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Baryogenesis for weakly interacting massive particles

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We propose a robust, unified framework, in which the similar baryon and dark matter cosmic abundances both arise from the physics of weakly interacting massive particles (WIMPs), with the rough quantitative success of the so-called "WIMP miracle." In particular the baryon asymmetry arises from the decay of a metastable WIMP after its thermal freeze-out at or below the weak scale. A minimal model and its embedding in R-parity violating supersymmetry are studied as examples. The new mechanism saves R-parity violating supersymmetry from the potential crisis of washing out primordial baryon asymmetry. Phenomenological implications for the LHC and precision tests are discussed.

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I. INTRODUCTION

The observed dark matter (DM) and baryon abundances $\Omega_{\rm DM} \simeq 23\%$, $\Omega_B \simeq 4\%$ have long been addressed with separate mechanisms at separate scales. The conventional paradigm for DM theory is the "weakly interacting massive particle (WIMP) miracle," which gives a striking yet *rough* guideline for $\Omega_{\rm DM}$: thermal relic abundance of a stable WIMP naturally falls in *the right ballpark* of the observed $\Omega_{\rm DM}$. The past few years have seen rising interest in the intriguing "coincidence" of $\Omega_{\rm DM} \sim \Omega_B$, bringing in the new paradigm of "asymmetric dark matter" [1]. However, antisymmetric dark matter's success is at the cost of the WIMP miracle. A unified mechanism that can both address the coincidence and preserve the WIMP miracle would surely be more desirable. Only very recently, a few attempts have been made in this direction [2–4], with partial success. However, Ref. [2] has extra parametrical sensitivity to a long lifetime; Ref. [3] proposes a novel baryogenesis triggered by WIMP DM annihilation, but moderate adjustment of parameters is required to suppress washout effects; Ref. [4] is also sensitive to washout, and its reliance on leptogenesis further restricts working parameters. In this paper we explore an alternative baryogenesis mechanism with a robust connection to the WIMP miracle and less sensitivity to model details.

Various scenarios addressing the electroweak hierarchy problem come with new particles of the WIMP type [5]. Generically there may be an array of WIMPs, some of which are stable, some of which decay promptly, some of which have long lifetimes, depending on protection from symmetries and mass hierarchies. Although conventionally, the WIMP miracle only applies to stable WIMPs as DM candidates, it has a more general application. We consider a *metastable WIMP* that first undergoes thermal freeze-out and later decays in a $\not{B}$, CP way, triggering baryogenesis [6]. The complex phases associated with the baryon parent WIMP can be large, just as in the Standard Model (SM). Consequently, without any special suppression mechanism such as the Glashow–Iliopoulos–Maiani mechanism in the SM, the CP effect responsible for baryogenesis can be generically near maximal, up to $\sim 10\%$. The resultant Ω_B therefore inherits the would-be miracle abundance from the WIMP parent up to only moderate suppression from CP asymmetry and the baryon/WIMP mass ratio and thus makes it roughly comparable to $\Omega_{\rm DM}$ of a WIMP DM. A precise fit to Ω_B, $\Omega_{\rm DM}$ only requires a $O(1)$ adjustment of the different WIMP parameters and is insensitive to the precise WIMP lifetime. Our mechanism thus shares the similar modest success of the WIMP miracle, in that both make predictions naturally around the observed values, yet up to a finite range. Furthermore, when embedded in R-parity violating (RPV) $\not{R}$ supersymmetry (SUSY), this mechanism provides a remedy to a cosmological problem there: $\not{R}$ leading to prompt decays at a collider typically washes out primordial baryon density and calls for baryogenesis below the weak scale. Alternative solutions to this problem [7,8] are less generic. References [9,10] considered low scale baryogenesis in $\not{R}$ SUSY to solve the gravitino problem, but the results are sensitive to details about the inflaton or gravitino. The scenario in Ref. [11] can barely achieve the currently observed Ω_B due to the strong suppression from heavy mediator mass. These works do not address the WIMP miracle or $\Omega_{\rm DM} - \Omega_B$ coincidence.

II. GENERAL FORMULATION

A. Stage 1: WIMP freeze-out

A thermal WIMP χ freezes out of equilibrium around $T_{\rm f}$ when its thermal annihilation rate $\Gamma_A \simeq n_\chi^{\rm eq}\langle\sigma_{\rm A} v\rangle$ matches Hubble rate H. This results in the estimate [12]

$$T_f \simeq m_\chi [\ln(0.038(g/g_*^{1/2}) m_\chi M_{\rm pl}\langle\sigma_{\rm A} v\rangle)]^{-1}, \qquad (1)$$

which is typically $\sim \frac{1}{20} m_\chi$. g counts the internal degrees of freedom of χ. g_* counts total degrees of freedom of relativistic species. At the end of this stage, the comoving density of χ is

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$$Y_\chi(T_\mathrm{f}) = \frac{n_\chi^\mathrm{eq}(T_\mathrm{f})}{s(T_\mathrm{f})} \simeq 3.8\frac{g_*^{1/2}}{g_{*s}}\frac{m_\chi}{T_\mathrm{f}}(m_\chi M_\mathrm{pl}\langle\sigma_\mathrm{A} v\rangle)^{-1}, \quad (2)$$

where s is entropy, $g_{*s} \equiv \frac{45}{2\pi^2}\frac{s}{T^3}$. If χ is stable, $Y_\chi(T_\mathrm{f}) \simeq Y_\chi(T_0)$, where T_0 is today's temperature, and its relic density today is

$$\Omega_\chi = \frac{m_\chi Y_\chi(T_\mathrm{f}) s_0}{\rho_0} \simeq 0.1\frac{\alpha_\mathrm{weak}^2/(\mathrm{TeV})^2}{\langle\sigma_\mathrm{A} v\rangle}$$
$$\simeq 0.1\left(\frac{g_\mathrm{weak}}{g_\chi}\right)^4\left(\frac{m_\mathrm{med}^4}{m_\chi^2\cdot\mathrm{TeV}^2}\right), \quad (3)$$

where $\rho_0 = \frac{3H_0^2}{8\pi G}$, H_0, and s_0 are the current energy density, Hubble rate, and entropy, respectively. The second line in Eq. (3) manifests the dependence on model parameters in the generic case of a heavier mediator with $m_\mathrm{med} \gtrsim m_\chi$. Now consider two species of WIMPs: χ_DM, which is stable DM, and χ_B, which decays at time τ, after freeze-out. The observation that Eq. (3) readily fits the measured dark matter abundance $\Omega_{\chi_\mathrm{DM}} \simeq 23\%$ is the well-known *WIMP miracle*. In the case of χ_B, $Y_{\chi_B}(T_\mathrm{f}) \equiv Y_{\chi_B}^\mathrm{ini}$ acts as the initial condition for later baryogenesis, as we now discuss.

B. Stage 2: Baryogenesis

Consider the baryogenesis "parent" χ_B to have CP, $\not{B}$ decay after its freeze-out but before big bang nucleosynthesis (BBN), i.e., 1 MeV $\sim T_\mathrm{BBN} < T_\mathrm{D} < T_\mathrm{f}$, so that we can treat the freeze-out and baryogenesis as nearly decoupled processes and retain the conventional success of BBN. Solving the Boltzmann equations [12], we get the asymmetric baryon density per comoving volume today $Y_B(T_0 \approx 0)$:

$$Y_B(0) = \epsilon_{CP}\int_0^{T_\mathrm{D}}\frac{dY_{\chi_B}}{dT}\exp\left(-\int_0^T\frac{\Gamma_\mathrm{W}(T')}{H(T')}\frac{dT'}{T'}\right)dT$$
$$+ Y_B^\mathrm{ini}\exp\left(-\int_0^{T_\mathrm{ini}}\frac{\Gamma_\mathrm{W}(T)}{H(T)}\frac{dT}{T}\right), \quad (4)$$

where we assume χ_B decay violates B by 1 unit. ϵ_{CP} is CP asymmetry in χ_B decay, Γ_W is the rate of the $\not{B}$ washout processes. Y_B^ini represents possible preexisting B asymmetry, which we first assume to be 0. In the case of a weak washout, i.e., $\Gamma_\mathrm{W} < H$, which can be easily realistic as we will estimate in model examples, the exponential factor in Eq. (4) can be dropped. Then using Eqs. (3) and (4), we obtain

$$Y_B(0) \simeq \epsilon_{CP} Y_{\chi_B}(T_\mathrm{f}), \qquad \Omega_B(0) = \epsilon_{CP}\frac{m_p}{m_{\chi_B}}\Omega_{\chi_B}^{\tau\to\infty}, \quad (5)$$

where $\Omega_{\chi_B}^{\tau\to\infty}$ is the would-be relic abundance of WIMP χ_B in the limit where it is stable, given by Eq. (3). Ω_B given in Eq. (5) is insensitive to the precise lifetime of χ_B as long as it survives thermal freeze-out. The observed $\Omega_B \simeq 4\%$ today corresponds to $Y_B(0) \equiv \frac{n_B}{s} \simeq 10^{-10}$. $\Omega_B(0)$ in Eq. (5) takes the form of the WIMP miracle, but with an extra factor $\epsilon_{CP}\frac{m_p}{m_{\chi_B}} \sim 10^{-4}$–$10^{-3}$ for weak scale χ_B and $O(1)$ couplings and phases, in the general case of CP at 1 loop as will be shown in our model examples. Nonetheless, as can be seen from Eq. (3), the observed $\frac{\Omega_B}{\Omega_\mathrm{DM}} \approx \frac{1}{5}$ can readily arise from a $O(1)$ difference in masses and couplings associated with the two WIMP species χ_DM and χ_B. This is our central result.

Note that as long as χ decays well before BBN, the produced baryons get thermalized efficiently because $\Gamma_{pX\to pX} \sim T \gg H$ at $T_\mathrm{BBN} \ll T \lesssim T_\mathrm{EW}$, where X can be $e^\pm$, p, $\bar{p}$ in the thermal bath. Thus, as in conventional baryogenesis, the symmetric component of baryons is rapidly depleted by thermal annihilation. Dilution/reheating from χ_B decay is negligible because at T_D the energy density of χ_B is much less than radiation density. To see this, recall that today $T_0 \approx 10^{-4}$ eV, $\frac{\Omega_B(T_0)}{\Omega_\mathrm{rad}(T_0)} \approx 10^3$. Redshifting back to T_D and using Eq. (5), we get $\frac{\Omega_{\chi_B}(T_\mathrm{D})}{\Omega_\mathrm{rad}(T_\mathrm{D})} \approx \frac{\Omega_B(T_0)}{\Omega_\mathrm{rad}(T_0)}\frac{m_{\chi_B}}{\epsilon_{CP} m_p}\frac{T_0}{T_\mathrm{D}} \ll 1$ for $T_\mathrm{D} > T_\mathrm{BBN}$ and sizeable ϵ_{CP}.

III. MINIMAL MODEL AND CONSTRAINTS

We add to the SM Lagrangian

$$\Delta\mathcal{L} = \lambda_{ij}\phi d_i d_j + \varepsilon_i\chi\bar{u}_i\phi + M_\chi^2\chi^2 + y_i\psi\bar{u}_i\phi + M_\psi^2\psi^2$$
$$+ \alpha\chi^2 S + \beta|H|^2 S + M_S^2 S^2 + \mathrm{H.c.}, \quad (6)$$

where H is the SM Higgs; d, u are right-handed (RH) SM quarks, with family indices $j = 1, 2, 3$; ϕ is a diquark scalar with the same SM gauge charge as u. χ, ψ are SM singlet Majorana fermions, and S is a singlet scalar. $\chi \equiv \chi_B$ is the earlier WIMP parent for baryogenesis. $\varepsilon_i \ll 1$ are our formal small parameters leading to long-lived χ. They can represent a naturally small breaking of a χ-parity symmetry under which only χ is odd. S mediates thermal annihilation of $\chi\chi$ into SM states. The first 3 terms of Eq. (6) give rise to the collective breaking of $U(1)_B$. Out-of-equilibrium decay $\chi \to \phi^* u$ is followed by the prompt decay $\phi \to dd$ with $\Delta B = 1$, $\epsilon_{CP} \neq 0$. CP asymmetry ϵ_{CP} in χ decay comes from the ψ-mediated interference between tree-level and loop diagrams as shown in Fig. 1. In the case of $M_\psi > M_\chi \gg M_\phi + M_{u_i}$, in close analogy to leptogenesis [13], we obtain

$$\epsilon_{CP} \simeq \frac{1}{8\pi}\frac{1}{\sum_i|\varepsilon_i|^2}\mathrm{Im}\left\{\left(\sum_i\varepsilon_i y_i^*\right)^2\right\}\frac{M_\chi}{M_\psi}, \quad (7)$$

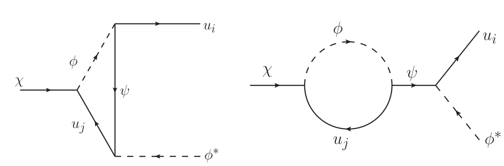

FIG. 1. Loop diagrams that interfere with tree-level decay to generate ϵ_{CP}.

which is nonzero for generic complex couplings. We omit extra phase space factors such as $(1-\frac{m_\phi^2}{m_\chi^2})$, which constitute only $O(1)$ modifications of Eq. (7), unless the masses are tuned to be close. We also see that the key to a large $\epsilon_{CP}\sim 10\%$ is to have $y_i\sim O(1)$ for at least one flavor i. Note the analogous ϵ_{CP} from ψ decay is $O(\varepsilon^2)$, with $\varepsilon\leftrightarrow y$, $M_\chi\leftrightarrow M_\psi$ in Eq. (7).

It is straightforward to incorporate WIMP DM by introducing another singlet $\chi_{\rm DM}$ with analogous interactions to χ, except with $\varepsilon_{\rm DM}=0$ enforced by an exact $\chi_{\rm DM}$ parity. We will not write out the $\chi_{\rm DM}$ physics explicitly. We next consider various constraints on this minimal model. We start with a generic flavor structure and drop family indices in y, ε for now.

A. Lifetime of χ

The decay rate of χ at $T<m_\chi$ is $\Gamma_{\rm D}\simeq\frac{\varepsilon^2 m_\chi}{8\pi}$. With $T_{\rm f}\sim 100$ GeV, our requirement of χ decay within the range $T_{\rm BBN}<T_{\rm D}<T_{\rm f}$ leads to the constraint $10^{-13}\lesssim\varepsilon\lesssim 10^{-8}$.

We next consider potential washout effects and discuss the constraints from the weak washout assumption, which leads to Eq. (5). We will focus on considering processes involving ψ; there are analogous diagrams with $\psi\to\chi$, but they give much looser constraints since $\varepsilon\ll y\sim O(1)$.

B. Early time washout at $T>\Lambda_{\rm QCD}$

As we will see, in this epoch Γ_W/H decreases with T. Thus, for each early washout process X, we define $T_{\rm W}^X$ such that $\Gamma_W^X\lesssim H$ for $T<T_{\rm W}^X$. We require $T_D<T_W^X$ to have a weak washout effect.

(A) Inverse decay $udd\to\psi$ via an on-shell ϕ^*:

$$\Gamma_W^{{\rm ID},\psi}\simeq\frac{n_\psi^{\rm eq}}{T^3}\Gamma_{{\rm D},\psi}\simeq\frac{n_\psi^{\rm eq}}{T^3}\frac{y^2 m_\psi}{8\pi}. \quad (8)$$

This gives the constraint

$$T_{\rm D}<T_{\rm W}^{{\rm ID},\psi}\simeq m_\psi\left[\ln\left(\frac{0.076}{g_*^{1/2}}\frac{y^2M_{\rm pl}}{8\pi m_\psi}\right)\right]^{-1}. \quad (9)$$

(B) $\Delta B=1$, $2\to 2$ scattering $\psi u\to\bar d\,\bar d$ via ϕ exchange:

$$\Gamma_W^{\Delta B=1}\simeq\frac{y^2\lambda^2}{16\pi m_\psi^2}n_\psi^{\rm eq},\quad \text{for } m_\psi>m_\phi, \quad (10)$$

$$T_{\rm D}<T_{\rm W}^{\Delta B=1}\simeq m_\psi\left[\ln\left(\frac{0.076}{g_*^{1/2}}\frac{\lambda^2y^2M_{\rm pl}}{16\pi m_\psi}\right)\right]^{-1}. \quad (11)$$

(C) $\Delta B=2$ $3\to 3$ scattering $udd\to\bar u\,\bar d\,\bar d$ via on-shell ϕ and ψ exchange. This is effectively $2\to 2$ $(\phi^* u\to\phi\bar u)$, and similarly to case B,

$$T_{\rm D}<T_{\rm W}^{\Delta B=2,2\to 2}\simeq m_\phi\left[\ln\left(\frac{0.076}{g_*^{1/2}}\frac{y^4M_{\rm pl}}{16\pi m_\psi}\right)\right]^{-1}. \quad (12)$$

(D) $\Delta B=2$ $3\to 3$, $2\to 4$, $4\to 2$ scattering: $udd\to\bar u\,\bar d\,\bar d$ via ψ exchange and off-shell ϕ, or $ud\to\bar u\,\bar d\,\bar d\,\bar d$.

Taking $3\to 3$, for example,

$$\Gamma_W^{3\to 3}\sim\frac{\lambda^4y^4}{16\pi(2\pi)^3}\frac{T^{10}}{m_\phi^8m_\psi^2}T, \quad (13)$$

$$T_{\rm D}<T_{\rm W}^{3\to 3}\simeq\left(\frac{1.66g_*^{\frac12}128\pi^4 m}{y^4\lambda^4M_{\rm pl}}\right)^{\frac19}m\sim\frac{m}{20(y\lambda)^{\frac49}}, \quad (14)$$

where we simplified the expression by taking all masses $\sim m$.

We compare the constraints on $T_{\rm D}$ given in Eqs. (9), (11), (12), and (14) with $T_{\rm f}$ given in Eq. (1), where for this model p-wave annihilation $\langle\sigma_{\rm A}v\rangle\sim\frac{m_\chi^2}{16\pi m_S^4}v^2$ for $m_\chi<m_S$ and $O(1)$ couplings, $v^2\sim\frac{T_f}{m_\chi}$. With nonhierarchical weak scale masses of χ, ψ, ϕ, S and $O(1)$ couplings, we find for all washout processes considered $T_{\rm W}\sim T_{\rm f}$. Therefore, with $T_{\rm D}<T_{\rm f}$, early washout is not a concern. Notice that a potential washout from an electroweak (EW) sphaleron is also easily avoided since the sphaleron shuts off at $\sim$100 GeV $\gtrsim T_{\rm f}>T_{\rm D}$ for m_χ up to $O(1)$ TeV.

After the QCD phase transition, the neutron and proton become new effective degrees of freedom to consider. $n-\bar n$ oscillation is the typical washout process in this era. The general formula for the transition probability is [14]

$$P_{n\to\bar n}(t)=\frac{4\delta m^2}{\Delta E^2+4\delta m^2}\sin^2\left(\frac{\sqrt{\Delta E^2+4\delta m^2}}{2}\cdot t\right), \quad (15)$$

where δm is the $\not B$ Majorana mass. The splitting $\Delta E\equiv E_n-E_{\bar n}$ is 0 in vacuum or in a medium where n, $\bar n$ are symmetric, e.g., the thermal bath shortly after QCD transition when baryons are dominated by the symmetric component. $\Delta E\gg\delta m$ may occur in an asymmetric medium, e.g., the thermal bath close to the BBN time or the nucleus environment after BBN, which strongly suppresses $P_{n\to\bar n}$. In a medium where there is a characteristic time scale τ, the washout rate can be estimated as

$$\Gamma_W^{n\to\bar n}\simeq P_{n\to\bar n}(\tau)/\tau. \quad (16)$$

C. Intermediate-time washout: $T\lesssim\Lambda_{\rm QCD}$

In this epoch n scatters off the thermal background, and τ is set by the mean free path of n, bound by H^{-1} from above. In reality both ΔE and τ are varying functions in this period. To simplify we consider the most "dangerous" limit where $\Delta E\to 0$ and $\tau\to H^{-1}$, which maximizes washout according to Eqs. (15) and (16), $\Gamma_W^{n\to\bar n,{\rm intm}}\simeq(\delta m)^2H^{-1}$. Requiring $\Gamma_W^{n\to\bar n,{\rm intm}}<H$ at $T\lesssim\Lambda_{\rm QCD}$, we find $\delta m\lesssim 10^{-25}$ GeV.

D. Late-time washout: $T < T_{\rm BBN}$

After BBN n is bound in the nucleus. Now the characteristic time τ is set by a nuclear time scale, which is $\tau_{\rm nuc} \sim (1~{\rm GeV})^{-1}$. In the nucleus $\Delta E \sim 100$ MeV [14]. Thus, in this era Eq. (15) becomes approximately $P_{n\to\bar{n}} \approx \frac{\delta m^2}{\Delta E^2}$. Thus, the washout rate is $\Gamma_W^{n\to\bar{n},{\rm late}} \sim \frac{\delta m^2}{(\Delta E)^2}/\tau_{\rm nuc}$. Requiring $\Gamma_W^{n\to\bar{n},{\rm late}} < H_0$, we find $\delta m \lesssim 10^{-22}$ GeV.

E. Current-day precision tests

$n - \bar{n}$ oscillation reactor experiments today set a bound $\delta m \leq 6\times 10^{-33}~{\rm GeV} \approx (10^8~{\rm sec})^{-1}$ [14], which is stronger than the washout constraints above. Now we consider constraints from δm on model parameters λ_{ij}. In this minimal model, λ_{ij} for $\phi d_i d_j$ have to be antisymmetric in i, j. Consequently the *uddudd* operator giving rise to δm is highly suppressed, and λ_{ij} are not effectively constrained by $n - \bar{n}$ oscillation [15]. A more relevant constraint comes from $pp \to K^+K^+$ decay via a higher-dimensional $\not{B}$ operator, which gives bound $\lambda_{12} \lesssim 10^{-7}$ for m_ϕ, $m_\psi \sim 1$ TeV, $y_i \sim 1$ [15]. As we will show later, when embedding this model in natural SUSY where additional fields such as $\tilde{d}_i$ and related interactions are involved, $n - \bar{n}$ oscillation gives strong bound on λ-type couplings. We are also constrained by flavor changing neutral currents such as $D_0 - \bar{D}_0$ mixing, which gives $y_1 y_2 \lesssim 10^{-2}$ with TeV masses. The large ϵ_{CP} required for baryogenesis may bring additional constraints from the *neutron electric dipole moment (EDM)*. If ϵ_{CP} comes from an $O(1)$ phase in m_ψ, y_i, in the minimal model where new couplings only involve RH u_i, then the contribution involving external quarks vanishes at 2 loops for a similar reason as in the SM [16,17]. An even safer option is to have large ϵ_{CP} come from phases m_χ, ε_i, so that the EDM is safely suppressed by $\sim \frac{\varepsilon^2}{16\pi^2} \lesssim 10^{-18}$.

Now we have seen that precision constraints require the new couplings to the first two generations of quarks to be suppressed. A simple solution is to consider a third-generation dominated pattern where the new fields couple mostly to b, t, with Cabibbo-Kobayashi-Maskawa–like suppressions to light quarks. This choice further strongly suppresses the earlier washout.

IV. SUSY INCARNATION AND PHENOMENOLOGY

The minimal model we presented can be easily mapped onto a SUSY model in the "natural SUSY" [18] framework with $\not{B}$ RPV couplings [19]. We promote singlets χ and S to chiral superfields, which we add to the Minimal Supersymmetric Standard Model (MSSM). Superpotential terms relevant to our setup are

$$W \supset \lambda_{ij} T D_i D_j + \varepsilon' \chi H_u H_d + y_t Q H_u T + \mu_\chi \chi^2 + \mu H_u H_d + \mu_S S^2 + \alpha \chi^2 S + \beta S H_u H_d. \quad (17)$$

We assume SUSY breaking such that the scalar component of χ and the first two generation squarks are heavy and decouple from the low energy spectrum, as in natural SUSY. The diquark ϕ in our minimal model is identified with the light $\tilde{t}_R$ in superfield T; Majorana ψ is identified as a gaugino (Dirac Higgsino mass is not $\not{B}$). In Eq. (17) the terms in the first line ensure $\not{B}$ and CP in χ decay, the μ terms give masses to fermions and also induce $S - H_u$ mixing which enables a promising channel for LHC search as we will discuss later, and the last two trilinear terms involving S provide WIMP annihilation for χ. ε' is a reflection of the ε in our non-SUSY model, enabling late decay $\chi \to \tilde{\bar{t}} t$ via $\chi - \tilde{H}_u$ mixing. Most of our earlier analysis for the non-SUSY model directly applies here, except for effects from additional fields and interactions. Here gaugino ψ has both left-handed (LH) and RH couplings. Therefore, if ϵ_{CP} is from a gaugino, the 1-loop neutron EDM with external quarks is nonvanishing but is well suppressed with third-generation-dominated flavor pattern [20]. The dominant contribution then arises from the gluonic Weinberg operator [21], which still allows phase up to $1/3$ for $O(1)$ couplings and TeV masses [20]. n, $\bar{n}$ oscillation now constrains λ_{12}, $\lambda_{31} \lesssim 10^{-3}$, but λ_{23} could be $O(1)$ [22], which are again naturally satisfied with third-generation dominance. On the other hand, such a third-generation dominance pattern can be within the reach of upcoming experiments such as Refs. [23,24].

RPV $\not{B}$ natural SUSY is intriguing in both theoretical and experimental aspects. However, this scenario suffers from a cosmological crisis. Assuming an otherwise successful conventional baryogenesis at or above the EW scale, RPV strong enough for prompt decays within the LHC would typically wash out any primordial B asymmetry [25]. Our SUSY model serves as a robust cure to this problem by having a baryogenesis below the weak scale when all washout effects decouple. To see the problem clearly, as shown in Ref. [19], for a natural stop that dominantly decays by $\not{B}$ couplings, $\lambda_{ij} \gtrsim 10^{-7}$ is required to have a prompt decay at the collider, i.e., decay length $L \lesssim 1$ mm. On the other hand, $\lambda_{ij} \gtrsim 10^{-7}$ happens to be the range where $\not{B}$ scattering such as $\tilde{H}_u t \to d_i d_j$ can efficiently destroy preexisting B asymmetry $Y_B^{\rm init}$ [25]. A simple estimate of such a washout effect can be read off by dropping the first term on the rhs of Eq. (4). With $\Gamma_{\rm W} \sim \lambda_{ij}^2 y_t^2 T$, we find an exponential reduction $Y_B(T\approx 0) \sim Y_B^{\rm init} e^{-\frac{\lambda_{ij}^2 y_t^2}{g_*^{1/2}} \frac{M_{\rm pl}}{m_{\rm EW}}}$.

A. LHC phenomenology

A promising channel is single resonance production of a mostly singlet heavy scalar admixture of H and S which dominantly decays to $\chi\chi$. The production channels are the same as for the SM Higgs, except for a mixing suppression. At the 14 TeV LHC run, a Higgs-like boson can be produced copiously, even when it is as heavy as 800 GeV, with say 10% mixing, $\sigma \sim 10$ fb. The produced χ must live beyond its freeze-out, so its lifetime $\tau_{\rm D} \gtrsim t_{\rm f} \sim (1\ \text{sec}) \times (\frac{\text{MeV}}{T_{\rm f}})^2 > 1$ cm, where $T_f \lesssim 100$ GeV so that $m_\chi \lesssim O$(TeV) is within the LHC reach. Close to this bound on τ_D, χ decay leaves a displaced vertex inside the detector involving t, $\bar{t}$. The search can be based on dedicated displaced vertex trigger [26,27] or triggered on two tagging jets in the vector boson fusion production channel. A challenging but exciting further step is to measure the $\not{C}\not{P}$ responsible for baryogenesis from the charge asymmetry in the $t\bar{t}$ system.

V. SUMMARY/OUTLOOK

We proposed a new mechanism addressing $\Omega_{\rm DM} - \Omega_B$ coincidence while preserving the merits of the WIMP miracle, presenting a simple example model as well as its incarnation in $\not{B}$ natural SUSY. Even independent of the physics associated with dark matter, it is a novel low scale baryogenesis mechanism with a WIMP miracle acting on the baryon abundance. Our basic idea allows for further elaborations, e.g., the WIMP parent may decay to both asymmetric DM and baryons, or baryogenesis may proceed through 3-body decay, accommodating a lighter χ. In minisplit SUSY [28–30] the latter has a natural incarnation [31]. On the phenomenology side, our mechanism brings the exciting possibility of having the cosmological origin of matter being testable at current-day colliders. It is also possible that with improvements low energy experiments will be another frontier to test the mechanism we proposed.

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