Recent CKM and CP violation results from BABAR

On Behalf of the BaBar Collaboration
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CKM Matrix and CP violation

- Leading source of CP violation established: CKM mechanism (BaBar & Belle)

- New Physics search in the flavor sector require precise & redundant measurements of sides and angles of the Unitarity Triangle

**Charmless SL Decays:**
- Access to $|V_{ub}|$, side opposite to angle $\beta$

**Charmless Hadronic Decays**
- Trees and Penguin contribute and lead to CP violation
- Access the CKM angle $\alpha$ (golden mode $\rho\rho$ and $\pi\pi$) and angle $\gamma$
- Open puzzles that need to be solved:
  - Direct CP violation in $K\pi$, polarization in $B \to VV$ (not covered here)

*Search for NP in Cabibbo Favored SL decays $B \to D(\ast)\tau\nu$
\[ |V_{ub}| \text{ from SL decays } B \to \pi / X_u \ell \nu \]

\[ B \to K\pi\pi^0 \]

\[ B \to \phi\phi K \]

\[ B \to D(\ast) \tau\nu \]
Semileptonic B decays: $|V_{ub}|$

- Large BF, only one hadronic current:

$$\Gamma(B \rightarrow \pi/X_u \ell \nu) = |V_{ub}|^2 F^2(q^2, M_X, p_\ell)$$

Complementary Measurements

- **Exclusive decays** $B \rightarrow \pi \ell \nu$:
  - QCD predictions of Form Factor required to parameterize hadronic effects
  - Lattice QCD, LCSR...

- **Inclusive decays** $B \rightarrow X_u \ell \nu$:
  - QCD corrections to parton level decay rate
  - Need perturbative and non-perturbative corrections
  - 4 approaches **BLNP, DGE, GGOU, ADFR**
  - Non-pert. parameters ($m_b, \mu, \pi$) from $B \rightarrow X_c \ell \nu$
  - and $B \rightarrow X_s \gamma$

Complementary Measurements

- Neubert et al PRD72, 073006 (2005)
- Gardi et al JHEP0601, 097 (2006)
- Gambino et al JHEP 0710, 058 (2007)
- Aglietti et al EPJC 59, 831 (2009)
**Exclusive $|V_{ub}|$ with $B \to \pi \ell \nu$**

- Two analysis recently published by BaBar:
  - Untagged analysis: reconstruct $\pi^+e/\mu$
  - Neutrino from the rest of the event

### 6-bin analysis

- Background reduced with a NN
- $S/B = 0.20$
- combined $m_{ES}$-$\Delta E$ fit to $\pi^+/\pi^0/\rho^+/\rho^0$ $\ell \nu$
- 6 bins of $q^2$

**Fitted signal events:**
- $\pi^+$: $6660 \pm 278$
- $\pi^0$: $606 \pm 43$

### 12-bin analysis

- Background reduced with $q^2$-dependet cuts
- $S/B = 0.09$
- $m_{ES}$-$\Delta E$ fit to $\pi^+\ell \nu$
- 12 bins of $q^2$

**Fitted signal events:**
- $\pi^+$: $11778 \pm 435$

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Untagged $B \rightarrow \pi^+ \ell \nu$

Small event overlap!
BaBar results compatible

- $q^2 > 16$ GeV$^2$
- $q^2 < 12$ GeV$^2$

<table>
<thead>
<tr>
<th>$V_{ub}$</th>
<th>HPQCD</th>
<th>12 bins</th>
<th>6 bins</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{ub}$</td>
<td>$3.28 \pm 0.20$</td>
<td>$3.21 \pm 0.18$</td>
<td>$3.23 \pm 0.16^{+0.57}_{-0.37}$</td>
<td></td>
</tr>
<tr>
<td>$V_{ub}$</td>
<td>$3.14 \pm 0.18$</td>
<td>$3.07 \pm 0.16$</td>
<td>$3.09 \pm 0.14_{-0.29}^{+0.35}$</td>
<td></td>
</tr>
<tr>
<td>$V_{ub}$</td>
<td>$3.70 \pm 0.11$</td>
<td>$3.78 \pm 0.13$</td>
<td>$3.72 \pm 0.10_{-0.39}^{+0.54}$</td>
<td></td>
</tr>
</tbody>
</table>

Result compatible with Belle and WA

Fits Provided by Jochen Dingfelder

Theory error reduced: FF shape from data
\[ |V_{ub}| \text{ From Inclusive } B \rightarrow X_u \ell \nu \]

- **Large background from** \( B \rightarrow X_c \ell \nu \)
  - Kinematics to extract the signal (lepton endpoint, \( M_X < M_D, \ldots \))
  
- **Use hadronic tag** \( B_{\text{tag}} \rightarrow D(*) Y \) \((Y=n\pi, m\pi^0, pK_s, qK)\), to reduce combinatorial and reconstruct \( M_X, q^2 \) and \( P_+ = E_X - p_X \) with good resolution

- **Veto** \( B \rightarrow D(*) \ell \nu \) with Kaons, soft pions, and missing mass

- Most precise \((\sigma_{\text{exp}} \oplus \sigma_{\text{theory}})\) result from a 2-D fit in \( q^2-M_X \) \((P_\ell > 1 \text{ GeV})\)

| QCD Calculation | \[ |V_{ub}|(10^{-3}) \] |
|------------------|--------------------------|
| BLNP             | \( 4.27 \pm 0.15 \pm 0.18^{0.23}_{-0.20} \) |
| DGE              | \( 4.34 \pm 0.16 \pm 0.18^{0.22}_{-0.15} \) |
| GGOU             | \( 4.29 \pm 0.15 \pm 0.18^{0.11}_{-0.14} \) |
| ADFR             | \( 4.35 \pm 0.19 \pm 0.20^{0.15}_{-0.15} \) |

- Arithm. Average \( 4.31 \pm 0.25 \) \(_{\text{exp.}}\) \pm 0.16 \(_{\text{th.}}\)

- Compatible fitting other kinematic variables. Good consistency with WA and Belle

**2\sigma Discrepancy with Exclusive**

Final BaBar result, to be submitted to PRD
$|V_{ub}|$ from SL decays $B \rightarrow \pi / X_u \ell \nu$

$B \rightarrow K \pi \pi^0$

$B \rightarrow \phi \phi K$

$B \rightarrow D(*) \tau \nu$
\[ B^0 \rightarrow K\pi\pi \text{ and } \gamma \text{ measurement} \]

- **Rich resonance structure, many observables:**
  - Direct CP asymmetry
  - Branching Ratios
  - Relative phases between components

\[ A_{CP} = \frac{N(B^-) - N(B^+)}{N(B^-) + N(B^+)} \]

- **Direct CP violation in the \( K^*\pi \) decays: „\( K\pi \) puzzle in \( K^*\pi \) decays?**

- **Access UT angle \( \gamma \) from phases related to the \( K^*\pi \) intermediate states in**
  \( B^0 \rightarrow K^+\pi^-\pi^0 \) and \( B^0 \rightarrow K_s\pi^+\pi^- \)
  - Combination free of QCD penguins

- **Same argument can be extended to** \( B^0 \rightarrow \rho K^+ \)

\[ A_{3/2}(\rho K) = \frac{1}{\sqrt{2}}A(\rho^{-}K^+) + A(\rho^0K^0) \]

\[ 3A^0_{3/2}(K^*) = A(K^{*+}\pi^-) + \sqrt{2}A(K^0\pi^0) \]

\[ 3\bar{A}^0_{3/2}(K^*) = A(K^{*-}\pi^+) + \sqrt{2}A(K^0\pi^0) \]

\[ \Phi_{3/2} = -0.5\text{Arg}(\bar{A}_{3/2}/A_{3/2}) \approx \gamma \]

From \( B^0 \rightarrow K^+\pi^-\pi^0 \) DP \( \rightarrow \) **Interference with \( K^*\pi \)** \( \rightarrow \) From \( B^0 \rightarrow K_s\pi^+\pi^- \) DP
**B^0 → K^+ π^- π^0 Dalitz Plot**

- Resonances populate the borders of the Dalitz Plot (DP)
  - Overlap region of resonances is small
  - Crucial understanding of backgrounds and efficiency in the corners

- ML fit with \( m_{ES}, \Delta E, NN_{out} \) and DP
  - Maximize the signal-background separation
  - Signal category includes signal from misreconstructed events

- Charmless signal yield:
  - \( N(K^+ π^- π^0) = 3670 \pm 96_{stat} \pm 94_{syst} \)
  - \( B^0 → D^0 π^0 \) and \( B^0 → D^- K^+ \) consistent with expectations

\[ B^0 \rightarrow K^+\pi^-\pi^0 \] Results

- BF\((B^0 \rightarrow K^+\pi^-\pi^0) = (38.5 \pm 1.0 \pm 3.9)x10^{-6}\)

- \(A_{CP}\) combined with published results with \(B^0 \rightarrow K_s\pi^-\pi^+\)
  - \(A_{CP}(K^+\pi^-) = -0.24 \pm 0.07 \pm 0.02\)
  - Evidence of direct CPV in \(B^0 \rightarrow K^{*+}\pi^-\) (3.1 \(\sigma\))

Destructive interference of the neutral and charged \(K^*\pi\) amplitude:
  - \(\overline{\Phi}_{3/2}\) \((K^*\pi)\) close to 0 \(\rightarrow\) no sensitivity to \(\Phi_{3/2}\)

Better possibilities from \(\rho K\):
  - \(\Phi_{3/2}(\rho K) = (-10^{+10}_{-20} + 7^{+7}_{-22})^\circ\)

<table>
<thead>
<tr>
<th>Isobar</th>
<th>(B \times 10^{-6})</th>
<th>(\overline{\Phi} \ [^\circ])</th>
<th>(\Phi \ [^\circ])</th>
<th>(A_{CP})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\rho(770)^-)K^+</td>
<td>6.6 \pm 0.5 \pm 0.8</td>
<td>0 (fixed)</td>
<td>0 (fixed)</td>
<td>0.20 \pm 0.09 \pm 0.08</td>
</tr>
<tr>
<td>(\rho(1450)^-)K^+</td>
<td>2.4 \pm 1.0 \pm 0.6</td>
<td>75 \pm 19 \pm 9</td>
<td>126 \pm 25 \pm 26</td>
<td>-0.10 \pm 0.32 \pm 0.09</td>
</tr>
<tr>
<td>(\rho(1700)^-)K^+</td>
<td>0.6 \pm 0.6 \pm 0.4</td>
<td>18 \pm 36 \pm 16</td>
<td>50 \pm 38 \pm 20</td>
<td>-0.36 \pm 0.57 \pm 0.23</td>
</tr>
<tr>
<td>(K^*(892)^+)π^-</td>
<td>8.0 \pm 1.1 \pm 0.8</td>
<td>33 \pm 22 \pm 20</td>
<td>39 \pm 25 \pm 20</td>
<td>-0.29 \pm 0.11 \pm 0.02</td>
</tr>
<tr>
<td>(K^*(892)^0)π^0</td>
<td>3.3 \pm 0.5 \pm 0.4</td>
<td>29 \pm 18 \pm 6</td>
<td>17 \pm 20 \pm 8</td>
<td>-0.15 \pm 0.12 \pm 0.04</td>
</tr>
<tr>
<td>((K\pi)^+_0)π^-</td>
<td>34.2 \pm 2.4 \pm 4.1</td>
<td>-167 \pm 16 \pm 37</td>
<td>-130 \pm 22 \pm 22</td>
<td>0.07 \pm 0.14 \pm 0.01</td>
</tr>
<tr>
<td>((K\pi)^-_0)π^-</td>
<td>8.6 \pm 1.1 \pm 1.3</td>
<td>13 \pm 17 \pm 12</td>
<td>10 \pm 17 \pm 16</td>
<td>-0.15 \pm 0.10 \pm 0.04</td>
</tr>
<tr>
<td>NR</td>
<td>2.8 \pm 0.5 \pm 0.4</td>
<td>48 \pm 14 \pm 6</td>
<td>90 \pm 21 \pm 15</td>
<td>0.10 \pm 0.16 \pm 0.08</td>
</tr>
</tbody>
</table>

BaBar, PRD80,112001

- \(\rho(770)K^+\)
$|V_{ub}|$ from SL decays $B \rightarrow \pi / X_u \ell \nu$

$B \rightarrow K\pi\pi^0$

$B \rightarrow \phi\phi K$

$B \rightarrow D(\ast) \tau\nu$
**$B \rightarrow \phi\phi K$**

- *Interference between tree and penguin amplitudes under the $\eta_c$ peak*

\[
\begin{align*}
\text{Tree } B &\rightarrow \eta_c K, \\
\eta_c &\rightarrow \phi\phi
\end{align*}
\]

\[
\text{New CP-violating phase}
\]

\[
\text{Penguin } B \rightarrow \phi\phi K
\]

- *In the SM, T and P have same weak phase: expect no direct CP-Violation*

- *Any observation of direct CP asymmetry would indicate NP phase in P process*
  
  - *Could be at the $\sim 40\%$ level (Hazumi, Phys. Lett B 583, 285 (2004))*
$B^+ \rightarrow \phi\phi K$

- Use 5 regions in the $m_\phi$-$m_\phi$ plane to distinguish final states with 5-Kaons
  - Fit in different regions

$446 \times 10^6$ BB

- Maximum likelihood fit to $m_{ES}$, $\Delta E$, Fisher (to suppress continuum $e^+e^- \rightarrow q\bar{q}$), $m_{\phi_1}, m_{\phi_2}$

$B^+ \rightarrow \phi\phi K^+$ $N_{sig} = 178 \pm 15$

$B^0 \rightarrow \phi\phi K_S$ $N_{sig} = 40 \pm 7$

- First Observation of $K_s$ mode
**B^+ → φφK: BR and A_{CP}**

*Partial BF (m_{φφ} < 2.84 GeV)*

\[
\text{BF( } B^+ \rightarrow φφK^+ \text{ )} = (5.6 \pm 0.5 \pm 0.3) \cdot 10^{-6}
\]

\[
\text{BF( } B^0 \rightarrow φφK_s \text{ )} = (4.5 \pm 0.8 \pm 0.3) \cdot 10^{-6}
\]

*First measurement!*

- \( A_{CP}(\phiφK^+) \) below and within the \( η_c \) region:
  - \( M(φφ) < 2.85 \text{ GeV} \): \(-0.10 \pm 0.08 \pm 0.02\)
  - \( M(φφ): 2.94-2.98 \text{ GeV} \): \(-0.10 \pm 0.15 \pm 0.02\)
  - \( M(φφ): 2.98-3.02 \text{ GeV} \): \(-0.08 \pm 0.14 \pm 0.02\)

- \textit{consistent with 0 and SM}

Result submitted to PRD
ArXiv: 1105.5159
$|V_{ub}|$ from SL decays $B \rightarrow \pi / X_u \ell \nu$

$B \rightarrow K\pi\pi^0$

$B \rightarrow \phi\phi K$

$B \rightarrow D(\ast)\tau\nu$
**B → D(\*)\tau\nu: motivation**

- Similar to B → \tau\nu, but:
  - From annihilation to exchange
  - From $V_{ub}$ to $V_{cb}$: not a rare decay!
  - (tau mass no negligible): 2 form factor for tl
    D, 4 for the D*, but HQET relates the extra to the well measured FF in light leptons

- Look only at $\tau \rightarrow \ell\nu\nu$ (\ell → e or \mu) 3\nu i
  the final state → **signal signature: large missing mass**

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**Extract directly the ratio \( R \)**

\[
R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \rightarrow D^{(*)}\ell\nu_\tau)}
\]

Reduce theoretical and experimental errors

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**Use the hadronic tag \( B_{tag} \rightarrow D^{(*)}Y \)**

- \( Y \) is a combination of \( \pi, \pi^0 \) and \( K \)
- Reduce combinatoric

**Reconstruct 4 signal decay channels (fitted together):**

- \( D^0, D^{*0}, D^+, D^{*+} \)
**$B \to D(\ast)\tau\nu$: fit**

- Simultaneous 2D un-binned ML-fit of missing mass $m_{\text{miss}}^2$ and $P_\ell$ to 4 signal samples and the $D^{**}$ control samples.

- $B \to D^{**}\ell\nu$ poorly known
  Select $D(\ast)\pi^0$ candidates and fitted together with the signal sample.
**B → D(*)τν: preliminary results**

- **Systematics are preliminary**: expected to improve for the publication
- **Results compatible with Belle latest results and previous BaBar one**
- **5σ in all channels**
- **1.8 σ from SM**
- **Results favors large tanβ**

- More details: Manuel F Sevilla talk at EPS11
Conclusions

- New results from Inclusive and Exclusive $|V_{ub}|$
  - Inclusive-Exclusive discrepancy still present: theoretical error in the inclusive?

- Improvements on $B \rightarrow D(*) \tau\nu$
  - Search for NP in CKM favored SL decays
  - All $D$ channels observed

- Charmless $B$ decays still source of many interesting results
  - News from $B \rightarrow K\pi\pi^0$, but weak limit on $\gamma$
  - $B \rightarrow \phi K_s K$: first observation of the $K_s$ mode
  - Most of these results agree with SM prediction, but some puzzles remain (Polarization & $K\pi$ puzzle)

- More statistics is crucial to fully understand the tensions and puzzles
  - LHCb: present!
  - SuperB and Belle-II: next future!