Studies of Higgs and flavour physics at the high p_T frontier with ATLAS (top & FCNC)

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on behalf of the ATLAS collaboration

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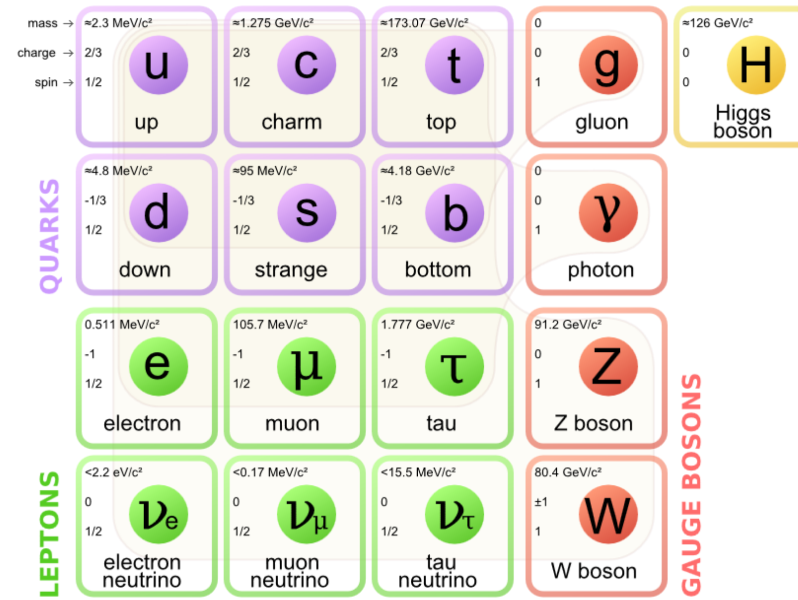
Introduction



Fundamental assumptions of the SM:

Flavour changing neutral currents (FCNC) forbidden on the tree level, suppressed at higher-orders

→ Lepton flavour conservation of the charged leptons
→ Absence of transition between top and other flavour quarks mediated by neutral gauge bosons

Any deviations would be indications for new physics!

Studies presented in this talk:

- Higgs boson couplings, top Yukawa coupling (ttH, ttZ)
- FCNC in top decays: t → qH and t → qZ
- Single top production via FCNC
- Search for LVF Higgs: H → ll'
- Search for LVF Z: Z → ll'

SM Higgs Productions and Couplings

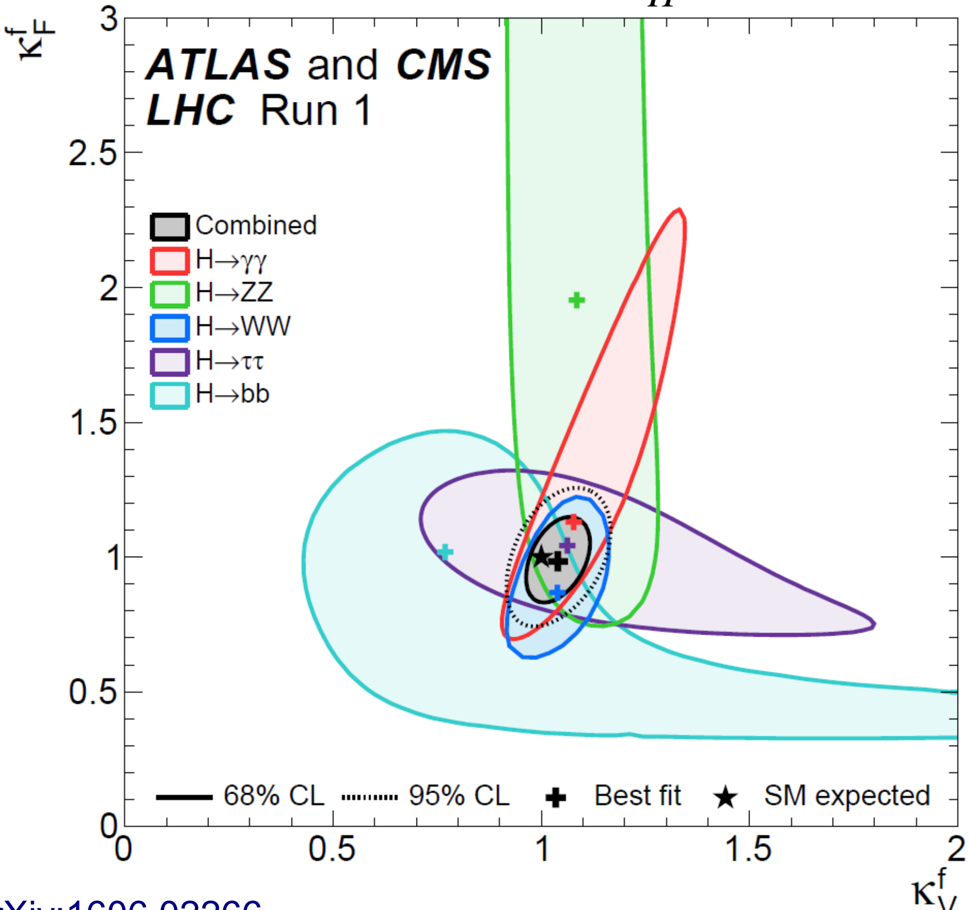
- ATLAS & CMS combined run-1 measurements of Higgs boson couplings
- Production signal strength μ_i: quantifies deviation of production cross section from the SM
- Coupling modifiers κ: Quantifying modification of the Higgs couplings related to BSM

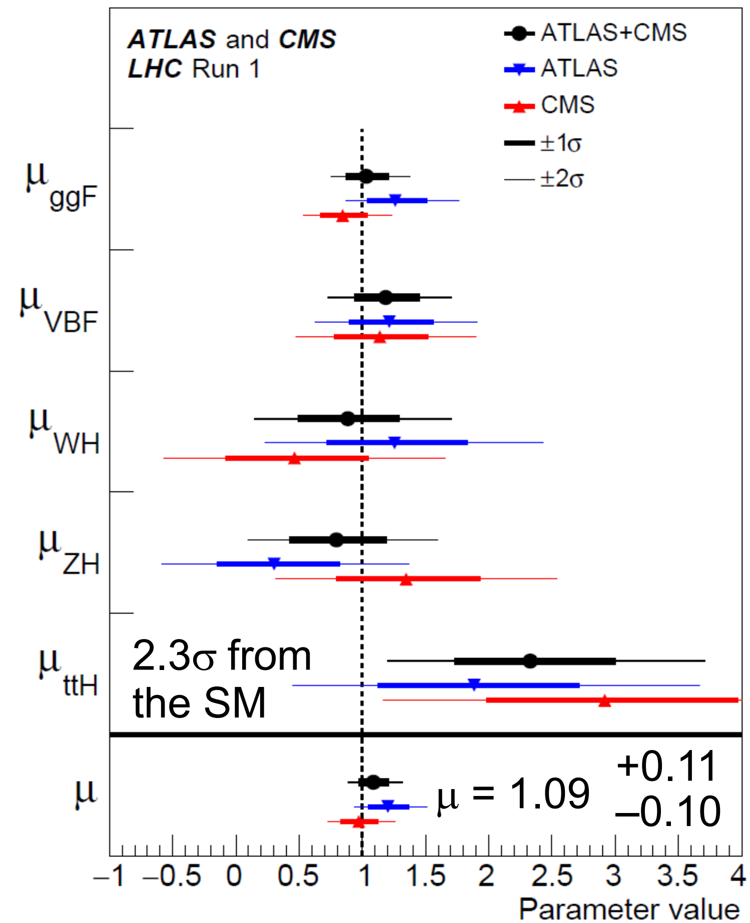
  κ_f: scale factor for all fermion couplings

  κ_V: scale factor for all weak vector boson couplings

$$\sigma_i \cdot \mathrm{B}^f = \frac{\sigma_i(\vec{\kappa}) \cdot \Gamma^f(\vec{\kappa})}{\Gamma_H}$$

$$\mu_i = \frac{\sigma_i}{(\sigma_i)_{\mathrm{SM}}}$$



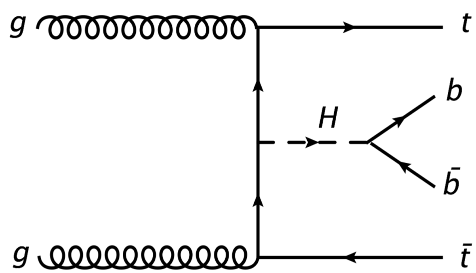


arXiv:1606.02266

Search for ttH → bb with 1 or 2 leptons

Top quark: Heaviest fundamental particle, decays before it hadronizes, access to Yukawa coupling

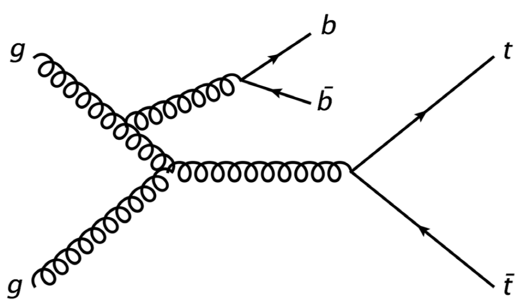
ttH, H→bb



S/B ratio: 4% in best category

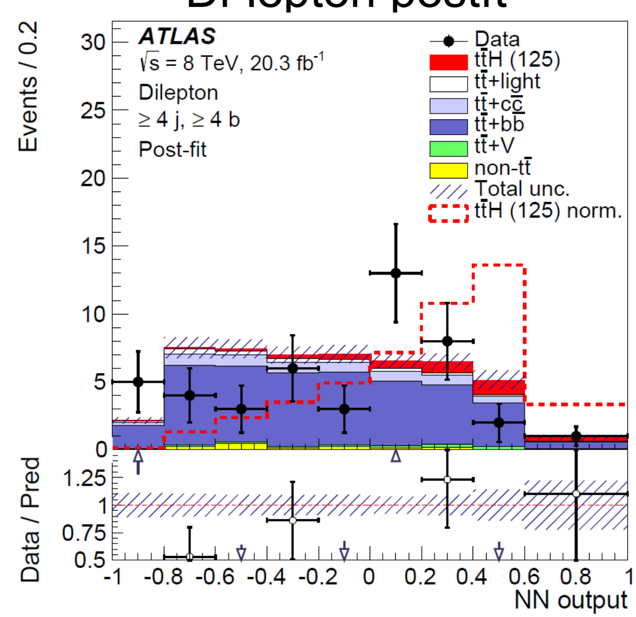
Eur. Phys. J. C (2015) 75:349

- Selecting events with one or two leptons, at least 4 jets, 2 of them btagged
- Neural network trained in 5 signal-enriched categories
  (single-lepton: 5j≥4b, ≥6j3b, ≥6j≥4b and dilepton: 3j3b, ≥4j3b, ≥4j≥4b)
- Matrix element discriminator one of NN input variables
- Large background uncertainties constrained from simultaneous fit of signal and control regions

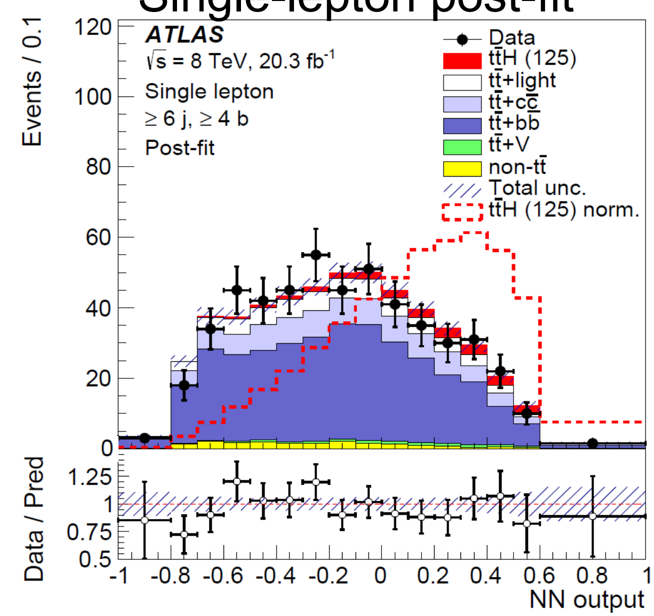


50% normalisation uncertainty on $t\bar{t}$+$b\bar{b}$ and tt+cc

Di-lepton postft



Single-lepton post-fit



Search for ttH → multi-leptons

Physics Letters B 749 (2015) 519-541

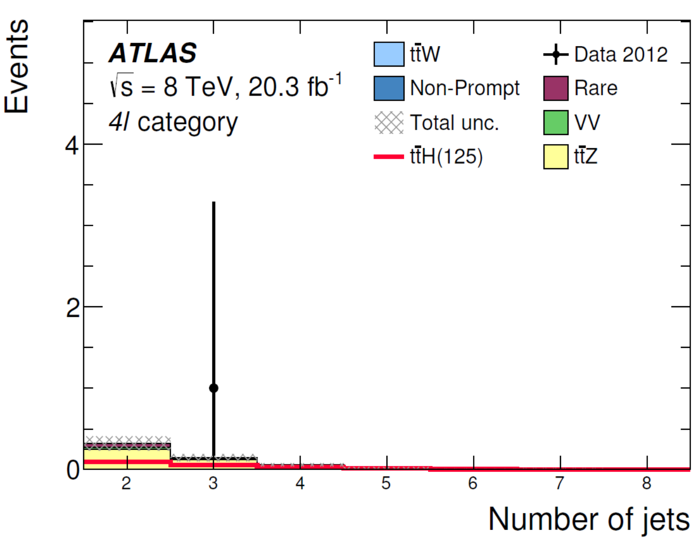
ttH → multi-leptons

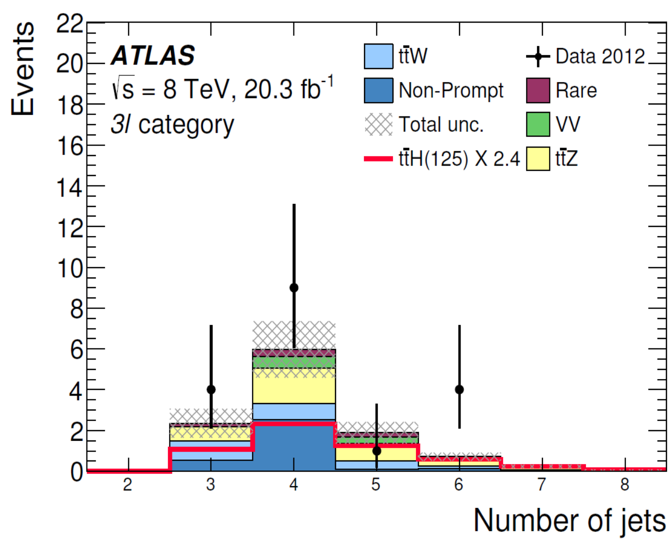
- “Cut & count” analysis
- Categorized by number and flavour of leptons:

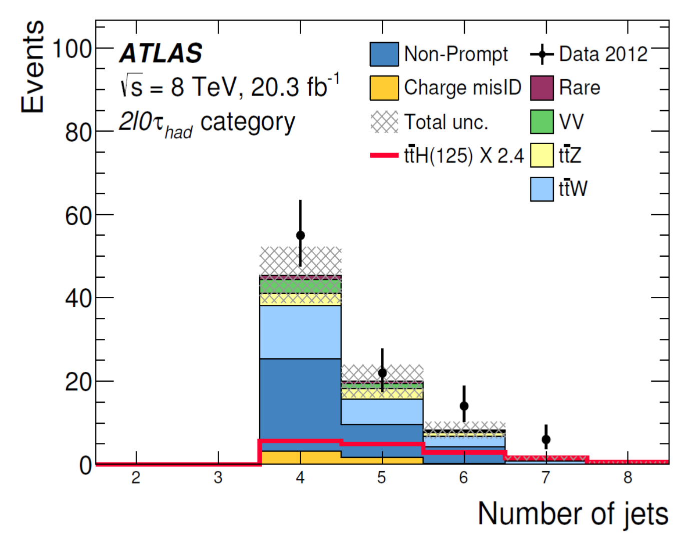
  2l (same sign) + 0τ + ≥ 4j
  2l (same sign) + 1τ + ≥ 4j
  3l (total charge ±1) + ≥ 4j
  4l + ≥ 2j
  1l + 2τ + ≥ 3j

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\rm had}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\rm had}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\rm had}$	4%	93%	0%	3%

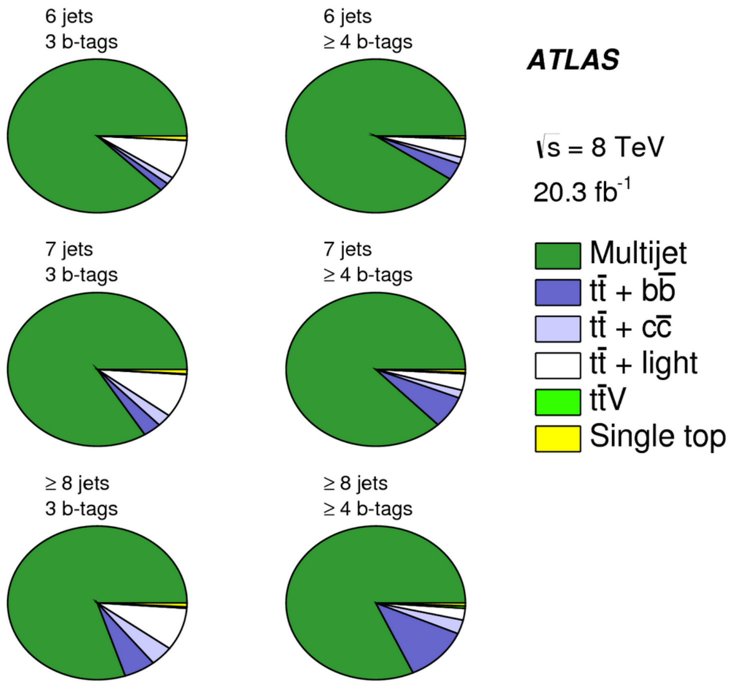
- Backgrounds estimated from MC and from data, validated in dedicated control regions







Search for ttH, H → bb with all-hadronic top-decays



"tt → all-jets" has largest BR (46%)

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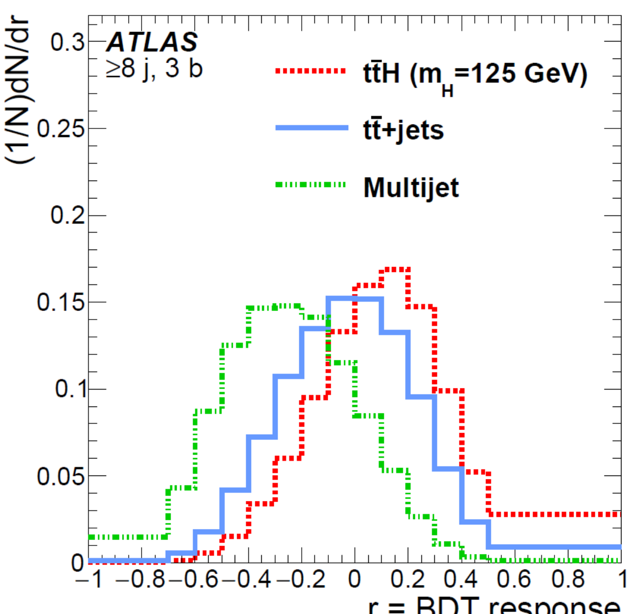
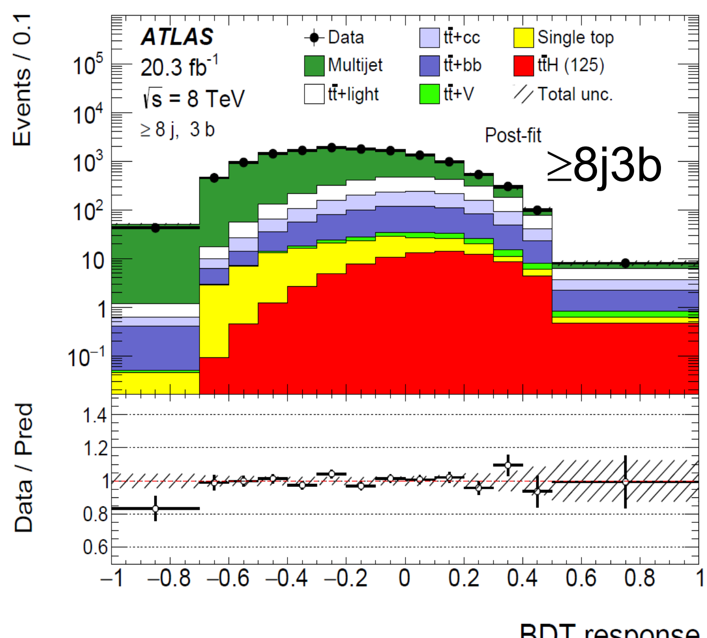
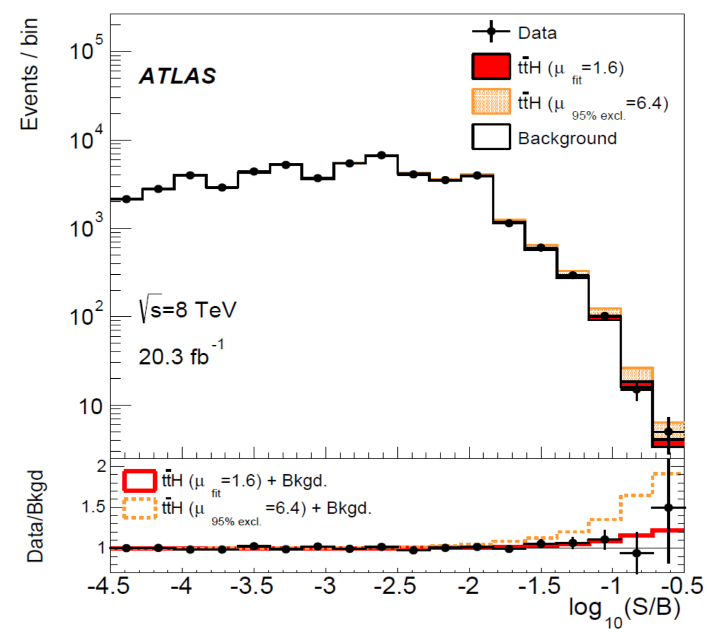
- Control regions: 6j3b, 6j≥4b
  Signal regions: 7j3b, 7j≥4b, ≥8j3b, ≥8j≥4b,
  S/B ranges from 0.2-1%
- BDT trained in each category to separate signal and background
  Inputs: sum of jet p_T divided by the inv. jet mass (centrality), min. m_{jj}, m_{bb} for bb closest in ΔR, masses of reconstructed tops, ...

Best-fit signal strength: **1.6 ± 2.6**







ATLAS ttH combination

No ttH evidence yet

Combined ttH significance wrt. bkg-only: 2σ, wrt. SM: 1σ

13 TeV ttH production cross section is factor 3.9 larger than at 8 TeV

→ stay tuned for the 13 TeV update

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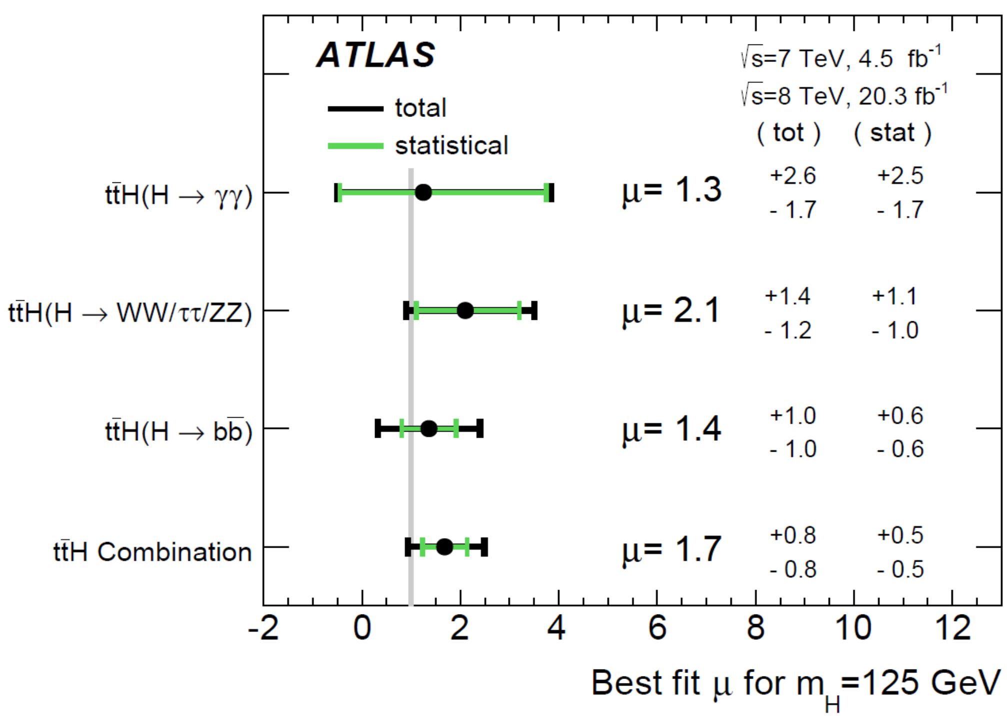
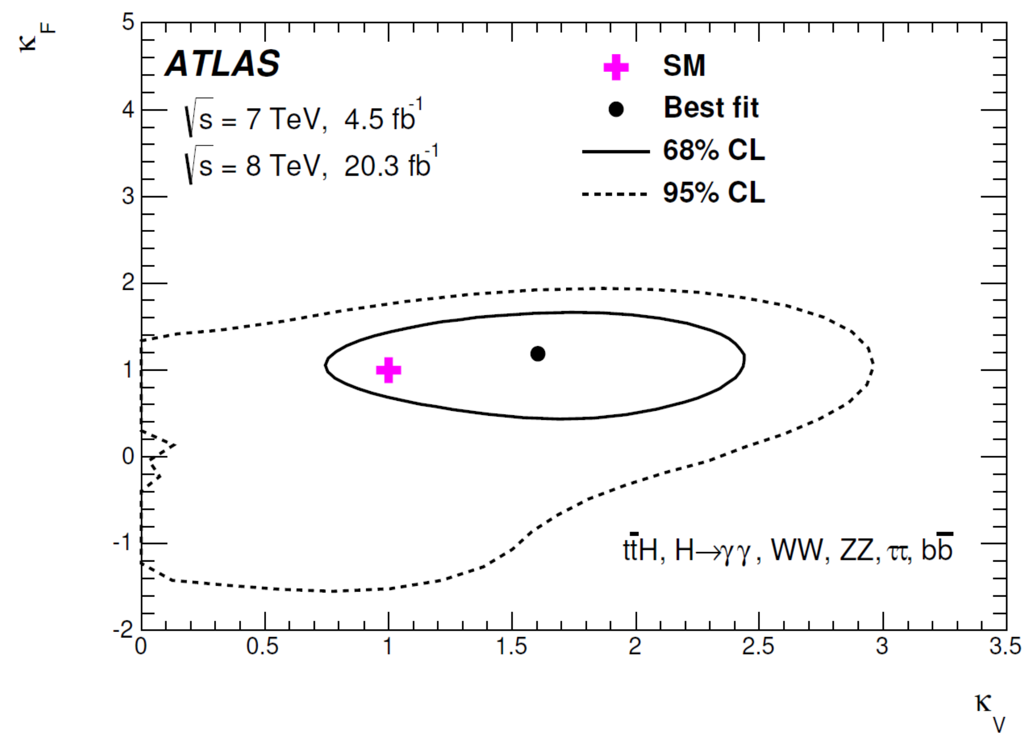
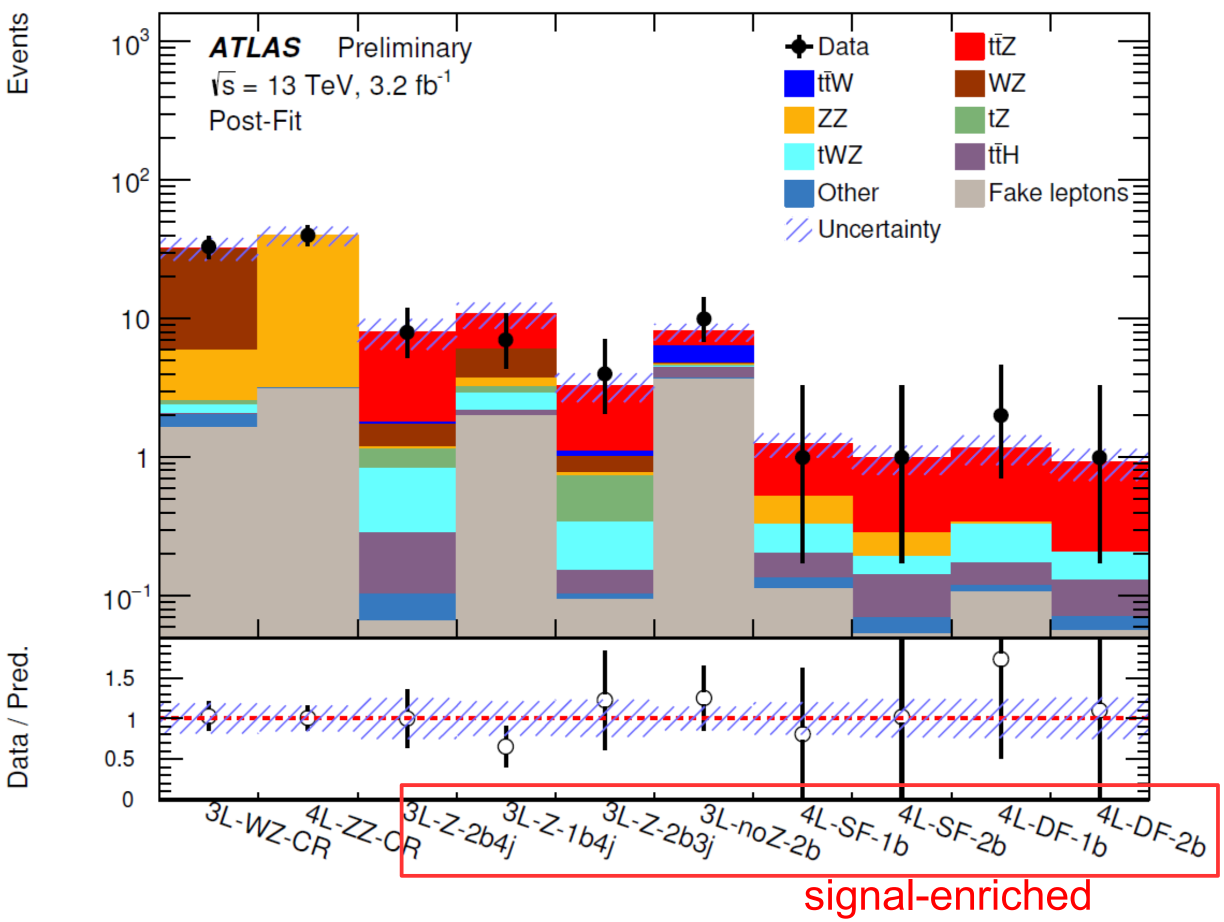


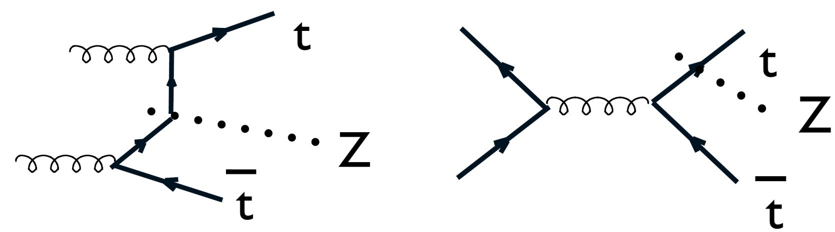


ttZ cross section

13 TeV

- Same production dynamics as ttH, similar kinematic scales (since $m_H \sim m_Z$)
- Cross section can be altered wrt. SM by presence of vector-like quarks, technicolor, …
- Channels: ttZ → tνb qqb + ll (3 leptons) or lνb lνb + ll (4 leptons)





ttZ cross section extracted from simultaneous fit to 8 signal regions and 2 control regions

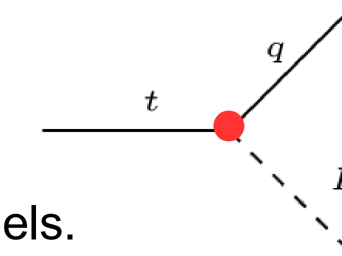
Leading uncertainties:
- Limited statistics
- reconstructed objects
- luminosity

ATLAS-CONF-2016-003

Results: σ (ttZ) = 0.9 ± 0.3 pb MG5_aMCatNLO: 0.76 ± 0.08 pb

σ (ttW) = 1.4 ± 0.8 pb MG5_aMCatNLO: 0.57 ± 0.06 pb

Search for FCNC $t \to qH$



- SM: BR($t\to uH$) ~10^{-17} and BR($t\to Hc$)~10^{-15}, negligible compared to $t\to Wb$
- Sizeable rate BR($t\to Hc$)~10^{-3} expected in 2HDM type-III (FCNC allowed on tree level).
  Can also appear in R-parity violating SUSY, extra quark and technicolor models.

Search for tt → Wb + Hq, with H→γγ

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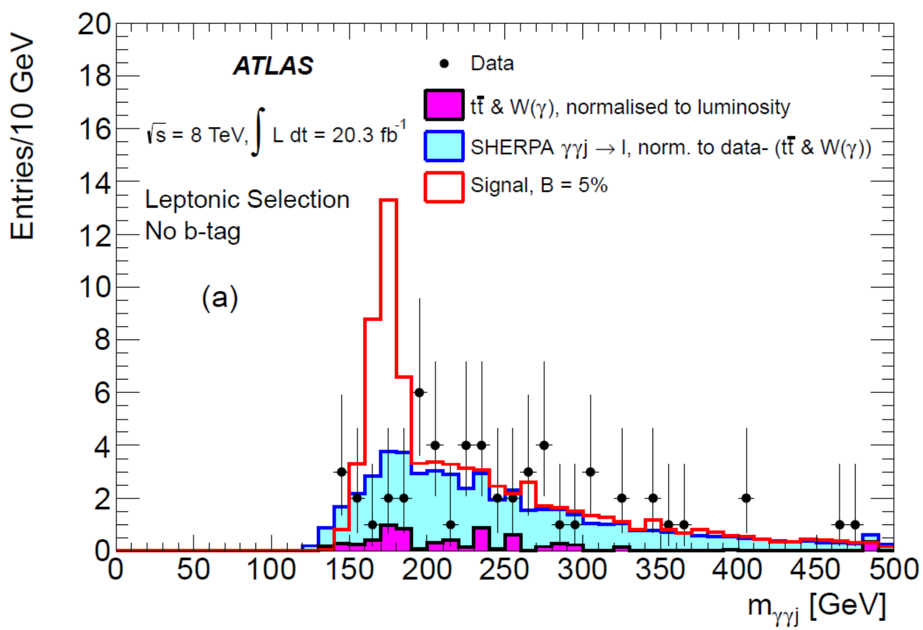
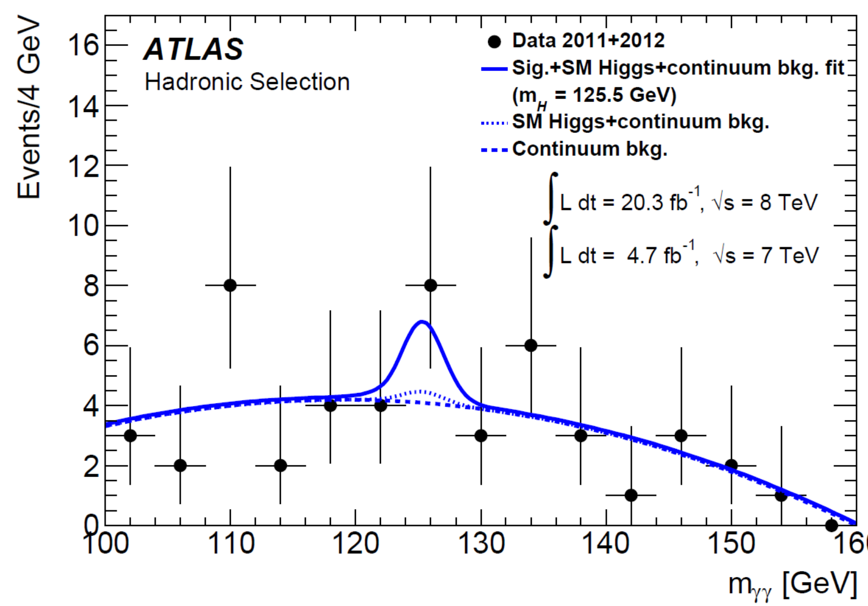
- BR($H\to\gamma\gamma$) 0.2%, but excellent mass resolution makes it easy to separate it from background
- Events selected containing two photons, and other objects consistent with either hadronic or leptonic top decays. Top decays fully reconstructed, cuts on the top masses applied.



Hadronic selection after all cuts:



In the leptonic selection only one data event remains ($m_{\gamma\gamma}$=147 GeV) → no shape fit, just counting

Upper limit on BR($t\to qH$): 0.79%, expected (0.51 +0.2 -0.1) % → 1σ

Search for FCNC t → qH

Search for t→Hq, with H→bb, single-lepton

BR(H→bb) = 58%

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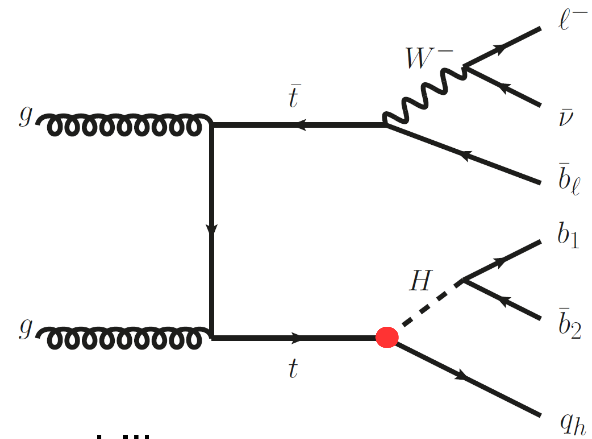
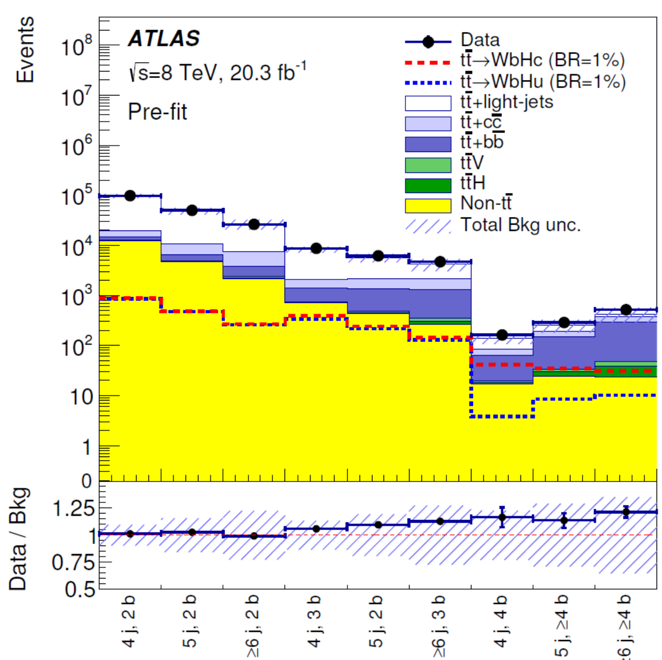
- Similar to ttH(bb) analysis, baseline selection ≥4j ≥2b, one lepton
- 9 categories, signal-enriched regions: 4j3b, 4j4b, 5j3b, 5j≥4b
- Signal-background-discriminant built in each category:



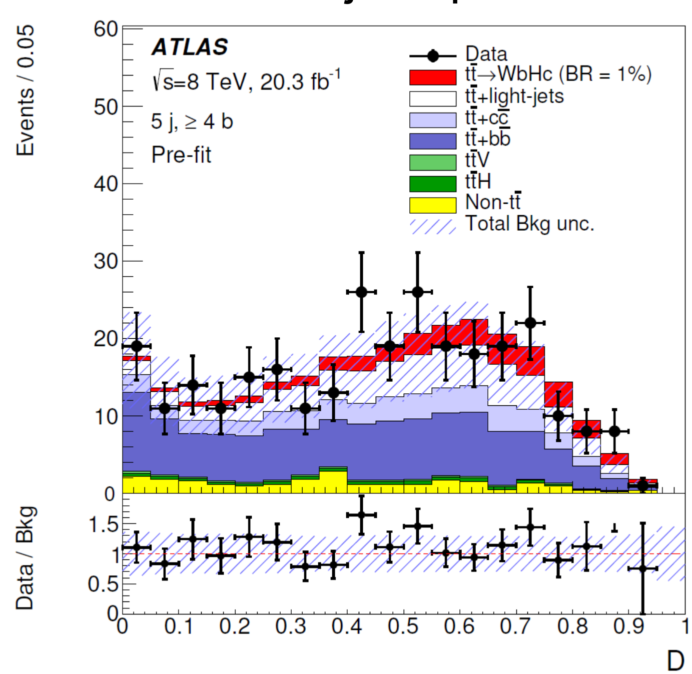
$$D(\mathbf{x}) = \frac{P^{\mathrm{sig}}(\mathbf{x})}{P^{\mathrm{sig}}(\mathbf{x}) + P^{\mathrm{bkg}}(\mathbf{x})}$$

P^{sig} and P^{bkg} probability functions for an event to be signal or background-like, function of all possible combinations of the selected objects.
Inputs: Reconstructed resonances (H and W), flavour content of the jets.

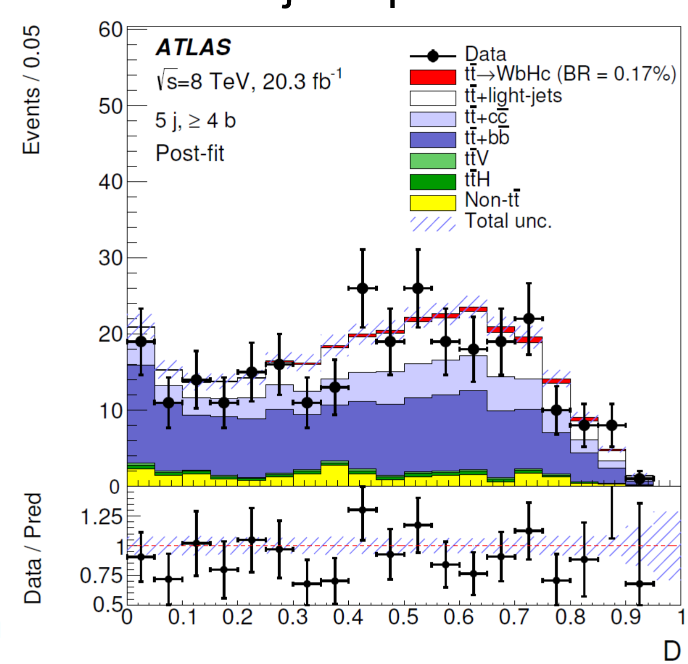
Prefit event yields:



D in 5j≥4b prefit:



D in 5j≥4b postfit:

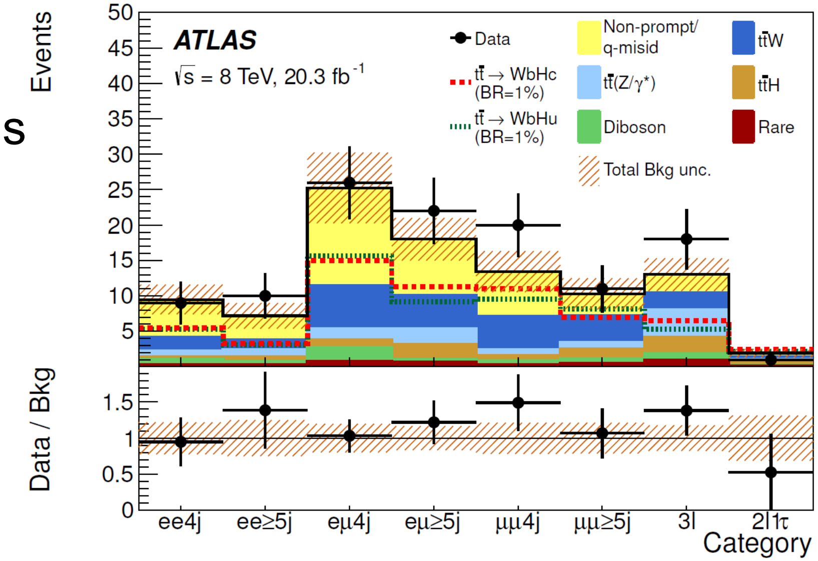


Search for FCNC t → qH

Search for t→Hq with H→WW/ττ

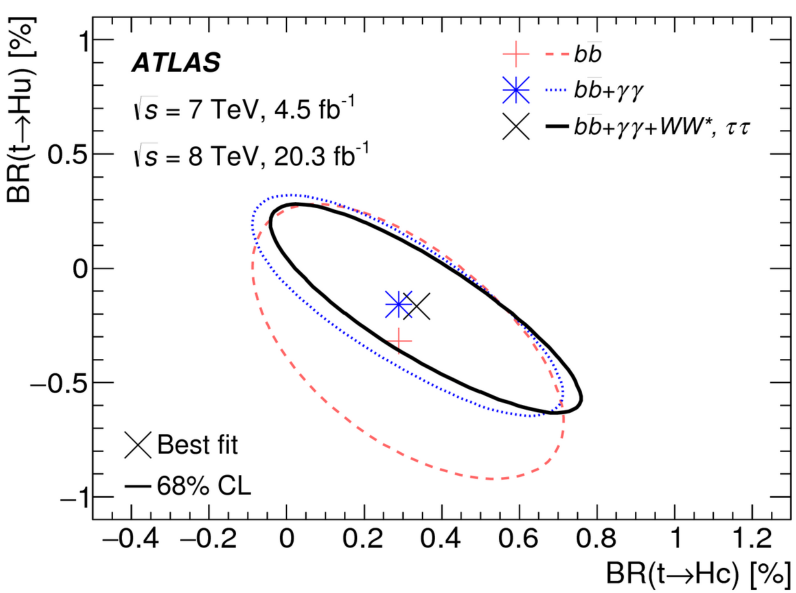
Reinterpretation of sensitive ttH→multi-lepton channels

- 3l + ≥3j with ≥2 b-tags or ≥4 jets with ≥1 b-tag
- 2l (same sign) + 0τ + ≥4jets with ≥1 b-tags
- 2l (same sign) + 1τ + ≥4 jets with ≥1 b-tag



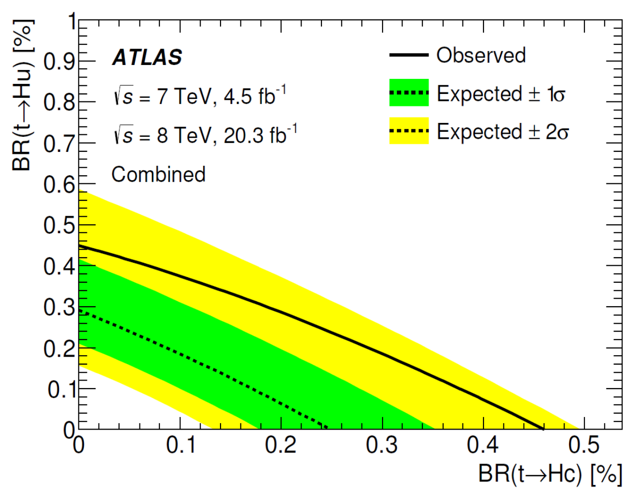
Combined results for t→qH: JHEP 12 (2015) 061

2D best-fit BR values:

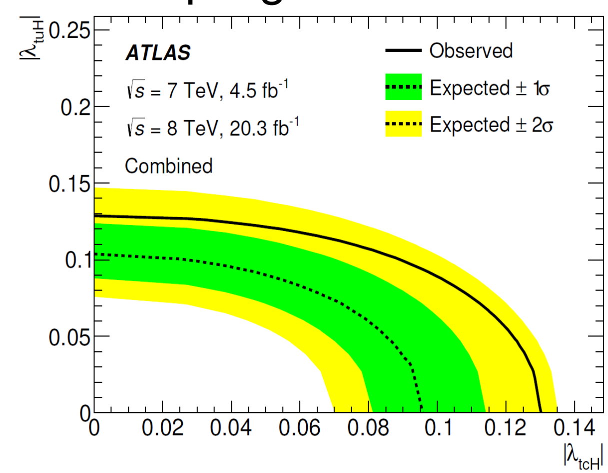


→ Slight excess wrt. SM (1σ)

Limits on BR and couplings:



Limit on BR(t→Hc): 0.46% (expected 0.25%)
Limit on BR(t→Hu): 0.45% (expected 0.29%)



$|\lambda_{tqH}| = (1.92 \pm 0.02)\sqrt{BR(t \to Hq)}$

Limit on $|\lambda_{tcH}|$: 0.13 (exp. 0.1)

Limit on $|\lambda_{tuH}|$: 0.13 (exp. 0.1)

Search for FCNC t → qZ

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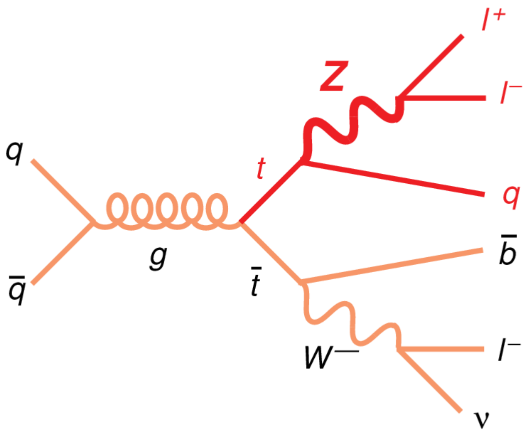
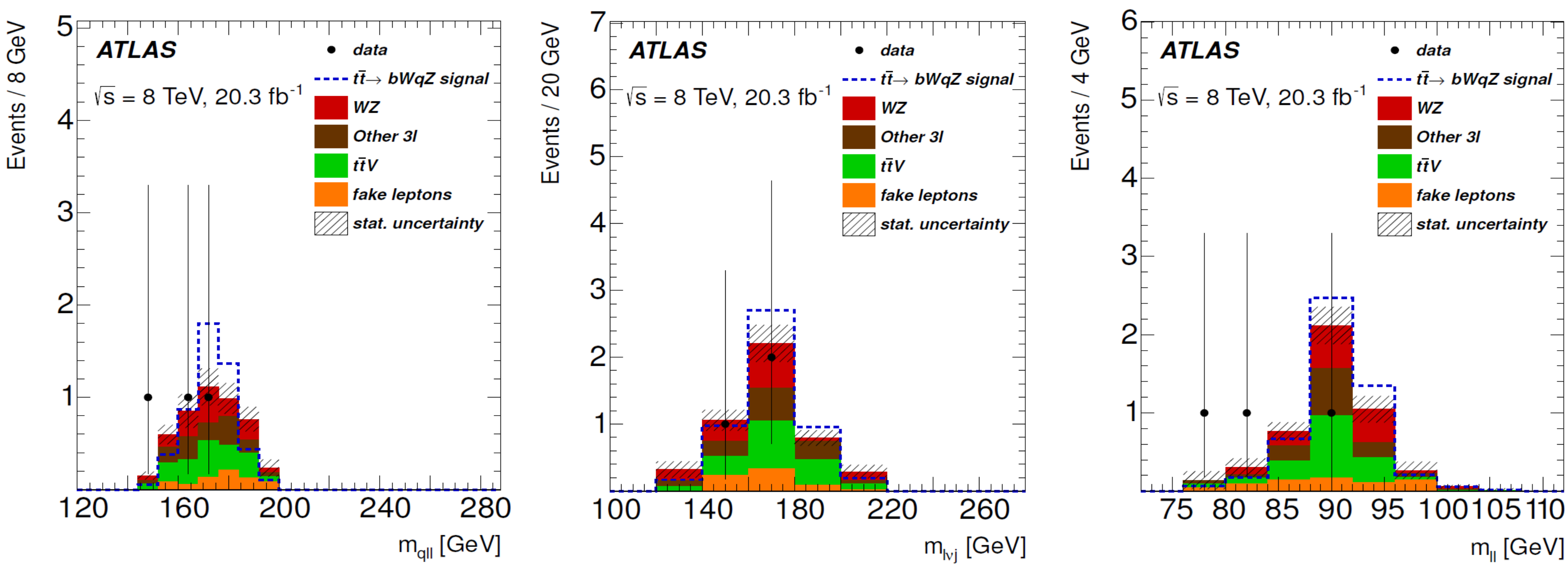


- Events with three leptons (two with same flavor and opposite charge, mass consistent with Z mass)
- 2 or 3 jets (p_T > 35 GeV), ≥1 of them b-tagged
- Top mass reconstruction

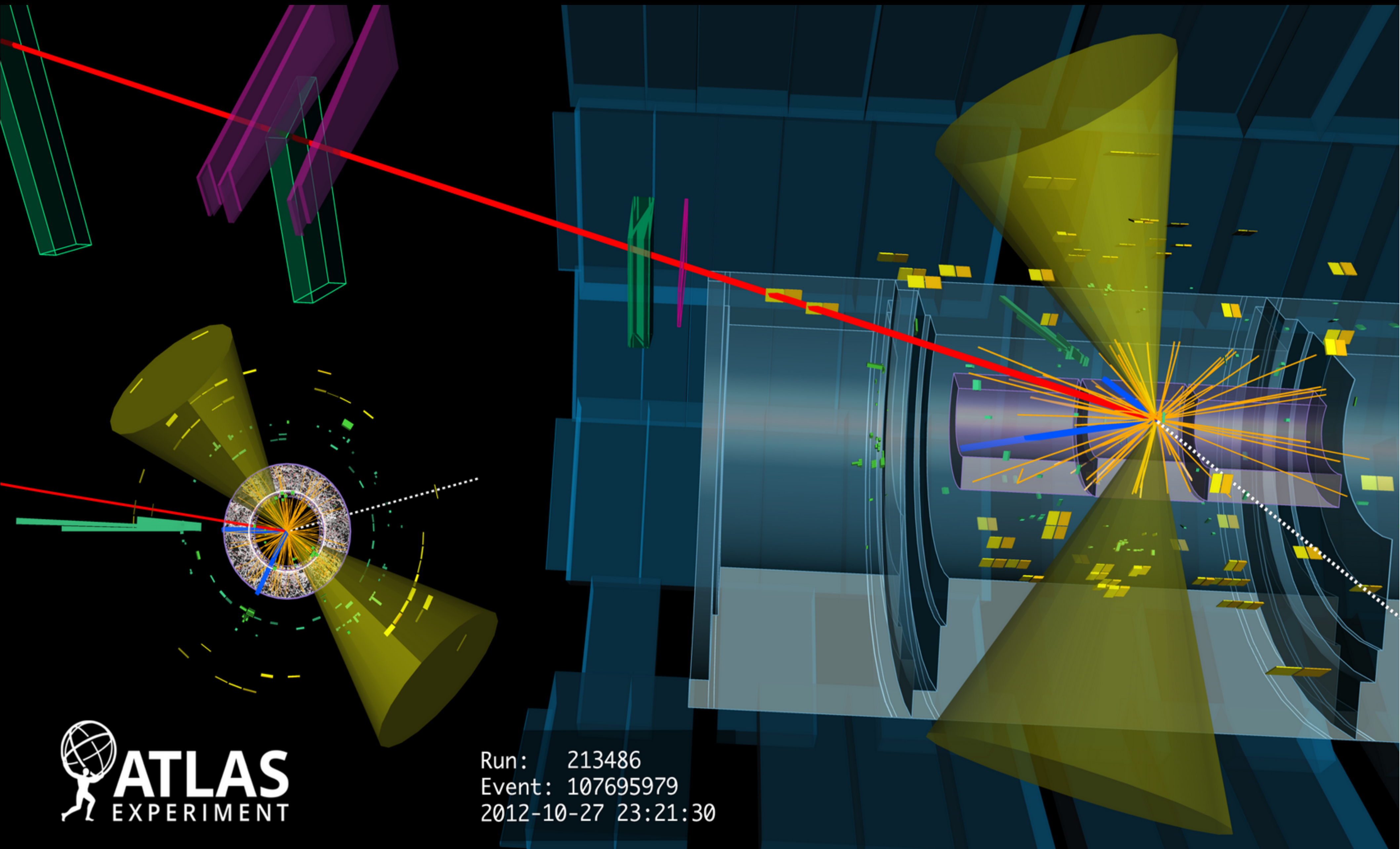
Sample	Yields
WZ	$1.3 \pm 0.2 \pm 0.6$
$t\bar{t}V$	$1.5 \pm 0.1 \pm 0.5$
tZ	$1.0 \pm 0.1 \pm 0.5$
Fake leptons	$0.7 \pm 0.3 \pm 0.4$
Other backgrounds	$0.2 \pm 0.1 \pm 0.1$
Total background	$4.7 \pm 0.4 \pm 1.0$
Data	3
Signal efficiency $[\times 10^{-4}]$	$7.8 \pm 0.1 \pm 0.8$

Reconstructed masses after signal selection:



With NNLO+NNLL calculation for $t\bar{t}$ cross section and BR(t→bW) = 1-BR(t→Zq) upper limits on BR(t→Zq): Expected: $(8\ {+12}\ {-6}) \times 10^{-4}$ Observed: 7×10^{-4}

$t\bar{t} \rightarrow bl\nu\ qll$ candidate event

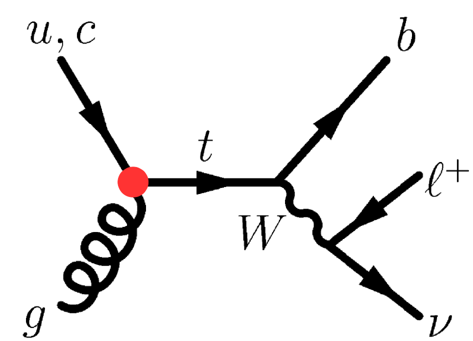


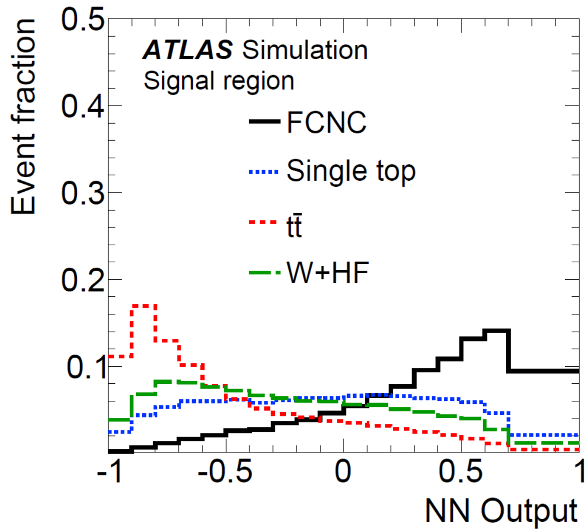
Muon 28 GeV Electrons (107 GeV, 19 GeV) MET (84 GeV)

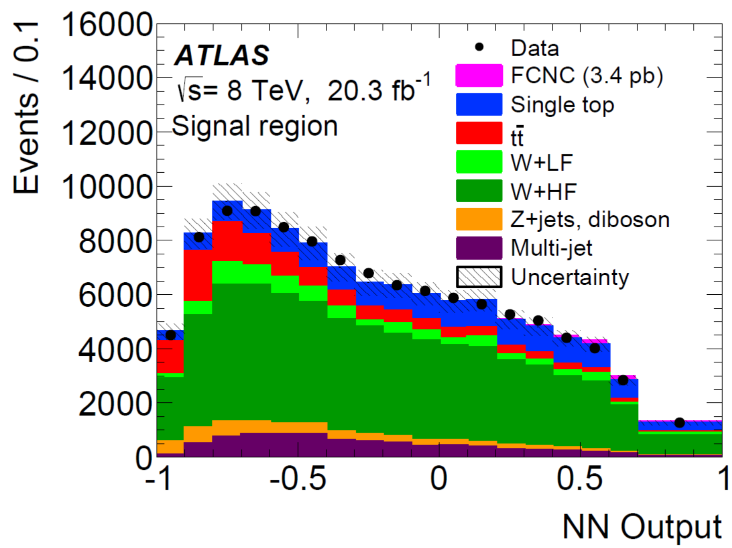
Search for single top produced via FCNC gq→t→blν

Eur. Phys. J. C (2016) 76:55

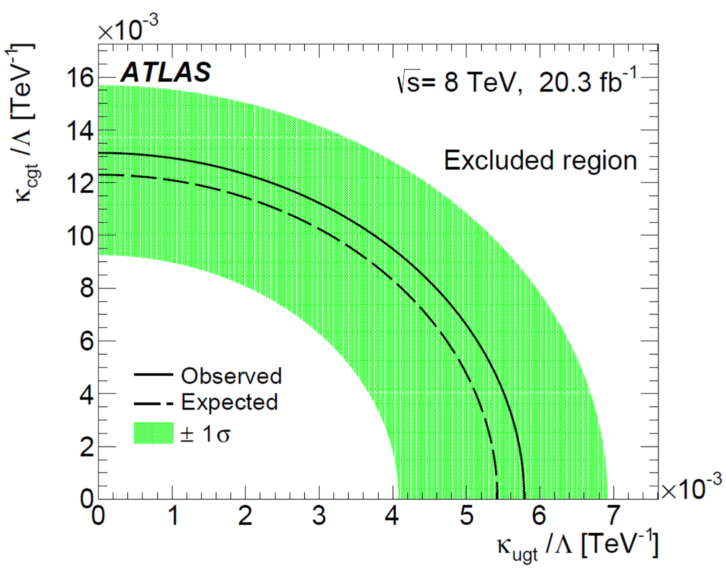
Single top produced via FCNC, decay via Wtb vertex
→ softer top p_T than in SM production
→ 4x more top than anti-top produced

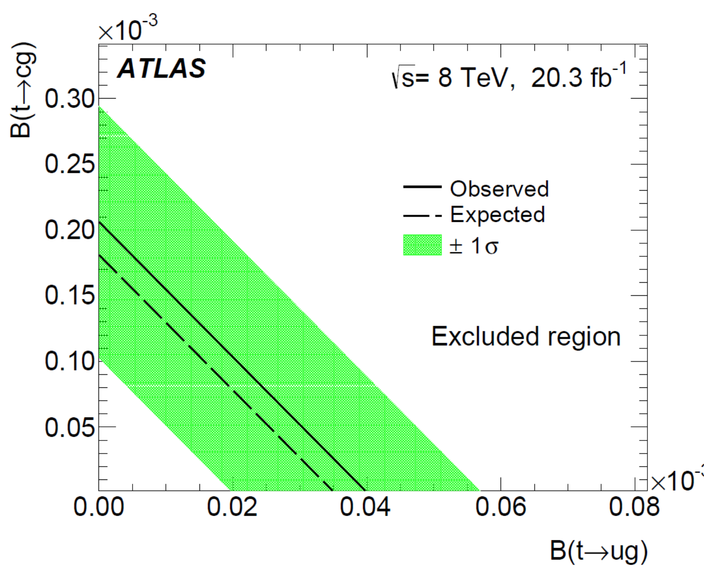






Analysis based on neural-network discriminant
Top ranked: m_T top, p_T lep, ΔR(t,lep), p_T b-jet, lep charge





Upper limit on σ*BR:
Expected 2.9 +1.9 -1.2 pb
Observed 3.4pb

Limits set on couplings κ_{cgt}/Λ and κ_{ugt}/Λ

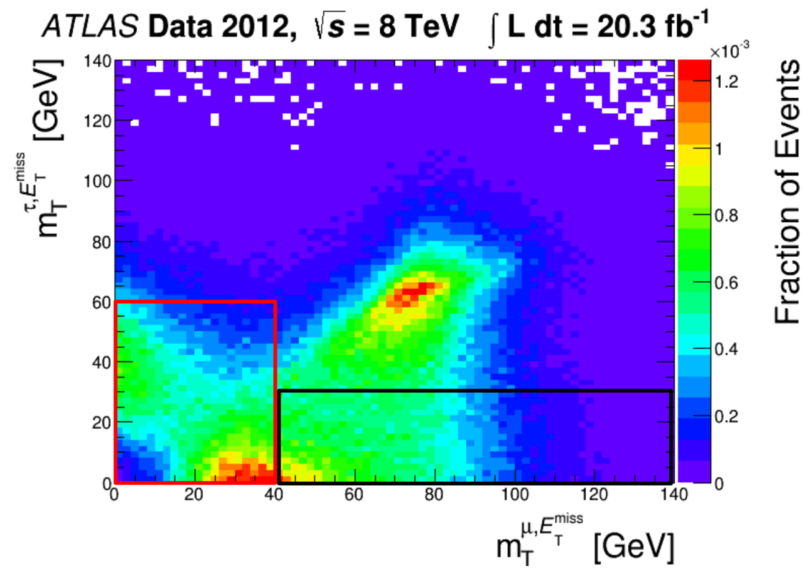
Using NLO FCNC calculation, limits converted and set on BR of t→cg and t→ug

Search for Lepton Flavor Violation in H decays

LFV of H decays can appear in composite Higgs, RS models, models with >1 Higgs doublet

Search for $H\rightarrow e\tau$ and $H\rightarrow\mu\tau$:

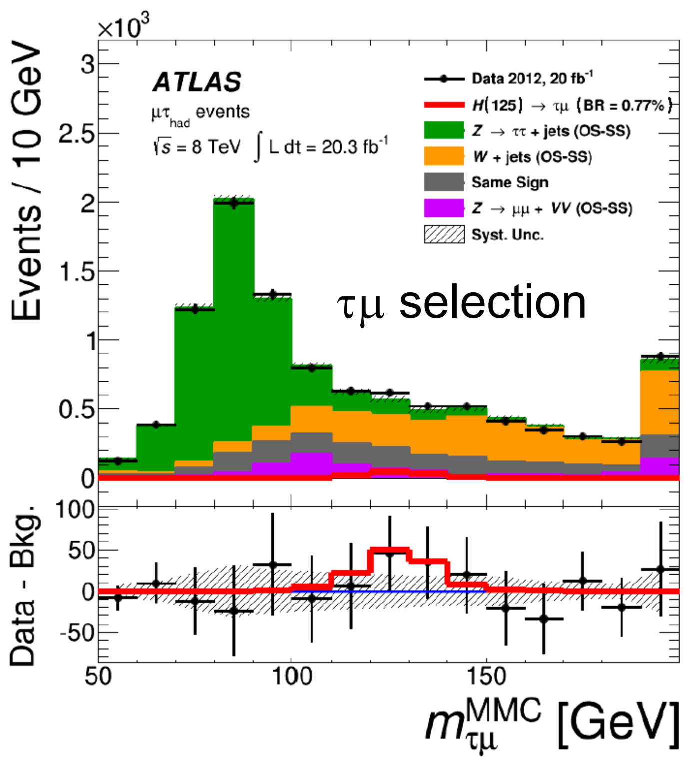
- Hadronic τ with p_T>45 GeV
- Electron or muon p_T>26 GeV
- Veto on b-jets, inclusive in #jets
- **SR1:** m_T(l,MET) > 40 GeV, $m_T(\tau$,MET) < 30 GeV
- **SR2:** m_T(l,MET) < 40 GeV, $m_T(\tau$,MET) < 60 GeV

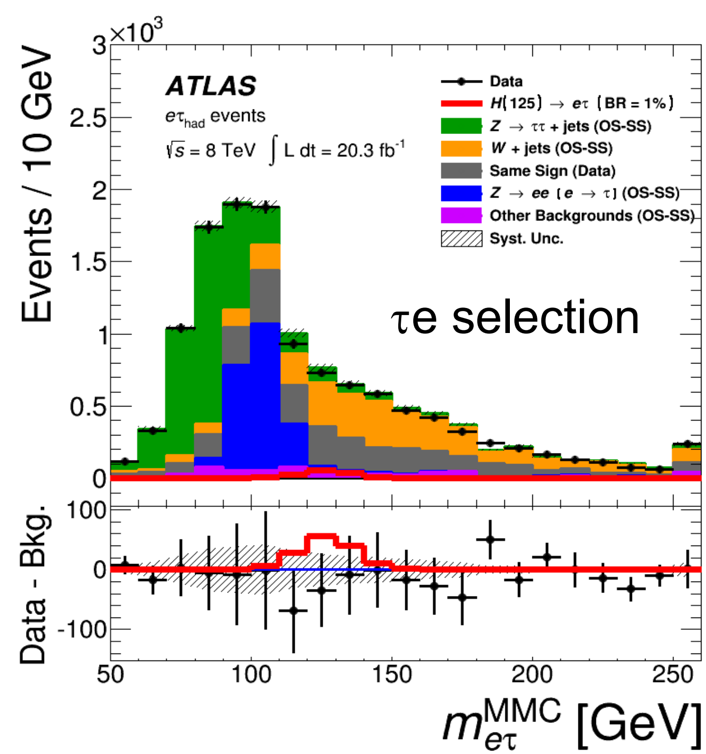


2.2σ excess in SR2 in $H\rightarrow\mu\tau$

reduced to 1.3σ combining both SR

CMS $H\rightarrow\mu\tau$: 2.4σ





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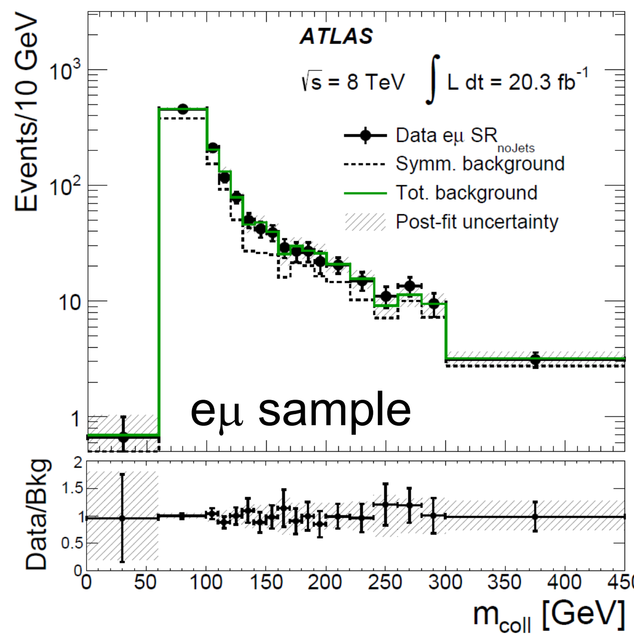
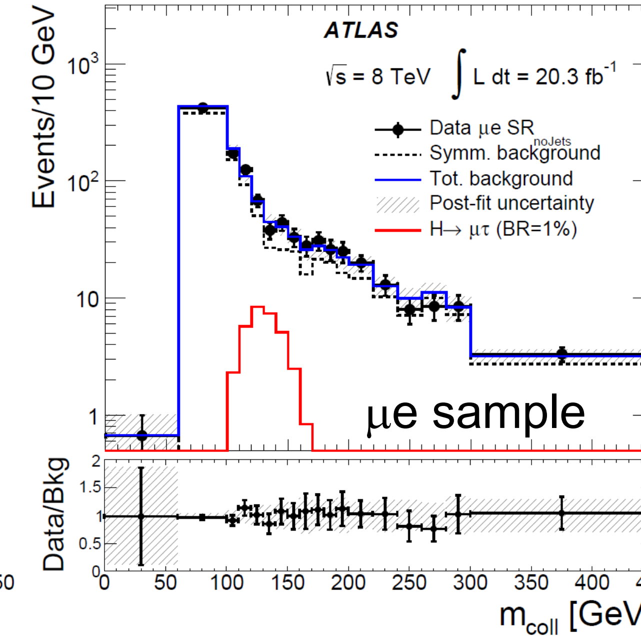
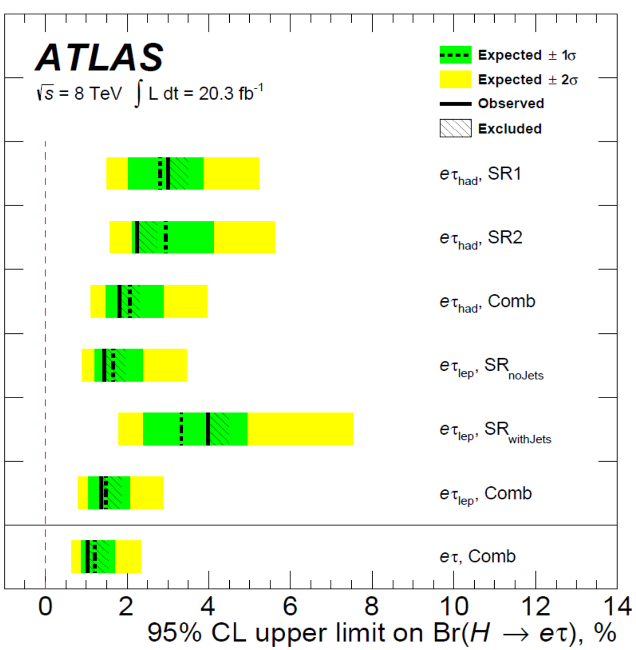
Search for Lepton Flavor Violation in H decays

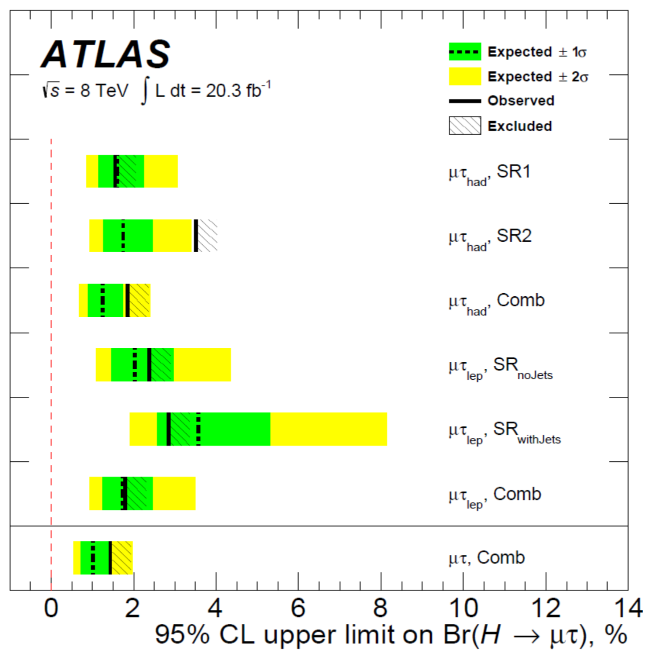
- Selecting events with OS e and μ
- $e\mu$ sample: e has leading p_T,
  μe sample: μ has leading p_T
- $H\to\tau\mu$ present only in μe sample since electron from τ decay is soft
- SM backgrounds symmetric under exchange of e with μ (except reco and trigger efficiencies)
  $\to$ $e\mu$ sample used for background estimation in the μe sample
- No excess over bkg. observed

Search for $H\to e\tau$ and $H\to\mu\tau$ with leptonic τ









Combination of τ_{had} and τ_{lep}:

$\mu\tau_{had}$ and $\mu\tau_{lep}$ combined: 1σ

Combined best-fit BR values:

$H\to e\tau$: -0.34 +0.64 -0.66
$H\to\mu\tau$: 0.53 $\pm$ 0.51

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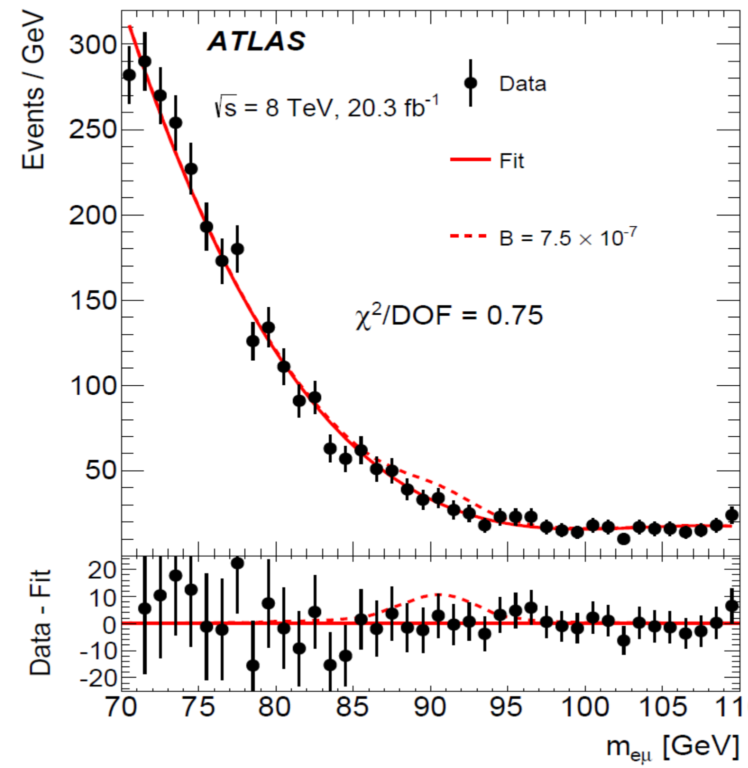
Search for Lepton Flavor Violation in Z decays

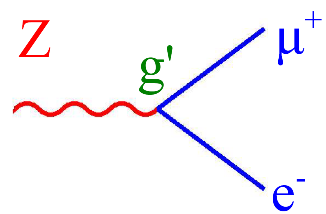
LVF in Z decays are predicted in models with heavy neutrinos, extended gauge models and SUSY

Search for Z→eμ: Phys. Rev. D. 90, 072010 (2014)

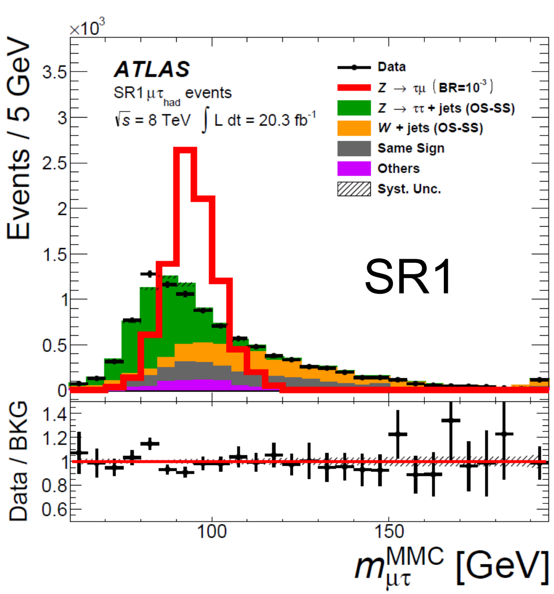
- Events with exactly 2 opposite-sign leptons
- No true MET → MET < 17 GeV
- Veto of high p_T jets to suppress tt
- Largest background: Z → ττ → eμ+4ν
- Background estimated from the data with a fit (Chebychev polynomial)

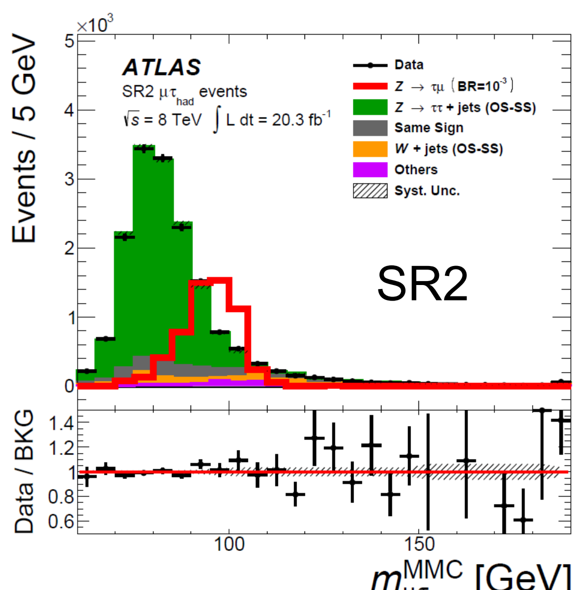


Upper limit on BR(Z→eμ): 7.5 * 10^{-7}



Search for Z→μτ: JHEP11(2015)211





Very similar analysis as H→μτ
Kinematic cuts slightly lowered wrt. H
No excess observed, a deficit in SR1

$Br(Z \to \mu\tau)[10^{-5}]$	SR1	SR2	Combined
Expected limit	$2.6^{+1.1}_{-0.7}$	$6.4^{-1.8}_{+2.8}$	$2.6^{+1.1}_{-0.7}$
Observed limit	1.5	7.9	1.7
Best fit	$-2.1^{+1.2}_{-1.3}$	$2.6^{+2.9}_{-2.6}$	$-1.6^{+1.3}_{-1.4}$

BRAND NEW!

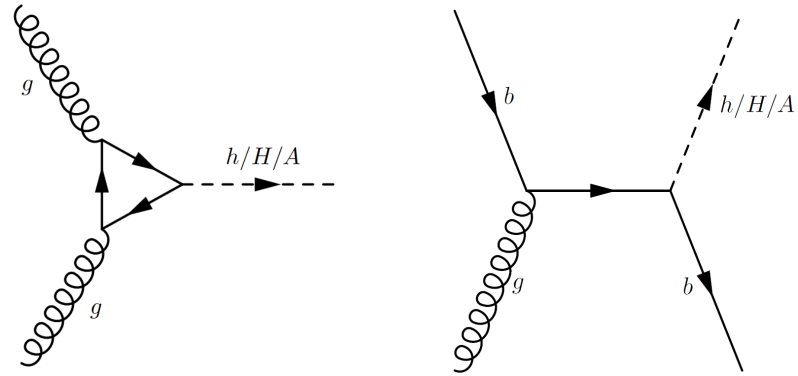
BSM Higgs searches: A/H → ττ and Z' → ττ

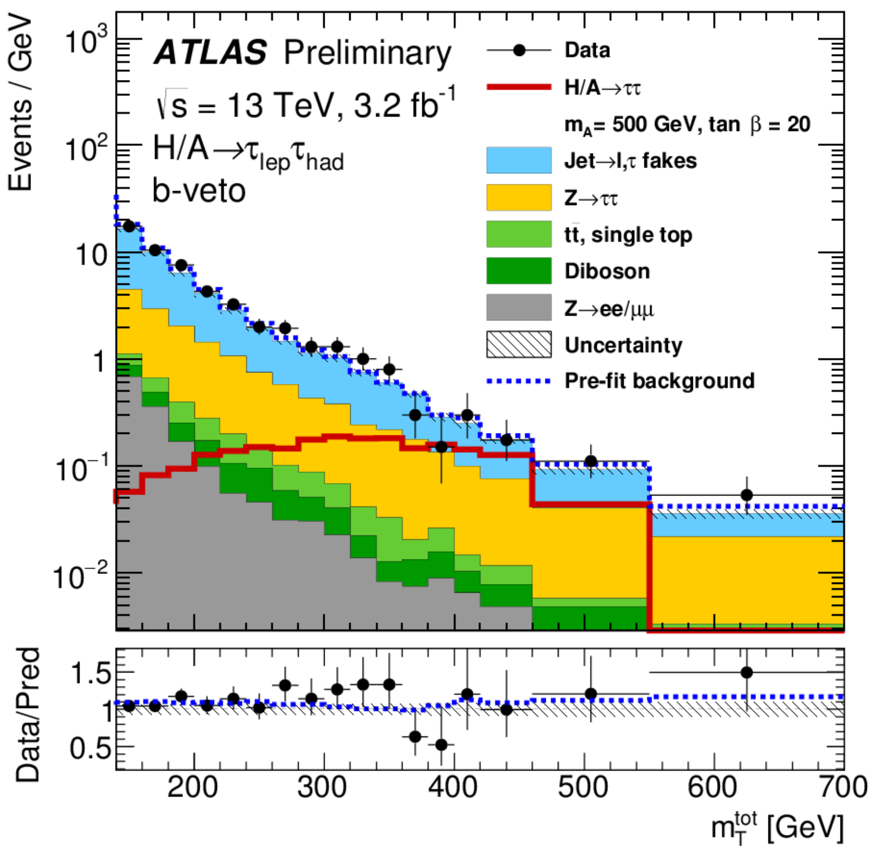
13 TeV

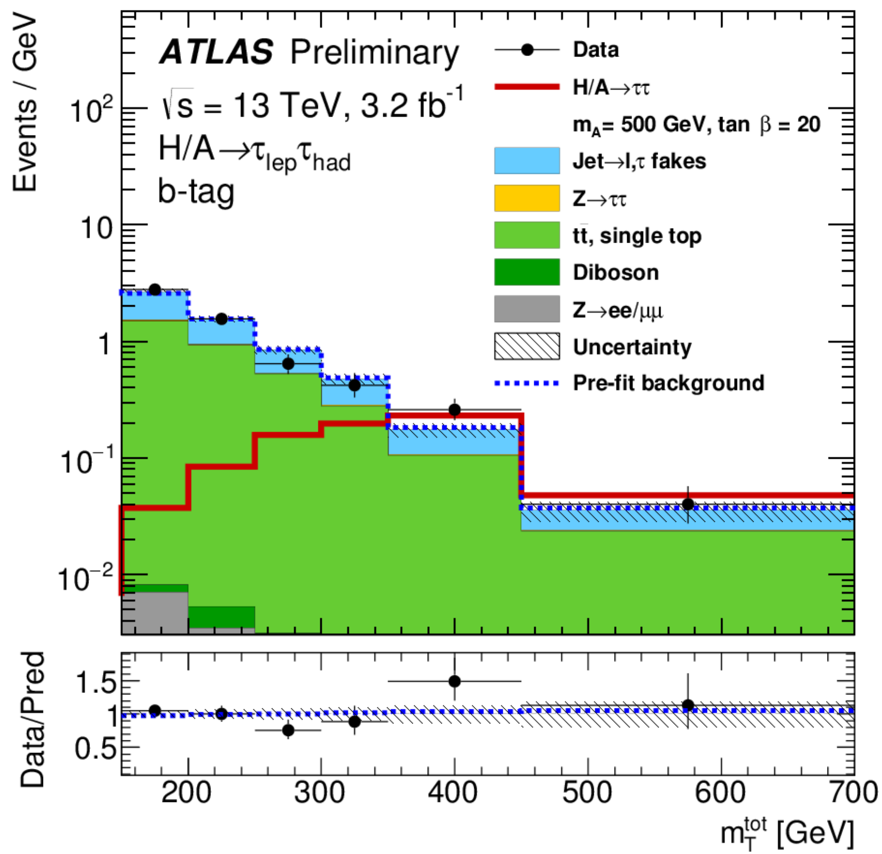
- Z' and A/H → ττ in had-had and lep-had final states
- b-tag and b-veto categories for A/H search to account for enhanced b-associated production
- Final discriminant $m_{T,tot}$:

$$m_T^{tot} = \sqrt{m_T^2(E_T^{miss},\tau_1) + m_T^2(E_T^{miss},\tau_2) + m_T^2(\tau_1,\tau_2)}$$

$$m_T(a,b) = \sqrt{2p_T(a)p_T(b)(1-\cos\Delta\phi(a,b))}$$







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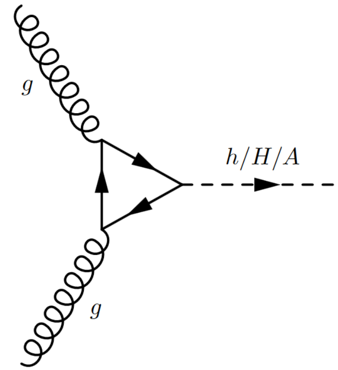
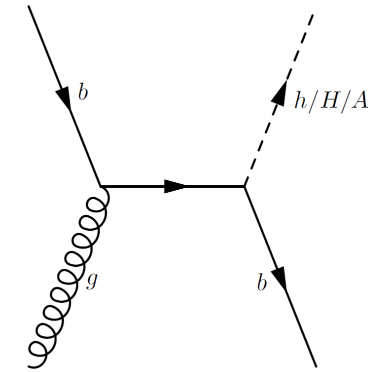
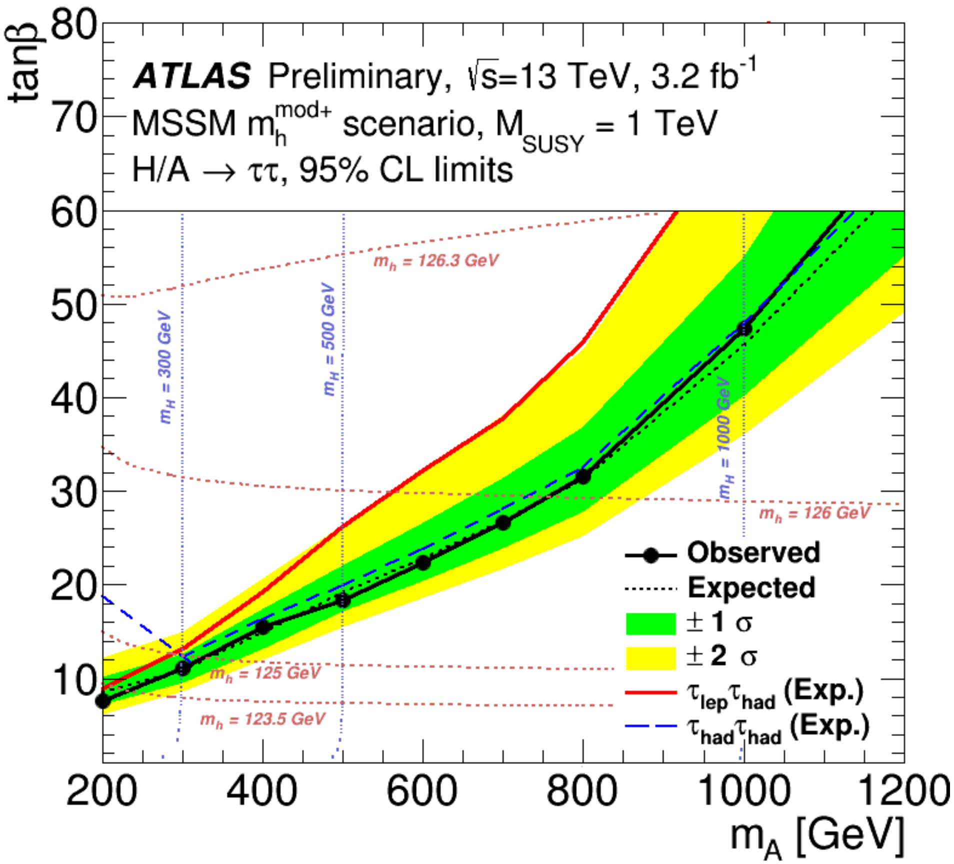
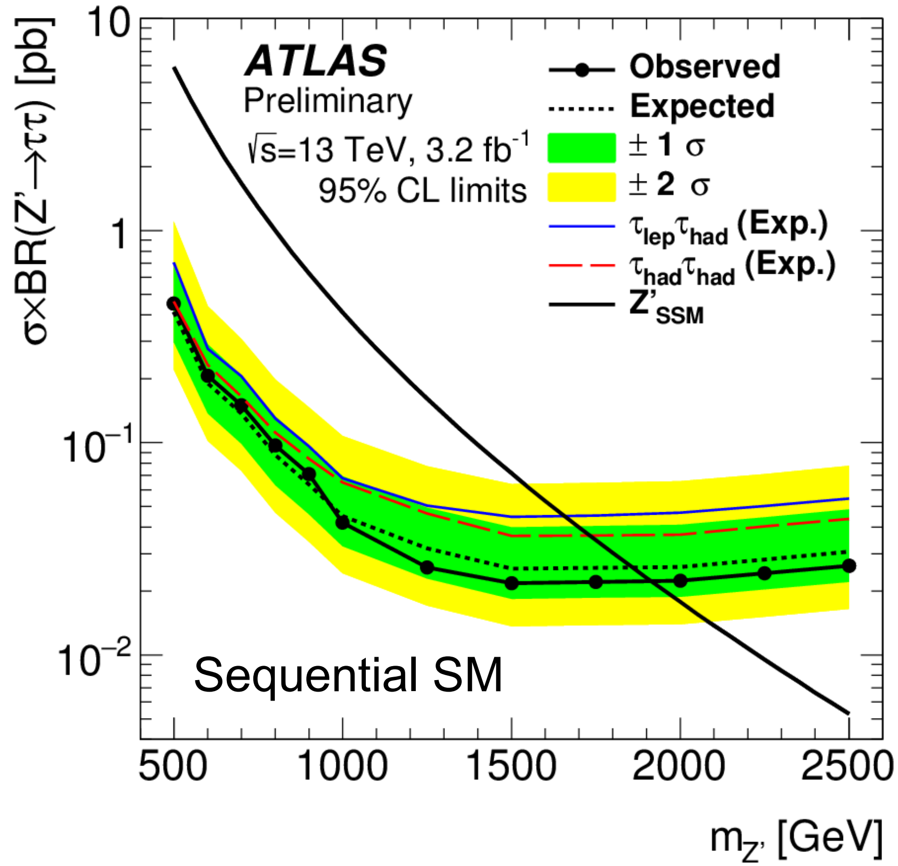


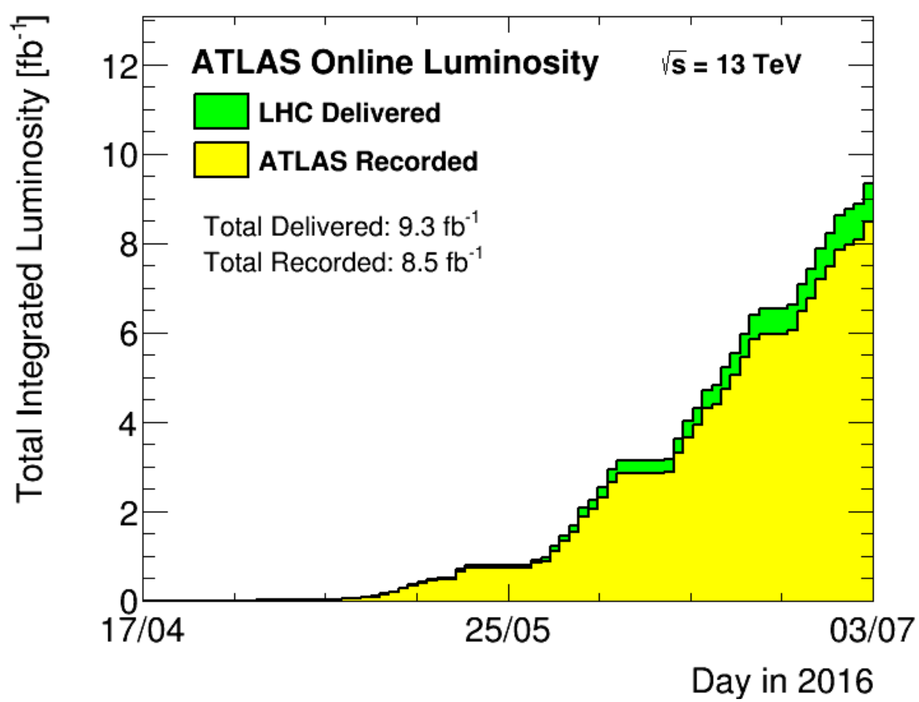






Conclusions

- Searches and measurements in the Higgs sector and flavour physics were presented:
- Higgs couplings consistent with that of the SM,
  ttH process of particular interest since it can probe the top Yukawa coupling
- ttZ 13 TeV cross section measurement
- Searches for FCNC with $t \rightarrow qH$ and $t \rightarrow qZ$, and single top production through FCNC
- Searches for LVF using Higgs and Z bosons
- No significant excess found anywhere
- Many ATLAS analyses will be updated soon, using around 10/fb of the 13 TeV dataset
- Run-2 expected to deliver 120/fb by end of 2018

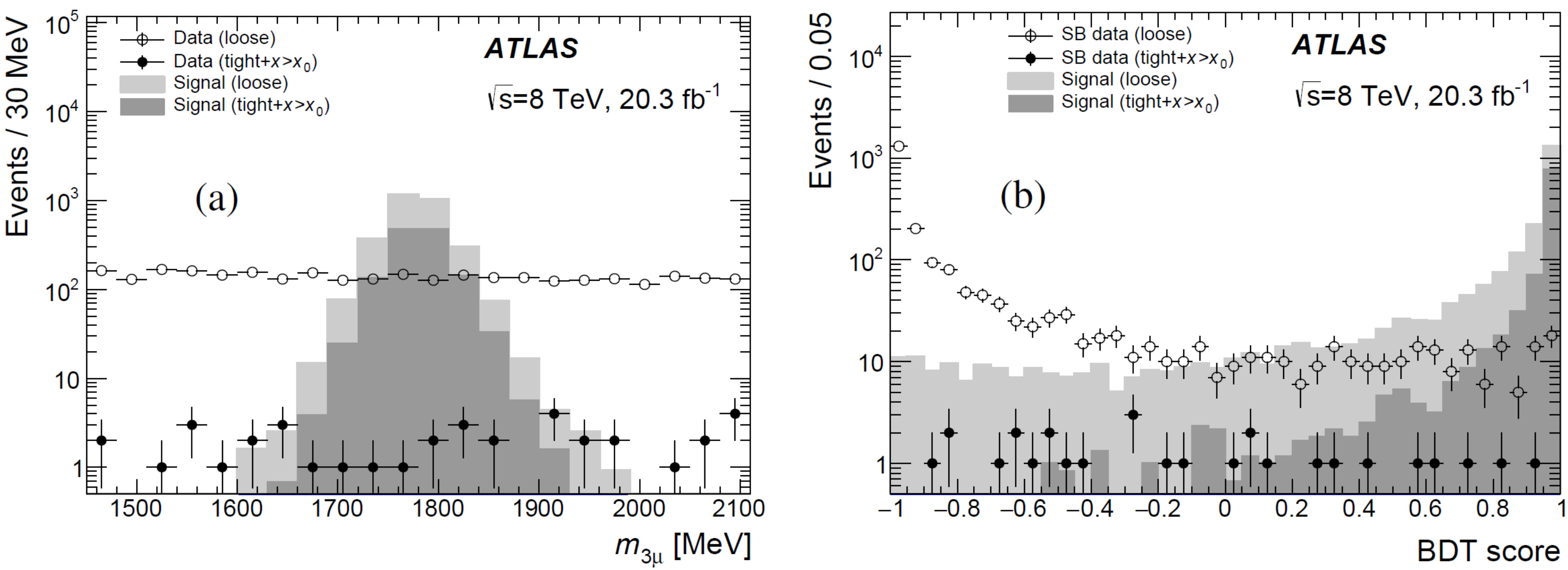


Backup

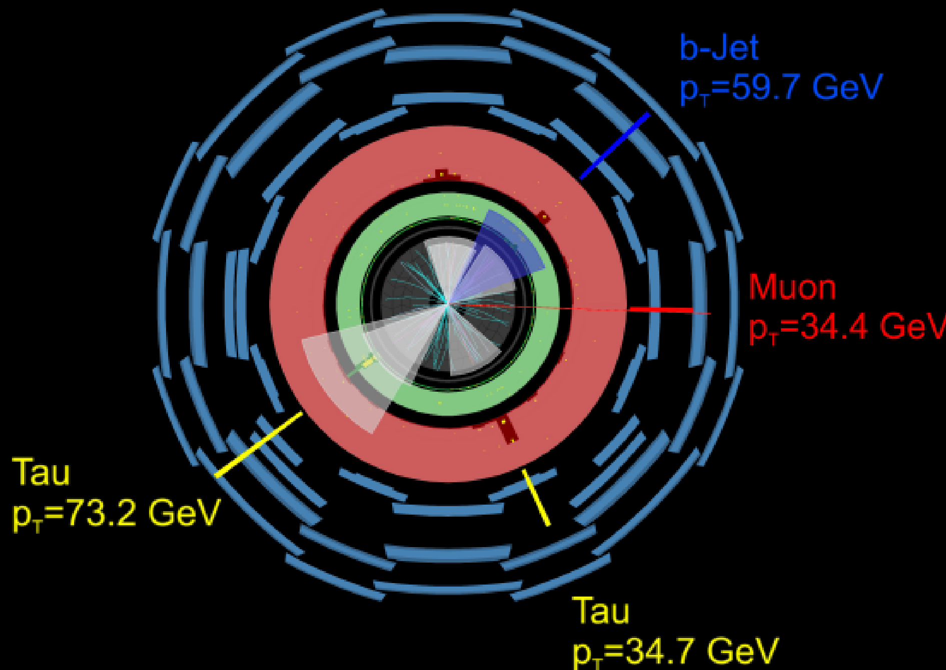
Search for $\tau \to 3\mu$

- In the SM extremely suppressed (10^{-14}), can be enhanced in BSM models
- ATLAS search for **$W \to \tau\nu$, $\tau \to 3\mu$** (neutrinoless)
  - MET expected to be back-to-back with the 3-muon-system
  - Invariant mass of the 3 muons equal to the τ mass: $|m_{3\mu} - m_{\tau}| < 1$ GeV *(loose selection)*
  - BDT to separate remaining background from the signal

Eur. Phys. J. C (2016) 76:232



- Tight selection: BDT score > 0.93
- No data event is found in the signal region after full selection, expected background: 0.19 events
- Observed upper limit on BR($\tau \to 3\mu$) = 3.76 * 10^{-7} (exp. 3.94 * 10^{-7}) at 90% CL



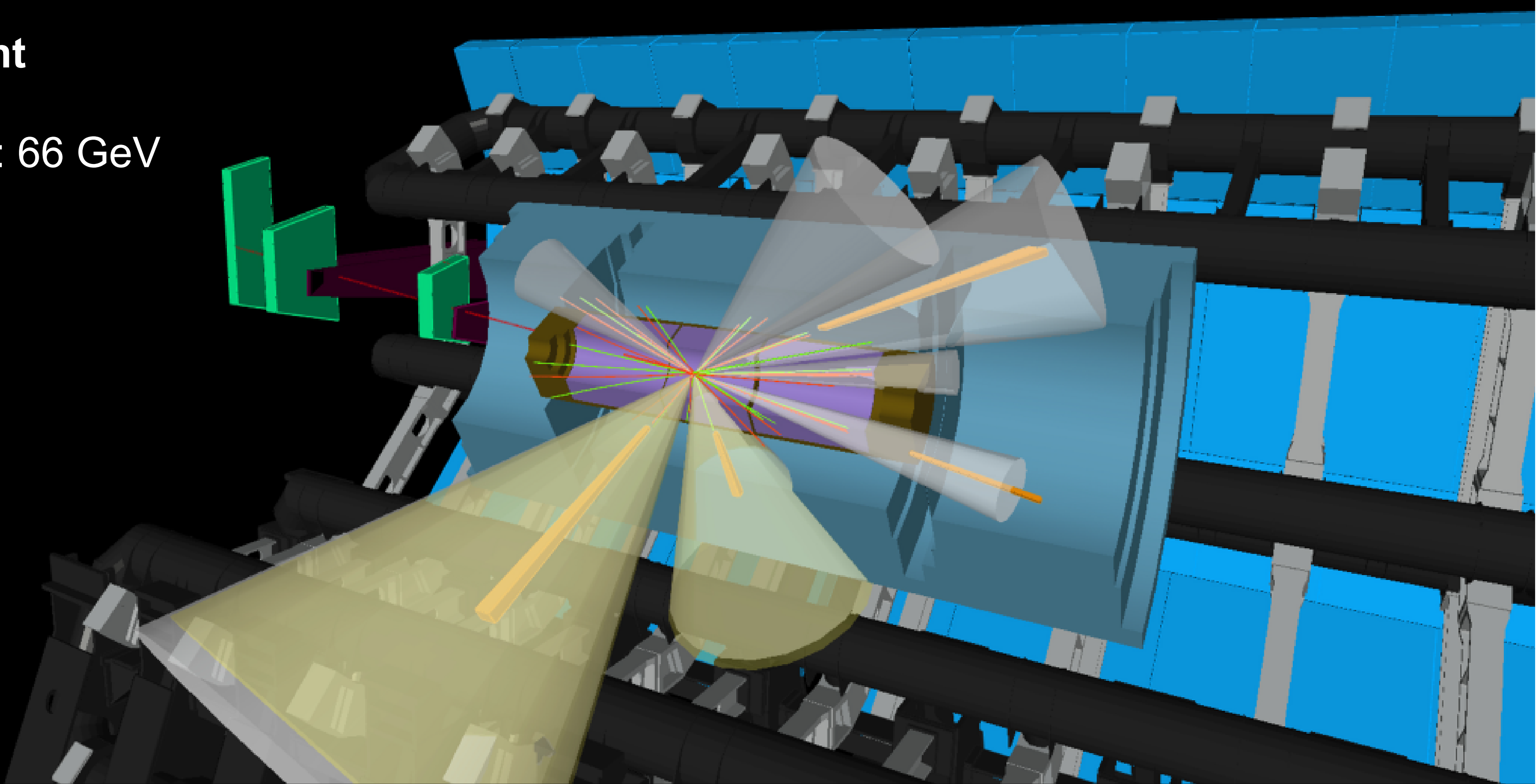
ATLAS EXPERIMENT

Run Number: 208970, Event Number: 128422540

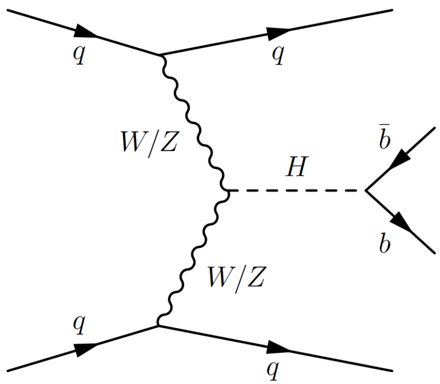
Date: 2012-08-21 19:39:51 CEST

ttH, H → ττ candidate event

Visible ττ mass: 66 GeV



Search for VBF-produced H → bb



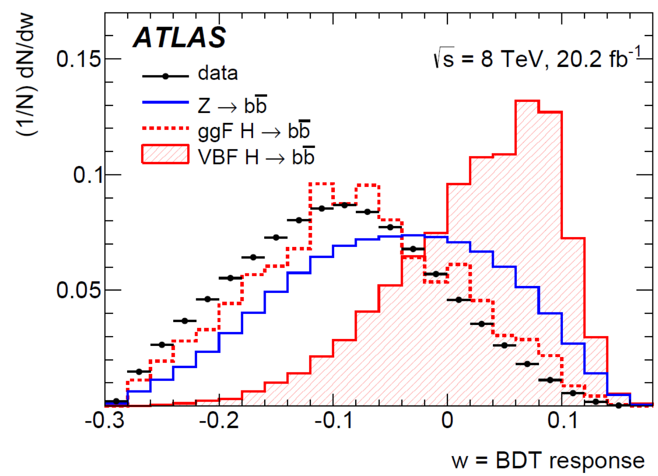
Dedicated L1 **VBF triggers**: Selecting events with either three jets, with one or two of them in the forward detector region (large |η|), complemented by at least one high p_T b-jet selected by high level trigger

→ VBF triggers increased signal acceptance by 25% compared to standard four-jet triggers

Four selected jets must satisfy p_T>50 GeV, central jets $p_{T,bb}$ > 100 GeV

BDT trained to separate VBF H → bb from non-resonant bkg ($t\bar{t}$, multi-jet, W+jets)

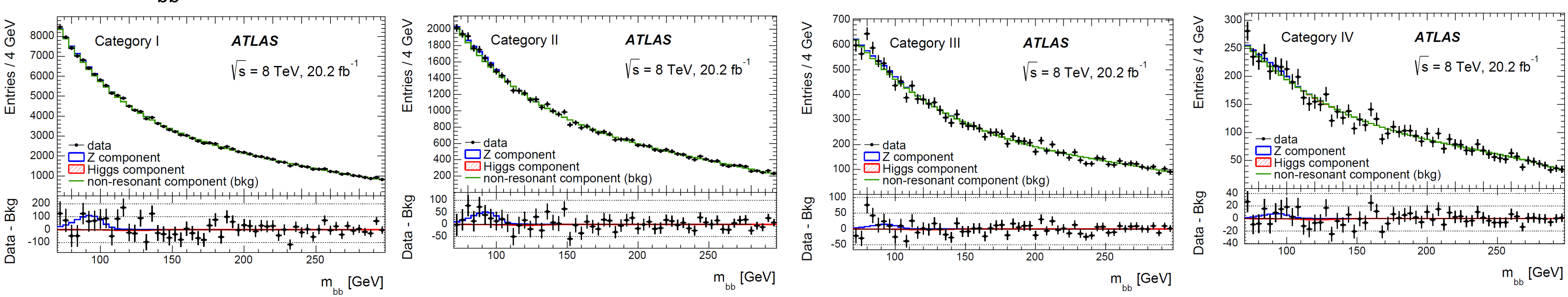
Top ranked input variables:
- jet widths of forward jets,
- p_T sum of central jets
- inv. mass of forward jets



Four signal regions defined by cutting on BDT output score

arXiv:1606.02181

m_{bb} distributions (70-300 GeV) in the four signal regions, which are simultaneously fit:



→ No excess seen in any category, best-fit μ=-0.8±2.3, upper limit on σxBR: 4.4xSM (expected 5.4)

Search for hh → $b\bar{b}b\bar{b}$

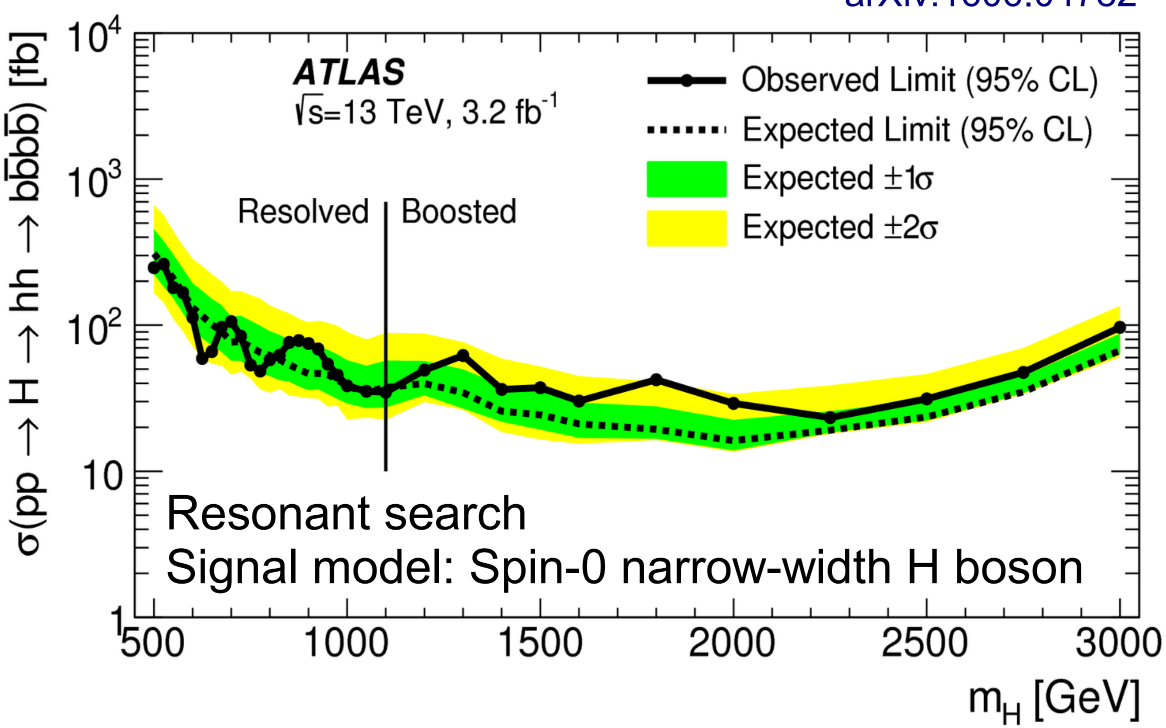
13 TeV

Higgs boson-pair production xs very small in the SM, but enhanced in extra dimension models or 2HDM.

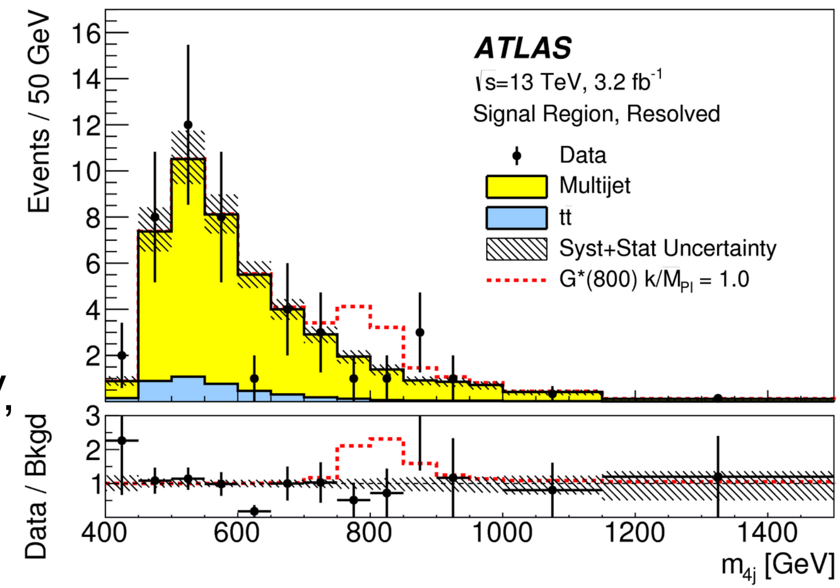
Resolved selection: 4 b-jets with $|\eta|<2.5$, p_T cuts dependent on $m_{4J.}$ m_{4j} resolution improved by 30% by scaling b-jet 4-momenta such that m_{bb} = 125 GeV.

Boosted selection: At least 2 large-R jets with p_T>250 GeV, jet mass > 50 GeV.

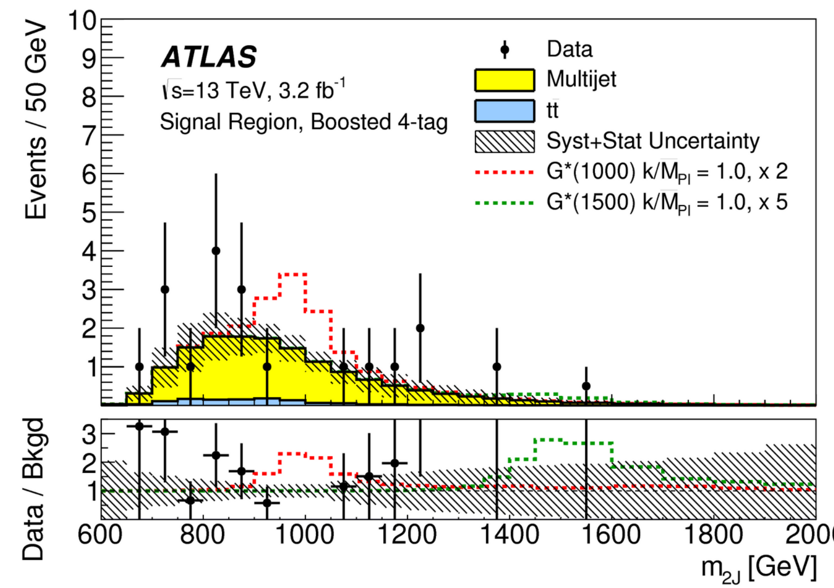
arXiv:1606.04782



Resolved analysis:



Boosted analysis:



Non-resonant search: Limit on $\sigma(pp\to hh\to b\bar{b}b\bar{b})$ < 1.22 pb

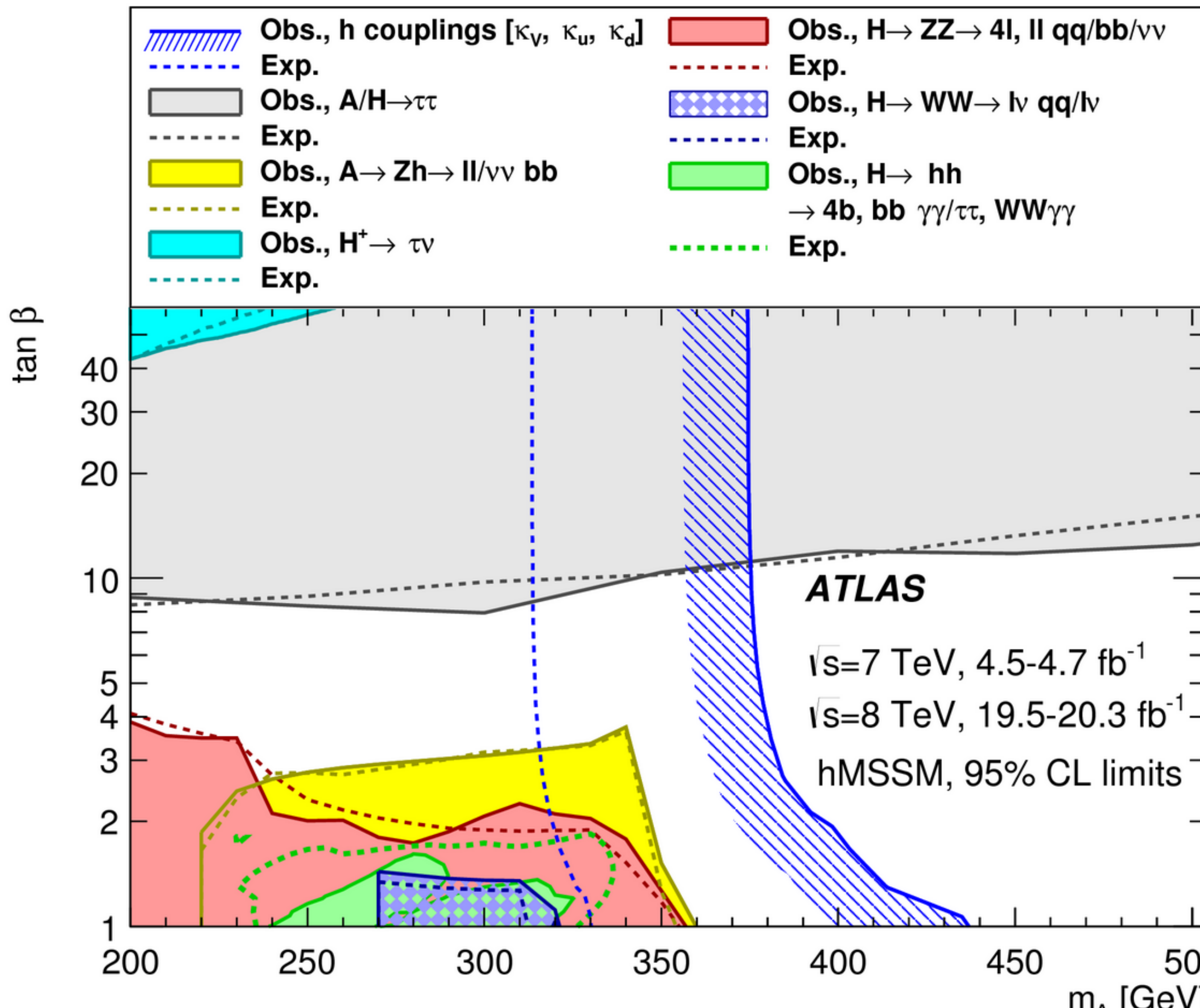
→ No significant excess

8 TeV BSM Higgs Searches

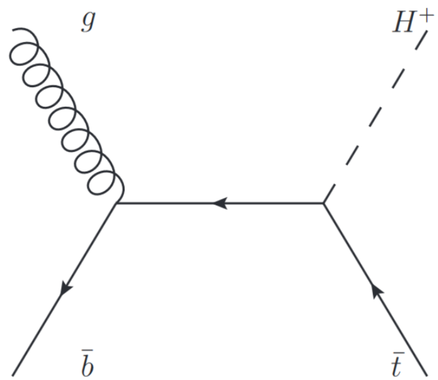
Additional Higgs bosons are predicted by many BSM extensions, such as 2HDM, MSSM, Higgs Singlett, Higgs Triplett models, NMSSM, etc.

All direct searches at 8 TeV yielded null results, first 13 TeV results extend run-1 sensitivity.

Combined 7 TeV and 8 TeV ATLAS upper limit on BR ($H \rightarrow$ invisible): 0.25 (expected 0.26)



Search for gb → tH⁺, H⁺ → tb



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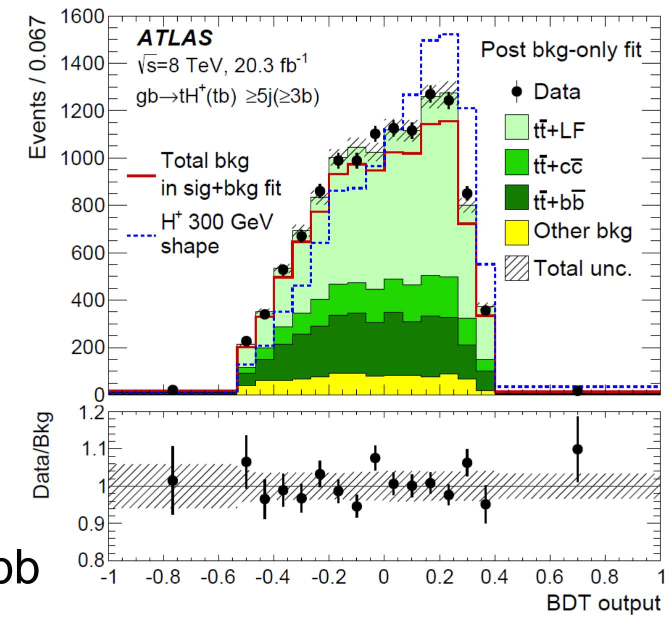
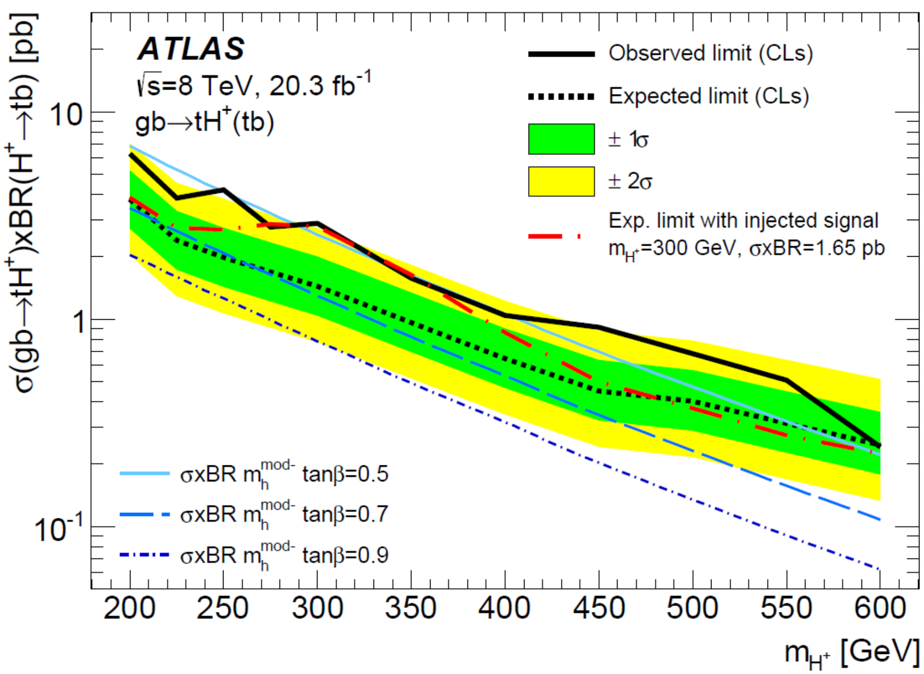
Production in association with a top
Decay to top-bottom when $m_{H+} > m_{top}$
→ Enhanced couplings at low and high tanβ
Dominant decay in 2HDM when $\cos(\alpha-\beta)\approx 0$

Post fit BDT outputs:



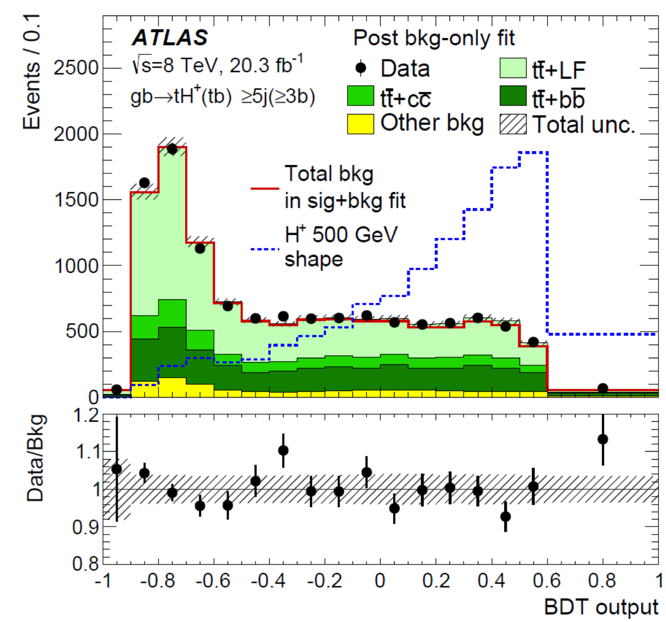
- Signal region: 5jets, 3 b-tagged jets, one high p_T lepton,
huge overlap with signal region for ttH, H→bb search
- Huge uncertainties on modelling of tt+bb background
- BDT trained at every mass hypothesis, to separate signal from tt+bb



Broad excess seen, at most 2.4σ

Excess inconsistent with expected signal

13 TeV analysis to be released soon!



$H^+ \rightarrow tb$ candidate event

Electron, p_T = 61 GeV

2 light jets

3 b-tagged jets