_2)$>20 GeV, |η|<2.4, H/E>0.15
- b-tagging: CSV point for j1
- MET>30
- Multijet removal: $m_T(W)$>50 GeV [ATLAS paper]
- No photon with p_T>10 GeV, |η|<2.5, I_{rel}<0.2

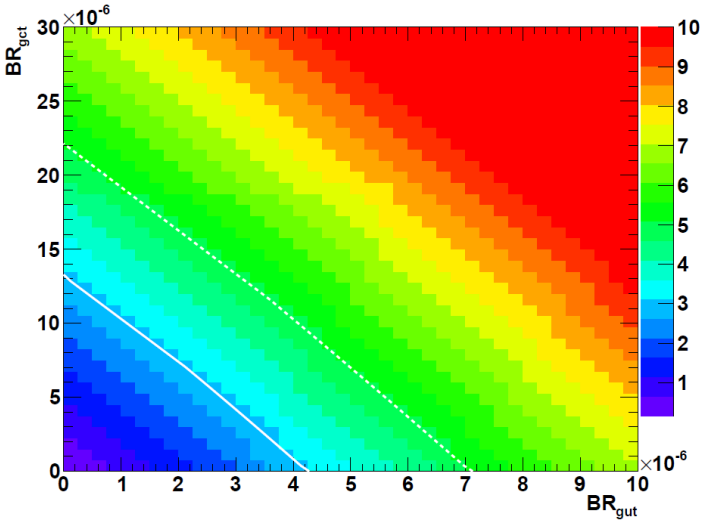
MVA

- One training for u and c coupling.
- Most discriminated variables: M_{top}, $m_T(W)$, $p_T(W)$, $p_T(b)$, Δφ(b,W), Δφ(l,b), Δφ(l,MET), η(l), Q(l)



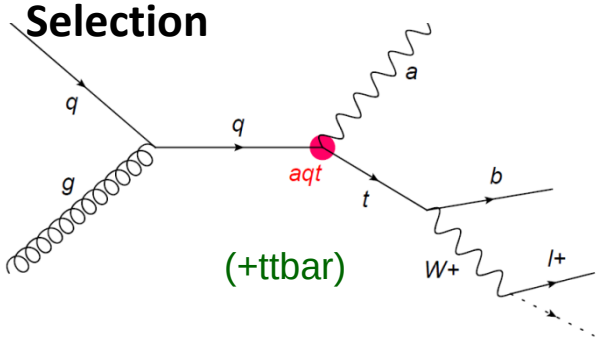
Results

2σ-limit on BR	B(t→ug)	B(t→cg)
Cut&count	4.3×10^{-6}	1.2×10^{-5}
MVA	2.9×10^{-6}	9.3×10^{-6}



Probing γqt coupling

Selection



- Only 1 lepton: p_T>30 GeV (no more with p_T>20 GeV), |η|<2.1, I_{rel}<0.2
- Only 1 photon: p_T>80 GeV (no more with p_T>30 GeV), |η|<2.5, I_{rel}<0.2
- Only 1 b-jet: H/E>0.15, p_T>30 GeV, |η|<2.1, CSV Tight
  (no more with p_T>20 GeV with CSV Loose)

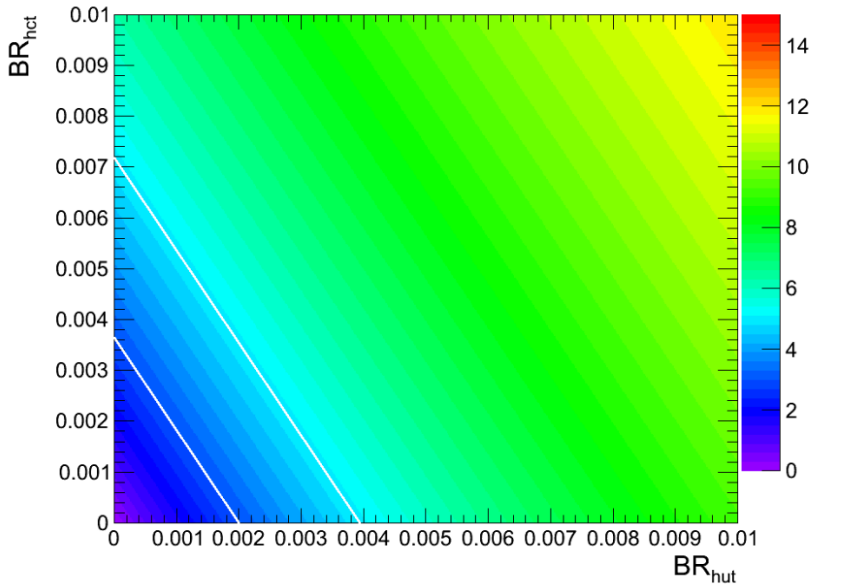
MVA

- One training for u and c coupling against tγq
- Most discriminated variables: M_{top}, m_T(W), p_T(W), p_T(b), Δφ(b,W), Δφ(l,b), Δφ(l,MET), η(l)xQ(l)

→ MVA seems to not improve the sensibility.

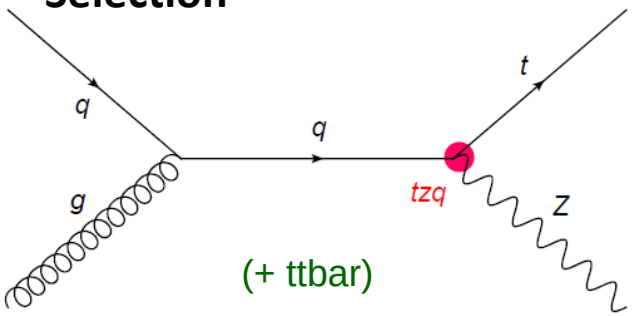
Results

2σ-limit on BR	B(t→uγ)	B(t→cγ)
Cut&count	2.0×10^{-3}	3.6×10^{-3}



Probing Zqt coupling – single top part

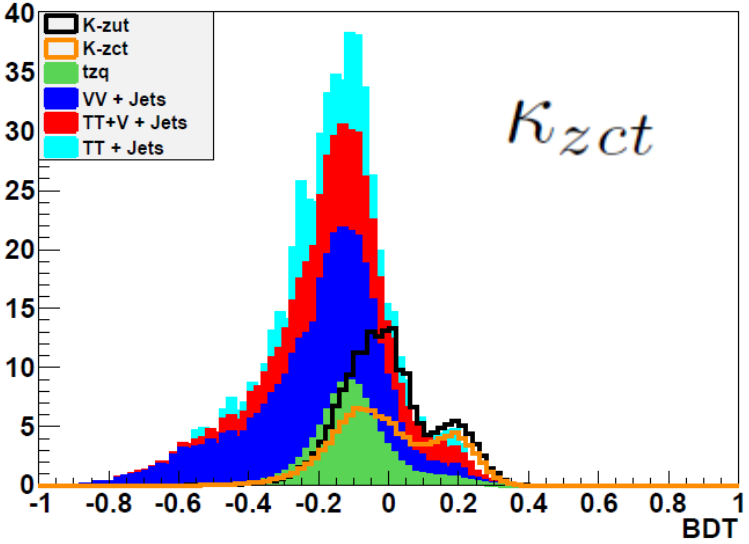
Selection



- Exactly 3 leptons: p_T>20 GeV, |η|<2.5, I_{rel}<0.2
- Z candidate = l+l- the closest to m_Z ± 15 GeV
- at least **1** jet: p_T(j)>40 GeV, |η|<2.4, H/E>0.15
- b-tagging: CSV Loose workpoint
- 10 GeV < m_T(W) < 150 GeV
- m_{top} < 220 GeV
- m(lb) < 150 GeV

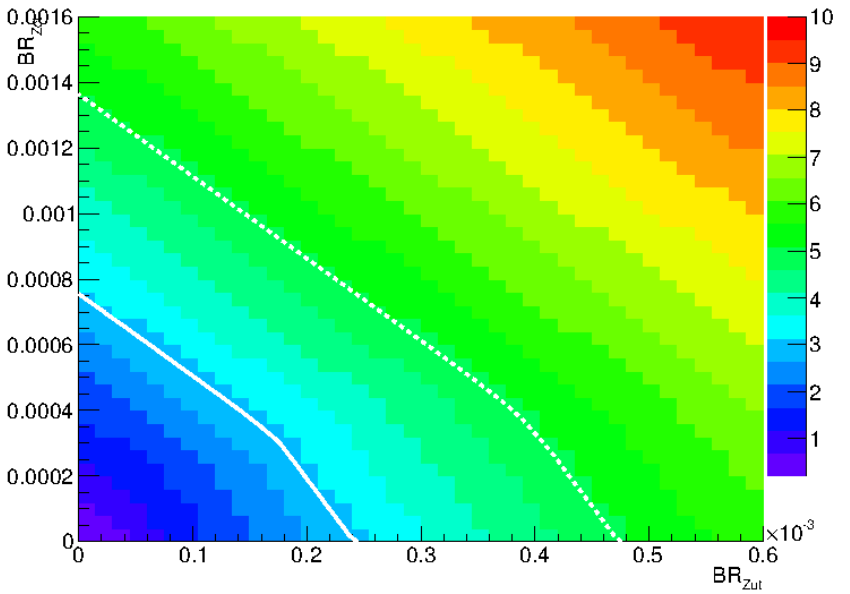
MVA

- One training for each coupling
- Most discriminated variables: m(l_Wb), m(jZ), pT(Z), ΔR(b,lW), m(tZ), p_T(j1), Q(l_W), ΔR(Z,l_W), ΔR(t,Z),



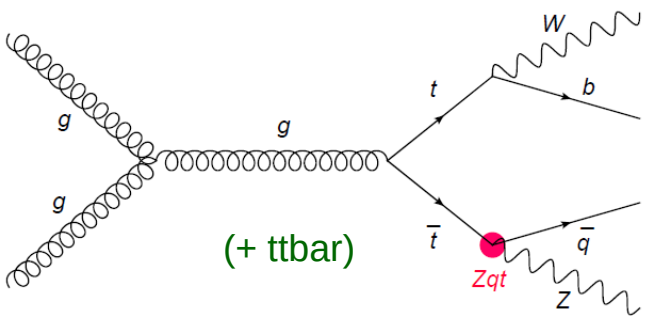
Results

2σ-limit on BR	B(t→uZ)	B(t→cZ)
MVA	1.4×10^{-4}	2.8×10^{-4}



Probing Zqt coupling – $t\bar{t}$ part

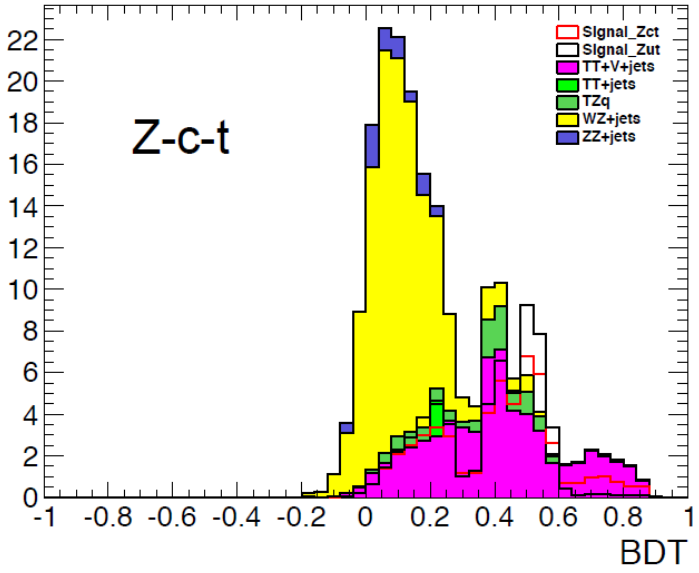
Selection



- Exactly 3 leptons: p_T>20 GeV, |η|<2.5, I_{rel}<0.2
- Z candidate = l+l- the closest to m_Z ± 15 GeV
- at least **2** jets: p_T(j)>40 GeV, |η|<2.4, H/E>0.15
- b-tagging: CSV Loose workpoint
- m_T(W) > 50 GeV
- 140 GeV < m_{top} <210 GeV

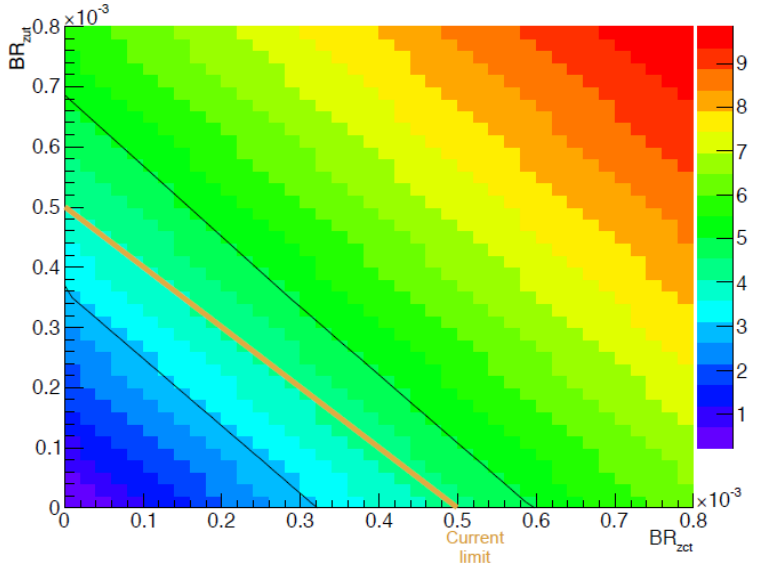
MVA

- One training for each coupling
- Most discriminated variables: m(l_W, b), m(Zj), n(b)



Results

2σ-limit on BR	B(t→uZ)	B(t→cZ)
MVA	2.0×10^{-4}	2.3×10^{-4}

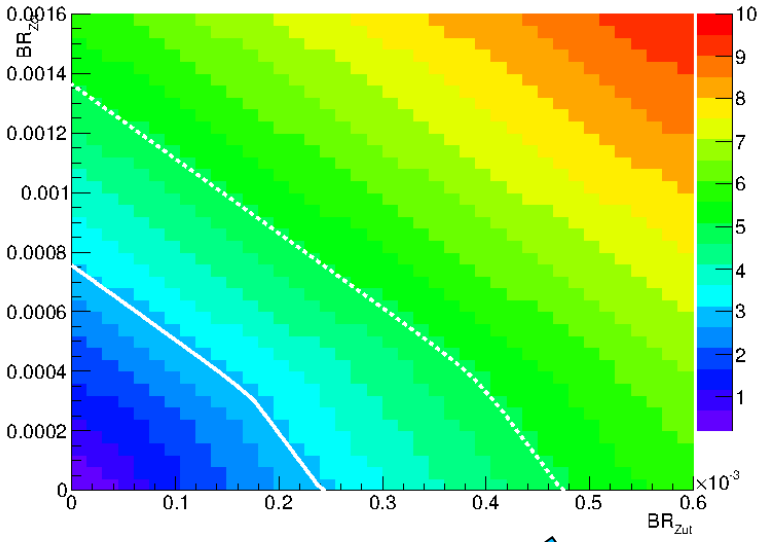


First summary

Couplings	Current BR limit CL=95%	Channel	2σ-limit on BR single top	2σ-limit on BR ttbar
κ_{gut}/Λ	3.1×10^{-5}		2.9×10^{-6}	
κ_{gct}/Λ	1.6×10^{-4}		9.3×10^{-6}	
$\kappa_{\gamma ut}/\Lambda$	1.6×10^{-4}		2.0×10^{-3}	
$\kappa_{\gamma ct}/\Lambda$	1.8×10^{-3}		3.6×10^{-3}	
κ_{Zut}/Λ	5×10^{-4}		1.4×10^{-4}	2.0×10^{-4}
κ_{Zct}/Λ	5×10^{-4}		2.8×10^{-4}	2.3×10^{-4}
κ_{hut}	4.2×10^{-3}	h > γγ	3.0×10^{-3}	9.5×10^{-3}
κ_{hct}	4.6×10^{-3}		8.0×10^{-3}	9.5×10^{-3}
κ_{hut}	4.2×10^{-3}	h > bb	2.5×10^{-3}	2.1×10^{-3}
κ_{hct}	4.6×10^{-3}		2.6×10^{-3}	1.9×10^{-3}
κ_{hut}	4.2×10^{-3}	h > WW*	?	9.4×10^{-4}
κ_{hct}	4.6×10^{-3}		?	1.2×10^{-3}

Probing Zqt coupling – combination

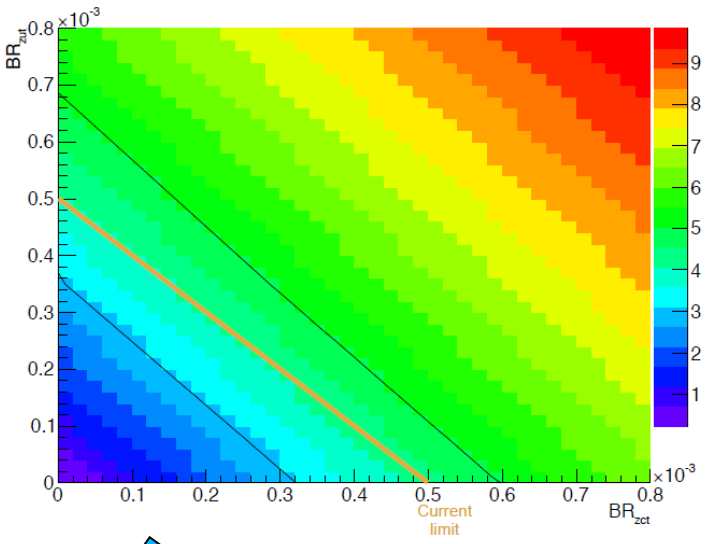
single top analysis

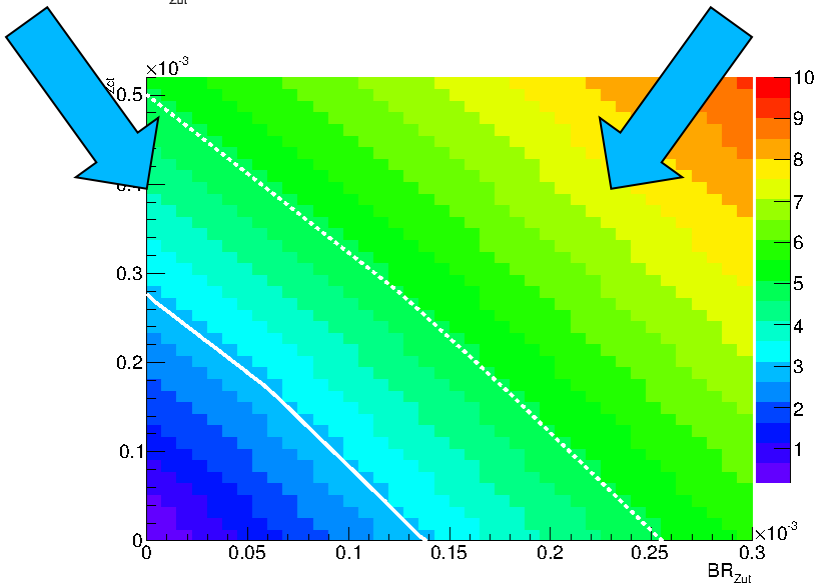


+

N jet = 1 (no loose jet with pT>30 GeV)

ttbar analysis





combination

(Last) Summary

- Research of FCNC in the top sector at 13 TeV, $L^{int}=100fb^{-1}$
- For Higgs & Z couplings, perform several analyses:
  - single top
  - ttbar
  - single top + ttbar
- BDT relevance is studied with a list of promising observables
- Potential for improvement of current limits at 13 TeV
- Work to finalize: global combination of all results
  Paper will be released soon…
- What's next?
  - Reinterpretation? Example: search for t' **[arXiv:1409.6962]**