Inclusive measurement of $|V_{ub}|$ at CKM 2005

Workshop on the Unitarity Triangle
March 18, San Diego

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for Belle collaboration
Belle detector @ KEK-B

5 years of data taking:
$L_{\text{max}} = 15.6 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
$L_{\text{int}} = 381 \text{ fb}^{-1} \ldots > 400 \text{ million B meson events}$

Beam energies
$e^+ (\text{HER}): 8.0 \text{ GeV}$
$e^- (\text{LER}): 3.5 \text{ GeV}$
$E_{\text{CM}} = 10.58 \text{ GeV}$

Belle Detector covers large part of solid angle
New inclusive $|V_{ub}|$ results from Belle

✓ Using endpoint of momentum spectrum for $e^\pm$ with 27 fb$^{-1}$

  Endpoint of momentum spectrum region above $1.9$ GeV/c

  Measure partial branching fraction + obtain $|V_{ub}|$

✓ Using full reconstruction tagging with 253 fb$^{-1}$

  3 kinematical selections where $b \to c$ decays are suppressed

  1) $M_x<1.7$ GeV/c$^2$ / $q^2>8$ GeV$^2$/c$^2$

  2) $M_x<1.7$ GeV/c$^2$ / no $q^2$ cut

  3) $P_+$ analysis : $P_+<0.66$ GeV

  Measure partial branching fractions + obtain $|V_{ub}|$
Electron spectrum endpoint: the method

Measurement region:

\[ 1.9 \text{ GeV}/c < p_e^* < 2.6 \text{ GeV}/c \text{ (CMS)} \]

Background estimation region:

\[ 1.5 \text{ GeV}/c < p_e^* < 1.9 \text{ GeV}/c \text{ (CMS)} \]

Deal with large backgrounds:

**BB backgrounds**
- \( B \rightarrow X_c l \nu \)
- Leptons from other decays
  - \( J/\psi, \psi (2S), \gamma \text{ conv.} \)
- Fake electrons

**MC simulation:**
- D** ev (ISGW2)
- D* ev (HQET)
- De ev (ISGW2)

QED radiative corrections included

Fit (D** D) l\nu / D** l\nu relative contributions

Veto on invariant mass

Estimated using \( K_s \rightarrow \pi^+ \pi^- \)

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How to deal with large non-BB background

Non BB backgrounds
- Continuum ($e^+e^- \rightarrow qq$)
- QED processes

Visible energy
Charged multiplicity
Fox-Wolfram moments
Fisher discriminant:
Energy flow variables
Thrust axis
Rare B decay tag

Subtraction of continuum
(8.8fb$^{-1}$ of offresonance data)

Energy flow variable

Rare B decay tag

Acceptance of selection requirements as a funct. of $q^2$
Electron spectrum endpoint: the result (27 fb⁻¹)

Systematic uncertainty:
- Model dependent signal efficiency ... 1.7%
- \( B \rightarrow X_c l \nu \) background estimation ... 17%

\[
\Delta Br(X_u l \nu) = \frac{N(X_u l \nu)}{2N_{BB} \varepsilon_{MC}}
\]

\[
\Delta Br \ (1.9 \text{ GeV/c} < p_{e^*} < 2.6 \text{ GeV/c}) = (8.47 \pm 0.37 \pm 1.53) \times 10^{-4}
\]

stat  syst
"Standard" $|V_{ub}|$ method

$$
\text{Belle measurement of } m_b \text{ and } \mu_\pi^2 \\
\text{spectral distortion due to final state radiation}
$$

$$
|V_{ub}| = 0.00424 \sqrt{\frac{Br(X_u l\nu) 1.61\text{ps}}{0.002 \tau_B}} \times (1 \pm 0.028 \lambda_{1,2} \pm 0.039 m_b)
$$

1.9 GeV/c $< p_e < 2.6$ GeV/c:

$$
|V_{ub}| = (5.01 \pm 0.47 \pm 0.17 \pm 0.32 \pm 0.24) \times 10^{-3}
$$

Total error on $|V_{ub}|$ ..... 13%
New $|V_{ub}|$ method

An improved treatment of shape function effects + weak annihilation effect estimated

Calculation of $|V_{ub}|$ directly from the partial fraction $\Delta Br$

$$|V_{ub}| = \sqrt{\frac{(1 + \delta_{rad}) \times \Delta Br \left(X_u l_v\right)}{\tau_B \ R}}$$

SF parameters (shape function scheme)
$$m_b(SF) = 4.63, \mu^2_{\pi}(SF) = 0.20$$

1.9 GeV/c $< p_c < 2.6$ GeV/c:

$$|V_{ub}| = (4.50 \pm 0.42 \pm 0.32 \pm 0.21) \times 10^{-3}$$

exp SF theo

Total error on $|V_{ub}|$ .... 13%
Analysis on a fully reconstructed sample

- Fully reconstruct the event → 4-momenta of both B’s are known:

- $p(B_{sig}) = Y(4S) - p(B_{reco})$

- On signal side identify the lepton from $B \rightarrow Xl\nu$

- Use Particle ID:
  - Calculate $P_+ \text{ and } M_x = \sqrt{p_x^2} : p_x = \Sigma p_{sig,rec} - p_{lept}$
  - Calculate $q^2$ distribution $q^2 = (p(B_{sig}) - p_x)^2$
  - Calculate $M_{miss}^2$ distribution $M_{miss}^2 = (q - p_{lept})^2$

- Use different cuts to suppress large $B \rightarrow X_c l\nu$

- Try to estimate no. of $B \rightarrow X_u l\nu$

- Interpret the result in terms of $|V_{ub}|$
Fully reconstructed sample

Clean environment but small sample: $\varepsilon_{\text{reco}} \approx 3 \cdot 10^{-3}$

Exclusive method: 180 decay channels

**Reconstructed channels:**

- $B^0 \rightarrow D^{(*)-}\pi^+ / D^{(*)-}\rho^+ / D^{(*)-}a_1^+ / D^{(*)-}D_s^{(*)+}$
- $B^+ \rightarrow D^{(*)0}\pi^+ / D^{(*)0}\rho^+ / D^{(*)0}a_1^+ / D^{(*)0}D_s^{(*)+}$
- $D^{*0} \rightarrow D^0\pi^0$
- $D^* \rightarrow D^0\pi / D^0\pi^0$
- $D_s^* \rightarrow D_s\gamma$

- $D^0 \rightarrow K\pi / K\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi / K\pi\pi\pi$
- $D \rightarrow K\pi\pi / K\pi\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi / K\pi\pi\pi$
- $D_s \rightarrow K_sK\pi / K\pi\pi\pi$

**Fit by Argus and Crystal Ball functions**

**B^0**
- Signal: 254411
- bkgd: 177669
- purity: 0.59

**B^+**
- Signal: 422753
- bkgd: 255446
- purity: 0.62

*253 fb⁻¹*
Selection of $B \to X_u \nu$ events

1. From reconstructed events select events with high momentum leptons $p^* > 1\text{GeV}/c$
   
   Charged B tag: require charge consistency
   
   → sample of semileptonic decays

2. Additional selection criteria:
   
   Require only one lepton $\Sigma Q=0$
   
   $-1 \text{GeV}^2 < |M_{\text{miss}}|^2 < 0.5\text{GeV}^2$
   
   $\text{No}(K^+)=0, \text{No}(K^0_S)=0$
   
   $\cos\theta_{MM} < 0.95$

3. Construct kinematical variable distributions by obtaining the yield in each bin by $M_{bc}$ fit

4. Fit the kinematical variable distribution with expected distributions from $b \to u$ and $b \to c$ and subtract the fitted $b \to c$ contribution

5. Calculate the partial branching fraction

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Branching fraction calculation

\[
\frac{\Delta Br(X_u l \nu)}{Br(X l \nu)} = \frac{N_{b \to u}}{N_{sl}} \cdot F \cdot \frac{\mathcal{E}_{b \to u}}{\mathcal{E}_{sl}} \cdot \frac{\mathcal{E}_{l \nu \to \nu \ell}}{\mathcal{E}_{l \nu \to \nu \ell}}
\]

Number of excess events

Unfolding factor F

Number of semileptonic events

Ratio of efficiencies for $b \to u$ and $sl$

selection efficiency

Use PDG value for $Br (X l \nu) = 0.1073 \pm 0.0028$

\[\Delta Br (X_u l \nu)\]

New $|V_{ub}|$ method

$|V_{ub}|$ directly from $\Delta Br (X_u l \nu)$

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**M**<sub>x</sub> analysis

**M**<sub>x</sub> < 1.7 GeV/c<sup>2</sup> / q<sup>2</sup> > 8 GeV<sup>2</sup>/c<sup>2</sup>

Total error on |V<sub>ub</sub>| ..... 12%

|V<sub>ub</sub>| = (4.34 ± 0.22 ± 0.19 ± 0.13 ± 0.12 ± 0.33<sup>±0.20</sup><sup>+0.20</sup><sup>−0.22</sup>) × 10<sup>−3</sup>

stat syst b→u b→c SF theo model dep.

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**M**<sub>x</sub> < 1.7 GeV/c<sup>2</sup> / no q<sup>2</sup> cut: total error on |V<sub>ub</sub>| ..... 11%

|V<sub>ub</sub>| = (3.80 ± 0.17 ± 0.13 ± 0.12 ± 0.04 ± 0.29<sup>±0.13</sup><sup>−0.14</sup>) × 10<sup>−3</sup>

stat syst b→u b→c SF theo model dep.
**P+ analysis**

**New proposed kinematical variable**


\[
P_+ = E_x - p_x \\
N_+ = E_x + p_x
\]

\[
(M_x^2 = P_+ P_-)
\]

\[
|V_{ub}| = (3.87 \pm 0.18 \pm 0.18 \pm 0.12 \pm 0.17 \pm 0.35 \pm 0.12 - 0.13) \times 10^{-3}
\]

stat syst b→c b→u SF theo model dep.

Total error on \(|V_{ub}|\) ..... 13%
Subtracted shapes of $M_x$ and $q^2$

(a) no $q^2$ cut

(b) $M_x < 1.7\text{GeV}/c^2$
Partial branching fractions

(What is actually being measured)

\[ \Delta Br (M_x < 1.7, q^2 > 8, p^* > 1) = (8.41 \pm 1.14 \pm 0.69) \times 10^{-4} \]
\[ \Delta Br (M_x < 1.7, p^* > 1) = (1.24 \pm 0.15 \pm 0.08) \times 10^{-3} \]
\[ \Delta Br (P_+ < 0.66, p^* > 1) = (1.10 \pm 0.15 \pm 0.12) \times 10^{-3} \]

| \( V_{ub} \) | Results

| \( V_{ub} \) | values are 10% lower with new method...

Lepton endpoint (\( p^* > 1.9 \) GeV/c)

\[ |V_{ub}| = (4.50 \pm 0.15 \pm 0.55) \times 10^{-3} \quad 13\% \]

Full reconstruction tagging

\[ |V_{ub}| = (4.34 \pm 0.29 \pm 0.43) \times 10^{-3} \quad 12\% \]
\[ |V_{ub}| = (3.80 \pm 0.21 \pm 0.35) \times 10^{-3} \quad 11\% \]
\[ |V_{ub}| = (3.87 \pm 0.25 \pm 0.43) \times 10^{-3} \quad 13\% \]
Conclusions

Lepton endpoint measurement

- With lowest cut (1.9 GeV/c)
- $|V_{ub}|$ error 13%, a competitive result

$|V_{ub}|$ errors for $M_x/q^2$ with 253 fb$^{-1}$: 11% / 12%

Mainly due to SF par. determination

Full reconstruction tagging

- $P_+$ usable (but with largest error)
- It seems avoiding SF region does not bring much profit ...

What can we expect from 500 fb$^{-1}$?

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$|V_{ub}|$ error

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$M_x/q^2$ | stat  | syst  | SF    | other | total |
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Appendix I

Analysis on a fully reconstructed sample

The endpoint analysis

Breakdown of errors on $|V_{ub}|$ for different lower momentum cutoffs

For events with $M_x > 1.7 \text{ GeV/c}^2$:

$M_x$ resolution $\sigma \approx 115 \text{ MeV/c}^2$