Charmless semileptonic B decays
and $|V_{ub}|$ at BaBar

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26 April 2011
UC Davis High Energy Seminar
Outline

- CKM Matrix and $V_{ub}$
- Charmless semileptonic decay rates
- BaBar experiment
- $B \rightarrow (\pi/\rho)lv$ decays
- $B \rightarrow \omega lv$ decays (combinatoric-$\omega$ background from data)
- Measurement of $|V_{ub}|$

combined fit to 4 channels

new fit reduces $|V_{ub}|$ theory error

first measurement of $q^2$ spectrum
CKM matrix and $V_{ub}$

\[
\begin{pmatrix}
  d' \\
  s' \\
  b'
\end{pmatrix}
= \begin{pmatrix}
  V_{ud} & V_{us} & V_{ub} \\
  V_{cd} & V_{cs} & V_{cb} \\
  V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
  d \\
  s \\
  b
\end{pmatrix}
\]

unitarity implies a closed triangle

\[
V_{CKM}^T V_{CKM} = 1 \Rightarrow V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0
\]

weak eigen-states
CKM matrix
mass eigen-states

$V_{ud} V_{ub}$ $V_{cd} V_{cb}$ $V_{td} V_{tb}$

$\beta$ known within 1° from $B \to J/\psi K_S$

$B \to (\pi/\rho/\omega) l\nu$, W. Wulsin
b → uW⁻ amplitude $\alpha V_{ub}$

weak doublet: $\begin{pmatrix} u \\ d' \end{pmatrix} = \begin{pmatrix} V_{ud} & d + V_{us} & s + V_{ub} & b \end{pmatrix}$

Leptonic Helicity-suppressed

$B(B^+ \to \tau^+ \nu) = 18(1 \pm 0.28) \times 10^{-5}$

Semileptonic Leptonic and hadronic currents factorize

$B(B^+ \to \pi^0 \ell^+ \nu) = 7.7(1 \pm 0.16) \times 10^{-5}$

Hadronic Complex QCD interactions

$B(B^+ \to \pi^+ \pi^0) = 0.57(1 \pm 0.09) \times 10^{-5}$
## Semileptonic $p_l$ spectra

### $B \rightarrow Xl\nu$

| Challenge | Inclusive $|V_{ub}|$: reconstruct lep. only | Exclusive $|V_{ub}|$: reconstruct lep. & $X_u$ |
|-----------|------------------------------------------|------------------------------------------|
| experimental | model large $B \rightarrow X_{c\ell} \nu$ background | better bkgd rejection; lower rates |
| theoretical | calculate partial decay rate in a region where background is suppressed | calculate hadronic current |

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**Figure:**

- **$B \rightarrow Xl\nu$**
- **$B \rightarrow X_{u\ell} \nu$**

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**Source:**

"The difference between the values for $|V_{ub}|$ obtained from inclusive and exclusive decays has persisted for many years, despite significant improvements in both theory and experiment for both methods. How to reconcile these results remains an intriguing puzzle."

-Kowalewski and Mannel, “Determination of $V_{cb}$ and $V_{ub}$,” PDG 2010
**Exclusive $|V_{ub}|$: tagged vs. untagged**

- **non-signal B**
  - untagged: not reconstructed
  - tagged: reconstructed as
    - $B \rightarrow Xlv$ ($\varepsilon = 1\%-3\%$)
    - $B \rightarrow$ hadrons ($\varepsilon = 0.3\%-0.5\%$)

**good agreement between tagged and untagged BF’s**

**Figure 3:** Exclusive $|V_{ub}|$, from HFAG.

**Figure 4:** $B \rightarrow X_{ul}v$ is reconstructed

<table>
<thead>
<tr>
<th>Dataset</th>
<th>$B \rightarrow \pi^0 l^+ \nu$</th>
<th>$B \rightarrow \pi^0 l^+ \nu \times 2\tau_0/\tau_+$</th>
<th>$B \rightarrow \pi^0 l^+ \nu \times 2\tau_0/\tau_+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BABAR SL tag:</td>
<td>$B^+ \rightarrow \pi^0 l^+ \nu$</td>
<td>$1.80 \pm 0.28 \pm 0.15$</td>
<td>$1.54 \pm 0.41 \pm 0.30$</td>
</tr>
<tr>
<td>BELLE SL tag:</td>
<td>$B^+ \rightarrow \pi^0 l^+ \nu$</td>
<td>$1.43 \pm 0.26 \pm 0.15$</td>
<td>$1.24 \pm 0.23 \pm 0.05$</td>
</tr>
<tr>
<td>BABAR $B_{reco}$ tag:</td>
<td>$B^+ \rightarrow \pi^0 l^+ \nu \times 2\tau_0/\tau_+$</td>
<td>$1.07 \pm 0.27 \pm 0.19$</td>
<td>$1.24 \pm 0.23 \pm 0.05$</td>
</tr>
<tr>
<td>BELLE $B_{reco}$</td>
<td>$B^+ \rightarrow \pi^0 l^+ \nu \times 2\tau_0/\tau_+$</td>
<td>$1.38 \pm 0.19 \pm 0.15$</td>
<td>$1.43 \pm 0.26 \pm 0.15$</td>
</tr>
<tr>
<td>CLEO untagged:</td>
<td>$B \rightarrow \pi^0 l^+ \nu$</td>
<td>$1.38 \pm 0.15 \pm 0.11$</td>
<td>$1.24 \pm 0.23 \pm 0.05$</td>
</tr>
<tr>
<td>BABAR untagged:</td>
<td>$B \rightarrow \pi^0 l^+ \nu$</td>
<td>$1.45 \pm 0.07 \pm 0.11$</td>
<td>$1.38 \pm 0.15 \pm 0.11$</td>
</tr>
<tr>
<td>BELLE $B_{reco}$</td>
<td>$B^0 \rightarrow \pi^0 l^+ \nu \times 2\tau_0/\tau_+$</td>
<td>$1.12 \pm 0.18 \pm 0.05$</td>
<td>$1.38 \pm 0.15 \pm 0.11$</td>
</tr>
<tr>
<td>Average:</td>
<td>$B^+ \rightarrow \pi^0 l^+ \nu$</td>
<td>$1.36 \pm 0.05 \pm 0.05$</td>
<td>$1.36 \pm 0.05 \pm 0.05$</td>
</tr>
<tr>
<td>$\chi^2$/dof = 5.4/9 (CL = 80%)</td>
<td>$\chi^2$/dof = 5.4/9 (CL = 80%)</td>
<td>$\chi^2$/dof = 5.4/9 (CL = 80%)</td>
<td>$\chi^2$/dof = 5.4/9 (CL = 80%)</td>
</tr>
</tbody>
</table>
Semileptonic B decay rate

Measure $d\Gamma/dq^2$

Need theory to calculate form factors $f_+$ or $A_1, A_2, V$
QCD calculation of form factors

\[ |V_{ub}| = \sqrt{\frac{\Delta B(q_{\text{min}}^2, q_{\text{max}}^2)}{\tau_+ \Delta \zeta(q_{\text{min}}^2, q_{\text{max}}^2)}} \]

\[ \Gamma = |V_{ub}|^2 \Delta \zeta \]

\[ \Delta \zeta(q_{\text{min}}^2, q_{\text{max}}^2) = \frac{G_F^2}{24\pi^3} \int_{q_{\text{min}}^2}^{q_{\text{max}}^2} |\vec{p}_\pi|^3 |f_+(q^2)|^2 dq^2 \]

\[ \Delta \zeta(q_{\text{min}}^2, q_{\text{max}}^2) = \frac{G_F^2 m_B^2}{96\pi^3} \int_{q_{\text{min}}^2}^{q_{\text{max}}^2} |\vec{p}_\rho|^2 q^2 (|H_0|^2 + |H_+|^2 + |H_-|^2) dq^2 \]

### Lattice QCD
- unquenched calculations available
- none yet for vector semileptonic decays
- accurate at high \( q^2 \)

### Light cone sum rules
- use QCD sum rules with twist expansions
- accurate at low \( q^2 \)

### Quark model calculations
- postulates forms for meson wave functions
- normalized at \( q_{\text{max}}^2 \)

#### References

- HPQCD: PRD 73, 074502 (2006)
- Ball/Zwicky: PRD 71, 014015 (2005)
PEP-II $e^+e^-$ Collider

- c.m. energy: 10.58 GeV = $m\Upsilon(4S)$
- Lorentz boost ($\beta\gamma =0.56$) reduces hermeticity
- 413 fb$^{-1}$ collected on-resonance: 454 million BB events in Runs 1-6
- 41 fb$^{-1}$ collected off-resonance
BaBar detector

Cerenkov Detector (DIRC)
144 fused silica bars
11000 PMTs

1.5 T Solenoid

Electromagnetic Calorimeter
6580 CsI(Tl) crystals

e^+ (3.1 GeV)

e^- (9 GeV)

Instrumented Flux Return
iron / RPCs (muon / neutral hadrons)

Drift Chamber
40 layers

Silicon Vertex Tracker
5 layers, double sided strips
B→(\(\pi/\rho\))lv selection

Untagged

\[ X_u = \pi, \rho \rightarrow \pi\pi \]

Hadron (\(\pi\) or \(\rho \rightarrow \pi\pi\))

|\(m_{\pi\pi} - m_\rho^{PDG}\) | ≤ 1 full width

Neutrino

Reconstructed from missing 4-momentum of event:

\[
(E_\nu, \bar{p}_\nu) = (E_{\text{miss}}, \bar{p}_{\text{miss}}) = (E_{e^+e^-}, \bar{p}_{e^+e^-}) - (\sum_i E_i, \sum_i \bar{p}_i)
\]

Lepton (\(\ell = e, \mu\))

Require high momentum.

\[ B \rightarrow X_u \ell \nu \]

\[ B^0 \rightarrow \pi^+ \nu \] after preselection; neural nets further enhance signal

Sample components

<table>
<thead>
<tr>
<th>Signal</th>
<th>small relative to bkgd</th>
</tr>
</thead>
<tbody>
<tr>
<td>B→X_u(\nu)lv</td>
<td>similar to signal</td>
</tr>
<tr>
<td>other BB</td>
<td>dominant background</td>
</tr>
<tr>
<td>e^+e^-→qq</td>
<td>off-resonance data used to correct fit variable shapes</td>
</tr>
</tbody>
</table>

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**Signal selection variables**

**plots from $B^0 \rightarrow K^0\bar{K}^0$ BaBar analysis**

**background**

**signal**

---

$$m_{ES} = \sqrt{\frac{(s/2 + \vec{p}_B \cdot \vec{p}_{e^+ e^-})^2}{E_{e^+ e^-}^2} - p_B^2}$$

signal peaks at $m_{ES} = m_B = 5.28 \text{ GeV/c}^2$

$$\Delta E = \frac{P_B \cdot P_{e^+ e^-} - s/2}{\sqrt{s}}$$

signal peaks at $\Delta E = 0$

---

$m_{ES}$ and $\Delta E$ test consistency of reconstructed $B$ with a true $B$
**B→πlν branching fraction**

Binned ML fit in $m_{ES}$, $ΔE$, and $q^2$ for $B → (π^±/π^0/ρ^±/ρ^0)ℓν$ simultaneously, with isospin constraint

$B^0 → π^- ℓ^+ ν$ in 6 $q^2$ bins

**Low $q^2$**

$B^0 → π^- ℓ^+ ν$ candidates for $0 < q^2 < 4$ GeV$^2$

**Mid $q^2$**

$B^0 → π^- ℓ^+ ν$ candidates for $8 < q^2 < 12$ GeV$^2$

**High $q^2$**

$B^0 → π^- ℓ^+ ν$ candidates for $q^2 > 20$ GeV$^2$

Signal peaks at $m_{ES} = m_B = 5.28$ GeV/c$^2$

$ΔE = \frac{P_B \cdot P_{e^+e^-} - s/2}{\sqrt{s}}$

Signal peaks at $ΔE = 0$

** backgrounds vary with $q^2$.**

- **signal**
- **B→X_lν**
- **other BB**
- **qq**

$m_{ES} \approx \sqrt{\frac{(s/2 + \vec{p}_B \cdot \vec{p}_{e^+e^-})^2}{E_{e^+e^-}^2} - p_B^2}$

**Single mode yields**

- $B^0 → π^- ℓ^+ ν$: $7181 ± 279$
- $B^+ → π^0 ℓ^+ ν$: $3446 ± 208$
- $B → πℓν$: $10604 ± 376$

**4-mode yield used to find BF**

$B(\bar{B} → π^- ℓ^+ ν) = (1.41 ± 0.05_{stat} ± 0.07_{syst}) \times 10^{-4}$

$σ_{stat} = 3.5\%; \ σ_{syst} = 5.0\%; \ σ_{tot} = 6.1\%$
B→ρℓν branching fraction

Binned ML fit in $m_{ES}$, $ΔE$, and $q^2$ for $B \to (π^±/π^0/ρ^±/ρ^0)\ellν$ simultaneously, with isospin constraint.

$B^0 \to ρ^−ℓ^+ν$ in 3 $q^2$ bins

Large $B\to X_{u}ℓν$ background is highly correlated with signal and must be fixed in the fit.

$B^0 \to ρ^−ℓ^+ν$: 1577 ± 130
$B^+ \to ρ^0ℓ^+ν$: 1970 ± 154
$B \to ρℓν$: 3332 ± 286

Smaller yield than $B\to πℓν$.

$B(B^0 \to ρ^−ℓ^+ν) = (1.75 \pm 0.15_{stat} \pm 0.27_{syst}) \times 10^{-4}$

$σ_{stat} = 8.6\%; σ_{syst} = 16\%; σ_{tot} = 18\%$

Systematic errors $B \to πℓν$ $B \to ρℓν$
detector effects 3.2% 4.9%
$K_L$ simulation 3.0% 7.5%
$B \to (π/ρ)ℓν$ FF 2.2% 9.4%
$B \to X_{u}ℓν$ bkgd. 0.9% 12.9%
$B \to X_{c}ℓν$ bkgd. 1.0% 1.5%
$qq$ bkgd. 2.0% 4.0%
other effects 1.5% 2.5%
Total 5.0% 15.7%
Comparison of $\text{BF}(B \to \pi/\rho l\nu)$ with theory

$B \to \pi l\nu$

Theory curves scaled to area of the data.

**BGL:** *PRL 74, 4608 (1995)*

Most precise measurement of $\text{BF}(B \to \pi/\rho l\nu)$

$B \to \rho l\nu$

$\Delta B/\Delta q^2$ (GeV$^{-2}$)

$q^2$ (GeV$^2$)

$\Delta B/\Delta q^2$ (GeV$^{-2}$)

$q^2$ (GeV$^2$)

Theory curves scaled to area of the data.

$B \to (\pi/\rho/\omega)l\nu$, W. Wulsin
B→ων selection

untagged

Preselection cuts

<table>
<thead>
<tr>
<th>Candidate [weighted events]</th>
<th>True-ω signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>18438.5</td>
<td></td>
</tr>
<tr>
<td>R2 &lt; 0.5</td>
<td>100.0</td>
</tr>
<tr>
<td>nTrk &gt; 3</td>
<td>99.8</td>
</tr>
<tr>
<td>Q_{tot} &lt;= 1</td>
<td>89.1</td>
</tr>
<tr>
<td>\left</td>
<td>p_z \right</td>
</tr>
<tr>
<td>Lepton fiducial cut: 0.4090 &lt; \theta &lt; 2.3720</td>
<td>98.9</td>
</tr>
<tr>
<td></td>
<td>m_{LX} - m_{FB}</td>
</tr>
<tr>
<td>2.16 &gt; m_{j/0} &amp; m_{j/0} &lt; 0.18%</td>
<td>52.4%</td>
</tr>
<tr>
<td>π^+ signal</td>
<td>52.4%</td>
</tr>
<tr>
<td>20%</td>
<td>9.3%</td>
</tr>
<tr>
<td>1.6%</td>
<td>0.015%</td>
</tr>
<tr>
<td>1.6%</td>
<td>0.012%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>true-ω signal</th>
<th>comb.-ω signal</th>
<th>B→Xcνv</th>
<th>cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>skim</td>
<td>52.4%</td>
<td>52.4%</td>
<td>12.6%</td>
<td>1.6%</td>
</tr>
<tr>
<td>presel.</td>
<td>9.3%</td>
<td>0.18%</td>
<td>0.015%</td>
<td>0.012%</td>
</tr>
<tr>
<td>NN</td>
<td>49%</td>
<td>20%</td>
<td>7.2%</td>
<td>9.3%</td>
</tr>
<tr>
<td>Total (est.)</td>
<td>2.4x10^{-2}</td>
<td>1.9x10^{-4}</td>
<td>1.4x10^{-6}</td>
<td>1.8x10^{-7}</td>
</tr>
</tbody>
</table>
Neural net selection

Input variables

- Event shape
  - L2
  - R2
  - $\cos\theta_{\text{thrust}}$
- Neutrino quality
  - $\theta_{\text{miss}}$
  - $m_{\text{miss}}^2/2E_{\text{miss}}$
  - $\cos\theta_{BY}$
- Other
  - $\cos\theta_{v1}$
  - $\text{Prob}(Y_{vtx})$
  - $\omega$ Dalitz amplitude

good data/MC agreement of NN input variables and output discriminants
To assess the systematic uncertainty of the assumption of MC correctly describing the combinatoric-

![Figure 6: Distributions of...](image)

...and subtract it from the nominal fit classification in Figure 8.

![Figure 53: Distributions before...](image)

...and background: one or more daughter \( \Pi \) does not come from a true \( \omega \).

- >80% of background in \( m_{3\pi} \) peak is combinatoric-\( \omega \)
- model it with data from the sidebands

**Classification**

**Traditional**

- MCAll (50042.9)
- Sig (2057.9)
- BB (38479.8)
- qq (9505.2)

**Sideband**

- MCAll (50042.9)
- Sig (1029.4)
- BB (1230.2)
- qq (823.4)
- MCComb (46959.9)

**true-\( \omega \) background**

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Test extrapolation from $m_{3\pi}$ sidebands to peak

$m_{3\pi}$ distribution of combinatoric-$\omega$ differs for qq, BB, signal

<table>
<thead>
<tr>
<th>source</th>
<th>comb.-$\omega$ in peak</th>
<th>weighted sideband</th>
<th>peak/sdband</th>
</tr>
</thead>
<tbody>
<tr>
<td>qq</td>
<td>2081</td>
<td>1969</td>
<td>1.06</td>
</tr>
<tr>
<td>BB</td>
<td>8256</td>
<td>8277</td>
<td>0.997</td>
</tr>
<tr>
<td>signal</td>
<td>265</td>
<td>238</td>
<td><strong>1.11</strong></td>
</tr>
<tr>
<td>Total</td>
<td><strong>10601</strong></td>
<td><strong>10484</strong></td>
<td>1.01</td>
</tr>
</tbody>
</table>

Sidebands are corrected by subtracting the comb.-$\omega$ signal before the $m_{3\pi}$ fit, then adding it afterward.
To assess the systematic uncertainty of the assumption of MC correctly describing the combinatoric-

Figure 6: Distributions of the nominal fit components are shown in Figure 6, along with the classification

distributions for the classification of the previous untagged analysis are shown in Figure 7 and for the
distribution, in Section 10.8 the fit is performed with all combinatoric-

>80% of background in $m_{3\pi}$ peak is combinatoric-$\omega$
$m_{3\pi}$ fit performed to:

\[
data - (\text{comb.-}\omega \text{ signal})
\]

with \(f = f_{\text{sig}} + f_{\text{bkg}}\)

\(f_{\text{sig}} = \text{relativistic Breit-Wigner, convoluted with Gaussian}\)

\(f_{\text{bkg}} = 2^{\text{nd}}\)-order polynomial

From \(f_{\text{bkg}}\), weights are calculated to scale upper, lower sidebands to area in peak.
ΔE vs. m_{ES} and fit parameters

- MCPeak (13294.3)
- SigTrue (900.2)
- BBTrue (1076.2)
- qqTrue (716.5)
- SigComb (264.9)
- QQBBComb (10336.5)

<table>
<thead>
<tr>
<th>Fit params</th>
<th>sig</th>
<th>BB</th>
<th>qq</th>
<th>sig</th>
<th>fixed</th>
</tr>
</thead>
</table>

(pre-fit yields)
ΔE vs. $m_{ES}$ binning

ΔE-$m_{ES}$ plane divided into 20 bins, with smaller bins where the signal changes more.
signal yield (combinatorial-ω bkgd from m_{3π} peak) : 802 ± 125
signal yield (combinatorial-ω bkgd from m_{3π} sidebands): 795 ± 121

Signal yield changes <1% using MC from m_{3π} sidebands instead of from m_{3π} peak.
Figures 53 and 54: Distributions before (left) and after (right) the fits. The signal yield is 1029.

\[ \text{BF}(B^+ \rightarrow \omega l^+\nu) = (1.25 \pm 0.16 \pm 0.13) \times 10^{-4} \]
Fit results: \( 5 \, q^2 \) bins

- 0\(<q^2<4 \text{ GeV}^2\)
  - signal yield = 263 ± 75

- 4\(<q^2<8 \text{ GeV}^2\)
  - signal yield = 197 ± 55

- 8\(<q^2<10 \text{ GeV}^2\)
  - signal yield = 178 ± 40

- 10\(<q^2<12 \text{ GeV}^2\)
  - signal yield = 219 ± 38

- 12\(<q^2<22 \text{ GeV}^2\)
  - signal yield = 236 ± 61

Sizable signal yield in each \( q^2 \) bin
# Systematics

<table>
<thead>
<tr>
<th>Source</th>
<th>Variation</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>event reconstruction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>track efficiency</td>
<td>kill tracks</td>
<td>4.7</td>
</tr>
<tr>
<td>photon efficiency</td>
<td>kill photons</td>
<td>4.3</td>
</tr>
<tr>
<td>$K_L$ prod./interaction</td>
<td>rate of $K_L$ prod. &amp; reco’d. energy</td>
<td>4.4</td>
</tr>
<tr>
<td>lepton ID</td>
<td>lepton selector efficiency</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>signal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>signal form factors</td>
<td>$A_1(q^2)$, $A_2(q^2)$, $V(q^2)$</td>
<td>4.1</td>
</tr>
<tr>
<td>$BF(\omega \rightarrow \pi\pi\pi)$</td>
<td>error from PDG</td>
<td>0.8</td>
</tr>
<tr>
<td>$qq$ $\Delta E-m_{ES}$ shapes</td>
<td>reweight with data ctrl. sample</td>
<td>0.7</td>
</tr>
<tr>
<td>$BB$ $\Delta E-m_{ES}$ shapes</td>
<td>reweight with data ctrl. sample</td>
<td>1.1</td>
</tr>
<tr>
<td>$m_{3\pi}$ shape of comb. sig.</td>
<td>remove signal sdband subtraction</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>true-\omega bkgd.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{3\pi}$ shape of comb. sig.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>scale ($m_{3\pi}$ statistical)</td>
<td>sideband weights</td>
<td>1.0</td>
</tr>
<tr>
<td>scale ($m_{3\pi}$ ansatz)</td>
<td>linear bkgd. fcn. (not quadratic)</td>
<td>3.2</td>
</tr>
<tr>
<td>$N(B^+B^-)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BB counting</td>
<td>$\pm 1.1%$</td>
<td>1.1</td>
</tr>
<tr>
<td>$f_{\pm}/f_{00}$</td>
<td>$\pm 1.2%$</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Total systematic</strong></td>
<td></td>
<td>10.5</td>
</tr>
<tr>
<td><strong>Total statistical</strong></td>
<td></td>
<td>12.6</td>
</tr>
<tr>
<td><strong>Total error</strong></td>
<td></td>
<td>16.5</td>
</tr>
</tbody>
</table>

- **statistical and systematic uncertainties are comparable**
- **evt reco is largest**
Systematics: true-ω ΔE-mES shapes

Original

Reweight with pω from qq:
Δsig = 0.7%

Reweight with pω from BB:
Δsig = 1.1%
Systematics: $m_{3\pi}$ distribution of comb.-$\omega$ signal

We rely on the MC to predict the $m_{3\pi}$ distribution for the combinatoric-$\omega$ signal. This distribution cannot be directly determined from data. To assess the uncertainty that results from this prediction, we repeat the fit in a way that does not rely on the MC prediction of the combinatoric-$\omega$ signal $m_{3\pi}$ distribution. Instead, it assumes that the combinatoric-$\omega$ signal has the same shape as the combinatoric-$\omega$, $B\bar{B}$, and $q\bar{q}$.

In this fit, the combinatoric-$\omega$ signal is not subtracted from the $m_{3\pi}$ sidebands, and the signal fit parameter only scales the true-$\omega$ signal contribution. This configuration is compared with the nominal fit sources configuration in Figure 58.

![Figure 58: $m_{3\pi}$ distribution for the nominal fit configuration (left) and for the unsubtracted sidebands (right).](image)

The difference from the default fit result is taken as an estimate of the uncertainty from the MC $m_{3\pi}$ shape prediction.

Assuming the combinatoric-$\omega$ signal has the same shape as the combinatoric-$\omega$, $B\bar{B}$, and $q\bar{q}$, the fit results are:

1. $\Delta$Band: 1 +- 0 (0% error)
2. $qq$: 1.38513 +- 0.376169 (27.1577% error)
3. $BB$: 0.624632 +- 0.229931 (36.8107% error)
4. $\omega_{\eta_\nu 1}$: 0.921123 +- 0.132512 (14.3859% error)

The difference from the nominal result (from Section 9.1) is taken as the systematic uncertainty of the corrected sidebands:

nominal fit

no signal correction of sidebands: $\Delta\text{sig} = 2.3\%$
Systematics: scale of non-signal background

nominal fit:
\[ f_{\text{bkg}} = \text{quadratic poly.} \]

\[ f_{\text{bkg}} = \text{linear poly.}: \quad \Delta \text{sig} = 3.2\% \]
Table 20: Branching fractions in bins of $q^2$

<table>
<thead>
<tr>
<th>$q^2$ range (GeV$^2$)</th>
<th>$\Delta B \times 10^{-5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 $&lt; q^2 &lt; 4$</td>
<td>2.6 $\pm$ 0.7 $\pm$ 0.8</td>
</tr>
<tr>
<td>4 $&lt; q^2 &lt; 8$</td>
<td>1.8 $\pm$ 0.5 $\pm$ 0.3</td>
</tr>
<tr>
<td>8 $&lt; q^2 &lt; 10$</td>
<td>1.7 $\pm$ 0.4 $\pm$ 0.2</td>
</tr>
<tr>
<td>10 $&lt; q^2 &lt; 12$</td>
<td>2.2 $\pm$ 0.4 $\pm$ 0.2</td>
</tr>
<tr>
<td>12 $&lt; q^2 &lt; 22$</td>
<td>4.0 $\pm$ 1.0 $\pm$ 1.0</td>
</tr>
<tr>
<td>0 $&lt; q^2 &lt; 22$</td>
<td>12.5 $\pm$ 1.6 $\pm$ 1.3</td>
</tr>
</tbody>
</table>
$|V_{ub}|$ from $B \to (\rho/\omega)lv$ 

$|V_{ub}| = \sqrt{\frac{\Delta B(q_{\min}^2, q_{\max}^2)}{\tau + \Delta \zeta(q_{\min}^2, q_{\max}^2)}}$

$\Gamma = |V_{ub}|^2 \Delta \zeta$

$\Delta \zeta(q_{\min}^2, q_{\max}^2) = \frac{G_F^2 m_B^2}{96 \pi^3} \int_{q_{\min}^2}^{q_{\max}^2} |\vec{p}_\rho| q^2 (|H_0|^2 + |H_+|^2 + |H_-|^2) dq^2$

$B \to \rho lv$

LCSR: $|V_{ub}| = (2.75 \pm 0.24) \times 10^{-3}$
ISGW2: $|V_{ub}| = (2.83 \pm 0.24) \times 10^{-3}$

$B \to \omega lv$

LCSR: $|V_{ub}| = (2.32 \pm 0.21) \times 10^{-3}$
ISGW2: $|V_{ub}| = (2.33 \pm 0.20) \times 10^{-3}$

theory errors not available
$|V_{ub}|$ from $B \rightarrow \pi l \nu$

**Solve rate equation for $|V_{ub}|$**

$$|V_{ub}| = \sqrt{\frac{\Delta B(q^2_{min}, q^2_{max})}{\tau_0 \Delta\zeta(q^2_{min}, q^2_{max})}}$$

$$\Delta\zeta(q^2_{min}, q^2_{max}) = \frac{G_F^2}{24\pi^3} \int_{q^2_{min}}^{q^2_{max}} \rho(q^2)|f_+(q^2)|^2 dq^2$$

**Theory needed to calculate**

---

**Simultaneous fit to data and theory**

- 3 parameters: BGL quadratic polynomial
- 4th parameter: relative normalization between theory and data, $\alpha |V_{ub}|^2$
- Theory points are correlated, so not all are used in fit.

- $|V_{ub}|$ (data BF) = 3%
- $|V_{ub}|$ (data $q^2$ shape) = 5%
- $|V_{ub}|$ (theory FF norm.) = 8.5%
- $\sigma_{total} = 10.5\%$

- $LCSR \quad (q^2 < 16 \text{ GeV}^2) \quad 3.63 \pm 0.12^{+0.59}_{-0.40}$
- $HPQCD \quad (q^2 > 16 \text{ GeV}^2) \quad 3.21 \pm 0.17^{+0.55}_{-0.36}$

$\sigma_{exp} = 3-5\%; \sigma_{thy} = \sim 15\%$

Theory error dominates

---

26 Apr 2011

B→($\pi/\rho/\omega$)lν, W. Wulsin
|V_{ub}| summary

 significance bands drawn relative to global fit of all other unitarity triangle constraints:
|V_{ub}| = (3.48 ± 0.16) \times 10^{-3}

|V_{ub}| from this B\rightarrow\pi l\nu analysis
- LCSR, low q^2 = (3.63 ± 0.51) \times 10^{-3}
- HPQCD, high q^2 = (3.21 ± 0.49) \times 10^{-3}
- FNAL/MILC, full q^2 = (2.95 ± 0.31) \times 10^{-3}

UT Fit values
+ exclusive average
\* inclusive average
Δ between inclusive and exclusive is <2σ
**Conclusions**

**improved BF’s**

\[
\begin{align*}
\text{BF}(B^0 \rightarrow \pi^+ l^- \nu) &= 1.41 \pm 0.05 \pm 0.07) \times 10^{-4} \\
\text{BF}(B^0 \rightarrow \rho^+ l^- \nu) &= 1.75 \pm 0.15 \pm 0.27 \times 10^{-4} \\
\text{BF}(B^+ \rightarrow \omega l^+ \nu) &= 1.25 \pm 0.16 \pm 0.13 \times 10^{-4}
\end{align*}
\]

**taking comb.-\(\omega\) bkgd from data reduces MC dependence and allows \(q^2\) spectrum measurement**

**combined fit to theory & data reduces exclusive \(|V_{ub}|\)**

error (but theory errors still dominate)

**Table 20: Branching fractions in bins of:**

- Ball-Zwicky \(q^2 < 16\)
  
  \[3.34 \pm 0.12 \pm 0.55 - 0.37\]

- HPQCD \(q^2 > 16\)
  
  \[3.40 \pm 0.20 \pm 0.59 - 0.39\]

- FNAL \(q^2 > 16\)
  
  \[3.62 \pm 0.22 \pm 0.63 - 0.41\]

- This analysis
  
  \[\text{HFAG} \text{ ICHEP08}\]