Prospects for non-standard Higgs Bosons at the LHC

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ABSTRACT: The Large Hadron Collider (LHC) at CERN will provide proton-proton collisions at a centre-of-mass energy of 14 TeV with a design luminosity of 10^{34} cm^{-2}s^{-1}. The present report will give a non-exhaustive panorama of the several search methods for the Higgs sector that have been elaborated by the ATLAS and CMS Collaborations

1. Introduction

The Minimal Supersymmetric extensions of the Standard Model predict two complex scalar field doublets, with a total of eight degrees of freeeedom. As in the Standard Model, three of them are associated to the longitudinal modes of the $W^{\pm}$ and Z^0 bosons. The remaining five degrees of freedom are manifested in five physical scalar Higgs states h^0, A^0, H^0, and the charged Higgs bosons $H^{\pm}$. Results are expressed in terms of two parameters which are generally chosen as m_A and $\tan\beta$, the ratio of vacuum expectation values of the two Higgs fields.

At the tree level, the mass of the lighter of the two CP-even Higgs bosons is limited to be less than the mass of the Z^0. Radiative corrections, particularly from loops containing the top quark, allow the lightest Higgs boson mass limit to go up to ≈ 135 GeV/c^2 [1]. The masses of the other four Higgs bosons are less constrained, but should essentially be degenerate once their mass is larger than ≈ 200 GeV/c^2.

The relative importance of the different production modes varies with $\tan\beta$. As low values of $\tan\beta$ have been largely exluded by LEP data, we will mainly concentrate on the large $\tan\beta$ scenario where the associated production mode $b\bar{b}H_{SUSY}$ is predominant. Over much of the parameter space considered, the neutral Higgs bosons decay predominantly to $b\bar{b}$ and $\tau^+\tau^-$, and the charged Higgs mainly decay to bt and $\tau\nu_\tau$. At relatively large masses ($m_{H_{SUSY}} \geq 300$ GeV/c^2), decay modes involving neutralinos or charginos may become important. These modes will not be discussed here, but ATLAS and CMS studies give promising perspectives.
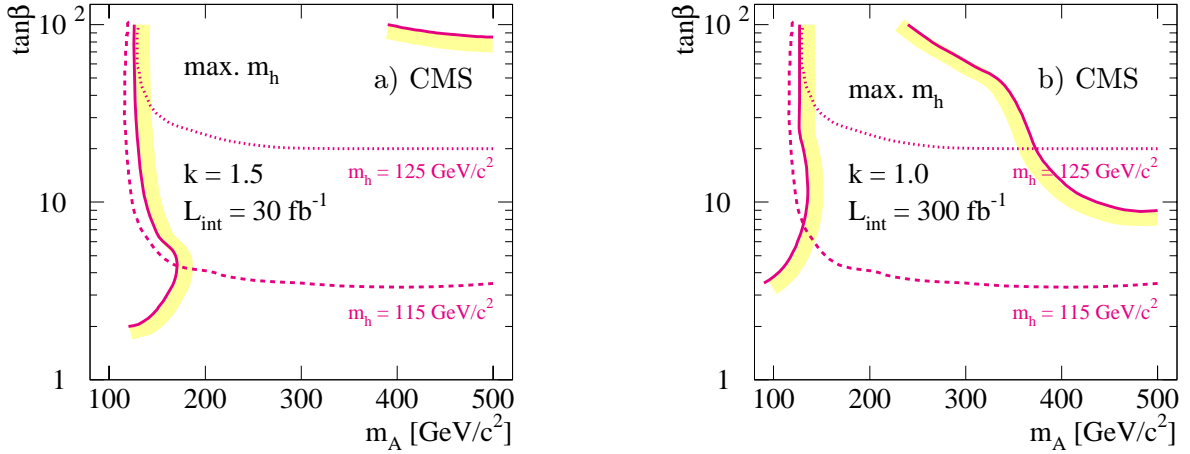
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Figure 1: a) Discovery contours in the MSSM (m_{h^0}-max scenario) parameter space for 30 fb^{-1}, using $t\bar{t}h^0$ associated production. $S/\sqrt{B} \geq 5$ to the right side of the solid line. The dotted and dashed lines are the isomass curves for $m_{h^0} = 125$ GeV/c^2 and $m_{h^0} = 115$ GeV/c^2. b) Discovery contours in the MSSM (m_{h^0}-max scenario) parameter space for 300 fb^{-1}, using $W^{\pm}h^0$ associated production. $S/\sqrt{B} \geq 5$ to the right side of the solid line. The dotted and dashed lines are the isomass curves for $m_{h^0} = 125$ GeV/c^2 and $m_{h^0} = 115$ GeV/c^2. In this scenario, $M_{SUSY} = 1$ TeV/c^2, $\mu = 0.2$ TeV/c^2, $M_2 = 0.2$ TeV/c^2, $M_{\tilde{g}} = 0.8$ M_{SUSY}, $X_t^{OS} = 2$ M_{SUSY}, $X_t^{\overline{MS}} = \sqrt{6}$ M_{SUSY}, $A_b = A_t$ [3]

2. Search methods

2.1 Neutral Higgs bosons

At masses above the range explored by LEP, the dominant decay of the neutral Higgs bosons is to $b\bar{b}$. This mode is essentially impossible to separate from the huge $b\bar{b}$ background from QCD in case of inclusive h^0 production. However, a signal can be extracted when the Higgs boson is produced in association with a $t\bar{t}$ pair or a $W^{\pm}$ [2]. In $t\bar{t}h^0$ associated production, using a full simulation of the physics processes and of the detector response, a signal significance [1] larger than 5 can be reached with 30 fb^{-1} for $m_{h^0} \leq 125$ GeV/c^2. The b-tagging performances (efficiency and purity) are crucial and the shape of the background must be measured from data. A good understanding of the jet-jet effective mass signal shape and of the background is essential. In $W^{\pm}h^0$ associated production, preliminary studies show that a signal significance of 6 can be obtained, requiring however ≈ 300 fb^{-1}, and full background subtraction is necessary to give evidence for a signal. Figure 1 shows the reach of the $h^0 \to b\bar{b}$ channel in the MSSM parameter space in the m_{h^0}-max scenario, the most unfavourable case as signal visibility decreases with increasing mass. These measurements will also provide information on tth and WWh couplings with a precision of $\approx 10\%$.

The most interesting decay channels of the heavy neutral Higgs bosons (A^0, H^0) are $\tau^+\tau^-$ and $\mu^+\mu^-$, as $b\bar{b}$ decays are essentially unseparable from the huge QCD $b\bar{b}$ background. In the $\tau^+\tau^-$ channel, three final states can be used: $e\mu$, lepton-τjet, 2 hadrons (from τjets) with opposite charges [4]. The use of a b-tag improves dramatically the detection of the signal at large $\tan\beta$ where the $b\bar{b}H_{SUSY}$ production mechanism dominates.

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[1]The signal significance is defined as $S/\sqrt{B}$, where S is the signal and B is the background
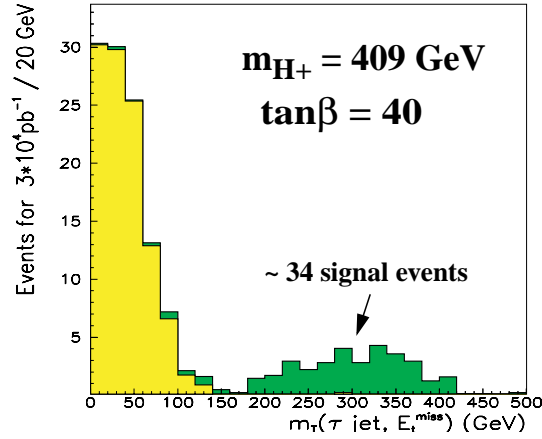
Figure 2: The transverse mass distribution of signal and backgrounds for a charged Higgs search using 30 fb^{-1}. The couplings are determined in the MSSM with $m_{H^\pm} = 409\,\mathrm{GeV}/c^2$ and $\tan\beta = 40$ [4]

Despite the 2 (or more) neutrinos from τ decays escaping detection, a $\tau^+\tau^-$ mass reconstruction is possible. Mass resolutions of 12 to 16% can be obtained in the various $\tau^+\tau^-$ final states. The 2 τjets final state provides the best mass resolution. The main difficulty in this channel is triggering in the presence of the large QCD background, however successful trigger strategies have been elaborated by CMS. An interesting new development is the use of τ-tagging by impact parameter measurements on one-prong leptonic or hadronic τ decays which are possible thanks to the expected impact parameter resolutions of $\approx$ 20-30 μm in the LHC pixel-trackers.

2.2 Charged Higgs bosons

A charged Higgs boson with a mass larger than the top mass will predominantly decay to bt, but this channel is highly contaminated by the QCD background. The $H^\pm \to \tau^\pm \nu_\tau$ channel turns ou to be the most interesting decay channel. Both ATLAS and CMS [5] have studied the production mechanism pp $\to$ H$^\pm$tb + X, followed by the decay H$^\pm \to \tau^\pm \nu_\tau$. The τ-polarization effects can be exploited to enhance the signal over the background. Due to the scalar nature of the decaying H$^+$, the τ^+ from the H$^+$ decay is produced in a left-handed polarization state, whilst, due to the vector nature of the W$^+$, the τ^+ from the W$^+$ decay is produced left-handed, when the W originates from $t\bar{t}$ which is the main background. Thus harder pions (from $\tau \to \pi\nu$) are expected from H$^\pm$ decays than from W$^\pm$ decays to taus. To improve the signal to background ratio, the W and top masses are reconstructed from jets, requiring one tagged b-jet. In the purely hadronic final states an almost background-free signal is found in the transverse mass distribution reconstructed from the τ-jet and the missing transverse energy (Figure 2).

3. MSSM Higgs parameter space coverage

All studies of the MSSM Higgs sector, including some which have not been discussed here, are summarized in terms of $(m_A, \tan\beta)$ parameter space coverage for a 5σ discovery
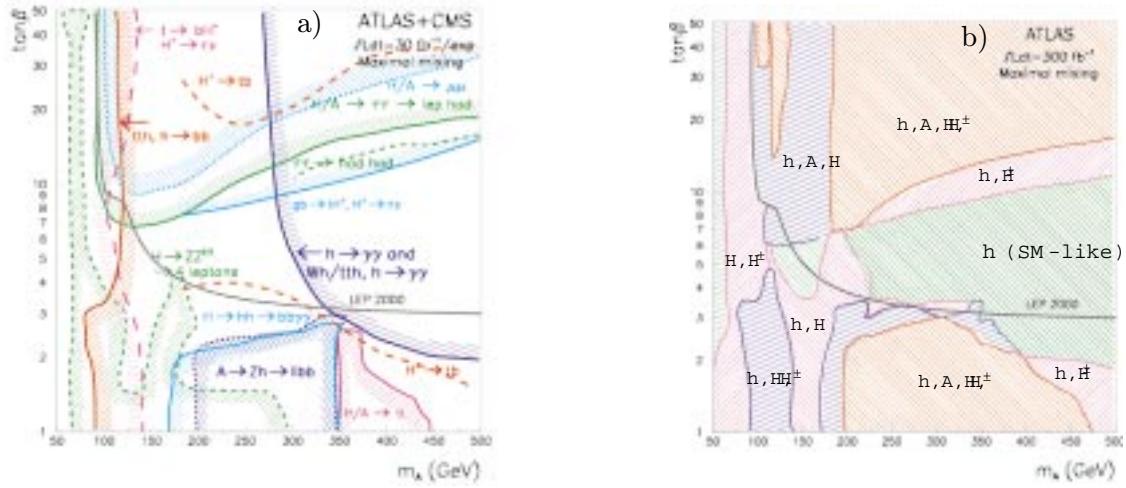
Figure 3: a) 5σ discovery contours in the $(m_A, \tan\beta)$ plane for $m_t = 175$ GeV/c^2, $M_{SUSY} = 1$ TeV/c^2 and maximal mixing, combining ATLAS and CMS with 30 fb^{-1} per experiment. Not all channels are shown and SUSY particles are assumed to be heavy. b) 5σ discovery contours in the $(m_A, \tan\beta)$ plane for 1, 2, 3, and 4 Higgs bosons using 300 fb^{-1} for ATLAS alone.
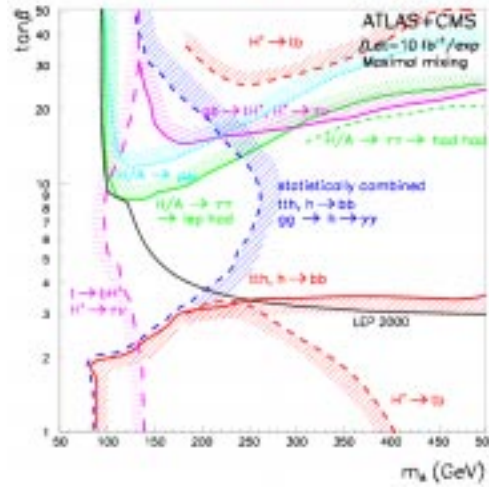

Figure 4: 5σ discovery contours in the $(m_A, \tan\beta)$ plane for $m_t = 175$ GeV/c^2, $M_{SUSY} = 1$ TeV/c^2 and maximal mixing, combining ATLAS and CMS with 10 fb^{-1} per experiment.

in Figure 3a. This figure shows the 5σ discovery contours in the $(m_A, \tan\beta)$ plane for $m_t = 175$ GeV/c^2, $M_{SUSY} = 1$ TeV/c^2, and maximal stop-mixing[2]. By combining the results of the two experiments, the plane is expected to be fully covered already with 30 fb^{-1}. Two or more Higgs bosons can be observed with 300 fb^{-1} over most of the parameter space, allowing to differentiate between the observation of a SM Higgs from that of a MSSM Higgs (Figure 3b). However there remains a region at $m_A \geq 200$ GeV/c^2 and $4 \geq \tan\beta \leq 10$ where only the h^0 would be seen and it would be indistinguishable

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[2]for minimal mixing, the range below 115 GeV/c^2 has been fully explored by LEP.

from a SM Higgs. Even if only 10 fb^{-1} are delivered to each experiment during the first year of running, Figure 4 shows that, nonetheless, a large part of the plane is expected to be explored with ATLAS and CMS combined data.

4. Conclusions

LHC has a large discovery potential for MSSM Higgs bosons. The MSSM Higgs sector can be fully explored, and two or more Higgs bosons should be observable over large portions of parameter space allowing for precise measurements of their parameters (masses, couplings, $\tan\beta$). New promising channels, such as Higgs decays to sparticles, are under investigation. Calculations are continuously improved to better understand the physics reach and to define the trigger strategies. ATLAS and CMS are actively preparing for discovery of the Higgs bosons and the measurement of their properties.

Acknowledgments

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