

# Radiative penguin $B_s$ decays at Belle

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**Abstract.** We report searches for the radiative penguin decays  $B_s^0 \rightarrow \phi\gamma$  and  $B_s^0 \rightarrow \gamma\gamma$  based on a  $23.6 \text{ fb}^{-1}$  data sample collected with the Belle detector at the KEKB  $e^+e^-$  energy-asymmetric collider operating at the  $\Upsilon(5S)$  resonance. We obtain the first observation of a radiative penguin decay of the  $B_s^0$  meson in the  $B_s^0 \rightarrow \phi\gamma$  mode and we measure  $\mathcal{B}(B_s^0 \rightarrow \phi\gamma) = (57_{-15}^{+18}(\text{stat})_{-17}^{+12}(\text{syst})) \times 10^{-6}$ . No significant  $B_s^0 \rightarrow \gamma\gamma$  signal is observed and we set an upper limit at 90% confidence level of  $\mathcal{B}(B_s^0 \rightarrow \gamma\gamma) < 8.6 \times 10^{-6}$ . These results are preliminary.

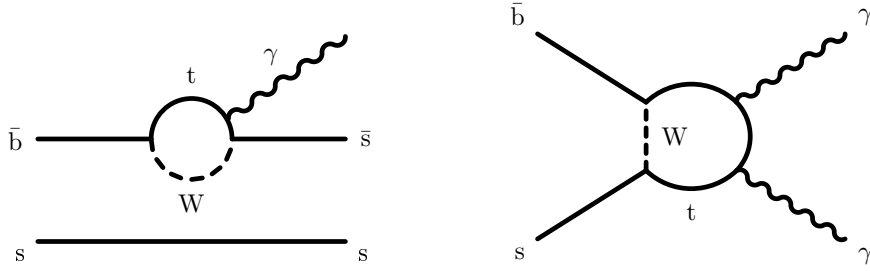
## 1. Introduction

The  $B_s^0 \rightarrow \phi\gamma$  mode is a radiative penguin decay characterized by the  $b \rightarrow s\gamma$  quark transition (Fig. 1 left); it is the strange counterpart of the  $B \rightarrow K^*(892)\gamma$  decay whose observation by CLEO in 1993 [1] proved the existence of penguin processes. In the Standard Model (SM), the branching fraction of  $B_s^0 \rightarrow \phi\gamma$  is predicted to be  $(39.4 \pm 11.9) \times 10^{-6}$  [2]. The  $B_s^0 \rightarrow \gamma\gamma$  mode is a penguin annihilation decay (Fig. 1 right) and its branching fraction has been calculated in the SM to be in the range  $(0.5 - 1.0) \times 10^{-6}$  [3, 4, 5].  $B_s^0 \rightarrow \phi\gamma$  and  $B_s^0 \rightarrow \gamma\gamma$  have not been observed yet and the most stringent limit at 90% confidence level (CL) on their branching fractions are respectively  $1.2 \times 10^{-4}$  [6] and  $53 \times 10^{-6}$  [7].

The study of radiative penguin decays is a good tool to search for physics beyond the SM. A strong constraint on the  $B_s^0 \rightarrow \phi\gamma$  branching fraction is generally expected due to the good agreement between SM expectations and experimental results in  $b \rightarrow s\gamma$  rates such as in the  $B^+ \rightarrow K^*(892)^+\gamma$  and  $B^0 \rightarrow K^*(892)^0\gamma$  decays [8, 9] or the inclusive  $B \rightarrow X_s\gamma$  decay [10, 11]. The  $B_s^0 \rightarrow \gamma\gamma$  decay is constrained in a similar way [12] but New Physics (NP) scenarios such as supersymmetry with broken R-parity [13], a fourth quark generation [14] or the two Higgs doublet model with flavor changing neutral currents [15], can increase the  $B_s^0 \rightarrow \gamma\gamma$  branching fraction up to one order of magnitude and still provide a small contribution to  $B \rightarrow X_s\gamma$ .

## 2. Data sample and analysis

In this study, we use a data sample with an integrated luminosity ( $L_{\text{int}}$ ) of  $23.6 \text{ fb}^{-1}$  that were collected with the Belle detector [16] at the KEKB asymmetric-energy  $e^+e^-$  (3.6 on 8.2 GeV) collider [17] operating at the  $\Upsilon(5S)$  resonance. The variety of hadronic events at the  $\Upsilon(5S)$  resonance is richer than at  $\Upsilon(4S)$ .  $B^+$ ,  $B^0$  and  $B_s^0$  mesons are produced through the decay of the  $\Upsilon(5S)$ . The  $B_s^0$  mesons are mostly produced in the  $\Upsilon(5S) \rightarrow B_s^*\bar{B}_s^*$  decay channel, with the subsequent decays of the excited  $B_s^*$  states to the ground states with the emission of a slow photon. Therefore, we search for  $B_s^0 \rightarrow \phi\gamma$  and  $B_s^0 \rightarrow \gamma\gamma$  in  $B_s^*\bar{B}_s^*$  events. The  $b\bar{b}$  production



**Figure 1.** Diagrams of the dominant processes for the  $B_s^0 \rightarrow \phi\gamma$  (left) and  $B_s^0 \rightarrow \gamma\gamma$  (right) decays.

**Table 1.** Efficiencies ( $\epsilon$ ), signal yields, branching fractions and significances ( $\mathcal{S}$ ) obtained from the fit. The first uncertainty is statistical, the second one is systematic. The upper limit is calculated at 90% CL.

Mode	$\epsilon$ (%)	$S_{B_s^* \bar{B}_s^*}$	$\mathcal{B}$ ( $10^{-6}$ )	$\mathcal{S}$
$B_s^0 \rightarrow \phi\gamma$	$24.7 \pm 0.2$	$18_{-5}^{+6}$	$57_{-15}^{+18+12}$	5.5
$B_s^0 \rightarrow \gamma\gamma$	$17.8 \pm 0.2$	$-6.8_{-1.9}^{+2.4}$	$< 8.6$	–

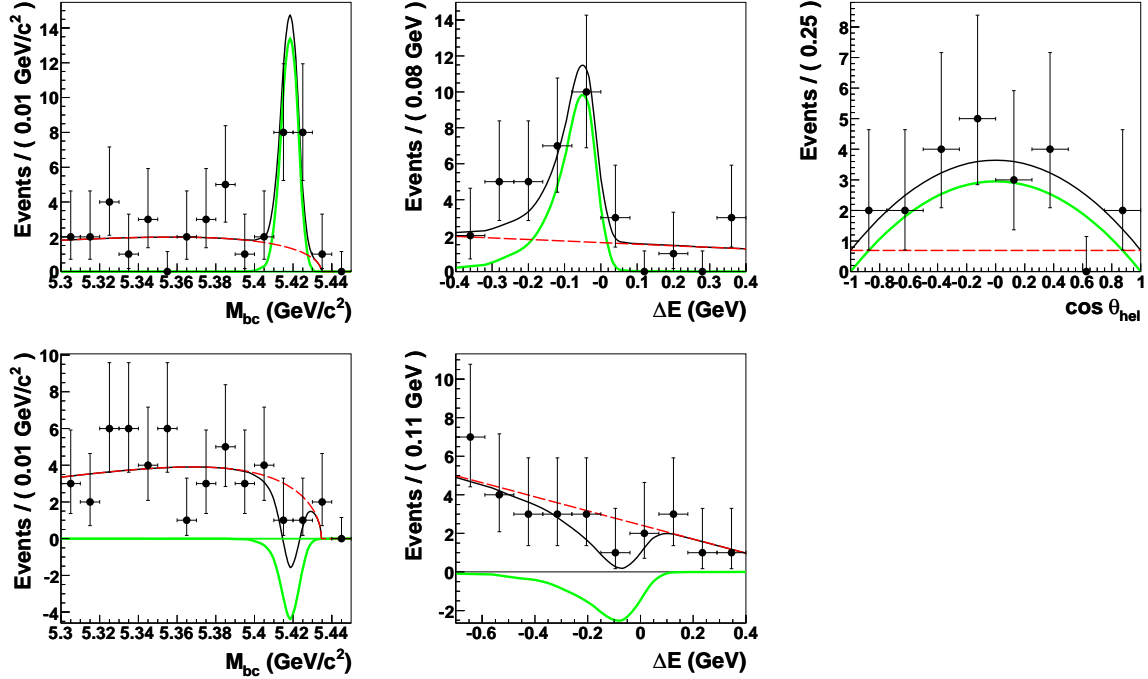
cross-section at  $\Upsilon(5S)$  has been measured to be  $\sigma_{bb}^{\Upsilon(5S)} = (0.302 \pm 0.015)$  nb [18], the fraction of  $B_s^{(*)} \bar{B}_s^{(*)}$  events in  $b\bar{b}$  events to be  $f_s = N(B_s^{(*)} \bar{B}_s^{(*)})/N(b\bar{b}) = (19.5_{-2.2}^{+3.0})\%$  [9] and the fraction of  $B_s^* \bar{B}_s^*$  events among  $B_s^{(*)} \bar{B}_s^{(*)}$  events to be  $f_{B_s^* \bar{B}_s^*} = (93_{-9}^{+7})\%$  [7].

We reconstruct  $\phi$  mesons in the decay mode  $\phi \rightarrow K^+ K^-$ .  $B_s^0$  mesons are selected by means of the beam-energy constrained mass  $M_{bc} = \sqrt{(E_{\text{beam}}^{\text{CM}})^2 - (p_{B_s^0}^{\text{CM}})^2}$  and the energy difference  $\Delta E = E_{B_s^0}^{\text{CM}} - E_{\text{beam}}^{\text{CM}}$  where  $p_{B_s^0}^{\text{CM}}$  and  $E_{B_s^0}^{\text{CM}}$  are the momentum and the energy of the  $B_s^0$  meson, all variables being evaluated in the center-of-mass (CM) frame.  $B_s^*$  mesons are not fully reconstructed due to the low energy of the photon from the  $B_s^*$  decay. The main background is due to continuum events coming from light-quark pair production ( $e^+e^- \rightarrow u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}$ ). This background is rejected using a Fisher discriminant based on modified Fox-Wolfram moments describing event topology and a veto of  $\pi^0$  and  $\eta$  mesons decaying to two photons. For the  $B_s^0 \rightarrow \phi\gamma$  ( $B_s^0 \rightarrow \gamma\gamma$ ) mode, we perform a three-dimensional (two-dimensional) unbinned maximum likelihood fit to  $M_{bc}$ ,  $\Delta E$  and  $\cos\theta_{\text{hel}}$  ( $M_{bc}$  and  $\Delta E$ ). The helicity angle  $\theta_{\text{hel}}$  is the angle between the  $B_s^0$  and the  $K^+$  evaluated in the  $\phi$  rest frame.

Both fits have four free fit variables: the branching fraction, the continuum background normalization, the  $M_{bc}$  continuum shape parameter and the continuum  $\Delta E$  slope. The signal yield is defined as  $S_{B_s^* \bar{B}_s^*} = \mathcal{B} \times \epsilon \times N_{B_s^0} \times f_{B_s^* \bar{B}_s^*}$ , where  $\mathcal{B}$  is  $\mathcal{B}(B_s^0 \rightarrow \phi\gamma) \times \mathcal{B}(\phi \rightarrow K^+ K^-)$  for the  $B_s^0 \rightarrow \phi\gamma$  mode and  $\mathcal{B}(B_s^0 \rightarrow \phi\gamma)$  for the  $B_s^0 \rightarrow \gamma\gamma$  mode,  $\epsilon$  is the MC signal efficiency listed in Table 1 and  $N_{B_s^0} = 2 \times L_{\text{int}} \times \sigma_{bb}^{\Upsilon(5S)} \times f_s = (2.8_{-0.3}^{+0.5}) \times 10^6$  is the number of  $B_s^0$  mesons.

### 3. Results and conclusion

We observe  $18_{-5}^{+6}$  signal events in the  $B_s^0 \rightarrow \phi\gamma$  mode and measure  $\mathcal{B}(B_s^0 \rightarrow \phi\gamma) = (57_{-15}^{+18}(\text{stat})_{-17}^{+12}(\text{syst})) \times 10^{-6}$  with a significance of  $5.5 \sigma$ . Results are reported in Table 1 and fit projections are shown in Fig. 2. This is the first observation of a radiative penguin decay of the  $B_s^0$  meson. The measured branching fraction is in agreement with SM expectation and with the measurement of the branching fractions of the  $B^+ \rightarrow K^*(892)^+ \gamma$  and  $B^0 \rightarrow K^*(892)^0 \gamma$  decays [9].



**Figure 2.**  $M_{bc}$ ,  $\Delta E$  and  $\cos\theta_{\text{hel}}$  projections together with fit results for the  $B_s^0 \rightarrow \phi\gamma$  mode (top) and the  $B_s^0 \rightarrow \gamma\gamma$  mode (bottom). The points with error bars represent data, the thin solid curves are the fit functions, the thick solid curves are the signal function and the dashed lines show the continuum contribution.

We see no significant signal in the  $B_s^0 \rightarrow \gamma\gamma$  mode and we extract an upper limit at 90% CL of  $\mathcal{B}(B_s^0 \rightarrow \gamma\gamma) < 8.6 \times 10^{-6}$ . This limit, obtained with an integrated luminosity of  $23.6 \text{ fb}^{-1}$ , is significantly more stringent than the published one [7], but still above the current NP predictions. However, it is only one order of magnitude larger than the SM prediction leaving good hope for a Super  $B$ -factory [19] to observe this decay in the future.

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