CKM elements from leptonic and semileptonic B, D and K decays

E. Barberio, University of Melbourne
LP07, Daegu, August 2007
They are fundamental parameters of the Standard Model and cannot be predicted.
They are fundamental parameters of the Standard Model and cannot be predicted.

\[ V = |V| \exp(i\varphi) \]

- $|V|$ from semi-leptonic decay rates
- $\varphi$ from CP asymmetries
- No new physics in $V$ but can show up in $\varphi$
New Physics?

- exploit the unitarity constraint to look for new physics → geometrical relation between CKM elements:
  - angle from CP asymmetries
  - size from $V$

- New precision era where new physics may appear as a few percent disagreement:
- Large new physics contributions to penguins would have already been seen.
- New physics contributions to decays such as $B \rightarrow \tau \nu$ is still open (e.g. minimum flavour violation)
Semileptonic decays

tree level, short distance:

\[ q_j \rightarrow q_i e \nu \]

decay properties depend directly on \(|V_{ij}|\) and \(m_i\) in perturbative regime \((\alpha_s^n)\)
Semileptonic decays

tree level, short distance:

\[ X_j \rightarrow X_i \, e \, \nu \]

decay properties depend directly on \(|V_{ij}|\) and \(m_i\) in
perturbative regime \((\alpha_s^n)\)

But quarks are bound by soft gluons: non-perturbative
long distance interactions of b quark with light quark
degrees of difficulty

\[ B \to D \pi \]

Very difficult

\[ B \to D e \nu \]

Still hadronic

\[ B \to \tau \bar{\nu} \]

helicity suppressed

\[ B \to \tau \bar{\nu} \]

simple!
Theoretical tools

The treatment of long distance interactions cannot be done with perturbative QCD - the choice of tools depends on the size of the quark masses, $m_j$ and $m_i$.

**Heavy Quark Effective Theory:** Beauty and Charm
Precise tools to describe the dynamics of the $b$ quark

**Lattice QCD:** for all
Lattice QCD now has precise results for kaons

**Chiral perturbation theory:** to extrapolate from strange to $u$ and $d$ quarks

The main error in the extraction of the CKM elements derives from the understanding of the long distance contribution.
Experiments related to CKM parameters: \(~ 2007\)

- $e^+e^- \text{ B factories}$
  - $(b, c, \tau)$

- Charm experiments

- Kaon experiments

- Tevatron $(t, b)$

- Major experiments ongoing or recently ended

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\[ \begin{align*} 
V_{ud} & \quad V_{us} \\
V_{cd} & \quad V_{cs} \\
V_{td} & \quad V_{ts} \\
V_{ub} & \\
V_{cb} & \\
V_{tb} & 
\end{align*} \]
Extraction of $|V_{us}|$ from $K \rightarrow \pi \ell \nu$ ($K_{l3}$)

$$\Gamma(K_{l3}) = \frac{BR(K_{l3})}{\tau_K} = \frac{G_F^2}{384\pi^3} m_K^5 S_{EW} |V_{us}|^2 |f_+(0)|^2 I_K (1+\delta_K)$$

Short-distance radiative correction

The measured quantity

Phase space integral containing
form-factor parameterization

Long-distance correction
(isospin symmetry breaking)

Experiments give:
$\Gamma(K_{3l})$: branching fraction and lifetime
Form factors

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## Summary of $|V_{us}|f_+(0)$ Results

| $|V_{us}|f_+(0)$ | Approx. contrib. to % err from: |
|-----------------|-----------------------------|
| 0.214 to 0.218  | % err | BR | $\tau$ | $\Delta$ |
| $K_L e3$        | 0.21614(59) | 0.27 | 0.09 | 0.19 | 0.15 |
| $K_L \mu 3$     | 0.21612(55) | 0.25 | 0.10 | 0.18 | 0.15 |
| $K_S e3$        | 0.21531(143) | 0.67 | 0.65 | 0.03 | 0.15 |
| $K^\pm e3$      | 0.21717(84) | 0.39 | 0.26 | 0.09 | 0.26 |
| $K^\pm \mu 3$   | 0.21731(104) | 0.48 | 0.40 | 0.09 | 0.26 |

### Average:

$|V_{ub}| = 0.22535 \pm 0.00116 \quad \chi^2/\text{ndf}=1.78/4 (78\%)$

$f_+(0) = 0.961\pm0.008 \quad (\text{Leutwyler & Roos 84})$

---

More in M. Antonelli talk

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Consistency of the first row

**Fit results, no constraint:**

\[ V_{ud} = 0.97372(26) \]
\[ V_{us} = 0.2256(10) \]
\[ \chi^2/\text{ndf} = 0.17/1 \text{ (68\%)} \]

**Fit results, unitarity constraint:**

\[ V_{us} = \sin\theta_c = \lambda = 0.2265(7) \]
\[ \chi^2/\text{ndf} = 2.24/2 \text{ (33\%)} \]

0.3\% accuracy
\[ \frac{d\Gamma(D^+ \rightarrow X\nu)}{dq^2} = \frac{G_F^2}{24\pi} p_X^3 \left| f_+(q^2) \right|^2 \]

Pseudoscalar hadronic final states preferred

- Charm decays are a good place to test lattice QCD: determination of form factor shapes
- Measurements of \( V_{cd} \) & \( V_{cs} \)
Experimental methods

- DD production at threshold: CLEO-c and BES-II.
  - Only DD produced
  - Large cross sections:
    - $\sigma(D^0D^0) = 3.72\pm0.09$ nb
    - $\sigma(D^+D^-) = 2.82\pm0.09$ nb

- B-factories ($e^+e^-$) + fixed target & collider experiments at hadron machines
  - D displaced vertex
  - $D^{**} \rightarrow \pi^+D^0$ tag
$D \rightarrow K, \pi e\nu$ Branching Fractions

**$D \rightarrow K e^+\nu$**

- PDG (2004)
- BES II
- LQCD
- CLEO-c (tag, 56 pb$^{-1}$) -- preliminary
- Belle (tag, 282 fb$^{-1}$)
- CLEO-c (tag, 281 pb$^{-1}$) -- preliminary
- CLEO-c (no tag, 281 pb$^{-1}$) -- preliminary

**$D \rightarrow \pi e^+\nu$**

- PDG (2004)
- BES II
- LQCD
- CLEO-c (tag, 56 pb$^{-1}$) -- preliminary
- Belle (tag, 282 fb$^{-1}$)
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- CLEO-c (no tag, 281 pb$^{-1}$) -- preliminary

FNAL-MILC-HPQCD precision lags experiment.

Belle uses also $m$, with similar precision

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Form-Factor Parameterizations

- In general

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{\text{pole}}^2}\right)}$$

- Modified Pole

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{\text{pole}}^2}\right) \left(1 - \frac{\alpha q^2}{m_{\text{pole}}^2}\right)}$$

- Series Expansion

$$f_+(q^2) = \frac{1}{P(q^2) \phi(q^2, t_0)} \sum_{k=0}^{\infty} a_k(t_0) [z(q^2, t_0)]^k$$

$$t_{\pm} = \left(M_D \pm m_{\pi(K)}\right)^2, \quad z(q^2, t_0) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

Normalization: experiments (2%) consistent with LQCD (10%)

Theoretical precision lags

Assuming $V_{cs} = 0.9745$

Curve courtesy Andreas Kronfeld

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shape and absolute normalization $f_+(q^2)$

Assuming $V_{cd} = 0.2238 \pm 0.0029$

**Shape:** Experiments compatible with LQCD
**Normalization:** experiments (4%) consistent with LQCD (10%)

Theoretical precision lags

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Leptonic decays: $D_s$

Belle only:

$$f_{D_s} = 275\pm16_{\text{stat}}\pm12_{\text{sys}} \text{ MeV}$$

using $V_{cs}$ from the PDG

$D_s \left\{ \begin{array}{c}
C \\
\text{gluons} \\
S
\end{array} \right\} V_{cs} \rightarrow W^+ \ell^+ \nu$

$BR = (6.44\pm0.76_{\text{stat}}\pm52_{\text{sys}}) \times 10^{-3}$

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Leptonic decays: $D^+$

$D^+ \rightarrow W^+ + \ell^+ + \nu$

CLEO-c results based on 281 pb$^{-1}$ (tagged)

$\text{BR}(D \rightarrow \mu \nu) = (4.4 \pm 0.7 \pm 0.1) \times 10^{-4}$

$\text{BR}(D \rightarrow e \nu) < 2.4 \times 10^{-5}$

$\text{BR}(D \rightarrow t \nu) < 3.1 \times 10^{-3}$

$R^{th}_{\ell s l} = 0.212 \pm 0.028$

$R^{exp}_{\ell s l} = 0.236 \pm 0.019$

Data and theory are consistent

Cleo-c:

$f_{D_s}/f_D = 1.23 \pm 0.11_{\text{stat}} \pm 0.04_{\text{sys}}$
$V_{cs}$ and $V_{cd}$ Result

Becher-Hill parameterization with (FNAL_MILC-HPQCD) for $f_+(0)$

From LEP2 on-shell $W^\pm$: $|V_{cs}| = 0.976 \pm 0.014$

CLEO-c: dominant uncertainty LQCD $\nu N$ remains most precise determination (for now)
Charm summary

- Best $|V_{cs}|$ direct determination, from D-$\rightarrow$Kε and lattice form factors:
  \[ |V_{cs}| = 0.996 \pm 0.008 \pm 0.015 \pm 0.104 \]

- Best $|V_{cd}|$ direct determination still from $\nu-\nu$ interactions
  \[ |V_{cd}| = 0.230 \pm 0.011 \]

- A lot of progress with the Form Factor measurements and the comparison with Lattice QCD

- Lattice QCD does not work as well as in the Kaon sector
**Consistency Test**

- Overlap still large enough for New Physics to hide
- Precision of $\sin2\beta$ outstripped the other measurements
  - we must make the yellow ring smaller
- Left side of the Triangle is $|V_{ub}/V_{cb}|$
  - Uncertainty dominated by $|V_{ub}|$

**Goal: Accurate determination of both $|V_{ub}|$ and $\sin2\beta$**

*Two methods to extract $V_{xb}$*

*Inclusive and Exclusive*
$V_{cb}$ exclusive $B^- \rightarrow D^{*0}e^-\nu$

$$B^- \rightarrow D^{*0}e^-\nu; \ D^* \rightarrow \pi^0D^0$$

$$\frac{d\Gamma(B \rightarrow D \ i/\nu)}{dw} = K(w)F^2(w)|V_{cb}|^2$$

$$W = \frac{m_B^2 + m_{b^*}^2 - q^2}{2m_Bm_{b^*}}$$

$$F(1) \cdot |V_{cb}| = (36.3 \pm 0.6 \pm 1.4) \cdot 10^{-3} \ ,$$

$$\rho_{A_1}^2 = 1.15 \pm 0.06 \pm 0.08 \ ,$$

$$\mathcal{B}(B^- \rightarrow D^{*0}e^-\nu_e) = (5.71 \pm 0.08 \pm 0.41)\% \ .$$

**Main physics background** $B \rightarrow D^{**}\nu$

- **Signal**
- $D^{**}$ ($\Delta m$-peaking)
- $D^0\nu$
- $D^{**}$ ($\Delta m$-flat)
- Combinatorial $D^{*0}$
- Correlated
- Uncorrelated
- $c\bar{c}$ events

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HFAG average uses $R_1$, $R_2$ from BaBar
this decrease $F(1)|V_{cb}|$

$F(1)|V_{cb}|=(35.9 \pm 0.6) \times 10^{-3}$ 

$\rho_A^2 = 1.23 \pm 0.05$

From $F(1)=0.919 \pm 0.033$:

$|V_{cb}|=(39.1 \pm 0.65 \pm 1.4) \times 10^{-3}$

error is dominated by the lattice calculation, no improvement in the near future

$B \to D^0 \nu$ has a small theoretical error but it’s more difficult experimentally and very few measurement
$\mathcal{B}(B^- \to D^+ \pi^- \ell^- \bar{\nu}_\ell) = (0.42 \pm 0.06_{stat.} \pm 0.03_{syst.})\%$

$\mathcal{B}(B^- \to D^{*+} \pi^- \ell^- \bar{\nu}_\ell) = (0.59 \pm 0.05_{stat.} \pm 0.04_{syst.})\%$

$\mathcal{B}(B^0 \to D^0 \pi^+ \ell^- \bar{\nu}_\ell) = (0.43 \pm 0.08_{stat.} \pm 0.03_{syst.})\%$

$\mathcal{B}(B^0 \to D^{*0} \pi^+ \ell^- \bar{\nu}_\ell) = (0.48 \pm 0.08_{stat.} \pm 0.04_{syst.})\%$
**$V_{cb}$ from inclusive semileptonic decays**

$$\Gamma_{sl}(b \rightarrow c \ell^{-}\nu) = \gamma_{th}|V_{cb}|^2 = \frac{\text{BR}(b \rightarrow c \ell^{-}\nu)}{\tau_b}$$

exp. $\Delta |V_{cb}| < 1\%$

$\Gamma_{sl}$ described by Heavy Quark Expansion in $(1/m_b)^n$ and $\alpha_s^k$

$$\Gamma(B \rightarrow X_c l \nu) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 \left[ 1 + A_{ew} \right] A_{\text{nonpert}} A_{\text{pert}}$$

Non-perturbative parameters need to be measured and arise at each order

$$< X^n > (E_{cut}) = \frac{\int (X - X^0)^n \frac{d\Gamma}{dX} \, dX}{\int \frac{d\Gamma}{dX} \, dX} \equiv f'_{\text{OPE}}(m_b, m_c, a_i)$$

$X^n$: sensitivity to non-perturbative parameters evaluated on part of the spectrum ($p_l > p_{\text{min}}$) in the $B$ rest frame

Expansions depend on $m_b$ definition
Heavy quark parameter determination - Big Picture

Semileptonic B decay

Inclusive $E_L$ spectrum

Inclusive $M_x$ spectrum

Experimental Challenge: go from the measured shape to the true shape

Rate

Shape

$|V_{cb}|$

$|V_{ub}|$

$m_b, m_c$

$\mu^2_G, \mu^2_\pi$

Shape($B \rightarrow X_s \gamma$)

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moments in semileptonic decays

fully-reconstructed B meson B flavor and momentum known.
rest of the event contains one “recoil” lepton in the recoil-B

Fit moments of these distribution to get $V_{cb}$ and HQ parameters
Heavy quark parameters

$E_l$: lepton energy spectrum in $B \rightarrow X_c l \nu$ (BaBar Belle CLEO DELPHI)

$M_X^2$: hadronic mass spectrum in $B \rightarrow X_c l \nu$ (BaBar CDF CLEO DELPHI)

$E_Y$: photon energy spectrum in $B \rightarrow X_s Y$ (Babar Belle CLEO)

Decay rate in terms of Operator Product Expansion up to $1/m_b^3$

<table>
<thead>
<tr>
<th>Expansions in terms of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{b, c}^{\text{kin}}, (m_{1S}^{1S})$ - mass of $b$ and $c$ quarks</td>
</tr>
<tr>
<td>$\Lambda_{QCD}^2/m_b^2$</td>
</tr>
<tr>
<td>$\mu_{\pi}^2(\lambda_1)$ - kinetic energy of $b$ quark,</td>
</tr>
<tr>
<td>$\mu_g^2(\lambda_2)$ - chromomagnetic coupling</td>
</tr>
<tr>
<td>$\Lambda_{QCD}^3/m_b^3$</td>
</tr>
<tr>
<td>$\rho_D, \rho_{LS} (\rho_1, T_{1-3})$</td>
</tr>
</tbody>
</table>

Two approaches:

Kinetic running mass

1S mass

... and $|V_{cb}|^2$ dependence on partial branching fractions

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Global fit with all available results (except the latest BaBar moments)

<table>
<thead>
<tr>
<th>1S</th>
<th>$V_{cb} \times 10^{-3}$</th>
<th>$m_b$ (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no $b \rightarrow s \gamma$</td>
<td>41.78 ± 0.30 ± 0.08</td>
<td>4.70 ± 0.03</td>
</tr>
<tr>
<td>Kinetic</td>
<td>$V_{cb} \times 10^{-3}$</td>
<td>$m_b$ (GeV)</td>
</tr>
<tr>
<td></td>
<td>41.91 ± 0.19 ± 0.28 ± 0.59</td>
<td>4.613 ± 0.022 ± 0.027</td>
</tr>
<tr>
<td>no $b \rightarrow s \gamma$</td>
<td>41.68 ± 0.39 ± 0.58</td>
<td>4.677 ± 0.053</td>
</tr>
</tbody>
</table>
Uncertainty dominated by theory errors, measurements with different methods

- Inclusive $B \rightarrow X_u \ell \nu$
  - Use difference in kinematics to separate $u \ell \nu$ from $c \ell \nu$
  - Theory must predict signal spectrum

- Exclusive $B \rightarrow \pi \ell \nu, \rho \ell \nu, \omega \ell \nu, ...$
  - Better S/B, esp.
  - Theory must predict form factor
$V_{ub}$ inclusive determination

$B \rightarrow X_u \ell \nu$ tree level rate same as $B \rightarrow X_c \ell \nu$

$$\frac{d\Gamma(B \rightarrow X_u \ell \nu)}{d(p.s.)} \sim \frac{m_b^5 G_F^2}{192 \pi^3} \left[ \text{parton model} + \sum_n C_n \left( \frac{\Lambda_{QCD}}{m_b} \right) \right]$$

but $\text{Br}(B \rightarrow X \ell \nu)/\text{Br}(B \rightarrow X_c \ell \nu) = 1/50$

selection to remove background removes a sizeble part of the phase space. Need theoretical extrapolation for the full phase space (Shape Function).
Inclusive $b \to u \ell \nu$

$m_u \ll m_c \to$ difference in kinematics

$E_\ell = \text{lepton energy}$
$q^2 = \text{lepton-neutrino mass squared}$
$m_X = \text{hadron system mass}$
$P^+ = E_X - |P_X|$}

Signal events have smaller $M_X$ and $P^+ \to$ Larger $E_\ell$ and $q^2$
### Inclusive $V_{ub}$

| Kinematic Region | $B(B \rightarrow X_{ul}ν)$ | $|V_{ub}| \times 10^{-3}$ | Theory |
|------------------|---------------------------|---------------------------|--------|
| $M_x < 1.55 \text{ GeV}/c^2$ | $1.18 \pm 0.09 \pm 0.07 \pm 0.01$ | $4.27 \pm 0.16 \pm 0.13 \pm 0.30$ | BLNP |
| $P_x < 0.66 \text{ GeV}/c^2$ | $0.95 \pm 0.10 \pm 0.08 \pm 0.01$ | $3.88 \pm 0.19 \pm 0.16 \pm 0.28$ | BLNP |
| $M_x < 1.7 \text{ GeV}/c^2 \& q^2 > 8.0 \text{ GeV}^2/c^2$ | $0.76 \pm 0.08 \pm 0.07 \pm 0.02$ | $4.48 \pm 0.22 \pm 0.19 \pm 0.30$ | BLNP |

![Graphs](image-url)
## Weak anihilation

### Different BR between $B^+$ and $B^0$

![Diagram showing $B$, $b$, $u$, $\bar{\nu}_i$, and $\ell$ with soft gluons]

<table>
<thead>
<tr>
<th>$\Delta p$ (GeV)</th>
<th>$\Delta B(B)$ $10^4$</th>
<th>$\Delta B(B^0)$ $10^4$</th>
<th>$A^{+/0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3-2.6</td>
<td>2.31±0.10±0.18</td>
<td>1.30±0.21±0.07</td>
<td>0.08±0.15±0.08</td>
</tr>
<tr>
<td>2.4-2.6</td>
<td>0.75±0.04±0.06</td>
<td>0.76±0.15±0.05</td>
<td>-0.05±0.20±0.10</td>
</tr>
</tbody>
</table>

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Inclusive $|V_{ub}|$: BLNP framework

$|V_{ub}|$ world average

- CLEO ($E_{x}$): $3.91 \pm 0.46 \pm 0.44$
- BELLE simu. ann. ($m_{X}$, $q^{2}$): $4.23 \pm 0.45 \pm 0.36$
- BELLE ($E_{x}$): $4.67 \pm 0.43 \pm 0.38$
- BABAR ($E_{x}$): $4.23 \pm 0.24 \pm 0.39$
- BABAR ($E_{x}$, $s_{\text{mix}}$): $4.37 \pm 0.29 \pm 0.49$
- BELLE $m_{X}$: $3.92 \pm 0.26 \pm 0.32$
- BABAR $m_{X}$: $4.09 \pm 0.20 \pm 0.39$

**Average +/- exp +/- (mb, theory)**

$4.31 \pm 0.17 \pm 0.35$

$Z/\text{data} = 8.17 \pm 0.16 \pm 0.41 \pm 0.04 \pm 0.11$

HFAG

**Statistical**

$\pm 2.0\%$

**Expt. syst.**

$\pm 2.6\%$

**$b \rightarrow c l v$ model**

$\pm 1.8\%$

**$b \rightarrow u l v$ model**

$\pm 1.1\%$

**SF params.**

$\pm 3.8\%$

**HQE param.**

$\pm 6.9\%$

**WA**

$\pm 1.7\%$

$|V_{ub}|$ determined to $\pm 8.9\%$

HQ parameters from $b \rightarrow c l v$ and $b \rightarrow s g$

- $m_{b}(\text{SF}) = 4.63 \pm 0.06$ GeV
- $\mu_{\pi}^{2}(\text{SF}) = 0.18 \pm 0.06$ GeV$^{2}$

$|V_{ub}| = (4.31 \pm 0.17 \pm 0.35) \times 10^{-3}$
b-mass form PDG
• $m_b(\text{MSbar}) = 4.20 \pm 0.07 \text{ GeV}$

$|V_{ub}| = (4.34 \pm 0.16 \pm 0.25) \times 10^{-3}$

| $|V_{ub}|$ world average |
|---------------------------|
| **CLEO (E2)** |
| $3.84 \pm 0.45 \pm 0.30$ |
| **BELLE sim. ann. ($m_x$, $\xi^2$)** |
| $4.42 \pm 0.47 \pm 0.26$ |
| **BELLE (E4)** |
| $4.79 \pm 0.45 \pm 0.26$ |
| **BABAR (E4)** |
| $4.29 \pm 0.29 \pm 0.28$ |
| **BABAR (E4, $g_1^{bs}$)** |
| $4.42 \pm 0.30 \pm 0.38$ |
| **BELLE $m_X$** |
| $4.29 \pm 0.28 \pm 0.28$ |
| **BABAR $m_X$** |
| $4.56 \pm 0.22 \pm 0.32$ |

Average +/- exp +/- (mb, theory)
$4.34 \pm 0.16 \pm 0.25$

χ^2/ndf = 2.3/6 (CL = 89 %)
Dressed Glashow Exponentiation (DGE)
HEP 0901097, 2006

$m_X$ input from $b \rightarrow c l v$ and $b \rightarrow s y$ moments

<table>
<thead>
<tr>
<th>Source</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical</td>
<td>±2.0%</td>
</tr>
<tr>
<td>Expt. syst.</td>
<td>±2.4%</td>
</tr>
<tr>
<td>b → clv model</td>
<td>±1.9%</td>
</tr>
<tr>
<td>b → ulv model</td>
<td>±1.0%</td>
</tr>
<tr>
<td>DGE theory</td>
<td>±3.1%</td>
</tr>
<tr>
<td>Rcut+total width</td>
<td>±4.2%</td>
</tr>
<tr>
<td>WA</td>
<td>±1.9%</td>
</tr>
</tbody>
</table>

$|V_{ub}|$ determined to ± 6.8%
Currently only $B \to \pi \ell \nu$ for $|V_{ub}|$ - one dominant form factor ($q^2$ shape and normalization needed)

- Form factor calculations from various methods:
  - “unquenched” lattice QCD (HPQCD, Fermilab, …)
  - Light-Cone Sum Rules (Ball & Zwicky, …)
  - quark models (ISGW2, …)

$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = \frac{G_F^2}{24\pi^2} |V_{ub}|^2 \frac{P_\pi^3}{f^+} |f(q^2)|^2$

LQCD and LCSR compatible with data

ISGW2 quark-model incompatible (Prob<0.06%).


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Approaches to Measuring $B(B \rightarrow X_u | \nu)$ Exclusive

**Untagged**
- Initial 4-momentum known.
- Missing 4-momentum = $\nu$.
- Reconstruct $B \rightarrow X_u | \nu$ using $m_B$ (beam-constrained) and $\Delta E = E_B - E_{\text{beam}}$.

**Semileptonic Tag**
- One $B$ reconstructed in a selection of $D(\ast) | \nu$ modes.
- Two missing $\nu$s in event.
- Use kinematic constraints.

**Full Reconstruction Tag**
- One $B$ reconstructed completely in known $b \rightarrow c$ mode.
- Many modes used.

**Efficiency Purity Luminosity**
- Effi.: High Low
- Purity: Low High
- Lumi.: $< 0.5 \text{ab}^{-1}$
- $< 1 \text{ab}^{-1}$
- $> 1 \text{ab}^{-1}$
D(*)ℓν tag Method

Tag side reconstruction

\[ B^0_{tag} \rightarrow D^{*-}l^-\nu/D^+l^-\nu \]
\[ B^-_{tag} \rightarrow D^{*-0}l^-\nu/D^0l^-\nu \]

Signal

\[ B^0_{\text{sig}} \rightarrow \pi^-l^+\nu/\pi^-\pi^0l^+\nu \]
\[ B^+_{\text{sig}} \rightarrow \pi^0l^+\nu/\pi^+\pi^-l^+\nu \]

\[ \rho^- \rightarrow \rho^0 \]

253 fb\(^{-1}\)
(275M BB pairs)

Full \( q^2 \) region

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Current status of $\text{Br}(B^0 \rightarrow \pi^0 l^+ \nu)$

- BABAR SL tag: $B^+ \rightarrow \pi^0 l^+ \nu \times 2 \tau_0/\tau_+ \quad L.36 \pm 0.33 \pm 0.15$
- BABAR $B_{(\text{tau})}$ tag: $B^+ \rightarrow \pi^0 l^+ \nu \times 2 \tau_0/\tau_+ \quad L.52 \pm 0.41 \pm 0.20$
- BELLE SL tag: $B^+ \rightarrow \pi^0 l^+ \nu \times 2 \tau_0/\tau_+ \quad L.43 \pm 0.26 \pm 0.15$
- BELLE $B_{(\text{tau})}$ tag: $B^+ \rightarrow \pi^0 l^+ \nu \times 2 \tau_0/\tau_+ \quad L.60 \pm 0.32 \pm 0.11$

- BABAR SL tag: $B^0 \rightarrow \pi^0 l^+ \nu \quad L.12 \pm 0.25 \pm 0.10$
- BELLE SL tag: $B^0 \rightarrow \pi^0 l^+ \nu \quad L.38 \pm 0.19 \pm 0.14$

$\chi^2$ dof = 3/2 (CL = 95 %)

- Ball-Zwicky $q^2 < 16 \quad 3.41 \pm 0.13 + 0.56 - 0.38$
- HPQCD $q^2 > 16 \quad 3.33 \pm 0.21 + 0.58 - 0.38$
- FNAL $q^2 > 16 \quad 3.55 \pm 0.22 + 0.51 - 0.40$
- APE $q^2 > 16 \quad 3.58 \pm 0.22 + 1.37 - 0.63$

$|V_{ub}| \times 10^{-3}$

E. Barberio
$|V_{ub}|$: inclusive vs exclusive

Most probable value of $V_{ub}$ from measurements of other CKM parameters

The inclusive value went down, mainly due to the new Babar result
Conclusion on B decays

\[ b \to c \ell \nu \]

\( V_{cb} \) 1% error with the inclusive determination dominated by theory and inclusive versus exclusive compatible within less than 2 sigma.

\[ b \to u \ell \nu \]

\( V_{ub} \) ~8% error shared between theoretical and experimental inclusive vs exclusive about 1.0 \( \sigma \) difference

Inclusive and exclusive determinations for \( V_{xb} \) are not in perfect agreement:

- \( V_{cb} \) is increasing the gap
- \( V_{ub} \) is decreasing the gap
CONCLUSION AND OUTLOOK

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Inclusive and exclusive determinations for \( V_{xb} \) are not in perfect agreement:

- \( V_{cb} \) is increasing the gap
- \( V_{ub} \) is decreasing the gap
Conclusion and outlook

- A lot of progress have been made in both theory and experiment
- The kaon sector has reached a high precision and provide good test of $G_F$ universality but for $V_{us}$ there is a tension between the kaon and tau decays
- Many new charm results are improving the knowledge of the second row
- The inclusive $V_{cb}$ has 1% error. The difference between inclusive and exclusive is less than 2 sigma.
- The error on $V_{ub}$ is about 8%, went up since last year. A lot of experimental and theoretical effort is going into improving this error. I still hope we will get to 5-6%.