Recent Results on the Higgs Boson Properties in the $H \to ZZ \to 4l$ decay channel at CMS

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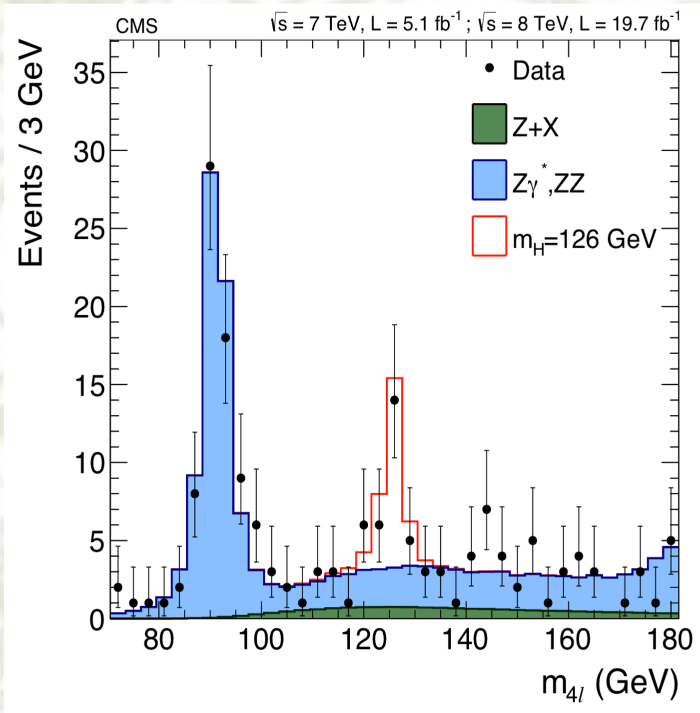
Abstract

The latest results on the measurement of the properties of the new boson with mass around 126 GeV [1][2] are measured in the $H \to ZZ \to 4\ell$ decay channel (ℓ = e, μ). The analysis uses pp collision data recorded by the CMS detector at the LHC, corresponding to integrated luminosities of 5.1 fb^{-1} at $\sqrt{s}$ = 7 TeV and 19.6 fb^{-1} at $\sqrt{s}$ = 8 TeV.

Analysis Strategy

The $H \to ZZ \to 4\ell$ analysis [3] is based on the **reconstruction**, **identification** and **isolation** of leptons. Each signal event consists of **two pairs of same-flavor and opposite-charge leptons** in the final state, compatible with a ZZ system.

The **sources of background** are the **irreducible four-lepton contribution** from direct ZZ (or Zγ*) production, the **reducible background** arising from *Zbb* and *tt* → *4ℓ* decays and the **instrumental contribution** due to a misidentification of the leptons.



Event selection and kinematics

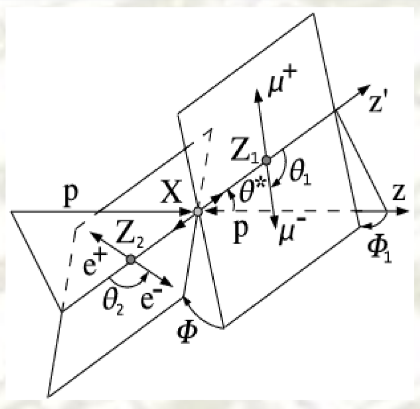
- $p_T^e > 5$ GeV and $p_T^\mu > 7$ GeV
- $p_T^1 > 20$ GeV and $p_T^2 > 10$ GeV
- $40 < m_{Z1} < 120$ GeV
- $12 < m_{Z2} < 120$ GeV
- $100 < m_{4\ell} < 1000$ GeV
- Isolation cut
- Impact parameter cut
- Final state radiation recovery

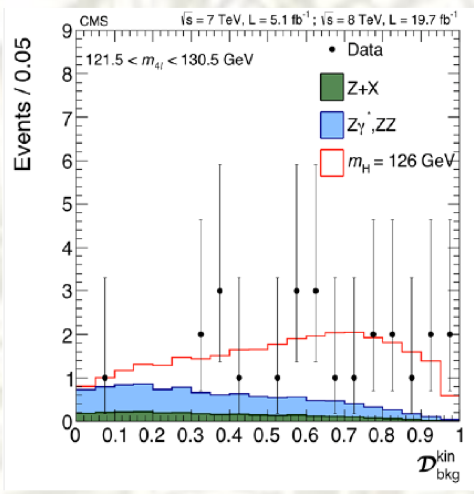
Kinematic Discriminant

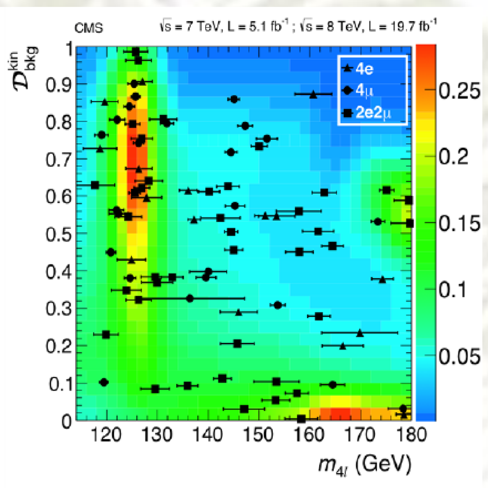
In order to **separate signal from background** events, a **kinematic discriminant** is defined ($\mathcal{D}_{bkg}^{kin}$), depending on the **five production and decay angles** and the **Z boson masses**. These variables fully describe the event topology and have a high discriminating power. The $\mathcal{D}_{bkg}^{kin}$ discriminant [4] is defined as

$$\mathcal{D}_{bkg}^{kin} = \frac{\mathcal{P}_{sig}^{kin}}{\mathcal{P}_{sig}^{kin} + \mathcal{P}_{bkg}^{kin}}$$

where $\mathcal{P}_{sig\,(bkg)}^{kin}$ is the probability for an event with given topology (angles and masses) to come from a signal (background) process.

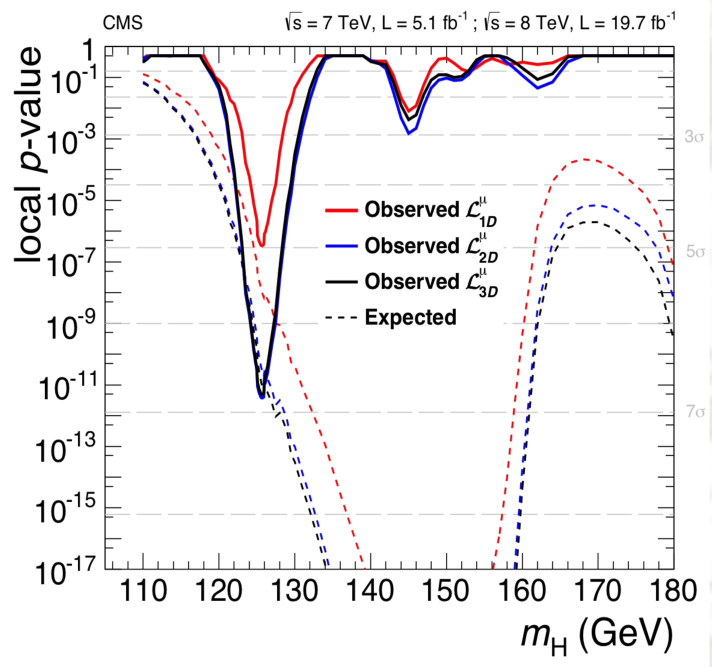






Significance and Signal Strength

The **minimum of the local p-value** is reached at $m_{4\ell}$ = 125.7 GeV and it corresponds to a local significance of 6.8 (for an expectation of 6.7). This is the only significant excess in the range m_H < 1 TeV.

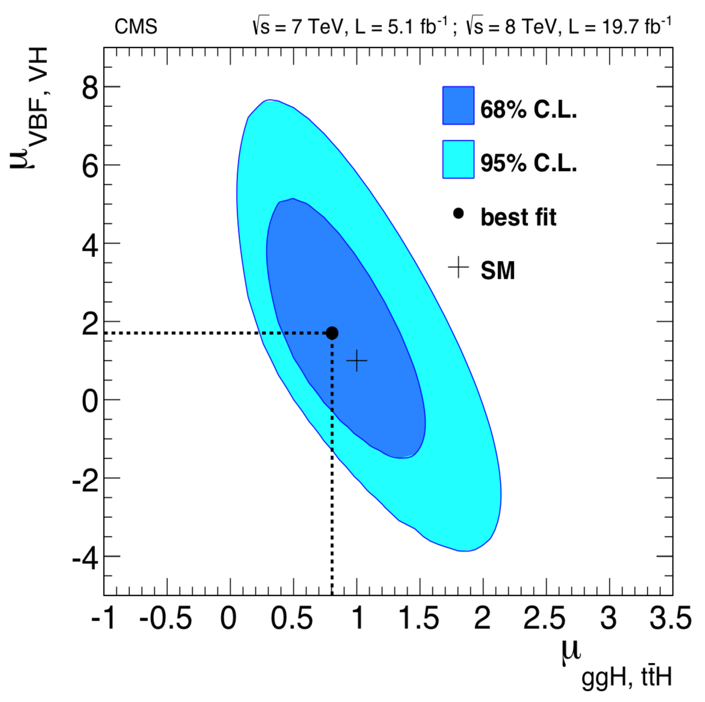


The parameter that describes the magnitude of the Higgs signal is the **signal strength modifier**, defined as the **ratio** of the **observed cross section** and the **cross section predicted by the SM** ($\mu = \sigma_{obs}/\sigma_{SM}$). The measured value of μ obtained at the best fit mass (m_H = 125.6 GeV) is:

$$\mu_H = 0.93^{+0.26}_{-0.23}\,(stat.)\,^{+0.13}_{-0.09}\,(syst.)$$

In addition, one can introduce two other **signal strength modifiers, sensitive to fermion** (gluon fusion, ttH) or **vector boson** (VBF, VH) **induced production**. A **2D fit** is thus performed in order to get the allowed region for ($\mu_{ggH,ttH}$, $\mu_{VBF,VH}$) and at 125.6 GeV it yields:

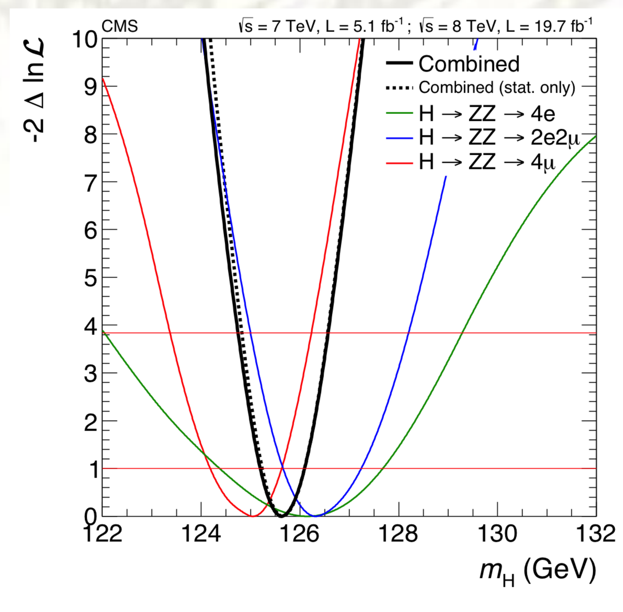
$$\mu_{ggH,ttH} = 0.80^{+0.46}_{-0.36}$$
$$\mu_{VBF,VH} = 1.7^{+2.2}_{-2.1}$$



Mass Measurement

The mass measurement is performed with a **three-dimensional fit** using for each event the **four-lepton invariant mass** ($m_{4\ell}$), the associated **per-event mass error** ($\mathcal{D}_m$) and the **kinematic discriminant** ($\mathcal{D}_{bkg}^{kin}$). Per-event errors are calculated from the **individual lepton momentum errors** and including them in the fit allows to gain 8% improvement in the Higgs boson mass measurement uncertainty. The fit procedure gives

$$m_H = 125.6 \pm 0.4\,(stat.) \pm 0.2\,(syst.)\text{ GeV.}$$

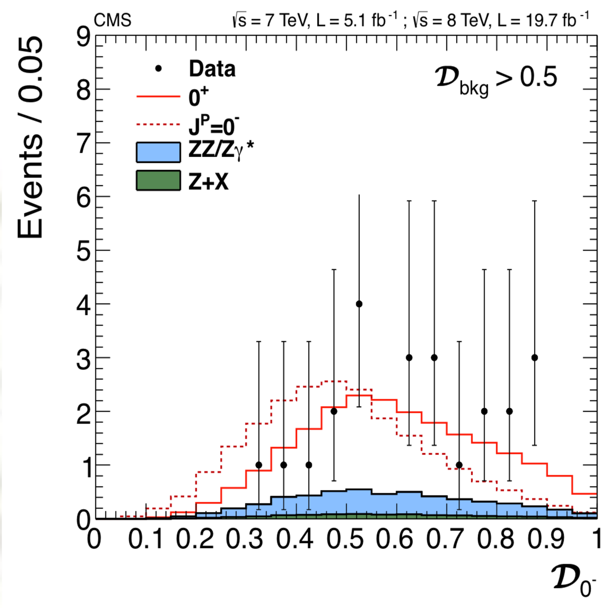


Spin-Parity Measurements

In order to determine the spin and the parity of the new boson, a **methodology with kinematic discriminants** is used. Two discriminants are defined:

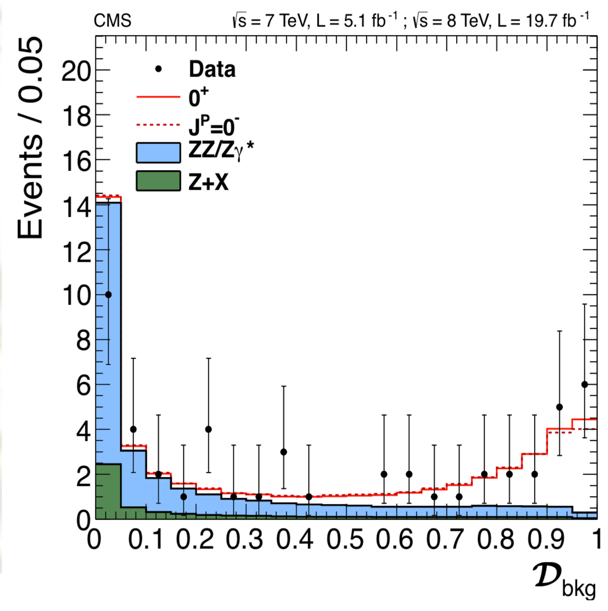
- $\mathcal{D}_{bkg}$, that separates SM Higgs from background events;
- $\mathcal{D}_{J^P}$, which discriminates an alternative hypothesis from the SM Higgs.

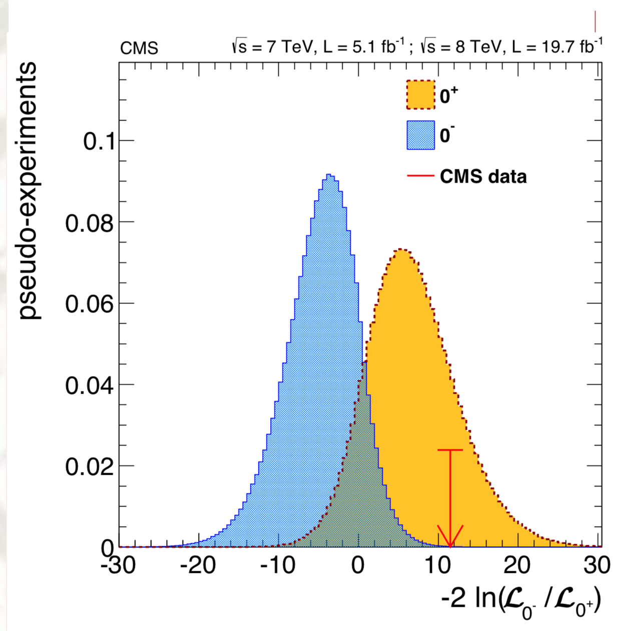
The different spin-parity hypotheses are thus tested using the **two-dimensional likelihood** $\mathcal{L}_{2D} = \mathcal{L}_{2D}(\mathcal{D}_{J^P}, \mathcal{D}_{bkg})$.

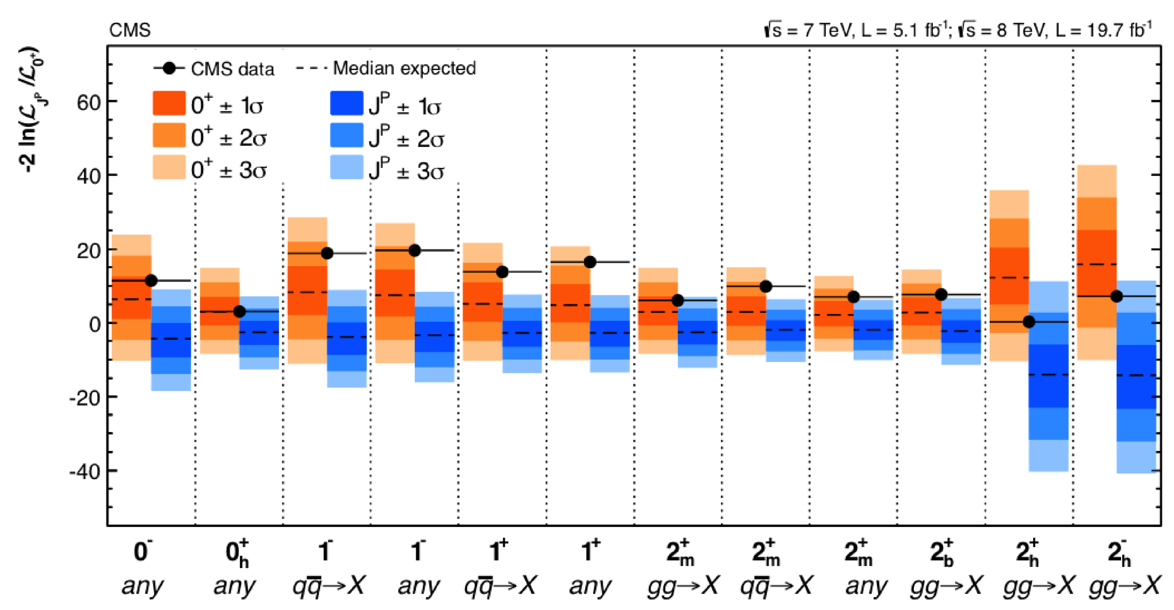


The **distribution of the test statistic** $q = -2\ln(\mathcal{L}_{J^P}/\mathcal{L}_{SM})$ is determined and it is examined with generated samples for m_H = 125.6 GeV.

A **confident levels** (CLs) **criterion** is defined as the ratio of the probabilities to observe, under the J^P and 0^+ hypotheses, a value of the test statistic q equal or larger than the one in the data. The data disfavor the alternative hypotheses J^P with a CLs value in the range 0.001 -10%.





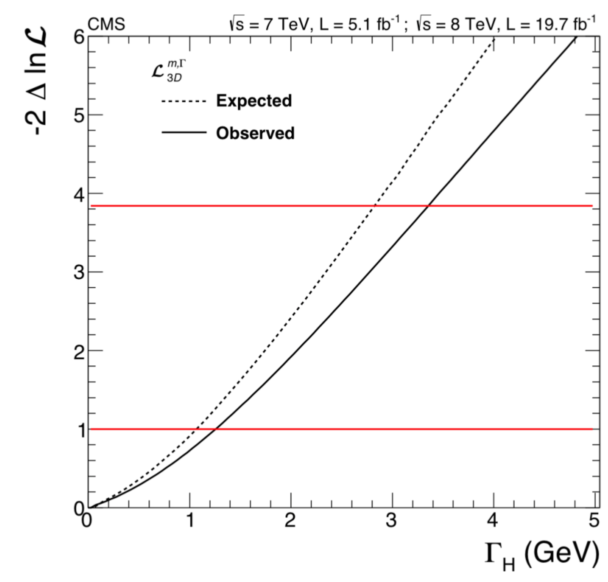


Width Measurement

At m_H = 125.6 GeV, the Standard Model predicts a Higgs **boson decay width** (Γ_H) of 4.15 MeV. A **direct** width **measurement** at the resonance peak is thus strongly **limited by experimental resolution**.

It is possible [5] to **constrain the Higgs boson width** using its **off-shell production and decay** away from the resonance. Indeed , one can obtain

$$\sigma^{on\text{-}shell}_{gg\to H\to ZZ} \sim \frac{g^2_{ggH}\,g^2_{HZZ}}{m_H\,\Gamma_H} \qquad \sigma^{off\text{-}shell}_{gg\to H\to ZZ} \sim \frac{g^2_{ggH}\,g^2_{HZZ}}{(2m_Z)^2},$$



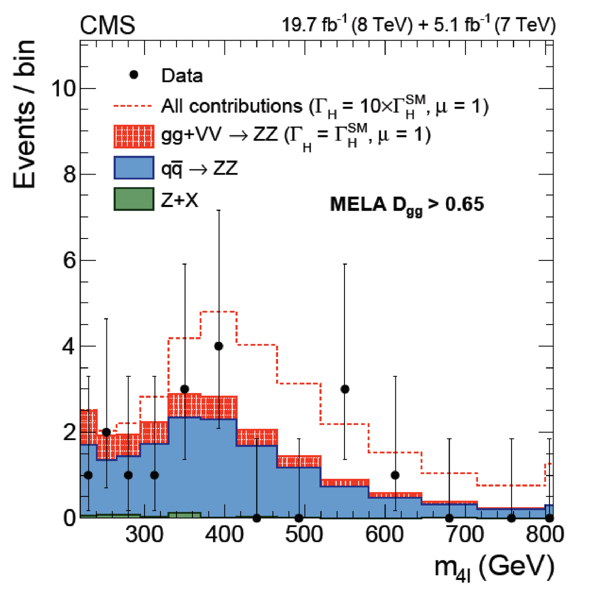
where g_{ggH} and g_{HZZ} are the couplings of the Higgs boson to gluons and Z bosons, respectively. Therefore, the value of Γ_H can be extracted by **measuring the ratio of the production in the off-shell and on-shell region**, taking into account the **destructive interference** with continuum $gg \to ZZ$, which is not negligible at high masses. In order to separate $gg \to ZZ$ events from the $qq \to ZZ$ process, the dominant background of the analysis, a kinematic discriminant is built ($\mathcal{D}_{gg}$).

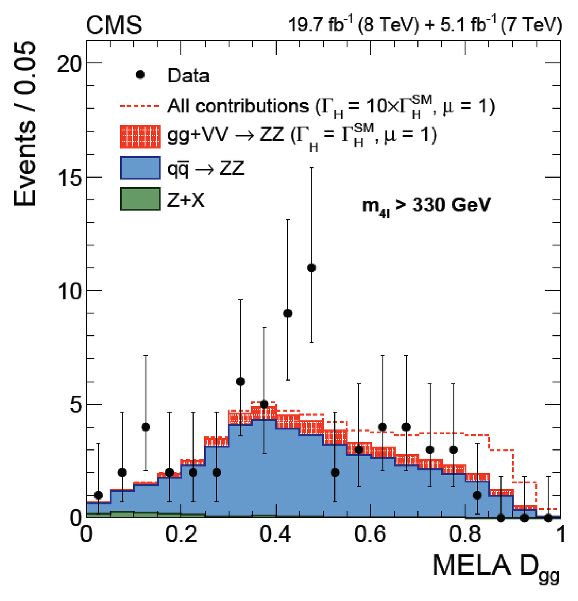
A **likelihood function** is defined for both the off-shell and the on-shell region, depending on the **total probability distribution functions**

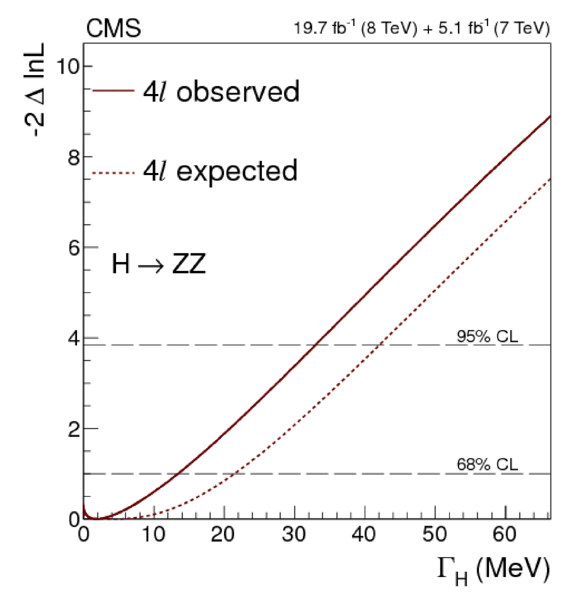
$$\mathcal{P}_{tot}^{off\text{-}shell} = \mu_{ggH} \times (\Gamma_H/\Gamma_0) \times \mathcal{P}_{sig}^{gg} + \sqrt{\mu_{ggH} \times (\Gamma_H/\Gamma_0)} \times \mathcal{P}_{int}^{gg} + \mathcal{P}_{bkg}^{gg} + \mathcal{P}_{bkg}^{qq} + \ldots$$

$$\mathcal{P}_{tot}^{on\text{-}shell} = \mu_{ggH} \times \mathcal{P}_{sig}^{gg} + \mathcal{P}_{bkg}^{gg} + \mathcal{P}_{bkg}^{qq} + \ldots$$

where parameters Γ_H and μ_{ggH} are left unconstrained in the fit. The simultaneous maximum likelihood fit leads to an observed (expected) upper limit of Γ_H < 33 MeV (42 MeV) at 95% C.L., 8.0 (10.1) times the Standard Model prediction.







References

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[2] The CMS Collaboration, "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC", *Phys. Lett. B* **716** (2012) 30

[3] The CMS Collaboration, "Measurement of the properties of a Higgs boson in the four-lepton final state", arXiv:1312.5353

[4] S. Bolognesi, Y. Gao, A. V. Gritsan, K. Melnikov, M. Schulze, N. V. Tran and A. Whitbeck, "On the spin and parity of a single-produced resonance at the LHC", *Phys. Rev. D* **86** (2012) 095031

[5] The CMS Collaboration, "Constraints on the Higgs boson width from off-shell production and decay to ZZ to llll and llνν", CMS-PAS-HIG-14-002, arXiv:1405.3455, submitted to *Phys. Lett. B*