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

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

NEW PHYSICS

- can compete with SM loop-level amplitudes

$$\left.\begin{array}{l} B_d - \bar{B}_d \text{ mixing} \\ b \to d \text{ penguin} \end{array}\right\} \quad b \to d \text{ FCNC}$$

$$\left.\begin{array}{l} B_s - \bar{B}_s \text{ mixing} \\ b \to s \text{ penguin} \end{array}\right\} \quad b \to s \text{ FCNC}$$

$\exists$ several clean, direct tests of NP in $b \to s$:

- $B^\pm \to D^\pm K$ vs. $B_s(t) \to D_s^\pm K^\mp$ [γ/ϕ_3]
- $B_d(t) \to \psi K_s$ vs. $B_d(t) \to \phi K_s$ [β/ϕ_1]
- $B_s(t) \to \psi\phi$ [0]

QUESTION: ARE THERE CLEAN, DIRECT TESTS FOR N.P. IN $b \to d$ FCNC?

- $b \to d$ penguin:

$$A^{(d)}_{peng} \sim \quad P_t \underbrace{V^*_{tb} V_{td}}_{\sim e^{-i\beta}}$$

$$\mathrm{Asym}\left(B_d(t) \to K^0 \bar{K}^0\right) = 0$$

$$\mathrm{Asym}\left(B_s(t) \to \phi K_S\right) = \sin 2\beta$$

$$P_u \underbrace{V_{ub}^{*} V_{ud}}_{\sim e^{i\gamma}} + P_c \underbrace{V_{cb}^{*} V_{cd}}_{\sim e^{i(0)}} +$$

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 $b \Rightarrow d$ FCNC.

BUT: <u>CAN</u> 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 $B \Rightarrow \pi\pi$, WHICH SUFFERS FROM PENGUIN "POLLUTION."

→ MEASUREMENTS OF $B \Rightarrow \pi\pi$, COMBINED WITH A PREDICTION FOR $|P/T|$, ALLOW ONE TO PROBE NEW PHYSICS IN THE $b \to d$ PENGUIN.

ISOSPIN ANALYSIS OF $B \to \pi\pi$:

$$A^f \equiv e^{i\beta} \, Amp(B \to f) \; ; \; \bar{A}^f \equiv e^{-i\beta} \, Amp(\bar{B} \to f)$$

$$\Gamma(B_d^0(t) \to \pi^+\pi^-) = e^{-\Gamma t} \left[\frac{|A^{+-}|^2 + |\bar{A}^{+-}|^2}{2} + \frac{|A^{+-}|^2 - |\bar{A}^{+-}|^2}{2} \cos \Delta M t \right.$$

$$\left. - \operatorname{Im}(A^{+-*} \bar{A}^{+-}) \sin \Delta M t \right]$$

→ measure 3 observables:

$$\left.\begin{array}{l}
B^{+-} \equiv \frac{1}{2}(|A^{+-}|^2 + |\bar{A}^{+-}|^2) \\[2ex]
a_{dir}^{+-} \equiv \dfrac{|A^{+-}|^2 - |\bar{A}^{+-}|^2}{|A^{+-}|^2 + |\bar{A}^{+-}|^2} \\[2ex]
2\alpha_{eff} \equiv \operatorname{Arg}(A^{+-*} \bar{A}^{+-}) \\[2ex]
\text{→ similarly, can also measure} \\[1ex]
B^{00}, \; a_{dir}^{00} \quad \text{in} \quad \overset{(-)}{B}_d \to \pi^0\pi^0 \\[1ex]
B^{+0} \quad \text{in} \quad B^+ \to \pi^+\pi^0
\end{array}\right\} \text{6 observables}$$

SM: $A^{+-} = T e^{i\delta} e^{-i\alpha} + P e^{i\delta_P}$

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

In particular,

$$r^2 \equiv \frac{P^2}{T^2} = \frac{1 - \sqrt{1-(a_{dir}^{+-})^2}\cos(2\alpha - 2\alpha_{eff})}{1 - \sqrt{1-(a_{dir}^{+-})^2}\cos 2\alpha_{eff}} .$$

IF $\exists$ NEW PHYSICS,

$$A^{+-} = T e^{i\delta} e^{-i\alpha} + P e^{i\delta_P} e^{-i\theta_{NP}}$$

$$\rightarrow r^2 = \frac{P^2}{T^2} = \frac{1 - \sqrt{1-(a_{dir}^{+-})^2}\cos(2\alpha - 2\alpha_{eff})}{1 - \sqrt{1-(a_{dir}^{+-})^2}\cos(2\theta_{NP} - 2\alpha_{eff})}$$

$\therefore$ given measurements of a_{dir}^{+-}, $2\alpha_{eff}$, 2α

$\boxed{\text{AND}}$ prediction for P/T, can extract θ_{NP}.

IN PRACTICE, MORE COMPLICATED:

(i) $\exists$ range for $r \equiv P/T$:

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

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

$r \sim 27\%$ (PQCD, Y-Y. KEUM, this conference)

WE TAKE: $\boxed{0.05 \leq r \leq 0.50}$

(ii) 2α: can come from

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

Ideally, we will have information about 2α from <u>all</u> of these sources.

(iii) EXPERIMENTAL ERRORS: CAN MASK THE PRESENCE OF A NONZERO θ_{NP}.

- TO APPROXIMATE THIS EFFECT, WE TAKE 2α 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 a_{dir}^{+-} AND $2\alpha_{eff}$, AND ASSUMING THAT 2α 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 $B_d^0 \to \pi^0\pi^0$ AND $B^+ \to \pi^+\pi^0$ MEASUREMENTS:

	a_{dir}^{00}	B^{00}/B^{+-}	B^{+0}/B^{+-}
Case A	$-1 - 1$	any value	any value
Case B	$-1 - 1$	$0 - 0.1$	$0.8 - 0.9$
Case C	$0.5 - 0.7$	$0.7 - 0.8$	$0 - 0.5$
Case D	$0.6 - 1$	$0.2 - 0.4$	$0.6 - 0.7$
Case E	$0.6 - 1$	$0.2 - 0.4$	$0.2 - 0.3$

NOTE: SCENARIO A: NO INFO

SCENARIO B: INFO ABOUT B^{+0}; UPPER LIMIT ON B^{00}; NO INFO ON a_{dir}^{00}

• IN A GIVEN SCENARIO, GENERATE VALUES FOR a_{dir}^{+-}, $2\alpha_{eff}$ IN FULL ALLOWED RANGE (-1 to $+1$), AND VALUES FOR a_{dir}^{00}, B^{00}/B^{+-}, B^{+0}/B^{+-} IN SPECIFIED RANGE IN SCENARIO.

(GENERATED 10^5 SETS OF VALUES)

IF A GIVEN SET OF VALUES

(i) REPRODUCES MEASURED VALUE OF 2α (IN ALLOWED RANGE) USING ISOSPIN

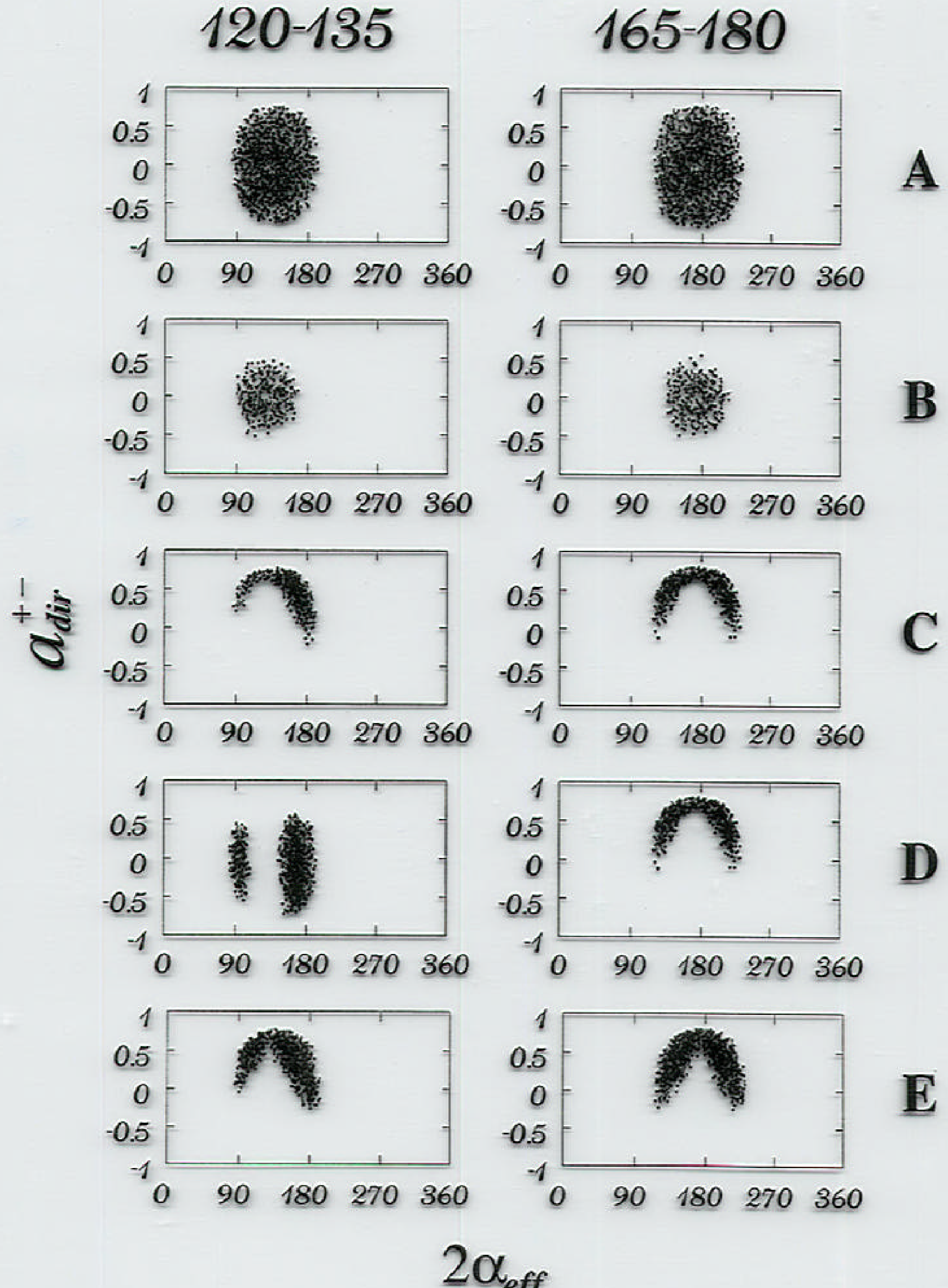
$\boxed{\text{AND}}$ (ii) GIVES r^2 IN THEORETICAL RANGE

THEN IT'S CONSISTENT WITH SM.

OTHERWISE: NEW PHYSICS

<figure>

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



120-135
165-180
A
B
C
D
E
a_{dir}^{+-}
$2\alpha_{eff}$
1
0.5
0
-0.5
-1
0
90
180
270
360

CONCLUSION:

- new physics affects CP violation in B system through loop-level processes: $B-\bar{B}$ mixing, penguin diagrams
- new physics in $b \to s$ FCNC relatively easy to detect; new physics in $b \to d$ FCNC may be hard to detect.
- $B \to \pi\pi$ system can be used to detect new physics in $b \to d$ FCNC. Need one piece of theoretical input – $|P/T|$.
- Note: don't need $B^0 \to \pi^0\pi^0$, $B^+ \to \pi^+\pi^0$ measurements if α is obtained independently. Ideally, will have independent info AND isospin analysis.