New Physics Search in B Decays (Leptonic and Neutrino Modes) & Super B Factory

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Heavy Quark and Leptons 2006 Munich
Talk Outline + Appology

- Introduction
- $B \rightarrow l\nu (\tau\nu, \mu\nu, e\nu, l\nu\gamma)$
- $B \rightarrow l l (e e, \mu\mu, \tau\tau, l l\gamma)$
- $B \rightarrow K(*)\nu\nu, \nu\nu$

- Super KEKB

Appology:
Due to limited time, some of them cannot be mentioned or have to be put in backup.
Introduction

- If New Physics found at LHC at TeV scale, they must appear in loops as well and change amplitudes.

- It is easier to see the effects when SM amplitudes are small (or zero).

- B decay has many patterns to test the effects.

**Rare Decays!!**
Hunting Rare Decays

In 1993...

CLEO
First evidence of $B \rightarrow K^* \gamma$

PRL 71, 674 (1993)
Hunting Rare Decays

- High luminosity
- Good detector (PID, vertex...)
- Analysis techniques
  - qq background suppression
  - Fully reconstructed tag

Evidence of $B \rightarrow \tau \nu$

Observation of $b \rightarrow d \gamma$

FB asymmetry in $B \rightarrow K^* \ell^+ \ell^-$

Direct CPV in $B^0 \rightarrow K^+ \pi^-$

Beginning of $B \rightarrow \phi K^0$ saga

Observation of $B \rightarrow K \ell^+ \ell^-$

CPV in B decay

Success of B factories brought rare B decays in leptonic and neutrino modes on the stage!
Proceed via W annihilation in the SM.

SM Branching fraction

\[ \mathcal{B}(B^\to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_{\ell}^2}{8\pi} \left(1 - \frac{m_{\ell}^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B \]

Provide \( f_B |V_{ub}| \)

In two Higgs doublets model, charged Higgs exchange interferes with the helicity suppressed W-exchange.

\[ \text{Br} = \text{Br}_{\text{SM}} \times r_H, \quad r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta\right)^2 \]

If \( \mu \nu \) is also measured, lepton universality can be tested.
\( \to \) SUSY correction etc.

\( \text{Br}(\tau \nu)=1.6 \times 10^{-4} \)
\( \text{Br}(\mu \nu)=7.1 \times 10^{-7} \)
\( \text{Br}(e \nu)=1.7 \times 10^{-11} \)
Full Reconstruction Method

- Fully reconstruct one of the B’s to tag
  - B production
  - B flavor/charge
  - B momentum

Single B meson beam in offline!

Powerful tools for B decays w/ neutrinos
**B$\to\tau\nu$ Analysis**

- **Extra neutral energy in calorimeter $E_{ECL}$**
  - Most powerful variable for separating signal and background
  - Total calorimeter energy from the neutral clusters which are not associated with the tag $B$

\[
E_{ECL} = E_{tot} - E_{rec.\ B} \quad (\pi^0 \quad \text{for } \pi^+\pi^-\pi^0\nu)
\]

- **Minimum energy threshold**
  - **Barrel**: 50 MeV
  - **Forward endcap**: 100(150) MeV

- **Zero or small value of $E_{ECL}$ arising only from beam background**

- **Higher $E_{ECL}$ due to additional neutral clusters**

- **MC includes overlay of random trigger data to reproduce beam backgrounds.**
The final results are deduced by unbinned likelihood fit to the obtained $E_{ECL}$ distributions.

Signal shape: Gauss + exponential
Background shape: second-order polynomial

$B \rightarrow \tau \nu$

Observe 17.2 $^{+5.3}_{-4.7}$ events in the signal region.
Significance decreased to 3.5 $\sigma$ after including systematics
Results (Br & f_B Extraction)

- Measured branching fraction:

\[ \text{Br}(B \to \tau\nu) = \left( 1.79 \pm 0.56 \pm 0.46 \right) \times 10^{-4} \]

- Product of B meson decay constant \( f_B \) and CKM matrix element \( |V_{ub}| \)

\[ f_B |V_{ub}| = \left( 10.1 \pm 1.6 \pm 1.3 \right) \times 10^{-4} \text{GeV} \]

- Using \( |V_{ub}| = (4.39 \pm 0.33) \times 10^{-3} \) from HFAG

\[ f_B = 0.229 \pm 0.036 \pm 0.034 \text{ GeV} \]

\[ 15\% \quad 16\% = 14\%(\text{exp.}) + 8\%(V_{ub}) \]

\[ f_B = 216 \pm 22 \text{ MeV} \]

[HPQCD, Phys. Rev. Lett. 95, 212001 (2005)]
Correction to the FPCP06 result

- Error in the efficiency calculation.
  - Due to a coding error, the efficiency quoted in the 1st Belle preliminary result was incorrect.

- Treatment of the peaking background component.
  - Peaking component is subtracted for the central value.
  - Re-evaluate its systematic uncertainty.

- The data plots and event sample are unchanged. However, $f_B$ and the branching fraction must be changed.

\[
\text{New value: } \quad BF(B^+ \rightarrow \tau^+\nu_\tau) = (1.79^{+0.56+0.39}_{-0.49-0.46}) \times 10^{-4}
\]

The revised paper has been resubmitted, and posted as hep-ex/0604018v2.
B → τν Search @ Babar

- Babar searches for in a sample of 324x10^6 BB events
  - Reconstruct one B in a semileptonic final state B → DlνX
    - D → K π, K π π π, K π π, K_s π π (X=γ, π from D^*0 is not explicitly reconstructed)
    - Require lepton CM momentum > 0.8 GeV
    - Require that -2 < cos(q_{B-Dl}) < 1
    - Parent B energy and momentum are determined from the beam energy
  - Tagged B reconstruction efficiency ~0.7%

- Discriminate signal from background using E_{extra}
  - τ lepton is identified in the 4 decay modes
    - τ → μ⁻ν̅ν, e⁻ν̅ν,
    - π⁻ν, π⁻π⁰ν

In the graph:
- Events/0.1 GeV
- Preliminary
- Sideband

**Babar**
B → τν Search @ Babar (cont.)

- Observed excess is not significant yet (1.3σ), and set a limit on the branching fraction and quote a central value.

<table>
<thead>
<tr>
<th>Selection</th>
<th>Background</th>
<th>Observed</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>μ⁻ν_μν_τ</td>
<td>41.9 ± 5.2</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>e⁻ν_eν_τ</td>
<td>35.4 ± 4.2</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>π⁻ν_τ</td>
<td>99.1 ± 9.1</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>π⁻π⁰ν_τ</td>
<td>15.3 ± 3.5</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>All modes</td>
<td>191.7 ± 11.8</td>
<td>213</td>
<td></td>
</tr>
</tbody>
</table>

\[ \mathcal{B}(B \to \tau \nu) < 1.8 \times 10^{-4} \text{ (90\% C.L.)} \]

\[ \mathcal{B}(B \to \tau \nu) = (0.88^{+0.68}_{-0.67} \text{ (stat)} \pm 0.11 \text{ (syst)}) \times 10^{-4} \]

Deduced \( f_B |V_{ub}| \)

\[ f_B \cdot |V_{ub}| = (7.0^{+2.3}_{-3.6} \text{ (stat)}^{+0.4}_{-0.5} \text{ (syst)}) \times 10^{-4} \text{ GeV} \]
### Constraints on Charged Higgs

\[
Br_{\text{exp}} = (1.79^{+0.56}_{-0.49}^{+0.46}_{-0.51}) \times 10^{-4}
\]

\[
Br_{\text{SM}} = (1.59 \pm 0.40) \times 10^{-4}
\]

\[
f_B \text{ from HPQCD}
\]

\[
|V_{ub}| \text{ from HFAG}
\]

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

\[
= \frac{Br_{\text{exp}}}{Br_{\text{SM}}} = 1.13 \pm 0.53
\]

These regions are excluded.

Much stronger constraint than those from energy frontier exp's.
Future Prospect: $B \to \tau \nu$

- Br($B \to \tau \nu$) measurement:
  More luminosity help to reduce both stat. and syst. errors.
  - Some of the syst. errors limited by statistics of the control sample.

- $|V_{ub}|$ measurement: $< 5\%$ in future is an realistic goal.

- $f_B$ from theory: $\sim 10\%$ now $\rightarrow 5\%$?
  My assumption $\Delta f_B(LQCD) = 5\%$

| Lum.   | $\Delta B(B \to \tau \nu)_{exp}$ | $\Delta |V_{ub}|$ |
|--------|----------------------------------|----------------|
| 414 fb$^{-1}$ | 36$\%$                          | 7.5$\%$       |
| 5 ab$^{-1}$    | 10$\%$                          | 5.8$\%$       |
| 50 ab$^{-1}$   | 3$\%$                           | 4.4$\%$       |

Higgs Mass (GeV/c$^2$)

- If $\Delta |V_{ub}| = 0$ & $\Delta f_B = 0$

Br($B \to \tau \nu$)/$\Delta m_d$ to cancel $f_B$?
G.Isidori&P.Paradisi, hep-ph/0605012

Preliminary
$B \rightarrow \mu \nu, e \nu$

- **BaBar @ 208.7 fb$^{-1}$**
  - w/ fully reconstructed tag:
  - $B \rightarrow D^{(*)} X$.

- **Belle @ 140 fb$^{-1}$**
  - w/ "inclusive" reconstruction of the companion $B$.

Nobs = 0 in the signal box.

$$\text{Br}(B \rightarrow e \nu) < 7.9 \times 10^{-6}$$
$$\text{Br}(B \rightarrow \mu \nu) < 6.2 \times 10^{-6}$$
@90% C.L.

$$\text{Br}(B \rightarrow e \nu) < 5.4 \times 10^{-6} (60 \text{ fb}^{-1})$$
$$\text{Br}(B \rightarrow \mu \nu) < 2.6 \times 10^{-6} (140 \text{ fb}^{-1})$$
@90% C.L.
Future Prospect: $B \to \mu \nu$

- $B \to \mu \nu$ is the next milestone decay mode.
- Measurements will offer a cross check to the results obtained by $B \to \tau \nu$.
  - $f_B |V_{ub}|$ determination.
  - Test the lepton universality.

Method?
- Inclusive-recon method has high efficiency but poor S/N.
  \[ \text{limit} \propto \frac{1}{\sqrt{L}} \]
- Hadronic tag will provide very clean and ambiguous signals, but very low efficiency.
  \[ \text{limit} \propto \frac{1}{L} \]

Extrapolation from the present Belle analysis (inclusive-recon.)

- $3\sigma$ at $1.3\,\text{ab}^{-1}$
- $5\sigma$ at $3.7\,\text{ab}^{-1}$

See also talk by Robertson at CERN flavour WS (May 2006)
$B^0 \rightarrow \ell^+\ell^-$

- Proceeds via box or penguin annihilation
- SM Branching fractions
  \[ \text{Br}(B^0_d \rightarrow e^+e^-) \sim 10^{-15} \]
  \[ \text{Br}(B^0_d \rightarrow \mu^+\mu^-) \sim 10^{-10} \]
  \[ \text{Br}(B^0_d \rightarrow \nu\bar{\nu}) = \text{zero} \]

Flavor violating channel ($B^0 \rightarrow e^+\mu^-$, etc.) are forbidden in SM.

- New Physics can enhance the branching fractions by orders of magnitude.
  ex.) loop-induced FCNC Higgs coupling

Note:
\[ \frac{\text{Br}(B_s \rightarrow \ell\ell)}{\text{Br}(B_d \rightarrow \ell\ell)} = \left( \frac{V_{ts}}{V_{td}} \right)^2 \approx 25 \]
\[ \frac{\text{Br}(B \rightarrow \tau\tau)}{\text{Br}(B \rightarrow \mu\mu)} = \left( \frac{m_\tau}{m_\mu} \right)^2 \approx 300 \]

Present CDF limit; \[ \text{Br}(B_s \rightarrow \mu\mu) < 1 \times 10^{-7} \ (95\% \text{CL}) \]
is equivalent to \[ \text{Br}(B_s \rightarrow \mu\mu) < 4 \times 10^{-9} \].

$B \rightarrow \tau\tau$ requires full-reco. tag.
$B^0 \rightarrow \ell^+\ell^-$ ($e^+e^-, \mu^+\mu^-, e^+\mu^-$)

Signal regions

Events observed

<table>
<thead>
<tr>
<th>channel</th>
<th>$N_{\text{obs}}$</th>
<th>$N_{\text{exp}}^{\text{bg}}$</th>
<th>$\varepsilon$</th>
<th>$B_{UL}(B^0 \rightarrow \ell^+\ell^-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow e^+e^-$</td>
<td>0</td>
<td>$0.71 \pm 0.31$</td>
<td>21.8 $\pm$ 1.2</td>
<td>$6.1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow \mu^+\mu^-$</td>
<td>0</td>
<td>$0.72 \pm 0.26$</td>
<td>15.9 $\pm$ 1.1</td>
<td>$8.3 \times 10^{-8}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow e^+\mu^-$</td>
<td>2</td>
<td>$1.29 \pm 0.44$</td>
<td>18.1 $\pm$ 1.2</td>
<td>$18 \times 10^{-8}$</td>
</tr>
</tbody>
</table>


$B(B^0 \rightarrow e^+e^-) < 6.1 \times 10^{-8} \ (90\% \text{CL})$
$B(B^0 \rightarrow \mu^+\mu^-) < 8.3 \times 10^{-8} \ (90\% \text{CL})$
$B(B^0 \rightarrow e^+\mu^-) < 18 \times 10^{-8} \ (90\% \text{CL})$


$B(B^0 \rightarrow e^+e^-) < 1.9 \times 10^{-7} \ (90\% \text{CL})$
$B(B^0 \rightarrow \mu^+\mu^-) < 1.6 \times 10^{-7} \ (90\% \text{CL})$
$B(B^0 \rightarrow e^+\mu^-) < 1.7 \times 10^{-7} \ (90\% \text{CL})$

B($B^0_d \rightarrow \mu^+\mu^-$) < $2.3 \times 10^{-8} \ (90\% \text{CL})$

It would be interesting to see results with more data. What about $\Upsilon(5S)$ data at Super-B?
$B^0 \rightarrow l l \gamma$ (BaBar@ 292 fb$^{-1}$)

- 320 M BB events
- $0.3 < m_{ll} < 4.9$ (4.7) GeV for $e e \gamma$ ($\mu \mu \gamma$)
- Background from $J/\psi$, $\psi$ (2S) decay (leptons) or $\pi^0$ decay ($\gamma$)
- Reject $qq$ background event shape in a Fisher discriminant
- Observe 0 (3) events in the signal box in electron (muon) events

$B(B^0 \rightarrow e^+ e^- \gamma) < 0.7 \times 10^{-7}$ (90% CL)
$B(B^0 \rightarrow \mu^+ \mu^- \gamma) < 3.4 \times 10^{-7}$ (90% CL)
B → K(*) ν ν (b → s w/ two ν’s)

- B → K(*)νν proceeds via one-loop radiative penguin and box diagrams.

- It is highly sensitive to new physics, and theoretically very clean.
- But, experimentally very challenging.
  - Signature: B → K(*) + nothing.

- Nothing may be light dark matter (see papers by Pespelov et al.).

Direct dark matter search cannot see M<10GeV region.
**B → K(*)νν**

- **Babar @82fb⁻¹**
  hadronic and semileptonic tagging
  \[ Br(B \rightarrow K^0 \nu \bar{\nu}) < 5.2 \times 10^{-5} \text{ (90\% C.L.)} \]

- **Belle @253fb⁻¹**
  hadronic tagging
  \[ Br(B \rightarrow K^- \nu \bar{\nu}) < 3.6 \times 10^{-5} \text{ (90\% C.L.)} \]

- **Belle @492fb⁻¹**
  hadronic tagging
  \[ Br(B \rightarrow K^{*0} \nu \bar{\nu}) < 3.4 \times 10^{-4} \text{ (90\% C.L.)} \]

**B → K⁺νν extrapolated sensitivity (if SM)**

- 3σ @ 12ab⁻¹, 5σ @ 33ab⁻¹

Need Super-B!!
SuperKEKB

- Asymmetric-energy $e^+e^-$ collider to be realized by upgrading the existing KEKB collider.

- Super-high luminosity $\approx 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 10^{10} \text{ BB per yr.}$
  $\rightarrow 8 \times 10^9 \tau^+\tau^- \text{ per yr.}$

- Letter of Intent is available at: [http://belle.kek.jp/superb/loi](http://belle.kek.jp/superb/loi)

$E_{\text{CM}} = M(\Upsilon(4s))$

Belle with improved rate immunity

Higher beam current, smaller $\beta_y*$ and crab crossing
$
\rightarrow L = 8 \times 10^{35}$
Flavor Physics at SuperKEKB

1. Are there new CP-violating phases?
2. Are there new right-handed currents?
3. Are there new flavor-changing interactions with $b$, $c$ or $\tau$?

SuperKEKB will answer these questions by scrutinizing loop diagrams.

![Graph showing $\Delta S_{\phi K^0}$ predictions and measurements over time](image)
LFV Search at Super-B

cf) Hayasaka at BNM2006

Search region enters into \( O(10^{-8} \rightarrow 10^{-9}) \)

Estimated upper limit range of \( Br \)

based on eff. and \( N_{BG} \) of most sensitive analysis
**Major Achievements Expected at SuperKEKEB**

**Case 1: All Consistent with Kobayashi-Maskawa Theory**

- **Discovery of** $\nu\nu$
- **CKM Angle Measurements with 1 degree precision**
- **Discovery of** $B \to K\nu\nu$
- **Discovery of New Subatomic Particles**
- **$\sin^2\theta_W$ with $O(10^{-4})$ precision**
- **$|V_{ub}|$ with 5% Precision**
- **Discovery of** $B \to D_{\tau\nu}$
- **Observations with Υ(5S), Υ(3S) etc.**
- **Search for New CP-Violating Phase in $b \to s$ with 1 degree precision**
- **Discovery of CP Violation in Charged B Decays**
- **Discovery of Direct CP Violation in $B^0 \to K\pi$ Decays (2005)**
- **Discovery of CP Violation in Neutral B Meson System (2001)**

"Discovery" with significance $> 5\sigma"
Major Achievements Expected at SuperKEKB

Case 2: New Physics with Extended Flavor Structure

Discovery of Lepton Flavor Violation in $\tau \rightarrow \mu \gamma$ Decays#

Discovery of New Right-Handed Current in $b \rightarrow s$ Transitions #

Discovery of New $CP$ Violation in $B^0 \rightarrow \phi K^0$ Decays#

Discovery of $CP$ Violation in Charged $B$ Decays

Discovery of Direct $CP$ Violation in $B^0 \rightarrow K \pi$ Decays (2005)

Discovery of $CP$ Violation in Neutral $B$ Meson System (2001)

“Discovery” with significance $> 5\sigma$

# $SUSY$ GUT with gluino mass = 600GeV, $\tan\beta = 30$

“Discovery” with significance $> 5\sigma$

# $SUSY$ GUT with gluino mass = 600GeV, $\tan\beta = 30$
Super-KEKB Status

- Super-high luminosity $\approx 8 \times 10^{35}$ cm$^{-2}$s$^{-1}$
  - Natural extension of KEKB
  - With technology proven at KEKB

- Many key components are tested at KEKB. Crab crossing will be tested in winter 2007.

Super-KEKB is a machine which can be build now.
Super-KEKB Status

- Letter of Intent (LoI) in 2004
  - 276 authors from 61 institutions
  - available at http://belle.kek.jp/superb/loi
  - “Physics at Super B Factory” hep-ex/0406071

- Updates of physics reach and also new measurements (Y(5S) run etc.) are extensively discussed.
  - 2nd meeting at Nara (Dec.18-19, after CKM2006@Nagoya)

A lot of activities for physics and detector studies! You are welcome to join!
Summary

- The first evidence of $B \rightarrow \tau \nu$ has obtained by Belle $@414 f b^{-1}$. Successful operation of B factories have finally brought the B leptonic decays on the stage.
- $O(ab^{-1})$ data will bring $B \rightarrow \mu \nu$ and $B_d \rightarrow \mu \mu$ for serious examination.
- These enable us to explore New Physics, esp. in large $\tan \beta$ region, together with other measurements; $\Delta m_{BS}$, $B_s \rightarrow \mu \mu$, $B \rightarrow X_s \gamma$ and also $\tau$ decays ($\tau \rightarrow \mu \eta$, $\tau \rightarrow \mu \gamma$). (see talk by A. Weiler)
- $O(10 ab^{-1})$ data will bring $B \rightarrow K \nu \nu$ at horizon.

We need a Super B Factory!

- Super-KEKB aims at $L=8 \times 10^{35} \text{cm}^{-2} \text{s}^{-1}$, with tech. proven at KEKB.
- A lot of activities for physics and detector studies.
- HEP community in Japan is now discussing “Grand Lepton Collider” plan to accommodate both Super-KEKB and ILC. Stay tuned!
Due to limited time, some of them cannot be mentioned or have to be put in backup
Backup
New Physics in large $\tan \beta$

- Leptonic decays ($B \rightarrow l\nu, l\bar{l}$) are theoretically clean, free from hadronic uncertainty.
- In particular, they are good probes in large $\tan \beta$ region, together with other measurements; $\Delta m_{BS}$, $B_s \rightarrow \mu \mu$, $B \rightarrow X_s \gamma$ and also $\tau$ decays ($\tau \rightarrow \mu \eta, \tau \rightarrow \mu \gamma$).

Ex.) G. Isidori & P. Paradisi, hep-ph/0605012

Charged Higgs

$$\begin{align*}
\bar{b} & \rightarrow H^+ u \\
\nu & \rightarrow \tau^+\tau^-
\end{align*}$$

Neutral Higgs

$$\begin{align*}
\bar{b} & \rightarrow A^0, H^0, h^0 d \\
\ell^- & \rightarrow \ell^+\ell^-
\end{align*}$$

See talk by A. Weiler
B$\rightarrow \tau \nu$ Candidate Event

$B^+ \rightarrow \overline{D^0} \pi^+$  
$K^+ \pi^- \pi^+ \pi^-$

$B^- \rightarrow \tau^- \nu$  
$e^- \nu \nu$

Belle
Cont’d

**Charged Higgs Mass Reach**  
(95.5%CL exclusion @ tanβ=30)

- Only exp. error  
  \(ΔV_{ub}=0\%, \ Δf_B=0\%\)  
  \(ΔV_{ub}=2.5\%, \ Δf_B=2.5\%\)  
  \(ΔV_{ub}=5\%, \ Δf_B=5\%\)

\[\text{Note) Ratio to cancel out } f_B \text{ may help (G.Isidori&P.Paradisi, hep-ph/0605012)}\]

\[
\frac{\text{Br}(B \to τν)}{Δm_d} \xrightarrow{\begin{vmatrix} V_{ub} \\ V_{td} \end{vmatrix}} \frac{V_{ub}}{V_{td}} \xrightarrow{\begin{vmatrix} V_{ub} \\ V_{td} \end{vmatrix}} \text{from other measurements}
\]
**B^0 \rightarrow \tau^+ \tau^- (BaBar \ @ \ 210\text{fb}^{-1})**

- Experimentally very very challenging (2-4 neutrinos in the final state!)
- High sensitive to NP

**Analysis**

- Reconstruct one B in a fully hadronic final state \( B \rightarrow D^{(*)} X \) =>280k events
- In the event remainder, look for two \( \tau \) decays (\( \tau \rightarrow \ell \nu \nu, \pi \nu, \rho \nu \))
- Kinematics of charged particle momenta and residual energy are fed into a neutral network to separate signal and BG

\[\text{Data} \quad \begin{array}{c}
\text{Entries/30 MeV} \\
0 & 20 & 40 & 60 & 80 & 100 & 120 & 140 & 160 \\
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
\end{array} \quad \text{Control sample} \quad \begin{array}{c}
\text{Entries/30 MeV} \\
0 & 20 & 40 & 60 & 80 & 100 & 120 & 140 & 160 \\
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
\end{array}\]

\[\text{Nobs}=263 \pm 19 \quad \leftrightarrow \quad \text{Nexpect}=281 \pm 48\]

\[\text{Br}(B \rightarrow \tau \tau) < 4.1 \times 10^{-3} \quad @90\%\text{C.L.}\]

$B^0 \rightarrow \bar{\nu} \nu (\text{invisible}) \ @\ Babar$

- **Semileptonic tags:**
  $B^0 \rightarrow D^{(*)-}\ell^+\nu$ ($D^{*-} \rightarrow D^0 \pi^-$)

- **Require nothing in recoil:**
  - no charged tracks,
  - limited # of neutral clusters.

- **ML fit to $E_{extra}$**
  
  $N_s = 17 \pm 9$
  $N_b = 19^{+10}_{-8}$

- **Upper limit (frequentist)**
  incl. systematics (additive: 7.4 events, multiplicative: 10.9%)

$B(B^0 \rightarrow \text{invisible}) < 22 \times 10^{-5} \ (90\% CL)$

B pairs used:
$(88.5 \pm 1.0) \times 10^6$

Future Prospect: $B \to K_{\nu\nu}$

- Belle @ 250fb$^{-1}$ (preliminary)
  - Fully reconstructed tag (by modifying the PID criteria used in $B \to \tau\nu$ analysis).

<table>
<thead>
<tr>
<th>Efficiency(%)</th>
<th>Sign. expected</th>
<th>42.8 ± 1.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background expected</td>
<td>0.70 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Observed Events</td>
<td>2.6 ± 1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Consistent with BG expected

$$\mathcal{B}(B^+ \to K\nu\bar{\nu}) < 3.6 \times 10^{-5} (90\% \text{ C.L.})$$

<table>
<thead>
<tr>
<th>Signif.</th>
<th>Lum (ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3σ</td>
<td>12</td>
</tr>
<tr>
<td>5σ</td>
<td>33</td>
</tr>
</tbody>
</table>

Need Super-B!
Advantages of SuperKEKB

- Clean environment $\rightarrow$ measurements that no other experiment can perform. Examples: CPV in $B \rightarrow \phi K^0$, $B \rightarrow \eta ' K^0$ for new phases, $B \rightarrow K_s \pi^0 \gamma$ for right-handed currents.

- "$B$-meson beam" technique $\rightarrow$ access to new decay modes. Example: discover $B \rightarrow K \nu \bar{\nu}$.

- Measure new types of asymmetries. Example: forward-backward asymmetry in $b \rightarrow s \mu \mu$, see.

- Rich, broad physics program including $B$, $\tau$ and charm physics. Examples: searches for $\tau \rightarrow \mu \gamma$ and $D$-$\bar{D}$ mixing with unprecedented sensitivity.

- No other experiment can compete for New Physics reach in the quark sector.
Role of SuperKEKB

- What is the origin of CP violation?
- What is the origin of the matter-dominated Universe?
- What is the flavor structure of new physics (e.g. SUSY breaking)?

These grand questions can only be answered by experiments both at the luminosity and energy frontiers. SuperKEKB will play an essential role.
SuperKEKB

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

Energy exchange C-band

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

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

will reach \( 8 \times 10^{35} \, \text{cm}^{-2}\text{s}^{-1} \).