IL NUOVO CIMENTO Vol. 32 C, N. 5-6 Settembre-Dicembre
DOI 10.1393/ncc/i2010-10555-7

Colloquia: LaThuile09

Rare decays and CP violation at B-factories

Y. Unno
Hanyang University - Seoul, South Korea

(ricevuto il 10 Novembre 2009; pubblicato online il 25 Gennaio 2010)

Summary. — Recent results on rare B decays from the two B-factories, Belle and BABAR, are presented. The Wilson Coefficients in $B \to K^{(*)} l^+ l^-$ and polarization puzzle in charmless $B \to VV$ decays are addressed.

PACS 13.25.Hw – Hadronic decays of bottom mesons.
PACS 13.20.He – Leptonic, semi-leptonic and radiative decays of bottom mesons.
PACS 11.30.Er – Charge conjugation, parity, time reversal, and other discrete symmetries.

1. – Introduction

Two B-factories, Belle at KEKB and BABAR at PEP-II, have observed CP violation in B meson decays and proved the correctness of KM mechanism which is included in the Standard Model (SM). On the other hand, some results which differ from the SM expectation are also observed. The direction of the B-factories has been modified to search for a hint of new physics beyond the SM. The study of rare B decays allows a thorough test of the SM. At the same time, it plays significant role to search for contributions from new physics. Belle and BABAR have collected integrated luminosity of more than $800\,\text{fb}^{-1}$ and $500\,\text{fb}^{-1}$, respectively, and the combined one has exceeded $1.4\,\text{ab}^{-1}$. From the large data samples, Belle and BABAR have analyzed up to 657M$B\overline{B}$ and 465M$B\overline{B}$ events, respectively. In this report, the recent results on a study of rare B decays; Wilson coefficients in $B \to K^{(*)} l^+ l^-$, and polarization puzzle in charmless $B \to VV$, $\rho^0 K^{*0}$, $K^{*0} K^{*+}$, and ωK^*, including PV and VT decays, from the B-factories are presented.

2. – Wilson coefficients from $B \to K^{(*)} ll$

In the SM, the decays $B \to K^{(*)} l^+ l^-$, where l represents either an electron or a muon, arise from flavor-changing neutral current processes that are forbidden at tree level, and proceed through either a Z/γ penguin or W^+W^- box diagrams. The amplitudes can be expressed with the effective Wilson coefficients, C_7, C_9, and C_{10}, for the electromagnetic penguin, the vector, and the axial-vector electroweak contributions, respectively. A contribution of new physics can enter the penguin and box diagrams by modifying

TABLE I. – *Isospin asymmetry in low-q^2 region.*

Mode	Belle($q^2 < 8.68\,\mathrm{GeV}^2/c^4$)	BABAR ($q^2 < 7.02\,\mathrm{GeV}^2/c^4$)
Kl^+l^-	$-0.31^{+0.17}_{-0.14} \pm 0.05$ (1.75σ)	$-1.43^{+0.56}_{-0.85} \pm 0.05$ (2.7σ)
$K^*l^+l^-$	$-0.29 \pm 0.16 \pm 0.03$ (1.40σ)	$-0.56^{+0.17}_{-0.15} \pm 0.03$ (3.2σ)
$K^{(*)}l^+l^-$	$-0.30^{+0.12}_{-0.11} \pm 0.04$ (2.24σ)	$-0.64^{+0.15}_{-0.14} \pm .03$ (3.9σ)

the Wilson coefficients at the same order as the SM. In this modes, there are many observables experimentally; branching fraction, isospin asymmetry, lepton flavor ratio, CP asymmetry, and lepton forward-backward asymmetry, so hints of new physics and variety models which predict such effects can be examined from various perspectives. Those have been studied by Belle and BABAR using 657M$B\overline{B}$ and 384M$B\overline{B}$ data samples, respectively [1-3].

The results of branching fraction measurements by Belle are $\mathcal{B}(K^*l^+l^-) = (10.7^{+1.1}_{-1.0} \pm 0.9) \times 10^{-7}$ and $\mathcal{B}(Kl^+l^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}$, and obtained CP asymmetries, which are expected to be very small in the SM, are $\mathcal{A}_{CP}(K^*l^+l^-) = -0.10 \pm 0.10 \pm 0.01$ and $\mathcal{A}_{CP}(Kl^+l^-) = 0.04 \pm 0.10 \pm 0.02$. The results are consistent with measurements by BABAR [2].

The lepton flavor ratios, defined as $R_{K^{(*)}} = \mathcal{B}(K^{(*)}\mu^+\mu^-)/\mathcal{B}(K^{(*)}e^+e^-)$, are expected to be 1.0 and 0.75 for R_K and R_{K^*} in the SM, respectively. R_K is sensitive to the size of the photon pole, and R_{K^*} is sensitive to neutral SUSY Higgs if $\tan\beta$ is large. The consistent results with the SM expectations are measured to be $R_{K^*} = 0.83 \pm 0.17 \pm 0.05(0.96^{+0.44}_{-0.34} \pm 0.05)$ and $R_K = 1.03 \pm 0.19 \pm 0.06(1.37^{+0.53}_{-0.40} \pm 0.09)$ by Belle(BABAR).

Isospin asymmetry $A_I^{K(*)} \equiv [(\tau_{B^+})/(\tau_{B^0}) \times \mathcal{B}(K^{(*)0}l^+l^-) - \mathcal{B}(K^{(*)\pm}l^+l^-)]/[(\tau_{B^+})/(\tau_{B^0}) \times \mathcal{B}(K^{(*)0}l^+l^-) + \mathcal{B}(K^{(*)\pm}l^+l^-)]$ is expected to be $(+6\% - 13\%)$ as $q^2 = m_{ll}^2 \to 0\,\mathrm{GeV}^2/c^4$ in the SM. Both Belle and BABAR found no significant isospin asymmetries in the high-q^2 regions. However, as shown in table I, BABAR found an evidence for large negative asymmetries in the low-q^2 region. Although Belle results are consistent with null asymmetries, those are in agreement with measurements by BABAR and also indicating large negative asymmetries.

Measurements of angular distributions as a function of q^2 are of particular interest because new physics contribution depends on q^2 due to the fact that $K^*l^+l^-$ is a three-body decay proceeding via three different processes, whose relative contributions vary as a function of q^2. The fraction of longitudinal polarization F_L at low q^2 is sensitive to effects from left-handed currents with complex phases different from the SM, or effects from right-handed currents in the photon penguin amplitude. The sign and magnitude of lepton forward-backward asymmetry can be modified significantly if new physics contributes. Results of F_L and A_{FB} measurements as a function of q^2 are shown in fig. 1, together with the SM predictions and sign flipped coefficients cases. The measured A_{FB} by both Belle and BABAR tend to be shifted toward the positive side from the SM expectation at all q^2 regions, and looks like wrong sign C_7 is favored.

3. – Polarization puzzle in $B \to VV$ (with PV and VT)

Results of small longitudinal polarization fraction $f_L \sim 0.5$ in charmless hadronic B decays to vector-vector final states, $B \to \phi K^*$, reported by both Belle and BABAR

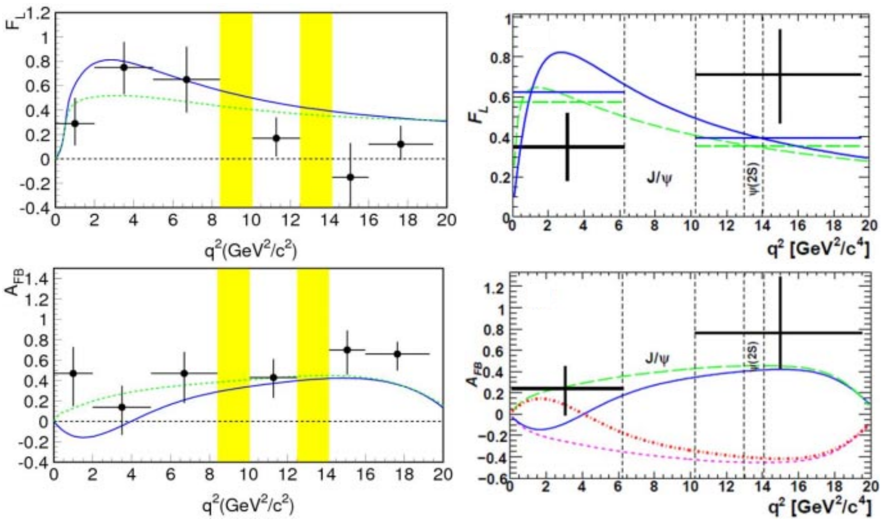

Fig. 1. – Results of F_L (top) and $A_{\rm FB}$ (bottom) measurements as a function of q^2 for the decay $B \to K^* l^+ l^-$ for Belle (left) and BABAR (right). SM predictions are shown as a solid curve together with sign flipped Wilson coefficients cases; $C_7 = -C_7^{\rm SM}$ (long dash), $C_9 C_{10} = -C_9^{\rm SM} C_{10}^{\rm SM}$ (short dash), and $C_7 = -C_7^{\rm SM}$, $C_9 C_{10} = -C_9^{\rm SM} C_{10}^{\rm SM}$ (dash-dot).

came as surprising observations [4,5]. A large f_L is predicted for both tree- and penguin-dominated $B \to VV$ decays in the SM. In fact, the large f_L in tree-dominated decays $B \to \rho\rho$ and $B^+ \to \omega\rho^+$ have been confirmed. In order to resolve the polarization puzzle, several theoretical attempts have been made within or beyond the SM. For the improved understanding on the puzzle, measurements of branching fraction and f_L for other modes dominated by penguin processes play a very important role.

3˙1. *$B^0 \to \rho^0 K^{*0}$ by Belle.* – The decay $B^0 \to \rho^0 K^{*0}$ proceeds via dominant penguin loop and Cabibbo-suppressed tree processes. First observation of this mode using 232M$B\overline{B}$ together with $B^0 \to f^0 K^{*0}$ observation was reported by BABAR [6]. The measured branching fractions are $\mathcal{B}(\rho^0 K^{*0}) = (5.6 \pm 0.9 \pm 1.3) \times 10^{-6}$ with 5.3σ and $\mathcal{B}(f^0 K^{*0}) = (2.6 \pm 0.6 \pm 0.9) \times 10^{-6}$ with 5.0σ, and small f_L in $\rho^0 K^{*0}$ decay is measured to be $0.57 \pm 0.09 \pm 0.08$, which disagree with the SM prediction. Belle has also searched for $\rho^0 K^{*0}$ with 657M$B\overline{B}$ [7] and the results including $f^0 K^{*0}$ and non-resonance decays are summarized in table II. Figure 2 shows projection plots on fitted variables. Belle found neither $\rho^0 K^{*0}$ nor $f^0 K^{*0}$, and set 2σ and 1σ lower upper limits than the branching fractions measured by BABAR. On the other hand, non-resonance decays, $\rho^0 K^+\pi^-$, $f_0(980)K^+\pi^-$, and $\pi^+\pi^- K^{*0}$, are observed with 5.0, 3.5, and 4.5σ significances, respectively.

3˙2. *$B^+ \to \overline{K}^{0*} K^{*+}$ by BABAR, and $B^+ \to \overline{K}^{0*} K^+$ by Belle.* – The decay $B^+ \to \overline{K}^{0*} K^{*+}$ occurs through $b \to d$ penguin process same as $B^0 \to \overline{K}^{0*} K^{*0}$ decay. Its branching fraction is expected to be of the same order as $\overline{K}^{0*} K^{*0}$. $B^0 \to \overline{K}^{0*} K^{*0}$ has been already observed by BABAR [8], and the measured branching fraction is $(1.28^{+0.35}_{-0.30} \pm 0.11) \times 10^{-6}$ and large f_L is measured to be $0.80^{+0.10}_{-0.12} \pm 0.06$. BABAR has performed a search for $\overline{K}^{0*} K^{*+}$ using 467M$B\overline{B}$, and found the evidence [9]. The obtained branching

Table II. – *Branching fraction measurements of* $\rho^0 K^{*0}$.

Mode	$\mathcal{B}(\times 10^{-6})$	$\mathcal{B}_{\rm UL}(\times 10^{-6})$	$\mathcal{S}(\sigma)$
$\rho^0 K^{*0}$	$2.1^{+0.8+0.9}_{-0.7-0.5}$	< 3.4	2.7
$f_0(980)K^{*0}$	$1.4^{+0.6+0.6}_{-0.5-0.4}$	< 2.2	2.5
$\rho^0 K^+\pi^-$	$2.8 \pm 0.5 \pm 0.5$	–	5.0
$f_0(980)K^+\pi^-$	$1.4 \pm 0.4^{+0.3}_{-0.4}$	–	3.5
$\pi^+\pi^- K^{*0}$	$4.5^{+1.1+0.9}_{-1.0-1.6}$	–	4.5
$\pi^+\pi^- K^+\pi^-$	$-0.1^{+1.2+1.4}_{-1.1-0.8}$	< 2.1	0.0

fraction and f_L are $\mathcal{B} = (1.2 \pm 0.5 \pm 0.1) \times 10^{-6}$ with 3.7σ, and $f_L = 0.75^{+0.16}_{-0.26} \pm 0.03$, which are in agreement with $\overline{K}^{0*}K^{*0}$ results and the SM prediction, but different from f_L in $b \to s$ penguin dominant modes. Similar decay, $B^+ \to \overline{K}^{0*}K^+$, was searched by Belle based on 657M$B\overline{B}$. This PV decay also proceeds through $b \to d$ penguin process. Belle found the first evidence with 4.4σ, and the resulting branching fraction is $(0.68 \pm 0.16 \pm 0.10) \times 10^{-6}$.

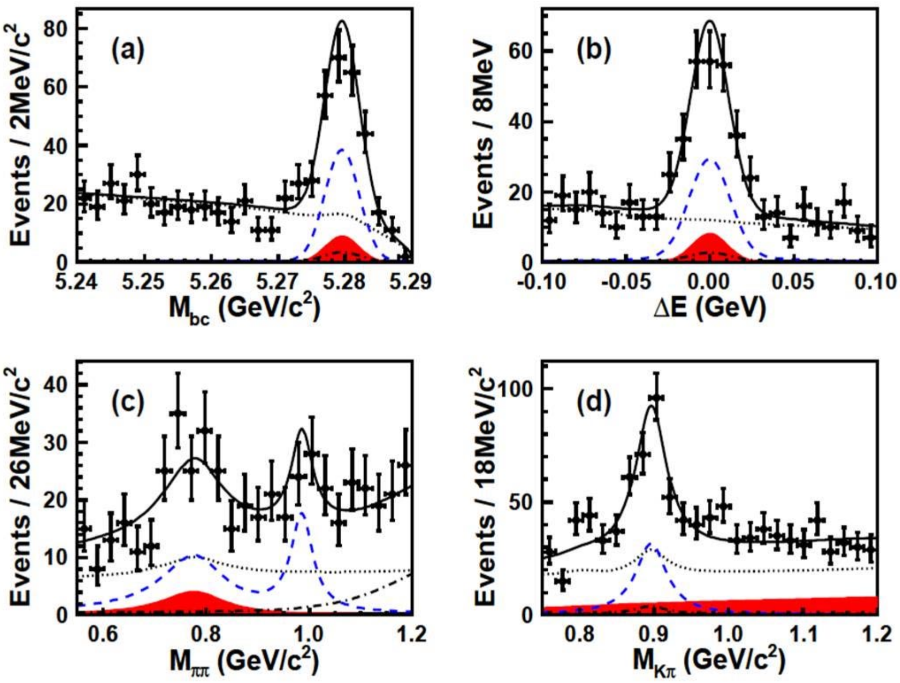

Fig. 2. – Projection plots of fitted results onto (a) M_{bc}, (b) ΔE, (c) $M_{\pi\pi}$, and (d) $M_{K\pi}$. The curves are for the $\rho^0 K^+\pi^-$ (solid-shaded), sum of $\rho^0 K^{*0}$ and $f_0 K^{*0}$ (dashed), $f_2(1270)K^{*0}$ and the sum of feed-down modes (dot-dashed), the sum of the backgrounds (dotted), and the total (solid).

TABLE III. – *Measurements of $\mathcal{B}$, f_L, and $\mathcal{A}_{\rm CP}$ for ωK^*, $\omega\rho$, and ωf_0.*

Mode	$\mathcal{B}$ ($\times 10^{-6}$) (U.L.)	$\mathcal{S}(\sigma)$	f_L	$\mathcal{A}_{CP}$
$\omega K^*(982)^0$	$2.2 \pm 0.6 \pm 0.2$	4.1	$0.72 \pm 0.14 \pm 0.02$	$+0.45 \pm 0.25 \pm 0.02$
$\omega K^*(982)^+$	$2.4 \pm 1.0 \pm 0.2 (< 7.4)$	2.5	$0.41 \pm 0.18 \pm 0.05$	$+0.29 \pm 0.35 \pm 0.02$
$\omega K_0^*(1430)^0$	$18.4 \pm 1.8 \pm 1.7$	9.8	–	$-0.07 \pm 0.09 \pm 0.02$
$\omega K_0^*(1430)^+$	$27.5 \pm 3.0 \pm 2.6$	9.2	–	$-0.10 \pm 0.09 \pm 0.02$
$\omega K_2^*(1430)^0$	$10.1 \pm 2.0 \pm 1.1$	5.0	$0.45 \pm 0.12 \pm 0.02$	$-0.37 \pm 0.17 \pm 0.02$
$\omega K_2^*(1430)^+$	$21.5 \pm 3.6 \pm 2.4$	6.1	$0.56 \pm 0.10 \pm 0.04$	$+0.14 \pm 0.15 \pm 0.02$
$\omega\rho^+$	$15.9 \pm 1.6 \pm 1.4$	9.8	$0.90 \pm 0.05 \pm 0.03$	$-0.20 \pm 0.09 \pm 0.02$
$\omega\rho^0$	$0.8 \pm 0.5 \pm 0.2 (< 1.6)$	1.6	–	–
ωf_0	$1.0 \pm 0.3 \pm 0.1 (< 1.5)$	4.5	–	–

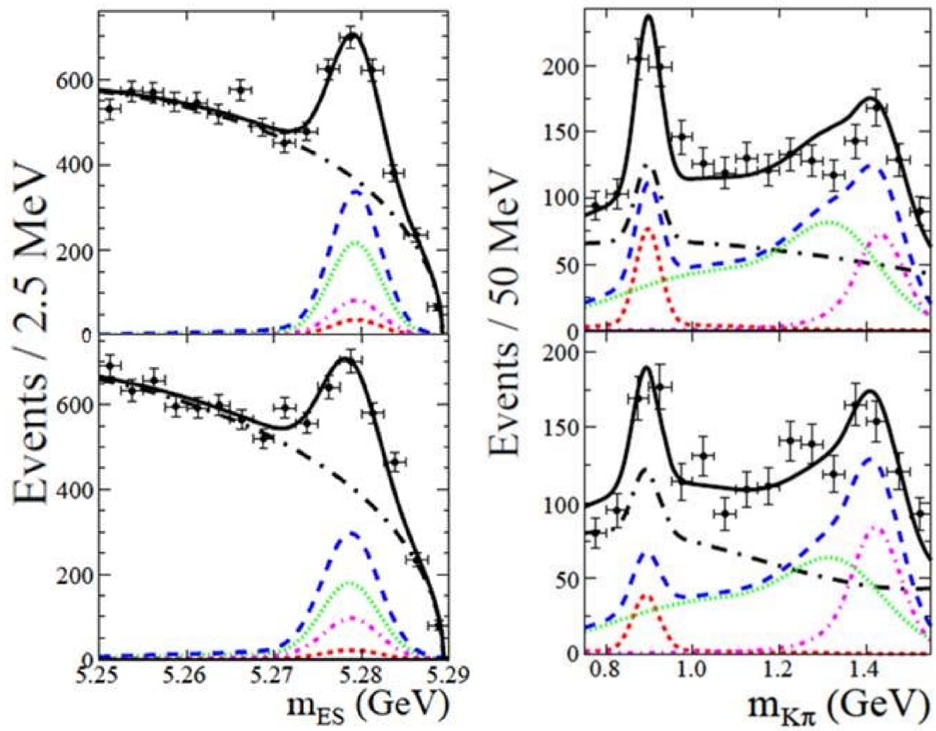

Fig. 3. – Projection plots onto m_{ES} (left) and $m_{K\pi}$ (right) for ωK^{*0} (top) and ωK^{*+} (bottom). The solid curve is the fit function, the long-dashed-dotted curve is the total background, and the dashed curve is the total signal contribution. The short-dashed line is $\omega K^*(892)$, the dotted line is $\omega(K\pi)_0$, and the dot-dashed line is $\omega K_2^*(1430)$.

3˙3. $B \to \omega K^*$ *by BABAR*. – $b \to s$ penguin dominant decay $B^0 \to \omega K^*(982)^0$ was found by Belle for the first time [10], and small f_L was measured to be $0.56 \pm 0.29^{+0.18}_{-0.08}$. Using 467M$B\overline{B}$ data sample, BABAR has also studied $B^0 \to \omega K^*(982)^0$ as well as $\omega K^*(982)^+$, $\omega K_0^*(1430)^{0/+}$, $\omega K_2^*(1430)^{0/+}$, and $\omega\rho^{0/+}$ [11]. The results of branching fraction, f_L, and CP asymmetry measurements are summarized in table III. Projection plots onto fitted variables are shown in fig. 3. $B^0 \to \omega K^*(982)^0$ is found with 4.1σ. The measured f_L agrees with the SM expectation, but it is also consistent with small f_L result measured by Belle. Small f_L in $\omega K^*(982)^+$ is seen although the yield significance is 2.5σ. All of $\omega K_0^*(1430)^{0/+}$ and $\omega K_2^*(1430)^{0/+}$ have been observed with significantly large branching fractions, which are one order larger than $\omega K^*(982)^{0/+}$ decays. Small f_L of both $\omega K^*(982)^{0/+}$ are measured. An interesting feature in the above f_L results is that f_L values between $B \to VV$ and VT are consistent, in contrast to those in $B \to \phi K^*$. BABAR found large f_L in $B \to VT$ decays, $\phi K_2^*(1430)^{0/+}$ [12,13], which are distinct from small f_L results in $B \to VV$ decays, $\phi K^*(982)^{0/+}$. It looks the situation on polarization puzzle extended to the decay to excited final state particles has became increasingly more complex and intringuing.

4. – Conclusions

Recent results of $B \to K^{(*)} l^+ l^-$, and charmless $B \to PV, VV$, and VT decays from the two B-factories are presented. Some of results show clear discrepancies from the SM expectations, but more statistics is needed to clarify if the effects come from new physics or not. This would be solved by upgraded B-factories and LHCb, however it is still very important to analyze all possible decays related to the polarization puzzle, which are yet to be studied, with current data sample of two B-factories.

REFERENCES

[1] Adachi I. *et al.* (Belle Collaboration), arXiv:hep-ex/0810.0335.
[2] Aubert B. *et al.* (*BABAR* Collaboration), arXiv:hep-ex/0807.4119.
[3] Aubert B. *et al.* (*BABAR* Collaboration), arXiv:hep-ex/0804.4412.
[4] Adachi I. *et al.* (Belle Collaboration), *Phys. Rev. Lett.*, **94** (2005) 221804.
[5] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. D*, **78** (2008) 092008.
[6] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. Lett.*, **97** (2006) 201801.
[7] Adachi I. *et al.* (Belle Collaboration), arXiv:hep-ex/0905.0763.
[8] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. Lett.*, **100** (2008) 081801.
[9] Aubert B. *et al.* (*BABAR* Collaboration), arXiv:hep-ex/0901.1223.
[10] Adachi I. *et al.* (Belle Collaboration), *Phys. Rev. Lett.*, **101** (2008) 231801.
[11] Aubert B. *et al.* (*BABAR* Collaboration), arXiv:hep-ex/0901.3703.
[12] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. Lett.*, **99** (2007) 201802.
[13] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. Lett.*, **101** (2008) 161801.