# Searches for bottom quark decays of the Higgs boson in CMS

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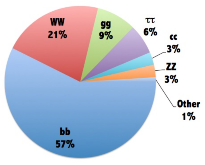
**Nadezda Chernyavskaya for the CMS collaboration**

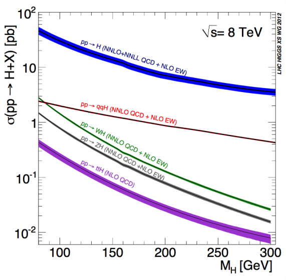
## Introduction

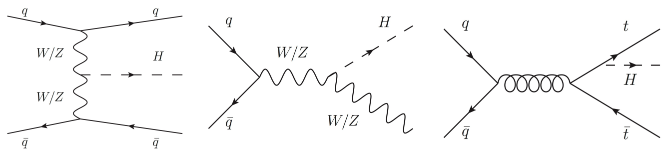
Measurements of the Higgs boson couplings through production cross sections and decay BR are important to verify the compatibility with the SM or find hints of BSM physics.
In the SM a Higgs boson with mass 125 GeV decays to bottom quarks with the *largest BR 58 %.*




*Production mechanisms*

Higgs bosons can be produced at the LHC via various mechanisms. To search for b-quark decays the important ones are the associated production with a vector boson(VH) or a top pair(ttH), and vector boson fusion(VBF).

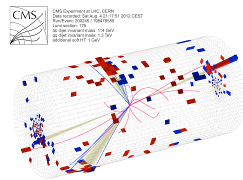



## VBF Analysis Strategy

The main challenge in the VBF H→bb channel is a *large QCD background.* A dedicated trigger is necessary for an adequate signal acceptance. The search is performed exploiting the very particular topology of the VBF process.

- 4-jets final state:
  - 2 VBF legs(large Δη and $m_{qq}$)
  - 2 b-jets
- no color flow between the VBF jets(central rapidity gap)



*The strategy of the analysis:*

1. develop dedicated topological trigger
2. use MVA methods to discriminate S/B
3. perform a fit on the $m_{bb}$ spectrum

*Samples:*

**Set A**(Nominal)
- dedicated trigger
  - L1: $p_T$ cuts for 3 leading jets
  - HLT: $p_T$ cuts for 4 leading Calo/PF jets + b-tag + VBF

**Set B**(Parked)
- general purpose trigger
  - L1: dijet
  - HLT: 2 Calo jets $p_T$>35 GeV + VBF kinematics

*Events selection:*

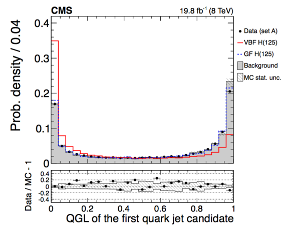
Set A:
$p_T^{1,2,3,4}$>80,70,50,40 GeV
$|\Delta\eta_{qq}|$>2.5 and $\Delta\phi_{bb}$<2.0
2 loose b-tags
$m_{qq}$>250 GeV

Set B:
$p_T^{1,2,3,4}$>30 GeV
$|\Delta\eta_{qq}|$>3.5 and $\Delta\phi_{bb}$<2.0
b-tags:loose,medium
$m_{qq}$>700 GeV

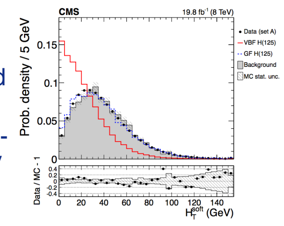
## VBF Event Properties

The sensitivity of the analysis could be improved using certain properties of the final state :

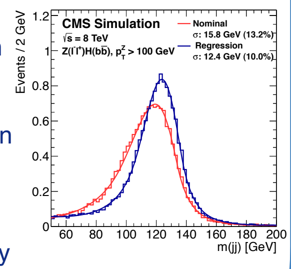
1. **QGL quark-gluon jets discriminator**
   - QCD BG - gluon jets
   - VBF signal - quark jets
   - QGL is built exploiting differences in jet composition and structure




2. **Soft QCD activity**
   - Discriminator between QCD processes with strong color flow and VBF signal without it
   - $H_T^{soft}$, reconstructed charged tracks - additional tracks associated with PV

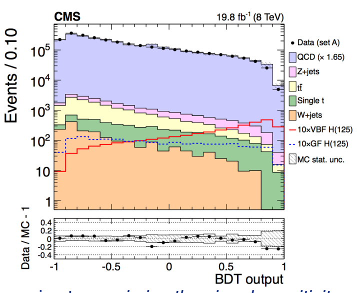



3. **b-jet energy regression**(*all production mechanisms*)
   - b-jet energy response and resolution are worse than one for light quarks(due to neutrinos)
   - train regression targeting jet $p_T$ at gen level
   - provide a corrective factor to the energy of b-jets
   - Higgs mass resolution is improved by ~ 20%




## BDT

Several discriminating variables are combined and used to train MVA(BDT) to separate VBF signal from the overwhelming QCD BG. ($m_{bb}$ is NOT used!)




Events are divided in 9 BDT output categories to *maximise the signal sensitivity.*

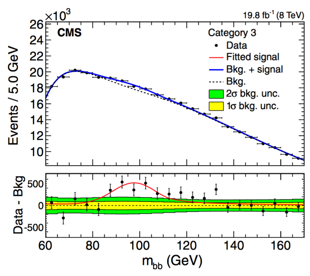
## Fit to data

QCD shape - data-driven + transfer functions for cats
Z&Top BG - from simulation
VBF - Crystal ball + pol BG

$$f(m_{bb}) = \mu_{i,H} \cdot N_{i,H} \cdot H_i(m_{bb};k_{JES},k_{JER}) + N_{i,Z} \cdot Z_i(m_{bb}) + N_{i,top} \cdot T_i(m_{bb}) + N_{i,QCD} \cdot R_i(m_{bb}) \cdot Q(m_{bb};p)$$

*Binned maximum-likelihood fit* of $m_{bb}$ is done in all cats.

The fit procedure is validated by fitting the known Z resonance. The best fitted signal strength is $\mu = 1.10^{+0.44}_{-0.33}$ with obs (exp) significance of 3.6σ (3.3σ).

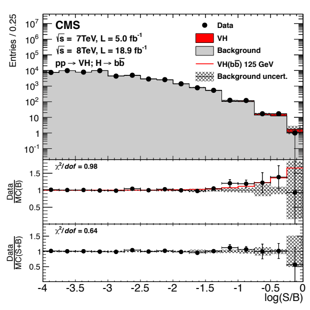


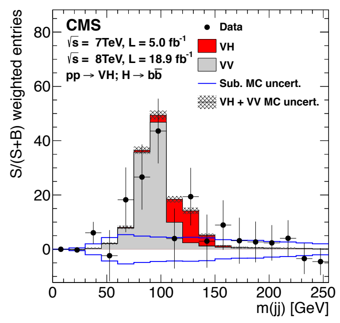

## VH

1. The presence of vector boson in final state highly suppress QCD BG. Requirement on large boost of the vector boson reduces BG from W/Z production associated with jets.

2. BDT is trained to distinguish Signal from BG for several categories(e/μ, $p_T$(V)). The cross-check is performed using dijet invariant mass spectrum(40% lower sensitivity).

3. Control regions enriched in V+light and heavy flavour jets and tt-bar events are used to assure Data/MC agreement in BDT and scale factors are derived and applied.



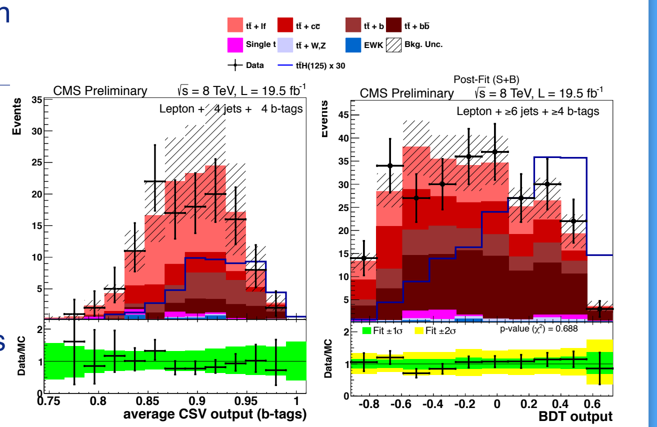




## ttH

1. ttH events are categorized according to the multiplicities of jets, b-jets and leptons. The main BG is tt-bar with additional jets.

2. BDT is trained to discriminate Signal from BG. BDT uses the information about object kinematics, event shape, and the CSV b-tag discriminant.

**Fit of the BDT output for the Signal**




## Results

Taking into account all systematic uncertainties we get final combination of all Standard Model CMS searches for H→bb.

| H → bb Channel | Best fit (68% CL) Observed | Upper limits (95% CL) Observed | Upper limits (95% CL) Expected | Signal significance Observed | Signal significance Expected |
|---|---|---|---|---|---|
| VH | $0.89 \pm 0.43$ | 1.68 | 0.85 | 2.08 | 2.52 |
| $t\bar{t}$H | $0.7 \pm 1.8$ | 4.1 | 3.5 | 0.37 | 0.58 |
| VBF | $2.8^{+1.6}_{-1.4}$ | 5.5 | 2.5 | 2.20 | 0.83 |
| Combined | $1.03^{+0.44}_{-0.42}$ | 1.77 | 0.78 | 2.56 | 2.70 |

Table. Observed and expected 95% CL limits, best fit values on the signal strength parameter μ = σ/σ$_{SM}$ and signal significances for m(H) = 125 GeV, for each H→bb channel and their combination.

**The fitted signal strength of the combination for m(H) = 125 GeV $\mu = 1.03^{+0.44}_{-0.42}$ with a significance of 2.6 standard deviations.**

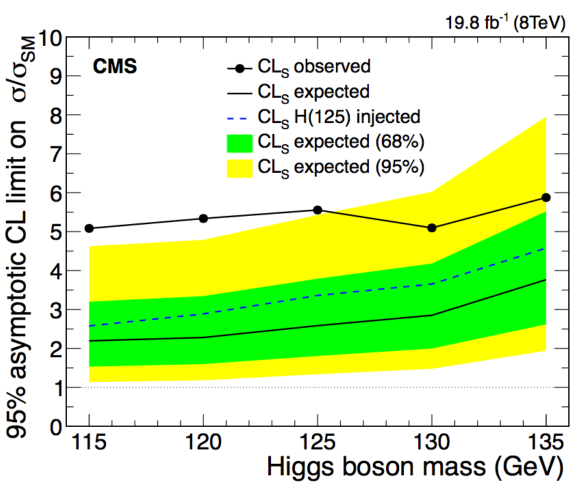



Figure. 95% asymptotic CL limits on the signal strength as a function of the Higgs boson mass for VBF production channel.

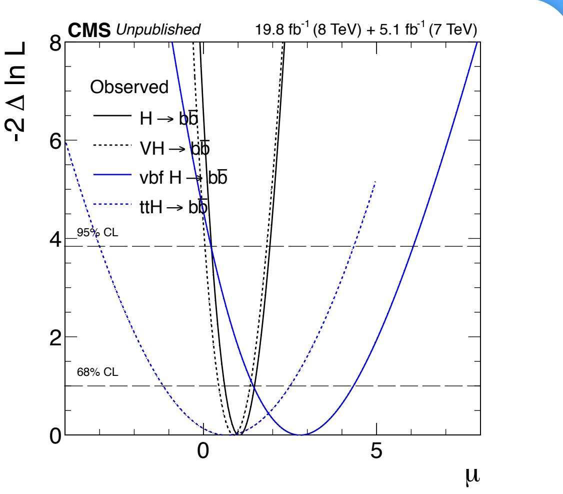



Figure. Observed likelihood for the VH, ttH and VBF production mode, with H→bb.

## References

1. Search for the standard model Higgs boson produced through vector boson fusion and decaying to bb. CMS PAS HIG-14-004. **PhysRevD.92 032008**
2. Search for the standard model Higgs boson produced in association with a W or a Z boson and decaying to bottom quarks. CMS-HIG-13-012. **Phys.Rev.D 89 012003**
3. Search for the SM Higgs produced in association with top quarks and decaying to bottom quarks or tau leptons. CMS-HIG-13-019. **JHEP05(2013)145**