論文内容の要旨

Measurement of CP-Violating Asymmetries in the Neutral B Meson Decaying to the $\rho\pi$ State Using a Time-Dependent Dalitz Plot Analysis

(中性 B 中間子の ρ 中間子と π 中間子への崩壊における CP 非対称の測定)

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In the standard model (SM), CP violation arises from an irreducible phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1, 2]. A Dalitz plot analysis of the decay $B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$ offers a unique way to determine the angle ϕ_2 in the CKM unitarity triangle without discrete ambiguities (for ϕ_2 in the range between 0 and π), which cannot be obtained from analyses of other modes sensitive to ϕ_2 such as $B \to \pi\pi$ or $B \to \rho\rho$ [3]. The Dalitz plot analysis uses isospin and takes into account a possible contamination from $b \to d$ penguin transitions. In addition, using measurements of the related charged decay modes $B^+ \to \rho^+\pi^0$ and $B^+ \to \rho^0\pi^+$ provides further improvement of the ϕ_2 determination [4, 5].

In this Thesis, we present the result of time-dependent Dalitz plot analysis in $B^0 \to \pi^+\pi^-\pi^0$ decays and a constraint on ϕ_2 based on the result. We use a 414 fb^{-1} data sample that contains $449 \times 10^6 B\bar{B}$ pairs collected on the $\Upsilon(4S)$ resonance. The data were taken at the KEKB collider [6] and collected with the Belle detector [7].

In the decay chain $\Upsilon(4S) \to B^0\overline{B}^0 \to f_{CP}f_{\rm tag}$, where one of the B mesons decays at time t_{CP} to a final state $f_{CP} = \pi^+\pi^-\pi^0$ and the other decays at time $t_{\rm tag}$ to a final state $f_{\rm tag}$ that distinguishes B^0 and $\overline{B}^0$, the time- and Dalitz plot-dependent differential decay rate is

$$\frac{d\Gamma}{d\Delta t\, ds_+ ds_-} \sim e^{-|\Delta t|/\tau_{B^0}} \Bigg\{ \left(|A_{3\pi}|^2 + |\overline{A}_{3\pi}|^2\right) - q_{\rm tag}\cdot\left(|A_{3\pi}|^2 - |\overline{A}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t) + q_{\rm tag}\cdot 2{\rm Im}\left[\frac{q}{p}A^*_{3\pi}\overline{A}_{3\pi}\right]\sin(\Delta m_d\Delta t)\Bigg\}.$$

Here $\overset{(-)}{A}_{3\pi}$ is the Lorentz-invariant amplitude of the $B^0(\overline{B}^0) \to \pi^+\pi^-\pi^0$ decay, b-flavor charge $q_{\rm tag} = +1\,(-1)$ when $f_{\rm tag}$ is a B^0 ($\overline{B}^0$) flavor eigenstate, and $\Delta t \equiv t_{CP} - t_{\rm tag}$; and p and q define the mass eigenstates of neutral B mesons as $pB^0 \pm q\overline{B}^0$, with average lifetime τ_{B^0} and mass difference Δm_d. The variables of Dalitz plot, s_+, s_-, and s_0 are defined as

$$s_+ \equiv (p_+ + p_0)^2, \quad s_- \equiv (p_- + p_0)^2, \quad \text{and} \quad s_0 \equiv (p_+ + p_-)^2,$$

where p_+, p_-, and p_0 are the four-momenta of the π^+, π^-, and π^0, respectively, in the decay of $B^0 \to \pi^+\pi^-\pi^0$. The amplitudes $\overset{(-)}{A}_{3\pi}$ have the following Dalitz plot dependences

$$\begin{aligned} A_{3\pi}(s_+, s_-) &= \sum_{\kappa=(+,-,0)} f_\kappa(s_+, s_-)A^\kappa, \quad \text{and} \\ \frac{q}{p}\overline{A}_{3\pi}(s_+, s_-) &= \sum_{\kappa=(+,-,0)} \overline{f}_\kappa(s_+, s_-)\overline{A}^\kappa, \end{aligned}$$

where $(\overline{A})^+$, $(\overline{A})^-$, and $(\overline{A})^0$ are complex amplitudes corresponding to $B^0(\overline{B}^0) \to \rho^+\pi^-$, $\rho^-\pi^+$, and $\rho^0\pi^0$, respectively.

By the Dalitz plot analysis, we determine all the relative sizes and phases of the amplitudes A^κ and $\overline{A}^\kappa$. The amplitudes are related to ϕ_2 through an isospin relation [4, 5] by

$$e^{+2i\phi_2} = \frac{\overline{A}^+ + \overline{A}^- + 2\overline{A}^0}{A^+ + A^- + 2A^0} .$$

Consequently, the Dalitz plot analysis allows us to constrain ϕ_2 without discrete ambiguities. Combining our analysis with information on charged B decay modes, we perform a full Dalitz and isospin analysis for the first time and obtain a constraint on the CKM angle ϕ_2,

$$68^\circ < \phi_2 < 95^\circ ,$$

as the 68.3% confidence interval consistent with the standard model (SM). A large SM-disfavored region also remains. This result is combined with the other measurements from $B \to \pi\pi$ and $B \to \rho\rho$, and its consistency with the SM expectation is examined; we confirm they are consistent with each other at a precision of $\sim 7^\circ$.

The amplitudes A^κ and $\overline{A}^\kappa$ can also be related to the quasi-two-body CP-violation parameters of $B^0 \to \rho^\pm\pi^\mp$ decay processes, $\mathcal{A}_{\rho\pi}^{CP}$, $\mathcal{C}$, $\Delta\mathcal{C}$, $\mathcal{S}$, and $\Delta\mathcal{S}$, which describe the time-dependent decay rates of the processes as

$$\frac{d\Gamma}{d\Delta t} \sim \frac{1 \pm \mathcal{A}_{\rho\pi}^{CP}}{2} e^{-|\Delta t|/\tau_{B^0}} \Big[1 - q_{\rm tag} \cdot (\mathcal{C} \pm \Delta\mathcal{C}) \cos(\Delta m_d \Delta t) + q_{\rm tag} \cdot (\mathcal{S} \pm \Delta\mathcal{S}) \sin(\Delta m_d \Delta t)\Big] ,$$

where the upper (lower) signs are taken for $B^0 \to \rho^+\pi^-$ ($\rho^-\pi^+$). Our analysis yields

$$\begin{aligned}
\mathcal{A}_{\rho\pi}^{CP} &= -0.12 \pm 0.05 \pm 0.04 , \\
\mathcal{C} &= -0.13 \pm 0.09 \pm 0.05 , \\
\Delta\mathcal{C} &= +0.36 \pm 0.10 \pm 0.05 , \\
\mathcal{S} &= +0.06 \pm 0.13 \pm 0.05 , \quad \text{and} \\
\Delta\mathcal{S} &= -0.08 \pm 0.13 \pm 0.05 ,
\end{aligned}$$

where the first and second errors correspond to statistical and systematic errors, respectively. We can relate the $\mathcal{A}_{\rho\pi}^{CP}$, $\mathcal{C}$, and $\Delta\mathcal{C}$ with the direct CP-violation parameters $\mathcal{A}_{\rho\pi}^{+-}$ and $\mathcal{A}_{\rho\pi}^{-+}$, which are defined by

$$\mathcal{A}_{\rho\pi}^{\pm\mp} = \frac{\Gamma(\overline{B}^0 \to \rho^\mp\pi^\pm) - \Gamma(B^0 \to \rho^\pm\pi^\mp)}{\Gamma(\overline{B}^0 \to \rho^\mp\pi^\pm) + \Gamma(B^0 \to \rho^\pm\pi^\mp)} .$$

We obtain

$$\begin{aligned}
\mathcal{A}_{\rho\pi}^{+-} &= +0.21 \pm 0.08 \pm 0.04 , \quad \text{and} \\
\mathcal{A}_{\rho\pi}^{-+} &= +0.08 \pm 0.17 \pm 0.11 .
\end{aligned}$$

Our measurement also includes the information on the quasi-two-body process of $B^0 \to \rho^0\pi^0$, whose time-dependent decay rate is

$$\frac{d\Gamma}{d\Delta t} \sim e^{-|\Delta t|/\tau_{B^0}} \Big[1 + q_{\rm tag} \cdot \mathcal{A}_{\rho^0\pi^0} \cos(\Delta m_d \Delta t) + q_{\rm tag} \cdot \mathcal{S}_{\rho^0\pi^0} \sin(\Delta m_d \Delta t)\Big] .$$

The CP-violation parameters $\mathcal{A}_{\rho^0\pi^0}$ and $\mathcal{S}_{\rho^0\pi^0}$ are measured to be

$$\begin{aligned}
\mathcal{A}_{\rho^0\pi^0} &= -0.49 \pm 0.36 \pm 0.28 , \quad \text{and} \\
\mathcal{S}_{\rho^0\pi^0} &= +0.17 \pm 0.57 \pm 0.35 ,
\end{aligned}$$

where $\mathcal{S}_{\rho^0\pi^0}$ is measured for the first time.

References

[1] N. Cabibbo, "Unitary Symmetry and Leptonic Decays," *Phys. Rev. Lett.* **10** (1963) 531–532.

[2] M. Kobayashi and T. Maskawa, "CP violation in the renormalizable theory of weak interaction," *Prog. Theor. Phys.* **49** (1973) 652–657.

[3] A. E. Snyder and H. R. Quinn, "Measuring CP asymmetry in $B \to \rho\pi$ decays without ambiguities," *Phys. Rev.* **D48** (1993) 2139–2144.

[4] H. J. Lipkin, Y. Nir, H. R. Quinn, and A. Snyder, "Penguin trapping with isospin analysis and CP asymmetries in B decays," *Phys. Rev.* **D44** (1991) 1454–1460.

[5] M. Gronau, "Elimination of penguin contributions to CP asymmetries in B decays through isospin analysis," *Phys. Lett.* **B265** (1991) 389–394.

[6] S. Kurokawa and E. Kikutani, "Overview of the KEKB accelerators," *Nucl. Instrum. Meth.* **A499** (2003) 1–7. and other papers included in this volume.

[7] **Belle Collaboration**. A. Abashian *et al.*, "The Belle detector," *Nucl. Instrum. Meth.* **A479** (2002) 117–232.