DETECT MSSM NEUTRAL HIGGS BOSONS AT LHC

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Abstract

Discovery potential for MSSM neutral Higgs bosons in in various MSSM scenarios are discusses. The region of tanβbetween 5 and 50 and mass between $\approx$ 95 and few hundred 100 GeV is considered in the framework of the experiments at the Large Hadron Collider (LHC), for a centre-of-mass energy $\sqrt{s} =$ 14 TeV. This parameter region is not fully covered by the present data either from LEP or from Tevatron. The h/A/H bosons search in decay channels in SM and supersymmetric particles is reviewed and the studies of the two LHC experiments ready to take data in the next future are discussed.

1 Introduction

The Minimal Supersymmetric Standard Model (MSSM) is the most investigated extension of the Standard Model (SM).

The theory requires two Higgs doublets giving origin to five Higgs bosons: two CP-even neutral scalars, h and H (h is the lighter of the two), one CP-odd neutral scalar, A, and one pair of charged Higgs bosons, $H^{\pm}$ [1, 2, 3]. The discovery of any one of these particles is a crucial element for the confirmation of the model. This is a key point in the physics program of future accelerators and in particular of the LHC.

After the conclusion of the LEP program in the year 2000, the experimental limit on the mass of the Standard Model Higgs boson H was established at 114.4 GeV with 95% CL [4]. Limits were also set on the mass of neutral [5] and charged [6] MSSM Higgs bosons for most of the representative sets of model parameters.

In this paper is discussed the potential of the LHC detectors for the discovery of neutral MSSM Higgs bosons in the parameter region not excluded by the LEP and Tevatron data. We will discuss the A , H and h, the lightest of the neutral Higgs bosons. Its mass, taking account of radiative corrections, is predicted to be smaller than 140 GeV, see [5]and references therein.

In the first part of this paper we review the MSSM framework, the production mechanism in hadron collisions, the present experimental situation and the discovery potential at the LHC.

In the second part, examples of their search in some decays channel are discussed

In the conclusion, results are presented on the neutral MSSM Higgs bosons discovery potential at the LHC based on the ATLAS [7] and CMS [8] detectors.

2 Minimal Supersymmetric Standard Model

In this paragraph the fundamental points of the model, useful for the following discussion, are summarized, referring to elsewhere for a complete review [9, 2].

The mass of the five Higgs bosons required by the MSSM, the two CP-even (h,H), the CP-odd A and the two charged $H^{\pm}$, at tree level can be expressed in terms of two independent input parameters, the ratio of the vacuum expectation values of the two Higgs fields, $\tan\beta$, and the pseudoscalar Higgs-boson mass, m_{A}. A simple relation holds between these particle masses :

$$m^2_{H,h} = \frac{1}{2}[m^2_A + m^2_Z \pm\sqrt{(m^2_A + m^2_Z)^2 - 4m^2_A m^2_Z \cos^2 2\beta}] \quad (1)$$

$$m^2_{H^{\pm}} = m^2_{\mathrm{W}} + m^2_{\mathrm{A}}$$

(Recent precise measurements of W and Z masses, m_{W} and m_{Z}, are available [10]).

In comparison with the SM, the MSSM requires more free parameters. However, the assumption that the scalar fermions masses, the gaugino masses and the trilinear Higgs-fermion couplings must unify at the Grand Unification scale (GUT) reduces the number of free parameters. In one of the possible constrained models the parameters chosen are:

- M_{SUSY}, a common mass for all sfermions (scalar fermions) at the electroweak scale.
- M_2, a common $\mathrm{S}U(2)_L$ gaugino mass at the electroweak scale.
- μ, the strength of the supersymmetric Higgs mixing.
- $\tan\beta$, the ratio of the vacuum expectation values of the two Higgs fields .
- $\mathrm{A} = \mathrm{A_t} = \mathrm{A_b}$ a common trilinear Higgs-squarks coupling at the electroweak scale. It is assumed to be the same for up-type squarks and for down-type squarks.
- m_{A}, the mass of the CP-odd Higgs boson.
- $m_{\tilde{\mathrm{g}}}$, the gluino mass.

Three of these parameters define the stop and sbottom mixing parameters $\mathrm{X_t} = \mathrm{A_t} - \mu \cot\beta$ and $\mathrm{X_b} = \mathrm{A_b} - \mu \cot\beta$.

Table 1: *CP-conserving benchmark scenarios.*

Parameter	$m_{\rm h}-max$	*no-mixing*	*large-μ*
$M_{\rm SUSY}$[GeV]	1000	1000	400
μ [GeV]	-200	-200	1000
M_2[GeV]	200	200	400
$\rm X_t$=A - μ cotβ	$2M_{\rm SUSY}$	0	- 300
$m_{\tilde{\rm g}}$[GeV]	$0.8M_{\rm SUSY}$	$0.8M_{\rm SUSY}$	200
$m_{\rm A}$[GeV]	0.1-1000	0.1-1000	0.1-400
tanβ	0.4-50	0.4-50	0.7-50

For the Higgs boson search, two extremes of the stop mixing are considered: the maximal mixing $\rm X_t$ = 2 $M_{\rm SUSY}$, and the minimal mixing, when $\rm X_t$ is zero. Usually a set of benchmarks are applied and also in this case there are only two free parameters: tanβ and $m_{\rm A}$. In this search three CP-conserving benchmark scenarios are considered (Tab.1).

The characteristics of the three scenarios are as follows.

- $m_{\rm h}-max$

  As the name indicates, it allows in the model the maximum value of $m_{\rm h}$ [5]. For fixed values of $m_{\rm t}$ and $M_{\rm SUSY}$, it gives the most conservative range of excluded tanβ values. A negative search of the h boson implies an exclusion of the model.

- *no-mixing*

  It assumes no-mixing between the scalar partners of the left-handed and the right-handed top quarks. The highest value of $m_{\rm h}$ can be 114 GeV.

- *large-μ*

  It is designed such that the h boson doesn't decay into pairs of b quarks due to large corrections from SUSY loop processes. The dominant decay modes are to $\rm c\bar{c}$, gg, $\rm W^+W^-$, $\tau^+\tau^-$. The highest value of $m_{\rm h}$ can be 108 GeV.

The difference between $m_{\rm h}-max$ and *no-mixing* scenario is mainly due to the fact that to the same point of the parameter space ($m_{\rm A}$, tanβ) corresponds a different mass of the h boson, thus a different sensitivity of the channel under consideration.

Table 2: *Standard Model Higgs boson couplings at tree level to fermions and massive gauge bosons.*

SM	Fermions	W^+W^-	ZZ
H	$\frac{igm_f}{2m_W}$	$igm_W g^{\mu\nu}$	$\frac{igm_Z}{2\cos\theta_W} g^{\mu\nu}$

Table 3: *MSSM correction factors to the SM Higgs boson couplings to fermions and massive gauge bosons at tree level.*

MSSM	$d\bar{d}$, $s\bar{s}$,$b\bar{b}$ e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$	$u\bar{u}$, $c\bar{c}$, $t\bar{t}$	W^+W^-, ZZ
h	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$\sin(\beta-\alpha)$
H	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos(\beta-\alpha)$
A	$-i\gamma_5\tan\beta$	$-i\gamma_5\cot\beta$	0

3 Production in hadronic interaction

3.1 Signal processes: the lightest Supersymmetric Higgs boson

The neutral h boson and the other Higgs bosons are important elements of the MSSM model. Their couplings at tree level to fermions and massive gauge bosons are easily obtained from the SM Higgs boson couplings (shown in Tab. 2 [11]) via correction factors summarized in Tab. 3 [11]. These correction factors depend on the parameters α and β which were introduced in Sec. 2 and are related by the following expression:

$$\cos 2\alpha = -\cos 2\beta \, \frac{m_A^2 - m_Z^2}{m_H^2 - m_h^2} \tag{2}$$

At high tanβ the MSSM correction factors to the SM Higgs bosons couplings to fermions and massive gauge bosons (see Tab. 3) are larger for down-type quarks (b) and leptons (τ and μ) than for up type-quarks. This fact implies that the MSSM coupling to down-type quarks and leptons are strongly enhanced in this region.

Since the MSSM and SM couplings differ only by a correction factor, the most natural choice is to explore the decay channels common to both, as mentioned in Sec. 4.2. The h, A, H decay channels $b\bar{b}$ and gg are extensively studied [7]. Other decay channels deserving consideration are $\tau^+\tau^-$ and $\mu^+\mu^-$. It should be mentioned that the identification of hadronic decays and jet showers of the third generation fermions (τ and b) may be problematic in hadronic enviroment as LHC either SM either for MSSM Higgs. The MSSM Higgs bosons have an alternative: decays of these Higgs bosons into sparticles, in particularly, charginos and neutralinos.

Before concluding this section it should be reminded [11] that the CP-odd supersymmetric boson A in the region of high $\tan\beta$ and $m_{\rm h}$ around 100 GeV has a mass slightly higher than the CP-even h and a competitive branching ratio (Tab. 3) in the corresponding decay channel. The same situation is reproduced at high $m_{\rm A}$ mass between H and A bosons. The cross-section, the mass and width difference, which are functions of the parameters $\tan\beta$ and $m_{\rm A}$, are close at low $m_{\rm A}$ mass of the parameters space between h A and at higher mass H and A. Thus in these points the CP-odd and CP-even bosons are indistinguishable from the experimental point of view. Therefore, it is more correct to think in terms of h/A search and at higher mass H/A.

4 Experimental search for Minimal Supersymmetric Standard Model Higgs

4.1 LEP and Tevatron results

High precision tests of the Standard Model have been performed at LEP setting a combined limit of $m_{\rm H}> 114.4$ GeV for the mass of the SM Higgs boson [4].

Again at LEP, the validity of the Minimal Supersymmetric Standard Model has been investigated within the constrained framework of Sec. 2. For the mass of the charged MSSM Higgs bosons a combined limit $m_{\rm H_\pm}> 78.6$ GeV was obtained [6]. Searching for neutral CP-even and CP-odd MSSM Higgs bosons, no indication of signal was found up to a center-of-mass energy of 209 GeV [5]. The corresponding lower limits on the masses were set as a function of $\tan\beta$ for several scenarios. In the $m_{\rm h}$-*max* scenario (Fig. 1) with a top mass $m_{\rm t}$=174.3 GeV the limits for $\tan\beta > 10$ at 95% CL are approximately :

$$m_{\rm h}, m_{\rm A} \geq 93 \text{ GeV}$$

A complementary search, providing sensitivity in the region $\tan\beta > 50$

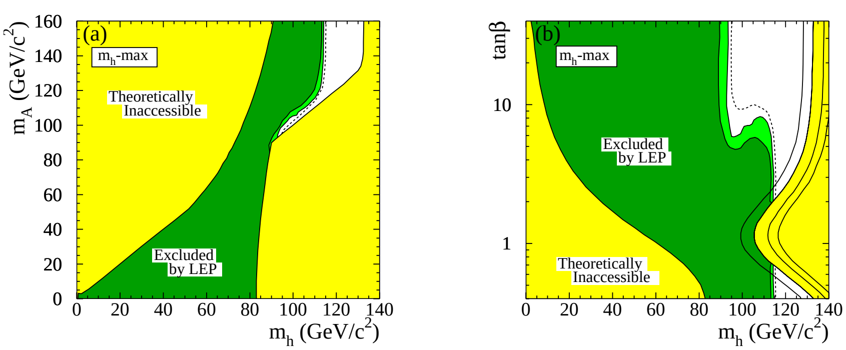

Figure 1: *The combined LEP results for the search for the MSSM neutral Higgs bosons (from Ref.* [5]*). The figure shows the theoretically inaccessible regions (light-grey/yellow) and the regions experimentally excluded by LEP searches, at 95% C.L. (medium-grey/light-green) and 99.7% C.L. (dark-grey/dark-green), for the* $\mathrm{m_h}$*-maxscenario with the top mass* $\mathrm{m_t}$= *174.3* GeV*, in two projections of the MSSM parameters* (m_{h}, m_{A})*,* (m_{h}, $\tan\beta$)*. The dashed lines indicate the boundaries of the regions which are expected to be excluded, at 95% C.L., on the basis of Monte Carlo simulations with no signal. In the* (m_{h}, $\tan\beta$) *projection, the upper boundary of the parameter space is indicated for four values of the top mass; from left to right:* $\mathrm{m_t}$= *169.3, 174.3, 179.3 and 183.0* GeV*.*

has been performed at the Tevatron Collider at $\sqrt{s}$= 1.96 TeV. In the MSSM scenario, a significant portion of the parameter space has been excluded by the D0 Collaboration, down to tanβ = 50 as a function of $m_{\rm A}$, by studying the associated production with two b quarks of h/A/H bosons and their decay into $\rm b\bar{b}$ [12]. Comparable results have been obtained by the CDF Collaboration exploring the h/A/H decays to $\tau^+\tau^-$, but extending the excluded region to higher values of $m_{\rm A}$ [13].

4.2 LHC discovery perspectives

The LEP and Tevatron data don't exclude the parameter space defined by tanβ larger than 10 and smaller than 50. Therefore, a natural continuation of the LEP and Tevatron physics is the investigation of the possible existence of MSSM Higgs bosons in this region of tanβ. The ATLAS [7] and CMS [8] experiments starting in the near future at the Large Hadron Collider (LHC), at CERN, constitute an excellent laboratory for such search.

The prospect for the detection of MSSM Higgs bosons at LHC was evaluated for benchmark sets preventing Higgs boson decays to SUSY particles [11, 7] and focusing on the discovery potential of decay modes common to MSSM and SM Higgs bosons [7]. It was concluded that the complete region of parameter space $m_{\rm A} = 50 - 500$ GeV and tan$\beta = 1 - 50$ is open to Higgs boson discovery by the ATLAS experiment, already with an integrated luminosity of $\int \mathcal{L}\, {\rm d}t = 30$ fb^{-1}, and that over a large part of this region more than one Higgs boson and more than one decay mode could be observed – the detection of a signal in more than one decay channel would constitute strong evidence for the MSSM model. It was also found that the region in the ($m_{\rm A}$, tanβ) plane which corresponds to $m_{\rm h} \approx 100$ GeV and tanβ > 10 is only accessible by a neutral h/A boson decaying to $\mu^+\mu^-$ or $\tau^+\tau^-$ [11, 7], and by a charged $\rm H^\pm$ boson decaying to $\tau\nu$ [14].

More recently the MSSM boson discovery potential in the MSSM scenario has been investigated [15] at two luminosities, $\int \mathcal{L}\, {\rm d}t$= 30 fb^{-1} and $\int \mathcal{L}\, {\rm d}t$= 300 fb^{-1} . At low luminosity the $\tau^+\tau^-$ decay mode represents the main contribution to the discovery potential and covers most of the parameter space not yet explored. However the contribution of $\rm b\bar{b}h \rightarrow \mu^+\mu^-$ appears to be crucial in the region of moderate tanβ and mass close to $m_{\rm Z}$.

At high luminosity channels such as: $\rm h/A/H \rightarrow \gamma\gamma$, $\rm h/A/H \rightarrow ZZ \rightarrow 4\ell$ and $\rm h \rightarrow b\bar{b}$ in associated production with $\rm t\bar{t}$ give a significant contribution. The channel $\rm h \rightarrow \gamma\gamma$, which requires an excellent $M_{\gamma\gamma}$ mass resolution and jet/γ separation, corresponds to MSSM rates suppressed with respect to the SM case but for a limited region of the parameter space where they could even be slightly enhanced. As for the channel $\rm h \rightarrow b\bar{b}$, only the $\rm t\bar{t}h$ production followed by the h $\rightarrow$ b$\bar{\rm b}$ decay can be observed clearly above the background, thus the extraction of the signal requires the identification of four b-jets and an excellent b-tagging performance. In the MSSM case the rates could be enhanced by 10-20% over the SM rates.

To complete all possible scenarios also the search channel in supersymmetric particles have been explored and discovery region in ($m_{\rm A}$,tanβ) plane defined. I would like to underline that the two different scenarios are based different hypotesis; in the first the sparticle decays are forbidden in the second allowed, as conquence their results can't be combined.

5 Discovery channels

In the scenario where only the MSSM neutral Higgs bosons can decay only in SM particles a relevant importance have final states containing leptons, e μ, for their clear identification in a hadronic environment.

Fig.(2) shows the 5 σ discovery regions for neutral Higgs boson Φ (Φ=h,H,A) produced in association with b quarks pp $\rightarrow$ $bb\phi$ with $\Phi \rightarrow \mu^+\mu^-$ and $\Phi \rightarrow \tau^+\tau^-$ modes in $m_{\rm h} - max$ scenario, as predicted from CMS Collaboration [8]. Large fraction of this space is accessible to more than a channel with a possibility to achieve a more robust evidence in case of discovery.

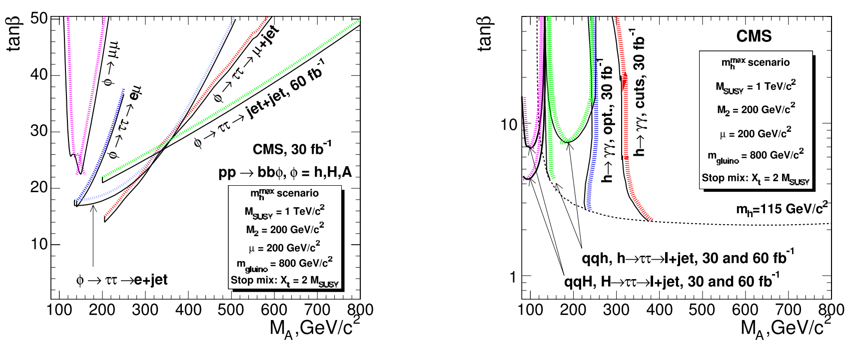

Figure 2: *The 5 σ discovery region for neutral Higgs bosons Φ (Φ=h,H,A) produced in association with b quarks for pp $\rightarrow$ $bb\phi$ with $\Phi \rightarrow \mu^+\mu^-$ and $\Phi \rightarrow \tau^+\tau^-$ modes in $m_{\rm h} - max$ scenario(on the left)* [8]*. The 5 σ discovery region for light neutral Higgs boson h from inclusive pp $\rightarrow$ h+ X with h $\rightarrow \gamma\gamma$ decay for light and heavy scalar Higgs bosons,h and H, produced in the $m_{\rm h} - max$ scenario (on the right)* [8]

Among the large variety of channels studied from ATLAS and CMS, we would focus the discussion few of them, representative of different categories:

- $p\bar{p} \to b\bar{b}\ h/H/A \to \mu^+\mu^-, \tau^+\tau^-$, at moderate and high tanβ. These channels cover a large range of m_A region and may give the possibility of a h/A discovery even at mass close to Z pole.
- $p\bar{p} \to A$ at low tanβ $A \to Z\ h$ and $Z \to \ell^+\ell^-$ ($\ell = e, \mu$) $h \to b\bar{b}$ this channel has the capability to extend the search to very low tanβ regions.
- $p\bar{p} \to A, H \to \widetilde{\chi}_2^0\widetilde{\chi}_2^0$ and
  $p\bar{p} \to A, H \to \widetilde{\chi}_2^0\widetilde{\chi}_3^0, \widetilde{\chi}_2^0\widetilde{\chi}_4^0, \widetilde{\chi}_3^0\widetilde{\chi}_3^0, \widetilde{\chi}_3^0\widetilde{\chi}_4^0, \widetilde{\chi}_4^0\widetilde{\chi}_4^0$
  as well as $A, H \to \widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^{\mp}, \widetilde{\chi}_2^{+}\widetilde{\chi}_2^{-}$
  These search channels explore the MSSM Higgs decaying in supersymmetric particles.

5.1 $bbh/A \to bb\mu^+\mu^-$

The associated $b\bar{b}$ (h,A,H) production is enhanced and becomes the dominant process in the production of MSSM bosons in the high tanβ region. The Feynman diagrams contributing to the process $gg \to b\bar{b}h \to b\bar{b}\mu^+\mu^-$ and $q\bar{q} \to b\bar{b}h \to b\bar{b}\mu^+\mu^-$ are shown in Fig. 3.

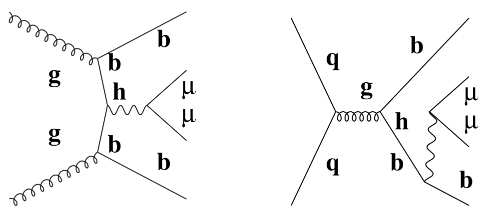

Figure 3: *Typical diagrams contributing at "tree level" to the process* $gg \to b\bar{b}h \to b\bar{b}\mu^+\mu^-$ *and* $q\bar{q} \to b\bar{b}h \to b\bar{b}\mu^+\mu^-$.

Indeed, although the Higgs boson couplings are proportional to the fermion mass, thus resulting in a branching ratio to $\tau^+\tau^-$ higher than to $\mu^+\mu^-$ by a factor $(\frac{m_\tau}{m_\mu})^2$, the experimental conditions favor the $\mu^+\mu^-$ channel[1]. These reasons encouraged both experiments to perform this search.

[1]The production advantage of the $\tau^+\tau^-$ channel is counterbalanced by the difficulty of identifying the hadronic decay of a τ-jet in hadronic events, by a smaller acceptance of the detector and by a worse mass resolution due to the presence of neutrinos in the final state. Instead, with a final state like

The signature of the h/A channel is a pair of well isolated high-energy muons with opposite charge and two hadronic jets containing b quarks. The invariant mass of the reconstructed muons is supposed to originate from a h or A boson and must be compatible, within the mass resolution, with the corresponding mass, $m_{\rm h}$ or $m_{\rm A}$. The main backgrounds to this process are:

- $b\bar{b}Z \rightarrow b\bar{b}\mu^+\mu^-$.
- $t\bar{t} \rightarrow b\bar{b}\mu^+\mu^-\nu\bar{\nu}$.
- $ZZ \rightarrow b\bar{b}\mu^+\mu^-$.

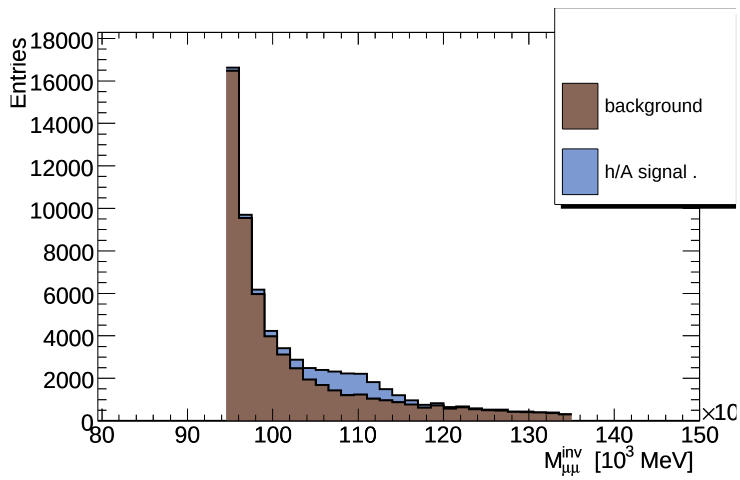

Figure 4: *Distributions of the reconstructed $\mu^+\mu^-$ invariant mass, $M^{\rm inv}_{\mu\mu}$, for signal and backgrounds events, after the selection cuts at the point (*$\tan\beta$ *= 45, $m_{\rm A}$ = 110.31* GeV*, $m_{\rm h}$ = 110.00* GeV*). The two distributions are normalized at* $\int\mathcal{L}\,{\rm d}t$*= 300* fb^{-1}*. The h/A signal (light blue) emerge over the background (*Z*, $t\bar{t}$ and* ZZ*) (dark brown). Entries are per bin width of* $1.5\cdot10^3$ *MeV* [21], [16].

A search for neutral Higgs bosons h/A has been performed in the ($m_{\rm A}$, $\tan\beta$) plane [21] . Fig. 4 shows the distributions of the reconstructed $\mu^+\mu^-$ invariant mass for signal (h and A) and background (Z, $t\bar{t}$ and ZZ added up)

$h \rightarrow \mu^+\mu^-$ the experiments would exploit the excellent combined performance of the muon spectrometer and inner detector.

events. The h/A signal (light blue) is clearly visible on top of the remaining background events (Z, $t\bar{t}$ and ZZ added up, dark brown).

We conclude that if $m_{\mathrm{h}} = 110.00$ GeV and consequently $m_{\mathrm{A}} = 110.31$ GeV there is a high probability for these bosons to be discovered at the beginning of data taking.

The search significance for the h/A neutral boson is shown as a function of m_{A} up to highest allowed value of m_{h}, in Fig. 5 for all scanned values of tanβ and three luminosity, $\int \mathcal{L}\,\mathrm{d}t = 300$ fb^{-1} ($S^{300}_{\mathrm{h,\ A}}$), 30 fb^{-1} ($S^{30}_{\mathrm{h,\ A}}$) and 10 fb^{-1} ($S^{10}_{\mathrm{h,\ A}}$) [21], [16]. The values for the two lower luminosities were derived from the first one, which corresponds to the highest statistics.
One should note that large h/A masses are penalized by a small cross section, thus implying a lower significance, while the masses near to m_{Z} suffer from the difficulty in disentangling the neutral Higgs boson signal from the Z background.

The best mass range for an early discovery of h is between 100 and 120 GeV at any given tanβ. If tan$\beta > 30$ a large range of masses is accessible to discovery even after the first year of data taking. More integrated luminosity, between ≈ 30 and 50 fb^{-1}, is needed for tanβ between 30 and 20. The discovery at tan$\beta = 15$ demands a luminosity of ≈ 150 fb^{-1}, making the exploration of this region possible only after a few years of data taking.

With a $\int \mathcal{L}\,\mathrm{d}t \approx 10$ fb^{-1}, corresponding to one year of data taking, most of the masses are accessible if tan$\beta > 30$. More integrated luminosity is needed for tan$\beta = 20$ and tan$\beta = 15$. Low masses need as well more luminosity in order to extract the evidence of a signal from the most copious Z background.

Discovery contours in the (tanβ, m_{A}) plane are shown, in Fig. 6(on the left), in different $\int \mathcal{L}\,\mathrm{d}t$ scenarios for a significance of 5 as predicted from ATLAS experiment. Analogous contour plot has been derived from CMS Collaboration (Fig. 6, the right) with an integrated luminosity of 30 fb^{-1} [8].

5.2 Method for $\mathbf{b\bar{b}Z \to b\bar{b}\mu^+\mu^-}$ background subtraction

The most copious background in the search of much new physics beyond Standard Model results from the production of the resonant $b\bar{b}Z \to \mu^+\mu^-$ final state.

The Monte Carlo simulation of these processes, taking account of all correction loops, is complex and will demand an enormous theoretical effort and a careful tuning on experimental data. As a consequence, the systematic error in the background evaluation, due to the theoretical uncertainty, has to be taken in account. A review of the up-to-dated Monte Carlo implementations for LHC is summarized in Ref. [17]. A strategy has been developed from ATLAS on the combined use of Monte Carlo and data to allow a realistic evaluation of that background at LHC. The method proposed in [18] exploits the two following

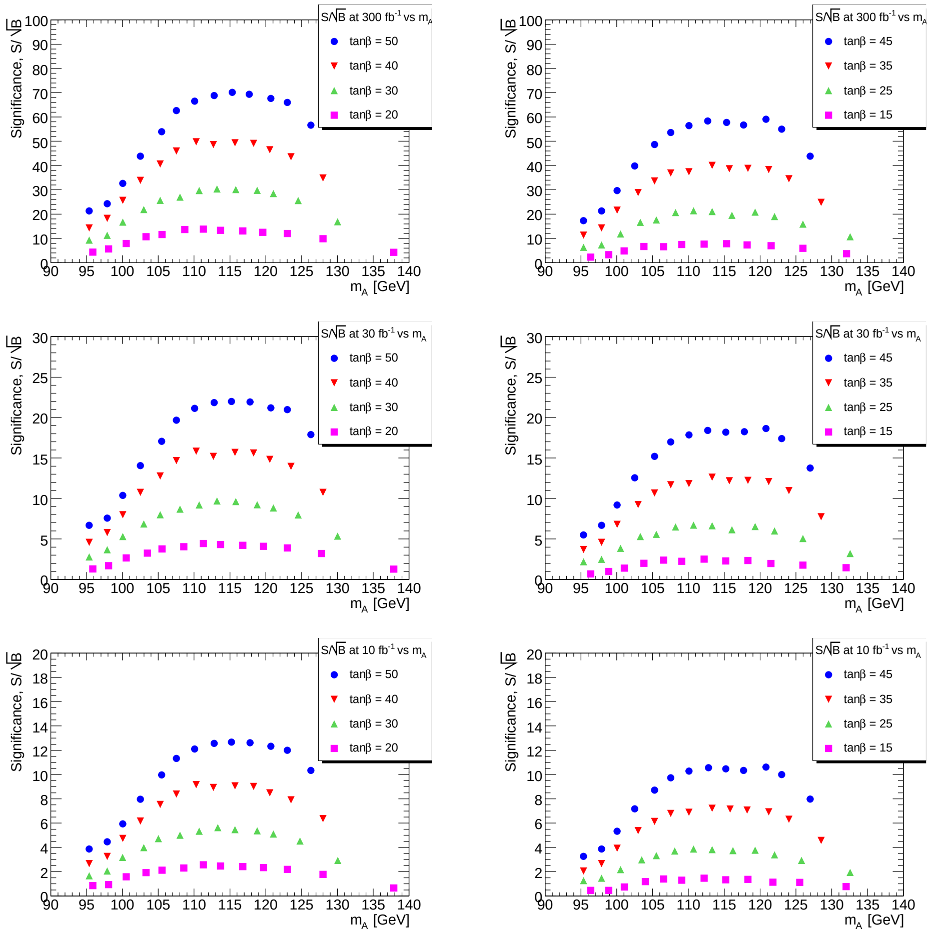

Figure 5: Search significance $\frac{S}{\sqrt{B}}$ for a h/A neutral Higgs boson, as a function of $m_{\rm A}$ up to the largest allowed value of $m_{\rm h}$ in three different data taking scenarios, $\int \mathcal{L}\, dt$ = 300, 30 and 10 fb^{-1} (S is the number of h/A signal events, B is the number of background events). On the left the results for tanβ = 50, 40, 30, 20, and on the right the results for tanβ = 45, 35, 25, 15. The data are listed in Ref. [16].

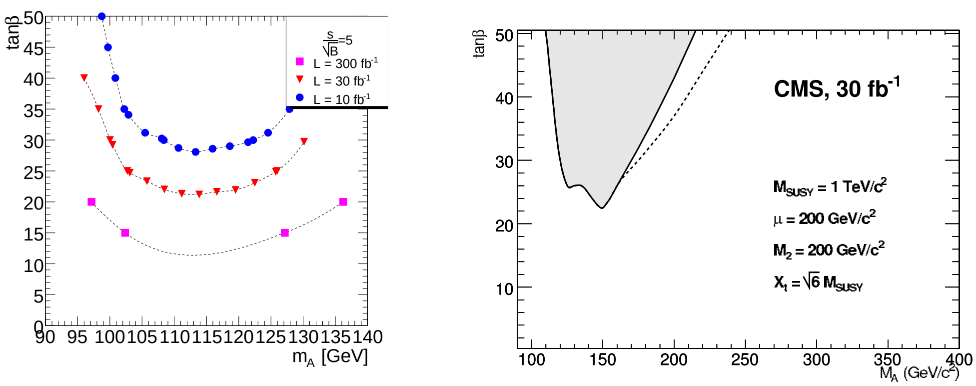

Figure 6: *Discovery potential for a neutral Higgs boson h/A of mass* $m_{\rm A}$ *decaying to* $\mu^+\mu^-$*, accompanied by two b-jets, in the* $m_{\rm h} - max$ *scenario (Sec. 2), as a function of* $m_{\rm A}$*: contours are drawn for a search significance* $\frac{S}{\sqrt{B}} = 5$ *(left) with an integrated luminosity of* $\int \mathcal{L}\,{\rm dt} = 300$ *(top), 30 (center) and 10 (bottom)* ${\rm fb}^{-1}$ *(ATLAS)* [21], [16]*. Discovery contour plot for the MSSM neutral Higgs di dimuon analysis. the signal significance inside the gray area is* > 5 *with an integrated luminosity of 30* ${\rm fb}^{-1}$*(CMS)* [8].

points (at the level of particle generation):
a) the rate of $h/A \to e^+e^-$ is expected to be suppressed with respect to the signal $h/A \to \mu^+\mu^-$ by a factor $\left(\frac{m_\mu}{m_e}\right)^2$,
b) the rate of the background $b\bar{b}Z \to b\bar{b}\mu^+\mu^-$ is equal to the rate of $b\bar{b}Z \to b\bar{b}e^+e^-$ because of the production diagrams which are the same, and of the lepton coupling universality in the Z decay.
In this context the associated Z production and decay in the channel $b\bar{b}Z \to \mu^+\mu^-$ has been studied using a control sample of $b\bar{b}Z \to e^+e^-$ events. The effect of *inner bremsstrahlung* (IB) radiation has been investigated and corrected for; the impact in the event reconstruction is not large. The ratio of the number of reconstructed events from the two samples in the region of mass higher than m_Z, interesting for new physics search, is stable and implies correction factors close to one as can be seen in Fig. (7)straight line is drawn for reader's eye 18) .

As a result, barring corrections for different *inner bremsstrahlung* and detector response, the number of $b\bar{b}Z \to b\bar{b}e^+e^-$ gives directly the number of background events $b\bar{b}Z \to b\bar{b}\mu^+\mu^-$.

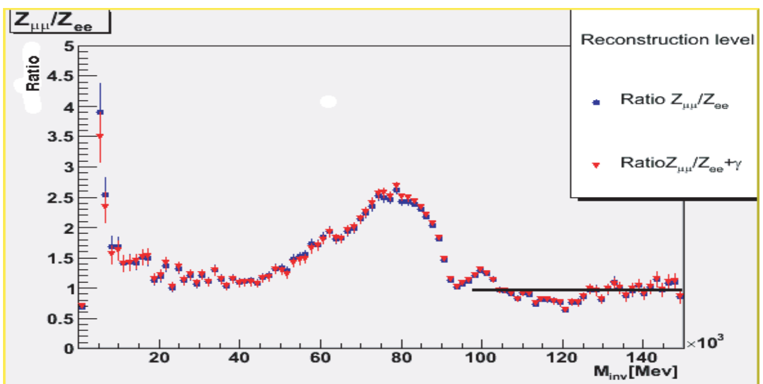

Figure 7: *Ratio between the number of events decaying in* $\mu^+\mu^-$ *and the number of events decaying in* e^+e^-, $\left(\frac{N_{Z\to e^+e^-}}{N_{Z\to\mu^+\mu^-}}\right)$, *before IB correction (blue symbols), and after (red symbols). All events of the reconstructed sample are included. The black solid line is for viewing purposes.*

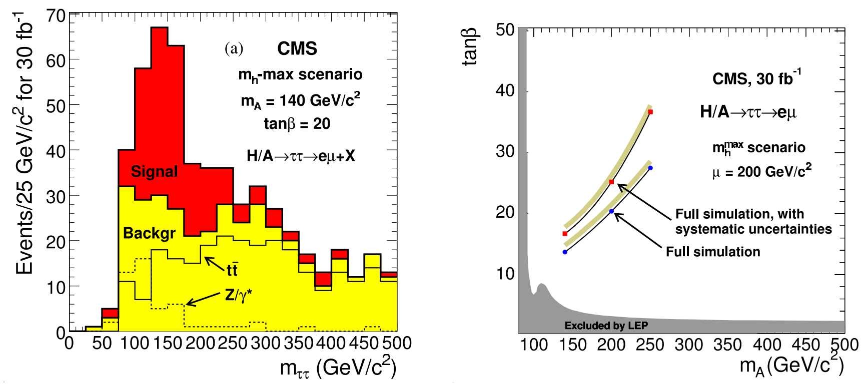

Figure 8: *The* $\tau^+\tau^-$ *reconstructed mass with 30* fb^{-1} *after selection but mass window, in the* $\mathrm{m_h}-max$ *scenario (Sec. 2) and background* $\mathrm{m_A}$= *140 GeV. The discovery region for* $gg \to \mathrm{b\bar{b}}H/A, H/A \to \tau^+\tau^- \to e\mu + X$ *in* m_A tanβ *plane in in the* $m_\mathrm{h} - max$ *scenario a search significance 5 (left) with an integrated luminosity of* $\int \mathcal{L}\,\mathrm{dt}$ = *30* fb^{-1} [8].

5.3 $bbh/A \to bb\tau^+\tau^-$

The discovery potential for the supersymmetric Higgs boson h/H/A in final state $\tau^+\tau^-$has been investigated from both Collaboration with both tau leptons decaying leptonically or in one lepton and one jet or both jets. As in the case $\mu^+\mu^-$ both Collaborations have studied the MSSM Higgs production either in inclusive mode either in bb association.

Compared with hadronic and semileptonic final state, the fully leptonic final states are suppressed by relatively small branching ratio br($\tau \to \mu\nu\nu \approx$) 0.174 and br($\tau \to \mathrm{e}\nu\nu \approx$) 0.178, but the signal is clean.

The signal consists of events in which the Higgs boson decays into two tau leptons which in turn decay leptonically. One possible choice any final state in two leptons or μ-e final state, which is characterized from a lower background. The $\tau^+\tau^-$reconstructed mass with 30fb^{-1}after all selections, but mass window, is shown in Fig. (8, right) for m_A= 140 GeV and tanβ= 20 in $m_\mathrm{h} - max$ scenario, as CMS collaboration [8]. The Fig.(8, left) shows the discovery reach in m_A , tanβ plane in $m_\mathrm{h} - max$ scenario. The lower curve correspond to the case when the background systematic uncertainty is taken in account.

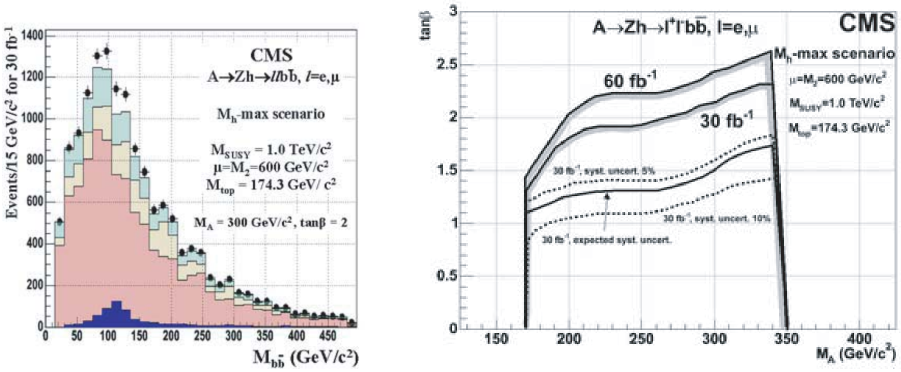

Figure 9: *Distributions of* $M_{\mathrm{b\bar{b}}}$ *for signal and background after event selection for 30* fb^{-1}*of integrated luminosity. Blue (black) distribution of signal (*m_{A}*=300,* $\tan\beta$*=2), black dots sum of signal+background(on the left)* [8] *in the* $m_{\mathrm{h}} - max$ *scenario (Sec. 2) and background. The 5* σ *discovery contour for* $\int \mathcal{L}\,\mathrm{dt} = 30$ *and 60* fb^{-1}*. The effect of background systematic uncertainty can be seen in the curve of 30* fb^{-1}*(right)* [8].

6 Others discovery Channels

6.1 Search for the $\mathbf{A \to Zh}$decay with $\mathbf{Z \to \ell^+\ell^-, h \to b\bar{b}}$

The observation of the CP-odd pseudo-scalar Higgs (A) via its decay into a Z boson and the lighter CP-even scalar Higgs (h) followed by Z $\to e^+e^-$, $\mu^+\mu^-$ and h $\to b\bar{b}$ decays provides an interesting way to detect A and h simultaneously. The branching ratio of A $\to$ Zh appears for the low $\tan\beta$ and $m_{\mathrm{Z}} + m_{\mathrm{h}} \le m_{\mathrm{A}} \le 2\mathrm{m_{top}}$ mass region.

The decays of A into charginos and neutralinos (A $\to \chi\chi$), however, can dominate at certain value of μ and M_2. Large values of these parameters are more favorable for this channel.

An interesting perspective in $m_{\mathrm{h}} - max$ scenario, with $\mu = M_2 = 600$ GeV has been studied from CMS collaboration [8]. The signal and background distributions of $\mathrm{M_{b\bar{b}}}$ are shown in Fig. 9 (left) for 30 fb^{-1}. Fig. 9 (right) shows the 5 σ discovery contours in (m_{A},$\tan\beta$) plane for 30 and 60 fb^{-1}.

6.2 Search for the $A/H \rightarrow \widetilde{\chi}_2^0\widetilde{\chi}_2^0 \rightarrow \ell^+\ell^-\ell^+\ell^-$

In all studies discussed so far, the interaction only between MSSM Higgs and SM particles were considered, in other words the SUSY mass scale was set heavy and it has been assumed no interaction between Higgs and sparticle sector. If this condition is released, different scenarios are opened and in some region of SUSY parameter space, heavy neutral Higgs bosons can be searched into supersymmetric particles. This may cover regions, which are not accessible to other SM Model particle decays. Few studies have been performed as pioneer works in this direction [19) 8)]. Recently a study possible decays of H/A bosons in MSSM and mSugra has been developed [20)] as: $\mathrm{H}, \mathrm{A} \rightarrow \widetilde{\chi}_2^0\widetilde{\chi}_2^0$, as well $\mathrm{H}, \mathrm{A} \rightarrow \widetilde{\chi}_2^0\widetilde{\chi}_3^0, \widetilde{\chi}_2^0\widetilde{\chi}_4^0, \widetilde{\chi}_3^0\widetilde{\chi}_3^0, \widetilde{\chi}_3^0\widetilde{\chi}_4^0, \widetilde{\chi}_4^0\widetilde{\chi}_4^0$ as well as $H^0, A^0 \rightarrow \widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^{\mp}, \widetilde{\chi}_2^{+}\widetilde{\chi}_2^{-}$. The final state considered in this search is 4 ℓ and missing energy. The m_{A} discovery reach for A and H is largely extended. Two sets of values of M_2 and μ have been chosen (Set1, Set2) to define two bench mark points in MSSM framework and this choice has been driven from consideration to have a point (Point1) where the signal most the signal events results from $\mathrm{H}, \mathrm{A} \rightarrow \widetilde{\chi}_2^0\widetilde{\chi}_2^0$ and another (Point2), whereas decays including heavier-inos make dominant contribution.

7 Conclusions

The ready to run experiments at LCH, ATLAS and CMS, will produce a harvest of enormous number of data. Based on these data the possibility to discover the neutral MSSM h/A/H Higgs in few representative decay channels are discussed in these pages, involving SM final states and MSSM final states, in different (m_{A},tanβ) regions.

Among the SM final state channels, a recent ATLAS study of the b-associated production of h/A and the following decay in $\mu^+\mu^-$ is discussed [21)]. In this channel a detection of neutral MSSM Higgs even in the region close to Z pole is possible, exploiting the high resolution of μ detectors. The other decay channels involving $\tau^+\tau^-$decaying in $\ell^+\ell^-$ with the ℓ=e,μ [8)],chracterized from a clean signal due to a low background final state, and the $\tau^+\tau^-$decay channel in ℓ and one jet with a larger significance for discovery especially in large m_{A} mass are also discussed.

In very low tanβ region,an interesting channel $\mathrm{A} \rightarrow \mathrm{Zh}$ decay with $\mathrm{Z} \rightarrow \ell^+\ell^-$ and $\mathrm{h} \rightarrow \mathrm{b}\bar{\mathrm{b}}$ [8)] can have access to discovery of MSSM neutral Higgs and simultaneously discovery of A and h.

A recent study [20)] involving A H decays in supersymmetric particles has demonstrated that for many interesting choices of the basic input parameters of the MSSM, heavier Higgs boson decay modes of the type $\mathrm{H}, \mathrm{A} \rightarrow \widetilde{\chi}_i^0\widetilde{\chi}_j^0$,with $i, j \neq 1$ could be possible channel to detect MSSM. The neutralinos' subsequent leptonic decays, as $\widetilde{\chi}_i^0 \rightarrow \ell^+\ell^-\widetilde{\chi}_1^0$, can yield a four-isolated-lepton (where here

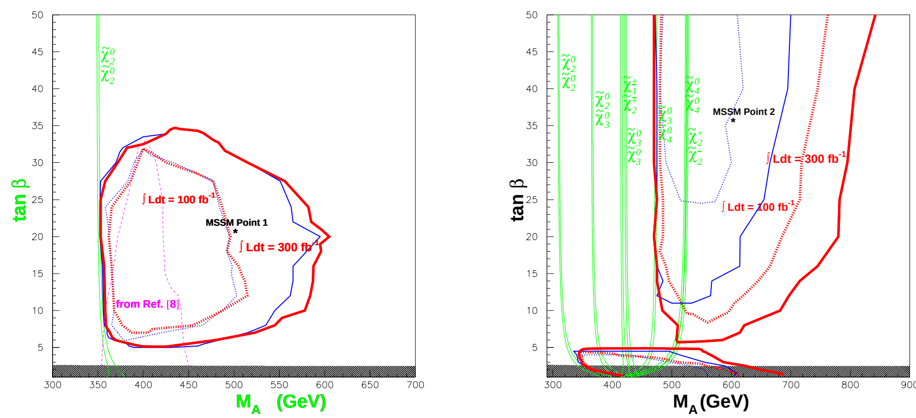

Figure 10: *Discovery region in red (m_A,tanβ) plane for -ino/spleton parameters* $\mu \approx 500$ GeV M_2*=180* GeV *(Set1) as in MSSM Point1 (located with an asterisk), where* $\widetilde{\chi}^0_2\widetilde{\chi}^0_2$ *is the dominating decay. Solid (dashed) red border delineate the discovery region for* $\int\mathcal{L}\,\mathrm{dt}$*=300* fb^{-1}*(100* fb^{-1}*) (on the left). Discovery region in red (m_A,tanβ) plane for -ino/spleton parameters* $\mu \approx 200$ GeV M_2*=200* GeV *(Set2) as in MSSM Point2 (located with an asterisk), where Higgs boson decays to a variety of higher mass -inos (see text) constitute the majority of signal events. Solid (dashed) red border delineate the discovery region for* $\int\mathcal{L}\,\mathrm{dt}$*= 300* fb^{-1}*(100* fb^{-1}*) (right). For complete set of MSSM parameters see Ref.* [20].

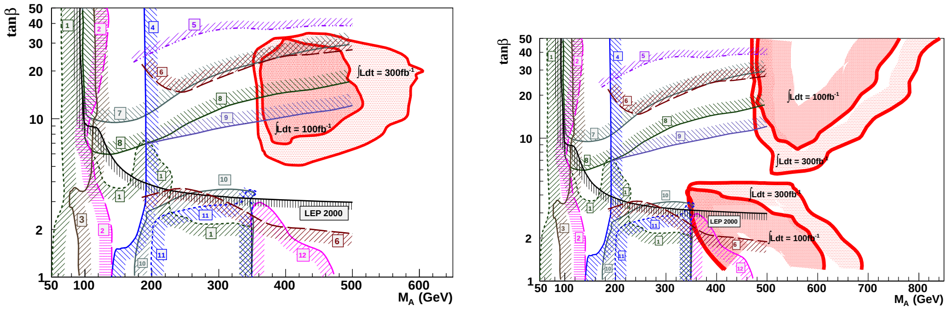

Figure 11: *On the left. Discovery region in* $(M_A, \tan\beta)$ *plane, here with a logarithmic* $\tan\beta$ *scale, for MSSM Parameter Set 1 and* $\mathcal{L}_{int} = 100\,fb^{-1}$ *and* $300\,fb^{-1}$ *for MSSM Higgs bosons'* 4ℓ *signals from their decays into neutralino or chargino pairs (here* H^0, A^0 *decays to* $\widetilde{\chi}_2^0\widetilde{\chi}_2^0$ *totally dominate), shown together with regions for other MSSM Higgs boson signatures from decays to SM particles based upon LEP results and ATLAS simulations* [7] *(which assume* $\mathcal{L}_{int} = 300\,fb^{-1}$*) where labels represent: 1.* $H^0 \to Z^0Z^{0*} \to 4\,leptons$*; 2.* $t \to bH^+$*,* $H^+ \to \tau^+\nu$ *+ c.c.; 3.* $t\bar{t}h^0$*,* $h^0 \to b\bar{b}$*; 4.* $h^0 \to \gamma\gamma$ *and* $W^\pm h^0/tth^0$*,* $h^0 \to \gamma\gamma$*; 5.* $b\bar{b}H^0, b\bar{b}A^0$ *with* $H^0/A^0 \to b\bar{b}$*; 6.* $H^+ \to t\bar{b}$ *+ c.c.; 7.* $H^0/A^0 \to \mu^+\mu^-$*; 8.* $H^0/A^0 \to \tau^+\tau^-$*; 9.* $g\bar{b} \to \bar{t}H+$*,* $H^+ \to \tau^+\nu$ *+ c.c.; 10.* $H^0 \to h^0h^0 \to b\bar{b}\gamma\gamma$*; 11.* $A^0 \to Z^0h^0 \to \ell^+\ell^-b\bar{b}$*; 12.* $H^0/A^0 \to t\bar{t}$*. Note that SM discovery regions are not for the same input parameters: they presume Higgs bosons cannot decay into sparticles, so more accurate estimates may well be smaller. For the* 4ℓ *signals from* $\widetilde{\chi}_i^0\widetilde{\chi}_j^0, \widetilde{\chi}_m^+\widetilde{\chi}_n^-$ *decays, the –ino/slepton parameters are* $\mu = -500\,GeV$*,* $M_2 = 180\,GeV$*,* $M_1 = 90\,GeV$ *and* $m_{\widetilde{\ell}_{soft}} = m_{\widetilde{\tau}_{soft}} = 250\,GeV$*.*

On the right. Discovery region in $(M_A, \tan\beta)$ *plane for for MSSM Parameter Set 2 and* $\mathcal{L}_{int} = 100\,fb^{-1}$ *and* $300\,fb^{-1}$ *for MSSM Higgs bosons'* 4ℓ *signals from their decays into neutralino or chargino pairs (here Higgs boson decays to higher-mass neutralinos typically dominate), shown together with regions for MSSM Higgs boson signatures from decays to SM particlesas in Fig. 11. For the* 4ℓ *signals from* $\widetilde{\chi}_i^0\widetilde{\chi}_j^0, \widetilde{\chi}_m^+\widetilde{\chi}_n^-$ *decays, the –ino/slepton parameters are* $\mu = -200\,GeV$*,* $M_2 = 200\,GeV$*,* $M_1 = 100\,GeV$*,* $m_{\widetilde{\ell}_{soft}} = 150\,GeV$ *and* $m_{\widetilde{\tau}_{soft}} = 250\,GeV$*, as in MSSM Point 2. Here Higgs boson decays to a variety of higher mass –inos (see text) constitute the majority of the signal events. Solid (dashed) red border delineates the discovery region for* $L_{int} = 300\,fb^{-1}$ *(*$100\,fb^{-1}$*). Other signal delineations from the ATLAS TDR all assume* $L_{int} = 300\,fb^{-1}$*. Note also that, since ATLAS discovery regions presume Higgs bosons cannot decay into sparticles, more accurate estimates may well be smaller (from Ref.* [20]*).*

ℓ refers to electrons and/or muons) plus missing-transverse-energy signature. Such leptonic neutralino decays may proceed via either an intermediate charged slepton or via an intermediate $Z^{0(*)}$, where in either case this intermediate state may be on- or off-mass-shell.

We can conclude that this variety of channels will give a possibility to explore in the next future the complete region of $m_{\mathrm{A}}\tan\beta$for a discovery of MSSM region with LHC data.

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