Search for flavour-changing neutral current top quark decays $t \rightarrow Hq$ in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector

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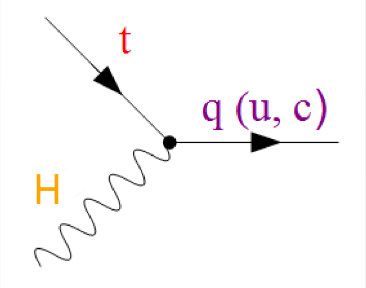
Outline

- Motivation
- Analysis Overview
- Discriminating Variable
- Systematic Uncertainties
- Results
- Summary

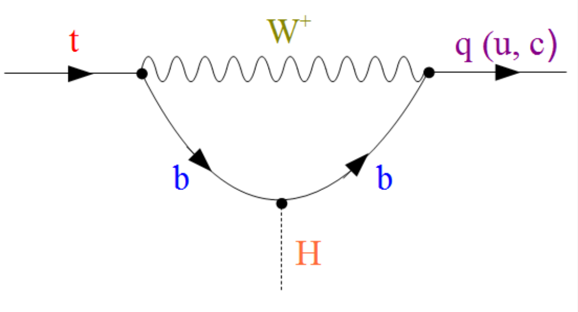
Motivation

- Much interest recently in flavour-violating Higgs interactions:
  - 2.4σ excess in H→μτ from CMS [Phys. Lett. B 749 (2015) 337].
- **Flavor-violating interactions could also be present in the quark sector.**



- t→Hq decays:
  - **Highly suppressed in the SM** (loop and GIM suppression).
  - Can receive large enhancements in BSM scenarios.

Process	SM	SUSY	MSSM	2HDM
t→Hc	$3 \cdot 10^{-15}$	10^{-6}	10^{-5}	10^{-3}
t→Hu	$2 \cdot 10^{-17}$	10^{-6}	$8 \cdot 10^{-5}$	10^{-4}

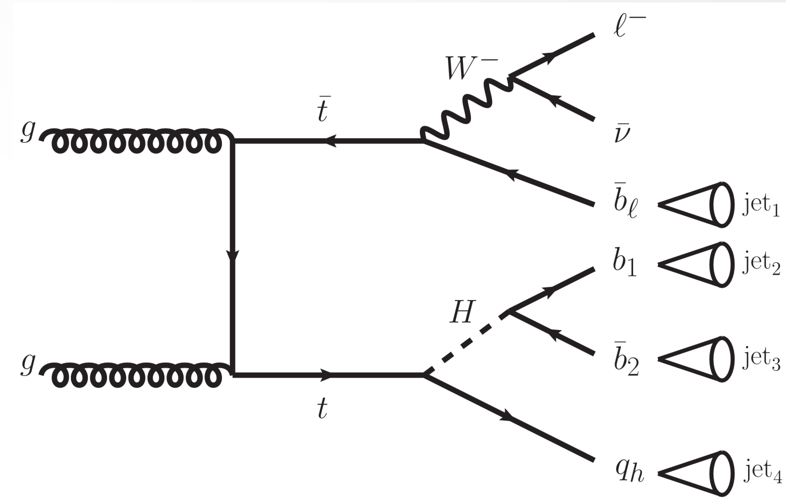


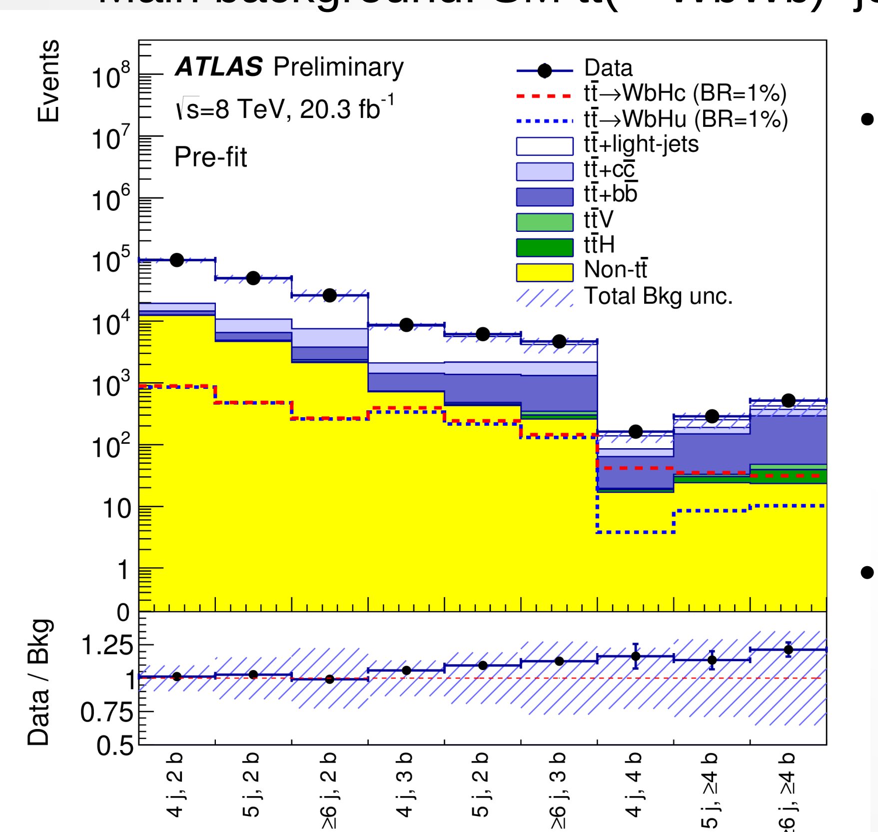
- Can exploit large $t\bar{t}$ samples to search for $t\bar{t}$→WbHq using Run 1 data.
  Three searches with the ATLAS detector:
  - **H→*γγ*:** tiny BR (**~0.2%**); diphoton+lepton+jets, diphoton+jets final states.
    Very small background, excellent mass resolution
  - **H→WW*,ττ:** sizable BR (WW*: **21.5%**, ττ: **6.3%**); SS dileptons, trileptons
    Small background, essentially no mass resolution
  - **H→bb:** largest BR (**~58%**); lepton+jets
    Large background, some mass resolution

Done for the first time!
Focus of this presentation!

Analysis Overview

- Focus on $t\bar{t} \to WbHq \to (l\nu)b(bb)q$ lepton+jets final state
- Event preselection:
  - Single lepton trigger
  - 1 lepton (e or μ), p_T >25 GeV, |η|<2.5
  - ≥4 jets, p_T >25 GeV, |η|<2.5
  - ≥2 b-tags (multivariate tagger at 70% b-tagging eff.)
- Main background: SM $t\bar{t}(\to WbWb)$+jets.





- Categorize events according to jet and b-tag multiplicities: (4, 5, ≥6 jets) x (2, 3, ≥4 b-tags)
  - Signal-rich regions:

    (4j, 3b) (WbHu and WbHc) and (4j, 4b) (WbHc)
  - Signal-depleted regions:
    rest of channels; play a key role in constraining background systematics via profile likelihood fit.
- Signal-to-background discrimination through a dedicated likelihood variable.

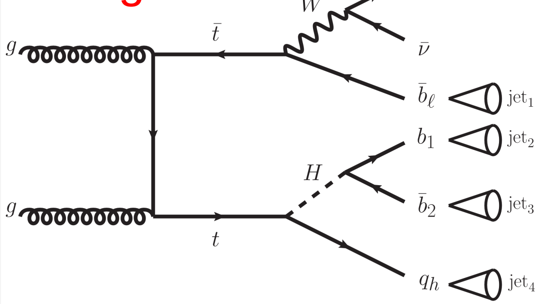
Discriminating Variable

- Build a likelihood discriminant exploiting invariant mass and b-tagging information as:

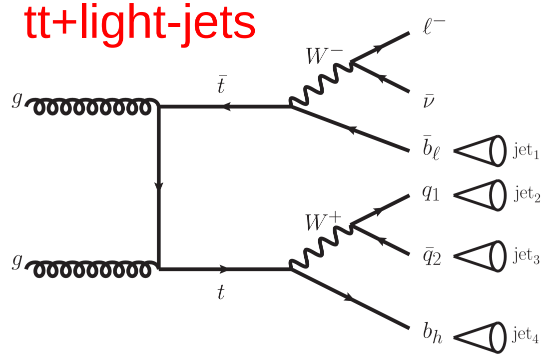
$$D(\mathrm{x}) = \frac{P^{\mathrm{sig}}(\mathrm{x})}{P^{\mathrm{sig}}(\mathrm{x}) + P^{\mathrm{bkg}}(\mathrm{x})}$$

- P^{sig}(x) and P^{bkg}(x) represent the probability density functions of a given event under the signal hypothesis (Signal) and the background hypothesis ($t\bar{t}$+light-jets & $t\bar{t}$+$b\bar{b}$, $t\bar{t}$+$c\bar{c}$) respectively.

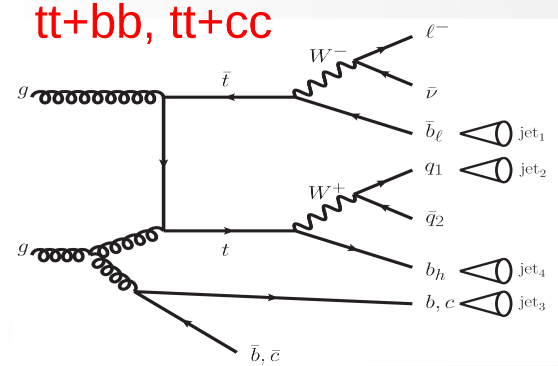
Signal



$t\bar{t}$+light-jets



$t\bar{t}$+$b\bar{b}$, $t\bar{t}$+$c\bar{c}$

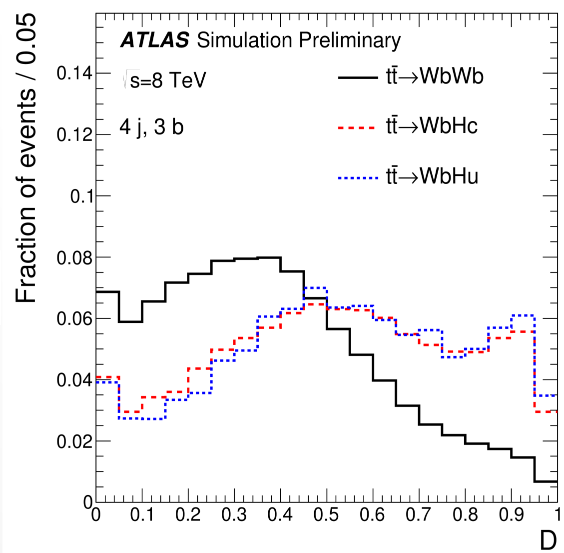


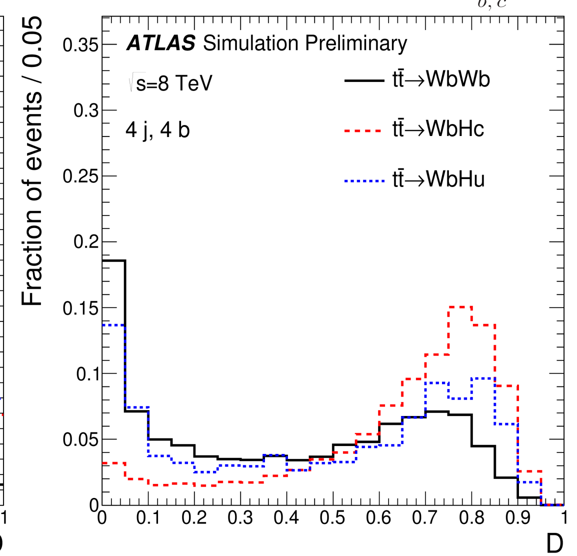
$$P^{\mathrm{sig}}(\mathbf{x}) = \frac{\sum_{k=1}^{N_p} P^{\mathrm{sig}}_{\mathrm{btag}}(\mathbf{x}^k) P^{\mathrm{sig}}_{\mathrm{kin}}(\mathbf{x}^k)}{\sum_{k=1}^{N_p} P^{\mathrm{sig}}_{\mathrm{btag}}(\mathbf{x}^k)}$$

$$P^{\mathrm{sig}}_{\mathrm{kin}}(\mathbf{x}) = P^{\mathrm{sig}}(M_{\ell\nu b_\ell}) P^{\mathrm{sig}}(X_{b_1 b_2 q_h}) P^{\mathrm{sig}}(M_{b_1 b_2})$$

$$X_{b_1 b_2 q_h} \equiv M_{b_1 b_2 q_h} \ominus M_{b_1 b_2}$$

$$P^{\mathrm{sig}}_{\mathrm{btag}}(\mathbf{x}) = P_b(\mathrm{jet}_1) P_b(\mathrm{jet}_2) P_b(\mathrm{jet}_3) P_{q_h}(\mathrm{jet}_4)$$





Systematic Uncertainties

Systematic uncertainty	Type	Components
Luminosity	N	1
Reconstructed Objects		
Electron	SN	5
Muon	SN	6
Jet reconstruction	SN	1
Jet vertex fraction	SN	1
Jet energy scale	SN	22
Jet energy resolution	SN	1
Missing transverse momentum	SN	2
b-tagging efficiency	SN	6
c-tagging efficiency	SN	4
Light-jet tagging efficiency	SN	12
High-p_{T} tagging	SN	1
Background Model		
$t\bar{t}$ cross section	N	1
$t\bar{t}$ modelling: p_{T} reweighting	SN	9
$t\bar{t}$ modelling: parton shower	SN	3
$t\bar{t}$+HF: normalisation	N	2
$t\bar{t}+c\bar{c}$: p_{T} reweighting	SN	2
$t\bar{t}+c\bar{c}$: generator	SN	4
$t\bar{t}+b\bar{b}$: NLO Shape	SN	8
W+jets normalisation	N	3
W p_T reweighting	SN	1
Z+jets normalisation	N	3
Z p_T reweighting	SN	1
Single top normalisation	N	3
Single top model	SN	1
Diboson normalisation	N	3
$t\bar{t}V$ cross section	N	1
$t\bar{t}V$ model	SN	1
$t\bar{t}H$ cross section	N	1
$t\bar{t}H$ model	SN	2
Multijet normalisation	N	4
Signal Model		
$t\bar{t}$ cross section	N	1
Higgs boson branching ratios	N	3
$t\bar{t}$ modelling: p_{T} reweighting	SN	9
$t\bar{t}$ modelling: p_{T} reweighting non-closure	N	1
$t\bar{t}$ modelling: parton shower	N	1

- Search uses a profile-likelihood fit to search for the signal while constraining the large background uncertainties.
- Use a sophisticated model for systematic uncertainties, including multiple components for several sources, to ensure consistent fit without artificial overconstraints.
- Examples:
  - jet energy scale uncertainty: 22 components
  - b-tagging uncertainty: 6 components
  - c/light-jet tagging uncertainties: 4/22 components
  - $t\bar{t}$ modeling uncertainties: 29 components
  - Leading systematic uncertainties after the fit include light-jet tagging, c-tagging, $t\bar{t}$+HF modeling, and the choice of parton shower/hadronisation model in $t\bar{t}$.

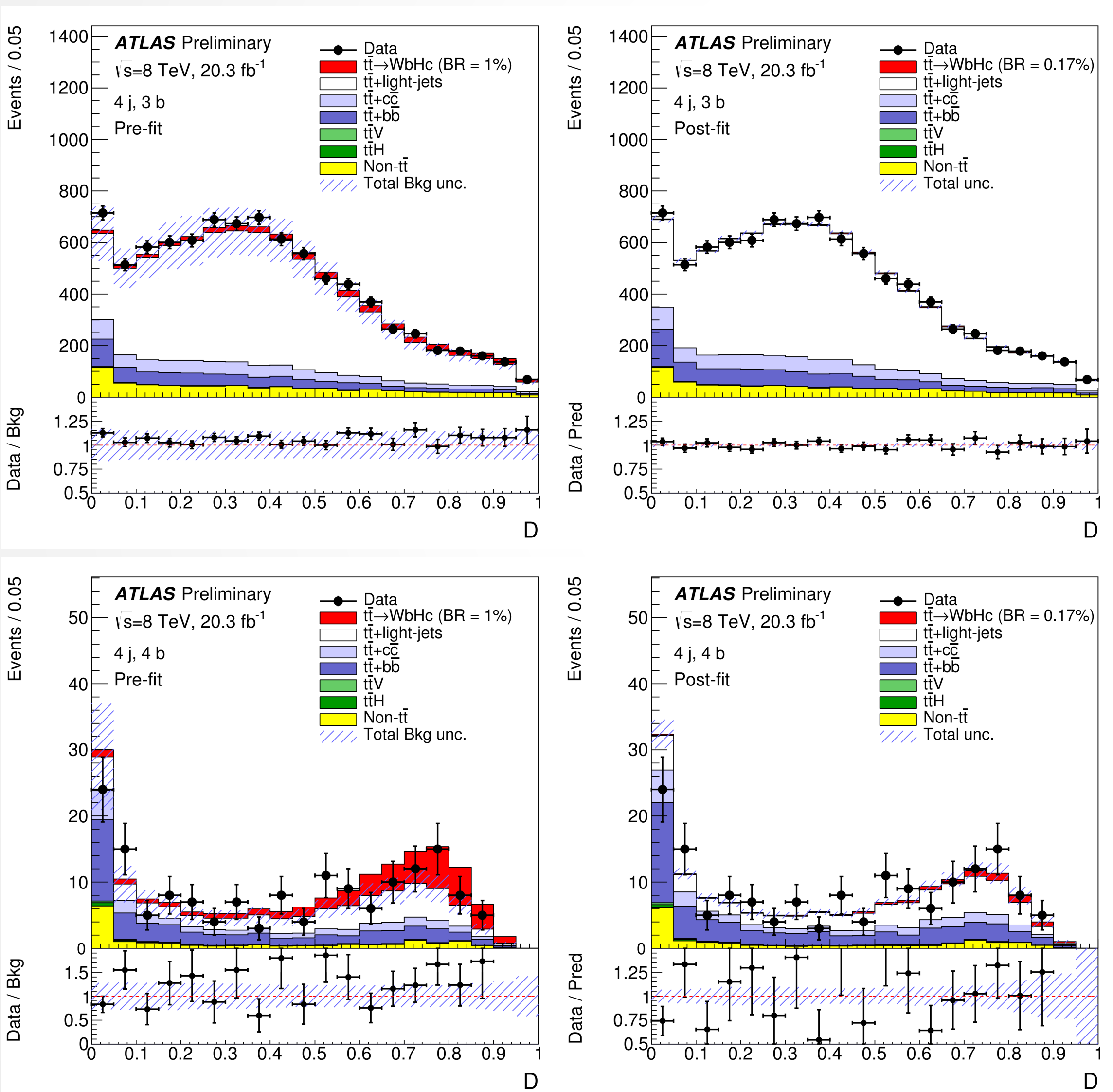
$H \rightarrow b\bar{b}$ search: Results

- Final discriminant pre- and post-fit in most sensitive channels for WbHc search:

Pre-fit　　Post-fit

(4j, 3b)

(4j, 4b)



- Best-fit branching ratios:

  $BR(t \rightarrow Hc) = (0.17 \pm 0.21)\%$
  (assuming $BR(t \rightarrow Hu)=0$)

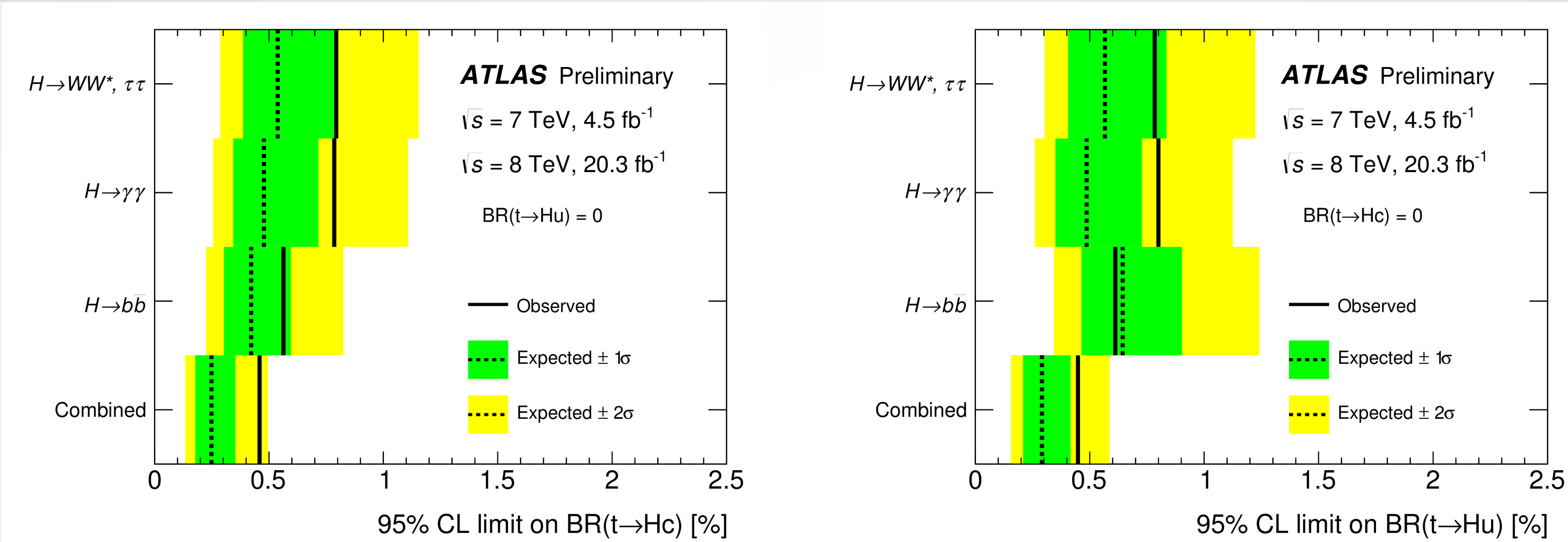
  $BR(t \rightarrow Hu) = (-0.07 \pm 0.33)\%$
  (assuming $BR(t \rightarrow Hc)=0$)

- No significant $t \rightarrow Hq$ excess.

- Obs (exp) 95% CL upper limits (one BR at a time):
  $BR(t \rightarrow Hc) < 0.56\%\ (0.42\%)$
  $BR(t \rightarrow Hu) < 0.61\%\ (0.64\%)$

- Different sensitivity to $t \rightarrow Hc$ and $t \rightarrow Hu$,
- Most sensitive single search for $t \rightarrow Hc$ (as we will see on next slide).

Results: Branching Ratio Limits

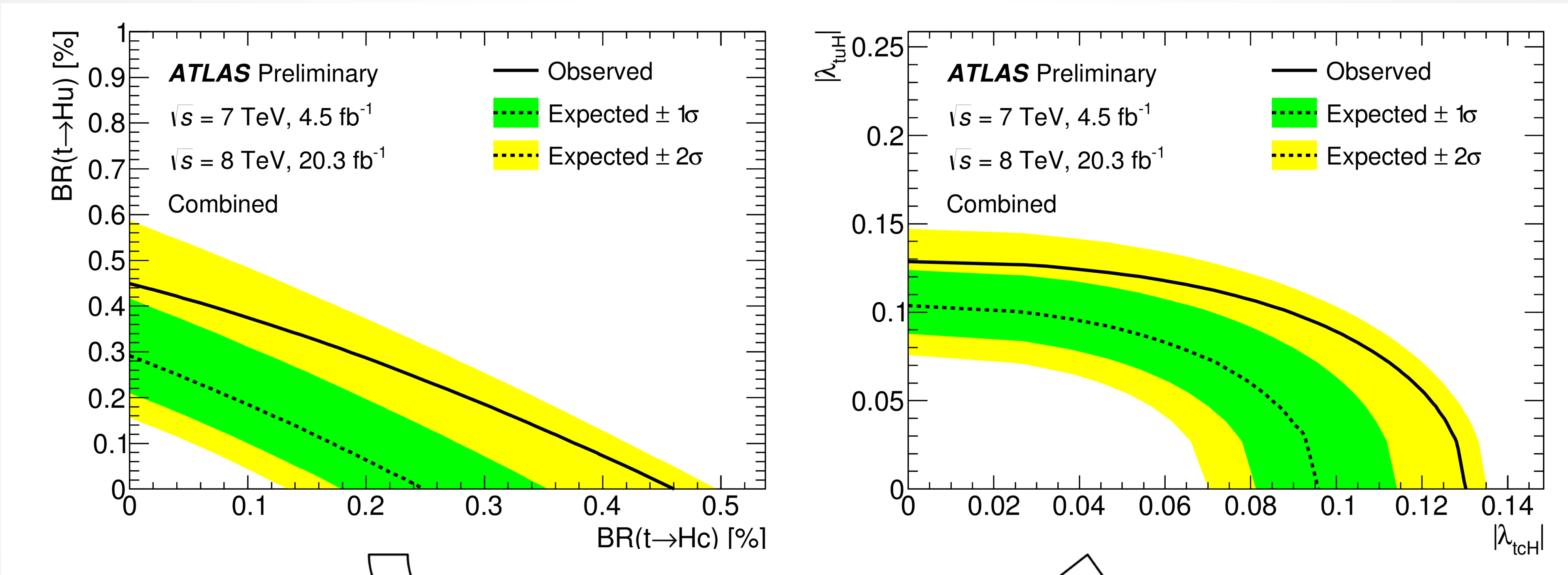


Collab.	Higgs boson decay mode	95% CL upper limits on $\mathcal{B}(t \to Hc)$		95% CL upper limits on $\mathcal{B}(t \to Hu)$		Ref.
		Observed	Expected	Observed	Expected	
CMS	$H \to \gamma\gamma$ (1)	0.69%	0.81%	–	–	PRD 90 (2014) 112013
	$H \to \gamma\gamma$ (2)	0.47%	0.71%	0.42%	0.65%	CMS-PAS-TOP-14-019
	$H \to WW^*, \tau^+\tau^-$ (3ℓ, 4ℓ)	1.28%	1.17%	–	–	PRD 90 (2014) 112013
	$H \to WW^*, \tau^+\tau^-$ (SS 2ℓ, 3ℓ)	0.93%	0.89%	–	–	CMS-PAS-TOP-13-017
	Combination $\gamma\gamma$ (1), 3ℓ, 4ℓ	0.56%	0.65%	–	–	PRD 90 (2014) 112013
ATLAS	$H \to \gamma\gamma$	0.79%	0.51%	0.79%	0.51%	JHEP 06 (2014) 008
	$H \to WW^*, \tau^+\tau^-$ (SS 2ℓ, 3ℓ)	0.79%	0.54%	0.78%	0.57%	PLB 749 (2015) 519
	$H \to b\bar{b}$	0.56%	0.42%	0.61%	0.64%	–
	Combination	**0.46%**	**0.25%**	**0.45%**	**0.29%**	–

- All three ATLAS searches have comparable sensitivity.
- The ATLAS combination represents a significant improvement over previous results.

Results: 2D Limits

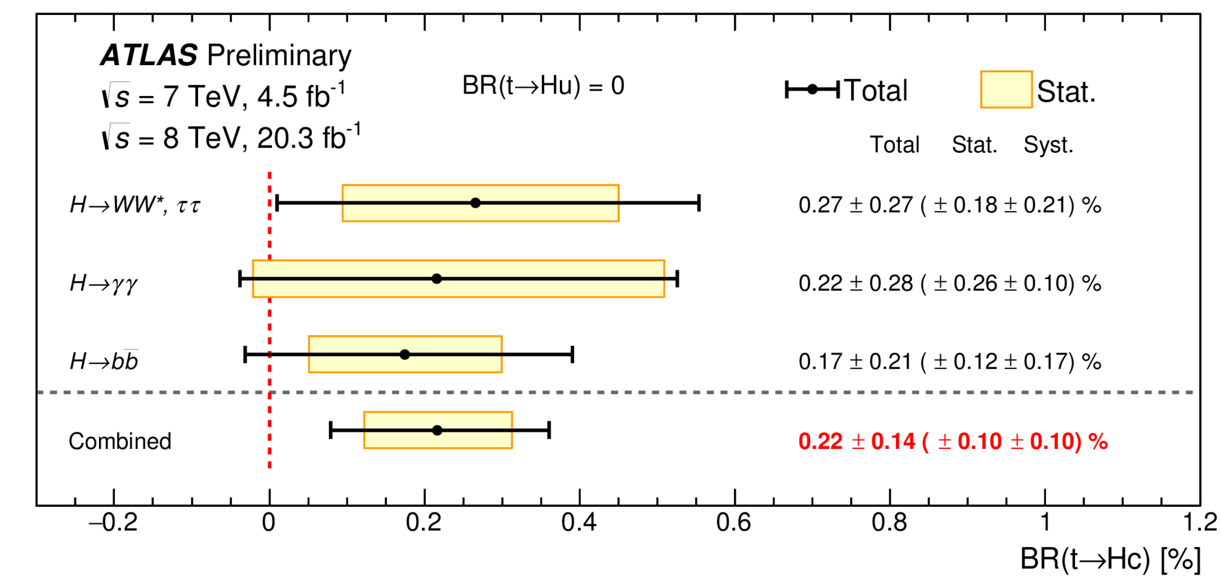
- First results scanning the BR($t \to Hc$) vs BR($t \to Hu$) plane for the combined search.
- Branching ratio limits translated to non-flavour-diagonal Yukawa couplings.

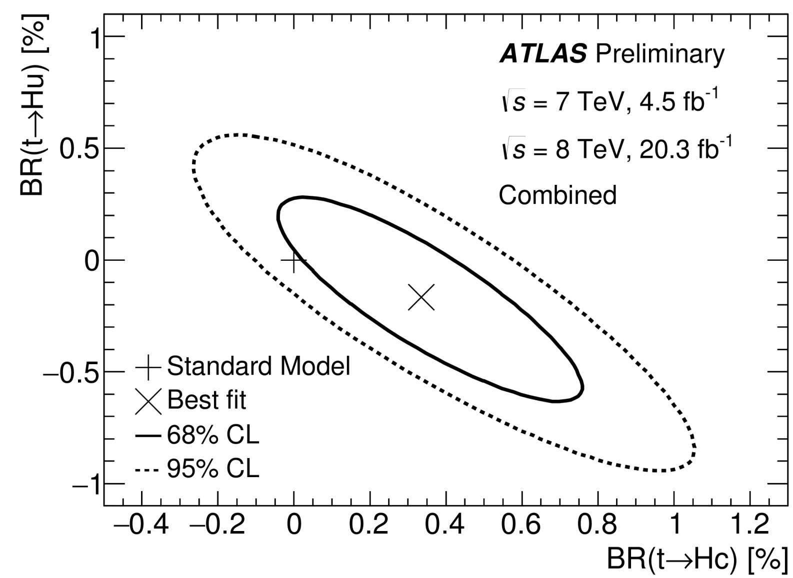


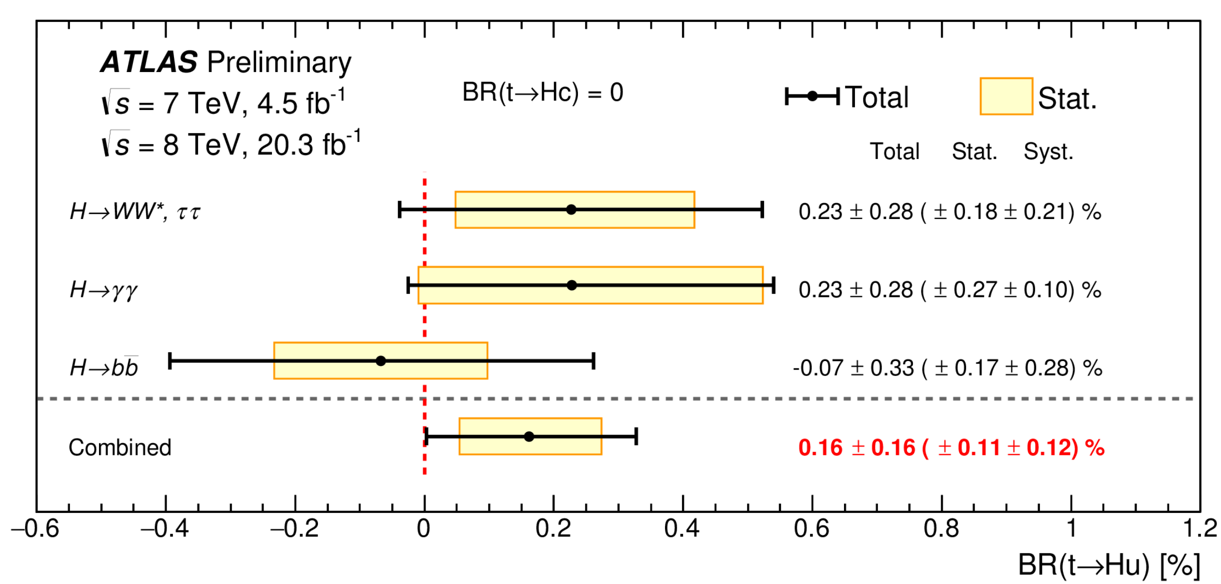
$$|\lambda_{tqH}| = 1.92\sqrt{\mathrm{BR}(t \to Hq)}$$

$$\mathcal{L}_{\mathrm{FCNC}} = \lambda_{tcH}\bar{t}Hc + \lambda_{tuH}\bar{t}Hu + h.c.$$

Results: Best-Fit Branching Ratios







- Best-fit branching ratios consistent with the SM prediction.
- Largest deviation for combined BR(t → Hc) is 1.6 s.d.

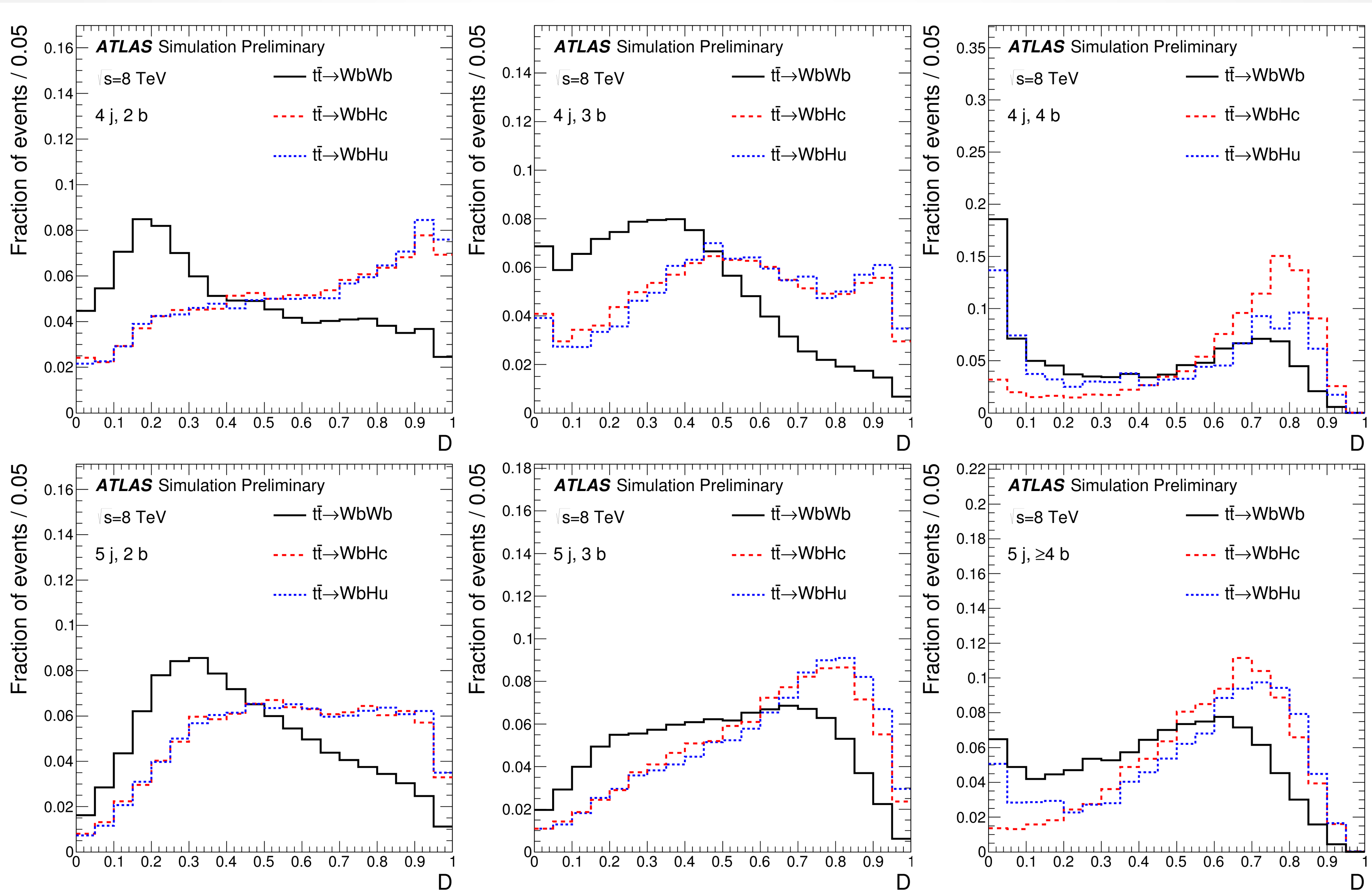
Summary

- The first search for $t\bar{t} \rightarrow WbHq$ with $H \rightarrow bb$, exploiting the lepton-plus-jets final state at high b-tag multiplicity, has been presented.
- A novel discriminant is built to separate signal from background, whose uncertainties are constrained via a profile likelihood fit to 9 analysis channels.
- This analysis constitutes the single most sensitive search for $t \rightarrow Hc$ decays to date.
- The combination of the three ATLAS searches exploiting the $H \rightarrow bb$, $H \rightarrow WW^*$, $\tau\tau$ and $H \rightarrow \gamma\gamma$ decay modes yields the most sensitive direct bounds on tqH interactions to date.
- This becomes the ATLAS Run 1 legacy result on this topic and a stepping stone for further improved searches during Run 2.

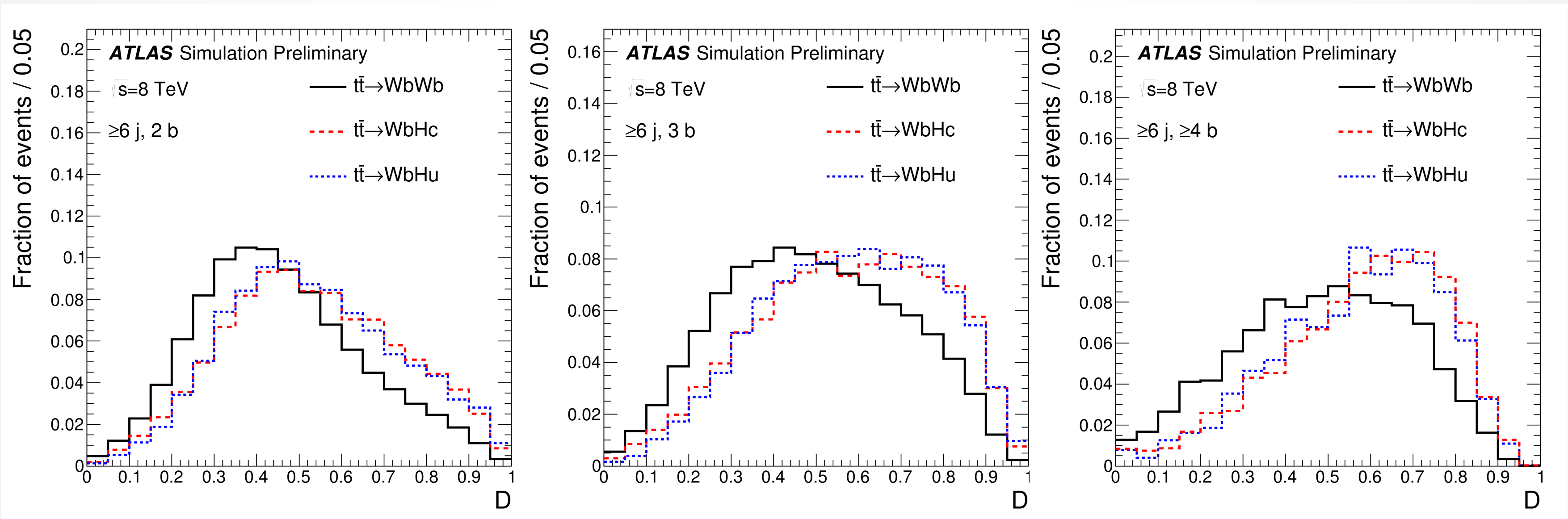
Thank you for
your attention!

Backup Slides

$H \rightarrow b\bar{b}$ search: Shape Comparison (1)



$H \to b\bar{b}$ search: Shape Comparison (2)



Other FCNC Analysis Results

- $H \to \gamma\gamma$: tiny BR (~0.2%); diphoton+lepton+jets, diphoton+jets final states. Very small background, excellent mass resolution.

- Best-fit branching ratios:

  BR($t \to Hc$) = [0.22 ± 0.26(stat.) ± 0.10(syst.)]% (assuming BR($t \to Hu$)=0)

  BR($t \to Hu$) = [0.23 ± 0.27(stat.) ± 0.10(syst.)]% (assuming BR($t \to Hc$)=0)
- Obs (exp) 95% CL upper limits (one BR at a time):

  BR($t \to Hc$) < 0.79% (0.51%)

  BR($t \to Hu$) < 0.79% (0.51%)

- $H \to WW^*, \tau\tau$: sizable BR (WW*: 21.5%, ττ: 6.3%); SS dileptons, trileptons Small background, essentially no mass resolution.

- Best-fit branching ratios:

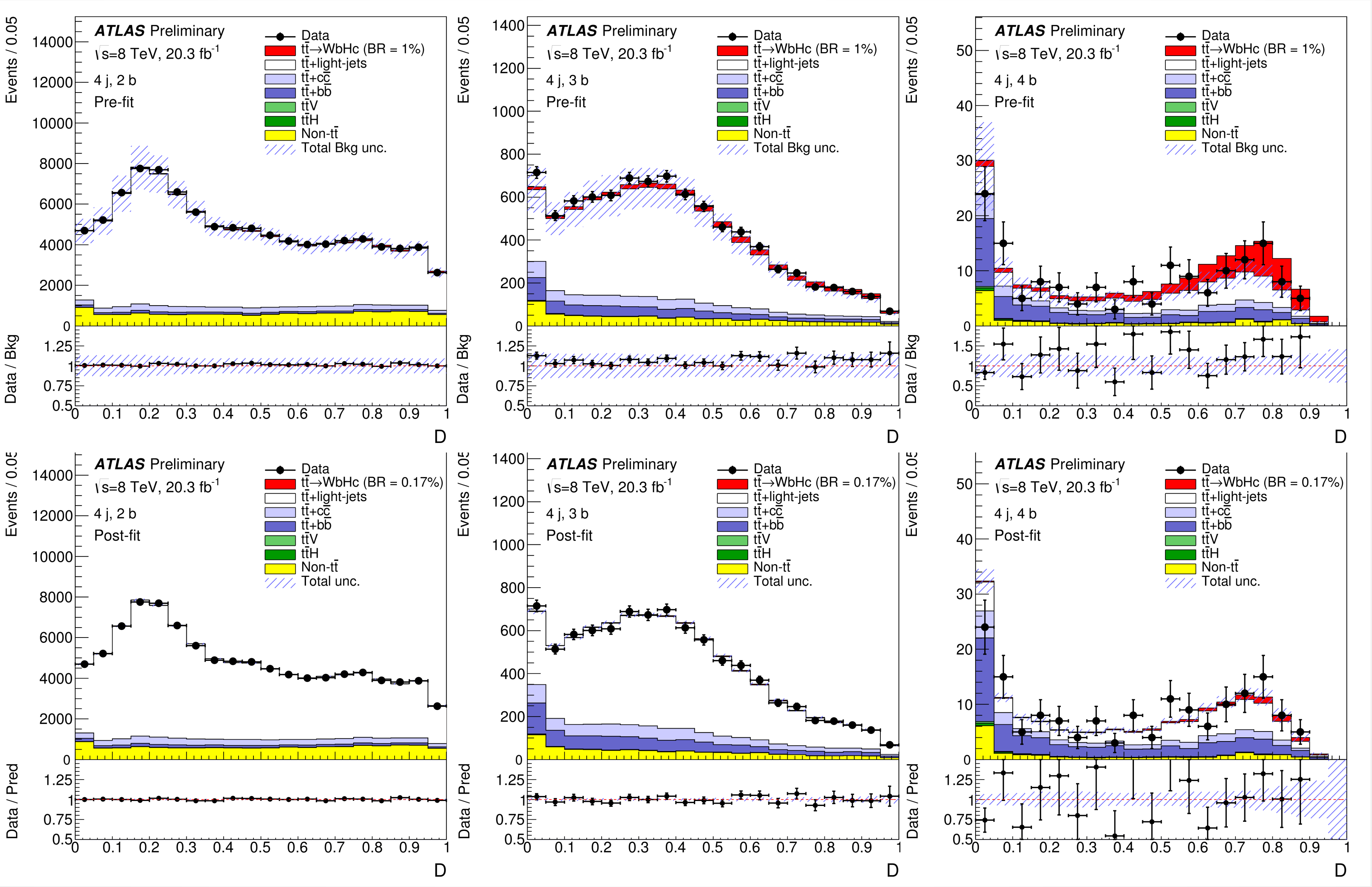
  BR($t \to Hc$) = [0.27 ± 0.18(stat.) ± 0.21(syst.)]% (assuming BR($t \to Hu$)=0)

  BR($t \to Hu$) = [0.23 ± 0.18(stat.) ± 0.21(syst.)]% (assuming BR($t \to Hc$)=0)
- Obs (exp) 95% CL upper limits (one BR at a time):

  BR($t \to Hc$) < 0.79% (0.54%)

  BR($t \to Hu$) < 0.78% (0.57%)

H → b$\bar{b}$ search: Pre/Post Fit Plots (1)



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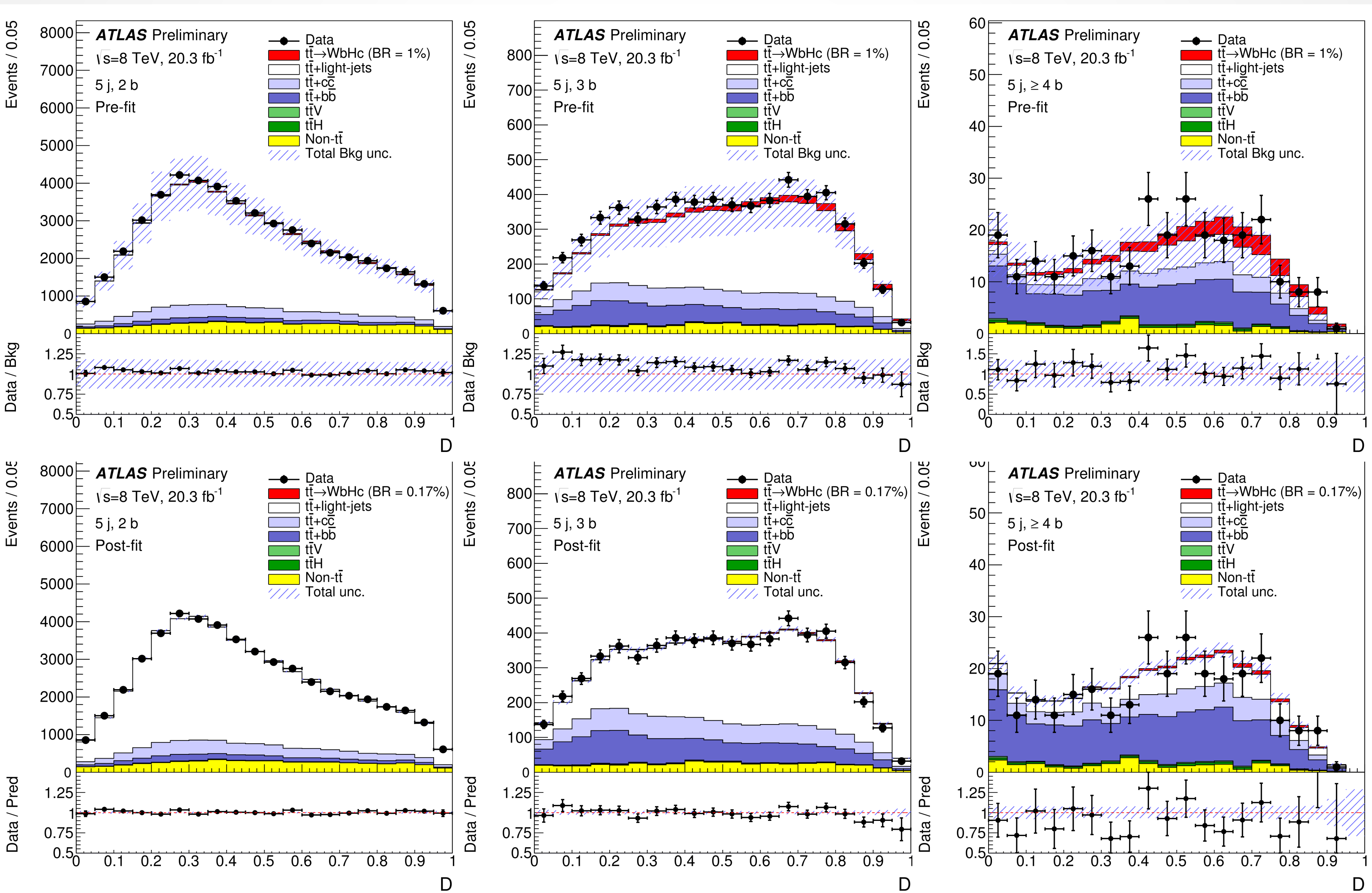
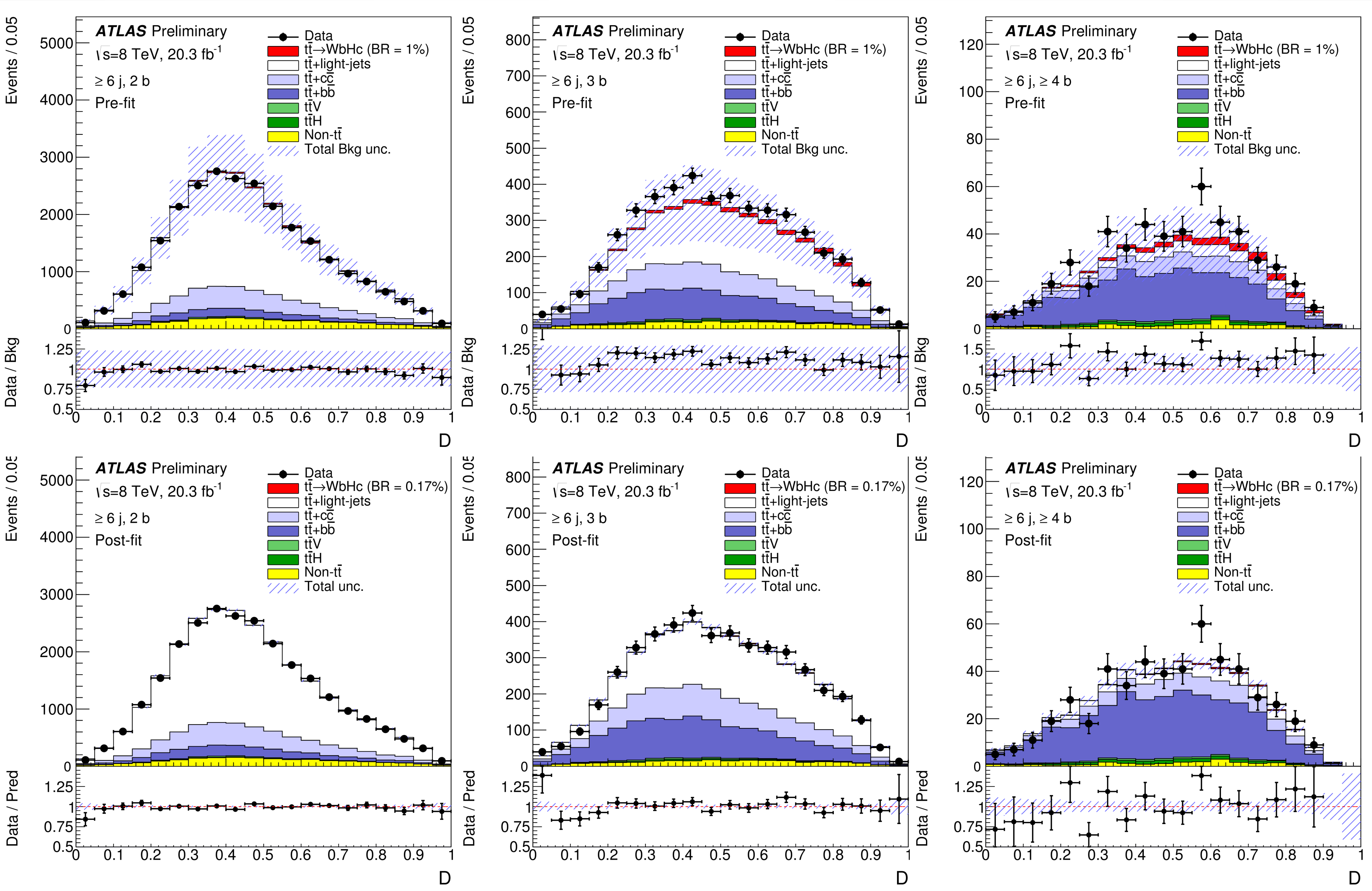
H → $b\bar{b}$ search: Pre/Post Fit Plots (2)



$H \to b\bar{b}$ search: Pre/Post Fit Plots (3)



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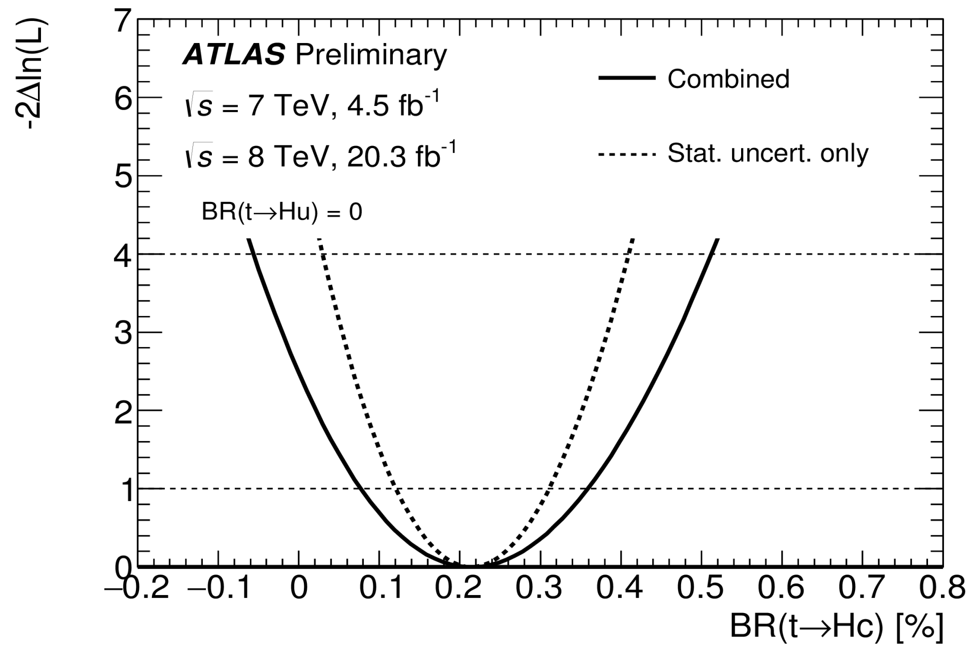
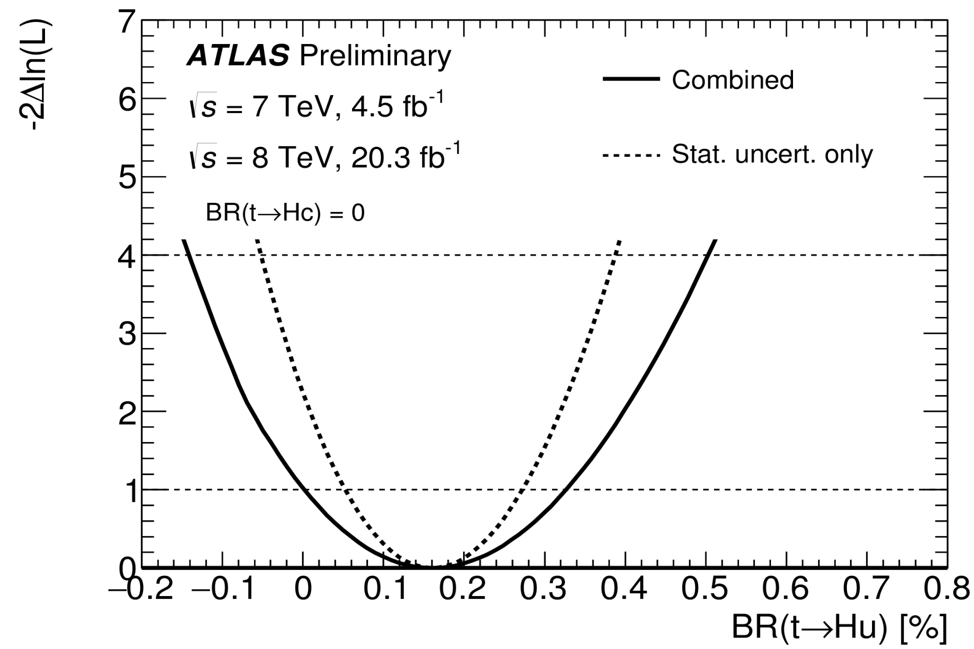
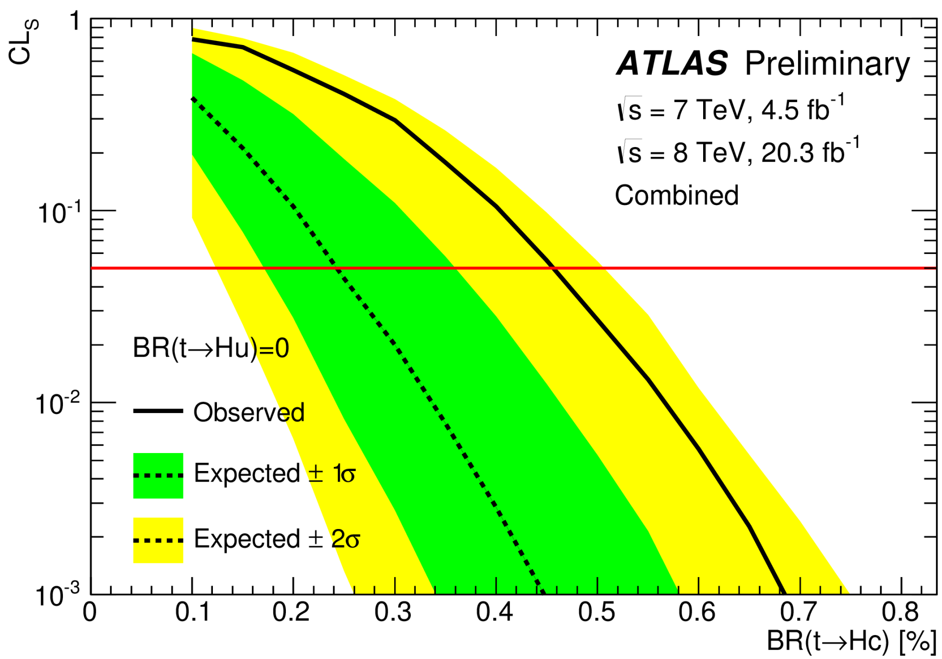
Combined Results: Best-Fit BR

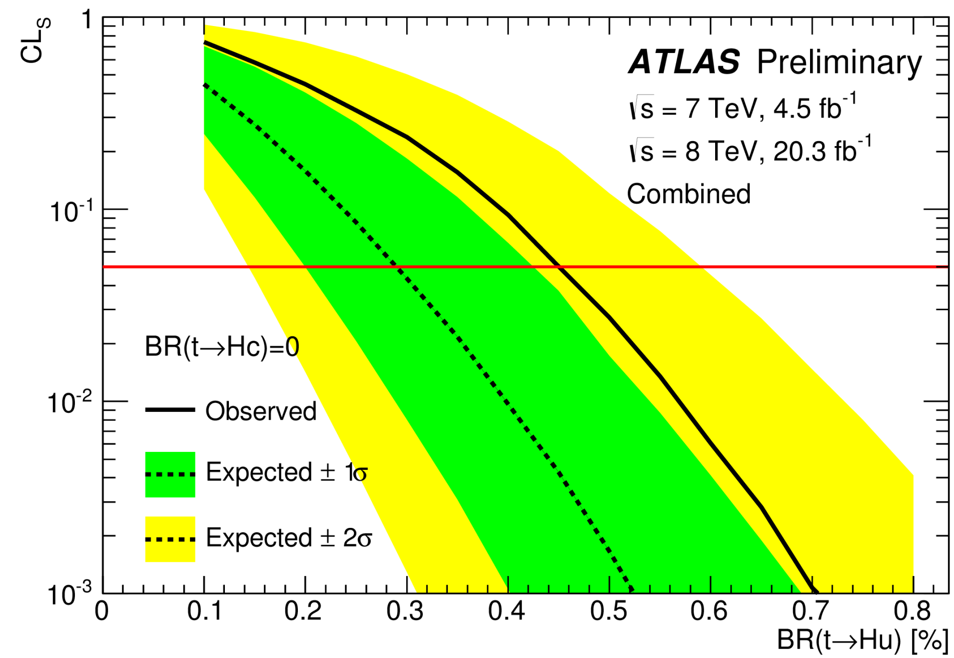




Combined Search: 1D Limits

- CL_s vs BR scan for the combined search.





- Obs (exp) 95% CL upper limits (one BR at a time):

  BR(t → Hc) < 0.46% (0.25%)

  BR(t → Hu) < 0.45% (0.29%)