Letter

Keeping it renormalizable: Minimal baryogenesis induced asymmetric dark matter

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Many asymmetric dark matter scenarios have been proposed to date. Among them, perhaps the most motivated ones are those in which the dark matter asymmetry is induced from the baryon/lepton asymmetries via chemical equilibration without any new sources of *CP* violation. However, most of the models put forward along these lines have been excluded by now and/or are based on complicated setups. In this Letter, we present a new, simple, and viable scenario. It assumes only two new fields: a scalar singlet and an inert scalar doublet, and is based only on *renormalizable* interactions, that slowly generate the dark matter asymmetry from the Standard Model Higgs asymmetry. The successful asymmetry transfer requires small (but technically natural) couplings which in turn make the model *CP* conserving in practice. The model allows for the direct detection of dark matter in the upcoming generation of experiments, and the inert doublet is predicted to be light enough to be potentially produced and observed at the LHC and future colliders, 46 GeV $< m_{H'} <$ 580 GeV. Quite remarkably, the mass and lifetime of the inert doublet may be inferred from direct detection experiments, indicating long-lived compressed electroweak states that can be searched for at the High-Luminosity LHC.

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Introduction and motivation. Ordinary matter in the Universe is asymmetric: we live in a Universe where structures are made of baryons with essentially no antibaryons. The baryons that form the Universe today are those generally expected to have survived the matter-antimatter annihilation in the early Universe at a temperature $T \simeq 40$ MeV [1,2]. Given this situation for the baryons, one wonders if the dark matter (DM) relic density today could also stem from a particle-antiparticle dark matter asymmetry created prior to a dark matter annihilation, and if the two asymmetries are connected in any way.

Among the many proposed asymmetric dark matter creation scenarios (see Refs. [3–7] for reviews), one particularly simple and motivated general class of models assumes that the dark matter asymmetry is induced via chemical equilibration from the primordial asymmetries created during baryogenesis. This is economical because it does not require an all-encompassing dark sector with its own *CP* violation to create the dark matter asymmetry. Here, the *CP* violation assumed reduces to the one that is at the origin of baryogenesis. For instance, within the leptogenesis mechanism [8], which, as of today, provides the most straightforward and motivated explanation for baryogenesis, lepton and Higgs asymmetries are generated by *CP* violation in the seesaw Yukawa interactions at the origin of the neutrino masses. These asymmetries are partly converted into a baryon asymmetry via the sphaleron processes. In this context, the question is whether these asymmetries could also be partially reconverted into a dark matter asymmetry, thereby dictating the dark matter relic density as well.

Several scenarios of this type have been proposed based on a higher-dimensional equilibration interaction [9–15] or with renormalizable interactions [15]; see also Ref. [14]. All these scenarios have some concerns. An important experimental one comes from direct-detection experiments that have significantly improved their sensitivity in recent years [16]. These bounds preclude using the Standard

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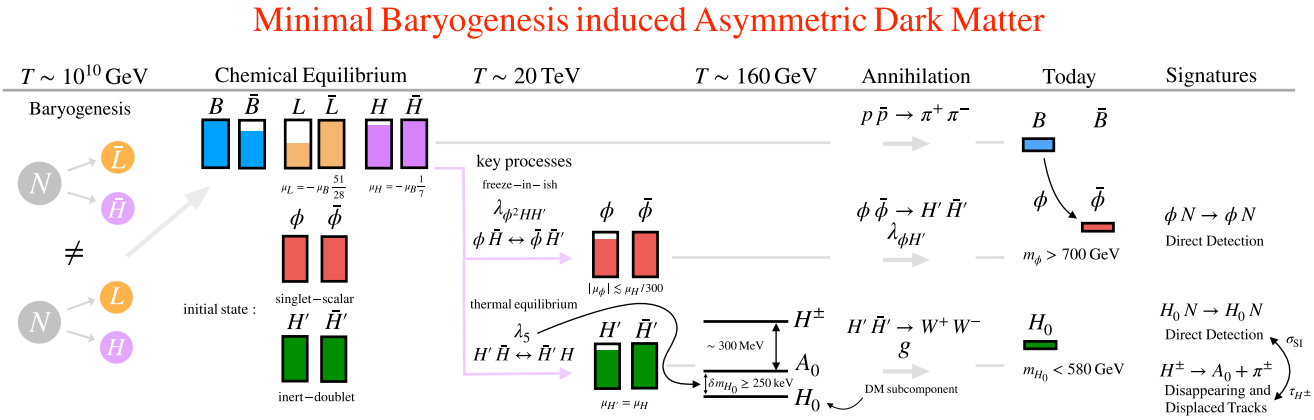


FIG. 1. Sketch of our scenario for minimal baryogenesis induced asymmetric dark matter, based on two new fields H' (a new inert Higgs doublet), and ϕ (a complex singlet scalar). Starting from a baryon asymmetry (generated by, e.g., thermal leptogenesis) chemical equilibrium implies an SM Higgs doublet asymmetry at $T > T_{\rm EW}$; see footnote 1. The $\lambda_{\phi^2 HH'} \sim 10^{-6}$ coupling slowly creates the ϕ asymmetry from the SM Higgs asymmetry, thus connecting it to the baryon asymmetry of the Universe. λ_5 triggers interactions that thermalize, leading to $\mu_{H'} = \mu_H$, and provides a mass splitting between A_0 and H_0 that avoids Z-mediated direct detection from the inert doublet. After annihilations, we end up with a two-component dark matter scenario: a dominant asymmetric ϕ population and a subleading symmetric H_0 population. $\Omega_{H_0} h^2 = 0.12 (m_{H_0}/580\ \text{GeV})^2$ and hence the lighter H_0 the more asymmetric is dark matter.

Model (SM) final states to induce fast dark matter annihilation processes that need to be more efficient than for weakly interactive massive particles, so that the DM relic abundance is dominated by a particle-antiparticle asymmetry. For instance, a $\overline{DM} DM H^\dagger H$ Higgs portal interaction is fully excluded for perturbative interactions for the complex scalar singlet case [17]. Other issues are theoretical. One is the need for a UV completion for scenarios based on higher-dimensional operators, which can be involved. Another concerns scenarios in which one assumes a Z_2 symmetry to stabilize the DM candidate and where the DM is hyperchargeless. In this case, a DM^2 quadratic term is allowed and would put any created DM asymmetry back to zero, unless very tiny. Large charged lepton flavor violation can also arise generically in setups involving standard model leptons in the equilibration interaction, unless a large flavor hierarchy between lepton generations is assumed.

The scenario: Minimal baryogenesis induced asymmetric dark matter. In this Letter, we propose a new baryogenesis induced asymmetric dark matter scenario that is perfectly viable, is simple, and has signatures; see Fig. 1 for a sketch. Our model is rather simple because it is based on the adjunction of only two new fields, and is based only on renormalizable interactions. This also maximizes its testability as all the physics at the origin of the dark matter asymmetry lies around the dark matter mass scale, or below. The two fields assumed are a complex singlet scalar ϕ, and an inert Higgs doublet H'.

In our scenario, the dark matter today arises predominantly from an asymmetric population of ϕ particles. On the other hand, the new Higgs doublet $H' = (H^+, (H_0 + iA_0)/\sqrt{2})^T$ is employed to 1) enable transport the SM asymmetries into the dark matter sector,[1] and 2) as a final state for $\phi\bar{\phi} \to H'\bar{H}'$ annihilations, in agreement with the lack of signals at direct detection experiments.

We assume a Z_4 DM stabilization symmetry, under which ϕ has charge $+1$ and H' charge -2. This forbids a quadratic term in the DM field, ϕ^2, which as already mentioned above, would diminish any asymmetry created, unless very tiny. Furthermore, this particle content and symmetry structure allow for two renormalizable particle-antiparticle asymmetry transfer channels: $\lambda_5 (H^\dagger H')^2$ and $\lambda_{\phi^2 HH'} \phi^2 H^\dagger H'$ (with H being the SM Higgs doublet), whose interplay will lead to the new dynamical scenario we present here for generating the asymmetry. Note importantly that there are very few possible renormalizable interactions that could transfer an SM asymmetry into a DM asymmetry, and these two interactions are the simplest ones.

The λ_5 interaction that involves only one new Beyond the Standard Model (BSM) field cannot lead on its own to the observed relic density with DM being the lightest neutral component of the inert doublet H'. The lightest neutral component of a H' inert doublet, H_0 or A_0, is excluded by direct detection experiments as a DM candidate, because it undergoes too fast Z-exchange scattering with nucleons, unless the latter is unavailable kinematically. As the Z boson couples to $H_0 A_0$, this will be the case provided that the neutral components split by $\delta m_{H_0} \equiv |m_{H_0} - m_{A_0}| \gtrsim 250$ keV [19–21]. This will be accomplished after

[1] In the presence of a baryon asymmetry and at $T > T_{\rm EW}$, all SM states but the $W^\pm$ have different numbers of particles and antiparticles, including the Higgs doublet [18].

electroweak symmetry breaking if the λ_5 interaction is sizable enough:

$$|\lambda_5| \gtrsim 1.65 \times 10^{-6} \left(\frac{m_{H_0}}{200\ \text{GeV}}\right)\left(\frac{\delta m_{H_0}}{250\ \text{keV}}\right). \quad (1)$$

However, a λ_5 interaction satisfying this bound turns out to be still in thermal equilibrium when the H' is already deeply nonrelativistic, largely Boltzmann suppressing the H' asymmetry, so that the resulting H' asymmetry is too small to account for the DM observed relic density (explaining why we consider the singlet ϕ to be responsible for most of the relic density rather than H'); see Ref. [15] and Eq. (3), below.

The $\lambda_{\phi^2 HH'}\phi^2 H^\dagger H'$ interaction also cannot lead on its own to the observed DM relic density. Without λ_5, there is no mass splitting and $m_{H'}$ must be heavier than twice the mass of ϕ so that it is unstable. But in this case, as a result of the fact that without λ_5 the Lagrangian has a global $U(1)$ symmetry, even if a ϕ asymmetry is created, it will be erased by the H' decay later on. However, the interplay of both $\lambda_{\phi^2 HH'}$ and λ_5 interactions can easily do the job.

The relevant terms of the scalar potential are the following:[2]

$$\begin{aligned} V(H,H',\phi) = {} & m_\phi^2|\phi|^2 + m_{H'}^2|H'|^2 + \lambda_{\phi H}|\phi|^2|H|^2 \\ & + \lambda_{\phi H'}|\phi|^2|H'|^2 + \lambda_3|H|^2|H'|^2 + \lambda_4|H^\dagger H'|^2 \\ & + \left(\frac{\lambda_{\phi^2 HH'}}{2}\phi^2 H^\dagger H' + \text{H.c.}\right) \\ & + \left(\frac{\lambda_5}{2}(H^\dagger H')^2 + \text{H.c.}\right). \end{aligned} \quad (2)$$

Note that $\frac{\lambda'_{\phi^2 HH'}}{2}$, $\phi^2 H H'^\dagger$ and $\lambda_{\phi 4}(\phi^4 + \text{H.c.})/4!$ interactions are also allowed by the Z_4 symmetry. We have explicitly checked that unless both $|\lambda'_{\phi^2 HH'}|$ and $|\lambda_{\phi^2 HH'}|$ are equal within ∼10%, or unless $|\lambda_{\phi 4}|$ is much bigger than the largest of these two, the produced dark matter asymmetry is not significantly reduced, see Supplemental Material [25]. For simplicity, in what follows, we neglect these other couplings.[3]

There are several dynamical ways along which the DM asymmetry could be created *a priori* in this setup, depending mostly on the mass spectrum assumed and on which of the λ_5 and $\lambda_{\phi^2 HH'}$ interactions reaches thermal equilibrium at some point. Several of them turn out to be excluded for various reasons, but one regime turns out to work very well generically, which we present in this Letter. It considers the $m_{H'} < m_\phi$ mass spectrum and the case where the λ_5 interaction reaches thermal equilibrium, whereas the $\lambda_{\phi^2 HH'}$ never does, leading to an out-of-equilibrium production of the DM ϕ asymmetry.

Before explaining how the produced ϕ asymmetry accounting for the observed DM relic density is created along this scenario, let us first discuss how a number of important constraints that appear to be fatal in many other potential setups are satisfied in this scenario.

(a) Fate of the symmetric DM ϕ component. To ensure that the DM symmetric component is subleading with respect to the asymmetric component turns out to be a very strong constraint for asymmetric dark matter scenarios. For instance, the direct detection constraints exclude the possibility that the $\lambda_{\phi H}$ Higgs portal interaction successfully depletes the symmetric dark matter abundance [17]. However, if $m_{H'} < m_\phi$, the $\phi\bar{\phi}$ annihilation into $H'\bar{H}'$, from the $\lambda_{\phi H'}$ interaction (which is less constrained) can do the job.

(b) Fate of the symmetric DM H' component. If $m_{H'} < m_\phi$ as we assume, DM is not only made of ϕ but also of the lightest neutral component of H', since it is stable, too. One should therefore wonder about the fate of its symmetric component. This will be subleading if $m_{H'} < m_{H'}^{\text{EW}}$, with $m_{H'}^{\text{EW}} = 580$ GeV (see Refs. [26,27]), the value of $m_{H'}$ for which the electroweak symmetric annihilations of H' leads to the observed dark matter abundance. Therefore, we will consider that $m_{H'} < m_{H'}^{\text{EW}}$.

(c) Fate of the asymmetric DM H' component. If the λ_5 interaction is in thermal equilibrium, then $\mu_{H'} = \mu_H$, which implies that when this interaction enters thermal equilibrium, the following equality holds:

$$\frac{\Delta H'}{\Delta H} = \frac{Y_{H'}^{eq}}{Y_H^{eq}} \propto e^{-m_{H'}/T}, \quad (3)$$

where Y_X refers to the number density, n_X, of a given species X, normalized to entropy, and $\Delta X \equiv Y_X - Y_{\bar{X}}$. For $T \gtrsim m_{H'}$ $\Delta H = \Delta H'$, but for $T \lesssim m_{H'}$ this gives instead a Boltzmann suppressed H' asymmetry.

The relation above holds approximately as long as chemical equilibrium is maintained, which happens until relatively low temperatures, due to $H\bar{H}' \to \bar{H}H'$ scatterings which are not Boltzmann suppressed. In any case, the fate of the H' asymmetry is to disappear as at the electroweak phase transition $T_{\text{EW}} \simeq 160$ GeV the H' will split into two neutral and two charged states, and the two neutral states will undergo very fast oscillations, which will set the asymmetry to zero (see, e.g., Ref. [15]).

(d) Direct detection constraints on ϕ and H'. Direct detection constraints on ϕ are trivially satisfied because ϕ interacts with the SM only through either

[2]Note that the same scalar singlet-doublet content has been used in different contexts, including for asymmetric DM [15] and symmetric DM [22–24].

[3]Note that all interaction couplings in Eq. (2) can be made real by an appropriate rephasing of the various fields, so that the only *CP* violation at the source of the DM asymmetry is the one at the origin of baryogenesis. Technically, only the secondary $\lambda'_{\phi^2 HH'}$ and $\lambda_{\phi 4}$ couplings can carry a physical phase, but their effect will be irrelevant.

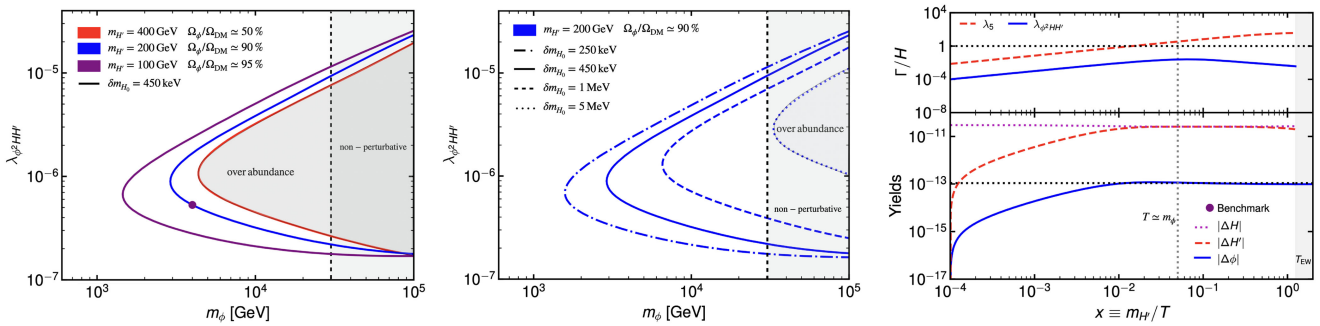


FIG. 2. Parameter space in the $\lambda_{\phi^2 HH'} - m_\phi$ plane, for various values of the doublet mass $m_{H'}$ (left) and of the neutral mass splitting $\delta m_{H_0} \equiv |m_{H_0} - m_A|$ (middle) that is directly related to the λ_5 coupling. For $m_\phi < 30$ TeV, the $\lambda_{\phi H'}$ coupling driving symmetric annihilations is expected to be perturbative [17]. In the right panel, we show the evolution for the benchmark point highlighted in the left panel as a purple dot. The upper subpanel represents the two relevant rates and the lower one the relevant yields.

the $\lambda_{\phi^2 HH'}$ interaction (which we assume to not enter into thermal equilibrium and thus be small) or the Higgs portal interaction $\lambda_{\phi H}$, which is not assumed to play any role in the scenario and thus can be small. Similarly, H' in our scenario also satisfies all direct detection constraints. As mentioned above, we work in a regime where $H'\bar{H} \to H\bar{H}'$ thermalizes, which means that the λ_5 coupling satisfies Eq. (1). Hence there is no dangerous tree-level Z mediated interaction rate with nuclei. Only a very small loop-suppressed contribution survives; see, e.g., Ref. [26]. Importantly, λ_3 and λ_4 lead to direct detection via Higgs exchange as well, but are not needed to ensure a fast enough H' annihilation, as below 580 GeV this is ensured by the electroweak $H'\bar{H}' \to W^+W^-$ channel.

While bounds are satisfied, the scenario perfectly allows that the values of these three couplings are below but close to the present direct detection sensitivity, so that ϕ or H' particles may be observed in the near future. The relevant interactions with nuclei are spin independent (see, e.g., Ref. [17]) and recasting the latest limit from LZ [16], one finds:

$$|\lambda_{Sh}| < 0.057\left(\frac{m_S}{\text{TeV}}\right)^{3/2}\sqrt{\frac{1}{f_S}}, \qquad \text{[LZ limit]}, \quad (4)$$

where $S = \phi, H_0/A_0$, with f_S being the fraction of the dark matter energy density in the form of S. For both dark matter components we have: $\lambda_{\phi h} = \lambda_{\phi H}$, $\lambda_{H_0 h} = \lambda_3 + \lambda_4 + \lambda_5 \simeq \lambda_3 - \frac{2}{v_H^2}(m_{H^\pm}^2 - m_H^2)$, $\lambda_{A_0 h} = \lambda_3 + \lambda_4 - \lambda_5 = \lambda_3 - \frac{2}{v_H^2} \times (m_{H^\pm}^2 - m_A^2)$, with $v_H = 246$ GeV.

Interestingly, assuming no strong cancellation between λ_3 and λ_4, we can impose a limit for each of these couplings, and the one for λ_4 actually leads to a limit on the induced mass splitting between the charged and neutral components, as follows:

$$m_{H^\pm} - m_{H_0} \simeq -\frac{\lambda_4 v_H^2}{4m_{H'}} \lesssim 1 \text{ GeV}. \quad [\text{LZ}, \lambda_3 = 0]. \quad (5)$$

As we will see later, this mass splitting dictates the lifetime of $H^\pm$ at colliders and hence leads to an interesting correlation between two different signatures to be measured by two distinct experiments.

Asymmetry generation and parameter space. At a temperature much larger than all masses involved, none of the asymmetric portal interactions are in thermal equilibrium as their rate scales as $\Gamma \sim \lambda^2 T$. As a result, a ϕ asymmetry, $\Delta\phi$, is created out of equilibrium by the processes induced by the $\lambda_{\phi^2 HH'}$ interaction, $\phi\bar{H} \to \bar{\phi}\bar{H}'$ and $H\bar{H}' \to \phi\phi$ (and conjugate processes). Considering the system in the ultra-relativistic limit, the ϕ asymmetry evolves as

$$\frac{d\Delta\phi}{dx} \simeq (\Delta H - \Delta H' - 4\Delta\phi) \times 3\frac{|\lambda_{\phi^2 HH'}|^2}{128\pi}\frac{m_{\rm Pl}}{1.66\pi^2\sqrt{g_\star}m_{H'}}, \quad (6)$$

where $x \equiv m_{H'}/T$, $m_{\rm Pl} = 1.22 \times 10^{19}$ GeV, and $g_\star \simeq 106$. At early times, $\Delta H' = \Delta\phi = 0$ and the $\Delta\phi$ asymmetry is generated through freeze-in from the Higgs ΔH asymmetry generated via baryogenesis.

The parameter space of the model in the $\lambda_{\phi^2 HH'} - m_\phi$ plane is shown in Fig. 2. From this figure, one observes that the right dark matter abundance is obtained in two branches for $\lambda_{\phi^2 HH'}$. The reason is simple: the lower branch corresponds to the case where the $\Delta\phi$ asymmetry is generated via almost freeze-in $\lambda_{\phi^2 HH'}$ coupling alone while the λ_5 interactions are still out of equilibrium. This can be explicitly understood from the right panel, which shows the temperature evolution of the asymmetries and rates for a successful set of couplings and masses. The upper branch corresponds on the other hand to a case where $\lambda_{\phi^2 HH'}$ interactions are out-of-equilibrium but not too far from the Hubble rate at a time where λ_5 interactions are deep in thermal equilibrium and $\Delta H' \simeq \Delta H$. This in turn actually suppresses the $\Delta\phi$ asymmetry and can lead to the correct dark matter abundance.

Note also that reducing m_ϕ, and keeping all other parameters fixed, leads to a smaller asymmetry, because in this case, both the λ_5 and $\lambda_{\phi^2 HH'}$ interactions thermalize more at $T \sim m_\phi$, whereas for too large a value of m_ϕ, the ϕ symmetric component cannot be suppressed enough with perturbative couplings. The efficiency of the mechanism then requires $m_\phi \gtrsim 400$ GeV. We refer to the Supplemental Material [25] for additional explanations and benchmark points illustrating all these features. The Supplemental Material includes references to Refs. [28,29].

Signatures. All in all, the parameter space of the scenario is

$$[\text{eff.}]\ 400\ \text{GeV} \lesssim m_\phi \lesssim 30\ \text{TeV}, \qquad [\text{pert.}], \tag{7a}$$

$$[\text{DD}]\ 250\ \text{keV} \lesssim \delta m_{H_0} \lesssim 5\ \text{MeV}, \qquad [\text{eff.}], \tag{7b}$$

$$[\text{LEP}]\ 46\ \text{GeV} \lesssim\ m_{H'} < 580\ \text{GeV}, \qquad [\text{DMab}], \tag{7c}$$

$$m_{H^\pm} - m_{H_0} \lesssim 1\ \text{GeV}, \quad [\text{DD, (for } \lambda_3 = 0)], \tag{7d}$$

$$\lambda_{\phi H'} > 0.35 m_\phi/(700\ \text{GeV}). \quad [\bar{\phi}\phi\text{annihilation}], \tag{7e}$$

where the origin of each bound has been indicated. The lower bound on $m_{H'}$ comes from the invisible decay of the Z [30] and quite remarkably a charged particle in line with Eqs. (7b) and (7d) evades all LEP searches for masses above 46 GeV; see Refs. [30,31]. The other bounds are described in previous sections (eff. refers to the efficiency of the mechanism, see Fig. 2). Note that $\Omega_{H_0} h^2 = 0.12(m_{H_0}/580\ \text{GeV})^2$, hence the lighter is H', the more asymmetric is dark matter.

A key prediction of the scenario is that the second inert Higgs doublet is light and therefore has clear discovery possibilities at the LHC, High-Luminosity LHC (HL-LHC), and future colliders. In particular, due to the compressed particle spectra in our scenario, H' can lead to disappearing and displaced charged tracks, $H^+ \to A_0 + \pi^+$. These types of signatures represent key channels of the flagship searches at the LHC, and very recently ATLAS and CMS have been able to supersede the LEP sensitivity for degenerate Higgsinos; see Refs. [32–36]. The inert doublet being a scalar has a smaller production cross section by a factor of ∼8 [37] and represents the next natural target. Critically, for a general inert doublet model, a light inert doublet would only be a subleading dark matter component, whereas in our case, it plays a major role as it is the portal to dark matter asymmetry. Furthermore, its lifetime is strongly correlated with the charged-neutral mass splitting, and in the absence of strong cancellations, it is directly controlled by the scattering with nuclei of H_0/A_0. Given that H' may be as light as 46 GeV and hence lighter than a xenon nucleus, it is possible that the next generation of direct detection experiments [38,39] could identify both its mass and its scattering rate and hence make a strong connection with the signatures at the HL-LHC. A detailed study of this phenomenology is beyond the scope of the present work, but depending upon $m_{H^\pm} - m_{H_0}$, the LHC may be already sensitive up to $m_{H'} \sim 170$ GeV [37], or up to 250 GeV by the end of the HL-LHC [32,40]. Since the displaced and disappearing charged track signatures are unique, it is quite plausible that new and bold trigger strategies could probe the parameter space even further [41].

Conclusions and discussions. In this Letter, we have investigated whether the DM relic density can originate from a primordial asymmetry directly related to the baryogenesis induced SM asymmetries, and showed that—despite strong constraints—this can be achieved in a simple, renormalizable, viable setup with a scalar singlet and a second inert scalar doublet. Along this scenario, the asymmetry is slowly produced in an out-of-equilibrium way, through an "asymmetric freeze-in." The minimality of the scenario and the fact that it is based only on renormalizable interactions make this possibility unique. It leads to several possibilities of tests in the near future, including in particular the existence of a rather light inert scalar doublet with mass $46\ \text{GeV} \lesssim m_{H'} \lesssim 580\ \text{GeV}$, which can lead to unique signatures at the HL-LHC, and possibilities for DM direct detection through a Higgs portal interaction for both dark matter components. Also, as the freeze-in production naturally converts only a small fraction of the lepton/baryon asymmetry into a DM asymmetry, the DM mass scale is well above the usual naïve (and often experimentally problematic) $m_{\text{DM}} \sim 5 \times m_p$ expectation which holds in many asymmetric dark matter scenarios from the observed ratio $\Omega_{\text{DM}}/\Omega_b \simeq 5.3$.

Symmetric dark matter freeze-in, unlike symmetric freeze-out, suffers from an initial condition dependence, as it is based on the assumption that there is no DM population with which to start. For asymmetric freeze-in instead, one assumes only that there is no DM asymmetry with which to start, which is a much weaker assumption, in the same way as for baryogenesis where one assumes that there is no baryon asymmetry with which to start (at the end of inflation).[4] In practice, this makes a crucial theoretical and experimental difference: along the asymmetric freeze-in scenario, the DM particles are perfectly allowed to couple efficiently to SM states (for example, through the various quartic couplings), whereas in the symmetric freeze-in scenario, all the portal interactions have to be assumed to be very tiny. Related to this discussion, the scenario we consider features a hierarchy between the symmetric couplings and the asymmetric ones. This is, while $\lambda_5, \lambda_{\phi^2 HH'}$ need to be $\sim 10^{-6}$, other quartics can be fairly large: $\lambda_{\phi H'} > 0.35 m_\phi/(700\ \text{GeV})$, λ_3, $\lambda_4 \lesssim 0.01$, $\lambda_{\phi H} \lesssim 0.06(m_\phi/\text{TeV})^{3/2}$. Even though small asymmetric couplings are technically natural, it would be worth

[4] See footnote 3.

investigating if this intriguing hierarchy could find an appealing theoretical explanation.

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Data availability. There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

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