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Standard model Higgs searches at CERN

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Abstract. The final result of the LEP searches for a Standard Model Higgs boson are shown. For the LHC the potential to discover a Standard Model Higgs boson, using the ATLAS and CMS detectors, is reviewed. The recent investigations into the weak boson fusion channels are discussed and results on expected measurements of Higgs boson parameters are presented.

1 Introduction

The Standard Model (SM) is in excellent agreement with the experimental measurements. However, one of the key points of the theory, the mechanism of electroweak symmetry breaking, is still not fully verified. The Higgs mechanism is a possible explanation for the origin of masses but still needs the experimental discovery of the Higgs boson as support.

2 Direct Higgs boson searches at LEP

No solid evidence for a Higgs boson could be found at LEP. Altogether the four LEP experiments collected a total integrated luminosity of 2461 pb^{-1} ($\sqrt{s}$ ≥189 GeV) that were used for direct Higgs boson searches. The combined LEP lower limit for a SM Higgs boson is $m_H \geq 114.4$ GeV at 95% confidence level [1] (see Fig. 1).

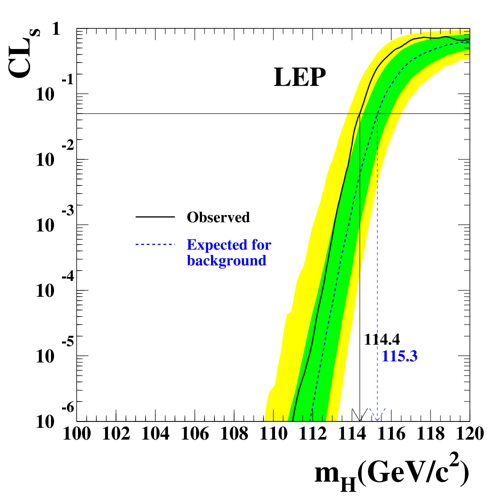

Fig. 1. Confidence level CL$_s$ for the background hypothesis and the observed data [1]

An indirect upper limit of $m_H \lesssim 200$ GeV on the mass of a SM Higgs boson can be derived using electroweak precision observables [2].

3 Prospective Higgs boson searches at the LHC

One of the main goals of the two LHC multi purpose detectors ATLAS [3] and CMS [4] is to discover the Higgs boson and verify - or falsify - the Higgs sector of the SM. This verification has to be done in three steps:

- Discovery of the Higgs boson
- Measurement of the Higgs boson properties (mass, width, spin and CP, couplings)
- Measurement of the Higgs boson self-coupling and the Higgs potential.

The question whether the LHC experiments are able to measure the Higgs boson self-coupling is not addressed here (see [5]).

3.1 SM Higgs boson discovery potential

During the last years the potential of the LHC experiments to discover the Higgs boson was studied using a large number of different Higgs boson production and decay modes in the entire possible mass range $80\,\text{GeV} \lesssim m_H \lesssim 1\,\text{TeV}$. A detailed discussion of the various channels and their individual discovery potential can be found in [6,7,8]. Figure 2 gives an overview of the Higgs boson discovery potential for an integrated luminosity of 30 fb^{-1}, corresponding to three years at low luminosity.

In the entire mass range a combined significance of 5 σ can be reached. For $m_H > 200$ GeV this is mainly due to the "golden" channel $H \to ZZ \to 4l$, in the low mass range ($m_H < 200$ GeV) this is possible by combining the decays $H \to b\bar{b}$, $H \to \gamma\gamma$, $H \to WW^*$ and $H \to ZZ^*$.

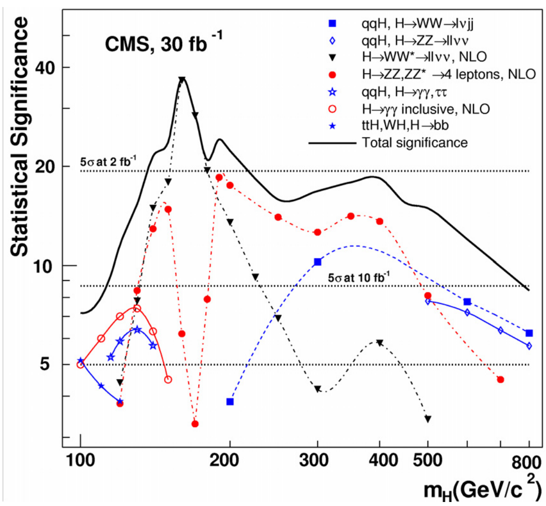

Fig. 2. Discovery potential for a SM Higgs boson [7,8]

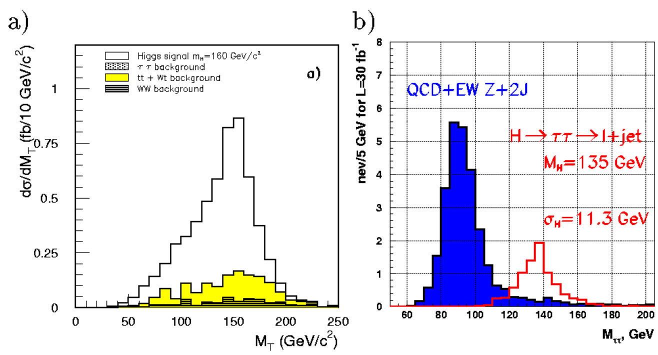

Fig. 3. Distribution of: **a** transverse mass M_T in WBF $H \to WW$ [12] and **b** invariant mass $M_{\tau\tau}$ in WBF $H \to \tau\tau$ [13]

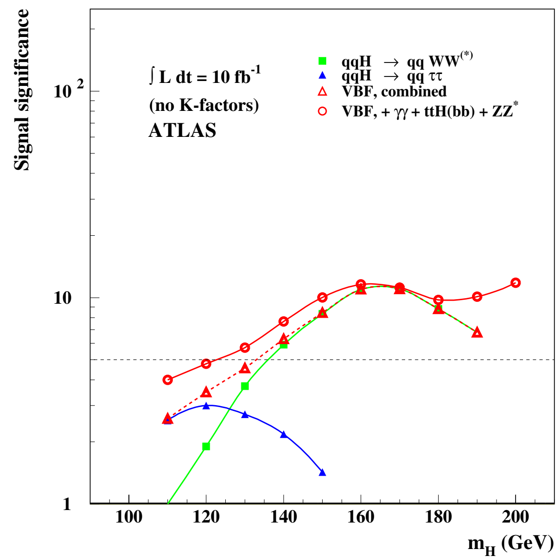

Fig. 4. Discovery potential for a SM Higgs boson in WBF [12]

3.2 Weak boson fusion

Recent analysis [9,10,11] show that it is very promising in this low mass range to look for a Higgs boson in the weak boson fusion (WBF) production mode.

In WBF the Higgs boson is produced together with two very energetic jets in the forward region of the detector. Since there is no colour flow between the jets, one does not expect extra jet activity in the central region of the detector. These two properties are very powerful in rejecting backgrounds.

Using WBF it is possible to extract a very clear signal from $H \to WW^* \to l\nu\, l\nu$ and - even more important - to discover the Higgs boson in the leptonic decay $H \to \tau\tau$ allowing a measurement of the τ-Yukawa coupling, which is not possible in gluon fusion due to the dominant Z background. Fig. 3 shows the expected distribution of the transverse mass in $H \to WW$ and the invariant mass $M_{\tau\tau}$ in $H \to \tau\tau$.

When combining the WBF channels with all other channels it is possible to discover a SM Higgs boson ($m_H > 120$ GeV) using only 10 fb^{-1} (see Fig. 4), which is the expected integrated luminosity per year for one detector at low luminosity.

3.3 Determination of the Higgs boson parameters

Provided that a Higgs boson is discovered, it is essential to verify that the discovered particle is really a CP-even, spin-0 boson that couples to all particles in proportion to their mass as predicted in the SM.

Determination of spin and CP

Information on the CP and spin state of the Higgs boson can be extracted from the angular correlations in the decay $H \to ZZ \to l^+l^-\, l^+l^-$ for a Higgs boson above the ZZ threshold [14]. Due to the good resolution in the fully leptonic decay, a complete reconstruction of the final state is possible. The analysis cuts on the reconstructed masses of the Z bosons and the Higgs boson do not change the angular distributions of the leptons. Using 100 fb^{-1} of data it is possible to exclude all anomalous spin and CP states at the 2 σ level (see Fig. 5).

For a light Higgs boson methods to exclude anomalous spin and CP states using $H \to ZZ^{(*)}$ and angular correlations in WBF $H \to WW$ and $H \to \tau\tau$ are under investigation.

Measurement of coupling parameters

A measurement of the Higgs boson coupling parameters is possible by combining all Higgs boson production and decay modes. Depending on the Higgs boson mass, it is possible to access the Higgs boson couplings to the W- and Z-boson and the Yukawa couplings to τ, b and t at the LHC.

However, for a light Higgs boson ($m_H < 200$ GeV) it is not possible to do an absolute measurement of these couplings since the total width of the Higgs boson is too small to be measured directly. Without this knowledge

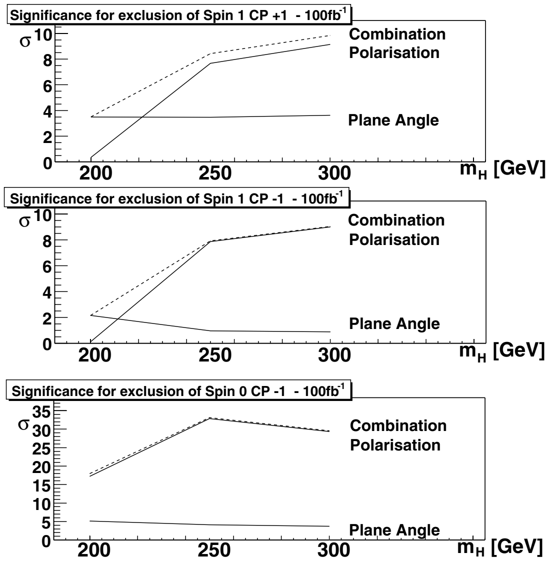

Fig. 5. Significance for the exclusion of anomalous spin and CP states [14]

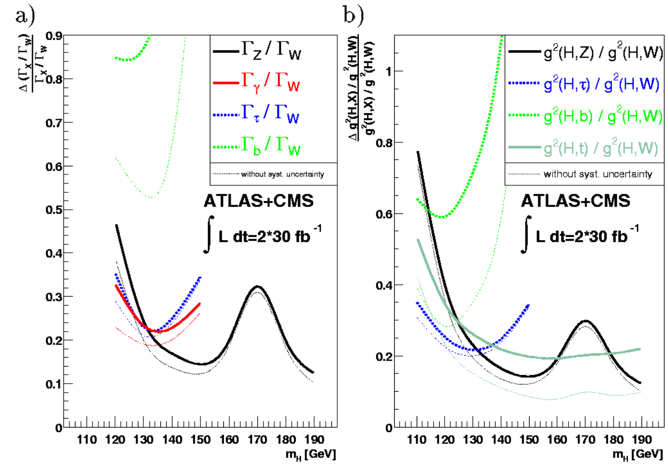

Fig. 6. Expected relative error on the measurement of **a** ratios of Higgs boson partial width and **b** ratios of Higgs boson couplings for a SM Higgs boson. The *thin dotted* (*dash-dotted*) *lines* give the expected error without systematic uncertainties

of the total width it is impossible to separate the Higgs boson production and decay modes, allowing only relative measurements of coupling parameters.

In [15] a global maximum likelihood fit to all relevant Higgs boson production and decay modes in the mass range of $110\,\text{GeV} \leq m_H \leq 190\,\text{GeV}$ was performed taking all experimental and theoretical systematic uncertainties into account that appear for the various Higgs boson channels.

Under the assumptions that there is only one Higgs boson that gives mass to all particles it is possible to measure ratios of Higgs boson branching ratios which is equivalent to ratios of the Higgs boson partial widths. For $m_H \geq 120$ GeV a combined relative precision of 50% or less on G_Z/G_W, G_γ/G_W and G_τ/G_W can be expected for 30 fb^{-1} per experiment (see Fig. 6 a).

Assuming that there are no new particles that couple to the Higgs boson and no extremely enhanced couplings of light fermions it is possible to measure ratios of the Higgs boson coupling strength. For $m_H > 120$ GeV a relative precision of 40% or less can be expected for g_Z^2/g_W^2, g_τ^2/g_W^2 and g_t^2/g_W^2 (see Fig. 6 b).

4 Conclusions

No direct evidence for a Higgs boson could be found at LEP resulting in a lower limit on the mass of a SM Higgs boson of $m_H > 114.4$ GeV. If a Higgs boson exists, the LHC experiments ATLAS and CMS are able to discover it within the first three years, in most cases one year is sufficient.

Furthermore, the LHC experiments will be able to measure the Higgs boson parameters with a good accuracy allowing to distinguish between the SM and models beyond the SM.

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