The Higgs boson and the signal at 750 GeV: Composite particles?

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Abstract

This article explores the possibility that the 125 GeV-mass particle discovered at CERN in 2012 is a composite particle. It then expands the theory to the hypothetical particle seeming to appear at 750 GeV. To that end, this ultra-relativistic quasi-classical model is presented. The results suggest the existence of a tauonium and quarkonia having the required mass.

***Keywords*:** Higgs boson, Composite particle

1. Introduction

A particle with a mass of around 125 GeV was discovered at CERN in 2012. This is the great experimental discovery of the 21st century in the field of elementary particle physics. The discovery of this particle was expected and hoped for as the Higgs boson in the Standard Model; it is now regarded as such by most physicists.

A review of all the measurements taken at CERN, however, leads to the following question: is there a single particle with a mass of around 125 GeV or more? Another question remains: is the particle detected at CERN an elementary or a composite particle? We can indeed see that two direct decay modes of this particle produce leptons $\boldsymbol{\tau}$ on one hand, and **b** quarks on the other, and that these two particles belong to the same family. This allows us to make the assumption that it might be a boson particle composed of either a tau lepton and an anti-tau connected by electromagnetic interaction – that is to say a "tauonium" — or a quark **b** and anti-**b** linked by strong interaction. A boson corresponding to the second case exists: the upsilon, a bottomonium whose mass of 9.46 GeV does not match the problem discussed here.

This article will explore the hypothesis of a composite particle in the case mentioned above, first by constructing an ultra-relativistic quasi-classical particle model consisting of a tau and an anti-tau, then by extrapolating this model in ultra-relativistic bottomonium; passage to quantum mode is achieved by applying the pre-quantum Bohr rule to the particle's vertices in a classical trajectory. This model provides a very simple mathematical layout, which nevertheless leads to results consistent with experimental values for the masses of these supposed composite particles.

2. Overall review of measurements performed at CERN

We will use here the article published recently by Lucia di Ciaccio and Gautier Hamel Monchenault in "Reflets de physique" [1]. The article presents a summary of the data set of proton collisions carried out by teams using the ATLAS and CMS detectors installed at the LHC at CERN. This synthesis led to the detection of a particle with a mass of125.09 ± 0.24 GeV, the result of the combination of all measurements taken by these two detectors, each dealing with only two decay mode measurements:

ZZ $\longrightarrow$ 4-leptons on one hand, and 2- photons on the other hand

However, considering the measurements provided by each of the detectors separately leads us to imagine the existence of two particles. In fact, CMS actually provides two values for the particle: 126 GeV for the 4-lepton decay and 124.7 GeV for the 2-photon decay; error bars are disjoint and ordinarily lead to the assumption of two particle masses, slightly yet significantly different, detected by CMS. The ATLAS detector provides two values as well: 125 GeV for the 4-lepton decay and 125.4 GeV for the 2-photon decay; both values are closer here and error bars overlap, so they are compatible with the hypothesis of a single particle. Overall, a separate examination of the data produced by the two detectors instead leads us to consider two particles of different masses: 125 and 126 GeV, the heaviest being detectable only by CMS. The remainder of this article will consist in examining the (theoretical) possibilities for the existence of two composite particles—in this case composed of quarks and leptons—using a model.

3. Modeling ultra-relativistic tauonium

Taking into account the mass of the boson studied (125 GeV) and that of its assumed constituent, the tau (1777 MeV), the model studied will necessarily be ultra-relativistic, as the mass comes essentially from the kinetic energy of its constituents. As we will see, modeling will automatically demonstrate the ultra-relativistic aspect.

Initially, we will consider the classical movement of two tau particles bound by electrostatic interaction within the framework of special relativity. We must consider the fact that the moving charges create an electric field as a function of their speed. Here, both charges are moving along symmetrical trajectories according to their common center of gravity (with at all times opposite velocity vectors and equal in modulus), therefore the strength of their interaction is a direct result of their speed. For the quantum-setting equation, the situation is different than that of the electron movement in the atom, because in this case the nucleus is assumed immobile; the electric field it generates is derived from a Coulomb potential and therefore depends only on the distance to the center.

For the above reason, we cannot use the Dirac equation and the results it provides for positronium. It has not been studied for the present case, where the electrostatic bond strength of the particles depends on their speed and does not derive from an electrostatic Coulomb potential, which is based only on the distance to the center of gravity of the system.

We will simplify the problem by writing the equations of motion for the peak classical trajectories of both particles and applying to these points the pre-quantum Bohr rule relating to their kinetic momentum. We will see that this method allows calculation of the mass-energy of the composite particle without requiring determination of the wave function.

The diagram below (figure 1) shows two tau particles moving around their common center of gravity G to one of the peaks of their classical trajectory:

$$\boldsymbol{v} \leftarrow \oplus \ \boldsymbol{\tau}^{+}$$

$$^{\circ}\,\mathrm{G}$$

$$\boldsymbol{\tau}^{-} \ \oplus \rightarrow \boldsymbol{v}$$

Figure 1. Velocities **v** of both particles are equal and opposite in module, perpendicular to the radius length r of their distance from the center of gravity G.

The attractive force acting between the two tau is [2]:

$$f = -\frac{\alpha\hbar c}{4r^2\sqrt{1-\frac{v^2}{c^2}}} \qquad (1)$$

$$\alpha = \frac{e^2}{\hbar c} = \frac{1}{137.04}$$

Where e is the electric charge of the electron, equal to that of the tau
Furthermore, the momentum of each tau (where m is its mass) is:

$$\boldsymbol{p} = \frac{m\boldsymbol{v}}{\sqrt{1-\frac{v^2}{c^2}}} \qquad (2)$$

$\boldsymbol{p}$ and **v** are collinear vectors tangent to the trajectory of the tau, and therefore perpendicular to the attractive force **f**. In this case, the derivative of the momentum,

$$\frac{d\boldsymbol{p}}{dt} = m\frac{\frac{dv}{dt}}{\sqrt{1-\frac{v^2}{c^2}}} \qquad (3)$$

is radial; expression of this component is, by introducing the radius of curvature ρ of the path:

$$\frac{mv^2}{\rho\sqrt{1-\frac{v^2}{c^2}}} = \frac{pv}{\rho} \qquad (4)$$

Here, **p** and **v** represent the modules of the momentum and speed at that point.
Equating (1) and (4) we have:

$$\frac{pvr^2}{\rho} = \frac{\alpha\hbar c}{4\sqrt{1-\frac{v^2}{c^2}}} \qquad (5)$$

We now introduce Bohr's quantization rule, applied to both tau systems, as follows:

$$2p\rho = n\hbar \qquad (6)$$

n : integer which consists of taking as principle the quantization of angular momentum.
The relation (5) becomes:

$$\frac{vr^2}{c\rho^2} = \frac{\alpha}{2n\sqrt{1-\frac{v^2}{c^2}}} \qquad (7)$$

Let : $s = \frac{\rho^2}{r^2}$

It is possible to fix the value of the relationship between the radius of curvature and the distance to the center of gravity by referring to the classical movement. The simplest case is that of a circular path for which we have, s=1. In general, the standard trajectory is not an ellipse but a rosette, because the issue is dealt with in the relativistic framework. However, at the vertices of this trajectory, the curve traced by each tau is very close to an ellipse, as the equations of motion at these points are identical to those that result in an ellipse in non-relativistic mechanics.

In the case of an ellipse with high eccentricity, the ratio ρ / r is near 2 for the vertice closest to the foci coinciding with the center of gravity, so s≃4.

Equation (7) is in fact an equation v (velocity at the peak trajectory of each tau), which can be put as follows:

$$\frac{v^2}{c^2}\left(1-\frac{v^2}{c^2}\right) = \frac{s^2\alpha^2}{4n^2} \qquad (8)$$

That simple equation has the following solutions:

Solution 1:

$$\frac{v^2}{c^2} = \frac{1}{2}\left(1-\sqrt{1-4\frac{s^2\alpha^2}{4n^2}}\right) \cong \frac{s^2\alpha^2}{4n^2} \qquad (9)$$

Solution 2:

$$\frac{v^2}{c^2} = \frac{1}{2}\left(1+\sqrt{1-4\frac{s^2\alpha^2}{4n^2}}\right) \cong 1-\frac{s^2\alpha^2}{4n^2} \cong 1 \qquad (10)$$

4. Discussion

--**The first solution** (9) is weakly relativistic, v is greatly inferior to c.

In this case, using the classical expression of the kinetic energy for the system of two tau particles, we obtain the energy levels (in absolute values):

$$E_n \simeq \frac{s^2\alpha^2 mc^2}{4n^2} \qquad (11)$$

Assuming that the classical trajectory is a circle or s = 1, we find for that reason the inferred relations for the positronium by quantum theory [3], corresponding to the principal quantum number n (for the Hamiltonian "undisturbed "). In absolute terms, these energy levels are defined by:

$$E_n = \frac{\alpha^2 mc^2}{4n^2} \qquad (12)$$

It is interesting to note that the solution to a purely relativistic algebraic equation, in which one has only postulated quantization of angular momentum, allows a result that is a solution to the Schrödinger equation, which is a non-relativistic quantum mechanics equation.

--**The second solution** (10), the one that interests us here, is ultra-relativistic, the velocity of the two particles is close to that of light; using the relationship:

$$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}} \qquad (13)$$

With (8) the energy levels are obtained:

$$E_n = n\frac{2mc^2}{s\alpha} \qquad (14)$$

We have a case in which the system of two tau particles has acquired considerable kinetic energy from the loss of its potential electrostatic energy. From a classical point of view, it is easily shown that this corresponds to a very elongated path, close to a highly eccentric ellipse. This point can be illustrated by the ratio of the extreme values of the distancesbetween the two tau at the opposed vertices (on the major axis) of the classical trajectory, such that it can be calculated using the model:

$$\frac{D_m}{D_M} = \alpha^2$$

It is thus possible to use s = 4, which gives the fundamental energy level n = 1 of a single tau to the ultra-relativistic vertices of the classical trajectory:

$$E_1 \simeq \frac{mc^2}{2\alpha} \qquad (15)$$

This value corresponds equally to the total kinetic quantum energy of tauoniumbecause the average energy of each tau must take into account the point where its classical speed is low and its energy level numerically negligible, which would mean dividing the value (15) by 2

5. The mass of tauonium

The kinetic quantum energy of tauonium is therefore:

$$E \simeq \frac{m_\tau c^2}{2\alpha} \qquad (16)$$

The total mass of tauonium is obtained by adding the rest mass of both tau particles to the above value, taking into account points in the trajectory where speed is minimal:

$$\boldsymbol{m_{\tau\tau} \simeq \left(\frac{1}{2\alpha} + 2\right) m_\tau} \qquad (17)$$

Numerically, the mass of tau being equal to 1777 MeV, we obtain for tauonium:

$$\boldsymbol{m_{\tau\tau} = 125.314\ GeV} \qquad (18\ )$$

The mass of the Higgs boson (considered as such) provided by the combined measurements taken by ATLAS and CMS at CERN is [3]:

$$\boldsymbol{m_H = 125.09 \pm 0.24\ GeV} \qquad (19)$$

It can be seen that the calculated value of ultra-relativistic tauonium corresponds closely to the measured value of the particle observed at CERN.

6. The mass of bottomonium

This particle consists of two **b** quarks should normally be studied within the QCD theoretical framework. We know that in this context, numerical calculation of the mass of a composite particle from the mass of its components is extremely difficult and out of reach of the author of this article. We will return to the previous case of tauonium, arguing that the intensity of the strong interaction of quarks tends toward the constant of the electrostatic interaction α at high energies, which is the case here. We can then venture the hypothesis that the above model for tauonium also applies to bottomonium. If the coupling of the strong interaction at high energy is α, and if f denotes the full elementary strong charge, we can write:

$$f^2 = e^2 = \alpha\hbar c \qquad (20)$$

The strong (or color) charge and the electric charge of both tau particles must intervene in the equations written above. It is known that the electric charge of the bottom is e / 3, thus the corresponding interaction with the anti-bottom is α / 9. Assume that the value of the color charge is 2f / 3 for this quark, or a value of interaction, for one color: 4α / 9. It is known that QCD introduces three colors and three anti-colors; for the overall value of the coupling, it will be necessary to multiply this amount by 6 and add the electrostatic coupling (all forces are attractive). The total value of the coupling is therefore 25α / 9,

$$E_n = n\frac{9mc^2}{50\alpha} \qquad (21)$$

Here, m is the bottom quark mass we will take equal to half that of the Upsilon boson mass; it is clearly not an ultra-relativistic composite particle, the quantum kinetic energy levels should be negligible compared to the rest mass of the constituents.

Where: $m_b = 4.73\ GeV$ (22)

Note that (21) is a containment relationship quark (during the lifetime of the particle)

As in the previous case, we calculate the mass of bottomonium for the fundamental level n = 1. It is the necessary to add the inert masses of the two bottoms. Thus we obtain

$$\boldsymbol{m_{bb}} = \left(\frac{\mathbf{9}}{\mathbf{50}\boldsymbol{\alpha}} + \mathbf{2}\right)\boldsymbol{m_b} \qquad (23)$$

or numerically, $\boldsymbol{m_{bb}} = \mathbf{126.136}$ **GeV**

This value corresponds to the measurement provided by the CMS detector for 4-leptons decay.

7. A particle with a mass of 750 GeV?

The ATLAS and CMS detectors have detected a signal at this level of energy, equal to six times that of the presumed Higgs, but there is as yet no indication that this is a new particle.

If new measurements are confirmed, this particle could be classified in the context of this model as a 6-bottomonium or 6-tauonium particle, composed of six pairs of bottom quarks and/or 6 pairs of tau leptons (with their antiparticles). Referring to classical mechanics, it would mean we would have two pairs of particles (with opposite angular momentum) for each of the three dimensions of space.

As we are in a very speculative field, note that this 750-GeV mass particle could be 6-leptoquarkonium $\boldsymbol{\tau}$**b**. Indeed, if we consider that a hypothetical hybrid particle that might be called a leptoquark with a mass equal to the half-sum of those of tau and bottom, and in which the interaction with its antiparticle would also be the half-sum of interactions, then we obtain with the present model a leptoquarkonium with a mass of 124.53 GeV, which corresponds to the measurement provided by CMS for single-photon decay 2 (124.70 GeV).

$$m_{\boldsymbol{\tau}b} = \frac{\left(\frac{9}{34\alpha} + 2\right)(m_{\boldsymbol{\tau}} + m_b)}{2} = 124.53\ GeV \qquad (24)$$

Now look at the situation globally by multiplying by six the mass of each of the three composite particles described by this model. This should be shown in the CERN detectors by three signals:

747(6-$\boldsymbol{\tau}$**b**); **752** (6-$\boldsymbol{\tau\tau}$); **757** (6-**bb**) GeV

With the usual caveats, the signal that has already been detected by ATLAS is found at 747 GeV and that detected by CMS at 758 GeV.

8. Incidence on the Z boson

Peaks corresponding to the Z boson appear in the measurements made by ATLAS and CMS for 4-lepton decay. As part of this model, the Z boson can be described as a leptoquarkonium consisting of a leptoquark (and its antiparticle), and having the mass of the tau and the properties of the bottom particles.

$$m_Z = \left(\frac{9}{25\alpha} + 2\right) m_{\tau} = 91.221\ GeV \qquad (25)$$

9. Conclusion

Measurements made at CERN as well as the results of the theoretical model presented here suggest the existence of two ultra-relativistic particles of masses near 125 GeV: a tauonium and a bottomonium or even three if we consider the possibility of leptoquarkonium $\boldsymbol{\tau}$**b**. This fact, if confirmed, does not exclude the existence of an elementary particle having the BEH boson properties of the Standard Model, but makes it unlikely at this energy level. In any event, only new measurements will (possibly)answer the question. It is the same for any future particles or mass near 750 GeV.

In addition, the model developed here may be of interest in itself, in allowing simple calculations of the mass of composite particles under QCD.

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