Radiative and Rare B-Decays at BaBar

Carsten Hast, SLAC
for the BaBar Collaboration
Pittsburgh, October 17

All results are preliminary unless journal ref. is given
limit values are 90% CL unless otherwise specified
Since this talk is nicely framed between a theoretical introduction and a Belle summary and outlook I will focus on newer results and analysis techniques from BaBar

- **FCNC**
  \[ b \rightarrow KVV \]

- **Purely Leptonic Decays**
  \[ b \rightarrow \tau\nu \]
  \[ b \rightarrow \mu\nu \]

- \( b \rightarrow Kll \) and \( b \rightarrow K^{*ll} \)
- \( B \rightarrow X_{sll} \)

- **Radiative Decays**
  \[ B^0 \rightarrow K_2^{*0}(1430)\gamma \] and \[ B^+ \rightarrow K_2^{*+}(1430)\gamma \]
The BaBar Detector

**DIRC (PID)**
- 144 quartz bars
- 11000 PMs

**EMC**
- 6580 CsI(Tl) crystals

**Instrumented Flux Return**
- Iron / RPCs (muon / neutral hadrons)

**Silicon Vertex Tracker**
- 5 layers, double sided strips

**Drift Chamber**
- 40 stereo layers

**e^- (9 GeV)**

**e^+ (3.1 GeV)**

**SVT+DCH:**
\[ \sigma(p_T)/p_T = 0.13 \% \times p_T + 0.45 \% \text{, good dE/dx} \]

**DIRC:**
- K-\pi separation
- 4.2 \( \sigma @ 3.0 \text{ GeV/c} \rightarrow 2.5 \sigma @ 4.0 \text{ GeV/c} \)

**EMC:**
- Very good electron identification and \( \pi^0 \) reconstruction

**IFR:**
- Decent muon identification
PEP-II Lumi Performance and Recorded BaBar Lumi

**Best Performance**

**PEP-II peak Luminosity:**

\[ 6.582 \times 10^{33} \text{ cm}^{-2} \text{ sec}^{-1} \]

**Integrated Luminosity Shift:**

135.2 pb\(^{-1}\) in 24 hours: 391.2 pb\(^{-1}\)

124.1 × 10\(^6\) BB

89.7 × 10\(^6\) BB

82 fb\(^{-1}\) on-peak data for analysis

<table>
<thead>
<tr>
<th>Run 1+2</th>
<th>82 (10) fb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 3</td>
<td>31 (4) fb(^{-1})</td>
</tr>
<tr>
<td>Run 4</td>
<td>6 (0) fb(^{-1})</td>
</tr>
</tbody>
</table>
e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB \rightarrow B \text{ produced almost at rest in } \Upsilon(4S) \text{ frame}

For B decay with no missing particles use beam energy to constrain mass and energy of the reconstructed B:

\[ \Delta E = E_B^* - E_{beam}^* \rightarrow 0 \text{ for signal} \]

\[ m_{ES} = \sqrt{(E_{beam}^2 - P_B^2)} \rightarrow m_B \text{ for signal} \]

\[ \Delta E \text{ and } m_{ES} \text{ provide uncorrelated measurement of energy and mass} \]
A rare flavour changing neutral current (FCNC) $b \to s \nu \nu$ decay
SM prediction: $\text{Br} (B \to K \nu \nu) \equiv 4 \times 10^{-6}$
Summed over all neutrino species

- **The best upper limits (@90% CL):**
  - CLEO: $\text{Br} (B \to K \nu \nu) < 2.4 \times 10^{-4}$
  - **BABAR:** $\text{Br} (B \to K \nu \nu) < 9.4 \times 10^{-5}$
  
  Semi-Leptonic B-tags: $B \to D \nu X$ ($X = \gamma$, $\pi^0$ or nothing) $50.7 \text{ fb}^{-1}$

- **New search (80 fb$^{-1}$) with hadronic B-tags**
  - $B^{\pm} \to D^0(*) (\pi^{\pm}) (K^{\pm}) (K^0_s) (\pi^0)$
    
    $(D^* \to D^0 \pi$ and $D^0 \to K \pi$, $K \pi \pi^0$, $K3\pi$, $K_s \pi \pi)$

  - **B constraining kinematic variables:** $\Delta_E$ and $m_{ES}$
• Identify tag $B$ in signal $\Delta E$ and $m_{ES}$ area
• All remaining tracks and neutrals belong to the recoiling signal-side $B$
  • One well identified Kaon
  • no $\pi^0$
  • Missing momentum not in the beam pipe
  • “extra” Energy < 300 MeV
• Selected events: 3
• Expected background events: 2.7 ± 0.8

\[ \text{Br} \left( B \to K\nu\nu \right) < 1.05 \times 10^{-4} \quad @ \ 90\% \ CL \]

• Combining this result with the previous, \((\text{Br} \left( B \to K\nu\nu \right) < 9.4 \times 10^{-5})\) statistically independent BABAR result, yields a new limit:

\[ \text{Br} \left( B \to K\nu\nu \right) < 7.0 \times 10^{-5} \quad @ \ 90\% \ CL \]
2 analyses of the 1999-2002 data sample: \( \sim 81 \text{ fb}^{-1} \)

Reconstruct one B meson as

- **Semi–Leptonic B-tag**
  \[ B \to D \ell \nu X \]

- **Hadronic B-tag**
  \[ B \to D X_{\text{had}} \]

The remaining neutrals and tracks are signal candidates

- \( \tau \to (e, \mu) \nu_{(e, \mu)} \nu_{\tau} \)
- \( \tau \to (\pi, \pi\pi^0, \pi\pi\pi) \nu_{\tau} \)

very clean but low efficiency (\( \sim 0.25 - 0.30 \% \))

The two samples of *tag* B mesons are statistically independent
**τ Signal Selection**

### Semi–Leptonic B-Tag

- $\tau^+\tau^-$ event veto
- Only one charged track having low impact parameter
- Track is not identified as a kaon
- Track is an identified lepton
- Residual neutral energy is used to model PDFs to extract signal and background contributions

### Hadronic B-Tag

- Three preselections
  - 1 track, 0 $\pi^0$
  - 1 track, 1 $\pi^0$
  - 3 tracks, 0 $\pi^0$
- Track is not identified as a kaon
- Track is identified as lepton or pion
- Additional cuts on
  - Missing momentum
  - Residual neutral energy
  - Track momentum
  - Invariant masses
- Background mainly from $V_{cb}$ events
- Signal efficiency: 11.3%

**Signal efficiency:** 22.5%

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### B → τν Results

#### Semi–Leptonic B-Tag

<table>
<thead>
<tr>
<th>Expected Bkg from MC</th>
<th>40.9 ± 3.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Bkg in onpeak data (sideband extrapolation)</td>
<td>39.9 ± 2.8</td>
</tr>
<tr>
<td>Observed events onpeak data</td>
<td>47.7 ± 7.0</td>
</tr>
</tbody>
</table>

#### Hadronic B-Tag

<table>
<thead>
<tr>
<th>Selection</th>
<th>Total Bkg</th>
<th>Data candidates</th>
</tr>
</thead>
<tbody>
<tr>
<td>τ→e νe ντ</td>
<td>6.7 ± 2.0 ± 0.6</td>
<td>10</td>
</tr>
<tr>
<td>τ→μ νμ ντ</td>
<td>5.0 ± 1.7 ± 0.4</td>
<td>8</td>
</tr>
<tr>
<td>τ→π ντ</td>
<td>11.2 ± 2.5 ± 0.5</td>
<td>6</td>
</tr>
<tr>
<td>τ→ππ0 ντ</td>
<td>10.4 ± 2.6 ± 1.2</td>
<td>7</td>
</tr>
<tr>
<td>τ→πππ ντ</td>
<td>4.3 ± 1.4 ± 0.3</td>
<td>4</td>
</tr>
<tr>
<td>All</td>
<td>37.6 ± 4.7 ± 1.5</td>
<td>35</td>
</tr>
</tbody>
</table>

**Expected Bkg from MC:** 40.9 ± 3.8

**Expected Bkg in onpeak data (sideband extrapolation):** 39.9 ± 2.8

**Observed events onpeak data:** 47.7 ± 7.0

**SM prediction:** < 9.2 × 10⁻⁵

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**Combined limit**

**Br (B⁻ → τ⁻ ν) < 4.1 × 10⁻⁴ @ 90% CL**

**SM prediction:** < 9.2 × 10⁻⁵

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B→μν Search

Data sample 1999–2002: ~81fb⁻¹

Two Body decay $\rightarrow p(\mu) \sim \frac{m_B}{2}$

- One well identified muon
- All the rest is from the companion $B$
  - do particle identification
  - No additional leptons allowed

- After the companion $B$ was found, $p(\mu)$ is re-reconstructed in the signal $B$ rest frame
All other tracks and neutrals make the *Companion-B*
Upper Limit for \( B \rightarrow \mu \nu \)

- Signal Selection efficiency: 2.09%
- Selected events: 11
- Expected background: \( 5.0^{+1.8}_{-1.4} \)
- Bg fluctuation prob. to the signal: 4%

\[ B \rightarrow \mu \nu \text{ MC} \]

Data

\[ B \rightarrow \mu \nu \]

\[ B \rightarrow \mu \nu < 6.6 \times 10^{-6} \]

@ 90% CL

BABAR-CONF-03-007

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Reconstruct $K^+$, $K_s \rightarrow \pi^+\pi^-$, $K^{*0} \rightarrow K^+\pi^-$, $K^{*+} \rightarrow K_s\pi^+$

Lepton identification for
$e^+e^-$ with $p(e) > 0.5$ GeV/c,
$\mu^+\mu^-$ with $p(\mu) > 1.0$ GeV/c
Events with the same final state: \[ B \rightarrow J/\psi \ K^{(*)}, \ \psi' \ K^{(*)} \]

Signal is scattered in this above area

\[ 500 \text{ fb}^{-1} \quad B \rightarrow J/\psi \ K^{(*)}, \ \psi' \ K^{(*)} \] Monte Carlo
little to no contribution
outside these veto bands
Background from lepton miss-identification

\[ B \rightarrow h^+h^- K^(*) \]

\[ h^+h^- K^(*) \] events in data convolved with rates for \( h \) to fake \( e, \mu \)

Included as part of the fit to data
b$\rightarrow$ $K\ell\ell$ Results

2-D unbinned maximum LH fit to $m_{ES}$ and $\Delta E$ on all 4 decays $K^+ee/\mu\mu$ and $K_s^0ee/\mu\mu$

![Graph showing two distributions: (a) $m_{ES}$ vs. Events/0.006 GeV/c$^2$ and (b) $\Delta E$ vs. Events/0.02 GeV.]

8.4$\sigma$ excess over background

$$\text{Br}(b \rightarrow K\ell\ell) = (6.5 \pm^{+1.4}_{-1.3} +/\ - 0.4 ) \times 10^{-7}$$

accepted by PRL
b → K* ll Results

3-D unbinned maximum LH fit to m_{ES}, ΔE and m_{KP}

![Graph showing 3D unbinned maximum likelihood fit to m_{ES}, ΔE, and m_{KP}]

3.3 σ excess over background

$$\text{Br}(b \rightarrow K^* ll) = (8.8^{+3.3}_{-2.9} +/- 1.0) \times 10^{-7}$$

Constrain: K^* ee = 1.33 X K^* µµ
$$\Gamma_{tot}(B^0) = 1.08 \times \Gamma_{tot}(B^+)$$

accepted by PRL
Comparison of $m_{ll}$ in data with simulation, normalized to the measured Br

Fits well
Semi-Inclusive $B \rightarrow X_s \ell\ell$

Sum of exclusive modes approach:
- reconstruct $X_s$ with $1 \, K^\pm$ or $K^0_s \rightarrow \pi^+\pi^-$, $\#(\pi^\pm + \pi^0) \leq 2$, $\# \pi^0 \leq 1$
- 10 modes, $\sim 50\%$ of $\text{BR}(B \rightarrow X_s \ell^+\ell^-)$ (75\% if assumed $K_S=K_L$)

Similar analysis as $b \rightarrow K^{(*)}\ell\ell$ but with higher combinatoric background

$B \rightarrow X_s e^+e^-$

$B \rightarrow X_s \mu^+\mu^-$

$E_{\text{ES}} [\text{Gev/c}^2]$

$E_{\text{ES}} [\text{Gev/c}^2]$
## Semi-Inclusive $B \to X_s / \ell$ Results

<table>
<thead>
<tr>
<th>Mode</th>
<th>$N_{\text{sig}}$</th>
<th>Significance</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($\pm$ stat)</td>
<td>(stat)</td>
<td></td>
</tr>
<tr>
<td>$B \to X_s \mu^+\mu^-$</td>
<td>$12.4 \pm 6.2$</td>
<td>2.2</td>
<td>1.2%</td>
</tr>
<tr>
<td>$B \to X_s e^+e^-$</td>
<td>$29.0 \pm 8.3$</td>
<td>4.0</td>
<td>2.5%</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>$41.4 \pm 10.3$</td>
<td>4.6</td>
<td></td>
</tr>
</tbody>
</table>

![Graph](image)

\[
\begin{align*}
\text{Br}(B \to X_s e^+e^-) &= (6.6 \pm 1.9 \pm 1.9_{-1.6}^{+1.9}) \times 10^{-6} \\
\text{Br}(B \to X_s \mu^+\mu^-) &= (5.7 \pm 2.8 \pm 1.7_{-1.4}^{+1.7}) \times 10^{-6} \\
\text{Br}(B \to X_s \ell^+\ell^-) &= (6.3 \pm 1.6 \pm 1.8_{-1.5}^{+1.8}) \times 10^{-6}
\end{align*}
\]
\[ B^0 \rightarrow K_2^{*0}(1430) \gamma \] and \[ B^+ \rightarrow K_2^{*+}(1430) \gamma \]

\[ Br (B^0 \rightarrow K_2^{*0}(1430) \gamma ) \quad Br (B^+ \rightarrow K_2^{*+}(1430) \gamma ) \]

BaBar (12.2 +/- 2.5 +/- 1.1) \times 10^{-6} \quad (14.4 +/- 4.0 +/- 1.3) \times 10^{-6}

Belle (13 +/- 5 +/- 1) \times 10^{-6}

Cleo (16.6 +/- 5.9 +/- 1.3) \times 10^{-6}
Summary (1)

- **FCNC**
  \[ b \to K\nu\nu \]  
  3 bg events expected  3 seen

- Purely Leptonic Decays
  \[ b \to \tau\nu \]  
  \[ b \to \mu\nu \]  
  difficult  
  looks quite interesting

- Radiative Decays
  \[ B^0 \to K^*_2(1430)\gamma \]  
  \[ B^+ \to K^*_2(1430)\gamma \]  
  BaBar is in the game
**B → s ll Summary**

Next step: measure angular and kinematic distributions

...and have fun with the next talk covering all the other interesting rare results measured by Belle

**Br(b → s ll) in good agreement within experiments and prediction**