Measurements of $\varphi_1$ and $\varphi_2$

Tagir Aushev
For the Belle Collaboration
(EPFL, Lausanne
ITEP, Moscow)

- $B \rightarrow K_S \pi^0 \pi^0$
- $B \rightarrow K_S K_S$
- $B \rightarrow K_S \pi^0$
- $B \rightarrow D^{*+} D^{*-}$
- $B \rightarrow a_1 \pi, a_1 K, b_1 \pi, b_1 K, \ldots$
- $Y(4S) \rightarrow B_{CP} B_{CP}$
CKM matrix & unitary triangle

\[ V^\dagger V = 1 \quad \Rightarrow \quad V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \]

\[ \alpha = \arg \left( -\frac{V_{td} V_{tb}^*}{V_{ud} V_{ub}^*} \right), \quad \beta = \arg \left( -\frac{V_{cd} V_{cb}^*}{V_{td} V_{tb}^*} \right), \quad \gamma = \arg \left( -\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right) \]
**CP Violation in the Standard Model**

- Triangle is well measured
- $\varphi_1(\beta)$ mainly from $B^0 \rightarrow J/\Psi K_S$ “golden mode”
- Smaller and smaller room for the vertex position, but it is still in
- New decay modes are examining to find a New Physics
TCPV measurement on $B$-factory

$B$s are produced in a boosted frame
$\rightarrow \Delta t$ is measured from vertex positions

$B$s are entangled
$\rightarrow$ flavor of $B_1$ at time $t_2$ is determined by $B_2$ decay
Belle & BaBar B-factories

KEKB B-Factory

- Superconducting cavities (HER)
- ARES copper cavities (LER)
- TRISTAN tunnel
- 8 GeV e⁻, 3.5 GeV e⁺, Linac
- e⁺ target

8 GeV (e⁻) × 3.5 GeV (e⁺)

Drift Chamber
- 40-layer, small cell

Silicon Vertex Tracker
- 5-layer, double-sided strips

1.5 T Solenoid

DIRC (PID)
- Quartz Cherenkov detector

EM Calorimeter
- CsI crystals

Flux Return
- RPC and LST instrumented iron
BaBar collected 510 fb\(^{-1}\)

\[ L_{\text{peak}} = 1.71 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \]

\[ \int L dt = 770 \text{ fb}^{-1} \]

Moriond EW, 3 Mar 2008
TagirAushev (EPFL, ITEP)
After evidence for DCPV in $B \rightarrow D^- D^+$ recently shown by Belle all $B \rightarrow DD$ decays has a special interest

$B$.R. and charge asym for $B \rightarrow D^+ D^0$ were updated by Belle:

$B$.R. = $(3.85 \pm 0.31 \pm 0.38) \cdot 10^{-4}$

BaBar'06: $(3.8 \pm 0.6 \pm 0.5) \cdot 10^{-4}$

$A = 0.00 \pm 0.08 \pm 0.02$

BaBar'06: $-0.13 \pm 0.14 \pm 0.02$

Also an upper limit for $B \rightarrow D^0 D^0$:

$B$.R. $< 0.43 \cdot 10^{-4}$@90%C.L.
TCPV in \( B^0 \rightarrow D^{**}D^* \)

- \( B^0 \rightarrow D^{**}D^* \) is \( b \rightarrow ccd \) transition and so sensitive to \( \sin^2 \varphi_L \) just like the “Golden” \( B^0 \rightarrow cc K^0 \) making it an important check.

- Series of papers were published by Belle and BaBar.

- Recently the results are updated with latest statistics.

- Belle result is the first time presented.

\[ B^0 \rightarrow D^{**}D^* \]
\[ N_{\text{sig}} = 638 \pm 38 \]

Helicity of $B^0 \rightarrow D^{*+}D^{*-}$

Since it is a decay of $S \rightarrow VV$ CP-eigenstate depends on angular momentum of the $VV$ system:

- Separating the CP-odd fraction, $R_\perp$, is done via a 1D angular analysis

**BaBar:** $R_\perp = 0.143 \pm 0.034 \pm 0.008$

**Belle:** $R_\perp = 0.116 \pm 0.042 \pm 0.004$

Moriond EW, 3 Mar 2008
Tagir Aushev (EPFL, ITEP)
TCPV in $B^0 \to D^*+D^*$

$$A_{CP}(t) = \frac{\Gamma_{B^0 \to f_{CP}}(t) - \Gamma_{B^0 \to f_{CP}}(t)}{\Gamma_{B^0 \to f_{CP}}(t) + \Gamma_{B^0 \to f_{CP}}(t)} = S \sin \Delta m_d t + A \cos \Delta m_d t$$

$$S = -\sin 2\varphi_1$$

$$A = -C$$

BaBar: $-0.66 \pm 0.19 \pm 0.04 + 0.02 \pm 0.11 \pm 0.02$

Belle: $-0.93 \pm 0.24 \pm 0.15 + 0.16 \pm 0.13 \pm 0.02$

Moriond EW, 3 Mar 2008
Tagir Aushev (EPFL, ITEP)
Searches for a New Physics

- Penguin dominated B decays are sensitive to NP

- New Physics may introduces extra CP phase in the decay

- Deviation of Time-dependent CP violation parameters from the SM expectation \( \rightarrow \text{Hint of New Physics} \)
TCPV in $B^0 \to K_S\pi^0\pi^0 : b \to s \bar{q}q$

$N_{\text{sig}} = 307 \pm 32$

$M_{bc} = \sqrt{E_b^2}$

$\pi^0 \pi^0 K_S \sin(2\phi_1^{\text{eff}})$ vs $C_{\text{CP}}$

Belle: $+0.43 \pm 0.49 \pm 0.09$
BaBar: $+0.72 \pm 0.71 \pm 0.08$
Average: $+0.52 \pm 0.41$

$S = -\sin 2\phi_1$

Belle: $-0.17 \pm 0.24 \pm 0.06$
BaBar: $-0.23 \pm 0.52 \pm 0.13$
Average: $-0.18 \pm 0.22$

$A = -C$

Contours give $2\Delta\ln L = \Delta \chi^2 = 1$, corresponding to 68.3% CL for 2 dof.
TCPV in $B^0 \rightarrow K_S \pi^0$

$N_{\text{sig}} = 459 \pm 29$
$\text{B.R.}= (10.3\pm0.7\pm0.6) \cdot 10^{-6}$

$S = \sin^2 \varphi_1$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle</td>
<td>$+0.33\pm0.35\pm0.08$</td>
</tr>
<tr>
<td>BaBar</td>
<td>$+0.40\pm0.23\pm0.03$</td>
</tr>
</tbody>
</table>

$A = -C$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle</td>
<td>$-0.05\pm0.14\pm0.05$</td>
</tr>
<tr>
<td>BaBar</td>
<td>$-0.24\pm0.15\pm0.03$</td>
</tr>
</tbody>
</table>

Measurements of $\phi_2$

$\phi_2(\alpha)$ was measured in $\pi\pi$, $\rho\pi$ and $\rho\rho$ systems.

The same matrix elements are also involved to the $B$ decays to axial vectors $a_1$, $b_1$ ...

Some of them can be used only with much larger statistics.

\[ \sim 90^\circ \pm 10^\circ \]
Measurement $B \rightarrow a_1 \pi$

First time-dep CP asymmetry in $B \rightarrow a_1^+ \pi^-$

$$\alpha_{\text{eff}} = (79 \pm 7)^\circ, \alpha = ?$$

$B.R.(B^0 \rightarrow a_1^\pm \pi^\mp)B.R.(a_1 \rightarrow \pi^\pm \pi^\pm \pi^\mp)$

$$= (14.9 \pm 1.6 \pm 2.3) \times 10^{-6}$$

Moriond EW, 3 Mar 2008
Tagir Aushev (EPFL, ITEP)
**Latest result from Belle:**

\[ \mathcal{B}(B^0 \rightarrow \rho^0 \rho^0) < 1.0 \times 10^{-6} \]

<table>
<thead>
<tr>
<th>Mode</th>
<th>Yield</th>
<th>Eff. (%)</th>
<th>$S$</th>
<th>$B(\times 10^{-6})$</th>
<th>UL($\times 10^{-6}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho^0 \rho^0$</td>
<td>$24.5^{+23.6+9.7}_{-22.1-9.9}$</td>
<td>9.16</td>
<td>1.0</td>
<td>$0.4 \pm 0.4 \pm 0.2$</td>
<td>$&lt; 1.0$</td>
</tr>
<tr>
<td>$\rho^0 \pi \pi$</td>
<td>$112.5^{+67.4+51.5}_{-65.6-53.7}$</td>
<td>2.90</td>
<td>1.3</td>
<td>$5.9^{+3.5+2.7}_{-3.4-2.8}$</td>
<td>$&lt; 11.9$</td>
</tr>
<tr>
<td>$4\pi$</td>
<td>$161.2^{+61.2+26.0}_{-59.4-28.5}$</td>
<td>1.98</td>
<td>2.5</td>
<td>$12.4^{+4.7+2.0}_{-4.6-2.2}$</td>
<td>$&lt; 19.0$</td>
</tr>
<tr>
<td>$\rho^0 f_0$</td>
<td>$-11.8^{+14.5+4.9}_{-12.9-3.6}$</td>
<td>5.10</td>
<td>0.0</td>
<td>0.0</td>
<td>$&lt; 0.6$</td>
</tr>
<tr>
<td>$f_0 f_0$</td>
<td>$-7.7^{+4.7+3.0}_{-3.5-2.9}$</td>
<td>2.75</td>
<td>0.0</td>
<td>0.0</td>
<td>$&lt; 0.4$</td>
</tr>
<tr>
<td>$f_0 \pi \pi$</td>
<td>$6.3^{+37.0+18.0}_{-34.7-18.1}$</td>
<td>1.55</td>
<td>0.0</td>
<td>$0.6^{+3.6}_{-3.4} \pm 1.8$</td>
<td>$&lt; 7.3$</td>
</tr>
</tbody>
</table>
$B$ decays to light mesons

- $B \rightarrow b_1^0 \pi^+: (6.7 \pm 1.7 \pm 1.0) \cdot 10^{-6}$
- $B \rightarrow a_1^0 \pi^+: (20.4 \pm 4.7 \pm 3.4) \cdot 10^{-6}$
- $B \rightarrow b_1^0 K^+: (9.1 \pm 1.7 \pm 1.0) \cdot 10^{-6}$
- $B \rightarrow a_1^+ K^0: (34.9 \pm 5.0 \pm 4.4) \cdot 10^{-6}$
- $B \rightarrow b_1^- \pi^+: (10.9 \pm 1.2 \pm 0.9) \cdot 10^{-6}$
- $B \rightarrow a_1^- \pi^0: (13.2 \pm 2.7 \pm 2.1) \cdot 10^{-6}$
- $B \rightarrow b_1^- K^+: (7.4 \pm 1.0 \pm 1.0) \cdot 10^{-6}$
- $B \rightarrow a_1^- K^+: (16.3 \pm 2.9 \pm 2.3) \cdot 10^{-6}$

No charge asym's found

PRL 99:261801, 2007
PRL 100:051803, 2008
PRL 99:241803, 2007
CP Violating Decays of the $Y(4S)$

- $\xi_{CP}=+1$
- $J/\psi K_S$, $\xi_1=-1$
- $J/\psi K_L$, $\xi_1=+1$
- $J/\psi K_S$, $\xi_1=-1$
- $J/\psi K_S$, $\xi_2=-1$
- $J/\psi K_L$, $\xi_2=+1$
- $J/\psi K_S$, $\xi_2=-1$
- $\eta_c K_S$, $\chi_{c1} K_S$, $\psi(2S) K_S$

$\xi_{CP}$ values:
- $+1$
- $-1$

CP violation!!
Partial reconstruction

Y(4S) → B^0 \bar{B}^0

Full reconstruction

\[ \mu^+ \rightarrow J/\psi \]
\[ \mu^- \]
\[ \pi^+ \rightarrow K_S \]
\[ \pi^- \]

Partial reconstruction

\[ \pi^+ \rightarrow K_S \]
\[ \pi^- \]

\[ \rightarrow J/\psi, \eta_c \]

About 40 times higher eff. than full reconstruction method

1.1(0.6) inclusive-J/\psi(\eta_c) events in 535 million Y(4S) decays

Moriond EW, 3 Mar 2008

Tagir Aushev (EPFL, ITEP)
Results with 535M $Y(4S)$ decays

Control sample

$B^0 \rightarrow D^*(\pi^+ \text{ and } D^{*-}\rho^+)$

$B^0 \rightarrow \eta_c K_S \text{ and } J/\psi K_S$

$\text{SM prediction : } 1.4 \times 10^{-7}$

$N_{\text{sig}}=-1.5^{+3.6}_{-2.8}$ events

With 30 billion $Y(4S)$ (30ab$^{-1}$), such decays will be observed with 5$\sigma$ significance
Summary

• CP violations was measured in various B decays
  - Both mixing-induced & direct CPV observed

• Excellent agreement with Standard Model
  - Small room for New Physics remains in flavour sector

• Next order of the statistics is needed to give an answer for the New Physics existence