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A closure relation relating particles' masses and Higgs field VEV in the scalar singlet dark matter model

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One of the simplest viable models for dark matter is, next to the standard model, an additional scalar singlet *S*, permitted by $\mathbb{Z}_2$ symmetry.

The Lagrangian density *L* is expressed then as [1]

$$L = L_{SM} + L_S \qquad (1)$$

where L_{SM} is the standard model density Lagrangian and L_S is the scalar singlet dark matter density Lagrangian

$$L_S = 1/2\ \mu_S^2\ S^2 + 1/2\ \lambda_{HS} S^2 H^* H + 1/4\ \lambda_S S^4 + 1/2\ \partial_\mu S \partial^\mu S. \qquad (2)$$

From left to right, we have the bare *S* mass, the Higgs-scalar singlet coupling, the S quartic self-coupling, and the *S* kinetic term.

The singlet mass m_S is obtained from

$$m_S^2 = \mu_S^2 + 1/2\ \lambda_{HS}\ v^2, \qquad (3)$$

where v = 246.22 GeV is the VEV of H, the Higgs field.

If $\lambda_{HS} = 0$, dark matter has no interaction with ordinary matter except through gravitational field.

We propose a sum rule or a closure relation relating particle masses and v :

$$m_H^2 + m_W^2 + m_Z^2 + (m_S^2 - \mu_S^2) + m_t^2 + m_b^2 + m_c^2 + m_\tau^2 + \ldots = v^2 \qquad (4)$$

Noticing that, in the electroweak standard model, the couplings of all particles to the *H* field are proportional to $1/v$, namely of the form m_i/v [3], we get from Eqs. (3) and (4)

$$2\lambda + g^2/4 + (g^2 + g'^2)/4 + \lambda_{HS}/2 + (y_t^2 + y_b^2 + y_c^2 + y_\tau^2 + \ldots)/2 = 1 \qquad (5)$$

In fact, what we propose is that v^2 is exclusively built on the particles' masses. v^2 is a paved parquet exclusively composed of particles' masses.

Case with $\lambda_{HS} = 0$ ($m_S^2 - \mu_S^2 = 0$) has been considered in Ref. [3].

With

$$m_H = 125.0 - 125.5 \text{ GeV (CMS 2017)}, \qquad (6)$$

$$m_H = 124.7 - 125.3 \text{ GeV (ATLAS 2017)}, \qquad (7)$$

we guess

$$m_H = 125.0 - 125.3 \text{ GeV}. \qquad (8)$$

Then Eqs. (3) and (4) imply

$$m_t = 173.6 - 173.9 \text{ GeV} \quad (9)$$

to be compared with

$$m_t = 172.0 - 172.9 \text{ GeV (CMS 2016)} \quad (10)$$

$$m_t = 172.1 - 173.5 \text{ GeV (ATLAS 2017)} \quad (11)$$

Now from Eqs. (10) and (11), we guess

$$m_t = 172.1 - 172.9 \text{ GeV} \quad (12)$$

With Eqs (3), (4), (8) and (12), we get

$$m_S^2 - \mu_S^2 = 1/2\, \lambda_{HS}\, v^2 = (15 - 25 \text{ GeV})^2 \quad (13)$$

or

$$\lambda_{HS} = 0.008 - 0.021 \quad (14)$$

In Refs. [2], [4] and [5], it has been noted that dark matter phenomenology is driven predominantly by m_S and λ_{HS}, with viable solutions known to exist in a number of regions, in particular where m_S is around $m_H/2$ and where coupling λ_{HS} is very small ($\lambda_{HS} < 0.01$). Furthermore the scalar singlet can constitute all the observed dark matter.

In the framework of the scalar singlet dark matter model — assuming Eq.(4) — a more precise value of λ_{HS} is dependent on more precise values of m_t and m_H.

References

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[2] For recent updates and references, see : The Gambit Collaboration, "Status of the scalar singlet dark matter model", *Eur. Phys. J.* C **77**, 568 (2017), https://arxiv.org/abs/1705.07931.

[3] G. López Castro and J. Pestieau, "Relation between masses of particles and the Fermi constant in the electroweak Standard Model" (2013), https://arxiv.org/abs/1305.4208.

[4] J. M. Cline, K. Kainulainen, P. Scott, and C. Weniger, "Update on scalar singlet dark matter", *Phys. Rev.* D **88** (2013) 055025, https://arxiv.org/abs/1306.4710.

[5] A. Beniwal, F. Rajec, et. al., "Combined analysis of effective Higgs portal dark matter models", *Phys. Rev.* D **93** (2016) 115016, https://arxiv.org/abs/1512.06458.