

From B mesons to the Baryon asymmetry

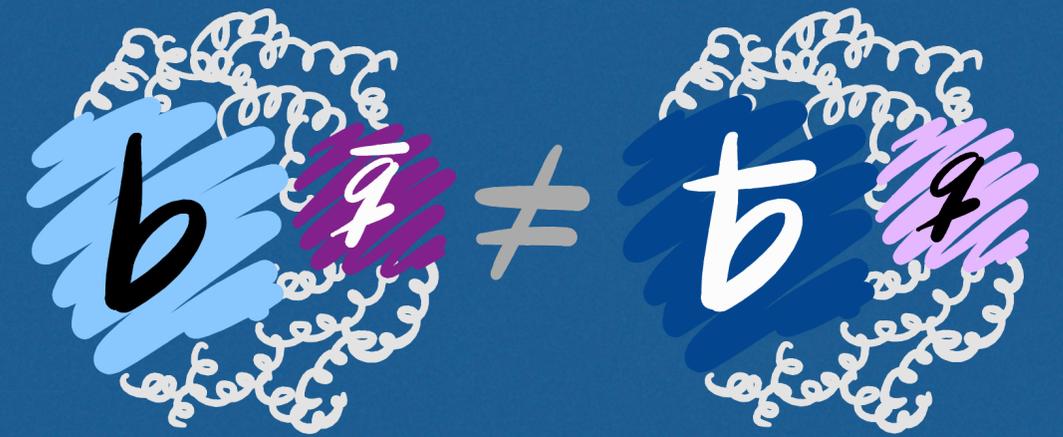
A Unified Mesogenesis framework

Based on [2601.19651](#)

Marta Burgos Marcos - Nikhef Theory Day - March 2026

Overview

- B mesons:
 - * Why are they interesting?
 - * Theory vs. Experiment: Hadronic decays
- Baryon asymmetry through B mesons: Mesogenesis
 - * Driving mechanisms
 - * Overall viability



B Mesons: Why are they interesting?

B Mesons

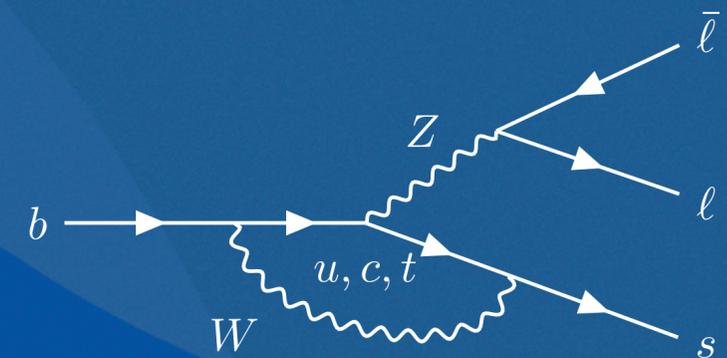
- Heavy bound states \mapsto hundreds of decay channels

B Mesons

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*Sensitive to potential **New Physics**:

$$B \rightarrow K^{(*)} \ell \bar{\ell}$$



B Mesons

- Heavy bound states \mapsto hundreds of decay channels
 - *Sensitive to potential **New Physics**
 - *Help to improve understanding of **QCD** and **Weak Interaction**

B Mesons

- Heavy bound states \mapsto hundreds of decay channels

*Sensitive to potential **New Physics**

*Help to improve understanding of **QCD** and **Weak Interaction**

*Laboratories for the study of **CP violation**



Matter - Antimatter
difference



Baryon asymmetry

B Mesons: Theoretically

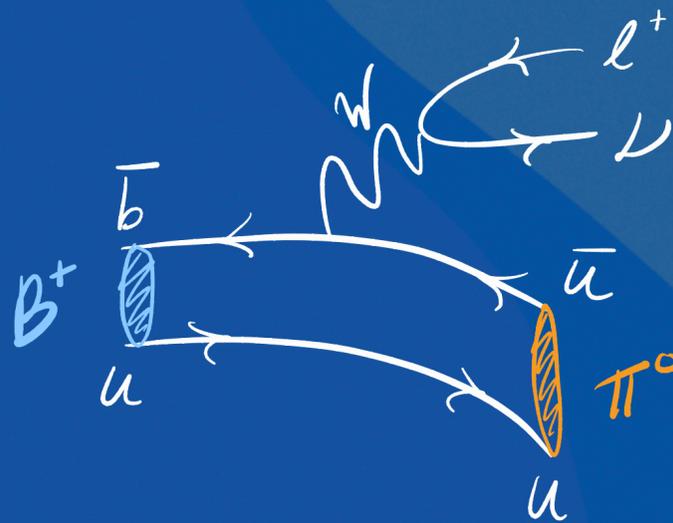
Leptonic



$$\propto \langle 0 | \mathcal{O} | B \rangle$$

Rens & Joan

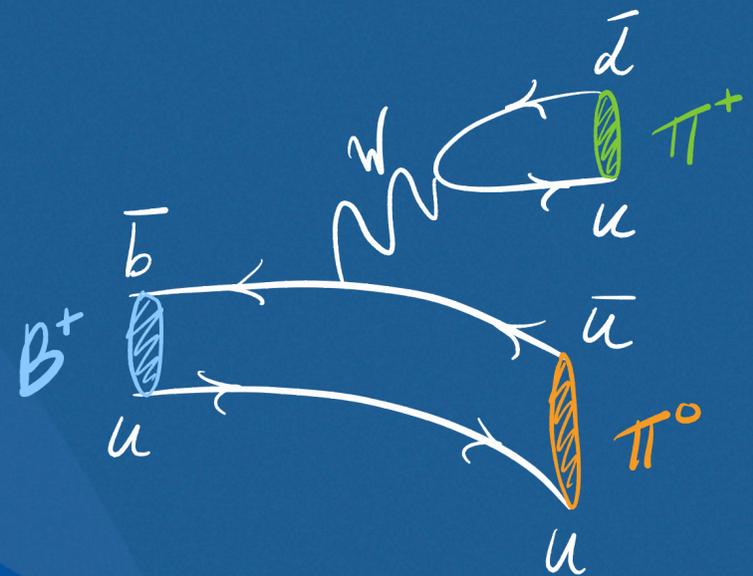
Semi-Leptonic



$$\propto \langle M | \mathcal{O} | B \rangle$$

Marta

Hadronic



$$\propto \langle M_1 M_2 | \mathcal{O} | B \rangle$$

B Mesons: Theoretically

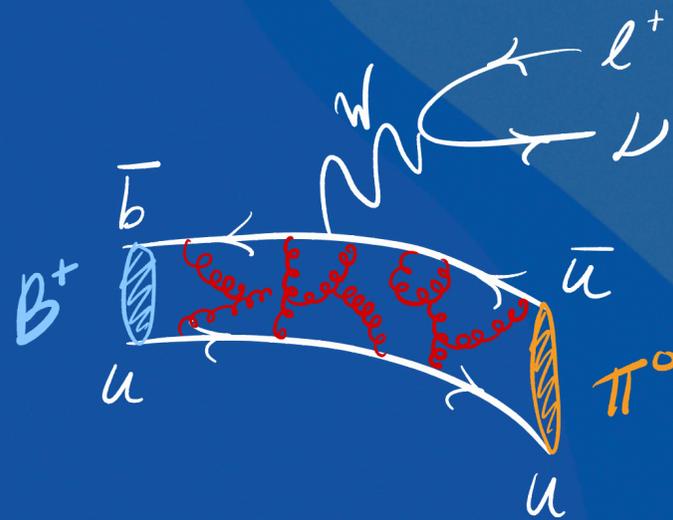
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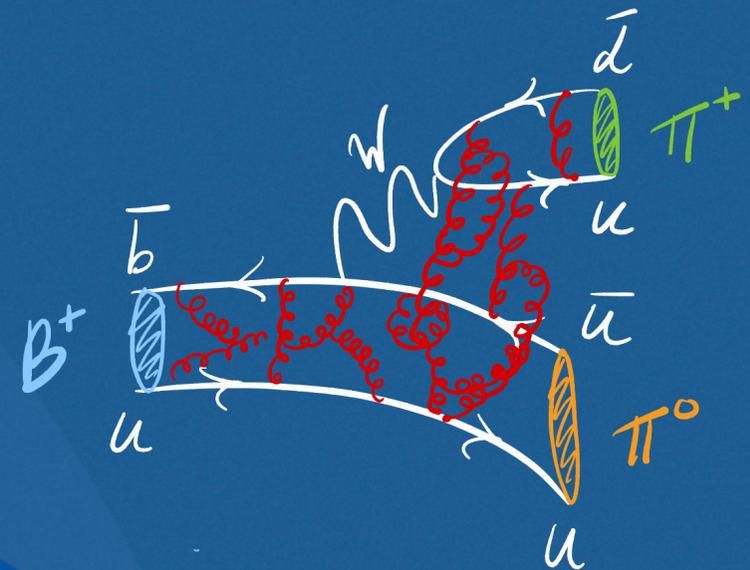
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Theoretical Complexity

B Mesons: Theoretically

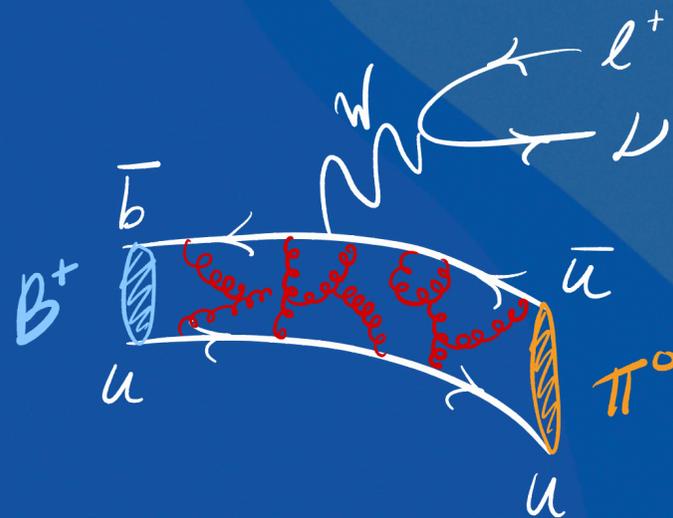
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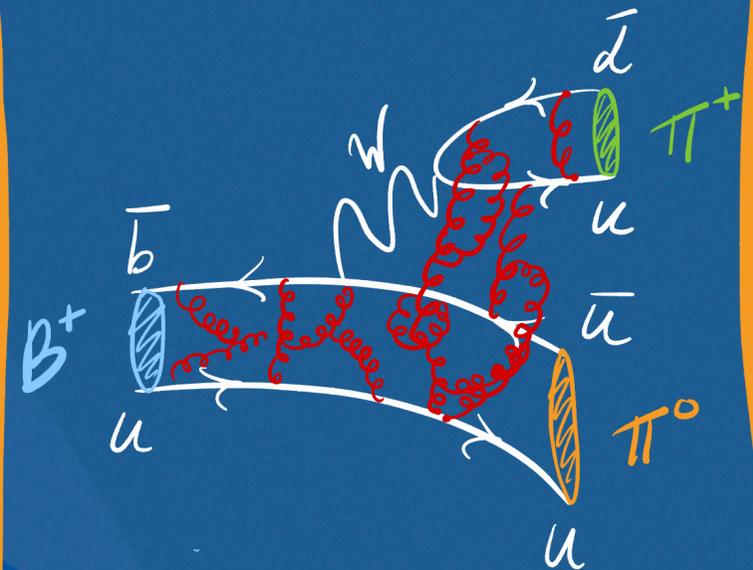
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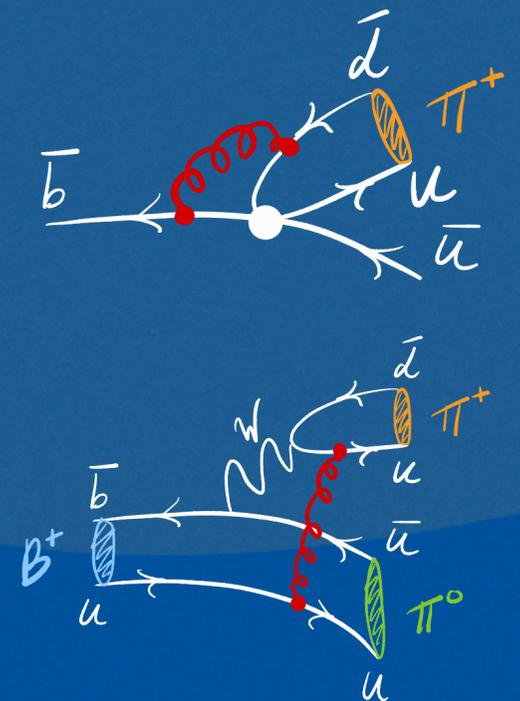
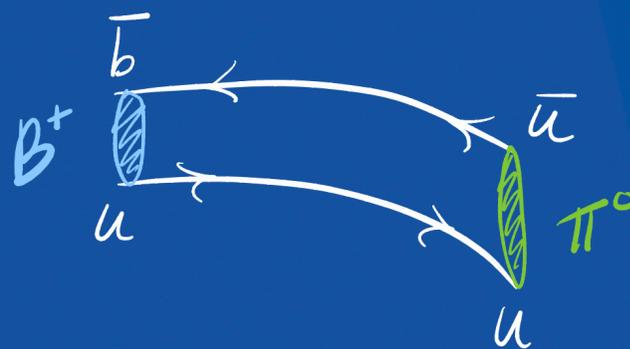
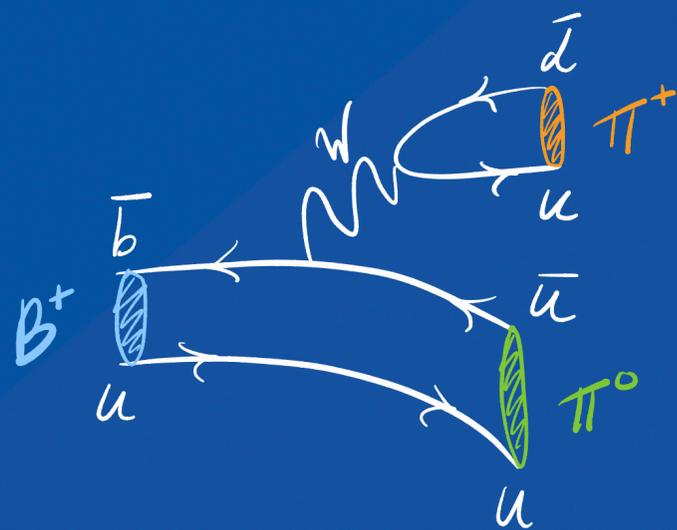


Theoretical Complexity

No model independent approach

Hadronic Decays: Theoretically

- We cannot calculate hadronic decays from first principles
- Theoretical predictions rely on QCD Factorization



$$\langle M_1 M_2 | \mathcal{O} | B \rangle$$

$$\langle M_1 | \mathcal{O} | B \rangle$$

$$\times$$

$$\langle M_2 | \mathcal{O} | 0 \rangle$$

$$+$$

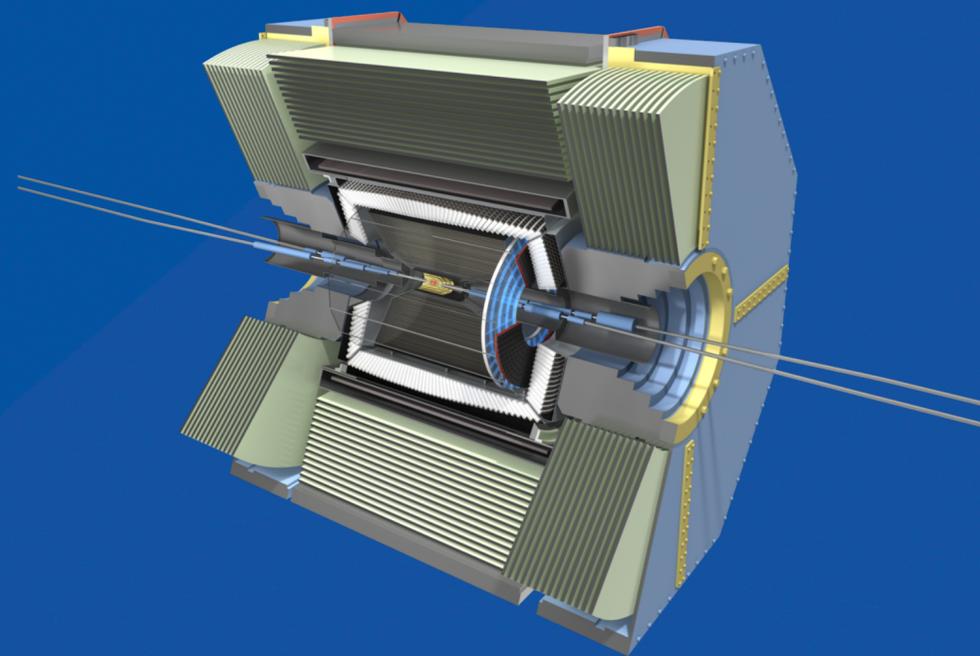
Corrections

Hadronic Decays: Theoretically

- We cannot calculate hadronic decays from first principles
- Theoretical predictions rely on QCD Factorization
- Work hand in hand with **experiments** to test models

B Mesons: Experimentally

Belle II

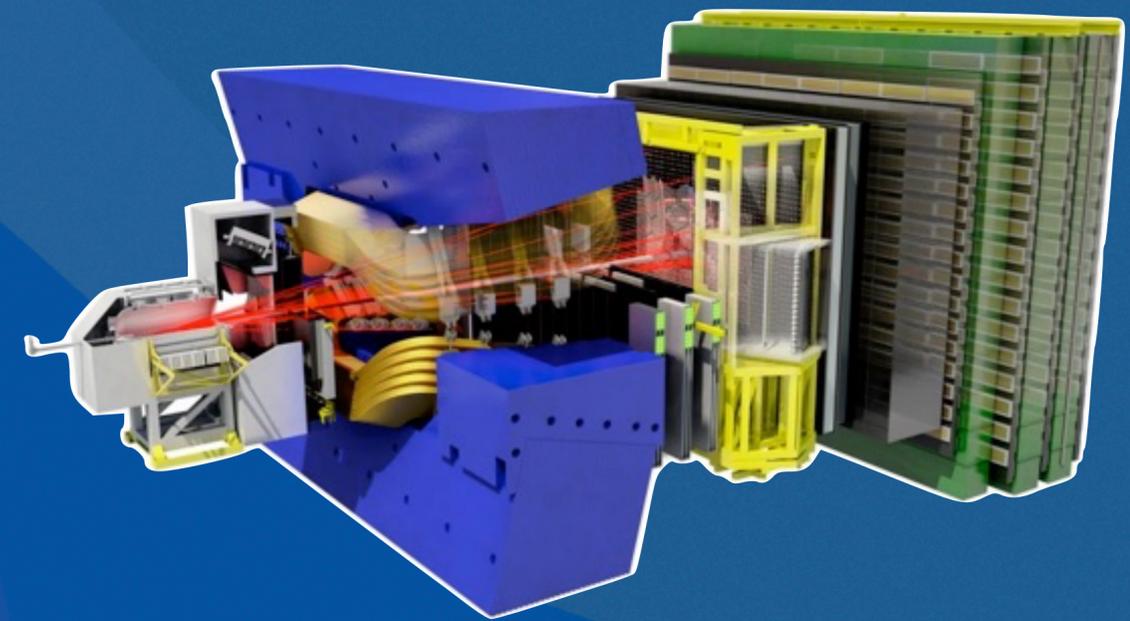


B factories: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow b\bar{b}$

Very clean production

Lower energy

LHCb



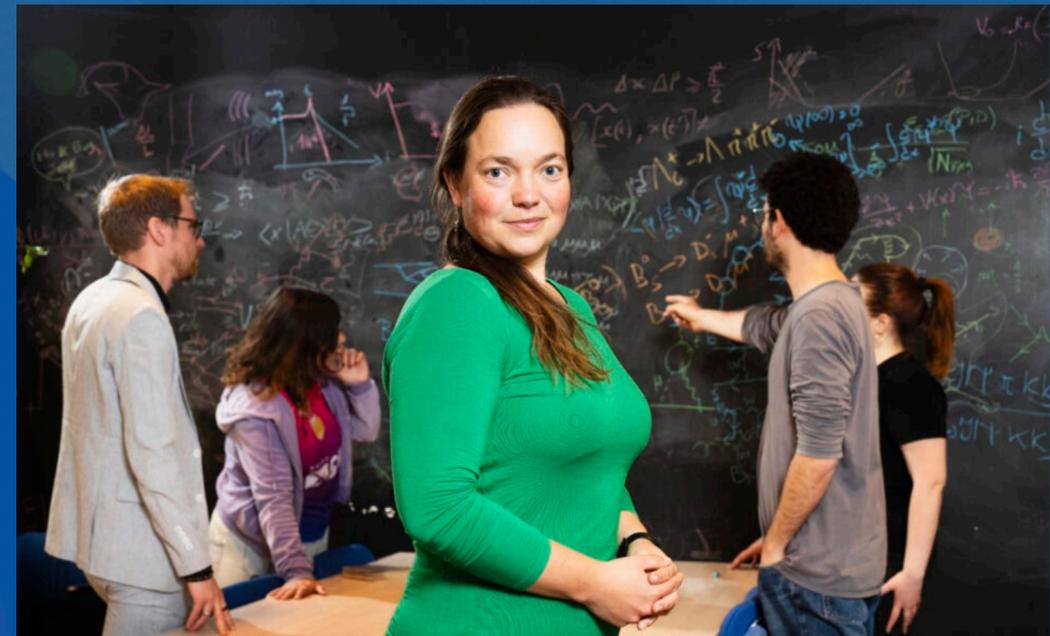
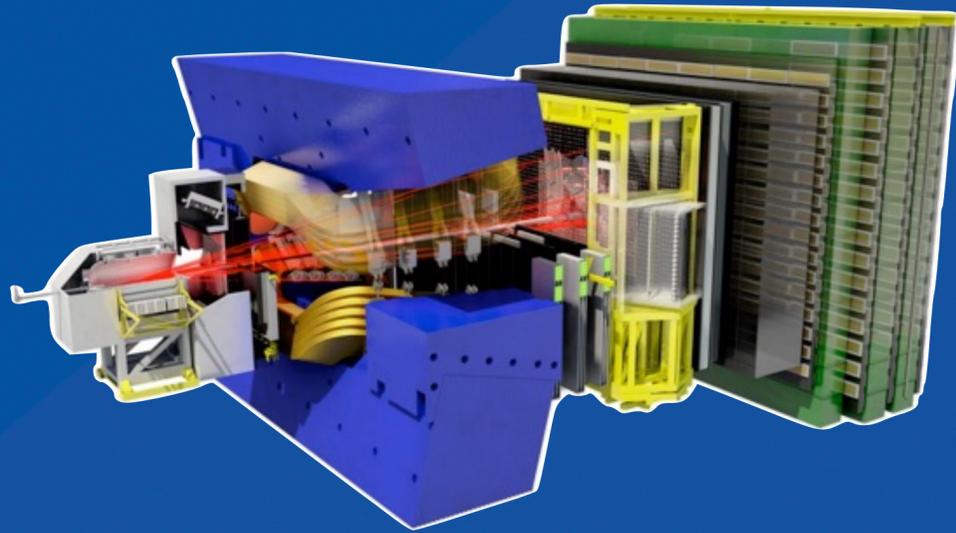
Forward spectrometer: $pp \rightarrow b\bar{b}$

Messy interactions

Full spectrum of *B* mesons, high lumi

Hadronic decays: Experimentally

What can we measure to better understand QCD and CP Violation?

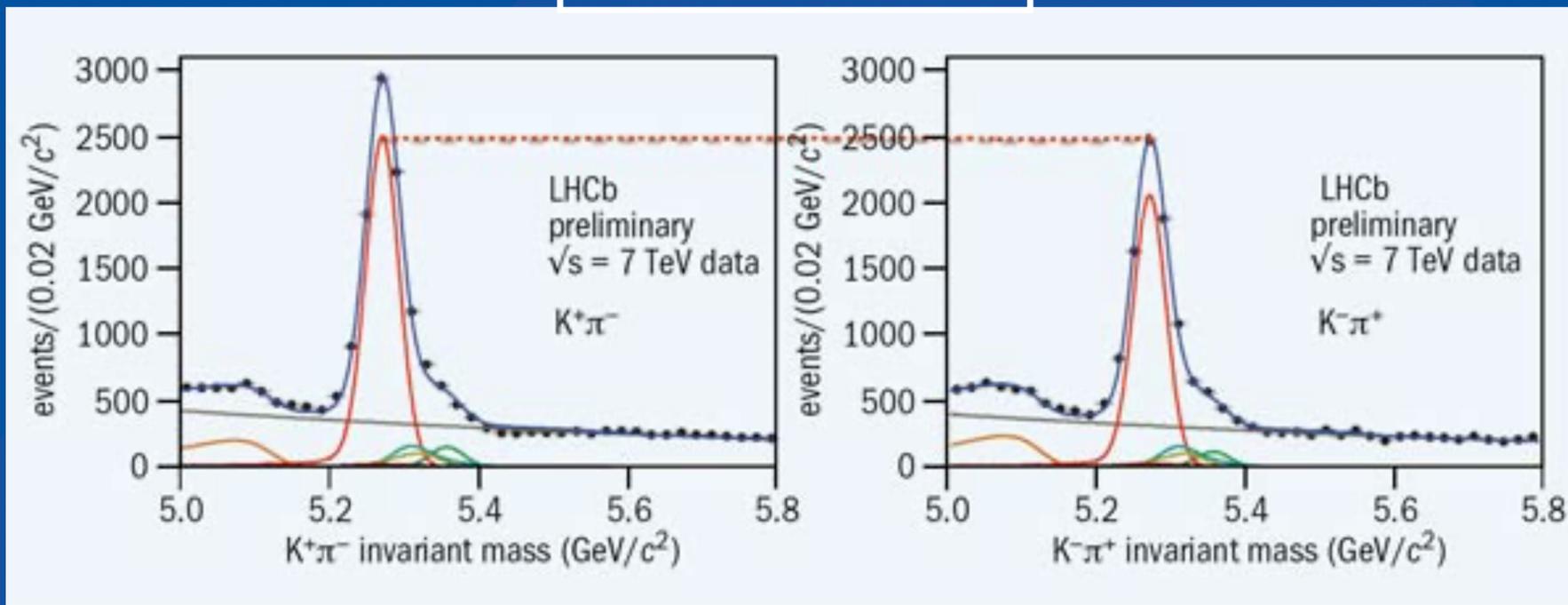


Which calculations can we do to improve measurements?

Hadronic decays: Experimentally

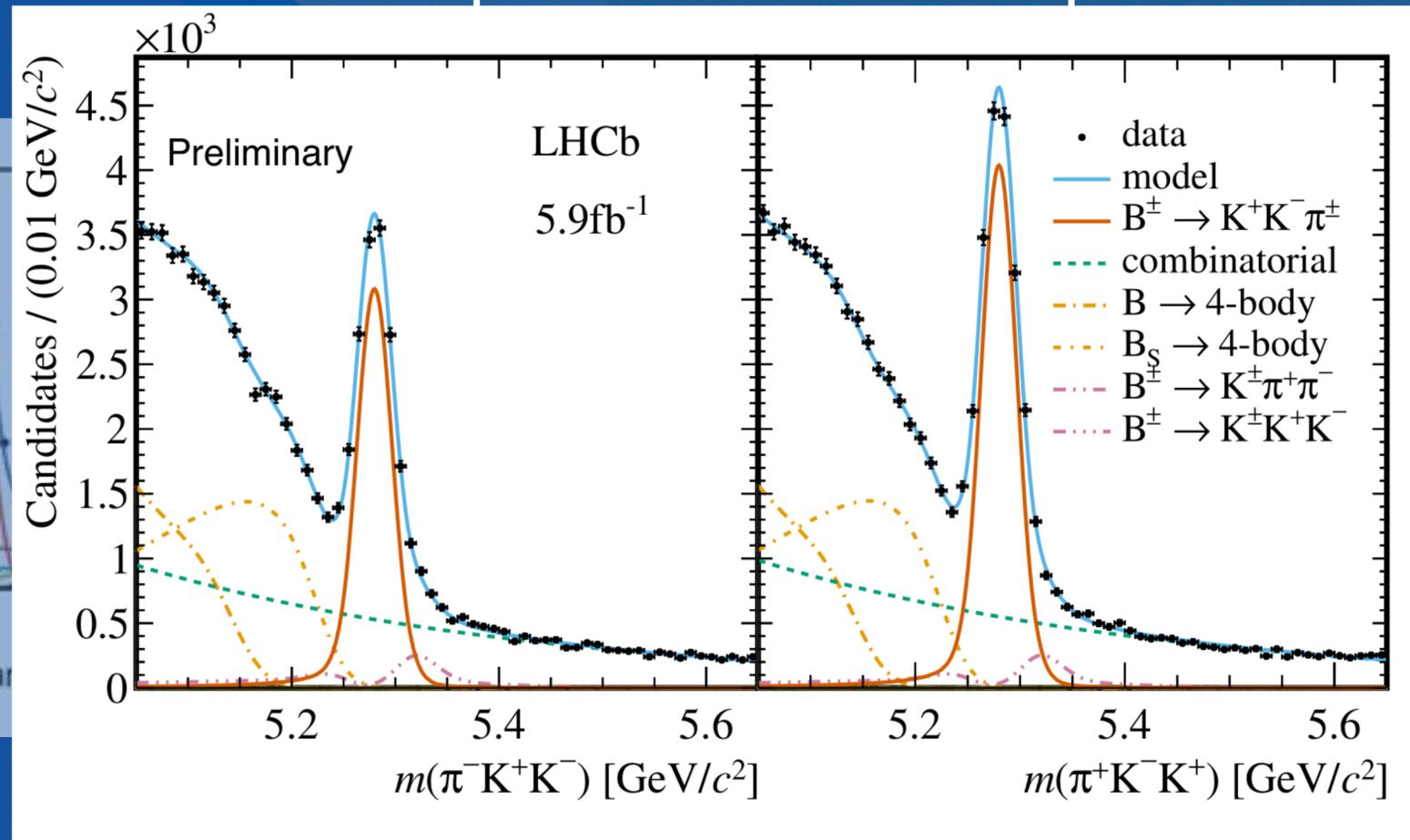
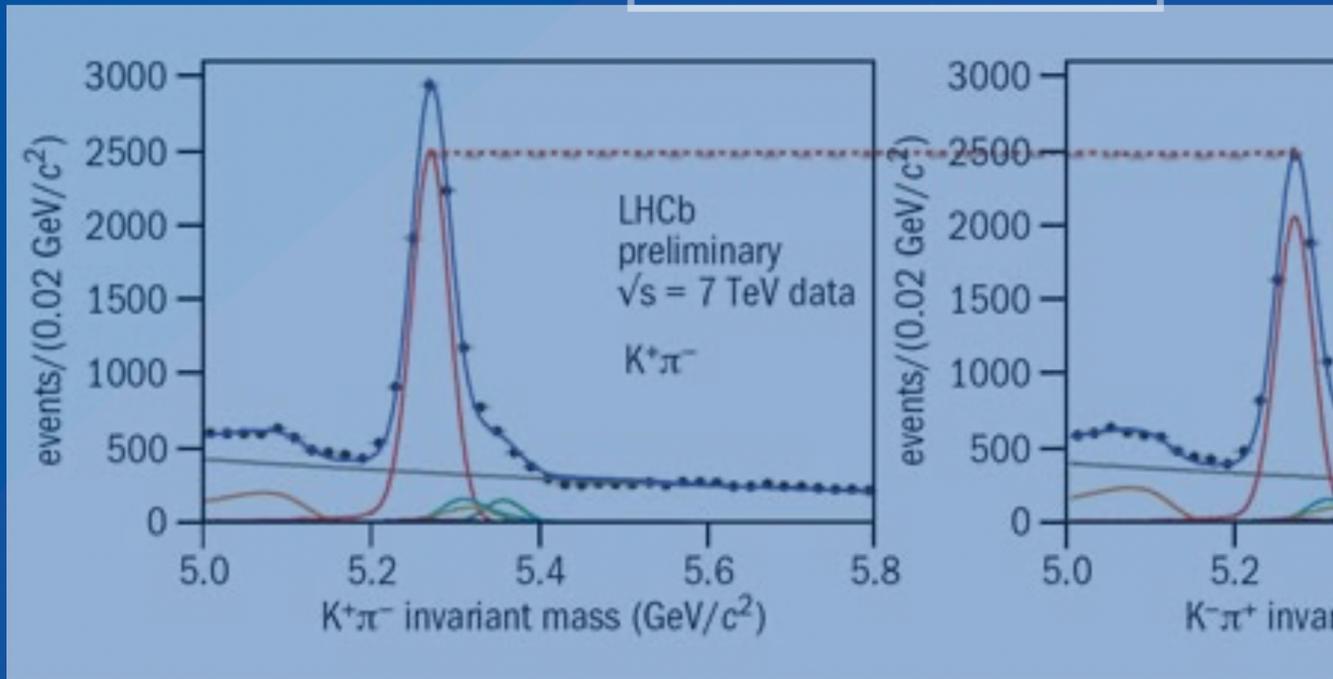
- Theoretically challenging but plenty of available experimental data: specially **CP asymmetries!**

$$B^0 \rightarrow K^+ \pi^-$$



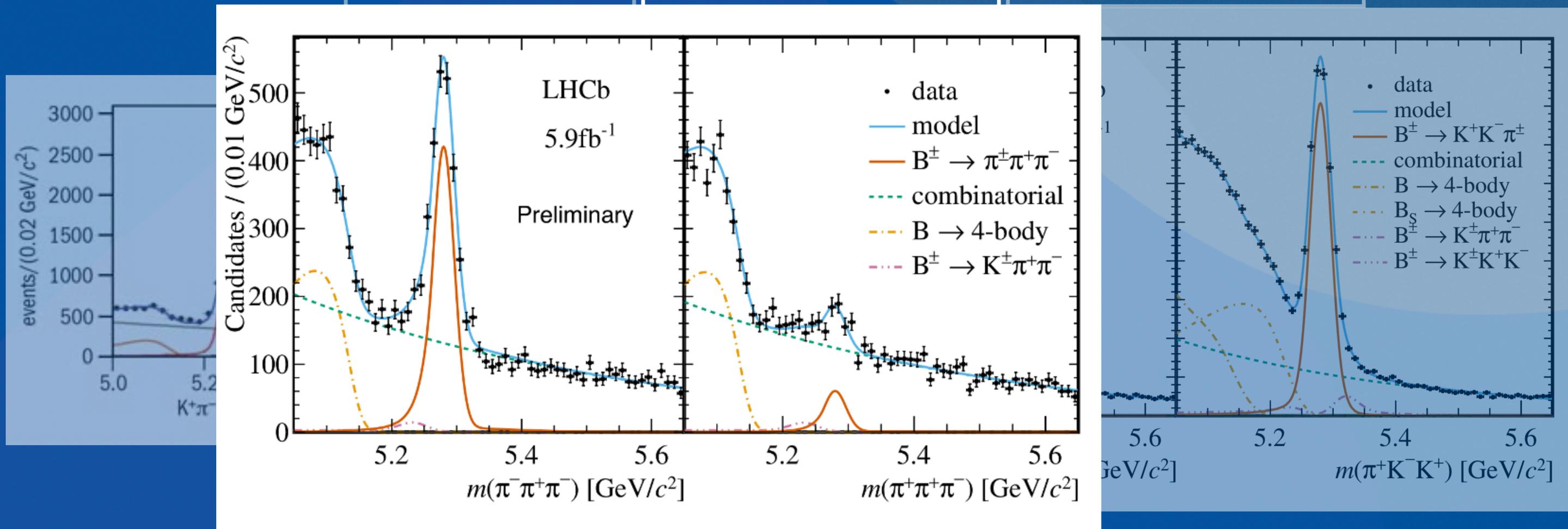
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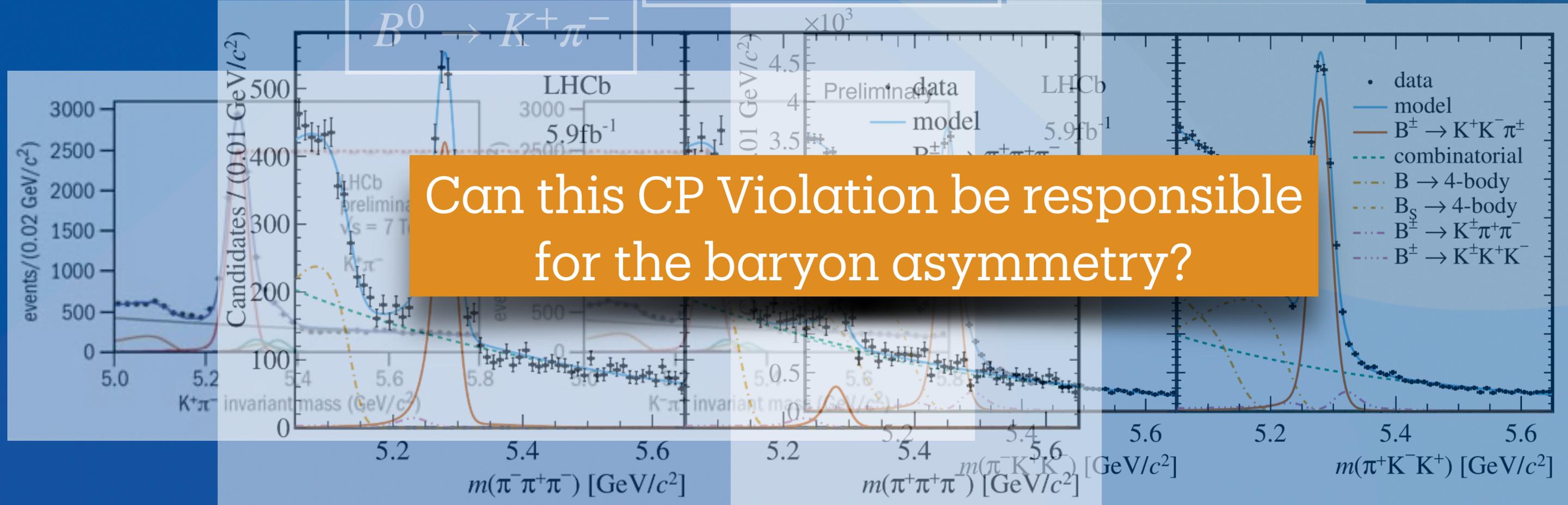
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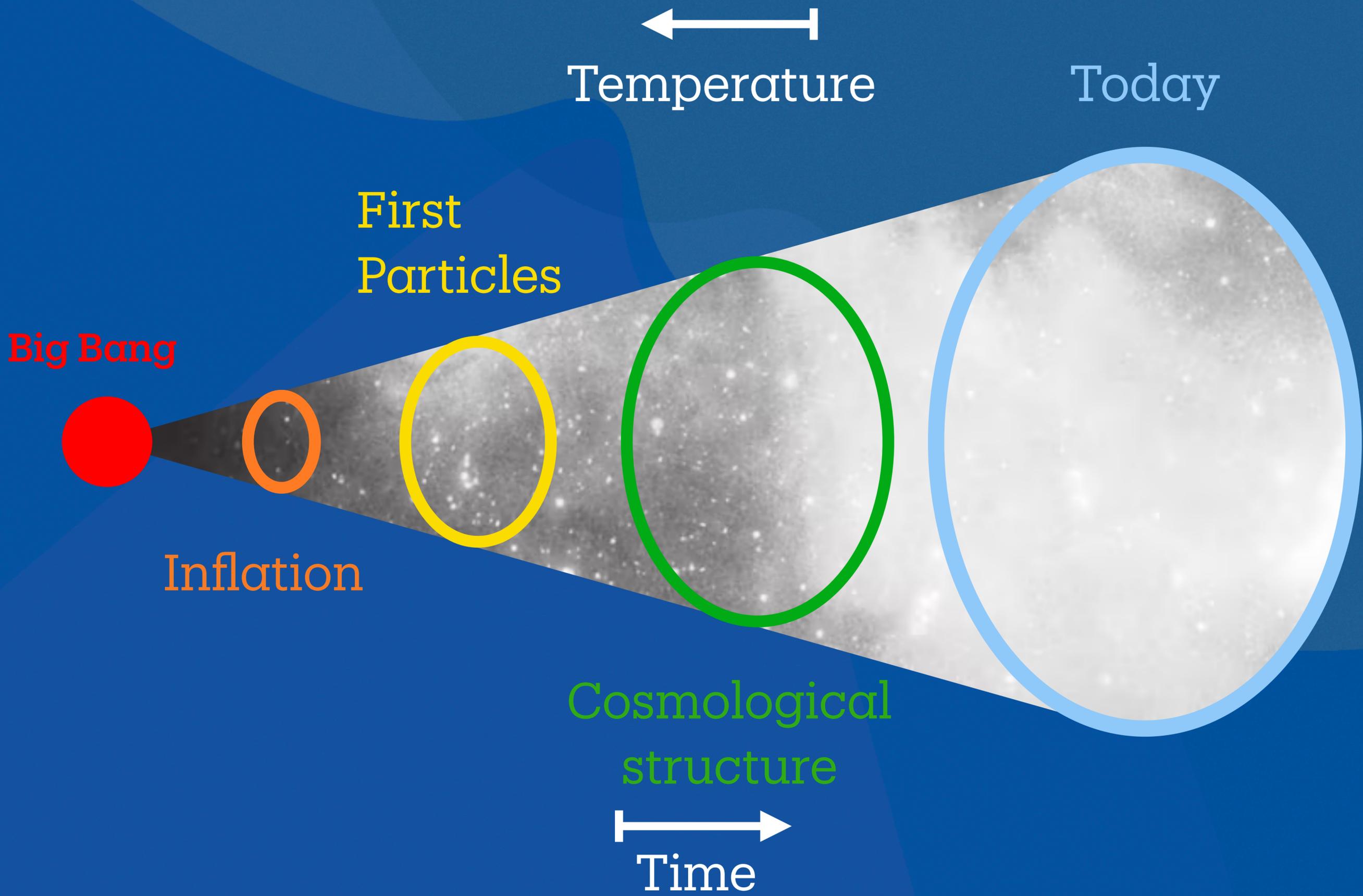
Hadronic decays: Experimentally

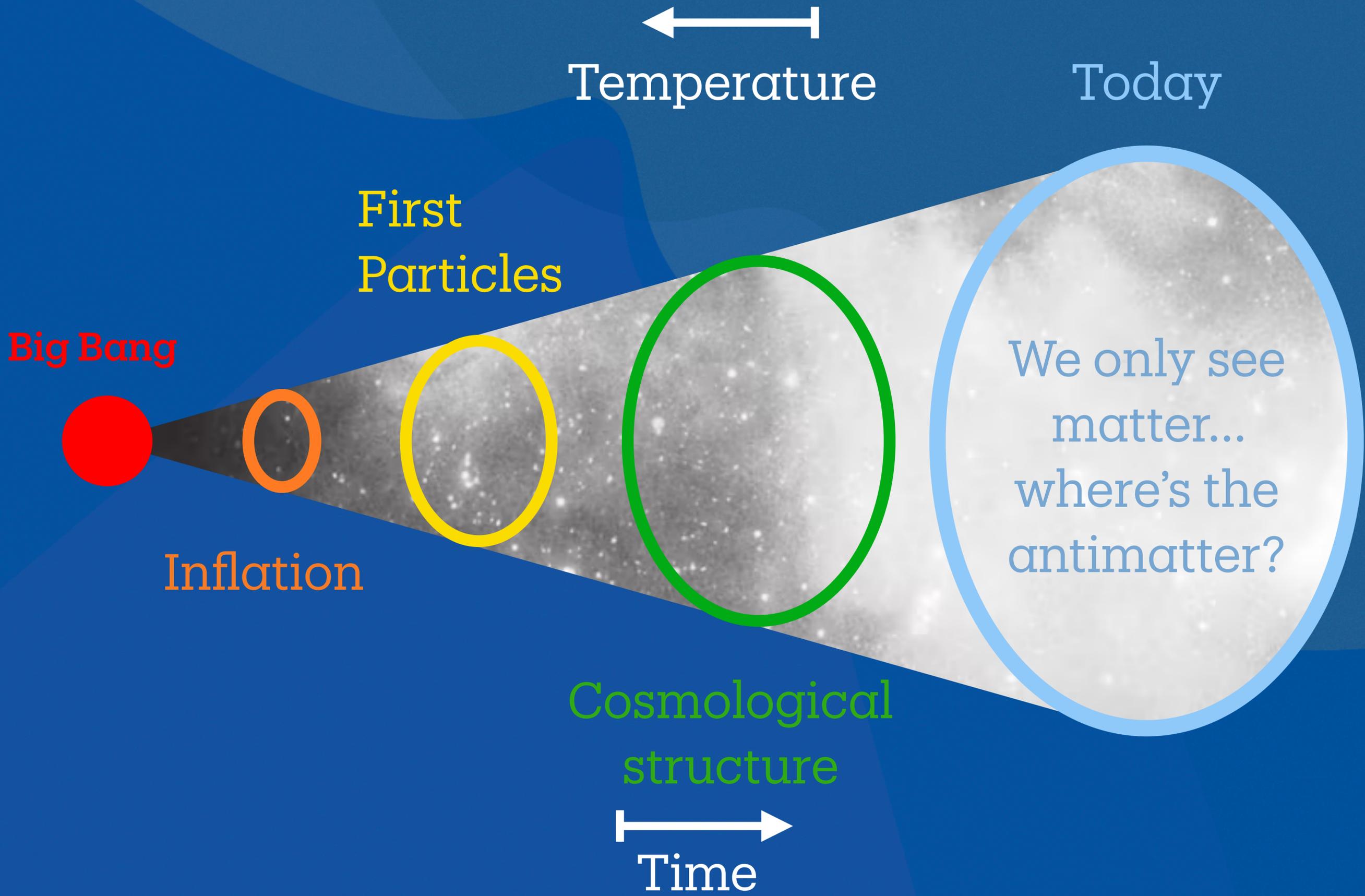
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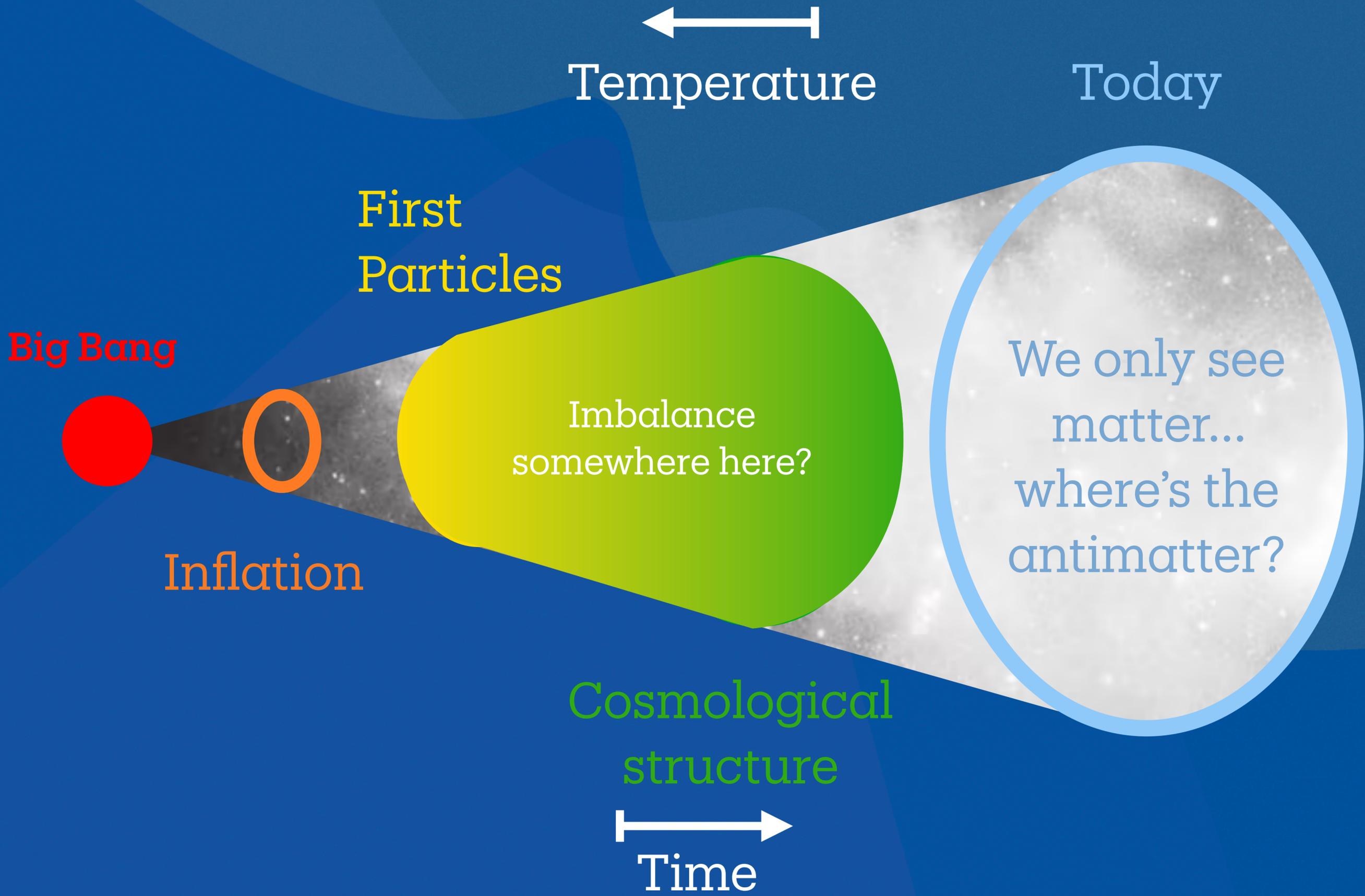


Can this CP Violation be responsible for the baryon asymmetry?

Baryon asymmetry







Matter - Antimatter Asymmetry

- What do we need? Sakharov conditions
 - CP Violation: changes particles for antiparticles
 - Out of equilibrium: otherwise the asymmetry is washed out
 - Baryon number violation: we want more baryons than anti baryons



Matter - Antimatter Asymmetry

- What do we need? Sakharov conditions
Not enough...?

- CP Violation: changes particles for antiparticles

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Not enough CP asymmetry

Why is CP violation in SM is not enough?

Early cosmological time ($T \sim 150 \text{ GeV}$):
asymmetry is washed out

Missing mechanism to translate it into
baryon asymmetry



B Meson

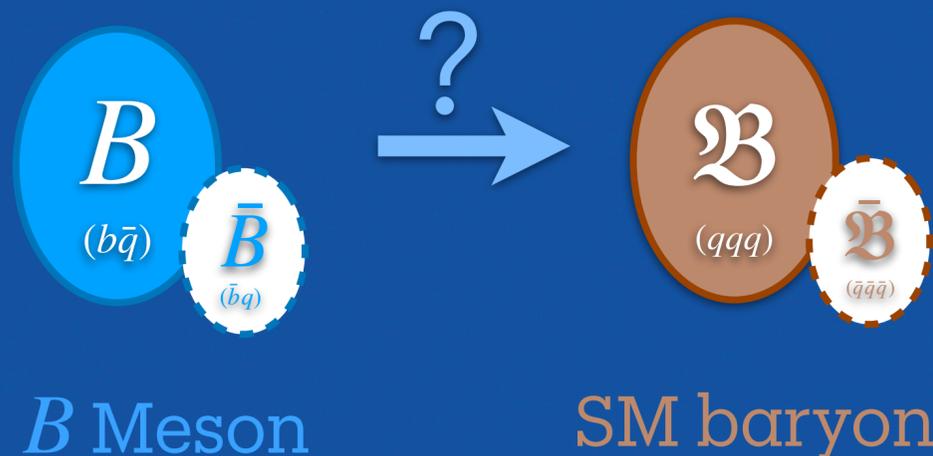
SM baryon

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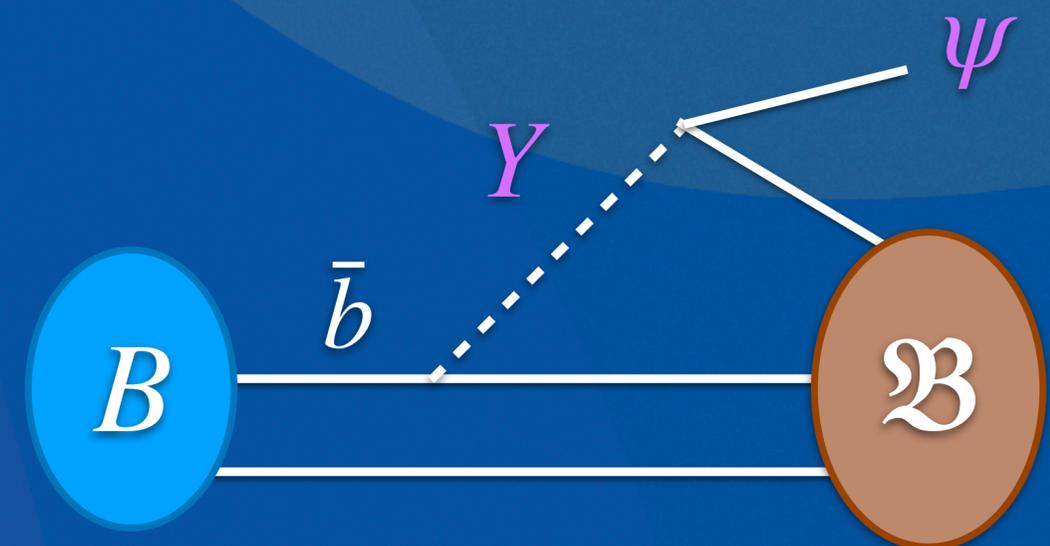
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B mesogenesis solves these two issues:

Very low temperatures ($T \sim 0.1 \text{ GeV}$)
(late times)

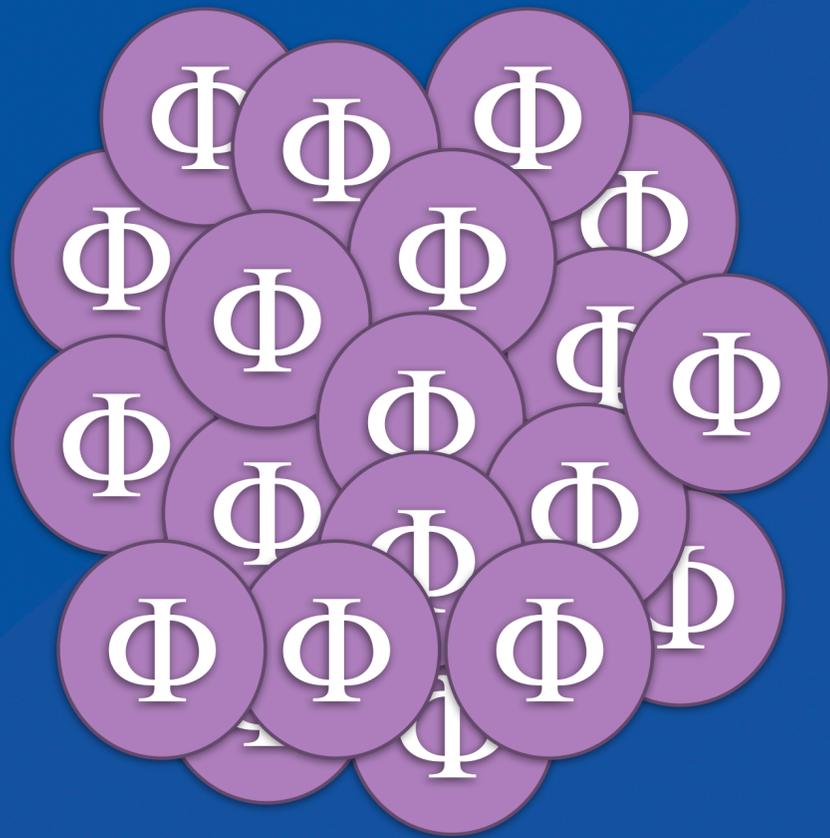
B mesons decay into baryons by
introducing Dark Matter fields



Fundamentals of B Mesogenesis

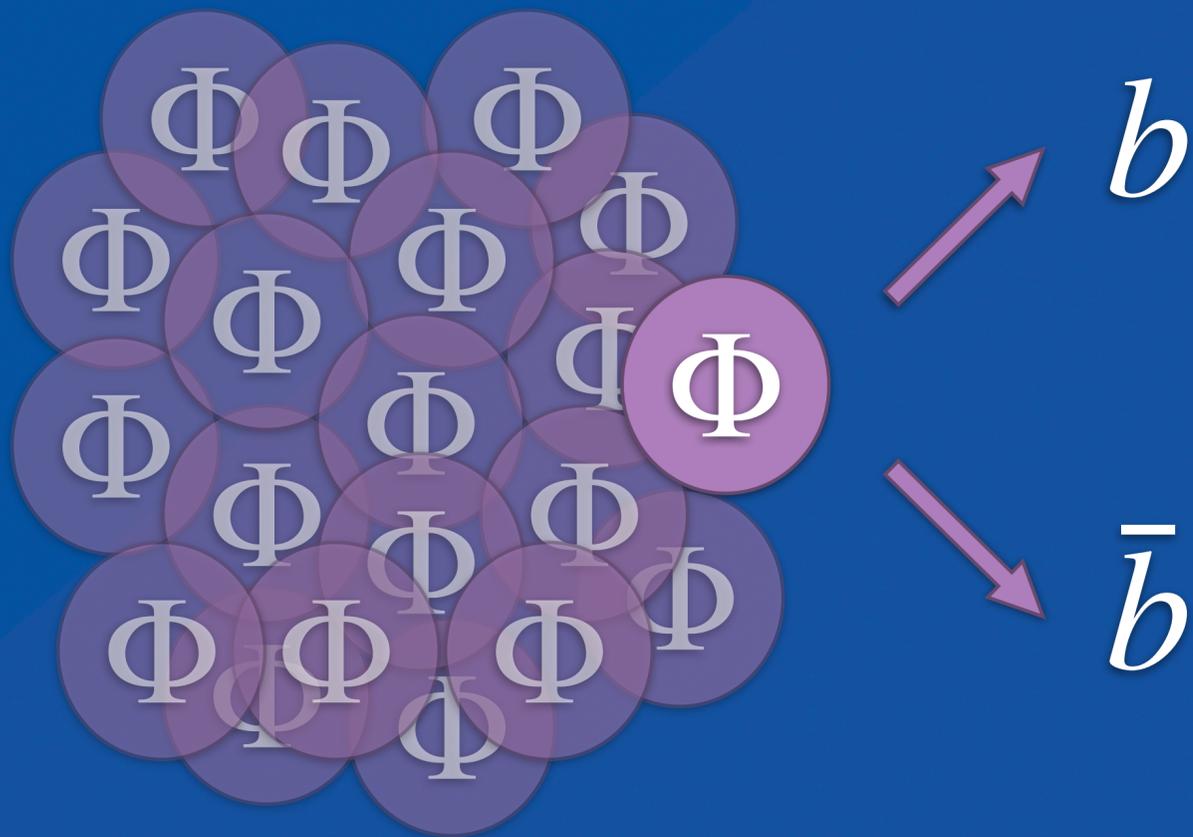
Fundamentals of B Mesogenesis

- We start from a scalar field (inflaton) Φ that permeates the whole plasma



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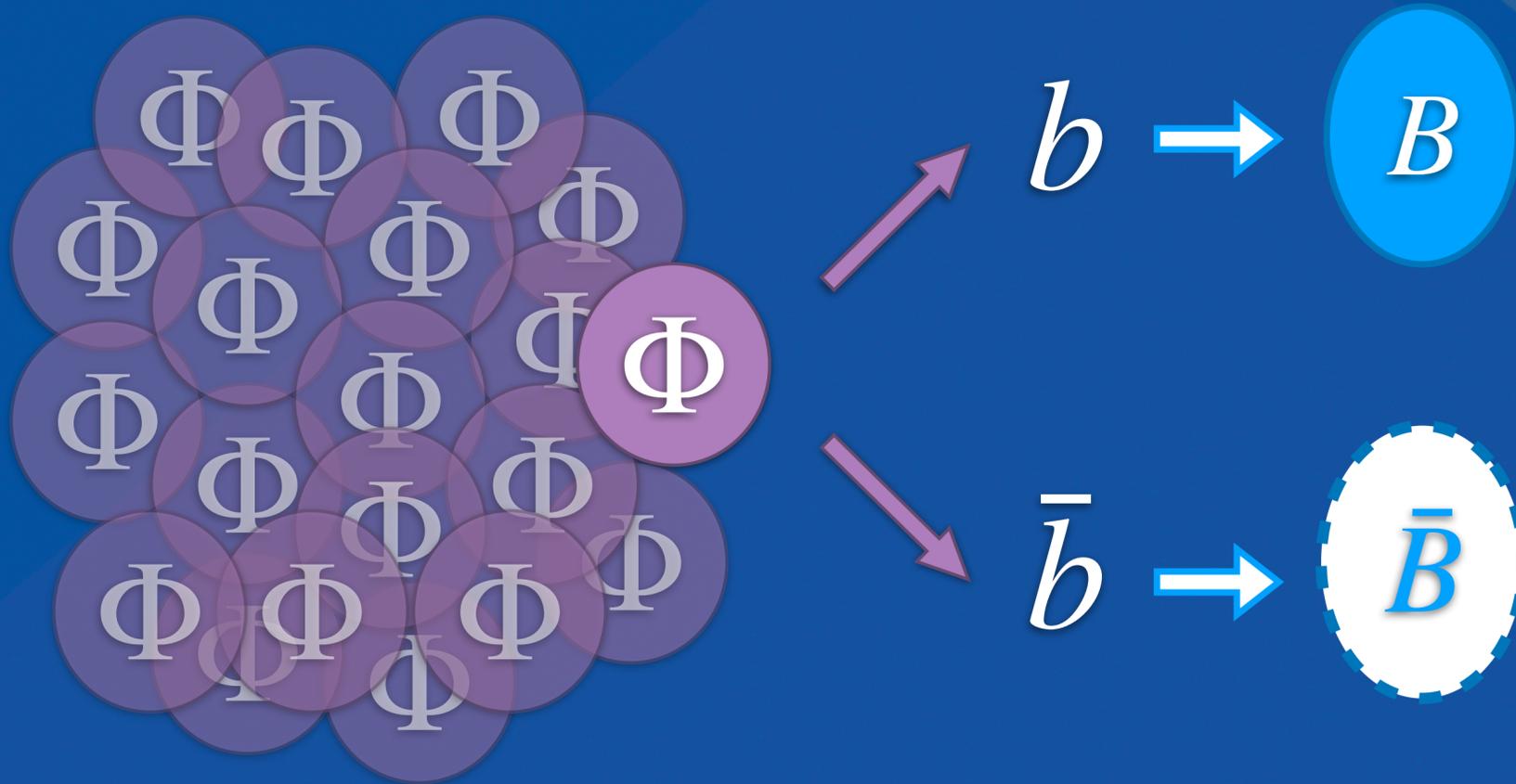


Decay into b quarks at
 $T_{\text{reh}} \sim 100 \text{ MeV} < \Lambda_{\text{QCD}}$

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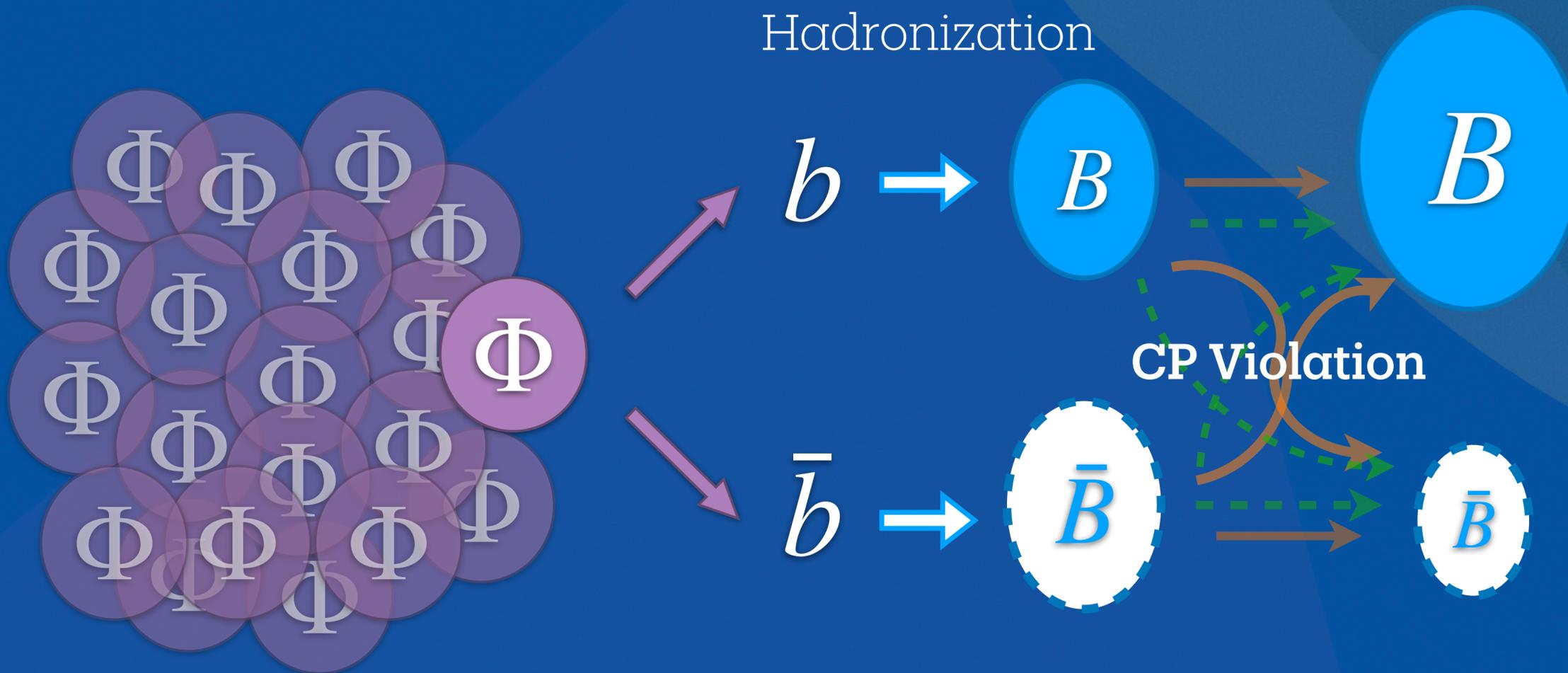
Hadronization



Decay into b quarks at
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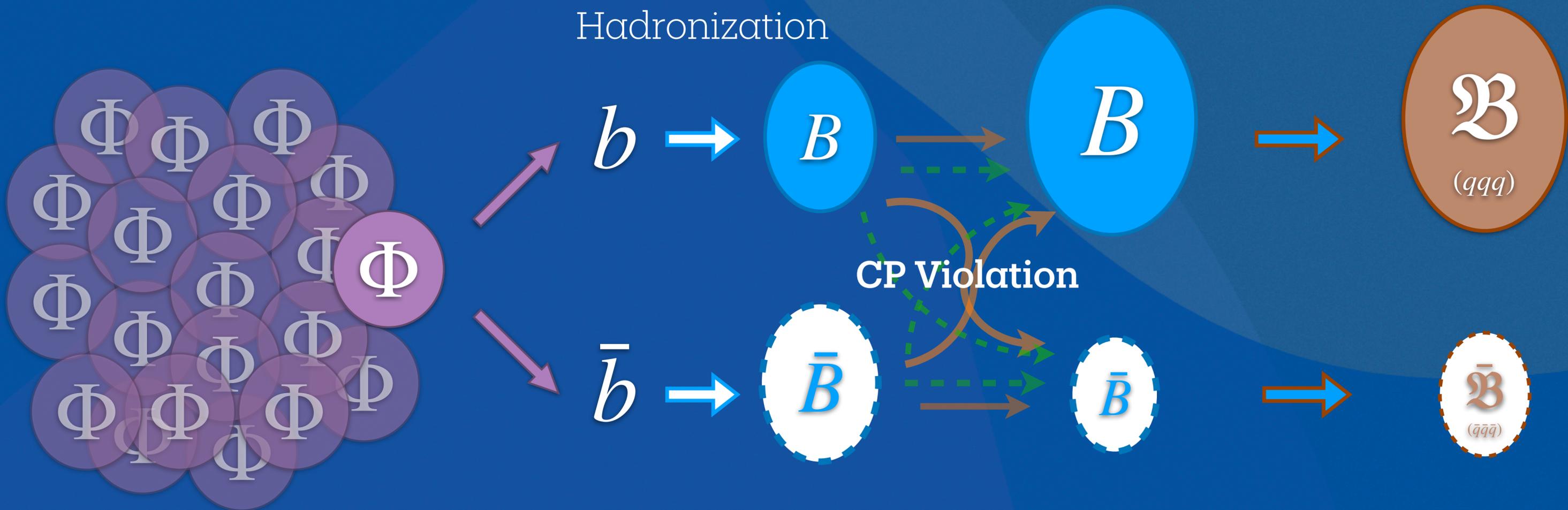
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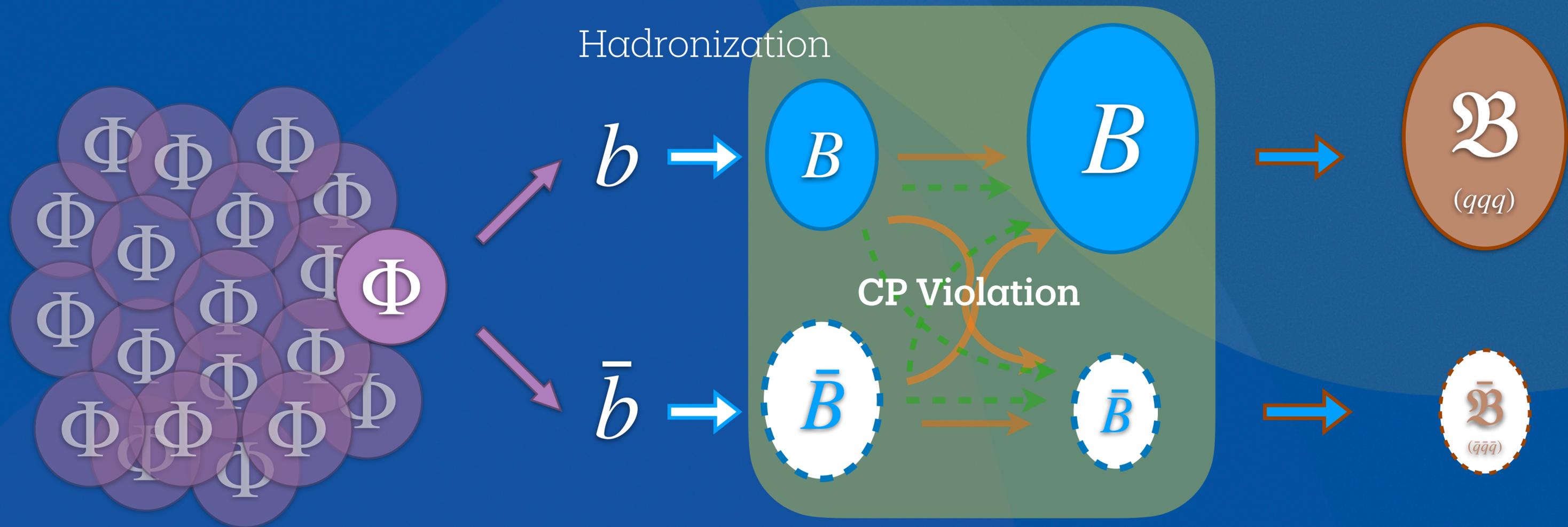


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Decay into baryons

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Decay into b quarks at
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Purely SM!!

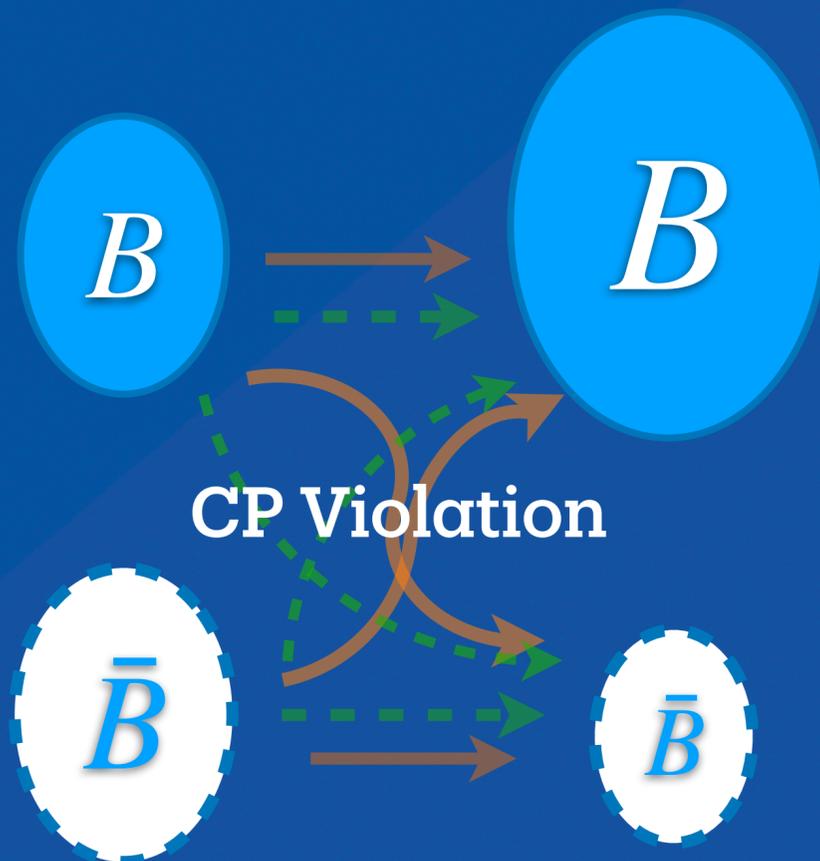
Decay into baryons

Fundamentals of B Mesogenesis

- How much CP violation do we need in the B system to generate the observed baryon asymmetry?

Observed:
$$Y_{\mathfrak{B}} = \frac{n_{\mathfrak{B}} - n_{\bar{\mathfrak{B}}}}{s} \simeq 8.7 \times 10^{-11}$$

Under mesogenesis:
$$Y_{\mathfrak{B}} = \alpha(T_{\text{reh}}) \frac{T_{\text{reh}}}{M_{\Phi}} \Delta_B$$



Fundamentals of B Mesogenesis

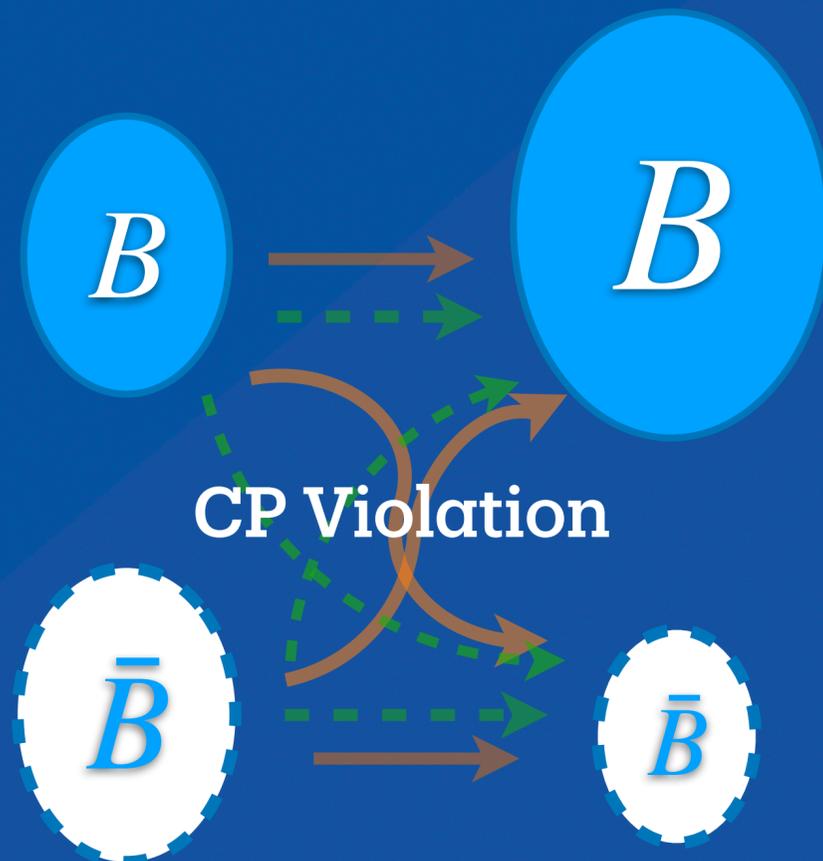
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$$\alpha(T_{\text{reh}}) \frac{T_{\text{reh}}}{M_{\Phi}} \sim 10^{-5} - 10^{-3}$$

Cosmology territory...

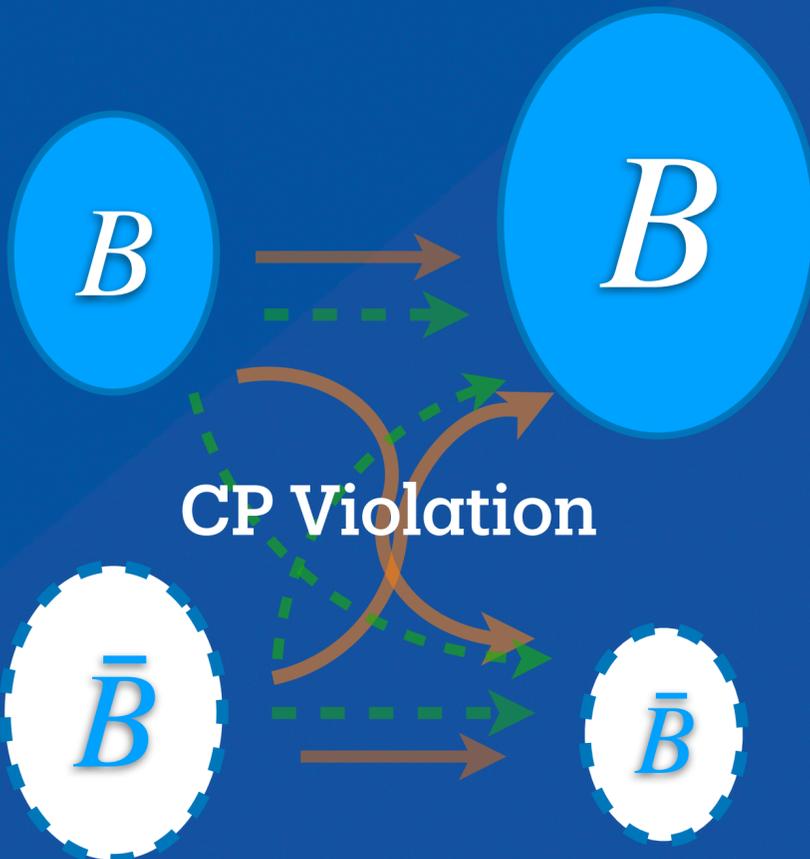


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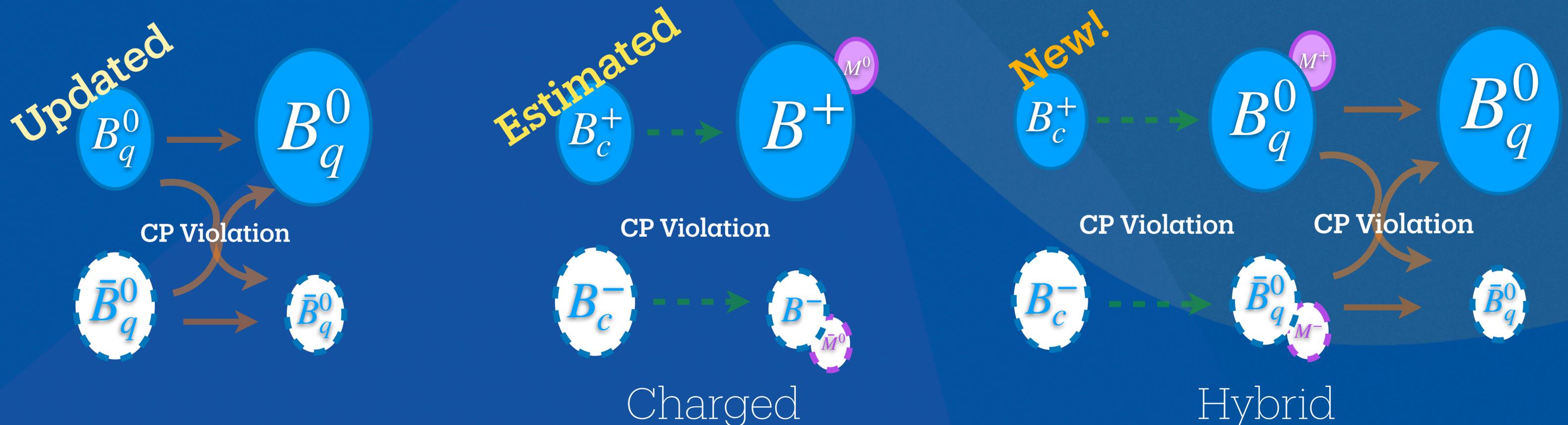
$$\alpha(T_{\text{reh}}) \frac{T_{\text{reh}}}{M_{\Phi}} \sim 10^{-5} - 10^{-3}$$

Cosmology territory...

$$\Delta_B \sim 10^{-8} - 10^{-6}$$

Calculable in Flavor Physics 13

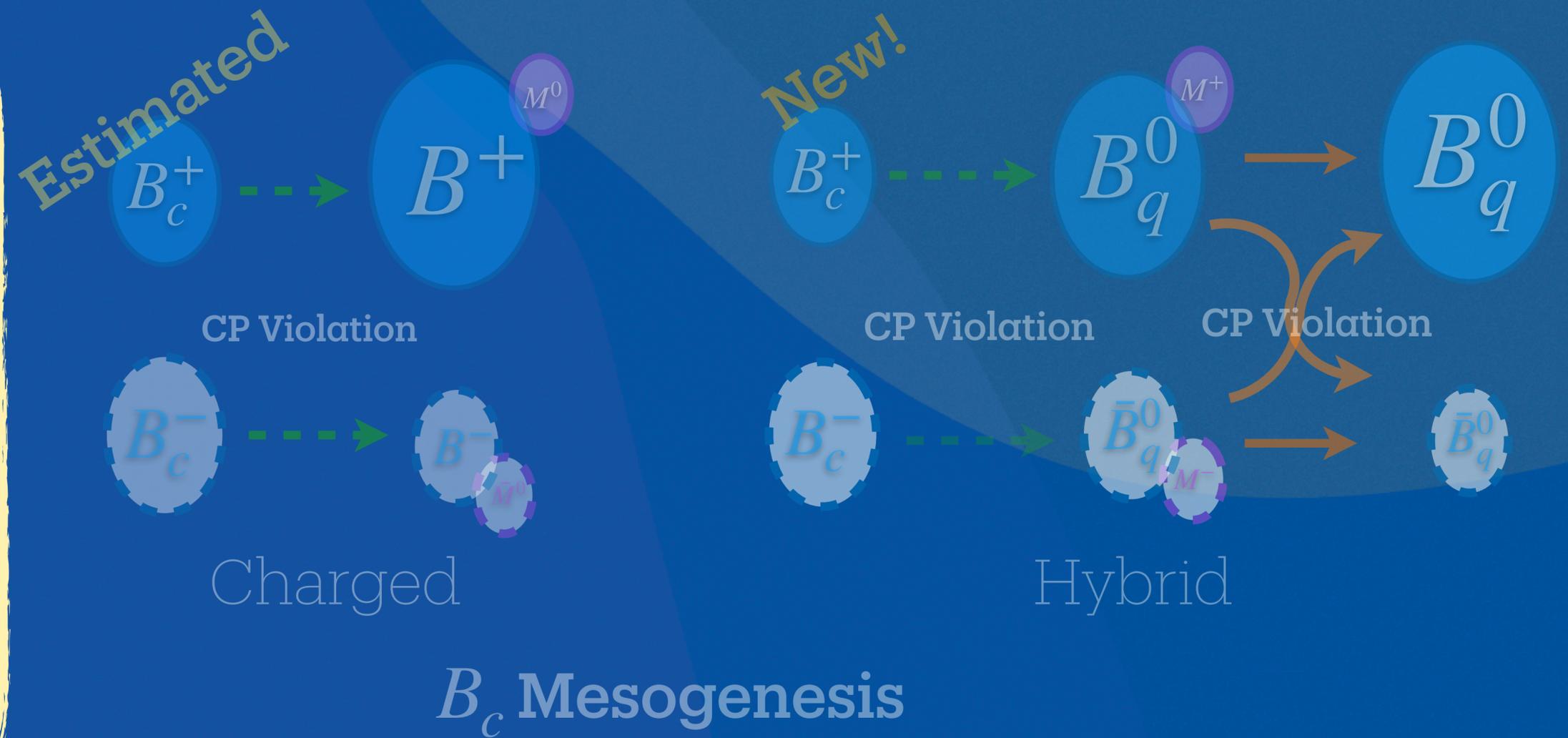
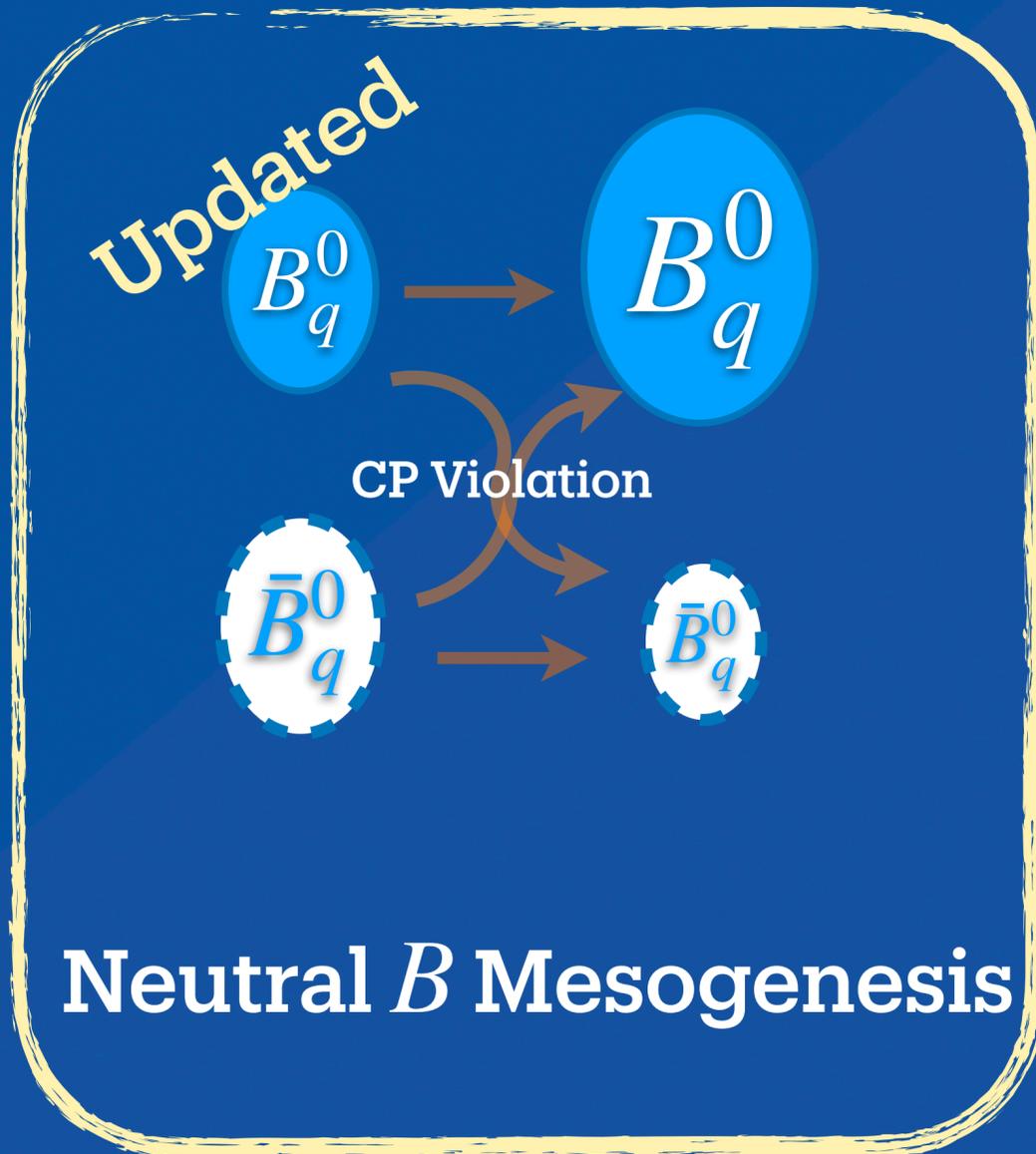
Contributions to Mesogenesis



Neutral B Mesogenesis

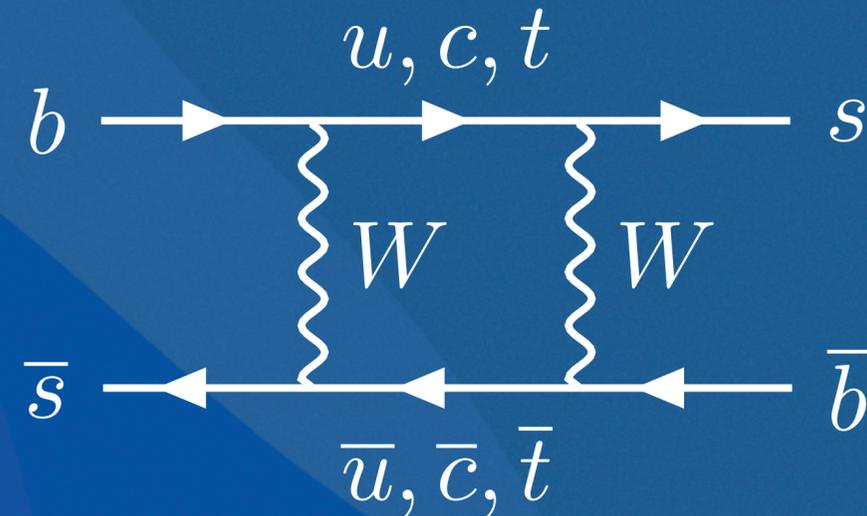
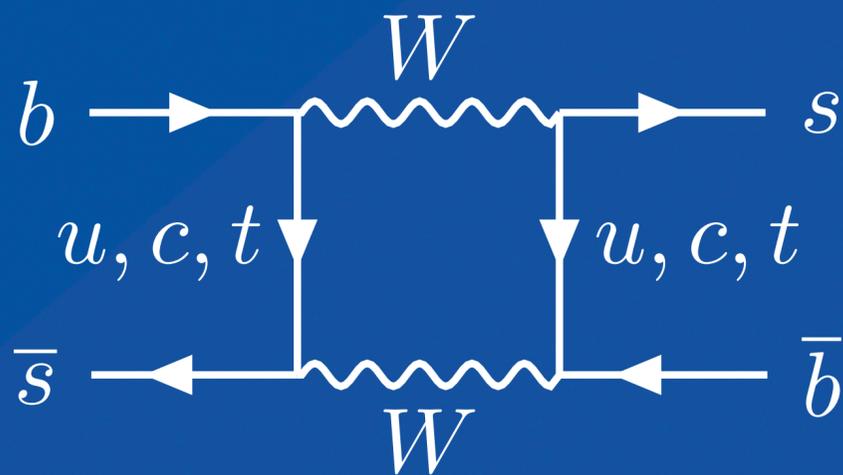
B_c Mesogenesis

Contributions to Mesogenesis



Neutral B Mesogenesis

- Baryon asymmetry generated by mixing of neutral B mesons



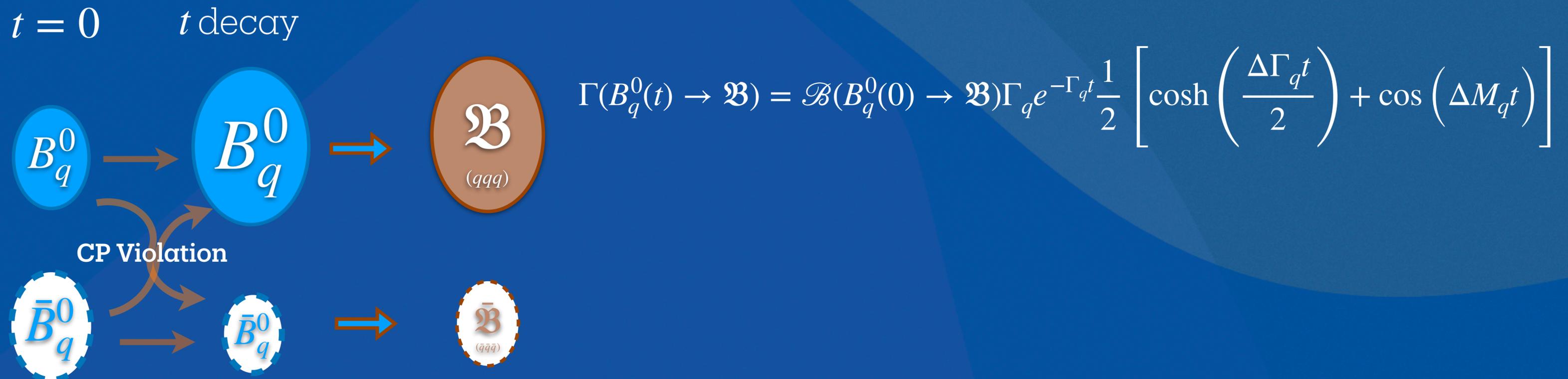
- Mixing appears as a mismatch between flavour and mass eigenstates

$$|B_{q,L}^0\rangle = \mathfrak{p}_q |B_q^0\rangle + \mathfrak{q}_q |\bar{B}_q^0\rangle$$

$$|B_{q,H}^0\rangle = \mathfrak{p}_q |B_q^0\rangle - \mathfrak{q}_q |\bar{B}_q^0\rangle$$

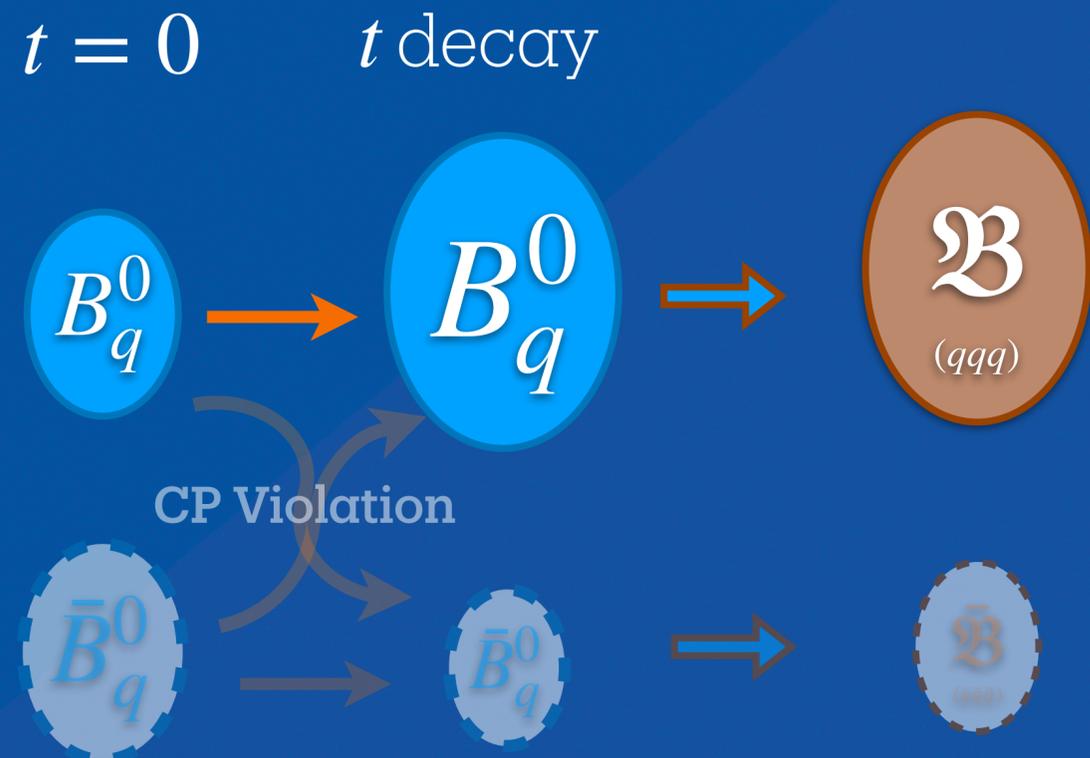
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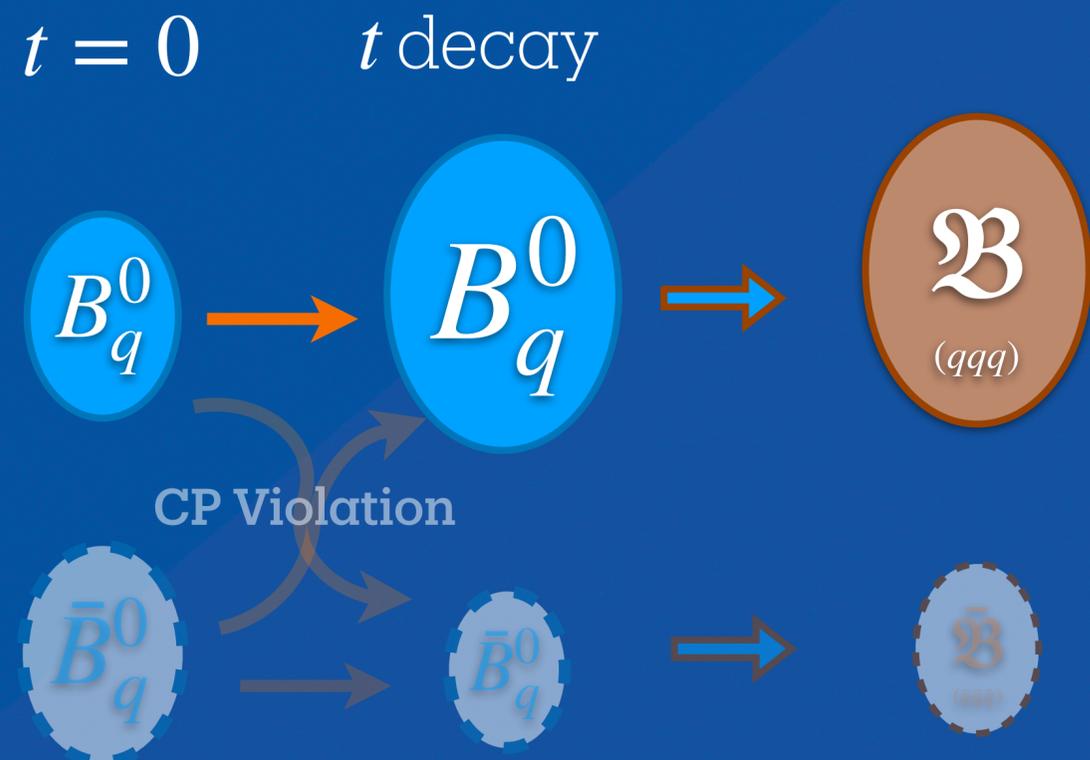


$$\Gamma(B_q^0(t) \rightarrow \mathfrak{B}) = \mathcal{B}(B_q^0(0) \rightarrow \mathfrak{B}) \Gamma_q e^{-\Gamma_q t} \frac{1}{2} \left[\cosh\left(\frac{\Delta\Gamma_q t}{2}\right) + \cos(\Delta M_q t) \right]$$

Branching ratio at $t=0$ (no mixing)

Neutral B Mesogenesis

- Baryon asymmetry generated by mixing of neutral B mesons

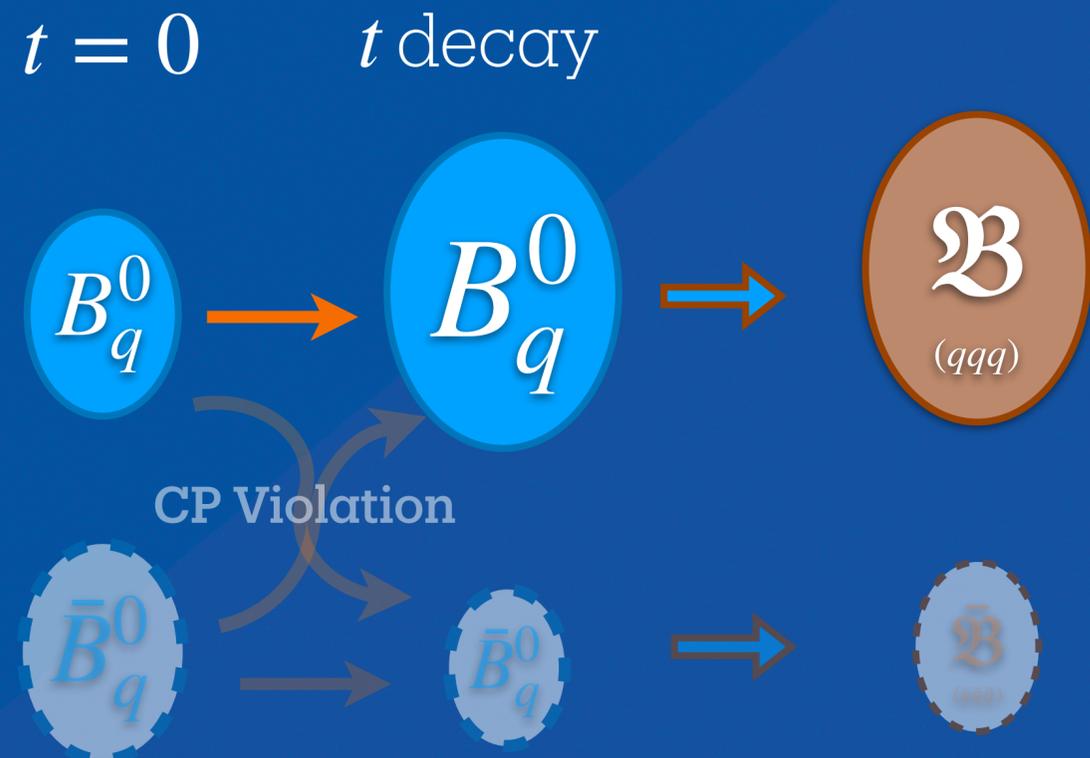


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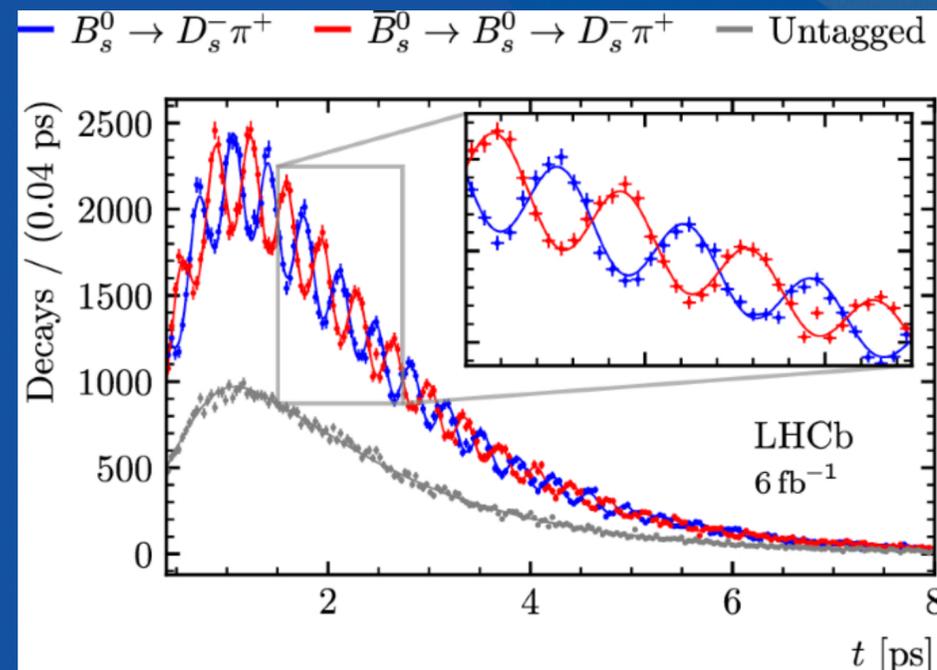
Modulates the standard exponential decay

Neutral B Mesogenesis

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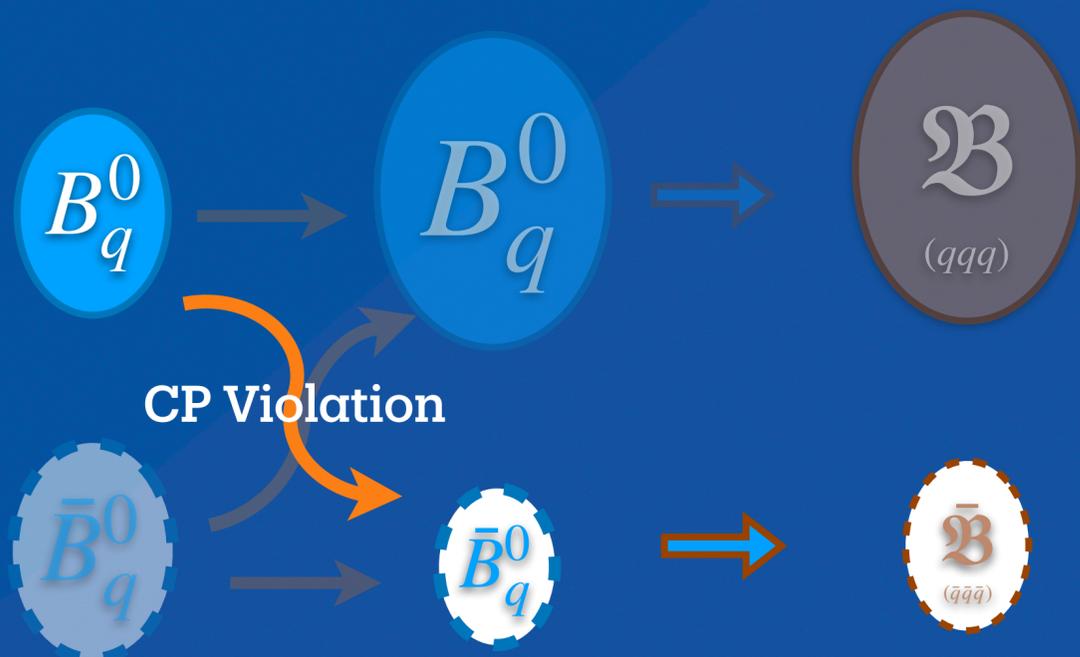


Produces the oscillations between states

Neutral B Mesogenesis

- Baryon asymmetry generated by mixing of neutral B mesons

$t = 0$ t decay



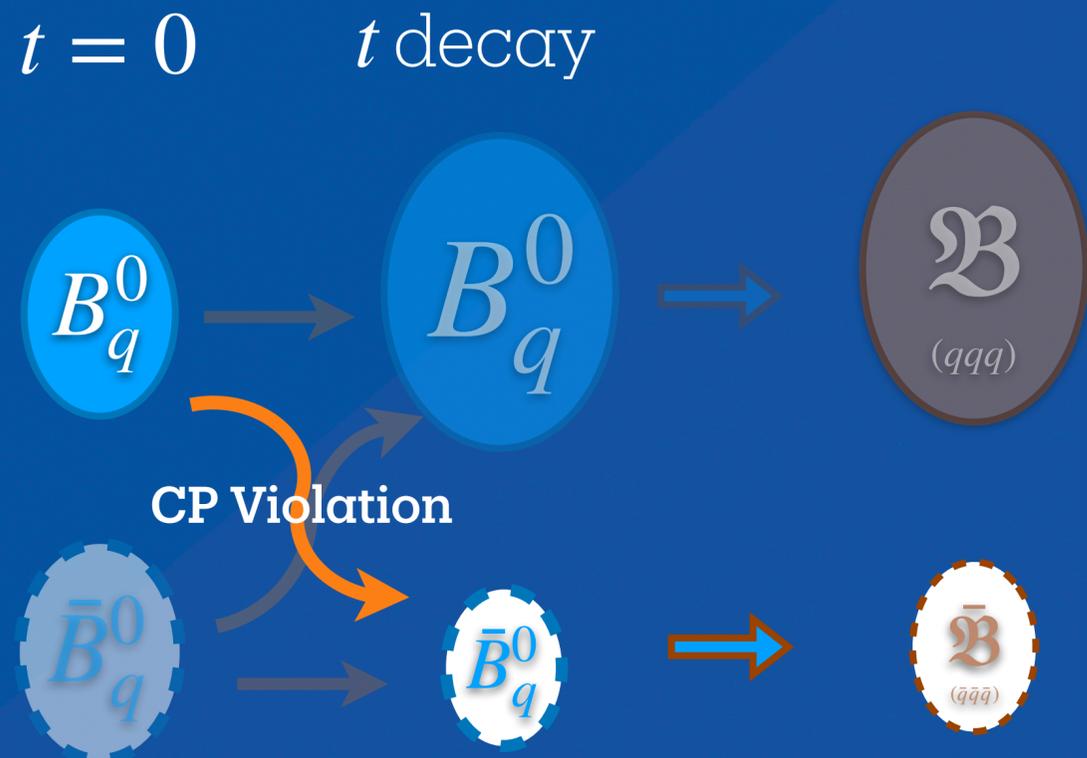
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$$\Gamma(B_q^0(t) \rightarrow \bar{\mathfrak{B}}) = \mathcal{B}(B_q^0(0) \rightarrow \bar{\mathfrak{B}})\Gamma_q e^{-\Gamma_q t} (1 - a_q) \frac{1}{2} \left[\cosh\left(\frac{\Delta\Gamma_q t}{2}\right) - \cos(\Delta M_q t) \right]$$

$$a_q = 1 - \left| \frac{\mathfrak{q}_q}{\mathfrak{p}_q} \right|^2 : \text{CP Violation in mixing}$$

Neutral B Mesogenesis

- Baryon asymmetry generated by mixing of neutral B mesons



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$$\mathcal{A}_{\text{CP}}^{\text{TI}}(B_q^0 \rightarrow \mathfrak{B}) \equiv \int_0^\infty \left[\Gamma(B_q^0(t) \rightarrow \mathfrak{B}) - \Gamma(B_q^0(t) \rightarrow \bar{\mathfrak{B}}) \right] dt$$

Neutral B Mesogenesis

- Asymmetry from initial (“tagged”) B_q^0

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Combined

$$\mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle) \equiv \mathcal{A}_{\text{CP}}^{\text{TI}}(B_q^0 \rightarrow \mathfrak{B}) + \mathcal{A}_{\text{CP}}^{\text{TI}}(\bar{B}_q^0 \rightarrow \mathfrak{B})$$

$$x_q \equiv \frac{\Delta M_q}{\Gamma_q}, y_q \equiv \frac{\Delta \Gamma_q}{2\Gamma_q}$$

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Combined

$$\mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle) = \frac{x_q^2 + y_q^2}{(1 + x_q^2)(1 - y_q^2)} a_q \mathcal{B}(B_q^0 \rightarrow \mathfrak{B})|_{t=0} + \mathcal{O}(a_q^2)$$

$$x_q \equiv \frac{\Delta M_q}{\Gamma_q}, y_q \equiv \frac{\Delta \Gamma_q}{2\Gamma_q}$$

Neutral B Mesogenesis

- Asymmetry from initial (“tagged”) B_q^0

$$\mathcal{A}_{\text{CP}}^{\text{TI}}(B_q^0 \rightarrow \mathfrak{B}) \equiv \int_0^\infty \left[\Gamma(B_q^0(t) \rightarrow \mathfrak{B}) - \Gamma(B_q^0(t) \rightarrow \bar{\mathfrak{B}}) \right] dt$$

- Asymmetry from initial (“tagged”) \bar{B}_q^0

$$\mathcal{A}_{\text{CP}}^{\text{TI}}(\bar{B}_q^0 \rightarrow \mathfrak{B}) \equiv \int_0^\infty \left[\Gamma(\bar{B}_q^0(t) \rightarrow \mathfrak{B}) - \Gamma(\bar{B}_q^0(t) \rightarrow \bar{\mathfrak{B}}) \right] dt$$

Combined

New

$$\mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle) = \frac{x_q^2 + y_q^2}{(1 + x_q^2)(1 - y_q^2)} a_q \mathcal{B}(B_q^0 \rightarrow \mathfrak{B})|_{t=0} + \mathcal{O}(a_q^2)$$

$$B_d^0 \sim 0.4 \quad B_s^0 \sim 1$$

$$x_q \equiv \frac{\Delta M_q}{\Gamma_q}, y_q \equiv \frac{\Delta \Gamma_q}{2\Gamma_q}$$

Neutral B Mesogenesis

- Asymmetry from initial (“tagged”) B_q^0

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- Asymmetry from initial (“tagged”) \bar{B}_q^0

$$\mathcal{A}_{\text{CP}}^{\text{TI}}(\bar{B}_q^0 \rightarrow \mathfrak{B}) \equiv \int_0^\infty \left[\Gamma(\bar{B}_q^0(t) \rightarrow \mathfrak{B}) - \Gamma(\bar{B}_q^0(t) \rightarrow \bar{\mathfrak{B}}) \right] dt$$

Combined

$$\mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle) = \frac{x_q^2 + y_q^2}{(1 + x_q^2)(1 - y_q^2)} \boxed{a_q} \mathcal{B}(B_q^0 \rightarrow \mathfrak{B})|_{t=0} + \mathcal{O}(a_q^2)$$

CP Violation in Mixing

$$x_q \equiv \frac{\Delta M_q}{\Gamma_q}, y_q \equiv \frac{\Delta \Gamma_q}{2\Gamma_q}$$

Neutral B Mesogenesis

- CP Violation in mixing: a_q

$$\text{Theory: } a_q = \left| \frac{\Gamma_{12}}{M_{12}} \right| \sin \phi_{12}$$

$$a_d^{\text{theo}} = (-5.1 \pm 0.5) \times 10^{-4}, \quad a_s^{\text{theo}} = (2.2 \pm 0.2) \times 10^{-5}$$

$$a_d^{\text{exp}} = (-2.1 \pm 1.7) \times 10^{-3}, \quad a_s^{\text{exp}} = (-0.6 \pm 2.8) \times 10^{-3}$$

Experiment (semileptonic asymmetry):

$$a_q = \frac{\Gamma(\bar{B} \rightarrow f) - \Gamma(B \rightarrow \bar{f})}{\Gamma(\bar{B} \rightarrow f) + \Gamma(B \rightarrow \bar{f})}$$

**Not only small, also
potentially negative!**

Neutral B Mesogenesis

$$\Delta_B \sim 10^{-8} - 10^{-6}$$

$$\mathcal{B}(B \rightarrow \mathfrak{B}) \sim 10^{-3}$$

- Contribution to the total asymmetry:

$$\Delta_B \supset f_d \Delta_{B_d^0} + f_s \Delta_{B_s^0}$$

$$\Delta_{B_q^0} \equiv \mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle)$$

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Fragmentation fractions:
how many mesons are produced?

Neutral B Mesogenesis

$$\Delta_B \sim 10^{-8} - 10^{-6}$$

$$\mathcal{B}(B \rightarrow \mathfrak{B}) \sim 10^{-3}$$

- Contribution to the total asymmetry:

$$\Delta_B \supset f_d \Delta_{B_d^0} + f_s \Delta_{B_s^0}$$

$$\Delta_{B_q^0} \equiv \mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle)$$

Experimental $a_q \xrightarrow{\text{green arrow}} \Delta_{B_d^0}^{\text{exp}} = (-7.8 \pm 6.3 |_{\text{SM}}) \times 10^{-7}$

$$\Delta_{B_s^0}^{\text{exp}} = (-6 \pm 28 |_{\text{SM}}) \times 10^{-7},$$

Theoretical $a_q \xrightarrow{\text{yellow arrow}} \Delta_{B_d^0}^{\text{theo}} = (-19 \pm 1.9 |_{\text{SM}}) \times 10^{-8}$

$$\Delta_{B_s^0}^{\text{theo}} = (2.2 \pm 0.2 |_{\text{SM}}) \times 10^{-8},$$

Neutral B Mesogenesis

$$\Delta_B \sim 10^{-8} - 10^{-6}$$

$$\mathcal{B}(B \rightarrow \mathfrak{B}) \sim 10^{-3}$$

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$$\Delta_B \supset f_d \Delta_{B_d^0} + f_s \Delta_{B_s^0}$$

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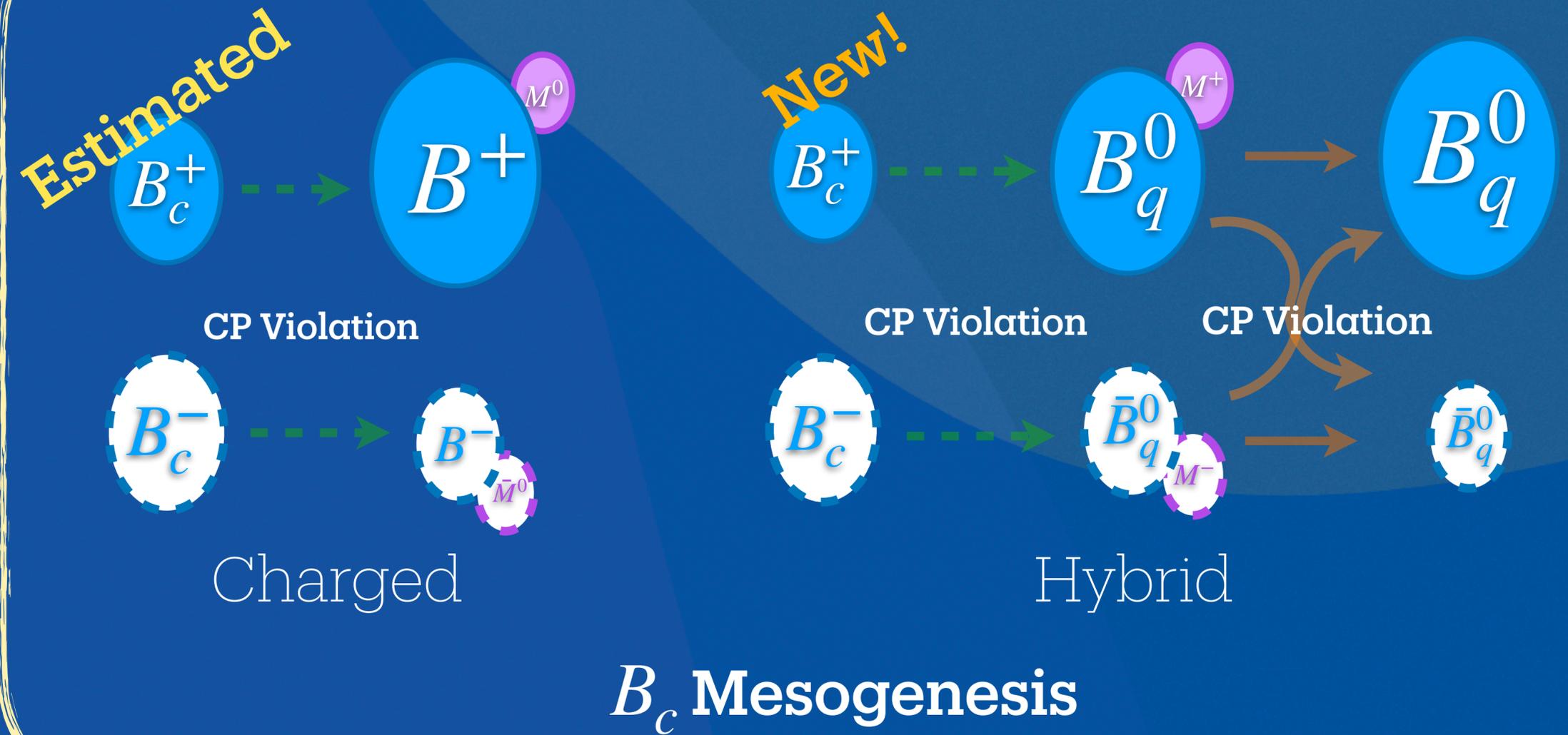
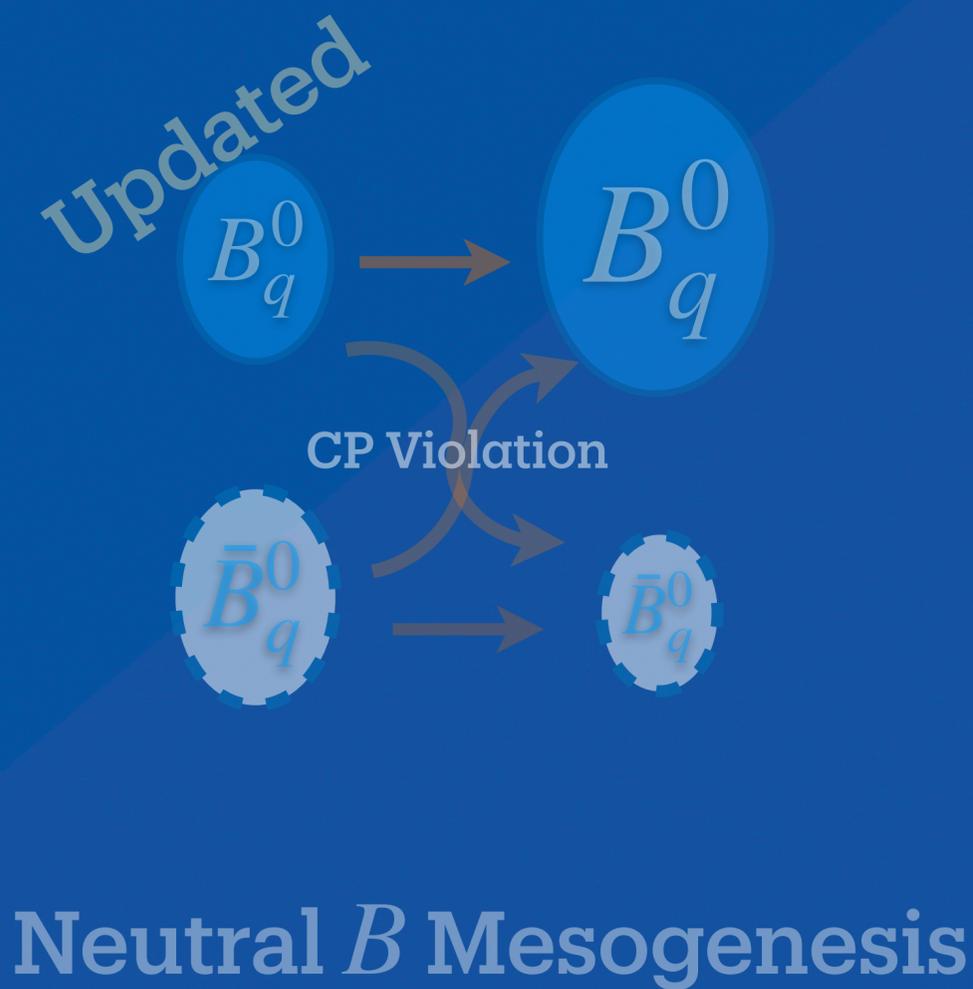
Can reach, big uncertainties

Experimental $a_q \longrightarrow \Delta_{B_d^0}^{\text{exp}} = (-7.8 \pm 6.3 |_{\text{SM}}) \times 10^{-7} \quad \Delta_{B_s^0}^{\text{exp}} = (-6 \pm 28 |_{\text{SM}}) \times 10^{-7},$

Theoretical $a_q \longrightarrow \Delta_{B_d^0}^{\text{theo}} = (-19 \pm 1.9 |_{\text{SM}}) \times 10^{-8} \quad \Delta_{B_s^0}^{\text{theo}} = (2.2 \pm 0.2 |_{\text{SM}}) \times 10^{-8},$

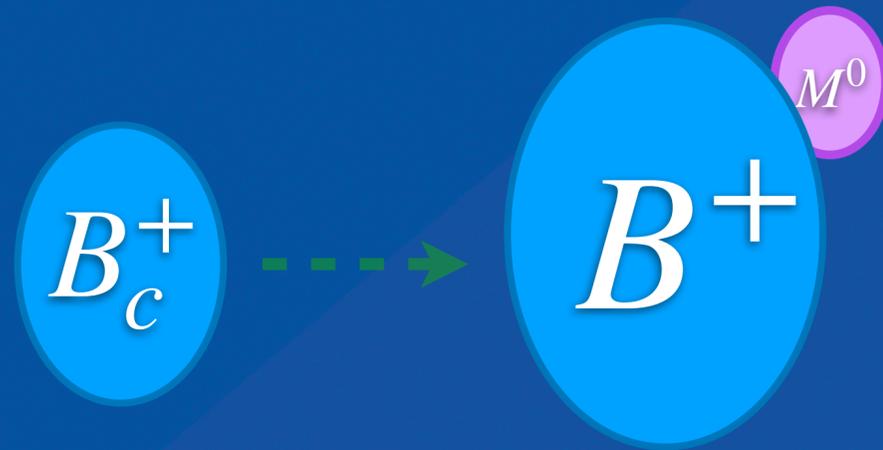
Needs (huge) enhancement from B_s^0

Contributions to Mesogenesis



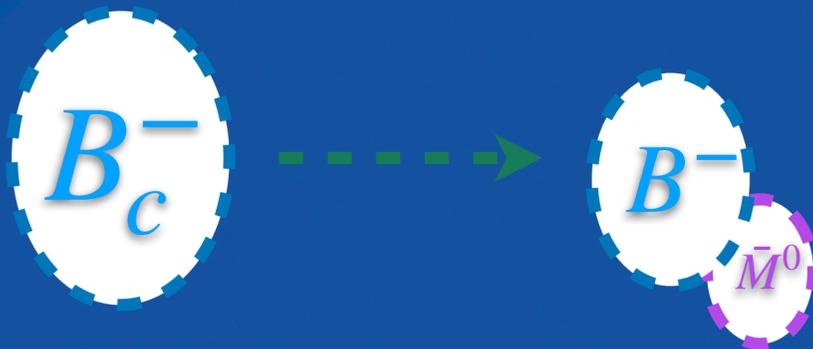
Charged B_c Mesogenesis

- Baryon asymmetry generated by direct CP asymmetry in $B_c \rightarrow B^+$ decays



$$\mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B^+ M^0) = \frac{\Gamma(B_c^+ \rightarrow B^+ M^0) - \Gamma(B_c^- \rightarrow B^- \bar{M}^0)}{\Gamma(B_c^+ \rightarrow B^+ M^0) + \Gamma(B_c^- \rightarrow B^- \bar{M}^0)},$$

CP Violation

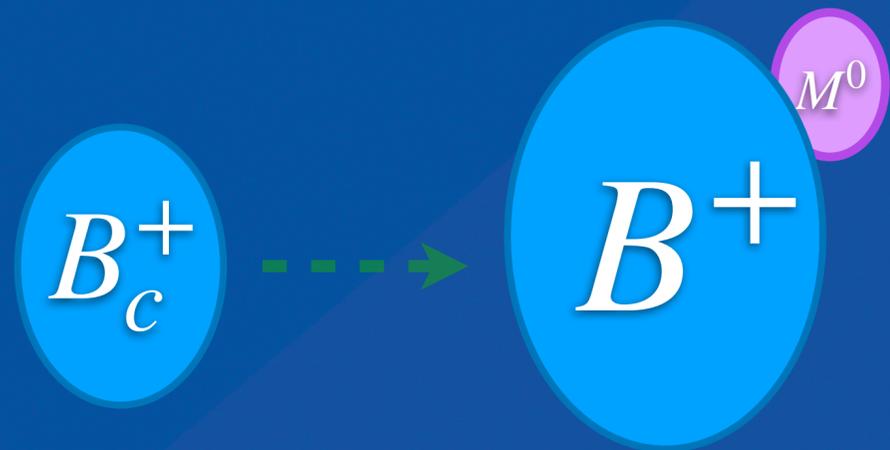


$$\Delta_B \supset f_c \sum_{M^0} \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B^+ M^0) \mathcal{B}(B_c^+ \rightarrow B^+ M^0) \mathcal{B}(B^+ \rightarrow \mathfrak{B})$$

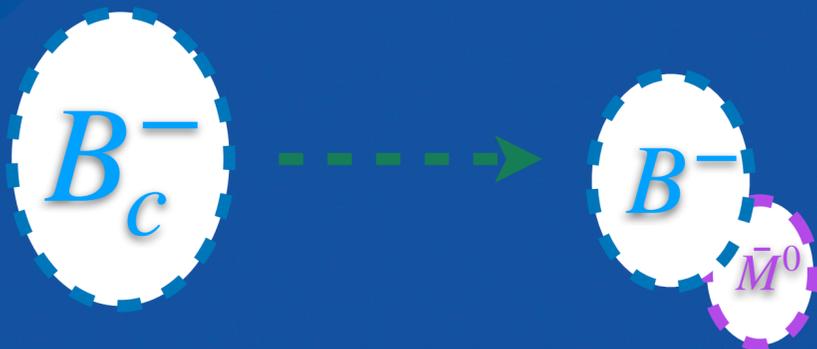
M = Light pseudoscalar or vector meson = π, K, ρ, K^*, \dots

Charged B_c Mesogenesis

- Baryon asymmetry generated by direct CP asymmetry in $B_c \rightarrow B^+$ decays



CP Violation



$$\mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B^+ M^0) = \frac{\Gamma(B_c^+ \rightarrow B^+ M^0) - \Gamma(B_c^- \rightarrow B^- \bar{M}^0)}{\Gamma(B_c^+ \rightarrow B^+ M^0) + \Gamma(B_c^- \rightarrow B^- \bar{M}^0)},$$

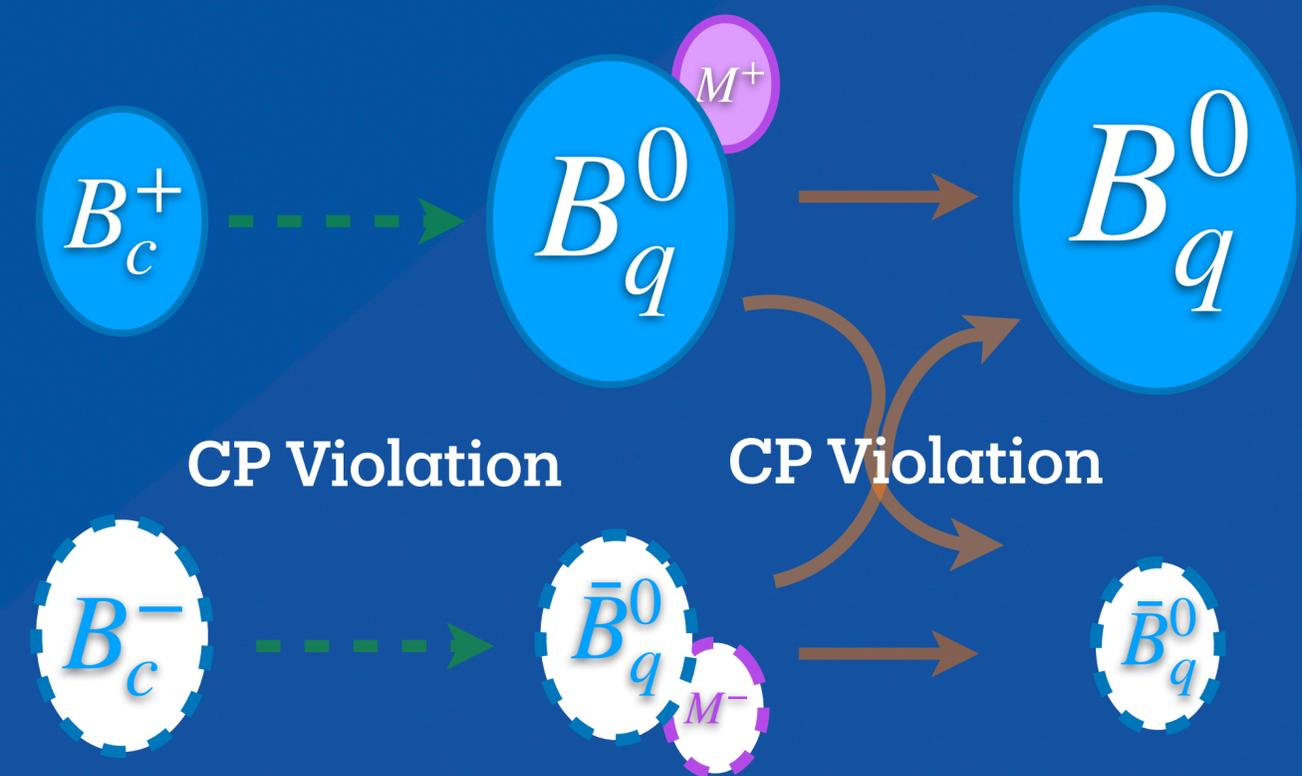
??

$$\Delta_B \supset f_c \sum_{M^0} \boxed{\mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B^+ M^0) \mathcal{B}(B_c^+ \rightarrow B^+ M^0)} \mathcal{B}(B^+ \rightarrow \mathfrak{B})$$

Missing values for $B_c^+ \rightarrow BM$ observables in SM

New! Hybrid B_c Mesogenesis

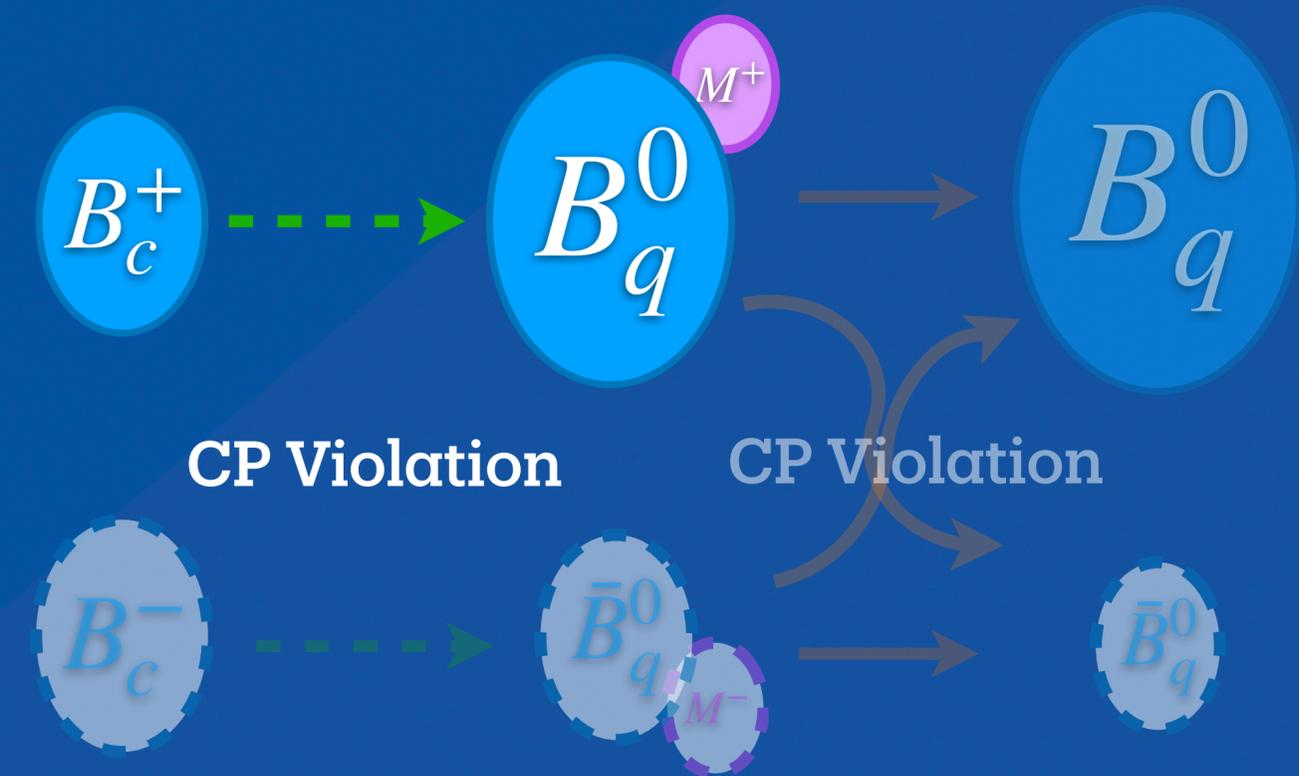
- Baryon asymmetry generated by both direct CP asymmetry in $B_c \rightarrow B^0$ decays and mixing in the daughter neutral mesons



$$\Delta_B \supset f_c \sum_M \left\{ \Gamma(B_c^+ \rightarrow B_q^0 M^+) \mathcal{A}_{CP}^{TI}(B_q^0 \rightarrow \mathfrak{B}) + \Gamma(B_c^- \rightarrow \bar{B}_q^0 M^-) \mathcal{A}_{CP}^{TI}(\bar{B}_q^0 \rightarrow \mathfrak{B}) \right\}$$

New! Hybrid B_c Mesogenesis

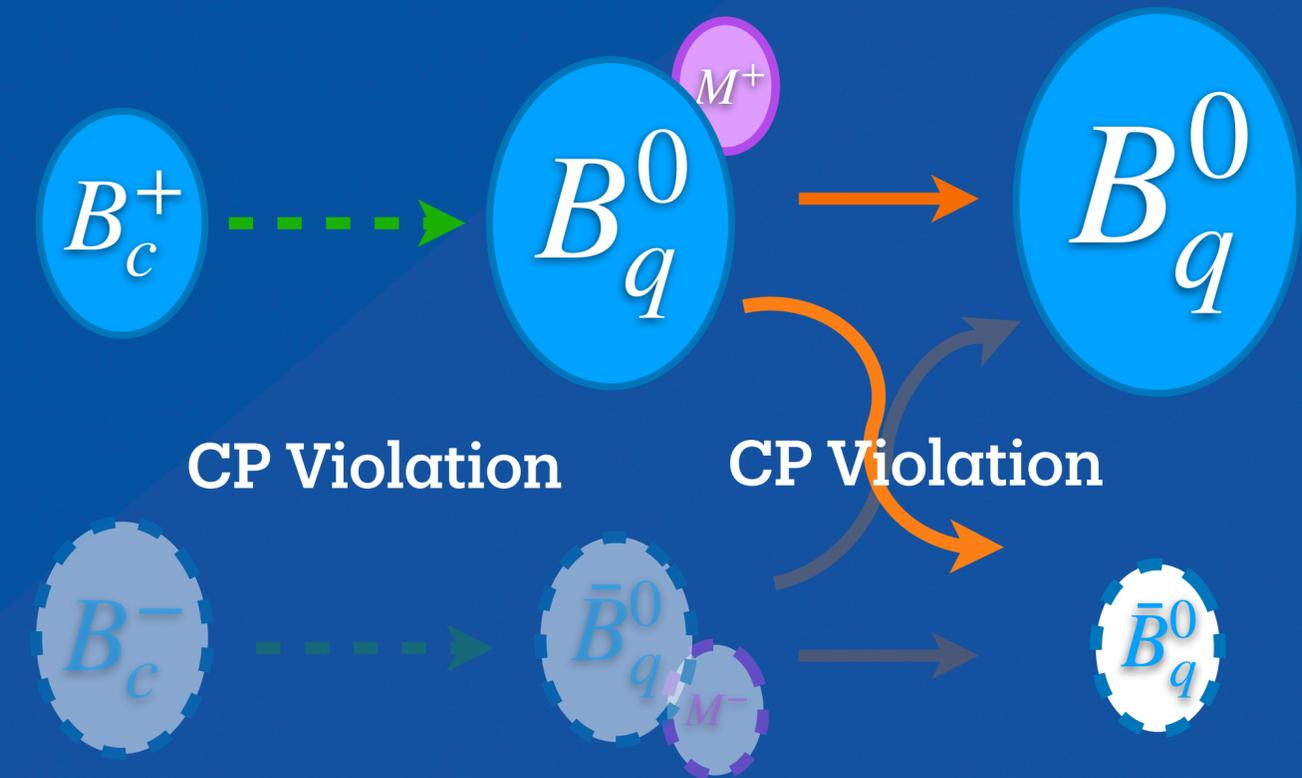
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$$\Delta_B \supset f_c \sum_M \left\{ \Gamma(B_c^+ \rightarrow B_q^0 M^+) \mathcal{A}_{CP}^{TI}(B_q^0 \rightarrow \mathfrak{B}) + \Gamma(B_c^- \rightarrow \bar{B}_q^0 M^-) \mathcal{A}_{CP}^{TI}(\bar{B}_q^0 \rightarrow \mathfrak{B}) \right\}$$

New! Hybrid B_c Mesogenesis

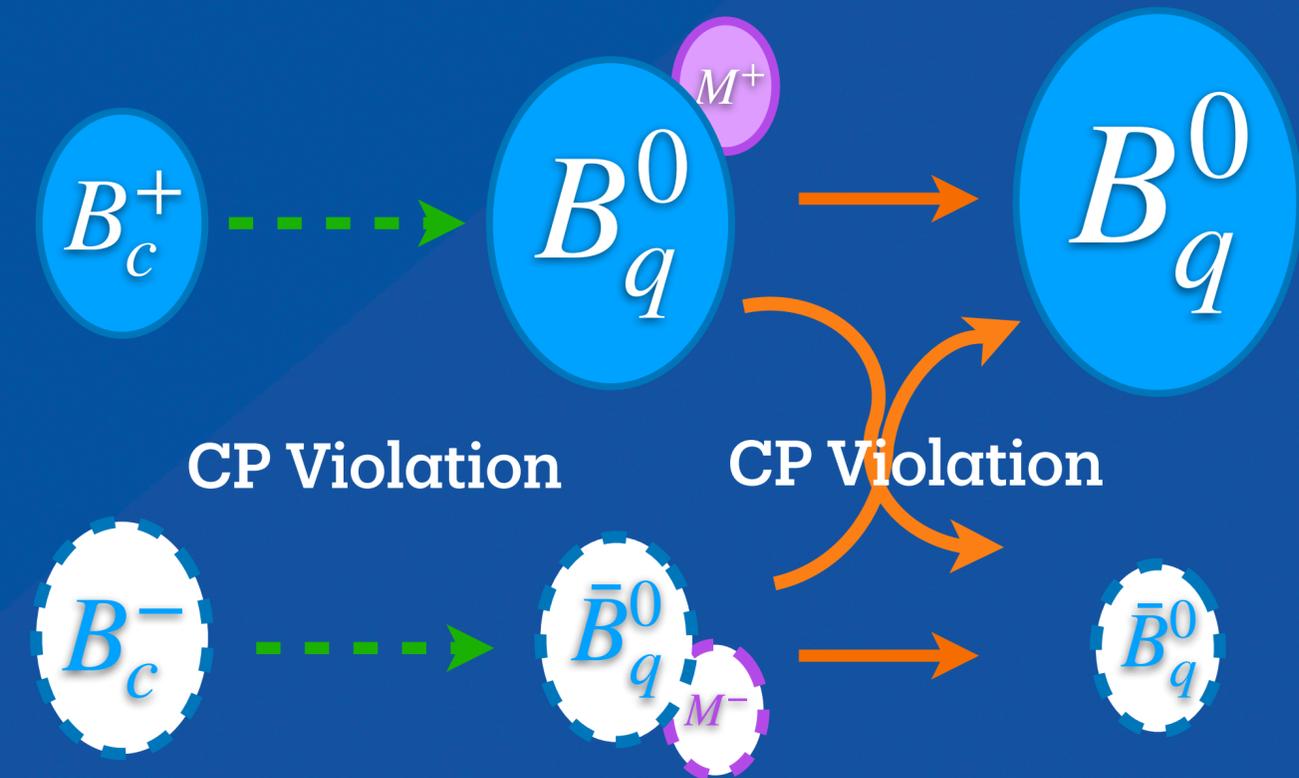
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$$\Delta_B \supset f_c \sum_M \left\{ \Gamma(B_c^+ \rightarrow B_q^0 M^+) \mathcal{A}_{\text{CP}}^{\text{TI}}(B_q^0 \rightarrow \mathfrak{B}) + \Gamma(B_c^- \rightarrow \bar{B}_q^0 M^-) \mathcal{A}_{\text{CP}}^{\text{TI}}(\bar{B}_q^0 \rightarrow \mathfrak{B}) \right\}$$

New! Hybrid B_c Mesogenesis

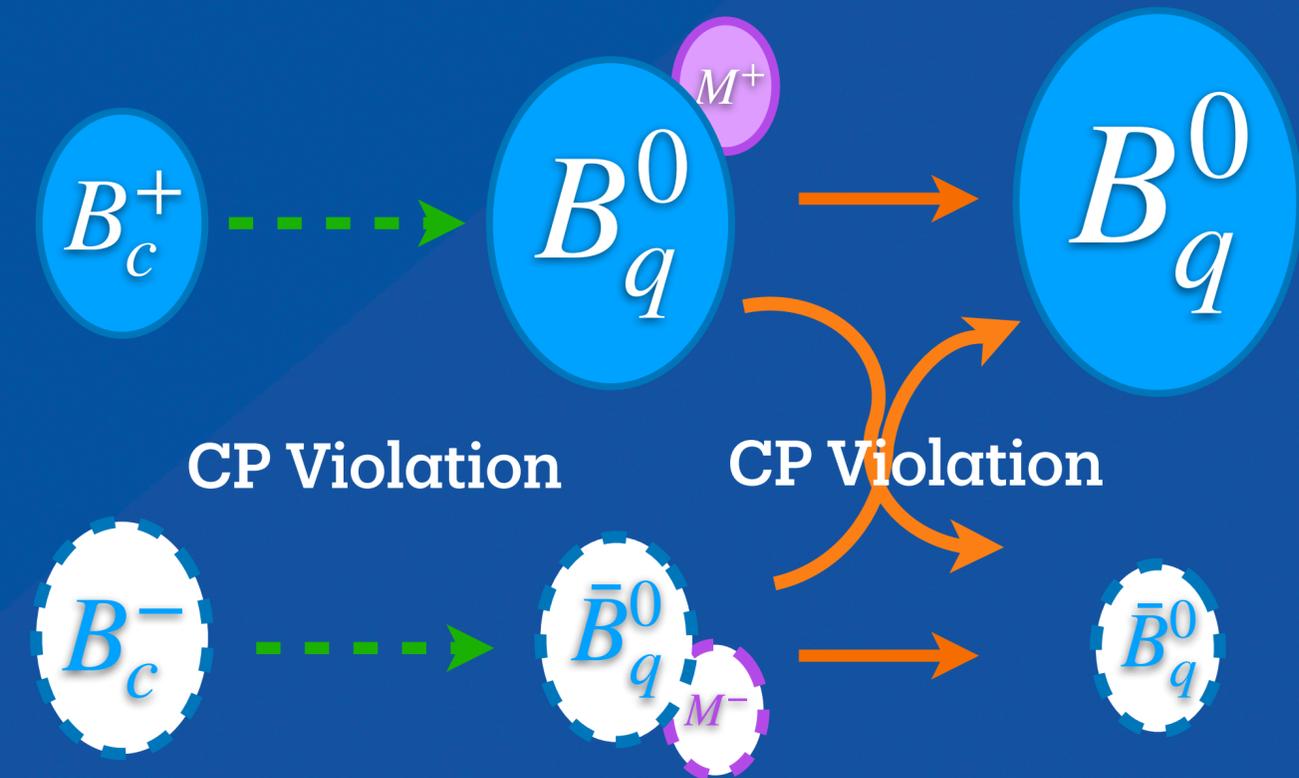
- Baryon asymmetry generated by both direct CP asymmetry in $B_c \rightarrow B^0$ decays and mixing in the daughter neutral mesons



$$\Delta_B \subset f_c \sum_{M^+} \mathcal{B}(B_c^+ \rightarrow B_q^0 M^+) \left[\mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle) + \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B_q^0 M^+) \left(\mathcal{A}_{\text{CP}}^{\text{TI}}(B_q^0 \rightarrow \mathfrak{B}) - \mathcal{A}_{\text{CP}}^{\text{TI}}(\bar{B}_q^0 \rightarrow \mathfrak{B}) \right) \right]$$

New! Hybrid B_c Mesogenesis

- Baryon asymmetry generated by both direct CP asymmetry in $B_c \rightarrow B^0$ decays and mixing in the daughter neutral mesons



$$\Delta_B \subset f_c \sum_{M^+} \mathcal{B}(B_c^+ \rightarrow B_q^0 M^+) \mathcal{A}_{\text{CP}}^{\text{TI}}(\langle B_q^0 \rightarrow \mathfrak{B} \rangle)$$

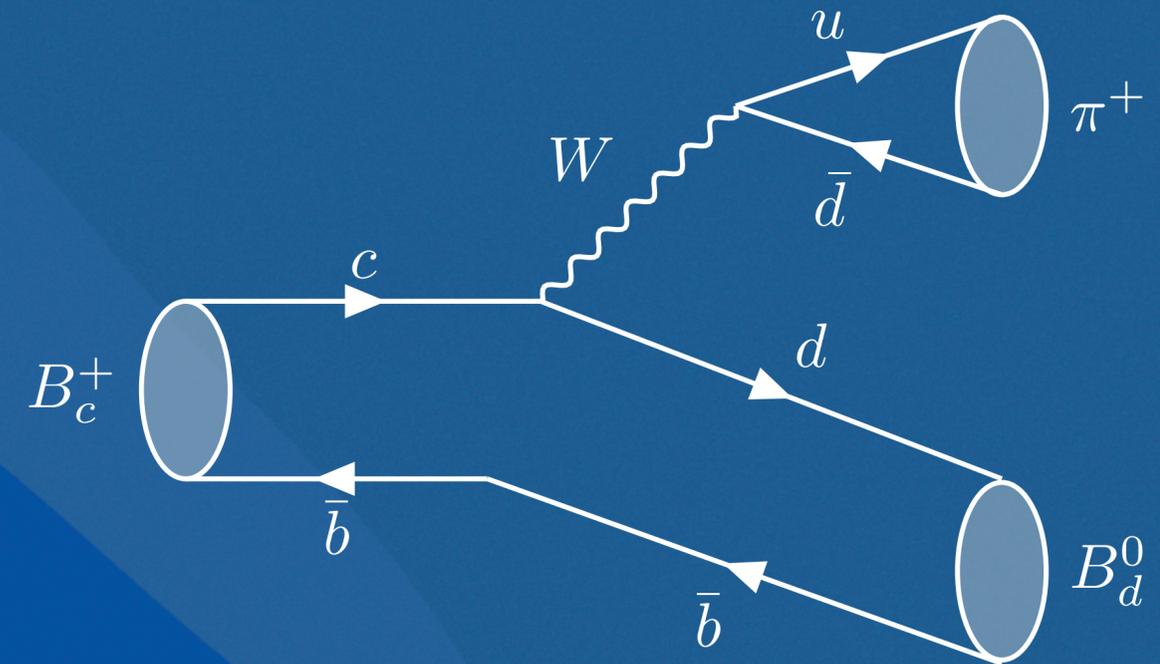
$$+ \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B_q^0 M^+) \left(\mathcal{A}_{\text{CP}}^{\text{TI}}(B_q^0 \rightarrow \mathfrak{B}) - \mathcal{A}_{\text{CP}}^{\text{TI}}(\bar{B}_q^0 \rightarrow \mathfrak{B}) \right)$$

Missing values for $B_c^+ \rightarrow BM$ observables in SM

Predictions for $B_c^+ \rightarrow BM$
decays

Structure of $B_c^+ \rightarrow BM$ decays

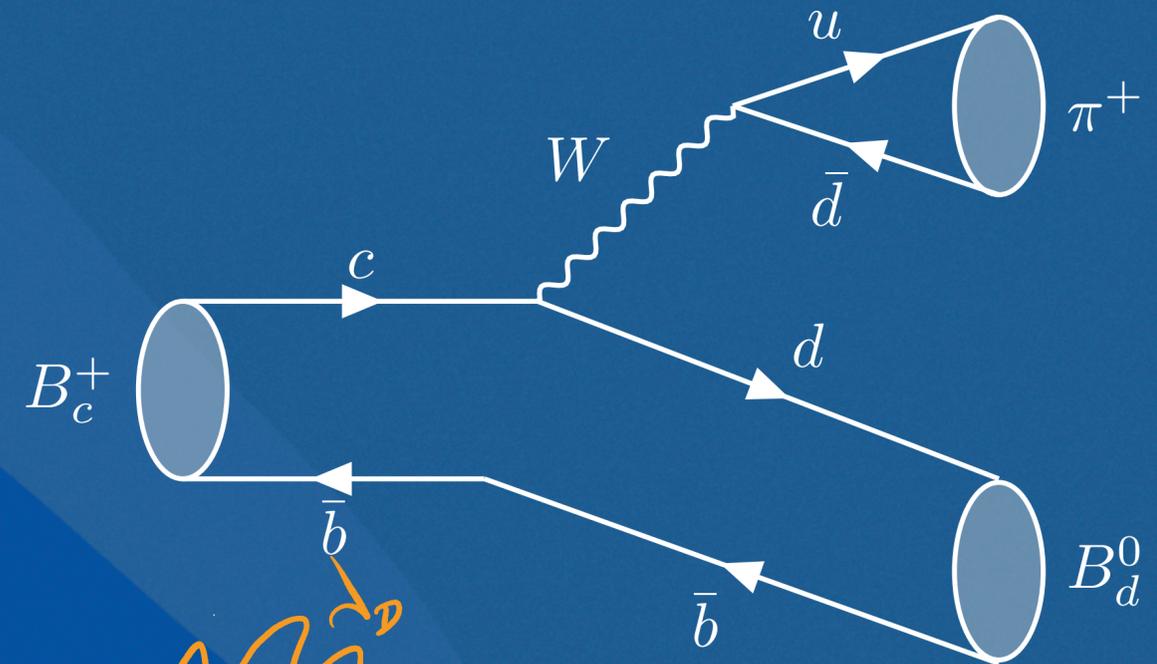
- b quark acts as spectator, c decays
- Same structure as $D(c\bar{q}) \rightarrow hh$
- Charm CKM classification



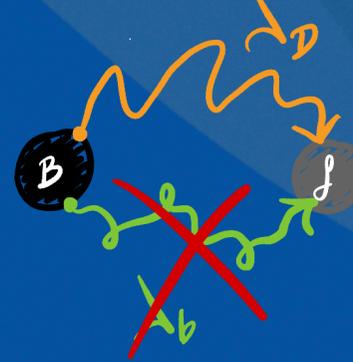
- Cabibbo Favoured (CF) $V_{cs}^* V_{ud} \sim 1$
- Singly Cabibbo Suppressed (SCS) $V_{cs}^* V_{ud}, V_{cd}^* V_{us} \sim \lambda = 0.22$
- Doubly Cabibbo Suppressed (DCS) $V_{cd}^* V_{us} \sim \lambda^2$

Structure of $B_c^+ \rightarrow BM$ decays

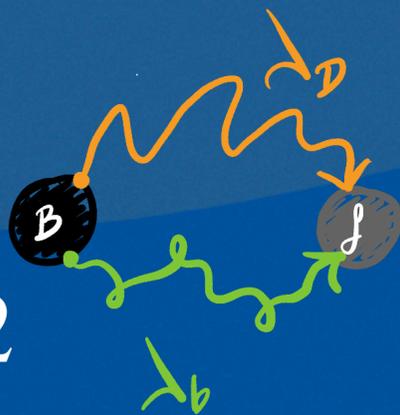
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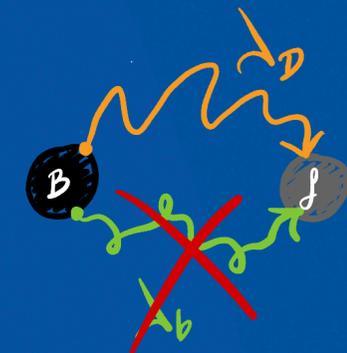
- Cabibbo Favoured (CF) $V_{cs}^* V_{ud} \sim 1$



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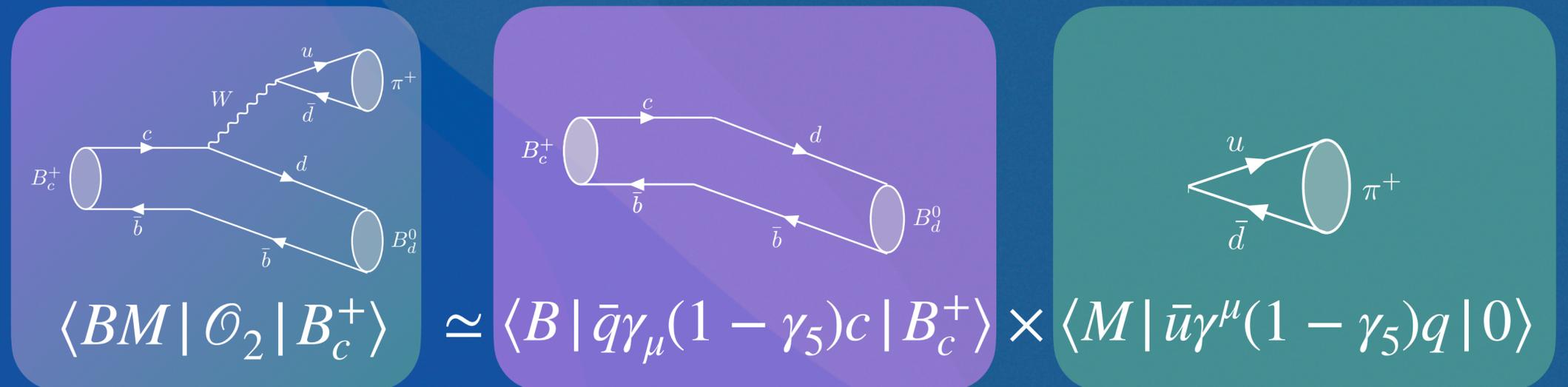
- Doubly Cabibbo Suppressed (DCS) $V_{cd}^* V_{us} \sim \lambda^2$



$B_c^+ \rightarrow BM$ Branching Ratios

- To estimate Branching Ratios we use:

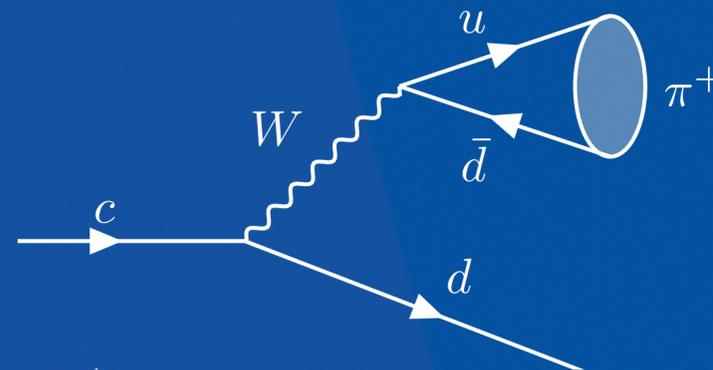
- Factorization:**



The diagram illustrates the factorization of the B_c^+ decay into two parts. On the left, a B_c^+ meson (represented as a cylinder) contains a charm quark c and an anti-bottom quark \bar{b} . A W boson is emitted from the c quark, which then decays into a u quark and an anti-down quark \bar{d} , forming a π^+ meson. The \bar{b} quark and the d quark from the W decay form a B_d^0 meson. This process is represented by the matrix element $\langle BM | \mathcal{O}_2 | B_c^+ \rangle$. This is approximately equal to the product of two matrix elements: $\langle B | \bar{q} \gamma_\mu (1 - \gamma_5) c | B_c^+ \rangle$ and $\langle M | \bar{u} \gamma^\mu (1 - \gamma_5) q | 0 \rangle$. The second part of the diagram shows a B_c^+ meson with c and \bar{b} quarks, where the c quark transitions to a d quark, and the \bar{b} quark transitions to a \bar{d} quark, forming a B_d^0 meson. The third part shows a π^+ meson formed from a u quark and an anti-down quark \bar{d} .

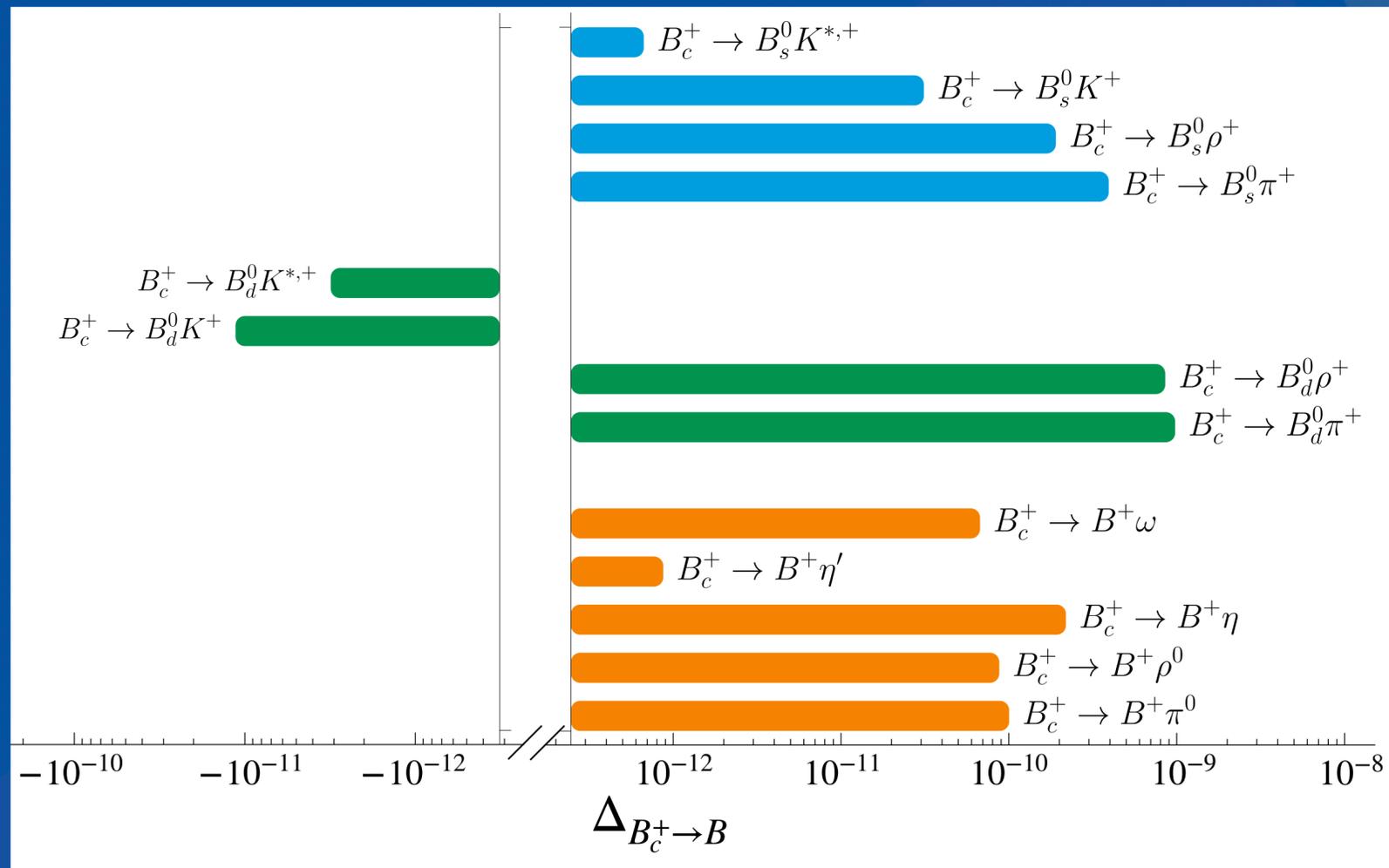
$$\langle BM | \mathcal{O}_2 | B_c^+ \rangle \simeq \langle B | \bar{q} \gamma_\mu (1 - \gamma_5) c | B_c^+ \rangle \times \langle M | \bar{u} \gamma^\mu (1 - \gamma_5) q | 0 \rangle$$

- Connection to D decays**



Results for B_c^+ Mesogenesis

Results B_c Mesogenesis



• Charged

$$\Delta_{B_c^+ \to B^+}^{\text{fac}} = (4.7 \times 10^{-7}) \times \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \to B^+ M^0)$$

• Hybrid

$$\Delta_{B_c^+ \to B_q^0}^{\text{fac,exp}} = (-0.3 \pm 1.4 |_{\text{SM}}) \times 10^{-7} + 4.2 \times 10^{-6} \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \to B_q^0 M^+)$$

$$\Delta_{B_c^+ \to B_q^0}^{\text{fac,theo}} = (5.4 \pm 1.3 |_{\text{SM}}) \times 10^{-10} + 4.2 \times 10^{-6} \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \to B_s^0 M^+)$$

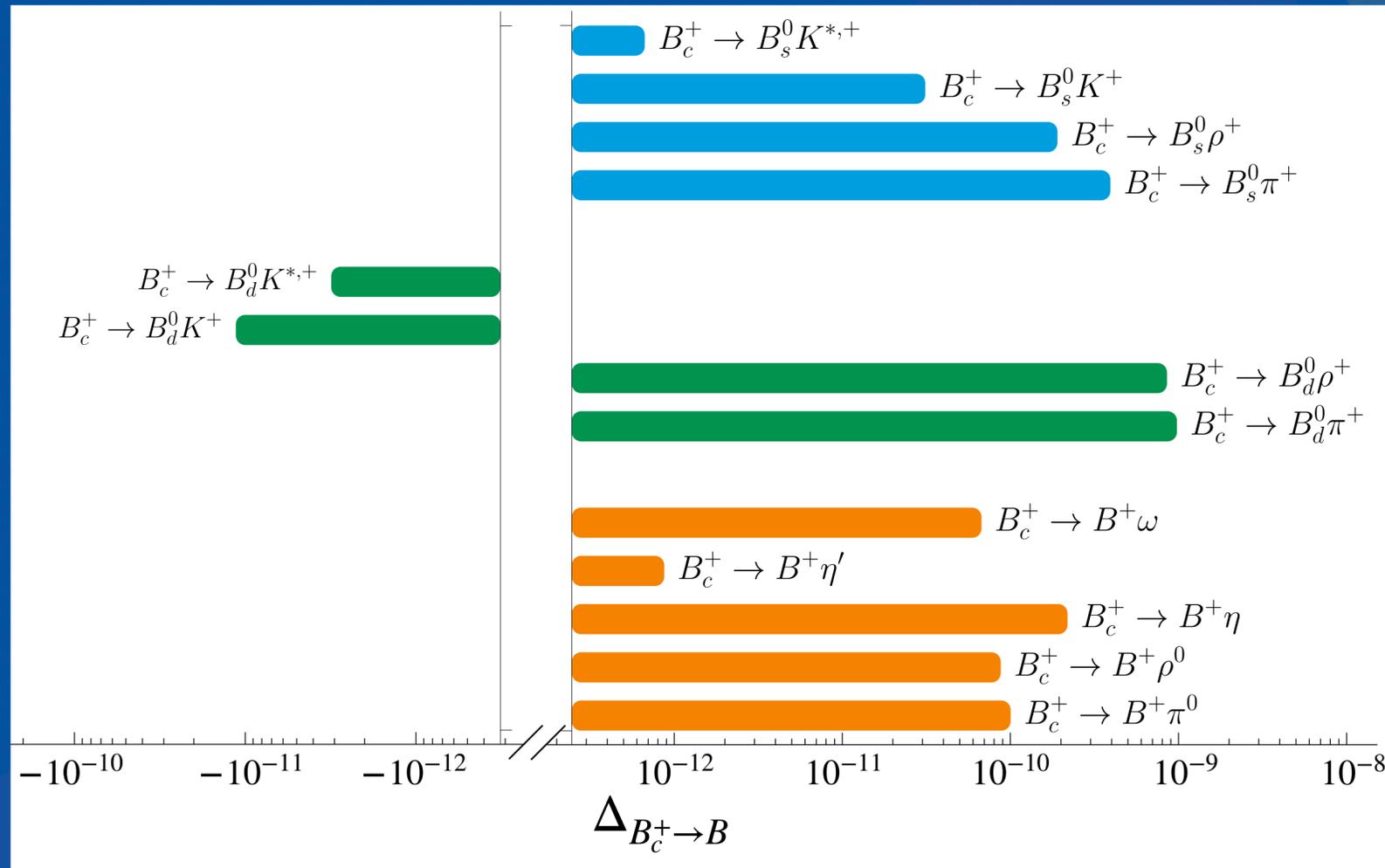
$$\mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \to BM) \sim 10^{-3}$$

Results B_c Mesogenesis

Hybrid > Charged

Mixing relevant

only if $a_q \rightarrow a_q^{\text{exp}}$



• Charged

$$\Delta_{B_c^+ \rightarrow B^+}^{\text{fac}} = (4.7 \times 10^{-7}) \times \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B^+ M^0)$$

• Hybrid

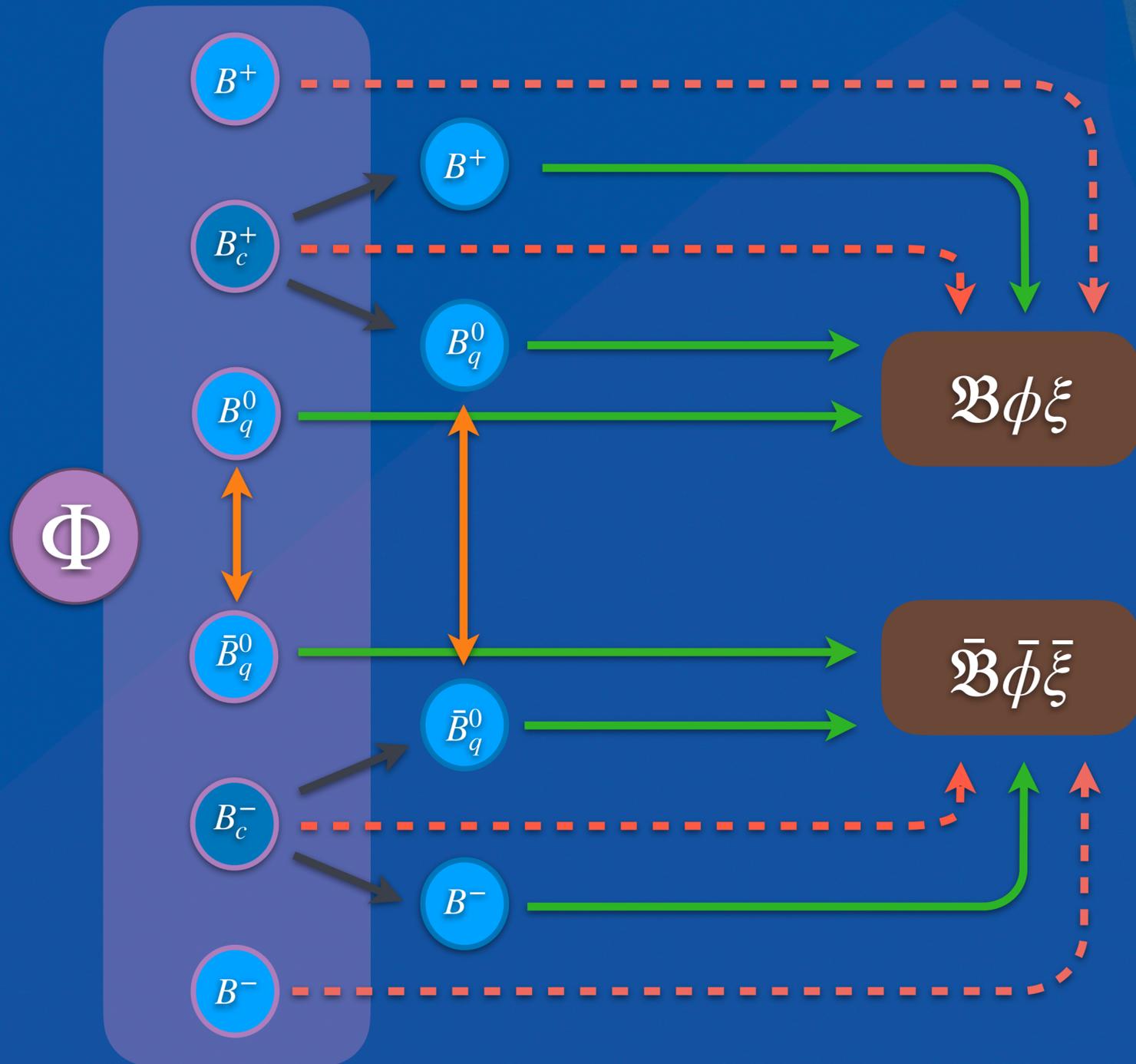
$$\Delta_{B_c^+ \rightarrow B_q^0}^{\text{fac,exp}} = (-0.3 \pm 1.4 |_{\text{SM}}) \times 10^{-7} + 4.2 \times 10^{-6} \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow B_q^0 M^+)$$

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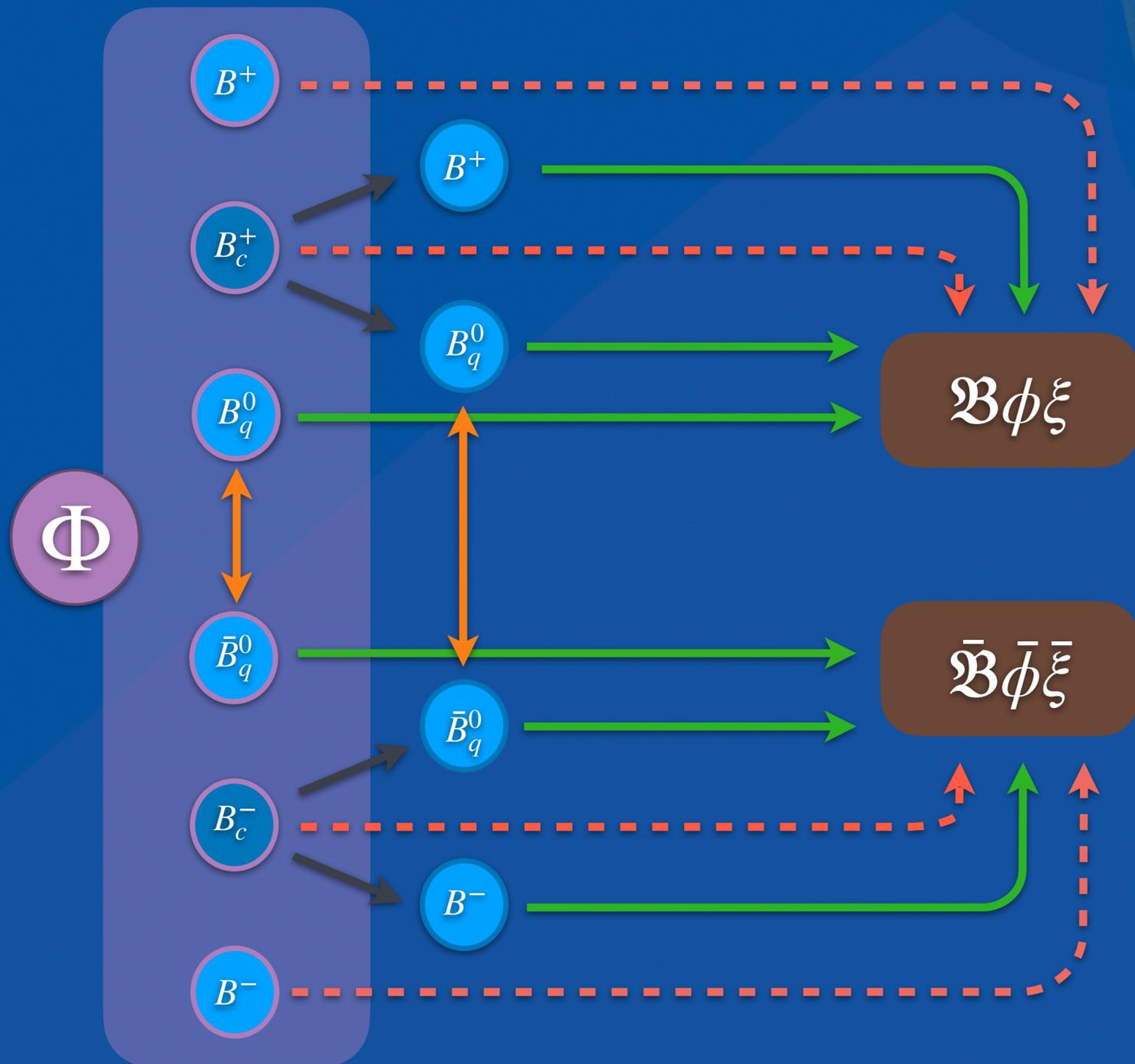
Results for Unified Mesogenesis

Unified Mesogenesis



$$\Delta_B \equiv \underbrace{f_d \Delta_{B_d^0} + f_s \Delta_{B_s^0}}_{\text{Neutral}} + \underbrace{f_c \left(\Delta_{B_c^+ \rightarrow B^+} + \Delta_{B_c^+ \rightarrow B_q^0} \right)}_{B_c^+}$$

Unified Mesogenesis



$$\Delta_B \equiv f_d \Delta_{B_d^0} + f_s \Delta_{B_d^0} + f_c \left(\Delta_{B_c^+ \rightarrow B^+} + \Delta_{B_c^+ \rightarrow B_q^0} \right)$$

Fragmentation fractions
in the early universe (??)

Unified Mesogenesis

- Fragmentation fractions: two scenarios
- “Vacuum” scenario: cold temperature, similar to colliders

$$f_d^{\text{coll.}} = f_u^{\text{coll.}} = 0.407, f_s^{\text{coll.}} = 0.101, f_c^{\text{coll.}} = 2.6 \times 10^{-3}$$

$$\Delta_B^{\text{fac,exp}} = (-3.8 \pm 3.8) \times 10^{-7} + 1.2 \times 10^{-8} \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow BM)$$

$$\Delta_B^{\text{fac,theo}} = (-7.5 \pm 0.8) \times 10^{-8} + 1.2 \times 10^{-8} \mathcal{A}_{\text{CP}}^{\text{dir}}(B_c^+ \rightarrow BM)$$

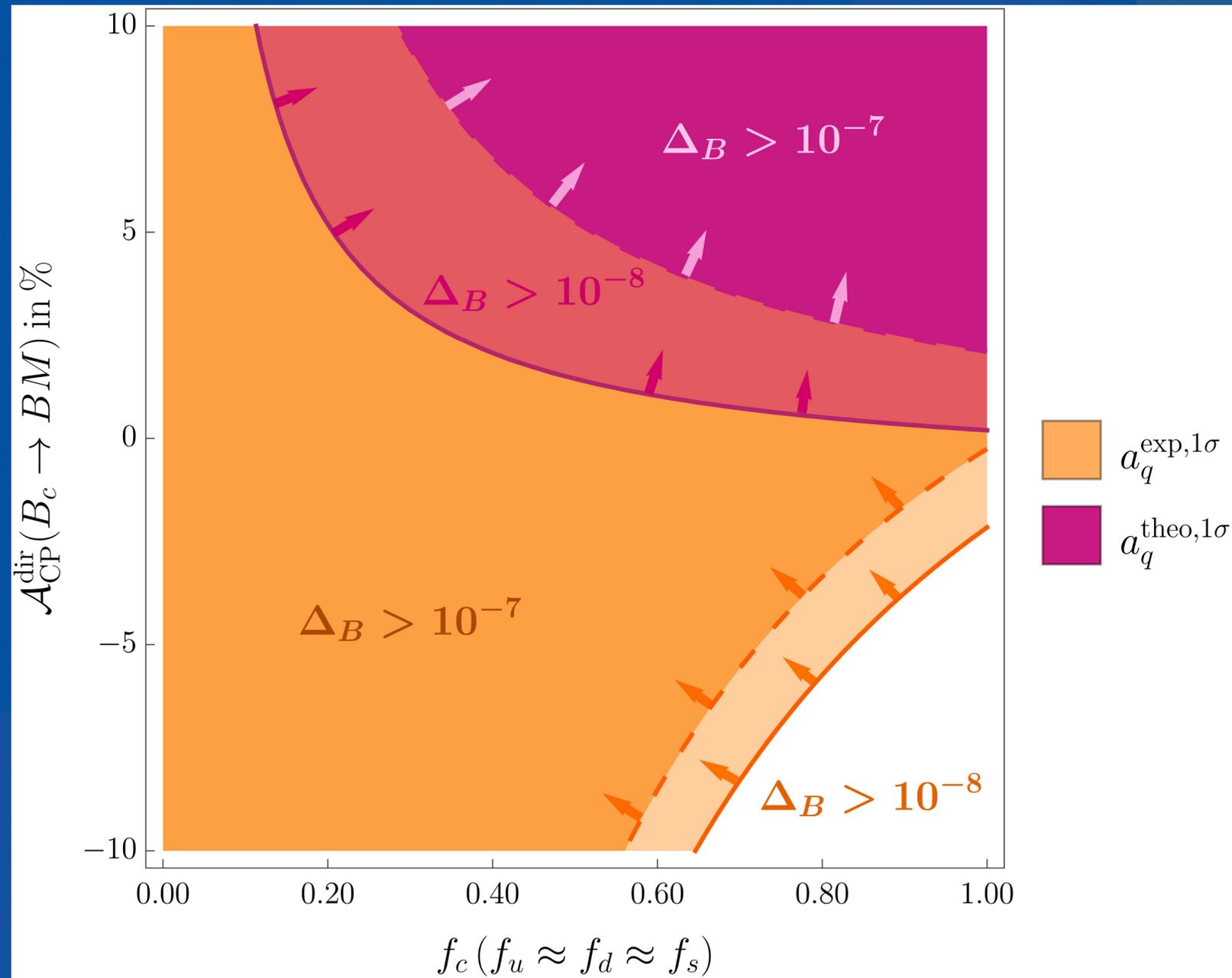
Unified Mesogenesis

- Fragmentation fractions: two scenarios
- “Vacuum” scenario: cold temperature, similar to colliders
- “High density” scenario: favours hadronization of heavier mesons

$$f_u \approx f_d \approx f_s$$

$$f_c + 3f_u = 1$$

Unified Mesogenesis



$$f_u \approx f_d \approx f_s$$

$$f_c + 3f_u = 1$$

- With exp. a_q at 1σ : no need for B_c^+ processes
- If a_q aligns with theory, contributions from $\mathcal{A}_{\text{CP}}^{\text{dir}}$ needed

Conclusions

Conclusions

- Under mesogenesis, the **CP violation** that generates baryon asymmetry comes exclusively **from SM**
- Neutral mesogenesis **depends strongly on a_q** : improved experimental precision needed
- In B_c^+ mesogenesis, generally the new **Hybrid** scenario **dominates** over the Charged
- **Fragmentation fractions** in the early universe **determines relative dominance** of mechanisms. If $a_q = a_q^{\text{theo}}$, B_c mesogenesis is needed.

Backup

$B_c^+ \rightarrow BM$ Branching Ratios

- First, construct the amplitudes

Only in SCS decays

$$\mathcal{A}(B_c^+ \rightarrow BM) = i \frac{G_F}{\sqrt{2}} \left(V_{cD}^* V_{uD'} \mathcal{T}_i + \overbrace{V_{cb}^* V_{ub}} \mathcal{P}_i \right) \quad D = d, s$$

- Then we assume factorization

$$\mathcal{T}_i = A_{BM}^{B_c} \alpha_i(BM)$$

$B_c^+ \rightarrow BM$ Branching Ratios

- Extract α_i

Leading Order (Theory)

$$\alpha_1 = C_2 + \frac{1}{N_c} C_1$$

$$\alpha_2 = \frac{\alpha_1}{N_c}$$

Data driven (Experiment)

- Assume factorization in $D \rightarrow hh$
- Apply it to $B_c^+ \rightarrow BM$

$$\mathcal{B}(B_c^+ \rightarrow BM) = \frac{\tau_{B_c^+} m_D}{\tau_D m_{B_c^+}} \frac{\Phi(m_B/m_{B_c^+}, m_M/m_{B_c^+})}{\Phi(m_{M_1}/m_D, m_{M_2}/m_D)} \left(\frac{A_{BM}^{B_c^+}}{A_{M_1 M_2}^D} \right)^2 \mathcal{B}(D \rightarrow M_1 M_2)$$

$B_c^+ \rightarrow BM$ Branching Ratios

$B_c^+ \rightarrow BP$ decay	$\mathcal{B}^{\text{fac}} [\mathcal{B}^{\text{dd}}]$ in %	$B_c^+ \rightarrow BV$ decay	$\mathcal{B}^{\text{fac}} [\mathcal{B}^{\text{dd}}]$ in %
$B_c^+ \rightarrow B^+ \bar{K}^0$	0.51 [1.9]	$B_c^+ \rightarrow B^+ \bar{K}^{*,0}$	0.14 [1.4]
$B_c^+ \rightarrow B_s^0 \pi^+$	3.3 [2.7]	$B_c^+ \rightarrow B_s^0 \rho^+$	1.6 [1.8]
$B_c^+ \rightarrow B^+ \pi^0$	$1.0 [4.8] \times 10^{-2}$	$B_c^+ \rightarrow B^+ \rho^0$	$0.88 [5.8] \times 10^{-2}$
$B_c^+ \rightarrow B^+ \eta$	$2.2 [x] \times 10^{-2}$	$B_c^+ \rightarrow B^+ \omega$	$0.67 [2.6] \times 10^{-2}$
$B_c^+ \rightarrow B^+ \eta'$	$8.7 [x] \times 10^{-5}$	—	—
$B_c^+ \rightarrow B_d^0 \pi^+$	0.18 [0.13]	$B_c^+ \rightarrow B_d^0 \rho^+$	0.16 [0.38]
$B_c^+ \rightarrow B_s^0 K^+$	0.23 [0.17]	$B_c^+ \rightarrow B_s^0 K^{*,+}$	$5.0 [3.6^*] \times 10^{-3}$
$B_c^+ \rightarrow B^+ K^0$	$1.5 [5.6^*] \times 10^{-3}$	$B_c^+ \rightarrow B^+ K^{*,0}$	$0.39 [4.0^*] \times 10^{-3}$
$B_c^+ \rightarrow B_d^0 K^+$	$1.3 [1.1^*] \times 10^{-2}$	$B_c^+ \rightarrow B_d^0 K^{*,+}$	$2.4 [3.1^*] \times 10^{-3}$

Role of interference in CP violation

Consider the amplitude of a certain process $B \rightarrow f$. CP violation arises if for a certain observable \mathcal{O} we have $\mathcal{O}(B \rightarrow f) \neq \mathcal{O}(\bar{B} \rightarrow \bar{f})$

Observables depend only on the modulus of the amplitude

Only weak phases are shifted when they are CP conjugated

We can define the amplitude of the process as $A = A_1 + A_2$

CP violation only appears if A_1 and A_2 have a relative weak phase, ϕ_2 , and strong phase, δ_2

$$A_1 = |A_1|$$

$$A_2 = e^{i\delta_2} e^{i\phi} |A_2|$$

