Observation of CP Violation in the Neutral B Meson System with Belle

S. Nishida

KEK

Workshop on Symmetry and Symmetry Breaking

Jul. 30, 2009
Contents

• Introduction
• Kobayashi Maskawa Theory and CP Violation
• Belle Experiment
• Observation of CP Violation in Neutral B Meson System
• More topics on CP Violation in B
• Summary
Introduction

2008 Nobel Prize in Physics

Makoto Kobayashi
Toshihide Maskawa

for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature

The spontaneous broken symmetries that Nambu studied, differ from the broken symmetries described by Makoto Kobayashi and Toshihide Maskawa. These spontaneous occurrences seem to have existed in nature since the very beginning of the universe and came as a complete surprise when they first appeared in particle experiments in 1964. It is only in recent years that scientists have come to fully confirm the explanations that Kobayashi and Maskawa made in 1972. It is for this work that they are now awarded the Nobel Prize in Physics. They explained broken symmetry within the framework of the Standard Model, but required that the Model be extended to three families of quarks. These predicted, hypothetical new quarks have recently appeared in physics experiments. As late as 2001, the two particle detectors BaBar at Stanford, USA and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier.

Press release by the Royal Swedish Academy of Science

Observation of CP Violation in the Neutral B Meson System with Belle

S.Nishida (KEK)
Jul. 30, 2009
CP Violation = Difference of the laws of the physics between matter and anti-matter

Discrete symmetry

\[ C = \text{Charge Conjugation: } q \rightarrow -q \]
\[ P = \text{Parity: } x \rightarrow -x \]
\[ T = \text{Time Reversal: } t \rightarrow -t \]

In the old days, C, P and T were considered to be the basic symmetries in Physics (e.g. Newton’s Law, Electromagnetism).

However,

- Parity Violation was experimentally observed by C.S.Wu in 1956 (using the beta decay of Co60).
- After that, CP was still considered to be a symmetry.
1964: discovered in $K^0$ decay (J. Cronin, V. Fitch et. al.)

[135x575][PRL 13, 138]

Observation of $K_L \rightarrow \pi^+\pi^-$ → CP Violation.

[$K^0$-$\bar{K}^0$ mixing]

\[
\begin{align*}
|K_1\rangle &= |K^0\rangle + |\bar{K}^0\rangle & [\text{CP}=+1] \\
|K_2\rangle &= |K^0\rangle - |\bar{K}^0\rangle & [\text{CP}=-1]
\end{align*}
\]

If CP conserves, $K_1 = K_S$, $K_2 = K_L$

$K_S \rightarrow \pi^+\pi^-$ (CP = +1), $K_L \rightarrow \pi^+\pi^-\pi^0$ (CP = −1)

What is the source of the CP Violation?

Note: CP Violation occurs only in the weak interaction.
Kobayashi Maskawa Theory

Complex phase in the quark mixing matrix → source of CPV in Weak Interactions

Requires 3 (or more) generation of quarks
- Only 3 quarks (u, d, s) were known at that time!
- All the 6 quarks are discovered.

\[
V = \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix} =
\begin{pmatrix}
1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\
-\lambda & 1 - \lambda^2/2 & A\lambda^2 \\
A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1
\end{pmatrix}
\]

CKM Matrix
(Cabibbo-Kobayashi-Maskawa)
\[
\begin{pmatrix}
d' \\
s' \\
b'
\end{pmatrix} =
\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
d \\
s \\
b
\end{pmatrix}
\]

**Weak Interaction**
(charged current)

Interpretation:
The state to be considered in the weak interaction is \(d'\) (not \(d\)).

- \(V\) (CKM matrix) is unitary (to preserve probability).
- If there exists only 2 families, complex phase vanishes; the matrix is real except for the trivial overall phase.
- At least 3 families are necessary to keep non-trivial complex number in the matrix.
Example: Direct CPV

Direct CP Violation: $|A| \neq |A|$

Expected in the KM mechanism

$$A_1 = |A_1|e^{i\Phi_1} e^{i\delta_1}$$
$$A_2 = |A_2|e^{i\Phi_2} e^{i\delta_2}$$

$A = A(B \rightarrow f) = A_1 + A_2$
$$= |A_1|e^{i\Phi_1} e^{i\delta_1} + |A_2|e^{i\Phi_2} e^{i\delta_2}$$

$\bar{A} = A(\bar{B} \rightarrow \bar{f}) = \bar{A}_1 + \bar{A}_2$
$$= |A_1|e^{-i\Phi_1} e^{i\delta_1} + |A_2|e^{-i\Phi_2} e^{i\delta_2}$$

$\Delta \Phi = \Phi_1 - \Phi_2, \Delta \delta = \delta_1 - \delta_2$

$$\Gamma(B \rightarrow f) \propto |A|^2 = |A_1|^2 + |A_2|^2 + 2|A_1||A_2|(\cos \Delta \Phi \cos \Delta \delta - \sin \Delta \Phi \sin \Delta \delta)$$

$$\Gamma(\bar{B} \rightarrow \bar{f}) \propto |\bar{A}|^2 = |A_1|^2 + |A_2|^2 + 2|A_1||A_2|(\cos \Delta \Phi \cos \Delta \delta + \sin \Delta \Phi \sin \Delta \delta)$$

$$A = \frac{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}$$
$$= \frac{2|A_1||A_2| \sin \Delta \sin \delta}{|A_1|^2 + |A_2|^2 + 2|A_1||A_2| \cos \Delta \Phi \cos \Delta \delta}$$

Direct CPV occurs differs when
- both strong and weak phases are different btw $A_1$ and $A_2$
- $|A_1| \sim |A_2|$
Unitarity Triangle

CKM matrix is unitary:

\[ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \]

• This relation becomes a triangle in the complex plane = Unitarity Triangle
• Other triangles tend to be “collapsed”.
• Non-zero \( \phi_1 \) or \( \phi_3 \)
  = Complex phase in the CKM matrix
  = Strong support of KM mechanism.

\[
V = \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix} = \begin{pmatrix}
1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\
-\lambda & 1 - \lambda^2/2 & A\lambda^2 \\
A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1
\end{pmatrix}
\]

• Precise measurement of Unitarity Triangle is one of the main goal of B factory experiments.
• Various B decay modes can be used to measure the angles and sides of the triangle.

Observation of CP Violation in the Neutral B Meson System with Belle

Jul. 30, 2009

S.Nishida (KEK)

Workshop on Symmetry
The typical CPV in the B meson system occurs through mixing.

**B^0-\bar{B}^0** mixing

\[ |B_1\rangle, |B_2\rangle : \text{mass eigenstate} \]

\[ |B_1\rangle = p|B^0\rangle + q|\bar{B}^0\rangle \]

\[ |B_2\rangle = p|B^0\rangle - q|\bar{B}^0\rangle \]

**Time evolution**

\[ |B_1(t)\rangle = |B_1(0)\rangle e^{-i\lambda_1 t} \]

\[ |B_2(t)\rangle = |B_2(0)\rangle e^{-i\lambda_2 t} \]

\[ \lambda_1 = m_1 + \frac{1}{2}\Gamma_1 \]

\[ \lambda_2 = m_2 + \frac{1}{2}\Gamma_2 \]

\[ \Delta m = m_1 - m_2 \]

\[ m = \frac{1}{2}(m_1 + m_2) \]

\[ q = \sqrt{M_{12}^* - (i/2)\Gamma_{12}} \]

\[ p = \sqrt{M_{12}^* - (i/2)\Gamma_{12}} \]

\[ \frac{q}{p} \approx \sqrt{\frac{M_{12}^*}{M_{12}}} \]

\[ M_{12} = \langle B^0|H^{\text{eff}}|\bar{B}^0\rangle \]
Time evolution of $B^0$ and $\bar{B}^0$

$$|B^0(t)\rangle = \frac{1}{2p}(|B_1(t)\rangle + |B_2(t)\rangle)$$

$$= \frac{1}{2}(e^{-i\lambda_1 t} + e^{-i\lambda_2 t})|B^0(0)\rangle + \frac{p}{2q}(e^{-i\lambda_1 t} - e^{-i\lambda_2 t})|\bar{B}^0(0)\rangle$$

$$= g_+(t)|B^0(0)\rangle + (q/p)g_-(t)|\bar{B}^0(0)\rangle$$

$$|\bar{B}^0(t)\rangle = (p/q)g_-(t)|\bar{B}^0(0)\rangle + g_+(t)|B^0(0)\rangle$$

$$g_{\pm}(t) = \frac{1}{2}(e^{-i\lambda_1 t} \pm e^{-i\lambda_2 t})$$

Time dependent asymmetry

Suppose both $B^0$ and $\bar{B}^0$ decay to common CP eigenstate.

$$\Gamma(B^0 \to f_{CP}) \propto \left| g_+(t)\langle f_{CP}|B^0\rangle + \frac{q}{p}g_-(t)\langle f_{CP}||\bar{B}^0\rangle \right|^2$$

$$\Gamma(\bar{B}^0 \to f_{CP}) \propto \left| \frac{p}{q}g_-(t)\langle f_{CP}|\bar{B}^0\rangle + g_+(t)\langle f_{CP}|B^0\rangle \right|^2$$
CPV in Neutral B Meson

\[ A(t) = \frac{\Gamma(B^0 \rightarrow f_{CP}) - \Gamma(B^0 \rightarrow \bar{f}_{CP})}{\Gamma(B^0 \rightarrow f_{CP}) + \Gamma(B^0 \rightarrow \bar{f}_{CP})} \]

\[ = \frac{2}{2 + c_d} \left[ \text{Im} \left( \frac{q}{p} \frac{\langle f_{CP} | B^0 \rangle}{\langle f_{CP} | B^0 \rangle} \right) \sin(\Delta mt) - \frac{c_d}{2} \cos(\Delta mt) \right] \]

\[ c_d = \left| \frac{\langle f_{CP} | B^0 \rangle}{\langle f_{CP} | B^0 \rangle} \right|^2 - 1 \]

- CP violation in neutral B meson system appears as the asymmetry in the proper time dependence.
- Generally, asymmetry follow as
  \[ A(t) = S \sin(\Delta mt) + A \cos(\Delta mt) , \]
  where \( S \) (mixing-induced CPV) and \( A \) (DCPV) depend on the final state.
- \( q/p \) (independent of final state)

\[ \frac{q}{p} = \frac{V_{td}V_{tb}^*}{V_{td}^*V_{tb}} \]

C.f. \[ \frac{q_{K}}{p_{K}} = \frac{V_{cd}V_{cs}^*}{V_{cd}^*V_{cs}} \]
CPV in Neutral B Meson

Gold-plated mode:
measurement of $\phi_1$ with $B^0 \rightarrow J/\psi K^0$

$$A(t) = \frac{2}{2 + c_d} \left[ \text{Im} \left( \frac{q}{p} \frac{\langle f_{CP} | B^0 \rangle}{\langle f_{CP} | B^0 \rangle} \right) \sin(\Delta mt) - \frac{c_d}{2} \cos(\Delta mt) \right]$$

$$c_d = 0 \text{ (no DCPV)}$$

no weak phase in $B^0 \rightarrow f_{CP}$

$\xi$ (CP eigenvalue) appears from

$$\frac{q}{p} = \frac{V_{td} V_{tb}^*}{V_{td} V_{tb}}$$

$$A_{CP}(\Delta t) = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$$

$$S = -\xi \sin(2\phi_1)$$

$$A = 0$$
Belle Experiment

• Experiment in KEK, Tsukuba, Japan.
• Asymmetric $e^+e^-$ collider KEKB
  • 3.5 GeV positron + 8 GeV electron
  • Circumference ~ 3km
  • Finite crossing angle (22mrad)
• World highest luminosity
  • $2.11 \times 10^{34}$ cm$^{-2}$s$^{-1}$ (2009/06/17)
• Started in 1999.

• 14 countries, 60 institutes, 400 members
• Produce enormous number of B mesons “B Factory experiment”.
• Integrated Luminosity = 950 fb$^{-1}$
  • 710 fb$^{-1}$ on $\Upsilon(4S)$: 770 M B pairs.

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ (1.1nb)

S. Nishida (KEK)  
Jul. 30, 2009  
Observation of CP Violation in the Neutral B Meson System with Belle  
Workshop on Symmetry
Belle Detector

Particle Identification

Aerogel Cherenkov Counter

3.5GeV $e^+$

Central Drift Chamber

Particle Identification

Particle Identification

TOF Counter

Silicon Vertex Detector

$8\text{GeV}$ $e^-$

$K_L, \mu$ detection

vertex

energy

SC Solenoid

CsI(Tl) Calorimeter

Particle Identification

Observation of CP Violation in the Neutral B Meson System with Belle

Workshop on Symmetry

Jul. 30, 2009

S. Nishida (KEK)
Observation of CP Violation in the Neutral B Meson System with Belle

Workshop on Symmetry
Time Dependent CPV

Measure position instead of time (B life time ~1.6ps)

tCPV = time-dependent CP Violation

Flavor-tag
(B^0 or \overline{B^0} ?)

Reconstruction

J/ψ(φ,η’)

f_{CP}

K_S

Vertexing

\varepsilon_{eff} \approx 30\%

\Delta z

\sigma_{\Delta t} \approx 140\text{ps}

\Delta t \approx \Delta z/c\beta\gamma

\beta\gamma = 0.425 \text{ (KEKB)}

Extract CPV

S.Nishida (KEK)
Jul. 30, 2009

Observation of CP Violation in the Neutral B Meson System with Belle

Workshop on Symmetry
Measurement of sin2φ₁

\[ B^0 \rightarrow J/\psi \ K^0 \]

\[ A_{CP}(\Delta t) = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t) \]

\[ S = -\xi \sin(2\phi_1) \]

\[ A = 0 \]

\( (\xi : \text{CP eigenvalue}) \)

Analysis procedure:

- Reconstruct \( B^0 \rightarrow J/\psi K_S^0 \) and \( B^0 \rightarrow J/\psi K_L^0 \) events.
- Measure \( \Delta t \) distribution.
Utilize special kinematics at $\Upsilon(4S)$

Energy difference:

$$\Delta E \equiv E_{J/\psi} + E_{K_S} - E_{CM}/2$$

Beam-constrained mass:

$$M_{bc} = \sqrt{(E_{CM}/2)^2 - (\vec{p}_{J/\psi} + \vec{p}_{K_S})^2}$$
B^0 \rightarrow J/\psi \ K^0

precise measurement of $\phi_1$

B^0 \rightarrow J/\psi \ K_S

N_{\text{sig}} = 7482
Purity 97 %
CP odd

B^0 \rightarrow J/\psi \ K_L

N_{\text{sig}} = 6512
Purity 59 %
CP even

S.Nishida (KEK)
Jul. 30, 2009

Observation of CP Violation in the Neutral B Meson System with Belle

Workshop on Symmetry
CPV in Neutral B Meson

\[ B^0 \rightarrow J/\psi \, K_S \, , \, J/\psi \, K_L \, \text{sum} \]

\[ A_{CP}(\Delta t) = \frac{\Gamma(\overline{B^0}(\Delta t) \rightarrow f_{CP}) - \Gamma(B^0(\Delta t) \rightarrow f_{CP})}{\Gamma(\overline{B^0}(\Delta t) \rightarrow f_{CP}) + \Gamma(B^0(\Delta t) \rightarrow f_{CP})} \]

\[ = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t) \]

\[ S = -\xi \sin(2\phi_1) \]

\[ A = 0 \]

\[ \sin 2\phi_1 = 0.642 \pm 0.031 \pm 0.017 \]

\[ A = 0.018 \pm 0.021 \pm 0.014 \]

CPV in neutral B system
Observation of CP Violation in the Neutral B Meson System

(Belle Collaboration)

We present a measurement of the standard model CP violation parameter $\sin 2\phi_1$ based on a $29.1 \text{ fb}^{-1}$ data sample collected at the $Y(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider. One neutral $B$ meson is fully reconstructed as a $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_cK_S$, $J/\psi K_L$, or $J/\psi K_{*0}$ decay and the flavor of the accompanying $B$ meson is identified from its decay products. From the asymmetry in the distribution of the time intervals between the two $B$ meson decay points, we determine $\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$. We conclude that we have observed CP violation in the neutral $B$ meson system.

DOI: 10.1103/PhysRevLett.87.091802

PACS numbers: 13.25.Hw, 11.30.Er, 12.15.Hh
Various measurements (from B factories and other experiments) have been made constraint to the Unitarity Triangle (angles, sides).

Precise test for the KM picture of the CP violation.

Complex phase in CKM matrix is the source of the CP violation.

So far, all the measurements show good agreement.
However, this does not mean all the mystery of the CP violation is solved.

At the birth of the Universe, equal amounts of matters and anti-matters were created, but the present Universe is dominated by matter.

Sakharov Conditions
- Out of thermal equilibrium
- Baryon number violation
- C violation and CP violation

However, CP violation by KM mechanism is too small to create matter-dominant Universe.

Next target is to search for other CP violation sources (New Physics)
CP Violation in \( B \rightarrow K\pi \)

\( B^0 \rightarrow K^+\pi^- \)

- Two diagrams with different weak phase. **Direct CP Violation is possible in the SM (KM mechanism).**
  - Tree diagram: \( V_{ub} \)
  - Penguin diagram: no CKM complex phase
  - Phase difference = \( \phi_3 \)
- Relatively high branching fraction \((\sim 2 \times 10^{-5})\); DCPV has been searched from the beginning of Belle experiment.
CP Violation in $B \to K\pi$

$$A(K^\pm\pi^\mp) = -0.094 \pm 0.018 \pm 0.008$$

$$A(K^\pm\pi^0) = +0.07 \pm 0.03 \pm 0.01$$

DCPV found: expected from the KM theory.

$$\Delta A = A(K^\pm\pi^0) - A(K^\pm\pi^\mp)$$

$$= 0.164 \pm 0.037 \quad (4.4\sigma)$$

But why different asymmetry between $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$?
CP Violation in $B \to K\pi$

Contribute to $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$

Contribute only to $B^+ \to K^+\pi^0$

c : color-suppressed decay : expected to be small effect
d : EW penguin (negligible CP violating phase in the SM. New Physics?)

Maybe an indication of New Physics, or some problems in theoretical calculation?

From the experimental side, more variables should be measured.
B^0 \rightarrow J/\psi \ K_{S/L}

A_{CP}(\Delta t) = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)

S = -\xi \sin(2\phi_1)
A = 0 

(\xi : CP eigenvalue)

precise measurement of \phi_1

b \rightarrow s

In the SM,
S = -\xi \sin(2\phi_1)

However, the value will change with non-SM contribution to the loop

Search for New Physics
Aug. 2003

“\(\sin 2\phi_1\) = -0.96 \pm 0.50^{+0.09}_{-0.11}\)

S. Nishida (KEK)

Observation of CP Violation in the Neutral B Meson System with Belle

Workshop on Symmetry
CP Violation in $b \to s$ Penguin

$B \to \eta' K^0$

```
“sin2$\phi_1$” = 0.64 ± 0.10 ± 0.04
A = −0.01 ± 0.07 ± 0.05
```

c.f.) $sin2\phi_1 = 0.642 \pm 0.031 \pm 0.017$

- Good agreement with $sin2\phi_1$.
  (No new physics unfortunately)
- First Observation of time dependent CPV in $b \to s$ penguin!! ($>5\sigma$)

$B \to \phi K_S$

Dalitz Analysis for $B \to K^+K^-K^0$

```
“$\phi_1$” = (21.2$^{+9.8}_{-10.4}$ ± 2.0 ± 2.0)$°$
```

```
“sin2$\phi_1$” = 0.67$^{+0.22}_{-0.32}$
```

Jul. 30, 2009
Observation of CP Violation in the Neutral B Meson System with Belle
CP Violation in $b \rightarrow s$ Penguin

The difference of and is getting smaller.

But, need more precise measurements for each mode.
Future

- PEP-II/BaBar finished its operation in 2008.
- KEKB/Belle will be shutdown this year.

SuperKEKB / Belle-II after 3 years’ shutdown

- Target luminosity $8 \times 10^{35}$ cm$^{-2}$s$^{-1}$
- 50 ab$^{-1}$ by ~2020

- Hopefully new phenomena might be seen:
  - CPV in B decays from the physics outside the KM scheme.
  - Lepton flavor violations in $\tau$ decays.

- Physics motivation is independent of LHC.
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/$\tau$ decays would be a unique way to search for the TeV scale physics.
Kobayashi-Maskawa Theory is proposed in 1972 in order to explain the CP Violation observed in the neutral kaon system in 1963.

In the KM theory, a complex phase in the quark-mixing matrix is the source of the CP Violation, and predicted at least three families of quarks.

If the KM theory is correct, CP violation appears in the proper time difference in the two neutral B meson system.

Belle (and BaBar) observed the CP violation in the B meson system, which established the KM picture of the CP violation.

The next target is to find another source of the CP violation in New Physics, which might explain the matter dominance of the Universe.
B Symposium

2009/08/31 10:00-

at Tokyo Univ.

Observation of CP Violation in the Neutral B Meson System with Belle

S.Nishida (KEK)
Jul. 30, 2009
End
Time Dependent CPV

$\textbf{B}^0$ $\xrightarrow{q/p} \overline{\textbf{B}}^0$ $\xrightarrow{f_{CP}}$

**CP Violation** manifests itself in proper-time difference ($\Delta t$) distributions of two $B$ meson decays.

\[
A_{CP} \equiv \frac{\Gamma(B_d^0(\Delta t) \rightarrow f_{CP}) - \Gamma(B_d^0(\Delta t) \rightarrow \overline{f}_{CP})}{\Gamma(B_d^0(\Delta t) \rightarrow f_{CP}) + \Gamma(B_d^0(\Delta t) \rightarrow \overline{f}_{CP})} = S \sin(\Delta m \Delta t) + A \cos (\Delta m \Delta t)
\]

- **Mixing induced CPV**
- **Direct CPV**

\[
S = \frac{2 \text{Im}\lambda_{CP}}{1 + |\lambda_{CP}|^2}
\]

\[
A = \frac{|\lambda_{CP}|^2 - 1}{|\lambda_{CP}|^2 + 1}
\]

\[
\lambda_{CP} = \frac{q}{p} \frac{A(B^0 \rightarrow f_{CP})}{A(\overline{B}^0 \rightarrow f_{CP})}
\]

Jul. 30, 2009

Observation of CP Violation in the Neutral B Meson System with Belle

Workshop on Symmetry
CP Violation in $B \rightarrow K\pi$

Sum Rule

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \approx A_{CP}(K^+\pi^0) + A_{CP}(K^0\pi^0)$$

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+}$$

$$= A_{CP}(K^+\pi^0) \frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0) \frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$
Observation of CP Violation in the Neutral B Meson System with Belle

**Discovery of CPV in B**


**Many new resonances**

- Phys.Rev.D71:071103,2005

**Evidence for B→τν**


**b→dγ transition**


**B→D*τν**

**D^0-D^0 mixing**

**A_{FB} in B→K^*±±**

- DPLR 96, 251801(2006)

**Belle, 2005**

**SM**

S.Nishida (KEK)  
Jul. 30, 2009  
Observation of CP Violation in the Neutral B Meson System with Belle  
Workshop on Symmetry
CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

In a framework of the renormalisable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quark scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

References

Observation of CP Violation in the Neutral B Meson System with Belle

Workshop on Symmetry

Jul. 30, 2009
Future

Belle-II Detector

SC solenoid
1.5T

CsI(Tl) 16\(X_0\)
→ pure CsI (endcap)

\(\mu / K_L\) detection
14/15 lyr. RPC+Fe
→ Bar scintillator

Aerogel Cherenkov counter + TOF counter
→ “TOP” + A-RICH

Tracking + \(dE/dx\)
small cell + He/C\(_2\)H\(_6\)
→ remove inner lyrs.

Si vtx. det.
4 lyr. DSSD
→ 2 pixel/striplet lyrs. + 4 lyr. DSSD
粒子の再構成（素粒子実験一般）

特殊相対論を使う

- 4元運動量の保存則（運動量とエネルギーの保存）
- \( E^2 = |p|^2 + m^2 \)

例えば、ある粒子が2つの粒子に崩壊したとする

\[
M = p_1 + p_2
\]

\[
(p_1, E_1) \quad m_1
\]

\[
(p_2, E_2) \quad m_2
\]

\( p_i \)とその粒子の種類（従って\( m_i \)）は検出器で測定される。\( E_i \)もわかる。

\[
M^2 = E^2 - |P|^2 = (E_1 + E_2)^2 - |p_1 + p_2|^2
\]

これで、もとの粒子の質量がわかる。
電子と陽電子が衝突 →
B中間子と反B中間子が生成 →
生成された（反）B中間子はすぐに崩壊 →
崩壊で出てきた粒子をBelle検出器で検出