Evidence for Higgs Boson Decays to the $\tau^+\tau^-$ Final State with the ATLAS Detector

Carl Jeske

University of Warwick

carl.jeske@cern.ch

April 8, 2014

Overview

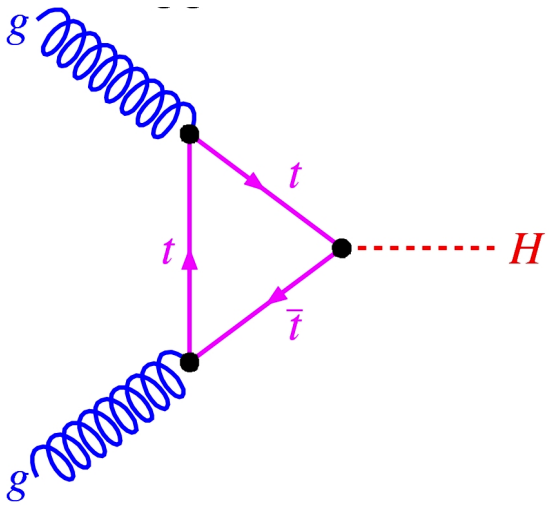
Strategy

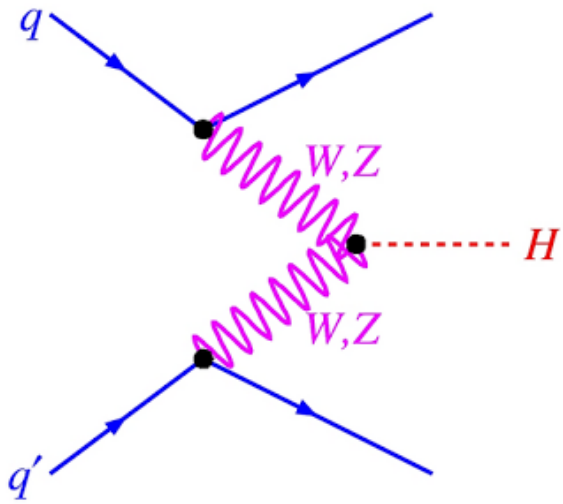
- Search for the decay to $\tau\tau$ for 125 GeV Higgs boson using data collected by ATLAS during Run I of LHC
- First direct evidence for coupling to fermions
- Used multivariate analysis (MVA)
  - Exploits correlations between variables
  - Allows increase in sensitivity of search
- Dataset consists of 20.3 fb^{-1} of pp collisions at centre of mass energy $\sqrt{s} = 8$ TeV

`https://cds.cern.ch/record/1632191`

Strategy

- Three channels considered: both taus decaying to leptons ('leplep'), both decaying to hadrons ('hadhad') and one of each ('lephad')
- Focus on gluon-gluon fusion (ggF) and vector boson fusion (VBF) production mechanisms

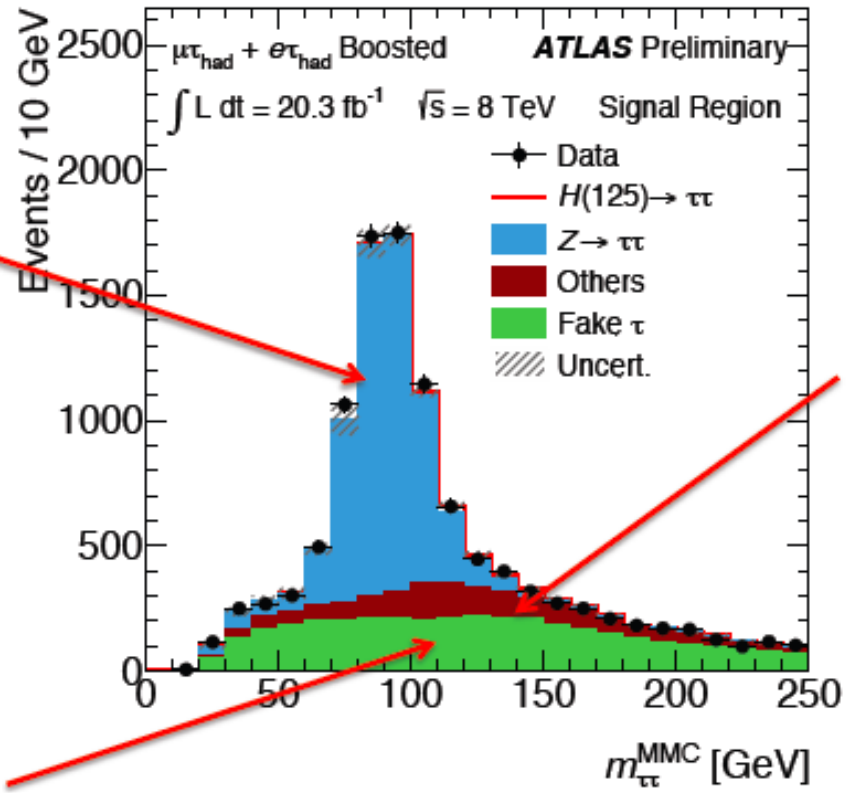




https://cds.cern.ch/record/1632191

Backgrounds

Z ττ: dominant background, modelled by data



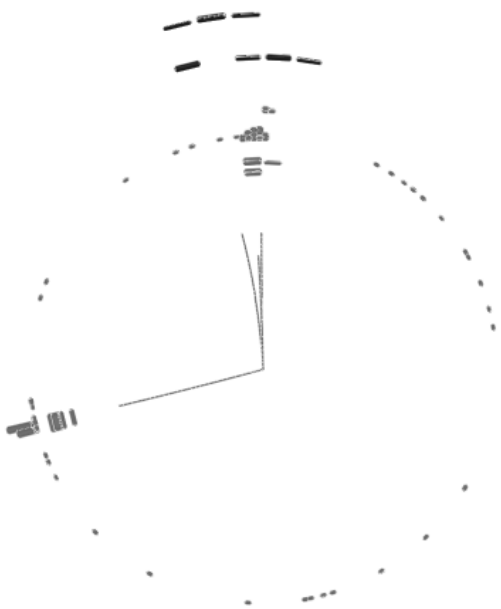
Others: MC for Dibosons, H WW

Data normalisation for Z ee/μμ and top

Fake e/μ/τ: W+jets, top, QCD multijet modelled by data

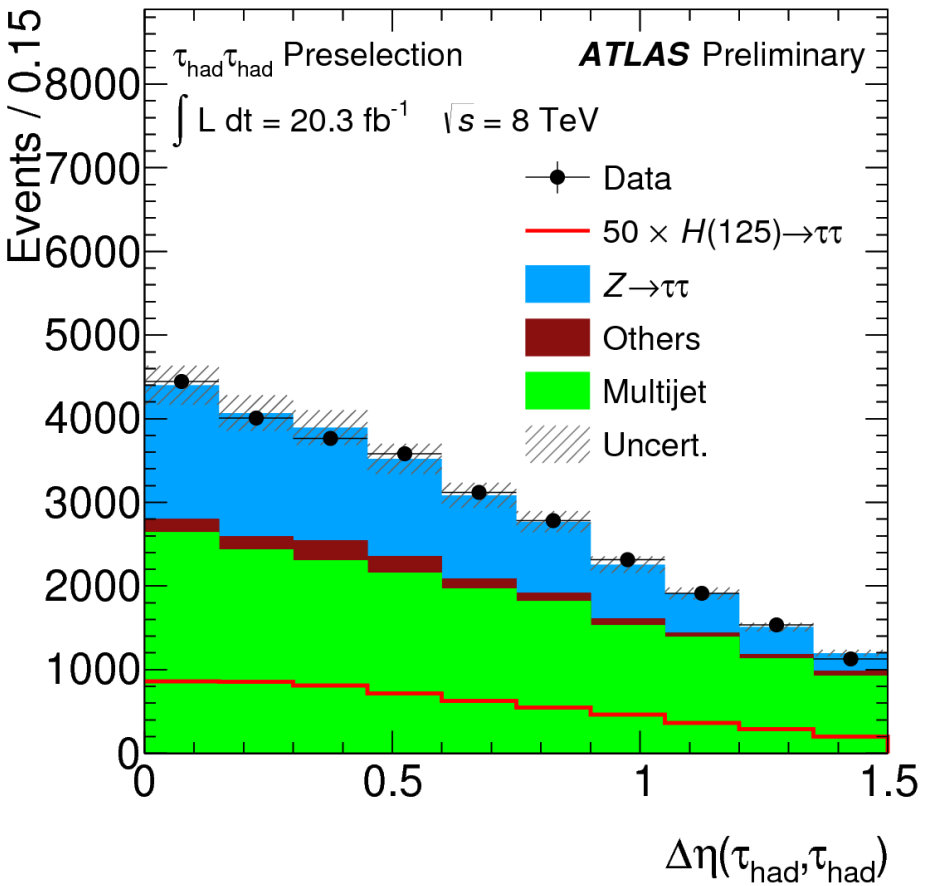
Embedding

- Used to model irreducible $Z \to \tau\tau$ background
- Muons removed from $Z \to \mu\mu$ data events and associated calorimeter deposits are subtracted
- Taus with same kinematics simulated using TAUOLA and added to each event
- Complex process but method has many benefits
  - Jets, MET and pileup conditions taken directly from data



Jet to Tau Fakes

- Jet $\rightarrow \tau$ fakes hard to model
- Hadhad and lephad channels need data driven methods to model fakes
- Hadhad use events where the two candidates do not have opposite charges
- Lephad use tau candidates failing final tau ID

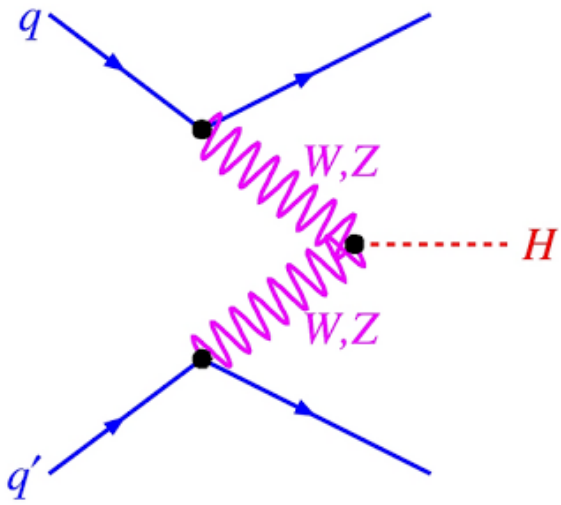


Boosted Decision Trees

- A boosted decision tree is a type of machine learning algorithm
- Exploits correlations between variables
- Increases sensitivity of search
- The $H \rightarrow \tau\tau$ BDT was used as the final discriminant in the analysis
- The BDT was trained using the 125 GeV signal samples so sensitivity is highest at 125 GeV

Categorisation

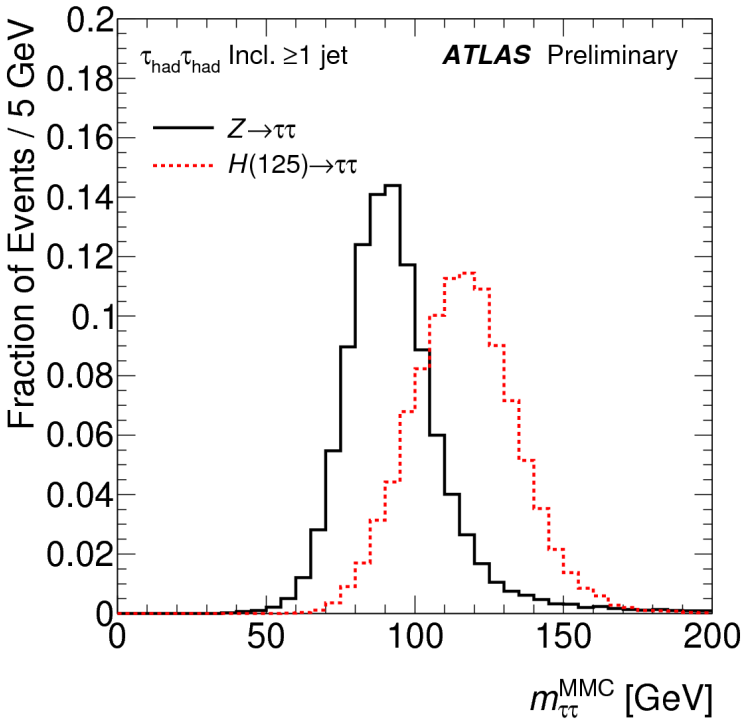
- Use two categories to target different Higgs production mechanisms
  - **VBF**: Two widely separated high energy jets, high sensitivity, 60% of signal in category are VBF
  - **Boosted**: Reconstructed Higgs has $p_T > 100$ GeV, good mass resolution, good sensitivity, 70% of signal is ggF

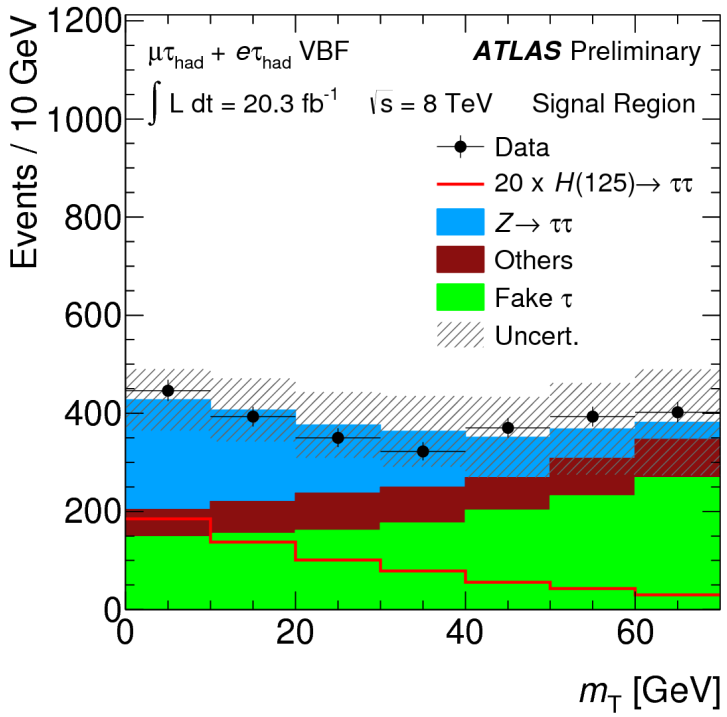


- Each category has a different BDT training using different sets of discriminating variables
  - For example, VBF category uses dijet mass and p_T
  - VBF BDT trained using only VBF Higgs sample as signal
  - Boosted category uses all Higgs signal samples

Example BDT Input Variables

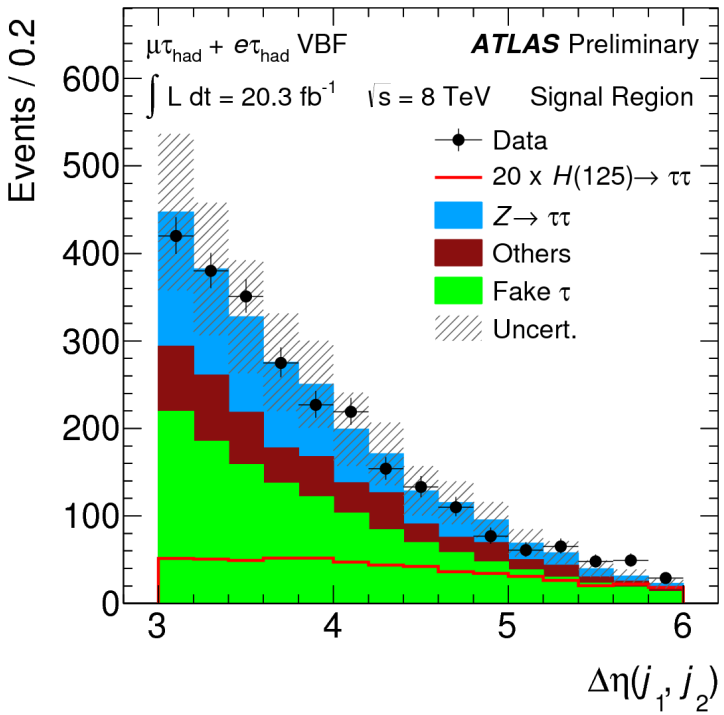
- Common amongst all categories and channels
  - **Ditau Mass**: Discrimination against irreducible $Z \to \tau\tau$
  - **Transverse Mass,** m_T: Discrimination against W+jets
  - $\Delta R_{\tau\tau}$

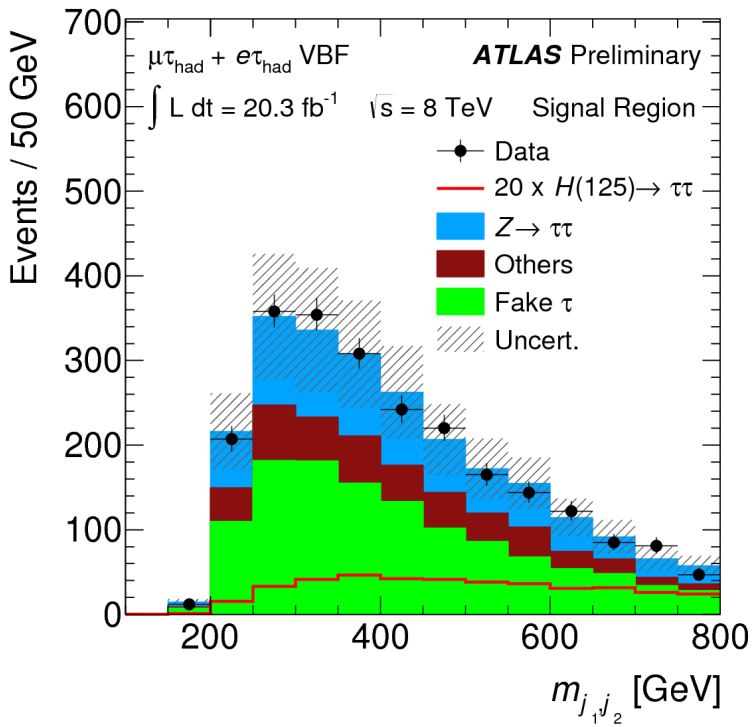




Example BDT Input Variables

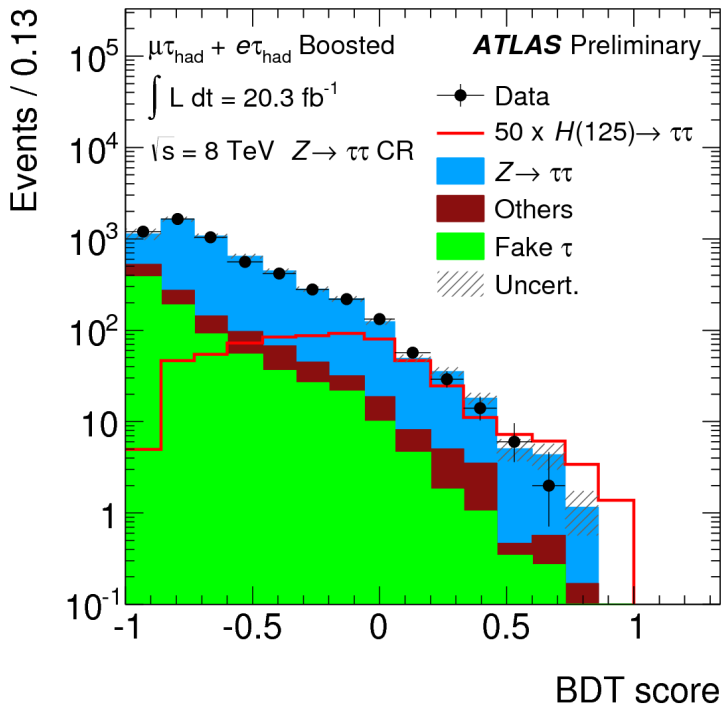
- VBF
  - **Dijet Kinematics**: For tagging VBF signature of two high energy jets with large η gap
- Boosted
  - **Sum** p_T: Tags high p_T Higgs candidates
- Complete list in backup

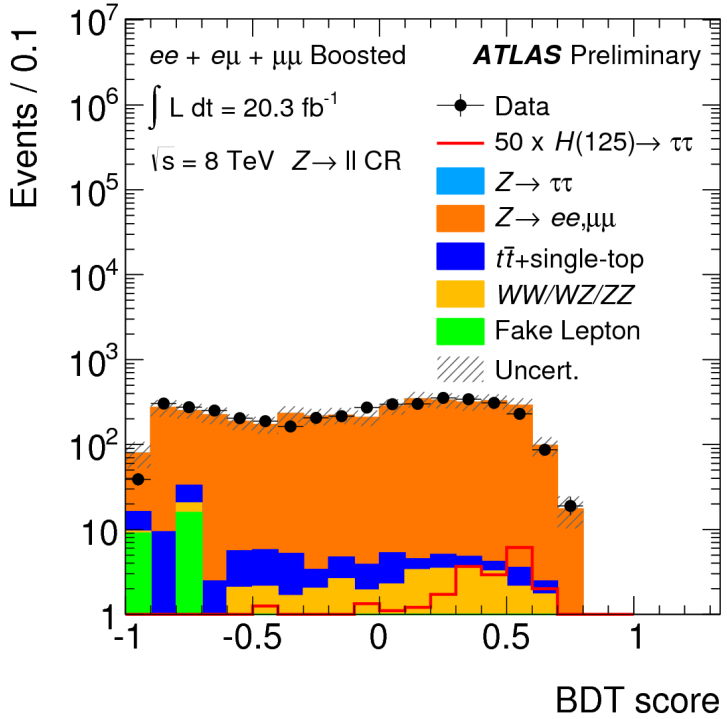




Validation

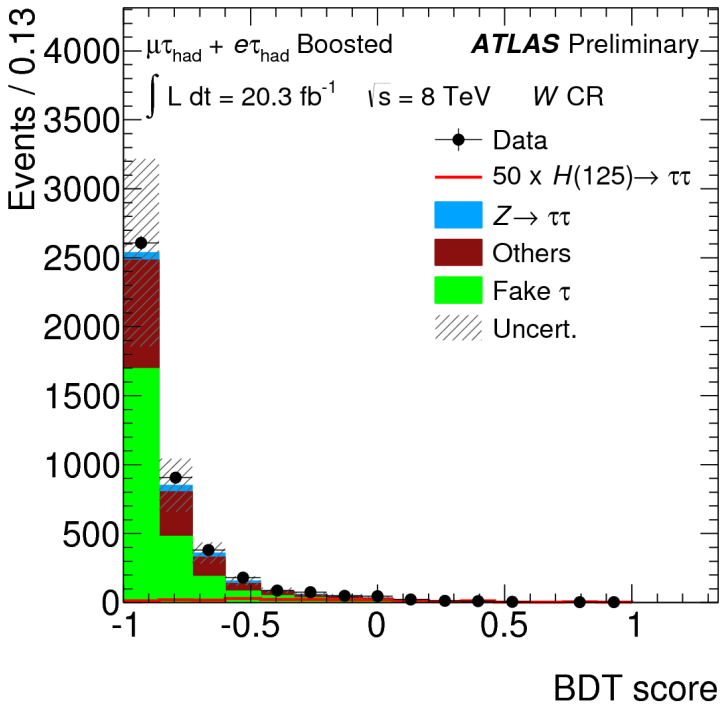
- Modelling of all BDT input variables as well as the BDT score verified in each multiple validation regions
- Also checked the modelling of correlations between each pair of variables
- Dedicated validation regions for our major backgrounds

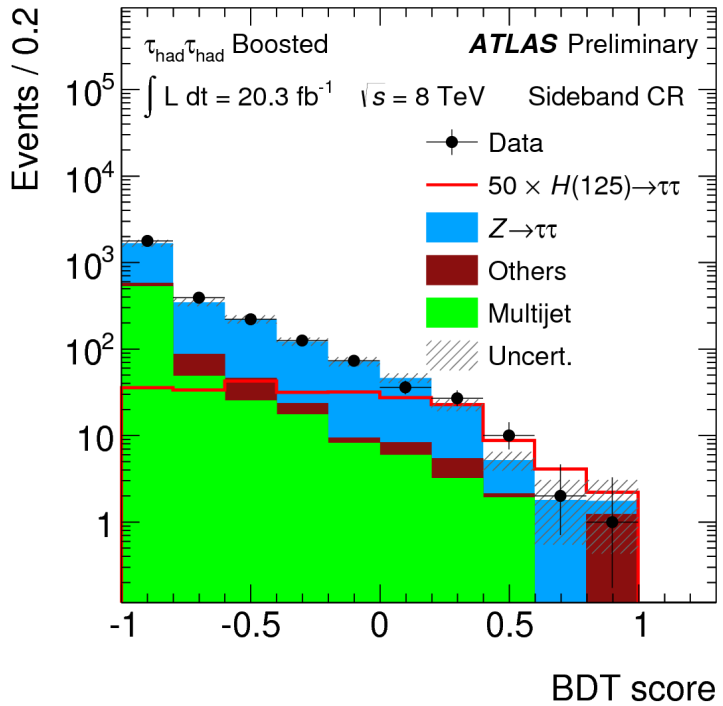




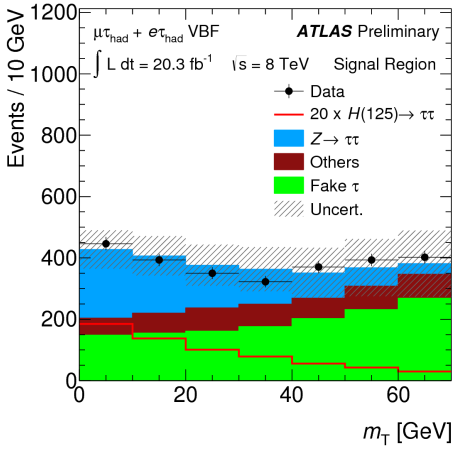
Validation

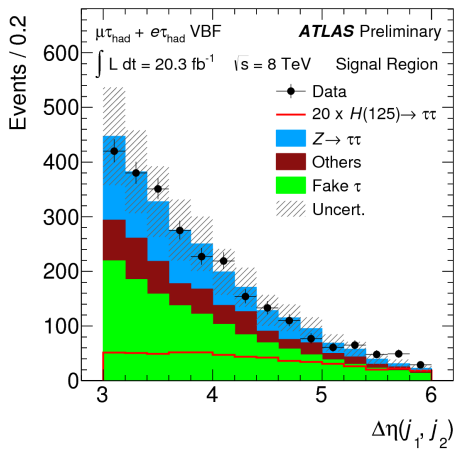
- Two additional validation regions
  - **Mass Sideband**: Signal region events not in the 100-150 GeV ditau mass window
  - **Low BDT Score**: Signal region events in the BDT score distribution up to signal efficiency of 30%

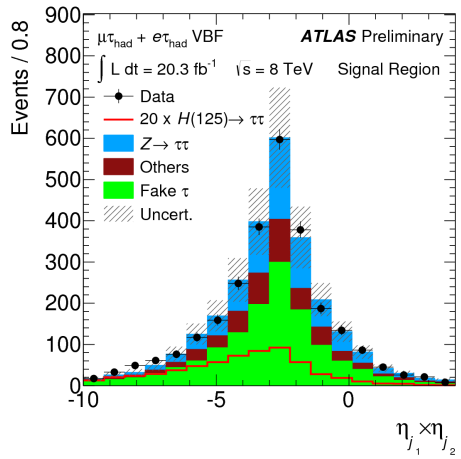


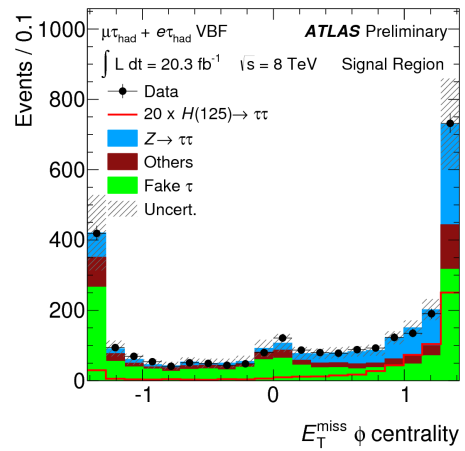


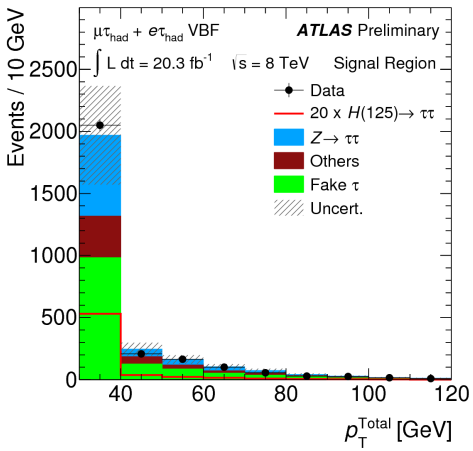
LepHad VBF Category Input Variables

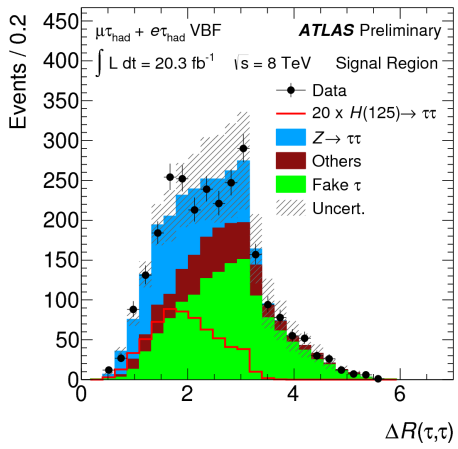


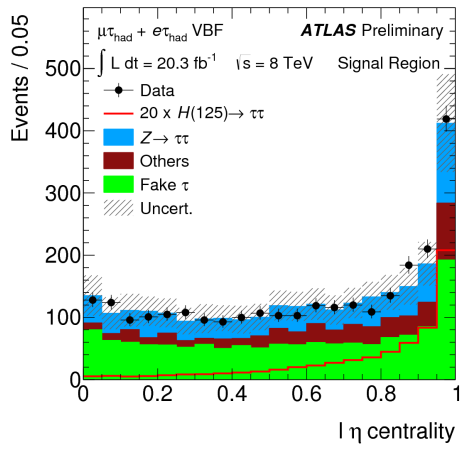


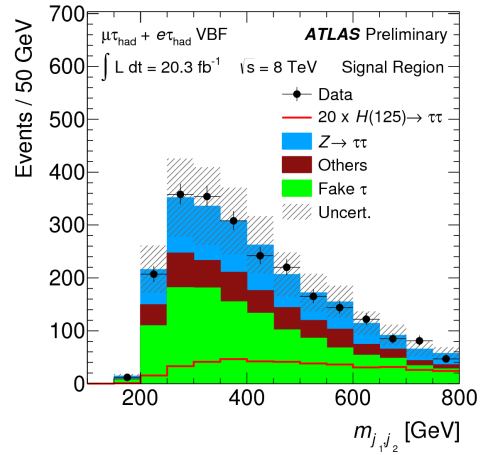






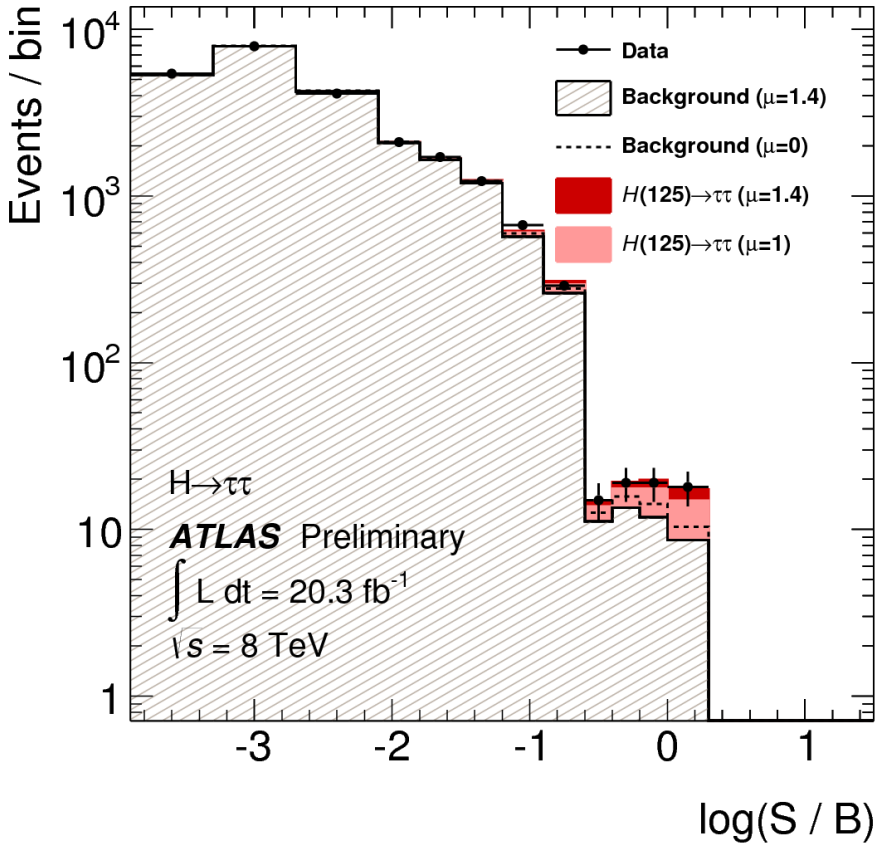






Results

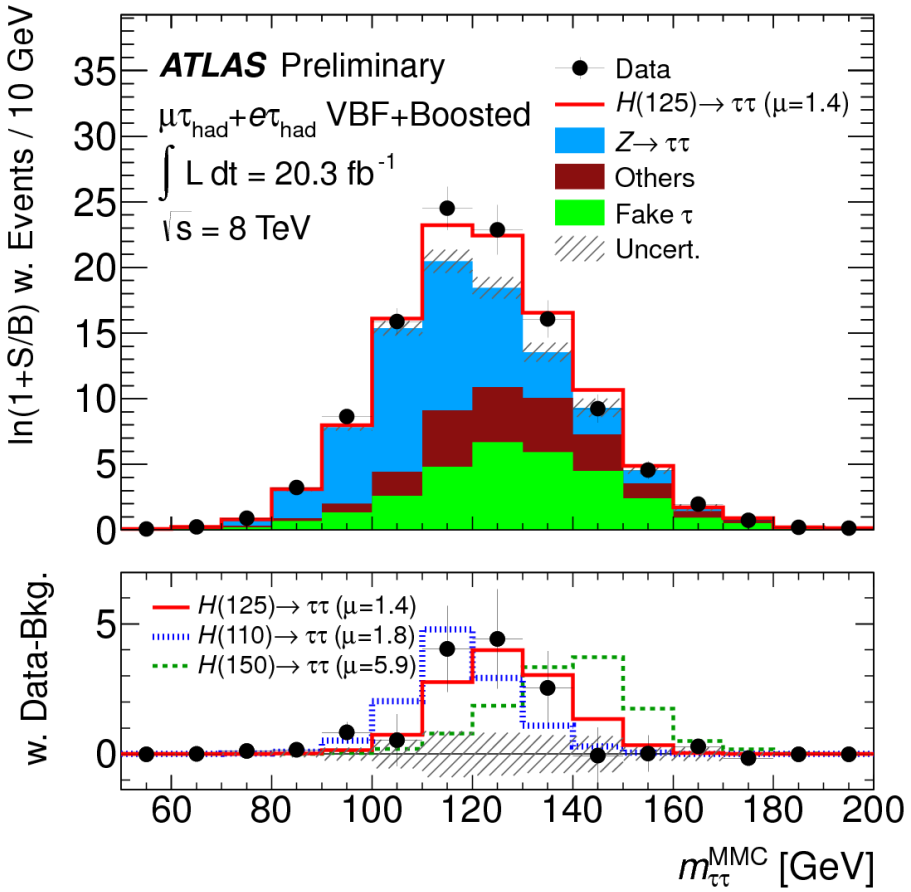
- The observed (expected) deviation from the background-only hypothesis corresponds to a significance of 4.1 (3.2) standard deviations
- This corresponds to a measured signal strength of $\mu = 1.4^{+0.5}_{-0.4}$
- This constitutes evidence for $H \to \tau^+\tau^-$ decays
- Result consistent with Standard Model expectation for Higgs boson with $m_H = 125$ GeV



https://cds.cern.ch/record/1632191

Results

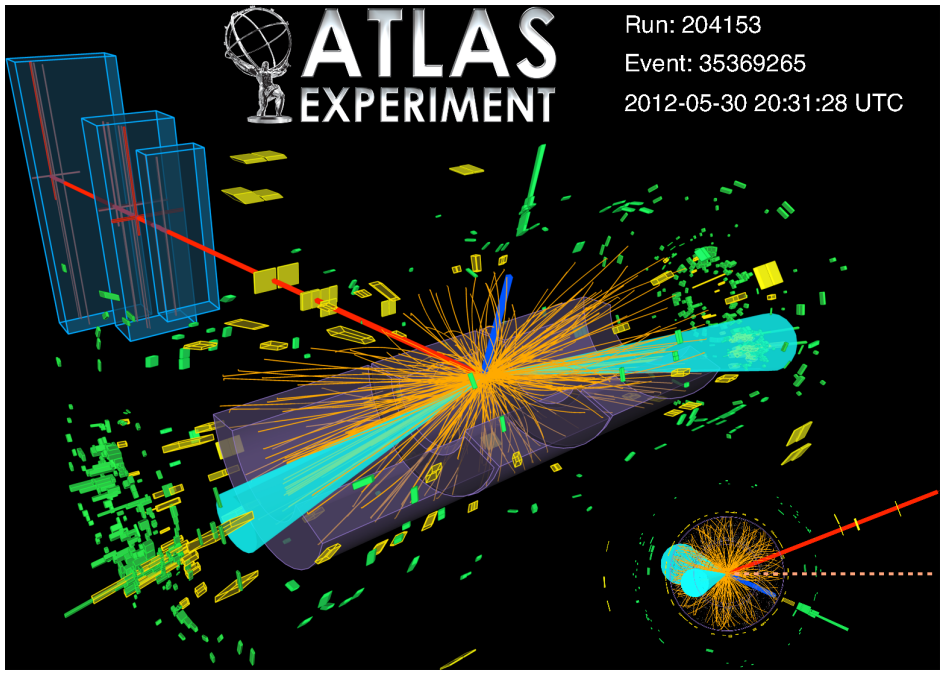
- The observed (expected) deviation from the background-only hypothesis corresponds to a significance of 4.1 (3.2) standard deviations
- This corresponds to a measured signal strength of $\mu = 1.4^{+0.5}_{-0.4}$
- This constitutes evidence for $H \to \tau^+\tau^-$ decays
- Result consistent with Standard Model expectation for Higgs boson with $m_H = 125$ GeV



https://cds.cern.ch/record/1632191

Outlook

- Decay of new boson to fermions confirmed
- Run II
  - Trigger challenges
  - Spin/CP
  - $> 5\sigma$ observation
  - Potential for further evidence for fermionic decays by studying $H \to \mu\mu$



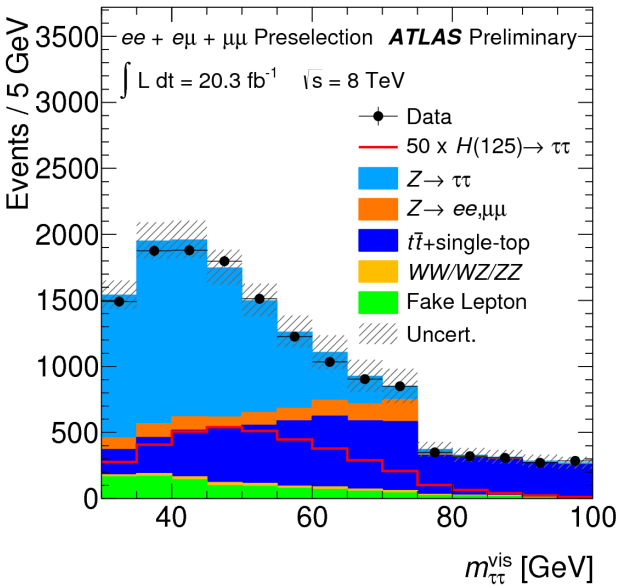
Backup

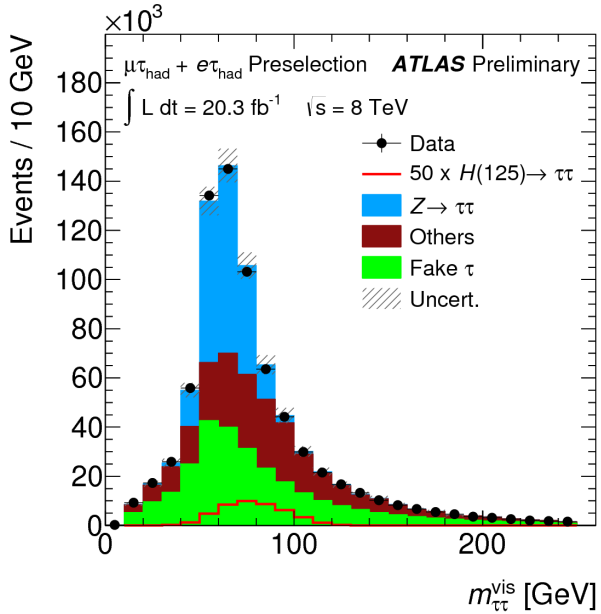
Preselection

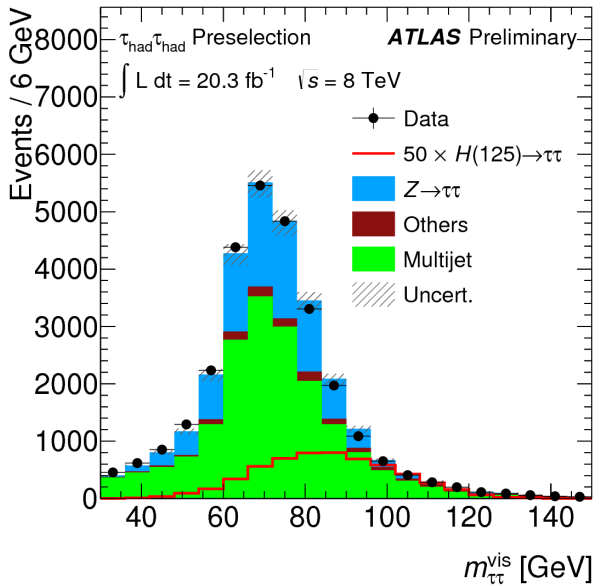
- Preselection cuts used to remove any entirely background dominated regions
- Deliberately kept loose to maximise the benefit of utilising an MVA

LepLep	LepHad	HadHad
Exactly 2 leptons, no tau–jet	Exactly 1 electron or muon	MET > 20 GeV
Opposite sign	Exactly 1 tau-jet	$0.8 < \Delta R(\tau_1,\tau_2) < 2.8$
$30 < m(l_1,l_2) < 75$ GeV (SF)	Opposite sign (lepton,τ)	$\Delta\eta(\tau_1,\tau_2)<1.5$
$30 < m(l_1,l_2) <100$ GeV (DF)	m_T(MET,lepton) < 70 GeV	2 medium, ≥ 1 tight taus
$p_T(l_1)+p_T(l_2) > 35$ GeV		Both taus from same pr. vx.
At least 1 jet ($p_T > 40$ GeV)		MET between taus or
MET > 40 GeV and		$\Delta\phi$(MET,τ) < π/2
HPTO_MET > 40 GeV (SF)		
MET > 20 GeV (DF)		
$0.1 < x_1,x_2 < 1$		
$\Delta\varphi(l_1,l_2) < 2.5$		

Preselection







Category Cuts

Category	Selection	$\tau_{\text{lep}}\tau_{\text{lep}}$	$\tau_{\text{lep}}\tau_{\text{had}}$	$\tau_{\text{had}}\tau_{\text{had}}$
VBF	$p_T(j1) >$ (GeV)	40	50	50
	$p_T(j2) >$ (GeV)	30	30	30
	$\Delta\eta(j1, j2) >$	2.2	3.0	2.0
	b-jet veto for jet $p_T >$ (GeV)	25	30	-
	Higgs $M_{vis} >$ (GeV)	-	40	-
	Higgs $p_T >$ (GeV)	-	-	40
Boosted	$p_T(j1) >$ (GeV)	40	-	-
	Higgs $p_T >$ (GeV)	100	100	100
	b-jet veto for jet $p_T >$ (GeV)	25	30	-

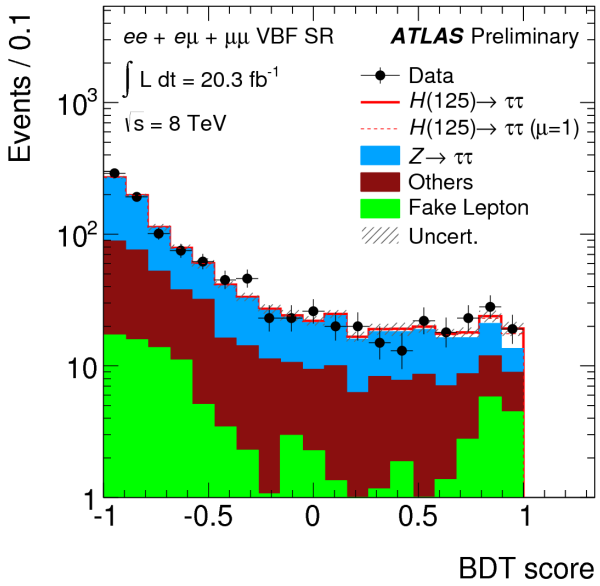
VBF Variables

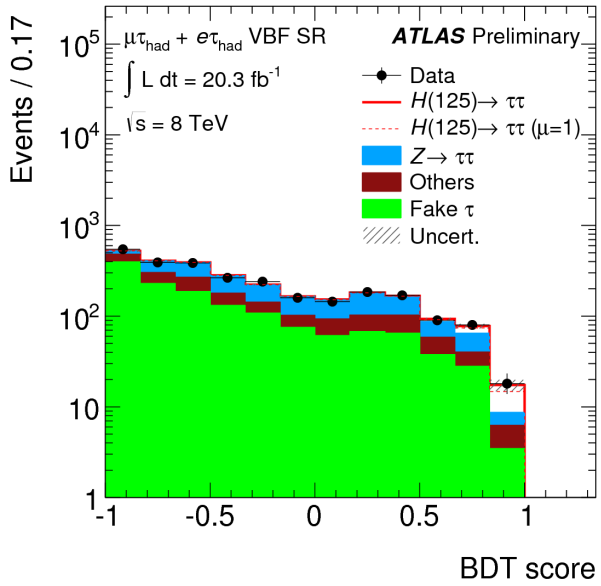
Variable	$\tau_{\text{lep}}\tau_{\text{lep}}$	$\tau_{\text{lep}}\tau_{\text{had}}$	$\tau_{\text{had}}\tau_{\text{had}}$
$M_{\tau\tau}^{MMC}$	●	●	●
$\Delta R_{\tau\tau}$	●	●	●
$\lvert\eta_{j2} - \eta_{j1}\rvert$	●	●	●
$m_{j1,j2}$	●	●	●
$\eta_{j1} \times \eta_{j2}$		●	●
p_T^{Total}		●	●
$E_T^{miss}\phi$ centrality		●	●
$min(\Delta\eta_{\ell 1\ell 2,jets})$	●		
$\ell 1 \times \ell 2$ η centrality	●		
$\Delta\eta_{j3,j1j2}$	●		
m_T		●	
ℓ η centrality		●	
τ_1 η centrality			●
τ_2 η centrality			●

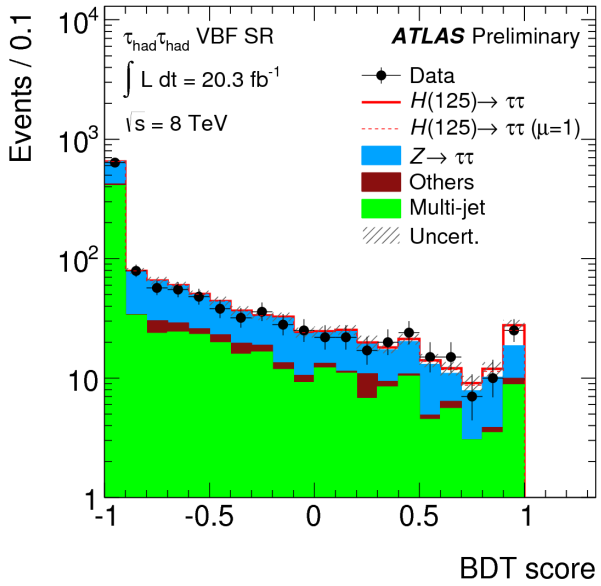
Boosted Variables

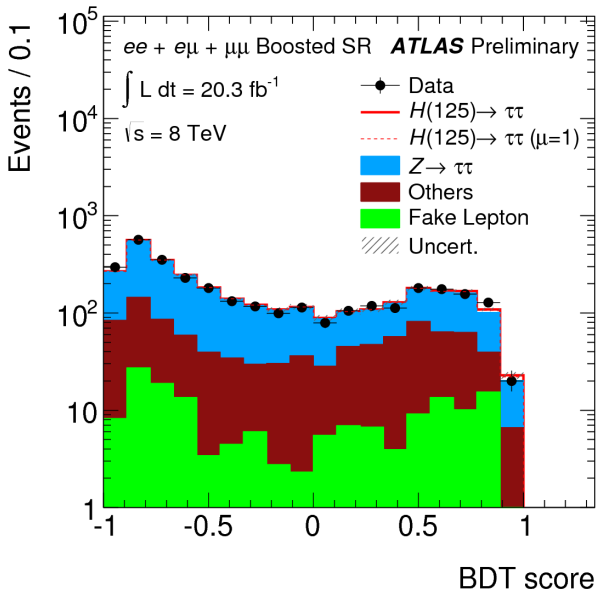
Variable	$\tau_{\text{lep}}\tau_{\text{lep}}$	$\tau_{\text{lep}}\tau_{\text{had}}$	$\tau_{\text{had}}\tau_{\text{had}}$
$M_{\tau\tau}^{MMC}$	●	●	●
$E_T^{miss}\phi$ centrality	●	●	●
$\Delta R_{\tau\tau}$		●	●
sum P_T		●	●
$P_T(\tau_1)/p_T(\tau_2)$		●	●
$m_{\tau\tau,j1}$	●		
$m_{\ell 1,\ell 2}$	●		
$\Delta\phi_{\ell 1,\ell 2}$	●		
sphericity	●		
$p_T^{\ell 1}$	●		
p_T^{j1}	●		
$E_T^{miss}/p_T^{\ell 2}$	●		
m_T		●	
τ_{1x}			●
τ_{2x}			●

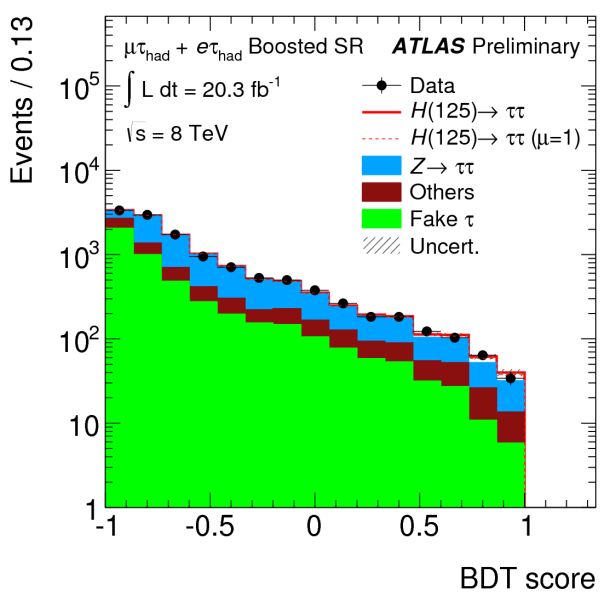
BDT Score Distributions (Prefit)

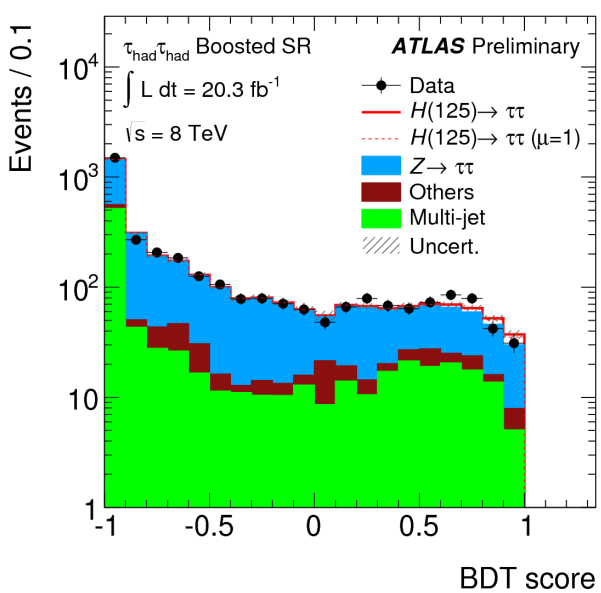




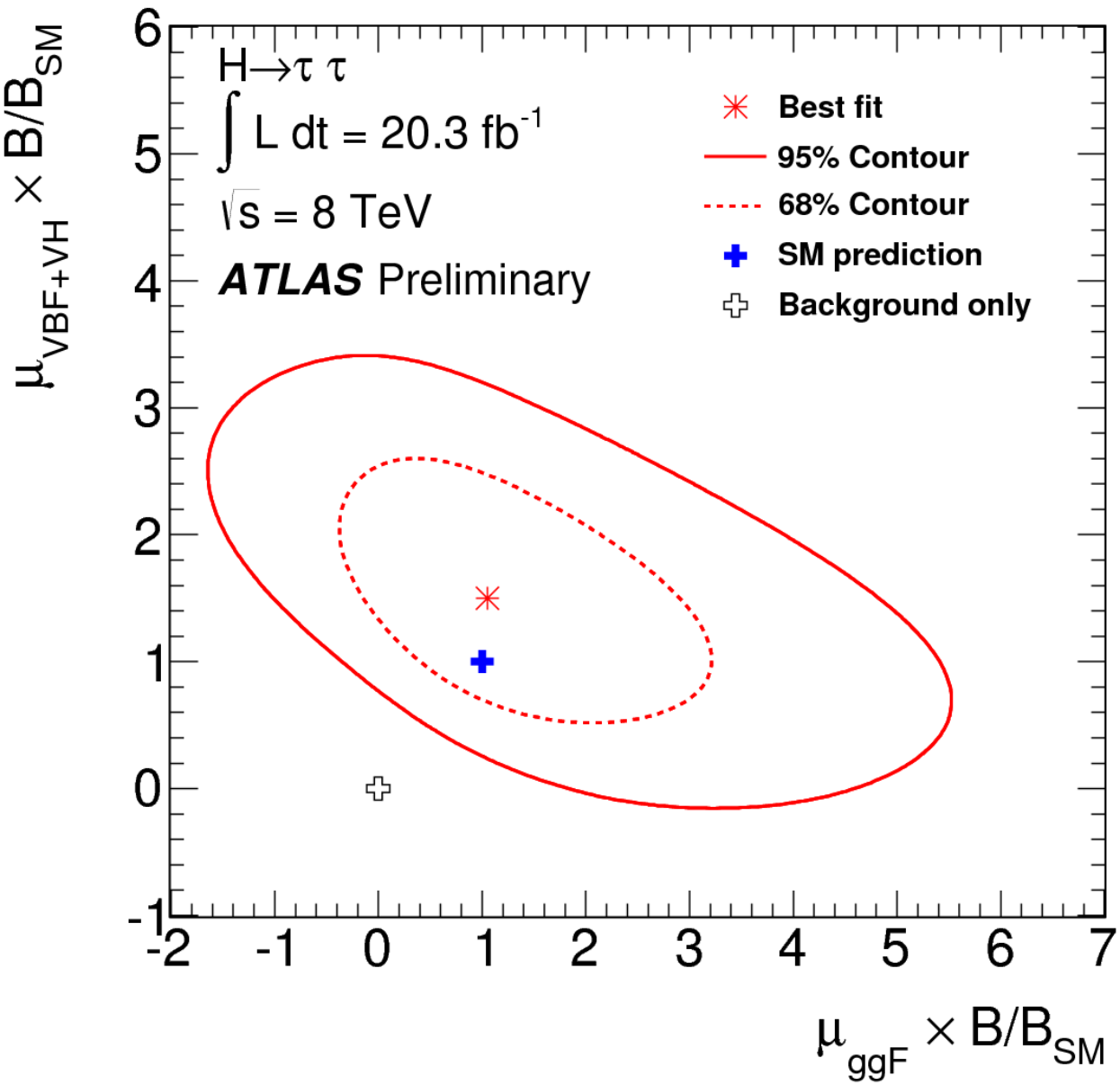








Results


H→τ τ
∫ L dt = 20.3 fb-1
√s = 8 TeV
ATLAS Preliminary
Best fit
95% Contour
68% Contour
SM prediction
Background only
μVBF+VH × B/BSM
μggF × B/BSM
6
5
4
3
2
1
0
-1
-2
-1
0
1
2
3
4
5
6
7