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Measurements of $b \rightarrow s\gamma$ Decays at *BABAR*

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Abstract. We present measurements of the Branching Fraction and photon energy spectrum in $B \rightarrow X_s\gamma$ decays in a sample of 89 million $B\bar{B}$ pairs collected at the *BABAR* detector at Stanford Linear Accelerator Center's PEP-II asymmetric B-factory. Results from a fully-inclusive and a sum of 38 exclusive final states techniques are presented and found to be consistent with the Standard Model calculations, as well as experimental results obtained from semileptonic $B \rightarrow X_c l\nu$ decays.

Keywords: B meson, radiative penguin decays, photon energy spectrum, semileptonic decays
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MOTIVATION

An overall goal of the *BABAR* experiment is to precisely measure and over-constrain parameters of the Cabbibo-Kobayashi-Maskawa (CKM) mixing matrix, which governs the weak couplings of quarks in the Standard Model (SM). The smallest element of the CKM matrix, V_{ub}, can be obtained from measurements of the Branching Fraction (BF) of semileptonic $B \rightarrow X_u l\nu$ decays that present a clean experimental signature. However, theoretical calculations of the decay amplitude are complicated by the Fermi motion of the b quark inside the B meson. While Operator Product Expansion (OPE) can be applied to deal with non-perturbative corrections to the quark-level calculations, the validity of this approach is limited by the kinematic restrictions imposed by experimental conditions. When the non-perturbative contributions are expanded in $1/m_b$ in what is known as Heavy Quark Expansion (HQE), the terms can be re-summed into a Shape Function, which cannot be calculated analytically. The decay rate is given by a convolution of the Shape Function and the perturbative part[1]. Since the Shape Function applies to all decays of B meson to light quarks, it can be measured in kinematically simple radiative penguin $B \rightarrow X_s\gamma$ decays by relating HQE parameters to moments of the E_γ spectrum: $\left\langle E_\gamma \right\rangle \approx \frac{m_b}{2}, \left\langle E_\gamma^2 - \left\langle E_\gamma \right\rangle^2 \right\rangle \propto \mu_\pi^2$ ([2], [3], and [4]). Theoretically, there's less dependence on the heavy quark distribution at low E_γ, where different expansion schemes agree the best, while higher energy photons constitute a cleaner experimental signature.

EXPERIMENTAL TECHNIQUE

Current next-to-leading-order theoretical calculations give, for example, $BF(B \rightarrow X_s\gamma,\ E_\gamma > 1.6\,\mathrm{GeV}) = (3.61^{+0.37}_{-0.49}) \times 10^{-4}$[5], making the measurement challenging. At the *BABAR* detector (described in detail in [6]), excellent energy resolution of the Electromagnetic Calorimeter allows for rather clean detection of high-energy photons, while superior performance of the particle identification system allows for $\sim 4\sigma$ sep-

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aration between K's and π's. This helps suppress the overwhelming background from continuum $e^+e^- \longrightarrow q\overline{q}$ events, where q is one of the lighter u, d, s, or c quarks.

Two separate analyses, both based on 89 million $B\overline{B}$ pairs collected at *BABAR* at the $\Upsilon(4s)$ resonance, were carried out. The fully-inclusive analysis[7] reconstructs the signal photon, but not the hadron, avoiding the issue of final state fragmentation and X_s modes missing from Monte Carlo simulation, problematic for the semi-inclusive method that uses a sum of 38 exclusive modes[8]. On the other hand, it suffers from a higher level of background and poorer E_γ resolution. The semi-inclusive analysis also has the benefit of working entirely in the B meson frame.

The fully-inclusive analysis applies a cut at $1.9\,\mathrm{GeV}$ on E_γ^* in the $\Upsilon(4s)$ rest frame. The $q\overline{q}$ background is suppressed using a lepton tag of the other B meson in the event, as well as event shape variables that take advantage of the fact that in the $\Upsilon(4s)$ frame, B's are produced almost at rest and decay isotropically, while continuum events tend to be jet-like. Photons consistent with the decay of a π^0 or η are vetoed. Data collected about $40\,\mathrm{MeV}$ below the $\Upsilon(4s)$ resonance is used to subtract remaining continuum background, while appropriate control samples are used to estimate the systematic effects of background resulting from non-signal decays of the B meson.

In the semi-inclusive analysis, 38 fully-reconstructed decay modes to π's, K's, π^0's, and η's are combined. The decays are simulated using JETSET[9], which requires control sample studies to correct for missing modes. The BF, calculated for $E_\gamma > 1.9\,\mathrm{GeV}$ and $0.6 < M(X_s) < 2.8\,\mathrm{GeV}$, is determined from a fit to beam energy substituted mass of the B meson, $m_{\mathrm{ES}} \equiv \sqrt{{E^*_{Beam}}^2 - {p^*_B}^2}$, where the star refers to the $\Upsilon(4s)$ frame.

RESULTS AND CONCLUSIONS

Both analyses carry out fits to the moments of the E_γ distributions, shown in Figure 1. The fully-inclusive analyses obtains $\langle E_\gamma \rangle = (2.288 \pm 0.025 \pm 0.017 \pm 0.015)\,\mathrm{GeV}$ and $\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle = (0.0328 \pm 0.0040 \pm 0.0023 \pm 0.0036)\,\mathrm{GeV}^2$, while the semi-inclusive results are $\langle E_\gamma \rangle = (2.321 \pm 0.038^{+0.017}_{-0.038})\,\mathrm{GeV}$ and $\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle = (0.0253 \pm 0.0101^{+0.0041}_{-0.0028})\,\mathrm{GeV}^2$. In the Kinetic scheme[2], these numbers correspond to $m_b = (4.44 \pm 0.08 \pm 0.14)\,\mathrm{GeV}$ and $\mu_\pi^2 = (0.64 \pm 0.13 \pm 0.24)\,\mathrm{GeV}^2$ for the fully-inlcusive and $m_b = (4.70^{+0.04}_{-0.08})\,\mathrm{GeV}$ and $\mu_\pi^2 = (0.29^{+0.09}_{-0.04})\,\mathrm{GeV}^2$ for the semi-inclusive analyses. The errors are statistical and systematic, respectively, for the fully-inclusive result, and a combination of the two for the semi-inclusive.

The measured BF's for $E_\gamma^{(*)} > 1.9\,\mathrm{GeV}$ are $BF(B \to X_s\gamma) = (3.67 \pm 0.29 \pm 0.34 \pm 0.29) \times 10^{-4}$ and $BF(B \to X_s\gamma) = (3.27 \pm 0.18^{+0.55+0.04}_{-0.40-0.09}) \times 10^{-4}$ for fully and semi-inclusive analyses, respectively. The errors are statistical, systematic, and due to the choice of the fit model. To compare BF results with theoretical calculations, one must choose a particular scheme and extrapolate the measurements down to $E_\gamma > 1.6\,\mathrm{GeV}$. For the fully-inclusive approach, this yields, in the Kinetic scheme, $BF(B \to X_s\gamma) = (3.94 \pm 0.31 \pm 0.36 \pm 0.21) \times 10^{-4}$. Similarly, the semi-inclusive analysis obtains $BF(B \to X_s\gamma) = (3.35 \pm 0.19^{+0.56+0.04}_{-0.41-0.09}) \times 10^{-4}$, except that here the Shape Function[3] and Kinetic schemes are averaged. The numbers agree well with the SM expectations.

Buchmüller and Flächer have recently combined all available measurements of the

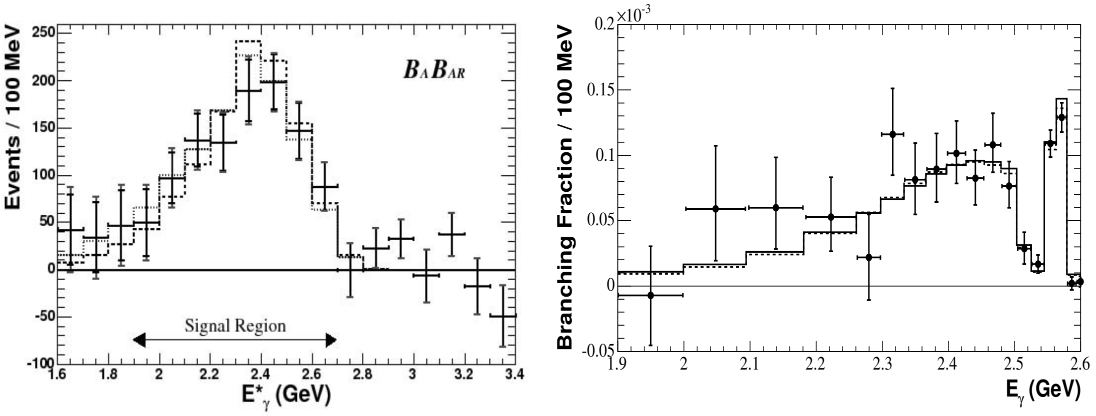

FIGURE 1. E_γ spectra for fully-inclusive (left) and semi-inclusive (right) analyses. Data points are compared to Kinetic (dashed or solid line) and Shape Function (dotted or dashed line) schemes for the best-fit HQE parameters provided in the text.

E_γ spectrum in $B \rightarrow X_s\gamma$ decays with lepton energy and hadron mass spectra from $B \rightarrow X_c l\nu$ decays[10]. Performing combined fits, they obtain, in Kinetic scheme, $m_b = (4.590 \pm 0.025_{exp} \pm 0.030_{HQE})$GeV and $\mu_\pi^2 = (0.401 \pm 0.019_{exp} \pm 0.035_{HQE})$GeV^2, as well as a value for $|V_{cb}| = (41.96 \pm 0.23_{exp} \pm 0.35_{HQE} \pm 0.59_{\Gamma_{SL}}) \times 10^{-3}$. The first error is a combination of experimental statistical and systematic errors, the second accounts for theoretical uncertainties from HQE, and Γ_{SL} is the semileptonic decay rate. The study also demonstrates good agreement between $B \rightarrow X_s\gamma$ and $B \rightarrow X_c l\nu$ decays, confirming the validity of universality assumption for the Shape Function approach to non-perturbative corrections in inclusive decays of the B meson.

The *BABAR* collaboration is working on updating $B \rightarrow X_s\gamma$ results with much greater statistical precision. The current full dataset consists of about 350 million $B\bar{B}$ pairs, with plans to more than double this number by the end of 2008. Precision measurements of radiative $B \rightarrow X_s\gamma$ decays are very important for assessing the validity of the Standard Model of particle physics. The current agreement between theoretical calculations and experimental results stands at around 10%, and the aim is to lower both errors to a 5% level in the near future.

REFERENCES

1. G. Ricciardi (2006), `hep-ph/0608220`.
2. D. Benson, I. I. Bigi, and N. Uraltsev, *Nucl. Phys.* **B710**, 371–401 (2005), `hep-ph/0410080`.
3. S. W. Bosch, B. O. Lange, M. Neubert, and G. Paz, *Nucl. Phys.* **B699**, 335–386 (2004), `hep-ph/0402094`.
4. A. L. Kagan, and M. Neubert, *Eur. Phys. J.* **C7**, 5–27 (1999), `hep-ph/9805303`.
5. T. Hurth, E. Lunghi, and W. Porod, *Nucl. Phys.* **B704**, 56–74 (2005), `hep-ph/0312260`.
6. B. Aubert, et al., *Nucl. Instrum. Meth.* **A479**, 1–116 (2002), `hep-ex/0105044`.
7. B. Aubert, et al., *Phys. Rev. Lett.* **97**, 171803 (2006), `hep-ex/0607071`.
8. B. Aubert, et al., *Phys. Rev.* **D72**, 052004 (2005), `hep-ex/0508004`.
9. T. Sjostrand (1995), `hep-ph/9508391`.
10. O. Buchmuller, and H. Flacher, *Phys. Rev.* **D73**, 073008 (2006), `hep-ph/0507253`.