Effective Higgs interactions of composite dark matter†

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The recent discovery of the Higgs boson has placed significant and direct constraints on models which predict new physics near the electroweak scale. At the same time, recent dark matter direct-detection experiments have greatly improved their sensitivity, pushing into the region of parameter space where dark matter interacts with the standard model through exchange of a Higgs boson.

These new constraints are particularly interesting in the context of composite dark matter models (e.g.[1)]). In such a model, the lightest stable bound state of a strongly-coupled gauge sector provides a dark matter candidate. Although the bound state itself must be net electroweak neutral due to direct-detection experimental constraints, its constituents may carry electroweak charges; the resulting interactions with the standard model in the early universe can explain the observed dark matter abundance, while scattering from present-day direct detection experiments is through suppressed higher-dimensional operators[2)].

If the dark gauge interaction spontaneously breaks a continuous symmetry, then some of the bound states will be massless Nambu-Goldstone bosons, which are ruled out by experiment if they are electroweak charged. A realistic composite dark matter model thus requires a mechanism for mass generation of the constituents. In most models the constituents are fermions, and they can be given mass through the Higgs mechanism; depending on the assignment of charges, "vector-like" mass terms may also be allowed[3)]. The Higgs couplings required for mass generation are directly constrained by direct-detection experiment, in terms of the Higgs coupling of the dark matter bound state itself.

We consider for concreteness a model consisting of an SU(4) dark gauge force, and a set of degenerate fermions m_f carrying electric charge $Q = \pm 1/2$. The dark matter candidate is a neutral baryon-like bound state of four such fermions, and has total mass m_B. The coupling of the Higgs boson to this baryon-like state is given by the formula

$$g_{h,B} = \frac{m_B}{v} \left(\sum_f \frac{v}{m_f} \left. \frac{\partial m_f(h)}{\partial h} \right|_{h=v} \right) f_f^{(B)} \qquad (1)$$

where $v = 246$ GeV is the vacuum expectation value of the Higgs field. The factor $f_f^{(B)}$ contains the scalar matrix element of the fermions inside the baryon-like state, $\langle B|\bar{f}f|B\rangle$. This matrix element can be extracted using the Feynman-Hellmann theorem from the slope of the baryon mass, $\partial m_B/\partial m_f$; this is a non-perturbative quantity, and is calculated using lattice simulations of the SU(4) theory. We find $0.15 \lesssim f_f^{(B)} \lesssim 0.34$ in the range of fermion masses simulated.

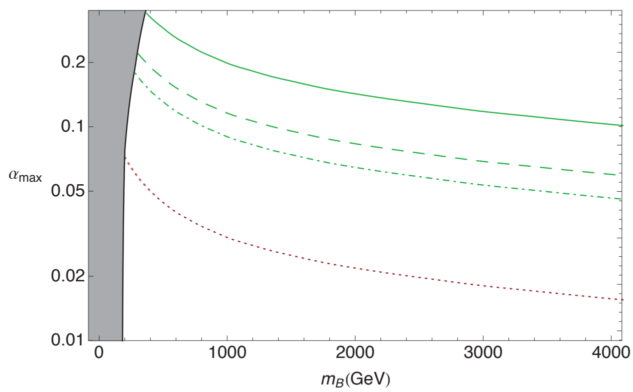

Fig. 1. From[3)], upper bound on the effective Higgs coupling α based on three lattice simulations at various values of the fermion mass (green curves) and in the heavy quark limit (red dotted curve). The filled region on the left shows values of m_B ruled out by experimental bounds on light charged particles from LEP.

Finally, the term in parentheses,

$$\alpha = \frac{v}{m_f} \left. \frac{\partial m_f(h)}{\partial h} \right|_{h=v}, \qquad (2)$$

is entirely model-dependent, and parameterizes the fraction of the fermion mass m_f which is generated due to the Higgs mechanism; if there are no "vector-like" mass terms, then $\alpha = 1$. The current upper bound on α in this model, based on our lattice calculation of $f_f^{(B)}$ and the latest experimental results from LUX[4)], is shown in Fig. 1. For the entire range of models considered, this constraint is significantly less than 1, indicating that generation of m_f in this model requires more than the Higgs mechanism alone.

References

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† Condensed from the article in Phys. Rev. **D89**, 094508 (2014)

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