Search for new physics at LHC

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Abstract

We review the search for new physics to be done at Large Hadron Collider, - search for Higgs boson, supersymmetry and exotic.

1 Introduction

The SM (Standard Model) [1] which describes within an unprecedental scale of energies and distances the strong and electroweak interactions of elementary particles relays on a few basic principles - the renormalizability, the gauge invariance and the spontaneous breaking of the underlying gauge symmetry. The principle of the renormalizability [2] which is considered often as something beyond the limits of experimental test is one of the most important (if not the major) ingredients of quantum field theory. The SM gauge group $SU_c(3) \otimes SU_L(2) \otimes U(1)$ is spontaneously broken to $SU_c(3) \otimes U_{em}(1)$ by the existence of scalar field with nonzero expectation value, leading to massive vector bosons - the $W^{\pm}$ and Z - which mediate the weak interactions; the photon remains massless. One physical degree of freedom remains in the scalar sector, a neutral scalar boson (Higgs boson) H, which is the last nondiscovered particle of the SM. It should be noted that the existence of the Higgs boson is direct consequence of the renormalizability of the SM model. The $SU_c(3)$ gauge group describes the strong interactions (quantum chromodynamics or QCD). The eight vector gluons carry colour charges and are selfinteracting. Due to the property of asymptotic freedom the effective QCD coupling constant α_s is small for large momentum transfers that allows to calculate reliably deep inelastic cross sections. The fundamental fermions in the SM are leptons and quarks; the left-handed states are doublets under $SU_L(2)$ gauge group, while the right-handed states are singlets. There are three generations of fermions, each generation identical except for mass.

Despite the apparent striking success of the SM, there are a lot of reasons why it is not the ultimate theory. In the SM the neutrinos are massless and hence there are no neutrino oscillations. However there is strong evidence for neutrino oscillations [3] coming from measurements of neutrinos produced in the atmosphere and from a defecit in the flux of electron neutrinos from sun. It is easy to extend the SM to include neutrino masses, however the natural explanation of small neutrino masses is rather untrivial and probably it requires qualitatively new physics. In the SM an elementary Higgs field generates masses for the W, Z and fermions. For the SM to be consistent the Higgs boson mass should be relatively light $M_H \leq 1~TeV$. The tree-level Higgs boson mass receives quadratically-divergent corrections at quantum level $\delta M_H^2 \sim \Lambda^2$, where Λ is some ultraviolet cutoff. The natural ultraviolet cutoff in particle physics is the Planck scale $M_P \sim 10^{19}~GeV$ or grand unification scale $M_G \sim 10^{14}~GeV$. Hence the natural scale for the Higgs boson mass is $O(\Lambda)$. To explain the smallness of the Higgs boson mass some delicate cancellation is required that is rather untrivial "fine tuning" or gauge hierarchy problem. At present the supersymmetric solution [4], [5] of the gauge hierarchy problem is the most fashionable one. It predicts that the masses of supersymmetric particles have to be lighter than $O(1)~TeV$. Other possible explanation is based on models with "technicolour" [6]. Also we can't exclude the possibility that the natural scale of the nature $\Lambda \sim O(1)~TeV$. At any rate all solutions of the gauge hierarchy problem predict the existence of new physics at TeV scale.

Other untrivial problem is that the SM can't predict the fermion masses, which vary over at least five orders of magnitude (fermion problem).

The scientific programme at the LHC (Large Hadron Collider) which will be the biggest particle accelerator complex ever built in the world consists in many goals. Among them there are two supergoals:

a. Higgs boson discovery,

b. supersymmetry discovery.

LHC [7] will accelerate mainly two proton beams with the total energy $\sqrt{s} = 14\ TeV$. At low luminosity stage (first two-three years of the operation) the luminosity is planned to be $L_{low} = 10^{33} cm^{-2} s^{-1}$ with total luminosity $L_t = 10\ fb^{-1}$ per year. At high luminosity stage the luminosity is planned to be $L_{high} = 10^{34} cm^{-2} s^{-1}$ with total luminosity $L_t = 100\ fb^{-1}$ per year. Also the LHC will accelerate heavy ions, for example, Pb-Pb ions at 1150 TeV in the centre of mass and luminosity up to $10^{27}\ cm^{-2} s^{-1}$. Bunches of protons will intersect at four points where detectors are placed. There are planned to be two big detectors at the LHC: the CMS (Compact Muon Solenoid) [8] and ATLAS (A Toroidal LHC Apparatus) [9]. Two other detectors are ALICE detector [10], to be used for the study of heavy ions, and LHC-B [11], the detector for the study of B-physics.

In this paper we briefly review the search for new physics to be performed at the LHC. To be precise we review the search for Higgs boson, the search for supersymmetry and the search for new physics beyond the SM and the MSSM. As a rule we review results based on full simulation of the CMS detector [12].

2 Search for standard Higgs boson

The current limit on the SM Higgs boson mass from LEP experiments is $m_H \geq 114.4\ GeV$ at 95% C.L. [13]. Analysis of high-precision measurements of electroweak observables lead to indirect upper bound [14] $m_H \leq 193\ GeV$ at 95% C.L. on the Higgs boson mass, so within the SM the Higgs boson should be relatively light.

The tree-level Higgs boson couplings to gauge bosons and fermions can be deduced from the SM lagrangian. Of these, the HW^+W^-, HZZ and $H\bar{\psi}\psi$ are the most important for the phenomenology. For $m_H \leq 2m_W$ Higgs boson decays mainly with (≈ 90 percent) probability into b quark-antiquark pair and with ≈ 7 percent probability into τ lepton-antilepton pair.

In the heavy Higgs mass regime ($2m_Z \leq m_H \leq 800$ GeV), the Higgs boson decays dominantly into gauge bosons. For Higgs boson mass slightly larger than the corresponding gauge boson mass the decay widths into pairs of off-shell gauge bosons play important role.

It should be noted that there are a number of important Higgs couplings which are absent at tree level but appear at one-loop level. Among them the couplings of the Higgs boson to two gluons and two photons are extremely important for the Higgs boson searches at supercolliders.

Typical processes that can be exploited to produce Higgs bosons at the LHC are [15], [16], [17]:

1. gluon fusion : $gg \to H$,
2. WW, ZZ fusion : $W^+W^-, ZZ \to H$,
3. Higgs-strahlung off W, Z : $q\bar{q}W, Z \to W, Z + H$,
4. Higgs bremsstrahlung off top : $q\bar{q}, gg \to t\bar{t} + H$.

Gluon fusion plays a dominant role throughout the entire Higgs mass range of the Standard Model whereas the WW/ZZ fusion process becomes increasingly important with Higgs boson mass rising. The last two reactions are important only for light Higgs masses.

One of the most important reactions for the search for Higgs boson at LHC is

$$pp \to (H \to \gamma\gamma) + \dots, \tag{1}$$

which is the most promising one [18] for the search for Higgs boson in the most interesting region 100 $GeV \leq m_H \leq 150\ GeV$. The general conclusion is that at 5σ level it would be possible to discover Higgs boson for 95 $GeV \leq m_H \leq 145\ GeV$ at low luminosity and at high luminosity the corresponding Higgs boson mass discovery interval is 85 $GeV \leq m_H \leq 150\ GeV$ [12].

The signature $pp \rightarrow H \rightarrow WW^* \rightarrow l^+ \nu l'^- \bar{\nu}'$ [19] provides the Higgs boson discovery for the Higgs boson mass region between 150 GeV and 180 GeV [12], [18]. Especially important is that the signature $H \rightarrow WW^* \rightarrow l^+ \nu l'^- \nu$ allows to discover Higgs boson in the mass region around 170 GeV where the branching ratio for $H \rightarrow 4l$ is small and the use of four lepton signature for the Higgs boson discovery does not help at least for low luminosity. This signature does not require extraordinary detector performance and only requires a relatively low integrated luminosity of about 5 fb^{-1}.

The weak boson fusion channels $qq \rightarrow qqH$ lead to energetic jets in the forward and backward directions, and the absence of colour exchange in the hard process [20],[21],[22], that allows to obtain a large reduction of backgrounds from $t\bar{t}$, QCD jets, W- and Z-production and compensate the smallness of the Higgs weak boson fusion cross section compared to inclusive $gg \rightarrow H$. Note that the process of Higgs boson production in the weak boson fusion with forward jet tagging has been considered first for the channels $H \rightarrow ZZ \rightarrow 4l, 2l2\nu$ in ref.[23]. The reaction $pp \rightarrow (H \rightarrow \gamma\gamma) +\ 2\ forward\ jets$ has been investigated at parton level in ref. [20] and at full CMS detector simulation level in ref. [24]. The main conclusion of ref.[24] is that the significance $S = 5$ is reached at the luminosities $\sim 100\ fb^{-1}$ for $m_H = 115 - 130\ GeV$. Additional advantage of this signature is that the ratio of signal to background $S/B \sim 1$ in comparison with $S/B \sim 1/15$ for inclusive $pp \rightarrow (H \rightarrow \gamma\gamma) + ...$ reaction.

The signature $H \rightarrow W^{(*)}W \rightarrow l^{\pm} l'^{\mp} E_T^{mis}$ in weak boson fusion mechanism with forward jet tagging has been investigated in ref.[12]. The spin correlations, leading to small opening angles between two charged leptons, are used to suppress the backgrounds. This mode provides the Higgs boson discovery for 180 $GeV \geq m_H \geq 130\ GeV$ for integral luminosity $L_t = 60\ fb^{-1}$.

The signature $H \rightarrow \tau\tau \rightarrow l\ +\ \tau_{jet} + E_T^{miss}$ in weak boson fusion mechanism was studied in ref.[25]. The main conclusion is that for integral luminosity 60 fb^{-1} the use of this signature allows to discover Higgs boson for mass interval 115 $GeV \leq m_H \leq 135\ GeV$ [25].

The channel $H \rightarrow ZZ^* \rightarrow 4l$ is the most promising one to observe Higgs boson in the mass range 130 GeV – 180 GeV. Below $2M_Z$ the event rate is small and the background reduction more difficult, as one of the Zs is off mass shell. In this mass region the width of the Higgs boson is small $\Gamma_H < 1\ GeV$, and the observed width is entirely determined by the instrumental mass resolution. The significance of the signal is proportional to the four-lepton mass resolution ($S = N_S/\sqrt{N_B}$ and $N_B \sim \sigma_{4l}$, so the lepton energy/momentum resolution is of decisive importance. The main conclusion [12] is that for the region 130 $GeV \leq m_H \leq 180\ GeV$ and for $L_t = 30\ fb^{-1}$ CMS will discover the Higgs boson with $\geq 5\sigma$ signal significance except narrow mass region around 170 GeV where $\sigma \times Br$ has a minimum due to the opening of the $H \rightarrow WW$ channel and drop of the $H \rightarrow ZZ^*$ branching ratio just below the ZZ threshold.

For 180 $GeV \leq m_H \leq 800\ GeV$, this signature is considered to be the most reliable one for the Higgs boson discovery at LHC, since the expected signal rates are large and the background is small. The main background to the $H \rightarrow ZZ \rightarrow 4l^{\pm}$ process is the irreducible ZZ production from $q\bar{q} \rightarrow ZZ$ and $gg \rightarrow ZZ$. The $t\bar{t}$ and $Zb\bar{b}$ backgrounds are small and reducible by a Z-mass cut. The use of this signature allows to detect the Higgs boson at $\geq 5\sigma$ level up to $m_H \approx 400\ GeV$ at 10 fb^{-1} and up to $m_H \approx 600\ GeV$ at 30 fb^{-1} [12].

The $WH \rightarrow lll + X$ final state is other promising signature for the Higgs boson search. The production cross section is smaller than the inclusive $H \rightarrow \gamma\gamma$ by a factor ≈ 30. However the isolated hard leptons from the W and H decays allow to obtain a strong background reduction. The main conclusion is that for an integrated luminosity $100 fb^{-1}$ it is possible to discover Higgs boson for 155 $Gev \leq m_H \leq 175\ GeV$ [26].

2.1 Investigation of the Higgs boson properties

For the most interesting Higgs boson mass region $114.4\ GeV \leq m_H \leq 193\ GeV$ the $H \to \gamma\gamma$ and $H \to ZZ/ZZ^* \to 4l^{\pm}$ channels provide a precision in mass determination better than $3 \cdot 10^{-3}$ [27], [28], [29]. Direct measurement of the SM Higgs boson width is possible only for $m_H \geq 200\ GeV$ where the natural width exceeds the experimental mass resolution $\sim 1\ GeV$. Precision at the $O(10^{-2})$ level is expected from $H \to ZZ^* \to 4l^{\pm}$. The use of weak fusion boson mechanism and $H \to WW^*$, $H \to \gamma\gamma$ decays allows to extract information on the HWW coupling. The ratio of the Higgs boson decay widths Γ_W/Γ_Z can be measured in the direct Higgs boson production using the evident equality $\sigma_H \times BR(H \to WW^*/\sigma_H \times BR(H \to ZZ^*) = \Gamma_W/\Gamma_Z$. The simultaneous use of the channels $H \to \gamma\gamma$ and $H \to ZZ^*$ allows to determine $\sigma_H \times BR(H \to \gamma\gamma)/\sigma_H \times BR(H \to ZZ^*) = \Gamma(H \to \gamma\gamma)/\Gamma(H \to ZZ^*)$. Precision of better than 20 percent is expected for these measurements with $300\ fb^{-1}$ [27], [28].

In conclusion let us stress that LHC will be able to discover Higgs boson from the lower LEP limit $m_H \geq 114.4\ GeV$ up to $m_H = 1\ TeV$ value (see Figs.1,2) where the Higgs boson is very broad $\Gamma_H \approx 0.5\ TeV$ and it is no longer sensible to consider it as an elementary particle. The most reliable signatures for the LHC Higgs boson search are:

1. $H \to \gamma\gamma$,
2. $H \to ZZ^*, ZZ \to 4l^{\pm}$,
3. $H \to WW^* \to l^+\nu l^-\nu$,
4. $H \to ZZ, WW, \to ll\nu\nu, lljj, l\nu jj$.

The simultaneous use of different channels allows to extract the ratio of the Higgs boson decay widths.

3 Supersymmetry search within MSSM

3.1 The MSSM model

Supersymmetry (SUSY) is a new type of symmetry that relates bosons and fermions [4], [5]. Locally supersymmetric theories necessary incorporate gravity [30]. SUSY is also an essential ingredient of superstring theories [31]. The interest in SUSY is due to the observation that measurements of the gauge coupling constants at LEP1 are in favour of the Grand Unification in a supersymmetric theory with superpartners of ordinary particles which are lighter than $O(1)\ TeV$ [5]. Besides supersymmetric electroweak models offer the simplest solution of the gauge hierarchy problem [5]. In real life supersymmetry has to be broken and to solve the gauge hierarchy problem the masses of superparticles have to be lighter than $O(1)\ TeV$. Supergravity provides natural explanation of the supersymmetry breaking [5], namely, an account of the supergravity breaking in hidden sector leads to soft supersymmetry breaking in observable sector.

The simplest supersymmetric generalization of the SM is the Minimal Supersymmetric Standard Model (MSSM) [5]. It is supersymmetric model based on standard $SU_c(3) \otimes SU_L(2) \otimes U(1)$ gauge group with electroweak symmetry spontaneously broken via vacuum expectation values of two different Higgs doublets. The MSSM consists of taking the SM and adding the corresponding supersymmetric partners. It should be stressed that the MSSM contains two hypercharges $Y = \pm 1$ Higgs doublets, which is the minimal structure for the Higgs sector of an anomaly-free supersymmetric extension of the SM.

At LHC sparticles can be produced via the following reactions [15], [32]:

a. $gg, qq, qg \to \tilde{g}\tilde{g},\ \tilde{g}\tilde{q},\ \tilde{q}\tilde{q}$,
b. $qq, gq \to \tilde{g}\tilde{\chi}_i^0,\ \tilde{g}\tilde{\chi}_i^{\pm},\ \tilde{q}\tilde{\chi}_i^0,\ \tilde{q}\tilde{\chi}_i^{\pm}$,
c. $qq \to \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{\mp},\ \tilde{\chi}_i^{\pm}\tilde{\chi}_j^0,\ \tilde{\chi}_i^0\tilde{\chi}_j^0$,
d. $qq \to \tilde{l}\tilde{\nu},\ \tilde{l}\tilde{l},\ \tilde{\nu}\tilde{\nu}$,

The decay widths of the superparticles depend rather strongly on the relations between superparticle masses.

3.2 Search for sparticles at LHC

Squarks and gluino. The gluino and squark production cross sections at LHC are the biggest ones compared to slepton or gaugino cross sections. Therefore gluinos and squarks production at LHC is the most interesting reaction from the SUSY discovery point of view with the cross sections around 1 pb for squark and gluino masses around 1 TeV. The squark and gluino decays produce missing transverse energy from the LSP plus multiple jets and varying numbers of leptons from the intermediate gauginos [33].

It is natural to divide the signatures used for the squark and gluino detections into the following categories [33]:

a. multi jets plus E_T^{miss} events,
b. 1l plus jets plus E_T^{miss} events,
c. 2l plus jets plus E_T^{miss} events,
d. 3l plus jets plus E_T^{miss} events,
e. 4l plus jets plus E_T^{miss} events,
f. $\geq 5l$ plus jets plus E_T^{miss} events.

Multileptons arise as a result of the cascade decays of neutralinos and charginos into W- and Z-bosons with subsequent decays of W- and Z-bosons into leptonic modes. For instance, the same sign and opposite sign dilepton events arise as a result of the cascade decay

$$\tilde{g} \to q^{'}\bar{q}\tilde{\chi}_i^{\pm},\ \tilde{\chi}_i^{\pm} \to W^{\pm}\tilde{\chi}_1^0 \to l^{\pm}\nu\tilde{\chi}_1^0\,, \tag{2}$$

where l stands for both e and μ. Opposite sign dilepton events can arise also as a result of cascade decay

$$\tilde{g} \to q\bar{q}\tilde{\chi}_i^0,\ \tilde{\chi}_i^0 \to Z\tilde{\chi}_1^0 \to l^+l^-\chi_1^0\,. \tag{3}$$

The main conclusion [12] is that for the MSUGRA model LHC(CMS) will be able to discover SUSY with squark or gluino masses up to 2 TeV for $L_{tot} = 30\ fb^{-1}$ (see Fig.3). The most powerful signature for squark and gluino detection in MSUGRA model is the signature with multijets and the E_T^{miss}. It should be stressed that the use of the signature $e^{\pm}\mu^{\mp}\ +\ E_T^{miss}$ allows not only to discover SUSY but to discover lepton flavour violation [34] in neutralino decay $\tilde{\chi}_2^0 \to e^{\pm}\mu^{\mp}\tilde{\chi}_1^0$.

Note that for the case of the MSSM model with arbitrary squark and gaugino masses the LHC SUSY discovery potential depends rather strongly on the relation between the LSP, squark and gluino masses and it decreases with the increase of the LSP mass [35]. For the LSP mass close to the squark or gluino masses it is possible to discover SUSY with the squark or gluino masses up to $(1.2 - 1.5)$ TeV [35].

Let us stress that multilepton supersymmetry signatures $(b\ -\ f)$ arise as a result of decays of squarks or gluino into charginos or neutralinos different from LSP with subsequent decays of charginos or neutralinos into W-, Z-bosons plus LSP. Leptonic decays of W-, Z-bosons is the origin of leptons. However, for the case of nonuniversal gaugino masses it is possible to realize the situation when all charginos and neutralinos except LSP are heavier than gluino and squarks. Therefore, gluino and squarks will decay mainly into quarks or gluons plus LSP, so cascade decays and as a consequence multilepton events will be negligible.

Chargino and neutralino pairs, produced through the Drell-Yan mechanism $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ may be detected through their leptonic decays $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to lll + E_T^{miss}$. So, the signature is three isolated leptons with E_T^{miss}. The main conclusion is that neutralino and chargino could be detected through the Drell-Yan mechanism provided their masses are lighter than 200 GeV [36].

Slepton pairs, produced through the Drell-Yan mechanism $pp \to \gamma^*/Z^* \to \tilde{l}^+\tilde{l}^-$ can be detected through their leptonic decays $\tilde{l} \to l + \chi_1^0$. So the typical signature used for sleptons detection is the dilepton pair with missing energy and no hadronic jets [37]. For $L_t = 60\ fb^{-1}$ LHC(CMS) will be able to discover sleptons with the masses up to 300 Gev [38],[39], [12].

After the LHC SUSY discovery the main problem will be to separate many different channels produced by the SUSY cascade decays and to extract the values of SUSY parameters (squark, gluino, neutralino, chargino and slepton masses). In the MSSM model, the decay products of SUSY particles always contain an invisible LSP $\tilde{\chi}_1^0$, so SUSY particles can not be reconstructed directly. The most promising approach to determine sparticle masses is to use kinematical endpoints [40] in different distributions. For example, the l^+l^- distribution from $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+l^-$ decay has an endpoint that determines $M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0}$. The distribution from the two-body decay $\tilde{\chi}_2^0 \to \tilde{l}^\pm l^\mp \to \tilde{\chi}_1^0 l^+l^-$ has a sharp edge at the endpoint $\sqrt{\frac{(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{l}})(M^2_{\tilde{l}} - M^2_{\tilde{\chi}_1^0})}{M^2_{\tilde{l}}}}$. When a longer decay chain can be identified, more combinations of masses can be measured [29], [41].

3.3 SUSY Higgs bosons search

The MSSM has three neutral and one charged Higgs bosons: h, H, A and $H^\pm$ [1]. As it has been mentioned before at tree level the lightest Higgs boson mass is predicted to be lighter than m_Z. However an account of radiative corrections [42] can increase the Higgs boson mass up to 135 GeV for stop masses less or equal to 1 TeV [42]. In MSUGRA model [15], [33] the Higgs sector is described mainly by two parameters: the mass of A boson and $\tan(\beta)$ - the ratio of the vacuum expectation values of the Higgs fields that couple to up-type and down-type quarks. In the limit of large A boson mass, the couplings of h boson coincide with the corresponding couplings of the SM Higgs boson.

At high $\tan\beta$ the H, A decay mainly into $b\bar{b}$. However this mode is not very useful due to huge $b\bar{b}$ background. The decays of H and A to $\tau^+\tau^-$ and $\mu^+\mu^-$ are the most important for the A and H bosons detection [29], [43]. In the MSSM, the $H \to \tau^+\tau^-$ and $A \to \tau^+\tau^-$ rates are enhanced over the SM for large $\tan(\beta)$. The production of the heavy neutral MSSM Higgs bosons is mainly through $gg \to H_{SUSY}$ and $gg \to b\bar{b}H_{SUSY}$. The Higgs boson coupling to b-quarks is enhanced at high $\tan\beta$ and the associated $gg \to b\bar{b}H_{SUSY}$ production dominates ($\sim 90\%$ of the total rate) for $\tan\beta \geq 10$ and $M_H \geq 300\ GeV$. The gluon fusion cross section is determined by quark loops and can be significantly reduced in the case of large stop mixing and light stop mass [44]. Due to the dominance of the $gg \to b\bar{b}H_{SUSY}$ production mechanism at high $\tan\beta$ production rates for the heavy Higgs bosons H and A are not sensitive to the loop effects.

For SUSY masses bigger than $O(300)$ Gev the decay widths and the production rates for the lightest Higgs boson h are approximately the same as for the SM Higgs boson (decoupling regime) and the most promising signature here is $h \to \gamma\gamma$. Also the signature $pp \to qq$ ($h \to WW^* \to l^+l^{'-}\nu\bar{\nu}$) is important. Note that in the case of large stop mixing and for light stop $m_{\tilde{t}_1} \leq 200\ GeV$ the rate $gg \to h \to \gamma\gamma$ could be significantly reduced due to the stop and top loops destructive interferences in $gg \to h$ which could lead to no discovery for this signature. For the most difficult region $m_h \sim m_A \sim m_H \sim 100\ GeV$ and high $\tan\beta$ the use of $gg \to b\bar{b}h \to b\bar{b}\mu^+\mu^-$ helps to detect the Higgs boson [27], [43], [45].

The main conclusion [12] is that almost the full $(m_A, \tan(\beta))$ -values can be explored with the $h \to \gamma\gamma$, $h \to WW^* \to l^+l^{'-}\nu\bar{\nu}$ decay modes for total luminosity $L_t = 30\ fb^{-1}$. The heavy H, A bosons will be discovered for $\tan\beta \geq 10$ using the $H, A \to \tau\tau$, $\mu\mu$ decay modes with the A, H boson masses up to 600 GeV (see Fig.4). For the search of the charged Higgs boson

[1] LEP2 experiments give lower bounds 91.0 GeV and 91.9 GeV for light h and pseudoscalar A-bosons. Besides, the excluded $\tan\beta$ regions are $0.5 \leq \tan\beta \leq 2.4$ for the maximal mixing scenario and $0.7 \leq \tan\beta \leq 10.5$ for the no mixing scenario [13].

$H^{\pm}$, the $gb \to tH^{\pm}, H^{\pm} \to \tau\nu$ channel is the most important one with a discovery reach for $\tan\beta \geq 20$ up to $m_{H^{\pm}} \approx 400\ GeV$. The most difficult region with $110\ GeV\ \leq m_A \leq 200\ GeV$, $3 \leq \tan(\beta) \leq 10$ could be explored with the SUSY particle decay modes provided the neutralinos and sleptons are light enough.

4 Search for new physics beyond the SM and the MSSM

There are a lot of models different from the SM and the MSSM. Here we briefly describe some of them.

4.1 Extra dimensions

There is much theoretical interest in models that have extra space dimensions [46], [47], [48], [49], [50], [51]. The main motivation is that models with big $R_c \geq O(1)\ TeV^{-1}$ extra space dimensions can explain the hierarchy between the electroweak and Planck scale. In such models new physics appears at a 1 TeV scale and therefore can be tested at the LHC.

In the ADD model [46] the metric looks like

$$ds^2 = g_{\mu\nu}(x)dx^{\mu}dx^{\nu} + \eta_{ab}(x,y)dy^a dy^b, \tag{4}$$

where $\nu, \nu = 0, 1, 2, 3$ and $a, b = 1, ...d$. All d additional dimensions are compactified with a characteristic size R_c. The relation between a fundamental mass scale in $D = 4 + d$ dimensions, M_D, and 4-dimensional Planck scale M_{PL} has the form

$$M_{PL}^2 = V_d M_D^{2+d}, \tag{5}$$

where V_d is a volume of the compactified dimensions ($V_d = (2\pi R_c)^d$ for toroidal form of extra dimensions). In the ADD model there are 2 free parameters, the number d of additional dimensions and the fundamental scale M_D. From the requirement that $M_D \sim 1\ TeV$ one can find that the compactification radius R_c^{-1} ranges from $10^{-3}\ eV$ to $10\ MeV$ if d runs from 2 to 6. In the ADD model all SM gauge and matter fields are to be confined to a 3-dimensional brane embedded into a $(3 + d)$-dimensional space and only gravity lives in the bulk.

Thus the KK gravitons behave like massive, almost stable non-interacting spin-2 particles. Their collider signature is an imbalance in missing mass of final states with a continuous mass distribution. The most promising signature of the graviton production at the LHC originates from the reaction $pp \to jet + E_T^{miss}$. Note that at parton level the subprocess $gq \to qG^{(n)}$ gives the largest contribution. The main background arises from the $Z + jet$, $Z \to \nu\bar{\nu}$ production. The use of this reaction allows to discover extra space dimensions at the LHC(ATLAS) with the inverse radius less than $9\ TeV$ [29]. Very interesting signature for the direct production of the massive gravitons is the process $pp \to \gamma + E_T^{miss}$ which can be used as an independent test, although it has the much lower rate.

In RS (Randall-Sundrum) model [47] gravity lives in a 5-dimensional Anti-de Sitter space with a single extra dimension compactified to the orbifold S^1/Z_2.

There are two 3-dimensional branes in the model with equal and opposite tension localised at the point $y = \pi r_c$ (so called the TeV brane) and at $y = 0$ (referred to as the Planck brane). All the SM fields are constrained to the TeV brane, while gravity propagates in the additional dimension.

In RS model [47] the first graviton excitation has a mass $O(1)\ TeV$ and it decays into jets, leptons or photons. The most promising mode for the graviton resonance detection at the LHC is the use of the lepton decay modes. The signature $q\bar{q}, gg \to G_{res1} \to l^+l^-$ has been studied in refs.[52]. The signal is visible for $M_{G,res1} \leq 2\ TeV$. Moreover, for $M_{G,res1} \leq 1.5\ TeV$ from the measurement of lepton angular distribution it is possible to confirm that the resonance is spin-2 particle.

4.2 Extra gauge bosons

Many string inspired supersymmetric electroweak models and grand unified models based on extended gauge groups ($SO(10), E_6, ..$) predict the existence of new relatively light neutral $Z^{'}$-bosons and charged $W^{'}$-bosons [53]. The LHC $Z^{'}$-boson discovery potential depends on the couplings of $Z^{'}$-boson with quarks and leptons. The main mechanism for the production of such new neutral vector bosons is the quark-antiquark fusion.

The best way to detect $Z^{'}$-bosons is to use the $Z^{'} \rightarrow e^+e^-, \mu^+\mu^-, jet\ jet$ decay modes. The study of the angular distribution of lepton pairs allows to obtain nontrivial information on $Z^{'}$-boson coupling constants with quarks and leptons and confirm that $Z^{'}$-boson is spin-1 particle. For considered $Z^{'}$-boson models new $Z^{`}$ bosons can be observed in the reaction $pp \rightarrow Z^{`} \rightarrow l^+l^-$, up to masses about 5 TeV for an integrated luminosity of 100 fb^{-1} [8], [29], [54]. The measurements of the forward-backward lepton charge asymmetry, both on $Z^{`}$ peak and in the interference region plus the measurement of the $Z^{`}$ rapidity distribution allow to discriminate between different $Z^{`}$ models for $Z^{`}$ masses up to $2 - 2.5\ TeV$ for total luminosity $L_t = 100\ fb^{-1}$ [54]. Note that dimuon signature $pp \rightarrow \mu\mu\ +\ ..$ was studied in ref. [55] as the signature for detection of graviton resonances

The most attractive candidate for $W^{'}$ is the W_R gauge boson associated with the left-right symmetric models [56]. These models provide a spontaneous origin for parity violation in weak interactions. The gauge group of left-right symmetric model is $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)_{B-L}$ with the SM hypercharge identified as $Y = T_{3R} + \frac{1}{2}(B - L)$, T_{3R} being the third component of $SU_R(2)$. The fermions transform under the gauge group as $q_L(3, 2, 1, 1/3) + q_R(3, 1, 2, 1/3)$ for quarks and $l_L(1, 2, 1, -1) + l_R(1, 1, 2, -1)$ for leptons. The model requires the introduction of right-handed neutrino ν_R which is the essential ingredient for the see-saw mechanism for explaining the smallness of the ordinary neutrino masses. A Higgs bidoublet $\Phi(1, 2, 3, 0)$ is usually introduced to generate fermion masses.

The main production mechanism for the $W^{'}$-boson is the quark-antiquark fusion similar to the case of $Z^{'}$-boson production. If right-handed neutrino ν_R is heavier than W_R the decay mode $W_R \rightarrow \nu_R + l$ is forbidden kinematically and the dominant decay of W_R will be into dijets. If ν_R is lighter than W_R the decay $W_R \rightarrow l\nu_R$ is allowed. The decay of $\nu_R \rightarrow lq\bar{q}^{'}$ leads to the $l\ l\ jet\ jet$ signature. The use of the signature $pp \rightarrow W_R \rightarrow l\nu_R \rightarrow llq\bar{q}$ allows to discover W_R boson up to masses of 4.6 TeV for $L_t = 30\ fb^{-1}$ and $m_{\nu_R} \leq 2.8\ TeV$ [57].

For the $W^{'}$ boson with coupling constants to the SM fermions equal to the ordinary W-boson coupling constants the best way to look for $W^{'}$-boson is through its leptonic decay mode $W^{'} \rightarrow l\nu$. For such model it would be possible to discover the $W^{'}$-boson through its leptonic mode with a mass up to 6 TeV [12], [29]. By the measurement of the $W^{'}$-boson transverse mass distribution it is possible to determine its mass with the accuracy $(50 - 100)\ GeV$.

Note that in ref. [58] $Z^{'}$ model woth continuously distrivuted mass was studied. Onr of possible LHC signatures for such model is the existence of broad resonance in Drell-Yan reaction $pp \rightarrow Z^{'} \rightarrow l^+l^-$.

5 Conclusion

There are no doubts that at present the supergoal number one of the experimental high energy physics is the search for the Higgs boson - the last non discovered cornerstone of the Standard Model. The LHC will be able to discover the Higgs boson and to check its basic properties. The experimental Higgs boson discovery will be the triumph of the idea of the renormalizability (in some sense it will be the "experimental proof" of the renormalizability of the electroweak interactions). The LHC will be able also to discover the low energy broken supersymmetry with the squark and gluino masses up to 2.5 TeV. Also there is nonzero probability to find something new beyond the SM or the MSSM (extra dimensions, $Z^{'}$-bosons, $W^{'}$-bosons, compositeness, ...).

At any rate after the LHC we will know the mechanism of the electroweak symmetry breaking (the Higgs boson or something more exotic?) and the basic elements of the matter structure at TeV scale.

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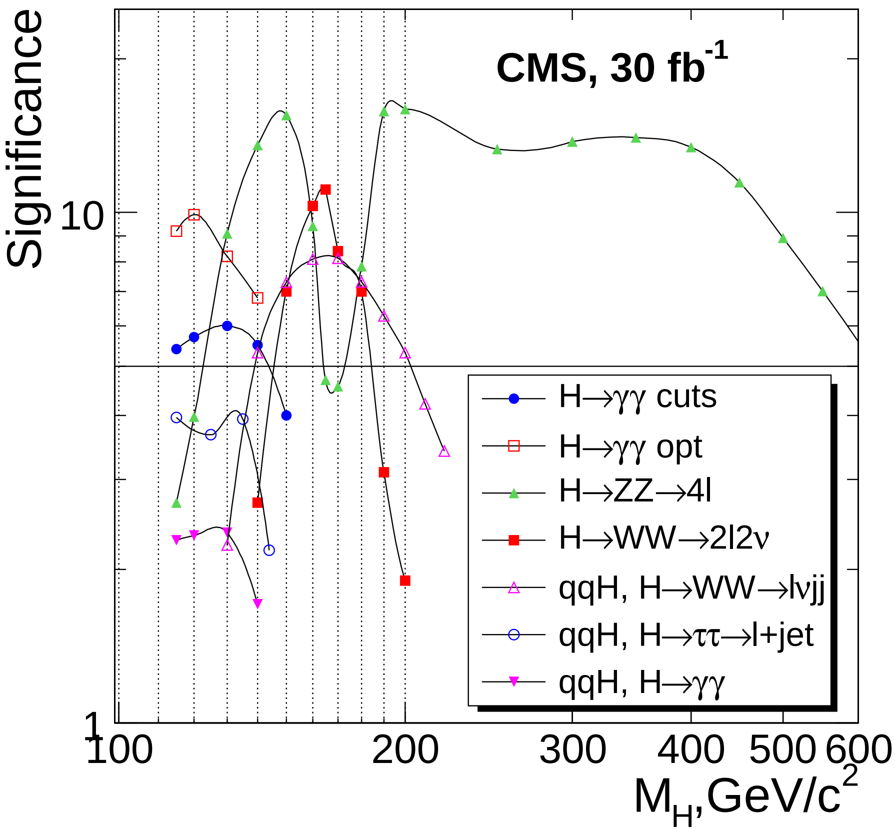

Figure 1: *The discovery reach of the SM Higgs boson in CMS for* 30 fb^{-1} *[12].*

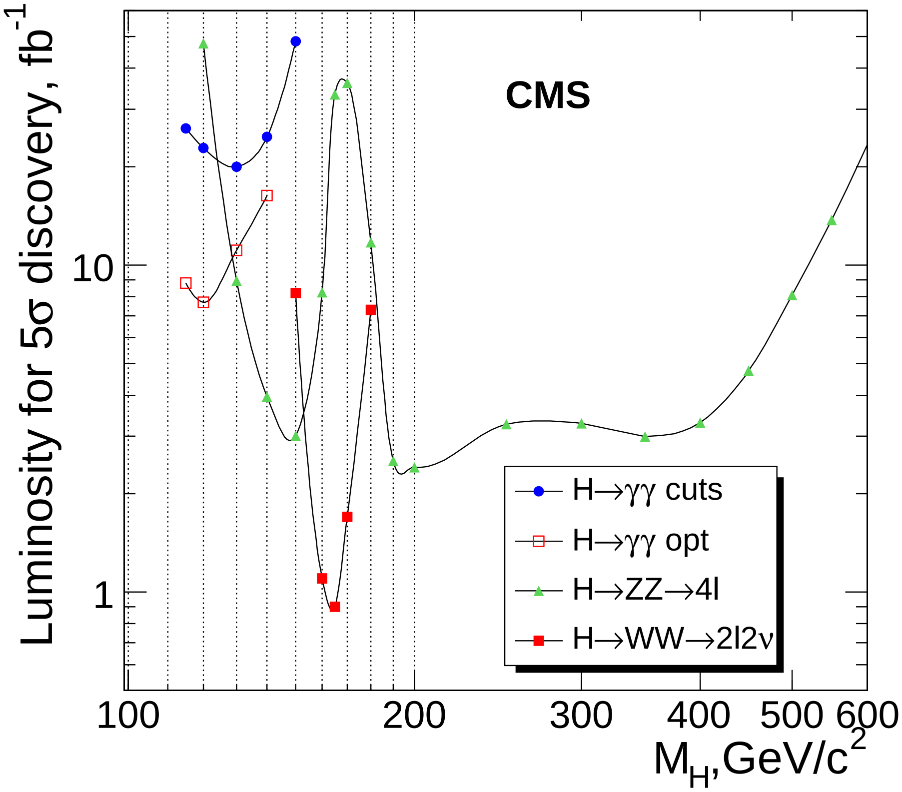

Figure 2: *The minimum luminosity to reach* 5σ *discovery in CMS [12].*

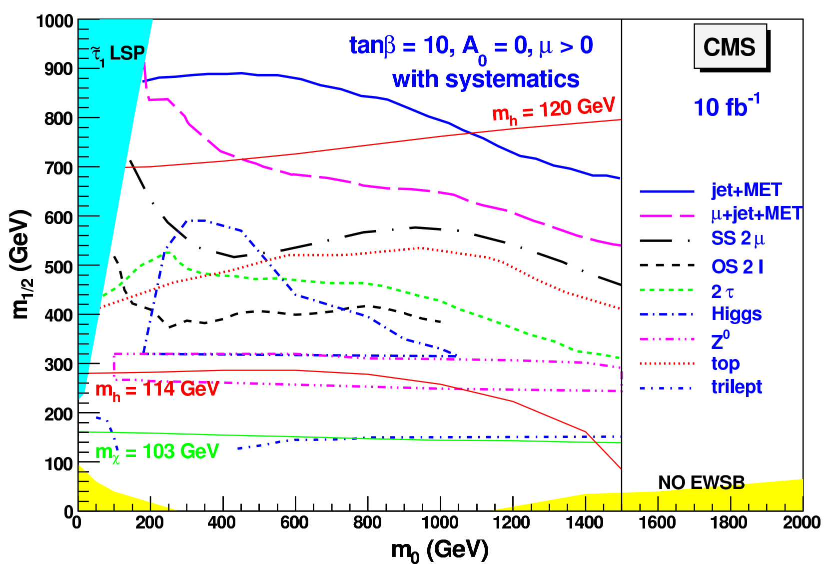

Figure 3: 5σ *discovey potential in* $m_0 - m_{1/2}$ *plane for the signature* E_T^{miss}+ *jets* + $n \geq 0$ *leptons at* 10 fb^{-1} *[12].*

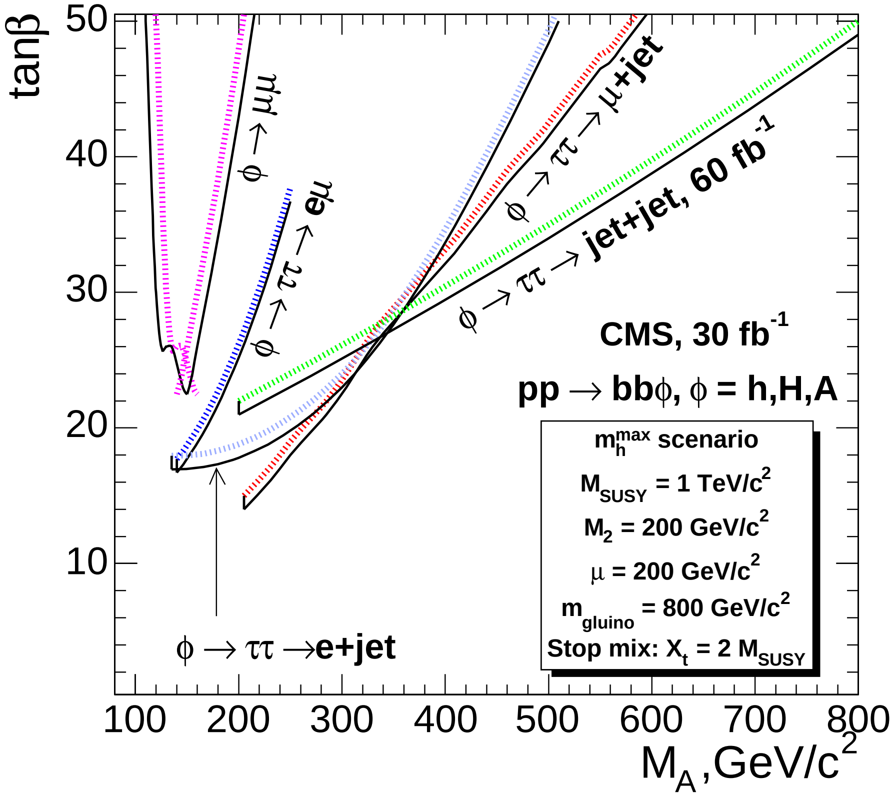

Figure 4: 5σ *discovery potential in* $m_A - \tan\beta$ *plane for neutral MSSM Higgs bosons [12].*