Properties of the Higgs-like boson in the $H \to ZZ \to 4l$ decay channel at CMS

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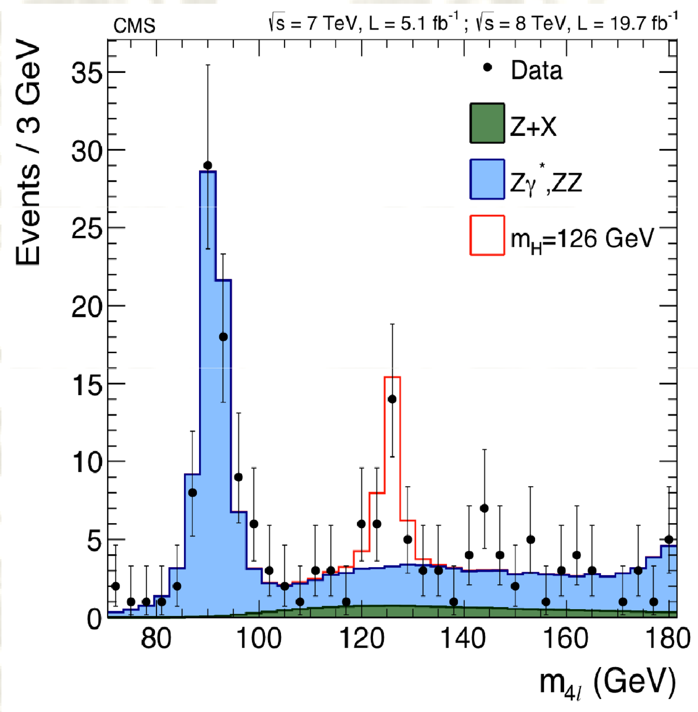
Abstract

The properties of a Higgs boson candidate 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

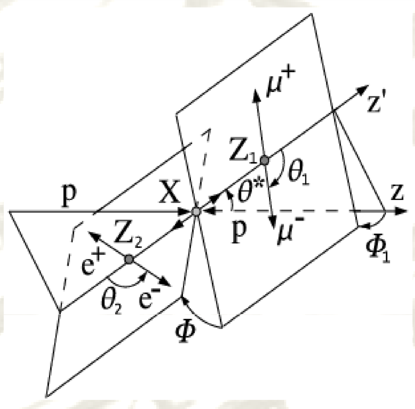
- $p_T^e > 5$ GeV and $p_T^\mu > 7$ GeV
- $p_T^1 > 20$ GeV and $p_T^2 > 10$ GeV
- $40 < m_{Z1} < 120$ GeV
- $12 < m_{Z2} < 120$ GeV
- $100 < m_{4\ell} < 1000$ GeV
- Isolation cut
- Impact parameter cut
- Final state radiation recovery

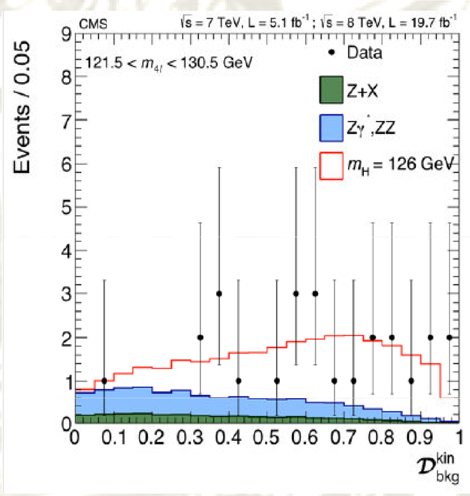
Kinematic Discriminant

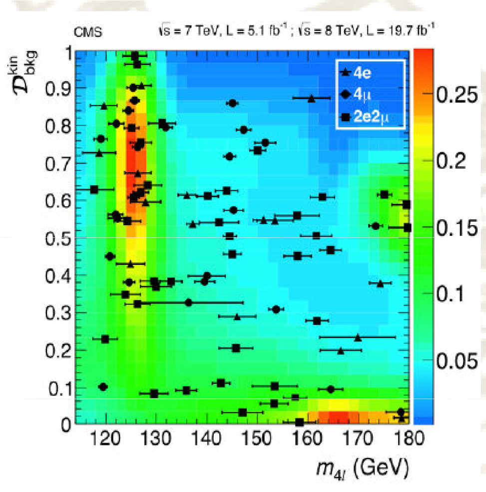
In order to **separate signal from background** events, a **kinematic discriminant** is defined ($\mathcal{D}_{bkg}^{kin}$), depending on the **five production and decay angles** and the **Z boson masses**. These variables fully describe the event topology and have a high discriminating power. The $\mathcal{D}_{bkg}^{kin}$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





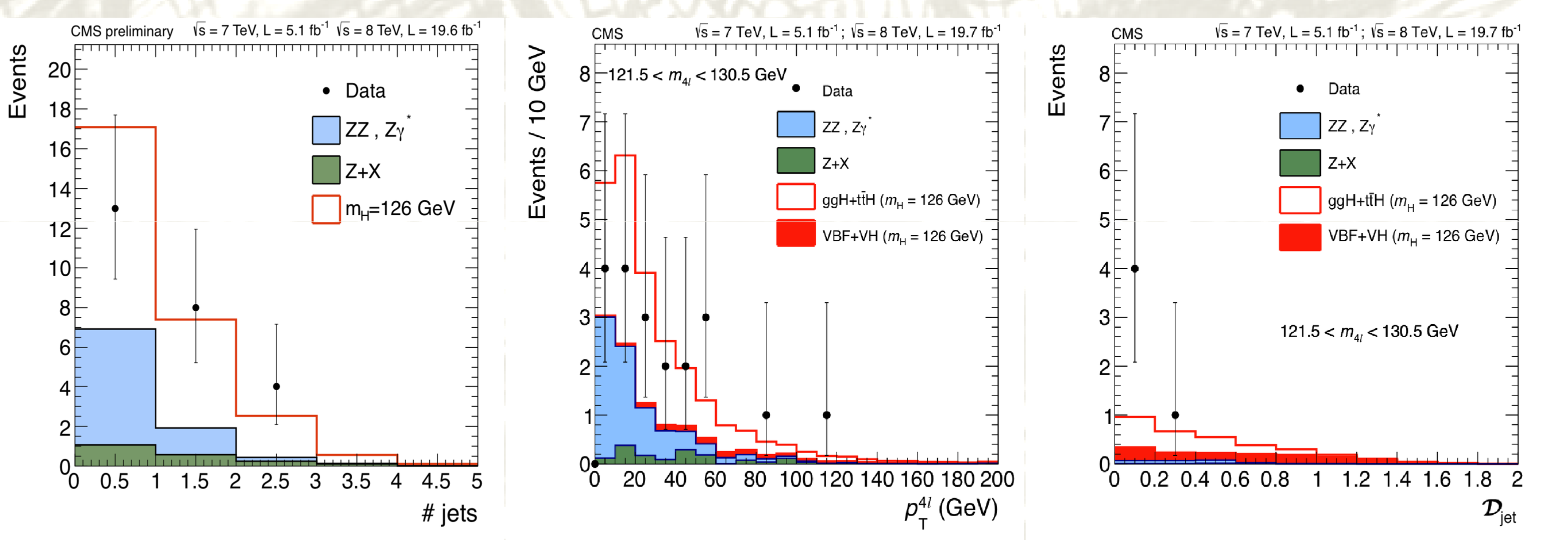


Jet Categories and Couplings

In order to improve the sensitivity to the different **production mechanisms**, a **categorization** based on the **jet multiplicity** is introduced. The event sample is thus split into two categories:

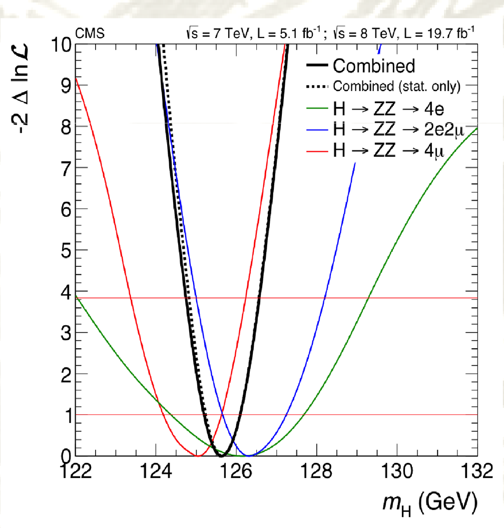
- **0/1-jet category** : events with fewer than two jets;
- **dijet category:** events with at least two jets.

Two discriminants are then **defined**, according to the category. In the 0/1-jet sample the $p_T^{4\ell}$ is used to **discriminate vector boson fusion** (VBF) and the **associated Higgs production with a W/Z** boson (VH) **from gluon fusion**. In the other category a linear discriminant ($\mathcal{D}_{jet}$) is formed combining two VBF sensitive variables. In the 0/1-jet (dijet) category, about 5% (20%) of the signal events are expected to come from VBF production mechanism.



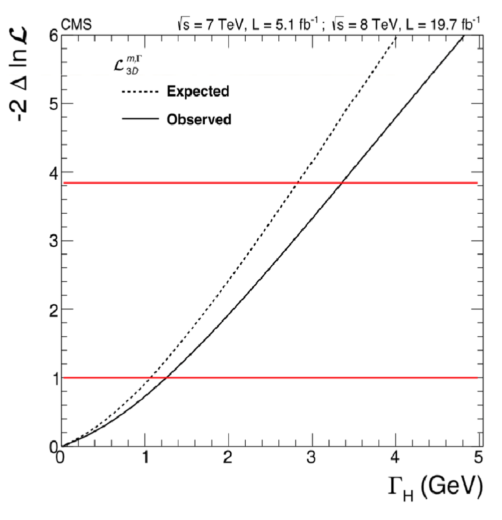
Mass Measurement and Width

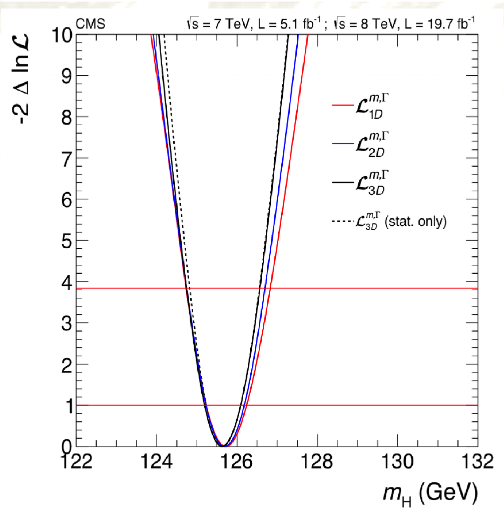
The mass measurement is performed with a **three-dimensional fit** using for each event the **four-lepton invariant mass** ($m_{4\ell}$), the associated **per-event mass error** ($\mathcal{D}_m$) and the **kinematic discriminant** ($\mathcal{D}_{bkg}^{kin}$). Per-event errors are calculated from the **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 ± 0.4 (*stat.*) ± 0.2 (*syst.*) GeV.

Data are compatible with a **narrow-width resonance**, $\Gamma_H = 0.0^{+1.3}_{-0.0}$ GeV, with an upper limit on the width of 3.4 GeV at a 95% CL, for an expected upper limit of 2.8 GeV.

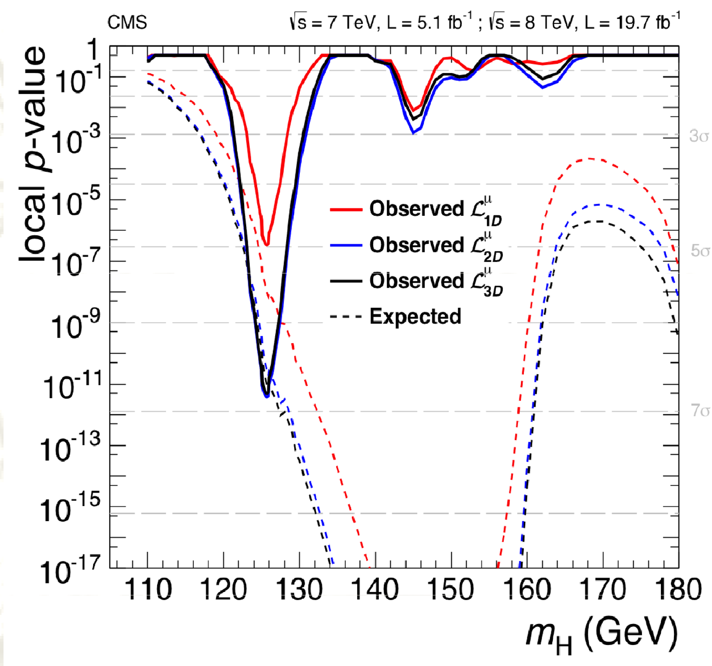




Significance of the Excess

The other properties of the new resonance are extracted performing a **multi-dimensional likelihood fit** that depends on the $\mathcal{D}_{bkg}^{kin}$ and $\mathcal{D}_{jet}$ (or $p_T^{4\ell}$) discriminants and on the four-lepton reconstructed mass of each event.

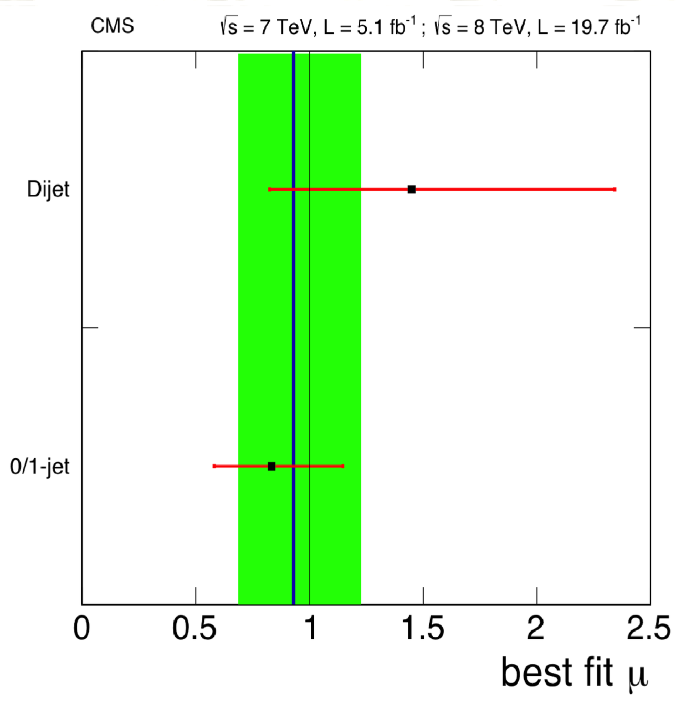
The **minimum of the local p-value** is reached at $m_{4\ell}$ = 125.7 GeV and it corresponds to a local significance of 6.8 (for an expectation of 6.7). This is the only significant excess in the range m_H < 1 TeV.



Signal Strength

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 is obtained using the **full 3D model** depending on ($m_{4\ell}$, $\mathcal{D}_{bkg}^{kin}$, $\mathcal{D}_{jet}$ /$p_T^{4\ell}$) at the best fit mass (m_H = 125.6 GeV):

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

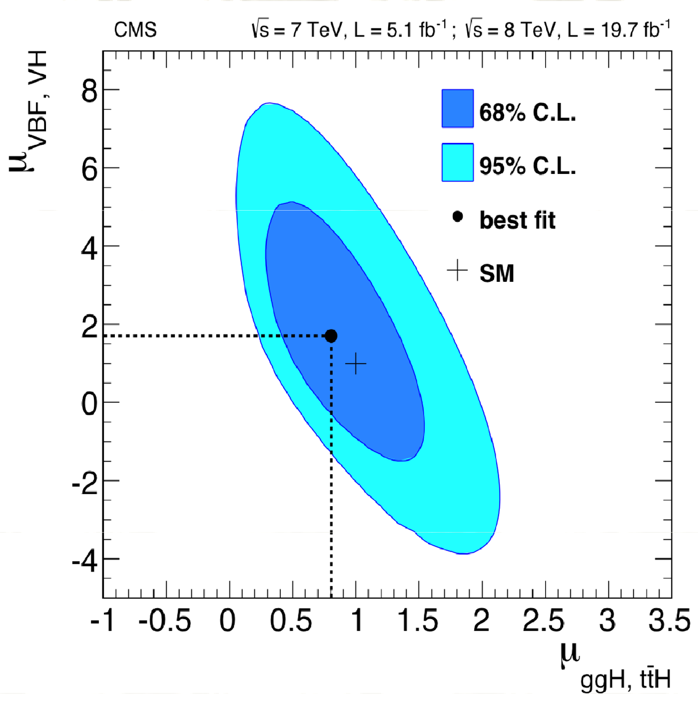


The signal strength is also calculated in each jet category separately:

$$\mu_{0/1\text{-jet}} = 0.83^{+0.31}_{-0.25}$$
$$\mu_{dijet} = 1.45^{+0.89}_{-0.62}$$

Both categories are compatible with the combined value and with the expected cross section by the SM (= 1). 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:

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



Spin-Parity Measurements

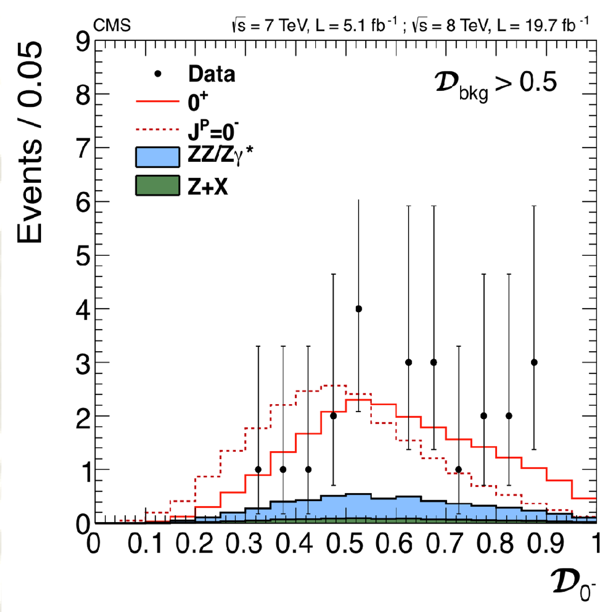
In order to determine the spin and the parity of the new boson, a **methodology with kinematic discriminants** is used. Two discriminants are defined:

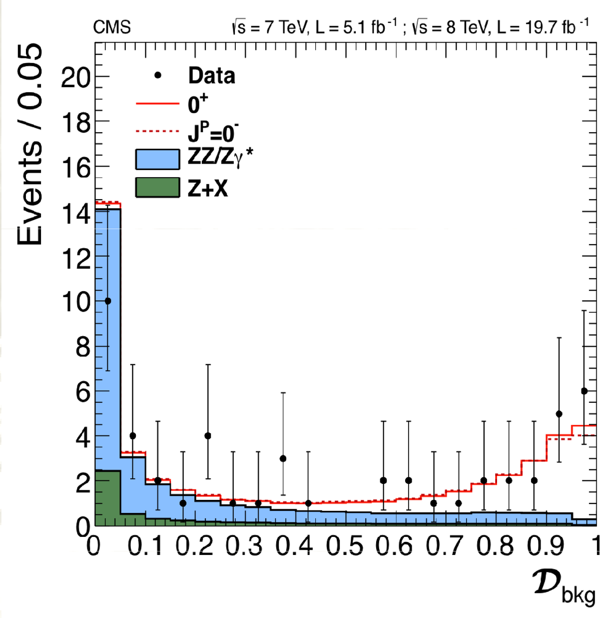
$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{0^+}}{\mathcal{P}_{0^+} + \mathcal{P}_{J^P}}$$

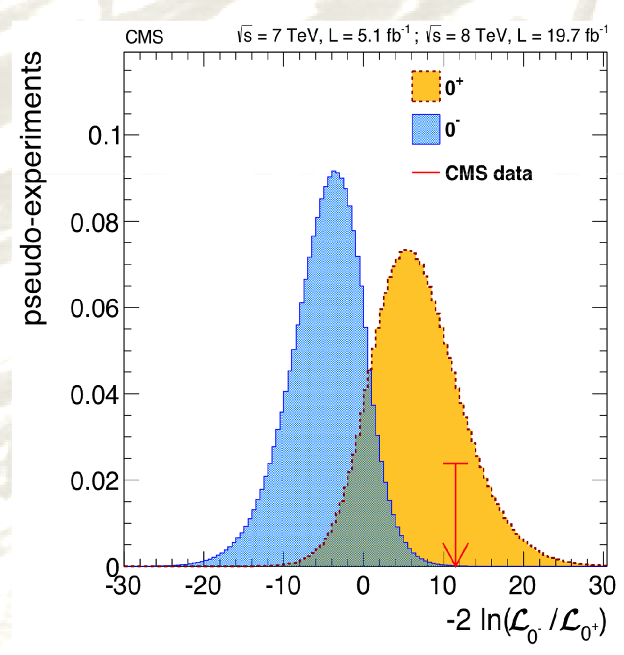
where $\mathcal{P}_{0^+}$ is the **probability distribution for the SM Higgs boson** (0$^+$) hypothesis and $\mathcal{P}_{J^P}$ is the **probability for an alternative model**, and

$$\mathcal{D}_{bkg} = \frac{\mathcal{P}_{0^+}}{\mathcal{P}_{0^+} + \mathcal{P}_{bkg}}$$

where $\mathcal{P}_{bkg}$ is the **probability distribution for the background.** 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%.

References

[1] The ATLAS Collaboration, "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC", *Phys. Lett. B* **716** (2012) 1

[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