MEASURING THE PROPERTIES OF THE HIGGS BOSON AT CMS

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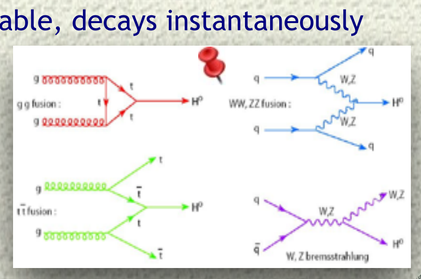
On behalf of the CMS Collaboration

Higgs Boson

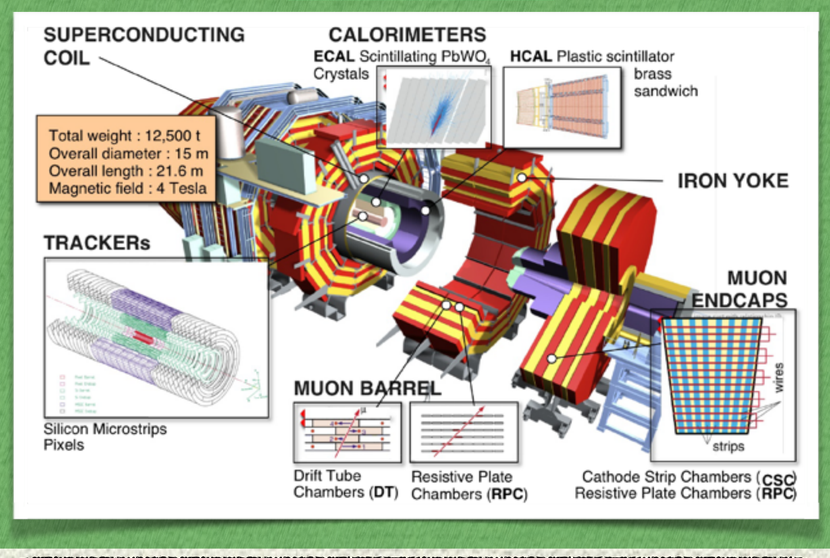
- Elementary particle
- Zero Spin
- No Electric charge
- No Color charge

- Highly unstable, decays instantaneously

Production of Higgs boson is possible via these four interactions shown in the figure



CMS Detector



Properties of Higgs Boson

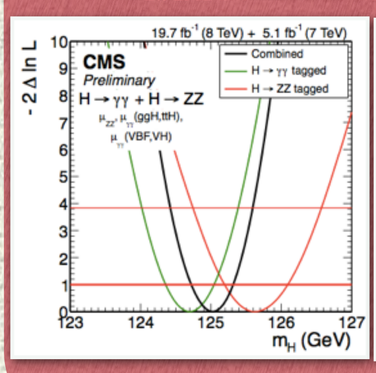
- After the discovery of a 125GeV particle it became very important to check whether it is really the Higgs boson as expected from the SM or does it imply physics beyond the SM.
- We perform some compatibility tests to check the consistency of various observations with the expectations for the SM Higgs Boson.

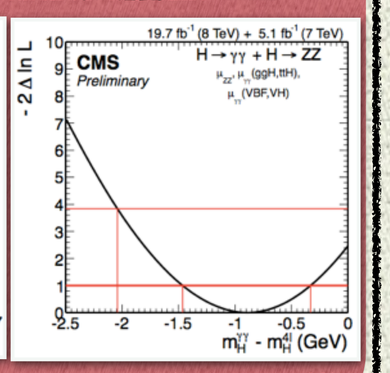
The properties of the Higgs Boson have been extensively studied in five decay modes: γγ, ZZ, WW, ττ, and bb

Mass Measurement

Measured the best-fit value of the **mass** of the new boson with the H → γγ and H → ZZ → 4l channels because of excellent mass resolution of the reconstructed diphoton and four leptons,

$$m_H = 125.03\ ^{+0.26}_{-0.27}\ (stat.)\ ^{+0.13}_{-0.15}\ (syst.)\ GeV$$





Two measurements agree at 1.6σ level & $m_H^{\gamma\gamma} - m_H^{4l} = -0.87^{+0.54}_{-0.59}$

Excess for m_H = 125 GeV

After measuring the mass at 125 GeV and fixing m_H, observed and expected significances for different decay modes were evaluated

Channel	Observed σ	Expected σ
H →ZZ	6.5	6.3
H →γγ	5.6	5.3
H →WW (t)	4.7	5.4
H →WW	4.3	5.4
H → ττ (t)	3.8	3.9
H → ττ	3.9	3.9
H →bb (t)	2.0	2.3
H →bb	2.1	2.3

(t) implies $t\bar{t}H$ production mode included

Higgs Boson Couplings

The event yield for a given production x decay modes is related as $(\sigma.\mathfrak{B})\ (x \to H \to ff) = \sigma_x\ .\ \Gamma_{ff}/\Gamma_{tot}$

where, σ_x : production cross section for x

Γ_{ff} : partial decay width for final state (ff)

Γ_{tot} : total decay width of Higgs Boson

Higgs boson can decay to particles beyond the standard model (BSM) so we keep:

$$\Gamma_{tot} = \Sigma\ \Gamma_{ff} + \Gamma_{BSM}$$

Difference from individual Higgs Analysis

1. Change in the value of m_H for which the significance of H → ZZ & H → WW analysis were done
2. Inclusion of channels from $t\bar{t}H$ analysis for H → WW, H → ττ and H → bb decay modes
3. Treating H → WW as part of the signal rather than background in H → ττ analysis

Combination Technique Used

I. To find *p*-values & Significance

- To quantify the presence of an excess of events over what is expected for the background, we use the test statistics *q*, where the likelihood appearing in the numerator is for the background only hypothesis :

$$q_0 = -2\ln\frac{L(obs\,|\,b,\hat{\theta}_0)}{L(obs\,|\,\hat{\mu}.s+b,\hat{\theta})}$$

where, s : signal expected under SM Higgs hypothesis
μ : signal strength modifier
b : backgrounds
q : nuisance parameters describing systematics uncertainties

- The value θ_0 maximises the likelihood in the numerator under the background only hypothesis, while μ and θ define the point at which the likelihood reaches its global maximum.
- Local *p*-value is defined as the probability under the background-only hypothesis, to obtain a value q_0 at least as large as that observed in the data, q_0^{data}:

$$p_0 = P(q_0 \geq q_0^{data}\,|\,b)$$

- The local significance *z* of a signal-like excess is then computed using one-sided Gaussian tail:

$$p_0 = \int_z^{+\infty} \frac{1}{\sqrt{2\pi}} \exp(-x^2/2)dx$$

II. To extract signal model parameter

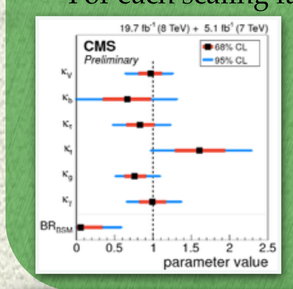
- Signal model parameters *a* are evaluated from a scan of the profile likelihood ratio *q(a)*.

$$q(a) = -2\ln\frac{L(obs\,|\,s(a)+b,\hat{\theta}_a)}{L(obs\,|\,s(\hat{a})+b,\hat{\theta})}$$

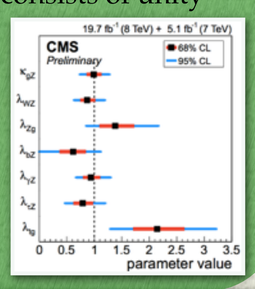
- The parameters $\hat{a}$ and $\hat{\theta}$ that maximise the likelihood, $L(obs\,|\,s(\hat{a})+b,\theta) = L_{max}$ are called the best-fit set.
- For 68% CL parameter of interest *a* are evaluated from $q(a_i) = 1$ and $q(a_i, a_j) = 2.30$ & for 95% CL as $q(a_i) = 3.84$ and $q(a_i, a_j) = 6.99$ for 1-D and 2-D respectively, with all other unconstrained model parameter treated in the same way as the nuisance parameters
- Overall statistical methodology for combination was developed by the ATLAS & CMS Collaborations in context of **LHC Higgs Combination Group.**

Model with six independent scaling factors

- Couplings to W & Z boson is scaled by κ_V
- Top quark, bottom quark & tau lepton are scaled by κ_t, κ_b & κ_τ
- Scale factor for I, II & III generation fermions are kept equal
- Effective couplings to gluons & photons have independent scaling factors κ_g & κ_γ & Partial width Γ_{BSM} is zero
- For each scaling factor, κ the measured 95% CL consists of unity



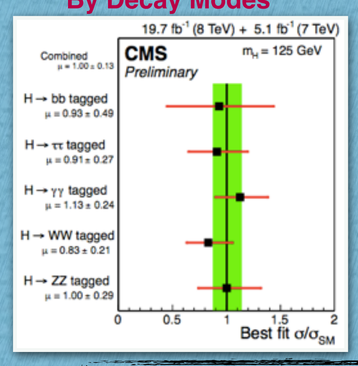
Plot on left summarise the fits for deviation in coupling for 6-parameter model and on right for 7-parameter including effective loop couplings



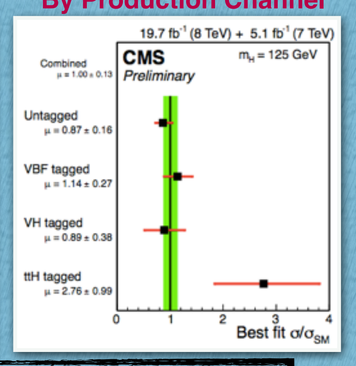
Signal Strength

The 68% CL region for the signal strength divided into different Decay Modes & Production Tags

By Decay Modes

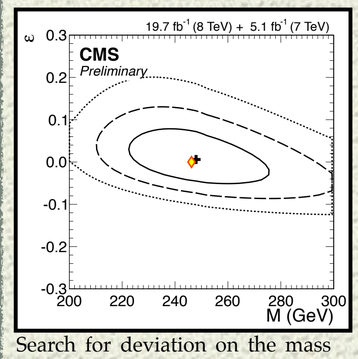


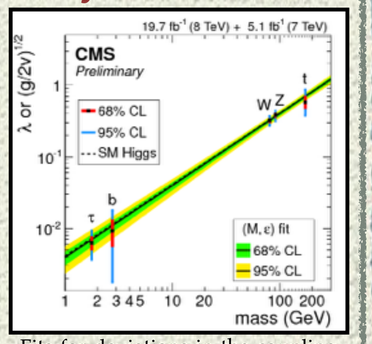
By Production Channel



$$\mu = 1.00\ \pm\ 0.09\ (stat.)\ ^{+0.08}_{-0.07}\ (theo.)\ \pm\ 0.07\ (syst.)$$

Best-fit results for independent signal strengths corresponding to decay modes (left) and main production processes (right) at 68% CL are shown:





In the left figure, the signal strength of the ***ggH*** & $t\bar{t}H$ and of the ***VBF*** & ***VH*** production modes are taken together

Other Compatibility Tests

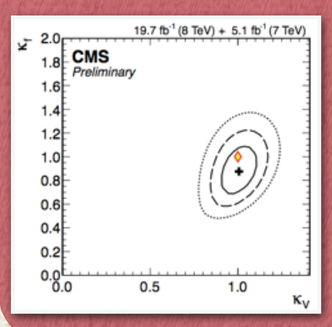
- **Custodial Symmetry :** For this test we check the consistency of the ratio $\lambda_{WZ} = \kappa_W/\kappa_Z$ with unity. λ_{WZ} comes out to be $0.94^{+0.22}_{-0.18}$.
- **Presence of BSM particles :** Parameters κ_γ and κ_g were scanned to get best-fit value at (1.14, 0.88) having (1, 1) within 95% CL. Also, $BR_{BSM} = \Gamma_{BSM}/\Gamma_{tot}$ is found to be in the interval [0.00,0.32] at 95% CL.
- **Asymmetries in couplings to fermions :** Ratios of couplings to down/up fermions ($\lambda_{du} = \kappa_d/\kappa_u$) or ratio with leptons and quarks ($\lambda_{lq} = \kappa_l/\kappa_q$) are close to unity.
- **Constraint on BR_{BSM} with free couplings : BR_{BSM}** is found to be in the interval [0.00,0.58] at 95% CL.

Summary

Search for deviation on the mass scaling factor ε and the vacuum expectation value parameter M

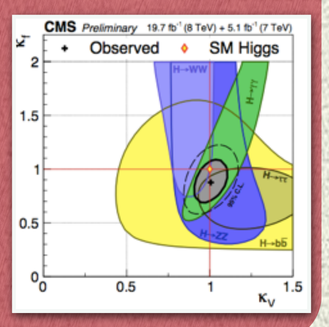
Fits for deviations in the coupling for the five-parameter model not effective loop couplings

Couplings to Vector Boson & Fermions



The left plot shows 2D likelihood scan for (κ_V, κ_f) phase space with 68% CL (solid), 95% CL (dashed) and 99.7% CL (dotted) curves. Point (1,1) lies within 68% CL.

The plot on right shows 68% CL coloured curves for individual channels and for overall combination (thick curve).



Conclusions

- ✔ Data corresponding to Run1 i.e. integrated luminosities up to 5.1fb^{-1} at 7TeV & 19.7fb^{-1} at 8TeV were considered for these studies
- ✔ The new particle ~125GeV is observed to decay to all gauge bosons & fermions with right proportion as expected from SM.
- ✔ Spin-parity measurements disfavour alternative hypotheses
- ✔ Signal strengths are consistent with the SM
- ✔ No sign for any other SM-like or BSM Higgs boson
- ✔ Compatibility tests are carried out to confirm properties of the Higgs Boson

REFERENCE: Precise determination of the mass of the Higgs boson and studies compatibility of its couplings with the Standard Model; *CMS PAS HIG-14-009*

ICHEP 2014 VALENCIA
37th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
2-9-JULY-2014-VALENCIA

ACKNOWLEDGEMENTS

I thank Dept. of Science and Technology (DST), Govt. of India for providing the financial support to work in the CMS experiment. I thank University Grants Commission (UGC), Govt. of India to help me carry out research work & make contributions towards the CMS project at LHC, CERN. I thank ICHEP organisers for providing the financial assistance to attend this conference.

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