\[ b \rightarrow s \gamma \]

- Why is it important?
  - “Penguin” loop diagram
  - SM: dominated by t quark, probes \( V_{ts} \)
  - Non-SM: via loop amplitude; interference on SM and non-SM may result in observable direct CP violating effects manifest in charge asymmetry of \( B \rightarrow K^* \gamma \)
Issues

• Theoretically prefer to measure inclusive decay $B \rightarrow X_s \gamma$
  – But harder experimentally …

• Experimentally measure exclusive decay $B \rightarrow K^* \gamma$
  – But harder theoretically …
<table>
<thead>
<tr>
<th>Ref</th>
<th>Expt</th>
<th>#particles</th>
<th>Decay</th>
<th>#events</th>
<th>BR(x10^-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7</td>
<td>CLEO</td>
<td>$2 \times 10^6 \ B\bar{B}$</td>
<td>$B \rightarrow X_s \gamma$</td>
<td>$263 \pm 104$ $110 \pm 26$</td>
<td>$23.2 \pm 5.7 \pm 3.5$</td>
</tr>
<tr>
<td>C2</td>
<td>CLEO</td>
<td>$9.7 \times 10^6 \ B\bar{B}$</td>
<td>$B^0 \rightarrow K^{*0} \gamma$</td>
<td>$88 \pm 12$</td>
<td>$4.55 \pm 0.7 \pm 3$</td>
</tr>
<tr>
<td>C2</td>
<td>CLEO</td>
<td>$9.7 \times 10^6 \ B\bar{B}$</td>
<td>$B^+ \rightarrow K^{*+} \gamma$</td>
<td>$37 \pm 8$</td>
<td>$4.76 \pm 0.8 \pm 3$</td>
</tr>
<tr>
<td>C2</td>
<td>CLEO</td>
<td>$9.7 \times 10^6 \ B\bar{B}$</td>
<td>$B \rightarrow K^{*2} \gamma$</td>
<td>$16 \pm 6$</td>
<td>$1.66 \pm 0.6 \pm 1$</td>
</tr>
<tr>
<td>C5</td>
<td>CLEO</td>
<td>$3.3 \times 10^6 \ B\bar{B}$</td>
<td>$b \rightarrow s \gamma$</td>
<td>$92 \pm 10 \pm 6$</td>
<td>$31.5 \pm 3.5 \pm 3.2 \pm 2.6$</td>
</tr>
<tr>
<td>Ba2</td>
<td>BaBar</td>
<td>$8.6 \times 10^6 \ B\bar{B}$</td>
<td>$B^0 \rightarrow K^{*0} \gamma$</td>
<td>$48 \pm 7$</td>
<td>$5.4 \pm 0.8 \pm 5$</td>
</tr>
<tr>
<td>Be1</td>
<td>Belle</td>
<td>$6.1 \times 10^6 \ B\bar{B}$</td>
<td>$B \rightarrow X_s \gamma$</td>
<td>$107 \pm 17$</td>
<td>$33.6 \pm 5.6 \pm 4.2 \pm 5$</td>
</tr>
<tr>
<td>Be1</td>
<td>Belle</td>
<td>$6.1 \times 10^6 \ B\bar{B}$</td>
<td>$B \rightarrow K^{*} \gamma$</td>
<td>?</td>
<td>3.8</td>
</tr>
<tr>
<td>A1</td>
<td>Aleph</td>
<td>$4 \times 10^6 \ Z$</td>
<td>$b \rightarrow s \gamma$</td>
<td>$70 \pm 20$</td>
<td>$31.4 \pm 8.3 \pm 5.3$</td>
</tr>
<tr>
<td>A1</td>
<td>Aleph</td>
<td>$4 \times 10^6 \ Z$</td>
<td>$B \rightarrow K^{*} \gamma$</td>
<td>5</td>
<td>?</td>
</tr>
<tr>
<td>A2?</td>
<td>Aleph</td>
<td>$4 \times 10^6 \ Z$</td>
<td>$B \rightarrow X_s \gamma$</td>
<td>?</td>
<td>$33.8 \pm 7.4 \pm 8.5$</td>
</tr>
<tr>
<td>L1</td>
<td>LHCb</td>
<td>?</td>
<td>$B^0 \rightarrow K^{*0} \gamma$</td>
<td>$26,000/10^7$ sec; S/N=1</td>
<td>?</td>
</tr>
</tbody>
</table>
Experimental Systematics

- CLEO (C2): total of 6.8% dominated by background shape (5%)
- BaBar (Ba2): total of 8.6% dominated by tracking efficiency (5%)
- Belle (Be1): total of 12.4% dominated by photon reconstruction (5.3%) and charged track reconstruction (4.7%). They also show separate 15% model error for extrapolating over the full $X_s$ mass range.
SM Theory $b \rightarrow s \gamma$

<table>
<thead>
<tr>
<th>Reference</th>
<th>BR x 10^{-5}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hewett &amp; Wells (PRD 55, 5549 (1997))</td>
<td>32.5 ± 3 ± 4</td>
</tr>
<tr>
<td>Chetyrkin et al (PLB 400, 206(1997); erratum PLB 425, 414 (1998)</td>
<td>32.8 ± 2.2 ± 2.5</td>
</tr>
</tbody>
</table>

- **1^{st} error:** Large dependence on scale $\mu$ (for $m_b/2 < \mu < 2m_b$)
  - LO $\sim$ 25%
  - NLO $\sim$ 5-10% (need NNLO?)

- **2^{nd} error:** Next largest dependence on $m_c/m_b$
  - $\sim$ 5%
Beyond SM

• Many authors…
    • Calculation where SUSY contribution is of the order of 10% of SM value
• Present SM theory error (~10%) is about the same size as the non-SM contribution
• Experiment is at 15% errors now
Conclusions?

• Need better SM theory predictions (NNLO?) to probe deviations from SM
  – Need to reduce errors from present 10% to 1%?
  – What about \( m_c/m_b \) error of 5%, can it be reduced?

• Experiment by the end of LHCb, BaBar, Belle should be at least systematics dominated (presently 5-10%), but it looks as if those systematics could be reduced? A few percent?
  – Maybe means that experiment at the end of LHC era will have achieved the necessary experimental precision?
Still missing…

• Need crisp predictions (including systematics) for
  – BaBar, Belle, BTeV, LHC(b)
  – Could not find in the literature…

• Better understanding of reasonable expectations for the reduction in the SM theory error
References

- C2 (CLEO): hep-ex/9912057 “Study of exclusive radiative B Meson decays”
- C5 (CLEO): CONF98-17; ICHEP98 1011 “Improved measurement of B(b->s gamma)”
- C7 (CLEO): PRL74, 2885 (1995) “First measurement of the rate for the inclusive radiative penguin decay b-> s gamma”
- Ba2 (BaBar): SLAC-PUB-8534; hep-ex/0008055 “A measurement of the branching fraction of the exclusive decay B^0->K^{*0} gamma”
- Be1 (Belle): KEK 2001-3; hep-ex/0103042 “A measurement of the branching fraction for the inclusive B^0->Xs gamma decays with Belle”
- A1 (Aleph): Williams thesis-99-017 “A measurement of the inclusive branching ratio for b->s gamma with the Aleph detector at LEP”