Beyond the Standard Model Physics at future B Factories and LHCb

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On the earthquake

As is now well known, Japan suffered a terrible earthquake and tsunami on March 11, which has caused tremendous damage, especially in the Tohoku area. Fortunately, all KEK personnel and users are safe and accounted for. The injection linac did suffer significant but manageable damage, and repairs are underway. The damage to the KEKB main rings appears to be less serious, though non-negligible. No serious damage has been reported so far at Belle. Further investigation is necessary. We would like to convey our deep appreciation to everyone for your generous expressions of concern and encouragement.

Information can be found in the KEK home page: http://www.kek.jp/intra-e/
See DG’s corner in HP for damage report and recovery plan.
Talk Outline

• Introduction:
  Why do we need continue B programs?
• Key measurements & physics cases
  Some examples
• Status of “future B factories”
  Accelerator & detector upgrades

Main players in this talk (references)

Apologies:
I cannot cover all subjects (there a lot).
I do not cover flavor physics at ATLAS/CMS.
Introduction

- We hope that New Physics will be seen directly at LHC (ATLAS/CMS).
  - Reasons to believe a TeV scale NP: hierarchy problem, unification of coupling constants, …
- If NP exists at a TeV scale, there is a good chance to see effects in heavy flavor (B/D/τ) decays.

2010’s = The decade of finding New Physics
Role of Flavor Physics

• Lessons from history:
  – GIM → charm quark
  – CPV → 3rd generation
  – B-B mixing → heavy top quark

• Also presently, flavor physics observables constrain NP most severely.
  – $b \rightarrow s \gamma$
  – $B \rightarrow \tau \nu$
  – $B_s \rightarrow \mu^+\mu^-$

• No sharp mass threshold for NP in flavor physics.
  Sensitivity reaches
  • $O(1\text{TeV})$ if MFV scenario
  • $O(100\text{TeV})$ if large flavor violating couplings
If NP is found, flavor physics observables provide useful information to test the NP models.

<table>
<thead>
<tr>
<th>Flavor physics observables</th>
<th>mSU GRA</th>
<th>MSSM+ν&lt;sub&gt;R&lt;/sub&gt;</th>
<th>SU(5)+ν&lt;sub&gt;R&lt;/sub&gt;</th>
<th>U(2) FS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>degenerate</td>
<td>non-degenerate</td>
<td>degenerate</td>
</tr>
<tr>
<td>A&lt;sub&gt;CP&lt;/sub&gt;(s&lt;sub&gt;γ&lt;/sub&gt;)</td>
<td></td>
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<td></td>
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<tr>
<td>S(K*&lt;sub&gt;γ&lt;/sub&gt;)</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>S(ρ&lt;sub&gt;γ&lt;/sub&gt;)</td>
<td></td>
<td>✔</td>
<td></td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>S(ϕK&lt;sub&gt;S&lt;/sub&gt;)</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>S(B&lt;sub&gt;s&lt;/sub&gt;→J/ψ ϕ)</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>µ→eγ</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>τ→μγ</td>
<td>✔ ✔ ✔</td>
<td></td>
<td>✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>τ→eγ</td>
<td>✔ ✔ ✔</td>
<td></td>
<td>✔</td>
<td>✔ ✔ ✔</td>
</tr>
</tbody>
</table>

[Based on T.Goto et.al. PRD77, 095010(2008)]

✔: deviation from SM expected
Current Status of CP/CKM

Still room for modifications by NP at O(0.1)!

2008 Nobel Prize in Physics

M. Kobayashi
T. Maskawa

Similar plot by the UT-fit group
Still room for improvement

- There are tree and loop diagrams involved in the CKM fit.
- We should determine the apex from $|V_{ub}|$ and $\phi_3$ more precisely and compared it to that from loop processes.

$$\phi_3(\gamma) = (73_{-24}^{+19})^\circ \text{ from } B\rightarrow DK$$
Limits on NP from $B_{d,s}$ mixing

- NP effects in B-B mixing can be expressed as:
  \[
  \langle B^0 | H_{\Delta B=2}^{SM+NP} | B^0 \rangle = \Delta_{d,s}^{NP} \langle B^0 | H_{\Delta B=2}^{SM} | B^0 \rangle, \quad \Delta_{d,s}^{NP} = \text{Re} \Delta_{d,s} + \text{Im} \Delta_{d,s}
  \]
- Possible NP in $\Delta m$, weak phases, $A_{SL}$ & $\Delta \Gamma$
- No NP in tree observables $|V_{ij}|$ and $\gamma (\phi_3)$.

CKM fitter @ FPCP2010
B($B \rightarrow \tau \nu$) removed.

Resolution is not enough!
Many channels to probe NP

There are many places to look for NP in rare B decays.

- $B \rightarrow l\nu, \tau\nu, D\tau\nu$
- $b \rightarrow s\gamma$
- $b \rightarrow sll$
- $b \rightarrow sg + b \rightarrow uqq$
- $B_{s,d} \rightarrow ll$

+ D decays & $\tau$ decays
Some hints in existing B factory data

**Kπ puzzle:** \( A_{CP}(B^0 \to K^+\pi^-) \neq A_{CP}(B^+ \to K^+\pi^0) \)

Forward-backward asymmetry in \( B \to K^{*0}l^+l^- \)

**2.8σ difference between direct and indirect sin2φ₁ and BR(\( B \to \tauν \))**

CPV in \( b \to s \) penguin modes

![Graphs and plots illustrating experimental measurements and CKM fit models.](Image)
### Coming Opportunities

**Clean environment**
- Coherent B pair production
- Good hermeticity, $\gamma$, $\pi^0$ detection

**SuperKEKB /Belle II**
- $L_{\text{peak}} = 8 \times 10^{35} \text{cm}^{-2} \text{s}^{-1}$
- $L_{\text{int}} = 50 \text{ab}^{-1}$ by ~2020

**Super B**
- Polarization (80%)
- Operation at TauCharm
- $L_{\text{peak}} = 10^{36(35)} \text{cm}^{-2} \text{s}^{-1} \text{[4S(t-charm)]}$
- $L_{\text{int}} = 75 \text{ab}^{-1}$ by ~2022

**Hadron machine**
- Large production rate
- Various B hadrons: $B_s$, $\Lambda_b$, ...
- $L_{\text{peak}} = 10^{32} \text{cm}^{-2} \text{s}^{-1}$
- $L_{\text{int}} = 5 \text{fb}^{-1}(1 \text{fb}^{-1}/\text{yr})$
- $L_{\text{peak}} = 10^{33} \text{cm}^{-2} \text{s}^{-1}$
- $L_{\text{int}} = 50 \text{fb}^{-1}(5 \text{fb}^{-1}/\text{yr})$

**LHCb**
- Phase 1
- Phase 2

(Don’t take the end-point of each arrow seriously)
Key Measurements at Belle II

- **CPV in b→s modes**
- **FCNC**
  - b→sγ
  - b→sll
- **Tauonic decays**
- **LFV tau decays**
- **Precision CKM**

**QCD correction/error in ΔS**

<table>
<thead>
<tr>
<th>Key Measurement</th>
<th>Belle’06 (~0.5ab⁻¹)</th>
<th>5ab⁻¹</th>
<th>50ab⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔS(φK⁰)</td>
<td>0.22</td>
<td>0.073</td>
<td>0.029</td>
</tr>
<tr>
<td>ΔS(η′K⁰)</td>
<td>0.11</td>
<td>0.038</td>
<td>0.020</td>
</tr>
<tr>
<td>ΔS(K_s K_s K_s)</td>
<td>0.33</td>
<td>0.105</td>
<td>0.037</td>
</tr>
<tr>
<td>ΔS(K_s π⁰γ)</td>
<td>0.32</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>Br(X_sγ)</td>
<td>13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A_CP(X_sγ)</td>
<td>0.058</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>C_9 [A_FB(K^*ll)]</td>
<td>---</td>
<td>11%</td>
<td>4%</td>
</tr>
<tr>
<td>C_10 [A_FB(K^*ll)]</td>
<td>---</td>
<td>13%</td>
<td>4%</td>
</tr>
<tr>
<td>Br(B⁺ → K⁺νν)</td>
<td>&lt;9Br(SM)</td>
<td>33ab⁻¹ for 5σ discovery</td>
<td></td>
</tr>
<tr>
<td>Br(B⁺ → τν)</td>
<td>3.5σ</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>Br(B⁺ → μν)</td>
<td>&lt;2.4Br(SM)</td>
<td>4.3ab⁻¹ for 5σ discovery</td>
<td></td>
</tr>
<tr>
<td>Br(B⁺ → Dτν)</td>
<td>---</td>
<td>7.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Br(τ → μγ)</td>
<td>&lt;45</td>
<td>&lt;30</td>
<td>&lt;8</td>
</tr>
<tr>
<td>Br(τ → μη)</td>
<td>&lt;65</td>
<td>&lt;20</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Br(τ → 3μ)</td>
<td>&lt;209</td>
<td>&lt;10</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Δsin2φ₁</td>
<td>0.026</td>
<td>0.016</td>
<td>0.012</td>
</tr>
<tr>
<td>ΔΦ₂ (ρπ)</td>
<td>68°–95°</td>
<td>3°</td>
<td>1°</td>
</tr>
<tr>
<td>ΔΦ₃ (Dalitz)</td>
<td>20°</td>
<td>7°</td>
<td>2.5°</td>
</tr>
<tr>
<td>ΔV_{ub} (incl.)</td>
<td>7.3%</td>
<td>6.6%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>
Photon polarization in $b \rightarrow s(d) \gamma$

- In SM, photons from $b \rightarrow s(d) \gamma$ processes are left handed, therefore, (almost) no CPV.
- If unknown right handed current exists, CPV may arise clear NP signal!

Possible deviation from SM

O(1): Warped extra dim.
O(1): L-R symmetric model
O(0.1): SUSY SU(5)

In SM,

$|S(K^{*0}\gamma)| < 0.02$, $S(\rho^{0}\gamma) \sim 0$

$\Delta S(K^{*0}\gamma) = 0.027 \ @ \ 50 \ ab^{-1}$

$\Delta S(\rho^{0}\gamma) = 0.075 \ @ \ 50 \ ab^{-1}$
B→τν: Search for charged Higgs

In SM, \[ B(B^{-} \to \ell^{-}\bar{v}) = \frac{G_{F}^{2}m_{B}m_{\ell}^{2}}{8\pi} \left( 1 - \frac{m_{\ell}^{2}}{m_{B}^{2}} \right)^{2} \left| f_{B} \right|^{2} V_{ub}^{*} \tau_{B} \]

In Type II HDM, \[ Br = Br_{SM} \times r_{H}, \quad r_{H} = \left( 1 - \frac{m_{B}}{m_{H}^{2}} \tan^{2}\beta \right)^{2} \]

• \( B \rightarrow \tau\nu/D\tau\nu \) probes \( b-H^{\pm}-u, b-H^{\pm}-c \) couplings to compare \( b-H^{\pm}-t \) coupling from LHC high \( P_{T} \) programs.
Lepton Flavor Violation

Quarks have flavor mixing.
Neutrino mixing has been found.
What about charged leptons?

$\nu_e \leftrightarrow \nu_\mu \leftrightarrow \nu_\tau$

B factory is also a tau factory
• SU(5)+ν_R, non-degenerate ν_R(I), normal Hierarchy

If MEG find μ→eγ at ~10^{-13}, good chance to see also τ→μγ at 10^{-8}→10^{-10}.
Even if MEG does not, still important to search for τ→μγ.
Future prospects

• Super B-factory:
  \[ L_{\text{int}} = 10 \rightarrow 50 \text{ab}^{-1} \]
  \[ N_{\tau} = (1 \rightarrow 5) \times 10^{10} \]

• Recent improvement in the analysis
  – BG understanding
  – Intelligent selection

• At 50 ab\(^{-1}\)
  \[ \text{Br}(\tau \rightarrow \mu\gamma) < O(10^{-9}) \]
  \[ \text{Br}(\tau \rightarrow \text{III}) < O(10^{-10}) \]

Good chance to see NP!
# B Physics @ Y(4S)

<table>
<thead>
<tr>
<th>Observable</th>
<th>B Factors (2 ab⁻³)</th>
<th>SuperB (75 ab⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>B(K^+K^-)</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>B(\bar{K}^0\bar{K}^0)</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>B(D^+\bar{D}^-)</td>
<td>)</td>
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<tr>
<td>(</td>
<td>B(\pi^0\pi^0)</td>
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<tr>
<td>(</td>
<td>B(\pi^+\pi^-)</td>
<td>)</td>
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<td>(</td>
<td>B(\pi^+\pi^-)</td>
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<td>(</td>
<td>B(\pi^0\pi^0)</td>
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<td>(</td>
<td>B(\pi^0\pi^0)</td>
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<td>(</td>
<td>B(\pi^0\pi^0)</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>B(\pi^0\pi^0)</td>
<td>)</td>
</tr>
</tbody>
</table>

### Charm mixing and CP

<table>
<thead>
<tr>
<th>Mode</th>
<th>Observable</th>
<th>( Y(4S) ) (75 ab⁻³)</th>
<th>( \psi(3770) ) (300 fb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D^0 \to K^+\pi^- )</td>
<td>( z^2 )</td>
<td>( 3 \times 10^{-5} )</td>
<td></td>
</tr>
<tr>
<td>( \psi(3770) \to D^0\bar{D}^0 )</td>
<td>( \phi^0 )</td>
<td>( 2^0 )</td>
<td></td>
</tr>
</tbody>
</table>

### Charm FCNC

<table>
<thead>
<tr>
<th>Observable</th>
<th>( D^0 \to e^+e^- )</th>
<th>( D^0 \to \mu^+\mu^- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \Gamma )</td>
<td>0.16 ps⁻¹</td>
<td>0.03 ps⁻¹</td>
</tr>
<tr>
<td>( \Gamma )</td>
<td>0.07 ps⁻¹</td>
<td>0.01 ps⁻¹</td>
</tr>
<tr>
<td>( \Delta \Gamma )</td>
<td>0.006</td>
<td>0.004</td>
</tr>
<tr>
<td>( \Delta \Gamma )</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>( B(B_s \to \mu^+\mu^-) )</td>
<td>0.08</td>
<td>( &lt; 8 \times 10^{-9} )</td>
</tr>
<tr>
<td>( B(B_s \to \mu^+\mu^-) )</td>
<td>0.38</td>
<td>7%</td>
</tr>
<tr>
<td>( B(B_s \to \mu^+\mu^-) )</td>
<td>10°</td>
<td>3°</td>
</tr>
<tr>
<td>( B(B_s \to \mu^+\mu^-) )</td>
<td>24°</td>
<td>11°</td>
</tr>
<tr>
<td>( B(B_s \to \mu^+\mu^-) )</td>
<td>1 × 10⁻⁸</td>
<td></td>
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<tr>
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<td>1 × 10⁻⁸</td>
<td></td>
</tr>
</tbody>
</table>

### \( \tau \) Physics

<table>
<thead>
<tr>
<th>Observable</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B(\tau \to \mu\gamma) )</td>
<td>2 \times 10⁻⁹</td>
</tr>
<tr>
<td>( B(\tau \to e\gamma) )</td>
<td>2 \times 10⁻⁹</td>
</tr>
<tr>
<td>( B(\tau \to \mu\mu\mu) )</td>
<td>2 \times 10⁻¹⁰</td>
</tr>
<tr>
<td>( B(\tau \to eee) )</td>
<td>2 \times 10⁻¹⁰</td>
</tr>
<tr>
<td>( B(\tau \to \mu\eta) )</td>
<td>4 \times 10⁻¹⁰</td>
</tr>
<tr>
<td>( B(\tau \to e\eta) )</td>
<td>6 \times 10⁻¹⁰</td>
</tr>
<tr>
<td>( B(\tau \to \ell\bar{K}_{s}^0) )</td>
<td>2 \times 10⁻¹⁰</td>
</tr>
</tbody>
</table>

### B, Physics @ Y(5S)

<table>
<thead>
<tr>
<th>Observable</th>
<th>Error with 1 ab⁻¹</th>
<th>Error with 30 ab⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \Gamma )</td>
<td>0.16 ps⁻¹</td>
<td>0.03 ps⁻¹</td>
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<tr>
<td>( \Gamma )</td>
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<td>11°</td>
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<td>( B(B_s \to \mu^+\mu^-) )</td>
<td>1 × 10⁻⁸</td>
<td></td>
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<td>1 × 10⁻⁸</td>
<td></td>
</tr>
<tr>
<td>( B(B_s \to \mu^+\mu^-) )</td>
<td>1 × 10⁻⁸</td>
<td></td>
</tr>
</tbody>
</table>
• Decays of $\psi(3770) \rightarrow D^0D^0$ produce coherent $C=-1$ pairs of $D^0$'s.
• $\rightarrow$ precision D mixing, CPV using quantum correlations.

<table>
<thead>
<tr>
<th></th>
<th>Now</th>
<th>SuperB</th>
<th>SuperB+BES</th>
<th>SuperB +BES+(\phi(3770))</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x \times 10^3$</td>
<td>$\pm3$</td>
<td>$\pm0.7$</td>
<td>$\pm0.4$</td>
<td>$\pm0.2$</td>
</tr>
<tr>
<td>$y \times 10^3$</td>
<td>$\pm2$</td>
<td>$\pm0.2$</td>
<td>$\pm0.2$</td>
<td>$\pm0.1$</td>
</tr>
<tr>
<td>$\delta_{\kappa\pi\pi}$</td>
<td>$\pm10^o$</td>
<td>$\pm3^o$</td>
<td>$\pm2^o$</td>
<td>$\pm1^o$</td>
</tr>
<tr>
<td>$\delta_{\kappa\pi\pi\pi}$</td>
<td>$\pm20^o$</td>
<td>$\pm5^o$</td>
<td>$\pm3^o$</td>
<td>$\pm1^o$</td>
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</table>
### Key measurements at LHCb (+ Upgrade)

<table>
<thead>
<tr>
<th>Type</th>
<th>Observable</th>
<th>Current precision</th>
<th>LHCb (5 fb(^{-1}))</th>
<th>Upgrade (50 fb(^{-1}))</th>
<th>Theory uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluonic penguin</td>
<td>(S(B_s \to \phi\phi))</td>
<td>-</td>
<td>0.08</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>(S(B_s \to K^{*0}\bar{K}^{*0}))</td>
<td>-</td>
<td>0.07</td>
<td>0.02</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td></td>
<td>(S(B^0 \to \phi K^0_S))</td>
<td>0.17</td>
<td>0.15</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>(B_s) mixing</td>
<td>(2\beta_s) ((B_s \to J/\psi\phi))</td>
<td>0.35</td>
<td>0.019</td>
<td>0.006</td>
<td>(\sim 0.003)</td>
</tr>
<tr>
<td>Right-handed currents</td>
<td>(S(B_s \to \phi\gamma))</td>
<td>-</td>
<td>0.07</td>
<td>0.02</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>(A^{\Delta T}_{s}(B_s \to \phi\gamma))</td>
<td>-</td>
<td>0.14</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>E/W penguin</td>
<td>(A_T^{(2)}(B^0 \to K^{*0}\mu^+\mu^-))</td>
<td>-</td>
<td>0.14</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>(s_0 A_{FB}(B^0 \to K^{*0}\mu^+\mu^-))</td>
<td>-</td>
<td>4%</td>
<td>1%</td>
<td>7%</td>
</tr>
<tr>
<td>Higgs penguin</td>
<td>(B(B_s \to \mu^+\mu^-))</td>
<td>-</td>
<td>30%</td>
<td>8%</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td></td>
<td>(B(B_s \to \mu^+\mu^-))</td>
<td>-</td>
<td>-</td>
<td>(\sim 35)%</td>
<td>(\sim 5)%</td>
</tr>
<tr>
<td>Unitarity triangle</td>
<td>(\gamma) ((B \to D^{(<em>)}K^{(</em>)}))</td>
<td>(\sim 20^\circ)</td>
<td>(\sim 4^\circ)</td>
<td>0.9(^\circ)</td>
<td>negligible</td>
</tr>
<tr>
<td>angles</td>
<td>(\gamma) ((B_s \to D_s K))</td>
<td>-</td>
<td>(\sim 7^\circ)</td>
<td>1.5(^\circ)</td>
<td>negligible</td>
</tr>
<tr>
<td></td>
<td>(\beta) ((B^0 \to J/\psi K^0))</td>
<td>1(^\circ)</td>
<td>0.5(^\circ)</td>
<td>0.2(^\circ)</td>
<td>negligible</td>
</tr>
<tr>
<td>Charm CPV</td>
<td>(A_T)</td>
<td>2.5 \times 10^{-3}</td>
<td>2 \times 10^{-4}</td>
<td>4 \times 10^{-5}</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(A_{CP}^{dir}(KK) - A_{CP}^{dir}(\pi\pi))</td>
<td>4.3 \times 10^{-3}</td>
<td>4 \times 10^{-4}</td>
<td>8 \times 10^{-5}</td>
<td>-</td>
</tr>
</tbody>
</table>
FCNC processes sensitive to NP via angular distribution.
LHCb measures also $B^+ \to K^+ \mu^+\mu^-$, $B_s \to \phi \mu^+\mu^-$, $\Lambda_b \to \Lambda^*\mu^+\mu^-$
Belle II /Super B measure $X_s l^+l^-$

Present LHCb
- Zero crossing in SM: $s_0=(4.36+0.36-0.33) \text{ GeV}^2$
- Measure $s_0$ to 0.4 GeV$^2$ in 2-3 years

LHCb upgrade
- More kinematic variables, e.g. transversity asymmetry $A_T^{(2)}$ sensitive to new RH currents
$B_{s,d} \rightarrow \mu^+\mu^-$

- Exploit statistical power LHCb
- Sensitivity of current limit (43 \times 10^{-9} @ 90\% C.L. with 40 \text{ pb}^{-1}) in agreement with MC roadmap
- Measurement of $f_s/f_d$ is currently stat. limited
- Upgrade:
  - SM \{BR $B_s \rightarrow \mu^+\mu^-$\} can be measured to 8\% precision @ 50 \text{ fb}^{-1}
    - Strong constraints for NP models
  - Correlation $B_s \rightarrow \mu^+\mu^-$ vs $B_d \rightarrow \mu^+\mu^-$ can be done in upgrade $\approx 35\%$
    - Challenge: low BR $B_d \rightarrow \mu^+\mu^-$ and background
Need $O(100x)$ more data $\rightarrow$ Next generation B-factories

SuperKEKB + SuperB

40 times higher luminosity
Luminosity formula

\[ L = \frac{\gamma^\pm}{2e\epsilon_r} \left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right) \left(\frac{I_\pm \xi_\pm y}{\beta_y^*}\right) \left(\frac{R_L}{R_y}\right) \]

Stored current

Beam-beam parameter

- Lorentz factor
- Classical electron radius
- Beam size ratio
- 1~2% @IP

Vertical \( \beta \) at the IP

Geometrical reduction factors due to crossing angle and hour-glass effect

0.8~1 (short bunch)

For higher Luminosity

1) Smaller \( \beta_y^* \)
2) Increase beam currents
3) Increase \( \xi_y \)

Invented by P. Raimondi for SuperB

“Nano-beam scheme”

Crab crossing
## SuperKEKB Design Parameters

### Machine design parameters

<table>
<thead>
<tr>
<th>parameters</th>
<th>KEKB</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LER</td>
<td>HER</td>
</tr>
<tr>
<td>Beam energy ( E_b )</td>
<td>3.5</td>
<td>8</td>
</tr>
<tr>
<td>Half crossing angle ( \phi )</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Horizontal emittance ( \varepsilon_x )</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Emittance ratio ( \kappa )</td>
<td>0.88</td>
<td>0.66</td>
</tr>
<tr>
<td>Beta functions at IP ( \beta_x^<em>/\beta_y^</em> )</td>
<td>1200/5.9</td>
<td></td>
</tr>
<tr>
<td>Beam currents ( I_b )</td>
<td>1.64</td>
<td>1.19</td>
</tr>
<tr>
<td>beam-beam parameter ( \xi_y )</td>
<td>0.129</td>
<td>0.090</td>
</tr>
<tr>
<td>Luminosity ( L )</td>
<td>(2.1 \times 10^{34})</td>
<td>(8 \times 10^{35})</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

M. Iwasaki, ICHEP2010
KEKB to SuperKEKB

- Replace short dipoles with longer ones (LER)
- New beam pipe & bellows
- Redesign the lattices of HER & LER to squeeze the emittance
- TIN-coated beam pipe with antechambers

Colliding bunches

- New superconducting/permanent final focusing quads near the IP
- Add / modify RF systems for higher beam current
- New positron target / capture section

Positron source

- Low emittance positrons to inject
- Low emittance gun

Low emittance electrons to inject

To get x40 higher luminosity
Belle II Detector

- Deal with higher background (10-20×), radiation damage, higher occupancy, higher event rates (L1 trigg. 0.5 → 30 kHz)
- Improved performance and hermeticity

CsI(Tl) EM calorimeter:
- Waveform sampling electronics, pure CsI for endcaps

RPC μ & K_L counter:
- Scintillator + Si-PM for end-caps

4 layers DS Si vertex detector → 2 layers PXD (DEPFET), 4 layers DSSD

Time-of-Flight, Aerogel Cherenkov Counter → Time-of-Propagation (barrel), prox. focusing Aerogel RICH (forward)

Central Drift Chamber:
- Smaller cell size, long lever arm
Vertex Detector w/ silicon pixels and strips

**Outer radius 10 cm → 14 cm**
- Better tracking efficiency/self tracking
- Larger acceptance for Ks (30% larger than Belle)

**Silicon strip layer (Layer 3-6)**
- 300 µm thick, DSSD
- Readout by APV25 ASIC (50ns shaping time)

**Pixel layer (Layer 1-2)**
- DEPFET technology
- 50µm x 75µm pixel

**IP resolution σ_z₀ ~ 50µm**
Novel ring imaging Cherenkov detectors to provide $>4\sigma$ K/$\pi$ separation up to 4GeV/c

**Barrel: TOP (Time-Of-Propagation)**
Focusing TOP concept:
- Reconstruct image of internally reflected Cherenkov in (X, T).
- Measure also Y w/ focusing mirror to correct chromatic dispersion effect.

**Endcap: Aerogel RICH**
- Proximity focusing RICH w/ hydrophobic aerogel radiator ($\lambda_T$>40mm)
- Multiple radiators with different indices (n=1.045-1.050) to correct emission point uncertainty

Quartz radiator
- Hamamatsu MCP-PMT ($\sigma_{TTS}$~40ps/photon)
- New 12x12ch HAPD array

Aerogel radiator
- n1=1.045
- n2=1.055

RICH test beam setup
- p=3GeV/c
KEKB to Super-KEKB

KEKB/Belle completed at 9:00am, June 30, 2010

Super-KEKB budget has been approved.

- Damping ring (~5.8M$, FY2010)
- “Very Advanced Research Supprt Program” (~100M$, FY2010-2012)
  + ~60 oku-yen/year for three years

Jan-March 2011: full approval by the Diet and Japanese government

Start construction (FY2010-2013)
Start commissioning (end of 2014)
Belle Disassembly

Taking out the Belle Vertex Detector

Taking out the Aerogel Cherenkov

Belle roll out (Dec. 9, 2010)
Belle II Collaboration

384 members, 57 institutions from 13 countries
SuperKEKB luminosity profile

Goals of Belle II/SuperKEKB

We will reach 50 ab\(^{-1}\) in 2021

Commissioning starts in late 2014.

9 months/year
20 days/month

Shutdown for upgrade

We are here
### Parameters for $1 \times 10^{36}$ Lumi (max $4 \times 10^{36}$)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base Line</th>
<th>Low Emittance</th>
<th>High Current</th>
<th>Tau/Charm (prelim.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HFR (e+)</td>
<td>1 FR (e-)</td>
<td>HFR (e+)</td>
<td>1 FR (e-)</td>
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<tr>
<td><strong>LUMINOSITY</strong></td>
<td>cm$^2$/s$^1$</td>
<td>1.00E+36</td>
<td>1.00E+36</td>
<td>1.00E+36</td>
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<td>Energy</td>
<td>GeV</td>
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<td>Circumference</td>
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<td>1258.4</td>
<td>1258.4</td>
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<td>X-Angle (full)</td>
<td>mrad</td>
<td>66</td>
<td>66</td>
<td>66</td>
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<td>Pizouki's angle</td>
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<td>18.50</td>
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<td>$\beta_x$ @ IP</td>
<td>cm</td>
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<td>3.2</td>
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<td>$\beta_y$ @ IP</td>
<td>cm</td>
<td>0.0279</td>
<td>0.0205</td>
<td>0.0145</td>
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<td>Coupling (full current)</td>
<td>%</td>
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<td>0.25</td>
<td>0.25</td>
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<tr>
<td>$\sigma_\phi$ (without IBS)</td>
<td>mm</td>
<td>1.00</td>
<td>0.91</td>
<td>1.00</td>
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<tr>
<td>$\sigma_\phi$ (with IBS)</td>
<td>mm</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
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<td>$a_x$ @ IP</td>
<td>pm</td>
<td>2.53</td>
<td>3.073</td>
<td>5.15</td>
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<tr>
<td>$a_y$ @ IP</td>
<td>pm</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
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<tr>
<td>$\Sigma_x$</td>
<td>mm</td>
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<td>$\Sigma_y$</td>
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<td>$\sigma_{10}$ (I current)</td>
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<td>$\sigma_{12}$ (I current)</td>
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<td>5.00</td>
<td>5.00</td>
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<td>Beam current</td>
<td>mA</td>
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<td>Buckets distance</td>
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<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Ion gap</td>
<td>%</td>
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<td>2</td>
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<td>Hz</td>
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<td>1.00E+06</td>
<td>1.00E+06</td>
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<td>Number of bunches</td>
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<td>978</td>
<td>978</td>
<td>978</td>
</tr>
<tr>
<td>N. Particle/bunch</td>
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<td>5.08E+10</td>
<td>5.08E+10</td>
<td>5.08E+10</td>
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<td>Tune shift x</td>
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<td>0.0020</td>
<td>0.0003</td>
<td>0.0003</td>
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<tr>
<td>Tune shift y</td>
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<td>0.0970</td>
<td>0.0971</td>
<td>0.0971</td>
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<tr>
<td>Long, damping time</td>
<td>µsec</td>
<td>13.4</td>
<td>13.4</td>
<td>13.4</td>
</tr>
<tr>
<td>Energy Loss/turn</td>
<td>MeV</td>
<td>2.11</td>
<td>2.11</td>
<td>2.11</td>
</tr>
<tr>
<td>$\phi$ (full current)</td>
<td>de/E</td>
<td>6.43E-04</td>
<td>6.43E-04</td>
<td>6.43E-04</td>
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<tr>
<td>CM de</td>
<td>de/E</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>4.18</td>
<td>3.05</td>
</tr>
<tr>
<td>Total RF Power</td>
<td>MW</td>
<td>17.08</td>
<td>12.72</td>
<td>30.48</td>
</tr>
</tbody>
</table>

**Tau/charm threshold running at $10^{35}$**

- Baseline +
- Lower $\gamma$-emittance
- Higher currents (twice bunches)

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

**RF power includes SR and HOM**

M. Giorgi, ICHEP2010
Nano-beam collision w/ Crab Waist

- Invented by P. Raimondi
- Move y-waist along z with a sextupole on both sides at proper phase.
- The concept has been successfully tested at DAFNE

Crab waist OFF

Crab waist ON
Super B Detector

Detector Design [arXiv:1007.4241]

Reuses much of BaBar e.g. CsI crystals

- Double Vertex resolution
- Improved hermiticity
- TOF Forward PID
- Cluster counting in drift chamber (improves dE/dx)
- Logging rate: 1.9 Gbytes/sec

Backward EMC
Optimized IFR (muons)

F. Wilson @ Beauty 2011
Approval Milestones in Italy

- **April 2010**: SuperB becomes one of 14 Italian National Research Program (PNR) Flagship Projects
  - Cooperation between INFN and IIT (Italian Institute of Technology)
    - HEP experiment and light source
- **Dec. 2010**: Approval by Ministry of Instruction, University and Research and Parliament with 19 M€ provided as first part of a multi-year funding plan.
- **April 2011**: Full Italian government approval of the PNR, including 250M€ for SuperB

+135M€ in-kind contribution through usage of PEP II and BaBar components.
Baseline for LHCb upgrade

- Increase luminosity to $L \approx 1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$
- Upgrade readout electronics and DAQ architecture to 40MHz
- Collect $\sim 5\text{fb}^{-1}$/year and $\sim 50\text{fb}^{-1}$ in 10 years

Main limitation of current detectors

- Bandwidth & rate limitation of L0 trigger
- Efficiency for hadronic channels flattens out at $L \approx 2-3 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$.
- Can accumulate 1fb-1 / year.

Pile-up:

- Expected pile-up rate at $L \approx 1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$ with 25ns BX-ings: $\mu \approx 2.3$.
- Detectors work already at $\mu = 2.7$ in 2010 run ($L = 1.6 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$, $n_b = 344$)
- Readout detector at 40MHz to run full software trigger.
  - Replace all sub-detector front-end electronics to 40MHz readout.
- Replace all silicon detectors attached to the current 1MHz readout.
  - VELO, IT, TT, RICH HPD’s
- Remove some detectors due to increased occupancies.
  - RICH1 aerogel, M1, possibly PS&SPD
- New PID to cover low momentum region (TORCH)

New VELOPIX w/ 55mm×55mm Timepix chip

MA-PMT for RICH1,2

New Tracker (IT, TT)
  - Silicon strips
  - Sci fiber w/ Si-PM readout

New PID TORCH for p <10GeV/c

New electronics for calorimeters
Summary

• Heavy flavor physics will play crucial roles to find & study NP, and is complementary to high $P_T$ LHC physics.
  – No mass threshold.
  – Off-diagonal couplings

  "Elucidation of New Physics"

• There are good prospects:
  – SuperKEKB / Belle II
  – INFN Super B
  – LHCb upgrade

Both projects are funded

R&D’s to allow 40MHz readout in progress.

Starting to swim!
Backup
References

- Physics at Super B Factory, arXiv:1002.5012
- sBelle Design Study Report, arXiv:0810.4084
- Super B Progress Report-- Physics, arXiv:1008.1541
- LHCb Upgrade LoI, CERN-LHCC-2011-001
  available at LHCb HP (http://lhcb.web.cern.ch/lhcb/)
In case of SUSY...

• The squark/slepton mass matrix
  – Sensitive to SUSY breaking mechanism.

\[
(m_{\tilde{q}}^2)_{ij} = \begin{pmatrix}
  m_{11}^2 & m_{12}^2 & m_{13}^2 \\
  m_{21}^2 & m_{22}^2 & m_{23}^2 \\
  m_{31}^2 & m_{32}^2 & m_{33}^2
\end{pmatrix}
\]

B and \( \tau \) are in the 3rd generation ("hub" quark & lepton) probe for both \( 3 \to 2 \), \( 3 \to 1 \) transitions.
CPV in $b \to s$ Penguins

$A_{CP}(t) = \sin 2(\phi + \phi_{NP}) \times \sin(m_d)$

Present upper limits
Measurements at upgraded KEKB

Present B factories
Upgraded KEKB

$\Delta S(B \to \phi K^0) \quad 50 \text{ab}^{-1}$

$\phi K^0$
The two decays have different sensitivity for different NP models.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Reference</th>
<th>$\tau \gamma \mu$</th>
<th>$\tau \mu \mu \mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM + heavy Maj $\nu_R$</td>
<td>PRD 66(2002)034008</td>
<td>$10^{-9}$</td>
<td>$10^{-10}$</td>
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<tr>
<td>Non-universal $Z'$</td>
<td>PLB 547(2002)252</td>
<td>$10^{-9}$</td>
<td>$10^{-8}$</td>
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<td>SUSY SO(10)</td>
<td>PRD 68(2003)033012</td>
<td>$10^{-8}$</td>
<td>$10^{-10}$</td>
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<tr>
<td>mSUGRA+seesaw</td>
<td>PRD 66(2002)115013</td>
<td>$10^{-7}$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>SUSY Higgs</td>
<td>PLB 566(2003)217</td>
<td>$10^{-10}$</td>
<td>$10^{-7}$</td>
</tr>
</tbody>
</table>

Searches in various LFV modes help to discriminate NP models.
Polarized beam

- Longitudinal polarization (~80%) improves LFV sensitivity.
- If LFV found, it provides information on helicity nature of NP.
- Also, $\tau$ CPT studies, $\sin^2\theta_W$, ...

**Benefits of Polarized Electron Beam**

1) LFV: Doubles Precision

2) $\tau$ EDM, $\tau g-2$: Measurement could prove or disprove discrepancy in $\Delta\alpha_\mu$ due to New Physics.
   - EDM sensitivity $\sim 2 \times 10^{-19}$ e cm
   - $\Delta\alpha_\mu$ (SM) $\sim 10^{-6}$
   - $\Delta\alpha_\mu$ (SUSY) $\sim 10^{-5}$
   - $\Delta\alpha_\mu$ (SuperB) precision $\sim 10^{-6}$

3) Electroweak:
   - Investigate LEP $A_{FB}$ vs. SLD $A_{LR}$ discrepancy.
   - Investigate NuTeV discrepancy.
   - Constrain Higgs mass
   - $\sin^2\theta_W$ resolution $\pm 0.00018$

F. Wilosn @ Beauty2011
Detector Upgrade

Issues
- Higher background (×20)
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- Higher event rate (×10)
  - higher rate trigger, DAQ and computing
- Require special features
  - low $p_\mu$ identification $\leftrightarrow s_{\mu\mu}$ recon. eff.
  - hermeticity $\leftrightarrow \nu$ “reconstruction”

Possible solution:
- Replace inner layers of the vertex detector with a silicon strip/pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter by pure CsI.
- Faster readout electronics and computing system.