b→sγ result from Belle

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• Total decay rate and CP Asymmetry
  • prove for the New Physics e.g. charged Higgs, SUSY

• Differential decay rate
  • photon as a messenger of the dynamics of the b-quark properties
Analysis Methods

• Fully Inclusive
  • measure the isolated photon only, small systematic bias
  • large statistics but large continuum background
  • smeared $E_\gamma$ by B-boost
  • lepton tag
    • useful for continuum suppression and flavor tagging

• Hadronic Tag
  • fully reconstruct a hadronic B decay, measure the photon in the rest
  • continuum background is suppressed but very low efficiency

• Sum of Exclusive
  • fully reconstruct as many modes as possible
  • clearly measured $E_\gamma$ and high efficiency
  • systematic bias due to missing modes
Fully Inclusive & Lepton Tag

World best measurement at Belle
PRL 103, 241801 (2009)
Fully Inclusive & Lepton tag

• Study with two method; fully inclusive & lepton tag.
• Find isolated photon in the EM calorimeter.
• High energy photon with $E_{c.m.s} > 1.4$ GeV.
• Veto $\gamma$ from $\pi^0$, $\eta$ and Bhabha and suppress continuum with event topology
• Estimate continuum using OFF resonance data
• Estimate $B$ decays using corrected MC sample; $B \rightarrow X(\pi^0/\eta)$
Continuum Subtraction

Continuum subtraction is performed considering difference
- b/w ON and OFF resonance for luminosity ($\alpha$),
- efficiency of hadronic event ($\beta$) and of signal event ($\gamma$),
- photon multiplicity ($F_N$),
- photon mean energy ($F_E$).

$$N^{B\bar{B}}(E^\gamma_{c.m.s.}) = N^{ON}(E^\gamma_{c.m.s.(ON)}) - \alpha \cdot \beta \cdot \gamma \cdot F_N \cdot N^{OFF}(F_E E^\gamma_{c.m.s.(OFF)})$$

$$\alpha = \frac{L_{ON} dt}{L_{OFF} dt} \cdot \frac{s_{OFF}}{s_{ON}} = 8.7577(\pm 0.3\%)$$

$$\beta = \frac{\varepsilon^{ON}_{Hadronic}}{\varepsilon^{OFF}_{Hadronic}} = -0.9986 \pm 0.0001$$

$$\gamma = \frac{\varepsilon^{ON}_{B \to X_s \gamma}}{\varepsilon^{OFF}_{B \to X_s \gamma}}$$

$$F_N = 1.0009$$
(difference in photon multiplicity)

$$F_E = 1.0036$$
(difference in photon mean energy)
Efficiency Corrections

- Selection efficiency in MC and data from the control sample
  - e.g. $\pi^0$ veto efficiency in a sample of partially reconstructed $D^* \rightarrow D \rightarrow K\pi\pi^0$, $\pi^0 \rightarrow \gamma\gamma$
• Corrected raw photon energy spectrum

\[ R(E_{\gamma}^{\text{true}}) = \frac{N_{\text{rec}}}{\varepsilon_{\text{sel}}} \]

Unfolding Procedure

\[ M(E_{\gamma}^{\text{true}}) = A^{-1} R(E_{\gamma}^{\text{meas}}) \]

Detection Efficiency

\[ T(E_{\gamma}^{\text{true}}) = \frac{M_{\text{unfolded}}}{\varepsilon_{\text{det}}} \]
Branching Fraction (Exp.)

Belle no-tag + lepton-tag for $E\gamma > 1.7$ GeV

$\mathcal{B}(B \rightarrow X_s \gamma) = (345 \pm 15 \pm 40) \times 10^{-6}$

If we use $E\gamma > 1.8$ GeV result, Belle’s no-tag + lepton-tag result becomes $(347 \pm 13 \pm 26 \pm 2) \times 10^{-6}$
Hadronic Tag

Comparison with BaBar
PRD 77, 051103(R) (2008)
no Belle result so far
Hadronic Tag Method

Tag side
Tag B is fully reconstructed in a hadronic mode

Signal side
Search for an isolated photon

• Advantage
  · small continuum background extracted from fit
  · information of B flavor, charge and momentum \( \rightarrow \) enables to study asymmetries

• Disadvantage
  · low efficiency of fully reconstructed B (tag efficiency \( \sim 0.45\% \))
Improved Hadronic Tag at Belle

• More decay modes.
• Event selection by NeuroBayes neural net program.
• Efficiency and purity can be adjusted by NeuroBayes output.
• Easy to include the continuum suppression in the candidate selection process.
• Already used in new Belle $B \to \tau \nu$ and other studies.

Efficiency and purity are decided based on the NeuroBayes output cut

Improved efficiency by a factor of $\sim 2$ at the same purity level

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NIMA 654, 432 (2011)
Analysis Strategy

• Hadronic tag with |ΔE|<0.06 GeV and good tag quality

• Select good photon (optimized for $E_\gamma$ in 1.8-2.0 GeV)
  • $1.4< E_\gamma < 2.6$ GeV, $\pi^0/\eta$ veto, off-timing QED background veto and E9/E25

• Background calibration for subtraction
  • $\pi^0/\eta$: MC/data difference is measured as a function of $p^*(\pi^0/\eta)$
  • others: examine the contribution in MC

• Raw signal yield by $M_{bc}$ fit

• Unfold the spectrum

• Measure the differential branching fraction
**π⁰ Calibration**

- Comparison of normalized yields in MC and data with \( B \rightarrow X \pi^0 \)
- Estimate \( B \) decays using calibrated MC sample;

\[ \text{Graph} \]

**Data**

**MC**

\[ \text{Graph} \]

\[ \text{Graph} \]
$\mathcal{L} = 210/fb$

$\mathcal{B}(B \to X_s \gamma, E_\gamma > 1.9 \text{ GeV})$

$= (3.66 \pm 0.85 \pm 0.60) \times 10^{-4}$

$\mathcal{L} = 710/fb$

Improved result is expected with new hadronic tag algorithm on full Belle data set.

At Belle II, hadronic tag is a promising method, since it will be still statistics dominated.
Summary

• $b \rightarrow s \gamma$ study
  - interesting topic at B factory; beyond Standard Model
  - world best measurement at Belle
  - prospect for the hadronic tag analysis

• Expectation
  - better results with improved analysis tools and increased data sample soon
  - more precise measurement at Belle II