Tree-level New Physics searches in semileptonic decays at Belle

Christoph Schwanda

*Institute of High Energy Physics*

*Austrian Academy of Sciences*
Outline of this talk

• Measurement of $B^0 \rightarrow D^{*-} \tau^+ \nu$ with semileptonic tag (winter 2016 preliminary)
  
  arXiv:1603.06711

• Search for $B^0 \rightarrow \pi^- \tau^+ \nu$ with hadronic tag
  
  Phys. Rev. D93, 032007 (2016)
1999 – 2010: B factory at KEK (Japan)

KEKB double ring $e^+e^-$ collider

$e^+e^- \rightarrow Y(4S) \rightarrow B\overline{B}$

Belle detector

- World largest B meson sample
  ~771 million $BB$ events
- Over 450 Belle physics publications
Tagging techniques for $Y(4S)$ events

- Tagging provides:
  - Background suppression
  - Information on $B_{\text{sig}}$ (4-momentum)

**Untagged**
- No requirement on $B_{\text{tag}}$
- High efficiency, low purity

**Semileptonic tag**
- $B_{\text{tag}} \rightarrow D^* l \nu$
- Efficiency $\sim O(0.2\%)$

**Hadronic tag**
- $B_{\text{tag}} \rightarrow$ hadrons
- Efficiency $\sim O(0.1\%)$
$B \rightarrow D^* \tau \nu$ with semileptonic tag
New Physics in $B \rightarrow D^*\tau\nu$

Semitauonic B decays of type $b \rightarrow c\tau\nu$ are sensitive probes to search for New Physics. NP can change the branching ratio and the $D^*/\tau$ polarization.

Type II 2HDM

- A charged Higgs of spin 0 mediates the decay instead of the $W$
- Can enhance or decrease the BR of $B \rightarrow D^*\tau\nu$

Leptoquark models

- LQs are bosons which couple to a lepton-quark pair
- Carry color and electric charge, baryon and lepton number
- LQ models which generate an effective tensor operator lead to an effect in $B \rightarrow D^*\tau\nu$
**Principle of the measurement**

- Simultaneously reconstruct signal and normalization events
- D* reconstruction: D*+ → D0π+, D+π0 (~100%)
  - 10 D0 modes (~37%)
  - 5 D+ modes (~22%)
- Semileptonic tag: combine D*+ with an oppositely charged lepton, calculate \( \cos \theta_{B,D^*l} \)
- Require two tagged B candidates per event of opposite charge

\[
\cos \theta_{B-D^*\ell} \equiv \frac{2E_{\text{beam}}E_{D^*\ell} - m_B^2 - M_{D^*\ell}^2}{2|p_B| \cdot |p_{D^*\ell}|}
\]
Principle of the measurement (2)

• Neural network to separate signal and normalization events using:
  – signal-side $\cos \theta_{B,D*}$
  – missing mass squared
  – visible energy

• Determine the number of signal and normalization events by a two dimensional maximum likelihood fit
  – Fit variable 1: neural network output
  – Fit variable 2: sum of energies of neutral clusters not associated to reconstructed particles $E_{ECL}$
  – Signal, normalization and $B \rightarrow D^{**} l \nu$ yields are floated in the fit, other components are fixed to MC expectation
Fit result

\[ \mathcal{R}(D^*) = \frac{\mathcal{B}(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{\mathcal{B}(B^0 \rightarrow D^{*-} \ell^+ \nu_\ell)} \]

\[ \mathcal{R}(D^*) = \frac{1}{\mathcal{B}(\tau^- \rightarrow l^- \bar{\nu}_l \nu_\tau)} \cdot \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}} \cdot \frac{N_{\text{sig}}}{N_{\text{norm}}} \]

\[ \mathcal{R}(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst}) \ (13.8\sigma) \]
Systematic uncertainty / stability

<table>
<thead>
<tr>
<th>Sources</th>
<th>$\mathcal{R}(D^*)$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\ell_{\text{sig}} = e, \mu$</td>
</tr>
<tr>
<td>MC statistics for PDF shape</td>
<td>2.2%</td>
</tr>
<tr>
<td>PDF shape of the normalization</td>
<td>+1.1%</td>
</tr>
<tr>
<td>PDF shape of $B \rightarrow D^{**} \ell \nu_\ell$</td>
<td>+1.0%</td>
</tr>
<tr>
<td>PDF shape and yields of fake $D^{(*)}$</td>
<td>1.4%</td>
</tr>
<tr>
<td>PDF shape and yields of $B \rightarrow X_c D^*$</td>
<td>1.1%</td>
</tr>
<tr>
<td>Reconstruction efficiency ratio $\varepsilon_{\text{norm}}/\varepsilon_{\text{sig}}$</td>
<td>1.2%</td>
</tr>
<tr>
<td>Modeling of semileptonic decay</td>
<td>0.2%</td>
</tr>
<tr>
<td>$B(\tau^- \rightarrow \ell^- \bar{\nu}<em>\ell \nu</em>\tau)$</td>
<td>0.2%</td>
</tr>
<tr>
<td>Total systematic uncertainties</td>
<td>+3.4%</td>
</tr>
</tbody>
</table>

Consistent results for individual samples (separated @ $B_{\text{sig}}$)

$\mathcal{R}(D^*) = 0.311 \pm 0.038 \pm 0.013$ ($\ell_{\text{sig}} = e$)

$\mathcal{R}(D^*) = 0.304 \pm 0.051 \pm 0.018$ ($\ell_{\text{sig}} = \mu$)
The difference with the SM prediction is at the level of 4.0 sigma for all four measurements combined.
B → $\pi\pi\nu$ with hadronic tag
Motivation

• Within the type II 2HDM, the branching fraction of $B \rightarrow \pi \tau \nu$ can be modified similarly to $B \rightarrow D^{(*)} \tau \nu$

• Current experimental situation: $B \rightarrow \tau \nu$ branching fraction is SM-like while $B \rightarrow D^{(*)} \tau \nu$ exhibits a $\sim 4\sigma$ anomaly

• $B \rightarrow \pi \tau \nu$ thus provides additional insight and in particular is an independent probe of the $b \rightarrow u \tau \nu$ transition
Principle of the measurement

• $B_{\text{tag}}$ reconstructed in a hadronic mode
• $\tau$ reconstruction ($\sim 71\%$):
  – $\tau \rightarrow e/\mu \nu \nu$
  – $\tau \rightarrow \pi/\rho(\pi \pi^0) \nu$
• Background is suppressed with a multivariate discriminator (boosted decision trees)
• Signal is extracted from a one-dimensional fit to $E_{ECL}$
Boosted decision trees (BDTs)

- One BDT for every $\tau$ mode
- Discriminant variables:
  - Missing energy and momentum
  - $K_L$ veto
  - ...
- Background: dominant $b \rightarrow c$ decays
Fit result

Electron mode

Pion mode

Rho mode

Signal events: $52 \pm 24$

$$\mathcal{B}(B^0 \rightarrow \pi^- \tau^+ \nu_\tau) = (1.52 \pm 0.74 \pm 0.13) \cdot 10^{-4}$$

Significance level: $2.4\sigma$

$$\mathcal{B}(B^0 \rightarrow \pi^- \tau^+ \nu_\tau) < 2.5 \cdot 10^{-4} \text{ @ 90\% CL}$$
## Systematic uncertainty

<table>
<thead>
<tr>
<th>systematic</th>
<th>relative uncertainty [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>e ID</td>
<td>1.4</td>
</tr>
<tr>
<td>(\pi) ID</td>
<td>1.6</td>
</tr>
<tr>
<td>(\pi^0) ID</td>
<td>1.0</td>
</tr>
<tr>
<td>Track efficiency</td>
<td>0.7</td>
</tr>
<tr>
<td>(N(B\bar{B}))</td>
<td>1.4</td>
</tr>
<tr>
<td>(K_L) veto</td>
<td>3.2</td>
</tr>
<tr>
<td>BG (B)</td>
<td>2.8</td>
</tr>
<tr>
<td>(D(\cdot)\ell\nu) model</td>
<td>0.5</td>
</tr>
<tr>
<td>Tagside</td>
<td>4.6</td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
</tr>
<tr>
<td>Rare MC</td>
<td>2.0</td>
</tr>
<tr>
<td>(B \to X_u\tau\nu)</td>
<td>2.2</td>
</tr>
<tr>
<td>Background Fit</td>
<td>0.2</td>
</tr>
<tr>
<td>Signal model</td>
<td>1.8</td>
</tr>
<tr>
<td>total</td>
<td>8.3</td>
</tr>
</tbody>
</table>
Summary

• New preliminary Belle result for $R(D^*)$ obtained with semileptonic tagging [arXiv:1603.06711]
  • $R(D^*) = 0.302 \pm 0.030\text{(stat)} \pm 0.011\text{(syst)}$
  • Confirms the excess seen by other experiments and brings to tension with the SM to $4.0\sigma$

• Search for $B^0 \rightarrow \pi^-\tau^+\nu$ at Belle [Phys. Rev. D93, 032007 (2016)]
  • $\text{Br}(B^0 \rightarrow \pi^-\tau^+\nu) < 2.5 \times 10^{-4}$ @ 90% C.L.

• We need the Belle II data to clarify the experimental situation