Search for the Higgs Boson decay into two photons with the CMS Experiment

João Pela, on behalf of the CMS Collaboration
joao.pela@cern.ch

The challenge

The current knowledge on the field of particle physics is summarized in the Standard Model (SM). This model is incomplete without the inclusion of a spontaneous symmetry breaking mechanism that would explain the observation that the electroweak bosons (the W and Z particles) have mass. This can be done with the Higgs Mechanism, which suggests the presence of new previously unobserved particle, the Higgs Boson.

The CMS Experiment

The Compact Muon Experiment (CMS) at the Large Hadron Collider (LHC) at CERN, is a general purpose 4π particle physics detector, where particles collide at 7 TeV (8 TeV) during 2011 (2012). This detector is composed of several sub-detectors aimed at measuring the properties of the particles produced in each collision.

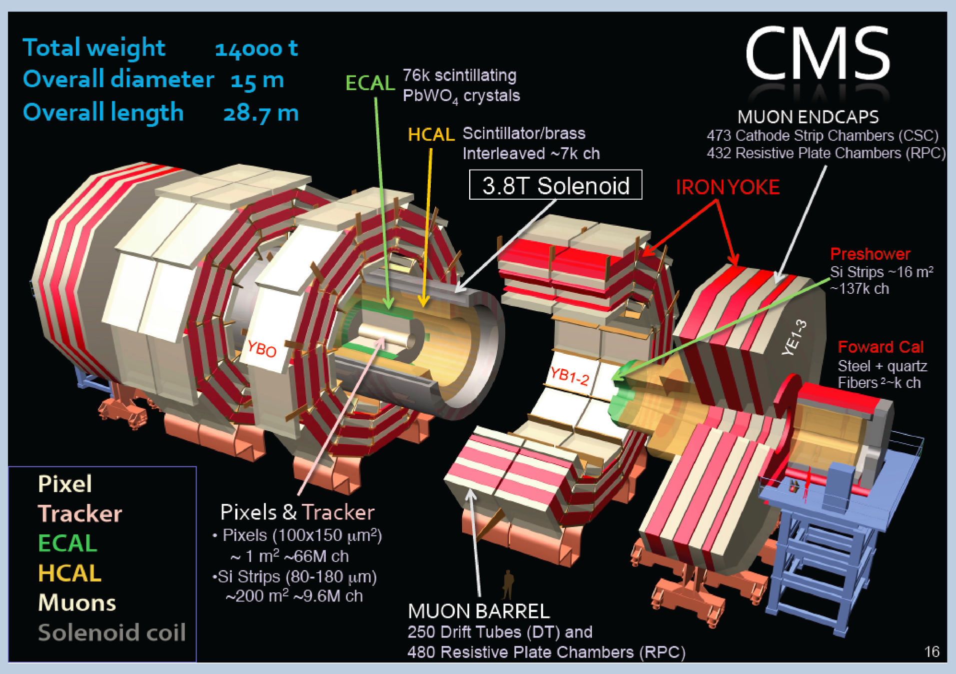

Figure 1: Diagram of the CMS Experiment. Disposition of main components and sub-systems is highlighted.

The $\gamma\gamma$ channel

In the $H \to \gamma\gamma$ analysis a search is made for a narrow peak in the diphoton invariant mass distribution in the range 110–150 GeV, sitting on a large background:

- Large irreducible background from QCD production of two photons;
- Reducible background where one or more of the reconstructed photons originate from misidentification of jet fragments

Early detailed studies indicated this to be one of the most promising channels in the search for a SM Higgs boson in the low-mass range.

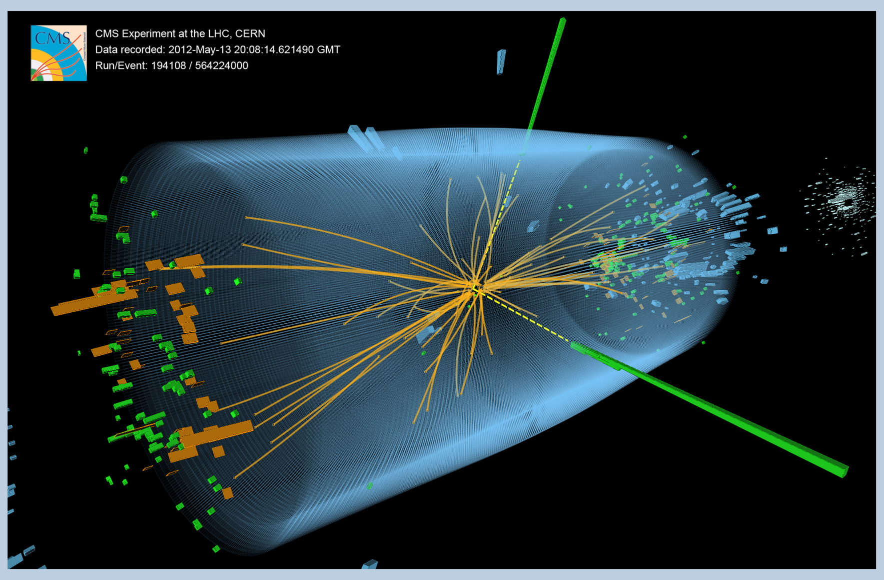

Figure 2: Event recorded with the CMS detector in 2012 at a proton-proton centre-of-mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM Higgs boson to a pair of photons.

Event categorization

Candidate diphoton events are separated into mutually exclusive categories of different expected signal-to-background ratios, based on the properties of the reconstructed photons and on the presence of two jets satisfying criteria aimed at selecting events in which a Higgs boson is produced through the VBF process. The analysis uses multivariate techniques for the selection and classification of the events. As an independent cross-check, an analysis is also performed, using simpler criteria based on the properties of the reconstructed photons to select and classify events. The multivariate analysis achieves 15% higher sensitivity than the cross-check analysis.

Event selection

The event selection requires two photon candidates satisfying:

- A p_T threshold for photon leading (subleading) of $m_{\gamma\gamma}/3$ ($m_{\gamma\gamma}/4$). Events passing the dijet selection, the requirement on the leading photon is $m_{\gamma\gamma}/2$;
- "Loose" photon identification criteria;
- Photons reconstructed within the fiducial region $|\eta| < 2.5$ (excluding barrel-endcap transition $1.44 < |\eta| < 1.57$);

Jet selection criteria are applied to the two jets of largest p_T in the event within $|\eta| < 4.7$:

- p_T thresholds for the two jets are 30 and 20 GeV;
- η separation is required to be greater than 3.5;
- The dijet invariant mass is required to be greater than 350 and 250 GeV for the 7 and 8 TeV data sets;

Additional pseudorapidity and agular requirements are made to the selected jets, dijet and diphoton.
Events containing a dijet are put at a single category t 7 TeV and 2 categories at 8 TeV where the separations is based on the dijet invariant mass and jet p_T

Expected yields

Expected signal and estimated background

	Event classes	SM Higgs boson expected signal (m_H=125 GeV) Total	ggH	VBF	VH	ttH	σ_{eff} (GeV)	FWHM/2.35 (GeV)	Background $m_{\gamma\gamma}$ = 125 GeV (ev./GeV)
7 TeV 5.1 fb^{-1}	Untagged 0	3.2	61%	17%	19%	3%	1.21	1.14	3.3 ± 0.4
	Untagged 1	16.3	88%	6%	6%	1%	1.26	1.08	37.5 ± 1.3
	Untagged 2	21.5	91%	4%	4%	–	1.59	1.32	74.8 ± 1.9
	Untagged 3	32.8	91%	4%	4%	–	2.47	2.07	193.6 ± 3.0
	Dijet tag	2.9	27%	73%	1%	–	1.73	1.37	1.7 ± 0.2
8 TeV 5.3 fb^{-1}	Untagged 0	6.1	68%	12%	16%	4%	1.38	1.23	7.4 ± 0.6
	Untagged 1	21.0	88%	6%	6%	1%	1.53	1.31	54.7 ± 1.5
	Untagged 2	30.2	92%	4%	3%	–	1.94	1.55	115.2 ± 2.3
	Untagged 3	40.0	92%	4%	4%	–	2.86	2.35	256.5 ± 3.4
	Dijet tight	2.6	23%	77%	–	–	2.06	1.57	1.3 ± 0.2
	Dijet loose	3.0	53%	45%	2%	–	1.95	1.48	3.7 ± 0.4

Table 1: Expected numbers of SM Higgs boson events (m_H = 125 GeV) and estimated back- ground (at $m_{\gamma\gamma}$ = 125 GeV) for all event categories of the 7 and 8 TeV data sets.

Multivariate analysis

For the multivariate analysis, a boosted decision tree (BDT) is trained to give a high output value (score) for signal-like events and for events with good diphoton invariant mass resolution, based on the following observables:

- The photon quality determined from electromagnetic shower shape and isolation variables;
- The expected mass resolution;
- The per-event estimate of the probability of locating the diphoton vertex within 10 mm of its true location along the beam direction;
- kinematic characteristics of the photons and the diphoton system;

The kinematic variables are constructed so as to contain no information about the invariant mass of the diphoton system. The diphoton events not satisfying the dijet selection are classified into five categories based on the output of the BDT, with category boundaries optimized for sensitivity to a SM Higgs boson. Events in the category with smallest expected signal-to-background ratio are rejected, leaving four categories of events.

Invariant mass

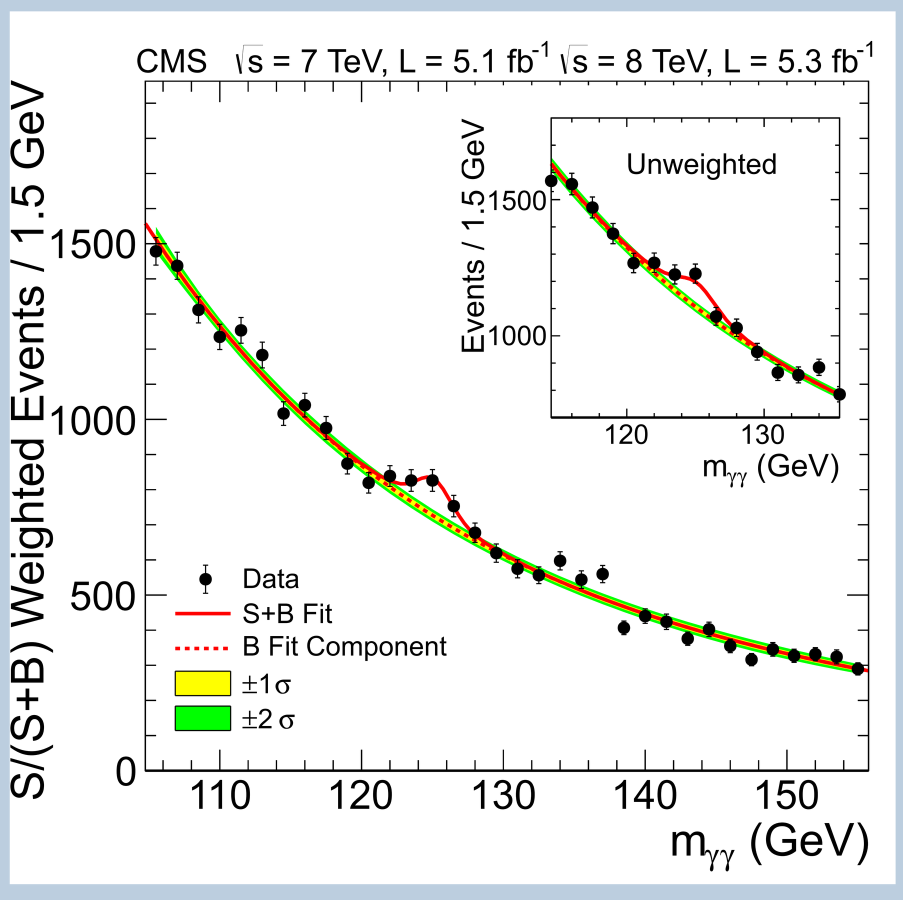

Figure 3: The diphoton invariant mass distribution with each event weighted by the $S/(S+B)$ value of its category. The lines represent the fitted background and signal, and the coloured bands represent the ±1 and ±2 standard deviation uncertainties on the background estimate. The inset shows the central part of the unweighted invariant mass distribution.

Results

The diphoton invariant mass distribution shown in Fig. 3 clearly shows an excess at mass of 125 GeV. A fit is preformed to the diphoton mass distribution in each category, with the background modeled using a polynomial and the signal using a parametric model from Monte Carlo simulation.
The local p-value is shown as a function of m_H in Fig. 4 for the 7 and 8 TeV data, and for their combination. The expected significance of the local p-value for a SM Higgs boson of mass 125 GeV is 2.8 σ. The minimum local p-value corresponding to the upward fluctuation of the observed limit at 125 GeV corresponds to 4.1σ. The significances of the corresponding minimum local p-values seen with the sideband-background-model and the cross-check analysis are 4.6 σ at $m_H = 125$ GeV and 3.7 σ at $m_H = 124$ GeV, respectively. The best-fit signal strength for a SM Higgs boson mass hypothesis of 125 GeV is $\sigma/\sigma_{SM} = 1.6 \pm 0.4$.
The excess is most significantly seen also in the ZZ decay channel, which together with $\gamma\gamma$ are the channels with best mass resolution. A fit to these signals gives a mass of $125.3 \pm 0.4(stat.) \pm 0.5(syst.)$ GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

p-Value

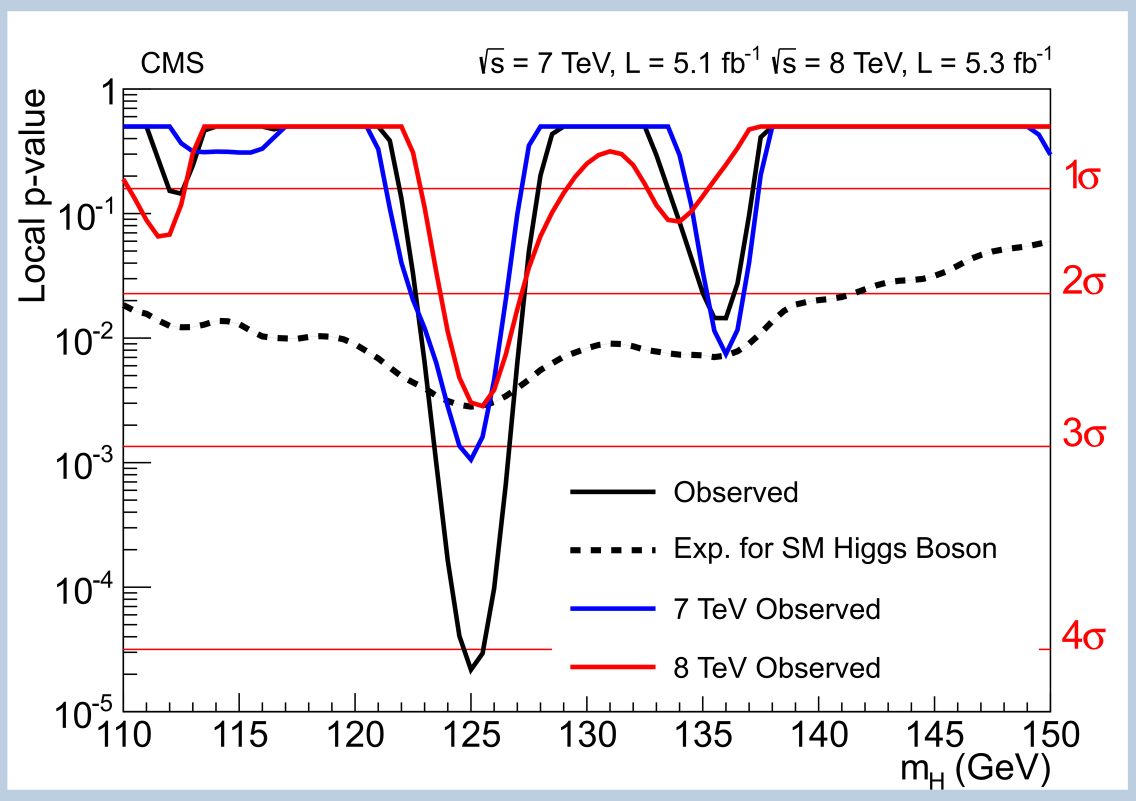

Figure 4: The local p-value as a function of m_H in the $\gamma\gamma$ decay mode for the combined 7 and 8 TeV data sets. The dashed line shows the expected local p-value for the combined data sets, should a SM Higgs boson exist with mass m_H.

References

[1] The CMS Collaboration: *Search for the standard model Higgs boson decaying into two photons in pp collisions at sqrt(s)=7 TeV*, CMS-HIG-11-033, CERN-PH-EP-2012-024, arXiv:1202.1487v1 [hep-ex]

[2] The CMS Collaboration: *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, CMS-HIG-12-028, CERN-PH-EP-2012-220, arXiv:1207.7235v1 [hep-ex]

Acknowledgements

The author thanks the Portuguese Government through Fundação para a Ciência e a Tecnologia (SFRH/BD/77979/2011) for supporting this research.