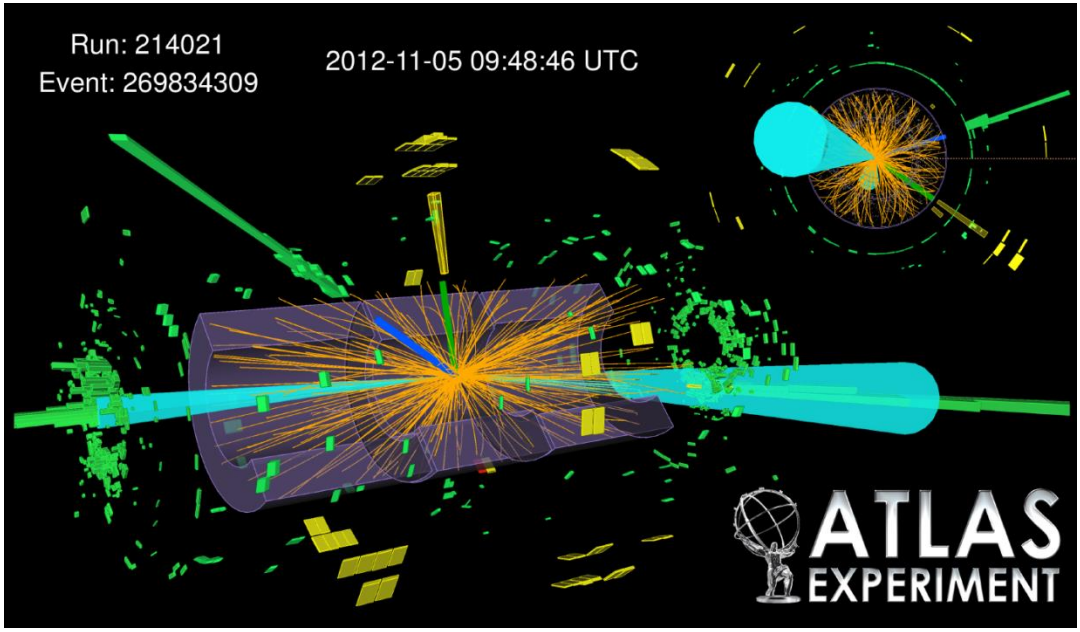
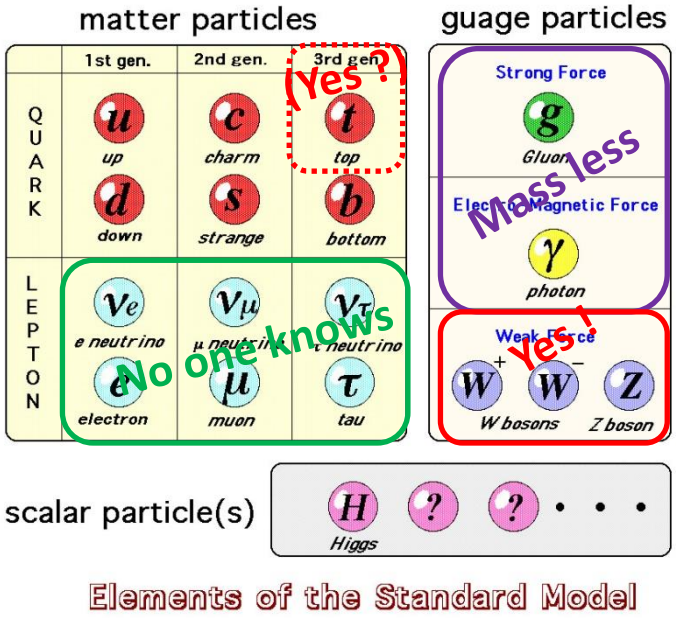


ATLAS Di-fermion Results

Koji Nakamura (KEK)
on behalf of ATLAS Collaboration

Motivation

Mass is given by Higgs Mechanism?

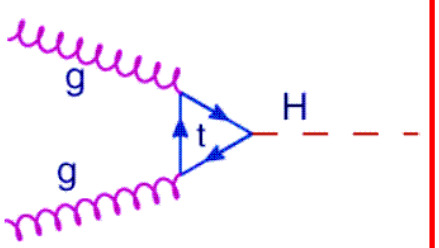


- Higgs boson has been observed by Bosonic decay channels (i.e. γγ,ZZ,WW)
  - Loop process in the production and decays indicated fermion (top) contribution indirectly.
- Observation of direct fermion couplings are quite important to complete the Higgs Mechanism.

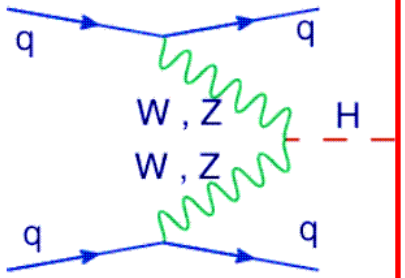
- ***Following channels are presented :***
  - H→ττ : highest sensitivity
  - H→μμ : small branching ratio
  - VH→bb : huge backgrounds
  - ttH→bb : small production rate

Higgs production and decay @ LHC

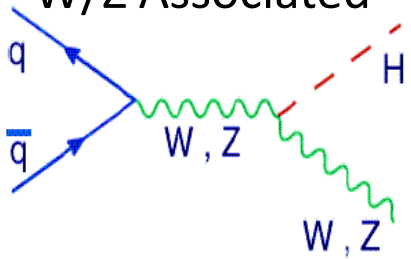
Gluon Fusion(ggF)



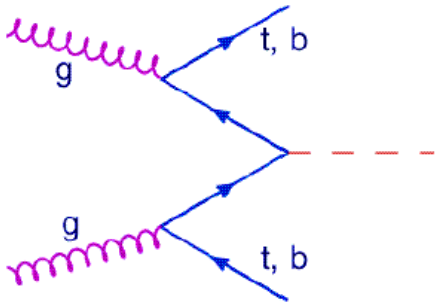
Vector Boson Fusion



W/Z Associated



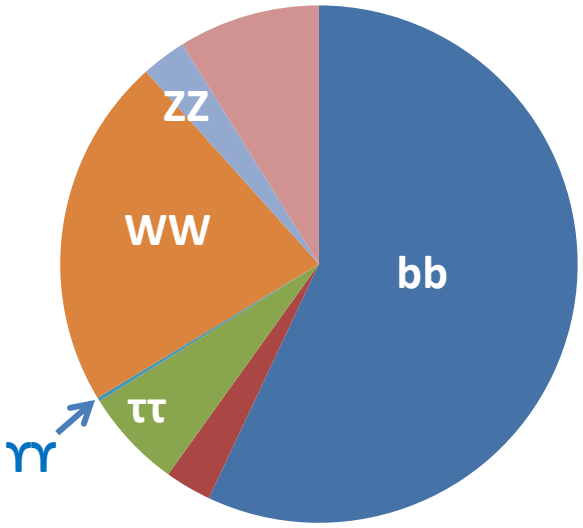
tt/bb Associated



Now we know expected cross section and Branching ratio!

Process	8TeV σ [pb]	13TeV σ [pb]
Gluon Fusion	**19.1**	**43.9**
Vector Boson Fusion	**1.57**	**3.73**
W/Z Associated	1.11	2.25
tt Associated	0.128	0.509

8TeV @125.5 GeV
13TeV @125 GeV

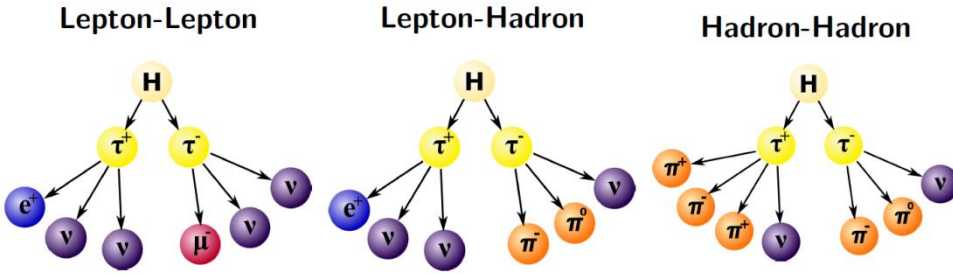


@125.5GeV

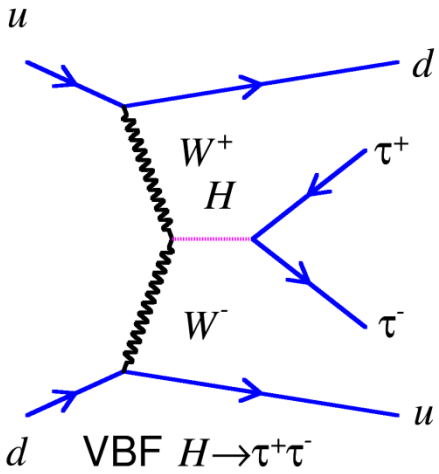
- bb (57%)
- cc (2.9%)
- ττ(6.2%)
- μμ(0.02%)
- γγ(0.23%)
- WW (22%)
- ZZ (2.8%)
- others

H→ττ analysis

- Analysis was optimized for each di-tau decay mode.
  - Different trigger, object selection and backgrounds.
  - Highest sensitivity channel is Lep-had.
- Categorize events to 2 category.

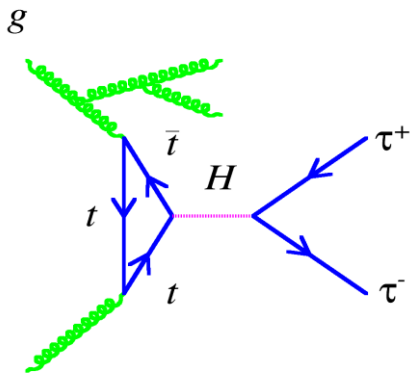


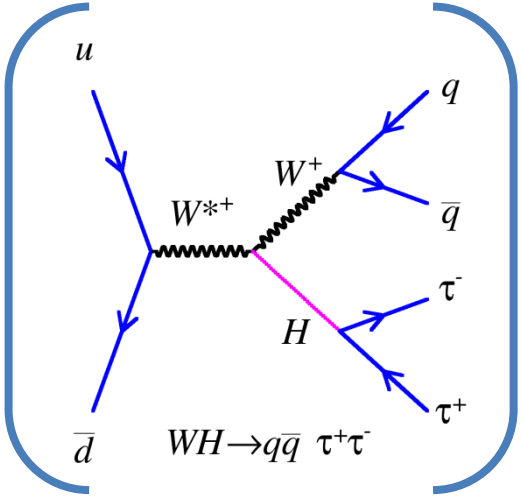
VBF category



- Find VBF jets with loose selection.
- Train BDT for VBF signal.

Boosted category

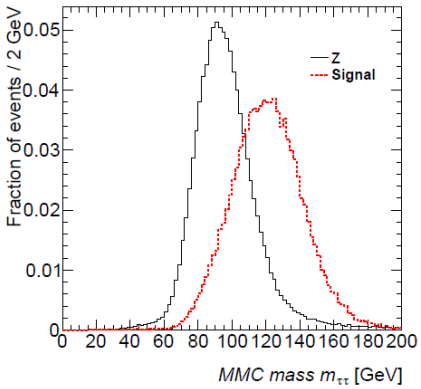




- Select events with high vector sum pT of tautau decay products.
- Not included non-boosted events.

BDT input variables

- Dominant backgrounds are Zττ+jets and Wjets, small S/B ratio.
- Trained BDT for each 3 channels and for VBF/Boosted separately. (total 6 categories)
  - **125GeV signal MC as the signal template.**
- Missing Mass Calculator (MMC) is used for $m_{\tau\tau}$ reconstruction and it is also included as one of the most powerful variable for the training.



VBF category

Variable	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
$M_{\tau\tau}^{MMC}$	•	•	•
$\Delta R_{\tau\tau}$	•	•	•
$\lvert\eta_{j2} - \eta_{j1}\rvert$	•	•	•
$m_{j1,j2}$	•	•	•
$\eta_{j1} \times \eta_{j2}$		•	•
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 category

Variable	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
$M_{\tau\tau}^{MMC}$	•	•	•
$E_T^{miss}\phi$ 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}			•

H→ττ results

For mH=125GeV,

Evidence for H→ττ decay!

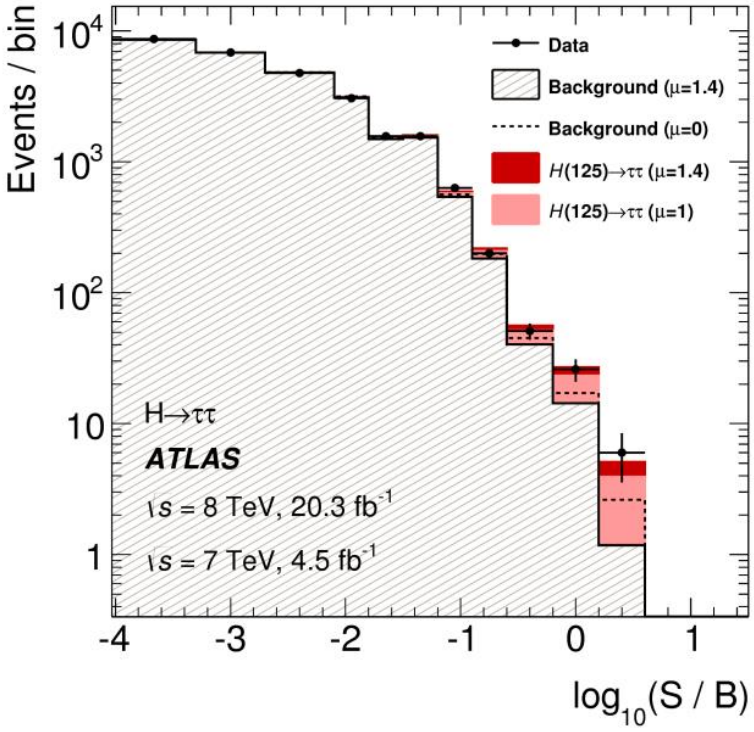
Sensitivity : 4.5σ (expected 3.4σ)

Assuming mH=125GeV :

$$\mu_{best} = 1.43^{+0.27}_{-0.26}(stat.)^{+0.32}_{-0.25}(syst.) \pm 0.09(theory)$$

Impact of uncertainty sources

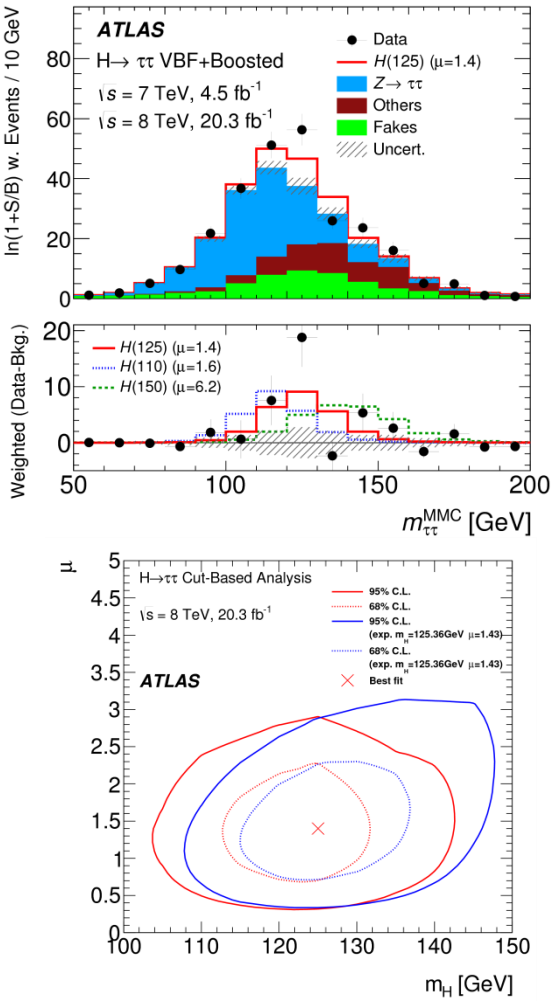
Source of Uncertainty	Uncertainty on μ
Signal region statistics (data)	$^{+0.27}_{-0.26}$
Jet energy scale	$\pm$ 0.13
Tau energy scale	$\pm$ 0.07
Tau identification	$\pm$ 0.06
Background normalisation	$\pm$ 0.12
Background estimate stat.	$\pm$ 0.10
BR ($H \to \tau\tau$)	$\pm$ 0.08
Parton shower/Underlying event	$\pm$ 0.04
PDF	$\pm$ 0.03
Total sys.	$^{+0.33}_{-0.26}$
Total	$^{+0.43}_{-0.37}$

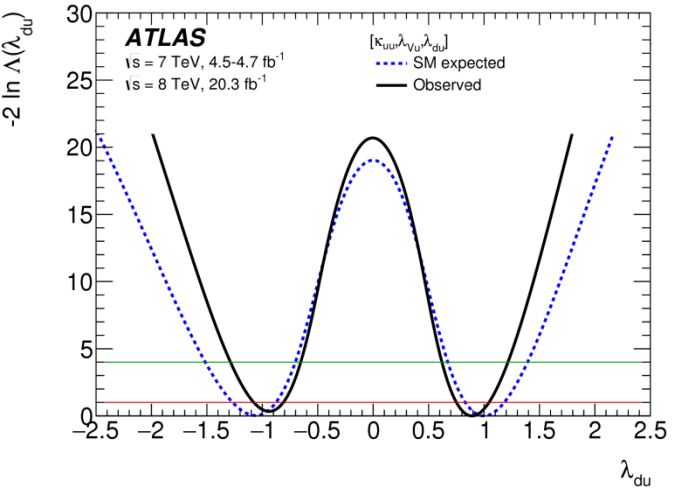


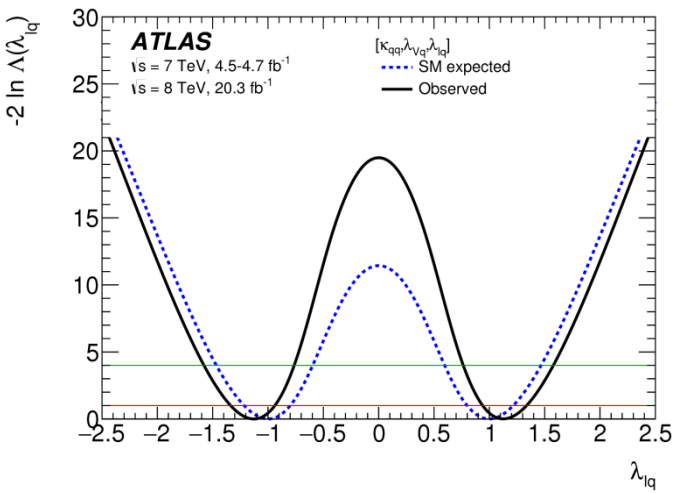
H→ττ results

- Checked Mass compatibility to 125GeV
- Strong Evidence for H→ττ (4.5σ)
  - First direct observation of fermion coupling
  - First observation of lepton coupling.
  - First observation of down type fermion coupling.
- Coupling ratio
  - Down/Up type Ratio : [-1.07,-0.81]U[0.75,1.04]
  - Lepton/Quark : [-1.33,0.94]U[0.94,1.33]

Mass compatibility to the observed Higss boson



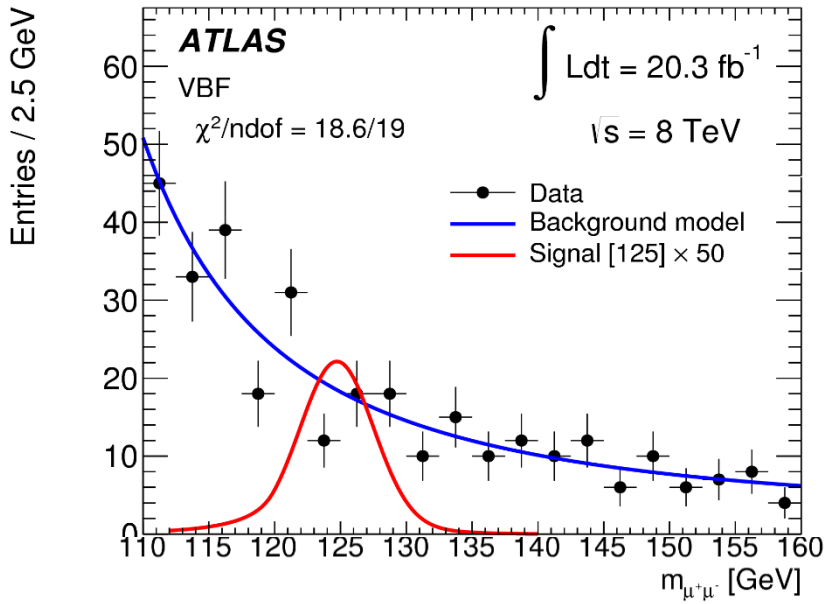


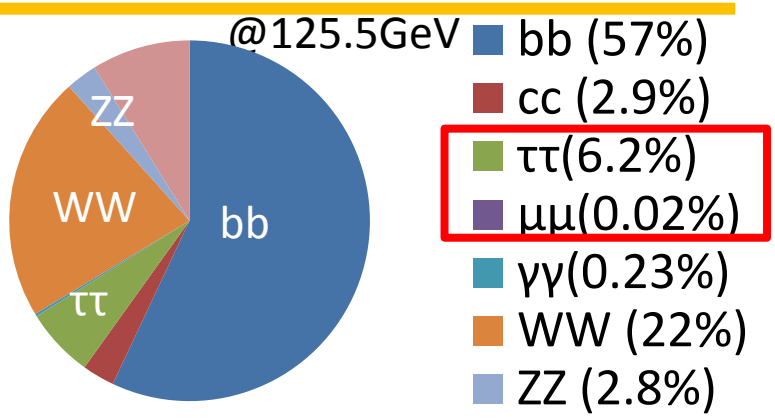


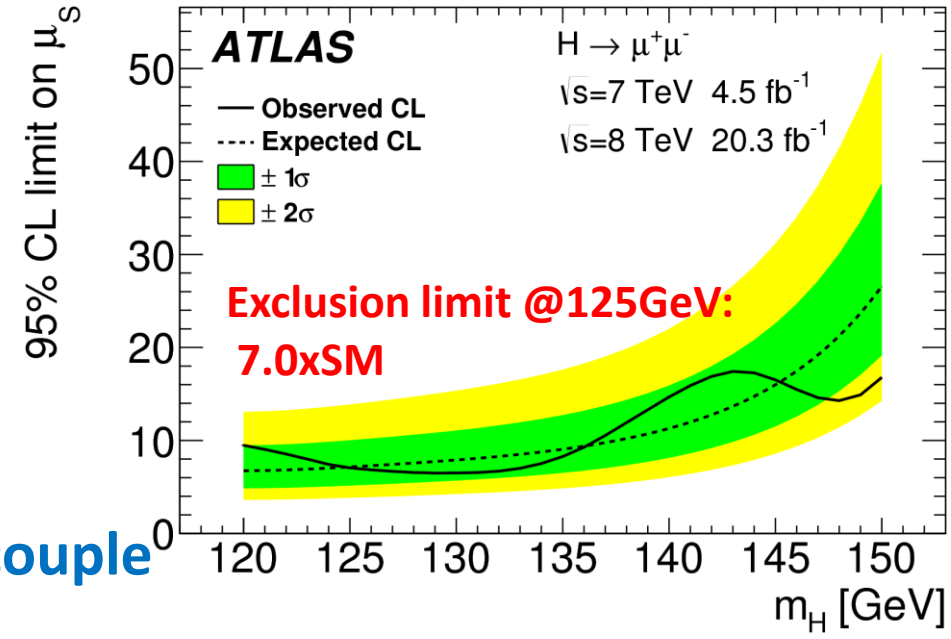
$$\lambda_{du} \in [-1.07, -0.81] \cup [0.75, 1.04] \qquad \lambda_{lq} \in [-1.33, -0.94] \cup [0.94, 1.33]$$

H→μμ and Lepton universality ?

- H→μμ decay is also searched.
  - Can prove 2nd generation lepton
  - Similar technique as H→γγ analysis





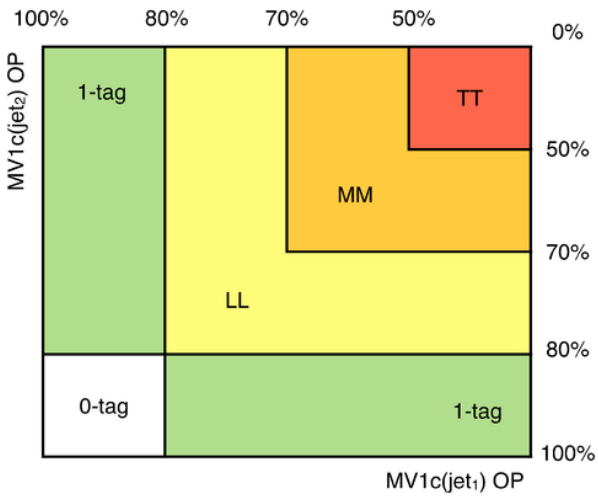


This correspond to the BR(H→μμ)<0.2%
So, BR(H→ττ) >> BR(H→μμ)

Higgs boson does not universally couple to leptons

VH,H→bb

- **Important channel to prove bottom Yukawa (Yb) coupling directly.**
  - Largest branching ratio but small S/B ratio due to huge QCD b-jets and vector boson + b-jets background processes.
- Analysis Strategy
  - Use W/Z associated production
  - Leptonic W/Z decays : Z→νν(0lep), ll(2lep) W→lν(1lep)
  - Both cut-based(di-jet mass) and Multivariate(BDT) analysis performed.



Multivariate Analysis

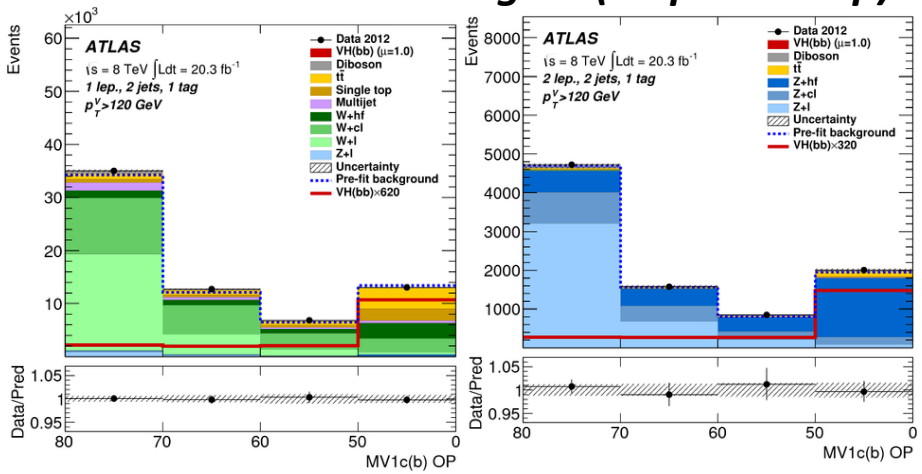
Z→νν (0lep)	W→lν (1lep)	Z→ll (2lep)
Require two b-tagged jets , P_T^{j1}>45GeV P_T^{j2}>20GeV + ≤1 extra jet		
E_T^{miss} > 100GeV	E_T^{miss}>20GeV (high p_T^V)	
P_T^{miss} > 30GeV with $\Delta\phi(E_T^{miss}, P_T^{miss}) < \pi/2$	H_T>180GeV (low p_T^V)	71<m_{ll}<121GeV
1 category : p_T^V >120GeV	2 categories : p_T^V = [0, 120], [120, inf]	
3 categ. : 1tag, LL, MM+TT	4 categ. : 1tag, LL, MM, TT	3 categ : 1tag, LL, MM+TT

BDT input variables

- Trained BDT using 2-tag (TT+MM+LL) events for each 0/1/2lep, each 2/3jets and each p_T^V bin separately.
- Input variables are :

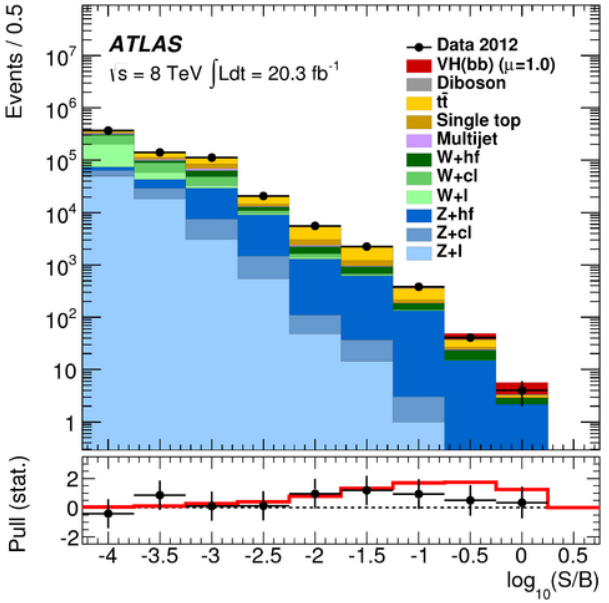
Variable	0-Lepton	1-Lepton	2-Lepton
p_{T}^{V}		×	×
$E_{\mathrm{T}}^{\mathrm{miss}}$	×	×	×
$p_{\mathrm{T}}^{b_1}$	×	×	×
$p_{\mathrm{T}}^{b_2}$	×	×	×
m_{bb}	×	×	×
$\Delta R(b_1, b_2)$	×	×	×
$\lvert\Delta\eta(b_1, b_2)\rvert$	×		×
$\Delta\phi(V, bb)$	×	×	×
$\lvert\Delta\eta(V, bb)\rvert$			×
H_{T}	×		
$\min[\Delta\phi(\ell, b)]$		×	
m_{T}^{W}		×	
$m_{\ell\ell}$			×
$MV1c(b_1)$	×	×	×
$MV1c(b_2)$	×	×	×
	Only in 3-jet events		
$p_{\mathrm{T}}^{\mathrm{jet}_3}$	×	×	×
m_{bbj}	×	×	×

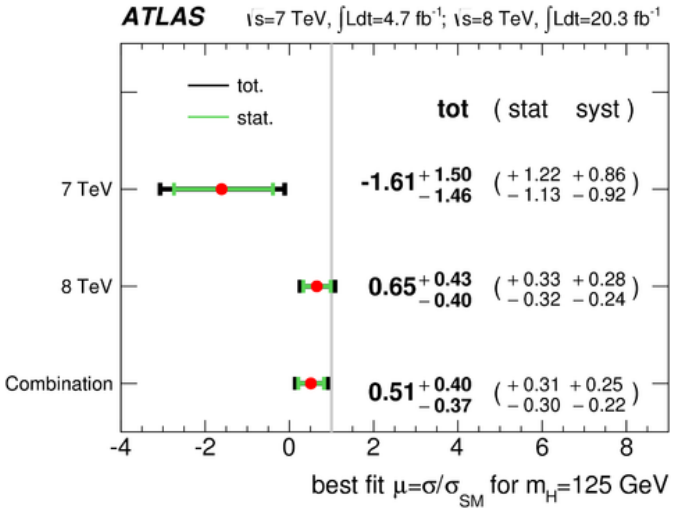
MVA1c variable in 1tag CR (1lep and 2lep)

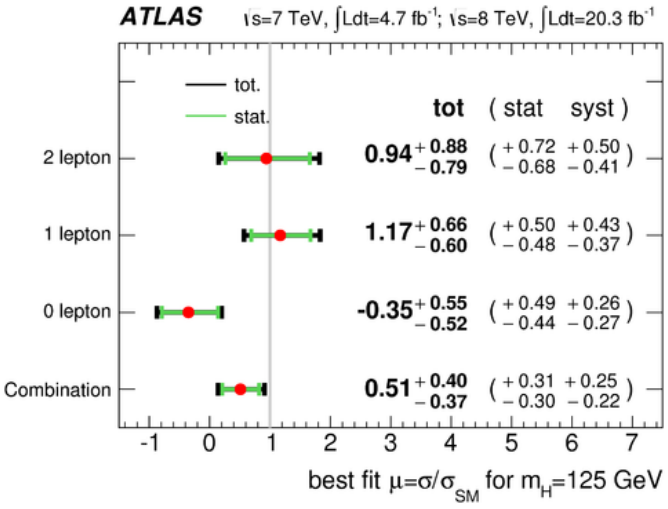


VH,H→bb results

- No significant excess observed yet
  - Significance : 1.4σ (2.5σ)
  - 95% C.L. limit : 1.2 times SM σ x BR
  - Signal strength : μ=0.51±0.31(stat.)±0.24(syst.)
- Sensitivity is quite close to 3σ
  - **Will see early 13TeV data.**

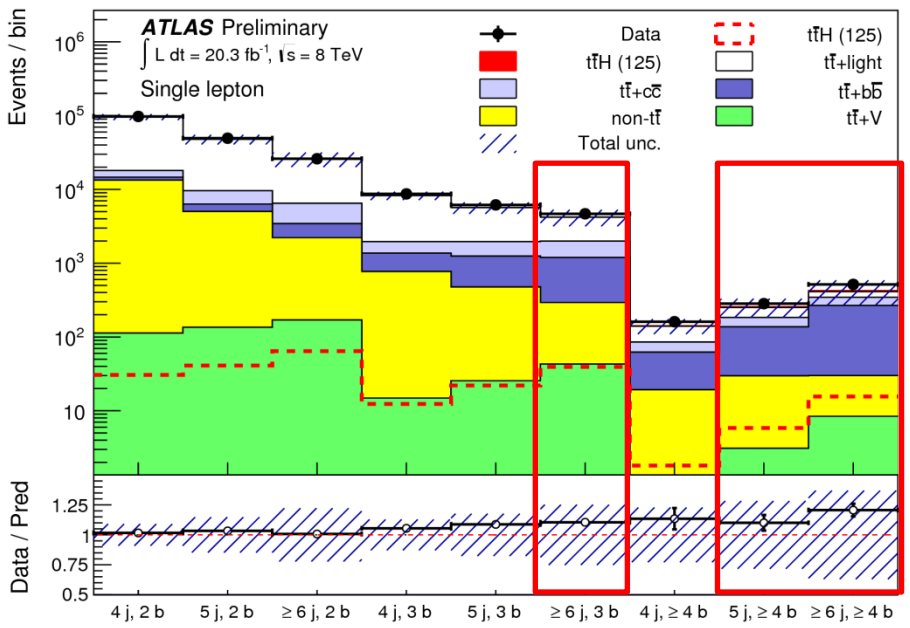


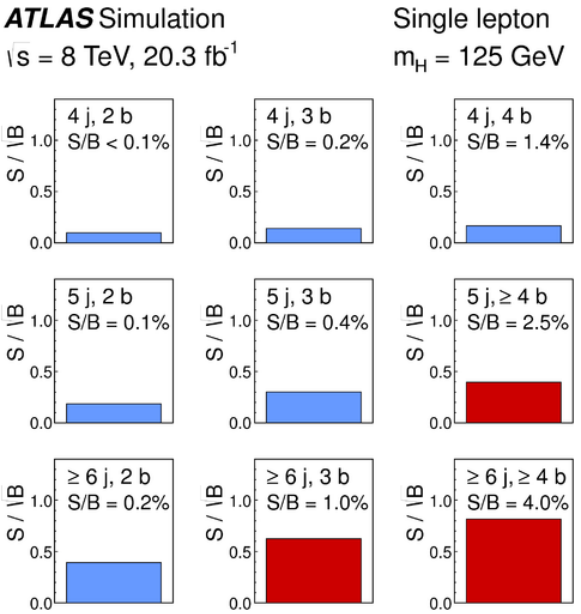




ttH,H→bb channel

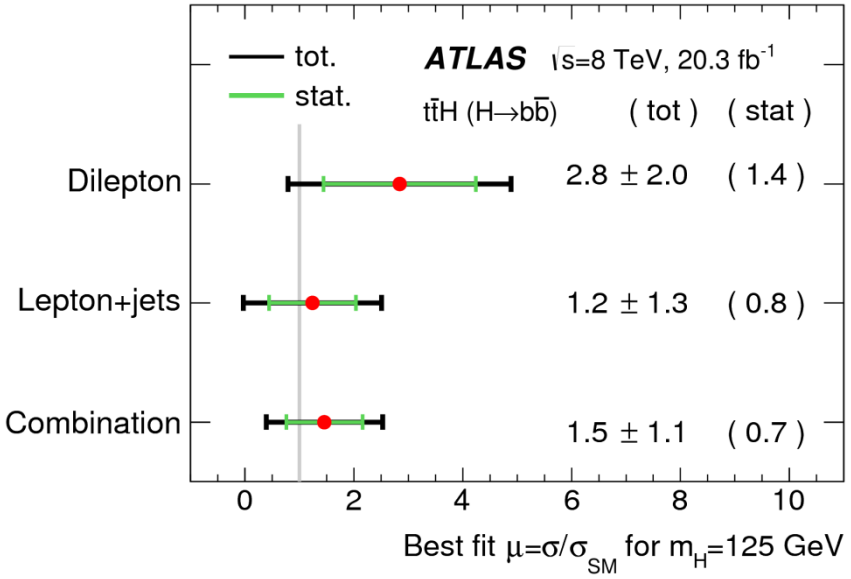
- Complicated final state (1lep+6j, 2lep+4j) and huge ttbar+X background as hard to identify the objects from top or Higgs.
- Sprit the jet-bin and n-b-tagged jet categories and use MVA analysis to maximize sensitivity.
  - 6j3b, 6j4b, 5j4b channels are signal rich regions.

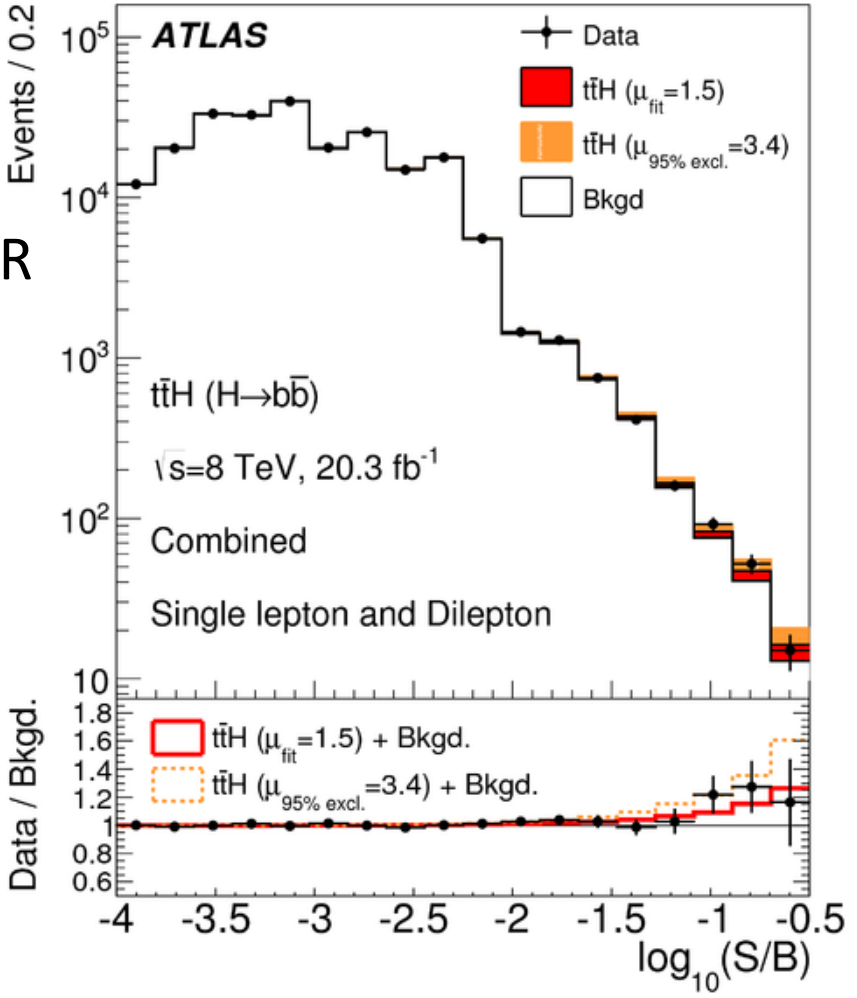




ttH,H→bb results

- No significant excess observed yet
  - Signal strength (mH=125GeV): $\mu = 1.5 \pm 0.7(\text{stat.}) \pm 0.7(\text{syst.})$
  - 95% C.L. limit : 3.4 times SM σ x BR





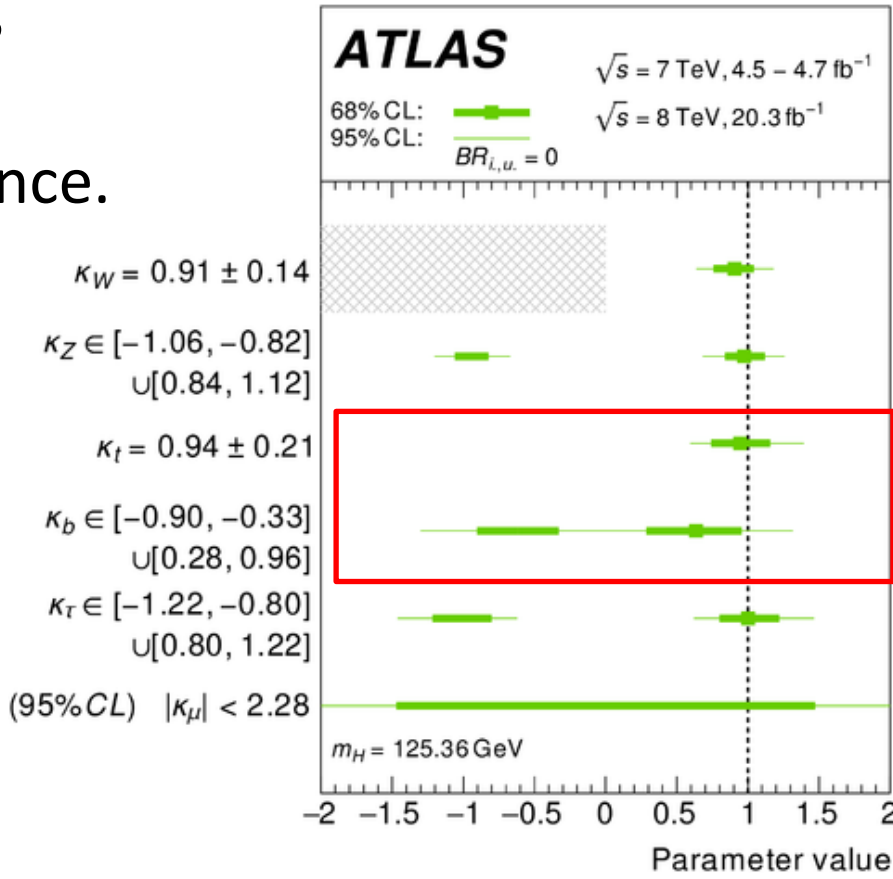
Conclusion

- All final results for Run1 was published.
  - Biggest impact is H→ττ evidence.

ATLAS 2011+2012 Full data

5fb^{-1}(7TeV)+20fb^{-1}(8TeV)

Decay channel	Expected sensitivity	Observed Sensitivity
(ggF),VBF:H→ττ	**3.4σ**	**4.5σ**
VH,H→bb	2.6σ	1.4σ
H→μμ	<7.2xSM	<7.0xSM
ttH:H→bb	<2.2xSM	<3.4xSM



For further sensitivity of fermion coupling measurement coming soon:

- Yb(H→bb) measurement in early data of Run2
- Direct Yt (ttH) measurement in Run2 data

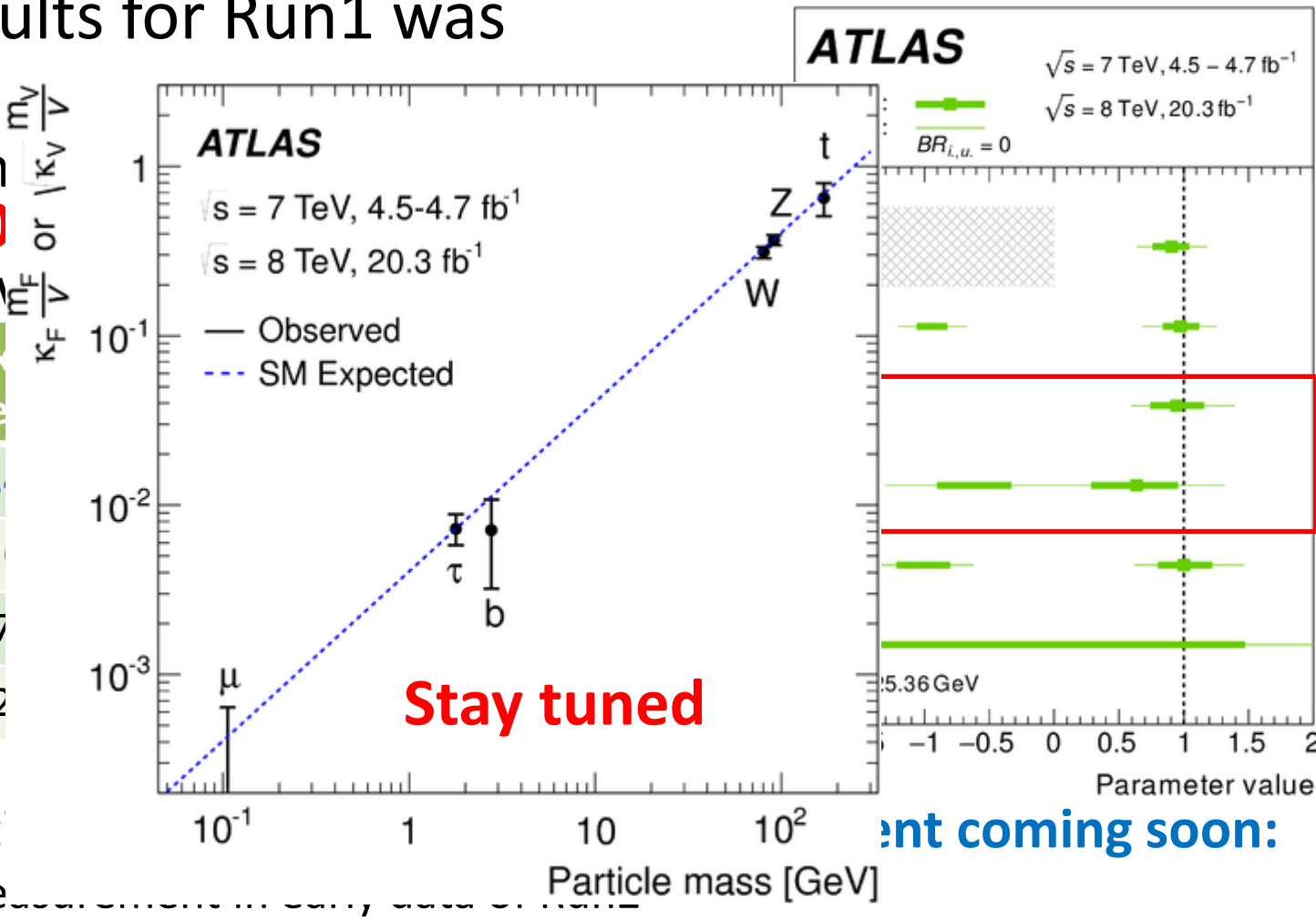
Conclusion

- All final results for Run1 was published.
  - Biggest im

ATLAS 2011+20

5fb^{-1}(7TeV)+20fb^{-1}(8Te

Decay channel	Ex se
(ggF),VBF:H→ττ	3.
VH,H→bb	2.
H→μμ	<7
ttH:H→bb	<2



For further sensit **ent coming soon:**

- Yb(H→bb) me
- Direct Yt (ttH) measurement in Run2 data

Backup