Inclusive $b \rightarrow u$ Decays and Determination of $V_{ub}$ at Belle

The 2009 Europhysics Conference on High Energy Physics

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• Precise Determination of $|V_{ub}|$ is important for the test of CKM mechanism
Sides measurement not as accurate as angles
KEKB B-Factory

Belle Detector

**KEKEB and Belle**

- Belle Detector, KEKB collider at KEK, Tsukuba, Japan
- World brightest collider $\mathcal{L} = 21 \text{ nb}^{-1}/s$
- Accumulated $\sim 950 \text{ fb}^{-1}$
Measurement of $V_{ub}$

Measurement is very straightforward, use a relation

$$\Gamma(b \rightarrow u\ell^−\bar{\nu}) = \frac{G_F^2}{192\pi^2} |V_{ub}|^2 m_b^5 \left(1 + \text{補正項}\right)$$

Only need to count the number of $b \rightarrow u\ell^−\bar{\nu}$ events, however in reality
Measurement of $V_{ub}$

- In reality,

To get 補正項, we have to know structure of B meson

- In inclusive case
  ⇒ HQET parameters, b and c quark masses
- in exclusive case
  ⇒ form factors
|V_{ub}| from Inclusive Semileptonic

- must deal with 50 times bigger background with identical topology.

\[
\frac{\Gamma(b \rightarrow u\ell^+\bar{\nu})}{\Gamma(b \rightarrow c\ell^-\bar{\nu})} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}
\]

- enhance \( b \rightarrow u\ell^+\bar{\nu} \) using kinematic variables,
  - \( E_\ell \): Lepton energy distribution around endpoint
  - \( m_X, q^2 \) or \( P_+ \equiv E_x - |p_x| \)

hence We actually measure,

\[
\Delta B(B \rightarrow X_u \ell^- \bar{\nu}) = f_u \cdot B(B \rightarrow X_u \ell^- \bar{\nu})
\]

- \( f_u \) is the fraction of phase space
Belle Endpoint Measurement

- 27 fb$^{-1}$
- Measure $\Delta B$ for $p_e^* > p_{\text{cut}}$
  ($p_e^*$: electron momentum in $\Upsilon(4S)$ frame)
- Lowest $p_{\text{cut}} = 1.9$ GeV
- Systematic error dominant because of large background

$\Delta B = (8.47 \pm 0.37(\text{stat.}) \pm 1.53(\text{syst.})) \times 10^{-4}$

for $p^* > 1.9$ GeV

with BLNP, Phys. Rev. D 72, 073006 (2005)

$V_{ub} = \left( 4.64 \pm 0.43^{+0.29}_{-0.31} \right) \times 10^{-3}$

HFAG Winter 2009 combination
Belle Hadronic Tag Measurement

- arXiv:0907.0379 (July 2009)
- "Fully" reconstruct one B ($B_{\text{tag}}$), exclusively
  - Total of $\sim 180$ exclusive modes
  - Known $B_{\text{sig}}$ 4-momentum
  - High purity, low efficiency
  - need many events
- 605 fb$^{-1}$ Belle Data (~2005)

<table>
<thead>
<tr>
<th></th>
<th>eff. (%)</th>
<th>purity</th>
<th>$N_{\text{tag}}$ ($\times 10^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>charged</td>
<td>0.29</td>
<td>0.25</td>
<td>689</td>
</tr>
<tr>
<td>neutral</td>
<td>0.28</td>
<td>0.30</td>
<td>479</td>
</tr>
</tbody>
</table>

- $m_{bc} > 5.27$ GeV, $|\Delta E| < 0.05$ GeV
- more than million reconstructed B
Event Selection with BDT

- One Lepton with $p^B > 1$ GeV
- Further suppression of $b \rightarrow c$ events with Boosted Decision Tree method
- 17 variables with correlations
  - Number of Kaons (charged and $K^{0}_S$)
  - $m_X$
  - $q^2$
  - $m_{\text{mis}}$
  - $P_+ \equiv E_X - |p_X|$
  - $m_{bc}, \Delta E$
  - Impact parameters
  - Total charge of the Event
  - ...

- single optimised cut in BDT classifier
- efficiency $\sim 22\%$
Signal Extraction

- Background subtracted prior to fit
  - not from B decay (scaled off resonance)
  - not correctly reconstructed B_tag
    (MC shape scaled to $m_{bc}$ sideband)
- Fit in 2D $m_X - q^2$ distribution (5x4 bins)
- 3 components (MC driven)
  - $X_u \ell \nu$ contribution
  - $X_c \ell \nu$ contribution
  - Secondary and fakes

<table>
<thead>
<tr>
<th>Source</th>
<th># Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDT selected</td>
<td>5544 ± 54</td>
</tr>
<tr>
<td>scaled off-resonance</td>
<td>35 ± 18</td>
</tr>
<tr>
<td>wrong B_tag</td>
<td>825 ± 38</td>
</tr>
<tr>
<td>$X_u \ell \nu$</td>
<td>1032 ± 91</td>
</tr>
<tr>
<td>$X_c \ell \nu$</td>
<td>3615 ± 32</td>
</tr>
<tr>
<td>Secondary and fakes</td>
<td>38 ± 2</td>
</tr>
</tbody>
</table>

Projected Distributions:

- $M_X$ (GeV/c$^2$)
- $q^2$ (GeV$^2$/c$^2$)
Result

- Partial branching fraction expressed by
  \[
  \Delta B(B \to X_u \ell^- \bar{\nu}, \Delta) = \frac{N^\Delta_{b \to u}}{\varepsilon^\Delta_{b \to u} N_{\text{tag}}}(1 - \delta_{\text{rad}})
  \]

- \(\delta_{\text{rad}}\): correction from QED radiation
- \(\varepsilon^\Delta_{b \to u}\): selection efficiency \(\sim 22\%\)

\[\Delta B = 1.963(1 \pm 0.088 \pm 0.081) \times 10^{-3}\]
for \(p_\ell^B > 1\) GeV

Systematic Errors

<table>
<thead>
<tr>
<th>(p_\ell^B &gt; 1.0) GeV</th>
<th>(\Delta B/B (%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\mathcal{B}(D^{(*)}\ell\nu))</td>
<td>1.2</td>
</tr>
<tr>
<td>((D^{(*)}\ell\nu)) form factors</td>
<td>1.2</td>
</tr>
<tr>
<td>(\mathcal{B}(D^{(*)}\ell\nu)) &amp; form factors</td>
<td>0.2</td>
</tr>
<tr>
<td>(B \to X_u \ell\nu) (SF)</td>
<td>3.6</td>
</tr>
<tr>
<td>(B \to X_u \ell\nu) ((g \to s \bar{s}))</td>
<td>1.5</td>
</tr>
<tr>
<td>(\mathcal{B}(B \to \pi/\rho/\omega \ell\nu))</td>
<td>2.3</td>
</tr>
<tr>
<td>(\mathcal{B}(B \to \eta, \eta' \ell\nu))</td>
<td>3.2</td>
</tr>
<tr>
<td>(\mathcal{B}(B \to X_u \ell\nu)) un-meas.</td>
<td>2.9</td>
</tr>
<tr>
<td>Cont./Comb.</td>
<td>1.8</td>
</tr>
<tr>
<td>Sec./Fakes/Fit.</td>
<td>1.0</td>
</tr>
<tr>
<td>PID/Reconstruction</td>
<td>3.1</td>
</tr>
<tr>
<td>BDT</td>
<td>3.1</td>
</tr>
<tr>
<td>Systematics</td>
<td>8.1</td>
</tr>
<tr>
<td>Statistics</td>
<td>8.8</td>
</tr>
</tbody>
</table>
\( \Delta B \) to \( V_{ub} \)

\( V_{ub} \) is obtained by relation,

\[
|V_{ub}|^2 = \frac{\Delta B(B \to X_u \ell^- \bar{\nu}, \Delta)}{\tau_B \Delta \mathcal{R}}
\]

- \( \tau_B \) average B lifetime
- \( \Delta \mathcal{R} \): partial rate from theory
  - GGOU, JHEP 0710, 058 (2007)

| Theory  | \( |V_{ub}| \times 10^3 \) | stat. | sys. | \( m_b \) | th. |
|---------|---------------------|-------|------|--------|-----|
| BLNP    | 4.37                | 4.3   | 4.0  | +3.1   | +4.3 |
| DGE     | 4.46                | 4.3   | 4.0  | +3.2   | +1.0 |
| GGOU    | 4.41                | 4.3   | 4.0  | 1.9    | +2.1 |

relative errors in %

- New combination will come later
終わり