Center for Particle Physics Siegen

TRR 257 - Particle Physics Phenomenology after the Higgs Discovery

Universität Siegen

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Implications of the B-Mesogenesis Model on the Lifetime and Mixing of B-mesons

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Ongoing collaboration with: Alexander Lenz, Maria Laura Piscopo, Aleksey Rusov, Zachary Wüthrich

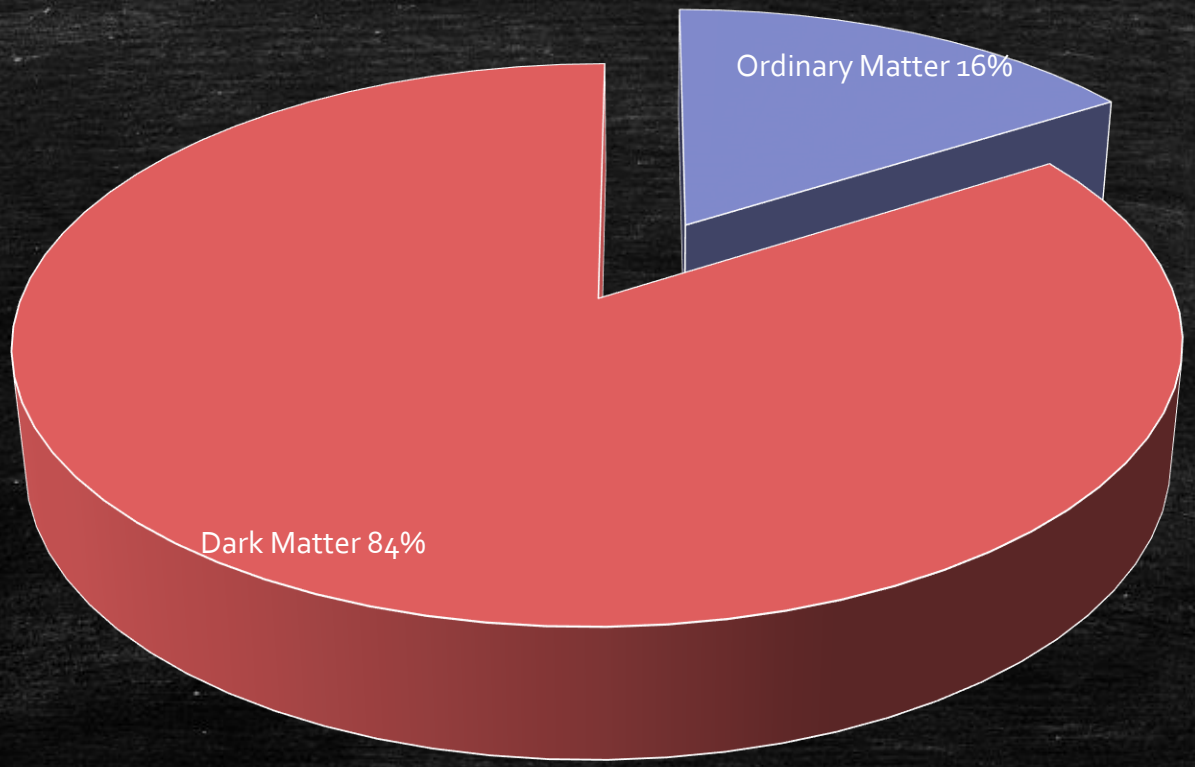
Part I:

Open Questions

1. Dark Matter

Total Mass of the Universe

"N. Aghanim et al. (Planck), arXiv:1807.06209."



2. Matter-antimatter Asymmetry in the Universe

- Baryon asymmetry measurement:

"N. Aghanim et al. (Planck), arXiv:1807.06209."

$$Y_B = \frac{n_B - n_{\bar{B}}}{s} = (8.718 \pm 0.004) \times 10^{-11}.$$

- What happened in the early Universe? **Baryogenesis!**
- Sakharov's Conditions for Baryogenesis:
  1. C and CP violation
  2. Departure from Thermal Equilibrium
  3. Baryon Number Violation

Part II:

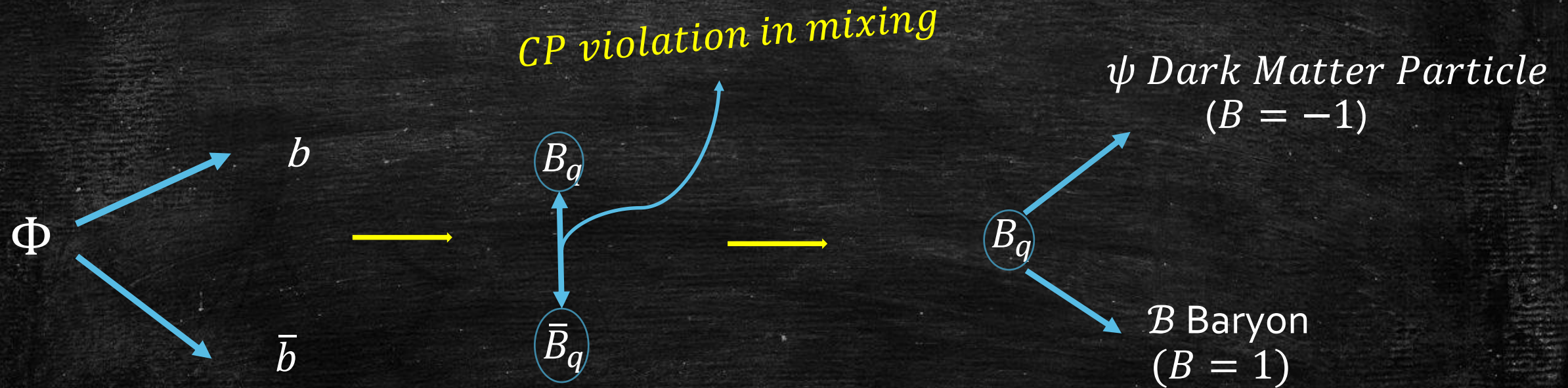
B-Mesogenesis Model

Can matter-antimatter asymmetry and dark matter be addressed in one model?

B-Mesogenesis

"G. Elor, M. Escudero, A. E. Nelson, arXiv:1810.00880."

"G. Alonso-Álvarez, G. Elor and M. Escudero, arXiv:2101.02706."

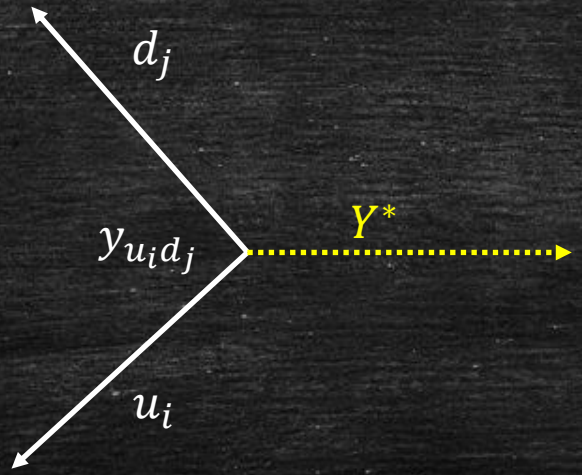


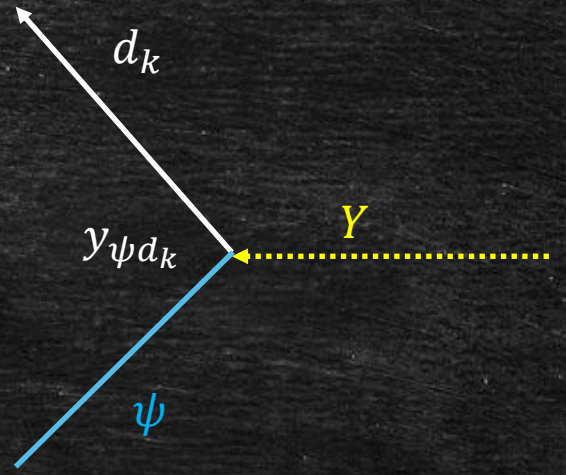
$M_\Phi \geq 11$ GeV.

$T_R \sim 15$ MeV $< T_{QCD} \sim 500$ MeV.

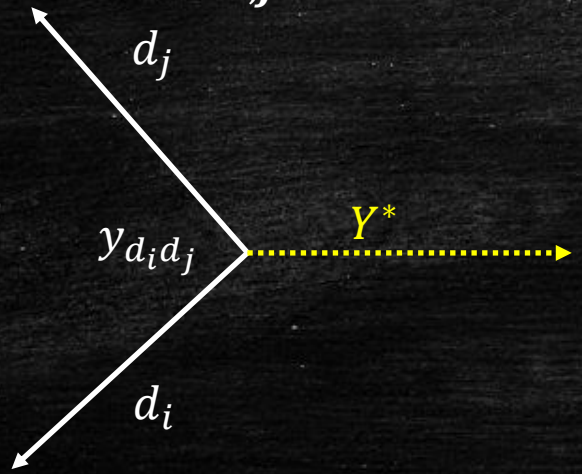
Explicit Model:

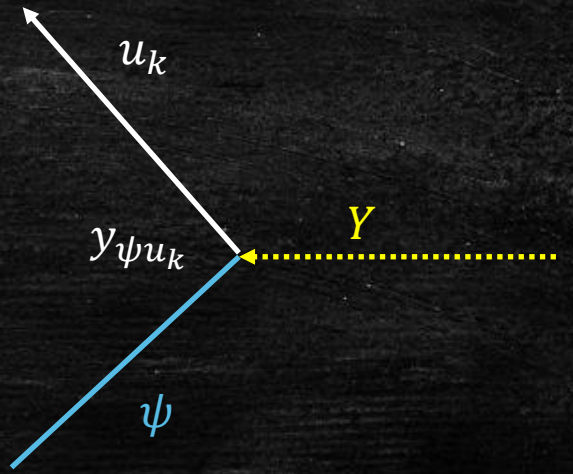
$$\mathcal{L}_{-1/3} = -\sum_{i,j} y_{u_i d_j} Y^* \bar{u}_{iR} d^c_{jR} - \sum_{k} y_{\psi d_k} Y \bar{\psi} d^c_{kR} + h.c.$$





$$\mathcal{L}_{2/3} = -\sum_{i,j} y_{d_i d_j} Y^* \bar{d}_{iR} d^c_{jR} - \sum_{k} y_{\psi u_k} Y \bar{\psi} u^c_{kR} + h.c.$$





$$\mathcal{L}_{-1/3} = -\sum_{i,j} y_{u_i d_j} Y^* \bar{u}_{iR} d^c_{jR} - \sum_k y_{\psi d_k} Y \bar{\psi} d^c_{kR} + h.c.$$

$u_i = u, c,$
$d_j = b, d, s.$

Integrating out the heavy scalar *Y*

$$\mathcal{H}_{-1/3} = -\frac{y_{ub} y_{\psi d}}{M_Y^2} i\epsilon_{\alpha\beta\gamma} (\bar{\psi} d_R^{c\alpha})(\bar{u}_R^{\beta} b_R^{c\gamma}) - \frac{y^*_{ub} y^*_{\psi d}}{M_Y^2} i\epsilon_{\alpha\beta\gamma} \left(\bar{b}_R^{c\alpha} u_R^{\beta}\right)\left(\bar{d}_R^{c\gamma} \psi\right) + \{d \leftrightarrow b\}.$$

⟶ **New effective operator for the *b*-quark**

Implications to the B-Meson Observables

- What is the contribution to the ratio $\frac{\tau(B^+)}{\tau(B^0)}$?

- What is the contribution to the mixing observables;
$M_{12}, \Gamma_{12}, a_{sl} = Im(\frac{\Gamma_{12}}{M_{12}})$?

Part III:

Heavy Quark Expansion

How to compute inclusive decay of *B* mesons.

HQE: Heavy Quark Expansion

Optical Theorem for decay width:

$$\Gamma(B) = \frac{1}{2m_B}\mathrm{Im}\langle B|\mathcal{T}|B\rangle,$$

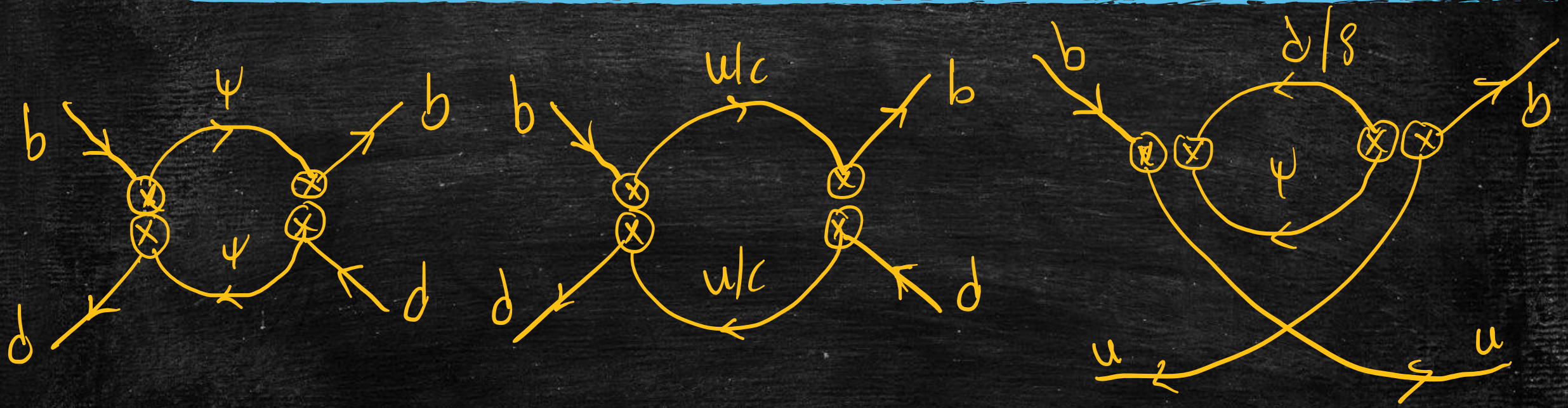
$$\mathcal{T} = i\int d^4x\ \mathrm{T}\{\mathcal{H}_{eff}(x), \mathcal{H}_{eff}(0)\}.$$

HQE:

$$\Gamma(B) = \Gamma_3 + \Gamma_5\frac{\langle \mathcal{O}_5\rangle}{m_b^2} + \cdots + 16\pi^2\left[\tilde{\Gamma}_6\frac{\langle \tilde{\mathcal{O}}_6\rangle}{m_b^3} + \tilde{\Gamma}_7\frac{\langle \tilde{\mathcal{O}}_7\rangle}{m_b^4} + \cdots\right].$$

$$\frac{\tau(B^+)}{\tau(B^0)} = 1 + 16\pi^2\left[\frac{(\tilde{\Gamma}_6\langle\tilde{\mathcal{O}}_6\rangle)_{B^0} - (\tilde{\Gamma}_6\langle\tilde{\mathcal{O}}_6\rangle)_{B^+}}{m_b^3} + \cdots\right] \times \tau_{B+}^{Exp}.$$

Lifetime Diagrams



$\mathcal{L}_{-1/3}$: 13 Diagrams for B_d, 16 Diagrams for B^+

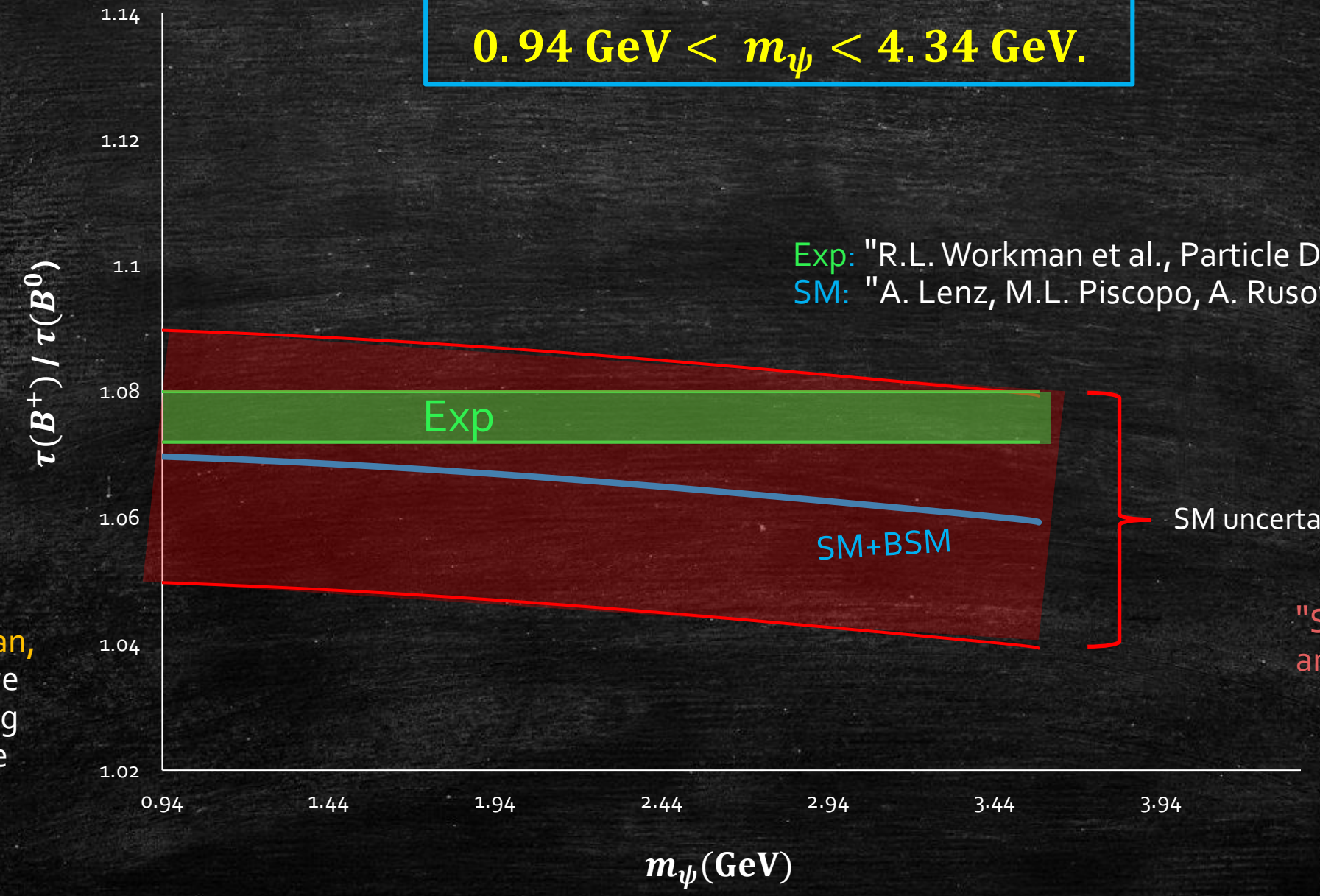
$\mathcal{L}_{2/3}$: 6 Diagrams for B_d, 2 Diagrams for B^+

Part IV:

(Preliminary) Results

$\mathcal{L}_{2/3}$ Total Contribution to the ratio $\tau(B^+) / \tau(B^0)$

$$0.94\ \text{GeV} < m_\psi < 4.34\ \text{GeV}.$$



Exp: "R.L. Workman et al., Particle Data Group, 2022."
SM: "A. Lenz, M.L. Piscopo, A. Rusov, arXiv: 2208.02643."

"See Mathew, and Zachary's talks"

Following [A.Khodjamirian, M.Wald '22], we set the coupling constant to the max value

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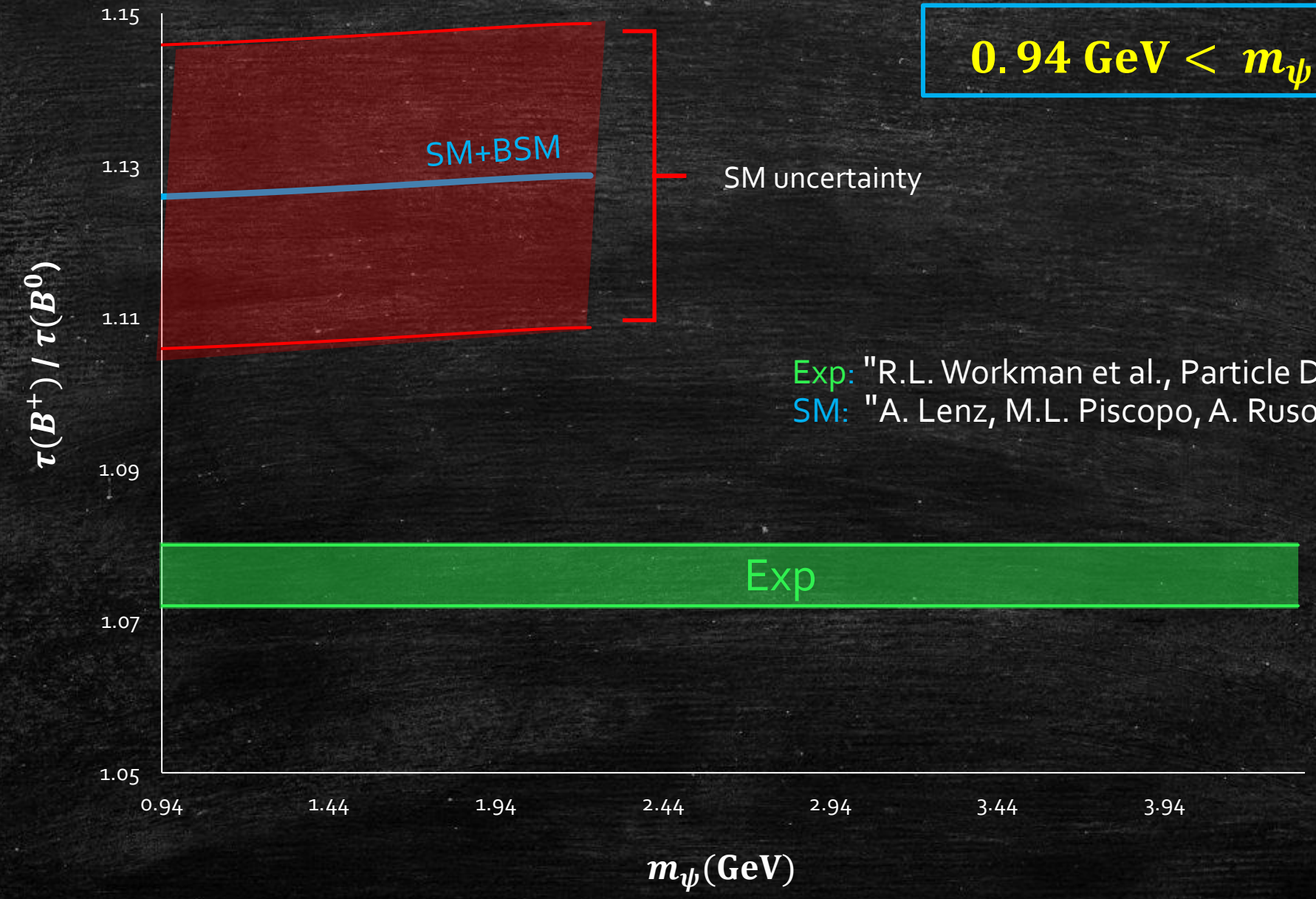

Exp: "R.L. Workman et al., Particle Data Group, 2022."
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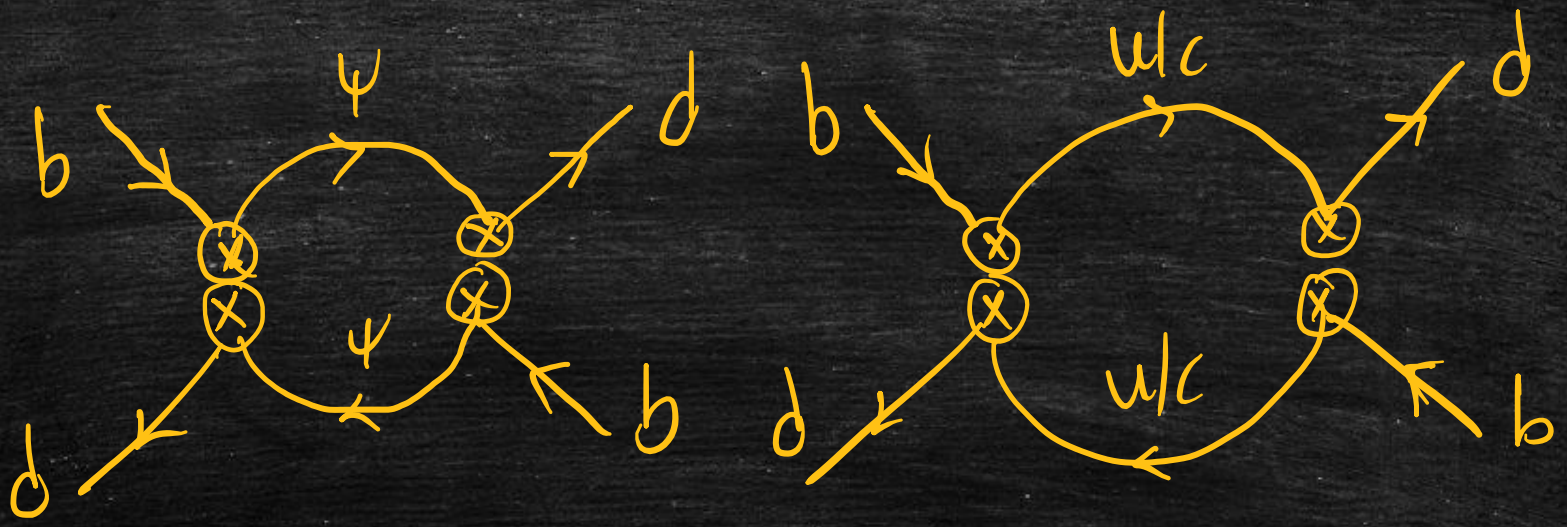
Mixing Diagrams



$\mathcal{L}_{-1/3}$: 9 Diagrams for B_d

$\mathcal{L}_{2/3}$: 2 Diagrams for B_d

Part IV:

Summary and Outlook

Summary and Further Questions

- The *B*-Mesogenesis links the matter-antimatter asymmetry to the dark matter
- The model introduces new decay channels to the *b*-quark
- We have calculated the contribution to the ratio $\tau(B^+)$ / $\tau(B^0)$. In $\mathcal{L}_{-1/3}$, the contribution is significant! For $\mathcal{L}_{2/3}$, due to the large SM uncertainty, there are no significant constraints on m_ψ beyond those imposed by the model
- Can we find a region in the parameter space which can accommodate these lifetime contributions?
- Can the new proposed decay introduce enough CP violation which can explain the asymmetry Y_B?
- What is the contribution to B_s?
- We can investigate the contribution of higher-order terms, e.g. the **Darwin term**

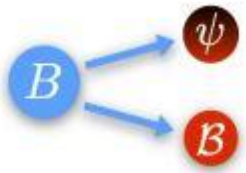
Collider Signals of Baryogenesis and Dark Matter from B Mesons (*B-Mesogenesis*)

Direct Signals

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

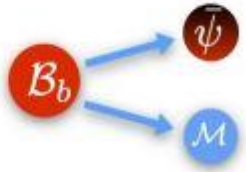
Belle II
LHCb
ATLAS
CMS

New B meson decay:



BaBar
Belle
Belle II
LHCb

New b-Baryon decay:



LHCb
ATLAS??
CMS??

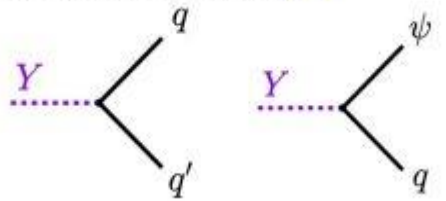
Indirect Signals

B^0 meson CPV and oscillation observables:

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

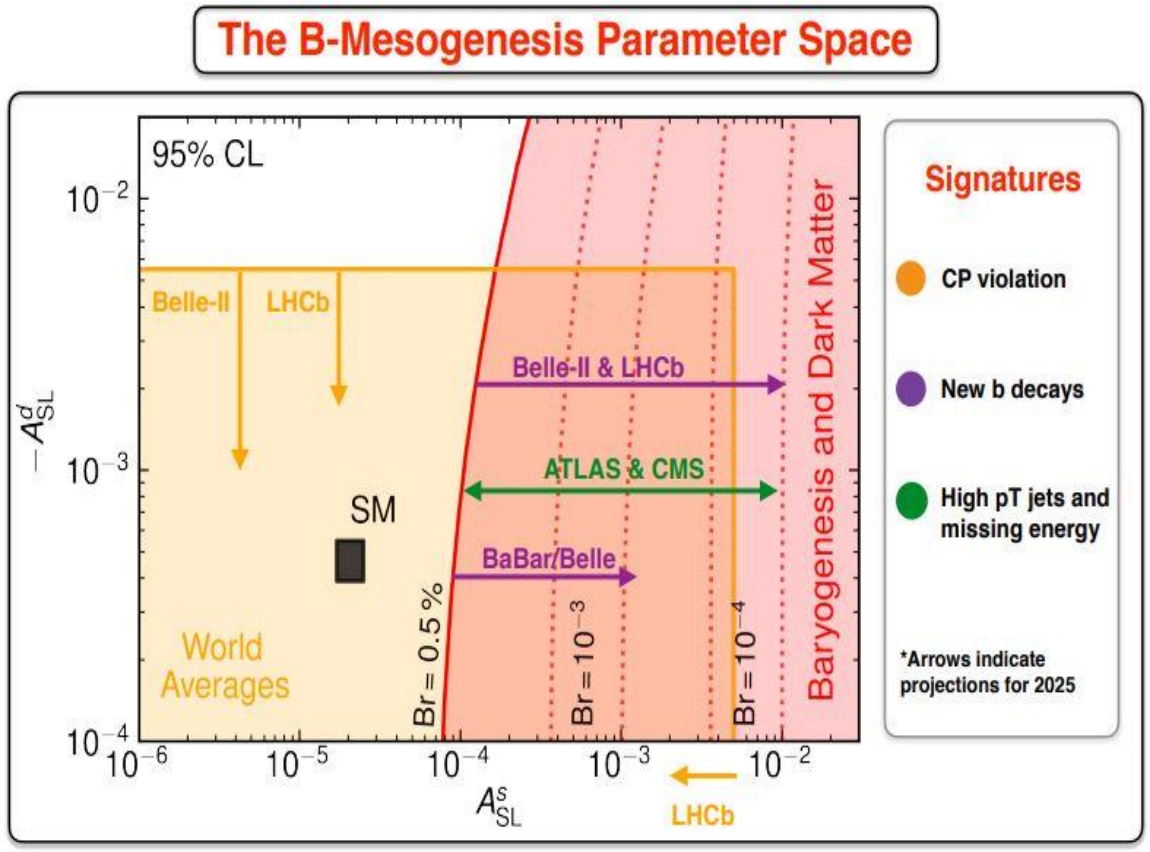
LHCb
Belle II
ATLAS
CMS

New TeV-scale color-triplet scalar, *Y*



ATLAS
CMS

$$Y_{\mathcal{B}} \simeq 8.7 \times 10^{-11} \, \frac{\mathrm{Br}(B \to \psi \, \mathcal{B} \, \mathcal{M})}{10^{-3}} \sum_q \alpha_q \, \frac{A_{\mathrm{SL}}^q}{10^{-3}} \, ,$$



Operator and Decay	Initial State	Final State	ΔM (MeV)
$\mathcal{O}_{ud} = \psi\, b\, u\, d$ $\bar{b} \to \psi\, u\, d$	B_d	$\psi + n\,(udd)$	4340.1
	B_s	$\psi + \Lambda\,(uds)$	4251.2
	B^+	$\psi + p\,(duu)$	4341.0
	Λ_b	$\bar{\psi} + \pi^0$	5484.5
$\mathcal{O}_{us} = \psi\, b\, u\, s$ $\bar{b} \to \psi\, u\, s$	B_d	$\psi + \Lambda\,(usd)$	4164.0
	B_s	$\psi + \Xi^0\,(uss)$	4025.0
	B^+	$\psi + \Sigma^+\,(uus)$	4090.0
	Λ_b	$\bar{\psi} + K^0$	5121.9
$\mathcal{O}_{cd} = \psi\, b\, c\, d$ $\bar{b} \to \psi\, c\, d$	B_d	$\psi + \Lambda_c + \pi^-\,(cdd)$	2853.6
	B_s	$\psi + \Xi_c^0\,(cds)$	2895.0
	B^+	$\psi + \Lambda_c^+\,(dcu)$	2992.9
	Λ_b	$\bar{\psi} + \overline{D}^0$	3754.7
$\mathcal{O}_{cs} = \psi\, b\, c\, s$ $\bar{b} \to \psi\, c\, s$	B_d	$\psi + \Xi_c^0\,(csd)$	2807.8
	B_s	$\psi + \Omega_c\,(css)$	2671.7
	B^+	$\psi + \Xi_c^+\,(csu)$	2810.4
	Λ_b	$\bar{\psi} + D^- + K^+$	3256.2