Search for BSM couplings in top quark events at CMS

Alexander Grohsjean

on behalf of the CMS Collaboration

HELMHOLTZ

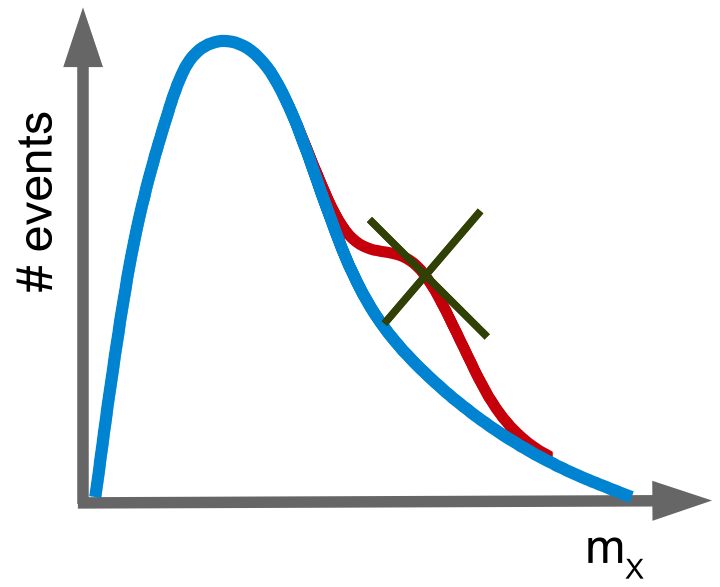
RESEARCH FOR GRAND CHALLENGES

Seoul 2018

39th International Conference on High Energy Physics

- LHC successfully running at 13 TeV since 2015
  - CMS collected up to ~110 fb^{-1} of data

→ no striking sign of new physics yet



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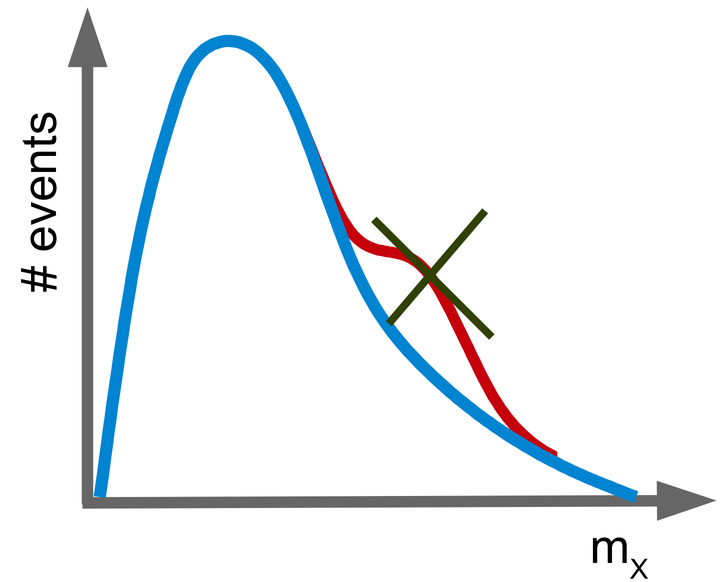

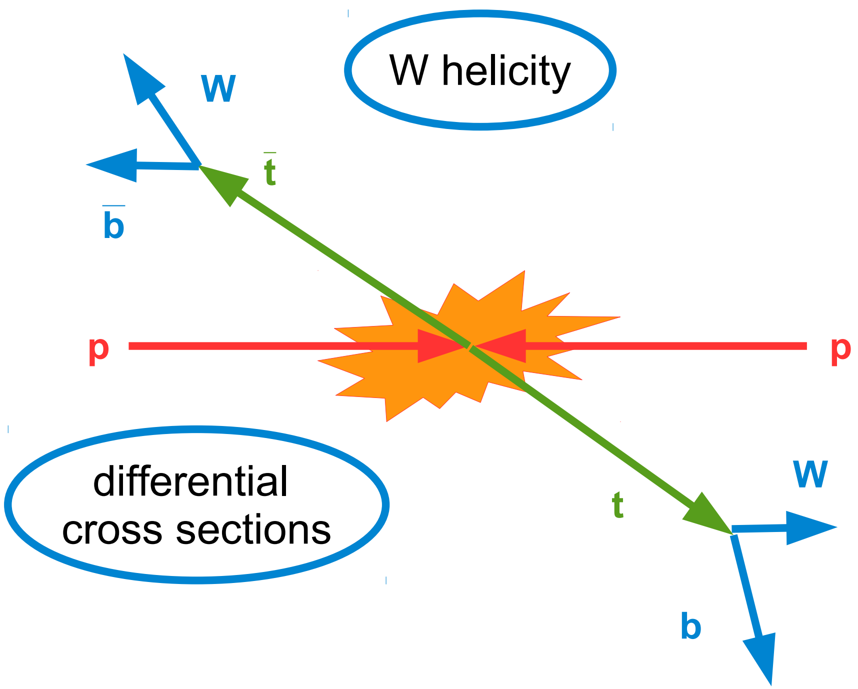

- still several exciting perspectives for discoveries
  - precision measurements

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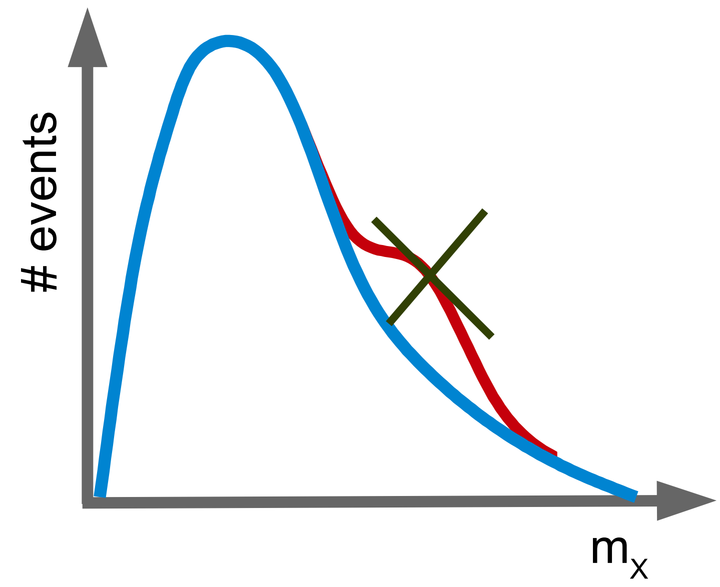

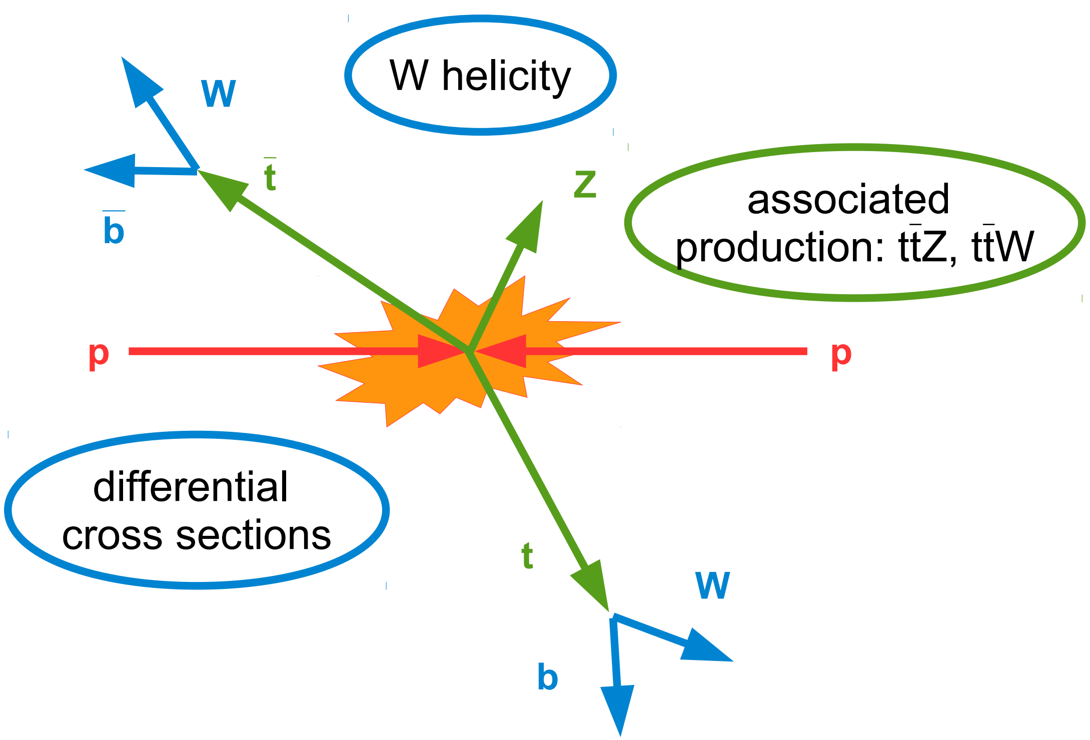

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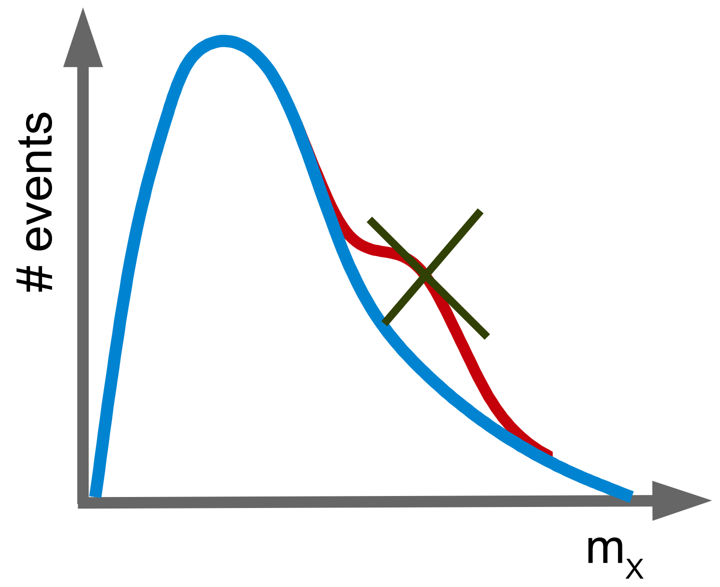
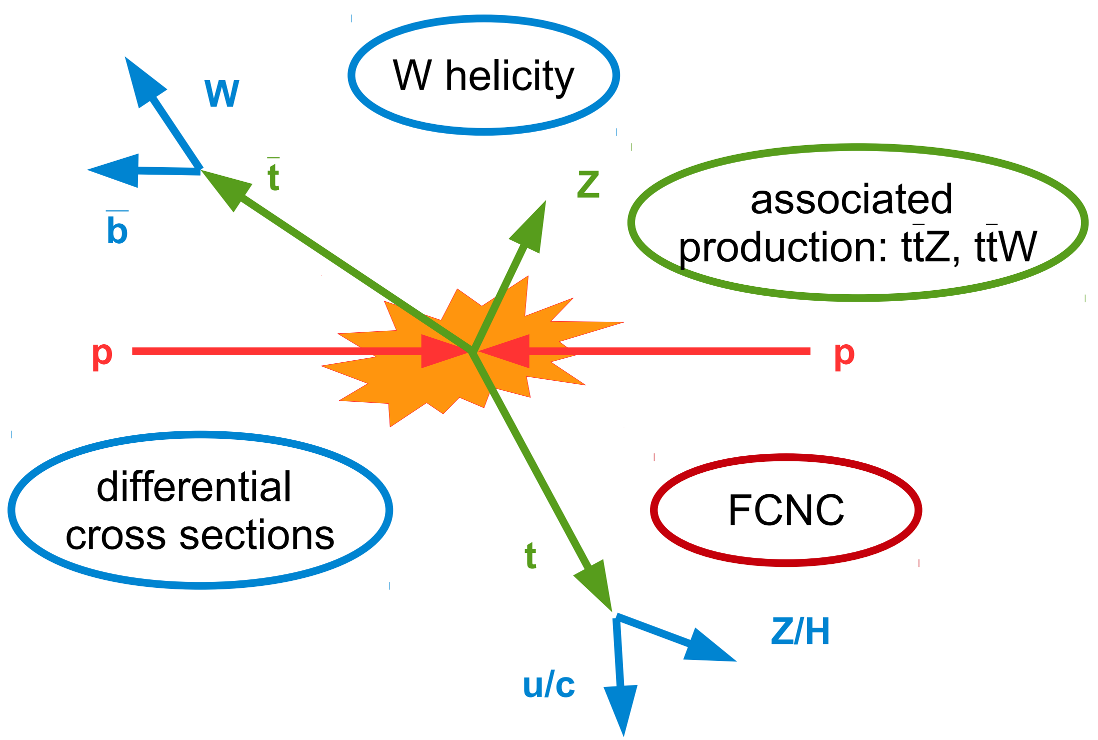




- still several exciting perspectives for discoveries
  - precision measurements
  - rare processes
  - SM suppressed processes

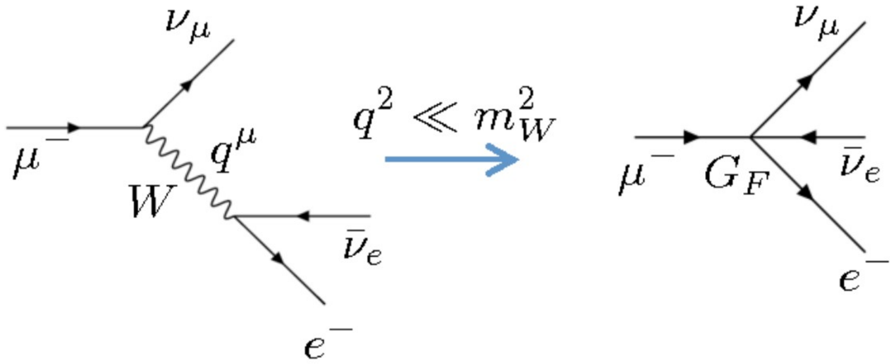
New Physics Interpretation: Effective Field Theory

- assume scale of new physics (NP) is larger than LHC scale: $\Lambda_{NP} > \Lambda_{SM}$

- extend the SM Lagrangian with higher-order operators to model new physics at Λ_{NP}

$$L_{EFT} = L_{SM} + \sum_i \frac{C_i}{\Lambda_{NP}^2} O_6 + ...$$

- famous example: Fermi theory of Beta decay



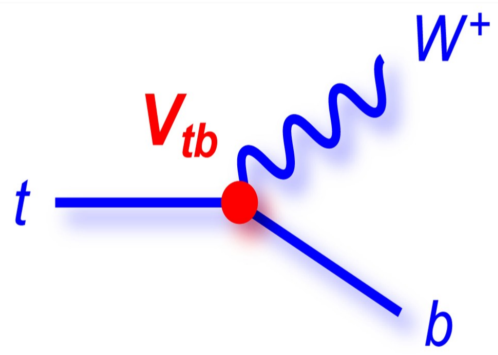
- searches for EFT are searches for new interactions

- special case: anomalous couplings

PLB 762 (2016) 512

- V-A structure of Wtb coupling

$$L_{tWb} \propto \bar{b} \gamma^{\mu} (V_L P_L) t W_{\mu}^{-} + h.c.$$



W Boson Helicity

PLB 762 (2016) 512

- V-A structure of Wtb coupling/V+A extension

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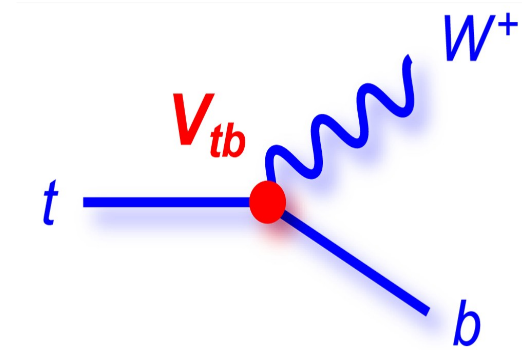
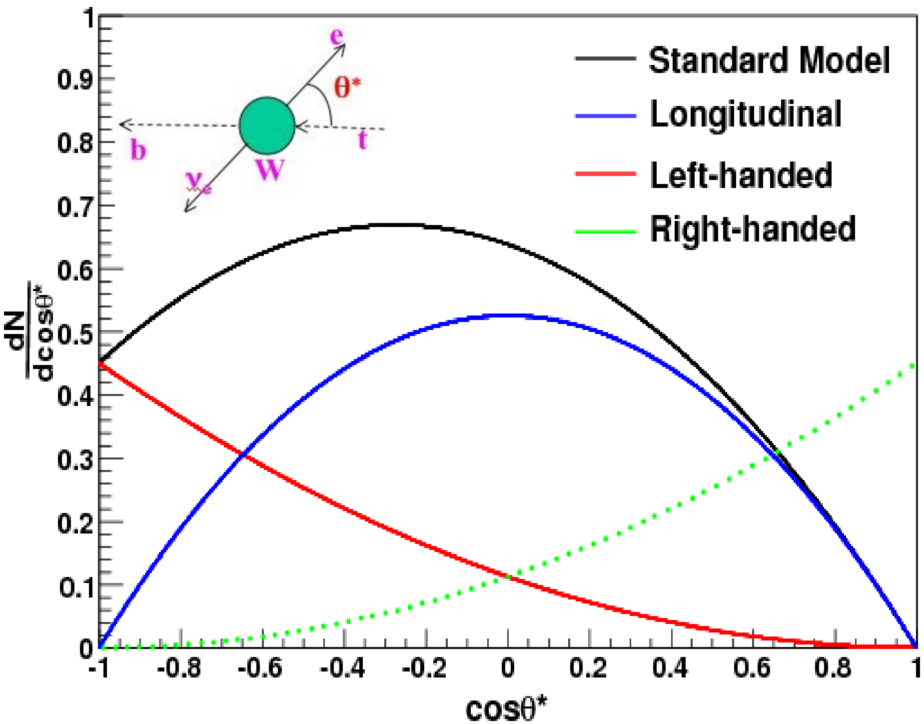
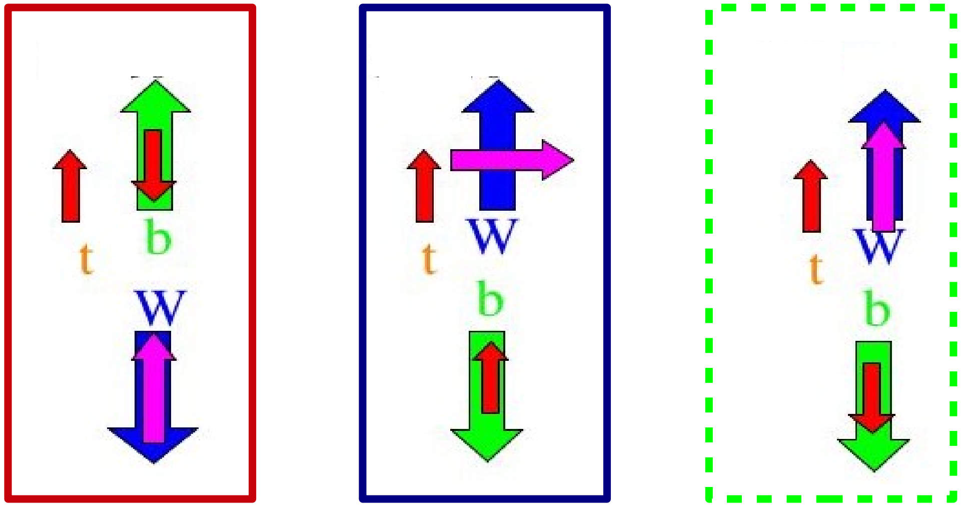
  - infer from W helicity measurement







SM(LO, massless b quarks):

left handed F_L=30%

longitudinal F_0=70%

right handed F_R=0%

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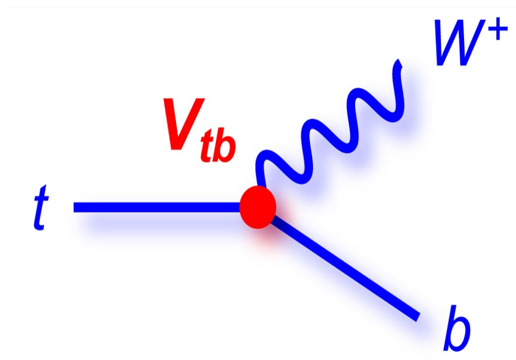

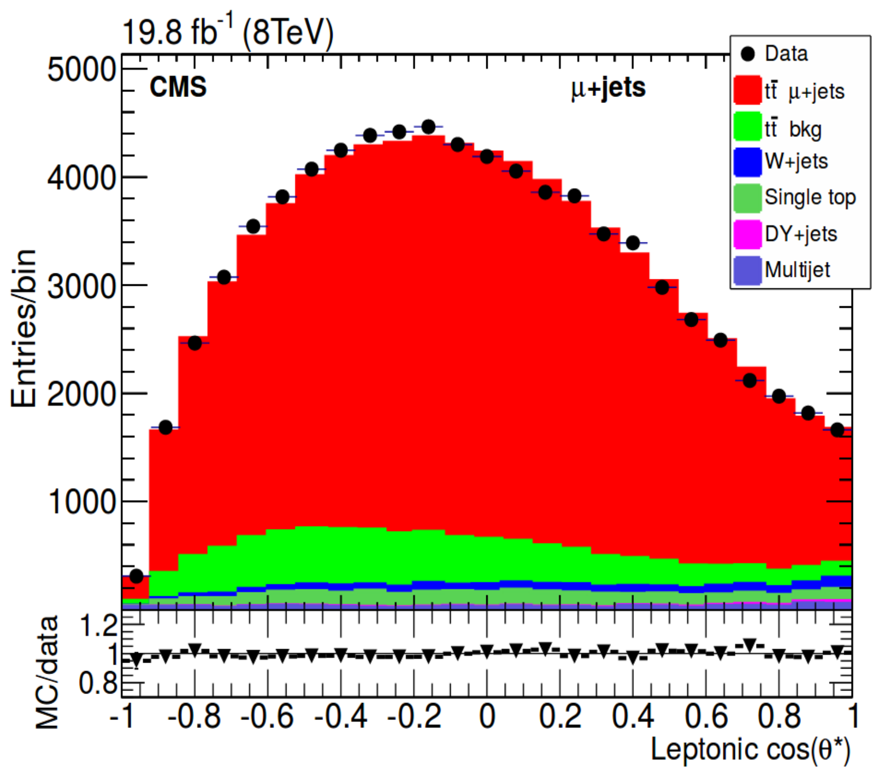

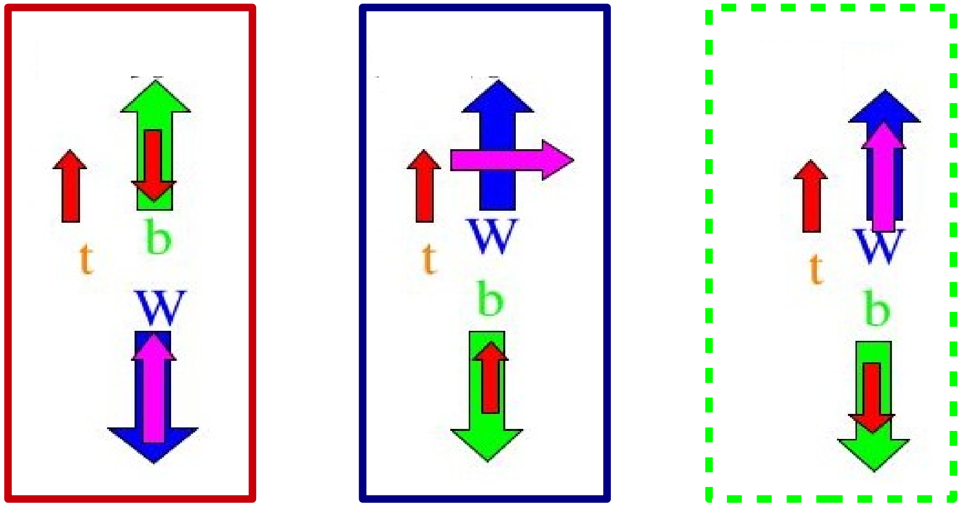

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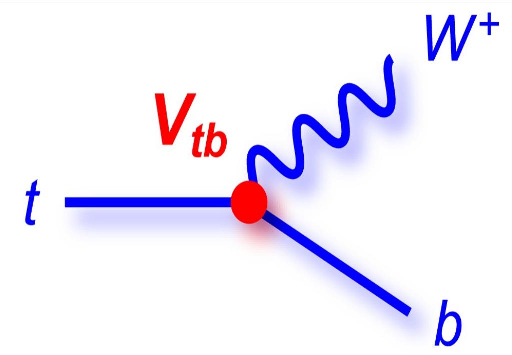
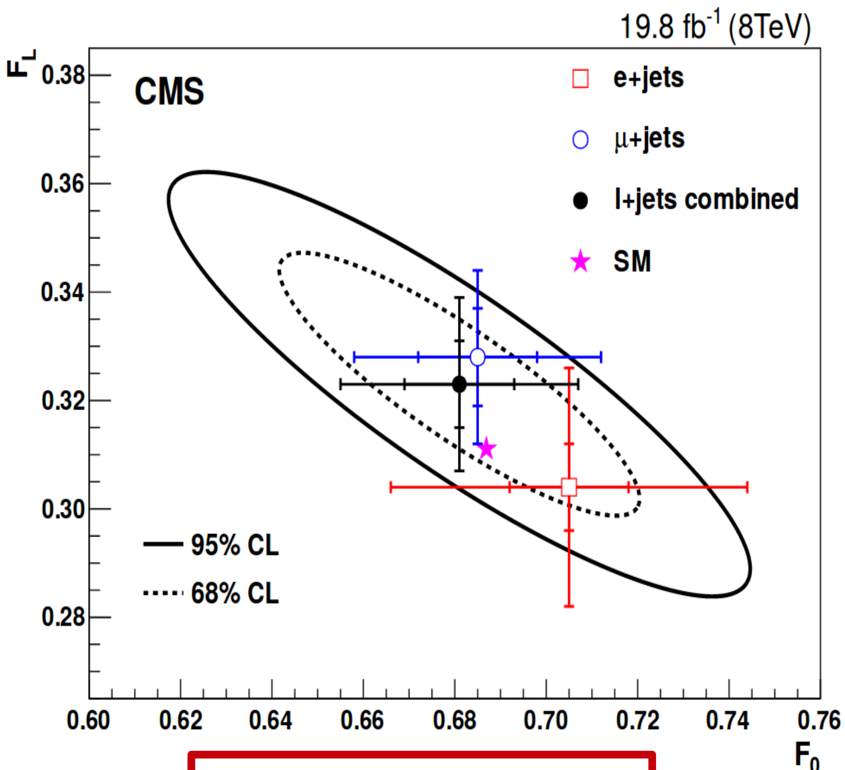
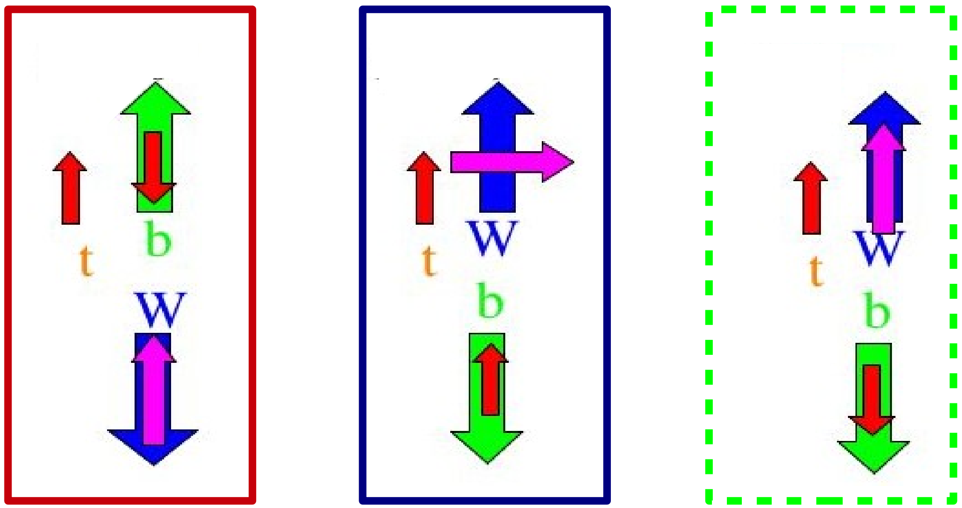




F_R= -0.004 ± 0.015



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Limits on Anomalous Couplings

PLB 762 (2016) 512

$$L_{tWb} \propto \bar{b}\,\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t\, W_{\mu}^{-} - \bar{b}\,\frac{i\sigma^{\mu\nu}\left(p_t - p_b\right)_{\nu}}{m_W}\left(g_L P_L + g_R P_R\right) t\, W_{\mu}^{-} + h.c.$$

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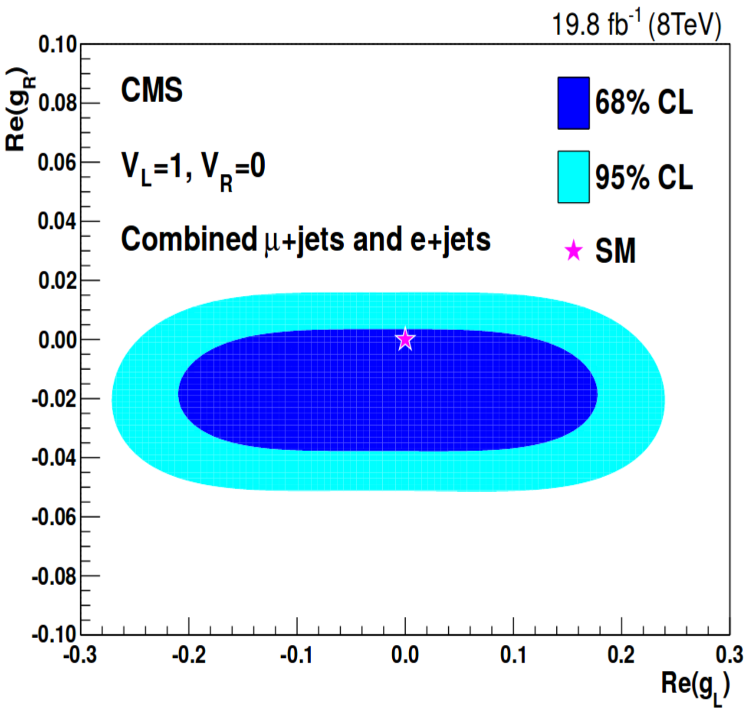

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JHEP 02 (2017) 028

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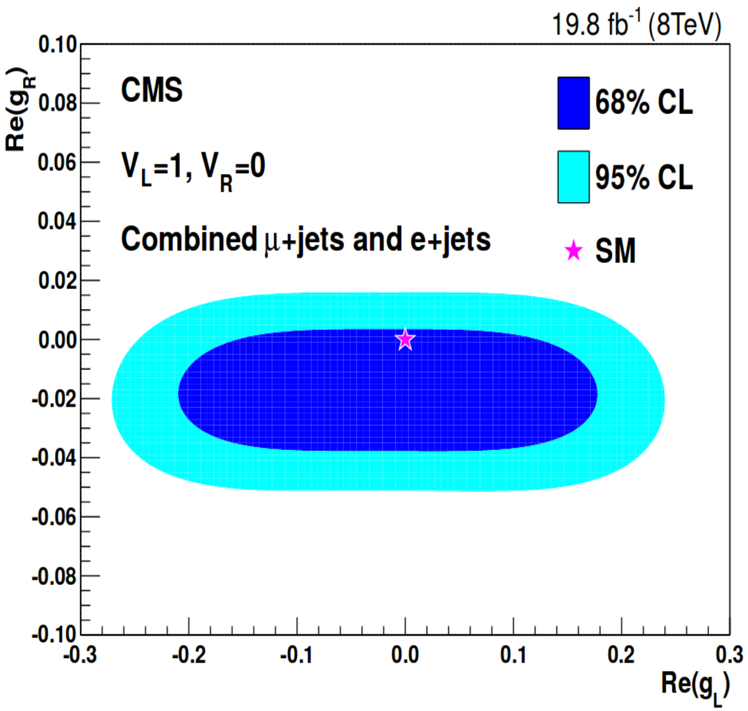
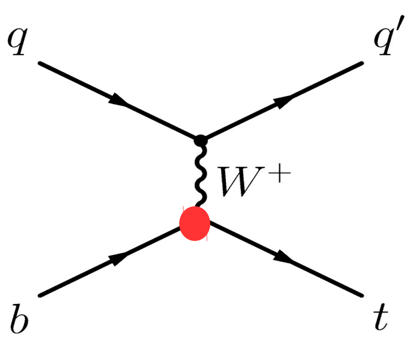


- Wtb vertex can also be probed in t production



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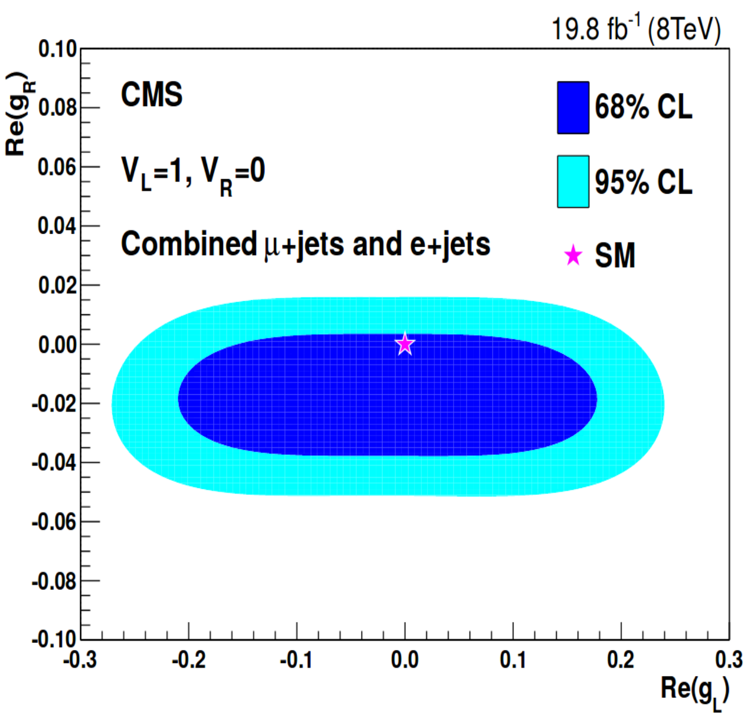
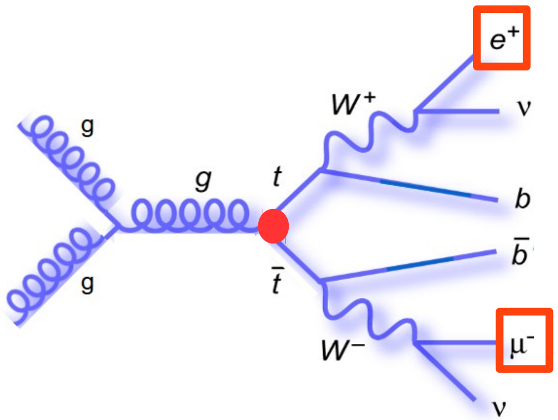


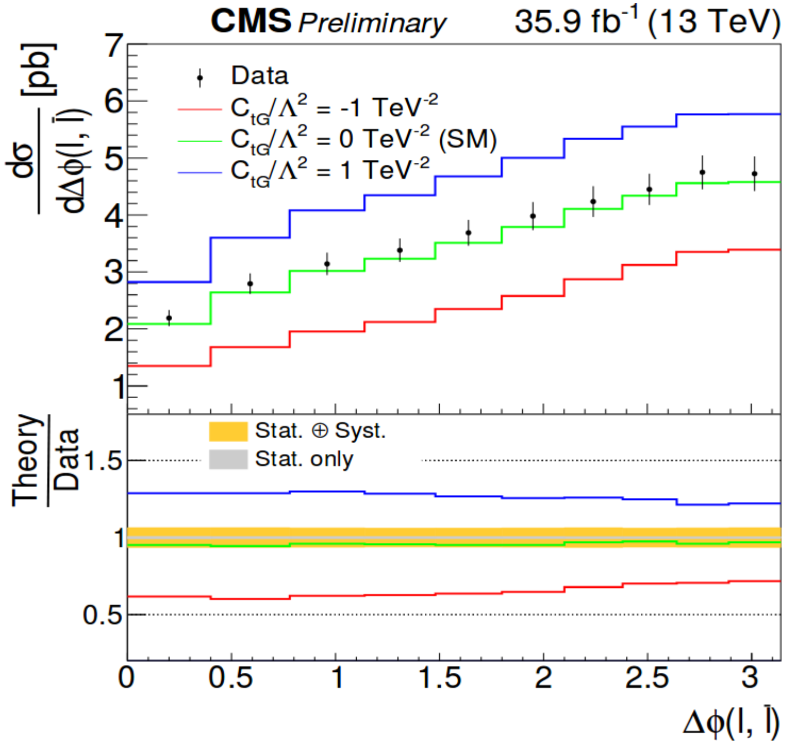
- Wtb vertex can also be probed in t production
- use neural networks
  - separate single top from background
  - enhance sensitivity to anomalous couplings
- expected (observed) 2D/3D limits @ 95% CL

scenario	V_L >	$\|V_R\|$ <	$\|g_L\|$ <	<g_R<	
V_L V_R	0.97 (0.92)	0.28 (0.31)			
V_L g_L	0.92 (0.92)		0.10 (0.14)		
V_L g_R	0.94 (0.93)			-0.046 (-0.050)	0.046 (0.041)
V_L g_L g_R	0.98 (0.97)		0.057 (0.10)	-0.049 (-0.051)	0.048 (0.046)
V_L V_R g_R	0.98 (0.97)	0.16 (0.22)		-0.049 (-0.049)	0.039 (0.037)

Differential $t\bar{t}$ Measurements

CMS-PAS-TOP-17-014





- modified gluon-top vertex affects rate and kinematics of $t\bar{t}$ production

$$O_{tG} = \bar{t}\sigma^{\mu\nu}T^A\tilde{\phi}G^A_{\mu\nu}$$

- azimuthal angle between leptons provides great sensitivity to potential top chirality flip from O_{tG}

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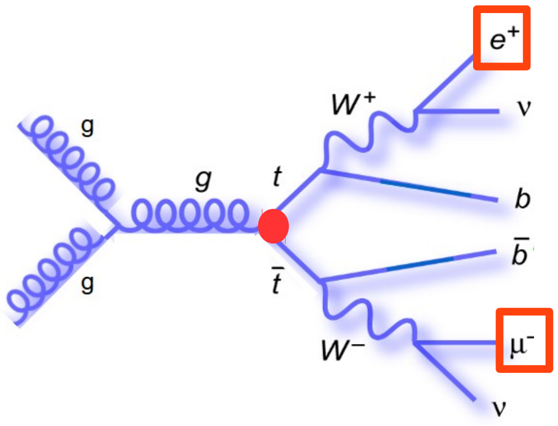

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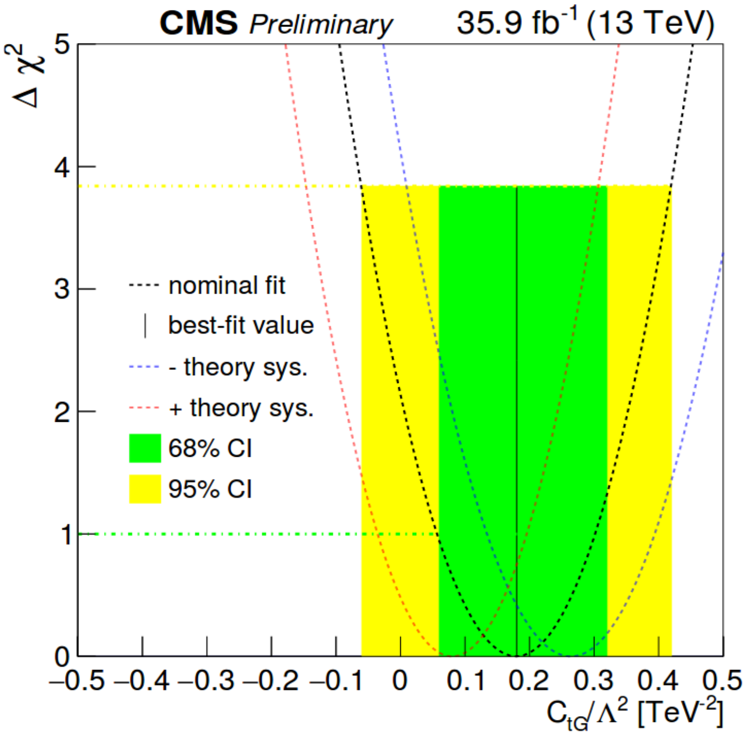
- differential distribution corrected for detector effects, $\Delta\chi^2$ test used to set limits

$-0.06 < C_{tG} / \Lambda^2 < 0.41$ at 95% CL



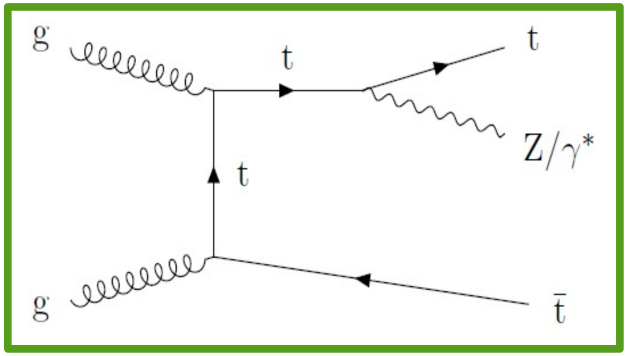
- significant improvement on existing 8 TeV constraints from CMS cross section measurement $-0.42 < C_{tG} / \Lambda^2 < 0.30$ (PRD 91 (2015) 114010)

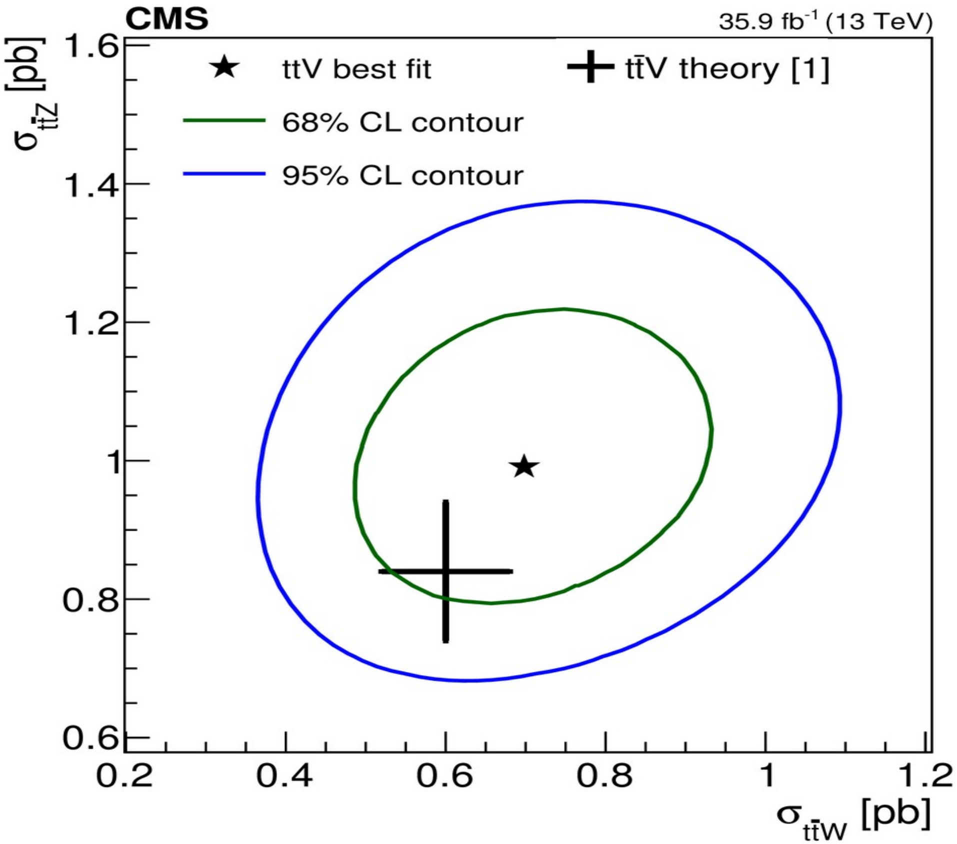
first top quark results using EFT with NLO precision

Rare Process: $t\bar{t}Z/t\bar{t}W$

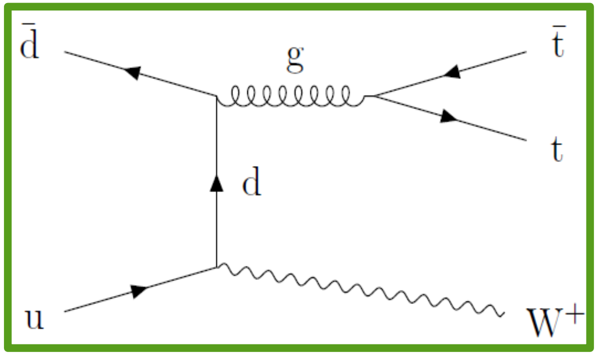
arXiv:1711.02547

- measurement of $t\bar{t}X$ cross sections at 13 TeV using 35.9 fb^{-1}
  - $t\bar{t}W$: same-sign dilepton events
  - $t\bar{t}Z$: final states with 3/4 leptons





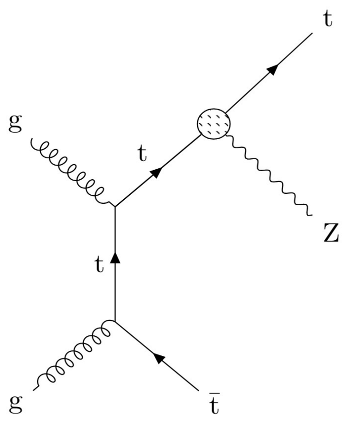
check talk by
N. Chanon
for more details



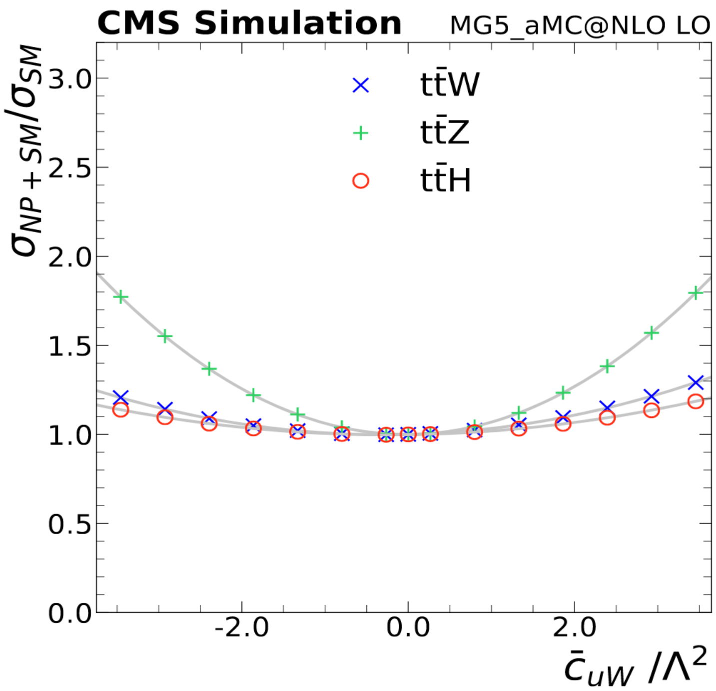
EFT Interpretation of $t\bar{t}X$ Cross Sections

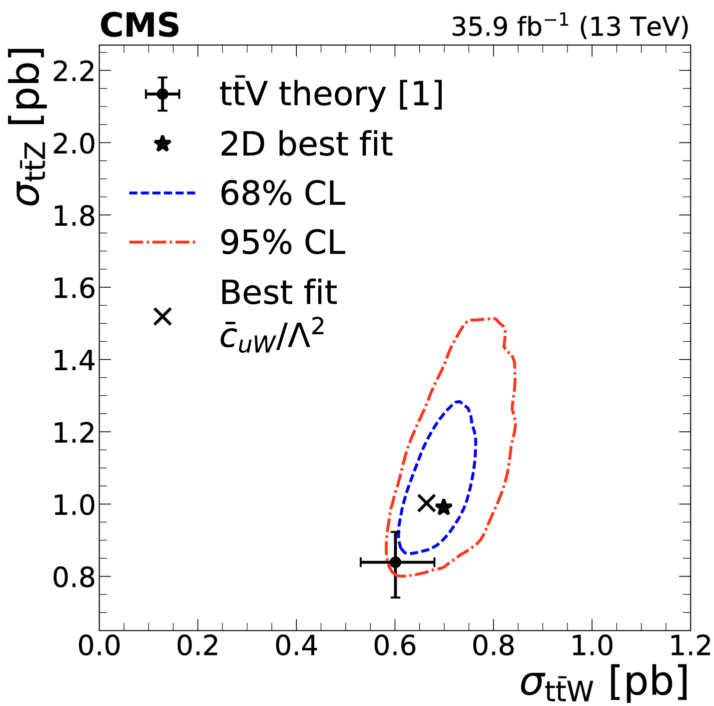
arXiv:1711.02547

- identified 8 Wilson coefficients C_i that affect $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}H$ without significantly impacting expected background yields



- fitting one Wilson coefficient at a time:
  - e.g. C_{uW} affecting mostly $t\bar{t}Z$ cross section





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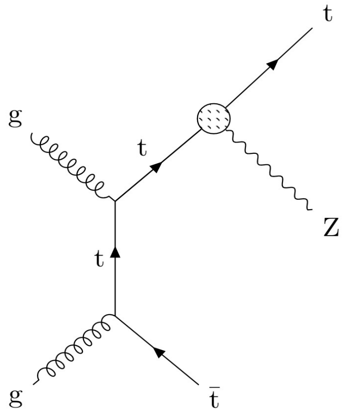
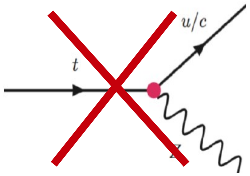


Wilson coefficient	Best fit [TeV^{-2}]	68% CL [TeV^{-2}]	95% CL [TeV^{-2}]
$\bar{c}_{uW}/\Lambda^2$	1.7	$[-2.4, -0.5]$ and $[0.4, 2.4]$	$[-2.9, 2.9]$
$\lvert\bar{c}_H/\Lambda^2 - 16.8\ \text{TeV}^{-2}\rvert$	15.6	$[0, 23.0]$	$[0, 28.5]$
$\lvert\tilde{\bar{c}}_{3G}/\Lambda^2\rvert$	0.5	$[0, 0.7]$	$[0, 0.9]$
$\bar{c}_{3G}/\Lambda^2$	-0.4	$[-0.6, 0.1]$ and $[0.4, 0.7]$	$[-0.7, 1.0]$
$\bar{c}_{uG}/\Lambda^2$	0.2	$[0, 0.3]$	$[-1.0, -0.9]$ and $[-0.3, 0.4]$
$\lvert\bar{c}_{uB}/\Lambda^2\rvert$	1.6	$[0, 2.2]$	$[0, 2.7]$
$\bar{c}_{Hu}/\Lambda^2$	-9.3	$[-10.3, -8.0]$ and $[0, 2.1]$	$[-11.1, -6.5]$ and $[-1.6, 3.0]$
$\bar{c}_{2G}/\Lambda^2$	0.4	$[-0.9, -0.3]$ and $[-0.1, 0.6]$	$[-1.1, 0.8]$

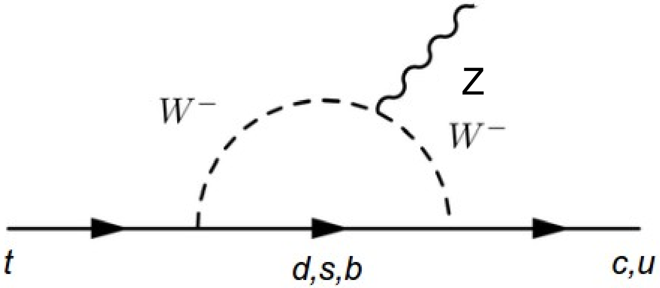
$t\bar{t}Z/t\bar{t}W/t\bar{t}H$ provide great complementary sensitivity to several EFT operators

Flavor Changing Neutral Currents

- forbidden at tree level in SM



- suppressed by GIM mechanism at higher orders



- many BSM models predict sizable FCNC branching fraction

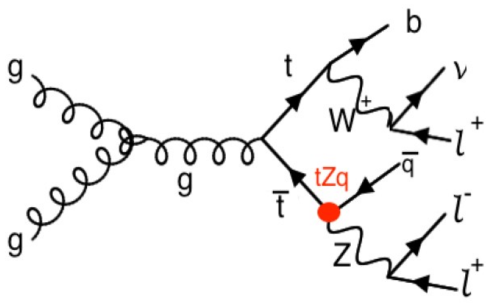
	SM	2HDM FC / FV	MSSM / w. RPV	RS
BR(t → cg)	10^{-12}	10^{-8} / 10^{-4}	10^{-7} / 10^{-6}	10^{-10}
BR(t → cZ)	10^{-14}	10^{-10} / 10^{-6}	10^{-7} / 10^{-6}	10^{-5}
BR(t → cγ)	10^{-14}	10^{-9} / 10^{-7}	10^{-8} / 10^{-9}	10^{-9}
BR(t → cH)	10^{-15}	10^{-5} / 10^{-3}	10^{-5} / 10^{-9}	10^{-4}

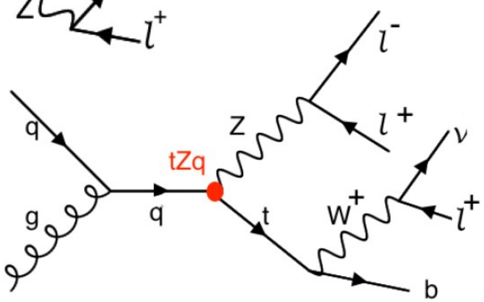
arXiv:1311.2028

- large variety of searches for enhanced couplings of top quarks to u/c quarks via g, Z, γ, H in top production and decay

CMS-PAS-TOP-17-017

- search for Z mediated FCNC in $t\bar{t}$ decay and single top production at 13 TeV using 35.9 fb^{-1}
- signature: 3 leptons, one Z candidate, ≥1 b-jet
  - two signal regions (SR): 2-3 jets for t→Zq decay and 1 jet for tZq production





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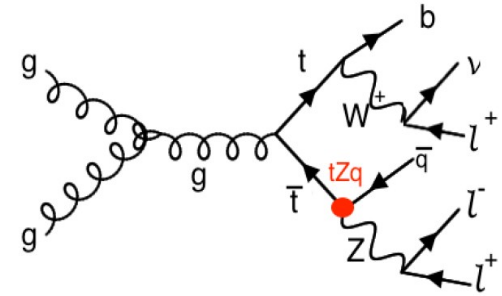

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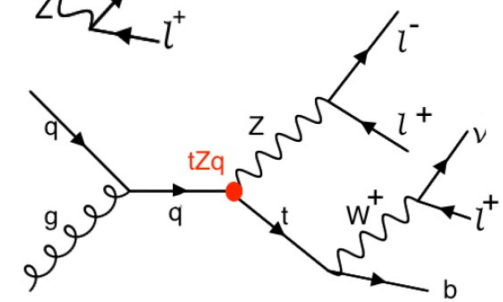
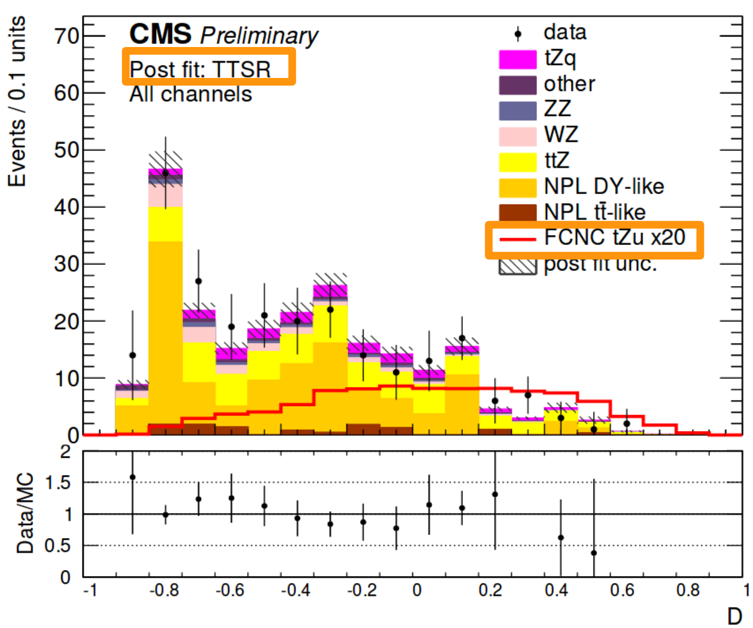
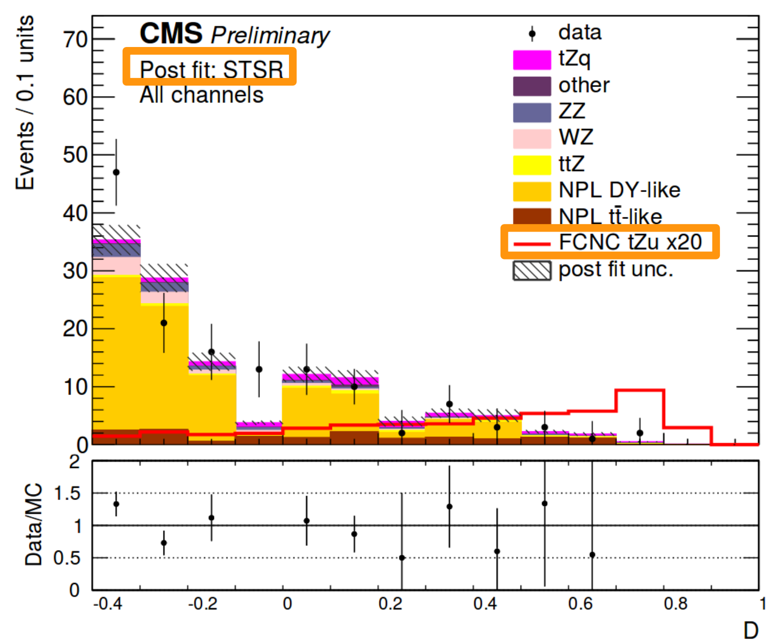


- use BDT to separate t→Zu (t→Zc) from background for $t\bar{t}$ SR (left) and single top SR (right)





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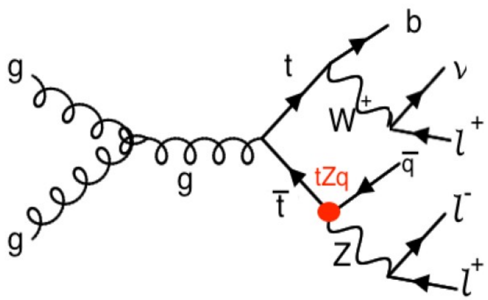

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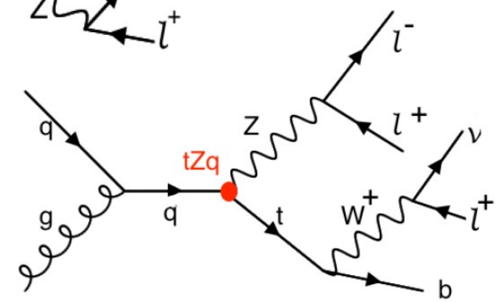


- use BDT to separate t→Zu (t→Zc) from background for $t\bar{t}$ SR (left) and single top SR (right)

- expected (observed) limits on branching ratios

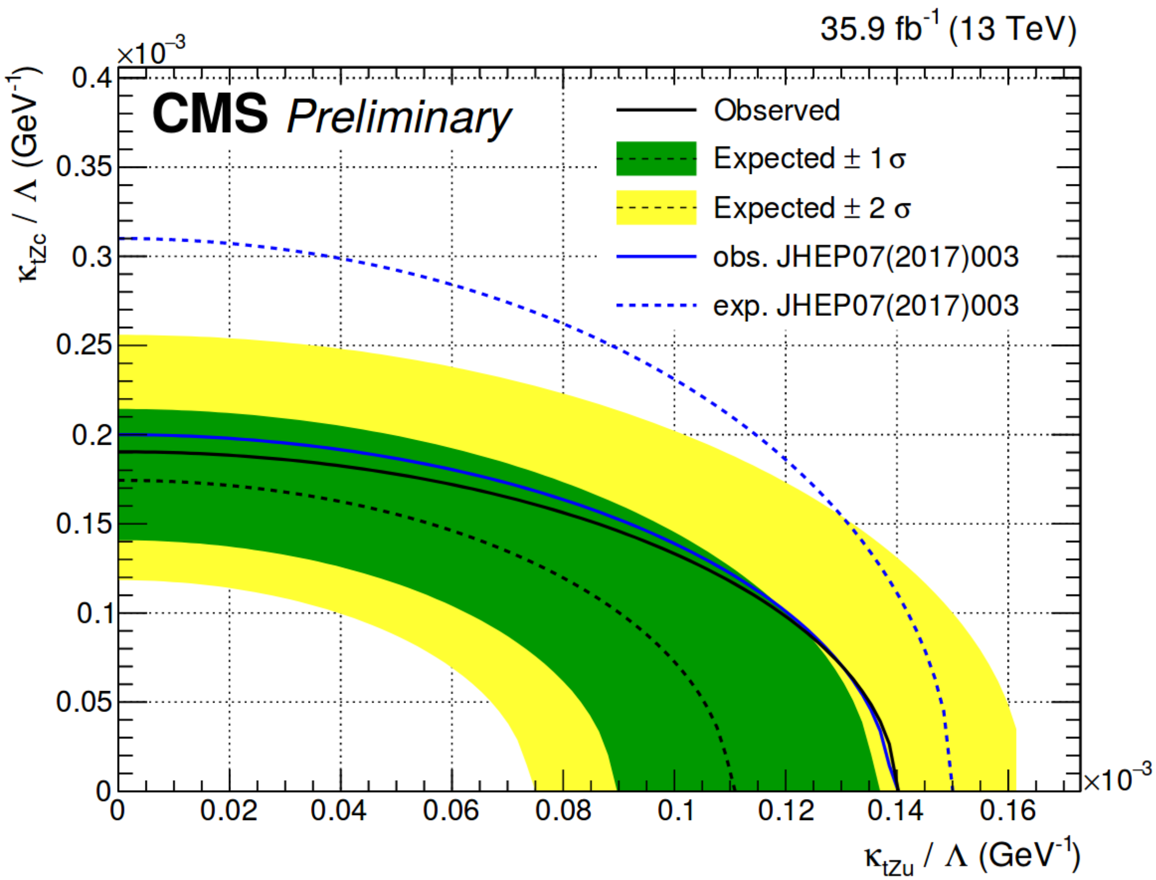
  BR(t → Zu) < 0.024 (0.015) %
  BR(t → Zc) < 0.045 (0.037) %

FCNC Interpretation in Terms of EFT

CMS-PAS-TOP-17-017

- set limits on trilinear top-quark-boson couplings

$$L = \sum_{q=u,c} \frac{g}{\sqrt{2}c_W} \frac{\kappa_{tZq}}{\Lambda} \bar{t}\sigma^{\mu\nu}(f^L_{Zq}P_L + f^R_{Zq}P_R)qZ_{\mu\nu}$$



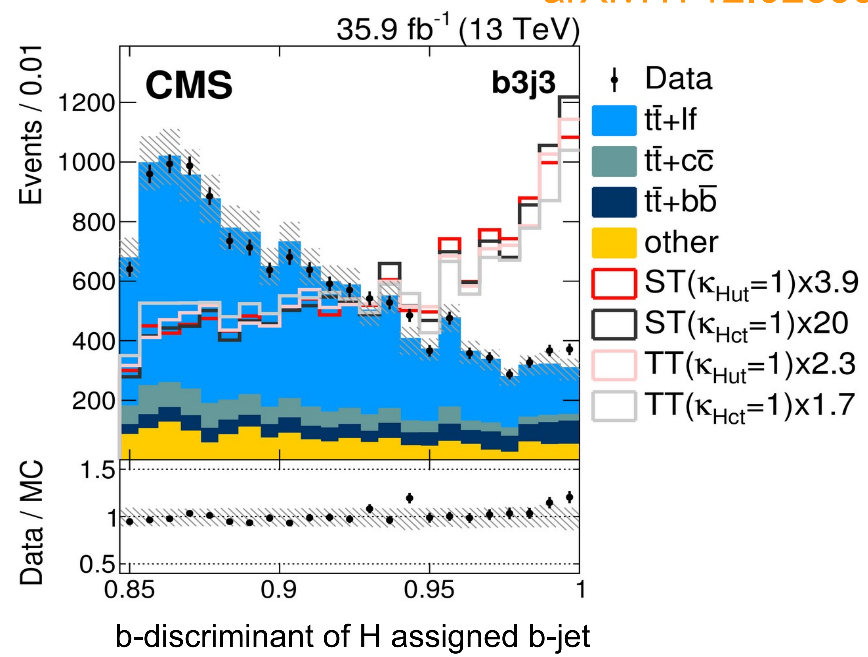
significant improvement compared to 8 TeV result arXiv:1712.02399

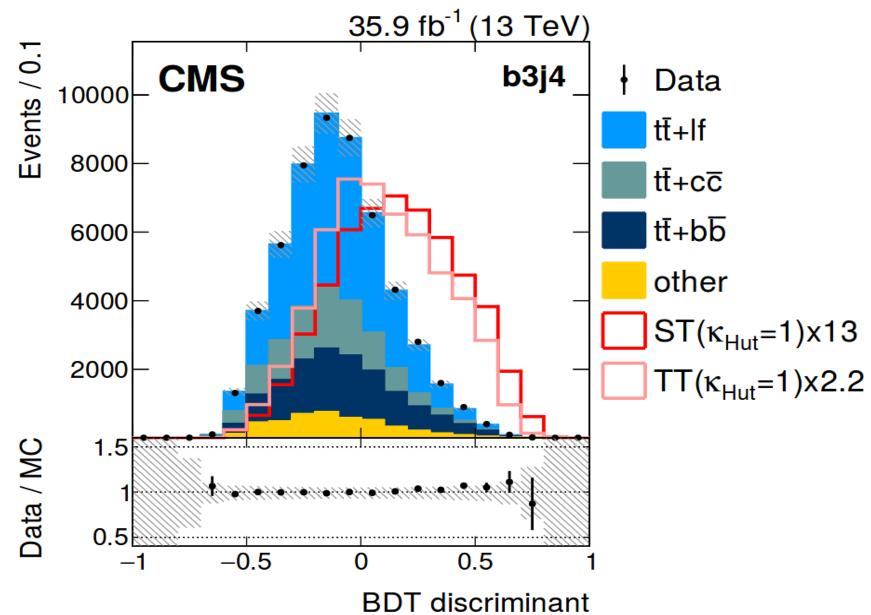
- search for Higgs FCNC at 13 TeV using 35.9 fb^{-1}
  - explore single lepton events in jet/bjet categories

- staggered BDT approach
  - assign b-jets to initial either top or Higgs: ~75% correct assignment
  - discriminate t→Hu/t→Hc from backgrounds

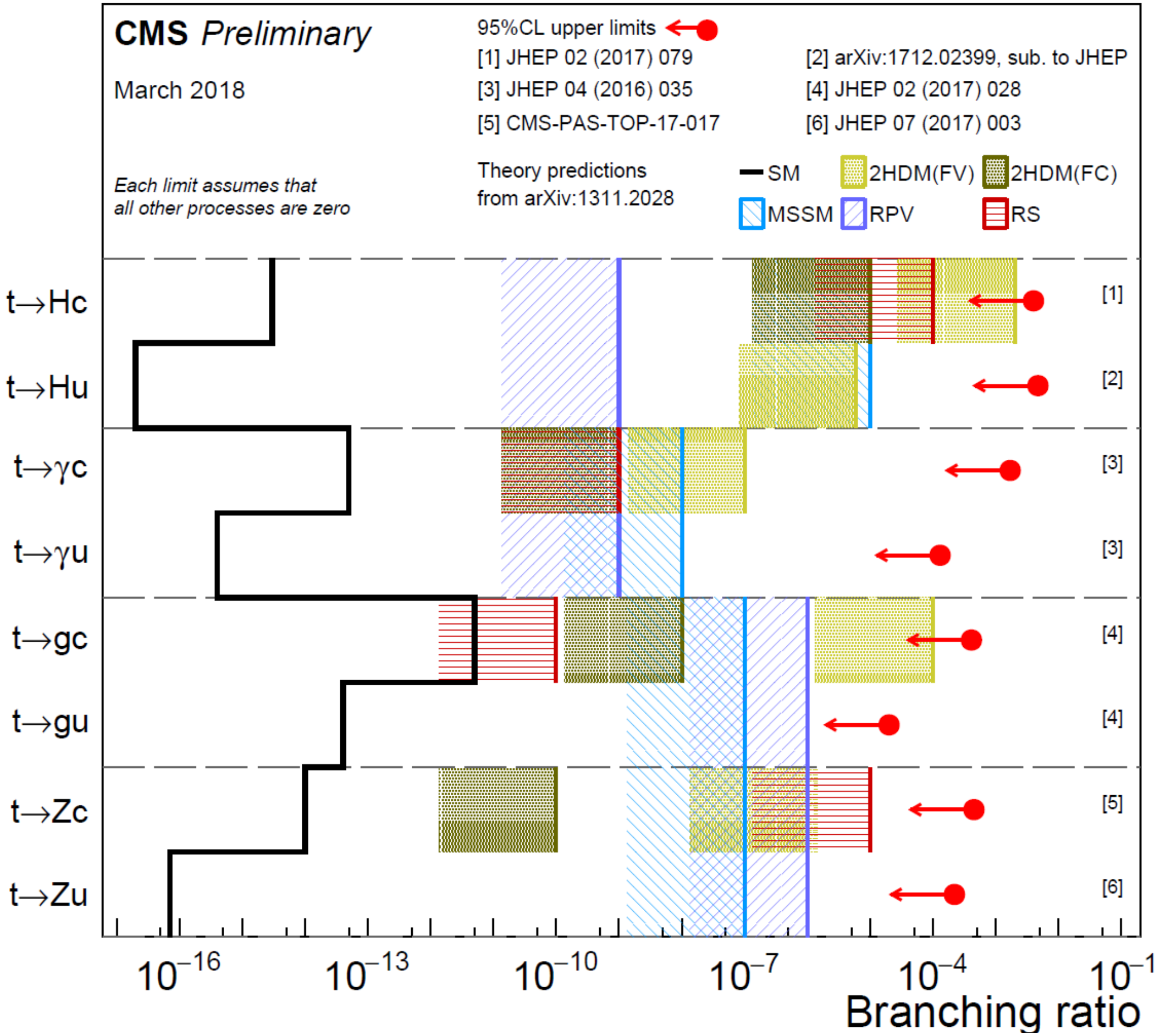
- expected (observed) limits on branching ratios

$$BR(t \rightarrow Hu) < 0.47(0.34)\ \%$$
$$BR(t \rightarrow Hc) < 0.47(0.44)\ \%$$



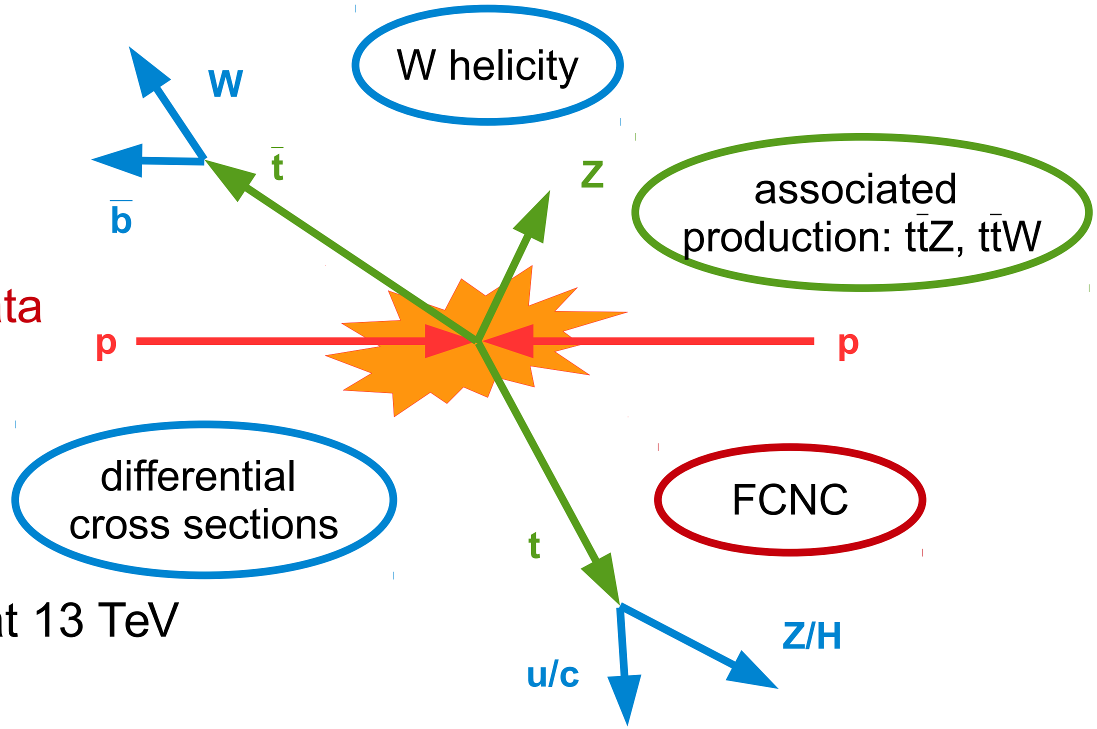


Limits on BSM Models of FCNC



start probing models predicting highest branching fractions

Summary and Outlook



- top quarks provide several interesting opportunities to search for new physics

- most presented results based on 2016 data
  - factor 4 more collisions to analyze during Run 2
  - few challenging top property measurements still to be published at 13 TeV

- measurements often interpreted in terms of anomalous couplings
  - consistent transition to theoretically better defined EFT just started
  - first results using NLO predictions already available

- large FCNC program during LHC Run 2
  - results already surpassing results at 7/8 TeV
  - several more channels still to explore

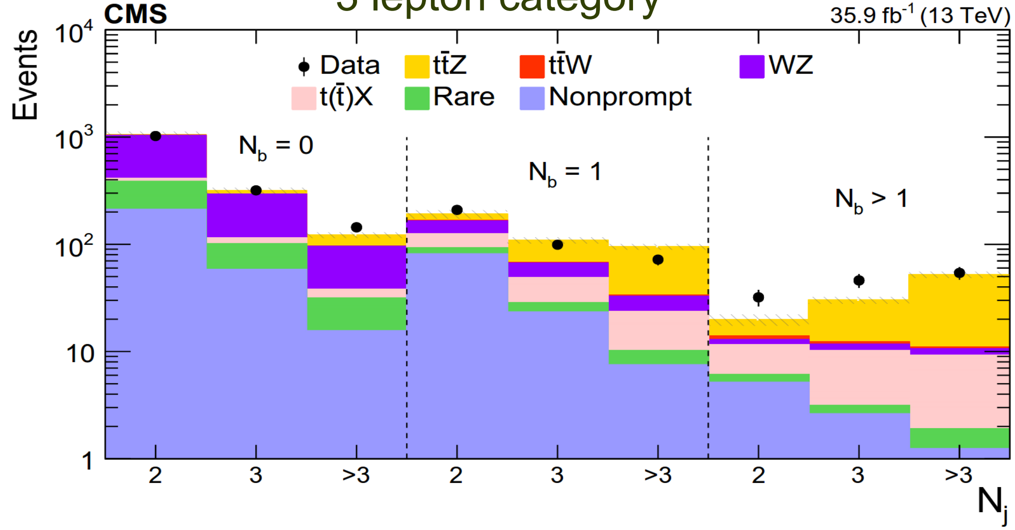
Back-Up

Rare Process: $t\bar{t}Z/t\bar{t}W$

arXiv:1711.02547

- measurement of $t\bar{t}X$ cross sections at 13 TeV using 35.9 fb^{-1}
  - $t\bar{t}W$ from same-sign dilepton events
  - $t\bar{t}Z$ from final states with 3 and 4 leptons

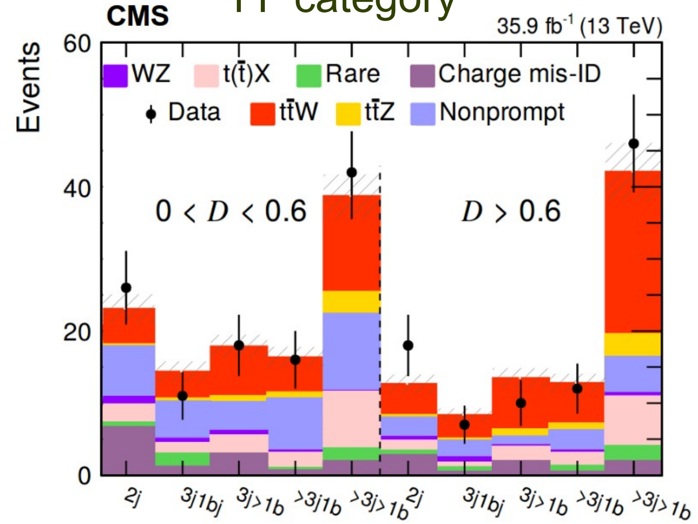
3 lepton category



- split events according to number of jets and b-tagged jets

- train BDT for same-sign dilepton events (“D”) to separate $t\bar{t}W$ from non-prompt leptons

l^+l^+ category



- fit across categories to extract $\sigma_{t\bar{t}W}$ vs $\sigma_{t\bar{t}Z}$