Precise discussion on T-asymmetry with B-meson decays

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Overview

- An asymmetry with B meson decays

(a) $\bar{B}^0 \to B_-$ ← CP value

(b) $B_- \to \bar{B}^0$

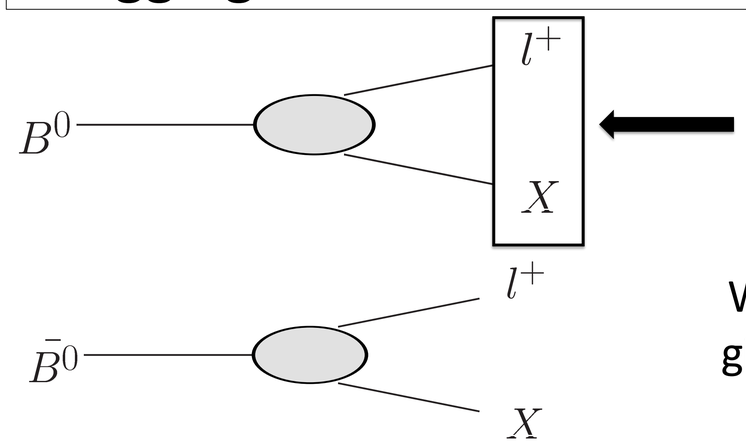
Two processes are naively related with Time Reversal.

Thus, time dependent asymmetry below is naively thought to be a T-violating quantity[1].

$$A_T = \frac{\Gamma_{(a)} - \Gamma_{(b)}}{\Gamma_{(a)} + \Gamma_{(b)}} \simeq \mathrm{T-odd}$$

naive thought

- Tagging : Method to identify B mesons

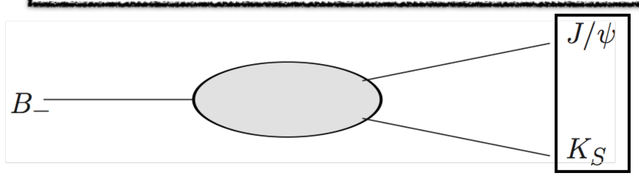


Flavor tagging to identify B^0

Wrong sign decay: giving ambiguity to the B^0 tagging.

Wrong sign decays cause ambiguity for tagging.

→ We cannot exactly identify B^0 or $\bar{B}^0$.



We cannot exactly identify B_- or B_+ .

- **Effect of ϵ_K should be clarified.**

○ **Our viewpoint: Precise discussion**

$$A(t) = \frac{\Gamma_{(a)} - \Gamma_{(b)}}{\Gamma_{(a)} + \Gamma_{(b)}} \simeq \mathrm{T-odd} + \Delta(\mathrm{T-even})$$

This part reveals.

- Our viewpoint is different from Bernabeu's[1].
- **Task: model independent analysis**

BaBar Asymmetry

- BaBar announced that they measured T-asymmetry through B meson system.

$$A_T^{\mathrm{BaBar}}(\Delta t) \simeq \frac{\Delta S_T^+}{2}\sin(\Delta m_d \Delta t) + \frac{\Delta C_T^+}{2}\cos(\Delta m_d \Delta t)$$

For observed values in the experiment [2]

$$\begin{cases} \Delta S_T^+ = -1.37 \pm 0.14 \pm 0.06 \\ \Delta C_T^+ = 0.10 \pm 0.14 \pm 0.08 \end{cases}$$

In the theoretical paper[3],

- BaBar asymmetry is slightly deviated from a T-odd.
- BaBar asymmetry is calculated with assumption $\epsilon_K = 0$

Asymmetry: Result

$$A_T = R_T + C_T\cos(x\Gamma t) + S_T\sin(x\Gamma t) + B_T\sin^2(x\Gamma t) + D_T\sin(x\Gamma t)\cos(x\Gamma t) + E_T(y\Gamma t)\sin(x\Gamma t)$$

$$\Gamma = \frac{\Gamma_H + \Gamma_L}{2} \qquad x = \frac{M_H - M_L}{\Gamma} \qquad y = \frac{\Gamma_H - \Gamma_L}{2\Gamma}$$

- Definition is different from BaBar asymmetry.

$$\Gamma_{(a)} = N_{(a)}e^{-\Gamma_d\Delta t}[1 + S^+_{\psi K_L, l^+}\sin(\Delta m_d\Delta t) + C^+_{\psi K_L, l^+}\cos(\Delta m_d\Delta t)] = N_{(a)}\Gamma'_{(a)}$$
$$\Gamma_{(b)} = N_{(b)}e^{-\Gamma_d\Delta t}[1 + S^+_{l^-, \psi K_S}\sin(\Delta m_d\Delta t) + C^+_{l^-, \psi K_S}\cos(\Delta m_d\Delta t)] = N_{(b)}\Gamma'_{(b)}$$

Overall nomalizations are removed in BaBar asym. →

$$A_T^{\mathrm{BaBar}} = \frac{\Gamma'_{(a)} - \Gamma'_{(b)}}{\Gamma'_{(a)} + \Gamma'_{(b)}}$$

T-odd T-even

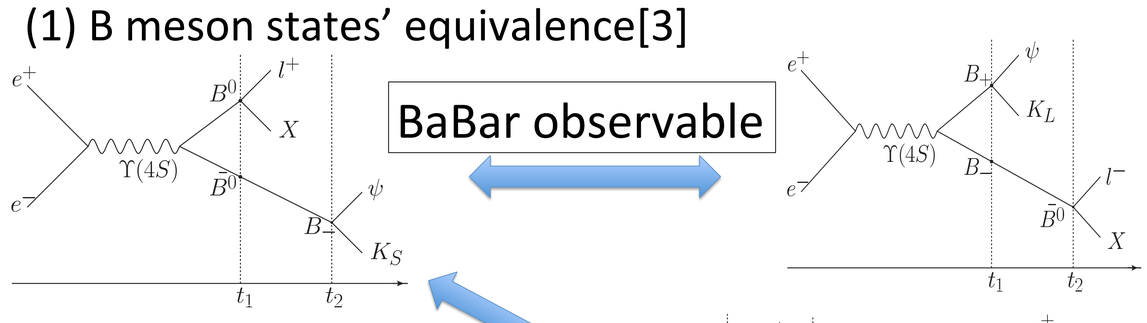
$$\begin{aligned}
R_T &= Sz^I - R_M + \xi_l^R + C_\xi^l - \hat{\lambda}^R_{\mathrm{wst}} + G\hat{\lambda}_l^R \\
C_T &= C' - 2\mathrm{Re}(\epsilon_K) - Sz^I + \theta_K^R + S\Delta\lambda_l^I \\
S_T &= -S[1 - Gz^R] + G\theta_K^I - GS\Delta\lambda_l^R \\
B_T &= S[Gz_K^I - z^I + SR_M - S\xi_l^R] - S^2C_\xi^l + S^2\hat{\lambda}^R_{\mathrm{wst}} - SG\Delta\lambda^I_{\mathrm{wst}} \\
D_T &= S[z_K^R - Gz^R] - S\Delta\lambda^R_{\mathrm{wst}} - S^2\hat{\lambda}_l^I \\
E_T &= GS
\end{aligned}$$

- In C_T, contribution from ϵ_K is extracted.
- All are expressed as phase convention independent parameters.

◎ We investigate the reason why T-even parts are allowed to contribute.

Conditions for Authentic Time Reversed Process

(1) B meson states' equivalence[3]



(2) Overall normalization

- Since overall normalization difference is included, $N_{(b)}/N_{(a)}$ contributes to the asymmetry. One also requires $N_{(b)}/N_{(a)}$ be T-odd.

When these two conditions are satisfied, T-even terms vanish.

Summary

- The event number asymmetry of B meson system is constructed.
- The asymmetry in our study takes account of overall factors of the two processes.
- The observables are written as phase conv. indep. parameters.
- The result shows the asymmetry is slightly deviated from T-odd.
- The contribution from ϵ_K is investigated.
- When the two conditions are satisfied, asym. is a T-odd quantity.

References

[1] J. Bernabeu, F. Martinez-Vidal and P. Villanueva-Perez, JHEP 1208, 064 (2012) [arXiv:1203.0171 [hep-ph]].
[2] J. P. Lees *et al*. [BaBar Collaboration], Phys. Rev. Lett. 109, 211801 (2012) [arXiv:1207.5832 [hep-ex]].
[3] E. Applebaum, A. Efrati, Y. Grossman, Y. Nir and Y. Soreq. Phys. Rev. D89, 076011(2013) [arXiv:1312.4164].