

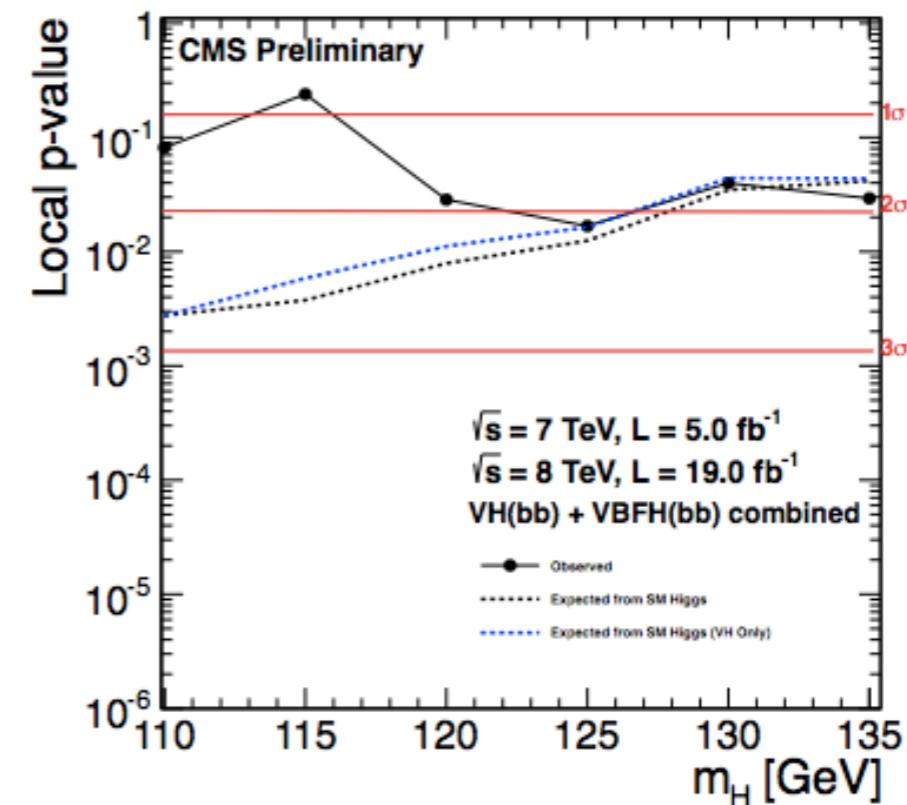
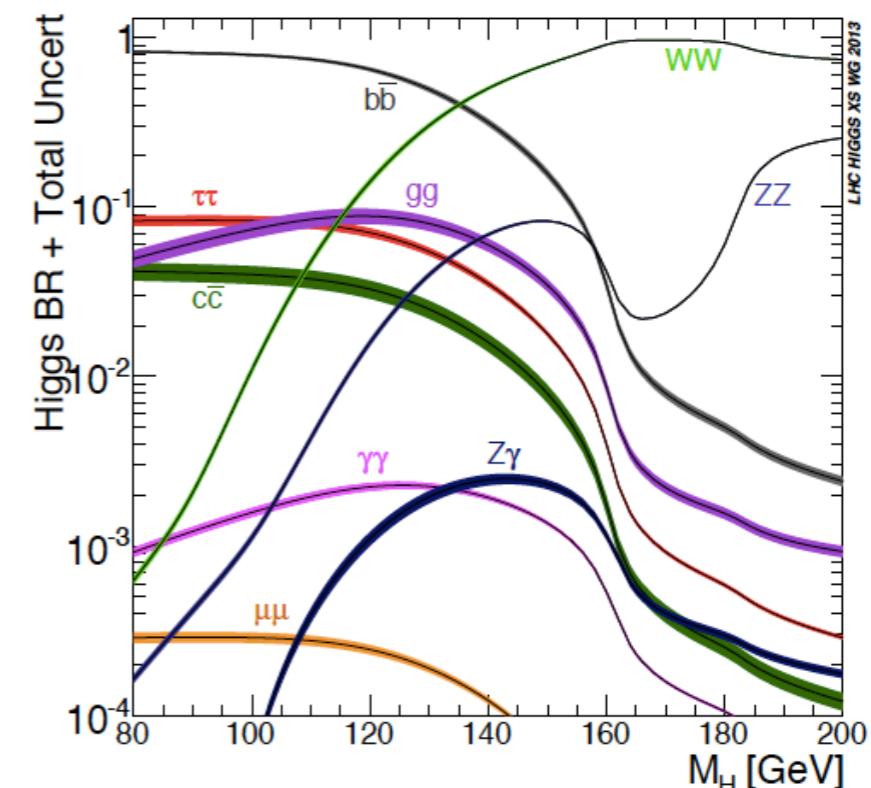
top pairs Higgs ($H \rightarrow bb$) associated production at LHC

Lorenzo Feligioni



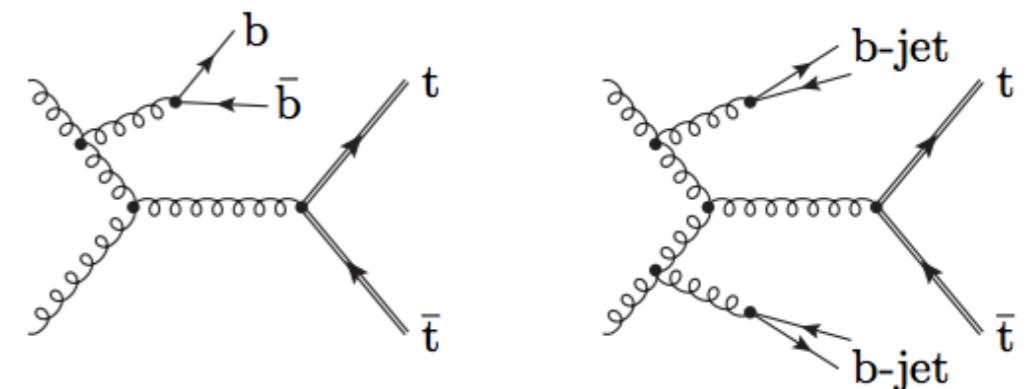
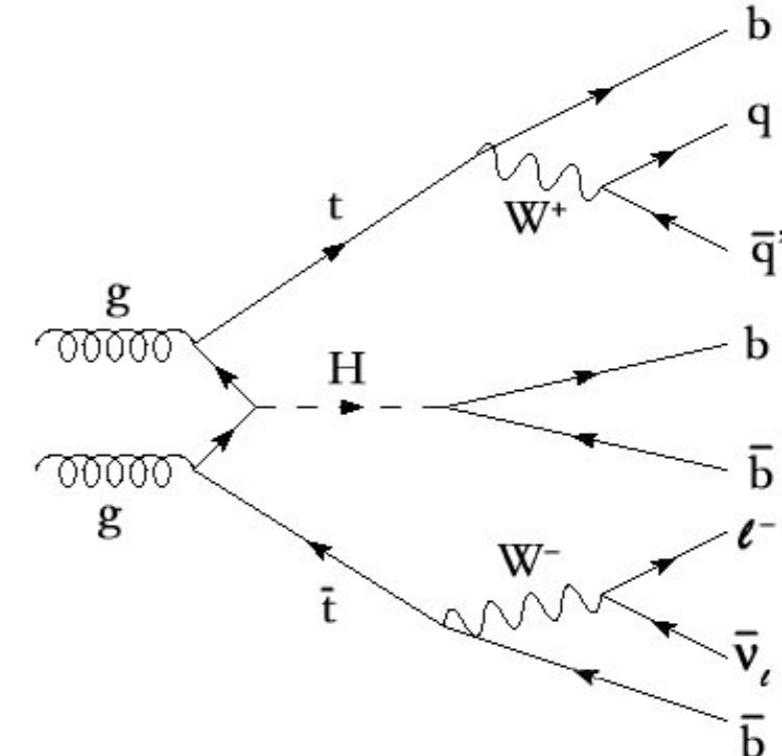
$H \rightarrow b\bar{b}$

- LHC measurements in the Higgs show impressive agreement with the SM prediction
- Boson couplings well established, fermionic sector is more difficult to investigate
 - Several analysis have been looking for signal in the most favorable disintegration channel $H \rightarrow b\bar{b}$: direct measure of down-type quark coupling
 - Backgrounds too high to probe gluon fusion $gg \rightarrow H \rightarrow b\bar{b}$, look at associated production.
 - Higgs produced in association with a vector boson
 - ATLAS for $m_H = 125$ GeV 95% C.L. upper limit on the cross section observed (expected) 1.4 (1.3) times SM cross section [ATLAS-CONF-2013-079](#)
 - CMS 1.9 (0.89) measures significance of 2.1 [Phys. Rev. D 89, 012003](#)
 - $t\bar{t}H$ extensively treated in this presentation



ttH production and signature

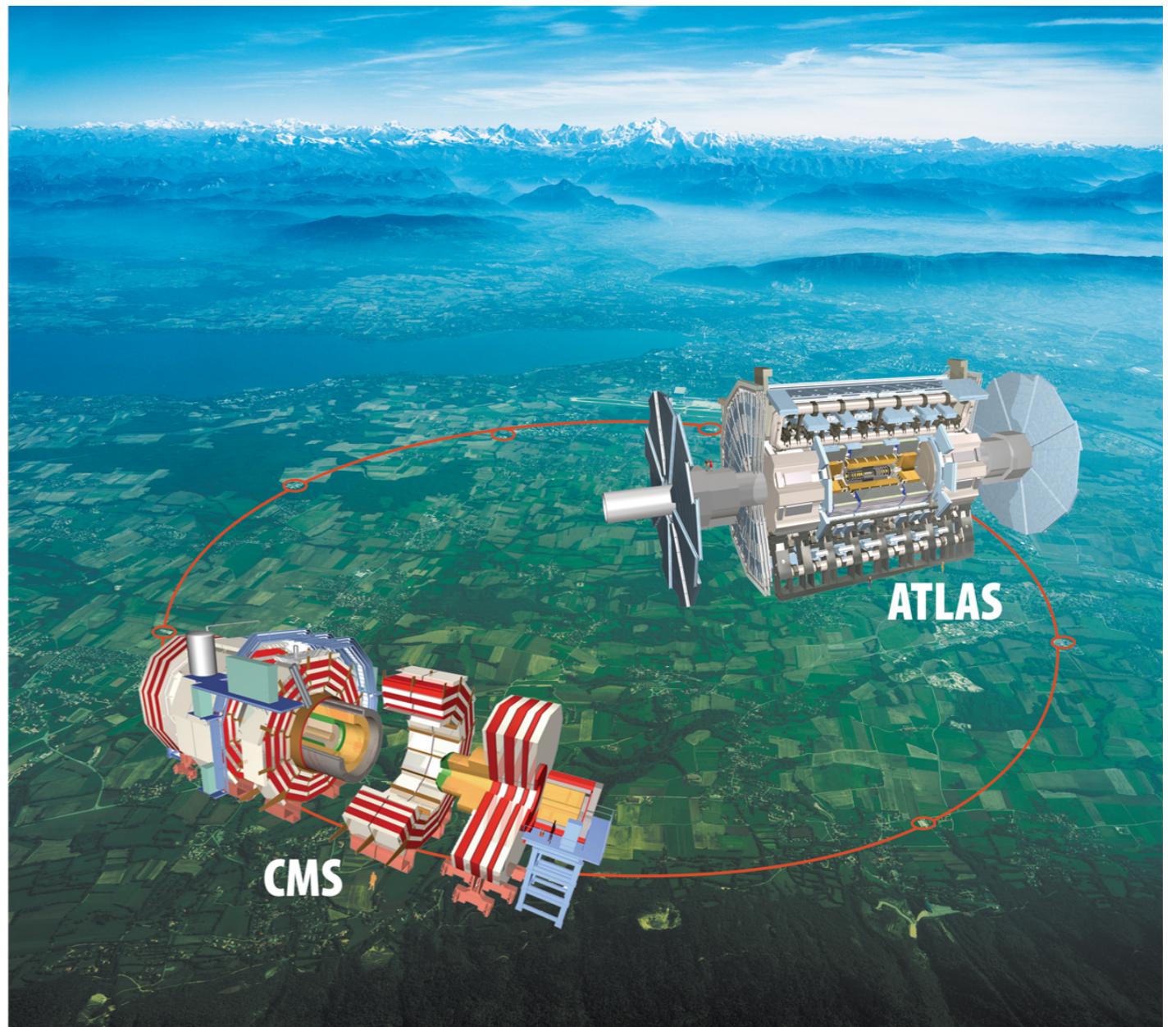
- ttH($H \rightarrow bb$) Phenomenology:
 - Distinctive final state with high jet b-jet multiplicity
 - Very busy events which are hard to reconstruct kinematically (large combinatorial background).
 - swamped in $t\bar{t}+jets$ background
- At the LHC, $\sigma(t\bar{t}H)$ known at NLO in QCD. For $m_H=125$ GeV $\sqrt{s}=8$ TeV: $\sigma(t\bar{t}H) = 130$ fb
 - Uncertainties: +3.8%/-9.3% (scale) $\pm 8.1\%$ (PDF)
 - Most rate goes to bb channel $BR(H \rightarrow bb) \sim 0.58$ for $m_H=125$ GeV
- Irreducible background $ttbb$ estimated at NLO to be $\sigma \sim 600$ fb at $\sqrt{s}=8$ TeV [arXiv:1309.5912]



ttH @ LHC

$\bar{c}s$				all-hadronic
$\bar{u}d$	electron+jets	muon+jets	tau+jets	
τ^-	$e\tau$	$\mu\tau$	$\tau\tau$	tau+jets
μ^-	$e\mu$	$\mu\tau$	$\mu\tau$	muon+jets
e^-	ee	$e\mu$	$e\tau$	electron+jets
W decay	e^+	μ^+	τ^+	$u\bar{d}$
				$c\bar{s}$

dileptons



- CMS
 - dilepton and lepton+jets final states
 - 19.5 fb^{-1} at $\sqrt{s}=8 \text{ TeV}$
 - CMS-PAS-HIG-13-019
- ATLAS
 - Lepton+jets and dilepton latest analysis uses 20.4 fb^{-1} at $\sqrt{s}=8 \text{ TeV}$
 - previously analysed 4.7 fb^{-1} at $\sqrt{s}=7 \text{ TeV}$
 - ATLAS-CONF-2014-011

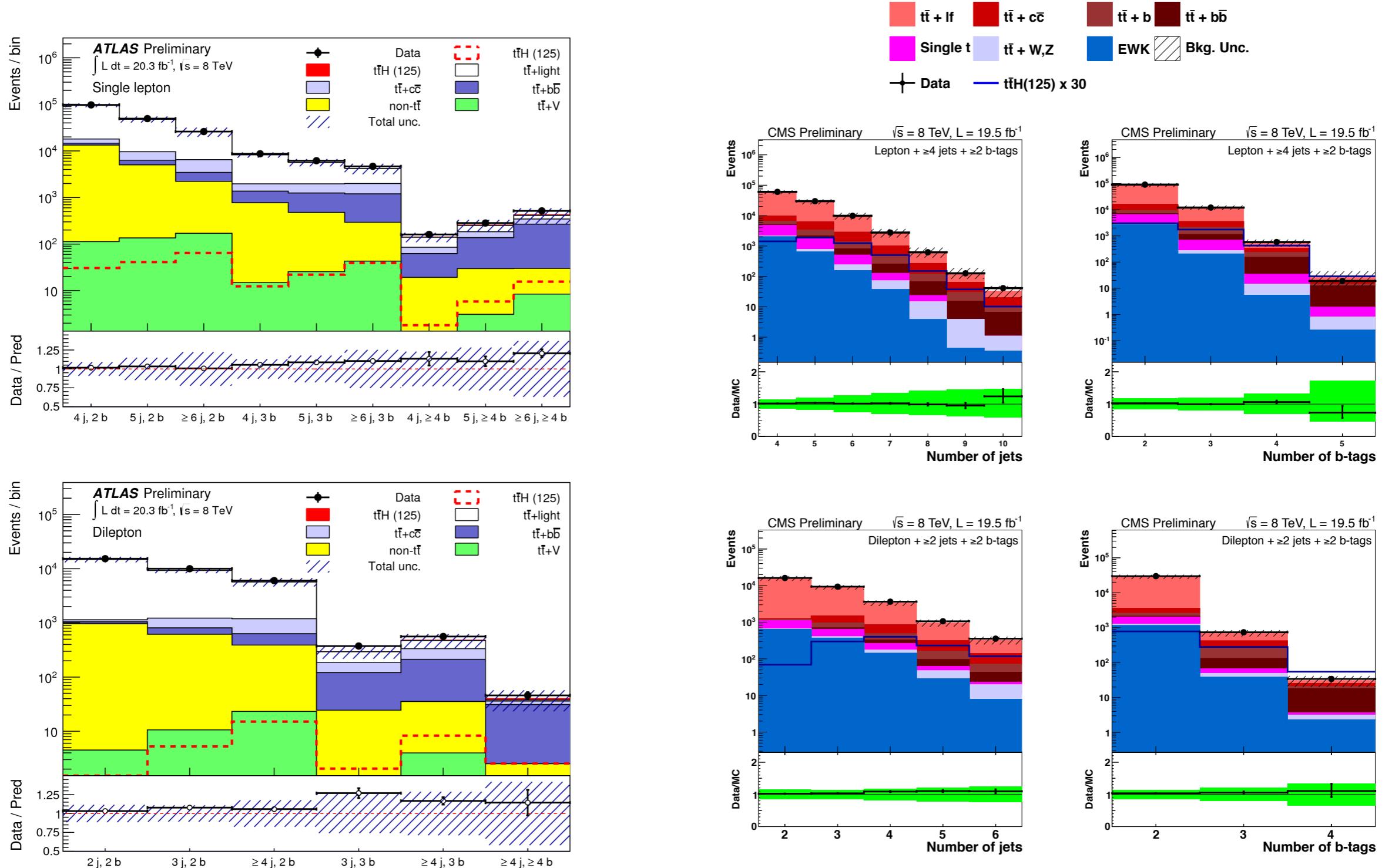
signal and background modelling

- Signal ttH:
 - PYTHIA [CMS], POWHEG [ATLAS]
- tt+jets:
 - POWHEG+PYTHIA [ATLAS] MADGRAPH+PYTHIA [CMS]
 - CMS reweighed for difference on DATA and MC top pT spectrum
 - ATLAS: reweigh for difference in tt pT and top pT
- tt+HF:
 - CMS samples is generated inclusively but then events classified according to HF content: ttbb, ttb, ttcc, ttc
 - ATLAS tt+bb compared to NLO SHERPA+OpenLoops generator
- ttW, ttZ:
 - MADGRAPH+PYTHIA [ATLAS, CMS]
- W/Z/ γ^* +jets:
 - ALPGEN+[HERWIG(Z), PYTHIA(W)] [ATLAS],MADGRAPH+PYTHIA [CMS]
- Single top:
 - POWHEG/AcerMC+PYTHIA [ATLAS], POWHEG+PYTHIA [CMS]
- Dibosons:
 - ALPGEN+HERWIG [ATLAS], PYTHIA [CMS]

preselection

- Trigger:
 - CMS trigger l+jets: μ isolated $pT > 24 \text{ GeV}$, e $pT > 27 \text{ GeV}$, dilepton 2 lepton $pT > 17$ and 8 GeV
 - ATLAS trigger : μ isolated $pT > 24 \text{ GeV}$, non isolated 36 GeV and electron isolated $pT > 24$, non isolated 36 GeV
- muons:
 - CMS: tight $|\eta| < 2.1$, tight $pT > 30 \text{ GeV}$ [$l+j$], 20 GeV [$d\ell$].
 - ATLAS: $pT > 25 \text{ GeV}$ [$l+j$], $pT 25$ and 15 GeV [$d\ell$], $|\eta| < 2.5$.
- Electrons:
 - CMS: CMS: $|\eta| < 2.5$, tight $pT > 30 \text{ GeV}$ [$l+j$], 20 GeV [$d\ell$]
 - ATLAS: $pT > 25 \text{ GeV}$ [$l+j$], $pT 25$ and 15 GeV
- hadronic jets:
 - CMS: ant-kt 0.5, $|\eta| < 2.4$, ≥ 3 jets $pT > 40 \text{ GeV}$ [$l+j$], , ≥ 2 jets $pT > 30 \text{ GeV}$ [$d\ell$].
 - b-tagging: 70% b-jet, 20% c-jet, 2% light jets
 - ATLAS: ant-kt 0.4, $|\eta| < 2.5$, $pT > 30 \text{ GeV}$.
 - b-tagging: 70% b-jet, 20% c-jet, 1% light jets

Event Yields



pre-fit yields comparison

5 jet \geq 4 b-tag **\geq 6 jet \geq 4 b-tag**

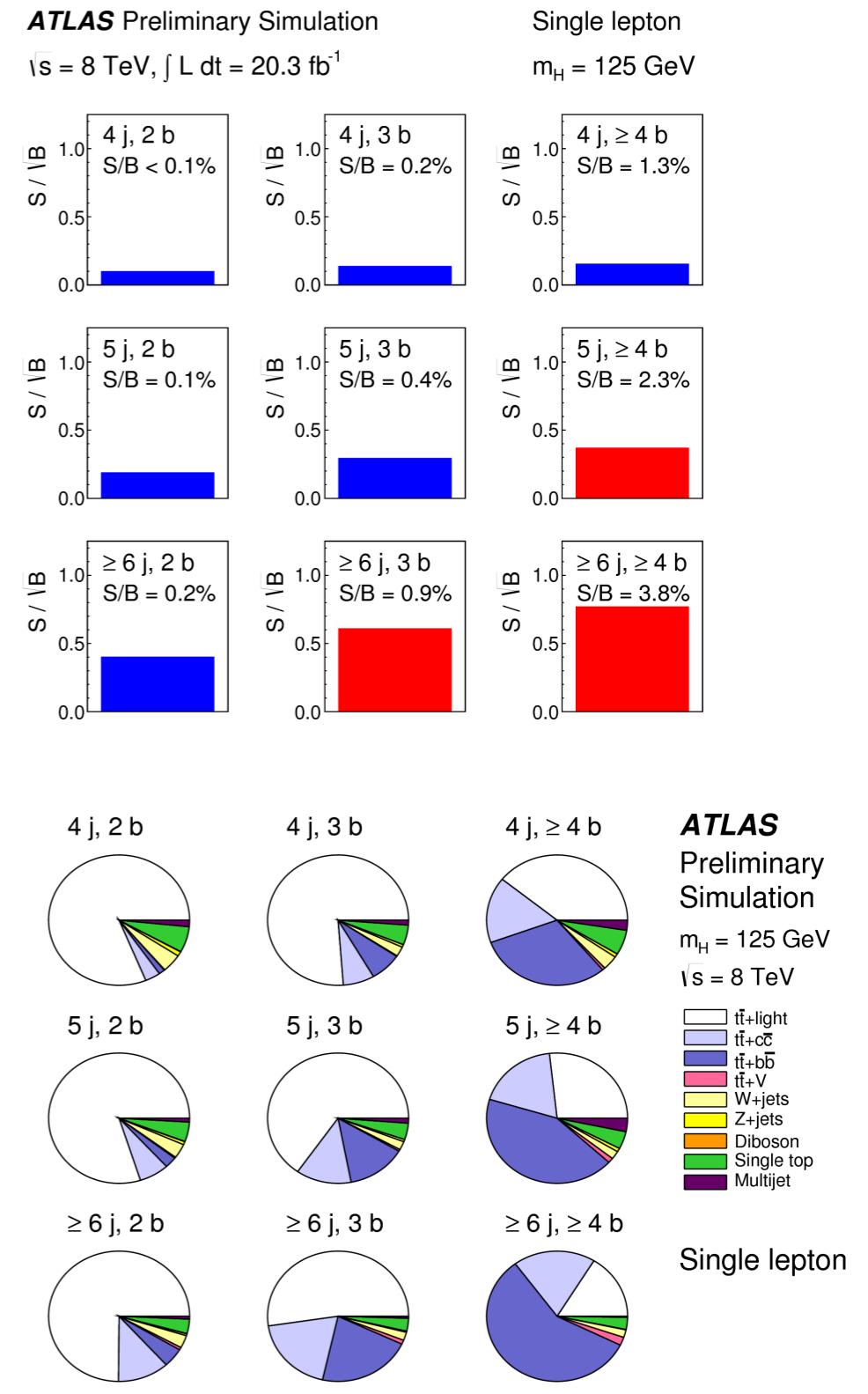
Single lepton	CMS	ATLAS	CMS	ATLAS
$t\bar{t}H$	5.3	5.8	8.3	16
$t\bar{t}+light$	79	70	71	70
$t\bar{t}+cc$	32	50	52	80
$t\bar{t}+bb$	67	110	111	200
S/B	2.7%	2.36%	3.5%	3.8%
S/\sqrt{B}	0.37	0.36	0.54	0.84

CMS **ATLAS**

dilepton	$\geq 3 j \geq 3 b$	$3 j 3 b$	$\geq 4 j 3 b$	$\geq 4 j \geq 4 b$
$t\bar{t}H$	11.2	2.0	8.3	2.5
$t\bar{t}+light$	289	105	138	1.6
$t\bar{t}+cc$	147	70	120	5
$t\bar{t}+bb$	229	100	180	29
S/B	2%	1%	2%	6%
S/\sqrt{B}	0.43	0.12	0.39	0.40

Analysis Strategy

- Analysis separates events according to jet and b-jet multiplicity
- Multivariate techniques used to discriminate signal and background
- Some regions have low sensitivity but can be combined in the fit to constrain systematics
 - Low jet multiplicity: large tt contribution used to constrain normalisation
 - High jet multiplicity: large tt+jets contribution used to constrain modelling of additional jets
 - 3 b-tag region: large contribution of c-jets tagged as b, used to constrain c-tagging
 - high b-tag multiplicity: use constrain relative contribution of tt+light from tt+HF



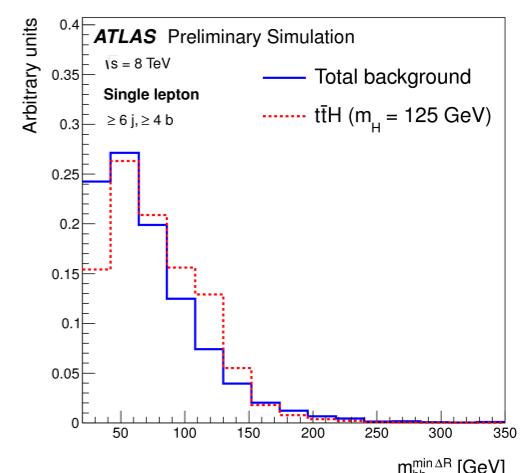
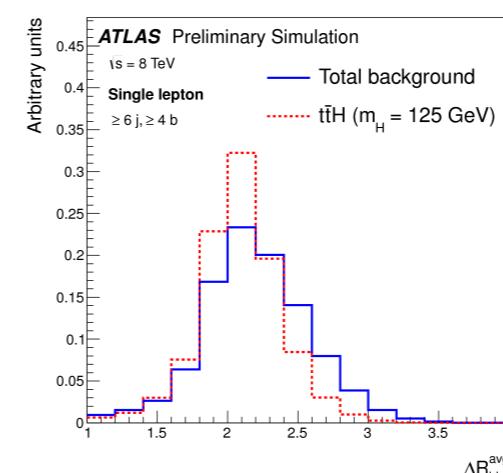
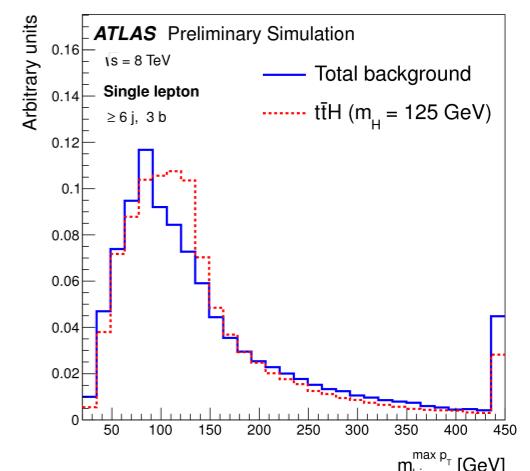
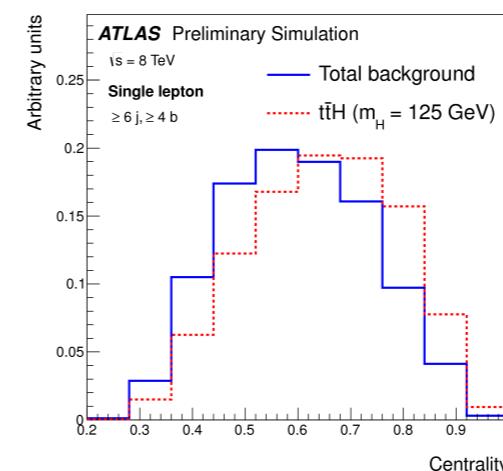
signal vs background discrimination

	2 b-tags	3 b-tags	≥ 4 b-tags
4 jets	H	H	H _{Thad}
5 jets	H	NN	NN
≥ 6 jets	H	NN	NN

	2 b-tags	3 b-tags	≥ 4 b-tags
2 jets	H		
3 jets	H	NN	
≥ 4 jets	H	NN	NN

- NN uses 10 discriminating variables

- object kinematics, global event variables, event shape, object pair properties
- no attempt to perform a kinematic reconstruction of the ttH system: low purity of algorithms given high combinatorics
- HT is used to be sensitive to tt+jets modelling

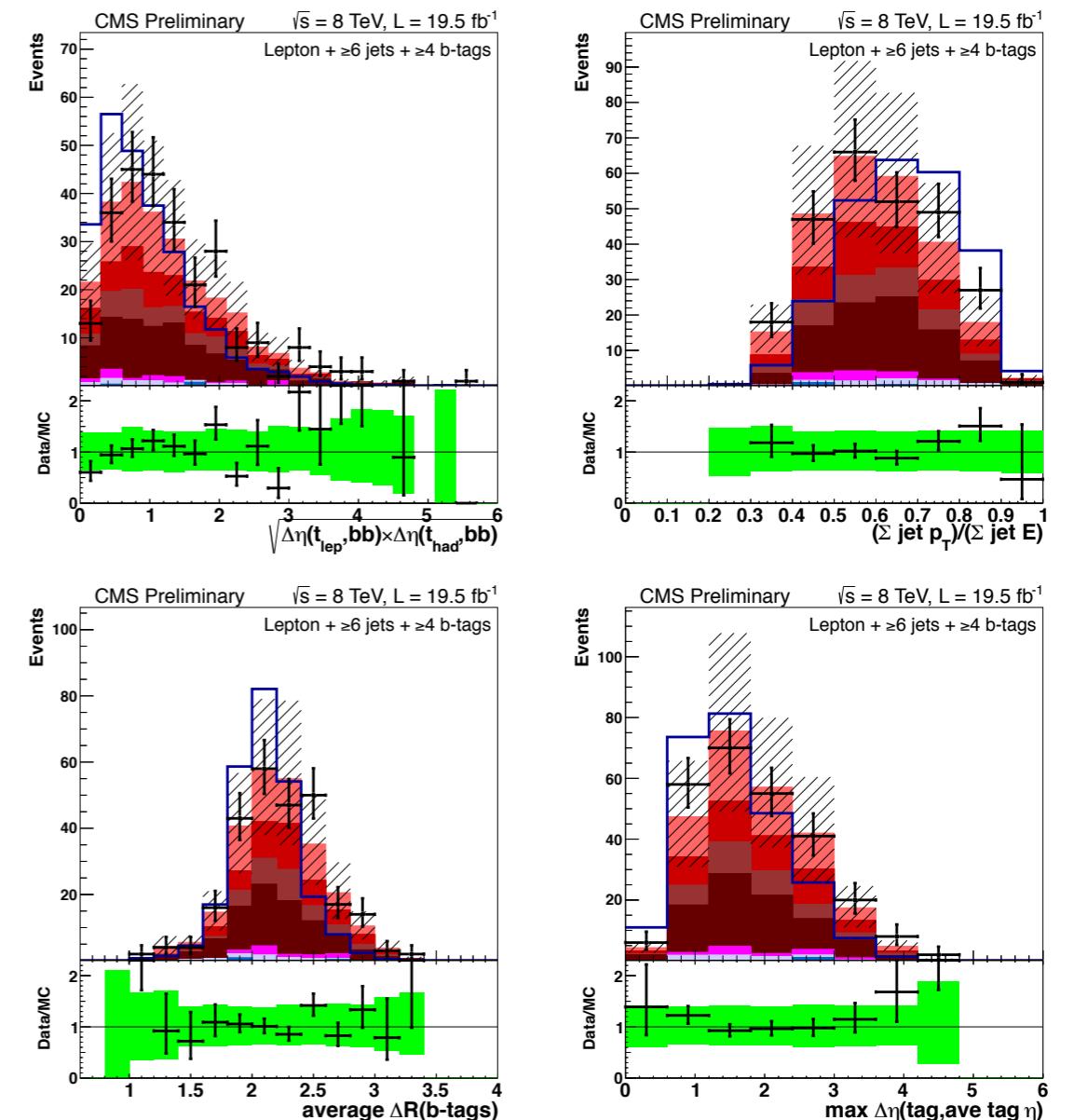


signal vs background discrimination

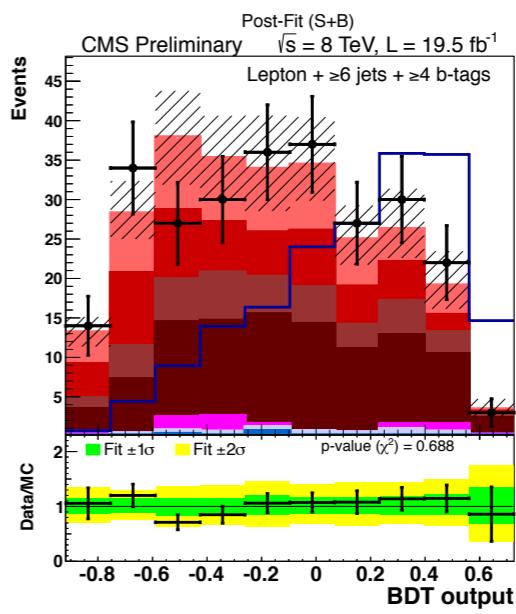
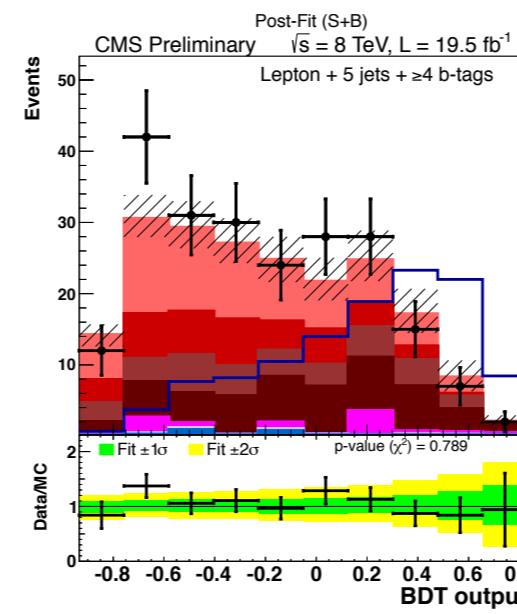
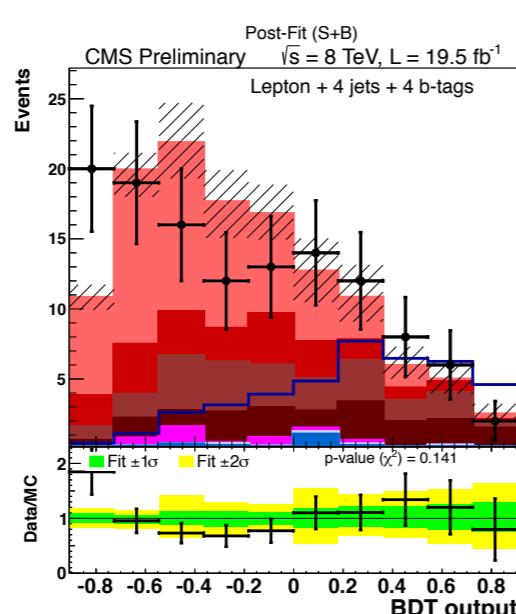
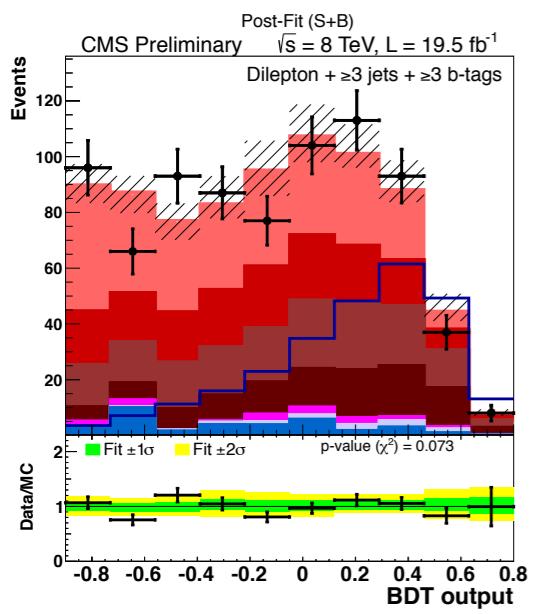
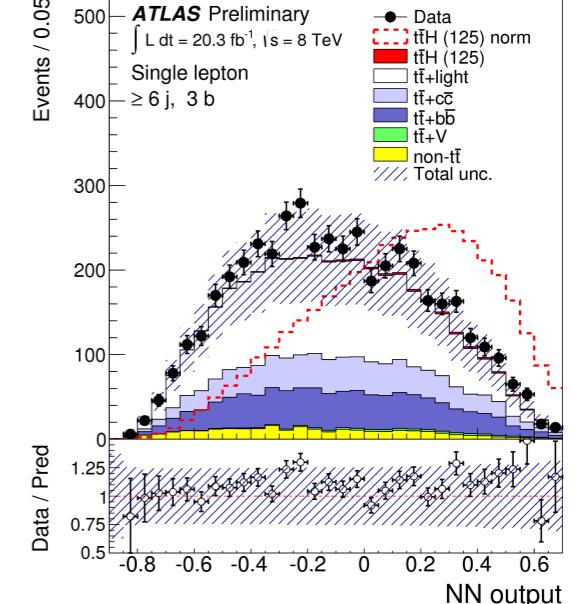
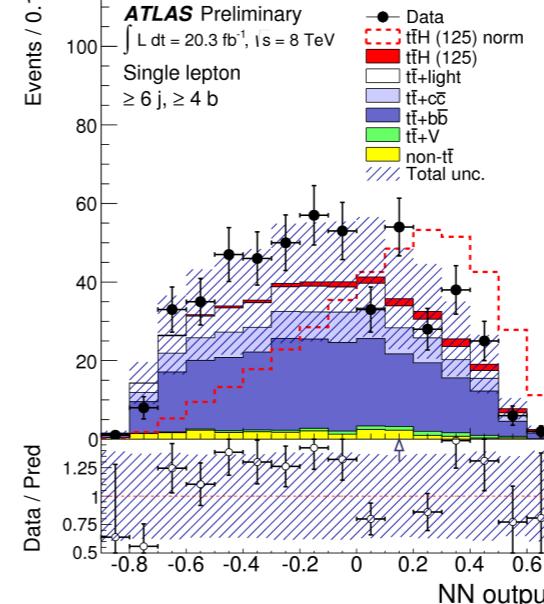
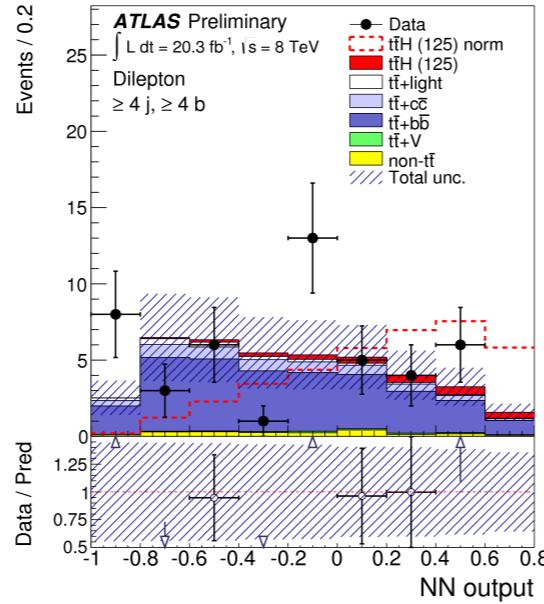
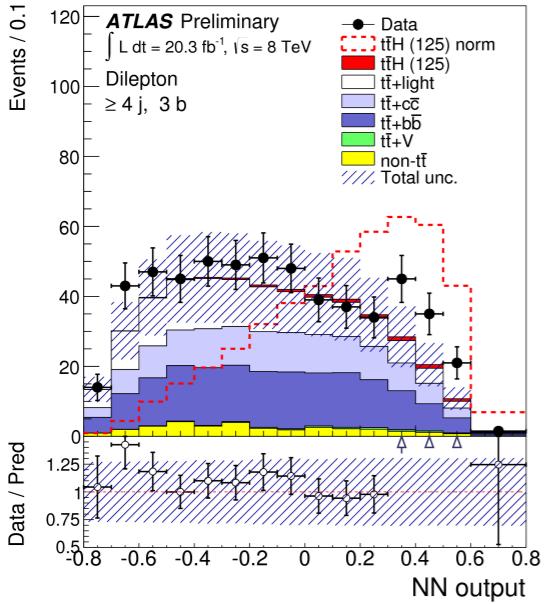
	2 b-tags	3 b-tags	≥ 4 b-tags
4 jets		BDT	BDT
5 jets		BDT	BDT
≥ 6 jets	BDT	BDT	BDT

	2 b-tags	≥ 3 b-tags
3 jets	BDT	
≥ 4 jets	BDT	
≥ 3 jets		BDT

- BDT used to improve sensitivity in all channels
 - different number of variables in different categories
 - b-tagging weight distribution used as input
- Most sensitive regions in the lepton+jets channel uses as input variable a separately trained “ttbb/ttH BDT”
 - 10 to 15 variables are used for this BDT
- For events with high jet multiplicity where it is possible to reconstruct the full event a mass chi2 algorithm select jets associated to the top
 - the two highest pT leftover jets are used to form the “best Higgs boson mass”



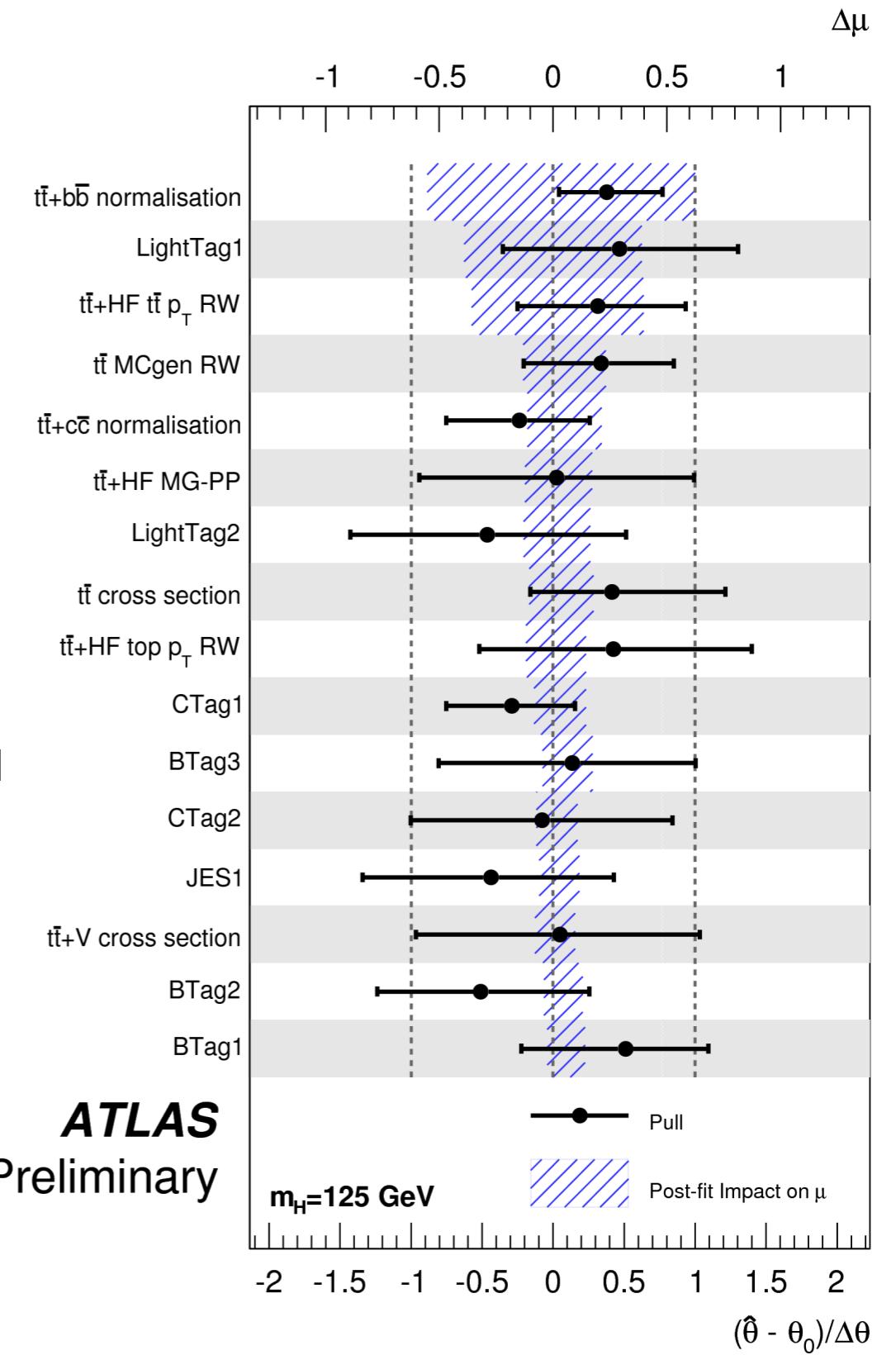
discriminant variables pre-fit



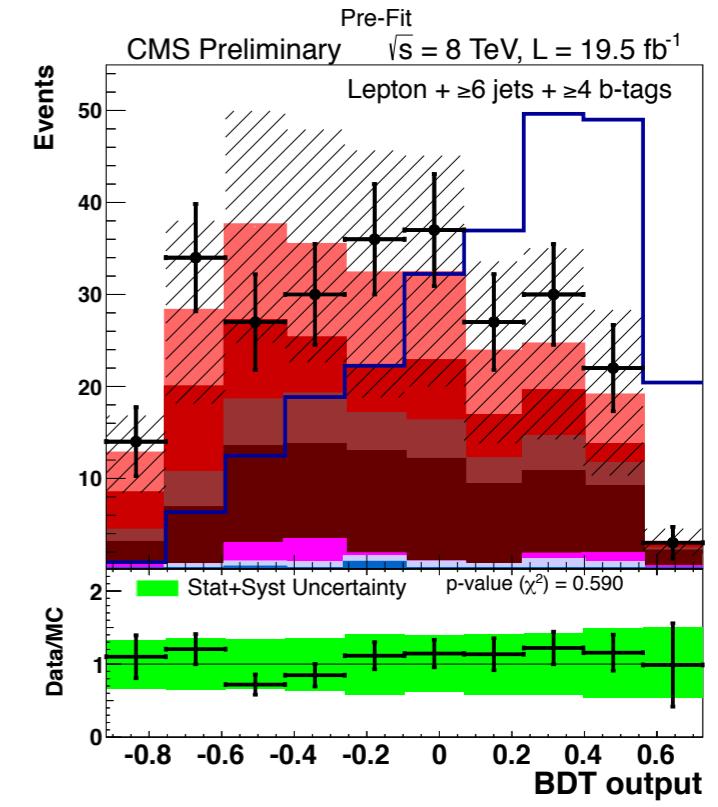
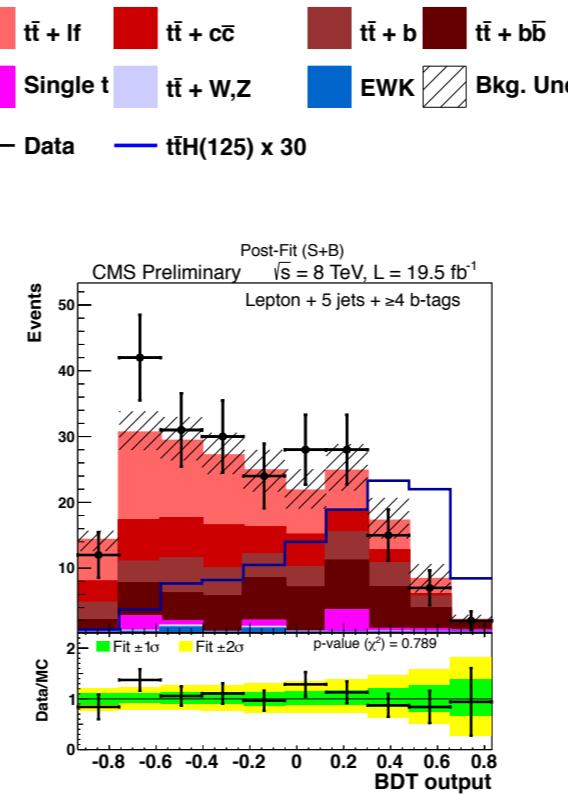
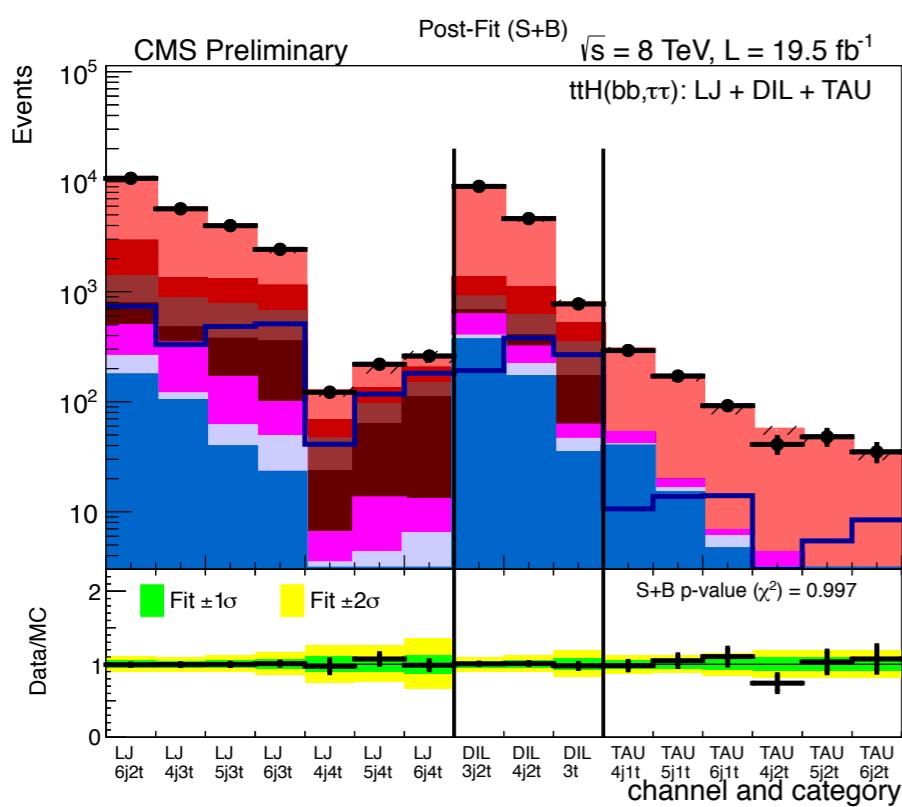
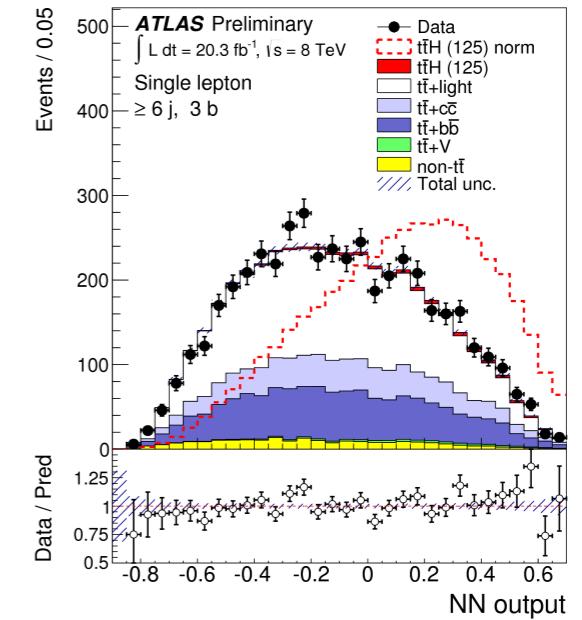
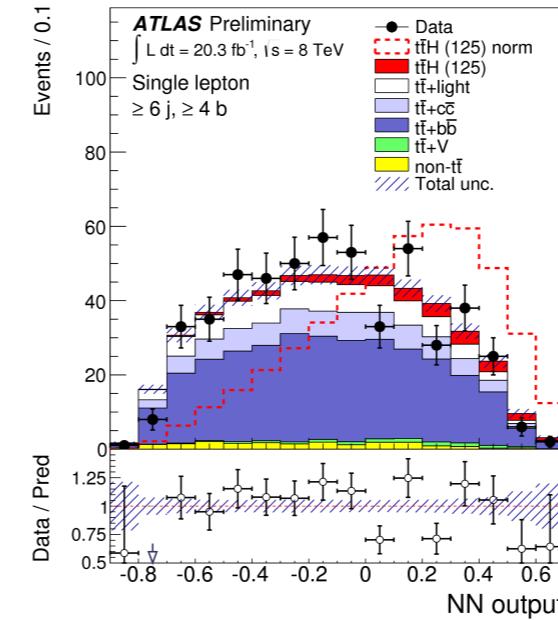
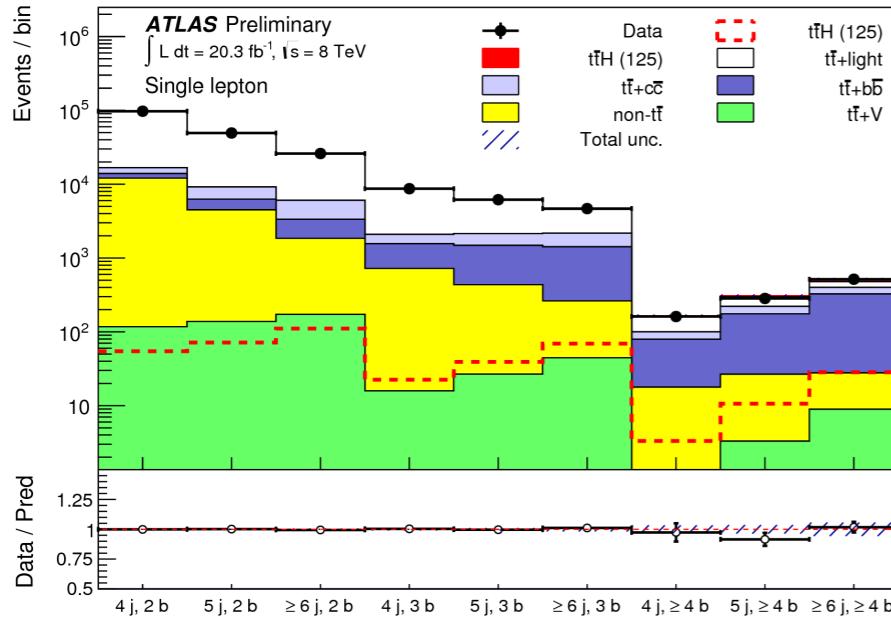
- A set of nuisance parameters that encode the effect of the large systematic uncertainties are implemented within the fit to extract the ttH limits

systematic uncertainties

- Jet energy scale:
 - ATLAS split 22 uncorrelated components
- b-tagging
 - ATLAS: b/c/light tagging (split into 6/6/12 uncorrelated components)
 - CMS: use full spectrum and consider shape distortion
- top pT reweighing
 - ATLAS: 9 leading systematic uncertainties from differential cross-section measurement of top pT and tt pT
 - CMS: doubling or removing the correction applied
- HF normalisation
 - CMS: 50% on tt+ bb, 50% on tt+ b, 50% on tt+ cc and additional 50% on tt +HF
 - ATLAS: 50% on tt+ bb, 50% on tt+ cc

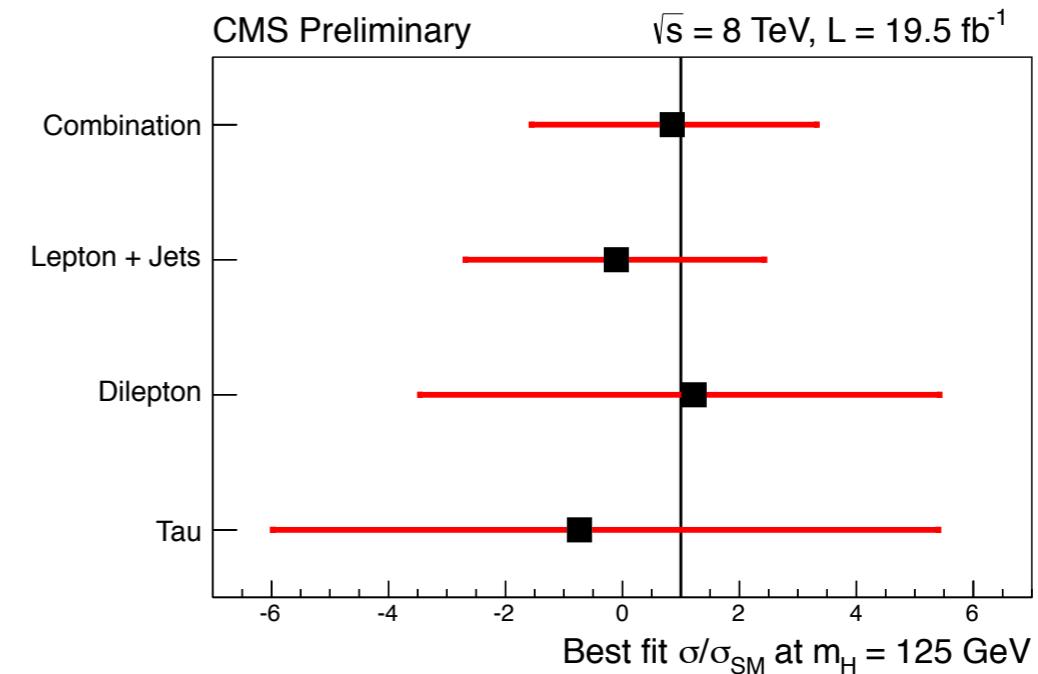
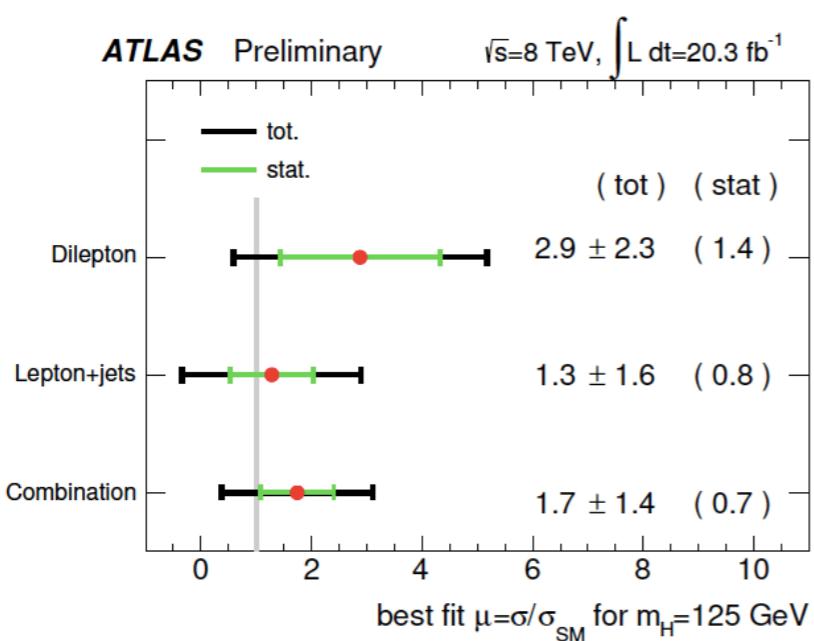
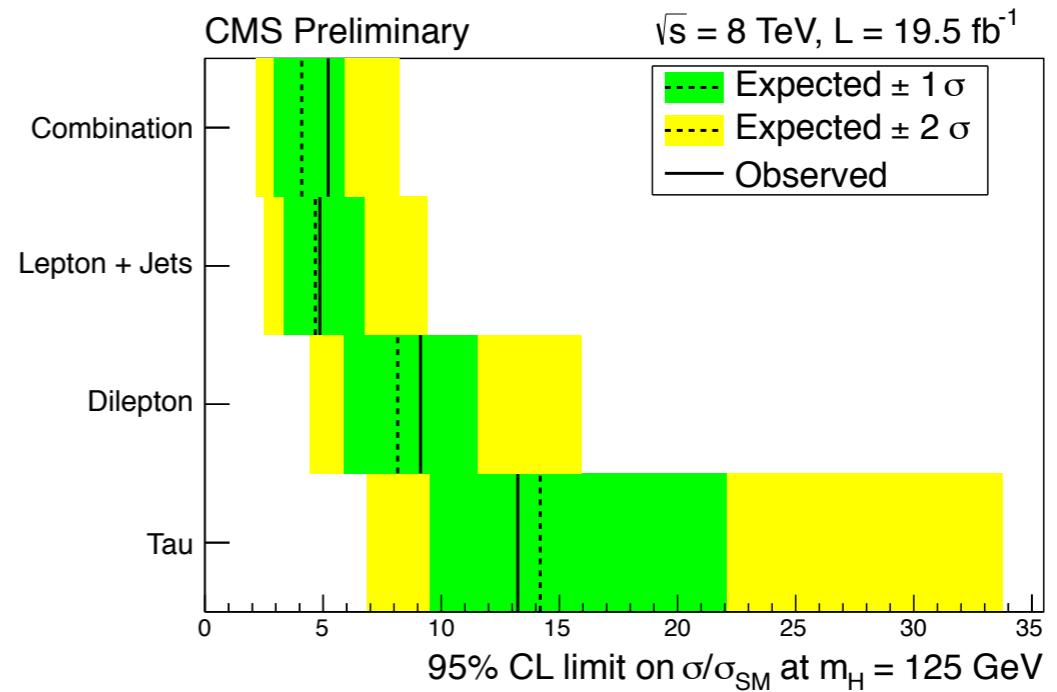
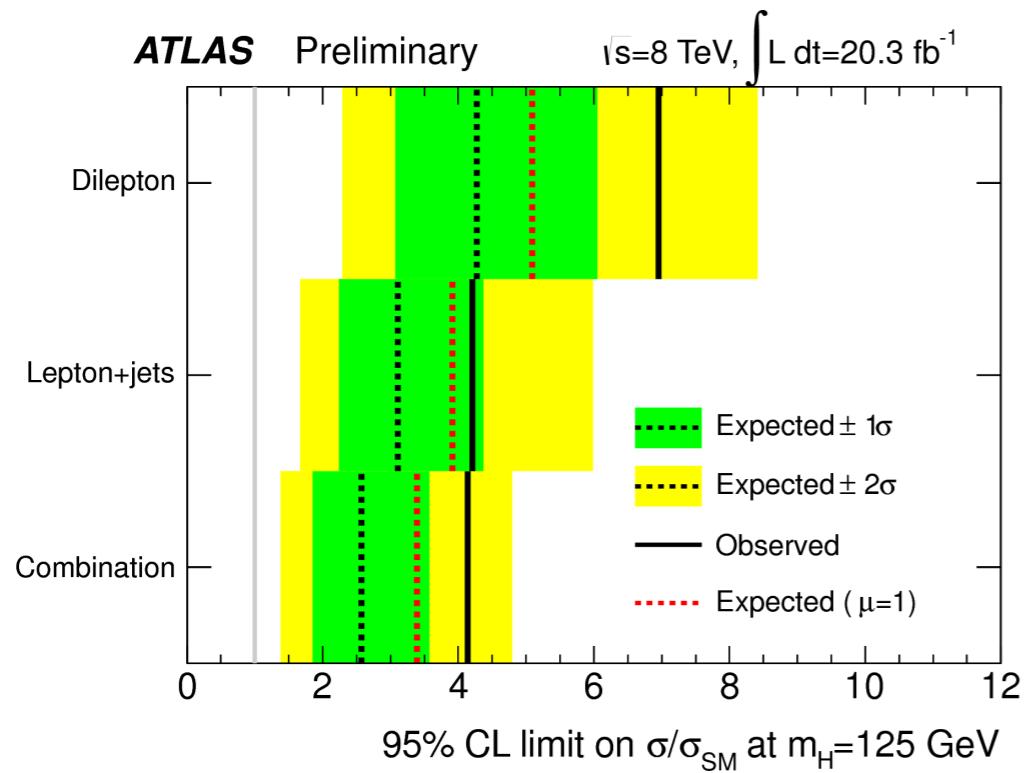


discriminant variables post-fit



- combined fit under signal plus background hypothesis, background normalised to the best fit value of all nuisance parameters and uncertainties are bands are constructed using post fit nuisance parameters

results



- ATLAS: 95% CL observed (expected) limit: $4.1 \times \text{SM}$ ($2.6 \times \text{SM}$), best $\mu=1.7 \pm 1.4$
- CMS: 95% CL observed (expected) limit: $5.2 \times \text{SM}$ ($4.1 \times \text{SM}$), best $\mu=0.85^{+2.47}_{-2.41}$

conclusions

- ATLAS and CMS searched for $t\bar{t}H(H \rightarrow b\bar{b})$ in their 2012 dataset at $\sqrt{s}=8$ TeV
 - approaching SM sensitivity with the latest ATLAS results showing an expected limit on the $t\bar{t}H$ cross section of 2.6 SM
 - Analyses are still limited by statistics
 - Main sources of systematics are due to the modelling of $t\bar{t}$ + jets and $t\bar{t}+HF$.
 - for the latest it is crucial to have high statistics control sample to check the distributions and constrain the normalisation
- Combination of the full $t\bar{t}H$ program
 - CMS already combined bb , $\gamma\gamma$, $\tau\tau$, 2 and 3 leptons
 - 95% CL observed (expected) limit: $4.3 \times SM$ ($1.8 \times SM$), best $\mu=2.5^{+1.1}_{-1.0}$

