CMS POTENTIAL FOR THE HIGGS BOSON DISCOVERY WITH 1 fb^{-1*}

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We present the prospects for the early Higgs boson searches at the CMS experiment. We discuss the sensitivity projections for searches for Standard Model and MSSM Higgs bosons with data expected to be collected during 2011 data taking period. We also report some of the 2010 data analyses validating the key aspects of Higgs searches.

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1. Introduction

The Higgs boson is the last missing piece of the Standard Model, therefore it is being searched for at least last three decades in many experiments. The direct lower limit on the Higgs boson mass comes from electron–positron collision data at LEP, and is $m_H > 114.4$ GeV/c^2 at 95% C.L. [1]. Recent results from Tevatron with up to 6.7 fb^{-1} of $p\bar{p}$ data exclude also a mass window of $158 < m_H < 175$ GeV/c^2 [2]. The Higgs boson search, within both Standard Model and its extensions frameworks, is also in the centre of the CMS experiment physics program [3]. The integrated luminosity delivered by the LHC machine in 2011 is expected to be of order of 1 fb^{-1}, and this amount of data will allow CMS to significantly increase the exclusion limits, and reach a discovery mode for some mass ranges. In this contribution we briefly describe the searches in most promising Standard Model and MSSM channels. All the 7 TeV exclusion and discovery results described in this contribution present projections of the detailed Monte Carlo (MC) studies at $\sqrt{s} = 14$ TeV [4]. Proper rescaling of the event yield and systematic errors is taken into account, while any differences of efficiencies originating from

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different kinematic distributions at 14 and 7 TeV are not included, as well as any improvements in the physics object reconstruction. Details of the projection procedure can be found in [5].

The main modes for the Standard Model Higgs production at the proton–proton collider are gluon–gluon fusion, yielding cross-sections of the order of 1 to 10 pb for Higgs masses of 400 GeV/c^2, and 110 GeV/c^2 at NNLO + NNLL QCD + NLO EW calculation order, Fig. 1, left [6]. The main decay paths are $b\bar{b}$ and $\tau\tau$ below threshold for decay to vector boson pair, and WW and ZZ above, as presented in Fig. 1, right [6].

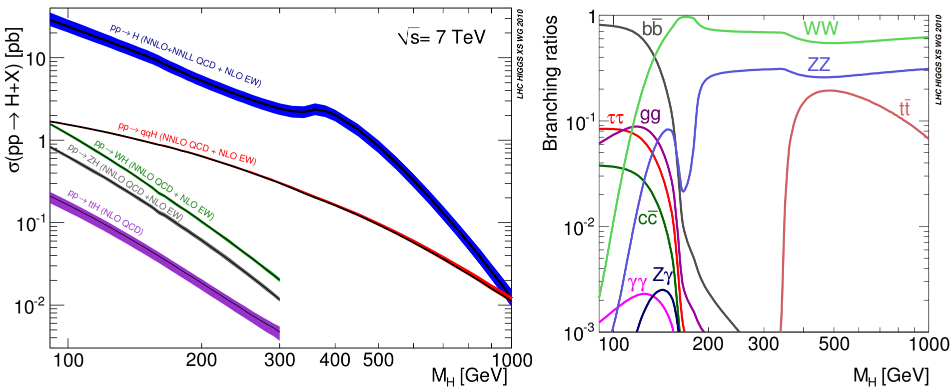

Fig. 1. Standard Model Higgs boson production cross-sections for 7 TeV pp collisions (left), and decay branching ratios (right) [6].

2. Searches in $H \to WW$ final state

The best search channel for $H \to WW$ is the case when both W bosons decay leptonically, providing excellent handle to select the signal events. The $H \to WW \to 2l + 2\nu$ final state signatures are two isolated high p_{T} leptons coming from W decays, large $E_{\mathrm{T}}^{\mathrm{miss}}$ due to the two neutrinos in the final state and low jet activity in the event. As WW bosons pair comes from spin 0 particle decay, specific lepton azimuthal correlations due to angular momentum conservation can be used to select the signal events.

The reducible background are the SM processes that can lead to two leptons in the final state, or one lepton and a jet that could be misidentified as electron. The main contribution comes from Drell–Yan lepton production, $t\bar{t}$, $W + t$, $W +$jets, WZ and ZZ. The genuine WW pair production is the irreducible background. The analysis selection is based on a classical cut based approach, or a neural network (NN) output. Figure 2, left presents example of variable used for the cut based selection, and Fig. 2, right presents NN output for all considered background processes and the signal with $m_H = 170$ GeV/c^2.

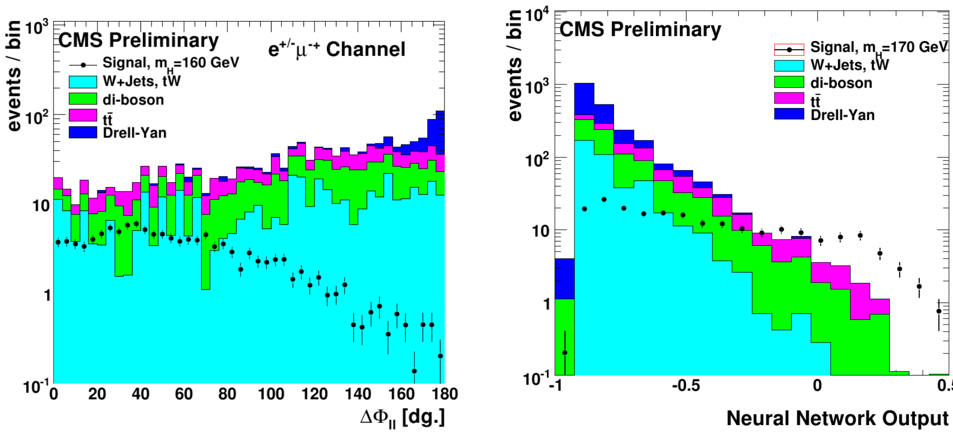

Fig. 2. Distribution of the azimuthal separation, $\Delta\Phi_{ll}$, of the leptons in the event for background processes, and the $H \to WW$ signal with $m_H = 160$ GeV$/c^2$ (left). Distribution of the neural network output for background processes, and the signal with $m_H = 170$ GeV$/c^2$ (right). Both figures are made with Monte Carlo events generated for $\sqrt{s} = 14$ TeV.

The SM $W \to l\nu$ analysis is being used to validate physics objects used by the $H \to WW$ analysis. The results obtained with 35 pb^{-1} of data collected in the 2010 run show excellent MC-Data agreement. More details can be found in contribution by Konecki in these proceedings [7].

The two neutrinos in the final state do not allow for Higgs boson mass reconstruction, therefore the exclusion limits and observation significance are obtained with event counting approach. Figure 3, left presents the expected

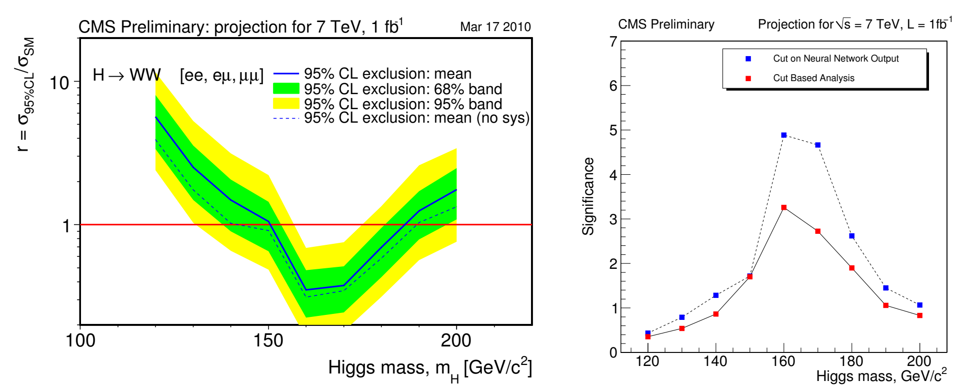

Fig. 3. Expected 95% C.L. exclusion limit for searches in the $H \to WW \to ll$ channel with 1 fb^{-1} of data collected at $\sqrt{s} = 7$ TeV (left). Expected signal significance for the $H \to WW \to ll$ analysis with cut based and neural network based approaches (right).

CMS exclusion limits for 1 fb^{-1} of data collected at $\sqrt{s} = 7$ TeV. It is possible to exclude the SM Higgs boson in mass range of $150 < m_H < 185$ GeV/c^2. Figure 3, right presents the expected CMS discovery reach, with the maximal significance in the region around $m_H = 165$ GeV/c^2. The cut based approach does not reach discovery limit of $5\,\sigma$, while with the NN based selection the $5\,\sigma$ could be reached for mass in range of $160 < m_H < 170$ GeV/c^2 [5].

3. Searches in $H \to ZZ$ final state

The most promising SM Higgs search mode is search in $H \to ZZ$ decay with subsequent $Z \to ll$ decay. The selection in this channel includes requirement for at least two isolated leptons and moderate Z mass constraint ($50 < m_{ll} < 100$ GeV/c^2) for one lepton pair, allowing other to come from off-shell Z with loose mass constraint ($20 < m_{ll} < 100$ GeV/c^2). The main background is the irreducible ZZ production, while the secondary background list includes $Z + b\bar{b}$, $Z +$ jets, $W +$ jet, $t\bar{t}$ and QCD. Figure 4, left presents invariant mass distribution for the second lepton pair after requiring $50 < m_{ll} < 100$ GeV/c^2 for the pair with mass closest to m_Z, the effect of the Z being off-shell is clearly visible in the $m_H = 150$ GeV/c^2 signal distribution. Figure 4, right presents the four lepton invariant mass distributions after all selections, with background and signal contributions shown.

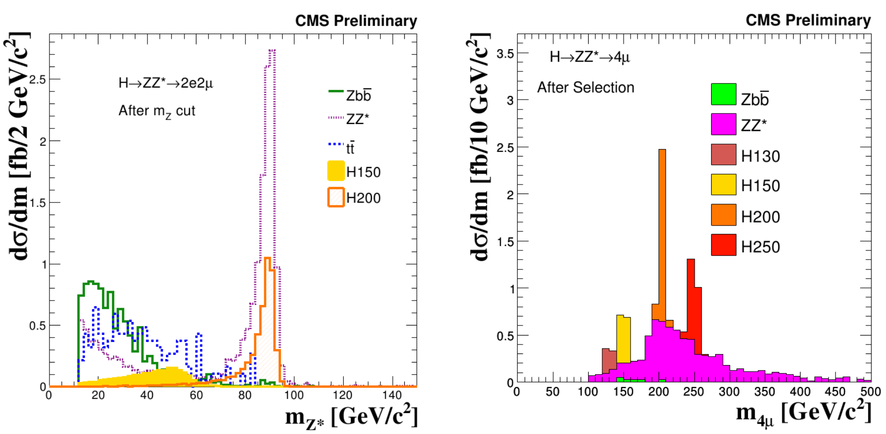

Fig. 4. Invariant mass distribution of the second lepton pair coming from the off-shell Z (left). Invariant mas distribution of four leptons after all selection steps (right). Both figures are made with Monte Carlo events generated for $\sqrt{s} = 14$ TeV.

The SM $Z \to ll$ analysis is used as a standard candle for the $H \to ZZ \to 4l$ analysis, in particular for the data driven selection efficiency estimates using the tag and probe method. More details can be found in contribution by Konecki in these proceedings [7].

The exclusion limits are obtained with event counting in a sliding mass window around the expected Higgs boson mass. Figure 5 presents the expected 95% C.L. exclusion limit as a function of the Higgs mass. In the SM this channel does not allow for exclusion, but in the model extended by additional fourth quark generation, which increases the Higgs production cross-section, one can expect exclusion for $m_H < 400$ GeV/c^2.

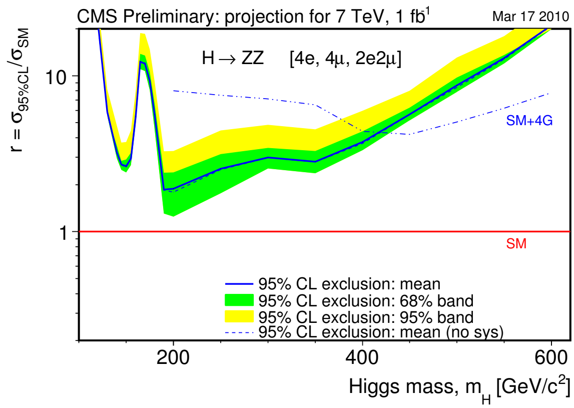

Fig. 5. Expected 95% C.L. exclusion limit for searches in the $H \to ZZ \to ll$ with 1 fb^{-1} of data collected at $\sqrt{s} = 7$ TeV. No exclusion is expected for SM. Dashed line corresponds to $r = 1$ limit for SM extended by fourth quark generation.

4. Searches in $H \to \gamma\gamma$ final state

The Higgs branching ratio to $\gamma\gamma$ is extremely small, at the level of 0.1%. Using excellent energy resolution of the CMS electromagnetic calorimeter one can reach resolution of two photons invariant mass of order of 0.7% making the searches in this channel viable.

The background for this final state are di-photon production, and γ+jet, or jet + jet, where one of QCD jets could be misidentified as a photon in the event reconstruction. The event selection includes photon isolation, and categorisation of events depending on the photon reconstruction quality, best in the barrel region of the detector, worst in the endcaps. Figure 6 presents the di-photon invariant mass distribution for the signal multiplied by factor of 10 over background for the best (left), and worst quality photons (right). Figure 7 presents the expected 95% C.L. exclusion limit as a function of the Higgs mass. In the SM this channel does not allow for exclusion, but in a fermiophobic models, where the Higgs $\sigma(H) \times \mathrm{BR}(H \to \gamma\gamma) > 4$ SM, region up to $m_H = 110$ GeV/c^2 could be excluded. Due to lack of sufficient information during the 14 TeV to 7 TeV results projection procedure, the exclusion limits are calculated without taking into account the photon reconstruction quality categories, therefore 2011 data analysis is expected to provide better exclusion limits than presented in Figure 7.

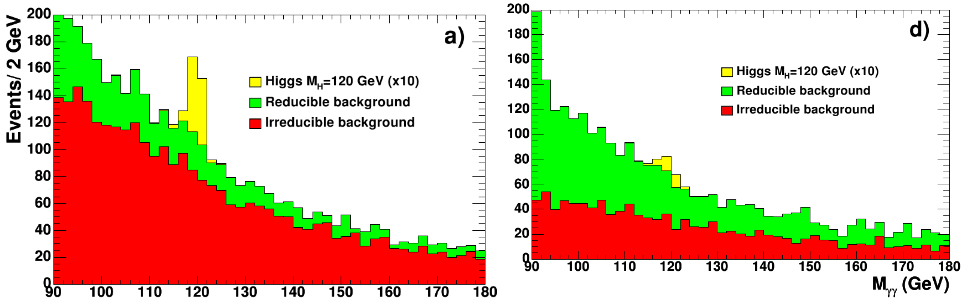

Fig. 6. Two photon invariant mass distribution for the background and signal events, with signal cross-section multiplied by factor of 10 for demonstration purposes. Figure on the left presents the photons in the best category: both photons in the ECAL barrel region, with a narrow shower, figure on the right presents the photons in the worst category: both photons in the ECAL endcap region, with a wide reconstructed shower. Both figures are made with Monte Carlo events generated for $\sqrt{s}$ =14 TeV.

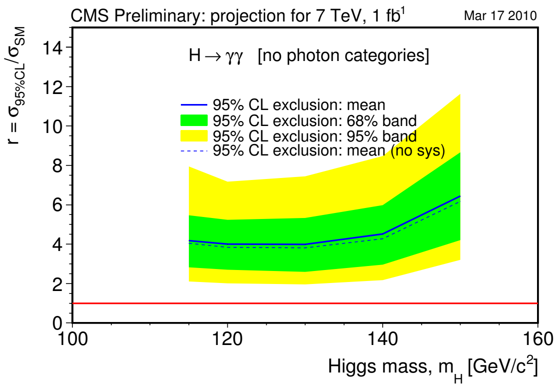

Fig. 7. Projected 95% C.L. exclusion limit for searches in the $H \to \gamma\gamma$ with 1 fb^{-1} of data collected at $\sqrt{s} = 7$ TeV. No exclusion is expected for SM. The exclusion limit calculation does not take into account photon reconstruction quality categorisation.

5. Combination of the SM Higgs searches

Figure 8 presents 95% exclusion limits after combining all the SM Higgs boson channels analysed by the CMS Collaboration. A few possible LHC scenarios are presented, with 1–5 fb^{-1} of data collected at 7 or 8 TeV. For 1 fb^{-1} of data collected at 7 TeV the CMS could exclude the SM Higgs boson for masses between 145 and 300 GeV/c^2, and with 5 fb^{-1} the whole interesting mass range $114 < m_H < 600$ GeV/c^2 could be excluded. Figure 9 presents the observation significance after combining all the search channels. With 1 fb^{-1} at $\sqrt{s} = 7$ TeV at most $4.5\,\sigma$ level can be reached for masses around $m_H \sim 160$ GeV/c^2. With 2 fb^{-1} at $\sqrt{s} = 7$ TeV $5\,\sigma$ discovery limit can be reached in the mass range of $155 < m_H < 170$ GeV/c^2.

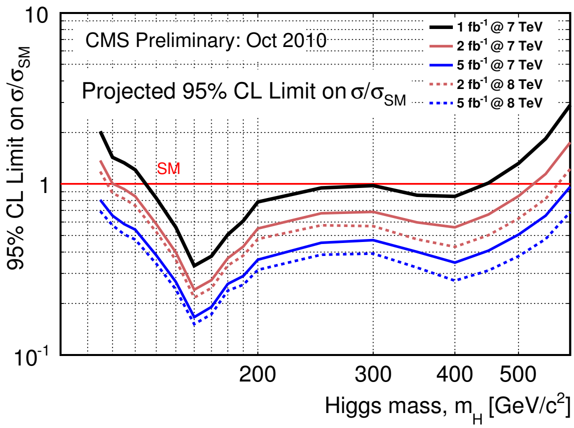

Fig. 8. The expected 95% C.L. exclusion limits for a SM Higgs search at $\sqrt{s} = 7$ and 8 TeV and a few selected luminosities. The limits are obtained as a projection from full Monte Carlo simulation for $\sqrt{s} = 14$ TeV.

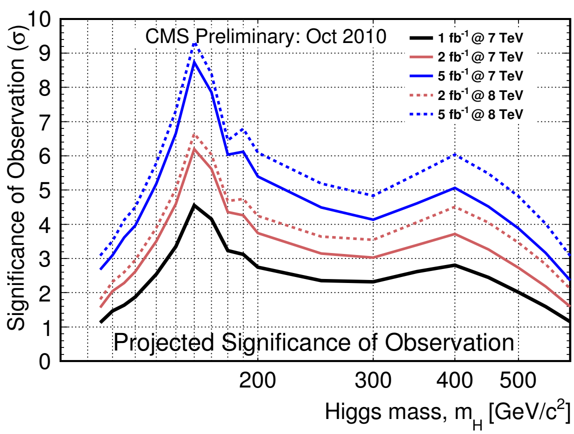

Fig. 9. The expected observation significance for a SM Higgs search at $\sqrt{s} = 7$ and 8 TeV and a few selected luminosities. The limits are obtained as a projection from full Monte Carlo simulation for $\sqrt{s} = 14$ TeV.

6. Searches in $h/H/A \to \tau\tau$ final state

In the MSSM there are five Higgs bosons: two scalars h (lighter) and H (heavier), one pseudoscalar A and charged H^+ and H^-. In this contribution we will describe searches for the neutral MSSM Higgs bosons in the $\tau\tau$ decay mode, with at least one τ decaying leptonically. The main production channel for moderate and high values of $\tan\beta$ is $pp \to b\bar{b}\phi$, where associated b quarks provide additional handle to select the signal events.

The signal signatures are isolated lepton from semileptonic tau decay, isolated tau-like jet in case one τ decays hadronically. The most challenging background is the irreducible $Z \to \tau\tau$, most important for the low mass region. Other background sources are QCD, $t\bar{t}$, W+jets, $Z \to ee$ and $Z \to \mu\mu$, where the second lepton can be lost in the reconstruction, or be misidentified as a single prong hadronic tau. The event selection includes lepton isolation, hadronic tau identification, cut on the $m_{\mathrm{T}}(l, E_{\mathrm{T}}^{\mathrm{miss}})$ to reduce the W background, b-jet tagging and veto on extra jets.

The exclusion limits are obtained with event counting in a sliding mass window, where the full $\tau\tau$ invariant mass is reconstructed with collinear approximation method. Figure 10 presents reconstructed $\tau\tau$ mass distribution for $e + \tau_{\mathrm{jet}}$ final state (left), and $\mu + \tau_{\mathrm{jet}}$ final state (right) and assumed pseudoscalar Higgs boson mass of 200 GeV/c^2.

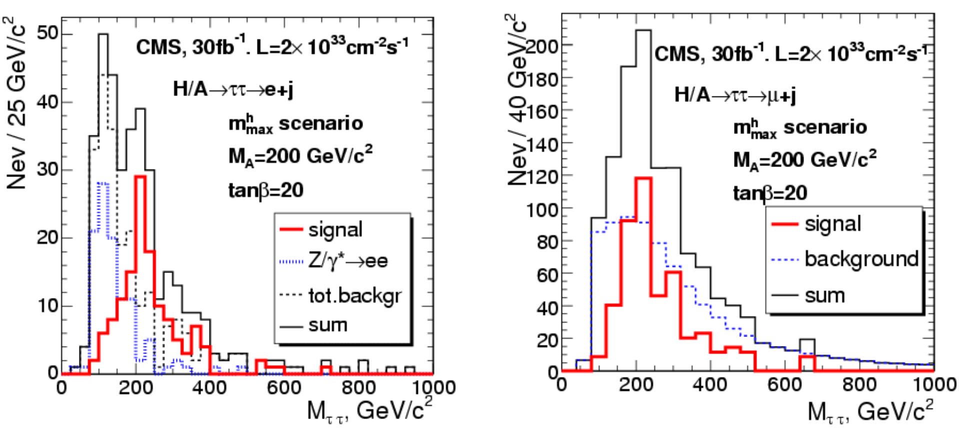

Fig. 10. Invariant mass of $\tau\tau$ system reconstructed with collinear approximation approach for $e + \tau_{\mathrm{jet}}$ final state (left), and $\mu + \tau_{\mathrm{jet}}$ final state (right). Signal and background contributions are shown. Both figures are made with Monte Carlo events generated for $\sqrt{s} = 14$ TeV, assuming 30 fb^{-1} integrated luminosity.

The MSSM Higgs sector is controlled by only two parameters at the leading order, which are often chosen as a ratio of vacuum expectation values of the two Higgs fields denoted as $\tan\beta$, and the pseudoscalar mass m_A.

After including higher orders corrections other parameters of the MSSM start to play a role. The experimental results are usually given as a function of the two above parameters, with all the other fixed in so-called "benchmark scenarios" [8]. The scenario maximising the mass of the lightest Higgs for given $\tan\beta$ and m_A values, called "$m_H^{\max}$" is used in this contribution. Figure 11 presents the expected CMS discovery reach and exclusion limits for the $m_H^{\max}$ scenario, on the $\langle m_A, \tan\beta\rangle$ plane. The existing limits from Tevatron and LEP are superimposed. With 1 fb^{-1} at $\sqrt{s} = 7$ TeV discovery reach is expected for $\tan\beta > 20$ for low m_A, and exclusion is expected for $\tan\beta > 15$ for low m_A.

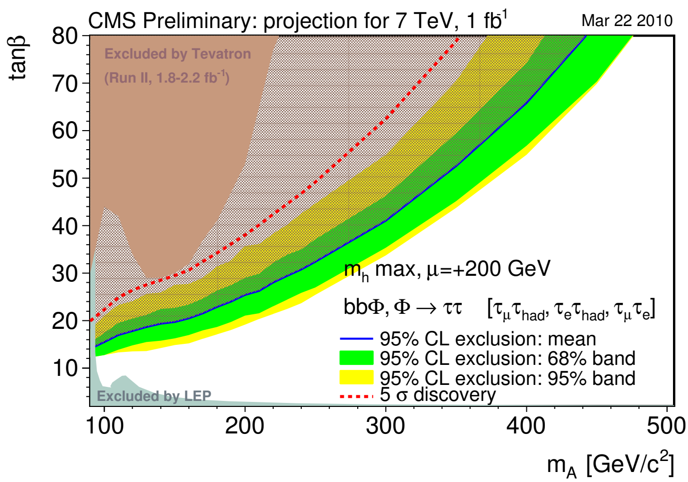

Fig. 11. The expected discovery and exclusion contours in the MSSM "$m_H^{\max}$" scenario on $\langle m_A, \tan\beta\rangle$ plane for a search for a neutral MSSM Higgs bosons in the $pp \to \phi b\bar{b} \to \tau\tau$ channel. The contours are obtained as a projection from full Monte Carlo simulation for $\sqrt{s} = 14$ TeV.

7. Conclusions

With 1 fb^{-1} at $\sqrt{s} = 7$ TeV the CMS experiment has enough potential to start exploring the Higgs sector. It should be able to exclude the SM Higgs boson in the range of 145 to 300 GeV$/c^2$, and with 2 fb^{-1} it would be able to discover Higgs boson in the range of $155 < m_H < 170$ GeV$/c^2$.

In the $m_H^{\max}$ scenario the neutral MSSM Higgs could be discovered in the $\langle m_A, \tan\beta\rangle$ region starting from $\tan\beta \sim 20$ for low m_A, or excluded from $\tan\beta \sim 15$.

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