Search for the standard model Higgs boson produced in vector boson fusion and decaying to bottom quarks using the Run 1 and 2015 Run 2 data samples in CMS

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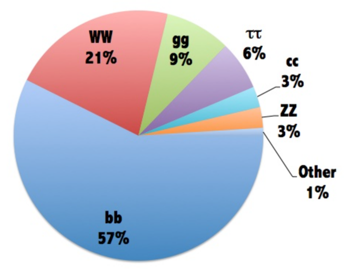
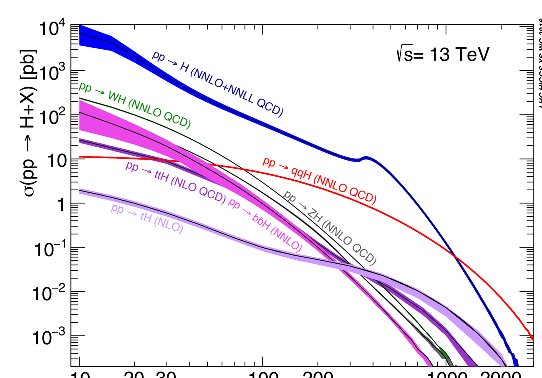
Introduction

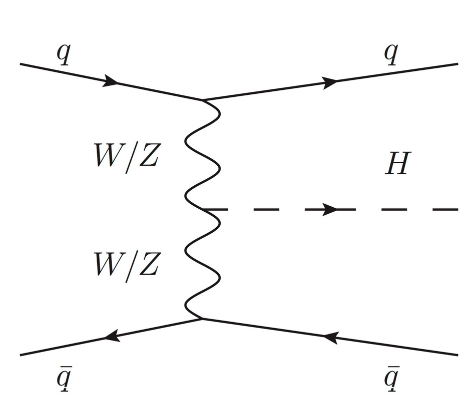
Measurements of the Higgs boson couplings through production cross sections and decay BR are important to verify the compatibility with the SM or find hints of BSM physics.
In the SM a Higgs boson with mass 125 GeV decays to bottom quarks with the *largest BR 58 %.*



Production mechanisms

Higgs bosons can be produced at the LHC via various mechanisms. Vector boson fusion(VBF) has the second largest production cross-section after gluon-fusion. However, fully hadronic final state brings challenges to the analysis.

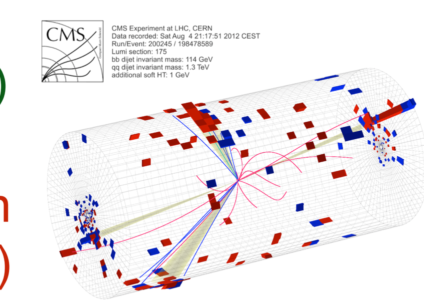




VBF Analysis Strategy

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 $\Delta\eta$ and m_{qq})
- 2 b-jets
- suppressed 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

Trigger paths:

L1 : 3 jets with $p_T(1^{st}) > 84$ GeV; $p_T(2^{nd}) > 68$ GeV; $p_T(3^{rd}) > 48$ GeV and at most 1 forward jet with $2.6 < \eta < 5.2$

The HLT b-tagging algorithms"Combined Secondary Vertex" (CSV) is evaluated using HLT regional tracking around the jets.

HLT : 4 PF jets with $p_T(1^{st}) > 92$ GeV; $p_T(2^{nd}) > 76$ GeV; $p_T(3^{rd}) > 64$ GeV; $p_T(4^{th}) > 15$ GeV and 1 PF jet with CSV > 0.78

DoubleB
- 2^{nd} b-jet with CSV > 0.58
- 2 q-jets with highest p_T

SingleB
- q-jets pair with the largest $|\Delta\eta_{qq}|$
- 2^{nd} b-jet remaining out of 4 p_T leading jets

Event Reconstruction

b-likelihood

b-jets are crucial for the analysis to reconstruct Higgs boson. The distinction between light and b-jets is done by the means of MVD that takes into account the jet b-tag, η and p_T and their respective rankings. For the SingleB set *signal reconstruction is improved by* **5%**.

Events selection:

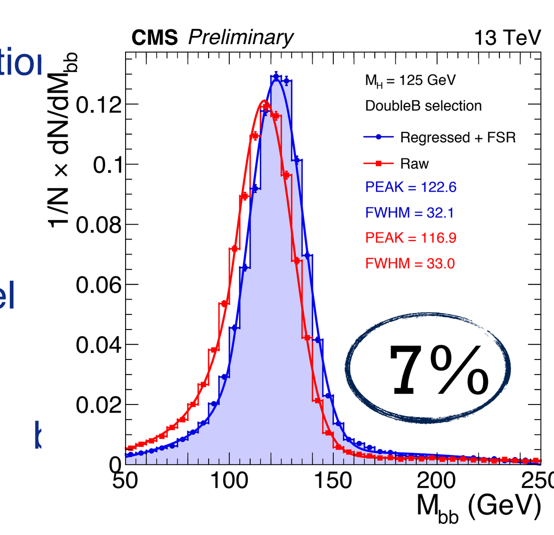
$p_T^{1,2,3,4} > 92, 76, 64, 30$ GeV

DoubleB
- CSV > 0.5
- $m_{qq} > 200$ GeV
- $|\Delta\eta_{qq}| > 1.2$
- $\Delta\phi_{bb} < 2.4$

SingleB
- 2 b-jets with highest b-likelihood
- $m_{qq} > 460$ GeV
- $|\Delta\eta_{qq}| > 4.1$
- $\Delta\phi_{bb} < 1.6$

b-jet energy regression

- b-jet energy response and resolution are worse than one for light quarks(due to neutrinos)
- it takes into account jet composition properties
- trained targeting jet p_T at gen level
- provides a corrective factor to the energy of b-jets
- Higgs mass resolution improved 5%. Recovering FSR jet gives a *final improvement 7%*

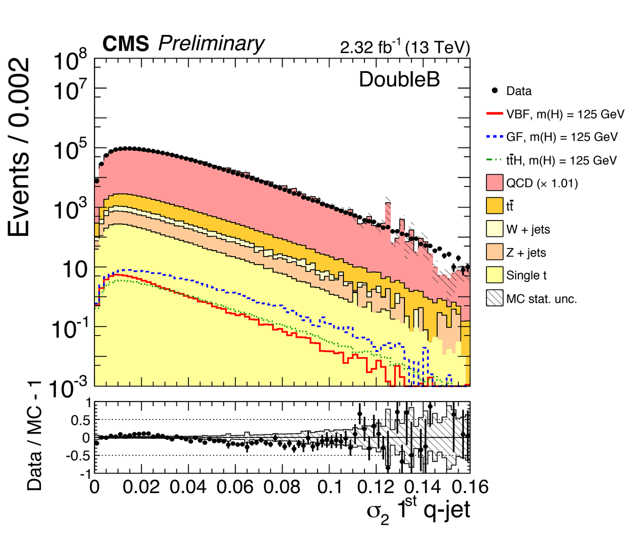


VBF Event Properties

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

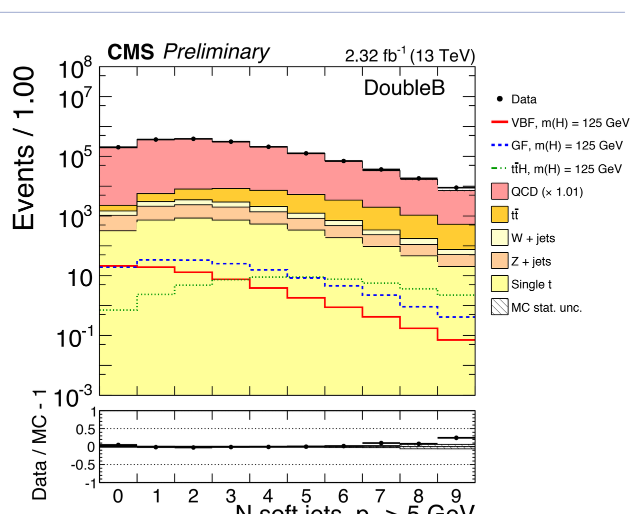
1. QGL quark-gluon jets discrimination

- QCD - mostly gluon jets
- VBF signal - quark jets
- VBF signal events have narrower jets wrt. to gluon enriched jets in QCD and GF signal
- single jet observable σ_2, the minor RMS of the distribution of jet constituents in the η-ϕ plane



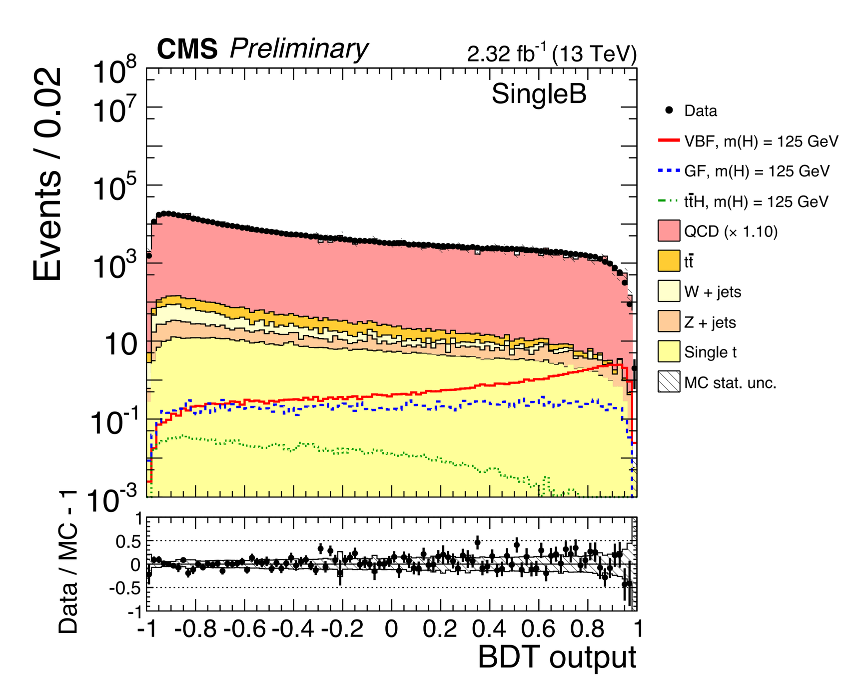
2. Soft QCD activity

- Discriminator between QCD processes with strong color flow and VBF signal with suppressed
- N^{soft}, reconstructed charged tracks - additional tracks associated with PV



BDT

Several discriminating variables are combined and used to train MVA(BDT) to separate VBF signal from the overwhelming QCD BG. The variables are NOT correlated to m_{bb}
Events are divided in 7 BDT output categories CAT1–7 to *maximise the signal sensitivity.*



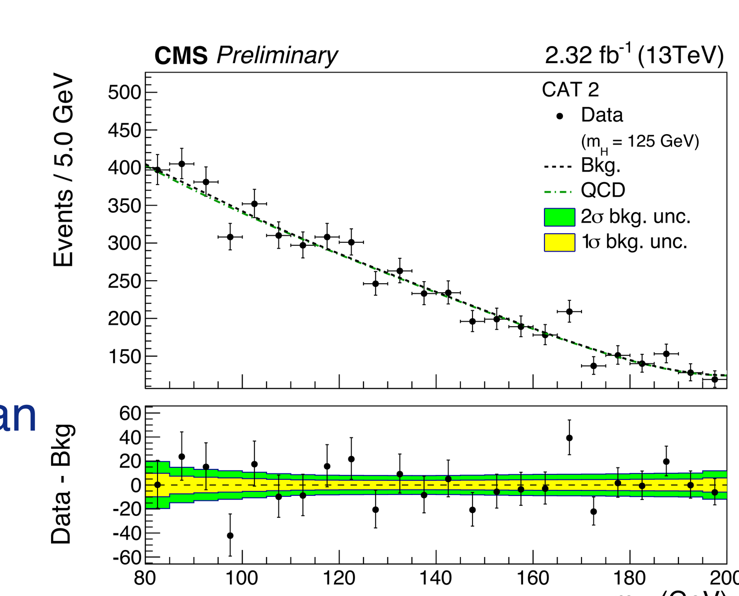
Fit to data

QCD shape - data-driven + transfer functions for cats
Z/W + jets - from simulation, gaussian curve
Top BG - from simulation, Crystal ball + 3^{rd} order polynomial
Signal(VBF+GF) - Crystal ball + 3^{rd} order polynomial

$$f_i(m_{b\bar{b}}) = \mu_H N_{i,H} H_i(m_{b\bar{b}}; k_{JES}, k_{JER}) + N_{i,z} Z_i(m_{b\bar{b}}; k_{JES}, k_{JER}) + N_{i,top} T_i(m_{b\bar{b}}; k_{JES}, k_{JER}) + N_{i,QCD} K_i(m_{b\bar{b}}) B(m_{b\bar{b}}; \vec{p}_{set})$$

- transfer functions K_i determined per category wrt. CAT1/4
- floating normalizations for top & Z+jets
- nuisances k_{JES} and k_{JER} for position and the width of the gaussian

Perform a simultaneous, binned maximum likelihood fit with full model in all categories CAT1–7



Results

Taking into account all systematic uncertainties we get final result of search for VBF H→bb with CMS at 13 TeV.

The expected **upper limits** in the absence of a signal is 5.0 σ_{SM}, while the observed upper limit is 3.0 σ_{SM}, and the **fitted signal strength** is $\mu = \sigma/\sigma_{SM} = -3.7^{+2.4}_{-2.5}$

Combination with 8 TeV :

$H \longrightarrow b\bar{b}$	Exp. limit	Obs. limit	Exp. sign.	Obs. sign.	expected μ	fitted μ
13 TeV	5.0	3.0	0.4	0.	$1^{+2.5}_{-2.4}$	$-3.7^{+2.4}_{-2.5}$
8 TeV + 13 TeV	2.2	3.4	0.9	1.2	$1^{+1.1}_{-1.1}$	$1.3^{+1.2}_{-1.1}$

The fitted signal strength of the combination 8 TeV + 13 TeV for m(H) = 125 GeV $\mu = 1.3^{+1.2}_{-1.1}$, with a significance of 1.2 σ.

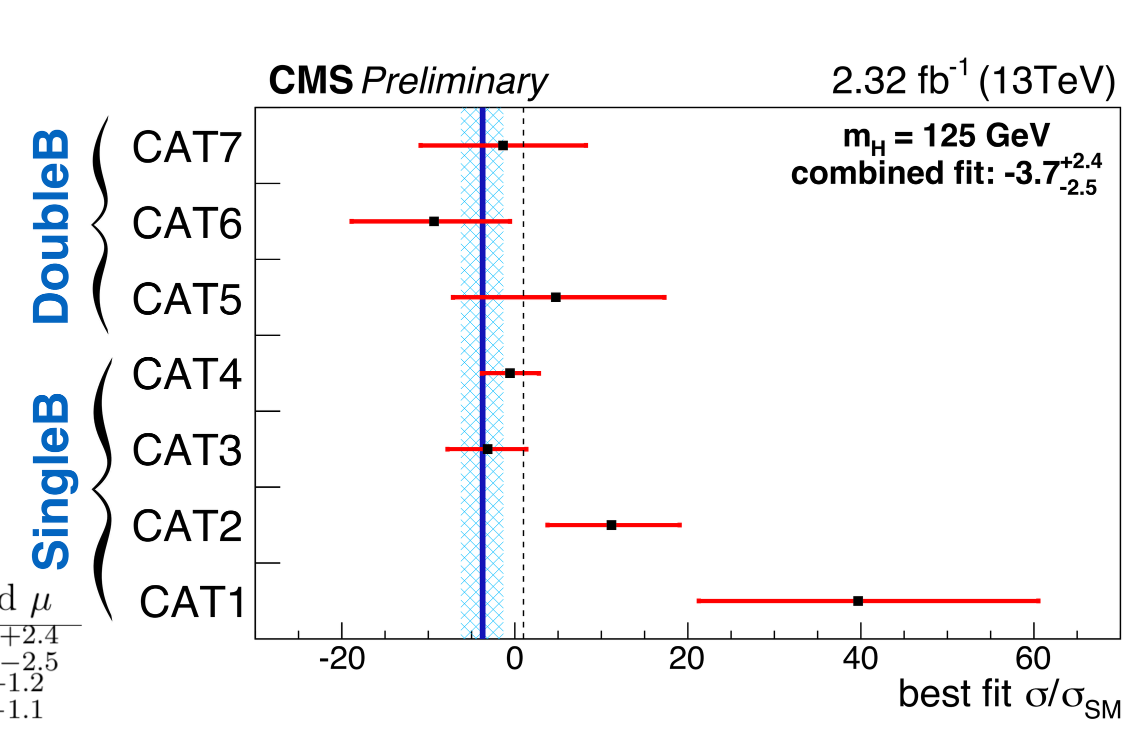


Figure. Fitted signal strengths $\mu = \sigma/\sigma_{SM}$, for each individual data category and with all categories combined, under the Higgs boson mass hypothesis m_H = 125 GeV.

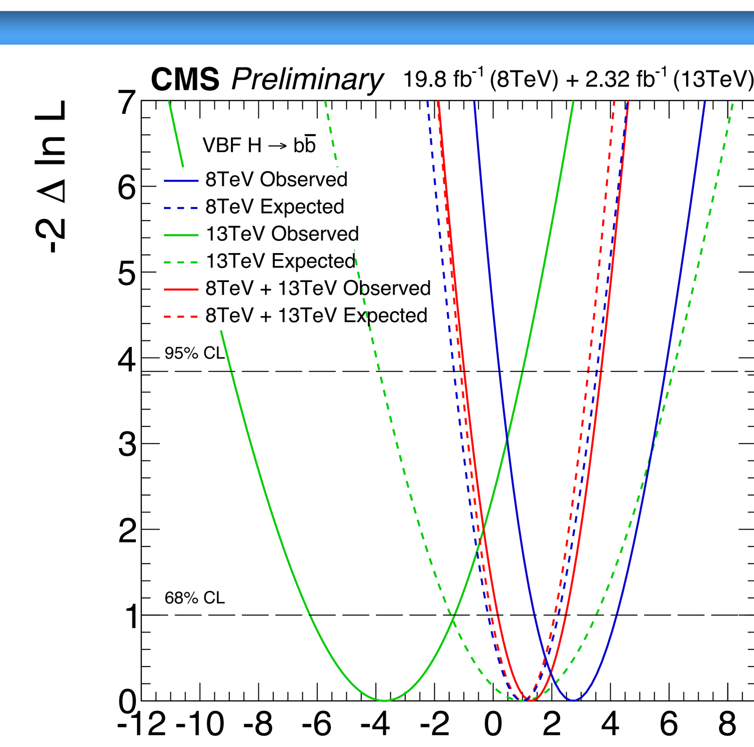


Figure. Likelihood profile of the signal strength $\mu = \sigma/\sigma_{SM}$ with m_H = 125 GeV, using 8 TeV, 13 TeV data and for the combination.

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 through vector boson fusion and decaying to bb with proton-proton collisions at √s = 13 TeV.* ***CMS PAS HIG-16-003***