Measurement of Exclusive $B \rightarrow Xu \nu$ at Belle
—Status & Prospect—

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|V_{ub}| from \( B \rightarrow \pi l\nu, \rho l\nu, \ldots\)

**Major issue**

= **Form Factor (FF)**

Uncertainties in

- Rate \( \leftrightarrow \) Ns (efficiency)
- \(|V_{ub}| \leftrightarrow\) Rate (normalization)

\[
\frac{d\Gamma(B^0 \rightarrow \pi^{-} l^+\nu)}{dq^2 dc\cos\theta_W} \propto |V_{ub}|^2 p_\pi^3 \sin^2 \theta_W f_1(q^2)^2
\]

Different theories give
Different q² distribution.

Experiment should provide q² distribution with minimum FF dependence in the rate.
Model Independent Approach

- FF by "unquenched" lattice QCD
  - FNAL
  - HPQCD
  - Talk by J. Shigemitsu

Limitations
- High $q^2 (> 16 \text{GeV}^2)$
- $B \to \pi$ only

Clean extraction of $\pi$ in high $q^2$ region is important.

Dispersive Bound

Fukunaga/Onogi
(hep-lat/0408037)

Talk by B. Grinstein
(Friday, WG2S3)

Low-med. $q^2$ data are also useful to constrain more.
Experimental Strategy

- Background Continuum $b \to c \ell \nu$
- + cross feed

S/N
- good
- mod.
- poor

Eff.
- low
- middle
- high

$D^{(*)} \ell \nu$ tag
- Full recon.
- advanced $\nu$ recon.
- trad. $\nu$ recon.

Lum.

How well can we measure the $q^2$ dist. (for $\pi \ell \nu$)?

B$\to \pi \ell \nu / \rho \ell \nu$ (140 fb$^{-1}$)
ICHEP04 preliminary hep-ex/0408145

B$\to \omega \ell \nu$ (78 fb$^{-1}$)
PRL 93, 131803 (2004)
Br($\omega\ell\nu$) = $(1.3 \pm 0.4 \pm 0.2 \pm 0.3) \times 10^{-4}$

$+ \pi \ell \nu / \rho \ell \nu$ (preliminary)
Belle Status (ν-recon.)

- Preliminary results ($\pi l \nu / \rho l \nu$) in the past conf.
  → Trying to finalize with increased statistics.

"In-progress" analysis:
- Event $P_{\text{miss}}, E_{\text{miss}} \rightarrow P_{\nu}, E_{\nu}$
- $P_{\nu} > 1.3$ GeV/c
- Hermeticity cuts
  - $#\text{lepton}$
  - Total Net Charge
  - $M_{\text{miss}}$
- Background supression
  - $\cos\theta_{\text{BY}}$
  - $\cos\theta_{\text{thrust}}$
  - etc.

$$\Delta E = E^*_{\text{beam}} - (E^*_{\pi} + E^*_{l} + E^*_{\nu})$$

$$M_{bc} = \sqrt{E^*_{\text{beam}} - \tilde{P}_{\pi}^* + \tilde{P}_{l}^* + \tilde{P}_{\nu}^*}^2$$

$p_{\text{miss}}$ resolution

$\sigma \sim 160$ MeV

- $85$ MeV @ CLEO

- Poor hermeticity due to the asymmetric collision?
- Difference in track selection?

$q^2$ resolution

$0.62$ GeV$^2$ (r.m.s.)

Improvement by adjusting $P_{\nu}$ w/ constraints

$\Delta E = 0$ GeV

$M_{bc} = 5.279$ GeV/c$^2$
Status at 140 fb$^{-1}$ ($\pi^+ l \nu$)

- Eff. $\sim$3.6% (whole q$^2$)
- S/N $\sim$ 0.2
- For each 8 GeV$^2$ q$^2$ bin,
  - Ns $\sim$ 500
  - $\Delta$(stat.) $= 10$-$18\%$ ($\approx$ CLEO'03)

$\Delta E$ distribution (w/ typical cut)

CLEO'03

- $q^2 > 16$ GeV$^2$

**High statistics available.**

Systematic $\sim 13\%$

**Extrapolation of CLEO'03**

**Belle $\Delta$(stat) @ 140 fb$^{-1}$**

- Preliminary plot
Belle D(*) \to \nu Tagging Analysis

- New method for clean extraction of $B \to \pi / \nu / \rho / \nu$:
  - Marginal Statistics, but
  - Eff. $\sim \times 4$ higher than hadronic decay tag.
  - Very high S/N ($> 2$)
  - The method originally developed for inclusive $X_u \to \nu$ measurement (A. Sugiyama's talk at Moriond'03).

- Preliminary Results at ICHEP04
  - Simultaneous extraction of $\pi^+ \to \nu$ and $\rho^+ \to \nu$ in 3 $q^2$ bin.
  - $P_L > 0.8$ GeV/c
    - Flat efficiency for the whole $q^2$
    - Minimum FF-dep. in the rate
  - $|V_{ub}|$ from high $q^2$ bin + unquenched Lattice QCD
Tag side reconstruction
\[ B_{\text{tag}} \rightarrow D^{*+} \ell^- \bar{\nu} / D^+ \ell^- \bar{\nu} \]
\[ \rightarrow D^0 \pi^+ / D^+ \pi^0 \]
\[ \rightarrow 4 \text{ decay modes} \]
\[ \rightarrow 7 \text{ decay modes} \]

Signal side reconstruction
\[ B_{\text{sig}} \rightarrow X_u \ell^+ \nu \]
\[ P_\ell > 0.8 \text{ GeV} / c \]
\[ \rightarrow \pi^- \text{ or } \pi^- \pi^0 \]
\[ N(\pi^-) = 1, N(\pi^0) \leq 1 \]

Kinematics of double semileptonic decay
Back-to-back correlation of the two B constrains their direction to the intersection of the 2 cones.
\[ x_B = \pm \sqrt{1 - \frac{1}{\sin \theta_{12}} (\cos^2 \theta_{B_1} + \cos^2 \theta_{B_2} - 2 \cos \theta_{B_1} \cos \theta_{B_2} \cos \theta_{12})} \]

To have intersection, must be \[ 0 \leq x_B^2 \leq 1 \]

2 fold ambiguity \[ \rightarrow q^2 \] calculated neglecting the B motion in \( \Upsilon(4S) \)
\[ q^2 \text{ resolution} = 0.75 \text{ GeV}^2 (\sigma) \]
Calibration with $B_{sig} \rightarrow D^*/\nu$ Decays

- Validity of the method for double semileptonic decay detection has been tested with $B_{sig} \rightarrow D^* \ell^+ \overline{\nu} \rightarrow D^0 \pi^- \rightarrow K^+ \pi^-$

$M(K^+\pi^-\pi^-)$ on the signal side

$X_B^2$ distribution

$\frac{N_{obs}}{N_{expected}} = 0.89 \pm 0.08$ is used to correct the MC efficiency for $\pi/\nu$ and $\rho/\nu$ detection.

The method works!
Signal Extraction

- We extract $\pi / \nu / \rho / \nu$ signals simultaneously by fitting 2D $(m_X, x_B^2)$ distribution.
  - Fitting components: $\pi / \nu$, $\rho / \nu$, other $X_u / \nu$, BB background.
  - PDF’s are based on MC.
  - Constraint for extracted Br:
    \[ Br(\pi / \nu) + Br(\rho / \nu) + Br(\text{other } X_u / \nu) = Br(X_u / \nu) \]

Fitting results for all $q^2$ data.

$\pi / \nu$ (72$\pm$11)

$\rho / \nu$ (59$\pm$15)

other $X_u / \nu$

$m_X$ GeV/c$^2$

$x_B^2$ dist. for $\pi$ mass region (I)

$x_B^2$ dist. for $\rho$ mass region (II)

$\pi / \nu$ decays are cleanly extracted!
Extraction of $q^2$ Distribution

$q^2$ distribution is extracted by fitting the $(m_X, x^2)$ distribution for three $q^2$ intervals.

$m_X$ dist. for three $q^2$ intervals

Extracted $q^2$ dist.

$\pi^{-} l^{+} \nu$

$\Delta (\text{stat}) = 21\% \; 27\% \; 37\%$

FF-dep. Very small

$B_{total} = [1.76 \pm 0.28 \pm 0.20 \pm 0.03] \times 10^{-3}$

$\rho^{-} l^{+} \nu$

At the present accuracy, the obtained $q^2$ dist. does not exclude any tested models

FF-dep.

$B_{total} = [2.54 \pm 0.78 \pm 0.85 \pm 0.30] \times 10^{-3}$

Preliminary

140fb$^{-1}$
$|V_{ub}|$ from $B^0 \rightarrow \pi^- \, \ell^+ \, \nu$

$|V_{ub}|$ determined from $q^2 > 16 \text{GeV}^2$ ($B^0 \rightarrow \pi^- \, \ell^+ \, \nu$) with lattice QCD.

- w/ quenched LQCD [FNAL/JLQCD/APE/UKQCD]:
  \[ |V_{ub}| = \sqrt{\frac{B(B \rightarrow \pi \ell \nu)}{\tilde{\Gamma}_{phy} \tau_B}} \]
  \[ \tilde{\Gamma}_{thy} = 1.92^{+0.32}_{-0.12} \pm 0.47 \]
  \[ (3.90 \pm 0.71 \pm 0.23^{+0.62}_{-0.48}) \times 10^{-3} \]

- w/ unquenched LQCD [FNAL/HPQCD]:
  Preliminary results reported at Lattice’04.
  \[ \tilde{\Gamma}_{thy} = 1.96 \pm 0.51 \pm 0.39 \]
  \[ (3.87 \pm 0.70 \pm 0.22^{+0.85}_{-0.51}) \times 10^{-3} \]
  \[ \tilde{\Gamma}_{thy} = 1.31 \pm 0.33 \]
  \[ (4.73 \pm 0.85 \pm 0.27^{+0.74}_{-0.50}) \times 10^{-3} \]

140 fb$^{-1}$, preliminary

4th error from $\tilde{\Gamma}_{thy}$

FF-dep. in Br is small for $\pi / \nu$ data
Systematic Uncertainty

Major contribution

- **D* lν calibration**
  - Statistics of detected $D^*/\nu$ (8.3%)
  - Error of $Br(B^0 \rightarrow D^*/\nu)$ (4.3%)

- **BB background shape**
  - Tested $\Delta B$ in MC by
    - Removing charged track by 1% (-4.2%)
    - Removing $\pi^0$ by 3% (-1.1%)
    - Replacing $K^\pm$ with $\pi^\pm$ by 2% (-0.5%)

Comments;

- D* calibration error improves as Lum.
- Some errors are doubly counted...
- If normalized to $Br(D^* l\nu)$, many errors cancel out

<table>
<thead>
<tr>
<th>Source</th>
<th>$\pi^-\rho^+\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking efficiency</td>
<td>1</td>
</tr>
<tr>
<td>$\pi^0$ reconstruction</td>
<td>-</td>
</tr>
<tr>
<td>Lepton identification</td>
<td>2.1</td>
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<tr>
<td>Kaon identification</td>
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<td>$D^* l\nu$ calibration</td>
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<td>$Br(X_{a l\nu})$ in the fitting</td>
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<td>$B\bar{B}$ background shape</td>
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<tr>
<td>$N_{B\bar{B}}$</td>
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<tr>
<td>$f_+/f_0$</td>
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</tr>
<tr>
<td>$\chi_d$</td>
<td>1.0</td>
</tr>
<tr>
<td>total</td>
<td>11.5</td>
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</table>
Prospect

- Stat. error: extrapolate the present error $1/\sqrt{L/L_0}$.
- Syst. error:
  - $\nu$-recon: error quoted by CLEO’03 (~Belle prelim.)
  - $D^{(*)}\nu$ tag: 5% + (stat. in $D^*\nu$ calibration).

![Graph showing relative error as a function of $L_{int}$ for different $q^2$ regions.]

<table>
<thead>
<tr>
<th></th>
<th>Whole $q^2$</th>
<th>$q^2 &gt; 16$GeV$^2$</th>
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<tbody>
<tr>
<td></td>
<td>$\Delta_{\text{stat.}}$</td>
<td>$\Delta_{\text{sys}}$</td>
</tr>
<tr>
<td>$\nu$-recon</td>
<td>$\sim 4% \times \sqrt{N_{\text{bin}}}$</td>
<td>$\sim 8%$</td>
</tr>
<tr>
<td>$D^{(*)}\nu$ tag</td>
<td>$\sim 8% \times \sqrt{N_{\text{bin}}}$</td>
<td>$\sim 7%$</td>
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</table>

- Also, we are trying to measure all $\pi/\rho$ charge states.
Two analyses in progress at Belle; $\nu$-recon & $D^(*) \rightarrow \nu$ tag.

$D^(*) \rightarrow \nu$ tag. provides clean extraction of $B \rightarrow X_u \rightarrow \nu$.

$B \rightarrow \pi \rightarrow \nu$ at 500 fb$^{-1}$
- Both will give precision $\sim 15$-$20\% / 8 \text{ GeV}^2 q^2$ bin
- $\nu$-recon: $\Delta \text{stat} < \Delta \text{sys}$ $\leftrightarrow$ $D^(*)\nu$ tag: $\Delta \text{stat} > \Delta \text{sys}$
- Results from the two methods may be combined (statistical overlap is small).

Beyond this, the $D^(*) \rightarrow \nu$ tag will be the major stream.
- Achievable precision $\rightarrow 5\%$ (in total)

How good is the hadronic decay tag? $\rightarrow$ J.Dingfelder
How good is the theory? $\rightarrow$ J.Shigemitsu and others.
Backup Slides
CLEO'03 $\pi l \nu$ (as a reference)


- **Analysis feature**
  - Higher $S/N$ w/ tight $\nu$ recon.
  - Wide $P_\perp$ range $\rightarrow$ FF-indep. Br
    - $P_\perp > 1.0(1.5) \text{GeV/c}$ for $\pi l \nu$ ($\rho l \nu$)
  - Simultaneous extraction of $\pi$ and $\rho$
  - Differential rate in 3 $q^2$ bins.
  - $|V_{ub}|$ by QCD based FF.
    - LQCD(LCSR) for $q^2 > 16 \text{GeV}^2$ ($< 16 \text{GeV}^2$)

| $q^2 (\text{GeV}^2)$ | $< 8$ | 8-16 | $> 16$
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<tbody>
<tr>
<td>$N_s$</td>
<td>~20</td>
<td>~60</td>
<td>~20</td>
</tr>
<tr>
<td>$\Delta_{\text{sta}}$</td>
<td>26%</td>
<td>17%</td>
<td>36%</td>
</tr>
<tr>
<td>$\Delta_{\text{sys}}$</td>
<td>12%</td>
<td>11%</td>
<td>16%</td>
</tr>
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</table>

$N_s$: estimated by quoted eff. and Br.

- Efficiency
  - Low continuum bkg by tagging
    - Low $P_{l}$ threshold ($P_{l} > 0.8\text{GeV}/c$)
    - Very flat $q^{2}$-dep.
  - Diagonal part of the efficiency matrix; $q^{2}$ gen $\rightarrow$ $q^{2}$ obs.

- $q^{2}$ resolution
  - The method has 2-fold ambiguity (in the B direction).
  - $q^{2}$ is calculated neglecting the B motion.

How good is it with hadronic decay tag?