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Search for the MSSM Higgs bosons at the LHC

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Summary. — We review the prospects for the Higgs boson searches in the Minimal Supersymmetric Standard Model (MSSM) with the ATLAS and CMS experiments at the Large Hadron Collider (LHC). The results are interpreted within the $m_h^{\max}$ benchmark scenario considering a center-of-mass energy of $\sqrt{s} = 14\,\text{TeV}$.

PACS 14.80.Da – Supersymmetric Higgs bosons.
PACS 12.60.Jv – Supersymmetric models.

1. – Introduction

In the Minimal Supersymmetric Standard Model (MSSM), to describe the electroweak symmetry breaking, two Higgs doublets are required, resulting in five observable Higgs bosons: three neutral (CP-even h and H, and CP-odd A), and two charged (H^+ and H^-) [1]. At the tree level their properties are fully determined by two free parameters, typically $\tan\beta$ (the ratio of the two vacuum expectation values from the two Higgs doublets) and the mass of the A boson m_A. While one of the two CP-even Higgs bosons is SM-like in most of the MSSM parameter space, the remaining Higgs bosons are characterized by enhanced couplings to down-type quarks and charged leptons. Thus, the production in association with b-quarks and the decays into τ-leptons and muons determine the signatures for the non-standard Higgs boson searches. In the following, the prospects for the neutral and charged MSSM Higgs boson searches with the ATLAS and CMS experiments at the Large Hadron Collider (LHC) are reviewed. The MSSM parameter space is constrained to the $m_h^{\max}$ benchmark scenario [2]. The studies are based on a detailed Monte-Carlo simulation of the detector, for a center-of-mass energy of $\sqrt{s} = 14\,\text{TeV}$ [3, 4].

2. – Neutral MSSM Higgs bosons search

The neutral MSSM Higgs boson is mainly produced by the gluon fusion ($gg \to h/H/A$) and in associated production with b-quarks ($gg \to b\bar{b}\ h/H/A$). For high $\tan\beta$ values, the latter production mode and the decays into $b\bar{b}$ pairs become dominant. Due to the large multi-jet background contribution, the $b\bar{b}$ final state is experimentally challenging.

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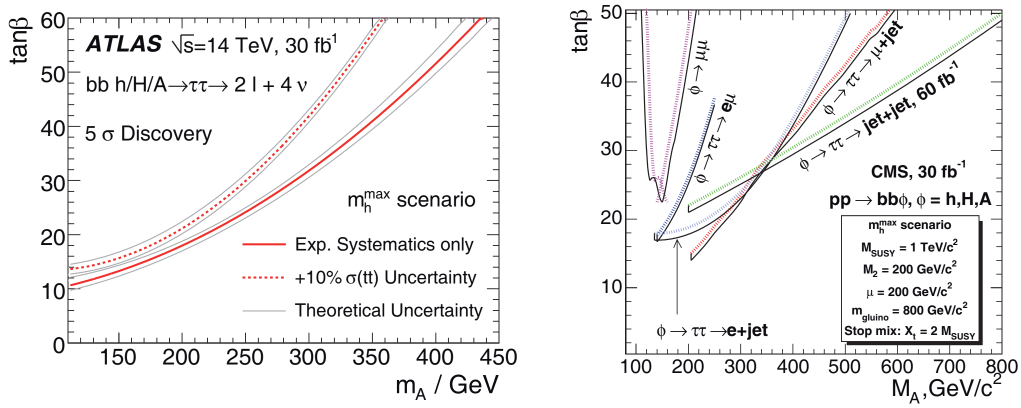

Fig. 1. – The 5-σ discovery contours in the (m_A, $\tan\beta$) plane for the $h/H/A \to \tau^+\tau^-$ decay channel at an integrated luminosity of $30\,\text{fb}^{-1}$ for the (left) fully leptonic ATLAS analysis and (right) CMS analyses in several different final state topologies.

Instead, the decays into $\tau^+\tau^-$ pairs, having the second largest branching ratio, provide the most promising signature, followed by the $h/H/A \to \mu^+\mu^-$ decay.

$h/H/A \to \tau^+\tau^-$: The Higgs boson search in the $h/H/A \to \tau^+\tau^-$ decay channel is performed separately for the three different decay modes of the τ-pair, considering the b-quark associated production.

Despite the presence of several neutrinos the Higgs boson mass can still be reconstructed. Assuming the collinearity between the highly boosted τ-leptons and their decay products, an invariant Higgs mass resolution of 20–30% is achieved.

Dominant background processes are $Z/\gamma^* + \text{jets}$, $W + \text{jets}$, $t\bar{t}$ and, in case of the fully hadronic final state, the QCD multi-jet events. The requirement of an additional 1 (≥ 1) b-jet in each CMS (ATLAS) event is applied to suppress the large Drell-Yan Z/γ^* background. The transverse mass distribution allows for the rejection of processes with W-bosons. The $t\bar{t}$ background is suppressed by the veto on additional jets in the central detector region.

Depending on the Higgs boson mass, the signal production cross-section is predicted with a theoretical uncertainty of 10–20%. Jet energy scale, missing transverse energy and the b-tagging efficiency are major sources of experimental systematic uncertainties. Theoretical and experimental background uncertainty can be reduced using dedicated signal-free control data samples. The $Z \to \tau^+\tau^-$ background, dominant at the lower Higgs masses, is estimated with an accuracy of 3% by replacing the leptons in $Z \to (ee)(\mu\mu)$ events with simulated τ decays. The $t\bar{t}$ background, which becomes more important at higher masses, can be controlled with an accuracy of about 10%. To reduce the total systematic uncertainty of the QCD multi-jets background, a control data sample with two τ-jet candidates of the same charge (same-sign sample) is used. The discovery potential with an integrated luminosity of $30\,\text{fb}^{-1}$, for different event topologies, is shown in fig. 1, with systematic uncertainties taken into account.

$h/H/A \to \mu^+\mu^-$: Compared to the Higgs decays into $\tau^+\tau^-$ pairs, the $h/H/A \to \mu^+\mu^-$ decay rate is about 300 times smaller. This is, however, compensated by an excellent dimuon mass resolution of 3%.

Dominant dimuon backgrounds originate from the $Z/\gamma^* + \text{jets}$ and the $t\bar{t}$ processes. Following a similar event selection strategy as in the $\tau^+\tau^-$ channel, the b-tagging require-

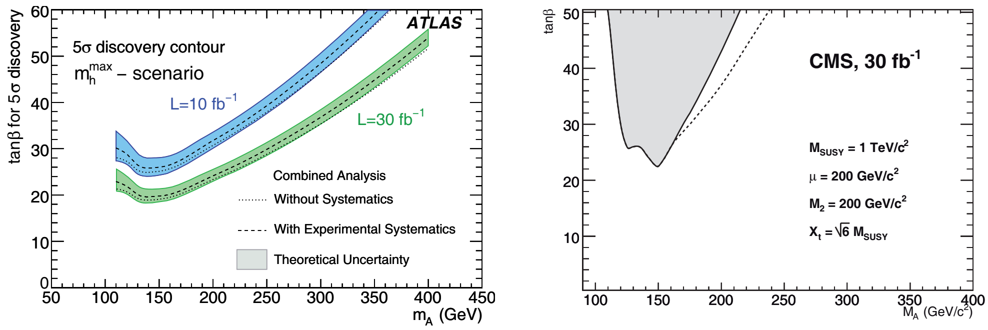

Fig. 2. – The 5-σ discovery contours in the (m_A, $\tan\beta$)-plane for the $h/H/A \to \mu^+\mu^-$ decay channel at an integrated luminosity of 10 and 30 fb^{-1} for the (left) combined 0 b-jet and 1 b-jet ATLAS analysis and (right) 1 b-jet CMS analysis.

ment (1 b-jet) is applied. The $t\bar{t}$ background and all other processes containing neutrinos are suppressed by an upper cut on the missing transverse energy. Further rejection of the $t\bar{t}$ background is achieved by a veto on additional jets (CMS) or by setting an upper bound on the p_T-sum of all jets in an event (ATLAS).

A complementary final state with zero b-jets is also studied in the ATLAS experiment.

Theoretical uncertainty on the signal production is the same as in the case of the $\tau^+\tau^-$ decay channel. Dominant experimental systematic uncertainties originate from the measurement of the jet energy scale and the b-tagging efficiency. The background uncertainty is significantly reduced once the $m_{\mu\mu}$ side-bands and the additional control data samples are taken into account. The total contribution of both Z/γ^* and $t\bar{t}$ backgrounds is estimated from the e^+e^- control sample, while the $t\bar{t}$ contribution alone is determined from the $e^\pm\mu^\mp$ final state. Figure 2 shows the discovery potential for both experiments.

3. – Charged MSSM Higgs bosons

The search strategies for charged Higgs bosons depend on their hypothesized mass $m_{H^\pm}$ and on $\tan\beta$, which dictates both the production rate and the available decay modes. Below the top quark mass, the main production mode is through top quark decays, $t \to H^+b$, and in this range the $H^+ \to \tau\nu_\tau$ decay mode is dominant. Above the top quark threshold, the production mainly takes place through $gb \to tH^+$ and $gg \to btH^+$, and the decay into a *top* and a b-quark dominates, $H^+ \to tb$. The second dominant decay is again $H^+ \to \tau\nu$.

For the light charged Higgs boson search, three signatures are considered. In the following, W_{had} and W_{lep} denote, respectively, the $W \to jj$ and the $W \to \ell\nu_\ell$ decays of the W-boson.

$t\bar{t} \to b(\tau_{\text{jet}}\nu_\tau\nu_\tau)bW_{\text{had}}$: This channel has the highest production rate and is therefore the most promising, even though experimentally challenging due to the absence of leptons. Dedicated jet pairing algorithm assigns the correct decay products to the W-boson and to its parent top quark. A likelihood discriminant built out of several kinematic variables is used for separating the signal from the $t\bar{t}$ background. Signal significance is obtained from the likelihood distribution and the transverse $H^\pm$ mass.

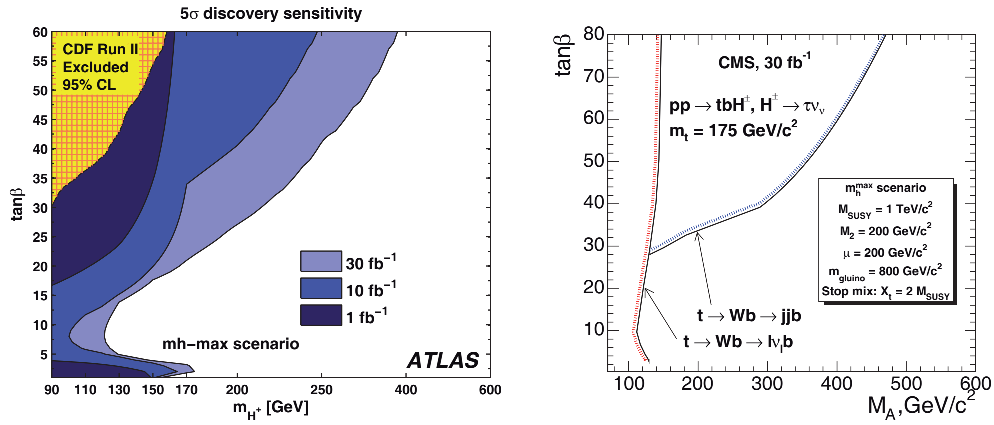

Fig. 3. – The 5-σ discovery contours for the charged Higgs boson search at an integrated luminosity of 10 to 30 fb^{-1} for the (left) ATLAS and (right) CMS experiment.

$t\bar{t} \to b(\ell\nu_\ell\nu_\tau\nu_\tau)bW_{\text{had}}$: Although it is much easier to trigger these events due to the presence of a lepton, the low decay rate $\ell\nu_\ell\nu_\tau$ results in a poorer discovery potential compared to the previous channel. Event selection strategy is similar as above.

$t\bar{t} \to b(\tau_{\text{jet}}\nu_\tau\nu_\tau)bW_{\text{lep}}$: High lepton trigger rate is combined with a high hadronic τ decay rate. Nevertheless, the neutrinos originating from both top-quarks make a complete event reconstruction very difficult. The signal is rather observed as an excess of τ-leptons in the $t\bar{t}$ process, due to different $H^\pm \to \tau^\pm\nu$ and $W^\pm \to \tau^\pm\nu$ branching ratios.

The $H^\pm \to \tau^\pm\nu$ decay provides also the highest sensitivity for the heavy charged Higgs bosons, through the $t[b]H^\pm \to bW[b](\tau^\pm\nu) \to bW_{\text{had}}[b]\tau_{jet}\nu_\tau\nu_\tau$ process.

The search in this final state is similar to the light charged Higgs searches in the first of the three topologies mentioned above.

The combined discovery potential for the charged Higgs boson searches is shown in fig. 3.

4. – Conclusions

With an integrated luminosity of 30 fb^{-1}, in the MSSM model, more than one Higgs boson could be observed with the ATLAS and the CMS experiments, in a large region of the parameter space. The most promising signatures are provided by Higgs decays into τ-leptons and muons.

REFERENCES

[1] Niles H. P., *Phys. Rep.*, **110** (1984) 1; Haber H. E. and Kane G. L., *Phys. Rep.*, **117** (1985) 75; Martin S. P., *Perspectives on Supersymmetry*, edited by Kane G. L. (World Scientific, Singapore) 1998, p. 1, hep-ph/9709356.

[2] Carena M. S., Heinemeyer S., Wagner C. E. M. and Weiglein G., *Eur. Phys. J. C*, **45** (2006) 797.

[3] The ATLAS Collaboration, *Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics*, CERN-OPEN-2008-020, arXiv:0901.0512 (2009), pp. 1197-1511.

[4] The CMS Collaboration, *CMS Physics Technical Design Report*, CERN-LHCC-2006-021, *J. Phys. G*, **34** (2007) 995.