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PHYSICS NEWS WITH TAUS FROM ATLAS

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ON BEHALF OF MANY VALIANT PEOPLE
16TH OF NOVEMBER 2015

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2015 ATLAS Results

- Evidence of Yukawa couplings to τ
  - JHEP04(2015)117
- Lepton Flavour Violating (LFV)H→τμ
  - submitted to JHEP
- ttbar-associated production
  - PLB 749
- hh→bbττ
  - PRD 92
- Embedding method
  - JINST 10
- H→aa→μμττ
  - PRD92
- charged H→τυ
  - JHEP03
- τ-reco commissioning for Run2
  - ATL-PHYS-PUB-2015-25

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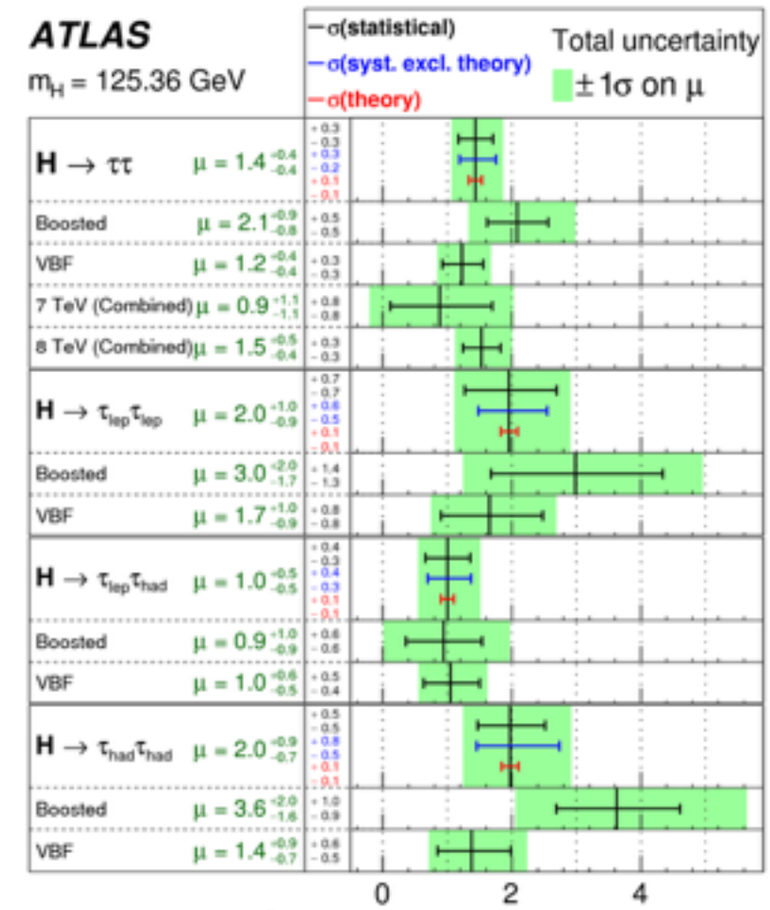
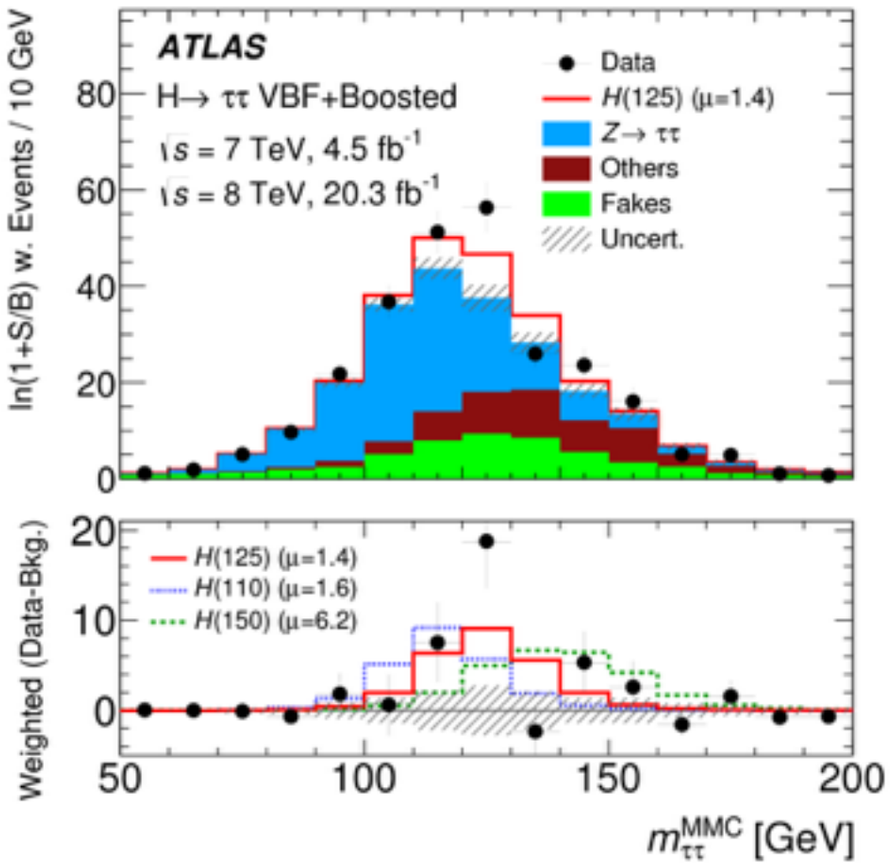
Evidence for SM H→ττ

- ATLAS sees evidence for Higgs boson yukawa couplings to τ leptons
- Consistent with SM couplings and mass of 125GeV
  - JHEP04(2015)117

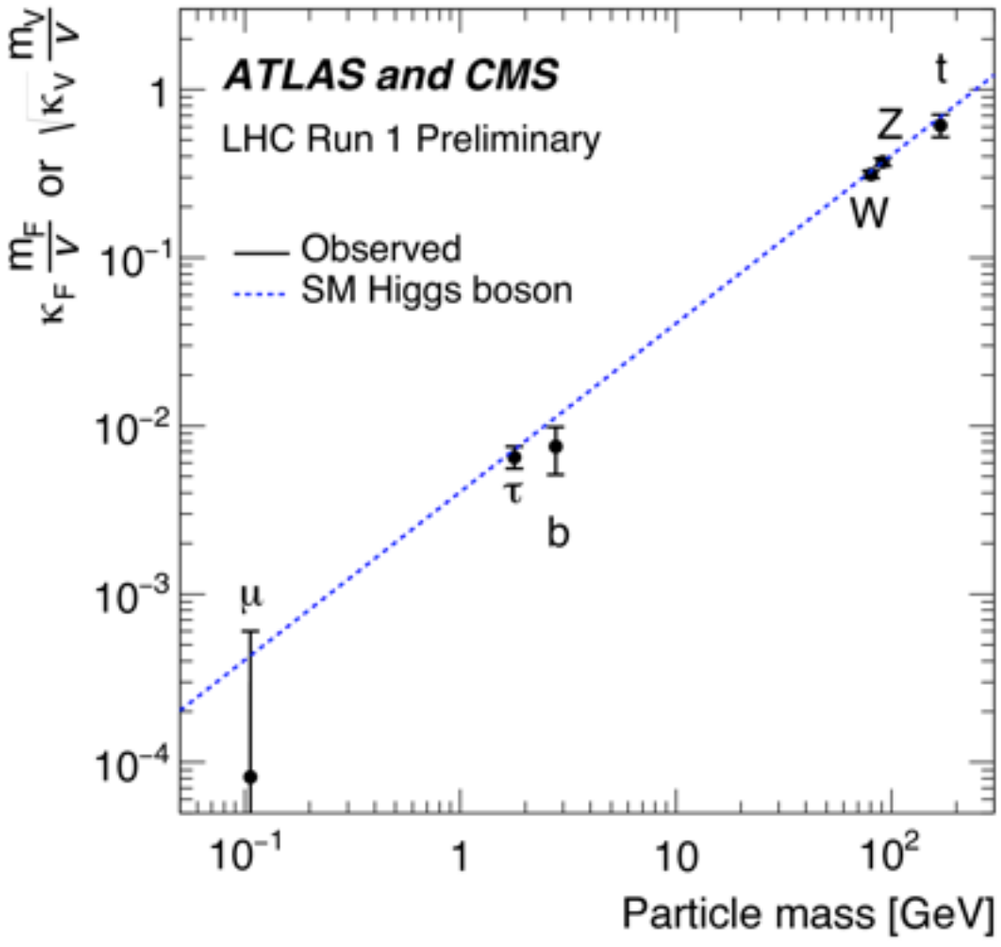


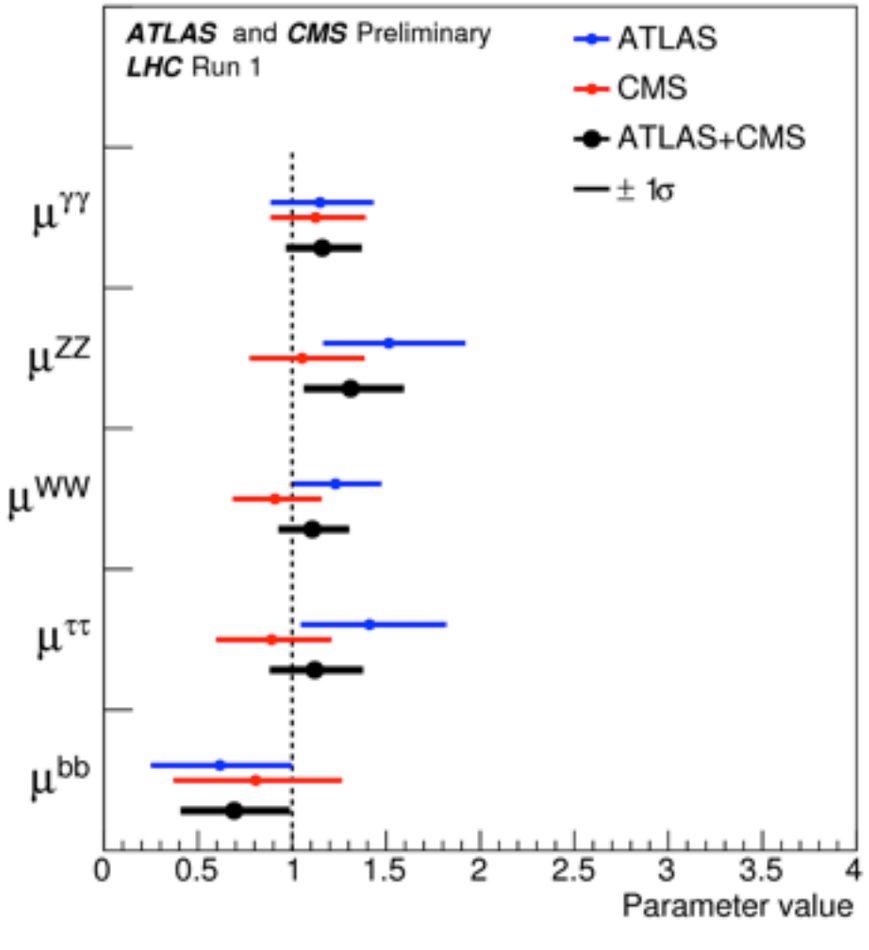


Channel and Category	Expected Significance (σ)	Observed Significance (σ)
$\tau_{lep}\tau_{lep}$ VBF	1.15	1.88
$\tau_{lep}\tau_{lep}$ Boosted	0.57	1.72
$\tau_{lep}\tau_{lep}$ Total	1.25	2.40
$\tau_{lep}\tau_{had}$ VBF	2.11	2.23
$\tau_{lep}\tau_{had}$ Boosted	1.11	1.01
$\tau_{lep}\tau_{had}$ Total	2.33	2.33
$\tau_{had}\tau_{had}$ VBF	1.70	2.23
$\tau_{had}\tau_{had}$ Boosted	0.82	2.56
$\tau_{had}\tau_{had}$ Total	1.99	3.25
Combined	3.43	4.54

Discovery for SM H→ττ

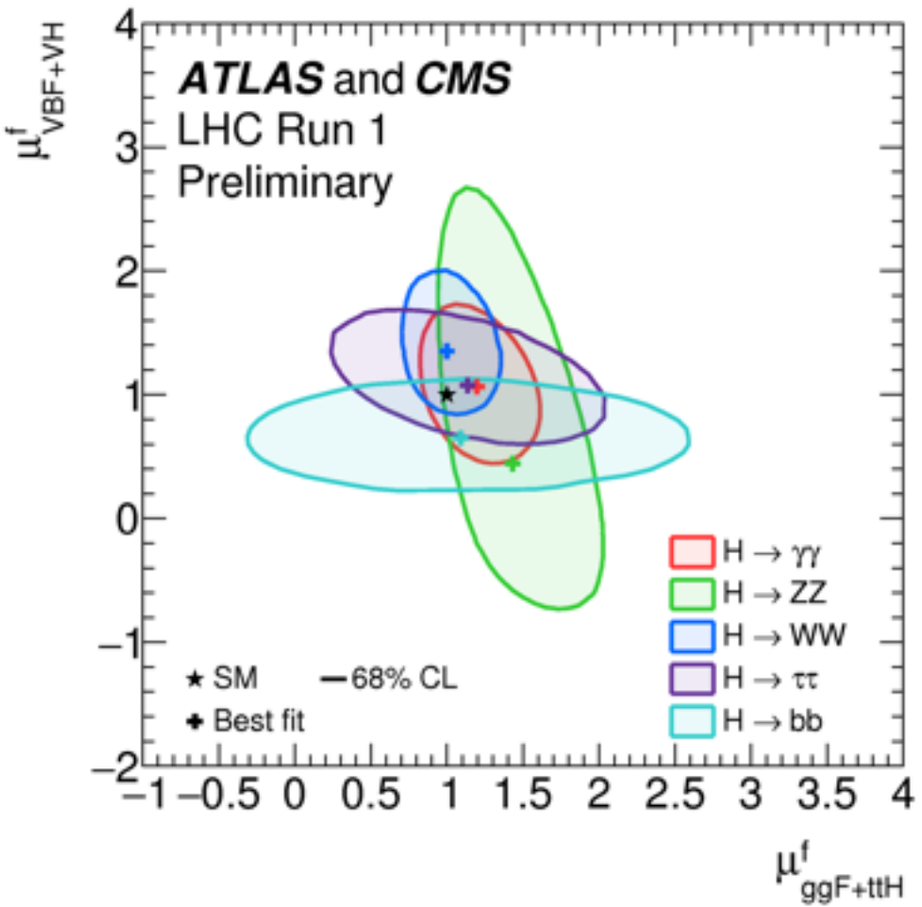
- CMS+ATLAS combination establishes discovery at 5.5σ significance
- Still consistent with SM Higgs rate
- Some call it CMS-PAS-HIG-15-002, others ATLAS-CONF-2015-044
- Let's agree to call it a fine example of cross-experiment collaboration

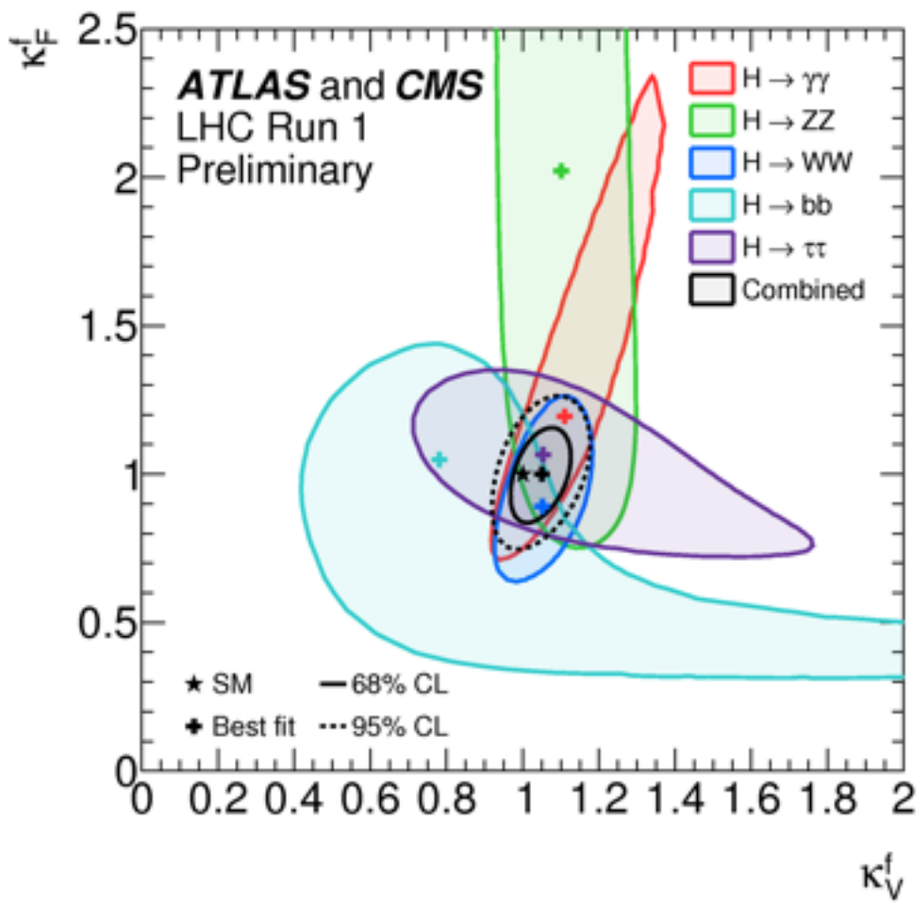




Discovery for SM H→ττ

- Higgs→ττ will continue to be an interesting channel also post-discovery
- Best constraint on Higgs coupling to fermions
- Also contributed strongly to measuring VBF production rate at 5.4σ significance
- Access to direct Higgs-fermion vertex allows CP measurement in τ decays





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top associated H→ττ

- Disambiguation of leptons and hadronic τ decays from H and t decays difficult
- Analysis also includes WW, ZZ and other Higgs decays
- Therefore categorise by number of leptons and taus
  - channels including hadronic τ decays are: 2leptons +1τ and 1lepton+2τ's

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

Category	q mis-id	Non-prompt	$t\bar{t}W$	$t\bar{t}Z$	Diboson	Expected bkg.	$t\bar{t}H$ $(\mu = 1)$	Observed
$ee + \geq 5j$	1.1 ± 0.5	2.3 ± 1.2	1.4 ± 0.4	0.98 ± 0.26	0.47 ± 0.29	6.5 ± 1.8	0.73 ± 0.14	10
$e\mu + \geq 5j$	0.85 ± 0.35	6.7 ± 2.4	4.8 ± 1.2	2.1 ± 0.5	0.38 ± 0.30	15 ± 3	2.13 ± 0.41	22
$\mu\mu + \geq 5j$	–	2.9 ± 1.4	3.8 ± 0.9	0.95 ± 0.25	0.69 ± 0.39	8.6 ± 2.2	1.41 ± 0.28	11
$ee + 4j$	1.8 ± 0.7	3.4 ± 1.7	2.0 ± 0.4	0.75 ± 0.20	0.74 ± 0.42	9.1 ± 2.1	0.44 ± 0.06	9
$e\mu + 4j$	1.4 ± 0.6	12 ± 4	6.2 ± 1.0	1.5 ± 0.3	1.9 ± 1.0	24 ± 5	1.16 ± 0.14	26
$\mu\mu + 4j$	–	6.3 ± 2.6	4.7 ± 0.9	0.80 ± 0.22	0.53 ± 0.30	12.7 ± 2.9	0.74 ± 0.10	20
3ℓ	–	3.2 ± 0.7	2.3 ± 0.7	3.9 ± 0.8	0.86 ± 0.55	11.4 ± 2.3	2.34 ± 0.35	18
$2\ell 1\tau_{\text{had}}$	–	$0.4\ ^{+0.6}_{-0.4}$	0.38 ± 0.12	0.37 ± 0.08	0.12 ± 0.11	1.4 ± 0.6	0.47 ± 0.08	1
$1\ell 2\tau_{\text{had}}$	–	15 ± 5	0.17 ± 0.06	0.37 ± 0.09	0.41 ± 0.42	16 ± 5	0.68 ± 0.13	10
4ℓ Z-enr.	–	$\lesssim 10^{-3}$	$\lesssim 3 \times 10^{-3}$	0.43 ± 0.12	0.05 ± 0.02	0.55 ± 0.15	0.17 ± 0.02	1
4ℓ Z-dep.	–	$\lesssim 10^{-4}$	$\lesssim 10^{-3}$	0.002 ± 0.002	$\lesssim 2 \times 10^{-5}$	0.007 ± 0.005	0.025 ± 0.003	0

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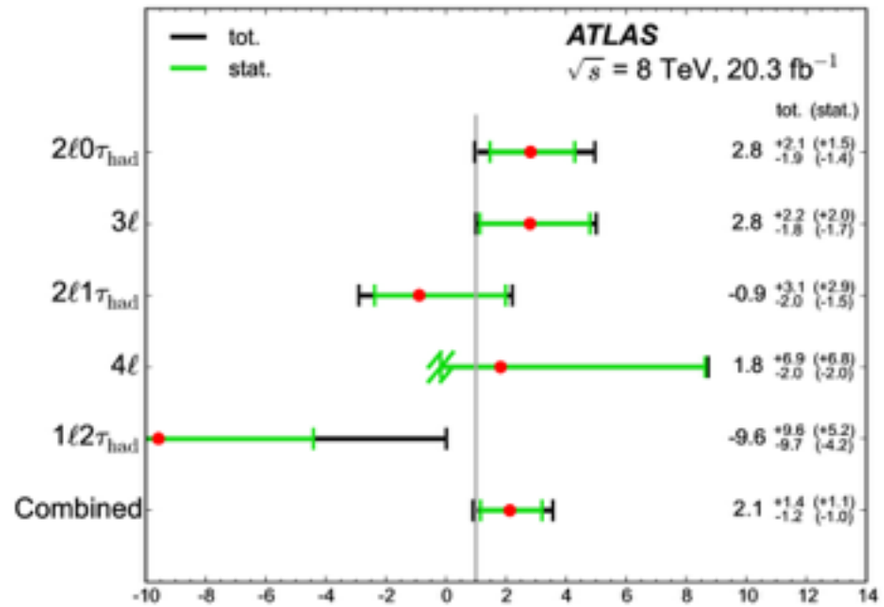
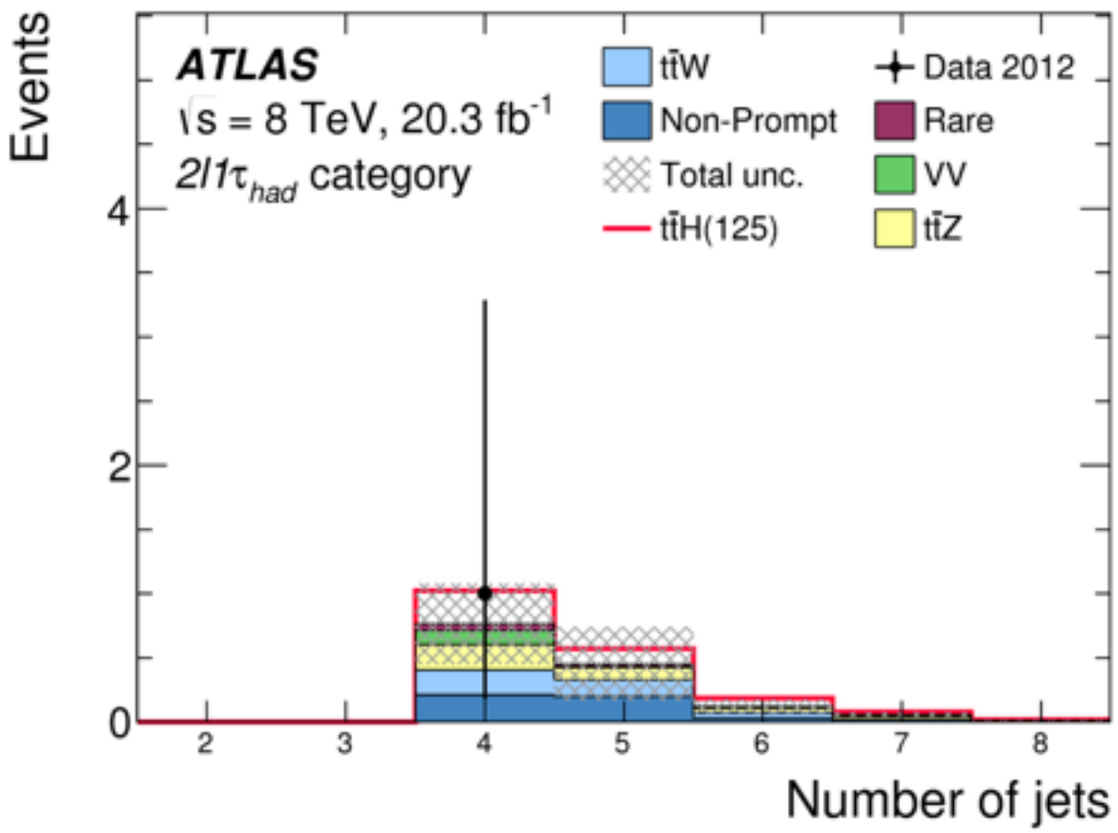
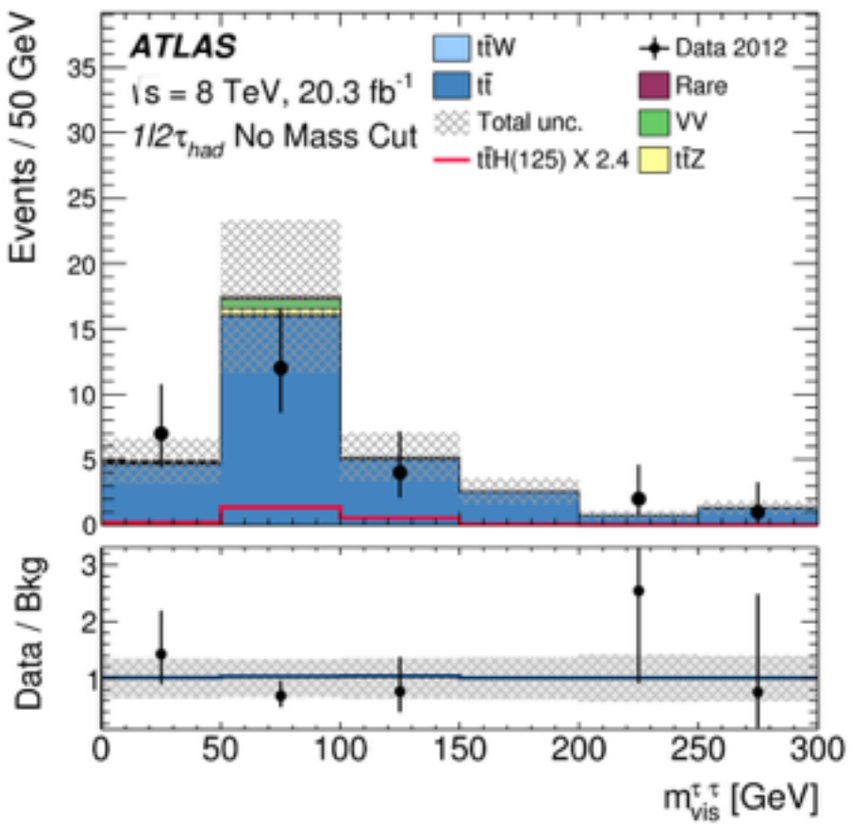
top associated H→ττ

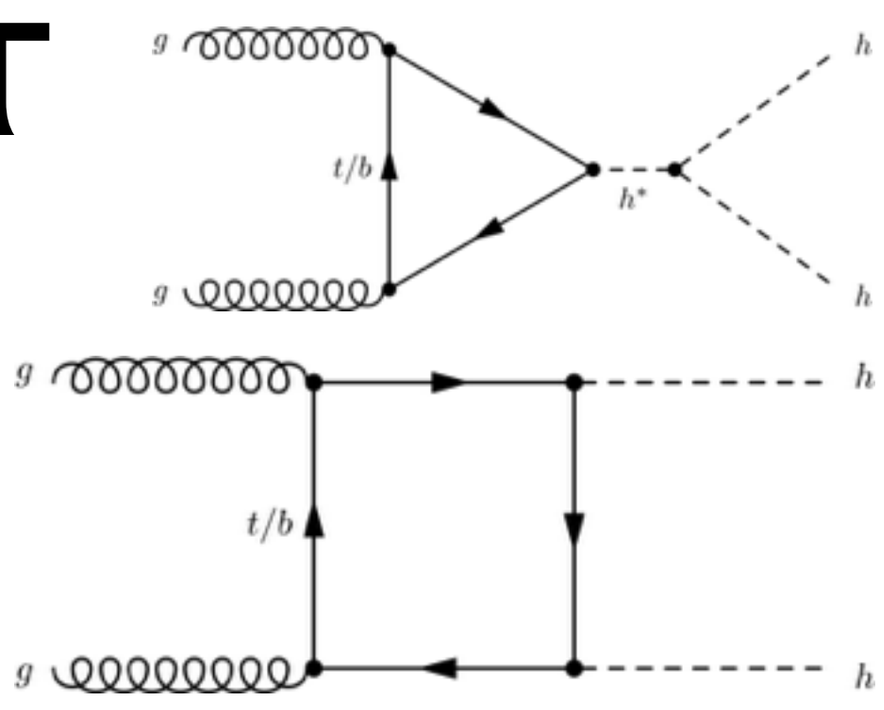
- Given the available luminosity, not sensitive to SM signal
- 95% CL at 4.7 (2.4) x SM observed (expected)
- Due to combinatorics of top pair+H decay products, currently use ditau visible mass
- Looking into disambiguation via kinematic fit



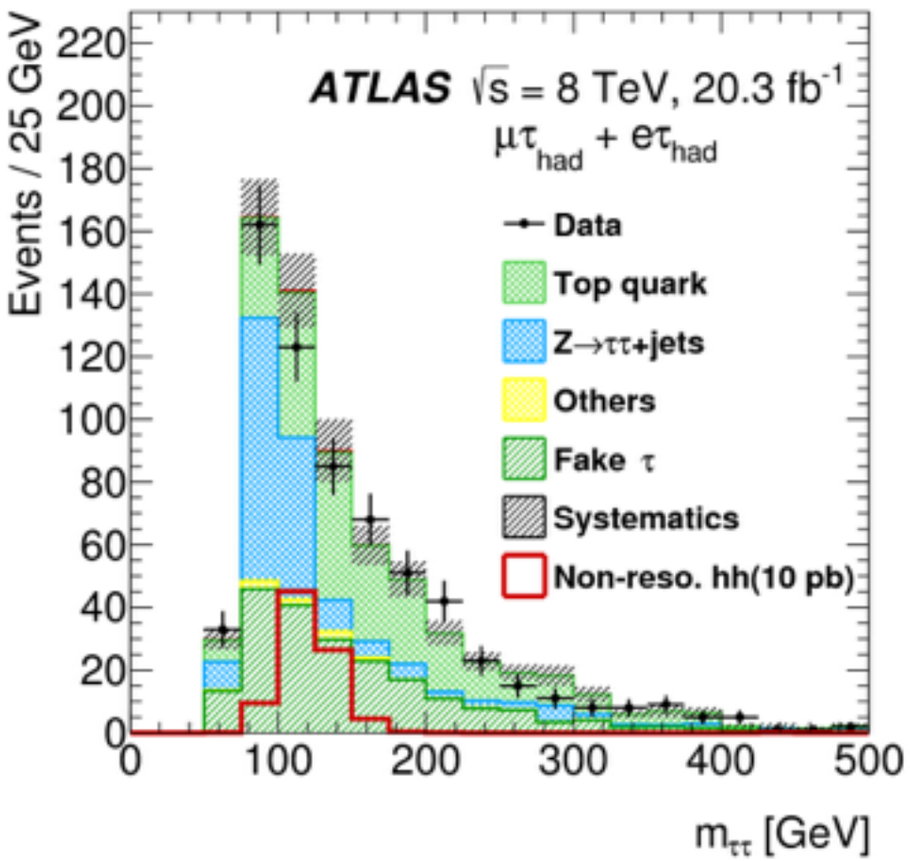


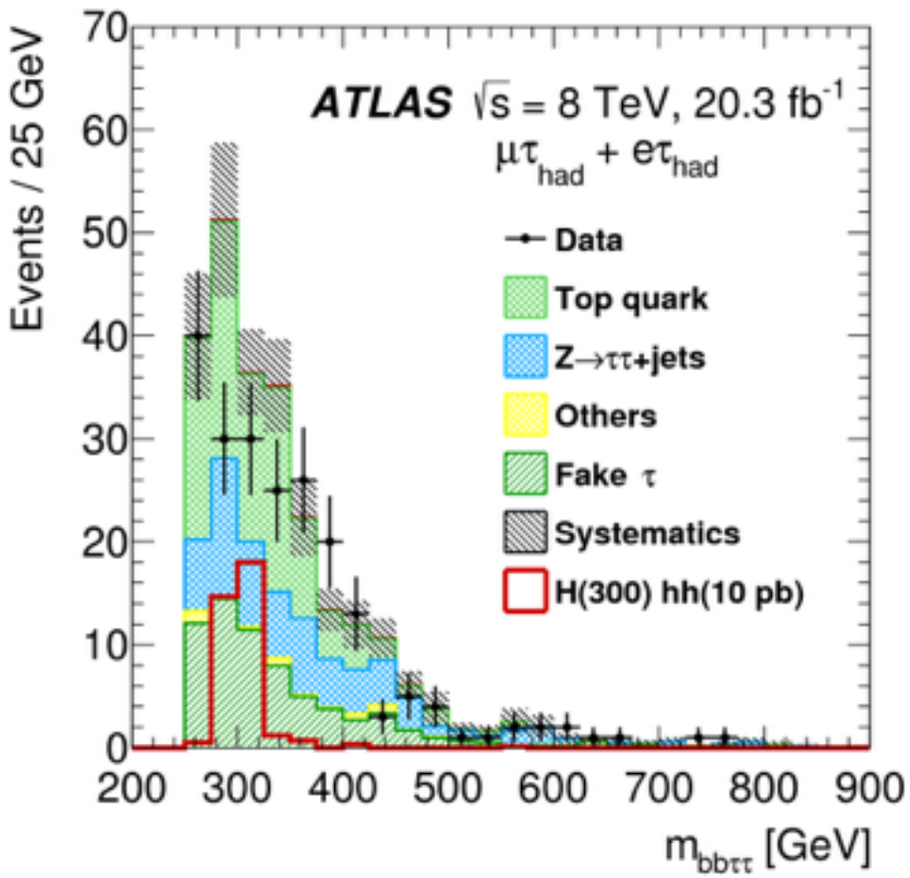


hh→bbττ



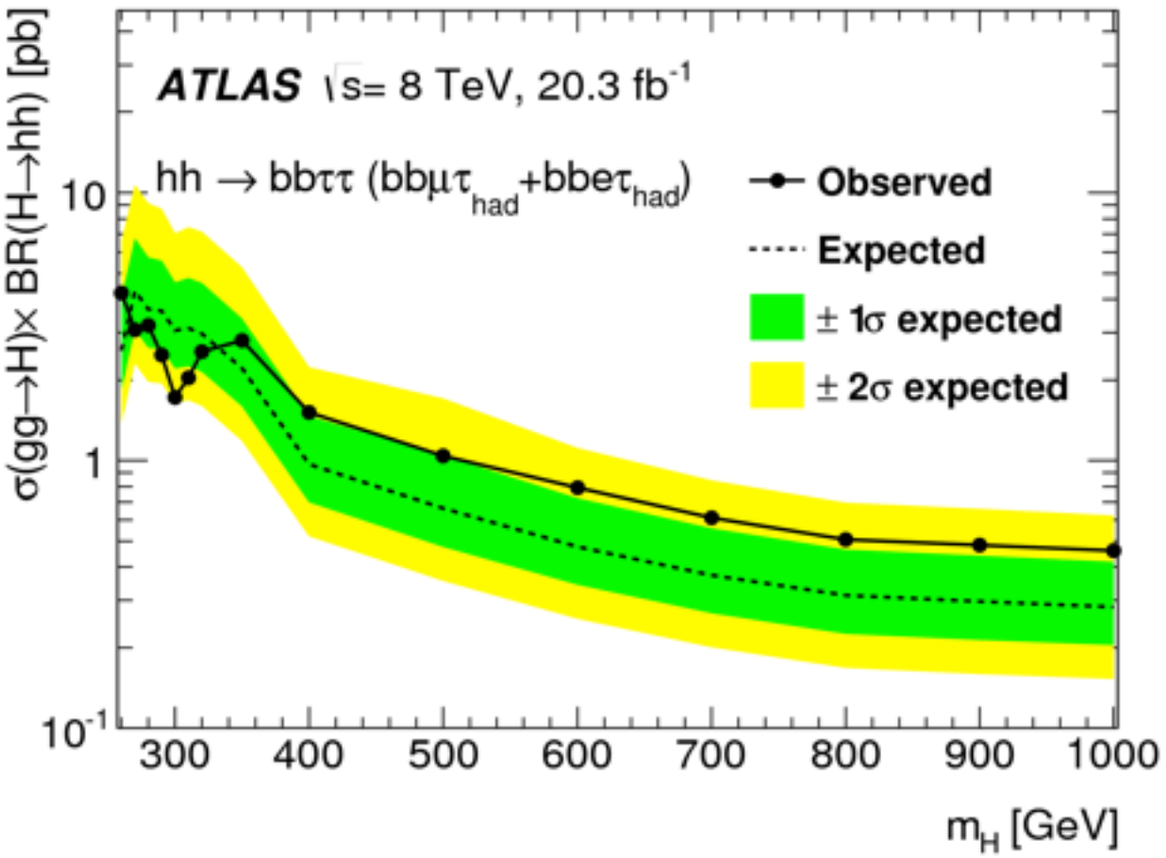
- Many different h decay mode combinations considered
- Both resonant and non-resonant hh production
  - non-resonant production: use MMC for ditau mass
  - for resonant combine MMC with bb invariant mass

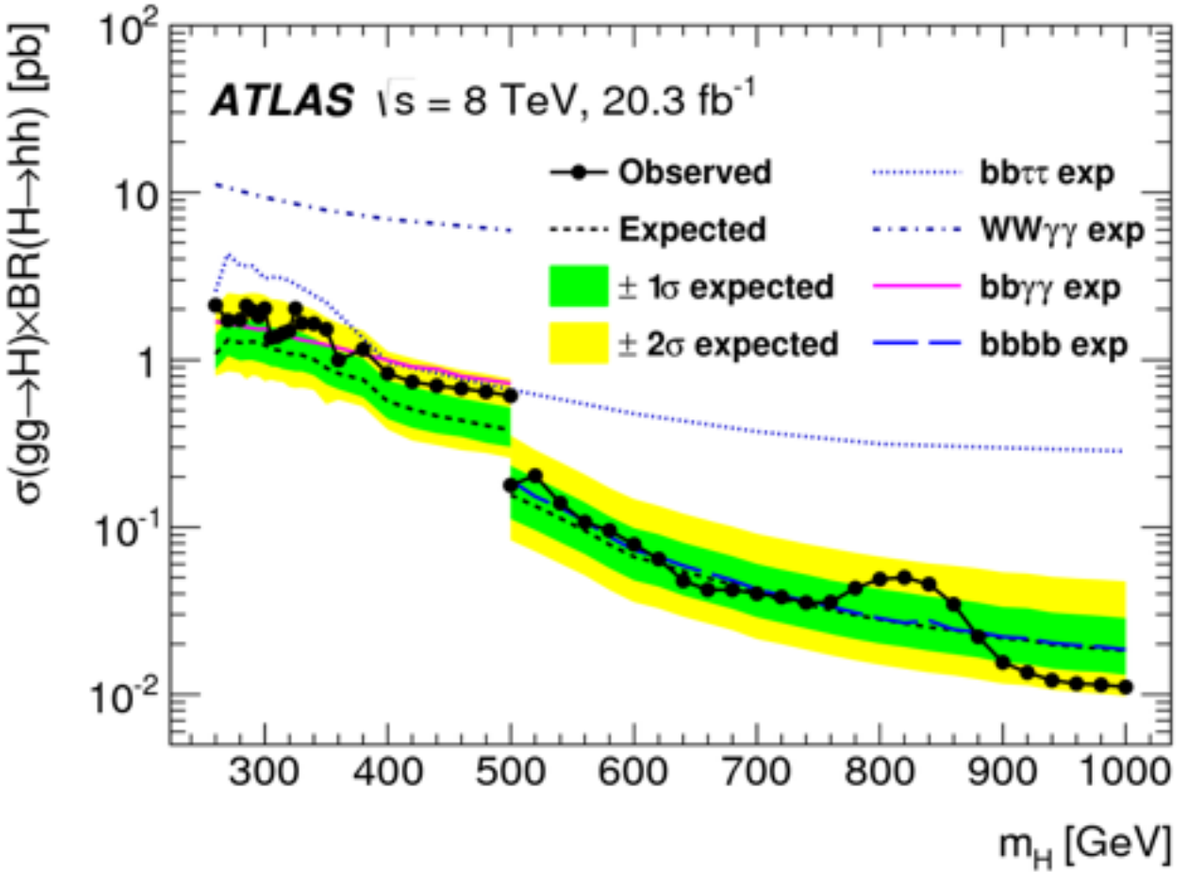




$hh \rightarrow bb\tau\tau$

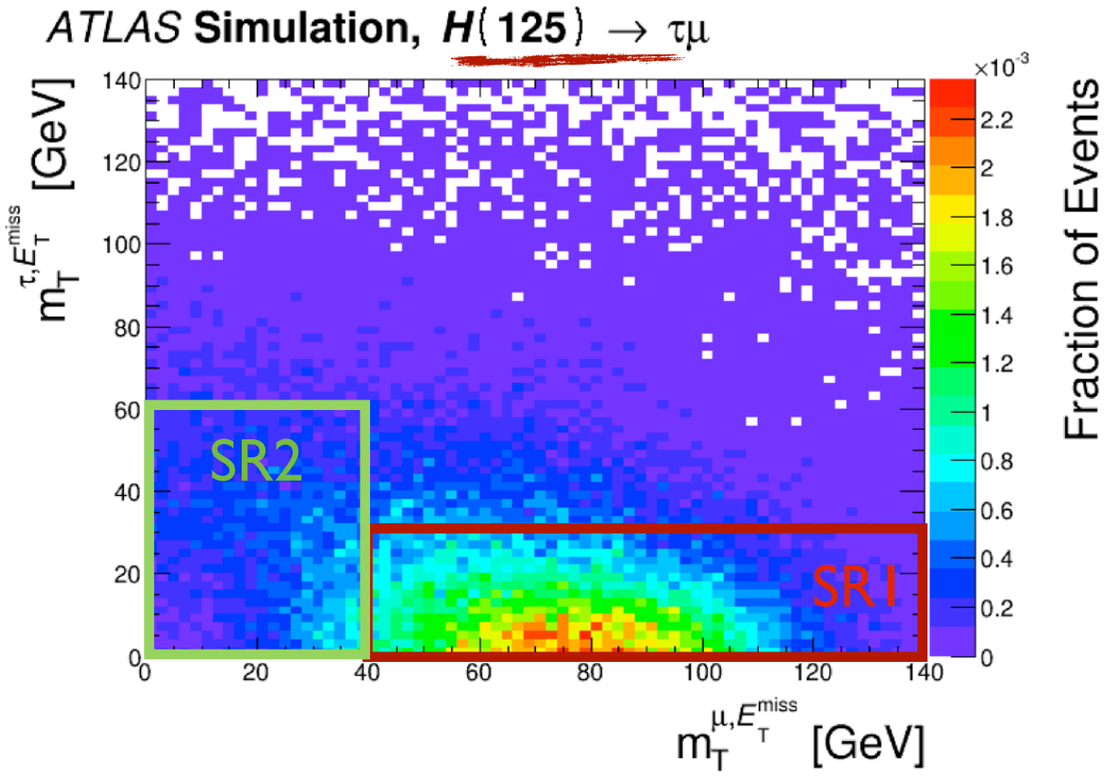
- No significant excess, so set 95% CL limits
- For non-resonant set combined limit on hh production cross section
  - observed (expected) at 0.69 (0.47) pb corresponds to 70 (48) x SM strength
- For resonant production 95% CL depends on mass of mother particle
  - ranges from 2.1 (1.1) pb at 260 GeV to 0.011 (0.018) pb at 1000 GeV

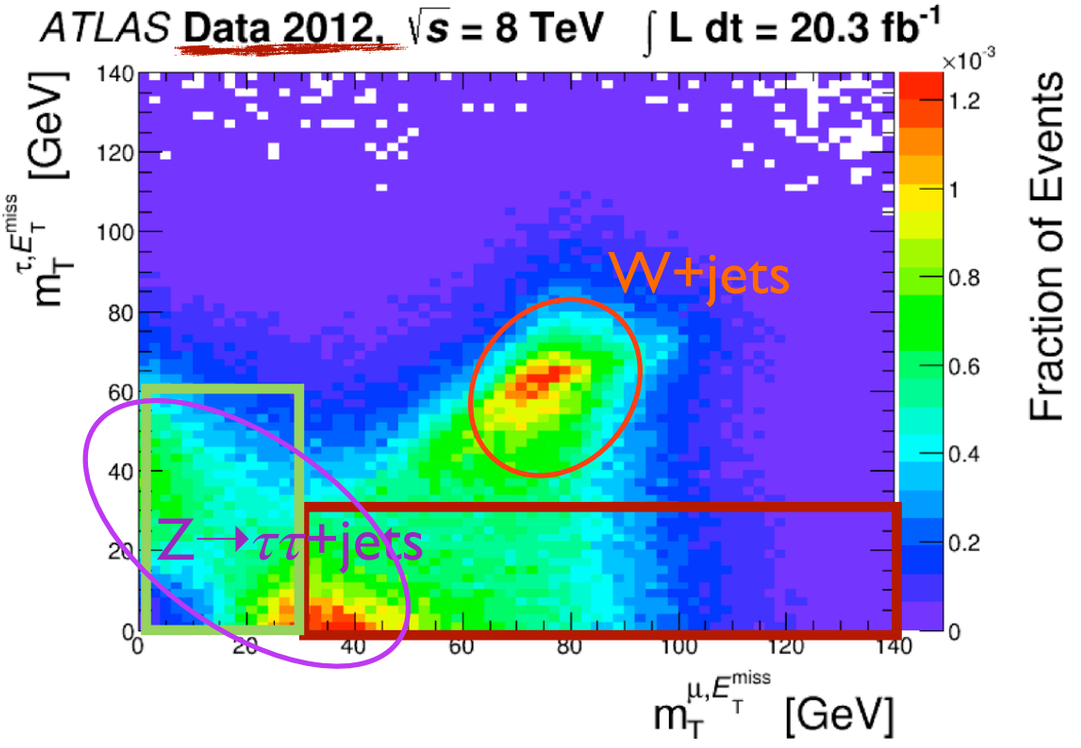




LFV H→μτ

- Recently seen ~2σ excess in CMS results
- OS muon and hadronic τ decay
- two signal regions in mT(μ)-mT(τ) plane
  - SR1: dominant BG W+jets
  - SR2: dominant BG Z→ττ + jets
- [submitted to JHEP]





Cut	SR1	SR2	WCR	TCR
$p_T(\mu)$	>26 GeV	>26 GeV	>26 GeV	>26 GeV
$p_T(\tau_{had})$	>45 GeV	>45 GeV	>45 GeV	>45 GeV
$m_T(\mu, E_T^{miss})$	>40 GeV	<40 GeV	>60 GeV	–
$m_T(\tau_{had}, E_T^{miss})$	<30 GeV	<60 GeV	>40 GeV	–
$\lvert\eta(\mu) - \eta(\tau_{had})\rvert$	<2	<2	<2	<2
N_{jet}	–	–	–	>1
N_{b-jet}	0	0	0	>0

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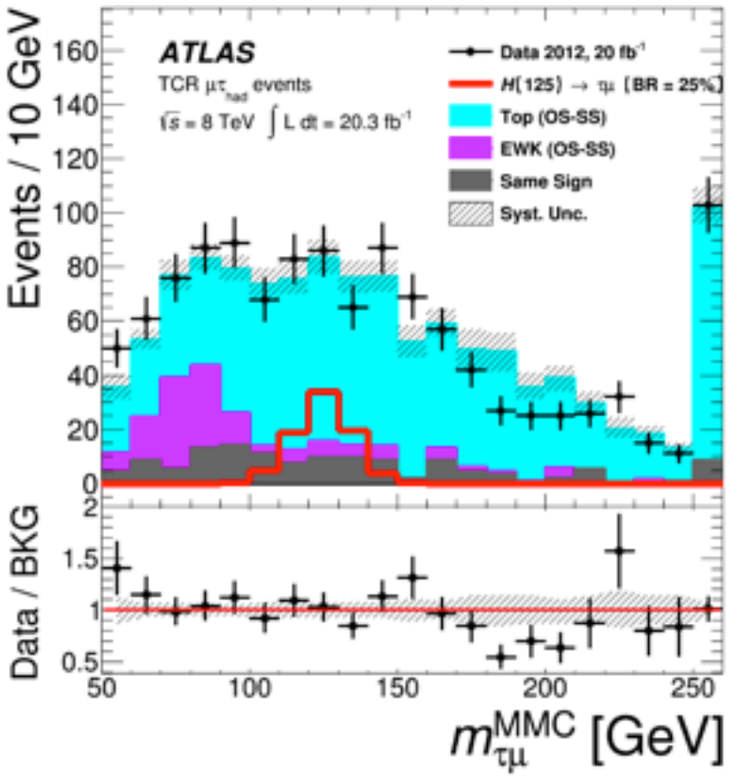
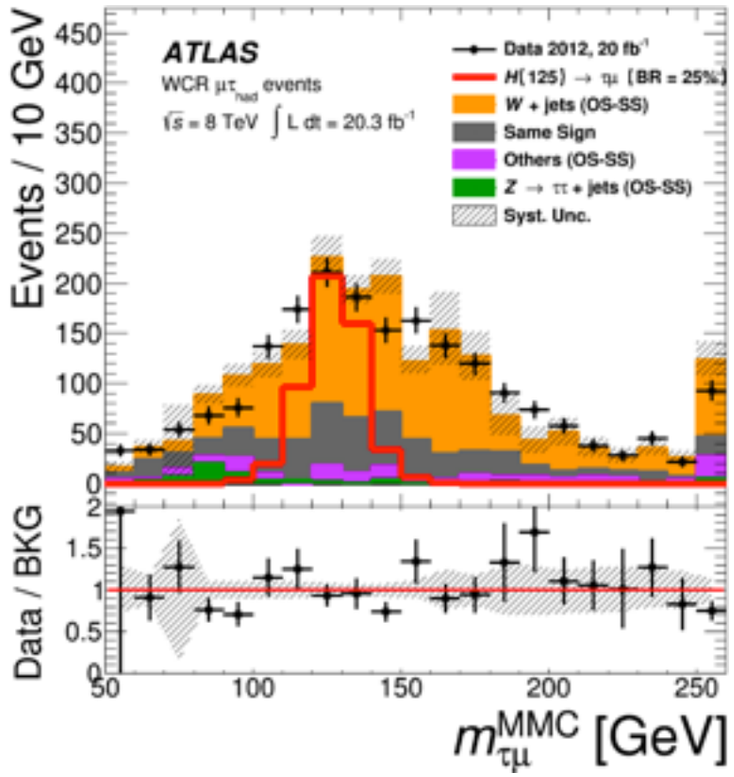
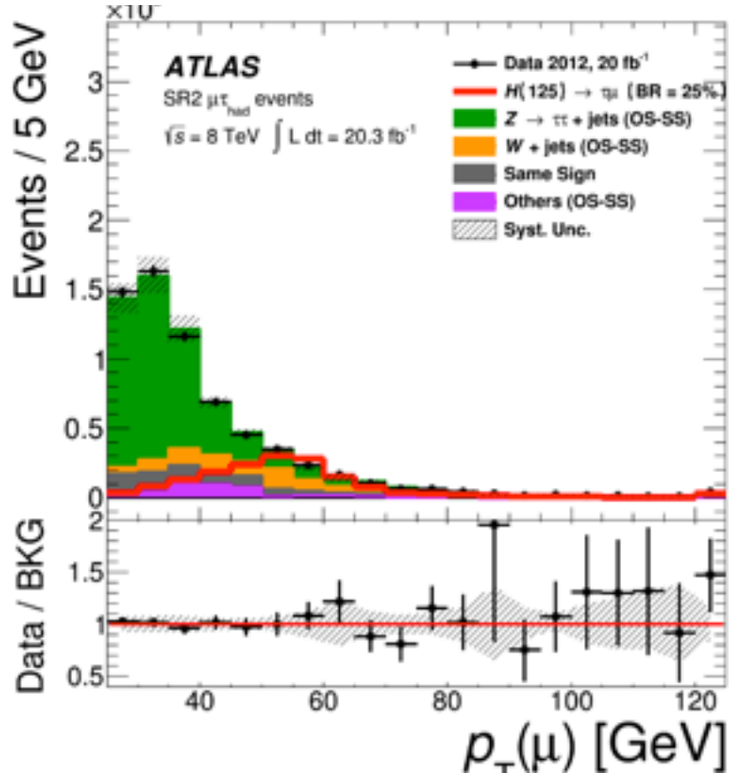
LFV H→μτ: BG Model

- Separate BG control regions for top, W+jets and Z+jets (SR2 started life as ZCR)
- QCD Multijet (plus some W+jets) modelled with SS data, other BG with MC OS-SS
- Z→ττ modelled with embedding
- Mass reconstructed with special MMC tune for prompt muon+hadronic τ decay

$$N_{\mathrm{OS}}^{\mathrm{bkg}} = r_{\mathrm{QCD}} \cdot N_{\mathrm{SS}}^{\mathrm{data}} + N_{\mathrm{OS-SS}}^{Z\to\tau\tau} + N_{\mathrm{OS-SS}}^{Z\to\mu\mu} + N_{\mathrm{OS-SS}}^{W+\mathrm{jets}} + N_{\mathrm{OS-SS}}^{\mathrm{top}} + N_{\mathrm{OS-SS}}^{VV} + N_{\mathrm{OS-SS}}^{H\to\tau\tau},$$





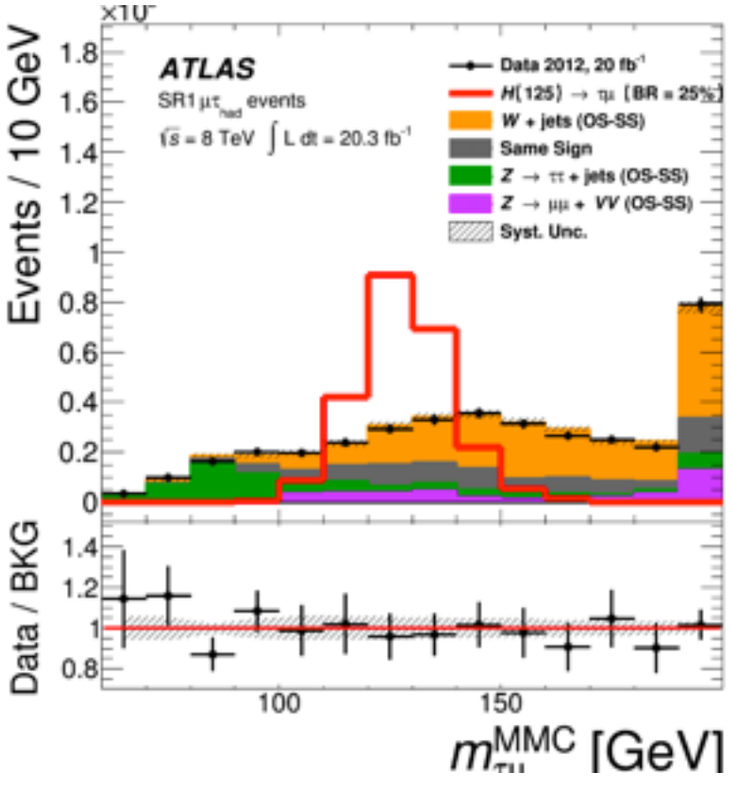


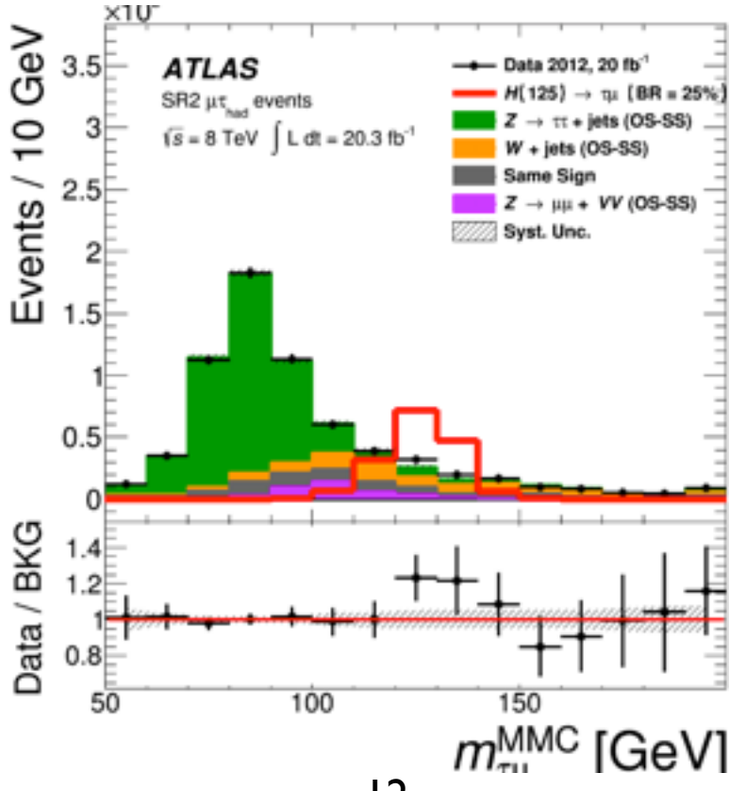
LFV H→μτ: Results

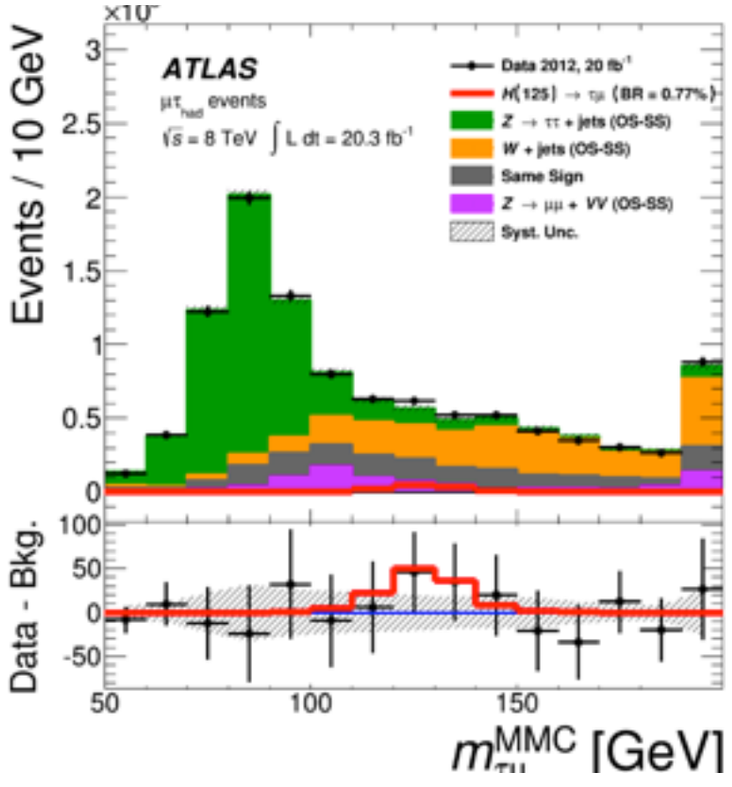
- 2.2 (1.3) σ local (global) excess in SR2
- Consistent within errors with SM and CMS results

	SR1	SR2	Combined
Expected limit on Br($H \to \mu\tau$) [%]	$1.60^{+0.64}_{-0.45}$	$1.75^{+0.71}_{-0.49}$	$1.24^{+0.50}_{-0.35}$
Observed limit on Br($H \to \mu\tau$) [%]	1.55	3.51	1.85
Best fit Br($H \to \mu\tau$) [%]	$-0.07^{+0.81}_{-0.86}$	$1.94^{+0.92}_{-0.89}$	0.77±0.62

	SR1	SR2
Signal	$69.1 \pm 0.8 \pm 9.2$	$48.5 \pm 0.8 \pm 7.5$
$Z \to \tau\tau$	$133.4 \pm 6.9 \pm 9.1$	$262.6 \pm 9.7 \pm 18.6$
W+jets	$619 \pm 54 \pm 55$	$406 \pm 42 \pm 34$
Top	$39.5 \pm 5.3 \pm 4.7$	$19.6 \pm 3.1 \pm 3.3$
Same–Sign events	$335 \pm 19 \pm 47$	$238 \pm 16 \pm 34$
$VV + Z \to \mu\mu$	$90 \pm 21 \pm 16$	$81 \pm 22 \pm 17$
$H \to \tau\tau$	$6.82 \pm 0.21 \pm 0.97$	$13.7 \pm 0.3 \pm 1.9$
Total background	$1224 \pm 62 \pm 63$	$1021 \pm 51 \pm 49$
Data	1217	1075

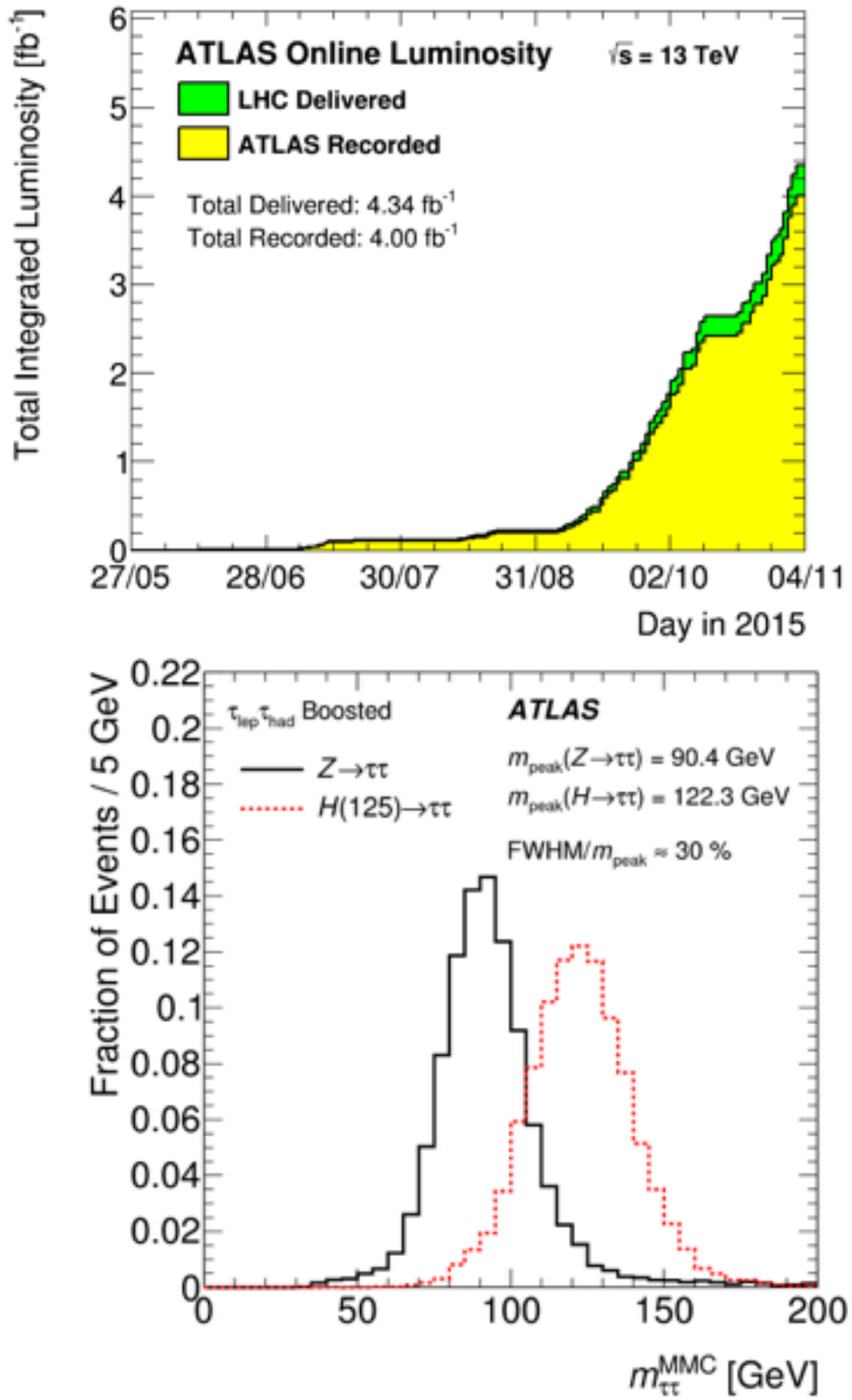






Outlook for Run2

- pp data-taking in 2015 done
- Lumi not sufficient for rediscovery of Higgs→ττ
- But still lots we can do with this data
- validate tau reconstruction → Peter's talk
  - especially want to utilize τ substructure
- understand backgrounds
  - re-establish embedding method → Juergen's talk
  - MC modelling at 13TeV
- re-tune mass reconstruction
  - MMC being tuned to 13TeV and 2015 pileup
  - other algorithms being tested



Summary

- SM H decay to τ-leptons discovered in CMS+ATLAS combination
- Hints in Run1 data that we should look closely at LFV H→τμ decay
- ~4fb-1 of 2015 data, not enough by itself to rediscover H→ττ at 13TeV
- But working on understanding our backgrounds
- Some development in ditau mass reconstruction
  - retuning old methods to Run2 conditions and
  - also new tune for existing mass reco for LFV H→τμ
- Eager to test drive new substructure reconstruction
  - allow access to CP properties of the Higgs boson in fermion decays
  - also improve analysis sensitivity by decay-mode categorization

Backup

Basic τ Properties

τ^- Branching ratios (m_τ=1.78 GeV):

$e^-/\mu^- \upsilon_{e/\mu} \upsilon_\tau$ (35%)

$\pi^- \upsilon_\tau$ (11%)
$\rho^- \upsilon_\tau$ (25%)
$\pi^- \pi^0 \pi^0 \upsilon_\tau$ (9%)
$\pi^- \pi^0 \pi^0 \pi^0 \upsilon_\tau$ (1%)
K^- + neutrals (1.5%)

} 1-prong

$\pi^- \pi^+ \pi^- \upsilon_\tau$ (9%)
$\pi^- \pi^+ \pi^- \pi^0 \upsilon_\tau$ (4.5%)
$K^- \pi^+ \pi^- \upsilon_\tau$ (0.4%)

} 3-prong

other modes (~3%)

- properties of hadronically decaying τ's:
- very well collimated object of charged and neutral pions
- charged component of τ reproduces the direction of visible τ well (particularly leading pion)
- most τ's have one or three charged decay products (pions)
- modest but significant proper lifetime (87 microns)