B Factory Measurements

of the $b \rightarrow s(d) \gamma$ “Radiative Penguin” Transition Rates

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Effective Neutral Currents: General Motivation

\( b \to s\gamma \) Penguins
- SUSY parameter space implications
- \( b \to s\gamma \) “Inclusive” approach
- \( B \to X_s\gamma \) “Semi-Inclusive” approach

\( b \to d\gamma \) Penguins and \(|V_{td}/V_{ts}|\)
- Motivation
- \( B \to (\rho,\omega)\gamma \) “Exclusive” approach
- \( B \to X_d \) “Semi-Inclusive” approach
- Status of \(|V_{td}/V_{ts}|\)

Conclusions
The SM b → s(d)γ transition is high order (two weak plus one EM vertex) …

so new physics can enter at leading order:

Although rare (≈ 5x10^-4 for sγ and ≈10^-5 for dγ), the isolated high-energy photon is a powerful signature.
Effective Neutral Currents: General Motivation

\[ b \rightarrow s_\gamma \]
- SUSY parameter space implications
- Inclusive approach
- Other approaches

\[ b \rightarrow d_\gamma \text{ and } |V_{td}/V_{ts}| \]
- Motivation
- \( B \rightarrow (\rho, \omega)_\gamma \) (“Standard” Approach)
- \( B \rightarrow X_d \) (“Semi-Inclusive” Approach)
- Status of \( |V_{td}/V_{ts}| \)

Conclusions
$b \to s\gamma$ has a significant impact on the $\tan\beta$-$m_A$ plane...
Fate of “Snowmass” MSSM study points

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS1a</td>
<td>killed by $b \rightarrow s\gamma$</td>
</tr>
<tr>
<td>SPS1a'</td>
<td>OK</td>
</tr>
<tr>
<td>SPS1b</td>
<td>killed by $b \rightarrow s\gamma$</td>
</tr>
<tr>
<td>SPS2</td>
<td>killed by $\Omega h^2$ (GUT) / OK(low)</td>
</tr>
<tr>
<td>SPS3</td>
<td>killed by $\Omega h^2$ (low) / OK(GUT)</td>
</tr>
<tr>
<td>SPS4</td>
<td>killed by g-2</td>
</tr>
<tr>
<td>SPS5</td>
<td>killed by $\Omega h^2$</td>
</tr>
<tr>
<td>SPS6</td>
<td>OK</td>
</tr>
<tr>
<td>SPS9</td>
<td>killed by Tevatron stable chargino</td>
</tr>
</tbody>
</table>
Explore $10^7$ points over 19-dimensional parameter space of CP-conserving MSSM

$b \rightarrow s\gamma$ most effective constraint (72% of models surviving prior constraints are eliminated; better than direct searches for SUSY partners)
The $\Upsilon(4S)$ resonance is the lightest $b\bar{b}$ resonance that decays into "open Beauty" ($B^+B^-$ or $B^0\bar{B}^0$).

$\Upsilon(4S)$ resonance is $\sim 1$ nb at peak, competing with a "continuum" background of $\sim 3$ nb.
B Factory Data Sets

**Transition Rates**

**Belle log total : 859067 pb^-1**

**BaBar Run 1**
- PEP II Delivered Luminosity: 553.48 fb
- BaBar Recorded Luminosity: 531.43 fb
- BaBar Recorded Y(4s): 432.89 fb
- BaBar Recorded Y(3s): 30.23 fb
- BaBar Recorded Y(2s): 14.45 fb
- Off Peak Luminosity: 53.65 fb

**Integrated Luminosity (fb^-1)**

- Delivered Luminosity
- Recorded Luminosity
- Recorded Luminosity Y(4s)
- Recorded Luminosity Y(3s)
- Recorded Luminosity Y(2s)
- Off Peak

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Davis 2/17/08 Seminar: b → s(d)γ Transition Rates
The Detectors

1.5 T Solenoid

CsI EM Colorimeter

DIRC Cerenkov System

Si Vertex Tracker

Belle Detector

SC solenoid 1.5T

CsI(Tl) 16X0

TOF counter

Aerogel Cerenkov cnt. n=1.015-1.030

Central Drift Chamber

8 GeV e+

μ / K_L detection

3 lyr. DSSD

Small cell + He/C_2H_6

14/15 lyr. RPC+Fe

Babar Detector

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Most exacting approach ("Inclusive") is aggressive:

Use only high-energy $\gamma$ as signature

Suppress continuum with event shapes, requirement of a high-energy lepton.

Estimate remaining contribution by scaling off-peak data.

**Challenge:** background from $\pi^0(\eta) \rightarrow \gamma\gamma$ decays (plus some fakes) in B decays
Inclusive Measurement of $b \to s \gamma$: Signal/Background

- After event selection, $S/B$ is roughly 1:1
- Continuum measured from below-peak running
- $B/$Bbar backgrounds must be identified and constrained
Inclusive Measurement of $b \rightarrow s\gamma$: Challenges

BaBar result with 81.5 fb$^{-1}$ (Phys. Rev. Lett. 97:171803, 2006)

$$\text{Br} \left( B \rightarrow X_s \gamma \right) = (3.67 \pm 0.29 \pm 0.34 \pm 0.29)$$

First round of B Factory results provide ~15% measurement of $b \rightarrow s\gamma$ transition rate

To exploit > 1 ab$^{-1}$ sample, need to focus on reducing systematics
Inclusive Measurement of $b \to s \gamma$: Model Dependence

Model dependence arises through $E_{\gamma}^*$ dependence of selection efficiency

Engineer event selection to flatten efficiency (some loss of statistics) $\Rightarrow$ reduce to < 3%
### Sources of Remaining B/Bbar Background

<table>
<thead>
<tr>
<th>Object</th>
<th>Source</th>
<th>Control Region</th>
<th>Signal Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>$\pi^0$</td>
<td>57.3%</td>
<td>66.6%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$\eta$</td>
<td>17.1%</td>
<td>15.7%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Other meson</td>
<td>8.7%</td>
<td>5.1%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$e$</td>
<td>9.3%</td>
<td>4.7%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Other</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
<tr>
<td><strong>Total $\gamma$</strong></td>
<td></td>
<td><strong>92.8%</strong></td>
<td><strong>92.4%</strong></td>
</tr>
<tr>
<td>$e$</td>
<td>Any</td>
<td>4.8%</td>
<td>3.7%</td>
</tr>
<tr>
<td>$n/n_{\bar{n}}$</td>
<td>Any</td>
<td>1.7%</td>
<td>2.9%</td>
</tr>
<tr>
<td>$p^+/p^-$</td>
<td>Any</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
<tr>
<td>$\pi/K$</td>
<td>Any</td>
<td>0.4%</td>
<td>0.8%</td>
</tr>
<tr>
<td><strong>Total non-$\gamma$</strong></td>
<td></td>
<td><strong>7.2%</strong></td>
<td><strong>7.6%</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
Inclusive Measurement of $b \rightarrow s \gamma$: $\pi^0, \eta$ Backgrounds

If high-energy $\gamma$ passes selection, then look for low-energy $\gamma$ and veto event

But, $\sim 50\%$ of the time the low-energy photon is missing, or $M_{\gamma\gamma}$ falls outside the veto window
Inclusive Measurement of $b \rightarrow s \gamma$: $\pi^0, \eta$ Backgrounds

Basic Idea: Use measured $\pi^0(\eta)$ peak (as a function of $E_{\pi, \eta}$) to estimate production rate and $M_{\gamma \gamma}$ shape; lower high-energy $E_\gamma$ cut to get more statistics.
Inclusive Measurement of $b \rightarrow s \gamma$: $\pi^0, \eta$ Backgrounds

Define $\cos \theta_h \equiv (E_{\gamma,\text{high}} - E_{\gamma,\text{low}})/(E_{\gamma,\text{high}} + E_{\gamma,\text{low}})$ = energy asymmetry

Signal selection requirement of $E_{\gamma}^* > 1.8$ GeV pushes asymmetry up, and energy of 2nd photon down.

$\rightarrow$ Sensitive to reconstruction efficiency for 30-80 MeV photons.

Measurement of $\pi^0$ reconstruction efficiency from $(\tau \rightarrow \rho \nu)/(\tau \rightarrow \pi \nu)$

Limiting Systematic

Expected/Measured
Inclusive Measurement of $b \rightarrow s\gamma$: Practicalities

Most up-to-date result is from BELLE, with all 605 fb$^{-1}$

BaBar still working ideas to reduce B background errors, particularly from $\pi^0, \eta$ contamination

BaBar goal is to get well below 10% in overall error

BELLE: $(3.37\pm0.43)\times10^{-4}$

arXiv:0804.1580 605 fb$^{-1}$

BaBar: $(3.92\pm0.56)\times10^{-4}$

PRL97,171803 82 fb$^{-1}$

NOTE: Measurements scaled to $E_{\gamma,\text{cms}} > 1.6$ GeV

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Reconstruct a total of 38 exclusive $b \rightarrow s\gamma$ final states that comprise about 55% of the total width.

Fit to reconstructed mass of exclusive final state to determine signal yield.

This “Semi-Inclusive” approaches employs a fit to the mass distribution, for which backgrounds tend to be self-calibrating…
But need to rely on models to correct for the 45% of states that are not measured (depends on mass $M(X_s)$ that photon recoils against).

**RESULT**

$\text{BF}(B \to s\gamma) = (3.49 \pm 0.57) \times 10^{-4}$

- 82 fb$^{-1}$ analyzed is less than 10% of world sample
- Has systematics independent of those of inclusive approach
Summary of Measurements of the $b \rightarrow s \gamma$ Rate

Experimental accuracy commensurate with theoretical control, but work continue on both ends

Most of BaBar data set still unanalyzed

A. Limosani, Melbourne

Most of BaBar data set still unanalyzed

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Davis 2/17/08 Seminar: $b \rightarrow s(d)\gamma$ Transition Rates
Effective Neutral Currents: General Motivation

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Conclusions
Measuring $|V_{td}/V_{ts}|$

Two independent diagrams provide sensitivity to CKM parameter $V_{td}$

B Mixing

Radiative Penguins

Note: In both cases, hadronic uncertainties minimized by comparing to corresponding $V_{ts}$ process ($B_s$ mixing, $b \rightarrow s\gamma$)

$\Rightarrow$ Observable is $|V_{td}/V_{ts}|$
|\frac{|V_{td}|}{|V_{ts}|} from Penguins: Motivation

ICHEP ’08 B Mixing Results [Farrington(CDF), Moulik(D0), averaged by DeLodovico(BaBar)]:

\[ \frac{|V_{td}|}{|V_{ts}|} = 0.207 \pm 0.001_{\text{exp}} \pm 0.006_{\text{theo}} \]

How do penguins fit into the picture?

Mixing: \[ x_d = \frac{\Delta m_B}{\Gamma_B} \sim 1 \rightarrow \Delta m_B \sim \Gamma_B \]

Penguins: \[ \text{Br}(b \rightarrow d \gamma) \sim 10^{-5} \rightarrow \Gamma_{d\gamma} \sim 10^{-5} \Gamma_B \]


“These [b \rightarrow d \gamma] vertices are CKM-suppressed in the standard model, but new physics contributions may not follow the CKM pattern in flavor-changing-neutral-current transitions and hence new physics effects may become more easily discernible in B \rightarrow X_d + \gamma (and its charge conjugate) than in the corresponding CKM-allowed vertices b \rightarrow s\gamma and b \rightarrow sg”

With |\frac{|V_{td}|}{|V_{ts}|}| precisely constrained by mixing, b \rightarrow d\gamma is a compelling testbed for new physics.
Standard ("Exclusive") Approach: measure exclusive rate \( \text{Br}(B \to \rho(\omega) \gamma) \); normalize with \( \text{Br}(B \to K^* \gamma) \)

\[
\frac{B(B \to \rho \gamma)}{B(B \to K^* \gamma)} = S_\rho \left| \frac{V_{td}}{V_{ts}} \right|^2 \left( \frac{1 - m_\rho^2/M_B^2}{1 - m_{K^*}^2/M_B^2} \right)^3 \zeta^2 [1 + \Delta R]
\]

Values of \( \zeta^2 \) and \( \Delta R \) are available from


at approximately 8% overall accuracy.
Measurement of $B(B \rightarrow \rho(\omega)\gamma)$

Belle: New result this Spring
351 fb$^{-1}$ (2006) $\rightarrow$ 598 fb$^{-1}$ (April 2008)

BaBar: New result this Summer
316 fb$^{-1}$ (April 2007) $\rightarrow$ 423 fb$^{-1}$ (July 2008)

Challenge: BRs are small ($<10^{-6}$); backgrounds are high
- continuum Multi-variate rejection with event shape, B tagging information, …
- $B \rightarrow K^*\gamma; K^* \rightarrow K\pi$ Require excellent particle ID
- $B \rightarrow (\rho^{\pm,0},\omega)(\pi^0,\eta)$ Veto if $\gamma$ found such that $M_{\gamma\gamma} \sim M_{\pi,\eta}$
Measurement of $B(B \rightarrow \rho(\omega) \gamma)$ (continued)

Remaining separation achieved by two-dimensional fit to the largely independent kinematic variables

$$M_{ES} = \sqrt{E_{\text{beam}}^* - p_B^*}$$

"Energy-substituted mass"; since $E_{\text{beam}} \sim M_B$, largely a measurement of momentum balance

$$\Delta E^* = E_B^* - E_{\text{beam}}^*$$

$E_B = E_{\text{beam}}$ for properly reconstructed candidate; total energy measurement

*In $e^+e^-$ CMS frame

Example: BaBar $B^0 \rightarrow \rho^0 \gamma$

- "self-calibrating" continuum background subtraction
- efficiencies (~5-15%) estimated with control samples

Continuum

Signal

$b \rightarrow s\gamma$ Feedthrough
### Recent Updates of B → ρ(ω) γ

**BELLE:** 598 fb⁻¹

<table>
<thead>
<tr>
<th>Mode</th>
<th>Belle ’06 (x10⁻⁷)</th>
<th>Belle ’08 (x10⁻⁷)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ⁺ γ</td>
<td>5.5 +4.2 +0.9</td>
<td>8.7 +2.9 +0.9</td>
</tr>
<tr>
<td></td>
<td>−3.6 −0.8</td>
<td>−2.7 −1.1</td>
</tr>
<tr>
<td>ρ⁰ γ</td>
<td>12.5 +3.7 +0.7</td>
<td>7.8 +1.7 +0.9</td>
</tr>
<tr>
<td></td>
<td>−3.3 −0.6</td>
<td>−1.6 −1.0</td>
</tr>
<tr>
<td>ω γ</td>
<td>5.6 +3.4 +0.5</td>
<td>4.0 +1.9</td>
</tr>
<tr>
<td></td>
<td>−2.7 −1.0</td>
<td>−1.7 ± 1.3</td>
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</tbody>
</table>

**BaBar:** 423 fb⁻¹

<table>
<thead>
<tr>
<th>Mode</th>
<th>BaBar ’07 (x10⁻⁷)</th>
<th>BaBar ’08 (x10⁻⁷)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ⁺ γ</td>
<td>11.0 +3.7 ± 0.9</td>
<td>12.0 +4.2 ± 2.0</td>
</tr>
<tr>
<td></td>
<td>−3.3</td>
<td>−3.7 ± 2.0</td>
</tr>
<tr>
<td>ρ⁰ γ</td>
<td>7.9 +2.2 ± 0.6</td>
<td>9.7 +2.4 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>−2.0</td>
<td>−2.2 ± 0.6</td>
</tr>
<tr>
<td>ω γ</td>
<td>4.0 +2.4 ± 0.5</td>
<td>5.0 +2.7 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>−2.0</td>
<td>−2.3 ± 0.9</td>
</tr>
</tbody>
</table>
Isopsin-Averaged Branching Fractions

Assuming SU$_3$(F) symmetry [$B(B \to \rho^0 \gamma) \sim B(B \to \omega \gamma)$] and

$$|\rho^0\rangle = \frac{1}{\sqrt{2}} (|u\bar{u}\rangle - |d\bar{d}\rangle) \quad |\omega\rangle = \frac{1}{\sqrt{2}} (|u\bar{u}\rangle + |d\bar{d}\rangle)$$

(approximately true by static quark model) we can write

$$\Gamma(B^+ \to \rho^+ \gamma) = 2 \Gamma(B^0 \to \rho^0 \gamma) = 2 \Gamma(B^0 \to \omega \gamma)$$

from which it follows

$$B[B \to (\rho, \omega)\gamma] \equiv \frac{1}{2} \left\{ B(B^+ \to \rho^+ \gamma) + \frac{\tau_{B^+}}{\tau_{B^0}} [B(B^0 \to \rho^0 \gamma) + B(B^0 \to \omega \gamma)] \right\}$$

⇒ Can combine $\rho^+, \rho^0, \omega$ results to derive $|V_{td}/V_{ts}|$ from

$$\frac{B(B \to (\rho, \omega)\gamma)}{B(B \to K^+ \gamma)} = \frac{V_{td}}{V_{ts}} \left( \frac{1 - m_{\rho}^2 / M_B^2}{1 - m_{K^+}^2 / M_B^2} \right) \zeta^2 [1 + \Delta R]$$
|V_{td}/V_{ts}| from Exclusive (\rho,\omega) Decays

Assuming static quark model, SU(3)\_F symmetry, can combine to get “isospin-averaged” BF, and then |V_{td}/V_{ts}|:

**BELLE:**

\[ B(B \rightarrow (\rho, \omega)\gamma) = (11.4 \pm 2.0^{+1.0}_{-1.2}) \times 10^{-7} \]

\[ |V_{td}/V_{ts}| = 0.195^{+0.020}_{-0.019} \pm 0.015 \]

\[ \text{Erratum-ibid.101:129904,2008} \]

**BaBar:**

\[ B(B \rightarrow (\rho, \omega)\gamma) = (16.3^{+3.0}_{-2.8} \pm 1.6) \times 10^{-7} \]

\[ |V_{td}/V_{ts}| = 0.233^{+0.025}_{-0.024} +0.022 -0.021 \]

\[ \text{Phys.Rev.D78:112001,2008} \]

assuming the world-average

\[ B(B \rightarrow K^{*}\gamma) = (4.16 \pm 0.17) \times 10^{-5} \]

Combining, for exclusive radiative decay overall:

\[ |V_{td}/V_{ts}| = 0.210 \pm 0.015 \pm 0.018 \]
“New” Approach (BaBar): Reconstruct seven exclusive final states $X_d\gamma$ in range $0.6 \text{ GeV}/c^2 < M_{X_d} < 1.8 \text{ GeV}/c^2$

$$|V_{td}/V_{ts}|^2 \text{ related to } \Gamma(b\to d\gamma)/\Gamma(b\to s\gamma) \text{ with } \sim 1\% \text{ theoretical uncertainty } [\text{Ali, Asatrian, Greub, Phys. Lett. B 429, 87 (1998)}]$$

However, must correct for unmeasured regions:
- Higher-multiplicity final states
- Higher-mass hadronic component (i.e. $M_{X_d} > 1.8 \text{ GeV}/c^2$)
Measured Regions for $B \rightarrow X_{d(s)} \gamma$

$X_s \gamma$

- K$^*$ Region

$X_d \gamma$

- $\rho\omega$ and $X_d$ analyses

$M_{\text{had}} (M_{X_d})$
**B → X_{(s,d)}γ** Partial Branching Fraction Results

Fit in high-mass $X_d \gamma$ region $1.0 < M_{\text{had}} < 1.6$ GeV/c²

<table>
<thead>
<tr>
<th>Mode</th>
<th>Mass Range</th>
<th>Yield</th>
<th>Efficiency</th>
<th>Partial B. F. ($\times 10^{-6}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \rightarrow s\gamma$</td>
<td>$0.6 &lt; M_{X_s} &lt; 1.0$</td>
<td>$1543 \pm 46$</td>
<td>8.5%</td>
<td>$23.7 \pm 0.7 \pm 1.7$</td>
</tr>
<tr>
<td>$b \rightarrow s\gamma$</td>
<td>$1.0 &lt; M_{X_s} &lt; 1.8$</td>
<td>$2279 \pm 75$</td>
<td>6.1%</td>
<td>$48.7 \pm 1.6 \pm 4.1$</td>
</tr>
<tr>
<td>$b \rightarrow d\gamma$</td>
<td>$0.6 &lt; M_{X_d} &lt; 1.0$</td>
<td>$66 \pm 26$</td>
<td>7.0%</td>
<td>$1.2 \pm 0.5 \pm 0.1$</td>
</tr>
<tr>
<td>$b \rightarrow d\gamma$</td>
<td>$1.0 &lt; M_{X_d} &lt; 1.8$</td>
<td>$107 \pm 47$</td>
<td>5.2%</td>
<td>$2.7 \pm 1.2 \pm 0.4$</td>
</tr>
</tbody>
</table>

Continuum background

BABAR

X$_s\gamma$, MisID background

$\Delta E$

$M_{\text{ES}}$

Yields and partial branching fractions:

High-mass $B \rightarrow X_d \gamma$

PRELIMINARY
**MC Simulation**

- Two-body $X_{s(d)}\gamma$ decay; mass spectrum of $X_{s(d)}$ system given by Kagan-Neubert model
  

- Fragment $X_s$ system via prior experimental constraint
- Fragment $X_d$ system via phase space

**Missing modes with $0.6 < M_X < 1.0$**

- MC suggests this region is dominated by resonances ($\rho$ and $\omega$); confirmed by $K^*$ dominance of $B \to X_s\gamma$
- Correction for missing modes well understood
Missing Modes with $1.0 < M_X < 1.8$

- Force 50% of decays to un-weighted mix of higher-mass resonances

- Force $X_d$ decay to be identical to $X_s$ decay up to substitution $s \leftrightarrow d$

**$B \to X_{(d,s)}\gamma$ Resonances**

**$B \to X_s\gamma$ Resonances**
- $K_1 (1270)$
- $K_1 (1400)$
- $K^* (1410)$
- $K_2^* (1430)$
- $K^* (1680)$

**$B \to X_d\gamma$ Resonances**
- $h_1^0 (1170)$
- $b_1^0 (1235)$
- $b_1^+ (1235)$
- $a_1^0 (1260)$
- $a_1^+ (1260)$
- $f_2^0 (1270)$
- $f_1^0 (1285)$
- $a_2^0 (1320)$
- $a_2^+ (1320)$
Conclusion from missing modes studies:

• Systematic incorporated by varying extra bodies and extra neutrals, independently, by ±50%
• Can improve with statistics via internal constraints (e.g. $X_s\gamma$ fragmentation)
• Dominant systematic error for $1.0 < M_X < 1.8$ GeV/c²

<table>
<thead>
<tr>
<th>Mass Range (GeV/c²)</th>
<th>$B(b \to d\gamma) \times 10^{-6}$</th>
<th>$B(b \to s\gamma) \times 10^{-6}$</th>
<th>$B(b \to d\gamma)/B(b \to s\gamma)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.6 &lt; M_{X(s,d)} &lt; 1.0$</td>
<td>$1.2 \pm 0.5 \pm 0.1$</td>
<td>$47 \pm 1 \pm 3$</td>
<td>$0.026 \pm 0.011 \pm 0.002$</td>
</tr>
<tr>
<td>$1.0 &lt; M_{X(s,d)} &lt; 1.8$</td>
<td>$6.0 \pm 2.6 \pm 2.3$</td>
<td>$168 \pm 14 \pm 33$</td>
<td>$0.036 \pm 0.015 \pm 0.009$</td>
</tr>
<tr>
<td>$0.6 &lt; M_{X(s,d)} &lt; 1.8$</td>
<td>$7.2 \pm 2.7 \pm 2.3$</td>
<td>$215 \pm 14 \pm 33$</td>
<td>$0.033 \pm 0.013 \pm 0.009$</td>
</tr>
</tbody>
</table>

Primary experimental result: $0.033 \pm 0.013 \pm 0.009$
Extrapolation to $\Gamma(b \rightarrow d\gamma)/\Gamma(b \rightarrow s\gamma)$

Measured region $0.6 < M_\chi < 1.8$ is ~50% of width

Extrapolate to full mass region via “KN Model”; KN calculation suggests negligible difference and uncertainty in extrapolation of the ratio (because $m_s, m_d << 1.8$ GeV/c$^2$?)

$\Gamma(b \rightarrow d\gamma) \over \Gamma(b \rightarrow s\gamma) = 0.033 \pm 0.013 \pm 0.009$

$|V_{td} / V_{ts}| = 0.177 \pm 0.043 \pm 0.001$

Expt. Theory
No evidence for non-Standard Model contribution to the decay width.
Concluding Remarks

- $B \rightarrow s \gamma$ continues to be leading constraint on MSSM parameter space
- More data exists (~80% of BaBar sample) to improve measurement, but “inclusive” approach starting to be limited by difficult systematics
- “Semi-inclusive” approach has systematics independent of inclusive approach; very little of existing sample has been analyzed in this way.

- Radiative measurements of $|V_{td}/V_{ts}|$ are becoming precise:
  $$|V_{td}/V_{ts}|_{\text{rad}} = 0.203 \pm 0.020$$
- Semi-inclusive approach works, and is independent of exclusive approach, with small theoretical uncertainty
- Agreement with SM (as constrained by B mixing) is good

In principle, the severe SM suppression of this radiative process ($\times 10^{-6}$ of B mixing) should make it very sensitive to new physics contributions.

Have we fully thought through the meaning of this constraint?
Backup Slides
Inclusive Measurement of $b \rightarrow s \gamma$: Practicalities
Inclusive Measurement of $b \rightarrow s\gamma$: Practicalities

Background + Signal function has 12 parameters.

\[
\text{Signal} = \begin{cases} 
A_g \left[ f_1 G(m, \mu_1, \sigma_1) + (1 - f_1) G(m, \mu_2, \sigma_2) \right] & \text{for } m > m_0 \\
N \left[ \frac{p \sigma_1 / \lambda}{(m_0 - m) + p \sigma_1 / \lambda} \right]^p & \text{for } m < m_0
\end{cases}
\]

where $m_0 \equiv \mu_1 - \lambda \sigma_1$

\[
\text{Background} = \frac{am^b}{(m^2 + c)^d}
\]

<table>
<thead>
<tr>
<th>1. Fit $\pi^0$ signal</th>
<th>Fixed Parameters</th>
<th>Floated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_2, \sigma_2/\sigma_1$</td>
<td>$\lambda, f_1, \mu_1, \sigma_1, p, A_g$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Fit $\pi^0$ signal+bkgd</th>
<th>Fixed Parameters</th>
<th>Floated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_2, \sigma_2/\sigma_1, \lambda, f_1$</td>
<td>$\mu_1, \sigma_1, p, A_g, a, b, c, d$</td>
<td></td>
</tr>
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<tr>
<th>3. Fit On-peak Data</th>
<th>Fixed Parameters</th>
<th>Floated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_2, \sigma_2/\sigma_1, \lambda, f_1$</td>
<td>$\mu_1, \sigma_1, p, A_g, a, b, c, d$</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>4. Fit Off-peak Data</th>
<th>Fixed Parameters</th>
<th>Floated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_2, \sigma_2/\sigma_1, \lambda, f_1, \mu_1, \sigma_1, p$</td>
<td>$A_g, a, b, c, d$</td>
<td></td>
</tr>
</tbody>
</table>
Which is the best cut to use?

Extrapolation factors used by HFAG from Buchmuller & Flacher PRD73 073008 (2006)

<table>
<thead>
<tr>
<th>Scheme</th>
<th>$E_\gamma &lt; 1.7$</th>
<th>$E_\gamma &lt; 1.8$</th>
<th>$E_\gamma &lt; 1.9$</th>
<th>$E_\gamma &lt; 2.0$</th>
<th>$E_\gamma &lt; 2.242$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic</td>
<td>0.986 ± 0.001</td>
<td>0.968 ± 0.002</td>
<td>0.939 ± 0.005</td>
<td>0.903 ± 0.009</td>
<td>0.656 ± 0.031</td>
</tr>
<tr>
<td>Neubert SF</td>
<td>0.982 ± 0.002</td>
<td>0.962 ± 0.004</td>
<td>0.930 ± 0.008</td>
<td>0.888 ± 0.014</td>
<td>0.665 ± 0.035</td>
</tr>
<tr>
<td>Kogan-Neubert</td>
<td>0.988 ± 0.002</td>
<td>0.970 ± 0.005</td>
<td>0.940 ± 0.009</td>
<td>0.892 ± 0.014</td>
<td>0.643 ± 0.033</td>
</tr>
<tr>
<td>Average</td>
<td>0.985 ± 0.004</td>
<td>0.967 ± 0.006</td>
<td>0.936 ± 0.010</td>
<td>0.894 ± 0.016</td>
<td>0.655 ± 0.037</td>
</tr>
</tbody>
</table>

Belle $E_\gamma > 1.7$ GeV
Belle $E_\gamma > 1.8$ GeV
Belle $E_\gamma > 1.9$ GeV
Belle $E_\gamma > 2.0$ GeV

HFAG Average

Winter 2008

arXiv:0804.1580 preliminary

$BF(B \to X_s \gamma) \times 10^{-4}$ scaled for $E_\gamma > 1.6$ GeV

(3.37 ± 0.43)$ \times 10^{-4}$
(3.35 ± 0.31)$ \times 10^{-4}$
(3.33 ± 0.24)$ \times 10^{-4}$
(3.29 ± 0.20)$ \times 10^{-4}$
(3.52 ± 0.25)$ \times 10^{-4}$

Much lower uncertainty if $E > 2.0$ GeV cut is used!
Summary of Fully Inclusive

**CLEO**
- 9.1/fb ON
- 4.4/fb OFF
- $E_\gamma > 2.0$ GeV

**BABAR**
- 81.5/fb ON
- 9.6/fb OFF
- $E_\gamma > 1.9$ GeV

**Belle**
- 140/fb ON
- 15/fb OFF
- $E_\gamma > 1.8$ GeV

**Belle**
- 605/fb ON
- 68/fb OFF
- $E_\gamma > 1.7$ GeV

PRL87, 251807 (2001)
PRL97, 171803 (2006)
PRL93, 061803 (2004)

More data, lower the photon energy cut


Antonio Limosani - University of Melbourne