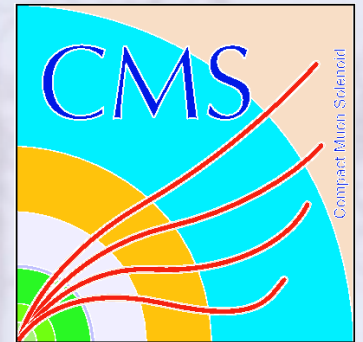


# Top FCNC Decay Searches on $tqZ/Z'$

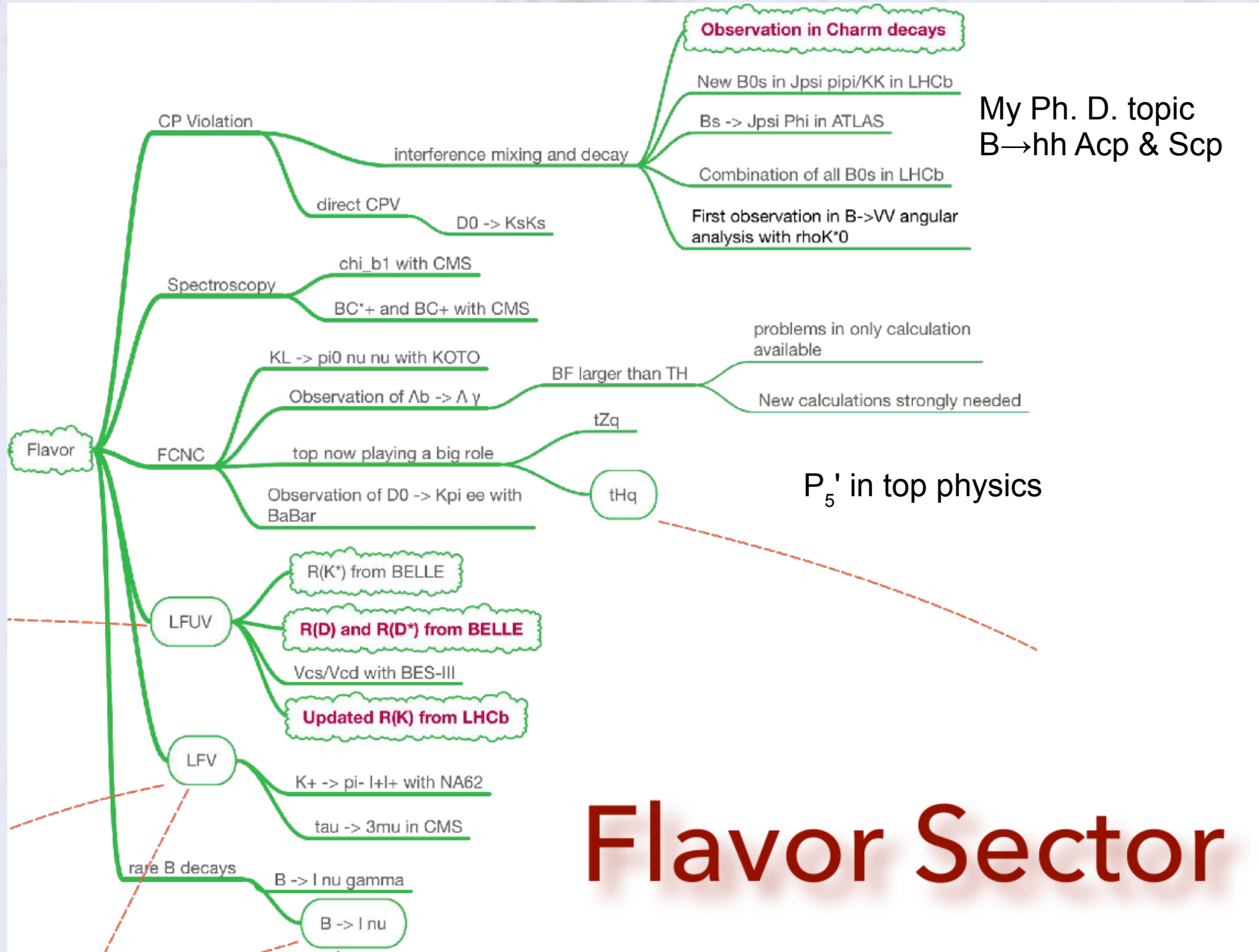


Yuan CHAO,

(National Taiwan University, Taipei, Taiwan)



Flavor/Collider Workshop @ NTU  
2019/04/02



My Ph. D. topic  
B → hh Acp & Scp



# Introduction



Wut

isn't it obvious?

From Physicist TV @ FB

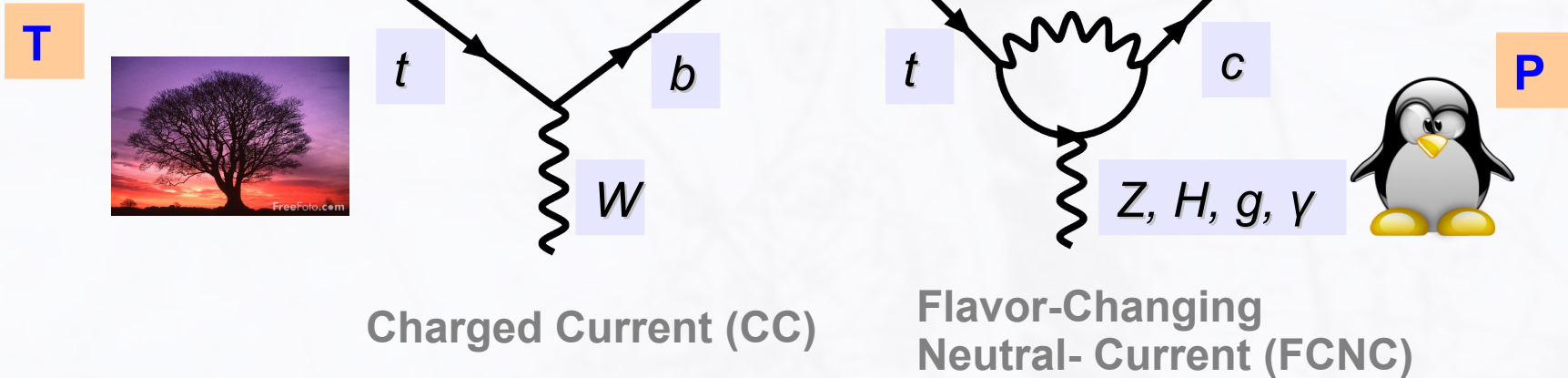
## Top Quark FCNC in popular science.

[http://bigbangtheory.wikia.com/wiki/User\\_blog:Sheldon\\_Cooper\\_PhD/Pilot](http://bigbangtheory.wikia.com/wiki/User_blog:Sheldon_Cooper_PhD/Pilot)



# Motivation

- Top quark decay channels:



FCNC plays an important role in NP and CPV studies

- FCNC suppressed by  $O(10^{-13}-10^{-15})$  by GIM Mechanism
- Occurs at quantum loop corrections only Phys. Rev. D2 (1970) 1285
- Could be enhanced through new physics at loop level

Models predict BRs of  $O(10^{-3}-10^{-5})$ :

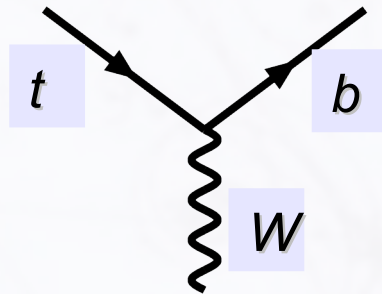
- MSSM, R-parity violating SUSY Phys. Lett. B502 (2001) 115-124
- Two Higgs doublet models arXiv: 1112.1707v1 [hep-ph]



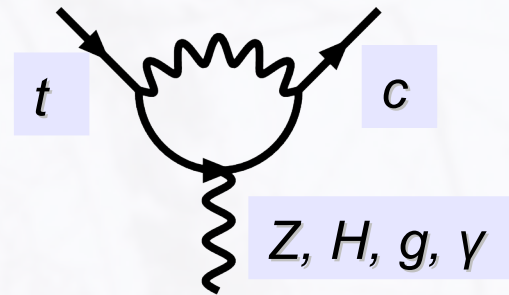
# Motivation

- Top quark decay channels:

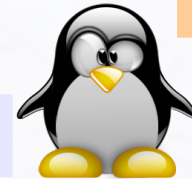
T



Charged Current (CC)



Flavor-Changing Neutral-Current (FCNC)



P

- A light  $Z'$  is proposed by several models
  - Gauged  $L_\mu - L_\tau$  symmetry Altmannshofer et al. (1403.1269), Crivellin et al. (1501.00993)
  - 331 models Buras and De Fazio (1604.02344; update of 1311.6729)
  - Gauge anomaly free  $U(1)'$  models Ellis et al. (1705.03447), Alonso et al. (1705.03858)
- Local theorists suggest  $Z'$  searches through FCNC decays
  - Well hidden from the former search spaces
  - Approach (semi)-reconstruction of top quarks considered.
  - Could be found in both  $t\bar{t}$  and single-top tagged events.

See George's talk on SM2



# Top FCNC Searches (cont.)

- Top quark anomalous couplings are studied

$$\Delta\mathcal{L}_{\text{eff}} = \frac{1}{\Lambda} \kappa_{tqV} \bar{t} \sigma_{\mu\nu} q F_V^{\mu\nu} + \text{h.c.}, \quad (q = u, c; V = Z, \gamma, g, H\dots)$$

- Search in  $t\bar{t}$  decay

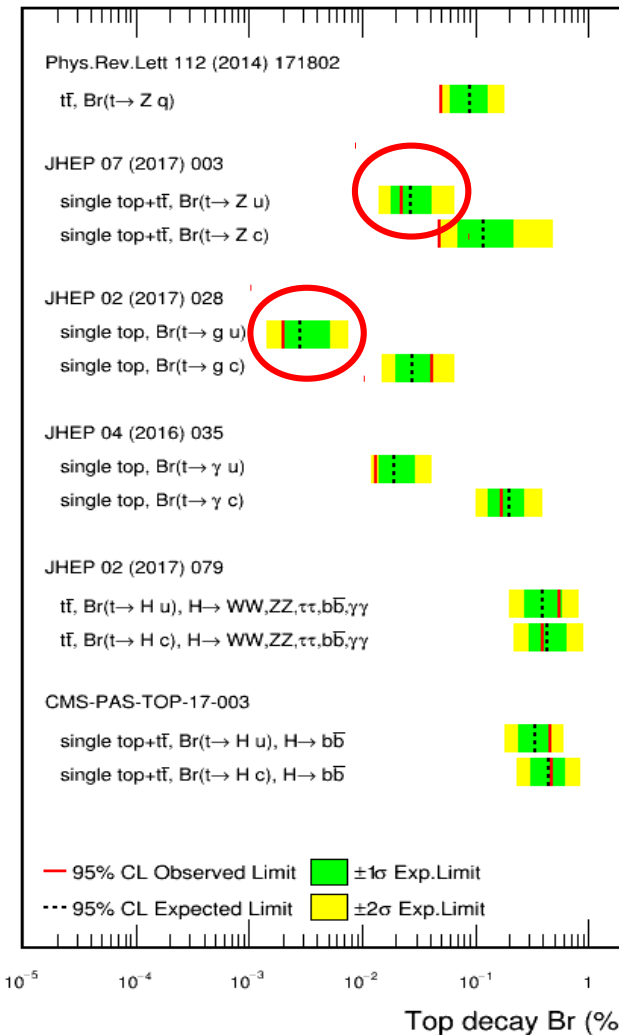
- On  $t \rightarrow Zq, Hq$
- Studies done on di-lepton and tri-lepton events ( $t \rightarrow Zq$ )

- Search in single top prod.

- Complementary to  $t\bar{t}$  decays
- On  $tZq, tgq, tyq$  vertices  
Done on tri-lepton mode ( $tZq$ )

CMS preliminary

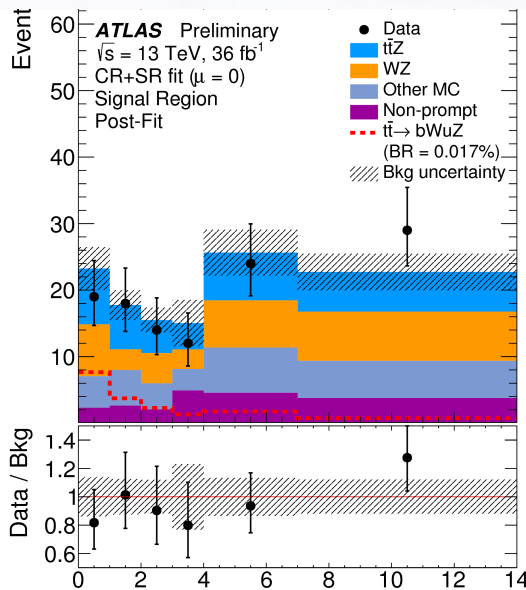
September 2017



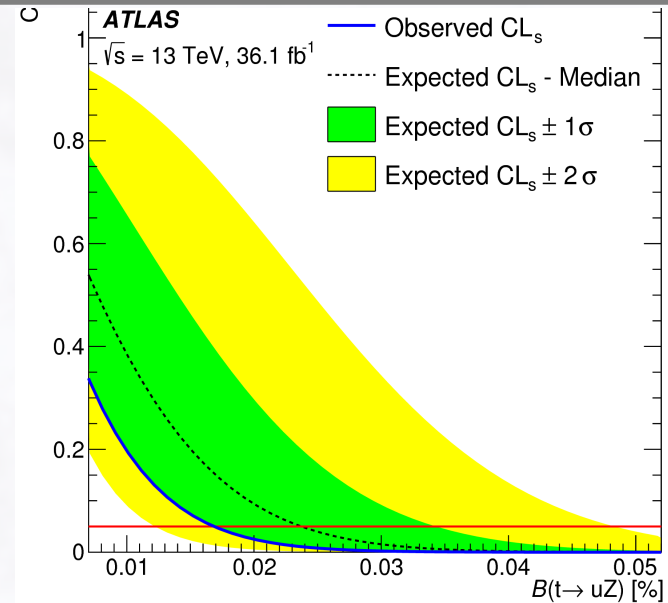


# Latest Result from Atlas

- Using tri-lepton channel
  - Simultaneous fit to  $\chi^2$
- Main source of uncertainty
  - Event modeling
  - Jet energy scale

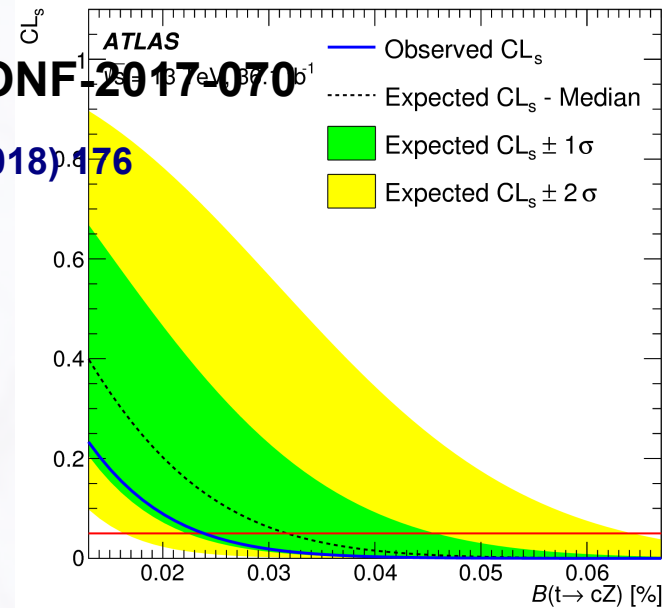


	$B(t \rightarrow uZ)$	$B(t \rightarrow cZ)$
Observed	$1.7 \times 10^{-4}$	$2.4 \times 10^{-4}$
Expected $-1\sigma$	$1.7 \times 10^{-4}$	$2.2 \times 10^{-4}$
Expected	$2.4 \times 10^{-4}$	$3.2 \times 10^{-4}$
Expected $+1\sigma$	$3.4 \times 10^{-4}$	$4.6 \times 10^{-4}$



ATLAS-CONF-2017-070

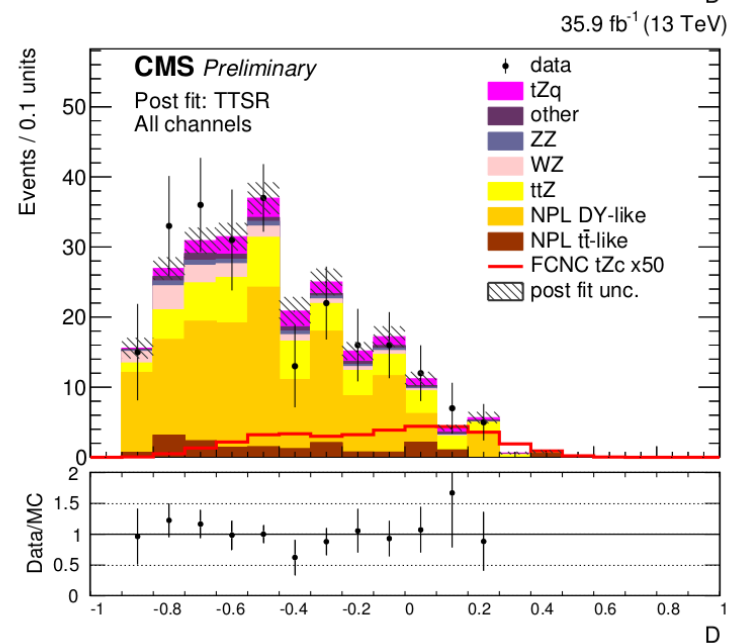
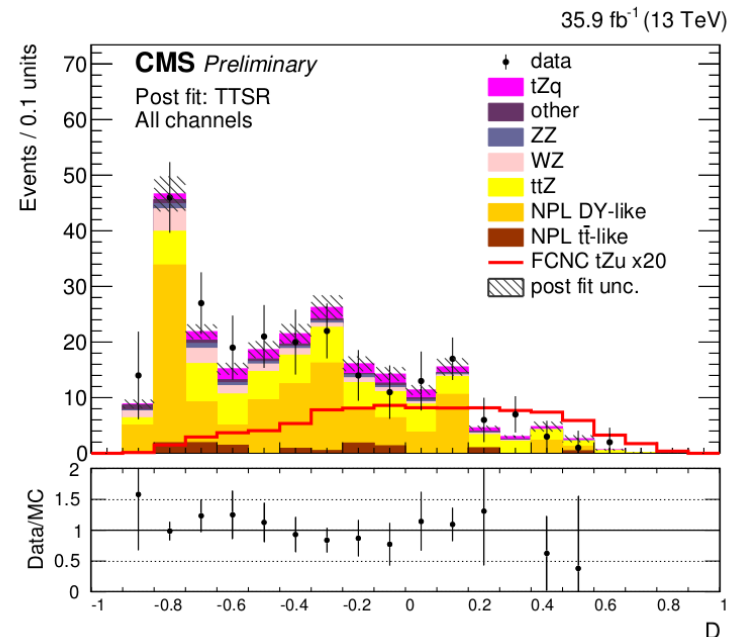
JHEP 07 (2018) 176





# Latest Result from CMS

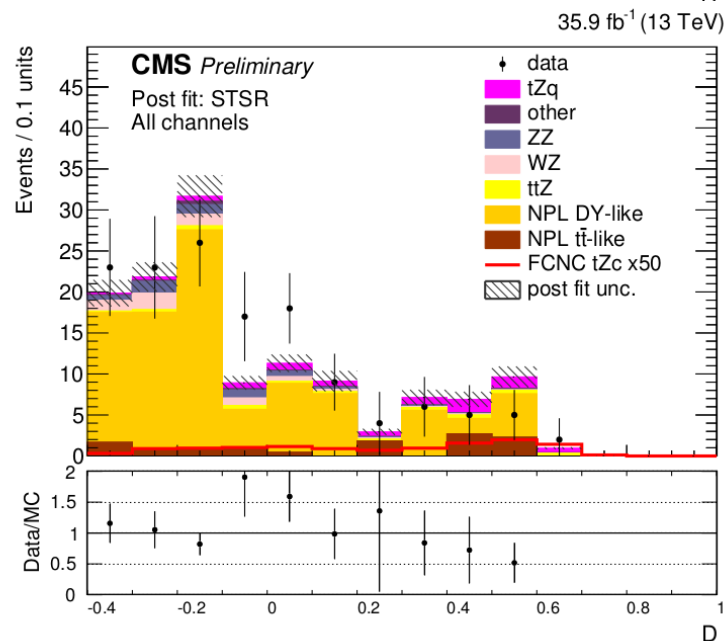
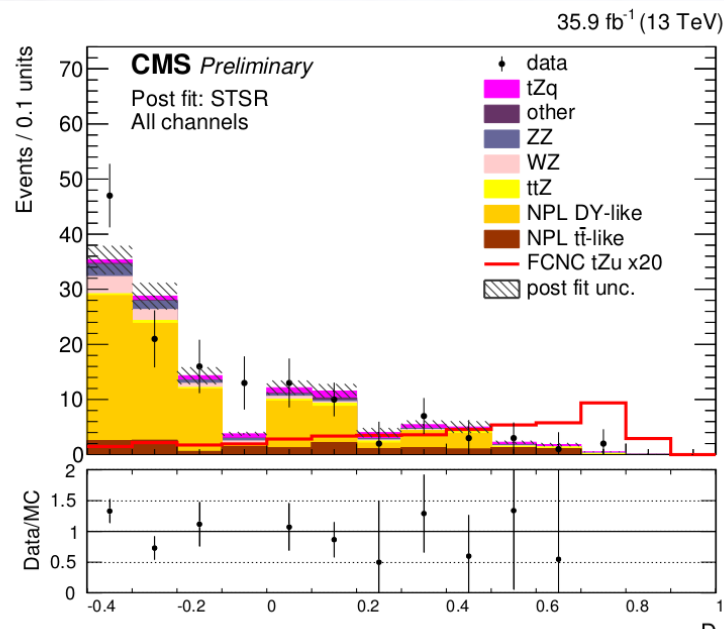
- Using tri-lepton channel
  - Requiring a Z candidate
  - Same MVA approach (event shape var.)
  - fits on **TTSR**, STSR
- Main source of uncertainty
  - Event modeling
  - Jet energy scale
  - b-tagging





# Latest Result from CMS

- Using tri-lepton channel
  - Requiring a Z candidate
  - Same MVA approach (event shape var.)
  - fits on TTSR, STSR
- Main source of uncertainty
  - Event modeling
  - Jet energy scale
  - b-tagging





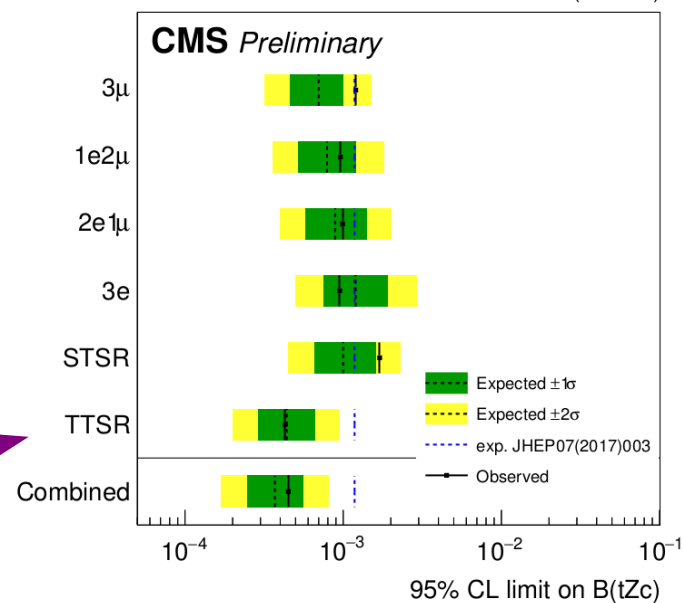
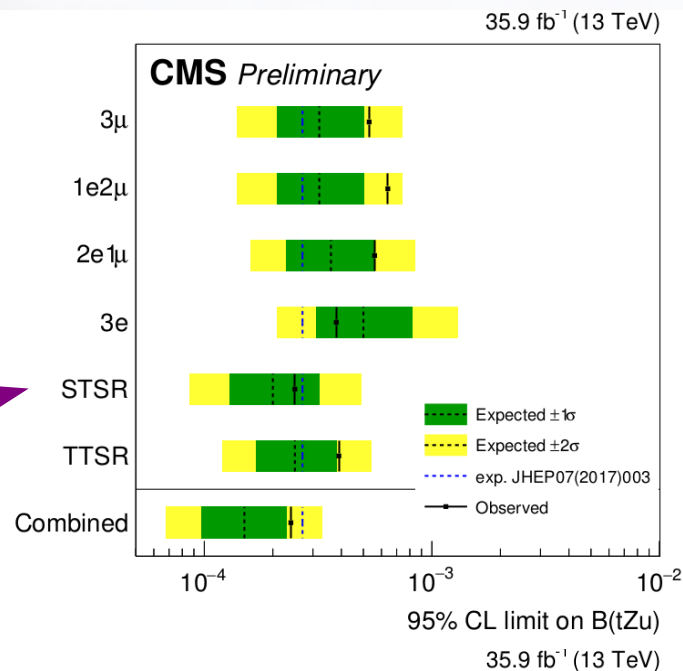
# Latest Result from CMS

- Using tri-lepton channel
  - Requiring a Z candidate
  - Same MVA approach (event shape var.)
  - fits on TTSR, STSR
- Main source of uncertainty
  - Event modeling
  - Jet energy scale
  - b-tagging
- Combined fit for the limits

**CMS-PAS-TOP-17-017**

$$\mathcal{B}(t \rightarrow uZ) < 0.024\% (0.015\%)$$

$$\mathcal{B}(t \rightarrow cZ) < 0.045\% (0.037\%)$$





# Status on Run2 Update

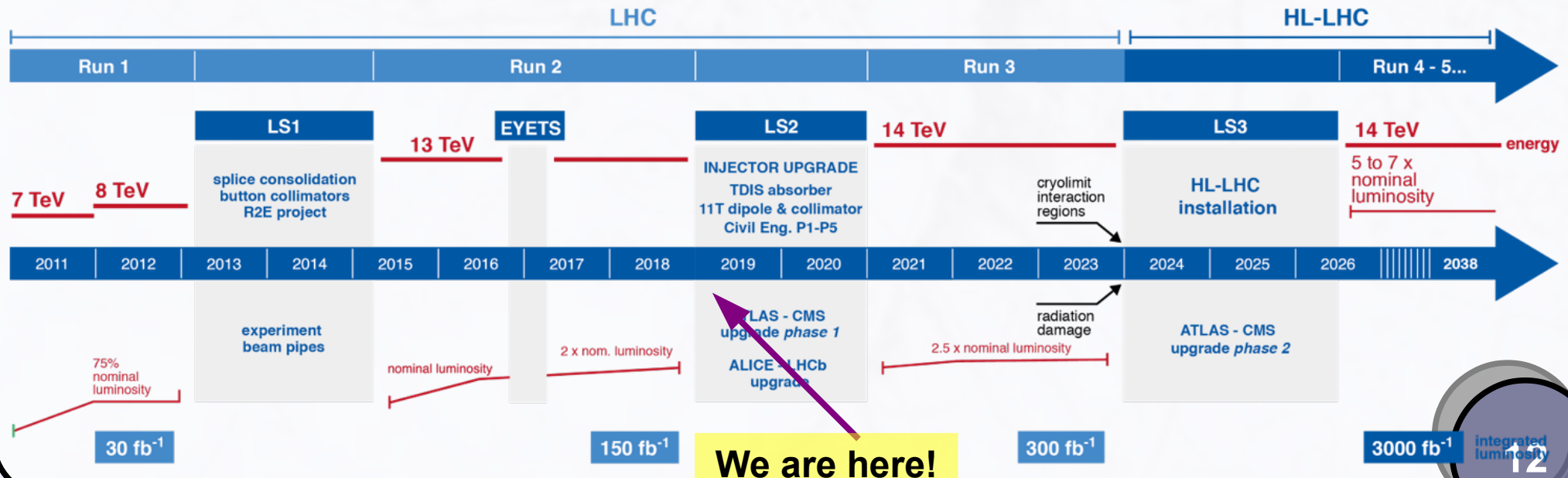
- For  $t\bar{t}$  FCNC on  $t \rightarrow qZ/qZ'$ 
  - Manpower: Chun-ting Lin, Yuan Chao of NTU
  - Focus on tri-lepton mode
  - Having very light or un-resonance  $Z'$  in mind
  - Improving analysis approaches
    - MC ready, using POG cuts on MiniAOD v2 samples
    - Reproducing 2016 results from Isis.
    - One-combination-per-event selection
    - Signal extraction with template fit
    - Possible improvements on current results
  - Aiming an update for winter conf. with 2017 data; ultimately with 2016+2017+2018 combined.
- For single top FCNC on  $cg \rightarrow tZ/tZ'$ 
  - Hwidong Yoo expressed his interests here
  - Having similar way to the decay approach
  - Aiming an update of 2017 together with  $t\bar{t}$  FCNC



# The Large Hadron Collider

- The four major experiments of LHC
  - Atlas, Alice, CMS, LHCb
- Run 2 starts at 13 TeV in 2015
  - Great performance through 2016 till end of 2018 with  $\sim 150 / \text{fb}$
- Now in Long Shutdown 2 (LS2)

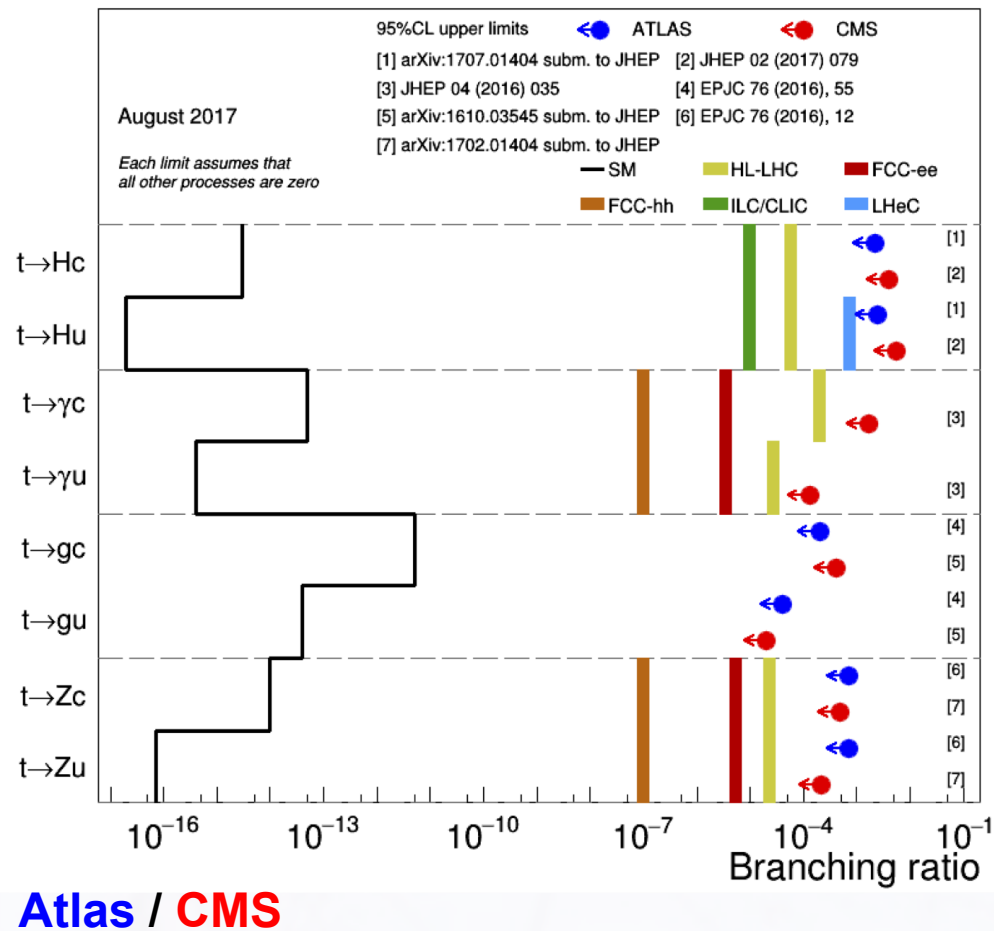
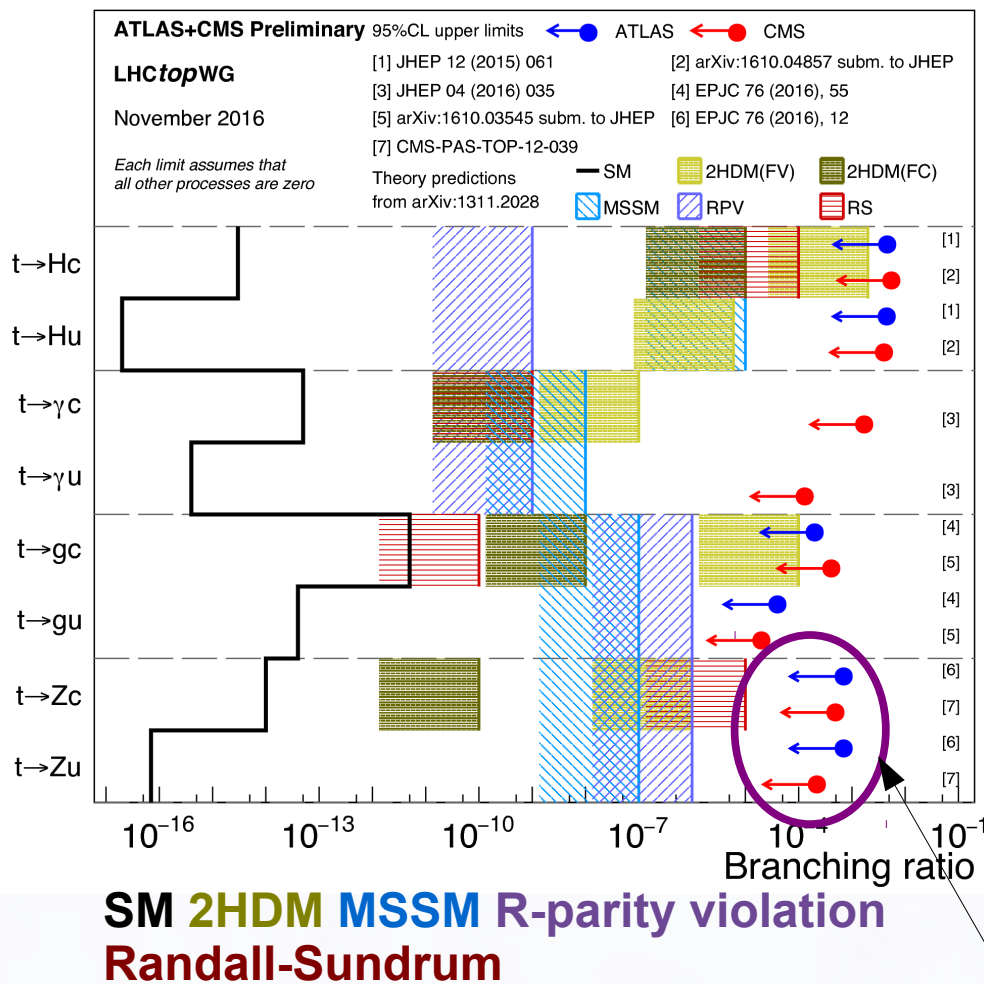
## LHC / HL-LHC Plan





# Top FCNC

## From LHC TOP WG summary:

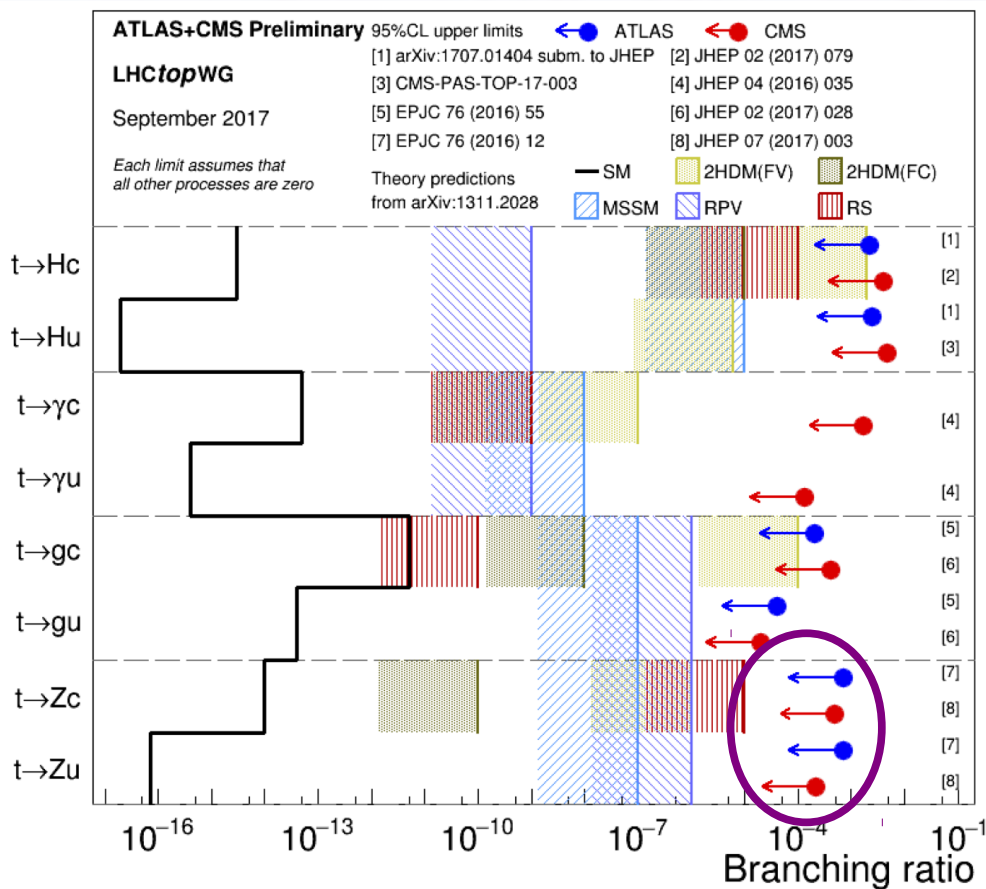


CMS has best limits with 8 TeV data

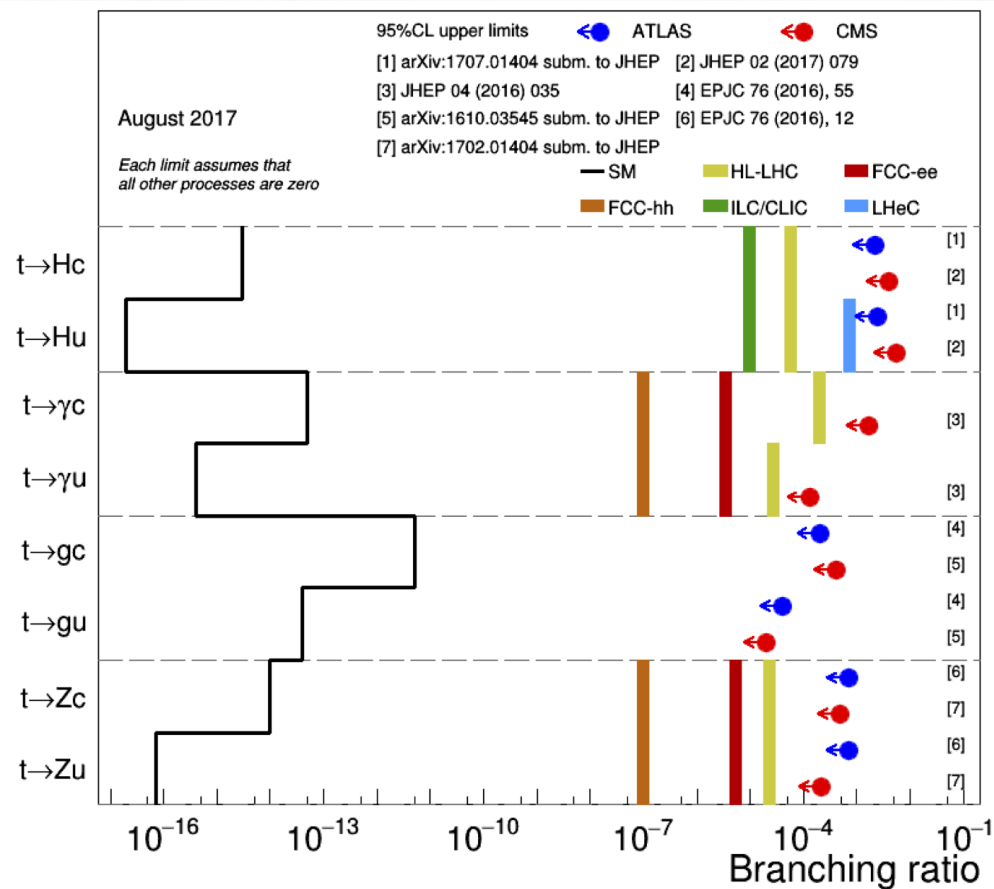


# Top FCNC

## • From LHC TOP WG summary:



SM 2HDM MSSM R-parity violation  
Randall-Sundrum

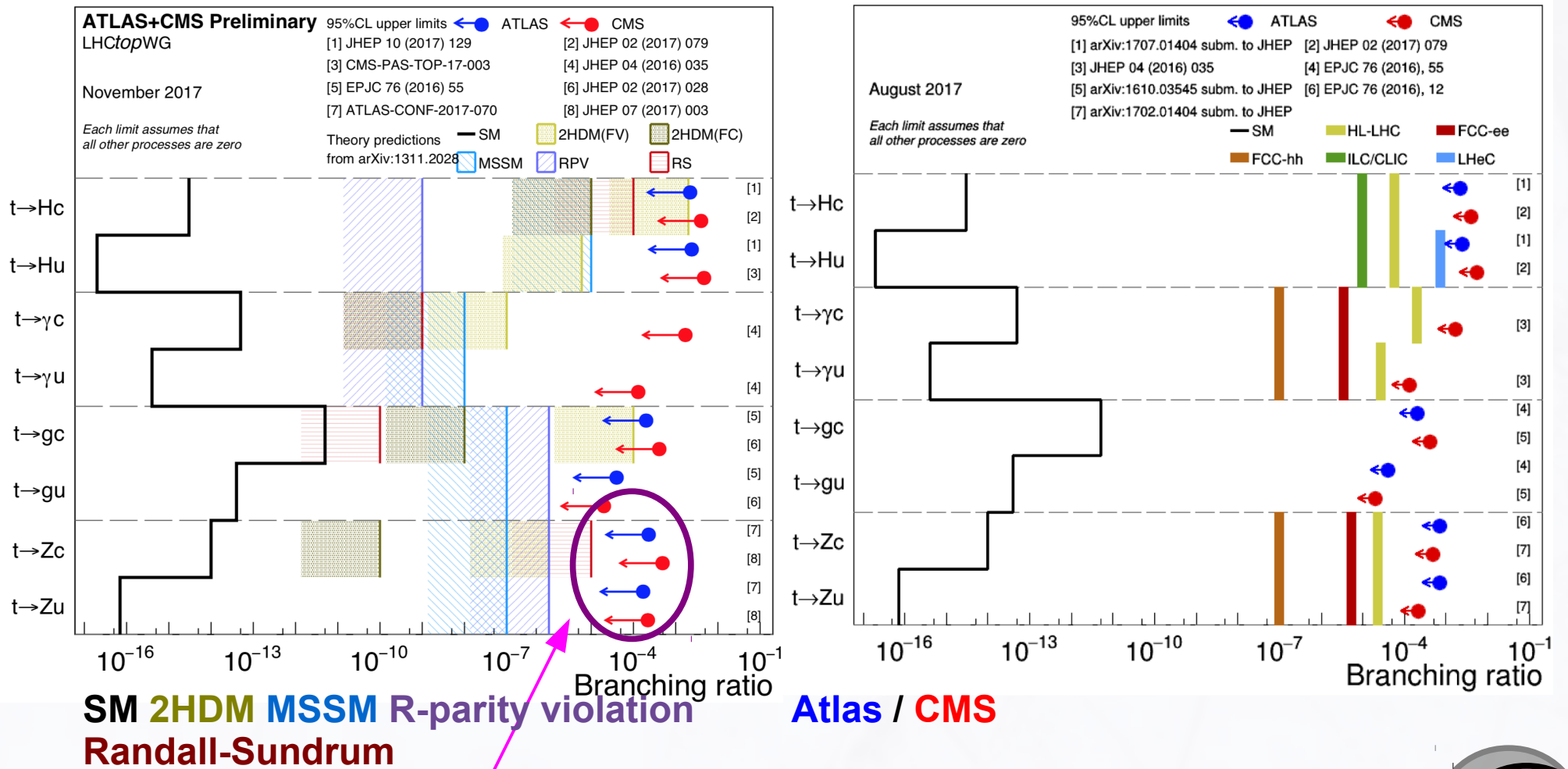


Atlas / CMS



# Top FCNC

## From LHC TOP WG summary:

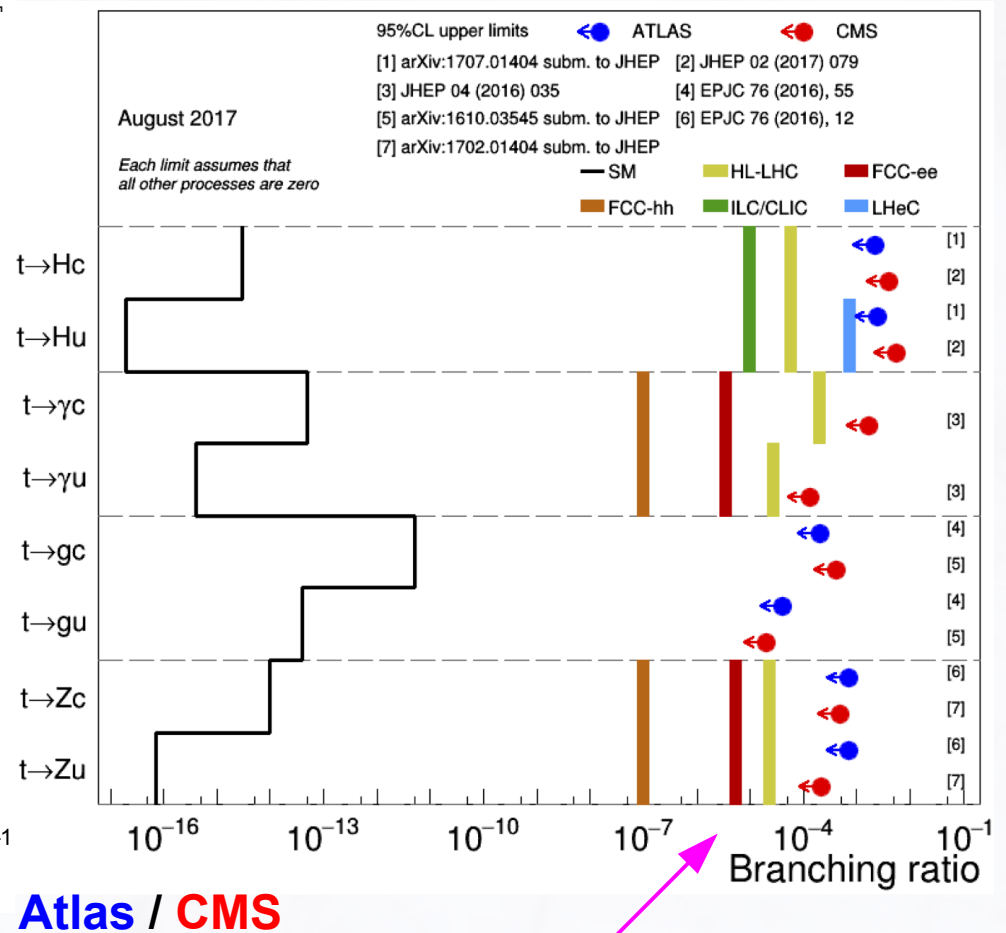
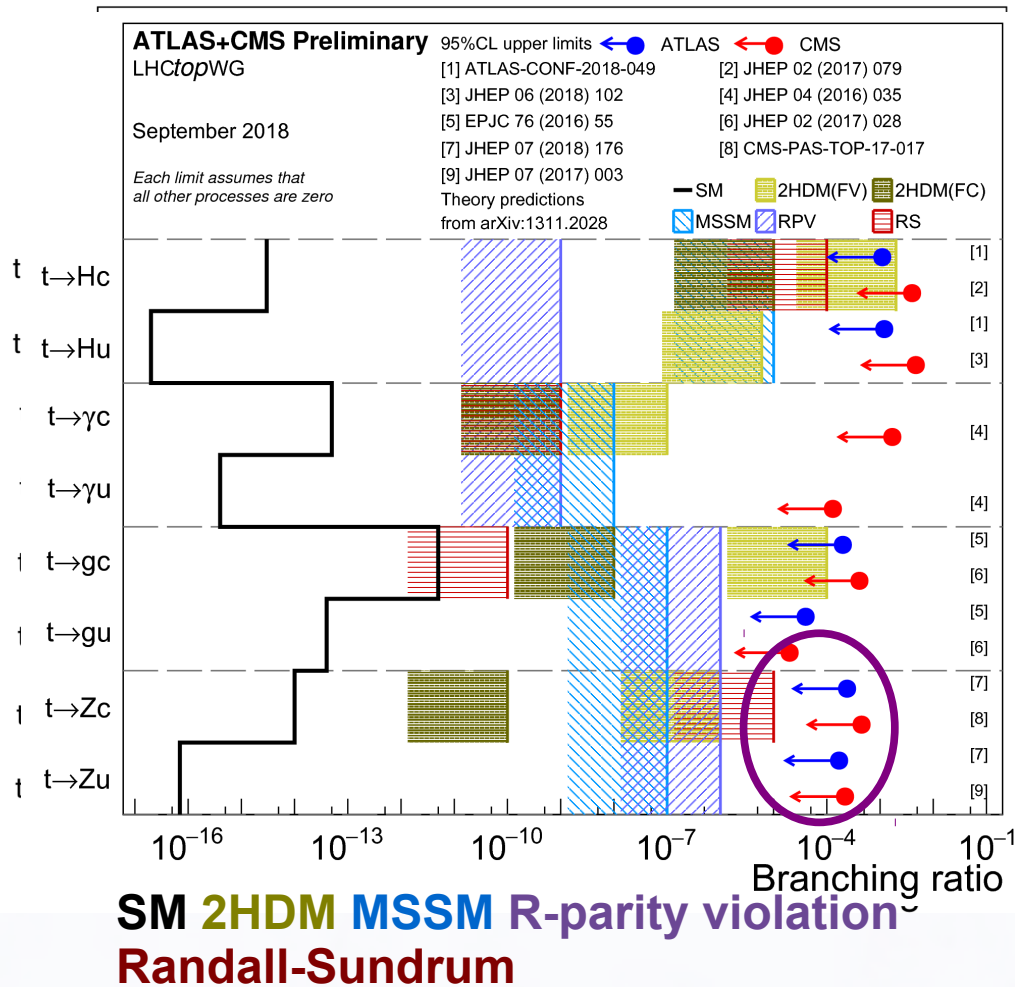


Atlas result updated with 13 TeV



# Top FCNC

## From LHC TOP WG summary:



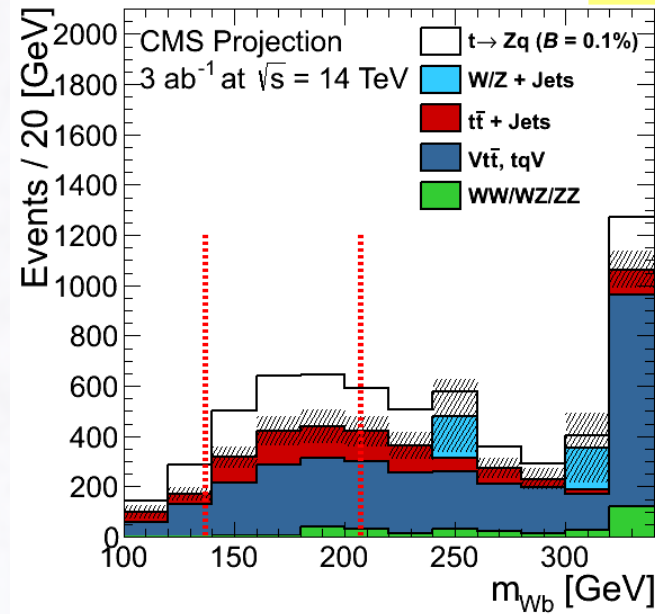
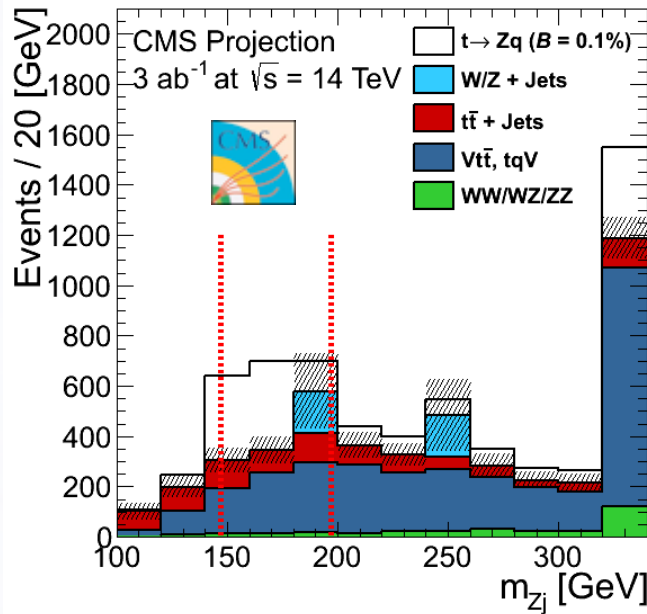
HL-LHC and future colliders will further probe BSM models



# Future Projections

- From an old CMS projection:

FTR-13-016



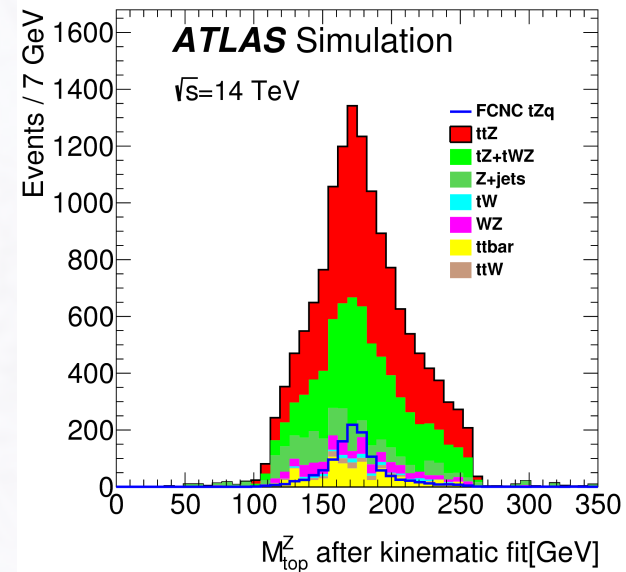
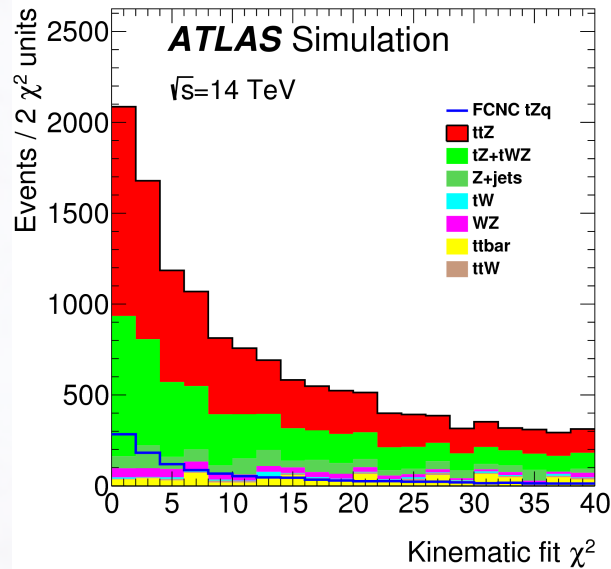
$\mathcal{B}(t \rightarrow Zq)$	$19.5 \text{ fb}^{-1} @ 8 \text{ TeV}$	$300 \text{ fb}^{-1} @ 14 \text{ TeV}$	$3000 \text{ fb}^{-1} @ 14 \text{ TeV}$
Exp. bkg. yield	3.2	26.8	268
Expected limit	$< 0.10\%$	$< 0.027\%$	$< 0.010\%$
$1 \sigma$ range	0.06 – 0.13%	0.018 – 0.038%	0.007 – 0.014%
$2 \sigma$ range	0.05 – 0.20%	0.013 – 0.051%	0.005 – 0.020%



# Future Projections

- From Atlas' projection:

ATL-PHYS-PUB-2016-019



	“ $\gamma$ ” $t \rightarrow Zu$	“ $\sigma$ ” $t \rightarrow Zu$	“ $\gamma$ ” $t \rightarrow Zc$	“ $\sigma$ ” $t \rightarrow Zc$	“ $\gamma$ ” $t \rightarrow Zu+Zc$	“ $\sigma$ ” $t \rightarrow Zu+Zc$
Reference	$4.3 \cdot 10^{-5}$	$4.3 \cdot 10^{-5}$	$5.6 \cdot 10^{-5}$	$5.8 \cdot 10^{-5}$	$2.4 \cdot 10^{-5}$	$2.5 \cdot 10^{-5}$
Middle	$4.5 \cdot 10^{-5}$	$4.6 \cdot 10^{-5}$	$6.0 \cdot 10^{-5}$	$6.3 \cdot 10^{-5}$	$2.6 \cdot 10^{-5}$	$2.7 \cdot 10^{-5}$
Low	$5.1 \cdot 10^{-5}$	$5.2 \cdot 10^{-5}$	$6.7 \cdot 10^{-5}$	$7.0 \cdot 10^{-5}$	$2.9 \cdot 10^{-5}$	$3.0 \cdot 10^{-5}$

Projection for 3000/fb integ. lum.



# Summary and Prospects

- Top FCNC searches on  $tqZ$ 
  - $t\bar{t}$  decays
  - Single top production
- Both Atlas and CMS has results on 2016 data ( $\sim 36/\text{fb}$ )
  - Atlas has best limits on both  $t \rightarrow uZ$  and  $t \rightarrow cZ$
  - Expected limits are compatible
  - Full Run 2 has  $\sim 150/\text{fb}$  to be analyzed
- A proposed  $Z'$  search could be done with FCNC events
  - $R5'$  in top flavour physics
  - Di-muon channel with top tagged event
- Challenges
  - Time and man-power
  - Various approaches for improvements WIP



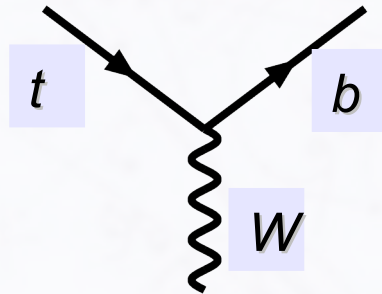
The background of the slide is a light blue color with a faint, repeating pattern of particle physics diagrams. These diagrams consist of various lines, circles, and dots, representing particle interactions and trajectories. The patterns are somewhat abstract and resemble Feynman diagrams or particle tracks.

# Thank YOU!

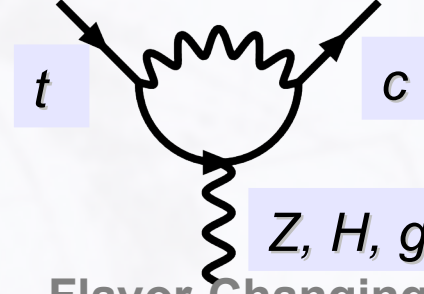


# Motivation

T

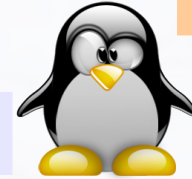


Charged Current (CC)



Flavor-Changing Neutral-Current (FCNC)

P



- Flavor-changing-neutral-current: loop diagrams
  - Suppressed under Standard Model
  - Could be enhanced through new physics
- Theoretical predictions
  - SM at quantum loop correction  $\sim O(10^{-14})$
  - Some SM extension models predicts up to  $\sim O(10^{-4})$   
e.g. R-parity violated SUSY, Top Color assistant technicolor...
- Studies done at LHC
  - Atlas with 2.1/fb data:  $BF < 0.73\%$  @ 95% C.L.
  - CMS TOP-11-028 with 5.0/fb data:  $BF < 0.21\%$
  - CMS TOP-12-037 with 5+19.5/fb data:  $BF < 0.05\%$
  - CMS TOP-17-017 with 36/fb data:  $BF < 0.045\%$
- Searching signature:  $t\bar{t} \rightarrow b\bar{b}W^+W^- + Z + b\bar{b} + 3\text{-lepton}$