$t\bar{t}H(H\rightarrow b\bar{b})$, ATLAS+CMS Results and Prospects

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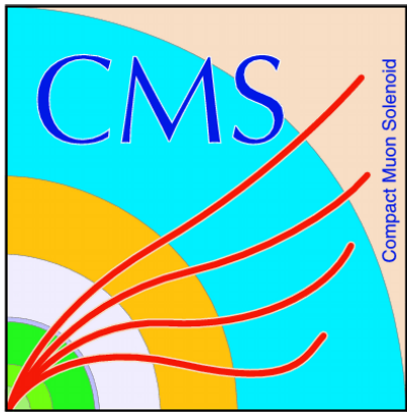
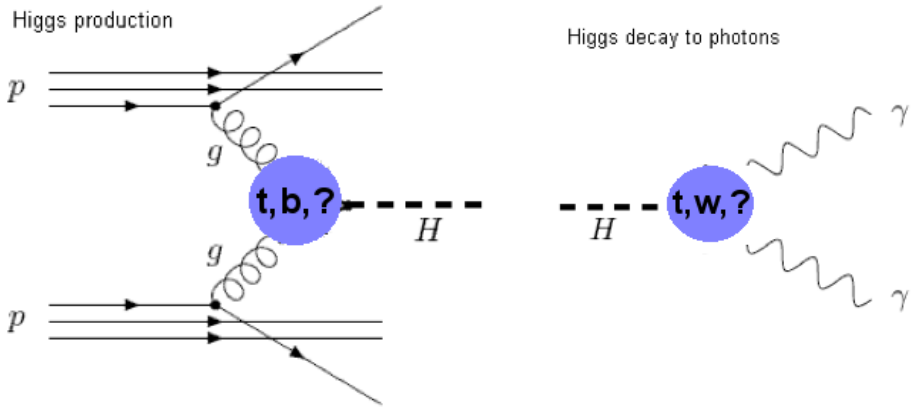


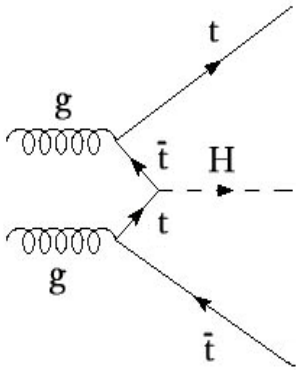
Motivation

- Top quark has large Yukawa coupling to the Higgs ($Y_t \sim 1$) in the SM

  - **Indirect constrain on the top Yukawa coupling Y_t**
    - measurements of the Higgs boson productions via gluon fusion are consistent with SM within experimental uncertainties

  - **Direct measurement of Y_t in ttH production**
    - A measurement of the rate of ttH production provides a direct test of this coupling



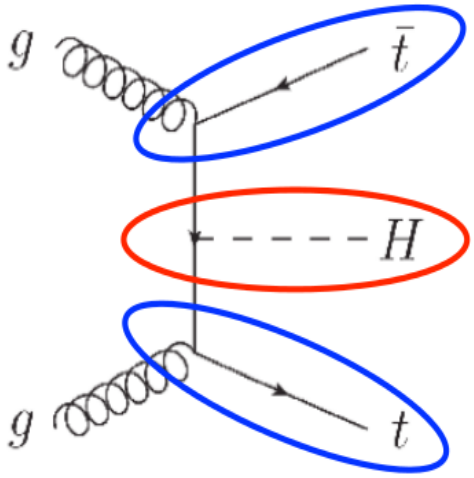


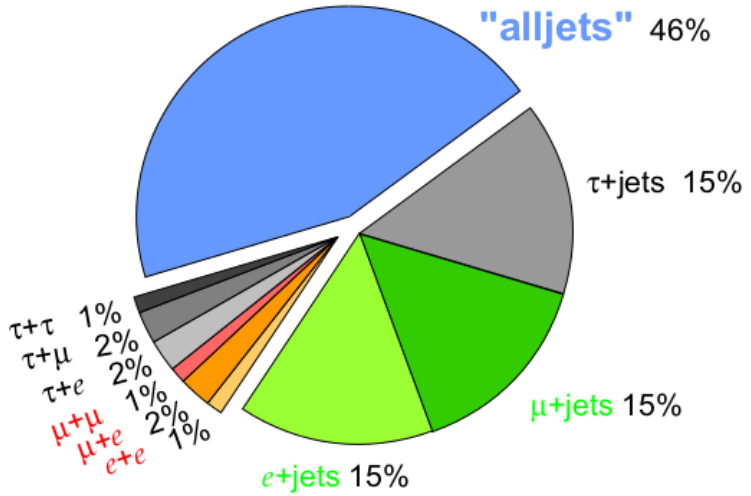
$$\sigma(ttH) \propto g^2_{ttH}$$

- Precision measurements of the Higgs coupling to the top and bottom quark is a major goal for precision physics in the scalar sector.

ttH(H→bb)

- **Higgs boson decay :**
  BR(H→bb) = 0.58, dominant mode
  but large background.
- **tt decay :**
  - **all jets (full hadronic) :** large BR but large background
  - **lepton+jets :** exploit lepton for triggering/ background reduction.
  - **di-lepton :** small BR, relatively small background.
- **Background** processes to consider :
  tt+light, tt+cc, tt+bb, tt+V, single top, W+jets, Z+jets, Diboson, Multi-jet.
  - tt+HF dominant background, very important for this analysis.
- Need sophisticated **MVA techniques** to separate ttH signal





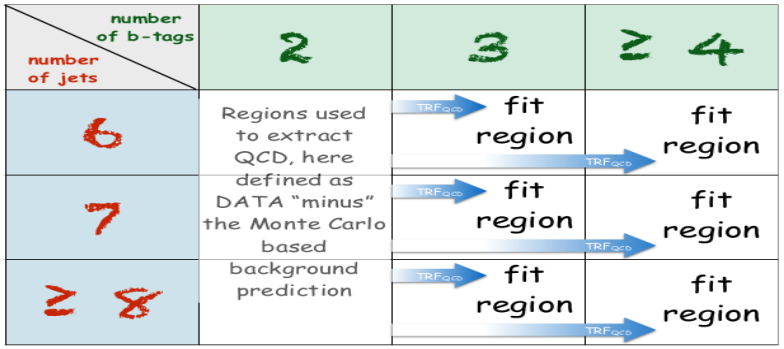
"di-leptop"

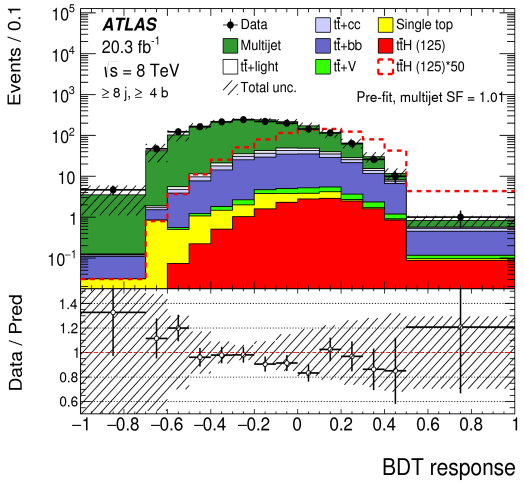
"lepton+jets"

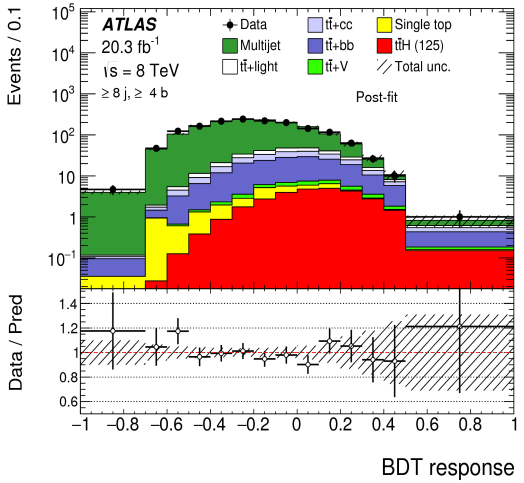
ATLAS – Run 1 : ttH(H→bb) all hadronic

CERN-EP-2016-058

- **Event Classification :**
  - two control regions (6j,3b), (6j, ≥4b) and four signal regions (7j, 3b), (7j, ≥4b), (≥8j, 3b) and (≥8j, ≥4b)
- **Multi-jet largest background**
  - Using Data-driven method to estimate it.
  - Defined in the exclusively 2 b-tagged jets region as the difference between data and the known simulated background.
  - Then propagated to the higher b-tag multiplicity regions using TRF_{MJ}
- **Signal separation :** BDT method
- **Results :**
  - signal strength : μ = 1.6 ± 2.6
  - At 95% CL for m_H =125GeV : **observed σ*BR/(σ*BR)$_{SM}$ < 6.4**
    expected σ*BR/(σ*BR)$_{SM}$ < 5.4







Run 1 : ttH(H→bb) overview

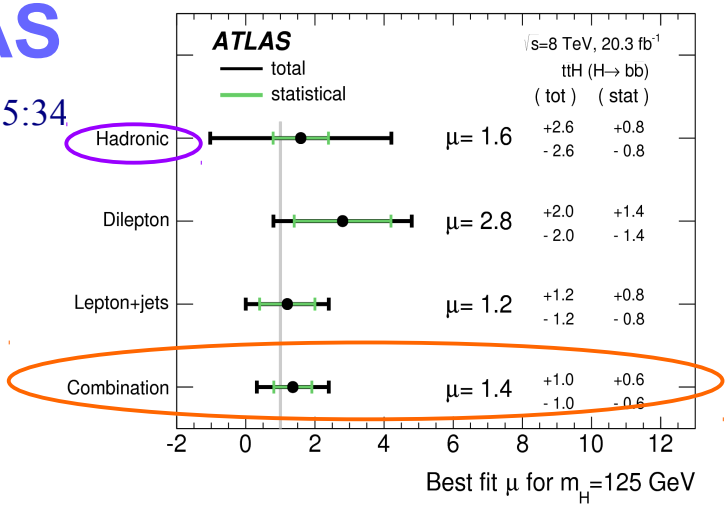
- No significant excess of events above the background expectation.

ATLAS

Eur. Phys. J. C (2015) 75:34

CERN-EP-2016-058
(submit to JHEP)
Include full **hadronic** channel

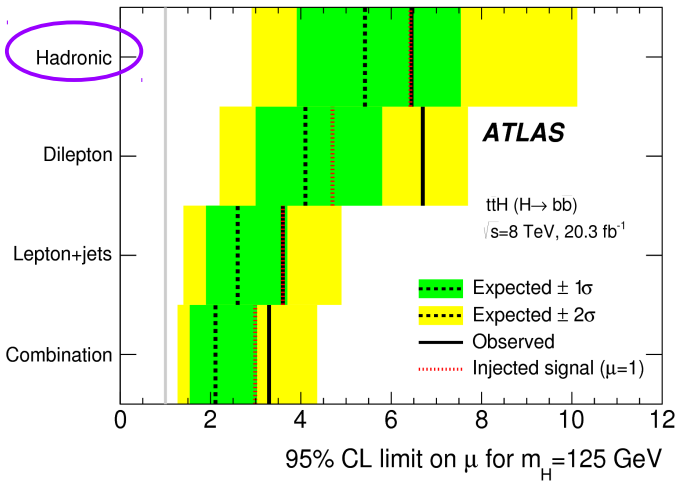
Best-fit value of the signal strength



Set limits at 95% CL for m_H =125GeV :

observed $\sigma^*BR/(\sigma^*BR)_{SM}$ < 3.1

expected $\sigma^*BR/(\sigma^*BR)_{SM}$ < 2.4

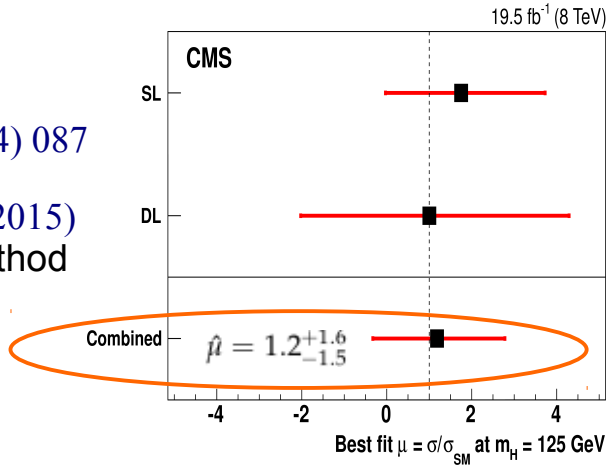


CMS

J. High Energy Phys. 09 (2014) 087

CMS-HIG-14-010EPJ C 75 (2015)
Using a matrix element method

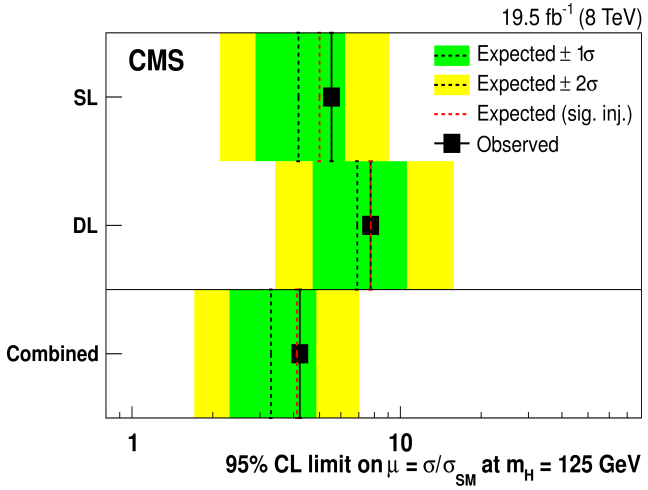
Best-fit value of the signal strength



Set limits at 95% CL for m_H =125GeV :

observed $\sigma^*BR/(\sigma^*BR)_{SM}$ < 4.2

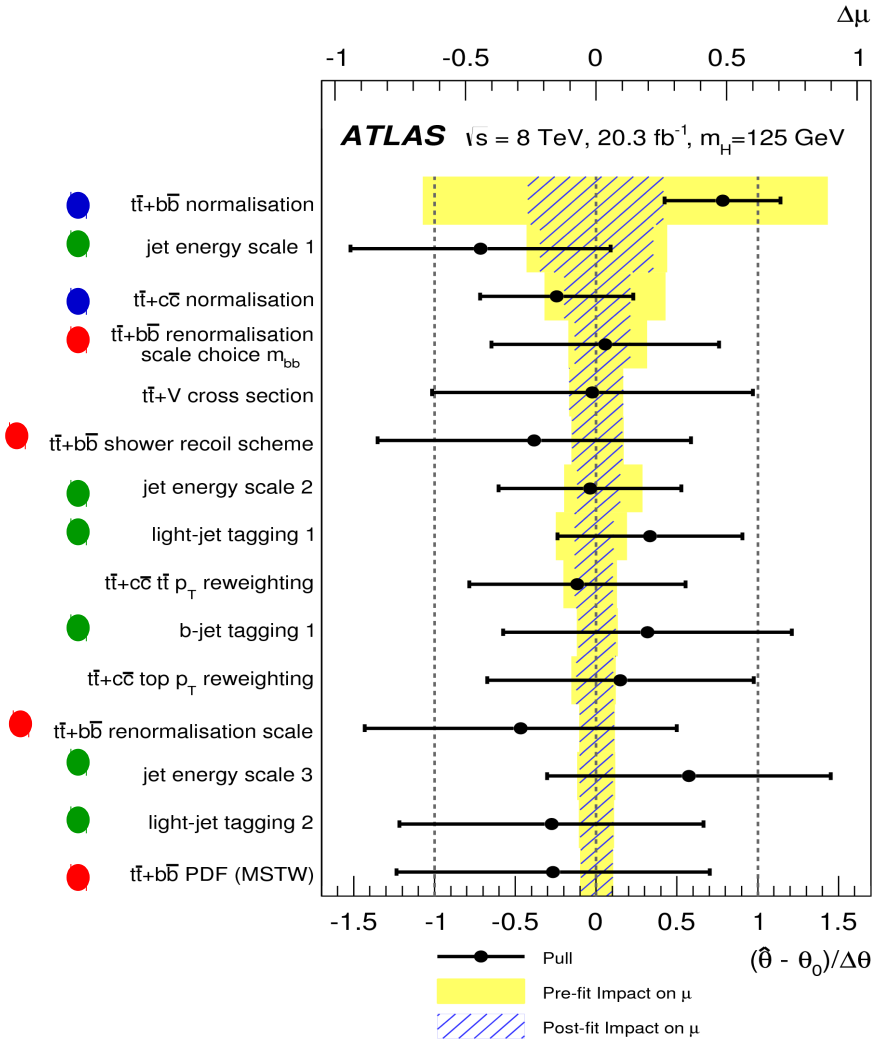
expected $\sigma^*BR/(\sigma^*BR)_{SM}$ < 3.3



Run 1 : ttH(H→bb) overview

- Analysis dominated by systematic uncertainties :

ATLAS



CMS

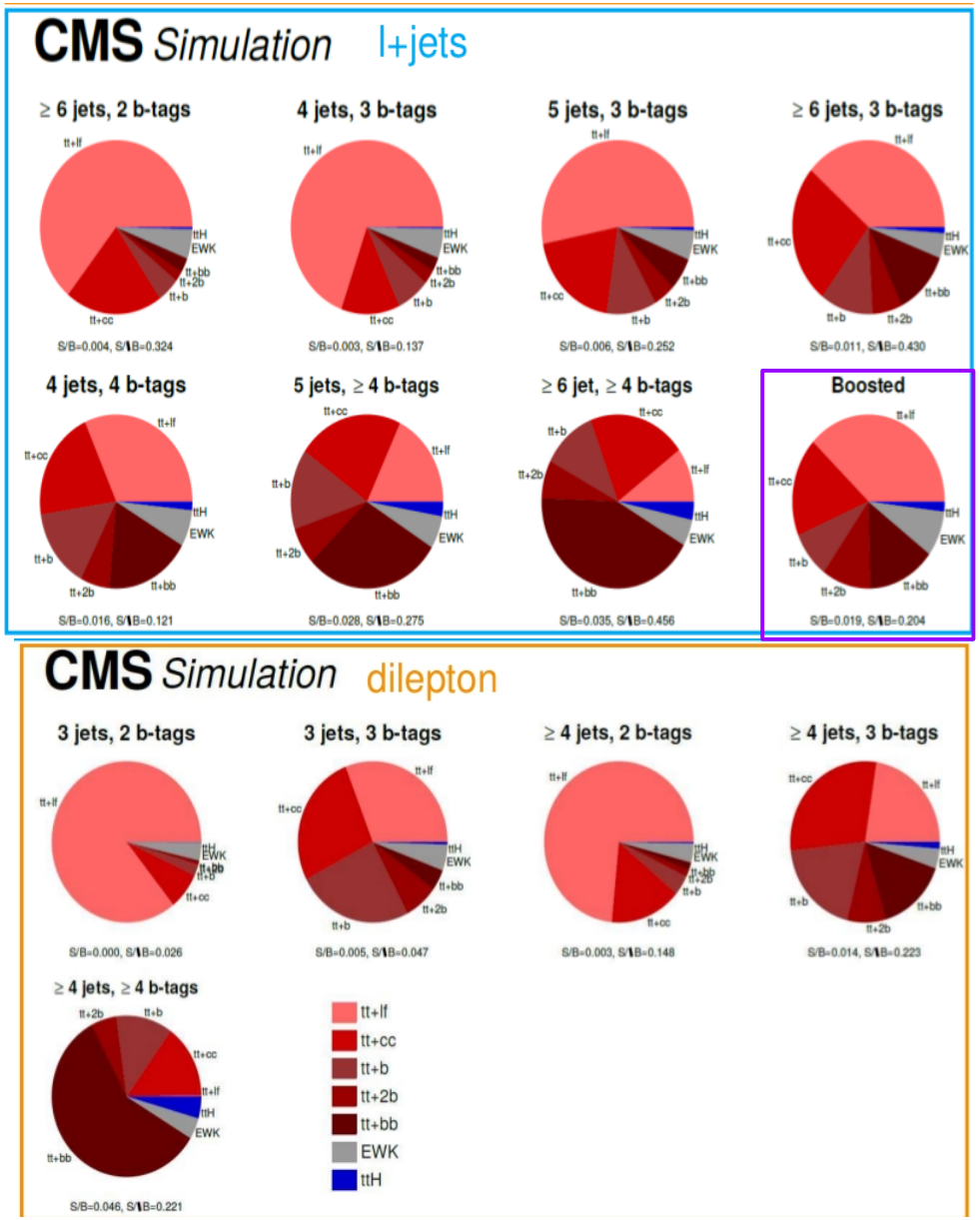
- Large pre-fit normalization uncertainties to the different tt+jets processes

Source	Rate uncertainty	Shape	Process		
			ttH	tt+jets	Others
Experimental uncertainties					
Integrated luminosity	2.6%	No	✓	✓	✓
Trigger and lepton identification	2–4%	No	✓	✓	✓
JES	4–13%	Yes	✓	✓	✓
JER	0.5–2%	Yes	✓	✓	✓
b tagging	2–17%	Yes	✓	✓	✓
Theoretical uncertainties					
Top p_T modelling	3–8%	Yes		✓	
μ_R/μ_F variations	2–25%	Yes		✓	
tt̄+bb̄ normalisation	50%	No		✓	
tt̄+b normalisation	50%	No		✓	
tt̄+cc̄ normalisation	50%	No		✓	
Signal cross section	7%	No	✓		
Background cross sections	2–20%	No		✓	✓
PDF	3–9%	No	✓	✓	✓
Statistical uncertainty (bin-by-bin)	4–30%	Yes	✓	✓	✓

- **normalisation of tt+bb̄ /tt+cc events, tt+bb̄ modelling,** detector effects (jet energy scale,flavour tagging)

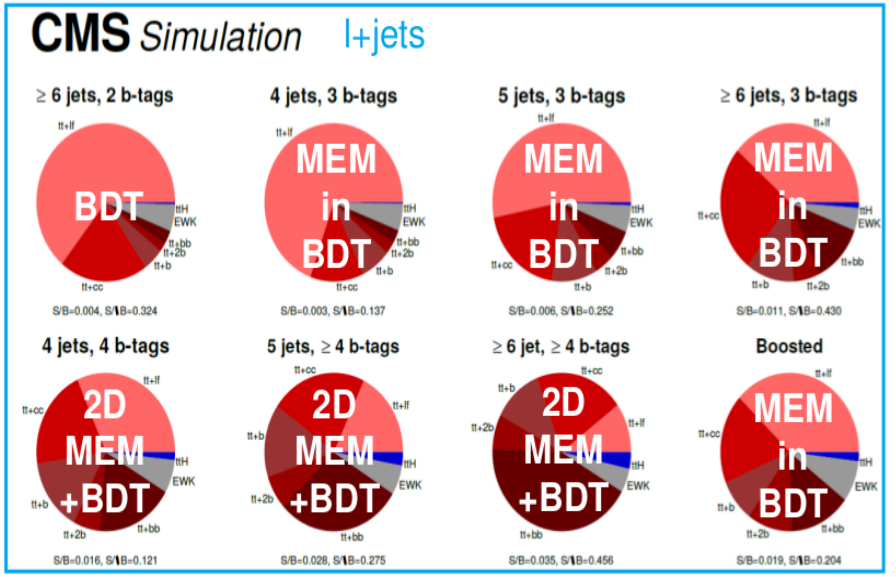
CMS – Run 2 : Event classification

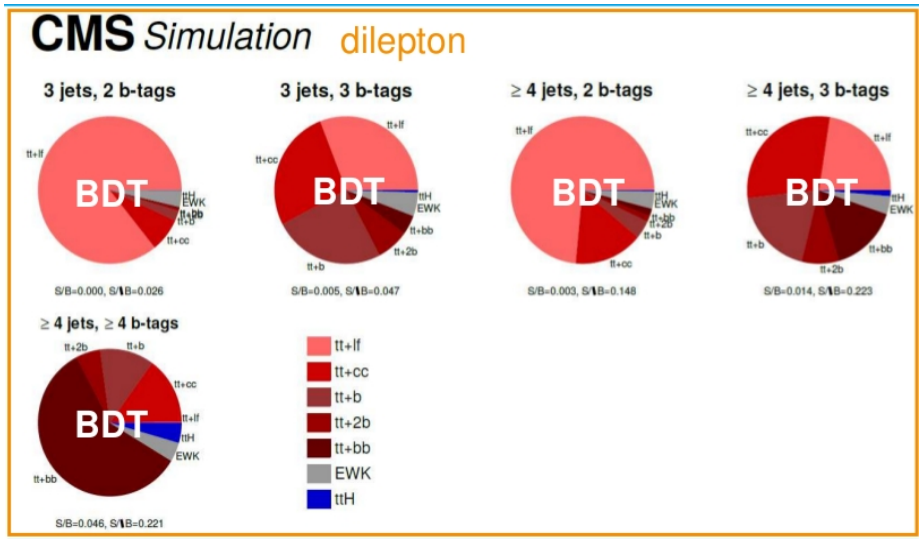
- Public 2015 results : CMS-HIG-16-004
- Same general strategy as Run1
- Events are divided into categories based on the number of jets and number of b-tagged jets.
  - **l+jets channel :**
    =1 lepton, ≥4 jets and ≥2 b-tags
  - **dilepton channel :**
    =2 opposite-sign (OS) leptons, ≥3 jets and ≥2 b-tags
- Boosted category for the first time in l+jets
  - Require ≥4 jets and ≥2 b-tags
  - Identify hadronic top and Higgs using substructure information
- 13 orthogonal categories



CMS – Run 2 : Signal separation

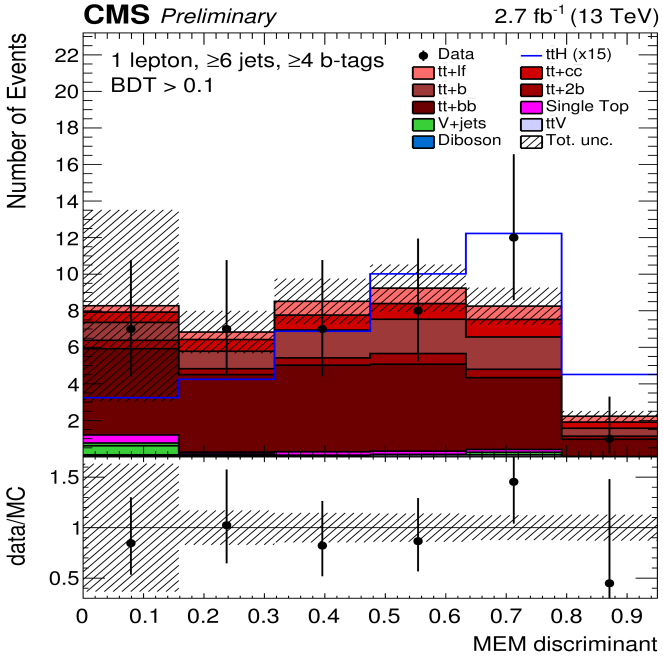
- Separate BDT is trained for each category
  - 8 BDTs in the lepton+jets and 5 in the dilepton channel
  - ttH vs tt+jets using object kinematics, event shape, the CSV b-tag discriminant
- In **l+jets**, inclusion of Matrix Element Method (MEM) in some regions.
- BDT better against tt+jets, MEM against tt+bb

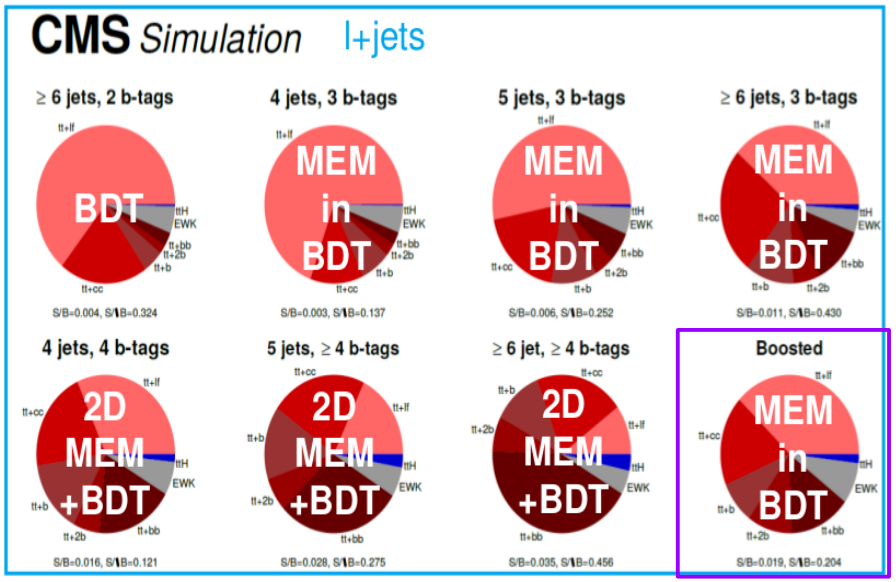




CMS – Run 2 : Signal separation

- **(l+jets)** regions with 3 b-tags, MEM added to BDT as input variable
- **(l+jets)** regions with 4 or more b-tags, split high and low BDT and fit MEM discriminant





- **(l+jets)** Boosted category
  - Large-radius jets with the Cambridge-Aachen (C/A) algorithm with a cone-size parameter of 1.5
  - Top-tagged and Higgs candidate with p_T > 200 GeV

CMS – Run 2 : Results

- Combined fit of all categories
- Fitted signal strength and limits
- Run 2, with 2.7 fb^{-1} , signal strength :

$$\hat{\mu}_{\text{obs}} = -2.0^{+1.8}_{-1.8}$$

- Run 2, at 95% CL for m_H =125GeV :

observed $\sigma^*BR/(\sigma^*BR)_{SM}$ < 2.6

expected $\sigma^*BR/(\sigma^*BR)_{SM}$ < 3.6

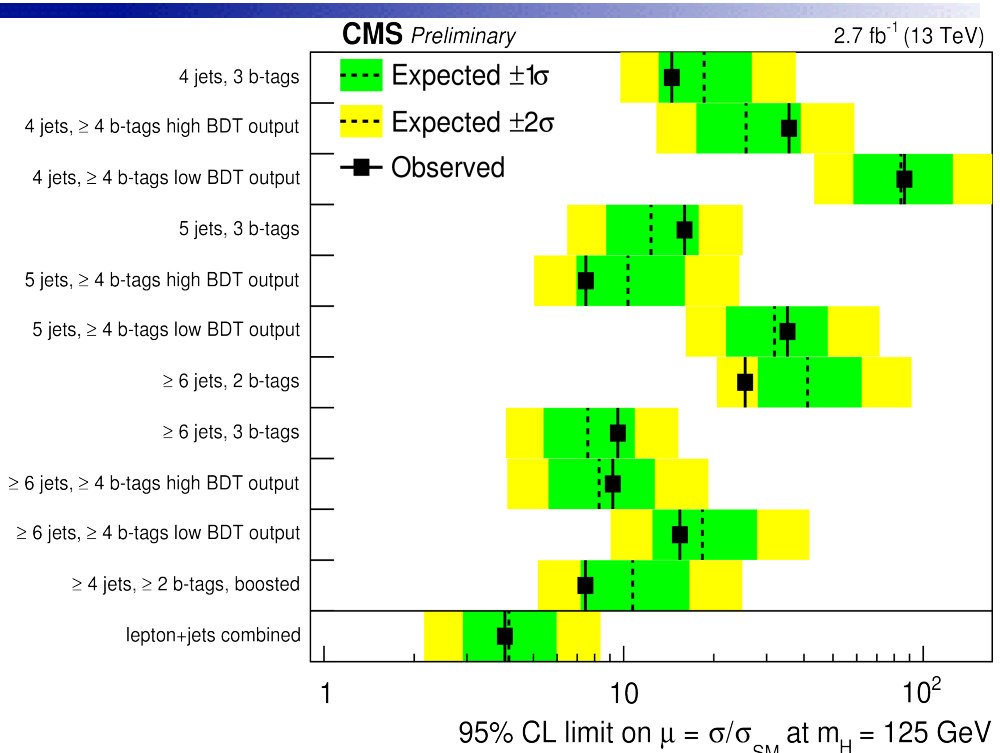
- Run 1, at 95% CL for m_H =125GeV :

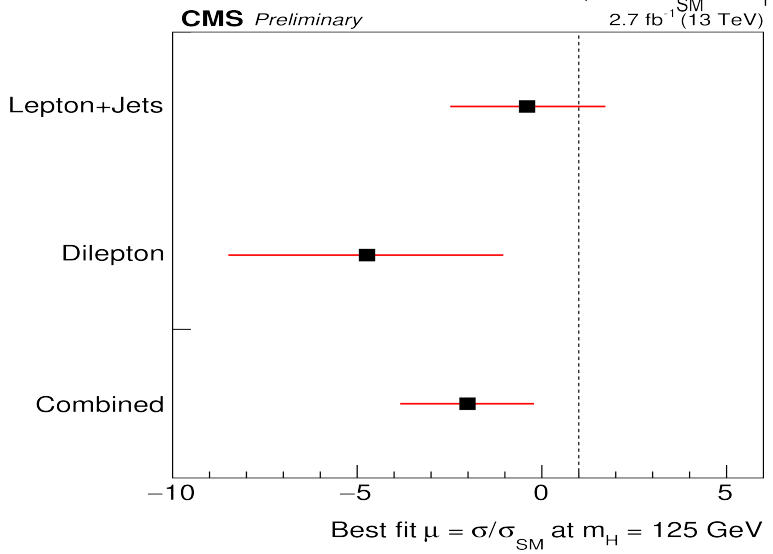
CMS : observed $\sigma^*BR/(\sigma^*BR)_{SM}$ < 4.2

expected $\sigma^*BR/(\sigma^*BR)_{SM}$ < 3.3

ATLAS : observed $\sigma^*BR/(\sigma^*BR)_{SM}$ < 3.1

expected $\sigma^*BR/(\sigma^*BR)_{SM}$ < 2.4





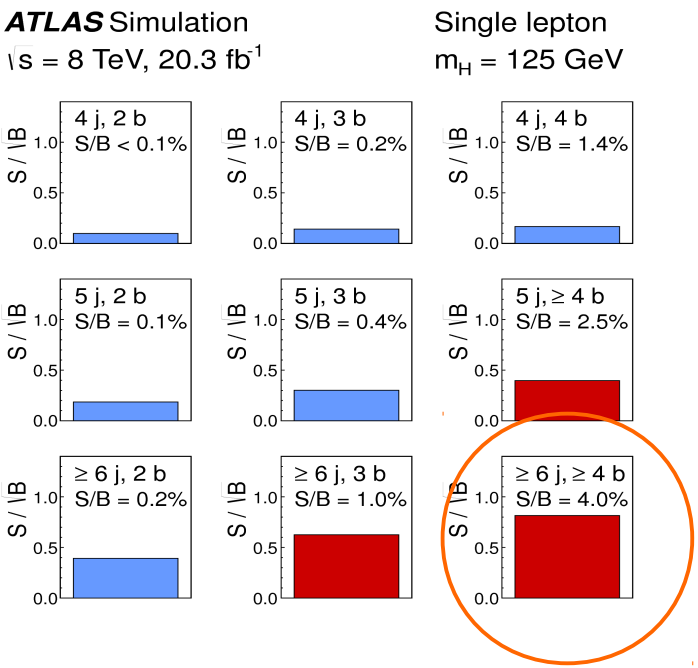
ATLAS – Run 2 : Strategy

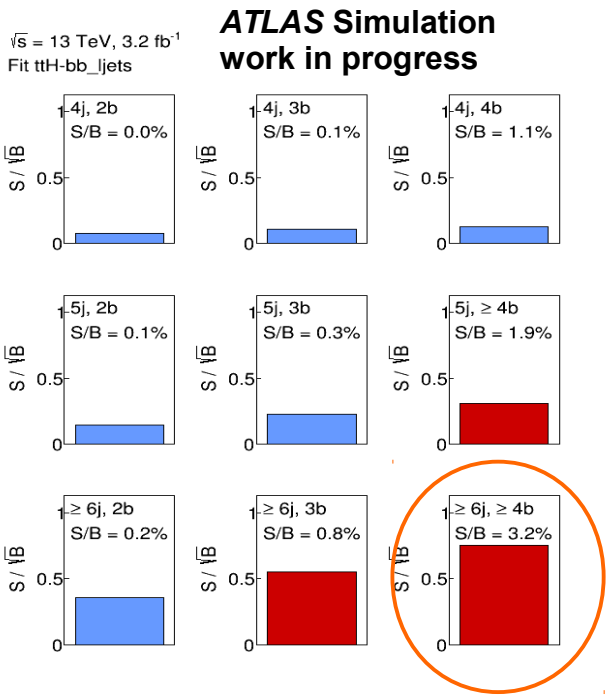
- Similar strategy as Run 1: categorizing events according to the number of jets and b-tagged jets :

  - **l+jets** :1 lepton (electron or muon) [≥4 jets, ≥2 b-tags]

  - **dilepton** : opposite sign lepton pair (ee, eμ, μμ) [≥2 jets, ≥2 b-tags]

- **signal depleted** and **signal enriched** regions

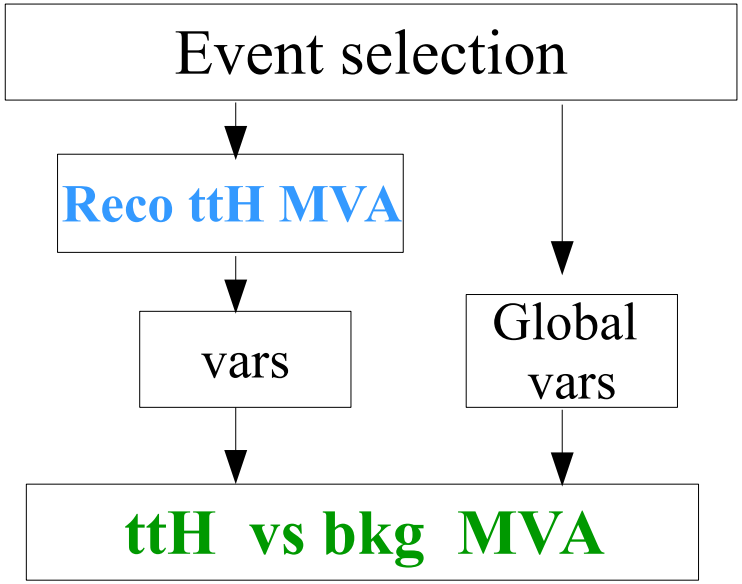


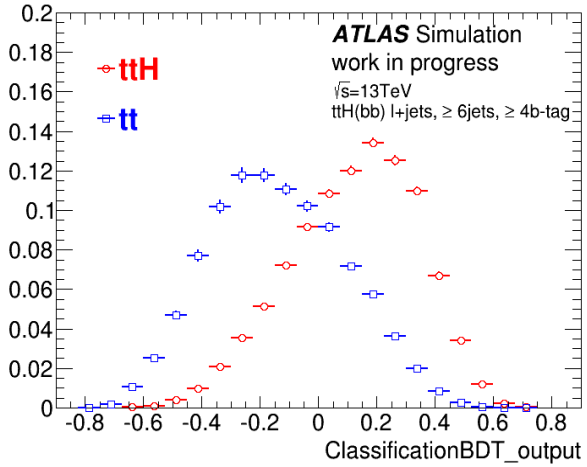


- Lower S/B at 13TeV than at 8 TeV at high jet multiplicity. Considering new categorization

- Split ≥6jets, ≥4 b-tags region to =6 jets, ≥4 b-tags and ≥7 jets, ≥4 b-tags increases purity

ATLAS – Run 2 : MVA techniques





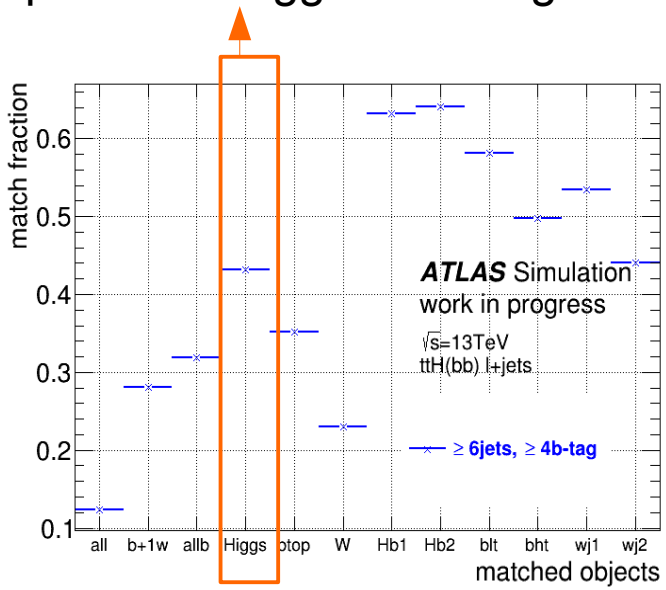
- In Signal-rich regions :
  - **Train MVA for jet assignment (Reco ttH MVA) :**
    - Jet → parton assignment
    - Reconstruct all combinations
    - Take combination with largest MVA output.
  - **Final MVA for S/B discrimination**
    - Variables from reco MVA :

      - Higgs mass candidate, dR(b,b) from Higgs candidate, etc
    - Global variables :

      - kinematic, event shape

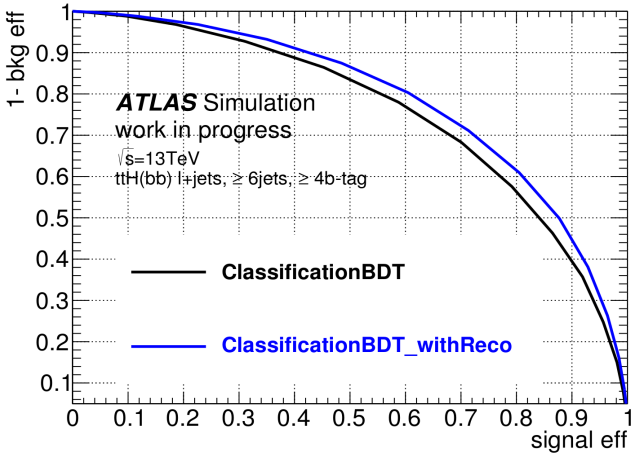
ATLAS – Run 2 : MVA techniques

- **Reco ttH MVA :**
  - Up to 42% Higgs matching efficiency



  - Matrix Element Method (MEM) used in Run 1 as input variable in the MVA for S/B discrimination

- **Final MVA for S/B discrimination**
  - Variables from the MVA reconstruction improve the signal-background separation.

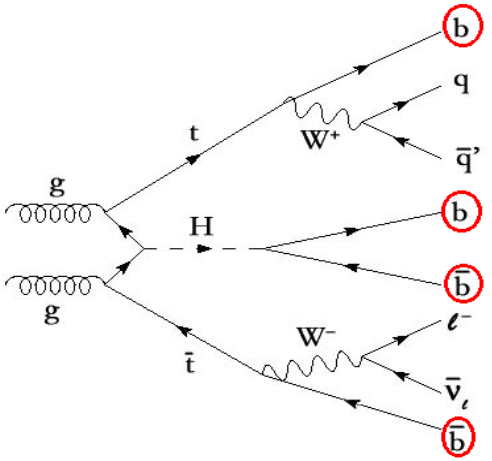


  - The improved signal-background separation achieved with help of the MVA reconstruction is the same as obtained in Run 1 with MEM

ATLAS – Run 2 prospects

- Many optimization studies ongoing in order to have a better analysis sensitivity.
- Further categorization to increase signal sensitivity.
- Exploiting MVA techniques
- Considering boosted scenario in l+jet
- 3.2 fb^{-1} of 13 TeV data collected in 2015.
  - Understanding of background ongoing
- Better detector :
  - Additional pixel layer strongly enhance b-tagging performance

	b-eff [%]	light rej
ATLAS Run1 Run2	70 70	140 440
CMS Run 1	70	50



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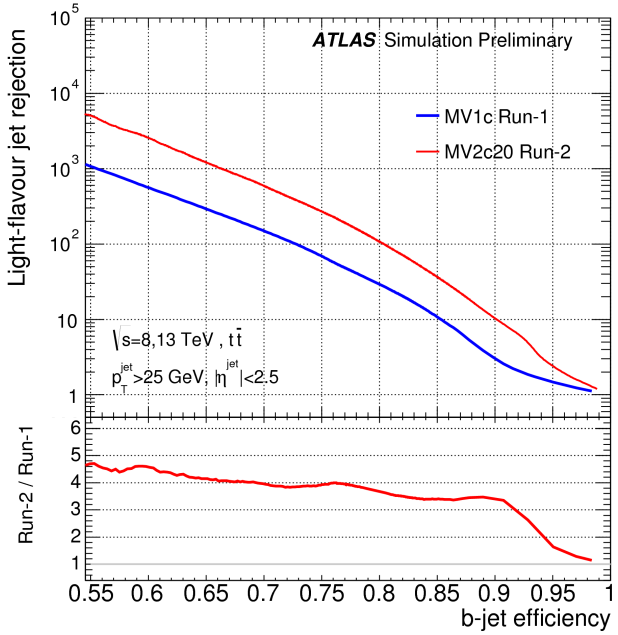
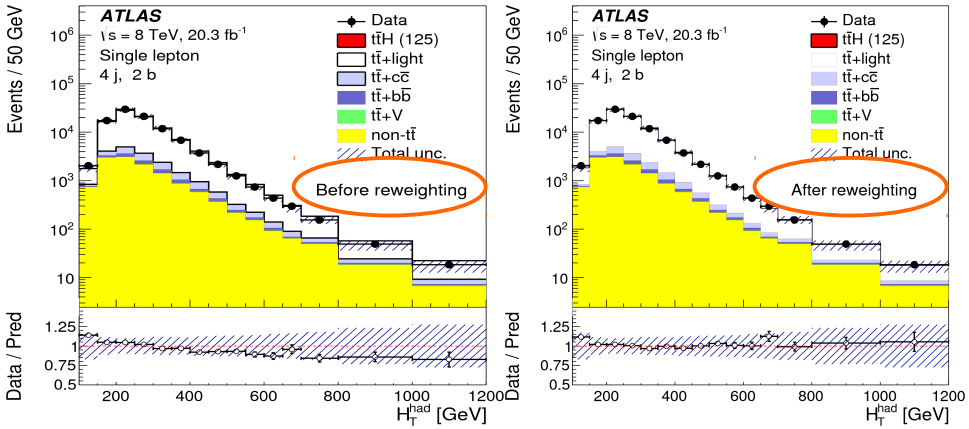


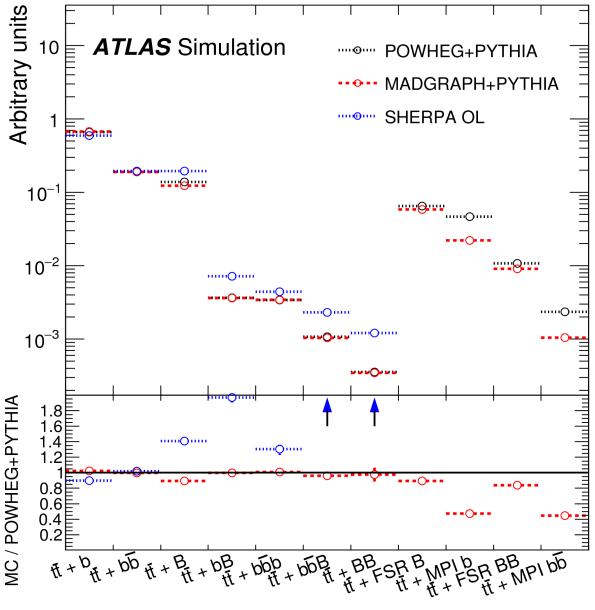
tt modelling

- tt+jets background is a key aspect of this analysis.
- **ATLAS Run1** :
  - Powheg+Pythia6 as nominal tt sample
  - Reweighting to 7 TeV σ(tt) differential measurement:
    - tt pT → improves nJet & nBtags
    - top pT → improves kinematic distributions:

    applied to tt+light & tt+cc
  - For tt+bb → reweighting to Sherpa+OpenLoop dedicated NLO
- *"The tt+bb background normalization is pulled up by about 40% in the fit, resulting in an increase in the observed tt+bb yield with respect to the Powheg+Pythia prediction."* Eur. Phys. J. C (2015) 75:349

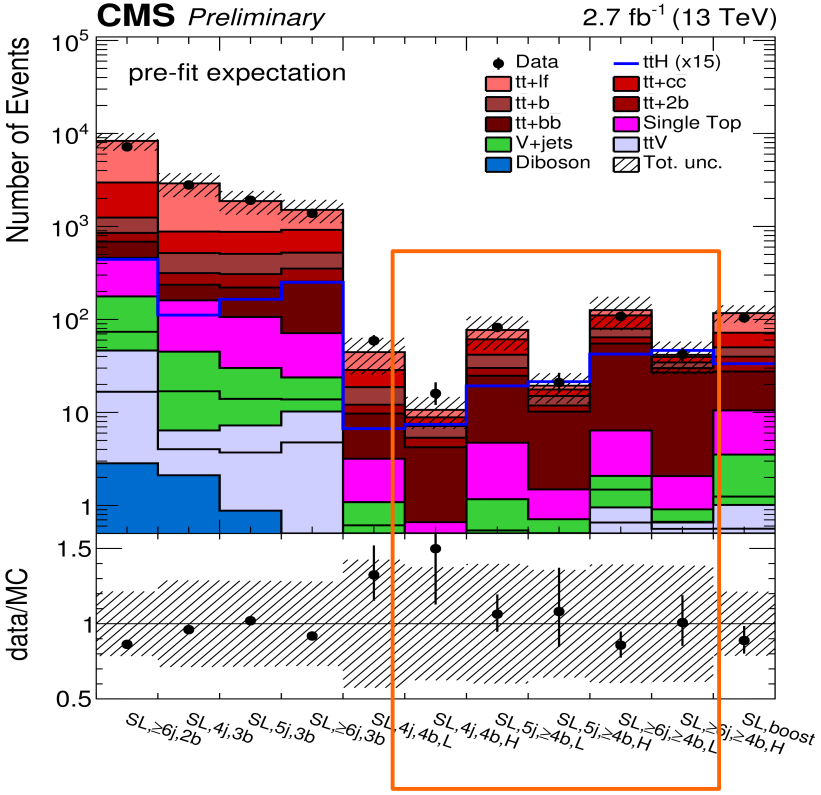
Eur. Phys. J. C (2015) 75:349





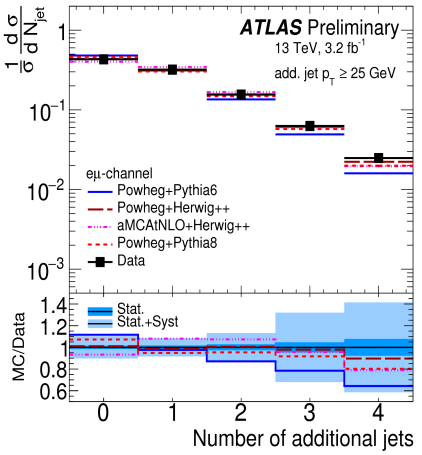
tt modelling

- CMS Run2 : Powheg+Pythia8 for tt simulation
- tt+HF modelling, good agreement in HF-enriched regions

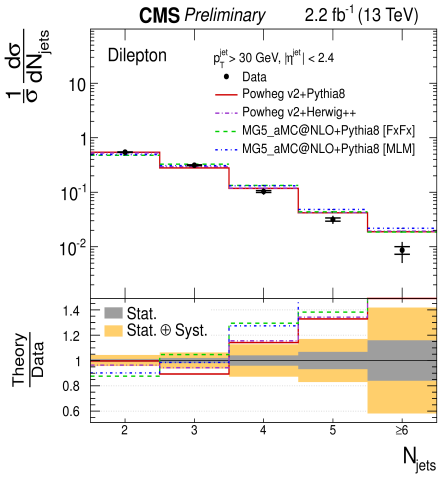


- tt + jets modeling, ATLAS and CMS have opposite trends in data/MC at high jet multiplicity (different generator)
- Testing different settings (tunes)

ATLAS-CONF-2015-065



CMS TOP-16-011



Differential cross-section of top-quark pair production as a function of multiplicity of additional jets

Summary

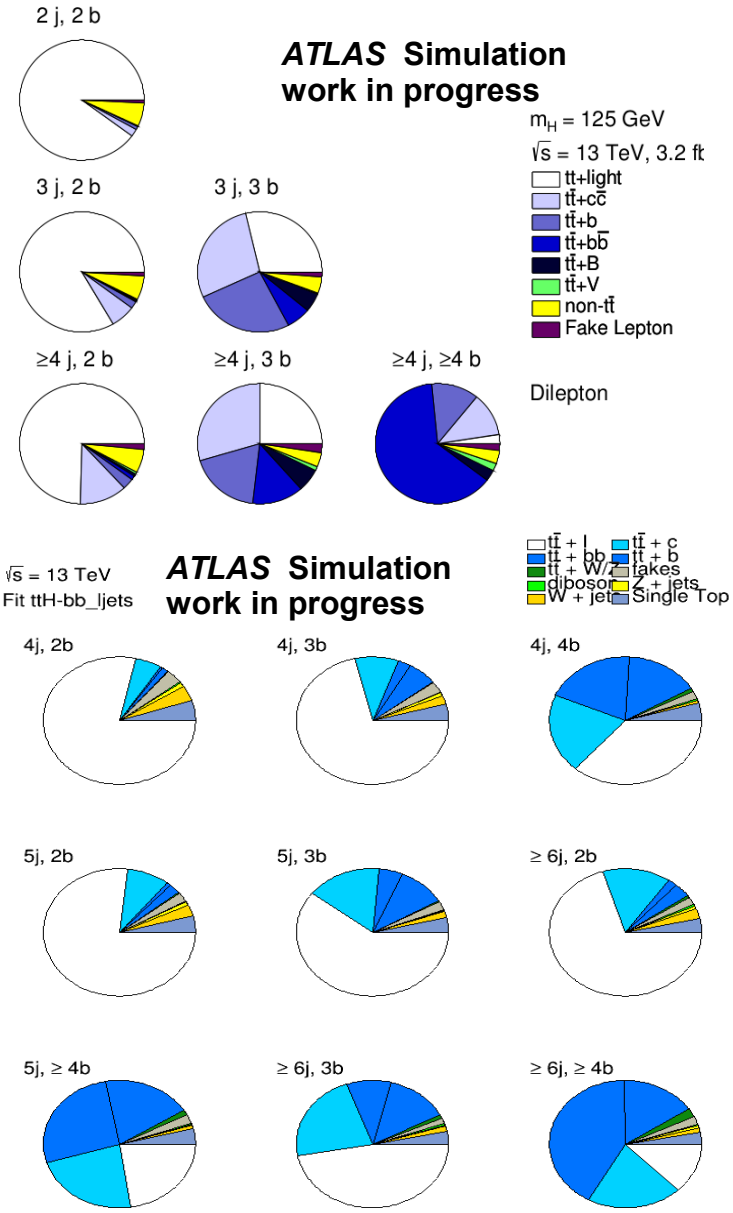
- Run 1, at 95% CL for m_H=125 GeV :
  - **CMS** : observed $\sigma^*BR/(\sigma^*BR)_{SM} < 4.2$
    expected $\sigma^*BR/(\sigma^*BR)_{SM} < 3.3$
  - **ATLAS** : observed $\sigma^*BR/(\sigma^*BR)_{SM} < 3.1$
    expected $\sigma^*BR/(\sigma^*BR)_{SM} < 2.4$
- First 13 TeV measurements with 2.7 fb^{-1} performed by **CMS** :
  - similar sensitivity to Run 1 analysis, in agreement with SM
  - at 95% CL for m_H =125 GeV : observed $\sigma^*BR/(\sigma^*BR)_{SM} < 2.6$
    expected $\sigma^*BR/(\sigma^*BR)_{SM} < 3.6$
- Prospects for **ATLAS** Run 2 :
  - improving analysis techniques, working on tt modeling
  - better b-tagging (additional pixel layer),
- Top-Higgs coupling should be accessible via associated ttH production in Run2
  - stay tuned

Backup

ATLAS – Run 2 : backgrounds

- **Reducible backgrounds :**
  - **tt+light / tt+cc :** contaminate signal regions due to mis-tagging.
  - **Non-tt :** single top, W+jets, Z+jes and di-bosons taken from MC, QCD Multijet fully data-driven.
- **Irreducible background** : **tt+bb**
  - Distribution across analysis regions depend on bb kinematic
  - Split in different categories depending on the number of b-jets with one B hadron or more than one B hadron not from top.

    Classification proposition :
    tt+b: 1 b-jet with 1 b-hadron
    tt+bb: 2 b-jets with each 1 b-hadron
    tt+B: 1 b-jet with 2 b-hadrons



ATLAS – Run 1 : ttH(H→bb) all hadronic