Does the Standard Model of Particle Physics Suffer from a Mass Problem?

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Abstract

In the Standard Model of particle physics massive fermions (quarks and leptons) and bosons ($W^{\pm}$, Z, H^{o}) are needed. However, the logic of nature requires that the universe emerged out of the vacuum and therefore all elementary particles should be massless. To test whether this requirement is consistent with the mass structure of the Standard Model, corresponding mesonic states as well as the systems $Z(91.2\ GeV)$, $W^{\pm}(80.4\ GeV)$ and $0^{+}(126\ GeV)$ have been investigated in a unified theory of all forces including gravity, in which all needed parameters are constrained by basic boundary conditions.

The results show that indeed for these states all basic boundary conditions are fulfilled. Thus, the quarks and massive bosons of the Standard Model should be interpreted as effective particles composed of massless elementary fermions and bosons, in full agreement with the structure of the universe.

Keywords: recommendation systems, numerical methods, algorithms.

Introduction

The understanding of the origin and evolution of the universe is one of the big challenges of fundamental physics. Since all fundamental forces contribute to this development, a good understanding of their structure is essential. From the logic of nature we have to assume that the universe emerged out of the vacuum, which requires that all elementary particles, fermions and bosons are massless. However, this could be inconsistent with the Standard Model of particle physics (SM), see ref. [1], in which massive fermions (quarks and leptons) and bosons (vector gauge bosons $W^{\pm}$, Z and a scalar Higgs-boson H^{o}) are required. Indeed, a dramatic inconsistency in estimates of the energy-density between first-order gauge theories and the universe - up to 40–120 orders of magnitude! - has been found e.g. in refs. [2].

The SM is based on phenomenological first-order Lagrangians, with a different structure for electromagnetic, weak and strong forces - gravitation is not included. This model needs in the order of 20-30 parameters, which have been determined by experimental data. But in this way a large body of particle data is described with high precision, in particular in the electroweak sector, where perturbative methods can be applied.

To study this apparent mass problem, an analysis of relevant structures has been made in a completely different and unified description of systems bound by all fundamental forces [3, 4, 5]. This formalism is based on first principles: all parameters of the theory have to be determined by basic boundary conditions related to geometry, energy and momentum conservation; external parameters, which could be adjusted to experimental data, are not allowed. This approach yields absolute predictions for hadrons and atoms [3], leptons [4], but also for gravitational systems [5, 6, 7] with satisfactory results.

In the present paper we discuss the application of this formalism to simple vector-mesons $\omega(782)$, $\phi(1008)$, $J/\psi(3098)$, and $\Upsilon(9460)$, which require the assumption of heavy fermions (quarks) in the SM; further, to the states $W^{\pm}(80.4\ GeV)$, $Z(91.2\ GeV)$ and $0^{+}(126\ GeV)$, which have been attributed to SM gauge vector-bosons $W^{\pm}$, Z and a scalar Higgs-boson H^{o}.

In particular, the Higgs-boson has been interpreted as a very special particle, which could be responsible for the generation of mass of quarks and leptons. Further, in quantum field theory it has been related to the hierarchy problem and the structure of the high energy regime. So, it is interesting, whether in a fundamental formalism the mass of this particle is correctly described.

2. Unified description of bound states of all fundamental forces

For the justification of the use of first-order Lagrangians a basic argument of field theory has been used, which states that non-divergent solutions can be obtained only in first-order theories. Therefore, the SM is based on first-order Lagrangians. But this argument is not generally valid: there is a higher-order Lagrangian, which gives rise to solutions which have no adjustable parameters and can therefore be considered as unified description of bound states of all fundamental forces [3, 4, 5].

The underlying Lagrangian has a structure quite similar to that of quantum electrodynamics (QED), but with additional boson-boson coupling

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

where $\tilde{m}$ is a mass parameter and Ψ in general a two-component fermion field $\Psi = (\Psi^+\ \Psi^o)$ and $\bar{\Psi} = (\Psi^-\ \bar{\Psi}^o)$ with charged and neutral part. Vector boson fields A_μ with charge coupling g are contained in the covariant derivatives $D_\mu = \partial_\mu - igA_\mu$ and the Abelian field strength tensor $F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$.

This third-order Lagrangian is not renormalizable and has therefore no relativistic solution. However, by going to three dimensions (3-momentum or separating space and time degree of freedom) bound state solutions can be constructed [3, 4] for all fundamental forces with a structure consistent with the finite mean square radii of hadrons, atoms and gravitational systems [5].

By introducing $D_\mu = \partial_\mu - igA_\mu$ in the above Lagrangian, the first term leads to eight terms, which include fermion and boson operators and their derivatives. Then, matrix elements of different structure - static, dynamic and accelerating - can be derived [5]. The crucial property of this Lagrangian is an explicit boson-boson coupling, which gives rise to a bound state structure of fermions **and** bosons. This allows to define geometric boundary conditions, momentum matching and energy-momentum conservation between fermions and bosons, by which all parameters of the model are constrained.

The static structure of bound states is given in r-space by two matrix elements in the form

$$M_{ng} = \psi(r)\ V_{ng}(r)\ \psi(r)\ , \tag{2}$$

with fermion wave functions $\psi(r)$ and two potentials $V_{2g}(r)$ and $V_{3g}(r)$ given by

$$V_{2g}(r) = \frac{\alpha^2(2s+1)(\hbar c)^2}{8\tilde{m}} \Big(\frac{d^2 w_s(r)}{dr^2} + \frac{2}{r}\frac{dw_s(r)}{dr}\Big)\frac{1}{w_s(r)} + E_o\ , \tag{3}$$

and

$$V_{3g}(r) = \frac{\alpha^2(\hbar c)}{\tilde{m}} \int dr'\ w_{s,v}(r')\ v_v(r-r')\ w_{s,v}(r')\ , \tag{4}$$

where s=0 stands for scalar and s=1 for vector states, boson wave functions $w_{s,v}(r)$ (for scalar and vector coupling) and an interaction $v_v(r) \sim -\alpha(\hbar c)\ w_v(r)$. The mass parameter $\tilde{m}$ for states bound by massless fermions is given by $\tilde{m} = M_s/2$, where M_s is the mass of the scalar state (negative of its binding energy). The potential $V_{3g}(r)$ is of boson-exchange form, whereas the potential $V_{2g}(r)$ has a dynamical structure.

There are geometric boundary conditions between fermions and bosons $\psi_{s,v}(r) \sim w_{s,v}(r)$ and $|V^v_{3g}(r)| \sim c\ w^2_s(r)$, which can be satisfied by boson wave functions of the form [3, 4]

$$w_s(r) = w_{s_o}\ exp\{-(r/b)^\kappa\} \tag{5}$$

and

$$w_v(r) = w_{v_o}\ [w_s(r) + \beta R\ \frac{dw_s(r)}{dr}]\ , \tag{6}$$

with the normalization factors obtained from the condition

$2\pi \int rdr\ w^2_{s,v}(r) = 1$ and $\beta R = -\int r^2 dr\ w_s(r) / \int r^2 dr\ [dw_s(r)/dr]$.

The double structure of bosons (g) and fermions (f) requires momentum matching

$$< q_g^2 >^{1/2} + < q_f^2 >^{1/2} = 0 \quad (7)$$

as well as energy-momentum conservation

$$< q_g^2 >^{1/2} + < q_f^2 >^{1/2} = -(E_g + E_f) \quad (8)$$

for both, scalar and vector state, with the definition of the boson and fermion mean square momenta $< q_{g,f}^2 >^{1/2}$ and binding energies $E_{g,f}$ given in ref. [6]. For magnetically bound states an additional factor (v/c) is required in eq. (8).

Since the entire formalism has only three (four) parameters, shape and slope parameters κ and b and a coupling constant α (for magnetic systems in addition a velocity factor (v/c)), they are well determined by the constraints (7) and (8) for scalar and vector states. Moreover, κ and α turned out to be the same for all systems studied. Therefore, for electrically bound states only the slope parameter b can be determined, which is highly overconstrained and allows to test the self-consistency of the entire formalism.

The fact that α is the same for very different systems indicates a binding by electromagnetic forces only. This is further supported by a mass-radius constraint, deduced from different formulations of the confinement potential $V_{2g}(r)$, which is given for electric binding by

$$Rat_{2g} = \frac{(\hbar c)^2}{\tilde{m}\ (M_s/2) < r^2 >} = 1\ , \quad (9)$$

where $< r^2 >$ is the mean square radius of the scalar state. This allows to describe e.g. hadrons and atoms consistently, see ref. [3]: hadrons have large masses and small radii, whereas atoms have small masses but large radii. This underlines the importance of a formalism, in which both binding energies/masses **and** radii can be deduced (this is not possible in first-order theories as those in the SM, in which the radial degree of freedom cannot be accessed explicitly due to the divergent structure of these theories).

The above formalism leads to radial forms of the scalar boson density $w_s^2(r)$ and the potentials $V_{2g}(r)$ and $V_{3g}(r)$ as shown in fig. 1 for the $\omega(782)$ meson. In the upper part one can see that the shape of $w_s^2(r)$, given by dot-dashed line, is very similar to that of the vector potential $V_{3g}^v(r)$, solid line, as required from the above geometrical constraint. The potential $V_{2g}(r)$, shown in the lower part, has a very different shape, characteristic of the empirical "confinement" potential required in hadron potential models [8]; a quite similar shape (given by closed and open points) has been found also in lattice simulations of quantum chromodynamics [9]. Importantly, to fulfill energy-momentum conservation the constant E_o has to be 0, which indicates a dynamical coupling of the theory to the vacuum [3]. In this way particles can be created out of the vacuum of fluctuating bosons during overlap of bosons [3].

From this brief discussion one may formulate the principle requirements of a unified theory of all fundamental forces, which are fulfilled in the present formalism:
1. Fully consistent description of hadrons, leptons, atoms as well as gravitational systems, in which all parameters of the theory are determined by severe boundary conditions.
2. For all existing systems (in form of particles or complex bound states) the conservation laws of physics have to be fulfilled explicitly, as conservation of charge, total spin, momentum and energy.
3. The electromagnetic coupling α_{QED} (see ref. [11]) and Newton's gravitational constant G_N (see ref. [5]) have to be explained and not taken as parameters.
4. Coupling of the theory to the vacuum. Consequently, all elementary fermions and bosons have to be massless.

3. Concrete tests of relevant structures

The above formalism has been applied to systems, for which massive elementary fermions or bosons are required in the SM.

3.1 Structure of simple meson states

The mesons $\omega(782)$, $\phi(1008)$, $J/\psi(3098)$, and $\Upsilon(9460)$ are interpreted in the SM as simple quark-antiquark states with massive quarks of different flavours, u/d, s, c and b, see e.g. ref. [8].

In the present formalism a quantitative description of these states is obtained assuming a $2(q\bar{q})$ structure (q massless quantons) with parameters $\kappa = 1.35$ and $\alpha = 2.14$ (as for many other systems [3, 4, 5]) and values of b as given in

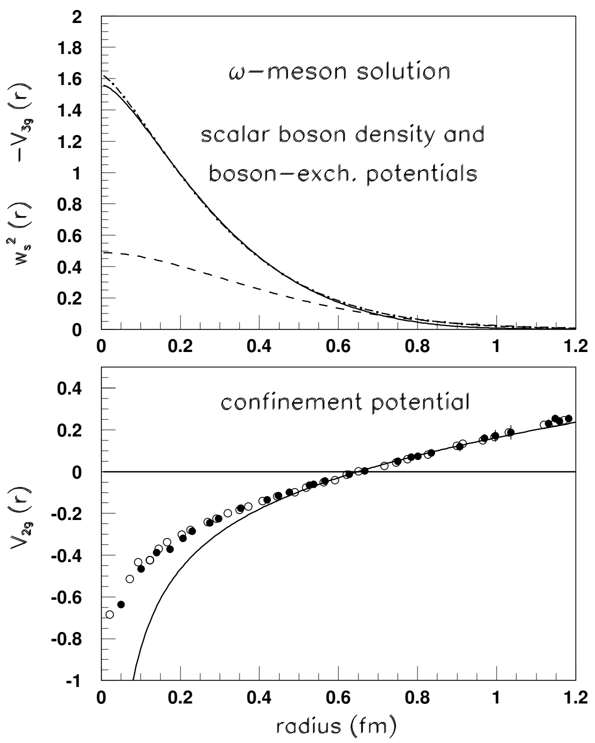

Figure 1: Radial dependence of the boson density and the potentials. Upper part: Scalar boson density $w^2(r)$ (dot-dashed line) and boson-exchange potentials -$V_{3g}(r)$, scalar given by dashed line, vector potential by solid line. Lower part: "Confinement" potential $V_{2g}(r)$. The closed and open point are renormalized lattice calculations, see ref. [9].

table 1. In table 2, boson and fermion momenta, corresponding binding energies or masses and contributions from the acceleration terms ΔE_g and ΔE_f, are given. The boson and fermion momenta are in reasonable agreement; further, consistent with the total boson energies defined by $E_g - \Delta E_g$. The contribution ΔE_f is expected to be spurious, but it could also contribute to the binding energy, if required by energy-momentum conservation. For the lighter systems ΔE_f is indeed spurious, but for $\Upsilon(9460)$ $M \simeq M_f - \Delta E_f$.

These results show that in the present approach the meson masses are well described, assuming indeed bound states of massless quantons. The geometric bound state conditions are fulfilled together with the matching of two boson and fermion momenta and five energy-momentum conditions. All this is achieved by adjusting **only** the slope parameter b. The fact that all constraints are fulfilled for the four different mesonic systems reassures that an entirely consistent description is obtained, in which the flavour and color degrees of freedom (introduced in the quark model) are not needed.

3.2 Structure of $Z(91.2\ GeV)$ and $W^{\pm}(80.4\ GeV)$

These states have been identified in the SM with gauge vector bosons of the weak interaction. However, in the present formalism they are well described by $2(q\bar{q})$ structure, similar to the above mesonic states in table 1. In table 2 one can see again a reasonable agreement between the boson and fermion momenta, and also with the boson energy $E_g - \Delta E_g$. As for the case of the $\Upsilon(9460)$ the overshooting fermion energy of $Z(91.2\ GeV)$ can be reduced by ΔE_f, yielding again an entirely consistent description. Interestingly, for the case of $W^{\pm}(80.4\ GeV)$ all constraints are fulfilled without readjusting the fermion mass by ΔE_f.

3.3 Vector states

For $2(q\bar{q})$ vector states again a good matching of the different constraints is obtained (see table 2). The vector state

Table 1: Solutions for different hadronic systems with $\kappa = 1.35$ and $\alpha = 2.14$, all quantities in GeV or fm. The symbols in brackets indicate the quark model structure (l=u/d quarks). The masses M_s, M_v and M_{0^+} are the negative of the corresponding binding energies.

system	b	M_s	M_v	M_{0^+}	M^s_{exp}	M^v_{exp}	$M^{0^+}_{exp}$	$< r^2_{\psi_s} >^{1/2}$
ω $(l\bar{l})$	$5.6\ 10^{-1}$	0.79	4.0	1.33	0.78	–	1.37	$6.5\ 10^{-1}$
ϕ $(s\bar{s})$	$4.7\ 10^{-1}$	1.02	5.4	1.8	1.02	–	–	$5.5\ 10^{-1}$
J/ψ $(c\bar{c})$	$1.43\ 10^{-1}$	3.09	13.6	4.5	3.09	–	–	$1.7\ 10^{-1}$
Υ $(b\bar{b})$	$4.75\ 10^{-2}$	9.46	46	15	9.46	–	–	$5.5\ 10^{-2}$
Z $(t\bar{t})$	$4.9\ 10^{-3}$	91.2	390	130	91.2	–	126	$5.7\ 10^{-3}$
$W^\pm$ $(t\bar{t})$	$5.68\ 10^{-3}$	80.4	350	-	80.4	350	–	$6.6\ 10^{-3}$

Table 2: Boson and fermion momenta, binding energies and masses (in GeV) of the solutions in table 1. Symbols in brackets see table 1.

system	s	$< q^2_g >^{1/2}$	E_g-ΔE_g	$< q^2_f >^{1/2}_{s,v}$	M_f	ΔE_g	ΔE_f
ω	0	0.79 ± 0.03	-0.79	0.77±0.04	0.79	-0.18	-0.13
$(l\bar{l})$	1	1.2 ± 0.2	-1.4	1.4±0.2/ 3.8±0.3	4.0	-0.44	-0.26
ϕ	0	1.0 ± 0.03	-1.0	1.0±0.04	1.02	-0.22	-0.16
$(s\bar{s})$	1	1.4 ± 0.2	-1.7	1.6±0.2/ 5.2±0.3	5.4	-0.54	-0.32
J/ψ	0	3.1 ± 0.1	-3.1	3.1±0.1	3.1	-0.76	-0.54
$(c\bar{c})$	1	5.5 ± 0.4	-5.8	5.5±0.4/ 15±0.5	13.8	-1.79	-1.04
Υ	0	9.5 ± 0.3	-9.5	9.5±0.3	9.5 (11.4)	-2.30	-0.1 (-1.94)
$(b\bar{b})$	1	18.0 ± 1.0	-17.8	18.3±1.0/ 46±2.0	47	-5.5	-3.15
Z	0	91.5 ± 3.0	-91.2	91.7±3.0	91.2 (108.3)	-22.3	-2.3 (-19.4)
$(t\bar{t})$	1	136 ± 20	-165	158±20/ 390±30	390	-53.2	-30.5
$W^\pm$	0	79.5 ± 3	-79.0	80.0±3	80.4	-19.1	-16.9
$(t\bar{t})$	1	130 ± 20	-149	140±20/ 360±30	350	-45.5	-26.2

For the estimated errors of the momenta, see ref. [3, 4].

corresponding to the $W^\pm$ system has a mass of 350 GeV/c^2, at which the top $(t\bar{t})$ state has been found experimentally. The width of about 10 GeV is much larger than found for the lighter flavour states. So, if we interpret $Z(91.2\ GeV)$ and $W^\pm(80.4\ GeV)$ as the (neutral and charged) scalar top $(t\bar{t})$ states (which have a width of about 2 MeV), a very consistent description of all flavour states in table 1 is obtained. For the $W^\pm$ system the boson density and potentials are given in fig. 2, which have very similar features as the $\omega(782)$ solution in fig. 1.

3.4 Scalar 0^+ states

In the present formalism scalar 0^+ states can be constructed similar to the vector states, but with a coupling to spin 0. This requires a spin factor (2s+1) of 1 instead of 3, indicating that the mass of these states are 1/3 of the vector states, see table 1. For the Z system the energy of the scalar state is about 130 GeV, in good agreement with a scalar particle interpreted as the SM Higgs-boson.

3.5 Lepton masses

In addition, leptons have been assumed in weak interaction theory as fermions with masses deduced from experimental data. However, these particles have a chiral structure, which indicates a complex structure. This can be well understood in the present formalism by assuming magnetic bound states of massless elementary fermions [4].

4. Discussion

For all states discussed above a satisfactory description is obtained, in which the various boundary conditions are fulfilled. This indicates that these states can be considered as bound states of massless elementary particles. On the other hand the same mesonic states have been interpreted in the SM either as quark-antiquark states, or (for the top

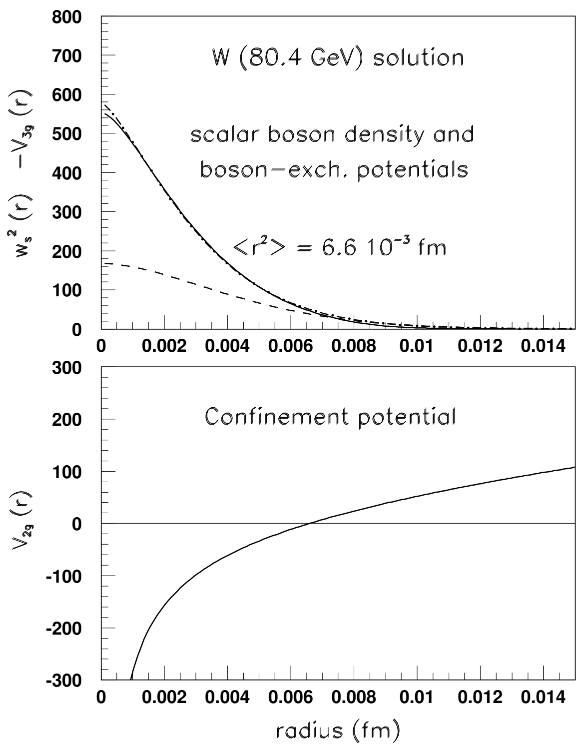

Figure 2: Radial dependence of the boson density and the potentials of a system corresponding to $W^{\pm}(80.4\ GeV)$. Upper part: Scalar boson density $w^2(r)$ (dot-dashed line) and boson-exchange potentials -$V_{3g}(r)$, scalar given by dashed line, vector potential by solid line. Lower part: Confinement potential $V_{2g}(r)$.

($t\bar{t}$) system) as heavy vector bosons and scalar Higgs-particle. This suggests that massive SM particles have to be interpreted as effective particles built out of elementary massless fermions and bosons.

So, we can conclude that there is no mass problem in the SM, this empirical model is in full agreement with the present fundamental approach [3, 5], in which the development of the universe has been explained [5, 7] as follows: generation of matter out of the vacuum and accumulation of a tremendously large gravitational system, breaking of the matter-antimatter symmetry by CP-violating processes, collapse and annihilation of antimatter (Big Bang), disintegration of matter with accelerated expansion towards larger distances, finally the formation of bound states in the universe in the form of galaxies and solar systems.

5. Summary

The present discussion within a fundamental bound state formalism has shown that a consistent description of the above systems can be obtained without the assumption of massive elementary fermions and bosons. This fulfills a principle requirement of a unified theory of all fundamental forces, which couples to the vacuum and allows to understand the genesis and evolution of the universe.

The main results are:
1. For the lighter quark-antiquark systems the massive fermions in the SM have to be understood as effective particles with masses given by bound state expectation values of the boson-exchange potential $V_{3g}(r)$, see also the very preliminary analysis of these states in ref. [10].

2. All three massive SM bosons $W^{\pm}$, Z and H^o have to be considered also as effective particles, being members of the top ($t\bar{t}$) system with a bound state structure similar to that of the other mesons in table 1. The experimentally found ($t\bar{t}$) state found at 350 GeV should be identified as the top state with vector coupling of its wave functions. In

total, this yields a very consistent picture of all mesonic systems.

3. The scalar SM Higgs-boson, identified with the $0^+(126\ GeV)$ state, is not of special significance[1], it has a structure similar to that of other scalar mesons.

4. The comparison of SM and fundamental approach has shown that both models can be considered as reliable and adequate descriptions of fundamental forces - without mass problem of the SM. However, these models are very different: The present model provides a physically complete description, in which all basic features of bound states are considered, radius, mass, momentum and energy. Further, a unified description of all systems is obtained with only **one** fundamental force, the electromagnetic interaction. Its main application is on basic questions and in the hadronic and gravitational sectors.
On the other hand, the empirically constructed SM consists of effective theories, in which two additional (effective) degrees are needed, flavour and color, which are not real: flavour is needed for the distinction of different quarks, color for the differentiation of gauge bosons (gluons). This model has its strength in the electroweak and high energy sectors, where the coupling constant is small and perturbative methods can be applied.

Finally, it is important to discuss other solutions and generalizations of the applied models. For the SM exotic states as glueballs, axions, magnetic monopoles as well as supersymmetric states have been predicted. But none of these objects have been found experimentally. Differently, the fundamental approach is based on a rather complex Lagrangian. Therefore, it is not clear, whether any other solution or extension exists at all. This should be subject of future studies. Since both models – with all possible extensions – have to be equivalent, we may have to face the final answer that we have reached already the full knowledge of the basis of our beautifully developed universe.

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There is no conflict of interest.

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