Search for top FCNC tqH interaction using taus with Run-2 data

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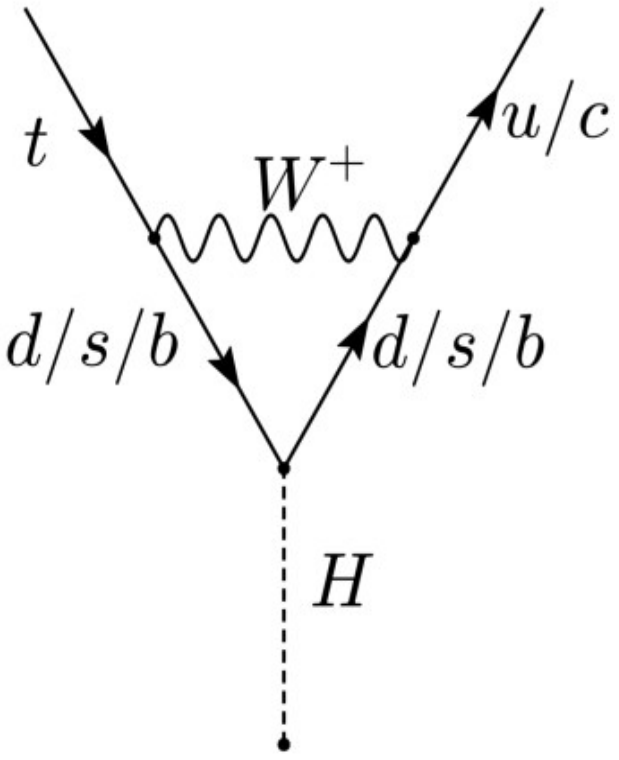
CLHCP 2020, Tsinghua University
November 6

Outline

- Introduction to tqH FCNC interaction
- Published results with 36fb^{-1}
- 140fb^{-1} tqH FCNC search at LHC
  - New mode added
  - New channels added
  - Signal regions
  - Fake tau/lepton estimation
  - BDT and limit setting
- Results

FCNC tqH interaction

- The Standard Model (SM) doesn't provide tree level tqH interactions.
- The interaction can happen only through loop diagrams, one of which is shown on the right.
- The diagram is further suppressed due to the GIM mechanism (Phys. Rev. D 2 (1970) 1285).
- The branching ration is far beyond the current detection capabilities. In short, it happens so rarely that we cannot see it.
- But there are models that can have them enhanced.
- Study the process using 6-dim EFT [1412.5594]:



$$\mathcal{L}_{EFT} = \frac{C_{u\phi}^{i3}}{\Lambda^2}(\phi^\dagger\phi)(\bar{q}_i t)\tilde{\phi} + \frac{C_{u\phi}^{3i}}{\Lambda^2}(\phi^\dagger\phi)(\bar{Q}u_i)\tilde{\phi} + H.c$$

Then measure the decay branching ratio, then derive the Wilson coefficient.

$$\Lambda = 1\text{TeV}$$

$$\text{BR}(t \to qH) = 0.1\,\% \;\to\; C = 1.3952$$

$$C = 1 \;\to\; \sigma(ug \to tH) = 365.2\text{fb}$$

$$\sigma(cg \to tH) = 52.9\text{fb}$$

Published results

- ATLAS
  - t→Hu
    - 1.2×10^{-3}
  - t→Hc
    - 1.1×10^{-3}

Regular Article - Experimental Physics | Open Access | Published: 21 May 2019

Search for top-quark decays $t \to Hq$ with 36 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS collaboration, M. Aaboud, [...] L. Zwalinski

Journal of High Energy Physics **2019**, Article number: 123 (2019) | Cite this article

409 Accesses | **14** Citations | **1** Altmetric | Metrics

- CMS
  - t→Hu
    - 4.7×10^{-3}
  - t→Hc
    - 4.7×10^{-3}

Search for the flavor-changing neutral current interactions of the top quark and the Higgs boson which decays into a pair of b quarks at $\sqrt{s} = 13$ TeV

The CMS collaboration, A. M. Sirunyan, [...] N. Woods

Journal of High Energy Physics **2018**, Article number: 102 (2018) | Cite this article

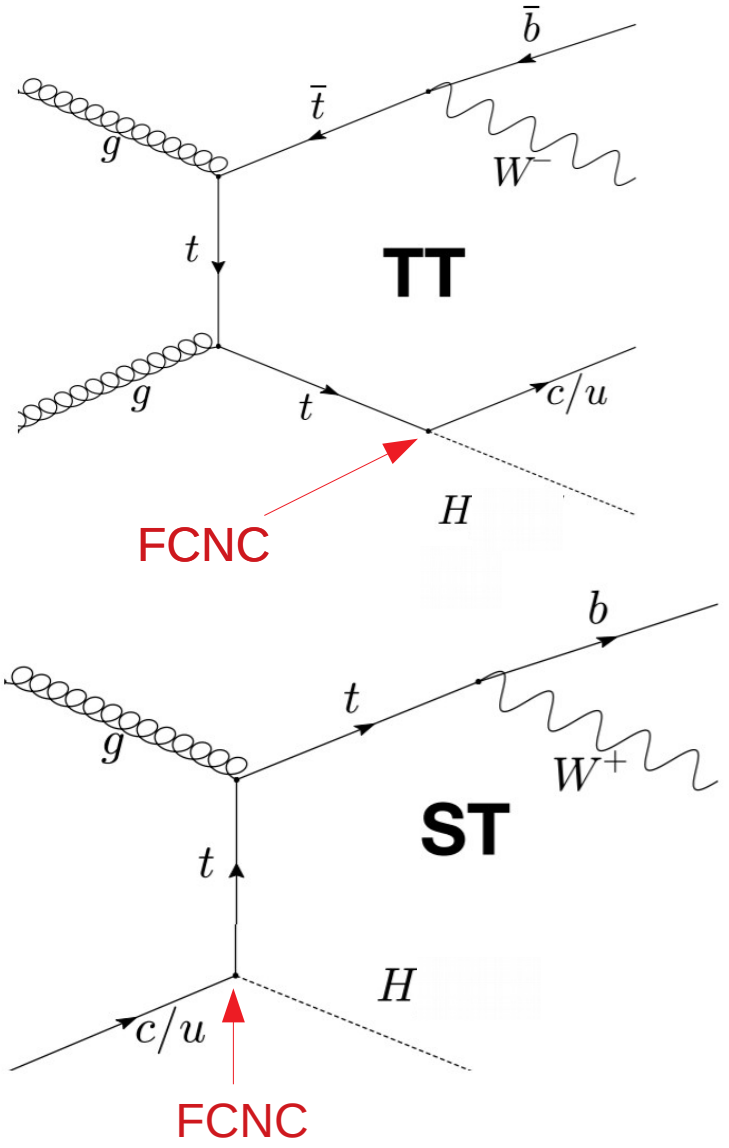
437 Accesses | **21** Citations | **7** Altmetric | Metrics

FCNC diagrams at LHC

- Published 36fb^{-1}: TT only
- *tcH* and *tuH* are the same in TT mode
- ST contributes more in *tuH* interaction than *tcH* due to PDF.
- Yields (stat only) in one of the signal region with 140fb^{-1} and BR=0.2%:

Yields	TT	ST
tuH	64.25 ± 0.63	22.24 ± 0.29
tcH	61.96 ± 0.61	4.76 ± 0.06

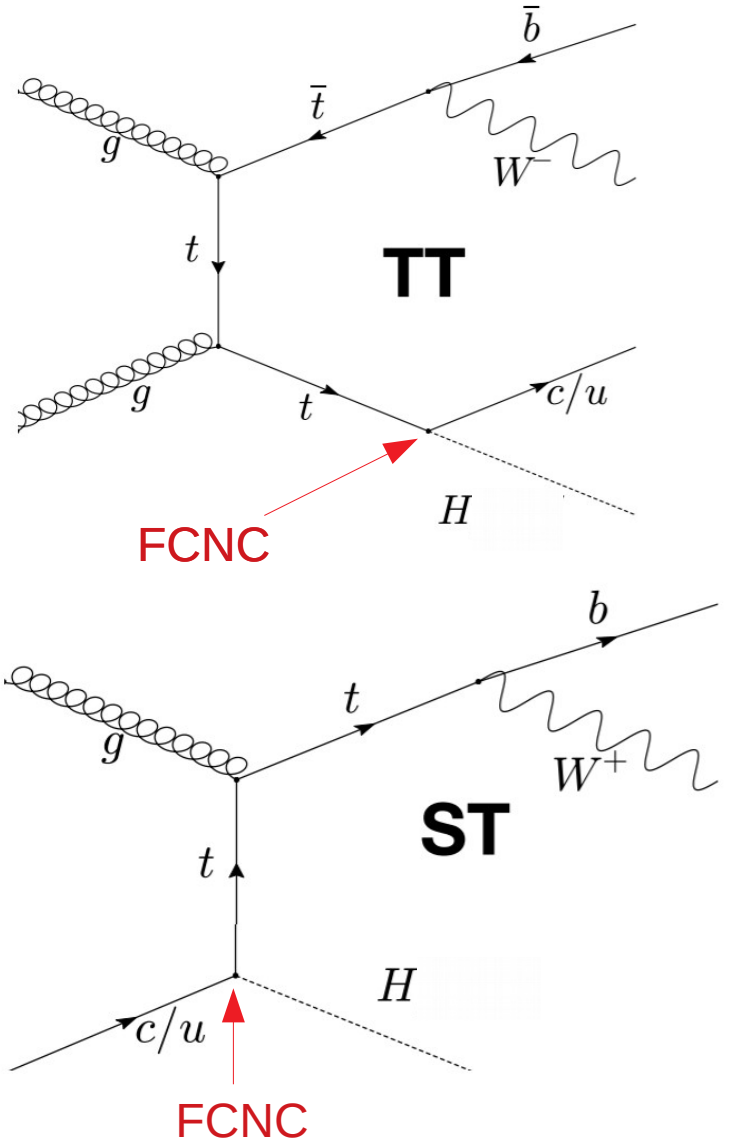
- 30% improvement in *tuH* interaction.



New channels

- Published: 36fb-1, W→ qq only
- New channels:
  - $W \to l\nu \quad H \to \tau_{\mathrm{had}}\tau_{\mathrm{had}}$
    - Lepton+(2 hadronic taus)(OS)
    - (Lepton+1 hadronic tau)(SS)

Significance	l+2tau	l+tau SS	l+tau+3j	l+tau+4j
tuH	8.09	2.25	1.37	2.49
tcH	6.3	1.85	0.74	2.02



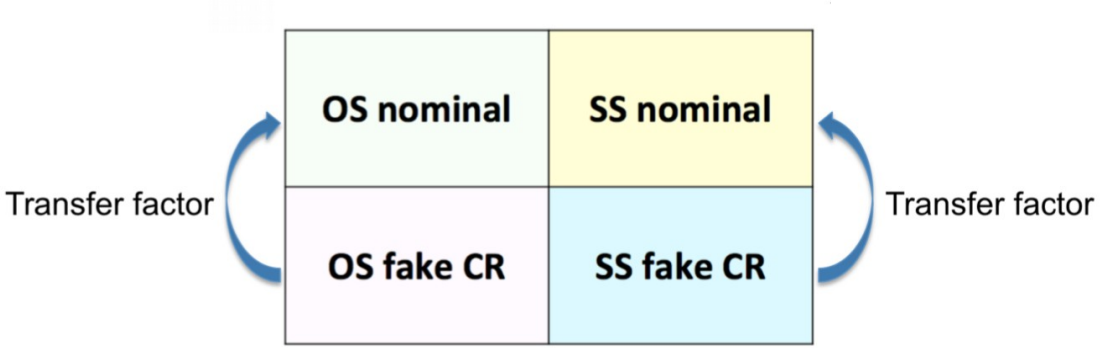
Signal regions

- $H \to \tau_{had}\tau_{had}, W \to q\bar{q}$
  - 1 b-jet + (2 hadronic taus)(OS) + (2/at least 3) light flavor jet
- $H \to \tau_{lep}\tau_{had}, W \to q\bar{q}$
  - 1 b-jet + (1 lepton + 1 hadronic tau)(OS) + (2/at least 3) light flavor jet
- $H \to \tau_{had}\tau_{had}, W \to l\nu$
  - 1 b-jet + 1 lepton + (2 hadronic tau)(OS)
  - 1 b-jet + (1 lepton + 1 hadronic tau)(SS) + at most 2 light flavor jet

Fake estimation

- New background estimation: Fake SF + Data Driven
  - Use calibrated MC to model non-QCD background
  - Use Fake Factor to model QCD background.
  - Also attempt ABCD method depending on the need of each region.

- Published: 36fb-1, BDT ID, Data Driven
- New RNN tau ID, with the same signal efficiency:
  - 50% less fake background in $H \rightarrow \tau_{\text{lep}}\tau_{\text{had}}$
  - 75% less fake background in $H \rightarrow \tau_{\text{had}}\tau_{\text{had}}$

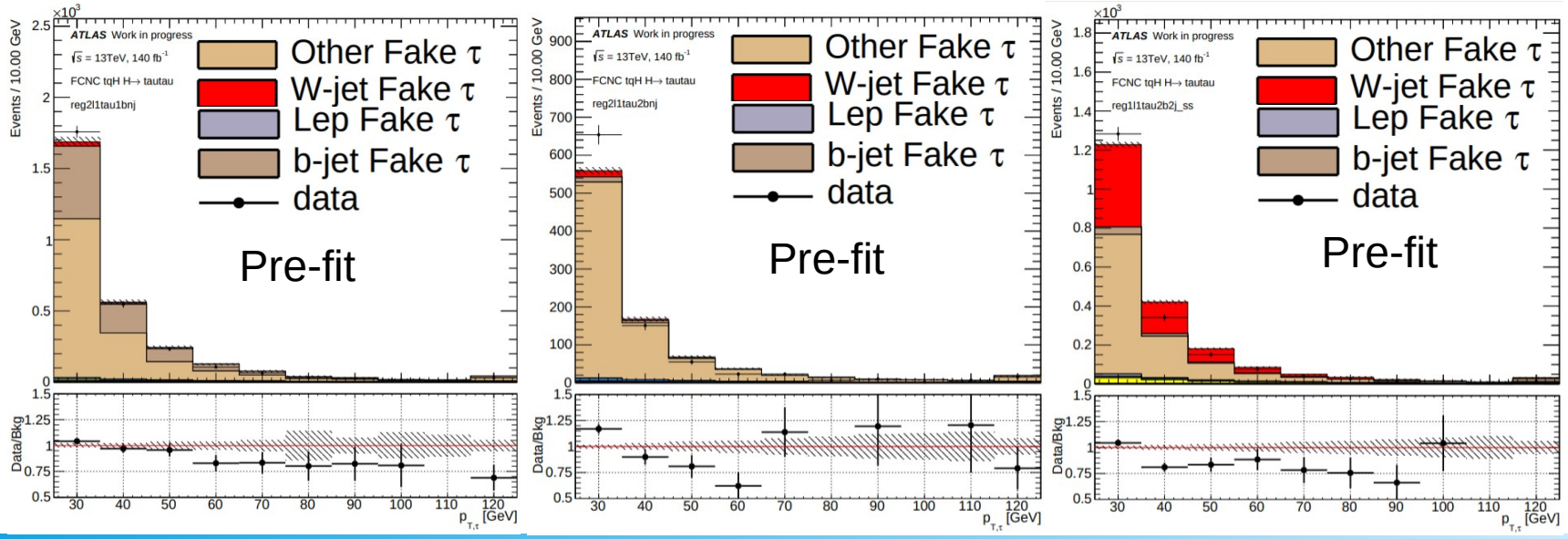


Lepton isolation		
	B	A (signal)
	D	C

MET

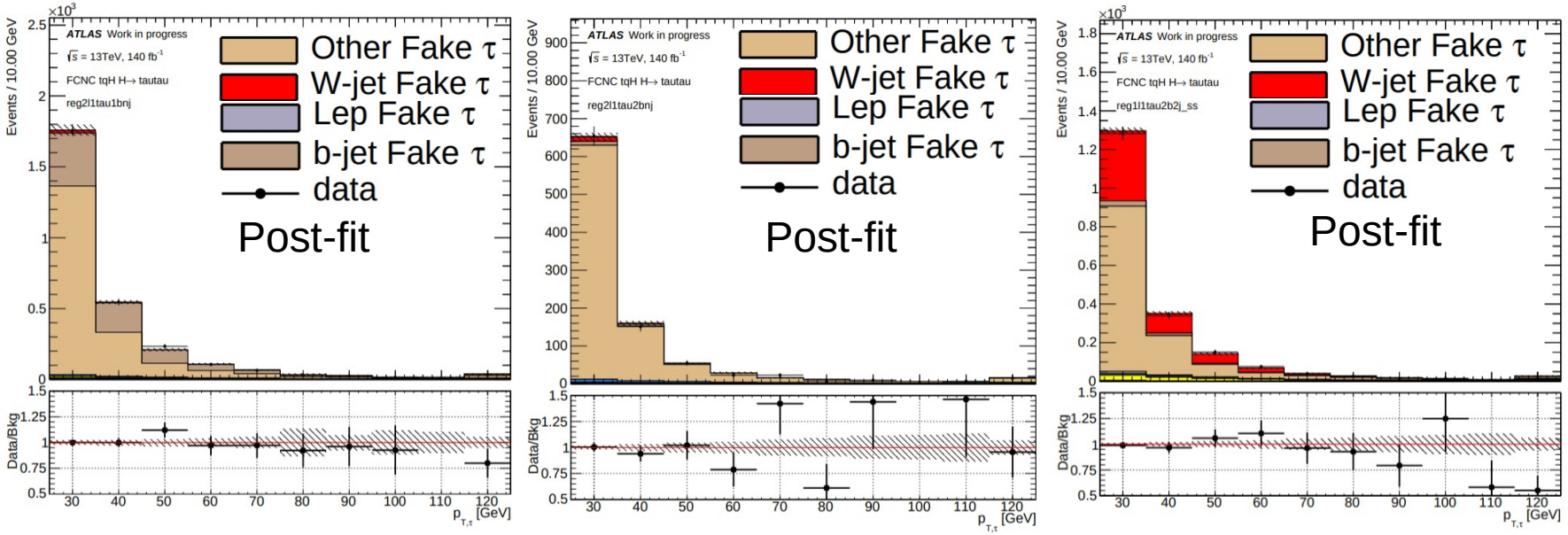
Fake estimation

- Calibrate fake taus in ttbar CR since the dominant background is ttbar.
- CRs are selected designated for different fake origin:
  - 2l+1tau+1bjet (left) for b-jet faking taus
  - 2l+1tau+2bjet (middle) for radiation jet faking taus
  - (1l+1tau)(SS)+2bjet (right) for W decaying jets faking taus



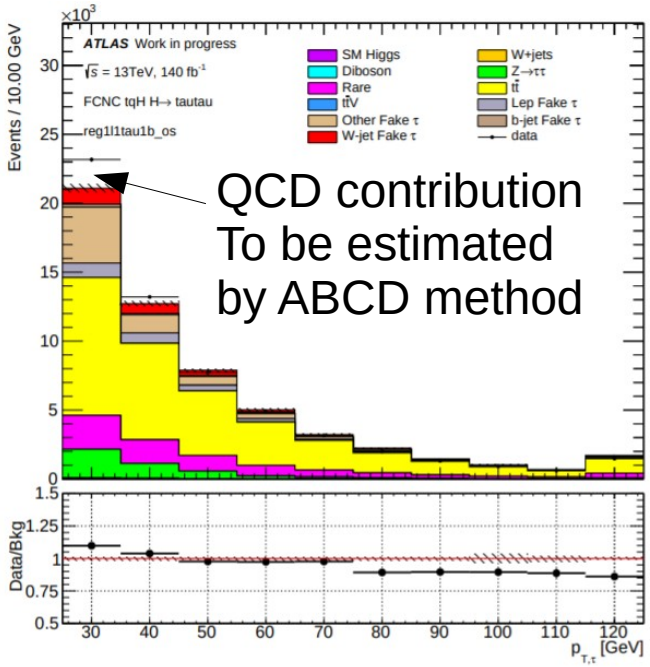
Fake estimation

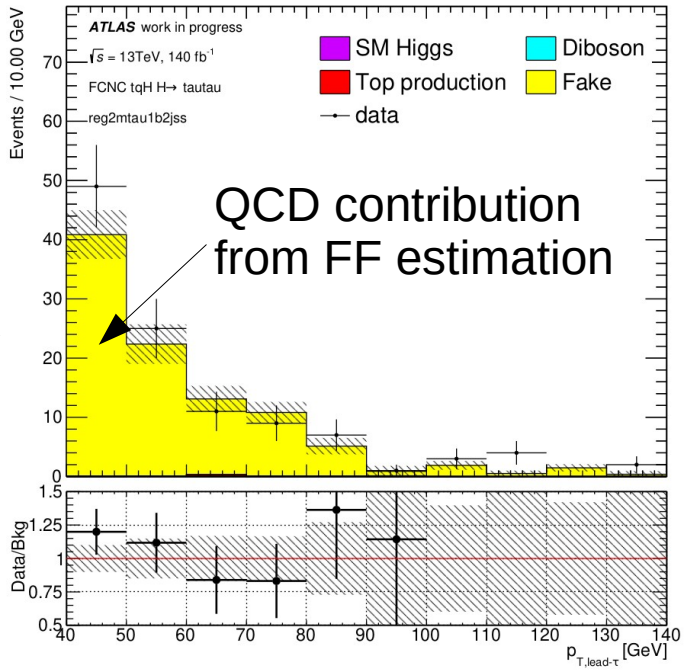
- Combined fit is done in the ttbar CRs to derive the SFs for fake taus with different origins.
- The SFs are applied both in SRs and CRs.
- The modeling in CRs should be good by definition.



Fake estimation

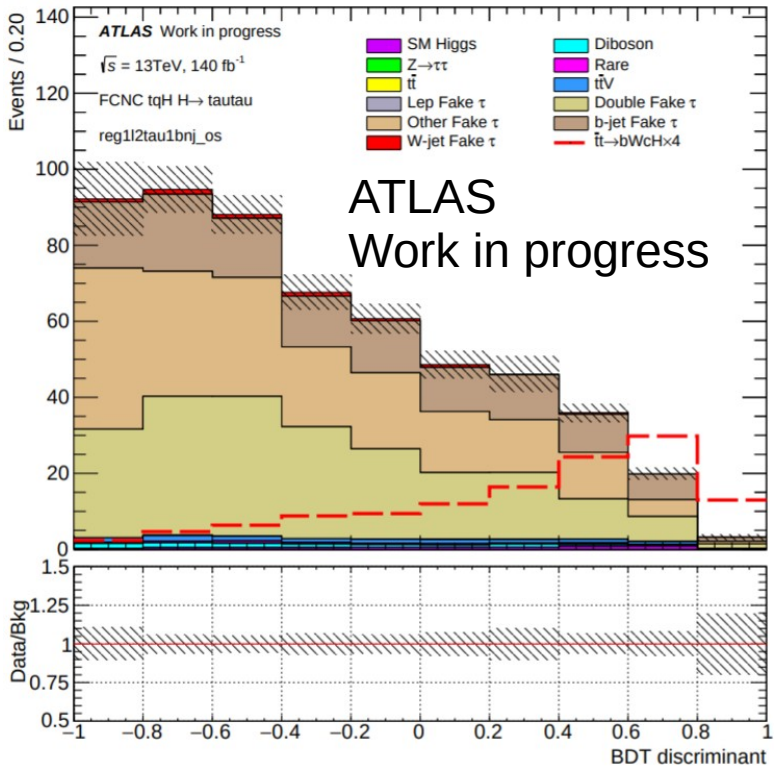
- Need Data Driven to estimate QCD background in the following regions:
  - 1 b-jet + (1 lepton + 1 hadronic tau)(SS)+ at most 2 light flavor jet: OS CR shown below
  - 1 b-jet + (2 hadronic taus)(OS) + at least 2 light flavor jet: SS CR shown below

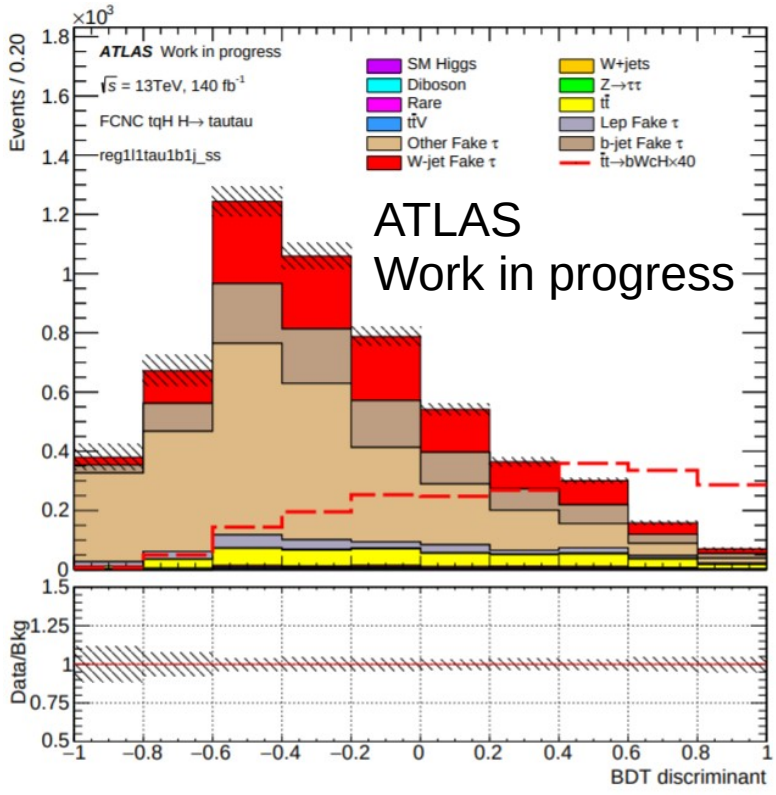




BDT and limit settings

- The BDT training is done to each region separately, optimized with different sets of variables.
- Limit are set by fitting the BDT discriminant.





Results

- Tau channels is getting more competitive after adding the leptonic channels.
- The comparison between new channel (3rd column) and the old channels (1st and 2nd column) is shown below.

Stats only limit	STH $\tau_{\text{lep}}\tau_{\text{had}}$ os	TTH $\tau_{\text{lep}}\tau_{\text{had}}$ os	$l\tau_{\text{had}}\tau_{\text{had}}$ os	Combined
$\bar{t}t \to bWcH$	$2.48^{+0.98}_{-0.69}$	$1.04^{+0.42}_{-0.29}$	$0.31^{+0.13}_{-0.09}$	$0.29^{+0.12}_{-0.08}$
$cg \to tH$	$23.16^{+9.85}_{-6.47}$	$24.66^{+10.87}_{-6.89}$	$3.86^{+1.67}_{-1.08}$	$3.74^{+1.60}_{-1.05}$
tcH merged signal	$2.25^{+0.89}_{-0.63}$	$1.00^{+0.40}_{-0.28}$	$0.29^{+0.12}_{-0.08}$	$0.27^{+0.11}_{-0.08}$
$\bar{t}t \to bWuH$	$2.44^{+0.97}_{-0.68}$	$0.99^{+0.40}_{-0.28}$	$0.29^{+0.12}_{-0.08}$	$0.27^{+0.12}_{-0.08}$
$ug \to tH$	$3.70^{+1.50}_{-1.03}$	$4.30^{+1.72}_{-1.20}$	$0.82^{+0.36}_{-0.23}$	$0.78^{+0.33}_{-0.22}$
tuH merged signal	$1.51^{+0.60}_{-0.42}$	$0.80^{+0.32}_{-0.22}$	$0.21^{+0.09}_{-0.06}$	$0.20^{+0.09}_{-0.06}$

Limits are in unit of BR=0.2%, which is the 36.1fb^{-1} result.

We are expecting a much better result after combining 6 signal regions.
So keep tuned.