On the structure of the new particle at 126 GeV
(Higgs- or not Higgs-boson?)

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Abstract

A new particle - discovered recently with the Atlas and CMS detectors at LHC - has been interpreted as the long sought Higgs-boson. A corresponding scalar field is needed to make the weak interaction gauge invariant and to understand the quark masses in the Standard Model.

However, the Standard Model is an effective theory with quark masses, which can be understood only in a fundamental theory. Such a theory has been constructed, based on a generalised second order extension of QED, in which the quarks can be understood as effective fermions with masses given by binding energies in a boson-exchange potential. In the present approach the Higgs-mechanism is not needed.

In this framework a good understanding of particles in the “top” regime is obtained. Two $J^P = 1^- q\bar{q}$ states are predicted, identified with $Z(91.2$ GeV) and the $t\bar{t}$ state at about 350 GeV. Further, two $0^+ q\bar{q}$ states are obtained, one with a mass consistent with that of the new particle, the other with a mass of about 41 GeV. A detection of the second scalar state will serve as a crucial test of the present model.

PACS/keywords: 11.15.-q, 12.40.-y, 14.40.-n/ Relativistic bound state description of $q\bar{q}$ states in the top-mass region. Scalar $0^+ q\bar{q}$ state identified with new particle found with a mass of 126 GeV. Higgs-field not needed.

In the study of fundamental forces hadronic and weak interactions give access to the smallest systems of nature with the existence of different flavour systems [1]. The observation of states in the top-mass region (with a mass significantly larger than the bottomonium-system) is of particular interest, since in addition to $t\bar{t}$ states this is the mass region of the heavy bosons of the weak interaction, but also of the Higgs-boson and supersymmetric particles, predicted in extensions of the Standard Model of particle physics [1] (SM).

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Therefore, experimentally large efforts have been made to study this mass region in detail. Recently, a new particle has been discovered at LHC, which has been interpreted with large confidence as the Higgs-boson. Evidence for supersymmetric particles has not been found.

The present experimental situation requires a critical view of the SM, a sum of first order gauge field theories for the description of the electromagnetic, weak and strong interaction. Although this model describes many particle properties, it is an effective theory with parameters and assumptions, which have to be understood in a more fundamental theory. Among the parameters of the SM is the electric coupling constant $\alpha \sim 1/137$, the number of flavour families and the masses of quarks and leptons. Big problems of this model are further the understanding of massive neutrinos and the relation to gravitation, which should be based also on particle properties. In a fundamental theory all these features should be understood. Therefore, extensions of the SM to explain only mass or flavour (as by the Higgs-mechanism and supersymmetry) have to be viewed critically, if they are not part of a fundamental theory.

From the general observation that nature is finite a fundamental theory may be finite and contain higher order terms. However, there is the general belief that the only possible theories to describe fundamental forces are first order gauge field theories. Divergent higher order theories are not renormalisable, whereas other higher order theories have been found to lead to non-physical results. But the latter theories cannot be a principal problem, if a physical Lagrangian can be found, which respects all basic features of a relativistic theory, as gauge invariance and energy-momentum relation.

Recently, a finite theory based on a second order extension of the QED Lagrangian by boson-boson coupling has been developed, in which a rather fundamental description of the electric force in light atomic systems is achieved. In this formalism all parameters needed are constrained by self-consistency conditions, so that a description without free parameters is obtained. Even the magnitude of the coupling constant $\alpha_{QED}$ is deduced (which is not understood in QED). Importantly, within this formalism not only the electric interaction between hadrons and leptons can be described, but also the structure of the individual particles, requiring the assumption of massless elementary fermions (quantons). In this framework confinement, creation of bound states as well as the existence of different flavour systems in hadrons is understood. No other theory is needed to understand
the masses and the flavour degree of freedom. In this approach the quarks in the SM can be understood as effective fermions with masses given by eigenvalues in a boson-exchange potential. Likewise, the heavy gauge bosons may be considered also as effective bosons, which cannot be detected experimentally.

The used Lagrangian is of the form

\[
\mathcal{L} = \frac{1}{\tilde{m}^2} \bar{\Psi} i\gamma_\mu D^\mu D^\nu \Psi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu},
\]

where \( \tilde{m} \) is the reduced mass and \( \Psi \) a two-component massless fermion (quantum, q) field \( \Psi = (\Psi^+ \Psi^-) \) and \( \bar{\Psi} = (\Psi^- \bar{\Psi}^+) \) with charged and neutral part. Vector boson fields \( A_\mu \) are contained in the covariant derivatives \( D_\mu = \partial_\mu - igA_\mu \) and the Abelian field strength tensor \( F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu \). Generalised couplings to the charge (\( g = g_c \)) and spin (\( g = g_s \)) of quantons have to be considered. A detailed discussion of the formalism is given in ref. [4, 5].

Contributions to stationary solutions can be studied by evaluating fermion matrix elements

\[
M_{ng} = \bar{\psi}(p') V_{ng}(q) \psi(p)
\]

with two potentials \( V_{2g}(q) \) and \( V_{3g}(q) \), which are due to coupling of two (\( 2g \)) and three boson (\( 3g \)) fields in the Lagrangian. The potential \( V_{2g}(q) \) has been identified with the confinement potential in hadrons, whereas \( V_{3g}(q) \) can be considered as second order boson-exchange potential. In r-space these potentials are given in the form

\[
V_{2g}(r) = \frac{\alpha^2 \tilde{m}}{4} \frac{r_w^2}{w_s(r)} \frac{d^2 w_s(r)}{dr^2} \left( \frac{2}{r} \frac{dw_s(r)}{dr} \right) \frac{1}{w_s(r)}
\]

and

\[
V_{3g}^{s,v}(r) = -\frac{\alpha^3 \hbar}{\tilde{m}} \int dr' w_s^{2,v}(r') v_s(r - r')
\]

These potentials involve bosonic (quasi) wave functions \( w_s(r) \) and \( w_v(r) \) of scalar and vector character, respectively, whereas \( v_s(r) \) can be regarded as boson-exchange interaction \( v_s(r) = -\hbar w_v(r) \). \( F_{2g} \) is a Fourier transformation factor due to the transformation of the boson kinetic energy to the potential \( V_{2g}(r) \). Both potentials [2] and [3] give rise to binding of fermions, but the potential [3] can be regarded also as bosonic matrix element, with a binding of bosons by the interaction \( v_v(r) \). This yields a boson binding energy \( E_b \).

The bosonic wave functions \( w_s(r) \) and \( w_v(r) \) give rise to two states with quantum numbers \( J^\pi = 1^- \) and fermion wave functions \( \tilde{\psi}_{s,v}(r) \sim w_{s,v}(r) \), which are normalised to 1. The

\[\text{leading to boson (quasi) densities } \hat{w}_{s,v}^2(q) \text{ with dimension } [\text{GeV}]^2.\]
wave function \( w_s(r) \) is used of the form

\[
w_s(r) = w_{s_0} \exp\{- (r/b)^{\kappa}\} ,
\]

where \( w_v(r) \) is written by

\[
w_v(\vec{r}) = w_{v_0} (w_s(r) + \beta R \frac{dw_s(r)}{dr}) .
\]

The factors \( w_{(s,v)_0} \) are obtained from the normalisation \( 2\pi \int rdr \ w_{s,v}^2(r) = 1 \). Further, \( \beta R = -(\int r^2 dr \ w_s(r))/ (\int r^2 dr \ |dw_s(r)/dr|) \) ensures orthogonality of the fermion wave functions and cancellation of spurious motion \( <r_{w_s, w_v}> = 0 \) for bosons.

In addition there are two p-states (with \( J^\pi = 0^+ \)) with similar wave functions. Here, angular momentum-spin fractions \( (<\frac{1}{2} |L = 1 \ S_{gg} | 0^+ > / <\frac{1}{2} |L = 0, 2 \ S_{gg} | 1^- >)^2 \) have to be taken into account, where \( S_{gg} \) is the spin coupling of the two bosons in \( w_s(r) \) and \( w_v(r) \). This yields spin reduction factors for the binding energies of \( 0^+ \) states, estimated to be \((2/3)^2\) and \((3/5)^2\) for \( w_s(r) \) and \( w_v(r) \), respectively.

For a self-consistent determination of the parameters \( \kappa, b \) and \( \alpha \) geometrical boundary conditions and energy-momentum relations are needed. Geometric boundary conditions arise from the requirement that for the most strongly bound \( 1^- \) state of the system the interaction should take place inside the bound state volume. This leads to a similar form of the fermionic and bosonic wave functions \( \psi_{s,v}(r) \sim w_{s,v}(r) \) and

\[
c \ w_{s}^2(r) \sim |V_{3g}^v(r)| .
\]

The mass of the system is defined by

\[
M_{n_{s,v}} = -E_{f_{s,v}}^{3g} + E_{f_{n}}^{2g} ,
\]

where \( E_{f_{s,v}}^{3g} \) are negative binding energies in \( V_{3g}^{s,v}(r) \) and \( E_{f_{n}}^{2g} \) positive binding energies in \( V_{2g}(r) \) (for \( n = 1 \) the index \( n \) is dropped). For the binding in \( V_{3g}^{s}(r) \) the total energy of the system is not increased, the negative fermion and boson binding energies \( E_f^s \) and \( E_g \) have to be compensated by the root mean square momenta of the corresponding potentials, giving rise to an energy-momentum relation

\[
<q_{V_{3g}}^2>^{1/2} + <q_{V_{v}}^2>^{1/2} = -(E_f^s + E_g) .
\]
A last constraint arises from the confinement potential \( \text{(2)} \), see ref. [5], which gives
\[
\text{Rat} = \frac{\hbar^2}{\bar{m}^2 \langle r_{ws}^2 \rangle} = 1. \tag{9}
\]

Altogether there are four constraints, orthogonality, relations [6], [8] and [9], by which the parameters \( \kappa, b \) and \( \alpha \) are unambiguously determined. The fact that there are no other parameters in the entire formalism indicates clearly that a fundamental theory is constructed. Nevertheless, there are small ambiguities arising from the used forms of the wave functions in eqs. [4] and [5], which gives rise to estimated uncertainties up to about 10 percent.

Different flavour\(^3\) systems are characterized in the present approach by a different slope parameter \( b \) only. Therefore, all flavour systems should have a rather similar structure with two \( 1^- \) states, a very narrow low mass state and a wider state at much larger mass, which is expected to decay rapidly to two mesons, baryons or leptons. Also for the top system this is expected. Therefore, the observed \( t\bar{t} \) peak at about 350 GeV, which decays to two mesons or two "single-top" states [6], has to be identified with the high mass \( 1^- \) state. The low mass \( 1^- \) state should have a mass about a factor 4 smaller, where the only state is \( Z(91.2 \text{ GeV}) \).

Here it should be recalled that \( Z(91.2 \text{ GeV}) \) has been interpreted in the past as gauge boson of the neutral weak interaction. However, as discussed above, particles (gauge bosons and quarks) needed in the effective theories of the SM should be considered as effective particles, which may not be identified with real physical states. This allows to interpret \( Z(91.2 \text{ GeV}) \) as \( q\bar{q} \) state. This is not inconsistent with the measured decays of this state into hadrons and leptons, if the calculated width is in agreement with the sum of experimental decay widths (smaller than the total width of 2.5 GeV).

By applying the above formalism to \( q\bar{q} \) states in the top-mass region, a boson-density with a mean radius square of about \( 10^{-5} \text{ fm}^2 \) is required from a vacuum potential sum rule [4, 7]. This yields a fundamental \( 1^- \) state with a mass in the order of 80-100 GeV. By adjusting the parameters \( b, \kappa \) and \( \alpha \) by the constraints discussed above, the potentials \( V_{3g}(r) \) and \( V_{2g}(r) \) are well determined. Results on the radial dependence of densities and

\(^3\)the term flavour is kept from the quark model
Table 1: Results for the top-system in comparison with the data \[1, 2\]. Masses are given in GeV, $b$ in fm, and mean radius squares in fm$^2$.

| System states | $M_s$ | $M_v$ | $M_{exp}^{low}$ | $M_{exp}^{high}$ |
|---------------|------|------|-----------------|-----------------|
| vector (1$^-$) $Z, t\bar{t}$ | 91.2 | 350 | 91.2$\pm$0.1 | 350$\pm$10 |
| scalar (0$^+$) new | 41 | 126 | 126$\pm$0.8 |
| $\kappa$ $b$ $\alpha$ | 1.4 | 4.69$\times$10$^{-3}$ | 2.61 | 1.63$\times$10$^{-5}$ |

potentials are given in fig. 1. In the upper part the interaction $v_v(r)$ is given by the solid line. Compared to a Coulomb like potential there are no divergencies for $r \to 0$ and $\infty$, consistent with the requirement of a finite theory.

In the middle part a comparison of the density $w_3^2(r)$ (dot-dashed line) with the potentials $V_3^v(r)$ (dashed line) and $V_3^c(r)$ (solid line) is made. We see that condition (6) for the vector potential is rather well fulfilled. The deduced parameters and radii are given in table 1. As expected, the low mass 1$^-$ state can be identified with $Z(91.2$ GeV), whereas the mass of the second 1$^-$ state was found to be about 330 GeV, which is at least 20 GeV smaller than the $t\bar{t}$ state observed experimentally [1]. This default can be cured easily by a small modification of the boson wave function $w_v(r)$. Replacing in eq. (5) the derivative $dw_s(r)/dr$ by a form $dw_s(r)/dr + c d^2w_s(r)/dr^2$ with a tiny amplitude $c$ of 6$10^{-4}$ fm$^2$, a value of $M_v$ of about 350 GeV is obtained consistent with the experimental $t\bar{t}$ peak. The root mean square momenta are found to be $<q^2_{V_3^g}>^{1/2}=109$ GeV and $<q^2_{V_3^c}>=231$ GeV, yielding a sum of 340 GeV. Further, $E_g$ was found to be $-249$ GeV leading to $E_{f}^g + E_g= -340$ GeV. This shows that the energy-momentum relation (8) is fulfilled.

In fig. 2 the potential $V_{2g}(r)$ is given, which has the typical form of the ‘confinement’ potential $V_{con.f} = -\alpha/r + l \cdot r$ deduced from potential models. However, in the present case this potential is very weak and gives only a small contribution to the mass in the order of 0.02-0.04 GeV. For lighter flavour systems (in particular for charmonium and bottomonium) excited states in the confinement potential have been found. Here, their masses are only 0.25, 0.45 and 0.63 GeV above the low mass 1$^-$ state. Therefore, within
the experimental width of 2.5 GeV these states cannot be observed.

In the lower part of fig. 2 the Fourier transform of the confinement potential $T_{2g}(q)$ is shown, which is directly related to the mass distribution and width of the low mass $1^-$ state in question. The numerical Fourier expansion of this potential depends strongly on the interpolation limits and detailed radial grid, and can be well approximated by a Gaussian. This peak becomes extremely narrow, if a high resolution in $r$ and $q$ together with integration to large radii is used. With logarithmic interpolation and integration up to 0.25 fm a width of less than 1.5 GeV is obtained, as shown in fig. 2, which is already smaller than the observed width of $Z(91.2\text{ GeV})$ of 2.5 GeV. For integration up to even larger radii a still narrower peak is observed, indicating that the real width is extremely small.

Mass distributions due to the potential $V_{3g}(r)$ are given by the Fourier transform of the kinetic energy distributions $T_{3g}(r) = \frac{1}{2} < r^2 > (d^2V_{3g}(r)/dr^2 + \frac{2}{r} dV_{3g}(r)/dr)$. These give rise to very broad distributions, which are shown by dot-dashed lines for the low mass $1^-$ state in the upper part and for the high mass state in the lower part of fig. 3. This shows clearly that the confinement potential alone is responsible for the observation of narrow $q\bar{q}$ states, but these small peaks are found on top of a large 'background' contribution from the potential $V_{3g}(r)$. This makes a detection of these states very difficult, as also found experimentally.

Concerning $0^+$ states, using the spin reduction factors given above one state is predicted with a mass of about 41 GeV, the other with a mass of 126 GeV, which is in agreement with the mass of the new particle.

The correctness of these results can be checked directly by realising that the present formalism can be considered also as a fundamental theory of the electric interaction in light atoms [4]. This has the consequence that many features and characteristics of bound states should be relatively similar in hydrogen and the top-system. So, the two $1^-$ states, $Z(91.2\text{ GeV})$ and $t\bar{t}(350\text{ GeV})$ may be related to the 1s and 2s levels in H, with a mass ratio $M_{Z(91.2\text{ GeV})}/M_{t\bar{t}(350\text{ GeV})}$ quite similar to the ratio of binding energies $E_f(2s)/E_f(1s)$ in hydrogen. The new $0^+$ states in the top-system should then be compared to the 2p and 3p states in H. In particular, the mass ratios between $0^+$ and $1^-$ states $M_{s,v}(0^+)/M_{s,v}(1^-)$ should be the same as the ratio of binding energies between corresponding p and s states,
since these quantities depend only on angular momentum-spin coupling coefficients, see above. However, this should be valid only for the binding energies in $V_{3g}(r)$. The relative strength of $V_{2g}(r)$ is drastically different in both cases, with very small binding energies $E_f^{2g}$ in the top system but about 10-40% of $E_f^{3g}$ for hydrogen. Since the relative strength of $V_{2g}(r)$ to $V_{3g}(r)$ is affected by the Fourier transformation factor $F_{2g}$, larger uncertainties are expected in $E_f^{3g}$ for hydrogen, whereas such errors are negligible for the top-system.

Inspecting the ratio of binding energies for $0^+$ and $1^-$ states in the analysis in ref. [4], between the 2p and 1s levels in H a ratio $E_f^{3g}(2p)/E_f^{3g}(1s)$ of 0.31 is found. By lowering $E_f^{3g}(1s)$ to -14.6 eV and increasing $E_f^{3g}(2p)$ to about -5 eV (which is within the estimated errors) this ratio becomes 0.34. This is in reasonable agreement with the spin reduction factor of 0.36 estimated for $M_{0^+}^{126 \text{ GeV}}/M_{t\bar{t}}(350 \text{ GeV})$. For the 3p and 2s levels in H a ratio $E_f^{3g}(3p)/E_f^{3g}(2s)$ of 0.44 is found, which is the same as estimated for the ratio $M_{0^+}(41 \text{ GeV})/M_Z(91.2 \text{ GeV})$. This shows indeed a consistent picture of the two very different systems and confirms the $0^+ q\bar{q}$ assignment of the new resonance at 126 GeV. However, to demonstrate the full applicability of the present formalism it will be important to find the second scalar state at about 41 GeV.

In summary, a fundamental (parameter free) description of the hadronic interaction has been applied to the mass region of top-states. Two $1^- q\bar{q}$ states have been predicted, which are in good agreement with states observed experimentally. $Z(91.2 \text{ GeV})$ has to be interpreted as the low mass $1^- q\bar{q}$ top-state and not as a gauge boson. Its calculated width is very small and consistent with the experimental widths. The high mass state is identified with the $t\bar{t}$ peak at about 350 GeV, which decays dominantly into two mesons or baryons. Further, two $0^+ q\bar{q}$ states are found, one with a mass in agreement with the recently discovered scalar state at 126 GeV. This indicates that this state can be interpreted as scalar $q\bar{q}$ state and does not require an exotic interpretation as Higgs-boson. A second scalar state is predicted with a lower mass of about 41 GeV, which should be searched for in high energy experiments. Its detection can be considered as a crucial test of the present model.

As a general conclusion, quarks and massive gauge bosons required in effective SM theories should be considered as effective particles, which cannot be observed experimentally. Furthermore, particles needed in extensions of the SM, as the Higgs-particle, should be
viewed also as effective particles. Thus, apart from photons real particles may exist only in the form of hadrons and leptons or in the form of more complex systems.

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Figure 1: Self-consistent solution for vector $q\bar{q}$ states in the top-mass region. Upper part: Interaction $w_v(r)$ given by solid line in comparison with a Coulomb like potential (dot-dashed line). Lower part: Bosonic density $w_s^2(r)$ given by dot-dashed line, potential $|V_{3g}^v(r)|$ (solid line) and $|V_{3g}^s(r)|$ shown by dashed line.
Figure 2: Confinement potential $V_{2g}(r)$ (upper part) and Fourier transform (lower part) given by dot-dashed line. The solid line corresponds to a Gaussian form with a full width at half maximum of $\sim 1.5$ GeV. Using increasingly larger radial limits in the Fourier expansion, the width of the peak reduces further.
Figure 3: Mass distributions for vector and scalar states. The pronounced peaks given by solid lines are due to the Fourier transforms of $V_{2g}(r)$ (with their widths arbitrarily enlarged), whereas the momentum distributions due to $V_{3g}(r)$ give rise to the wide dotted-dashed distributions (shown only for $1^-$ states). The $0^+$ state with a mass of 120-130 GeV can be identified with the new scalar state found in Atlas and CMS data [2].