Non-perturbative Higgs boson mass bounds

Constraining the Standard Model

Non-perturbative Higgs boson mass bound calculations by the NIC group using lattice field theory methods are discussed. The results help to constrain the validity range of the standard model and, in particular the existence of a heavy fourth fermion generation.

The standard model (SM) of elementary particle interaction is by now very well explored and tested. The only missing link in the SM is the Higgs boson which is in fact a central part of the SM since it is believed to provide masses to a number of elementary particles, see fig. 1. Although the mass of the Higgs boson cannot be predicted by the SM itself, theoretical bounds for the mass of it can be computed. To this end, it is sufficient to look at only a certain part of the standard model, namely the Higgs-Yukawa sector. In the Higgs-Yukawa model, all gauge bosons, i.e. the photon and the vector bosons are neglected as well as the strong interaction. In this way, the Higgs-Yukawa model can be studied with non-perturbative lattice field theory techniques by putting the theory on a 4-dimensional grid of discretized space-time points which lead to non-perturbative results for the Higgs boson mass bounds.

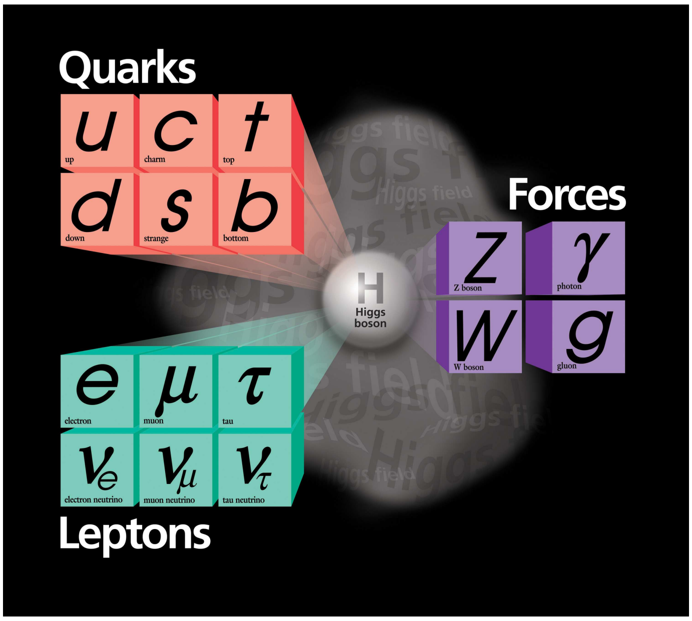

Figure 1: The Higgs boson as the central part of the standard model providing mass to elementary particles.

The Higgs-Yukawa sector of the Standard Model (SM) describes the generation of fermion masses via the non-vanishing vacuum expectation value (*vev*) acquired by the Higgs field. In principle, the involved couplings of the theory, the quartic self-interaction of the Higgs field and the Yukawa-coupling between the Higgs field and the fermions, can grow strong. This happens, when the involved masses are large and then perturbation theory might fail to analyze the theory. There are indeed examples where the applicability of perturbation theory is questionable. The first is the upper Higgs boson mass bound which is based on triviality arguments. Here the Higgs boson mass can become large, resulting in a strong value of the quartic coupling such that perturbation theory may not work anymore. The second is the lower Higgs boson mass bound which is based on vacuum instability arguments. Here, the convexity properties of the effective potential suggest that the instability argument is an artefact of perturbation theory and that non-perturbative calculations are mandatory to determine the lower Higgs boson mass bounds. A third example is provided by the possibility of a heavy fourth generation of quarks which offers the attractive possibility to explain the baryon asymmetry of the universe. However, large fermion masses lead to strong values of the Yukawa coupling and perturbation theory shows large corrections indicating that it may fail to give the correct answer.

Therefore, non-perturbative lattice field theory simulations are mandatory to address the Higgs boson mass bounds. Lattice computations became possible when a lattice modified chiral invariant formulation of Higgs-Yukawa theories on the lattice was found. In figs. 2 and 3 we show the results of the Higgs boson mass bound calculations performed by the NIC group.

The graphs in fig. 2 and fig. 3 have a very interesting interpretation in the light of the SM and also the fourth fermion generation. Concerning the SM, a Higgs boson mass of about 125GeV just seems to escape the Higgs boson mass bounds. This leaves the possibility that the SM is valid up to very high energies. On the other hand a fourth fermion generation seems to be ruled out for fermion masses larger than about 300GeV. Combining this with the LHC observation that additional quarks with masses smaller than about 500GeV are excluded, one finds that a simple extension of the SM with a fourth fermion generation is not compatible with the experimental finding of a 125GeV Higgs boson mass.

An open question is, whether the Higgs boson mass bounds shown in fig. 2 and fig. 3 could change when so-called higher dimensional terms are added to the theory such as a $\lambda_6\Phi^6/\Lambda^2_{\rm cut}$ term. Preliminary analyses by the NIC group indicate that when the coupling λ_6 assumes a value of $\lambda_6 \geq 0.1$, the perturbative corrections start to become large and perturbation theory is not adequate to analyze the situation. Again non-perturbative lattice calculations will be necessary to test the stability of the Higgs boson mass bounds. The NIC group is actively pursuing such computations and it will be very interesting to see, whether the Higgs boson mass bounds can be altered.

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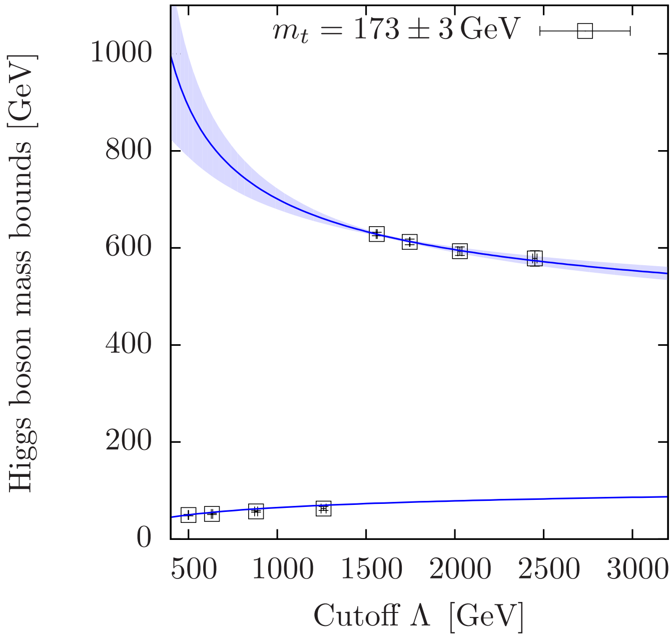

Figure 2: The cut-off dependence of the upper and lower Higgs boson mass bounds for a fermion mass of about ∼ 173GeV.

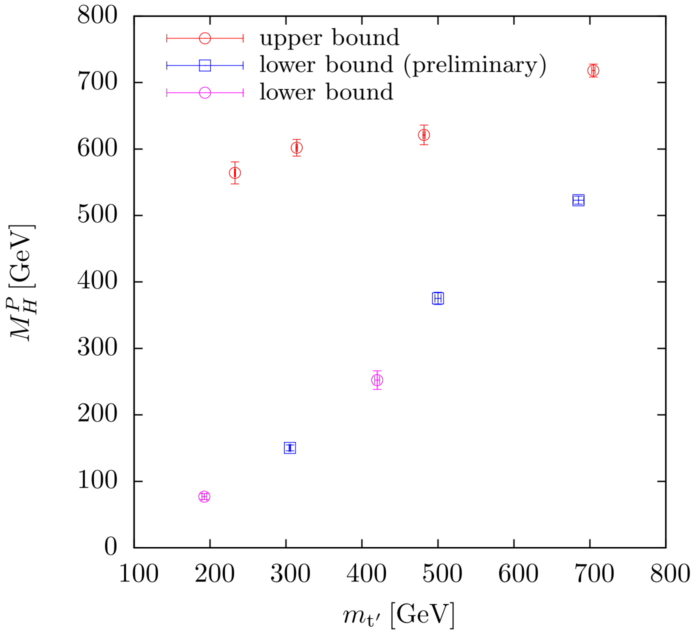

Figure 3: The fermion mass dependence of the lower and upper Higgs boson mass bounds at a cut-off of about 1.5TeV.