**V_{ub} measurements with the BaBar detector**

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(on behalf of the BaBar collaboration)

Outline:

**Inclusive \( b \rightarrow ulv \) measurements:**
- Endpoint
- \( \nu \) reconstruction
- \( m_X \) on recoil of Breco tags
- \( m_X \) vs \( q^2 \) on recoil of Breco tags

**Exclusive \( b \rightarrow ulv \) measurements:**
- \( B^0 \rightarrow \pi^+ \nu \) on recoil of Partial tags
- \( B \rightarrow (\pi,\rho,\omega,\eta,\eta',a_0) \nu \) on recoil of Breco tags
charmless semileptonic B decays, $B \to X_u l \nu$, allow for the measurement of $|V_{ub}|$

experimentally challenging, because

- $B \to X_c l \nu$ background (50 times higher)
- tight cuts are needed and signal is analyzed in limited region of phase space
- extrapolation introduces uncertainties

i will present two approaches:

1. **inclusive:** look at kinematic quantities inclusively, use duality assumption and study $b \to ul \nu$. once total $B(b \to ul \nu)$ is obtained $|V_{ub}|$ can be extracted with small uncertainties.

2. **exclusive:** study exclusive decays, use form factor to extract branching ratio and $|V_{ub}|$
Three Experimental Techniques

Three ways of studying $B \rightarrow X_u l \nu$ decays in BaBar:

- **Method**
  - **Untagged**
    - No recoil and $\nu$ reco from miss. momentum
  - **Partial Tags**
    - Recoil of partially reconstructed $D^*$
  - **Breco Tags**
    - Recoil of fully recon. $B \rightarrow D(*)X$

- **signal**
  - $X_u \ l \ \nu$
  - $X_u \ l \ \nu$
  - $X_u \ l \ \nu$

- **recoil**
  - $(n h^\pm, m \gamma)$
  - $\pi_{\text{soft}} \ l(D^0\nu X)$
  - $D(*) \ X$

**Fully Had. Reco**

- $D^0$
- $\pi^+$
- $\pi^−$
- $\nu$
- $l^−$

---

- **efficiency**
- **purity**

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**Inclusive: Endpoint and \( \nu \) Reco**

**Endpoint:**
- one high energy electron \((2.0\text{GeV}<E_e<2.6\text{GeV})\)
- cut on the missing momentum \((p_{\text{miss}} = p_{e^+ e^-} - p_{\text{vis}})\) and event shape cuts
- Continuum bkg using off-peak data and on-peak for \(E_l>2.8\text{GeV}\).
- BB\(_\text{bar}\) bkg fitting \(E_l\) spectrum (\(\text{Dev}, \text{D}^*\text{ev}, \text{D}^{**}\text{ev}, \text{D}^{(*)}\pi\text{ev}, X_u\text{ev}\) and non semileptonic components)

**\( \nu \) Reconstruction:**
- Same approach as in the endpoint method (same \(p^*>2\text{GeV/c}\)) but it selects a refined subset of events (much better S/B)
- \(b\rightarrow c\nu \) background separated by:

\[
\begin{align*}
    s_h^{\text{max}} &= m_B^2 + q^2 - m_B E_e \left( 1/1 + \beta \right) - 2m_B \left( q^2 / 4E_e \right) \sqrt{1/1 + \beta}
\end{align*}
\]

where \(\beta = 0.06\) is the boost of the B in the \(Y(4S)\) rest frame. Less sensitive to non perturbative parameters than \(m_X\)
- efficiency and shape modeling checked using pure \(B\rightarrow D^0 l\nu(X)\) control sample
Inclusive: Endpoint and $\nu$ Reco

**Endpoint**

![Endpoint graph](image)

$$B(B \to X_u \nu) = (1.73 \pm 0.22_{\text{exp}} \pm 0.33_{(m_b,a) \text{ syst}}) \times 10^{-3}$$

$$|V_{ub}| = (3.94 \pm 0.25_{\text{exp}} \pm 0.37_{(m_b,a) \text{ syst}} \pm 0.19_{\text{HQET}}) \times 10^{-3}$$

**$\nu$ reco**

![$\nu$ reco graph](image)

$$B(B \to X_u \nu) = (2.37 \pm 0.22_{\text{stat}} \pm 0.26_{\text{det syst}} \pm 0.34_{\text{bkg syst} - 0.30(m_b,a) \text{ syst}}) \times 10^{-3}$$

$$|V_{ub}| = (4.63 \pm 0.21_{\text{stat}} \pm 0.25_{\text{det syst}} \pm 0.34_{\text{bkg syst} - 0.29(m_b,a) \text{ syst}} \pm 0.21_{\text{HQET}}) \times 10^{-3}$$

08/17/04

Daniele del Re (UCSD) - ICHEP 04
Inclusive: $m_X$ vs. $q^2$

Extension of the already published result (PRL92,071802).

- **Recoil selection and reconstruction of X system:**
  - One and only one lepton with $p^* > 1$ GeV/c
  - Correlation between lepton charge and $B_{\text{reco}}$ flavor
  - Cut on the missing mass: $M_{\text{miss}}^2 < 0.5$ GeV$^2$
  - Charge conservation: $Q_{\text{tot}} = 0$
  - Partially reconstructed neutrino to reject $B^0 \rightarrow D^* l \nu$ events
  - Kinematic fit (2-C): improve hadronic mass resolution
  - Kaon veto

- **Systematics due to lepton ID and tag normalization reduced by measuring**

  
  a ratio of BRs \[ R_{u/sl} = \frac{B(B \rightarrow X_u l\nu)}{B(B \rightarrow Xl\nu)} \]

- $m_X < 1.7$ GeV and $q^2 > 8$ GeV$^2$ using the approach by Bauer et al. Dependence on shape function parameters is much reduced

This approach and sample have been also used to unfold the $m_X$ spectrum.
Unfolded $m_X$ spectrum and cumulative distribution for $b \to ul \nu$ decays

$|V_{ub}| = (4.92 \pm 0.39_{\text{stat}} \pm 0.36_{\text{exp syst}} \pm 0.46_{\text{theo syst}}) \times 10^{-3}$

$\Delta B(B \to X_u l \nu) = (0.88 \pm 0.14_{\text{stat}} \pm 0.13_{\text{exp syst}} \pm 0.02_{(m_b, a) \text{ syst}}) \times 10^{-3}$

Stability of $|V_{ub}|$ as a function of the $q^2$ cut

80fb$^{-1}$
Exclusive Decays on Recoil

- **Semil Tags** ($B^0 \to D^* l \nu$): measurement in bins of $q^2 (0-8-16 \text{GeV}^2/c^4)$
  
  Signal yields are extracted by fitting $M_{\nu}^2$ (event missing mass).
  
  $$B(B^0 \to \pi^- l^+ \nu) = (1.46 \pm 0.27_{\text{stat}} \pm 0.28_{\text{syst}}) \times 10^{-4}$$

- **Breco Tags** ($B \to D^{(*)} X$): 9 $B \to X_u l \nu$ modes: $X_u = \pi^+, \pi^0, \rho^+, \rho^0, \omega, \eta, \eta', a_0^0, a_0^+$
  
  Approach similar to the inclusive analysis but resonances are exclusively and fully reconstructed on recoil.
  
  $$B(B^0 \to \pi^- l^+ \nu) = (1.08 \pm 0.28_{\text{stat}} \pm 0.16_{\text{syst}}) \times 10^{-4}$$
  
  $$B(B^0 \to \rho^- l^+ \nu) = (2.57 \pm 0.52_{\text{stat}} \pm 0.59_{\text{syst}}) \times 10^{-4}$$

80 fb$^{-1}$ (upper limits for $\eta, \eta', a_0^0, a_0^+$, results in backup slides)
Conclusions

We measured $|V_{ub}|$ with different experimental inclusive techniques:

- Dominant error from modellization of non-perturbative effects (Shape Function, SF). Fitted on $b \rightarrow s\gamma$ events; two fits available not yet combined: CLEO(2001), Belle(2004)
- We measured the unfolded $m_X$ distribution. In future $b \rightarrow ul\nu$ decays can be used to put constraints on SF parameters.

\[ q^2 - E_I (\nu\text{ reco}) \]
\[ 4.63 \pm 0.21_{\text{stat}} \pm 0.42_{\text{exp}} \pm 0.49_{\text{theo}} \]

\[ \text{endpoint} \]
\[ 3.94 \pm 0.23_{\text{stat+exp}} \pm 0.42_{\text{theo}} \]

\[ m_X (\text{Breco tags}) \]
\[ 4.77 \pm 0.28_{\text{stat}} \pm 0.28_{\text{exp}} \pm 0.55_{\text{theo}} \]

\[ m_X - q^2 (\text{Breco tags}) \]
\[ 4.92 \pm 0.39_{\text{stat}} \pm 0.36_{\text{exp}} \pm 0.46_{\text{theo}} \]
### $V_{ub}$ measurements with BaBar

<table>
<thead>
<tr>
<th>method</th>
<th>S/B</th>
<th>Pros &amp; Cons</th>
<th>$V_{ub}(x10^{-3})$</th>
</tr>
</thead>
</table>
| **Untagged** inclusive                      | 0.05→0.2 | • High statistics  
• Duality valid for tight $E_e$ cuts?  
• Bkg subtraction | 3.94 ± 0.23$_{\text{exp}}$ ± 0.42$_{\text{theo}}$ |
| Electron spectrum endpoint                  |      |                                                  |                           |
| $E_e > 2.0 \text{GeV}$                      |      |                                                  |                           |
| Total rate using DeFazio-Neubert            |      |                                                  |                           |
| **Untagged** inclusive                      | ~0.5 | • High statistics  
• Lower syst. on shape functions  
• Bkg subtraction | 4.63 ± 0.47$_{\text{exp}}$ +0.62$_{\text{theo}}$ |
| $E_e$ vs $q^2$ and neutrino reconstruction |      |                                                  |                           |
| $E_e > 2.0 \text{GeV}$ and $s_h < 3.5 \text{GeV}^2/c^4$ |      |                                                  |                           |
| Total rate using DeFazio-Neubert            |      |                                                  |                           |
| **Breco Tags** inclusive                    | ~1.7 | • Low background  
• High resolution  
• Low statistics  
• Shape func. syst. | 4.77 ± 0.40$_{\text{exp}}$ +0.69$_{\text{theo}}$ |
| $m_X$ analysis (1-D)                        |      |                                                  |                           |
| $m_X < 1.55 \text{ GeV}/c^2$                |      |                                                  |                           |
| Total rate using DeFazio-Neubert            |      |                                                  |                           |
| **Breco Tags** inclusive                    | ~2   | • Low background  
• Very small syst. on SF param.  
• Small statistics | 4.92 ± 0.53$_{\text{exp}}$ ± 0.46$_{\text{theo}}$ |
| $m_X$ vs $q^2$ analysis                     |      |                                                  |                           |
| $m_X < 1.7 \text{ GeV}/c^2$ and $q^2 > 8.0 \text{GeV}^2/c^4$ |      |                                                  |                           |
| $V_{ub}$ using Bauer et al.                 |      |                                                  |                           |
| **Partial Tags** exclusive                  | 1→20 | • Very small bkg  
• No cut on kinem  
• Small statistics | (B($B^0 \rightarrow \pi^+ l^+ \nu$)) = (1.22 ± 0.26)×10$^{-4}$ |
| Total rate using Form Factors calc.         |      |                                                  |                           |
BACKUP SLIDES
Incl. Decays: Theory and Uncertainties

Relevant issues

- hadronization effects and Fermi motion (b quark mass)
- non-perturbative parametrizations (Shape Function, SF) affected by large uncertainties.

Two approaches to extract $|V_{ub}|$ and estimate theo. systematics:

1. DeFazio-Neubert paper (DFN), tri-differential parametrization ($E_e, m_X, q^2$) to extrapolate.

   $|V_{ub}|$ extracted by

   $$|V_{ub}| = 0.00424 \sqrt{\frac{B(B \rightarrow X_u l \nu)}{0.002}} \times (1 \pm 0.028_{\text{OPE}} \pm 0.039_{m_b})$$

2. $q^2$ vs $m_X$ approach by Bauer et al. (BLL).

   Partial BR with $q^2$ vs $m_X$ cut. $|V_{ub}|$ is extracted using

   $$|V_{ub}| = \sqrt{\frac{192\pi^4}{\tau_B G^2_f m_b^5} \Delta B(B \rightarrow X_u l \nu; m_X < 1.7\text{GeV}/c^2, q^2 > 8\text{GeV}^2/c^4)}$$

   Dependence on SF (here in G) is much reduced.

Theo. uncertainties on non-perturbative effects are evaluated using

$\lambda^\text{SF}$ and $\Lambda^\text{SF}$ ellipse from $b \rightarrow s \gamma$ from CLEO. Belle ellipse as an alternative.
Excl. Decays: Theory and Uncertainties

- primary challenge is calculation of the form factors (containing hadronization effects and non-pert. contributions)
- Large uncertainties both extrapolation to full phase space and determination of $|V_{ub}|$
- different theoretical models predict different $q^2$ distributions.
- discriminate among models by a precise measurement of differential BRs.

The differential branching ratio can be related to $|V_{ub}|$ by the following relation:

$$\frac{dB(B^0 \rightarrow \pi^- l^+ \nu)}{dq^2 d(\cos \theta_{Wl})} = |V_{ub}|^2 \tau_{B^0} \frac{G_F^2 k^3}{32\pi^3} \sin^2 \theta_{Wl} |f(q^2)|^2$$

The bigger the integrated region the smaller the uncertainty on $|V_{ub}|$
Inclusive: Endpoint Method

- one high energy electron \((p^* > 1.1\text{GeV})\)
- cut on the missing momentum \((p_{\text{miss}} = p_{\text{e}^+\text{e}^-} - p_{\text{vis}})\) and event shape cuts

- Continuum bkg using off-peak data and on-peak for \(E_l > 2.8\text{GeV}\).
- \(BB_{\text{bar}}\) bkg fitting \(E_l\) spectrum (\(\text{Dev}, D^*\text{ev}, D^{**}\text{ev}, D^{(*)}\pi\text{ev}, X_u\text{ev}\) and non semileptonic components)

- For \(2.0\text{GeV} < E_l < 2.6\text{GeV}\) we obtain (using \(DFN\)):

\[
B(B \rightarrow X_u\text{ev}) = (1.73 \pm 0.22_{\text{exp}} \pm 0.33_{(m_b,a)\text{syst}}) \times 10^{-3}
\]

\[
|V_{ub}| = (3.94 \pm 0.25_{\text{exp}} \pm 0.37_{(m_b,a)\text{syst}} \pm 0.19_{\text{HQET}}) \times 10^{-3}
\]

Results are stable by applying tighter cuts on \(E_l\).

Main exp. systematics from signal modeling (~2-8%) and event selection efficiency (~6%), and \(D^{(*)**,}\text{ev}\) description (~3%)
Inclusive: \( \nu \) Reconstruction Method

Same approach as in the endpoint method but it select a refined subset of events (much better S/B):

- one high energy electron (\( p^* > 2 \text{GeV/c} \)) is identified
- visible 4-momentum by using charged tracks (with particle ID) and energy deposits in the calorimeter
- missing momentum defined as \( p_{\text{miss}} = p_{e^+e^-} - p_{\text{vis}} \) and used to estimate neutrino
- cuts on the missing momentum and on the event shape.

- \( b \rightarrow c l \nu \) background separated by:

\[
s_h^{\text{max}} = m_B^2 + q^2 - m_B E_e \sqrt{\frac{1-\beta}{1+\beta}} - 2m_B \left( \frac{q^2}{4E_e} \right) \sqrt{\frac{1-\beta}{1+\beta}}
\]

where \( \beta = 0.06 \) is the boost of the B in the \( Y(4S) \) rest frame. Less sensitive SF parameters than \( m_X \)

- efficiency and shape modeling checked using a pure \( B^0 \rightarrow D^{*+} l \nu (X) \) control sample

![Data-MC agreement for \( p_{\text{miss}} \)](image)
Inclusive: $\nu$ Reconstruction Method

- BR extracted by applying the following cuts $E_{l}>2\text{GeV}$ and $s_{h}<3.5\text{ GeV}^{2}/c^{4}$
- The region $s_{h}>4.25\text{ GeV}^{2}/c^{4}$ is used to normalize the MC bkg to the data
- De Fazio-Neubert parametrization to extrapolate to full phase space

Results:

$$B(B \rightarrow X_{u}\nu) = (2.37 \pm 0.22_{\text{stat}} \pm 0.26_{\text{det syst}} \pm 0.34_{\text{bkg syst} - 0.30(m_{b}, a) \text{ syst}} \pm 0.60) \times 10^{-3}$$

$$|V_{ub}| = (4.63 \pm 0.21_{\text{stat}} \pm 0.25_{\text{det syst}} \pm 0.34_{\text{bkg syst} - 0.29(m_{b}, a) \text{ syst}} \pm 0.59_{\text{HQET}}) \times 10^{-3}$$

Main experimental systematics are from: Neutrals ($\sim6\%$), $K_{L}$ ($\sim7\%$), $B \rightarrow X_{c}\nu$ modeling: ($7\%$), stability in scans ($\sim12\%$)
Inclusive: $m_X$ vs. $q^2$

For Breco tags the reconstructed modes are ($\sim$1000 modes):

$B \rightarrow D(*)\pi, D(*)\pi\pi^0, D(*)3\pi,$ etc...

The eff. is $\sim0.4\%$ corresponding to $\sim4000$ B/fb$^{-1}$
($\sim2500$ B/fb$^{-1}$ B$^+$ and B $\sim1500$ B/fb$^{-1}$ B$^0$)

The sample has low purity but it improves a lot once cuts on recoil are applied.

Recoil selection and reconstruction of X system:

One and only one lepton with $p^* > 1$ GeV/c
Correlation between lepton charge and B$_{reco}$ flavor
Cut on the missing mass: $M_{miss}^2 < 0.5$GeV$^2$
charge conservation: $Q_{tot}=0$
Partially reconstructed neutrino to reject $B^0 \rightarrow D^* l \nu$ events
kinematic fit (2-C): improve hadronic mass resolution

Separate $B \rightarrow X_u l \nu$ in signal enriched and depleted based on veto on $K^\pm$ and $K_S$

Systematics reduced by measuring $R_{u/sl} = \frac{B(B \rightarrow X_u l \nu)}{B(B \rightarrow Xl \nu)}$
Inclusive: $m_X$ and $m_X$ vs. $q^2$

Breco Tags

![Graphs showing $q^2$ distribution for different $M_X$ ranges](image)
m_X spectrum can be converted in a universal variable by unfolding detector and selection effects.

relationship between measured and true spectra is:
\[
\tilde{x}_{\text{meas}} = \hat{A} \tilde{x}_{\text{true}}
\]
where \( \hat{A} \) is the detector response matrix, in general is non-invertible.

Unfolding method is based on procedure specified in hep-ph/9509307.

Systematics effects are properly taken into account. First and second moment of the b→ulv m_X distribution are extracted:

<table>
<thead>
<tr>
<th>( M_{X,0} \text{ (GeV/c}^2 )</th>
<th>( M )</th>
<th>( \sigma(M) )</th>
<th>Correlation</th>
<th>( \sigma_{\text{stat}} )</th>
<th>( \sigma_{\text{det}} )</th>
<th>( \sigma_{\text{sig}} )</th>
<th>( \sqrt{\sigma_{\text{stat}}^2 + \sigma_{\text{det}}^2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_1 )</td>
<td>1.86</td>
<td>1.363</td>
<td>0.089</td>
<td>0.063</td>
<td>0.023</td>
<td>0.018</td>
<td>0.039</td>
</tr>
<tr>
<td>( M_2 )</td>
<td>1.86</td>
<td>0.143</td>
<td>0.037</td>
<td>-0.824</td>
<td>0.027</td>
<td>0.010</td>
<td>0.006</td>
</tr>
<tr>
<td>( M_1 )</td>
<td>5</td>
<td>1.602</td>
<td>0.244</td>
<td>0.150</td>
<td>0.075</td>
<td>0.061</td>
<td>0.142</td>
</tr>
<tr>
<td>( M_2 )</td>
<td>5</td>
<td>0.271</td>
<td>0.095</td>
<td>0.782</td>
<td>0.048</td>
<td>0.036</td>
<td>0.022</td>
</tr>
</tbody>
</table>

80fb^{-1}
## Comparison Using Belle’s \((m_b,a)\) Ellipse

<table>
<thead>
<tr>
<th></th>
<th>CLEO ellipse</th>
<th>BELLE ellipse</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{ub}) reco</td>
<td>(</td>
<td>V_{ub}</td>
<td>= (4.63 \pm 0.47 \pm 0.62_{\text{exp}} \pm 0.36_{\text{theo}}) \times 10^{-3})</td>
</tr>
<tr>
<td>Endpoint</td>
<td>(</td>
<td>V_{ub}</td>
<td>= (3.94 \pm 0.23 \pm 0.42_{\text{theo}}) \times 10^{-3})</td>
</tr>
<tr>
<td>(m_X)</td>
<td>(</td>
<td>V_{ub}</td>
<td>= (4.77 \pm 0.40 \pm 0.69_{\text{exp}} \pm 0.45_{\text{theo}}) \times 10^{-3})</td>
</tr>
<tr>
<td>(m_X) vs (q^2)</td>
<td>(</td>
<td>V_{ub}</td>
<td>= (4.92 \pm 0.53 \pm 0.46_{\text{theo}}) \times 10^{-3})</td>
</tr>
<tr>
<td>unfolding</td>
<td><img src="image1" alt="Unfolded Spectrum CLEO" /> <img src="image2" alt="Unfolded Spectrum BELLE" /></td>
<td><img src="image1" alt="Unfolded Spectrum CLEO" /> <img src="image2" alt="Unfolded Spectrum BELLE" /></td>
<td>Unfolded spectrum seems to prefer Belle ellipse. Comparison with expected (m_X) shape is better.</td>
</tr>
</tbody>
</table>
Exclusive: \( B^0 \rightarrow \pi^+ l^- \nu \)

Partially reco’ed sample is selected by following variables combined in a likelihood ratio:

- Some preselection cuts on shape and multiplicity
- lepton mom. \((p^* > 1.3 \text{GeV})\)
- soft pion mom. \((50 \text{MeV} < p_\pi < 200 \text{MeV})\)
- lepton-\(\pi\) Vtx probability

Signal yield is extracted via \( M_{\nu}^2 \) (mis. mass squared)

\( D^* \) is assumed to be collinear with the soft \( \pi \)

Then:

\[
E_D^* = \frac{E_\pi}{M_\pi} M_{D^*} \quad \Rightarrow \quad M_{\nu}^2 = (p_{B^0} - p_l - p_{D^*})^2
\]

Additional cuts to:

- remove \( b-\overline{b} \) background (like the charge correlation of the two reconstructed leptons and quantities related to the remainder of the event)
- remove continuum background (like the invariant mass and the opening angle of the two electrons)
Exclusive: $B^0 \rightarrow \pi^+ l^- \nu$

- Measurement is performed in bins of $q^2$
- Three bins: $(q^2 < 8 \text{GeV}^2; 8 \text{GeV}^2 < q^2 < 16 \text{GeV}^2; q^2 > 16 \text{GeV}^2)$
- Signal yields are extracted by fitting $M_{\nu}^2$ (missing mass of the full event).

We obtain:

$$B(B^0 \rightarrow \pi^- l^+ \nu) = (1.46 \pm 0.27_{\text{stat}} \pm 0.28_{\text{syst}}) \times 10^{-4}$$

Main experimental systematics are due to detector (~8%), background composition (~10%) and shape of BBbar background (~15%)
Exclusive: $B \rightarrow (\pi, \rho, \omega, \eta, a_0) l\nu$

9 $B \rightarrow X_u l\nu$ modes are studied:

$$X_u = \pi, \pi^0, \rho^+, \rho^0, \omega, \eta, \eta', a_0^0, a_0^+$$

Resonances are exclusively reconstructed on the recoil.

Similar cuts as for the inclusive $m_X$ analysis, such as $p^* > 1\text{GeV}$ and miss. mass squared of the event.

Further per mode cuts to reject $b \rightarrow c$ and crossfeed background are used

<table>
<thead>
<tr>
<th>Mass (MeV)</th>
<th>Width (MeV)</th>
<th>Decay modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0 l\nu$</td>
<td>139.57</td>
<td>-</td>
</tr>
<tr>
<td>$\pi^0 l\nu$</td>
<td>134.98</td>
<td>-</td>
</tr>
<tr>
<td>$\rho^0 l\nu$</td>
<td>775</td>
<td>150</td>
</tr>
<tr>
<td>$\rho^0 l\nu$</td>
<td>775</td>
<td>150</td>
</tr>
<tr>
<td>$\omega l\nu$</td>
<td>782.6</td>
<td>8.5</td>
</tr>
<tr>
<td>$\eta l\nu$</td>
<td>547.8</td>
<td>-</td>
</tr>
<tr>
<td>$\eta' l\nu$</td>
<td>957.8</td>
<td>-</td>
</tr>
<tr>
<td>$a_0^\pm l\nu$</td>
<td>985</td>
<td>50-100</td>
</tr>
<tr>
<td>$a_0^0 l\nu$</td>
<td>985</td>
<td>50-100</td>
</tr>
</tbody>
</table>
Exclusive: $B \to (\pi, \rho, \omega, \eta, a_0) l\nu$

Similar approach to the inclusive analysis but resonances are exclusively and fully reconstructed on recoil.

We measure:

$$B(B^0 \to \pi^- l^+ \nu) = (1.08 \pm 0.28_{\text{stat}} \pm 0.16_{\text{syst}}) \times 10^{-4}$$

$$B(B^0 \to \rho^- l^+ \nu) = (2.57 \pm 0.52_{\text{stat}} \pm 0.59_{\text{syst}}) \times 10^{-4}$$

$$B(B^+ \to \eta l\nu) < 1.2 \times 10^{-4} (90\% \text{CL})$$

$$B(B^+ \to \eta' l\nu) < 4.5 \times 10^{-4} (90\% \text{CL})$$

$$B(B^+ \to a_0^0 l\nu) B(a_0^0 \to \eta \pi^0) < 5.3 \times 10^{-4} (90\% \text{CL})$$

$$B(B^+ \to a_0^+ l\nu) B(a_0^+ \to \eta \pi^+) < 3.3 \times 10^{-4} (90\% \text{CL})$$

These two results make use of:

$$B(B^0 \to \pi^- l^+ \nu) = 2B(B^+ \to \pi^0 l^+ \nu)$$

$$B(B^0 \to \rho^- l^+ \nu) = 2B(B^+ \to \rho^0 l^+ \nu)$$

$$B(B^+ \to \rho^0 l^+ \nu) = B(B^+ \to \omega l^+ \nu)$$

Systematics are dominated by MC statistics. Large systematics due to non-resonant contribution in $B \to \rho l\nu$. Theoretical systematics are small (~4-7%).
Results (80 fb$^{-1}$)

- $B^\pm \rightarrow \pi^0 l\nu$
- $B^0 \rightarrow \rho^0 l\nu$
- $B^0 \rightarrow \rho^0 l\nu$
- $B^0 \rightarrow \omega l\nu$

\[ B(B^0 \rightarrow \pi^0 l\nu) = (0.89 \pm 0.34_{\text{stat}} \pm 0.12_{\text{syst}}) \times 10^{-4} \]
\[ B(B^+ \rightarrow \pi^0 l\nu) = (0.91 \pm 0.28_{\text{stat}} \pm 0.14_{\text{syst}}) \times 10^{-4} \]
\[ B(B^0 \rightarrow \rho^0 l\nu) = (3.5 \pm 1.1_{\text{stat}} \pm 0.7_{\text{syst}}) \times 10^{-4} \]
\[ B(B^+ \rightarrow \rho^0 l\nu) = (1.04 \pm 0.39_{\text{stat}} \pm 0.16_{\text{syst}}) \times 10^{-4} \]
\[ B(B^0 \rightarrow \omega l\nu) = (1.26 \pm 0.55_{\text{stat}} \pm 0.24_{\text{syst}}) \times 10^{-4} \]
Results (80 fb$^{-1}$)

$B^\pm \to \eta l\nu$

$B^\pm \to \eta^* l\nu$

$B^\pm \to a^0 l\nu$

$B^0 \to a^0 l\nu$

$B(B^+ \to \eta l\nu) = (0.39 \pm 0.41_{\text{stat}} \pm 0.22_{\text{syst}}) \times 10^{-4}$

$\Rightarrow B(B^+ \to \eta l\nu) < 1.2 \times 10^{-4} (90\% CL)$

$B(B^+ \to \eta^* l\nu) = (2.7 \pm 1.2_{\text{stat}} \pm 0.5_{\text{syst}}) \times 10^{-4}$

$\Rightarrow B(B^+ \to \eta^* l\nu) < 4.5 \times 10^{-4} (90\% CL)$

$B(B^+ \to a^0_0 l\nu) B(a^0_0 \to \eta \pi^0) =$

$(2.7 \pm 1.4_{\text{stat}} \pm 0.9_{\text{syst}}) \times 10^{-4}$

$\Rightarrow B(B^+ \to a^0_0 l\nu) < 5.3 \times 10^{-4} (90\% CL)$

$B(B^+ \to a^+_0 l\nu) B(a^+_0 \to \eta \pi^+) =$

$(0.7 \pm 1.6_{\text{stat}} \pm 0.3_{\text{syst}}) \times 10^{-4}$

$\Rightarrow B(B^+ \to a^+_0 l\nu) < 3.3 \times 10^{-4} (90\% CL)$
<table>
<thead>
<tr>
<th>method</th>
<th>S/B</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Untagged</strong> inclusive</td>
<td>0.1→1</td>
<td>(</td>
</tr>
<tr>
<td><strong>Untagged</strong> inclusive</td>
<td>~0.3</td>
<td>(</td>
</tr>
<tr>
<td><strong>Breco Tags</strong> inclusive</td>
<td>~1.7</td>
<td>(</td>
</tr>
<tr>
<td><strong>Breco Tags</strong> inclusive</td>
<td>~2</td>
<td>(</td>
</tr>
</tbody>
</table>
| **Partial Tags** exclusive | 1→20 | \( B(B^0 \rightarrow \pi^- l^+ \nu) = (1.22 \pm 0.19^{\text{stat}} \pm 0.18^{\text{syst}}) \times 10^{-4} \)  
\( B(B^0 \rightarrow \rho^- l^+ \nu) = (2.57 \pm 0.52^{\text{stat}} \pm 0.59^{\text{syst}}) \times 10^{-4} \) |
$V_{ub}$ measurements

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>$4.12 \pm 0.67 \pm 0.71$</td>
</tr>
<tr>
<td>L3</td>
<td>$5.70 \pm 1.00 \pm 1.40$</td>
</tr>
<tr>
<td>DELPHI</td>
<td>$4.07 \pm 0.65 \pm 0.61$</td>
</tr>
<tr>
<td>OPAL</td>
<td>$4.00 \pm 0.71 \pm 0.71$</td>
</tr>
<tr>
<td>CLEO (endpoint)</td>
<td>$4.69 \pm 0.23 \pm 0.63$</td>
</tr>
<tr>
<td>BELLE ($m_X - Q^2$)</td>
<td>$4.75 \pm 0.46 \pm 0.46$</td>
</tr>
<tr>
<td>BELLE (endpoint)</td>
<td>$4.45 \pm 0.23 \pm 0.61$</td>
</tr>
<tr>
<td>BABAR (endpoint)</td>
<td>$4.40 \pm 0.15 \pm 0.44$</td>
</tr>
<tr>
<td>BABAR $m_X$</td>
<td>$5.22 \pm 0.38 \pm 0.44$</td>
</tr>
<tr>
<td>BABAR ($m_X, Q^2$)</td>
<td>$5.18 \pm 0.52 \pm 0.42$</td>
</tr>
<tr>
<td>BABAR ($E_1, Q^2$)</td>
<td>$4.99 \pm 0.34 \pm 0.51$</td>
</tr>
</tbody>
</table>

Average
$4.69 \pm 0.44$

HFAG

$\chi^2/\text{dof} = 4.7/6$ (CL = 58.8\%)
Conclusions for Exclusive Decays

We also developed novel methods to measure EXCL. CHARMLESS decays:

- **Breco tags:**
  \[ B(B^0 \rightarrow \pi^- l^+ \nu) = (1.08 \pm 0.28_{\text{stat}} \pm 0.16_{\text{syst}}) \times 10^{-4} \]
  \[ B(B^0 \rightarrow \rho^- l^+ \nu) = (2.57 \pm 0.52_{\text{stat}} \pm 0.59_{\text{syst}}) \times 10^{-4} \]

- **Semil tags:**
  \[ B(B^0 \rightarrow \pi^- l^+ \nu) = (1.46 \pm 0.27_{\text{stat}} \pm 0.28_{\text{syst}}) \times 10^{-4} \]

**AVERAGE**

\[ B(B^0 \rightarrow \pi^- l^+ \nu) = (1.22 \pm 0.19_{\text{stat}} \pm 0.18_{\text{syst}}) \times 10^{-4} \]