$B \rightarrow \tau\nu$ and $B \rightarrow D(\ast) \tau\nu$ decays at BaBar

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36th International Conference on High Energy Physics
July 2012, Melbourne, Australia
Tagging method

• Weak signal signature
  - Decay with missing momentum (many neutrinos in the final state)
  - Lack of kinematics constraints in final state

• Background rejection improved reconstructing the companion B

• Look for signal in the rest of the event
  - Expect to find nothing more than visible signal decay products
  - No additional track and little activity in the calorimeter
Leptonic B decays

• $B \rightarrow l\nu$ very clean theoretically. SM uncertainty in the B decay constant $f_B$ and $|V_{ub}|$ value.

$$ \mathcal{B}(B \rightarrow l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B $$

• Interesting probe of physics beyond the SM, since also a charged Higgs can mediate the decay

$$ \mathcal{B}(B \rightarrow l\nu)_{2HDM} = \mathcal{B}(B \rightarrow l\nu)_{SM} \times (1 - \tan^2 \beta \frac{m_B^2}{m_H^2})^2 $$

$$ \mathcal{B}(B \rightarrow l\nu)_{SUSY} = \mathcal{B}(B \rightarrow l\nu)_{SM} \times (1 - \frac{\tan^2 \beta}{1 + \epsilon_0 \tan \beta m_H^2})^2 $$

• $B \rightarrow \tau\nu$ used in global UT fits. $B \rightarrow \mu\nu$ out of reach of current B-factories
B → τν with hadronic tags at BaBar

- Fit to residual energy in calorimeter simultaneously in 4 reconstructed modes (τ → eνν, τ → μνν, τ → πν, τ → ρν)
- Floating parameters: BF and 4 background yields
- Combinatorial B tag background estimated from data. B+ background shape from MC
- Excess of events over background of 3.8 σ

\[ B(B^+ → τ^+ \nu) = (1.83^{+0.53}_{-0.49}(\text{stat.}) \pm 0.24(\text{syst.})) \times 10^{-4} \]


MC modelling of signal E_{extra} PDF checked with double tags
Comparison with the 2HDM type II

\[ \mathcal{B}(B \to l\nu)_{2HDM} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - \tan^2 \beta \frac{m_B^2}{m_H^2})^2 \]

- Uncertainty in Standard Model prediction mostly due to \(|V_{ub}|\)
  \(|V_{ub}|_{\text{incl}} = (4.33 \pm 0.28) \times 10^{-3}\)
  \(|V_{ub}|_{\text{excl}} = (3.13 \pm 0.30) \times 10^{-3}\)
  \(f_B = (189 \pm 4)\) MeV (HPQCD arXiv:1202.4914)
**Constraints on the tan $\beta$ vs $m_{H^+}$ plane in 2HDM type II**

Most of the parameter space of 2HDM is excluded at 90% C.L., if we assume exclusive $|V_{ub}|$ determination.

90% C.L. exclusion for $m_{H^+}$ up to 1 TeV at very high tan $\beta$ (>70) using inclusive $|V_{ub}|$. 

![Graph showing exclusions at 2\sigma and 3\sigma for both exclusive and inclusive $|V_{ub}|$.]
Ratio of $B \to D(\ast) \tau\nu$ to $B \to D(\ast) \tau\nu$

- Semileptonic decays with a $\tau$

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2|V_{cb}|^2|p|q^2}{96\pi^3m_B^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \left[\left(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2\right)\left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2}m_\tau^2|H_{0\ell}|^2\right]$$

- We test the SM measuring the ratios

$$R(D) = \frac{Br(\bar{B} \to D\tau\nu)}{Br(\bar{B} \to D\ell\nu)} \quad R(D^\ast) = \frac{Br(\bar{B} \to D^\ast\tau\nu)}{Br(\bar{B} \to D^\ast\ell\nu)}$$

- SM predictions are $R(D) = 0.297 \pm 0.017$ and $R(D^\ast) = 0.252 \pm 0.003$
Analysis strategy

• Full reconstruction of a tag B in hadronic decays.
• Identify e or µ and reconstruct a D meson (D*+, D*0, D+, D0)
• Kinematic requirement: $q^2 > 4 \text{ GeV}^2$

• 2D likelihood fit to $M^2_{\text{miss}} = (P_{ee} - p_{\text{tag}} - p_D - p_l)^2$ and $p^*_l$

Yields floating:
- $B \to D \ell \nu$ normalization
- $B \to D \tau \nu$ signal
- $B \to D^{**} \ell \nu$ background
  (from a $D^{(*)} \pi^0 \ell \nu$ CS)

Fixed parameters:
- BB combinatorial and continuum bkgds
- cross-feeds among modes

arXiv:1205.5442[hep-ex]

PDF taken from Monte Carlo
# \( B \to D^* \tau \nu \) results

<table>
<thead>
<tr>
<th></th>
<th>( D^{*0} \tau \nu )</th>
<th>( D^{*+} \tau \nu )</th>
<th>( D^* \tau \nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{\text{sig}} )</td>
<td>( 639 \pm 62 )</td>
<td>( 245 \pm 27 )</td>
<td>( 888 \pm 63 )</td>
</tr>
<tr>
<td>Significance (( \sigma ))</td>
<td>11.3</td>
<td>11.6</td>
<td>16.4</td>
</tr>
<tr>
<td>( R(D^*) )</td>
<td>( 0.322 \pm 0.032 )</td>
<td>( 0.355 \pm 0.039 )</td>
<td>( 0.332 \pm 0.024 )</td>
</tr>
</tbody>
</table>
## $B \to D \tau \nu$ Results

<table>
<thead>
<tr>
<th>$N_{\text{sig}}$</th>
<th>$D^0_{\tau\nu}$</th>
<th>$D^+_{\tau\nu}$</th>
<th>$D_{\tau\nu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>314 ± 60</td>
<td>177 ± 31</td>
<td>489 ± 63</td>
</tr>
<tr>
<td>$R(D)$</td>
<td>0.429 ± 0.082</td>
<td>0.469 ± 0.084</td>
<td>0.440 ± 0.058</td>
</tr>
</tbody>
</table>

**Graphs:**
- BABAR $D^0$
- BABAR $D^+$
- Events/25 MeV
- $M^2_{\text{miss}}$ (GeV$^2$)
- $p_{T}^*$ (GeV)

**Graphs (continued):**
- BABAR $D^0$
- 1.0 $\leq m^2_{\text{miss}} < 12.0$ GeV$^2$
- Events/100 MeV
- $p_{T}^*$ (GeV)

**Graphs (continued):**
- Free yields
- Fixed yield

**Result:**
$D^0 + D^+$ $m^2_{\text{miss}} > 1$ GeV.
Systematic Uncertainties

- Main systematics uncertainties
  - $D^{**}$ background yield from a $D^{(*)} \pi^0 l \nu$ Data control sample
  - Signal MC statistic
    - For PDF extraction
  - BB and continuum background

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty (%)</th>
<th>$R(D)$</th>
<th>$R(D^*)$</th>
<th>$\rho$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^{**}l\nu$ background</td>
<td>5.8</td>
<td>3.7</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>MC statistics</td>
<td>5.0</td>
<td>2.5</td>
<td>-0.48</td>
<td></td>
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<tr>
<td>Cont. and $B\bar{B}$ bkg.</td>
<td>4.9</td>
<td>2.7</td>
<td>-0.30</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon_{\text{sig}}/\varepsilon_{\text{norm}}$</td>
<td>2.6</td>
<td>1.6</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Systematic uncertainty</td>
<td>9.5</td>
<td>5.3</td>
<td>0.05</td>
<td></td>
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<tr>
<td>Statistical uncertainty</td>
<td>13.1</td>
<td>7.1</td>
<td>-0.45</td>
<td></td>
</tr>
<tr>
<td><strong>Total uncertainty</strong></td>
<td><strong>16.2</strong></td>
<td><strong>9.0</strong></td>
<td><strong>-0.27</strong></td>
<td></td>
</tr>
</tbody>
</table>

$D^{(*)} \pi^0 l \nu$ Control sample
Comparison with Standard Model

<table>
<thead>
<tr>
<th></th>
<th>R(D)</th>
<th>R(D*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BABAR</td>
<td>$0.440 \pm 0.071$</td>
<td>$0.332 \pm 0.029$</td>
</tr>
<tr>
<td>SM</td>
<td>$0.297 \pm 0.017$</td>
<td>$0.252 \pm 0.003$</td>
</tr>
<tr>
<td>Difference</td>
<td>$2.0 \sigma$</td>
<td>$2.7 \sigma$</td>
</tr>
</tbody>
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Combinination yields $\chi^2 / \text{n.d.o.f.} = 14.6/2$
(probability: $6.9 \times 10^{-4}$)
3.4\sigma away from SM

Z. Phys C46, 93 (1990)  
PRD 82, 0340276 (2010)  
PRD 85, 094025 (2012)  
and recent updates
2HDM type II cannot explain the excess

- A Charged Higgs within 2HDM type II contribution:

\[ H_{t}^{2\text{HDM}} = H_{t}^{\text{SM}} \times \left( 1 - \frac{\tan^{2}\beta}{m_{H_{\pm}}^{2}} \frac{q^{2}}{1 + m_{c}/m_{b}} \right) \]

- for \( D_{\tau\nu} \)
- for \( D^{*}_{\tau\nu} \)

\[ R(D_{\tau\nu}) = 0.44 \pm 0.02 \]
\[ R(D^{*}_{\tau\nu}) = 0.75 \pm 0.04 \]

Mutually exclusive with CL > 99.8%

Taking into account the effect of \( \tan \beta/m_{H} \) on efficiency

\[ R(D) \rightarrow \tan \beta/m_{H} = 0.44 \pm 0.02 \]
\[ R(D^{*}) \rightarrow \tan \beta/m_{H} = 0.75 \pm 0.04 \]
Conclusions

• Updated result on $B \to \tau \nu$ with hadronic tagging

$$BF(B \to \tau \nu) = (1.8 \pm 0.5 \pm 0.2) \times 10^{-4}.$$  

Agreement with the SM in tension using exclusive $|V_{ub}|$ measurements (2.4σ)  
Better agreement using inclusive $|V_{ub}|$ (1.6σ)

• Improved measurement of $R(D^{(*)}) = BF(B \to D^{(*)} \tau \nu) / BF(B \to D^{(*)} l \nu)$

$$R(D^*) = 0.332 \pm 0.024 \pm 0.018 \quad R(D) = 0.440 \pm 0.058 \pm 0.042$$

exceeding the SM predicted values by 3.4σ.


• 2HDM type II (alone) cannot accommodate the results and theorists already at work building models