

New track in the standard model ?

Jean Pestieau¹

1 May 2019

For 10 years, since the opening of the LHC, no fundamental particles beyond the standard model $SU(3) \times SU(2) \times U(1)$ have been discovered. In this situation, it seems desirable to us to follow E. Schrödinger's advice : "The task is, not so much to see what no one has yet seen, but to think what nobody has yet thought, about that which everybody sees". It is with this in mind that we will try to identify some "hidden" relationships between the masses of the heavy particles in the standard model, namely W, Z, H and t .

1 Data

Let's start by collecting the necessary data to base our explanation.

– W mass [1] :

$$m_W = 80.380 \pm 0.013 \text{ GeV (experimental data)} \quad (1a)$$

$$m_W = 80.360 \pm 0.006 \text{ GeV (global fit of standard model)} \quad (1b)$$

– Z mass [1] :

$$m_Z = 91.1875 \pm 0.0021 \text{ GeV} \quad (2)$$

– H mass [1] :

$$m_H = 125.10 \pm 0.14 \text{ GeV} \quad (3)$$

– t mass :

$$m_t^{\text{pole}} = 172.90 \pm 0.47 \text{ GeV [1]} \quad (4a)$$

$$m_t^{\text{pole}} = 173.1 \pm 0.9 \text{ GeV (from cross-section measurement) [2]} \quad (4b)$$

– Higgs vacuum expectation value, v :

$$v = 246.21965 \pm 0.00006 \text{ GeV [1],[2]} \quad (5)$$

¹jean.pestieau@gmail.com

Center for Cosmology, Particle Physics and Phenomenology (CP3), UCLouvain
chemin du Cyclotron 2, 1348 Louvain-la-Neuve (Belgium)

where $v = 1/(2^{1/2}G_F)^{1/2}$ and G_F is the Fermi coupling constant
– fine-structure constant, $\alpha[\alpha = e^2/4\pi]$

$$\alpha^{-1} = 137.035\ 999\ 139(31)(\text{CODATA 2014}) \quad [2] \quad (6a)$$

$$\alpha^{-1} = 137.035\ 999\ 1491(331) \quad [3] \quad (6b)$$

$$\alpha^{-1} = 137.935\ 999\ 046(27) \quad [4] \quad (6c)$$

2 $m_Z, m_W, v, e, \tan(\pi/4 - \theta_W)$

From Equations (1a) and (1b), we can estimate the mass of W is around 80.365 GeV. We have such a result when

$$m_W - m_B = ev/2 \quad [5] \quad (7)$$

with

$$m_B = (m_Z^2 - m_W^2)^{1/2}.$$

Eq. (7) can be rewritten as follows

$$m_Z = [\cos \theta_W - \sin \theta_W]^{-1} \cdot ev/2 = 1/2^{1/2} \cdot [1 + \tan^2(\pi/4 - \theta_W)]^{1/2} \cdot e/\tan(\pi/4 - \theta_W) \cdot v/2 \quad (8)$$

with

$$\cos \theta_W = m_W/m_Z.$$

From Eq. (8), using Eq. (2) together with Eqs. (5) and (6a-b), we get

$$m_W = 80.3664 \pm 0.0016 \text{ GeV} \quad (9)$$

$$\tan(\pi/4 - \theta_W) = 0.301982 \mp 0.000008 \quad (10)$$

$$e/\tan(\pi/4 - \theta_W) = 1.002783 \pm 0.000025 \quad (11)$$

$$[1 - \tan^2(\pi/4 - \theta_W)]/3e = 1.000375 \pm 0.000005. \quad (12)$$

A possible common origin for e and $\tan(\pi/4 - \theta_W)$ cannot be excluded.

Observing that

$$[1 - e^2]/3e = 0.999815514 \quad (13)$$

we get

$$[1 - \tan^2(\pi/4 - \theta_W)]/3e = 3.000006 \pm 0.000005. \quad (14)$$

It is tentazing to consider case where

$$[1 - \tan^2(\pi/4 - \theta_W)]/3e + 2[1 - e^2]/3e = 3. \quad (15)$$

Observing [6] that

$$[1 - e^2]/3e = 1 - (1/3)e\delta = 1 - 0.000184486 \quad (16)$$

with

$$\delta = \alpha/4[1 + \alpha/4 + x(\alpha/4)^2], \quad (17)$$

[x is around 0 if α is given by Eq. (6a-b) and around 0.75 if α is given by Eq. (6c)], we deduce from Eq. (15) that

$$[1 - \tan^2(\pi/4 - \theta_W)]/3e = 1 + (2/3)e\delta = 1 + 0.000368972 \quad (18)$$

$$\tan^2(\pi/4 - \theta_W) = e^2(1 - 3\delta) = (0.301990793)^2. \quad (19)$$

Then, from Eq. (8), we get

$$m_Z = 91.1850 \text{ GeV} \quad (20)$$

and

$$m_W = 80.3446 \text{ GeV}. \quad (21)$$

3 $m_H, m_Z, v, e, \tan(\pi/4 - \theta_W)$

From the analysis of the data, we propose the following relation between m_H and m_Z :

$$\begin{aligned} m_Z &= e/(\sin \theta_W \cos \theta_W) \cdot e/\tan(\pi/4 - \theta_W) \cdot m_H \\ &= 2e \cdot [1 + \tan^2(\pi/4 - \theta_W)]/[1 - \tan^2(\pi/4 - \theta_W)] \cdot e/\tan(\pi/4 - \theta_W) \cdot m_H. \end{aligned} \quad (22)$$

From Eqs. (8) and (22), we get

$$\begin{aligned} m_H &= (\sin \theta_W \cos \theta_W)/(\sin \theta_W + \cos \theta_W) \cdot v/2e \\ &= [1 - \tan^2(\pi/4 - \theta_W)]/[8(1 + \tan^2(\pi/4 - \theta_W))]^{1/2} \cdot v/2e. \end{aligned} \quad (23)$$

With Eqs. (2), (5), (6a-c) and (10), we find

$$m_H = 125.0492 \pm 0.0009 \text{ GeV}. \quad (24)$$

With Eqs. (5), (6a-c) and (19), we find

$$m_H = 125.0481 \text{ GeV}. \quad (25)$$

to be compared with Eq. (3).

Observe that

$$m_H \cdot m_Z = (\tan 2\theta_W)/2 \cdot (v/2)^2. \quad (26)$$

It is worthwhile to go back to the known formula

$$m_Z = (\sin \theta_W \cos \theta_W)^{-1} \cdot (1 - \Delta r)^{-1/2} \cdot ev/2 \quad (27)$$

where Δr includes the radiative corrections relating alpha, G_F , m_W et m_Z .

See Eq. (10.10) in Ref.[7].

Comparing Eqs. (8) and (27), we find

$$(1 - \Delta r)^{1/2} = 1/\sin \theta_W - 1/\cos \theta_W$$

where all radiative corrections are encapsuled.

4 m_t, m_H, m_Z, m_W and v

In the standard model, the masses of all elementary particles (H, Z, W , quarks, leptons) are obtained using the Brout-Englert-Higgs mechanism and are proportional to the Higgs vacuum expectation value, v . The experimental data suggest that v is reciprocally constituted by the masses of the elementary particles as follows [8].

$$m_H^2 + m_Z^2 + m_W^2 + m_t^2 + m_b^2 + m_c^2 + m_t^2 + \dots = v^2$$

provided that $m_t = 173.8$ GeV. If m_t is smaller than 173.8 GeV, then there is room for Higgs boson to couple to dark particles, for example in the scalar singlet dark matter model [9].

References

- [1] Jens Erler, Matthias Schott, *Precision Tests of the Standard Model after the Discovery of the Higgs Boson*, <https://arxiv.org/abs/1902.05142> (2019).
- [2] M. Tanabashi *et al.* (Particle Data Group) Phys. Rev. D98, 030001 (2018), <http://pdg.lbl.gov/>
- [3] Tatsumi Aoyama, Toichiro Kinoshita, Makiko Nio, *Revised and Improved Value of the QED Tenth-Order Electron Anomalous Magnetic Moment*, Phys. Rev. D97, 036001 (2018), <https://arxiv.org/abs/1712.06060>
- [4] Richard. H. Parker, Chenghui Yu, Weicheng Zhong, Brian Estey, Holger Müller, *Measurement of the fine-structure constant as a test of the Standard Model*, Science, 13 April 2018, Vol. 360, Issue 6385, pp. 191-195, <https://arxiv.org/abs/1812.04130>
- [5] In the approximation where $\tan(\pi/4 - \theta_W) = e$, see G. Lopez Castro, J. Pestieau, *The unit of electric charge and the mass hierarchy of heavy particles*, Mod. Phys. Lett. A22, 2909-2916 (2007), <https://arxiv.org/abs/hep-ph/0609131>
- [6] J. Pestieau, *Variations on the Gauge Sector of the Electroweak Model*, <http://www.d-meeus.be/physique/40years.xhtml> (2009) ; *Exploration in the Boson Sector of the Glashow-Salam-Weinberg model*, <http://www.d-meeus.be/physique/bosonGSWmodel.pdf> (2012).
- [7] <http://pdg.lbl.gov/2018/reviews/rpp2018-rev-standard-model.pdf> in M. Tanabashi *et al.* (Particle Data Group) Phys. Rev. D98, 030001 (2018).
- [8] G. Lopez Castro, J. Pestieau, *Relation between masses of particles and the Fermi constant in the electroweak Standard Model*, <https://arxiv.org/abs/1305.4208> (2013).
- [9] J. Pestieau, *A closure relation relating particles' masses and Higgs field VEV in the scalar singlet dark matter model*, <http://www.d-meeus.be/physique/>

ScalarSingletDarkMatterModel.html(2017) ; The Gambit Collaboration, Peter Athron *et al.*, *Status of the scalar singlet dark matter model*, Eur. Phys. J. C77, 568 (2017), <https://arxiv.org/abs/1705.07931>