B-Mesogenesis: Baryogenesis and Dark Matter from B Mesons

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Based on:

arXiv:1810.00880, PRD 99, 035031 (2019)
with: Gilly Elor & Ann Nelson
arXiv:2101.02706, under review in PRD
with: Gonzalo Alonso-Álvarez & Gilly Elor

Workshop on ϕ_s and $A_{\rm SL}^s$ in B-Mesogenesis
19-04-2021

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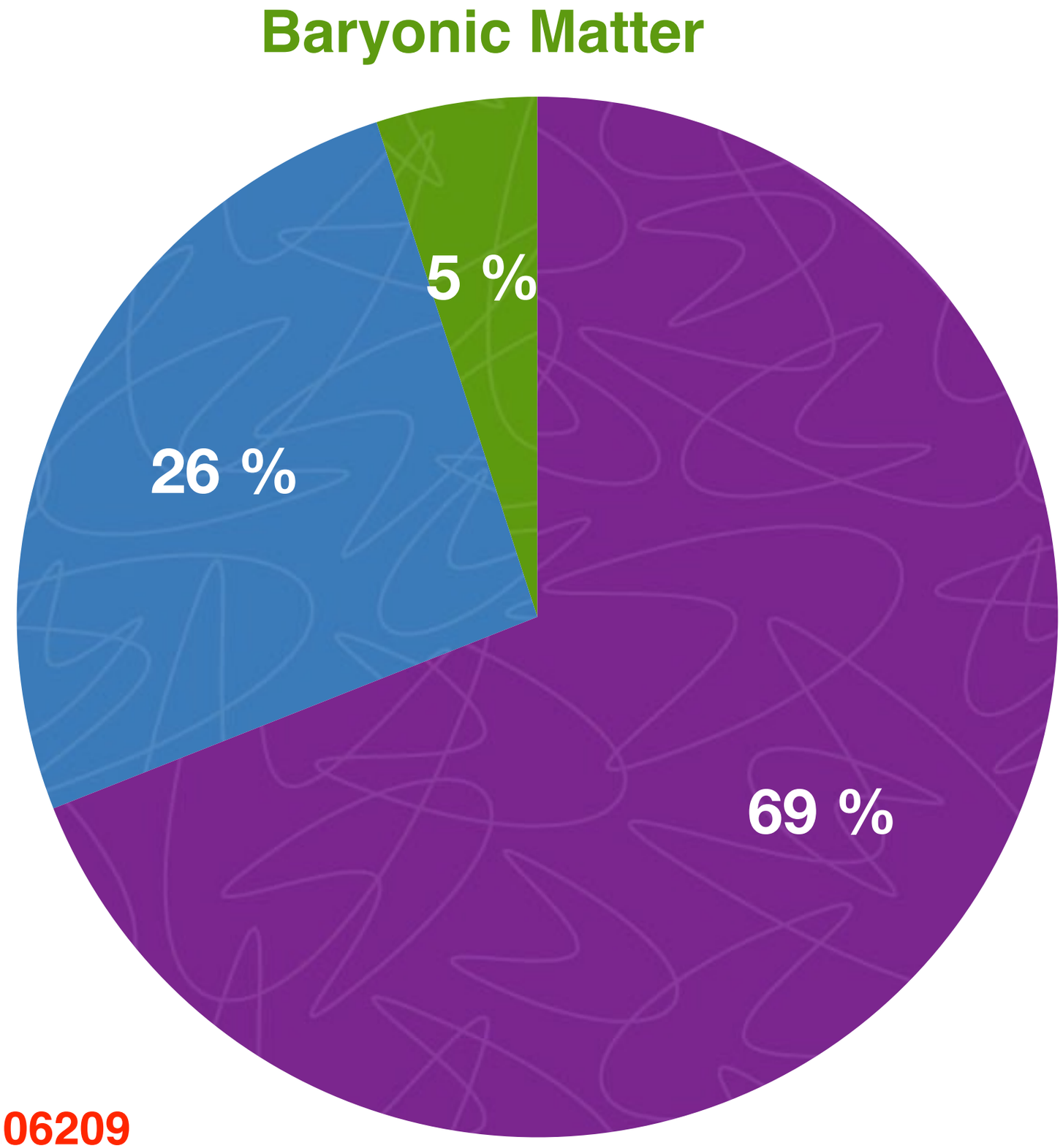
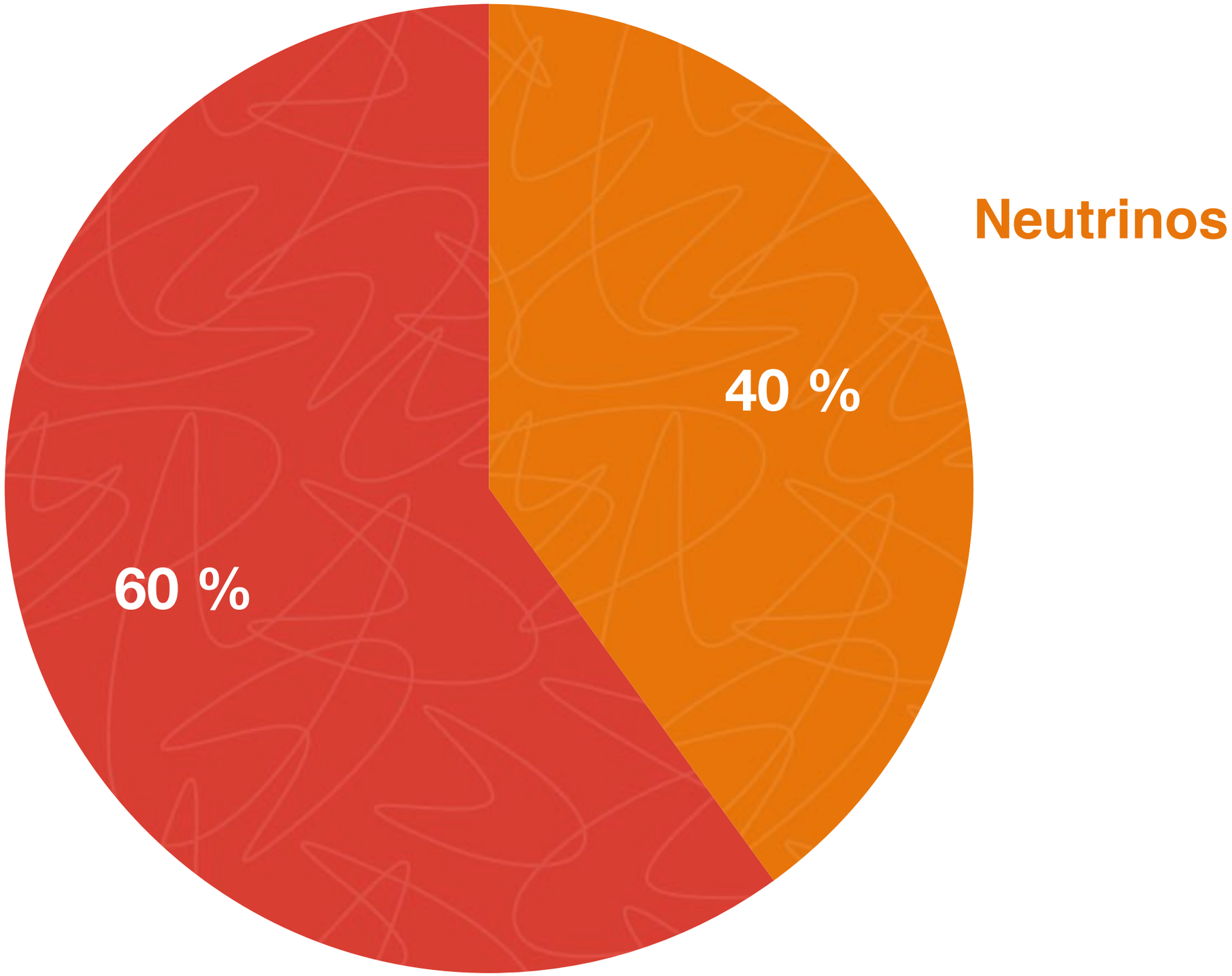
The Universe

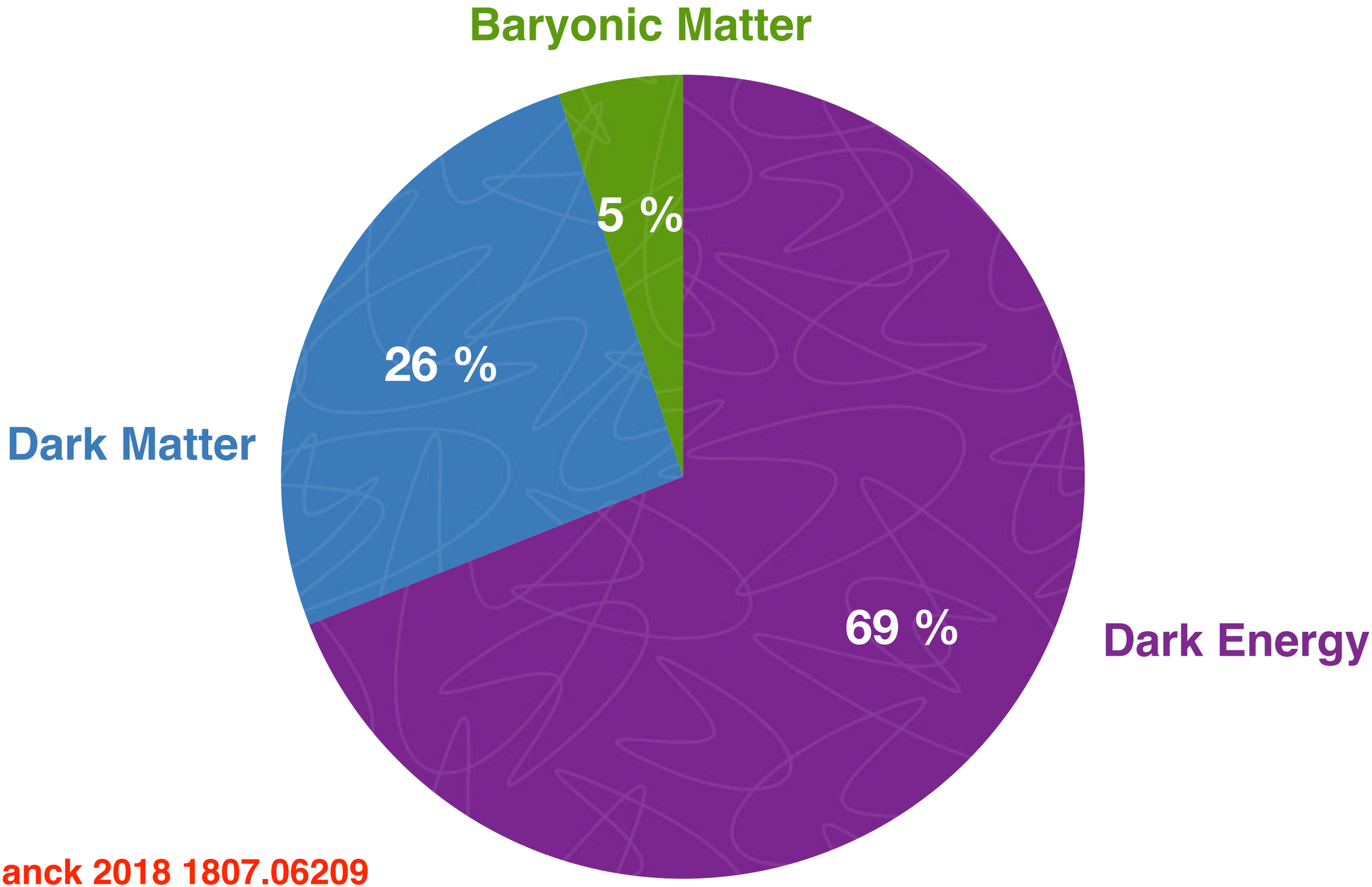


Planck 2018 1807.06209

SM Prediction:



The Universe



Planck 2018 1807.06209

B-Mesogenesis: Baryogenesis and Dark Matter from B Mesons

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**

arXiv:2101.02706 Alonso-Álvarez, Elor & Escudero

Outline

1) **B-Mesogenesis: Baryogenesis and Dark Matter from B Mesons**

2) **Collider implications:**

   1) **CP violation in the B meson system**

   2) **Missing energy decays of B mesons**

3) **Conclusions**

Baryogenesis

The three Sakharov Conditions (1967):

1) C and CP violation

2) Out of equilibrium

3) Baryon number violation

Baryogenesis from B Mesons

The three Sakharov Conditions (1967):

1) C and CP violation

Neutral B-Meson system

2) Out of equilibrium and B meson production

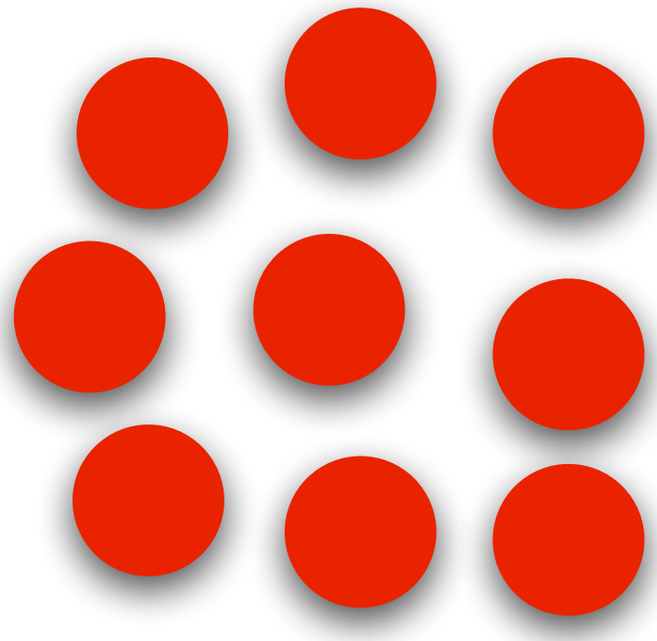
Late time ($\tau \sim 0.01$ s, $T_{RH} \sim 20$ MeV) decaying particle into b-quarks

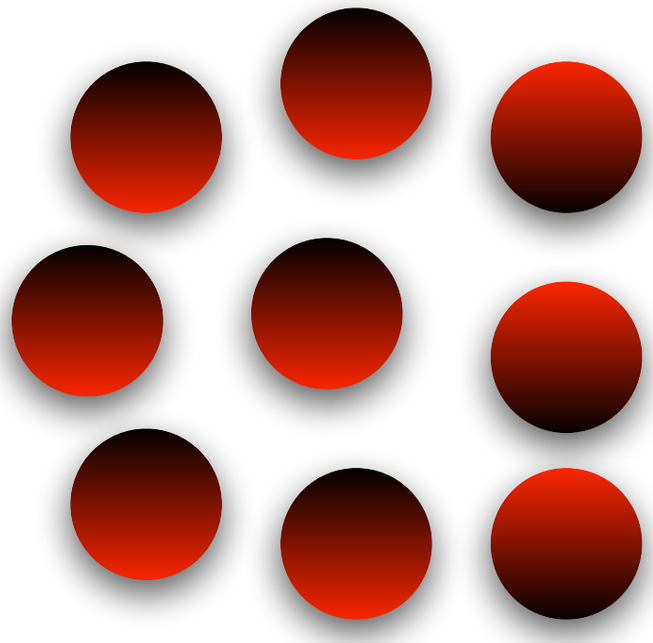
3) Baryon number violation

Baryon number is conserved! Dark Matter is antibaryonic

New decay mode of B mesons into Dark Matter and a Baryon

B-Mesogenesis





Visible Sector (Baryons)

Dark Sector (anti-Baryons)

Baryogenesis

$$Y_B = 8.7 \times 10^{-11}$$

and

Dark Matter

$$\Omega_{\rm DM} h^2 = 0.12$$

With the Baryon asymmetry:

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

Distinctive Collider Signatures

1) Extra CP violation in B Meson decays

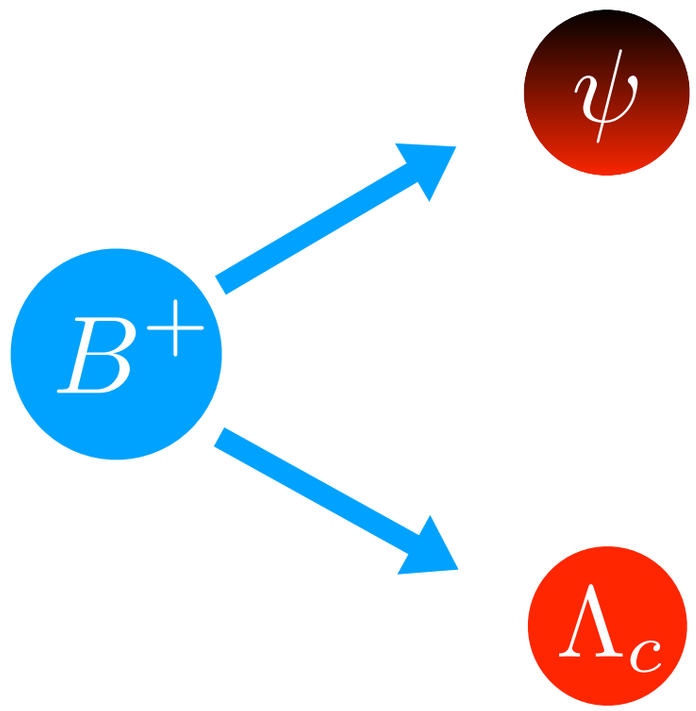
a) Semileptonic asymmetries

b) CP violation in $b \to c\bar{c}s$ decays

2) New B Meson decay into ME and a Baryon

a) Constraints from ALEPH

b) Indirect constraints from the LHC



Indirect CP violation

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

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

Lenz & Tetlalmatzi-Xolocotzi 1912.07621

see Talk by Alexander

Measurements

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

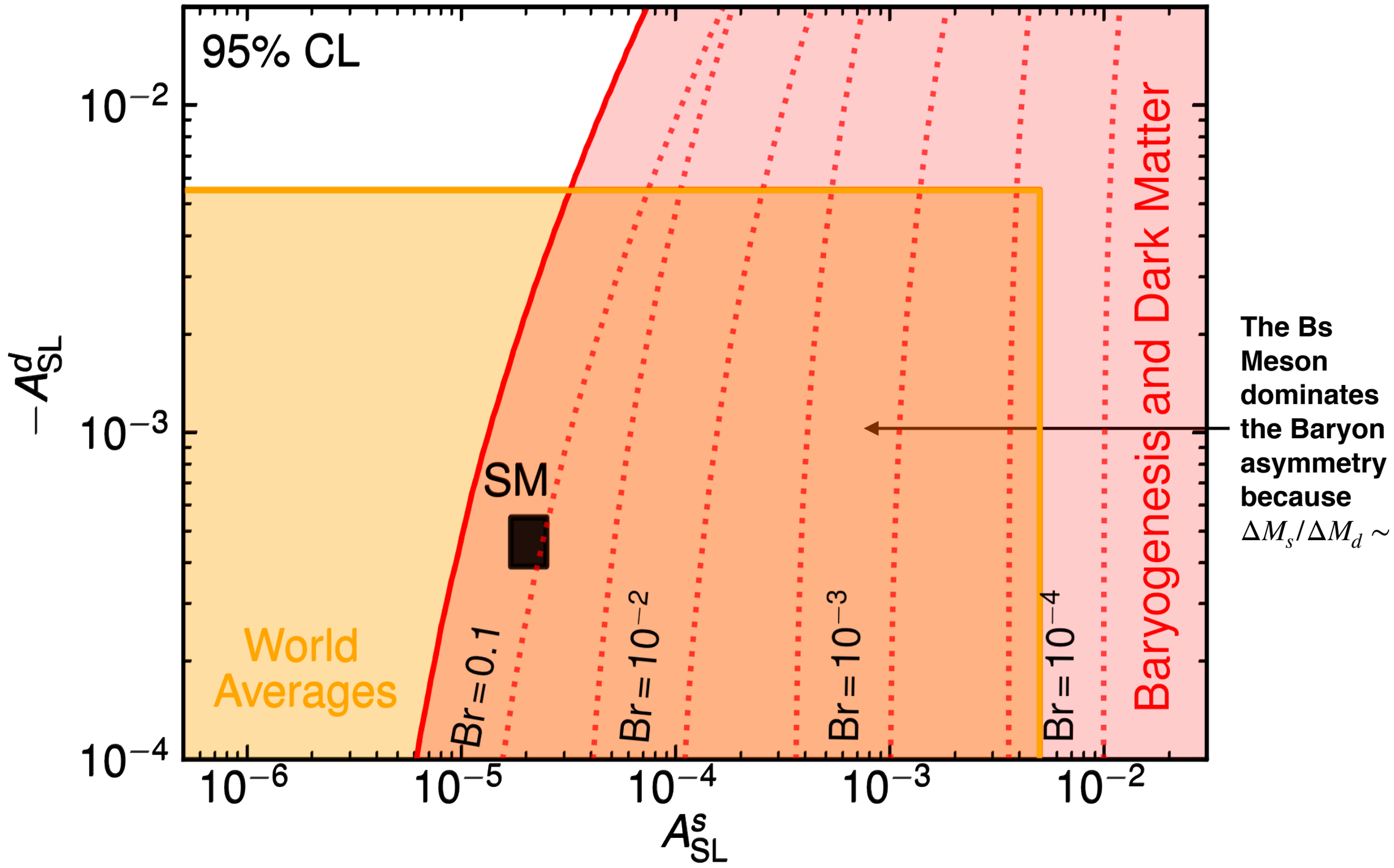
World averages (HFLAV)

see Talk by Lucia

Baryogenesis

$$A_{\rm SL}^q > 10^{-4}$$

Parameter Space

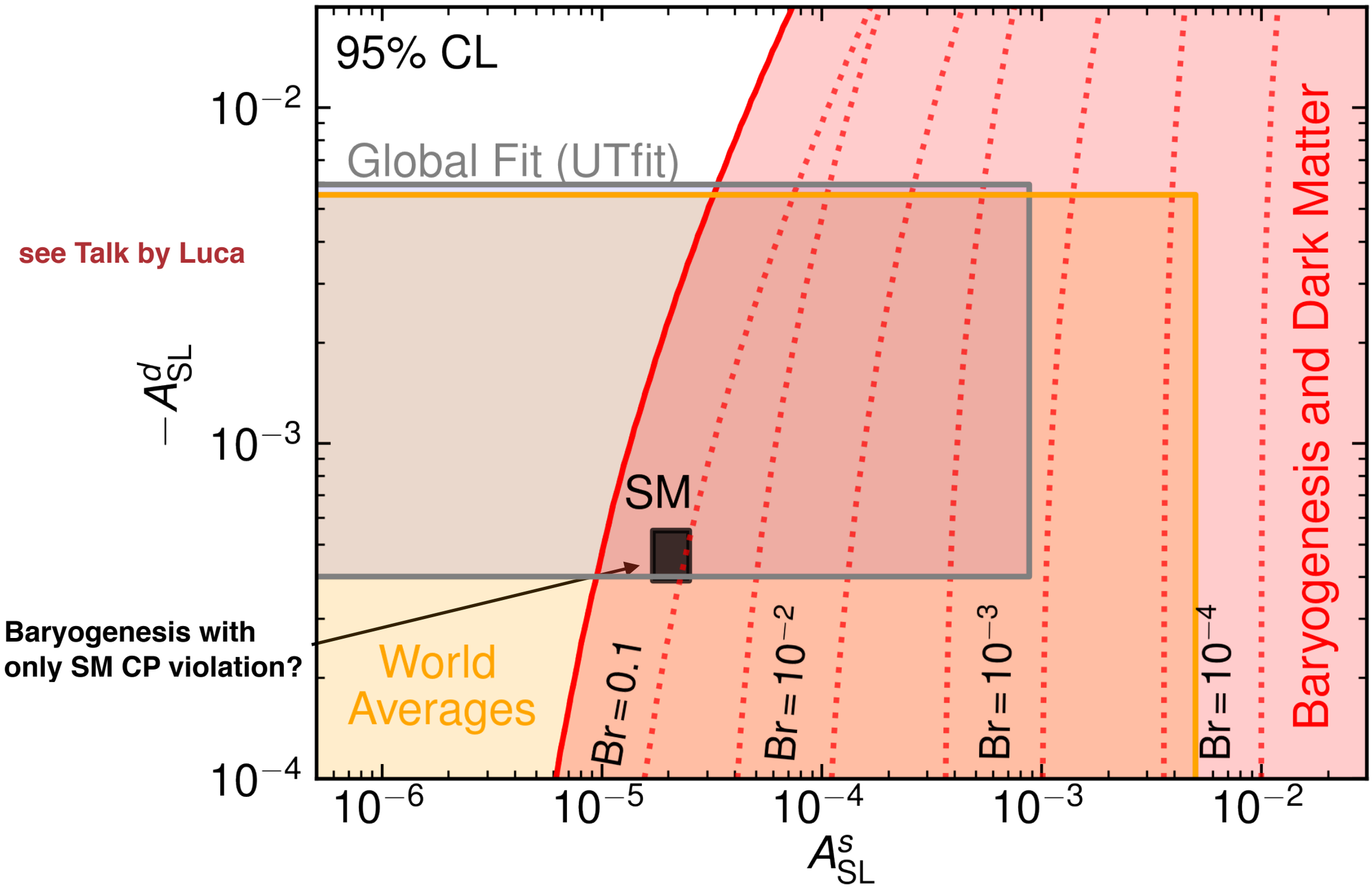


Measured A_{SL} imply:

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

Parameter Space

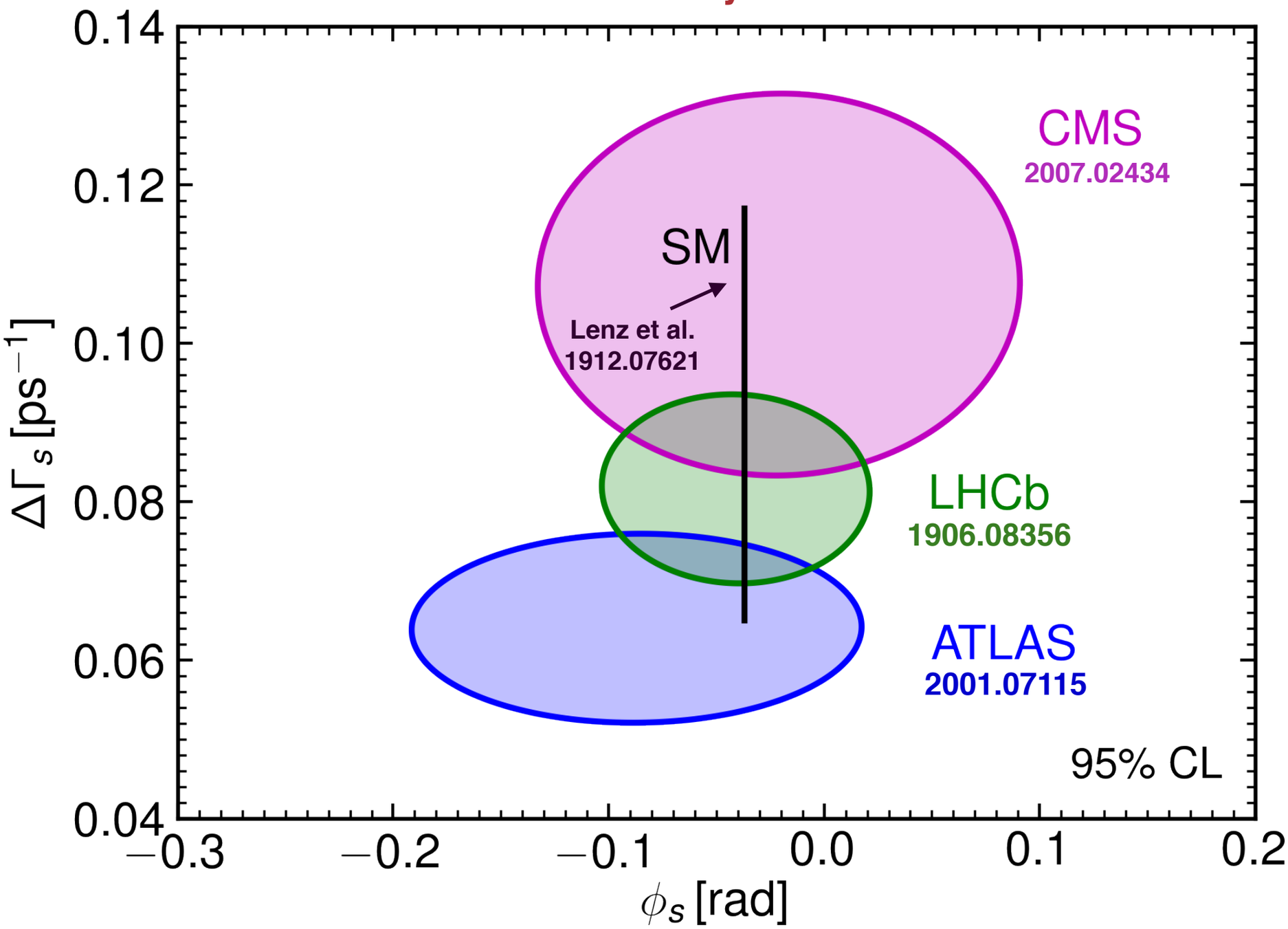
see Talk by Luca



Global fits indicate: $\mathrm{Br}\,(B \to \psi + \mathrm{Baryon} + \mathcal{M}) \gtrsim 10^{-3}$

CP violation in $b \to c\bar{c}s$

see Talk by Veronika



ϕ_s is strongly related to $A_{\rm SL}^s$

CP violation in $b \to c\bar{c}s$ and A_{SL}

$$A_{\rm SL}^q = -\frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_{12}^q$$

$$\phi_{12}^s = \phi_{12}^{\rm SM} + \phi_M^{\rm NP} + \phi_\Gamma^{\rm NP}$$ see Talk by Alexander

$$\phi_s = -2\beta_s + \phi_M^{\rm NP} + \delta_{\rm pen}^{\rm SM} + \delta_{\rm pen}^{\rm NP}$$

B_d: penguins do seem to contribute non-negligibly

B_s: penguins, at least in the SU(3) limit seem negligible

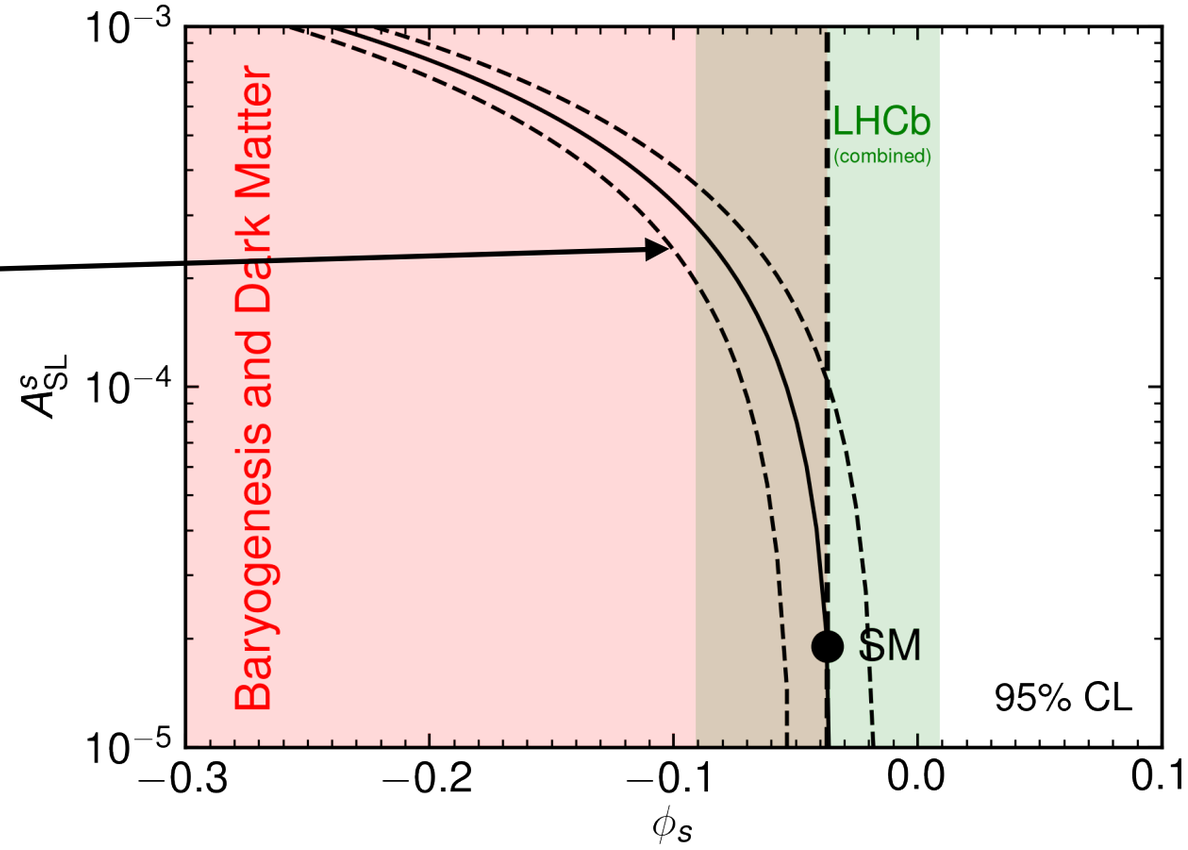
2010.14423: Barel, De Bruyn, Fleischer, Malami

see Talk by Kristof

The effect of penguins in B_s can be dramatic for $A_{\rm SL}^s$ because $\phi_{12}^s \simeq -0.2^\circ$ is very small:

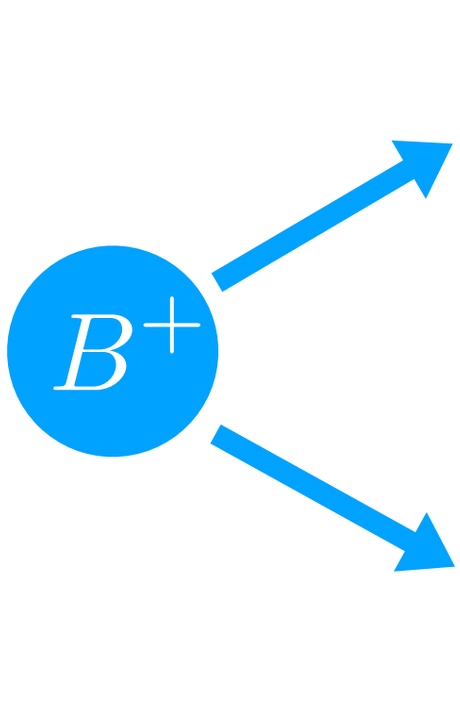
Bands indicate $\delta_{\rm pen}^{\rm SM} + \delta_{\rm pen}^{\rm NP} = \pm 1^\circ$, with $\phi_\Gamma^{\rm NP} = 0$, and $\Delta M_s = \Delta M_s|_{\rm SM}$, $\Delta\Gamma_s = \Delta\Gamma_s|_{\rm SM}$

Similarly, contributions to $\phi_\Gamma^{\rm NP} \lesssim 1^\circ$ could occur in our scenario



It appears key to understand the NP fit of UTFit see Talk by Luca

New B-Meson decay



Dark Sector
anti-Baryon

Baryon

Baryogenesis requires:

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

(Inclusive)

Parameter space is: $1.0\,\mathrm{GeV} < m_\psi < 4.0\,\mathrm{GeV}$

4 Flavourful variations exist: **(All work equally well for Baryogenesis)**

$\psi\, b\, u\, s$	$\psi\, b\, u\, d$	$\psi\, b\, c\, s$	$\psi\, b\, c\, d$
$B_d \to \psi + \Lambda\,(usd)$	$B_d \to \psi + n\,(udd)$	$B_d \to \psi + \Xi_c^0\,(csd)$	$B_d \to \psi + \Lambda_c + \pi^-\,(cdd)$
$B_s \to \psi + \Xi^0\,(uss)$	$B_s \to \psi + \Lambda\,(uds)$	$B_s \to \psi + \Omega_c\,(css)$	$B_s \to \psi + \Xi_c^0\,(cds)$
$B^+ \to \psi + \Sigma^+\,(uus)$	$B^+ \to \psi + p\,(duu)$	$B^+ \to \psi + \Xi_c^+\,(csu)$	$B^+ \to \psi + \Lambda_c\,(dcu)$
$\Lambda_b \to \bar{\psi} + K^0$	$\Lambda_b \to \bar{\psi} + \pi^0$	$\Lambda_b \to \bar{\psi} + D^- + K^+$	$\Lambda_b \to \bar{\psi} + \overline{D}^0$

New B-Meson decay

There is no available dedicated search for these processes!

Ways to constrain these new decay modes:

1) Indirectly from inclusive searches involving Baryons

$$\mathrm{Br}\,(B \to \psi + \mathrm{Baryon} + \mathcal{M}) \lesssim 10\,\%$$

(ARGUS, CLEO & BaBar)

2) Direct exclusive searches at B factories

sensitivity should be $\mathrm{Br}(B \to \psi + \mathrm{Baryon}) \sim 10^{-6} - 10^{-5}$

given that $\mathrm{Br}(B \to K\bar{\nu}\nu) \sim 10^{-6} - 10^{-5}$

There are ongoing searches at BaBar, Belle and Belle-II Echenard et al. Strube et al.

3) Searches for resonances at LHCb Cid Vidal et al.

4) Searches for b-flavor baryon decays LHCb Georgieva Chobanova, Martinez Santos et al.

5) At ALEPH! Inclusive search for missing energy of b decays hep-ex/0010022

6) Indirectly at ATLAS and CMS by constraining the mediator that should be M < 10 TeV

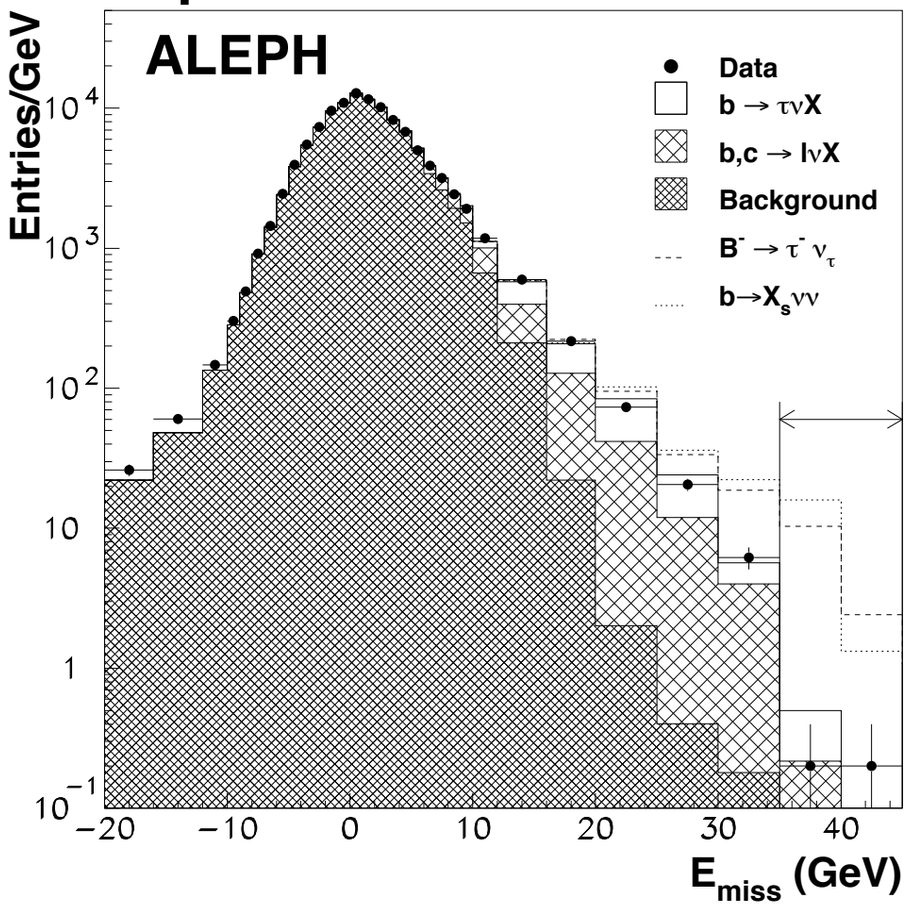
$$\mathrm{Br}\,(B \to \psi + \mathrm{Baryon} + \mathcal{M}) \lesssim 6 \times 10^{-3}$$

ALEPH search for b decays with E_{miss}

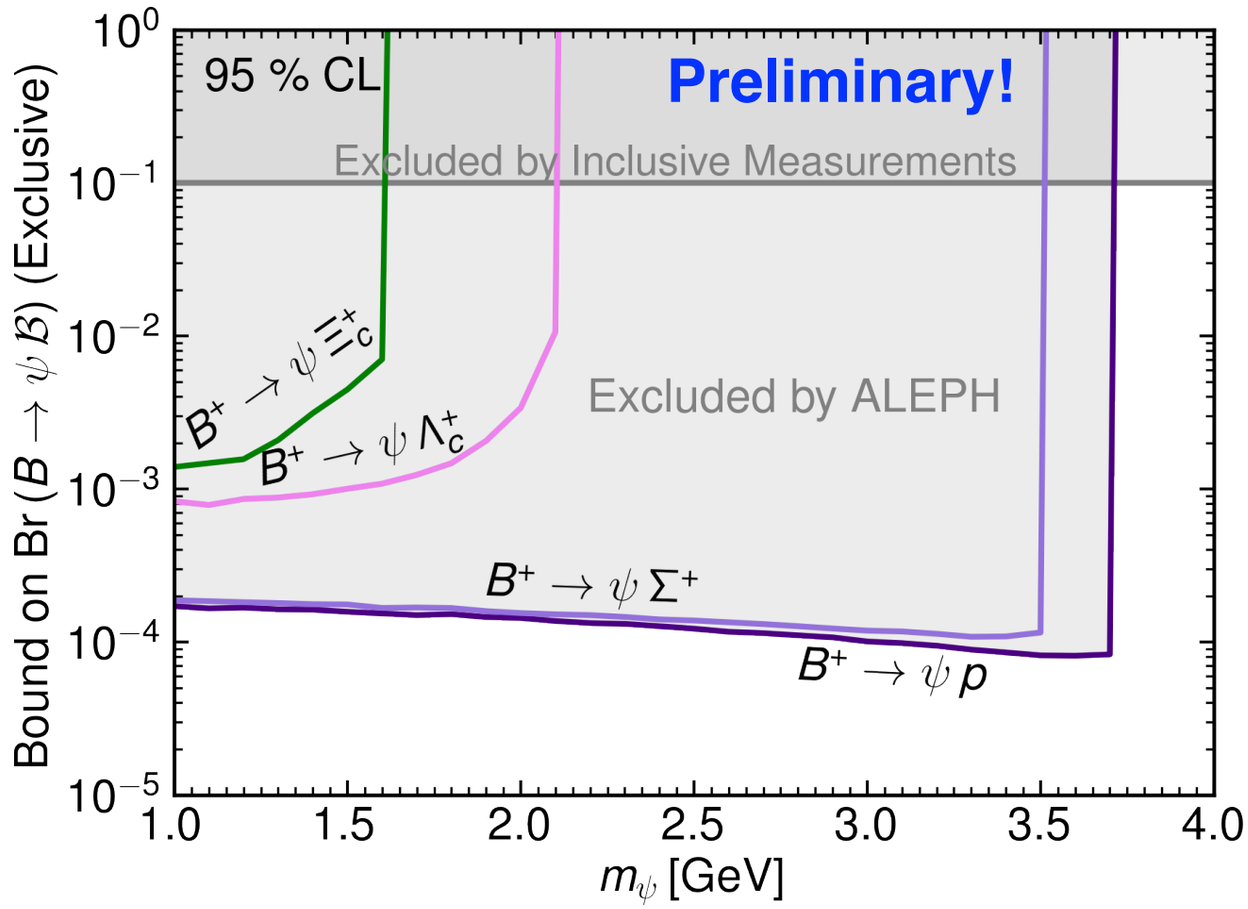
Our Referee has pointed out the existence of this search that was used to constrain $B \to \tau\nu$ and $b \to s\bar{\nu}\nu$ decays, see Grossman, Ligeti and Nardi hep-ph/9510378

The results do seem to apply to our exclusive 2-body decays

hep-ex/0010022



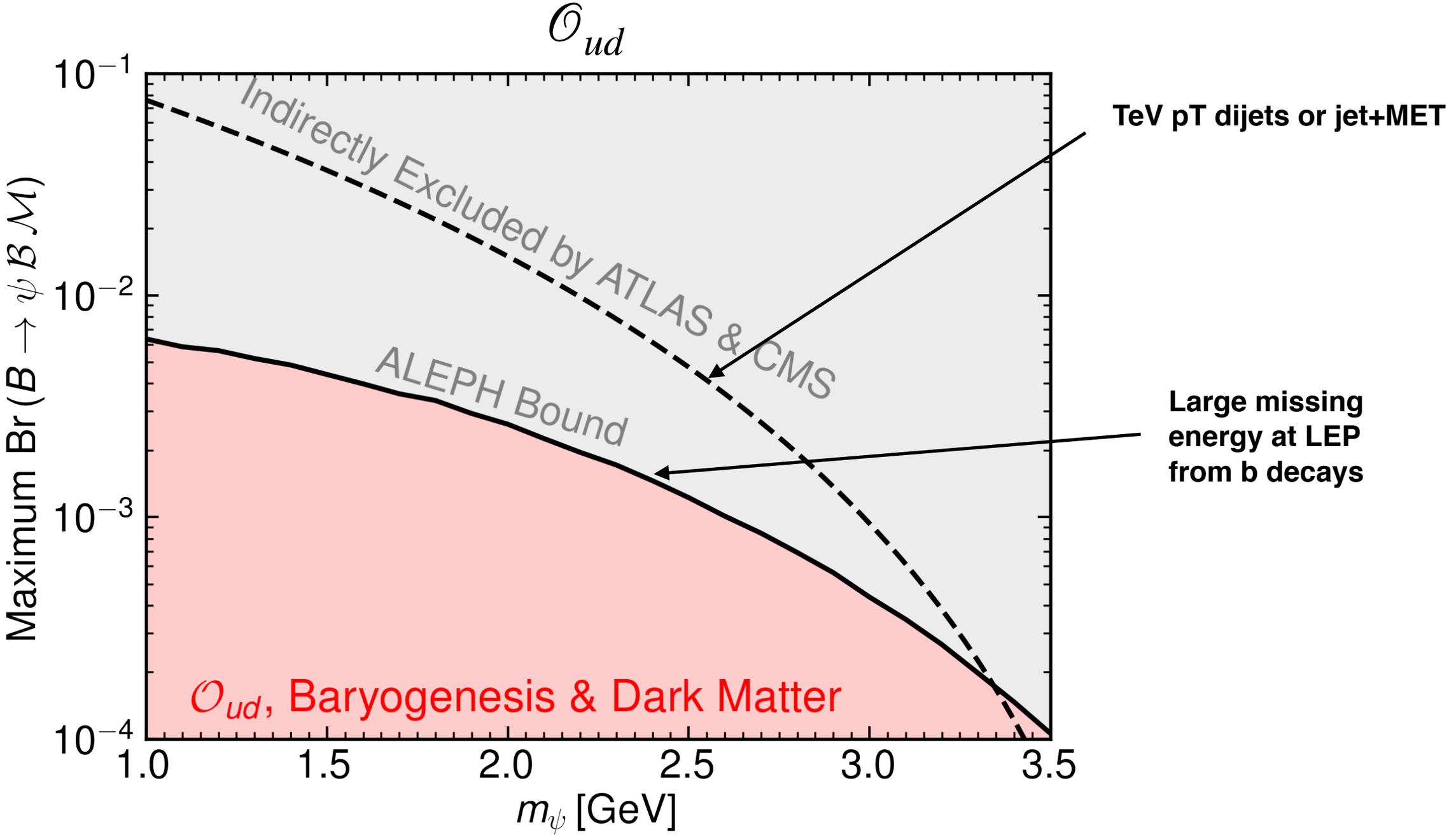
Our recast shows that:



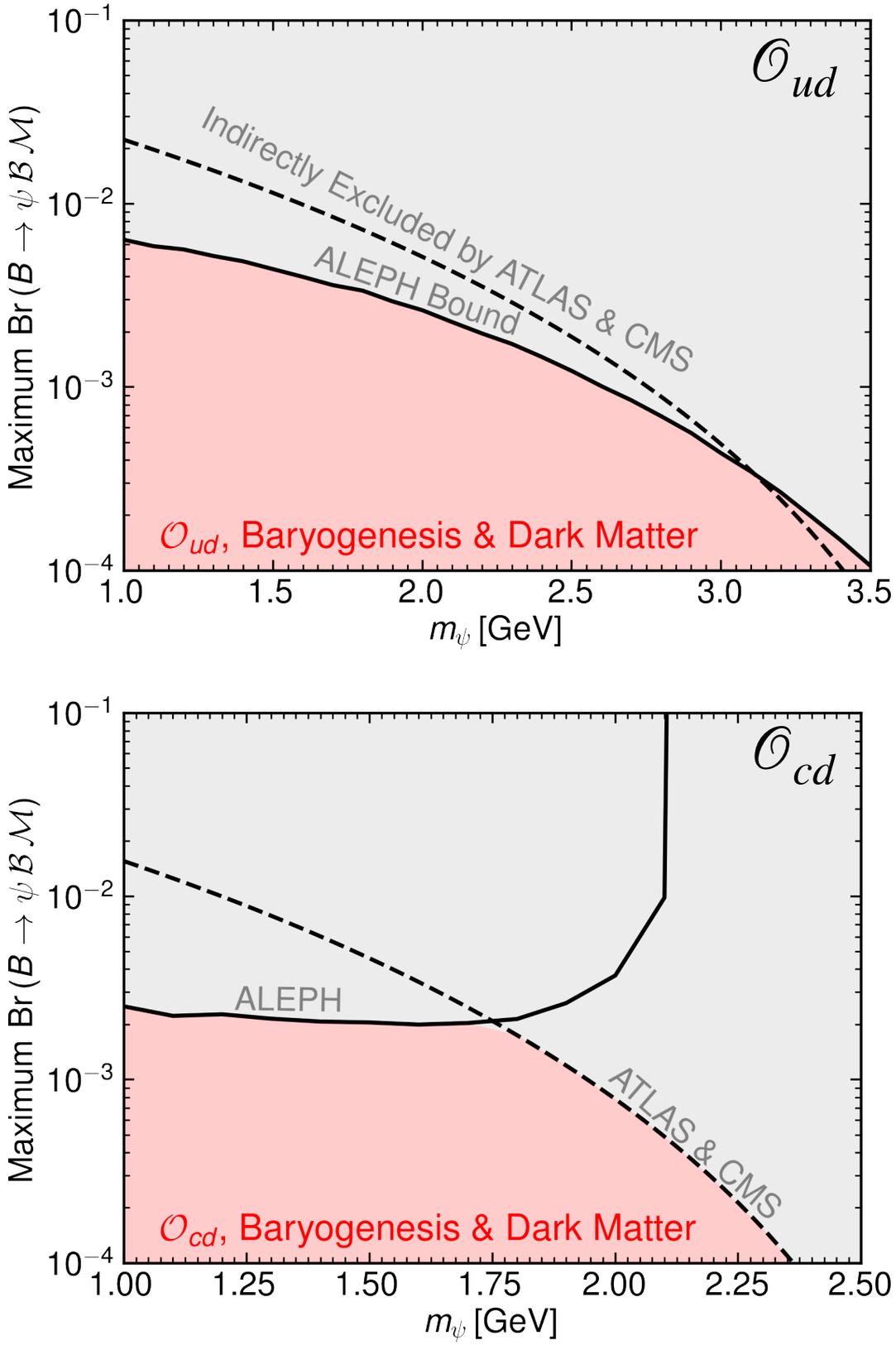
Implications for the mechanism depend upon the rather uncertain and large ratio between exclusive (no mesons) and inclusive (any mesons)!

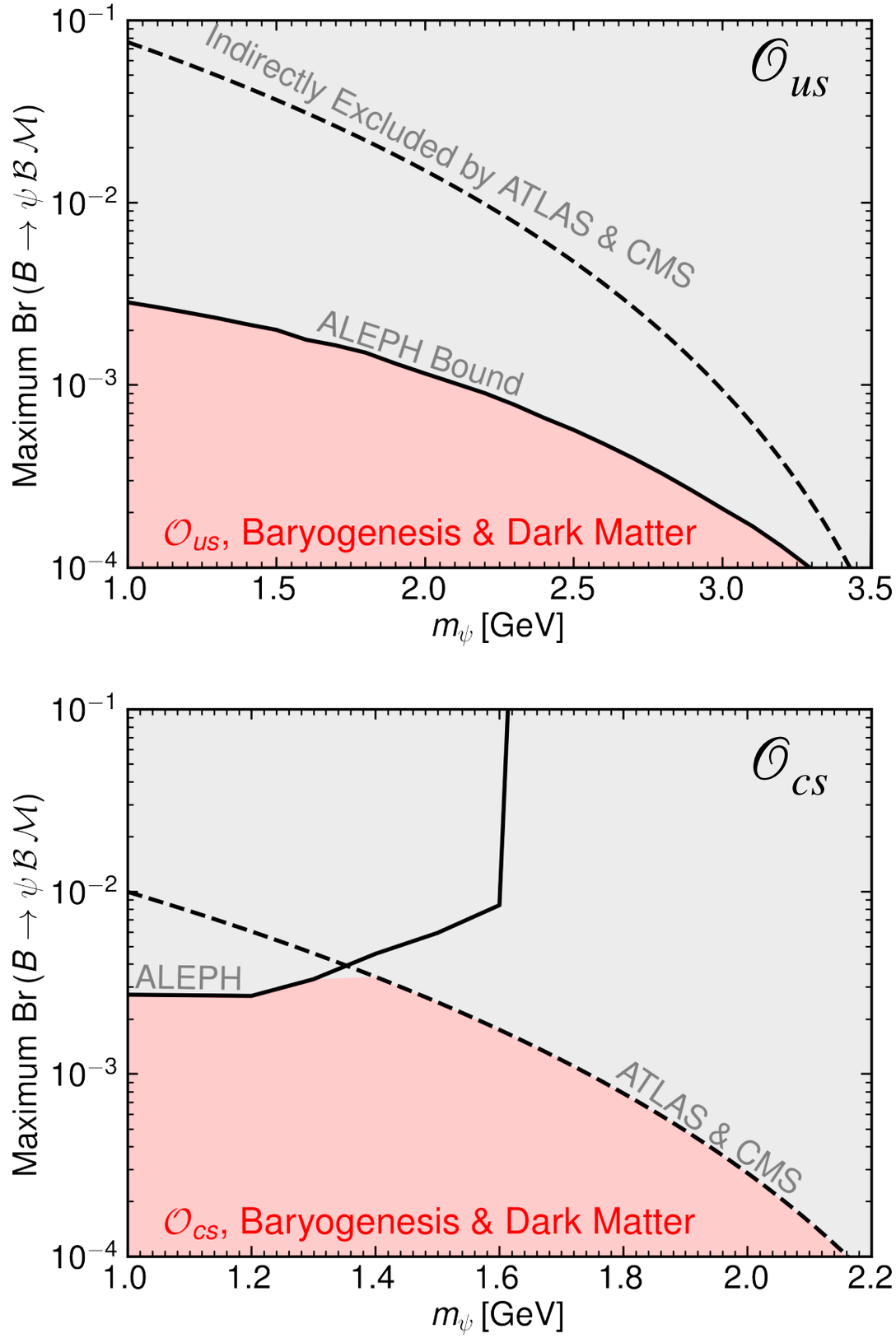
$$\frac{\mathrm{Br}(B^0 \to p\bar{p}K^+\pi^-)}{\mathrm{Br}(B^0 \to p\bar{p})} \simeq 500$$

Parameter Space

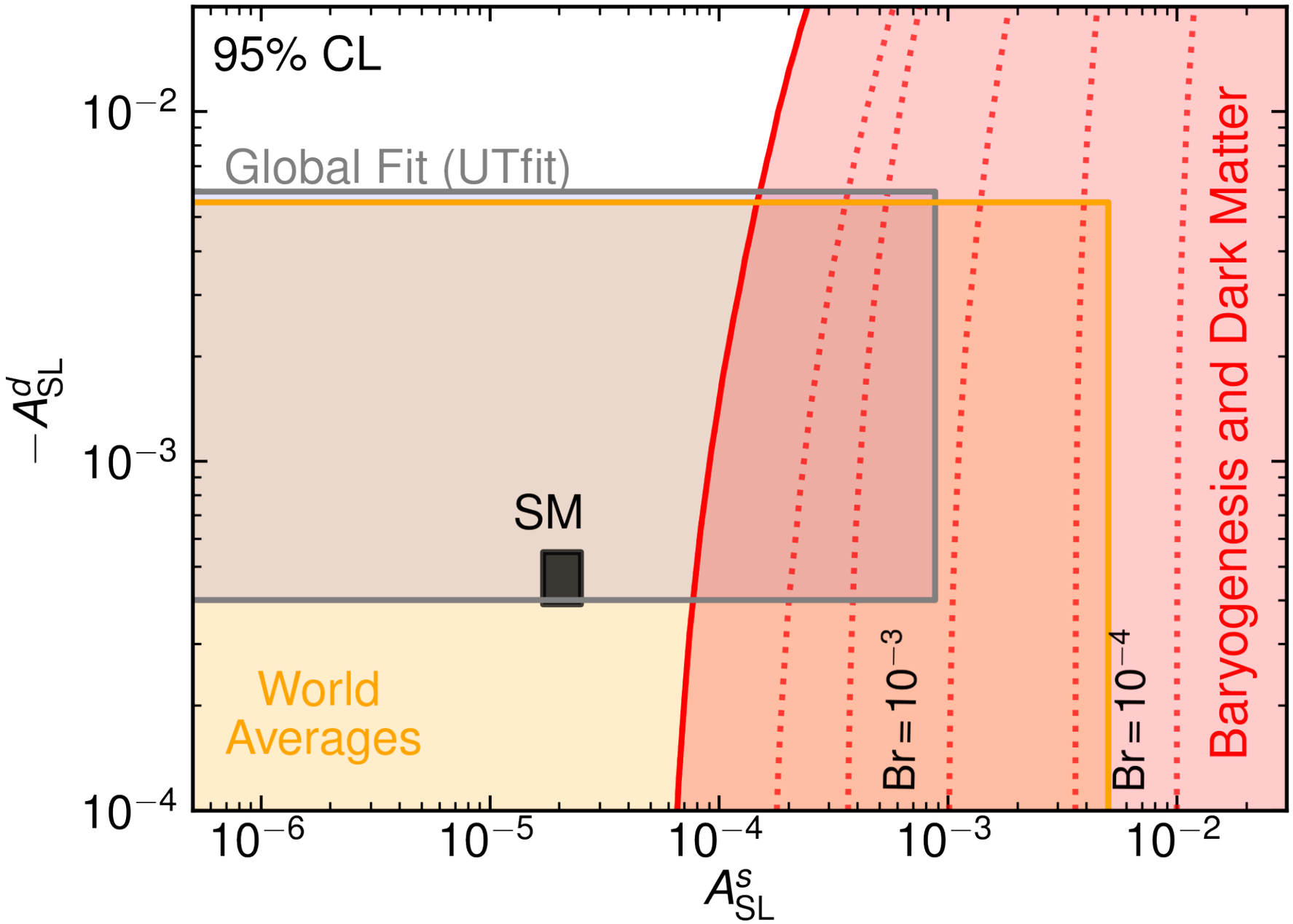


Parameter Space





Parameter Space



Viable parameter space after taking into account all relevant bounds

$$A_{\rm SL}^q > 10^{-4}$$

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**

Distinctive experimental signatures:

- **Neutral and charged B mesons decay into baryons and missing energy**

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

- **Positive leptonic asymmetry in B meson decays** $A_{\mathrm{SL}}^{q} > 10^{-4}$

As of today we know:

$$\mathrm{Br}(B \to \psi + \mathrm{Baryon} + \not{M}) \lesssim 6 \times 10^{-3}$$ **From ALEPH + ATLAS & CMS**

$$A_{\mathrm{SL}}^{q} \lesssim (2-3) \times 10^{-3}$$ **From LHCb, ATLAS, CMS, BaBar, Belle**

What we will learn soon:

Results on $B \to \psi \Lambda$ should appear soon from BaBar and Belle data sets

This workshop: CP Violation. Can current data tell us that $A_{\mathrm{SL}}^{q} < 10^{-4}$?

Questions & Comments

The B-Mesogenesis Team

Gonzalo Alonso

Gilly Elor

Ann Nelson

Great thanks to my collaborators and great thanks to YOU for participating!