Leptonic B Decays at Belle and Babar

A. Ishikawa
for the Belle Collaboration
(KEK)

Introduction

- Leptonic B decays are sensitive probes for new physics
  - Small uncertainty due to QCD compared with hadronic decays
  - $P \to f\bar{f}$ decays are helicity suppressed in the SM
  - Sensitive to helicity allowed coupling
    - charged Higgs propagation
    - Higgs mediated FCNC
  - Modes involving τ have larger branching fractions but need to tag the other B meson because of multi neutrinos in the final states.
- In this talk, following decay modes are covered
  - $B^0 \to e^+e^-$, $B^0 \to \mu^+\mu^-$: no neutrinos
  - $B^0 \to \tau^+\tau^-$, $B^+ \to \tau^+\nu$: at least two neutrinos in the final states

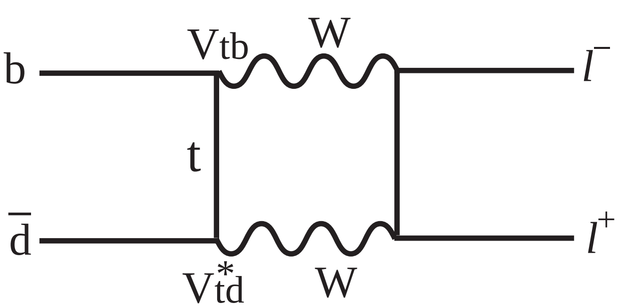
$B^0 \rightarrow l^+l^-$ decays

- Neutral B mesons decay to l^+l^- via box or penguin annihilation diagrams.
- The branching fractions are suppressed by lepton mass

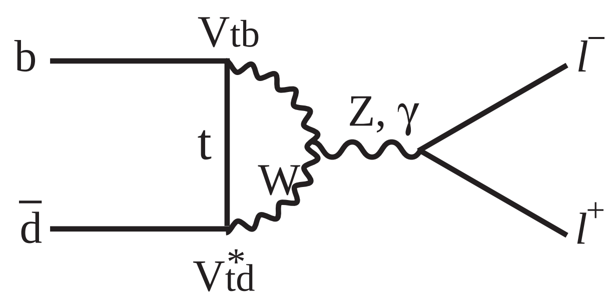
$$\mathcal{B}(B \to \ell^+\ell^-) = \tau_B \frac{G_F^2}{\pi} \eta_Y^2 \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 F_B^2 m_\ell^2 m_B |V_{tb}^* V_{td}|^2 Y^2(x_t)$$

$$\mathcal{B}(B^0 \to e^+e^-)_{\rm SM} \sim 10^{-15}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)_{\rm SM} \sim 10^{-10}$$
$$\mathcal{B}(B^0 \to \tau^+\tau^-)_{\rm SM} \sim 10^{-8}$$

- New physics(2HDM, Z-FCNC, Higgs FCNC) enhances the BFs by two orders of magnitude.
- None of the decay modes are observed yet.



Box



Penguin Annihilation

$B^+ \to \tau^+\nu$ decays

- Charged B mesons decay to $l^+\nu$ via an annihilation diagram in the SM
- The Branching fractions are suppressed by lepton mass

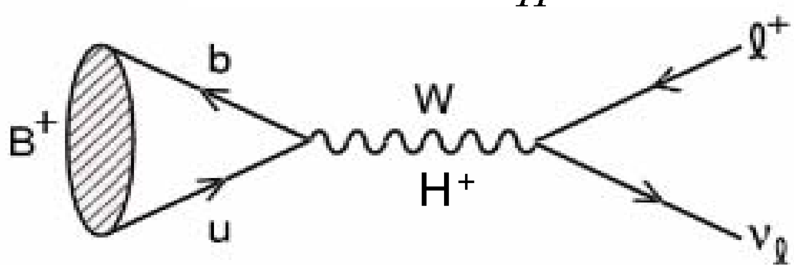
$$\mathcal{B}(B^+ \to \ell^+\nu) = \frac{G_F^2 m_B}{8\pi} m_\ell^2 (1 - \frac{m_\ell^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}(B^+ \to \tau^+\nu)_{\mathrm{SM}} = (1.59 \pm 0.40) \times 10^{-4}$$

- The best upper limit was given by Babar $< 2.6 \times 10^{-4}$
- Charged Higgs contribution changes the branching fraction

$$\mathcal{B}(B \to \tau\nu)_{\mathrm{2HDM}} = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H$$

$$r_H = (1 - \frac{m_B^2}{m_H^2} \tan^2\beta)^2$$



$B^0 \rightarrow e^+e^-$ and $B^0 \rightarrow \mu^+\mu^-$

Modes with no neutrinos

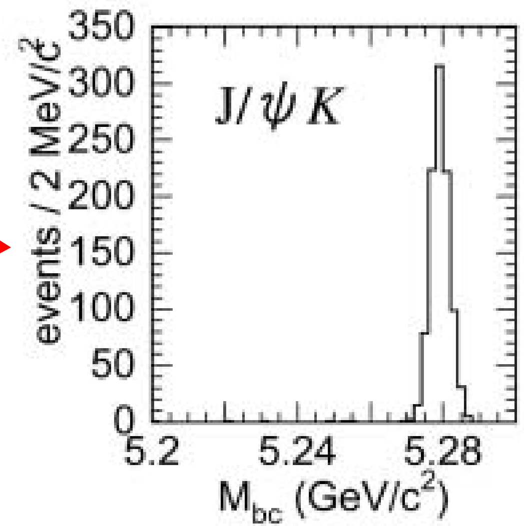
B meson reconstruction for $B^0 \rightarrow e^+e^-, \mu^+\mu^-$

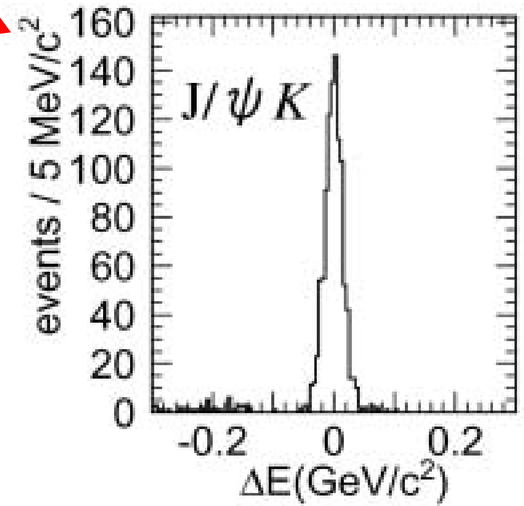
- Two variables are used to identify the B mesons
  - Beam Energy constraint mass

    $$M_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^2}$$

  - Energy difference

    $$\Delta E = E_B - E_{\text{beam}}$$





- Background suppression
  - Event shape
  - Multiplicity
  - Energy sum of the remaining particles

$B^0 \to e^+e^-, \mu^+\mu^-$ by Babar

- $B^0 \to e^+e^-$

$$\mathcal{B}(B^0 \to e^+e^-) < 6.1 \times 10^{-8}$$

(Babar, 111/fb)

  - The upper limit is O(10^7) above the prediction within the SM: ~10^{-15}.
  - Impossible to observe even at super B-factory

- $B^0 \to \mu^+\mu^-$

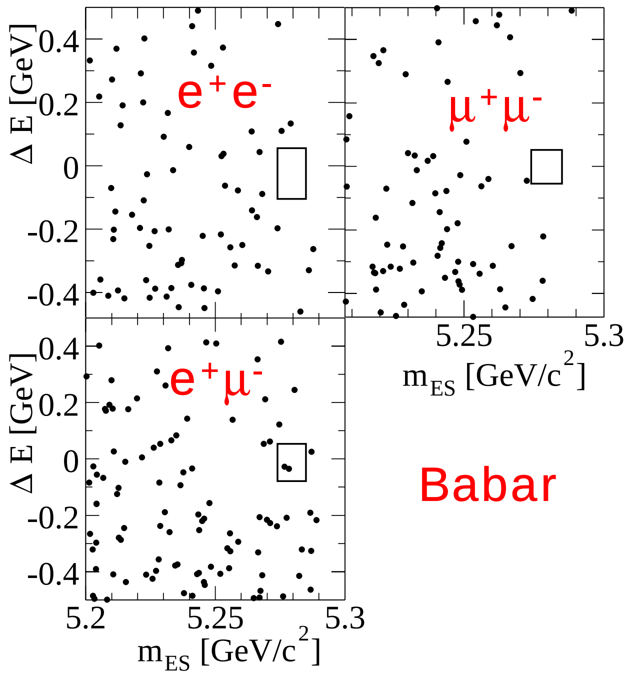
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 8.3 \times 10^{-8}$$

(Babar, 111/fb)

  - 800 times larger than the prediction in the SM.
  - CDF gives better limit with 364/pb

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.9 \times 10^{-8}$$

  - Statistics limited at both lepton and hadron colliders
  - Future hadron collider experiments may find the signal.

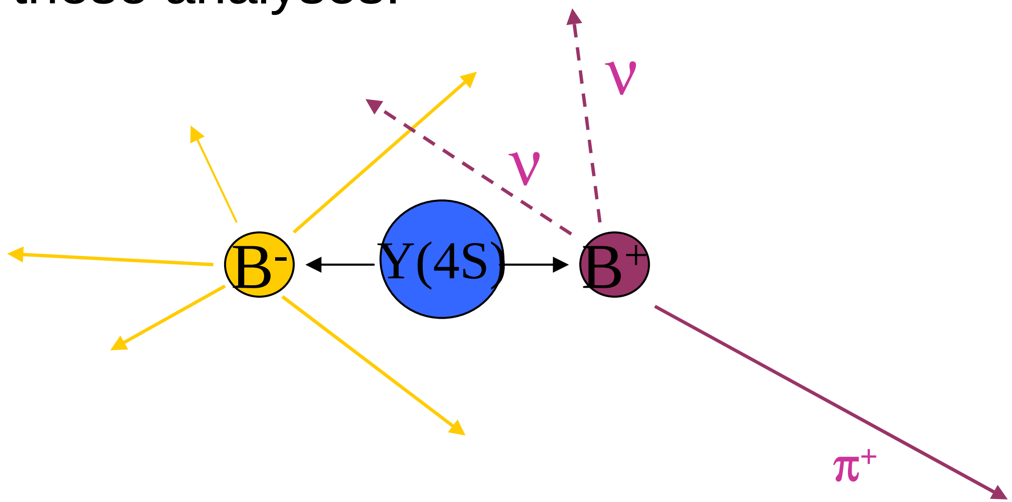


$B^0 \rightarrow \tau^+\tau^-$ and $B^+ \rightarrow \tau^+\nu$

Modes with at least two neutrinos

$B^0 \rightarrow \tau^+\tau^-$ and $B^+ \rightarrow \tau^+\nu$

- In the decay chains for $B \rightarrow \tau\tau$ and $B \rightarrow \tau\nu$, there are at lease two neutrinos.
- Usual kinematic variables (M_{bc} and ΔE) to identify B mesons cannot be used for these analyses.



- Reconstruct the decay of the non-signal B (tagging side), then look for the signal decay in whatever is left over

Tagging side :
Reconstruct hadronic modes

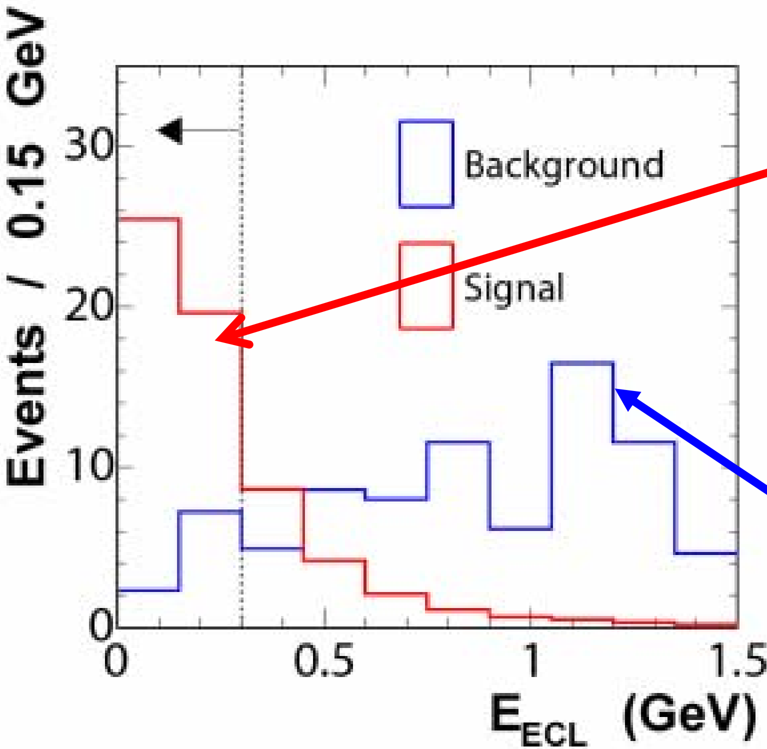
Signal side :
Reconstruct particles from τ decay

Identification of multi neutrino modes

- Extra neutral energy in calorimeter : E_{ECL}(Belle), E_{ECL}(Babar)
  - Total calorimeter energy from the neutral clusters which are not associated with the tagged B and signal B

$$E_{ECL} = E_{\mathrm{tot}} - E_{\mathrm{tag}} - E_{\mathrm{sig}}$$

  - Most powerful variable for separating signal and background



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

Higher E_{ECL} due to additional neutral clusters

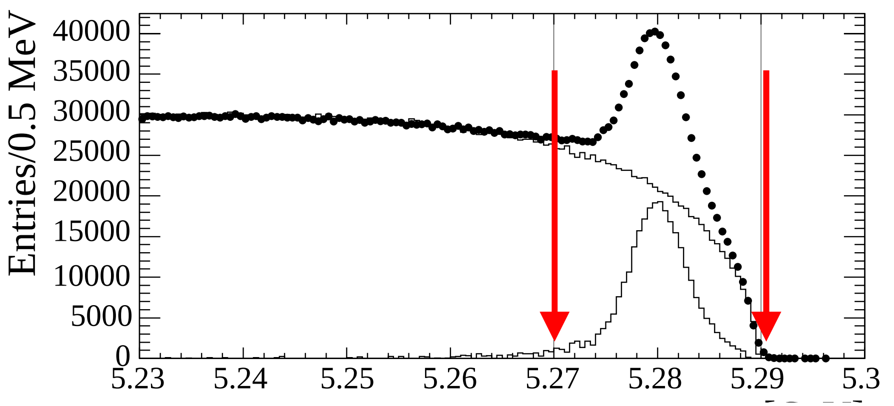
$B^0 \rightarrow \tau^+\tau^-$ by Babar

- 210/fb data is used.
- The other B meson is tagged with hadronic decays.

$$B \rightarrow D^{(*)}X$$
$$D^{*+} \rightarrow D^0\pi^+$$
$$D^0 \rightarrow K^-\pi^+, K^-\pi^+\pi^0, K\pi^+\pi^-\pi^+ \text{ and } K^0_S\pi^+\pi^-$$
$$D^+ \rightarrow K^0_S\pi^+, K^-\pi^+\pi^+, K^0_S\pi^+\pi^0, K^0_S\pi^+\pi^+\pi^- \text{ and } K^+K^-\pi^+$$
$$X = i\pi^\pm + j\pi^0 + kK^\pm + lK^0_S\ (i+j+k+l \leq 5)$$

- Cleaner 147 decay channels are selected as tagging modes.

$$(2.80 \pm 0.27) \times 10^5,\ B^0\overline{B}^0 \text{ events}$$



Signal region : -0.09 < ΔE < 0.06 GeV, 5.27< M_{bc} < 5.29 GeV/c^2

τ decay modes for $B^0 \to \tau^+\tau^-$ by BaBar

- Four τ decay modes are used.
  - These cover about 71% of total decay width of τ.
  - All combinations of τ^+ and τ^- decays are used except for $e\nu\nu/\rho\nu$, $\mu\nu\nu/\rho\nu$ and $\pi\nu/\rho\nu$ combinations.
  - About 30% of $B^+ \to \tau^+\tau^-$ is covered with these combinations.

$$\begin{matrix} \tau^+ \to e^+\nu\nu \\ \tau^+ \to \mu^+\nu\nu \\ \tau^+ \to \pi^+\nu \\ \tau^+ \to \rho^+\nu \end{matrix} \quad \times \quad \begin{matrix} \tau^- \to e^-\nu\nu \\ \tau^- \to \mu^-\nu\nu \\ \tau^- \to \pi^-\nu \\ \tau^- \to \rho^-\nu \end{matrix}$$

- Further selections are applied to reduce backgrounds
  - Momentum balance of τ^+ and τ^- daughters
  - Neural net

Result for $B^0 \rightarrow \tau^+\tau^-$ by BaBar

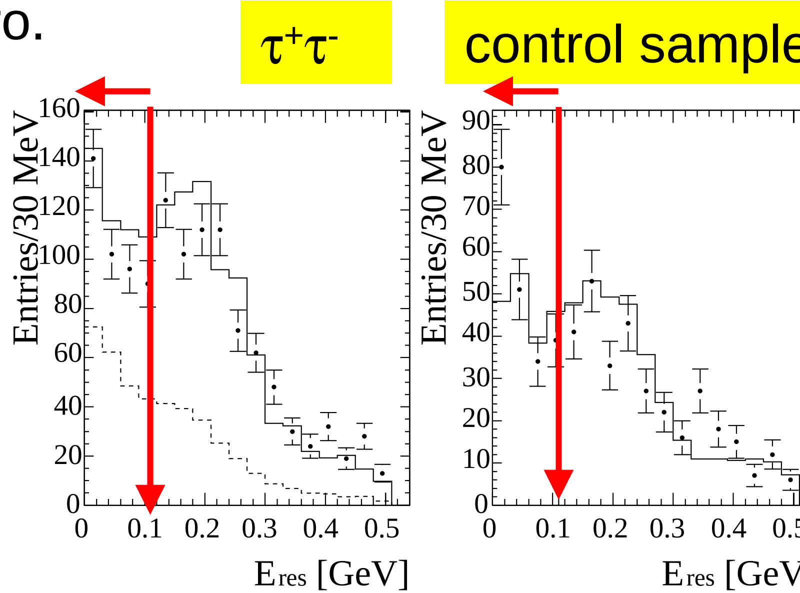
- Require the E_{res} is consistent with zero.

  Expected events: 281 ± 48

  Observed events: 263 ± 19

  Efficiency: 4.3 ± 0.9 %

  Observed number of events is consistent with expected.



$$\mathcal{B}(B^0 \rightarrow \tau^+\tau^-) < 4.1 \times 10^{-3}$$

  - The limit is O(10⁴) larger than predictions in the SM

- J.Kalinowski pointed out at EPS2005 that the limit on BF(B → μμ) gives better sensitivity in the SM.

$$\mathcal{B}(B^0 \rightarrow \tau^+\tau^-) \; < \; UL(B^0 \rightarrow \mu^+\mu^-)_{\rm CDF} \times \frac{m_\tau^2}{m_\mu^2}$$

$$< \; \sim 1.0 \times 10^{-5}$$

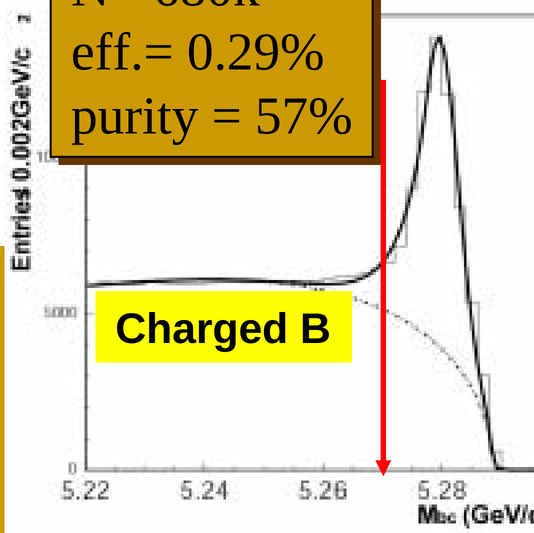
$B^+ \to \tau^+\nu$ by Belle

- 414/fb data.
- About 180 decay channels are used for tagging.

N= 680k
eff.= 0.29%
purity = 57%

$$B^+ \to \bar{D}^{(*)0} + \pi^+ / \rho^+ / a_1^+ / D_S^{(*)+}$$
$$\bar{D}^{*0} \to \bar{D}^0\pi^0 / \bar{D}^0\gamma \qquad D_S^{*+} \to D_s^+\gamma$$
$$B^0 \to D^{(*)-} + \pi^+ / \rho^+ / a_1^+ / D_S^{(*)+}$$
$$D^{*-} \to \bar{D}^0\pi^- / D^-\pi^0 \qquad D_S^{*+} \to D_s^+\gamma$$

$\bar{D}^0 \to$ 7 modes
$D^- \to$ 6 modes
$D_s^+ \to$ 2 modes



m ~ 5.28 GeV/c²

σ~ 3 MeV/c² due to σ(E_{beam})

Signal region : $-0.08 < \Delta E < 0.06$ GeV, $M_{bc} > 5.27$ GeV/c^2

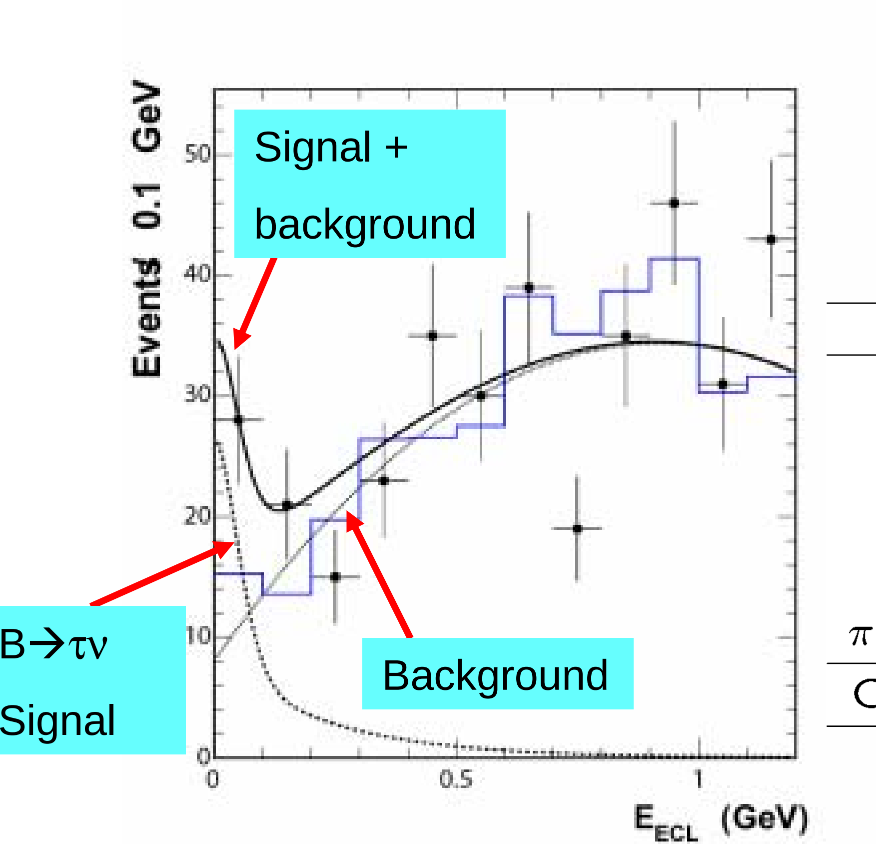
- τ lepton is identified in 5 decay modes
  - 81% of total width is covered

$$\tau^- \to e^-\nu\bar{\nu},\ \mu^-\nu\bar{\nu},\ \pi^-\nu,\ \pi^-\pi^0\nu,\ \pi^-\pi^+\pi^-\nu$$

- Background suppressions
  - Missing momentum
  - Momentum of hadronic system

Fit Result for $B^+ \rightarrow \tau^+\nu$

- Unbinned Likelihood fit to the obtained E_{ECL} distributions



Observe $21.2^{+6.7}_{-5.7}$ events with a significance of 4.2σ

	N_{obs}	N_s	N_b	Σ
$\mu^-\bar{\nu}_\mu\nu_\tau$	13	$5.4^{+3.2}_{-2.2}$	$9.1^{+0.2}_{-0.1}$	2.3σ
$e^-\bar{\nu}_e\nu_\tau$	12	$3.9^{+3.5}_{-2.5}$	$9.2^{+0.2}_{-0.2}$	1.5σ
$\pi^-\nu_\tau$	9	$3.4^{+2.6}_{-1.6}$	$4.0^{+0.2}_{-0.1}$	1.9σ
$\pi^-\pi^0\nu_\tau$	11	$6.2^{+3.9}_{-2.7}$	$4.2^{+0.3}_{-0.3}$	2.6σ
$\pi^-\pi^+\pi^-\nu_\tau$	9	$3.1^{+3.1}_{-2.6}$	$3.7^{+0.3}_{-0.2}$	1.2σ
Combined	54	$21.2^{+6.7}_{-5.7}$	$30.2^{+0.5}_{-0.4}$	4.2σ

Σ : Significance with systematics

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

Background yield is consistent with the expectation from the MC simulation

First Evidence for a leptonic B decay!!

Branching Fraction for $B^+ \rightarrow \tau^+\nu$

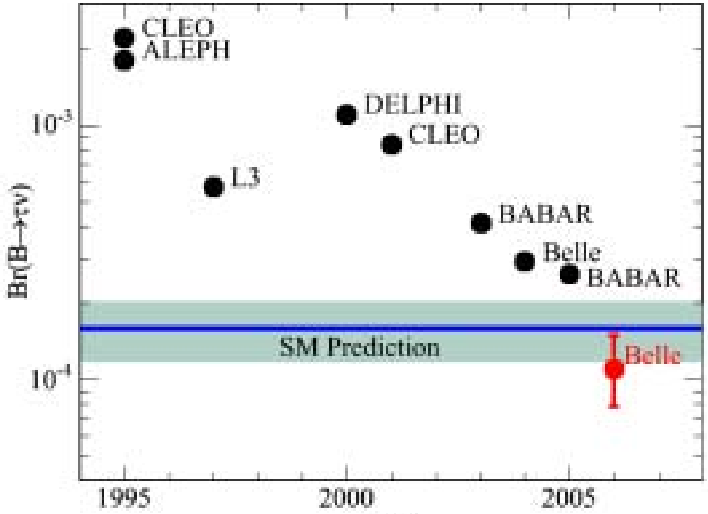
- All τ decay modes combined

$$\mathcal{B}(B \to \tau\nu) = (1.06^{+0.34}_{-0.28}{}^{+0.18}_{-0.16}) \times 10^{-4}$$

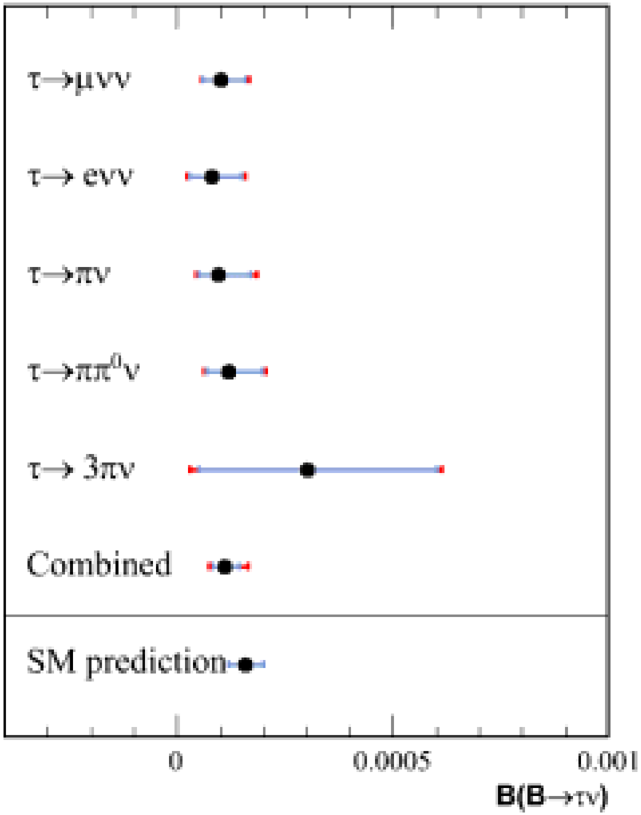
(Preliminary)

SM : $B(B \rightarrow \tau\nu) = (1.59 \pm 0.40) \times 10^{-4}$

Result is consistent with SM expectation with $f_B = 0.216 \pm 0.022$ GeV and $V_{ub} = (4.39 \pm 0.33) \times 10^{-3}$.



Extracted branching fraction for each τ decay mode



Constraint on 2HDM Parameter space

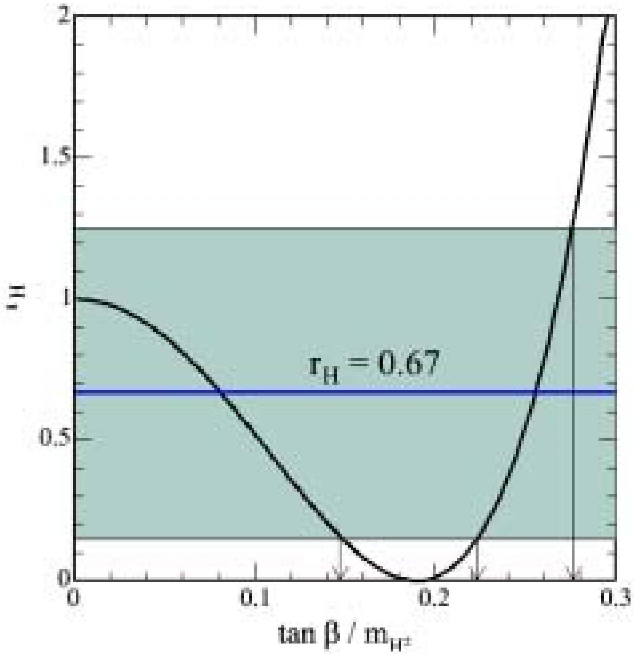
- Constraint on Charged Higgs

$$\mathcal{B}(B \to \tau\nu)_{\mathrm{2HDM}} = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H$$

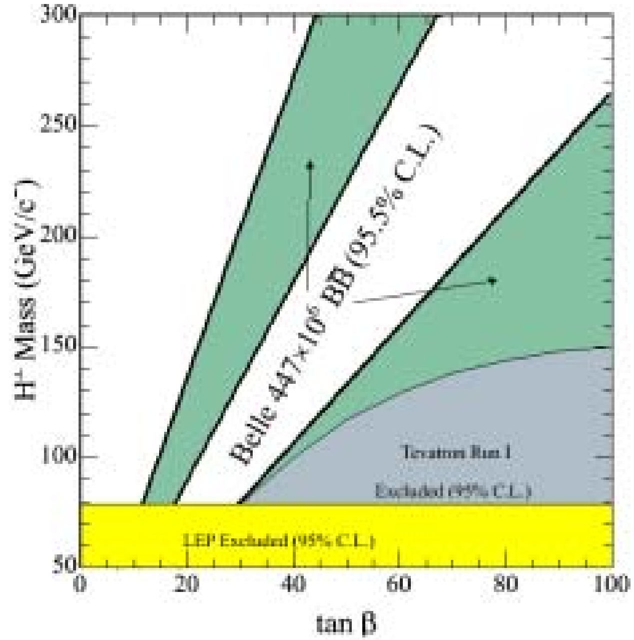
$$\mathcal{B}(B \to \tau\nu) = (1.06^{+0.34}_{-0.28}(\mathrm{stat})^{+0.18}_{-0.16}(\mathrm{syst})) \times 10^{-4}$$

$$\mathrm{SM} : \mathcal{B}(B \to \tau\nu) = (1.59 \pm 0.40) \times 10^{-4}$$

$$r_H = (1 - \frac{m_B^2}{m_H^2}\tan^2\beta)^2 \longrightarrow r_H = 0.67^{+0.29}_{-0.26}$$



2σ



95.5%C.L. exclusion boundaries

Summary

- Leptonic B decays are sensitive probes for new physics
- We searched for $B^0 \rightarrow e^+e^-$, $B^0 \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow \tau^+\tau^-$ and found no signals.
- Belle finds Evidence for $B^+ \rightarrow \tau^+\nu$!!
- This gives a strong constraint on 2HDM parameter space.