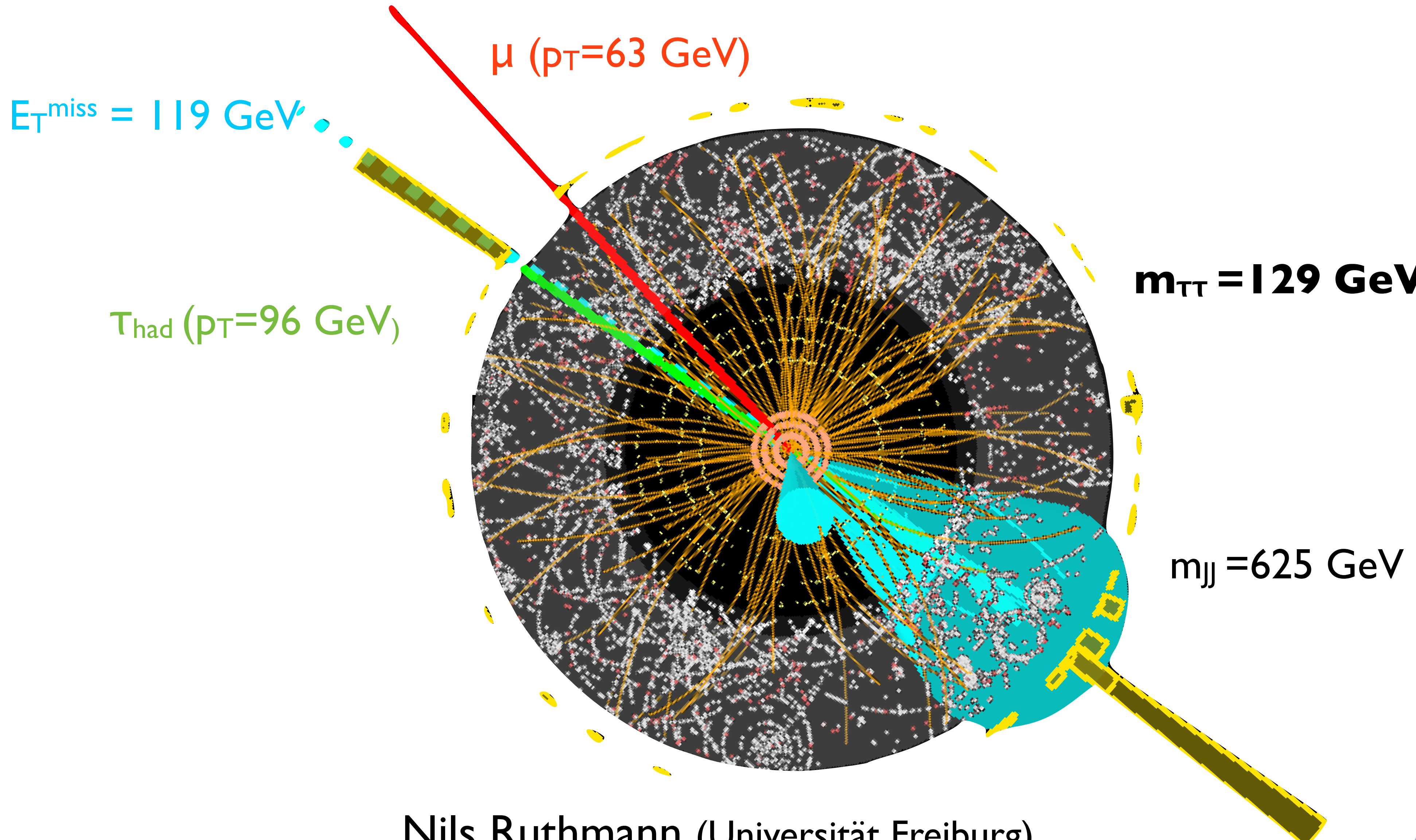
ATLAS FSP 101

Deutsche Forschungsgemeinschaft DFG

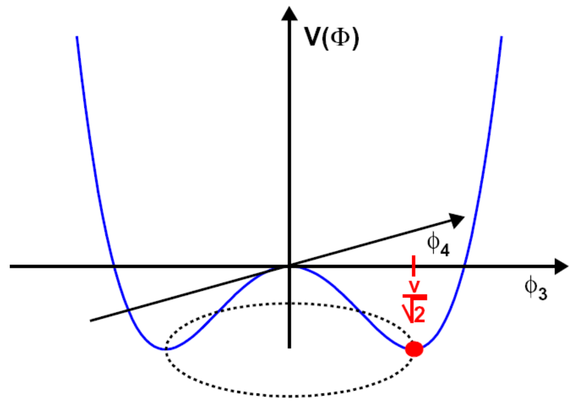
Evidence for Higgs Boson Decays to a Pair of τ-Leptons



Nils Ruthmann (Universität Freiburg)
On Behalf of the ATLAS Collaboration

Rencontres de Moriond EW 2014
La Thuile - 21 March 2014

UNI FREIBURG



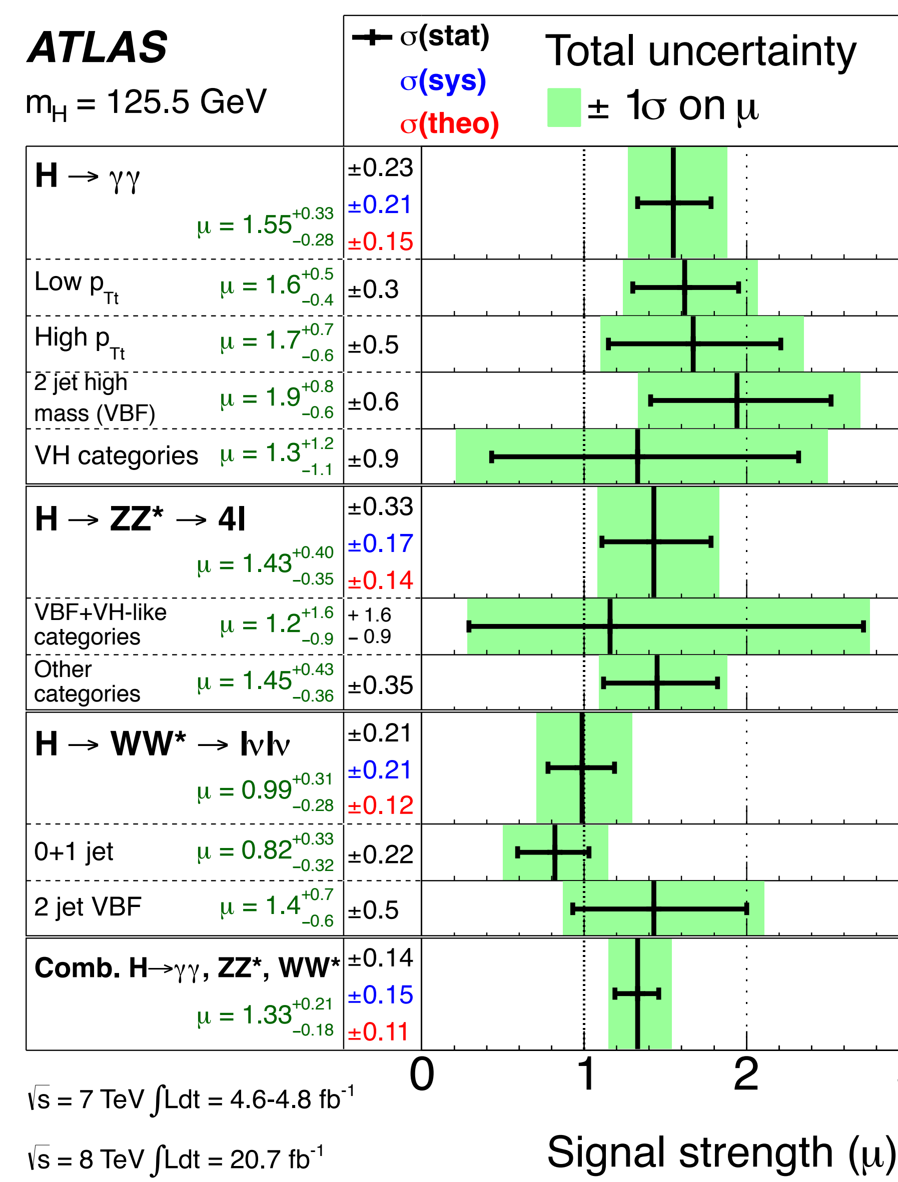
$$V(\phi^\dagger\phi) = \mu^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2$$

- BEH mechanism major ingredient of the SM
  - Spontaneous breaking of the $U(1)_Y \otimes SU(2)_L$ symmetry generating W,Z mass terms
  - Lepton masses generated via **independent** Yukawa couplings

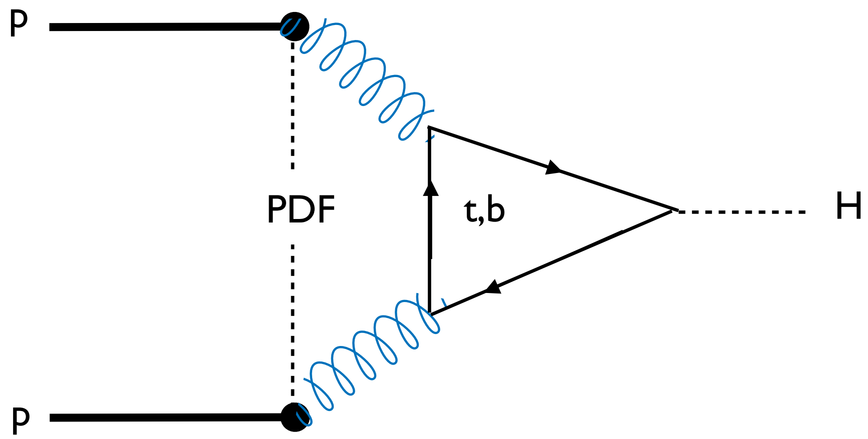
$$\mathcal{L}_{\text{Yukawa}} = -\frac{\lambda_f v}{\sqrt{2}}\bar{f}f - \frac{\lambda_f}{\sqrt{2}}\bar{f}fH$$

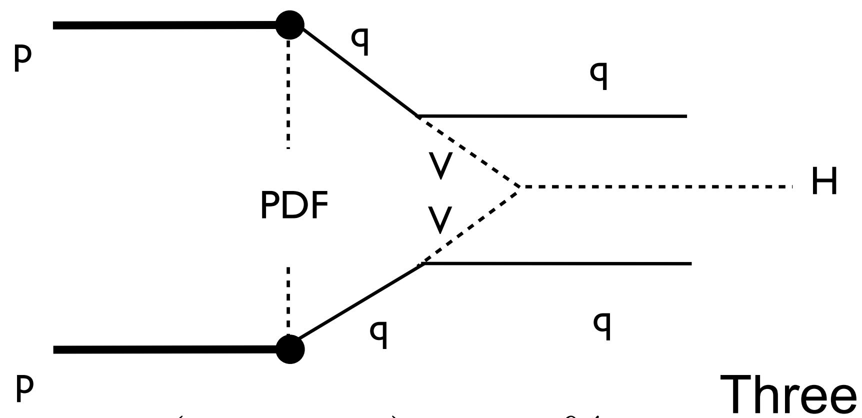
$\lambda_f \sim m_f$

- Huge progress in the past 2 years
  - Discovery (γγ, ZZ*, WW*) ✓
  - Mass measurement ($m_H \sim 125.5 \pm 0.7$ GeV) ✓
  - Coupling measurements (all SM like so far) ✓
  - Spin determination (strong preference for 0^+) ✓
  - **Coupling to fermions assessed via loop contributions so far**
  - Direct confirmation of fermionic couplings important for identification as SM Higgs boson



Phys. Lett. B 726 (2013) 88

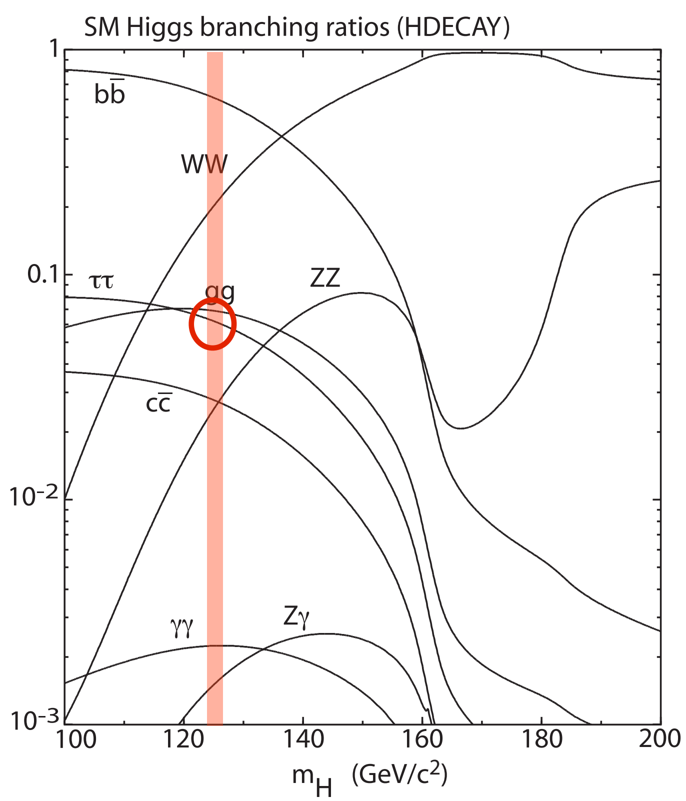




σ @ LHC (8 TeV)

- **Gluon-Fusion:** — 19.27 pb
  - Colored initial state & quark loop: important corrections
  - Radiation leading to significant **transverse momentum**
- **Vector-Boson-Fusion:** — 1.58 pb
  - **2 well separated Jets at Tree-Level !**

$$BR(H \to \tau\tau) = 6.3\%$$



Three **ττ decay** channels:

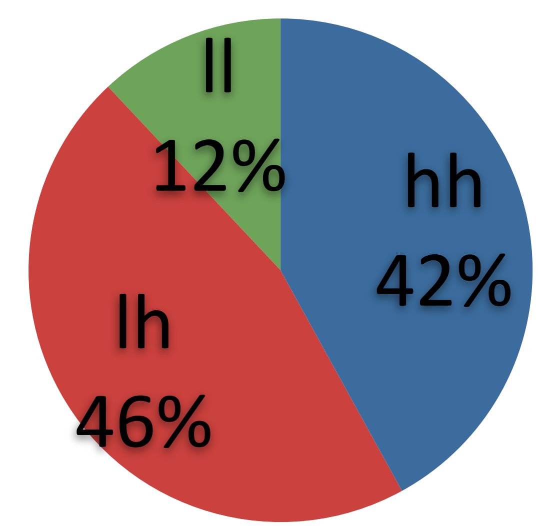
- **Leptonic** (2 light leptons + 4 ν)
- **Hadronic** (2 had. τ + 2 ν)
- **Semi-leptonic** (1 light lepton + 1 had. τ + 3 ν)

Dominant background processes

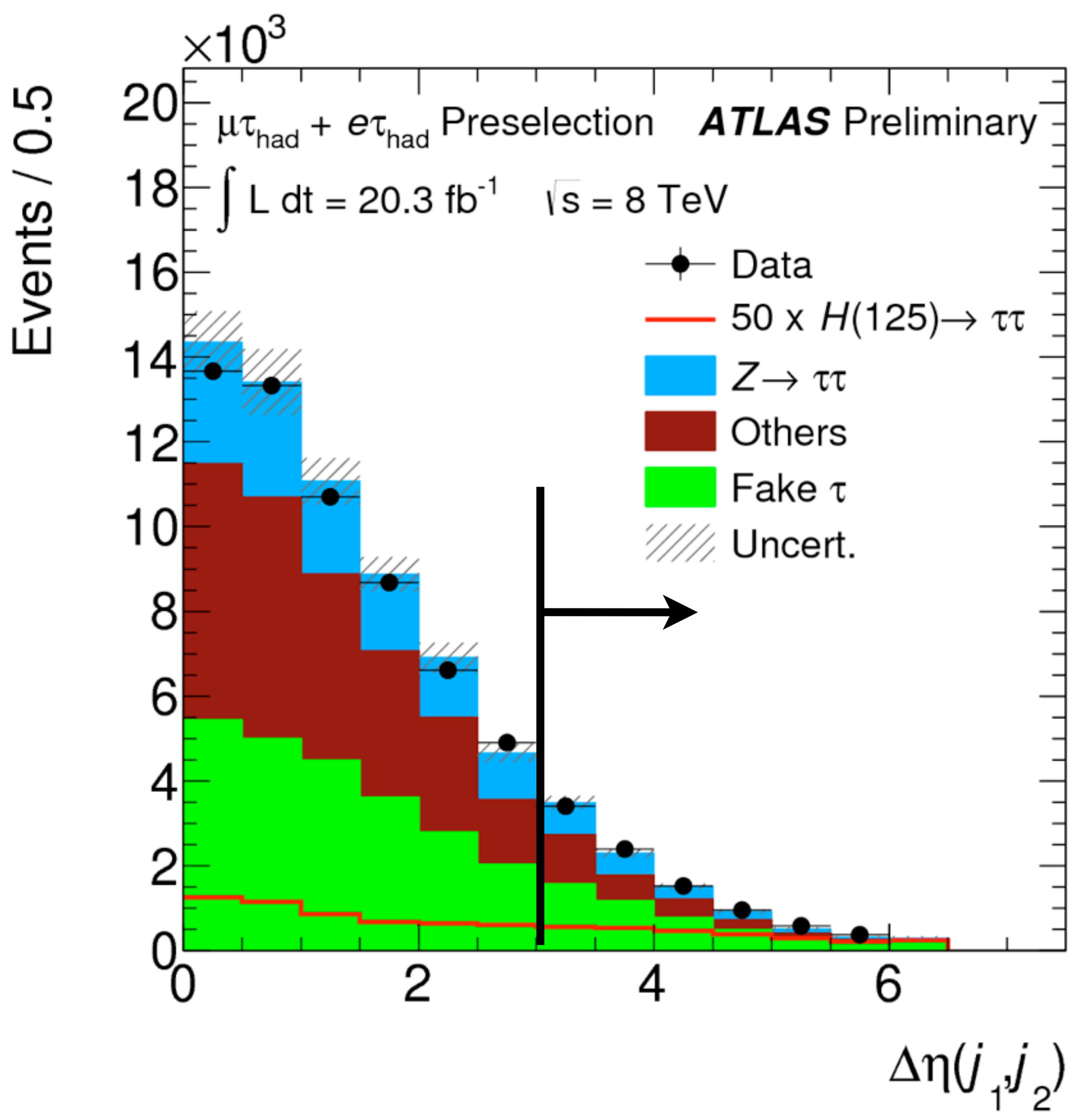
- $Z \to \tau\tau$
- top pair production
- $Z \to ee$ / $\mu\mu$

- $Z \to \tau\tau$
- Multijets

- $Z \to \tau\tau$
- W + Jets
- Multijets



- Very loose preselection
- Categorization exploiting signal-sensitive phase-space:
- **VBF category** (VBF signal fraction 55% -75%)
  - Identified by 2 well separated jets
- **High p_T category** (Gluon-fusion signal fraction 70% - 75%)
  - Large transverse momentum of Higgs Boson candidate



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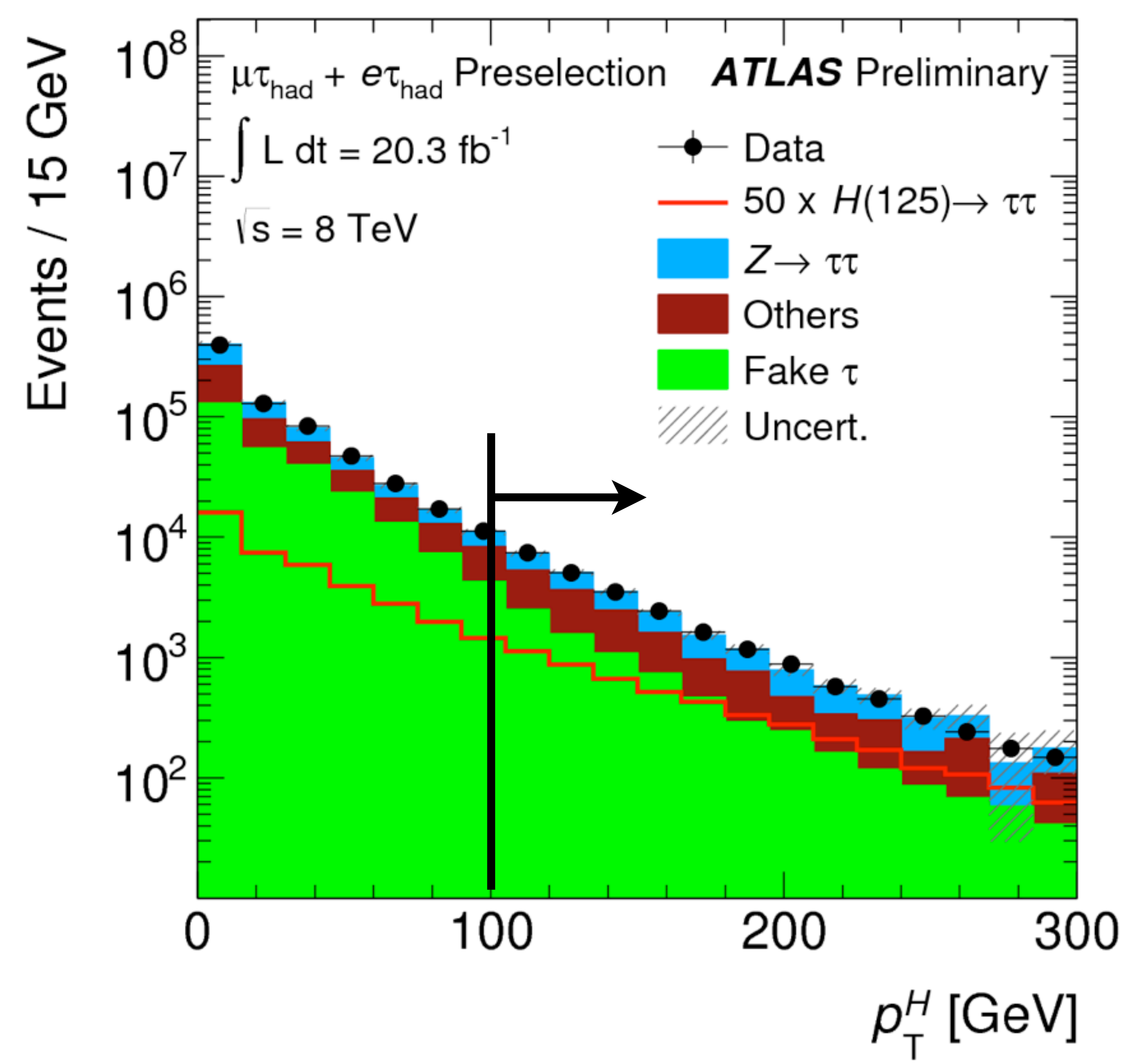
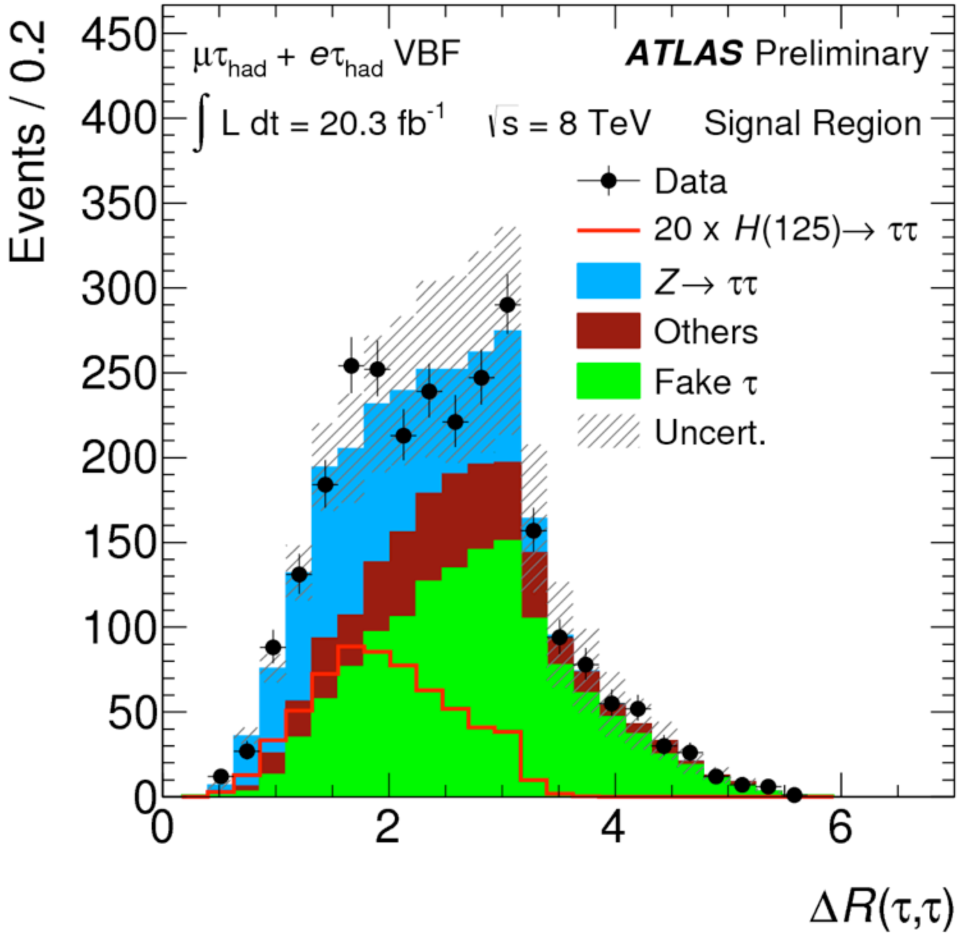
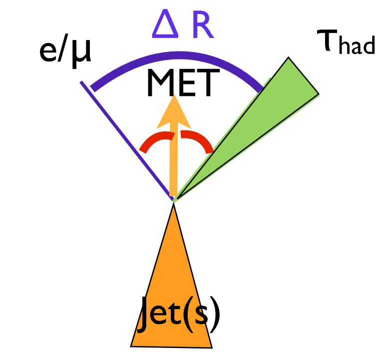
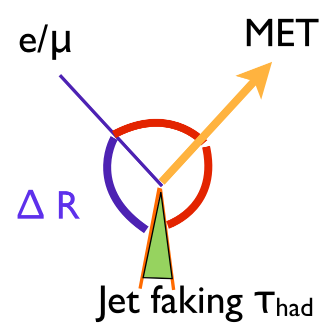


Discriminating Variables & Signal Extraction





Resonant ττ-system



Non-Resonant ττ-system

- Variety of background processes
  Real τ's & Misidentified τ's
- Multiple variables needed to suppress them
  - **Z→ττ: VBF tagging-jets** topology
  - **Misidentified τ's**: Use **angular variables**

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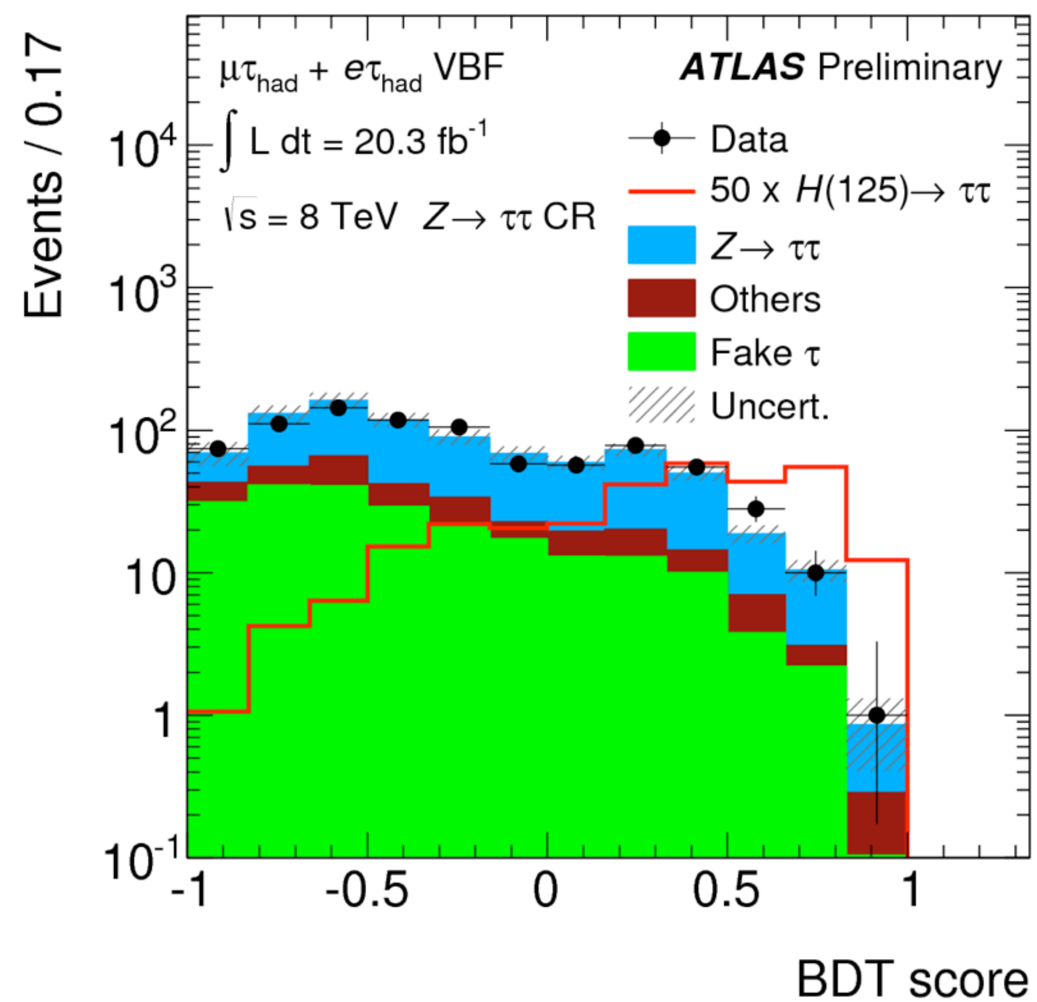
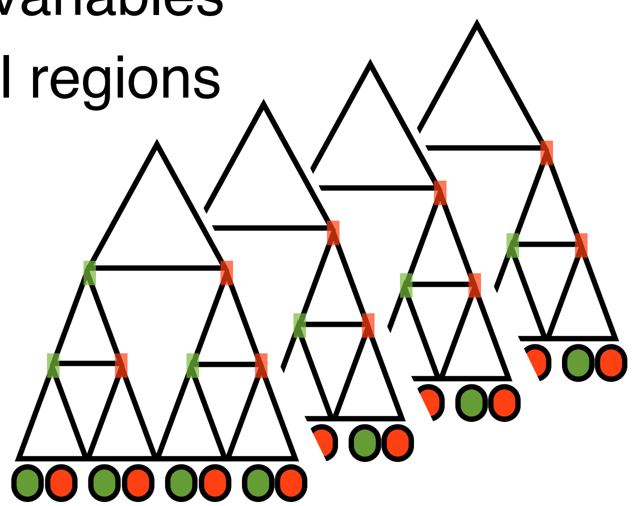
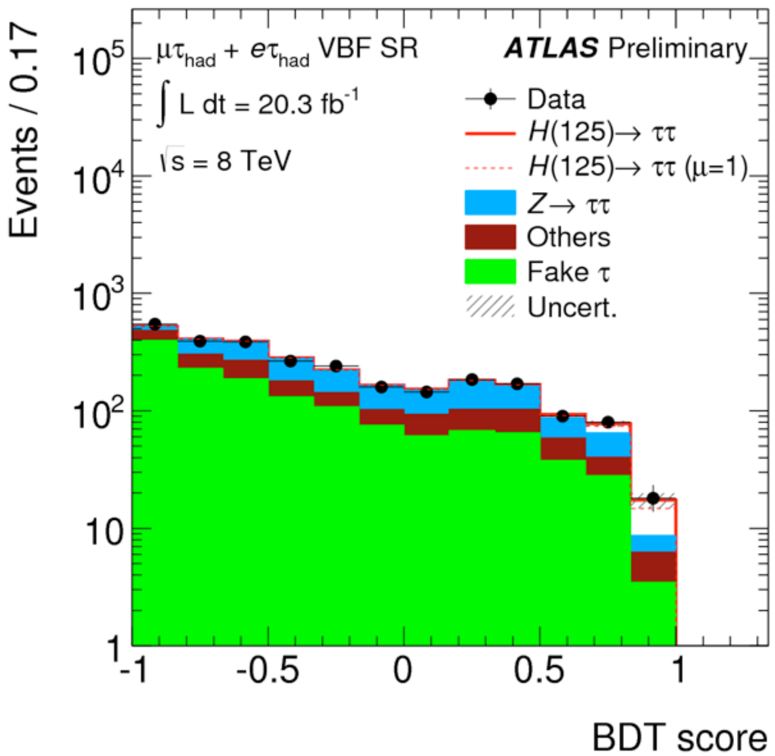
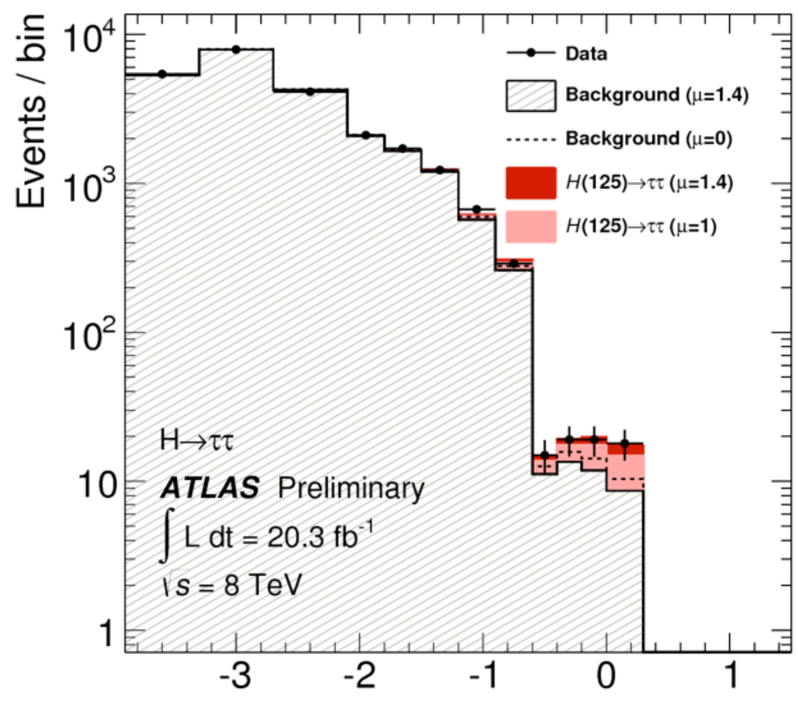


- Combining up to 9 variables in **B**oosted **D**ecision **T**rees
- Exploiting correlations across variables
- Extensively validated in control regions

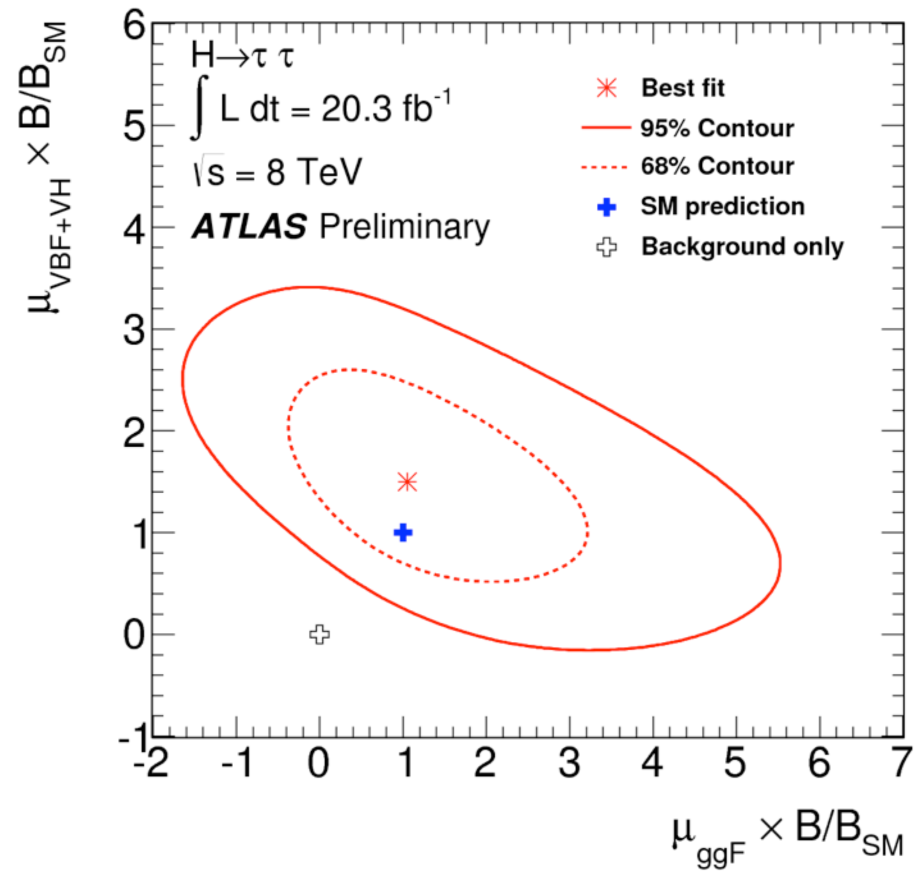


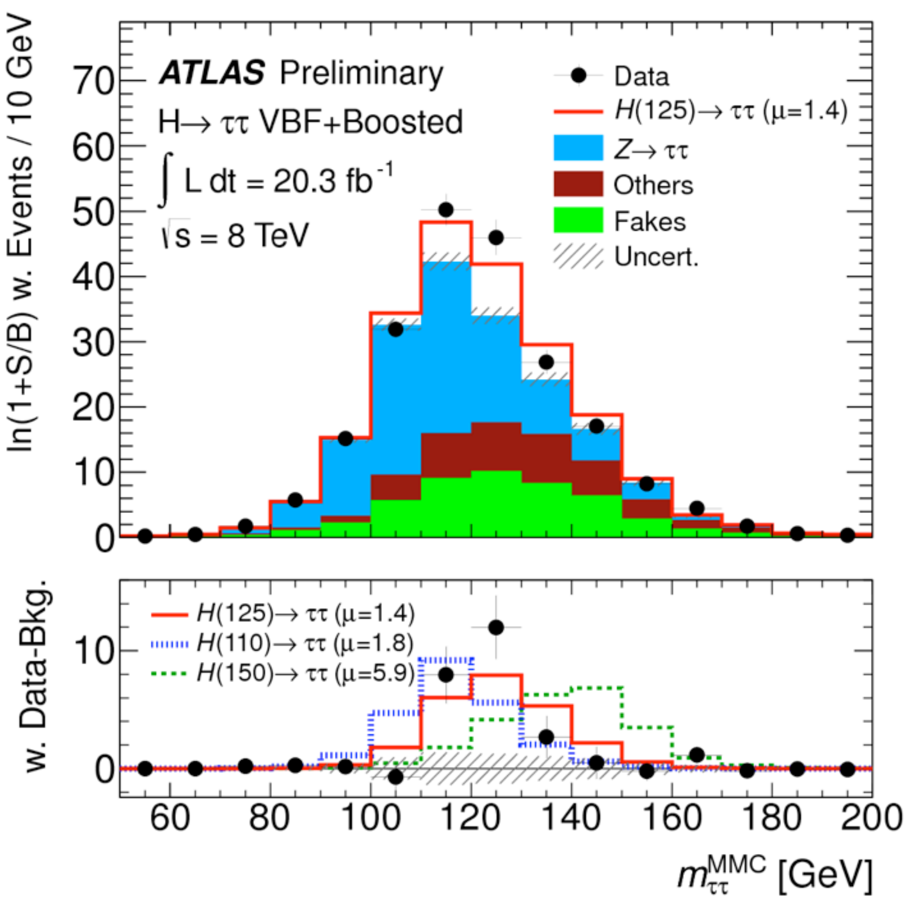
Results





Combing all 6 BDT distributions





- ATLAS observes a significant excess of events
- Corresponding to **4.1 σ @ 125 GeV** (3.2 σ expected)
- Present in **all three decay channels** and categories
- The fitted signal strength corresponds to:
  - $\mu_{comb} = 1.4^{+0.5}_{-0.4}$
  - $\mu_{ggF} \times B/B_{SM} = 1.1^{+1.3}_{-1.1}$
  - $\mu_{VBF,VH} \times B/B_{SM} = 1.6^{+0.8}_{-0.7}$

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BACKUP

ATLAS Higgs combination

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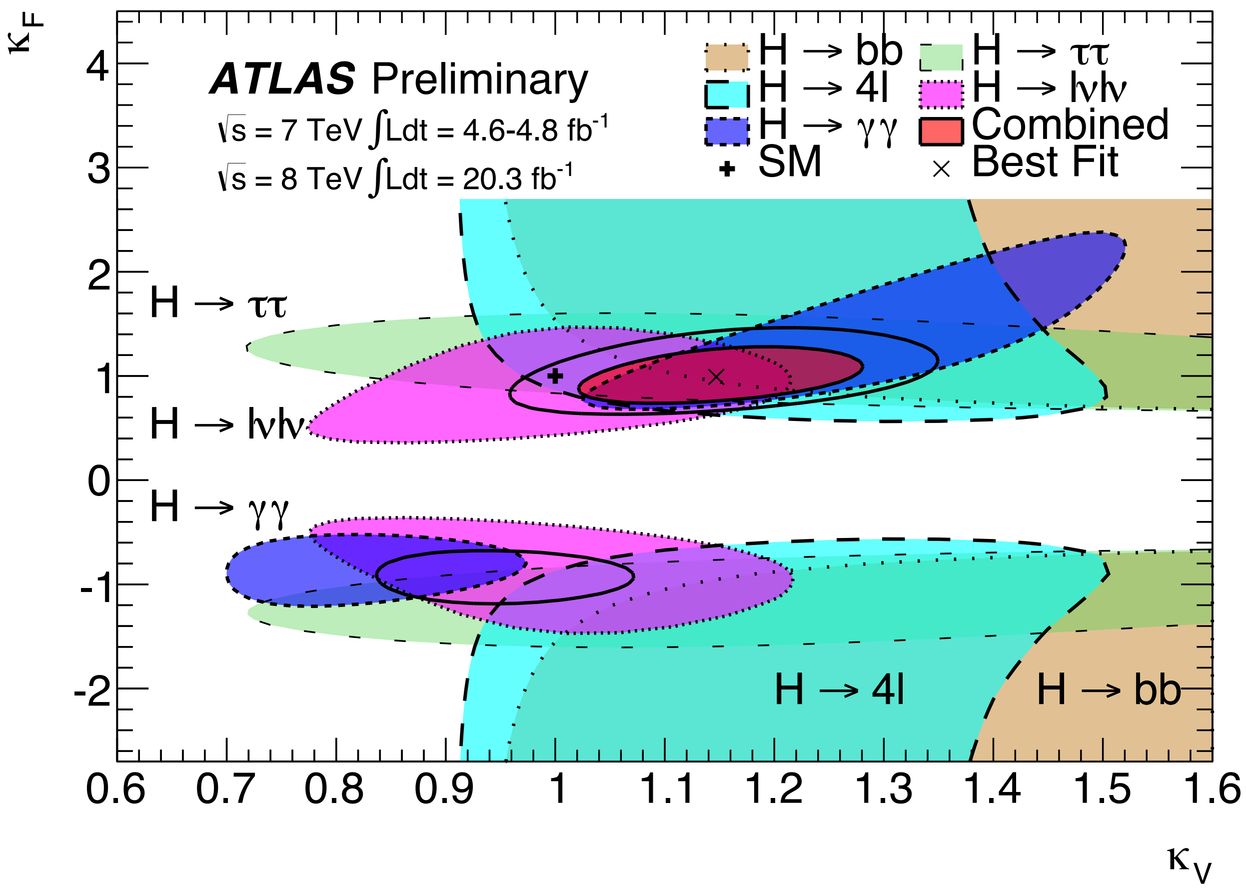
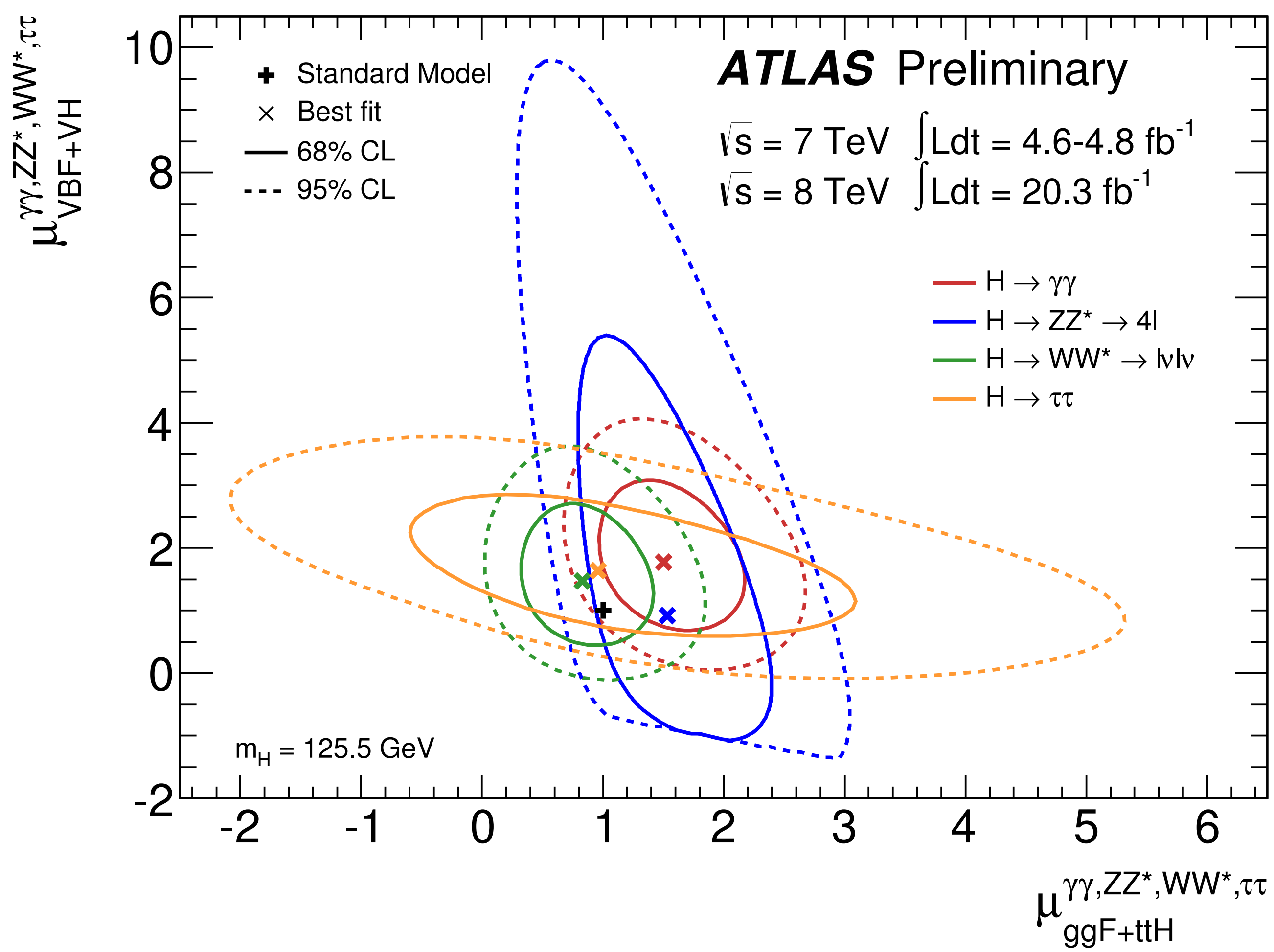
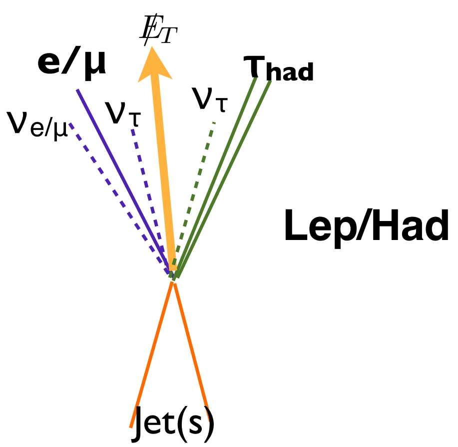


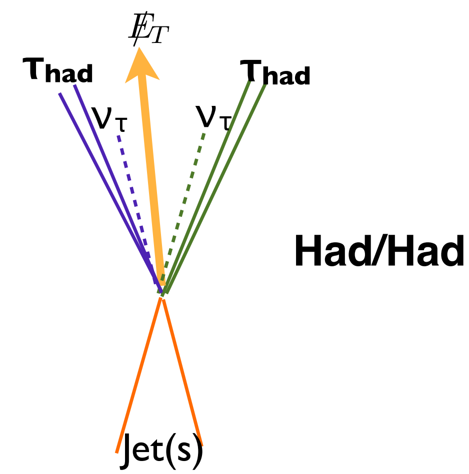


- $H \rightarrow \tau\tau$ contributes majorly to the overall ATLAS coupling fits
  - particularly constraining the signal strength in VBF production
  - and the fermion coupling

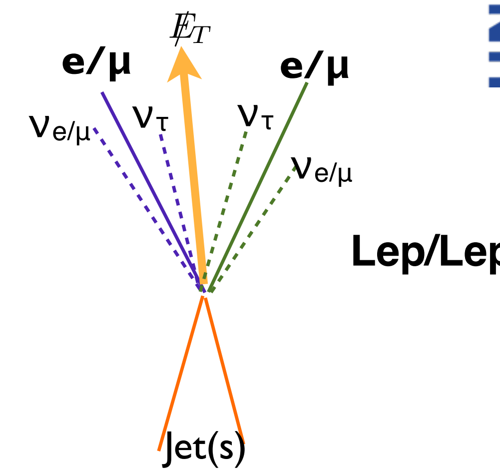
Event Selection



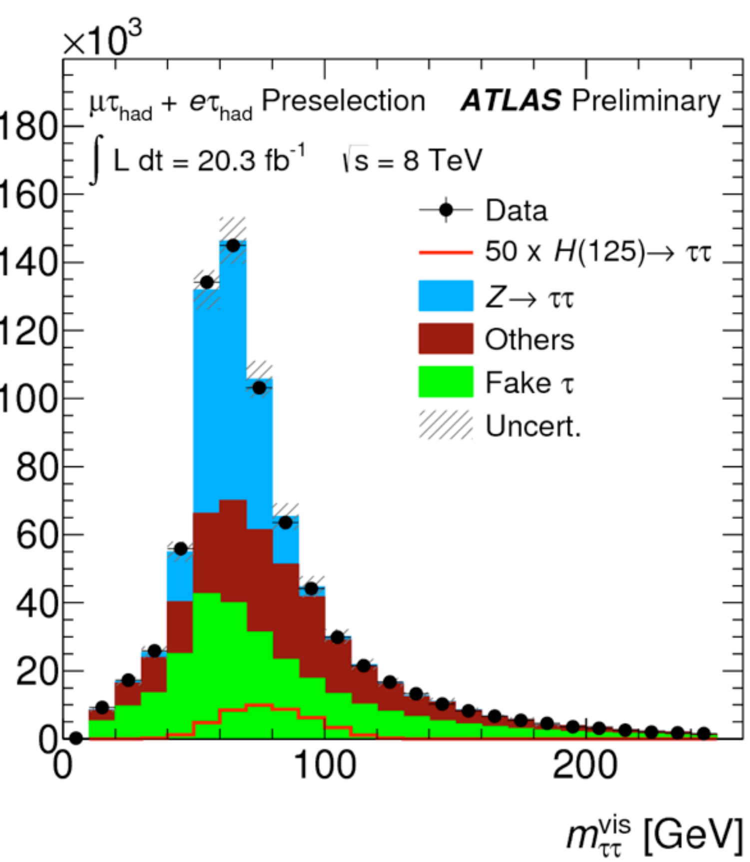
- Exactly **1 e/μ**
- Exactly **1 hadronic tau**
- Opposite charge
- Single lepton trigger
  - or tau+lepton trigger

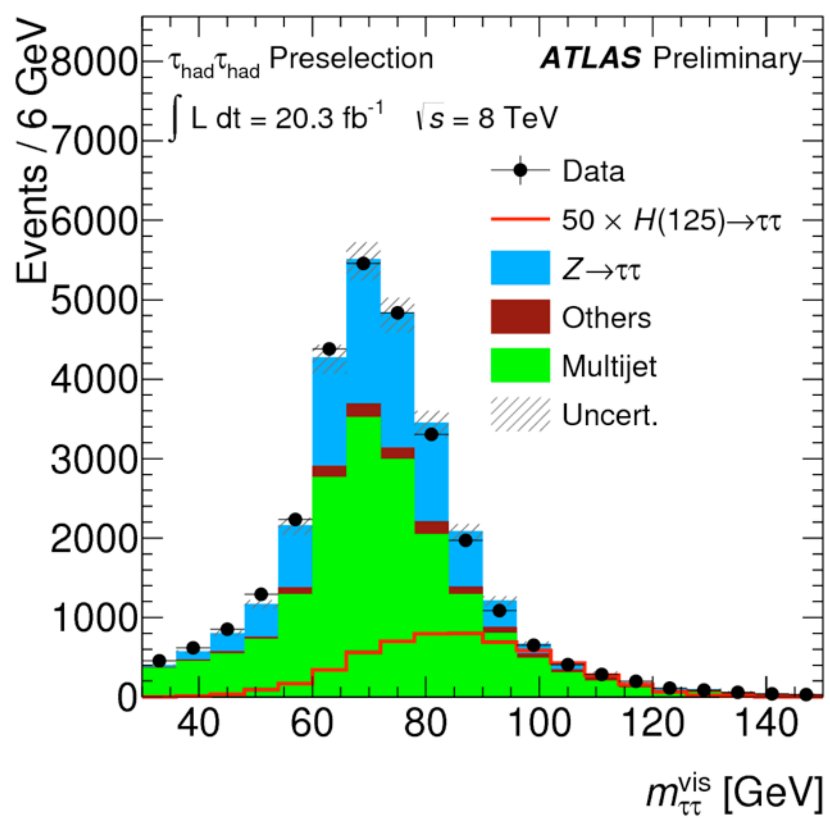


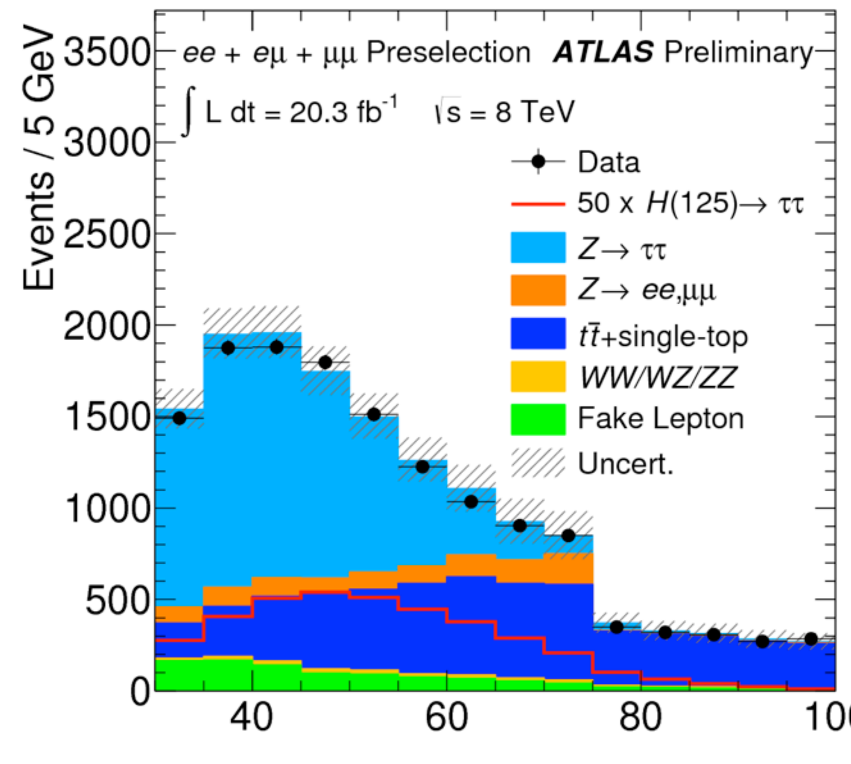
- Exactly **2 hadronic taus**
  - At least one of them passing a tighter ID criteria (~40% signal eff.)
- Opposite charge
- Di-tau trigger



- Exactly **2 light leptons**
  - 30 GeV < m_{ll} < 75 GeV (same flavour)
  - 30 GeV < m_{ll} < 100 GeV (diff. flavour)
- No hadronic taus
- Opposite sign
- Single electron trigger
- Di-lepton trigger







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Mass Compatibility

- Weighting each event by ln(1+ S/B) of its corresponding BDT bin
- Visualizing the compatibility of the observed excess with a Higgs Boson of 125 GeV

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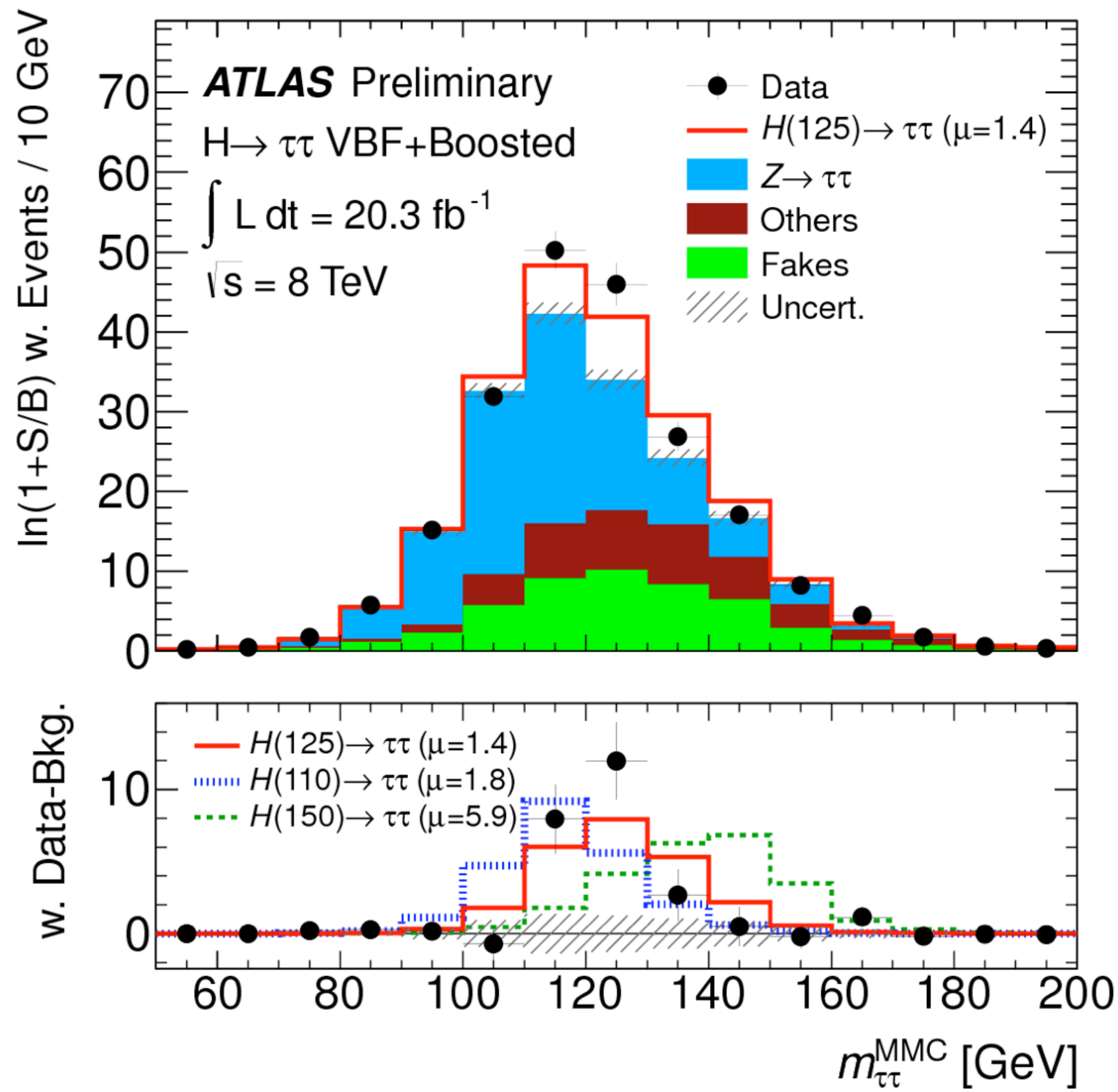
- Alternative signal hypothesis are scaled to their fitted signal strength
- .. to focus on the shape difference



Event Yields

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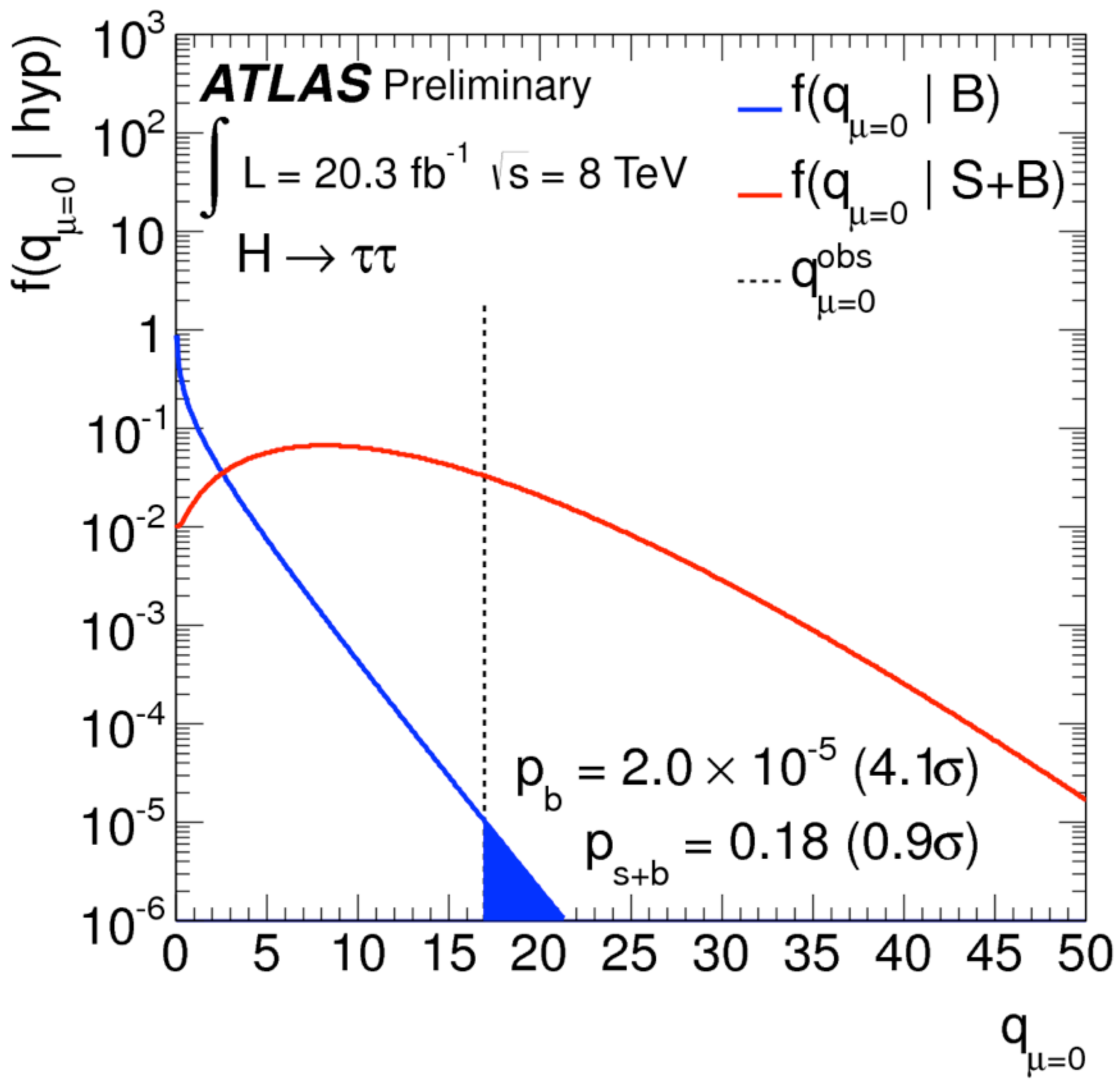

Numbers of events in highest BDT-score bin

		Lep-lep	Lep-had	Had-had
VBF	Signal	5.7±1.7	8.7±2.5	8.8±2.2
	Bckg	13.5±2.4	8.7±2.4	11.8±2.6
	Data	**19**	**18**	**19**
Boosted	Signal	2.6±0.8	8.0±2.5	3.6±1.1
	Bckg	20.2±1.8	32±4	11.2±1.9
	Data	20	34	15

- ATLAS observes a significant excess of events in all decay channels
- Corresponding to 4.1 σ @ 125 GeV (with 3.2 σ expected)

Categorisation

Category	Selection	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
VBF	$p_T(j_1) >$ (GeV)	40	50	50
	$p_T(j_2) >$ (GeV)	30	30	30/35
	$\Delta\eta(j_1, j_2) >$	2.2	3.0	2.0
	b-jet veto for jet $p_T >$ (GeV)	25	30	-
	$p_T^H >$ (GeV)	-	-	40
Boosted	$p_T(j_1) >$ (GeV)	40	-	-
	$p_T^H >$ (GeV)	100	100	100
	b-jet veto for jet $p_T >$ (GeV)	25	30	-

Table 2: Selection criteria applied in each analysis category for each channel. Only event that fail VBF category selection are considered for the boosted category. Events in the $\tau_{lep}\tau_{had}$ VBF category must also satisfy $m_{vis}^{\tau\tau} > 40$ GeV, and those that fail this requirement are not considered for the $\tau_{lep}\tau_{had}$ boosted category. The $\tau_{had}\tau_{had}$ $p_T(j_2)$ threshold is 30 (35) GeV for jets within (outside of) $|\eta| < 2.4$.

Major Uncertainties

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- Impact of dominating uncertainties on the measured signal strength

Source of Uncertainty	Uncertainty on μ
Signal region statistics (data)	0.30
$Z \to \ell\ell$ normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ boosted)	0.13
ggF $d\sigma/dp_T^H$	0.12
JES η calibration	0.12
Top normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ VBF)	0.12
Top normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ boosted)	0.12
$Z \to \ell\ell$ normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ VBF)	0.12
QCD scale	0.07
di-τ_{had} trigger efficiency	0.07
Fake backgrounds ($\tau_{\text{lep}}\tau_{\text{lep}}$)	0.07
τ_{had} identification efficiency	0.06
$Z \to \tau^+\tau^-$ normalization ($\tau_{\text{lep}}\tau_{\text{had}}$)	0.06
τ_{had} energy scale	0.06

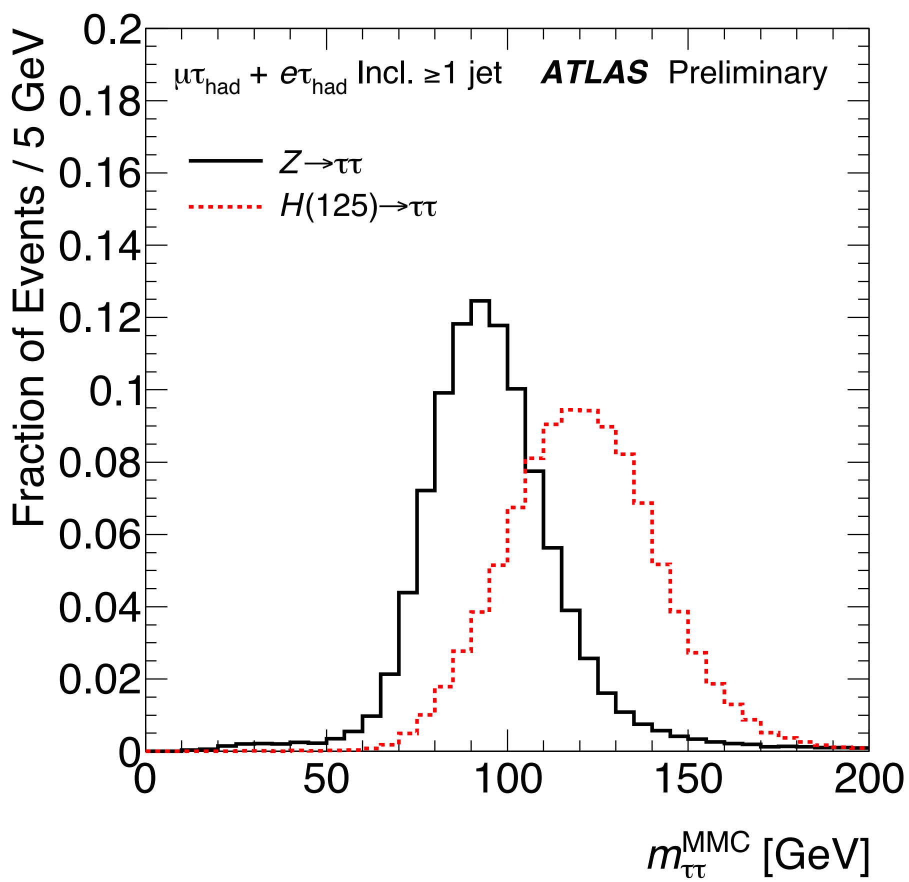
Table 7: The important sources of uncertainty on the measured signal strength parameter μ, given as absolute uncertainties on μ.

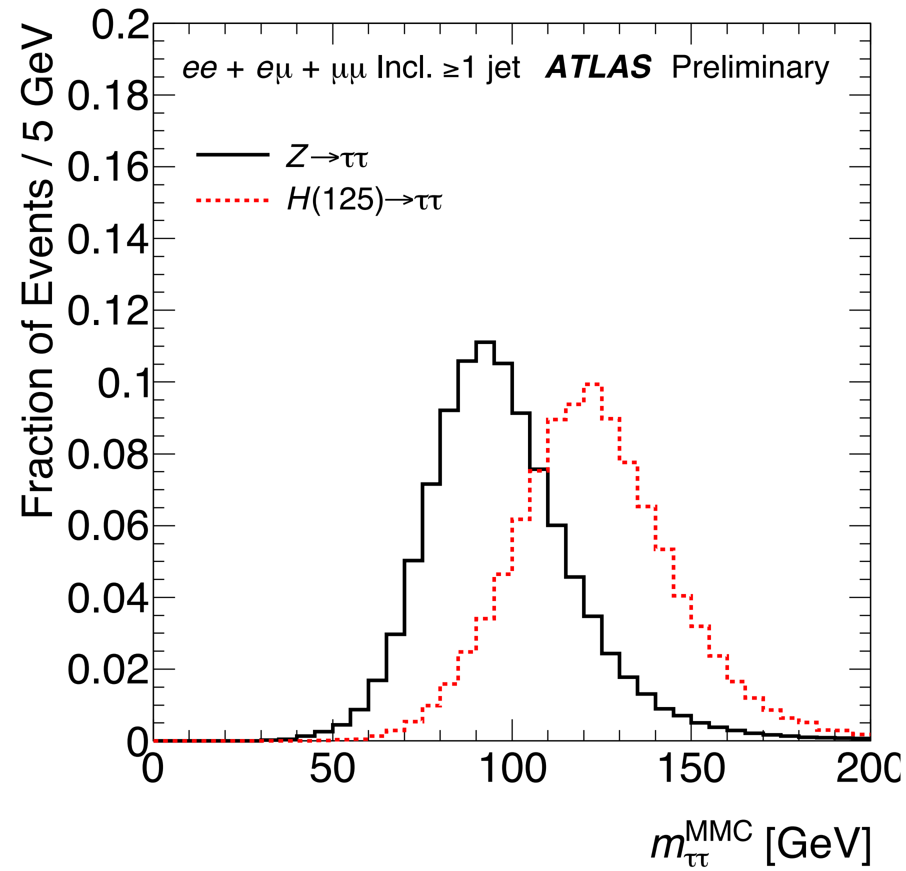
Input Variables

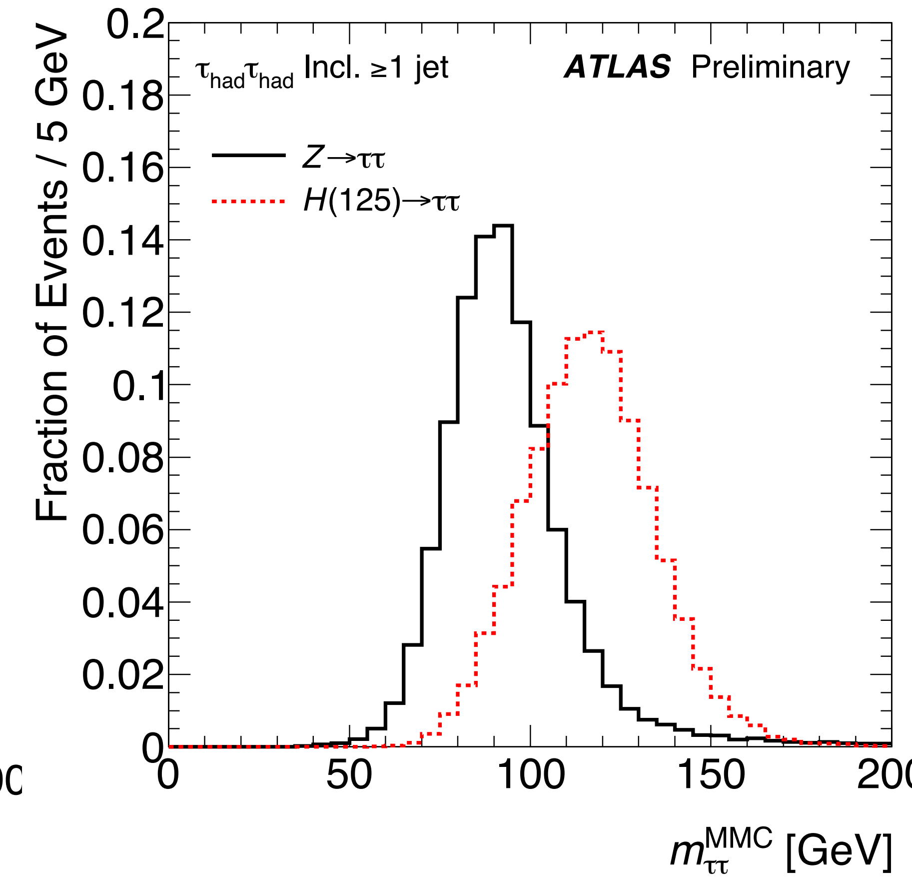
Variable	VBF			Boosted		
	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
$m_{\tau\tau}^{\mathrm{MMC}}$	•	•	•	•	•	•
$\Delta R(\tau,\tau)$	•	•	•		•	•
$\Delta\eta(j_1,j_2)$	•	•	•			
m_{j_1,j_2}	•	•	•			
$\eta_{j_1}\times\eta_{j_2}$		•	•			
$p_{\mathrm{T}}^{\mathrm{Total}}$		•	•			
sum p_{T}					•	•
$p_{\mathrm{T}}(\tau_1)/p_{\mathrm{T}}(\tau_2)$					•	•
$E_{\mathrm{T}}^{\mathrm{miss}}\phi$ centrality		•	•	•	•	•
$x_{\tau 1}$ and $x_{\tau 2}$						•
$m_{\tau\tau,j_1}$				•		
m_{ℓ_1,ℓ_2}				•		
$\Delta\phi_{\ell_1,\ell_2}$				•		
sphericity				•		
$p_{\mathrm{T}}^{\ell_1}$				•		
$p_{\mathrm{T}}^{j_1}$				•		
$E_{\mathrm{T}}^{\mathrm{miss}}/p_{\mathrm{T}}^{\ell_2}$				•		
m_{T}		•			•	
$\min(\Delta\eta_{\ell_1\ell_2,\mathrm{jets}})$	•					
j_3 η centrality	•					
$\ell_1\times\ell_2$ η centrality	•					
ℓ η centrality		•				
$\tau_{1,2}$ η centrality			•			

Table 3: Discriminating variables used for each channel and category. The filled circles identify which variables are used in each decay mode. Note that variables such as $\Delta R(\tau,\tau)$ are defined either between the two leptons, between the lepton and τ_{had}, or between the two τ_{had} candidates, depending on the decay mode.

Mass Reconstruction







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- Estimating the neutrino four momenta using known tau decay kinematics
- Majorly improving the mass resolution

	$Z\rightarrow\tau\tau$
Lep-lep	21.4%
Lep-had	18.1%
Had-had	14.3%

Fake Estimate LepHad

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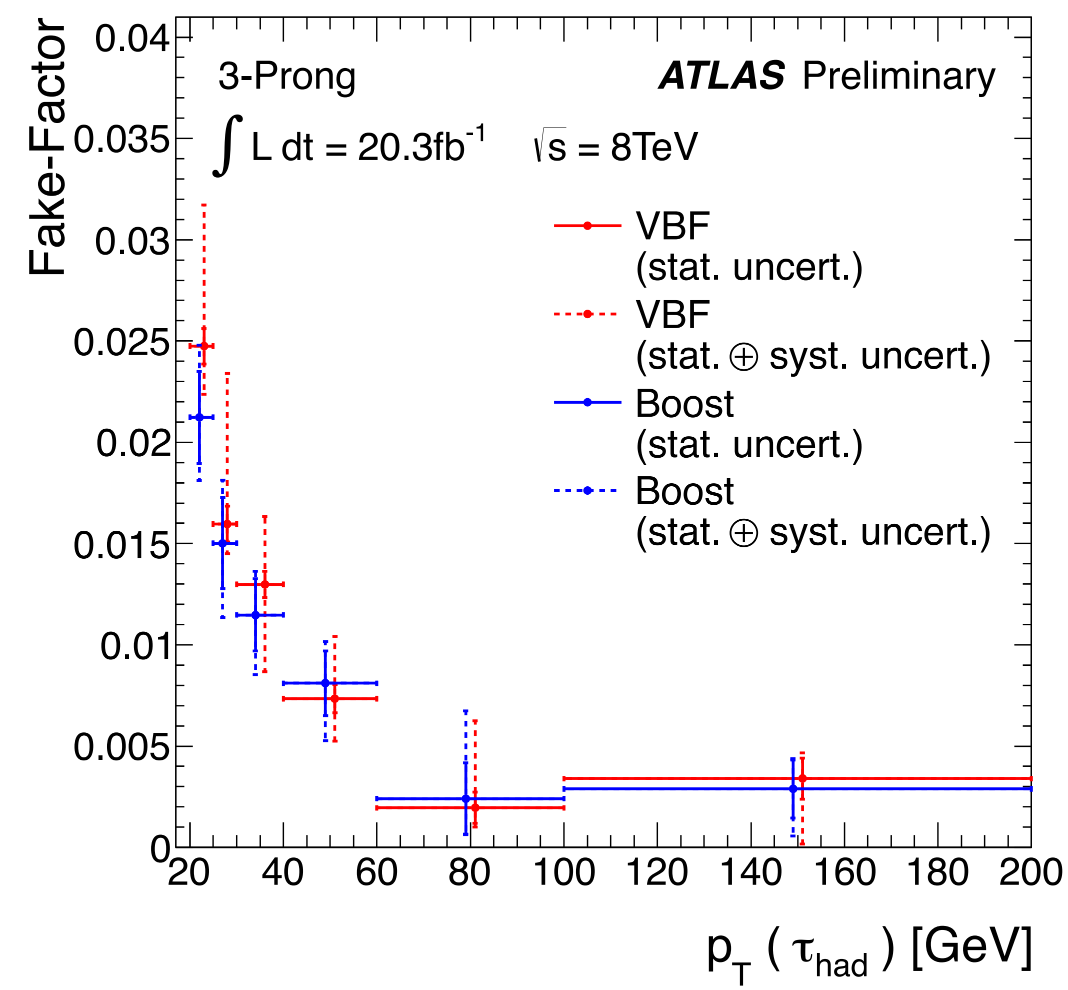
- Statistically huge sample of misidentified τ's available in reversed ID region (*„Anti-Taus“*)
- Scaling it with a fake rate measurement: **Shape & yield** can be extrapolated into signal region

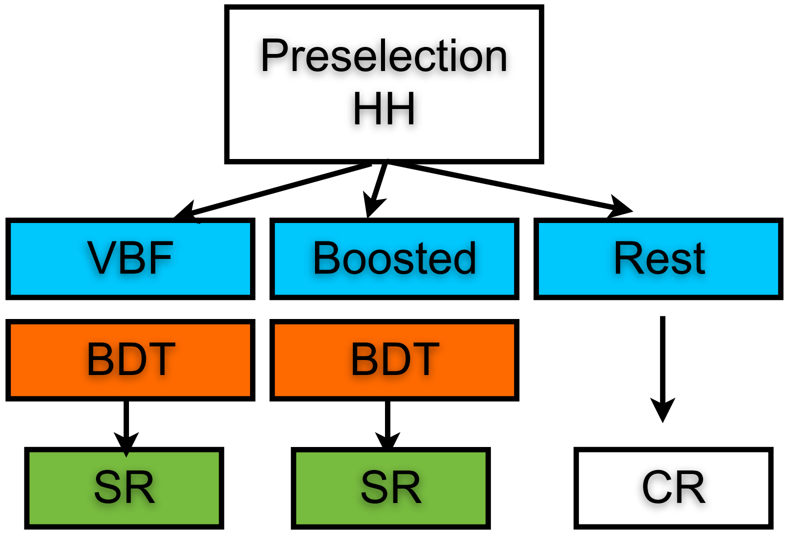
$$N_{\text{SR,ID}} = \underbrace{\frac{N_{\text{CR,ID}}}{N_{\text{CR,Fail ID}}}} N_{\text{SR,Fail ID}}$$

$$FF = f_{\text{W+Jets}} FF_W + (1 - f_{\text{W+Jets}}) FF_{QCD}$$

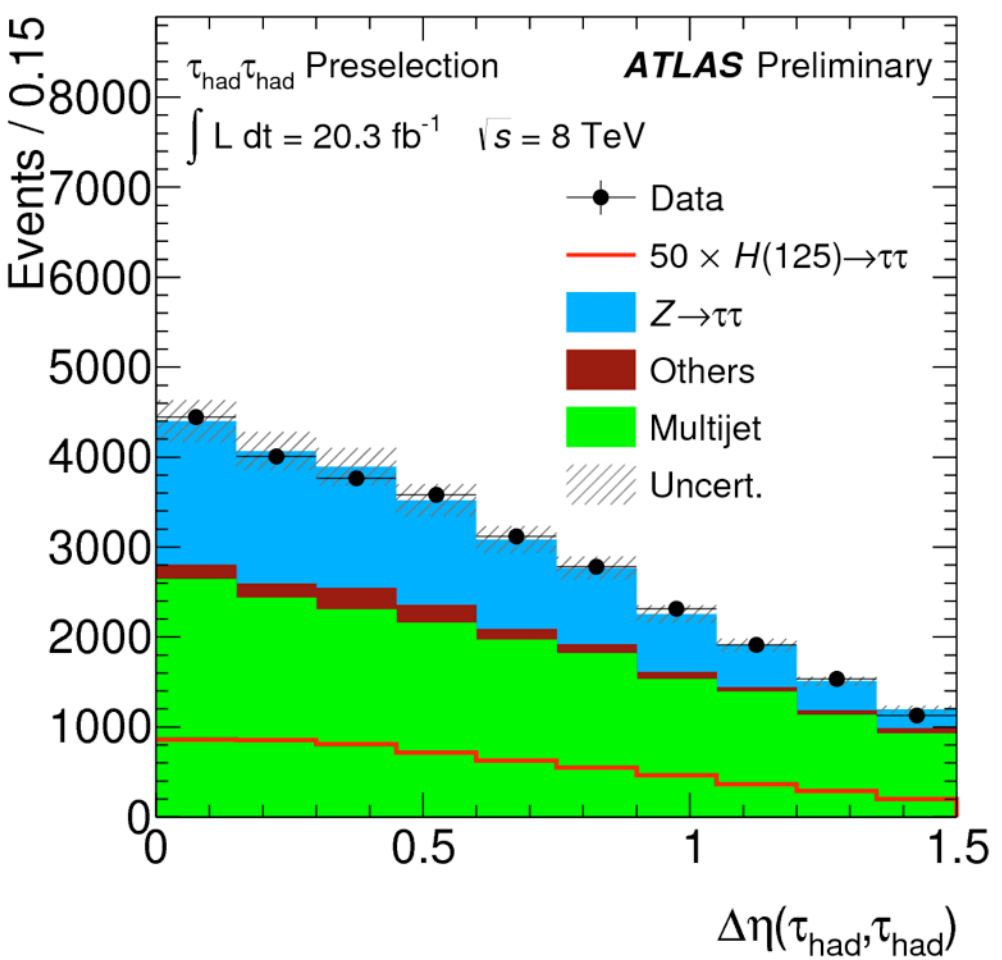


- ***Fake Factor*** measured **separately** in a W and a QCD control region
  - combined into effective fake rate (estimated fractional W/QCD contribution in SR)
  - Large (~30%) uncertainties due to unknown q/g fractions in signal region

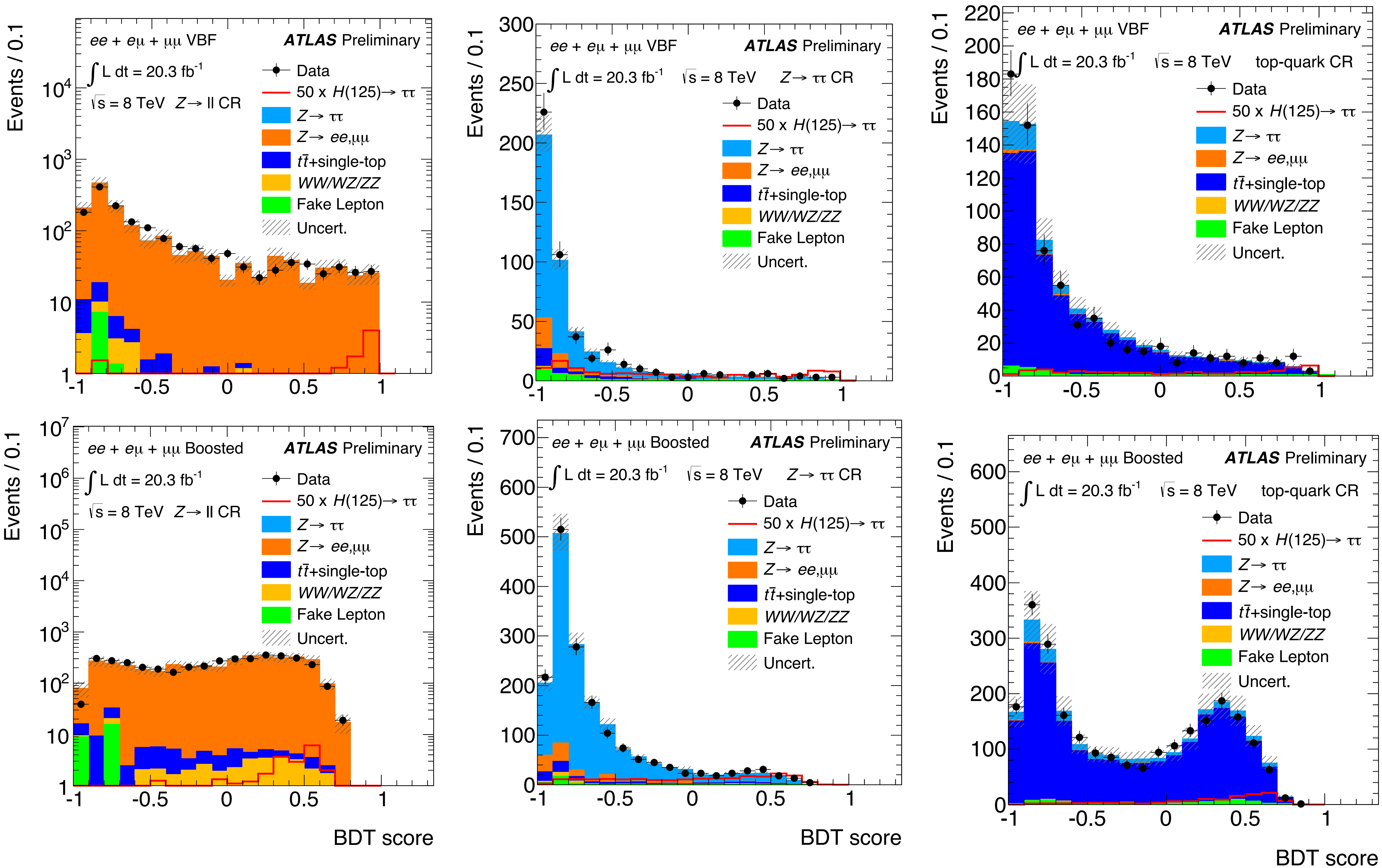
Fake Estimate HadHad



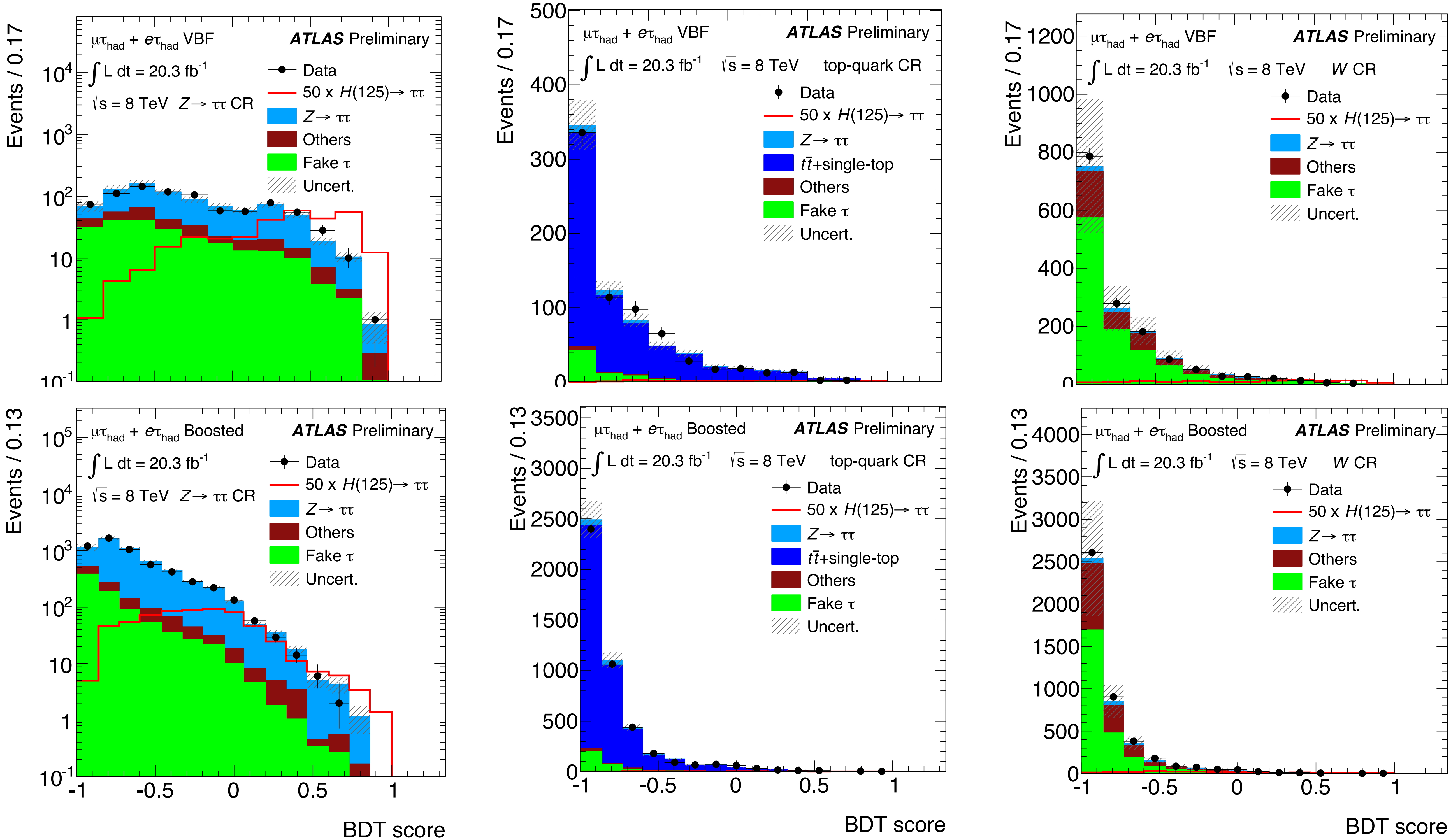
- A Multijet template is built from not opposite sign events
  - Charge (τ_1) * Charge (τ_2) >= 0
- Enhanced in Multijet background due to little charge correlation
- Normalization extracted in combined Fit
  - $\Delta\eta$ (τ_1,τ_2) included in the fit for its separation power between $Z \rightarrow \tau\tau$ and the Multijet background



Additional Control Region BDTs LepLep



Additional Control Region BDTs LepHad



Additional Control Region BDTs HadHad