Future Opportunities: Leptonic B Decays

- **Modes**: $B \rightarrow \pi \nu, (\nu \pi X), \mu \nu, X_s \nu \nu, X_d \nu \nu$
- **Accessible Physics**: CKM elements $|V_{ub}|, |V_{ts}|, |V_{td}|, f_B$
- **Standard Model** Physics is very clean.
- **New Physics...?** [hep-ph/9510378]
- **Experimental challenges** are very large: weak signal, large background, expected BR are $10^{-7} \rightarrow 10^{-4}$. Note $\tau \nu, X_s \nu \nu$ have similar BR, $\sim 5 \times 10^{-5}$
- **Hadron collider** experiments probably can’t touch these modes
- **Giga-Z** machine (?!?) might be useful...?
- Corresponding $K \rightarrow \pi \nu \nu$ also useful but won’t be discussed here. (BCP4)
- Follow ground rules: up to $10^{11}$ B mesons.

(NOTE: throughout, “$\nu \nu$” means “$\nu \nu$”)

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Focus on $\tau \nu$ issues:
- most information
- $s \nu \nu$ exp’ly similar
**Physics in $B \rightarrow \tau \nu, \mu \nu, e\nu$**

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

- helicity suppression $\tau : \mu : e = 10^{-2} : 10^{-5}$
- radiative decay $l\gamma$ lifts helicity suppression but theory murky.
- Eliminate $f_B$ dependence by comparing to $B\bar{B}$ mixing rate:

\[
\Delta m_d = \frac{G_F^2}{6\pi^2} \eta_B m_B m_w^2 f_B^2 B_B S_0(x_t) |V_{td}|^2
\]

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B -> τν: Experimental Approaches...

LEP searches ALEPH, DELPHI, L3.
- B mesons produced at high momentum
  --> complete separation of decay products.
  - b tag opposite hemisphere
  - reject cases with leptons
  - Look for high missing E.
- Data sample is small (328,000 B±) but signal efficiency is high (8%)
- This is really a totally inclusive missing-E measurement. There is no distinguishing power between τν and sνν.
- ALEPH (2000) sees 2 candidates, expects 2.5 bkg. BR < 8.3E-4.

hep-ex/0010022

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**B \rightarrow \tau \nu:** Experimental Approaches... 2

- **Upsilon(4S):**
  - B mesons produced at rest
  - No extra tracks

- Tracks from opposite B's mix
  - K_L, n, other losses look like \nu

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**CLEO 1995:** high efficiency, 4%  
high background. S/B \sim 1/200

**CLEO 2000:** low efficiency, 7 \times 10^{-4}
low background. S/B \sim 1

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**Inclusive**  
Require Only \Delta E And M_B

**Exclusive**  
Reconstr 144 excl modes

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One interesting event...

Run: 84460  
Event: 48020

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\( B \to \tau \nu \) Extrapolations to Far Future - 1

- Assume S/B \sim 1
- Efficiency \sim 7 \times 10^{-4}

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**B -> \tau\nu Extrapolations to Far Future - 2**

- **Extrapolation behaviour:**
  - \( B=0 \Rightarrow \text{limit } \sim \frac{1}{\text{Lumi}} \)
  - \( B=\text{large} \Rightarrow \text{limit } \sim \frac{1}{\sqrt{\text{Lumi}}} \)
  
  \{ \text{Rethink strategy for signal measurement} \}

- **Physics Backgrounds -- suppression should improve in the future.**
  - \( \text{B}B \) backgrounds. \( D^0 \) reconstruction, \( K_L \) recognition
  - Babar, Belle should have advantage of \( K_L \) suppression
  - Improved PID (relative to CLEO II) should help \( D^0 \)
  - continuum, \( \tau^+\tau^- \), two-photon backgrounds

- \( B \) vertex separation may help suppress these bkgs

- **Machine Backgrounds -- will probably get worse in the future.**
  - Cut on left-over energy after all reconstructions
  - Requires low machine backgrounds. But hi lumi \( \leftrightarrow \) hi beam curr.
    - backgrounds will grow as \( I^2 \), or as \( I \)
    - Problematic? Harder cuts will mean lower eff.... Reoptimize
  - machine-dependent. Hard to generalize or predict.

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What About Alternatives: $B \rightarrow \mu\nu, B \rightarrow \tau\nu\gamma$

- $B \rightarrow \mu\nu$
  - 225 smaller BR than $\tau\nu$.
  - 13% efficiency (CLEO 1995) (=186x higher than $\tau\nu$.)
  - Usefulness may depend on how bkgs turn out. Sources include continuum, fakes, and $B \rightarrow \pi^0\mu\nu$
  - Not to be discounted.

- $B \rightarrow \tau\nu\gamma$
  - helicity suppression is relieved but...
  - theory becomes complex with many unknown parameters.
  - Little useful information could be extracted even if the measurement were made.

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Physics in $B \to X_s \nu \bar{\nu}$, $X_d \nu \bar{\nu}$

\[ BR(B \to X_s \nu \bar{\nu}) = BR(B \to X_c e \bar{\nu}) \frac{3\alpha^2}{4\pi^2 \sin^4 \Theta_W} \left( \frac{X^2(x_L)}{f(z)} \frac{\eta}{\kappa(z)} \right) \left| \frac{V_{ts}}{V_{cb}} \right|^2 \]

$s_{\nu \bar{\nu}} \sim 4 \times 10^{-5}$
$K_{\nu \bar{\nu}} \sim 2 \times 10^{-6}$
$K_{* \nu \bar{\nu}} \sim 5 \times 10^{-6}$

\[ \frac{BR(B \to X_d \nu \bar{\nu})}{BR(B \to X_s \nu \bar{\nu})} = \left| \frac{V_{td}}{V_{ts}} \right|^2 \]
$B \rightarrow X_s^{\nu\nu}, X_d^{\nu\nu}$: Present Knowledge

- Little experimental information yet.

- Current limits

  - **ALEPH**: $\text{BR}(b \rightarrow s^{\nu\nu}) < 6.4 \times 10^{-4}$

  - **DELPHI**: $\text{BR}(B \rightarrow K^*(892)^{\nu\nu}) < 10 \times 10^{-4}$

  - **CLEO**: $\text{BR}(B^\pm \rightarrow K^{\pm}\nu\nu) < 2.4 \times 10^{-3}$

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**B→Kνν: Projections for future**

- Specific final states, Kνν, K*νν, probably ~5-20% of total sνν BR.
- νν visible in leptonic & pionic modes: 50% of BR.
- Thus there is a 10:1 problem... The challenge to establish Kνν and related states is to separate from the larger but similar τν.
- Even if this can be done, many giga-B will be needed to see any signal.
- Fully inclusive sνν attempt even harder.

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**B -> X_{s, d}^{0} \nu\nu: Projections for Future**

- Background issues same as noted above for \( \tau \nu \) + additional combinatoric issues for (K\pi)\nu\nu modes.
- In addition, there are problematic crossfeed modes, including:
  - \( B \rightarrow \tau \nu \rightarrow \pi \nu \nu \) mistaken for \( B \rightarrow K \nu \nu \) (PID \( \pi \) fakes \( K \sim 6\% \))
  - \( B \rightarrow \tau \nu \rightarrow K \nu \nu \) mistaken for \( B \rightarrow K \nu \nu \) (\( \tau \rightarrow K \nu \sim 1\%)\)
  - \( B \rightarrow \tau \nu \rightarrow \pi \nu \nu \) will be huge bkg for \( B^\pm \rightarrow \pi^\pm \nu \nu \)
- Note in principle, neutral \( B^0 \rightarrow X^0 \nu\nu \) is less susceptible to this xfeed (but \( X_d^{0} \nu\nu \) is probably susceptible to everything...)

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Can “Giga-Z” do this physics?

At LEP the searches for $\tau\nu$, $X\nu\nu$, enjoy high efficiency and low background. Is this maybe the best way to go?

A speculative future possibility is the Giga-Z machine - perhaps as an early phase of a linear collider or even VLHC. 1000 times the LEP sample.

- Signal yields produced for $1 \times 10^9$ $Z^0$ produced:
  - $N(sv\nu) \sim 6000$; $N(K\nu\nu) \sim 300$; $N(K^*\nu\nu) \sim 1000$
- Detected yields ...? LEP measurements inclusive. Eff $\sim 8\%$
  - Efficiency of exclusive measurements will be lower....
- Will require good particle ID, b-tagging (vertex?).
- Backgrounds ....? !! Essentially impossible to estimate now.

Challenge will be to transform the inclusive measurements into exclusive ones. Can $\tau\nu$ really be identified as such? Can $sv\nu$ be separated?

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Summary

- $B \to \tau \nu$, $X_{\nu\nu}$ are difficult measurements because branching ratios are small, the signal is weak, and backgrounds are high (or efficiencies low).

- Need \( \sim 200-300M \) BB for first light in $\tau \nu$. Need Giga-B samples for CKM elements to be usefully restricted. ($4 \times 10^9$ B sample will yield \( \sim 10\% \) measurement of $BR(B \to \tau \nu)$). Use $\pi, \epsilon$ lepton momentum spectra to confirm that it is $\tau \nu$.

- $X_{s\nu\nu}$ suffers same challenges as $\tau \nu$, with the addition that $\tau \nu$ modes feed down into $X_{s\nu\nu}$ samples. Roughly speaking, $X_{s\nu\nu}$ is $\sim 10x$ harder than $\tau \nu$, and will require $10x$ more luminosity. Use neutral modes for confirmation.

- $X_{d\nu\nu}/X_{s\nu\nu}$ would offer clean determination of $V_{td}/V_{ts}$, but may be hopeless due to low branching ratio and high bkg. $X_{d\nu\nu}$ is at least another factor of 10 harder, beyond $X_{s\nu\nu}$.

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