Prospects for Rare $b \rightarrow \tau$ Decays at B Factories

Karen Lingel
SLAC

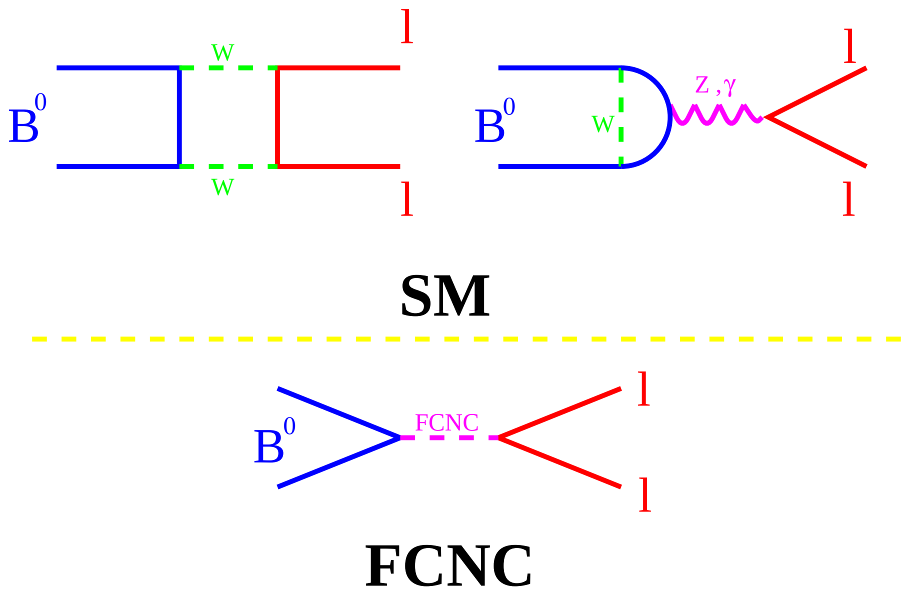
25 Mar 97

B Physics and CP Violation Conference, Honolulu, Hawaii

Outline:

- Theoretical introduction
- Current techniques for $B \to \tau\nu$ decays
  - ⋆ CLEO's "neutrino reconstruction" technique
  - ⋆ ALEPH's B tag + missing energy technique
  - ⋆ L3's missing energy + large impact parameter technique
- Proposed techniques for $B \to \tau\nu$ decays
  - ⋆ $\tau \to \ell\nu\nu$ kinematical technique
  - ⋆ $\tau \to \ell\nu\nu$ topological technique
  - ⋆ $\tau \to$ 3-prong vertex technique

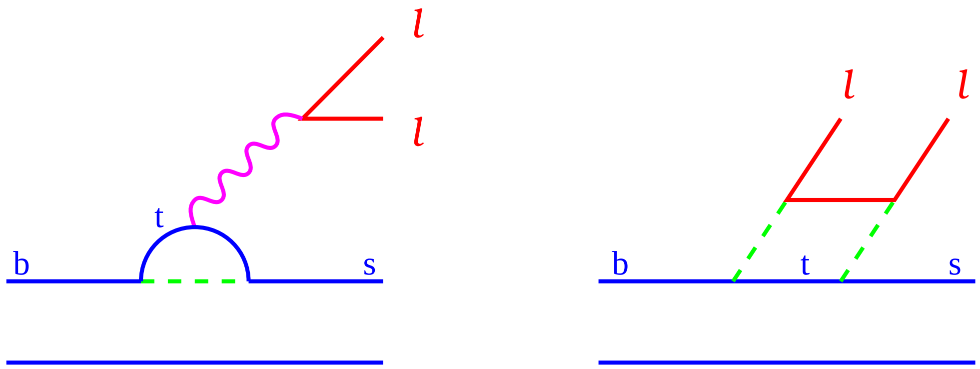
$B^0,\ B_s^0 \to \tau^+\tau^-$



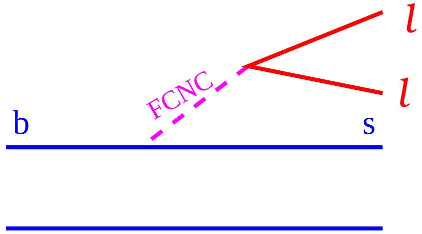
- Decays such as $B \to \ell^+\ell^-$ are very suppressed in the SM, but excellent place to look for FCNC.
- Standard Model:

$$\mathcal{B}(B^0 \to \tau^+\tau^-) \sim 10^{-8} \qquad \mathcal{B}(B_s^0 \to \tau^+\tau^-) \sim 10^{-7}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) \sim 10^{-10} \qquad \mathcal{B}(B_s^0 \to \mu^+\mu^-) \sim 10^{-9}$$
$$\mathcal{B}(B^0 \to e^+e^-) \sim 10^{-15} \qquad \mathcal{B}(B_s^0 \to e^+e^-) \sim 10^{-14}$$

$B \to X_s \tau^+ \tau^-$



SM



FCNC

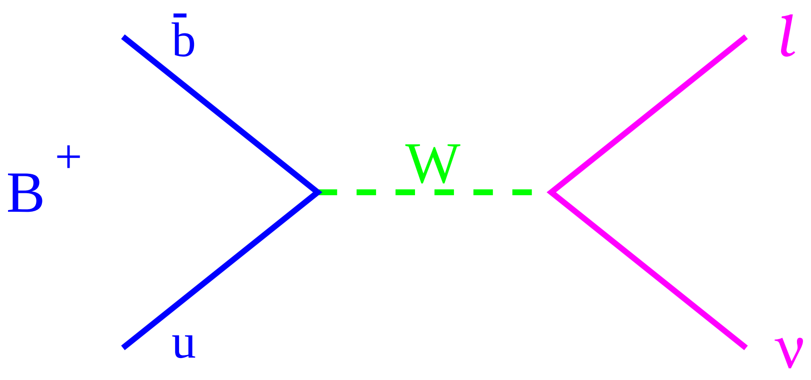
- Electroweak penguin or box diagram

$$\mathcal{B}(B \to X_s \tau^+ \tau^-) \approx 3 \times 10^{-7}$$

$$\mathcal{B}(B \to X_s \mu^+ \mu^-) \approx 6 \times 10^{-6}$$

$$\mathcal{B}(B \to X_s e^+ e^-) \approx 6 \times 10^{-6}$$

$B \to \tau\nu$

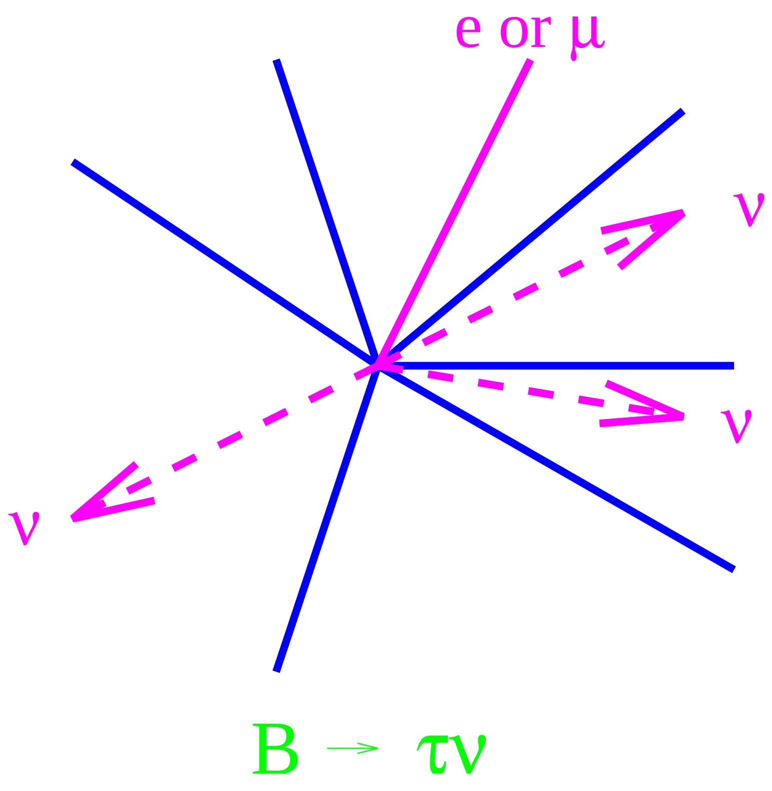


$$\Gamma(B^+ \to \ell^+\nu) = \frac{G_F^2 M_B M_\ell^2}{8\pi}\left(1 - \frac{M_\ell^2}{M_B^2}\right) f_B^2 |V_{ub}|^2$$

- SM Predictions:
  - $\star$ $\mathcal{B}(B^+ \to \tau^+\nu) \sim 10^{-4}$
  - $\star$ $\mathcal{B}(B^+ \to \mu^+\nu) \sim 10^{-7}$
  - $\star$ $\mathcal{B}(B^+ \to e^+\nu) \sim 10^{-12}$
- Theory: $f_B = 120 - 300$ MeV.
- Use f_B and $B^0\bar{B}^0$ mixing to extract V_{td}:

$$\frac{\Delta m}{\Gamma} = \frac{G_F^2}{6\pi^2}|V_{td}|^2 M_t^2 F\left(\frac{M_t^2}{M_W^2}\right) M_B f_B^2 B_B \eta_B \tau_{B^0}$$

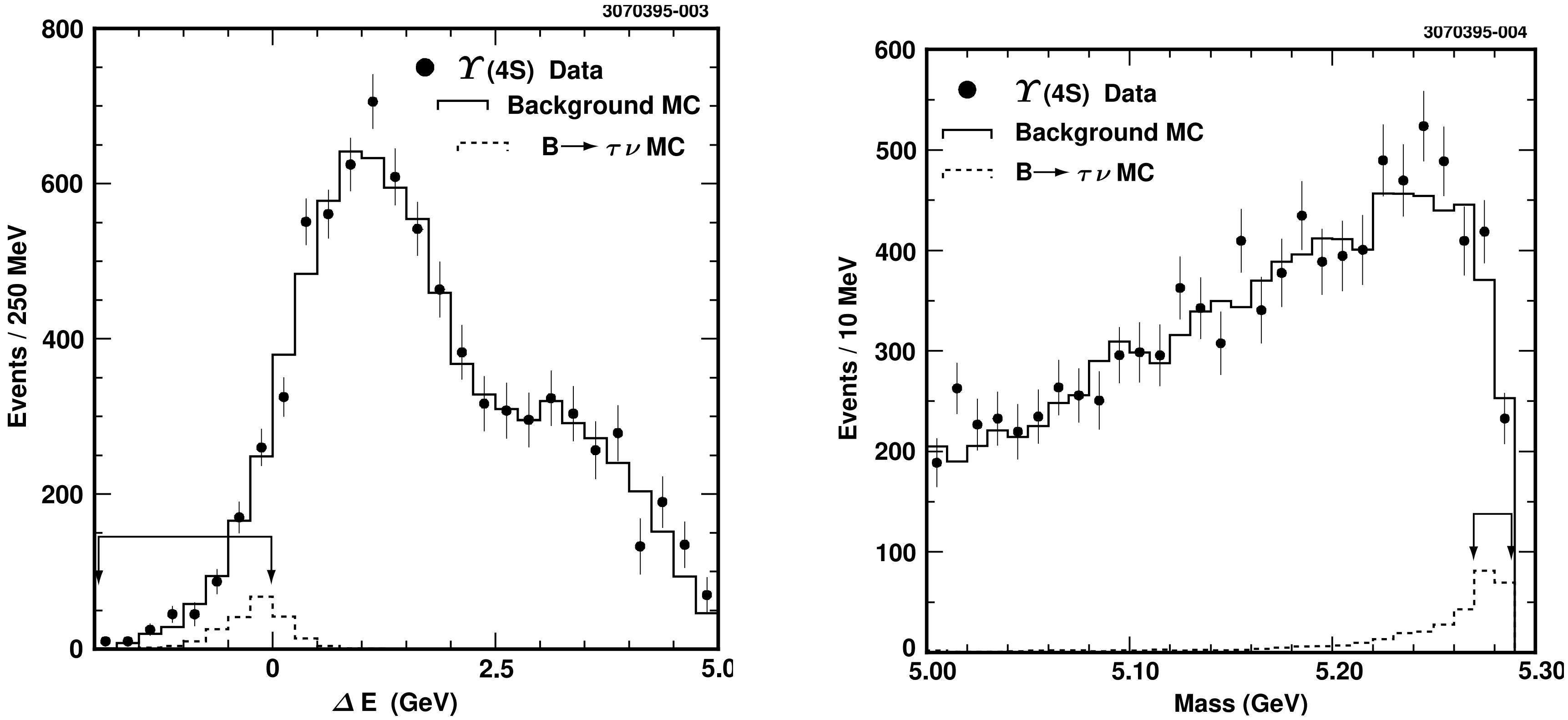
$B \to \tau\nu$ at CLEO



- Events with large missing energy
- Fully reconstruct neutrinos using $(E, \overrightarrow{p})_{3\nu} = (E, \overrightarrow{p})_{\rm miss}$ of the event.
- $\Delta E = E_\ell + E_{3\nu} - E_{\rm beam}$
- $M_B = \sqrt{E_{\rm beam}^2 - (\overrightarrow{p}_\ell + \overrightarrow{p}_{3\nu})^2}$

- 2-dimensional fit to ΔE and M_B:

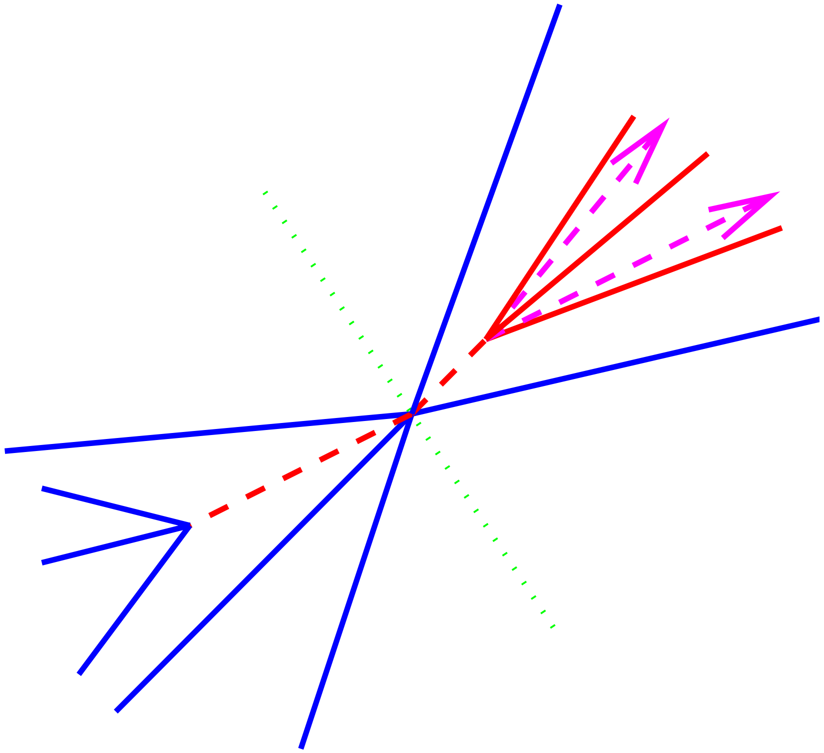
CLEO 1995 (PRL **75**, 785).



$$\text{yield} = -9 \pm 36$$

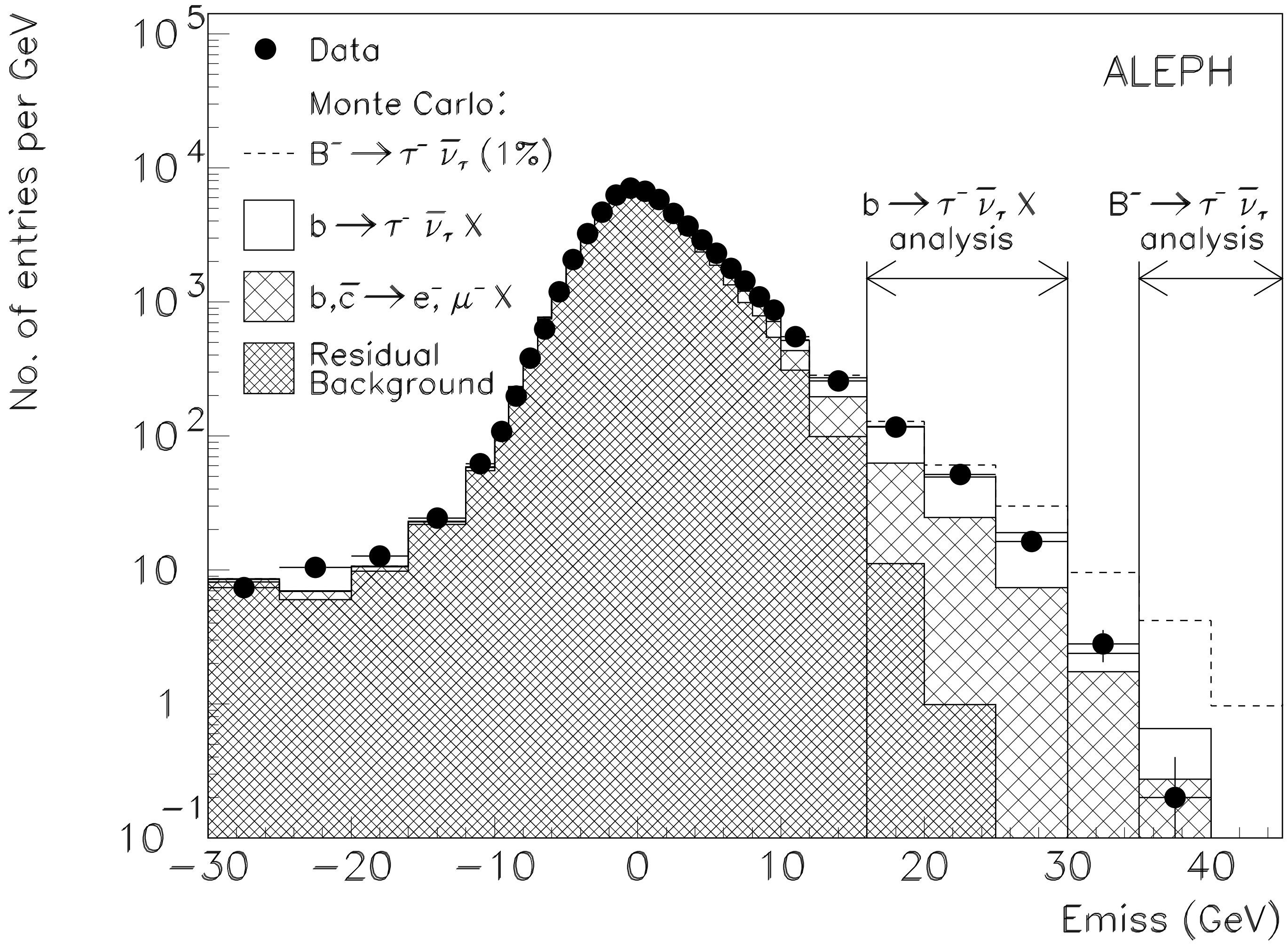
$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 22 \times 10^{-4}$$

$B \to \tau\nu$ at ALEPH



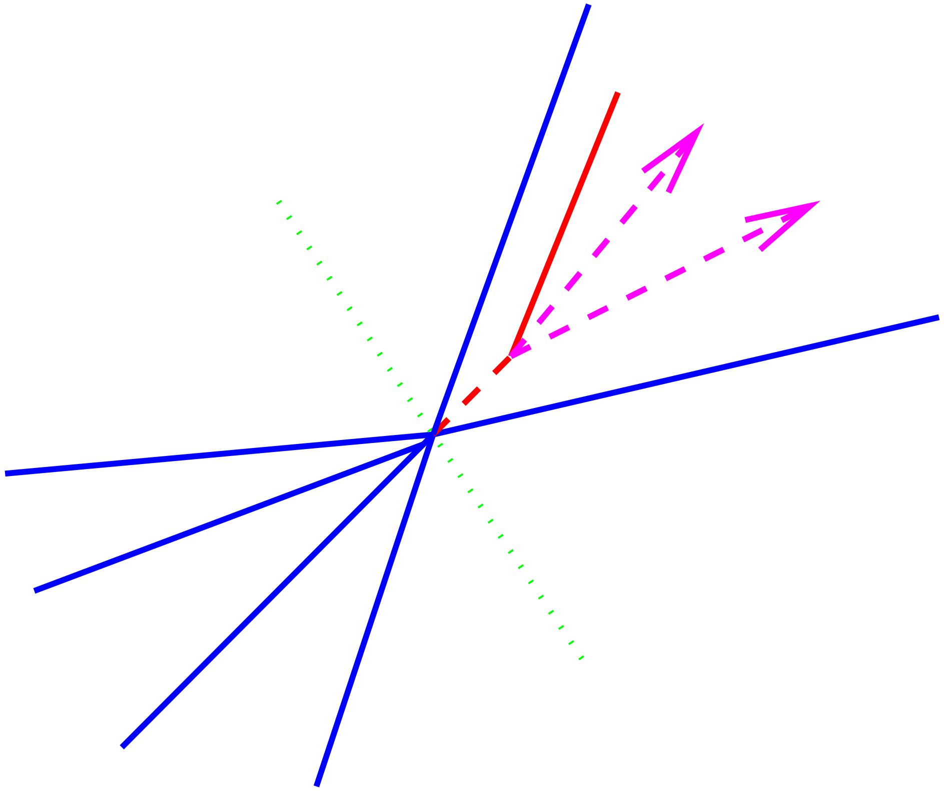
- Divide event into two halves
- Require detached vertex in one half (B tag)
- Look for events with large missing energy
- Suppress $c, b \to X\ell\nu$ background by rejecting events with identified leptons.

ALEPH 1995, PLB **343**, 444.



$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 18 \times 10^{-4}$$

$B \to \tau\nu$ at L3



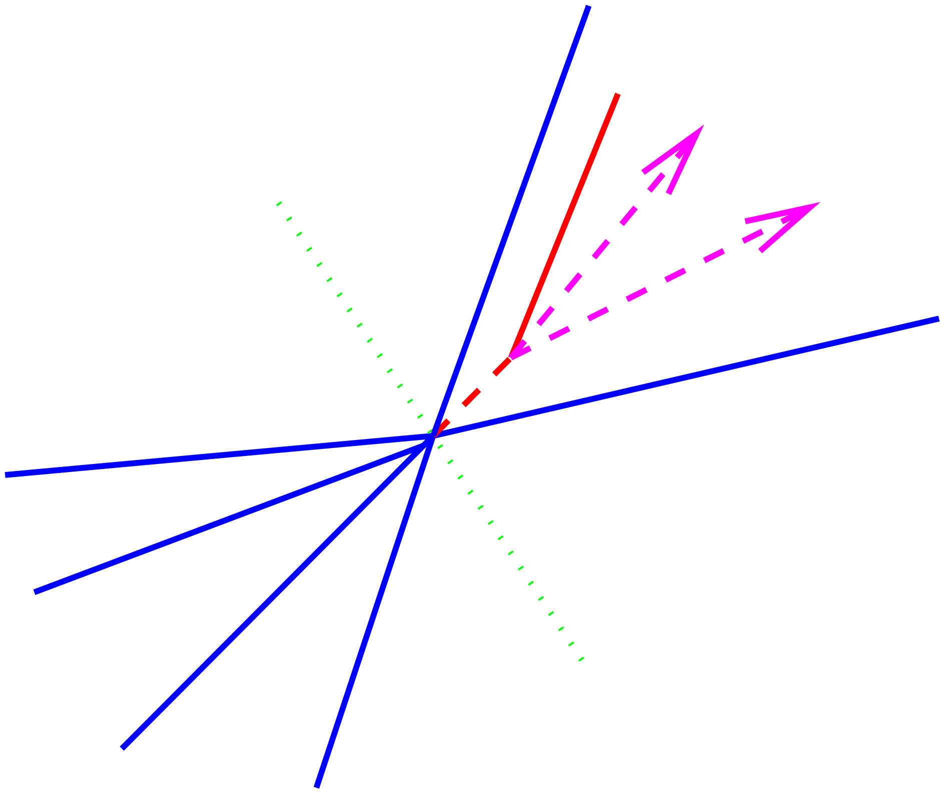
- Least energetic hemisphere
- τ decay tagged by hadron or lepton
  - ⋆ with $p > 1$ GeV
  - ⋆ inconsistent with primary vertex (4σ)

- B^+ energy and momentum given by

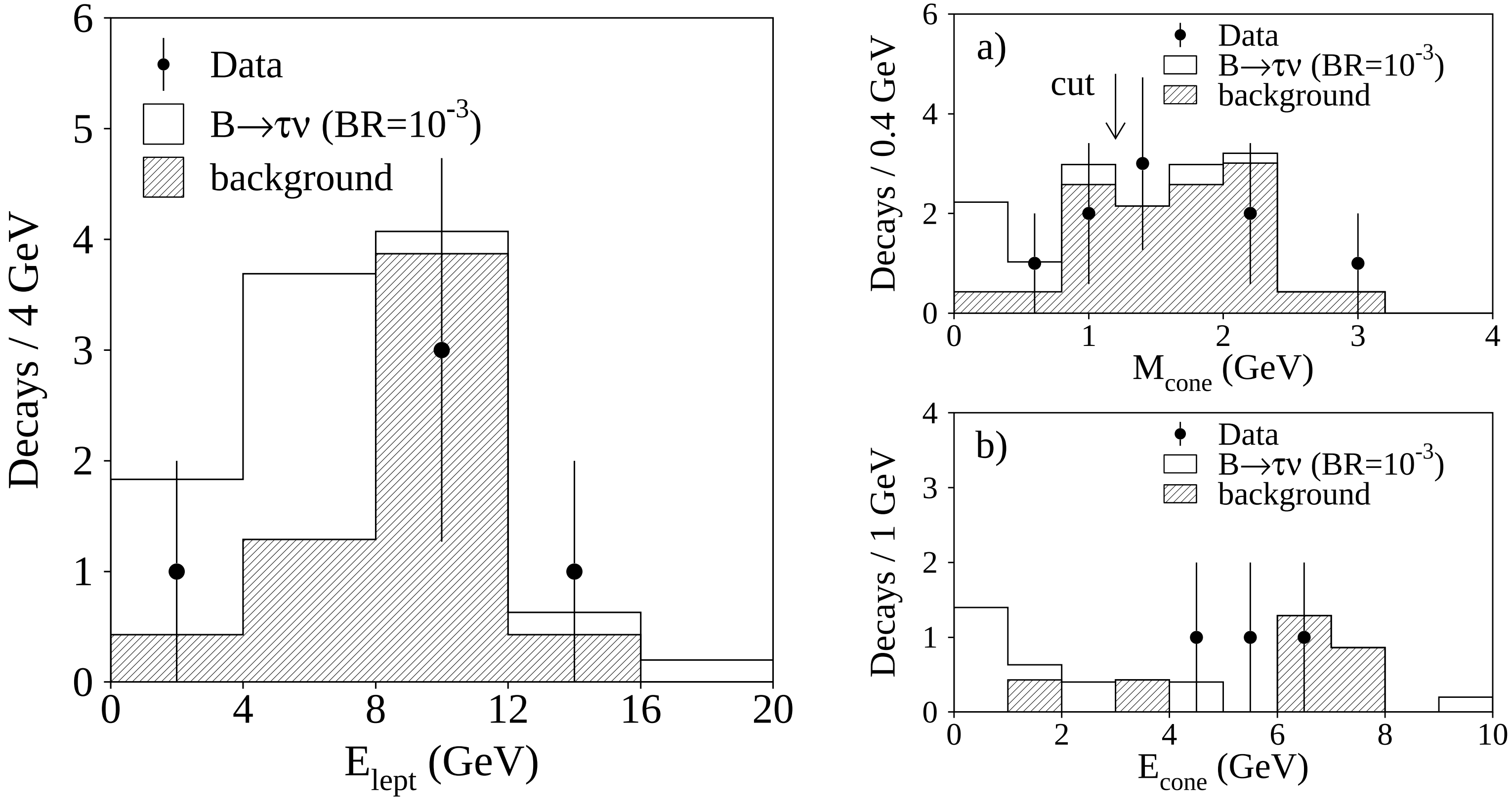
$$E_B = \sqrt{s} - \sum_{i \neq \tau \ \mathrm{tag}} E_i \qquad \overrightarrow{P}_B = - \sum_{i \neq \tau \ \mathrm{tag}} \overrightarrow{p}_i$$

- Require $P_B > 30$ GeV (reduces semileptonic background)

- In hadronic sample, require low invariant mass in cone around B direction.



L3 1996 (CERN-PPE/96-198)



$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 5.7 \times 10^{-4}$$

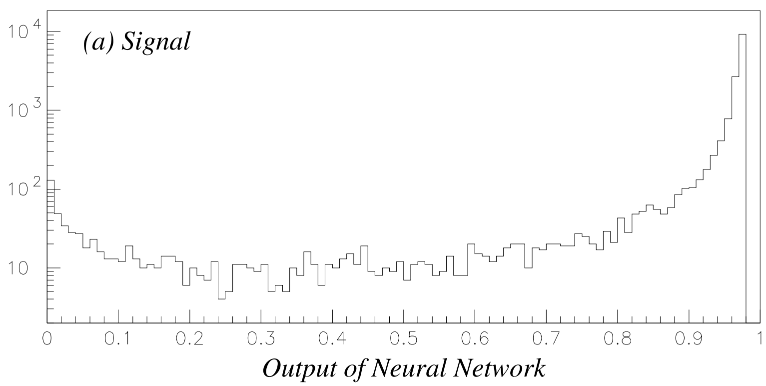
Prospects at B factories

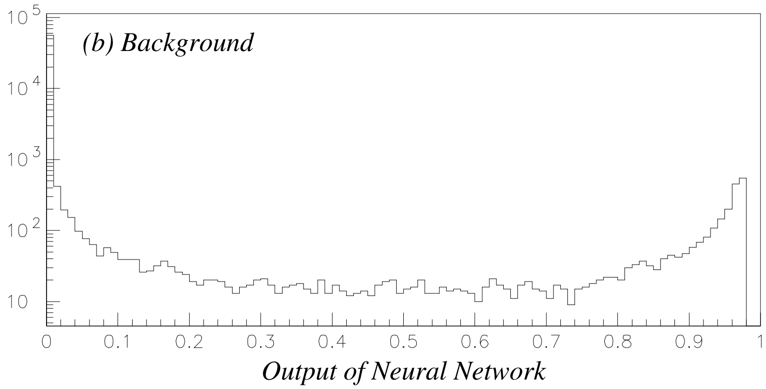
- CDF: B's are very highly boosted $\Rightarrow$ can use LEP-like techniques
- Belle, BaBar: B's are boosted, neutrinos can be inferred
- CLEO: B's at rest, neutrinos can be inferred

Belle $\tau \to \ell\nu\nu$ Kinematical Approach

(K. Namba, *et al.*)

- Neutrino reconstruction: $P_\nu = P_{\rm missing}$
- Require $N_\ell = 1,\ \sum Q = 0,\ N_{K_L} = 0$
- Neural Network utilizing: $P^*_\ell,\ \Delta E,\ M_B,\ N_p,\ N_{cp}$



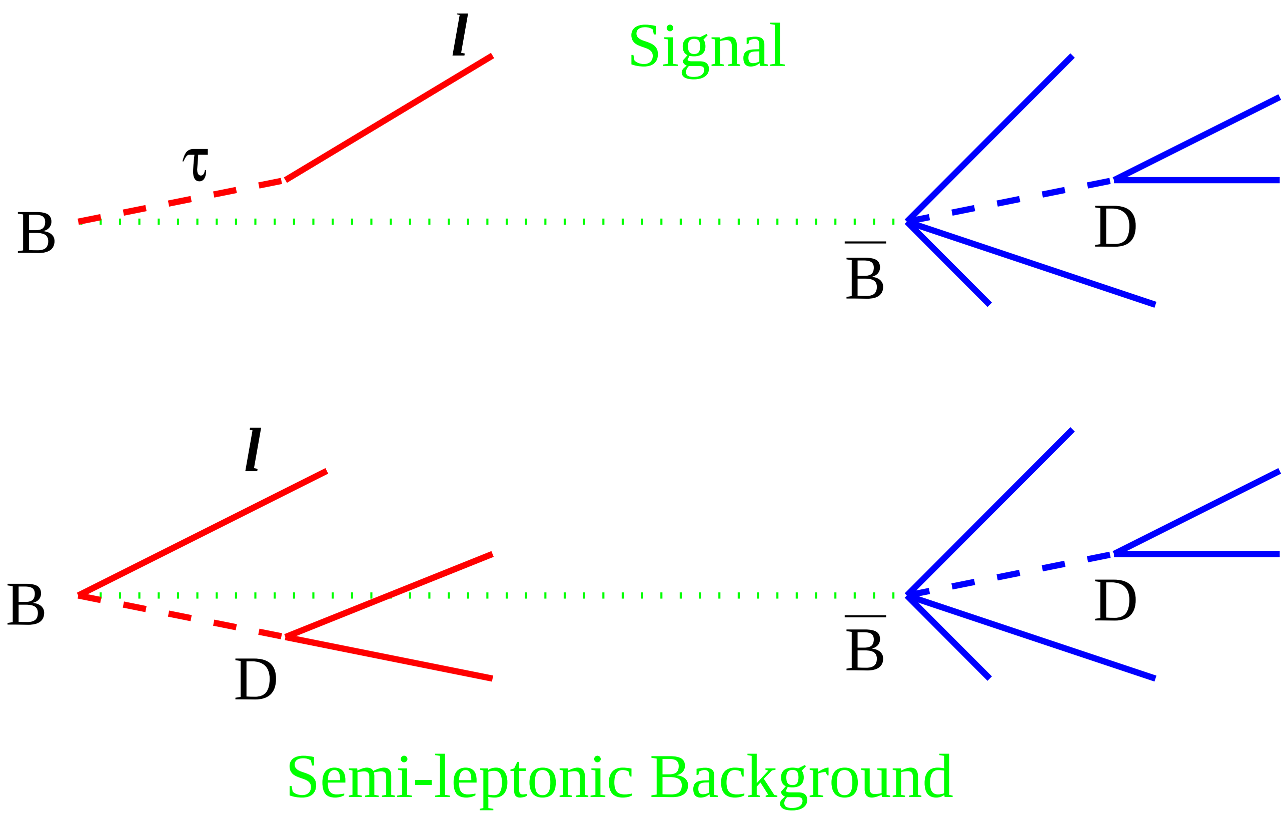


Assuming $\mathcal{B}(B \to \tau\nu) = 4 \times 10^{-5}$ and luminosity $= 100\ {\rm fb}^{-1}$

	$\tau \to e\nu\nu$	$\tau \to \mu\nu\nu$	combined
Expected signal	28	40	68
Expected $B\bar{B}$ background	8300	2800	11000

BaBar $\tau \to \ell\nu\nu$ Topological Approach

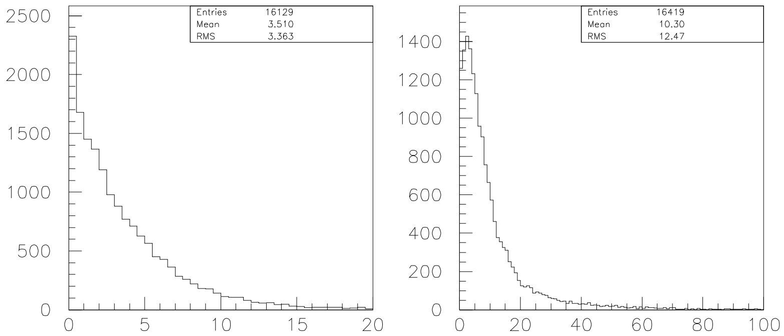
(S. Bettarini, M. Carpinelli, M. Giorgi)



Reduce semileptonic background using topological variables:

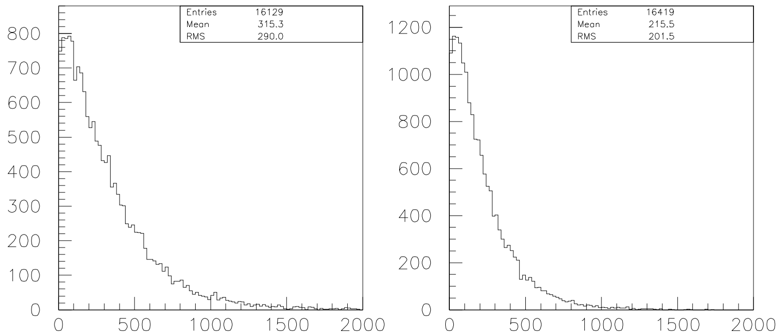
- Signal has 2 vertices; Background has 3 vertices $\Rightarrow$ more spread out along z-axis
- Lepton is closer to a vertex in background than in signal

Signal Background



$$\chi^2 = \sum_i^n \frac{(z_i - < z >)^2}{\sigma_i^2}$$

Signal Background



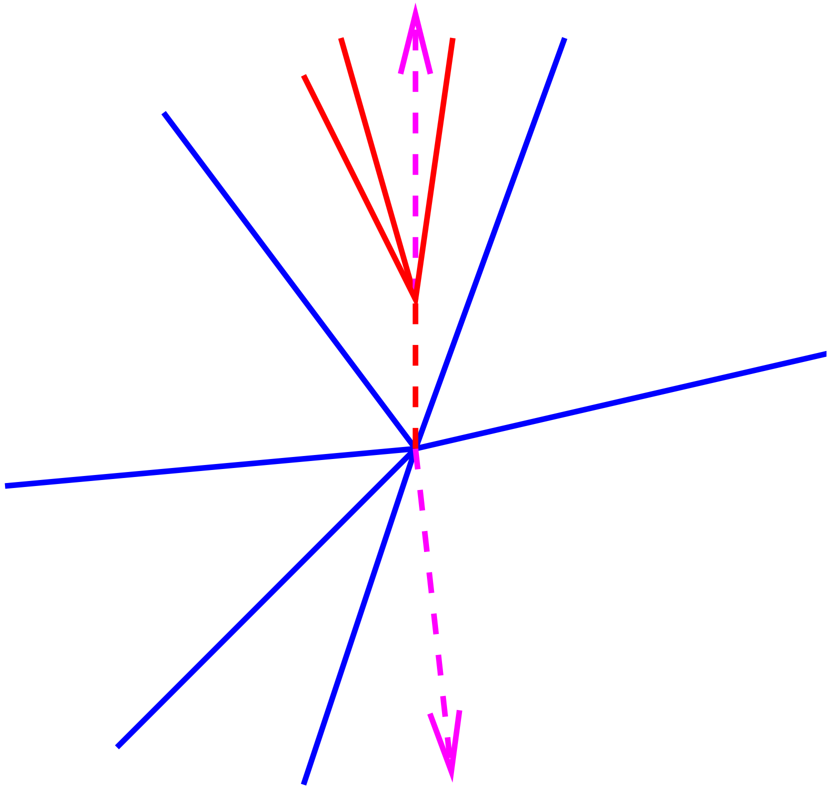
distance between lepton and $< z >$

Making appropriate cuts on these sorts of variables:

- 98% background reduction
- 12% signal efficiency

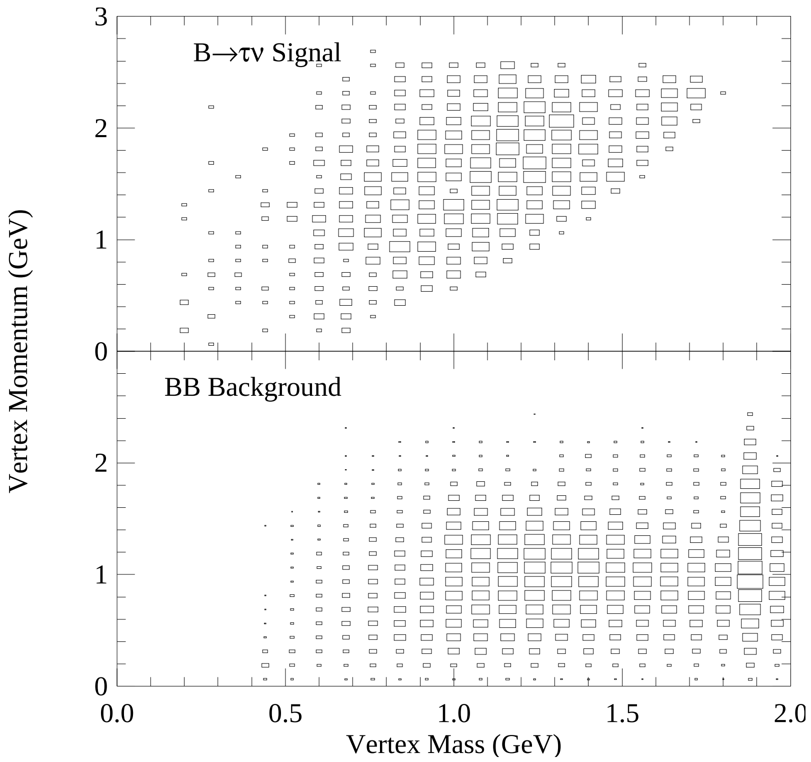
CLEO $\tau \to$ 3-prong Displaced Vertex Approach

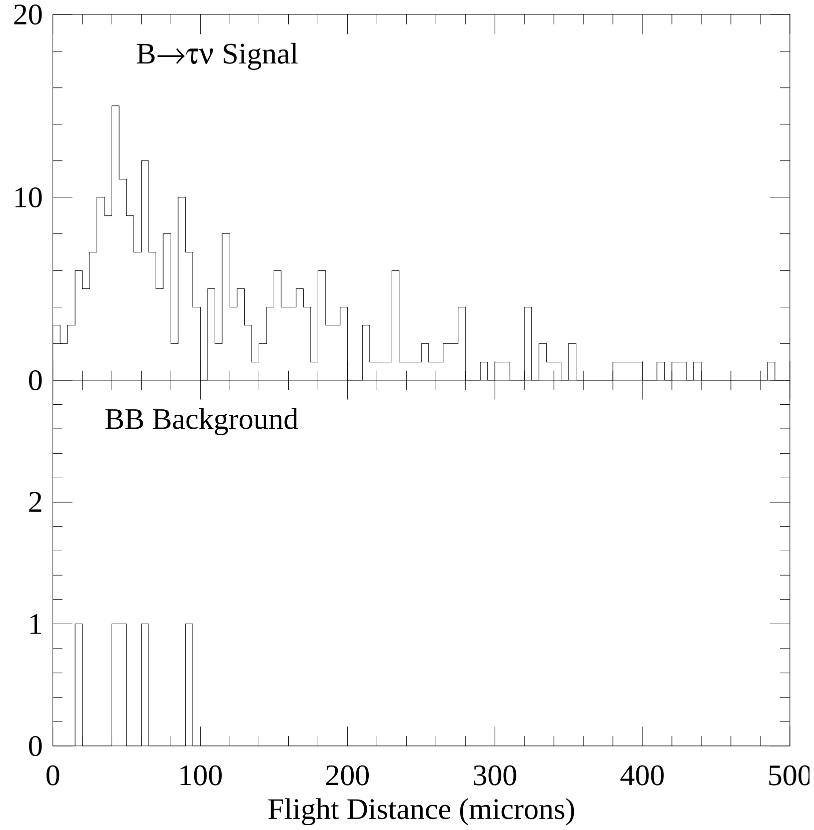
(D. Cinabro)



- Select events with significant missing energy
- Find a 3-track displaced vertex
- Require rest of the event to have $(E, \overrightarrow{p})$ consistent with a B.

- Kinematically separate signal and $b \to c$ background using vertex mass and momentum.





- Flight distance may distinguish leftover background from $b \to c$.

Summary

- $B \to \tau\nu$ is the most promising of the rare $B \to \tau$ decays.
- Current techniques include:
  - ⋆ CLEO neutrino reconstruction
  - ⋆ LEP missing energy + vertex techniques
- Techniques being developed:
  - ⋆ $\tau \to \ell\nu\nu$: not promising using kinematical variables only
  - ⋆ $\tau \to \ell\nu\nu$: boosted B's offer additional topological variables
  - ⋆ $\tau \to$ 3-prong: 3-prong vertex momentum and mass looks promising