PROCEEDINGS OF SCIENCE

Measuring $\mathbf{b \to s\gamma, b \to d\gamma}$ and $|\mathbf{V_{td}/V_{ts}}|$ at BaBar

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Using a sample of 471 million $B\overline{B}$ events collected with the BaBar detector, we study the sum of seven exclusive final states $B \to X_{s(d)}\gamma$, where $X_{s(d)}$ is a strange (non-strange) hadronic system with a mass of up to 2.0 Gev/c^2. After correcting for unobserved decay modes, we obtain a branching fraction for $b \to d\gamma$ of $(9.2 \pm 2.0(stat.) \pm 2.3(syst.)) \times 10^{-6}$ in this mass range, and a branching fraction for $b \to s\gamma$ of $(23.0 \pm 0.8(stat.) \pm 3.0(syst.)) \times 10^{-5}$ in the same mass range. We find $\frac{BF(b\to d\gamma)}{BF(b\to s\gamma)} = 0.040 \pm 0.009(stat.) \pm 0.010(syst.)$, from which we determine $|V_{td}/V_{ts}| = 0.199 \pm 0.022(stat.) \pm 0.024(syst.) \pm 0.002(th.)$.

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$B \to X_d\gamma$	$B \to X_s\gamma$
$B^0 \to \pi^+\pi^-\gamma$	$B^0 \to K^+\pi^-\gamma$
$B^+ \to \pi^+\pi^0\gamma$	$B^+ \to K^+\pi^0\gamma$
$B^0 \to \pi^+\pi^-\pi^+\gamma$	$B^0 \to K^+\pi^-\pi^+\gamma$
$B^+ \to \pi^+\pi^-\pi^0\gamma$	$B^+ \to K^+\pi^-\pi^0\gamma$
$B^0 \to \pi^+\pi^-\pi^+\pi^-\gamma$	$B^0 \to K^+\pi^-\pi^+\pi^-\gamma$
$B^+ \to \pi^+\pi^-\pi^+\pi^0\gamma$	$B^+ \to K^+\pi^-\pi^+\pi^0\gamma$
$B^+ \to \pi^+\eta\gamma$	$B^+ \to K^+\eta\gamma$

Table 1: The reconstructed decay modes. Charge conjugate states are implied throughout this paper.

1. Introduction

Radiative penguin decays are flavour changing neutral currents which cannot occur at tree level in the standard model (SM) and must proceed via one loop or higher diagrams. These transitions are therefore suppressed in the SM, but offer access to poorly-known SM parameters and are also a sensitive probe of new physics. In the SM, the rate is dominated by the top quark contribution to the loop, but non-SM particles could also contribute with a size comparable to leading SM contributions.

In the SM the rate for $b \to d\gamma$ is suppressed with respect to $b \to s\gamma$ by a factor of around 20, and is particularly sensitive to new physics. The ratio of CKM matrix elements $|V_{td}/V_{ts}|$ can be obtained from the ratio of the $b \to d\gamma$ and $b \to s\gamma$ branching fractions (BFs). Measurements of $|V_{td}/V_{ts}|$ using the exclusive modes $B \to (\rho,\omega)\gamma$ and $B \to K^*\gamma$ [1, 2] are now well-established, with theoretical uncertainties of 7% from weak annihilation and hadronic form factors [3]. This ratio can also be obtained from the B_d and B_s mixing frequencies with small experimental uncertainties, and found to be be $0.206 \pm 0.0007(exp.)^{+0.0081}_{-0.0060}(th.)$ [4]. It is important to confirm the consistency of the two methods of determining $|V_{td}/V_{ts}|$, since new physics effects would enter in different ways in mixing and radiative decays. A measurement of the BFs of inclusive $b \to d\gamma$ relative to $b \to s\gamma$ would determine $|V_{td}/V_{ts}|$ with significantly reduced theoretical uncertainties compared to that from exclusive modes [7].

2. Analysis

We measure partial BFs as the sum of seven decay modes for $B \to X_s\gamma$ and $B \to X_d\gamma$, given in Table 1. $B \to X_s\gamma$ decays are reconstructed in the same way as $B \to X_d\gamma$ decays, with the particle identification requirement on one charged particle reversed to obtain a K^+ instead of a π^+. Significant backgrounds come from continuum ($e^+e^- \to q\overline{q}, q = u,d,s,c$) background processes. These are jet-like compared to isotropic $B\overline{B}$ events, and so are rejected using information from the event topology.

We reconstruct decays in two hadronic mass regions - the low mass region $0.5 < m_{had} < 1.0\ GeV/c^2$ which is dominated by the exclusive decays $B \to K^*\gamma$ and $B \to (\rho,\omega)\gamma$; and the high mass region $1.0 < m_{had} < 2.0\ GeV/c^2$, which contains non-resonant decays.

We enhance sensitivity by performing multi-dimensional likelihood fits to signal and background in two kinematic variables: $\Delta E = E^*_B - E^*_{\rm beam}$, where E^*_B is the energy of the B meson candidate and $E^*_{\rm beam}$ is the beam energy, and $m_{ES} = \sqrt{E^{*2}_{\rm beam} - \vec{p}^{*2}_B}$, where $\vec{p}^*_B$ is the momentum of the B candidate. The distribution of signal events in these variables peaks around zero in ΔE, and around the B mass in m_{ES}, whereas the background event distributions are smoothly varying.

Figure 1 shows the projections of m_{ES} and ΔE from the fits to data for $B \rightarrow X_s\gamma$ and $B \rightarrow X_d\gamma$ in the high mass region.

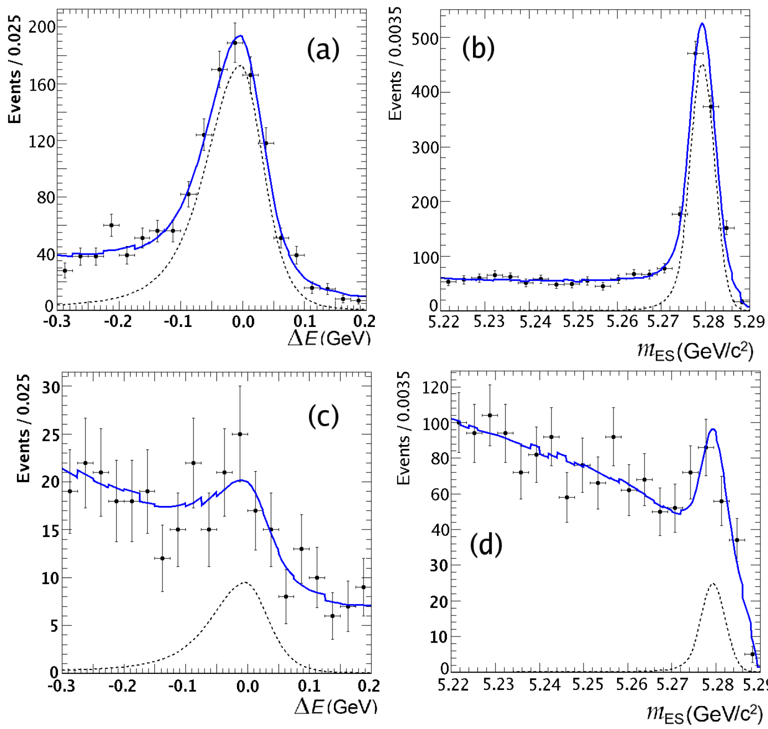

Figure 1: Projections of ΔE with $5.275 < m_{ES} < 5.286\ GeV/c^2$ for (a) $B \rightarrow X_s\gamma$ and (c) $B \rightarrow X_d\gamma$, and of m_{ES} with $-0.1 < \Delta E < 0.05\ GeV$ for (b) $B \rightarrow X_s\gamma$ and (d) $B \rightarrow X_d\gamma$ in the mass range 1.0-2.0 GeV/c^2. Data points are compared with the sum of all the fit contributions (solid line). The jagged line is an artifact of the fit projection over the sum of several binned histograms. The dashed line shows the signal component.

3. Systematic Errors

Systematic errors are calculated from data/Monte Carlo simulation comparisons, given in Table 2. The largest contributions are from the fit bias, uncertainties in background estimation, fragmentation of the hadronic system and choice of the photon spectrum model. The partial BFs given as a sum of the seven decay modes within each mass range is given in Table 3.

4. Inclusive Branching Fractions and $|V_{td}/V_{ts}|$

To extrapolate to the inclusive branching fractions, we must correct for un-reconstructed decay modes within the measured mass range. The low mass regions contain no non-resonant component,

Systematic Error Source	$M(X_s)$ 0.5-1.0	$M(X_s)$ 1.0-2.0	$M(X_d)$ 0.5-1.0	$M(X_d)$ 1.0-2.0
Track selection	0.3%	0.4%	0.3%	0.4%
Photon reconstruction	1.8%	1.8%	1.8%	1.8%
π^0/η reconstruction	0.9%	1.1%	1.4%	1.6%
Neural network	1.1%	4.9%	1.1%	4.9%
B counting	0.6%	0.6%	0.6%	0.6%
PID (*)	2.0%	2.0%	2.0%	2.0%
Fit bias (*)	0.1%	0.9%	4.9%	6.5%
PDF shapes (*)	2.3%	0.6%	3.7%	3.4%
Histogram binning (*)	0.8%	0.2%	1.8%	1.8%
Background (*)	0.8%	1.2%	5.9%	7.0%
Fragmentation (*)	-	3.3%	-	5.1%
Signal model	-	5.8%	-	6.0%
Error on partial BF	4.0%	9.0%	9.3%	14.2%
Missing ≥ 5 body		9.6%		18.2%
Other missing states		7.5%		15.3%
Spectrum Model		1.8%		1.6%
Error on inclusive BF	4.0%	15.2%	9.3%	27.7%

Table 2: Systematic errors on the measured partial and inclusive branching fractions. Systematic errors that do not cancel in the ratio of rates are marked with (*).

	N_S	ε	PBF($\times 10^{-6}$)	BF($\times 10^{-6}$)	$\frac{\mathrm{BF}(b\to d\gamma)}{\mathrm{BF}(b\to s\gamma)}$
$M(X_s)0.5-1.0$	804 ± 33	4.5%	$19\pm1\pm1$ ‘	$38\pm2\pm2$	$0.033\pm0.009\pm0.003$
$M(X_d)0.5-1.0$	35 ± 9	3.1%	$1.2\pm0.3\pm0.1$	$1.3\pm0.3\pm0.1$	
$M(X_s)1.0-2.0$	990 ± 42	1.6%	$66\pm3\pm6$	$192\pm8\pm29$	-
$M(X_d)1.0-2.0$	56 ± 14	1.9%	$3.2\pm0.8\pm0.5$	$7.9\pm2.0\pm2.2$	
$M(X_s)0.5-2.0$	-	-	-	$230\pm8\pm30$	$0.040\pm0.009\pm0.010$
$M(X_d)0.5-2.0$	-	-	-	$9.2\pm2.0\pm2.3$	

Table 3: Signal yields (N_S), efficiencies (ε), partial branching fractions (PBF), inclusive branching fractions (BF) and the ratio of inclusive branching fractions for the measured decay modes. The first error is statistical and second is systematic (including an error from extrapolation to missing decay modes, for the inclusive BF).

so we simply correct for the known un-reconstructed K^*/ω decays. In the high-mass region, the extrapolation is based on the MC fragmentation model, corrected for the measured $B \to X_s\gamma$ decay modes. The systematic error is determined from varying the fragmentation within physically-motivated bounds to obtain the uncertainty on the fragmentation correction, which results in large systematic errors (see Table 2). The BFs in the low mass regions (see Table 3) are in excellent agreement with the world average measurements [6].

The theoretical formula for $|V_{td}/V_{ts}|$ is based on the fully inclusive BF. To extrapolate to all masses we use the Kagan-Neubert [5] photon spectrum model, assuming a b-quark mass of 4.65 GeV/c^2. The error on the extrapolation is found by considering different KN spectra, but this cancels in the ratio of BFs. Table 3 shows the fully extrapolated BF, and the ratio. We find a BF for $b \to s\gamma$ in good agreement with the world average [6].

Conversion of the ratio of inclusive BFs to the ratio $|V_{td}/V_{ts}|$ is done according to [7], which required the Wolfenstein parameters $\overline{\rho}$ and $\overline{\eta}$ as input. Since the world average of these quantities relies on previous measurements of $|V_{td}/V_{ts}|$ we re-express $\overline{\rho}$ and $\overline{\eta}$ in terms of the world average of the independent CKM angle β. This procedure yields a value of $|V_{td}/V_{ts}| = 0.199 \pm 0.022(stat.) \pm 0.025(syst.) \pm 0.002(th.)$, compatible and competitive with more model-dependent determinations from the measurement of the exclusive modes $B \to (\rho, \omega)\gamma$ and $B \to K^*\gamma$.

5. Conclusion

In summary, we have measured the inclusive $b \to s\gamma$ and $b \to d\gamma$ transition rates using a sum of seven final states in the hadronic mass range up to $2.0 Gev/c^2$, making the first significant observation of the $b \to d\gamma$ transition in the region above $1.0 Gev/c^2$. The value of $|V_{td}/V_{ts}|$ derived from these measurements has an experimental uncertainty approaching that from the measurement of exclusive decays $B \to (\rho, \omega)\gamma$ and $B \to K^*\gamma$, but a significantly smaller theoretical uncertainty.

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