Rare B meson decays involving leptons at BaBar

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Representing the BaBar Collaboration

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Outline

- Untagged $B \rightarrow e/\mu \nu$
- Semileptonic tagged $B \rightarrow \tau \nu, \mu \nu, e \nu$
- Hadronic tagged $B \rightarrow e/\mu \nu \gamma$ (NEW RESULT)
- Semileptonic tagged $B \rightarrow K^{(*)} \nu \nu$
B → lν decays in the SM

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

Helicity suppression

Experimental sensitivity to \( f_B \) assuming \( V_{ub} \)

- Mediated by the W boson
- \( \mu\nu \) and \( e\nu \) rare because of helicity suppression (\( \sim 10^{-7} \) e, \( \sim 10^{-11} \) mu)
- B meson decay constant \( f_B \) can be measured assuming \( V_{ub} \)
- \( V_{ub} \) (exp. + theory) and \( f_B \) (theory) uncertainties dominate the SM expectation uncertainty:

Using \( f_B = 190 \pm 13 \text{ MeV} \) and \( V_{ub} = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3} \) **

\[ BF_{SM} (B \rightarrow \tau\nu) = (1.20 \pm 0.25) \times 10^{-4} \]

*HPQCD collaboration arXiv:0902.1815v2
**Heavy Flavor Averaging Working Group 2008
New Physics with purely leptonic decays

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


\[ \mathcal{B}(B \to l\nu)_{SUSY} = \mathcal{B}(B \to l\nu)_{SM} \times \left(1 - \frac{\tan^2\beta}{1 + \epsilon_0\tan\beta} \frac{m_B^2}{m_H^2}\right)^2 \]


- Additional tree level contribution from a charged Higgs
- Branching fraction theoretical expression depends on NP model
- \( B \to \tau\nu \) measurement already allows 90% exclusion plot in the \( M_H \times \tan\beta \) plane

- Comparing different leptonic final states may be interesting for new physics

\[ R_{\tau\mu} = \frac{\Gamma(B \to \mu\nu)}{\Gamma(B \to \tau\nu)} \quad R_{e\tau} = \frac{\Gamma(B \to e\nu)}{\Gamma(B \to \tau\nu)} \]

- Non minimal FV models predictions: \( R_{\tau\mu} \sim 10\% \quad R_{\tau\mu,SM} \quad R_{e\tau} \sim 10^3 \quad R_{e\tau,SM} \)

- Out of reach for present B factories; golden channel for super flavor factory
**B → K(∗) ν ν theoretical overview**

- **SM**: the process requires at least one-loop diagram via FCNC

\[
\text{BR}_{SM} (B \rightarrow K^* \nu \nu) = (6.8^{+1.0}_{-1.1}) \times 10^{-6}
\]

\[
\text{BR}_{SM} (B \rightarrow K \nu \nu) = (4.5 \pm 0.7) \times 10^{-6}
\]


- **NP**: add particles to the loop diagrams → enhancement of a factor up to 10
Untagged B → e/μ ν: experimental techniques

- At Y(4S) a pair of B mesons is produced
- SM prediction: B→eν ~ 10^{-7} and B→μν ~ 10^{-11}
- Strong experimental signature: monochromatic lepton in the rest B frame
  (distribution is smeared in the CM frame)
- Inclusive approach on the rest of the event
- High efficiency but high background

- Identify lepton candidate applying PID requirements (max one lepton required)
- Form a total 4-momentum from the rest of the event (only PID track but no intermediate particle reconstruction)
- Kinematical and topological variables combined in Fisher discriminant to suppress background

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Apply PID, measure p

Ignore the detail, Measure inclusive observables

Y(4S) → B^- + B^+

B^- + B^+ → e^- + μ^+ + e^- + μ^- + ν_μ (distribution is smeared in the CM frame)
Untagged $B \to e/\mu \nu$: results

$B \to ev$ signal MC

- $m_{ES}$
- $P_{fit}$

Extended Maximum Likelihood fit with 2 variables:

- $m_{ES}$ using the inclusive $B$
  \[ m_{ES} = \sqrt{E_{beam}^2 - p_B^2} \]
- $P_{FIT}$, output of Fisher discriminant

<table>
<thead>
<tr>
<th></th>
<th>$B \to ev$</th>
<th>$B \to \mu\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal efficiency</td>
<td>(4.7 ± 0.2) %</td>
<td>(6.1 ± 0.2) %</td>
</tr>
<tr>
<td>Fitted signal yield</td>
<td>17.9 ± 17.6</td>
<td>1.4 ± 17.2</td>
</tr>
</tbody>
</table>

$BF( B \to ev ) < 1.9 \times 10^{-6}$
$BF( B \to \mu\nu ) < 1.0 \times 10^{-6}$

@ 90% C.L.
Tagged B: experimental techniques

- Background rejection improved reconstructing the $B_{\text{TAG}}$
- Two kind of tags exploited

Semileptonic decays

+ Higher tag efficiency ($\sim 1.5\%$)
- More background, B momentum unmeasured

Hadronic decays

+ Cleaner events, B momentum reconstructed (no neutrinos in tag side)
- Smaller tag efficiency ($\sim 0.15\%$)
B → τ ν with semileptonic tags

Reconstructed τ decays

Branching Fraction (%)

- Separate decay modes using PID and π⁰ reconstruction
- Use event topology and signal kinematics variables to suppress background
- Unassigned objects energy E_{extra} is the most discriminating variable
  (peak at zero for signal)
B → τν with semileptonic tags

<table>
<thead>
<tr>
<th>Mode</th>
<th>Expected BKG</th>
<th>Observed</th>
<th>Eff. (x 10^-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>τ→eνν</td>
<td>91 ± 13</td>
<td>148</td>
<td>3.08 ± 0.14</td>
</tr>
<tr>
<td>τ→μνν</td>
<td>137 ± 10</td>
<td>148</td>
<td>2.28 ± 0.11</td>
</tr>
<tr>
<td>τ→πν</td>
<td>233 ± 19</td>
<td>243</td>
<td>3.89 ± 0.15</td>
</tr>
<tr>
<td>τ→ππν</td>
<td>59 ± 9</td>
<td>71</td>
<td>1.30 ± 0.07</td>
</tr>
<tr>
<td>B→τν</td>
<td>521 ± 31</td>
<td>610</td>
<td>10.54 ± 0.41</td>
</tr>
</tbody>
</table>

Semileptonic tag

BF (B→τν) = (1.8 ± 0.8 ± 0.1) x 10^-4

Hadronic tag

BF (B→τν) = (1.8 ± 0.9 ± 0.4 ± 0.2) x 10^-4


Combined hadronic and semileptonic

BF (B→τν) = (1.8 ± 0.6) x 10^-4
B → e/µ ν with semileptonic tags

- The tag B momentum is not univocally determined.
- The lepton momentum is boosted to the rest B frame using the average value of the tag B momentum.
- Signal is identified requiring $p^* > 2.52$ (2.45) GeV for electrons (muons).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Expected</th>
<th>Observed</th>
<th>Eff. ($\times 10^{-4}$)</th>
<th>UL 90% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>B → eν</td>
<td>24 ± 11</td>
<td>17</td>
<td>36.9 ± 1.5</td>
<td>7.7 $\times 10^{-6}$</td>
</tr>
<tr>
<td>B → µν</td>
<td>15 ± 10</td>
<td>11</td>
<td>27.1 ± 1.5</td>
<td>11 $\times 10^{-6}$</td>
</tr>
</tbody>
</table>

arXiv:0809,4027
459 $\times 10^6$ B pairs
$B \rightarrow l\gamma \gamma$ with hadronic tags

- Not helicity suppressed, extra $\alpha_{EM}$ in the BF

$$\frac{dB}{dE_\gamma} = \frac{\alpha_{EM} G_F^2 |V_{ub}|^2}{48\pi^2} m_B^4 \left[ f_A^2 (E_\gamma) + f_V^2 (E_\gamma) \right] (1 - 2E_\gamma/m_B)(2E_\gamma/m_B)^3$$

- Form factors model dependent
  HQET to leading order: $f_A = f_V$
  Other models suggest $f_A = 0$

- Correlations with the photon kinematics must be avoided to minimize model dependence; no requirement on photon or lepton momenta

- Combinatorial background reduced by event topology
  likelihood ratio with 5 discriminating observables

- Selection requirement in the recoil of the tag B include
  Exactly 1 opposite signed charged track + PID requirements on the signal track
  The most energetic neutral cluster is the signal candidate
  Missing momentum in detector acceptance + $\pi^0,\eta,\omega$ veto on $\gamma\gamma$ and $\pi^0\gamma$

- Residual backgrounds:
  Incorrectly reconstructed B tags estimated from data in $m_{ES}$ sideband
  Correctly reconstructed semileptonic B decays estimated from dedicated MC simulation

- Signal box defined by:
  $5.26 \text{ GeV} < m_{ES} < 5.29 \text{ GeV}$, $M_{miss} < 0.5 \text{ GeV}^2$
B → lνγ with hadronic tags results

Cut and count analysis and frequentist (FC) estimation of the U.L. on the branching fraction:

<table>
<thead>
<tr>
<th></th>
<th>B → eνγ</th>
<th>B → μνγ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected bkg</td>
<td>2.7 ± 0.4 ± 0.4</td>
<td>3.4 ± 0.7 ± 0.7</td>
</tr>
<tr>
<td>Observed events</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Signal efficiency</td>
<td>(7.8 ± 0.1 ± 0.3) x 10^{-4}</td>
<td>(8.1 ± 0.1 ± 0.3) x 10^{-4}</td>
</tr>
<tr>
<td>BF 90 % CL</td>
<td>&lt; 17 x 10^{-6}</td>
<td>&lt; 26 x 10^{-6}</td>
</tr>
</tbody>
</table>

Model dependent limits

Requiring a cut on the angle between the lepton and the photon and on the angle between the photon and the neutrino, the signal is searched assuming the f_A = f_V and the f_A = 0 hypothesis.

<table>
<thead>
<tr>
<th>mode</th>
<th>f_A = f_V hypothesis</th>
<th>f_A = 0 hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expected</td>
<td>Observed</td>
</tr>
<tr>
<td>B → eνγ</td>
<td>0.6 ± 0.1</td>
<td>0</td>
</tr>
<tr>
<td>B → μνγ</td>
<td>1.0 ± 0.4</td>
<td>0</td>
</tr>
<tr>
<td>combined</td>
<td>&lt; 3.0 x 10^{-6}</td>
<td>&lt; 18 x 10^{-6}</td>
</tr>
</tbody>
</table>
Combined results from the semileptonic and hadronic recoil analyses

**Semileptonic tag**
- BaBar 454 M BB
- No cuts on $K^*$ kinematics
- First completely model independent analysis

**Hadronic tag**

**NN output**

<table>
<thead>
<tr>
<th>UL @ 90%CL</th>
<th>$B^+ \rightarrow K^{*+} \nu \nu$</th>
<th>$B^0 \rightarrow K^{*0} \nu \nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAD</td>
<td>$21 \times 10^{-5}$</td>
<td>$11 \times 10^{-5}$</td>
</tr>
<tr>
<td>SL</td>
<td>$9 \times 10^{-5}$</td>
<td>$18 \times 10^{-5}$</td>
</tr>
<tr>
<td>Combined</td>
<td>$8 \times 10^{-5}$</td>
<td>$12 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>351 M BB (preliminary) UL @90%CL</th>
<th>$B^+ \rightarrow K^+ \nu \nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined (SL+HAD)</td>
<td>$4.2 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
• Searches for decays involving leptons:
  
  test for the SM prediction
  
  indirect search for NP (no significant NP signal seen so far)
  
  experimental measurements allow to constraint parameters defining NP
  
  complementary to direct search of NP at high energy machines
  
  need more precision and statistics → Super Flavor Factories