Search for New Physics at Super-B Factories

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Scenarios

- Super-B
- End of KEKB/PEP2
- Now
Scenarios

The diagram shows the integrated luminosity (fb⁻¹) for different years and scenarios. The current year is labeled as "now," and the end of KEKB/PEP2 is also indicated. The "Super-B" scenario is significantly higher, approximately 100 times greater than the current level. The KEK scenario is indicated as "~10 ab⁻¹." The bar graph is labeled with years 00, 02, 04, 06, and a question mark for the future year, "??."
Scenarios

- Now
- End of KEKB/PEP2
- Super-B

Integrated Luminosity (fb⁻¹)

Year

00 02 04 06 ??

- SLAC ~100ab⁻¹
- ~×1000
Goal

• look for non-SM physics in B decays:
  – CP Violating processes
  – EW penguin processes
  – rare b decays
This talk:

• Where we are now with $\sim 100 \text{ fb}^{-1}$.

• Where we will be with $\sim 500 \text{ fb}^{-1}$.

• What we could do with $\geq \sim 10 \text{ ab}^{-1}$.
CPV in the Standard Model

$$\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}$$

CPV phases are here

$V_{td}$

$V_{*td}$

$V_{*tb}$

$V_{tb}$

$b ightarrow u$ trees

$D^+, K^+, \pi^+$

$\pi, \rho, \ldots$

$B - \bar{B}$ mixing

$B^0$

$\bar{B}^0$

$b$
CKM unitarity triangle

Is that all there is?

• Does $\phi_1 + \phi_2 + \phi_3 = 180^\circ$ ?
• Are there non-SM CPV phases?
Does $\phi_1 + \phi_2 + \phi_3 = 180^\circ$?

Status and prospects
\[ \phi_1 (\beta) \]

phase of \( V_{td} \)
\( \phi_1(\beta) : \text{interfere } B \to f_{CP} \text{ with } B \leftrightarrow \bar{B} \to f_{CP} \)

Sanda, Bigi & Carter:

\( B^0 \) 

\( \propto V_{td}^* \propto \sin 2\phi_1 \) (aka \( \sin 2\beta \))

theory errors \( \sim 1\% \)
What do we measure?

- Flavor-tag decay
  \( (B^0 \text{ or } \bar{B}^0 ?) \)

- More \( B \) tags
- More \( \bar{B} \) tags

Now an established & well understood expt'l technique
Belle and BaBar World Avg for sin (2 $\phi_1$)

$\sin^2 \phi_1$ (BaBar)
$= 0.741 \pm 0.067 \pm 0.033$

$\sin^2 \phi_1$ (Belle)
$= 0.719 \pm 0.074 \pm 0.035$

$\sin^2 \phi_1$ (World Av.)
$= 0.734 \pm 0.055$

theory errors $\sim 1\%$
by 2006, $\phi_1 (\beta)$ will be in good shape (ie, close to theory errors)

how about $\phi_2 (\alpha)$?

$180^\circ$ – phase of $V_{td} V_{ub}$
$\phi_2 (\alpha)$ from $B \to \pi^+\pi^-$

$B^0 \to \pi^+ \pi^-$

$V_{ub} \propto \sin^2 \alpha$ (aka $\sin 2\alpha$)

$B^0 \to V_{td}^* V_{ub}^2 \propto \sin 2\phi_2$
Must deal with “Penguin Pollution”
i.e. additional, non-tree amplitudes

\[ R_q(\Delta t) \propto 1 + q \left[ A_{\pi \pi} \cos(\Delta m \Delta t) + S_{\pi \pi} \sin(\Delta m \Delta t) \right] \]

- \(q = +1 \rightarrow B^0\) tag
- \(-1 \rightarrow \overline{B}^0\) tag
Current status of $\phi_2 (\alpha)$ measurements

$A_{\pi\pi} = +0.30 \pm 0.25 \pm 0.04$

$S_{\pi\pi} = 0.02 \pm 0.34 \pm 0.05$

Consistent with (0,0)

$A_{\pi\pi} = +0.94 \pm 0.25 \pm 0.09$

$S_{\pi\pi} = -1.21$ +0.38 +0.16

~2.5σ from (0,0) !!!
$\phi_2$ precision depends on the strong phase $\delta$

$A_{\pi\pi}$ is large

$\pm 5^\circ \sim 10^\circ$ is possible??

$A_{\pi\pi}$ small

$S_{\pi\pi}$

$\beta = 26^\circ, b_c = 7.7$

$\delta$

will require all $B \to \pi \pi$ Br's
$\phi_3 (\gamma)$

phase of $V_{ub}$
Strategies for $\phi_3$

Gronau, London, Wyler

$V_{cb}$

$\lambda^2$

$D^0 \to CP$

$\lambda^3$

$\bar{D}^0 \to CP$

$A_{max} \sim 2R \sim 0.2$

@ 31 fb$^{-1}$

23 CP-even evts

26 CP-odd evts

$A = 0.25 \pm 0.19$

@ 500 fb$^{-1}$: $\delta A/A_{max} \to \sim 0.3$
Strategies for $\phi_3$ (cont’d)

Atwood, Dunietz, Soni

\[ A_{\text{max}} \sim 1; \text{ but rate is small} \]

\[ 80 \text{ fb}^{-1}: \]

Only $\sim 15$ $D^0\pi$ evts, Cabibbo-suppressed $D^0K$ down by $\sim 1/20$

This strategy is very clean but requires lots & lots of data
Does $\phi_1 + \phi_2 + \phi_3 = 180^\circ$?

My estimate for BaBar & Belle (~500 fb$^{-1}$ each):

$\delta\phi_1 \sim 1^\circ$

$\delta\phi_2 \sim 5^\circ \rightarrow 10^\circ$

$\delta\phi_3 \sim 25^\circ$

statistics limited
Are there non-SM CPV phases?
Measure $\sin^2\phi_1^{\text{eff}}$ using loop-dominated processes:

**Example:**

$$B \to \eta', K^+K^-$$

**SM:** $\sin^2\phi_1^{\text{eff}} = \sin^2\phi_1$ from $B \to J/\psi K_S$

unless there are other, non-SM particles in the loop
similar to $\mu(g-2)$

look for effects of heavy new particles in a well understood SM loop process

$\mu(g-2)$:

$\sin 2\phi_1^{\text{eff}}$:

SM loop particle: $\gamma$

look for ppm effects

SM loop particles: $t$ & $W$

look for pp1 effects (i.e.~$100\%$)

lowest-order SM diagrams
These channels are very clean & the techniques are understood

Won’t reach experimental limits until ~100 x more data
Hunting for new phases in $b \to s$ penguins

**$\sin 2\phi_1^{\text{eff}}$ results:** (target = $\sin 2\phi_1 = +0.72 \pm 0.05$)

(Amsterdam 2002)

<table>
<thead>
<tr>
<th>channel</th>
<th>BaBar</th>
<th>Belle</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \to \eta'K_S$</td>
<td>+0.76 ± 0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B \to K^+K^-K_S$</td>
<td>+0.52 ± 0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B \to \phi K_S$</td>
<td>-0.19 ± 0.52</td>
<td>-0.73 ± 0.66</td>
<td>-0.39 ± 0.41</td>
</tr>
</tbody>
</table>

2.7σ off
a SuperB target:

\[ \sin 2\phi_1^{\text{eff}} \]

with a precision

\[ \approx \text{theory errors} \]

\[ (\sim 5\%) \]

requires \[ \approx 10 \text{ ab}^{-1} \]
physics with EW penguins

(loops with virtual t’s, W’s, & Z’s)

\[ B \rightarrow K l^+ l^-, \quad K^* l^+ l^-, \quad \& X_s l^+ l^- \]
$A_{FB} (B \rightarrow K^* \ l^+ l^-)$ is very sensitive to new physics not yet established.

Polar angle of lepton in dilepton rest frame.

current status

with 80 fb\(^{-1}\)

\(B \rightarrow X_s l^+ l^-\)

K\(^*l^+l^-\) is still not established.

with \(~500\text{fb}^{-1}\), it will likely look about like this

Rates consistent with the SM. Statistics are low
\[ \sin 2\phi_1^{\text{eff}} \text{ for } B \to K_S l^+l^- \]

do SM weak phases:

\[ \therefore \, \sin 2\phi_1^{\text{eff}} (K_S ll) = \sin 2\phi_1 (J/\psi K_S) \text{ (in SM)} \]

requires \( \approx 100 \text{ ab}^{-1} \)
Summary

• Current B-factories will (probably):
  – establish CKM mechanism
    • measure $\phi_1 (\beta)$ with good precision
    • make crude 1st measurements of $\phi_2 (\alpha)$ and $\phi_3 (\gamma)$
    • test $\sin^2 \phi_1^{\text{eff}}(\text{loops}) = \sin^2 \phi_1 (J/\psi K_S)$ with $\sim 20\%$ precision
  – establish $B \rightarrow K l^+ l^-, X_s l^+ l^-, & K^* l^+ l^-$
    • measure rates and $m(l^+ l^-)$ distributions

• Super B factories will allow:
  – measurements near theory limits of
    • $\phi_2 (\alpha)$ & $\phi_3 (\gamma)$ (and other CKM parameters)
    • $\sin^2 \phi_1^{\text{eff}}(\text{loops})$ in $B \rightarrow K \phi, K \eta', X_s \gamma (\sim 5\% \text{ precision})$
  – quantitative tests of SM with EW penguins
    • $m(l^+ l^-)$ and $l^+ l^-$ asymmetries for $K^* l^+ l^-$, etc
    • $\sin^2 \phi_1^{\text{eff}}(\text{loops})$ measurements for $B \rightarrow K_s l^+ l^-$
  – searches for rare B decays
    • $B \rightarrow \tau \tau, \tau \nu, K \nu \nu, \mu \epsilon$, etc
### Some comparisons
(numbers of evts)

<table>
<thead>
<tr>
<th>mode</th>
<th>CDF</th>
<th>BTeV</th>
<th>Atlas CMS</th>
<th>e^+e^- 0.5ab^-1</th>
<th>e^+e^- 10 ab^-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>K^*γ</td>
<td>170</td>
<td>25K</td>
<td>6K</td>
<td>120K</td>
<td></td>
</tr>
<tr>
<td>ρ(ω)γ</td>
<td></td>
<td></td>
<td>300</td>
<td>6K</td>
<td></td>
</tr>
<tr>
<td>X_sγ</td>
<td></td>
<td></td>
<td>11K</td>
<td>220K</td>
<td></td>
</tr>
<tr>
<td>X_sμ^+μ^-</td>
<td></td>
<td>3.6K</td>
<td>300</td>
<td>6K</td>
<td></td>
</tr>
<tr>
<td>X_s e^+e^-</td>
<td></td>
<td></td>
<td>350</td>
<td>7K</td>
<td></td>
</tr>
<tr>
<td>K^*μ^+μ^-</td>
<td>150</td>
<td>4.5K</td>
<td>4.2K</td>
<td>120</td>
<td>2.4K</td>
</tr>
<tr>
<td>K^* e^+e^-</td>
<td></td>
<td></td>
<td>150</td>
<td>3K</td>
<td></td>
</tr>
<tr>
<td>X_s γγ</td>
<td></td>
<td></td>
<td>8</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>K^* γγ</td>
<td></td>
<td></td>
<td>1.5</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

(from D. Hitlin)
# Super KEKB design parameters

## Machine Parameters of the SuperKEKB

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LER</th>
<th>HER</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Emittance</td>
<td>33</td>
<td>33</td>
<td>nm</td>
</tr>
<tr>
<td>Vertical Emittance</td>
<td>2.1</td>
<td>2.1</td>
<td>nm</td>
</tr>
<tr>
<td>x-y coupling</td>
<td>6.4</td>
<td>6.4</td>
<td>%</td>
</tr>
<tr>
<td>Beam current</td>
<td>9.4</td>
<td>4.1</td>
<td>A</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>5018 (2% abort gap)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bunch current</td>
<td>1.87</td>
<td>0.817</td>
<td>mA</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>0.6</td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Half crossing angle</td>
<td>15</td>
<td></td>
<td>mrad</td>
</tr>
<tr>
<td>Luminosity reduction $R_l$</td>
<td>0.748</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta_x$ reduction $R_{\delta x}$</td>
<td>0.691</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta_y$ reduction $R_{\delta y}$</td>
<td>0.916</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bunch length</td>
<td>3</td>
<td>3</td>
<td>mm</td>
</tr>
<tr>
<td>Radiation loss $U_0$</td>
<td>1.23</td>
<td>3.48</td>
<td>MeV/turn</td>
</tr>
<tr>
<td>Betatron tune $V_x / V_y$</td>
<td>45.515 / 43.57 ?</td>
<td>44.515 / 41.57 ?</td>
<td></td>
</tr>
<tr>
<td>beta's at IP $\beta^*/\beta_y$</td>
<td>15 / 0.3</td>
<td>15 / 0.3</td>
<td>cm</td>
</tr>
<tr>
<td>beam-beam parameters $\xi_\perp / \xi_y$</td>
<td>0.068 / 0.05</td>
<td>0.068 / 0.05</td>
<td></td>
</tr>
<tr>
<td>Beam lifetime</td>
<td>~150</td>
<td>~150</td>
<td>min.</td>
</tr>
<tr>
<td>Luminosity</td>
<td>1.0</td>
<td></td>
<td>$10^{35}$/cm$^2$/sec</td>
</tr>
</tbody>
</table>


# Super-PEP II

## Parameter Set for $\mathcal{L}=10^{36}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam particle</td>
<td>$e^+$</td>
<td>$e^-$</td>
</tr>
<tr>
<td>Beam energy (GeV)</td>
<td>8.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Circumference (m)</td>
<td></td>
<td>2200</td>
</tr>
<tr>
<td>Number of bunches</td>
<td></td>
<td>7000</td>
</tr>
<tr>
<td>Bunch length (mm)</td>
<td></td>
<td>1.75</td>
</tr>
<tr>
<td>Beam lifetime (min)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Beam current (A)</td>
<td>10.3</td>
<td>23.5</td>
</tr>
<tr>
<td>Beta * (x/y) (mm)</td>
<td></td>
<td>150/1.5</td>
</tr>
<tr>
<td>Emittances (x/y) ($\pi$nm)</td>
<td></td>
<td>44/0.44</td>
</tr>
<tr>
<td>IP beam sizes ($\mu$m x/y)</td>
<td></td>
<td>81/0.8</td>
</tr>
<tr>
<td>Beam-beam tune shifts</td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>RF Frequency (MHz)</td>
<td></td>
<td>952</td>
</tr>
<tr>
<td>Luminosity ($cm^{-2}/s^{-1}$)</td>
<td></td>
<td>$10^{36}$</td>
</tr>
<tr>
<td>Wall plug power (MW)</td>
<td></td>
<td>$\approx 110$</td>
</tr>
</tbody>
</table>

*U. Wienands, SLAC-PEP-II*  
*Belle High $\mathcal{L}$Workshop, 7-Aug-02*
Situation similar to (better than?) $g$-2

- well defined technique & target
  - theory & expt’l errors are well controlled
  - errors on SM expectations are small (~5%)

- SM terms are highly suppressed
  - SM loops contain t-quarks & W-bosons
  - ∴ effects of heavy non-SM particles can be large

$g$-2:

lowest-order
SM diagram

looking for ppm effects
BaBar/Belle $\phi_2$ precision will depend on the answer

$$\pm \sim 10^\circ$$ is possible

$A_{\pi\pi}$ large

$A_{\pi\pi}$ small

will require all $B \to \pi\pi$ Br’s