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α, γ and Beyond

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XIV Rencontres De Blois
Matter-Antimatter Asymmetry

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Outline

I) B Factories confront the CKM Paradigm

- **a)** $\sin 2\beta$: Today and Tomorrow
- **b)** Cautious on Theory
  - **1)** $B_K \sim 10$–15% below previously thought
  - **2)** ξ lattice determination problematic

II) Existing Prominent Methods for α (and possible problems?)

- **a)** Gronau & London (PRL '90)
- **b)** Quinn *et al.* (PRD '93)

III) γ without Penguins (Atwood, Dunietz, Soni, PRL '97, PRD00)

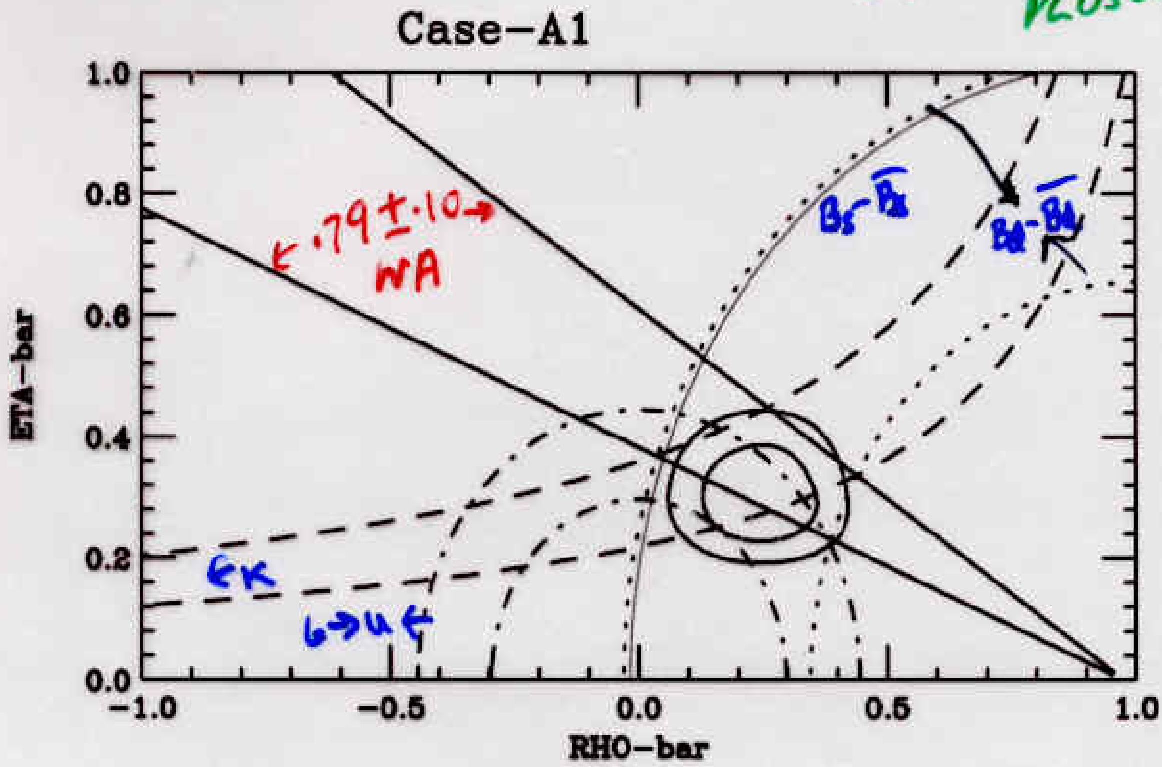
IV) α (and β?) without Penguins (Atwood & Soni, hep-ph/0206045)

V) χ (BSM phase): Strategies for Model Independent Searches

VI) Summary

WONDERS of the KOBAYASHI-MASKAWA MECHANISM of $\not{CP}$

ATWOOD + AS
PLB508, 17(01)



$\not{CP}$ Asymmetry in $B \to \psi K_S$: $\sin 2\phi \overset{SM}{=} .70 \pm .10$

Indirect " in $K_L \to \pi\pi$ $\epsilon_K \approx 2.3 \times 10^{-3}$

$O(10^3)$

χ 7

Table 1: Comparison of some fits.

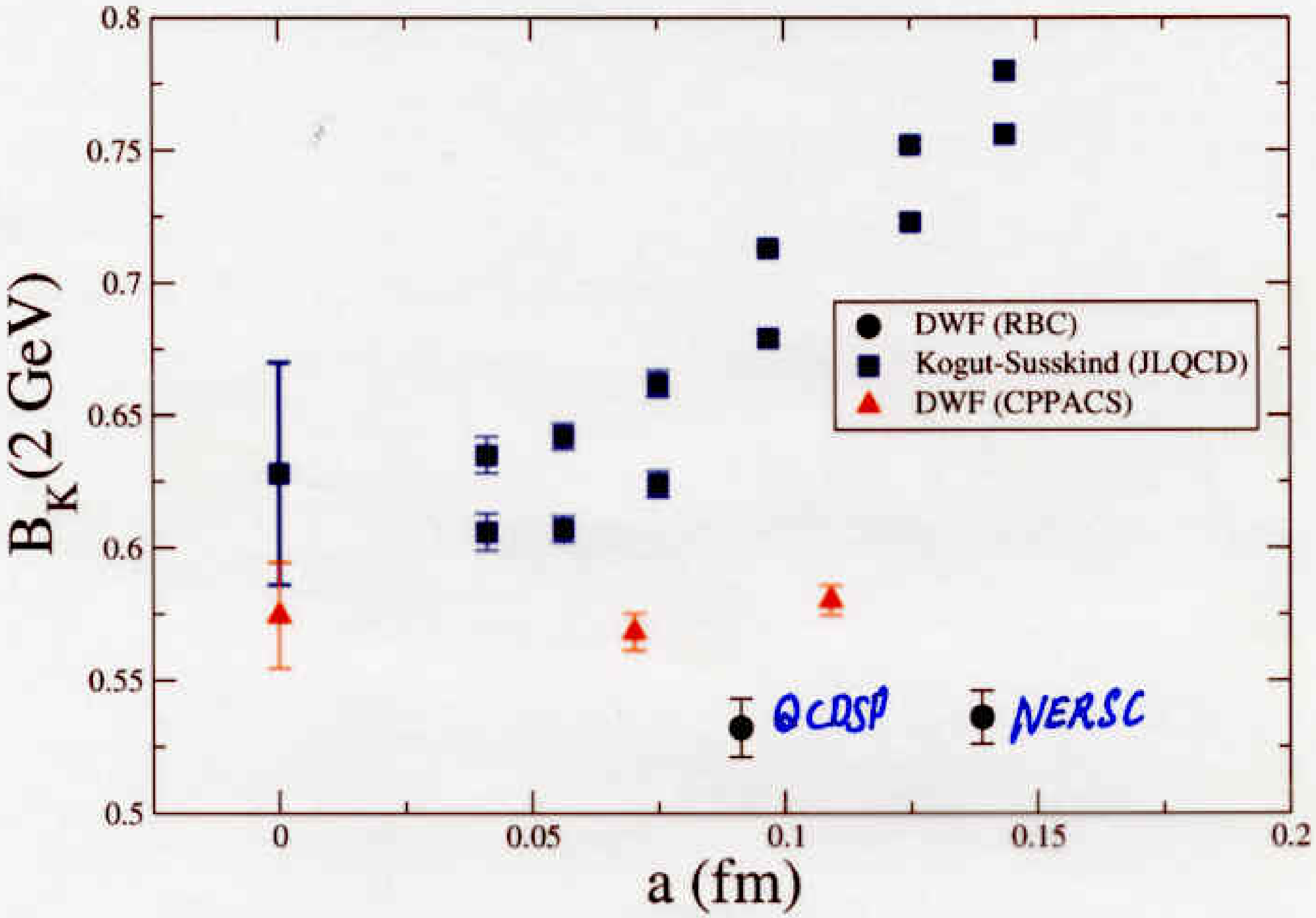
Input Quantity	Atwood & Soni (PL '01)	Ciuchini *et al* (PL '01)	Hocker *et al* (PL '01)
$R_{uc} \equiv \lvert V_{ub}/V_{cb}\rvert$	$.085 \pm .017$	$.089 \pm .009$	$.087 \pm .006 \pm .014$
$F_{B_d}\sqrt{\hat{B}_{B_d}}$ MeV	230 ± 50	$230 \pm 25 \pm 20$	$230 \pm 28 \pm 28$
ξ	$1.16 \pm .08$	$1.14 \pm .04 \pm .05$	$1.16 \pm .03 \pm .05$
$\hat{B}_K$	$.86 \pm 0.15$	$.87 \pm 0.06 \pm 0.13$	$.87 \pm .06 \pm .13$
Output Quantity			
$\sin 2\beta$	$.70 \pm .10$	$.695 \pm .065$	$.68 \pm .18$
$\sin 2\alpha$	$-.50 \pm .32$	$-.425 \pm .220$	
γ	$46.2^\circ \pm 9.1^\circ$	54.85 ± 6.0	56 ± 19
$\bar{\eta}$	$.30 \pm .05$	$.316 \pm .040$	$.34 \pm .12$
$\bar{\rho}$	$.25 \pm .07$	$.22 \pm .038$	$.22 \pm .14$
$\lvert V_{td}/V_{ts}\rvert$	$.185 \pm .015$		$.19 \pm .04$
$\Delta m_{B_s} (ps^{-1})$	19.8 ± 3.5	$17.3^{+1.5}_{-0.7}$	24.6 ± 9.1
J_{CP}	$(2.55 \pm .35) \times 10^{-5}$		$(2.8 \pm .8) \times 10^{-5}$
$BR(K^+ \to \pi^+ \nu\bar{\nu})$	$(0.67 \pm 0.10) \times 10^{-10}$		$(.74 \pm .23) \times 10^{-10}$
$BR(K_L \to \pi^0 \nu\bar{\nu})$	$(0.225 \pm 0.065) \times 10^{-10}$		$(.27 \pm .14) \times 10^{-10}$

$$\left.\begin{array}{l}\beta \sim 25^\circ \\ \gamma \sim 45^\circ \\ \alpha \sim 110^\circ\end{array}\right\}\text{ expectations}$$

The kaon B parameter B_K

$\overline{MS}$ scheme, $\mu \approx 2$ GeV

Leading error is a^2 in each case



(JLQCD: S. Aoki, *et al.*, PRL 80 (1998); CP-PACS: Ali-Khan, *et al.*, PRD 64, 114506;

RBC Collaboration: T. Blum *et al.*, hep-lat/0110075 (2001).)

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Renormalization group invariant B Parameter (NLO):

$$\hat{B}_K = \alpha_s(2)^{-2/9}\left(1 + \frac{\alpha_s(2)}{4\pi} J_3\right) B_K = 1.36919\, B_K$$

Buchalla, Buras, Lautenbacher, Rev. Mod. Phys. (1995)

Fermion type	$\hat{B}_K$ (quenched)
Kogut-Susskind	0.860 ± 0.058 (sys)
DWF	0.758 ± 0.033 (stat + sys)

↑ central value should be used for phen. Appl.

- Quenching ? $\pm$ 5%. (Partially quenched, scaling is a problem). χPT indicates this is a small effect.
- SU(3) breaking $(m_s \neq m_d)$? χPT $\sim +$ 4-8%

Reviews by A. Soni and S. Sharpe, NPB 47 and 53 (Proc. Suppl) (1996-1997)

B_d-$\bar{B}_d$ & B_s-$\bar{B}_s$ Osc. Frequency
DIRECT METHOD

(BBS PRD '98)

$$M_{B_D}(\mu) \equiv \langle \bar{B}_d | (\bar{b}\gamma_\rho(1-\gamma_5)d)(\bar{b}\gamma_\rho(1-\gamma_5)d) | B_d \rangle \equiv \frac{8}{3}\underbrace{f^2_{B_d} m_{B_d} B_{B_d}}_{\text{indirect}}$$

direct

$$\begin{aligned} x_{B_d} &\equiv \Delta m_{B_d}/\Gamma_{B_d} \\ &= \frac{G_F^2}{16\pi^2} M_W^2 \frac{\tau_{B_d}}{m_{B_d}} b(\mu)\eta_{QCD} S(x_t) M_{B_d}(\mu)|V_{td}|^2 \\ &= \frac{G_F^2}{16\pi^2} M_W^2 \tau_{B_d} m_{B_d} b(\mu)\eta_{QCD} S(x_t) B_{B_d}(\mu) f^2_{B_d}|V_{td}|^2 \end{aligned}$$

$$\frac{X_{B_d}}{X_{B_s}} = \frac{\tau_{B_d}}{\tau_{B_s}} \frac{m_{B_s}}{m_{B_d}} \frac{|V_{td}|^2}{|V_{ts}|^2} \left\{ \frac{M_{B_d}(\mu)}{M_{B_s}(\mu)} \equiv r_{sd}^{-1} \equiv \xi^{-2} \right\}$$

$\frac{X_{B_s}}{X_{B_d}}$ via "Indirect" Method (i.e. thru ξ) is now (almost) universally being used. Method grew from an historical accident. Concern is that practical implementation tends to underestimate SU(3) breaking. "DIRECT" method NEEDS NO EXTRA lattice computation. Two methods provide with diff systematics with littel extra cost.

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	$\frac{f_{B_s}}{f_B}$	ξ	indirect r_{sd} (avg ξ^2)	direct r_{sd}
Bernard, Blum, AS.	$1.17 \pm 2 \pm ^{12}_{6}$	$\Leftarrow$	$1.42 \pm 5 \pm ^{28}_{15}$	$1.76 \pm 10 \pm ^{57}_{42}$
Lellouch + Lim	$1.16 \pm 6 ^{+2}_{-3}$	$1.15 \pm 3 ^{+2}_{-3}$	$1.37 \pm 14 ^{+4}_{-6}$	$1.71 \pm 28 ^{+8}_{-11}$
HASHIMOTO here	$1.184 \pm 26 \pm 20 \pm 15$			
BERNARD LAT2000	1.16 ± 4	1.16 ± 8		

TO PLAY IT SAFE should take wt AV of DIRECT & Indirect

CIUCHINI et al $1.14 \pm .03 \pm .05$

ATWOOD + AS $1.16 \pm .10$

(ERRORS increased due to this concern) STILL MAY not be adequate.

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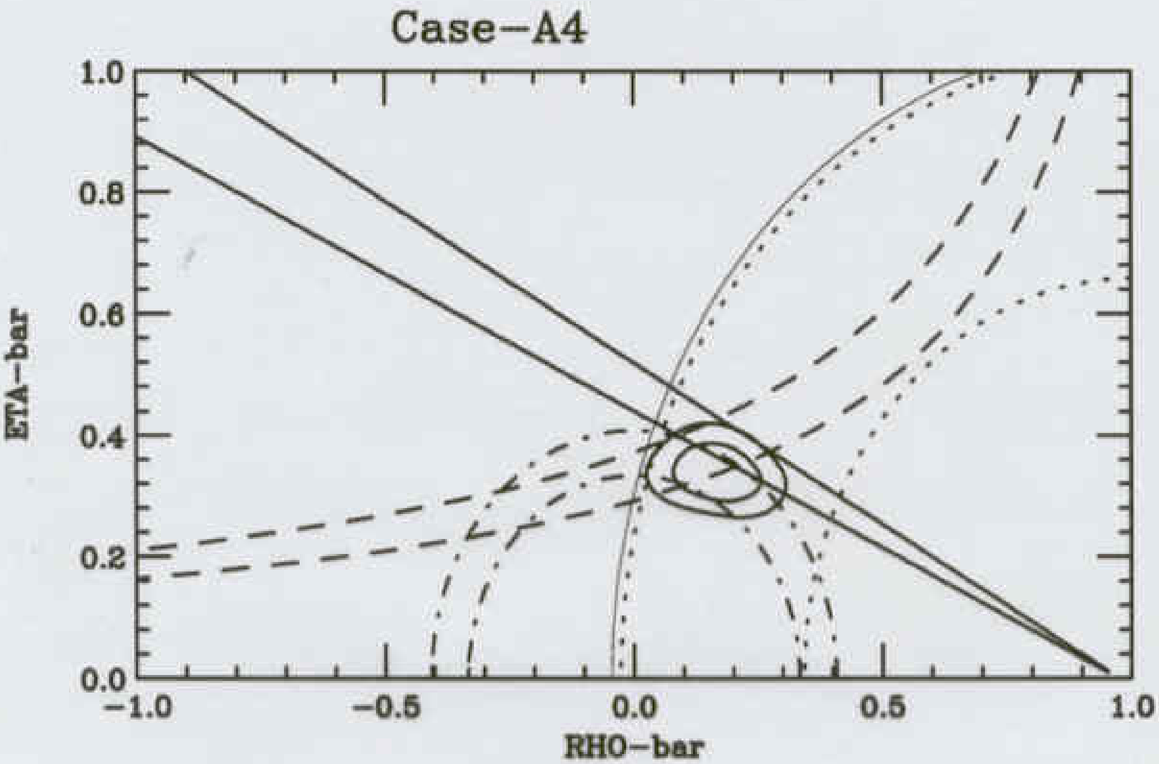
Stability of fits

Table 2: ~~Comparison of some fits~~.

Input Quantity	Atwood & Soni (PL '01)	New $\hat{B}_K$	New $\hat{B}_K$ + ξ
$R_{uc} \equiv \|V_{ub}/V_{cb}\|$	$.085 \pm .017$		
$F_{B_d}\sqrt{\hat{B}_{B_d}}$ MeV	230 ± 50 MeV		
ξ	$1.16 \pm .08$		$1.25 \pm .10$
$\hat{B}_K$	$.86 \pm 0.15$	$.75 \pm .13$	$.75 \pm .13$
Output Quantity			
$\sin 2\beta$	$.70 \pm .10$	$.73 \pm .10$	$.72 \pm .10$
$\sin 2\alpha$	$-.50 \pm .32$		
γ	$46.2^\circ \pm 9.1^\circ$	48.7 ± 8.5	52.3 ± 12.1
$\bar{\eta}$	$.30 \pm .05$	$.32 \pm .05$	$.33 \pm .05$
$\bar{\rho}$	$.25 \pm .07$		
$\|V_{td}/V_{ts}\|$	$.185 \pm .015$		
$\Delta m_{B_s} (ps^{-1})$	19.8 ± 3.5		
J_{CP}	$(2.55 \pm .35) \times 10^{-5}$		
$BR(K^+ \to \pi^+ \nu\bar{\nu})$	$(0.67 \pm 0.10) \times 10^{-10}$		
$BR(K_L \to \pi^0 \nu\bar{\nu})$	$(0.225 \pm 0.065) \times 10^{-10}$		

Futuristic



$V_{bc} = .04 \pm .001$

$\frac{V_{ub}}{V_{cb}} = .085 \pm .0085$

$\xi = 1.25 \pm .05$

$B_K = .751 \pm .065$

$\Rightarrow \sin 2\beta^{SM} = .71 \pm .05$

overlay $\sin 2\beta^{expt}$ $.79 \pm .04$

JUST IMPROVING $\sin 2\beta$ MAY NOT BE ENOUGH
MUST TARGET α & γ AS WELL

Beating γ to Death via $B^{\pm} \to K^{\pm} D$ (non-CP-ES)

(ATWOOD, DUNIETZ + A.S) PRL97; PRD00

Φ_3

1. Uniquely clean (No theoretical assumptions)
2. No EWP; in fact NO Penguins ⇒ ULTIMATE Theory error ~ 0.
3. Large Direct CP ~ tens of percents POSSIBLE
4. Time Dependent Measurement NOT Needed
5. Many Modes (only 2 essential)

Does need ~ 10^8–10^9 Bees

(As far as Theoretical cleanliness goes (see later) if this is not gold plated then what is?)

<u>Modes</u>

CLA * DCS ⟷ CLS * CBA
MAXIMAL Interference ⇒ LARGE CP

CLA * DCS

$$\begin{array}{l} B^- \to K^-(K^{-*}) + D^0 \\ B^- \to K^-(K^{-*}) + \bar{D}^0 \end{array} \Rightarrow K^+\pi^-, K^+\rho^-, K^+a_1^-, K^{*+}\pi^-$$

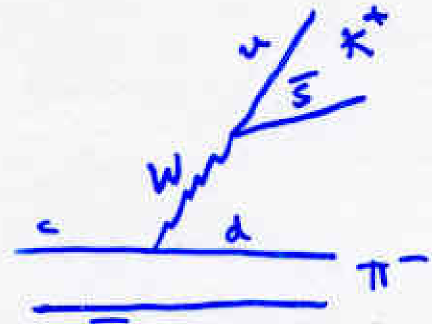
CLS * CBA

With a minimum of 2 modes, the method has 4 equations and 4 unknows:

$$2 \text{ strong phases}, \gamma, Br(B^- \to K^-\bar{D}^0)$$

Note this branching ratio is <u>not</u> accessible to direct experimental measurement a(K)

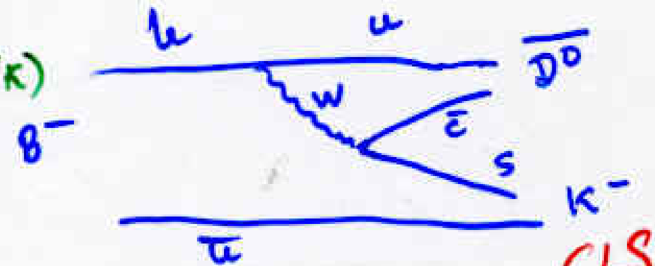
CLA



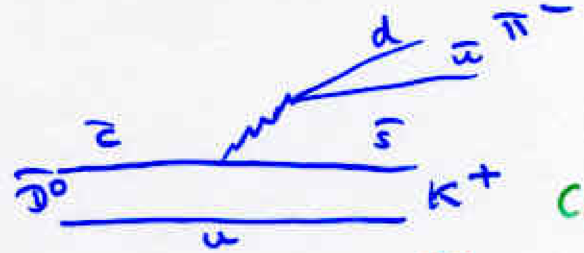
c(fi)

DCS

b(K)



CLS



$c(\bar{f_i})$

CBA

BASIC Eq^{ns} $\quad$ $i = 1, 2$ $\quad$ 4 Eq^{ns}

$$d(K, f_i) = a(K)\,c(f_i) + b(K)\,c(\bar{f_i}) + 2\sqrt{abc\bar{c}}\,\cos(\xi^K_{f_i} + \gamma)$$

$$\bar{d}(K, f_i) = a(K)\,c(f_i) + b(K)\,c(\bar{f_i}) + 2\sqrt{abc\bar{c}}\,\cos(\xi^K_{f_i} - \gamma)$$

$\xi^K_{f_1}$, $\xi^K_{f_2}$, $b(K)$, γ ← gem

4 unknowns

strong phases $\quad$ ↳ "unmeasurable" BR

[NOTE In SM $\;a(K) \equiv B(B^- \to K^- D^0) = \bar{a}(K) \equiv B(B^+ \to K^+ \overline{D^0})$

$\quad$ /// $\;\bar{b}(K) = b(K)$

$\quad$ ALSO $\;\bar{c}(f_i) = c(f_i)$ and $\bar{c}(\bar{f_i}) = c(\bar{f_i})$]

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Recall Gronau and Wyler use D^0_{CP}, small interference and small CP asymmetry.

More serious problem is that it requires six branching ratios:

$K^- D^0$, $K^- D^0_{CP}$ and $K^- \bar{D}^0$ + conjugates

However, recall that $Br(B \to K^- \bar{D}^0)$ CANNOT be experimentally measured.

1. Hadronic tag of $\bar{D}^0$ (say via $\bar{D}^0 \to K^+\pi^-$) suffers from $O(1)$ interference effects with the D^0 channel i.e. $B^- \to K^- D^0[\to K^+\pi^-]$

Indeed it is this large interference that makes ADS work and infact leads to large CP asymmetries in the ADS method.

2. Semileptonic tag via $\bar{D}^0 l^- \bar{\nu}_l X_{\bar{s}}$ suffers from very large background from $B^- \to l^- \bar{\nu}_l X_c$.

Interestingly although GW method cannot be used by itself, due to this difficulty, once ADS (CP non-eigenstates) is used $Br(B^- \to K^- \bar{D}^0)$ becomes an output of the ADS analysis then the GW (with CP eigenstates) may also be used.

FOR an illustrative example study in a MODEL Calculation

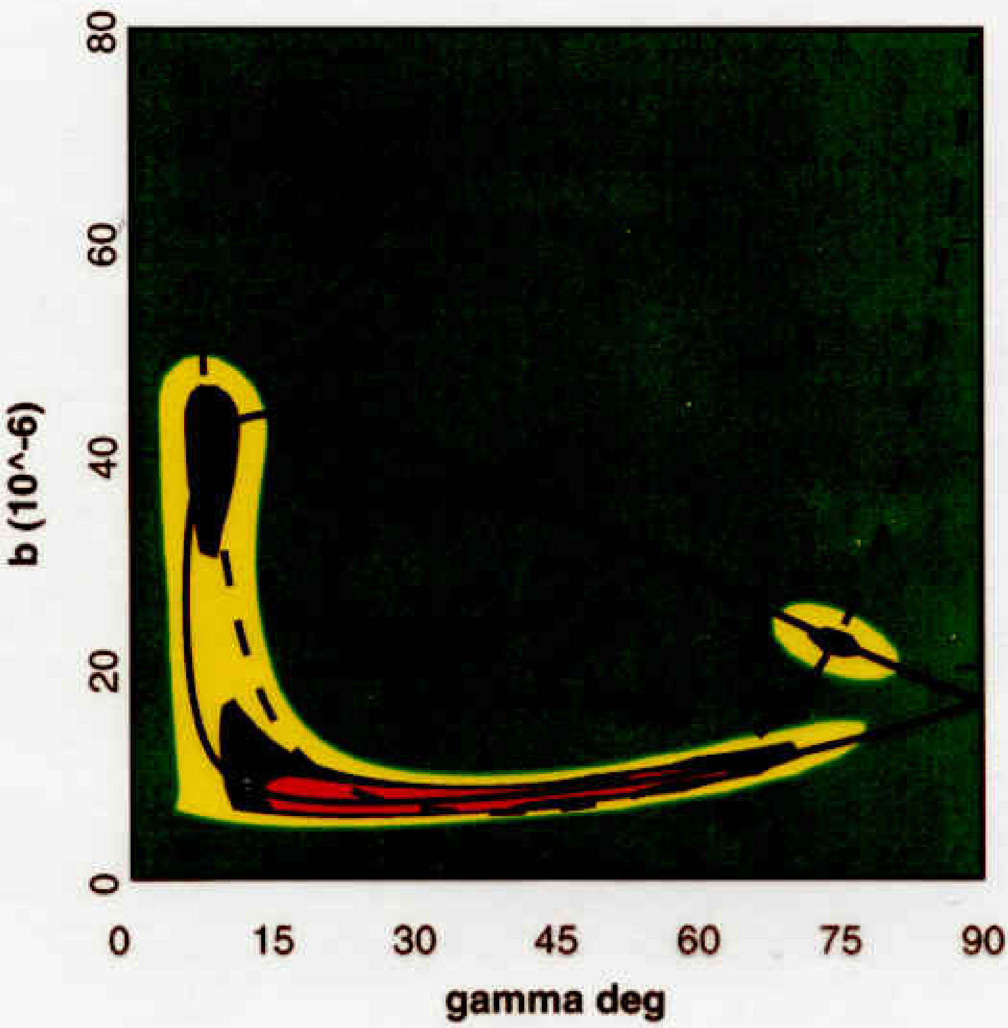
$B^- \to K^{*-} D^0$, with $D^0 \to$
- $K^+\pi^-$
- $K_S\pi^0$
- $K^+\rho^-$
- $K^+a_1^-$
- $K_S\rho^0$
- $K^{*+}\pi^-$

MODE	α' (PRA)
$K^+\pi^-$	9.6 %
$K_S\pi^0$	6.4 %
$K^+\rho^-$	28.8 %
$K^+a_1^-$	38.3 %
$K_S\rho^0$	8.1 %
$K^{*+}\pi^-$	47.7 %

$N_B^{3\sigma}$ (# of B-$\bar{B}$ needed for 3σ observability of CP)
for these modes $\Rightarrow (3 - 7) \times 10^7$
Detector efficiency <u>NOT</u> included.

- Just two modes used:
  - $K^+\pi^-$ (solid)
  - $K_s\pi^0$ (short dashes)
- Confidence regions assuming that $N_B(acceptance) = 10^8$: 99%; 90%; 68%

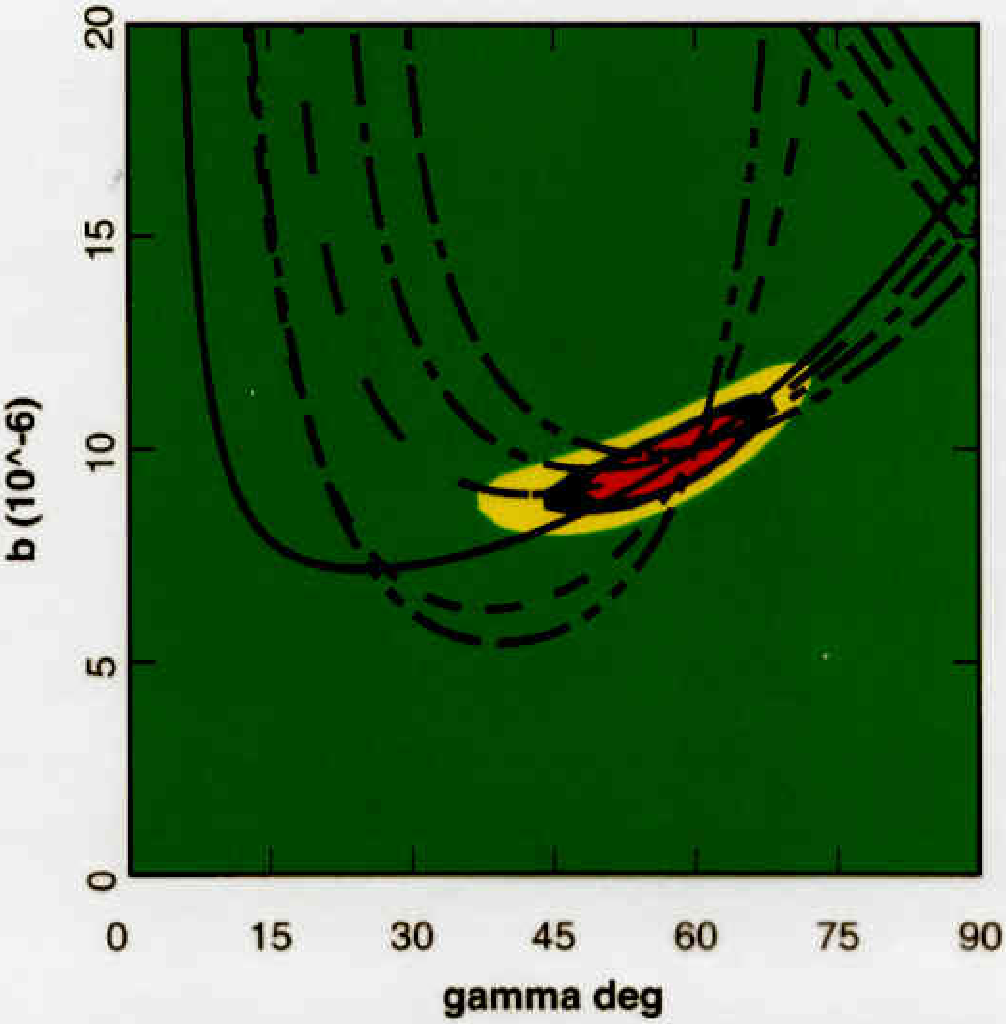
20 ~~23~~ ~~27~~
19 ~~28~~



ADS PRD00

~~25~~ 29 ~~21~~ 20

- ~~All the~~ MANY modes used:
- $K^+\pi^-$ (solid) $K_s\pi^0$ (short dashes)
  $K^+\rho^-$ (long dashes) $K^+a_1^-$ (dash-dot)
  $K_s\rho^0$ (dash-dot-dot) $K^{*+}\pi^-$ (dash-dash-dot)
- Confidence regions assuming that $N_B(acceptance) = 10^8$:
  99%; 90%; 68%

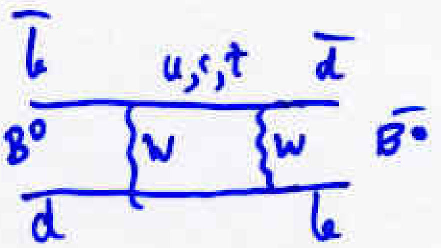


CP Phases in Time Dependent CP Asymmetry (TDCPA)

BIGI + Sanda

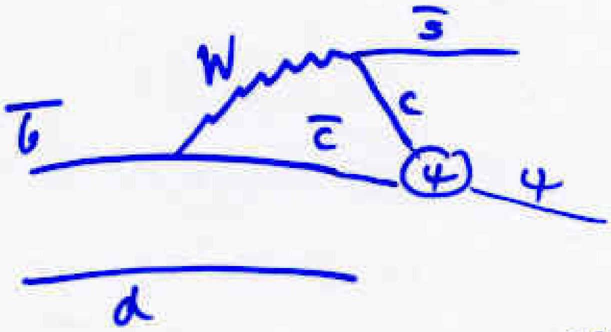
$B \to \psi K_S$

$B^0 - \bar{B}^0$ Mixing Phase



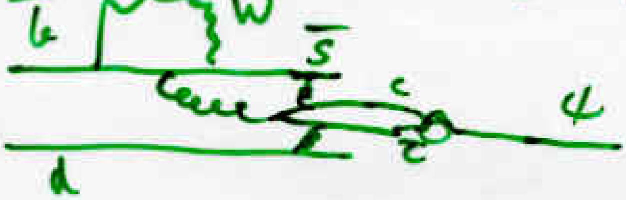
$\beta \equiv \mathrm{Arg}\, V_{td}$

$B^0 - \bar{B}^0 \to \psi K_S$



DOMINANT Tree Phase $\cancel{=}$ 0

Penguin Contribution extremely suppressed

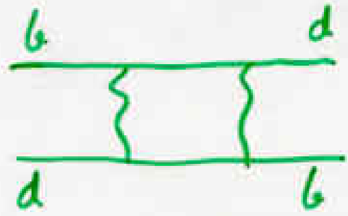


TDCPA in $B \to \psi K_S$ Measures $\sin 2\beta$ Very CLEANLY

α via $\pi\pi$, $\rho\pi$

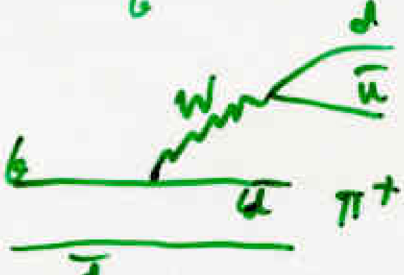
$B \to \pi^+\pi^-$

Mixing



$V_{td} \to \beta$

Decay : Tree



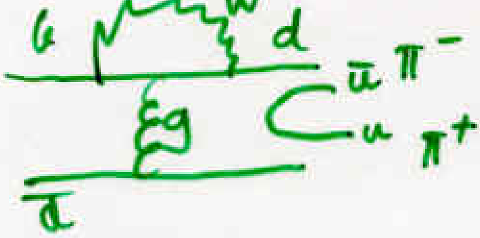
$V_{ub} \to \gamma$

$\Delta I_{Tree} = 1/2 + 3/2$

Mixing + Decay $\Rightarrow \alpha$

BUT Appreciable Penguin Contribution. ($P/T \sim 30\%$)

QCDP



$\Delta I_{QCDP} = 1/2$

GRONAU + LONDON isospin analysis

Need B decays to charged + neutral modes

including $B^0, \overline{B^0}(t) \to \pi^0\pi^0$ needed.

EXPTAL Difficulty

$2\pi^0$ makes FS Difficult

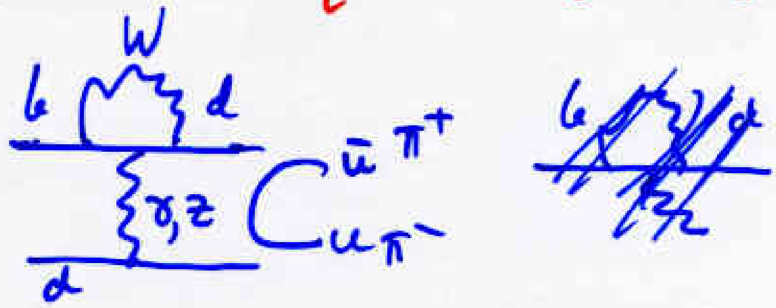
esp. so as $BR(B^0 \to \pi^0\pi^0) \sim 5\times10^{-7}$?

Recall $\dfrac{Br(B \to \psi K_s,\ \psi \to \ell^+\ell^-)}{Br(B \to \pi^0\pi^0)} \sim \dfrac{10^{-5}}{5\times10^{-7}} \sim 20$ of DETECTION Efficiency

MAY NEED $(10-50)\times10^8$ $B\bar{B}$

THEORETICAL DIFFICULTY [α VIA $B \to \pi\pi$]

EWP



NOT NEGLIGBLE

ISOSPIN ANALYSIS FAILS TO SUBTRACT EWP Contribution

EWP $\Delta I_{EWP} = 1/2 + 3/2$

(SAME AS Tree)

α from $B(t) \to \rho\pi$ QUINN et al

can use isospin analysis similar to $\pi\pi$

THEORETICAL DIFFICULTIES

(1) EWP contribution again spoils the isospin analysis

(2) $B \to 3\pi$ continuum needs to be separated from (resonant) $B \to \rho\pi$; necessitates modelling uncertainty

Needed # of $B\bar{B}$ pairs $\sim (5-25) \times 10^8$

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IV. α (and β?) without Penguins

ϕ_2 ϕ_1

Atwood & Soni, hep-ph/0206045

Basic Tool: Time-Dependent CP-Asymmetry (TDCPA) in $B^0(\bar{B}^0) \to K^0 D^0$, $K^0 \bar{D}^0$

History:

I. Gronau and London (only a brief mention) 1990; Branco, Lavoura, DeSilva (1999); Sanda (2002)

Compare TDCPA in $B^0 \to K_s D^0$ with $\bar{B}^0 \to K_s \bar{D}^0$ to get $\delta \equiv \beta - \alpha + \pi$.

Serious experimental difficulty in implementing as D^0, $\bar{D}^0$ flavor-tagging via semi-leptonic decays suffers from serious background from prompt semi-leptonic B-decays. Hadronic tag suffers from interference from doubly-Cabibbo suppressed decays.

Same problem as afflicts Gronau & Wyler extraction of γ via $B^\pm \to K^\pm D^0$.

II: Kayser and London '99; Rectify this with CPNES (solution exactly the same as ADS), e.g. $D^0 \to K^- \pi^+$

In principle, this is fine except suffers seriously from (8-fold) discrete ambiguities with poor determination.

We suggest significant improvements.

Improved method for getting $\delta \equiv \beta - \alpha + \pi$ without penguins. At least 3 ways:

1. $D^0(\bar{D}^0)$ decays to CPES; need include both CP-even and CP-odd FS to have enough observables.

   Sharp contrast with $B \to \psi K_S$, ψK_L wherein inclusion of K_L does *not* increase # of observables, only improves statistics. Herein, inclusion of CP-even and CP-odd final states increases the number of observables from 3 to

5 to render the system of equations solvable.
[4 UNKNOWNS : A, r_B, r_D, δ]

2. CPES & CPNES, each with exclusive mode(s) [NO. of OBS: 9 ; UNKNOWNS: 5 ↳ ONLY K_S] [INC. K_L Adds 2 MORE OBS]

3. Inclusive D^0 Decay,
   CPNES, $D^0 \to K^- + X (BR \sim 53\%)$
   CPES, $D^0 \to K^0 + X (BR \sim 21\%)$

4. $3 + 1$
   3 is especially effective

Note: Inclusion of both K_L and K_S final states for the CPNES case increases also the number of obserbables from 6 to 12 with 5 parameters:

$\{\hat{A}, r_B, \eta_B, \delta, \eta_D\}$

Or one may also include β as a parameter and solve for it too to provide an important check against the value obtained from $B \Rightarrow \psi K_S$

Formalism

[Use Wolfenstein representation for the CKM matrix]

For each f_i the four relevant amplitudes are:

$$\begin{aligned}
\mathcal{A}_1(f_i) &\equiv \mathcal{A}(\bar{B}^0 \to K_S[D^0 \to f_i]) = A \\
\mathcal{A}_2(f_i) &\equiv \mathcal{A}(B^0 \to K_S[\bar{D}^0 \to f_i]) = A r_D e^{+i\eta_D} \\
\mathcal{A}_3(f_i) &\equiv \mathcal{A}(\bar{B}^0 \to K_S[\bar{D}^0 \to f_i]) = A r_D r_B e^{+i(\eta_D+\eta_B-\gamma)} \\
\mathcal{A}_4(f_i) &\equiv \mathcal{A}(B^0 \to K_S[D^0 \to f_i]) = A r_B e^{+i(\eta_B+\gamma)} \qquad (1)
\end{aligned}$$

where, without loss of generality, we can choose the strong phase convention so that $\mathcal{A}_1 = A$ is real. The quantity r_D is the ratio $\left|\mathcal{A}(\bar{D}^0 \to f_i)/\mathcal{A}(D^0 \to f_i)\right|$ which we will assume is known from the study of D^0 decay. The strong phase $\eta_D(f_i) = arg\left(\mathcal{A}(\bar{D}^0 \to f_i)/\mathcal{A}(D^0 \to f_i)\right)$ we will assume to be not known apriori. Likewise the parameter r_B and the strong phase η_B given by

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$r_B e^{i\eta_B} = e^{-i\gamma} \mathcal{A}(B^0 \to K_S D^0)/\mathcal{A}(\bar{B}^0 \to K_S D^0)$ are also assumed to be not known apriori. Note that $\{r_D, \eta_D, A\}$ depend on the state f_i while $\{r_B, \eta_B\}$ are independent.

The time dependent decay rates for this decay is:

$$2\frac{d}{d\tau}\Gamma(B^0/\bar{B}^0(t) \to K_S F)$$

$$=\mathrm{e}^{-|\tau|}(X(F) + bY(F)\cos(x_B\tau) - bZ(F)\sin(x_B\tau))$$

where $F \equiv \{f_i\}$ and in general $F \neq \bar{F}$, $\tau = \Gamma_B t$ and $x_B = \Delta m_B/\Gamma_B$ while $b = +1$ for $B(t)$ and $b = -1$ for $\bar{B}(t)$. Defining $\mathcal{A}(f_i) = \mathcal{A}_2(f_i) + \mathcal{A}_4(f_i)$ and $\bar{\mathcal{A}}(f_i) = \mathcal{A}_1(f_i) + \mathcal{A}_3(f_i)$, the coefficients X, Y and Z in Eqn. (2) are given by:

(30)

$$2X(F) = \sum_i (|\mathcal{A}(f_i)|^2 + |\bar{\mathcal{A}}(f_i)|^2) \qquad (2)$$

$$2Y(F) = \sum_i (|\mathcal{A}(f_i)|^2 - |\bar{\mathcal{A}}(f_i)|^2) \qquad (3)$$

$$Z(F) = \sum_i Im(e^{-2i\beta}\mathcal{A}(f_i)^* \bar{\mathcal{A}}(f_i)) \qquad (4)$$

We can expand these quantities in terms of eqn. (1) and obtain

$$\begin{aligned} X(F) &= \big((1+\hat{r}_D^2)(1+r_B^2)/2 \\ &+ 2R_F r_B \hat{r}_D \cos(\hat{\eta}_D - \gamma)\cos\eta_B\big)\hat{A}^2 \\ Y(F) &= -\big((1-\hat{r}_D^2)(1-r_B^2)/2 \end{aligned}$$

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$-2\mathrm{R}_F r_B \hat{r}_D \sin(\hat{\eta}_D - \gamma) \sin\eta_B\big)\hat{A}^2$

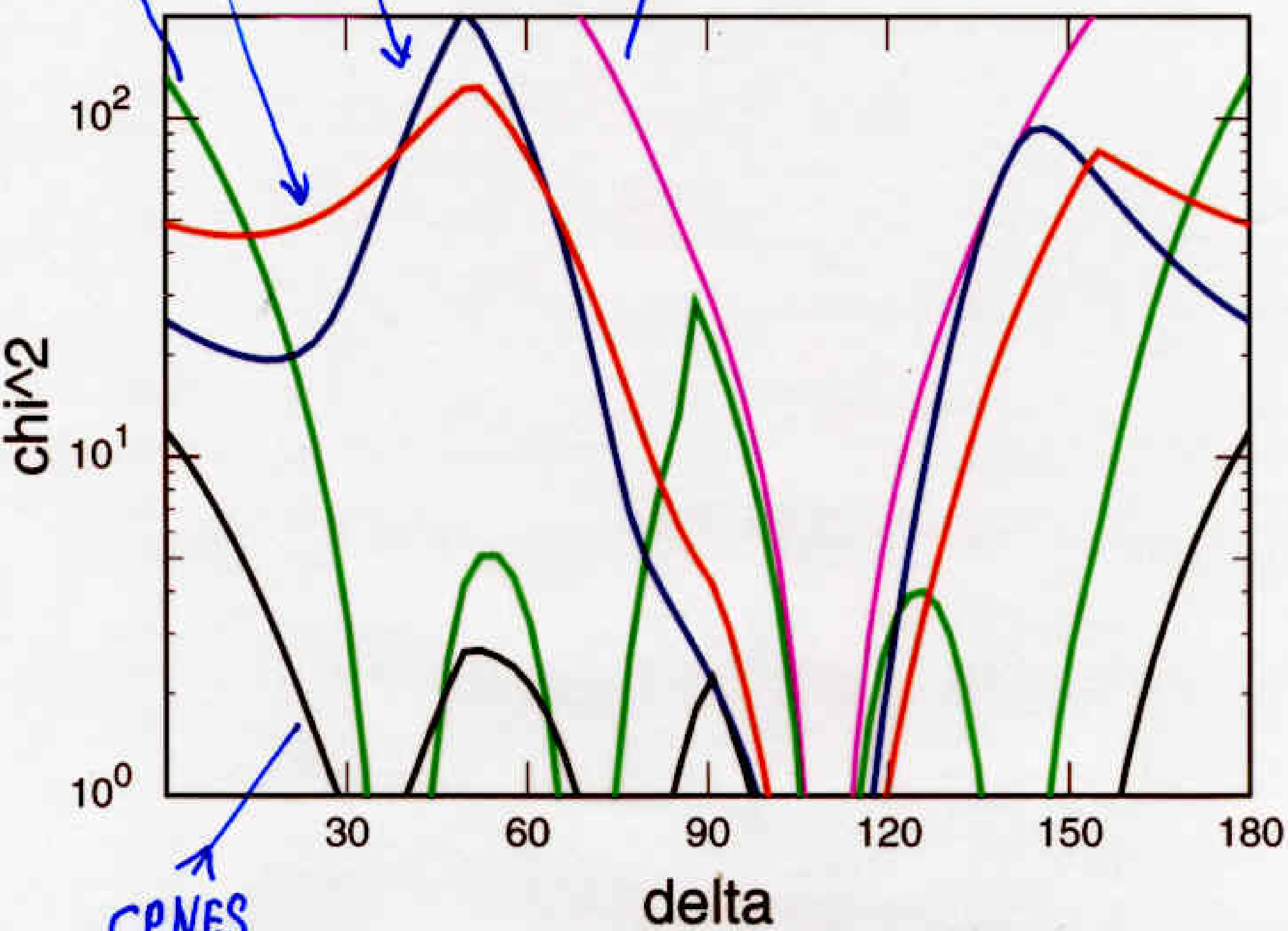
$Z(F) = \big(R_F r_B^2 \hat{r}_D \sin(2\alpha + \hat{\eta}_D) - R_F \hat{r}_D \sin(2\beta + \hat{\eta}_D)$

$+ \hat{r}_D^2 r_B \sin(\eta_B - \delta) - r_B \sin(\eta_B + \delta)\big)\hat{A}^2$

where $\hat{A}^2 = \sum_i A^2(f_i)$, $\hat{r}_D^2 = (\sum_i A^2(f_i) r_D^2(f_i))/\hat{A}^2$ and $R_F e^{i\hat{\eta}_D} = (\sum_i A(f_i) r_D(f_i) e^{i\eta_D(f_i)})/(\hat{A}\hat{r}_D)$.

The corresponding quantities for $\bar{F}$ are given by $X(\bar{F})\ (\eta_B, \eta_D, \gamma) = X(F)(-\eta_B, -\eta_D, \gamma)$; $Y(\bar{F})(\eta_B, \eta_D, \gamma) = -Y(F)(-\eta_B, -\eta_D, \gamma)$ and $Z(\bar{F})(\eta_B, \eta_D, \gamma) = Z(F)(-\eta_B, -\eta_D, \gamma)$ assuming that there is no additional CP violation in D^0 (as well as in K^0) decay.

$\delta \equiv \beta - \alpha + \pi$



[TRUE VALUE $\delta = 110°$]

$\hat{N}_B = (\# \text{ of } B\bar{B}) * \text{acceptance}$
$= 10^9$

1 Assume $\eta_{tag} = .25$
$\eta_{K_L} = 0.5\, \eta_{K_S}$

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Case	Accuracy
CPES with K_S and with K_L	$\pm 8.5^\circ$
CPNES $K^-\pi^+$ with K_S and with K_L	$\pm 5^\circ$
The CPNES $K^-\pi^+$ together with CPES, both with K_S only	$\pm 9.0^\circ$
$K^- + X$ together with K_S CPES	$\pm 2.5^\circ$
$K^- + X$ together with K_S as well as K_L CPES	$\pm 2.4^\circ$

Table 1: *A*ttainable one sigma accuracy with various data sets given $\hat{N}_B = 10^9$; note the 2nd and 5th cases are omitted from Fig 1 for clarity.

[For $\hat{N}_B = 10^8$ for $\underline{\text{IV}}$ $2.5^\circ \rightarrow 11.4^\circ$]

[TRUE VALUE of $\delta = 110^\circ$]

$\delta \equiv \beta - \alpha + \pi$

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Prospects for determining angles of the unitarity triangle

Angle	Mode(s)	Original Ref.	Type of CP	Pollution QCDP	Pollution EWP	Limiting Theory Error	# of B's Needed $*10^8$
β (ϕ_1)	$B \to \psi K^0$	Bigi + Sanda	time dep.	$\sim$ 1–2%	$\sim$ 1%	$\sim$ 1–2%	0.5–5
α (ϕ_2)	$\pi\pi$	Gronau + London	time dep.	$\approx$ 30%	few% (5–10%)	$\sim$ 5–10%	10–50
	$\rho\pi$	Quinn *et al*	"	$\approx$ 30%	"	$\sim$ 5–10%	5–50
	$\rho(\omega)P$ ($P = \pi$, $\eta, a_0 \ldots$)	Atwood + Soni	"	$\approx$ 30%	"	$\sim$ 1–2%	5–50
	$\rho\pi + \rho(\omega)P$	Combination of above 2	"	"	"	$\sim$ 1%	5–50
$\alpha(\phi_2)$	$B^{\pm}, B^0(\bar{B}^0) \to \rho\omega$, $\to K^{*0}\rho^+$	Atwood + AS	Direct	$\approx$ 20%	$\approx$ 5%	$\lesssim$ 5%	5–50
$\gamma(\phi_3)$	$B^{\pm}, B^0(\bar{B}^0) \to k^* \rho(\omega)$	"	"	"	"	"	5–50
γ (ϕ_3)	$K^{\pm} D^0(\bar{D}^0)$, $\to K^+\pi^-$ NO Penguins	Atwood Dunietz, Soni	Direct	0	0	$\sim$ 0	5–50
$\alpha(\phi_2)$	$B^0(\bar{B}^0) \to K^0 D^0(\bar{D}^0)$ CPNES, CPES, INC	A+S	TDCPA	0	0	$\sim$ 0	5–50

NO Penguins

"des"

approach limiting Theory error

$\boxed{\text{BOTH } \alpha \text{ \& } \gamma \text{ can be cleanly obtained from } B^{\pm}, B^0(\bar{B}^0) \to K D^0(\bar{D}^0) \text{ W/O ANY PENGUINS.}}$

VI. (Model Independent) Search for the Beyond (via $\not{CP}$)

Two complementary approaches:

1. Precision extraction of $U\Delta$ and test unitarity
2. Search for $\not{CP}$ experimentally where CKM predicts ~ 0.

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Desperately Seeking BSM $\not{CP}$ Phase(s)

χ

⇒ Nothing sacred about $\not{CP}$ in Field Theory.

⇒ Addition of fermions, gauge bosons, Higgs. . . should entail new $\not{CP}$ phases.

⇒ Baryogenesis is difficult to account for in CKM model. Best Places to Hunt BSM

phases(s) (via B's)?
Look for large BR where CKM $\not{CP}$ is ≈ 0

⇒ $b \to s$ penguin transitions

(37)

Table: Model Independent Searches for χ

		Ref.	BR
$B \to \eta' X_s$	DIRCP	Atwood + Soni, Hou + Tseng	$\sim 10^{-3}$ [ANOMALOUSLY HIGH]
$\to \gamma X_s$	DIR CP	Soares; Wolfenstein + Wu; Kagan + Neubert; Kiers, Wu, AS	$\sim 2 \times 10^{-4}$
I Compare β from $B \to \Psi K_s$ with β from $B^0 \to \phi(\eta', \pi^0, \rho^0, \omega, \eta) + K_s$ (using any or all)	TDCPA	London + Soni, Hurth + Mannel	$\sim 10^{-4}$; $\sim$ few $\times 10^{-5}$
II $B^\pm \to \Psi K^\pm$ Exptally V Clean Exc. Probe of $H^\pm$ phase	DIRCP	Wu + Soni	$\sim 10^{-4}$
V $B^0 \to \Psi K_s^0$ $a_{CP}(\Psi K_s) = sin[2\beta_{CKM} + \theta_{New}]$	TDCPA	Wolfenstein; Nir; Ball, Frere + Matias;; Kiers, Wu + AS	$\sim 10^{-4}$

If no BSM phase is found via these processes ($\lesssim$ 3–5 years)

$\Rightarrow$ "crisis" in our understanding of $\not{C}\not{P}$...

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Model Independent Description of $B \to \eta' X_s$

Assume some contribution to the large rate comes from BSM physics

$$\Lambda_\mu^{bsg} = V_t \frac{G_F}{\sqrt{2}} \bar{s}_i T_{ij}^a \{-iF(q^2)(q^2\gamma_\mu - q_\mu X)L$$

$$+ \frac{g_s}{2\pi^2} m_b q_\mu \epsilon_\nu \sigma^{\mu\nu} G(q^2) R\} b_j$$

$$F(q^2) = e^{i\delta_{st}} F_{SM} + e^{i\chi_F} F_\chi$$

$$G(q^2) = G_{SM} + e^{i\chi_G} G_\chi$$

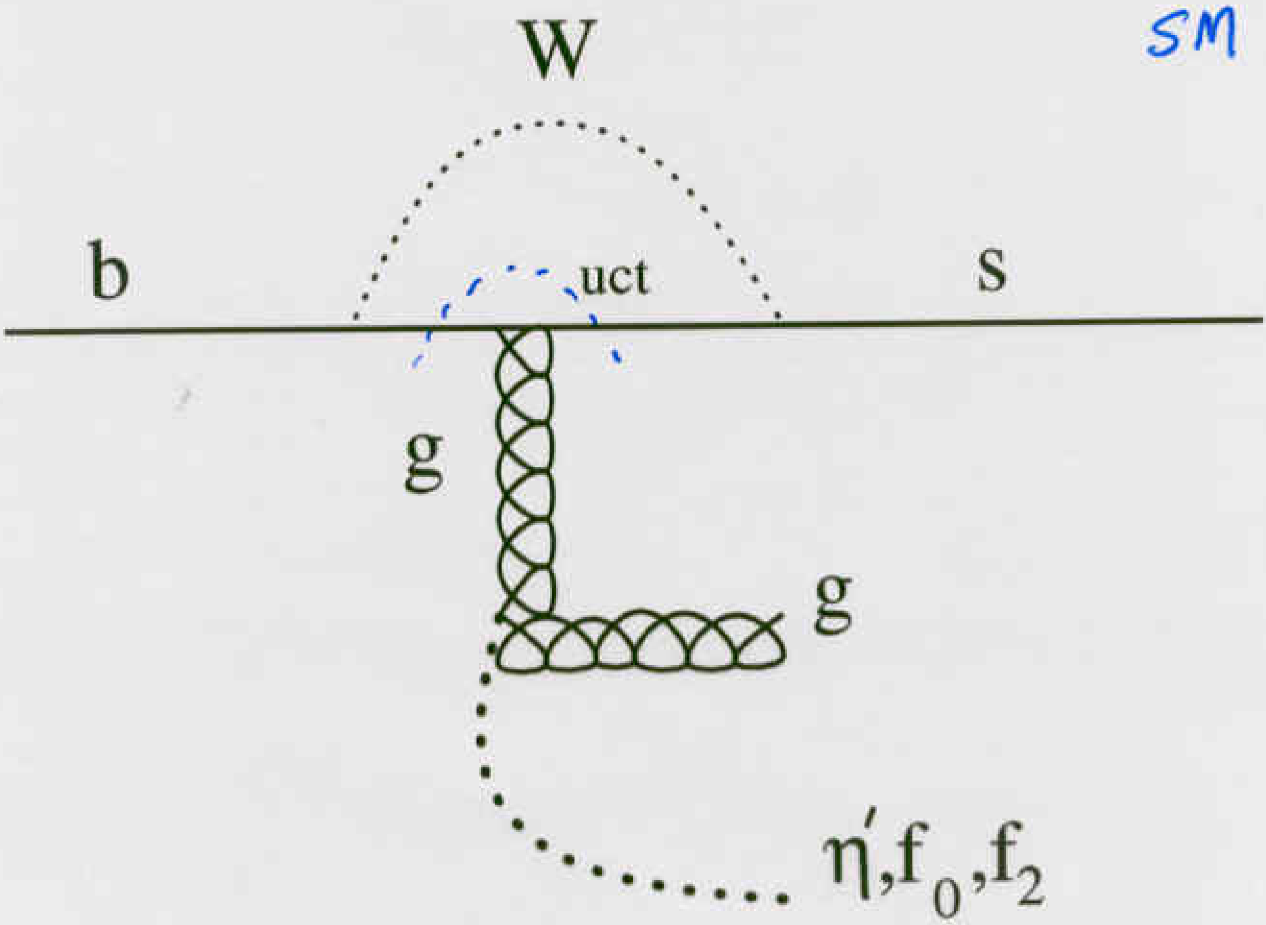
$\chi \equiv$ BSM CP-odd Phase: $\delta_{st} =$ CP-even, FSI phase

$$\Gamma_A = \frac{1}{2}\frac{d(\Gamma - \bar{\Gamma})}{dsdt} =$$
$$2 \sin\delta_{ST} F_{SM}[F_X \Gamma_1 \sin\chi_F + G_X \Gamma_3 \sin\chi_G]$$

$s \equiv (p_b - p_s)^2, t = (p_s - p_g)^2$

Γ_1 and Γ_3 are functions of s, t and masses..

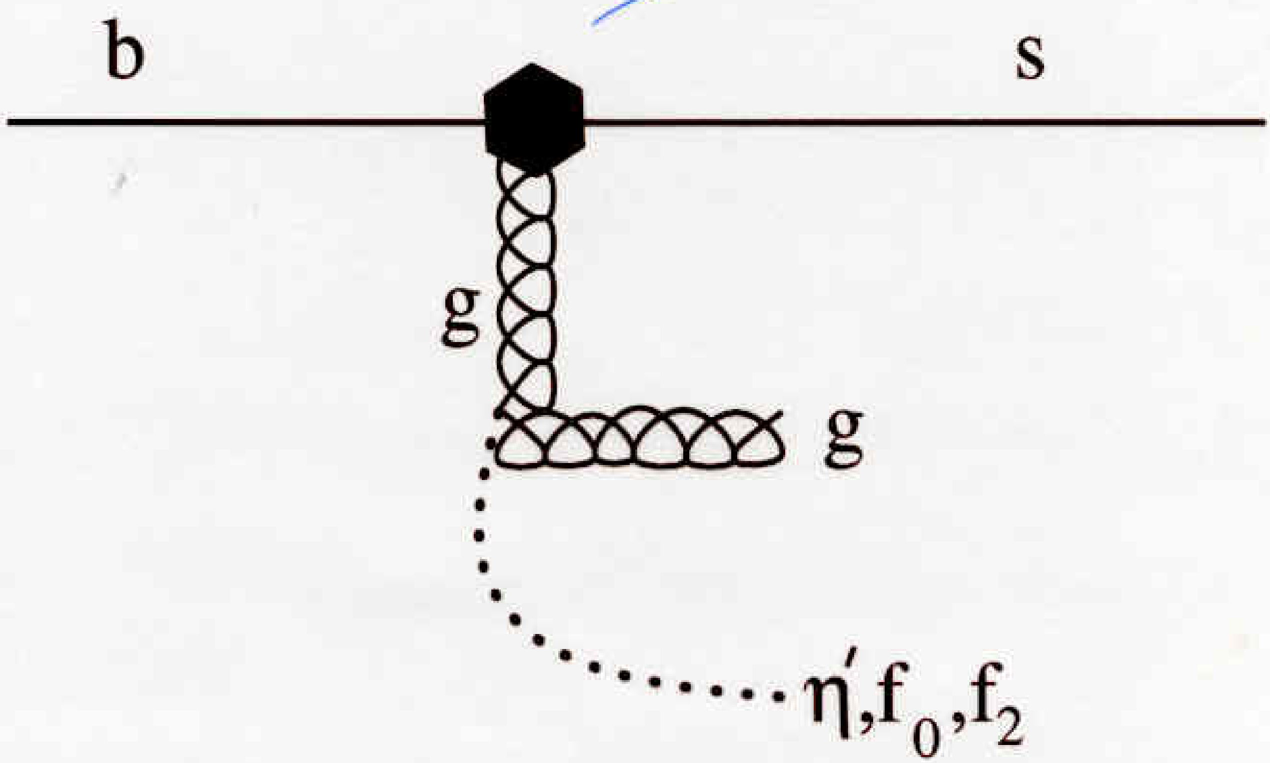
SM



$u\bar{u} \to u\bar{u}$, $c\bar{c} \to c\bar{c}$ provide FSI phase

CKM phase CP-odd ≈ 0

BSM · $x \neq 0$



CKM phase $\cong 0$

(4)

Figure 2a

Assume BSM contributes 10% to rate of $\eta' X_s$

$\sin\chi = 1$

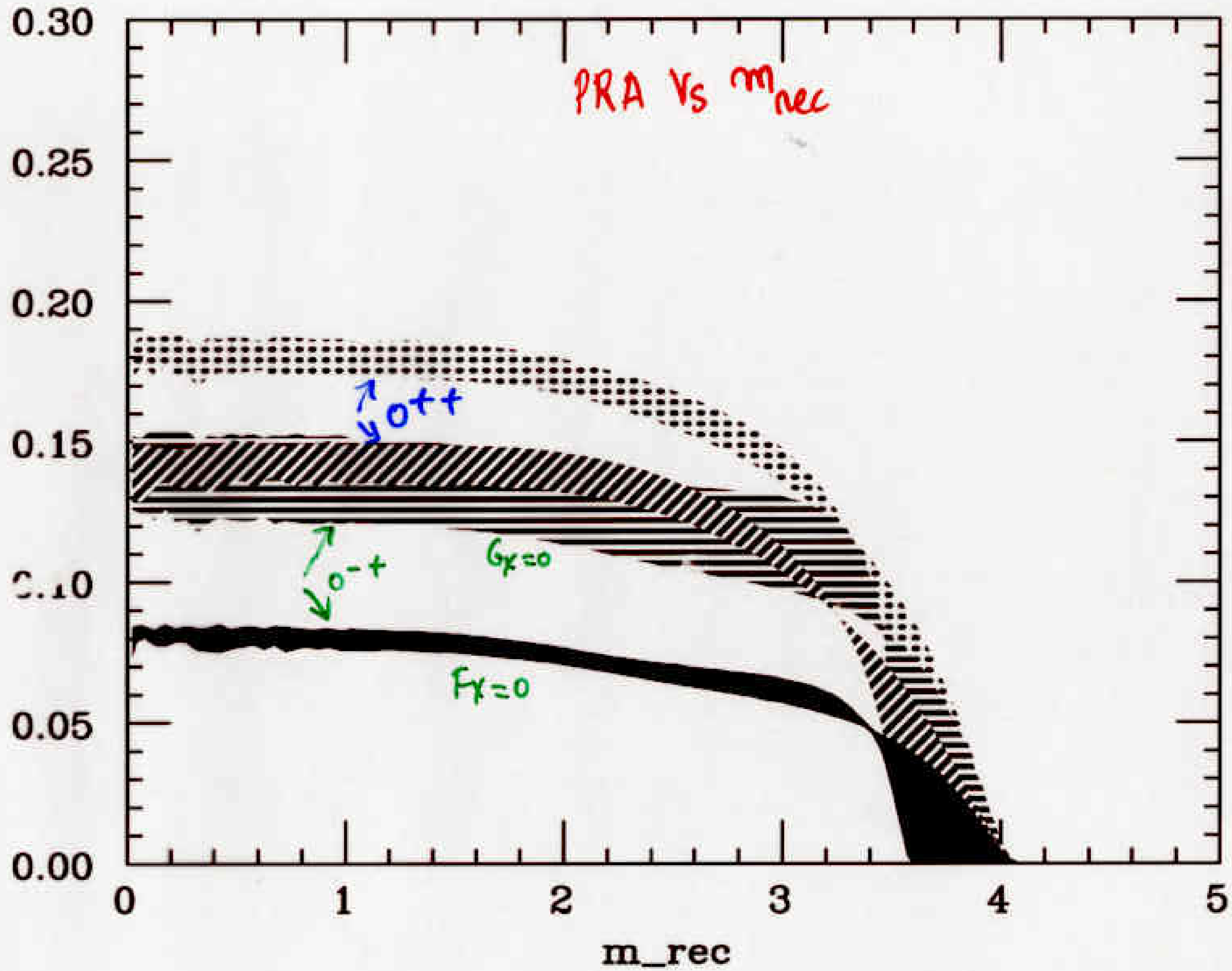
Asymmetry

24%

28%
24%

12%

⇑
For 50% contribution to rate



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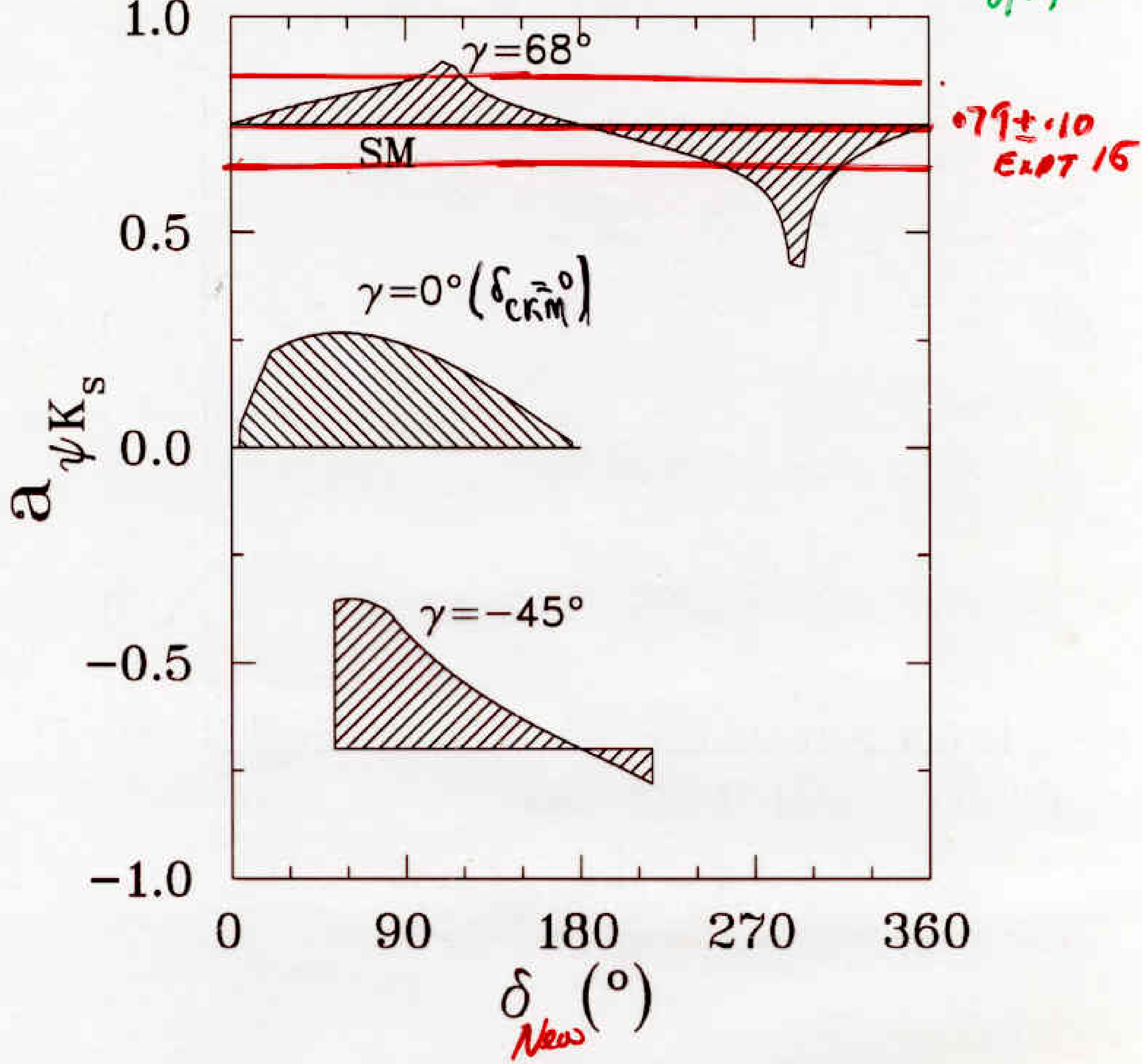
KIERS, S, Wu PRD 99

$a_{\psi K_S} = \sin(2\beta_{CKM} + \underset{New}{\theta})$

(model can accomodate ϵ_K with $\delta_{CKM} = 0$) NOT TRUE ANY MORE 3/10/02



⇒ ILLUSTRATES that BELLE/BABAR/CDF..

⇒ CKM phase dominant in ψK_S^0

③

Summary

I) B Factories confront the CKM Paradigm

ϕ_1 **a)** $\sin 2\beta$: Today and Tomorrow SM ⇒ .70 ± .10 VERY ROBUST

$\Rightarrow$ *Improvementsclearlynotenough.*

b) Cautious on Theory

1) $B_K \sim 10$–15% below previously thought $\hat{B}_K \simeq .76 \pm .13$ Should be used in pheno.

2) ξ lattice determination problematic ~~[illegible]~~ quoted error .05 UNDERESTIMATE

II) Existing Prominent Methods for α (and possible problems?)

a) Gronau & London (PRL '90) EWP

b) Quinn *et al.* (PRD '93) EWP + Continuum 3π

ϕ_3 **III)** γ without Penguins (Atwood, Dunietz, Soni, PRL '97, PRD00) $B^\pm \to K^\pm \underbrace{D^0 (\bar{D^0})}_{\to \text{CPNES}}$

ϕ_2 **IV)** α (and β?) without Penguins (Atwood & Soni, hep-ph/0206045) TDCP $B^0, \bar{B^0} \to K^0 \underbrace{D, \bar{D^0}}_{\text{CPES, CPNES}}$ ......

V) χ (BSM phase): Strategies for Model Independent Searches $\underbrace{\eta' X_s}_{\text{DIRCP}}$, $\underbrace{\eta'(\phi) K_s}_{\text{TDCP}(\beta)}$ ...