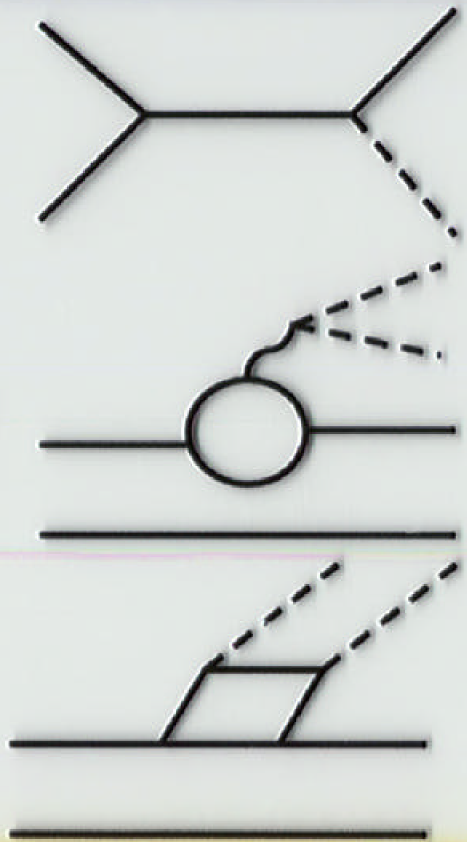
Future Opportunities: Leptonic B Decays



- Modes : B --> $\tau\nu$, ($\tau\nu X$), $\mu\nu$, $X_s\nu\nu$, $X_d\nu\nu$,
- 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} -- 10^{-4}. Note $\tau\nu$, $X_s\nu\nu$ have similar BR, ~5×10^{-5}
- Hadron collider experiments probably can't touch these modes
- Giga-Z machine (?!) might be useful...?
- Corresponding $K \to \pi\nu\nu$ also useful but won't be discussed here. (BCP4)
- Follow ground rules: up to 10^{11} B mesons.

(NOTE: throughout, "$\nu\nu$" means "$\nu\bar{\nu}$")

Focus on $\tau\nu$ issues:
- most information
- $s\nu\nu$ exp'ly similar

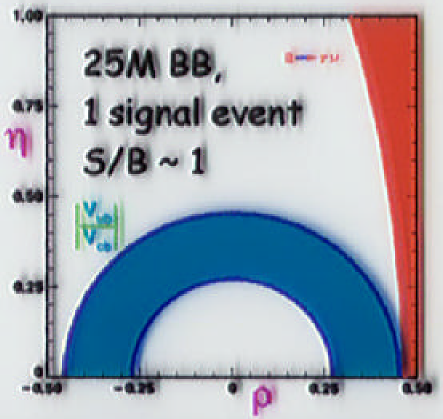
Physics in B -> τν, μν. eν

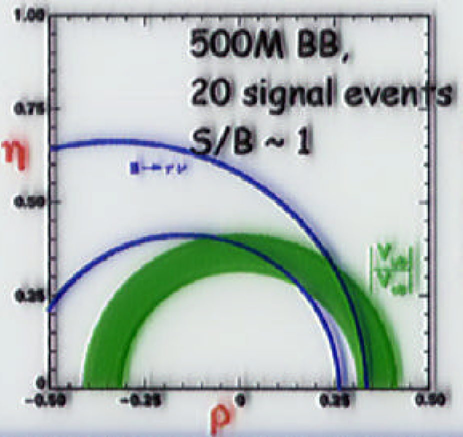
$$BR(B \to \ell\overline{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 \left|V_{ub}\right|^2 \tau_{B^\pm}$$

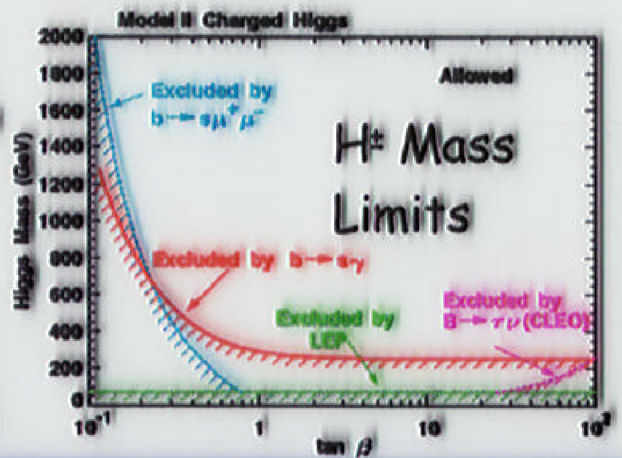
τν ~ 6E-5
μν ~ 3E-7
eν ~ 7E-12

- helicity suppression τ : μ : e = 1 : 10^{-2} : 10^{-5}
- radiative decay lνγ lifts helicity suppression but theory murky.
- Eliminate f_B dependence by comparing to BB mixing rate:

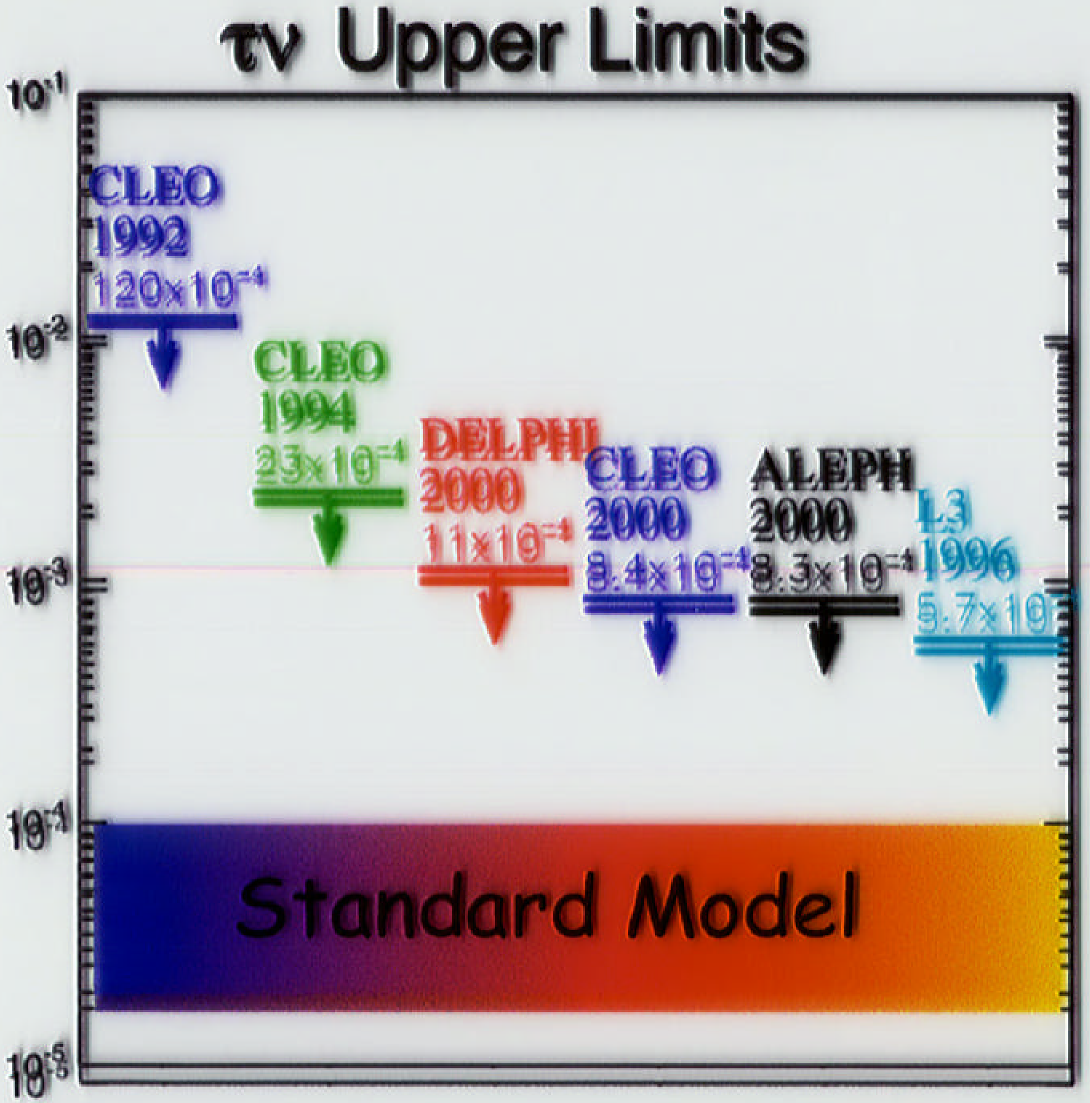
$$\Delta m_d = \frac{G_F^2}{6\pi^2}\eta_B m_B m_W^2 f_B^2 B_B S_0(x_t)\left|V_{td}\right|^2$$







B *dge*

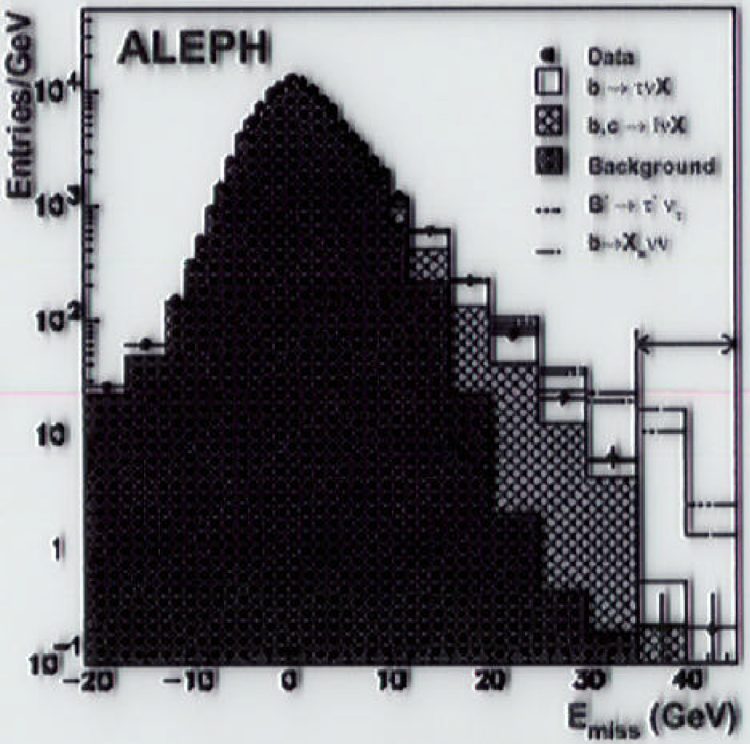

τν Upper Limits
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
CLEO 1992 120×10^{-4}
CLEO 1994 23×10^{-4}
DELPHI 2000 11×10^{-4}
CLEO 2000 8.4×10^{-4}
ALEPH 2000 8.3×10^{-4}
L3 1996 5.7×10^{-4}
Standard Model

Ji

$B \to \tau\nu$: *Experimental Approaches... 1*

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 $B^{\pm}$) but signal efficiency is high (8%)
- This is really a totally inclusive missing-E measurement. There is no distinguishing power between $\tau\nu$ and $s\nu\nu$.
- ALEPH (2000) sees 2 candidates, expects 2.5 bkg. BR < 8.3E-4.



hep-ex/0010022

$B \to \tau\nu$: Experimental Approaches... 2

·Upsilon(4S):

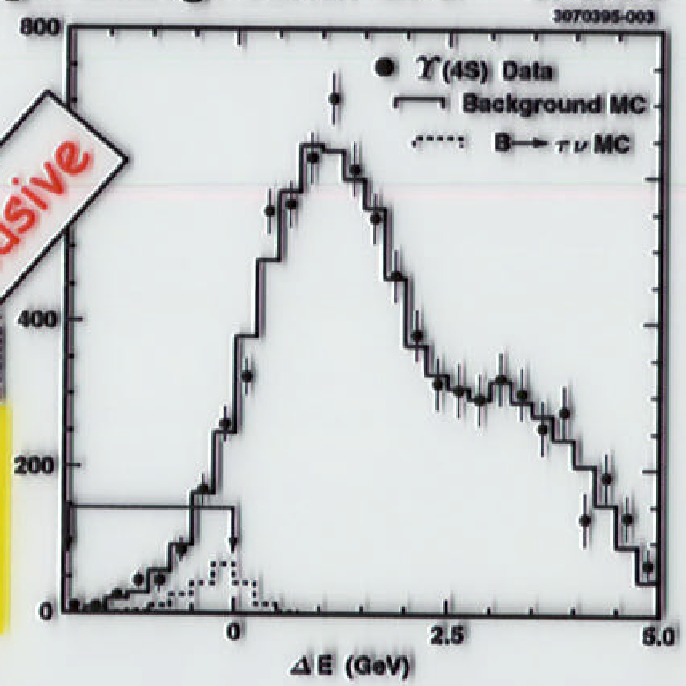
- B mesons produced at rest
- No extra tracks
- Tracks from opposite B's mix
- K_L, n, other losses look like ν

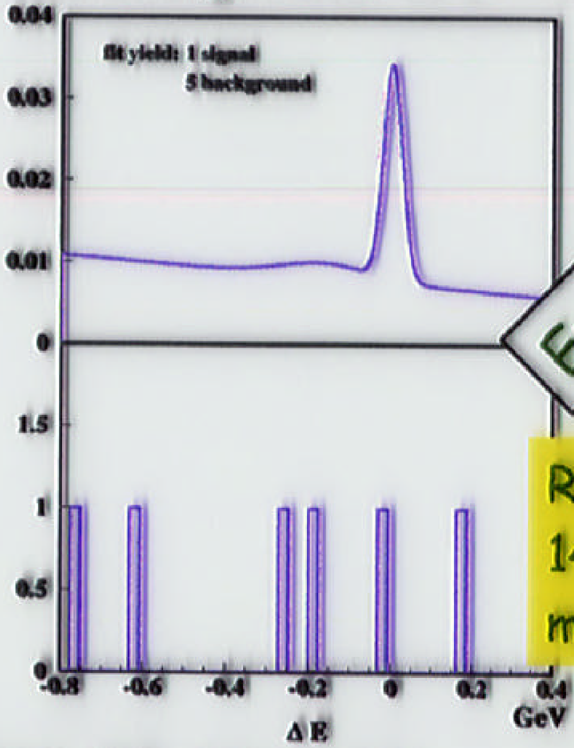
CLEO 1995: high efficiency, (4%) high background. S/B ~ 1/200

CLEO 2000: low efficiency, (7×10^{-4}) low background. S/B ~ 1

Inclusive

Require Only ΔE And M_B

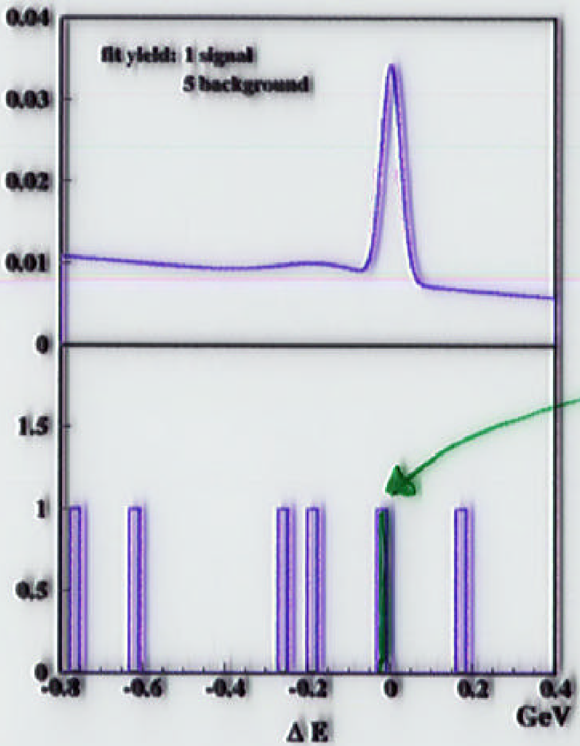


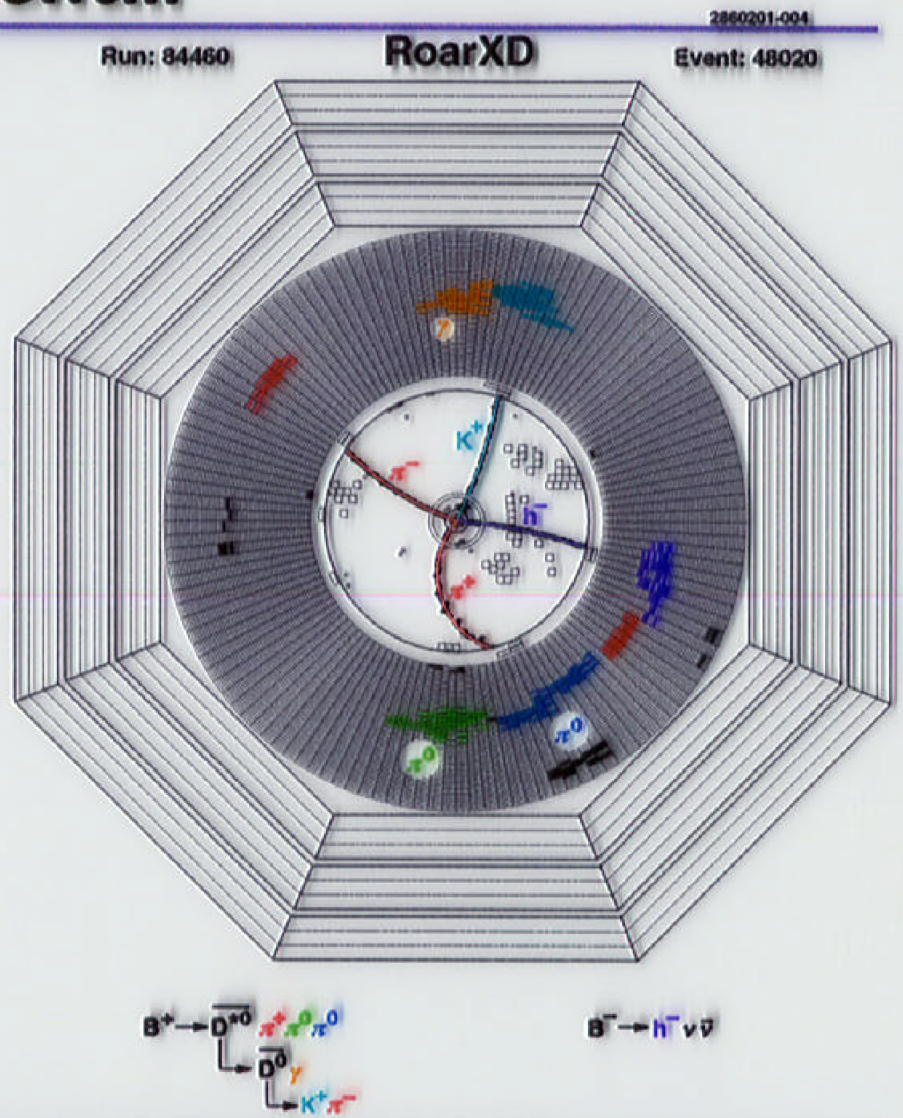


Exclusive

Reconstr 144 excl modes

One interesting event...

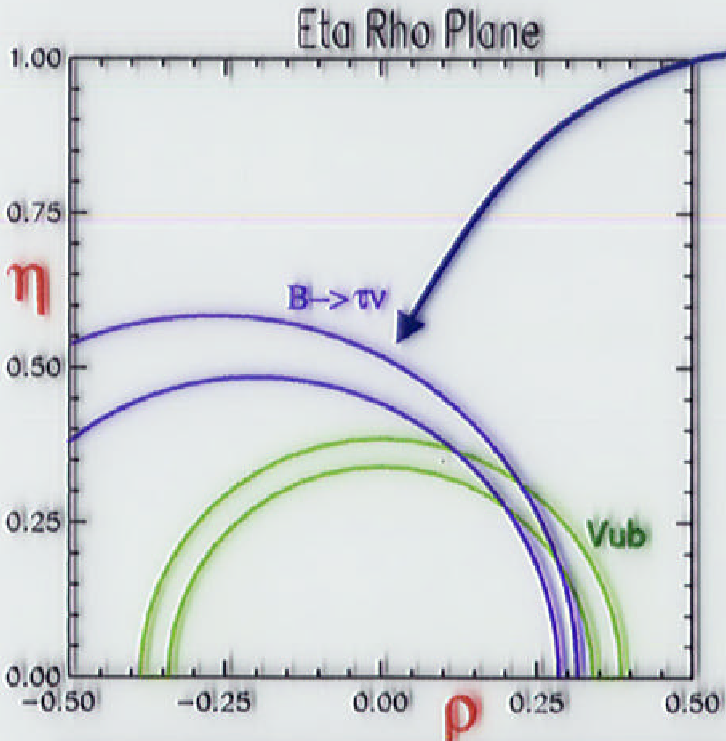


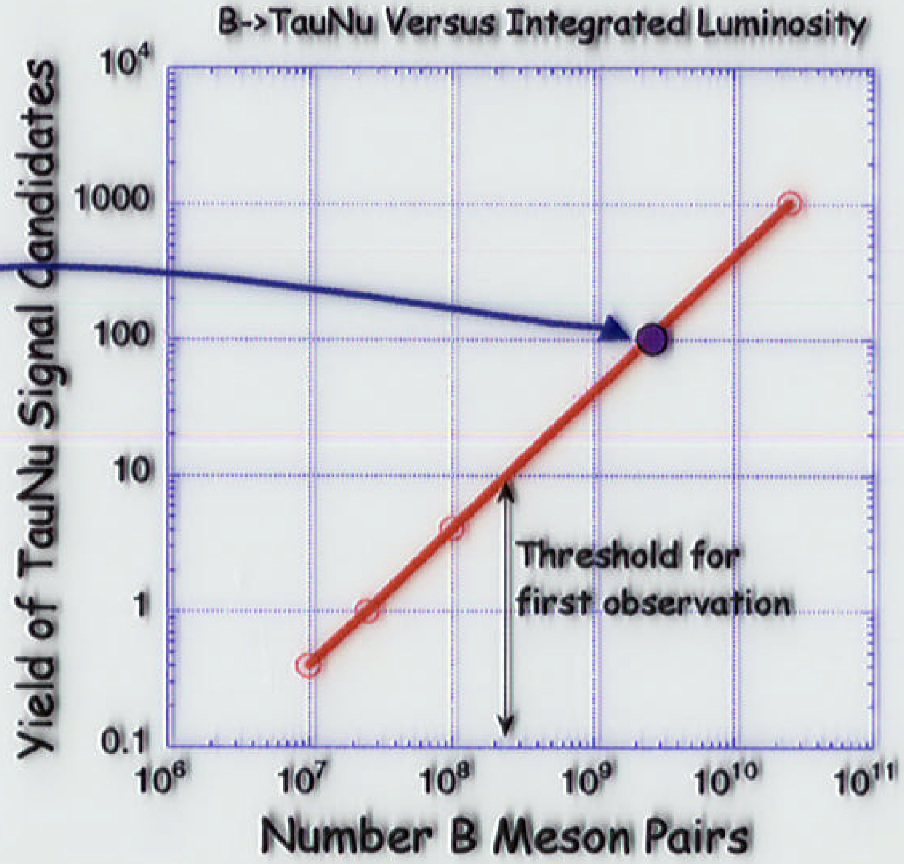


Jim Alexander, @ B Physics and CP Violation (BCP4), 賢島, February 2001

$B \to \tau\nu$ Extrapolations to Far Future - 1

- Assume S/B~1
- Efficiency ~7×10^{-4}





$B \to \tau\nu$ Extrapolations to Far Future - 2

- Extrapolation behaviour:
  - B=0 ==> limit ~ 1/Lumi
  - B=large ==> limit ~ 1/sqrt(Lumi)

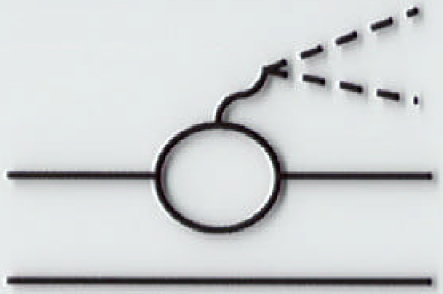
  Rethink strategy for signal measurement
- Physics Backgrounds-- suppression should improve in the future.
  - BB backgrounds. D^0 reconstruction, K_L recognition
    - Babar, Belle should have advantage of K_L suppression
    - Improved PID (relative to CLEO II) should help D^0
  - continuum, $\tau^+\tau^-$, two-photon backgrounds
    - B vertex separation <u>may</u> 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 <-> 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.

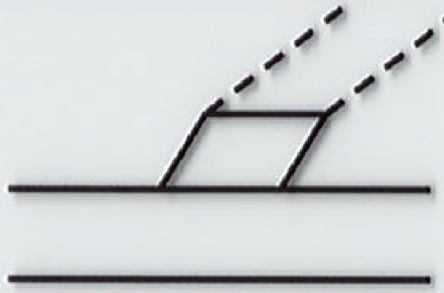
What About Alternatives: $B \to \mu\nu$, $B \to \tau\nu\gamma$

- $B \to \mu\nu$
  - 225 smaller BR than $\tau\nu$.
  - 13% efficiency (CLEO 1995) (=186x higher than $\tau\nu$.)
  - bkg? CLEO 1995: 2 ± 1 events --> $1/40 < S/B < 1/13$
  - Usefulness may depend on how bkgs turn out. Sources include continuum, fakes, and $B \to \pi^0\mu\nu$
  - Not to be discounted.

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

Physics in B->$X_s\nu\nu$, $X_d\nu\nu$





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

s$\nu\nu$ ~ 4E-5
K$\nu\nu$ ~ 2E-6
K*$\nu\nu$ ~5E-6

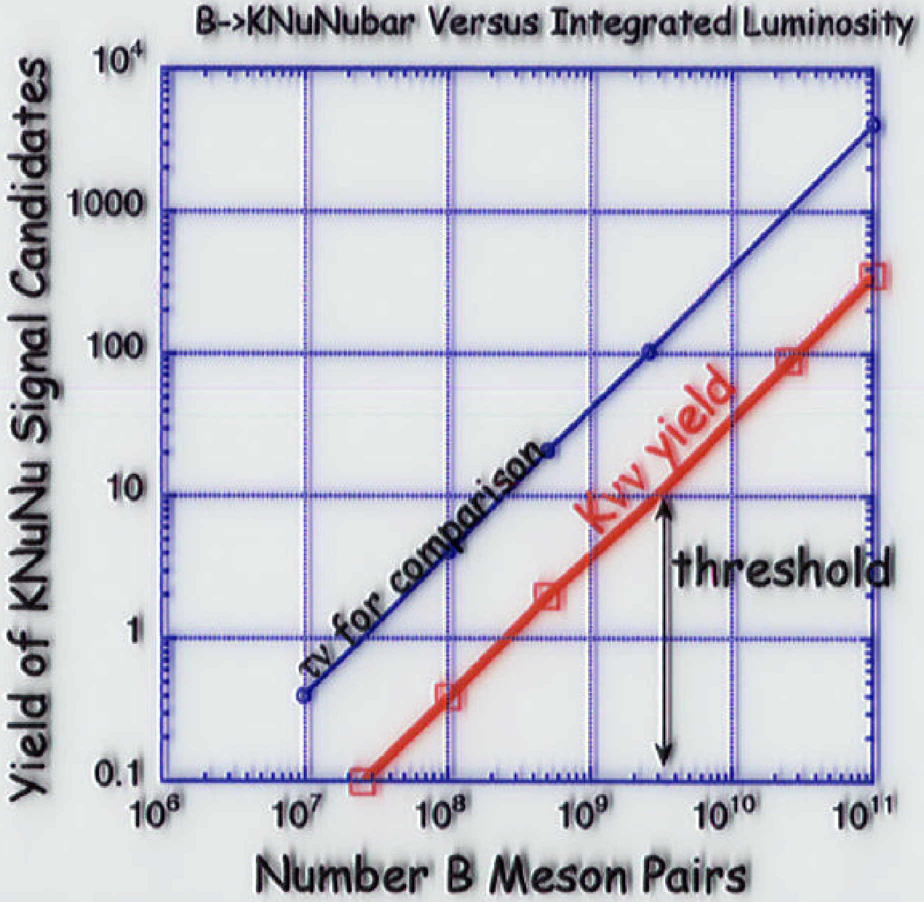
$$\frac{BR(B \to X_d \nu\overline{\nu})}{BR(B \to X_s \nu\overline{\nu})} = \frac{\left|V_{td}\right|^2}{\left|V_{ts}\right|^2}$$

$B \to X_s \nu\nu$, $X_d \nu\nu$: *Present Knowledge*

- Little experimental information yet.
- Current limits
  - ALEPH: BR($b \to s\nu\nu$) < 6.4×10^{-4}
  - DELPHI: BR($B \to K^*(892)\nu\nu$) < 10×10^{-4}
  - CLEO: BR($B^\pm \to K^\pm\nu\nu$) < 2.4×10^{-4}

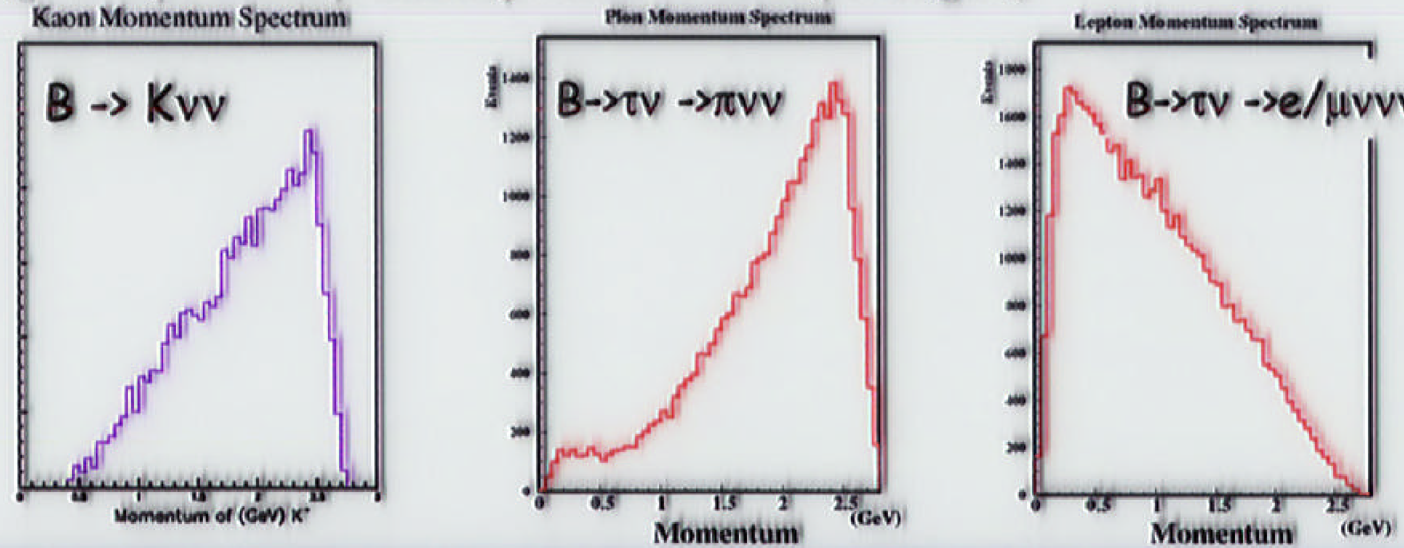
B->Kνν: Projections for future

- Specific final states, Kνν, K*νν, probably ~5-20% of total sνν BR
- τν 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.



$B \to X_s \nu\nu$, $X_d \nu\nu$: Projections for Future

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



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 <u>produced</u> for 1×10^9 Z^0 produced:
  - $N(s\nu\nu) \sim 6000$; $N(K\nu\nu) \sim 300$; $N(K^*\nu\nu) \sim 1000$
- <u>Detected</u> yields ... ? LEP measurements inclusive. Eff ~ 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 $s\nu\nu$ be separated?

Summary

• B -> $\tau\nu$, $X\nu\nu$ are difficult measurements because branching ratios are small, the signal is weak, and backgrounds are high (or efficiencies low).

• Need ~ 200-300M BB for first light in $\tau\nu$. Need Giga-B samples for CKM elements to be usefully restricted. (4×10^9 B sample will yield ~10% measurement of BR(B->$\tau\nu$)). Use π,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 ~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 Vtd/Vts, 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 $X_s\nu\nu$.