Search for Flavor-changing Neutral Current Decays $t \rightarrow qH$ at $\sqrt{s} = 8$ TeV

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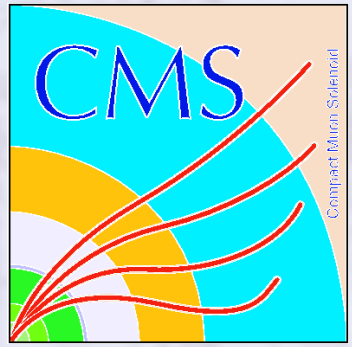
For the CMS collaboration

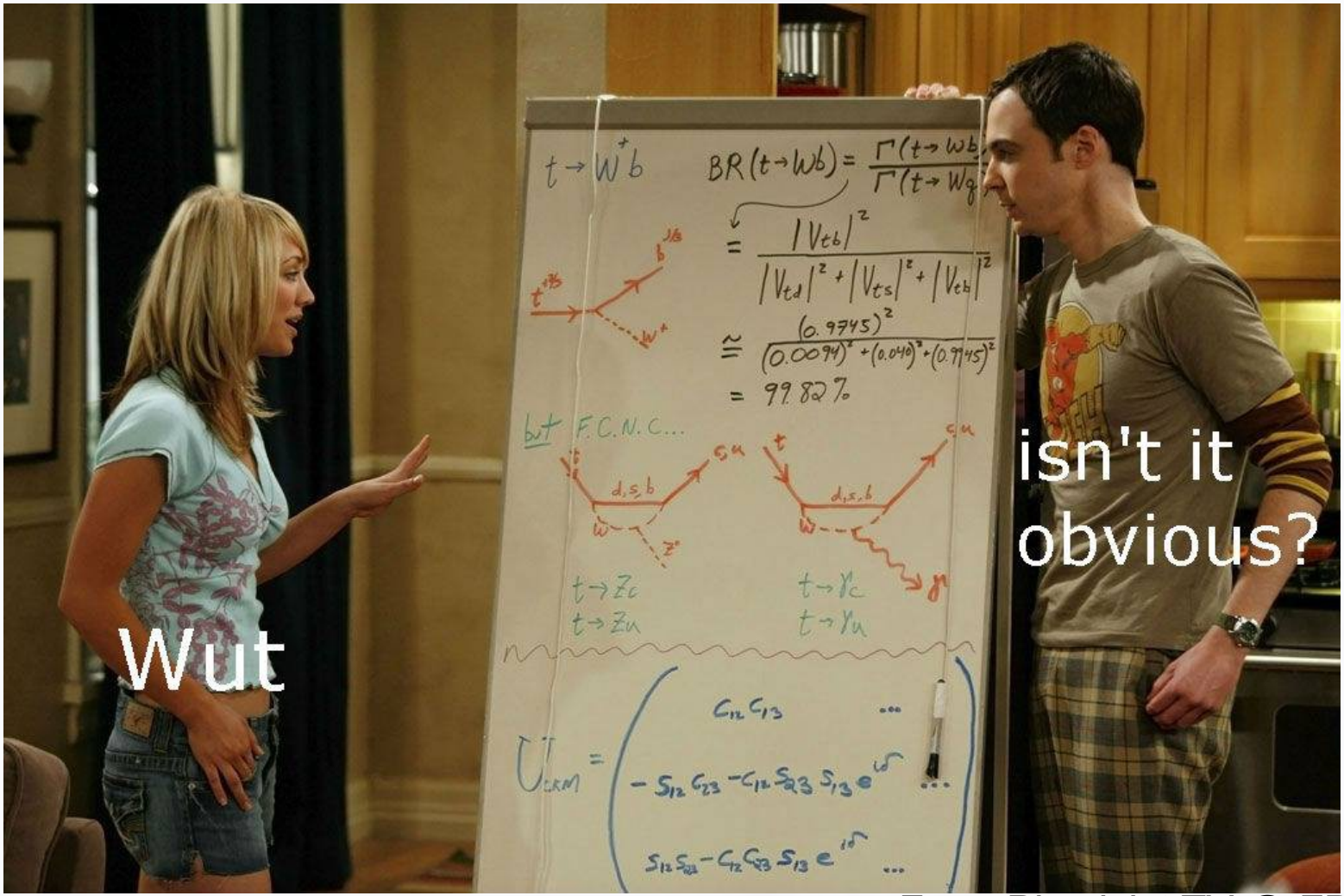


Lake Louise Winter Institute

University of Alberta

2016/02/07-13

Introduction



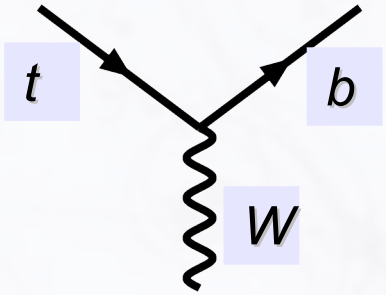
From Physicist TV @ FB

Top quark decays as **t → bW** ~100%, but...

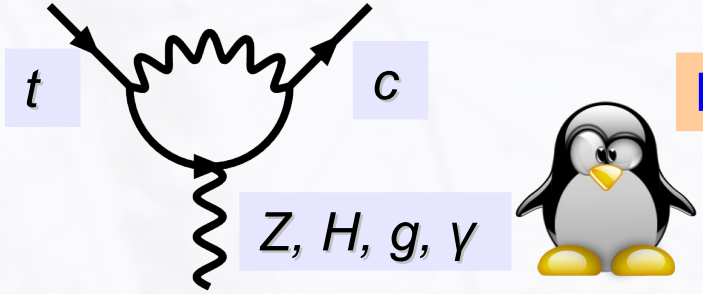
Motivation

- Top quark decay channels:

T



Charged Current (CC)



P

Flavor-Changing
Neutral- Current (FCNC)

FCNC plays an important role in NP and CPV studies

- FCNC suppressed by $O(10^{-13}\text{-}10^{-15})$ 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 $O(10^{-3}\text{-}10^{-5})$:
  - MSSM, R-parity violating SUSY Phys. Lett. B502 (2001) 115-124
  - Two Higgs doublet models arXiv: 1112.1707v1 [hep-ph]

Motivation (cont.)

- Any observation would indicate new physics
- Previous studies: Search for $t \rightarrow qZ$ decays
  - Combined 7 + 8 TeV results

    BR($t \rightarrow qZ$) < 0.05% with 25/fb (current best limit)

    Phys. Rev. Lett. **112** 171802
- Higgs is found with mass ~126 GeV, lighter than top quark
  - Search for $t \rightarrow qH$ are therefore possible
  - Studies done by both Atlas and CMS
    - Looking at bb, $\gamma\gamma$, $WW/ZZ/\tau\tau$

Top FCNC Searches (cont.)

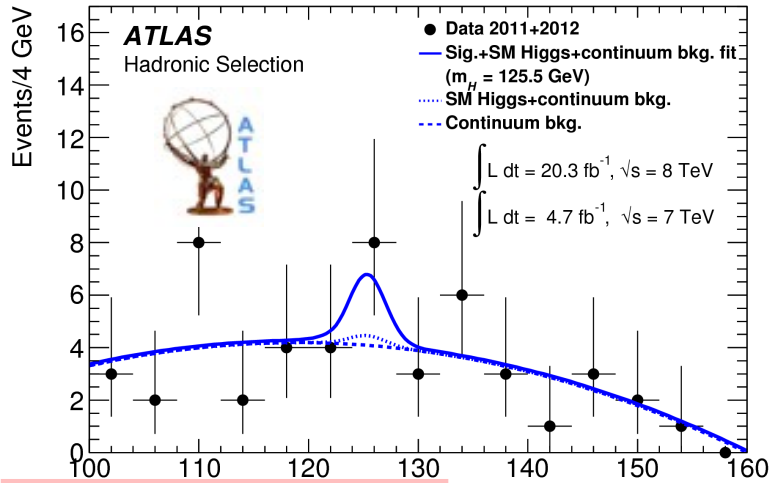
Search for $t \to qH$ decays

- ATLAS using 7+8 TeV data (direct search)
  - $H \to \gamma\gamma$
  - $H \to WW, ZZ, \tau\tau$
  - $H \to bb$

  combined limits:

  $$\mathcal{B}(t \to cH) < 0.46\% \text{ (exp. } 0.25\%)$$
  $$\mathcal{B}(t \to uH) < 0.45\% \text{ (exp. } 0.29\%)$$

  ArXiv: 1509.06047



ATLAS JHEP 06 008

- CMS (two approaches)
  - Re-interpret from SUSY mult.-lep. studies
    - $H \to WW, ZZ, \tau\tau$
    - Combining $H \to \gamma\gamma$

      $$\mathcal{B}(t \to cH) < 0.56\%$$
  - Direct searches
    - Multi-lepton ch. $H \to WW, ZZ, \tau\tau$
      - Using 8 TeV data only
      - Tri-lepton & same-sign di-lep.
    - Di-photon ch. $H \to \gamma\gamma$
    - Di-b_jet ch. $H \to bb$

Higgs Decay Mode	observed	expected	1σ range
$H \to WW^*$ ($\mathcal{B}$ = 23.1 %)	1.58 %	1.57 %	(1.02–2.22) %
$H \to \tau\tau$ ($\mathcal{B}$ = 6.15 %)	7.01 %	4.99 %	(3.53–7.74) %
$H \to ZZ^*$ ($\mathcal{B}$ = 2.89 %)	5.31 %	4.11 %	(2.85–6.45) %
combined multileptons (WW^*, $\tau\tau$, ZZ^*)	1.28 %	1.17 %	(0.85–1.73) %
$H \to \gamma\gamma$ ($\mathcal{B}$ = 0.23 %)	0.69 %	0.81 %	(0.60–1.17) %
combined multileptons + diphotons	0.56 %	0.65 %	(0.46–0.94) %

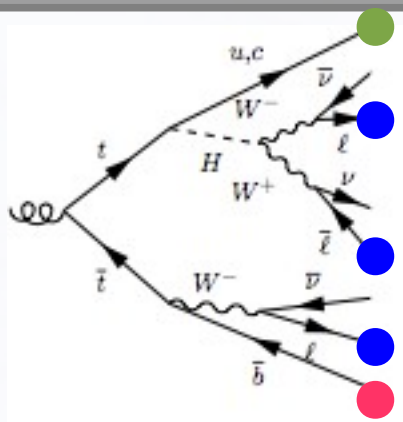
CMS PAS SUS-13-034

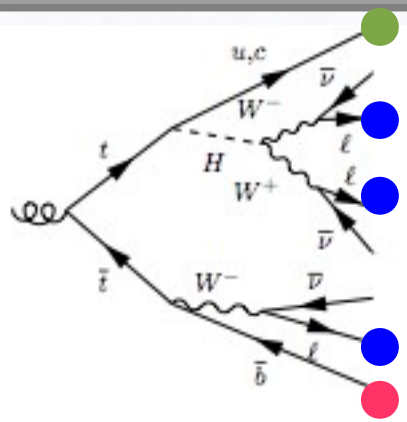
CMS PAS TOP-13-017

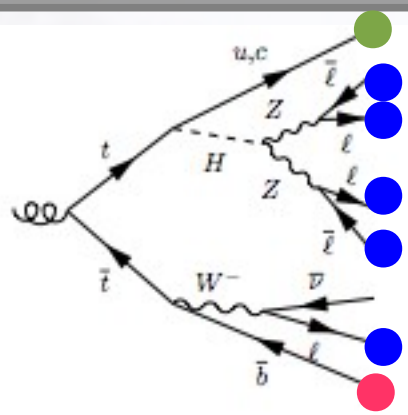
CMS PAS TOP-14-019, 20

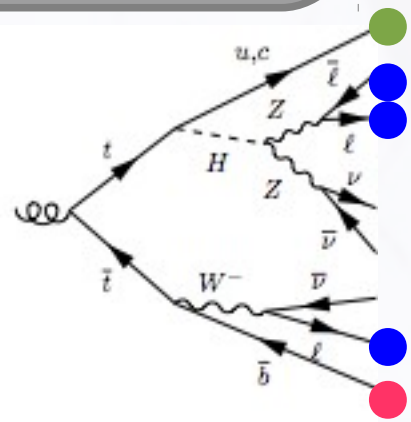
New!

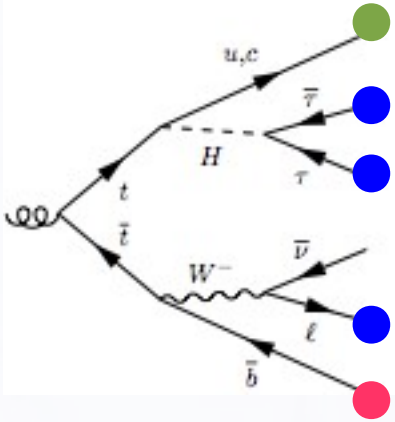
Signal Process

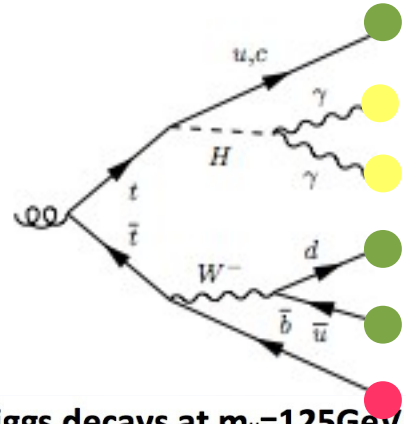


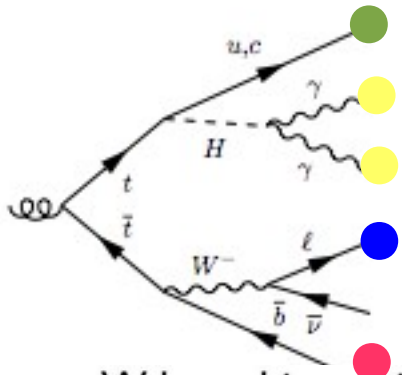


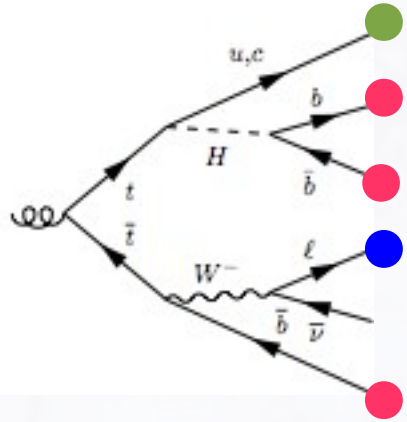




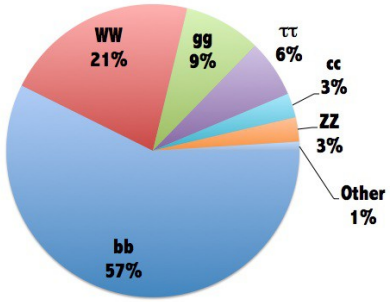




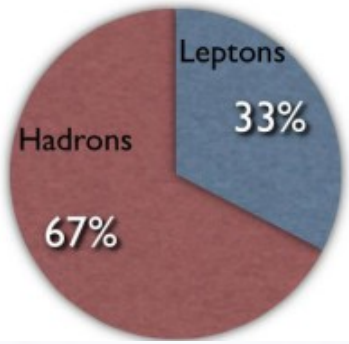




Higgs decays at m_H=125GeV



W branching ratio



Light jet
b-jet
Photon
Lepton

Event Selection

- Multi-lepton $H \to WW,\ ZZ,\ \tau\tau$ DoubleMu, DoubleEle, MuEG
  - Three leptons (20, 10, 10) plus >=2 jets
  - Same-signed di-lepton
    - Z veto for $|M_{ee} - M_Z| > 15$, MET dept. HT cut
  - Trilepton
    - $|M_{OSSF} - M_Z| > 15$, $|M_{lll} - M_Z| > 10$, $M_{OSSF} > 40$
- Di-photon $H \to \gamma\gamma$ di-photon trigger
  - Leptonic channel: one lepton + >= 2 jets (one b-jet)
  - Hadronic channel: >= 4jets (one b-jet)
- Di-bjets $H \to b\bar{b}$ single lepton trigger
  - One lepton + >= 4 jets (including >= 3 b-jets)
  - 2nd lepton veto
- No event overlapping between channels

Channels	leptons	photon	jets	b-jets
$H \to WW, ZZ, \tau\tau$ & $W \to \ell\nu$	eee, eeμ, e$\mu\mu$, $\mu\mu\mu$	–	≥ 2	–
$H \to WW, ZZ, \tau\tau$ & $W \to \ell\nu$	$e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$	–	≥ 2	–
$H \to \gamma\gamma$ & $W \to \ell\nu$	$e^{\pm}$, $\mu^{\pm}$	≥ 2	≥ 2	=1
$H \to \gamma\gamma$ & $W \to q_1q_2$	–	≥ 2	≥ 4	=1
$H \to b\bar{b}$ & $W \to \ell\nu$	$e^{\pm}$, $\mu^{\pm}$	–	≥ 4	≥ 3

Table 1: The basic topology for the twelve $pp \to t\bar{t} \to Hq + Wb$ channels.

Event Selection

- Multi-lepton $H \to WW,\ ZZ,\ \tau\tau$ DoubleMu, DoubleEle, MuEG
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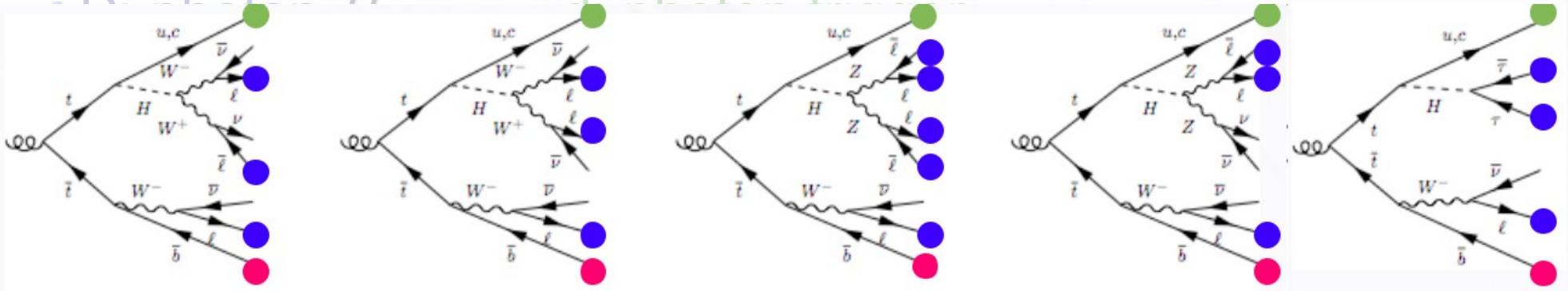

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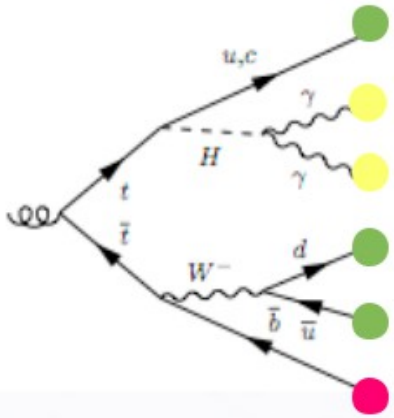

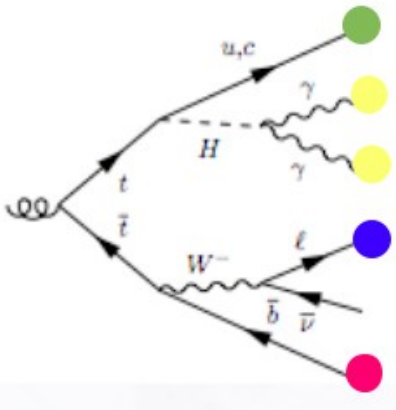

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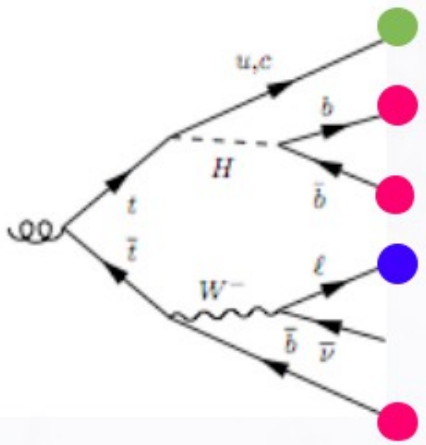

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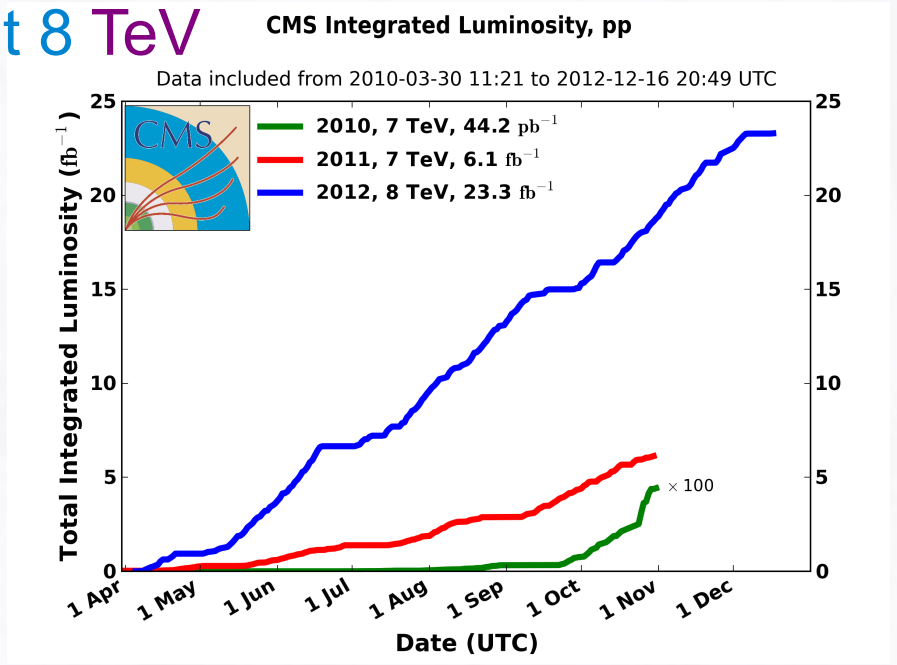
Table 1: The basic topology for the twelve $pp \to t\bar{t} \to Hq + Wb$ channels.

Data & Analysis Strategy

- Data recorded with the CMS detector
  - Integrated luminosity: ~20/fb at 8 TeV
- One top goes to FCNH
- Event signature:

  $t\bar{t} \rightarrow b(W \rightarrow l\nu, jj) + qH + jj$

  where $H \rightarrow bb, \gamma\gamma, WW/ZZ/\tau\tau$



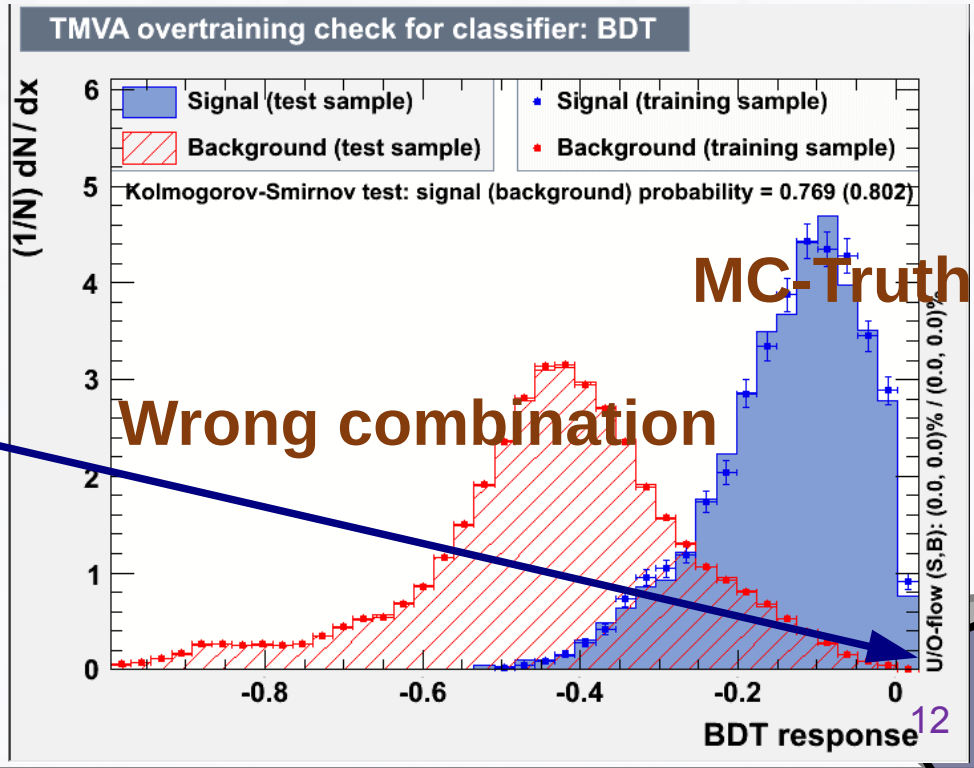
- Signal MC:
  - Generated with Madgraph 5, while $t\bar{t}$ decay in Pythia 6
  - BR($H \rightarrow WW, ZZ, \tau\tau, \gamma\gamma, bb$) from LHC Higgs working group
- Backgrounds:
  - Dominated by $t\bar{t}$ + jets
  - Background suppression with MVA algorithms
- Signal yields extracted with counting or template fit

Per Event Candidate Selection

Taking $H \to b\bar{b}$ as example:

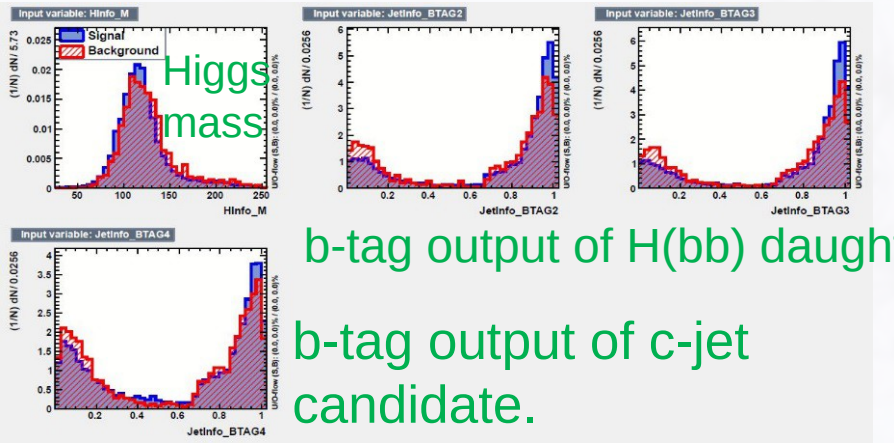
1. Getting the "signal correct combination" with BDT.
2. Consider all combination of final state 4+ jets in the selected event.
3. Signal is the MC-truth combination and wrong combinations are the background.
4. The one with the largest BDT value is the best candidate.

Input Variables	
Hadron top inv. mass	$t\bar{t}$ $\Delta\phi$
Lepton top inv. mass	Lep-bjet(lep) $\Delta\phi$
C-jet candidate energy in top(had) reference frame	Higgs-cjet $\Delta\phi$
	bbpair $\Delta\phi$



Signal Extraction

ANN input variables:
1.Higgs candidate invariant mass
2.CSV value of three jets on hadronically top decay side.

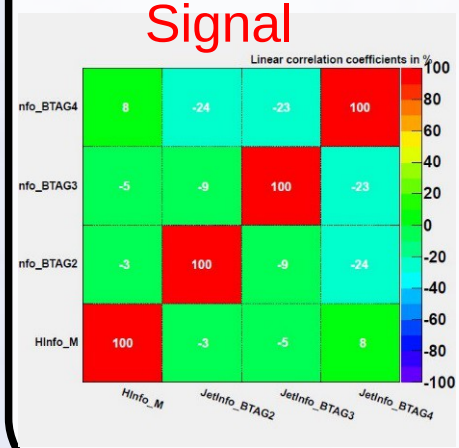


Higgs mass

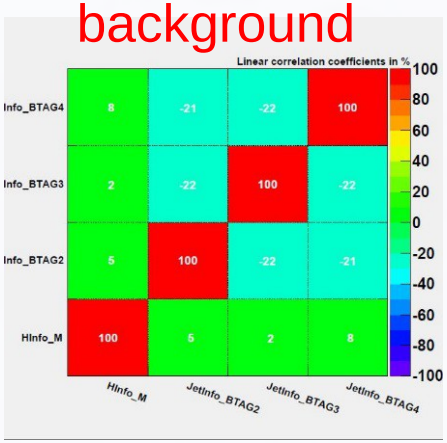
b-tag output of H(bb) daughters

b-tag output of c-jet candidate.

Signal

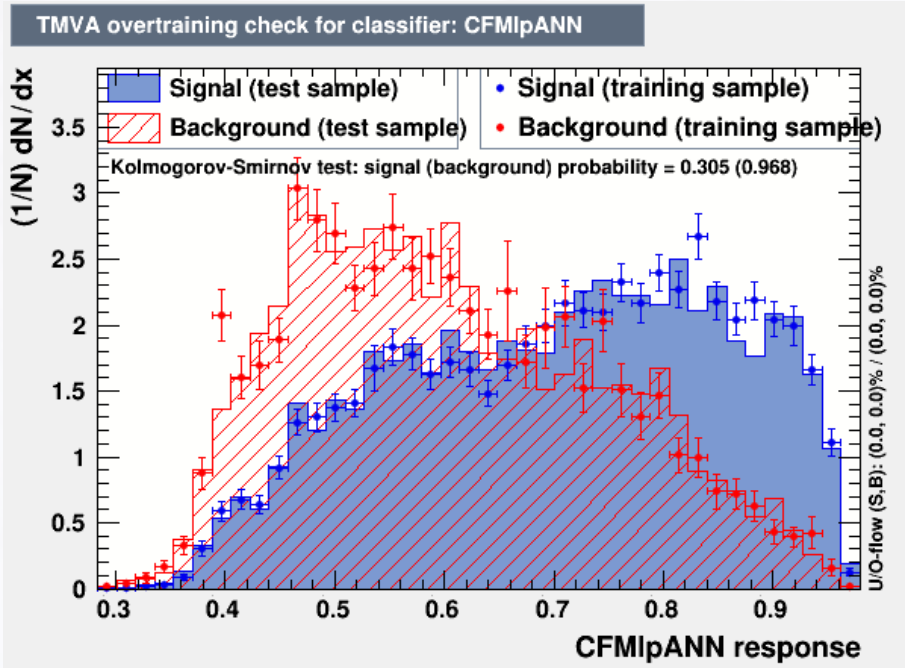


background



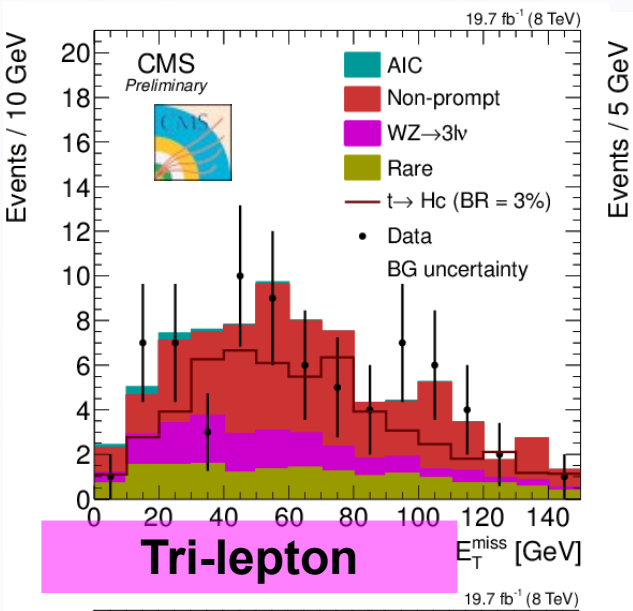
It's hard to model the ANN with the simple function.

Model signal and bkg PDF with histogram function. (root hist PDF)

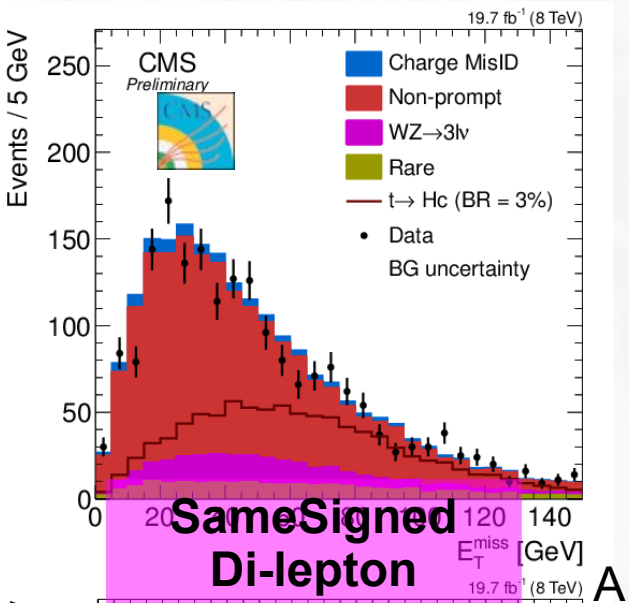


Results

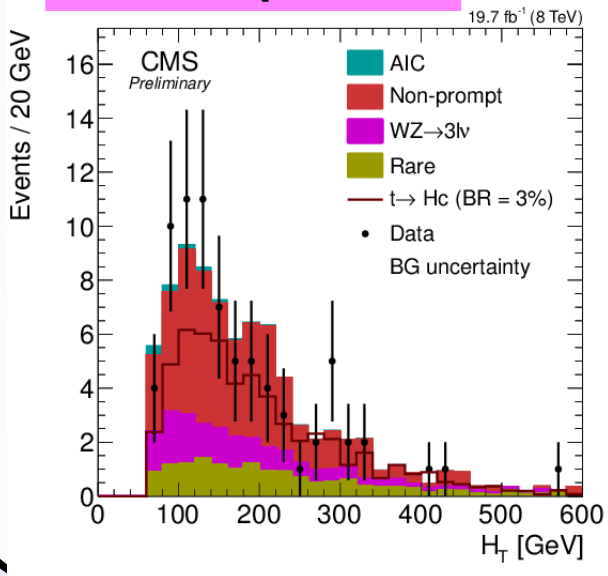
- Multi-lepton $H \to WW,\ ZZ,\ \tau\tau$

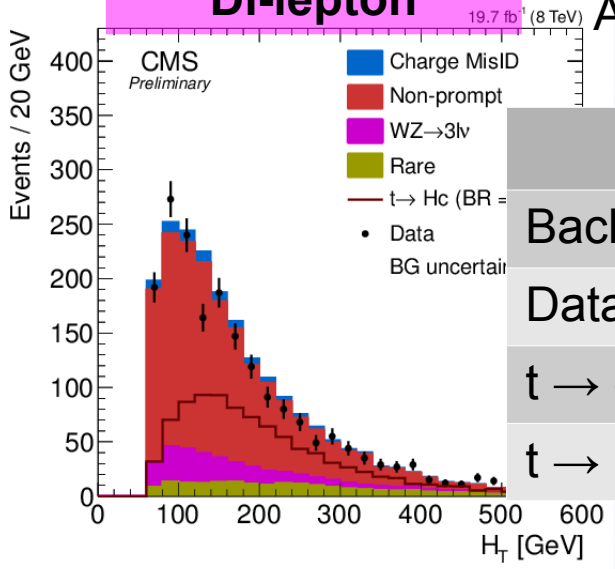


Tri-lepton



SameSigned Di-lepton





CMS-PAS-TOP-2013-017

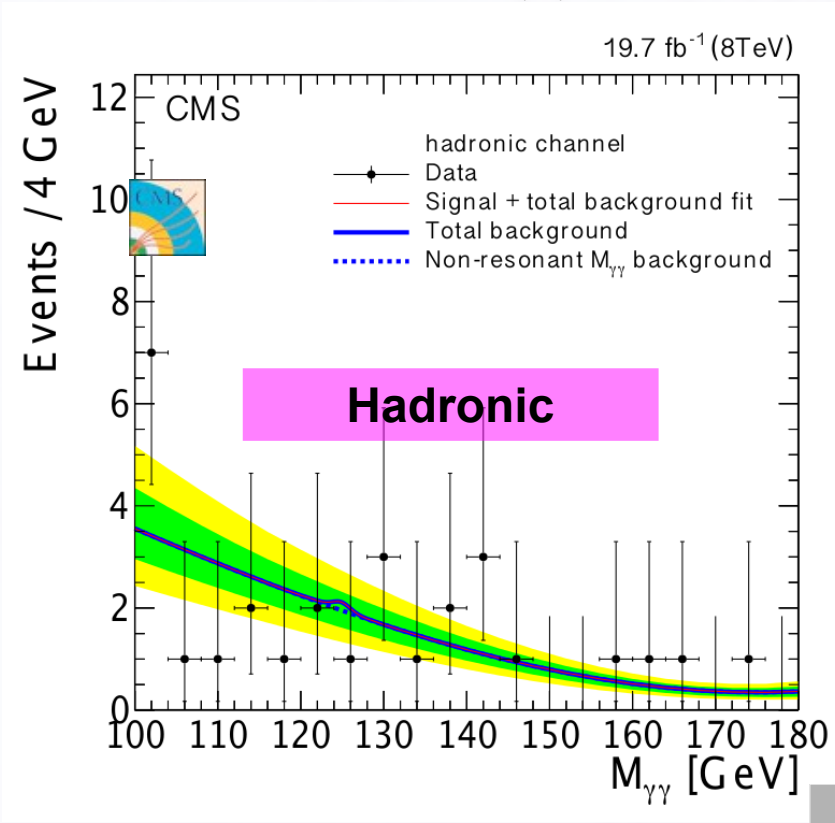
AIC: asymmetric internal conversions

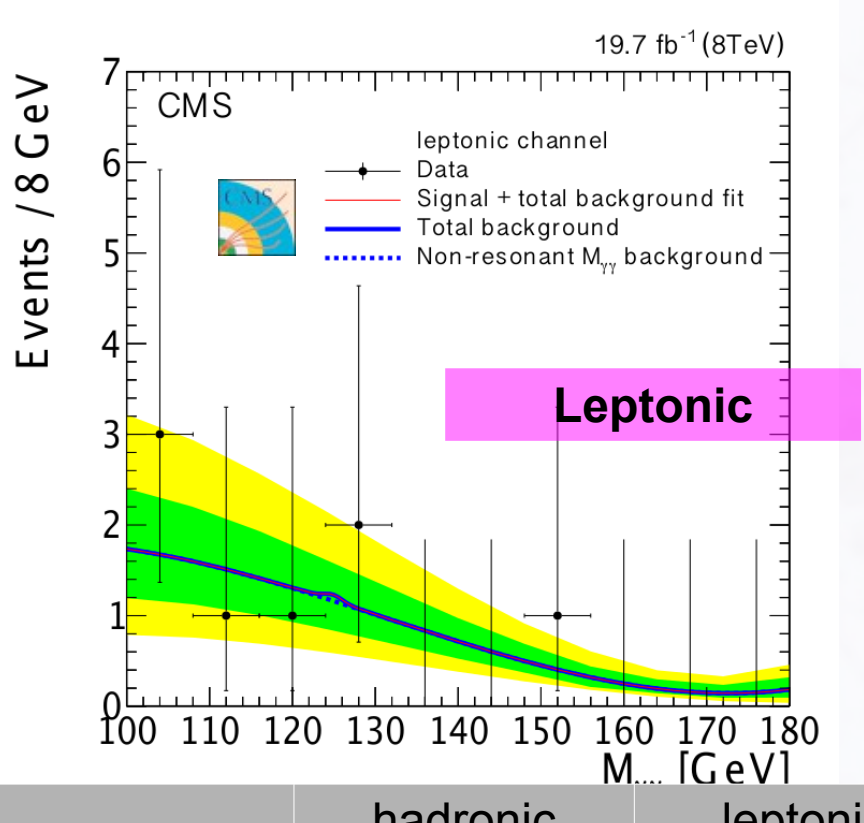
	tri-lepton	SS di-lepton
Background	84.2 ± 9.2	646.2 ± 73.0
Data obs.	79	631
t → cH	< 1.26%	< 0.99%
t → uH	< 1.34%	< 0.93%

Results

- Di-photon $H \rightarrow \gamma\gamma$

CMS-PAS-TOP-2014-019





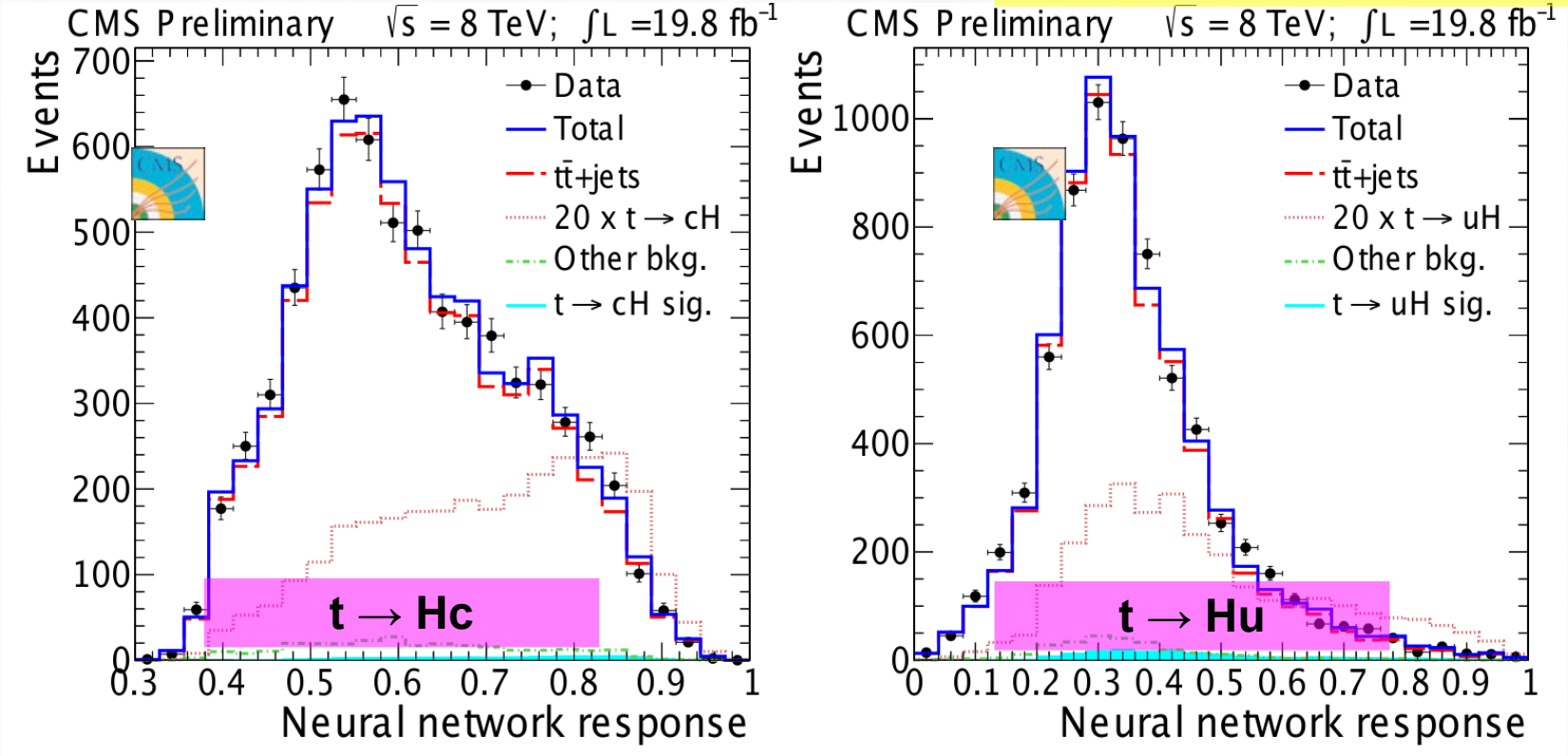
- Signal extracted with template fit

	hadronic	leptonic
Background	29.05 ± 5.40	8.04 ± 2.81
Data obs.	29	8
t → cH	< 0.63%	< 1.59%
t → uH	< 0.57%	< 1.56%

Results

- Di-bjets $H \rightarrow b\bar{b}$

CMS-PAS-TOP-2014-020



- Signal extracted with template fit

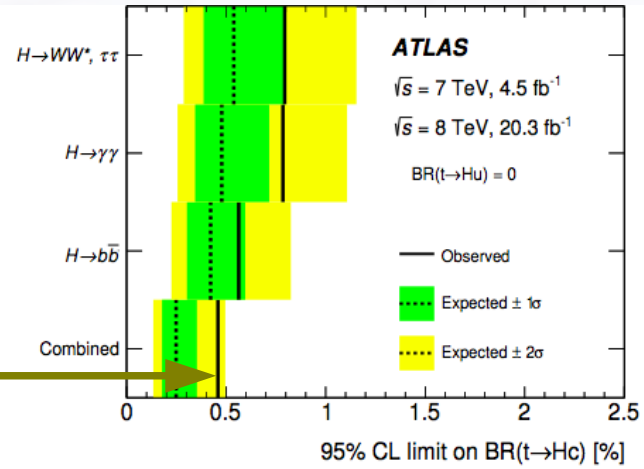
	t → cH	t → uH
Background	6766 ± 979.5	6636 ± 826.2
Data obs.	6840	6840
limit	< 1.16%	< 1.92%

Combined Result

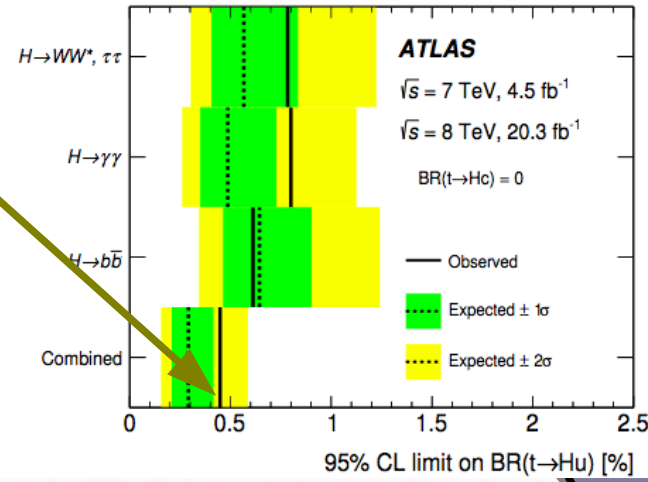
- Re-fitted simultaneously on all sub-channels with (un)correlated systematic uncertainties
  - Comparable result to Atlas' study

	$-\sigma$	$\mathcal{B}_{exp}(t\to Hc)$	$+\sigma$	$\mathcal{B}_{obs}(t\to Hc)$
Trilepton	0.95	1.33	1.87	1.26
Same-sign dilepton	0.68	0.93	1.26	0.99
Multilepton combined	0.65	0.89	1.22	0.93
Diphoton combined	0.44	0.67	1.06	0.47
b-jet plus multijet plus lepton	0.60	0.89	1.37	1.16

	$-\sigma$	$\mathcal{B}_{exp}(t\to Hu)$	$+\sigma$	$\mathcal{B}_{obs}(t\to Hu)$
Trilepton	1.05	1.47	2.09	1.34
Same-sign dilepton	0.62	0.85	1.16	0.93
Multilepton combined	0.60	0.82	1.14	0.86
Diphoton combined	0.39	0.60	0.96	0.42
b-jet plus multijet plus lepton	0.57	0.84	1.31	1.92



ATLAS: JHEP 12 (2015)

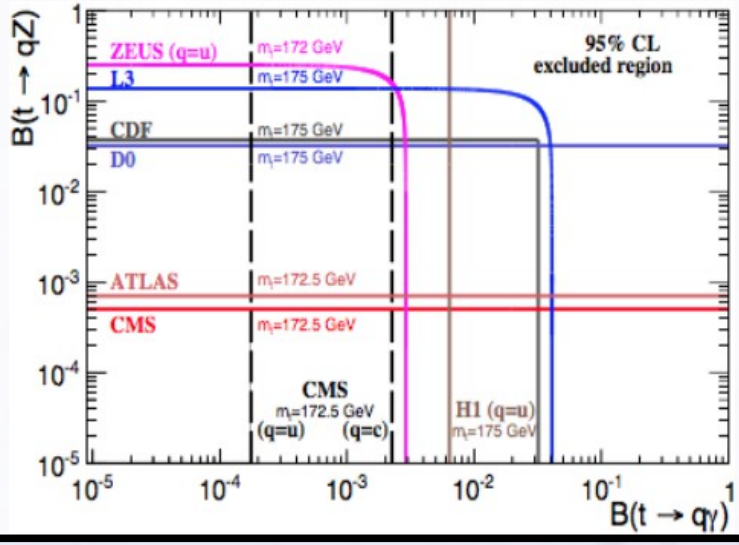


CMS-PAS-TOP-2013-017
CMS-PAS-TOP-2014-019
CMS-PAS-TOP-2014-020

Combined results currently under internal review

Summary & Outlook

- Searches for "Flavor changing neutral currents" on top quark done with Atlas and CMS
  - Studies with either top decay or production
  - Best limit on BR(t → qZ) < 0.05% Phys. Rev. Lett. 112 171802 (2013)
- Search for FCNC on t → qH with 2012 data at 8 TeV:
  - So far no exceeds beyond SM predictions seen
  - Upper limits on BR(t → qH, H→WW/ZZ/ττ, γγ, bb) given by Atlas and CMS
- Stay tuned for 2016 new results with 13 TeV data!



謝謝

Thank YOU!