

# Top quark properties from top quark decays ( W-helicity, FCNC )

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On behalf of the **ATLAS**, **CDF**, **CMS** and **DO** Collaborations

**LHCP**

Fourth Annual Conference On  
Large Hadron Collider Physics

13-18 June  
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**2016**



# Top physics Menu

## INTRINSIC PROPERTIES

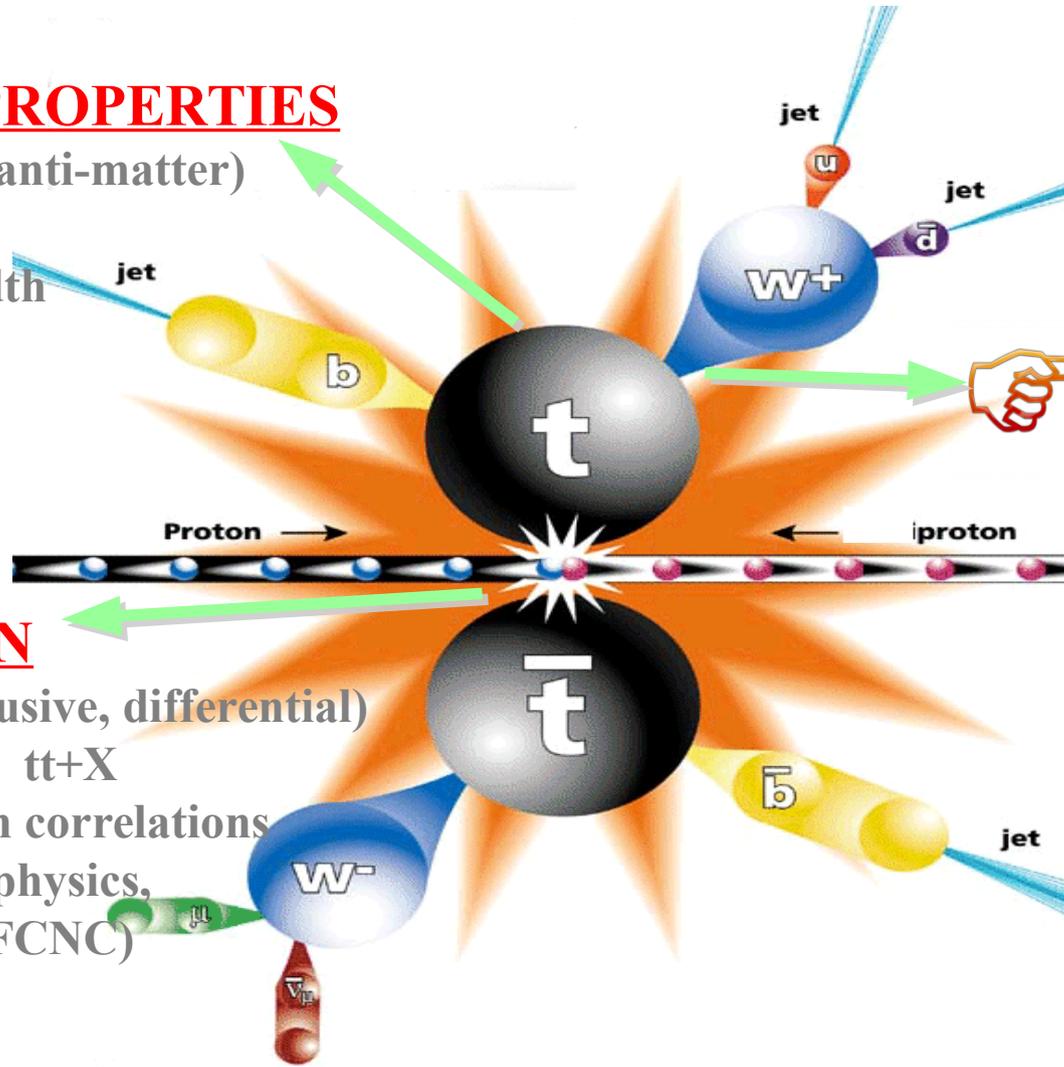
Mass (matter vs. anti-matter)  
 Charge, spin  
 Life time and width

## PRODUCTION

Cross section (inclusive, differential)  
 QCD parameters,  $tt+X$   
 Asymmetries, spin correlations  
 Resonances, new physics,  
 Flavour physics (FCNC)

## DECAY

W helicity  
 Couplings  
 Branching ratios  
 CKM matrix elements  
 New particles  
 $B(t \rightarrow Wb)$   
 Rare decays (FCNC)



**only small selection of results will be shown with a focus on the most recent ones.**

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP>

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults>

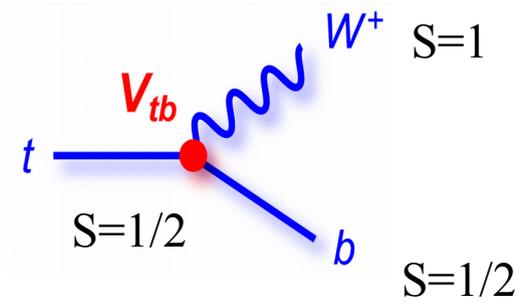
<http://www-cdf.fnal.gov/physics/new/top/top.html>

[http://www-d0.fnal.gov/Run2Physics/top/top\\_public\\_web\\_pages/top\\_public.html](http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html)

# W boson helicity measurement



# W Boson helicity(motivation)



➤ The **tWb** vertex is written as V-A structure within the SM.

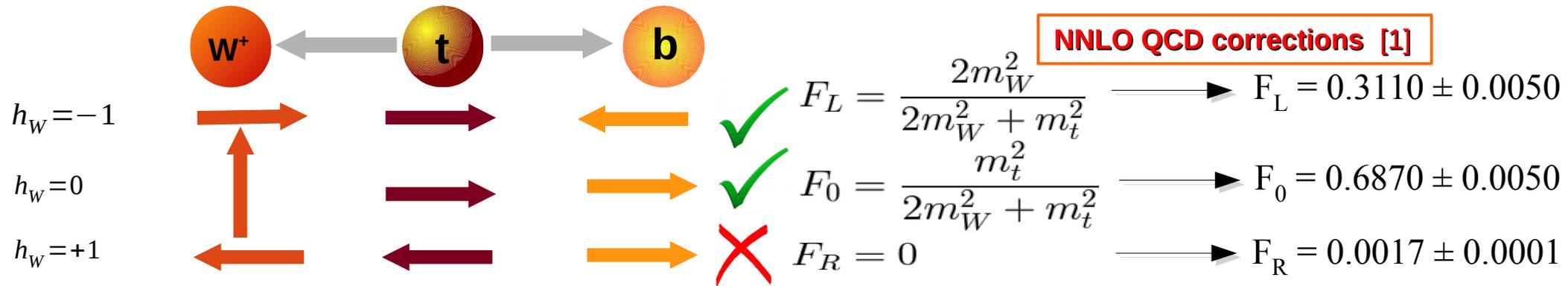
$$\mathcal{L}_{tWb} = \frac{-ig_W}{\sqrt{2}} \bar{b} \gamma^\mu V_{tb} P_L t W_\mu^- + h.c$$

➤ The W boson is spin 1  $\Rightarrow$  it can be produced with a left-handed( $F_L$ ), longitudinal( $F_0$ ), or right-handed( $F_R$ ) helicity.

➤ SM prediction[LO,  $m_b = 0$ ] :

$$F_{0/L/R} = \frac{\Gamma_{0/L/R}(t \rightarrow Wb)}{\Gamma_{total}}$$

**NNLO QCD corrections [1]**



➤ The W boson helicity can be affected by non-SM **tWb** couplings.

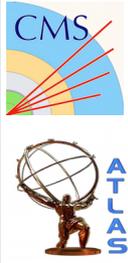
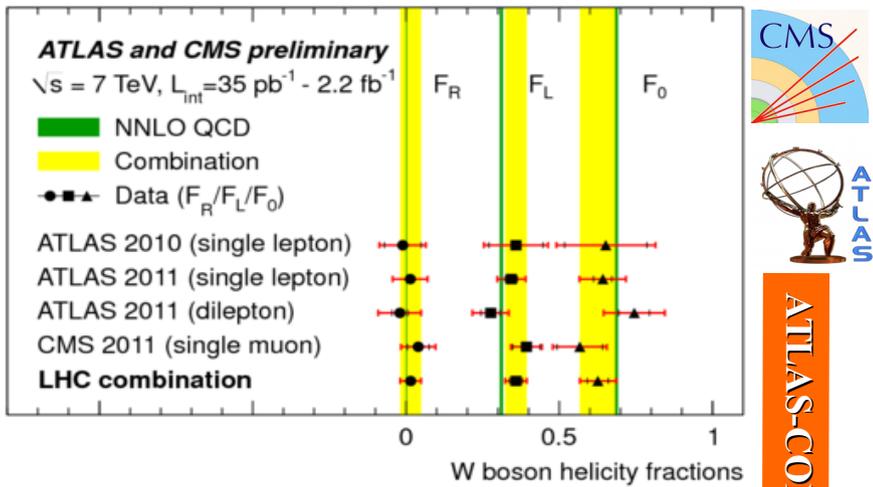


[1] Phys. Rev. D81(2010)111503

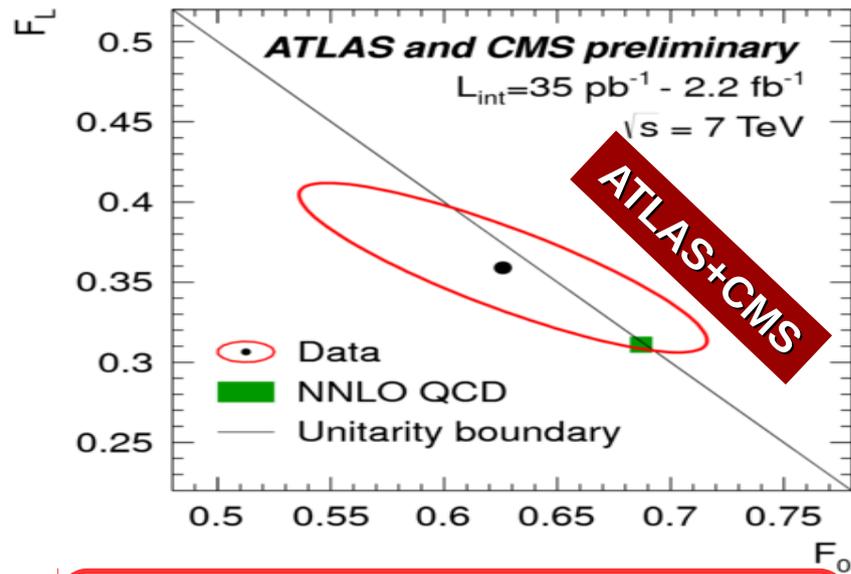
# W Helicity at LHC @ 7 TeV

Results with ATLAS+CMS(35pb<sup>-1</sup>-2.2fb<sup>-1</sup>)

♦  $t\bar{t}$  events in the lepton+jets and di-lepton final state



ATLAS-CONF-2013-033

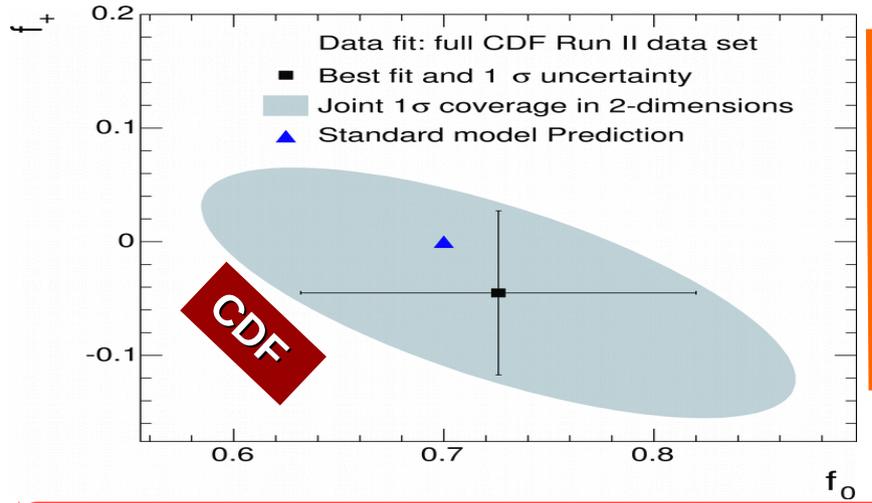


$F_0 = 0.626 \pm 0.034(\text{stat.}) \pm 0.048(\text{syst.})$   
 $F_L = 0.359 \pm 0.021(\text{stat.}) \pm 0.028(\text{syst.})$   
 $F_R = 0.015 \pm 0.034(\text{stat.}+\text{syst.})$

# W helicity at Tevatron

Results with CDF (8.7fb<sup>-1</sup>)

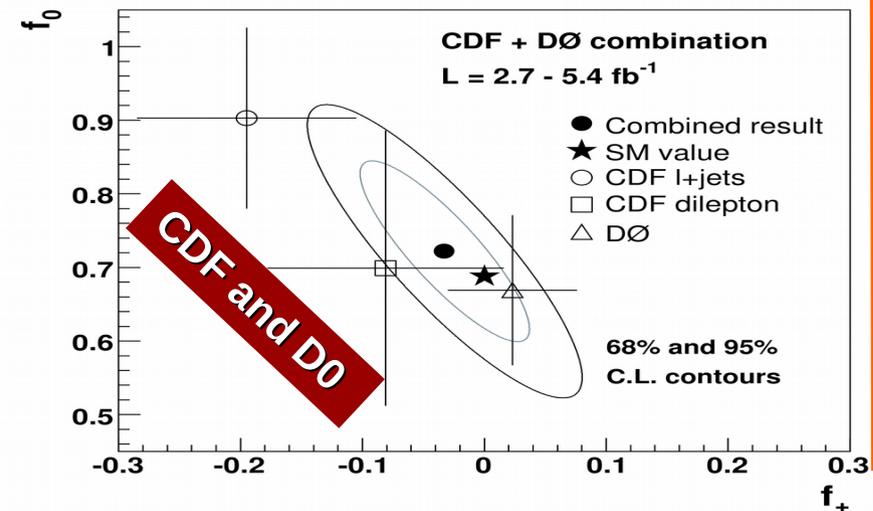
♦  $t\bar{t}$  events in the lepton+jets final state



PRD 87 031104(R)



$F_0 = 0.726 \pm 0.066 (\text{stat.}) \pm 0.067 (\text{syst.})$   
 $F_R = -0.045 \pm 0.043 (\text{stat.}) \pm 0.058 (\text{syst.})$



Phys. Rev. D 85, 071106(R)

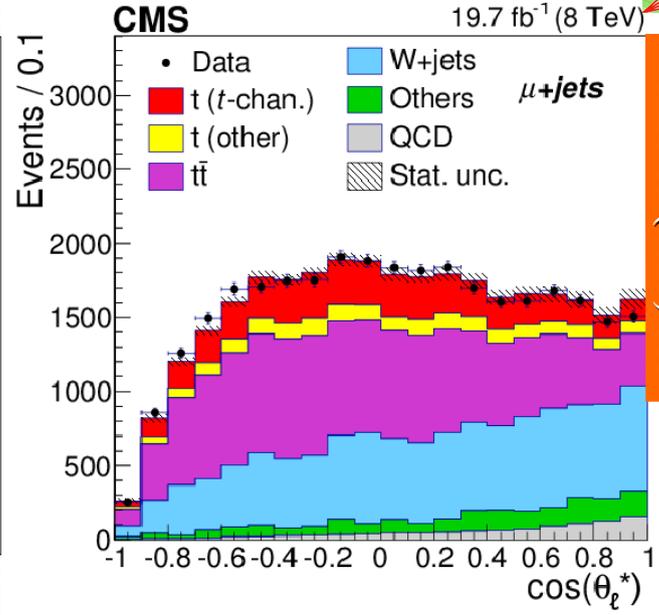
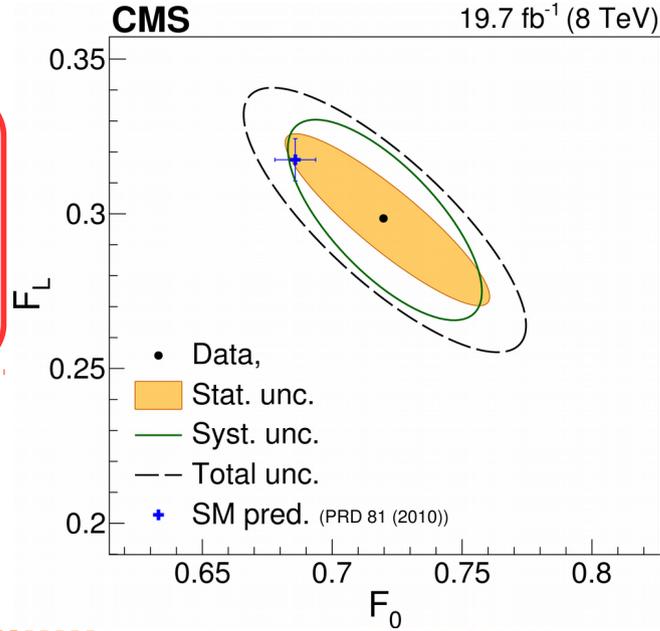


$F_0 = 0.722 \pm 0.062 (\text{stat.}) \pm 0.052 (\text{syst.})$   
 $F_R = -0.033 \pm 0.034 (\text{stat.}) \pm 0.031 (\text{syst.})$



# W helicity in single top(t-ch.) signature @ 8 TeV(19.7 fb<sup>-1</sup>)

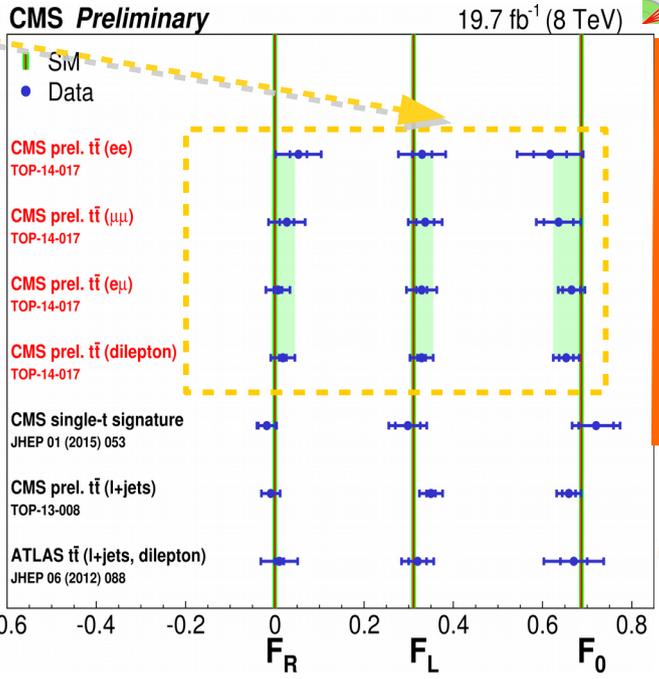
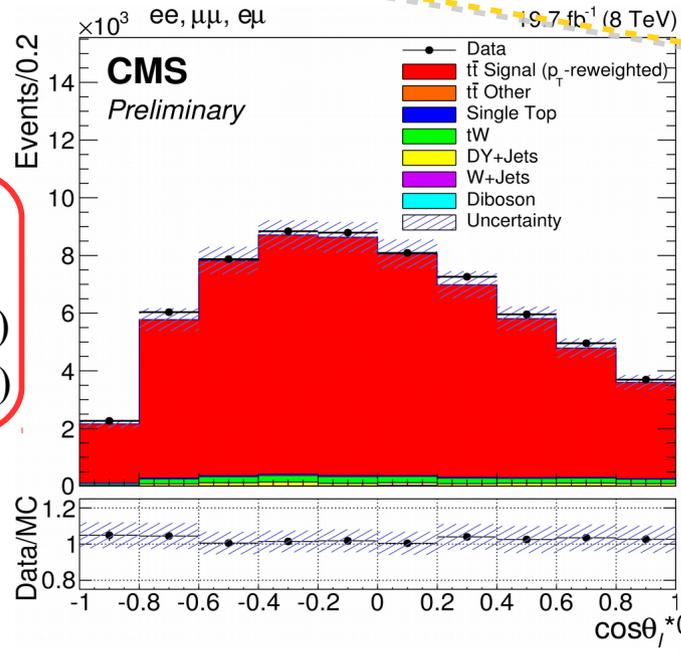
**Combination(e+jets, μ+jets):**  
 $F_0 = 0.720 \pm 0.039(\text{stat.}) \pm 0.037(\text{syst.})$   
 $F_L = 0.298 \pm 0.028(\text{stat.}) \pm 0.032(\text{syst.})$   
 $F_R = -0.018 \pm 0.019(\text{stat.}) \pm 0.011(\text{syst.})$



JHEP 01 (2015) 053

# W helicity in top pair(l+jets) signature @ 8 TeV(19.7 fb<sup>-1</sup>)

**Combination:**  
 $F_0 = 0.653 \pm 0.016(\text{stat.}) \pm 0.024(\text{syst.})$   
 $F_L = 0.329 \pm 0.009(\text{stat.}) \pm 0.025(\text{syst.})$   
 $F_R = 0.018 \pm 0.008(\text{stat.}) \pm 0.026(\text{syst.})$



CMS PAS TOP-14-017



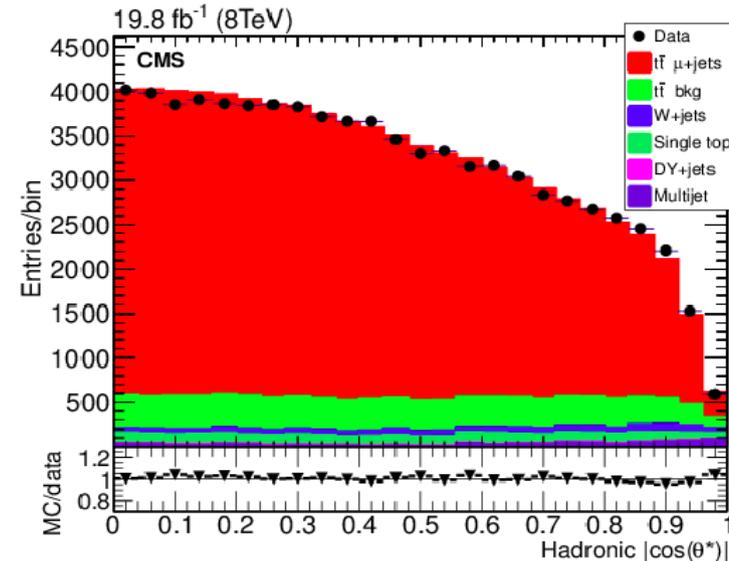
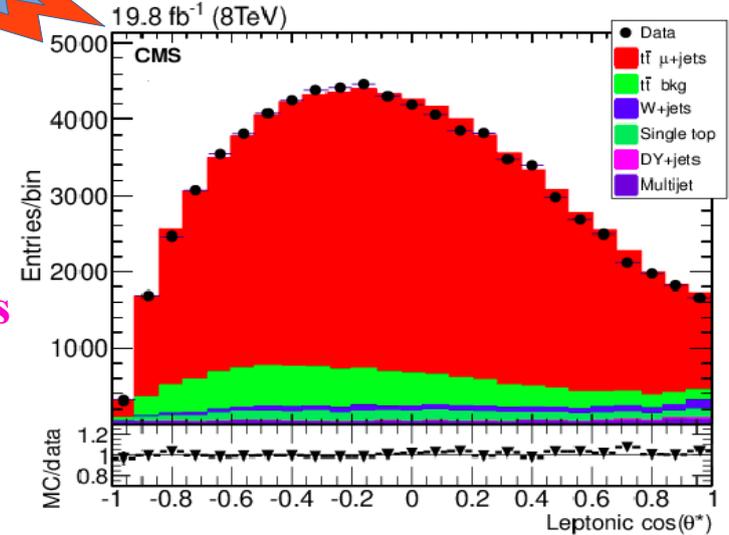
# W helicity in top pair(l+jets) signature @ 8 TeV(19.8 fb<sup>-1</sup>)

New

arXiv:1605.09047, submitted to PLB

$$t\bar{t} \rightarrow (W^+b)(W^-\bar{b}) \rightarrow (\ell^+\nu_b)(q\bar{q}\bar{b})$$

- ◆ Main backgrounds: **top pair**, **single top**, **W+jets**, **DY+jets**
- ◆ Transverse mass of the W boson:  $30 < M_T < 200$  GeV
- ◆ Top pair reconstruction using the kinematic fit



For all processes **containing top quarks**, each event is re-weighted as:

$$w_{\text{lep/had/single-t}}(\cos \theta_{\text{gen}}^*; \vec{F}) \equiv \frac{\frac{3}{8}F_L(1 - \cos \theta_{\text{gen}}^*)^2 + \frac{3}{4}F_0 \sin^2 \theta_{\text{gen}}^* + \frac{3}{8}F_R(1 + \cos \theta_{\text{gen}}^*)^2}{\frac{3}{8}F_L^{\text{SM}}(1 - \cos \theta_{\text{gen}}^*)^2 + \frac{3}{4}F_0^{\text{SM}} \sin^2 \theta_{\text{gen}}^* + \frac{3}{8}F_R^{\text{SM}}(1 + \cos \theta_{\text{gen}}^*)^2}$$

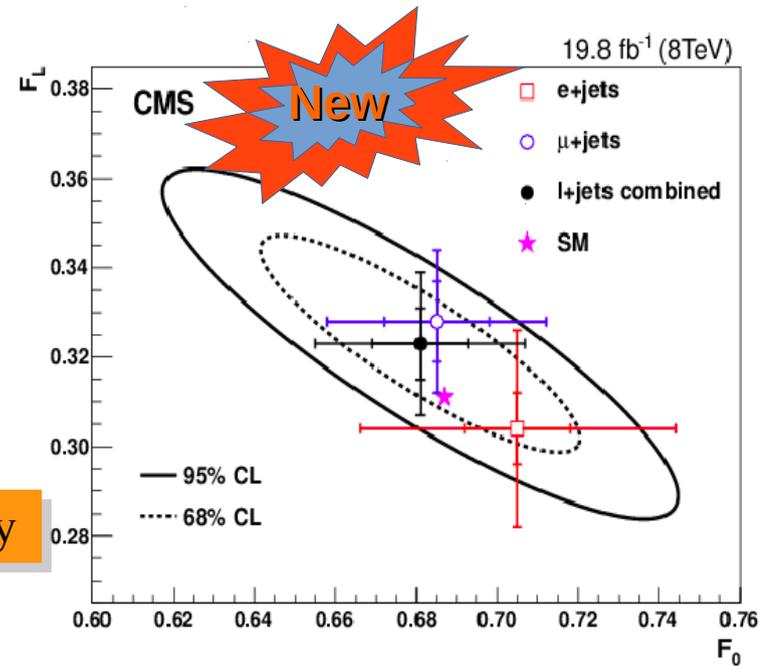
**Combination(e+jets, μ+jets):**

$$F_0 = 0.681 \pm 0.012(\text{stat.}) \pm 0.023(\text{syst.})$$

$$F_L = 0.323 \pm 0.008(\text{stat.}) \pm 0.014(\text{syst.})$$

$$F_R = -0.004 \pm 0.005(\text{stat.}) \pm 0.014(\text{syst.})$$

precision of better than 5%

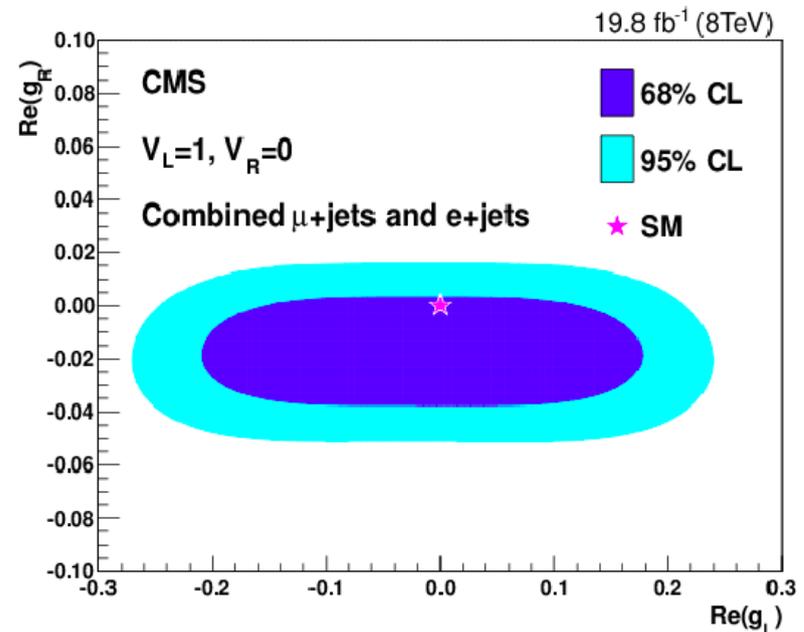


The most accurate experimental results of W boson helicity

The potential deviation from the SM can be interpreted in terms of anomalous tWb couplings.

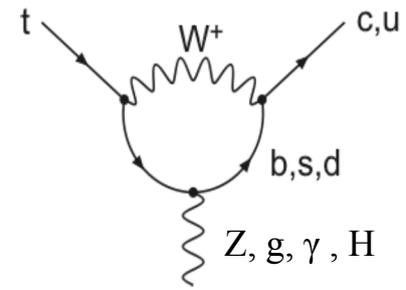
$$\mathcal{L} = -\frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (V_L P_L + V_R P_R) t W_\mu^- - \frac{g}{\sqrt{2}} \bar{b} \frac{i\sigma^{\mu\nu} q_\nu}{M_W} (g_L P_L + g_R P_R) t W_\mu^- + \text{h.c.}$$

**Vector ( $V_R$ ) and Tensor like couplings ( $g_L, g_R$ ) are zero @ tree level in SM.**



# Searches for Rare Top Decays

Flavour Changing Neutral Currents



**SM:** FCNC is forbidden at tree level

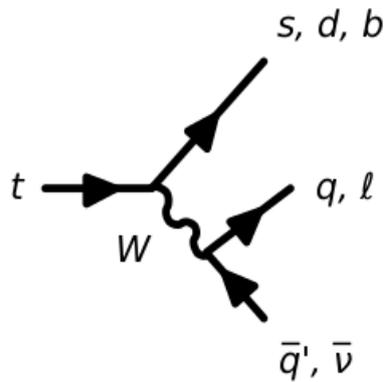
highly suppressed at higher orders  $O(10^{-12} - 10^{-17})$  by GIM Mechanism

**BSM:** FCNC couplings are enhanced up to  $O(10^{-4} - 10^{-5})$  [1]

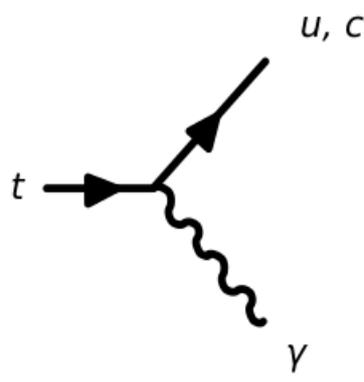
powerful probe for new physics

**SM prediction:**

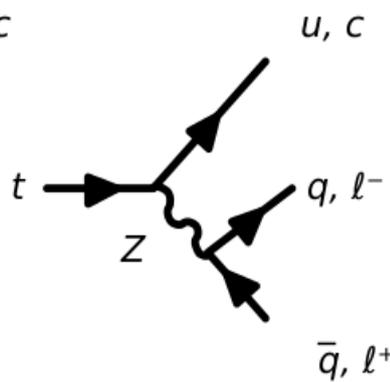
$Br = 9.98 \times 10^{-1}$  [2]



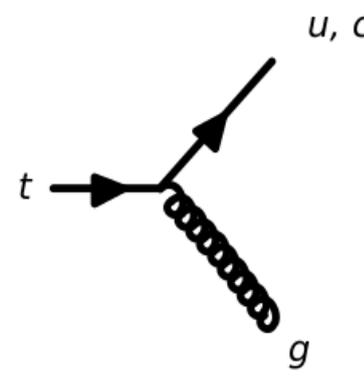
$Br \leq 10^{-14}$  [2]



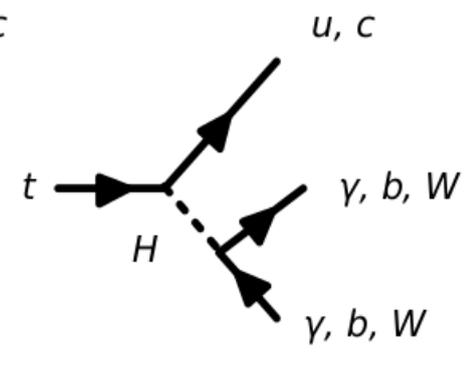
$Br \leq 10^{-14}$  [2]



$Br \leq 10^{-12}$  [2]



$Br \leq 10^{-15}$  [3]



➤ To probe FCNC effects in the top sector, a useful approach is to adopt a model independent search.

➤ The FCNC searches are performed either **in decays of top pair** events or in **single top production**.

**will only cover the most recent results in the next slides.**

[1] arXiv:1311.2028  
 [2] Nucl.Phys.B812:181-204, 2009  
 [3] Nucl.Phys.B821:215-227, 2009

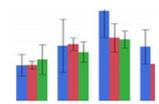
# $t \rightarrow Zq (q = u, c)$ in $t\bar{t}$



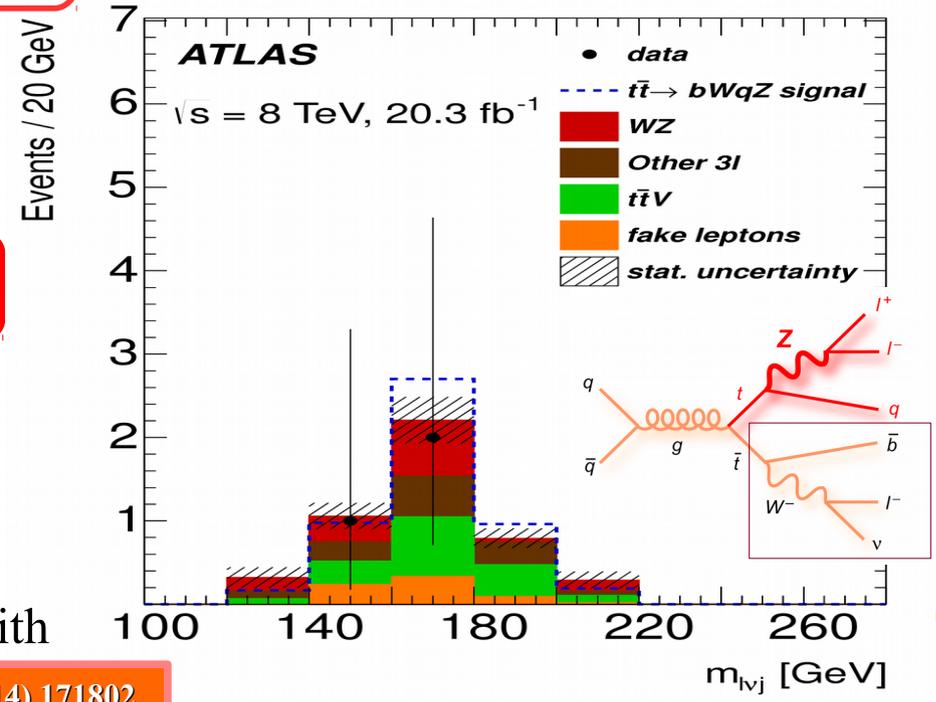
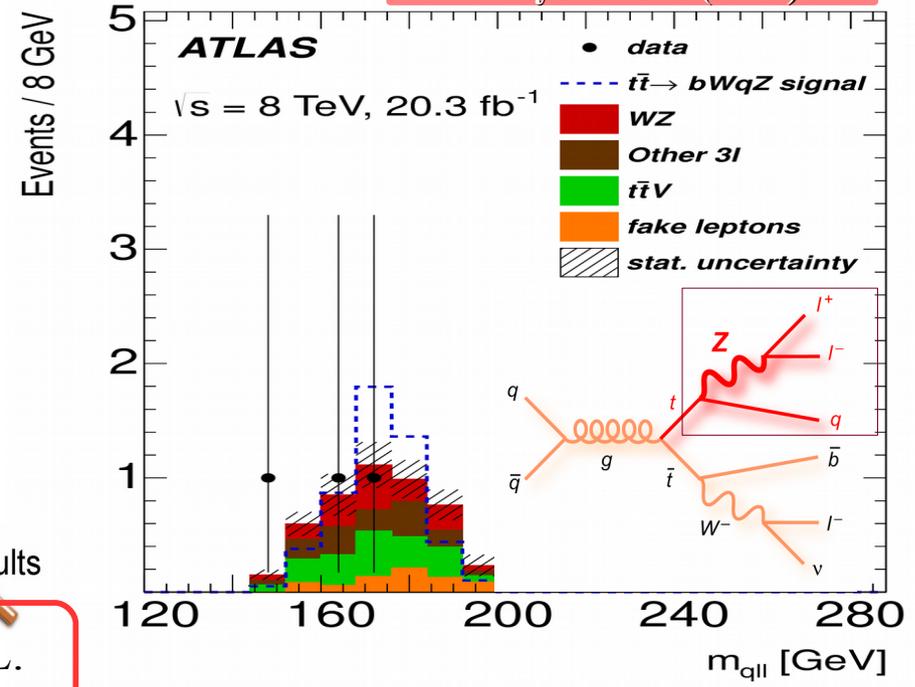
- ◆ 3 isolated leptons(e,μ)
- ◆ 2-3 jets, 1-2 b-tag
- ◆ Missing energy
- ◆  $\chi^2$  cut(from masses)

Results

$B(t \rightarrow qZ) < 0.07\%$  (0.08%) for obs.(exp.) at 95% CL.



Main sys.: Modeling, b-tagging, Jet energy scale



CMS excludes the branching ratio above **0.05%** with combination of 7+8 TeV datasets.

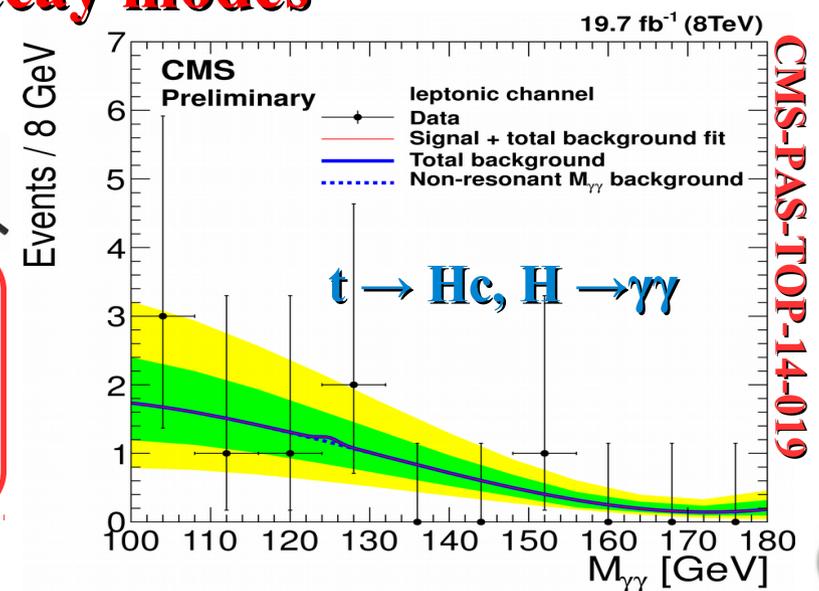
Phys. Rev. Lett. 112 (2014) 171802

# Comparing $t \rightarrow qH \rightarrow \gamma\gamma$ with other decay modes



$t \rightarrow Hq \rightarrow \gamma\gamma q$  and  $t \rightarrow Wb \rightarrow l\nu b$  or  $qqb$

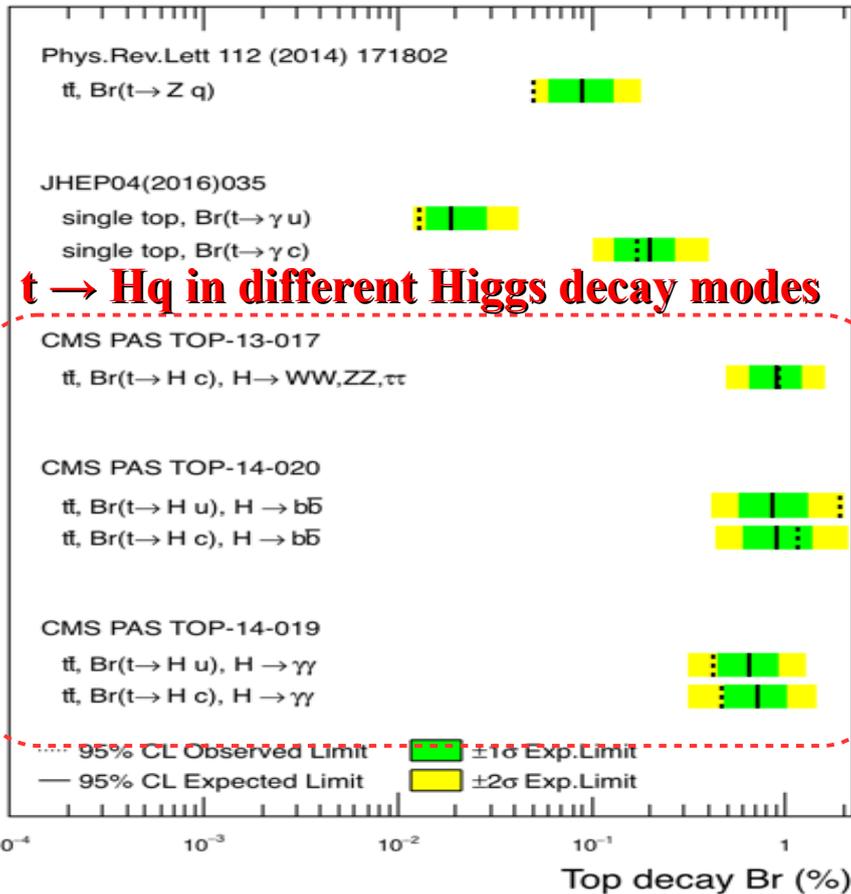
**Two high energetic photons:**  
 Leptonic channel: one lepton and  $\geq 2$  jets (one b-jet)  
 Hadronic channel:  $\geq 4$  jets (one b-jet),  
 W boson and top invariant mass cuts



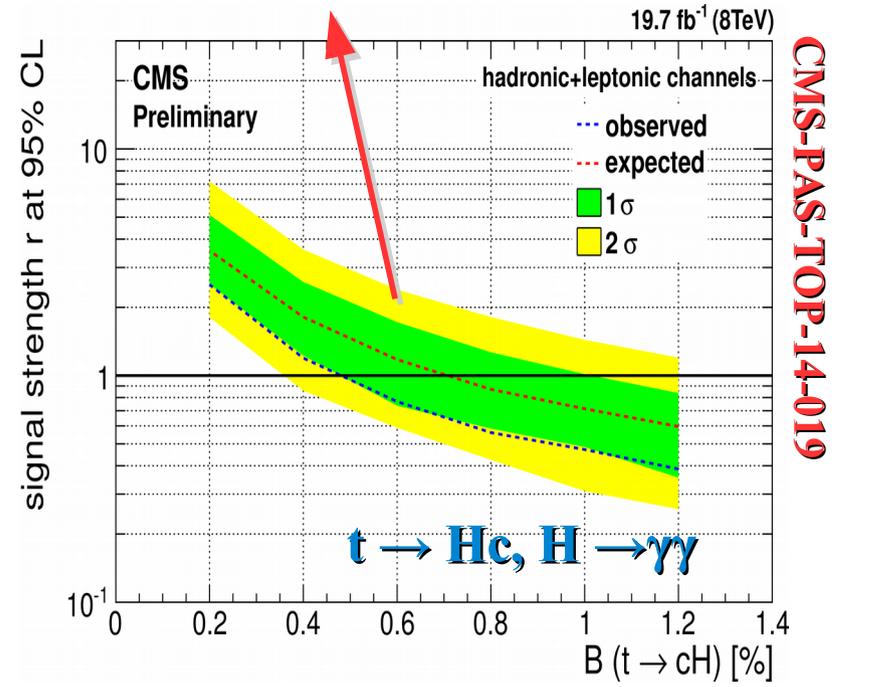
Results

$B(t \rightarrow Hc) < 0.47\%$  (0.71%) for obs.(exp.) at 95% CL  
 $B(t \rightarrow Hu) < 0.42\%$  (0.65%) for obs.(exp.) at 95% CL

CMS Preliminary, 8 TeV March 2016



## $t \rightarrow Hq$ in different Higgs decay modes



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# $t \rightarrow Hq \rightarrow bbq$ and combined results



JHEP12 (2015) 061

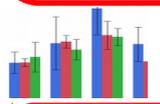


Categories based on (jet, b-tag) multiplicity, (4j, 3b) and (4j, 4b) are most sensitive channels, Signal/background discriminant:

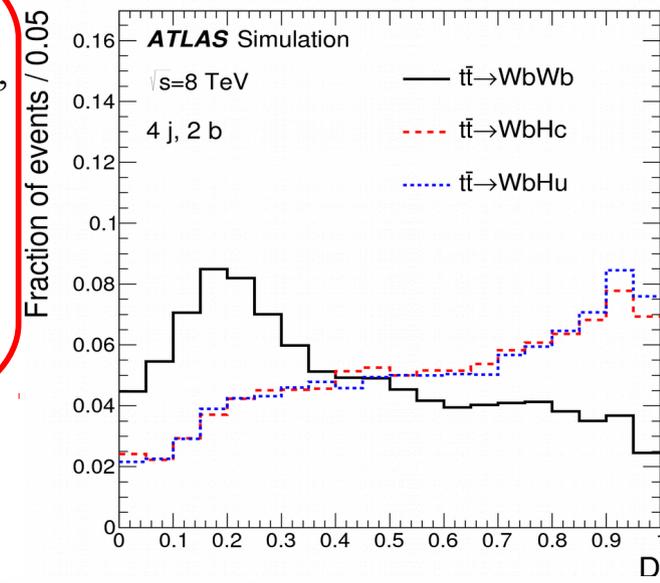
$$D(x) = \frac{P^{sig}(x)}{P^{sig}(x) + P^{bkg}(x)}$$

with  $P^{sig}$ ,  $P^{bkg}$  PDFs using the resonances and jet flavour content of final state

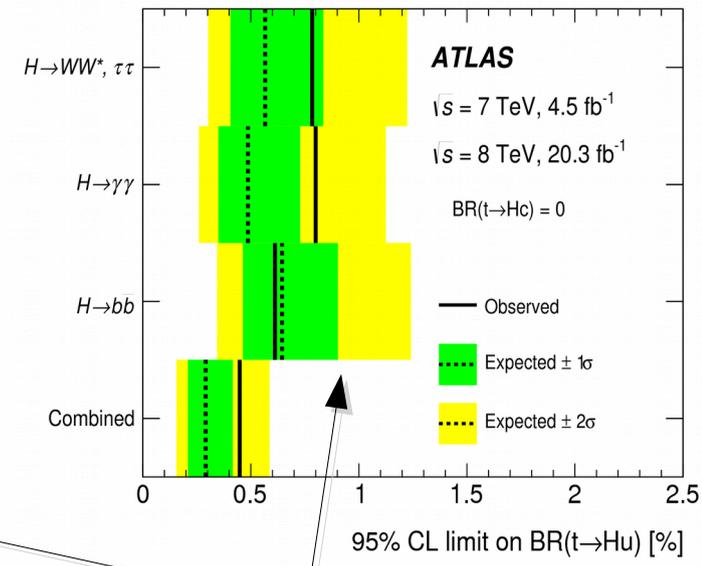
an isolated lepton (e,  $\mu$ ),  $\geq$  four jets ( $\geq$  2b-tagged), Backgrounds: top pair, single top, W+jets



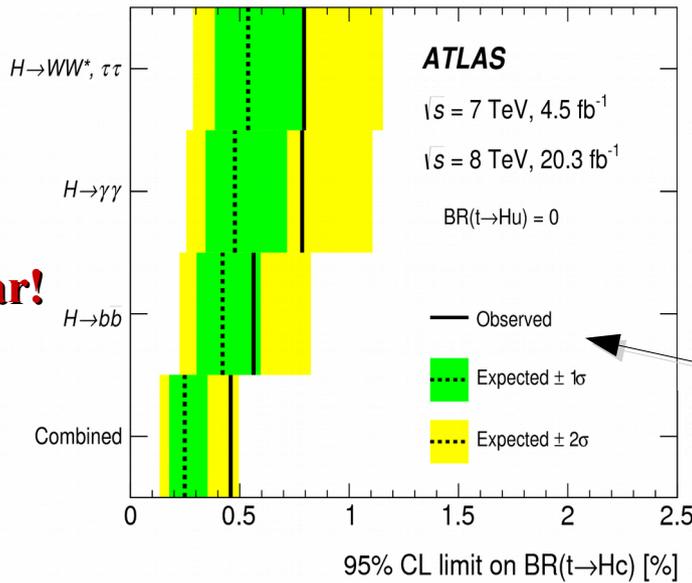
Main sys:  $t\bar{t}$  + jets modeling, b-tagging



95% CL.	$H \rightarrow bb$ obs.(exp.)	$H \rightarrow WW/\tau\tau, \gamma\gamma, bb$
$t \rightarrow Hu$	0.61%(0.64%)	0.45%(0.29%)
$t \rightarrow Hc$	0.56%(0.42%)	0.46%(0.25%)



**Combined results are best limit on tqH interactions measured so far!**



Combination with single channel searches



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## Getting close to BSM scenarios

Example: Branching ratios in **FV 2HDM** and **R SUSY** are predicted to be:

$$\begin{aligned} \text{Br}(t \rightarrow ug) &\sim 10^{-4}, \\ \text{Br}(t \rightarrow cg) &\sim 10^{-4}, \\ \text{Br}(t \rightarrow cH) &\sim 10^{-3} \end{aligned}$$

**Acta Phys.Polon.B35,2695(2004),  
arXiv:1311.2028**

Exp.	$t \rightarrow uZ$	$t \rightarrow cZ$	$\sqrt{s}$	Ref.	
CDF	$3.7 \times 10^{-2}$		1.96 TeV	PRL 101 (2008) 192002	
D0	$3.2 \times 10^{-2}$		1.96 TeV	PLB 701 (2011) 313	
ATLAS	$7.3 \times 10^{-3}$		7 TeV	JHEP 09 (2012) 139	
CMS	$5.1 \times 10^{-3}$	$1.1 \times 10^{-1}$	7 TeV	CMS TOP-12-021	
CMS	$5.0 \times 10^{-4}$		7+8 TeV	PRL 112 (2014) 171802	
ATLAS	$7 \times 10^{-4}$		8 TeV	Eur. Phys. J. C76 (2016) 12	
		$t \rightarrow uy$	$t \rightarrow cy$		
CDF		$3.2 \times 10^{-2}$		1.96 TeV	PRL 80 (1998) 2525
CMS		$1.3 \times 10^{-4}$	$1.7 \times 10^{-3}$	8 TeV	JHEP 04 (2016) 035
		$t \rightarrow ug$	$t \rightarrow cg$		
CDF		$3.9 \times 10^{-4}$	$5.7 \times 10^{-3}$	1.96 TeV	PRL 102 (2009) 151801
D0		$2.0 \times 10^{-4}$	$3.9 \times 10^{-3}$	1.96 TeV	PLB 693 (2010) 81
ATLAS		$5.7 \times 10^{-5}$	$2.7 \times 10^{-4}$	7 TeV	PLB 712 (2012) 351
ATLAS		<b><math>3.1 \times 10^{-5}</math></b>	<b><math>1.6 \times 10^{-4}</math></b>	8 TeV	ATLAS CONF-2013-063
CMS		$3.6 \times 10^{-4}$	$3.4 \times 10^{-3}$	7 TeV	CMS TOP-14-007
ATLAS		$4 \times 10^{-5}$	$1.7 \times 10^{-4}$	8 TeV	ATLAS TOPQ-2014-13
		$t \rightarrow uH$	$t \rightarrow cH$		
ATLAS		$4.5 \times 10^{-3}$	<b><math>4.6 \times 10^{-3}</math></b>	7+8 TeV	JHEP 12 (2015) 061
CMS		-	$5.6 \times 10^{-3}$	8 TeV	PRD 90 (2014) 112013
CMS		-	$9.3 \times 10^{-3}$	8 TeV	CMS TOP-13-017
CMS		$4.2 \times 10^{-3}$	$4.7 \times 10^{-3}$	8 TeV	CMS TOP-14-019



# Summary



- ◆ So far, no significant deviation with respect to the SM prediction has been observed in top quark properties measurements.

- ◆ Current measurements are mostly limited by systematic uncertainties.

## On W boson helicity:

- ◆ The most precise measurement of helicity fractions is obtained from semi leptonic top pair process. The measurement precision is better than 5%.

## On FCNC:

- ◆ No evidence for top FCNC is found and upper limits are set on the branching ratios.

- ◆ The results are still far above SM prediction, but the exclusion limits are becoming tight.

→ sensitivity to some BSM models (FV 2HDM) is within reach.

- ◆ Upper limits on  $BR(t \rightarrow qH, H \rightarrow WW/ZZ/\tau\tau, \gamma\gamma, bb)$  have been reported by ATLAS and CMS.

**Exciting times ahead in top quark sector**



# Backup



Performed on  $4.6 \text{ fb}^{-1}$  of pp collisions @ 7 TeV

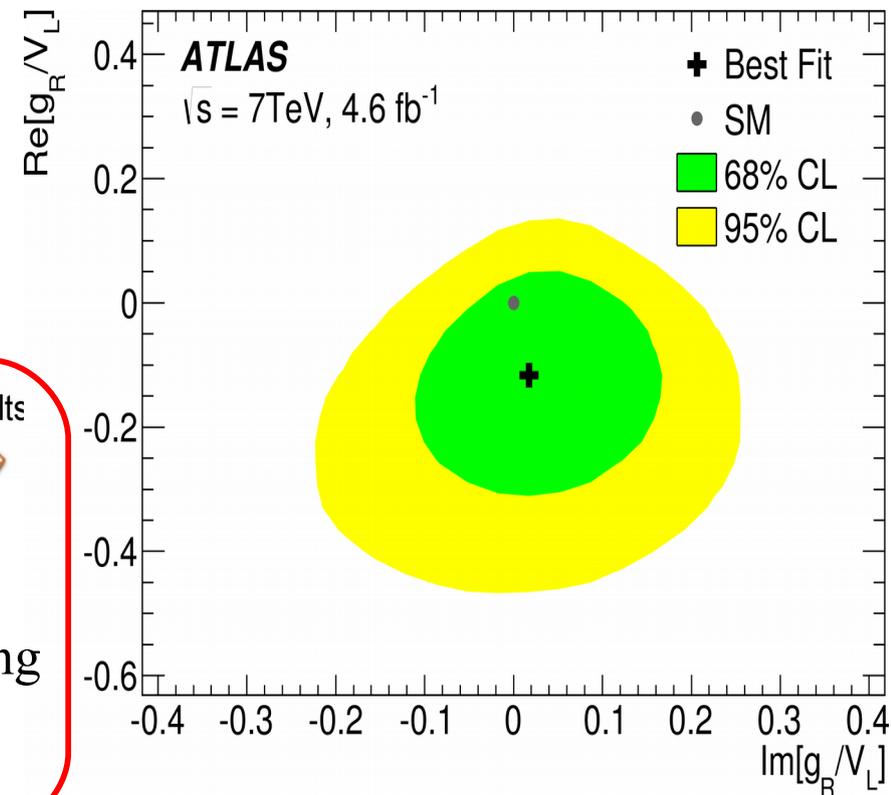
- ◆ Extracted from the double differential angular decay rates of t-ch single top quark
- ◆ Limits on the couplings  $\text{Re}[g_R/V_L]$  and  $\text{Im}[g_R/V_L]$  with  $V_R = g_L = 0$

## Limit @ 95% CL:

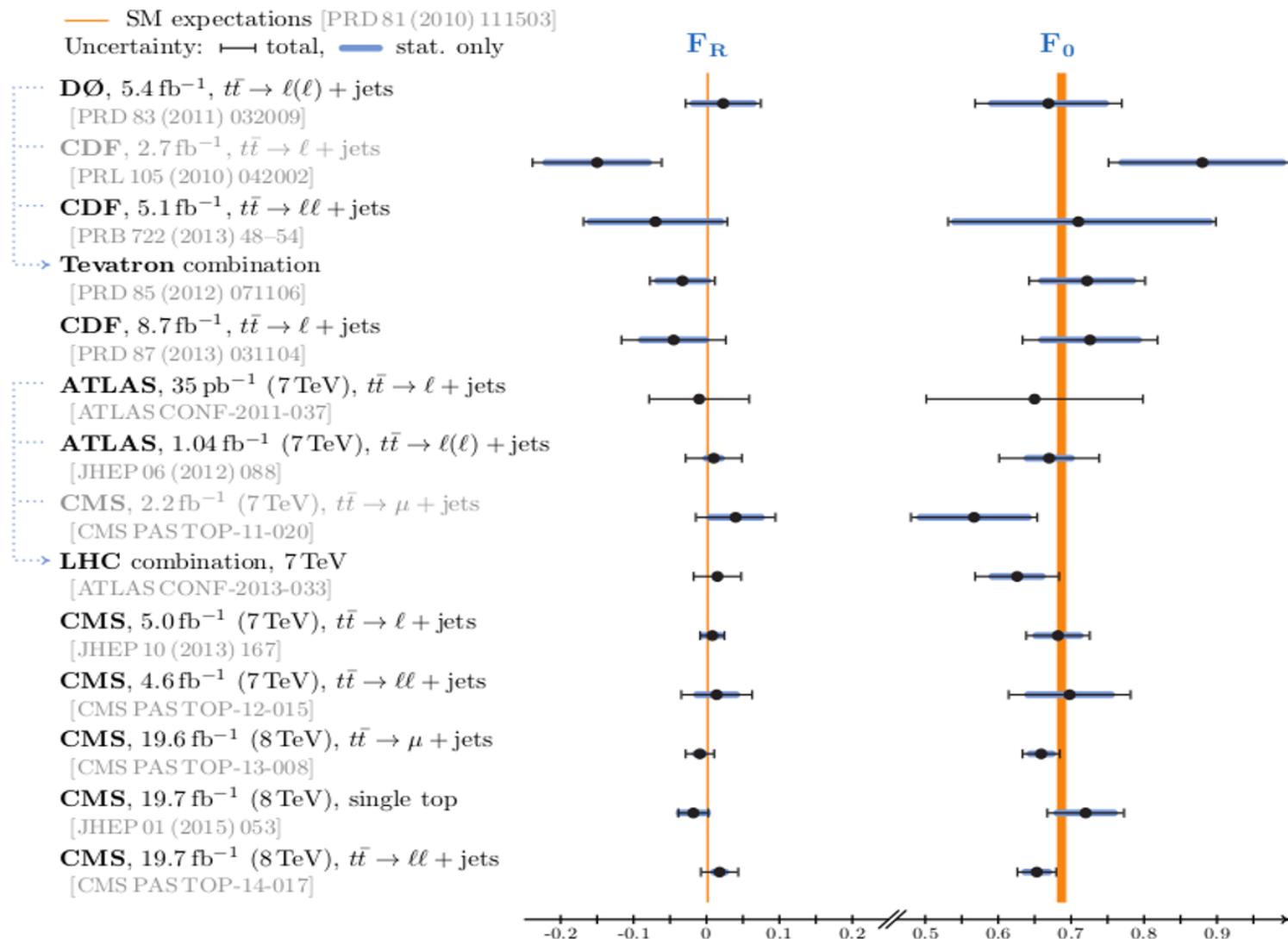


$$\text{Re}[g_R/V_L] \in [-0.36, 0.10] \text{ and } \text{Im}[g_R/V_L] \in [-0.17, 0.23]$$

Complementary to W helicity measurements, containing previously unmeasured information about  $\text{Im}[g_R/V_L]$



# Results on W boson helicities



The results are consistent with the SM at NNLO and previous measurements.

# *b* flavour content in top decay

# b flavor content, width and $V_{tb}$

## CKM matrix:

$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \begin{bmatrix} 0.97 & 0.23 & 0.04 \\ 0.23 & 0.99 & 0.04 \\ 0.0 & 0.04 & 1.02 \end{bmatrix}$$

## Measure the flavor content of quarks:

$$\mathcal{R} = \frac{\mathcal{B}(t \rightarrow Wb)}{\sum \mathcal{B}(t \rightarrow Wq)}, \quad q = b, s, d$$

- ◆ The magnitude of the top-bottom charged current is proportional to  $|V_{tb}|$ ,
- ◆ Assuming the CKM unitary:  $\mathcal{R} = |V_{tb}|^2$
- ◆ The combination of  $\mathbf{R}_b$  measurement with the **t-channel single-top** cross section provides an indirect measurement of the top-quark width.

Measured t-channel Cross section

Measured  $\mathbf{R}_b$

$$\Gamma_t = \frac{\sigma_{t-ch.}}{\mathcal{B}(t \rightarrow Wb)} \cdot \frac{\Gamma(t \rightarrow Wb)}{\sigma_{t-ch.}^{theory}}$$

theory

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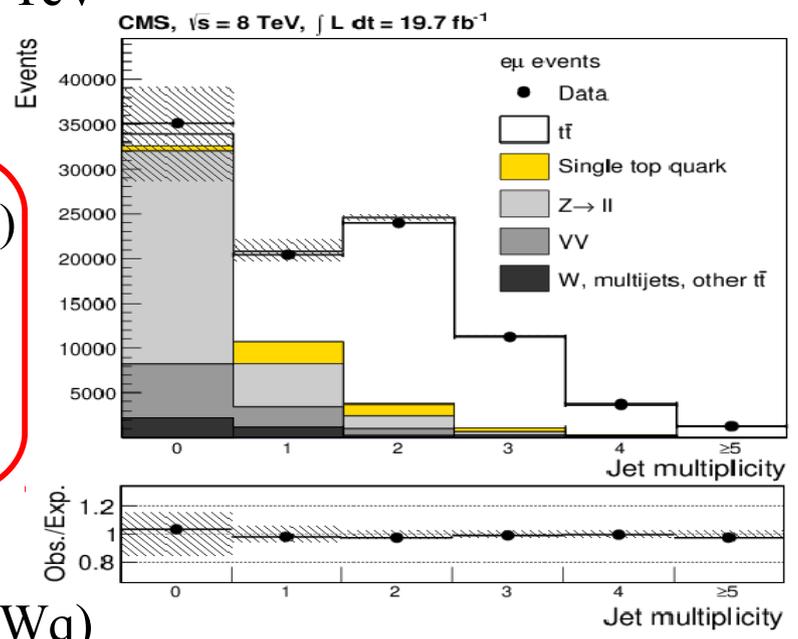
# b flavor content, width and $V_{tb}$

Selecting  $t\bar{t}$  di-lepton events in data  $19.7 \text{ fb}^{-1} \text{ p-p @ } 8 \text{ TeV}$

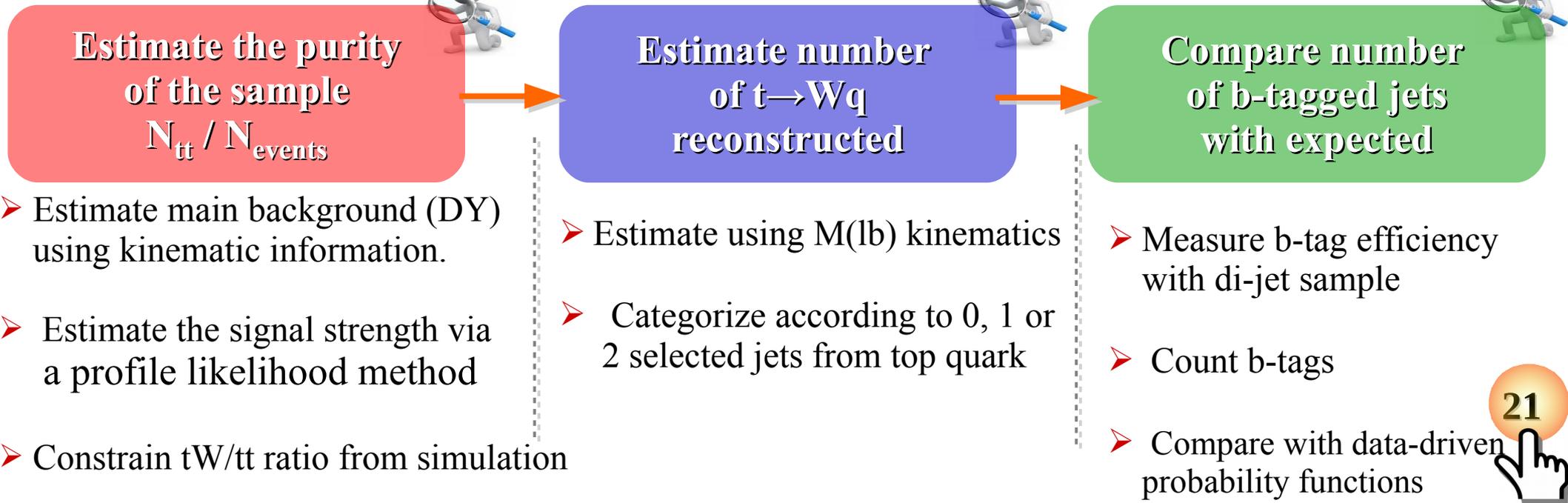
$$t\bar{t} \rightarrow WqWq \rightarrow (\ell^+ \nu_{\ell} q)(\ell^- \bar{\nu}_{\ell} q)$$



- ◆ lower branching ratio but high purity sample (70-90%)
- ◆ two isolated oppositely charged leptons (e or  $\mu$ )
- ◆ at least two jets
- ◆ large missing energy for ee,  $\mu\mu$  channels

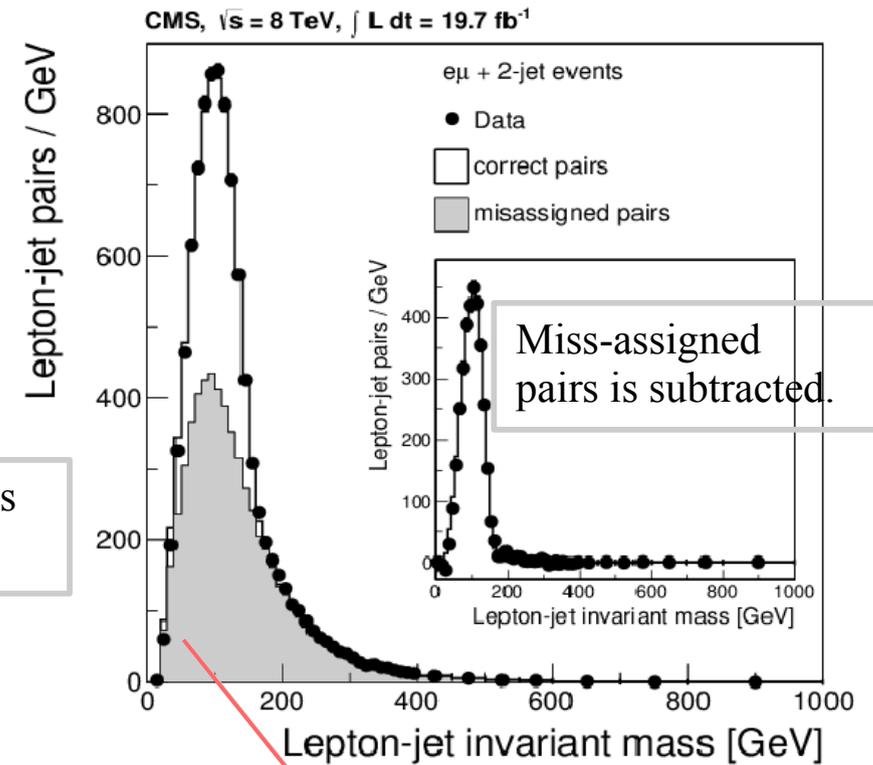
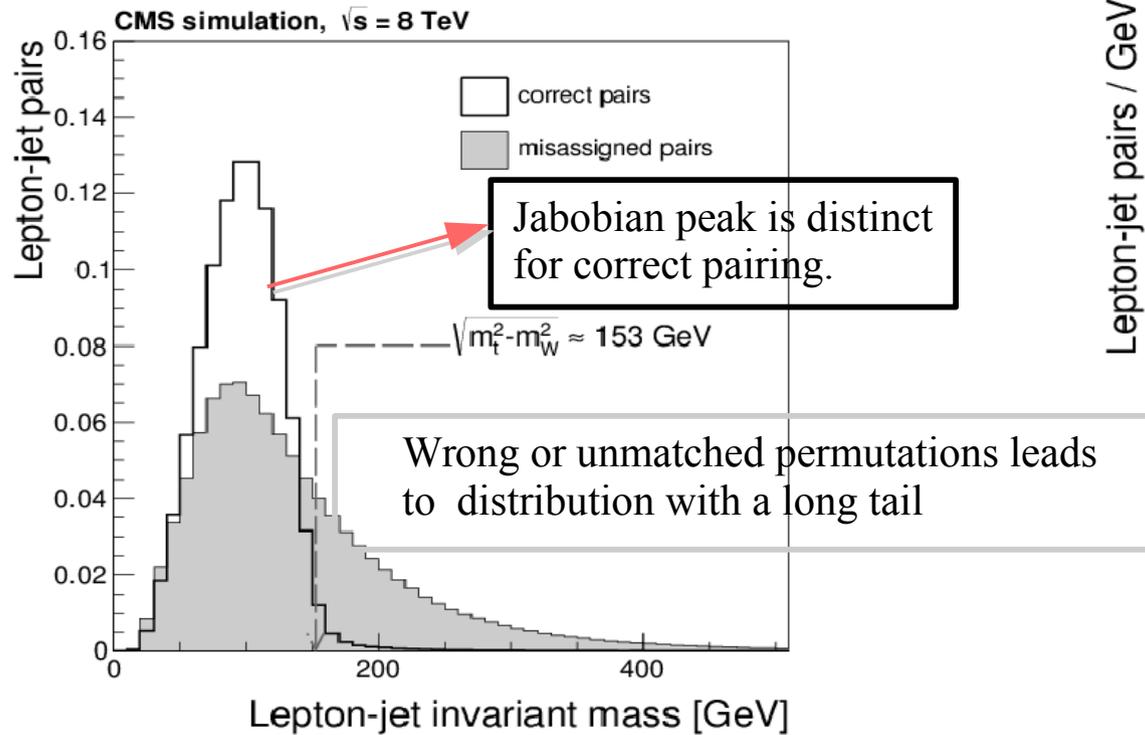


Counting  $N(t \rightarrow Wb)$  and compare to the total  $N(t \rightarrow Wq)$



## How many $t \rightarrow Wq \rightarrow lvj$ are correctly reconstructed?

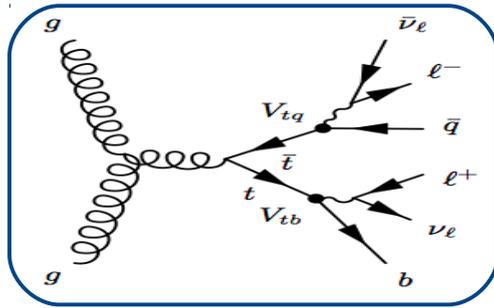
The number of selected jets from top-quark decays is derived from the lepton-jet invariant-mass ( $M_{lj}$ ) distribution.



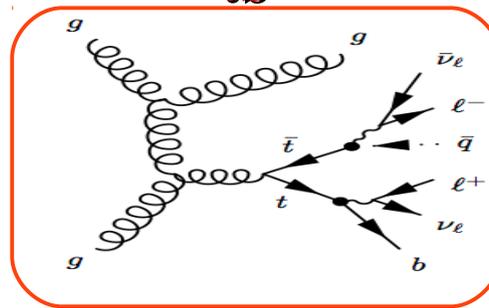
Model lepton-jet mis-assignment with randomly rotated leptons

Dilepton channel	# jets	$f_{\text{correct}}^{\text{data}}$	$f_{\text{correct}}^{\text{MC}}$	data/MC
ee	2	$0.28 \pm 0.05$	$0.277 \pm 0.001$	$1.03 \pm 0.19$
	3	$0.22 \pm 0.07$	$0.223 \pm 0.001$	$0.99 \pm 0.29$
	4	$0.19 \pm 0.07$	$0.175 \pm 0.001$	$1.09 \pm 0.43$
$\mu\mu$	2	$0.28 \pm 0.06$	$0.276 \pm 0.001$	$1.00 \pm 0.21$
	3	$0.24 \pm 0.06$	$0.227 \pm 0.001$	$1.05 \pm 0.25$
	4	$0.20 \pm 0.07$	$0.181 \pm 0.001$	$1.08 \pm 0.37$
e $\mu$	2	$0.36 \pm 0.06$	$0.3577 \pm 0.0007$	$1.01 \pm 0.16$
	3	$0.26 \pm 0.05$	$0.2625 \pm 0.0007$	$1.00 \pm 0.18$
	4	$0.21 \pm 0.06$	$0.2047 \pm 0.0008$	$1.00 \pm 0.27$

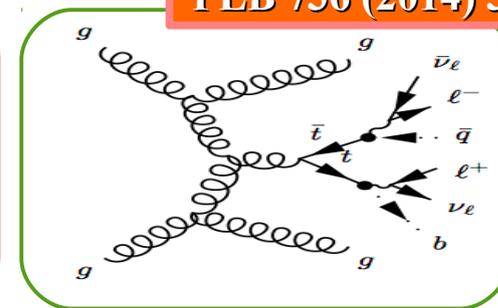
# b flavor content, width and $V_{tb}$



(signal like)



(single top like)



(background like)

- The expected b-tagged jet multiplicity modeled as a function of  $\mathcal{R}$  and tagging efficiencies.

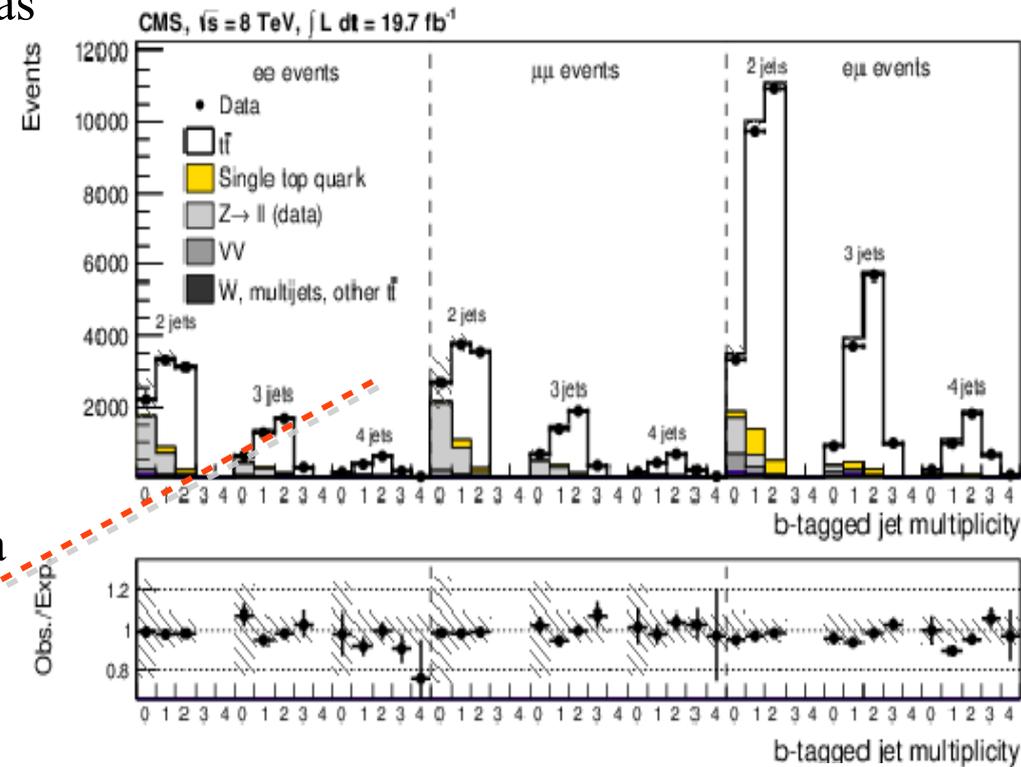
**Example** : two jets from  $t \rightarrow Wq$

$$P_{2j,2t,2d} = \mathcal{R}^2 \varepsilon_b^2 + 2\mathcal{R}(1 - \mathcal{R})\varepsilon_b \varepsilon_q + (1 - \mathcal{R})^2 \varepsilon_q^2$$

$\varepsilon_b$  = b-jet tag efficiency ;  $\varepsilon_q$  = light flavor tag efficiency

- Fitting the observed b-tagged jet distribution with a parametric model,

**extracted from a fit to 36 event categories**



**Quantity of interest**

$$\mathcal{L}(\mathcal{R}, f_{t\bar{t}}, k_{st}, f_{correct}, \varepsilon_b, \varepsilon_q, \varepsilon_{q*}, \theta_i) = \prod_{ll} \prod_{N_{jets}=2...4} \prod_{k=0}^{N_{jets}} \mathcal{P}[N_{ev}^{ll, N_{jets}}(k), \hat{N}_{ev}^{ll, N_{jets}}(k)] \prod_i \mathcal{G}(\theta_i^0, \theta_i, 1)$$

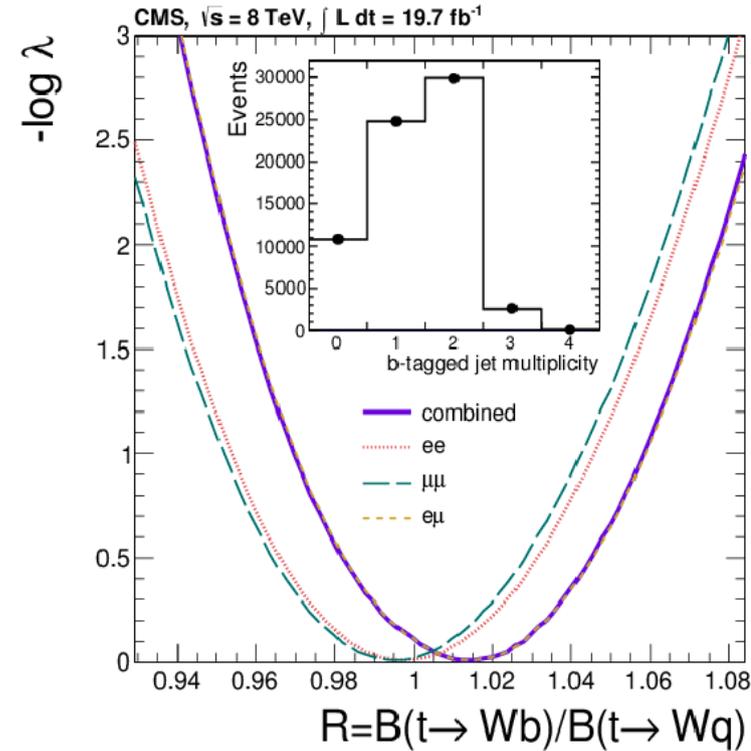
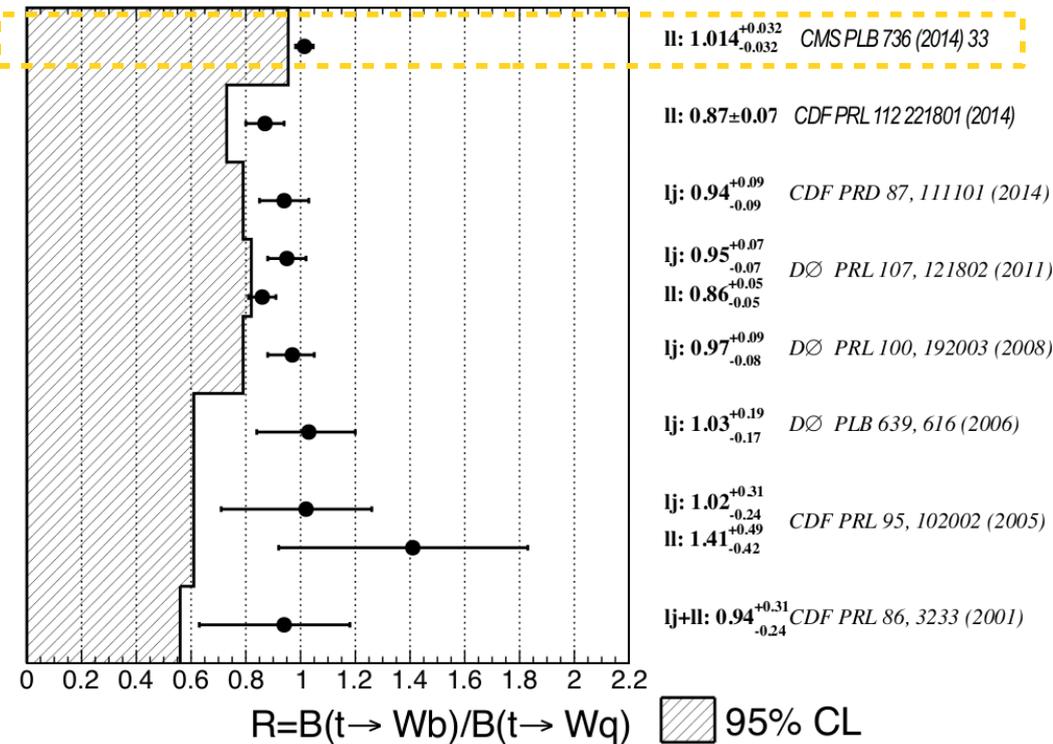
**Purity of sample**

**$N(t \rightarrow Wq)$**

**Tagging efficiency**

**uncertainties**

# b flavor content, width and $V_{tb}$



$R_b$  unconstrained  $1.014 \pm 0.003(\text{stat.}) \pm 0.032(\text{syst.})$

leading systematic uncertainty:

b-tagging efficiency measurement  $\rightarrow 2.4\%$

$|V_{tb}| = 1.007 \pm 0.016(\text{stat+syst})$

$R_b$  constrained  $< 1$  @ 95% CL 0.955

$|V_{tb}|$  constrained  $< 1$  @ 95% CL 0.975

## Combine $R=B(t \rightarrow Wb)$ with single top t-channel cross section measurement @ 7TeV

$$\Gamma_{\text{total}} = 1.36 \pm 0.02(\text{stat}) + 0.14/-0.11 (\text{syst}) \text{ GeV}$$

leading systematic uncertainties:

$\sigma_{\text{exp}} \rightarrow 9.2\%$

b-tagging efficiency measurement  $\rightarrow 4.3\%$

Most precise direct measurement of  $|V_{tb}|$

7 TeV  $\sigma_{\text{th}}$  Kidonakis, PRD 83, 091503 (2011)  
 7 TeV  $\sigma_{\text{exp}}$  CMS, JHEP 12, 035 (2012)

# FCNC theoretical predictions

Acta Phys. Polon. B35, 2695(2004), arXiv:1311.2028

Process	SM	QS	2HDM	FC 2HDM	MSSM	R SUSY	RS
$t \rightarrow uZ$	$8 \times 10^{-17}$	$1.1 \times 10^{-4}$	-	-	$2 \times 10^{-6}$	$3 \times 10^{-5}$	-
$t \rightarrow cZ$	$1 \times 10^{-14}$	$1.1 \times 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$2 \times 10^{-6}$	$3 \times 10^{-5}$	$\leq 10^{-5}$
$t \rightarrow u\gamma$	$3.7 \times 10^{-16}$	$7.5 \times 10^{-9}$	-	-	$2 \times 10^{-6}$	$1 \times 10^{-6}$	-
$t \rightarrow c\gamma$	$4.6 \times 10^{-14}$	$7.5 \times 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$2 \times 10^{-6}$	$1 \times 10^{-6}$	$\leq 10^{-9}$
$t \rightarrow ug$	$3.7 \times 10^{-14}$	$1.5 \times 10^{-7}$	-	-	$8 \times 10^{-5}$	$2 \times 10^{-4}$	-
$t \rightarrow cg$	$4.6 \times 10^{-12}$	$1.5 \times 10^{-7}$	$\sim 10^{-4}$	$\sim 10^{-8}$	$8 \times 10^{-5}$	$2 \times 10^{-4}$	$\leq 10^{-10}$
$t \rightarrow uH$	$2 \times 10^{-17}$	$4.1 \times 10^{-5}$	$5.5 \times 10^{-6}$	-	$10^{-5}$	$\sim 10^{-6}$	-
$t \rightarrow cH$	$3 \times 10^{-15}$	$4.1 \times 10^{-5}$	$1.5 \times 10^{-3}$	$\sim 10^{-5}$	$10^{-5}$	$\sim 10^{-6}$	$\leq 10^{-4}$

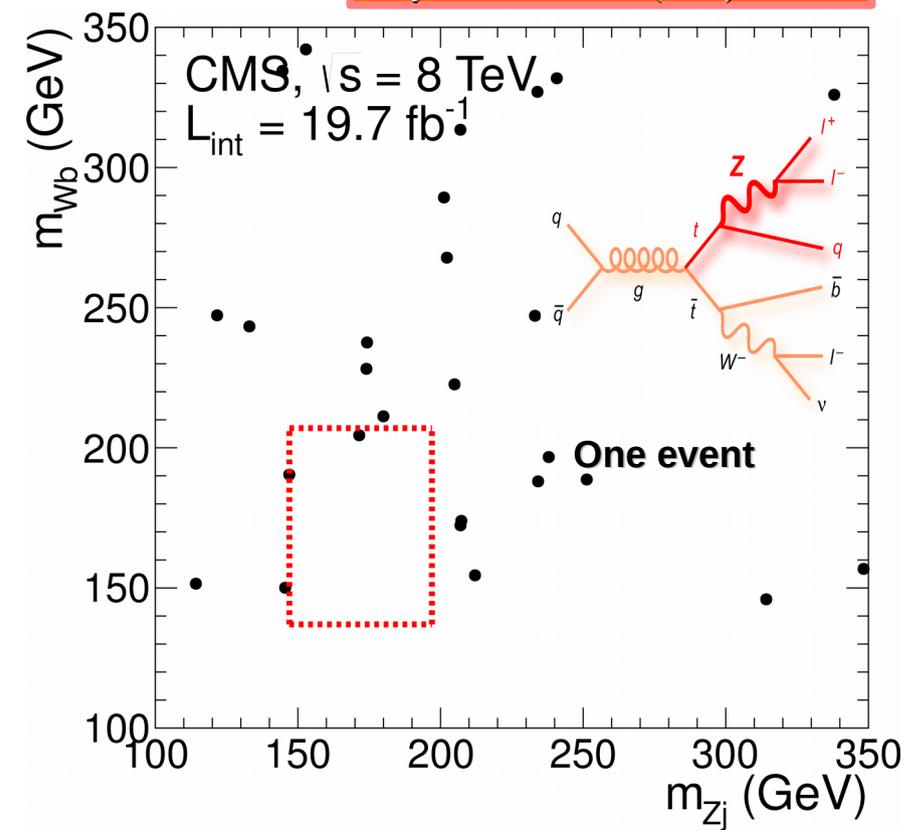
# $t \rightarrow Zq (q = u, c)$ in $t\bar{t}$



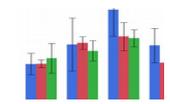
- 3 isolated leptons (e,  $\mu$ )
- $\geq 2$  jets, only one b-tag
- Missing energy and mass cuts on  $m_{Zj}$  and  $m_{Wb}$



- Main backgrounds: di-boson, DY  $t\bar{t}$ ,  $t\bar{t} + V$
- Data driven BKG estimation via b-tag bins information (0: Diboson, 1: FCNC signal, 2:  $t\bar{t} + X$ )



95% limit	$-\sigma$	Exp.	$+\sigma$	Obs.
8 TeV	0.06%	0.10%	0.13%	0.06%
7+8TeV	0.06%	0.09%	0.13%	<b>0.05%</b>



Main sys.: b-tagging, renormalization/factorization. scale, PDF

# Search for $t \rightarrow qH$ decays(CMS):

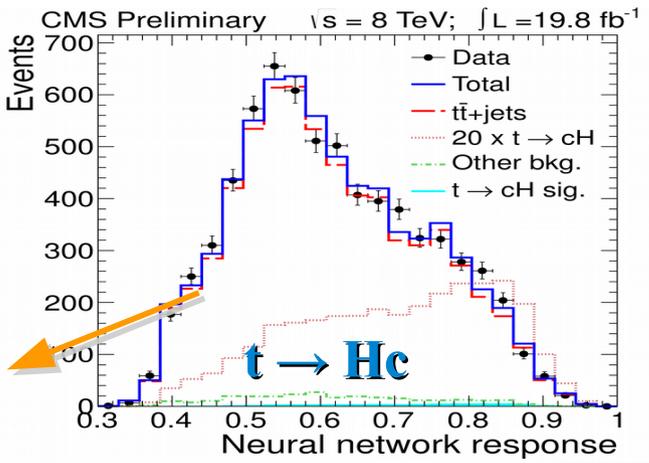
CMS-PAS-TOP-14-020



$t \rightarrow Hq \rightarrow bbq$  and  $t \rightarrow Wb \rightarrow lvb$

One isolated lepton and  $\geq 4$  jets (with  $\geq 3$  b-jets)

$B(t \rightarrow Hc) < 1.16\%$  (0.89%) for obs.(exp.) at 95% CL  
 $B(t \rightarrow Hu) < 1.92\%$  (0.85%) for obs.(exp.) at 95% CL



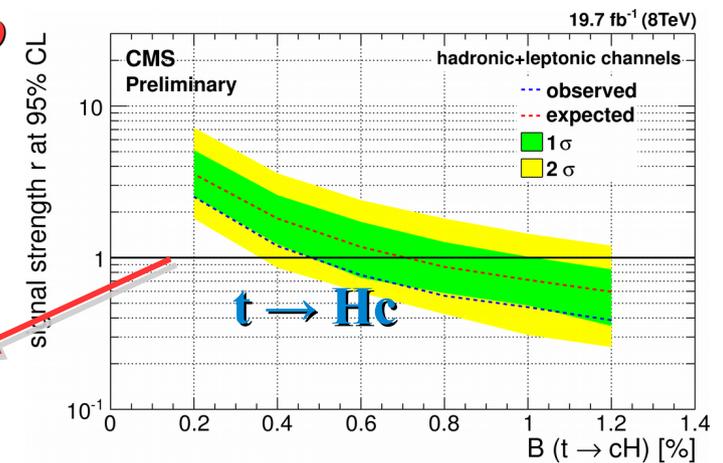
CMS-PAS-TOP-14-019



$t \rightarrow Hq \rightarrow \gamma\gamma q$  and  $t \rightarrow Wb \rightarrow lvb$  or  $qqb$

Two high energetic photons:  
 Leptonic channel: one lepton and  $\geq 2$  jets (one b-jet)  
 Hadronic channel:  $\geq 4$  jets (one b-jet),  $m_T(W)$  and top mass cuts.

$B(t \rightarrow Hc) < 0.47\%$  (0.71%) for obs.(exp.) at 95% CL  
 $B(t \rightarrow Hu) < 0.42\%$  (0.65%) for obs.(exp.) at 95% CL



CMS-PAS-TOP-13-017



$t \rightarrow Hc \rightarrow Zzc, WWc$  or  $\tau\tau c$  and  $t \rightarrow Wb \rightarrow lvb$

Selections: Same-sign di-lepton, trilepton

Combined:  $B(t \rightarrow Hc) < 0.93\%$  (0.89%) for obs.(exp.) at 95% CL

