Baryogenesis and Dark Matter from B Mesons: B-Mesogenesis

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Based on:

arXiv:1810.00880, PRD 99, 035031 (2019)
with: Gilly Elor & Ann Nelson
arXiv:2101.XXXXX
with: Gonzalo Alonso-Álvarez & Gilly Elor

New Trends in Dark Matter
09-12-2020

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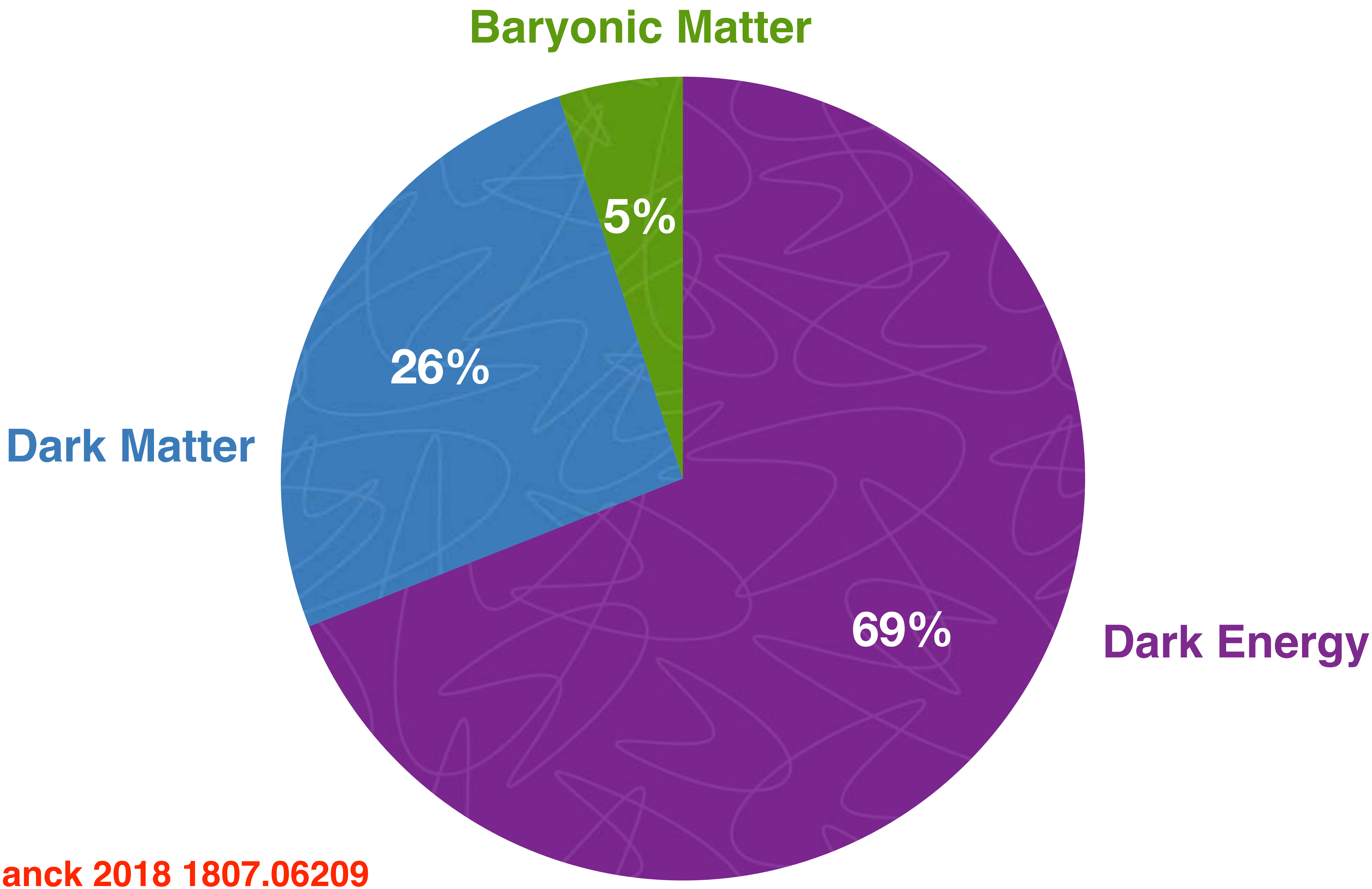
The Universe



Planck 2018 1807.06209

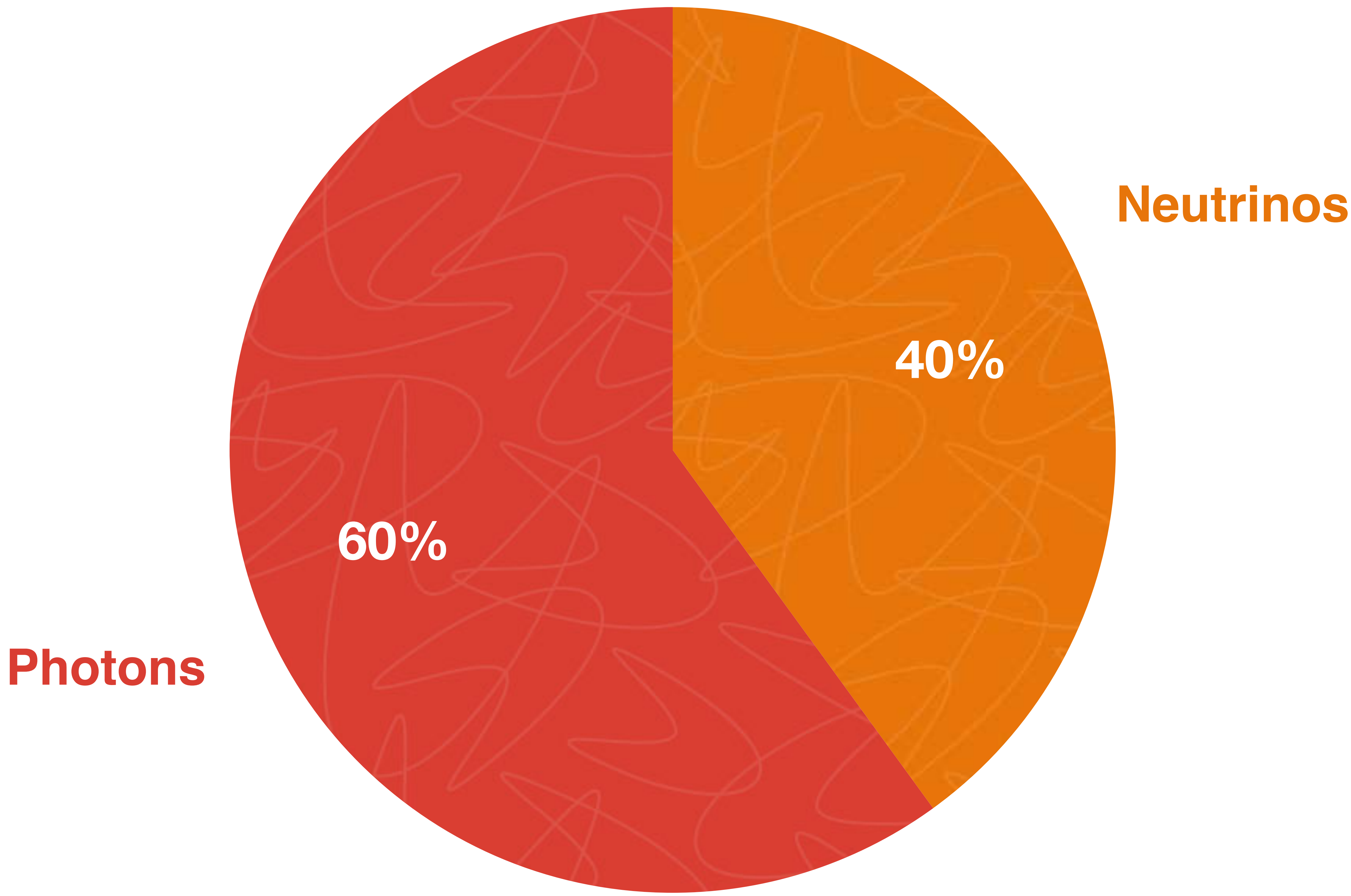
Theoretical Understanding?

Motivating Question:

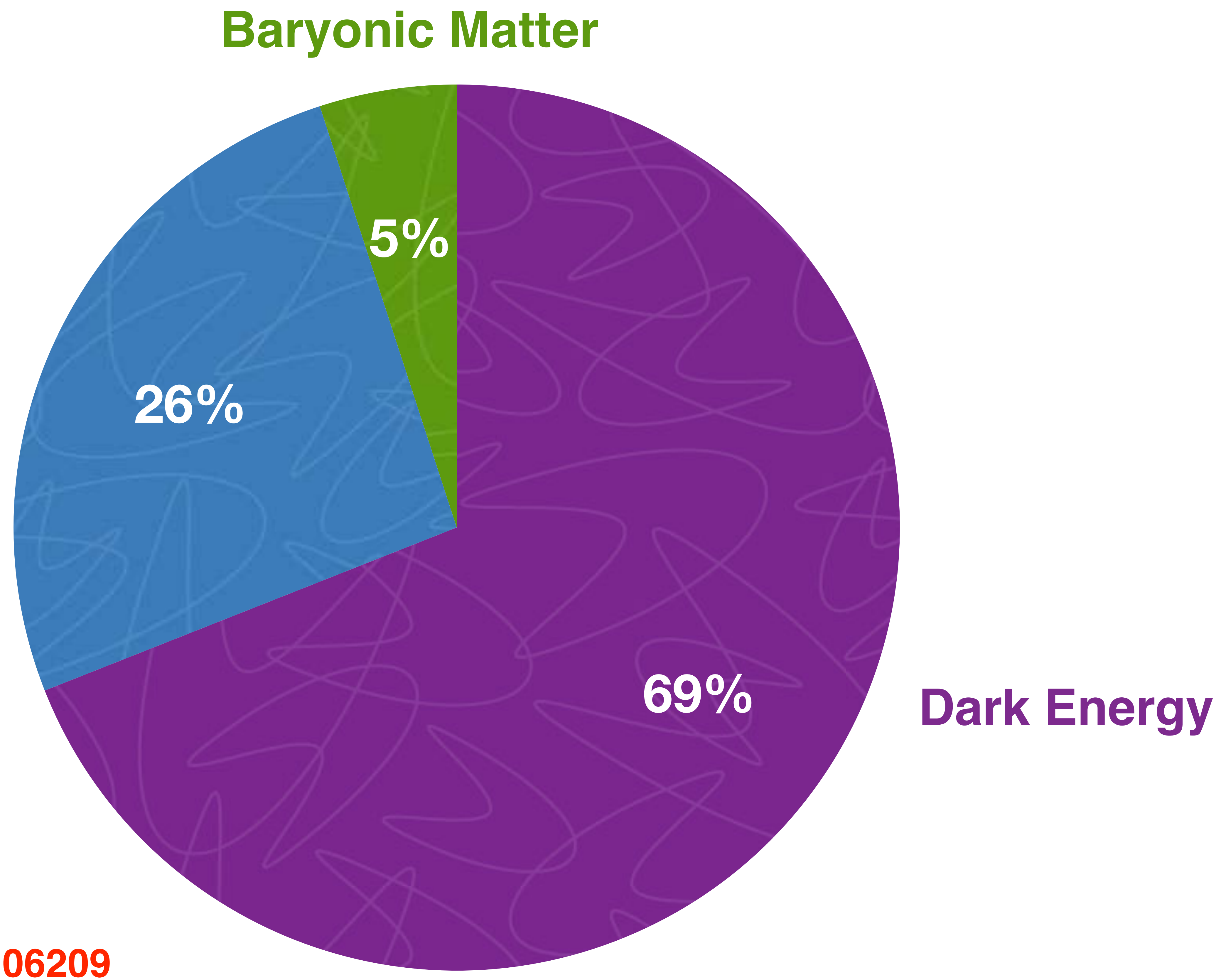
What fraction of the Energy Density of the Universe comes from Physics Beyond the Standard Model?

99.85%!

SM Prediction:



The Universe



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Baryogenesis and Dark Matter from B Mesons: B-Mesogenesis

arXiv:1810.00880 Elor, Escudero & Nelson

1) **Baryogenesis and Dark Matter are linked**

2) **Baryon asymmetry directly related to B-Meson observables**

3) **Leads to unique collider signatures**

4) **Fully testable at current collider experiments**

Outline

1) B-Mesogenesis
   1) C/CP violation
   2) Out of equilibrium
   3) Baryon number violation?

2) A Minimal Model & Cosmology

3) Implications for Collider Experiments

4) Dark Matter Phenomenology

5) Summary and Outlook

Baryogenesis

The three Sakharov Conditions (1967):

1) C and CP violation

2) Out of equilibrium

3) Baryon number violation

Baryogenesis from B Mesons

1) C and CP violation

The key quantity: the semileptonic asymmetry,

$$A_{\rm SL}^q = {\rm Im}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right) = \frac{\Gamma(\overline{B}_q^0 \to B_q^0 \to f) - \Gamma(B_q^0 \to \overline{B}_q^0 \to \bar{f})}{\Gamma(\overline{B}_q^0 \to B_q^0 \to f) + \Gamma(B_q^0 \to \overline{B}_q^0 \to \bar{f})}$$

Standard Model

Lenz & Tetlalmatzi-Xolocotzi 1912.07621

$$A_{\rm SL}^d|_{\rm SM} = (-4.7 \pm 0.4) \times 10^{-4}$$
$$A_{\rm SL}^s|_{\rm SM} = (2.1 \pm 0.2) \times 10^{-5}$$

small because $(m_b/m_t)^2$ is small

Measurements

$$A_{\rm SL}^d = (-2.1 \pm 1.7) \times 10^{-3}$$
$$A_{\rm SL}^s = (-0.6 \pm 2.8) \times 10^{-3}$$

World averages (HFLAV)

- **Plenty of BSM models that can enlarge the asymmetries up to 10^{-3}: SUSY, Extradim, LR, 2HDM, new generations, Leptoquarks, *Z′* models (see e.g. 1511.09466, 1402.1181).**

Baryogenesis from B Mesons

2) Out of equilibrium and production of B Mesons

- Require the presence of an out of equilibrium particle that dominates the energy density of the Universe and reheats it to a temperature of

$$T_{RH} = \mathcal{O}(10\,\mathrm{MeV})$$

- This particle should be very weakly coupled, with lifetimes

$$\tau_\Phi = \mathcal{O}(10^{-3}\,\mathrm{s})$$

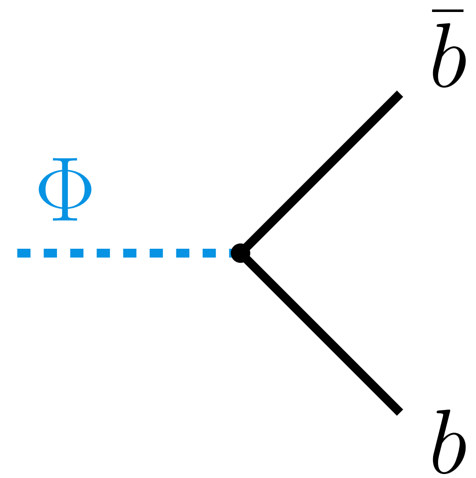
- The decays don't spoil BBN or the CMB provided $T_{RH} > 5\,\mathrm{MeV}$

de Salas *et al*. 1511.00672
Hasegawa *et al*. 1908.10189

Baryogenesis from B Mesons

2) Out of equilibrium and production of B Mesons

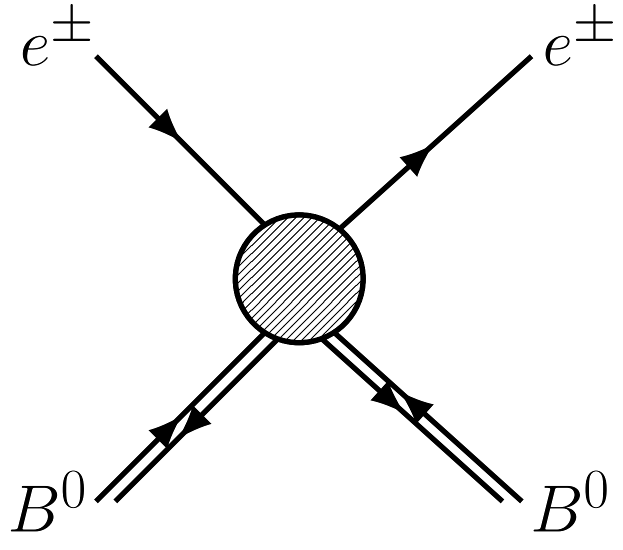
- **Scalar particle with** $m_\Phi \in 11 - 100\,\mathrm{GeV}$ **and** $\tau_\Phi = \mathcal{O}(10^{-3}\,\mathrm{s})$ **generically decays into b-quarks**



- **b-quarks Hadronize at** $T < T_{\mathrm{QCD}} \sim 200\,\mathrm{MeV}$

- **Coherent oscillations in the** B^0 **system are maintained in the early Universe for Temperatures:**

$$T \lesssim 20\,\mathrm{MeV}$$



Baryogenesis and DM from B Mesons

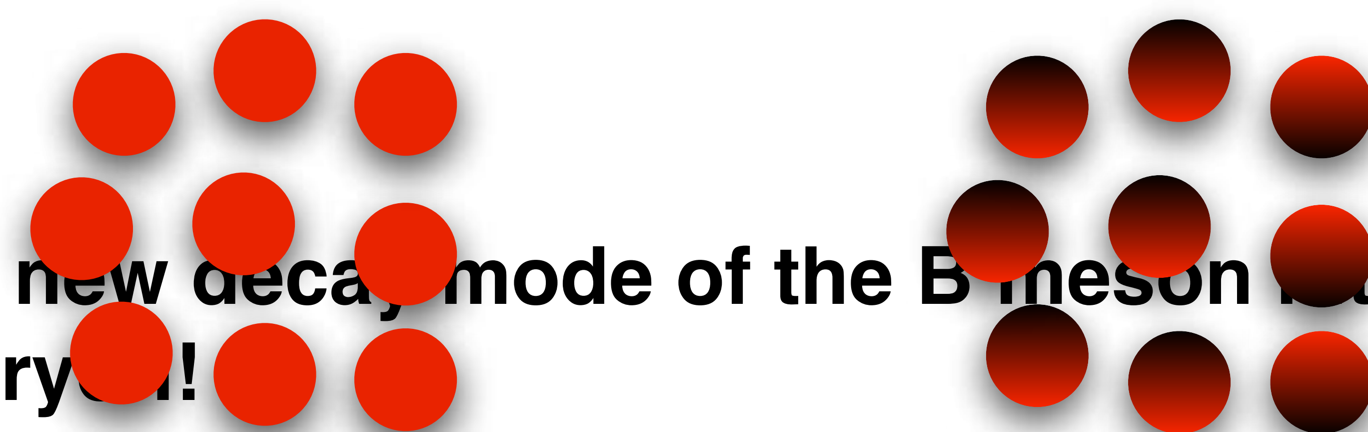
3) Baryon number violation?

- **Baryon number is conserved in our scenario:** $\Delta B = 0$

  In a similar spirit to *Hylogenesis* by Davoudiasl, Morrissey, Sigurdson, Tulin 1008.2399

- **We make Dark Matter an anti-Baryon and generate an asymmetry between the two sectors thanks to the CP violating oscillations and subsequents decays of B-mesons.**

- **Require a new decay mode of the B meson into DM and a visible Baryon!**



Visible Sector (Baryons)

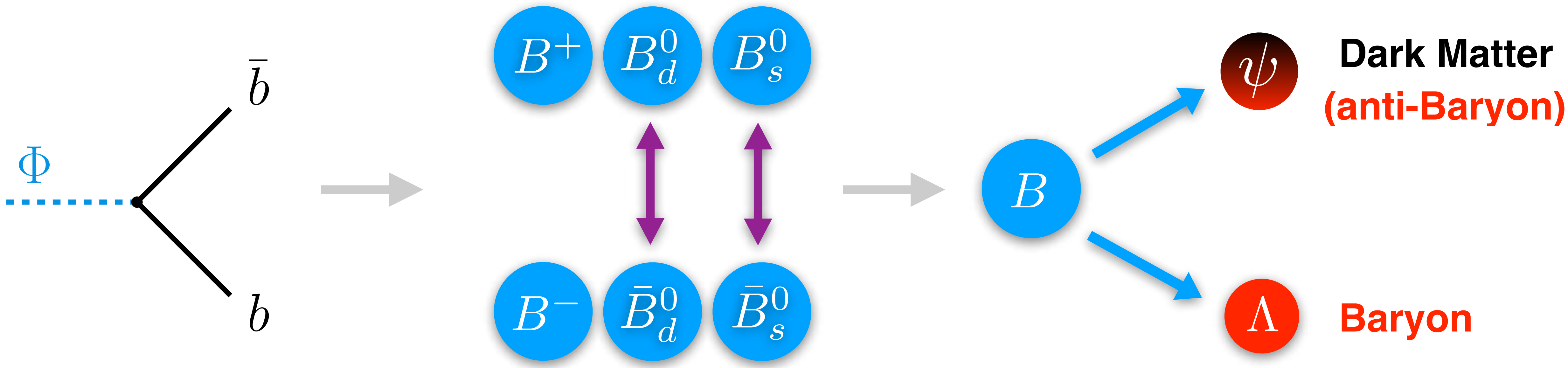
Dark Sector (anti-Baryons)

A Summary of B-Mesogenesis

Out of equilibrium late time decay

CP violating oscillations

B-mesons decay into Dark Matter and hadrons



$T_R \sim 15\,\text{MeV}$ $\quad A_{\text{SL}}^d \;\; A_{\text{SL}}^s$ $\quad \text{Br}\left(B \to \psi + \mathcal{B} + \mathcal{M}\right)$

Baryogenesis and **Dark Matter**

$$Y_B = 8.7 \times 10^{-11} \qquad \Omega_{\text{DM}} h^2 = 0.12$$

With:

$$Y_B \simeq 8.7 \times 10^{-11} \, \frac{\text{Br}(B \to \psi + \mathcal{B} + \mathcal{M})}{10^{-2}} \sum_q \alpha_q \, \frac{A_{\text{SL}}^q}{10^{-4}}$$

New B-Meson decay

$$\mathcal{L} \supset -y_{ub}\, Y^{*}\, \bar{u}\, b^{c} - y_{\psi s}\, Y \bar{\psi}\, s^{c} + \text{h.c}$$

$1.2\,\text{GeV} \lesssim m_{\phi,\,\xi} \lesssim 2.5\,\text{GeV}$

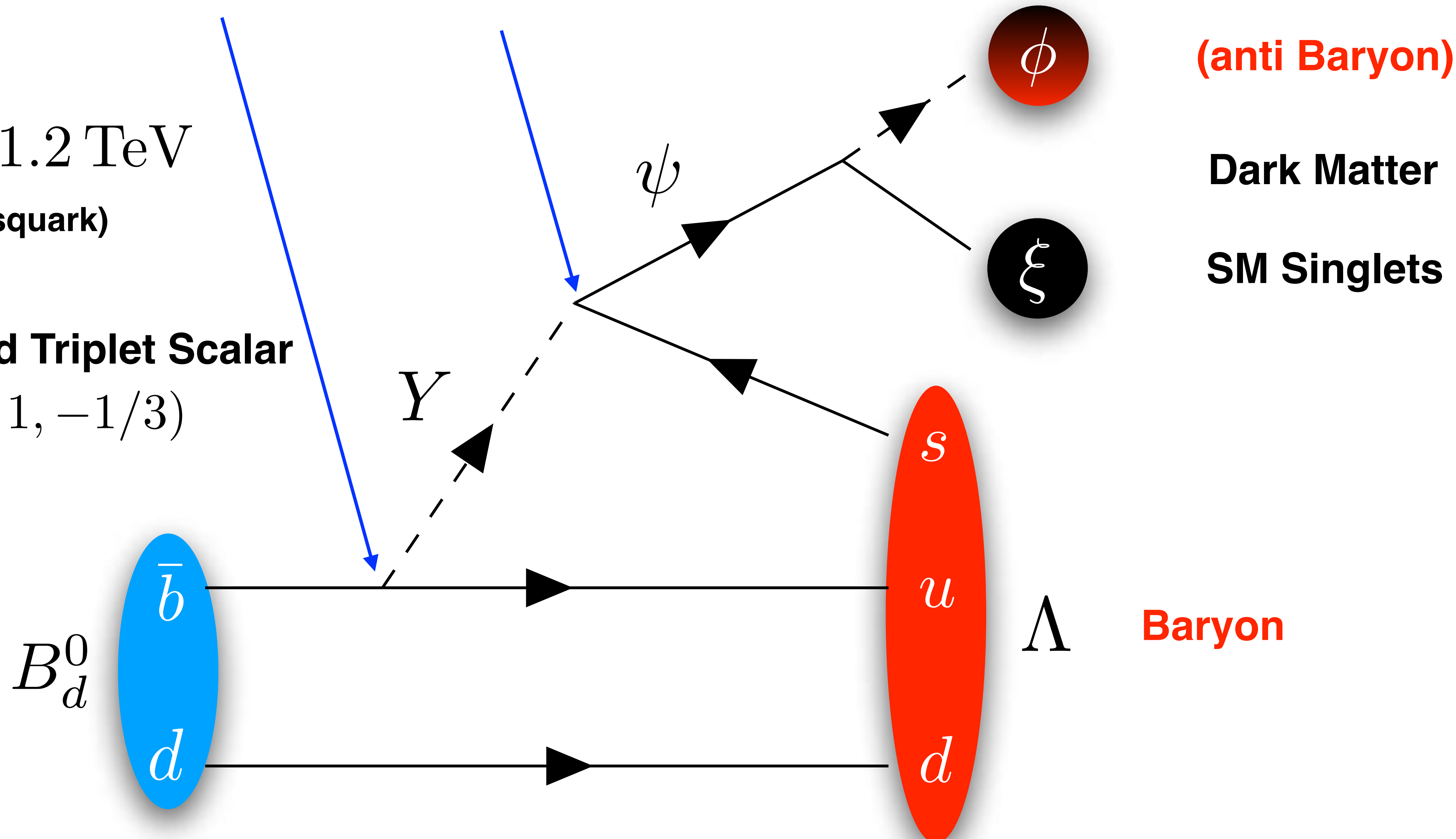
(McKeen et. al.)

$M_Y > 1.2\,\text{TeV}$

(4-jet/squark)

Y: Colored Triplet Scalar

$Y \sim (3, 1, -1/3)$



$$\text{Br}\,(B \to \psi + \text{Baryon} + \mathcal{M}) \simeq 10^{-3} \left(\frac{m_B - m_\psi}{2\,\text{GeV}}\right)^4 \left(\frac{1.6\,\text{TeV}}{M_Y}\,\frac{\sqrt{y_{ub}y_{\psi s}}}{0.6}\right)^4$$

The Boltzmann Equations

Universe's Evolution

$$H^2 \equiv \left(\frac{1}{a}\frac{da}{dt}\right)^2 = \frac{8\pi}{3m_{Pl}^2}\left(\rho_{\rm rad} + m_\Phi n_\Phi\right)$$

Late time Decay and Radiation

$$\frac{dn_\Phi}{dt} + 3Hn_\Phi = -\Gamma_\Phi n_\Phi$$

$$\frac{d\rho_{\rm rad}}{dt} + 4H\rho_{\rm rad} = \Gamma_\Phi m_\Phi n_\Phi$$

DM evolution

$$\frac{dn_\xi}{dt} + 3Hn_\xi = -\langle\sigma v\rangle_\xi\left(n_\xi^2 - n_{{\rm eq},\xi}^2\right) + 2\,\Gamma_\Phi^B\, n_\Phi \qquad \Gamma_\Phi^B = \Gamma_\Phi \times {\rm Br}\left(B \to \psi + {\rm Baryon} + \mathcal{M}\right)$$

$$\frac{dn_\phi}{dt} + 3Hn_\phi = -\langle\sigma v\rangle_\phi(n_\phi n_{\phi^\star} - n_{{\rm eq},\phi}n_{{\rm eq},\phi^\star}) + \Gamma_\Phi^B\, n_\Phi \times [1 + \sum_q A_{\ell\ell}^q\, {\rm Br}(\bar b \to B_q^0)\, f_{\rm deco}^q]$$

$$\frac{dn_{\phi^\star}}{dt} + 3Hn_{\phi^\star} = -\langle\sigma v\rangle_\phi(n_\phi n_{\phi^\star} - n_{{\rm eq},\phi}n_{{\rm eq},\phi^\star}) + \Gamma_\Phi^B\, n_\Phi \times [1 - \sum_q A_{\ell\ell}^q\, {\rm Br}(\bar b \to B_q^0)\, f_{\rm deco}^q]$$

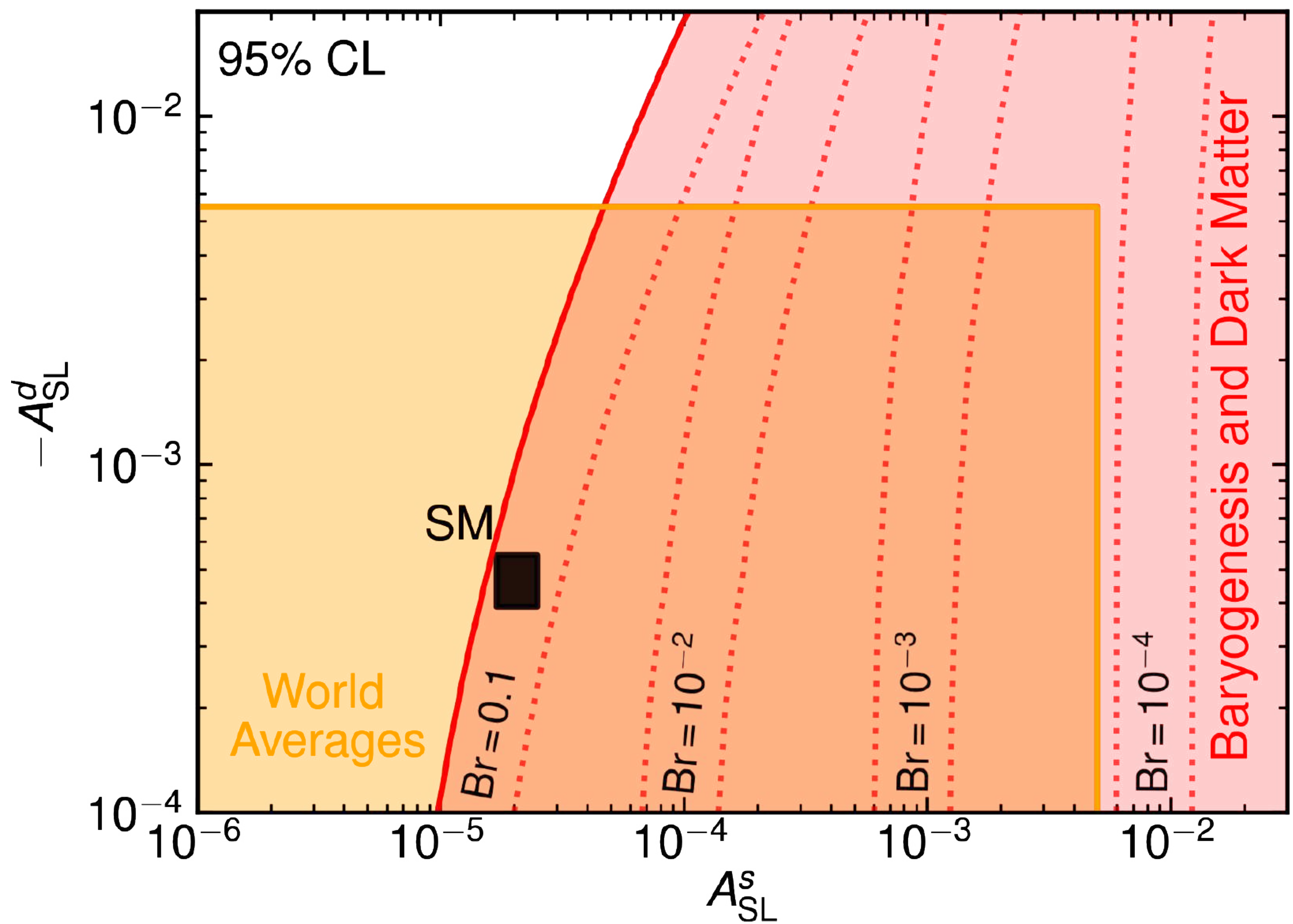
Baryon asymmetry:

$$n_{\mathcal{B}} = n_\phi - n_{\phi^\star}$$

$$\frac{n_{\mathcal{B}}}{dt} + 3Hn_{\mathcal{B}} = 2\Gamma_\Phi n_\Phi \sum_q {\rm Br}\left(\bar b \to B_q^0\right) f_{\rm deco}^q\, A_{\rm SL}^q\, {\rm Br}\left(B \to \psi + {\rm Baryon} + \mathcal{M}\right)$$

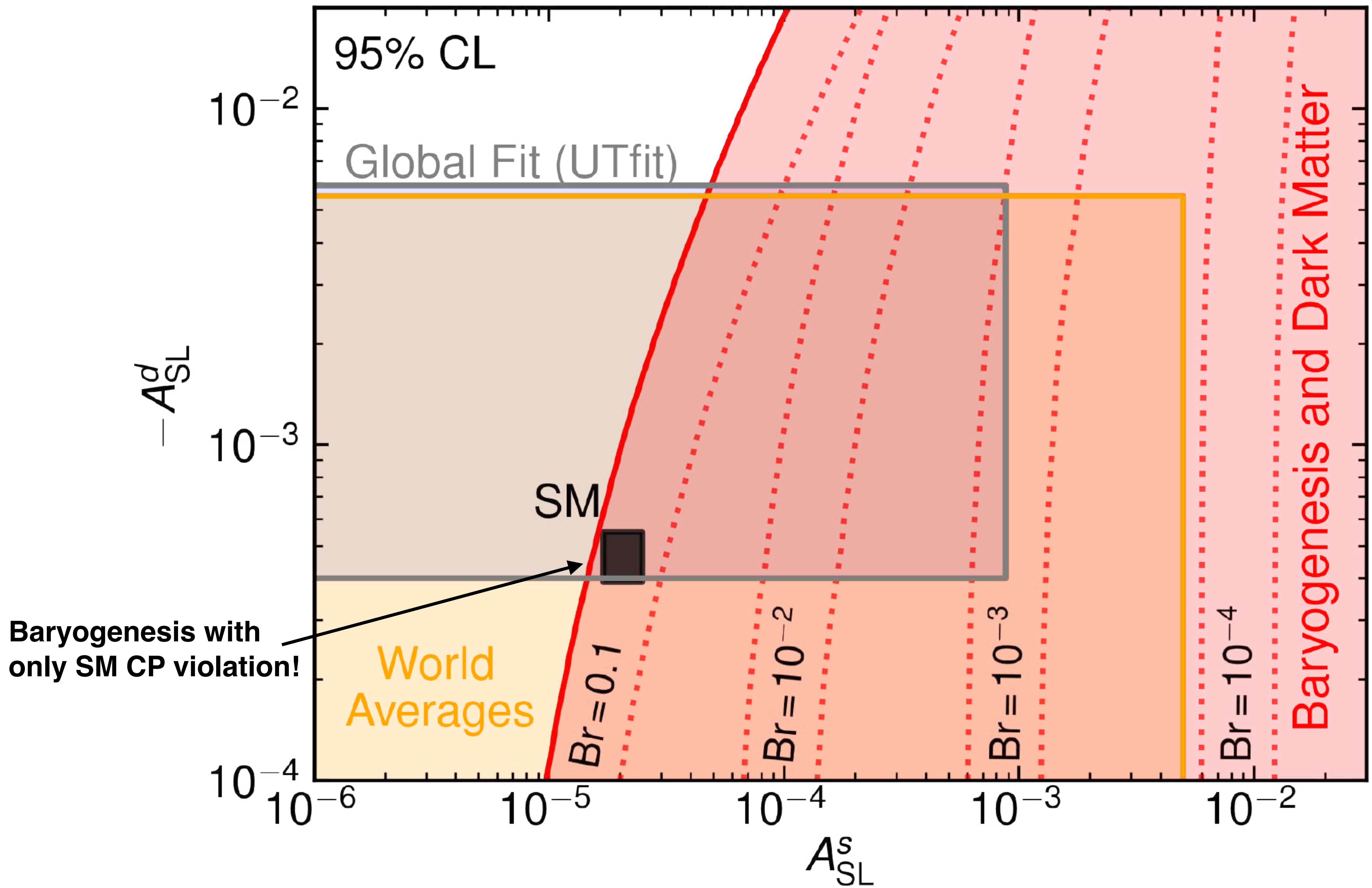
- **Baryon asymmetry directly related to the CP violation in the B^0 system and to the new decay of B mesons to a visible Baryon and missing energy.**
- **We take into account the decoherence of the B^0 system in the early Universe.**

Parameter Space



Measured A_{SL} imply: $\mathrm{Br}\left(B \to \psi + \mathrm{Baryon} + \mathcal{M}\right) \gtrsim 10^{-4}$

Parameter Space



Global fits suggest

$$\mathrm{Br}\left(B \to \psi + \mathrm{Baryon} + \mathcal{M}\right) \gtrsim 10^{-3}$$

Any room for a new decay mode?

Targeted decay modes are very constrained/well measured:

B-Factories $\mathrm{Br}(B^+ \to K^+ \bar{\nu}\nu) < 10^{-5}$

LHC $\mathrm{Br}(B_s^0 \to \mu^+\mu^-) = (2.7 \pm 0.6) \times 10^{-9}$

But our decay mode has not been targeted!

$$B \to \psi + \mathrm{Baryon}$$

What about the total width of B-Mesons?

Measurement: $\mathrm{Br}\,(B \to p/\bar{p} + \mathrm{anything}) = (8.0 \pm 0.4)\,\%$

Most stringent current constraint: $\mathrm{Br}\,(B \to \psi + \mathrm{Baryon} + \mathcal{M}) \lesssim 10\,\%$

Future Searches

Baryogenesis Requires:

$$\mathrm{Br}\left(B \to \psi + \mathrm{Baryon} + \mathcal{M}\right) \gtrsim 10^{-4}$$

B-factories expected sensitivity: **(given that** $\mathrm{Br}(B^+ \to K^+ \bar{\nu}\nu) < 10^{-5}$**)**

$$\mathrm{Br}\left(B \to \psi + \mathrm{Baryon}\right) \sim 10^{-5}$$

Ongoing searches with BaBar, Belle and Belle-II data!

The mechanism should be fully testable!

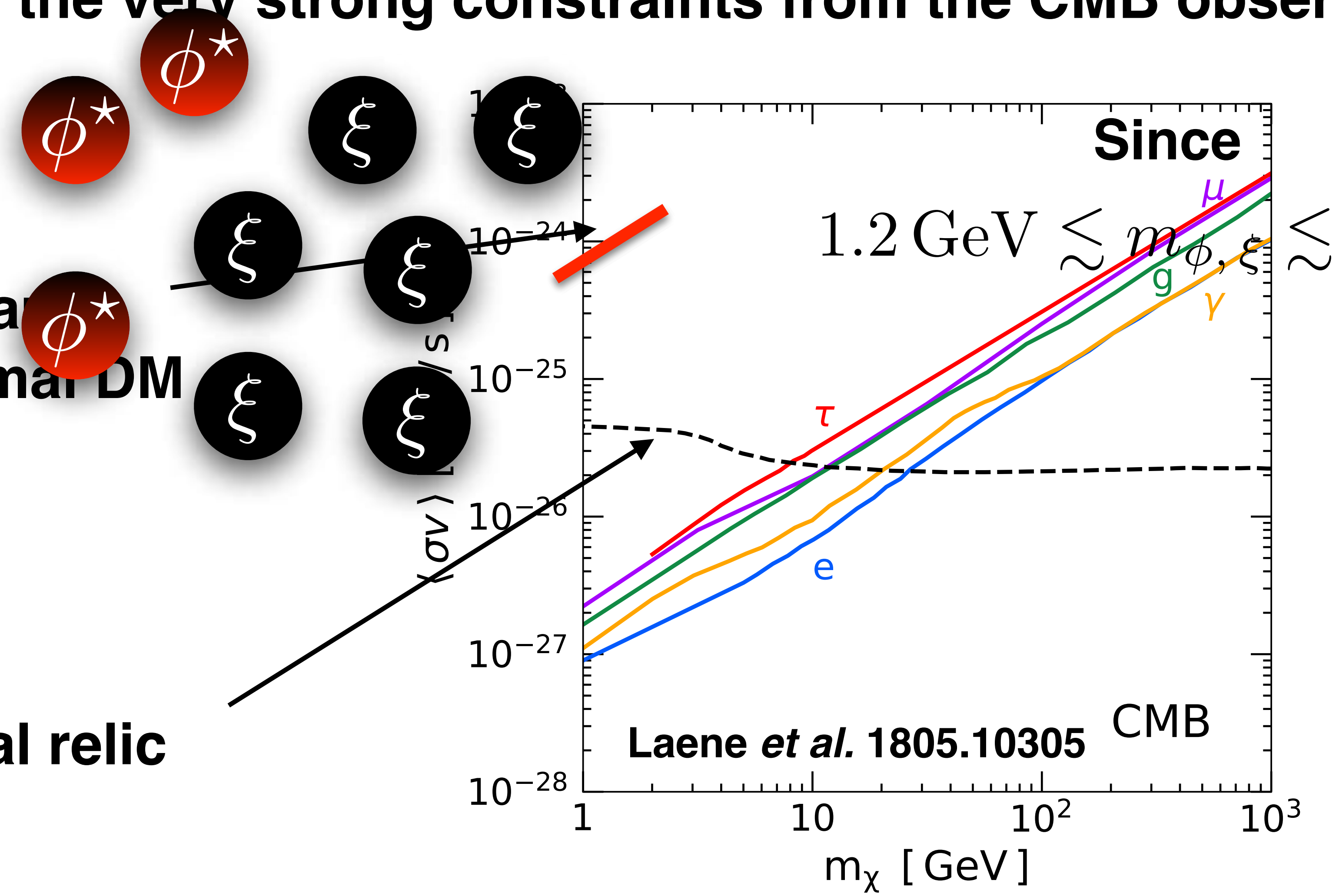
Dark Matter Phenomenology

- **Relic abundance obtained with:**

$$\Omega_{\rm DM} h^2 = 0.12 \quad \longrightarrow \quad \langle \sigma v \rangle_{\rm dark} \simeq 25 \, \langle \sigma v \rangle_{\rm WIMP} \, \min[m_\phi, m_\xi]/\mathrm{GeV}$$

- **What kind of Dark Sector could allow for such cross sections but being compatible with the very strong constraints from the CMB observations?**

Our scenario:
Non-thermal DM



Thermal relic

See update in Planck 2018 1807.06209

Possible Dark Sectors

1) Annihilation into Sterile Neutrinos

0711.4866 Pospelov, Ritz, Voloshin

The annihilation can be predominantly p-wave: **1607.02373, Escudero, Rius, Sanz**

2) Annihilation into Active Neutrinos

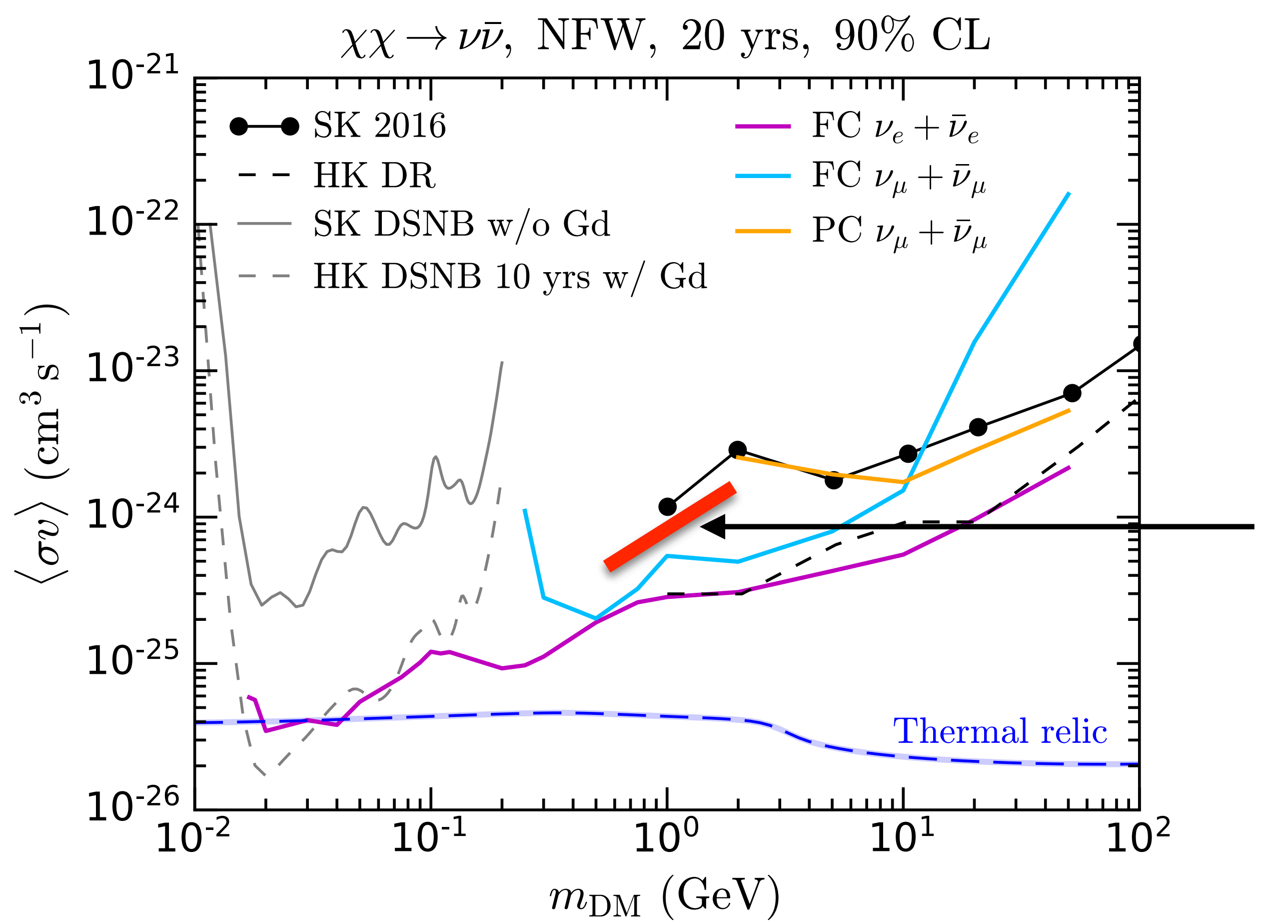
González-Macias, Illana and Wudka, 1506.03825,1601.05051, Blennow et. al. 1903.00006

Constraints on dark matter annihilating to neutrinos are very mild

Figure from 2005.01950 Bell, Dolan, Robles

see also Olivares-Del Rio, Boehm, Palorames-Ruiz, Pascoli 1711.05283

see also Argüelles, Vincent et al. 1912.09486



Our scenario: Non-thermal DM

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3) Additional particles carrying baryon number

- **New scalar Baryon with B = 1/3:** $\mathcal{A}$

$$\phi^\star + \phi \to \mathcal{A} + \mathcal{A}^\star$$
$$\phi + \mathcal{A} \to \mathcal{A}^\star + \mathcal{A}^\star$$

- **Which in order to get** $\Omega_{\rm DM}/\Omega_b = 5.36$ **will require** $m_{\mathcal{A}} \sim \frac{5}{3} m_p \sim 1.6\,\mathrm{GeV}$
- **Gives an understanding for the observed Dark Matter to Baryon energy density ratio.**

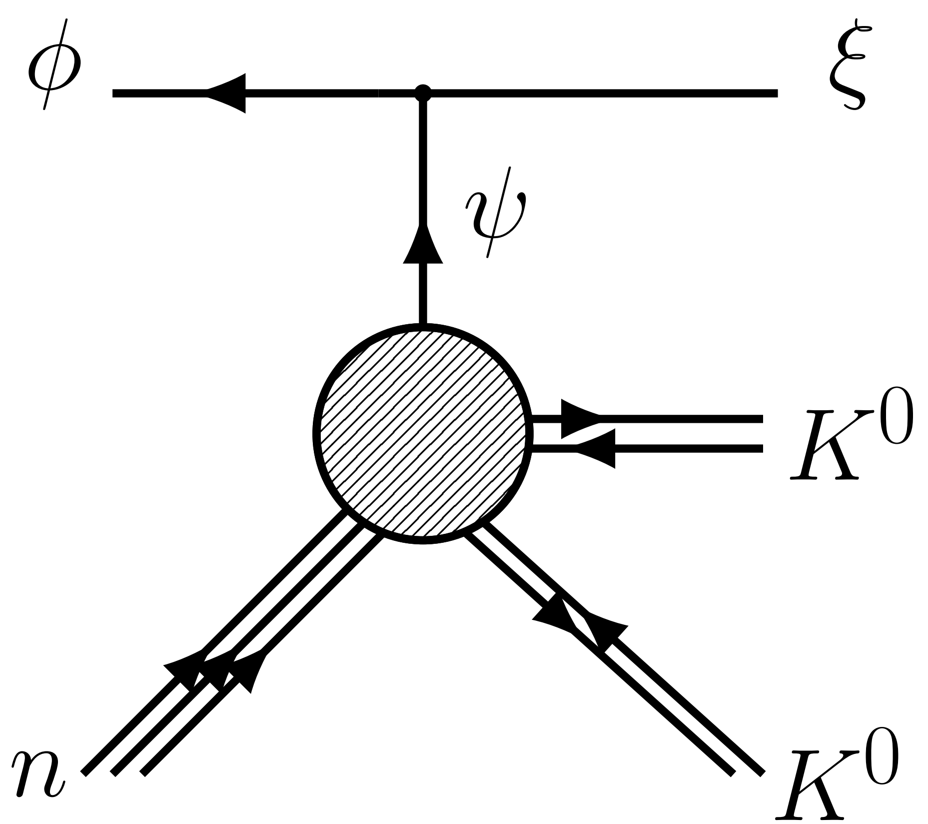
No Direct Detection Signatures

No direct coupling between the dark matter and light quarks

Coupling can be generated through weak loops:

$$u\,s\,b\,\psi \to f_\pi^2 G_F V_{tb} V_{ts}^\star\, u\,s\,s\,\psi \sim 10^{-8}\, u\,s\,s\,\psi$$

These processes are possible and could be searched for at Super-Kamiokande:



But the rate is tiny, hence unobservable see
1008.2399 by Davoudiasl, Morrissey, Sigurdson & Tulin

Summary

Baryogenesis and Dark Matter from B-mesons:

- **Which actually relates the CP violation in the B^0 system to Baryogenesis**
- **Baryon number is conserved and hence Dark Matter is anti-Baryonic**

Distinct experimental signatures:

- **Positive semileptonic CP asymmetry in B meson decays** $A^q_{\rm SL} > 10^{-5}$
- **Neutral and charged B mesons decay into baryons and missing energy**

$$\mathrm{Br}\left(B \to \psi + \mathrm{Baryon} + \mathcal{M}\right) \gtrsim 10^{-4}$$

Ongoing search for this process at BaBar, Belle and Belle-II!

B-factories should test this scenario given the constraints on other missing energy channels:

$$\mathrm{Br}(B^+ \to K^+ \bar{\nu}\nu) < 10^{-5}$$

We expect the mechanism to be testable at current collider experiments!

Outlook

Theory

- **Are the flavor anomalies ($b \to s\mu^+\mu^-$) in B-decays related to our required positive semileptonic asymmetry?**

- **Are there other possibilities for the dark sector?**

- **What kind of UV theory contains our required heavy colored scalar plus our dark matter particles at the GeV scale?**

E.g.: SUSY, 1907.10612 Alonso-Álvarez, Elor, Nelson, Xiao

Experiment

- **How well will BaBar/Belle/Belle-II constraint or measure?**

$$\mathrm{Br}\left(B \to \psi + \mathrm{Baryon}\right)$$

To appear very soon

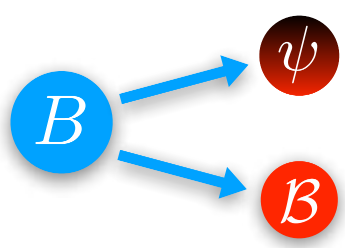
Collider Signals of Baryogenesis and Dark Matter from B Mesons (*B-Mesogenesis*)

Direct Signals

Semileptonic asymmetry: $A_{\rm SL}^q > 10^{-5}$

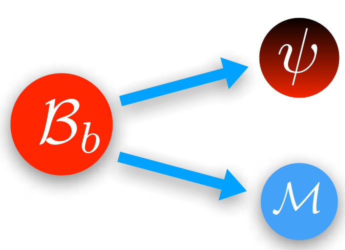
Belle II
LHCb
ATLAS
CMS

New B meson decay:



BaBar
Belle
Belle II
LHCb

New b-Baryon decay:



LHCb?
ATLAS??
CMS??

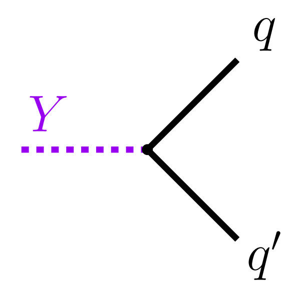
Indirect Signals

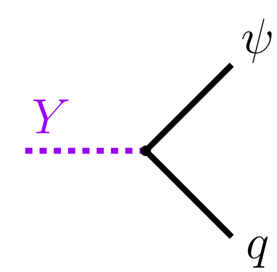
B⁰ meson CPV and oscillation observables:

$\phi_{12}^{d,s}$ $\Delta M_{d,s}$ $\Delta\Gamma_{d,s}$

LHCb
Belle II
ATLAS
CMS

New colored TeV-scale triplet scalar, *Y*

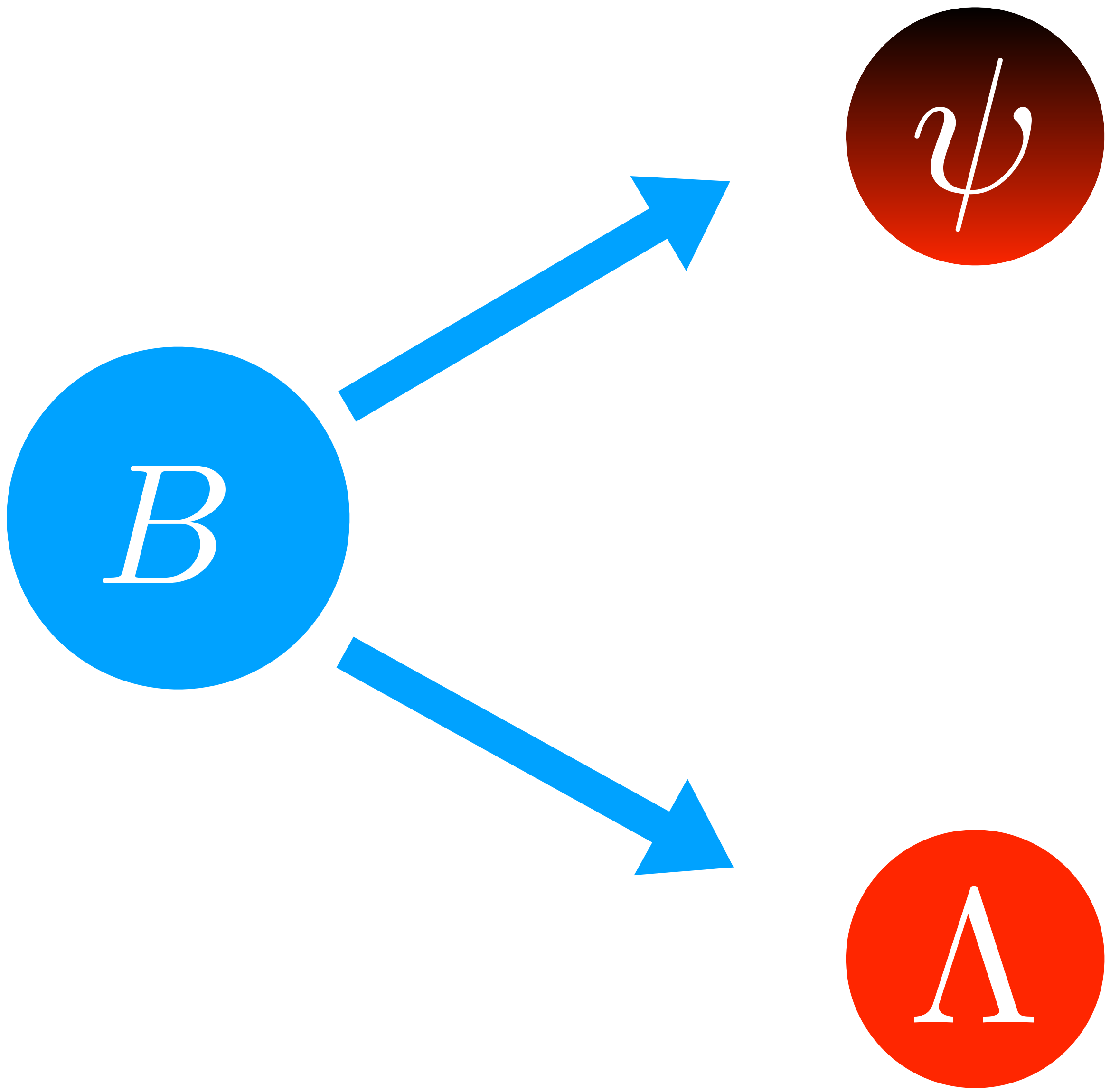




ATLAS
CMS

arXiv:2101.XXXXX with: Gonzalo Alonso-Álvarez & Gilly Elor

Thank You!



Back Up

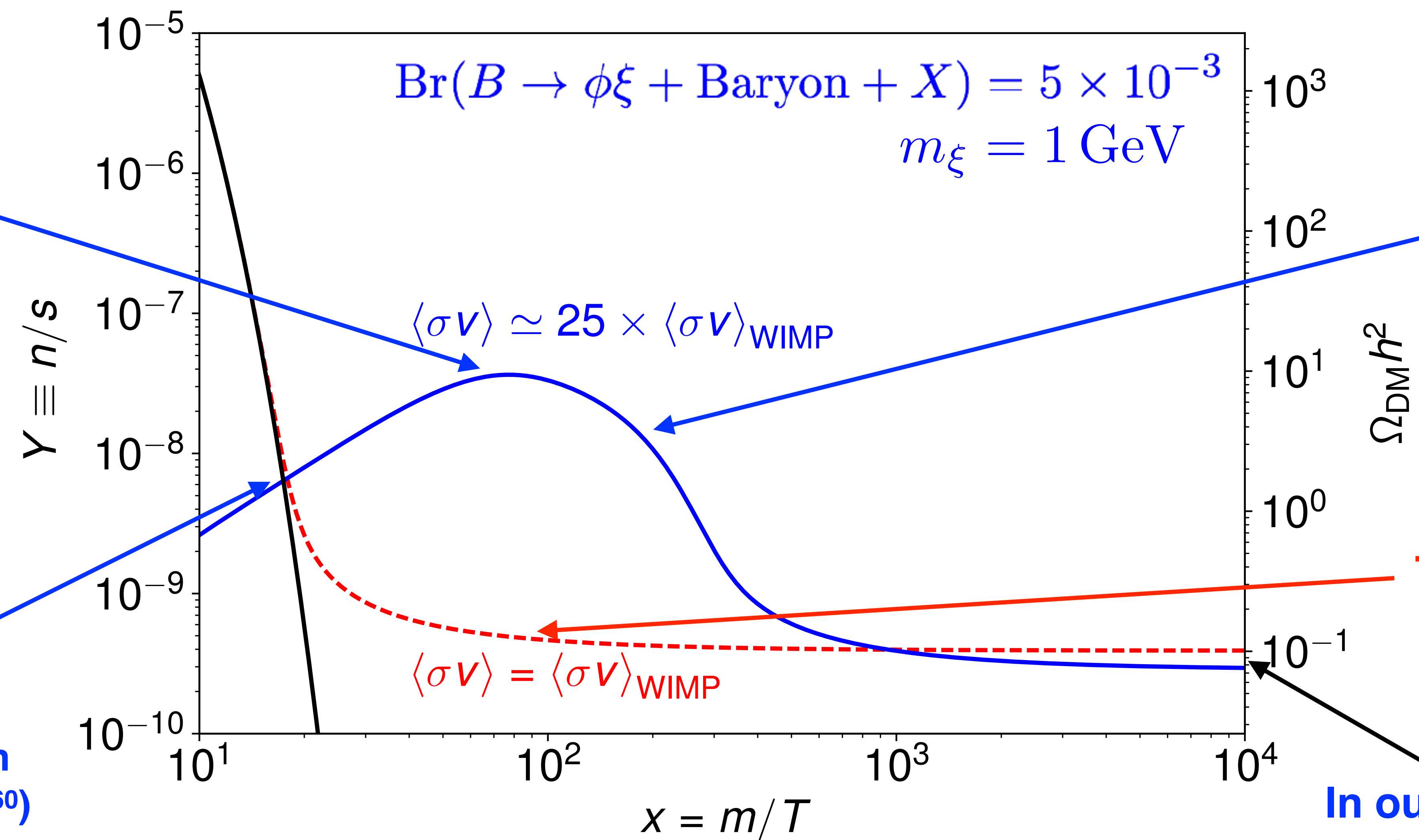
Dark Matter Abundance: Baryon Symmetric Component

Dark Matter generation terminates there

$\Phi \to B \to DM$

Non thermal

(inverse annihilation negligible $e^{-2m/T} \sim 10^{-60}$)



Our case

Thermal Relic (WIMP)

In our case is only part of the DM!

- $\langle \sigma v \rangle$ **in our scenario is about one order of magnitude larger than for WIMPS because** $\Omega h^2 \propto x_{\mathrm{FO}} / \langle \sigma v \rangle$ **and for WIMPS** $x = m/T \simeq 20$ **but in our case** $x = m/T \simeq 2\,\mathrm{GeV}/10\,\mathrm{MeV} \simeq 200$**.**

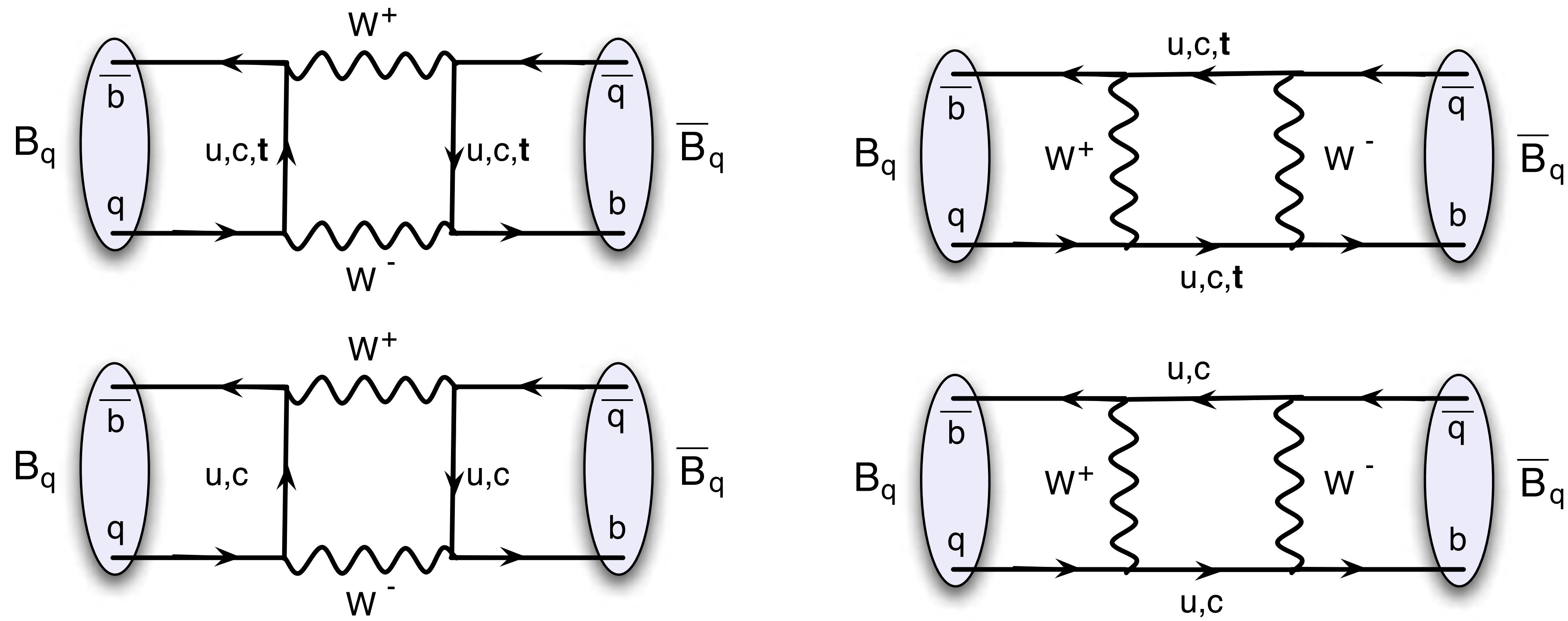
Baryogenesis from B Mesons

1) CP violation in the Meson System

SM: Box Diagrams

$M_{12} \propto$

$\Gamma_{12} \propto$



CP violating mixing requires a relative phase between Γ_{12} and M_{12}

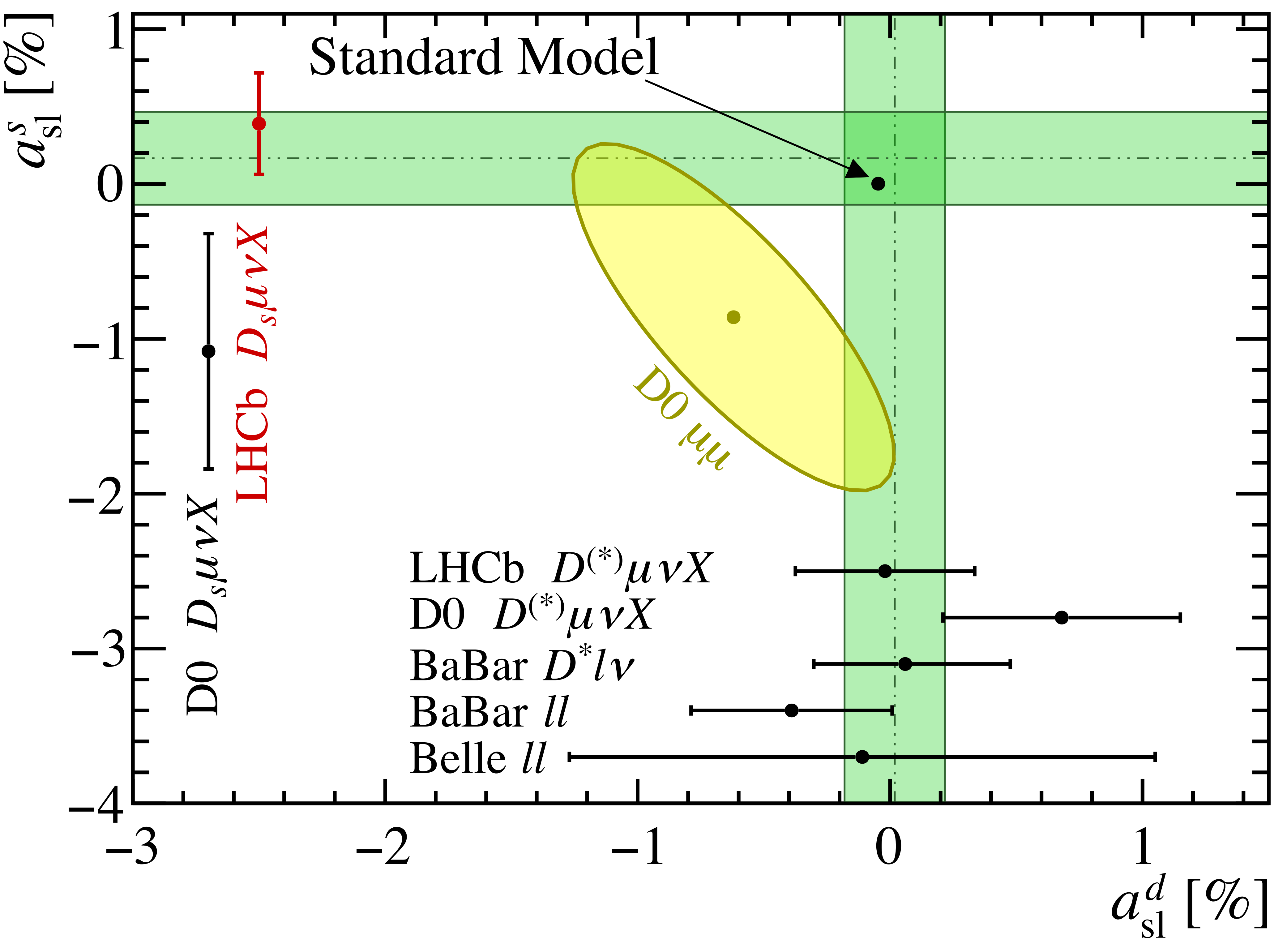
BSM?

***Z'* models (even at tree level), Leptoquarks etc ...**

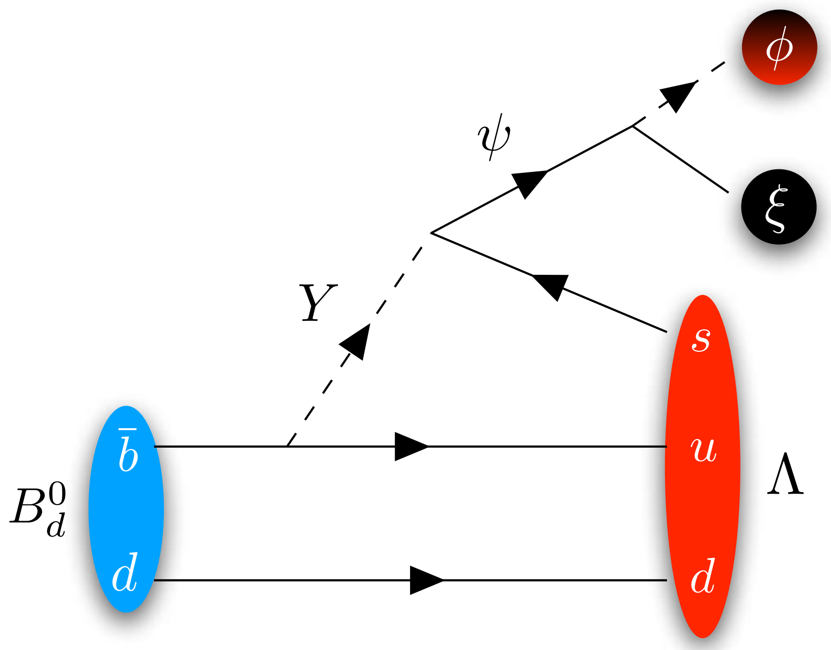
see *e.g.* Nir 9911321

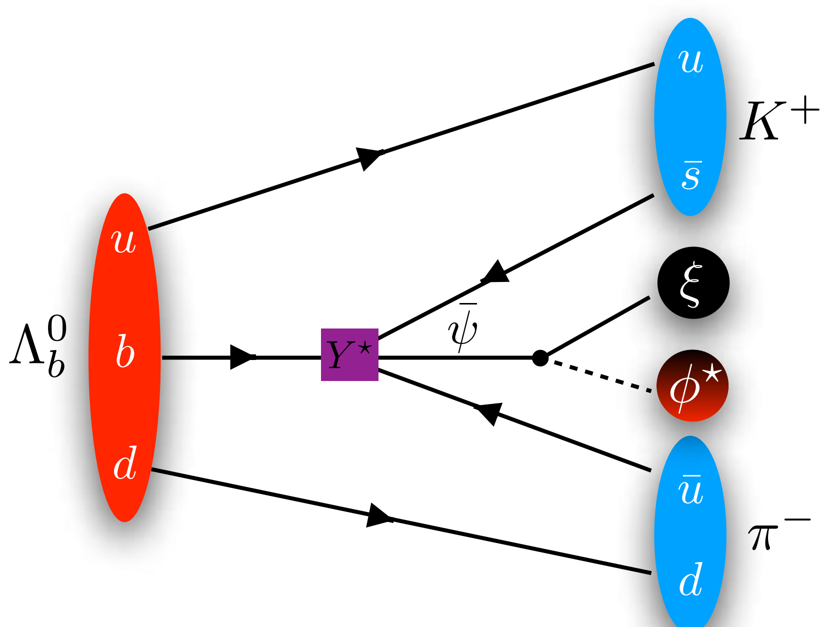
Semileptonic Asymmetry measurements

Lenz et al 1511.09466



Back Up: Flavourful Variations





Operator	Initial State	Final state	ΔM (MeV)
$\psi\, b\, u\, s$	B_d	$\psi + \Lambda\,(usd)$	4163.95
	B_s	$\psi + \Xi^0\,(uss)$	4025.03
	B^+	$\psi + \Sigma^+\,(uus)$	4089.95
	Λ_b	$\bar{\psi} + K^0$	5121.9
$\psi\, b\, u\, d$	B_d	$\psi + n\,(udd)$	4340.07
	B_s	$\psi + \Lambda\,(uds)$	4251.21
	B^+	$\psi + p\,(duu)$	4341.05
	Λ_b	$\bar{\psi} + \pi^0$	5484.5
$\psi\, b\, c\, s$	B_d	$\psi + \Xi_c^0\,(csd)$	2807.76
	B_s	$\psi + \Omega_c\,(css)$	2671.69
	B^+	$\psi + \Xi_c^+\,(csu)$	2810.36
	Λ_b	$\bar{\psi} + D^- + K^+$	3256.2
$\psi\, b\, c\, d$	B_d	$\psi + \Lambda_c + \pi^-\,(cdd)$	2853.60
	B_s	$\psi + \Xi_c^0\,(cds)$	2895.02
	B^+	$\psi + \Lambda_c\,(dcu)$	2992.86
	Λ_b	$\bar{\psi} + \overline{D}^0$	3754.7

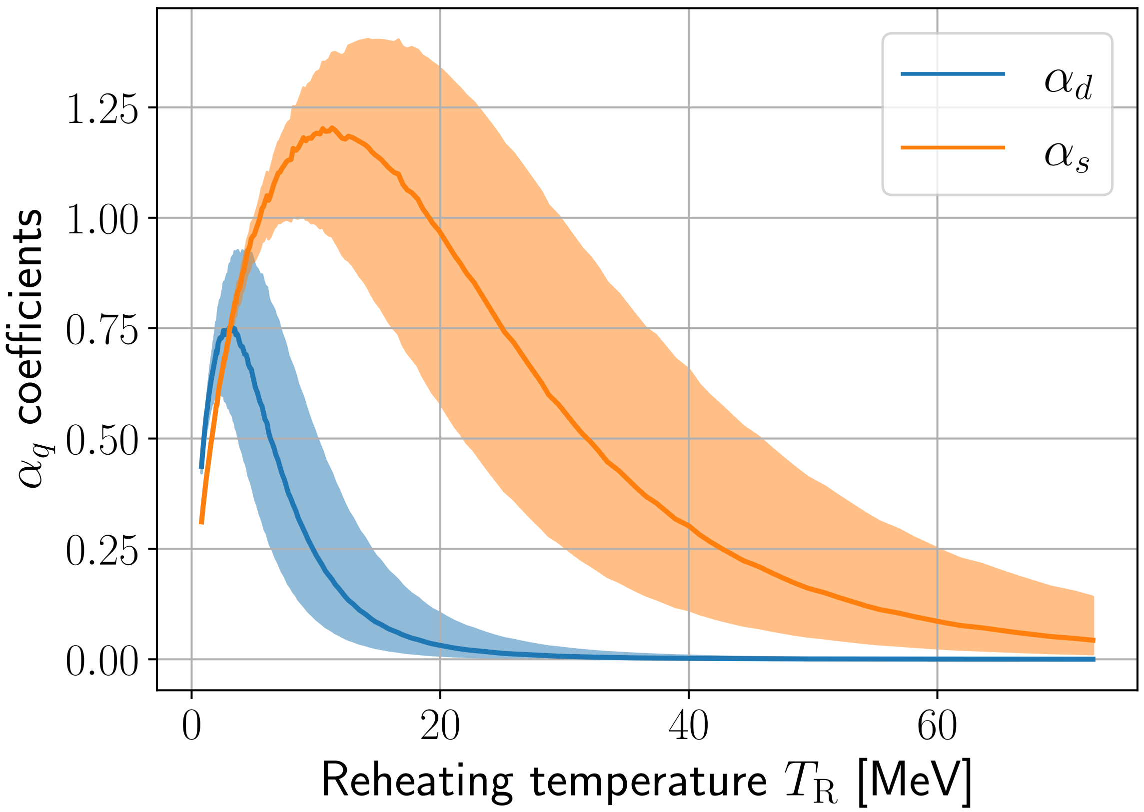
Table 1: Here we itemize the lightest possible initial and final states for the B decay process to visible and dark sector states resulting from the four possible operators. The diagram in Figure ?? corresponds to the first line. The mass difference between initial and final visible sector states corresponds to the kinematic upper bound on the mass of the dark sector ψ baryon.

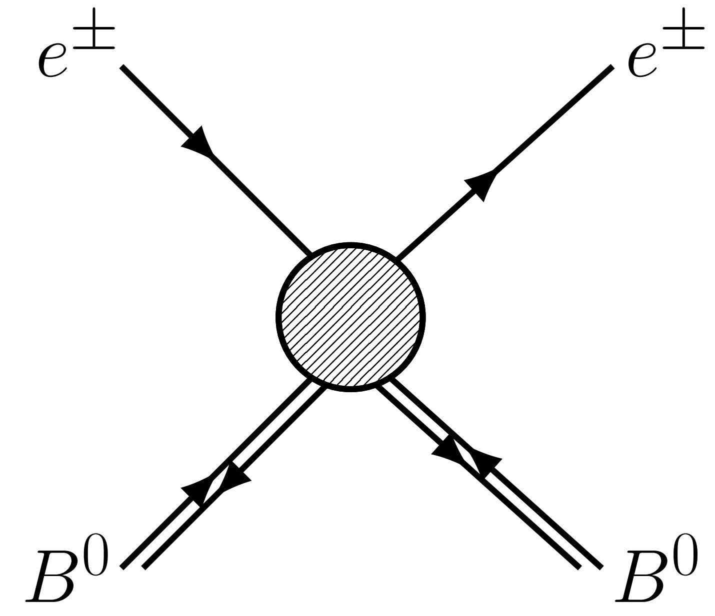
Back Up: Parameters

Parameter	Description	Range	Benchmark Value	Constraint
m_Φ	Φ mass	$11 - 100$ GeV	25 GeV	-
Γ_Φ	Inflaton width	$3\times10^{-23} < \Gamma_\Phi/\mathrm{GeV} < 5\times10^{-21}$	10^{-22} GeV	Decay between $3.5\,\mathrm{MeV} < T < 30\,\mathrm{MeV}$
m_ψ	Dirac fermion mediator	$1.5\,\mathrm{GeV} < m_\psi < 4.2\,\mathrm{GeV}$	3.3 GeV	Lower limit from $m_\psi > m_\phi + m_\xi$
m_ξ	Majorana DM	$0.3\,\mathrm{GeV} < m_\xi < 2.7\,\mathrm{GeV}$	1.0 and 1.8 GeV	$\lvert m_\xi - m_\phi\rvert < m_p - m_e$
m_ϕ	Scalar DM	$1.2\,\mathrm{GeV} < m_\phi < 2.7\,\mathrm{GeV}$	1.5 and 1.3 GeV	$\lvert m_\xi - m_\phi\rvert < m_p - m_e$, $m_\phi > 1.2\,\mathrm{GeV}$
y_d	Yukawa for $\mathcal{L} = y_d\bar{\psi}\phi\xi$		0.3	$< \sqrt{4\pi}$
$\mathrm{Br}(B\to\phi\xi+..)$	Br of $B \to \mathrm{ME} + \mathrm{Baryon}$	$2\times10^{-4} - 0.1$	10^{-3}	< 0.1 [5]
$A^s_{\ell\ell}$	Lepton Asymmetry B_d	$5\times10^{-6} < A^d_{\ell\ell} < 8\times10^{-4}$	6×10^{-4}	$A^d_{\ell\ell} = -0.0021\pm0.0017$ [5]
$A^s_{\ell\ell}$	Lepton Asymmetry B_s	$10^{-5} < A^s_{\ell\ell} < 4\times10^{-3}$	10^{-3}	$A^s_{\ell\ell} = -0.0006\pm0.0028$ [5]
$\langle\sigma v\rangle_\phi$	Annihilation Xsec for ϕ	$(6-20)\times10^{-25}\,\mathrm{cm}^3/\mathrm{s}$	$10^{-24}\,\mathrm{cm}^3/\mathrm{s}$	Depends upon the channel [3]
$\langle\sigma v\rangle_\xi$	Annihilation Xsec for ξ	$(6-20)\times10^{-25}\,\mathrm{cm}^3/\mathrm{s}$	$10^{-24}\,\mathrm{cm}^3/\mathrm{s}$	Depends upon the channel [3]

Back Up: Decoherence

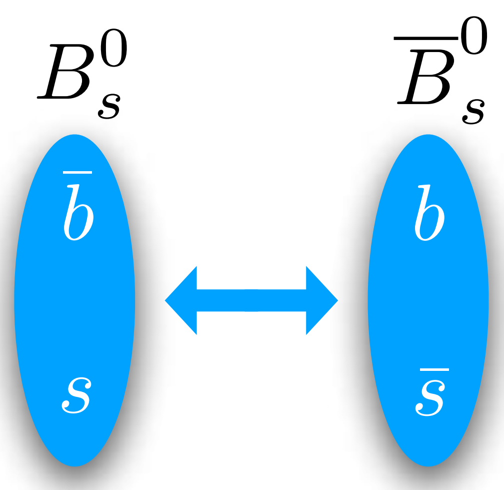
$$Y_B \simeq 8.7 \times 10^{-11} \, \frac{\mathrm{Br}(B \to \psi + \mathcal{B} + \mathcal{M})}{10^{-2}} \sum_q \alpha_q \, \frac{A_{\rm SL}^q}{10^{-4}}$$





$$\Gamma(e^\pm B^0 \to e^\pm B^0) < \Delta m_{B^0}$$

$$\Gamma_{e^\pm B_0 \to e^\pm B_0} \simeq 10^{-11}\,\mathrm{GeV} \left(\frac{T}{20\,\mathrm{MeV}}\right)^5 \left(\frac{\langle r_{B_0}^2\rangle}{0.187}\right)^2$$

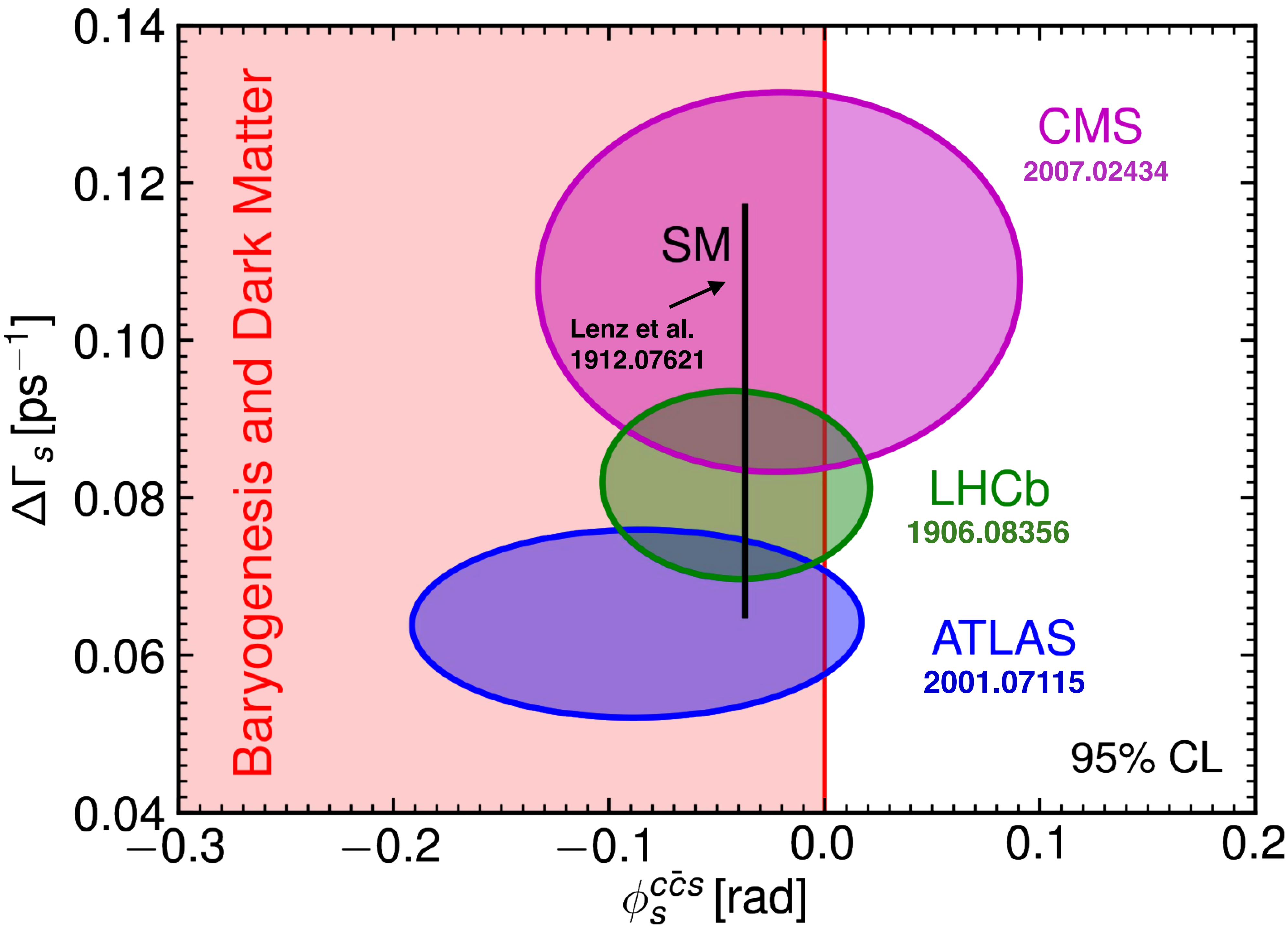


$$\tau_B = 1.52\,\mathrm{ps}$$

$$\Delta m_{B_s}/\Gamma_{B_s} = 26.9$$

$$\Delta m_{B_d}/\Gamma_{B_d} = 0.77$$

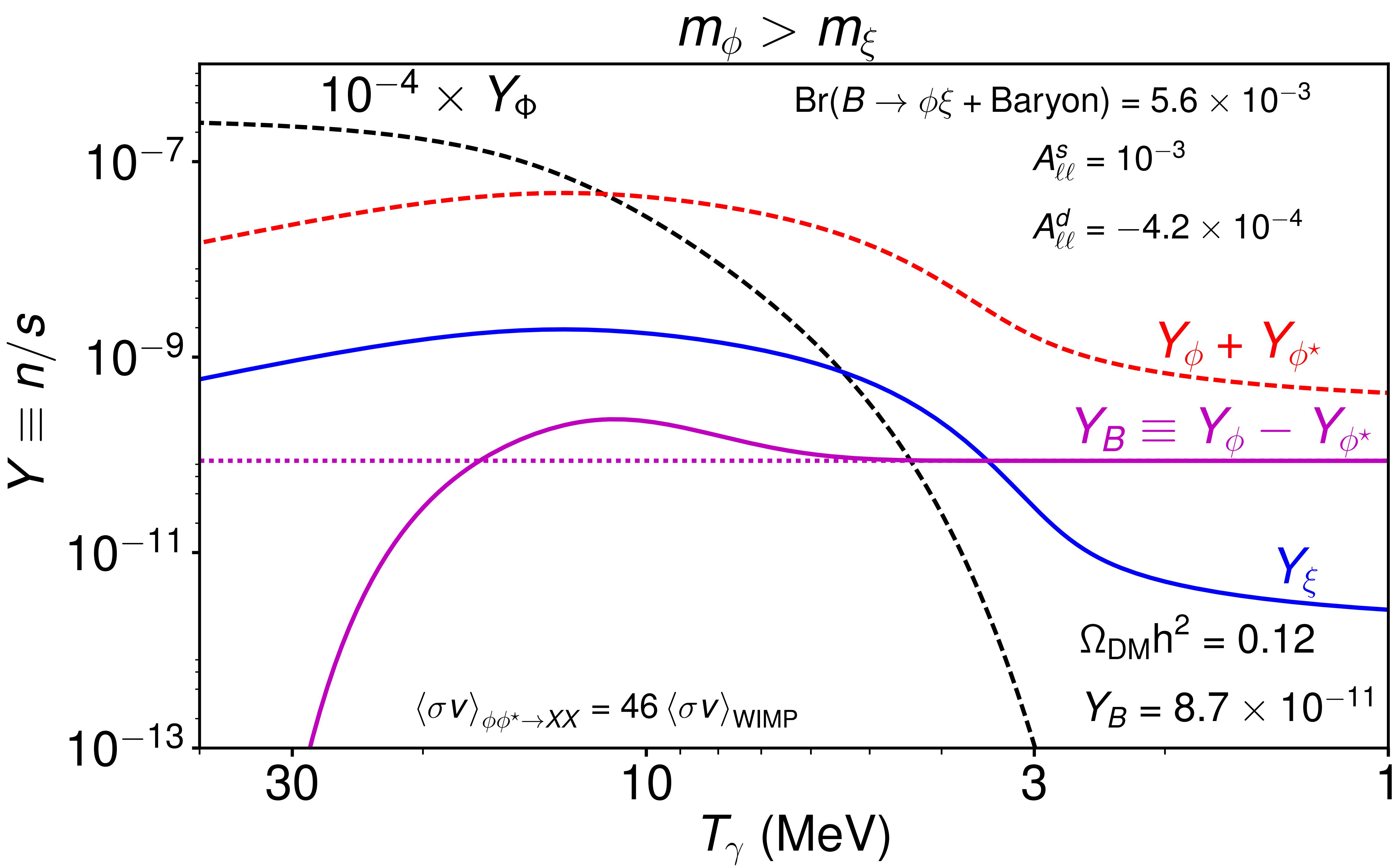
CP violation in b → cĉs



The sign of $\phi_s^{c\hat{c}s}$ determines the sign of A_{SL}!

Results: $A^d < 0$ and $A^s > 0$

$m_\xi = 1.8\,\mathrm{GeV} \quad m_\phi = 1.3\,\mathrm{GeV}$

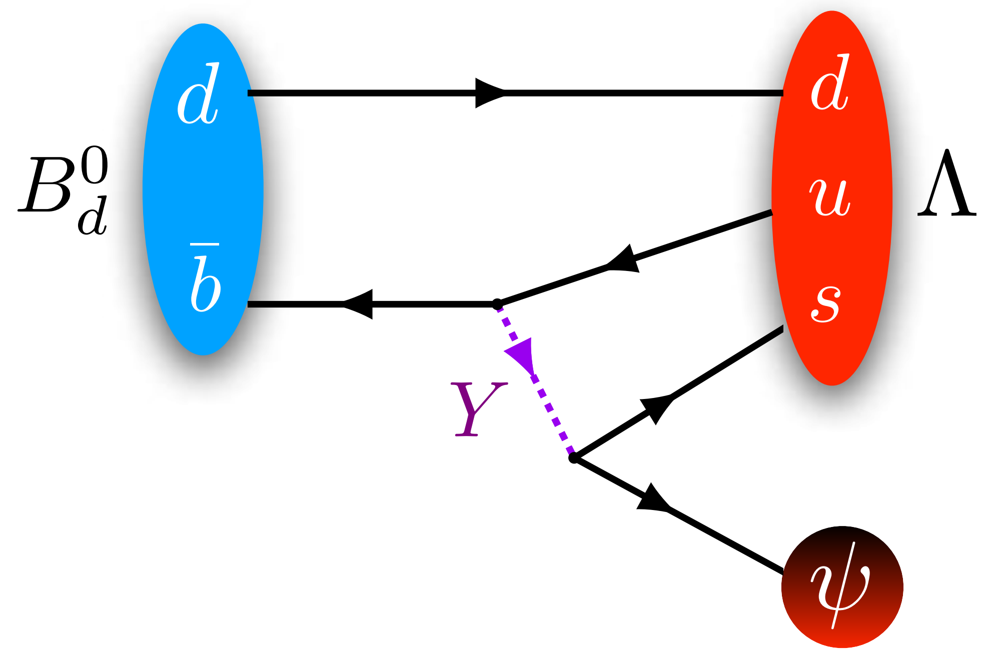


An Explicit Model

Minimal Particle Content

Field	Spin	Q_{EM}	Baryon no.	$\mathbb{Z}_2$	Mass
Φ	0	0	0	$+1$	$11 - 100\,\text{GeV}$
Y	0	$-1/3$	$-2/3$	$+1$	$\mathcal{O}(\text{TeV})$
ψ	1/2	0	-1	$+1$	$\mathcal{O}(\text{GeV})$
ξ	1/2	0	0	-1	$\mathcal{O}(\text{GeV})$
ϕ	0	0	-1	-1	$\mathcal{O}(\text{GeV})$

B-mesons decay into DM (missing energy) and a Baryon



Heavy Colored Triplet Scalar: $Y \sim (3, 1, -1/3)$

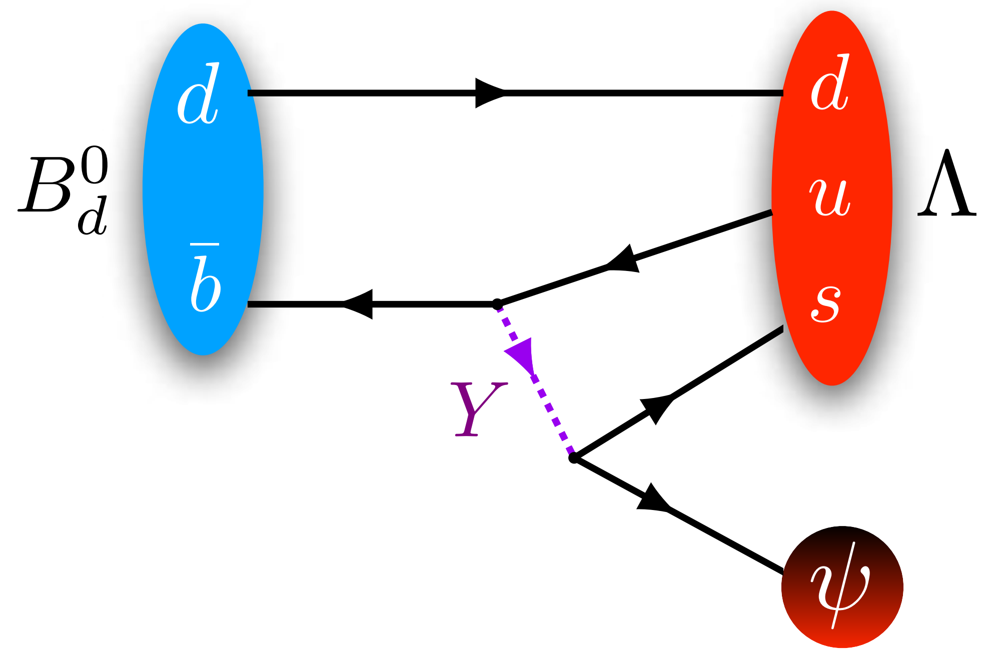
- $\mathcal{L} \supset -y_{ub}\, Y^*\, \bar{u}\, b^c - y_{\psi s}\, Y \bar{\psi}\, s^c + \text{h.c}$ $\quad m_Y > 1.2\,\text{TeV}$ **(4-jet/squark)**
- $\mathcal{H}_{eff} = \dfrac{y_{ub} y_{\psi s}}{m_Y^2} u\, s\, b\, \psi$ also possible $c\,s\,b\,\psi\,,\; u\,d\,b\,\psi\,,\; c\,d\,b\,\psi$
- $\Delta B = 0$ **operator induces new b-quark decay** $\bar{b} \to \psi u s$ **(CP and Baryon number conserving)**
- $\text{Br}\,(B \to \psi + \text{Baryon} + \mathcal{M}) \simeq 10^{-3} \left(\dfrac{m_B - m_\psi}{2\,\text{GeV}}\right)^4 \left(\dfrac{1.6\,\text{TeV}}{M_Y} \dfrac{\sqrt{y_{ub} y_{\psi s}}}{0.6}\right)^4$

An Explicit Model

Minimal Particle Content

Field	Spin	Q_{EM}	Baryon no.	$\mathbb{Z}_2$	Mass
Φ	0	0	0	$+1$	$11 - 100\,\text{GeV}$
Y	0	$-1/3$	$-2/3$	$+1$	$\mathcal{O}(\text{TeV})$
ψ	$1/2$	0	-1	$+1$	$\mathcal{O}(\text{GeV})$
ξ	$1/2$	0	0	-1	$\mathcal{O}(\text{GeV})$
ϕ	0	0	-1	-1	$\mathcal{O}(\text{GeV})$

B-mesons decay into DM (missing energy) and a Baryon



The Dark Sector:

ψ : **Dirac Dark Baryon**

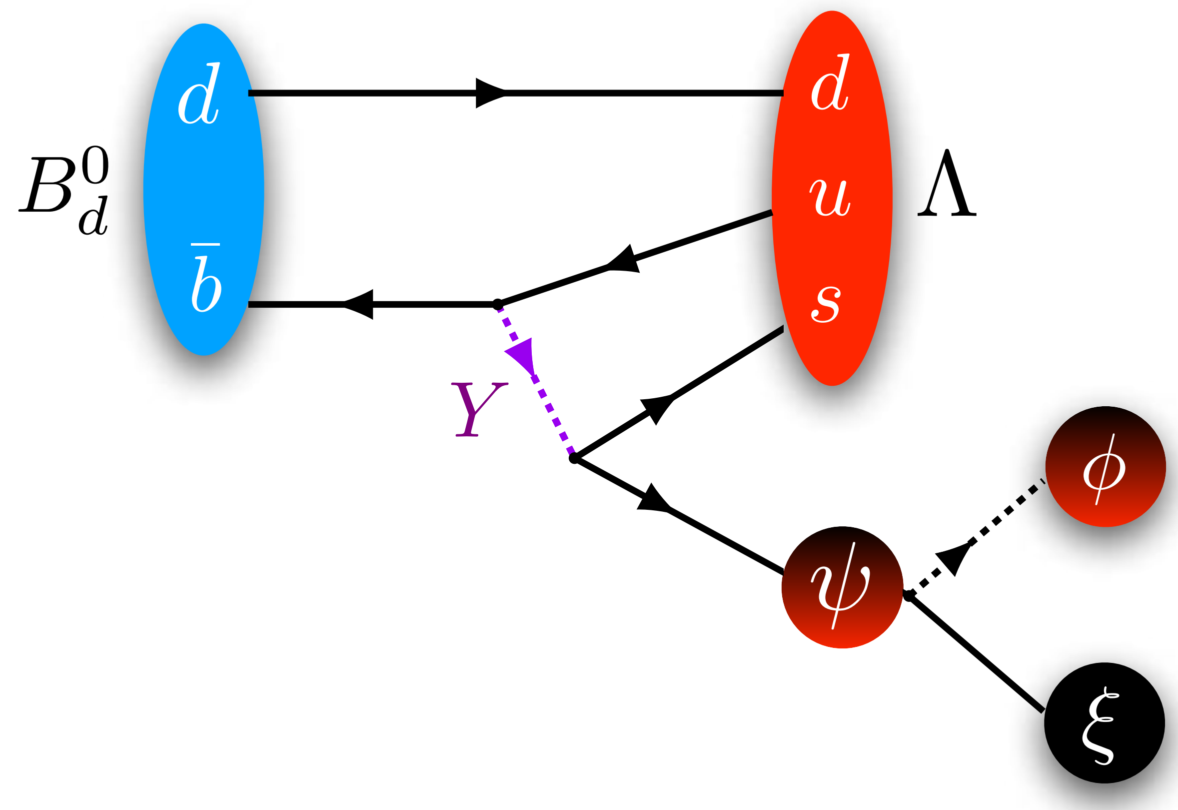
- **For the b-quark decay to happen:** $m_\psi < m_B - m_{\text{Baryon}} < 4.3\,\text{GeV}$
- ψ **needs to have decays into other dark sector particles or will decay back to visible baryons and undo the Baryogenesis** $\tau(\psi \to p + \pi^-) \sim 10^4\,\text{years}$

An Explicit Model

Minimal Particle Content

Field	Spin	Q_{EM}	Baryon no.	$\mathbb{Z}_2$	Mass
Φ	0	0	0	+1	$11 - 100\,\text{GeV}$
Y	0	$-1/3$	$-2/3$	+1	$\mathcal{O}(\text{TeV})$
ψ	1/2	0	-1	+1	$\mathcal{O}(\text{GeV})$
ξ	1/2	0	0	-1	$\mathcal{O}(\text{GeV})$
ϕ	0	0	-1	-1	$\mathcal{O}(\text{GeV})$

B-mesons decay into DM (missing energy) and a Baryon



The Dark Sector:

ϕ : **Charged *Stable* Scalar anti-Baryon**

ξ : **Dark *Stable* Majorana Fermion**

- **Minimal Dark sector interaction** $\mathcal{L} \supset -y_d\, \bar{\psi}\, \phi\, \xi$ **with Z_2 symmetry**
- **Constraints:**
  - $\psi \to \phi\xi$ **Decay:** $m_\phi + m_\xi < m_\psi < 4.3\,\text{GeV}$
  - **DM Stability:** $|m_\xi - m_\phi| < m_p + m_e$
  - **Neutron Star Stability:** $m_\psi > m_\phi > 1.2\,\text{GeV}$

McKeen, Nelson, Reddy, Zhou 1802.08244