Higgs searches at LHC

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1 Introduction

In the Standard Model (SM) the elementary particles acquire their mass through the Higgs mechanism. This mechanism foreseens the existence of the Higgs boson a scalar particle which couples to massive particles. Its mass is the only yet unknown parameter of the SM. Constraints on its value come from the theory and from the experimental results from LEP [1]. In the SM the allowed mass range is 114.4 GeV/c$^2 \div 1$ TeV/c^2 and the production cross section is of the order of a few pb.

The Large Hadron Collider (LHC) is the machine designed for its discovery. Thanks to its high center of mass energy (14 TeV) the LHC will be able to explore the whole allowed mass range while its high instantaneous luminosity (10^{34} cm^{-1}s^{-1}) will allow to assess the small cross sections involved in the Higgs production.

2 Higgs production and decay channels

Figure 1 shows the tree level diagrams of the four main Higgs production channels in p-p collisions and their cross sections, as a function of the Higgs mass, for a center of mass energy of 14 TeV. The gluon-gluon fusion is the dominant process over the whole mass spectrum. Its cross section suffers of high QCD corrections and large uncertainties due to the gluon structure functions. The Vector Boson Fusion (VBF) cross section is about one order of magnitude lower than the gg fusion one for a large range of the Higgs masses. The two processes become comparable for high values of the Higgs mass. This process has a well known next-to-leading-order cross section, small QCD corrections and a very clear experimental signature, due to the presence of the two spectator jets with high invariant mass in the forward region. The remaining production processes have very small cross sections, orders of magnitude lower than those of gg and VBF. They will be used for the Higgs discovery in association with particular Higgs decay modes to exploit final states with a clear signature.

The branching ratio of all the possible Higgs decay channels as a function of the Higgs mass is shown in Figure 2. For Higgs masses up to 150 GeV/c fermionic decay

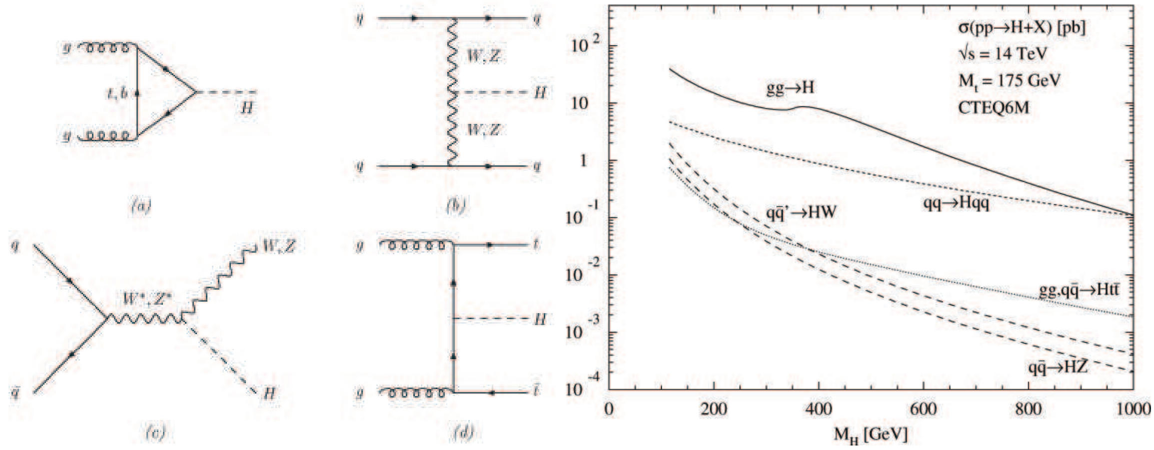

Figure 1: [Left side] Higgs boson production mechanisms at tree level in proton-proton collisions: (a)gluon-gluon fusion; (b) Vector Boson Fusion, (c) W and Z associated production (or *Higgsstrahlung*); (d) $t\bar{t}$ associated production. [Right side] Higgs boson production cross sections at $\sqrt{s} = 14$ TeV as a function of the Higgs boson mass. The cross sections are calculated using HIGLU [2]; they contain higher order corrections and the CTEQ6m [6] p.d.f. has been adopted.

modes are dominating. When the decay channels into vector boson pairs open up, they quickly dominate. At high masses (above 350 GeV/c^2) also $t\bar{t}$ pairs can be produced.

Depending on the Higgs mass, ATLAS [3, 4] and CMS [5], the two general purpose experiments at the LHC, have been developed different strategies for its search. The experimental techniques and the expected sensitivity are discussed in the following.

3 Higgs Searches at the LHC

3.1 Low mass region

The most promising discovery channels for $M_H < 130$ GeV/c^2 are the decay modes into a pair of photons or τ leptons thanks to their clear signature.

The first process suffers of a very high background coming from Drell-Yan e^+e^-, $pp \rightarrow \gamma\gamma$, $pp \rightarrow jets + \gamma$, $pp \rightarrow jets$ where one or more jets are misidentified as γ. The suppression of the last two contributions will require a good understanding of the performance of the electromagnetic calorimeter and a reliable modeling of the amount of material in front of it.

The analysis on the $H \rightarrow \tau\tau$ decay mode focus on the VBF production channel because of its higher signal over background ratio. The most promising final state is

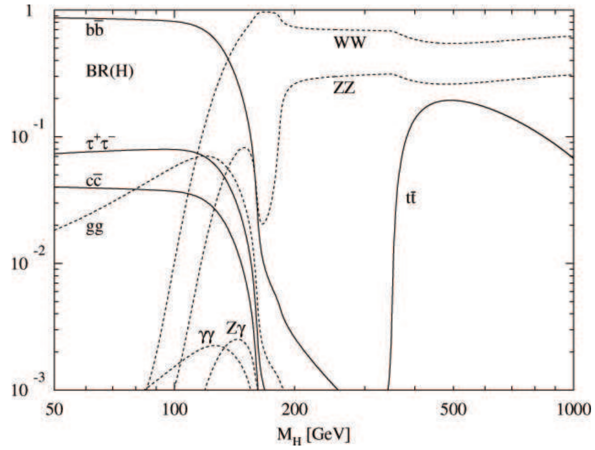

Figure 2: Branching ratios for different Higgs boson decay channels as a function of the Higgs boson mass. They are calculated with the program HDECAY [7] which includes the dominant higher order corrections to the decay width.

the one with one τ decaying into leptons and the other into hadrons. The irreducible backgrounds to this process are the QCD and EW production of two τ leptons from Z or $\gamma^{\star}$ with associated jets. Contributions also come from W+multi-jets production and $t\bar{t}$ events in which one of the jets can be misidentified as a τ jet. The signature is characterized by the hadronically decaying τ (associated to a little (ΔR=0.4) isolated jet), the leptonically decaying τ (identified from the electron or the muon with highest transverse momentum $p_t > 15$ GeV/c) and the two quarks emitting the bosons in the VBF process which have a high energy and rapidity gap.

The high branching ratio of the Higgs boson into a pair of b quarks can only be exploited in the study of the Higgs production via $t\bar{t}$ fusion. The most promising final states have at least one of the two t quark decaying leptonically thanks to the clear signature offered by the presence of at least one high p_t lepton from one of the two W, missing energy and 4 b-tagged jets (of which two from the Higgs). The 4 jets are the responsible of a very high background, mostly composed by $ttbb$, Zbb, $tt + Njets$ and multi-jets QCD events and are the main sources of uncertainty. A pioneer novel study [8] has obtained good results on the signal over background ratio by reconstructing the $H \to b\bar{b}$ decay (produced through VBF) asking the presence of a central high p_t photon in the final state.

3.2 High mass region

This region corresponds to values of the Higgs boson mass above the threshold of $2M_w$, where the Higgs analysis are focused on the Higgs decays into a couple of vector bosons.

The main channels of interest are those where the two vector bosons decay leptonically. The clear experimental signature of these events compensates for their low branching ratio, which is about one order of magnitude lower than the hadronic ones.

In the $H \to WW \to l\nu l\nu$ channel it is not possible to reconstruct the H invariant mass due to the presence of the two neutrinos. Since the signal selection can not exploit this variable other techniques must be used for the discrimination and a good control of the background shape is mandatory. The final state presents 2 isolated high p_t leptons pointing to the primary vertex, high missing energy and no hadronic activity. The signal selection relies mainly on the request of a central jet veto, high missing energy and of a small angle between the two leptons due to the V-A structure of the weak interaction.

The $H \to ZZ \to 4l$ (l = muons or electrons) channels are the "golden channels" for the Higgs discovery. The main backgrounds are: $t\bar{t}$, $Zb\bar{b}$ and the irreducible $ZZ^{\star}/\gamma^{\star}$. The trigger and the offline cuts rely on the presence of isolated charged leptons coming from the primary vertex, with high transverse momentum. The instrumental backgrounds become negligible with the request of lepton isolation and using different cuts on the sorted lepton transverse momenta. The irreducible background can be suppressed applying cuts on angular variables. The main sources of systematic uncertainties come from the choice of the PDF and the QCD scale, the NLO versus the LO dynamics, the isolation cut and its efficiency, the electron reconstruction efficiency, the energy and the momentum scale and the charge identification.

As discussed above, the VBF production channel becomes important in the very high mass region thanks to its clear experimental signature given by the two spectator jets and the Higgs decay products, which allows a good rejection of dominant background coming from $V + njets$, $VV + njets$ and $t\bar{t}$ production. These jets are well separated in pseudo-rapidity and have a very high invariant mass.

Moreover, the Vector Boson Fusion cross section (with or without a production of an Higgs particle) is an extremely interesting process because the cross section $\sigma(pp \to VVjj)$ and the polarization of the VV pair depend sensitively on the presence or absence of a light Higgs in the physical spectrum. If a massive Higgs boson exists, a resonance will be observed in the VV invariant mass spectrum in correspondence of the Higgs mass. In the absence of the Higgs particle the SM predicts that the scattering amplitude of longitudinally polarized vector bosons grows linearly with s ad violates unitariety at about $1 - 1.5$ TeV. This means that the measurement of the cross section at large $M(VV)$ could provide information on the existence of the Higgs boson independently of its direct observation.

3.3 Higgs discovery significance

The Higgs expected significance in the different channels, after an integrated luminosity of 30 fb^{-1}, is showed in Figure 3 for the ATLAS and CMS experiments.

In the low Higgs mass region CMS will focus on the $H \to \gamma\gamma$ channel, relying on its excellent electromagnetic calorimetric system, while ATLAS can exploit the performance of its hadronic calorimeter investigating the $qqH \to qq\tau\tau$ channel. In the high Higgs mass region both ATLAS and CMS will concentrate their efforts in the study of decay modes into a pair of vector bosons. The highly performant tracker system of the CMS experiment plays a key role in these analysis. Combining the results of both experiments, it is foreseen that, for Higgs masses larger than 140 GeV/c^2, the significance will be close to 5σ already after an integrated luminosity of 1 fb^{-1}. For a light Higgs the situation is instead more complex because of the need to combine several channels. The minimum luminosity for the discovery will be around 5 fb^{-1}. It is however important to remark that these values of luminosity refer to a scenario where the two experiments have already reached a deep understanding of their detectors, of the systematic uncertainties involved in the measurements and of the accuracy of the simulation of signal and background processes.

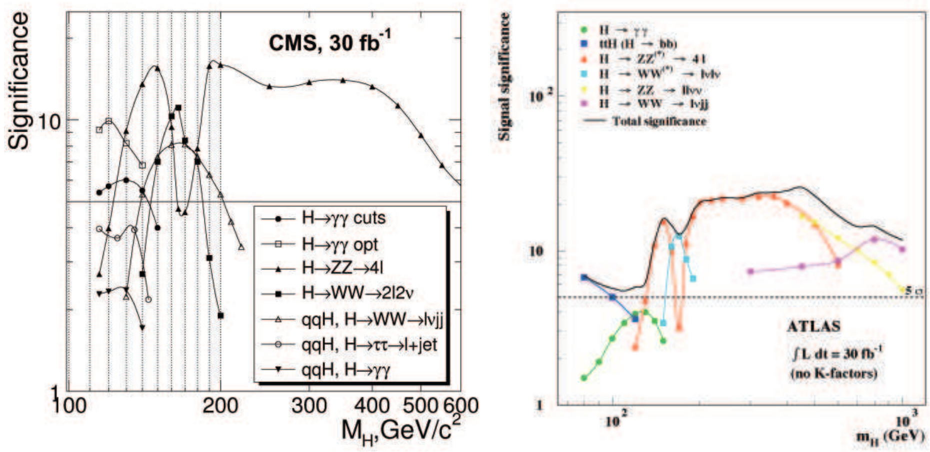

Figure 3: The signal significance as a function of the Higgs Boson mass for 30 fb^{-1} of the integrated luminosity for the different Higgs Boson production and decay channels. Analysis results from CMS [9] (left) and ATLAS [10] (right).

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