Superb prospects:
Physics at Belle II/SuperKEKB

cf G. Varner, talk 3H-1
SuperKEKB & Belle II projects

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Primary goal: establish unitarity & complex phase of CKM matrix

Kobayashi & Maskawa (1973)
- propose 3rd generation of particles
- Explain CP violation in K, predict for B
Primary goal: establish unitarity & complex phase of CKM matrix

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• propose 3\textsuperscript{rd} generation of particles
• Explain CP violation in K, predict for B

B-Factories (1999–)
• CP asymmetry manifested in diverse processes in B decay
  \( \rightarrow \) many measurements, (over)constrain CKM, found consistent with unitarity
Advantages of $e^+e^-$: $\gamma$, $K_L$ detection; hermeticity $\rightarrow$ neutrinos

This talk: focus on prospects that are unique to high-lum $e^+e^-$
Flavor - (i.e. wrt weak interaction) essential properties:
• L-R asymmetry
• unitarity of charged current coupling matrix
• 3 generations
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Discovery & phenomenology
• maximal P violation [V-A]
• unitarity: GIM → charm
• CP violation → Kobayashi-Maskawa → 3rd generation
• B mixing → high mass t-quark (imperfect loop cancellation)
Why a Super-B-factory? Role of Flavor in SM history

Flavor - (i.e. wrt weak interaction) essential properties:
- L-R asymmetry
- unitarity of charged current coupling matrix
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Bottom line: flavor in SM imposes cancellations & precise relationships that both test SM and constrain New Physics (NP) to higher mass scales
- “Unitarity triangle” [18 dof → 4 dof ]
- lepton universality
Search for Right-Handed Currents
Right-handed currents

in SM

$B^0 \rightarrow X_s \gamma$ is

~flavor-specific ($\gamma$ polarization)

$\rightarrow$ low CP-asymmetry, $O(3\%)$

$O(0)$ for $B^0 \rightarrow X_d \gamma$

Atwood, Gronau, Soni (PRL 79, 185 (1997))
Atwood, Gershon, Hazumi, Soni (PRD 71, 076003 (2005))

large asymmetry

$\leftrightarrow$

right-handed current
**Right-handed currents**

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\leftrightarrow

right-handed current

Current results:

consistent with no RH currents (S\~\text{<}30\%)
Possible contributions from NP
- $O(1)$: Warped extra dimensions
- $O(1)$: L-R symmetric model
- $O(0.1)$: SUSY SU(5)

with 50 $ab^{-1}$
- $\Delta S(K^{*0}\gamma) = 0.027$
- $\Delta S(\rho^0\gamma) = 0.075$
Search for CP Anomalies
CP asymmetry: “standard” $\sin 2\varphi_1$ ($\sin 2\beta$)

for $B \rightarrow J/\psi K_S$

**Tree (real $V_{ij}$)** $\propto V_{cb}^* V_{cs}$

**Mixing+Tree** $\propto V_{tb}^{*2} V_{td}^{*2} V_{cb} V_{cs}^*$

Well-measured rate

Phase $= \arg(V_{tb}^{*2} V_{td}^{*2}) = 2\varphi_1$

**Identical hadronic processes $\rightarrow$ same $|Amplitude|$**

$V_{cb}^* V_{cs}$ real $\Rightarrow$ zero phase difference

$\Rightarrow$ relative phase $= 2\varphi_1$, CP asymmetry $\sim \sin 2\varphi_1$
CP asymmetry: “other” \( \sin 2\phi_1 \)

for \( b \to s\bar{s}s \): identical reasoning

\[
\text{Direct (real } V_{ij}) \propto V_{tb}^* V_{ts}
\]

\[
\text{mixing+direct } \propto V_{tb}^* V_{td}^* V_{tb} V_{ts}^*
\]

\[V_{tb}^* V_{ts}\text{ real } \Rightarrow \text{zero phase difference}\]

\[\Rightarrow \text{relative phase } = 2\phi_1,\]

\( CP \text{ asymmetry } \sim \sin 2\phi_1 \)

w/ minor theory corrections
$CP$ asymmetry: “other” $\sin 2\varphi_1$

for $b \to s\bar{s}s$: identical reasoning

$$\text{tree (real } V_{ij}) \propto V_{tb}^* V_{ts}$$

$$\text{mixing+tree } \propto V_{tb}^* V_{td}^* V_{tb} V_{ts}$$

$V_{tb}^* V_{ts}$ real $\Rightarrow$ zero phase difference

$\Rightarrow$ relative phase $= 2\varphi_1$, $CP$ asymmetry $\sim \sin 2\varphi_1$

$NP$ process $w$ complex phase $\varphi_{\text{new}}$

$\Rightarrow CP$ asymmetry $\neq \sin (2\varphi_1)$
Naïve World Average
\[ \sin^2 \varphi_1 (b \to sqq) = 0.64 \pm 0.04 \]

Compare to \(cc\):
\[ \sin^2 \varphi_1 (b \to ccs) = 0.679 \pm 0.020 \]

\[ CL = 0.28 \ (1.1\sigma) \]

Sensitivity to NP depends on
- statistics
- reduced systematics
- theory corrections
Leptons
Precision measurement & Universality
In SM, $B \rightarrow \tau \nu_{\tau}$ BF is predicted precisely

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

**CKMfitter:**
2.8σ “tension”

$B(B \rightarrow \tau \nu_{\tau}), \sin 2\phi_1$ vs all other CKM constraints
$B^{+} \rightarrow \tau^{+}\nu_{\tau}$: constraints on charged Higgs

\[
\mathcal{B}(B \rightarrow \tau\nu) = \mathcal{B}(B \rightarrow \tau\nu)_{\text{SM}} \times r_{H}
\]
\[
r_{H} = \left(1 - \frac{m_{B}^{2}}{m_{H}^{2}} \tan^{2} \beta\right)^{2}
\]

(2HDM)

(Belle) 0.65 ab$^{-1}$

\[
\mathcal{B}(B \rightarrow \tau\nu) = (1.7 \pm 0.4 \pm 0.4) \times 10^{-4}
\]

(extrapolation) 50 ab$^{-1}$

\{WS Hou, PRD 48, 2342 (1993)\}
**B Factories versus LHC (ATLAS) for the charged Higgs**

Current flavour constraints are already very competitive with LHC expected direct search sensitivity for charged Higgs.

$B \rightarrow \mu \nu$

$SM:\nB(B \rightarrow \tau \nu) = 1.6 \times 10^{-4}\nB(B \rightarrow \mu \nu) = 7.1 \times 10^{-7}\nB(B \rightarrow e \nu) = 1.7 \times 10^{-11}\n$
**SM:**

- $B(B\rightarrow\tau\nu) = 1.6 \times 10^{-4}$
- $B(B\rightarrow\mu\nu) = 7.1 \times 10^{-7}$
- $B(B\rightarrow e\nu) = 1.7 \times 10^{-11}$

Deviation from SM sensitive to NP

Observation with $\sim 5$ ab$^{-1}$
Lepton universality via semileptonic decays

\[ m_b \tan \beta + m_c \cot \beta \]

- Ratio (\( \tau / \mu \)) is sensitive to charged Higgs (similar to \( B \rightarrow \tau \nu \))
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- Ratio (\( \tau/\mu \)) is sensitive to charged Higgs (similar to \( B \rightarrow \tau \nu \))

\( B \rightarrow \tau X \) decays probe NP in different ways:

- \( B \rightarrow \tau \nu \): H-b-u vertex
- \( B \rightarrow D \tau \nu \): H-b-c vertex
$B \rightarrow D^{(*)} \tau \nu$

- $\frac{B(B \rightarrow D^{*-} \tau \nu)}{B(B \rightarrow D^{*-} \ell \nu)} = R_\tau = 0.29 \pm 0.10$ [PDG 2011]

\[ B = \frac{\Gamma(B \rightarrow D\tau\nu_{\tau})}{\Gamma(B \rightarrow D\mu\nu_{\mu})} \]

$M_H$ vs $\tan \beta$ sensitivity

$H^+/W^+$

$\tan \beta$

$\nu_\tau$

$
\begin{align*}
m_b \tan \beta &+ m_c \cot \beta \\
H^+ &/ W^+ \end{align*}$

$\tau^+$

$\nu_\tau$

$\tan \beta$

$M_H$ vs $\tan \beta$ sensitivity

LEP Excluded (95% C.L.)

Tevatron Run I Excluded (95% C.L.)

$B \rightarrow D^{\tau} \nu_{\tau}$

$B \rightarrow D^{\tau} \nu_{\tau}$
Charm
• Mixing/CP
D mixing/CP violation

Current status (HFAG)

$MC \ 75 \ ab^{-1}$

$|q/p|=0.9$

$\sim 4\sigma \ on \ 1-|q/p|$
what we need:
Billions
and
Billions
of B’s!

SuperKEKB & Belle II
(cf G. Varner, talk 3H-1)
Summary

• B-factories 1999-2010, >1.4x10^9 B pairs:
  established CKM as source of CP asymmetry in weak interaction
  multiple measurements on CKM with increasing precision
  -> probe New Physics at ~ few hundred GeV scale
  + discoveries: D mixing, new hadronic states
  possible hints of NP: Kπ CP asymmetry, imperfect CKM fit

• ~10^2X luminosity will probe significantly into >1 TeV mass scale
  precision CKM, CP, lepton universality, LFV
• SuperKEKB/Belle II well underway
  complementary to LHC in sensitivity