CP Violation: Circa 2005

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Outline

- Introduction: B-Factory + Lattice …help attain an imp. milestone ->
- Improved Searches for χ_{BSM} in the light of BF results:

  Indirect Searches with theory input

  Indirect Searches w/o theory input: Elements of a Pristine UT

  Direct Searches:

  Penguin dominated hadronic modes

  Radiative B-decays

  Null Tests

- K-UT
- NEDM
- TEDM
- Link with ν-Physics: Leptogenesis
- Summary

Types of CP

- CPV in Mixing (a la neutral K)
- CPV in interference of mixing and decays
- Direct CPV
- Uniqueness of B…In the SM – CKM paradigm implies that only in B CPVeffects are large.In K's they are minisicule, also extremely small in charm, and vanishingly small in t-physics. Thus it is extremely important that we explore all types of CPV effects in B as that's the only place where SM effects are expected to be largest to allow us to precisely nail down CKM-parameters

B-factories help attain an important milestone

- CKM constraints using expts. $[\epsilon_K,\ b \to ul\nu,\ \Delta m_d,\ \Delta m_s/\Delta m_d]$ + lattice + phenom. $\Rightarrow (\sin 2\beta)_{SM} \approx 0.70 \pm 0.10$
- $a_{CP}(B \to \psi K^0)$ [BELLE/BABAR/CDF....] $\Rightarrow \sin 2\beta = 0.734 \pm 0.055 \Rightarrow$ **CKM phase is the dominant contributor to** a_{CP} $\Rightarrow$ CP-odd phase(s) due BSM (χ_{BSM}) may well cause only small deviations from SM in B-Physics

Search must go on

Search for CP-odd phase(s) [χ_{BSM}] due BSM-physics is especially well motivated as there are essentially compelling reasons that they exist:

Extensions of SM invariably lead to new phase(s), besides baryogenesis is difficult to account for by the CKM paradigm

Atwood +Soni, CKMfit PLB’01

Table 1: Fits using “nominal” and “conservative” values for the four input parameters. The QCD correction coefficients η_1, η_2, η_3 and η_b are taken from [35] and $V_{cb} = 0.040 \pm 0.002$ [36].

Input Quantity	Nominal		Conservative	
$R_{uc} \equiv \lvert V_{ub}/V_{cb} \rvert$	$0.085 \pm .017$		$0.085 \pm .0255$	
$f_{B_d}\sqrt{\hat{B}_{B_d}}$	230 ± 50 MeV		217 ± 50 MeV	
ξ	1.16 ± 0.08		1.16 ± 0.10	
$\hat{B}_K$	0.86 ± 0.15		0.90 ± 0.15	
Output Quantity	68% CL	95% CL	68% CL	95% CL
$\sin 2\beta$	$0.60 \to 0.80$	$0.51 \to 0.88$	$0.58 \to 0.83$	$0.47 \to 0.93$
$\sin 2\alpha$	$-0.81 \to -0.18$	$-0.96 \to 0.17$	$-0.82 \to -0.14$	$-0.96 \to 0.27$
γ	$37.1^\circ \to 55.3^\circ$	$30.2^\circ \to 65.4^\circ$	$36.4^\circ \to 56.3^\circ$	$29.5^\circ \to 63.3^\circ$
$\overline{\eta}$	$0.25 \to 0.35$	$0.21 \to 0.41$	$0.24 \to 0.36$	$0.20 \to 0.44$
$\overline{\rho}$	$0.17 \to 0.32$	$0.10 \to 0.39$	$0.16 \to 0.34$	$0.07 \to 0.42$
$\lvert V_{td}/V_{ts} \rvert$	$0.17 \to 0.20$	$0.15 \to 0.21$	$0.16 \to 0.20$	$0.15 \to 0.22$
Δm_{B_s} (ps^{-1})	$16.3 \to 23.4$	$15.3 \to 29.3$	$16.3 \to 24.6$	$15.3 \to 31.8$
J_{CP}	$(2.2 \to 2.9) \times 10^{-5}$	$(1.9 \to 3.4) \times 10^{-5}$	$(2.1 \to 3.0) \times 10^{-5}$	$(1.8 \to 3.5) \times 10^{-5}$
$Br(K^+ \to \pi^+ \nu\overline{\nu})$	$(0.57 \to 0.77) \times 10^{-10}$	$(0.49 \to 0.90) \times 10^{-10}$	$(0.55 \to 0.78) \times 10^{-10}$	$(0.47 \to 0.91) \times 10^{-10}$
$Br(K_L \to \pi^0 \nu\overline{\nu})$	$(0.16 \to 0.29) \times 10^{-10}$	$(0.12 \to 0.38) \times 10^{-10}$	$(0.15 \to 0.30) \times 10^{-10}$	$(0.11 \to 0.41) \times 10^{-10}$

More sophisticated recent updates (CKMfitter, J.Charles et al ’04; Utfit M.Bona et al’05) with similar numbers

Theory vs. Expt ('04)

Angle	Theory	Expt.
$\sin 2\beta$	.70+-.10	.726+-.037
α	$[98 \pm 16]^o$	$[103 \pm 11]^o$
γ	$[60 \pm 7]^o$	$\sim[70 \pm 30]^o$

EXPT MEANS "DIRECT DETERMINATIONS"

-→ Most likely effect of any BSM-CP-odd phase on B-physics is (from now on) a perturbation. …..A SIGNIFICANT CAVEAT

Important Lesson from the CKM-paradigm

- We know now that CKM-phase is O(1)
- CP asymmetries in K-decays are at most (.001)
- In charm decays CPV expected to be very small
- In top physics asymmetries are completely negligible
- Only in B decays effects are O(1)
- If there is BSM-CP-odd phase of O(1) it would be quite a coincidence if B's are favored again

Remember the m_ν

Situation wrt χ_{BSM} is reminiscent of m_ν

There were no good reason(s) to think that m_ν should be zero; similarly there are none for χ_{BSM} to be zero either.

In the case of ν's there were the solar neutrino results that were suggestive for a very longtime; similarly in the case of χ_{BSM} baryogenesis is the beacon.

It took decades to show m_ν is not zero; [Δm^2 had to be lowered (around 1983) from $O(1-10)\,ev^2$ down to $O(10^{-4})\,ev^2$ before m_ν was discovered.] let's hope we have better luck with χ_{BSM} but there is no good reason to be too optimistic; therefore dont think we ought to rely on luck.

Soni's$^{\mathrm{RECENT}}$ Obsession

- Post-Bfactory confirmation that CKM phase is the dominant source in a_{CP} (B $\to \psi K_s$) suggests that even if X_{BSM} exists and is $O(1)$ its effects in B-physics may well be small.
- While difficult to reliably say, how small; in planning B-expts, it may be best to target $a_{CP}[\chi_{BSM}]$ very small, say $O(10^{-3}) \approx \epsilon_K$ Our enlightened understanding of the CKM-phase (post B-factory results) is that it is $O(1)$ and while it causes large asymmetry in B-physics, in K-decays its effects are miniscule.
- In suggesting the target, $a_{CP}[\chi_{BSM}] \approx 10^{-3}$, we are taking cue from this SM example. Thus even isospin symmetry (widely used) can cause problems. So:

  $\Rightarrow$ Need lots and lots of **CLEAN** B's (i.e. $O(10^{10})$ or more).

  $\Rightarrow$ Intensive study of B_s mesons (in addition to B's) becomes very important.

  $\Rightarrow$ Need extremely clean predictions from theory.

Indirect Searches w/o theory input: Elements of a Superclean UT

This is a gold plated method for searching for NP in B-decays. [illegible]

- TDCPA in $B^0 \to \psi K^0$; gives β
- DIRCP in $B^\pm \to$ "$K^\pm$" $D^0, \bar{D}^0$; gives γ
- TDCPA in $B^0 \to$ "K^0" $D^0, \bar{D}^0$; gives γ OR α AND β

  Also, incidentally

- TDCPA in $B_s \to K D_s$; gives γ.
- AND DIRCP in $K_L \to \pi^0 \nu \bar{\nu}$ gives eta

  Note that the irreducible theory error (ITE) in each of these methods is expected to be $< 1\%$

- Using TDCPA studies in *all* three final states $B \to \pi\pi$, $\rho\pi$ and $\rho\rho$ should give a very good determination of α (may be with $ITE \approx 1\%$?) although each final state by itself is likely to have (at least) several percent theory error, with our present level of understanding.

It is extremely important that we make use of the opportunity afforded to us by as many of these very clean redundant measurements as possible.

In order to exploit these methods to their fullest potential and get the angles with errors of order ITE will, for sure, require a SUPER-B Factory.

This end in itself constitutes a strong enough reason for a SBF, as it represents a great opportunity to precisely nail down the important parameters of the CKM paradigm, therefore not going in that direction is a serious mistake.

DIRECT SEARCHES…illustrations

- Penguin dominated hadronic FS…
- Radiative B-decays
- Tests aglore

A tantalizing posiibilty:

Signs of a BSM CP-odd phase in penguin dominated b ->s transitions?

Search for χ_{BSM} via penguin dominated hadronic FS

[See Grossman and Worah (97); London and Soni (97)]

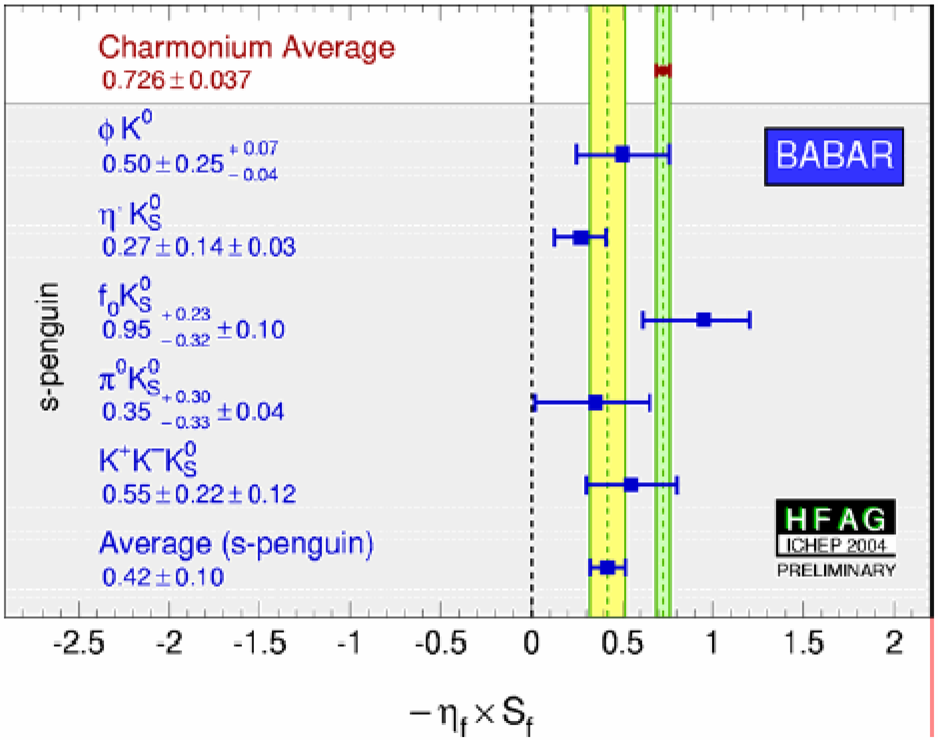
GW, PLB 97 suggested that the penguin dominated reaction $B \to \phi K_s$ can be used to test presence of BSM phase as in the SM TDCP asymmtery should give to a very good approximation $\sin(2\beta)$.

LS PLB '97 pointed that not only ϕK_s but also $K_s[\eta', \eta, \pi^0, \omega, \rho^0]$ should all be used by TDCPA measurments to test the SM in a similar fashion since $Tree/Penguin < 0.04$, according to their estimate.

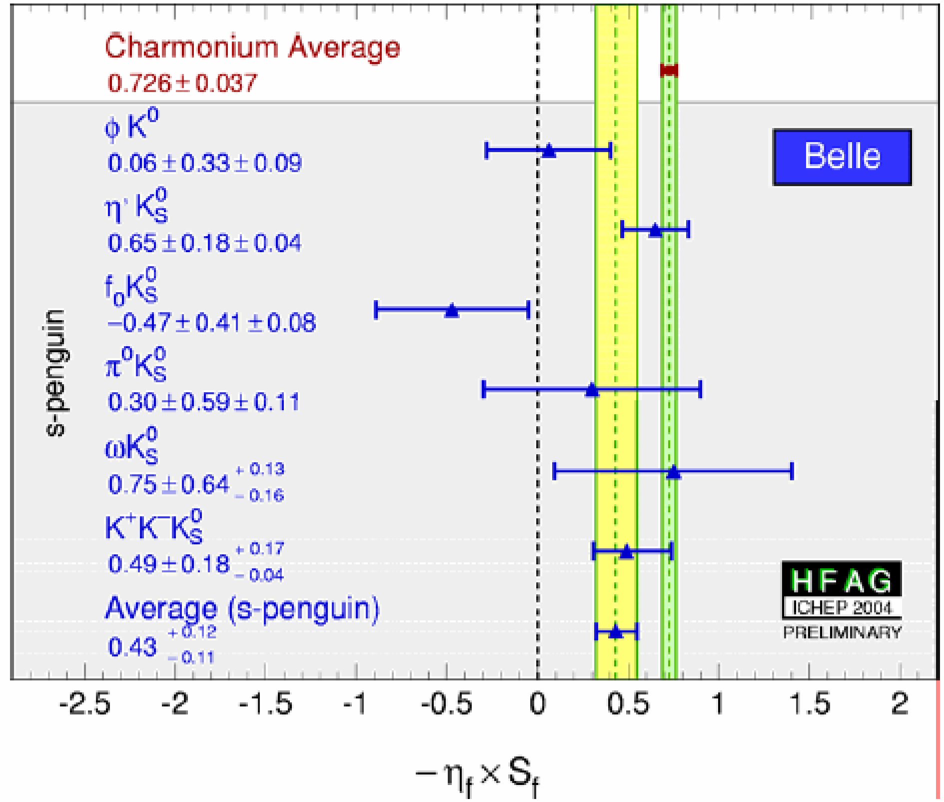
(Recall tree is Cabibbo and color-suppressed)

Results on sin2β from s-penguin modes

All new!



All new!



2.7σ from s-penguin to sin2β ($c\bar{c}$)

2.4σ from s-penguin to sin2β ($c\bar{c}$)

Final State	Type of Tree	BELLE	BABAR
ϕK^0	NT	$0.06 \pm 0.33 \pm 0.09$	$0.50 \pm 0.25^{+0.07}_{0.04}$
$\eta' K_s^0$	CST	$0.65 \pm 0.18 \pm 0.04$	$0.27 \pm 0.14 \pm 0.03$
$f_0 K_s$	CST	$-0.47 \pm 0.41 \pm 0.08$	$0.95^{+0.23}_{0.32} \pm 0.10$
$\pi^0 K_s$	CST	$0.30 \pm 0.59 \pm 0.11$	$0.35^{+0.30}_{0.33} \pm 0.04$
ωK_s	CST	$0.75 \pm 0.64^{+0.13}_{-0.16}$	
$K^+ K^- K_s^0$	CAT	$0.49 \pm 0.18^{+0.17}_{-0.04}$	$0.55 \pm 0.22 \pm 0.12$
Average		$0.43^{+0.12}_{-0.11}$	0.42 ± 0.10

TABLE III: Experimental status of search of time-dependent CP in some penguin-dominated modes [14, 15]. NT means no tree, CST is color suppressed tree and CAT is color allowed tree

A possible complications: large FSI phases in 2-body B decays

- The original papers predicting $\Delta S_f = S_f - S_{\psi K} \sim 0$ used naïve factorization ideas; in particular FSI were completely ignored.

A remarkable discovery of the past year is that direct CP in charmless 2-body modes is very large-> FS phases in B-decays need not be small

Why FSI in charmless B decays?

1. Direct CP violation

- Direct CPV (5.7σ) in $B^0 \to K^+ \pi^-$ was established by BaBar and Belle

  A= -0.133±0.030±0.009 BaBar

  -0.101±0.025±0.005 Belle

- Combined BaBar & Belle data ⇒ 3.6σ DCPV in $B^0 \to \rho^- \pi^+$

  A= $-0.48^{+0.14}_{-0.15}$

- For DCPV in $B^0 \to \pi^+ \pi^-$

  2004: -- Belle claimed a 3.2σ effect based on 152 M $B\bar{B}$ pairs

  A=0.58±0.15±0.07

  -- not confirmed by BaBar (227 M pairs): A=0.09±0.15±0.04

  2005: -- reconfirmed by Belle (275 M pairs): A=0.56±0.12±0.06 (3.4σ)

	Expt(%)	QCDF(default)	QCDF(S4)	pQCD
$B^0 \to K^+\pi^-$	-11 ± 2	$4.5^{+9.1}_{-9.9}$	-4.1	-17 ± 5
$B^0 \to \rho^-\pi^+$	-48^{+14}_{-15}	$0.6^{+11.6}_{-11.8}$	-12.9	$-7.1^{+0.1}_{-0.2}$
$B^0 \to \pi^+\pi^-$	37 ± 24	$-6.5^{+13.7}_{-13.3}$	10.3	23 ± 7

DCPV $\propto$ sinϕ sinδ (δ: weak phase, ϕ: strong phase)

For penguin dominated modes,e.g $(\pi,\omega)K_S$ the subdominant tree is color suppressed, but FS rescattering phases arise from color allowed tree so can have large effects

It is important **to consider LD strong phases induced from final-state interactions**

$$\frac{\Gamma(\overline{B}(t) \to f) - \Gamma(B(t) \to f)}{\Gamma(\overline{B}(t) \to f) + \Gamma(B(t) \to f)} = \mathcal{S}_f \sin(\Delta m t) - \mathcal{C}_f \cos(\Delta m t), \tag{1.1}$$

where Δm is the mass difference of the two neutral B eigenstates, $\mathcal{S}_f$ monitors mixing-induced CP asymmetry and $\mathcal{C}_f$ measures direct CP violation. The CP-violating parameters $\mathcal{C}_f$ and $\mathcal{S}_f$ can be expressed as

$$\mathcal{C}_f = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2}, \qquad \mathcal{S}_f = \frac{2\,\mathrm{Im}\lambda_f}{1 + |\lambda_f|^2}, \tag{1.2}$$

where

$$\lambda_f = \frac{q_B}{p_B} \frac{A(\overline{B}^0 \to f)}{A(B^0 \to f)}. \tag{1.3}$$

In the standard model $\lambda_f \approx \eta_f e^{-2i\beta}$ [see Eq. (2.12) below] for $b \to s$ penguin-dominated or pure penguin modes with $\eta_f = 1$ (-1) for final CP-even (odd) states. Therefore, it is expected in the Standard Model that $-\eta_f S_f \approx \sin 2\beta$ and $C_f \approx 0$ with β being one of the angles of the unitarity triangle.

The mixing-induced CP violation in B decays has been already observed in the golden mode $B^0 \to J/\psi K_S$ for several years. The current average of BaBar [1] and Belle [2] measurements is

$$\sin 2\beta \approx S_{J/\psi K_S} = 0.726 \pm 0.037\,. \tag{1.4}$$

However, the time-dependent CP-asymmetries in the $b \to sq\bar{q}$ induced two-body decays such as $B^0 \to (\phi, \omega, \pi^0, \eta', f_0)K_S$ are found to show some indications of deviations from the expectation of the Standard Model (SM). The BaBar [3] and Belle [4] results and their averages are shown in Table I. In the SM, CP asymmetry in all above-mentioned modes should be equal to $S_{J/\psi K}$ with a small deviation *at most* $\mathcal{O}(0.1)$ [5]. As discussed in [5], this may originate from the $\mathcal{O}(\lambda^2)$ truncation and from the subdominant (color-suppressed) tree contribution to these processes. From Table I we see some possibly sizable deviations from the SM, especially in the $\eta' K_S$ mode in which the discrepancy $\Delta S_{\eta' K_S} = -0.31 \pm 0.12$ is a 2.7σ effect where

$$\Delta S_f \equiv -\eta_f S_f - S_{J/\psi K_S}. \tag{1.5}$$

If this deviation from $S_{J/\psi K}$ is confirmed and established in the future, it may imply some New Physics beyond the SM.

Effects of FSI on penguin dominated modes (Cheng,Chua and AS)

TABLE V: Direct CP asymmetry parameter C_f and the mixing-induced CP parameter ΔS_f^{SD+LD} for various modes. The $f_0 K_S$ channel is not included as we cannot make reliable estimate of FSI effects on this decay. The theory errors arise from the theoretical uncertainties in S_f^{SD+LD} together with the experimental errors in $\sin 2\beta$.

Final State	ΔS_f		C_f	
	Theory	Expt	Theory	Expt
ϕK_S	0.029 ± 0.037	-0.39 ± 0.20	$0.025^{+0.002}_{-0.005}$	-0.04 ± 0.17
ωK_S	$0.010^{+0.043}_{-0.040}$	0.024 ± 0.66	$0.151^{+0.016}_{-0.020}$	-0.26 ± 0.50
$\eta' K_S$	0.006 ± 0.038	-0.30 ± 0.12	-0.021 ± 0.000	-0.04 ± 0.08
$\pi^0 K_S$	0.048 ± 0.038	-0.39 ± 0.28	$-0.024^{+0.012}_{-0.007}$	0.09 ± 0.14

→ ΔS_f >0.10 would be a compelling evidence for BSM-CP odd phase!

Highlight of the experimental status

(Based on Summaries by Yoshi Sakai (Belle) and Marcello Giorgi (BABAR) …ICHEP'04)

1) For now, no compelling evidence for a significant difference from the $\psi\ K_0$ ….
determination (0.726 +-0.037) although each
expt. seems to see an interesting ~ 2.5 σ effect when all such modes are combined.

2) For a cleaner theoretical interpretation:

a) it is much better when some particular modes see a compelling difference; rather than a significant difference arising only when averaging over many modes.

b) The error on individual modes needs to be reduced to ~$O(\lambda^2)$ ~0.05…This will very likely require about 10^{10} clean B's (at a Super-B Factory [SBF] and/or otherwise)

Model Independent Remarks

Divide NP sources contributing to $B \to \phi K_s$ into 2 types:

I. NP leads to modification of $b \to s$ form-factor(s):

$\Lambda_\mu^{bs} = \bar{s}_i T_{ij}^a [-iF(q^2)(q^2\gamma_\mu - q_\mu \not{q})L + m_b q_\mu \varepsilon_\nu \sigma^{\mu\nu} G(q^2) R] b_j$

$F(q^2) = e^{i\delta_{st}} F_{SM} + e^{i\lambda_F} F_x$; $G(q^2) = G_{SM} + e^{i\lambda_G} G_x$ cBI where δ_{st} is the strong phase generated by the absorptive part resulting form the $c\bar{c}$ cut for $q^2 > 4m_c^2$; λ_F and λ_G are the CP-odd non-standard phases. For simplicity CKM phase in $b \to s$ is assumed negligibly small .$glu \to q\bar{q}$ interactions as dictated by QCD. So, $glu \to s\bar{s}$ leads to the ϕK_s anomally; but at the same time has serious ramifications for $\eta' K_s$. Infact recall that such a BSM modification was introduced to enahance rate for $B \to \eta' X_s(K)$ leading possibly to non-standard **direct CP** signals. [see Hou & Tseng PRL'98; Atwood & Soni PRL '97] Note $gluon \to c\bar{c}, \ldots$ is also inevitable. Should lead to deviations from SM in numerous channels, in particular, all FS with (net) $\Delta s = \pm 1$ are susceptible to effects of NP: RATES, DIRCP, TDCP, TCA should all be effected. NOT ONLY ϕK_s but also $\phi K^{\pm}$, ϕK^* (TCA), $K\bar{K}K(X)$;$pi^0 K_s$, $\eta' K_s$, $\eta' K^{\pm}$...; $\sin(2\beta)$ via $D_s D$ should NOT equal that from ψK_s; also DIRCP in $D_s D^-(D^0)$, TCA in $D_s^* D^*$...; Similarly in $\gamma X_s(K^*, K\pi...)$;$l^+ l^- X_s(K, K^*, K\pi...)$

II. NP as 4–fermi interaction in $b \longrightarrow s\bar{s}s$ vertex:

$L_{4f}^{b3s} = G_{b3s} e^{i\chi_{b3s}} [\bar{s}\Gamma_\mu b][\bar{s}\Gamma'_\mu s]$

G_{b3s} is effective 4–fermi coupling, assumed real; χ_{b3s} is the associated non-standard CP–odd phase. This is much more restrictive and yet such a NP should effect not just TDCP in ϕK_s but also DIRCP in $\phi K_s(K^{\pm}, K^*...)$ also TCA in ϕK^*; Similarly $K\bar{K}K(X)$; $\eta' K_s(K^{\pm}, K^*)$

1. Its impossible to isolate NP only in TDCP in ϕK_s
2. All channels affected by II are also affected by I (but not the otherway around)
3. many NP effects in B_s as well; e.g. Δm_s, TDCP and TCA in $\phi(\phi, K\bar{K}(X))$, $\phi\eta'$

	Z-penguins	MSSM with $(\delta^D_{23})_{RR}$
$\mathcal{B}(b \to s\ell^+\ell^-)$, $A_{FB}(b \to s\ell^+\ell^-)$	up to $\mathcal{O}(1)$ effects	MFV MSSM like [2]
$\mathcal{B}(B_s \to \mu^+\mu^-)$	up to $\mathcal{O}(10) \cdot \mathcal{B}_{SM}$ [13]	up to $\mathcal{B}_{exp.\,bound} \sim \mathcal{O}(10^3) \cdot \mathcal{B}_{SM}$
Δm_s	up to $0.5 \cdot \Delta m_{s\,SM}$ [11]	$\approx \Delta m_{s\,SM}$ up to few 100 ps^{-1}
$b \to s\gamma$ helicity flip	SM like	$\lvert C_{7\gamma}(\mu_b)'/C_{7\gamma}(\mu_b)\rvert \lesssim 0.4$
$a_{CP}(b \to s\gamma)$	SM like	SM like

Table 2: Predictions of two beyond the SM models.

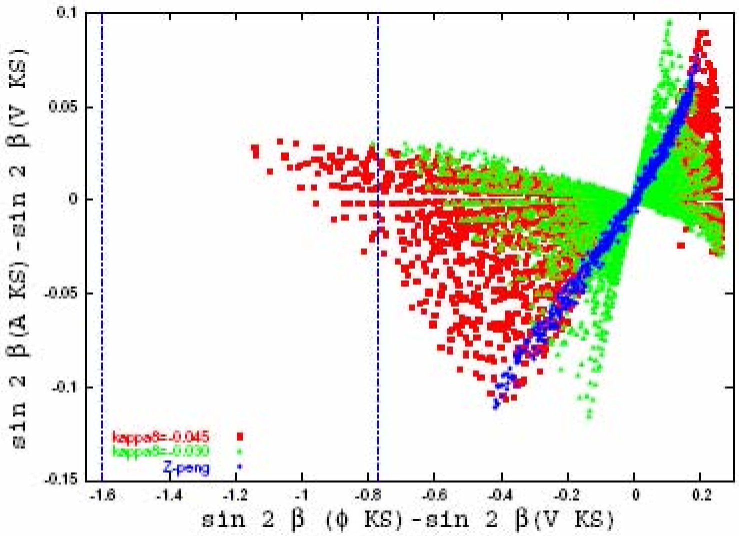


Figure 3: $\sin 2\beta_{AK_S} - \sin 2\beta_{VK_S}$ as a function of $\sin 2\beta_{\phi K_S} - \sin 2\beta_{VK_S}$ in the non-SM Z-scenario (blue) and in the MSSM with additional flavor violation induced by $\delta^D_{RR\,23}$. The latter butterfly type correlation is shown for two values of the matrix element of $\mathcal{O}^{(\prime)}_{8g}$. Figure taken from [11].

Summary on ϕK_s

- Many BSMs can accomodate (largish) asym. in ϕK_s.
- Virtually impossible to confine effects of a new phase just in ϕK_s, esp. if its large $\Rightarrow$ TDCPA, DIRCP, TCA should be seen in a multitude of channels. In particular, TCA and other anomalous effects in ϕK^*, $\pi^0 K_s$, $KKK(n\pi)$, $\eta' K(n\pi)$, $\gamma K^*(n\pi)$, $l^+ l^- K(n\pi)$ should be vigorously studied.
- Serious concern regarding somewhat conflicting results from the two experiments (both on ϕK_s and $\pi\pi$); its clearly important to resolve these.
- Future experimental effort should target definitive measurments of asymmetry of $O(\approx theo.errors) \approx \lambda^2$ i.e. about 5%..Given Br $\approx 10^{-5}$ and assuming 10% efficiency requires about $10^{10} B\bar{B}$ pairs for a convincing (5σ) signal i.e. a Super-B.

Mixing Induced CP in Radiative B-decays

Key point: γ in b decays is predominantly LH whereas γ in $\bar{b}$ decays is predominantly RH

$\Rightarrow$ esp. sensitive to presence of RH currents due BSM

In the SM TDCP in $B \to \gamma[\rho, \omega, K^*, ..] \propto m_d/m_b$ or m_s/m_b.

BSM [e.g. LRSM, SUSY...] can cause large asymmetries

See: Atwood, Gronau and A. S. PRL, '97; recent ext. to several models Chua and Hou hep-ph/0110106; Gotto et al hep-ph/0306093; Gronau and Pirjol hep-ph/0205065.. In General, (for $q = s, d$)

$$H_{eff} = -\sqrt{8} G_F \frac{e m_b}{16\pi^2} F_{\mu\nu} [\frac{1}{2} F_L^q \bar{q} \sigma^{\mu\nu} (1+\gamma_5) b + \frac{1}{2} F_R^q \bar{q} \sigma^{\mu\nu} (1-\gamma_5) b]$$

In the SM, $\frac{F_R^q}{F_L^q} \approx \frac{m_q}{m_b}$ Mixing induced CP asymmetry in $B - \bar{B}$ decay requires both B and $\bar{B}$ be able to decay to the same final state i.e. a state with the same photon helicity $\propto \frac{F_R^q}{F_L^q} \to m_q/m_b \to 0$. In contrast, in a LR model as an example $\frac{F_R^q}{F_L^q}$ can be appreciably bigger as presence of RH currents $\Rightarrow m_t/m_b$ enhancement for $\frac{F_R^q}{F_L^q}$

Time Dependent CP Asymmetry in $B(t) \to M^0\gamma$

For a state tagged as a B rather than a $\bar{B}$ at $t = 0$ and with $CP|M^0 >= \xi|M^0 >$; with $\xi = \pm 1$:

$$
\begin{aligned}
A(\bar{B} \to M^0\gamma_L) &= A\cos\psi e^{i\phi_L} \ , \\
A(\bar{B} \to M^0\gamma_R) &= A\sin\psi e^{i\phi_R} \ , \\
A(B \to M^0\gamma_R) &= \xi A\cos\psi e^{-i\phi_L} \ , \\
A(B \to M^0\gamma_L) &= \xi A\sin\psi e^{-i\phi_R} \ .
\end{aligned}
$$

Here $tan\psi = \frac{F_R^q}{F_L^q}$ and $\phi_{L,R}$ are CP-odd weak phases. Thus, with ϕ_M as the mixing phase, $\Gamma(t) \equiv \Gamma(B(t) \to M^0\gamma)$,

$$\Gamma(t) = e^{-\Gamma t}|A|^2[1 + \xi\sin(2\psi)\sin(\phi_M - \phi_L - \phi_R)\sin(\Delta m t)] \ .$$

This leads to a time-dependent CP asymmetry,

$$A(t) \equiv \frac{\Gamma(t) - \bar{\Gamma}(t)}{\Gamma(t) + \bar{\Gamma}(t)} = \xi\sin(2\psi)\sin(\phi_M - \phi_L - \phi_R)\sin(\Delta m t) \ .$$

LRSM: $G = SU(2)_L X SU(2)_R X U(1)$

$$\begin{pmatrix} u \\ d \end{pmatrix}_{L,R}$$
$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_{L,R}$$

Many attractive features,e.g. ν mass arises naturally. Using $K_L - K_S$ mass diff one gets a rather imposing bound $m_R \geq 1.5TeV$ [Beall, Bander and A. S'82]. Given that $m_\nu \neq 0$ (and TeV no longer such an imposing scale) model ought to reconsidered as a nice effective low energy theory. Done recently [Kiers et al, hep-ph/0205082] Taking, $< \Phi >= \begin{pmatrix} \kappa & 0 \\ 0 & \kappa' \end{pmatrix}$ and setting $|\kappa'/\kappa| = m_b/m_t$ leads to striking simplification:

$\Rightarrow$ CKM angle hierarchy arises

$\Rightarrow (CKM)_R = (CKM)_L$

$\Rightarrow \delta_R = \delta_L$

endowing the model with considerable predictive power.

The $W_L - W_R$ mixing is described by

$$\begin{pmatrix} W_1^+ \\ W_2^+ \end{pmatrix} = \begin{pmatrix} \cos\zeta & e^{-i\omega}\sin\zeta \\ -\sin\zeta & e^{-i\omega}\cos\zeta \end{pmatrix} \begin{pmatrix} W_L^+ \\ W_R^+ \end{pmatrix} .$$

Although ζ is small, $\leq 3\times10^{-3}$, [see Beall and A.S'81; Wolfenstein '84] that's considerably offset by helicity enhancement factor m_t/m_b

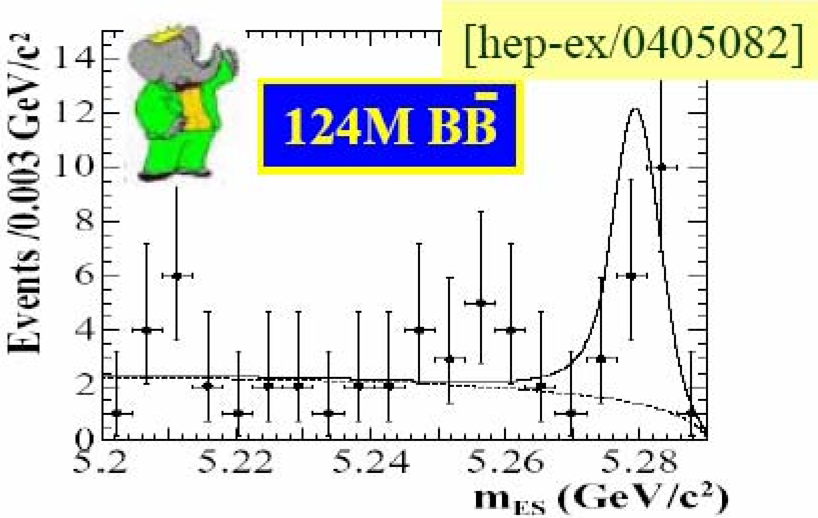
Radiative B-decays previously examined in LRSM [see Fujikawa and Yamada, '94; Basu, Fujikawa, Yamada,'94; Cho and Misiak,'94]

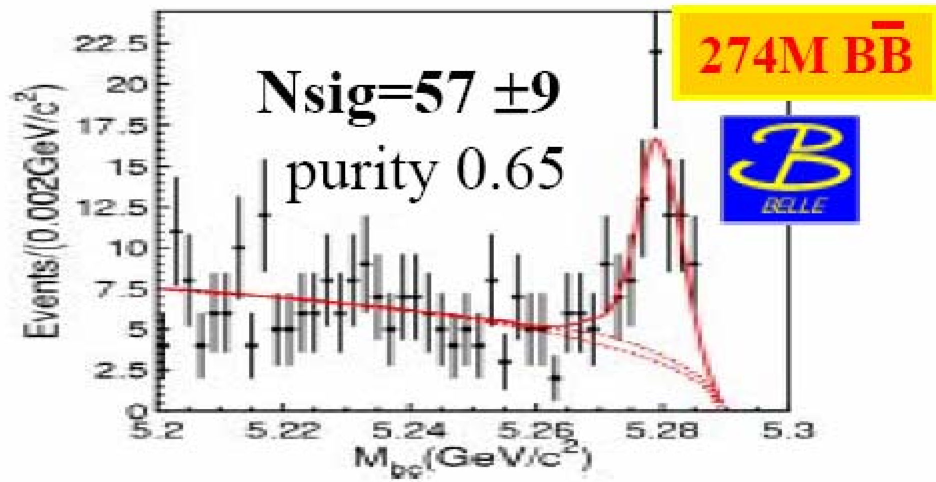
$F_L \propto F(x) + \eta_{QCD} + \zeta\frac{m_t}{m_b}e^{i\omega}\tilde{F}(x)$; $F_R \propto \zeta\frac{m_t}{m_b}e^{-i\omega}\tilde{F}(x)$. where $x = (m_t/m_{W_1})^2$, $\eta_{QCD} = -0.18$. Also Assuming $\frac{BR(B\to X_s\gamma)_{EXP}}{BR(B\to X_s\gamma)_{SM}} = 1.0 \pm 0.1 \Rightarrow |\sin(2\omega)| = 0.67$

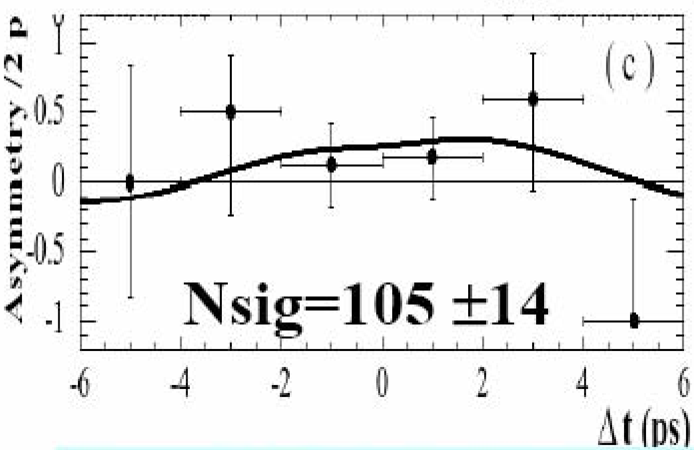
Process	SM	LRSM
$A(B \to K^* + \gamma)$	$2\frac{m_s}{m_b}\sin 2\beta \sin(\Delta m_t)$	$\sin 2\omega \cos 2\beta \sin(\Delta m_t)$
$A(B \to \rho\gamma)$	≈ 0	$\sin 2\omega \sin(\Delta m_t)$

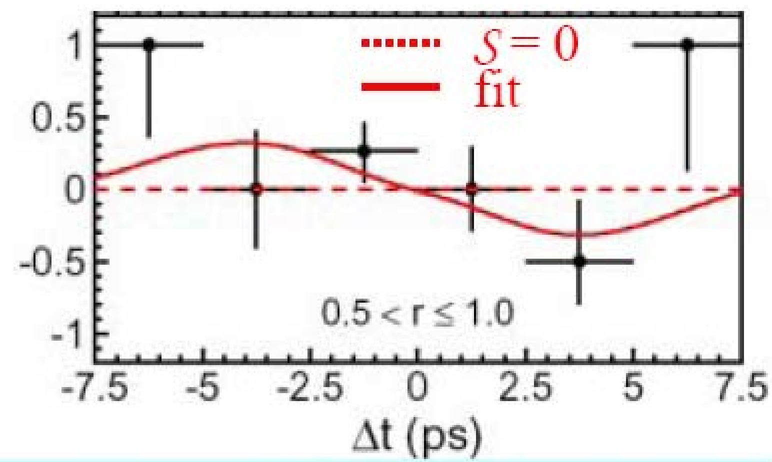
$\Rightarrow$ whereas in the SM negligible asymmetries, in the LRSM can be O(50%) even if $BR(B \to X_s\gamma)$ is in very good agreement with the SM.

$B \to K^*[K_S\pi^0]\gamma$ TCPV









$\mathcal{S} = +0.25 \pm 0.63 \pm 0.14$ $\qquad$ $\mathcal{S} = -0.79 \pm^{0.63}_{0.50} \pm 0.09$

$\mathcal{A} = +0.57 \pm 0.32 \pm 0.09 = -C$ $\qquad$ $\mathcal{A} = -0.00 \pm 0.38$

First step for new era of $b \to s\gamma$!

$B \to \gamma P_1 P_2$

- In this case there is potentially additional information from the angular distribution of the two mesons.
- There are two different cases of how the angular information enters

1) $P_1 = P_2$ e.g. $B^0 \to \pi^+\pi^-\gamma$. In this case the angular distribution gives you the information to calculate $\sin(2\psi)$ and $\sin(\varphi L+\varphi R+\varphi M)$ separately.

2) P_1 and P_2 are C eigenstates e.g. $B^0 \to K_S \pi^0 \gamma$. In this case you can obtain no additional informaton from angular distributions but you can add all the statistics (as unlike AGS K pi need not be resonant) and thereby it allows a more stringent test for NP, that is, a more accurate value of **the NP phase**

- In both cases the variation with E_γ tests whether dipole

emission is an accurate model (see eq)

AG'HS (hep-ph/0410036)

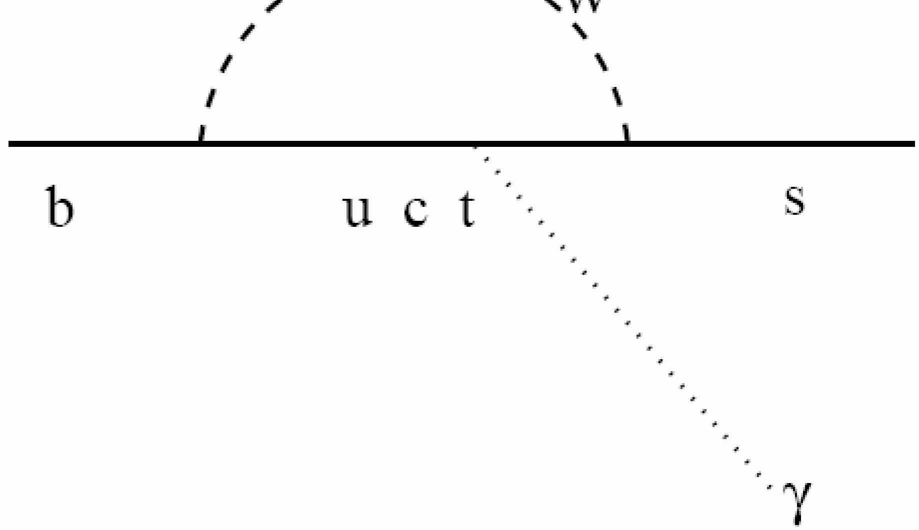


FIG. 1: The Caption

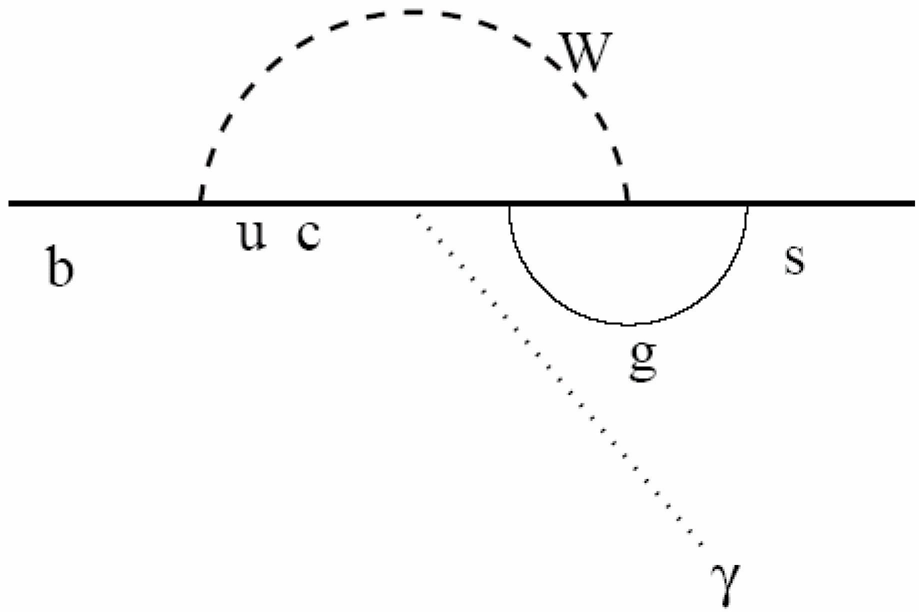


FIG. 2: The Caption

Intutive elaboration of why/how AGHS idea works

In AGS eq.3, strong interaction (meaning leaving out weak phase) info is in (A sin ψ).

For 3-body modes of AGHS interest, such quantities,

in general,

become functions of Dalitz variables, s_1 and $\cos\Theta = z$:

$S_1 = (p1 + p2)^2$; $S_2 = (p1 + k)^2$; $S_3 = (p2 + k)^2$

k is photon momentum, so $z = (S_2 - S_3)/(S_2 + S_3)$.

Now for L,R helicities particle and antiparticle decays

we have 4 amplitudes so we have 4 such quantities now: f_L , f_R and similar 2 for anti-particle. Each is now a function of

s_1 and z. But QCD respects P, C and therefore for (I) the

case of $K_s \pi^0$ all 4 become identically the same upto a sign.

Thus time-dependent CP asymmetry A(t) becomes independent of Dalitz variables.

→ Expression for A(t) holds whether $K_s \pi^0$ are resonant or not or

from more than one resonance, in fact!

→ Since A(t) is independent of s1 all points in Dalitz plot can be added.

→ Significant improvement in statistics and in implementation.

Combining the data together one gets significantly improved info on

$\sin(\psi)\sin(\Phi)$ …the product of strong and weak phase which allows putting

lower bound on each.

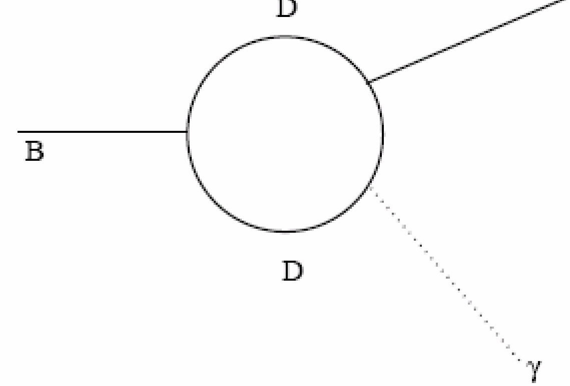


FIG. 3: The Caption

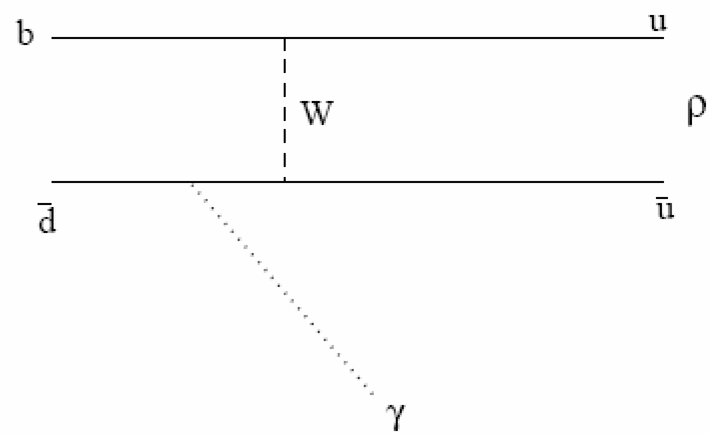


FIG. 4: The Caption

AGHS for $\pi + \pi^{-}$ + gamma

This is the generalization for b -> d penguin of the rho gamma case…Since pi+ pi- are now antiparicles . Therefore, under C,

S2 and S3 get interchanged and as a result z->-z.

So angular distribution becomes non-trivial.

Once again, resonant and non-resonant info can be combined but now additional angular info becomes available to allow a separate determination of the strong and the weak phase (up to dis. Ambig)!

Some Details

- Usual Expt. Cuts to ensure underlying 2 body $b \rightarrow s(d) + \gamma$ is necessary…that is, HARD PHOTON…in particular to discriminate against Brehmms
- Departure from that will show up as smears around a central value on the Dalitz plot
- In principle, annhilation graph is a dangerous contamination, due to enhanced emission of (LD) photons off of light (initial) quark leg (see Atwood,Blok and A.S). This is relevant only to b ->d case. Fortunately,can prove that these photons have have same helicity as from the penguin. See AGHS for details.

Implications for B -> K ή γ of AGH'S

- AGH'S not only allows K π γ from all

Kaonic resonances (irrespective of J^{CP}) as well as from non-resonant continuum to be included even a more important repercussion

off AGH'S is that K ή γ can be used.

This is significant as Br(K ή)/Br(K π) ~ 7

For these reasons expect AG'HS to allow improvement over AGS (resonance only) by

factor O(2-5) so that with current $O(10^{8.5})$ luminosities asymmetries O(0.20) may become accessible.

With 10^{10} B's may be able to get down to O(few%)

Hierarchy of CP asymmetries in radiative B-decays

	MIXCP	DIRCP
b->s	$O(\lambda^2) \sim 3\%$	0.6%
b->d	O(.1%)	O(15%)

Direct Searches for NP [esp. χ_{BSM}] & their worthiness

Final State	Observable	Worthiness
$\gamma[K_s^*, \rho, \omega]$	TDCP	5×5
$K_s[\phi, \pi^0, \omega, \eta', \eta, \rho^0]$	TDCP	4.5×5
$K^*[\phi, \rho, \omega]$	TCA	4.5×5
$[\gamma, l^+l^-][X_s, X_d]$	DIRCP	4.5×5
same	Rates	3.5×5
ψK	TDCP, DIRCP	4×4
ψK^*	TCA	5×4
$D(*)\tau\nu_\tau$	TCA (p_t^τ)	5×4
same	Rate	4×4

W=C [for how clean or accurate] X

S[sensitivity to NP], each with 1-5 *

K-Unitarity Triangle

- There is considerable interest in constructing the
- UT purely from K-decays…relevant reactions being
- pursued:
- Indirect CP violation parameter ε with B_K from lattice
- $K^+ \to \pi^+ \upsilon\, \upsilon$ can give clean V_{td}
- $K_L \to \pi^0 \upsilon\, \upsilon$ can give super-clean η (expt. very challenging)
- Direct CP ε' with lattice matrix elements (theo. Very
- Challenging)

Neutron EDM: a classic “null” test

- In the SM NEDM cannot arise at least to two
- loops in EW……..expect < 10^{-31} ecm
- Long series of experiments now place
- a 90% CL bound, <6.3 X 10^{-26} ecm (Harris et
- al, ’99)
- In numerous BSM, including SUSY, Warped
- extra-dimensions, …… neutron edm close
- to current bound is expected

Top quark EDM: a clean "null" test

- Top is so heavy compared to other quarks that
- GIM mechanism is super-effective -> all SM
- CP violation effects are vanishingly small.
- As one concrete illustration is the top quark
- Electric dipole moment….In the SM you need to
- Go to 2 loops in EW

type of moment $(e-cm)$ $\Downarrow$	$\sqrt{s}$ (GeV) $\Downarrow$	Standard Model	neutral Higgs $m_h = 100 - 300$	charged Higgs $m_{H^+} = 200 - 500$	Supersymmetry $m_{\tilde{g}} = 200 - 500$
$\|\Im m(d_t^\gamma)\|$	500	$< 10^{-30}$	$(4.1 - 2.0) \times 10^{-19}$	$(29.1 - 2.1) \times 10^{-22}$	$(3.3 - 0.9) \times 10^{-19}$
	1000		$(0.9 - 0.8) \times 10^{-19}$	$(15.7 - 1.0) \times 10^{-22}$	$(1.2 - 0.8) \times 10^{-19}$
$\|\Re e(d_t^\gamma)\|$	500	$< 10^{-30}$	$(0.3 - 0.8) \times 10^{-19}$	$(33.4 - 1.5) \times 10^{-22}$	$(0.3 - 0.9) \times 10^{-19}$
	1000		$(0.7 - 0.2) \times 10^{-19}$	$(0.3 - 2.7) \times 10^{-22}$	$(1.1 - 0.3) \times 10^{-19}$
$\|\Im m(d_t^Z)\|$	500	$< 10^{-30}$	$(1.1 - 0.2) \times 10^{-19}$	$(15.8 - 2.5) \times 10^{-22}$	$(1.1 - 0.3) \times 10^{-19}$
	1000		$(0.2 - 0.2) \times 10^{-19}$	$(9.2 - 1.2) \times 10^{-22}$	$(0.4 - 0.3) \times 10^{-19}$
$\|\Re e(d_t^Z)\|$	500	$< 10^{-30}$	$(1.6 - 0.2) \times 10^{-19}$	$(22.9 - 0.8) \times 10^{-22}$	$(0.1 - 0.3) \times 10^{-19}$
	1000		$(0.2 - 1.4) \times 10^{-19}$	$(0.6 - 1.9) \times 10^{-22}$	$(0.4 - 0.1) \times 10^{-19}$

Table 5: *Attainable 1-σ sensitivities to the CP-violating dipole moment form factors in units of* 10^{-18} *e-cm, with* ($P_e = \pm 1$) *and without* ($P_e = 0$) *beam polarization.* $m_t = 180$ *GeV. Table taken from [175].*

	$20\ \mathrm{fb}^{-1}, \sqrt{s} = 500$ GeV			$50\ \mathrm{fb}^{-1}, \sqrt{s} = 800$ GeV		
	$P_e = 0$	$P_e = +1$	$P_e = -1$	$P_e = 0$	$P_e = +1$	$P_e = -1$
$\delta(\Re\mathrm{e} d_t^{\gamma})$	4.6	0.86	0.55	1.7	0.35	0.23
$\delta(\Re\mathrm{e} d_t^{Z})$	1.6	1.6	1.0	0.91	0.85	0.55
$\delta(\Im\mathrm{m} d_t^{\gamma})$	1.3	1.0	0.65	0.57	0.49	0.32
$\delta(\Im\mathrm{m} d_t^{Z})$	7.3	2.0	1.3	4.0	0.89	0.58

Summary (1 of 2)

- Spectacular success of B-factories -> milestone in
- our understanding of CP violation: CKM-paradigm
- is confirmed.
- Direct measurements of β agree remarkably with
- theoretical expectations to about 10% ; so also the
- 1^{st} relatively crude measurements of α and γ ->any
- beyond SM CP-odd phase likely to cause a small
- perturbation in B-physics…..Likely to require
- lots and lots of clean B-samples and super clean predictions from theory to search BSM phase

Summary (2)

- In particular, we know now how to determine
- γ and α also (β was already known) to accuracy
- of better than 1%….this will require 10^{10} B's,
- some 20 times more than current luminosties
- but is extremely well motivated
- Penguin dominated hadron FS, much in the news
- but for now no convincing "deviation" from SM;
- However, it is a powerful test and its extremely important to
- reduce errors to O(5%) …may well need a SBF
- K-UT, NEDM, TEDM…need be pursued with renewed vigor