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Standard Model Higgs Searches at the LHC

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The search for the Higgs boson, a key component in the Standard Model description of electroweak symmetry breaking, is a major goal of the physics program at the Large Hadron Collider (LHC) at CERN. Both ATLAS and CMS, experimental collaborations at LHC, have done extensive simulation and performance studies to optimize their strategies for this search. Some of these studies are discussed, as well as the resulting discovery potential (as a function of the Higgs boson mass), for the main experimental signatures that will be addressed by the two collaborations.

1. Introduction

One of the main experimental goals of the LHC physics program is the search for the Higgs boson, a scalar particle predicted in the Standard Model as a key component of the electroweak symmetry breaking mechanism [1]. So far, direct experimental searches for the Higgs boson have been able to put a lower limit on its mass (114.4 GeV/c^2 at 95% confidence level). Also, using the recent precise measurements of the W and top masses, the LEP Electroweak Working Group [3] quotes an upper limit of about 144GeV/c^2 (95% confidence level; this value increases to 182GeV/c^2 when including the direct search limit of 114.4GeV/c^2 [2]).

The ATLAS and CMS experiments, both close to completion and scheduled to begin taking data in mid 2008, have been designed to be sensitive to many of the possible signatures of the Standard Model Higgs boson. This paper is a partial overview of the corresponding searches. Section 2 briefly describes the main production mechanisms of the Higgs boson; the next section discusses some of the decay channels of interest for experimental searches. Section 4 then goes over the expected experimental conditions at the LHC. Section 5 discusses a selection of search channels, and the expected significance of these searches is summarized on section 6 for both ATLAS and CMS.

2. Standard Model Higgs production

Figure 1 shows the Higgs production cross sections, in the Standard Model, as a function of the Higgs mass for the most important processes at the LHC. For the mass range favored by current limits (and well above, up to about 1 TeV), the main production mechanism is gluon-gluon fusion via a top quark loop (labeled as $gg \to H$ in the plot); *Vector Boson Fusion* (VBF), labeled Hqq in fig. 1) is about an order of magnitude below gg fusion; however, VBF-restricted searches can still be very powerful, as we'll describe in section 5. Associated production with a W or Z bosons (WH, ZH), and with a top quark pair ($t\bar{t}H$) have even lower cross sections, but can still be used in search strategies. Currently, QCD computations of these cross sections are available at either NLO (next to leading order) or NNLO, with uncertainties of 10-20% for gluon-gluon fusion, ∼5% for VBF, ∼10-20% for $t\bar{t}H$ and ∼5% for WH, ZH production.

3. Higgs decays

Figure 2 shows the branching ratios of the Standard Model Higgs boson as a function of Higgs mass. Below the weak vector bosons are kinematically accessible (at around $2m_W$), the dominant mode is $b\bar{b}$, which is, however, a hard channel to use for searches due to the huge $b\bar{b}$ background. The $H \to \tau\tau$ decay, with a smaller branching ratio, has a much higher potential. The decay into

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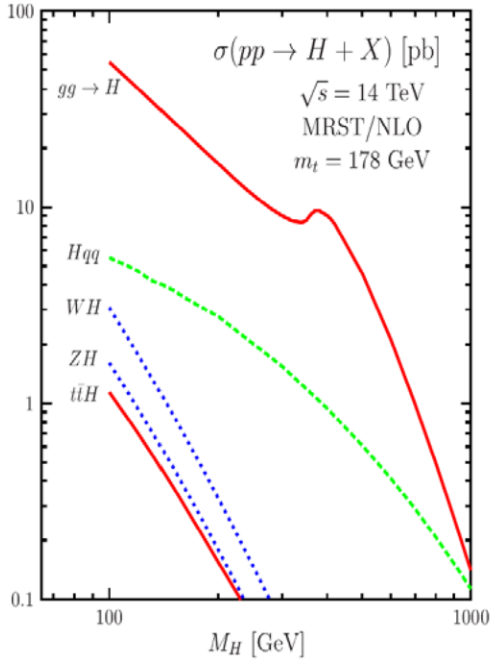

Figure 1. Higgs production cross sections in the main channels at LHC (from [4])

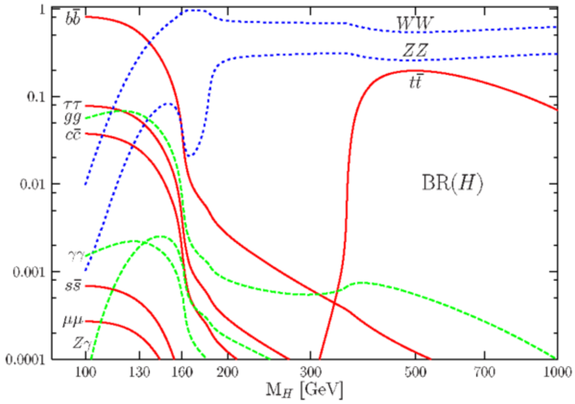

Figure 2. Decay branching ratios of the Standard Model Higgs boson (from [4])

two photons can also be used at low masses if a high enough rejection against jets is achieved.

Once the WW and ZZ modes are available, they provide powerful probes for the search. The former because it takes about 95% of the branching ratio, the latter because, if the two Z bosons decay into lepton pairs, provides a signature that is easy to trigger on, and which allows the full reconstruction of the Higgs mass. For m_H less than about 200 GeV, the natural width of the Higgs boson is well below experimental resolution, and it grows very rapidly after that.

4. LHC startup and physics environment

As of this writing, the LHC startup is well under way. All magnets are already in the tunnel; electrical, cryogenic and vacuum interconnections are in progress, while many ATLAS and CMS detector subsystems, already installed on the caverns, are entering the commissioning phase.

Proton-proton collisions are expected to start in mid 2008 at the full 14 TeV center of mass energy. During the first, "low-luminosity" phase, with an instantaneous luminosity of $10^{33}\ cm^{-2}s^{-1}$, each experiment will be able to gather about 30 fb^{-1} of data. Later, the "high-luminosity" phase, at $10^{34}\ cm^{-2}s^{-1}$, will run up to an integrated luminosity of the order of 300 fb^{-1}.

One important consequence of the running conditions at LHC is the fact that, in both regimes, there will be multiple pp interactions per bunch crossing; the expected number is ~ 2 for low luminosity and about 25 for high luminosity, which entails a degradation of the energy resolution and the particle identification capabilities of both detectors. In what follows, we'll be focusing on the low luminosity phase of the Higgs searches.

The total inelastic cross section at LHC is expected to be around 80 mb. On the other hand, starting from a Standard Model Higgs production cross section in the pb range, branching ratios and reconstruction efficiencies will reduce the expected signal rates to the order of fb or tens of fb; i.e., 12 orders of magnitude below the total rates.

The ATLAS and CMS detectors, described in detail elsewhere ([7], [8]), were designed to have powerful identification capabilities in order to cope with this environment. Photon reconstruction, for example, can achieve an 80% efficiency while having a rejection factor of a few thousands