The SuperB Project: the Quantum Path to New Physics

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Outline

- The Physics Case.
- The Machine.
- The Detector.
- The SuperB Approval Process.
The B-Factories: a Story of Success

- BaBar and Belle together have collected \( \sim 1.5 \text{ ab}^{-1} \) of data.
- Huge harvest of physic results.
  - Well beyond the original goals.
  - The PDG book has gotten significantly thicker.
  - Already some limits on New Physics models.

**Unitarity Triangle**

**D^0 Mixing**

**B^+ \rightarrow \tau^+ \nu**

Limits on 2HDM/MSSM models

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F. Bianchi
The Quest for New Physics

The relativistic path:
Increase the energy and look for direct production of new particles.

The quantum path:
Increase the luminosity and look for effects of physics beyond the standard model in loop diagrams.
High Luminosity Flavor Factory
Complementary to Energy Frontier

• Precision measurements in the flavor sector are sensitive to New Physics (NP)
  – Interference effects in known processes
  – SM rare or forbidden decays
• NP effects are controlled by
  – NP scale: \( \Lambda \)
  – Effective couplings: \( C \)
    • Different coupling intensity (different interactions)
    • Different patterns (e.g. because of symmetries)
• With \( 5-10 \times 10^{10} \) bb, cc, \( \tau \tau \) pairs (50-100 ab\(^{-1}\)) one can:

LHC finds NP(\( \Lambda \))
• Determine detailed structure of couplings of NP
• Look for heavier states
• Study NP flavor structure

LHC does not find NP(\( \Lambda \))
• Look for indirect NP signals
• Connect them to models
• Exclude regions in parameters space

Some phenomena as LFV in \( \tau \) decays are unambiguous signals of NP
### B Physics @ Y(4S)

<table>
<thead>
<tr>
<th>Observable</th>
<th>B Factories (2 ab$^{-1}$)</th>
<th>SuperB (75 ab$^{-1}$)</th>
<th>Observable</th>
<th>B Factories (2 ab$^{-1}$)</th>
<th>SuperB (75 ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sin(2\beta)$ $(J/\psi K^0_S)$</td>
<td>0.018</td>
<td>0.005 (+)</td>
<td>$</td>
<td>V_{ub}</td>
<td>$ (exclusive)</td>
</tr>
<tr>
<td>$\cos(2\beta)$ $(J/\psi K^0_S)$</td>
<td>0.30</td>
<td>0.05</td>
<td>$</td>
<td>V_{ub}</td>
<td>$ (inclusive)</td>
</tr>
<tr>
<td>$\sin(\phi)$ $(D^0\bar{D}^0)$</td>
<td>0.10</td>
<td>0.02</td>
<td>$</td>
<td>V_{ub}</td>
<td>$ (exclusive)</td>
</tr>
<tr>
<td>$\cos(\phi)$ $(D^0\bar{D}^0)$</td>
<td>0.20</td>
<td>0.04</td>
<td>$</td>
<td>V_{ub}</td>
<td>$ (inclusive)</td>
</tr>
<tr>
<td>$S(J/\psi \pi^0)$</td>
<td>0.10</td>
<td>0.02</td>
<td>$B(B \to \tau\nu)$</td>
<td>20%</td>
<td>4% (+)</td>
</tr>
<tr>
<td>$S(D^+\bar{D}^-)$</td>
<td>0.20</td>
<td>0.03</td>
<td>$B(B \to \mu\nu)$</td>
<td>visible</td>
<td>5%</td>
</tr>
<tr>
<td>$S(\phi K^0)$</td>
<td>0.13</td>
<td>0.02 (+)</td>
<td>$B(B \to D\nu)$</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>$S(\phi K^0)$</td>
<td>0.05</td>
<td>0.01 (+)</td>
<td>$B(B \to \rho\gamma)$</td>
<td>15%</td>
<td>3% (+)</td>
</tr>
<tr>
<td>$S(K^*\bar{K}^0\pi^0)$</td>
<td>0.15</td>
<td>0.02 (+)</td>
<td>$B(B \to \omega\gamma)$</td>
<td>30%</td>
<td>5%</td>
</tr>
<tr>
<td>$S(K_2^0\pi^0\pi^0)$</td>
<td>0.15</td>
<td>0.02 (+)</td>
<td>$S(K^0\pi^0\gamma)$</td>
<td>0.15</td>
<td>0.02 (+)</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$\sim 1.5^\circ$</td>
<td>2.5^\circ</td>
<td>$A_{CP}(B \to K^*\gamma)$</td>
<td>0.007 (+)</td>
<td>0.004 (+)</td>
</tr>
<tr>
<td></td>
<td>$\sim 12^\circ$</td>
<td>7.0^\circ</td>
<td>$A_{CP}(B \to \rho\gamma)$</td>
<td>0.20</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>$\sim 9^\circ$</td>
<td>1.5^\circ</td>
<td>$A_{CP}(b \to s\gamma)$</td>
<td>0.012 (+)</td>
<td>0.004 (+)</td>
</tr>
<tr>
<td></td>
<td>$\sim 6^\circ$</td>
<td>2.0^\circ</td>
<td>$A_{CP}(b \to s\gamma)$</td>
<td>0.03</td>
<td>0.006 (+)</td>
</tr>
<tr>
<td>$\alpha$ $(B \to \pi\pi)$</td>
<td>$\sim 16^\circ$</td>
<td>3^\circ</td>
<td>$S(K^0\pi^0\gamma)$</td>
<td>0.15</td>
<td>0.02 (+)</td>
</tr>
<tr>
<td>$\alpha$ $(B \to \rho\rho)$</td>
<td>$\sim 7^\circ$</td>
<td>1-2^\circ (+)</td>
<td>$S(\rho\gamma)$</td>
<td>possible</td>
<td>0.10</td>
</tr>
<tr>
<td>$\alpha$ $(B \to \omega\omega)$</td>
<td>$\sim 12^\circ$</td>
<td>2^\circ</td>
<td>$A_{CP}(B \to K^*\ell\ell)$</td>
<td>7%</td>
<td>1%</td>
</tr>
<tr>
<td>$\alpha$ $(\text{combined})$</td>
<td>$\sim 6^\circ$</td>
<td>1-2^\circ (+)</td>
<td>$A_{CP}(B \to K^*\ell\ell)$</td>
<td>25%</td>
<td>9%</td>
</tr>
<tr>
<td>$\alpha$ $(\text{combined})$</td>
<td>$\sim 6^\circ$</td>
<td>1-2^\circ (+)</td>
<td>$A_{CP}(B \to X_s\ell\ell)$</td>
<td>35%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$B(B \to K^0\nu\bar{\nu})$</td>
<td>visible</td>
<td>20%</td>
</tr>
<tr>
<td>$\gamma + \tau$ $(D^{(<em>)+}\pi^+\pi^-, D^{(</em>)+}K^0_S\pi^+\pi^-)$</td>
<td>20^\circ</td>
<td>5^\circ</td>
<td>$B(B \to \pi\nu\bar{\nu})$</td>
<td>possible</td>
<td></td>
</tr>
</tbody>
</table>

### Charm FCNC

<table>
<thead>
<tr>
<th>Mode</th>
<th>Observable</th>
<th>$\Upsilon(4S)$</th>
<th>$\psi(3770)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \to K^+\pi^-$</td>
<td>$x^2$</td>
<td>$3 \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$y$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$7 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>$D^0 \to K^+K^-$</td>
<td>$y_{CP}$</td>
<td>$5 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$x$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4.9 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$y$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$3.5 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$</td>
<td>q/p</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\phi$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$2^\circ$</td>
</tr>
<tr>
<td>$\psi(3770) \to D^{<em>}D^</em>$</td>
<td>$x^2$</td>
<td>$(1-2) \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$y$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$(1-2) \times 10^{-3}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\cos\delta$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$(0.01-0.02)$</td>
</tr>
</tbody>
</table>

### Charm mixing and CP

<table>
<thead>
<tr>
<th>Channel</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$</td>
<td>$1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^0 \to \pi^0e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$</td>
<td>$2 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$</td>
<td>$3 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S \mu^+\mu^-$</td>
<td>$3 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$</td>
<td>$1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^0 \to e^\pm\mu^\mp$</td>
<td>$1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^+ \to \pi^+e^\pm\mu^\mp$</td>
<td>$1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^0 \to \eta e^\pm\mu^\mp$</td>
<td>$2 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^0 \to \eta\mu^\pm\mu^\mp$</td>
<td>$3 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^0 \to K^0_S e^\pm\mu^\mp$</td>
<td>$3 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^+ \to \eta e^\pm\mu^\mp, D^+ \to K^-e^+e^+$</td>
<td>$1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^+ \to \pi^+\mu^+\mu^+, D^+ \to K^-\mu^+\mu^+$</td>
<td>$1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$D^+ \to \pi^-e^+\mu^-, D^+ \to K^-e^-\mu^+$</td>
<td>$1 \times 10^{-8}$</td>
</tr>
</tbody>
</table>
Physics at a Super B Factory

- Test of CKM Paradigm at 1% level.
  - CPV in B decays from the new physics (non CKM).

- The B recoil technique: $B \rightarrow K(\ast)\mu\nu$, $B\rightarrow\tau\nu$, $B\rightarrow D(\ast)\tau\nu$

- $\tau$ physics: lepton flavor violations, $g-2$, EDM, CPV.

- Many more topics: $\Upsilon(5S)$, CPV in charm, new hadrons, ...

- Physics motivation is independent of LHC.
  - If LHC finds NP, precision flavor physics is compulsory.
  - If LHC finds no NP, high statistics $B/\tau$ decays would be a unique way to search for the $>\text{TeV}$ scale physics (=TeV scale in case of MFV).
As a first approximation, the weak charged current interaction couples fermions of the same generation. The Standard Model explains couplings between quark generations in terms of the Cabibbo-Kobayashi-Maskawa (CKM) matrix.
The CKM Paradigm

The Cabibbo-Kobayashi-Maskawa (CKM) matrix transforms flavor eigenstates to weak eigenstates at the quark level:

$$
\begin{pmatrix}
    d' \\
    s' \\
    b'
\end{pmatrix} =
\begin{pmatrix}
    V_{ud} & V_{us} & V_{ub} \\
    V_{cd} & V_{cs} & V_{cb} \\
    V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
    d \\
    s \\
    b
\end{pmatrix}
$$

The CKM matrix should be unitary:

$$
\begin{pmatrix}
    V_{ud}^* & V_{cd}^* & V_{td}^* \\
    V_{us}^* & V_{cs}^* & V_{ts}^* \\
    V_{ub}^* & V_{cb}^* & V_{tb}^*
\end{pmatrix}
\begin{pmatrix}
    V_{ud} & V_{us} & V_{ub} \\
    V_{cd} & V_{cs} & V_{cb} \\
    V_{td} & V_{ts} & V_{tb}
\end{pmatrix} =
\begin{pmatrix}
    1 & 0 & 0 \\
    0 & 1 & 0 \\
    0 & 0 & 1
\end{pmatrix}
$$

E.g.,

$$V_{ub}V_{ud} + V_{cb}V_{cd}^* + V_{tb}V_{td}^* = 0$$

In the Wolfenstein parameterization:

$$V_W =
\begin{pmatrix}
    1 - \frac{1}{2} \lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\
    -\lambda & 1 - \frac{1}{2} \lambda^2 - iA^2\lambda^4\eta & A\lambda^2 \\
    A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1
\end{pmatrix}
$$
Test of CKM Paradigm

Today

With a Super Flavor Factory @ 75 fb^{-1}

Generalized UT fits:
CKM at 1% in the presence of NP!

<table>
<thead>
<tr>
<th>Today</th>
<th>with a Super Flavor Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\rho} = 0.187 \pm 0.056$</td>
<td>$\pm 0.005$</td>
</tr>
<tr>
<td>$\bar{\eta} = 0.370 \pm 0.036$</td>
<td>$\pm 0.005$</td>
</tr>
</tbody>
</table>
Time Dependent Analysis

\[ \Delta t \approx \Delta z/(\beta \gamma) \]

BaBar: \( \beta \gamma = 0.56 \)
SuperB: \( \beta \gamma = 0.28 \)

- \( f_+(t) : \Delta t \) distribution function for \( B^0 (\bar{B}^0) \) tagged events (not accounting for experimental effects)

\[
 f_\pm(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [1 \pm S \sin(\Delta m \Delta t) \mp C \cos(\Delta m \Delta t)]
\]

- \( S \) and \( C \) related to CPV in the interference between mixing and decay (CKM angles, i.e. \( f = J/\Psi \) \( K_s \), \( S = \sin 2\beta \)) and direct CPV + indirect CPV, resp.
Time Dependent Analysis: BaBar vs SuperB

Changes in two main ingredients:

- **\( \Delta t \) resolution**: SuperB boost < BaBar boost -> smaller \( \Delta z \), worst \( \Delta t \).
  - To cure this:
    - Add SVT layer 0, reducing SVT inner radius from 3.32 cm to 1.60 cm.
    - Reduce beam spot size.
    - Lower material budget in the beam pipe.
  - Preliminary studies: \( \Delta t \) determined with comparable precision wrt BaBar

- **Flavor tagging algorithm**:
  - **BaBar**: Neural Network approach to isolate high momentum lepton and K and soft \( \pi \) (from D* decay)
    - Figure of merit: \( Q = \varepsilon_{\text{tag}} (1 - 2\omega)^2 \)
    - \( \varepsilon_{\text{tag}} \) = tagging efficiency, \( \omega \) = mistag probability
    - Resolution on S and C: \( \sigma_{S,C} \propto \frac{1}{\sqrt{Q}} \)
  - **SuperB**: expect to increase \( Q \) thanks to larger tracking coverage, improved PID, better vertexing
Status of $\beta$ Measurements

- Golden modes: three and penguin diagrams have $\sim$ same weak phase $\rightarrow$ measure $\beta$

- Penguin dominated modes: interference between diagrams with different weak phases.
  - Discrepancies with respect to $\beta$ from golden modes is hint of new physics in loop diagram.

$\sin(2\beta_{\text{eff}}) \equiv \sin(2\phi_{1\text{eff}})$

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**Raw Text**

- Golden modes: three and penguin diagrams have $\sim$ same weak phase $\rightarrow$ measure $\beta$

- Penguin dominated modes: interference between diagrams with different weak phases.
  - Discrepancies with respect to $\beta$ from golden modes is hint of new physics in loop diagram.

**Image**

- A graph showing $\Delta\sin^2\beta$ with various modes such as $\phi K_S$, $\eta K_S$, $\pi^0 K_S$, $\omega K_S$, etc., and a note on $\Delta S$ from penguin mode.

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**Footnotes**

- Theory error on $\Delta S$ from penguin mode
- Some recent QCDF estimates $\sin^2\beta_{\text{eff}} - \sin^2\beta$
  - QCDF: (Beneke, PLB620 (2005), 143-150, Cheng et al., PRD72 (2005) 094003 etc.
  - SCET: (Williamson & Zupan, hep-ph/0601214)

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**Figures**

- A graph showing $\sin(2\beta_{\text{eff}})$ with data points from various experiments like BaBar and Belle, and average values.
• Summary of $\beta$ measurement with current precision and integrated luminosity of 75 ab$^{-1}$.
  – Scale statistics error and reducible systematic by luminosity.
  – Detector performance improvement not accounted for.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Current Precision</th>
<th>Predicted Precision (75 ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi K^0_S$</td>
<td>0.022 0.010 &lt; 0.01</td>
<td>0.002 0.005 &lt; 0.001</td>
</tr>
<tr>
<td>$\eta' K^0_S$</td>
<td>0.08 0.02 0.014</td>
<td>0.006 0.005 0.014</td>
</tr>
<tr>
<td>$\phi K^0_S\pi^0$</td>
<td>0.28 0.01 –</td>
<td>0.020 0.010 –</td>
</tr>
<tr>
<td>$f_0 K^0_S$</td>
<td>0.18 0.04 0.02</td>
<td>0.012 0.003 0.02</td>
</tr>
<tr>
<td>$K^0_S K^0_S K^0_S$</td>
<td>0.19 0.03 0.013</td>
<td>0.015 0.020 0.013</td>
</tr>
<tr>
<td>$\phi K^0_S$</td>
<td>0.26 0.03 0.02</td>
<td>0.020 0.010 0.005</td>
</tr>
<tr>
<td>$\pi^0 K^0_S$</td>
<td>0.20 0.03 0.025</td>
<td>0.015 0.015 0.025</td>
</tr>
<tr>
<td>$\omega K^0_S$</td>
<td>0.28 0.02 0.035</td>
<td>0.020 0.005 0.035</td>
</tr>
<tr>
<td>$K^+ K^- K^0_S$</td>
<td>0.08 0.03 0.05</td>
<td>0.006 0.005 0.05</td>
</tr>
<tr>
<td>$\pi^0 \pi^0 K^0_S$</td>
<td>0.71 0.08 –</td>
<td>0.038 0.045 –</td>
</tr>
<tr>
<td>$\rho K^0_S$</td>
<td>0.28 0.07 0.14</td>
<td>0.020 0.017 0.14</td>
</tr>
<tr>
<td>$J/\psi \pi^0$</td>
<td>0.21 0.04 –</td>
<td>0.016 0.005 –</td>
</tr>
<tr>
<td>$D^{*+} D^{-}$</td>
<td>0.16 0.03 –</td>
<td>0.012 0.017 –</td>
</tr>
<tr>
<td>$D^+ D^-$</td>
<td>0.36 0.05 –</td>
<td>0.027 0.008 –</td>
</tr>
</tbody>
</table>
Recoil Analysis Technique (1)

Breco: full (partial) reconstruction of one B into a hadronic (semi-leptonic) final state

Brecoil: look for the signal signature, e.g. K^{(*)} not accompanied by additional (charged+neutral) particles + Missing Energy

Recoil technique at B-Factories:
- search for rare decays ($\sim 10^{-5}$) with missing energy

(Not possible at hadronic machines)
- Several benchmark channels at SuperB: $B \rightarrow \tau \nu$, $B \rightarrow K^{(*)} \nu \nu$, ...
Recoil Analysis Technique (2)

- Aim: collect as many as possible fully/partially reconstructed B mesons in order to study the properties of the Brecoil
- 1st step: reconstruction $D \rightarrow \text{hadrons}$

$$
\begin{align*}
D^*+ &\rightarrow D^0\pi^+ \\
D^*0 &\rightarrow D^0\pi^0 \\
D^*0 &\rightarrow D^0\gamma \\
D^0 &\rightarrow K^-\pi^+ \\
D^0 &\rightarrow K^-\pi^+\pi^0(\gamma\gamma) \\
D^0 &\rightarrow K^-\pi^+\pi^- \\
D^0 &\rightarrow K^0_S\pi^+\pi^- \\
D^+ &\rightarrow K^-\pi^+\pi^-
\end{align*}
$$

2nd step:

**Hadronic Breco: $B \rightarrow DX$**
- Use $D$ as a seed and add $X$ to have system compatible with $B$ hypothesis ($X = n\pi^\pm mK^\pm rK^0_S q\pi^0$ and $n+m+r+q<6$)
- Sample of 1100 $B$ decay modes with different purities
- Kinematics completely constrained 😊
- Low reconstruction efficiencies 😞
  (~0.4%)

**Semi-Leptonic Breco: $B \rightarrow D^{(*)}\ell\nu$**
- Use $D$ as a seed and a lepton to form a $D\ell$ pair ($\ell = e^\pm, \mu^\pm$)
- Sample of 14 $B$ decay modes
- Kinematics is unconstrained due to neutrino
- Higher reconstruction efficiencies 😊
  (~2.0%)
$B \rightarrow K^{(*)} \nu \nu$

- **Electroweak penguin (loop diagram) radiated processes ($b \rightarrow s$):**
  - Flavor changing neutral current (FCNC) prohibited in SM at tree level
  - Sensitive New Physics (NP): Susy particles, light dark matter (LDM), ...

**b→svν model independent phenomenology:**

- $\text{BR}(B \rightarrow K\nu\nu) = (4.5\pm0.7) \times 10^{-6} (1-2\eta)\epsilon^2$
- $\text{BR}(B \rightarrow K^*\nu\nu) = (6.8\pm1.1) \times 10^{-6} (1+1.31\eta)\epsilon^2$
- $F_L(B \rightarrow K^*\nu\nu) = (0.54\pm0.01) (1+2\eta)/(1+1.31\eta)$

$$\frac{d\Gamma}{d\cos \theta} \propto \frac{3}{4} (1 - <F_L>) \sin^2 \theta + \frac{3}{2} <F_L> \cos^2 \theta$$

θ(helicity) = angle between:
  - K* direction in B rest frame
  - K direction in K* rest frame
$B \rightarrow K^{(*)} \nu \nu$: expected sensitivity

- Performed a very simple cut and count analysis
- Not enough statistics for background samples for studying background reduction
- Only estimate efficiency gains on signal samples: $\sim 5\%$ to $10\%$
- Pessimistic assumption: backgrounds increases in efficiency such that $S/B$ ratio stays constant $\Rightarrow$ overall increase in statistics for all samples

**BR(B$\rightarrow$K$\nu\nu$)**

- **Preliminary**

**BR(B$\rightarrow$K$^*$\nu\nu)**

- **Preliminary**

- 5 years of data taking
$B \rightarrow K^{(*)} \nu \nu$: constraint on NP

- Warning: very preliminary results
- Still need to quantify the effect of:
  - Bwd-EMC on background rejection
  - SuperB machine backgrounds rates
Charged Higgs limits from $B^{-} \rightarrow \tau^{-} \nu_{\tau}$

$$r_{H} = \frac{BF(B \rightarrow \tau\nu)}{BF(B \rightarrow \tau\nu)_{SM}} = \left(1 - \frac{m_{B}^{2}}{m_{H}^{2}} \tan^{2} \beta \right)^{2}$$

→ limit on charged Higgs mass vs. $\tan \beta$

Peter Križan
Semileptonic decay sensitive to charged Higgs

\[
R(D) = \frac{B(B \to D\tau\nu)}{B(B \to D\ell\nu)}
\]

Compared to \(B \to \tau\nu\)

1. Smaller theoretical uncertainty of \(R(D)\)

\[
\begin{align*}
\text{For } B \to \tau\nu, \\
\text{(There is } O(10\%) \text{ } f_B \text{ uncertainty from lattice QCD)}
\end{align*}
\]

2. Large expected \(\text{Br}\)

\[
\begin{align*}
B(B^- \to D^0\tau^-\bar{\nu}_\tau)^{SM} &= (0.71 \pm 0.09)\% \\
B(B^0 \to D^+\tau^-\bar{\nu}_\tau)^{SM} &= (0.66 \pm 0.08)\% \\
|B(B \to \tau\nu)| &= [1.65^{+0.38}_{-0.37}(\text{stat})^{+0.15}_{-0.37}(\text{syst})] \times 10^{-4}
\end{align*}
\]

3. Differential distributions can be used to discriminate \(W^+\) and \(H^+\)

4. Sensitive to different vertex \(B \to \tau\nu\): H-b-u, \(B \to D\tau\nu\): H-b-c

(LHC experiments sensitive to H-b-t)
Lepton Flavor Violation in $\tau$ Decays (1)

- Constrained MSSM-seesaw and NUHM SUSY expectations from
  - Several other refs. in 2010 SuperB physics report
  - G.Isidori and P.Paradisi in the 2010 SuperB physics report itself

<table>
<thead>
<tr>
<th>Snowmass Points and Slopes reference points</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1 a</td>
</tr>
<tr>
<td>1 b</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
Lepton Flavor Violation in $\tau$ Decays (2)

$N_i$ = right-handed neutrinos
$\nu_i$ = left-handed neutrinos
$\theta_i$ = N complex mixing angles
$\theta_{13}$ refers to PNMS mixing matrix
other info on JHEP11(2006)090

- tau LFV decays up to present limits for some SPS points
- $\tau \rightarrow \mu\gamma$ complementary to $\theta_{13}$-sensitive $\mu \rightarrow e\gamma$
Lepton Flavor Violation in $\tau$ Decays (3)

\[ \text{NUHM BF}(\tau \to 3\mu) \]

\[ \text{NUHM BF}(\tau \to \mu f_0(980)) \]

\[ \delta_1, \delta_2 \text{ parametrize non-universal Higgs masses} \]
other info in JHEP06(2008)079 for left plot

\[ \text{with NUHM SuperB may be more sensitive to} \]
\[ \tau \to \mu f_0(980), \tau \to \mu \eta \text{ than to } \tau \to \mu \gamma \]
SuperB Sensitivity to $\tau \rightarrow \mu \gamma$, $\tau \rightarrow e \gamma$

- use BABAR efficiency, scale expected background with ratio of luminosity
  - i.e. analysis not re-optimized for SuperB
- assume 35% reduction of signal region from smaller beam-spot, better vertex detector
  (better resolution is planned to compensate smaller boost)
- assume 20% efficiency increase for photons from better hermeticity, DIRC redesign
- approximate frequentistic upper limits, only Poissonian BKG uncertainty
- at least 5 observed events for evidence

<table>
<thead>
<tr>
<th>process</th>
<th>efficiency</th>
<th>expected background</th>
<th>expected 90% CL upper limit</th>
<th>3$\sigma$ evidence reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>$BF(\tau \rightarrow \mu \gamma)$</td>
<td>7.3%</td>
<td>335</td>
<td>$2.4 \cdot 10^{-9}$</td>
<td>$5.4 \cdot 10^{-9}$</td>
</tr>
<tr>
<td>$BF(\tau \rightarrow e \gamma)$</td>
<td>3.9%</td>
<td>149</td>
<td>$3.0 \cdot 10^{-9}$</td>
<td>$6.8 \cdot 10^{-9}$</td>
</tr>
</tbody>
</table>
SuperB Sensitivity to $\tau \rightarrow 3\ell$

- selection requirements re-optimized for best upper limit at SuperB
  - fair simulation of background through lepton mis-id
  - only very approximate simulation of BKG from true leptons or Bhabha/dimuon events
- no detector improvement has been assumed
- approximate frequentistic upper limits, only Poissonian BKG uncertainty
- at least 5 observed events for evidence
- SuperB sensitivity improvement $\sim 150$

<table>
<thead>
<tr>
<th>Process</th>
<th>Expected 90% CL upper limit</th>
<th>$3\sigma$ evidence reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>$BF(\tau \rightarrow \ell\ell\ell)$</td>
<td>$2.3 - 8.2 \cdot 10^{-10}$</td>
<td>$1.2 - 4.0 \cdot 10^{-9}$</td>
</tr>
</tbody>
</table>
LFV in $\tau$ Decays with Polarization

$\tau \rightarrow \mu\nu\nu$

signal

$\tau \rightarrow \mu\gamma$ vs $\tau \rightarrow \pi\nu$

$\cos(\text{helicity})$

background

Applying a rectangular cut eff. on signal $\sim 40-45\%$

bkg retained $\sim 10-15\%$

$B(\tau \rightarrow \mu\gamma) \times 10^{-9}$

$B(\tau \rightarrow e\gamma) \times 10^{-9}$

Sensitivity improves at least by a factor 2.

Equivalent to a factor 4 increase in luminosity.
τ g–2 at SuperB with Beam Polarization

- MSSM would shift muon g–2 by about the presently observed discrepancy $\Delta a_\mu \approx 3\cdot10^{-9}$

<table>
<thead>
<tr>
<th>SPS</th>
<th>1 a</th>
<th>1 b</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta a_\mu \times 10^{-9}$</td>
<td>3.1</td>
<td>3.2</td>
<td>1.6</td>
<td>1.4</td>
<td>4.8</td>
<td>1.1</td>
</tr>
<tr>
<td>$\Delta a_\tau \times 10^{-6}$</td>
<td>0.9</td>
<td>0.9</td>
<td>0.5</td>
<td>0.4</td>
<td>1.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

(specific parameters can produce $\Delta a_\tau$ as high as $1\cdot10^{-5}$)

- J. Bernabeu et al., JHEP098P1108 estimate SuperB $\sigma(a_\tau) = [0.75 - 1.7]\cdot10^{-6}$
  - SuperB actually measures $a_\tau(q^2)$ from final state distributions of $e^+e^- \rightarrow \tau^+\tau^-$
    - however, $\Delta a_\tau$ from high energy NP contributions is constant for small $q^2$
  - real part from $\tau$ polar angle distribution or transv.&long. polarization

- from tau EDM studies (see next slides) with more realistic assumptions

SuperB $\sigma(a_\tau) \sim 2.4\cdot10^{-6}$
SuperB sensitivity to $\tau$ EDM, with beam polarization

- $|d_\text{e}| < 1.6 \times 10^{-27}$ e cm at 90% CL, 10.1103/PhysRevLett.88.071805 / PDG10
- most NP models expect $|d_\tau| \propto (m_\tau/m_e)|d_\text{e}|$
- SuperB 2010 Physic Report reviews NP models expectations and concludes that:
  - $|d_\text{e}|$ upper limit $\Rightarrow$ $|d^{NP}_\tau| < 10^{-22}$ e cm
- SuperB actually measures $d_\tau(q^2)$ form factor from final state distributions of $e^+e^- \rightarrow \tau^+\tau^-$
  - however, high energy NP contributions are constant for small $q^2$

- beam polarization permits measurements based on single tau distributions
- J.Bernabeu et al., arXiv:0707.1658v1 [hep-ph], estimate $\text{SuperB } \sigma(d_\tau) \approx 7.2 \times 10^{-20}$ e cm
  - 100% electron beam polarization, no uncertainty
  - only $\tau \rightarrow \pi \nu$, $\tau \rightarrow \rho \nu$, no reconstruction uncertainty
- with some additional realistic assumptions
  - electron beam with a linear polarization of 80% $\pm$ 1%.
  - 80% geometric acceptance
  - track reconstruction efficiency 97.5% $\pm$ 0.1%
  - $\text{SuperB } \sigma(d_\tau) \approx 10.1 \times 10^{-20}$ e cm (integrated angular asymmetry $\approx 3 \times 10^{-5}$)
- note that information can be obtained also from the other decay channels
CPV in $\tau$ Decays

- SM predictions in general very small
  $$(\tau^{\pm} \rightarrow K^{\pm}\pi^{0}\nu) \text{ CP asymmetry } O(10^{-12})$$, D. Delepine et al., PRD 72, 033009 (2005), hep-ph/0503090

- small SM CP asymmetry in $\tau^{\pm} \rightarrow K_{S}\pi^{\pm}\nu$ from CPV in $K^{0}\bar{K}^{0}$
  $3.3 \cdot 10^{-3} \pm 2\%$ relative, I.I. Bigi & A. I. Sanda, PLB 625, 47 (2005), hep-ph/0506037

- most NP models do not induce measurable tau CPV

- R-parity violating SUSY $\rightarrow$ CPV related asymmetries up to 10%, saturating existing limits
  - sizable asymmetries in $\tau \rightarrow K\pi\nu_{\tau}$, $\tau \rightarrow K\eta^{(')}\nu_{\tau}$, and $\tau \rightarrow K\pi\pi\nu_{\tau}$

- CLEO, PRL 88, 111803 (2002), hep-ex/0111095, 13.3 fb$^{-1}$, $\tau \rightarrow K_{S}\pi\nu$
  - optimal asymmetry observable $\langle \xi \rangle = (-2.0 \pm 1.8) \cdot 10^{-3}$
  - data calibration with $\tau \rightarrow \pi\pi\pi\nu$

- extrapolating at SuperB, $\sigma(\xi) \approx 2.4 \cdot 10^{-5}$
  - assume also systematics scale with $1/\sqrt{L}$
  - will update the extrapolation using Belle analysis presented at Tau10

- beam polarization can provide extra equivalent luminosity (to be studied)
Electroweak Measurement with Polarization

$A_{LR} = \frac{\sigma(P)-\sigma(-P)}{\sigma(P)+\sigma(-P)} = \frac{16}{\sqrt{2}} \left( \frac{G_F q^2}{4 \pi \alpha} \right) \left( \frac{g_A^b}{Q_b} \right) P$

- Measurable for all $B^0 \bar{B}^0$ and $B^+ B^-$ final states, both resonant and continuum.
- All QCD corrections included in the single form factor that cancels in the asymmetry.
- Very clean measurement, no large theoretical corrections (in progress...)

$\Rightarrow$ Excellent opportunity to measure $g_V$ & $\sin^2 \theta_W$ at SuperB with polarized beams!!

0.5% polarization syst.
0.3% stat. error $\Rightarrow$ 0.0021

Important point:
The L-R luminosity asymmetry has to be very well controlled. Possibly done using monitoring using Bhabhas. Thought needed.
Charm Mixing:
Time-Evolution of $D^0 \rightarrow K\pi$ Decays

\[ RS = CF \]

\[ W^+ \rightarrow u \bar{d} \pi^+ \]
\[ WS = DCS \]

\[ K^+ \]
\[ W^+ \rightarrow u \bar{s} K^+ \]
\[ K^- \]
\[ W^+ \rightarrow d \bar{u} \pi^- \]

DCS and mixing amplitudes interfere to give a “quadratic” WS decay rate ($x, y \ll 1$):

\[
\frac{\Gamma_{WS(t)}}{e^{-t/\tau}} \propto R_D + \sqrt{R_D y'} \left( \frac{t}{\tau} \right) + \left( \frac{x'^2 + y'^2}{4} \right) \left( \frac{t}{\tau} \right)^2
\]

\[ x' = x \cos \delta + y \sin \delta \]
\[ y' = y \cos \delta - x \sin \delta \]

$\delta$ is the phase difference between DCS and CF decays.
Simplified Fit Strategy & Validation

Rate of WS events clearly increases with time:

\[
\frac{\Gamma_{WS}(t)}{e^{-t/\tau}} \propto R_D + \sqrt{R_D} y' \left( \frac{t}{\tau} \right) + \left( \frac{x'^2 + y'^2}{4} \right) \left( \frac{t}{\tau} \right)^2
\]

Consistent with prediction from full likelihood fit: \( \chi^2 = 1.5 \)

Inconsistent with no-mixing hypothesis: \( \chi^2 = 24 \)
Running at Open Charm
Threshold: 500 fb\(^{-1}\) at \(\Psi(3770)\)

- Decays of \(\Psi(3770) \rightarrow D^0 D^0\) produce coherent (\(C=-1\)) pairs of \(D^0\)s. Quantum correlations in their subsequent decays allow measurements of strong phases.
  - Required for improved measurement of CKM angle \(\gamma\).
  - Also required for \(D^0\) mixing studies.

\[ \text{Dalitz plot model uncertainty shrinks} \]

\[ \text{Information on overall strong phase is added} \]

\[ \text{Uncertainty in } x_D \text{ improves more than that of } y_D \]
Summary of Physics Goals and special requirements

- Increase by $O(10)$ the precision of BaBar & Belle.
- Challenge CKM at the level of 1%.
- Improve sensitivity for LFV in $\tau$ decays by a factor between 10 and 100.
- Explore $T$-violation in $\tau$.
- Search for magnetic structure of $\tau$.
- Explore CPV in Charm also with time dependent asymmetries.
- Great new Spectroscopy exploration.

In SuperB option for beam polarization and possibility to run in asymmetric mode at charm threshold

This rich menu can be effectively mined with 75 $ab^{-1}$ in 5 years at $\Upsilon(4S)$ and a few months at Charm threshold with peak luminosity of $10^{35} \text{ cm}^2 \text{s}^{-1}$. 
# Machine: Parameter Requirements from Physics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity (top-up mode)</td>
<td>$\geq 10^{36} \text{ cm}^{-2}\text{s}^{-1} @ Y(4S)$</td>
<td>It can extend up to an ultimate peak luminosity of $4 \times 10^{36} \text{ cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>Integrated luminosity</td>
<td>75 ab$^{-1}$</td>
<td>Based on a “New Snowmass Year” of $1.5 \times 10^7$ seconds (PEP-II experience-based)</td>
</tr>
<tr>
<td>CM energy range</td>
<td>$\tau$ threshold to $Y(5S)$</td>
<td></td>
</tr>
<tr>
<td>Minimum boost</td>
<td>$\beta\gamma = 0.28$</td>
<td>1 cm beampipe radius. First measurement at 1.5 cm</td>
</tr>
<tr>
<td>$e^{-}$ Polarization</td>
<td>60-85%</td>
<td>Enables $\tau CP$ and $T$ violation studies, measurement of $\tau g$-2 and improves sensitivity to lepton flavor-violating decays. Detailed simulation, needed to ascertain a more precise requirement, are in progress.</td>
</tr>
</tbody>
</table>
e$^+$$e^-$ Colliders
How to get 100 times more luminosity?

\[ L = 2.17 \times 10^{34} \frac{n \xi_y EI_b}{\beta_y^*} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (GeV)</td>
<td>9x3.1</td>
</tr>
<tr>
<td>( I_b )</td>
<td>1x1.6</td>
</tr>
<tr>
<td>n</td>
<td>1700</td>
</tr>
<tr>
<td>I (A)</td>
<td>1.7x2.7</td>
</tr>
<tr>
<td>( \beta_y^* ) (cm)</td>
<td>1.1</td>
</tr>
<tr>
<td>( \xi_y )</td>
<td>0.08</td>
</tr>
<tr>
<td>L (x10^{34})</td>
<td>1</td>
</tr>
</tbody>
</table>

Answer:
- Increase \( I_b \)
- Decrease \( \beta_y^* \)
- Increase \( \xi_y \)
- Increase \( n \)
A New Idea

- Pantaleo Raimondi came up with a new scheme to attain high luminosity in a storage ring:
  - Change the collision so that only a small fraction of one bunch collides with the other bunch
    - Large crossing angle
    - Long bunch length
  - Due to the large crossing angle the effective bunch length (the colliding part) is now very short so we can lower $\beta_y^*$ by a factor of 50
  - The beams must have very low emittance - like present day light sources
    - The x size at the IP now sets the effective bunch length
  - In addition, by crabbing the magnetic waist of the colliding beams we greatly reduce the tune plane resonances enabling greater tune shifts and better tune plane flexibility
    - This increases the luminosity performance by another factor of 2-3
How the Crabbed Waist Works

Crab-sextupoles off:
waist line is orthogonal to the axis of the beam

Crab-sextupoles on:
waist moves parallel to the axis of other beam: maximum particle density in the overlap between bunches

All particles in both beams collide in the minimum $\beta_y$ region, with a net luminosity gain
# SuperB Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Base Line</th>
<th>Low Emittance</th>
<th>High Current</th>
<th>Tau/Charm (prelim.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUMINOSITY</td>
<td>cm(^{-2}) s(^{-1})</td>
<td>1.00E+36</td>
<td>1.00E+36</td>
<td>1.00E+36</td>
<td>1.00E+35</td>
</tr>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
<td>1.00E+35</td>
</tr>
<tr>
<td>Circumference</td>
<td>m</td>
<td>1256.4</td>
<td>1256.4</td>
<td>1256.4</td>
<td>1256.4</td>
</tr>
<tr>
<td>X-Angle (full)</td>
<td>mrad</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>Piwinski angle</td>
<td>rad</td>
<td>22.88</td>
<td>18.60</td>
<td>32.36</td>
<td>14.43</td>
</tr>
<tr>
<td>(\beta_{x}) @ IP</td>
<td>cm</td>
<td>2.6</td>
<td>3.2</td>
<td>2.6</td>
<td>5.06</td>
</tr>
<tr>
<td>(\beta_{y}) @ IP</td>
<td>cm</td>
<td>0.0253</td>
<td>0.0205</td>
<td>0.0179</td>
<td>0.0292</td>
</tr>
<tr>
<td>Coupling (full current)</td>
<td>%</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>(\epsilon_{x}) (without IBS)</td>
<td>nm</td>
<td>1.97</td>
<td>1.02</td>
<td>1.00</td>
<td>1.97</td>
</tr>
<tr>
<td>(\epsilon_{y}) (with IBS)</td>
<td>nm</td>
<td>2.00</td>
<td>2.16</td>
<td>1.00</td>
<td>2.00</td>
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<tr>
<td>(\sigma_{x})</td>
<td>pm</td>
<td>5</td>
<td>6.10</td>
<td>2.5</td>
<td>10</td>
</tr>
<tr>
<td>(\sigma_{y})</td>
<td>pm</td>
<td>7.244</td>
<td>8.872</td>
<td>3.899</td>
<td>10.060</td>
</tr>
<tr>
<td>(\sigma_{x}) @ IP</td>
<td>\mu m</td>
<td>0.036</td>
<td>0.036</td>
<td>0.021</td>
<td>0.054</td>
</tr>
<tr>
<td>(\sigma_{y}) @ IP</td>
<td>\mu m</td>
<td>11.433</td>
<td>8.085</td>
<td>15.944</td>
<td>29.732</td>
</tr>
<tr>
<td>(\Sigma_{x})</td>
<td>\mu m</td>
<td>0.050</td>
<td>0.030</td>
<td>0.076</td>
<td>0.131</td>
</tr>
<tr>
<td>(\Sigma_{y})</td>
<td>\mu m</td>
<td>4.69</td>
<td>4.29</td>
<td>4.73</td>
<td>4.03</td>
</tr>
<tr>
<td>(\sigma_{x}) (0 current)</td>
<td>mm</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4.4</td>
</tr>
<tr>
<td>(\sigma_{y}) (full current)</td>
<td>mm</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Beam current</td>
<td>mA</td>
<td>1892</td>
<td>244</td>
<td>1460</td>
<td>3094</td>
</tr>
<tr>
<td>Buckets distance</td>
<td>#</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ion gap</td>
<td>%</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>RF frequency</td>
<td>Hz</td>
<td>4.76E+08</td>
<td>4.76E+08</td>
<td>4.76E+08</td>
<td>4.76E+08</td>
</tr>
<tr>
<td>Number of bunches</td>
<td></td>
<td>978</td>
<td>978</td>
<td>1956</td>
<td>1956</td>
</tr>
<tr>
<td>N. Particle/bunch</td>
<td></td>
<td>5.06E+10</td>
<td>6.56E+10</td>
<td>3.92E+10</td>
<td>4.15E+10</td>
</tr>
<tr>
<td>Tune shift x</td>
<td></td>
<td>0.0021</td>
<td>0.0033</td>
<td>0.0017</td>
<td>0.0044</td>
</tr>
<tr>
<td>Tune shift y</td>
<td></td>
<td>0.0970</td>
<td>0.0971</td>
<td>0.0891</td>
<td>0.0684</td>
</tr>
<tr>
<td>Long. damping time</td>
<td>msec</td>
<td>21.1</td>
<td>20.3</td>
<td>20.3</td>
<td>13.4</td>
</tr>
<tr>
<td>Energy Loss/turn</td>
<td>MeV</td>
<td>2.11</td>
<td>0.865</td>
<td>2.11</td>
<td>0.865</td>
</tr>
<tr>
<td>(\sigma_{e}) (full current)</td>
<td>d/E</td>
<td>6.43E-04</td>
<td>7.34E-04</td>
<td>6.43E-04</td>
<td>6.43E-04</td>
</tr>
<tr>
<td>CM</td>
<td>d/E</td>
<td>5.00E-04</td>
<td>5.00E-04</td>
<td>5.00E-04</td>
<td>5.00E-04</td>
</tr>
<tr>
<td>Total lifetime</td>
<td>min</td>
<td>4.23</td>
<td>4.48</td>
<td>3.05</td>
<td>7.08</td>
</tr>
<tr>
<td>Total RF Power</td>
<td>MW</td>
<td>17.08</td>
<td>12.72</td>
<td>30.48</td>
<td>3.11</td>
</tr>
</tbody>
</table>

**Baseline charm threshold running at 10^35**

Baseline + other 2 options:
- Lower y-emittance
- Higher currents (twice bunches)

Baseline:
- Higher emittance due to IBS
- Asymmetric beam currents

RF power includes SR and HOM

J. Seeman
Polarization is understood and feasible!
Parameter flexibility allows $10^{36}$ peak lumi without stressing limits!
No impediment caused by the photon operation is seen so far to prevent design operations of SuperB for HEP.
Machine-Detector Interface: Background Studies

<table>
<thead>
<tr>
<th></th>
<th>Cross section</th>
<th>Evt/bunch xing</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Strahlung</td>
<td>( \sim 340 \text{ mbarn} ) ( \text{ (E}<em>\gamma / \text{E}</em>{\text{beam}} &gt; 1% ) }</td>
<td>( \sim 850 )</td>
<td>0.3THz</td>
</tr>
<tr>
<td>( e^+e^- ) pair production</td>
<td>( \sim 7.3 \text{ mbarn} )</td>
<td>( \sim 18 )</td>
<td>7GHz</td>
</tr>
<tr>
<td>( e^+e^- ) pair (seen by L0 @ 1.5 cm)</td>
<td>( \sim 0.07 \text{ mbarn} )</td>
<td>( \sim 0.2 )</td>
<td>70 MHz</td>
</tr>
<tr>
<td>Elastic Bhabha</td>
<td>( O(10^{-4}) \text{ mbarn} ) ( \text{(Det. acceptance)} )</td>
<td>( \sim 250/\text{Million} )</td>
<td>100KHz</td>
</tr>
<tr>
<td>Y(4S)</td>
<td>( O(10^{-6}) \text{ mbarn} )</td>
<td>( \sim 2.5/\text{Million} )</td>
<td>1 KHz</td>
</tr>
<tr>
<td></td>
<td>Loss rate</td>
<td>Loss/bunch pass</td>
<td>Rate</td>
</tr>
<tr>
<td>Touschek (LER)</td>
<td>4.1KHz / bunch ( (+/- 2 \text{ m from IP}) )</td>
<td>( \sim 3/100 )</td>
<td>( \sim 5 \text{ MHz} )</td>
</tr>
</tbody>
</table>

Radiative Bhabha \( \rightarrow \text{ dominant effect on lifetime} \)

Two colliding beams:
- \( e^+e^- \rightarrow \text{e}^+\text{e}^- \) production \( \rightarrow \text{important source for SVT layer-0} \)
  - \( \text{impact on beam pipe, vertex detector design and b physics} \)

Single beam:
- Synchrotron radiation \( \rightarrow \text{strictly connected to IR design} \)
- Touschek \( \rightarrow \text{negligible in BaBar, important in SuperB} \)
- Beam-gas
- Intra-beam scattering

Collimators, dynamic aperture and energy acceptance optimization solve the problem of Touschek Background in LER
Requirements to Detector

Impact of Geometry on sensitivity
Background related issues
\( B \rightarrow K \nu \nu, B \rightarrow \tau \nu \)
+ Polarimetry for 
\( \tau \rightarrow \mu \gamma \)

PID/EMC Material
IFR Optimisation
Detector Layout

IFR Optimized layout. Plan to reuse yoke. Still need to resolve engineering questions.

BEMC Inexpensive Veto device bringing 8-10% sensitivity improvements for $B \to \tau \nu$. Low momentum PID via TOF? Technical Issues?

6Layer SVT L0 Striplets @ 1.6cm if background is acceptable as default. MAPS Option

FPID Physics gains about 5% in $B \to K(*)\nu \nu$. Somewhat larger gains for higher multiplicities
Where are we with the process?

• Pre-TDR white papers have been released:

• TDR is on the right path.

• While activity continues with further developments for:
  – better understanding of SuperB Physics.
  – optimization of Accelerator and Detector.

• We move on with MOU’s:
  – MOU’s with Canada, France, Russia and USA are in operation.
The Approval Path

- A substantial financial request from Ministry of research has been addressed to the Infrastructure Inter-ministerial panel (CIPE).

- An exploitation program with the Italian Institute of Technology (IIT) of synchrotron light from SuperB has been designed with photon beam lines to be in operation since the beginning.

- The corresponding funding for construction and operation has been preliminary favorably discussed at IIT and adds to the construction funds in the Government plan.

- A formal commitment with INFN for the project with the declaration of some available budget in the current year is expected.

- This commitment will set the start of the project.
Gelmini aggiorna il piano nazionale

Innovazione. Più spazio all'industria

Eugenio Bruno

ROMA


La lista degli interventi su cui il Muir vuole dirigersi le prime risorse che il Par intercetterà contiene 14 voci. Fermi restano che da qui alla sua ufficializzazione potrebbe anche subire delle modifiche, l'elenco si presenta estremamente variegato. Alle azioni sulla formazione nel campo del nucleare, sull'approfondimento dei rapporti tra invesciviamante una e alle misure per l'agroalimentare e i beni culturali – anticipati dallo stesso ministro al Sole 24 ORE il 26 marzo scorso – ci si aspetta nei prossimi giorni che il Par prenderà decisioni.

### Gli interventi

<table>
<thead>
<tr>
<th>Progetto</th>
<th>Settore</th>
<th>Valore stimato (milioni)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super B Factory</td>
<td>Fisica</td>
<td>660</td>
</tr>
<tr>
<td>Cosmo - Skymed II generation</td>
<td>Aerospazio</td>
<td>N.D.</td>
</tr>
<tr>
<td>Epigenomica</td>
<td>Medicina</td>
<td>N.D.</td>
</tr>
<tr>
<td>3N - Network nazionale delle nanotecnologie</td>
<td>Industria</td>
<td>700</td>
</tr>
<tr>
<td>Ritma - Ricerca ita. per il mare</td>
<td>Industria</td>
<td>700</td>
</tr>
<tr>
<td>Sintonia - Sistema integrato di telecomunicazioni</td>
<td>Aerospazio</td>
<td>800</td>
</tr>
<tr>
<td>Imp - Invecchiamento e pop. isolate</td>
<td>Industria</td>
<td>700</td>
</tr>
<tr>
<td>Agro Alimentare</td>
<td>Agricoltura</td>
<td>500</td>
</tr>
<tr>
<td>L'ambito nucleare</td>
<td>Energia</td>
<td>150</td>
</tr>
<tr>
<td>Recupero e rilancio della Villa dei Papiri</td>
<td>Beni culturali</td>
<td>20</td>
</tr>
<tr>
<td>Elettrico-Fermi-Eurofot</td>
<td>Industria</td>
<td>101</td>
</tr>
<tr>
<td>Astris - Astrophysics con specchi a tecnologia regolante italiana</td>
<td>Aerospazio</td>
<td>50</td>
</tr>
<tr>
<td>Controllo del dr. in sistemi complessi socio-economici</td>
<td>Economica</td>
<td>500</td>
</tr>
<tr>
<td>La fabbrica del futuro</td>
<td>Industria</td>
<td>500</td>
</tr>
</tbody>
</table>

Se dovessimo sapere di più tra fine aprile e i primi di maggio quando ministri e governatori si siederanno allo stesso tavolo. Dopodiché il Par sarà pronto per andare a Palazzo Chigi, prima, e al Cipe, poi.

F. Bianchi
Meanwhile in Japan: SuperKEKB

Machine design parameters

<table>
<thead>
<tr>
<th>parameters</th>
<th>KEKB</th>
<th>SuperKEKB</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LER</td>
<td>HER</td>
<td>LER</td>
</tr>
<tr>
<td>Beam energy</td>
<td>$E_b$</td>
<td>3.5</td>
<td>8</td>
</tr>
<tr>
<td>Half crossing angle</td>
<td>$\phi$</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Horizontal emittance</td>
<td>$\varepsilon_x$</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Emittance ratio</td>
<td>$\kappa$</td>
<td>0.88</td>
<td>0.66</td>
</tr>
<tr>
<td>Beta functions at IP</td>
<td>$\beta_x^<em>/\beta_y^</em>$</td>
<td>1200/5.9</td>
<td></td>
</tr>
<tr>
<td>Beam currents</td>
<td>$I_b$</td>
<td>1.64</td>
<td>1.19</td>
</tr>
<tr>
<td>beam-beam parameter</td>
<td>$\xi_y$</td>
<td>0.129</td>
<td>0.090</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$L$</td>
<td>$2.1 \times 10^{34}$</td>
<td></td>
</tr>
</tbody>
</table>

- Small beam size & high current to increase luminosity
- Large crossing angle
- Change beam energies to solve the problem of LER short lifetime

F. Bianchi
SuperKEKB/Belle II Funding Status

- 5.8 oku yen (~MUSD) for Damping Ring (FY2010)
- 100 oku yen for machine -- Very Advanced Research Support Program (FY2010-2012)

Continue efforts to obtain additional funds to complete construction as scheduled.

Several non-Japanese funding agencies have already allocated sizable funds for the upgrade.

→ construction started!
Summary and Outlook

- A super B-factory with 100 times the luminosity of present day B-factories is becoming more and more feasible.

- SuperB and SuperKEKB designs have converged to the “Italian” scheme of low emittance beams with a large crossing angle and a longer (more typical) bunch length.
  - SuperB effort hope to get government approval in the near future.

- A very high luminosity B-factory is a strong compliment to the energy frontier (LHC):
  - There are hundreds of new entries in the particle data book from the data generated by the B-factories.
  - The surprising fact is that the B-factories have NOT found any new physics.
  - The Standard Model is (amazingly) still intact.

- A super B-factory will push the Standard Model limits into regions where SUSY models and Higgs models start making predictions.
  - The LHC alone may have a hard time digging out all of the new physics.
  - A complimentary super B-factory could be a great help in finding any new physics.

- I think that with the combination of the LHC, a super B-factory and possibly the ILC, HEP has a strong future.
Backup
Measurements of $\alpha$

- examine $b\to u\bar{u}d$ decays
  - $\sin2\alpha_{\text{eff}} = \sin2(\alpha - \Delta\alpha)$ entering time dependent rate: $S = \sqrt{1 - C^2\sin2\alpha_{\text{eff}}}$
  - $\Delta\alpha$ due to penguin pollution

- time dependent analysis allows to measure $\sin2\alpha_{\text{eff}}$, SU(X) symmetries allows to disentangle $\alpha$ and $\Delta\alpha$, i.e.:
  - SU(2) analysis: $B\to\pi\pi, \rho\rho$
  - SU(3) analysis: $B\to\rho\rho, a_1\pi$

- Dominant uncertainties on $C$ and $S$ common to $\sin2\beta$ analysis

- Should consider also syst on the Branching Fraction (BF) and longitudinal polarization fraction $(f_i)$, used in the SU(2) and SU(3) method
  - $\approx 1\degree$ level precision reachable with $75\text{ab}^{-1}$ using SU(2) $\pi\pi$ and $\rho\rho$ analysis
  - combination of measurements, in particular $B^0 \to (\rho\pi)$, will resolve ambiguities
  - at high lumi, measurements will be dominated by systematics $\to$ need to work on analysis techniques (i.e. improve tagging algorithm and/or use lepton tag only, more accurate treatment of correlation)
\[ \mathbf{B} \rightarrow \pi\pi \]

**BaBar analysis**  
[arXiv:0807.4220]  
467 million BB pairs

\[ 1 - \text{C.L.} \]

\[ \alpha \in [71^\circ, 109^\circ] \text{ at 68\% CL} \]

6 physics observables:
- \( \mathcal{B}(B^0 \rightarrow \pi^+\pi^-) \), \( \mathcal{B}(B^0 \rightarrow \pi^0\pi^0) \), \( \mathcal{B}(B^+ \rightarrow \pi^+\pi^0) \)
- \( C(\pi^+\pi^-) \), \( S(\pi^+\pi^-) \), \( C(\pi^0\pi^0) \)
- \( S(\pi^0\pi^0) \) not measured (hard to make vertex)

- solution clearly separated
- \( \sigma(\alpha) = 0.9^\circ \pm 1.9^\circ \)
- \( S_{00} \) measurements feasible @ 50 ab\(^{-1}\) using photon conversion\(^{\text{ref. sa4}}\) → further resolve ambiguities

**Systematic uncertainties:**
- CP parameters: common to sin2β analysis
- BF: important contribution from discrepancy between data and MC affecting selection efficiencies estimation (overall signal selection, \( \pi^0 \) selection, ...) → room for improvement
\[ \mathbf{B} \rightarrow \rho \rho \]

\textbf{BaBar analysis:} PRD 78 (2008), 071104
465 million BB pairs

\[ \frac{\mathcal{B}(\mathbf{B}^+ \rightarrow \rho^+ \rho^0)}{\text{CL}} = 16.8 \times 10^{-6} \text{(OLD)} \]
\[ \frac{\mathcal{B}(\mathbf{B}^+ \rightarrow \rho^+ \rho^0)}{\text{CL}} = 23.7 \times 10^{-6} \text{(NEW)} \]

\[ \alpha = (92.4^{+6.0}_{-6.5})^\circ \text{ @ 68\% CL} \]

\textbf{SuperB with 75ab}^{-1}

- \text{blue histo: ignoring } C_{00} \text{ and } S_{00} \rightarrow \text{ambiguities not solved}
- \text{red curve: OLD } \mathcal{B}(\mathbf{B}^+ \rightarrow \rho^+ \rho^0) \text{ measurement}
- \sigma(\alpha) \sim 0.75^\circ

\textbf{Physics observables:}
- \((\text{BF} + f_L) \times 3 \text{ and } (C_L, S_L) \times 2 \)
- 3 \sigma \text{ evidence for } \mathbf{B}^0 \rightarrow \rho^0 \rho^0, \text{ will benefit of SuperB higher stat.}
- \text{NEW } \mathcal{B}(\mathbf{B}^+ \rightarrow \rho^+ \rho^0): \text{ ambiguities degenerate}

\textbf{Systematic uncertainties:}
- \text{CP parameters: common to sin2\(\beta\) analysis}
- \text{BF and } F_L: \text{ important contribution from fit biases and bkg characterization} \rightarrow \text{improvements in the analysis technique needed}
Measurements of $\gamma$ (1)

- $\gamma$-dependent observables in $B \rightarrow D^{(*)0}K^{(*)}$ processes:
  - interference between $b \rightarrow c$ color favoured vertex and $b \rightarrow u$ color suppressed transition
  - use D final states accessible to $D^0$ and $\bar{D}^0$
  - consider processes with tree level diagrams @ leading order $\rightarrow$ negligible NP effects (if any)
  - exp. challenging due to small BF & sensitivity to $\gamma^{-1/r_B}$ with $r_B = |A(b \rightarrow u)|/|A(b \rightarrow c)| \sim 0.1 - 0.2$

- different methods for different D final states:
  - Dalitz plot or GGSZ method $^{\text{ref}_1}$: Cabibbo favoured 3-body final states
  - GLW $^{\text{ref}_2}$: Cabibbo suppressed CP eigenstates
  - ADS $^{\text{ref}_3}$: doubly Cabibbo suppressed modes
Measurements of $\gamma$ (2)

Expected precision on $\gamma$ measurements combining GGSZ+GLW+ADS @ 75 fb$^{-1}$:
✓ GGSZ only : $\sigma(\gamma) = 2.8^\circ$
✓ GGSZ+GLW : $\sigma(\gamma) = 2.5^\circ$
✓ GGSZ+GLW+ADS : $\sigma(\gamma) = 1.7^\circ$

GGSZ method provides most precise constraint, main syst due to Dalitz Model $\rightarrow$ room for improvements?
✓ hard to reduce Dalitz Plot model error down to 3$^\circ$
✓ can combine measurements from different multi-body final states ($D \rightarrow K_S K \pi$, $K_S \pi^0 \pi \pi, KK \pi \pi$)
  - GGSZ (multi-Dalitz analysis) + GLW + ADS : $\sigma(\gamma) = 1^\circ$
✓ perform a model independent analysis$^\text{ref.} \ref{1}$ using a high statistic $\Psi(3770) \rightarrow DD$
correlated data sample to study the Dalitz plot
  - estimated 1 week of running to reduce $\sigma(x)$ and $\sigma(\gamma)$ down to 0.003 (stat error)
  - GGSZ (model independent) + GLW+ADS : $\sigma(\gamma) = 0.72^\circ$

F. Bianchi
GGSZ Method

✓ $D^0 \rightarrow K_s h^+ h^-$ with $h = K, \pi$ : $A(B^- \rightarrow [K_S h^+ h^-]_{D^0} K^-) \propto A_{D^+} + r_B e^{-i\delta_B - i\gamma} A_{D^-}$
  
  $A(B^+ \rightarrow [K_S h^+ h^-]_{D^0} K^+) \propto A_{D^-} + r_B e^{+i\delta_B + i\gamma} A_{D^+}$

✓ measure $\gamma$ from Dalitz plot distribution of $D^0$ daughters:
  
  - equations for $B \rightarrow D K$ (similarly for $B \rightarrow D^* K$ and $B \rightarrow D K^*$)
  
  $\Gamma_\pm (m_\pm^2, m_\mp^2) \propto |A_{D\pm}|^2 + r_B^2 |A_{D\mp}|^2 + 2\lambda \{x_\pm Re[A_{D\pm} A_{D\mp}^*] + y_\pm Im[A_{D\pm} A_{D\mp}^*]\}$

  $m_\pm = m(K_S h^\pm)$

  $A_{D\pm} : D^0/\bar{D}^0$ decay amplitudes

  $\lambda = +1$ for $B \rightarrow D^0 K, D^{*0}(D^0 \pi^0) K, D^0 K^*$

  $\lambda = -1$ for $D^{*0}(D^0 \gamma) K$

  $x_\pm = r_B \cos(\delta_B \pm \gamma)$;

  $y_\pm = r_B \sin(\delta_B \pm \gamma)$;

  $\delta_B : A(b \rightarrow u) - A(b \rightarrow c)$ strong phase difference;

  $r_B^2 = (|A(b \rightarrow u)|/|A(b \rightarrow c)|)^2 = x^2 + y^2$

✓ measure $(x, y)$ (12 params) to extract $3x(r_B, \delta) + \gamma$

hep-ex:10051096
463 million BB pairs

$\gamma = (68 \pm 1.1^{\text{stat}} \pm 4^{\text{syst}} \pm 3^{\text{model}})^\circ$
(mod 180°)

✓ Main contribution to syst error reducible with higher statistics

✓ 3° error related to Dalitz model

→ estimated precision on $(x, y)$ pairs due to syst = 0.003, due to model = 0.006
GLW and ADS Methods

- **GLW**
  - reconstruct $D_{CP} \rightarrow K^+K^- / \pi^+\pi^- / K_S\pi^0/K_S\phi/K_S\omega$ and $D_{flav} \rightarrow K\pi$ and measure
  
  \[
  A_{CP\pm} \equiv \frac{\Gamma(B^- \rightarrow D_{CP\pm}K^-) - \Gamma(B^+ \rightarrow D_{CP\pm}K^+)}{\Gamma(B^- \rightarrow D_{CP\pm}K^-) + \Gamma(B^+ \rightarrow D_{CP\pm}K^+)} = \frac{\pm 2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma}
  \]

  \[
  R_{CP\pm} = \frac{2\Gamma(B^- \rightarrow D_{CP\pm}K^-) + \Gamma(B^+ \rightarrow D_{CP\pm}K^+)}{\Gamma(B^- \rightarrow D_{CP\pm}K^-) + \Gamma(B^+ \rightarrow D_{CP\pm}K^+)} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma
  \]

  - results:
      - 467 million BB pairs

  - Systematics
    - estimated irreducible systematics on $R_{CP\pm}$ and $A_{CP\pm} = 0.02$ and 0.01

- **ADS**
  - Reconstruct $D \rightarrow K^\pm\pi^\mp$ and measure charge-averaged decay rate ($R_{ADS}$) and CP asymmetry $A_{ADS}$ to constrain $\gamma$
  - less stringent than other two methods measurements
  - estimated irreducible systematics on $R_{ADS}$ and $A_{ADS} = 0.02 \times 10^{-2}$ and 0.01 respectively
Signal-side selection:

- $B \rightarrow K^{(*)} \nu \bar{\nu}$: look for a single $K^{+}(K_{S}^{0})$ in Brecoil
- $B^{*} \rightarrow K^{*} \nu \bar{\nu}$: look for a $K^{*+}(K^{*0})$ in Brecoil. Several modes:
  $K^{*+} \rightarrow K_{S}^{0} (\rightarrow \pi^{+}\pi^{-})\pi^{+}$, $K_{S}^{0} (\rightarrow \pi^{0}\pi^{0})\pi^{+}$, $K^{+}\pi^{0}$ (charged); $K^{*0} \rightarrow K^{+}\pi^{-}$ (neutral)
- Opposite (same) charges of Breco and Brecoil for charged (neutral) modes
- No extra tracks in the event
- Kinematic cuts: $K_{S}^{0}$ and $K^{*}$ mass
- Kaon ($K^{+}, K_{S}^{0}$) $K^{*}$ CM momentum
- Missing energy ($E_{\text{beams}}$ – energy of charged and neutral objects in event)

**Main discriminant variable:**
$E_{\text{extra}} = \Sigma$(extra neutrals in the EMC)
**B → K(∗)νν: Analysis Strategy (2)**

**Fit strategy for B→K*νν analysis:**
- The plan is to extract BR and $F_L$ by performing a 2D fit on $E_{extra}$ and $\theta$(helicity).

**Assume:**
- 75ab⁻¹ statistics
- $S/B = 1/10$

- Signal enhanced by cut on $E_{extra} < 0.3$ GeV

**Drawback for angular analysis:** need to know Brecoil reference frame (RF)
  - Hadronic Breco: constrained kinematics $\Rightarrow$ Brecoil RF can be inferred from Breco reconstruction and beams information
  - Semi-leptonic Breco: unconstrained kinematics due to neutrino
    - Still can use the available information to build an estimator for $\theta$(helicity)
    - Expect worse resolution effects w.r.t Hadronic Breco