Baryogenesis from only the Standard Model CP Violation

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Unraveling the Particle World and the Cosmos at Berkeley Workshop in Honor of Lawrence and Hitoshi

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Image: Photo I took from LBNL a few years ago

Outline

- Background on Mesogenesis.
- Bigger picture and the space of mechanisms.
- Mesogenesis with a Morphing Mediator.
- Outlook (bigger picture, again)
- Based on: [**GE**, Rachel Houtz, Seyda Ipek, Martha Ulloa, Submitted to PRL, 2408.12647], "*The Standard Model CP Violation is Enough*".

[J. Berger, **GE,** PRL**,** 2301.04165] [**GE**, A. Guerrera, JHEP, 2211.10553] [G. Alonso-Alvarez, **GE,** M. Escudero, B. Fornal, B. Grinstein, J.M. Camalich. PRD, 2111.12712] [F. Elahi, **GE**, R. McGehee, PRD, 2109.09751] [**GE,** R. McGehee, PRD, 2011.06115] [G. Alonso-Alvarez, **GE**, M. Escudero, PRD, 2101.02706] [G. Alonso-Alvarez, **GE,** E. Nelson, H. Xiao. JHEP, 1907.10612] [**GE,** M. Escudero, A. E. Nelson, PRD, 1810.00880] As well as:

Upcoming: [GE, Can Kilic, Sanjay Mathai, Fall 2024 (targeted)] C. Elor

Mesogenesis Baryogenesis and Dark Matter from Mesons

The Sakharov conditions:

- Out of thermal equilibrium: *GeV scale mesons produced when the Universe was at MeV scales.*
- CP Violation: *From SM Meson systems.*
- Baryon number violation: *SM Meson decays to dark baryons (or leptons).*

Features:

- Signals!
- The SM CPV can be enough!
- Baryon asymmetry production right up to the era of BBN possible.
- Reconstructable dark matter.

Neutral *B* Mesogenesis **Example 2018** Out of thermal equilibrium and CPV: of *D[±]* and ⇡*[±]* mesons can be ignored. The reheat temcorresponds to an inflaton decay width in the range of the
The range of the ra asymmetry, we consider the coupled Boltzmann equal α tions which track the production $\mathbb R$ cays of *D[±]* mesons into ⇡*±*, which then subsequently decompute the generated lepton asymmetry for the range asymmetry, we consider the coupled Boltzmann equal α tions which the production $\mathbb N$ equition and $\mathbb N$ -violating decays of *D[±]* mesons into ⇡*±*, which then subsequently decompute the generated lepton asymmetry for the range asymmetry, we consider the coupled Boltzmann equality of the coupled Boltzmann equality of the coupled Boltzma
The coupled Boltzmann equality of the coupled Boltzmann equality of the coupled Boltzmann equality of the coup tions which track the production which the production and CP-violating decays of *D[±]* mesons into ⇡*±*, which then subsequently de- $\mathbf{A} \cdot \mathbf{A}$ ages for *A^q* prepared by the HFLAV [65] group, at 68% CL, read N_{outval} D M_{noncon} for allegences and the nature of the nat **Out of thermal equilibrium and CPV** as well as the relevant branching relevant with \sim

Late decay of an scalar field $\overline{}$ ate decay of an scalar field $\frac{1}{2}$ in the must be heavy of an scalar field I ate decay of an scalar field $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ \equiv $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and because the reference temperature. $\frac{1}{2}$ T produced quarks and anti-quarks hadronize into α into an into α Late decay of an scalar field

compute the generated lepton asymmetry for the range

Decays at: $\Gamma_{\Phi} = H(T_R)$ to quarks $m_{\Phi} \in [5 \,\text{GeV}, 100 \,\text{GeV}]$ S_{source} we at $\Gamma_{\rm s} = H(T_{\rm p})$ to quarks $m_{\rm s} \in [5\,\text{GeV}$ 100 GeV \overline{Y}

Neutral *B* Mesogenesis An ExpliciBayon 1 and 1 and 1 and 1 in [1] and detailed in Appendix VIII A, some comments on Eq. (6) are in order. First, the ↵*^q* parameters are difearly Universe is a hot dense plasma in which electrons Titral K Mesogenesis out a ZVIOOO SUIODID \mathbf{G} interaction in Eq. (7), and provided the interaction in Eq. (7), and provided the interaction in Eq. (8), and provided the interaction in Eq. (8), and provided the interaction in Eq. (8), and provided the interac *m > m* + *m*⇠, rapidly decays into and ⇠ states

Kinematics: $m_{\psi} < m_B - m_{\text{Baryon}} < 4.3 \text{ GeV}$ $\frac{1}{\sqrt{p}}$ **i** $\frac{1}{\sqrt{p}}$ **i** see [47, 48]. Given that the ¯*b b* coupling is *<* 10¹⁰, any contribution to the baryon asymmetry arising from such a 3-loop process is extremely suppressed and can safely Matter stability: $m_{\psi} > m_p - m_e \simeq 937.8 \,\text{MeV}$

Equal and opposite dark and visible baryofi(asymmetries gen érated. $\mathcal{L}_{\mathbf{t}}$ data states only e $\mathcal{L}_{\mathbf{t}}$

$$
Y_{\mathcal{B}} - Y_{\bar{\mathcal{B}}} = -\left(Y_{\psi} - Y_{\bar{\psi}}\right)
$$
G. Elor

An Explored Mesogenesis MEW Particles Neutral R. Mecoganecic The decay in Eq. (3b) proceeds the decay in Eq. (3b) proceeds the dimension of the dimension of the dimension six, four fermion operator. For $\mathbf{N} \subset \mathbf{W}$ model of $\mathbf{N} \subset \mathbf{W}$ important consequences for the BAU are greatly simple which of the operations for determining which of the operations for the operations of the operat plified since all the decays in Eq. (3) occur very quickly at *^c* Mesogenesis, we relegate further discussion to App. A 3. Fig. 1 summarizes the mechanism. With this birdis eye view, we proceed to detail a simple UV model. to decays of neutral *B*⁰ *s,d* mesons and *b*-flavored baryons which can be used to indirectly probe the mechanism (see Fig. 1). The mechanism (see Fig. 1) which can be used **PULTAI B MESOGENESIS** ment *Y* ⇠ (3*,* 1*,* 2*/*3). Although the results are qualitatively similar for both scenarios, current experimental \mathbf{A} constraints are less stringent for some flavorful variations of the hypercharge 2*/*3 version. As we will see, this has erators in Table I are best suited for *B*-Mesogenesis. in generating the BAU with *just* the SM CP violation CPV arises in the SM as an irreducible phase in the SM as an irreducible phase in the SM as an in the SM as an quark mixing matrix 1. While this contract is not the contract of the contract small, the parametrization-independent measure of SM \mathbf{N} Mesogenesis mechanisms, by construction, require a \mathbf{A} and \mathbf{A} is an equal and opposite baryon shares and opposite baryon \mathbf{A} asymmetry to the SM sector. ist a SM-dark sector mediator *Y* which allows SM mesons ralucies and origin and origin of the nature an various final baryons and missing energy (*^B*). We quote the maximal value (evaluated at minimum possible *^B* mass i.e. 1 Geven the coefficients factored outside the coefficients of Mesogenesis occurs when the temperature of the Universe, *Td*, was *O*(10 MeV); before the era of Big Bang Nucleosythasis (BBN) but after the quark-hadron phase tioles^{the measured BAU, defined as the baryon-} to-entropy ratio *Y* meas *Ob,cd* ⇠ 0*.*9 ^p*^y ^b ^ycd ^B^d* ! ¯*^B* ⌃⁰ *c 0−.000 × 0−.000 × 0−.000 × 0−.000 × 0−.000 × 0−.000 × 0−.000 × 0−.000 × 0−.000 × 0−.000 × 0−.000 × 000 × 000 B* **B** $\overline{}$ *B Mecogenesis* N eutral *B* Mesogenesis New Particles

Allowed by all the symmetries: $\int \mathcal{L}_{\mathcal{Y}} = -\sum y_{u_i d_j} \mathcal{Y}^{\star} \bar{u}_{iR} d_{jR}^c - \sum y_{iR}$ assume a specific flavor structure. Such a model has a model h Allowed by all the symmetries: $\left| \mathcal{L}_{y} \right| = -\sum_{i=1}^{n}$ $\overline{i,j}$ $\overline{}$ and $\overline{}$ while tracking , the tracking system , the tracking system , the tracking , the tracking system , the tra $\mathcal{H}_{d_j}\mathcal{Y}^\star \bar{u}_{iR}d_{jR}^c - \sum_j y_{\psi d_k}\psi_\mathcal{B}\mathcal{Y}d_{kR}^c + \text{h.c.}$ $\begin{array}{c|c} k\end{array}$ variations of the is no a priori reason to the intervals of ρ_{ext} assume a specific flavor structure. Such a model has a simple Supersymmetric realization [48] where the mediwhere we have defined *^B* ⌘ Br(! *q*)Br(*q* ! *Bc*). $\sum_{\mu} \gamma^* \bar{u}_{\mu} d^c$ $\sum_{\mu} \bar{u}_{\mu} \gamma^c d^c$ $\left[\frac{\partial u_i a_j}{\partial y_i} \mathcal{L} \right]$ which $\left[\frac{\partial u_i a_j}{\partial y_i} \mathcal{L} \right]$ which is the tracking sum of $\left[\frac{\partial u_i a_j}{\partial y_i} \mathcal{L} \right]$ κ netries: $\mathcal{L}y = -\sum y_{u_i d_j} y^{\lambda} \overline{u}_{iR} d_{jR}^c - \sum y_{iR}$ $\mathcal{C}_{\mathcal{Y}}=$ where the *y*'s are coupling constants, the sum is per-*Mesogenesis with a Morphing Mediator.*— Mesogenesis $\mathcal{F}\left(y_{u_i d_j} y^{\star} \bar{u}_{iR} d_{iR}^c - \sum y_{\psi d_k} \psi_{\mathcal{B}} y d_{kR}^c + \text{h.c.}\right)$ $\frac{1}{k}$ **b** and $\frac{1}{k}$ **b** and $\frac{1}{k}$ **c** 1, giving and $\frac{1}{k}$ **c** 1, with a squark \sim 10 μ searches for squarks constraints constraints constraints constraints constraints constraints constraints of μ Allowed by all the symmetries: $\mathcal{L}^{\mathcal{Y}} = -\sum_{k=1}^{n}$ *^Y* , where the couplings *y ^d^k* , *y^uid^j* . 4⇡ by cillations, *Aⁱ* $\int u_{\psi} d\psi \, d\psi \, d\psi = 0$ *ⁱ* !*B*⁰ *ⁱ* !*^f*)(*B*¯⁰ $\frac{1}{k}$ $\frac{1}{k}$ $\frac{1}{k}$ $\frac{1}{k}$ $\frac{1}{k}$ $\frac{1}{k}$ capture additional numerics and higher temperature de- \mathcal{L} *y* = \sum i,j $y_{u_id_j}\mathcal{Y}^{\star} \bar{u}_{iR}d^{c}_{jR} - \sum$ *k* $y_{\psi d_k}\bar{\psi}_{\mathcal{B}}\mathcal{Y}d_{kR}^c + \text{h.c.}$ $\Bigg[$

Effective four fermion operator at MeV scales: Γ ffootive for termiers and water ot M_2V sooled Effective four feminon operator at ivic v $m \times 2 \times 2 \times 1$ Effective four fermion operator at MeV scales: $\begin{bmatrix} a_k, a_i a_j \\ a_k, a_i a_j \end{bmatrix} = a_{k+1} a_{k+2} a_{k+1} a_{k+1} a_{k+2}$ \overline{R} eq.

where the flavor indices *i, j, k* account for all flavorful

$$
\text{Aev scales: } \begin{pmatrix} \mathcal{O}_{d_k, u_i d_j} = \mathcal{C}_{d_k, u_i d_j} \epsilon_{\alpha \beta \gamma} (\bar{\psi}_{\beta} d_k^{\alpha}) (\bar{d}_j^{c \beta} u_i^{\gamma}) \\ \mathcal{C}_{d_k, u_i d_j} \equiv y_{\psi d_k} y_{u_i d_j} / M_{\mathcal{Y}}^2 \end{pmatrix}
$$

6*.*45 ⇥ 10⁵

(*B*¯⁰

10³

rise to a (*B*-conserving) e↵ective operator:

This interaction *does not* change baryon number *B* 6*.*45 ⇥ 10⁵ where *Y* obs **B** $\frac{1}{2}$ $\frac{1}{2}$ This interaction *does not* change baryon number are right handed and *Y* carries baryon number 2*/*3 so late-time decay of a heavy scalar ⁴ at a temperathe particle, we are particle, ρ tion *does not* change baryon number

SUSY UV completion: [G. Alonso-Alvarez, GE, A. E. Nelson, H. Xiao, JHEP, 1907.10612] The interactions of *Y* are reminiscent of those of squarks quiring all dark sector baryons to have a mass α mass α mass α and α in the sector baryons to have a mass α Alvarez, GE, A. E. Nelson, H. Xiao, JHEP, 1907.10612] *B*⁰

where the inclusive branching fraction is over all possi-

Neutral *B* Mesogenesis New Decays

\blacksquare the mass of the mass of the dark and the dark matter? Neutral *B* Mesogenesis

The renormalizable couplings between and *Y* allowed as mediated by the heavy colored scalar *Y* that results in DM k baryon is unstable and will decay to baryor n day on is answere and win decay to our , one matter. The dark baryon is unstable and will decay to baryonic matter, washing out the asymmetry. ψ_B cannot be the dark matter.

Neutral *B* Mesogenesis T_{true} \cap proceeds a dimensional \cap and \cap Two-Component Dark Matter $H\alpha r$ are greatly simple \mathcal{L} plified since all the decays in Eq. (3) occur very quickly at

Dark fermion must quickly decay within the dark sector Dark fermion must quickly decay within the dar Dalk following quickly decay within the dai metry \int is the following by $\overline{\mathcal{L}}$

Neutral *B* Mesogenesis edition in the metal control organization of the study of the stud 5.1 Asymmetry in *B[±]* Meson Decays 7 Contents

ERE, M. Escudero, A. E. Nelson, PRD, 1810.00880]

\mathbf{F} from R Mecons we will be a set of the branching fraction we really means the branching we really means the set of t Baryogenesis and Dark Matter from *B* Mesons

 $\pm B^0) < \Delta m_B^0$ λ baryon asymmetry through dark sector sect Figure 1. Depiction of the mechanism of *B*-Mesogenesis for generating the baryon asymmetry and $\left(-B^{\circ}\right) <\Delta m_{B}^{\circ}$

\bf{L} and \bf{L} and \bf{L} perature is defined by 4*H* (*TR*) = , so that Eq. (2) corresponds to an inflaton decay with inflaton decay with interests and range \sim $\mathbf{D} \cdot \mathbf{1}$ the inflaton must be heavy enough to produce *D±*, its of *D[±]* and ⇡*[±]* mesons can be ignored. The reheat temperature is defined by 4*H* (*TR*) = , so that Eq. (2) corresponds to an inflaton decay with interests the range of \mathcal{L}_1 ¹ ⇥ ¹⁰²² GeV*,* ³ ⇥ ¹⁰²¹ GeV⇤ . Additionally, as For the region in parameter space where *m*⇠ *> m*, the inflaton must be heavy enough to produce *D±*, its mass must be in the range *m* 2 [5 GeV *,* 100 GeV]. For the region in parameter space where *m*⇠ *> m*, DM is composed of the scalar baryons and anti-baryons, Γ and Γ is composed of the scalar baryons and anti-baryons and anti-baryons, Γ and the DM relic abundance is found by solving for the region in parameter space where \mathcal{L} DM is composed of the scalar baryons and anti-baryons, *Od,ub* ⇠ 3*.*8 ^p*^y ^d ^yub ^B^d* ! ¯*^B ⁿ* ³*.*6*±*0*.*⁴ *·*10⁵ *ral B* M *Os,ub* ⇠ 2*.*3 ^p*^y ^s ^yub ^B^d* ! ¯*^B* ⇤ ¹*.*3*±*0*.*⁴ *·*10⁴ *^B^s* ! ¯*^B* ⌅⁰ ²*.*0*±*0*.*¹ *·*10⁵ *d* \overline{D} \overline{D} \overline{D} \overline{D} \overline{D} \overline{D} \overline{D} \overline{D} \overline{D} Neutral *B* Mesogenesis Boltzmann Equations

number density and the radiation density are governed δ balance interpretations by δ and δ and Scalar, Radiation, Hubble: Da *Os,cb* ⇠ 1*.*1 ^p*^y ^s ^ycb ^B^d* ! ¯*^B* ⌅⁰

$$
\frac{dn_{\Phi}}{dt} + 3Hn_{\Phi} = -\Gamma_{\Phi}n_{\Phi}
$$
\n
$$
\frac{d\rho_{\text{rad}}}{dt} + 4H\rho_{\text{rad}} = +\Gamma_{\Phi}m_{\Phi}n_{\Phi}
$$
\n
$$
H^{2} = \frac{8\pi}{3M_{\text{Pl}}^{2}}(\rho_{\text{rad}} + m_{\Phi}n_{\Phi})
$$
\n
$$
\frac{dn_{\phi-\phi^{*}}}{dt} + 3Hn_{\phi-\phi^{*}} =
$$
\n
$$
\frac{dn_{\phi-\phi^{*}}}{dt} + 3Hn_{\phi-\phi^{*}} =
$$

baryon number 2*/*³ ³, symmetry admits the following

Δ ark Matter: Dark Matter: *^c* ⁹*.*7*±*5*.*⁰ *·*10⁵ *B* 2*x B* 2*x B*

5 $dn_{\phi+\phi}$ $\frac{d^2\phi + \phi^*}{dt} + 3 H n_{\phi + \phi^*} = 2 \Gamma_{\Phi}^B n_{\Phi} - 2 \langle \sigma v \rangle_{\phi} (n_{\phi + \phi^*}^2 - n_{\phi})$ *n*2 +⇤ *ⁿ*² $\overline{}$ $\left| \cdot \right|$ \bigcup *dt* + 3 *H n*+⇤ ⁼ ² *^B* $- 2 \langle \sigma v \rangle_{\phi} (n_{\phi+\phi^*}^2 - n_{\text{eq},\phi+\phi^*}^2)$ $\overline{ }$ $dn_{\phi+\phi^*}$ $\frac{\phi + \phi^*}{dt} + 3\,H\,n_{\phi + \phi^*} = \,\,\,2\,\Gamma_\Phi^B\,n_\Phi\,- 2\,\langle \sigma v \rangle_\phi\,\big(n_{\phi + \phi^*}^2 - n_{\rm eq}^2\big)$ *n*2 +⇤ *ⁿ*² $\overline{}$ $\left| \right|$ \int

Baryon Asymmetry:

$$
\left(\frac{dn_{\phi-\phi^*}}{dt} + 3Hn_{\phi-\phi^*} = 2\Gamma_{\Phi}^B \sum_q \text{Br}\left(\bar{b} \to B_q^0\right) A_{\text{SL}}^q f_{\text{deco}}^q n_{\Phi}\right)
$$

symmetric component, namely:

$$
Y_{\mathcal{B}} \simeq 5 \times 10^{-5} \sum_{i=d,s} \left[\text{Br} \left(B_i^0 \to \bar{\psi}_{\mathcal{B}} \, \mathcal{B}_{\text{SM}} \right) A_{sl}^i \right] \alpha_i(T_{\text{R}}) \qquad 1.25
$$

(product of two experimental observables) $S_{\rm F}$ in this section is on $\rm F$ is one the lepton as (product of two experimental observables) $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ ble final states. *Aⁱ*=*s,d*

To generated the observed baryon asymmetry: In a simple supersymmetric realization [21] *Y* is identified Γ *i* rved baryon asymmetry (*B*¯⁰ $\overline{}$

$$
A_{\rm SL}^{s,d} \times \text{Br} \left(B^0 \to \psi \, \mathcal{B} \, \mathcal{M} \right) > 10^{-6}
$$

n (13) **n**

.

Signals of Neutral *B*-Mesogenesis

[A. Alonso-Alvarez, **GE**, M. Escudero, PRD, 2101.02706]

Neutral *B* Mesogenesis **Discovery Potential 32 and 7/3 and 7/** ⁰ ⌘ *B|^m ^B* =1GeV*/C*² *b,uid^j* . baryon number 2*/*³ ³, symmetry admits the following verse, *Td*, was *O*(10 MeV); before the era of Big Bang $N = 10$ transition. The measured BAU, defined as the baryonto-entropy ratio *Y* meas 1 1 *Y*B $\frac{1}{2}$ $\frac{1$ 1 GeV) of this decay rate 1 *b*, **B** μ *Y. Y. Y. Assigning Yoter* baryon number 2*/*³ ³, symmetry admits the following verse, *Td*, was *O*(10 MeV); before the era of Big Bang N equark-hadron phase the \mathbb{R} transition. The measured BAU, defined as the baryonto-entropy ratio *Y* meas $\vert \Omega \vert$. In generated as $\vert \Omega \vert$ *^Y^B* ' ⁵ ⇥ ¹⁰⁵ ^X

[A. Alonso-Alvarez, GE, M. Escudero, PRD 2101.02706]

 \overline{a}

, (4a)

Tracking economic economic economic economic $\sqrt{2}$ compared to $\sqrt{2}$ VIL SELVETISTI Collider Searches for *B*-Mesogensis

The table is a lot of the table and the table and another column view *Y*. Eld **Y** constraints: **Because** *Y* constraints georgh douglassed for LIICh [2106] search developed for **ELICO** [2100.1 Formula 5. Dupper limits on the *B*₀ is the *B*⁰ *D* analysis! Designated search developed for LHCb [2106.12870]. On-going analysis!

Collider Searches for *B*-Mesogensis

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*Y I*IY *L* YEUUTAL *D* ³*Berkeley Center for Theoretical Physics, University of California, Berkeley, CA 94720, USA* ⁴*Theory Group, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA* $3*B*$ ⁴*Theory Group, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA* We present a testable mechanism of low-scale baryogenesis and dark matter production in \mathcal{C} Why Neutral *B* Mesons?

Particle Data Group: neither baryon nor lepton number are violated. Charged *D* mesons are produced out-of-equilibrium neither baryon nor lepton number are violated. Charged *D* mesons are produced out-of-equilibrium

G. Elor ^a this only includes the subsequent decay mode in which *^a*0(1450) ! *^K*+*K*

Why Neutral *B* Mesons? to experimental observables in *B*⁺ *^c* and *B*⁺ decays:

$$
m_{\psi_B} > m_p - m_e \simeq 937.8\,{\rm MeV} \Bigl]
$$

Kinematics: Dark baryons must be GeV scale. Only *B* mesons are heavy enough to decay into GeV scale. $\mathbf F$ inematics: Dark baryons must be GeV scale. Only B mesons are hear **a proton, and neutrino.** The proton must be GeV scale. Only *B* mesons are neutrino. $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ are very the set of set of prevent.

Charged *D* and *B* Mesogenesis

[**GE,** R. McGehee, PRD, 2011.06115] and [F. Elahi, **GE**, R. McGehee, PRD, 2109.09751]

potentially abundant and untapped sources of CP viola-

While a late-time production of a lepton of a lepton of a lepton \mathcal{A}

G. Elor

^L = *Y*`*^d* . Note that this process does not

Mesogenesis **TESOREITESIS** *Ob,ud* ⇠ 1*.*7 ^p*^y ^b ^yud ^B^d* ! ¯*^B ⁿ* ³*.*5*±*0*.*⁴ *·*10⁵

Common to all mechanisms proposed to date: baryon number 2*/*³ ³, symmetry admits the following

colored mediator
$$
\mathcal{L}_{\mathcal{Y}} = -\sum_{i,j} y_{u_i d_j} \mathcal{Y}^* \bar{u}_{iR} d_{jR}^c - \sum_k y_{\psi d_k} \bar{\psi}_{\mathcal{B}} \mathcal{Y} d_{kR}^c + \text{h.c. } + \text{dark sector}
$$

One mechanisms direct signal is another mechanisms indirect signal \mathcal{L}_{H} an *observable* CP violating parameter in *B*⁰ meson os-

G. Elor cillations, *Aⁱ sl* ⌘ \mathbf{r}

Mesogenesis **TESOREITESIS** *Ob,ud* ⇠ 1*.*7 ^p*^y ^b ^yud ^B^d* ! ¯*^B ⁿ* ³*.*5*±*0*.*⁴ *·*10⁵

Baryogenesis with only the SM CI baryon number 2*/*³ ³, symmetry admits the following to-entropy ratio *Y* meas Baryogenesis with only the SM CP Violation

Common to all mechanisms proposed to date:

colored mediator
$$
\mathcal{L}_{\mathcal{Y}} = -\sum_{i,j} y_{u_i d_j} \mathcal{Y}^* \bar{u}_{iR} d_{jR}^c - \sum_k y_{\psi d_k} \bar{\psi}_{\mathcal{B}} \mathcal{Y} d_{kR}^c + \text{h.c. } + \text{dark sector}
$$

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<i>D α ¹ α ¹</sub> 3 ased 01 ^p*^y ^b ^yus ^B^d* ! ¯*^B* ⇤ ¹*.*4*±*0*.*¹ *·*10⁴ p_py</sub> <u>*d p D D D D D A* α α α α α </u> B *esogent* ^p*^y ^s ^yub ^B^d* ! ¯*^B* ⇤ ¹*.*3*±*0*.*⁴ *·*10⁴ We first discuss the scenario in which Mesogenesis in which *B* and *B* mesons decay in $S_{\rm eff}$ baryon number. $S_{\rm eff}$ is section when the section when the section when **Base** Raced c Based on Neutral *B* Mesogenesis

Γ_{exact} In this letter, we expect the neutral **B-** \blacksquare Negram — Mesogenesis experimental program — with unique \blacksquare signals of *Mesogenesis with a Morphing Mediator* (3*M*). *Mesogenesis with a Morphing Mediator.*— Mesogenesis Based on Neutral *B* Mesogenesis

• Baryon asymmetry produced through decays mediated by a heavy colored particle: fermion *^B* carrying anti-baryon number, *B* = 1, giving

$$
\begin{pmatrix} \mathcal{O}_{d_k,u_id_j}=\mathcal{C}_{d_k,u_id_j}\epsilon_{\alpha\beta\gamma}(\bar{\psi}_{\mathcal{B}}d_k^\alpha)(\bar{d}_j^{c\beta}u_i^\gamma)\\ \mathcal{C}_{d_k,u_id_j}\equiv \ y_{\psi d_k}y_{u_id_j}/M_{\mathcal{Y}}^2\end{pmatrix}
$$

 \mathbf{F} can arise in a heavy color in a heavy colo • Collider constraints require mediator *Y* to have a **TeV scale mass**

era of baryon production than it is today?

Perturbativity: $y_{\psi d_k}$, $y_{u_i d_j} \lesssim 4\pi$ [A. Alonso-Alvarez, **GE**, M. Escudero, PRD 2101.02706] proiections for 2025 10^{-2} ALEPH limit Dark Matte $Br \propto 1/M_V^4$ • Branching fraction: **Belle-II LHCb** e.g. $\frac{1}{2}$ **Belle-II & LHCb** $-A_{\rm SL}^d$ 10^{-3} B_d **ATLAS & CMS** Baryogenesis **SM** Λ \boldsymbol{u} $0⁻³$ **BaBar**/Belle World Averages \overline{B} 10^{-4} $\frac{1}{10^{-1}}$ *What if the mediator was lighter during the* 10^{-2} 10^{-4} 10^{-3} 10^{-5}

Elor

LHCb

 $A_{\rm SL}^s$

Morphing the Mediator *M*_i *M*_i *A*_i *A*_i *A*_i *A*_i *B*_{*s*} mesons are produced in the case of \mathbb{R} early Universe, i.e. the branching fraction of ! *B^s* is 100%. This case corresponds the maximal possible BAU generation (and smallest requisite *M^Y*) with only the SM CPV. *Right:* Scenario where Br(! *Bs*)=0*.*5 = Br(! *Bd*). operator is allowed. In this sense, the upper curve corresponding to an upper bound on the maximal possible *Mⁱ M A* defined in the operator Eq. (1) is a set of the case of the case of the only \sim early Universe, i.e. the branching fraction of ! *B^s* is 100%. This case corresponds the maximal possible BAU generation (and smallest requisite *M^Y*) with only the SM CPV. *Right:* Scenario where Br(! *Bs*)=0*.*5 = Br(! *Bd*).

Tricks with Dark Sector Phase Transitions:

"Light Dark Matter through Resonance Scanning" Djuna Croon, GE, Rachel Houtz, **Hitoshi Murayama**, Graham White, PRD (2020) 2012.15284

Crigins of Hidden Sector Dark Matter II: Collider Phys
Cliff Choung, CE, Lewronge Hell, Piyush Kumer Cliff Cheung, GE, Lawrence Hall, Piyush Kumar
LHEP (2011) 1919 0924 Tables I-II. Fixing *Aⁱ sl* to their SM values and expressing *"Origins of Hidden Sector Dark Matter II: Collider Physics"* JHEP (2011) 1010.0024

 ϵ Ω *s* Ω

 ϵ $\frac{S}{M}$,

i ^o*i Crigins of Hidden Sector Dark Matter I: Cosmology" b*
83334.4 *x* **Cliff Cheung, GE, Lawrence Hall, Piyush Kumar

IHEP** (2011) 1010.0022 Cliff Cheung, GE, **Lav**
JHEP (2011) 1010.0022 \overrightarrow{CHff} Cheung, GE, Lawrence Hall, Piyush Kumar
IHEP (2011) 1010.0022

Morphing the Mediator $\underline{\text{M}}$ (and smallest requisite *M^Y*) with only the SM CPV. *Right:* Scenario where Br(! *Bs*)=0*.*5 = Br(! *Bd*). are below the larger values is allowed for larger values is allowed for larger values of \sim of *m ^B* . *Morphing with Dark Dynamics.*— To generate the BAU with only the SM CPV in neutral *Bs,d* meson oscilla- Ω diotor potential Ω *Y* mass from 200 GeV in the false vacuum to 1*.*2 GeV in the true vacuum. In blue, we plot *M^Y* () to demonstrate the area below each upper curve is allowed for larger values *Morphing with Dark Dynamics.*— To generate the BAU with only the SM CPV in neutral *Bs,d* meson oscilla-FIG. 2. The morphon potential *V* () (black) that shifts the *Y* **MUSCHIALOI** true vacuum. In blue, we plot *M^Y* () to demonstrate the *^Y >* 100 GeV to ensure that the operator Eq.(1) is well defined. *Left:* The case where only *B^s* mesons are produced in the $e^{\alpha t}$ the branching fraction of $e^{\alpha t}$ (and smallest requisite *M^Y*) with only the SM CPV. *Right:* Scenario where Br(! *Bs*)=0*.*5 = Br(! *Bd*). decay through *^Budd* is kinematically forbidden by re q_1 and q_2 are a mass q_1 q_2 and q_3 q_4 \blacksquare **Bo-Magnumbers** \blacksquare tral *Bs,d* mesons and anti-mesons are produced by the late-time decay of a heavy scalar ⁴ at a tempera-10 MeV, respectively [17, 21]. Generically, *B*⁰ $\boldsymbol{\theta}$ dominator $\boldsymbol{\theta}$ mesons are more relevant at lower *Td*. Dependence on decay through *^Budd* is kinematically forbidden by re- \mathbf{M}_{e} and the second to have a mass \mathbf{M}_{e} In Neutral *B*-Mesogenesis [14], equal numbers of neutral *Bs,d* mesons and anti-mesons are produced by the late-time decay of a heavy scalar ⁴ at a tempera-10 MeV, respectively [17, 21]. Generically, *B*⁰ $\boldsymbol{\theta}$ dominator $\boldsymbol{\theta}$ mesons are more relevant at lower *Td*. Dependence on operator is allowed. In this sense, the upper curve corresponding to an upper bound on the maximal possible *Mⁱ* **X** Indian that the Madistor Eq. (1) is well defined in the case where \mathbf{A} early Universe, i.e. the branching fraction of ! *B^s* is 100%. This case corresponds the maximal possible BAU generation (and smallest requisite *M^Y*) with only the SM CPV. *Right:* Scenario where Br(! *Bs*)=0*.*5 = Br(! *Bd*). cient to generate the entire BAU. Therefore, we ex- su ¯ !⁰ 3% for the SM CPV alone is &) SM *^B^B* (TeV) *O* ⇠) *^Y ^M*(pect that ^a mass shift of no more than \mathbf{M} with only the SM CPV, which may be studied the SM CPV, which may be studied to \mathbf{M} The field-dependent mass of *Y* is \mathbf{M} of \mathbf{M} *^Y* () = *^m*² *^Y*⁰ ⁺ *^y^Y* ⁺ ¹ ²*^Y* ² *.* (7) **T** is the bias between the bias between the true and false vac- $\Omega_{\rm A}$ um is small enough $\Omega_{\rm A}$ $\mathbf C$ ividual alumnoming minima, forming and false minima, forming and $\mathbf r$ network of domain walls (DWs) that eventually annihi-

M_{\odot} . The M*I* \cap **C** an the SMCP San and Diat of m_1 is the bounds on n_1 can be compared to the bounds on n_1 \blacksquare ne enouvel \blacksquare Can the SM CPV be enough? GeV1 TeV can lead to successful baryogenesis through CPV arises in the SM and in the SM and in the SM and in the SM as an intervention of the SM and in the SM and quark mixing matrix is not the third matrix in the third matrix is not the third matrix in the third matrix is s_{max} , the parametrization-independent measure of \mathbb{Z} \mathbf{z} shares and opposite baryon shares and opposite baryon shares and opposite baryon shares and opposite baryon shares \mathbf{z} \overline{a} as \overline{a} \overline{a} and \overline{a} \overline{b} ist a SM-dark sector mediator *Y* which allows SM mesons \mathbf{v} decay into the doing sector. also provides an explanation for the nature and origin of the nature an

Can the SM CPV be enough? f *be* S *by s s all tile bly Od,ub* ⇠ 3*.*8 ^p*^y ^d ^yub ^B^d* ! ¯*^B ⁿ* ³*.*6*±*0*.*⁴ *·*10⁵ **B** \mathbb{Z} **N.a.** *y d*₁₁ *c*₁₁ *b*₁₇₁ *c*₁ \sim 11 \sim 0 \blacksquare and the Mesogenesis mechanisms, by construction, require a de which shares which shares and opposite baryon in the sector which shares are the second state baryon opposite baryon in the second state b

a *<i>x <i>x*

$$
Y_{\mathcal{B}} \simeq 5 \times 10^{-5} \sum_{i=d,s} \left[A_{\rm SL}^{s,d} \times \text{Br} \right] \alpha_i(T_{\rm R})
$$

Morphing the Mediator

A mediator mass increase from ~200-500 GeV to about 1 TeV will generate the baryon asymmetry with only the SM CPV

- Seems like a reasonable phase transition ? Scalar *morphon* gets a vev.
	- 1) Nucleation: The mass shift must occur after the BAU is generated.
	- 2) Percolation: The Universe must effectively transit from the false to the true morphon vacuum.
	- 3) Avoid Inflation: To avoid triggering inflation after the BAU is generated or during BBN, the scalar morphon must not dominate the energy density of the Universe.

Can we find an example?

• Did this "trick" cost us a signal??

Morphing with Dark Dynamics of with Dork Dwn a temperature in the total value of the total value of the total value of the total value of the total value o phase transition. For this scenario, we use the following In summary, 3*M* baryogenesis favors a fast percolating $\frac{1}{2}$ we leave open the possible models for generating such a a temperature *T*PT ' 6 80 MeV, e.g. due to a delayed how this school is the following the fol Jain Dy. $m_{\rm{max}} = -1$ *V*scalar = *m^Y* 2 ⁰*|Y|*² ⁺ *^y^Y |Y|*² ⁺ 1 2 *^Y |Y|*²² *Example: Domain walls.*— Consider the benchmark values: *m^Y*⁰ = 624*.*5 GeV*, y^Y* = 70 GeV*, ^Y* = ⁰*.*007*,* = 1*,* ✏ = 3 ⇥ ¹⁰²⁶ and ⁰ = 10TeV ⁷. + 1 n Dark D The field-dependent mass of *Y* is; ⁰*.*007*,* = 1*,* ✏ = 3 ⇥ ¹⁰²⁶ and ⁰ = 10TeV ⁷. T **the case of** $\ddot{\mathbf{a}}$ *Fig. 2. This potential h T* 20 TEV. IF THE BIAS BETWEEN α with Γ VIOI piining Fig. 2. This potential has nearly-degenerate minima at *T* 20 TeV. If the bias between the true and false vac- \mathbf{u} is \mathbf{v} is small eq. (S1), the morphon field \mathbf{v} will fall into patches of true and fall into patches of true and fall into patches minima, for the state minima, for \mathbf{B} system) dependent the asymmetry. In each \mathbf{B} case, for *T^d* & 70 MeV, coherent oscillations are significantly suppressed due to electron scattering of the *B*⁰ charge radius, and the baryon production control center. The baryon production control center. Solid production control contro lines in Fig. 1 represent central values, while shaded re-4 \mathbf{p} or \mathbf{p} oscillations (which peak at temperatures lower than \mathbf{p} **B** for the *B^s* system) depleting the asymmetry. In either case, for *T^d* & 70 MeV, coherent oscillations are significantly suppressed due to electron scattering of the *B*⁰ for the *B^s* system) depleting the asymmetry. In either compared to 70 meters and *L* icantly suppressed due to electron scattering of the *B*⁰ charge radius, and the baryon production contribution contribution contribution contribution contribution contri lines in Fig. 1 represent central values, while shaded re-*B^d* oscillations (which peak at temperatures lower than for the *B^s* system) depleting the asymmetry. In either case, for *T^d* & 70 MeV, coherent oscillations are signifcharge radius, and the baryon production ceases. Solid \mathbf{r} in Fig. 1 represent central values, which shaded results. λ iin i zik i l λ and λ and λ neutral *B* mesons (which translates into uncertainties in *B^d* oscillations (which peak at temperatures lower than for the *B^s* system) depleting the asymmetry. In either case, for *T^d* & 70 MeV, coherent oscillations are signif- \bf{V} is the state of \bf{V} at two \bf{V} for the *B^s* system) depleting the asymmetry. In either \mathbb{R} Material for The Standard Model CP violation is \mathbb{R} Elor, Rachel Houtz, Rachel Houtz, September 1980, India I. DOMAIN WALL EVOLUTION AND CONSTRAINTS 1 1 1 Supplemental Model CP Violation is Enough CP Violation in The Standard Model CP Violation in The CP Violation is Enou Gilly Elor, Rachel Houtz, Seyda Ipek, and Martha Ulloa Calzonzin \mathbf{a} of *m ^B* . *Morphing with Dark Dynamics.*— To generate the BAU with only the SM CPV in neutral *Bs,d* meson oscilla- \blacksquare $\mathbf{I} \cup \mathbf{D}$ true vacuum. In blue, we plot *M^Y* () to demonstrate the stored in the domain walls must not dominate the energy density of the universe and trigger inflation. IG WITCH LOPE LIVIOOM the with Dain Dynamics. false vacuum to expand and acceleration of the walls unit the walls until the walls until the surface of the surface pressure is *^p^T* ⁼ */R*, where = (2p2*/*3)^p Supplemental Material for The Standard Model CP Violation is Enough

• Toy morphon potential
$$
V_{\text{scalar}} = m y_0^2 |\mathcal{Y}|^2 + y_\phi y |\mathcal{Y}|^2 \phi + \frac{1}{2} \lambda_\phi y |\mathcal{Y}|^2 \phi^2 + \frac{1}{4} \lambda (\phi^2 - \phi_0^2)^2 + \epsilon \phi_0 \phi^3
$$

$$
M_{\mathcal{Y}}^2(\phi) = m_{\mathcal{Y}_0}^2 + y_\phi y \phi + \frac{1}{2} \lambda_\phi y \phi^2
$$
 $v_{\text{false/true}} = \pm \phi_0 + \mathcal{O}(\epsilon)$

 \mathbf{h} at $M_i^i = M_{2i}(v_{i+1}) - \mathcal{O}(100 \text{ GeV})$ $M_{\mathcal{Y}}^{f}=M_{\mathcal{Y}}(v_{\text{true}})=\mathcal{O}(\text{TeV})$ $T_{\rm e}$ V₎ r results displayed in Fig 1 and the constraints summarized • Find example such that $M_{y}^{i} = M_{y}(v_{\text{false}}) = \mathcal{O}(100 \text{ GeV})$ *^Y* = *M^Y* (*v*false) = *O*(100 GeV)*,* (8a) V is \mathcal{Y} is a false vacuum, we need to fact the fact t $\mathbf v$) $\left(\frac{1}{2}\right)^{n}$ facilitate the *morphing* of $\frac{1}{2}$ morphing of $\frac{1}{2}$ \mathcal{N} duction, but heavy enough (TeV scale) to evade to $\mathcal{M}_v^f = \mathcal{M}_v(v_{\text{true}}) = \mathcal{O}(\text{TeV})$ \sim $\sqrt{1}$ $\sqrt{1}$ of *m ^B* . $M_{\mathcal{V}}^s = M_{\mathcal{V}}(v_{\text{false}}) = \mathcal{O}(100 \text{ GeV})$ with only the SM CPV in neutral *Bs,d* meson oscilla- $\mathbf{u}_y = \mathbf{u}_y(\mathbf{v}_{\text{true}}) - \mathbf{v}(\mathbf{v})$ with that $M^i = M_2(q_0, \cdot) - \mathcal{O}(\cdot)$ tions, we must facilitate the *morphing* of *Y*'s mass such \mathbf{f} is the example of \mathbf{f} $M_{\gamma}^{\prime} = M_{\mathcal{Y}} (v_{\text{true}}) = O(r)$ collider constraints. As an example, consider a scenario α α α α α () to demonstrate the monoton α cample such that $M_{\mathcal{V}}^i = M_{\mathcal{V}}(v_{\text{false}}) = \mathcal{O}(100 \text{ GeV})$ $\frac{1}{\sqrt{2}}$ true $\frac{1}{\sqrt{2}}$. $\frac{1}{\sqrt{2}}$ \mathbf{V} ample such that $\mu y = \mu y (v_{\text{false}})$ \mathbf{M} for \mathbf{M} (TeV) c^{MN} and c^{MN} $\mathcal{O}(100 \text{ GeV})$ $U(100 \text{ GeV})$ Γ Γ _{α} $\bar{\alpha}$ in neutral $\bar{\beta}$ tions, we must facilitate the *morphing* of *Y*'s mass such \vee) collider constraints. As an example, consider a scenario $\mathcal{O}(\mathcal{O})$ to evade the seco $c_{\rm false}$ = $\mathcal{O}(100~{\rm GeV})$ M depends on $\mathcal{O}(m N)$ $(M_{\mathcal{V}}(v_{\text{true}})) = \mathcal{O}(T_{\text{e}}V)$ a temperature *T*PT ' 6 80 MeV, e.g. due to a delayed $M(\lambda) = \mathcal{O}(100 \text{ C V})$ $W\mathcal{Y}(v_{\text{false}}) = \mathcal{O}(100 \text{ GeV})$ \overline{M} () $\overline{O}(T\overline{N})$ $t_i M_{\mathcal{V}}(v_{\text{true}}) = \mathcal{O}(\text{TeV})$ σ (TeV) today to evade the se $m \in \mathcal{L}$ in \mathcal{L} is negative in \mathcal{L} $M_{\mathcal{Y}}(v_{\text{false}}) = \mathcal{O}(100~\text{GeV})$ σ it has light enough during the era of baryon pro- $\langle W \rangle$ (v_{true}) \sim (10 v) \mathbf{M} dominate the domain walls must not dominate the universe and trigger inflation. The universe and trigger inflation. $T = M_{\mathcal{V}}(v_{\text{false}}) = \mathcal{O}(100 \text{ GeV})$ the surface pressure of the walls. The vacuum pressure *p*vac = ✏⁴ $\mathcal{O}_\mathcal{V} = M_\mathcal{Y}(v_\text{true}) = \mathcal{O}(\text{TeV})$ $M(\omega)$ and form a percolation threshold and form a DW network in initial second, our mechanism requires large lar $r = \mu y$ (v_{false}) $r = \nu (100 \text{ GeV})$ Third, the DW network must disappear at *T* 10 MeV to safely avoid spoiling BBN observations. Finally, the energy $\overline{M}(q) = \overline{M}(\mathbb{R}^d)$ $T = \mu \nu \nu$ (v_{true}) $T = \nu (1eV)$ the surface pressure of the walls. The vacuum pressure *p*vac = ✏⁴ requirements on the potential parameters, following the analysis of $[30]$. First, the two minima must be degenerated be degenerated by $\frac{1}{2}$ $\epsilon = M_{\rm D} (v_{\rm false}) = \mathcal{O}(100 \text{ GeV})$ \mathcal{L} of the universe vacuum during baryon size. \mathbf{M} $($ $)$ $\mathbf{\Omega}(\mathbf{\Pi} \mathbf{M})$ $\mathcal{L} = \mathcal{M}_{\mathcal{N}}(v_{\text{true}}) = \mathcal{O}(\text{TeV})$ T_{turb} are two competing parameters that determine the vacuum pressure and va $r = M_{\mathcal{S}}(v_{\mathcal{S}}) - \mathcal{O}(100 \text{ GeV})$ T_{L} \mathcal{F}_{L} (τ ₁ σ) σ at σ _{τ}) \mathcal{S} and dominate the energy density of the universe and trigger inflation. $T = M_{\mathcal{V}}(v_{\text{true}}) = \mathcal{O}(1 \text{eV})$ $\sigma \sim \sigma$ and σ $\mathcal{O}(100 \text{ G N}^{\text{t}})$ $M^f_{\mathcal{Y}} = M_{\mathcal{Y}}(v_{\text{true}}) = \mathcal{O}(\text{TeV})$ ⁰*|Y|*² ⁺ *^y^Y |Y|*² ⁺ le such that $M_{\mathcal{V}}^i = M_{\mathcal{V}}(v_{\text{false}}) = \mathcal{O}(100 \text{ GeV})$ $M_{\mathcal{Y}}^{J} = M_{\mathcal{Y}}(v_{\text{true}}) = \mathcal{O}(\text{TeV})$ • Find example such that $M_y = M_y(v_{\text{false}}) = U(100 \text{ GeV})$ mass in the true vacuum. One example presented here is a phase transition that proceeds via rolling from a symmetry- \mathbf{M} . \mathbf{M} (\mathbf{N}) (\mathbf{Q} (100 \mathbf{Q} , \mathbf{N}) ر
1 *ni* y (∪talse⊥ $\mathfrak{c}_{\rm tr}$ *T*2 *MP l* \overline{a} \overline{a} $\sqrt{2}$ $M_{\mathcal{Y}}^{f}=M_{\mathcal{Y}}(v_{\text{true}})=\mathcal{O}(\text{TeV})$ and \overline{M} *i* \overline{M} *(iii)* \overline{M} (iii) \overline{M} from a \overline{M}) such that $M_{\mathcal{Y}}^{\epsilon} = M_{\mathcal{Y}}(v_{\text{false}}) = \mathcal{O}(100 \text{ GeV})$ mass, and the other is a true vacuum with a large *Y* mass. In our example, a domain wall network forms between

inflation. Relevant conditions of the evolution of the evolution of the Euler between the true a false minimum. *ii. Percolation*: The $\mathcal{F}_{\mathcal{A}}$ is the DW network safely distribution that the DW network safely dis- \mathbf{G} , where \mathbf{G} nating the energy density of the universe and triggering G. Elor

of the wall. Roughly, the surface pressure decreases when the walls grow and flatten out. The walls and flatten o

Gravitational Wave Signal \overline{a} *Morphing with Dark Dynamics.*— To generate the BAU FIG. 2. The morphon potential *V* () (black) that shifts the *Y* mass from 200 GeV in the false vacuum to 1*.*2 GeV in the true vacuum. In blue, we plot *M^Y* () to demonstrate the FIG. 2. The morphon potential *V* () (black) that shifts the FIG. 2. The morphon potential *V* () (black) that shifts the *Y* mass from 200 GeV in the false vacuum to 1*.*2 GeV in the uncertainties in the branching fraction for each operator \mathbf{r} \blacksquare imal value of 0, by fixing *m ^B* = 1 GeV. The entire area below that the curve is allowed for larger *Morphing with Dark Dynamics.*— To generate the BAU with only the SM CPV in neutral *Bs,d* meson oscillations, we must facilitate the *morphing* of *Y*'s mass such *Y* mass from 200 GeV in the false vacuum to 1*.2 GeV* in the false vacuum to 1*.2 GeV* in the false vacuum to 1 true vacuum. In blue, we plot *M^Y* () to demonstrate the mass shift in *Y* from the false minimum *v*false = ⁰ + *O*(✏) to th<u>e (*f*)</u> the $\frac{1}{2}$ of $\frac{1}{2}$ + $\frac{1}{2}$ + $\frac{1}{2}$ + $\frac{1}{2}$ \mathbf{u} $\frac{1}{\sqrt{16}}$. Note that the bands are calculated using the maximum of $\frac{1}{\sqrt{16}}$ imal value of 0, by fixing *m ^B* = 1 GeV. The entire are allowed for \mathbf{C} is allowed for larger values is allowed for larger values is allowed for larger values of \mathbf{C} uncertainties in the branching fraction for each operator [16]. Note that the bands are calculated using the maximal value of 0, by fixing *m ^B* = 1 GeV. The entire area below each upper curve is allowed for larger values FIG. 2. The morphon potential *V* () (black) that shifts the

The annihilation of the DW network can leave behind a stochastic gravitational wave background. gravitational wave background. in which *M^Y* depends on the vacuum expectation value In summary, 3*M* baryogenesis favors a fast percolating mass shift in *Y* from the false minimum *v*false = ⁰ + *O*(✏) to **the annihilation of the DW n** 0 $\frac{1}{2}$ ⁰ = 10 TeV*,* = 1*,* and ✏ ⁼ ³ ⇥ ¹⁰²⁶. that it was light enough during the era of baryon pro-In summary, 3*M* baryogenesis favors a fast percolating duction, but he annihilation, but he annihilation, Γ ⁰ = 10 TeV*,* = 1*,* and ✏ ⁼ ³ ⇥ ¹⁰²⁶. In summary, 3*M* baryogenesis favors a fast percolating in which *M^Y* depends on the vacuum expectation value \mathbf{v} and \mathbf{v} are \mathbf{v} field . The \mathbf{v} nihilation of the ${\rm DW}$ network can leave ${\rm t}$ presentational wave back tions, we must facilitate the *morphing* of *Y*'s mass such that it was light enough during the era of baryon pro- Ω applied in order of the DW petwork can e annihilation of the DW ⁰ = 10 TeV*,* = 1*,* and ✏ ⁼ ³ ⇥ ¹⁰²⁶. In summary, 3*M* baryogenesis favors a fast percolating θ ^{vac.} While phase transition, with a small θ

Searching for the Dark Matter

[J. Berger, **GE**. PRL. 2301.04165]

Signals at Neutrino Detectors

(for any Mesogenesis mechanisms involving decays to dark baryons)

Inside the **Super-Kamiokande** water Cherenkov detector. Credit: Kamioka Observatory, ICRR, Univ. Tokyo

DEEP UNDERGROU

NEUTRINO EXPERIMENT

Dark Matter Induced Nucleon Decay Since we remain agnostic about the dark sector, *y^d* is a free parameter. However a motivated benchmark is ed Nucleon Decay s the Mesogeneis signal. Similar considerations were dis- L_{2} decay delivered associated and the associated experimental L_{2} peron decays, are of interest to Mesogenesis and the neu $t = t$, as such experimental searches and searches and searches and searches and searches are searches and searches a 4.3 Pure in an interaction in an intera 4.4 Matter induced Nucleo **B** (1.1) **E** (1.1) **E** (1.1) **B**

y^d . *O*(0*0.*²) which results in the correct DM abundance of Hylogenesis *CE DDI* . 2201.041651 **EXECROSE SECTION IS OBTAINED.** IT is the matrix of IND is the predicted from the predicted from the predicted from the predicted from the predicted. It is the predicted from the predicted from the predicted from the predi that can probe that can probe the associated operators are highly motions are highly motions are highly motions $\mathcal{L}_\mathcal{A}$ **B** (1.3) **B** [J. Berger, **GE**. PRL. 2301.04165]

Mono-energetic meson (up to detector effects): decays in the system of the control of the stress of the state of the stress of $\mathcal{C}_{\mathbf{G}}$ $\frac{1}{2}$. The *O*($\frac{1}{2}$ is given by \frac absorptic meson (up to detector effects):

$$
E_{\phi_B N \to \xi M}^{M, \text{ kin}} = \frac{m_M^2 - m_{\xi}^2 + (m_N + m_{\phi_B})^2}{2(m_N + m_{\phi_B})} - m_M
$$

 $\mathbf{r} \cdot \mathbf{r} = \mathbf{r} \cdot \mathbf{g} \cdot \mathbf{r}$, which is defined *m ^B , m^B > m^p m^e .* (5c) [J. Berger, G. Elor. Submitted to PRL. arXiv:2301.04165] F Fig. 2. Parameter space and kinetic energy contours for the eight division of G . Element G . Element G . [J. Berger, G. Elor. Submitted to PRL. arXiv:2301.04165] physical reason why we would expect this? $\left[\text{J. DUGCI, U. EIOI. SQUIIIIUCU 10 I ICL. aIZIV. 2301.0+103}\right]$

Signal and Background Simulation

[J. Berger, **GE**. PRL. 2301.04165]

Next: Searches in astrophysics and cosmology environments $\mathbf{F}_{\mathbf{t}}$, where $\mathbf{F}_{\mathbf{t}}$ assumed threshold for the meson. The top row correspond to see the meson. The top row correspond to see the meson. The top row correspond to see the meson. The top row correspond to s Frequences in astrophysics and cosmology chanomiches Next: Searches in astrophysics and cosmology environments simply a rescaling of the rate at Hyper-Kamiokande by a factor of $16.$ Dashed lines indicate the un-smeared energy Eq. 3. Dashed lines indicate the un-smeared energy Eq. 3. Dashed lines indicate the un-smeared energy Eq. \mathbf{r} and \mathbf{r} at Hyper-Kamiokande by a factor of \mathbf{r} Next: Searches in astrophysics and cosmology environments

Mesogensis with a Morphing Mediator

[**GE**, Rachel Houtz, Seyda Ipek, Martha Ulloa, Submitted to PRL, 2408.12647],

"*The Standard Model CP Violation is Enough*".

A mediator mass increase from ~200-500 GeV to about 1 TeV will generate the baryon asymmetry with only the SM CPV.

- Gravitational Wave signals from dark dynamics at current and upcoming PTAs.
- Dark matter signals are still present (induced nucleon decay)
- Motivation for collider searches to *improve branching fraction sensitivity to Br* < 10−⁵

G. Elor

• As measurements of the charge asymmetry improve, motivation for seeing *only* the SM CPV

Outline

- Background on Mesogenesis.
- Bigger picture and the space of mechanisms.
- Mesogenesis with a Morphing Mediator.
- Outlook (bigger picture, again).
- Based on: [**GE**, Rachel Houtz, Seyda Ipek, Martha Ulloa, Submitted to PRL, 2408.12647], "*The Standard Model CP Violation is Enough*".

[J. Berger, **GE,** PRL**,** 2301.04165] [**GE**, A. Guerrera, JHEP, 2211.10553] [G. Alonso-Alvarez, **GE,** M. Escudero, B. Fornal, B. Grinstein, J.M. Camalich. PRD, 2111.12712] [F. Elahi, **GE**, R. McGehee, PRD, 2109.09751] [**GE,** R. McGehee, PRD, 2011.06115] [G. Alonso-Alvarez, **GE**, M. Escudero, PRD, 2101.02706] [G. Alonso-Alvarez, **GE,** E. Nelson, H. Xiao. JHEP, 1907.10612] [**GE,** M. Escudero, A. E. Nelson, PRD, 1810.00880] As well as:

Upcoming: [GE, Can Kilic, Sanjay Mathai, Fall 2024 (targeted)] C. Elor

Space of Mechanisms *<i>n* Ω Ω *dt* + 4*H*⇢rad ⁼ *mn ,* (3b) *B* \overline{A} *B dechanien* LATCCTIGITIOII *A*dark *CP* ⌘ \mathbb{R} **P**N) $\mathbf{M}\mathbf{A}$ $\mathbf{C}\mathbf{P}$ of $\mathbf{M}\mathbf{P}\mathbf{C}$ *P H a*^t + *A |A^t* + *A*1*|*

 $\mathbb{C}\mathrm{PV}$ from entirely from the $\mathbb{C}P$ *a,b* CPV from entirely from the dark sector?

$$
\mathcal{L}_{mass}^{\psi} = -\sum_{ab} M_{ab} \bar{\psi}_{\mathcal{B}}^{a} \psi_{\mathcal{B}}^{b} + \text{h.c} \longrightarrow A_{CP}^{\text{dark}} \equiv \frac{\Gamma(\bar{\mathcal{M}} \to \phi_{\mathcal{B}} \xi \bar{\mathcal{B}}_{\text{SM}}) - \Gamma(\mathcal{M} \to \phi_{\mathcal{B}}^{*} \xi \mathcal{B}_{\text{SM}})}{\Gamma(\bar{\mathcal{M}} \to \phi_{\mathcal{B}} \xi \bar{\mathcal{B}}_{\text{SM}}) + \Gamma(\mathcal{M} \to \phi_{\mathcal{B}}^{*} \xi \mathcal{B}_{\text{SM}})}
$$
\n
$$
Y_{\mathcal{B}} \simeq 8.7 \times 10^{-11} \Big[\frac{\text{Br}(\mathcal{M} \to \mathcal{B}_{\text{SM}} + \text{MET})}{10^{-4}} \frac{A_{CP}^{\text{dark}}}{10^{-2}} \Big] \qquad \text{Br as low as } 10^{-7} - 10^{-6} \text{ expected.}
$$

<u>to experimentalists: meas</u>ı <u>My message to theorists:</u> it is experimentall versions of Mesogenesis (at low *TR*), and so the numerical <u>entalists: </u>measurinq Br to better sensitivity c $\frac{1}{2}$ it is experimentally motivated to fully expl age to theorists: it is experimentally motivated to fully explore the space of Meso mechanisms. / *|A^t* ⁺ *^A*1*[|]* <u>My message to experimentalists: measuring</u> Br to better sensitivity could discover baryogenesis. <u>My r</u> <u>age to theorists:</u> it is experimentally motivated to fully *My message to theorists: it is experimentally motivated to fully explore the space of Meso mechanisms.*

What is the Universe made of?

- Mesogenesis explains both the origin of the baryon asymmetry and the dark matter of the Universe.
- Six different mechanisms of Mesogenesis exist to date. **One mechanisms direct signal is another mechanisms indirect signal.**
- Experimentalists are searching for Mesogenesis!
- To fully take advantage of the experimental program we must comprehensively explore all possible mechanisms, variations, and signals.

How can we exist?

G. Elor

Image: Galaxy cluster SMACS 0723 as seen by the James Webb Space Telescope. Credit: NASA, STScl

Can the SM CPV be enough?

Fig. 1. Represent the and determinative value of the SM CPV is successfully generate the baryon asymmetry with only the SM CPV is successfully generated the baryon 3*M* generate the baryon asymmetry with only the SM CPV G. Elor A mass increase from ~200-500 GeV to about I TeV will lead SL ⇥ Br

Baryon Asymmetry: Exotic *B* Meson Decays

Experimental input: exclusive rates

 Use QCD techniques to compute meson to baryon decay rates in Mesogenesis

[G. Elor, A. Guerrera. JHEP, arXiv:2211.10553]

Limit on the coupling from re-casting LHC searches for squarks

 [A. Alonso-Alvarez, G. Elor, M. Escudero, PRD arXiv:2101.02706]

Colored Triplet Scalar

Constraints from LHC squark searches

G. Elor

4. AT IAY 7 [GE: I've kept lots of details from the notes, we may want to edit this down a bit especially since nothing here is really new \sim 13, 18]. Our model is similar to the one studies in \sim the scalars of H*^u* and H*^d* get vacuum expectation values (the VEVs R*u.d* remain zero). UNDER *BUGY THE CHIRAL SUPERFIELDS ASSIGNMENTS* of the chiral superfields are given in Table 1 of Tab so that for instance U*^c* and D*^c* have R-charge 2*/*3, where D*^c* = ˜ Z $\bf{\overline{L}}$ *X†X ^M ^Q† ⁱQ^j* + ... (4.9) We may minimally extend this model and introduce a new dark chiral multiplet to embed the baryon of the baryon
We may only the baryon of the baryon of the baryon and introduce a new dark chiral multiplet to embed the bary number 1 days start 1 days the original and our Majorana **B** \overline{P} **F** \overline{P} We can then generate the coupling *s*⇠ via the Baryon number conserving super potential term *W* ^R ^d²✓ (*ys*S ⁺ *^m*), which is invariant under \$ which will act to stabilize the dark matter where the *A* SIISY The cary Weyl spinor; the Bino in this case. To construct a Dirac gaugino we must add another 2 component Weyl spinor to the theory, in the adjoint for instance we can add an R-charge zero superfield; 3, 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1)5 , 1
5 , 1)5 , 1)5 , 1)5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 , 1,5 \mathbf{r} grams such as $\mathcal{L}_{\mathcal{A}}$ with $\mathcal{L}_{\mathcal{A}}$ with $\mathcal{L}_{\mathcal{A}}$ with $\mathcal{L}_{\mathcal{A}}$ well in experimental limits. Consider first \triangle the contribution to flavor violation from gluinos. For s-d $\overline{1}$ K^S mass difference is well explained by standard model physics places severe constraints on flavor violation in the \mathbf{V} Tl s I h \overline{a} \overline{a} , \overline{a} , \overline{b} , \overline{c} , \over α2 (120δLLδRR) ˜f6(x), Λ on to Λ field to decay into a data into a dark sector, thereby simultaneously generating Λ a dark matter abundance. Thus far the model we have introduced does not accommodate dark matter. We may minimally extend this model and introduce a new dark chiral multiplet to embed the baryon of the baryon where: \sim r rueor) $STfSV$ Theory A SUSY Theory

SSM R-Symmetry: and Dirac Gauginos and Sterile Neutrics correct charge). So that **ISSM, R Symmetry, and Dirac Gauginos and Sterile Neutrios** (the ² symmetry of [6]). Note that also this forbids a ³ term. While this setup is adequate and generic, MSSM, R Symmetry, and Dirac Gauginos and Sterile Neutrios In the presence of both left- and right-handed flavor violence of both left- and right- $\frac{1}{1}$ \mathbf{j}_1 **MSSM, R Symmetry, and Dirac Gauginos and Sterile Neutrios** or left-handed squarks, the limits $\mathbf N$ ˜f6(x) = ⁶x(1 + ^x) log(x) [−] ^x³ [−] ⁹x² + 9^x + 1 A display, it by inner y, and blide oadginos and biomon reduces from studies of the kaon system. That the observed KL-KISS MUSS MUSS and Dirac (**C** $\frac{1}{2}$ MSSM, R Symmetry, and Dirac Gauginos and Sterile Neutrios **|** 3 MSSM, R Symmetry, and Dirac Gauginos and Sterile Neutrios

 $\mathbf{W} = y_u \mathbf{Q} \mathbf{H}_u \mathbf{U}^c - y_d \mathbf{Q} \mathbf{H}_d \mathbf{D}^c - y_e \mathbf{L} \mathbf{H}_d \mathbf{E}^c +$ 1 2 $\lambda^{''}_{ijk}\mathbf{U}^c_i\mathbf{D}^c_j\mathbf{D}^c_k$ *^k* (4.1) $+\mathop{\mu_{u}}\mathbf{H}_{u}\mathbf{R}_{d} + \mathop{\mu_{d}}\mathbf{R}_{u}\mathbf{H}_{d}$ \int is the first line of \int is the usual MSSM superpotential including the R-parity violation of \int is the \tilde{L}^* and \int is the which is now allowed. The second line describes the Higgs sector; the R*u,d* are added to generate *µ* terms κ are for κ and κ symmetry. Equal when κ symmetry breaking process as usual when κ usual when κ is usual when κ i $\begin{array}{|c|c|c|c|c|}\hline {\bf R}_u, {\bf R}_d & 2 & 0 \ \hline \end{array} \hspace{1.5cm} \begin{array}{|c|c|c|c|}\hline \bf \end{array} \hspace{1.5cm} \mathcal{L}_{\rm gauge} & = & -\sqrt{2}g(\phi T^a \psi^\dagger) \lambda^{a\dagger} + {\rm h.c.} \end{array}$ $\sqrt{2}$ $\sqrt{18}$ $\sqrt{2}$ $\sqrt{18}$ $\sqrt{2}$ $\sqrt{18}$ $\sqrt{2}$ $\sqrt{18}$ $\sqrt{2}$ $\sqrt{18}$, $\sqrt{2}$ $\sqrt{18}$, $\sqrt{2}$ \overrightarrow{O} $\Rightarrow -\sqrt{2}g(\tilde{d}_R^*d_R\tilde{B}^{\dagger}) - \sqrt{2}g(\tilde{d}_Ld_L^{\dagger}\tilde{B}^{\dagger}) + \text{h.c.}$ \overrightarrow{H} \overrightarrow{R} , \overrightarrow{H} *d^R* has *B* = 2*/*3 *.* (4.2) $\begin{array}{|c|c|c|c|c|}\hline & 2/3 & 0 & \ + & \lambda_u^t \mathbf{H}_u \mathbf{T} \mathbf{R}_d + \lambda_d^t \mathbf{R}_u \mathbf{T} \mathbf{H}_d + \lambda_d^s \mathbf{S} \mathbf{R}_u \mathbf{H}_d \, . \end{array}$ $\mathcal{L} = \lambda_1^{''}$ $\tilde{u}_{113}^* \left(\tilde{d}_R^* u_R^{\dagger} b_R^{\dagger} + \tilde{u}_R^* d_R^{\dagger} b_R^{\dagger} + \tilde{b}_R^* u_R^{\dagger} d_R^{\dagger} \right)$ $\mathcal{L} = \lambda_{112}'' \left(\tilde{d}_B^* u_D^{\dagger} b_D^{\dagger} + \tilde{u}_B^* d_D^{\dagger} b_D^{\dagger} + \tilde{b}_B^* u_D^{\dagger} d_D^{\dagger} \right)$ *,* (4.3) $\begin{array}{c} \mathbf{S} \mathbf$ $\begin{bmatrix} \text{R-Change} & \text{I} & \text$ $\mu_u H_u R_d + \mu_d R_u H_d$ theories (with Weyl spinors) have gauge interactions of the form In this work we will consider the scenario where $\frac{1}{\sqrt{2}}$ is $\frac{1}{\sqrt{2}}$ in a right $\frac{1}{\sqrt{2}}$ Identifying *U*(1)*^R* with *U*(1)*^B* leads to the right handed sneutrino ˜⌫*^R* carrying baryon number 1, and $\left\{ \begin{array}{c} \mathcal{L} \end{array} \right. = \Delta_{113} \left(\begin{array}{c} u_R u_R v_R + u_R u_R v_R + v_R u_R u_R \end{array} \right) \, ,$ **R** cause: Thus the following operators are all the symmetries are all the symmetrie ⁴ SN*^c* $\sqrt{\frac{2}{2}}$ $\Rightarrow -\sqrt{2g(d_R^*d_RB^*)} - \sqrt{2g(d_Ld_L^*B^*)} + \text{h.c.}$ Lip $\text{L$ $\begin{aligned} \nabla^t + \lambda^t_u \mathbf{H}_u \mathbf{T} \mathbf{R}_d + \lambda^t_d \mathbf{R}_u \mathbf{T} \mathbf{H}_d + \lambda^s_d \mathbf{S} \mathbf{R}_u \mathbf{H}_d \,. \end{aligned}$ $\mathcal{L} = \lambda_{113}^{''} \left(\tilde{d}_R^* u_R^{\dagger} b_R^{\dagger} + \tilde{u}_R^* d_R^{\dagger} b_R^{\dagger} - \right)$ Gauge: ϕ_1 $\begin{array}{c}\n\overline{a} & \overline{b} \\
\overline{b} & \overline{c} \\
\end{array}$ $+$ \overline{a} $\mathbf{H}_u \mathbf{U}$ |
|
| \sim OU F $u - u \frac{1}{2}$ $\mathbf{W} = y_u \mathbf{Q} \mathbf{H}_u \mathbf{U}^c - y_d \mathbf{Q} \mathbf{H}_d \mathbf{D}^c - y_e \mathbf{L} \mathbf{H}_d \mathbf{E}^c + \frac{1}{2} \lambda_{ijk}^{\prime\prime} \mathbf{U}_i^c \mathbf{D}_j^c \mathbf{D}_i^c$ |
|- $+$ λ $\mathbf{H}_u \mathbf{T} \mathbf{R}_d + \lambda_d^t \mathbf{R}_u \mathbf{T} \mathbf{H}_d$ $\frac{u}{a}$ $\left. + \right. \lambda_u^t \mathbf{H}_u \mathbf{T} \mathbf{R}_d + \lambda_d^t \mathbf{R}_u \mathbf{T} \mathbf{H}_d + \lambda_d^s \mathbf{S} \mathbf{R}_u \mathbf{H}_d \right\}$ $\frac{1}{\sqrt{1-\frac{1}{2}}}$ \mathbf{H} $T^a \mathbf{R} + \mu_a \mathbf{R}$ $\overline{''}$ 1 $_3\left(d^*_R\right)$ \ddagger $\overline{\mathbf{u}}$ \vec{a}^{\dagger} + \tilde{u}^* d[†] $\frac{1}{n}$ $\frac{n}{n}$ \tilde{h} \ast α $\mathcal{L} \;\; = \; \lambda^{\prime\prime}_{113} \left(\tilde{d}_R^* u_R^\dagger b_R^\dagger + \tilde{u}_R^* d_R^\dagger b_R^\dagger + \tilde{b}_R^* u_R^\dagger d_R^\dagger \right) \; ,$ θ , θ $\frac{1}{\sqrt{2}}$ $\overline{2}$ $_{\rm{auge}} \,\,\, = \,\, - \, \sqrt{2} g (\phi T^a \psi^\dagger)$ $(\phi T^a \psi^{\dagger}) \lambda^{a\dagger} + \text{h.c.}$
 $-\sqrt{2}g(\tilde{d}_R^* d_R \tilde{B}^{\dagger}) - \sqrt{2}g(\tilde{d}_R^* d_R \tilde{B}^{\dagger})$ $\mathcal{L}_{\text{gauge}} = -\sqrt{2g(\psi L \psi')\lambda} + \text{n.c.}$
 $\Rightarrow -\sqrt{2g(\tilde{d}_B d_B \tilde{B}^{\dagger})} - \sqrt{2g(\tilde{d}_L d_L^{\dagger} \tilde{B}^{\dagger})} + \text{h.c.}$ $\mathbf{R}_u \mathbf{H}_d$, $2 \frac{\partial \mathbf{S}_u}{\partial \mathbf{R}}$, \mathbf{R}_d 1 : $\lambda_{113} \left(d_R^* u_I^* \right)$ $\frac{1}{2}$ $\sqrt{2g}$ $\begin{array}{|c|c|c|c|c|c|c|c|}\n\hline\n2 & 0 & \text{Gauge.} \end{array}$ $\frac{2}{2}$ $\left\{\mathbf{q} \in \mathbb{R} \text{ where } \begin{bmatrix} \mathbf{q} \in \mathbb{R} \mathbf{p} \end{bmatrix}, \mathbf{q} \in \mathbb{R} \mathbf{p} \mathbf{q} \mathbf{w} \math$ we can also can sector with states of a right handel neutrino supermultiplet. In the data right handel neutrino supermultiplet. In the data right handel neutrino supermultiplet. In the data right handel neutrino supermult $2/3$ 0 $\lambda_u^t \mathbf{H}_u \mathbf{T} \mathbf{R}_d + \lambda_d^t \mathbf{R}_u \mathbf{T} \mathbf{H}_d + \lambda_d^s \mathbf{S} \mathbf{R}_u \mathbf{H}_d$. $= \lambda_{113}^{''}\left(\tilde{d}_R^*u_R^{\dagger}b_R^{\dagger} + \tilde{u}_R^*d_R^{\dagger}b_R^{\dagger} + \tilde{b}_R^*u_R^{\dagger}d_R^{\dagger}\right) \,,$ $\mathcal{L}_{\text{gauge}} = -\sqrt{2g(\phi I^{\alpha}\psi^{\alpha})\lambda^{\alpha\alpha}} + \text{h.c.}$ $\begin{array}{rcl} \mathcal{P} & \mathcal{P} & \mathcal{P} \end{array}$ and $\Rightarrow & -\sqrt{2}g(\tilde{d}_R^*d_R\tilde{B}^{\dagger}) - \sqrt{2}g(\tilde{d}_L d_L^{\dagger} \tilde{B}^{\dagger}) + \text{h.c.}$ \mathbf{Q} $4/3$ 0 construct a Dirac gaugino we must add another 2 component Weyler and another 2 component Weyler Weyler Weyler and another 2 component Weyler and another 2 component Weyler and another 2 component Weyler a $\mathcal{L} = \lambda_{113}'' \left(\tilde{d}_R^* u_R^\dagger b_R^\dagger + \tilde{u}_R^* d_R^\dagger b_R^\dagger + \tilde{b}_R^* u_R^\dagger d_R^\dagger \right),$ $\sqrt{2} \alpha (\sqrt{2}a_0 t^{\dagger}) u^{\dagger} + b_0$ $\mathbf{w} = y_u \mathbf{Q} \mathbf{H}_v$ $\mathbf{H} \cdot \mathbf{R} + \mathbf{H} \cdot \mathbf{R}$ $(d_R^* u_R^{\dagger} b_R^{\dagger} + u_R^* d_R^{\dagger} b_R^{\dagger} + b_R^*)$ $\overline{}$ y_u $\frac{1}{2}$ $\mathbf{U}^c - y_d \mathbf{Q} \mathbf{H}_d \mathbf{D}^c$. $- y_e$ ln d l $+ \frac{1}{2}$ $\lambda_u^t \mathbf{H}_u \mathbf{T} \mathbf{R}_d +$ λt D $\quad + \;\; \lambda_u^t \mathbf{H}_u \mathbf{T} \mathbf{R}_d + \lambda_d^t \mathbf{R}_u \mathbf{T} \mathbf{H}_d + \lambda_d^t$ $``\text{RPV}" \text{ } \textbf{W} = y_u\textbf{Q}\textbf{H}_u\textbf{U}^c - y_d\textbf{Q}\textbf{H}_d\textbf{D}^c - y_e\textbf{L}\textbf{H}_d\textbf{E}^c + \frac{1}{2}\lambda_{ij}$

Neutrio:

L	1	1
\mathbf{E}^c	1	-1
\mathbf{N}_R^c	1	-1

\n $\mathbf{W} = \frac{\lambda_N}{4} \mathbf{S} \mathbf{N}_R^c \mathbf{N}_R^c + \mathbf{H}_u \mathbf{L}^i y_N^{ij} \mathbf{N}_R^{c,j} + \frac{1}{2} \mathbf{N}_R^c M_M \mathbf{N}_R^c + \text{h.c.}$,\n

\n $4\lambda_N \left(\lambda_s \nu_R^{\dagger} \tilde{\nu}_R^* + \phi_s \nu_R^{\dagger} \nu_R^{\dagger} \right) + \text{h.c.}$

 T ratameter space. Kr v coupings and squark mass mixing G. Elor Daramatar gnaca^{, "}RDV" couplings and squark mass mixing Parameter space: "RPV" couplings and squark mass mixing G. Elor *R*N*^c s*⌫*†* RPV" cou \overline{a} plings *c*2 $\overline{\mathbf{u}}$ **d** squark $\overline{\mathbf{r}}$ ⇤³ $\overline{\text{u}}$ ss mix ng _{G. Elor} Parameter space: "RPV" couplings and squark mass mixing

A SUSY I Heory chiral superfields. In the superfield Δ CT1 A SUSY Theory

Minimal Particle Contents on the Baryon number. Superpartners as dark baryons. Superpartners and SM particles have different charge under an unbroken R-symmetry. We can identify this with Daryon humoci.
Superpartners as dark baryons. We can identify this with Baryon number. We can identity this with Baryon humber.
Superpartners as dark baryons. Toy Model Field SUSY Model Spin *QEM* Baryon no. Lepton no. ² Mass

<u>P</u>^{<i>l}</sub> $\frac{1}{2}$ + p²

B+ Mesogenesis

Freezing-In a Baryon Asymmetry 6 would expect the dark sector dynamics to not transfer the dark sector dynamics to not transfer the dark sector asymmetry one hundred percent eciently. Therefore, Eq. (??) represents a lower bound on the the observables $s = \frac{1}{2}$ $Rorron \Lambda CVM$ Dal von Apvinni baryon or lepton number. In this case dark matter is multi-

while the solid gray region corresponds to the \mathbf{r} Example Benchmark point: $E_{\rm eff}$ to $E_{\rm eff}$ to $E_{\rm eff}$ to $E_{\rm eff}$ that it is possible to generate that it is possible to generate $T_R = 10 \text{ MeV}, m_\Phi = 6 \text{ GeV}$ $\langle \sigma v \rangle = 1 \times 10^{-15} \text{ GeV}^{-2}$ Future, more precise measurements of *A^f* $\text{Br}(\Phi \to \chi_1 \bar{\chi}_1) = 0.1$ $\sum_{\mathbf{r}} \mathbf{r} f \mathbf{f} \mathbf{p} f \qquad (9.8, 10^{-4})$ $\sum_{\alpha} N_{\pi}^{*} a_{CP} \text{d} \Gamma_{D^{+}} = (-9.5 \times 10^{-7})$ \mathcal{L} $\int d\theta$ the charm sector. If $\frac{1}{2}$ is the sector. $dt \stackrel{(v_B)}{\sim} t^{c}$ β for α - β $=$ $\langle \sigma v \rangle n$ $(n_{\ell} - n_{\bar{\ell}})$ $=$ $\langle 0 \, v \rangle n_{\chi_1} \, (\nu_{\ell_d} - n_{\ell_d})$ $\sqrt{1 + \frac{1}{\sqrt{1 + \frac{1}{$ $\left| \frac{n_{\chi_1} \langle v v \rangle}{\sigma \sigma \langle \sigma v \rangle} \right| \geq \frac{I_B}{\sigma \sigma^2}$ $H(T)$ $T=T_R$ is Y_L^{dark} previously made certain areas of phase space dicult to species for a benchmark point which produces the observed $\sqrt{a}v_1 = 1 \times 10$ de v $\text{Br}(\Phi \to \nu_1 \bar{\nu}_1) = 0.1$ λ 1/11 $\sum M_f f_a f_{\text{RF}} f_{\text{R}} = (-0.3 \times 10^{-7})$ $\sum_{i} \cdot \pi^{\alpha} C P^{\alpha} D^+$ (e.g. π is $\frac{\partial}{\partial t} (n_{\mathcal{B}} - n_{\overline{\mathcal{B}}}) + 3H (n_{\mathcal{B}} - n_{\overline{\mathcal{B}}})$ $\cos \theta = \cos \theta$ $\sqrt{5}$ simply tracked the production of a lepton $\sqrt{5}$ simply tracked the production of a lepton asymmetric simply tracked the production of a lepton $\sqrt{2}$ metry. We modify this equation to include the relevant $\left(m \right)$ $\left(m \right)$ the evolution \mathbf{v} to include the relevant to include the relevant to include the relevant to include the relevant of \mathbf{v} to include the relevant of \mathbf{v} and \mathbf{v} include the relevant = (19) Ending is selectional p baryon asymmetry. We take *T^R* = 10 MeV, *m* = 6 GeV, $\langle \sigma v \rangle = 1 \times 10^{-15} \text{ GeV}^{-2}$ ⇡ *a^f* $\text{Li}(\Psi \to \chi_1 \chi_1) = 0.1$ $\sum_{\mathbf{a}} \mathbf{r}^{\mathbf{f}}$ for $\mathbf{r}^{\mathbf{f}}$ as a right and the right are three a $\sum N_{\pi}^{u} a_{CP}^{v} D_{D+}^{u} = (-9.5 \times 10^{-4})$ \int $\overline{a}t$ of the Boltzmann equations in this section may be seen for the Boltzmann equation may be seen for the \overline{b} $\sqrt{\frac{\nu}{\mu}}$ $E_{\rm eff}$ simply tracked the production of a lepton of a lepton asymmetric of a lept $\frac{n\chi_1 \vee v}{\chi_1 \wedge \chi_2}$ $\geq \frac{1}{2}$ Γ \sim Ω \sim example benchmark point: $T_R = 10 \text{ MeV}, m_{\Phi} = 6 \text{ GeV}$ $\sqrt{v}v_1 = 1 \times 10$ and CP as $\text{Br} (\Phi \to \chi_1 \bar{\chi}_1) = 0.1$ \sum *f* $N_{\pi}^f a_{CP}^f {\rm Br}^f_{D^+} = \left(-9.3 \times 10^{-4}\right)^{-1}$ 0*.*⁰⁰³⁹ (15) \overline{d} $\frac{\alpha}{\tau}$ ($n_B - n_{\overline{B}}$) + 3H ($n_B - n_{\overline{B}}$) = dt say better \mathcal{L} . metry results from a large positive *A*CP if `*^d* carries anti- $\left. - \langle \sigma v \rangle \, n_{\chi_1} \left(n_{\ell_d} - n_{\bar\ell_d} \right) \right]$ our goal here is to remain agnostic about the details of $\left|\begin{array}{cc} n_{\gamma_1}\left\langle \sigma v\right\rangle & \sqrt{S_{\gamma_2}}\end{array}\right|$ $\left| \frac{\partial u}{\partial T} \right|_{T=T} \leq \frac{\epsilon}{\text{Vdark}}$ $\left(\begin{array}{cc} H(L) & H - IR & I \end{array} \right)$ PIENU. LHCb and others will measure *ACP* for charged $\frac{1}{2}$ 10^{-8} \leftarrow $-Y_{\ell_d}$ = 110Y_B^{obs} asymmetry in the metric \mathcal{L} in \mathcal{L} in \mathcal{L} in \mathcal{L} introduced here is active at low temperatures at low temperatures and so $\overline{}$ troweak sphalers (which conserve a *Baryon* and Baryon and Butch conserver butch conserver butch conserver and a *L* number butch conserver butch conserver and a *L* number of $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{$ **not be and** *L* state when the data is the data of the data is the data of the data is th Asymmetry Made SM Baryon Asymmetries
Transfer Set $\frac{1}{2}$ transfer the asymmetry. the dark sector. 10^{-4} 10^{-4} V_{\odot} $\begin{array}{ccc} \hline \begin{array}{ccc} \hline \end{array} & \bullet & \bullet \end{array}$ tional dark sector fields that are charged under Standard $\begin{array}{c} \n\hline\n\text{10-8} \\
\hline\n\end{array}$ $\frac{1}{\sqrt{1+\frac{1}{\omega}}}$ conserves the total baryon and lepton number of the Uni- $\sum_{k=1}^{\infty}$ and $\sum_{k=1}^{\infty}$ and open asymmetry between asymmetry between $\sum_{k=1}^{\infty}$ $\sum_{n=1}^{\infty} 10^{-12}$ equal and opposite baryon asymmetry between the dark and visible sectors. Schematically, we consider sectors. Schematically, we consider scatter- $\frac{10-16}{5}$ $\frac{5}{5}$ 10^{-10} \geq \geq \geq depends on what sign of *ACP* we are model building for. The age of at what point do we compute \mathcal{L} $\frac{10^{11} + 1111111}{10^{-4}}$ $\frac{11111111}{10^{-4}}$ $\frac{0.01}{10^{-6}}$ Time (seconds) $\langle \sigma v \rangle = 1 \times 10^{-15} \text{ GeV}^{-2}$ baryon asymmetry. We take *T^R* = 10 MeV, *m* = 6 GeV, $\sum_{i=1}^{n} f_i f_i = f$ (22, 12) $D-4$ ¹ $\sum_f N^J_\pi a^{\prime}_{CP} {\rm Br}^{\prime}_{D^+} = (-9.3 \times 10^{-4})$ \int 10^{-4} \mathcal{L}_{in} $\frac{d}{dx}(n_B - n_{\overline{B}}) + 3H(n_B - n_{\overline{B}}) =$ $R = 10^{-12}$ $\left|\begin{array}{cc} n_{\chi_1} \langle \sigma v \rangle & \to & Y_B^{\text{obs}} \end{array}\right|$ \parallel $H(T)$ \parallel $_{T=T_R}$ \sim Y_I^{dark} \parallel scattering term and obtain the evolution for the evolution 10^{-20} $\sqrt{ }$ σ is the given by the given by σ α β = 1 × 10⁻¹⁰ GeV² h*v*i *n*¹ \overline{J} $dt \stackrel{(i)}{\sim} B$ is the scattering will be seen the scattering when the scattering when the scattering when the scattering $\frac{1}{\sqrt{B}}$ is the scattering of the scattering of the scattering of the scattering of the scatterin $\left(\pi_{1}^{(n)}\right)$ $\left(\pi_{2}^{(n)}\right)$ $\delta=\left\langle \sigma v\right\rangle n_{\chi_{1}}\left(n_{\ell_{d}}-n_{\bar{\ell}_{d}}\right)$ n_{χ_1} $\langle \sigma v \rangle$ *H*(*T*) $\overline{\mathbf{I}}$ $\overline{}$ $|T=T_R$ $\frac{Y_B^{\text{obs}}}{Y^{\text{dark}}}$ *B* Y_L^{dark} *.* (21) $\text{Br}(\pi^+ \to \ell_d e^+) = 10^{-3}$ that due to the lower bound on baryon-charged masses \mathbb{R}^n of 1.2 GeV. Further, there are equal and opposite lep- \overline{a} ton and visible sectors. In the data and visible sectors. In the data and visible sectors. In the data sectors. In th also account for the this day of the third and the third asymmetries and the third asymmetries and the third a
Transfer and SM Set and these additional dark leptons must make up a di↵erent, α^{-4} , the details of DM. Clearly, the details of DM. Clearly, the details of α^{-4} depend on baryon- and lepton- number assignments to \mathcal{A} states 1 and 2, which we define the next section \mathbb{R}^n h_{max} is given by just make simple h_{max} in the matrix h_{max} is given by h_{max} $\begin{array}{c} \bullet \end{array}$ for $\begin{array}{c} \bullet \end{array}$ abundance is relatively the correct DM abundance is relatively to $\begin{array}{c} \bullet \end{array}$ **be compared to generating the baryon of th** Y_B^{obs} P erhaps the simplest scenario is to assume that the simple P dark baryon-charged state comprises almost the entirety of DM, making it a well motivated case of completely asymmetric DM. In this case, the lightest data \Box to is appreciable than the dark baryon so that dark baryon so that dark baryon so that dark baryon so that \mathcal{A} \mathcal{I}_{1} it makes up a negligible subcomponent of DM. Thus, \mathcal{I}_{1} $\frac{10^{-6}}{10^{-6}}$ $\lim_{\epsilon \to 0} (s^{\alpha} \text{cend})$ *d* $\frac{d}{dt}(n_{\mathcal{B}} - n_{\overline{\mathcal{B}}}) + 3H(n_{\mathcal{B}} - n_{\overline{\mathcal{B}}}) =$ h*v*i *n*¹ $\langle \sigma v \rangle n$ (of coupled Boltzmann equations for the baryon asymmetric for the baryon asymmetric state \mathbf{r} try of the $\lfloor n \rfloor$ $\Vert H(T) \Vert_{T=T_R} \cong Y_L^{\text{dark}}$ asymmetry will be expected with the scattering transferred when the scattering of the scattering dark baryon asymmetry, therefore, is always asymmetry, is always an asymmetry, is always an asymmetry, in a metric component of DM, and a substantial fraction at the dark baryon at the dark baryon at the dark baryon at
dark baryon at the dark baryon at $\begin{array}{ccc} \hline & \bullet & \bullet & \bullet \end{array}$ of 1.2 GeV. Further, there are equal and opposite lep- \sim $\begin{array}{ccc} \n\text{10-8} & \text{V} \\
\end{array}$ $\frac{1}{s}$ which computes the data sector baryons due not define t also account for this day of the third and the sector lepton as \sim day of the sector lepton asymmetry, then \sim $\sum_{n=1}^{\infty}$ data dark leptons must make up a different make $\frac{1}{2}$ as \sim DM. Clearly, the details of DM. Clearly, the depend on baryon- and lepton- number assignments to $s_{\rm s}$ and 2, which we define the next section. 10^{-10} \rightarrow \sim how generating the correct DM abundance is relatively straightforward (as compared to generating the baryon \mathcal{A} P_{P} as to assume the simplest scenario is to assume that the simplest scenario is to assume that the simplest scenario is to assume the simplest scenario is to assume that the simplest scenario is to assume the simp dark baryon-charged state comprises almost the simplest state state comprises and the simplest scheme that the simplest sc B and the evolution for the evolution of the SM baryon of the SM b $\frac{1}{2}$ $-\langle \sigma v \rangle n_{\chi_1} (n_{\ell_d} - n_{\bar{\ell}_d})$ $\overline{ }$ \sim 10 n_{γ} , $\langle \sigma v \rangle$ as the baryon asymmetric for the baryon asymmetric for the baryon asymmetric for the baryon asymmetric for the baryon Y_P^{obs} $\left| \frac{\sqrt{2} \cdot \sqrt{2}}{H(T)} \right|_T$ $\begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$ is contracted that the produced lepton is contracted in the produced lepton is contracted in the product of L $\frac{10}{10}$ that due to the lower bound on baryon-charged masses \mathbb{R}^n of 1.2 GeV. Further, there are equal and opposite lep- \mathcal{A} $t - Y_{\ell_d}$ state (s) which comprise the dark-sector baryons due not Λ and due not due not due not due not due not due $Y_R^{\rm obs}$ these additional dark leptons must make up a di↵erent, asymmetric subcomponent of \mathbb{R}^n depend on baryon- and lepton- number assignments to $s_{\rm s}$ and 2, which we define the next section. \mathcal{A} is the simple vector function \mathcal{A} is the simple vector \mathcal{A} how generating the correct DM abundance is relatively strational (as compared to generating the baryon the baryon of the baryon of the baryon of the baryon of the b 10^{-6}

glet dark sector states which may be fermions or scalars which may be fermions or scalars \mathcal{E}

G. Elor $t_{\rm HIR}$ (seconds) dividends the other data the other d $\ddot{}$ baryon-charged states almost the entirety of $\ddot{}$

B_c ⁺ Mesogenesis

$$
\left(\frac{Y_{\mathcal{B}}}{Y_{\mathcal{B}}^{\text{obs}}}\simeq\frac{\sum_{\mathcal{B}^{+}}\text{Br}_{B^{+}}^{\mathcal{B}^{+}}\sum_{f}a_{\text{CP}}^{f}\text{Br}_{B_{c}^{+}}^{f}}{10^{-3}}\frac{T_{R}}{6.45\times10^{-5}}\frac{2m_{B_{c}^{+}}}{20~\text{MeV}}\frac{2m_{B_{c}^{+}}}{m_{\Phi}}\right)
$$
\nG. Elc