B and Charm semileptonic decays with BaBar

SUSY 2011

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- $B \rightarrow D^{(*)}\tau \nu$
- $B \rightarrow X_u \ell \nu$
- Charm sl decays
B and charm semileptonic decays are tree level processes involving CKM matrix elements:

\[
V_{\text{CKM}} = \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\]

New Physics contributions can only be seen:

→ in semileptonic decays involving \( \tau \) leptons: coupling \( \sim m_b m_\tau \tan^2 \beta \)

→ by comparing CKM matrix elements in leptonic and semileptonic decays

→ \( V_{ub} \): Inclusive \( B \to X_u \ell \nu \), exclusive \( B \to \pi \ell \nu \)

Note: Must control (by measuring) QCD effects (form factors)
Sensitivetocharged-Higgs effects

- Involve form factors which can be measured in \(B \to D^{(*)} e/\mu \nu\) decays

- Observables: \(R(D)\) and \(R(D^*)\) ratios

\[
R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)} \tau \nu_\tau)}{\mathcal{B}(B \to D^{(*)} \ell \nu_\ell)}
\]

- can be enhanced by the charged-Higgs \((\tan \beta/m_H)\)
- several syst. and theo. uncertainties cancel out

**SM predictions:**
- \(R(D) = 0.31 \pm 0.02\) \[Nierste, Trine, Westhoff PRD78 (08) 015066\]
- \(R(D^*) = 0.25 \pm 0.02\)
Analysis procedure:

- Complete BaBar data sample: 426 fb$^{-1}$
- Improved efficiencies (lepton and Btag)
- Btag fully reconstructed into hadrons
- Bsigg: D$(\ast)$ and lepton ($\mu$, e)
  - 4 signal samples: ($D^0$, $D^+$, $D^{\ast 0}$, $D^{\ast +}$)$\ell\nu$
    (to extract $B \rightarrow D^{(*)}\tau\nu$)
  - 4 control samples: ($D^0$, $D^+$, $D^{\ast 0}$, $D^{\ast +}$)$\pi^0\ell\nu$
    (to derive $D^{**}\ell\nu$ bkg)
- 2D unbinned ML fit $m_{\text{miss}}^2 - p^*_{\ell}$ (3x4 par.)
  Yields for:
  
  \[
  B \rightarrow (D^0, D^+, D^{\ast 0}, D^{\ast +})\tau\nu \\
  B \rightarrow (D^0, D^+, D^{\ast 0}, D^{\ast +})\ell\nu \\
  B \rightarrow (D^0, D^+, D^{\ast 0}, D^{\ast +})\pi^0\ell\nu
  \]
Fit results (preliminary):

<table>
<thead>
<tr>
<th></th>
<th>$D^{*0}$</th>
<th>$D^{*+}$</th>
<th>$D^*$ (isospin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{sig}$</td>
<td>511 ± 48</td>
<td>220 ± 23</td>
<td>730 ± 50</td>
</tr>
<tr>
<td>Signif.</td>
<td>11.9</td>
<td>12.1</td>
<td>17.1</td>
</tr>
<tr>
<td>$R(D^*)$</td>
<td>0.314 ± 0.030</td>
<td>0.356 ± 0.038</td>
<td>0.325 ± 0.023</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th></th>
<th>$D^0$</th>
<th>$D^+$</th>
<th>$D$ (isospin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{sig}$</td>
<td>226 ± 39</td>
<td>139 ± 21</td>
<td>368 ± 42</td>
</tr>
<tr>
<td>Signif.</td>
<td>6.2</td>
<td>7.5</td>
<td>9.6</td>
</tr>
<tr>
<td>$R(D)$</td>
<td>0.422 ± 0.074</td>
<td>0.513 ± 0.081</td>
<td>0.456 ± 0.053</td>
</tr>
</tbody>
</table>

→ large signal significance (> 5σ) for all channels

Systematics (preliminary):
- Selection cuts: ~6%(D*), ~9%(D)
- $D^{**}$ fitted in $D^{(*)}\pi^0\ell\nu$ samples:
  ~4%(D*), ~5%(D)
Results (preliminary):

$R(D) = 0.456 \pm 0.053 \pm 0.056$

$R(D^*) = 0.325 \pm 0.023 \pm 0.027$

1.8σ larger than SM prediction
$
\rightarrow \text{favors large tan}\beta$

Comparison with previous results:
• Charmless semileptonic decays allow us to measure $V_{ub}$
  → key for the CKM picture: defines the upper UT vertex

• Challenge: suppress charm background $B \rightarrow X \ell \nu = B \rightarrow X_c \ell \nu + B \rightarrow X_u \ell \nu$ (50 : 1)

• Two different experimental methods:
  - **Inclusive:** reconstruct the lepton
  - **Exclusive:** reconstruct the lepton and the final meson ($\pi, \rho, \omega...$)
Inclusive vs exclusive:

- **Inclusive:**
  → Larger statistics, but a lot of charm background
  → Use kinematic variables to suppress as much as possible \( b \rightarrow c \):
    - \( E_L, q^2, M_X \) and \( p^+ = E_X - |p_X| \)
  → Need shape function from QCD

- **Exclusive:**
  → Smaller statistics but better background rejection
  → Need form factors from QCD

\[
\text{Inclusive } |V_{ub}| \neq \text{Exclusive } |V_{ub}|
\]

~2\(\sigma\) difference since many years ago
and \(V_{ub}\) from \(B \rightarrow \tau\nu\) larger than for \(B \rightarrow \pi\ell\nu\)

**New Physics contribution?**
(RH currents modification)

\[
|V_{ub}|_{B \rightarrow X_u\ell\nu} \rightarrow \sqrt{|V_{ub}|^2 + \epsilon_R^2 |\tilde{V}_{ub}|^2} \\
|V_{ub}|_{B \rightarrow \pi\ell\nu} \rightarrow |V_{ub} + \epsilon_R \tilde{V}_{ub}| \\
|V_{ub}|_{B \rightarrow \tau\nu} \rightarrow |V_{ub} - \epsilon_R \tilde{V}_{ub}|
\]

→ Need to have precise \(|V_{ub}|\) measurements
**B → X_uℓν: inclusive**

**Analysis procedure:**

- Complete BaBar data sample: 426 fb\(^{-1}\)
- Btag fully reconstructed hadronically (ε ~0.3-0.5%)
- A lepton (μ or e) from the Bsigg
- X\(_u\) from all remaining tracks and neutral clusters
- ν estimated from missing energy and momentum

**Bkg supression:**
- Combinatorial substracted from m\(_{ES}\)
- Charm: B → D\(^*\)ℓν partial reconstructed, kaon veto, only 1 lepton p\(_{ℓ}^* > 1\) GeV

- Several PS regions: M\(_x\) < 1.55 GeV, M\(_x\) <1.7 GeV
  - p\(_{ℓ} > 1.0\) GeV, p\(_{ℓ} > 1.3\) GeV
  - P\(_+ < 0.66\) GeV
  - q\(^2 > 8\) GeV\(^2\)

- 2D fit for \(ΔB(B→X_uℓν)/B(B→Xℓν)\) in q\(^2\)-M\(_x\)
Fit results:

- Most precise result: 2D fit $q^2 - M_x$ for $p_{\ell}^* > 1$ GeV
- Fit for $B \to X_u \ell \nu$ bkg and $B \to X_u \ell \nu$ signal yields

\[
\mathcal{B}(\bar{B} \to X_u \ell \nu) = (1.80 \pm 0.13 \pm 0.15) \times 10^{-3}
\]

$V_{ub}$ extraction:

\[
|V_{ub}| = \sqrt{\frac{\Delta \mathcal{B}(\bar{B} \to X_u \ell \nu)}{\tau_B \cdot \Delta \Gamma_{\text{theory}}}}
\]

QCD Calculation | $\Delta \Gamma_{\text{theory}}$ (ps$^{-1}$) | $|V_{ub}|$ (10$^{-3}$) |
--- | --- | --- |
BLNP | $62.7^{+4.3}_{-3.9}$ | $4.22 \pm 0.15 \pm 0.20$ |
DGE | $60.2^{+4.4}_{-3.1}$ | $4.20 \pm 0.15 \pm 0.11$ |
GGOU | $62.1^{+7.8}_{-6.1}$ | $4.35 \pm 0.19 \pm 0.20$ |
ADFR | $60.2^{+7.8}_{-6.1}$ | $4.35 \pm 0.19 \pm 0.20$ |

Average:

$|V_{ub}| = (4.31 \pm 0.25_{\exp} \pm 0.16_{\text{theo}}) \times 10^{-3}$

[Bosch et al., PRD 72 (05) 073006]

[Andersen et al., JHEP 0601 (06) 097]

[Gambino et al., JHEP 0710 (07) 058]

[Aglietti et al., EPJ. C 59 (09) 831]
The exclusive B semileptonic decay rate is described as function of form factors:

\[
\frac{d \Gamma(B \to \pi \ell \nu)}{dq^2} = \frac{G_F^2}{24 \pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2
\]

QCD calculations:
Analyses procedure:

- BaBar data samples: 423 fb$^{-1}$, 349 fb$^{-1}$
- Untagged analyses (high stat., more bkg.), e + $\mu$
- Loose $\nu$ reconstruction from full event ($p_\nu = p_{\text{beams}} - \Sigma p_i$)
- Background suppression by cuts or NN
- 2D or 3D fit $\Delta E = (p_B p_{\text{beams}} - s/2)/\sqrt{2}$, $m_{ES} = [(s/2 + p_B p_{\text{beams}})^2 / E_{\text{beams}}^2 - p_B^2]^{1/2}$
- $q^2 = (p_\ell + p_\nu)^2 = (p_B - p_\pi)^2$

  to extract the signal yield

- $q^2$ in 12 or 6 bins

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.42 \pm 0.05 \pm 0.07) \times 10^{-4}$$

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.41 \pm 0.05 \pm 0.07) \times 10^{-4}$$
**BaBar combined result:**

- Small event overlap of $B^0 \rightarrow \pi \ell \nu$ (<1%)
- Uncorrelated statistical uncertainties
- Highly correlated systematics

\[
|V_{ub}| = \sqrt{\frac{\Delta B}{\tau_0 \Delta \zeta}}
\]

(\(\Delta B\) : LCSR \(q^2 < 12\text{GeV}^2\), LQCD \(q^2 > 16\text{GeV}^2\))

<table>
<thead>
<tr>
<th>(\times 10^{-3})</th>
<th>12 bins</th>
<th>6 bins</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>_{\text{HPQCD}})</td>
<td>3.28 ± 0.20</td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>_{\text{FNAL}})</td>
<td>3.14 ± 0.18</td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>_{\text{LCSR}})</td>
<td>3.70 ± 0.11</td>
</tr>
</tbody>
</table>

\(f_+(0)|V_{ub}| = (9.4\pm0.4)\times10^{-4}\)

\(f_+(0)|V_{ub}| = (9.6\pm0.4)\times10^{-4}\)

\(f_+(0)|V_{ub}| = (9.6\pm0.4)\times10^{-4}\)

- fits from J. Dingfelder and V. Luth

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**Summary of $V_{ub}$ measurements:**

- **Exclusive:** (V. Luth, J. Dingfelder)

| Theory | Experiment | $q^2$ range | $\Delta B$ | $|V_{ub}|$ |
|--------|------------|-------------|----------|---------|
| LCSR   | BaBar+Belle Untagged+tagged | 0 – 12 | 0.79 ± 0.03 | 3.35 ± 0.06±0.36 |
| HPQCD  | BaBar+Belle Untagged+tagged | 16 – 26.4 | 0.37 ± 0.03 | 3.46 ± 0.14±0.39 |
| FNAL/MILC | BaBar+Belle Untagged+tagged | 16 – 26.4 | 0.37 ± 0.03 | 3.31 ± 0.13±0.37 |

- **Inclusive:** $|V_{ub}| = (4.34 ± 0.13 ± 0.15) \times 10^{-3}$ (V. Luth, [NS61CH06-Luth])

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**Diagram:**

- $|V_{ub}| = (3.19 ± 0.14 ± 0.27) \times 10^{-3}$

**Table:**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Selection</th>
<th>$\Delta B (10^{-4})$</th>
<th>$V_{ub} (10^{-4})$</th>
<th>BLNP</th>
<th>$V_{ub} (10^{-4})$</th>
<th>GGOU</th>
<th>$V_{ub} (10^{-4})$</th>
<th>DGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO</td>
<td>$p_T^* &gt; 2.2$ GeV</td>
<td>2.30 ± 0.15 ± 0.30</td>
<td>4.00 ± 0.47 ± 0.34</td>
<td>3.81 ± 0.45±0.22±0.39</td>
<td>3.70 ± 0.43±0.30±0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belle</td>
<td>$p_T^* &gt; 1.9$ GeV</td>
<td>8.47 ± 0.37 ± 1.53</td>
<td>4.81 ± 0.45±0.32±0.29</td>
<td>4.65 ± 0.43±0.19±0.29</td>
<td>4.66 ± 0.43±0.26±0.29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaBar</td>
<td>$p_T^* &gt; 2.0$ GeV</td>
<td>5.72 ± 0.41 ± 0.51</td>
<td>4.35 ± 0.25±0.31±0.30</td>
<td>4.17 ± 0.24±0.20±0.33</td>
<td>4.15 ± 0.28±0.28±0.25</td>
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</tr>
<tr>
<td>BaBar</td>
<td>$p_T^* &gt; 2.0$ GeV, $s^{max.} &gt;3.5$ GeV $^2$</td>
<td>4.41 ± 0.42 ± 0.42</td>
<td>4.48 ± 0.30±0.39±0.37</td>
<td>—</td>
<td>—</td>
<td></td>
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</tr>
<tr>
<td>Average</td>
<td>Untagged</td>
<td>—</td>
<td>4.41 ± 0.17 ± 0.32</td>
<td>4.20 ± 0.19±0.20±0.32</td>
<td>4.16 ± 0.17±0.28±0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belle</td>
<td>$M_x \times q^2$, $p_T^* &gt; 1.0$ GeV</td>
<td>19.6 ± 1.7 ± 1.6</td>
<td>4.45 ± 0.27±0.24±0.21</td>
<td>4.47 ± 0.27±0.11±0.15</td>
<td>4.53 ± 0.27±0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaBar</td>
<td>$M_x \times q^2$, $p_T^* &gt; 1.0$ GeV</td>
<td>18.0 ± 1.3 ± 1.5</td>
<td>4.27 ± 0.23±0.23±0.20</td>
<td>4.29 ± 0.24±0.11±0.14</td>
<td>4.34 ± 0.24±0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>Tagged</td>
<td>18.7 ± 1.0 ± 1.1</td>
<td>4.35 ± 0.18±0.24±0.21</td>
<td>4.37 ± 0.18±0.11±0.15</td>
<td>4.42 ± 0.18±0.15</td>
<td></td>
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</tbody>
</table>
Charm semileptonic decays allow to measure form factors in the charm sector, validating LQCD methods
→ increase theory precision involving B decays
→ trust LQCD calculations ensuring possible New Physics signs

Example: the leptonic constant $f_{D_s}$:

Several charm semileptonic channels have been studied at BaBar:

$D \rightarrow K \nu \nu$ [PRD 76, 052005 (2007)]
$D_s \rightarrow K K \nu \nu$ [PRD 78, 051101(R) (2008)]
$D^+ \rightarrow K \pi \nu \nu$ [PRD 83, 072001 (2011)]
$D \rightarrow \pi \nu \nu$ soon

$r_2 = A_2(0)/A_1(0)$
$r_v = V(0)/A_1(0)$
Analysis procedure:

- Partial reconstruction method; \( e^+e^- \rightarrow cc \); only electrons

- \( \text{D}^* \) tag in case of \( D \rightarrow \text{K}e\nu\nu \), no tag for \( D_s \) or \( D^+ \) decays

- Compute the \( D_{(s)} \) direction from all tracks \( \neq \) signal tracks

- \( q^2 \) and angular distributions: kinematic fit with signal tracks momenta and missing energy information

- Background suppression using event shape and topological variables

- Background control, test of the analysis technique and the normalization are obtained from hadronic data samples (ex: \( D \rightarrow \text{K}\pi, D \rightarrow \text{K}\pi\pi \))
Charm sl decays

• Quite precise form factor measurements from BaBar → need LQCD improvements

\[ D^0 \rightarrow K^* e^+ \nu \]

\[ D_s \rightarrow \phi e^+ \nu \]

\[ D_s \rightarrow \phi e^+ \nu \]

\[ D_s \rightarrow \phi e^+ \nu \]

\[ D^+ \rightarrow K^* e^+ \nu \]

\[ D^+ \rightarrow K^* e^+ \nu \]

\[ D^+ \rightarrow K^* e^+ \nu \]

Experiments

\[ r_2 = A_2(0)/A_1(0) \]

\[ r_v = V(0)/A_1(0) \]

\[ r_2 = A_2(0)/A_1(0) \]

\[ r_v = V(0)/A_1(0) \]

\[ r_2 = A_2(0)/A_1(0) \]

\[ r_v = V(0)/A_1(0) \]

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**Summary**

- **B → D(*)τν**
  
  Improved measurements at BaBar
  
  B→D^0τν and B→D^+τν more than 5σ significance
  
  R(D(∗)) exceed by 1.8 σ the SM values→favors large tanβ

- |V_{ub}|_{excl.} = (3.19 ± 0.14 ± 0.27) x 10^{-3}

- |V_{ub}|_{incl.} = (4.34 ± 0.13 ± 0.15) x 10^{-3}

  Despite the experimental and theoretical efforts the discrepancy between exclusive and inclusive measurements remains: what does it means? what don’t we understand?

- **Charm Semileptonic form factors**

  Quite precise results from BaBar for D→Kν, D_s→φν, D→K^*ν, form factors allow to check QCD methods: need LQCD improvements