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Higgs portal and Dark Matter

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We summarize in this letter the implications of the LHC Higgs searches for Higgs-portal models of dark matter for a 125 GeV Higgs. Their impact on the cosmological relic density and on the direct detection rates are studied in the context of generic scalar, vector and fermionic thermal dark matter particles. Assuming a sufficiently small invisible Higgs decay branching ratio, we find that current data, in particular from the XENON experiment, essentially exclude fermionic dark matter as well as light, i.e. with masses below $\approx$ 60 GeV, scalar and vector dark matter particles.

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Introduction

The ATLAS and CMS collaborations have recently reported excess of events in the data which could correspond to a SM like Higgs boson with a mass of 125 ± 1 GeV. Given the fact that the ATLAS and CMS signal is close to what one expects for a Standard Model–like Higgs particle, there is little room for invisible decays. In what follows, we will assume that 10% is the upper bound on the invisible Higgs decay branching ratio, although values up to 20% will not significantly change our conclusions. We adopt a model independent approach and study generic scenarios in which the Higgs-portal DM is a scalar, a vector or a Majorana fermion.

The models

Following the model independent approach of Ref. [1], we consider the three possibilities that dark matter consists of real scalars S, vectors V or Majorana fermions χ which interact with the SM fields only through the Higgs-portal. The stability of the DM particle is ensured by a Z_2 parity, whose origin is model–dependent. For example, in the vector case it stems from a natural parity symmetry of abelian gauge sectors with minimal field content [2]. The relevant terms in the Lagrangians are

$$\begin{aligned}
\Delta\mathscr{L}_S &= -\frac{1}{2}m_S^2 S^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{4}\lambda_{hSS} H^\dagger H S^2 \,, \\
\Delta\mathscr{L}_V &= \frac{1}{2}m_V^2 V_\mu V^\mu + \frac{1}{4}\lambda_V (V_\mu V^\mu)^2 + \frac{1}{4}\lambda_{hVV} H^\dagger H V_\mu V^\mu , \\
\Delta\mathscr{L}_f &= -\frac{1}{2}m_f \bar{\chi}\chi - \frac{1}{4}\frac{\lambda_{hff}}{\Lambda} H^\dagger H \bar{\chi}\chi \,. \qquad (1)
\end{aligned}$$

The most important formulas relevant to our study. Related ideas and analyses can be found in [2, 3, 4, 5, 6] and more recent studies of Higgs-portal scenarios have appeared in [7, 8]. We should note that in our numerical analysis, we take into account the full set of relevant diagrams and channels, and we have adapted the program micrOMEGAs [9] to calculate the relic DM density.

The properties of the dark matter particles can be studied in direct detection experiments. The DM interacts elastically with nuclei through the Higgs boson exchange. The resulting nuclear recoil is then interpreted in terms of the DM mass and DM–nucleon cross section. The spin–independent DM–nucleon interaction can be found in [1] Moreover, if the DM particles are light enough, $M_{\rm DM} \le \frac{1}{2}m_h$, they will appear as invisible decay products of the Higgs boson. For the various cases, the Higgs partial decay widths into invisible DM particles are given by

$$\begin{aligned}
\Gamma^{\rm inv}_{h\to SS} &= \frac{\lambda_{hSS}^2 v^2 \beta_S}{64\pi m_h} \,, \\
\Gamma^{\rm inv}_{h\to VV} &= \frac{\lambda_{hVV}^2 v^2 m_h^3 \beta_V}{256\pi M_V^4}\left(1 - 4\frac{M_V^2}{m_h^2} + 12\frac{M_V^4}{m_h^4}\right) , \\
\Gamma^{\rm inv}_{h\to\chi\chi} &= \frac{\lambda_{hff}^2 v^2 m_h \beta_f^3}{32\pi\Lambda^2} \,, \qquad (2)
\end{aligned}$$

where $\beta_X = \sqrt{1 - 4M_X^2/m_h^2}$.

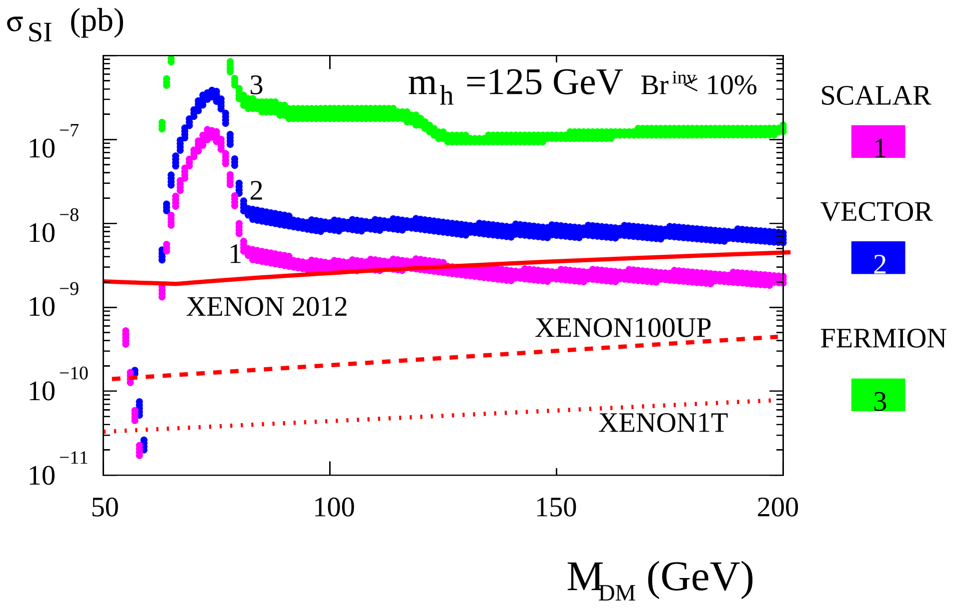

Figure 1: Spin independent DM–nucleon cross section versus DM mass. The upper band (3) corresponds to fermion DM, the middle one (2) to vector DM and the lower one (1) to scalar DM. The solid, dashed and dotted lines represent XENON100 (2012 data [11]), XENON100 upgrade and XENON1T sensitivities, respectively.

Astrophysical consequences

The first aim of our study was to derive constraints on the various DM particles from the WMAP satellite [10] and from the current direct detection experiment XENON100 [11], and to make predictions for future upgrades of the latter experiment, assuming that the Higgs boson has a mass $m_h = 125$ GeV and is approximately SM–like such that its invisible decay branching ratio is smaller than 10%; we have checked that increasing this fraction to 20% does not change our results significantly.

We find that light dark matter, $M_{\rm DM} \lesssim 60$ GeV, violates the bound on the invisible Higgs decay branching ratio and thus is excluded. This applies in particular to the case of scalar DM with a mass of 5–10 GeV considered, for instance, in Ref. [5]. On the other hand, heavier dark matter, particularly for $M_{\rm DM} \gtrsim 80$ GeV, is allowed by both $\rm BR^{inv}$ and XENON100. We note that almost the entire available parameter space will be probed by the XENON100 upgrade. The exception is a small resonant region around 62 GeV, where the Higgs–DM coupling is extremely small.

This can be seen from Fig. 1, which displays predictions for the spin–independent DM–nucleon cross section $\sigma_{\rm SI}$ (based on the lattice f_N) subject to the WMAP and $\rm BR^{inv} < 10\%$ bounds. The prospects for the upgrade of XENON100 (with a projected sensitivity corresponding to 60,000 kg-d, 5-30 keV and 45% efficiency) and XENON1T are shown by the dotted lines. We find that light dark matter, $M_{\rm DM} \lesssim 60$ GeV, violates the bound on the invisible Higgs decay branching ratio and thus is excluded. This applies in particular to the case of scalar DM with a mass of 5–10 GeV considered, for instance, in Ref. [5] The upper band corresponds to the fermion Higgs-portal DM and is excluded by XENON100. On the other hand, scalar and vector DM are both allowed for a wide range of masses. Apart from a very small region around $\frac{1}{2}m_h$, this parameter space will be probed by XENON100–upgrade and XENON1T. The typical value for the scalar $\sigma_{\rm SI}$ is a few times 10^{-9} pb, whereas $\sigma_{\rm SI}$ for vectors is larger by a factor of 3 which accounts for the number of degrees of freedom.

Conclusion

We have analyzed the implications of the recent LHC Higgs results for generic Higgs-portal models of scalar, vector and fermionic dark matter particles. Requiring the branching ratio for invisible Higgs decay to be less than 10%, we find that the DM–nucleon cross section for electroweak–size DM masses is predicted to be in the range $10^{-9} - 10^{-8}$ pb in almost all of the parameter space. Thus, the entire class of Higgs-portal DM models will be probed by the XENON100–upgrade and XENON1T direct detection experiments, which will also be able to discriminate between the vector and scalar cases. The fermion DM is essentially ruled out by the current data, most notably by XENON100. Furthermore, we find that light Higgs-portal DM $M_{\rm DM} \lesssim 60$ GeV is excluded independently of its nature since it predicts a large invisible Higgs decay branching ratio, which should be incompatible with the production of an SM–like Higgs boson at the LHC. A more detailed analysis can be found in [12].

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