Roadmap for the Unitarity Triangle and the Beyond

1

Amarjit Soni

High Energy Theory, BNL

(soni@bnl.gov)

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Key Points

Impressive Performance of B factories:
10^8 B's Now$\rightarrow$ 10^9 B's soon

β Determination with negligible THEORY ERROR $\sim 0(1\text{-}2\%)$ well underway via $B \rightarrow \psi K_s$.

Two Important Goals for the near future

1. TARGET α, β, γ Extraction with ZERO THEORY ERROR
2. TARGET χ (BSM phase)

COUPLED

WHY IS #1 SO IMPORTANT ?
$\because$ RESIDUAL THEORY ERRORS IN #1 CAN EASILY MASK χ AND PREVENT US FROM UNCOVERING χ

Outline

I) B Factories confront the CKM Paradigm

a) $\sin 2\beta$: Today and Tomorrow

b) Cautio~~n~~s on Theory

$\hat{B}_K^{DWQ} = .76 \pm .$

1) B_K~10–15% below previously thought

2) ξ lattice determination problematic ± 0.05 is AN underestimate

II) Recall Existing Prominent Methods for α Gronau and London, PRL '90 ($\pi\pi$), Quinn *et al.*, PRD '93 ($\rho\pi$). Theory problems due penguin pollution esp. EWP, model dependence. MAY NEGATE SEARCHES for χ.

III) γ with Zero Theory Error (Atwood, Dunietz, Soni, PRL '97, PRD00), No Penguins, dir CP, Large CP Asym: $B^\pm \to K^\pm D^0(\bar{D}^0)$; $D^0(\bar{D}^0) \to$ CP Non ES.

D^0 F States are CRUCIAL

IV) α (and β?) with Zero Theory Error (Atwood & Soni, hep-ph/0206045); No Penguins, Time Dependent CP, Large CP Asym: $B^0, \bar{B}^0 \to K^0 D^0, \bar{D}^0$; $D^0, \bar{D}^0 \to$ CPES, A

CPNES, inclusive. FOR BOTH III & IV CLEO-C CAN PLAY A SPECAIL ROLE.

V) χ (BSM phase): Strategies for Model Independent Searches e.g. $B \to \eta' x_s$ (dir CP); $B \to \eta' K_s, \phi K_s \ldots$ time dependent CP.

VI) Summary

HUNT FOR x_{BSM}

WHAT SIZE of EFFECT (IN B-physics) should we expect ? WE DONT HAVE THE FOGGEST IDEA.

HOWEVER SM SERVES AN IMP. LESSON:

$$a^{CP}_{SM}(K_L \to \pi\pi) \sim \epsilon_K \sim 10^{-3}$$ even though δ_{KM} $(\sim \gamma)$ is NOT SMALL.

$\Rightarrow$ MANIFESTATION OF x_{BSM} in CP OBSERVABLE IN B-PHYSICS MAY WELL BE $O(10^{-3})$ even if x is NOT SMALL.

ASSUME $BR \sim 10^{-3}$ (OPTIMISTIC) e.g. $B \to \eta' X_s$, $\eta' K_S$

$$\#\text{ OF } B\text{'s NEEDED} \sim \frac{10}{(10^{-3})^2 (10^{-3})} \sim 10^{10}$$

$\Rightarrow$ FROM BELLE / BABAR / CDF / Dϕ CONTINUED EFFORTS TO SUPER (BELLE, BABAR), BTEV, LHCB MAY WELL BECOME NECESSARY

$\Rightarrow$ PRECISION tests of UT: $\alpha + \beta + \gamma = \pi$

ARE ESSENTIAL AS THEY ARE AN INCLUSIVE PATH to x.

THEORY ERROR OR ASSUMPTIONS WILL SHORTCHANGE EXPERIMETAL EFFORT to x_{BSM} as deviations ~~from~~ from unitarity MAY WELL BE SMALL.

CKM Constraints - Theory

I

$$|\epsilon_K| = \hat{B}_K C_K \lambda^6 A^2 \bar{\eta}\{\eta_1 S(x_c) + \eta_2 S(x_t)[A^2\lambda^4(1-\bar{\rho})] + \eta_3 S(x_c, x_t)\} \qquad C_K = \frac{G_F^2 f_K^2 m_K m_W^2}{6\sqrt{2}\pi^2 \Delta m_K}$$

II $\Delta m_d = C_{B_d} \hat{B}_{B_d} C_{B_d} \lambda^6 A^2 \eta_c S(x_t)[(1-\bar{\rho})^2 + \bar{\eta}^2]$

III $\frac{\Delta m_d}{\Delta m_s} = \xi^{-2} \frac{m_{B_d}}{m_{B_s}} \lambda^2 [(1-\bar{\rho})^2 + \bar{\eta}^2]$

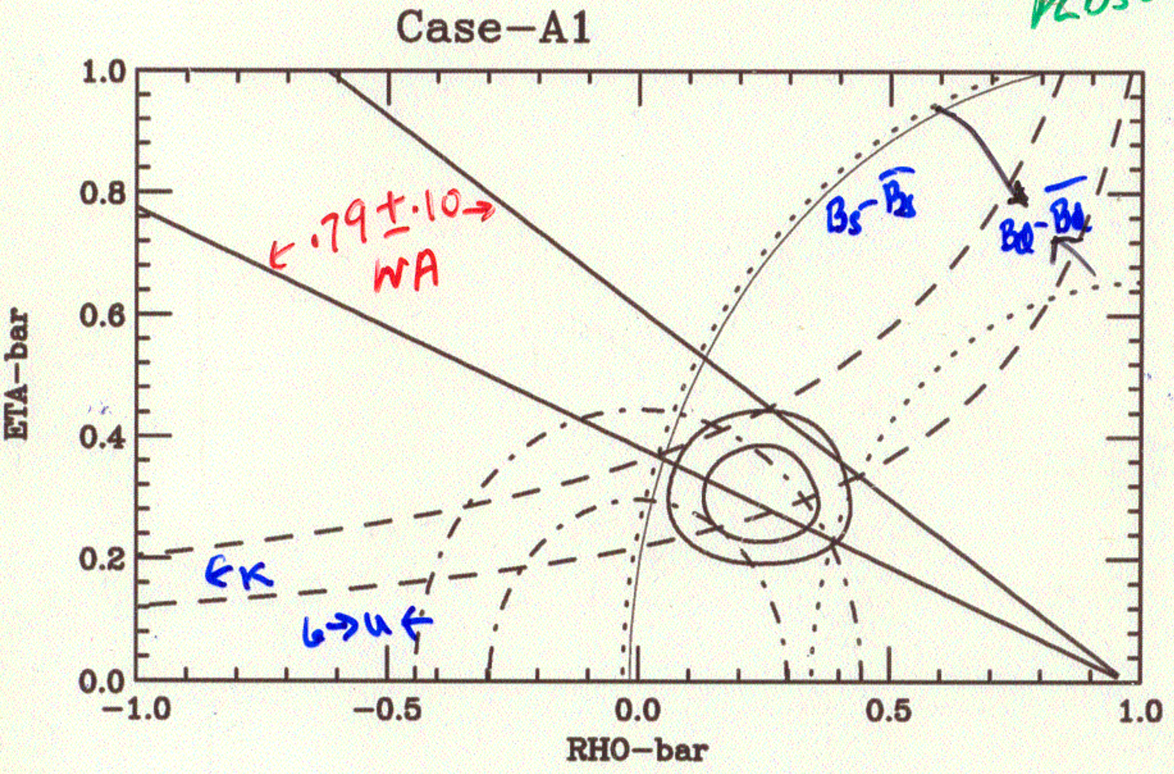
LEP/SLD Bound on Δm_s

$$\xi \equiv f_{B_s}\sqrt{\hat{B}_{B_s}}/f_{B_d}\sqrt{\hat{B}_{B_d}}$$

IV. $R_{uc} \equiv \frac{|V_{ub}|}{|V_{cb}|} = \lambda(\bar{\rho}^2 + \bar{\eta}^2)^{1/2}/(1-\lambda^2/2)$

WONDERS of the KOBAYASHI-MASKAWA MECHANISM of $\cancel{CP}$

ATWOOD + AS
PLB508, 17(01)



$\cancel{CP}$ Asymmetry in $B \to \psi K_s$: $\sin 2\phi^{SM} = .70 \pm .10$

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

$O(10^{3})$

Table 1: Comparison of some fits.

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

Expectation from our fit:

$\beta \sim 25^\circ$

$\gamma \sim \cancel{41^\circ}$ 45°

$\alpha \sim 110^\circ$

8

Table 1: Comparison of some fits.

Input Quantity	Atwood & Soni (PL '01)	Ciuchini *et al* (PL '01)	Hocker *et al* (PL '01)
$R_{uc} \equiv \|V_{ub}/V_{cb}\|$	$.085 \pm .017$	$.089 \pm .009$	$.087 \pm .006 \pm .014$
$F_{B_d}\sqrt{\hat{B}_{B_d}}$ 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
$\bar{\eta}$	$.30 \pm .05$	$.316 \pm .040$	$.34 \pm .12$
$\bar{\rho}$	$.25 \pm .07$	$.22 \pm .038$	$.22 \pm .14$
$\|V_{td}/V_{ts}\|$	$.185 \pm .015$		$.19 \pm .04$
$\Delta m_{B_s} (ps^{-1})$	19.8 ± 3.5	$17.3^{+1.5}_{-0.7}$	24.6 ± 9.1
J_{CP}	$(2.55 \pm .35) \times 10^{-5}$		$(2.8 \pm .8) \times 10^{-5}$
$BR(K^+ \to \pi^+ \nu\bar{\nu})$	$(0.67 \pm 0.10) \times 10^{-10}$		$(.74 \pm .23) \times 10^{-10}$
$BR(K_L \to \pi^0 \nu\bar{\nu})$	$(0.225 \pm 0.065) \times 10^{-10}$		$(.27 \pm .14) \times 10^{-10}$

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

9

Table 2: Stability of our Fit

Input Quantity	Atwood & Soni (PL '01)		
$R_{uc} \equiv \lvert V_{ub}/V_{cb} \rvert$	$.085 \pm .017$		
$F_{B_d}\sqrt{\hat{B}_{B_d}}$ 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
$\bar{\eta}$	$.30 \pm .05$	$.32 \pm .05$	$.33 \pm .05$
$\bar{\rho}$	$.25 \pm .07$		
$\lvert V_{td}/V_{ts} \rvert$	$.185 \pm .015$		
$\Delta m_{B_s} (ps^{-1})$	19.8 ± 3.5		
J_{CP}	$(2.55 \pm .35) \times 10^{-5}$		
$BR(K^+ \to \pi^+ \nu\bar{\nu})$	$(0.67 \pm 0.10) \times 10^{-10}$		
$BR(K_L \to \pi^0 \nu\bar{\nu})$	$(0.225 \pm 0.065) \times 10^{-10}$		

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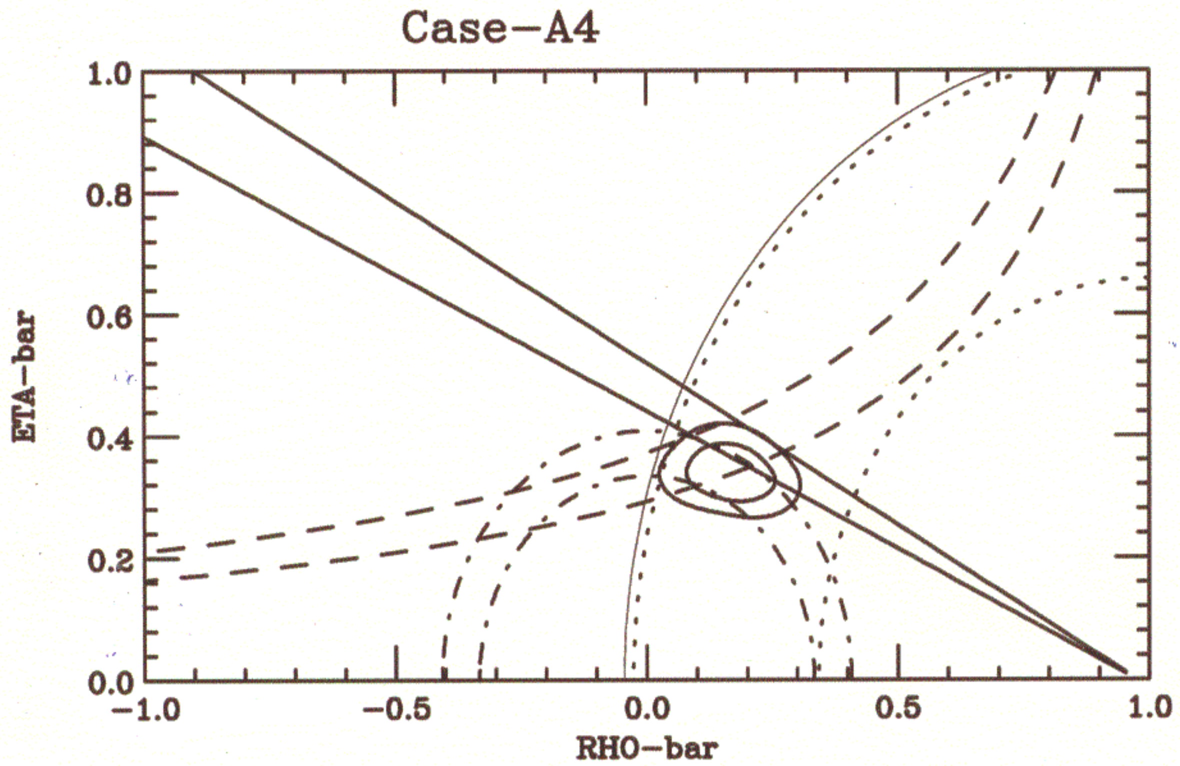
Futuristic



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

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

$\xi = 1.25 \pm .05$

$B_K = .751 \pm .065$

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

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

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

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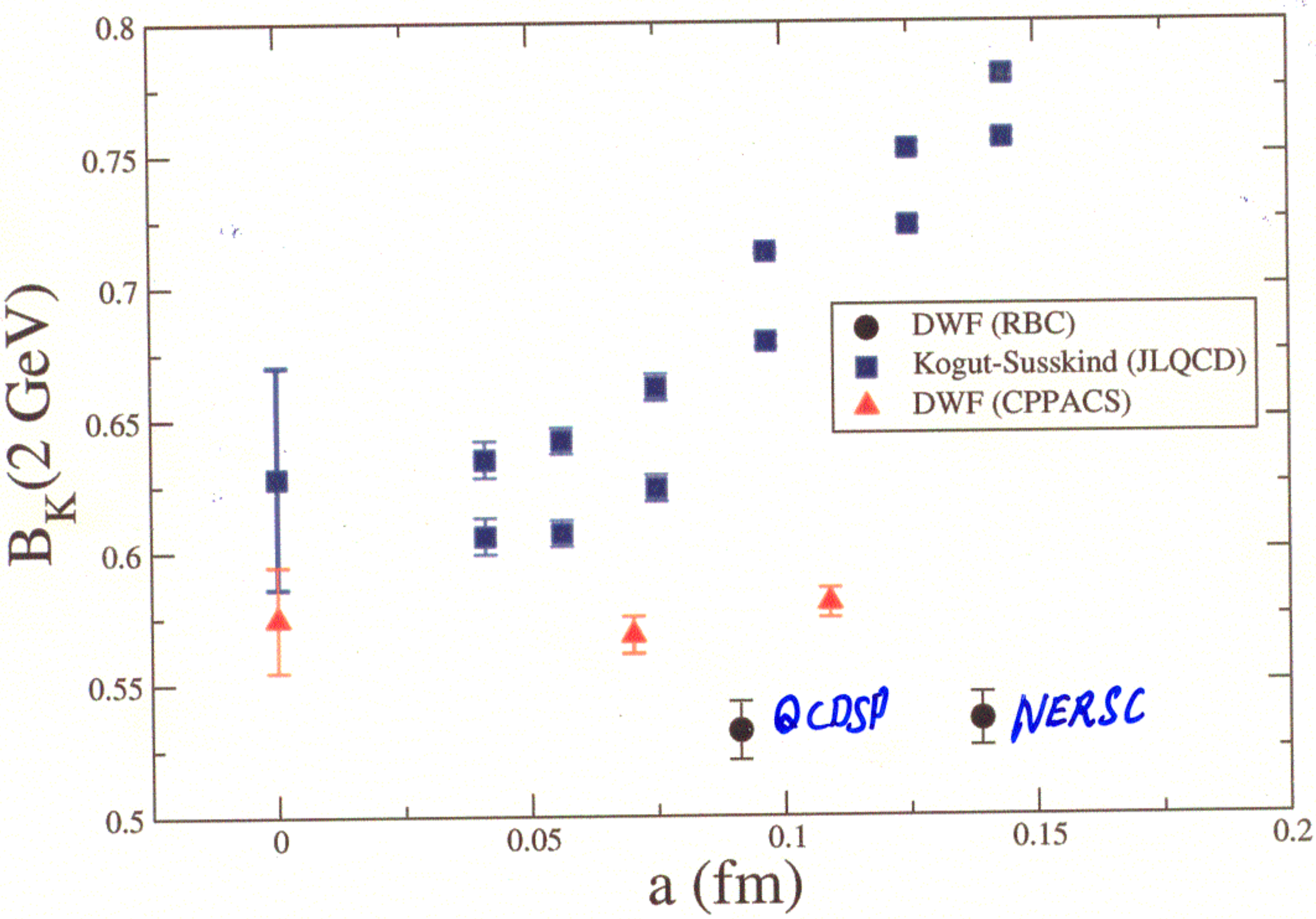
The kaon B parameter B_K

$\overline{MS}$ 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).)

12

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

Bernard + Blum + AS PRD 98

$$M_{B_D}(\mu) \equiv \langle \bar{B}_d | (\bar{b}\gamma_j(1-\gamma_5)d)(\bar{b}\gamma_j(1-\gamma_5)d)|B_d\rangle \equiv \frac{8}{3} f_{B_d}^2 m_{B_d} B_B$$

$$\begin{aligned} x_{B_d} &\equiv \Delta m_{B_d}/\Gamma_{B_d} \\ &= \frac{G_F^2}{16\pi^2} M_W^2 \frac{\tau_{B_d}}{m_{B_d}} b(\mu)\eta_{QCD} S(x_t) M_{B_d}(\mu)|V_{td}|^2 \\ &= \frac{G_F^2}{6\pi^2} M_W^2 \tau_{B_d} m_{B_d} b(\mu)\eta_{QCD} S(x_t) B_{B_d}(\mu) f_{B_d}^2 |V_{td}|^2 \end{aligned}$$

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

$$\xi \equiv \frac{f_{B_s}\sqrt{B_{B_s}(\mu)}}{f_{B_d}\sqrt{B_{B_d}(\mu)}}$$

$\frac{X_{B_s}}{X_{B_d}}$ via "Indirect" Method (i.e. thru ξ) is now (almost) universally being used. "DIRECT" method NEEDS NO EXTRA lattice computation.

Provides with diff systematics.

12

14

	$\frac{f_{B_s}}{f_B}$	ξ	indirect r_{sd} $(\sim \xi^2)$	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 + Lin	$1.16 \pm 6 {}^{+2}_{-3}$	$1.15 \pm 3 {}^{+2}_{-3}$	$1.37 \pm 14 \pm {}^{4}_{6}$	$1.71 \pm 28 {}^{+8}_{-11}$
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 $1.14 \pm .03 \pm .05$ BOTH Central Value & esp error probably underestimated.

ATWOOD + AS $1.16 \pm .10$

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

B_s-$\bar{B}_s$ Osc.

REMARKS

1. Δm_{B_s} determination of CDF near future (≤ 2 yr)

2. With Δm_{B_s} LEP bound lattice determination of $\frac{\Delta m_{B_s}}{\Delta m_{B_d}}$ has become very important for extraction of V_{td}/V_{ts}

3. Concern is that r_{sd}^{indirect} may underestimate SU(3) breaking (due to the common practice of using linear fits). r_{sd}^{direct} needs no xtra lattice computations.

4. With the anticipated CDF result, lattice determination of ξ with <u>both methods</u> is urged.

III γ Extractions with Zero Theory Error via $B^{\pm} \to K^{\pm} D$ (non-CP-ES) ADS PRL'97; PRD'00

1. Uniquely clean (No theoretical assumptions)
2. No EWP; in fact NO Penguins ONLY 2 Tree graphs $b \to c$ V_s $b \to u$
3. Large Direct CP $\sim$ tens of percents
4. Time Dependent Measurement NOT Needed SO ANY B-FACILITY CAN BE USED
5. Many Modes (only 2 essential)

Does need $\sim 10^8$–10^9 Bees

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

Modes

MAXIMIZE Interference $\Rightarrow$ LARGE CP

$$B^- \to K^-(K^{-*}) + D^0 \to \text{CLA * DCS}$$
$$\Rightarrow K^+\pi^-, K^+\rho^-, K^+a_1^-, K^{*+}\pi^-$$
$$B^- \to K^-(K^{-*}) + \bar{D}^0 \to \text{CLS * CBA}$$

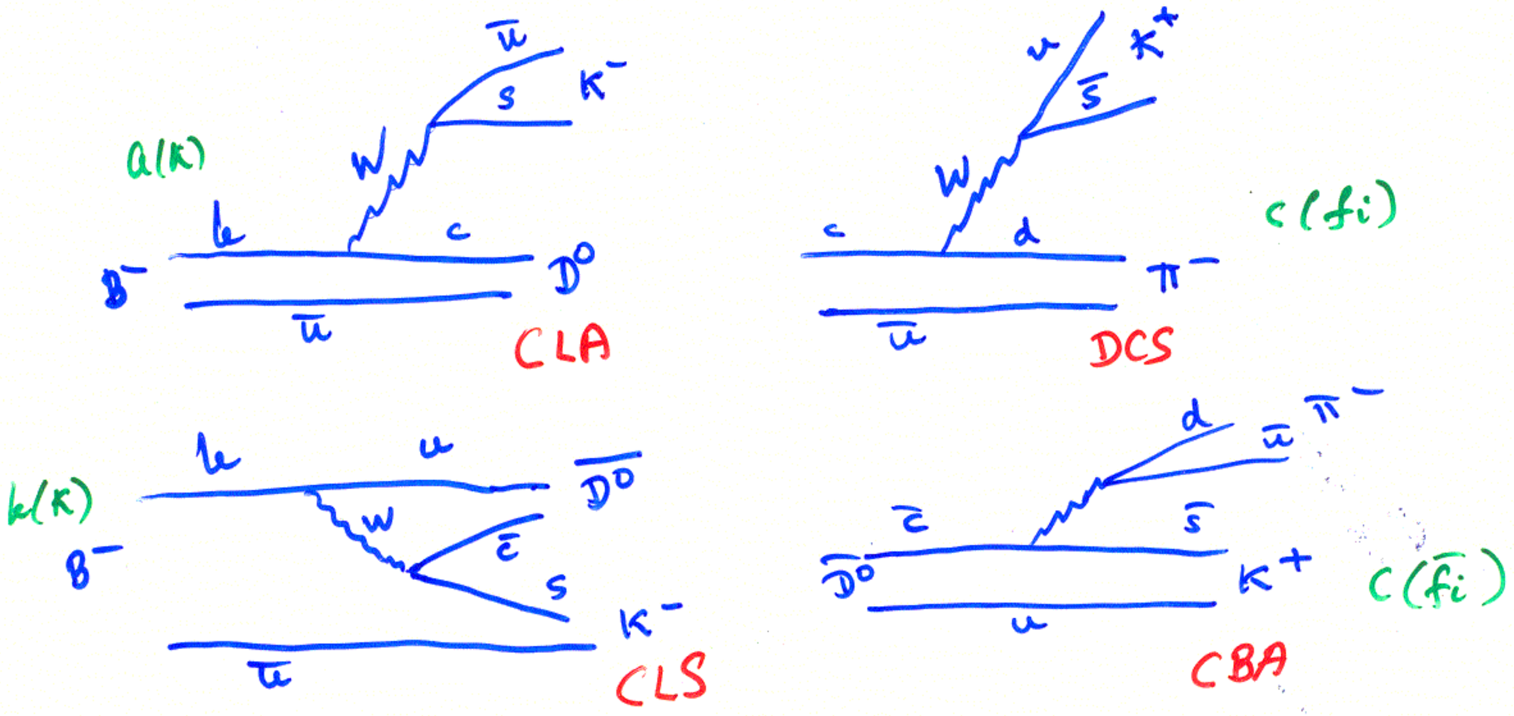
With a minimum of 2 modes, the method has 4 equations and 4 unknowns:

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

Note this branching ratio is <u>not</u> accessible to direct experimental measurement

* ITS just a matter of SOLVING 4 EQNS WITH 4 UNKNOWNS. NO THEORY OR ASSUMTIONS are involved

* MORE (≥ 2) modes $\Rightarrow$ IMPROVED DETERMINATION (MANY AVAILABLE)



BASIC Eq^{ns} $\qquad i = 1, 2 \qquad$ 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 $\qquad$ ↳ "unmeasurable" BR

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

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

ALSO $\bar{c}(f_i) = c(f_i)$ and $\bar{c}(\bar{f}_i) = c(\bar{f}_i)$]

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.

IMPORTANT NOTE

Use of models to calculate $Br(B^- \to K^- \bar{D}^0)$ which is needed with the CPES method of γ defeats the goal of zero theory error.

FOR an illustrative example study in a MODEL Calculation

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

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.

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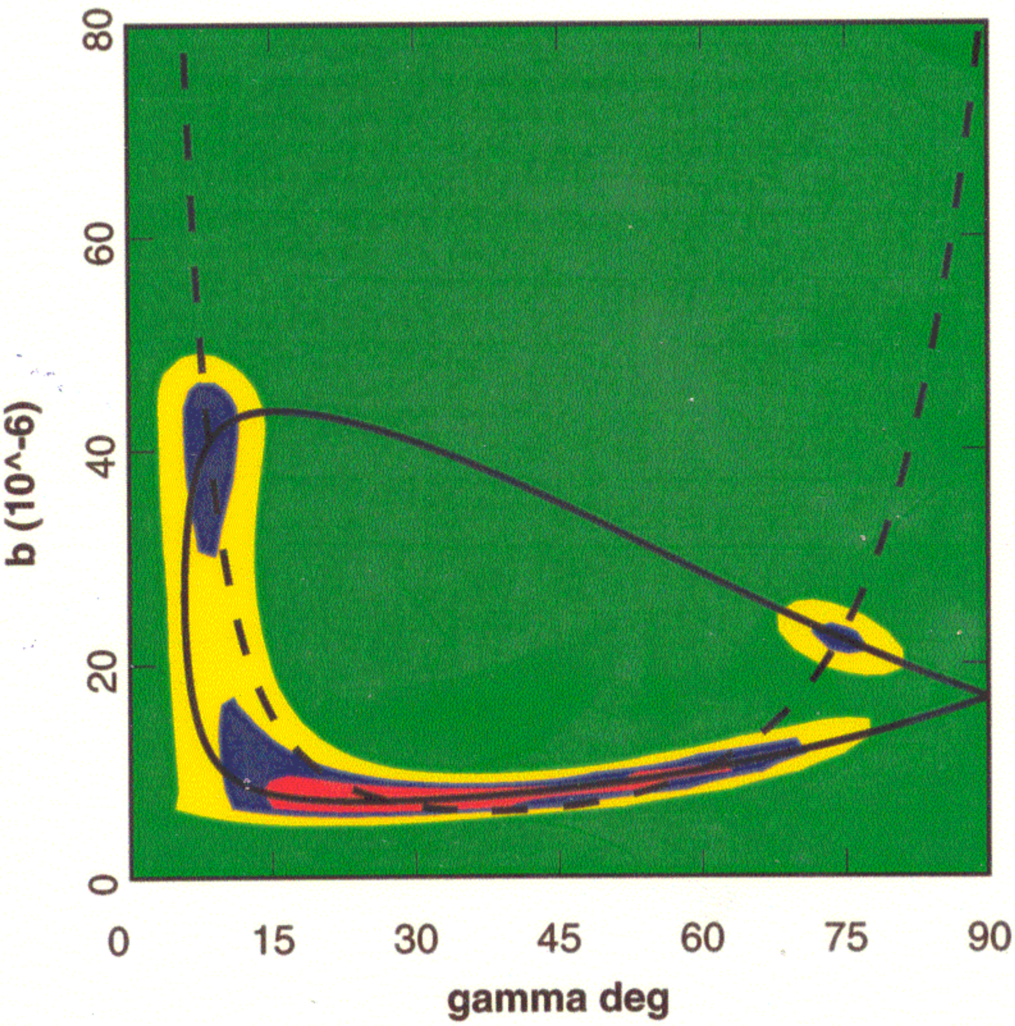
- Just two modes used:
  - $K^+\pi^-$ (solid)
  - $K_s\pi^0$ (short dashes)
- Confidence regions assuming that $N_B(acceptance) = 10^8$:
  99%; 90%; 68%



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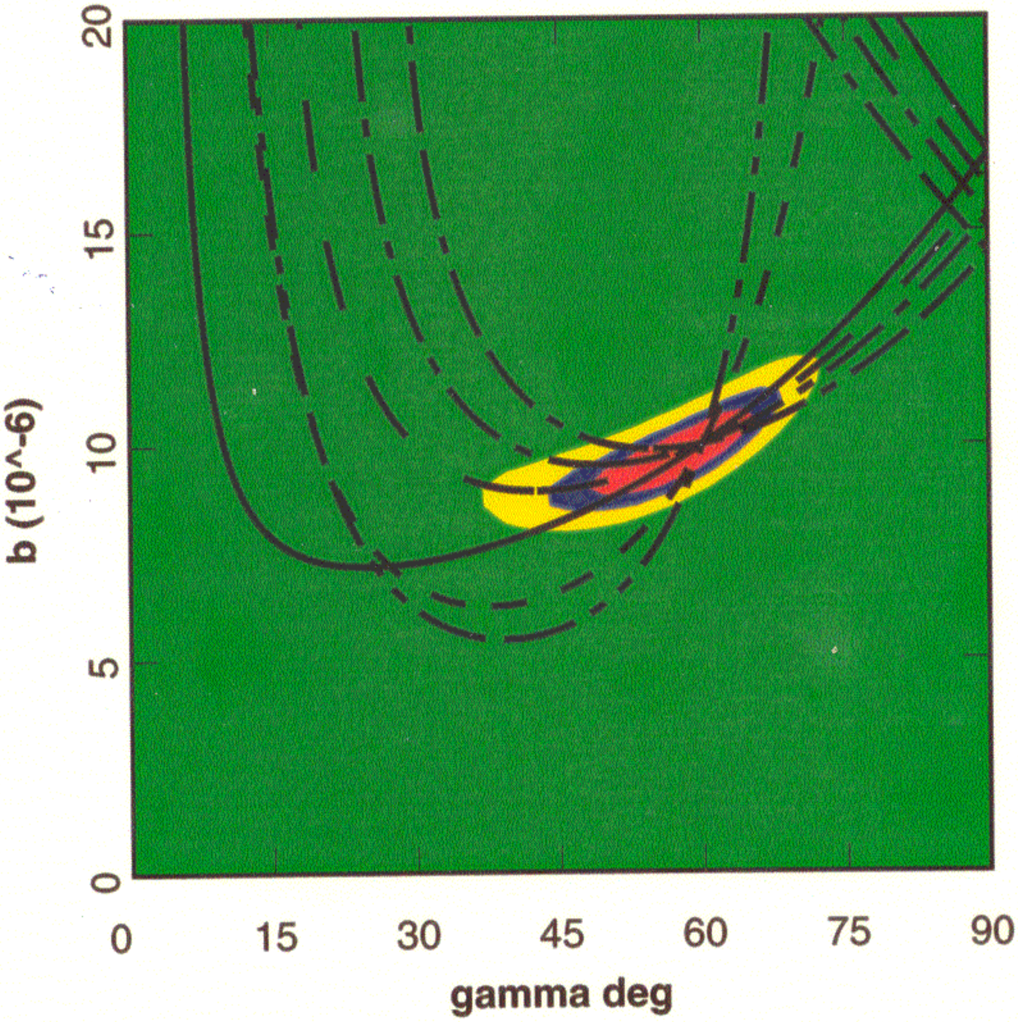
ADS PRD00

- ~~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%



IV. Getting α (and β~~?~~) with Zero Theory Error

Atwood & Soni, hep-ph/0206045;
AND IN PREPARATION.

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

As such this has 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 resulting in 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.
2. CPES & CPNES, each with exclusive mode(s)
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

The important point is that the procedure allows for a number of observables a lot larger than number of parameters.

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

$\Rightarrow$ Key is always to have enough # of OBSERVABLES THAT you can ~~solve~~ algebraically solve simultaneously for strong & weak phase(s)

MODE	# OBS	# PARAM
e.g. I. $B^0 \to K_S^0 D^0$, $\hookrightarrow K^+\pi^-$	6	5 $\{A, r_B, \eta_B, \delta, \eta_D\}$
II $B^0 \to K_S^0 D^0$, $\hookrightarrow K_S \pi^0$	3	4 of above 5
I + II	9	5

wk. ph.

NOTE: CLEO-C CAN PLAY A CRUCIAL ROLE IN DETERMINING r_D & η_D

27

Formalism

strong phase

[Use Wolfenstein representation for the CKM matrix]

For each f_i the four relevant amplitudes are:

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

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 $|\mathcal{A}(\bar{D}^0 \to f_i)/\mathcal{A}(D^0 \to f_i)|$ 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

$r_B e^{i\eta_B} = e^{-i\gamma}\mathcal{A}(B^0 \to K_S D^0)/\mathcal{A}(\bar{B}^0 \to K_S D^0)$ 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:

$$2\frac{d}{d\tau}\Gamma(B^0/\bar{B}^0(t) \to K_S F) = e^{-|\tau|}(X(F) + bY(F)\cos(x_B\tau$$

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:

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

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

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

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

$$\begin{aligned} X(F) &= ((1+\hat{r}_D^2)(1+r_B^2)/2 \\ &+ 2R_F r_B \hat{r}_D \cos(\hat{\eta}_D - \gamma)\cos\eta_B)\hat{A}^2 \\ Y(F) &= -((1-\hat{r}_D^2)(1-r_B^2)/2 \end{aligned} \tag{5}$$

$$
\begin{aligned}
& - \quad 2R_F r_B \hat{r}_D \sin(\hat{\eta}_D - \gamma) \sin\eta_B \big) \hat{A}^2 \\
Z(F) \quad = \quad & \big(R_F r_B^2 \hat{r}_D \sin(2\alpha + \hat{\eta}_D) - R_F \hat{r}_D \sin(2\beta + \hat{\eta}_D) \\
& + \quad \hat{r}_D^2 r_B \sin(\eta_B - \delta) - r_B \sin(\eta_B + \delta)\big) \hat{A}^2 \qquad (6)
\end{aligned}
$$

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.

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

Table 1: *Attainable 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 IV $2.5° \rightarrow 11.4°$]

[TRUE VALUE of $\delta = 110°$]

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

[UNLIKE ψK_L where only statistics is improved with K_L, here if K_L is doable then it also increases # of observables]

$K^- + X$

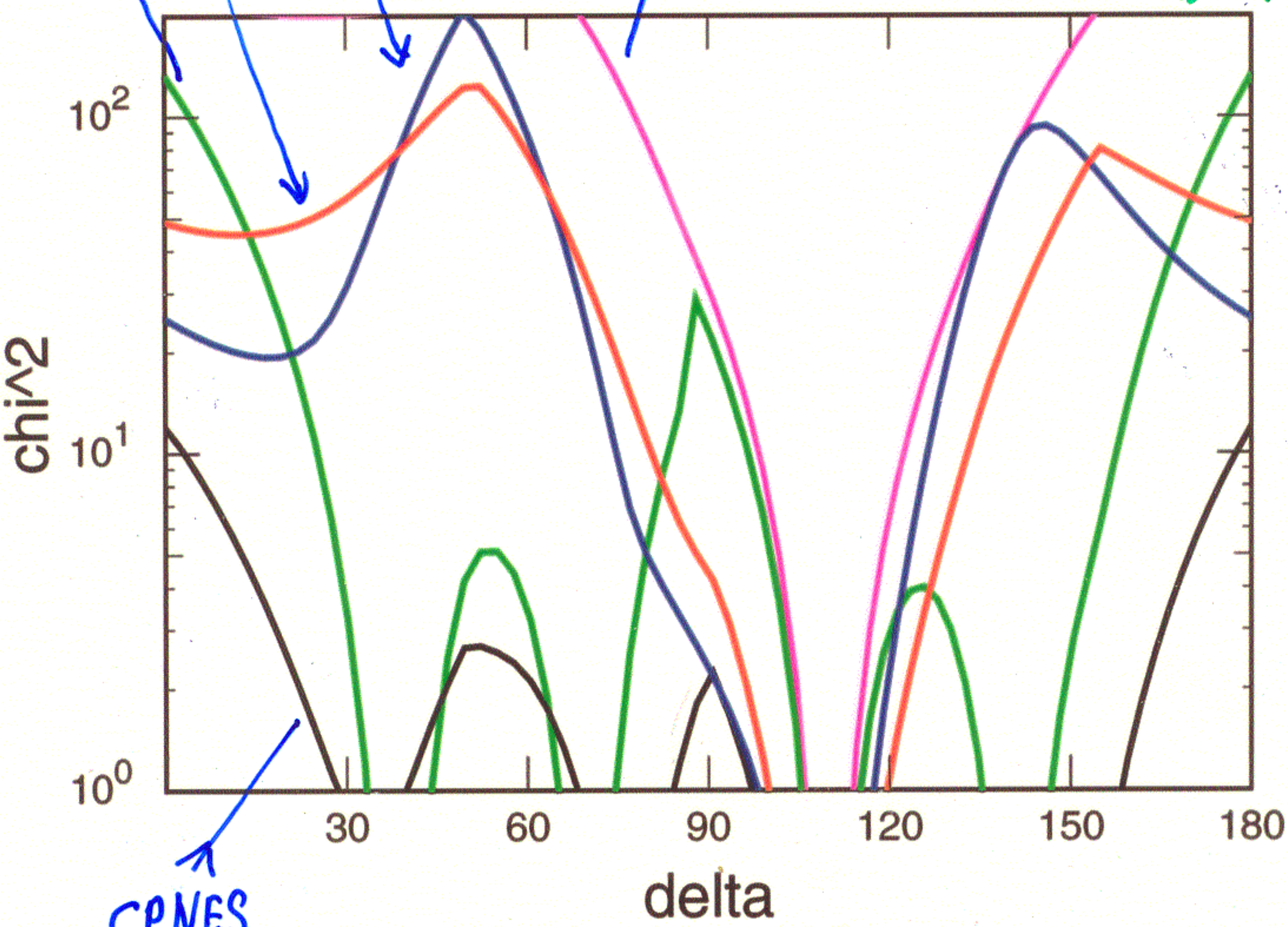
CPNES + CPES (K_S only)

CPES (K_S & K_L)

$K^- + X$ & CPES (K_S)

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

[β IS FIXED here from $B \to \psi K_S^0$]



CPNES

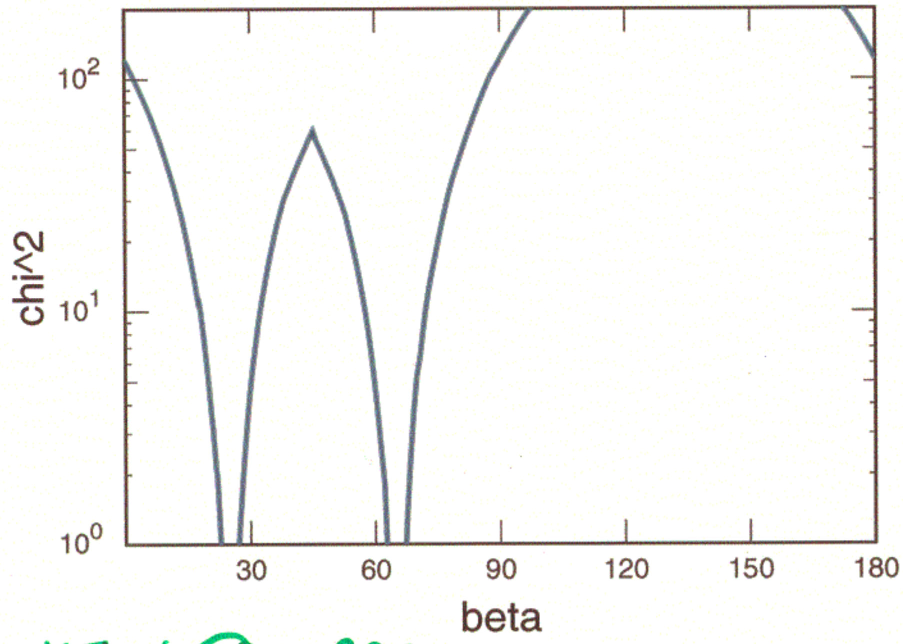
[TRUE VALUE $\delta = 110°$]

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

1 Assume $\eta_{tag} = .25$

$\eta_{K_L} = 0.5\, \eta_{K_S}$

β DETERMINATION with $B^0 \to \rho^0 K^0$ $\hat{N}_B = 10^9$



INPUT: $K^- + X \oplus$ CPES

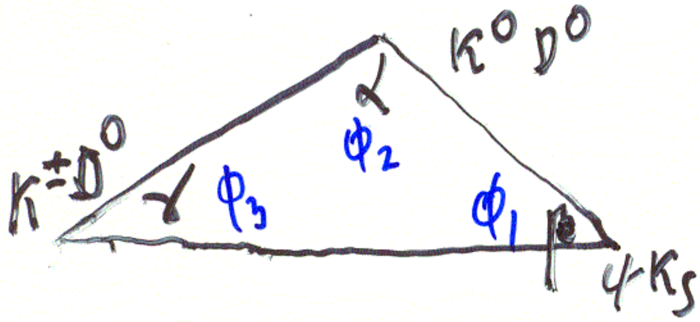
(15) ERROR ON $\beta \sim 2^\circ$

PROVIDES AN EXTREMELY IMP. ~~TEST~~ CHECK of β from $B \to \psi K_s$

$\Longrightarrow$ CRUCIAL TEST OF CKM PARADIGM

Methods for Extracting the UT with Zero Theory Error

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
γ (ϕ_3)	$K^\pm D^0_\downarrow(\bar{D}^0_\downarrow)$ $K^+\pi^-$	Atwood Dunietz, Soni	Direct	0	0	~ 0	5–50
α (ϕ_2)	$K^0 D^0(\bar{D}^0)$ $\downarrow$ CPES, CPNES, Inclusive	Atwood +AS	~~Direct~~ TDCP	0	0	~ 0	5–50



LOWER # for INITIAL DETERMINATION

HIGER # for APPROACHING LIMITING THEORY ERROR

NOTE # of B's for $B^\pm, B^0 \to K D$ methods

$\sim$ # needed for $\underbrace{\rho\pi \;(\pi\pi \text{ may be a bit worse})}_{\text{APRECIABLE THEORY ERROR}}$

35

Sample of Methods for Extracting the UT

ngle	Mode(s)	Original Ref.	Type of CP	Pollution QCDP	Pollution EWP	Limiting Theory Error	# of B's Needed $/10^8$
ϕ_1)	$B \to \psi K^0$	Bigi + Sanda	time dep.	$\sim$ 1–2%	$\sim$ 1%	$\sim$ 1–2%	0.5–5
ϕ_3)	$K^\pm D^0_{\downarrow}(\bar{D}^0_{\downarrow})$ $K^+\pi^-$	Atwood Dunietz, Soni	Direct	0	0	$\sim$ 0	5–50
(ϕ_2)	$K^0 D^0(\bar{D}^0)$ $\downarrow$ CPES,CPNES, Inclusive	Atwood +AS	time dep.	0	0	$\sim$ 0	5–50
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
	$\rho\pi + \rho(\omega)P$	Comb. of above 2	"	"	"	$\sim$ 1%	5–50
(ϕ_2)	$B^\pm$, $B^0_{\downarrow}(\bar{B}^0_{\downarrow})$ $\rho\omega$, $K^{*0}\rho^+$	Atwood +AS	Direct	$\approx$ 20%	$\approx$ 5%	$\lesssim$ 5%	5–50
(ϕ_3)	$B \to K^*\rho(\omega)$	"	"	"	"	"	5–50

36

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

Two complementary approaches:

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

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

$\Rightarrow$ Nothing sacred about $\not{C}\not{P}$ in Field Theory.

$\Rightarrow$ Addition of fermions, gauge bosons, Higgs...should entail new $\not{C}\not{P}$ phases.

$\Rightarrow$ 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 $\not{C}\not{P}$ is ≈ 0

$\Rightarrow$ $b \to s$ penguin transitions

Table: Model Independent Searches for χ

		Ref.	BR
I $B \to \eta' X_s$	DIRCP	Atwood + Soni, Hou + Tseng	$\sim 10^{-3}$
II 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)	TDCP	Grossman + Worah, London + Soni, Hurth + Mannel	$\sim$ few $\times 10^{-5}$ $\eta' K_s$ (ALL $\sim 10^{-4}$)
III $B^0 \to \Psi K^0_s$ $a_{CP}(\Psi K_s) = sin[2\beta_{CKM} + \theta_{New}]$	TDCP	Wolfenstein; Nir; Ball, Frere + Matias; Kiers, Wu + AS	$\sim 10^{-4}$
IV $B^\pm \to \Psi K^\pm$ Exptally V Clean Exc. Probe of $H^\pm$ phase	DIRCP	Wu + Soni	$\sim 10^{-4}$
V $B \to \gamma X_s$	DIRCP	Soares; Wolfenstein + Wu; Kagan + Neubert; Kiers, Wu, AS	$\sim 2 \times 10^{-4}$

If no BSM phase is found via these processes ($\lesssim$ [redacted] 3–10 years)

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

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

ATWOOD+AS PRL97

Assume some contribution to the large rate comes from BSM physics

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

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

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

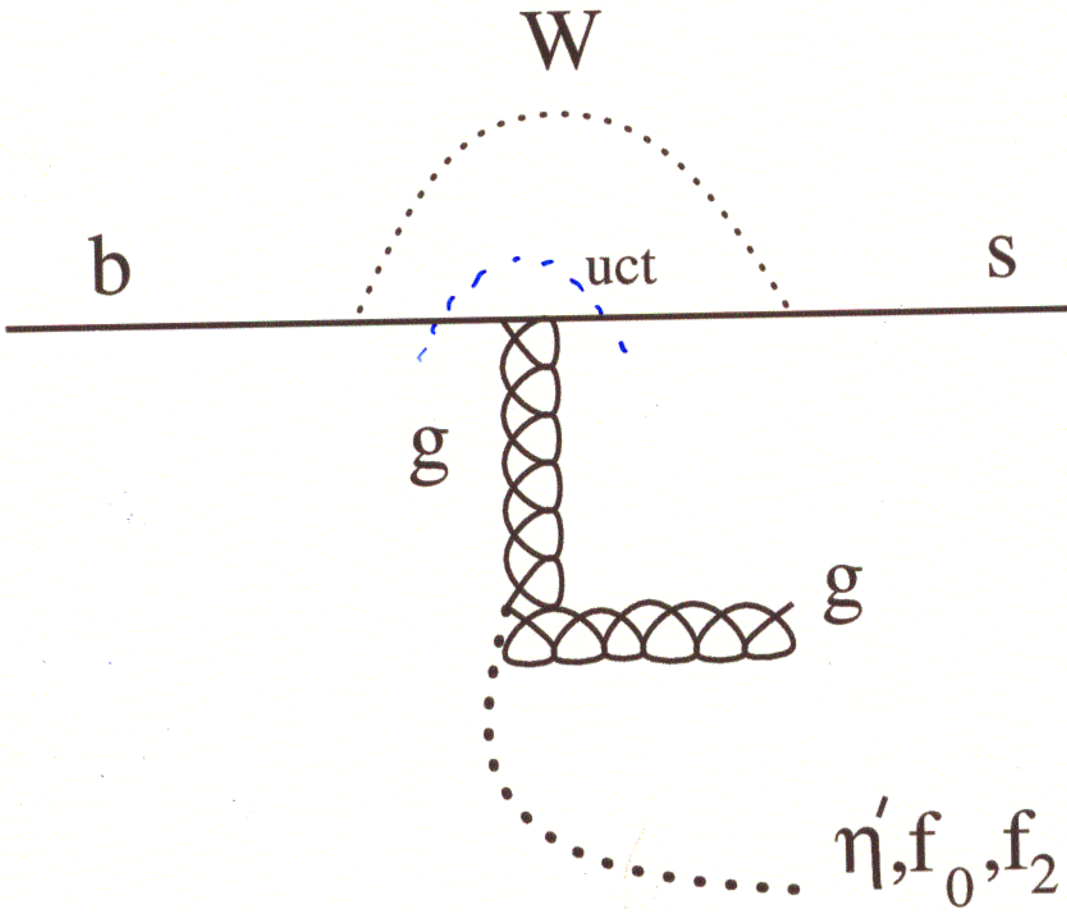
$$G(q^2) = G_{SM} + e^{i\chi_G} G_\chi$$

$\chi \equiv$ 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..

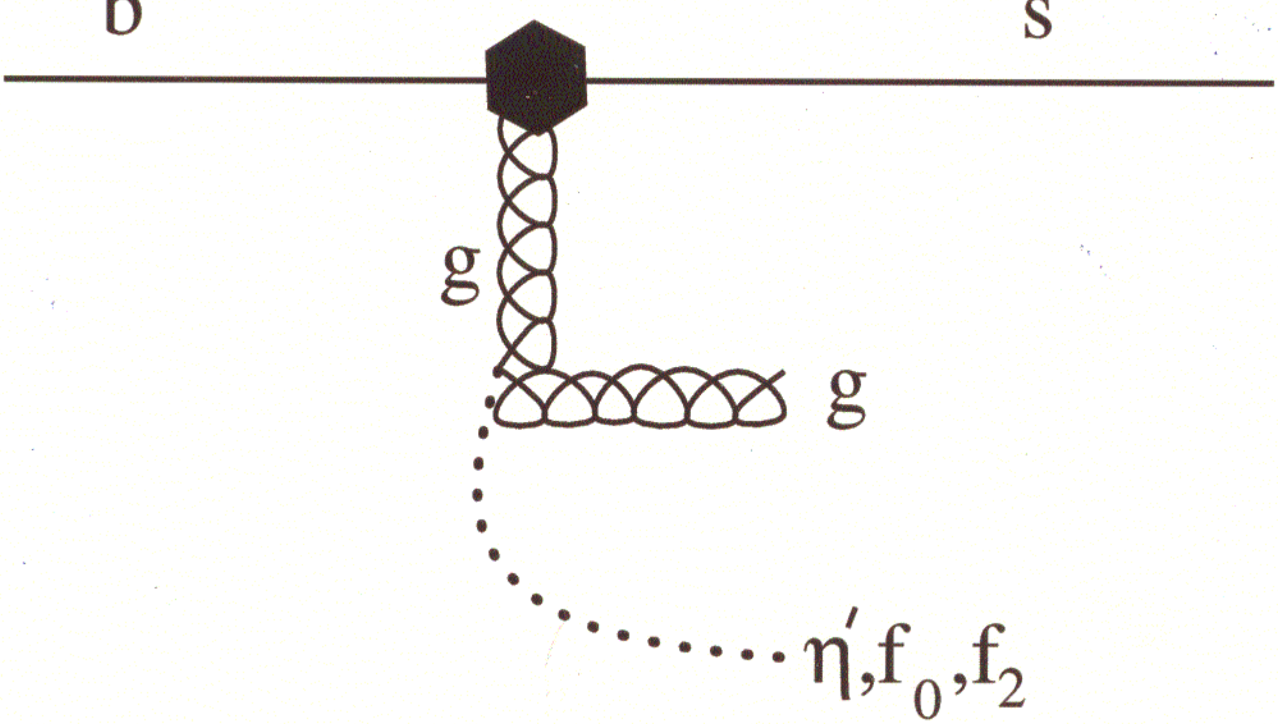
SM



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

CKM phase CP-odd ≈ 0

BSM $x \neq 0$



CKM phase $\simeq 0$

41 42

ATWOOD+AS PRL97

Figure 2a

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

$\sin\chi = 1$

Asymmetry

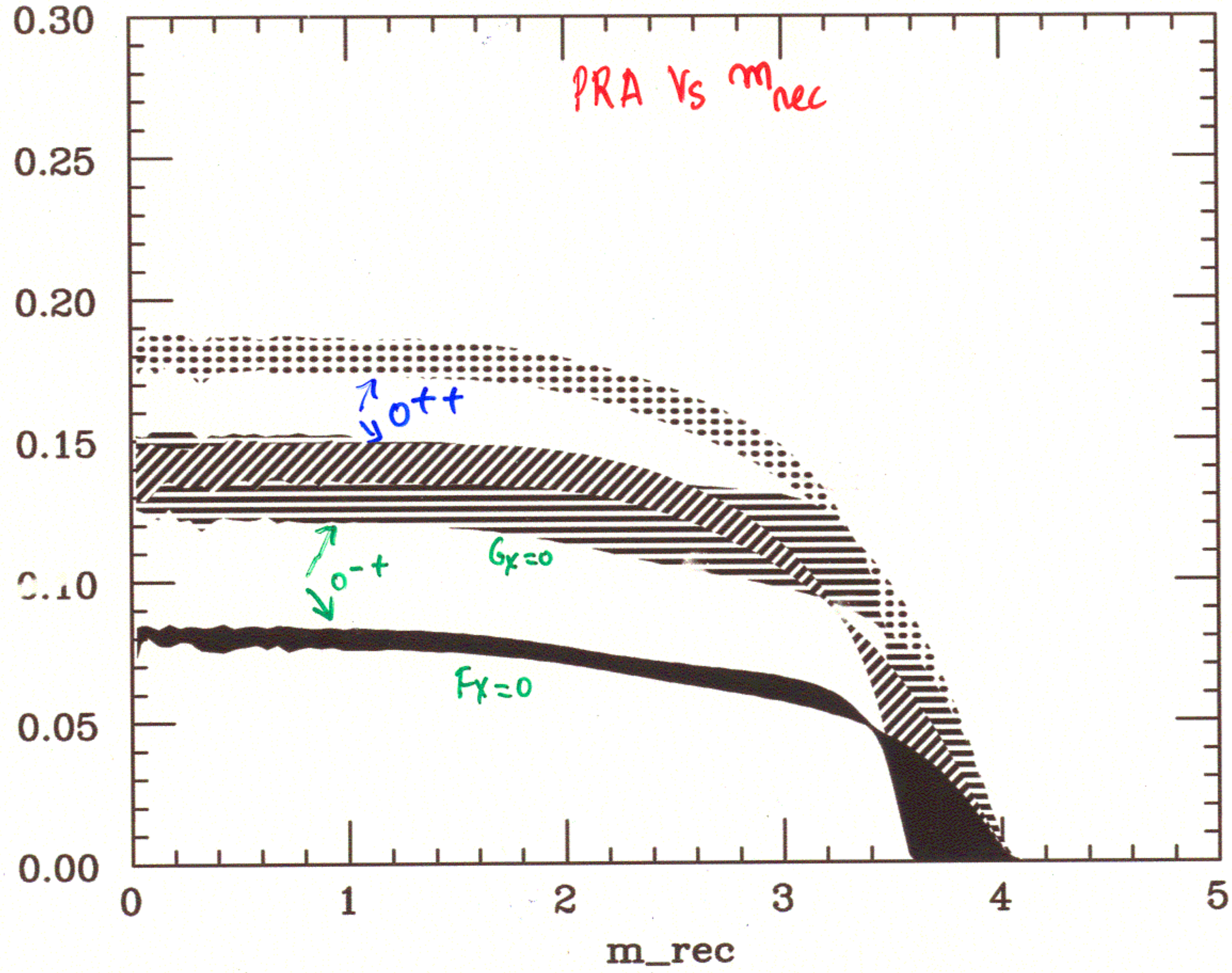
34%

28%

24%

12%

⇑ For 50% contribution to rate



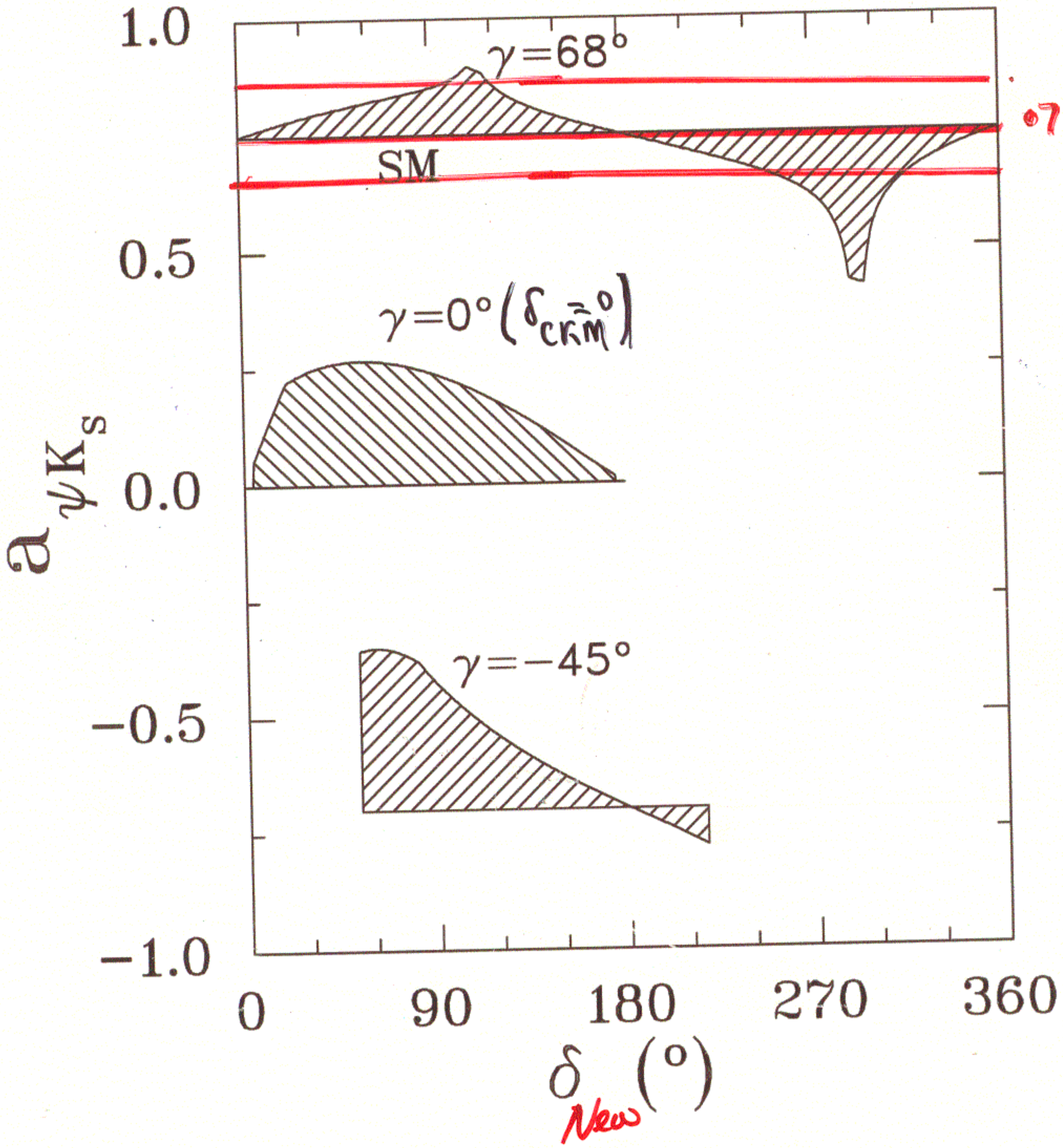
20

30 41 43

KIERS, S, Wu PRD 99

$a_{\psi K_s} = \sin(2\beta_{CKM} + \theta_{New})$

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



.79 ± .10 EXPT 16

⇒ ILLUSTRATES that BELLE/BABAR/CDF..

⇒ CKM phase dominant in ψK_S^0

~~CP~~ in RADIATIVE B Decays

Kiers, liu + A.S.;
HURTH + MANNEL
MISIAK et al

TABLES

Model	$A_{CP}^{b\to s\gamma}$ (%)	$A_{CP}^{b\to d\gamma}$ (%)
SM	0.6	−16
2HDM (Model II)	~ 0.6	~ -16
3HDM	−3 to +3	−20 to +20
T2HDM	~ 0 to +0.6	~ -16 to +4
Supergravity [40,41,47]	~ -10 to +10	$-(5-45)$ and $+(2-21)$
SUSY with squark mixing [42,43,9]	~ -15 to +15	
SUSY with R-parity violation [46]	~ -17 to +17	

TABLE I. CP asymmetries in various models. Quoted ranges are approximate; see the text for details. The blank entries represent quantities that have not, to our knowledge, been considered in the literature. The rate asymmetry for $b \to s\gamma$ from SUSY with squark mixing could be larger than the quoted ±15% if the gluino mass is significantly lighter than the squark masses [9]. Note that the range quoted for the R-parity violating case assumes $m_{\nu_\tau} \sim 10$ keV. The asymmetry is negligible if $m_{\nu_\tau} \ll 10$ keV, as is indicated by the SuperKamiokande atmospheric neutrino oscillation data [52].

NOTE $B^0 \to \rho^0 + \gamma$ ALSO Very imp. for $\frac{V_{td}}{V_{ts}}$
(NOT B^-)

45

Summary

1a) Cautions on Theory

DWQ : $\hat{B}_K \simeq .76 \pm .13$

1) $B_K \sim$ 10–15% below previously thought

2) ξ lattice determination problematic QUOTED ERROR 0.05 IS AN UNDERESTIMATE

1b) Improved determinations of $\sin 2\beta$ are well underway, but alone they will not be enough to test SM & to look for NP as significant input from theory is being used.

$(\sin 2\beta)^{SM} = .70 \pm .1$ VERY ROBUST

Ic) Existing Prominent Methods for α using $\pi\pi$, $\rho\pi$, $K\pi$...suffer from penguin pollution esp EWP and model dependence. May negate searches for NP if their effects are small.

EWP CONTINUUM 3π modelling

Must target EXTRACTION of all 3 angles with Zero Theory Error.

ϕ_3 **II)** γ with Zero Theory Error (Atwood, Dunietz, Soni, PRL '97, PRD00) via $B^\pm \to K^\pm D^0, \bar{D}^0$; $D^0, \bar{D}^0 \to$ CPNES e.g. $K^+\pi^-$

ϕ_2 **III)** α (and β? ϕ_1) with Zero Theory Error (Atwood & Soni, hep-ph/0206045) via

$B^0(\bar{B}^0) \to K^0 D^0(\bar{D}^0)$; $D^0, \bar{D}^0 \to$ CPES, CPNES, inclusive... (# of B's Need Comparable to $\rho\pi$ method)

IV) χ (BSM phase): Strategies for Model Independent Searches e.g. $B \to \eta' x_s$ (dir CP); $B^0 \to \eta' K_s, \phi K_s \ldots$ (time Dep. CP) Compare sin 2β from pure penguin modes with that from $B \to \psi K_s$.