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Properties of the Higgs boson with the H$\rightarrow$ZZ$\rightarrow$4 leptons channel

Christophe Ochando*
Laboratoire Leprince-Ringuet, UMR 7638, Ecole Polytechnique, 91128 Palaiseau Cedex, France
E-mail: ochando@llr.in2p3.fr

On 2012 July 4th, the ATLAS and CMS experiments reported the discovery of a new boson. The measurement of its properties is now of prime interest to determine whether its the standard model (SM) Higgs or not. In the X$\rightarrow$ ZZ$\rightarrow$ 4 leptons (electrons or muons) channel, the final state can be fully reconstructed and with high precision, thanks to the excellent performances of the CMS detector. It therefore offers a unique opportunity to precisely measure the properties of the new boson. The analysis reported here uses pp collisions data recorded by the CMS experiment at the LHC, corresponding to the full Run I statistics (5.1 fb^{-1} at $\sqrt{s}$=7 TeV, 19.6 fb^{-1} at $\sqrt{s}$=8 TeV). The mass of the new boson is measured. The spin-parity state is studied using Matrix Element methods, where the SM Higgs hypothesis is confronted to other spin-parity hypothesis. Measurement of the cross-sections, relative the SM expectations, from the different production modes, either via fermions (gluon fusion, ttH) or vector bosons (VBF, VH) are also reported. All the measurements, still statistically limited, are compatible so far with the production of a SM Higgs boson.

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*Speaker.

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1. Introduction

The H→ $ZZ \to 4\ell$ analysis [1] exhibits a clean experimental signature consisting of a narrow resonance over a small continuum background. The mass peak is built from four primary isolated and identified leptons. As low signal yields are expected, this channel critically relies on the performances of the leptons reconstruction and selection algorithms. The dominant irreducible background is from non-resonant ZZ (or Zγ^*) production. Additional reducible background sources arise from process involving at least one jet misidentified as lepton. The analysis reported in this letter uses pp collisions data recorded by the CMS [2] experiment at the LHC, corresponding to the full Run I statistics: 5.1 fb^{-1} (19.6 fb^{-1}) at $\sqrt{s} = 7$ (8) TeV.

The reconstructed four-lepton invariant-mass (m_{4l}) distribution is shown on Fig. 1 (left). A clear peak around $m_{4\ell} = 126$ GeV is seen. A matrix element likelihood approach is used to build a kinematic discriminant (K_D) so as to further improve the separation between signal and background. To enhance the sensitivity to the production mechanisms, the event sample is split into two categories based on the jet multiplicity: events with fewer than two jets (C1) and events with at least two jets (C2).

The local p-values, representing the significance of local excesses relative to the background expectation are shown on Fig. 1 (right). The minimum is reached around $m_{4\ell} = 125.8$ GeV and corresponds to an observed (expected) local significance of 6.7 (7.1) σ. The signal strength μ_{SM}, relative to the expectation for the standard model (SM) Higgs boson, is measured to be $\mu_{SM} = 0.91^{+0.30}_{-0.24}$ at 125.8 GeV.

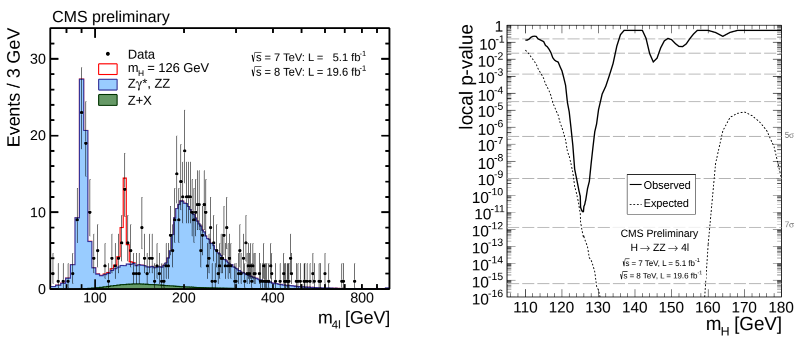

Figure 1: Distribution of the four-lepton reconstructed mass (left). Points represent the data, shaded histograms represent the background and the unshaded histogram the signal expectation. Expected (dashed) and observed (solid) local p-values (right) as a function of the Higgs boson mass.

2. Measurement of the properties

The mass m_X and its uncertainty are extracted from a one-dimensional scan of the test statistic $q(m_X)$. It is shown on Fig. 2.The resulting fit gives $m_X = 125.8 \pm 0.5$ (stat) ± 0.2 (syst) GeV.

The production mechanisms can be slit into two categories depending on whether the production is induced by vector bosons (VBF, VH) or fermions (ggH, ttH). Two signal strength modifiers (μ_V, μ_F) are introduced as scale factors to the SM expected cross section. A two-dimensional (μ_V,

μ_F) fit is performed. The result, in agreement with the expectations from the production of a SM Higgs boson, is shown on Fig. 2 (middle).

The kinematics of the production and decay of the new boson in the $ZZ \to 4\ell$ channel are sensitive to its spin and parity. To distinguish two spin-parity hypothesis, we build discriminants D_J^P similar to K_D but meant to separate the SM Higgs boson from the tested alternative hypothesis. We also define D_{SB}, a discriminant similar to K_D but where $m_{4\ell}$ is also included. No categorization is used and a 2D model (D_{SB}, D_J^P) is utilized to perform the hypothesis tests. The studied pseudo-scalar, spin-1 and spin-2 models are excluded at 95 % C.L. or higher.

The most general decay amplitude for a spin-zero boson can be defined as

$$A = v^{-1}\varepsilon_1^{*\mu}\varepsilon_2^{*\nu}\left(a_1 g_{\mu\nu}m_H^2 + a_2 q_\mu q_\nu + a_3\varepsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta\right) = A_1 + A_2 + A_3\,, \tag{2.1}$$

where ε_i are the Z boson polarization vectors, q_i are their momenta, and $q = q_1 + q_2$ is the four-momentum of the spin-zero boson. The SM Higgs boson decay is dominated by the A_1 amplitude, while the $J^P = 0^-$ state decay is expected to be dominated by the A_3 amplitude. In addition to simple hypothesis testing, we perform a fit for a continuous parameter which, neglecting the $|A_2|^2$ contribution, we define as: $f_{a3} = |A_3|^2/(|A_1|^2 + |A_3|^2)$. The presence of both A_3 and A_1 in the decay would indicate CP violation. Using D_{0^-}, we find $f_{a3} < 0.58$ at 95% CL (see Fig. 2 , right).

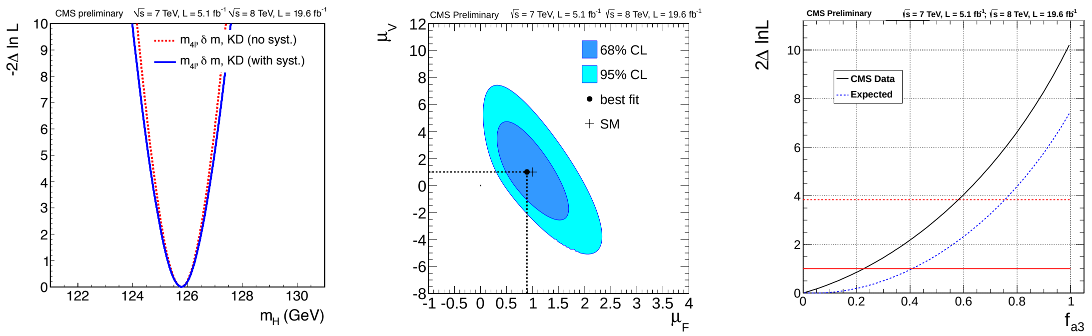

Figure 2: 1D test statistics q(m_X) $= -2\Delta\ln\mathscr{L}$ scan vs tested m_X (left). Likelihood contours on the signal strength modifiers associated with fermions (μ_F) and vector bosons (μ_V) for the ZZ (middle). Average expected and observed distribution of $-2\Delta\ln\mathscr{L}$ as a function of f_{a3} (right).

3. Conclusion

The measurement of the properties of the newly discovered Higgs boson has been reported with the H→ZZ→ 4ℓ channel and using the full Run I statistics. Altough still statistically limited, they are all compatible with the production of a SM Higgs boson.

References

[1] [CMS Collaboration], "Properties of the Higgs-like boson in the decay H→ZZ→4ℓ in pp collisions at $\sqrt{s}$ =7 and 8 TeV," CMS-PAS-HIG-13-002.

[2] S. Chatrchyan *et al.* [CMS Collaboration], "The CMS experiment at the CERN LHC," JINST **3** (2008) S08004.