Lepton Photon 2021 Poster Session

The measurement of a Standard Model Higgs boson, produced in association with a W or Z boson, decaying into a pair of b-quarks in pp collisions at 13 TeV with the ATLAS detector

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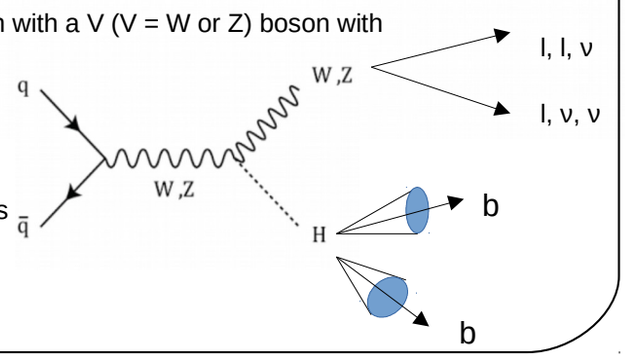
Introduction

H→bb decay mode has highest branching fraction at ~60%:
- gluon-gluon fusion (ggF) is most dominant Higgs production mode at LHC:
  - Large multi-jet backgrounds make search in ggF production mode very difficult at hadron colliders
- Allows overall Higgs width to be constrained

Associated production of a Higgs with a W or Z boson is preferred production mode:
- Most sensitive to measure H→bb
- First observation in 2018
- Leptonic decay of vector boson enables efficient triggering and a significant multi-jet (MJ) background reduction

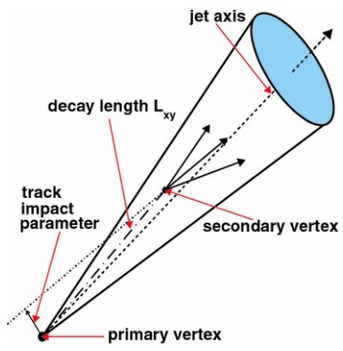
VH(->bb) Production:
- Higgs boson decaying to two b-quarks produced in association with a V (V = W or Z) boson with leptonic V decays
- Three sub-channels depending on charged lepton multiplicity:
  - Z→νν, W→lν, and Z→ll decays (l = e or μ)
- Signal event contains at least 2 jets and exactly 2 b-tagged jets



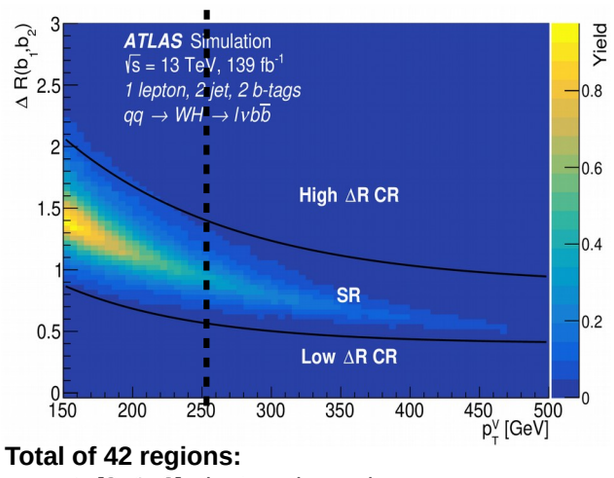
Event Categorisation

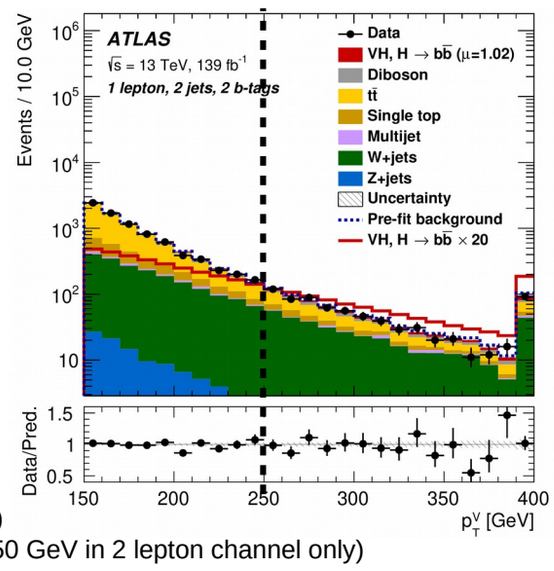
W/Z boson reconstruction and their decays defines lepton channels:
- 0-lepton: Large missing transverse energy (MET) (proxy to P^T_V - transverse mass of vector boson)
- 1-lepton: 1 charged lepton l = [e, μ] + MET from neutrino (ν)
- 2-lepton: 2 charged leptons ll = [ee, μμ] + $m_{ll} \sim m_Z$

H(->bb) candidate reconstruction:
- Jets are b-tagged using machine learning algorithm called MV2:
  - Gives probability whether jet is a b-jet or not
  - Based on properties of b-hadron decays
  - 70% b-jet efficiency
  - light-jet and c-jet misidentification efficiencies of 0.3% and 12.5% respectively.
- m_{bb} reconstructed from two b-tagged jets



ΔR(b,b) between the two Higgs candidate jets vs. P^V_T is used to categorise the signal (SR) and control regions (CRs) which are then binned in P^V_T:
- CRs provide control of dominant backgrounds
- With increasing P^V_T S/B improves and this is exploited by the categorisation method





Total of 42 regions:
- [0, 1, 2] - lepton channels
- [2, 3(+)] - jets (3+ jets in 2 lepton channel only)
- [75, 150, 250+] GeV – P^V_T bins (75 < P^V_T < 150 GeV in 2 lepton channel only)
- [CR_{Low}, SR, CR_{HIGH}] – Control and Signal regions

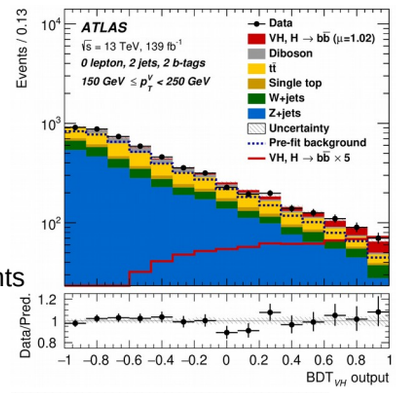
Multivariate Analysis

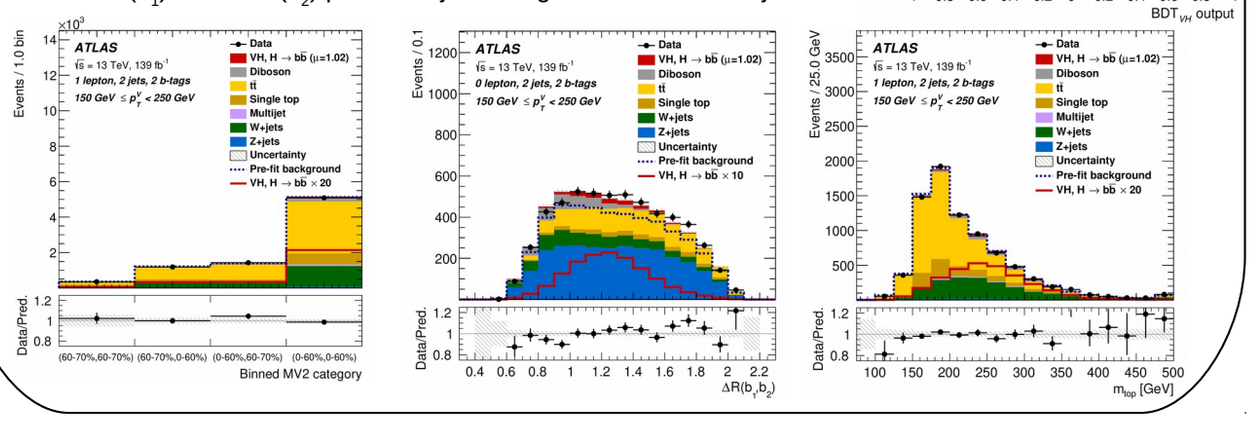
A boosted decision Tree (BDT) is used to discriminate the VH(->bb) signal from backgrounds

BDT is trained inclusively on 8 regions:
- Obtained by merging some of the analysis regions

22 variables to form final BDT discriminant:
- Different variables are used for different regions
  - Dependent on number of jets and lepton channel
- Outputs of BDT evaluated in each signal region

5 variables provide most distinguishing power:
- ΔR(b,b), P^T_V, m_{Top} (top quark mass) , and MV2 b-tagging discriminants
- m_{Top} helps with rejection of tt background
- MV2(b_1) and MV2(b_2) provide rejection against misidentified jets

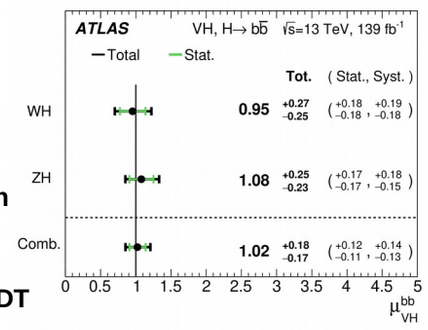




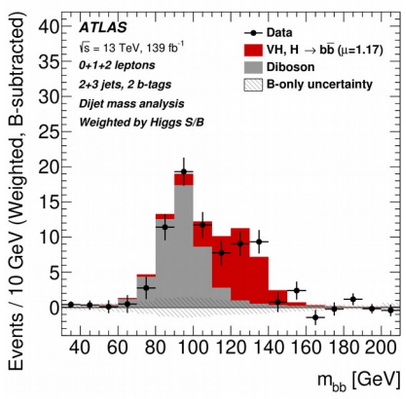
Results

Simultaneous binned likelihood fit in the 3-lepton channels using yields in the CRs and the BDT distributions in the SRs:
- Likelihood function, L(μ,θ), constructed as product of Poisson probability over the bins of input distributions
- Parameters of interest (PoI) extracted by maximising the likelihood
- Systematic uncertainties enter likelihood as nuisance parameters (NPs), θ

VH(->bb) signal strength defined as ratio of the observed signal yield to the expected yield is determined from combining all channels:
- Signal strength (μ), μ^{bb}_{VH} = 1.02 ± 0.18
- Observation of VH with 6.7σ
- Observation of ZH with 5.3σ
- Strong evidence of WH with 4.0σ

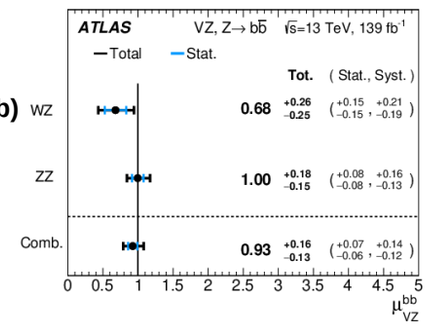


Di-jet mass and diboson cross checks performed to validate main results

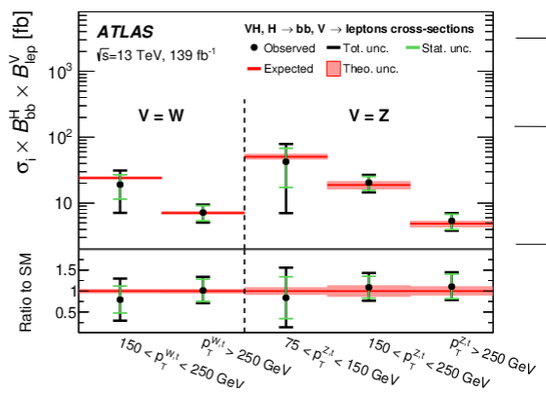


Use di-jet mass (m_{bb}) instead of BDT discriminant in the SR:
- μ^{bb}_{VH} = 1.17 ± 0.24
- Observation of VH with 5.0σ

Validation with diboson (VZ, Z→bb) analysis using BDT:
- Validates VH(->bb) analysis
- μ^{bb}_{VZ}= 0.93 ±0.15
- Good agreement with SM prediction

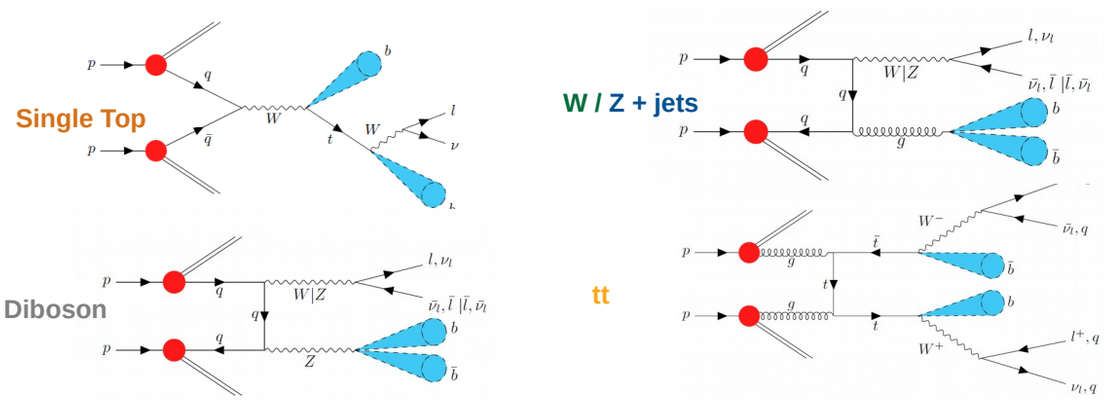


Differential measurements of the VH, H→bb cross section reached unprecedented precision:



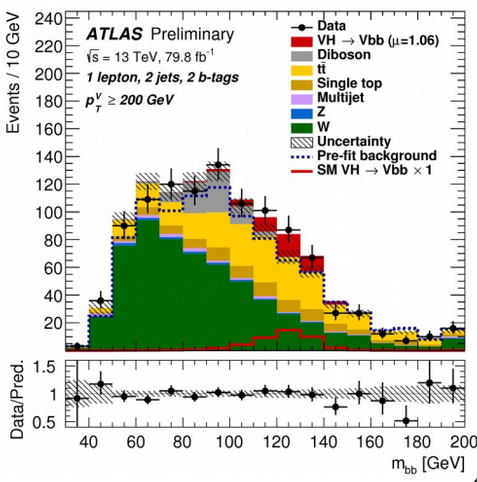
- Simplified template cross section measurement in 5 P^T_V bins
- Measured VH cross section times the H→bb and V→leptons branching fractions, σ X B, together with SM predictions
- Cross sections are consistent with SM expectations

Background Modelling



Four dominant backgrounds modelled using Monte Carlo generators:
- Most normalisations determined from final fits to data
- Exceptions use data driven method for estimation of:
  - MJ background in 1 lepton channel using template fit
  - Top background in 2 lepton channel using e-μ CR data

BDT re-weighting technique:
- Extract shape uncertainties in W+jets and tt backgrounds.



References:
[1] ATLAS Collaboration, Measurements of WH and ZH production in the H→bb̄ decay channel in pp collisions at 13 TeV with the ATLAS detector, Eur. Phys. J. C 81 (2021) 178
[2] Feynman Diagrams courtesy of Dwayne Spiteri, Higgs boson studies: associated production with a vector boson and decay into b-quarks using the ATLAS Run-2 dataset, CERN-THESIS-2021-002

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ATLAS EXPERIMENT