The role of SuperB in unraveling the nature of physics beyond the SM

ICHEP 2012

David Hitlin
Caltech
Scenarios – the relevance of flavor

1. LHC finds NP compatible with flavor data - flavor data constrains couplings
2. LHC finds NP incompatible with flavor data – modify the theory
3. LHC finds nothing – flavor studies indirectly probe high energy effects

Flavor measurements – from Super $\tau$/charm factories, Super $B$ factories, LHC and rare muon and kaon decays are crucial to sorting through the large number of still viable New Physics models
- Both the quark and lepton sectors are important
  - Quark sector
    - Precision Unitarity Triangle measurements
    - Rare decay $b, c$ decay branching fractions
    - New sources of $CP$ violation in $b$ and $c$ decays
    - Modifications to kinematic distributions
  - Lepton sector
    - Charged lepton flavor violation in $\tau$ decay
    - $CP$ violation in $\tau$ decay
    - $\tau$ g-2 and EDM limits
• $\mathcal{L} = 10^{36} \text{ cm}^{-2}\text{s}^{-1}$ at $\Upsilon(4S)$ (with headroom for higher $\mathcal{L}$)
  – Will integrate 75 ab$^{-1}$ in $\sim$5 years
  – Crabbed waist scheme produces high luminosity (50x PEP-II) with very small beam sizes and currents, and therefore wall plug power, similar to PEP-II
  – Circumference $\sim$1350m
  – Electron beam is polarized (60-80%)
  – Can run in $\tau$/charm region with $\mathcal{L} = 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
  – Many components from PEP-II
  – Uses upgraded $BABAR$ detector
  – Linac can function as FEL
  – Incorporates synchrotron radiation beamlines
How will current stresses in the Unitarity Triangle resolve?

\[ \sim 1 \text{ ab}^{-1} \]

<table>
<thead>
<tr>
<th>Observable/mode</th>
<th>Current</th>
<th>LHCb (2017)</th>
<th>SuperB (5 years)</th>
<th>LHCb upgrade</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>\sim 1 \text{ ab}^{-1}</td>
<td>5 fb(^{-1})</td>
<td>75 ab(^{-1})</td>
<td>50 fb(^{-1})</td>
<td></td>
</tr>
<tr>
<td>(\alpha) from (b \to c\bar{c}s)</td>
<td>No result</td>
<td>Moderately precise</td>
<td>Moderately clean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(B_d \to J/\psi \pi^0)</td>
<td></td>
<td>Precise</td>
<td>Clean – needs lattice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(B_s \to J/\psi K_S^0)</td>
<td></td>
<td>Very precise</td>
<td>Clean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>) inclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>) exclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>V_{cb}</td>
<td>) inclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>V_{cb}</td>
<td>) exclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How will current stresses in the Unitarity Triangle resolve?

\[ \sim 1 \text{ ab}^{-1} \]

<table>
<thead>
<tr>
<th>Observable/mode</th>
<th>Current</th>
<th>LHCb (2017)</th>
<th>SuperB (5 years)</th>
<th>LHCb upgrade</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>\alpha \beta \text{ from } b \to c \bar{c}s</td>
<td></td>
<td></td>
<td></td>
<td>Moderate clean</td>
<td></td>
</tr>
<tr>
<td>B_d \to J/\psi \pi^0</td>
<td></td>
<td></td>
<td></td>
<td>Precise</td>
<td></td>
</tr>
<tr>
<td>B_s \to J/\psi K^0</td>
<td></td>
<td></td>
<td></td>
<td>Clean – needs lattice</td>
<td></td>
</tr>
<tr>
<td>V_{ub}</td>
<td></td>
<td></td>
<td></td>
<td>Very precise</td>
<td></td>
</tr>
<tr>
<td>V_{cb}</td>
<td></td>
<td></td>
<td></td>
<td>Clean</td>
<td></td>
</tr>
</tbody>
</table>

Experiment | Theory
--- | ---
No result | Moderate clean
Moderately precise | Precise
Precise | Clean – needs lattice
Very precise | Clean
How will current stresses in the Unitarity Triangle resolve?

~ 1 ab⁻¹

<table>
<thead>
<tr>
<th>Observable/mode</th>
<th>Current</th>
<th>LHCb (2017)</th>
<th>SuperB (5 years)</th>
<th>LHCb upgrade</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>~ 1 ab⁻¹</td>
<td>5 fb⁻¹</td>
<td>75 ab⁻¹</td>
<td>50 fb⁻¹</td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$ from $b \to c\bar{c}s$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_d \to J/\psi \pi^0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s \to J/\psi K_S^0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ inclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ exclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$ inclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$ exclusive</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Experiment

- No result
- Moderately precise
- Precise
- Very precise

Theory

- Moderately clean
- Clean – needs lattice
- Clean
Improvement in precision of $\gamma$ and $V_{ub}$ provides a strong constraint.

Assuming only 1) three generation unitarity
2) no New Physics at tree level

This constraint must be obeyed by any New Physics model:

\[
\gamma = (-103.9 \pm 9.2)^\circ \\
(75.7 \pm 9.2)^\circ \\
|V_{cb}| = (41.0 \pm 1.0) \times 10^{-3} \\
|V_{ub}| = (3.82 \pm 0.52) \times 10^{-3} \\
\bar{\rho} = \pm 0.089 \pm 0.061 (69\%) \\
\bar{\eta} = \pm 0.385 \pm 0.057 (15\%)
\]

post-LHCb: $\delta\gamma \sim 4^\circ$, $|V_{cb,ub}|$ unchanged
\[
\bar{\rho} = \pm 0.098 \pm 0.031 (32\%) \\
\bar{\eta} = \pm 0.386 \pm 0.056 (15\%)
\]

post-SuperB: $\delta\gamma \sim 1^\circ$, $\delta|V_{cb}|/|V_{cb}| \sim 1\%$
$\delta|V_{ub}|/|V_{ub}| \sim 2\%$
\[
\bar{\rho} = \pm 0.093 \pm 0.007 (8\%) \\
\bar{\eta} = \pm 0.371 \pm 0.009 (2.5\%)
\]
Squark mass matrices and the mass scale $\Lambda_{\text{NP}}$

Example: the MSSM with generic squark mass matrices:
Use the mass insertion approximation with $m_{\tilde{q}} \sim m_{\tilde{g}}$ to constrain couplings:

$$ (\delta_{ij}^q)_{AB} = \frac{(\Delta_{ij}^q)_{AB}}{m_{\tilde{q}}^2} $$

Can constrain the $\delta_{ij}^q$'s using

- $\mathcal{B}(B \to X_s \gamma)$
- $\mathcal{B}(B \to X_s \ell^+ \ell^-)$
- $\mathcal{A}_{\text{CP}}(B \to X_s \gamma)$
Squark mass matrices and the mass scale $\Lambda_{NP}$

Example: the MSSM with generic squark mass matrices:
Use the mass insertion approximation with $m_{\tilde{q}} \sim m_{\tilde{g}}$ to constrain couplings:

$$ (\delta_{ij}^q)_{AB} = \frac{\Delta_{ij}^q}{m_{\tilde{q}}^2} \quad (\Delta_{ij}^q)_{AB} = \frac{\Delta_{ij}^q}{m_{\tilde{q}}^2} $$

Can constrain the $\delta_{ij}^q$'s using

$B(B \rightarrow X_s \gamma)$

$B(B \rightarrow X_s \ell^+ \ell^-)$

$A_{CP}(B \rightarrow X_s \gamma)$

Hypothetical:
- LHC excludes 1 TeV gluinos
- SuperB measures $(\delta_{23}^d)_{LR} \sim 0.05$

$\Rightarrow \Lambda_{NP} < 3.5$ TeV
Probes of New Physics – CPV in exclusive modes

- In the Standard Model we expect the same value for “sin2β” in $b \rightarrow c\bar{c}s$, $b \rightarrow c\bar{c}d$, $b \rightarrow s\bar{s}s$, $b \rightarrow d\bar{d}s$ modes, but different models of SUSY breaking or extra dimensions, or …. can produce different asymmetries.

- Since the penguin modes have branching fractions one or two orders of magnitude less than tree modes, a great deal of luminosity is required to make these measurements to meaningful precision.

$$B^0 \rightarrow J/\psi K_S^0 \quad b \quad \ldots \quad B^0 \rightarrow \eta' K_S^0, \phi K_S^0, \ldots$$

$$\lambda_{\text{tree}} = \frac{q}{p} \frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{cb}^* V_{cs}}{V_{cb} V_{cs}^*} = (-1)e^{-2i\beta}$$

$$\lambda_{\text{penguin}} = \frac{q}{p} \frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{td}^*}{V_{tb}^* V_{td}} \frac{V_{tb} V_{ts}^*}{V_{tb}^* V_{ts}} = (-1)e^{-2i\beta}$$

$$\lambda = e^{i(2\beta + \phi^{\text{SUSY}})} \left| \frac{\bar{A}}{A} \right| \Rightarrow S_{\phi_K} = \sin(2\beta + \phi^{\text{SUSY}})$$
\[ b \to s\bar{s}s \text{ decays have 1 to 5% the rate of } b \to c\bar{c}s \text{ decays} \]

<table>
<thead>
<tr>
<th>Gold</th>
<th>Silver</th>
<th>Bronze</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \propto V_{tb}V_{ts}^* \sim \lambda^2 ]</td>
<td>[ \propto V_{tb}V_{ts}^* \sim \lambda^2 ]</td>
<td>[ \propto V_{tb}V_{ts}^* \sim \lambda^2 ]</td>
</tr>
<tr>
<td>[ \phi ]</td>
<td>[ \eta', f_0 ]</td>
<td>[ \pi^0, \rho^0, \omega ]</td>
</tr>
<tr>
<td>[ K^0 ]</td>
<td>[ K^0 ]</td>
<td>[ \pi^0, K^0 ]</td>
</tr>
</tbody>
</table>

Corrections of up to 20% due to additional penguin or tree amplitudes are possible. These corrections can be calculated and/or bounded.

\[ J/\psi K_S^0 \times 10^{-6} = 440 \]
Search for new sources of $CP$ violation in $s$ penguin modes

- With 1 ab$^{-1}$, there is insufficient sensitivity to see NP effects
- At 75 ab$^{-1}$, statistical uncertainty in many of these $s$-penguin modes will be comparable to current precision for $B^0 \to J/\psi K^0_S$, providing mass insertion scale sensitivity approaching 1 TeV at standard coupling

\[ \sin(2\beta^{\text{eff}}) = \sin(2\phi^{\text{eff}}) \]

<table>
<thead>
<tr>
<th>Mode</th>
<th>Stat</th>
<th>Syst</th>
<th>Th</th>
<th>Stat</th>
<th>Syst</th>
<th>Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\psi K^0_S$</td>
<td>0.022</td>
<td>0.010</td>
<td>0.01</td>
<td>0.002</td>
<td>0.005</td>
<td>0.001</td>
</tr>
<tr>
<td>$\eta' K^0_S$</td>
<td>0.08</td>
<td>0.02</td>
<td>0.015±0.015</td>
<td>0.006</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>$\phi K^0_S$</td>
<td>0.26</td>
<td>0.03</td>
<td>0.03±0.02</td>
<td>0.020</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>$f_0 K^0_S$</td>
<td>0.18</td>
<td>0.04</td>
<td>0.0±0.02+LD</td>
<td>0.012</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>$K^0_S K^0_S$</td>
<td>0.19</td>
<td>0.03</td>
<td>0.02±0.01</td>
<td>0.015</td>
<td>0.020</td>
<td></td>
</tr>
</tbody>
</table>
Heavy flavor studies provide a “DNA Chip” for New Physics

<table>
<thead>
<tr>
<th></th>
<th>AC</th>
<th>RVV2</th>
<th>AKM</th>
<th>δLL</th>
<th>FBMSSM</th>
<th>LHT</th>
<th>RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 - D^0$</td>
<td>★★★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>?</td>
</tr>
<tr>
<td>$\varepsilon_K$</td>
<td>★</td>
<td>★★★</td>
<td>★★★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★</td>
</tr>
<tr>
<td>$S_{\psi\phi}$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$S_{\phi K_S}$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$A_{\text{CP}} (B \to X_s \gamma)$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>?</td>
</tr>
<tr>
<td>$A_{T,8} (B \to K^* \mu^+ \mu^-)$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★</td>
</tr>
<tr>
<td>$A_0 (B \to K^* \mu^+ \mu^-)$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★★★</td>
<td>?</td>
</tr>
<tr>
<td>$B \to K^{(*)} \nu \bar{\nu}$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★★★</td>
<td>★</td>
</tr>
<tr>
<td>$B_s \to \mu^+ \mu^-$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$K^+ \to \pi^+ \nu \bar{\nu}$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$K_L \to \pi^0 \nu \bar{\nu}$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$\mu \to e \gamma$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$\tau \to \mu \gamma$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$\mu + N \to e + N$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$d_n$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$d_e$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>$(g-2)_\mu$</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>?</td>
</tr>
</tbody>
</table>

The pattern of measurement:

- ★★★ large effects
- ★★ visible but small effects
- ★ unobservable effects

is characteristic, often uniquely so, of a particular model.

These are a subset of a subset listed by Buras and Girrbach
MFV, CMFV, 2HDM$\overline{\text{MFV}},$ LHT, SM4, SUSY flavor. SO(10) – GUT,
SSU(5)$_{\text{HN}},$ FBMSSM, RHMFV, L-R, RS$_0,$ gauge flavor, ……….

---

**GLOSSARY**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>RH currents &amp; U(1) flavor symmetry</td>
</tr>
<tr>
<td>RVV2</td>
<td>SU(3)-flavored MSSM</td>
</tr>
<tr>
<td>AKM</td>
<td>RH currents &amp; SU(3) family symmetry</td>
</tr>
<tr>
<td>δLL</td>
<td>CKM-like currents</td>
</tr>
<tr>
<td>FBMSSM</td>
<td>Flavor-blind MSSSM</td>
</tr>
<tr>
<td>LHT</td>
<td>Little Higgs with T Parity</td>
</tr>
<tr>
<td>RS</td>
<td>Warped Extra Dimensions</td>
</tr>
<tr>
<td>Observable/mode</td>
<td>Current</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
</tr>
<tr>
<td>Luminosity</td>
<td>~ 1 ab(^{-1})</td>
</tr>
</tbody>
</table>

**τ Decays**
- \(\tau \rightarrow \mu \gamma\)
- \(\tau \rightarrow e \gamma\)

**B\(_{u,d}\) Decays**
- \(B \rightarrow \tau \nu, \mu \nu\)
- \(B \rightarrow K^{(*)}+\nu\overline{\nu}\)
- S in \(B \rightarrow K^0\pi^0\gamma\)
- S (other penguin modes)
- \(A_{CP} (B \rightarrow X_s\gamma)\)
- \(\text{BR}(B \rightarrow X_s\gamma)\)
- \(\text{BR}(B \rightarrow X_s\ell\ell)\)
- \(\text{BR}(B \rightarrow K^{(*)}\ell\ell)\)

**B\(_s\) Decays**
- \(B_s \rightarrow \mu\mu\)
- \(\beta_s\) from \(B_s \rightarrow J/\psi\phi\)
- \(B_s \rightarrow \gamma\gamma\)
- \(a_{sl}\)

**D Decays**
- Mixing parameters
- CP Violation

**Precision Electroweak**
- \(\sin^2 \theta_W\) at \(\Upsilon(4S)\)
- \(\sin^2 \theta_W\) at Z-Pole

**Experiment:**
- No Result
- Moderately precise
- Precise
- Very precise

**Theory:**
- Moderately clean
- Clean, needs Lattice
- Clean
Rare processes in a U(2)³ model

- Weakly coupled 3rd generation
  \[
  W^d_{L,R} = \begin{pmatrix}
  c_d & \kappa^* & -\kappa^* s_L e^{i\gamma_L} \\
  -\kappa & c_d & -c_d s_L e^{i\gamma_L} \\
  0 & s_L e^{-i\gamma_L} & 1
  \end{pmatrix}
  \]

- Correlations in a variety of rare processes (\(\Delta F=1\)):
  \[
  S_{\eta'K_S} - S_{\psi K_S}, S_{\phi K_S} - S_{\psi K_S}, A_{CP}(b \rightarrow s\gamma), A_\gamma
  \]

- Also consistent with recent \(B_{d,s}\) mixing results

Barbieri, Campli, Isidori, Sala & Straub
Beyond the Unitarity Triangle

- **SuperB** has the needed sensitivity

<table>
<thead>
<tr>
<th>Observable</th>
<th>SM prediction</th>
<th>Experiment</th>
<th>Future sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{BR}(B \to X_s \gamma)$</td>
<td>$(3.15 \pm 0.23) \times 10^{-4}$ [14]</td>
<td>$(3.52 \pm 0.25) \times 10^{-4}$</td>
<td>$\pm 0.15 \times 10^{-4}$</td>
</tr>
<tr>
<td>$A_{CP}(b \to s \gamma)$</td>
<td>$(-0.6 \div 2.8)%$ [15]</td>
<td>$(-1.2 \pm 2.8)%$</td>
<td>$\pm 0.5%$</td>
</tr>
<tr>
<td>$\text{BR}(B \to X_d \gamma)$</td>
<td>$(1.54^{+0.26}_{-0.31}) \times 10^{-5}$ [16]</td>
<td>$(1.41 \pm 0.49) \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>$S_{\phi K_S}$</td>
<td>$0.68 \pm 0.04$ [17, 18]</td>
<td>$0.56^{+0.16}_{-0.18}$</td>
<td>$\pm 0.02$</td>
</tr>
<tr>
<td>$S_{\eta' K_S}$</td>
<td>$0.66 \pm 0.03$ [17, 18]</td>
<td>$0.59 \pm 0.07$</td>
<td>$\pm 0.01$</td>
</tr>
<tr>
<td>$\langle A_7 \rangle$</td>
<td>$(3.4 \pm 0.5) \times 10^{-3}$ [19]</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$\langle A_8 \rangle$</td>
<td>$(-2.6 \pm 0.4) \times 10^{-3}$ [19]</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Correlation between the branching ratios for $B_s \to \mu^+ \mu^-$ and $B \to X_s \nu \nu$ in the **minimal RS model**

M. Bauer et al., arXiv:0912.1625 [hep-ph]
Charged lepton flavor violation

- Charged lepton flavor violation can be large in SUSY GUTs
- LFV branching fractions are very sensitive to the details of the Yukawa couplings and the mass scale of a heavy $\nu_R$

$$A(\ell_i \to \ell_j \gamma) = a[Y e^T Y \gamma]_{ij} + b[Y U^T Y U]_{ij}$$

<table>
<thead>
<tr>
<th>PMNS mixing</th>
<th>CKM mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>dominant if $M_{\nu_R} &gt; 10^{12}$ GeV</td>
<td>dominant if $M_{\nu_R} &lt; 10^{12}$ GeV</td>
</tr>
</tbody>
</table>

$$\mathcal{B}(\tau \to \mu \gamma) : \mathcal{B}(\tau \to e \gamma) : \mathcal{B}(\mu \to e \gamma)$$

$[500-10] : 1:1 \quad 10^4 : 500 : 1$

Correlations between $\mathcal{B}(\mu \to e \gamma)$ and $\mathcal{B}(\tau \to \mu \gamma)$, $\mathcal{B}(\tau \to e \gamma)$ in an SU(5) model with right-handed neutrinos, with different structures for the neutrino Yukawa couplings (I and II)

Sensitivity of $\tau \to \mu \gamma$ decay searches

- $\tau \to \mu \gamma$ searches suffer from irreducible backgrounds:
  
  Thus sensitivity improves as $1/\sqrt{\int L \, dt}$

  $e^+e^- \to \tau \tau \gamma$ backgrounds are reduced by a hadronic tag, leaving $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$ as the main background

- A polarized electron beam can reduce this background by exploiting the correlation between the $\nu$ direction in hadronic tag and the helicity of the polarized $\tau$, leading to an improvement in sensitivity of a factor of $\sim 2$

  
  Trapezoidal cuts
  
  Effect on signal:
  
  41.6% $\pi \nu$ tag  
  49.4% $\rho \nu$ tag
  
  Background retained
  
  11.5% $\pi \nu$ tag  
  9.8% $\rho \nu$ tag
Sensitivity of $\tau \rightarrow \ell\ell\ell$ decay searches

- Current branching fraction limits, typically in the several $x10^{-8}$ range, don’t have measurable backgrounds. Is this the case with 100× the data?

- It is difficult to do a realistic Monte Carlo simulation of potential backgrounds at a Super B Factory. Simulations are underway.

- The no-background regime improves as $1/\int L\,dt$

- If there are background events, the improvement is $1/\sqrt{\int L\,dt}$

Studies ongoing
Polarization not yet incorporated
SuperB sensitivity directly confronts New Physics models of $\tau$ CLFV

Preliminary estimates

nb: there is coverage in all modes. Studies not yet complete
LFV rates discriminate between models

SO(10) GUT

Impact of $\theta_{13}$ in a SUSY seesaw model

Antusch, Arganda, Herrero and Teixeira

Calibbi, Faccia, Masiero and Vempati

nb: only [pink] area is now relevant
There are correlations in the $\tau \rightarrow \mu \gamma$ and $\ell \ell \ell$ branching fractions

$\mathcal{B}(\tau \rightarrow \mu \gamma)$ vs. $\mathcal{B}(\tau \rightarrow e \gamma)$ in a general fourth generation scenario (Buras)

$\mathcal{B}(\tau \rightarrow \mu \gamma)$ vs. $\mathcal{B}(\tau \rightarrow e \gamma)$ are anti-correlated. Observation of both modes would be evidence against a fourth generation.
CPV in $\tau$ decay

Unpolarized $\tau$s

- Measure asymmetries in decay rates of tagged $\tau$ decays with two or more hadrons

$$B(\tau^- \rightarrow \pi^- \pi^0 \nu_\tau) \neq B(\tau^+ \rightarrow \pi^+ \pi^0 \bar{\nu}_\tau)$$

CLEO

$$B(\tau^- \rightarrow K^- \pi^0 \nu_\tau) \neq B(\tau^+ \rightarrow K^+ \pi^0 \bar{\nu}_\tau)$$

CLEO

$$B(\tau^- \rightarrow \pi^0 \pi^+ \pi^- \nu_\tau) \neq B(\tau^+ \rightarrow \pi^0 \pi^+ \pi^- \bar{\nu}_\tau)$$

Belle

$$B(\tau^- \rightarrow K^0_S \pi^- (\geq 0\pi^0) \nu_\tau) \neq B(\tau^+ \rightarrow K^0_S \pi^+ (\geq 0\pi^0) \bar{\nu}_\tau)$$

BABAR

- The $\tau^- \rightarrow K^0_S \pi^- (\geq 0\pi^0) \nu_\tau$ mode is interesting for two reasons:
  1) Due to the $K^0_S$ it has an SM CP asymmetry of $(0.36 \pm 0.01)\%$
  2) BABAR has recently measured an asymmetry of opposite sign:
     $$(-0.45 \pm 0.24 \pm 0.11)\% \ 3\sigma \text{ from the Standard Model}$$

Interpretation of any observed CPV requires understanding of final state interactions

- Measure CP-violating or $T$-odd correlations in $\tau^+\tau^-$ decays

Polarized $\tau$s - new, more sensitive, observables

- Search for $T$-odd rotationally invariant products, e.g. $w_e^- \cdot (p_{\pi^+} \times p_{\pi^0})$
  in $\tau^+$ and $\tau^-$ decays such as $\tau^- \rightarrow K^0_S \pi^- \nu_\tau$, $K^- \pi^0 \nu_\tau$, $K^- \pi^+ \pi^- \nu_\tau$, $\pi^- \pi^0 \nu_\tau$, $\pi^- \pi^+ \pi^- \nu_\tau$

The sensitivity of SuperB with 75 ab$^{-1}$ should approach $2 \times 10^{-5}$ in the $\tau^- \rightarrow K^- \pi^0 \nu_\tau$ mode

- Search for $T$-odd correlation between $\tau$ polarization and $\mu$ polarization in $\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$
**τ magnetic moment and EDM**

**τ magnetic moment**

SM prediction: \( a_{\tau}^{\text{SM}} = (g-2)/2 = 1177.21(5) \times 10^{-6} \).

SUSY contribution \( \frac{\Delta a_{\tau}}{\Delta a_{\mu}} = \frac{m_{\tau}^2}{m_{\mu}^2} \approx 300 \)

Model-independent bound on New Physics contributions (LEP):

\[-0.007 < a_{\tau}^{\text{NP}} < 0.005 \text{ @ 95 % CL} \]

- \( a_{\tau} \) measurement can be done in \( e^+e^- \rightarrow \tau^+\tau^- \) with unpolarized beams
  - The real part of the form factor \( F_2(0) = \text{Re}\{F_2(0)\} = a_{\tau} = (g-2)/2 \) needs the measurement of correlations on the \( \tau \) decay products of both polarized \( \tau \)s

\[
\frac{d\sigma(e^+e^- \rightarrow \tau^+\tau^-)}{d\cos\theta_{\tau^-}} = \frac{\pi\alpha^2}{2s} \beta \left( 2 - \beta^2 \sin^2\theta_{\tau^-} \right) |F_1(s)|^2 + 4\text{Re} F_2(s)
\]

- SuperB has the sensitivity to improve this measurement by three orders of magnitude using a polarized electron beam

\[
A_{\tau}^\pm = \frac{\sigma_R^\pm}{\sigma} \left| P_e - \sigma_L^\pm \right| P_e = \mp \alpha_\pm \frac{3\pi}{8(3 - \beta^2)\gamma} \left[ |F_1|^2 + (2 - \beta^2)\gamma^2 \text{Re}\{F_2\} \right]
\]

\[
A_L^\pm = \sigma_{FB}^\pm(+) \left| P_e - \sigma_{FB}^\pm(-) \right| P_e = \mp \alpha_\pm \frac{3}{4(3 - \beta^2)} \left[ |F_1|^2 + 2\text{Re}\{F_2\} \right]
\]

\[
\text{Re}\{F_2(s)\} = \mp \frac{8(3 - \beta^2)}{3\pi\gamma\beta^2} \frac{1}{\alpha_\pm} \left( A_{\tau}^\pm - \frac{\pi}{2\gamma} A_L^\pm \right)
\]
### Sensitivity

<table>
<thead>
<tr>
<th></th>
<th>15 ab(^{-1})</th>
<th>75 ab(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Re{F(_2}}</td>
<td>Im{F(_2}}</td>
</tr>
<tr>
<td>SuperB at (\Upsilon(4S)) unpolarized beams</td>
<td>1.1 × 10(^{-5})</td>
<td>7.8 × 10(^{-6})</td>
</tr>
<tr>
<td>SuperB at (\Upsilon(4S)) polarized (e^-) beam</td>
<td>3.7 × 10(^{-6})</td>
<td>7.8 × 10(^{-6})</td>
</tr>
</tbody>
</table>

**Caveats:**
- perfect tracking
- 100% \(e^-\) polarization.
- \(\pi\nu\) and \(\rho\nu\) modes only
- Systematic error \(\sim\)10% of statistical error

J. Bernabéu, G.A. González-Sprinberg and J. Vidal
J. Bernabéu, G.A. González-Sprinberg, J. Papavassiliou and J. Vidal

- A more recent evaluation, made using an 80% polarized beam, a more recent detector performance simulation and all \(\tau\) decay modes, yields

\[
\Delta a_{\tau} = (1.0–2.6) \times 10^{-6},
\]

depending on decay modes included
\( \tau \) EDM

New Physics sensitivity for a \( \tau \) EDM is boosted by \( \sim m_\tau/m_e = 3.5 \times 10^3 \)

Some predictions in the \( 10^{-19} \) range (SM < \( 10^{-34} \) ecm)

Can be done with unpolarized beams

\[-0.22 \text{ ecm} < \text{Re}\{d_\tau^y\} \times 10^{16} < 0.45 \text{ ecm} @ 95\% \text{ CL} \quad \text{Belle} \]

Polarized \( \tau \)s provide a new, more sensitive \( CP \)-odd \( T \)-odd observable:

\[
A_{N}^{CP} = \frac{1}{2} \left( A_{N}^{+} + A_{N}^{-} \right) = \alpha_h \frac{3\pi\gamma\beta}{8(3 - \beta^2)} \frac{2m_\tau}{e} \text{Re}\{d_\tau^y\}
\]

where the azimuthal asymmetry for the two polarizations is

\[
A_{N}^{\mp} = \frac{\sigma_{L}^{\mp} - \sigma_{R}^{\mp}}{\sigma} = \alpha_{\mp} \frac{3\pi\gamma\beta}{8(3 - \beta^2)} \frac{2m_\tau}{e} \text{Re}\{d_\tau^y\}
\]

This allows the use of single \( \tau \) polarization observables, improving sensitivity

Sensitivity estimate for SuperB (Bernabéu et al.) :

\[
\left|\text{Re}\{d_\tau^y\}\right| \leq 7.2 \times 10^{-20} \text{ e cm for } 75 \text{ ab}^{-1} @ 95\% \text{ CL} \quad \text{using } \tau^- \rightarrow \pi^- \bar{\nu}_\tau, \rho^- \bar{\nu}_\tau \text{ decay modes}
\]

Belle II: \( \sigma\left(\text{Re}\{d_\tau^y\}\right) \sim 3 \times 10^{-19} \text{ e cm for } 50 \text{ ab}^{-1} \text{ using } \tau^- \rightarrow \pi^- \bar{\nu}_\tau, \rho^- \bar{\nu}_\tau \text{ decay modes}

Either estimate brings the sensitivity into the regime of New Physics predictions
Conclusions

• High precision, high sensitivity flavor physics measurements, from the next generation of experiments, Super\(B\) in particular, will be crucial to relating new phenomena found at the LHC to particular New Physics models.

• The goal, reconstructing the NP Lagrangian, will require explicit production of new particles and comprehending the detailed pattern of departures from, or adherence to, precise SM predictions in the flavor sector.
  – This interplay will continue over the next decade, combining discovered new particles, SM discrepancies found in flavor measurements and/or constraints from the quark and lepton decay sector.
THE END