Weak decays, CP violation and CKM: Theoretical Status

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Apologies

- **I have chosen only a few subjects**

- **I quote only a few references**

(so many articles… so little time…)

- $(\alpha,\beta,\gamma) = (\varphi_2,\varphi_1,\varphi_3)$

Outline

1 – CKM, unitarity triangle and all that

2 – Provocations

3 – Some current issues

4 – Conclusions

1 – CKM, Unitarity triangle and all that

- **Theory, Phenomenology and Experiment**

  hadronic "messy" elements

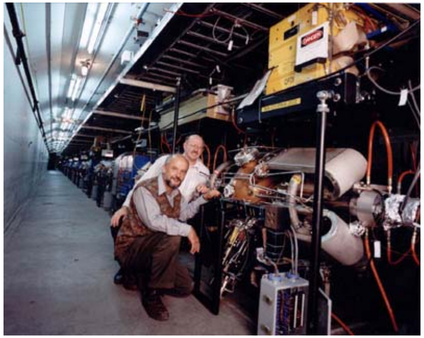
- **The (ρ, η) plane**

  the goal: detect or constrain New Physics

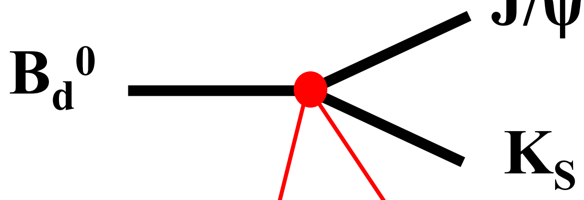
- **The unitary triangle**

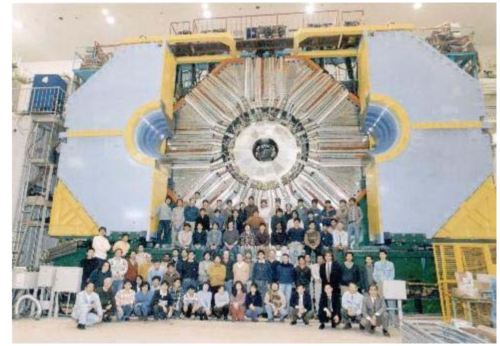
  gives only one of many tests

Generic analysis



Phenomenology (hadrons)

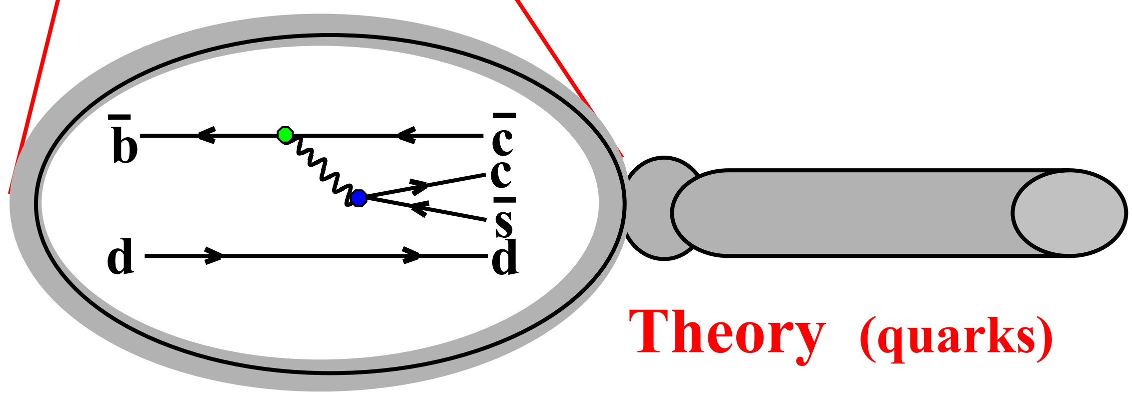




Produce initial state

Detect final state

Experiment



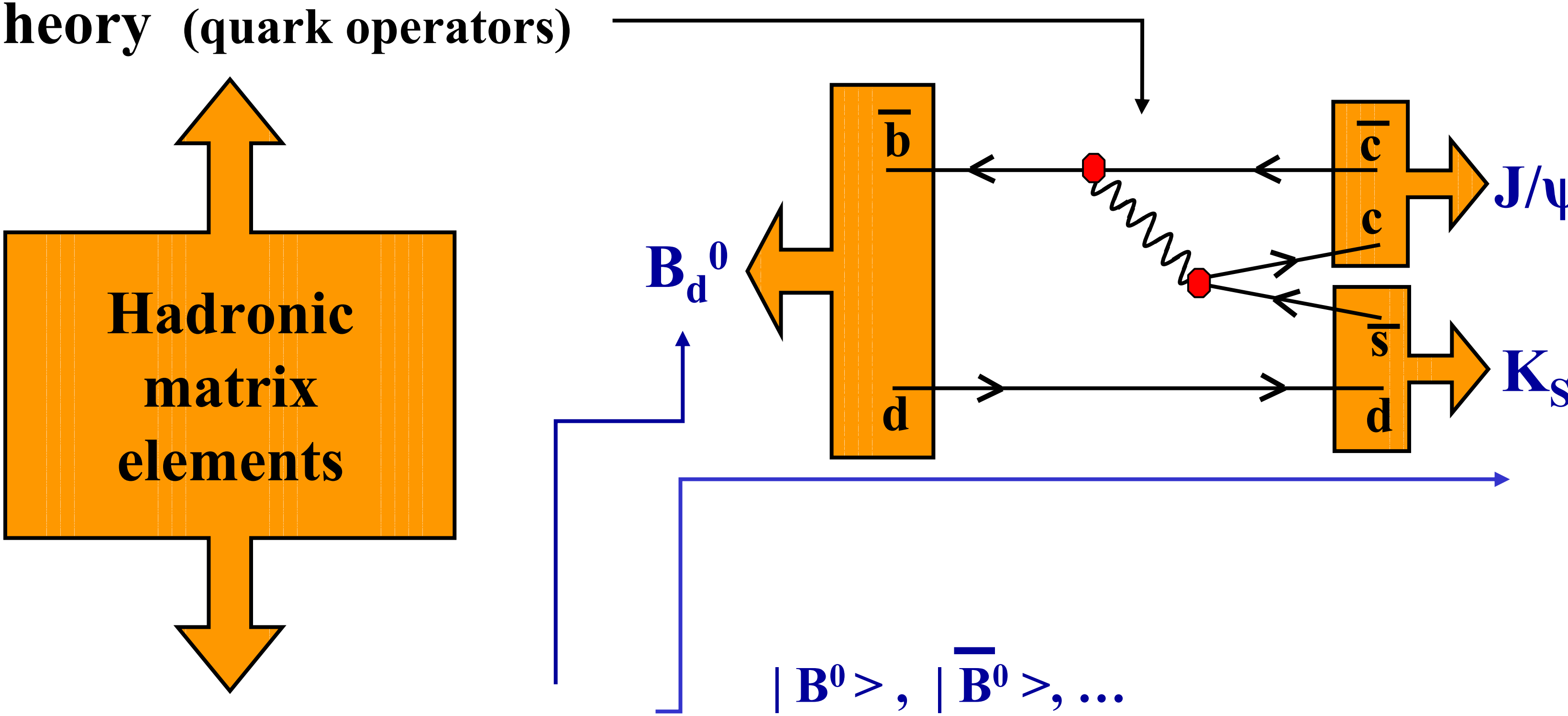
Theory (quarks)

The big problem: hadronic "messy" elements

u, d, s, c, b, t, …

Operator rephasing: $\hat{\psi} \rightarrow e^{i\varphi_{quark}}\,\hat{\psi}$

Theory (quark operators)



$|\,B^0 >,\ |\,\overline{B}^0 >, \ldots$

Phenomenology (hadron states)

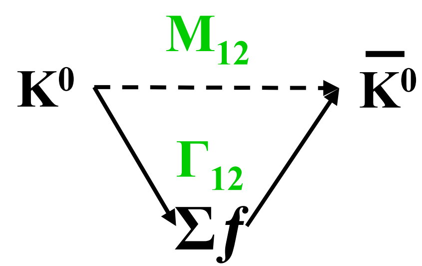
State rephasing: $|\,B^0 > \ \rightarrow e^{i\,\alpha_{hadrons}}\,|\,B^0 >$

CPV observables: phenomenology

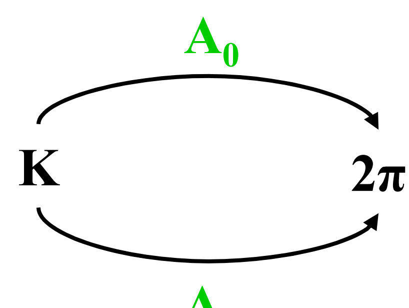
$| B^0 > \rightarrow e^{i\alpha} | B^0 >$ freedom

==> CPV observables require clash of two phases

1. Clash mixing M_{12} with Γ_{12}: $|q/p|-1$
   - CPV in mixing
   - Measured in kaon system through ε_K



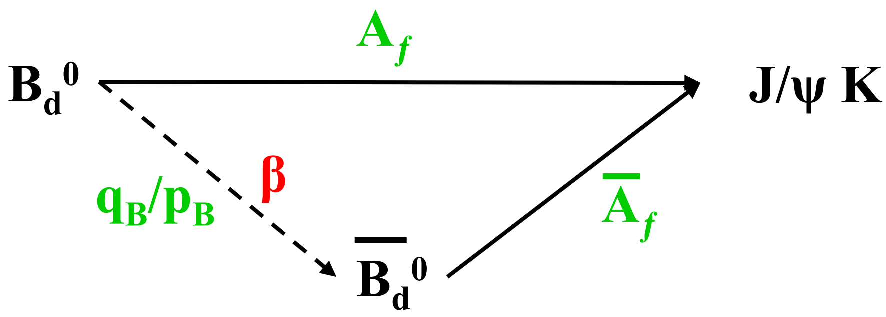
2. Clash two direct decay paths: $|\bar{A}/A|-1$
   - CPV in decay
   - Measured in kaon system through ε'_K



3. Clash direct path with mixing path; first mix, then decay

$\lambda_f = q_B/p_B \; \overline{A}_f/A_f$

Measured in B_d system through sin 2β



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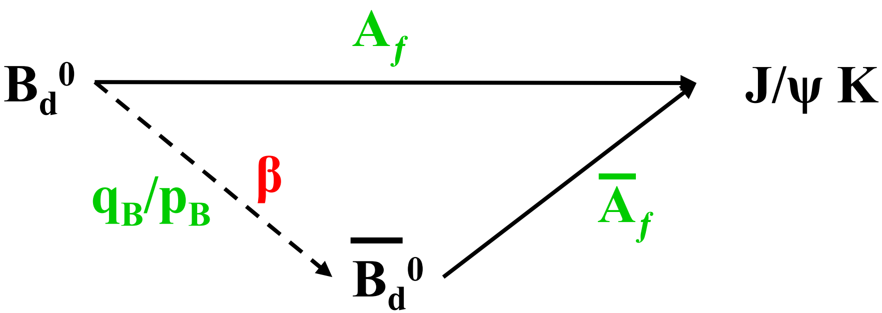
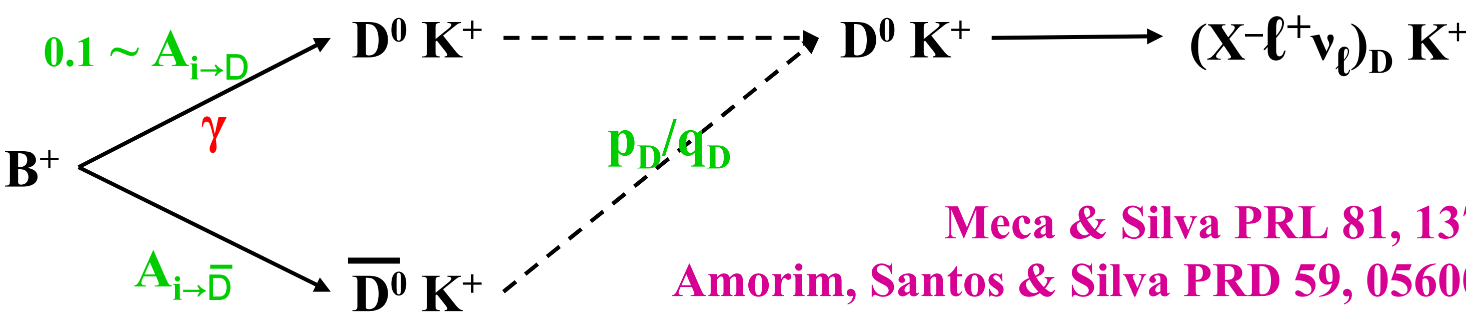


4. Clash direct path with mixing path; first decay, then mix

$\xi_i = A_{i\to D}/A_{i\to\overline{D}} \; p_D/q_D$

Never measured; <u>but</u> can affect measurements of γ in B →D



Meca & Silva PRL 81, 1377 (1998

Amorim, Santos & Silva PRD 59, 056001 (1999

In the SM $|q/p|^2-1 \sim 10^{-3}$

The other CPV observables are measured in

$$\Gamma[B^0(t) \to f] \sim e^{-\Gamma t}[1 + C_f \cos(\Delta m\, t) - S_f \sin(\Delta m\, t)]$$

$$\Gamma[\overline{B^0}(t) \to f] \sim e^{-\Gamma t}[1 - C_f \cos(\Delta m\, t) + S_f \sin(\Delta m\, t)]$$

Direct CPV $$C_f \equiv \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \xrightarrow{\text{if } \lambda_f \approx e^{-2i\varphi}} 0$$

Interference CPV $$S_f \equiv \frac{2\mathrm{Im}(\lambda_f)}{1+|\lambda_f|^2} \xrightarrow{\text{if } \lambda_f \approx e^{-2i\varphi}} -\sin(2\varphi)$$

CPV observables: theory

1. **Phases can come from $\Delta B=2$ terms**

   phases in the mixing

2. **Phases can come from $\Delta B=1$ terms**

   phases in the decay

In the SM all effects arise from a single CPV phase in the charged current interactions

Wolfenstein parametrization of the CKM matrix

$1 - \lambda^2/2$	λ	$A\,\lambda^3\,(\rho - i\eta)$
$-\lambda$	$1 - \lambda^2/2$	$A\,\lambda^2$
$A\,\lambda^3\,(1-\rho - i\eta)$	$-A\,\lambda^2$	1

Wolfenstein PRL51, 1945 (1983)

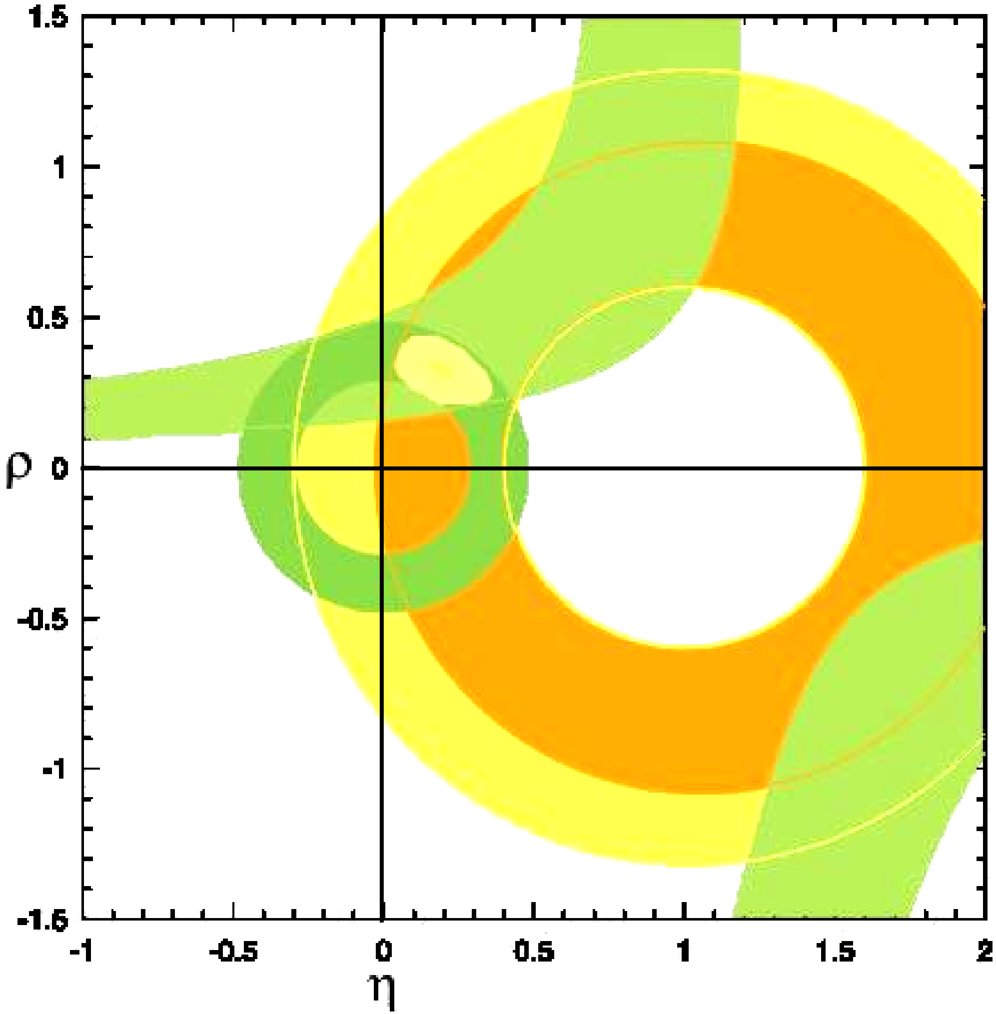
$\lambda = 0.2196 \pm 0.0026$ from $s \to u$ transitions

$A = 0.85 \pm 0.06$ from $b \to c$ transitions

"All" other experiments probe some combination of ρ and η

Our main goal is to detect new physics

Look for a lack of overlap among different constraints in



Thanks to Laplace

Redundant "parametrization" of the CKM matrix

1	$\lambda\, e^{i\chi'}$	$A\, R_b\, \lambda^3\, e^{-i\gamma}$
$-\lambda$	1	$A\, \lambda^2$
$A\, R_t\, \lambda^3\, e^{-i\beta}$	$-A\, \lambda^2\, e^{i\chi}$	1

- **In the SM**

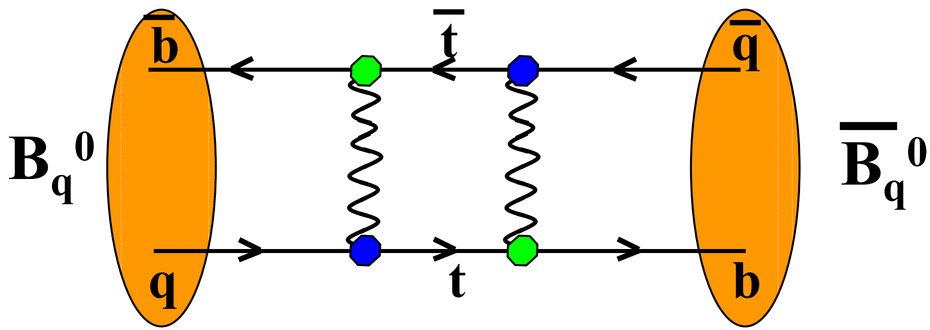
$$R_t\, e^{-i\beta} \approx 1 - \rho - i\,\eta$$
$$R_b\, e^{-i\gamma} \approx \rho - i\,\eta$$
$$\chi \approx \lambda^2\, \eta$$
$$\chi' \approx A^2\, \lambda^4\, \eta$$

Aleksan, Kayser & London
PRL73, 18 (1994)

- **Beyond the SM**
  - there are nine independent magnitudes
  - but there are only four independent phases: $\beta, \gamma, \chi, \chi'$

Branco, Lavoura & Silva
"CP violation"

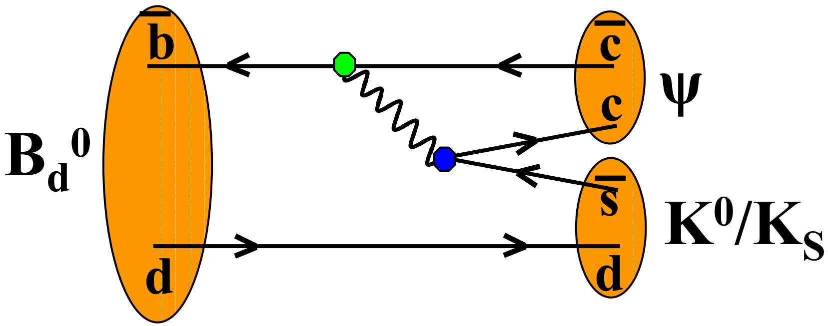
Mixing in the SM



B_d^0 ==> $(V_{tb}^* V_{td})^2 = 1\ (AR_t\lambda^3 e^{-i\beta})^2$ ==> $q/p = e^{-2i\tilde{\beta}}$

B_s^0 ==> $(V_{tb}^* V_{ts})^2 = 1\ (-A\lambda^2 e^{i\chi})^2$ ==> $q/p = e^{2i\tilde{\chi}}$

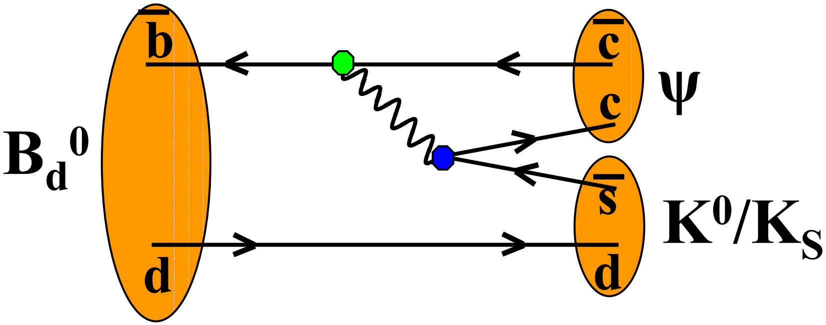
$B \to \psi K_S$

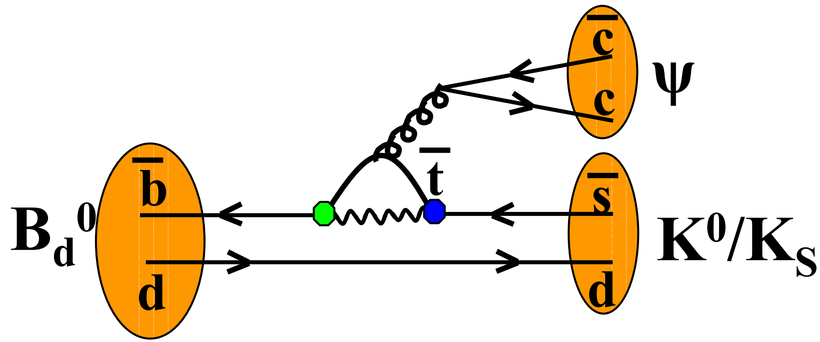


$$V_{cb}^{*} V_{cs} = A\lambda^2 \; 1$$

$$\lambda_{\psi K_S} = \frac{q}{p} \frac{A(\overline{B} \to \psi K_S)}{A(B \to \psi K_S)} = e^{-2i\beta} \frac{-\text{h.m.e.}}{\text{h.m.e.}} = -\, e^{-2\, i\, \tilde{\beta}}$$

$B \to \psi K_S$





$V^*_{cb}\, V_{cs} = A\lambda^2\, 1$

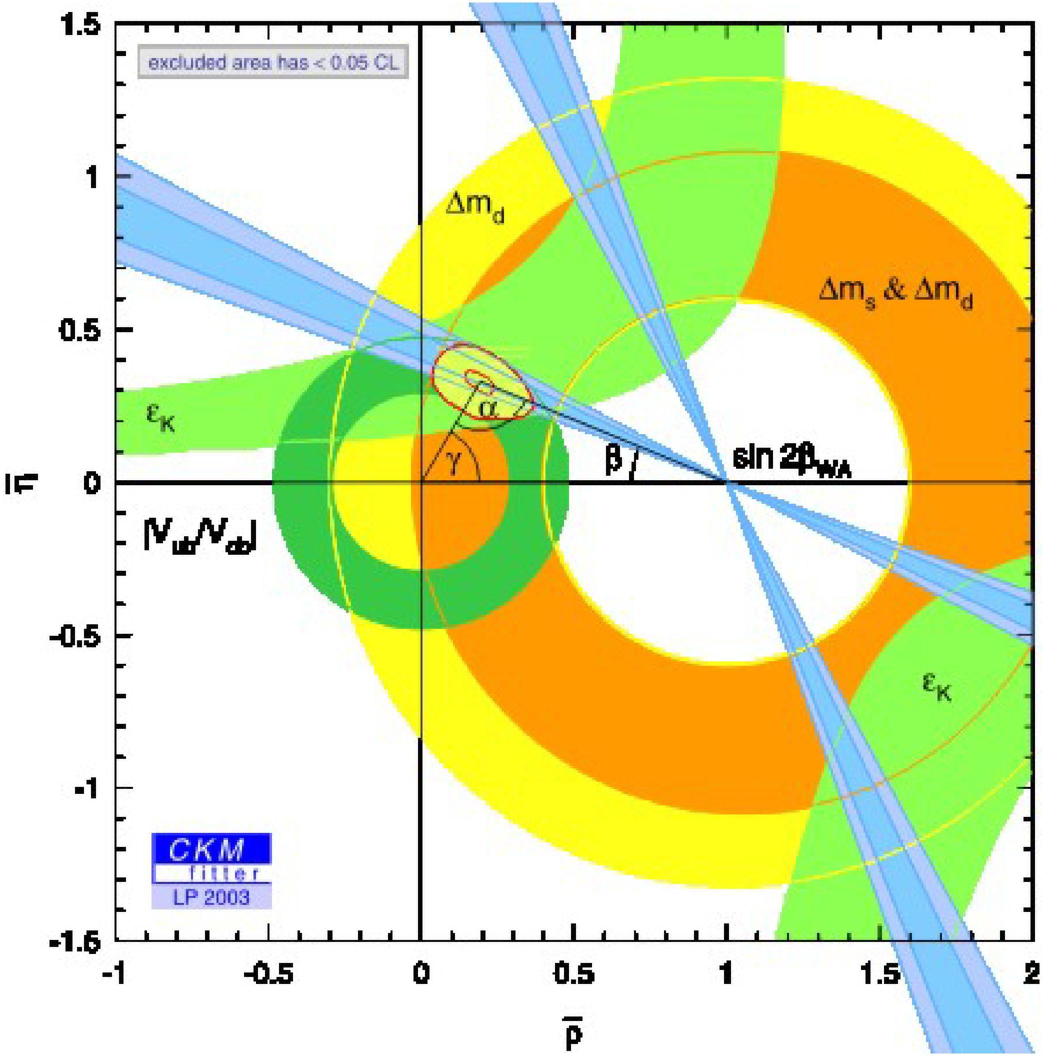
$V^*_{tb}\, V_{ts} = 1\, (-A\lambda^2 e^{i\chi})$

- $S_{\psi Ks}= \sin(2\beta)$ at LP'03:
  - Belle 140 fb^{-1} $0.733 \pm 0.057 \pm 0.028$
  - BaBar 81 fb^{-1} $0.741 \pm 0.067 \pm 0.033$
- New World Average (Browder from Höcker):

$$\sin(2\beta) = 0.736 \pm 0.049$$

Precision Measurement

Constraints on the ρ-η plane

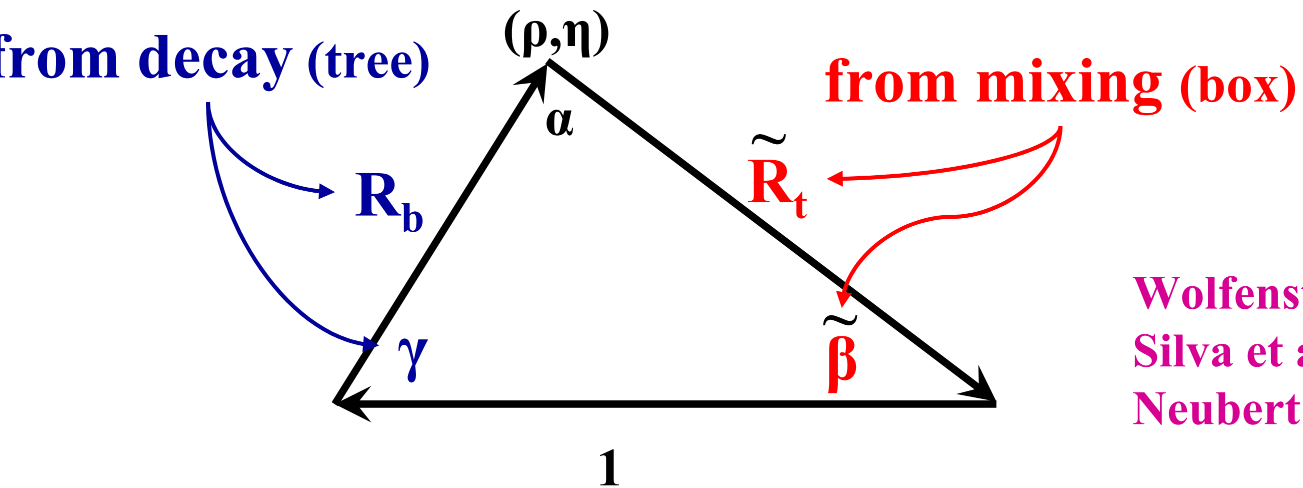


http://ckmfitter.in2p3.f
Höcker et al.
EPJ C21, 225 (2001)

Unitarity triangle

1	$\lambda\, e^{i\chi'}$	$A\, R_b\, \lambda^3\, e^{-i\gamma}$
$-\lambda$	1	$A\, \lambda^2$
$A\, R_t\, \lambda^3\, e^{-i\beta}$	$-A\, \lambda^2\, e^{i\chi}$	1

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \quad ==> \quad R_b\, e^{+i\gamma} + R_t\, e^{-i\beta} = 1$$



Wolfenstein since 1964
Silva et al. PRD67, 036004 (2003)
Neubert ph/0308224

2 – Provocations

- goal is to uncover NP; not to test the SM
- 4th type of CPV to be measured
- unitary triangle
  - compares mixing versus decay
  - is only one of many tests of the SM picture of CPV

- **$\alpha + \beta + \gamma = \pi$ by definition**

  - **only two large phases in the CKM: β and γ**

  - **testing this relation makes exactly the same sense as testing the relation $\beta=\beta$**

3 – Some current issues

- **Hints from $B \to \Phi K_S$**
- **$B \to \pi\pi$ and penguin pollution**
- **Usefulness of $B \to \pi^0\pi^0$**
- **Hints from $B \to K\pi$ decays**

"Testing the relation β=β"

The angle β can be probed in a variety of channels:

- $B_d \rightarrow \Phi K_S$, $B_d \rightarrow \eta' K_S$ and (-) $B_d \rightarrow K^+ K^- K_S$

  should yield the same angle β found in $B_d \rightarrow \psi K_S$

- $b \rightarrow ccd$ decays, $B_d \rightarrow \psi \pi^0$ and $B_d \rightarrow D^{(*)+} D^{(*)-}$

  $(b \rightarrow ccd) \sim \lambda\, (b \rightarrow ccs)$ could be more sensitive to $b \rightarrow d$ penguins than $(b \rightarrow ccs)$ is to $b \rightarrow s$ penguins

- $B_d \rightarrow A K_S$, with $A = \chi_1\ \eta_c$

  comparison with $B_d \rightarrow \psi K_S$ tests models which break P and CP

  Atwood & Hiller ph/0307251

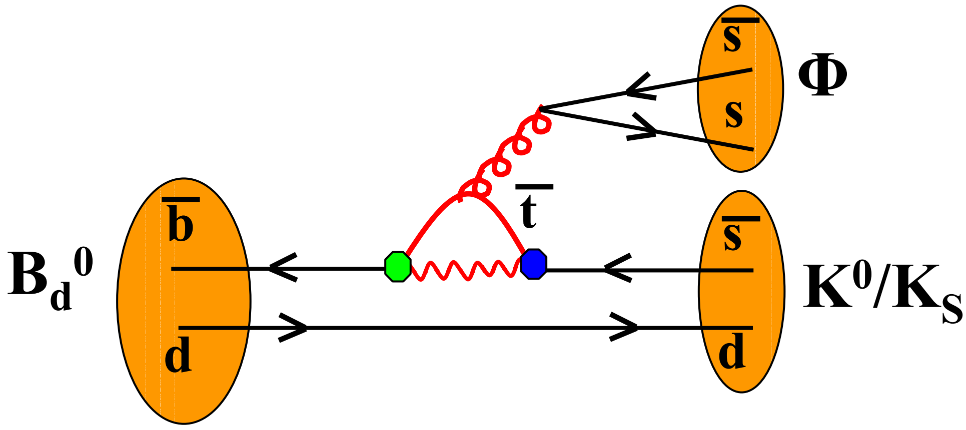
- $B_d \rightarrow J/\psi K_L$

  comparison with $B_d \rightarrow J/\psi K_S$ tests CPT and exotic $B \rightarrow \overline{K}$ decays

  Lavoura PRD62, 056002 (2000)

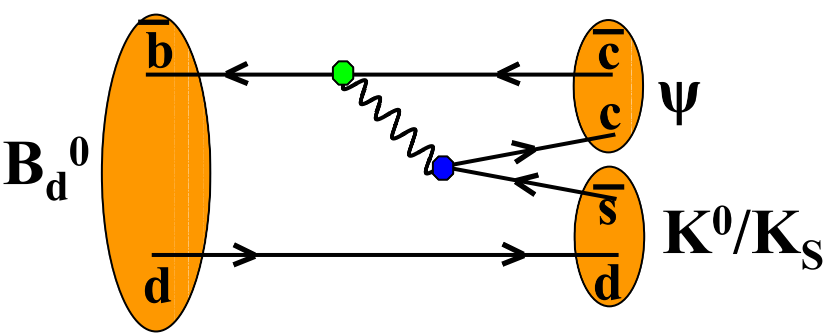
  Grossman et al. PLB538, 327 (2002)

$B \to \Phi K_S$ is a penguin decay

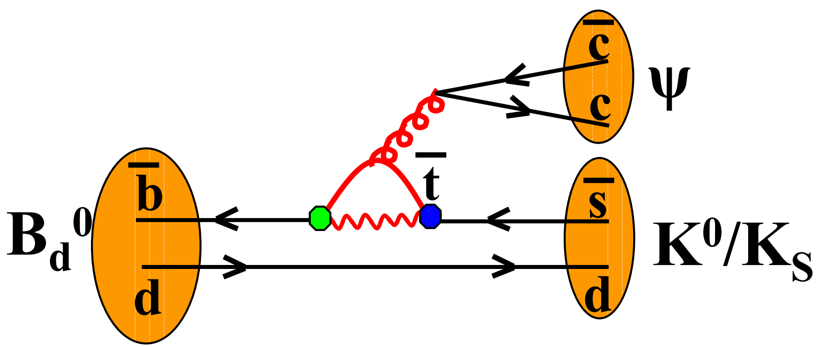


$V_{tb}^* V_{ts} = 1\ (-A\lambda^2 e^{i\chi})$

- **Recall**



$V_{cb}^* V_{cs} = A\lambda^2\ 1$



$V_{tb}^* V_{ts} = 1\ (-A\lambda^2 e^{i\chi})$

Simple predictions

- A “prediction” of the SM is

  Phase β ($b \to s$ penguin) = Phase β ($b \to c\bar{c}s$)

- Since $B_d \to \Phi K_S$ and $B_d \to \eta' K_S$ are $b \to s$ penguin decays, they are more likely to be affected by NP

- Due to the different hadronic matrix elements, the impact may be different in the two decays

Measurements of $B \to \Phi K_S$

Obs.	Date	BaBar	Belle	Average
$S_{\Phi Ks}$	previous	$-0.18 \pm 0.51 \pm 0.07$	$-0.73 \pm 0.64 \pm 0.22$	-0.38 ± 0.41
	LP'03	$+0.45 \pm 0.43 \pm 0.07$	$-0.96 \pm 0.50 \pm 0.10$	-0.14 ± 0.33
$C_{\Phi Ks}$	previous	$-0.80 \pm 0.38 \pm 0.12$	$+0.56 \pm 0.41 \pm 0.16$	-0.19 ± 0.30
	LP'03	$-0.38 \pm 0.37 \pm 0.12$	$+0.15 \pm 0.29 \pm 0.08$	-0.04 ± 0.24

- Table from LP'03 talks, specially Browder, and HFAG
- Compare with $\sin(2\beta) = 0.736 \pm 0.049$
- BaBar came closer to $S_{\psi Ks}$
- Belle's disagreement worsened
- Overall same 2.7σ with $S_{\psi Ks}$ remained

==> Possibility of New Physics

What would be needed to explain $S_{\Phi Ks} = -0.14$?

- **New Physics in $b \to s$ penguins**
- **with amplitude comparable to the SM**
- **and, with a large relative CP phase**

One possibility: Non-SM sZb couplings

$$L_Z^{\text{new}} = \frac{g^2}{4\pi} \frac{g}{2\cos\theta_W} \left[Z_{sb} \bar{b}_L \gamma_\mu s_L + Z'_{sb} \bar{b}_R \gamma_\mu s_R \right] Z^\mu + h.c.$$

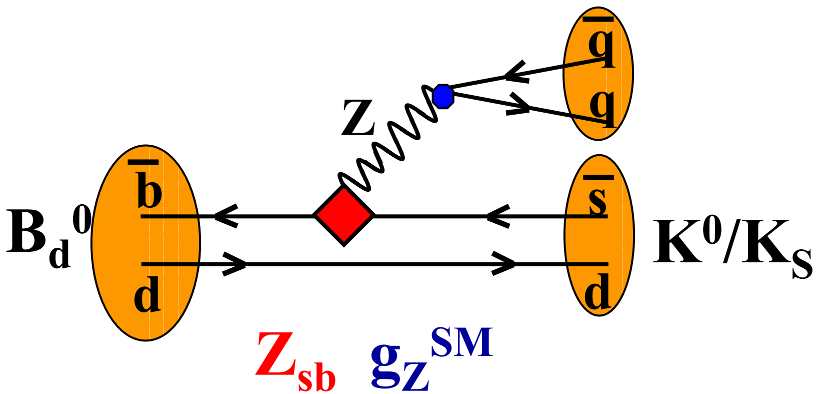
- **Experimental constraint from inclusive $B_d \rightarrow X_s e^+ e^-$ decays**

$$\sqrt{\left|Z_{sb} + Z_{sb}^{\text{SM}}\right|^2 + \left|Z'_{sb}\right|^2} \leq 0.08 \quad \text{with} \quad Z_{sb}^{\text{SM}} = -V_{tb}^* V_{ts} \sin^2\theta_W C_{10}^* \approx -0.04$$

imply that new Z penguins are at most 2-3 larger than SM

- **These new vertices also affect BR and A_{FB} in $b \rightarrow s\, \ell^+\ell^-$ (~SM), $B_s \rightarrow \mu^+\mu^-$ (~10 SM), Δm_s (~0.5 SM), while $b \rightarrow s\gamma$ remains SM-like.**

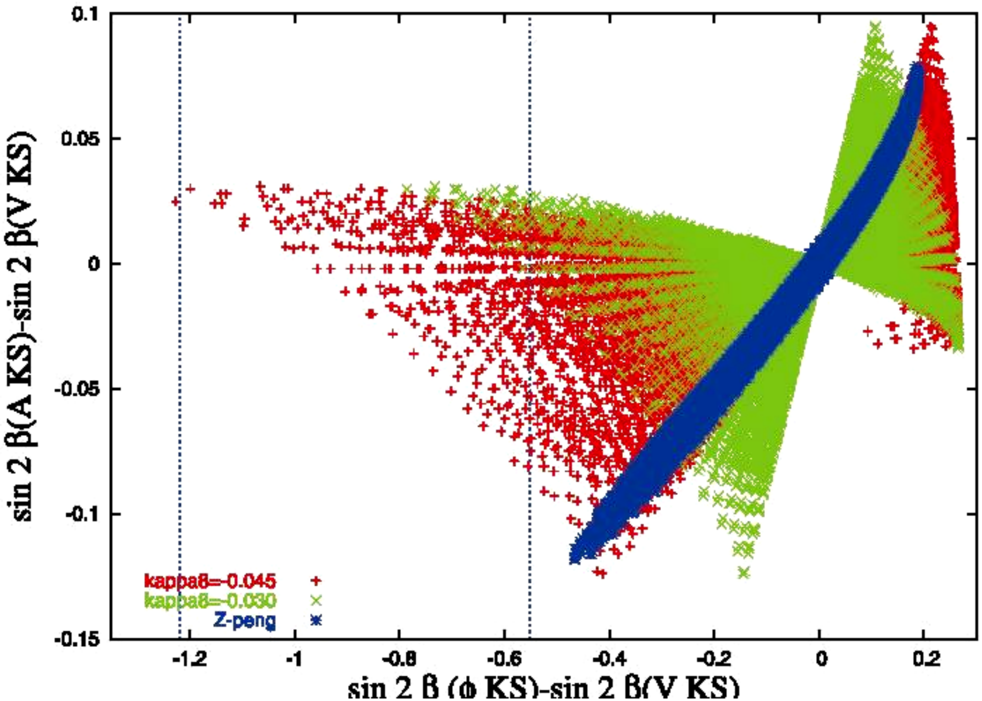
Non-SM sZb couplings



$g_Z^{SM,V}$ (ss) = –0.35 $g_Z^{SM,A}$ (ss) = +0.5

$g_Z^{SM,V}$ (ψ,ψ') = +0.19 $g_Z^{SM,A}$ (η_c,χ_1) = –0.5

Atwood & Hiller ph/0307251



Experimentally

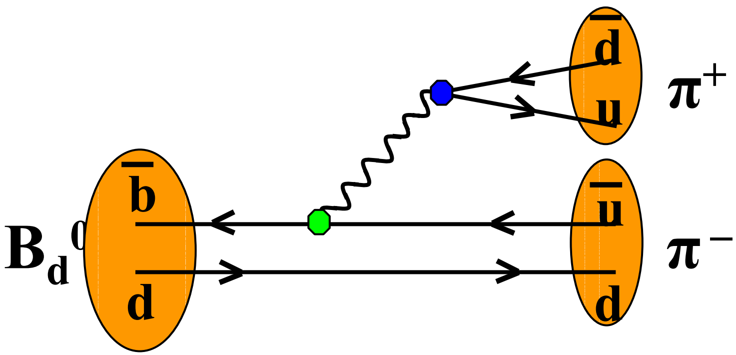
$\sin 2\beta_{AKs} - \sin 2\beta_{VKs} = -0.05 \pm 0.26$

Thanks to Hiller

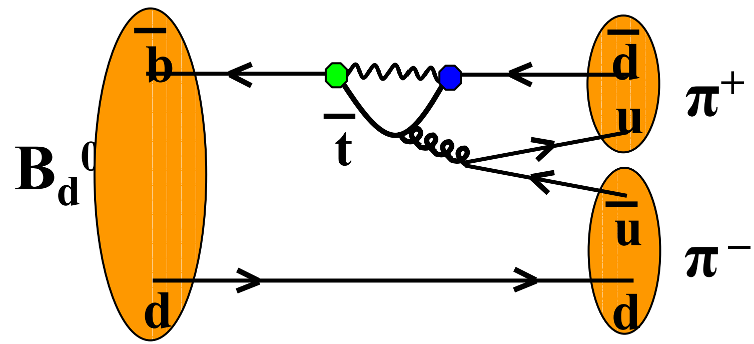
Status of $B \to \Phi K_S$

- **Experimental central values are in a state of flux**
- **Current average for $\beta_{\Phi Ks}$ differs from $\beta_{\Psi Ks}$ by 2.7σ**
- **If the effect remains, comparison with other measurements of β could discriminate between different NP models**

$B \to \pi^+ \pi^-$ is affected by penguin pollution



$V^*_{ub}\, V_{ud} = (A R_b \lambda^3 e^{i\gamma})\ 1$



$V^*_{tb}\, V_{td} = 1\ (A R_t \lambda^3 e^{-i\beta})$

$$\lambda_{\pi\pi} = \frac{q}{p}\,\frac{A(\bar{B} \to \pi^+ \pi^-)}{A(B \to \pi^+ \pi^-)} = e^{-2i\beta}\,\frac{e^{-i\gamma} < t > + e^{+i\beta} < p >}{e^{+i\gamma} < t > + e^{-i\beta} < p >}$$

$$= e^{-2\,i\,(\tilde{\beta}+\gamma)}\ \frac{1 + r\,e^{i\delta}\, e^{i(\beta+\gamma)}}{1 + r\,e^{i\delta}\, e^{-i(\beta+\gamma)}} \qquad r e^{i\delta} = \frac{< p >}{< t >}$$

What can we learn from $B \to \pi^+ \pi^-$?

$$\lambda_{\pi\pi} = e^{-2i(\tilde{\beta}+\gamma)} \frac{1 + r\, e^{i\delta} \quad e^{i(\beta+\gamma)}}{1 + r\, e^{i\delta} \quad e^{-i(\beta+\gamma)}}$$

- **SM**

  $\beta = \tilde{\beta}$ from ΨK_S; δ γ r unknown

- **NP**

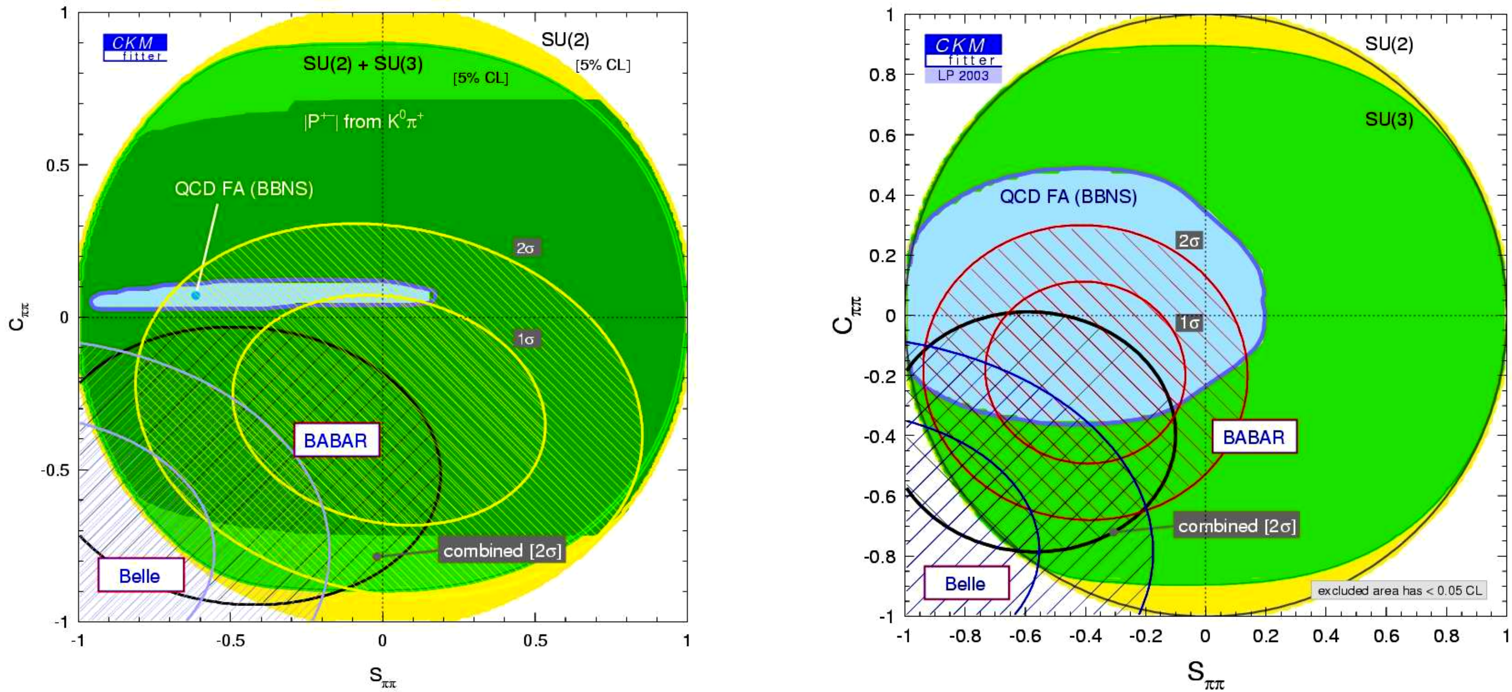
  $\tilde{\beta}$ from ΨK_S; δ γ r <u>and</u> β unknown

Note: **$S_{\pi\pi}$ + [sin(2β) = 0.736±0.049] also probes direct CPV**

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

from HFAG

Obs.	Date	BaBar	Belle	Average
$S_{\pi\pi}$	previous	–0.02 ± 0.34 ± 0.05	–1.23 ± 0.41 ± 0.08	–0.47 ± 0.26
	2003	–0.40 ± 0.22 ± 0.03		–0.58 ± 0.20
$C_{\pi\pi}$	previous	–0.30 ± 0.25 ± 0.04	–0.77 ± 0.27 ± 0.08	–0.49 ± 0.19
	2003	–0.19 ± 0.19 ± 0.05		–0.38 ± 0.16



Trapping the penguin: r

- **Use isospin** Gronau & London PRL65, 3381 (1990)

  measure $BR_{av}(\pi^+\pi^-)$, $C_{\pi+\pi-}$, $S_{\pi+\pi-}$, $BR_{av}(\pi^0\pi^0)$, $C_{\pi0\pi0}$, $BR_{av}(\pi^+\pi^0)$

  ==> determine α with 16-fold ambiguity

  (if one could) measure also $S_{\pi0\pi0}$

  ==> determine α with usual 4-fold ambiguity

- **Use "partial isospin"** Grossman & Quinn PRD58, 017504 (1998)

  measure $S_{\pi+\pi-}$, $C_{\pi+\pi-}$, $BR_{av}(\pi^0\pi^0)$, $BR_{av}(\pi^+\pi^0)$

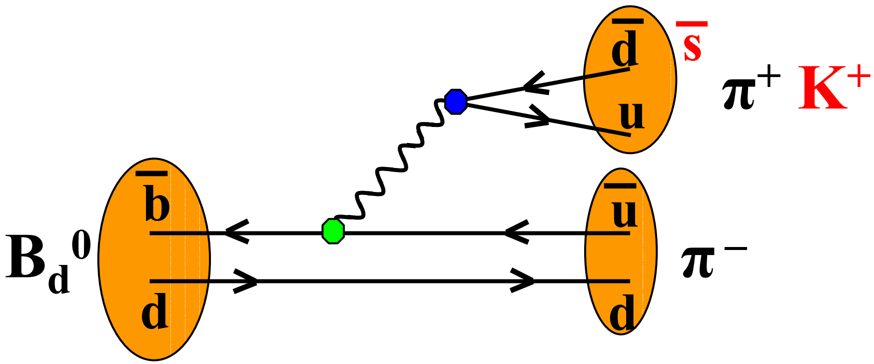
  ==> $\delta_\alpha \leq 48^0$ at 90%c.l. Jawahery LP03

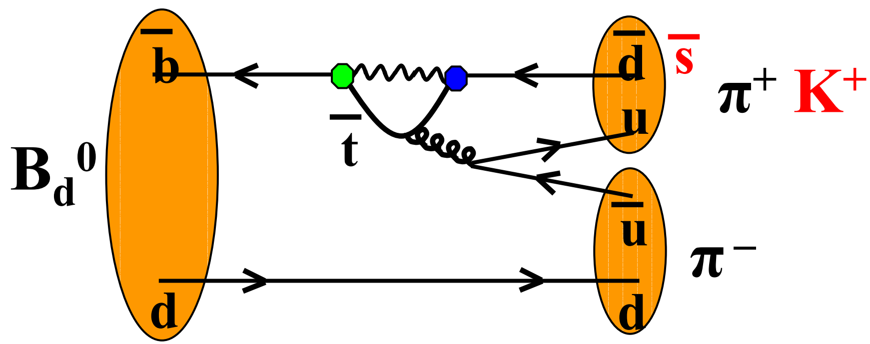
$$S_{\pi^+\pi^-} = \sqrt{1 - C^2_{\pi^+\pi^-}}\ \sin 2(\alpha + \delta_\alpha)$$

Trapping the penguin: r

- **Use SU(3) [U-spin]** Silva & Wolfenstein PRD49, 1151 (1994)

measure $S_{\pi+\pi-}$, $BR_{av}(B \to K^+\pi^-)$





$V^*_{ub}\, V_{ud} = (AR_b\lambda^3 e^{i\gamma})\ 1$ $\qquad$ $V^*_{tb}\, V_{td} = 1\ (AR_t\lambda^3 e^{-i\beta})$

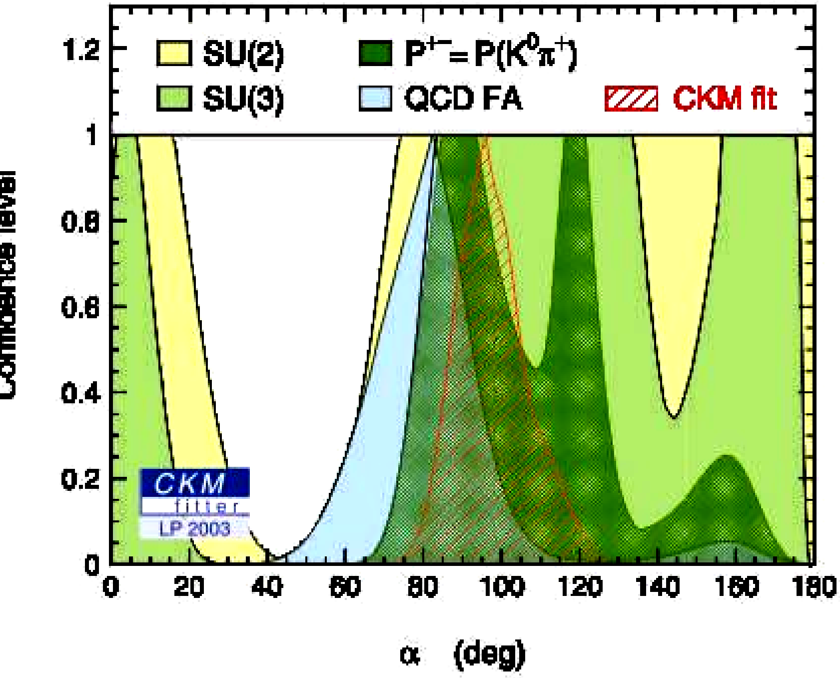
$V^*_{ub}\, V_{us} = (AR_b\lambda^3 e^{i\gamma})\ 1$ $\qquad$ $V^*_{tb}\, V_{ts} = 1\ (-A\lambda^2 e^{i\chi})$

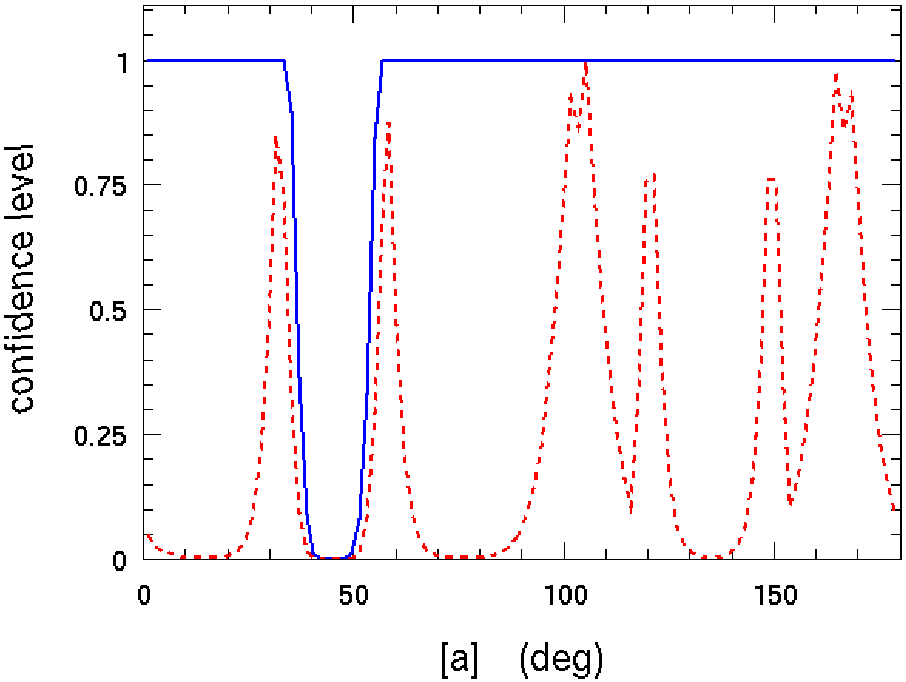
Expect $B \to K\pi$ to be penguin dominated

==> good source of information on the penguin

- **Trust calculations of hadronic matrix elements**

Trapping the penguin: r





Current Situation

Futuristic

central: $BR_{av}(\pi^+\pi^0)$, $BR_{av}(\pi^+\pi^-)$, $BR_{av}(\pi^0\pi^0)$

central: $C_{\pi+\pi-}$, $S_{\pi+\pi-}$ **from BaBar**

errors: current/5

Enormous courtesy of Höcker

$|\lambda_{\pi 0\pi 0}| = 1.00 \pm 0.08$

The usefulness of $B \to \pi^0 \pi^0$

- **Current measurement of $BR_{av}(\pi^0\pi^0)$ provides bound on α**

- **$C_{\pi^0\pi^0}$ is the next goal since it enables the isospin analysis**

- **Current measurement of $BR_{av}(\pi^0\pi^0)$ is at odds with QCD based calculations of the hadronic matrix elements**

Some B $\rightarrow$ PP decays

The next table has been compiled from the following references:

- **Fry LP'03**
- **Keum and Sanda ph/0306004** — **pQCD**
- **Beneke & Neubert ph/0308039** — **QCDF**
- **Chiang, Gronau & Rosner ph/0306021 and Gronau & Rosner ph/0307095** — **SU(3)**
- **Fu, He & Hsiao ph/0304242** — **U(3)**

Mode	pQCD	QCDF	SU(3)	U(3)	BR_{exp}
$B^0 \to \pi^+ \pi^-$	6 – 11	$8.9^{+4.0\,+3.6\,+0.6\,+1.2}_{-3.4\,-3.0\,-1.0\,-0.8}$			
$B^0 \to \pi^0 \pi^0$	0.33 – 0.65	$0.3^{+0.2\,+0.2\,+0.3\,+0.2}_{-0.2\,-0.1\,-0.1\,-0.1}$	0.4 – 1.6	1.2 – 2.7	
$B^+ \to \pi^+ \pi^0$	2.7 – 4.8	$6.0^{+3.0\,+2.1\,+1.0\,+0.4}_{-2.4\,-1.8\,-0.5\,-0.4}$			
$B^0 \to K^+ \pi^-$	13 – 19	$16.3^{+2.6\,+9.6\,+1.4\,+11.4}_{-2.3\,-6.5\,-1.4\,-4.8}$			
$B^0 \to K^0 \pi^0$	8 – 14	$7.0^{+0.7\,+4.7\,+0.7\,+5.4}_{-0.7\,-3.2\,-0.7\,-2.3}$			
$B^+ \to K^0 \pi^+$	14 – 26	$19.3^{+1.9\,+11.3\,+1.9\,+13.8}_{-1.9\,-7.8\,-2.1\,-5.6}$			
$B^+ \to K^+ \pi^0$	8 – 14	$11.1^{+1.8\,+5.8\,+0.9\,+6.9}_{-1.7\,-4.0\,-1.0\,-3.0}$			
$B^0 \to K^0 \overline{K}^0$	1.4	$1.35^{+0.41\,+0.71\,+0.13\,+1.09}_{-0.36\,-0.48\,-0.15\,-0.45}$	0.6 – 0.8	0.5 – 1.1	
$B^+ \to K^+ \overline{K}^0$	1.4	$1.36^{+0.45\,+0.72\,+0.14\,+0.91}_{-0.39\,-0.49\,-0.15\,-0.40}$	0.6 – 0.9	0.6 – 1.2	

Note: $B^0 \to K^+K^-$, not shown, is annihilation-dominated and expected to be $\sim 10^{-8}$

All BR x 10^{-6}

Mode	pQCD	QCDF	SU(3)	U(3)	BR_{exp}
$B^0 \to \pi^+ \pi^-$	6 – 11	$8.9^{+4.0\ +3.6\ +0.6\ +1.2}_{-3.4\ -3.0\ -1.0\ -0.8}$			4.55±0.44
$B^0 \to \pi^0 \pi^0$	0.33 – 0.65	$0.3^{+0.2\ +0.2\ +0.3\ +0.2}_{-0.2\ -0.1\ -0.1\ -0.1}$	0.4 – 1.6	1.2 – 2.7	1.90±0.47
$B^+ \to \pi^+ \pi^0$	2.7 – 4.8	$6.0^{+3.0\ +2.1\ +1.0\ +0.4}_{-2.4\ -1.8\ -0.5\ -0.4}$			5.27±0.79
$B^0 \to K^+ \pi^-$	13 – 19	$16.3^{+2.6\ +9.6\ +1.4\ +11.4}_{-2.3\ -6.5\ -1.4\ -4.8}$			18.16 ± 0.79
$B^0 \to K^0 \pi^0$	8 – 14	$7.0^{+0.7\ +4.7\ +0.7\ +5.4}_{-0.7\ -3.2\ -0.7\ -2.3}$			11.21 ± 1.36
$B^+ \to K^0 \pi^+$	14 – 26	$19.3^{+1.9\ +11.3\ +1.9\ +13.8}_{-1.9\ -7.8\ -2.1\ -5.6}$			20.62 ± 1.35
$B^+ \to K^+ \pi^0$	8 – 14	$11.1^{+1.8\ +5.8\ +0.9\ +6.9}_{-1.7\ -4.0\ -1.0\ -3.0}$			12.82 ± 1.07
$B^0 \to K^0 \overline{K}^0$	1.4	$1.35^{+0.41\ +0.71\ +0.13\ +1.09}_{-0.36\ -0.48\ -0.15\ -0.45}$	0.6 – 0.8	0.5 – 1.1	<2.4
$B^+ \to K^+ \overline{K}^0$	1.4	$1.36^{+0.45\ +0.72\ +0.14\ +0.91}_{-0.39\ -0.49\ -0.15\ -0.40}$	0.6 – 0.9	0.6 – 1.2	<1.3

Note: $B^0 \to K^+K^-$, not shown, is annihilation-dominated and expected to be $\sim 10^{-8}$

All BR x 10^{-6}

$B \to K\,\pi$ decays: diagrammatic decomposition

- **Neglect annihilation and exchange diagrams**
- **Color-suppressed (tree and EW-penguin) are easily included:** $C+P_{EW}$, $T+P^c_{EW}$, $P-1/3P^c_{EW}$

$$A(B^0 \longrightarrow K^+\pi^-) = -(P + e^{i\gamma}\, T)$$

R Fleischer-Mannel

$$A(B^+ \longrightarrow K^0\pi^+) = P$$

Buras-Fleischer R_n

$$\sqrt{2}\, A(B^0 \longrightarrow K^0\pi^0) = P - P_{EW}$$

R_c Neubert-Rosner

$$\sqrt{2}\, A(B^+ \longrightarrow K^+\pi^0) = -(P + e^{i\gamma}\, T + P_{EW})$$

Ratios of B → K π decays

- From Gronau & Rosner ph/0307095

Mode	Branching ratio$_{av}$ (10^{-6})	Partial width$_{av}$ (10^{-9}eV)	A_{CP}
$B^0 \rightarrow K^+ \pi^-$	18.16 ± 0.79	7.77 ± 0.35	–0.088 ± 0.040
$B^0 \rightarrow K^0 \pi^0$	11.21 ± 1.36	4.79 ± 0.58	
$B^+ \rightarrow K^0 \pi^+$	20.62 ± 1.35	8.19 ± 0.54	0.003 ± 0.059
$B^+ \rightarrow K^+ \pi^0$	12.82 ± 1.07	5.10 ± 0.43	0.035 ± 0.071

$$R = \frac{\Gamma(B^0 \rightarrow K^+\pi^-)}{\Gamma(B^+ \rightarrow K^0\pi^+)} = 0.948 \pm 0.074$$

$$R_c = \frac{2\,\Gamma(B^+ \rightarrow K^+\pi^0)}{\Gamma(B^+ \rightarrow K^0\pi^+)} = 1.24 \pm 0.13$$

$$R_n = \frac{\Gamma(B^0 \rightarrow K^+\pi^-)}{2\,\Gamma(B^0 \rightarrow K^0\pi^0)} = 0.81 \pm 0.10$$

- penguins have been measured and dominate the decays

- there are problems involving R_c and R_n

Fleischer-Mannels's insight

- $$R = \frac{\Gamma(B^0 \to K^+\pi^-) + \Gamma(\overline{B}^0 \to K^-\pi^+)}{\Gamma(B^+ \to K^0\pi^+) + \Gamma(B^- \to \overline{K}^0\pi^-)} = 1 - 2\frac{T}{P}\cos\gamma\,\cos\delta + \left(\frac{T}{P}\right)^2$$
- **Imagine that $R<1$; assume $\cos\delta>0$**
- **==> γ <u>cannot</u> be $\pi/2$, regardless of the exact values of $\cos\delta>0$ and T/P**
- **==> can learn more about γ with knowledge of T/P and δ**

Fleischer & Mannel PRD57, 2752 (1998)

Gronau-Rosners's improvement

- **Can cope with R>1**

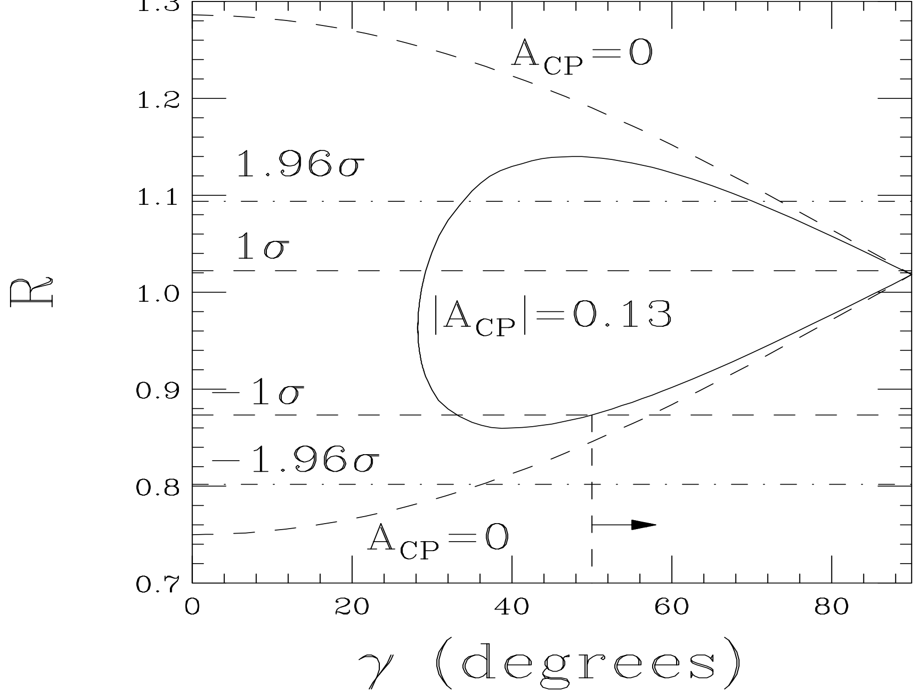
- **Eliminate δ using CP asymmetry**

$$A_{CP} = \frac{\Gamma(\overline{B^0} \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B^0} \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)} = -2\frac{T}{P}\sin\gamma\,\sin\delta/R$$

==> Extract a value for γ, rather than a bound

(if you know T/P)

Gronau & Rosner PRD57, 6843 (1998)



Thanks to Gronau & Rosner

- **Upper (lower) branch when cosγ cosδ <0 (>0)**
- **Used T/P_{low} = 0.17–0.04 from $B^+ \to K^0\pi^+$ and $B \to \pi\ell\nu$**

- **==> Improvement on the CP conserving R is much more important for γ than the CP violating A_{CP}!!**

Intriguing B →Kπ relation

So far:

- R–1 = 0.052±0.074 & asym ==> constraint on γ
- Can also use R_c+R_n-2 = 0.05±0.23
- However, R_c-R_n=0.43±0.23 is difficult to explain because

$$\Delta_{cn} \equiv R_c - R_n = O\left(\frac{P_{EW}, T}{P}\right)^2$$

→ In a ΔI=1 combination

==> 2σ hints seen in B → Kπ decays

Look back at diagrammatic decomposition

$$A(B^0 \longrightarrow K^+ \pi^-) = -\,(P + e^{i\gamma}\, T)$$

R Fleischer-Mannel

$$A(B^+ \longrightarrow K^0 \pi^+) = P$$

Buras-Fleischer $\mathbf{R_n}$

$$\sqrt{2}\, A(B^0 \longrightarrow K^0 \pi^0) = P - P_{EW}$$

$\mathbf{R_c}$ Neubert-Rosner

$$\sqrt{2}\, A(B^+ \longrightarrow K^+ \pi^0) = -\,(P + e^{i\gamma}\, T + P_{EW})$$

==> Problems occur in the ratios involving P_{EW} and π^0

Possible explanations

- **Possible problem with estimate of π^0 detection**

Gronau & Rosner ph/0307095

- **Study γ with $R_c R_n$ instead**

- **Enhanced $\Delta I=1$ pieces, electroweak penguins**

Grossman, Neubert & Kagan JHEP9910, 029 (1999)

Yoshikawa ph/0306147, Gronau & Rosner ph/0307095, Buras et al. ph/0309012

- **It is possible to fit simultaneously R_c and R_n with P_{EW}**
- **This requires $P_{EW} \approx i\, P/2$**
- **Such a large strong phase is at odds with QCD factoriz.**

4 – Conclusions

- **Progress in the field is finally dictated by experimentalists** **(Free at last! Free at last…)**

- **$\beta_{\Phi Ks}$ differs from $\beta_{\Psi Ks}$ by 2.7σ**

- **2σ hint for isospin violating new physics seen in $B \to K\pi$ decays**

4 – Conclusions

- **$BR_{av}(\pi^0\pi^0)$ disagrees with QCD based calculations**

- **$C_{\pi0\pi0}$ is the next big thing**

- **Further information on γ will come from $B \rightarrow D$ decays**
- **B_s to get complete picture**

Very Bright Future

artist's impression of the very bright future ahead of us