Probing new physics in $B_s \rightarrow (K, K^*)\tau\nu$ and $B \rightarrow \pi\tau\nu$ decays

N Rajeev and Rupak Dutta

National Institute of Technology Silchar, Assam

Presenting at XXIII DAE-BRNS HEP Symposium, 13th Dec 2018, IIT Madras
Introduction

- The electroweak interactions mediated via $Z^0$ and $W^\pm$ bosons are categorized into FCNC and FCCC interactions.

See talk by S. Nandi, A. Kundu, A. Soni
Introduction

- The electroweak interactions mediated via $Z^0$ and $W^\pm$ bosons are categorized into FCNC and FCCC interactions.
- The SM states that the electroweak gauge bosons have identical couplings to all three lepton flavors - LFU.

---

1 See talk by S. Nandi, A. Kundu, A. Soni
Introduction\textsuperscript{1}

- The electroweak interactions mediated via $Z^0$ and $W^\pm$ bosons are categorized into FCNC and FCCC interactions.
- The SM states that the electroweak gauge bosons have identical couplings to all three lepton flavors - LFU.
- Deviations from the SM predictions are observed in decays mediated via the $b \rightarrow (c, u)l\nu$ charged current and $B \rightarrow \tau\nu$ such as,

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau\nu)}{\mathcal{B}(B \rightarrow D^{(*)}l\nu)}, \quad R_{J/\Psi} = \frac{\mathcal{B}(B_c \rightarrow J/\Psi\tau\nu)}{\mathcal{B}(B_c \rightarrow J/\Psi l\nu)}$$

\textsuperscript{1}See talk by S. Nandi, A. Kundu, A. Soni
Introduction

- The electroweak interactions mediated via $Z^0$ and $W^\pm$ bosons are categorized into FCNC and FCCC interactions.

- The SM states that the electroweak gauge bosons have identical couplings to all three lepton flavors - LFU.

- Deviations from the SM predictions are observed in decays mediated via the $b \rightarrow (c, u) l \bar{\nu}$ charged current and $B \rightarrow \tau \nu$ such as,

$$R_D^{(*)} = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu)}{\mathcal{B}(B \rightarrow D^{(*)} l \bar{\nu})}, \quad R_{J/\Psi} = \frac{\mathcal{B}(B_c \rightarrow J/\Psi \tau \nu)}{\mathcal{B}(B_c \rightarrow J/\Psi l \bar{\nu})}$$

- We define other two ratios $R^l_\pi$ and $R_\pi$ as,

$$R_{\pi}^l = \frac{\tau_{B^0}}{\tau_{B^-}} \frac{\mathcal{B}(B \rightarrow \tau \nu)}{\mathcal{B}(B \rightarrow \pi l \bar{\nu})}, \quad R_\pi = \frac{\mathcal{B}(B \rightarrow \pi \tau \nu)}{\mathcal{B}(B \rightarrow \pi l \bar{\nu})}.$$

---

1 See talk by S. Nandi, A. Kundu, A. Soni
Introduction

- The electroweak interactions mediated via $Z^0$ and $W^\pm$ bosons are categorized into FCNC and FCCC interactions.
- The SM states that the electroweak gauge bosons have identical couplings to all three lepton flavors - LFU.
- Deviations from the SM predictions are observed in decays mediated via the $b \rightarrow (c, u)l\nu$ charged current and $B \rightarrow \tau\nu$ such as,

$$R_{D^{(*)}} = \frac{B(B \rightarrow D^{(*)}\tau\nu)}{B(B \rightarrow D^{(*)}l\nu)}, \quad R_{J/\Psi} = \frac{B(B_c \rightarrow J/\Psi\tau\nu)}{B(B_c \rightarrow J/\Psi l\nu)}$$

- We define other two ratios $R_{\pi}^l$ and $R_{\tau}$ as,

$$R_{\pi}^l = \frac{\tau_{B^0}}{\tau_{B^-}} \frac{B(B \rightarrow \tau\nu)}{B(B \rightarrow \pi l\nu)}, \quad R_{\pi} = \frac{B(B \rightarrow \pi\tau\nu)}{B(B \rightarrow \pi l\nu)}.$$

- $R_{\pi}^l$ is obtained by the measured values of $B(B \rightarrow \tau\nu)$, $B(B \rightarrow \pi l\nu)$ (BaBar and Belle) and the $\tau_{B^0}/\tau_{B^-} = 1.076 \pm 0.004$ (direct measurements)

---

1 See talk by S. Nandi, A. Kundu, A. Soni
Introduction

- The electroweak interactions mediated via $Z^0$ and $W^\pm$ bosons are categorized into FCNC and FCCC interactions.
- The SM states that the electroweak gauge bosons have identical couplings to all three lepton flavors - LFU.
- Deviations from the SM predictions are observed in decays mediated via the $b \to (c, u) l \nu$ charged current and $B \to \tau \nu$ such as,

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)} \tau \nu)}{\mathcal{B}(B \to D^{(*)} l \nu)}, \quad R_{J/\Psi} = \frac{\mathcal{B}(B_c \to J/\Psi \tau \nu)}{\mathcal{B}(B_c \to J/\Psi l \nu)}$$

- We define other two ratios $R^l_{\pi}$ and $R_{\pi}$ as,

$$R^l_{\pi} = \frac{\tau_{B^0}}{\tau_{B^-}} \frac{\mathcal{B}(B \to \tau l \nu)}{\mathcal{B}(B \to \pi l \nu)} \quad R_{\pi} = \frac{\mathcal{B}(B \to \pi \tau l \nu)}{\mathcal{B}(B \to \pi l \nu)}$$

- $R^l_{\pi}$ is obtained by the measured values of $\mathcal{B}(B \to \tau l \nu), \mathcal{B}(B \to \pi l \nu)$ (BaBar and Belle) and the $\tau_{B^0}/\tau_{B^-} = 1.076 \pm 0.004$ (direct measurements)

- There is an upper limit on $\mathcal{B}(B \to \pi \tau l \nu) < 2.5 \times 10^{-4}$ from Belle implies $R_{\pi} < 1.784$.

1 See talk by S. Nandi, A. Kundu, A. Soni
## Introduction

<table>
<thead>
<tr>
<th>Ratio of branching ratio</th>
<th>SM prediction</th>
<th>Experimental prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_D^2$</td>
<td>$0.299 \pm 0.003$</td>
<td>$0.407 \pm 0.039 \pm 0.024$</td>
</tr>
<tr>
<td>$R_D^{*2}$</td>
<td>$0.258 \pm 0.005$</td>
<td>$0.304 \pm 0.013 \pm 0.007$</td>
</tr>
<tr>
<td>$R_{J/\Psi}$</td>
<td>$[0.20, 0.39]^{3}$</td>
<td>$0.71 \pm 0.17 \pm 0.18^{4}$</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to \tau \nu)^{5}$</td>
<td>$(0.84 \pm 0.11) \times 10^{-4}$</td>
<td>$(1.09 \pm 2.4) \times 10^{-4}$</td>
</tr>
<tr>
<td>$R_{\pi}^{I}$</td>
<td>0.566</td>
<td>0.698 $\pm$ 0.155</td>
</tr>
<tr>
<td>$R_\pi$</td>
<td>0.641</td>
<td>&lt; 1.784</td>
</tr>
</tbody>
</table>

- The combined deviation of $3.78\sigma$ is observed in $R_D$ and $R_{D^*}$ and around $1.3\sigma$ in $R_{J/\Psi}$ from the SM expectations.

---

HFLAV

$^2$JHEP **1809**, 168 (2018)


Introduction

<table>
<thead>
<tr>
<th>Ratio of branching ratio</th>
<th>SM prediction</th>
<th>Experimental prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_D^2$</td>
<td>0.299 ± 0.003</td>
<td>0.407 ± 0.039 ± 0.024</td>
</tr>
<tr>
<td>$R_{D^*}^2$</td>
<td>0.258 ± 0.005</td>
<td>0.304 ± 0.013 ± 0.007</td>
</tr>
<tr>
<td>$R_{J/\Psi}$</td>
<td>[0.20, 0.39]</td>
<td>0.71 ± 0.17 ± 0.18</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to \tau\nu)^5$</td>
<td>(0.84 ± 0.11) × 10^{-4}</td>
<td>(1.09 ± 2.4) × 10^{-4}</td>
</tr>
<tr>
<td>$R_\pi^I$</td>
<td>0.566</td>
<td>0.698 ± 0.155</td>
</tr>
<tr>
<td>$R_\pi$</td>
<td>0.641</td>
<td>&lt; 1.784</td>
</tr>
</tbody>
</table>

- The combined deviation of $3.78\sigma$ is observed in $R_D$ and $R_{D^*}$ and around $1.3\sigma$ in $R_{J/\Psi}$ from the SM expectations.
- These indirect hints of existence of NP led the physics community to look for various NP scenarios.

---

2HFLAV  
3JHEP 1809, 168 (2018)  
Introduction

<table>
<thead>
<tr>
<th>Ratio of branching ratio</th>
<th>SM prediction</th>
<th>Experimental prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_D^2$</td>
<td>$0.299 \pm 0.003$</td>
<td>$0.407 \pm 0.039 \pm 0.024$</td>
</tr>
<tr>
<td>$R_{D^*}^2$</td>
<td>$0.258 \pm 0.005$</td>
<td>$0.304 \pm 0.013 \pm 0.007$</td>
</tr>
<tr>
<td>$R_{J/\Psi}$</td>
<td>$[0.20, 0.39]^3$</td>
<td>$0.71 \pm 0.17 \pm 0.18^4$</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to \tau\nu)^5$</td>
<td>$(0.84 \pm 0.11) \times 10^{-4}$</td>
<td>$(1.09 \pm 2.4) \times 10^{-4}$</td>
</tr>
<tr>
<td>$R_{\pi}^l$</td>
<td>0.566</td>
<td>0.698 $\pm$ 0.155</td>
</tr>
<tr>
<td>$R_{\pi}$</td>
<td>0.641</td>
<td>$&lt; 1.784$</td>
</tr>
</tbody>
</table>

- The combined deviation of $3.78\sigma$ is observed in $R_D$ and $R_{D^*}$ and around $1.3\sigma$ in $R_{J/\Psi}$ from the SM expectations.
- These indirect hints of existence of NP led the physics community to look for various NP scenarios.
- Here, we discuss the NP effects in $B_S \to (K, K^*)\tau\nu$ and $B \to \pi\tau\nu$ semileptonic decays mediated via $b \to u\tau\nu$ charged current interactions.

---

$^2$ HFLAV

$^3$ JHEP 1809, 168 (2018)


### Introduction

The combined deviation of $3.78\sigma$ is observed in $R_D$ and $R_{D^*}$ and around $1.3\sigma$ in $R_{J/\Psi}$ from the SM expectations.

These indirect hints of existence of NP led the physics community to look for various NP scenarios.

Here, we discuss the NP effects in $B_s \to (K, K^*)\tau\nu$ and $B \to \pi\tau\nu$ semileptonic decays mediated via $b \to u\tau\nu$ charged current interactions.

We impose $2\sigma$ experimental constraints from the measured values of the ratio of branching ratios $R_D$, $R_{D^*}$, $R_{J/\Psi}$ and $R_{\pi}^I$.

<table>
<thead>
<tr>
<th>Ratio of branching ratio</th>
<th>SM prediction</th>
<th>Experimental prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_D^2$</td>
<td>$0.299 \pm 0.003$</td>
<td>$0.407 \pm 0.039 \pm 0.024$</td>
</tr>
<tr>
<td>$R_{D^*}^2$</td>
<td>$0.258 \pm 0.005$</td>
<td>$0.304 \pm 0.013 \pm 0.007$</td>
</tr>
<tr>
<td>$R_{J/\Psi}$</td>
<td>$[0.20, 0.39]^{3}$</td>
<td>$0.71 \pm 0.17 \pm 0.18^{4}$</td>
</tr>
<tr>
<td>$B(B \to \tau\nu)^{5}$</td>
<td>$(0.84 \pm 0.11) \times 10^{-4}$</td>
<td>$(1.09 \pm 2.4) \times 10^{-4}$</td>
</tr>
<tr>
<td>$R_{\pi}^I$</td>
<td>$0.566$</td>
<td>$0.698 \pm 0.155$</td>
</tr>
<tr>
<td>$R_{\pi}$</td>
<td>$0.641$</td>
<td>$&lt; 1.784$</td>
</tr>
</tbody>
</table>

---

2. HFLAV
3. JHEP 1809, 168 (2018)
Introduction
Methodology

- The most general effective Lagrangian in the presence of NP couplings is given by \(^6\),

\[
\mathcal{L}_{\text{eff}} = - \frac{4 G_F}{\sqrt{2}} V_{cb} \left\{ (1 + V_L) \bar{l} \gamma_\mu \nu_L \bar{c} \gamma^\mu b_L + V_R \bar{l} \gamma_\mu \nu_L \bar{c} \gamma^\mu b_R \right. \\
\left. + \tilde{V}_L \bar{l} \gamma_\mu \nu_R \bar{c} \gamma^\mu b_L + \tilde{V}_R \bar{l} \gamma_\mu \nu_R \bar{c} \gamma^\mu b_R + \\nS_L \bar{l} \nu_L \bar{c} b_L + S_R \bar{l} \nu_L \bar{c} b_R + \bar{S}_L \bar{l} \nu_R \bar{c} b_L + \bar{S}_R \bar{l} \nu_R \bar{c} b_R \right\} + \text{h.c.},
\]

---


\(^7\) Phys. Rev. D 88, no. 11, 114023 (2013)
Methodology

- The most general effective Lagrangian in the presence of NP couplings is given by \(^6\),

\[
\mathcal{L}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{cb} \left\{ (1 + V_L) \bar{l}_L \gamma_\mu \nu_L \bar{c}_L \gamma^\mu b_L + V_R \bar{l}_L \gamma_\mu \nu_L \bar{c}_R \gamma^\mu b_R \\
+ \bar{V}_L \bar{l}_R \gamma_\mu \nu_R \bar{c}_L \gamma^\mu b_L + \bar{V}_R \bar{l}_R \gamma_\mu \nu_R \bar{c}_R \gamma^\mu b_R + \\
S_L \bar{l}_R \nu_L \bar{c}_R b_L + S_R \bar{l}_R \nu_L \bar{c}_L b_R + \bar{S}_L \bar{l}_L \nu_R \bar{c}_R b_L + \bar{S}_R \bar{l}_L \nu_R \bar{c}_L b_R \right\} + \text{h.c.},
\]

- By considering NP contributions from the vector type NP couplings alone, the effective Lagrangian will take the form as \(^7\):

\[
\mathcal{L}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{ub} \left\{ G_V \bar{l}_\gamma_\mu (1 - \gamma_5) \nu_l \bar{u} \gamma^\mu b - G_A \bar{l}_\gamma_\mu (1 - \gamma_5) \nu_l \bar{u} \gamma^\mu \gamma_5 b + \\
\bar{G}_V \bar{l}_\gamma_\mu (1 + \gamma_5) \nu_l \bar{u} \gamma^\mu b - \bar{G}_A \bar{l}_\gamma_\mu (1 + \gamma_5) \nu_l \bar{u} \gamma^\mu \gamma_5 b \right\} + \text{h.c.},
\]

where,

\[
G_V = 1 + V_L + V_R, \quad G_A = 1 + V_L - V_R, \quad \bar{G}_V = \bar{V}_L + \bar{V}_R, \quad \bar{G}_A = \bar{V}_L - \bar{V}_R.
\]


\(^7\text{Phys. Rev. D 88, no. 11, 114023 (2013)}\)
The differential decay distribution for the $B \to (P, V) l \nu$ decays

\[
\frac{d\Gamma}{dq^2 d\cos \theta} = \frac{G_F^2 |V_{ub}|^2 |\vec{P}_{(P,V)}|}{2^9 \pi^3 m_B^2} \left(1 - \frac{m_l^2}{q^2}\right) L_{\mu\nu} H^{\mu\nu}
\]
The differential decay distribution for the $B \rightarrow (P, V) l \nu$ decays

$$\frac{d\Gamma}{dq^2 d \cos \theta} = \frac{G_F^2 |V_{ub}|^2 |\vec{P}_{(P,V)}|}{2^9 \pi^3 m_B^2} \left(1 - \frac{m_l^2}{q^2}\right) L_{\mu\nu} H^{\mu\nu}$$

Where the $L_{\mu\nu}$ and $H^{\mu\nu}$ are calculated from the helicity techniques\textsuperscript{8}.

The differential decay distribution for the $B \rightarrow (P, V) l \nu$ decays

$$\frac{d\Gamma}{dq^2 d \cos \theta} = \frac{G_F^2 |V_{ub}|^2 |\vec{P}_{(P,V)}|}{2^9 \pi^3 m_B^2} \left( 1 - \frac{m_l}{q^2} \right) L_{\mu\nu} H^{\mu\nu}$$

Where the $L_{\mu\nu}$ and $H^{\mu\nu}$ are calculated from the helicity techniques\(^8\).

The differential decay distribution for $B \rightarrow (P, V) l \nu$ decays

$$\frac{d\Gamma^P}{dq^2} = \frac{8N |\vec{P}_P|}{3} \left( G_V^2 + \tilde{G}_V^2 \right) \left\{ H_0^2 \left( 1 + \frac{m_l^2}{2 q^2} \right) + \frac{3 m_l^2}{2 q^2} H_t^2 \right\}$$

$$\frac{d\Gamma^V}{dq^2} = \frac{8N |\vec{P}_V|}{3} \left\{ \mathcal{A}^2_{AV} + \frac{m_l^2}{2 q^2} \left[ \mathcal{A}^2_{AV} + 3 \mathcal{A}^2_t (G_A^2 + \tilde{G}_A^2) + \tilde{\mathcal{A}}^2_{AV} \right] + \tilde{\mathcal{A}}^2_{AV} \right\}$$

where,

$$N = \frac{G_F^2 |V_{ub}|^2 q^2}{256 \pi^3 m_B^{(s)}^2} \left( 1 - \frac{m_l}{q^2} \right)^2$$

---

Helicity amplitudes will look like

\[ H_0 = \frac{2 m_{B(s)} |\vec{P}_P|}{\sqrt{q^2}} f_+(q^2), \quad H_t = \frac{m_{B(s)}^2 - m_P^2}{\sqrt{q^2}} f_0(q^2), \]

\[ \mathcal{A}_{AV} = \mathcal{A}_0^2 G_A^2 + \mathcal{A}_{||}^2 G_A^2 + \mathcal{A}_{\perp}^2 G_V^2, \quad \tilde{\mathcal{A}}_{AV} = \mathcal{A}_0^2 \tilde{G}_A^2 + \mathcal{A}_{||} \tilde{G}_A^2 + \mathcal{A}_{\perp} \tilde{G}_V^2 \]

\[ \mathcal{A}_0 = \frac{8m_{B_s} m_V A_{12}}{\sqrt{q^2}}, \quad \mathcal{A}_{||} = \frac{2(m_{B_s} + m_V) A_1(q^2)}{\sqrt{2}}, \]

\[ \mathcal{A}_{\perp} = -\frac{4m_{B_s} V(q^2) |\vec{P}_V|}{\sqrt{2}(m_{B_s} + m_V)}, \quad \mathcal{A}_t = \frac{2m_{B_s} |\vec{P}_V| A_0(q^2)}{\sqrt{2}}, \quad \mathcal{A}_P = -\frac{2m_{B_s} |\vec{P}_V| A_0(q^2)}{(m_b(\mu) + m_c(\mu))} \]

For various meson to meson transition form factors, we use very recent lattice QCD results of Refs. 9.

Helicity amplitudes will look like

\[ H_0 = \frac{2 m_{B(s)} |\vec{P}_P|}{\sqrt{q^2}} f_+(q^2), \quad H_t = \frac{m_{B(s)}^2 - m_P^2}{\sqrt{q^2}} f_0(q^2) \]

\[ A_{AV}^2 = A_0^2 G_A^2 + A_{||}^2 G_A^2 + A_{\perp}^2 G_V^2, \quad \tilde{A}_{AV}^2 = A_0^2 \tilde{G}_A^2 + A_{||}^2 \tilde{G}_A^2 + A_{\perp}^2 \tilde{G}_V^2 \]

\[ A_0 = \frac{8 m_{B_s} m_V A_{12}}{\sqrt{q^2}}, \quad A_{||} = \frac{2(m_{B_s} + m_V) A_1(q^2)}{\sqrt{2}}, \]

\[ A_{\perp} = -\frac{4 m_{B_s} V(q^2) |\vec{P}_V|}{\sqrt{2}(m_{B_s} + m_V)}, \quad A_t = \frac{2m_{B_s}|\vec{P}_V|A_0(q^2)}{\sqrt{2}}, \quad A_P = -\frac{2m_{B_s}|\vec{P}_V|A_0(q^2)}{(m_b(\mu) + m_c(\mu))} \]

For various meson to meson transition form factors, we use very recent lattice QCD results of Refs.\textsuperscript{9}.

$q^2$ dependent observables

$$DBR(q^2) = \frac{d\Gamma/dq^2}{\Gamma_{\text{Tot}}}$$

$$R(q^2) = \frac{B(B_s \rightarrow (P, V)\tau\nu)}{B(B_s \rightarrow (P, V)\ell\nu)}$$

$$A^{(P,V)}_{\text{FB}}(q^2) = \left( \int_{-1}^{0} - \int_{0}^{1} \right) d\cos\theta \frac{d\Gamma^{(P,V)}}{dq^2 d\cos\theta}$$

$$P^{l}_{(P,V)}(q^2) = \frac{d\Gamma^{(P,V)}(-)/dq^2}{d\Gamma^{(P,V)}(+)/dq^2} - \frac{1}{d\Gamma^{(P,V)}(-)/dq^2 + d\Gamma^{(P,V)}(+)/dq^2}$$

$$C^{(P,V)}_{F}(q^2) = \frac{1}{(d\Gamma^{(P,V)}/dq^2)} \frac{d^2}{d(\cos\theta)^2} \left[ \frac{d\Gamma^{(P,V)}}{dq^2 d\cos\theta} \right]$$

where $d\Gamma^{(P,V)}(+)/dq^2$ and $d\Gamma^{(P,V)}(-)/dq^2$ represents differential branching ratio of positive and negative helicity leptons.
Results and discussion\textsuperscript{10}

Standard model predictions

<table>
<thead>
<tr>
<th>Process</th>
<th>BR $\times 10^{-4}$</th>
<th>$\langle A^i_{FB} \rangle$</th>
<th>$\langle P^i \rangle$</th>
<th>$\langle C_F^i \rangle$</th>
<th>$R_{B_sK}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow Kl\nu$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu$ mode</td>
<td>Central value</td>
<td>1.520</td>
<td>6.647 $\times 10^{-3}$</td>
<td>0.982</td>
<td>-1.479</td>
</tr>
<tr>
<td>$1\sigma$ range</td>
<td>[1.098, 2.053]</td>
<td>[0.006, 0.007]</td>
<td>[0.979, 0.984]</td>
<td>[-1.482, -1.478]</td>
<td></td>
</tr>
<tr>
<td>$\tau$ mode</td>
<td>Central value</td>
<td>0.966</td>
<td>0.284</td>
<td>0.105</td>
<td>-0.607</td>
</tr>
<tr>
<td>$1\sigma$ range</td>
<td>[0.649, 1.392]</td>
<td>[0.262, 0.291]</td>
<td>[-0.035, 0.279]</td>
<td>[-0.711, -0.525]</td>
<td>[0.586, 0.688]</td>
</tr>
<tr>
<td>$B_s \rightarrow K^*l\nu$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu$ mode</td>
<td>Central value</td>
<td>3.259</td>
<td>-0.281</td>
<td>0.993</td>
<td>-0.417</td>
</tr>
<tr>
<td>$1\sigma$ range</td>
<td>[2.501, 4.179]</td>
<td>[-0.342, -0.222]</td>
<td>[0.989, 0.995]</td>
<td>[-0.575, -0.247]</td>
<td></td>
</tr>
<tr>
<td>$\tau$ mode</td>
<td>Central value</td>
<td>1.884</td>
<td>-0.132</td>
<td>0.539</td>
<td>-0.105</td>
</tr>
<tr>
<td>$1\sigma$ range</td>
<td>[1.449, 2.419]</td>
<td>[-0.203, -0.061]</td>
<td>[0.458, 0.603]</td>
<td>[-0.208, -0.007]</td>
<td>[0.539, 0.623]</td>
</tr>
<tr>
<td>$B \rightarrow \pi l\nu$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu$ mode</td>
<td>Central value</td>
<td>1.369</td>
<td>4.678 $\times 10^{-3}$</td>
<td>0.988</td>
<td>-1.486</td>
</tr>
<tr>
<td>$1\sigma$ range</td>
<td>[1.030, 1.786]</td>
<td>[0.004, 0.006]</td>
<td>[0.981, 0.991]</td>
<td>[-1.489, -1.481]</td>
<td></td>
</tr>
<tr>
<td>$\tau$ mode</td>
<td>Central value</td>
<td>0.878</td>
<td>0.246</td>
<td>0.298</td>
<td>-0.737</td>
</tr>
<tr>
<td>$1\sigma$ range</td>
<td>[0.690, 1.092]</td>
<td>[0.227, 0.262]</td>
<td>[0.195, 0.385]</td>
<td>[-0.781, -0.682]</td>
<td>[0.576, 0.725]</td>
</tr>
</tbody>
</table>

\textsuperscript{10}Phys. Rev. D 98, no. 5, 055024 (2018)
New physics predictions in the presence of $V_L$

<table>
<thead>
<tr>
<th></th>
<th>$R$</th>
<th>$BR \times 10^{-4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \to K\tau\nu$</td>
<td>[0.644, 0.891]</td>
<td>[0.735, 1.746]</td>
</tr>
<tr>
<td>$B_s \to K^*\tau\nu$</td>
<td>[0.593, 0.804]</td>
<td>[1.684, 2.993]</td>
</tr>
<tr>
<td>$B \to \pi\tau\nu$</td>
<td>[0.630, 0.915]</td>
<td>[0.793, 1.368]</td>
</tr>
</tbody>
</table>
New physics predictions in the presence of $\tilde{V}_L$

<table>
<thead>
<tr>
<th></th>
<th>$R$</th>
<th>$BR \times 10^{-4}$</th>
<th>$\langle P^\tau \rangle$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \to K\tau\nu$</td>
<td>[0.638, 0.898]</td>
<td>[0.731, 1.774]</td>
<td>$[-0.026, 0.217]$</td>
</tr>
<tr>
<td>$B_s \to K^*\tau\nu$</td>
<td>[0.582, 0.802]</td>
<td>[1.579, 3.098]</td>
<td>[0.249, 0.513]</td>
</tr>
<tr>
<td>$B \to \pi\tau\nu$</td>
<td>[0.631, 0.926]</td>
<td>[0.765, 1.391]</td>
<td>[0.117, 0.315]</td>
</tr>
</tbody>
</table>
New physics predictions in the presence of $\tilde{V}_L$
Conclusion

- Motivated by the anomalies present in $R_D$, $R_{D^*}$, $R_{J/Ψ}$, and $R^l_{π}$, we report the SM and BSM predictions of various observables in $B_s \rightarrow K \tau ν$, $B_s \rightarrow K^* \tau ν$ and $B \rightarrow π τ ν$ decays in a model dependent way.
Conclusion

- Motivated by the anomalies present in $R_D$, $R_{D^*}$, $R_{J/\psi}$, and $R_{\pi}^l$, we report the SM and BSM predictions of various observables in $B_s \to K \tau \nu$, $B_s \to K^* \tau \nu$ and $B \to \pi \tau \nu$ decays in a model dependent way.

- In SM, the $q^2$ dependence of all the observables for the $\mu$ mode is quite different from that of the $\tau$ mode.
Conclusion

- Motivated by the anomalies present in $R_D$, $R_{D^*}$, $R_{J/\psi}$, and $R_{\pi}$, we report the SM and BSM predictions of various observables in $B_s \rightarrow K \tau\nu$, $B_s \rightarrow K^* \tau\nu$ and $B \rightarrow \pi\tau\nu$ decays in a model dependent way.

- In SM, the $q^2$ dependence of all the observables for the $\mu$ mode is quite different from that of the $\tau$ mode.

- The deviation from the SM prediction are observed with $V_L$ and $\tilde{V}_L$ NP couplings.
Conclusion

Motivated by the anomalies present in $R_D$, $R_{D^*}$, $R_{J/\Psi}$, and $R_{\pi}^l$, we report the SM and BSM predictions of various observables in $B_s \rightarrow K \tau \nu$, $B_s \rightarrow K^* \tau \nu$ and $B \rightarrow \pi \tau \nu$ decays in a model dependent way.

In SM, the $q^2$ dependence of all the observables for the $\mu$ mode is quite different from that of the $\tau$ mode.

The deviation from the SM prediction are observed with $V_L$ and $\tilde{V}_L$ NP couplings.

However $V_L$ and $\tilde{V}_L$ NP couplings are distinguished by $P^\tau$ for all the decay modes.
Conclusion

- Motivated by the anomalies present in $R_D$, $R_{D^*}$, $R_{J/\psi}$, and $R_\pi^l$, we report the SM and BSM predictions of various observables in $B_s \to K \tau \nu$, $B_s \to K^* \tau \nu$ and $B \to \pi \tau \nu$ decays in a model dependent way.

- In SM, the $q^2$ dependence of all the observables for the $\mu$ mode is quite different from that of the $\tau$ mode.

- The deviation from the SM prediction are observed with $V_L$ and $\tilde{V}_L$ NP couplings.

- However $V_L$ and $\tilde{V}_L$ NP couplings are distinguished by $P^\tau$ for all the decay modes.

- Study of these decay modes is very well motivated as these can provide complementary information regarding NP.
Conclusion

- Motivated by the anomalies present in $R_D$, $R_{D^*}$, $R_{J/\Psi}$, and $R_{\pi}^I$, we report the SM and BSM predictions of various observables in $B_s \rightarrow K \tau \nu$, $B_s \rightarrow K^* \tau \nu$ and $B \rightarrow \pi \tau \nu$ decays in a model dependent way.
- In SM, the $q^2$ dependence of all the observables for the $\mu$ mode is quite different from that of the $\tau$ mode.
- The deviation from the SM prediction are observed with $V_L$ and $\tilde{V}_L$ NP couplings.
- However $V_L$ and $\tilde{V}_L$ NP couplings are distinguished by $P^\tau$ for all the decay modes.
- Study of these decay modes is very well motivated as these can provide complementary information regarding NP.
- It will have the direct consequence on predictions or the measurements of the CKM matrix element $|V_{ub}|$. 
...Thank you for your patience...