New physics search in hadronic penguins and leptonic $B$ decays

Youngjoon Kwon

Dept. of Physics
Yonsei Univ., Seoul, Korea

July 24, 2009 @ FLAVIA.net Workshop
Prelude and Varations

- (Prelude)
Prelude and Varations

- (Prelude)
- (Theme I) Leptonic $B$ decays
  
  - $B^+ \rightarrow \tau^+ \nu$
  - $B^+ \rightarrow \ell^+ \nu(\gamma)$
  - $B \rightarrow D(\ast)^+ \tau^+ \nu$
• (Prelude)

• (Theme I) Leptonic $B$ decays
  - $B^+ \rightarrow \tau^+ \nu$
  - $B^+ \rightarrow \ell^+ \nu(\gamma)$
  - $B \rightarrow \bar{D}^{(*)} \tau^+ \nu$

• (Theme II) Hadronic penguins
  - $\Delta S$ puzzle
  - $K\pi$ puzzle
  - $WV$ polarization puzzle

• (Coda) Summary & Outlook
The B’s Gallery

mostly, before B-factories

ARGUS $e^+e^- (Y_{4s})$  PLB192, 245 (1987)
Conclusive observation of $B^0_s$ mixing
Excess of like-sign lepton pairs

$\Rightarrow$ Top quark heavy  $m_{top} > 50$ GeV

New physics search in hadronic penguins and leptonic $B$ decays
Two asymmetric B-factories

**PEP-II at SLAC**

9GeV (e⁻) × 3.1GeV (e⁺)

peak luminosity:

$1.2 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$

**KEKB at KEK**

8GeV (e⁻) × 3.5GeV (e⁺)

peak luminosity:

$2.1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$

**Belle**

13 countries,
57 institutes,
~400 members

**BaBar**

11 nations,
80 institutes,
~600 members

world record
• Critical role of the $B$-factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation

• A single irreducible phase in the weak int. matrix accounts for most of the $CP$ violation observed in the $K$'s and in the $B$'s

• $CP$-violating effects in the $B$ sector are $\mathcal{O}(1)$ rather than $\mathcal{O}(10^{-3})$ as in the $K^0$ system.
The (still) open questions

- Why flavors; why 3?
- Why the mass & mixing patterns?
- Why/how did the antimatter disappear?
- ...

- Questions may remain unanswered even if SUSY or new physics is found at LHC and/or Super-B...
- But, step-by-step experimental approach in flavor physics is definitely needed to address these grand questions
Prelude and Variations

- (Prelude)
- (Theme I) Leptonic $B$ decays
  - $B^+ \rightarrow \tau^+ \nu$
  - $B^+ \rightarrow \ell^+ \nu(\gamma)$
  - $B \rightarrow D^{(*)} \tau^+ \nu$
- (Theme II) Hadronic penguins
  - $\Delta S$ puzzle
  - $K\pi$ puzzle
  - $WV$ polarization puzzle
- (Coda) Summary & Outlook
Motivations for $B^+ \rightarrow \ell^+ \nu$

\[ \Gamma(B^+ \rightarrow \ell^+ \nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \]

- very clean place to measure $f_B$ (or $V_{ub}$?) and/or search for new physics (e.g. $H^+$, LQ)
- but, helicity-suppressed: $\Gamma(B^+ \rightarrow e^+ \nu) \ll \Gamma(B^+ \rightarrow \mu^+ \nu) \ll \Gamma(B^+ \rightarrow \tau^+ \nu)$
Features of $B^+ \rightarrow \ell^+ \nu$

SM predictions

- $\mathcal{B}(B^+ \rightarrow \tau^+ \nu) \sim 10^{-4}$
- $\mathcal{B}(B^+ \rightarrow \mu^+ \nu) \sim \mathcal{B}(B^+ \rightarrow \tau^+ \nu)/225$
- $\mathcal{B}(B^+ \rightarrow e^+ \nu) \sim \mathcal{B}(B^+ \rightarrow \tau^+ \nu)/10^7$

Experimental features

- $B^+ \rightarrow \tau^+ \nu$ large BF, but many ($\geq 2$) $\nu$'s
- $B^+ \rightarrow \ell^+ \nu \ (\ell \neq \tau)$ \quad $E_\ell \sim M_B/2$, but small BF
\[ B^+ \rightarrow \tau^+ \nu \]

PRL 97, 251801 (2006)
PRD 77, 011107 (2008)
PRD 76, 052002 (2007)
$\mathcal{B}^+ \rightarrow \tau^+ \nu$) the two methods

What are they?

- "hadronic tagging" - full recon. of the ‘other B’
- "semileptonic tagging" - by $B^+ \rightarrow \bar{D}^{(*)} \ell^+ \nu$

Why bother?

- $B^+ \rightarrow \tau^+ \nu$ has many (≥ 2) $\nu$’s
- need extra kinematic constraints to improve sensitivity
- exploit $\Upsilon(4S)$ producing $B\bar{B}$ and nothing else
\((B^+ \rightarrow \tau^+ \nu)\) the two methods

Can use \(\sim 0.2\% B\bar{B}\) sample with very clean envir’mt.

\[ \Delta M \equiv M(K\pi\pi_s) - M(K\pi) \]

with \(M(K\pi) \sim m(D^0)\)

In spite of a missing \(\nu\), semilept. tagging is clean enough and gives more statistics!
(B^+ \rightarrow \tau^+ \nu) hadronic tagging

The ‘other B’ tagged by full recon. with 383 M B\overline{B} events.

Energy sum of the extra ECL clusters, not associated with the full-recon (B_{tag}), nor matched to tracks from B_{sig}.
First evidence with $3.5\sigma$,
\[ \mathcal{B}(B^+ \rightarrow \tau^+\nu) = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4} \]

Using $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ (HFAG ’06),
\[ f_B = (229^{+36+34}_{-31-37}) \text{ MeV} \]
(\(B^+ \rightarrow \tau^+ \nu\)) semileptonic tagging

- Statistically independent sample from hadronic tagging
(\(B^+ \rightarrow \tau^+ \nu\)) semileptonic tagging

- Statistically independent sample from hadronic tagging
- Tagging side
  - Reconstruct \(B^+ \rightarrow \bar{D}^{(*)} \ell^+ \nu\)
  - Kinematic relation for good-tag id.

\[
\cos \theta_{B-\bar{D}^{(*)} \ell^+} = \frac{2E_B E_{\bar{D}^{(*)} \ell^+} - M_B^2 - M_{\bar{D}^{(*)} \ell^+}^2}{2P_B P_{\bar{D}^{(*)} \ell^+}}
\]
\((B^+ \rightarrow \tau^+ \nu)\) semileptonic tagging

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\]

- Signal side
  - Use 1-prong \(\tau^-\) modes: \(\ell^- \bar{\nu} \nu, \pi^- \nu\)
  - \(E_{\text{ECL}}\) to extract \(N_{\text{sig}}\)
(B^+ \to \tau^+ \nu) semileptonic tagging

- Statistically independent sample from hadronic tagging

- Tagging side
  - Reconstruct B^+ \to D^{(*)} \ell^+ \nu
  - Kinematic relation for good-tag id.
    \[
    \cos \theta_{B-D^{(*)}\ell^+} = \frac{2E_BE_{D^{(*)}\ell^+} - M_B^2 - M_{D^{(*)}\ell^+}^2}{2P_BP_{D^{(*)}\ell^+}}
    \]

- Signal side
  - Use 1-prong \tau^- modes: \ell^- \bar{\nu} \nu, \pi^- \nu
  - E_{ECL} to extract \text{\(N_{\text{sig}}\)}}

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(B⁺ → τ⁺ν) semileptonic tagging

- Max. likelihood fit to $E_{ECL}$ distribution
- Systematic err.
  - SL tagging eff’y (12%)
  - BG shape (12%), peaking BG (8%)
- Significance: 3.8σ incl. syst. err.

\[ B(B^+ \rightarrow \tau^+ \nu) = (1.65^{+0.38+0.46}_{-0.37-0.51}) \times 10^{-4} \]

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Signal Yield</th>
<th>$\varepsilon$</th>
<th>$B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau^- \rightarrow e^- \nu \bar{\nu}_\tau$</td>
<td>78^{+23}_{-22}</td>
<td>$5.9 \times 10^{-4}$</td>
<td>$(2.02^{+0.59}_{-0.56}) \times 10^{-4}$</td>
</tr>
<tr>
<td>$\tau^- \rightarrow \mu^- \nu \bar{\nu}_\tau$</td>
<td>15^{+18}_{-17}</td>
<td>$3.7 \times 10^{-4}$</td>
<td>$(0.62^{+0.76}_{-0.71}) \times 10^{-4}$</td>
</tr>
<tr>
<td>$\tau^- \rightarrow \pi^- \nu_\tau$</td>
<td>58^{+21}_{-20}</td>
<td>$4.7 \times 10^{-4}$</td>
<td>$(1.88^{+0.70}_{-0.66}) \times 10^{-4}$</td>
</tr>
<tr>
<td>Combined</td>
<td>154^{+36}_{-35}</td>
<td>$14.3 \times 10^{-4}$</td>
<td>$(1.65^{+0.38}_{-0.37}) \times 10^{-4}$</td>
</tr>
</tbody>
</table>
(\(B^+ \to \tau^+ \nu\)) semileptonic tagging

- tagged by \(D^0 \ell^- \nu X\)
  \((X = \gamma, \pi^0\), not explicitly reconstr’ed\)
- fit to \(E_{\text{extra}}\); shape is validated by double-tagged events

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Exp’ed bkgd.</th>
<th>obsv’ed events</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tau^+ \to e^+ \nu \bar{\nu})</td>
<td>44.3 ± 5.2</td>
<td>59</td>
</tr>
<tr>
<td>(\tau^+ \to \mu^+ \nu \bar{\nu})</td>
<td>39.8 ± 4.4</td>
<td>43</td>
</tr>
<tr>
<td>(\tau^+ \to \pi^+ \nu \bar{\nu})</td>
<td>120.3 ± 10.2</td>
<td>125</td>
</tr>
<tr>
<td>(\tau^+ \to \pi^+ \pi^0 \nu \bar{\nu})</td>
<td>17.3 ± 3.3</td>
<td>18</td>
</tr>
<tr>
<td>All modes</td>
<td>221.7 ± 12.7</td>
<td>245</td>
</tr>
</tbody>
</table>

\[ \mathcal{B}(B^+ \to \tau^+ \nu) = (0.9 \pm 0.6 \pm 0.1) \times 10^{-4} \]

\[ < 1.7 \times 10^{-4} \]

\[ f_B = (167^{+48}_{-66}) \text{ MeV} \]
(\(B^+ \rightarrow \tau^+ \nu\)) hadronic tagging

- \(N_{B \bar{B}} = 383 \, M\)
- \(\mathcal{B}(B^+ \rightarrow \tau^+ \nu) = (1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2) \times 10^{-4}\)
- combined w/ SL-tag result, 
  \(\mathcal{B}(B^+ \rightarrow \tau^+ \nu) = (1.2 \pm 0.4 \pm 0.3 \pm 0.2) \times 10^{-4}\)
$(B^+ \to \tau^+ \nu)$ Constraints on new physics


$$r_H \equiv \frac{\mathcal{B}(B^+ \to \tau^+ \nu)}{\mathcal{B}(B^+ \to \tau^+ \nu)_{SM}} = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta \right)^2$$

- (Figure) from Belle SL-tag results
\((B^+ \rightarrow \tau^+\nu)\) Compared with CKM fit

- \(B_{SM} \propto (f_B|V_{ub}|)^2\)
- \(f_B\) cancels if taken ratio with \(B^0\) mixing
- provides a constraint on \(V_{ub}\) in CKM \(\Delta\) fit
- \(\exists\) a tension?
\[ \mathcal{B}(B^+ \rightarrow \ell^+ \nu) < \mathcal{O}(10^{-6}) \]

\[ \mathcal{B}(B^+ \rightarrow \ell^+ \nu\gamma) < \mathcal{O}(10^{-5}) \]
\[ B \rightarrow \overline{D}^{(*)} \tau^+ \nu \]

PRL 99, 191807 (2007)
preliminary

PRL 100, 021801 (2008)
(\(B \rightarrow \bar{D}^{(*)} \tau^+\nu\)) Overview

- missing piece of \(B\) semileptonic decays

\[ (\bar{d} \rightarrow \bar{d}, \bar{b} \rightarrow \bar{c}) \]

\[ W \rightarrow \nu, \tau \]

\[ (\bar{d} \rightarrow \bar{d}, \bar{b} \rightarrow \bar{c}) \]

\[ m_b \tan \beta + m_c \cot \beta \rightarrow H^\pm \]

\[ m_\tau \tan \beta \]

\[ \bar{H} \rightarrow \nu, \tau \]
(\( B \rightarrow \overline{D}^{(*)} \tau^+ \nu \)) Overview

- missing piece of \( B \) semileptonic decays
- **good features**
  - due to heavy \( m_\tau \), sensitive to \( H^+ \)
  - \( \mathcal{B}(B \rightarrow \overline{D}^{(*)} \tau^+ \nu) \gg \mathcal{B}(B^+ \rightarrow \tau^+ \nu) \)
  - access to more dynamical info. through \( \tau \) polarization

\[
(\text{SM}) \quad \mathcal{B}(B \rightarrow \overline{D}^* \tau^+ \nu) \approx 1.4\%,
\quad \mathcal{B}(B \rightarrow \overline{D} \tau^+ \nu) \approx 0.7\% 
\]
(\(B \to \overline{D}^{(*)} \tau^+ \nu\)) Overview

- missing piece of \(B\) semileptonic decays

- good features
  - due to heavy \(m_\tau\), sensitive to \(H^+\)
  - \(\mathcal{B}(B \to \overline{D}^{(*)} \tau^+ \nu) \gg \mathcal{B}(B^+ \to \tau^+ \nu)\)
  - access to more dynamical info. through \(\tau\) polarization

- but, very difficult for analysis
  - multiple \(\nu\)'s
  - large background from \(B \to DX\ell^+ \nu\)

- \(B \to \overline{D}^{(*)} \tau^+ \nu\) depends on form-factor
  - but, it can be deduced from \(B^+ \to \overline{D}^{(*)} \ell^+ \nu\)

\[(\text{SM}) \mathcal{B}(B \to \overline{D}^* \tau^+ \nu) \approx 1.4\%, \quad \mathcal{B}(B \to \overline{D} \tau^+ \nu) \approx 0.7\%\]
\( (B^0 \rightarrow D^{*-} \tau^+ \nu) \) first observation

- full-recon tagging (à la \( B^+ \rightarrow \tau^+ \nu \))
- but a different implementation – ‘inclusive recon’
  - not pay attention to any specific sub-resonance, but just collect particles to make a “B”
  - use all remaining particle after selecting candidate particles for \( B_{\text{sig}} \)
- increased effic’y compared to exclusive full-recon
- \( M_{\text{tag}}, \Delta E_{\text{tag}} \) as useful variables

\[ \text{calibration:} \quad B^0 \rightarrow D^{*-} \pi^+ \]
(\(B^0 \rightarrow D^{*-} \tau^+ \nu\)) first observation

Background suppression

- Need to suppress huge backg’d from \(B \rightarrow D^* e\nu\)
- Useful variables
  - \(X_{\text{mis}}\): similar to \(M_{\text{mis}}^2\); most powerful
  - \(E_{\text{vis}} (\equiv \sum E_i)\) is useful, too

\[
E_{\text{mis}} = E_{\text{beam}} - E_{D^*} - E_{e/\pi}
\]
\[
X_{\text{mis}} = \frac{E_{\text{mis}} - \left| \vec{p}_{D^*} + \vec{p}_{e/\pi} \right|}{\sqrt{E_{\text{beam}}^2 - M_B^2}}
\]
\((B^0 \rightarrow D^{*-} \tau^+ \nu)\) first observation

Background suppression

![Graphs showing before and after cuts for different categories: signal, other \(\tau\), \(D^*\) ev, \(D^{**}\) ev, generic B, continuum.](image)
$(B^0 \rightarrow D^{*-} \tau^+ \nu) \text{ first observation}$

Signal extraction

- Max. likelihood fit to $M_{\text{tag}}$
- signal shape from MC
- non-peaking bkgd. – weighted sum of various comp’nts
- peaking bkgd. – fixed by MC

<table>
<thead>
<tr>
<th>Subchannel</th>
<th>$N_b^{\text{MC}}$</th>
<th>$N_p$</th>
<th>$N_s$</th>
<th>$N_b$</th>
<th>$N_{\text{obs}}$</th>
<th>$\epsilon \times 10^{-4}$</th>
<th>$B(%)$</th>
<th>$\Sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow K^+ \pi^-, \tau^+ \rightarrow e\bar{\nu}<em>e \nu</em>\tau$</td>
<td>$26.3^{+5.4}_{-3.7}$</td>
<td>$1.2^{+1.6}_{-1.5}$</td>
<td>$19.5^{+5.8}_{-5.0}$</td>
<td>$19.4^{+5.8}_{-5.0}$</td>
<td>40</td>
<td>$3.25 \pm 0.11$</td>
<td>$2.44^{+0.74}_{-0.65}$</td>
<td>$5.0\sigma$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^- \pi^+ \pi^0, \tau^+ \rightarrow e\bar{\nu}<em>e \nu</em>\tau$</td>
<td>$50.8^{+5.5}_{-5.1}$</td>
<td>$5.0^{+2.6}_{-2.2}$</td>
<td>$11.9^{+6.0}_{-5.2}$</td>
<td>$43.1^{+8.0}_{-7.2}$</td>
<td>60</td>
<td>$0.78 \pm 0.07$</td>
<td>$1.69^{+0.84}_{-0.74}$</td>
<td>$2.6\sigma$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^- \pi^+, \tau^+ \rightarrow e\bar{\nu}<em>e \nu</em>\tau$</td>
<td>$138.0^{+9.2}_{-8.8}$</td>
<td>$-1.0^{+3.6}_{-3.2}$</td>
<td>$29.9^{+10.0}_{-9.1}$</td>
<td>$118.0^{+14.0}_{-13.0}$</td>
<td>148</td>
<td>$1.07^{+0.17}_{-0.15}$</td>
<td>$2.02^{+0.68}_{-0.61}$</td>
<td>$3.8\sigma$</td>
</tr>
<tr>
<td>Combined</td>
<td>$215^{+12}_{-11}$</td>
<td>$6.2^{+4.7}_{-4.2}$</td>
<td>$60^{+12}_{-11}$</td>
<td>$182^{+15}_{-14}$</td>
<td>248</td>
<td>$1.17^{+0.10}_{-0.08}$</td>
<td>$2.02^{+0.72}_{-0.68}$</td>
<td>$6.7\sigma$</td>
</tr>
</tbody>
</table>

$$B(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau) = (2.02^{+0.40}_{-0.37} \pm 0.37)\% \text{ with } 5.2\sigma$$
(\(B \rightarrow \bar{D}\tau^+\nu\)) first evidence

Analysis strategy

- full-recon tag. in 1114 final states
- extract \(\bar{D}\tau^+\nu\) and \(\bar{D}^*\tau^+\nu\) simultan'ly
- also extract \(\bar{D}\ell^+\nu\) and \(\bar{D}^*\ell^+\nu\) for normalization
- exploit 2D features of \(m_{\text{miss}}^2\) vs. \(|\mathbf{p}_\ell^*|\)

\[
\begin{align*}
\text{FIG. 4: Distributions of} & \quad (a) \quad (b) \\
\text{\(|p_{\ell}\) \ (GeV/c)} & \quad \text{with the remaining particles in the event, adding and removing light hadrons to the} \\text{raw} \\
\text{ES} & \quad \text{sample after the signal} \\
\begin{array}{ll}
D^0\ell^-\bar{\nu}_\ell & \Rightarrow D^0\ell^- \\
D^*0\ell^-\bar{\nu}_\ell & \Rightarrow D^0\ell^- \\
D^0\tau^-\bar{\nu}_\tau & \Rightarrow D^0\ell^- \\
D^*0\tau^-\bar{\nu}_\tau & \Rightarrow D^0\ell^- \\
D^{**}\ell^-\bar{\nu}_\ell & \Rightarrow D^0\ell^- \\
D^0\ell^-\bar{\nu}_\ell & \Rightarrow D^{*0}\ell^- \\
\end{array}
\end{align*}
\]
(B → Dτ⁺ν) first evidence

\[ B(B \to D\tau^+\nu) = (0.86 \pm 0.24 \pm 0.11 \pm 0.06)\% \ (3.6\sigma) \]

\[ B(B \to D^*\tau^+\nu) = (1.62 \pm 0.31 \pm 0.10 \pm 0.05)\% \ (6.2\sigma) \]

First measurement of **kinematic distributions**: \( q^2, |p^*_\ell| \)
(\( B \rightarrow \overline{D}^{(*)} \tau^+ \nu \)) new anal.

Tagging side

- Full reconstruction of \( B \) hadronic modes
- \( N_{B^+}^{\text{fit}} \sim 1.0 \times 10^6 \) (purity = 0.58)
- \( N_{B^0}^{\text{fit}} \sim 0.6 \times 10^6 \) (purity = 0.51)

Signal side: \( \tau^+ \rightarrow \ell^+ \nu \bar{\nu} \) only

- \( P_{\tau \rightarrow X} < 1.2\text{GeV/c} \)
- \(-2 < MM^2 < 8\)
- \( E_{\text{ECL}} < 1.2\)

\[
B^+ \rightarrow \overline{D}^0 \tau^+ \nu
\]
(B → D^{(*)} \tau^+ \nu) new anal.

**Signal fitting**

- unbinned max. likelihood fit to \( M_{\text{mis}}^2 \) and \( E_{\text{ECL}} \)
- Fitting components
  - \( D\tau^+\nu, D^*\tau^+\nu, D\ell^+\nu, D^*\ell^+\nu \), and “others”
- Check before fitting
  - calibrate with \( D^*\ell^+\nu \): \( E_{\text{ECL}} \) correction factor
  - side-band check
  - toy MC; null test with generic MC
\[(B \rightarrow \bar{D}^{(*)} \tau^+ \nu) \text{ new anal.}\]

Results

<table>
<thead>
<tr>
<th>Quantity (N(\bar{D}^{(*)} \tau^+ \nu))</th>
<th>(B^+ \rightarrow \bar{D}^0 \tau^+ \nu)</th>
<th>(B^+ \rightarrow \bar{D}^{*0} \tau^+ \nu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>98.6^{+26.3}_{-25.0}</td>
<td>99.8^{+22.2}_{-21.3}</td>
<td></td>
</tr>
<tr>
<td>(N(\bar{D}^{(*)} \ell^+ \nu))</td>
<td>1155.8 ± 43.9</td>
<td>2151.9 ± 76.2</td>
</tr>
<tr>
<td>significance</td>
<td>3.8</td>
<td>3.9</td>
</tr>
<tr>
<td>(\mathcal{B})</td>
<td>1.51^{+0.41}<em>{-0.39}^{+0.24}</em>{-0.19} ± 0.15</td>
<td>3.04^{+0.69}<em>{-0.66}^{+0.40}</em>{-0.47} ± 0.22</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Quantity (N(\bar{D}^{(*)} \tau^+ \nu))</th>
<th>(B^0 \rightarrow D^- \tau^+ \nu)</th>
<th>(B^0 \rightarrow D^{*-} \tau^+ \nu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.2^{+7.69}_{-6.88}</td>
<td>25.0^{+7.17}_{-6.27}</td>
<td></td>
</tr>
<tr>
<td>(N(\bar{D}^{(*)} \ell^+ \nu))</td>
<td>337.9 ± 21.2</td>
<td>768.7 ± 34.5</td>
</tr>
<tr>
<td>significance</td>
<td>2.6</td>
<td>4.7</td>
</tr>
<tr>
<td>(\mathcal{B})</td>
<td>1.01^{+0.46}<em>{-0.41}^{+0.13}</em>{-0.11} ± 0.10</td>
<td>2.56^{+0.75}<em>{-0.66}^{+0.31}</em>{-0.22} ± 0.10</td>
</tr>
</tbody>
</table>
\[ B \rightarrow D^{(*)} \tau^+ \nu \]
$B \rightarrow \overline{D}^{(*)} \tau^+ \nu$ and $B^+ \rightarrow \tau^+ \nu$ together

Kamenik & Mescia, PRD (2008)
Prelude and Variations

- (Prelude)
- (Theme I) Leptonic $B$ decays
  - $B^+ \rightarrow \tau^+ \nu$
  - $B^+ \rightarrow \ell^+ \nu(\gamma)$
  - $B \rightarrow D^{(*)} \tau^+ \nu$
- (Theme II) Hadronic penguins
  - $\Delta S$ puzzle
  - $K\pi$ puzzle
  - $VV$ polarization puzzle
- (Coda) Summary & Outlook
Why hadronic penguins?

- SM is a very good approx. for reality i.e. $A_{\text{Nature}} \simeq A_{\text{SM}}$ for most processes

- Need to look where $A_{\text{SM}}$ is small, in order to be sensitive to NP e.g. $b \to s$ penguins

- Compare $A_{\text{Nature}}$ with $A_{\text{SM}}$, then Find new physics or learn new lessons!
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  e.g. $b \to s$ penguins

- Compare $A_{\text{Nature}}$ with $A_{\text{SM}}$, then
  Find new physics or learn new lessons!

- Some puzzles
  - $\Delta S$ puzzle
  - $K\pi$ puzzle
  - $VV$ polarization puzzle
$\Delta S$ puzzle
$\sin(2\beta) \equiv \sin(2\phi_1)$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar $\chi_{cs} K_s$</td>
<td>$0.687 \pm 0.028 \pm 0.012$</td>
</tr>
<tr>
<td>BaBar $J/\psi$ (hadronic) $K_S$</td>
<td>$0.690 \pm 0.520 \pm 0.040 \pm 0.070$</td>
</tr>
<tr>
<td>Belle $J/\psi K^0$</td>
<td>$1.560 \pm 0.420 \pm 0.210$</td>
</tr>
<tr>
<td>Belle $\psi(2S) K_S$</td>
<td>$0.642 \pm 0.031 \pm 0.017$</td>
</tr>
<tr>
<td>Average HFAG</td>
<td>$0.718 \pm 0.090 \pm 0.031$</td>
</tr>
<tr>
<td>HFAG $\chi_{cs} K_s$</td>
<td>$0.671 \pm 0.024$</td>
</tr>
</tbody>
</table>
\[ \phi_1 \text{ from } b \to ss\bar{s}s \]

E.g. \[ B^0 \to \phi K_S \]

Two \( V_{td} \) vertices \( e^{-i(2\phi_1)} \)

Relative phase = \( e^{i2(\phi_1 + \Delta)} \neq e^{i2\phi_1} \)

\( \sin(2\phi_{1\text{eff}}) \neq \sin(2\phi_1) \)
$B \rightarrow \phi K_S$ and $B \rightarrow \eta' K_S$

$B \rightarrow \phi K_S$: B.F. = $(4.3 \pm 0.6) \times 10^{-6}$

Even with small rates, clear CP violation observed in penguin decays

$B \rightarrow \eta' K_S$: B.F. = $(3.4 \pm 0.2) \times 10^{-5}$
(In 2003, $> 3\sigma$ effect seen in $B \to \phi K_S$ with low stats)

Latest generation of $b \to s$ time dependent CPV analyses
- more data and advanced analysis for three-body decay modes

Previous ‘slice and dice’ analyses have been modified.
Now use time-dependent Dalitz analyses with
interference between multiple common final states for
tCPV in $\phi K_S$ and $f_0 K_S$

need a model of resonances that contribute in the Dalitz plot
\[ \sin(2\beta_{\text{eff}}) \equiv \sin(2\phi_{1}^{\text{eff}}) \]

For NP, need to improve the precision of the golden modes.
$K \pi$ puzzle
$A_{K^-\pi^+} \equiv \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$ < 0 by \( \sim 8\sigma \)
CP violation in $B \rightarrow K\pi$

CPV through interference

\[ V_{ub} \]

CPV in $B^0 \rightarrow K^+\pi^-$ is not unexpected, but ...
Direct CPV in $B \rightarrow K \pi$

$N_{B\bar{B}} = 535 \times 10^6$

$A_{K^\mp \pi^\mp} \equiv \frac{N(\bar{B}^0 \rightarrow K^- \pi^+) - N(B^0 \rightarrow K^+ \pi^-)}{N(\bar{B}^0 \rightarrow K^- \pi^+) + N(B^0 \rightarrow K^+ \pi^-)}$

$A_{K^\pm \pi^0} = +0.07 \pm 0.03 \pm 0.01$

$A_{K^\pm \pi^0} - A_{K^\mp \pi^\mp} = +0.164 \pm 0.037$

a $4.4 \sigma$ effect!

Figure 2 | $M_{bc}$ projections for $K^- \pi^+$ (a), $K^+ \pi^-$ (b), $K^- \pi^0$ (c) and $K^+ \pi^0$ (d). Histograms are data, solid blue lines are the fit projections, point-dashed lines are the signal components, dashed lines are the continuum background, and grey dotted lines are the $\pi^\pm \pi$ signals that are misidentified as $K^\pm \pi$. The $M_{bc}$ projections are made by requiring $|\Delta E| < 0.06$ GeV for $K^\pm \pi^\mp$ and $-0.14 < \Delta E < 0.06$ GeV for $K^\pm \pi^0$. 

Youngjoon Kwon
New physics search in hadronic penguins and leptonic $B$ decays
July 24, 2009 @ FLAVIAnet Workshop
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$A_{CP}(K\pi)$ current status

$A_{CP}(K^+\pi^0)$

$A_{CP}(K^+\pi^-)$

$\Delta A_{K\pi} \equiv A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0)$

$= -0.147 \pm 0.028$

a 5.3$\sigma$ effect!
Diagrams for $B \rightarrow K\pi$

(a) $\bar{b} \rightarrow \bar{s}, \bar{d} \rightarrow u, d$  
(b) $\bar{b} \rightarrow \bar{s}, \bar{d} \rightarrow u, d$  
(c) $\bar{b} \rightarrow \bar{u} \rightarrow u$  
(d) $\bar{b} \rightarrow \bar{d}, \bar{s} \rightarrow u, d$
Conjectures for $\Delta A \neq 0$

- Enhanced color-suppressed tree?
  - can it be bigger than color-allowed diagram??

- EW penguin?
  - EW penguin has negligible CP phase in the SM, hence cannot affect $\Delta A$ by much
  - perhaps, picking up a new CP phase from NP?
one important but poorly constrained piece in the puzzle

$$B \rightarrow K_S^0\pi^0$$

+ 1st obs. of $$B \rightarrow K_L^0\pi^0$$

3-d fit gives a signal of 657±37 events

Use flavor tagging to distinguish $$B^0$$ and anti-$$B^{0}$$

(Using $$K_S^0$$ decays that are inside the SVD, we measure TCPV)

285±52±57 (3.7σ incl. systematics)

These modes will be very difficult at a hadron machine
Model-indep. detection of NP in the $B \to K\pi$ system

\[ A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{B(K^0\pi^+)}{B(K^+\pi^-)} \frac{\tau_0}{\tau_+} = A_{CP}(K^{+}\pi^{0}) \frac{2B(K^{+}\pi^{0})}{B(K^{+}\pi^{-})} \frac{\tau_0}{\tau_+} + A_{CP}(K^{0}\pi^{0}) \frac{2B(K^{0}\pi^{0})}{B(K^{+}\pi^{-})} \frac{\tau_0}{\tau_+} \]

$B \to K\pi$  HFAG, ICHEP08

<table>
<thead>
<tr>
<th>$A(K^0\pi^+)$</th>
<th>$A(K^+\pi^-)$</th>
<th>$A(K^0\pi^0)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.009 ± 0.025</td>
<td>0.050 ± 0.025</td>
<td>-0.098 ± 0.012</td>
</tr>
<tr>
<td>-0.01 ± 0.10</td>
<td>-0.098 ± 0.012</td>
<td>-0.01 ± 0.10</td>
</tr>
</tbody>
</table>

Youngjoon Kwon  New physics search in hadronic penguins and leptonic $B$ decays  July 24, 2009 @ FLAVIAnet Workshop

Sum rule proposed by:
VV puzzle
VV puzzle?

- $B$ decays to vector + vector final states are actually three separate decays, corresponding to the polarizations of the final-state vector mesons.

- Naive SM expectation predicts dominance of longitudinal polarizations
  - by helicity conservation arguments
    \[ f_L \sim 1 - \frac{m_V^2}{m_B^2} \]

- But, a puzzling pattern of $f_L$ are measured in $B \to VV$ decays
VV puzzle?

Polarizations of Charmless Decays

Longitudinal Polarization Fraction ($f_L$)

HFAG
April 2009

$\phi K^+_2(1430)^+$
$\phi K^*_2(1430)^0$

$\phi K^+_1(1270)$
$\phi K^{*+}$

$K^{*0} \rho^+$
$K^{*0} \rho^0$
$K^{*+} K^{*0}$
$K^{*0} K^{*0}$

$\omega K^*_2(1430)^0$
$\omega K^*_2(1430)^+$
$\omega K^{*+}$

$\rho^+ \rho^0$
$\rho^+ \rho^-$

New Avg.
Belle
BABAR
Polarization patterns in $B \to VV$

- $f_L \sim 1$ for $\rho \rho$, $\rho \omega$
  - tree-dominated decays
  - the naive picture works!

- $f_L \sim 0.5$ for $\phi K^*$
  - beginning of the puzzle, c. 2003
  - penguin-dominated decays
  - $\delta f_L \sim 0.05$

- What about $\rho K^*$, $\omega K^*$?

$$\frac{d^2 \Gamma}{\Gamma d \cos \theta_1 d \cos \theta_2} = \frac{9}{4} \left[ f_L \cos^2 \theta_1 \cos^2 \theta_2 + \frac{1}{4} (1 - f_L) \sin^2 \theta_1 \sin^2 \theta_2 \right]$$
Ploarization patterns in $B \rightarrow VV$

- $f_L \sim 1$ for $\rho \rho$, $\rho \omega$
  - tree-dominated decays
  - the naive picture works!

- $f_L \sim 0.5$ for $\phi K^*$
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- What about $\rho K^*$, $\omega K^*$?

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\varphi K^*(892)^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_J \ (10^{-6})$</td>
<td>$9.7 \pm 0.5 \pm 0.5$</td>
</tr>
<tr>
<td>$f_{LJ}$</td>
<td>$0.494 \pm 0.034 \pm 0.013$</td>
</tr>
<tr>
<td>$f_{\perp J}$</td>
<td>$0.212 \pm 0.032 \pm 0.013$</td>
</tr>
</tbody>
</table>
Ploarization patterns in $B \rightarrow VV$

- $f_{L} \sim 1$ for $\rho \rho$, $\rho \omega$
  - tree-dominated decays
  - the naive picture works!
- $f_{L} \sim 0.5$ for $\phi K^*$
  - beginning of the puzzle, c. 2003
  - penguin-dominated decays
  - $\delta f_{L} \sim 0.05$

- What about $\rho K^*$, $\omega K^*$?
  - $\rho K^*$, $\omega K^*$ tend to have $f_{L} \sim 0.5$
    just like $\phi K^*$
VV puzzle?

Not completely understood, but improving

- Enhanced annihilation and non-factorizable contributions
  - Cheng, K.-C. Yang, PRD 78, 094001 (2008)
- Final-state interactions
- New physics?
<table>
<thead>
<tr>
<th>Decay</th>
<th>Theory</th>
<th>Expt</th>
<th>Theory</th>
<th>Expt</th>
<th>Theory</th>
<th>Expt</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^ - \rightarrow \rho^ - \rho^0$</td>
<td>$20.0^{+4.0+2.0}_{-1.9-0.9}$</td>
<td>$18.2 \pm 3.0$</td>
<td>$0.96^{+0.02}_{-0.02}$</td>
<td>$0.912^{+0.044}_{-0.045}$</td>
<td>$0.02 \pm 0.01$</td>
<td></td>
</tr>
<tr>
<td>$\bar{B}^0 \rightarrow \rho^+ \rho^-$</td>
<td>$25.5^{+1.5+2.4}_{-2.6-1.5}$</td>
<td>$24.2^{+3.1}_{-3.2}$</td>
<td>$0.92^{+0.01}_{-0.02}$</td>
<td>$0.978^{+0.025}_{-0.022}$</td>
<td>$0.04^{+0.01}_{-0.00}$</td>
<td></td>
</tr>
<tr>
<td>$\bar{B}^0 \rightarrow \rho^0 \rho^0$</td>
<td>$0.9^{+1.5+1.1}_{-0.4-0.2}$</td>
<td>$0.68 \pm 0.27$</td>
<td>$0.92^{+0.06+1.0}_{-0.36}$</td>
<td>$0.70 \pm 0.15$</td>
<td>$0.04^{+0.14}_{-0.03}$</td>
<td></td>
</tr>
<tr>
<td>$B^ - \rightarrow \rho^- \omega$</td>
<td>$19.2^{+3.3+1.7}_{-1.6-1.0}$</td>
<td>$10.6^{+2.8}_{-2.3}$</td>
<td>$0.96^{+0.02}_{-0.02}$</td>
<td>$0.82 \pm 0.11$</td>
<td>$0.02 \pm 0.01$</td>
<td></td>
</tr>
<tr>
<td>$\bar{B}^0 \rightarrow \rho^0 \omega$</td>
<td>$0.1^{+0.1+0.4}_{-0.1-0.0}$</td>
<td>$&lt; 1.5$</td>
<td>$0.55^{+0.47}_{-0.29}$</td>
<td>$0.22^{+0.16}_{-0.23}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B^ - \rightarrow K^{*0} \rho^- a$</td>
<td>$9.2^{+1.2+3.6}_{-1.1-5.4}$</td>
<td>$9.2 \pm 1.5$</td>
<td>$0.48^{+0.52}_{-0.40}$</td>
<td>$0.48 \pm 0.08$</td>
<td>$0.26^{+0.20}_{-0.26}$</td>
<td></td>
</tr>
<tr>
<td>$B^ - \rightarrow K^{*-} \rho^0 b$</td>
<td>$5.5^{+0.6+1.3}_{-0.5-2.5}$</td>
<td>$&lt; 6.1$</td>
<td>$0.67^{+0.31}_{-0.48}$</td>
<td>$0.96^{+0.06}_{-0.16}$</td>
<td>$0.16^{+0.24}_{-0.15}$</td>
<td></td>
</tr>
<tr>
<td>$\bar{B}^0 \rightarrow K^{*-} \rho^+$</td>
<td>$8.9^{+1.1+4.8}_{-1.0-5.5}$</td>
<td>$&lt; 12$</td>
<td>$0.53^{+0.45}_{-0.32}$</td>
<td>$0.24^{+0.16}_{-0.22}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{B}^0 \rightarrow K^{*0} \rho^0$</td>
<td>$4.6^{+0.6+3.5}_{-0.5-3.5}$</td>
<td>$5.6 \pm 1.6$</td>
<td>$0.39^{+0.60}_{-0.31}$</td>
<td>$0.57 \pm 0.12$</td>
<td>$0.30^{+0.15}_{-0.30}$</td>
<td></td>
</tr>
<tr>
<td>$B^ - \rightarrow K^{*0} \phi c$</td>
<td>$10.0^{+1.4+12.3}_{-1.3-6.1}$</td>
<td>$10.0 \pm 1.1$</td>
<td>$0.49^{+0.51}_{-0.42}$</td>
<td>$0.50 \pm 0.05$</td>
<td>$0.25^{+0.21}_{-0.25}$</td>
<td></td>
</tr>
<tr>
<td>$\bar{B}^0 \rightarrow \bar{K}^{*0} \phi$</td>
<td>$9.5^{+1.3+11.9}_{-1.2-5.9}$</td>
<td>$9.5 \pm 0.8$</td>
<td>$0.50^{+0.50}_{-0.42}$</td>
<td>$0.484 \pm 0.034$</td>
<td>$0.25^{+0.21}_{-0.25}$</td>
<td></td>
</tr>
<tr>
<td>$B^ - \rightarrow K^{*-} \phi$</td>
<td>$3.5^{+1.5+3.0}_{-0.4-1.7}$</td>
<td>$&lt; 3.4$</td>
<td>$0.66^{+0.32}_{-0.38}$</td>
<td>$0.17^{+0.20}_{-0.17}$</td>
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<tr>
<td>$\bar{B}^0 \rightarrow \bar{K}^{*-} \phi$</td>
<td>$3.0^{+0.5+2.9}_{-0.4-1.8}$</td>
<td>$&lt; 2.7$</td>
<td>$0.57^{+0.44}_{-0.46}$</td>
<td>$0.21^{+0.25}_{-0.22}$</td>
<td></td>
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<tr>
<td>$B^ - \rightarrow K^{<em>0} K^{</em>-} d$</td>
<td>$0.6^{+0.1+0.3}_{-0.1-0.3}$</td>
<td>$&lt; 71$</td>
<td>$0.45^{+0.55}_{-0.38}$</td>
<td>$0.27^{+0.19}_{-0.27}$</td>
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<tr>
<td>$\bar{B}^0 \rightarrow K^{<em>-} K^{</em>+}$</td>
<td>$0.1^{+0.0+0.1}_{-0.0-0.1}$</td>
<td>$&lt; 141$</td>
<td>$1$</td>
<td>$0$</td>
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<tr>
<td>$\bar{B}^0 \rightarrow K^{*0} \bar{K}^{*0}$</td>
<td>$0.6^{+0.1+0.2}_{-0.1-0.3}$</td>
<td>$1.28^{+0.37}_{-0.32}$</td>
<td>$0.52^{+0.48}_{-0.48}$</td>
<td>$0.80^{+0.12}_{-0.13}$</td>
<td>$0.24^{+0.24}_{-0.24}$</td>
<td></td>
</tr>
</tbody>
</table>

Free parameters in the models taken from experiment from J. Smith @ FPCP 2009
<table>
<thead>
<tr>
<th>Decay</th>
<th>$B$</th>
<th>Expt</th>
<th>$f_L$</th>
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<th>$f_\perp$</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$B^- \rightarrow \rho^- \rho^0$</td>
<td>$20.0_{-1.9}^{+4.0} \pm 2.0$</td>
<td>$24.0 \pm 2.0$</td>
<td>$0.96_{-0.02}^{+0.02}$</td>
<td>$0.950_{-0.016}^{+0.016}$</td>
<td>$0.02 \pm 0.01$</td>
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<td>$25.5_{-2.6}^{+1.5} \pm 2.4$</td>
<td>$24.2 \pm 3.1$</td>
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<td>$0.9_{-0.4}^{+1.5} \pm 1.1$</td>
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<tr>
<td>$B^- \rightarrow \rho^- \omega$</td>
<td>$19.2_{-1.6}^{+3.3} \pm 1.7$</td>
<td>$15.9 \pm 2.1$</td>
<td>$0.96_{-0.02}^{+0.02}$</td>
<td>$0.90 \pm 0.06$</td>
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<td>$\bar{B}^0 \rightarrow K^{*-} \rho^+$</td>
<td>$8.9_{-1.0}^{+1.1} \pm 4.8$</td>
<td>$&lt; 12$</td>
<td>$0.53_{-0.32}^{+0.45}$</td>
<td>$&lt; 12$</td>
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<td>$0.30_{-0.30}^{+0.15}$</td>
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<td>$2.0 \pm 0.5$</td>
<td>$0.21_{-0.22}^{+0.25}$</td>
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<tr>
<td>$B^- \rightarrow K^{<em>0} K^{</em>-}$</td>
<td>$0.6_{-0.1}^{+0.1} \pm 0.3$</td>
<td>$1.2 \pm 0.5$</td>
<td>$0.45_{-0.38}^{+0.55}$</td>
<td>$0.75_{-0.26}^{+0.16}$</td>
<td>$0.27_{-0.27}^{+0.19}$</td>
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</tr>
<tr>
<td>$\bar{B}^0 \rightarrow K^{<em>-} K^{</em>+}$</td>
<td>$0.1_{-0.0}^{+0.0} \pm 0.1$</td>
<td>$&lt; 2.0$</td>
<td>$0.57_{-0.46}^{+0.44}$</td>
<td>$&lt; 2.0$</td>
<td>$0$</td>
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<td>$\bar{B}^0 \rightarrow K^{*0} \bar{K}^{*0}$</td>
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<td>$1.28_{-0.32}^{+0.37}$</td>
<td>$0.52_{-0.48}^{+0.48}$</td>
<td>$0.80_{-0.13}^{+0.12}$</td>
<td>$0.24_{-0.24}^{+0.24}$</td>
<td></td>
</tr>
</tbody>
</table>

Free parameters in the models taken from experiment Excellent agreement

from J. Smith @ FPCP 2009
What about other spins?

- New measurements of $B \rightarrow V T$ modes from BaBar
  - No theory predictions!
  - $f_L(\omega K_2(1430)^*) \sim 0.5$
    but, $f_L(\phi K_2(1430)^*) \sim 0.9$ – why??

- Our understanding of $VV$ polarizations is clearly incomplete,
  not to mention $VT$...
Prelude and Varations

• (Prelude)
• (Theme I) Leptonic $B$ decays
  - $B^+ \rightarrow \tau^+ \nu$
  - $B^+ \rightarrow \ell^+ \nu(\gamma)$
  - $B \rightarrow \bar{D}^{(*)} \tau^+ \nu$
• (Theme II) Hadronic penguins
  - $\Delta S$ puzzle
  - $K\pi$ puzzle
  - $VV$ polarization puzzle
• (Coda) Summary & Outlook
Concluding Remarks

- **Status of the “tensions”**
  - There are several intriguing results from the $B$-factory experiments, indicating hints of something unknown
    * leptonic $B$ decays
    * hadronic penguin decays
  - NP or non-NP, we do not have clear understanding, yet.

- **What’s ahead**
  - The case for flavor physics in the LHC era is still compelling (*although I didn’t say a word about it*)
  - LHC experiments, especially LHCb will be great tools for heavy-flavor physics
  - But some aspects, e.g. modes with $\nu$’s and $\pi^0$’s will require next-generation $B$-factory (**Belle-II**)
on $B^+ \rightarrow \tau^+ \nu$

$\Delta f_B(LQCD) = 5\%$ (?)

for 50 ab$^{-1}$
assuming $\Delta |V_{ub}| = 0$ & $\Delta f_B = 0$

$2\sigma$ band for $r_H$
on $\Delta S$ puzzle

**Extrapolation:** $B \rightarrow \phi K^0$ at 50/ab

with present WA values

Compelling measurement in a clean mode

This would establish the existence of a NP phase
on $K\pi$ puzzle

e.g. Belle II, 50 ab$^{-1}$
“Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed”

–A. Soni@Super KEKB proto-collaboration meeting

A lesson from history

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

- Lev Okun, "The Vacuum as Seen from Moscow"

(1964) $B = 2 \times 10^{-3}$

A failure of imagination, or lack of patience?