IL NUOVO CIMENTO Vol. 34 C, N. 6 Novembre-Dicembre 2011
DOI 10.1393/ncc/i2011-11107-5

Colloquia: IFAE 2011

Analysis strategy for the Higgs boson search in the four-lepton final state in CMS

A. Graziano on behalf of the CMS Collaboration

Università di Torino and INFN, Sezione di Torino - Torino, Italy
CERN - Geneva, Switzerland

(ricevuto il 29 Luglio 2011; pubblicato online il 21 Dicembre 2011)

Summary. — The current status and future prospects for SM Higgs boson searches in the $H \to ZZ^{(*)} \to 4\ell$ ($\ell = e, \mu$) channel with the CMS detector are presented. The whole analysis strategy for rejecting the backgrounds while keeping very high signal efficiencies is discussed, with a particular emphasis on the usage of data-driven techniques and on the estimation of systematic uncertainties.

PACS 14.80.Bn – Standard Model Higgs bosons.

The analysis strategy for SM Higgs boson searches in the $H \to ZZ \to 4\ell$ channel with the CMS detector [1] is described.

Three final states have been considered for this 4ℓ analysis: $4e$, 4μ, $2e2\mu$. The main backgrounds are ZZ, $t\bar{t}$, $Zb\bar{b}$, $Zc\bar{c}$ and other processes with jets misidentified as leptons, such as $Z + \text{jets}$, $W + \text{jets}$, QCD. The signature of signal events is very clean: two pairs of same-flavour, opposite-charge, high-p_T isolated leptons pointing to the same vertex are looked for. Mass constraints can be set on the dilepton invariant mass.

The analysis consists of a set of cuts aiming to reduce the background contributions by preserving a high signal efficiency, as described in [2]. First of all, electrons and muons must satisfy some reconstruction and identification quality requirements. Invariant mass cuts are then applied both on each $\ell^+\ell^-$ lepton pair and on 4ℓ-candidates. Also a loose isolation cut is set on the four leptons: a cone is drawn around each lepton track and a variable is defined as the sum of the transverse momenta of the tracks in the cone (but the lepton track itself) and of their calorimetric deposits. At this point the ambiguity due to combinatorics in events with extra fake leptons is strongly reduced and the "best 4ℓ-candidate" is chosen. The two leptons with the largest isolation variable are then considered. The sum of their isolation values divided by their p_T is required to be lower than a threshold; then it must pass a cut that correlates it to the p_T of the third largest-p_T lepton, which tends to be soft and non-isolated in background events, stiff and isolated in signal ones. Moreover, the displaced vertex of leptons originating from b-quark decays can be a handle for further background rejection. A cut is therefore applied on the

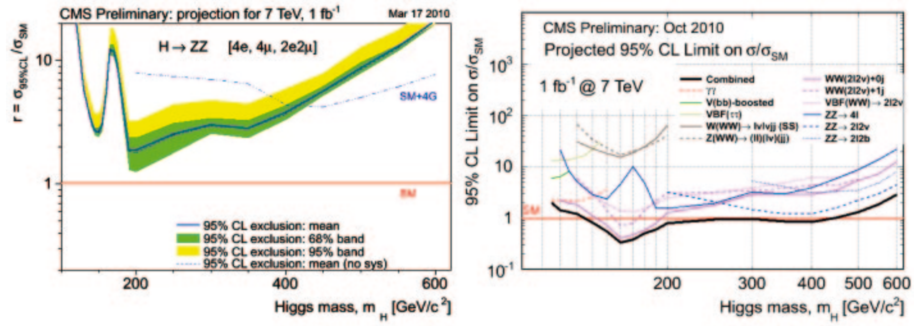

Fig. 1. – Expected excluded cross-sections for a SM-like Higgs boson, with $\sqrt{s} = 7\,\text{TeV}$, $L = 1\,\text{fb}^{-1}$, as a function of m_H and normalized to the SM Higgs boson cross-sections, for the $H \to ZZ$ subchannels (left) and for all $H \to \gamma\gamma$, $H \to WW$, $H \to ZZ$ subchannels and their combination (right).

significance of the 3D impact parameter of the lepton track with respect to the primary vertex. Finally, additional constraints are set on the invariant mass of both lepton pairs.

The background contributions in the signal region can be estimated by reversing the selection cuts, so as to define a phase space region populated by as few signal events as possible. The background yield can be measured in this region and propagated to the signal one by relying on the theory. The ZZ background, which is the main one after the whole event selection, is estimated from the number of $Z \to 2\ell$ events observed in data:

$$N_{ZZ\to 4\ell} = \frac{\sigma^{NLO}_{pp\to ZZ\to 4\ell}}{\sigma^{NNLO}_{pp\to Z\to 2\ell}} \cdot \frac{\varepsilon^{MC}_{ZZ\to 4\ell}}{\varepsilon^{MC}_{Z\to 2\ell}} \cdot N^{observed}_{Z\to 2\ell}\,. \tag{1}$$

This method exploits the fact that most Feynman diagrams are shared by the two processes. The results are compatible with those obtained directly from MC, but the systematic uncertainties are smaller because most of them cancel out in the ratio.

In the $\sqrt{s} = 7\,\text{TeV}$, $L = 1\,\text{fb}^{-1}$ scenario, the $H \to ZZ^{(*)} \to 4\ell$ analysis alone does not allow to exclude any SM Higgs boson mass range. However, if a fourth generation of quarks exists, the exclusion could be possible for $m_H \lesssim 420\,\text{GeV}/c^2$, as shown in fig. 1 (left) and in [3]. The limits obtained from the $H \to \gamma\gamma$, $H \to WW$, $H \to ZZ$ subchannels and from their combination as a function of m_H are shown in fig. 1 (right). With $\sqrt{s} = 7\,\text{TeV}$, $L = 1\,\text{fb}^{-1}$ the range $155 < m_H < 450\,\text{GeV}/c^2$ could be ruled out.

REFERENCES

[1] CMS Collaboration, *JINST*, **3** (2008) S08004.476, doi:10.10881748-0221308S08004.
[2] CMS Collaboration, CMS PAS HIG-08-003, "Search strategy for the Higgs boson in the $ZZ^{(*)}$ decay channel with the CMS experiment".
[3] CMS Collaboration, CMS Note 2010/008, "The CMS physics reach for searches at 7 TeV".