Searches for BSM Higgs Bosons at the LHC

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Searches for Higgs bosons in different extensions of the Standard Model which predict additional neutral and charged Higgs bosons are presented. These include the Minimal Supersymmetric extension of the Standard Model (MSSM), the next-to Minimal Supersymmetric extension of the Standard Model (nMSSM), two Higgs doublet models, four-generation and fermiophobic models. Results are based on data collected by the ATLAS and CMS experiments in proton-proton collisions at centre-of-mass energies of 7 TeV and 8 TeV. No excess is found in either charged nor neutral Higgs Boson searches. Model-independent and model-dependent exclusion limits are presented for these searches.

1 Introduction

The ATLAS and CMS experiments have performed many searches for beyond the standard model (BSM) Higgs bosons at the LHC. An overview of the most recent results focusing on analyses with an integrated lumiosity above $1\,\text{fb}^{-1}$ is presented, classified as charged or neutral Higgs boson searches.

2 Charged Higgs Boson Searches

2.1 Charged Higgs Boson Searches for $H^+ \to \tau\nu$

Both ATLAS and CMS perform searches for light charged Higgs bosons that assume $m_{H^+} < m_{\text{top}}$, where the charged Higgs bosons are produced in top-quark decays. Since H^+ decays predominantly into $\tau + \nu$, top-quark pair events with tau lepton final states are investigated.

The ATLAS analysis[1] is based on $4.6\,\text{fb}^{-1}$ of pp collisions at $\sqrt{s} = 7\,\text{TeV}$. The final states jets+τ_{lep}, τ_{lep}+τ_{had} and $\tau_{had} + jets$ are considered. The results agree with SM expectations and 95% CL upper limits on $\mathcal{BR}(t \to bH^+)$ between 5% and 1% are set for $90\,\text{GeV} < m_H^+ < 150\,\text{GeV}$, assuming $\mathcal{BR}(H^+ \to \tau\nu) = 100\%$. An update of this analysis[2] exploits the fact that top-quark pair decays with charged Higgs bosons would violate the lepton universality due to the enhanced coupling to the tau leptons. The ratio of event yields with and without tau leptons are compared with SM expectations, reducing systematic uncertainties while improving the upper limit on the $\mathcal{BR}(t \to H^+b)$ to 0.8%-3.4% after combining with the τ_{had}+jets final state from Ref[1]. Limits in the Minimal Supersymmetric extension of the Standard Model (MSSM) are set for the m_h^{max} scenario[4], shown in Figure 1 (left).

The analogous CMS search[3] uses $2\,\text{fb}^{-1}$ of data in four final states: $e\tau_{had}$, $\mu\tau_{had}$, $e\mu$, and τ_{had}+jets. Upper limits on $\mathcal{BR}(t \to H^+b)$ in the range of 2-4% are achieved. In the m_h^{max} scenario, $\tan(\beta)$ values above 16 can be excluded (Fig 1(right)). An update in the $\mu\tau_{had}$ channel[5] with a luminosity of $4.9\,\text{fb}^{-1}$ improves the upper limits on $\mathcal{BR}(t \to H^+b)$ to 2-3% for $90 < m_H^+ < 160$ GeV.

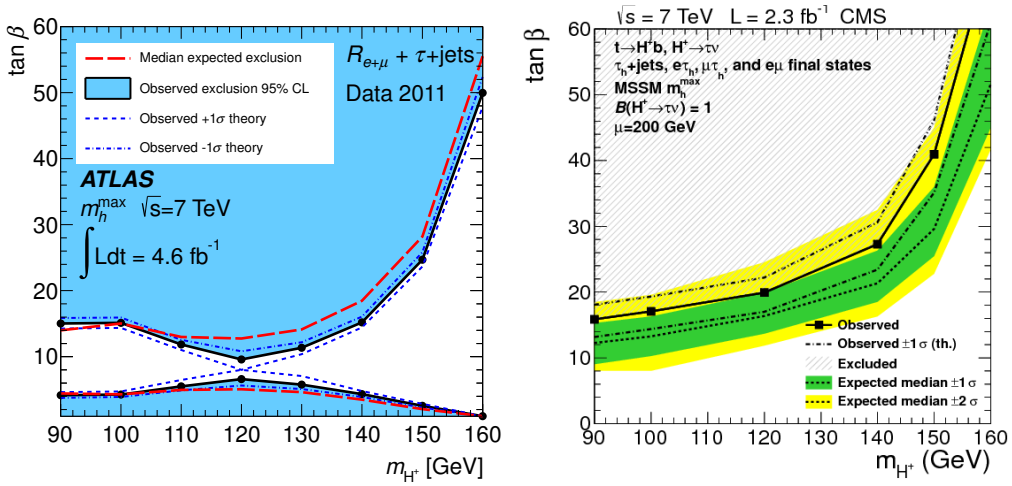

Figure 1: Limits for charged Higgs boson production from top-quark decays in the m_{H^+}-tan β plane. ATLAS results[2] (left) are derived using τ_{had}+jets events and the ratio $R_{e+\mu}$, while CMS results[3] (right) are shown in the context of the m_h^{max} scenario of the MSSM.

2.2 Doubly-charged Higgs Boson Searches

ATLAS and CMS searches for doubly-charged Higgs bosons use 4.9 fb^{-1} of data at $\sqrt{s} = 7$ TeV. The CMS analysis[6] uses three and more charged leptons of any flavour and is sensitive to pair-produced ϕ^{++},ϕ^{--} and $\phi^{\pm\pm}$,$\phi^{\mp}$ associated production with degenerate masses. No excess is observed and both upper limits at 95 % CL on the ϕ^{++} production cross section and lower bounds on the $\phi^{\pm\pm}$ masses are reported. For $\mathcal{BR}(\phi^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) = 100\%$ in the different lepton final states, doubly-charged Higgs boson masses between 204 and 459 GeV can be excluded. Four benchmark scenarios with different BR are studied and doubly-charged Higgs boson masses between 383 and 408 GeV are excluded.

The ATLAS analysis[7] searches for a narrow resonance in the mass spectrum of prompt, high-p_{T} leptons pairs with the same electric charge. Lower bounds on doubly-charged Higgs bosons masses of 409, 409, and 398 GeV are obtained, assuming pair production, coupling to left-handed fermions, and a branching ratio of 100% for final states ee, eμ, and $\mu\mu$, respectively.

3 Neutral Higgs Boson Searches

3.1 Neutral Higgs Boson Searches for $\phi \to \tau\tau$

The ATLAS analysis[8] uses up to 4.9 fb^{-1} of 7 TeV data to search for Higgs Boson decays into muon or tau lepton pairs. No significant excess is observed and exclusion limits for the production cross-section at 95% CL are derived separately for a generic Higgs boson ϕ as a function of the mass for both gluon-gluon fusion and b-quark associated production (see Fig. 2(left)). Exclusion limits in the m_h^{max} scenario as a function m_A and tan β are also set.

The CMS analysis[9] focuses on di-tau final states, based on the data corresponding to the integrated luminosities of 4.9 fb^{-1} at 7 TeV and 12.1 fb^{-1} at 8 TeV. Final states with and without additional b-quarks are considered. No excess is observed in the di-tau mass-spectra and exclusion limits are interpreted in the m_h^{max} scenario. The combined limit is shown in Fig. 2(right), where tan β values down to 5 are excluded for $m_A < 220$ GeV.

3.2 Searches for invisible Higgs boson decays

The ATLAS search for invisible Higgs decays[13] considers events with Higgs bosons produced in association with a Z boson. Leptonic Z boson decays are used to tag the events. The

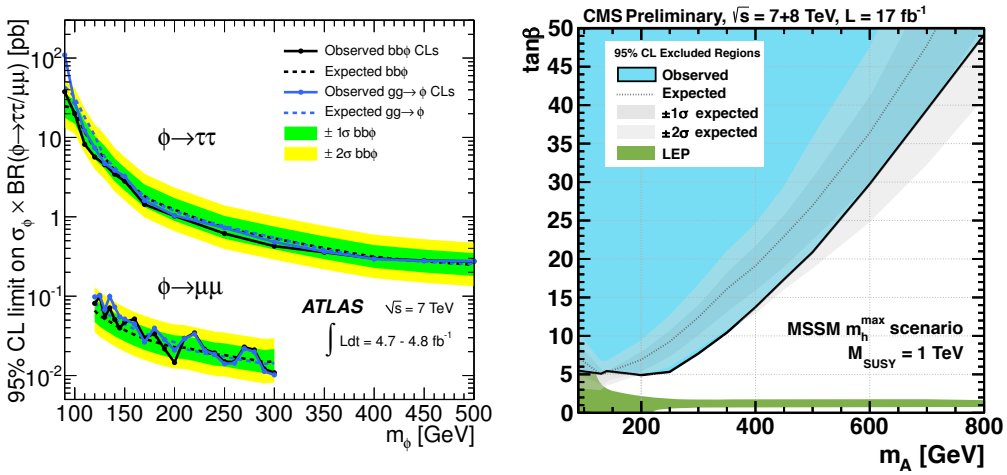

Figure 2: Expected (dashed line) and observed (solid line) ATLAS 95% CL limits on the cross-section for gluon-fusion and b-associated Higgs boson production times the branching ratio into τ and μ pairs, respectively[8] (left). CMS exclusion at 95% CL in the $\tan\beta$-m_A parameter space for the MSSM m_h^{max} scenario[9] (right).

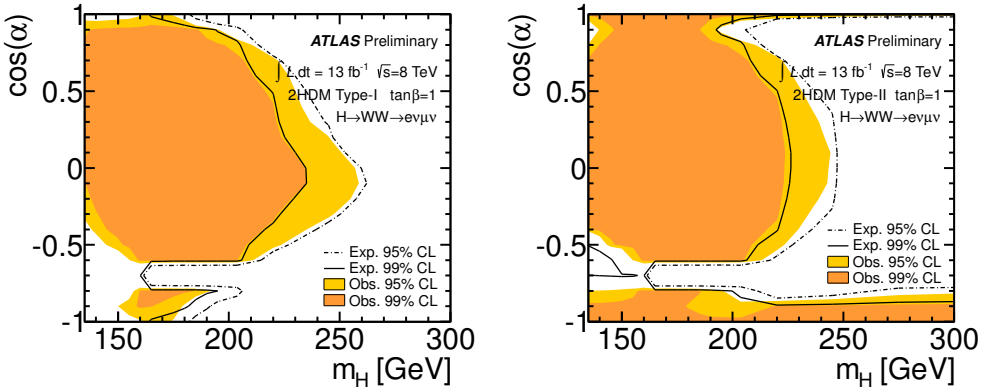

Figure 3: Exclusion contours at the 95% and 99% CL are determined in the $\cos\alpha$-m_H-plane for different values of $\tan\beta$ ranging from 1 to 50 (here the plots for $\tan\beta = 1$ are shown) for type-I (a) and type-II (b) 2HDMs[10].

$E_{\mathrm{T}}^{\mathrm{miss}}$ variable is used to search for an excess in 4.7 fb^{-1} and 13.0 fb^{-1} of 7 TeV and 8 TeV data. Assuming a ZH production rate for a SM Higgs boson with $m_h = 125$ GeV, branching fractions for invisible Higgs decays greater than 65% are excluded at 95% CL. Limits are also set on the cross section times invisible branching fraction of a possible additional Higgs-like boson exclude masses from 170–300 GeV at 95% CL.

3.3 Searches for Higgs bosons in Two Higgs Doublet Models

Given the observation a Higgs boson with $m_{\mathrm{H}} = 125$ GeV, searches for additional neutral Higgs bosons in extensions such as two-Higgs-doublet models (2HDM) are important. The ATLAS analysis[10] searches for a heavier CP-even scalar boson in $H \to WW \to e\nu\mu\nu$ decay modes in 13.0 fb^{-1} of data at 8 TeV. To maximise the sensitivity of the analysis, an artificial neural network technique is used. No evidence for a second scalar boson is observed in the mass range 135 to 300 GeV. Exclusion limits are set for 2HDM of type-I and type-II[11,12] as a function of the two mixing angles α and β and the Higgs mass m_H. Figure 3 shows the exclusion limits in the m_H-$\cos\alpha$ plane for $\tan\beta = 1$ for a 2HDM of type-I (a) and type-II (b).

3.4 Four-generation and Fermiophobic Higgs Searches

CMS searches for Higgs bosons in the context of the SM extension including a fourth generation of fermions with masses up to 600 GeV (SM4) and in fermiophobic models[14]. The searches include up to 5.1 fb^{-1} of 7 TeV and up to 5.1 fb^{-1} of 8 TeV data. Three decay modes ($\tau\tau$, WW and ZZ) are investigated and combined to exclude a SM4 Higgs boson in the mass range 110-600 GeV at 99% CL. The fermiophobic analysis exploits diphoton decays, excluding a fermiophobic Higgs boson in the mass range 110-147 GeV at 95% CL.

The ATLAS SM4 Higgs search[15] analyses up to 2.3 fb^{-1} of data at 7 TeV, and Higgs boson masses are excluded at 95% CL between 119-593 GeV. The fermiophobic search[16] uses 4.7 fb^{-1} at 7 TeV and excludes Higgs masses between 110-118.0 GeV and 119.5-121.0 GeV.

3.5 Searches for Higgs Boson Decays to light CP-odd Scalars

In some extensions of the SM, such as Minimal Composite Higgs Model or Next-to-Minimal Supersymmetric Standard Model, the Higgs boson can couple to light CP-odd scalar particles. The ATLAS experiment presents a study[17] of Higgs decays with di-photon final states based on 4.9 fb^{-1} of 7 TeV data. The Higgs decays via $H \to aa$, where a is a light CP-odd scalar that decays in two collimated photons, mimicking di-photon final states. Using a modified photon identification for this topology, exclusion limits of 0.1, 0.1 and 0.2 pb are set on the Higgs production cross-section times $\mathcal{BR}(H \to aa \to 4\gamma)$ in the range of 110 GeV $< m_H <$ 150 GeV for the $m_a = 100$, 200, and 400 MeV, respectively.

The CMS analysis[18] studies Higgs bosons decays into a pair of new light bosons decaying into di-muons with 5.3 fb^{-1} of 7 TeV data. An upper limit of 0.78$\pm$0.05 fb on the production cross section times BR times acceptance is obtained.

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