Measurement of $B \to \tau \nu$
Contents

• Introduction
• Review of latest results
• Interpretation
**B → τν in Standard Model**

- In the SM, **annihilation process mediated by W⁺.**

- **Branching fraction proportional to** $f_B^2 |V_{ub}|^2$.

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

- $f_B$: B meson decay constant. **Can be calculated from Lattice QCD.**
- $V_{ub}$: CKM matrix element. **Can be measured from $b \rightarrow u\nu\nu$ decays.**

*Both can also be obtained from a CKM global fit.*
Effect of charged Higgs for $B \rightarrow \tau \nu$

- $B \rightarrow \tau \nu$ could be affected by charged Higgs.

- An example of modifications is:

$$B(B^- \rightarrow \tau^- \bar{\nu}_\tau) = B(B^- \rightarrow \tau^- \bar{\nu}_\tau)^{SM} \times r_H$$

where

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

Type II of two Higgs doublet model,
Methods for analyzing $B \to \tau \nu$

Exploit that a B meson pair is generated by $e^+e^- \to \Upsilon(4S) \to BB$ for “seeing” multiple neutrinos.

Two independent tags are used.

- **Hadronic tag**: tag B in hadronic decays $B \to D^{(*)}\pi$, etc.
- **Semileptonic tag**: tag B in semileptonic decays $B \to D^{(*)}l\nu$. ($l = e$ or $\mu$)
Summary for $B \to \tau \nu$ in early 2012

Consistent with a SM expectation $\mathcal{B} = (1.10 \pm 0.30) \times 10^{-4}$ based on

- $f_B = (190 \pm 13)$ MeV from HPQCD, PRD80, 014503 (2009),
- $|V_{ub}| = (4.15 \pm 0.49) \times 10^{-3}$ from PDG 2012 ($b \to u \ell \nu$ transitions).
Tension with a CKM fit prediction

Compare measured $\mathcal{B}(B \to \tau \nu)$ with a SM prediction obtained from a CKM global fit.

Discrepancy by $2.8\sigma$.

Relation with $\sin 2\Phi_1$.

Hint of new physics...?
Data samples used for $B \to \tau \nu$

Semileptonic tag
($\sim 85\%$ of full data)

Hadronic tag
($\sim 60\%$ of full data)

Hadronic and semileptonic tags
(full data)
Data samples used for $B \rightarrow \tau \nu$

We focus on the updates on hadronic-tag results.

Update on hadronic tag, ICHEP2012, arXiv:1208.4678

Update on hadronic tag, ICHEP2012, arXiv:1207.0698

Semileptonic tag (~85% of full data)

Hadronic tag (~60% of full data)

Hadronic and semileptonic tags (full data)
Belle, increased tagged events

- Improved hadronic tag:
  - Add decay modes ($B \to D\pi\pi\pi$, etc.) which have several final-state particles.
  - Use NeuroBayes package for a better separation with backgrounds.

NIMA 654, 432 (2011)

3.0 times larger tagged events in total

(Efficiency slightly larger if signal side is $B \to \tau\nu$.)
Belle, event selection for signal side

For tagged events, signal side is reconstructed from \( B \rightarrow \tau \nu \).

\( \tau \rightarrow e \nu \nu, \tau \rightarrow \mu \nu \nu, \tau \rightarrow \pi \nu, \) and \( \tau \rightarrow \rho \nu \) are used.

- Find \( e, \mu, \pi, \) or \( \rho \).
- Select events with no other charged tracks, \( \pi^0 \), or \( K_L \).
- \( K_L \) efficiency is calibrated by using \( D^0 \rightarrow \Phi K_S, \phi \rightarrow K_SK_L \).
- By introducing \( K_L \) veto, expected sensitivity for \( B \rightarrow \tau \nu \) is improved by a factor of about 5%.
Belle, method of signal extraction

• Signal extraction based on two variables.
  
  • $E_{ECL}$: remaining energy in electromagnetic calorimeter (peak at $E_{ECL} = 0$ GeV for signal).
  
  • $M_{miss}^2$: missing mass squared (larger for $e\nu\nu/\mu\nu\nu$, smaller for $\pi\nu/\rho\nu$).

In this analysis, we remove momentum cuts for $e$, $\mu$, $\pi$, and $\rho$, and we newly include $M_{miss}^2$ in the fit.

• Sensitivity for $B \rightarrow \tau\nu$ improved by a factor of about 20%.
• Result less sensitive to the backgrounds which peak at $E_{ECL} = 0$ GeV.
Belle, signal extraction

Simultaneous fit to different $\tau$ decay samples. Figures shown for the sum of different $\tau$ decays.

- Signal yield: $62^{+23}_{-22}$ (stat) $\pm 6$ (syst).

- $B(B \rightarrow \tau\nu) = [0.72^{+0.27}_{-0.25}$ (stat) $\pm 0.11$ (syst)] $\times 10^{-4}$. 

Significance: $3.0\sigma$ (including syst)
Belle, systematic uncertainties

\[
\mathcal{B}(B^- \rightarrow \tau^- \nu_\tau) = [0.72^{+0.27}_{-0.25}\text{(stat)} \pm 0.11\text{(syst)}] \times 10^{-4}
\]

- Uncertainties due to background PDFs are estimated by varying the background yields by BR and MC-statistics errors.
- Uncertainties due to tag efficiency and $K_L$ veto are estimated by using a clean control sample $B \rightarrow D^* l \nu$.

<table>
<thead>
<tr>
<th>Source</th>
<th>$\mathcal{B}$ syst. error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal PDF</td>
<td>4.2</td>
</tr>
<tr>
<td>Background PDF</td>
<td><strong>8.8</strong></td>
</tr>
<tr>
<td>Peaking background</td>
<td>3.8</td>
</tr>
<tr>
<td>$B_{\text{tag}}$ efficiency</td>
<td><strong>7.1</strong></td>
</tr>
<tr>
<td>Particle identification</td>
<td>1.0</td>
</tr>
<tr>
<td>$\pi^0$ efficiency</td>
<td>0.5</td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>0.3</td>
</tr>
<tr>
<td>$\tau$ branching fraction</td>
<td>0.6</td>
</tr>
<tr>
<td>MC efficiency statistics</td>
<td>0.4</td>
</tr>
<tr>
<td>$K_L^0$ efficiency</td>
<td>7.3</td>
</tr>
<tr>
<td>$N_{B+B^-}$</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>14.7</td>
</tr>
</tbody>
</table>
Belle, $\tau$ mode independence

As a check, we fit by floating the yields for different $\tau$ modes.

Take $\tau \to e\nu\nu$, $\mu\nu\nu$, $\rho\nu$ cross-feeds in $\tau \to \pi\nu$ candidates as signal.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Number of signal</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^-\nu_e\nu_\tau$</td>
<td>$15.5^{+11.2}_{-9.4}$</td>
<td>$2.98 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\mu^-\bar{\nu}<em>\mu\nu</em>\tau$</td>
<td>$25.6^{+15.1}_{-13.8}$</td>
<td>$3.12 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\pi^-\nu_\tau$</td>
<td>$7.8^{+9.5}_{-7.9}$</td>
<td>$1.76 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\rho^-\nu_\tau$</td>
<td>$13.6^{+18.7}_{-16.1}$</td>
<td>$3.37 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Belle Preliminary (stat. errors only)

ICHEP 2012

Consistent results.
BaBar, signal extraction

- Signal extraction by fitting $E_{\text{extra}}$ (remaining energy) distribution.
- Simultaneous fit to four $\tau$ decays: $\tau \rightarrow e\nu\nu$, $\tau \rightarrow \mu\nu\nu$, $\tau \rightarrow \pi\nu$, and $\tau \rightarrow \rho\nu$.

(Figure shown for the sum of different $\tau$ decays.)

- Signal yield: $62.1 \pm 17.3$ (stat).
- $B(B \rightarrow \tau\nu) = [1.83^{+0.53}_{-0.49} \text{ (stat)} \pm 0.24 \text{ (syst)}] \times 10^{-4}$.

Systematic uncertainties from background PDFs, tag efficiency, etc.
BaBar, $\tau$ mode independence

- Fit by floating signal yields for different $\tau$ modes.
- Results are consistent within $\sim 2\sigma$.

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>$\epsilon_k (\times 10^{-4})$</th>
<th>Signal yield</th>
<th>$B (\times 10^{-4})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau^+ \rightarrow e^+ \nu \bar{\nu}$</td>
<td>2.47 ± 0.14</td>
<td>4.1 ± 9.1</td>
<td>0.35$^{+0.84}_{-0.73}$</td>
</tr>
<tr>
<td>$\tau^+ \rightarrow \mu^+ \nu \bar{\nu}$</td>
<td>2.45 ± 0.14</td>
<td>12.9 ± 9.7</td>
<td>1.12$^{+0.90}_{-0.78}$</td>
</tr>
<tr>
<td>$\tau^+ \rightarrow \pi^+ \nu$</td>
<td>0.98 ± 0.14</td>
<td>17.1 ± 6.2</td>
<td>3.69$^{+1.42}_{-1.22}$</td>
</tr>
<tr>
<td>$\tau^+ \rightarrow \rho^+ \nu$</td>
<td>1.35 ± 0.11</td>
<td>24.0 ± 10.0</td>
<td>3.78$^{+1.65}_{-1.45}$</td>
</tr>
<tr>
<td>combined</td>
<td>62.1 ± 17.3</td>
<td>1.83$^{+0.53}_{-0.49}$</td>
<td></td>
</tr>
</tbody>
</table>
Comparison of the results

Belle combined: $\mathcal{B} = (0.96 \pm 0.26) \times 10^{-4}$

BaBar combined: $\mathcal{B} = (1.79 \pm 0.48) \times 10^{-4}$

Consistent with a SM expectation $\mathcal{B} = (1.10 \pm 0.30) \times 10^{-4}$ based on

- $f_B = (190 \pm 13) \text{ MeV}$ from HPQCD, PRD80, 014503 (2009),
- $|V_{ub}| = (4.15 \pm 0.49) \times 10^{-3}$ from PDG 2012 ($b\to u\ell\nu$ transitions).
Comparison with CKM fit prediction

Compare measured $B(B \to \tau \nu)$ with a SM prediction obtained from a CKM global fit.

Results consistent with CKM fit prediction.
Constraint on charged Higgs

- Assume Type II of two Higgs doublet model.

\[ \mathcal{B}(B \rightarrow \tau \nu) = \mathcal{B}(B \rightarrow \tau \nu)_{\text{SM}} \times r_H \quad r_H = \left( 1 - \frac{m_B^2}{m_H^2} \tan^2 \beta \right)^2 \]

**Belle**

95% C.L. excluded.

**BaBar**

\[ V_{ub} \text{ from exclusive + inclusive } b \rightarrow u \]

\[ V_{ub} \text{ from exclusive } b \rightarrow u \]

\[ V_{ub} \text{ from inclusive } b \rightarrow u \]

Constraint depends on central values of \( \mathcal{B}(B \rightarrow \tau \nu) \) and \( |V_{ub}| \) ...
Comparison with $B \to D^{(*)}\tau\nu$

Compare constraints on $\tan\beta/m_H$ assuming Type II.

- **Belle, $B \to \tau\nu$**
  - 95% C.L. excluded

- **BaBar, $B \to \tau\nu$**
  - $V_{ub}$ from exclusive $b \to u$
  - $V_{ub}$ from inclusive $b \to u$

- **$B \to D\tau\nu$**
  - Preferred

- **$B \to D^{*}\tau\nu$**
  - Preferred

$B \to \tau\nu$, $D\tau\nu$, and $D^{*}\tau\nu$ prefer different regions of $\tan\beta/m_H$.

Type II disfavored...?
Need further studies.
Summary

- **Updates on $B \rightarrow \tau \nu$ hadronic-tag analyses.**
  - Belle: increased data and improved analysis.
  - BaBar: slight improvement in analysis.
- **Results consistent with SM within errors.**
- **Constraint on charged Higgs discussed.**
  - Interesting relation with $B \rightarrow D^{(*)} \tau \nu$. 
Backup slides
Tag efficiency correction

Efficiency correction by fitting $M_{bc}$ for $E_{ECL}$ sideband data.

Validity of tag efficiency correction using $B \rightarrow D^{(*)} l \nu$ control sample.

After applying selection for the signal side.

$\mathcal{B}(B^- \rightarrow D^{*0} l^- \bar{\nu}_l) = (5.60 \pm 0.22\text{(stat)} \pm 0.28\text{(syst)})\%$

PDG: $\mathcal{B}(B^- \rightarrow D^{*0} l^- \bar{\nu}_l) = (5.68 \pm 0.19)\%$
**K_L veto**

- Background rejection using K_L is introduced.
- Effective to reduce peaking backgrounds.
- Improves the statistical significance about 5%.

![Graph showing B^0-tagged total without and with reconstructed K_L](image)
**$K_L$ veto**

- Efficiency difference in data and MC calibrated by $D^0 \rightarrow \Phi K_S$, $\Phi \rightarrow K_SK_L$ (normalized by $\Phi \rightarrow K^+K^-$).
- Validity checked using $B^0 \rightarrow D^*-\pi^+$, $D^*-\rightarrow D\pi^-$, $D \rightarrow K_L\pi^0$.

Check done also for $B \rightarrow \tau\nu$ BG in $E_{ECL}$ sideband data.

\[ \text{w/ } K_L \text{ veto, w/o } K_L \text{ veto efficiency correction} \quad \text{w/ } K_L \text{ veto, w/ } K_L \text{ veto efficiency correction} \]
Signal PDFs for $E_{ECL}$ and $M_{miss}^2$

Signal PDF for $E_{ECL}$ is checked using $D^*\ell\nu$ control sample.

Signal PDF for $M_{miss}^2$ is affected by momentum resolutions. Since $M_{miss}^2$ for $B\to\tau\nu$ has wide distribution, do not apply correction.
Peaking backgrounds

- At least one of $E_{ECL}$ and $M_{miss}^2$ distributions have difference from signal. Result is less sensitive to peaking backgrounds.

- If BR is known, error of BR and MC statistics in Syst.

- If BR is not known, assume SM value in the nominal fit. SM value $\pm 50\%$ and MC statistics in Syst.

MC: data $\times 10^{(*)}$ for $b \rightarrow c$.

MC: data $\times 20$ for $b \rightarrow u$.

MC: data $\times 50$ for rare modes.
Comparison with the previous hadronic-tag result

<table>
<thead>
<tr>
<th></th>
<th>PRL 97 (2006)</th>
<th>This analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tag</td>
<td>Hadronic tag</td>
<td>Hadronic tag (new)</td>
</tr>
<tr>
<td>Number of $B\overline{B}$ events ($\times 10^8$)</td>
<td>4.49</td>
<td>4.49</td>
</tr>
<tr>
<td>Efficiency ($\times 10^{-4}$)</td>
<td>3.0</td>
<td>11.2</td>
</tr>
<tr>
<td>Signal yield</td>
<td>24.1$^{+7.6}_{-6.6}$</td>
<td>54.1$^{+18.8}_{-17.4}$</td>
</tr>
<tr>
<td>$\mathcal{B}(B^- \rightarrow \tau^-\bar{\nu}_\tau)$ ($\times 10^{-4}$)</td>
<td>1.79$^{+0.56}_{-0.49}$</td>
<td>1.08$^{+0.37}_{-0.35}$</td>
</tr>
</tbody>
</table>

- New analysis is based on improved tag, loose event selection, and reprocessed data.
- Most of the data after the selection are independent from old analysis.
- Assuming that all events in old analysis are included in new analysis, the remaining data sample in $N_{BB} = 4.49 \times 10^8$ provides $\mathcal{B} \sim (0.6\pm0.4) \times 10^{-4}$ (1.9σ from old result).
Constraints on $m_{H^±}$ and $\tan\beta$ from Belle

- Assume type II two-Higgs-doublet model.

$$B(B \rightarrow \tau \nu) = B(B \rightarrow \tau \nu)_{SM} \times r_H$$

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

WA for winter 2012
$$BR(B \rightarrow \tau \nu) = (1.67 \pm 0.30) \times 10^{-4}$$

Belle had+semil combined
$$BR(B \rightarrow \tau \nu) = (0.96 \pm 0.26) \times 10^{-4}$$

for $f_B = 190 \pm 13$ MeV from HPQCD, PRD80, 014503
and $|V_{ub}| = (4.15 \pm 0.49) \times 10^{-3}$ from PDG2012 (inclusive + exclusive semileptonic $b \rightarrow u$ decays).
Constraint on charged Higgs from Belle

- Assume Type II of two Higgs doublet model.

\[
\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{SM} \times r_H \quad r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta \right)^2
\]

\[\tan\beta / m_H \text{ [GeV}^{-1}\text{c}^2]\]

\[m_H \text{ [GeV}/\text{c}^2]\]

\[B(B \to \tau\nu)_{SM}\text{ is calculated from } f_B = 190\pm 13 \text{ MeV (HPQCD, PRD80, 014503) and } |V_{ub}| = (4.15\pm 0.49) \times 10^{-3} \text{ (PDG2012, inclusive + exclusive semileptonic } b \to u \text{ decays).}\]
First evidence for $\text{B} \rightarrow \tau \nu$ (Belle, hadronic)

- First evidence for $\text{B} \rightarrow \tau \nu$ signal obtained by Belle using hadronic tag for 449M BB data (3.5\sigma).

  \[ \mathcal{B} = [1.79^{+0.56}_{-0.49}(\text{stat})^{+0.46}_{-0.51}(\text{syst})] \times 10^{-4} \]

- 60% of full data

- Syst. from BG PDF, tag efficiency, etc.

\[
\begin{array}{cccccc}
\tau \text{ decay} & N_{\text{obs}} & N_s & N_b & \mathcal{B}(10^{-4}) & \Sigma \\
\hline
\mu^- \bar{\nu}_\mu \nu_\tau & 13 & 5.6^{+3.1}_{-2.8} & 8.8^{+1.1}_{-1.1} & 2.57^{+1.38}_{-1.27} & 2.2\sigma \\
e^- \bar{\nu}_e \nu_\tau & 12 & 4.1^{+3.3}_{-2.6} & 9.0^{+1.1}_{-1.1} & 1.50^{+1.20}_{-0.95} & 1.4\sigma \\
\pi^- \nu_\tau & 9 & 3.8^{+2.7}_{-2.1} & 3.9^{+0.8}_{-0.8} & 1.30^{+0.89}_{-0.70} & 2.0\sigma \\
\pi^- \pi^0 \nu_\tau & 11 & 5.4^{+3.9}_{-3.3} & 5.4^{+1.6}_{-1.6} & 4.54^{+3.26}_{-2.74} & 1.5\sigma \\
\pi^- \pi^+ \pi^- \nu_\tau & 9 & 3.0^{+3.5}_{-2.5} & 4.8^{+1.4}_{-1.4} & 6.42^{+7.58}_{-5.42} & 1.0\sigma \\
\end{array}
\]

Fitted by smooth PDFs.

PRL 97, 251802 (2006)
B→τν by semileptonic tag from Belle

- Using 657 M BB (85% of full data).
- Evidence of signal (3.6σ).
- Precision better than hadronic-tag result.

$$B = [1.54^{+0.38}_{-0.37}^{\text{(stat)}} + 0.29^{\text{(syst)}}] \times 10^{-4}$$

Syst. from BG PDF, tag efficiency, etc.

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>Signal yield</th>
<th>ε, 10^{-4}</th>
<th>B, 10^{-4}</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tau^- \rightarrow e^- \bar{\nu}<em>e \nu</em>\tau)</td>
<td>73^{+23}_{-22}</td>
<td>5.9</td>
<td>1.90^{+0.59+0.33}_{-0.57-0.35}</td>
</tr>
<tr>
<td>(\tau^- \rightarrow \mu^- \bar{\nu}<em>\mu \nu</em>\tau)</td>
<td>12^{+18}_{-17}</td>
<td>3.7</td>
<td>0.50^{+0.76+0.18}_{-0.72-0.21}</td>
</tr>
<tr>
<td>(\tau^- \rightarrow \pi^- \nu_\tau)</td>
<td>55^{+21}_{-20}</td>
<td>4.7</td>
<td>1.80^{+0.69+0.36}_{-0.66-0.37}</td>
</tr>
<tr>
<td>Combined</td>
<td>143^{+36}_{-35}</td>
<td>14.3</td>
<td>1.54^{+0.38+0.29}_{-0.37-0.31}</td>
</tr>
</tbody>
</table>

Fitted by histogram PDFs.

PRD 82, 071101(R) (2010)
B→τν by hadronic tag from BaBar

- Using 468 M BB.
- Evidence of signal (3.3σ).

\[ \mathcal{B} = \left[ 1.80^{+0.57}_{-0.54} \text{(stat)} \pm 0.26 \text{(syst)} \right] \times 10^{-4} \]

Syst. from BG PDF, tag efficiency, etc.

Fitted by histogram PDFs.

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>( \epsilon \times 10^{-4} )</th>
<th>Branching Fraction (( \times 10^{-4} ))</th>
<th>Significance ( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tau^+ \to e^+\nu\bar{\nu} )</td>
<td>2.73</td>
<td>0.39^{+0.89}_{-0.79}</td>
<td>0.5</td>
</tr>
<tr>
<td>( \tau^+ \to \mu^+\nu\bar{\nu} )</td>
<td>2.92</td>
<td>1.23^{+0.89}_{-0.80}</td>
<td>1.6</td>
</tr>
<tr>
<td>( \tau^+ \to \pi^+\nu )</td>
<td>1.55</td>
<td>4.0^{+1.5}_{-1.3}</td>
<td>3.3</td>
</tr>
<tr>
<td>( \tau^+ \to \rho^+\nu )</td>
<td>0.85</td>
<td>4.3^{+2.2}_{-1.9}</td>
<td>2.6</td>
</tr>
<tr>
<td>combined</td>
<td>8.05</td>
<td>1.80^{+0.57}_{-0.54}</td>
<td>3.6</td>
</tr>
</tbody>
</table>

arXiv:1008.0104
B→τν by semileptonic tag from BaBar

- Using 459 M BB.
- Excess of signal (2.3σ).

\[ \mathcal{B} = [1.7 \pm 0.8(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-4} \]

Syst. from BG yield, tag efficiency, etc.

<table>
<thead>
<tr>
<th>Mode</th>
<th>(N_{\text{bg}}^{\text{data}})</th>
<th>(N_{\text{obs}})</th>
<th>Branching fraction (\times 10^{-4})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau)</td>
<td>81 ± 12</td>
<td>121</td>
<td>(3.6 ± 1.4)</td>
</tr>
<tr>
<td>(\tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau)</td>
<td>135 ± 13</td>
<td>148</td>
<td>(1.3(_{-1.6}^{+1.8}))</td>
</tr>
<tr>
<td>(\tau^+ \rightarrow \rho^+ \bar{\nu}_\tau)</td>
<td>59 ± 9</td>
<td>71</td>
<td>(2.1(_{-1.8}^{+2.0}))</td>
</tr>
<tr>
<td>(\tau^+ \rightarrow \pi^+ \bar{\nu}_\tau)</td>
<td>234 ± 19</td>
<td>243</td>
<td>(0.6(_{-1.2}^{+1.4}))</td>
</tr>
</tbody>
</table>

Counted in signal region. (Region depends on \(\tau\) modes.)

PRD 81, 051101 (2010)
$B \to D^{(*)} \tau \nu$ from BaBar

$R(D^{(*)})$: ratio btw tau and l modes.
Blue: this result, red: Type II of 2HDM.

Type II of 2HDM is excluded by 99.8%...