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TESTING THE STANDARD MODEL WITH RADIATIVE PENGUIN DECAYS AT *BABAR*[*]

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I discuss two recent results in $b \to s\gamma$ decays from *BABAR*. The first is a measurement of the branching fraction and photon energy spectrum in the B meson frame of the decay $B \to X_s\gamma$. The second result probes the photon polarization via time-dependent *CP* violation in neutral B decays to $K^{*0}\gamma$.

1. Introduction

Processes that are suppressed in the standard model (SM) are natural places to search for new physics. In $b \to s\gamma$ decays, deviations from the SM can appear in the overall branching fraction, the *CP* and isospin asymmetries, and the photon polarization. Furthermore, the photon energy spectrum contains information on the kinematics of the b quark inside the B meson. I discuss two recent *BABAR* results that measure all of these observables.

2. Standard Model Predictions

Because the $b \to s\gamma$ process only occurs through a loop diagram at leading order in the SM, it is sensitive to the possible existence of non-SM particles contributing to the loop. The most recent calculation of the SM branching fraction for $B \to X_s\gamma$ is at the next-to-next-to-leading order in QCD corrections[1]: $\mathcal{B}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ for photon energy $E_\gamma > 1.6\,\mathrm{GeV}$ in the B rest frame. The *CP* asymmetry is expected to be 0.6% for $b \to s\gamma$ decays[2]. No isospin asymmetry is expected. The shape of the photon energy spectrum can be used to extract the mass of the b quark and its fermi momentum inside the B meson using the kinetic scheme[3].

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Due to the chirality of the weak interaction, the photon produced in the decay is expected to be left-handed for $\overline{B}^0$ decays and right-handed for B^0 decays. A low rate of "wrongly-polarized" photons allowed by nonzero quark masses is expected, permitting interference between decay and $B^0-\overline{B}^0$ mixing in $b \to s\gamma$ final states that are accessible to both B flavors. The amount of this interference, denoted S, is expected to be about -0.02 in the SM[4,5], although possible hadronic corrections could allow values as large as -0.1[6,7]. Any significant measured deviation from the predictions in this section would be an indication of new physics.

3. $B \to X_s\gamma$ Recoil Technique

Complementary to other inclusive $b \to s\gamma$ analyses, *BABAR* has developed an analysis technique that uses fully-reconstructed hadronic decays of the non-signal B. This analysis uses $210\,\mathrm{fb}^{-1}$ of data[8]. Hadronic decays are defined by 1114 exclusive decay channels of the form $B \to D^{(*)}Y^{\pm}$, where $Y^{\pm}$ is a combination of up to nine pions and kaons[9]. Although this allows determination of the $b \to s\gamma$ photon in the B frame, the efficiency to reconstruct the recoil system is 0.3%.

The recoil system is checked for consistency with a B decay using two variables, $m_{\mathrm{ES}} = \sqrt{s/4 - p_B^2}$ and $\Delta E = E_B - \sqrt{s}/2$, where, in the e^+e^- frame, s is the total energy-squared and E_B and p_B are the energy and momentum of the recoil system. We require $|\Delta E| < 60$ MeV and $m_{\mathrm{ES}} > 5.2$ GeV/c^2. The remaining particles in the event must contain an isolated photon of energy greater than 1.3 GeV in the B frame. The invariant mass of the photon combined with another photon in the event must not be consistent with a π^0 or η meson. Background from $e^+e^- \to q\overline{q}$ decays ($q = \{u, d, s, c\}$) is suppressed using a Fisher discriminant of event-shape variables. The surviving events are divided into 100- MeV-wide bins in photon energy from 1.3–2.7 GeV. The peaking yield in each bin is determined by a fit to m_{ES}. Because the region below 1.9 GeV is dominated by $B\overline{B}$ backgrounds, the Monte Carlo (MC) sample used for this background is scaled to the data yield in this range, then subtracted from the entire range up to 2.7 GeV. A total of 119 ± 22 signal $B \to X_s\gamma$ events are observed over a background of 145 ± 9 $B\overline{B}$ events.

The systematic uncertainties arise mainly from the $B\overline{B}$ background shape. We apply E_γ-dependent corrections to account for shape differences resulting from vetoing π^0 and η mesons. The remaining backgrounds have a roughly linear slope in E_γ, which is varied by ±30%. Relatively smaller uncertainties due to the $m_{\rm ES}$ fits and the assumed E_γ shape are also included.

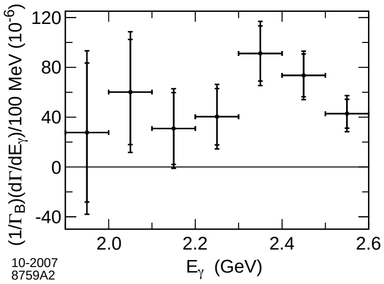

Figure 1. The partial branching fractions $(1/\Gamma_B)(d\Gamma/dE_\gamma)$ with statistical (inner) and total (outer) uncertainties.

The photon spectrum is shown in Fig. 1. After lowering the branching fraction by 4% to account for $b \to d\gamma$ decays, we find

$$\mathcal{B}(B \to X_s\gamma) = 3.66 \pm 0.85_{\rm stat} \pm 0.60_{\rm syst} \times 10^{-4}.$$

The *CP* and isospin asymmetries (A_{CP} and Δ_{0-} respectively) in the signal region, $E_\gamma > 2.2$ GeV, are not corrected for $b \to d\gamma$ contamination, and are found to be

$$A_{CP} = \frac{\mathcal{B}(B \to X_{s,d}\gamma) - \mathcal{B}(\overline{B} \to X_{s,d}\gamma)}{\mathcal{B}(B \to X_{s,d}\gamma) + \mathcal{B}(\overline{B} \to X_{s,d}\gamma)} \frac{1}{1-2\omega} = 0.10 \pm 0.18_{\rm stat} \pm 0.05_{\rm syst},$$

where ω is the flavor mistag probability, and

$$\Delta_{0-} = \frac{\Gamma(\overline{B}^0 \to X_{s,d}\gamma) - \Gamma(B^- \to X_{s,d}\gamma)}{\Gamma(\overline{B}^0 \to X_{s,d}\gamma) + \Gamma(B^- \to X_{s,d}\gamma)} = -0.06 \pm 0.15_{\rm stat} \pm 0.07_{\rm syst}.$$

Using the kinetic scheme, we determine the heavy quark parameters $m_b = 4.46^{+0.21}_{-0.23}$ GeV/c^2 and $\mu_\pi^2 = 0.64^{+0.39}_{-0.38}$ GeV^2.

4. Photon Polarization in $B^0 \to K^{*0}\gamma$

The $b \to s\gamma$ photon polarization can be inferred through time-dependent *CP* violation in decays to final states accessible by both B^0 and $\overline{B}^0$. This is a preliminary result for time-dependent *CP* violation in $B^0 \to K^{*0}(\to K^0_S\pi^0)\gamma$ decays using $391\,{\rm fb}^{-1}$ of data[10].

The proper-time difference between the decay of the signal B and the tagging B, $\Delta t \equiv t_{\rm sig} - t_{\rm tag}$, follows the probability distribution

$$\mathcal{P}_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \times \left[1 \pm S \sin(\Delta m_d \Delta t) \mp C \cos(\Delta m_d \Delta t)\right],$$

where the upper and lower signs correspond to the tag-side B having flavor B^0 and $\overline{B}^0$ respectively, τ_B is the B^0 lifetime, Δm_d is the $B^0 - \overline{B}^0$ mixing frequency, and $C = -A_{CP}$. Any major deviation from $S = 0$ would be a signal of new physics.

To determine Δt, the decay vertex of the signal side is calculated by constraining the K^0_S momentum to intersect with the beam spot, within errors. The decay vertex of the tagged B is reconstructed[11] based on the tracks in the event that are not used for the signal B. We constrain the sum of the decay times of both B mesons in the event to be twice the B lifetime with an uncertainty of $\sqrt{2}\tau_{B^0}$.

We select events with a photon of energy $1.5 < E_\gamma < 3.5$ GeV in the e^+e^- frame, using the same photon quality requirements as in Sec. 3. We impose requirements on K^0_S and π^0 masses, the K^0_S flight length divided by its uncertainty, and the event shape. We require $|\Delta t| < 20$ ps and the Δt uncertainty $\sigma_{\Delta t} < 2.5$ ps. Four variables are combined into a maximum likelihood fit to separate signal from continuum and $B\overline{B}$ backgrounds: $m_{\rm ES}$, ΔE, K^{*0} mass, and L_2/L_0[a]. The S and C parameters are extracted based on the signal Δt distribution.

To evaluate the systematic uncertainty associated with assuming $S = C = 0$ for the $B\overline{B}$ background, we vary its value of S by ± 0.4 and C by ± 0.3. We also include uncertainties in the fit model due to differences between MC and data, and MC statistics. Finally, data-MC differences in the Δt resolution function are evaluated using $B^0 \to J/\psi\, K^0_S$ events.

The results of the fit are shown in Fig. 2. We find 316 ± 22 signal events, and measure

$$S = -0.08 \pm 0.31_{\rm stat} \pm 0.05_{\rm syst} \text{ and } C = -0.15 \pm 0.17_{\rm stat} \pm 0.03_{\rm syst}.$$

5. Summary

The $B \to X_s\gamma$ recoil technique has much less background than other inclusive analyses, allows the determination of the photon energy spectrum

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[a] $L_i = \sum_j |p^*_j| |\cos\theta^*_j|^i$, where p^*_j is the momentum in the e^+e^- frame of each particle j not used to reconstruct the signal B candidate, and θ^*_j is the angle between p^*_j and the thrust axis of the signal B candidate in the same frame.

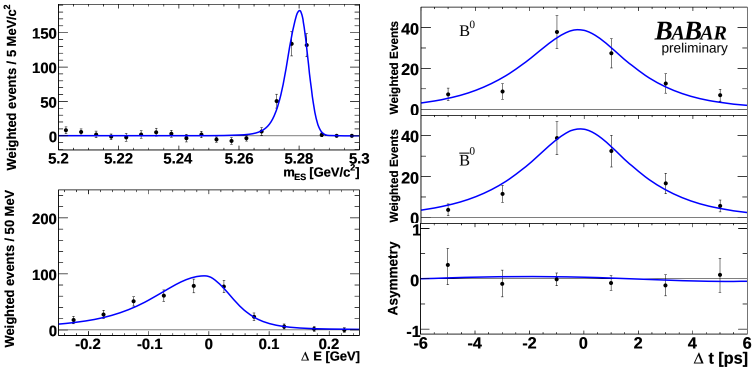

Figure 2. On the left are the signal distributions for m_{ES} (top) and ΔE (bottom), using the event weighting technique described in the preprint. On the right are the signal distributions for Δt, with B_{tag} tagged as B^0 (top) or $\overline{B}^0$ (center), and the asymmetry (bottom).

in the B frame, and provides information on the b quark kinematics inside the B meson. Time-dependent *CP* violation in $b \to s\gamma$ decays is the only known tool to measure the photon polarization at the B-Factories, offering another way to look for new physics. These measurements test the standard model in all aspects of the $b \to s\gamma$ interaction: the rate, *CP* asymmetry, isospin asymmetry, photon spectrum, and photon polarization. The measured values are consistent with the standard model.

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