Invisible Higgs and scalar dark matter

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Abstract. In this proceeding, we show that when we combined WMAP and the most recent results of XENON100, the invisible width of the Higgs to scalar dark matter is negligible ($\lesssim 10\%$), except in a small region with very light dark matter ($\lesssim 10$ GeV) not yet excluded by XENON100 or around 60 GeV where the ratio can reach 50\% to 60\%. The new results released by the Higgs searches of ATLAS and CMS set very strong limits on the elastic scattering cross section.

1. Introduction
Two of the most important issues in particle physics phenomenology are the nature of the dark matter and the mechanism to realize spontaneously the electroweak symmetry breaking of the Standard Model (SM). The observations made by the WMAP collaboration show that the matter content of the universe is dark, making up about 85\% of the total amount of matter whereas the XENON collaboration recently released its constraints on direct detection of dark matter. These constraints are the most stringent in the field nowadays, and begin to exclude a significant part of the parameter space of the Weakly Interacting Massive Particle (WIMP) paradigm. On the other front, the accelerator collaborations ATLAS, CMS and D0/CDF [1] have obtained important results concerning the Higgs searches. It is obvious that the Higgs hunting at LHC is intimately linked with measurement of elastic scattering on nucleon, especially in Higgs-portal like models where the Higgs boson is the key particle exchanged through annihilation/scattering processes. It has already been shown recently that a combined LEP/TEVATRON/XENON/WMAP analysis can restrict severely the parameter space allowed in generic constructions [2]. In this work, we apply such analysis in the specific context of a scalar singlet dark matter extension of the SM and show that most of the region allowed by WMAP will be excluded/probed by LHC and XENON100 by the end of next year.

2. The model
The simplest extension of the SM is the addition of a real singlet scalar field. Although it is possible to generalize to scenarios with more than one singlet, the simplest case of a single additional singlet scalar provides a useful framework to analyze the generic implications of an augmented scalar sector to the SM. The most general renormalizable potential involving the SM Higgs doublet $H$ and the singlet $S$ is

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + (D_{\mu}H)^\dagger(D^{\mu}H) + \frac{1}{2}\mu_H^2H^\dagger H - \frac{1}{4}\lambda_H H^4$$
\[
\begin{align*}
+ \frac{1}{2} \partial_\mu S \partial^\mu S - \frac{\lambda_S}{4} S^4 - \frac{\mu_S^2}{2} S^2 - \frac{\lambda_H S}{4} S^2 H^1 H \\
- \frac{\kappa_1}{2} H^1 HS - \frac{\kappa_3}{3} S^3 - V_0
\end{align*}
\]

(1)

where \( D_\mu \) represents the covariant derivative.

Different aspects of scalar singlet extension of the SM has already been studied in [3] whereas a nice preliminary analysis of its dark matter consequences can be found in [4]. Some authors also tried to explain the DAMA/LIBRA and/or CoGeNT excess [5] whereas other authors probed the model by indirect searches [6], or looked at the consequences of earlier XENON data [7] or at the LHC [8] or all combined [9].

Recently the XENON100 collaboration released new data, the most stringent in the field of dark matter detection. Moreover, recently CRESST experiment released their analysis in the low mass region [12] and seems to converge with DAMA/LIBRA and CoGeNT toward a possible light dark matter signal for a mass around 10 GeV [13]. In the meantime, if \( m_S \lesssim M_H/2 \) the invisible width decay\(^2\) of the Higgs \( H \rightarrow SS \) could perturbate the Higgs searches at LHC based on SM Higgs branching ratio (see Eq. 2). However, one can easily understand that there exists a tension between the direct detection measurement and the invisible branching ratio. Indeed, for decreasing mass of DM \( (m_S \lesssim 100 \text{ GeV}) \), the spin independent cross section increases. Quantitatively speaking, one needs to compare the invisible Higgs width \( (H \rightarrow SS) \)

\[
\Gamma^\text{inv}_H = \frac{\lambda_H^2 m_H^4}{32\pi g^2 M_H^2} \sqrt{M_H^2 - 4m_S^2}
\]

(2)

with the spin independent scattering cross section on the proton

\[
\sigma^\text{SI}_{S-p} = \frac{m_p^4 \lambda_H^2 (\sum_q f_q)^2}{16\pi (m_p + m_S)^2 M_H^4}
\]

(3)

Combining Eq. (2) and (3) one obtains

\[
\frac{\Gamma^\text{inv}_H}{\sigma^\text{SI}_{S-p}} = \frac{(m_S + m_p)^2 M_H^2 M_W^2 \sqrt{M_H^2 - 4m_S^2}}{2g^2 f^2 m_p^4}
\]

(4)

Some points with high invisible width still survive. They correspond to two distinct regions:

- A region with very light scalar \( (m_S \lesssim 10 \text{ GeV}) \) still not yet excluded by the precision of XENON100 experiments due to its high threshold. This corresponds to very large invisible branching ratio.
- A region with \( 50 \text{ GeV} \lesssim m_S \lesssim 70 \text{ GeV} \) with branching ratio which can reach 60\% – 70\% which is the region taken in consideration in [15].

We show the effects of combining WMAP and XENON100 data in Fig. 1 and 2. As one can see, in Fig. 2 except for these two particular regions, the majority of points respecting WMAP and XENON100 constraints give very low invisible width. As a conclusion, we can affirm that the Higgs searches at LHC with a scalar dark matter is not affected for \( M_H \gtrsim 150 \text{ GeV} \) It means that we can use the standard Higgs limit searches of ATLAS and CMS and apply them in the

1

\footnotesize{Keeping an eye on the results of CoGeNT collaboration, recent works showed there exists a tension between XENON100 and CoGeNT [10], or not [11]. We thus safely decided not to discuss in detail the CoGeNT issue in our analysis.}

\footnotesize{See the works in [14] for an earlier study of invisible width of the Higgs. Moreover, during the revision of this study, several independant works confirming our results were published in [15].}
Figure 1. Branching ratio for the invisible Higgs decay into scalars as a function of the Higgs mass. The scan is over \((m_H, m_S, \lambda_{hs})\) and subject to the WMAP, XENON100 and ATLAS/CMS constraints.

Due to the last data released recently by CRESST collaboration [12] it is interesting to notice that some points in the parameter space around \(m_S \simeq 10 \text{ GeV}\) are not yet excluded by the latest XENON100 constraints as can be seen in the upper left corner of Fig. 2. These points generates a Higgs completely invisible at the LHC. This corresponds to the region near \(\text{Br}(H \rightarrow SS) \simeq 100\%\) in Fig. 1.

It is also interesting to point out that the Higgs-portal construction is similar by several aspects to the Z'-portal model of dark matter [17]: as any Higgs searches restrict severely the parameter space of the model, any Z' searches at LHC should be use in complementarity with

In our numerical study, we obviously took into consideration the invisible Higgs width to apply the CMS and ATLAS constraints
direct detection searches to probe the entire parameter space allowed by WMAP. A vectorial dark matter will also give similar results [16] At the same time, the analysis should be done is SUSY scenario where light Higgses are the main annihilation channel, leading to sever direct detection constraints [18]. Writing the conclusion of this work, we noticed that authors just looked at some consequences of recent Higgs searches at LHC in the NMSSM case [19] and extended scalar sectors [20].

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