If ever any beauty I did see,
Which I desired, and got, was but a dream of thee.

John Donne, The Good Morrow

B – decay as a tool to search for physics extending the
Standard Model
SM forbids direct FCNC
FCNC proceed via a “penguin” loop

Weak decay vertices are governed by the CKM matrix.

The off diagonal elements are small as shown in the wolfenstein parameterization. The factor of $\lambda \sim 0.22$.

\[
V_{\text{CKM}} = \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\sim
\begin{pmatrix}
1- & \lambda & \lambda^3(1-\rho-i\eta) \\
0.5\lambda & 1- & \lambda^2 \\
-\lambda & 0.5\lambda & 1
\end{pmatrix}
\]
Why b-penguins?

The b-quark and s-quark have no kinematically allowed CKM-favored decays. So tree level decays to lighter quarks are CKM suppressed.

\[ V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \sim \begin{pmatrix} 1 - \lambda & \lambda & \Lambda \lambda^3 (\rho - i \eta) \\ 0.5 \lambda & 1 - \lambda & 0.5 \Lambda \lambda^2 \\ -\lambda & 1 - 0.5 \lambda & \Lambda \lambda^2 (1 - \rho - i \eta) \end{pmatrix} \]

The massive t-quark is the main contributor to the loop \( V_{tb} \gg V_{cb}, V_{ub} \). This creates high sensitivity to processes beyond the SM which occur at high energies.
Electroweak Penguins \( (B \rightarrow X_s l^+ l^-) \)

The effective hamiltonian comes from reducing the loop diagrams to the corresponding effective point theory similar to the operator product expansion leading to the four point fermi theory.

\[
H_{\text{eff}}(B \rightarrow X_s l^+ l^-) = -\frac{4G_F}{\sqrt{2}} \lambda_t \sum_{i=1}^{10} C_i(\mu) \mathcal{O}_i(\mu)
\]

Where \( \lambda_t = V_{ts}^* V_{tb} \) and \( C_i(\mu) \) are the wilson coefficients which represent the relative weights of the loops whose local operators at each interaction are \( \mathcal{O}_i(\mu) \).
Electroweak Penguins \((B \rightarrow X_s l^+ l^-)\)

The wilson coefficients that contribute to the decay are \(C_7, C_9\) and \(C_{10}\). These are adjusted in models beyond the SM, to take high energy effects of new physics into account.

The magnitude and sign of the wilson coefficients are determined by:

- the invariant dilepton mass spectrum \(d\Gamma(B \rightarrow X_s l^+ l^-)/d\hat{s}\),
- the forward-backward charge asymmetry
  \[
  A(s) = \int_{-1}^{1} d\cos\theta \ d^2\Gamma(B \rightarrow X_s l^+ l^-)/d\hat{s} \ d\cos\theta \ \text{sgn}(\cos\theta)
  \]
- and the decay rate of \(B \rightarrow X_s \gamma\). \(\Gamma(B \rightarrow X_s \gamma)\)
Electroweak Penguins \( (B \to X_s l^+ l^-) \)

Analysis of the supersymmetric contributions to the Wilson coefficients is done in terms of the quantities:

\[
R_i = C_i^{\text{SUSY}} / C_i^{\text{SM}} - 1 = C_i^{\text{new}} / C_i^{\text{SM}}
\]

The 95% C.L. projections in the \( C_9 - C_{10} \) and \( C_7 - C_{10} \) planes. The solid, dashed and dotted contours correspond to \( 3 \times 10^7, 10^8 \) and \( 5 \times 10^8 \) BB̅ar pairs. The central value of the SM is labeled by the diamond.
Electroweak Penguins \( (B \to X_s l^+ l^-) \)

Figure 5: The maximum value of (a) \( R_9 \) and (b) \( R_{10} \) achievable for general supersymmetric models. The top solid line comes from the \( l - H^\pm \) contribution and is displayed versus the \( H^\pm \) mass. The bottom solid line is from the \( \tilde{l}_i - \chi_i^\pm \) contribution with \( \tan \beta = 1 \) and is shown versus the \( \chi_i^\pm \) mass. The dashed line is the \( \tilde{l}_i - \chi_i^\pm \) contribution with \( \tan \beta = 2 \). The other mass parameters which are not plotted are chosen to be just above the reach of LEP II and the Tevatron.
Electroweak Penguins \( (B \rightarrow X_s l^+l^-) \)

Figure 7: Upper limits on the branching fractions for each \( B \rightarrow K^{(*)} \ell \ell \) mode (preliminary). Our results are compared to theoretical predictions and upper limits from previous experiments.
### Vertical Electroweak Penguins

<table>
<thead>
<tr>
<th>$B^0$ decay mode</th>
<th>Exp.</th>
<th>UL $\mathcal{B}$ $(10^{-6})$</th>
<th>Theory</th>
<th>$B_s$ decay mode</th>
<th>Exp.</th>
<th>UL $\mathcal{B}$ $(10^{-6})$</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma \gamma$</td>
<td>L3</td>
<td>38</td>
<td>$10^{-8}$</td>
<td>$\gamma \gamma$</td>
<td>L3</td>
<td>148</td>
<td>$10^{-7}$</td>
</tr>
<tr>
<td>$e^+ e^-$</td>
<td>CLEOII</td>
<td>5.9</td>
<td>$10^{-15}$</td>
<td>$e^+ e^-$</td>
<td>L3</td>
<td>54</td>
<td>$10^{-14}$</td>
</tr>
<tr>
<td>$\mu^+ \mu^-$</td>
<td>CDF</td>
<td>0.68</td>
<td>$10^{-10}$</td>
<td>$\mu^+ \mu^-$</td>
<td>CDF</td>
<td>2</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>$\tau^+ \tau^-$</td>
<td></td>
<td>10$^{-8}$</td>
<td></td>
<td>$\tau^+ \tau^-$</td>
<td></td>
<td>10$^{-7}$</td>
<td></td>
</tr>
</tbody>
</table>
### Present and Future B-Physics Prospects

<table>
<thead>
<tr>
<th>Expt.</th>
<th>Collider</th>
<th>Beams</th>
<th>(\sqrt{s}) (GeV)</th>
<th>Year online</th>
<th>(\mathcal{L} (10^{33} \text{cm}^{-1} \text{s}^{-1}))</th>
<th>(\sigma(b\bar{b})) (nb)</th>
<th>(b\bar{b}) pairs ((10^7/\text{yr}))</th>
<th>(\beta_{\gamma\tau c}) ((\mu m))</th>
<th>(\sigma(b\bar{b})/\sigma(q\bar{q}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO III</td>
<td>CESR</td>
<td>(e^+e^-)</td>
<td>10</td>
<td>1999</td>
<td>1.2</td>
<td>1</td>
<td>12</td>
<td>30</td>
<td>3 \cdot 10^{-1}</td>
</tr>
<tr>
<td></td>
<td>CESR-IV</td>
<td>(e^+e^-)</td>
<td>10</td>
<td>?</td>
<td>30</td>
<td>1</td>
<td>30</td>
<td>30</td>
<td>3 \cdot 10^{-1}</td>
</tr>
<tr>
<td>BaBar</td>
<td>PEP-II</td>
<td>(e^+e^-)</td>
<td>10</td>
<td>1999</td>
<td>3-10</td>
<td>1</td>
<td>3-10</td>
<td>270</td>
<td>3 \cdot 10^{-1}</td>
</tr>
<tr>
<td>Belle</td>
<td>KEK-B</td>
<td>(e^+e^-)</td>
<td>10</td>
<td>1999</td>
<td>3-10</td>
<td>1</td>
<td>3-10</td>
<td>200</td>
<td>3 \cdot 10^{-1}</td>
</tr>
<tr>
<td>HERA-B</td>
<td>HERA</td>
<td>(pN)</td>
<td>40</td>
<td>1998</td>
<td>—</td>
<td>6-12</td>
<td>50-100</td>
<td>9000</td>
<td>1 \cdot 10^{-6}</td>
</tr>
<tr>
<td>CDF II</td>
<td>Tevatron</td>
<td>(p\bar{p})</td>
<td>1800</td>
<td>2000</td>
<td>0.2-1.0</td>
<td>100000</td>
<td>20000</td>
<td>500</td>
<td>1 \cdot 10^{-3}</td>
</tr>
<tr>
<td>D0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTeV ‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHC-B ‡</td>
<td>LHC</td>
<td>(pp)</td>
<td>14000</td>
<td>2005</td>
<td>0.15</td>
<td>500000</td>
<td>75000</td>
<td>7000</td>
<td>5 \cdot 10^{-3}</td>
</tr>
<tr>
<td>Atlas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Asymmetric beam energies. ‡ Forward detector.
References:
5) A. Ali, “Photonic and Leptonic Rare B Decays,” [hep-ph/0101154]
7) K. T. Pitts “CP Violation, Mixing and Rare Decays at the Tevatron Now and in Run II,” Proc. of the 4th Workshop on Heavy Quarks at Fixed Target (HQ98), Fermilab-Conf-98/380-E.
8) T. Iijima, “Study of Rare B Meson Decays at Belle” [hep-ex/0105005].