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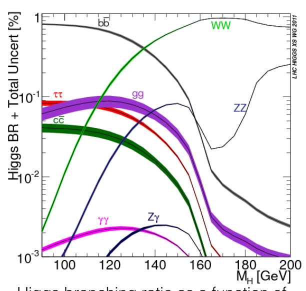
Search for the Standard Model Higgs Boson Produced in Association with a Z Boson, and Decaying to Bottom Quarks.

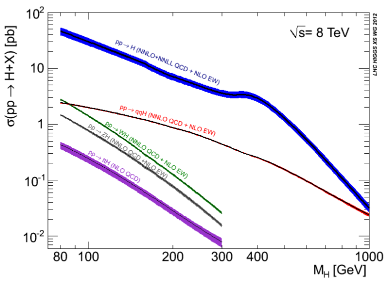
Gaël L. Perrin (ETH Zurich), on behalf of the CMS Collaboration

Motivations

- The **Higgs boson** was discovered in 2012 by the CMS and ATLAS collaborations at CERN, using leptonic decay channels ($H\rightarrow\gamma\gamma$, $H\rightarrow ZZ^{*}$). A measurement of the **Yukawa coupling between the Higgs and the b quark** is an important test of the Standard Model of particle physics (SM).
- In the SM, a Higgs boson with mass 125 GeV decays to bottom quarks with the **largest BR: 58%**.
- The additional vector boson highly suppress the QCD background, while also providing an efficient trigger path.

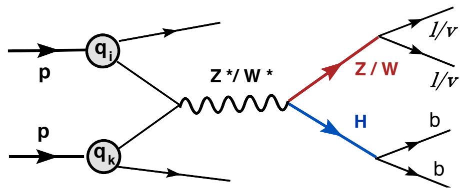


Higgs branching ratio as a function of the Higgs mass. The branching ratio is 58% for a mass of 125 GeV.



Standard Model Higgs boson production cross sections as functions of the Higgs mass at centre-of-mass energy of 8 TeV.

Analysis Strategy



The search is performed on **Higgs decaying to bb, produced with an associated Z boson decaying leptonically (Z(ll)Hbb)**.This channel is combined with two other topologies: one with the Z decaying into two neutrinos (Z(vv)Hbb)and the second where the Higgs is produced with an associated W decaying to a neutrino and a lepton (W(lv)Hbb).

The **Higgs boson requires to be boosted (p_T > 100 GeV).** This selection reduces large backgrounds from W and Z production in association with jets and top quark production, makes accessible the Z(vv)Hbb channel via large missing transverse energy and improves mass resolution of the Higgs candidates.

The **dominant backgrounds** are coming from:

- production of a Z boson associated with jets
- production of vector boson pairs
- production of top quark pair or a single top quark.

Signal and Control Regions

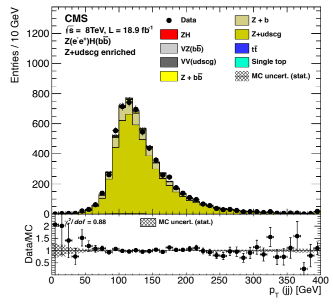
Signal Regions (SR) are event selections, defined to optimize the signal purity. Since this search is targeting events with a large boost, two signal regions split in the Z boson p_T are defined: a sensitive region with p_T > 100 GeV and a less sensitive with 50 GeV < p_T < 100 GeV.

Control Regions (CR) are defined to optimize the purity of specific backgrounds. They are used to study the modelling of the simulation.

Scale Factors (SF), correcting differences in normalisation between data and MC are derived by performing a simultaneous fit on the SR and CR.

Three CR are used in this analysis:

- CR enriched in DY +light quark and gluon jets
- CR enriched in DY+b jets
- CR enriched in top-antitop process.



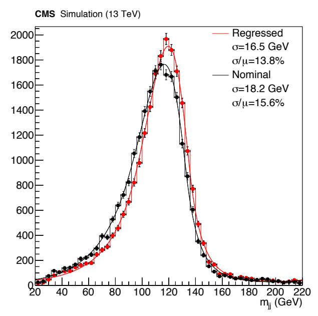
Dijet p_T distribution in the Z + light quarks control region for the electron channel.

b-jet Energy Regression

One of the **most discriminating variable** for this search is the **reconstructed dijet mass** (mjj), which is affected by energy losses due to neutrino emission within the b-jets. A **regression technique** is used to **correct the energy resolution and scale bias** for each of the b-jets.

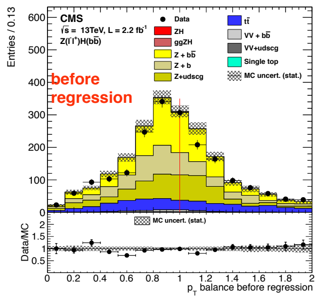
The regression is trained on simulations, targeting the generator level jet-p_T, and applied to each b-jet.

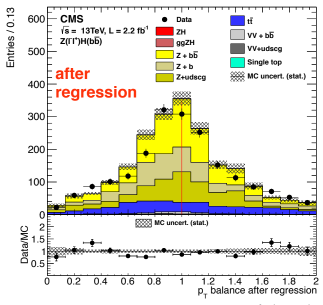
After applying the jet energy regression, the invariant mass distribution is **improved** by **12%**.



Reconstructed dijet m_{jj} mass before (black) and after (red) the regression. The improvement on the resolution for the regressed distribution is clearly visible.

The **regression is validated on data** using the ratio of the dilepton and dijet p_T (**p_T balance**). Applying the regression reduces the width of the p_T balance distribution, and shifts the mean peak closer to 1.



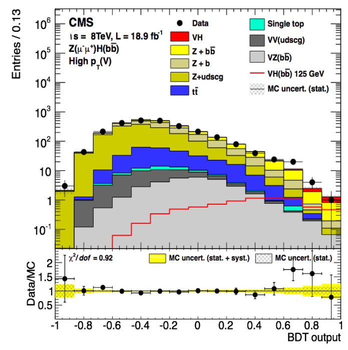


p_T balance distribution before (after) applying the regression is shown on the left (right) plot. The regression reduces the width of the distribution, while shifting the mean peak closer to 1.

Boosted Decision Tree

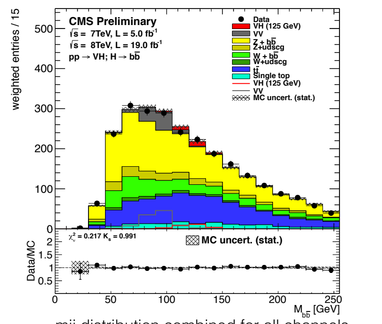
The **optimisation of the signal-background discrimination** within the SR is **performed** by requiring main selection cuts and using a **Boosted Decision Tree** (BDT), a multivariate analysis technique.

The BDT is trained on MC using a set of discriminating variables, as the dijet mass, to separate signal from background events. A **maximum likelihood fit** is then applied on the BDT output to **extract** the observed **signal contribution**.



BDT output trained on events with Z decaying to two muon. Events with low (large) BDT output values are more likely to be background (signal) events.

The **mjj-analysis** is performed as a cross-check to the BDT-based analysis. It is a simpler analysis done by performing **a fit to the shape of the mjj** distribution of the two jets associated to the reconstructed Higgs boson. The event selection for this analysis is more restrictive than the one used in the BDT analysis and is optimized for sensitivity in this single variable.

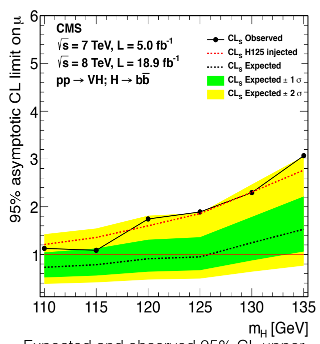


mjj distribution combined for all channels, reweighted in each vector boson p_T bin by a s/(s+b) factor computed in a mjj window between 105 and 150 GeV.

Results from Run I

Limits:

The results of all channels for both the 7 TeV and 8 TeV data are combined to obtain the upper limits on the product of the VH production cross section times the H → bb branching ratio relative to the SM cross section (signal strength μ). At a Higgs boson mass of 125 GeV and 95% CL, **the observed limit is 1.89 and the expected limit is 0.95**. The local **expected significance is 2.14σ** and **the observed 2.07σ**.



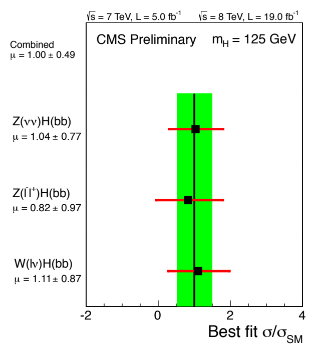
Expected and observed 95% CL upper limits on the signal strength as functions of the Higgs mass.

Signal Strength:

The **best fit of the signal strength** for the **Z(ll)H** channel is **0.82 ±0.97**.

The best fit of signal strength for **the combination of the three channels is 1 ±0.5**.

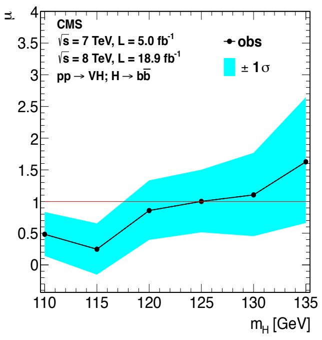
All the channels are compatible within errors and match very well with the standard model predictions. The cross-check mjj-analysis gives a signal strength of 0.8 ±0.7.



Most likely signal strength μ of all the three channels and their combination (green band), for a 125 GeV Higgs boson.

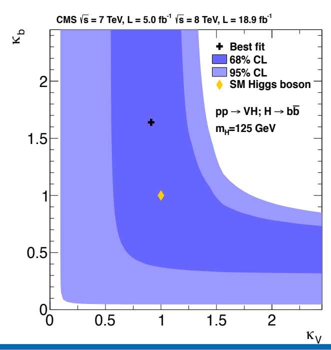
Mass dependency on μ :

The right plot shows the combined signal strength μ for all the channel, distributed as a function of the Higgs boson mass



Coupling Strenght in H→bb:

The right plot shows the best-fit values for the κ_V and κ_b parameters, where κ_V quantifies the ratio of the measured Higgs boson couplings to vector bosons, and κ_b the ratio of the measured Higgs boson partial width into bb; both are given relative to the SM values. The cross indicating the measured value is well compatible with the standard model point (κ_V, κ_b) =(1,1).



Reference:

1. *Search for the standard model Higgs boson produced in association with a W or a Z boson and decaying to bottom quarks. CMS PAS HIG-13-012.* ***PhysRev.D.89 012003***

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