On the Super-B Physics Potential: the “other” physics cases

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1 The golden goal: Bd & Bs physics + τ LFV
2 The next-to-main goal: LFC τ physics
3 The last-but-not-least goal: charm physics
   $D\bar{D}$ mixing + D CPV decays

thanks to: I. Bigi, P. Paradisi, M. Pierini, V. Porretti, L. Silvestrini
   and G. Gonzalez
From Super-B to Super-Flavour Factory

\[ 10^{10} \tau^+ \tau^- \]

\[ 10^{10} B \bar{B} \]

\[ 10^{10} B_s \bar{B}_s \]

\[ 10^9 D \bar{D} \]
Push the present B factory physics program to unprecedented accuracy.

Redundancy + precision is the key to new physics.

A plethora of new opportunities with the $B_s$ (+ rare modes - $B_s \rightarrow \mu \mu$)
### CPV in Rare Decays

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Goal</th>
<th>3/ab</th>
<th>10/ab</th>
<th>50/ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S(B^0 \to \phi K_S^0)$</td>
<td>$\approx 5%$</td>
<td>16%</td>
<td>8.7%</td>
<td>3.9%</td>
</tr>
<tr>
<td>$S(B^0 \to \eta' K_S^0)$</td>
<td>$\approx 5%$</td>
<td>5.7%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>$S(B^0 \to K_S^0 \pi^0)$</td>
<td></td>
<td>8.2%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>$S(B^0 \to K_S^0 \pi^0 \gamma)$</td>
<td>SM: $\approx 2%$</td>
<td>11%</td>
<td>6%</td>
<td>4%</td>
</tr>
<tr>
<td>$A_{CP} (b \to s \gamma)$</td>
<td>SM: $\approx 0.5%$</td>
<td>1.0%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>$A_{CP} (B \to K^* \gamma)$</td>
<td>SM: $\approx 0.5%$</td>
<td>0.6%</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

### Rare Decays

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<tr>
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<th>10/ab</th>
<th>50/ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>V_{td}</td>
<td>/</td>
<td>V_{ts}</td>
<td>\sim \sqrt{\frac{\mathcal{B}(b \to d \nu)}{\mathcal{B}(b \to s \nu)}}$</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to D^* \nu \nu)$</td>
<td>$\mathcal{B} = 8 \times 10^{-3}$</td>
<td>10%</td>
<td>5.6%</td>
<td>2.5%</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to s \nu \nu)$</td>
<td>1 exclusive: $\sim 4 \times 10^{-6}$ (per mode)</td>
<td>$\sim 1\sigma$ (per mode)</td>
<td>$&gt; 2\sigma$ (per mode)</td>
<td>$&gt; 4\sigma$ (per mode)</td>
</tr>
<tr>
<td>$\mathcal{B}(B_d \to \text{invisible})$</td>
<td>$\sim 8 \times 10^{-11}$</td>
<td>$&lt; 2 \times 10^{-6}$</td>
<td>$&lt; 1 \times 10^{-6}$</td>
<td>$&lt; 4 \times 10^{-7}$</td>
</tr>
<tr>
<td>$\mathcal{B}(B_d \to \mu \mu)$</td>
<td>$\sim 8 \times 10^{-11}$</td>
<td>$&lt; 3 \times 10^{-8}$</td>
<td>$&lt; 1.6 \times 10^{-8}$</td>
<td>$&lt; 7 \times 10^{-9}$</td>
</tr>
<tr>
<td>$\mathcal{B}(B_d \to \tau \tau)$</td>
<td>$\sim 1 \times 10^{-8}$</td>
<td>$&lt; 10^{-3}$</td>
<td>$O(10^{-4})$</td>
<td>?</td>
</tr>
</tbody>
</table>
\[
\text{Re} \left( \delta_{23}^d \right)_{AB} \quad \text{vs} \quad \text{Im} \left( \delta_{23}^d \right)_{AB}
\]

\( AB = LL \)

\( AB = LR \)

\( b \rightarrow s \gamma \) only

\( b \rightarrow s \) ll only

All constraints
Lepton Flavour Violation: $\tau \rightarrow \mu/e\gamma$

Unmistakable signal of new physics

Negative results still powerful in constraining GUT scenarios

Interesting interplay between quark and lepton FV
All the LFV $\tau$ decay modes are interesting and can be exploited to identify the source of NP contribution. For instance, in supersymmetry gaugino-mediated LFV predicts

$$\frac{\text{BR}(\tau \rightarrow l_j l_k l_k)}{\text{BR}(\tau \rightarrow l_j \gamma)} \sim \frac{\alpha_e}{3\pi} \left( \log\left(\frac{m_\tau^2}{m_k^2}\right) - 3 \right)$$

Higgs-mediated LFV does not exhibit this correlation.

P. Paradisi, hep-ph/0508054
Other topics in $\tau$ physics

$\tau$ properties: mass, lifetime ($CPT \sim 10^{-4}-10^{-5}$)

Universality of lepton (charged) currents

\[
\frac{g_\mu}{g_\tau}, \quad \frac{g_e}{g_\tau}, \quad \frac{g_\mu}{g_e}
\]

with an error $\sim 10^{-4}$
Universality violation in SUSY are induced by

- tree-level charged Higgs exchange

- neutralino/chargino-slepton loop

High precision measurements might constrain SUSY parameters: quantitative study under way

P. Paradisi
CPV in $\tau$ decays: $T$-odd moments

(1) $\tau^- \rightarrow \nu K^-\pi^0 / K^0\pi^- : \langle s_\tau \cdot (p_K \times p_\pi) \rangle$

(2) $e^+ (p) e^- (-p) \rightarrow \tau^+ (k, S_+) \tau^- (-k, S_-) \rightarrow \bar{B}(q_B) \nu_\tau + A(q_A) \nu_\tau$

$$O_1 = \frac{1}{2} \left[ \hat{p} \cdot (q_B^- \times q_A^-) + \hat{p} \cdot (q_A^- \times q_B^-) \right]$$

$$\text{Re}(d_\tau) = \frac{1}{c_{AB} \sqrt{s}} \frac{e}{(\langle O_1(P) \rangle - \langle O_1(-P) \rangle)}$$

Error on $\tau$ EDM

$\sim 5 \times 10^{-21} \text{ e cm}$

$(d_e < 1.6 \times 10^{-27} \text{ e cm})$

Sensitivity to new physics to be assessed
Charm Physics

Unique opportunity: D's are the only mesons available to study oscillations in the up-quark sector

Charm is not light nor heavy wrt the QCD scale
- large long-distance effects
- large strong phases
- very large theoretical uncertainty

GIM suppression of FCNC extremely efficient

Huge NP contributions still possible
The predictions of the relevant mixing parameters $x_d = \Delta M / \Gamma$ and $y_d = \Delta \Gamma / 2\Gamma$ span 2 orders of magnitude.

Long-distance dominated $x_d^{SD} \sim 10^{-5}$

Case for NP based on $x_d$ uncertain!! (I. Bigi)
Yet NP contributions can be so large that non-trivial bounds can be obtained anyway

For example: MSSM with non-diagonal squark mass matrices

<table>
<thead>
<tr>
<th>$x$</th>
<th>$\sqrt{\text{Re} \left( \delta_{12}^u \right)_{LL}^2}$</th>
<th>$\sqrt{\text{Re} \left( \delta_{12}^u \right)_{LR}^2}$</th>
<th>$\sqrt{\text{Re} \left( \delta_{12}^u \right)<em>{LL} \left( \delta</em>{12}^u \right)_{RR}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>$4.7 \times 10^{-2}$</td>
<td>$6.3 \times 10^{-2}$</td>
<td>$1.6 \times 10^{-2}$</td>
</tr>
<tr>
<td>1.0</td>
<td>$1.0 \times 10^{-1}$</td>
<td>$3.1 \times 10^{-2}$</td>
<td>$1.7 \times 10^{-2}$</td>
</tr>
<tr>
<td>4.0</td>
<td>$2.4 \times 10^{-1}$</td>
<td>$3.5 \times 10^{-2}$</td>
<td>$2.5 \times 10^{-2}$</td>
</tr>
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</table>

$\Delta m_d < 1.32 \times 10^{-10} \text{ MeV}$

Gabbiani et al.
Rare D decays

Again one has to fight against long distance to disentangle NP effects

- $c \rightarrow u \gamma$ transitions driven by LD contributions

- $D \rightarrow V l^+l^-$ gets large NP effects in the low invariant mass region of the leptons

Burdman et al.
CPV in D decays

Direct CPV

😊 Cabibbo favour. (CF) modes: need New Physics (except *)

😊 1x Cabibbo supp. modes (SCS)

possible with KM -- benchmark: $O(\lambda^4) \sim O(10^{-3})$

New Physics models: $O(\%)$ conceivable

if observe direct $CP \sim 1\%$ in SCS decays -- is it New Physics?

must analyze host of channels

😊 2x Cabibbo supp. modes (DCS): need New Physics (except *)

CPV in t-dependent CPA $\sim \sin(\Delta m_D t) \text{Im}(q/p) \rho_f$

$D^0 \rightarrow K_S \phi/\pi^0$ vs. $\bar{D}^0 \rightarrow K_S \phi/\pi^0$

$D^0 \rightarrow K^+K^-/\pi^+\pi^-$ vs. $\bar{D}^0 \rightarrow K^+K^-/\pi^+\pi^-$

$D^0 \rightarrow K^+\pi^-$ vs. $\bar{D}^0 \rightarrow K^-\pi^+$

SM: CPA $\sim 10^{-6}$
Conclusions (i)

B physics + \( \tau \) LFV

\( \tau \) physics (lepton cc univ. + CPV)

charm physics (mixing + rare + CPV)
Conclusions (ii)

Design considerations:

- Hermeticity of detector & low backgrounds most helpful or even essential for beauty, $\tau$ & charm decays to control systematics; e.g., $B \to \tau\tau, \tau\nu, \tau\nu D, \tau\nu X/ \tau \to \nu\nu, \nu K\pi$

- The resolution of the microvertex detector should be driven by the presumably much more demanding requirements of charm physics, in particular concerning $D^0 - \bar{D}^0$ oscillations and $CP$ there. This should benefit also
  - Searches for $CP$ in $\tau$ decays
  - Searches for $CP$ in $B_s$ decays on $\Upsilon(5S)$ driven by $\Delta\Gamma$

- A polarized $e$-beam most helpful for $CP$ studies in $\tau$ & $\Lambda_c$ decays -- also to address systematics
Conclusions (iii)

No problem to establish the physics case

Program complementary to the LHC helps understanding NP models

Measurable NP virtual effects probes scales beyond the LHC reach

$O(10)$ interesting measurements

Phenomenological analyses not always match the foreseen accuracy: dedicated work is required