

Models of DM, Baryogenesis, and Naturalness through the Kinetic Mixing Portal

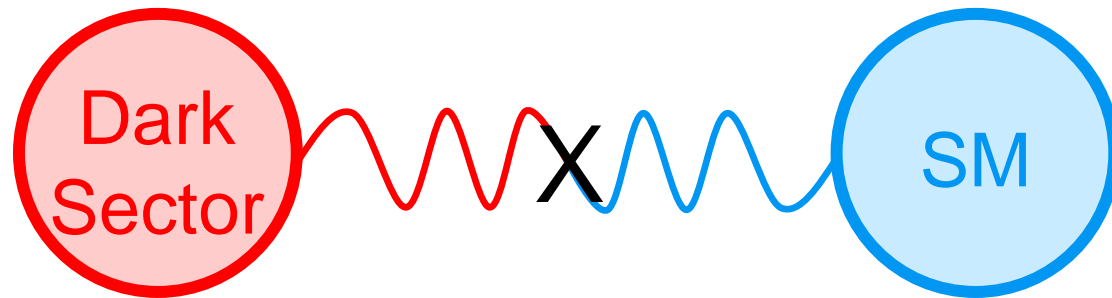
Robert McGehee



RF6 Dark Sector Theory Day 1

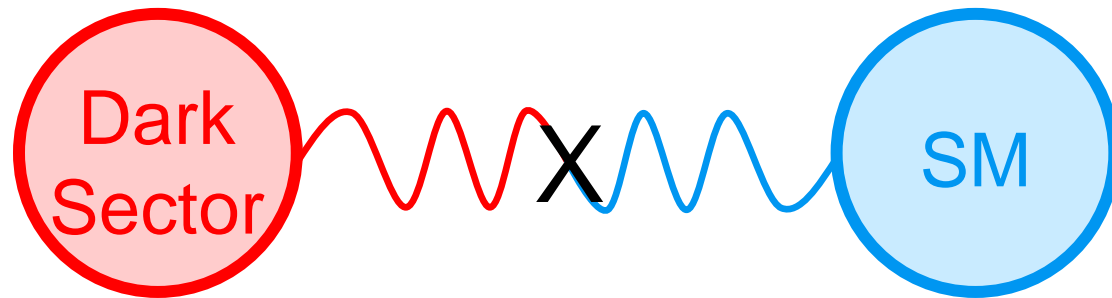
The Kinetic Mixing Portal

$$\mathcal{L} \supset \frac{1}{2} \frac{\epsilon}{\cos \theta_W} F'_{\mu\nu} B^{\mu\nu} \xrightarrow{\text{EWSB}} \frac{1}{2} \epsilon F'_{\mu\nu} F^{\mu\nu}$$



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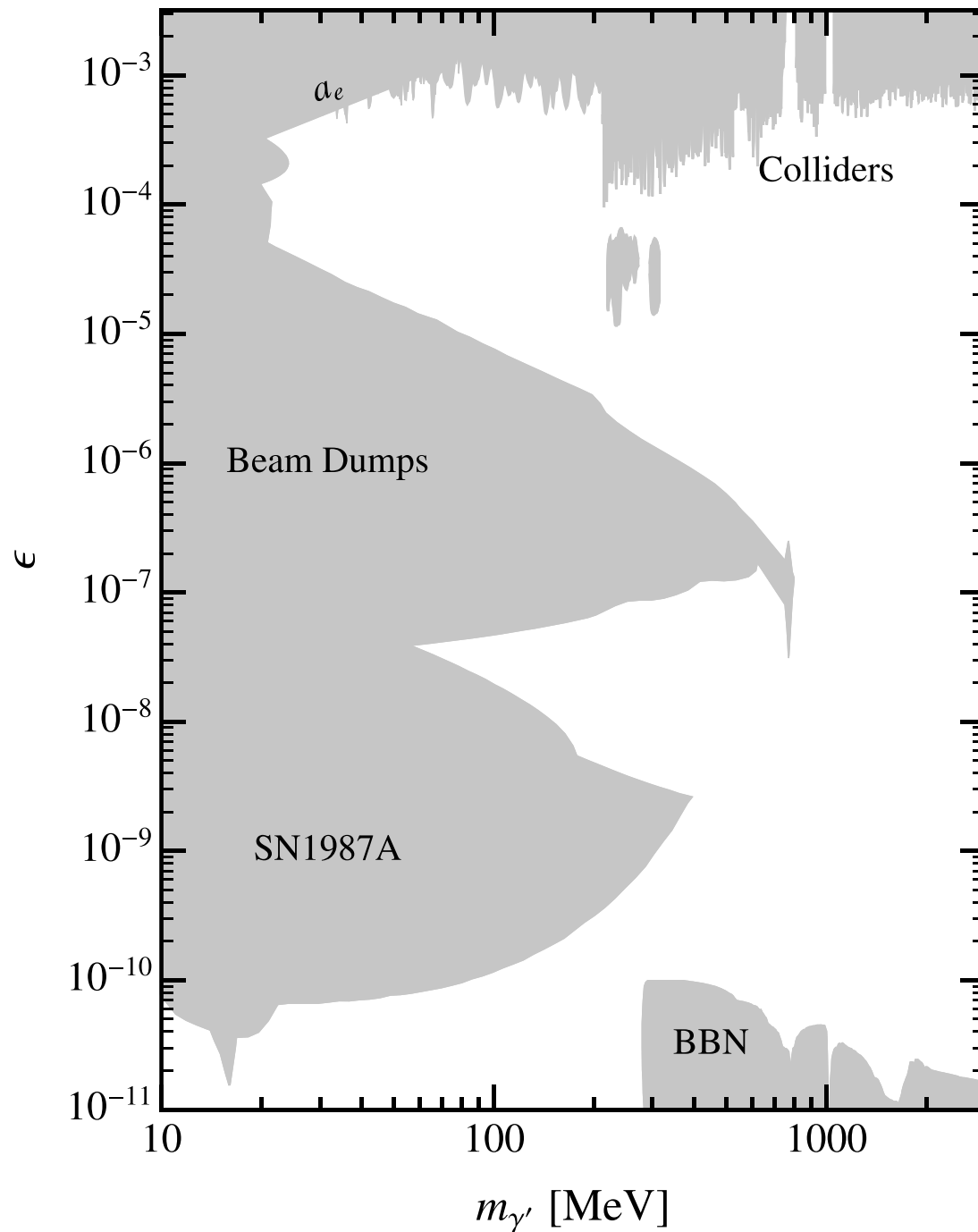
1 of 4 “main” portals to DS

Generically expected, but small

Thermal targets of LDM (see Asher Berlin’s talk)

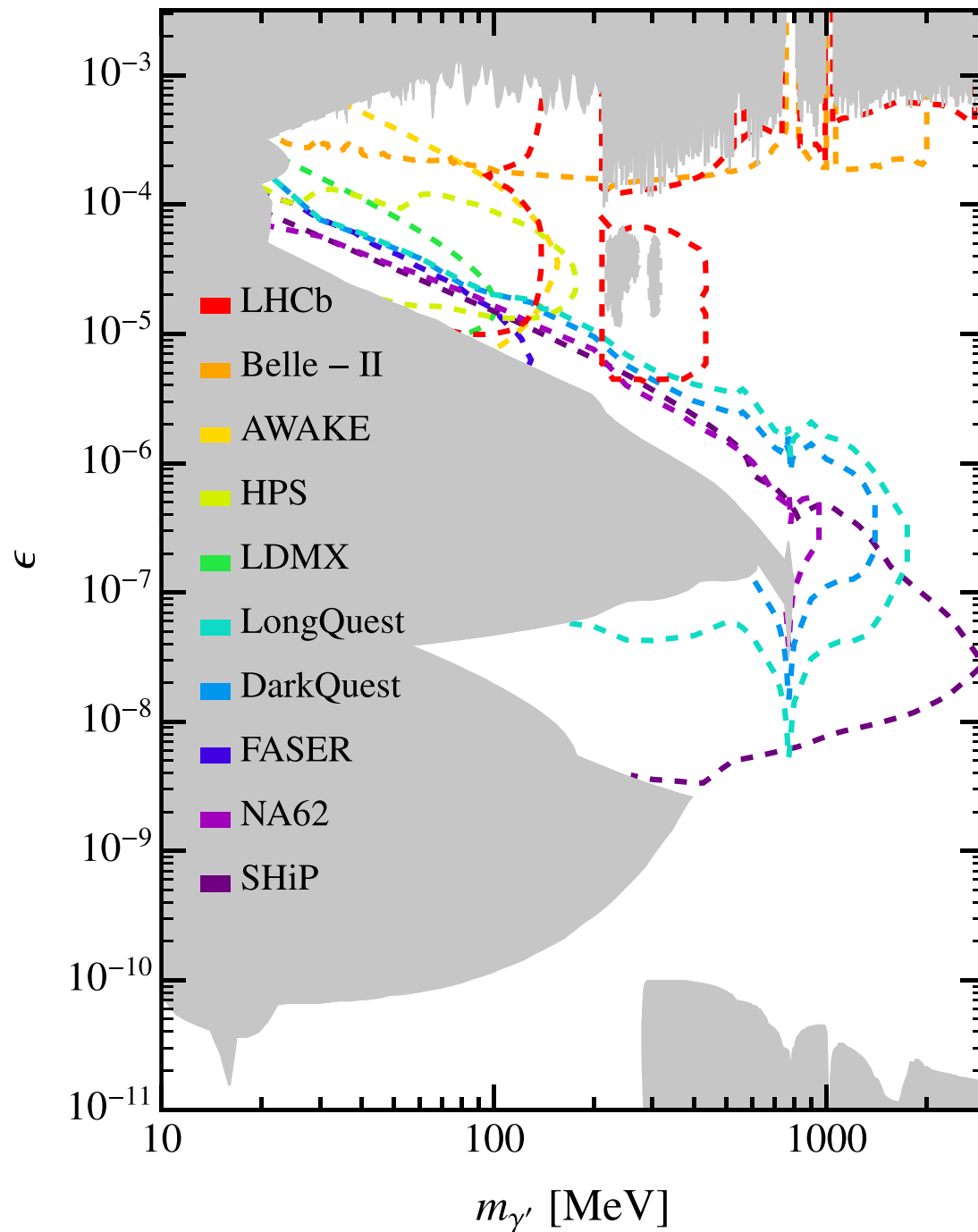
This talk: 3 models motivated by DM, baryogen, & EW FT

Constraints for Visibly Decaying Dark Photons



See e.g.
1407.0993
1608.08632
1611.03864
1611.05852
1706.00424
1710.02867
1803.07748
1812.04130
1908.07525
1910.06926

Constraints for Visibly Decaying Dark Photons



See e.g.
1502.00084
1504.04855
1505.02025
1509.06765
1603.08926
1608.08632
1804.00661
1807.01730
1811.12522
1812.11164
1908.07525

1) Resonant Self-Interacting Dark Matter from Dark QCD

Y. Tsai, R. McGehee, H. Murayama 2008.08608

(Resonant) Self Interacting Dark Matter

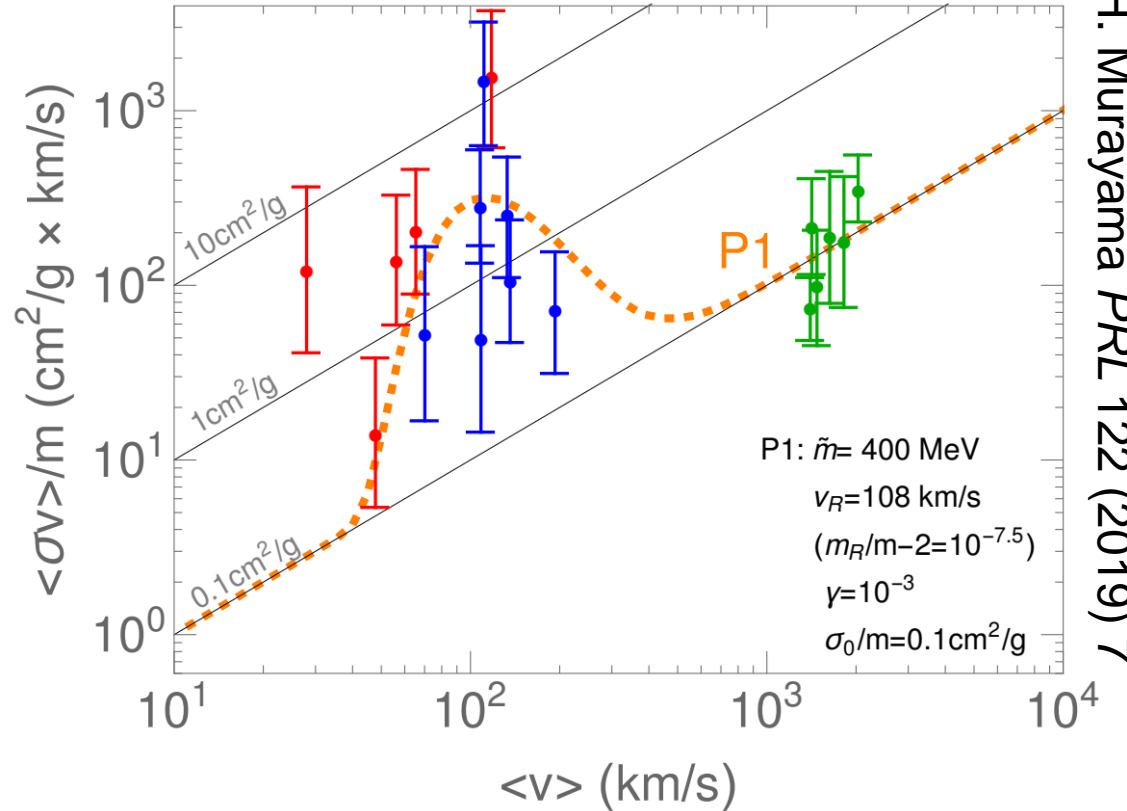
SIDM explains possible small-scale structure issues

Dwarf, LSB, cluster data

from M. Kaplinghat, S. Tulin, H.-B. Yu
PRL 116 (2016) 4

See Hai-Bo Yu's talk next!

Resonant SIDM can fit the
inferred velocity-dependence



X. Chu, C. Garcia-Cely,
H. Murayama *PRL* 122 (2019) 7

RSIDM, Inspired by QCD

Dark QCD

1 light quark u

2 heavy quarks c, b

$m_c = m_b \equiv m_Q$ and $n_c = n_{\bar{b}}$

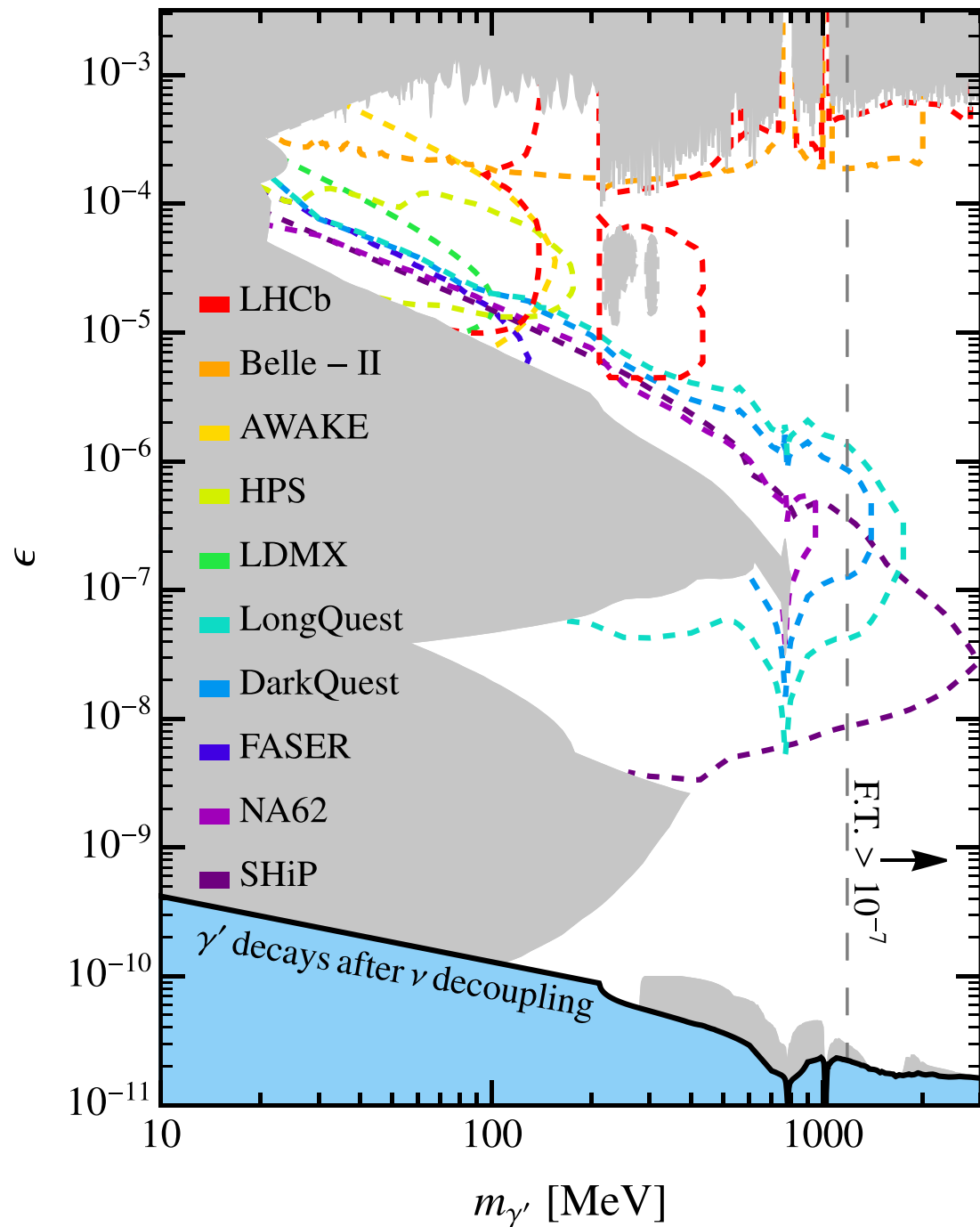
$D(c\bar{u})B(u\bar{b}) \longrightarrow \Upsilon(c\bar{b})(nS)$

Introduce $U(1)'$ to allow pions to decay

Dark photon transfers entropy from DS to SM

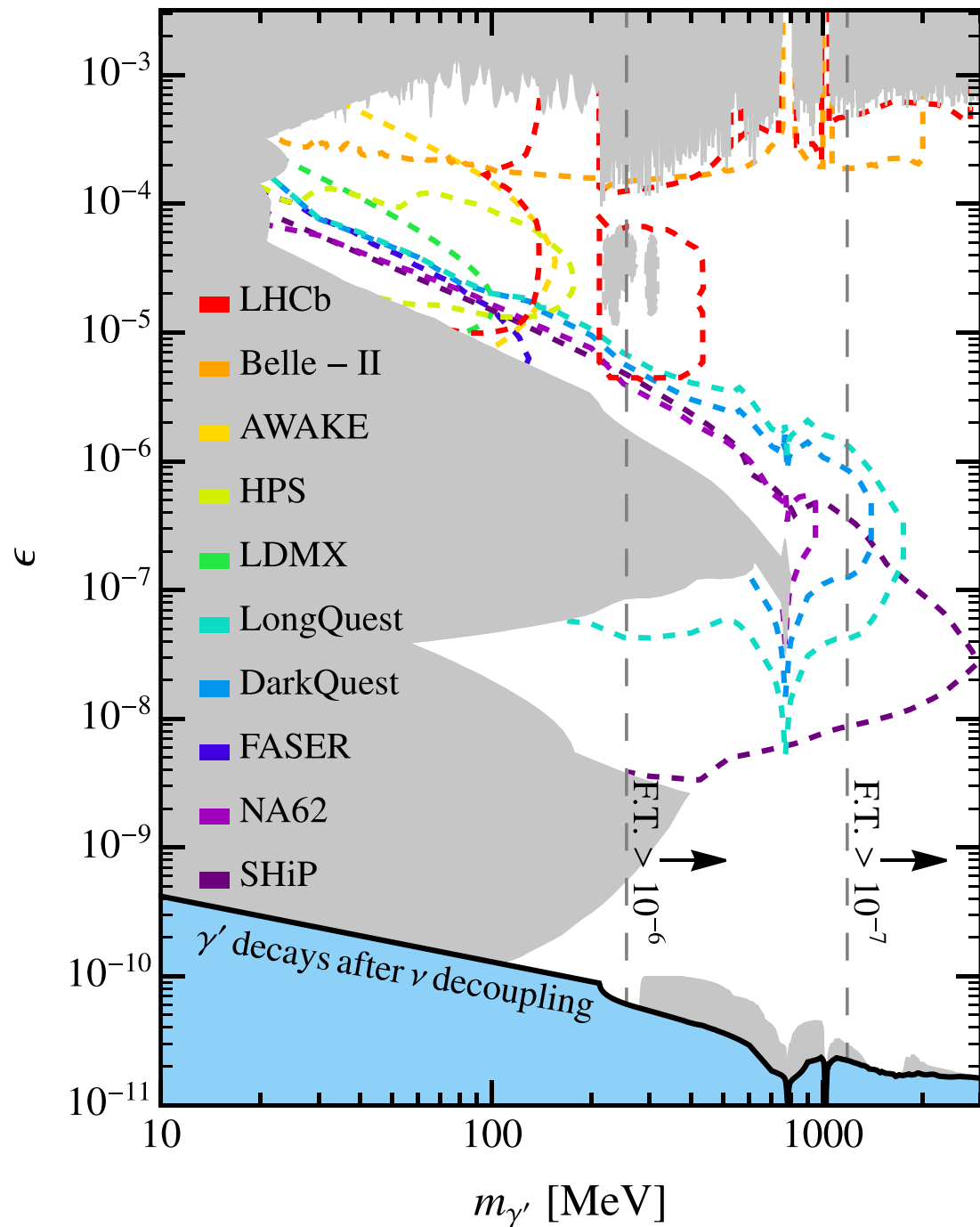
$$\frac{m(\Upsilon(4S)) - 2m(B^0)}{m(\Upsilon(4S))} = 0.0019 \quad \text{SM QCD}$$

Resonant Self-Interacting Dark Matter from Dark QCD



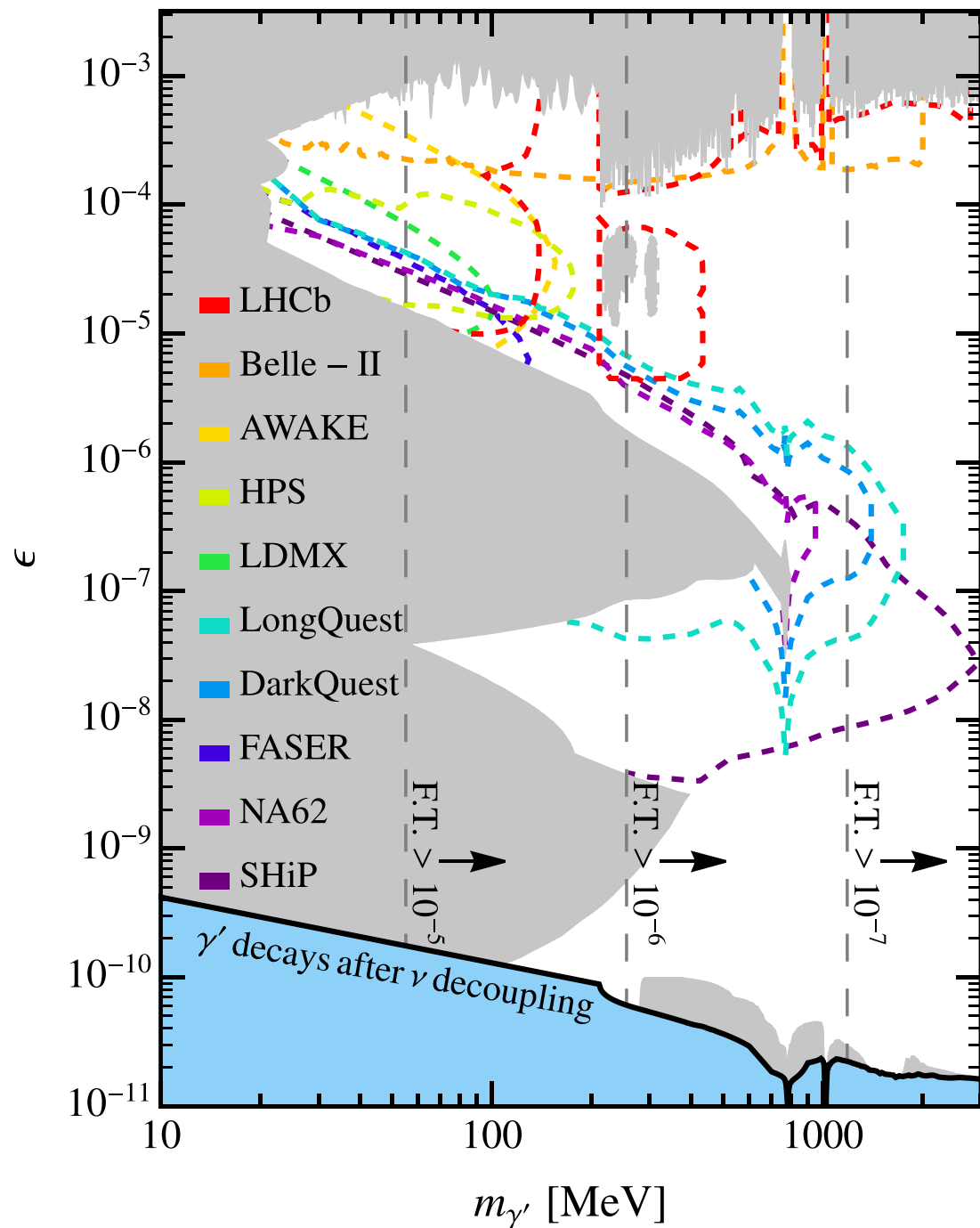
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Resonant Self-Interacting Dark Matter from Dark QCD



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2) Asymmetric Matters from a Dark First-Order Phase Transition

E. Hall, T. Konstandin, **R. McGehee**, H. Murayama 1911.12342

Baryogenesis & Asymmetric DM

Ω_b requires explanation

$\Omega_c \approx 5\Omega_b$ suggests DM may also be **asymmetric**

Common origin?

ADM + SM gauge copy \rightarrow

Mirror world models

See e.g. hep-ph/0312335, astro-ph/0407623, 1805.06876, 1811.10232, 1907.03404

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Our Model Content:

$$SU(3)' \times SU(2)' \times U(1)'$$

$$\Phi_1, \Phi_2, Q', u'_R, d'_R$$

$$L', e'_R, N'_R \leftarrow Y_e \text{ large}$$

$$\mathcal{L} \supset Y_N^a \bar{L}' \tilde{\Phi}_a N'_R + y_N \bar{L} \tilde{H} N'_R + \text{c.c}$$

Dark-Sector Baryogenesis

1. **SFOPT** + **CP-violating** potential + **sphalerons** in DS
2. 2 Higgs doublet, EW-like baryogenesis in DS \rightarrow **B'+L'**

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4. **SM sphalerons** then generate some B

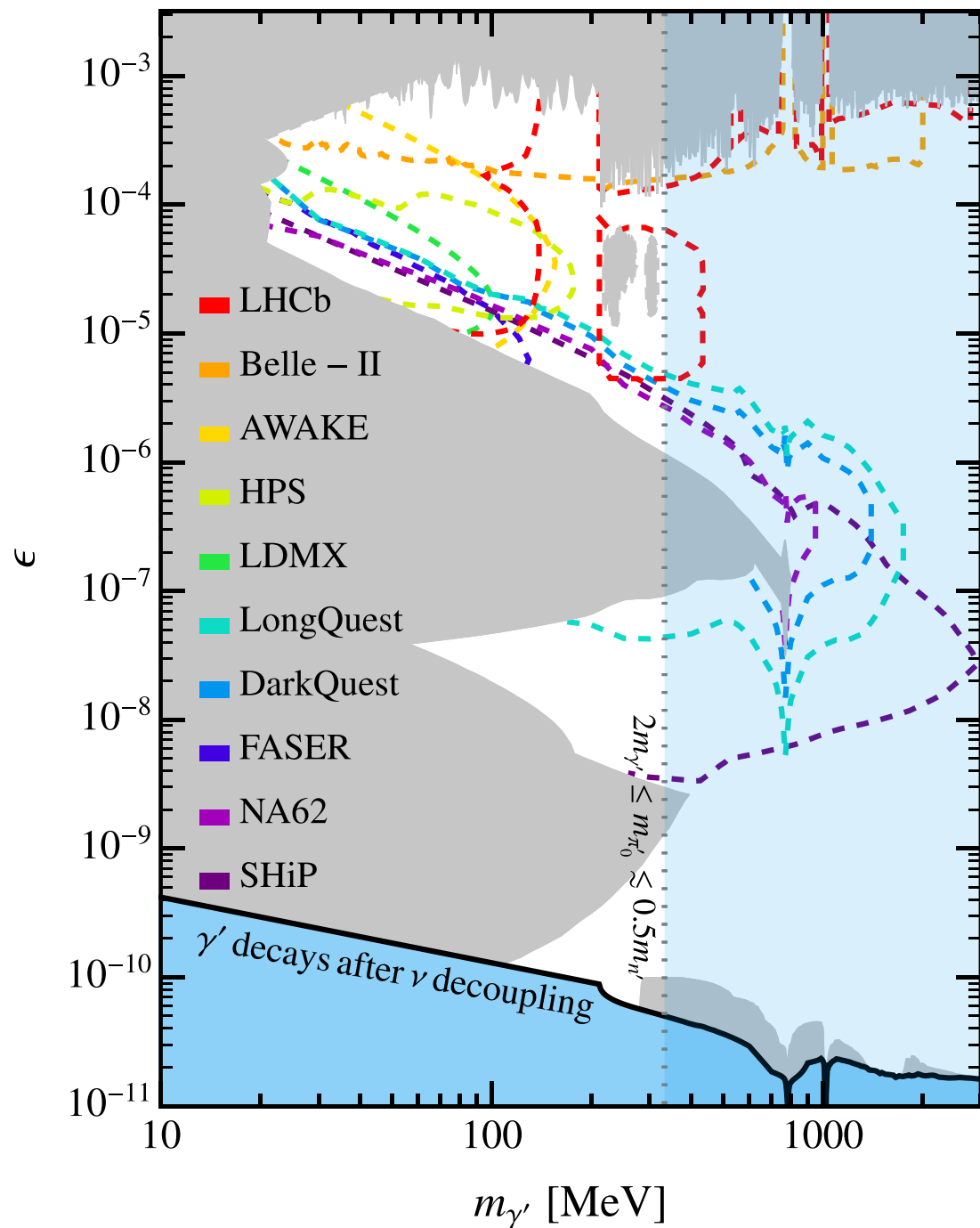
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2. 2 Higgs doublet, EW-like baryogenesis in DS \rightarrow **B'+L'**
3. Dark leptons in equilibrium via **neutrino portal**
4. **SM sphalerons** then generate some B
5. Symmetric part of dark hadrons **annihilate to dark photons**, which transfer excess entropy to SM
6. Remaining **B'** forms (part of) **ADM**

Other DS, SFOPT baryogenesis mechanisms

see e.g. 1008.1997, 1012.1341, 1111.4786, 1202.2348, 1304.3464

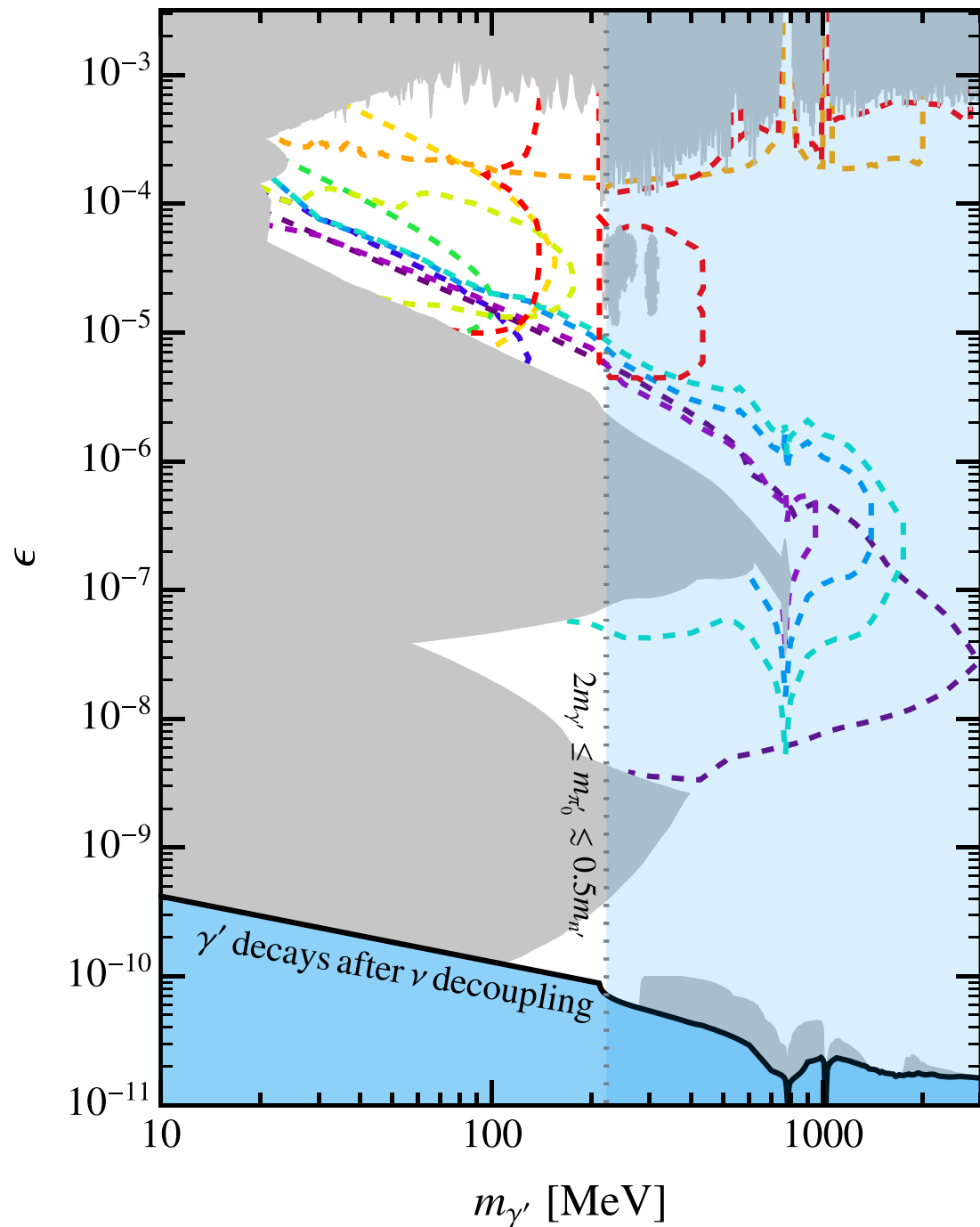
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E. Hall, T. Konstandin, R. McGehee, H. Murayama 1911.12342

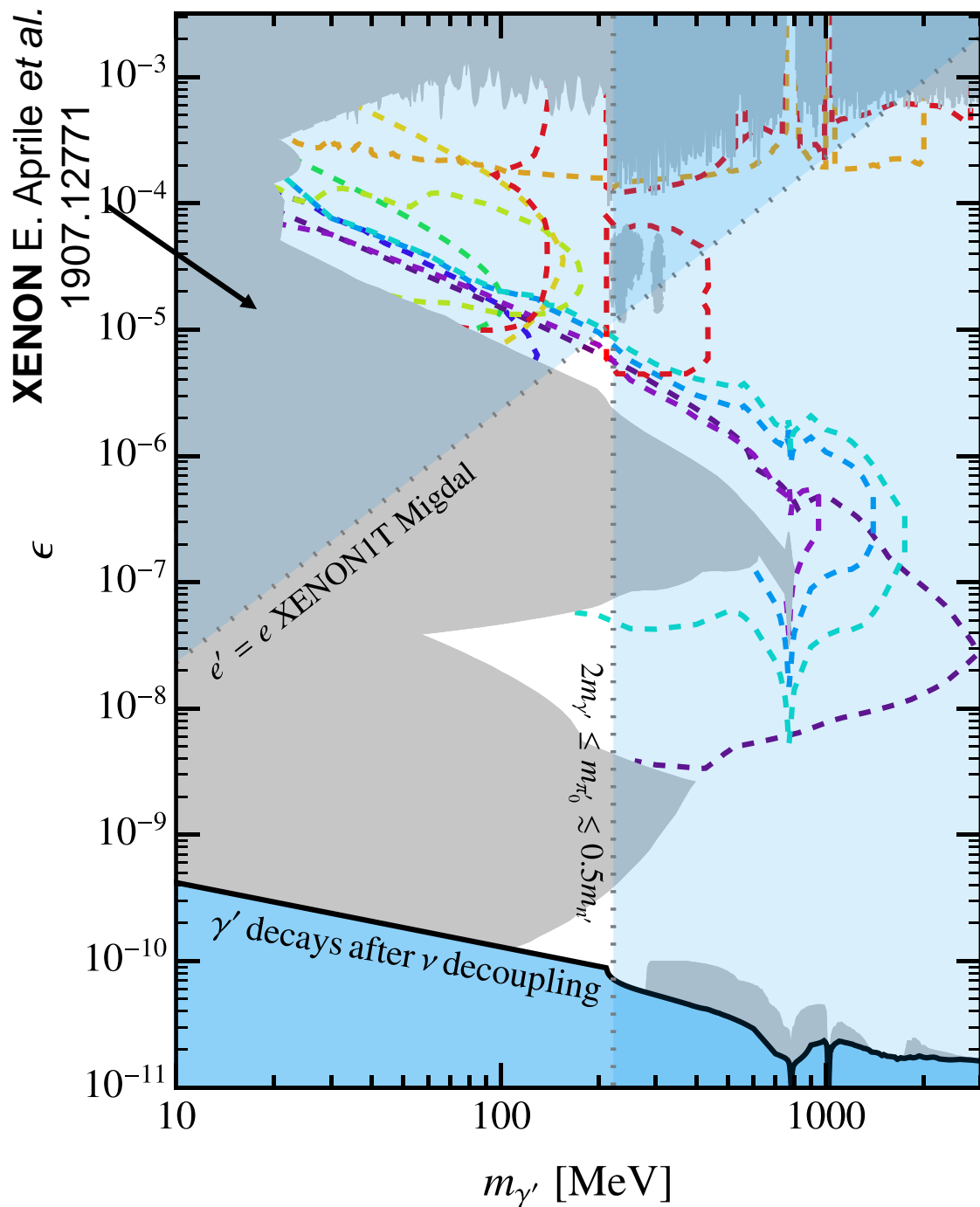
Dark Neutron
Dark Matter
 $m_{n'} = 1.33$ GeV

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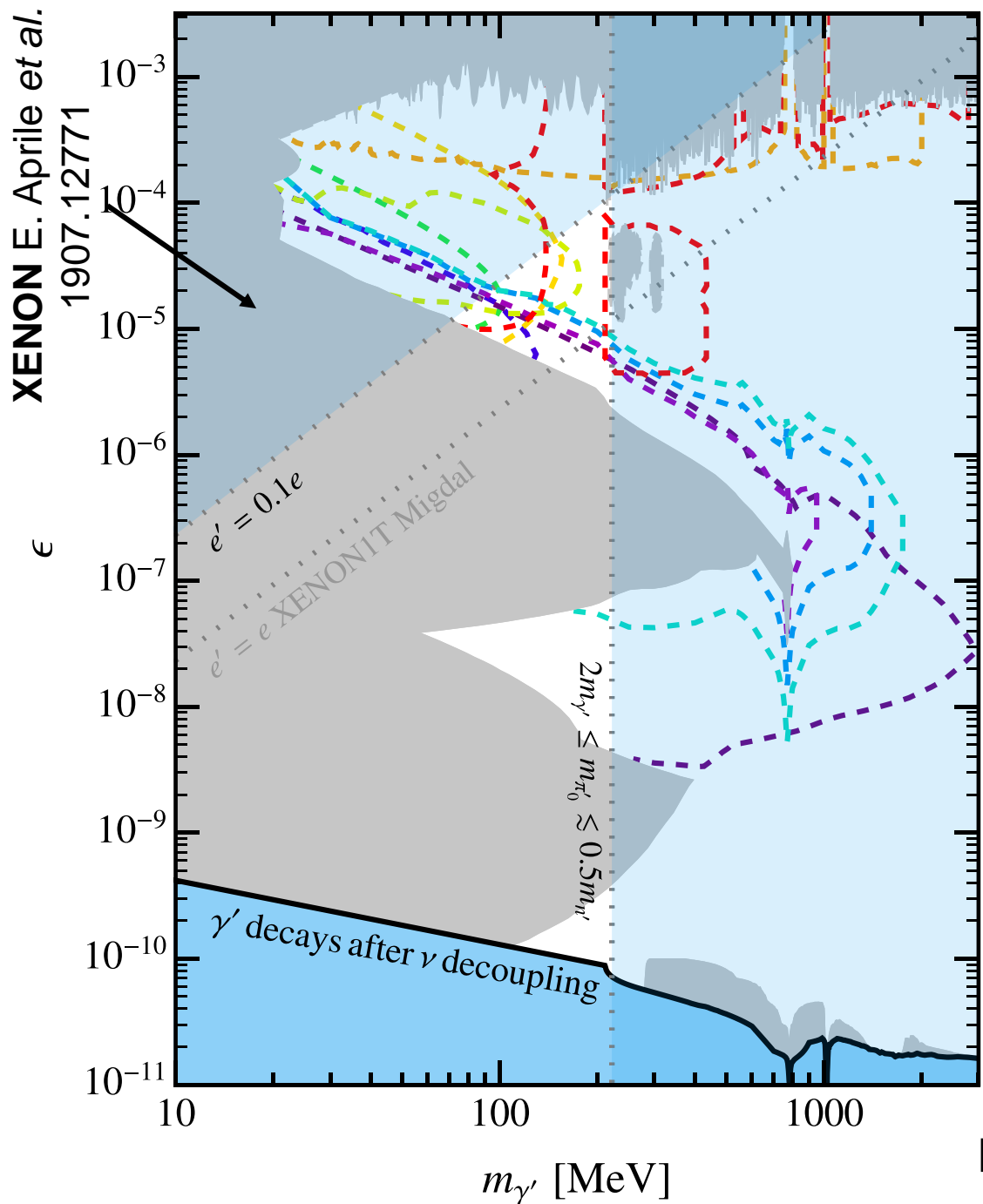
Asymmetric Matters from a Dark First-Order Phase Transition



E. Hall, T. Konstandin, R. McGehee, H. Murayama 1911.12342

Dark Proton & Pion
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 $m_{p'} = 0.887 \text{ GeV}$

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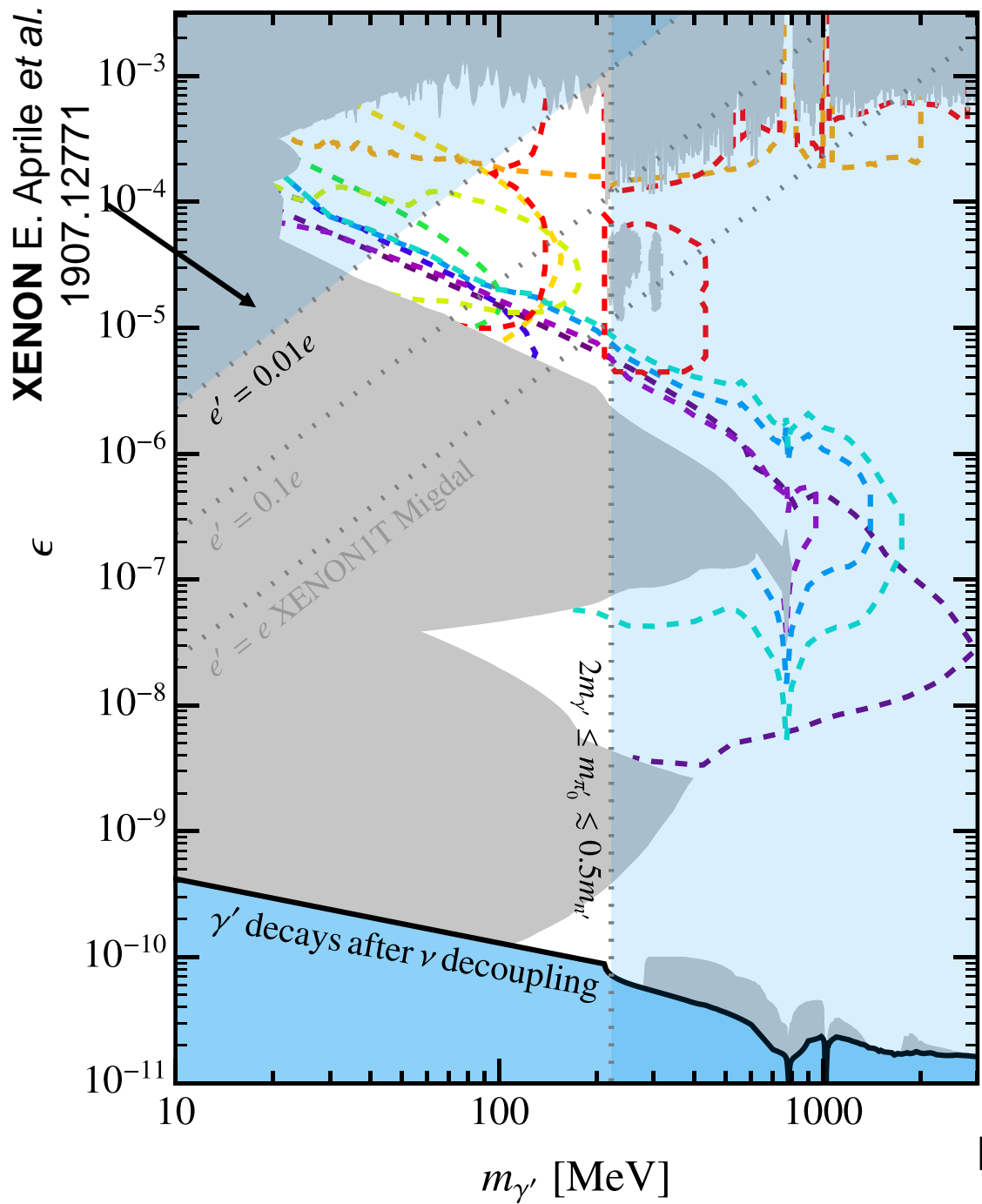


XENON E. Aprile et al.
1907.12771

E. Hall, T. Konstandin, R. McGehee, H. Murayama 1911.12342

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3) A Predictive Mirror Twin Higgs with Small Z_2 Breaking

K. Harigaya, R. McGehee, H. Murayama, K. Schutz JHEP 05 (2020) 155

Mirror Twin Higgs

Z. Chacko, H.-S. Goh, R. Harnik
Phys. Rev. Lett. **96** (2006) 231802



Z_2 mirror copy of SM introduced (twin sector)

SU(4) global symmetry permits SM Higgs to be PNgB

Z_2 protects Higgs mass up to ~ 5 -10 TeV cutoff

The N_{eff} Problem

$$\rho_r = \left(1 + \frac{7}{8} \left(\frac{4}{11} \right)^{4/3} N_{\text{eff}} \right) \rho_\gamma$$

$$N_{\text{eff}}^{\text{SM}} = 3.046$$

$$N_{\text{eff}}^{\text{Pl}} = 2.99^{+0.34}_{-0.33}$$

$$\Delta N_{\text{eff}} = N_{\text{eff}}^{\text{Pl}} - N_{\text{eff}}^{\text{SM}} < 0.284$$

from Planck, N. Aghanim et al.
Astron. Astrophys. 641 (2020) A6

$$\Delta N_{\text{eff}}^{\text{MTH}} \sim 5.6$$

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Fraternal Twin Higgs: only 3rd gen. twin fermions & no U(1)'

N. Craig, A. Katz, M. Strassler, and R. Sundrum,
JHEP 07 (2015) 105

Raise twin neutrino masses,
raise the twin photon mass,
inject entropy asymmetrically
after decoupling, or adjust twin
Yukawas

See 1601.07181, 1609.05589, 1611.07975,
1611.07977, 1703.06884, 1706.05548, 1803.03263,
1805.09345, 1805.12139, 1904.10468, 1905.00861

A New Solution

Raise (non-top) twin Yukawas

Twin neutrinos decouple earlier,
as high as a few GeV

Early decoupling dilutes
contribution to N_{eff}

Stuckelberg mass for dark
photon allows it to transfer
excess entropy to the SM

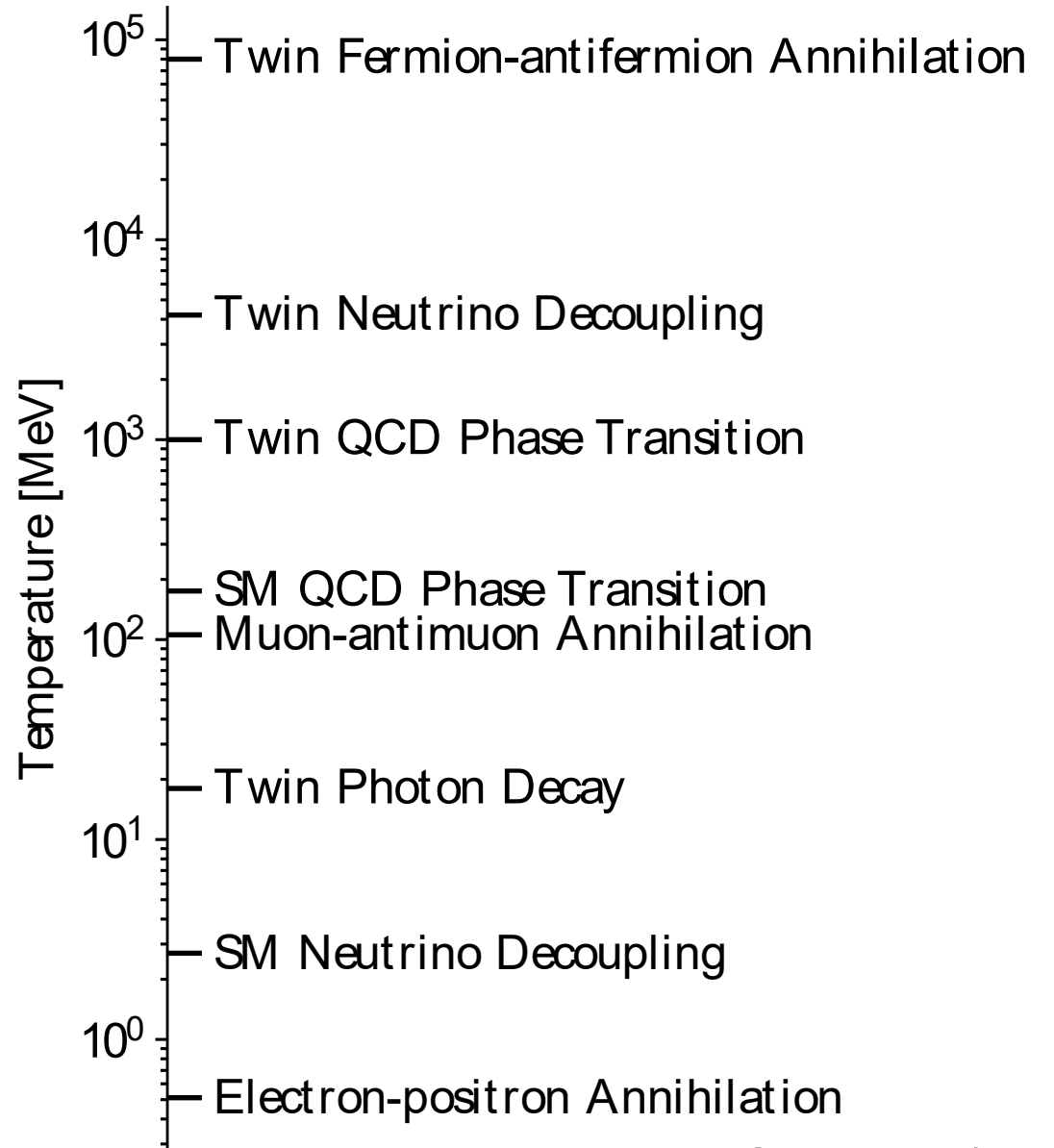
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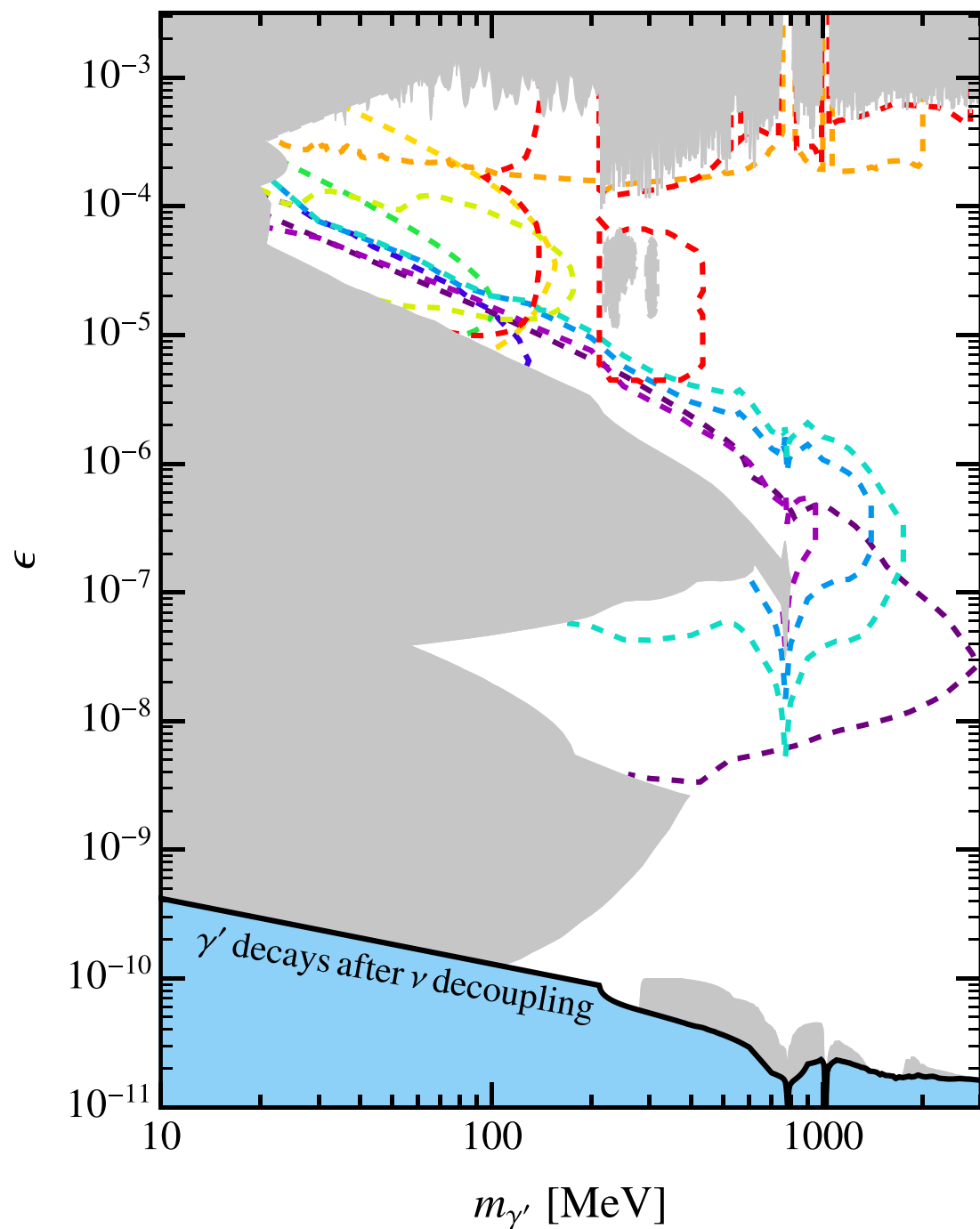
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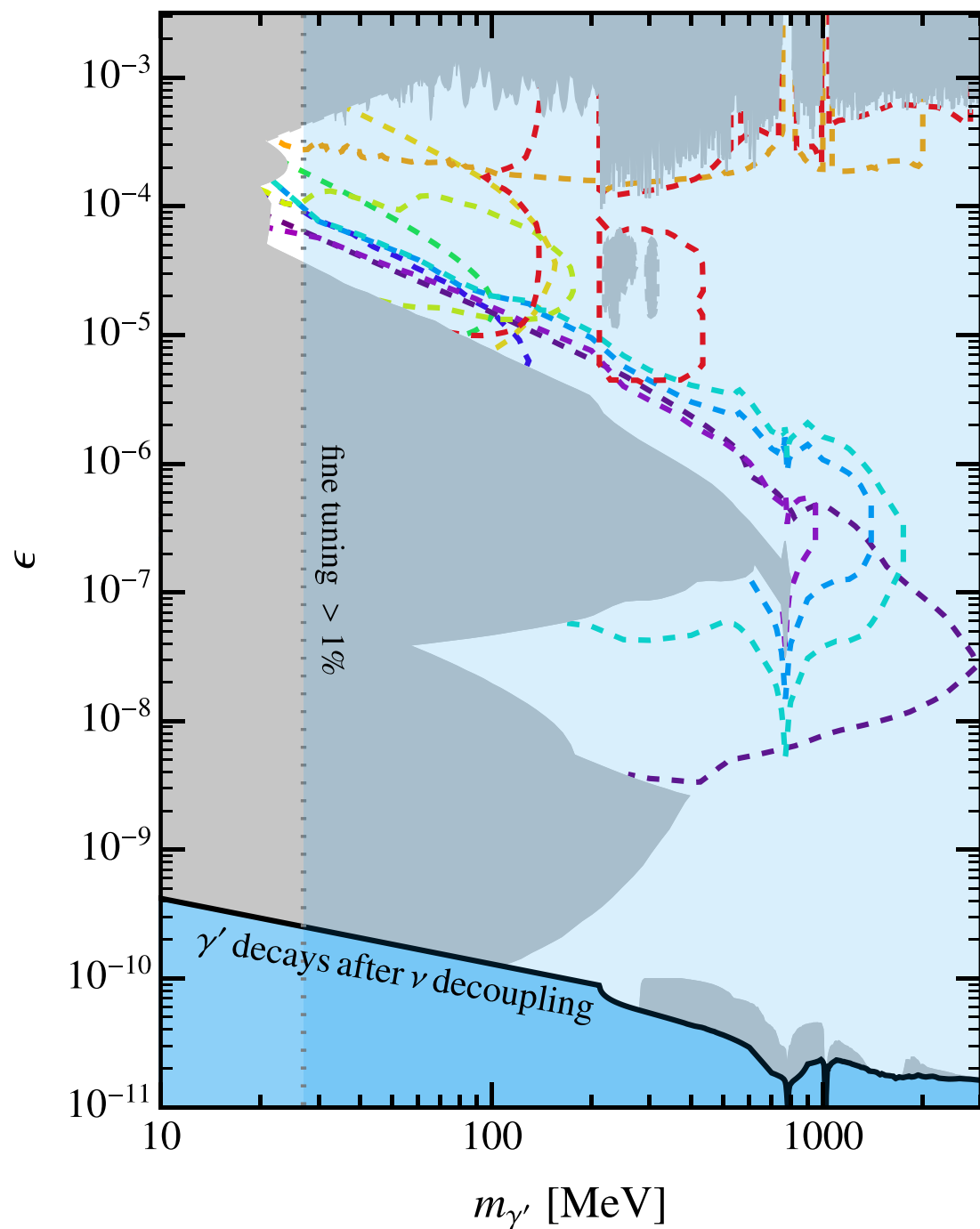


A Predictive Mirror Twin Higgs with Small Z_2 Breaking



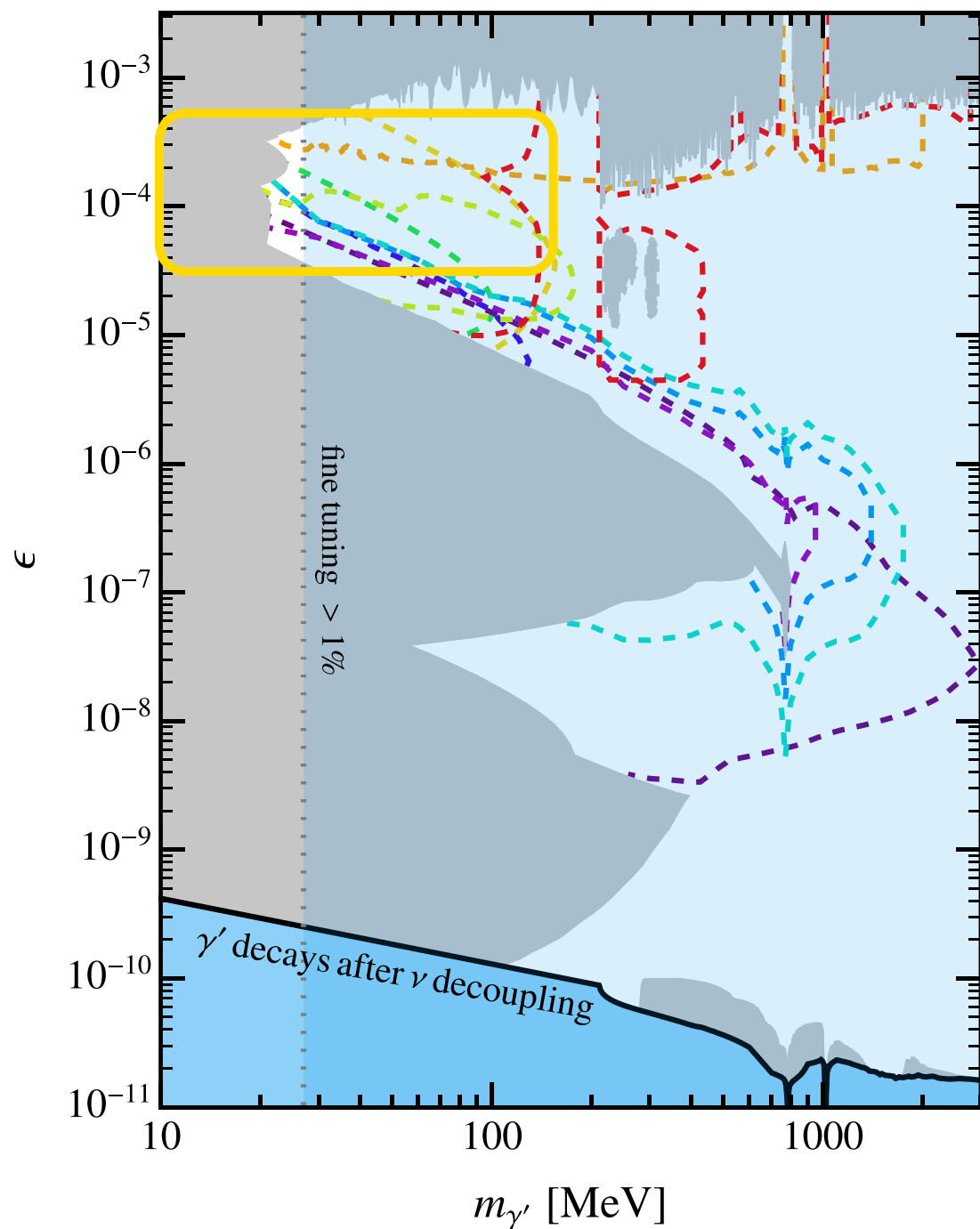
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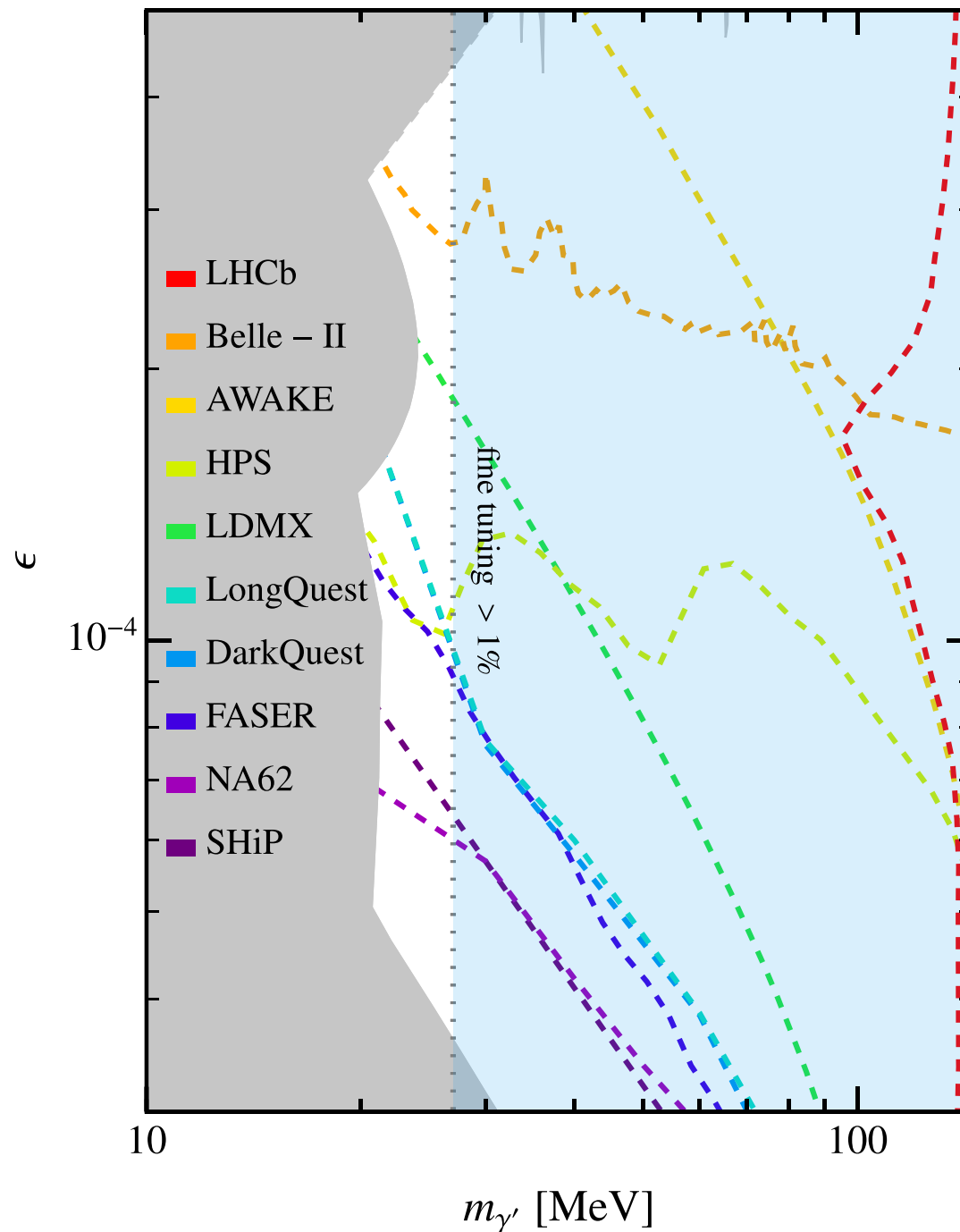
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Full param space
probe-able by
LHCb or AWAKE!

Summary

The **vector portal** is motivated by theory targets, old and new.

The exciting parameter space for visibly decaying dark photons will be probed by **current** and **near-future** experiments.

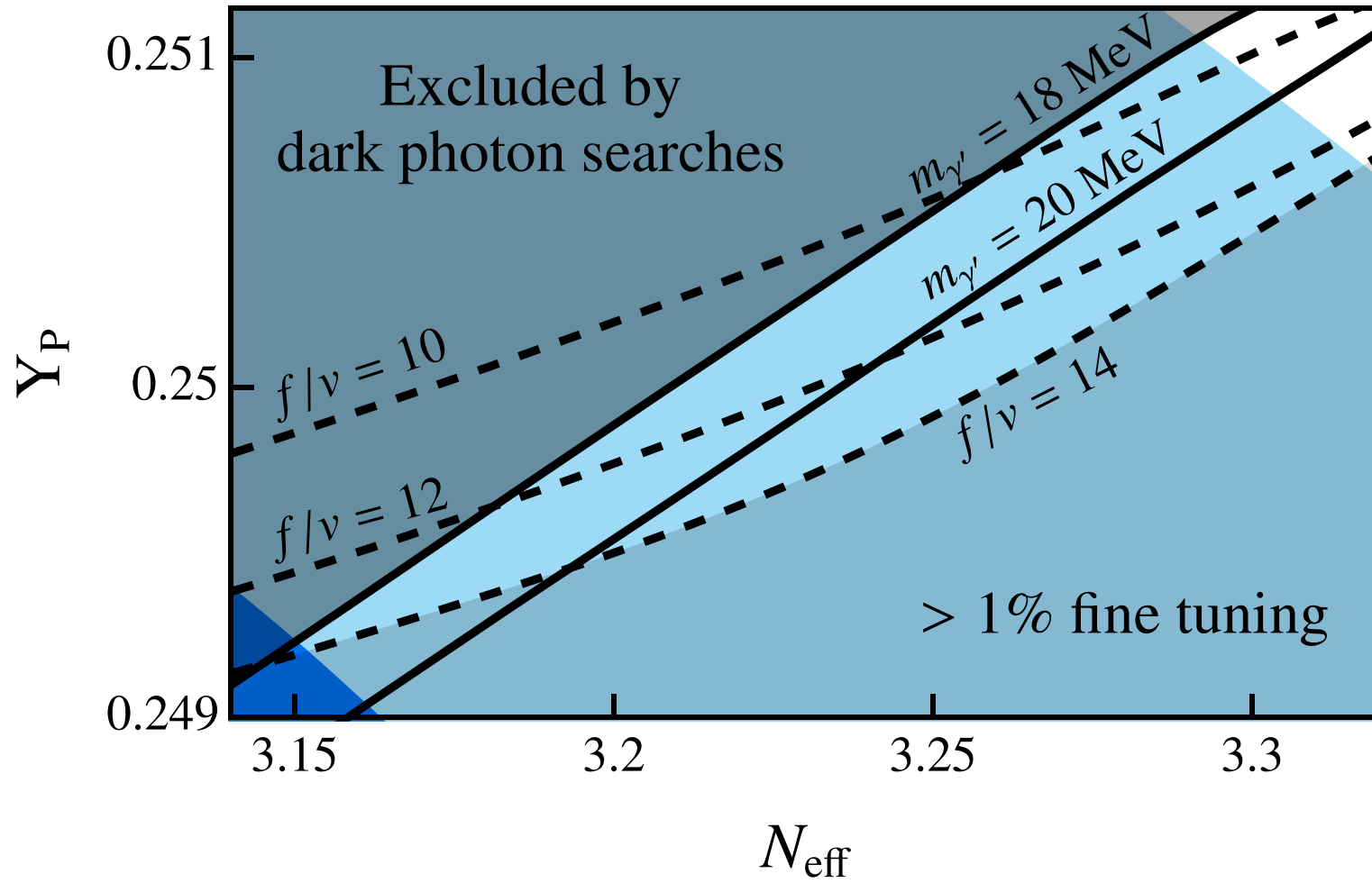
3 new theory targets

Resonant Self-Interacting Dark Matter from Dark QCD

Asymmetric Matters from a Dark 1st-Order Phase Transition

A Predictive Mirror Twin Higgs with Small Z_2 Breaking

More Details



$$\Delta \sim 10^{-7.8}$$

$$\text{F.T.} \equiv \Delta \times \frac{m_Q}{\Delta_n} \approx \Delta \times \left(\frac{4}{3e}\right)^2 n^3$$

$$\Lambda \approx m_Q \left(\frac{3e\Delta}{4\text{F.T.}}\right)^{2/3} \sim m_p \frac{\Omega_{\text{DM}}}{\Omega_{\text{B,SM}}} \left(\frac{3e\Delta}{4\text{F.T.}}\right)^{2/3}$$

Y. Tsai, **R. McGehee**, H. Murayama 2008.08608