The trivial Higgs boson: first evidences from LHC

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Abstract

We further elaborate on the triviality and spontaneous symmetry breaking scenario where the Higgs boson without self-interaction coexists with spontaneous symmetry breaking. The trivial Higgs boson is rather heavy with mass $m_H = 754 \pm 20\,\text{(stat)} \pm 20\,\text{(syst)}\ \text{GeV}$ and total width $\Gamma(H) \simeq 320\ \text{GeV}$. We briefly discuss the experimental signatures of our trivial Higgs and compare with the recent results from ATLAS collaboration. We argue that experimental data seem to support our scenario.
A cornerstone of the Standard Model is the mechanism of spontaneous symmetry breaking that, as is well known, is mediated by the Higgs boson. Then, the discovery of the Higgs boson is the highest priority of the Large Hadron Collider (LHC).

Usually the spontaneous symmetry breaking in the Standard Model is implemented within the perturbation theory \[1–4\] which leads to predict that the Higgs boson mass squared, \(m_H^2\), is proportional to \(\lambda_R v_R^2\), where \(v_R\) is the known weak scale (246 GeV) and \(\lambda_R\) is the renormalized scalar self-coupling. However, it is known since long time that strictly local self-interacting four dimensional scalar field theories are trivial, namely \(\lambda_R \to 0\). Quite recently \[5\] we have enlightened the scenario where the Higgs boson without self-interaction could coexists with spontaneous symmetry breaking. The point is that, due to the peculiar rescaling of the Higgs condensate, the relation between \(m_H\) and the physical \(v_R\) is not the same as in perturbation theory. Indeed, according to this picture one expects that the ratio \(m_H/v_R\) would be a cutoff-independent constant. In other words, one should have \[5\]:

\[
m_H = \xi v_R
\]

where \(\xi\) is a constant.

It is noteworthy to point out that Eq. (1) can be checked by non-perturbative numerical simulations of self-interacting four dimensional scalar field theories on the lattice. Indeed, in previous studies \[5\] we found numerical evidences in support of Eq. (1). Moreover, our numerical results showed that the extrapolation to the continuum limit leads to the quite simple result:

\[
m_H \simeq \pi v_R
\]

pointing to a rather massive Higgs boson without self-interactions (triviality) \[5\]:

\[
m_H = 754 \pm 20 \text{ (stat)} \pm 20 \text{ (syst) GeV}.
\]

One could object that our lattice estimate of the Higgs mass is not relevant for the physical Higgs boson. Indeed, the scalar theory relevant for the Standard Model is the \(O(4)\)-symmetric self-interacting theory. However, the Higgs mechanism eliminates three scalar fields leaving as physical Higgs field the radial excitation whose dynamics is described by the one-component self-interacting scalar field theory. Therefore, we are confident that our determination of the Higgs mass applies also to the Standard Model Higgs boson.
For Higgs mass in the range $700 - 800$ GeV the main production mechanism at LHC is the gluon fusion $gg \rightarrow H$. The gluon coupling to the Higgs boson in the Standard Model is mediated by triangular loops of top and bottom quarks. Since the Yukawa coupling of the Higgs particle to heavy quarks grows with quark mass, thus balancing the decrease of the triangle amplitude, the effective gluon coupling approaches a non-zero value for large loop-quark masses. On the other hand, we already argued [5] that the Higgs condensate rescaling suggests that, if the fermions acquire a finite mass through the Yukawa couplings, then the coupling of the physical Higgs field to the fermions must vanish or be suppressed. Fortunately, for large Higgs masses the vector-boson fusion mechanism becomes competitive to gluon fusion Higgs production. At $\sqrt{s} = 7$ TeV we estimate:

$$
\sigma(W^+ W^- \rightarrow H) \simeq 0.03 - 0.05 \text{ pb , } \ 700 \text{ GeV} < m_H < 800 \text{ GeV} .
$$

(4)

The main difficulty in the experimental identification of a very heavy Standard Model Higgs ($m_H > 650$ GeV) resides in the large width which makes impossible to observe a mass peak. However, in the triviality and spontaneous symmetry breaking scenario the Higgs self-coupling vanishes so that the decay width is mainly given by the decays into pairs of massive gauge bosons. Since the Higgs is trivial there are no loop corrections due to the Higgs self-coupling and we obtain for the Higgs total width:

$$
\Gamma(H) \simeq \Gamma(H \rightarrow W^+ W^-) + \Gamma(H \rightarrow Z^0 Z^0)
$$

(5)

where [6]

$$
\Gamma(H \rightarrow W^+ W^-) \simeq \frac{G_F m_H^3}{8\sqrt{2\pi}} \sqrt{1 - 4x_W} \left( 1 - 4x_W + 12x_W^2 \right) , \ x_W = \frac{m_W^2}{m_H^2}
$$

(6)

$$
\Gamma(H \rightarrow Z^0 Z^0) \simeq \frac{G_F m_H^3}{16\sqrt{2\pi}} \sqrt{1 - 4x_Z} \left( 1 - 4x_Z + 12x_Z^2 \right) , \ x_Z = \frac{m_Z^2}{m_H^2}
$$

(7)

Assuming $m_H \simeq 750$ GeV, $m_W \simeq 80$ GeV and $m_Z \simeq 91$ GeV, we obtain:

$$
\Gamma(H) \simeq 320 \text{ GeV} .
$$

(8)

Recently, the ATLAS collaboration [7] reported the experimental results for the search of the Standard Model Higgs boson at the Large Hadron Collider running at $\sqrt{s} = 7$ TeV, based on a total integrated luminosity of about 40 pb$^{-1}$. In particular, in Fig. 1 we display the distribution of the invariant mass for the Higgs boson candidates corresponding to the
FIG. 1: Distribution of the invariant mass $m_{\ell\nu qq}$ for the process $H \rightarrow WW \rightarrow \ell\nu qq$ corresponding to an integrated luminosity of $35 \text{ pb}^{-1}$. The data has been extracted from Fig. 4, panel b) of Ref. [7]. The continuous line is a falling exponential function which models the background invariant mass spectrum. The squares are the Higgs event distribution according to Eq. (9) with $N_H = 50$ binned in energy intervals of 20 GeV.

The process $H \rightarrow WW \rightarrow \ell\nu qq$. According to Ref. [7], the events were selected requiring exactly one lepton with $p_T > 30$ GeV. The missing transverse energy in the event were required to be $E_T^{\text{miss}} > 30$ GeV. The invariant mass continuum background is parametrized as a falling exponential function. To compare the invariant mass spectrum of our trivial Higgs with the experimental data, we observe that the energy distribution of the Higgs events is parametrized by the lorentzian distribution:

$$\frac{d n}{dE} = N_H \frac{1.15}{\pi} \frac{\Gamma(H)}{(E - m_H)^2 + \Gamma(H)^2} ; \quad \Gamma(H) \simeq 320 \text{ GeV} ,$$

(9)

where $N_H$ is the number of Higgs events. In Fig. 1 we compare the lorentzian distribution of the invariant mass binned in energy intervals of 20 GeV assuming $m_H \simeq 750$ GeV and $N_H = 50$, which would correspond to an integrated luminosity of a few fb$^{-1}$. For
The continuum background is strongly suppressed, while the trivial Higgs event distribution is almost flat up to 1000 GeV. It is remarkable that the experimental data do show an excess of three events in this region. This compare quite well with our estimate of $\sigma(W^+ W^- \to H)$, Eq. (4). In fact, tacking into account the uncertainties on the gluon-fusion production mechanism and the decay branching ratio, we estimate about 1 - 2 Higgs events for an integrated luminosity of 35 pb$^{-1}$. Even though the very low statistics do not allow to draw definitive conclusions, we expect that by increasing the statistics the region $m_{\ell\nu qq} > 700$ GeV will be almost uniformly populated by Higgs events.

To conclude, we proposed that strictly local scalar fields are compatible with spontaneous symmetry breaking. In this case, the Standard Model Higgs boson turns out to be rather heavy. We compared our proposal with the recent results from ATLAS collaboration and argued that experimental data seem to support our scenario. Moreover, we pointed out that our trivial Higgs boson scenario can be confirmed or rejected by simply increasing the statistics. Since both the ATLAS and CMS collaborations have already collected an integrated luminosity of about 1 fb$^{-1}$, we expect that in the near future the experimental data will corroborate our proposal.

Finally, we would like to comment on the fact that our previous paper was sent to a scientific journal for publication and was rejected by an anonymous referee with the following motivation:

*Therefore we can conclude that the analysis presented in the paper is simply not solid enough to corroborate the great claims about the Higgs mass in the SM.*

We decided to leave to LHC the reply to the anonymous referee. Indeed, we feel that the time is coming to undertake a profound revision of the peer review process.

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