How large could CP violation in *B* meson mixing be? Implications for baryogenesis and upcoming searches

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In collaboration with
Miguel Escudero & *Miguel Nebot*
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Outline

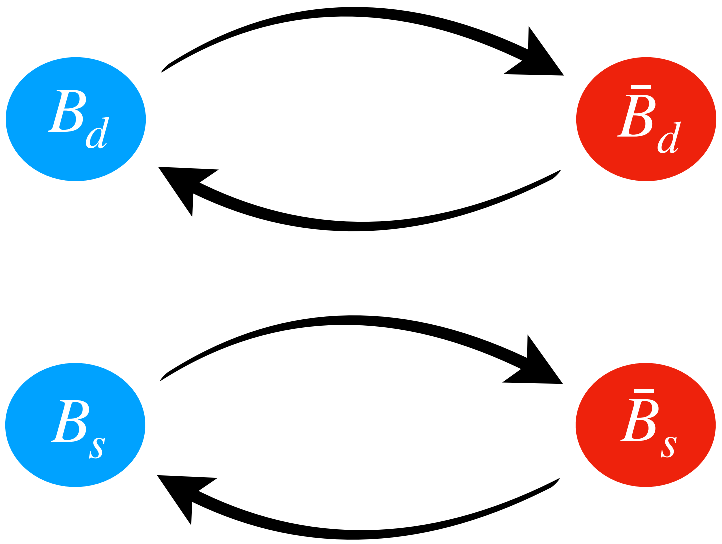
- Mixing parameters and CP asymmetries
- SM prediction *vs* Experiment
- BSM scenarios
    - Heavy New Physics in mass mixing M_{12}^q
    - Deviations of 3x3 CKM unitarity
    - New Physics in decay mixing Γ_{12}^q
- Overall picture
- Conclusions

Mixing parameters and CP asymmetries

Neutral B meson systems

- The time evolution of a superposition $|\psi(t)\rangle = a(t)\,|B_q\rangle + b(t)\,|\bar{B}_q\rangle$ is controlled by the following effective Hamiltonian:

Neutral B meson oscillations



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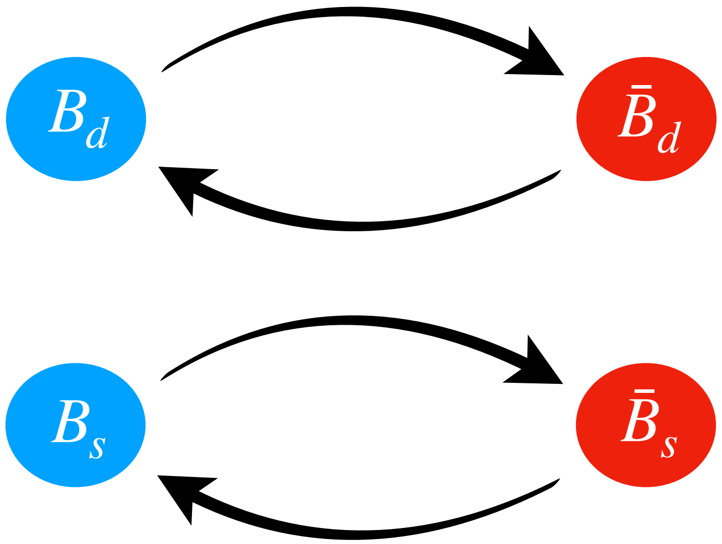

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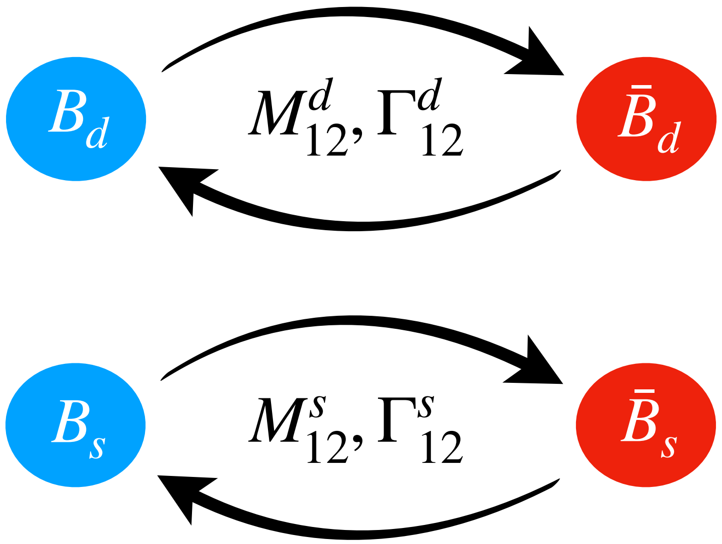

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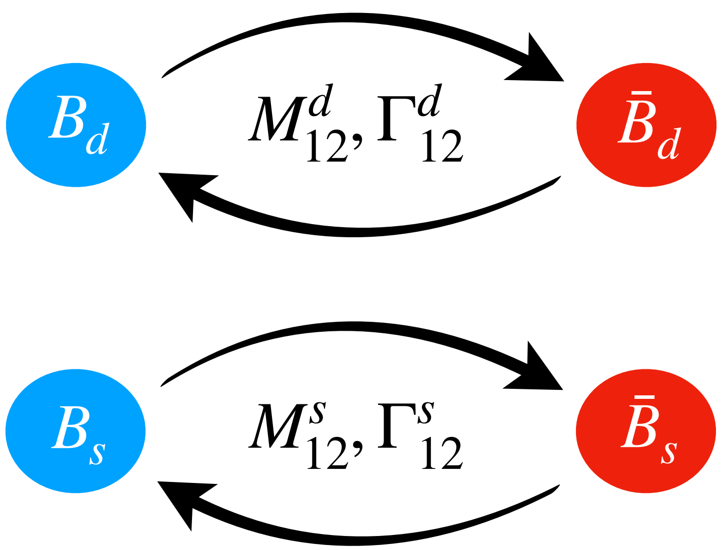

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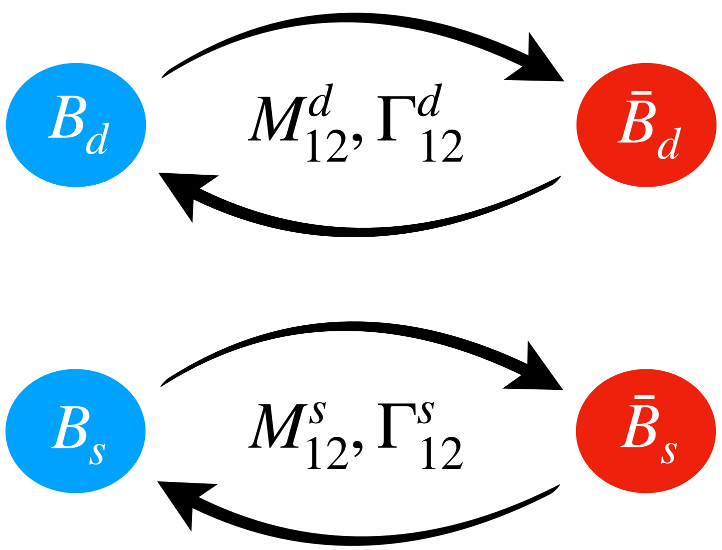

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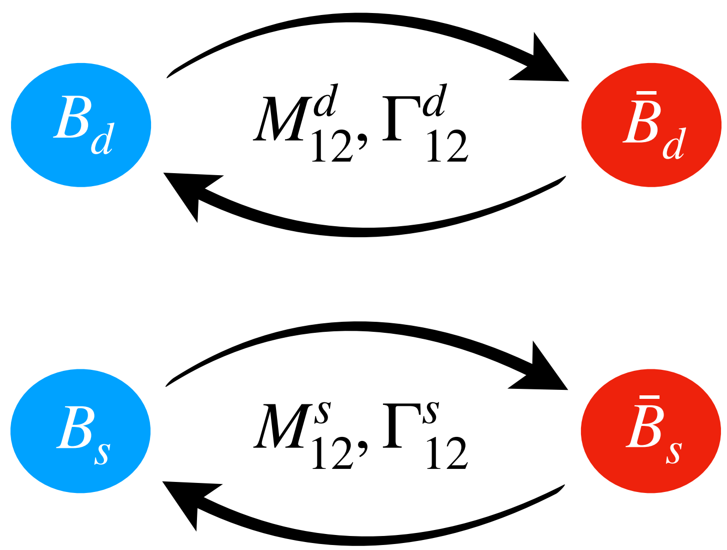

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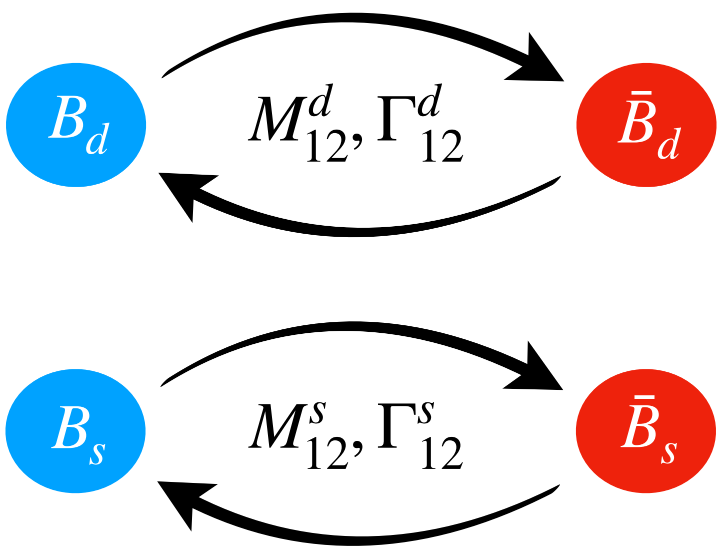

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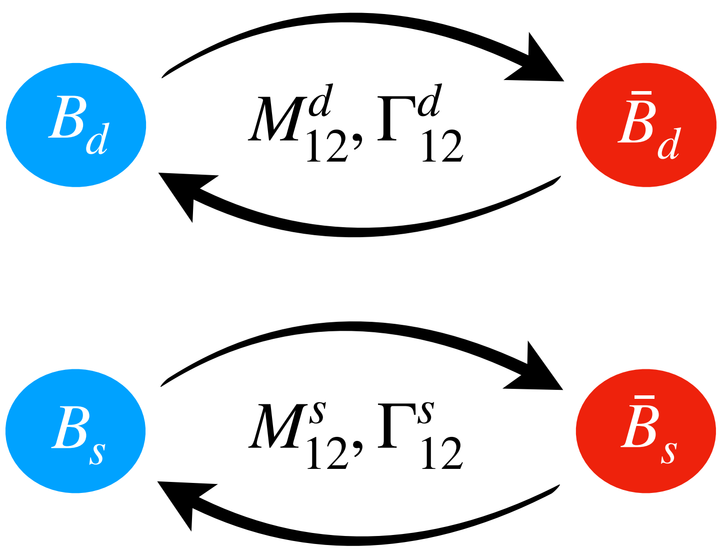

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Semileptonic asymmetries: $A^q_{\mathrm{SL}} \equiv \dfrac{\Gamma(\bar{B}_q(t) \to f) - \Gamma(B_q(t) \to \bar{f})}{\Gamma(\bar{B}_q(t) \to f) + \Gamma(B_q(t) \to \bar{f})}$

$$A^q_{\mathrm{SL}} = \mathrm{Im}\left(\frac{\Gamma^q_{12}}{M^q_{12}}\right)$$

SM prediction *vs* Experiment

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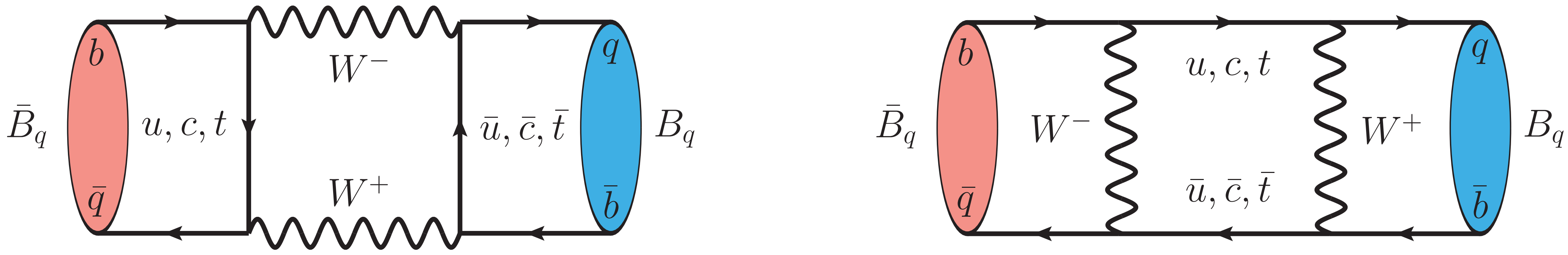

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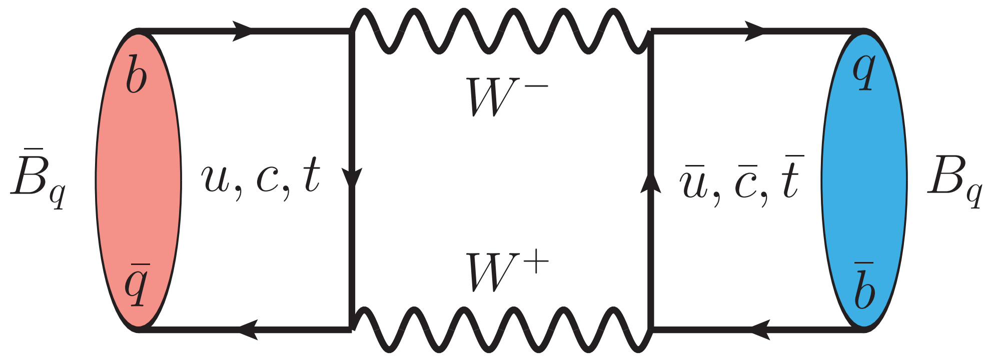
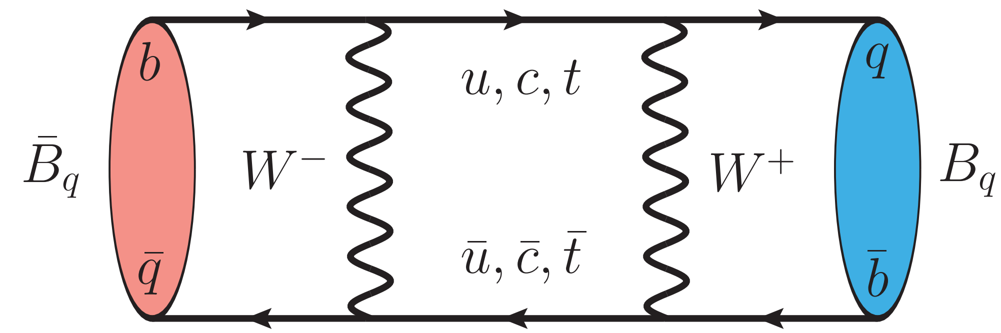


M^q_{12} : internal *off-shell* particles (top dominated)



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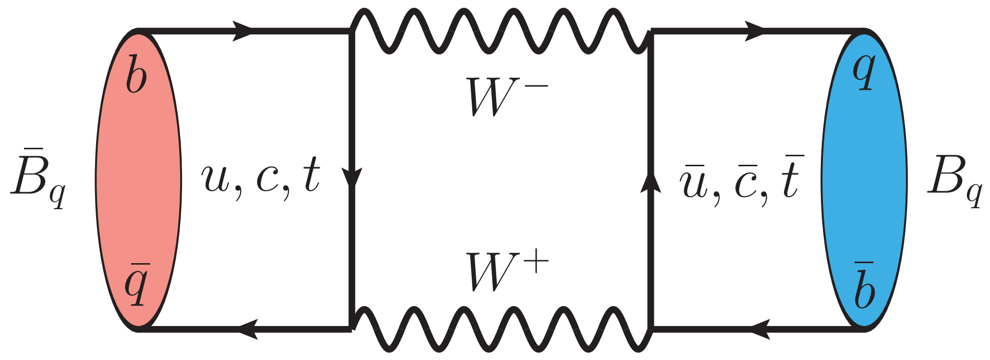

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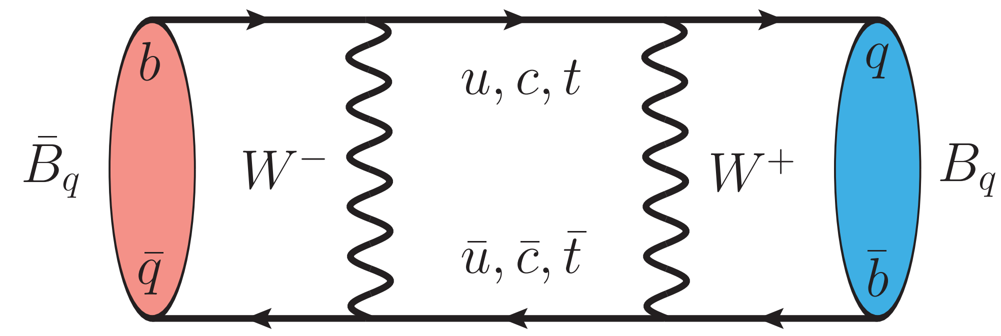

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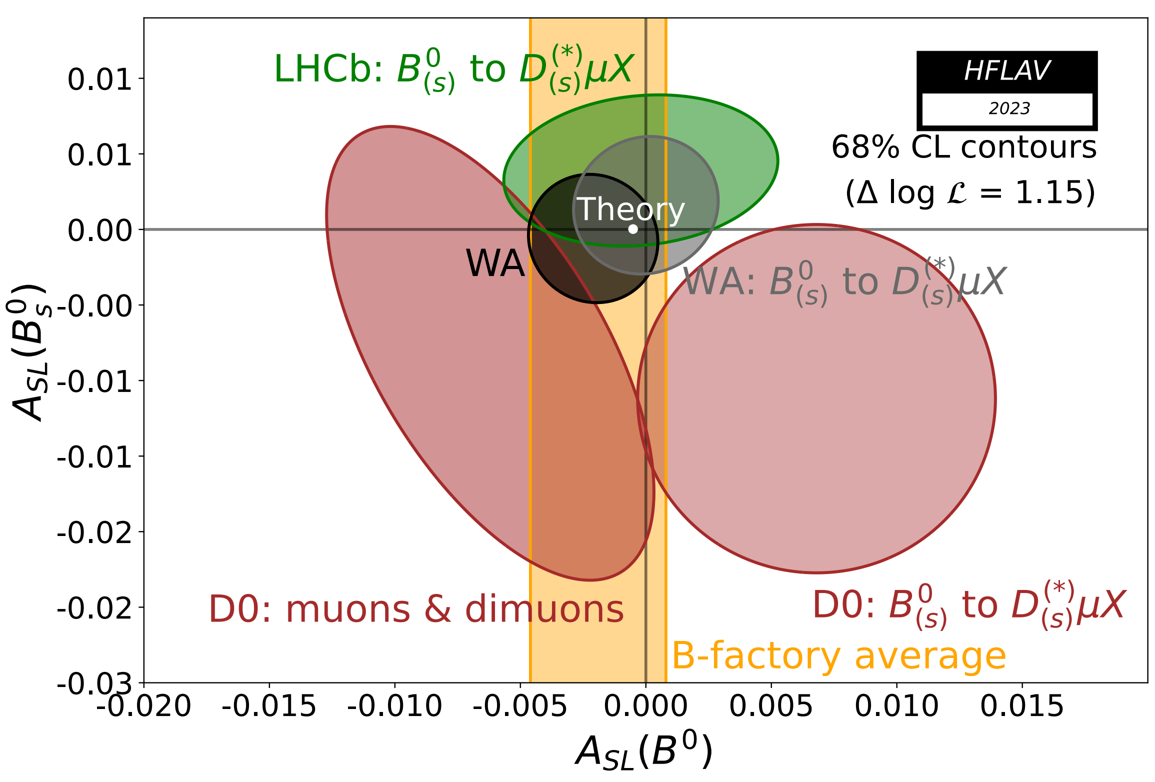

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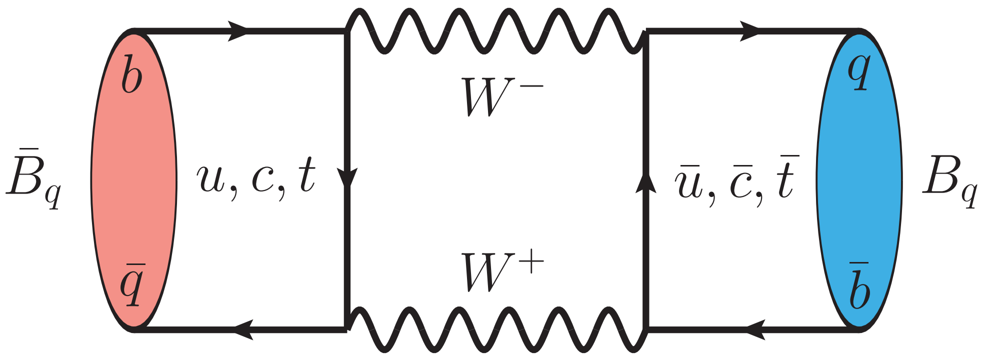

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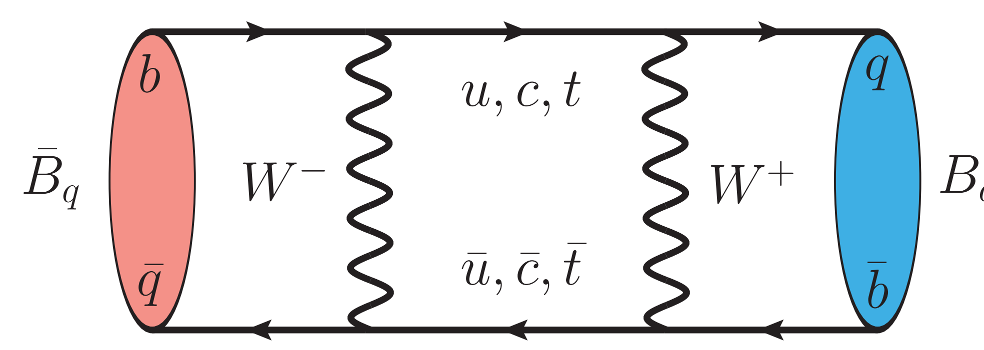

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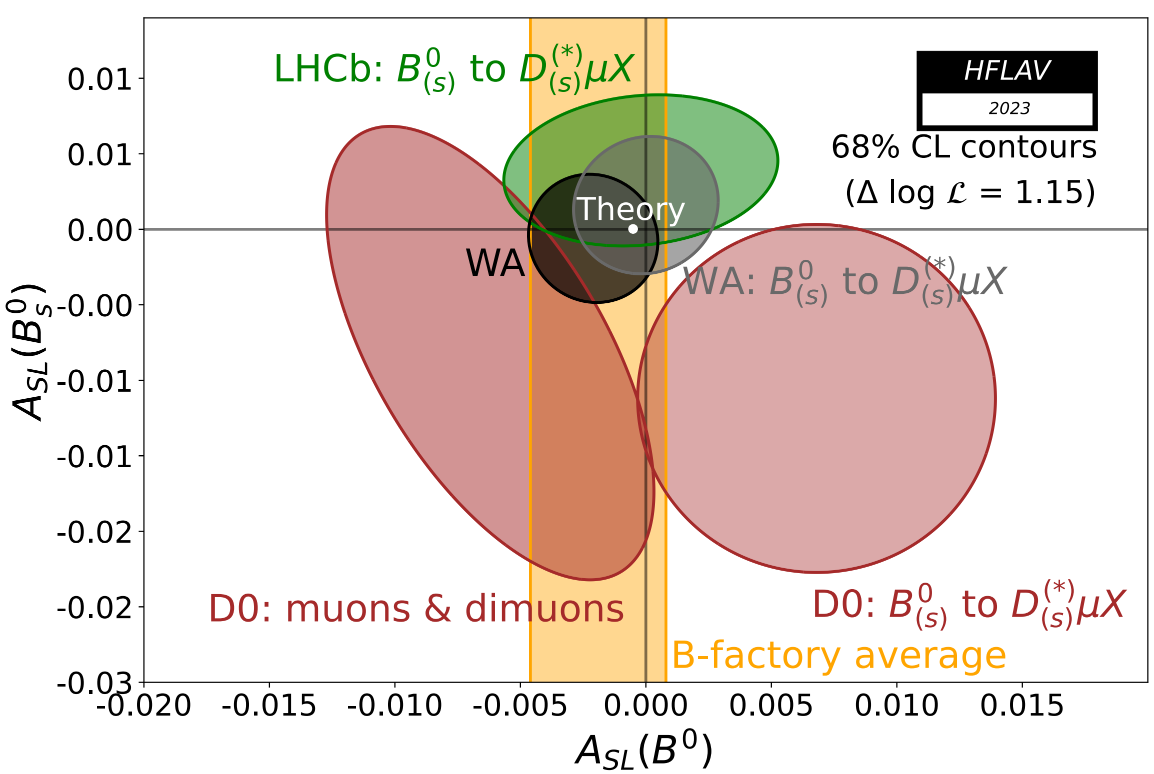

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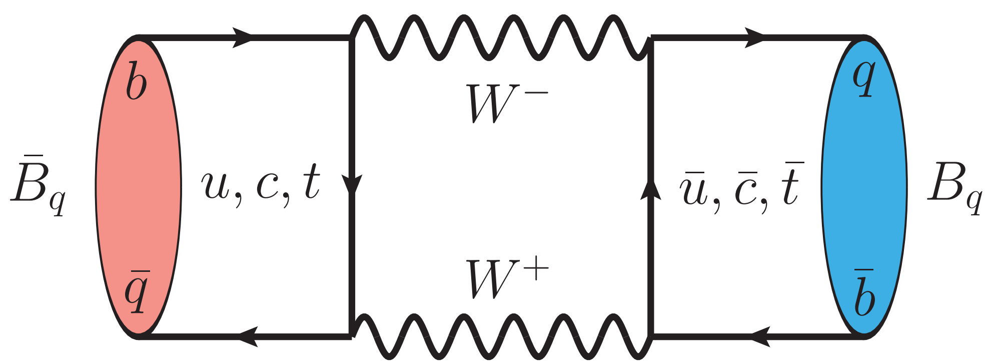

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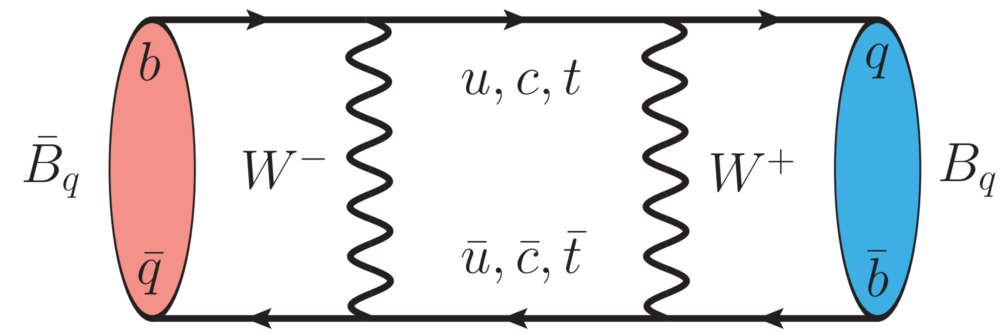

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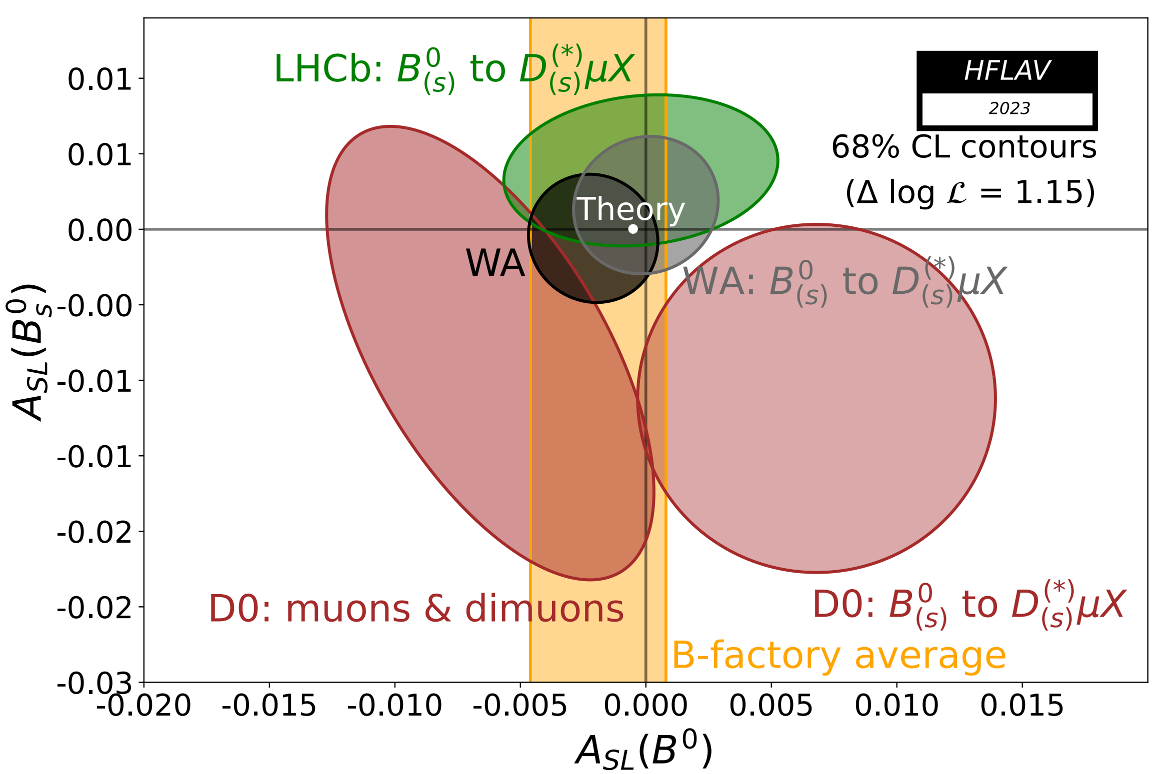

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x130

There is ample room for New Physics!

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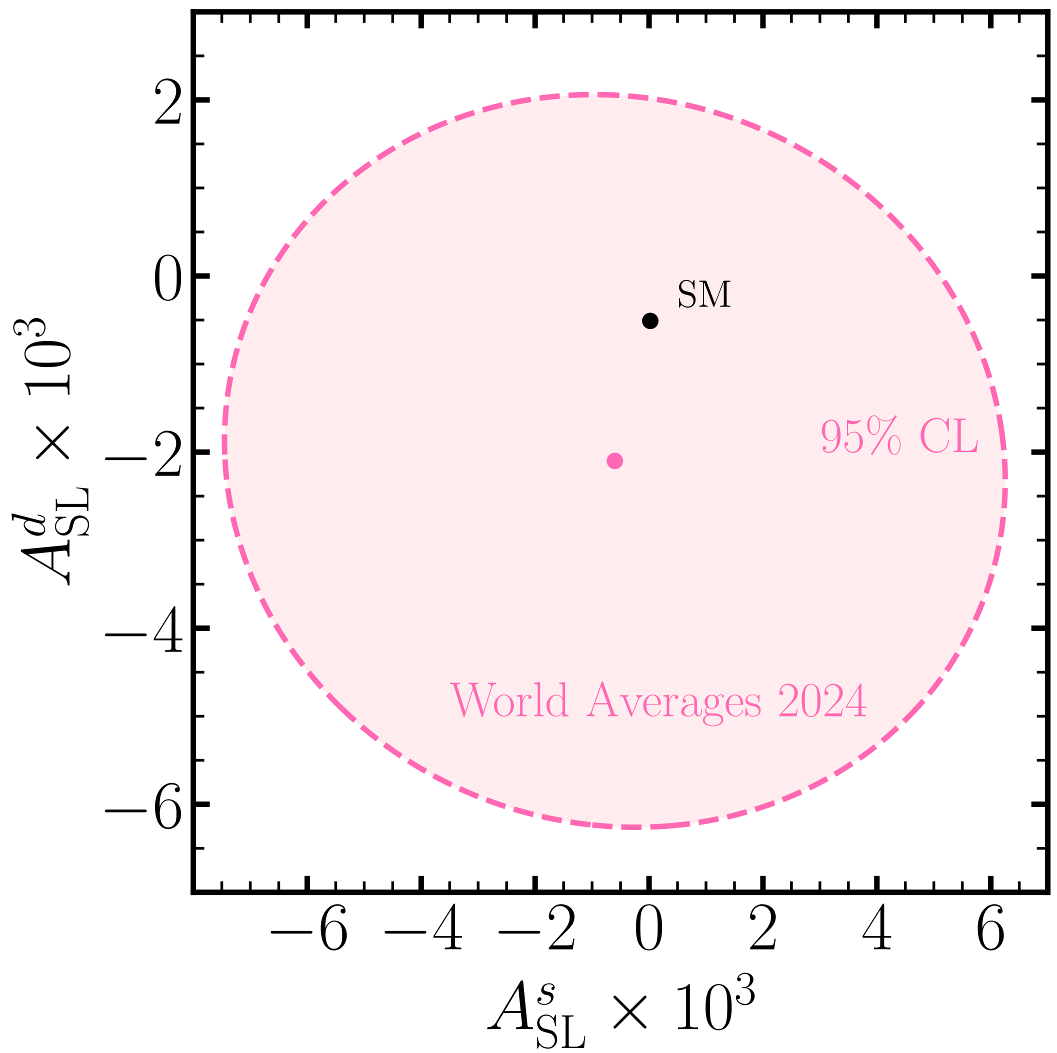

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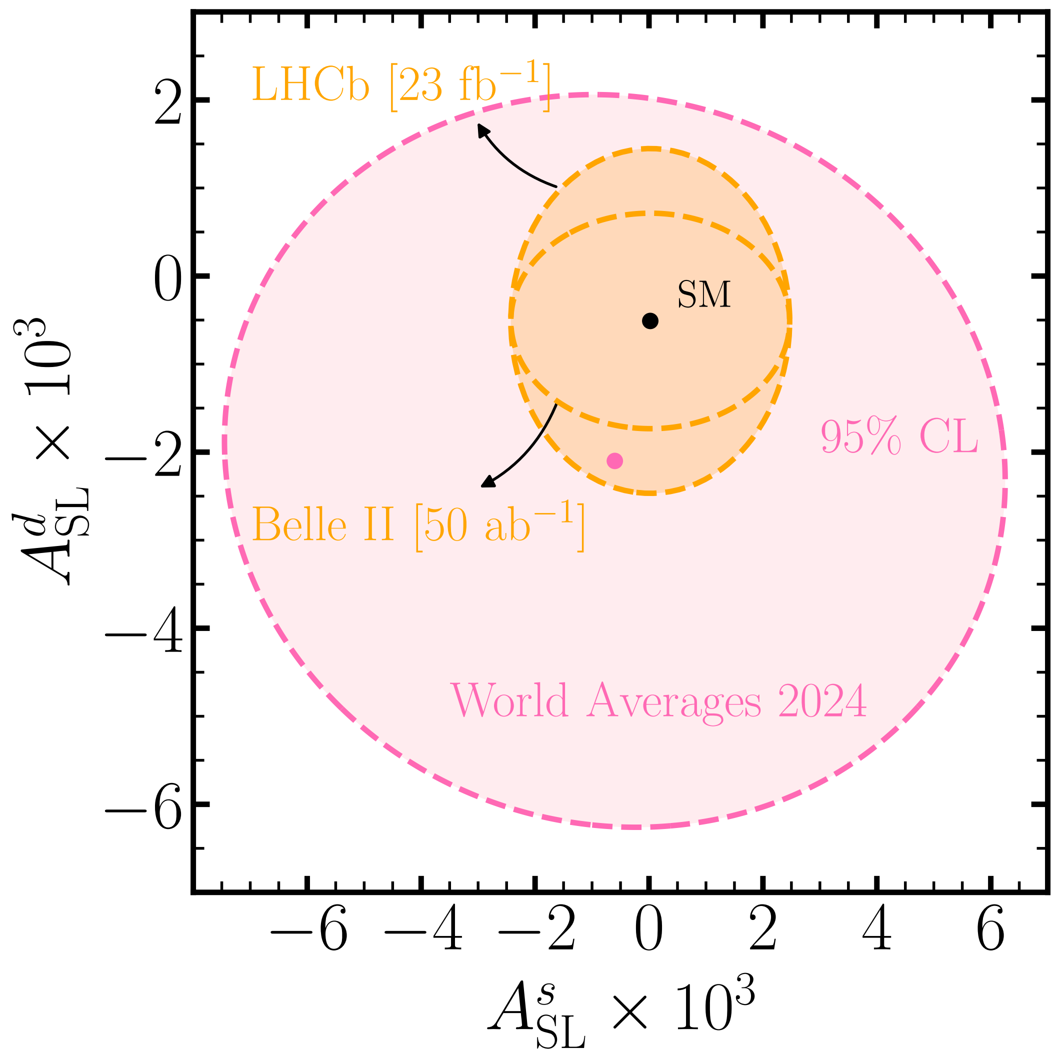

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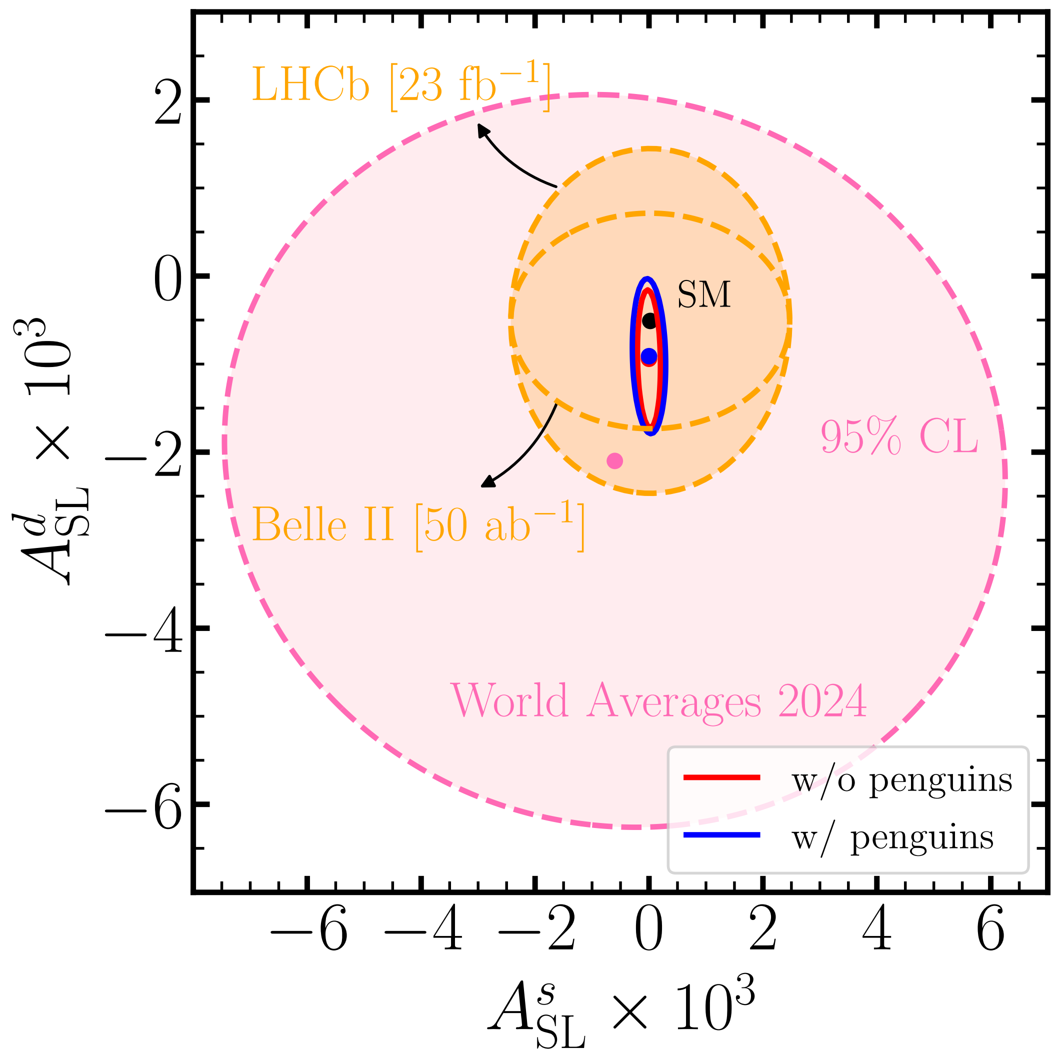

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$$|\Delta_d| = 0.98^{+0.10}_{-0.07}$$
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$$|\Delta_s| = 1.00^{+0.06}_{-0.04}$$
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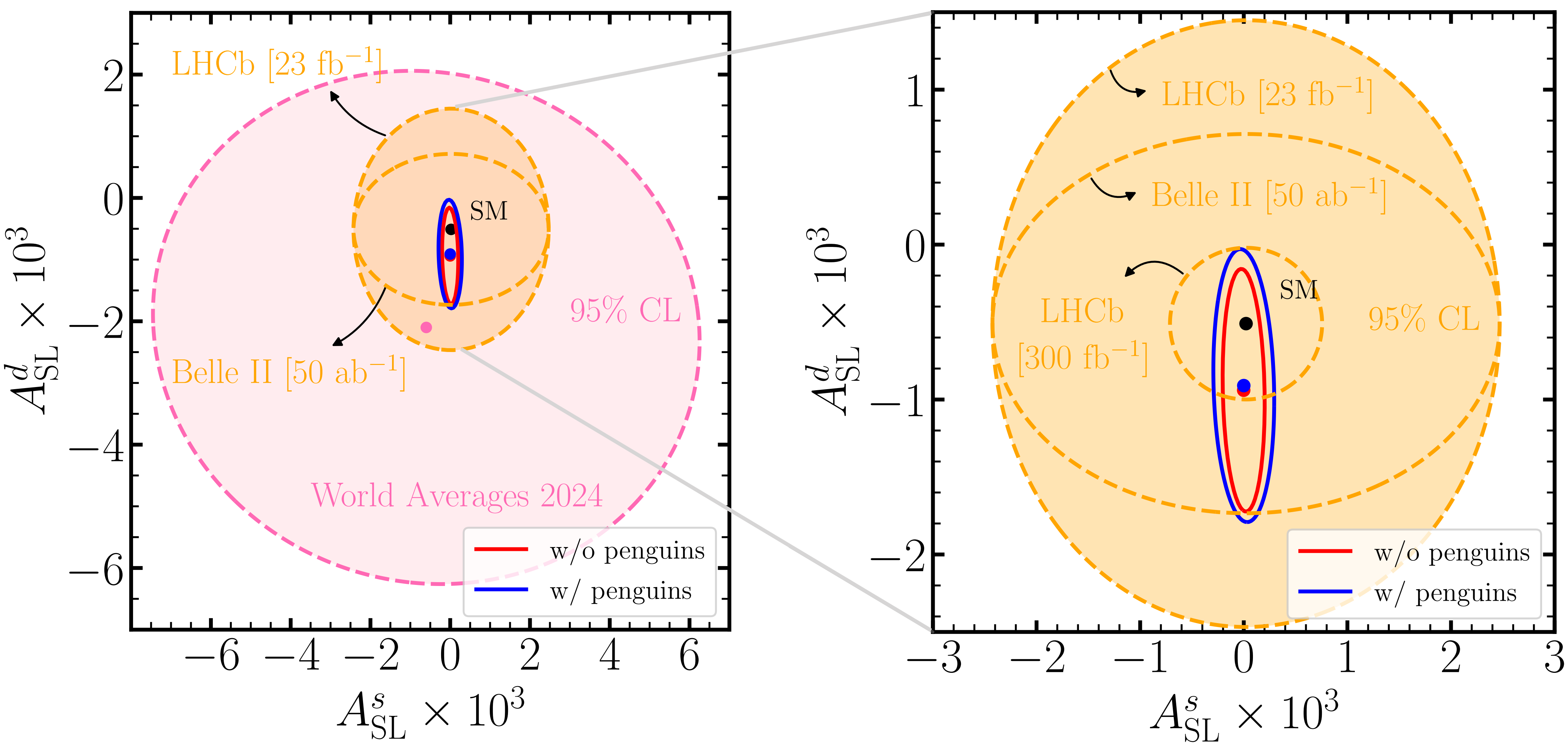

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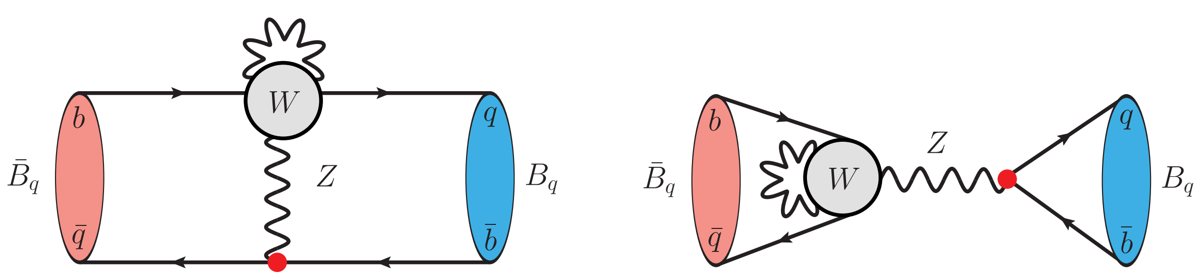
Z-FCNC diagrams arising in DVLQ models



BSM scenarios

Deviations of 3x3 CKM unitarity

- Why is it interesting to consider deviations of 3x3 CKM unitarity?

In the SM…

$$\arg M_{12}^q \sim \arg \Gamma_{12}^q \longrightarrow \mathrm{Im}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right) \sim 0$$

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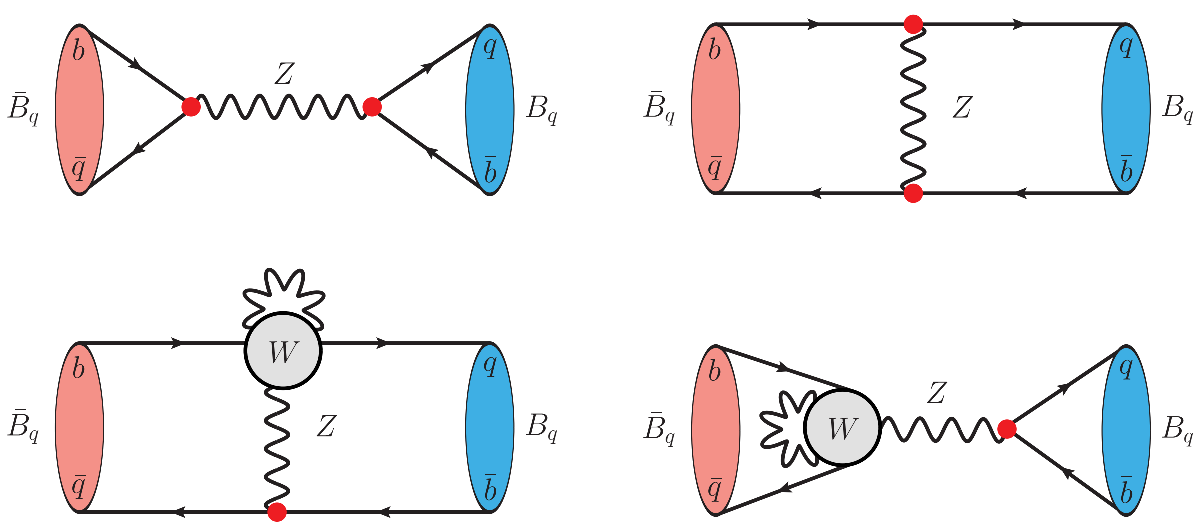

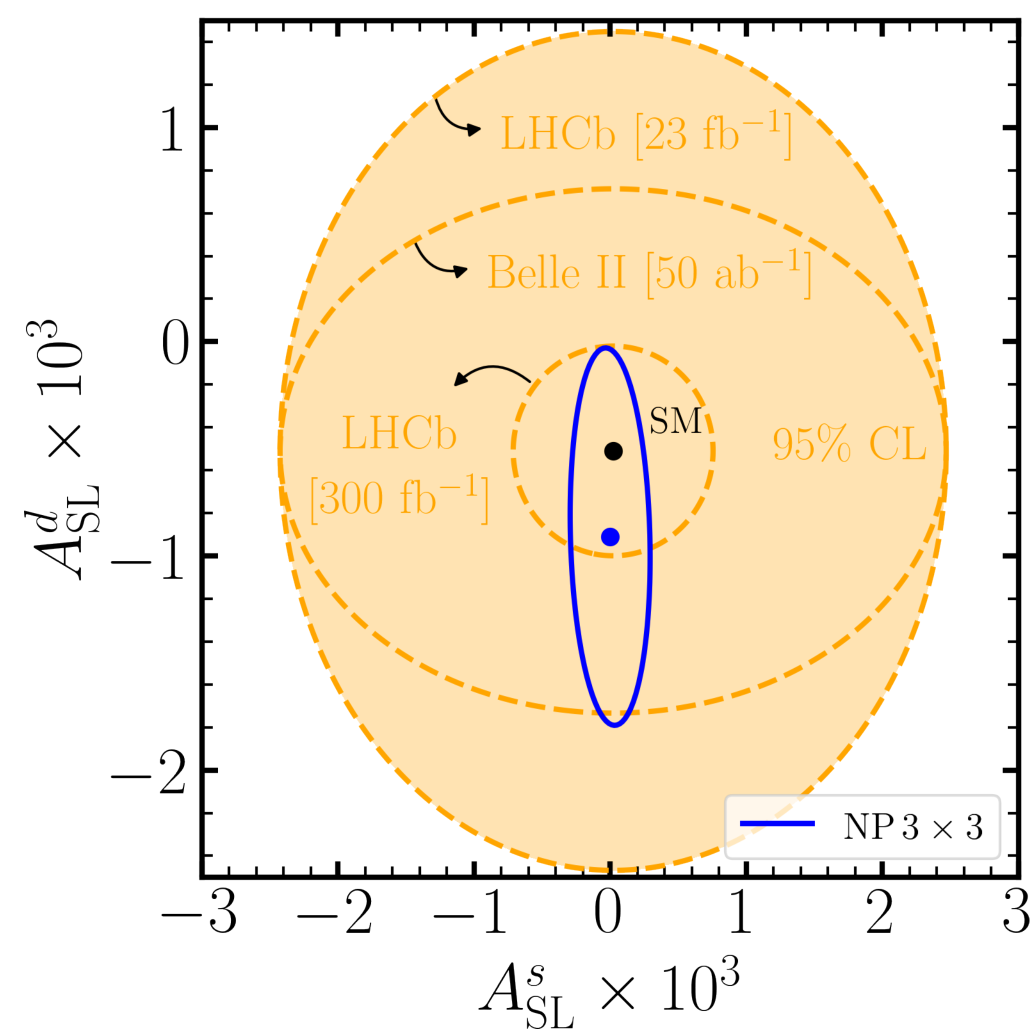

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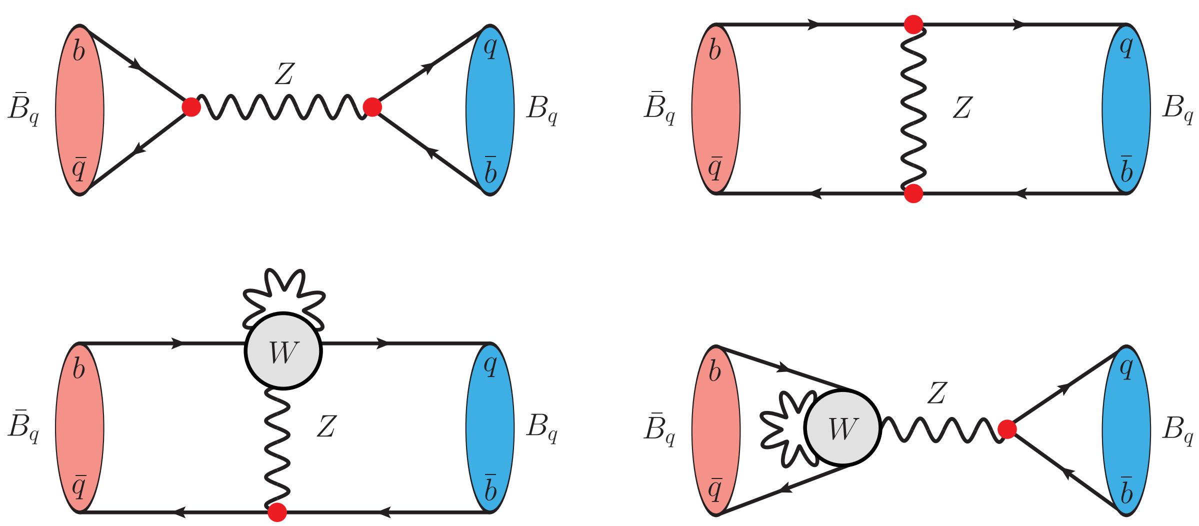
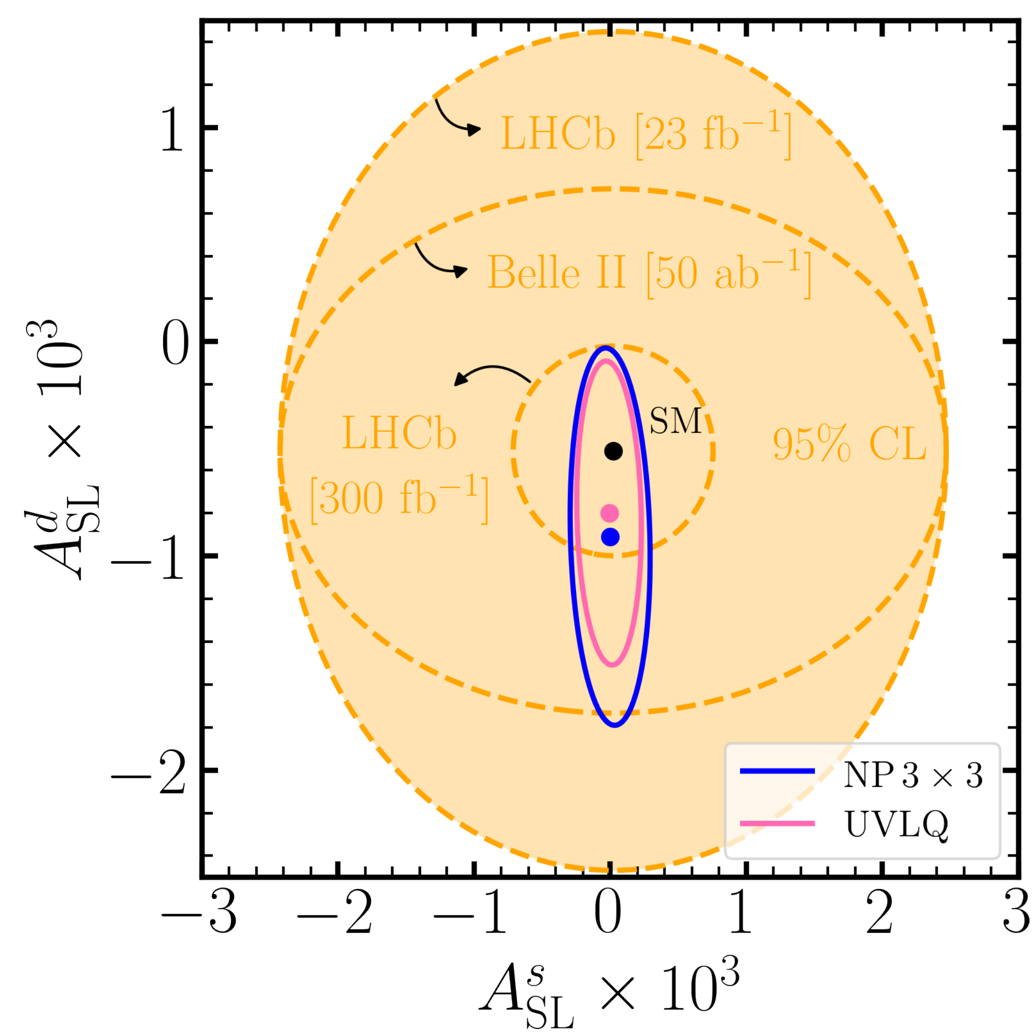


$m_T > 1.6\,\mathrm{TeV}$



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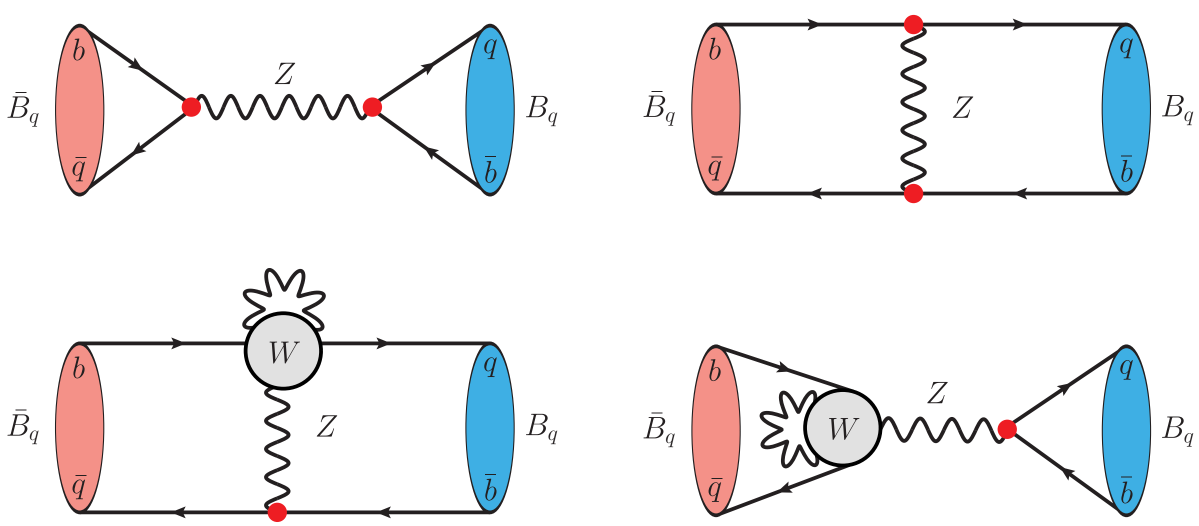
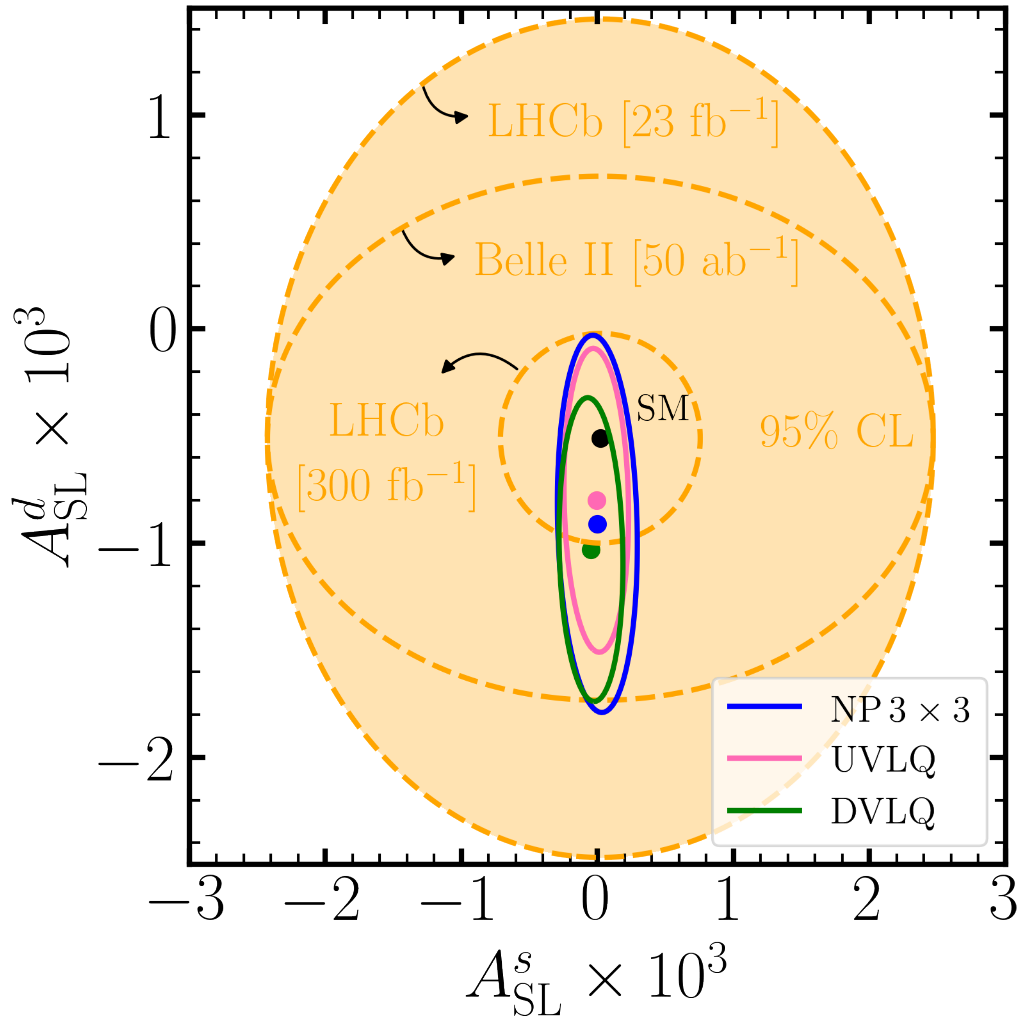


$\lvert\lambda_{bd}^T\rvert \sim 4 \times 10^{-4}$	$\lvert(D_L)_{db}\rvert \sim 2 \times 10^{-4}$
$\lvert\lambda_{bs}^T\rvert \sim 8 \times 10^{-4}$	$\lvert(D_L)_{sb}\rvert \sim 5 \times 10^{-4}$

$m_T > 1.6\,\mathrm{TeV}$



BSM scenarios

New Physics in decay mixing Γ_{12}^q

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New Physics in decay mixing Γ_{12}^q

I) Channels that are common to both B_q and $\bar{B}_q$ that can still accommodate new physics effects through $\Delta B = 1$ operators (see, e.g., 1912.07621 and 2307.07013 for model-independent bounds on these operators): $A_{\rm SL}^q \sim \mathcal{O}(10^{-3})$, but…

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Caveat

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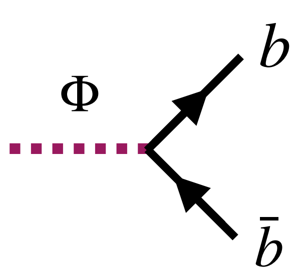
Out of equilibrium late time decay

$m_\Phi \in [10, 100]$ GeV



$4\,\text{MeV} \lesssim T \lesssim 100\,\text{MeV}$

BBN **QCD**

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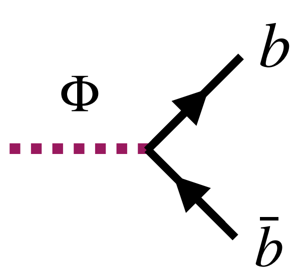

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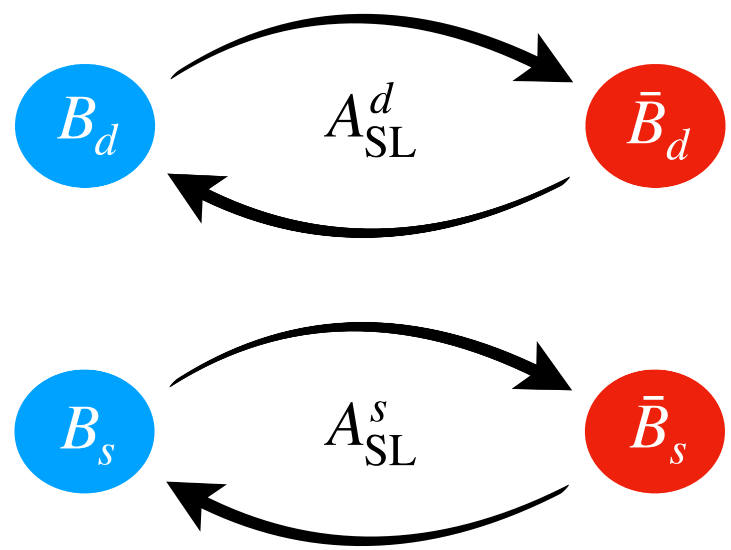
CP violating oscillations



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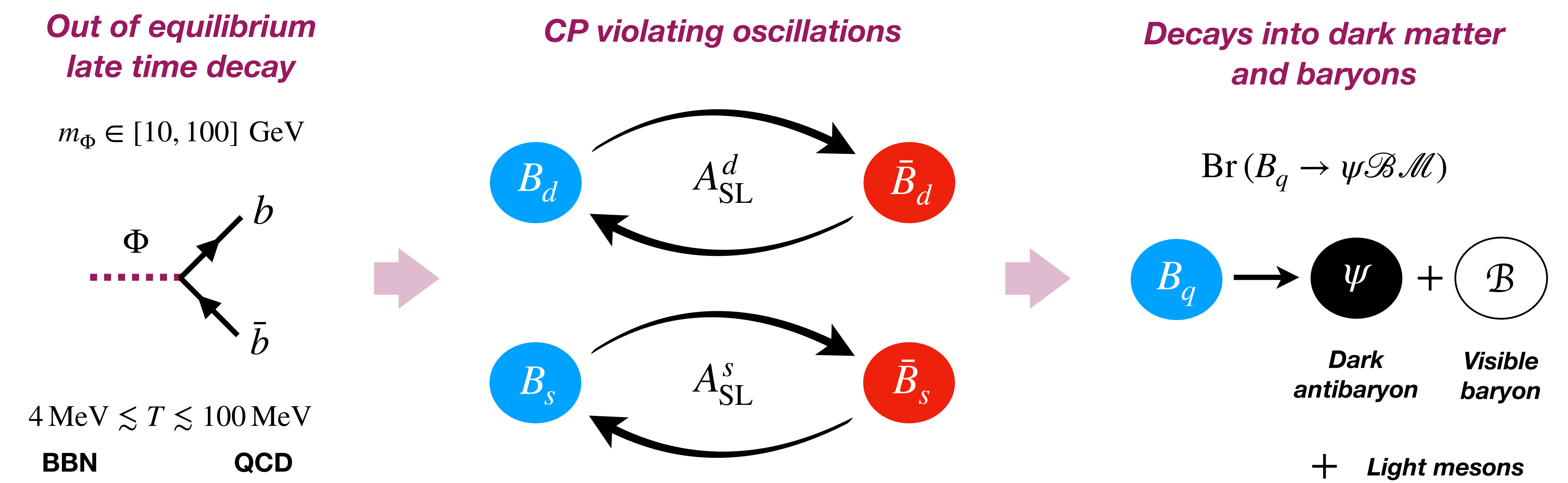

Figure adapted from 1810.00880 and 2101.02706

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$$Y_B \simeq 8.7 \times 10^{-11} \frac{\mathrm{Br}\,(B_q \to \psi \mathscr{B} \mathscr{M})}{10^{-3}} \sum_{q=s,d} \alpha_q \frac{A_{\rm SL}^q}{10^{-3}} \quad \Rightarrow \quad \left(\alpha_s A_{\rm SL}^s + \alpha_d A_{\rm SL}^d\right) \mathrm{Br}\,(B_q \to \psi \mathscr{B} \mathscr{M}) = 10^{-6}$$

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$\mathrm{Br}\,(B_q \to \psi \mathscr{B} \mathscr{M}) < 0.5\,\%$ (incl.) [ALEPH at 95% CL]

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- At least one $A_{\rm SL}^q$ must be positive
- Minimal value: $A_{\rm SL}^q > +10^{-4}$

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New decay $b \to \psi \bar{\psi} q$ **Modifies** $b \to u_i \bar{u}_j q$

$Y \sim (3,1)_{-1/3}$ *scalar boson* $M_Y > 500\,\text{GeV}$

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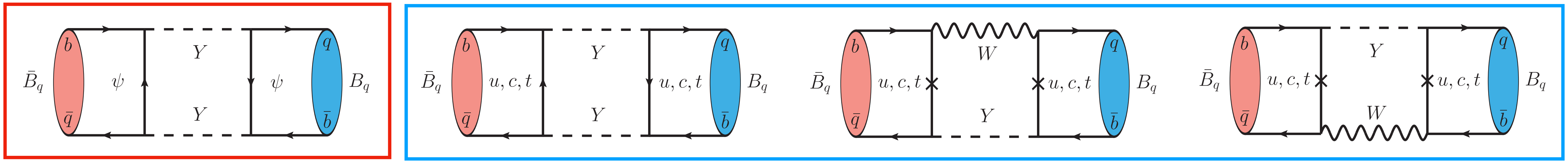

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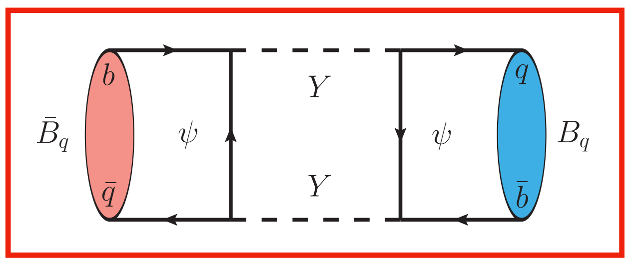

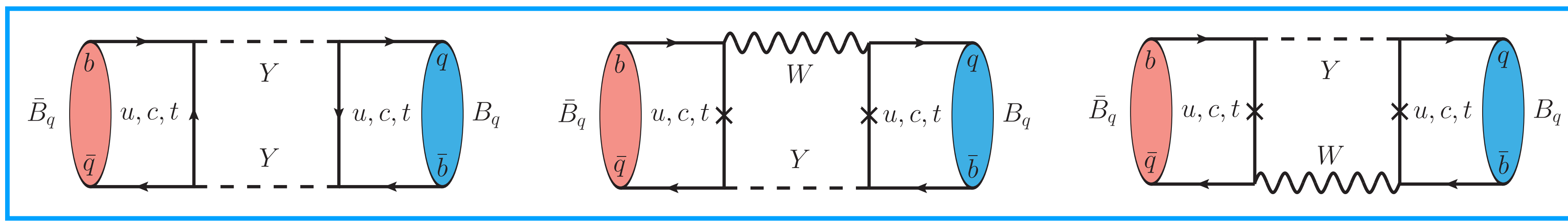

$$|\delta A_{SL}^q(\psi)| \leq \mathcal{O}(10^{-5}) \left(\frac{500\,\text{GeV}}{M_Y}\right)^2$$

$$|\delta A_{SL}^q(\not\psi)| \leq \mathcal{O}(10^{-4}) \left(\frac{500\,\text{GeV}}{M_Y}\right)$$

Stronger bounds than in the Heavy New Physics scenario

with a general modification of M_{12}^q

Overall picture

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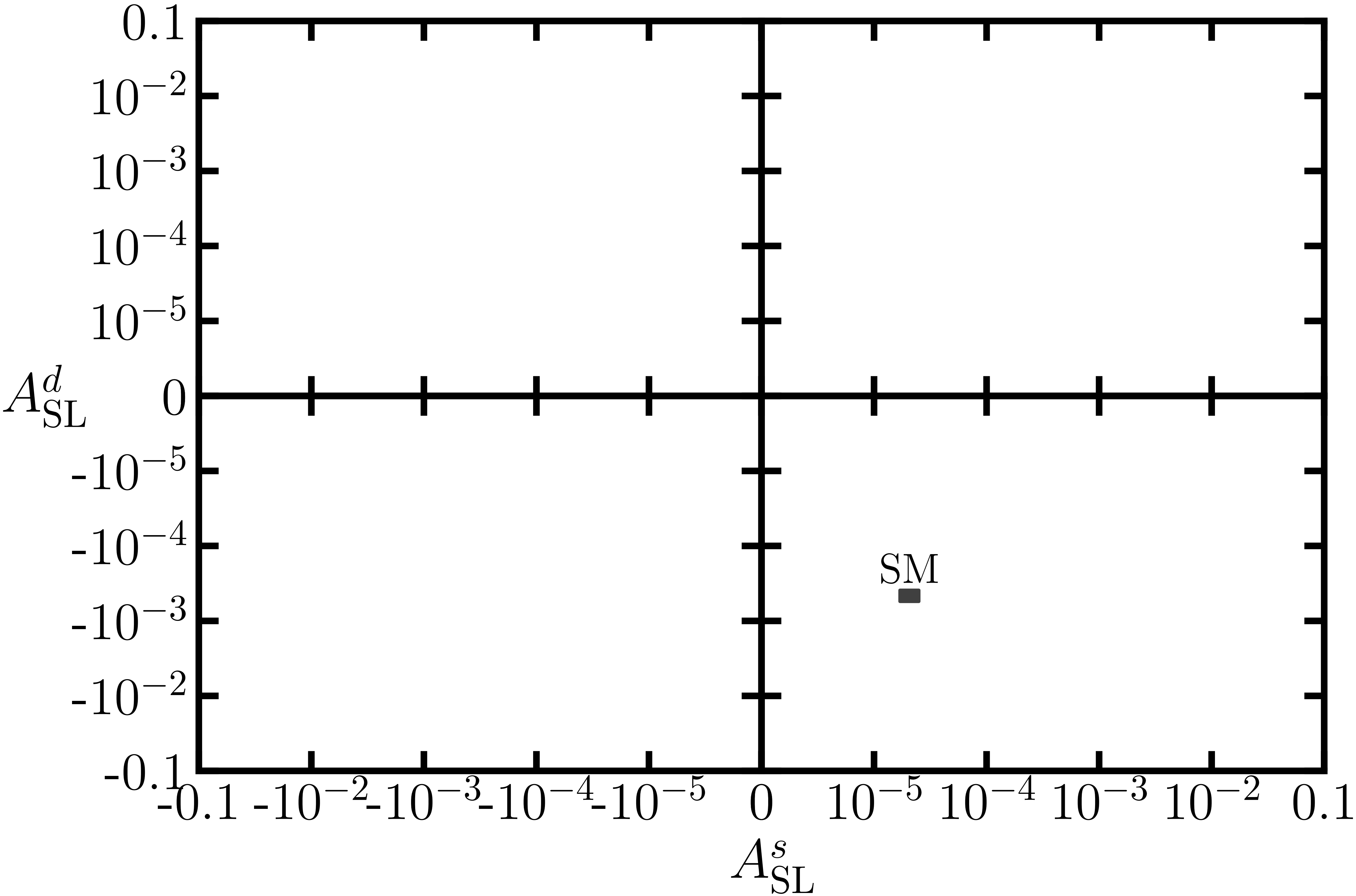

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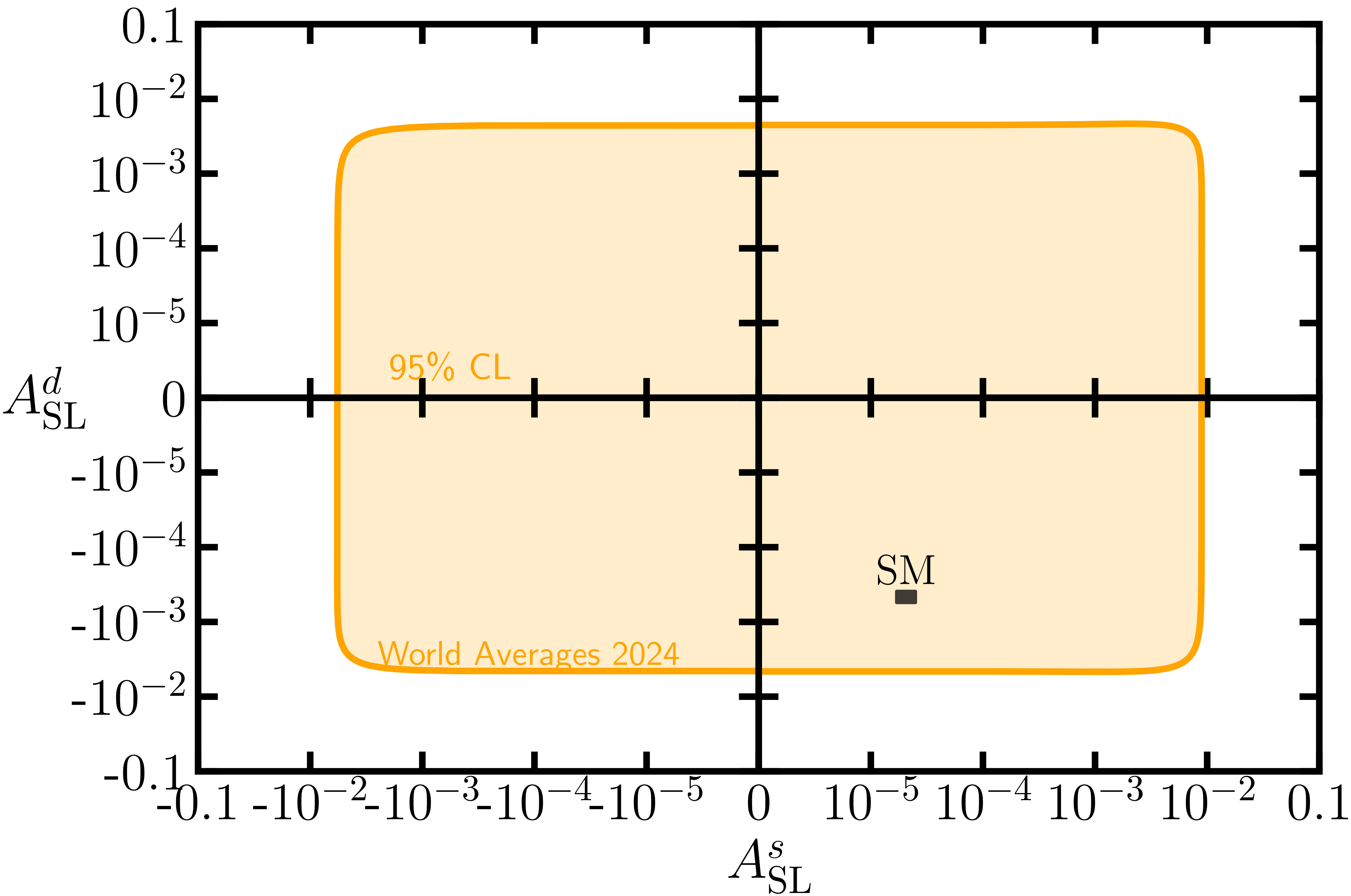

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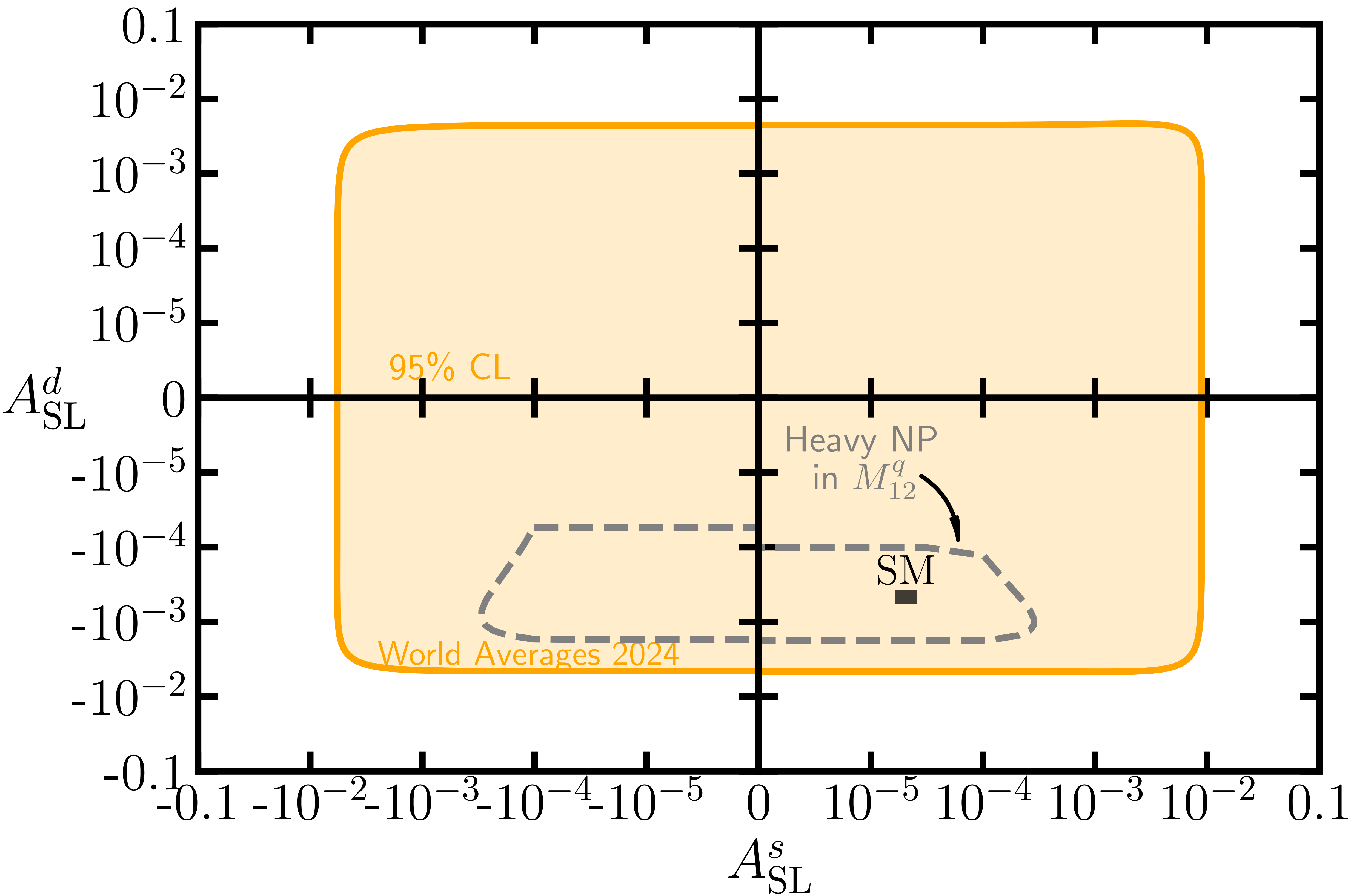

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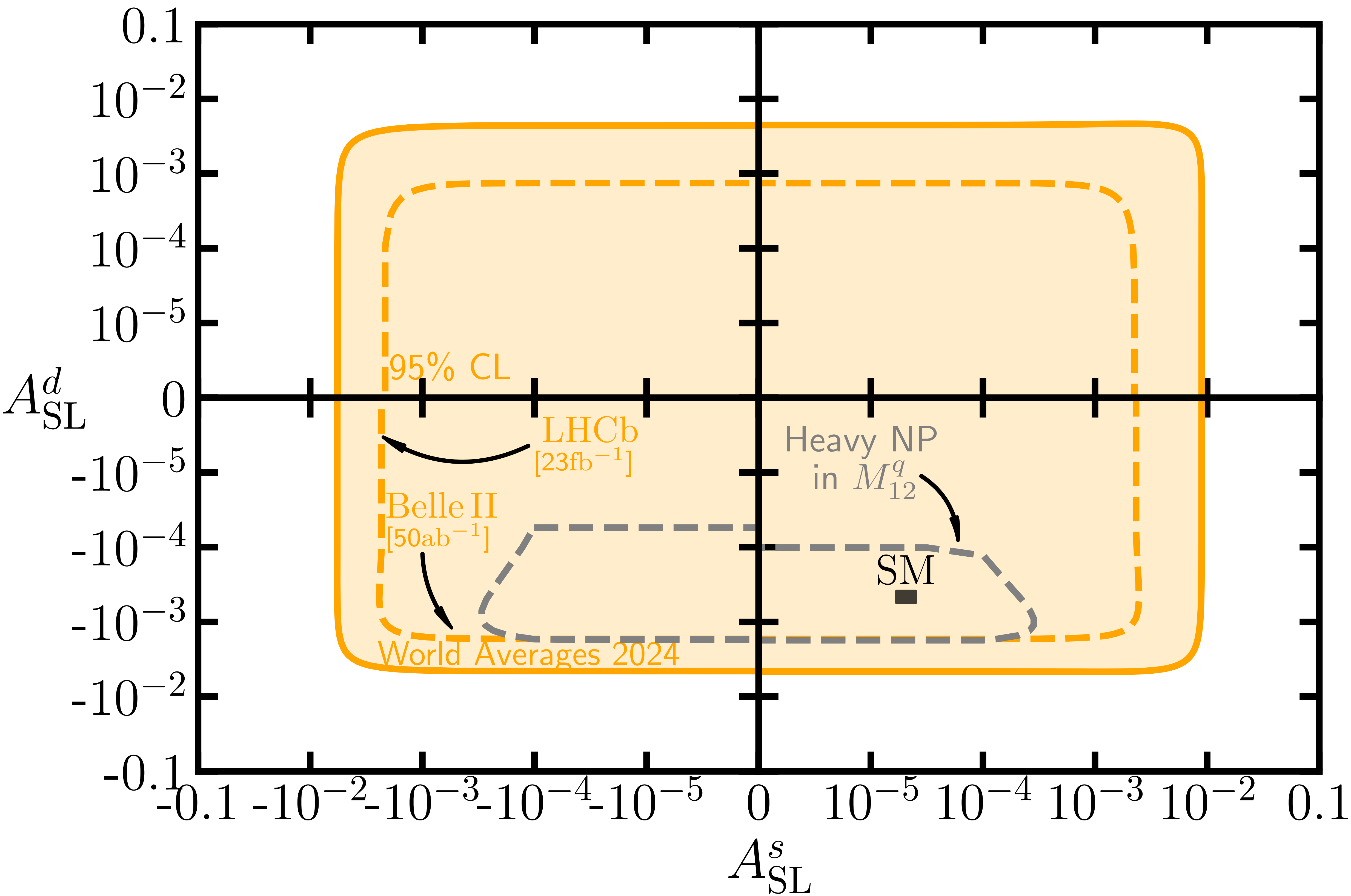

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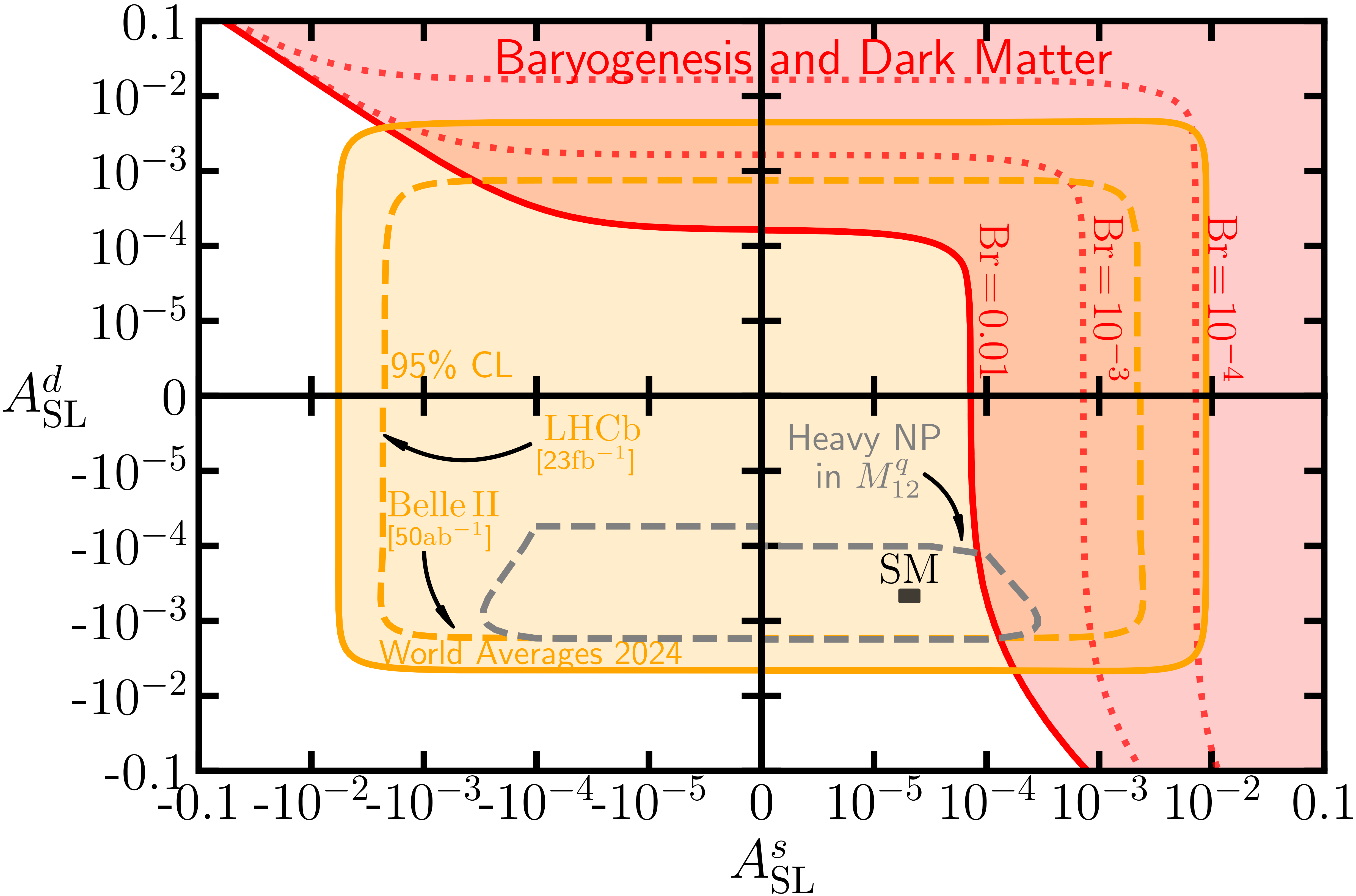


Conclusions

- General modification of M_{12}^q can lead to $A_{\rm SL}^d \sim \mathcal{O}(10^{-3})$ and $A_{\rm SL}^s \sim \mathcal{O}(10^{-4})$
- Similar results with VLQ extensions inducing deviations of 3x3 CKM unitarity
- Modifications of Γ_{12}^q give much smaller enhancements in realistic UV completions
- B-Mesogenesis in tension: small enhancements of $A_{\rm SL}^q$ require larger $\mathrm{Br}(B_q \to \psi \mathscr{B} \mathscr{M})$
- Upcoming LHCb and Belle II searches for CP asymmetries are not expected to probe new regions of the parameter space in the most generic models (chance at FCC-ee…)

THANK YOU!

Back up

Mixing parameters

Neutral B meson systems

- In the absence of weak interactions, $|\psi(t)\rangle = a(t)|B_q\rangle + b(t)|\bar{B}_q\rangle$ evolves in time according to:

$\mathscr{H}^q$ is hermitian

$$\mathscr{H}^q = \begin{pmatrix} M_{B_q} & 0 \\ 0 & M_{B_q} \end{pmatrix}$$

M_{B_q} is the common mass of B_q and $\bar{B}_q$

$$M_{B_q} = \langle B_q | \mathscr{H}^q | B_q \rangle = \langle \bar{B}_q | \mathscr{H}^q | \bar{B}_q \rangle$$

N.B. CPT invariance is assumed

- Once the weak interaction is considered, B_q and $\bar{B}_q$ can decay to other states ($\mathscr{H}_q$ is not hermitian anymore) and oscillate between themselves ($\mathscr{H}_q$ is not diagonal anymore):

$$\mathscr{H}^q = M^q - i\frac{\Gamma^q}{2} \quad \Rightarrow \quad \mathscr{H}^q = \begin{pmatrix} M^q_{11} - i\Gamma^q_{11}/2 & M^q_{12} - i\Gamma^q_{12}/2 \\ M^{q*}_{12} - i\Gamma^{q*}_{12}/2 & M^q_{22} - i\Gamma^q_{22}/2 \end{pmatrix}$$

$$M^q = M^{q\dagger}$$
$$\Gamma^q = \Gamma^{q\dagger}$$

- The underlying fundamental physics effects can be encoded into the matrix elements of $\mathscr{H}^q$ using the framework of perturbation theory (in the weak interaction $\mathscr{H}_W$):

$$M^q_{12} = \langle B_q | \mathscr{H}_W | \bar{B}_q \rangle + \sum_n \mathrm{P}\frac{\langle B_q | \mathscr{H}_W | n \rangle \langle n | \mathscr{H}_W | \bar{B}_q \rangle}{M_{B_q} - E_n} + \ldots$$

- $\Delta B = 2$ transition through virtual intermediate states
- Sensitive to heavy virtual particles

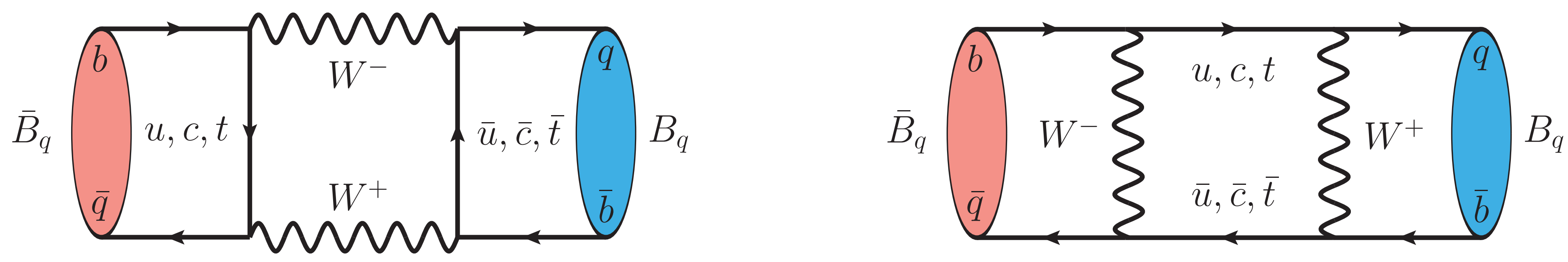
$$\Gamma^q_{12} = 2\pi \sum_n \delta(M_{B_q} - E_n) \langle B_q | \mathscr{H}_W | n \rangle \langle n | \mathscr{H}_W | \bar{B}_q \rangle + \ldots$$

- Two $\Delta B = 1$ transitions through real intermediate states
- Sensitive to light particles with masses below $M_{B_q} \sim m_b$
- Decay modes common to both B_q and $\bar{B}_q$

Mixing observables

SM prediction

- $M_{12}^{q,\mathrm{SM}}$ in the Standard Model:



q = s : $O(\lambda^4)$
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$$M_{12}^{q,\mathrm{SM}} \propto (\lambda_{bq}^c)^2\left[F(c,c) - 2F(u,c) + F(u,u)\right] + 2\lambda_{bq}^c\lambda_{bq}^t\left[F(c,t) - F(u,t) - F(u,c) + F(u,u)\right] + (\lambda_{bq}^t)^2\left[F(t,t) - 2F(u,t) + F(u,u)\right]$$

GIM cancellation | *GIM cancellation* | *Top dominance*

$$M_{12}^{q,\mathrm{SM}} = \frac{G_F^2 M_W^2}{12\pi^2}(\lambda_{bq}^t)^2 S_0(x_t) M_{B_q} f_{B_q}^2 B_{B_q} \hat{\eta}_B$$

EW box diagrams — Matrix element dim-6 operator (lattice)

- $\lambda_{bq}^t = V_{tb}V_{tq}^*$: CKM elements
- $S_0(x_t) \simeq 2.29$: Inami-Lim function (loop integral)
- f_{B_q} : *B* meson decay constant
- B_{B_q} : bag parameter (deviation from VIA)
- $\hat{\eta}_B$: two-loop perturbative QCD corrections (renormalization scale and scheme independent)

$$\Delta M_d^{\mathrm{SM}} = 0.535 \pm 0.021\ \mathrm{ps}^{-1}$$
$$\Delta M_s^{\mathrm{SM}} = 18.23 \pm 0.63\ \mathrm{ps}^{-1}$$

Mixing observables

SM prediction

- $\Gamma_{12}^{q,\mathrm{SM}}/M_{12}^{q,\mathrm{SM}}$ in the Standard Model:

$$-\Gamma_{12}^{q,\mathrm{SM}} = (\lambda_{bq}^c)^2\Gamma_{12}^{q,cc} + 2\lambda_{bq}^c\lambda_{bq}^u\Gamma_{12}^{q,uc} + (\lambda_{bq}^u)^2\Gamma_{12}^{q,uu}$$

$$\lambda_{bq}^u + \lambda_{bq}^c + \lambda_{bq}^t = 0$$

$$M_{12}^{q,\mathrm{SM}} = (\lambda_{bq}^t)^2\tilde{M}_{12}^{q,\mathrm{SM}}$$

Top-dominance

$$\frac{\lambda_{bq}^u}{\lambda_{bq}^t} = \begin{cases} 1.7\times10^{-2} - 4.2\times10^{-1}\, i, & q=d \\ -8.8\times10^{-3} + 1.8\times10^{-2}\, i, & q=s \end{cases}$$

GIM cancellation *GIM cancellation*

$$\Rightarrow\ -\frac{\Gamma_{12}^{q,\mathrm{SM}}}{M_{12}^{q,\mathrm{SM}}} = \frac{\Gamma_{12}^{q,cc}}{\tilde{M}_{12}^{q,\mathrm{SM}}} + 2\left(\frac{\lambda_{bq}^u}{\lambda_{bq}^t}\right)\frac{\Gamma_{12}^{q,cc} - \Gamma_{12}^{q,uc}}{\tilde{M}_{12}^{q,\mathrm{SM}}} + \left(\frac{\lambda_{bq}^u}{\lambda_{bq}^t}\right)^2\frac{\Gamma_{12}^{q,cc} - 2\Gamma_{12}^{q,uc} + \Gamma_{12}^{q,uu}}{\tilde{M}_{12}^{q,\mathrm{SM}}}$$

CKM suppression *CKM suppression*

$$\Rightarrow\ \frac{\Gamma_{12}^{q,\mathrm{SM}}}{M_{12}^{q,\mathrm{SM}}} = c_q + a_q\left(\frac{\lambda_{bq}^u}{\lambda_{bq}^t}\right) + b_q\left(\frac{\lambda_{bq}^u}{\lambda_{bq}^t}\right)^2$$

$c_d = (-49.5 \pm 8.5)\times10^{-4}$ $c_s = (-48.0 \pm 8.3)\times10^{-4}$

$a_d = (11.7 \pm 1.3)\times10^{-4}$ $a_s = (12.3 \pm 1.4)\times10^{-4}$

$b_d = (0.24 \pm 0.06)\times10^{-4}$ $b_s = (0.79 \pm 0.12)\times10^{-4}$

$$\Rightarrow\ A_{\mathrm{SL}}^q = \mathrm{Im}\left(\frac{\Gamma_{12}^{q,\mathrm{SM}}}{M_{12}^{q,\mathrm{SM}}}\right) = a_q\ \mathrm{Im}\left(\frac{\lambda_{bq}^u}{\lambda_{bq}^t}\right) \sim O(10^{-5})$$

$$A_{\mathrm{SL}}^{d,\mathrm{SM}} = (-5.1 \pm 0.5)\times10^{-4}$$
$$A_{\mathrm{SL}}^{s,\mathrm{SM}} = (0.22 \pm 0.02)\times10^{-4}$$

Mixing parameters and CP asymmetries

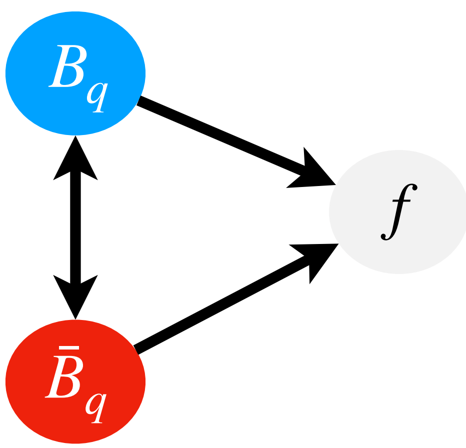
Relevant observables

- Meson mass differences between the heavy and light eigenstates:

$$\Delta M_q = 2\,|M_{12}^q|$$

- Golden CP phases:

Gold-plated modes
Tree-level dominated



$$\Gamma(B_q(t) \to f) \neq \Gamma(\bar{B}_q(t) \to f)$$

due to the presence of two different *interfering* amplitudes

$$B_d \to J/\psi\, K_S \quad \text{with} \quad A_{\rm CP} \propto \sin\phi_d^{\rm tree}$$

$$B_s \to J/\psi\, \phi \quad \text{with} \quad A_{\rm CP} \propto \sin\phi_s^{\rm tree}$$

$$\phi_q^{\rm tree} \sim \arg M_{12}^q$$

- However, SM gluon penguin exchange diagrams may give a contribution comparable to the current experimental sensitivity:

$$\phi_q = \phi_q^{\rm tree} + \phi_q^{\rm peng}$$

Penguin "pollution"

Non-perturbative effects

$\mathcal{O}(1^\circ)$ in the SM

P. Frings, U. Nierste & M. Wiebusch, 1503.00859

M. Z. Barel, K. De Bruyn, R. Fleischer & E. Malami, 2010.14423

Mixing observables

Current measurements and future prospects

- Current experimental status of mixing observables (see 2411.18639 for the latest update):

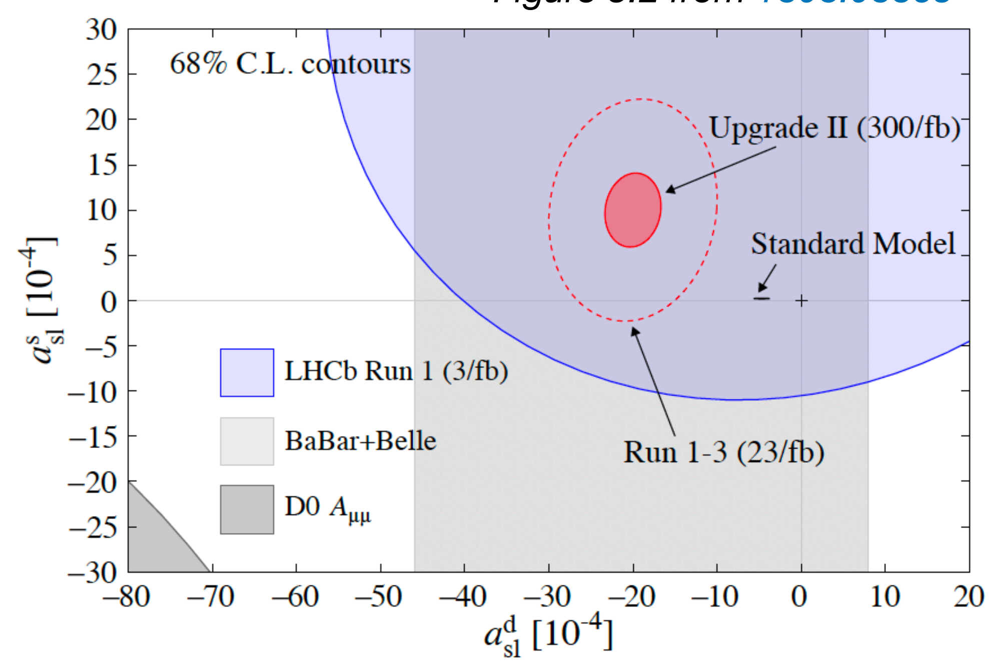
B_d system	B_s system
$\Delta M_d^{\text{Exp}} = 0.5069(19)\,\text{ps}^{-1}$	$\Delta M_s^{\text{Exp}} = 17.766(6)\,\text{ps}^{-1}$
$\dfrac{\Delta\Gamma_d^{\text{Exp}}}{\Gamma_d^{\text{Exp}}} = 0.001(10)$	$\Delta\Gamma_s^{\text{Exp}} = 0.076(4)\,\text{ps}^{-1}$
$A_{\text{SL}}^{d,\text{Exp}} = (-21 \pm 17) \times 10^{-4}$	$A_{\text{SL}}^{s,\text{Exp}} = (-6 \pm 28) \times 10^{-4}$

- Projected 1σ sensitivities (according to 1808.08865, 1808.10567, 2101.02706, 2406.19421):

$$\delta A_{\text{SL}}^s = 10 \times 10^{-4} \quad [\text{LHCb}\,(23\,\text{fb}^{-1}) - 2025]$$
$$\delta A_{\text{SL}}^s = 3 \times 10^{-4} \quad [\text{LHCb}\,(300\,\text{fb}^{-1}) - 2040]$$
$$\delta A_{\text{SL}}^d = 8 \times 10^{-4} \quad [\text{LHCb}\,(23\,\text{fb}^{-1}) - 2025]$$
$$\delta A_{\text{SL}}^d = 2 \times 10^{-4} \quad [\text{LHCb}\,(300\,\text{fb}^{-1}) - 2040]$$
$$\delta A_{\text{SL}}^d = 5 \times 10^{-4} \quad [\text{Belle II}\,(50\,\text{ab}^{-1}) - 2035]$$

It has been suggested that FCC-ee could reach $\delta A_{\text{SL}}^s \sim 10^{-5}$ *(see 2106.01259).*

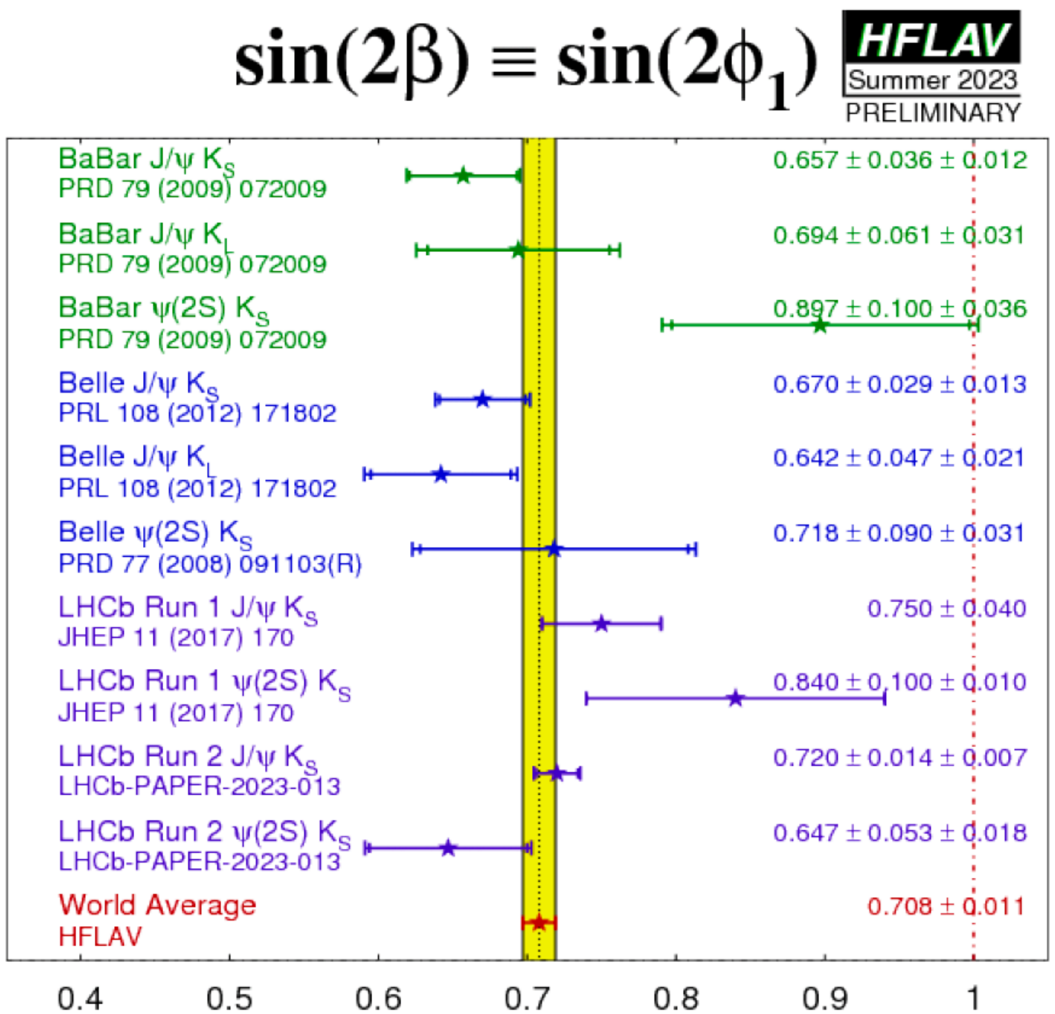
Figure 5.2 from 1808.08865



Golden CP asymmetries

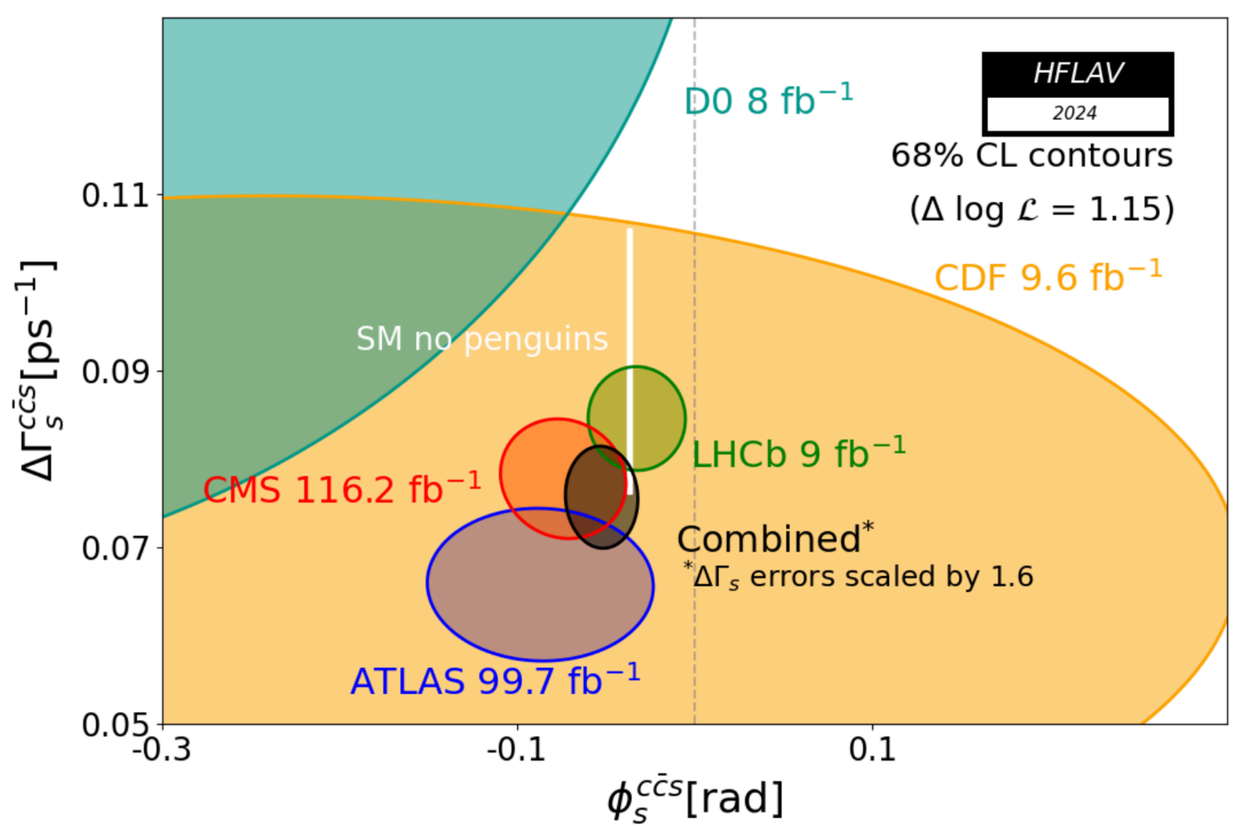
Experimental world averages

B_d system



Plot from LHCb seminar June 13, 2023

B_s system



Plot from 2411.18639

$$\sin \phi_d^{\text{Exp}} = 0.708 \pm 0.011$$

$$B_d \to J/\psi K_{S/L}\,,\, B_d \to \psi(2S)K_L,\, B_d \to \chi_{c1}K_S \ldots$$

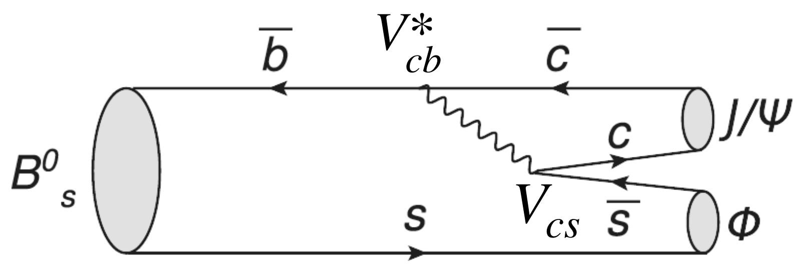
$$\phi_s^{\text{Exp}} = -\,0.052 \pm 0.013$$

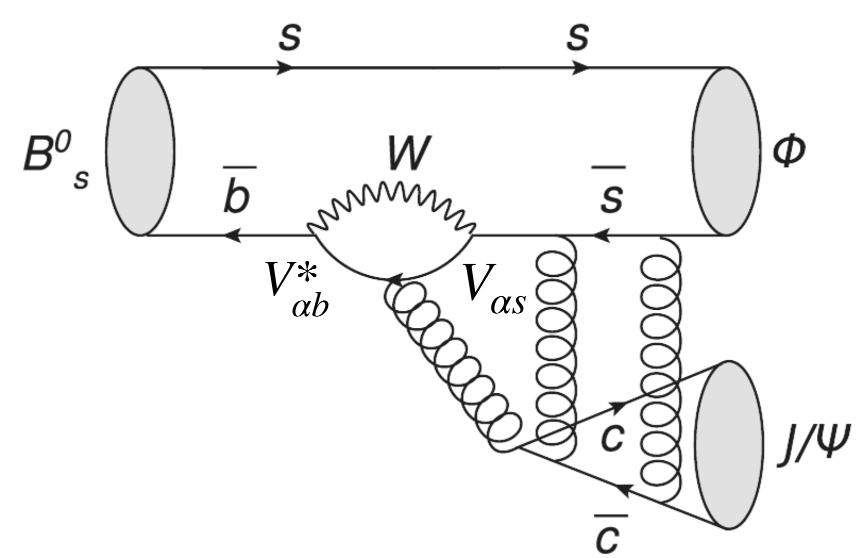
$$B_s \to J/\psi\,\phi\,,\, B_s \to \psi(2S)\,\phi,\, B_s \to D_s^+D_s^- \ldots$$

Golden CP asymmetries

Penguin pollution

- $B_s \rightarrow J/\psi\ \phi$





Figures extracted from M. Artuso, G. Borissov & A. Lenz, 1511.09466

- $B_d \rightarrow J/\psi\ K_S$

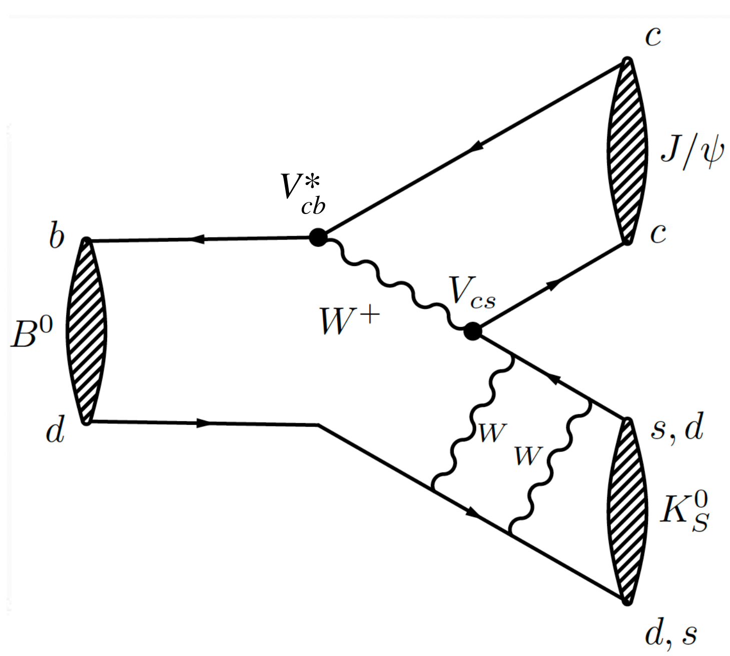
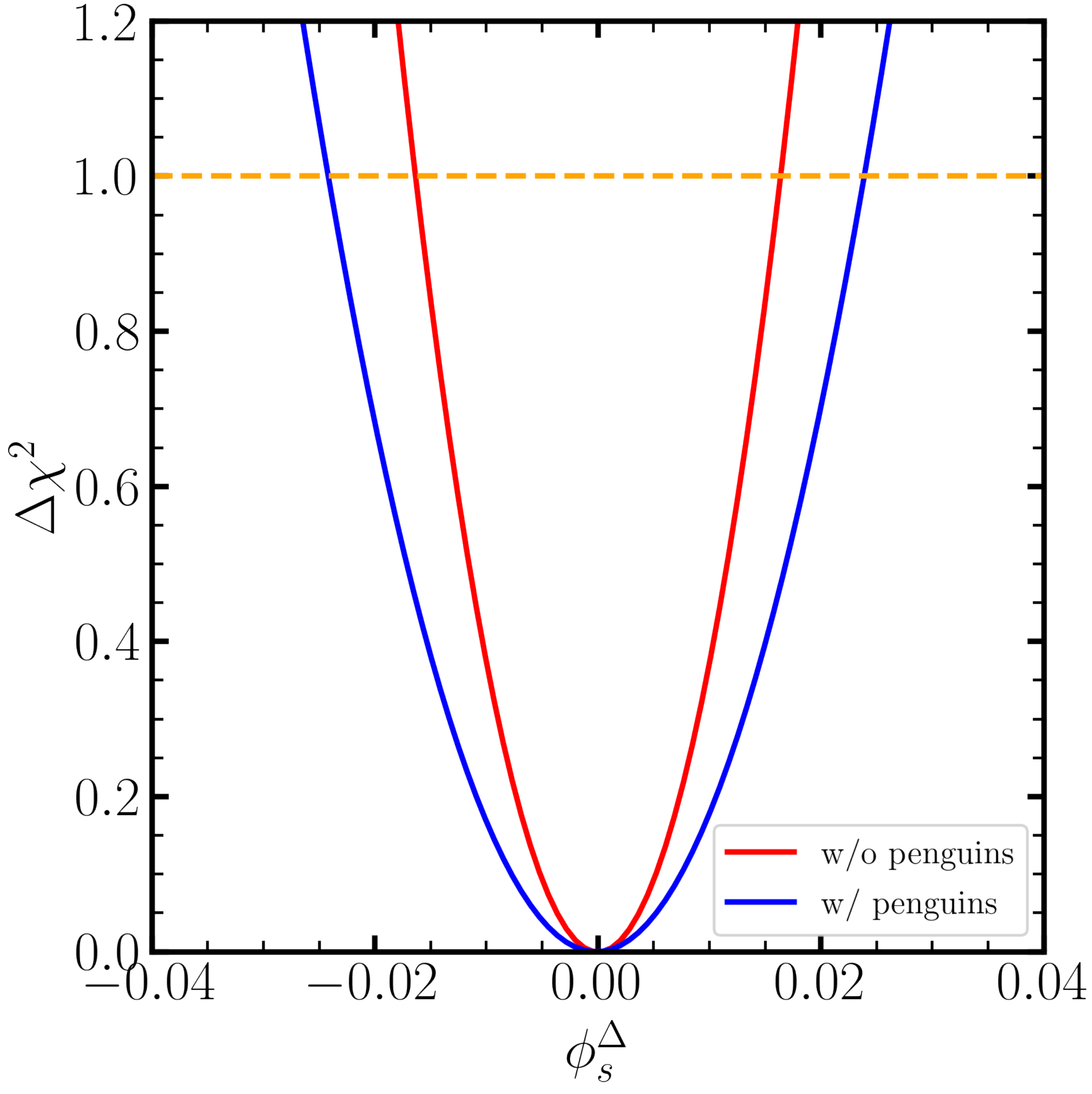


Figure extracted from N. Tunning, "Lecture notes on CP violation"

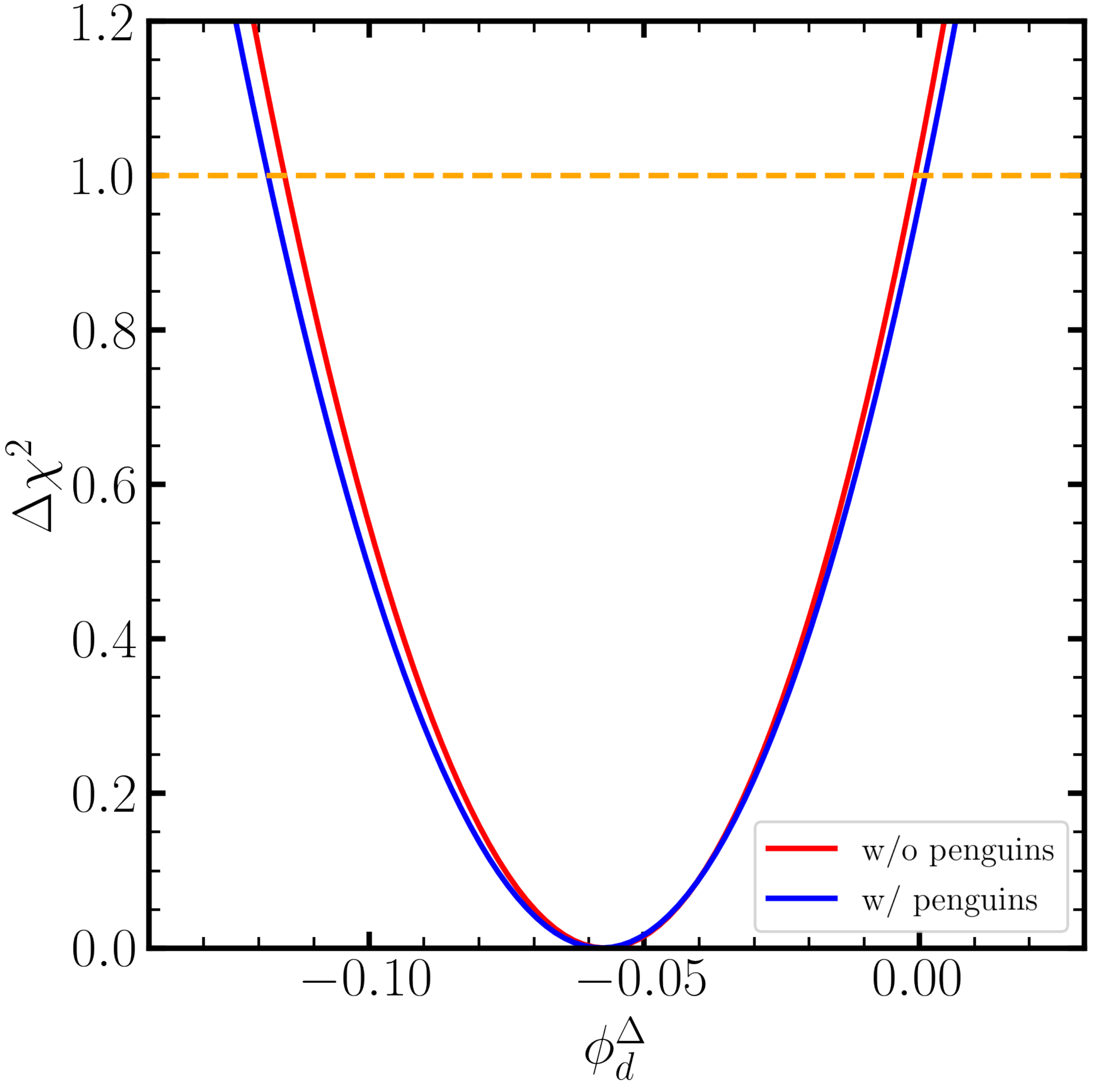
Golden CP asymmetries

Penguin pollution

B_s **system**



B_d **system**

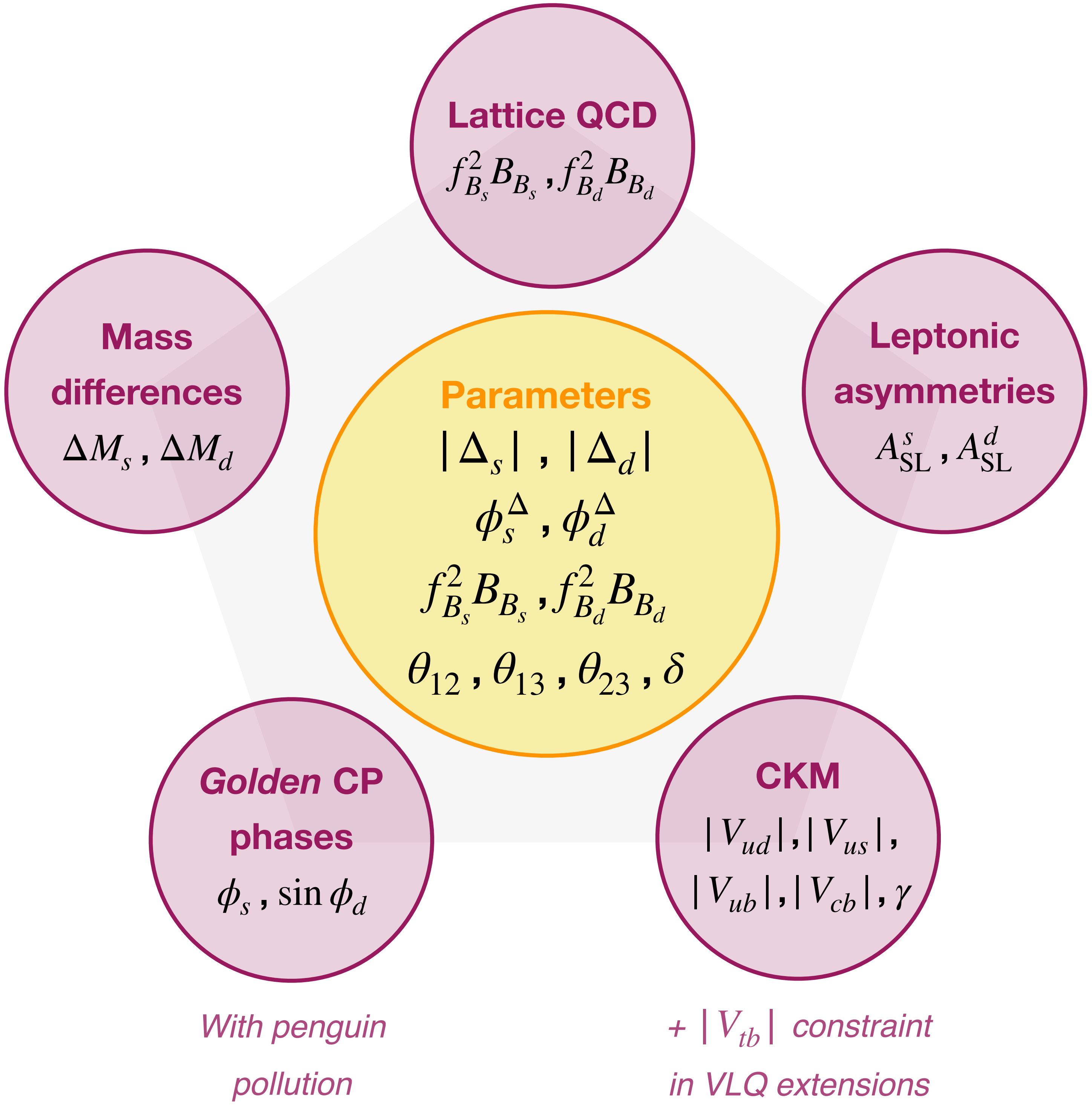


BSM scenarios

Experimental and theoretical constraints

- Taking our model-independent analysis (assuming that heavy NP only enters in M_{12}^q) as a benchmark:

  - Meson mass differences: $\Delta M_q = \Delta M_q^{\rm SM} |\Delta_q|$
  - Golden CP asymmetries: $\phi_q = \phi_q^{\rm SM} + \phi_q^\Delta$
    - Penguin pollution, $\mathcal{O}(1^\circ)$, summed in quadrature with experimental error
  - CKM mixing:
    - 3x3 CKM unitarity is implicit in the PDG parametrization: $\{\theta_{12}, \theta_{13}, \theta_{23}, \delta\}$
    - In our VLQ extensions, the CKM mixing is embedded in 4x4 unitary matrix: $\{\theta_{12}, \theta_{13}, \theta_{23}, \theta_{14}, \theta_{24}, \theta_{34}, \delta, \delta_{14}, \delta_{24}\}$
    - In VLQ extensions, $|V_{tb}|$ constraint must be included
  - Heavy quark: $m_T > 1.6\,\text{TeV}$ to avoid direct lower bounds (production and decay)



BSM scenarios

Vector-like quark contributions to mass mixing M_{12}^q

- In UVLQ models:

$$\frac{M_{12}^{q,\mathrm{UVLQ}}}{M_{12}^{q,\mathrm{SM-like}}} = 1 + \frac{\lambda_{bq}^T}{\lambda_{bq}^t}\frac{C_1^{\mathrm{up}}(x_t, x_T)}{S_0(x_t)} + \left(\frac{\lambda_{bq}^T}{\lambda_{bq}^t}\right)^2 \frac{C_2^{\mathrm{up}}(x_T)}{S_0(x_t)}$$

- Dependence on heavy T quark mass m_T
- New contributions: proportional and quadratic in the deviation of unitarity λ_{bq}^T

- In DVLQ models:

$$\frac{M_{12}^{q,\mathrm{DVLQ}}}{M_{12}^{q,\mathrm{SM-like}}} = 1 + \frac{(D_L)_{qb}}{\lambda_{bq}^t}\frac{C_1^{\mathrm{down}}(x_t)}{S_0(x_t)} + \left(\frac{(D_L)_{qb}}{\lambda_{bq}^t}\right)^2 \frac{C_2^{\mathrm{down}}}{S_0(x_t)}$$

- No dependence on heavy quark masses.
- New contributions: proportional and quadratic in the deviation of unitarity $(D_L)_{qb}$

- Loop functions:

$$C_1^{\mathrm{up}}(x_t, x_T) = 2S_0(x_t, x_T) \qquad C_1^{\mathrm{down}}(x_t) = -4Y(x_t)$$

$$C_2^{\mathrm{up}}(x_T) = S_0(x_T) \qquad C_2^{\mathrm{down}} = \frac{2\sqrt{2}\pi^2}{G_F M_W^2}$$

$$Y(x) = \frac{x}{4(x-1)}\left[x - 4 + \frac{3x\ln x}{x-1}\right]$$

$$S_0(x) \equiv \lim_{y\to x} S_0(x,y) = \frac{x}{(1-x)^2}\left[1 - \frac{11x}{4} + \frac{x^2}{4} - \frac{3x^2\ln x}{2(1-x)}\right]$$

$$S_0(x,y) = xy\left[-\frac{3}{4(1-x)(1-y)} + \left(1 - 2x + \frac{x^2}{4}\right)\frac{\ln x}{(1-x)^2(x-y)} + \left(1 - 2y + \frac{y^2}{4}\right)\frac{\ln y}{(1-y)^2(y-x)}\right]$$

BSM scenarios

New Physics in decay mixing Γ_{12}^q

I) Channels that are common to both B_q and $\bar{B}_q$ that can still accommodate new physics effects through $\Delta B = 1$ operators (see e.g., *A. Lenz & G. Tetlalmatzi-Xolocotzi, 1912.07621*, and *M. Bordone & M. Fernández Navarro, 2307.07013* for model-independent bounds on these operators)

$b \to u_i \bar{u}_j q \;\; (u_i = u, c)$	$b \to \tau\tau s$
• Large hadronic uncertainties • Be careful with rare processes: $b \to q\gamma$, $b \to q\ell\ell$ • $Q_1^{d,cc} = (\bar{c}_L^\beta \gamma^\mu b_L^\alpha)(\bar{d}_L^\alpha \gamma_\mu c_L^\beta) \longrightarrow \lvert A_{\rm SL}^d \rvert \lesssim 2 \times 10^{-3}$ • $Q_2^{s,cc} = (\bar{c}_L^\alpha \gamma^\mu b_L^\alpha)(\bar{s}_L^\beta \gamma_\mu c_L^\beta) \longrightarrow \lvert A_{\rm SL}^s \rvert \lesssim 2 \times 10^{-3}$	• Final state particles hard to detect • $\mathrm{Br}(B_s \to \tau\tau) < 6.8 \times 10^{-3}$ • $\lvert A_{\rm SL}^s \rvert \lesssim 10^{-3}$

e.g. scalar diquark $\phi \sim (3,1)_{-1/3}$

A. Crivellin & M. Kirk, 2309.07205

$$A_{\rm SL}^s \approx -4 \times 10^{-5}$$

e.g. vector leptoquark $U_1^\mu \sim (3,1)_{2/3}$

C. Cornella et al., 2103.16558

$$A_{\rm SL}^s \lesssim 10^{-5}$$

BSM scenarios

Minimal realization of B-Mesogenesis

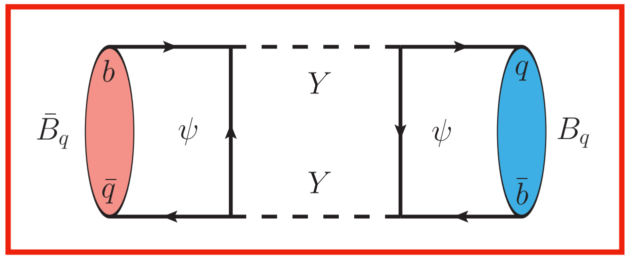
- Interactions involving a color triplet scalar Y with hypercharge $-1/3$ and a dark antibaryon ψ

$$\mathscr{L} = -\sum_k y_{\psi d_k} Y d^c_{kR} \bar{\psi} - \sum_{i,j} y_{u_i d_j} Y^\star \bar{u}_{iR} d^c_{jR} + \text{h.c.}$$

New decay $b \to \psi \bar{\psi} q$ **Modifies** $b \to u_i \bar{u}_j q$

$Y \sim (3,1)_{-1/3}$ *scalar boson* $M_Y > 500\,\text{GeV}$

ψ *dark sector antibaryon* $m_\psi \lesssim m_b/2$



$$\Gamma_{12}^{q,\text{NP}}(\psi) = -\frac{f_{B_q}^2 M_{B_q}}{256\pi} \frac{y_{\psi q} y_{\psi b}^* m_b^2}{M_Y^4} \left(1 - \frac{2}{3}\frac{m_\psi^2}{m_b^2}\right) \sqrt{1 - 4\frac{m_\psi^2}{m_b^2}}$$

$$M_{12}^{q,\text{NP}}(\psi) = \frac{f_{B_q}^2 M_{B_q}}{384\pi^2} \frac{y_{\psi q} y_{\psi b}^*}{M_Y^2} G(x_{\psi Y})$$

$$G(x) = \frac{1+x}{(1-x)^2} + \frac{2x \ln x}{(1-x)^3} \qquad x_{\alpha\beta} = \frac{m_\alpha^2}{m_\beta^2}$$

ΔM_q constraint:

$$|y_{\psi d} y_{\psi b}| < (2-4) \times 10^{-2} \frac{M_Y}{1.5\,\text{TeV}}$$

$$|y_{\psi s} y_{\psi b}| < (1-2) \times 10^{-1} \frac{M_Y}{1.5\,\text{TeV}}$$

BSM scenarios

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$$\mathscr{L} = -\sum_k y_{\psi d_k} Y d^c_{kR} \bar{\psi} - \sum_{i,j} y_{u_i d_j} Y^\star \bar{u}_{iR} d^c_{jR} + \mathrm{h.c.}$$

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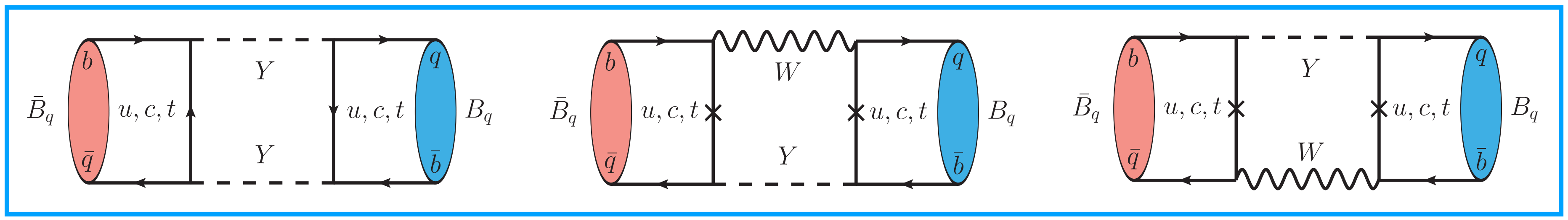


$$\Gamma^{q,\mathrm{NP}}_{12}(\psi) = \frac{f^2_{B_q} M_{B_q}}{384\pi^2} \sum_{i,j=u,c} \frac{\pi\sqrt{\lambda(m_b^2, m_i^2, m_j^2)}}{m_b^2} \times \left[(V_{ib}V^\star_{jq} y_{iq} y^\star_{jb}) \frac{m_i m_j}{M_W^2 M_Y^2} 8 g_W^2 + (y_{iq} y^\star_{ib} y_{jq} y^\star_{jb}) \frac{m_b^2}{12 M_Y^4} (8 g_2^{ij} - 5 g_3^{ij}) \right]$$

Dominant contribution: cc *channel*

$$M^{q,\mathrm{NP}}_{12}(\psi) = -\frac{f^2_{B_q} M_{B_q}}{384\pi^2} \sum_{i,j=u,c,t} \left[(V_{ib}V^\star_{jq} y_{iq} y^\star_{jb}) \frac{m_i m_j}{M_W^2 M_Y^2} g_W^2 f_1^{ij} - (y_{iq} y^\star_{ib} y_{jq} y^\star_{jb}) \frac{1}{M_Y^2} f_2^{ij} \right]$$

Dominant contribution: tt

ΔM_q *constraint:*

$$|y_{cd} y_{cb}| < (2-4) \times 10^{-2} \frac{M_Y}{1.5\,\mathrm{TeV}}$$

$$|y_{cs} y_{cb}| < (1-2) \times 10^{-1} \frac{M_Y}{1.5\,\mathrm{TeV}}$$

$$f_1^{ij}(x_{iW}, x_{jW}, x_{iY}, x_{jY}, x_{WY}) = \frac{x_{iW}(x_{iW}-4)\ln x_{iY}}{(x_{iW}-1)(x_{iY}-1)(x_{iW}-x_{jW})} + \frac{x_{jW}(x_{jW}-4)\ln x_{jY}}{(x_{jW}-1)(x_{jY}-1)(x_{jW}-x_{iW})} - \frac{3\ln x_{WY}}{(x_{iW}-1)(x_{jW}-1)(x_{WY}-1)}$$

$$f_2^{ij}(x_{iY}, x_{jY}) = \frac{1}{(x_{iY}-1)(x_{jY}-1)} + \frac{x_{iY}^2 \ln x_{iY}}{(x_{iY}-x_{jY})(x_{iY}-1)^2} + \frac{x_{jY}^2 \ln x_{jY}}{(x_{jY}-x_{iY})(x_{jY}-1)^2}$$

$$g_2^{ij}(m_b^2, m_i^2, m_j^2) = -\frac{\lambda(m_b^2, m_i^2, m_j^2)}{m_b^4} \qquad g_3^{ij}(m_b^2, m_i^2, m_j^2) = \frac{2(m_b^4 - 2m_i^4 - 2m_j^4 + m_b^2 m_i^2 + m_b^2 m_j^2 + 4 m_i^2 m_j^2)}{m_b^4}$$

$g_W : SU(2)_L$ *weak coupling*

$$x_{\alpha\beta} = \frac{m_\alpha^2}{m_\beta^2}$$

$$\lambda(x,y,z) = x^2 + y^2 + z^2 - 2xy - 2xz - 2yz$$

BSM scenarios

Minimal realization of B-Mesogenesis

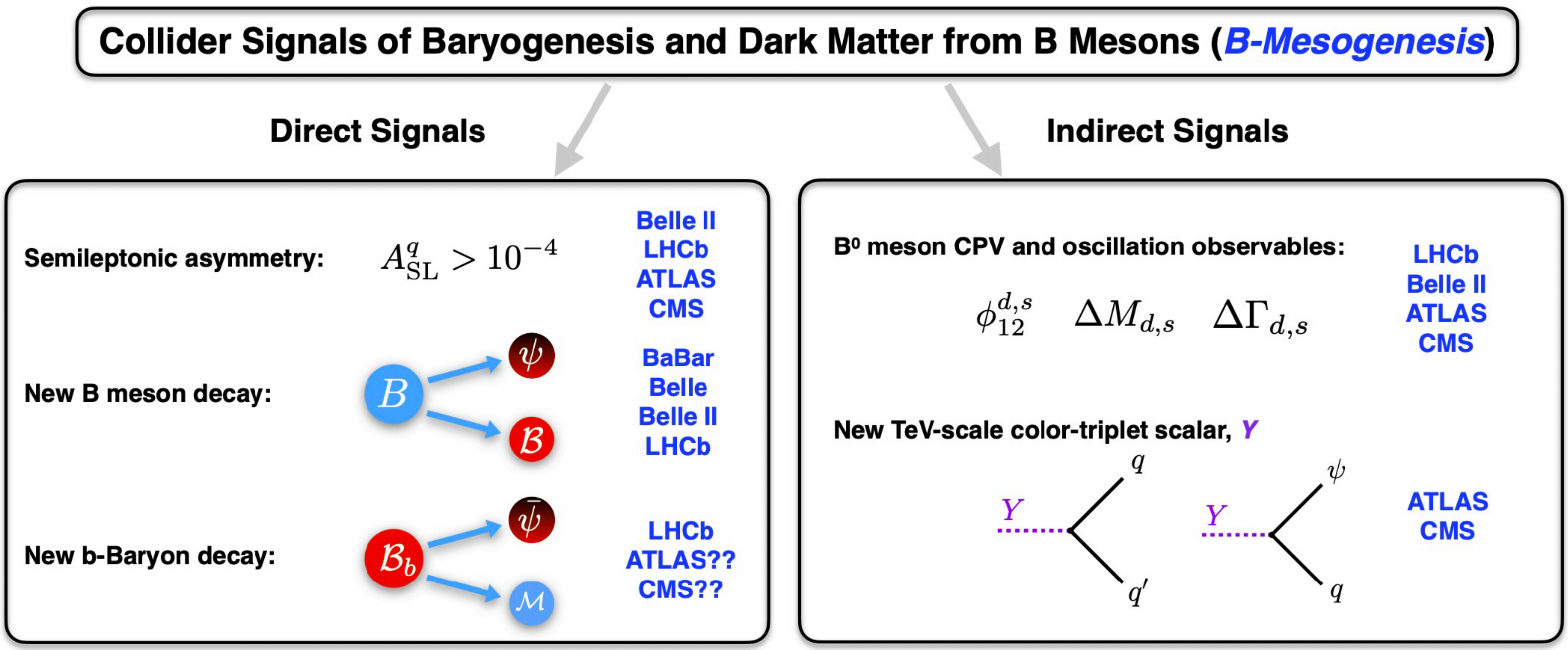


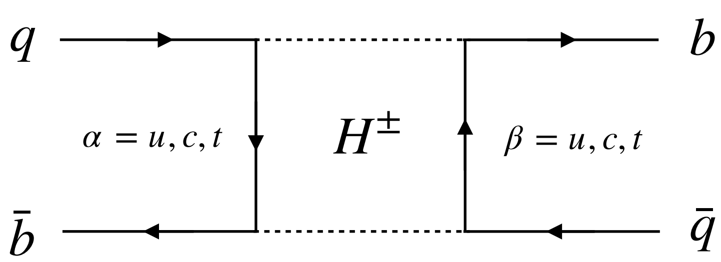
Fig. 1 from G. Alonso-Álvarez, G. Ellor & M. Escudero, 2101.02706

BSM scenarios

Some examples

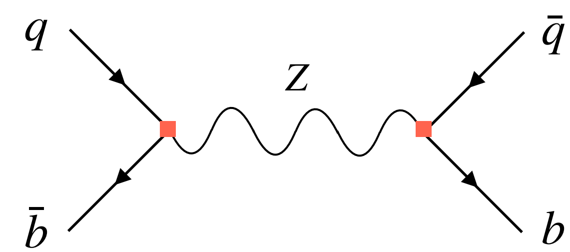
- There is a plethora of models that induce modifications on mixing observables, e.g.:

Two-Higgs-doublet models



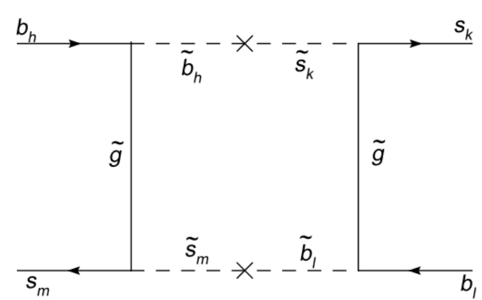
S. Iguro & Y. Omura, 1802.01732

Additional fermions



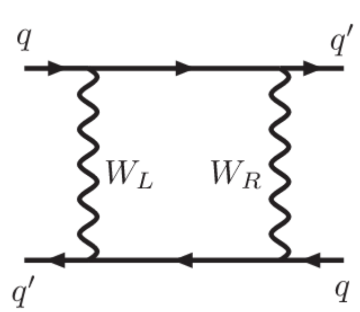
We will explore this framework…

Supersymmetric models



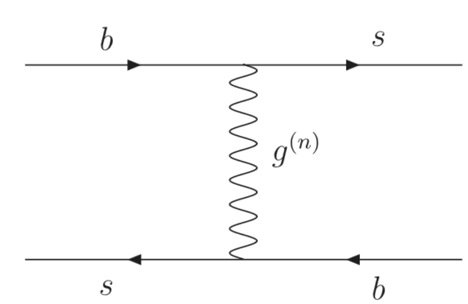
R-M. Wang et al., 1102.2031

Left-right symmetric models



S. Bertolini et al., 1403.7112

Extra dimensions



A. Datta et al., 1011.5979