Scientific Research Publishing

Journal of High Energy Physics, Gravitation and Cosmology, 2024, 10, 1670-1674
https://www.scirp.org/journal/jhepgc
ISSN Online: 2380-4335
ISSN Print: 2380-4327

Structure of Massive "Standard Model" Particles

Hans-Peter Morsch

HOFF, Jülich, Germany
Email: h.p.morsch@gmx.de

How to cite this paper: Morsch, H.-P. (2024) Structure of Massive "Standard Model" Particles. *Journal of High Energy Physics, Gravitation and Cosmology*, **10**, 1670-1674.
https://doi.org/10.4236/jhepgc.2024.104094

Received: July 19, 2024
Accepted: October 11, 2024
Published: October 14, 2024

Abstract

The massive vector bosons Z^o, $W^{\pm}$ and the scalar Higgs-boson H^o assumed in weak interaction theory, but also the six quarks required in strong interactions are well understood in an alternative quantum field theory of fermions and bosons: Z^o and $W^{\pm}$ as well as all quark-antiquark states (here only the $t\bar{t}$ state is discussed) are described by bound states with scalar coupling between their massless constituents and have a structure similar to leptons. However, the scalar Higgs-boson H^o corresponds to a state with vector coupling between the elementary constituents. Similar scalar states are expected also in the mass region of the mesons ω (0.782 GeV) - Υ (9.46 GeV). The underlying calculations can be run on line using the Web-address https://h2909473.stratoserver.net.

Keywords

Quantum Field Theory of Fermion and Bosons, Z^o and $W^{\pm}$ Boson as Well as the $t\bar{t}$ Quark-Antiquark State Are Well Described as Bound States of Massless Fermions and Bosons with Scalar Coupling between the Elementary Constituents, The Scalar H^o-Boson Involves Vector Coupling between Them

1. Introduction and Theoretical Framework

Quantum field theories of electromagnetic, weak and strong interactions [1] [2]—combined in the *Standard Model of particle physics* [3]—have been widely used in the analysis of particle physics. Although in this way many high energy physics data are described with remarkably accuracy, more than 20 parameters are needed, in particular masses of special particles adjusted to experimental data. For weak interactions heavy vector bosons Z^o and $W^{\pm}$, as well as a scalar Higgs-boson H^o are assumed, whereas heavy fermions (quarks) are used in the strong interaction domain. Since their masses are taken as fit parameters, the intrinsic structure of these particles cannot be revealed. Also, if in a modern view of fundamental systems one assumes that the universe emerged out of the vacuum, the assumption of massive elementary particles would violate mass. Therefore, these particles have to be interpreted as bound states of massless particles or in case of the quarks as bound state components of quark-antiquark or complex states.

To determine the structure of these particles a different (more fundamental) theoretical framework is needed, in which all parameters can be deduced from basic conditions, as energy and momentum conservation. Such a formalism has been developed [4] [5], in which massive particles are described as bound states of massless elementary fermions and bosons. The underlying Lagrangian has the form

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

where $\tilde{m}$ is a mass parameter, Ψ a fermion 4-vector charge spinor $\Psi = \Psi^+$ and $\bar{\Psi} = \Psi^-$; further a 3-dimensional vector boson field A_μ with a charge coupling g between the fermion fields Ψ and $\bar{\Psi}$, contained in the covariant derivatives $D_\mu = \partial_\mu - igA_\mu$. Finally, the second part of Equation (1) is the Maxwell Lagrangian, containing Abelian field strength tensors $F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$.

Apart from a boson force term included in D^μ, this Lagrangian has a completely fermion-boson symmetric form, which leads to a bound state description, which can be applied to atoms, hadrons and leptons, but also to gravitational systems. A first complete evaluation has been published in ref. [4] and a detailed discussion of leptons and simple hadrons is given in ref. [5].

A special property of the present theory is that there are two basis states, one of scalar structure (with scalar coupling between the bound state constituents), the other of vector structure (with vector coupling between the constituents). The radial dependence of their wave functions are given for bosons by

$$w_s(r) = w_{s_o} \exp\left\{-(r/b)^\kappa\right\} \tag{2}$$

and

$$w_v(r) = w_{v_o} \left[w_s(r) + \beta R \frac{\mathrm{d}w_s(r)}{\mathrm{d}r} \right]. \tag{3}$$

The factors w_{s_0} and w_{v_0} are obtained from the normalization $2\pi \int r\mathrm{d}r\, w_{s,v}^2(r) = 1$, whereas βR is given by $\beta R = -\int r^2 \mathrm{d}r\, w_s(r) \big/ \int r^2 \mathrm{d}r \left[\mathrm{d}w_s(r)/\mathrm{d}r\right]$, indicating that both states are orthogonal: $\int r\mathrm{d}r\, w_s(r) w_v(r) = 0$. The fermion wave functions $\psi_{s,v}(r)$ are of similar radial shape $\psi_{s,v}(r) \sim w_{s,v}(r)$, normalized by $4\pi \int r^2 \mathrm{d}r\, \psi_{s,v}^2(r) = 1$ (the different normalization of the boson and fermion wave functions is due to their two and three dimensional structure).

Using these wave functions, in the whole analysis only three or four parameters are needed, shape and slope parameters κ and b and a coupling constant α for electric binding, whereas for magnetic binding an addition parameter (v/c)

related to a rotation of the system is required.

These parameters can be determined by the following boundary conditions:

1) Energy-momentum conservation (combining energy and momentum conservation) demands that the average fermion 3-momenta and the average boson 2-momenta cancel each other, equally the corresponding energies

$$\left[\left\langle q_f^2\right\rangle^{1/2} - \left\langle q_g^2\right\rangle^{1/2}\right](v/c) \sim \left(E_f + E_g\right) \quad (4)$$

where $\left\langle q_f^2\right\rangle^{1/2}$ and $\left\langle q_g^2\right\rangle^{1/2}$ are the average momenta of fermions and bosons and E_f and E_g the corresponding energies obtained from the central potentials (of zeroth and second order in r).

2) A mass-radius relation

$$Rat_{2g} = \frac{(\hbar c)^2 (v/c)^2}{\tilde{m}^2 \left\langle r_g^2\right\rangle N} = 1, \quad (5)$$

where $N = 1$ for scalar and 2 for vector states. This relation shows that in the present formalism particles with different masses and radii can be described.

Another point, the interaction is attractive for fermions, but repulsive for bosons. Therefore, the total energy $E_{tot} = E_f + E_g$ vanishes, if the above conditions are fulfilled. This led to the important conclusion [5] that particles can be generated out of the vacuum.

Recoil corrections

Since the momenta of fermions and bosons are different, recoil corrections of the form $rec = f_{rec}\left(\left\langle q_f^2\right\rangle^{1/2} - \left\langle q_g^2\right\rangle^{1/2}\right) \big/ \left(\left\langle q_f^2\right\rangle^{1/2} + \left\langle q_g^2\right\rangle^{1/2}\right)$ have been included, with sign negative for fermions and positive for bosons. However, these corrections act differently on the different binding energy contributions. As discussed in ref. [5], for scalar states only the zeroth and second order terms (central and acceleration potentials) contribute, the derivative terms (kinetic and confinement potentials) do not. For vector states the recoil corrections are expected to be opposite, for recoil only derivative potentials should contribute.

2. Description of the Vector Bosons *Z* (91.2 GeV) and *W* (80.4 GeV)

The analysis of these particles is quite similar to that of leptons and mesons of simple structure ω (0.782 GeV) - Υ (9.46 GeV) in ref. [5], also with three participating bosons. The uncharged vector boson Z^o (91.2 GeV) is described by electric binding, whereas the charged vector boson $W^\pm$ (80.4 GeV) is described by magnetic binding. For the latter the parameters b and (v/c) are coupled by Equation (5). Concerning the recoil corrections, for Z^o the average momenta of fermions and bosons are 115.9 and 87.0 GeV, respectively, but the (absolute) fermion energies are smaller. Therefore, a negative recoil factor of −0.0161 has been used. The same recoil factor is also needed for $W^\pm$. This leads to parameters and resulting radii and energies as given in Table 1. One can see that the sum of fermion and boson masses amounts to zero, supporting the earlier results that particles are coupled to the vacuum.

Table 1. Results on fermion root mean square radii $\langle r_f^2 \rangle^{1/2}$ and recoil corrected energies, using slope and velocity parameters b and $(v/c)^2$, as well as $\kappa = 1.375$, $\alpha = 2.158$. All dimensions are in fm or GeV.

System	b	$(v/c)^2$	$\langle r_f^2 \rangle^{1/2}$	E_{ferm}	E_{boson}
Z^o (91.2 GeV)	5.0914×10^{-3}	1	5.796×10^{-3}	−91.2	91.2
$W^{\pm}$ (80.4 GeV)	4.550×10^{-5}	6.2065×10^{-5}	5.179×10^{-5}	−80.4	80.4
H^o (126 GeV)	7.330×10^{-3}	1	8.344×10^{-3}	−126	126
top ($t\bar{t}$) at ~360 GeV	1.2898×10^{-3}	1	1.468×10^{-3}	−360	360

3. The Scalar Higgs Boson H^o

To get a fermion-antifermion boson-antiboson system of scalar structure, a vector coupling between the participating particles is needed, given by wave functions in Equation (3). Further, the number of bosons has to be two. Different from the other states the mean fermion momentum is a factor of ~1.65 larger than of bosons, but also the (absolute) fermion energy is larger. This gives rise to a positive recoil factor of 0.1122.

4. Description of the $t\bar{t}$ Bound State

Simple mesons have been interpreted in strong interaction theory (quantum chromodynamics) as quark-antiquark states. Because this model contains 6 quarks, the mesons ω (0.78 GeV), ϕ (1.02 GeV), J/ψ (3.98 GeV), Υ (9.46 GeV) were interpreted as light quark-antiquark, $s\bar{s}$, $c\bar{c}$ and $b\bar{b}$ states, respectively; it rests the $t\bar{t}$ (top) state, experimentally observed at about 360 GeV. The other states have been discussed already in ref. [5]. For the top state we assume a similar structure as the Z^o boson, with the same recoil factor and just a smaller slope parameter b. The results are also included in Table 1.

5. Discussion

The above results show that all massive Standard Model particles are well understood in the present theory with a total energy of fermions and bosons $E_{ferm} + E_{bos} = 0$, see Table 1. This indicates a coupling to the vacuum [6] (the fingerprint of genesis), indispensable in a modern view of the evolution of the universe.

In a similar way all essential features of leptons, including magnetic moments and accompanying neutrinos, as well as the properties of hadrons are well understood. In particular, a quantitative description of the structure of nucleons [7] is obtained, which explains the high stability of the proton.

6. Conclusions

We have seen that the massive bosons and fermions needed in weak and strong interaction theories can be well understood in a quantum field theory of fermions and bosons as bound states of elementary particles. They show an intrinsic structure, which cannot exist in elementary particles. Also the scalar Higgs-particle cannot play the role of a special particle—as often speculated, which gives mass to quarks and leptons.

The fact that all essential properties of particles are described without free adjustable parameters indicates that the present formalism represents a fundamental theory based on first principles, which should finally allow to get reliable information on the evolution of the universe. This will be the subject of a forthcoming article.

All calculations can be run on line under the address https://h2909473.stratoserver.net, where also the underlying fortran source code (in gfortran) can be inspected.

Acknowledgements

I am grateful to many colleagues for numerous discussions. In particular, I am thankful to Benoit Loiseau for his help with the evaluation of the Lagrangian and Thomas Sefzick for his engaged help with setting up the Web-presentation.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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