A la recherche de l’Higgs perdu.

We’ve got the Higgs – what now?

The year 2012 saw the spectacular discovery at the LHC at CERN of a new particle that to our present knowledge is compatible with being a scalar, i.e. spinless, particle known as a boson, with all the properties predicted by the electroweak Standard Model of particle physics in the 1960s. Though the measurements indicate that the new particle is indeed the Standard Model Higgs boson, the data are not yet precise enough to conclusively settle the issue. If it is the Higgs boson, or very much like it, it is also the remnant of the Higgs field, which pervades the whole universe and has the heavy responsibility of imparting mass to all elementary particles. The Higgs boson’s ability to confer mass comes from a very important property of the Higgs field: it couples to all elementary particles with a strength proportional to the mass of the particle. Therefore, it couples only negligibly to electrons, but quite strongly to the heavy electroweak force carriers (gauge bosons), $W^{\pm}$ and Z, and the top quark.

One of the main open questions in particle physics relates to the properties of the potential of the Higgs field: in contrast to the gauge fields, the minimum of the Higgs field is not at zero (Fig. 1). This non-zero vacuum expectation value is responsible for electroweak gauge invariance being intact despite having a spectrum of excitations that does not reflect electroweak symmetry (e.g. the massive electroweak gauge bosons, $W^{\pm}$ and Z). In the theoretical description of the potential of this non-zero Higgs field, quantum fluctuations due to the Heisenberg uncertainty principle cause the potential, as described in the Standard Model, to be unstable. Indeed, given the most recent data from the top and Higgs mass measurements, the outer rim of the potential appears to turn over at very high energies due to such quantum fluctuations, and therefore the potential is unstable. This implies that the vacuum we are presently in is not the true vacuum of the universe and that our universe could decay into its true vacuum, thereby destroying all known structures! This state of affairs is called a metastable vacuum state. Fortunately for us, the lifetime for such a “vacuum decay” is larger than the age of the present universe. However, up to now it is not clear in the theory if the Higgs field could have found the vacuum it is now in, given the potential the Standard Model gives it!

Another important point related to the instability of the Standard Model description of the Higgs potential is variously named the hierarchy, fine tuning, or vacuum stability problem of the Higgs and the electroweak Standard Model. Together with the gravitational evidence for the existence of dark matter, it is one of the strongest motivations for suspecting fascinating physics beyond the Standard Model (BSM). BSM models, most of which introduce new symmetries, new interactions and particles, are called supersymmetric models, little Higgs models, extra dimensions, composite models etc. Generically they predict the existence of many particles between a hundred GeV and several TeV of mass. The details of their properties, such as spins, couplings and mass patterns, depend on the specific setup of the corresponding model. Two examples, the minimal supersymmetric model (MSSM) and a generic little Higgs model, are shown in Fig. 2.

Since the discovery of the Higgs-like particle in 2012 was the sensational event in the field, most theoretical studies concentrated on the interpretation of BSM models in the light of the LHC Higgs measurement. Figure 3 shows an example of a specific little Higgs model (from arXiv:1212.5930), where the yellow and green areas indicate regions of the parameter space of this model that are still allowed by the data at 95% and 99% confidence level, respectively. The blue region leads to a better fit of the little Higgs model to the data than the Standard Model does.

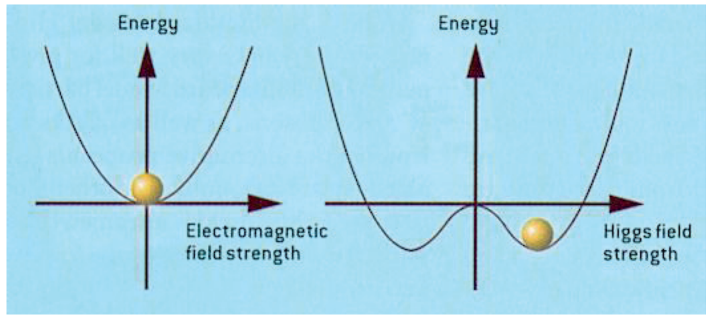

Figure 1

The non-vanishing ground state of the Higgs field

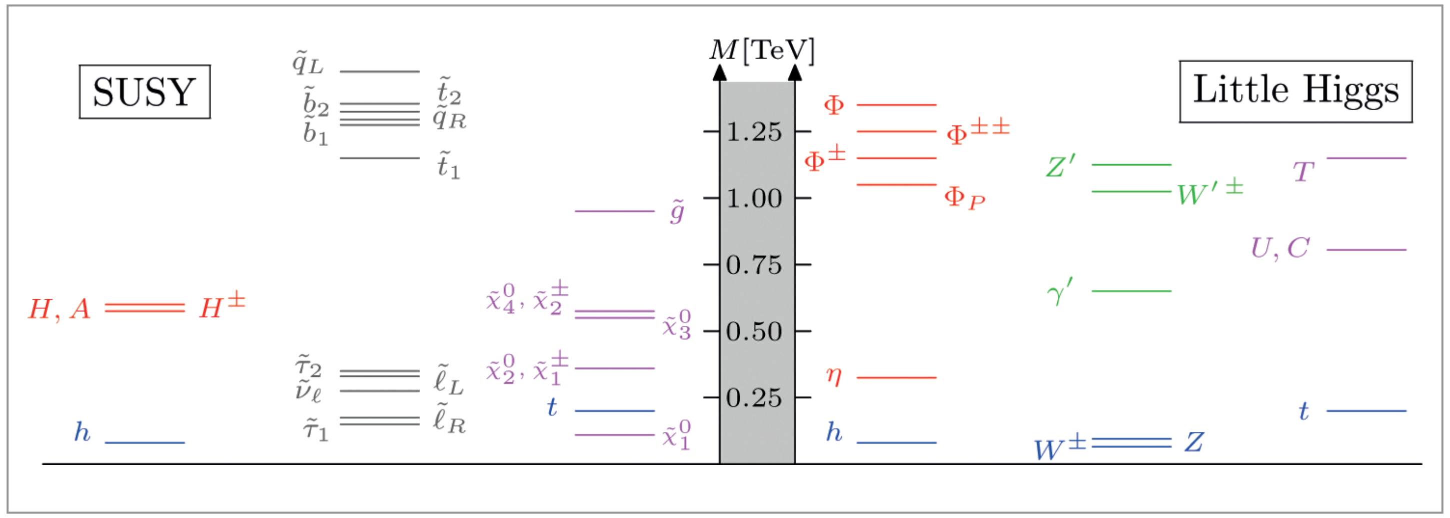

Figure 2

Spectra of additional particles predicted by two BSM models: a supersymmetric model and a little Higgs model

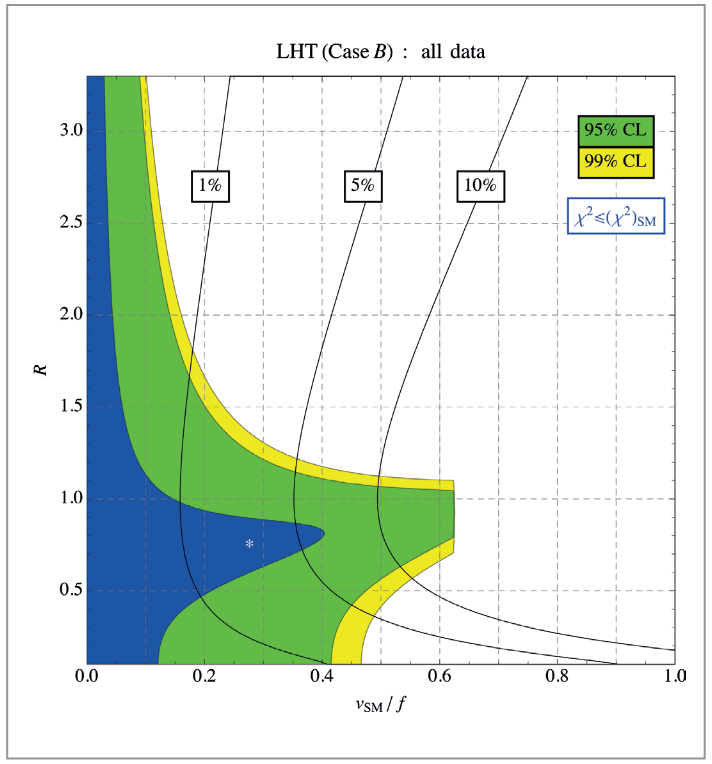

Figure 3

Example of an exclusion region from LHC Higgs data for a parameter space of a BSM model (the littlest Higgs model)

Until now, the LHC Higgs measurements – as spectacular as they are – are not very precise, so most of the constraints on BSM models still come from precision electroweak measurements from earlier collider experiments like LEP, SLC and Tevatron. We therefore eagerly await the analysis of more of the LHC data taken in 2012. Searches for other predicted particles (Fig. 2) have so far failed to yield any evidence for their existence. Unfortunately, in the hadronic environment of the LHC, any BSM particle produced will likely be “coloured” (i.e. carry the colour quantum number, like quarks). Discriminating the signals of coloured particles from Standard Model backgrounds is theoretically and experimentally extremely challenging. For examples, see arXiv:1204.6264, arXiv:1206.2146, and arXiv:1212.5559.

At the end of 2012, depending on the analysis, between one quarter and one half of the data from the LHC 2012 run had been completely analysed. Unless the analysis of the Higgs decay channels in the remaining 2012 data set gives a big boost in precision and hence information, no ground-shaking discovery can be expected in the searches for heavy particles until after the LHC restarts in early in 2015 at full energy, and thereby opens a vast new territory for exploration and the exciting possibility of discovering new particles, new interactions, or new forms of matter.

Contact:
Jürgen Reuter, juergen.reuter@desy.de