PROCEEDINGS OF SCIENCE

Search for a new Higgs boson-like low-mass resonance in the diphoton final state at $\sqrt{s}$ = 8 TeV in pp collisions at CMS

Linda Finco* **on behalf of the CMS Collaboration**
IPN Lyon (IN2P3-CNRS)/UCB Lyon 1, France
E-mail: linda.finco@cern.ch

The results of a search for a new resonance decaying into two photons using proton-proton collision data at $\sqrt{s}$ = 8 TeV are presented for a diphoton invariant mass in the range between 80 and 110 GeV. The analysis uses a data set of 19.7 fb^{-1} integrated luminosity. The expected and observed 95% confidence level upper limits on the product of the cross-section times branching ratio into two photons are presented. No significant excess with respect to the expected limit is observed.

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*Speaker.

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1. Theoretical and Experimental Motivations

In 2012 both the ATLAS [1] and the CMS [2] collaborations observed a new boson with an invariant mass of approximately 125 GeV, whose properties are at present compatible with those of the Standard Model (SM) Higgs boson. However, new theories beyond the SM (BSM), like the Next-to-Minimal Supersymmetric Model (NMSSM) [3, 4] and the generalized two-Higgs-Doublet Model (2HDM) [5, 6, 7], can also provide a modified and extended Higgs sector where the Higgs boson at 125 GeV is identified as the next-to-lightest scalar, allowing the existence of a possible lighter particle. It is therefore well-justified to extend the lower limit of the Higgs boson search mass range as much as possible.
A small excess of events was observed at around 98 GeV at LEP by 3 of the 4 experiments in the $bb/\tau\tau$ channels [8].

2. Analysis Strategy

The analysis [9] extends the method developed in CMS [10] for the observation and the study of the Higgs boson discovered in 2012 [11], by searching for a localized excess of diphoton events over a smoothly falling background due to prompt diphoton production and to events with at least one jet misidentified as a photon. The invariant mass range explored is 80 GeV $< m_{\gamma\gamma} <$ 110 GeV, where the lower limit is imposed by trigger requirements.
The $H \to \gamma\gamma$ decay channel provides a clean final-state topology, with two isolated and highly energetic photons, allowing the mass of any Higgs boson in the search range to be reconstructed with high precision. Basic ingredients for a precise mass measurement are the photon energy, which is reconstructed by building clusters of energy deposits in the electromagnetic calorimeter, and the diphoton vertex identification, based on a multi-variate approach. Prompt photons are separated from non-prompt photons (largely from neutral meson decay) by a boosted decision tree (BDT), combining lateral shower shape variables, isolation variables, the energy median density, the pseudorapidity, and the raw energy. Photon candidates are then subject to a preselection, designed to be slightly more stringent than the trigger selection, which imposes requirements on transverse momenta, hadronic leakage, shower shape and an electron veto based on the pixel detector.
Finally, a multivariate event classifier is built to discriminate diphotons from Higgs boson decays from the diphoton continuum. It incorporates the kinematic properties of the diphoton system (excluding $m_{\gamma\gamma}$), a per-event estimate of the diphoton mass resolution, and the photon identification BDT output value. In this analysis, events are separated into four classes based on the classifier score; events having a score below a minimum value are rejected.

3. Signal and Background Models

In order to statistically interpret the observed data, it is necessary to have a description of the signal which includes the overall efficiency$\times$acceptance, as well as the shape of the diphoton mass distribution in each of the four classes. Simulated $H \to \gamma\gamma$ signal events are used to build a parameterized model which is defined continuously for any value of a Higgs boson mass between 80 and 110 GeV. The signal shape is modeled empirically by a sum of N Gaussian functions (with N from

1 to 6), depending on the event class and on the correct/incorrect primary vertex selection. The full signal model is then defined by a linear interpolation of each fit parameter between the ensemble of mass values (from 80 to 110 GeV, with 5 GeV steps), which thus gives rise to a smooth evolution of the signal shape. The final parameterized shape for all event classes combined is shown in Fig. 1 (left) for a Higgs boson mass of 95 GeV.
The background is modeled by fitting analytic functions to the observed diphoton mass distributions, in each of the event classes, over the range $75 < m_{\gamma\gamma} < 120$ GeV, extending slightly above and below that in which the search is performed. The large irreducible background from QCD production of two photons is fitted using Bernstein polynomial functions. Moreover, an explicit component intended to describe the background from the Drell-Yan process in which the two electrons survive all the selection requirements, and are thus misidentified as photons, is added to the smoothly-falling contribution. This additional component is modeled by a double-sided crystal ball (DCB) function, similar to a Gaussian function, but with asymmetric tails. Fits of the chosen background models to the diphoton mass distribution, on the hypothesis of no signal, are shown for the most sensitive class in Fig. 1 (right).

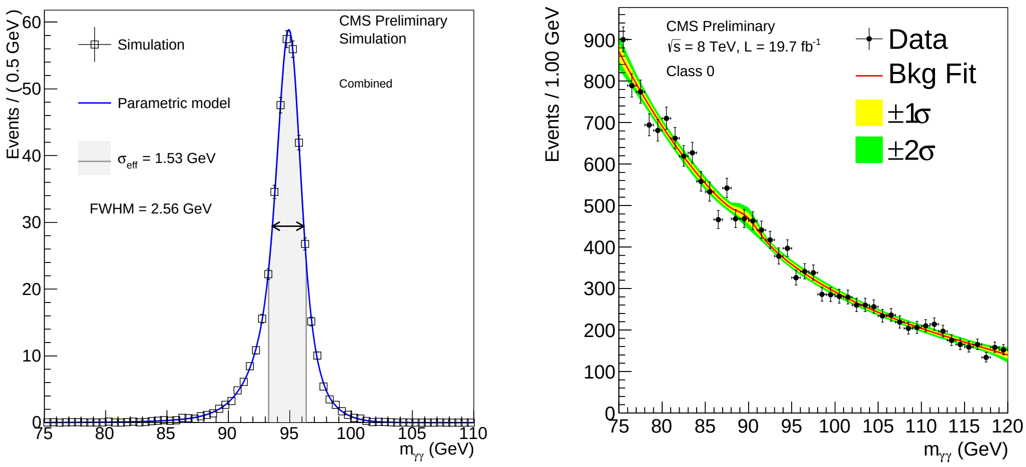

Figure 1: Left: Full parameterized signal shape integrated over all four event classes in simulated signal events with $m_H = 95$ GeV at $\sqrt{s} = 8$ TeV [9]. The open points are the weighted MC events and the blue line is the corresponding parametric model. Also shown are the effective σ value and the corresponding FWHM. Right: Background model fits to data in the most sensitive event class (class 0) at $\sqrt{s} = 8$ TeV [9]. The deviations from monotonically decreasing behavior in the neighborhood of $m_{\gamma\gamma} = 90$ GeV are consistent with surviving double-fake events from the Z $\rightarrow$ ee Drell-Yan process.

4. Results

The expected and observed 95% confidence level upper limits on the product of the production cross-section times branching ratio into two photons for an SM-like second Higgs boson are presented in Fig. 2 (left) for the parametric signal model. The asymptotic CLs procedure from the likelihood fit to the diphoton mass distribution in the different event classes is used. No significant excess with respect to the expected limits is observed. The minimum(maximum) observed upper limit on the production cross-section times branching ratio is approximately 31(130) fb corresponding to a mass hypothesis of 102.8(91.1) GeV. The expected and observed local p-values as a function of the SM Higgs boson mass hypothesis is reported in Fig. 2 (right). The maximum significance is 1.9 signal deviations (without considering the look-elsewhere effect) and corresponds to m_H = 97.5 GeV.

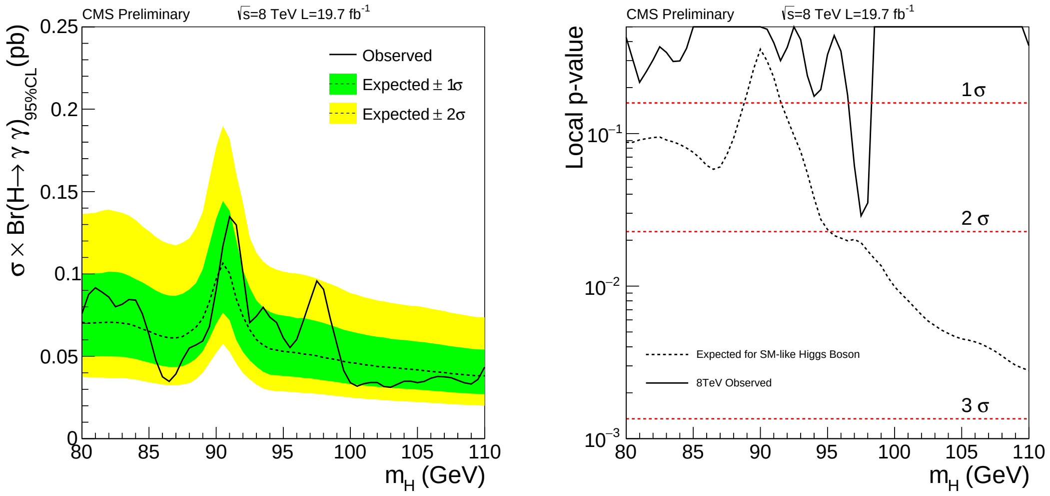

Figure 2: Left: Expected and observed exclusion limits (95% CL) on the product of the cross-section times branching ratio into two photons in the asymptotic CLs approximation, for an SM-like second Higgs boson [9]. A significant sensititvity deterioration can be noticed around the Z boson mass value. Right: Expected and observed local p-values as a function of the SM Higgs boson mass hypothesis, for an SM-like second Higgs boson [9].

5. Conclusions

A search for new low-mass resonances decaying to two photons has been described. It is based upon data samples corresponding to an integrated luminosity of 19.7 fb^{-1} collected at a center-of-mass energy of 8 TeV in 2012. The search is performed in a mass range between 80 and 110 GeV. The expected and observed 95% confidence level upper limits on the product of the cross-section times branching ratio into two photons are presented. No significant excess with respect to the expected limit is observed.

New results based on data collected by CMS at 13 TeV in 2016, not available at the time of the conference, have been published [12], together with their combination with the 8 TeV results described in this note.

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