Search for New Physics at Super-KEKB

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(University of Hawaii)
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A decade of discovery at B-factories…

Scenario when we started …

Step 1
Discovery of CPV in B decay

Step 2
Precise test of KM(CPV) and SM

Step 3
Search/Evidence for New Physics

This session
Hints for NP?

Summer 2001

2008

SuperB-factory

Search for new physics at Super-KEKB, SUSY09 (Boston) – June 2009

Need >50(75) ab⁻¹ data

( L \sim 10^{36}\text{cm}^{-2}\text{s}^{-1} )
Super B-factory options

KEKB/Belle

PEP-II/BaBar

"Super KEKB"/Belle2

SuperB

Search for new physics at Super-KEKB, SUSY09 (Boston) – June 2009
Crab cavities installed and undergoing testing in beam.

The superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW.

Higher current
More RF
New vacuum system

Aiming $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$

New IR
$\beta^*_y = \sigma_z = 3 \text{ mm}$

SuperKEKB

Damping ring

3.5 GeV
$e^- 9.4 \text{ A}$

8 GeV
$e^- 4.1 \text{ A}$

The beam pipes and all vacuum components will be replaced with higher-current design.

The state-of-art ARES copper cavities will be upgraded with higher energy storage ratio to support higher current.
Projected luminosity

Integrated Luminosity [10^{-1}ab]

- 50ab\(^{-1}\) by ~2020
- L\approx 8 \times 10^{35}
- 10ab\(^{-1}\) ~ 2016
- L\approx 2 \times 10^{35}
- 10's of Giga B and \(\tau\)

3year shutdown for upgrade
Strength: a very broad program...

**Discovery of CPV in B**


**Many new resonances**

- Belle, 2005
- AFB in B\(\rightarrow K^*\pi\)

**Evidence for B\(\rightarrow\tau\nu\)**


**b\(\rightarrow d\gamma\) transition**

- PRL 96, 251801 (2006)

**B\(\rightarrow D^*\tau\nu\)**


**D^0-D^0 mixing**


**Z(4430)**

- MC expectation (background)
- 449 M BB

**X(3872)**

- Discovery of CPV

**B\(\rightarrow\tau\nu\)**

- Phys. Rev. D71:071103, 2005
Search strategy – continue to squeeze

CKM UT triangle

Now

NP effect

$$\sin(2\phi_1) = 0.87^{+0.09}_{-0.09}$$ (Lunghi+Soni, hep-ph/08034340)

50 ab$^{-1}$

Search for new physics at Super-KEKB, SUSY09 (Boston) – June 2009
Search strategy – consistency

\[ \sin(2\beta_{\text{eff}}) \equiv \sin(2\phi_{\text{eff}}) \]

New CP phase

50 ab\(^{-1}\) Theory errors

Search for new physics at Super-KEKB, SUSY09 (Boston) – June 2009
### Search strategy – consistency

\[ C_f = -A_f \]

#### Table

<table>
<thead>
<tr>
<th>System</th>
<th>BaBar</th>
<th>Belle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K^0 )</td>
<td>-0.14 ± 0.19 ± 0.02</td>
<td>-0.31 ± 0.23 ± 0.09</td>
<td>-0.23 ± 0.15</td>
</tr>
<tr>
<td>( \phi K^0 )</td>
<td>-0.08 ± 0.06 ± 0.02</td>
<td>0.01 ± 0.07 ± 0.05</td>
<td>-0.05 ± 0.05</td>
</tr>
<tr>
<td>( K^0 K^+ K^- )</td>
<td>-0.16 ± 0.17 ± 0.03</td>
<td>-0.31 ± 0.20 ± 0.07</td>
<td>-0.23 ± 0.13</td>
</tr>
<tr>
<td>( K^0 \pi^0 K^+ K^- )</td>
<td>-0.14 ± 0.13 ± 0.06</td>
<td>0.01 ± 0.10</td>
<td>-0.05 ± 0.05</td>
</tr>
<tr>
<td>( K^0 \pi^0 K^+ K^- )</td>
<td>-0.05 ± 0.26 ± 0.10</td>
<td>0.13 ± 0.23 ± 0.11</td>
<td>0.01 ± 0.10</td>
</tr>
<tr>
<td>( K^0 \pi^0 K^+ K^- )</td>
<td>-0.03 ± 0.23 ± 0.11</td>
<td>0.01 ± 0.10</td>
<td>-0.06 ± 0.20</td>
</tr>
</tbody>
</table>

#### Diagram

Contour plots showing the relationship between \( \sin(2\beta_{\text{eff}}) \) and \( \sin(2\alpha_{\text{eff}}) \) with respect to \( C_{CP} = -A_{CP} \). The plots indicate exclusions at 90% C.L. for various decay modes: \( b \to c e \nu \), \( \phi K^0 \), \( \eta' K^0 \), \( K^0 K^0 \), \( K^0 K^0 \), \( K^0 K^+ K^- \), \( K^0 \pi^0 K^+ K^- \), \( K^0 \pi^0 K^+ K^- \), and \( K^0 \pi^0 K^+ K^- \).
Search – constrained observables

\[ A_{FB}(B \rightarrow K^* \ell^+ \ell^-) = -C_{10} \xi(q^2) \left[ Re(C_9) F_1 + \frac{1}{q^2} C_7 F_2 \right] \]

\[ B \rightarrow K^* \ell^+ \ell^- : A_{FB} \]

Forward

Backward

NP in \( C_{7,9,10} \)

50ab\(^{-1}\)

Y.-G. Xu et al., PRD74, 114019 (2006)
New observations – where SM \( \sim 0 \)

LFV processes forbidden in SM (even with \( \nu \) mixing \( \rightarrow \) negligible)
examples: \( \tau \rightarrow \ell \gamma \), \( \tau \rightarrow \ell \ h \), \( \tau \rightarrow \ell \ell \ell \)

\( \tau \rightarrow \ell \gamma \) : bkg from
\( \text{ee} \rightarrow \tau \tau \gamma \) (U.L. \( \propto 1/\sqrt{\mathcal{L}} \))

\( \tau \rightarrow \ell \ h \), \( \tau \rightarrow \ell \ell \ell \) : bgk free (U.L. \( \propto 1/L \))
example:
Higgs mediated LFV, \( \tau \rightarrow \mu \eta \)
sensitivity \( \sim 10^{-9} \) and \( \sim 7 \times 10^{-9} \) @ 50 ab\(^{-1} \)
Unambiguous NP

\[ \varphi \sim \frac{2 \eta A^2 \lambda^5}{\lambda} \sim O(10^{-3}) \]  
CPV in D system negligible in SM

CPV in interf. mix./decay:

\[ \text{Im} \frac{q}{p} \frac{A_f}{A_f} \equiv (1 + \frac{A_M}{2}) e^{i\varphi} \neq 0; \varphi \neq 0 \]

Currently \( \sim \pm 20^0 \)

50 ab\(^{-1}\) go below 2\(^0\)

D\(^0\)-mixing

**LFV, CPV in D/\(\tau\) : Clear Indication of New Physics !**
Part of combined approach

LHC, ILC

Higgs boson mass and couplings. New particle searches

ν expts accel, reactor, $g_\mu$-2, $\mu \rightarrow e\gamma$, etc.

ν mass and mixing, CPV, and LFV

τ LFV, CPV

Flavor mixing, CPV phases

Super B Factory, LHCb, BESIII, Rare K expts, …
Example complementarity

NP Flavor couplings

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

Diagonal: Energy frontier
(LHC, ILC)

Off-diagonal: Lum. Frontier
(Super BF, LHCb)

- Settle NP models
- Search higher scale NP

Super BF vs LHCb

S. Stone

Common

No IP

S. Stone

Preliminary

Search for new physics at Super-KEKB, SUSY09 (Boston) – June 2009
Motivation for $\mathbf{B^+ \rightarrow \tau^+ \nu}$

Sensitivity to new physics from charged Higgs if the B decay constant is known

$$B(B \rightarrow \tau \nu) = (0.78^{+0.09}_{-0.13}) \times 10^{-4}$$

The B meson decay constant, determined by the B wavefunction at the origin

$$\mathcal{B}(B^+ \rightarrow \tau^+ \nu_{\tau}) = \frac{G_F^2 m_B}{8\pi} m^2_{\tau} \left(1 - \frac{m^2_{\tau}}{m^2_B}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

(CKMfitter 2008 prediction)
Why measuring $B \to \tau \nu$ is non-trivial

The experimental signature is rather difficult: $B$ decays to a single charged track + nothing
Constraints on charged Higgs mass

Now

\[ r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta \right)^2 \]

\[ \mathcal{B}(B \to \tau \nu) = (1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4} \]

arXiv:0809.3834

With 50ab^{-1}

Search for new physics at Super-KEKB, SUSY09 (Boston) – June 2009
Summary

- Excellent performance of the B-factories
- Numerous, precise Physics Results → Hints of NP

Super B-factories: $L \sim 10^{36}, >50 \text{ ab}^{-1}$ data

Complementary to LHC(b)
SUSY may enter $b \rightarrow s$

**SUSY**

- With enough data an effect can be seen:

  O(1) processes allowed even if SUSY scale is above 2TeV

Many new phases are possible in SUSY
Models with Extra Dimensions

New Kaluza-Klein (K.K) particles are associated with the extra dimension ("Tower of states")

Some may induce new phases and flavor-changing neutral currents

e.g. K. Agashe, G. Perez, A. Soni, PRD 71, 016002 (2005)

<table>
<thead>
<tr>
<th>RS1</th>
<th>SM</th>
<th>( S_{B_d \to \psi} )</th>
<th>( S_{B_d \to K} )</th>
<th>( Br[b \to s l^+ l^-] )</th>
<th>( S_{B_{d,s} \to K^*} )</th>
<th>( S_{B_{d,s} \to \beta^*} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>O(1)</td>
<td>sin2(\beta) ± O(1)</td>
<td>( Br^{SM}[1 + O(1)] )</td>
<td>O(1)</td>
<td>O(1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Constant \( \varepsilon_K \)?

Model: K.K. Gluon near 3 TeV

+CPV in D decay