SEARCHING FOR NEW PHYSICS VIA CP VIOLATION IN $B \rightarrow \pi \pi$

Based on work done in collaboration with Nita Sinha and Rahul Sinha.

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NEW PHYSICS
- can compete with SM loop-level amplitudes

$B_d - \bar{B}_d$ mixing $\not\rightarrow b \rightarrow d$ FCNC
$b \rightarrow d$ penguin

$B_\pm - \bar{B}_\mp$ mixing $\not\rightarrow b \rightarrow s$ FCNC
$b \rightarrow s$ penguin

Several clean, direct tests of NP in $b \rightarrow s$:

- $B^+ \rightarrow D^+ K$ vs. $B_\pm (s) \rightarrow D_{\pm}^\mp K^\mp$
- $B_d (t) \rightarrow \Upsilon K_5$ vs. $B_d (t) \rightarrow \phi K_5$
- $B_\pm (t) \rightarrow \Upsilon \phi$
QUESTION: ARE THERE CLEAN, DIRECT TESTS FOR $W$ $b \to d$ FCNC?

\[ b \to d, \text{ penguin:} \]

\[ A_{\text{penguin}}^{(1)} \]

\[ \text{Asym} \left( B_d \to K^0 \bar{K}^0 \right) = 0 \]

\[ \text{Asym} \left( B_s \to \phi K_s \right) = \sin 2\beta \]
\[ \frac{P_u}{e^{i\gamma}} V_{ub} V_{ud} + \frac{P_c}{e^{i\phi}} V_{cb} V_{cd} + \]  

**Question:** Can one cleanly measure the weak phase of the \( t \)-quark contribution to the \( b \rightarrow d \) penguin?  

**Answer:** No. (D.L., R. Sinha, N. Sinha)
It is impossible to cleanly test for N.P. in the $b \to d$ FCNC.

But: can test for N.P. if we make a single assumption about the theoretical (hadronic) parameters describing the decay.

(D.L., N. Sinha, R. Sinha)

Apply this to $B \to \pi\pi\pi$, which suffers from penguin "pollution."

Measurements of $B \to \pi\pi\pi$, combined with a prediction for $|P/T|$, allow one to probe new physics in the $b \to d$ penguin.
ISOSPIN ANALYSIS OF $B \rightarrow \pi \pi$:

$$A^f = e^{i \theta} \text{Amp}(B \rightarrow f); \quad \overline{A}^f = e^{-i \theta} \text{Amp}(\overline{B} \rightarrow f)$$

$$\Gamma(B_d^0 (u) \rightarrow \pi^+ \pi^-) = e^{-\frac{1}{\tau} \left[ \frac{1}{2} (A^+ \overline{A}^- + 1 \overline{A}^+ \overline{A}^- 2) + \frac{1}{2} (A^+ \overline{A}^+ - 1 \overline{A}^+ \overline{A}^- 2) \right] \cos \Delta m t}$$

$$- \Im (A^+ \overline{A}^-) \sin \Delta m t$$

$\Rightarrow$ measure 3 observables:

$$B^{++} \equiv \frac{1}{2} (1A^+ \overline{A}^- 2 + 1 \overline{A}^+ \overline{A}^- 2)$$

$$\chi_{\text{dir}} \equiv \frac{1A^+ \overline{A}^+ - 1 \overline{A}^+ \overline{A}^- 2}{1A^+ \overline{A}^- 2 + 1 \overline{A}^+ \overline{A}^- 2}$$

$$2 \chi_{\text{eff}} \equiv \text{Arg} (A^+ \overline{A}^-)$$

$\Rightarrow$ similarly, can also measure

$$B^0, \quad \chi_{\text{dir}} \quad \text{in} \quad B_d \rightarrow \pi^0 \pi^0$$

$$B^{+0} \quad \text{in} \quad B^+ \rightarrow \pi^+ \pi^0$$
\[ A^+ = T e^{i \delta} e^{-i \chi} + P e^{i \delta} e^{-i \chi} \]

**ISOSPIN ANALYSIS CONTAINS ENOUGH INFORMATION TO DETERMINE ALL THE THEORETICAL PARAMETERS: T, P, etc.

In particular,

\[ r^2 = \frac{p^2}{T^2} = \frac{1 - \sqrt{1 - (\alpha_{\text{fin}})^2} \cos (2 \chi - 2 \chi_{\text{eff}})}{1 - \sqrt{1 - (\alpha_{\text{fin}})^2} \cos 2 \chi_{\text{eff}}} \]

**IF THERE IS NEW PHYSICS,**

\[ A^+ = T e^{i \delta} e^{-i \chi} + P e^{i \delta} e^{-i \chi} \]

\[ r^2 = \frac{p^2}{T^2} = \frac{1 - \sqrt{1 - (\alpha_{\text{fin}})^2} \cos (2 \chi_{\text{fin}} - 2 \chi_{\text{eff}})}{1 - \sqrt{1 - (\alpha_{\text{fin}})^2} \cos (2 \theta_{\text{fin}} - 2 \chi_{\text{eff}})} \]

\[ \text{given measurements of } \alpha_{\text{fin}}, \text{ and predictions for } \frac{p}{T}, \text{ can extract } \theta_{\text{fin}}. \]
IN PRACTICE, MORE COMPLICATED:

(i) $\exists$ range for $r \equiv \frac{p_T}{r}$:

$0.07 \leq r \leq 0.23$ (Fleischer, Mannel, 1997)

$r = 0.3 \pm 0.1$ (Gorman, this conference)

$r = 27\%$ (PACD, Y-Y, KEUM, this conference)

WE TAKE: $0.05 \leq r \leq 0.50$

(ii) 2nd: can come from

- isospin analysis
- Dalitz-plot analysis of $B \to \rho\pi$
- $\Delta = \pi - \rho - \gamma$ [holds even in the presence of new physics.]

Ideally, we will have information about 2nd from all of these sources.
Experimental errors can mask the presence of a nonzero $\Theta_{np}$.

To approximate this effect, we take $2\Delta$ to lie in a range.

Two illustrative choices:

(a) $120^\circ - 135^\circ$
(b) $165^\circ - 180^\circ$

The procedure is now as follows:

Given measurements of $\Theta_{\text{dir}}$ and $2\Delta_{4\nu}$, and assuming that $2\Delta$ lies in range (a) or (b), see if $\Theta_{np} = 0$ gives $r$ in allowed range. If not, this indicates new physics.
We consider 5 scenarios for \( B_d^- \rightarrow \pi^+ \pi^- \) and \( B^+ \rightarrow \pi^+ \pi^- \) measurements:

<table>
<thead>
<tr>
<th>Case</th>
<th>( a_{dir} )</th>
<th>( B^{00}/B^{++} )</th>
<th>( B^{0+}/B^{++} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>-1 - 1</td>
<td>any value</td>
<td>any value</td>
</tr>
<tr>
<td>Case B</td>
<td>-1 - 1</td>
<td>0 - 0.1</td>
<td>0.8 - 0.9</td>
</tr>
<tr>
<td>Case C</td>
<td>0.5 - 0.7</td>
<td>0.7 - 0.8</td>
<td>0 - 0.5</td>
</tr>
<tr>
<td>Case D</td>
<td>0.6 - 1</td>
<td>0.2 - 0.4</td>
<td>0.6 - 0.7</td>
</tr>
<tr>
<td>Case E</td>
<td>0.6 - 1</td>
<td>0.2 - 0.4</td>
<td>0.2 - 0.3</td>
</tr>
</tbody>
</table>

Note: Scenario A: no info

Scenario B: info about \( B^{00} \); upper limit on \( B^{0+} \); no info on \( a_{dir}^{00} \)

In a given scenario, generate values for \( a_{dir}^{++} \), \( 2 \times 10^5 \) in full allowed range \((-1 \text{ to } +1)\), and values for \( a_{dir}^{00}, B^{0+}/B^{++} \) \( B^{0+}/B^{++} \) in specified range in scenario.

(Generated \( 10^5 \) sets of values)
IF A GIVEN SET OF VALUES

(2) REPRODUCES MEASURED VALUE OF
2x (IN ALLOWED RANGE) USING ISOSPIN
AND
(3) GIVES $r^2$ IN THEORETICAL RANGE

THEN IT'S CONSISTENT WITH SM.
OTHERWISE: NEW PHYSICS

<figure>

CONSIDER SCENARIO A [NO INFO
ABOUT $B_d^0 \rightarrow \pi^0 \pi^0$ AND $B^+ \rightarrow \pi^+ \pi^0$] : CAN
FIND NEW PHYSICS, THOUGH ONLY
$B_d^0 (\pi) \rightarrow \pi^+ \pi^-$ MEASURED!
CONCLUSION:

- new physics affects CP violation in B system through loop-level processes: B-$\bar{B}$ mixing, penguin diagrams

- new physics in $b\rightarrow s$ FCNC relatively easy to detect; new physics in $b\rightarrow d$ FCNC may be hard to detect.

- $B \rightarrow \pi\pi$ system can be used to detect new physics in $b\rightarrow d$ FCNC. Need one piece of theoretical input = IP/T1.

- Note: don't need $B^{0}\rightarrow \pi^{0}\nu\nu$, $B^{+}\rightarrow \pi^{+}\nu\nu$ measurements if $\chi$ is obtained independently. Ideally, will have independent info AND isospin analysis.