Electroweak Penguin $B$ Decays at Belle

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Abstract. We summarise the most recent results of the Belle experiment about flavour changing neutral current (FCNC) radiative and (semi-) leptonic $B$ decays. In particular, we report about the first observation of the decays $B \rightarrow K^\ast \ell^+\ell^-$, $B \rightarrow \phi K\gamma$, the inclusive $B \rightarrow X_s \ell^+\ell^-$. We also report about searches for $B \rightarrow \ell^+\ell^-$ decay and for CP asymmetries in $B \rightarrow K^\ast \gamma$.

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1 Introduction

Since the first observation of a penguin decay ten years ago \cite{Belle01}, radiative $B$ decays have been a powerful tool to constrain physics beyond the Standard Model. Today we enter an era of precision measurements as the error on the $B \rightarrow K^\ast \gamma$ branching fraction is about to become systematics-dominated and we as start to observe more rare decays like $b \rightarrow s\bar{s}s\gamma$. In the future $b \rightarrow s\gamma$ transitions may be used to probe the kinematic properties the $B$ decays, which is useful to understand the $V_{ub}$ extraction from semileptonic decays, and may also provide a handle on $V_{cd}$ once the Cabbibo-suppressed $b \rightarrow d\gamma$ decays are seen.

At the price of an additional suppression by $v_{e.m.}$, one gets flavour-changing neutral current (FCNC) semileptonic $b \rightarrow s\ell\ell$ decays, where the lepton pair provides other observables, like the forward-backward charge asymmetry, which are much more powerful to constrain the Standard Model and its extensions.

In this report we summarise the latest results from Belle \cite{Belle} about the above mentioned decays and also about purely leptonic $B \rightarrow \ell\ell$ decays.

2 Radiative decays

While we start to perform precise branching fraction and CP asymmetry measurements in the $B \rightarrow K^\ast \gamma$ decay, which cannot be considered as “rare” at $B$ factories anymore, most of the partial width of $B \rightarrow X_s \gamma$ is yet still unknown. Thus the search for more exclusive final states is needed to achieve a better understanding of the hadronic structure of this decay.

2.1 First observation $B \rightarrow K\phi\gamma$

Using 90 fb$^{-1}$, we observe the decay $B^- \rightarrow \phi K^-\gamma \ \cite{Belle}$. This is the first observation of a radiative $b \rightarrow s\bar{s}s\gamma$ process. The decay is reconstructed using a high-energy photon, two oppositely charged kaons required to form the $\phi$ mass within 10 MeV ($\sim 3\sigma$), and one additional $K^-$ or $K^0_S$. We observe $21.6 \pm 5.6$ events in the charged mode, (corresponding to a statistical significance of $5.5\sigma$), and $5.8 \pm 3.0$ events in the neutral mode ($3.3\sigma$). The preliminary measured branching fractions are:

\[ B(B^- \rightarrow K^-\phi\gamma) = (3.4 \pm 0.9 \pm 0.4) \times 10^{-6} \]
\[ B(B^0 \rightarrow K^0\phi\gamma) = (4.6 \pm 2.4 \pm 0.6) \times 10^{-6}. \]

In the latter mode we also give an upper limit for the branching fraction at $8.3 \times 10^{-6}$ at 90% confidence level.

The beam-constrained mass fit for the charged mode is shown in Fig. \textbf{F}left\). The right hand side figure shows that the $\phi K^-$ mass distribution differs from a naive three-body phase-space decay model. Yet the low statistics do not allow to draw any conclusion about the structure.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Left: $m_{bc}$ fit (left) and $m_{\phi K}$ (right) for $K\phi\gamma$ final state. The measured (solid) $m_{\phi K}$ distribution is compared to MC simulations basing on a phase-space model (circles) or adjusted to follow the data (squares connected by a line).}
\end{figure}
2.2 CP asymmetry in $B \to K^*\gamma$

Among radiative penguin decays, the $B \to K^*\gamma$ decay allows the most precise measurements. We observe 700 such decays $^{[4]}$, using a 78 fb$^{-1}$ data sample and reconstructing the $K^*$ in all visible final states $K^+\pi^-$, $K_S^0\pi^0$, $K^+\pi^0$, $K_S^0\pi^\pm$ (charge conjugation is implied throughout this report except where mentioned). The corresponding beam-constrained mass ($m_{bc}$) distributions are shown in Fig. 2. The preliminary branching fractions are found to be

\[
B (B^0 \to K^{*0}\gamma) = (4.09 \pm 0.21 \pm 0.19) \cdot 10^{-5} \\
B (B^+ \to K^{*+}\gamma) = (4.40 \pm 0.33 \pm 0.24) \cdot 10^{-5},
\]

where the first error is statistical and the second systematic. Fitting the event yields separately for the two flavour eigenstates of the $B$ meson (thus excluding the $K_S^0\pi^0\gamma$ final state) we get a measurement of the CP asymmetry:

\[
A_{CP} (B \to K^*\gamma) = -0.001 \pm 0.044 \pm 0.008.
\]

3 Semileptonic Penguin decays

Semileptonic FCNC decays $B \to X_c \ell^+\ell^-$ are known since the first observation of the $B \to K\ell^+\ell^-$ decay by Belle $^[5]$. Here we report about the first observation of the long awaited $B \to K^*\ell^+\ell^-$ decay and about a semi-inclusive analysis.

3.1 First observation of $B \to K^*\ell\ell$

This analysis $^[6]$ searches for $B \to K^*\ell\ell$ and $B \to K\ell\ell$ using the full 140 fb$^{-1}$ data sample available in Summer 2003. The candidates are formed using an oppositely-charged lepton pair (muons or electrons) and a $K^+$, $K_S^0$, or a $K^*$ candidate formed as $K^+\pi^-$, $K_S^0\pi^+$ or $K^+\pi^0$. The lepton pair is vetoed if its mass is below 140 MeV/c$^2$, or compatible with the $J/\psi$ or $\psi'$ masses. In the $eeK^*$ case, we also consider $ee\gamma$ and $ee\gamma\gamma$ combinations to suppress the $\psi(\prime)$ background due to Bremsstrahlung. The fitted $m_{bc}$ distributions are shown in Fig. 3. We observe 36 $\pm 8$

\[
B (B \to K^*\ell^+\ell^-) = 38 \pm 8 \\
B (B \to K\ell^+\ell^-) = 4.8 \pm 1.0 \pm 0.3 \pm 0.1) \cdot 10^{-7},
\]

where the third error is due to model-dependence. Fig. 4 shows the measured squared dilepton mass ($q^2$) distributions compared to theoretical predictions $^[7]$.

3.2 Semi-inclusive analysis

We performed a semi-inclusive analysis using 60 fb$^{-1}$ $^[8]$. In this case the lepton pair is combined with any of 18

\[
q^2 = (11.5 \pm 2.6 \pm 0.8 \pm 0.2) \cdot 10^{-7} \\
q^2 = (4.8 \pm 1.0 \pm 0.3 \pm 0.1) \cdot 10^{-7},
\]

where the third error is due to model-dependence. Fig. 4 shows the measured squared dilepton mass ($q^2$) distributions compared to theoretical predictions $^[7]$. 

![Fig. 2. Beam-constrained mass fits for $K^*\gamma$ final states.](image)

![Fig. 3. $m_{bc}$ fits for $K^*\ell\ell$ and $K\ell\ell$ final states.](image)

![Fig. 4. $q^2$ distributions for $K\ell\ell$ and $K^*\ell\ell$. Points show data while bands show the expectation range of various models $^[7]$.](image)
combinations made of one kaon ($K^\pm$ or $K^0$) and up to four pions, one of which may be neutral. The so formed $X_s$ system is required to have a mass below 2.6 GeV/c^2. The $m_{bc}$ mass fits are shown in Fig. 5 for $B \to X_s e\mu$, $B \to X_s\mu\mu$ and the sum $B \to X_s\ell\ell$, where peaks are seen at the $B$ mass. The forbidden $B \to X_s e\mu$ mode is also shown as a control sample. We observe $60 \pm 14_{-5}^{+9}$ $B \to X_s\ell\ell$ events with a statistical significance of 5.4$\sigma$. The branching fractions are:

$$B (B \to X_s e^+ \ell^-) = (6.1 \pm 1.4 \pm 1.1) \cdot 10^{-6} \quad (5.4\sigma)$$

$$B (B \to X_s e^+ e^-) = (5.0 \pm 2.3 \pm 1.1) \cdot 10^{-6} \quad (3.4\sigma)$$

$$B (B \to X_s \mu^+ \mu^-) = (7.9 \pm 2.1 \pm 1.5) \cdot 10^{-6} \quad (4.7\sigma).$$

### 4 Leptonic FCNC $B$ decays

Finally, we report about the search for the FCNC decays $B \to ee$ $B \to \mu\mu$ and $B \to e\mu$, using a data sample of 78 fb$^{-1}$. The Standard Model (SM) branching fractions predictions for the first two decays are about $10^{-10}$ and $10^{-15}$ respectively, but they could be enhanced by two order of magnitude in models including two Higgs doublets or Z-mediated FCNC. Apart from the negligibly small contribution form neutrino oscillations, the $B \to e\mu$ is forbidden in the SM, but could occur in some SUSY models or the Pati-Salam leptoquark model.

The selection is based on stringent requirements for the particle-identification of the two leptons and strong requirements for the $q\bar{q}$ ($q = u,d,s,c$) and $\tau\tau$ background rejections. In particular, to favour $BB$ events, we require the presence of five charged tracks in the event.

We find no events in the signal box defined in the $\Delta E - m_{bc}$ plane, as shown in Fig. 6. while we expect about 0.2 to 0.3 events from background, depending on the mode. We set upper limits on the branching fractions as:

$$B (e^+ e^-) < 1.9 \cdot 10^{-7} \quad (90\% CL)$$

$$B (\mu^+ \mu^-) < 1.6 \cdot 10^{-7} \quad (90\% CL)$$

$$B (e^+ \mu^-) < 1.7 \cdot 10^{-7} \quad (90\% CL).$$

The former allows to set a 90\% CL lower limit on the mass of the Pati-Salam leptoquark at 46 TeV/c^2.

The details of the extraction are given in Ref. \[9\].

### 5 Conclusion

While radiative $B$ decays become tools to understand the QCD structure of the $B$ meson, semileptonic FCNC decays become hot candidates to test extensions of the Standard Model. After a long wait, we finally observed the decay $B \to K^\ast\ell\ell$, opening the road to measurements of the lepton forward-backward asymmetry.

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