

# Is the scalar Higgs boson observed at the LHC, a supersymmetric Higgs boson or a standard model one?

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**Abstract.** Recently, a SM-like Higgs particle is reported to be discovered at CMS and ATLAS experiments at CERN with a mass of about 124 GeV. The present paper is related to an attempt to understand a very important question: Is the scalar Higgs boson observed at the LHC, a supersymmetric Higgs boson or a standard model one? Actually, after briefly reviewing the theoretical studies on Higgs mass in the context of Standard Model (SM) and Minimal Supersymmetric Standard Model (MSSM), we compare the values of Higgs mass obtained in several theoretical works on SM and MSSM, including those of the present author. We comment critically as regards the identification of the Higgs boson as SM Higgs or MSSM Higgs. In particular, certain models show that MSSM can give the mass of the lightest Higgs at a value near the observed value of nearly 124 GeV of SM-like Higgs, for a suitable choice of parameters. We suggest that repeated experimental confirmation as well as studies of other distinguishing properties of the discovered Higgs particle can probably discriminate the SM Higgs boson from the lightest MSSM one?

## 1. Introduction

Recently a Higgs-like particle is discovered in Large Hadron Collider experiment [1] at CERN on July 4, 2012 and this first LHC result suggests that the Higgs mass lies at 125-126 GeV. In fact, the standard model is a very successful model of strong and electroweak interaction and is due to the independent works of Glashow, Weinberg and Salam [2]. All predictions of the model has met with extreme success except that the Higgs particle, required for giving mass to the particles of the standard model other than the photon, is not yet confirmed experimentally. This particle was predicted by Higgs and other scientists [3]. Unfortunately, the Higgs mass is a free parameter in the standard model.

In particle physics, symmetries are believed to permit ultimately a classification of all observed particles. Supersymmetry (SUSY) arises as a symmetry [4] which combines bosons and fermions in the same representation or multiplet of the enlarged group which encompasses both the transformation of the Poincare group and the appropriate transformations, so that every bosonic particle must have a supersymmetric partner and vice versa. Since such a spectrum of particles is not compatible with observations, SUSY must be broken badly at the level of presently available energies. Experimental observation of a Higgs particle of supersymmetry, for example, can help us decide as to whether supersymmetry indeed is inherent in nature.



The purpose of the present paper is to throw light on the identification of the discovered Higgs on the basis of several theoretical studies on SM and MSSM Higgs i. e. whether theory favours it to be SM Higgs or a SUSY Higgs boson. Interpretation of the new particle within SM or within supersymmetric Higgs sector and conclusions about the nature of the Higgs boson (SM or SUSY etc. ) are necessary.

The paper is organised as follows: a short introduction to a few theoretical models of SUSY Higgs and the Higgs mass predictions are given in section 2; the problem of discrimination among SM Higgs and MSSM Higgs are analysed in section 3. Discussions are given in section 4, where the role of symmetry, aesthetics and beauty in the theoretical high energy physics are also mentioned. Conclusions are given in section 5.

## 2. A brief review of theories and theoretical predictions on SUSY Higgs mass

Supersymmetry(SUSY) is one of the most beautiful theoretical ideas that tries to explain the origin of the scale of the electroweak interaction. The minimal supersymmetric standard model(MSSM) is the most economical models and gives physics beyond the standard model(SM). In MSSM every quark,lepton and gauge boson has a supersymmetric partner associated with it. Moreover,the MSSM requires two Higgs doublets so as to give masses to up-type and down-type fermions, by keeping consistency with supersymmetry and by avoiding gauge anomalies due to the fermionic super-partners of the Higgs bosons. In MSSM ,after electroweak symmetry breaking there remain a total of five physical Higgs bosons. These can be classified as two neutral CP-even bosons,one neutral CP-odd boson and two charged bosons. The formalism of MSSM and mathematical details of calculations of the tree-level masses of supersymmetric Higgs may be found in a review [5], where the five tree level Higgs masses (the symbols having their usual meaning) satisfy the bounds given as follows

$$m_{H^\pm} \geq M_W, \quad (1)$$

$$m_{H_2^0} \leq m_Z \leq m_{H_1^0}, \quad (2)$$

$$m_{H_3^0} \geq m_{H_2^0}. \quad (3)$$

Although at tree level the condition  $m_{H_2^0} \leq m_Z$  holds, no Higgs has ever been detected at LEP and hence there is necessity of one and two-loop radiative corrections. For models which give 1-loop radiative corrections we refer to the work [6]. For some related works giving the lightest Higgs mass in MSSM to be  $< 130 GeV$  one may see [7]. A recent work for Higgs mass in MSSM is given in [8]. For detailed studies on phenomenological aspects of SUSY particle one may see [9].

A compilation of Higgs mass predictions in the standard model and supersymmetric standard model is given in the work of ref. [10]. Out of a list containing 64 Higgs mass predictions mentioned here, supersymmetry is behind 18 of them and with the exception of two,their central values lie between 120 and 160 GeV. Some of these predictions compiled in ref. [10],which lie near the observed value of Higgs mass (125 GeV), are shown in table1.

## 3. The problem of discrimination among SM Higgs and MSSM Higgs boson

In an article Jason L. Evans [11] has stated that SUSY prefers light Higgs boson but SM does not care; post LEP bounds are 114 - 600 GeV while SUSY expected mass range is 90 to 130 GeV. This author has posed the question : if the Higgs particle discovered is SM Higgs, why did it fall in the MSSM window?In another article Pran Nath [12] has assumed SUSY Higgs to be the underlying model for explaining the new boson by considering SUSY breaking. He concluded that the Higgs boson mass is less than 150 GeV (130 GeV) in MSSM (mSUGRA). He also concluded that the prospect for SUSY discovery at LHC are brighter as a consequence of the discovery of the Higgs boson. In another article entitled Consequences of a 125 GeV

**Table 1.** A compilation of Higgs mass ( $m_H(\text{GeV})$ ) predictions [10], which are near the recent LHC experimental result (125 GeV) are shown here

| $m_H$ (GeV)      | Authors                 | Idea                 | Techniques       |
|------------------|-------------------------|----------------------|------------------|
| $120 \pm 6$      | Ellis et al (2005)      | Supersymmetry        | MSSM             |
| $121 \pm 6$      | Feldman et al (2006)    | Superstring inspired | RG flow          |
| $121.8 \pm 11$   | Froggatt et al (1995)   | Degenerate vacua     | RGE              |
| $122 \pm 10$     | Djouadi (2004)          | SUSY SU(5)           | RG flow          |
| $124 \pm 21$     | Barger et al (2007)     | Susy broken          | R G flow         |
| $124 \pm 10$     | Arbuzov et al (2007)    | Condensates etc.     | Coleman-Weinberg |
| $124.2 \pm 13.2$ | Codoban et al (1999)    | Supersymmetry        | MSSM             |
| $125 \pm 4$      | Gogoladze et al (2007)  | Extra-dimension      | R G flow         |
| $127.5 \pm 7.5$  | Chankowski et al (2004) | Susy                 | MSSM             |

**Table 2.** Maximum value of lightest Higgs mass  $M_h$  in different models of MSSM [13]

| $M_h^{max}$ | mSUGRA | no scale | CNMSSM | VCNMSSM |
|-------------|--------|----------|--------|---------|
| value       | 128.0  | 123.0    | 123.5  | 124.5   |

Higgs on constrained MSSM scenarios by Mahmoudi [13] the author suggests that SM gives a Higgs mass which is essentially a free parameter, whereas MSSM gives the lightest CP-even Higgs particle as bounded from above. In different models of MSSM ,maximum value of lightest MSSM Higgs mass  $M_h$  lies near 125 GeV approximately (see table2 [13]). The main purpose of this section has been to mention about the theoretical results on supersymmetric Higgs related to the LHC result. Probably SUSY could be discovered even before the Higgs [14]! The current SUSY Higgs particle mass bounds are given elsewhere [15].

#### 4. Discussions

The present studies are based on predictions of theoretical models of supersymmetry on Higgs mass by different authors including ours. The Higgs boson discovered is also likely to be MSSM Higgs based on the predictions compiled in tables 1 and 2 , although one cannot surely distinguish between SM and MSSM Higgs at this stage.

In the context of LHC result on Higgs mass, we try to pin point the problem by going into details of theories on SM and MSSM. May be the Higgs particle is lightest SUSY Higgs particle, if discrepancy is noticed with respect to SM. The problem of resolving the issue of newly discovered boson may be understood through independent discovery, with caution in accepting new ideas and after critical enquiry into the evidence of discovery of the Higgs particle.

Hence connecting the theoretical models, bounds and constraining the parameters are very important. We may use symmetry to choose the correct option for the theory. Often, the symmetry principles [16] are the most important guides for understanding the unknown domain of nature. The concept of gauge invariance, formal relations between symmetries, unification and conservation laws are found to be very useful. Symmetry should be the guiding principle in the analysis of experimental data with reference to the theoretical models in high energy physics. There is a role of aesthetics in scientific theories [17]. One may use aesthetics in science to choose the most beautiful option in the matter of introduction of new ideas through economy,

simplicity, harmony and unified description giving a connection. The theory should be based on unbiased experimental results [18]. Beauty in particle physics [19] should also be considered.

## 5. Conclusions

The experimentalist, observation on Higgs-like particle and the analyses of theoretical results on models of SM and MSSM are likely to give feedback to the future search of the particle. Confining our attention to the mass spectra, we give a general survey based on theoretical works of different workers including ours. The MSSM Higgs mass varies with different parameters which are not precisely known as yet. We suggest that symmetry, aesthetics and match with experimental data are to be used for selecting the correct theory in SM and MSSM. If SM-like Higgs is SM Higgs, why does the Higgs mass predicted by many SUSY models lie in the range of values near the LHC value of Higgs Mass?

In this paper we have reviewed the current situation in LHC and Higgs mass to some extent. We think that more exhaustive and systematic studies on both SM and MSSM are necessary. We comment on the value of Higgs mass in LHC vs. predictions of Higgs mass in SM and MSSM [10]. We tabulated the predictions by different workers. On the basis of experimental data in LHC and the present theoretical scenario we come to the conclusion that the Higgs particle discovered is likely to be SM-like MSSM lightest Higgs. Sometimes it may happen that scientists trying to discover one thing fail to do so but they may discover some other new thing by chance. Unfortunately, the Higgs mass bounds in SM is over a large range (114 - 600 GeV). Probably, SUSY is discovered through the LHC experiment in July 2012. Its a great triumph for the experimentalists (CMS and ATLAS in CERN) as well as the theorists who have predicted the Higgs mass in SUSY over this range. It is hoped that more experiments are needed in order to confirm or reject this viewpoint. This study also reveals that there is a confusion regarding the true identity of the particle discovered in LHC experiments in July, 2012. On the basis of a critical analysis we come to the following conclusions

- undoubtedly the experiment should be repeated at least two more times and the result should be checked
- the detail properties of the discovered ( Higgs!) particle should be found out
- once it is firmly established that it is a Higgs particle, the problem remains as to whether it is a SM Higgs, MSSM-Higgs or a new particle
- since supersymmetry is a more complete theory than the standard model and the mass of the lightest Higgs in SUSY is more probable in view of the recent discovery at CERN, there may be a probability that the discovered particle is a Higgs particle of the Supersymmetric Standard Model.

Hence these ideas are useful for successfully connecting the theoretical models and bounds on Higgs mass and constraining the parameters for a true theory compatible with confirmed experimental result. Only those theoretical results matching with experimental data may be given importance, which are based on general principles of symmetry, aesthetics, beauty and scientific methodology of research. The Higgs like particle discovered at CERN in 2012 may be a SM Higgs or a MSSM lightest Higgs. More experiments about the detailed properties of the particle are needed in order to confirm these aspects. All these new experimental results should be reproduced before final conclusion.

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