THU ATLAS Report for TeV physics

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HEPSummerDay
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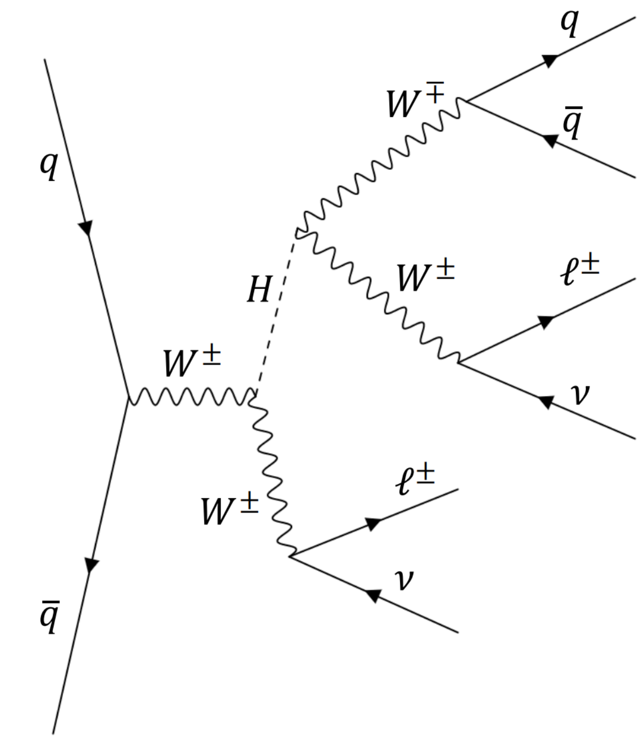
Outline

- A search for heavy Higgs bosons decaying into vector bosons in same-sign two-lepton final states with the ATLAS detector (ATLAS-CONF-2022-033)
  - Analysis contact, reported at LHCP2022
- Search for FCNC interactions of the top quark and the Higgs boson in di-tau final states with the ATLAS detector (ATLAS-CONF-2022-014)
  - Analysis contact, reported at ICHEP2022
- Observation of di-charmonium excess in the four-muon final state with the ATLAS detector (ATLAS-CONF-2022-040)
  - Analysis contact, reported at ICHEP2022
- Summary

Generic Heavy Higgs—Motivation

- No hint of existence of CP even heavy Higgs bosons from previous searches with specific models PRD.98.052008.
- (New Ideas!) Model-independent search for a Generic Heavy Higgs boson (H) having both dim-4 and dim-6 interactions with SM particles
  - Phenomenology study (PLB 804 (2020) 135358): same-sign di-lepton final state (**SS2L**) of associated production with vector boson (VH) channel dominates the sensitivity



$$\mathcal{L}^{(6)}_{HVV} = \sum_n \frac{f_n}{\Lambda^2}\mathcal{O}_n, \quad \Lambda = 5TeV$$

Light Higgs

$$\mathcal{L}^{(4)}_{hWW} = \rho_h g m_W h W^\mu W_\mu$$

$$\mathcal{L}^{(4)}_{hZZ} = \rho_h \frac{g m_W}{2cos^2\theta_W} h Z^\mu Z_\mu$$

heavy Higgs

$$\mathcal{L}^{(4)}_{HWW} = \rho_H g m_W H W^\mu W_\mu$$

$$\mathcal{L}^{(4)}_{HZZ} = \rho_H \frac{g m_W}{2cos^2\theta_W} H Z^\mu Z_\mu$$

$$\mathcal{L}^{(6)}_{HWW} = \rho_H g m_W \frac{f_W}{2\Lambda^2}(W^+_{\mu\nu}W^{-\mu}\partial^\nu H + h.c.) - \rho_H g m_W \frac{f_{WW}}{\Lambda^2} W^+_{\mu\nu}W^{-\mu\nu} H$$

$$\mathcal{L}^{(6)}_{HZZ} = \rho_H g m_W \frac{c^2 f_W + s^2 f_B}{2c^2\Lambda^2} Z_{\mu\nu}Z^\mu\partial^\nu H - \rho_H h m_W \frac{c^4 f_{WW} + s^4 f_{BB}}{2c^2\Lambda^2} Z_{\mu\nu}Z^{\mu\nu} H$$

$$s = sin\theta_W, \quad c = cos\theta_W$$

$$f_B = f_{BB} = 0,$$
$$\rho_h = 1,\ \rho_H = 0.05$$

Only f_W, f_{WW}, m_H are free parameters

Generic Heavy Higgs—Analysis strategy

- Signal signature: two same-sign leptons (e or μ) in association with one large-R jet (J) or two small-R jets (j), and E_T^{miss}.
- **Boosted SR**: leading large-R jet passing LCTopo W-tagger
- **Resolved SR**: invariant mass of two leading small-R jets consistent with a hadronically decaying W-boson

Same-sign 2 lepton (SS2L)

WH(WW)

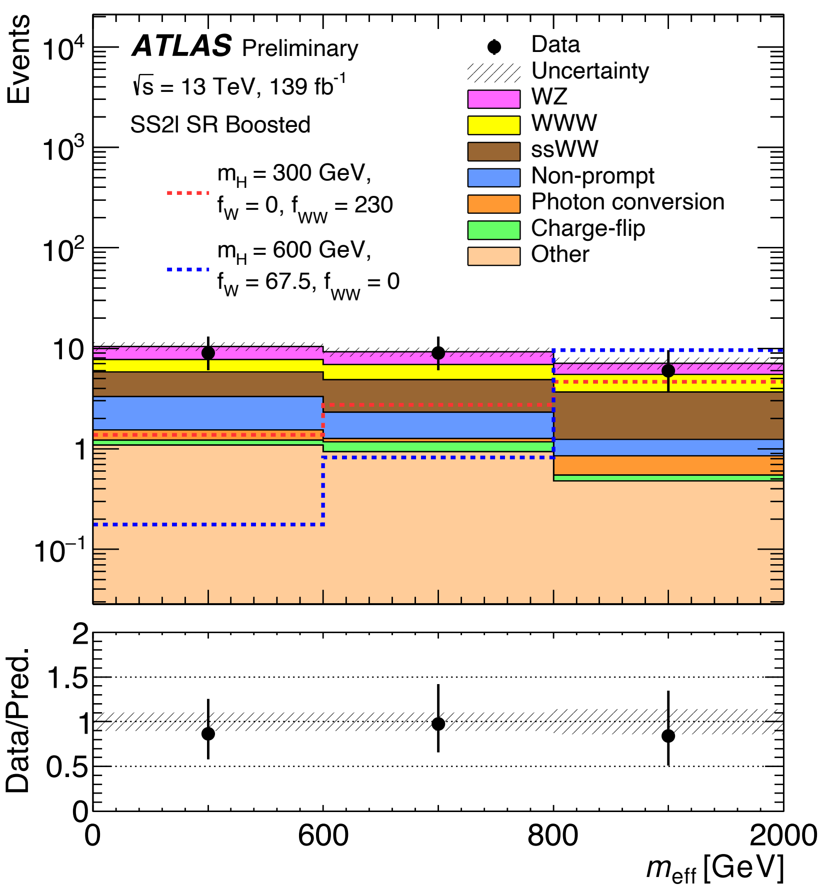
Observable: $M_{eff} = \sum p_T^{\text{Lepton}} + \sum p_T^{\text{V-jets}} + E_T^{\text{miss}}$

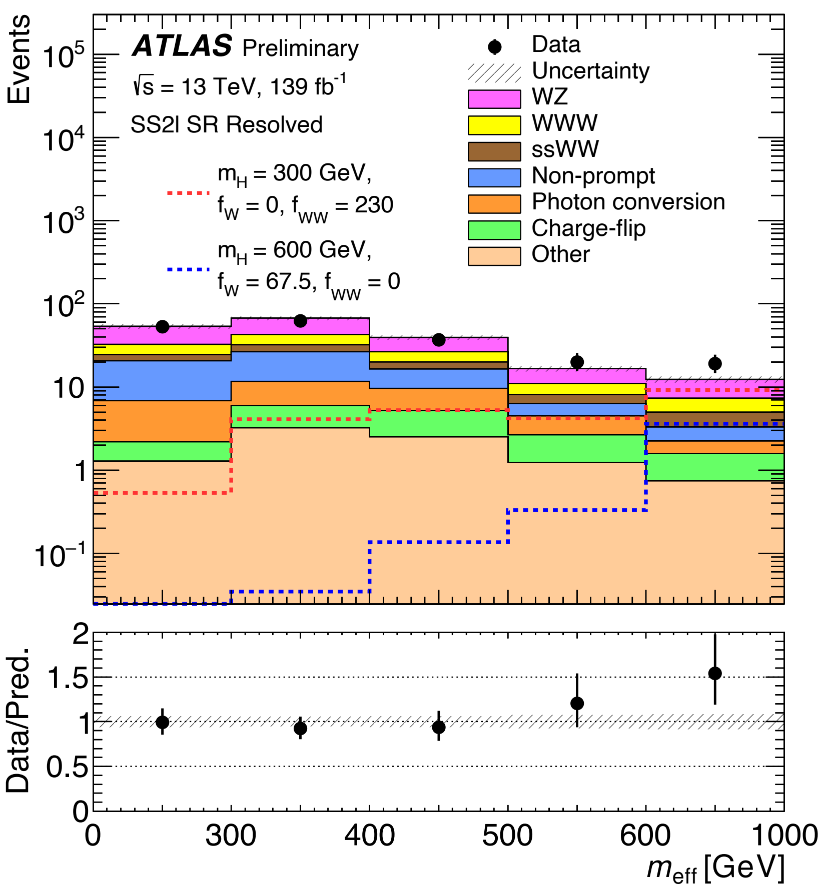
- Dominant Backgrounds:
  - **WZ** and same-sign WW (**ssWW**): MC driven with normalisation from data using dedicated CRs.
  - **WWW**: MC driven
  - **Non-prompt**: data driven

Selections	Boosted SR	Resolved SR	*ssWW* CR	Boosted *WZ* CR	Resolved *WZ* CR
Trigger	Single lepton				
Leptons	two same-sign leptons with $p_T > 27, 20$ GeV; zero additional veto leptons			three leptons with $p_T > 27, 20, 20$ GeV at least one SFOS lepton pair; zero additional veto leptons	
$m_{\ell\ell}$	> 100 GeV			-	
$m_{\ell\ell\ell}$	-			> 100 GeV	
b-jets	zero b-tagged small-R jets				
E_T^{miss}	> 80 GeV	> 60 GeV	> 40 GeV		
Large-R jets	at least one large-R jet with $p_T > 200$ GeV, $\|\eta\| < 2.0$ 50 GeV $< m_J <$ 200 GeV and pass 80% W-tagger WP	zero large-R jets with $p_T > 200$ GeV, $\|\eta\| < 2.0$ 50 GeV $< m_J <$ 200 GeV		at least one large-R jet with $p_T > 200$ GeV, $\|\eta\| < 2.0$ 50 GeV $< m_J <$ 200 GeV and pass 80% W-tagger WP	zero large-R jets with $p_T > 200$ GeV, $\|\eta\| < 2.0$ 50 GeV $< m_J <$ 200 GeV
Small-R jets	-	at least two small-R jets with $p_T > 20$ GeV and $\|\eta\| < 2.5$		-	at least two small-R jets with $p_T > 20$ GeV and $\|\eta\| < 2.5$
m_{jj}	-	50 GeV $< m_{jj} <$ 110 GeV	> 200 GeV	-	-

Generic Heavy Higgs—Fits

- Post-fit distributions for boosted SR and resolved SR with background-only fit
- Good agreement between data and background
- Theoretical systematics have the largest impact in boosted SR, while systematics of non-prompt background estimation have the largest impact in resolved SR
- No obvious excess is observed

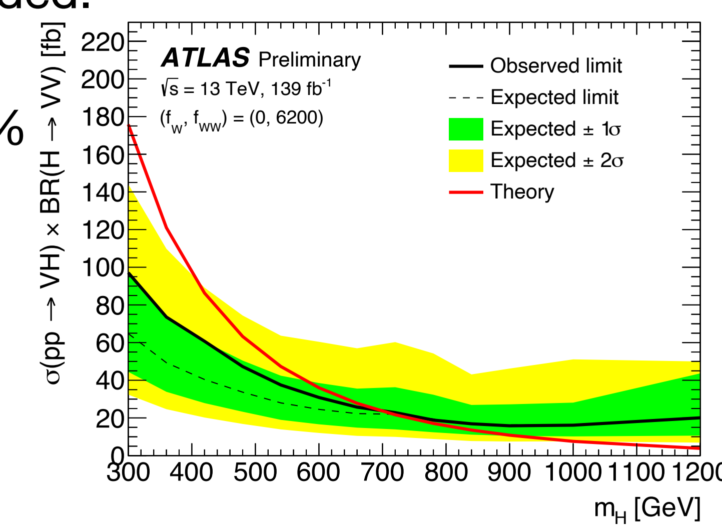


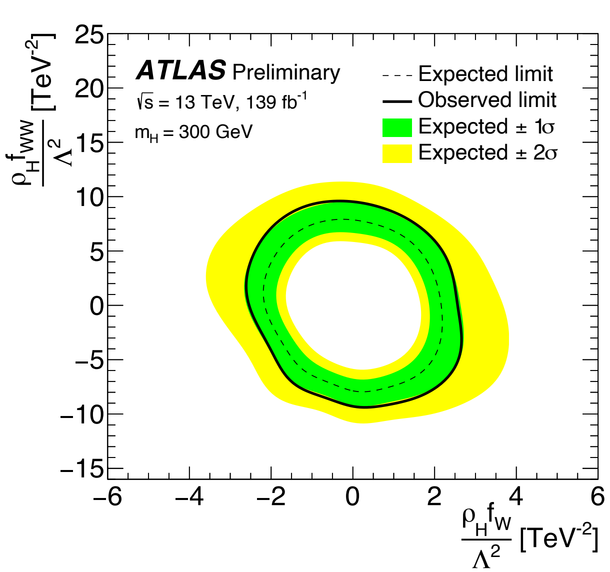


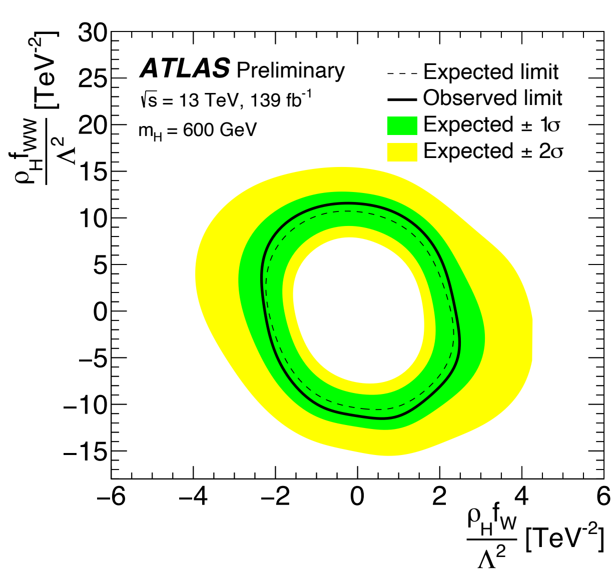
Uncertainty of channel	Boosted SR	Resolved SR
Total systematic uncertainties	10.0%	4.1%
Data driven non-prompt	1.3%	3.3%
Theoretical uncertainties	8.9%	2.6%
MC statistical uncertainties	3.0%	1.9%
Floating normalizations	3.5%	1.2%
Small-*R* jet	-	1.1%
Data driven photon conversion	0.2%	0.9%
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.2%	0.7%
b-tagging	0.8%	0.5%
Data driven charge-flip	0.1%	0.3%
Electron	0.5%	0.2%
Muon	0.6%	0.2%
Pile-up reweighting	0.2%	0.2%
Large-*R* jet	1.1%	0.2%
W-tagger	3.7%	-

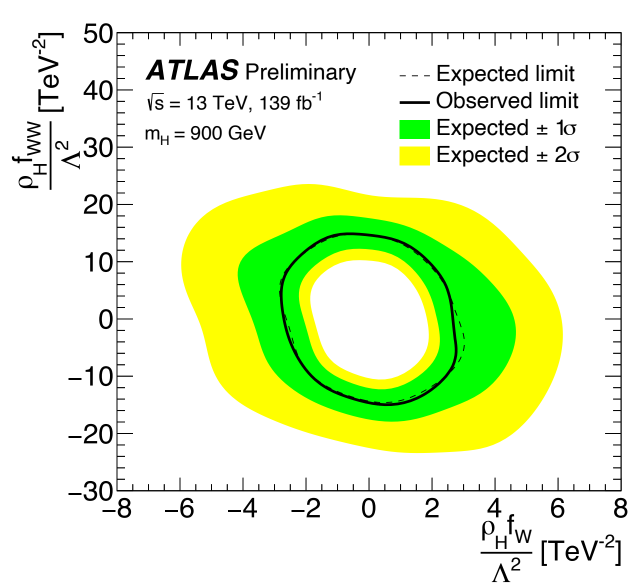
Generic Heavy Higgs—Results

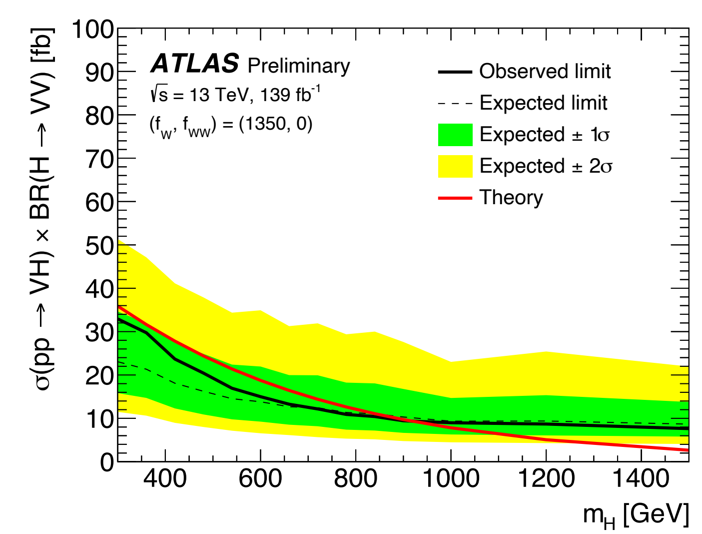
- Observed and expected exclusion contours at 95% confidence level in $(\frac{\rho_H f_W}{\Lambda^2}, \frac{\rho_H f_{WW}}{\Lambda^2})$ parameter space.
  - With m_H = 300 GeV, $|\frac{\rho_H f_W}{\Lambda^2}| > 2.7\ \text{TeV}^{-2}$ and $|\frac{\rho_H f_{WW}}{\Lambda^2}| > 10\ \text{TeV}^{-2}$ can be excluded.
  - With m_H = 600 GeV, $|\frac{\rho_H f_W}{\Lambda^2}| > 2.5\ \text{TeV}^{-2}$and $|\frac{\rho_H f_{WW}}{\Lambda^2}| > 12\ \text{TeV}^{-2}$ can be excluded.
  - With m_H = 900 GeV, $|\frac{\rho_H f_W}{\Lambda^2}| > 2.9\ \text{TeV}^{-2}$ and $|\frac{\rho_H f_{WW}}{\Lambda^2}| > 15\ \text{TeV}^{-2}$ can be excluded.
- Upper limit on heavy Higgs production (pp->VH) cross section as a function of m_H at 95% confidence level with 2 set of fixed (f_W, f_{WW}): (0, 6200) and (1350, 0).
  - With (f_W, f_{WW}) = (0, 6200), heavy Higgs with mass up to **700** GeV can be excluded,
  - with (f_W, f_{WW}) = (1350, 0), heavy Higgs with mass up to **900** GeV can be excluded.











FCNC tqH — Motivation

Flavor-changing neutral currents (FCNC) decays

- are forbidden at tree level
- occur at one-loop level but are strongly suppressed by the **GIM mechanism**
- significantly enhanced in BSM extensions (maximum up to ~10^{-3})
- Any observation of top FCNC = BSM physics

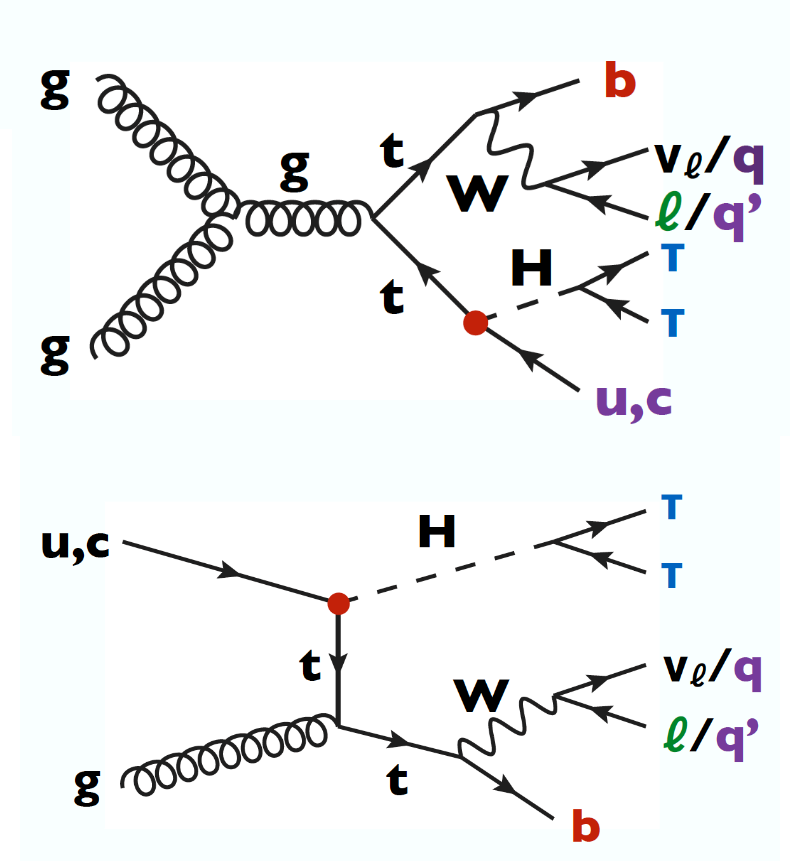
Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

1311.2028

FCNC tqH—Analysis strategy

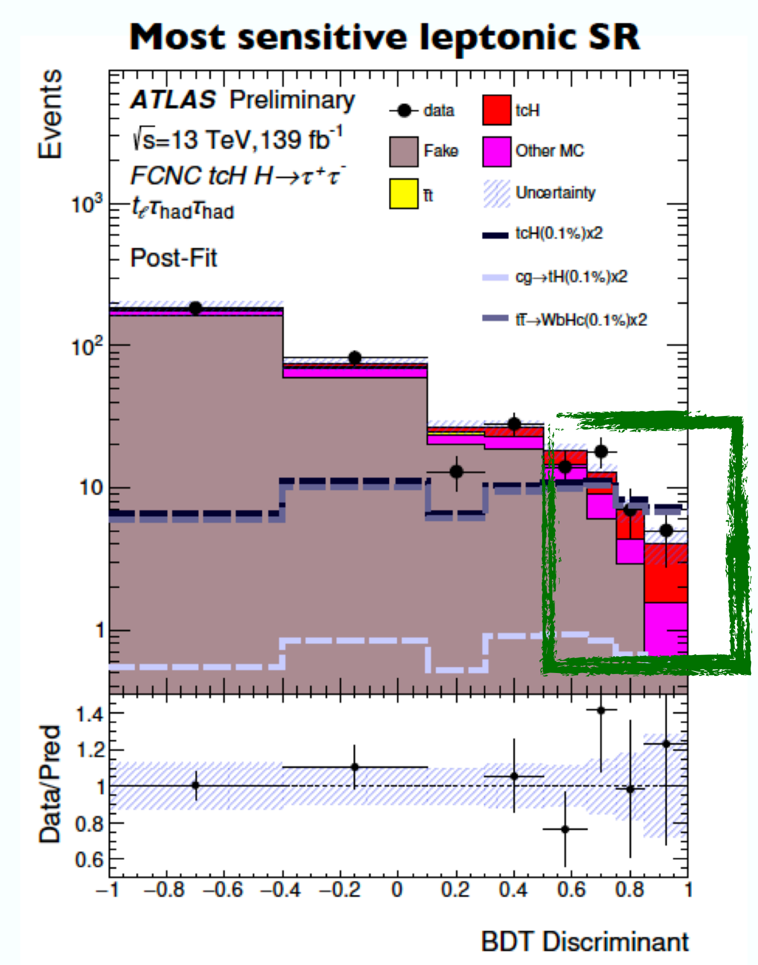
- 7 SRs are defined based on:
  - # of leptons, (b-)jet multiplicities, tau decay mode, W decay mode
  - $t_\ell(t_h)$: W from SM top decays leptonically (hadronically)
  - $\tau_{lep}(\tau_{had})$: tau lepton decays leptonically (hadronically)
- Lep channel: data-MC scale factors from tt CRs (2 b-tags or 2 leptons)
- Had channel: events with looser τ ID multiplied with fake factors (from W+jets CR)

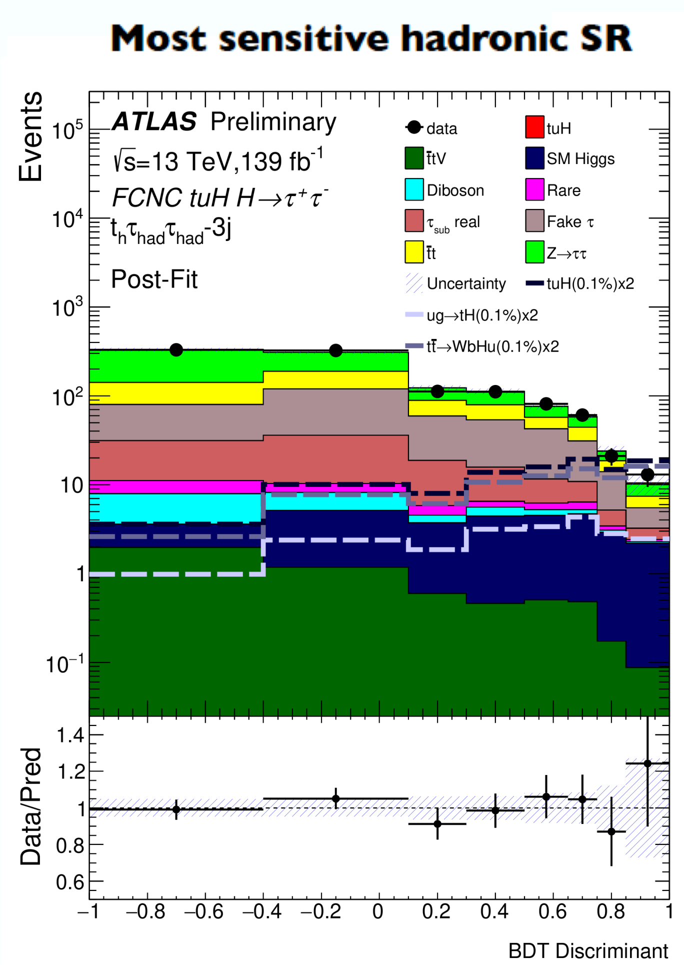
Requirement	leptonic channel $t_h\tau_{\text{lep}}\tau_{\text{had}}$	$t_l\tau_{\text{had}}\tau_{\text{had}}$	$t_l\tau_{\text{had}}$	hadronic channel $t_h\tau_{\text{had}}\tau_{\text{had}}$
Trigger	single-lepton trigger			di-τ trigger
Leptons	=1 isolated e or μ			no isolated e or μ
τ_{had}	=1 τ_{had}	2 τ_{had}	=1 τ_{had}	2 τ_{had}
Electric charge (Q)	$Q_\ell \times Q_{\tau_{\text{had},1}} < 0$	$Q_{\tau_{\text{had},1}} \times Q_{\tau_{\text{had},2}} < 0$	$Q_\ell \times Q_{\tau_{\text{had},1}} > 0$	$Q_{\tau_{\text{had},1}} \times Q_{\tau_{\text{had},2}} < 0$
Jets	3, ≥ 4 jets	≥1 jets	2, ≥3 jets	3, ≥4 jets
b-tagging	=1 b-tagged jets			



FCNC tqH—Fits

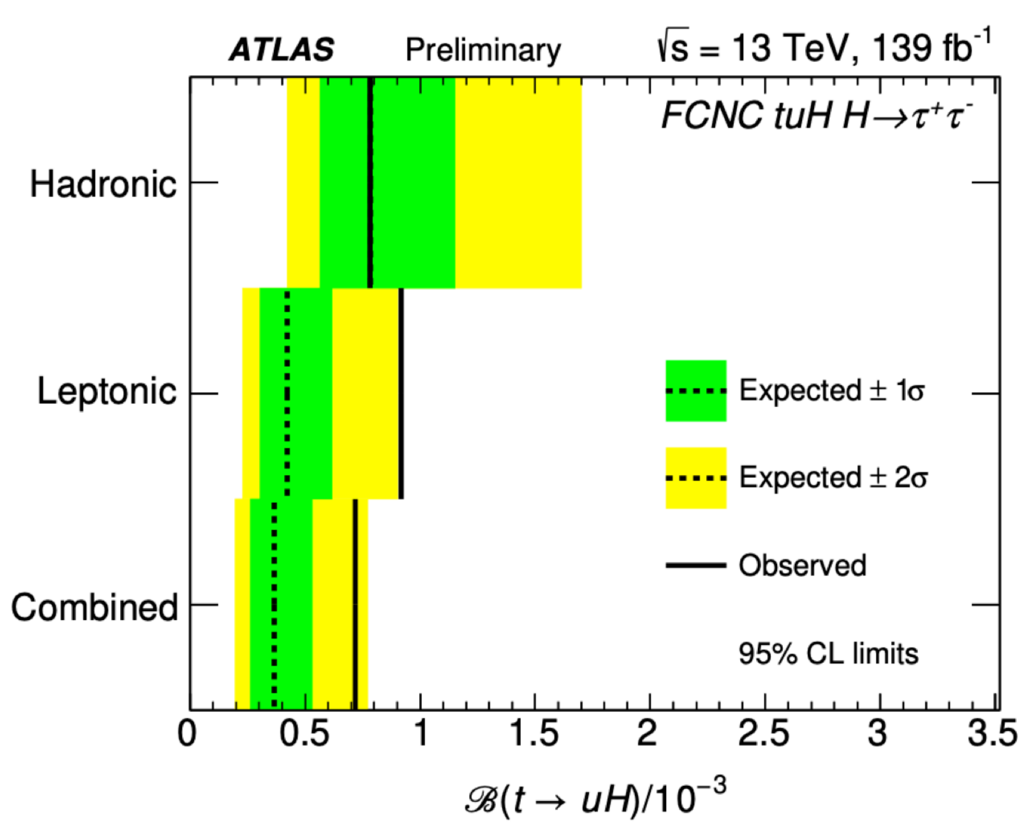
- Separation of both signal modes from background using GBDT method
- Train BDT separately for decay and production processes, tcH and tuH, but it gives similar sensitivity.
  - One BDT per signal region with 12-17 kinematic input features
- BDT output score as an input to the profile-likelihood fit to data
- Small excess of data are observed with significance of 2.3σ, mainly in tlep+2hadtau

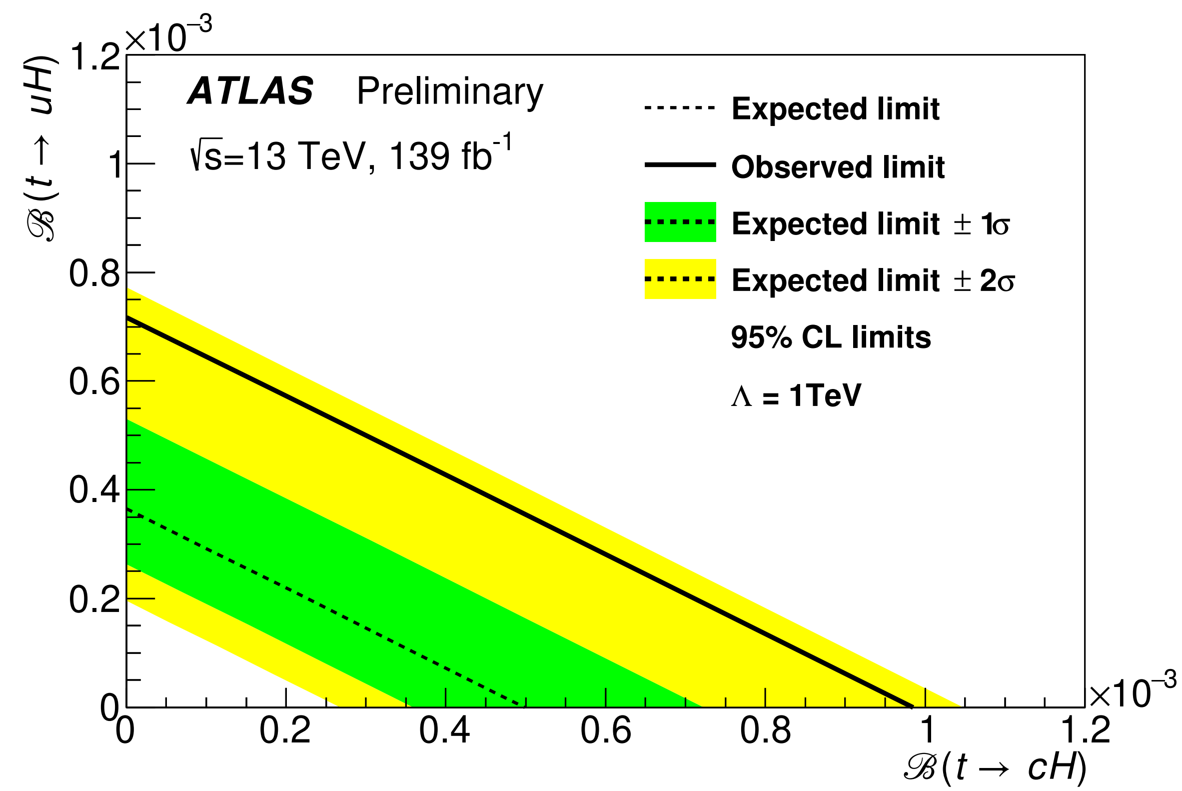




FCNC tqH—Results

- Comparison between previous (36fb^{-1} JHEP05(2019)123) and current observed limits show a significant improvement using the full Run-2 dataset with:
  - a factor of ~5 (2.5) for expected (observed) upper limit
  - The statistical uncertainty is the dominant contribution





di-charmonium

Observation of di-charmonium excess in the four-muon final state with the ATLAS detector

NEW

Using $\mathcal{L} = 139\ \text{fb}^{-1}$ of 13 TeV of ATLAS Run-2 data collected in 2015 to 2018

Search in the 4μ final state through the di-J/ψ and $J/\psi + \psi(2S)$ channels

di-$\psi(2S) \rightarrow 4\mu$ statistically not accessible with Run-2 data

Signal simulated with JHU: TQ mass = 6.9 GeV, width = 0.1 GeV, spin = 0

Background processes (simulated with Pythia8):

prompt di-J/ψ : Single Parton Scattering (SPS) and Double Parton Scattering (DPS)

non prompt di-J/ψ : $b\bar{b} \rightarrow J/\psi J/\psi$

"Others" background: single (prompt or non prompt) charmonium plus fake muons, non-peaking background containing no real charmonium candidates

(CRs defined in sidebands and by requiring one charmonium containing a non muon track)

Event selection and signal and control regions:

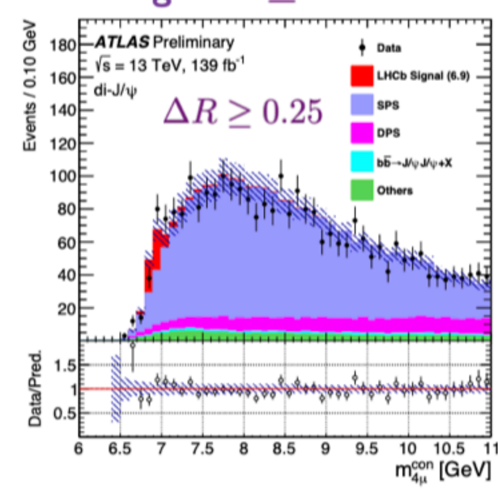
Signal region	SPS/DPS control region	non-prompt region
Di-muon or tri-muon triggers, Opposite charged muons from the same J/ψ or $\psi(2S)$ vertex, Loose muon ID, $p_T^{1,2,3,4} > 4, 4, 3, 3$ GeV and $\lvert\eta_{1,2,3,4}\rvert < 2.5$ for the four muons, $m_{J/\psi} \in \{2.94, 3.25\}$ GeV, or $m_{\psi(2S)} \in \{3.56, 3.80\}$ GeV, Loose vertex cuts $\chi^2_{4\mu}/N < 40$ and $\chi^2_{\text{di-}\mu}/N < 100$,		
Vertex $\chi^2_{4\mu}/N < 3$, $L^{4\mu}_{xy} < 0.2$ mm, $\lvert L^{\text{di-}\mu}_{xy}\rvert < 0.3$ mm,		Vertex $\chi^2_{4\mu}/N > 6$, $\lvert L^{\text{di-}\mu}_{xy}\rvert > 0.4$ mm
$m_{4\mu} < 7.5$ GeV, $\Delta R < 0.25$ between charmonia	7.5 GeV$< m_{4\mu} < 12.0$ GeV (SPS) 14.0 GeV$< m_{4\mu} < 25.0$ GeV (DPS)	

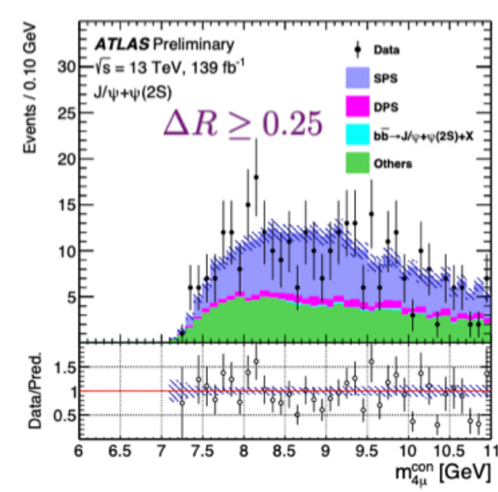
N = 5

w.r.t primary vertex closest in z

9

SPS mass shape validated using $\Delta R \geq 0.25$ CR





Cite Evelina's talk at ICHEP2022

di-charmonium

Observation of di-charmonium excess in the four-muon final state with the ATLAS detector

Fit Models

Unbinned maximum likelihood fits on the four-muon mass spectra < 11 GeV, no ΔR cut

fit signal region $\Delta R < 0.25$, fit control region $\Delta R \geq 0.25$, with transfer factors for background yields from MC or data driven methods

The signal probability density function (PDF) consists of several interfering S-wave Breit-Wigner resonances, convoluted with a mass resolution function $R(\alpha)$

$$f_s(x) = \left|\sum_{i=0}^{2} \frac{z_i}{x^2 - m_i^2 + i m_i \Gamma_i}\right|^2 \sqrt{1 - \frac{4m_{J/\psi}^2}{x^2}} \otimes R(\alpha)$$

z_i : complex numbers representing the amplitudes
z_1 fixed to unity with zero phase

no interference with NRSPS (LHCb model)

di-J/ψ channel:

models with different numbers of resonances (2 or 3) are compared in terms of χ^2 or toy MC distributions

$J/\psi + \psi(2S)$ channel:

Model A: same resonances as in di-J/ψ, plus a 4th standalone resonance

$$f_s(x) = \left(\left|\sum_{i=0}^{2} \frac{z_i}{x^2 - m_i^2 + i m_i \Gamma_i}\right|^2 + \left|\frac{z_3}{x^2 - m_3^2 + i m_3 \Gamma_3}\right|^2\right) \sqrt{1 - \left(\frac{m_{J/\psi} + m_{\psi(2S)}}{x}\right)^2} \otimes R(\alpha)$$

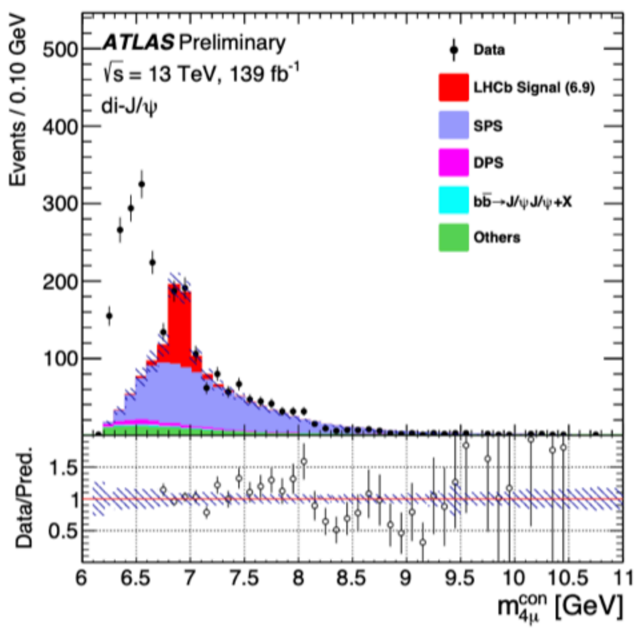
Model B: a single resonance

di-charmonium

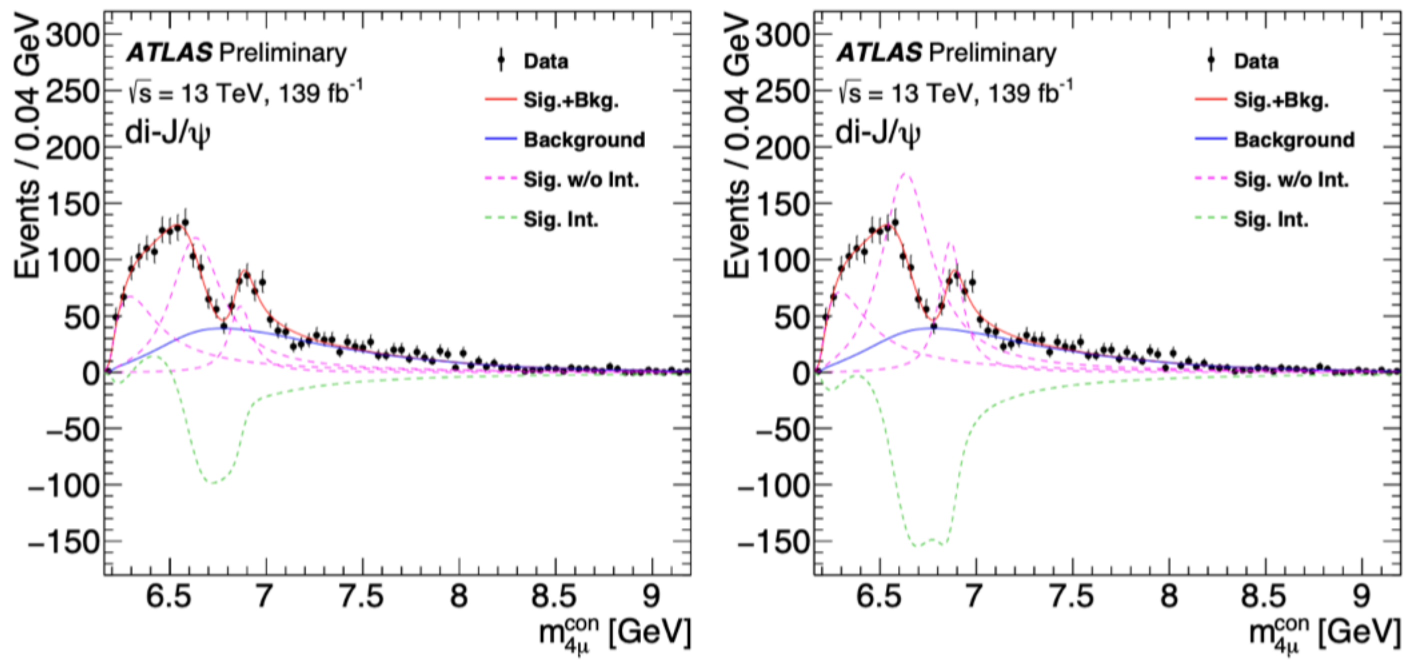
Observation of di-charmonium excess in the four-muon final state with the ATLAS detector

Results in di-J/ψ channel

4μ mass distribution from data and background predictions before fit



fitted mass in SR, 3-resonance fit (2 out of 4 degenerate solutions for z_i)



feed-down from $J/\psi + \psi(2S)$ or higher di-charmonium resonances not included

significance of third resonance: 10σ

using LHCb Model I values for 3rd resonance gives similar results

LHCb Model II fit (interference with NRSPS) disfavoured based on fit quality

70% worse fit quality for 2-resonance fit

Fitted masses and widths

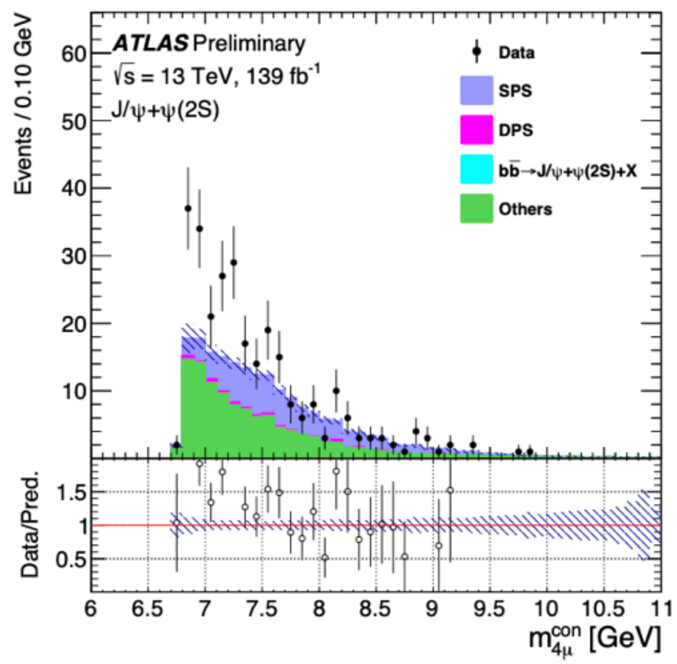
(GeV)	m_0	Γ_0	m_1	Γ_1
di-J/ψ	$6.22 \pm 0.05^{+0.04}_{-0.05}$	$0.31 \pm 0.12^{+0.07}_{-0.08}$	$6.62 \pm 0.03^{+0.02}_{-0.01}$	$0.31 \pm 0.09^{+0.06}_{-0.11}$
	m_2	Γ_2	—	
consistent with LHCb	$6.87 \pm 0.03^{+0.06}_{-0.01}$	$0.12 \pm 0.04^{+0.03}_{-0.01}$	—	

6.9 GeV resonance confirmed, best fit with 3 interfering resonances, other explanations possible

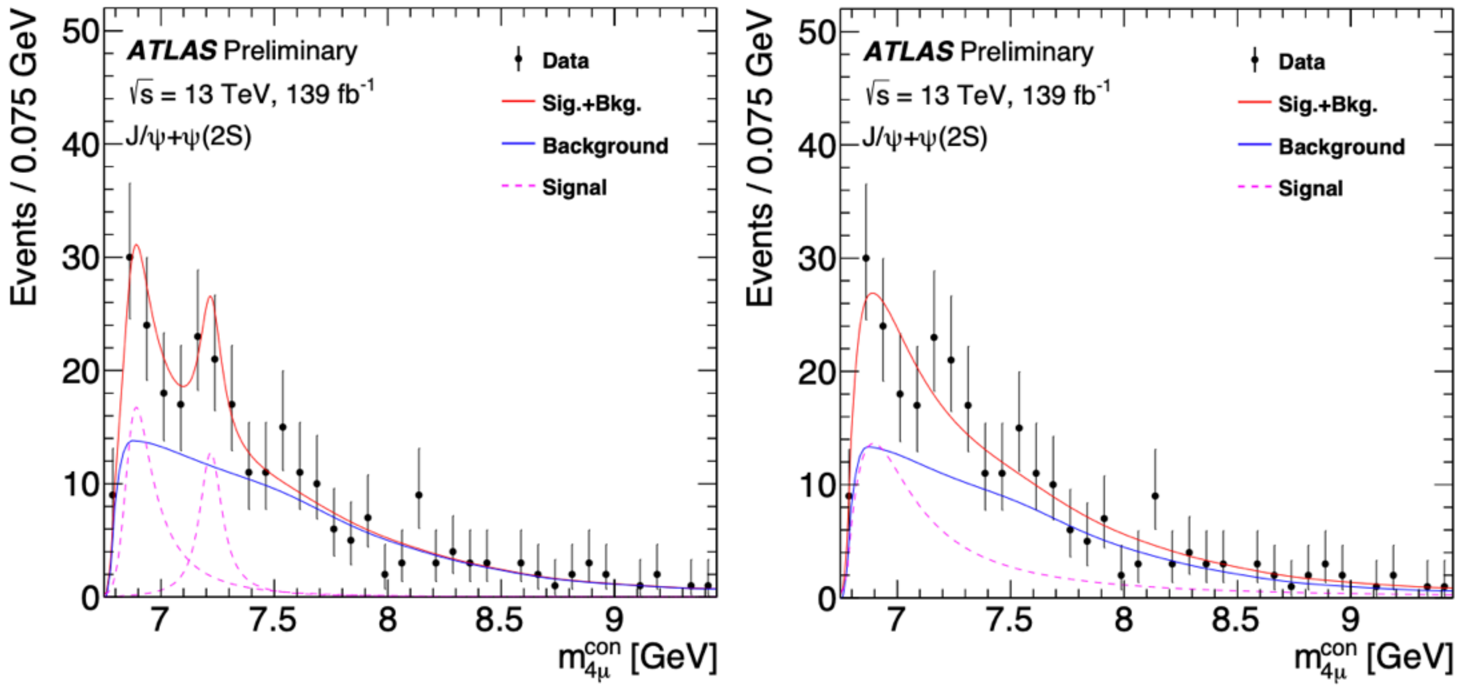
Observation of di-charmonium excess in the four-muon final state with the ATLAS detector

Results in $J/\psi + \psi(2S)$ channel

4μ mass distribution from data and background predictions before fit



fitted mass in SR (Model A and Model B)



significance Model A: 4.6σ

second resonance (7.2 GeV): 3.2σ

(hint for a 7.2 GeV resonance in LHCb data)

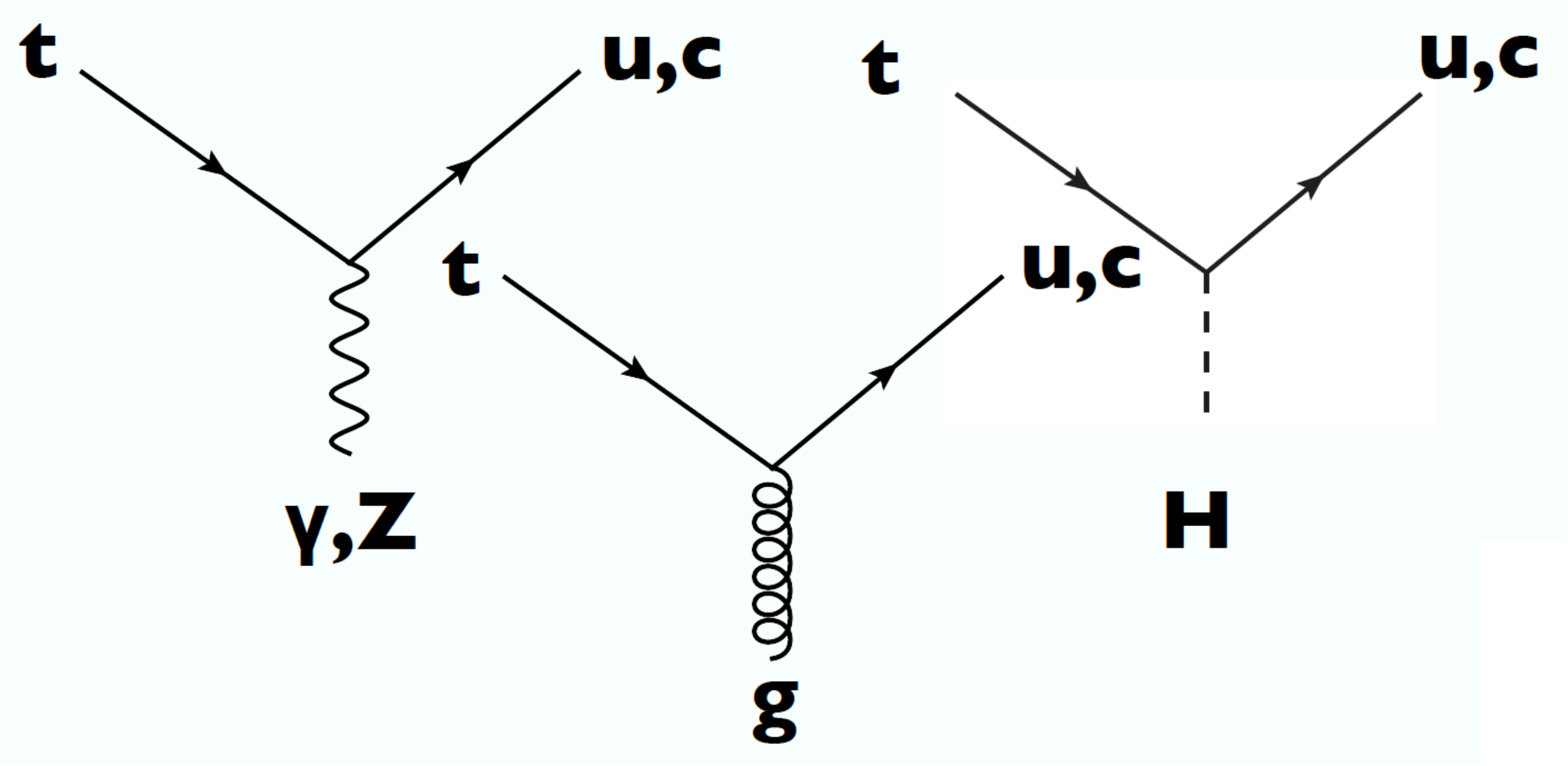
significance Model B: 4.3σ

Fitted masses and widths

(GeV)		m_3	Γ_3
$J/\psi+\psi(2S)$	model A	$7.22 \pm 0.03^{+0.02}_{-0.03}$	$0.10^{+0.13+0.06}_{-0.07-0.05}$
	model B	$6.78 \pm 0.36^{+0.35}_{-0.54}$	$0.39 \pm 0.11^{+0.11}_{-0.07}$

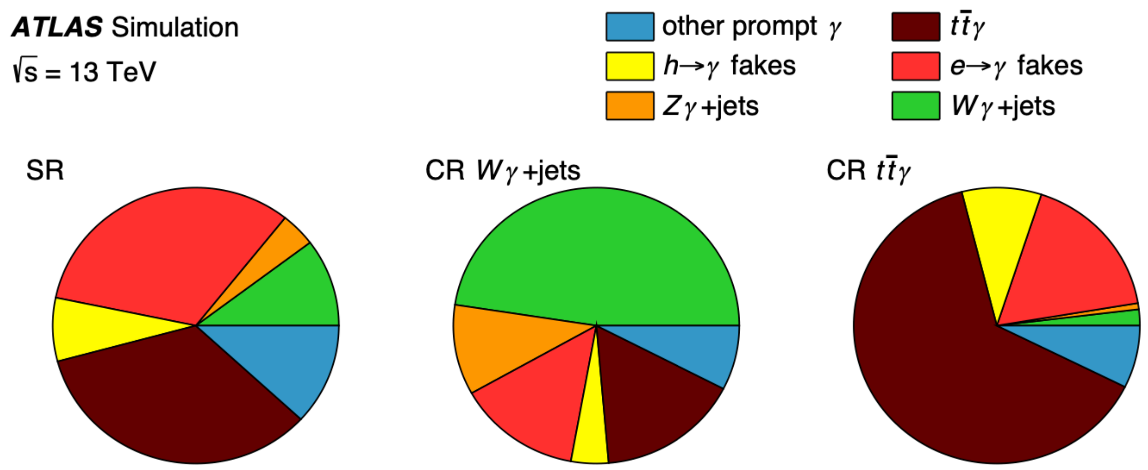
Evidence for an enhancement at 6.9 GeV and a resonance at 7.2 GeV, other explanations possible

FCNC decay via other bosons

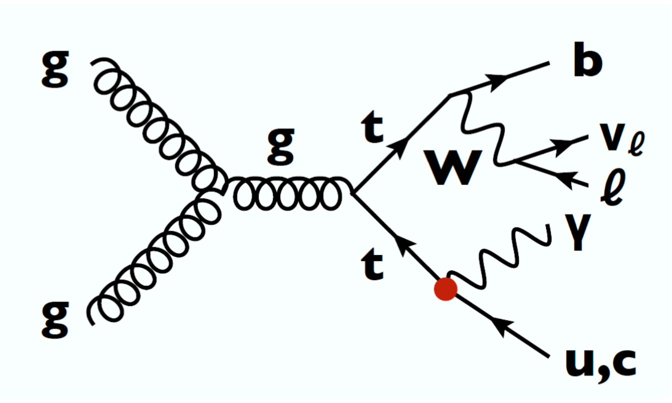


FCNC $t \to q\gamma$ 2205.02537

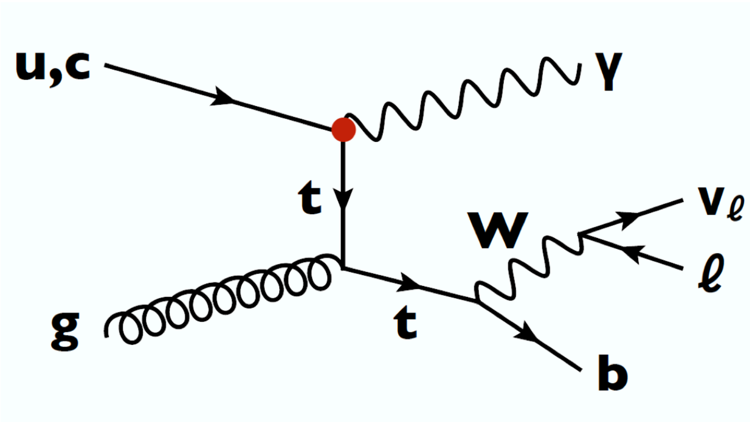
- Analysis Strategy:
  - optimize for FCNC production & decay
  - One SR: 1γ + 1lep + missing Et >30GeV + 1 b-jet + >= 1jet
  - Control regions for main background processes with prompt photons
    - CR $t\bar{t} + \gamma$
    - CR $W + \gamma +$ jets
    - Normalization of $t\bar{t} + \gamma$ and $W + \gamma +$ jets free-floating in the fit
  - Other main background: photon fakes (data-driven estimate of $e \to \gamma$ and $h \to \gamma$ fakes)



Background composition



FCNC decay



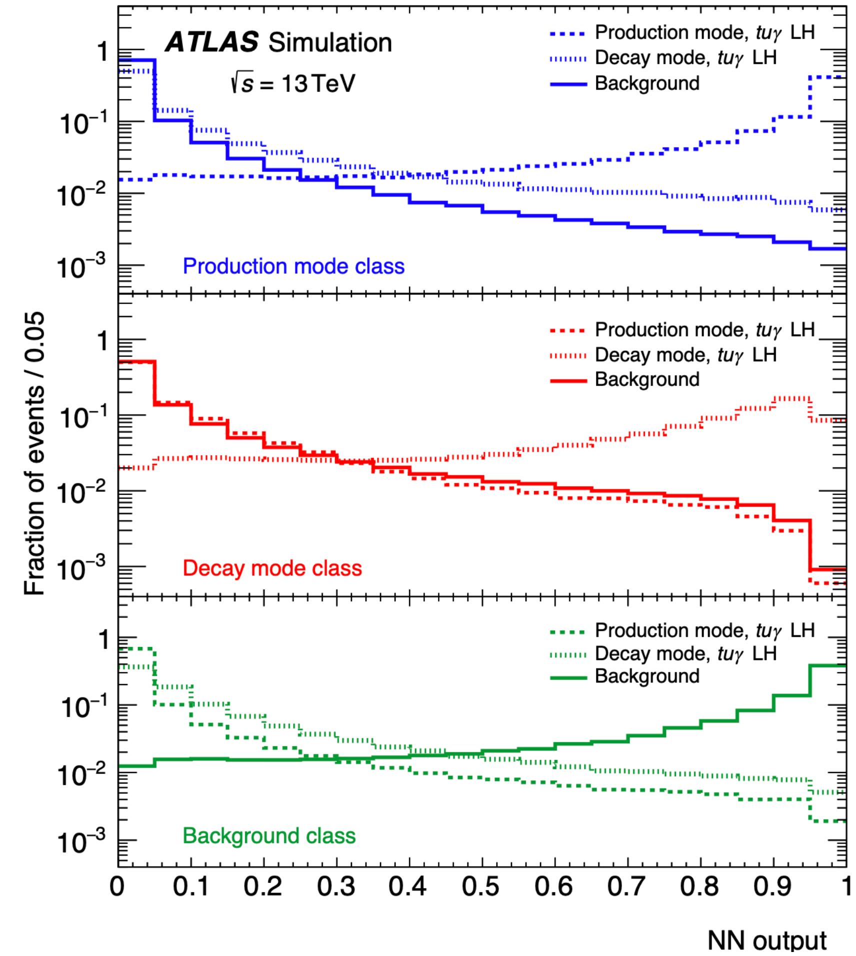
FCNC production

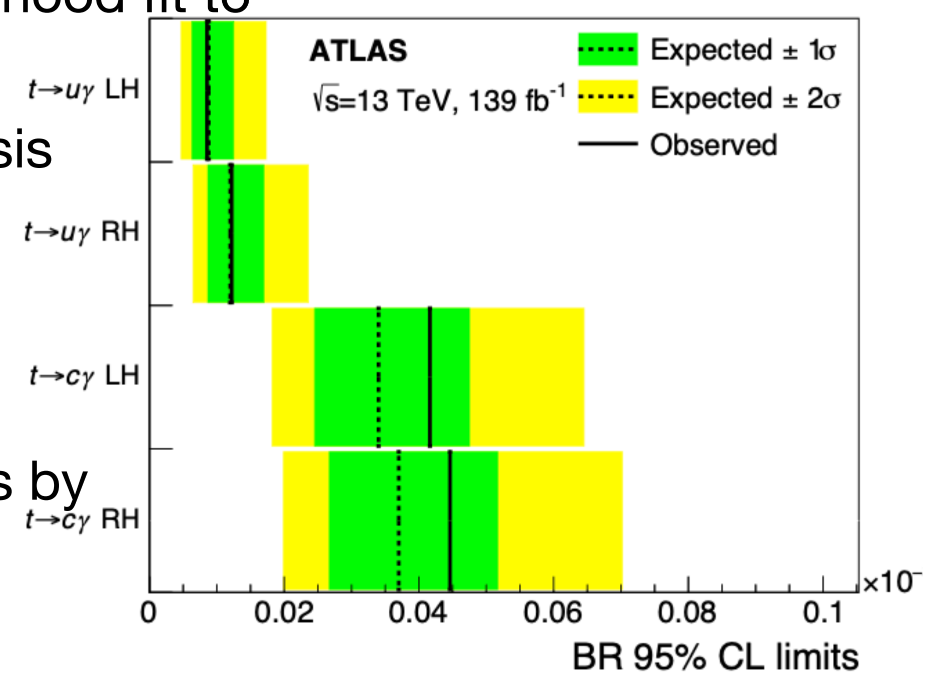
FCNC $t \to q\gamma$ [2205.02537]

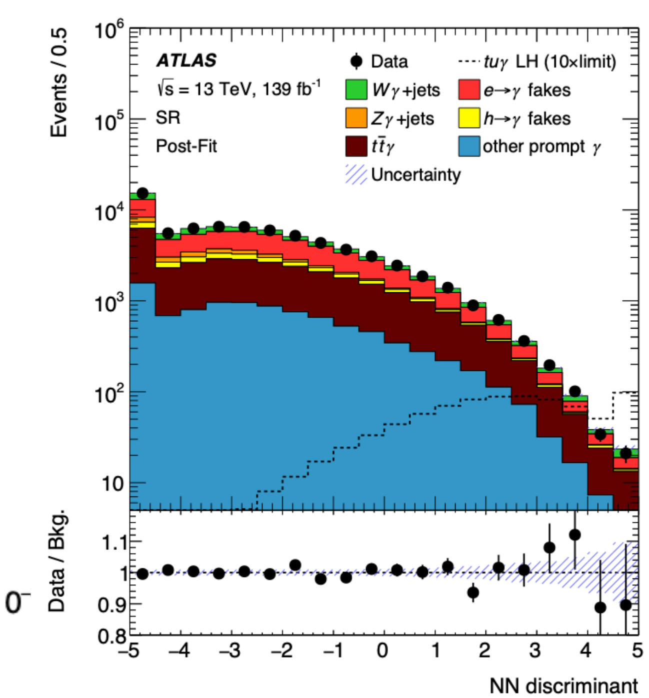
- Multi-class neural network (NN): for separation of both signal modes from background
  - ~ 30% better than binary classification
  - separate network for up & charm (2 NNs)
  - for classification of prod, decay, bkg (three output class, multinomial classifier)
    - $\overrightarrow{y} = (y_{prod}, y_{de}, y_{bkg})$
- Signal outputs combined in **likelihood ratio**:

$$D = \ln \frac{a * y_{prod} + (1 - a) * y_{dec}}{y_{bkg}}$$

- background model in agreement with data
- NN output distribution used for a profile-likelihood fit to data
  - Factors 3.3 - 5.4 better than 81fb^{-1} analysis ([1908.08461])
    - adding events with more than one jet
  - Statistical uncertainties dominate
    - All systematics together worsen limits by ~20% ($tu\gamma$) or ~40% ($tc\gamma$)





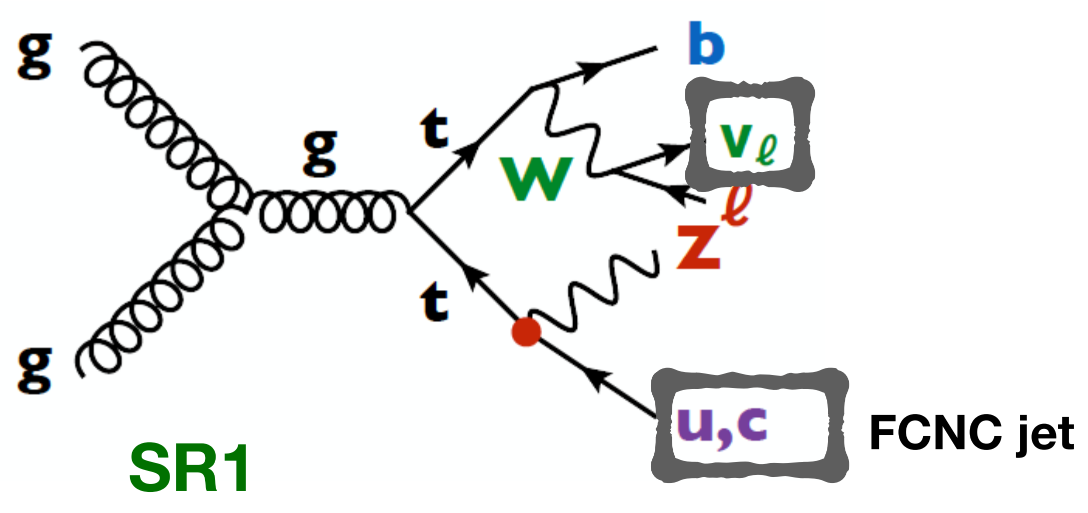


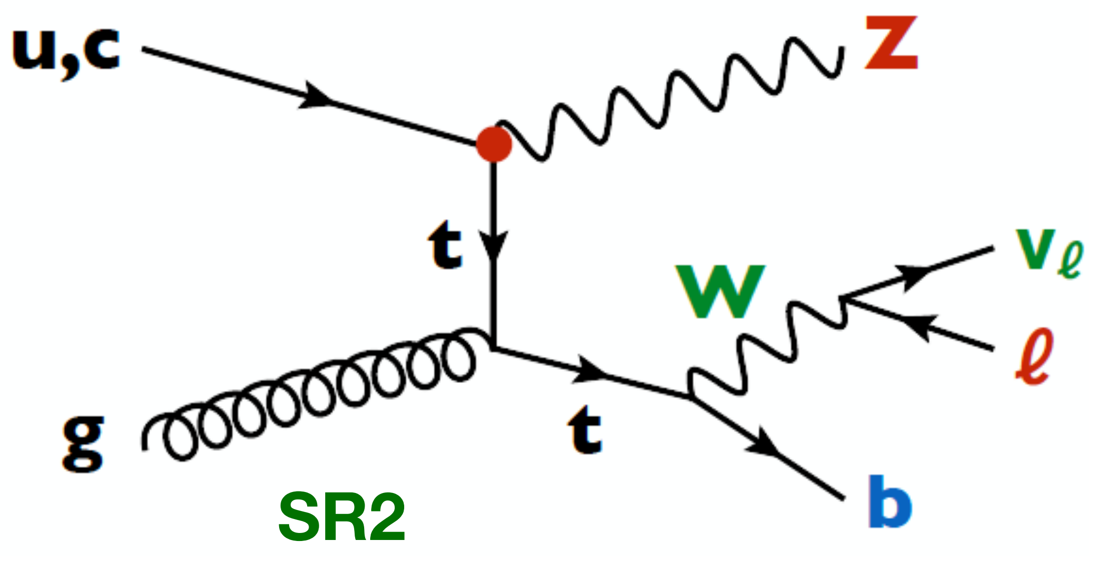
FCNC $t \to qZ$ ATLAS-CONF-2021-049

- Analysis Strategy
  - $Z \to \ell\ell$ with $\ell = e, \mu$ isolated leptons and $m_{\ell\ell} \sim m_Z$, 1b-jet, W decay leptonically
  - **2 SRs**: SR1 (FCNC decay) SR2 (FCNC production)
  - 4 CRs: ttbar CR, ttbarZ CR, Side-band CRs (mass of SM top and FCNC top)
  - χ^2 minimization to

$$\chi^2_{t\bar{t}} = \frac{(m^{reco}_{j_a\ell\ell} - m_{t_{FCNC}})^2}{\sigma^2_{t_{FCNC}}} + \frac{(m^{reco}_{j_b\ell_W\nu} - m_{t_{SM}})^2}{\sigma^2_{t_{SM}}} + \frac{(m^{reco}_{\ell_W\nu} - m_W)^2}{\sigma^2_W}$$

    - Central value of masses and widths are taken from fit to reconstructed FCNC decay signal events.
    - Select FCNC jet (for FCNC decay only, for FCNC production, χ^2_{tZ} is constructed.)
    - Fit $P_z(\nu)$





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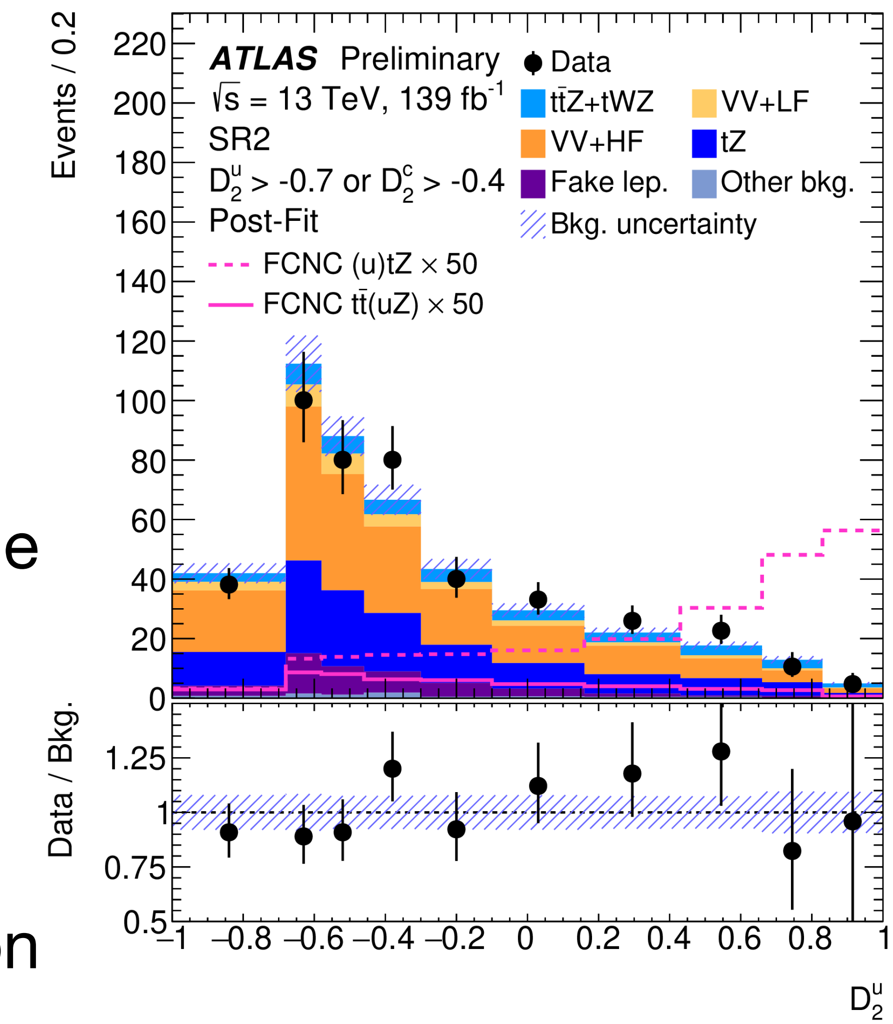
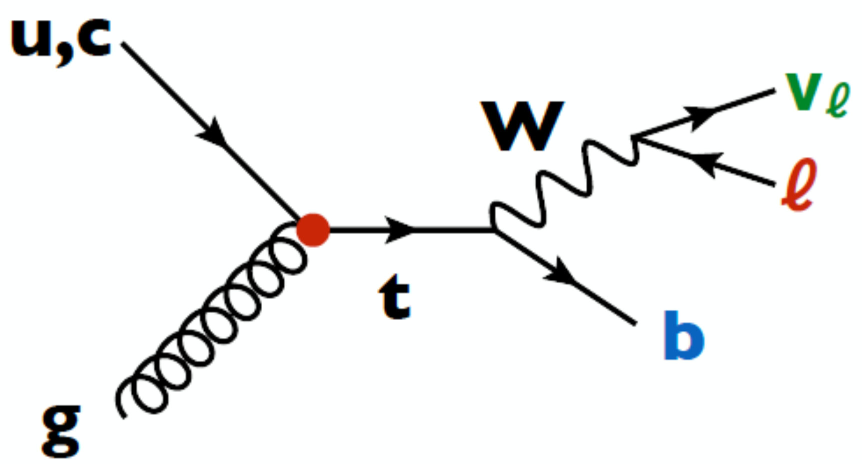
			SRs+CRs	
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	LH	6.2	$4.9^{+2.1}_{-1.4}$
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	RH	6.6	$5.1^{+2.1}_{-1.4}$
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZc	LH	13	11^{+5}_{-3}
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZc	RH	12	10^{+4}_{-3}
$\lvert C_{uW}^{(13)*}\rvert$ and $\lvert C_{uB}^{(13)*}\rvert$	tZu	LH	0.15	$0.13^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(31)}\rvert$ and $\lvert C_{uB}^{(31)}\rvert$	tZu	RH	0.16	$0.14^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(23)*}\rvert$ and $\lvert C_{uB}^{(23)*}\rvert$	tZc	LH	0.22	$0.20^{+0.04}_{-0.03}$
$\lvert C_{uW}^{(32)}\rvert$ and $\lvert C_{uB}^{(32)}\rvert$	tZc	RH	0.21	$0.19^{+0.04}_{-0.03}$

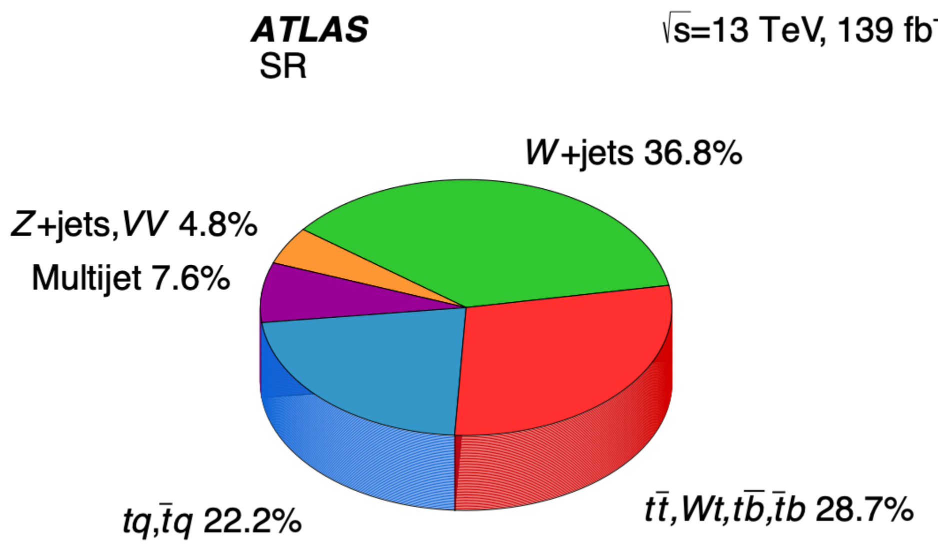
- Signal separation:
  - GBDTs were built in each SR
  - Applying 5-fold Cross-Validation
  - Training BDTs for:
    - FCNC decay
    - FCNC production via up quark
    - FCNC production/decay with charm
- Upper limits on Branching ratio and Wilson coefficient are extracted from profile-likelihood fit to BDT scores.
- Comparison between previous (36fb^{-1}) and current observed limits show a significant improvement using the full Run-2 dataset with:
  - a factor of ~3 for tZu ~2 for tZc coupling
  - 36 fb^{-1} result: decay mode only
  - The statistical uncertainty is the dominant contribution



FCNC $t \to qg$ Eur.Phys.J.C82(2022)334

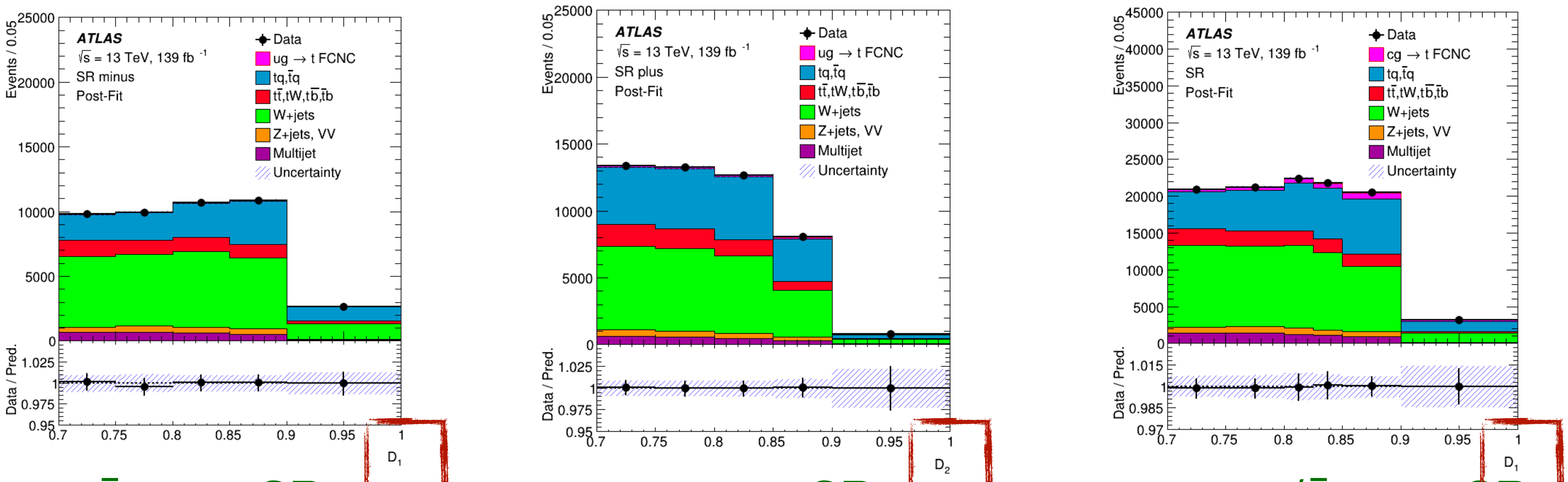
- Analysis Strategy:
  - 1 b-jet + high-P_T leptons (e or μ) + large missing Et
  - Consider **production ONLY**
    - decay mode contains a jet initiating gluon, indistinguishable with QCD bkg.
  - Top quark can be constructed using 4-momentum conservation (W on-shell)
  - Fake rate determined in a data-driven way for multi-jet estimation (jets fake leptons)
  - Custom very tight b-tag to suppress light-jets





FCNC $t \to qg$ Eur.Phys.J.C82(2022)334

- Train artificial neural networks to obtain discriminants separating signal and background
  - 2 NNs: **D1 for $\bar{u}g\bar{t}, cgt, \bar{c}g\bar{t}$** **D2 for ugt**
  - three-layer feed forward NN with transformation of 12/9 input variables
- Profile maximum-likelihood fit to the NN discriminant
- Factors of 1.5 - 2 better than run-1 analysis, main systematics: bkg modelling, jet/MET-related
  - BR($t \to ug$) < 0.61 x 10^{-4} (expected: BR($t \to ug$)< 0.49 x 10^{-4})
  - BR($t \to cg$) < 3.7 x 10^{-4} (expected: BR($t \to cg$)< 2.0 x 10^{-4})



$\bar{t} \to \bar{u}g$ **SR** $t \to ug$ **SR** $t \to cg/\bar{t} \to \bar{c}g$ **SR**

Summary

- THU-ATLAS team:
  - 1 staff, 1 postdoc, 5 PhD student (**5 ATLAS author**)
  - obtained fruitful physics results on searches for TeV physics (still going-on)
    - **Generic Heavy Higgs, FCNC tqH(tautau), low mass resonance, FCNC tqH(combination), Generic ZX resonance, LFV …**
  - Run-3 expects more exciting opportunities