VHBB ANALYSIS WITH THE ATLAS DETECTOR USING RUN2 DATA

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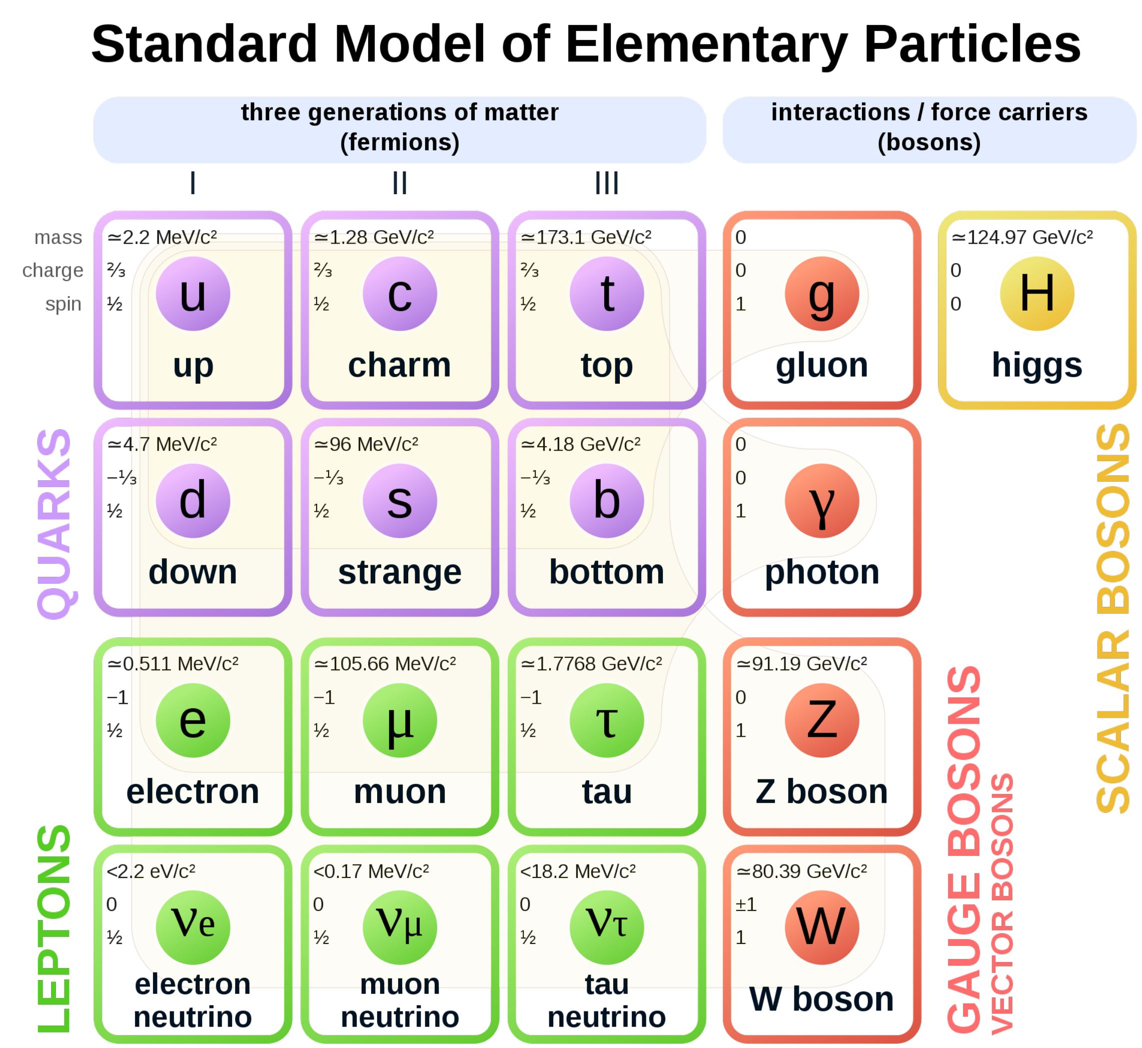
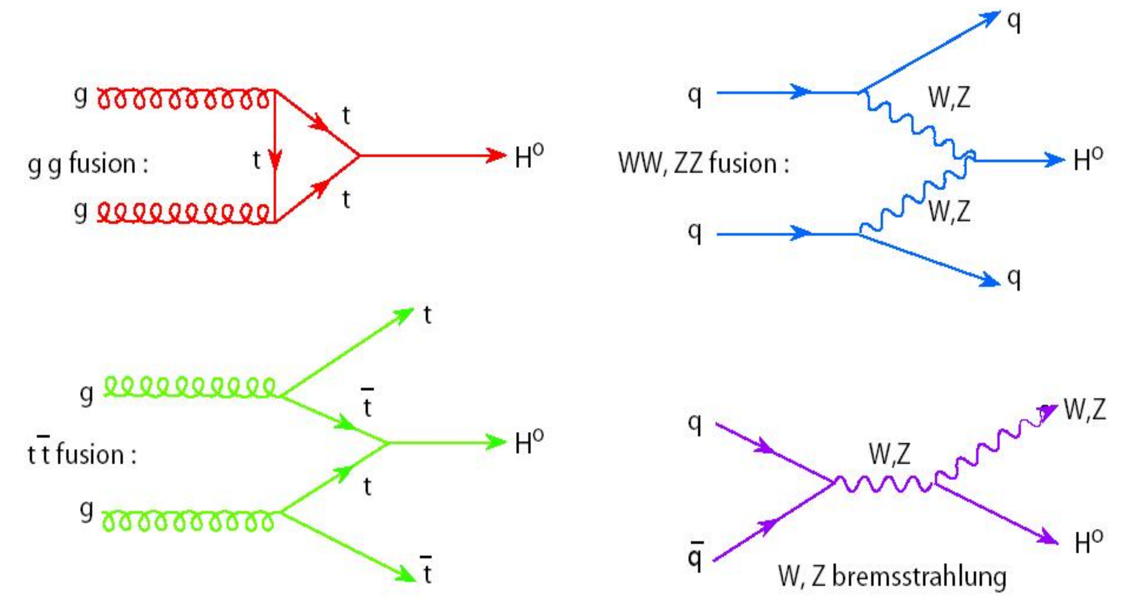
THE STANDARD MODEL OF PARTICLES

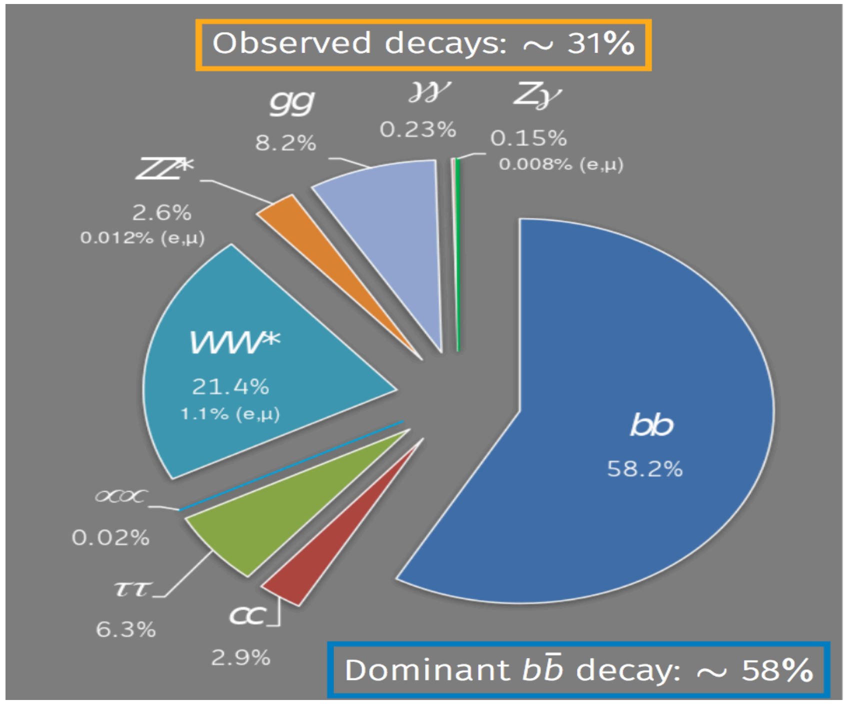
- 2 types of particles make up the universe: fermions and bosons
- There are 12 fermions that are the components of matter: 6 quarks (u, d, c, s, t, b) and 6 leptons (e, μ, τ and their neutrinos ν)
- Boson are the force mediators and there are: the photon (for the electromagnetic force) , $W^{\pm}$ and Z (Week force), gluon (for the strong force) and the **Higgs** boson
- Higgs boson, a representation of the Higgs field that gives mass to particles, was discovered by ATLAS and CMS experiments the at LHC



THE HIGGS BOSON AT THE LHC: PRODUCTIONS AND DECAYS

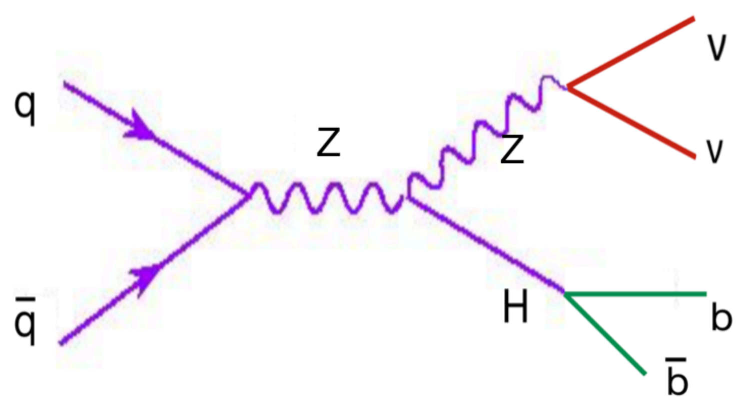
- 4 main production modes: gluon-gluon fusion (the dominant mode), vector boson fusion, top pair fusion and the associate production with a vector boson



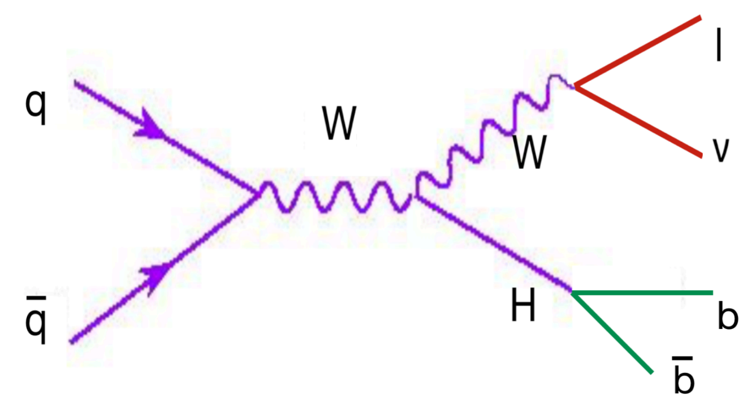


- Higgs was first discovered in both γγ and 4lepton channels
- H→bb is the dominant decay:
  - Was observed last summer by ATLAS and CMS
  - Strong background contamination ➜ Hard to observe because of low s/b

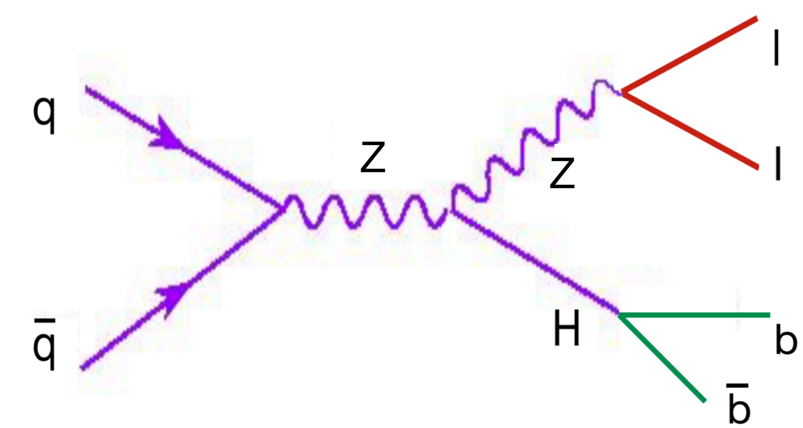
VHBB ANALYSIS: CHANNELS AND CATEGORIES



0-lepton channel



1-lepton channel



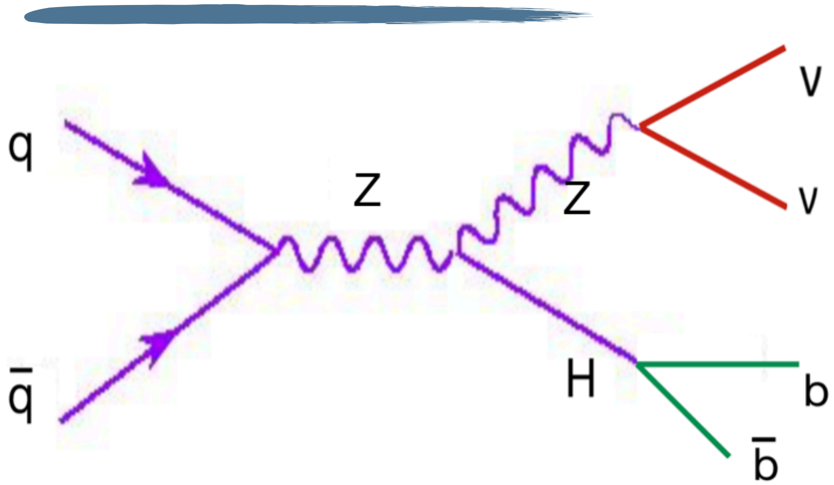
2-lepton channel

- VHbb is the production mode of interest for Hbb:
  - The leptonic decay of the vector boson allows QCD bkg suppression
  - Clean signature in the detector
- 3 channels of study depending on the number of charged leptons (e, μ) in the final state: 0 (Z→vv) ,1(W→lv) and 2 lepton (Z→ll)
- 2 categories per channel: 2 jets or 3jets (3+jets in the 2lepton channel only)

VHBB ANALYSIS: EVENTS SELECTION

- Large amount of data collected during Run2 (from 2015 to 2018) : 140 fb-1
- Many sources of background coming from different processes: ttbar events, single top, W+jets, Z+jets, diboson, multi-jet
- Cuts in each channel to eliminate background and increase sensitivity
- Since the search is for 2-b jets events: select exactly 2-b jets tagged events using a b-tagging algorithm

0-lepton channel

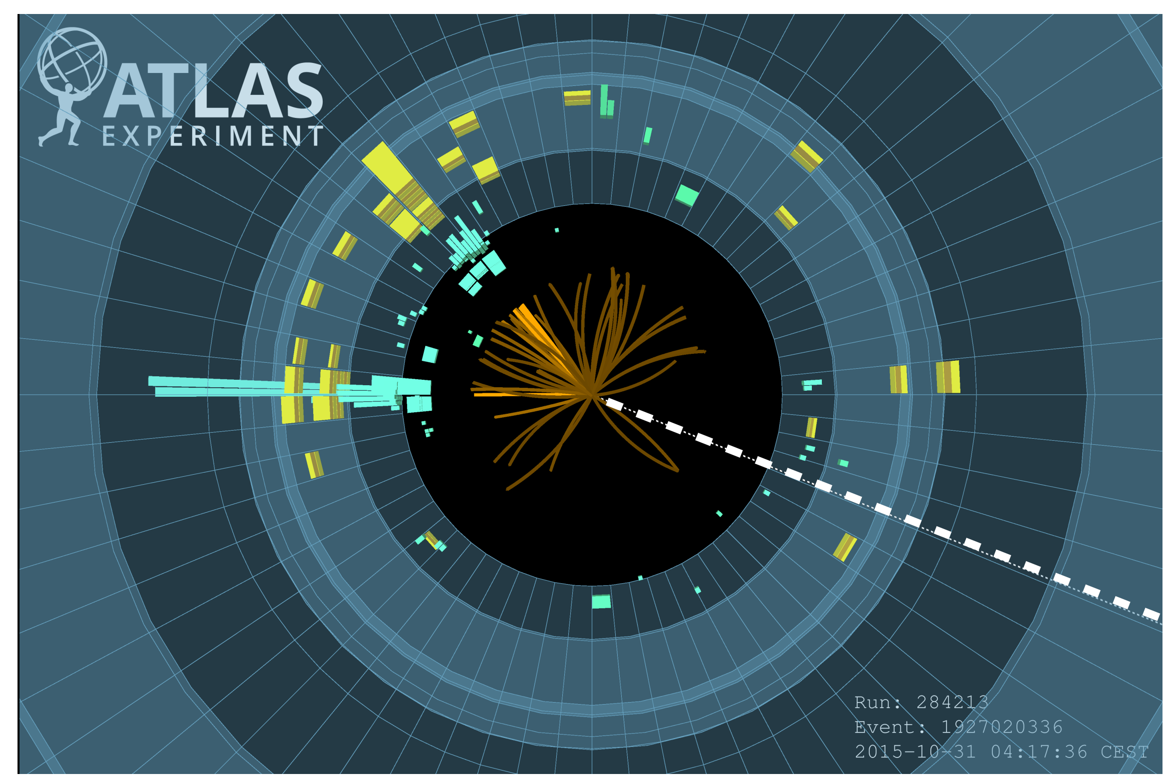


MET >150GeV

pT b-jet1 >45GeV

pT b-jet2 >20GeV

Angular cuts to remove events with fake MET



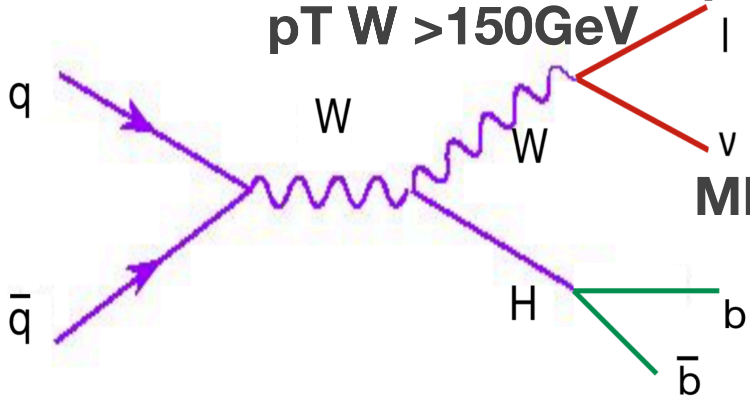
VHBB ANALYSIS: EVENTS SELECTION

1-lepton channel

pT electron >27GeV

pT muon >25GeV

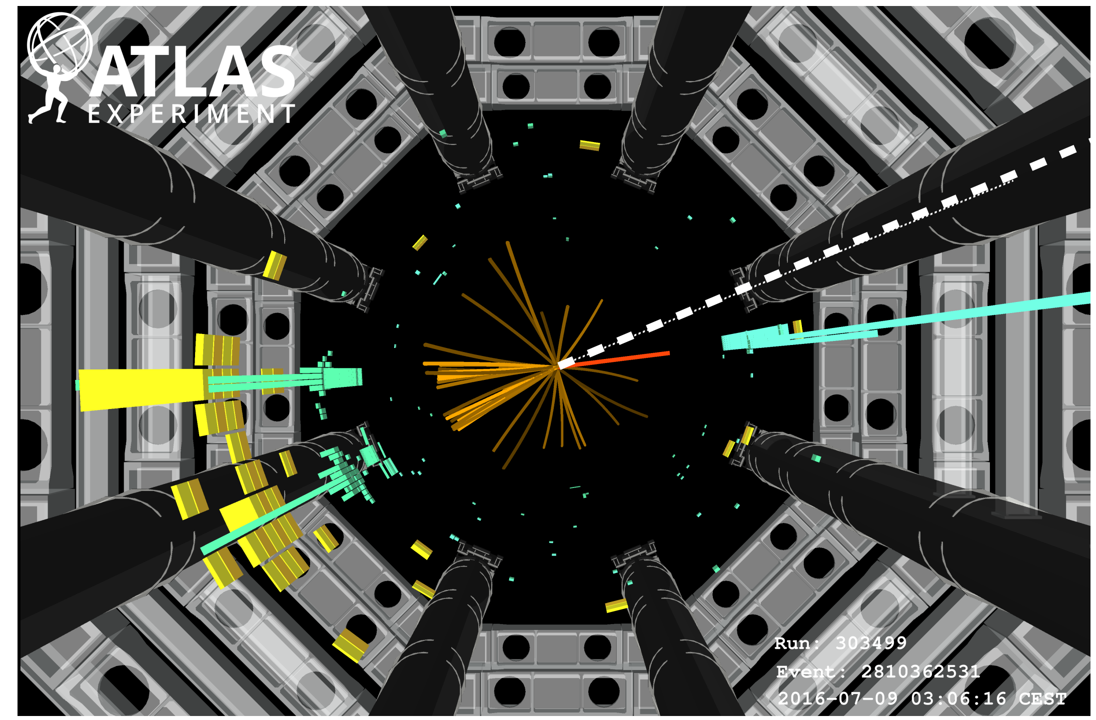
pT W >150GeV



MET electron >30GeV

pT b-jet1 >45GeV

pT b-jet2 >20GeV

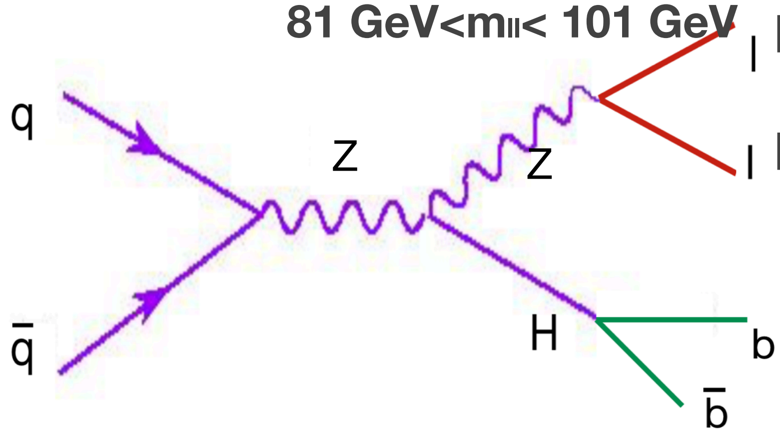


2-lepton channel

81 GeV<m_{ll}< 101 GeV

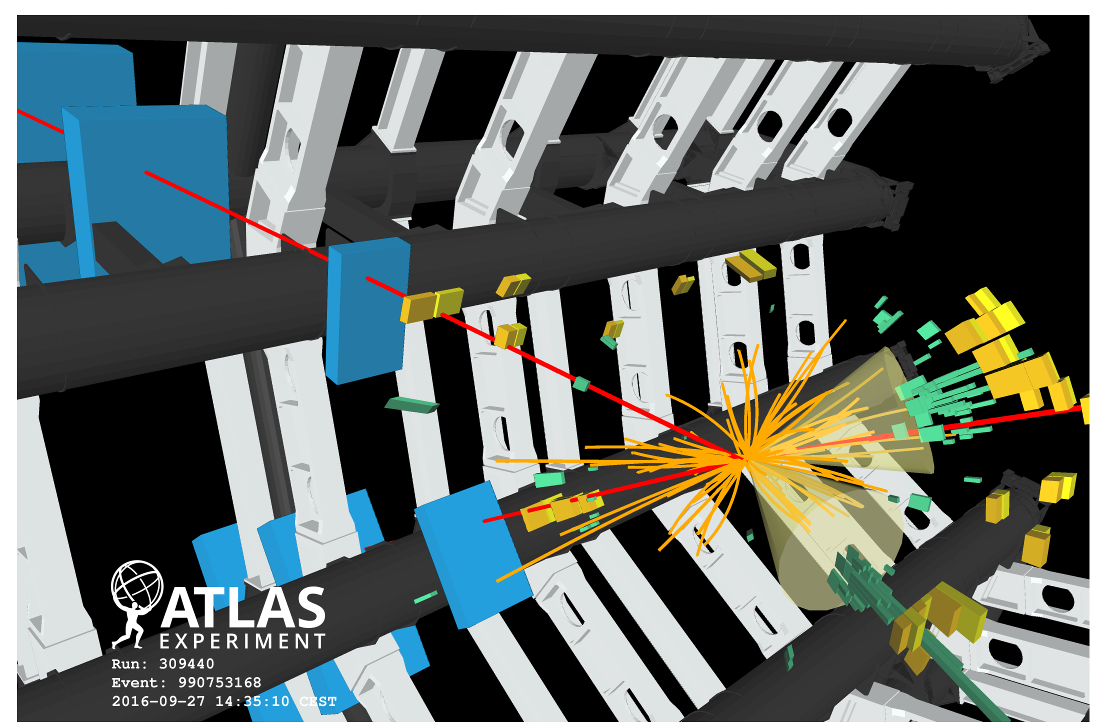
pT L1 >27GeV

pT L2 >7GeV

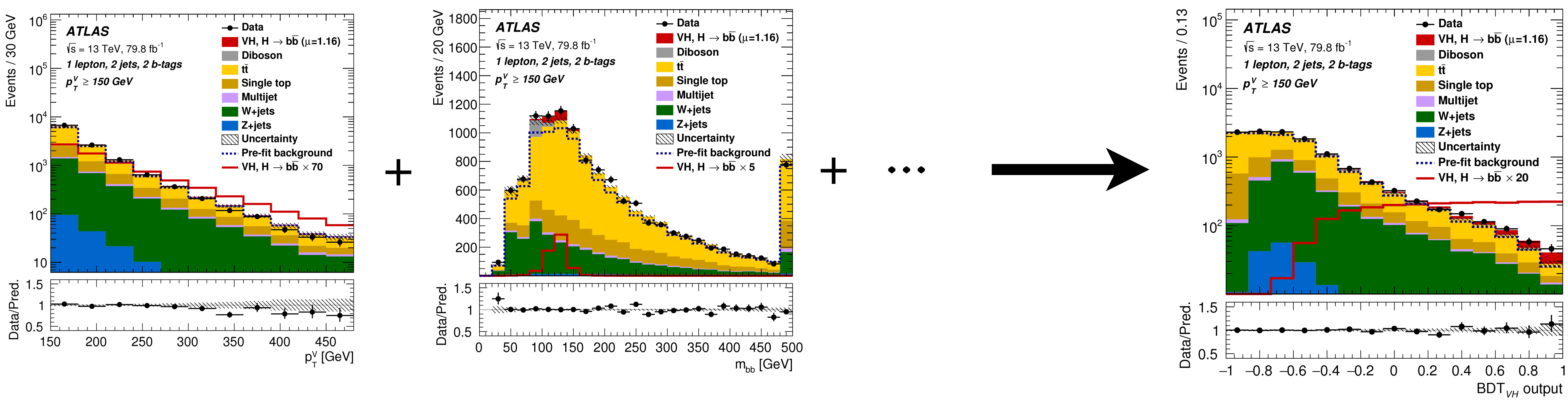


pT b-jet1 >45GeV

pT b-jet2 >20GeV



VHBB ANALYSIS: MVA

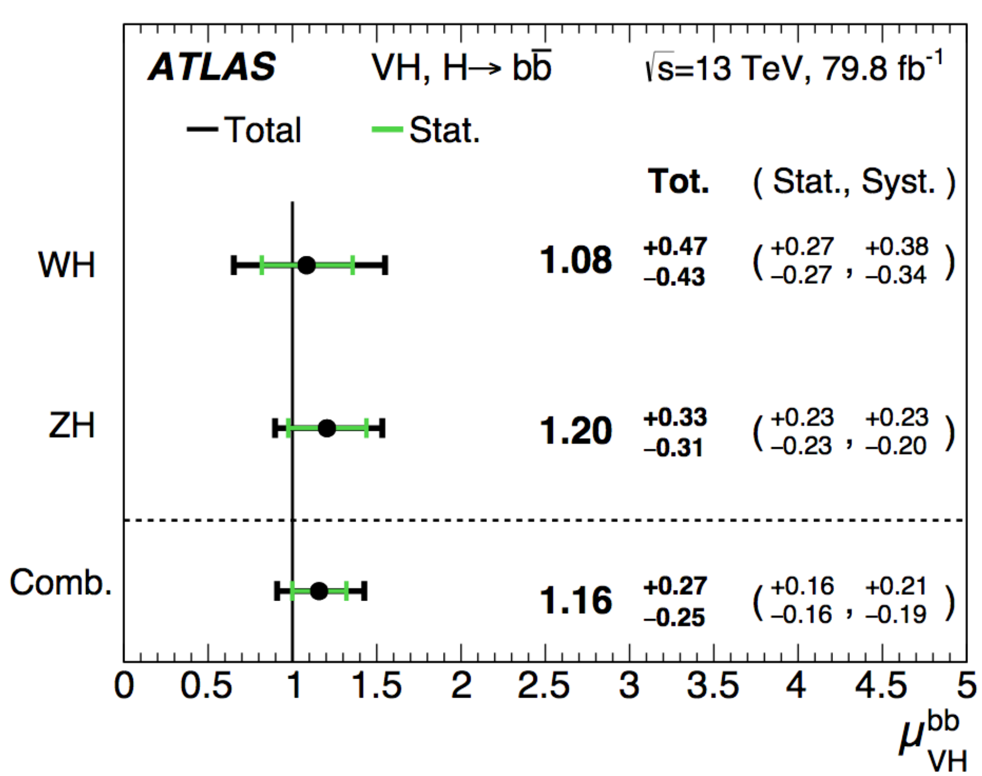


- VHbb uses a Multivariate analysis to have a better signal-background separation
- It is reconstructed from many kinematic variables (variables depend on the channel)
- The BDT is trained on Monte-Carlo events and then applied to collected data events
- mBB (the invariant mass of 2-b jets system), pTV (transverse momentum of the vector boson) and dRBB (the angular distance between the 2 b-jets) are the most important variables to the classification
- A binned likelihood fit is then performed on mva to extract the significance

VHBB ANALYSIS: FINAL FIT AND RESULTS

Source of uncertainty		σ_μ
Total		0.259
Statistical		0.161
Systematic		0.203
Experimental uncertainties		
Jets		0.035
E_T^{miss}		0.014
Leptons		0.009
b-tagging	b-jets	0.061
	c-jets	0.042
	light-flavour jets	0.009
	extrapolation	0.008
Pile-up		0.007
Luminosity		0.023
Theoretical and modelling uncertainties		
Signal		0.094
Floating normalisations		0.035
Z + jets		0.055
W + jets		0.060
$t\bar{t}$		0.050
Single top quark		0.028
Diboson		0.054
Multi-jet		0.005
MC statistical		0.070

- ➤ Statistical and systematic uncertainties determine the measurement uncertainty of the significance (μ)
- ➤ Systematic uncertainties account for jets and MET calibrations, b-tagging efficiencies, pile-up corrections, luminosity uncertainties and MC modelling predictions
- ➤ Modelling systematics have a significant impact

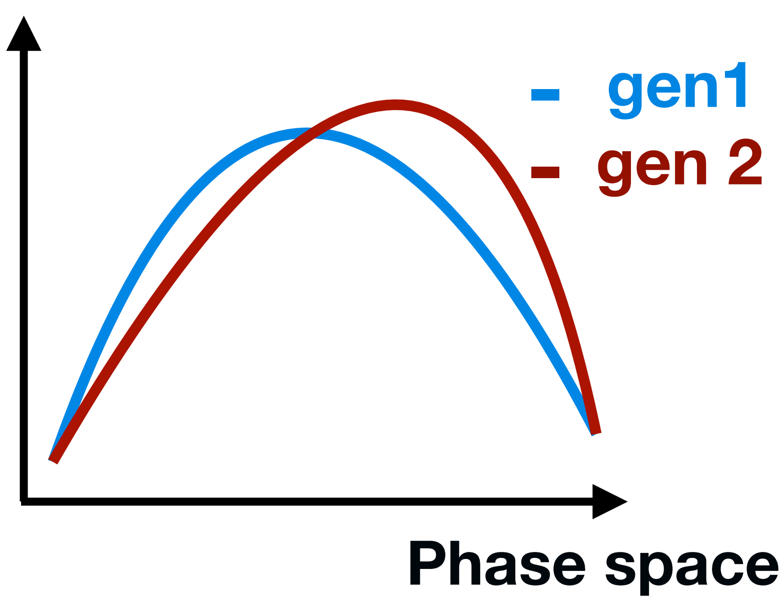


- ➤ **Results with 80fb-1 Run2 data @13TeV:**
- ➤ VHbb analysis:
  - ➤ 4.9σ significance
  - ➤ μ =1.16 ± 0.26
- ➤ Observation of Hbb decay:
  - ➤ 5.4σ with combination with ttH and VBF production modes
  - ➤ μ =1.01 ± 0.2
- ➤ Observation of VH production channel:
  - ➤ 5.3σ with combination with γγ and 4l channel
  - ➤ μ =1.13 ± 0.24

VHBB ANALYSIS: MC PREDICTIONS AND UNCERTAINTIES

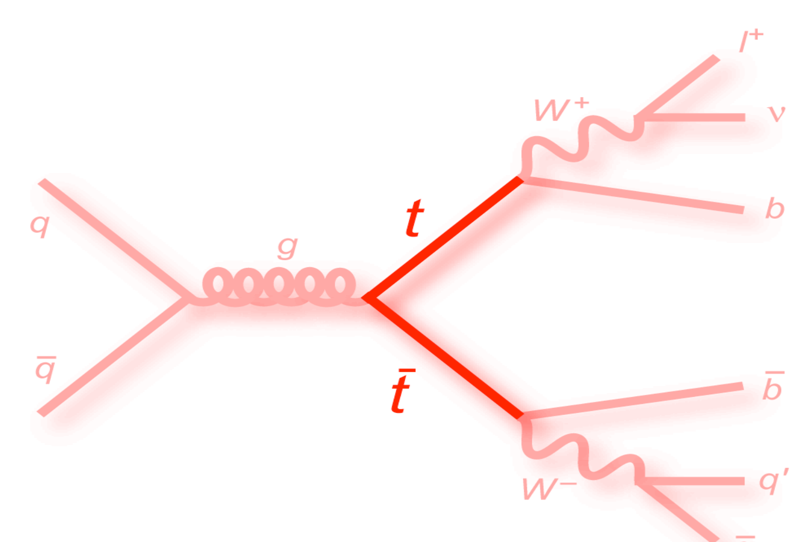
- MC samples are needed to model both signal and background
- Systematic uncertainties are assigned to these prediction
- These uncertainties are derived by comparing the MC generator that is used for the mva (called nominal) to another generator (called alternative)
- The two generators can differ in either the Matrix Element (ME) or the Parton Shower (PS)
- The usual method is to compare bin-by-bin to all possible variation on the final discriminant of the analysis

- Does not apply in this case due to lack of MC statistics to see effect at the percent level (and we need need systematics at few percent level because s/b is low)
- The number of events passing all cuts and selections in the alternative sample is very low compared to the nominal



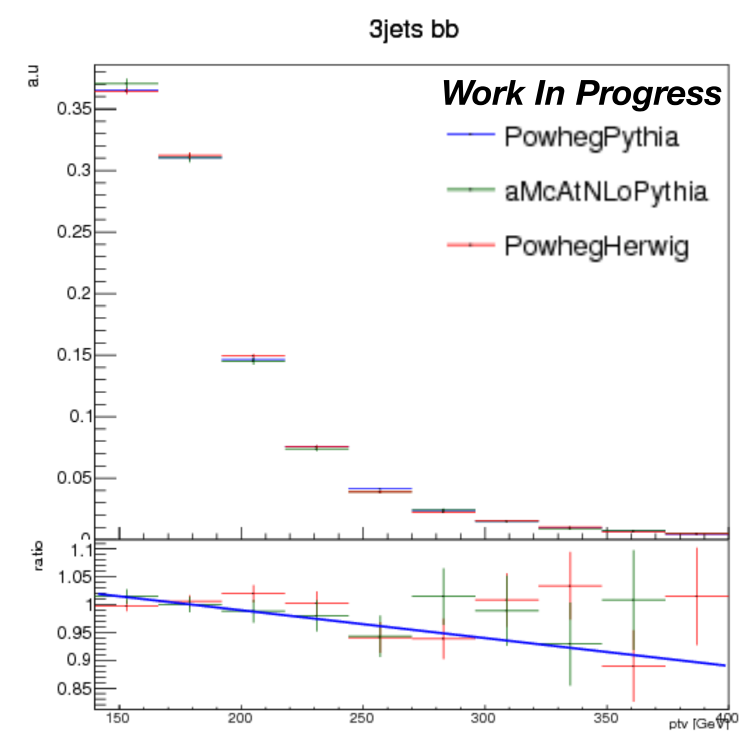
VHBB ANALYSIS: BACKGROUND MODELLING SYSTEMATICS

- It is very difficult to just add more events to the MC samples
- The solution is to derive the systematics by re-weighting method
- It is done by looking at the difference between the nominal generator and the alternative, parametrise the difference and represent it with weights
- The weights are then applied to the nominal generator to mimic the alternative
- The estimation is done at what is called truth-particle level where there is enough statistics
- The weights are obtained from kinematic variables distributions considered important or that show a difference between generators
- The weights are derived to each of the background samples independently and applied to the corresponding nominal generator
- Study presented here focuses on ttbar 1-lepton channel



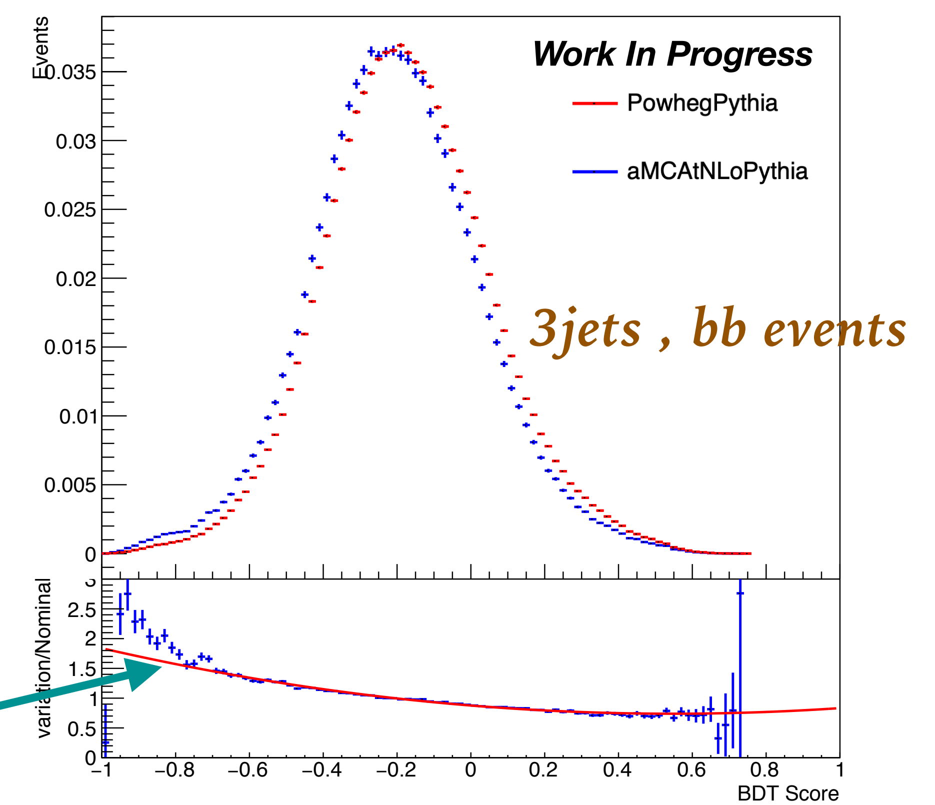
VHBB ANALYSIS: CURRENT SYSTEMATICS

- The systematics for ttbar modelling are derived from pTV and mBB distribution (for being the most important variables for the analysis)
- These systematics come from comparing mBB and pTV distribution between PowhegPythia (the nominal generator for the analysis) and aMCAtNLoPythia (alternative generator)
- The weights are computed as follows:
  ratio of the distribution (mBB and pTV
  separately) is fitted to get the weighting function
- This method is proven reliable in computing systematics
- Difficulties: need to look at all kinematic variables to check for non closure
- A new method is proposed to not focus on two variables but rather use many variables to represent the whole phase space
- New method: BDT to use one variable “BDT score” (instead of two) in assigning systematics



VHBB ANALYSIS: NEW METHOD USING BDT

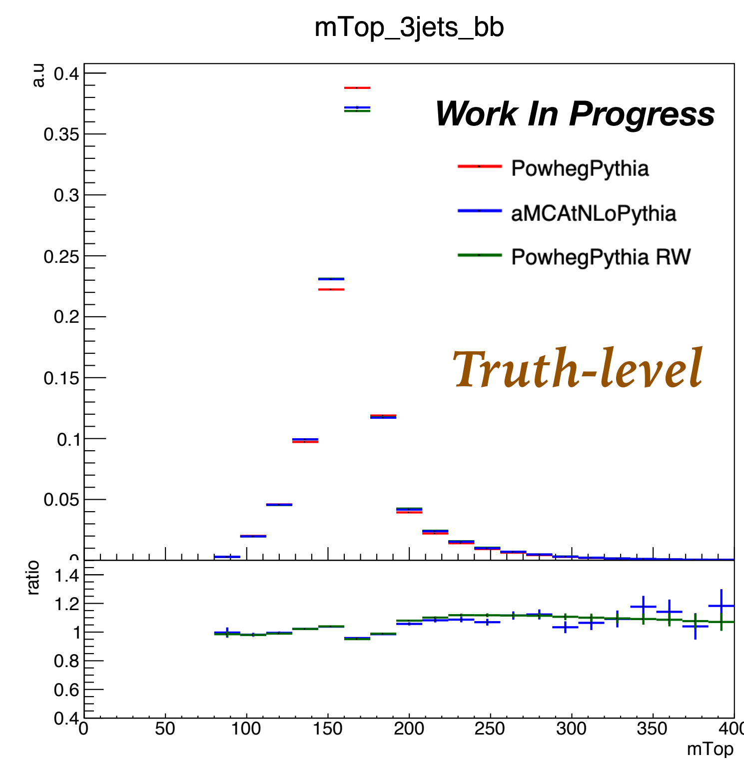
- Same kinematic variables as the BDT-analysis (at truth level) are used to construct the BDT
- The dedicated BDT is trained by taking PowhegPythia as signal input and aMCAtNLoPythia as background input
- Want also to introduce a systematics related to the PS generator -> Also train a BDT to compare PowhegPythia and PowhegHerwig
- Different categories of events are treated separately
- The BDT score (is a value between -1 and 1) is assigned to each event by being more signal like or background like
- The ratio of the BDT distributions of the two generators is then computed for ME and PS comparison

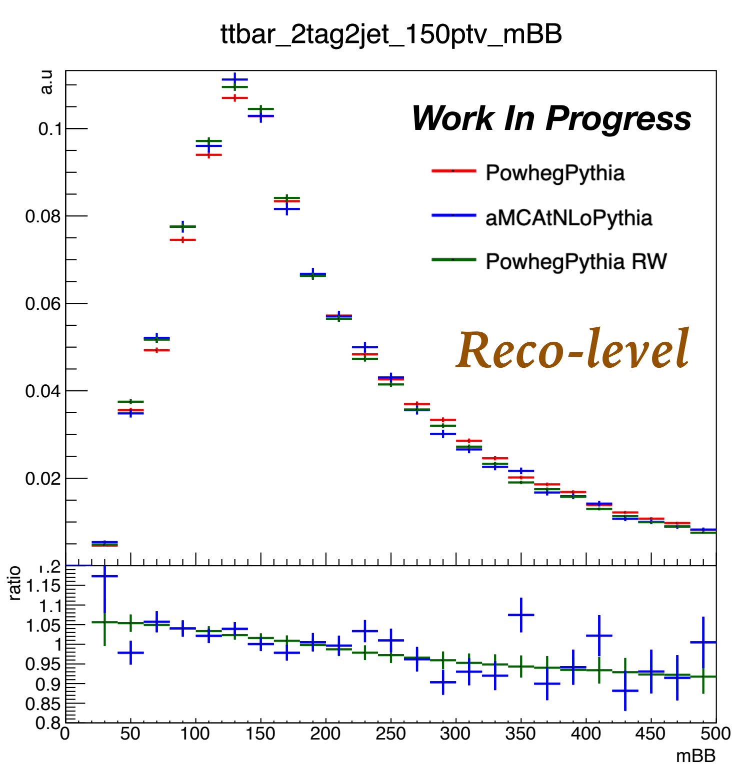


The fitting function allows to get the weights

VHBB ANALYSIS: PERFORMANCE OF THE NEW METHOD

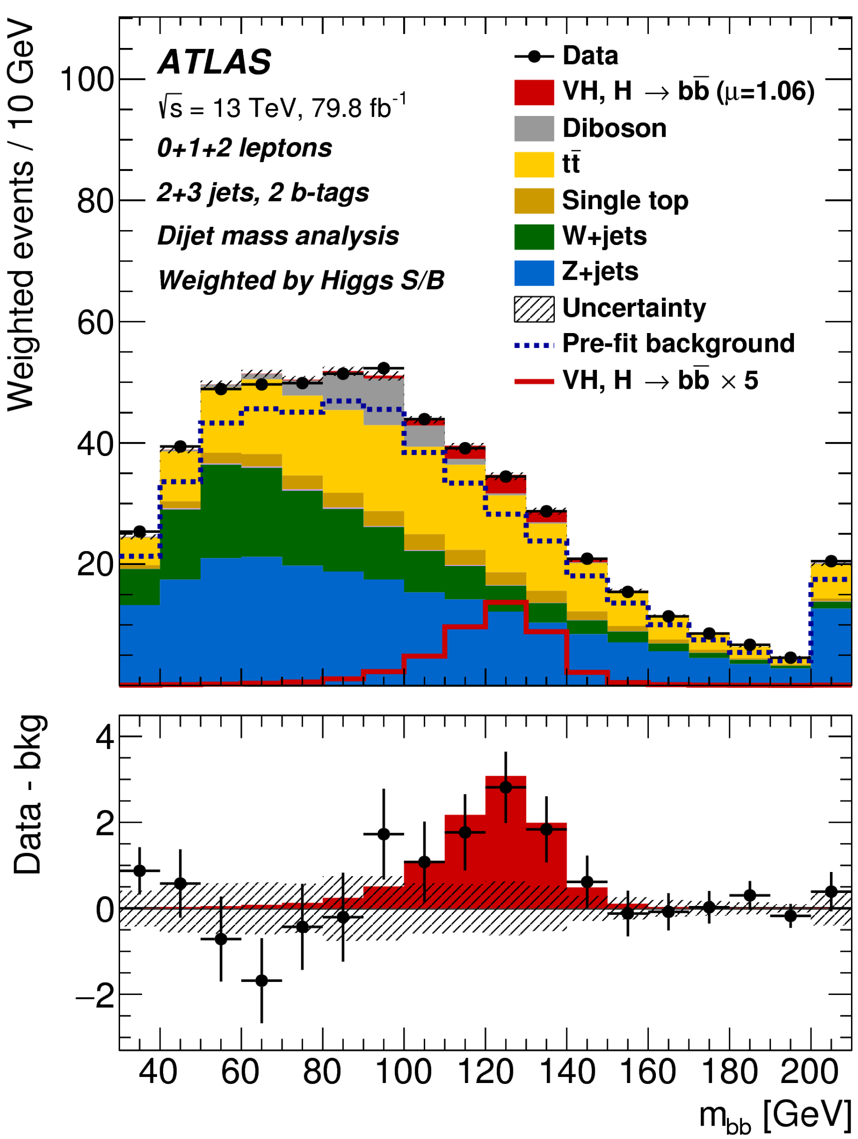
- First test for the new method is to apply the weights on the variables used for the BDT training (truth-level)
- The weights are applied on the nominal sample to morph it into the alternative generator
- Reweighting validated at truth level -> Need to apply to events after ATLAS reconstruction





- To be coherent with the training -> Access the truth information of the reconstructed events
- Same as truth-level reweighting, good closure at reco level
- The idea is to replace the current ttbar_pTV and ttbar_mBB systematics with the new new systematics and propagate them to the final fit

CONCLUSION



- VH production and H→bb decay were observed with the ATLAS detector with Run2 data
- A new method to compute systematic uncertainties is being studied for VHbb analysis
- The new method uses BDTs to parametrise the difference between two generators
- It is a new method using one variable to represent all the phase space
- So far the results show promising (good closure)
- The study will be propagated to other backgrounds and other channels
- Hopefully we will have a more precise estimation of our background modelling systematics for the analysis of the full Run2 data in 2019