# *Clues from CP Studies for sub-TeV scale New Physics at the LHC*

**(Interplay of Collider and Flavour Physics,CERN )**

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# *Outline*

- **Motivation**
- **FOUR ANOMALIES**
- **Some possible solutions**
- **A NATURAL solution that fits the pattern of anomalies**
- **Broader repercussions**
- **Conclusion & Summary**

# Motivation

- While a compelling & conclusive evidence for breakdown of SM in flavor physics cannot be made at present, in the last few years several interesting (and possibly strong) hints have emerged.
- Although, taking too seriously every little deviation

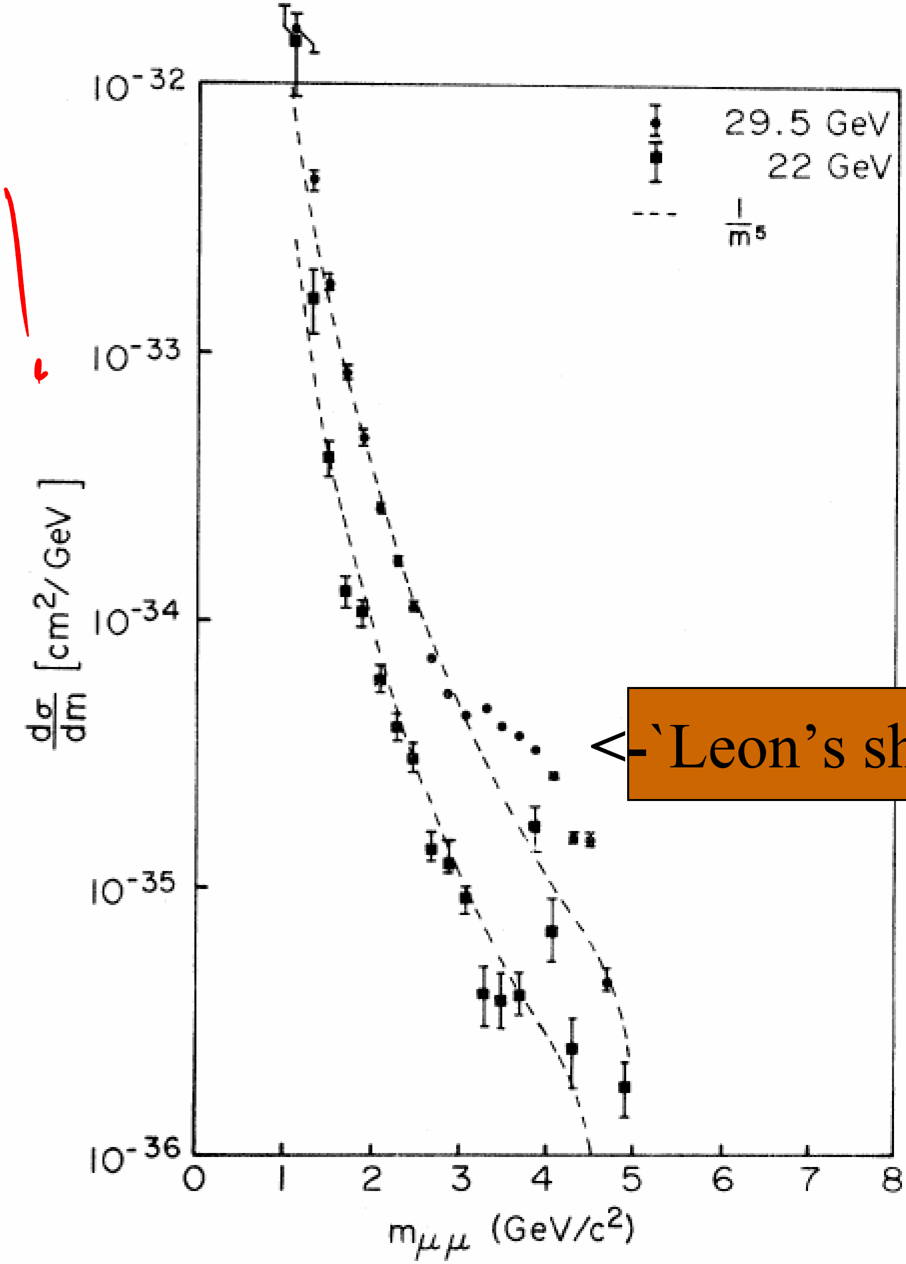
  can be unwise and may be counterproductive; disregarding or overlooking the hints can be painfully unwise and in fact can be more damaging {LESSON FROM HISTORY} . Following these up in flavor & collider physics and in theory may be a much wiser path.

{ based in part on Enrico Lunghi + A. S. 0707.0212; 0803.4340; & in progress; Alok,Giri, Mohanti, Nandi +AS (WHEPP X,Chennai):0807.1971 & in progress}

DRELL-YAN
@ its
INFANCY!

PRD '72

$p p \to \mu^+ \mu^- X$
@ BNL



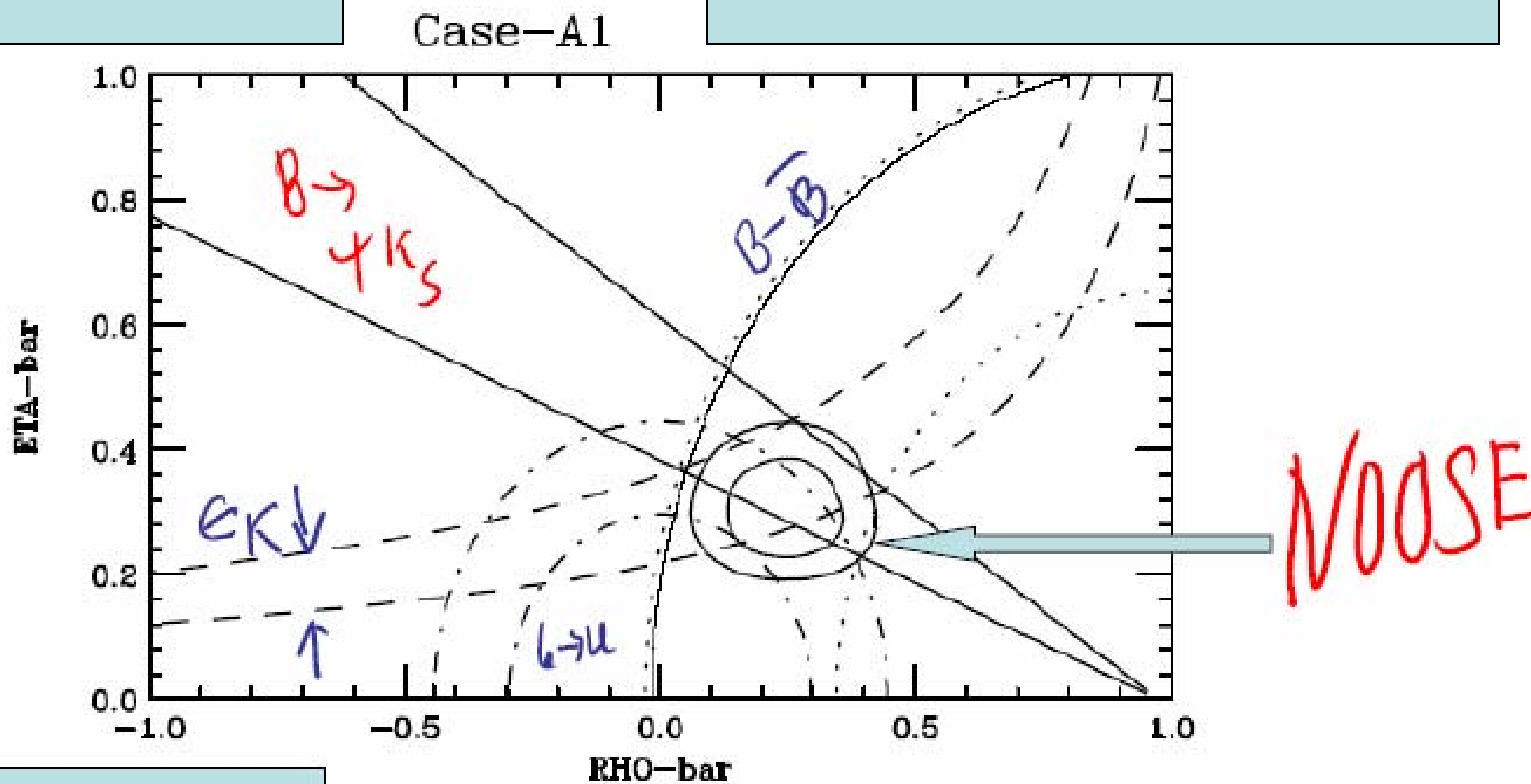

<-`Leon's shoulder

FIG. 15. Experimental cross sections at two energies compared with a simple $1/m^5$ continuum.

**1st Hint of confirmation of CKM CP description**

**Atwood &AS, hepph/0103197**

B-CP
e
ISE
Feb~01




Most bands due
To theory errors

**New physics will be a perturbation, important to use clean theory and will need lots of statistics.**

# *B-CP Anomalies*

- Fitted ("SM-predicted") value of sin 2 beta vs directly measured a) via tree decays
- b) via loop decays
- Dir CP in K+π- vs K+π0
- Bs->ψφ ?

EACH ~ 2 to 3.5 σ effects

# *Anomalies in B($B_s$)-CP asymmetries (I)*

- **Using $B_K$ (& $\varepsilon_K$ ),$\xi_s$ (&$\Delta m_s$ /$\Delta m_d$),|$V_{ub}$|/|$V_{cb}$| &|$V_{cb}$ | yields sin2β ~ 0.78 +-0.04 to be compared to 0.681+-0.025 (ψ$K_s$) or 0.58 +-0.06 ("clean" penguin modes(CPM)) i.e ~ 2.2 to ~2.7 σ [CONCERN |$V_{ub}$| ]**
- **Sin 2 β from penguin-dominated "clean"modes**

**is smaller than from the value obtained via B->ψ $K_S$ ~1.5 σ (in addition an intriguing trend of central values of almost all modes are low)**

- **ACP($K^+ \pi^-$)) – ACP($K^+ \pi^0$) =14.4+-2.9% & not ~0** [2.5±1.5]%

**-> these anomalies suggest NEW CP phase in b->s penguin transitions (Lunghi + AS 0707.0212)**

**-> BOTH b->s penguin (DeltaF=1) and therefore also in DeltaF=2 box relevant for Bs-mixing& Bs->ψφ**

# Lunghi+AS,arXiv.0707.0212

## (Sin 2 β = 0.78+-.04 )

**Directly measured via (gold-plated) B->ψ $K_S$ ,' sin β = 0.68+-.026**

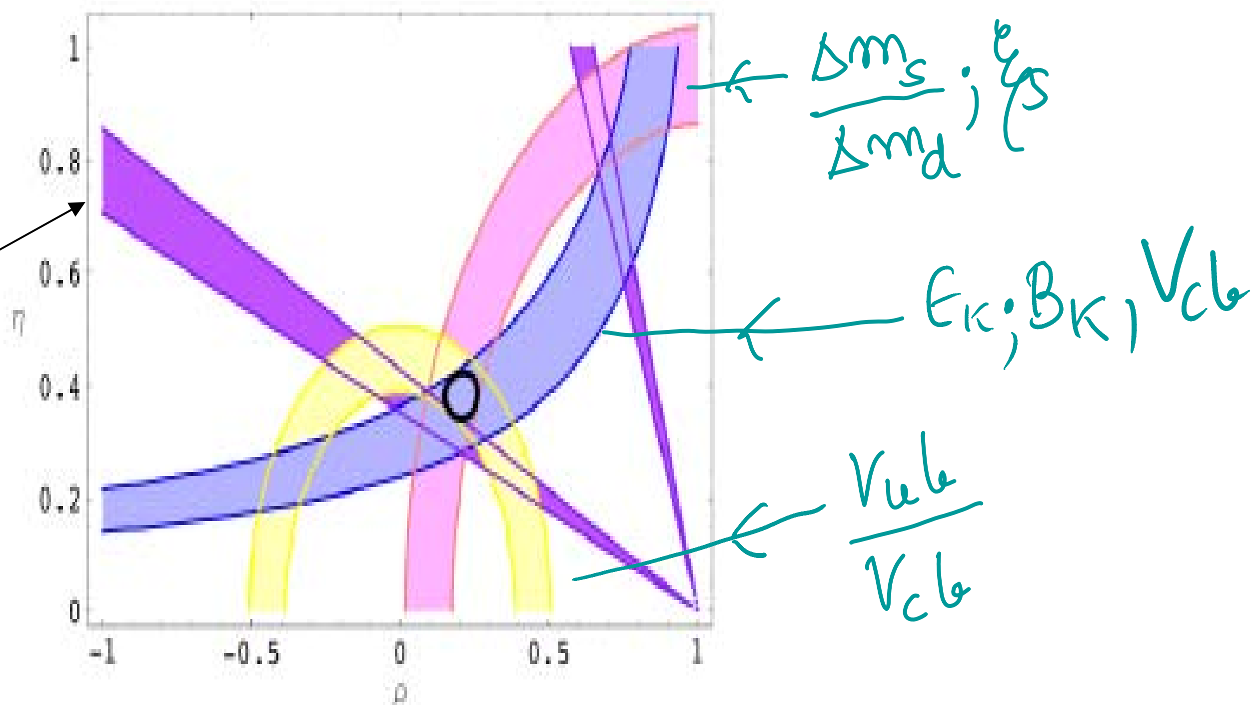



Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, $\varepsilon_K$, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

# *Anomalies in $B(B_s)$-CP asymmetries(II)*

MORE RECENTLY

- Increased accuracy in $B_K$ from the lattice, along with $\xi_s$ from the lattice suffices now **{w/o use of $V_{ub}$}** to determine sin2 β to be around 0.87+-0.09 (Lunghi+AS, 0803.4340)[thanx to lattice remove $|V_{ub}|$ CONCERN] but heightens discrepancy for SM

-> If true suggests problem in Δb=2 &/or Δs=2 (ASSUMING Vcb is not too far off)

{See L&S above; Buras & Guadagnoli 0805.3887}

**Leave out Vub**

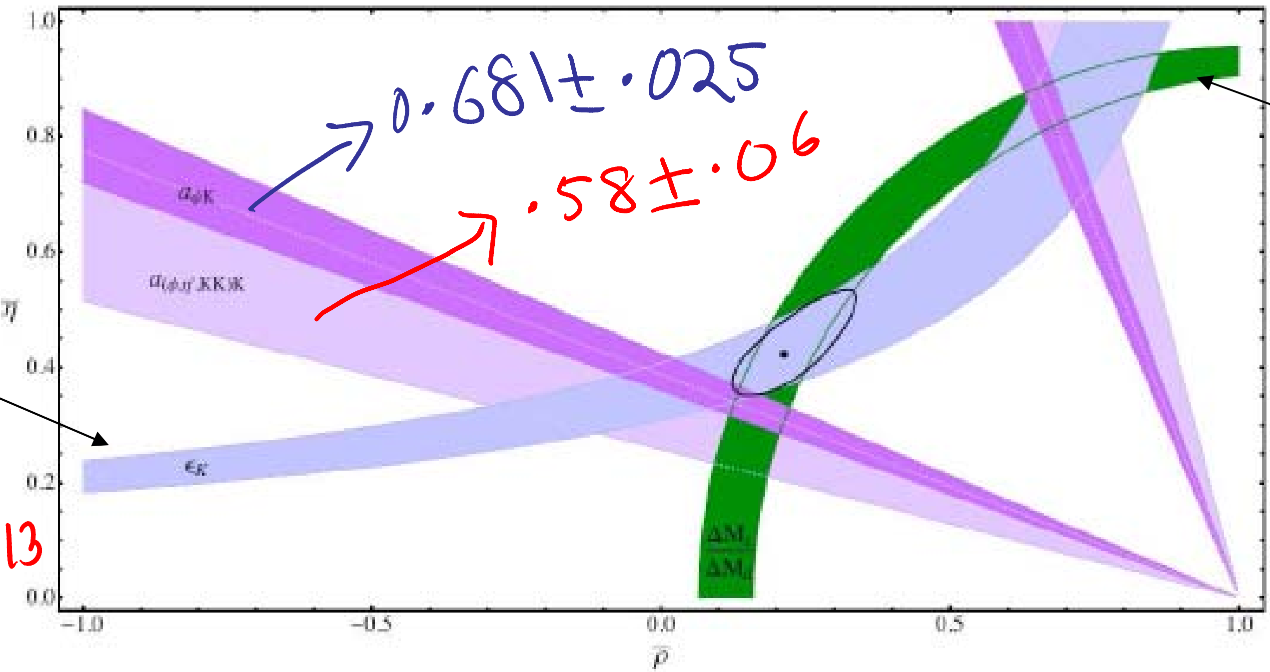
**sin 2 β = 0.87+-.09{Lunghi+AS,hep-ph/08034340}**

***( became possible only due significantly reduced error in $B_K$)***

**Antonio et al (RBC-UKQCD) 0702042**

$\hat{B}_K = .720 \pm .013 \pm .037$

$|V_{cb}| = 40.8 \pm .6 \times 10^{-2}$




**Gamiz et al; Becirevic; Tantalo**

.

$\xi = 1.20 \pm .06$

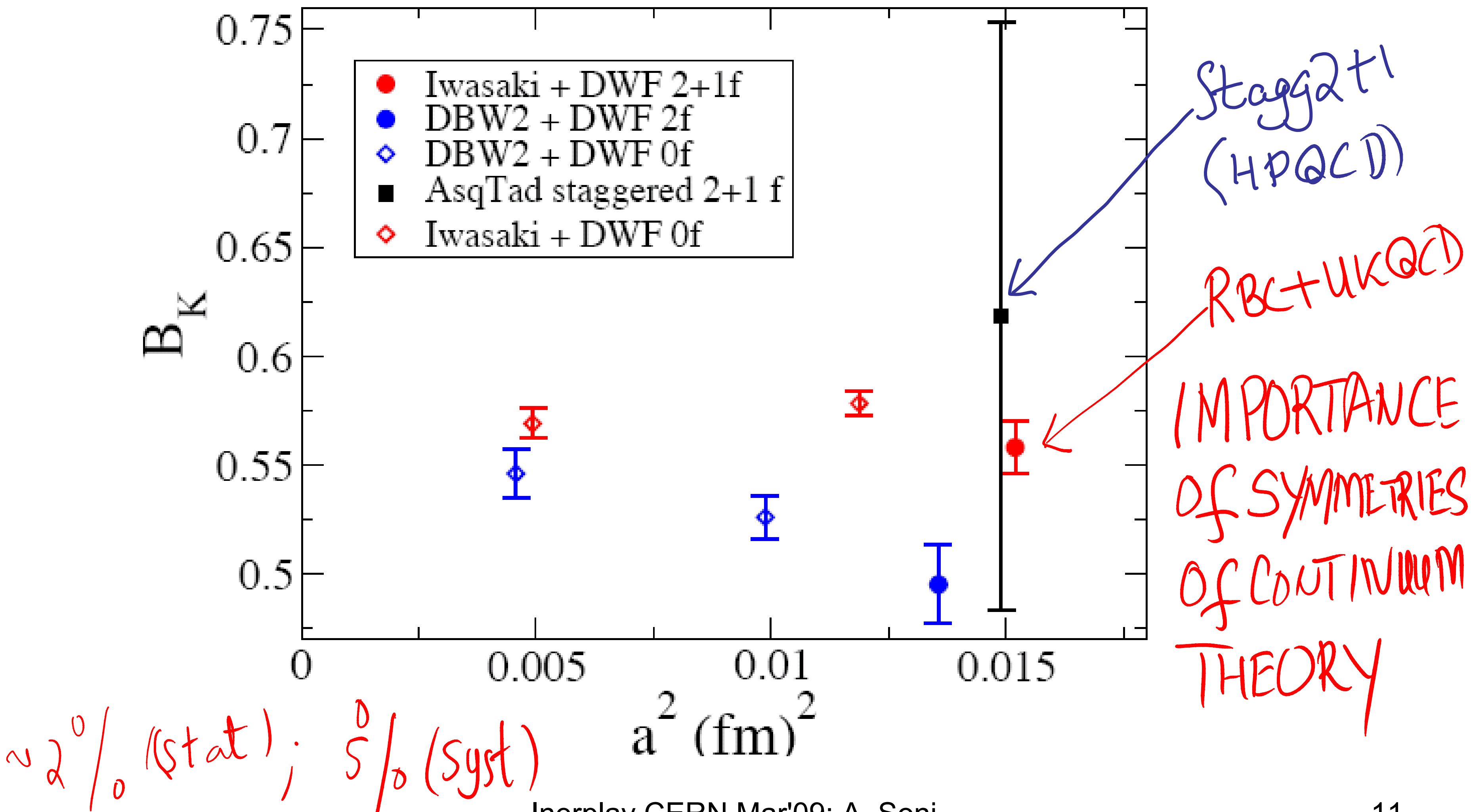
FIG. 1: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.. The solid contour is obtained using the constraints from $\varepsilon_K$ and $\Delta M_{B_s}/\Delta M_{B_d}$. The regions allowed by $a_{\psi K}$ and $a_{(\phi+\eta'+2K_s)K_s}$ are superimposed.

**2.1-2.7 σ- deviation from the directly measured values of sin 2 β require careful follow-up**

# RBC-UKQCD 2+1 dynamical DWQ,hep-ph/0702042

$$B_K^{\overline{\rm MS}}(2\ {\rm GeV}) = 0.524(10)(28)$$

PRL Jan25,08



BROOKHAVEN NATIONAL LABORATORY

HEP office of high energy physics

# Brief (~25 years) History of $B_K$

UNCONTROLLABLE APPROXIMATION

, ~'83 DGH use $K^+$ lifetime + LOChPT + SU(3)->
$B_K$ ~0.33… no error estimate, no scale dependence…

~'84 Lattice method for WME born…many attempts & improvements for $B_K$ evaluations

~88,Large N, Bardeen, Buras and Gerhard, BK-hat ~0.70+-0.10 (its like quenched)

~'98 JLQCDstaggered $B_K$ (2GeV)= 0.628(42)quenched(~110).

~'97 1st $B_K$ with DWQ(T.Blum&A.S),0.628(47) quenched.

~'01 RBC $B_K$ with DWQ, quenched=0.532(11) quenched

~'05 RBC , nf=2, dyn. DWQ, $B_K$ =0.563(21)(39)(30)

*~'06 Gimnez et al (HPQCD; stagg.) 2+1, $B_K$ =0.618(18)(19)(30)(130)*

***~07,RBC-UKQCD DWQ 2+1 …..0.524(10)(28)*** .720(13)(37)

***DWQ lower $B_K$ -> requiring larger CKM-phase***

**~'08 Target 2+1 dyn. DWQ, $B_K$ with total error 5%**

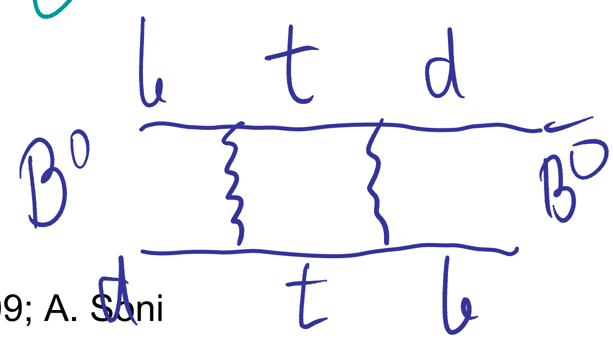
# Sin2β from penguin dominated modes

$$\Delta S \equiv S_{penguin} - S_{\psi K_S} = O(\lambda^2)$$


$$S^{Decay}_{peng} \simeq O(\lambda^2) \sim few\%$$

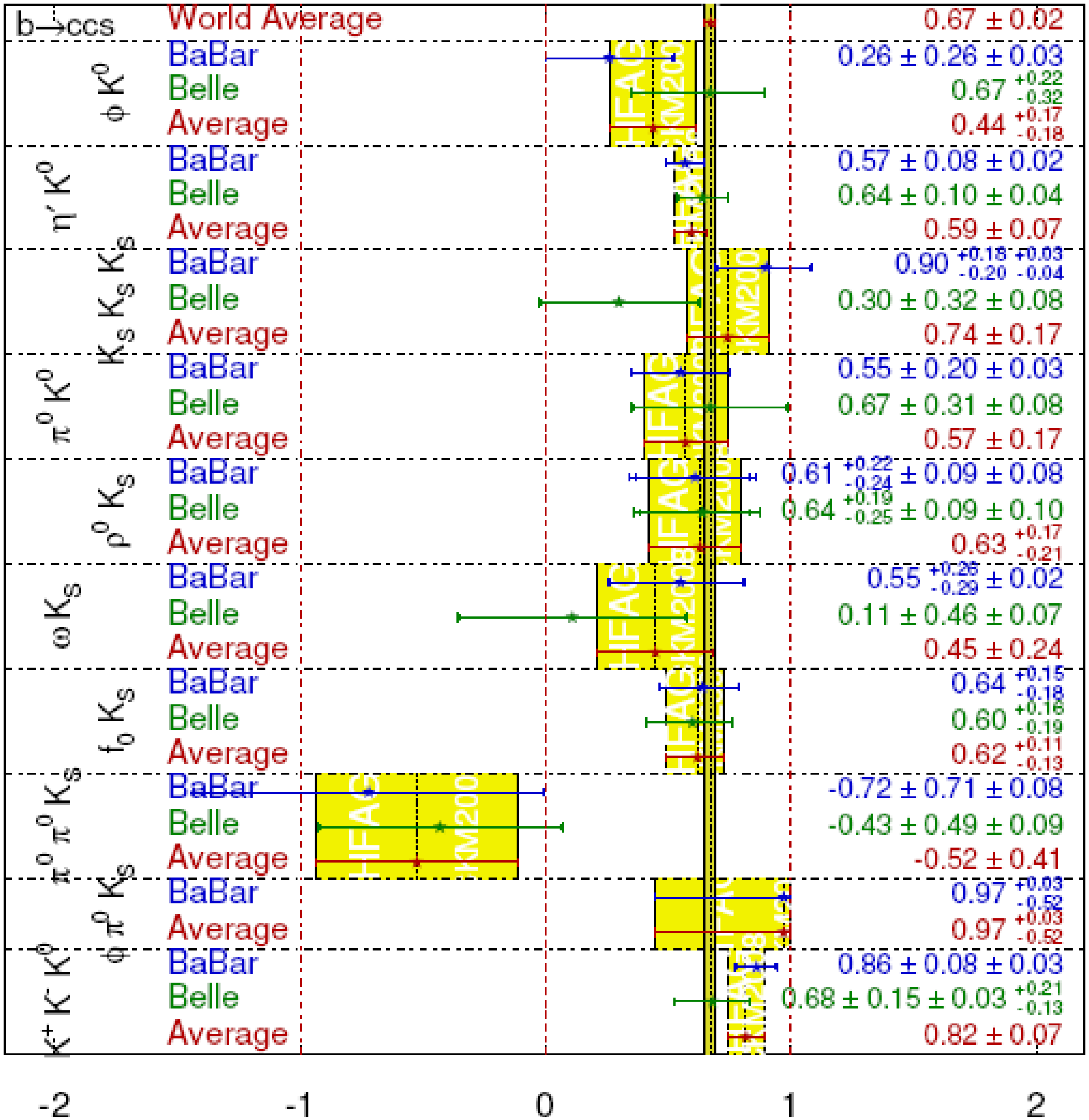

$$S^{Decay}_{\psi K_S} = 0$$

OSC is COMMON



# $\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$

HFAG CKM2008 PRELIMINARY




Intriguing: Practically all have $\sin 2\beta < (\sin 2\beta)_{SM}$

Most have $\sin 2\beta < (\sin 2\beta)_{\phi K_S}$

**What is this test of?**

Cheng, Chua, AS '05 PRD

M.Beneke PLB'05

Buchalla, Hiller, Nir+Raz JHEP'05

Williamson+Zupan PRD'06

TABLE I: Some expectations for $\Delta S$ in the cleanest modes.

| Mode | QCDF+FSI [20, 21] | QCDF [23] | QCDF [24] | SCET [25] |
|---|---|---|---|---|
| $\eta' K^0$ | $0.00^{+0.00}_{-0.04}$ | $0.01 \pm 0.01$ | $0.01 \pm 0.02$ | $-0.019 \pm 0.009$<br>$-0.010 \pm 0.001$ |
| $\phi K^0$ | $0.03^{+0.01}_{-0.04}$ | $0.02 \pm 0.01$ | $0.02 \pm 0.01$ | |
| $K_S K_S K^0$ | $0.02^{+0.00}_{-0.04}$ | | | |

# CLEANEST MODES

## M.Beneke, hep-ph/0505075 (PLB)

| Mode | $\Delta S_f$ (Theory) | $\Delta S_f$ [Range] | Experiment [3] (BaBar/Belle) |
|---|---|---|---|
| $\pi^0 K_S$ | $0.07^{+0.05}_{-0.04}$ | [+0.02, 0.15] | $-0.39^{+0.27}_{-0.29}$ ($-0.38^{+0.30}_{-0.33}$/$-0.43^{+0.60}_{-0.60}$) |
| $\rho^0 K_S$ | $-0.08^{+0.08}_{-0.12}$ | [−0.29, 0.02] | — |
| $\eta' K_S$ | $0.01^{+0.01}_{-0.01}$ | [+0.00, 0.03] | $-0.30^{+0.11}_{-0.11}$ ($-0.43^{+0.14}_{-0.14}$/$-0.07^{+0.18}_{-0.18}$) |
| $\eta K_S$ | $0.10^{+0.11}_{-0.07}$ | [−1.67, 0.27] | — |
| $\phi K_S$ | $0.02^{+0.01}_{-0.01}$ | [+0.01, 0.05] | $-0.39^{+0.20}_{-0.20}$ ($-0.23^{+0.26}_{-0.25}$/$-0.67^{+0.34}_{-0.34}$) |
| $\omega K_S$ | $0.13^{+0.08}_{-0.08}$ | [+0.01, 0.21] | $-0.18^{+0.30}_{-0.32}$ ($-0.23^{+0.34}_{-0.38}$/$+0.02^{+0.65}_{-0.66}$) |

ONLY $\eta' K_S$ & $\phi K_S$ are clean amongst 2-body

Table 1: Comparison of theoretical and experimental results for $\Delta S_f$.

**Similar conclusions from Cheng, Chua &AS PRD'05**

∴ NAIVE AVERAGE OVER ALL MODES Should Not be done


**Courtesy: Tom Browder**

Critical Role of the B factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation

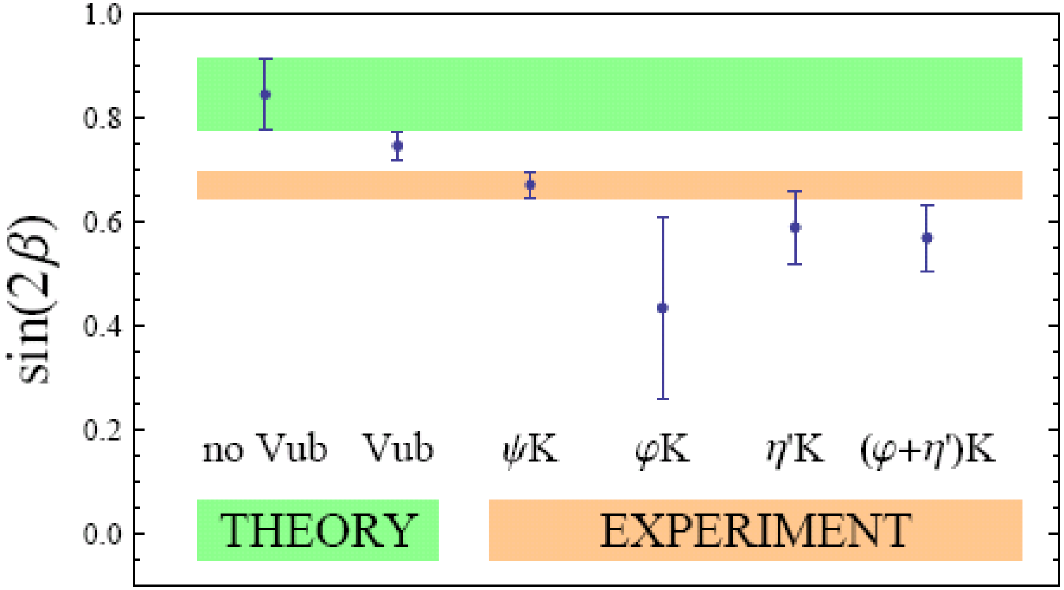
A single irreducible phase in the weak interaction matrix accounts for most of the CPV observed in kaons and B's.

CP violating effects in the B sector are O(1) rather than O($10^{-3}$) as in the kaon system.

# *Sin2β Tests of the SM*

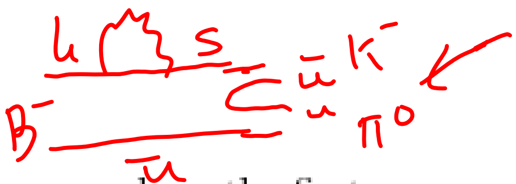
- **Sin2β (ψ Ks) should be compared with Sin2β (fitted by using KL->π π )**
- **SIMILARLY Sin2β (φ Ks, η' Ks…) needs to be *directly* compared with Sin2β (fitted by using KL-> π π)**
- **Strictly speaking, comparing Sin2β (ψ Ks) with Sin2β (φ Ks, η' Ks…) DOES NOT test whether a single phase in the 3X3 CKM matrix describes all observed CPV…(Since Bd-mixing effects both, it could be "polluted" by NP)**

LUNGHI + A S
(WIP)




gure 2: Comparison between the SM predictions Eq. (2.5) and the direct determinati
$\to c\bar{c}s$ and $b \to s$ penguin modes.

# ΔACP(Kπ) (Lunghi +AS,'07)




$$A_{CP}(B^- \to K^-\pi^0) \; = \; \left(7.1^{+1.7+2.0+0.8+9.0}_{-1.8-2.0-0.6-9.7}\right)\% \qquad (1)$$

$$A_{CP}(\bar{B}^0 \to K^-\pi^+) \; = \; \left(4.5^{+1.1+2.2+0.5+8.7}_{-1.1-2.5-0.6-9.5}\right)\% , \qquad (2)$$


where the first error corresponds to uncertainties on the CKM parameters and the other three correspond to variation of various hadronic parameters; in particular, the fourth one corresponds to the unknown power corrections. The main point is that the uncertainties in the two asymmetries are highly correlated. This fact is reflected in the prediction for their difference; we find:

RELATED BY ISOSPIN

$$\Delta A_{CP} = A_{CP}(B^- \to K^-\pi^0) - A_{CP}(\bar{B}^0 \to K^-\pi^+) = (2.5 \pm 1.5)\% \, . \qquad (3)$$

In evaluating the theory error for this case, we followed the analysis presented in Ref. [31] and even allowed for some extreme scenarios (labeled S1-S4 in Ref. [31]) in which several inputs are simultaneously pushed to the border of their allowed ranges. The comparison of the SM prediction in Eq. (3) to the experimental determination of the same quantity [14]

$A_{CP}$ $K^+\pi^- = -9.5 \pm 1.3\%$
$K^+\pi^0 = 4.7 \pm 2.6\%$

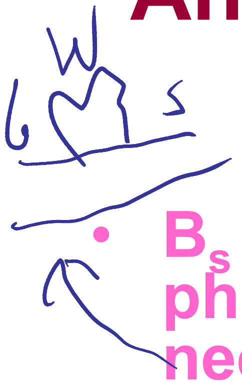
$$\Delta A^{\rm exp}_{CP} = (14.4 \pm 2.9)\% \, , \qquad (4)$$

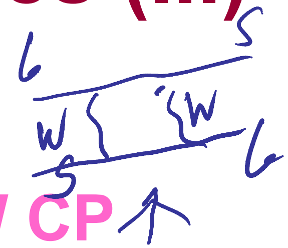
yields a $3.5\sigma$ effect.

$\sim 3.5\sigma$

BENEKE+NEUBERT
0308039

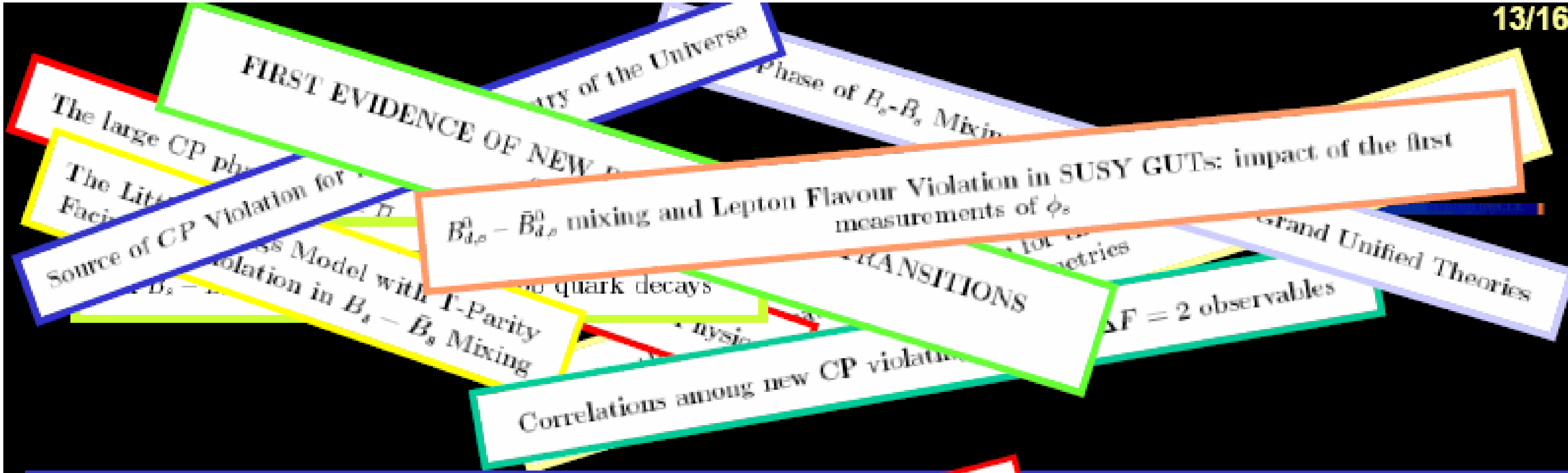
# Anomalies in B($B_s$)-CP asymmetries (III)





- $B_s$ -> ψ φ (CDF,D0) requires a sizeable NEW CP phase in b->s (see M. Bona et al, UTFIT 0803.0659; needed already in L&S 0707.0212 )

- As of ICHEP08 & CKM08 , CDF , D0 report a ~2.2 σ deviation in Bs->ψφ




## *Tevatron combination*

ICHEP update

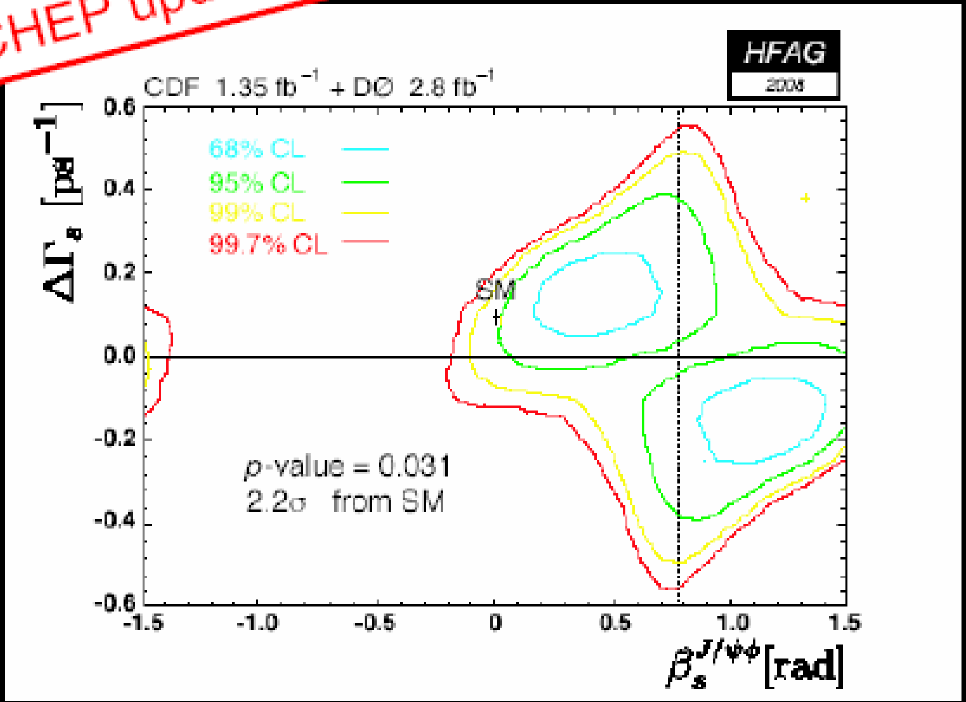
D0 observes a fluctuation consistent with CDF (see J. Ellison just after me)

Combine CDF and D0 iso-CL regions previously checked for coverage:

2.2σ consistency with SM.

0.24 < βs < 0.57 OR
0.99 < βs < 1.33 at 68% CL

hep.physics.indiana.edu/~rickv/hfag/combine_dGs.html



# *B-CP anomalies & clues for TeV scale physics (LATEST #s here)*

- **Key observation (Following Lunghi & AS): values of sin 2 beta:**
- **SM "predicted" :0.75+-0.03(with Vub)**

  **0.85+-0.07(no Vub)**
- **Seen via B->psi Ks: 0.672+-0.024**
- **Seen via B->(phi,eta',3..)Ks:0.59+-0.05**

# *Possible Resolution within the SM*

- Sin2β Fitted higher than directly measured by ψ Ks……May be a lattice problem?
- Sin2β (φ, η',….) Ks tends to be smaller than even ψ Ks….Recall many modes…May be needs more statistics?
- ΔACP(K+π- vs K+ π0)….May be VERY Large QCD corrections?
- Bs->ψφ…..May be need more statistics?
- *(MAY BE)$^{3-4}$ ~ each implausible*

ASSUME FOR NOW THIS PATH IS IMPLAUSIBLE & discuss NP explanation(s)

## Model independent determination of scale of new physics with a non-standard CP phase needed to fix B-CP anomalies {Lunghi + AS (WIP)}

| Scenario | Operator | $\Lambda$ (TeV) | $\varphi$ (°) |
|---|---|---|---|
| $B_d$ mixing | $O_1^{(d)}$ | $\begin{cases} 1.1 \div 2.1 & \text{no } V_{ub} \\ 1.4 \div 2.3 & \text{with } V_{ub} \end{cases}$ | $\begin{cases} 15 \div 92 & \text{no } V_{ub} \\ 6 \div 60 & \text{with } V_{ub} \end{cases}$ |
| $B_d = B_s$ mixing | $O_1^{(d)}$ & $O_1^{(s)}$ | $\begin{cases} 1.0 \div 1.4 & \text{no } V_{ub} \\ 1.1 \div 2.0 & \text{with } V_{ub} \end{cases}$ | $\begin{cases} 25 \div 73 & \text{no } V_{ub} \\ 9 \div 60 & \text{with } V_{ub} \end{cases}$ |
| $K$ mixing | $O_1^{(K)}$<br>$O_4^{(K)}$ LR | $< 1.9$<br>$< 24$ | $130 \div 320$ |
| $\mathcal{A}_{b\to s}$ | $O_4^{b\to s}$<br>$O_{3Q}^{b\to s}$ | $.25 \div .43$<br>$.09 \div .2$ | $0 \div 70$<br>$0 \div 30$ |

GREAT NEWS for LHC & for SBF!

**C also Bona et al 0707.0636 (but impt. differences)**

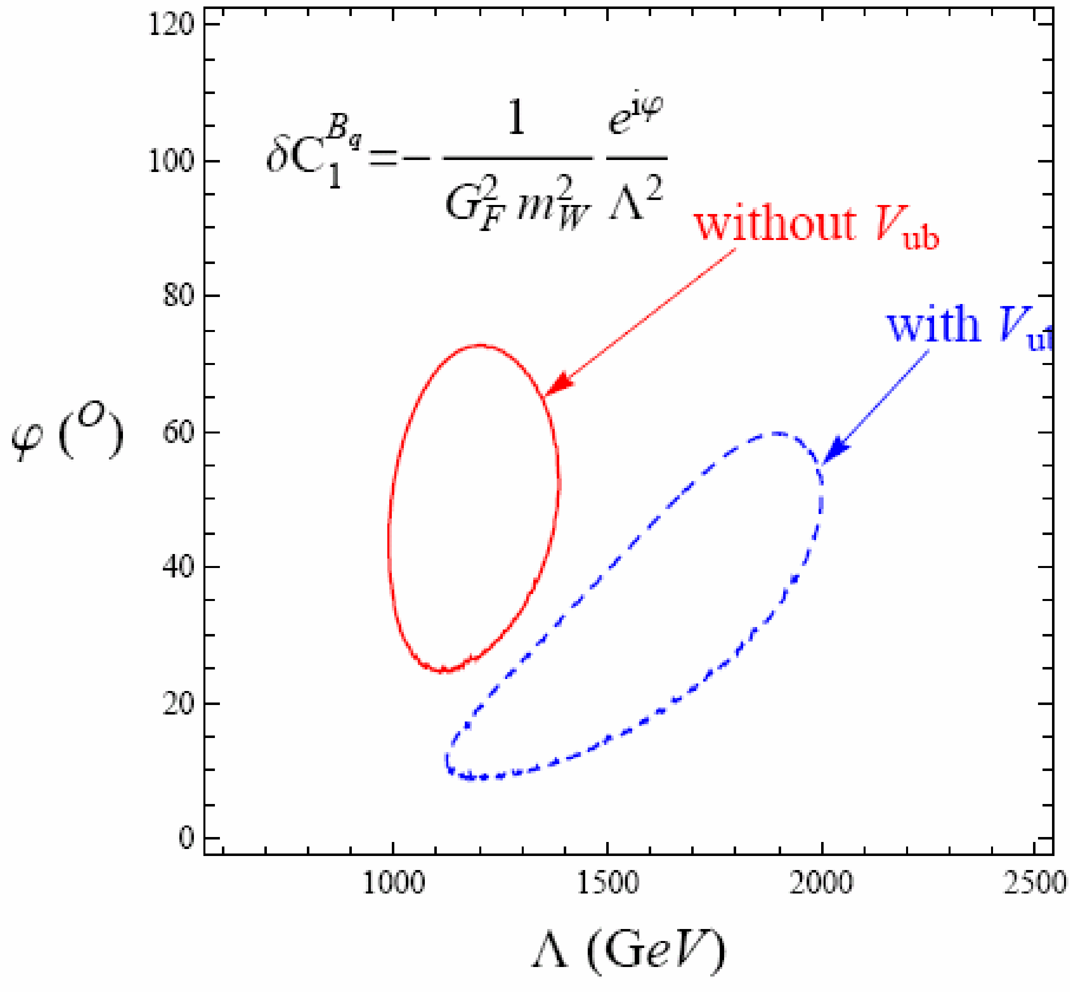



**Figure 4:** New physics contributions to $B_d$ and $B_s$ mixing.

**Lunghi + AS (WIP)**

***WHODUNIT?***

# *Honest answer &*

- **Don't really know (too many possibilities…)**
- **But theoretically the most interesting possibility is that we may be witnessing**

**Dawning of the age of**

***"Warped Quantum Flavordynamics"***

However - -

# *Many other possiblities*

- **Susy …**
- **Extra Higgs, Extra Z,…**
- **Extra gen.…**
- ***What's the simplest solution that "can do the job"***

# Contrasting B-Factory Signals from WED with those from SM

**Agashe,Perez &AS, PRL'04**
**(Assumed Bd-mixing is SM )**
**O(1) uncertainties stressed**

[ALSO D Mixing, D-CP & nedm]

| | $\Delta m_{B_s}$ | $S_{B_s\to\psi\phi}$ | $S_{B_d\to\phi K_s}$ | $Br[b\to s l^+ l^-]$ | $S_{B_{d,s}\to K^*,\phi\gamma}$ | $S_{B_{d,s}\to\rho,K^*\gamma}$ |
|---|---|---|---|---|---|---|
| RS1 | $\Delta m_{B_s}^{SM}[1+O(1)]$ | $O(1)$ | $\sin 2\beta \pm O(.2)$ | $Br^{SM}[1+O(1)]$ | $O(1)$ | $O(1)$ |
| SM | $\Delta m_{B_s}^{SM}$ | $\lambda_c^2$ | $\sin 2\beta$ | $Br^{SM}$ | $\frac{m_s}{m_b}\left(\sin 2\beta, \lambda_c^2\right)$ | $\frac{m_d}{m_b}\left(\lambda_c^2, \sin 2\beta\right)$ |

$m_{KK} \gtrsim 3$ TeV

**At this meeting many very nice talks(Blanke,Buras,Falkowski, Perez,Weiler…)**
**reported further works along these lines**
**(C also Casagrande, Goertz,Haisch,Neubert &Pfoh)**

# *EXTREMELY INTERESTING SUBTELTY of warped models*

- Maldacena conjecture
- ***“Warped Quantum Flavordynamics” is DUAL to strong dynamics->***

***Focus for now on the SIMPLEST 4d Explanation***

***Thus by process of elimination one arrives at***

# *HINTS*

I. **CP observables are crucial; CP conserving processes seem to see hardly any effect.**

**II. EWP seems to have a NP component to it:**

**Reminiscent of the non-decoupling effects in SBGT's**

**III. HIERARCHY of effects due to the "New Physics" is suggestive of flavor dependence.**

**->This is suggestive of a "$4^{th}$ family"**

**-> 2 entirely new phases..THEREFORE NOT A PERTURBATION for CPV..NULL TESTS of SM-CKM MAY FAIL A LOT…Bs->ψφ , Bd->φ Ks are null tests whereas Brs show little effect.**

**-> 3 new mixing angles, 2 new masses: total of 7 parameters**…

# *How does 4$^{th}$ family fit in?*

For details see AS+ Alok,Giri, Mohanta & Soumitra in WHEPPX (Jan,'08) & arXiv:0807.1971 & in progress

-> 4th family with rather heavy t'(b'), masses ~ 400-600 GeV provides perhaps the simplest explanation (AS et al, 0807.1971)

{suggestion of 4th family in the context of some of these deviations also made by Hou et al JHEP'06;PRL'05;PRL'07 though their discussions confined to lighter mt'}

-> IN OUR WORK mt' 400-600GeV -> If true then it likely plays an impt. ROLE IN DYNAMICAL EWSB thereby providing a possible resolution to EW-Planck hierarchy{ see, e.g. He, Hill & Tait, hepph/0108041}

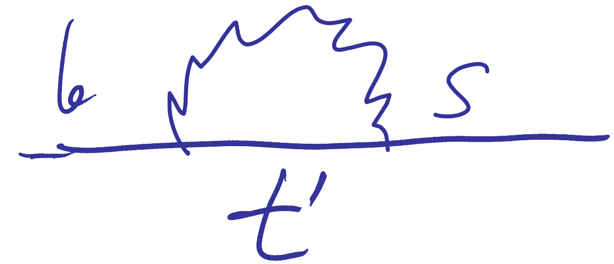
INPUTS & Constraints

| |
|---|
| $B_K = 0.72 \pm 0.05$ |
| $f_{bs}\sqrt{B_{bs}} = 0.281 \pm 0.021$ GeV |
| $\Delta M_s = (17.77 \pm 0.12) ps^{-1}$ |
| $\Delta M_d = (0.507 \pm 0.005) ps^{-1}$ |
| $\xi_s = 1.2 \pm 0.06$ |
| $\gamma = (75.0 \pm 22.0)^\circ$ |
| $\lvert\epsilon_k\rvert \times 10^3 = 2.32 \pm 0.007$ |
| $\sin 2\beta_{\psi K_S} = 0.672 \pm 0.024$ ← |
| $\mathcal{BR}(K^+ \to \pi^+ \nu\nu) = (0.147^{+0.130}_{-0.089}) \times 10^{-9}$ |
| $\mathcal{BR}(B \to X_c \ell\nu) = (10.61 \pm 0.17) \times 10^{-2}$ |
| $\mathcal{BR}(B \to X_s \gamma) = (3.55 \pm 0.25) \times 10^{-4}$ |
| $\mathcal{BR}(B \to X_s \ell^+ \ell^-) = (0.44 \pm 0.12) \times 10^{-6}$ ← |
| ( High $q^2$ region ) |
| $R_{bb} = 0.216 \pm 0.001$ |
| $\lvert V_{ub}\rvert = (37.2 \pm 2.7) \times 10^{-4}$ ← |
| $\lvert V_{cb}\rvert = (40.8 \pm 0.6) \times 10^{-3}$ |
| $\eta_c = 1.51 \pm 0.24$ [21] |
| $\eta_t = 0.5765 \pm 0.0065$ [22] |
| $\eta_{ct} = 0.47 \pm 0.04$ [23] |
| $m_t = 172.5$ GeV |

TABLE I: Inputs that we use in order to constrain the SM4 parameter space, we have considered the $2\sigma$ range for $V_{ub}$.

$\lambda^s_{t'} = |V^*_{t's} V_{t'b}| \sim |V^*_{ts} V_{tb}|$

5 – 100




| $m_{t'}$ | 400 | 500 | 600 | 700 |
|---|---|---|---|---|
| $\lambda^s_{t'}$ | (0.08 - 1.4) | (0.06 - 0.9) | (0.05 - 0.7) | (0.04 - 0.55) |
| $\phi'_s$ | -80 $\rightarrow$ 80 | - 80 $\rightarrow$ 80 | -80 $\rightarrow$ 80 | -80 $\rightarrow$ 80 |

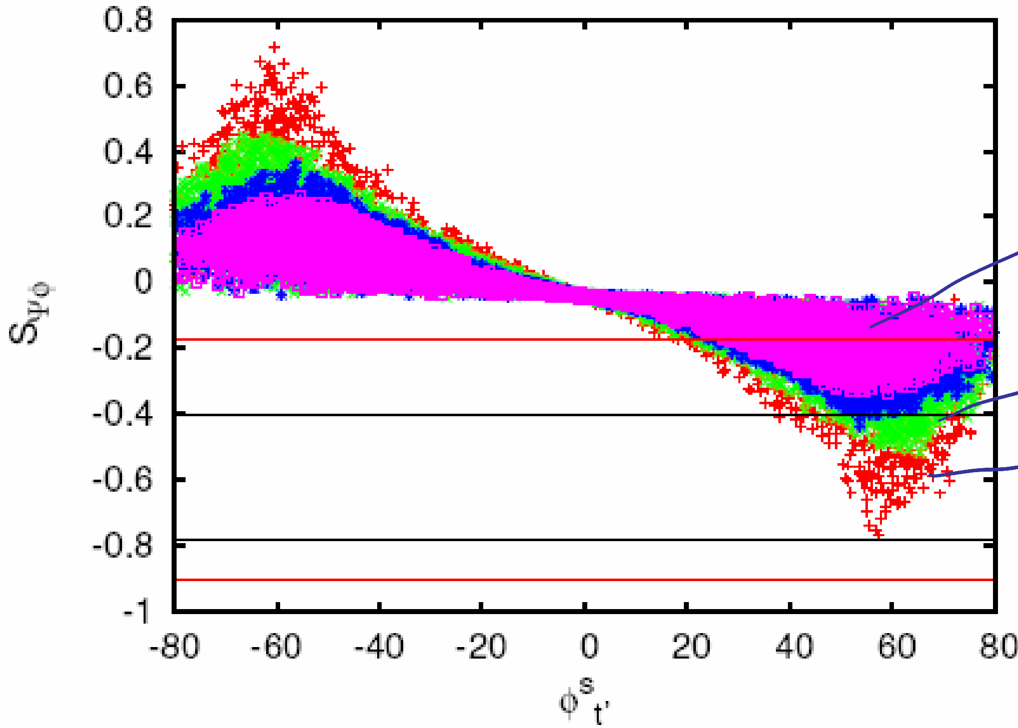
NOTE

TABLE II: Allowed ranges for the parameters, $\lambda^s_{t'}$ $(\times 10^{-2})$ and phase $\phi'_s$ (in degree) for different masses $m_{t'}$ ( GeV), that has been obtained from the fitting with the inputs in Table I.

New CP phase of $V_{t's}$ Responsible for $\phi K_s$, $\eta' K_s$ ... $\not\subset \phi$

Recall $\lambda^s_t = 0.04$
arg $V_{ts} \sim 0$

CURRENT DATA MILDLY FAVORS $m_{t'} \sim 400-500$




600 GeV

500 GeV

400 GeV

FIG. 2: The allowed range for $S_{\psi\phi}$ in the $(S_{\psi\phi} - \phi^s_{t'})$ plane for $m_{t'} = 400$ (red), 500 (green), 600 (magenta) and 700 (blue) GeV respectively. Black and red horizontal lines in the figure indicate 1-$\sigma$ and 2-$\sigma$ experimental ranges for $S_{\psi\phi}$ respectively.

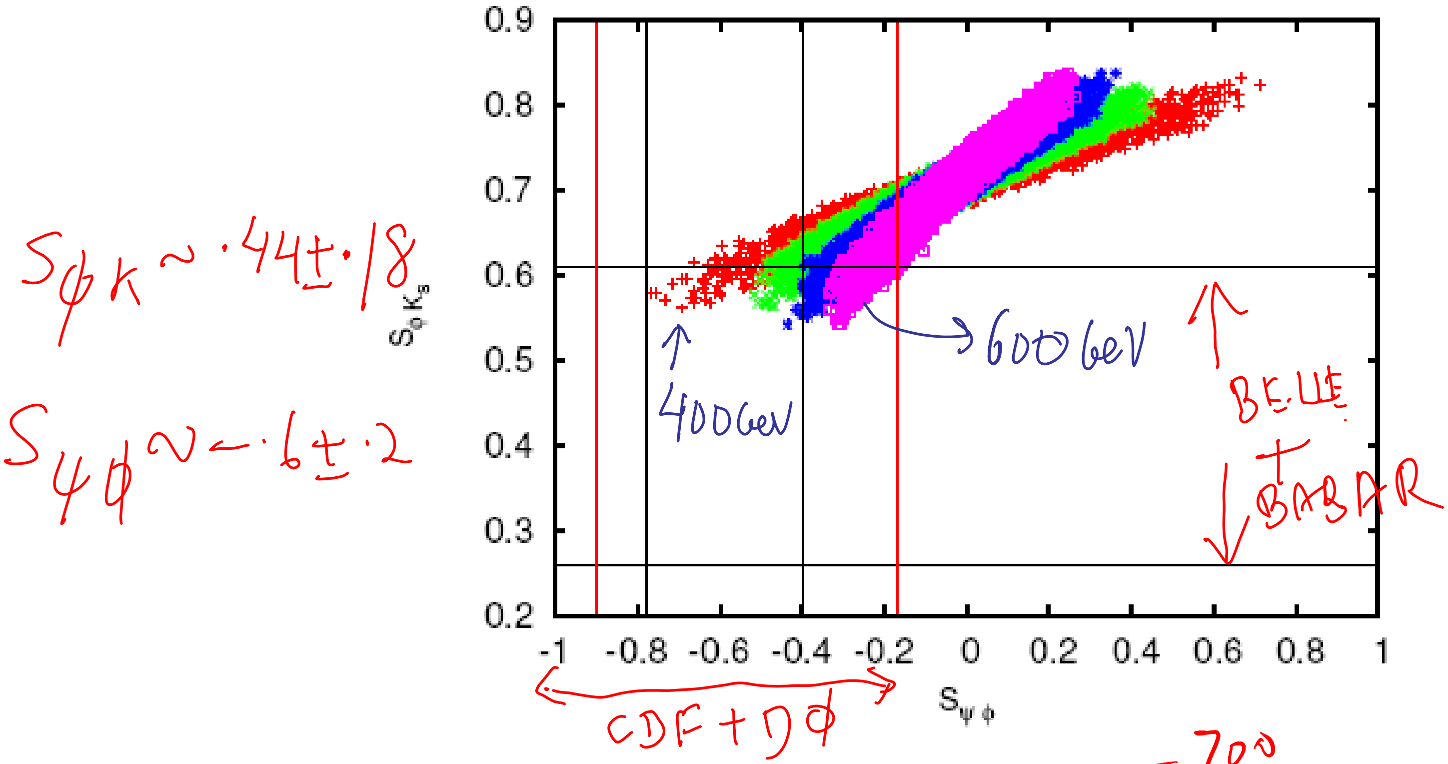
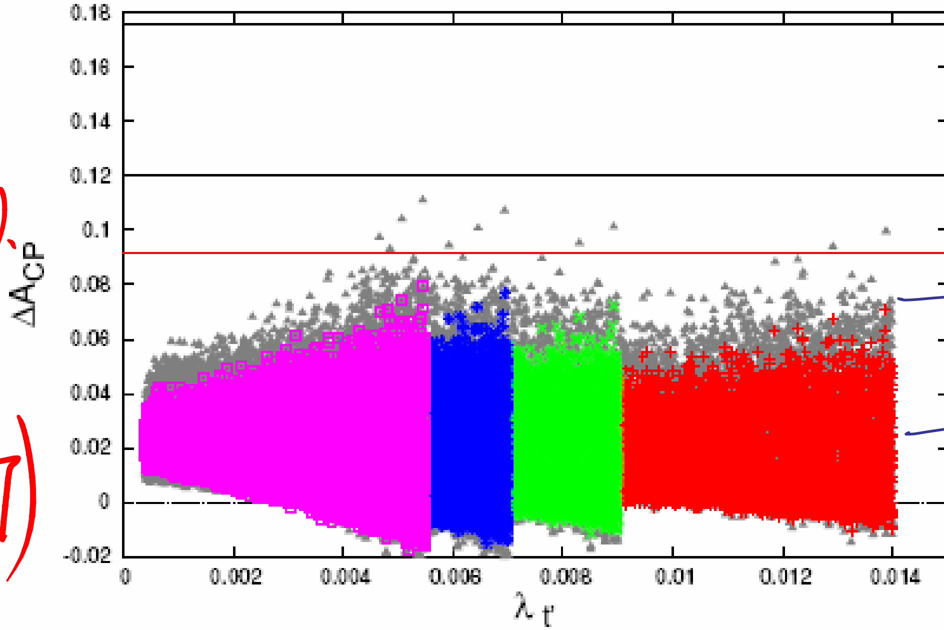



FIG. 3: Correlation between $S_{\phi K_s}$ and $S_{\psi\phi}$ for $m_{t'} = 400$ (red), 600 (green), 800 (magenta) and 1000 (blue) GeV respectively. The horizontal lines represent the experimental $1\sigma$ range for $S_{\phi K_s}$ whereas the vertical lines (Black 1-$\sigma$ and red 2-$\sigma$ ) represent that for $S_{\psi\phi}$ .

NONDECOUPL.

Color Allowed EWP

(See also HWS '87)




40% error

1σ range due CKM's

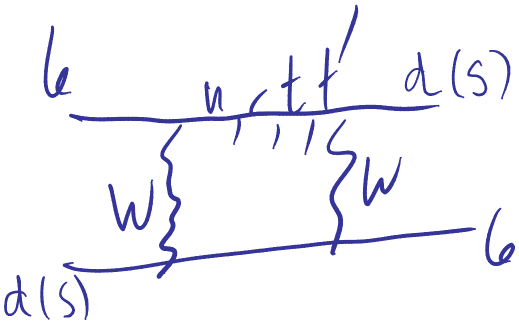
FIG. 1: The allowed range of the CP asymmetry difference ($\Delta A_{CP}$) in the ($\Delta A_{CP} - \lambda^s_{t'}$) plane, where the red, green, magenta and blue regions correspond to $m_{t'} = 400$, 500, 600 and 700 GeV. The 30 % error bars due to hadronic uncertainties [5] are shown by grey bands. The balck and red horizontal lines correspond to the experimentally allowed 1 and 2-$\sigma$ range respectively.

# *Early (~87-88) studies on 4th gen.*

- **Hou, Willey and AS, PRL (88)..b->s l l…**
- **Hou, AS, Steger, PRL 87……b-> s g**
- **Hou, AS, Steger, PLB 87**

**4X4 mixing matrix and b -> s gamma**

**Importance of B-decays for studying 4th gen. due to non-decoup emphsized long ago**




# *THUS*

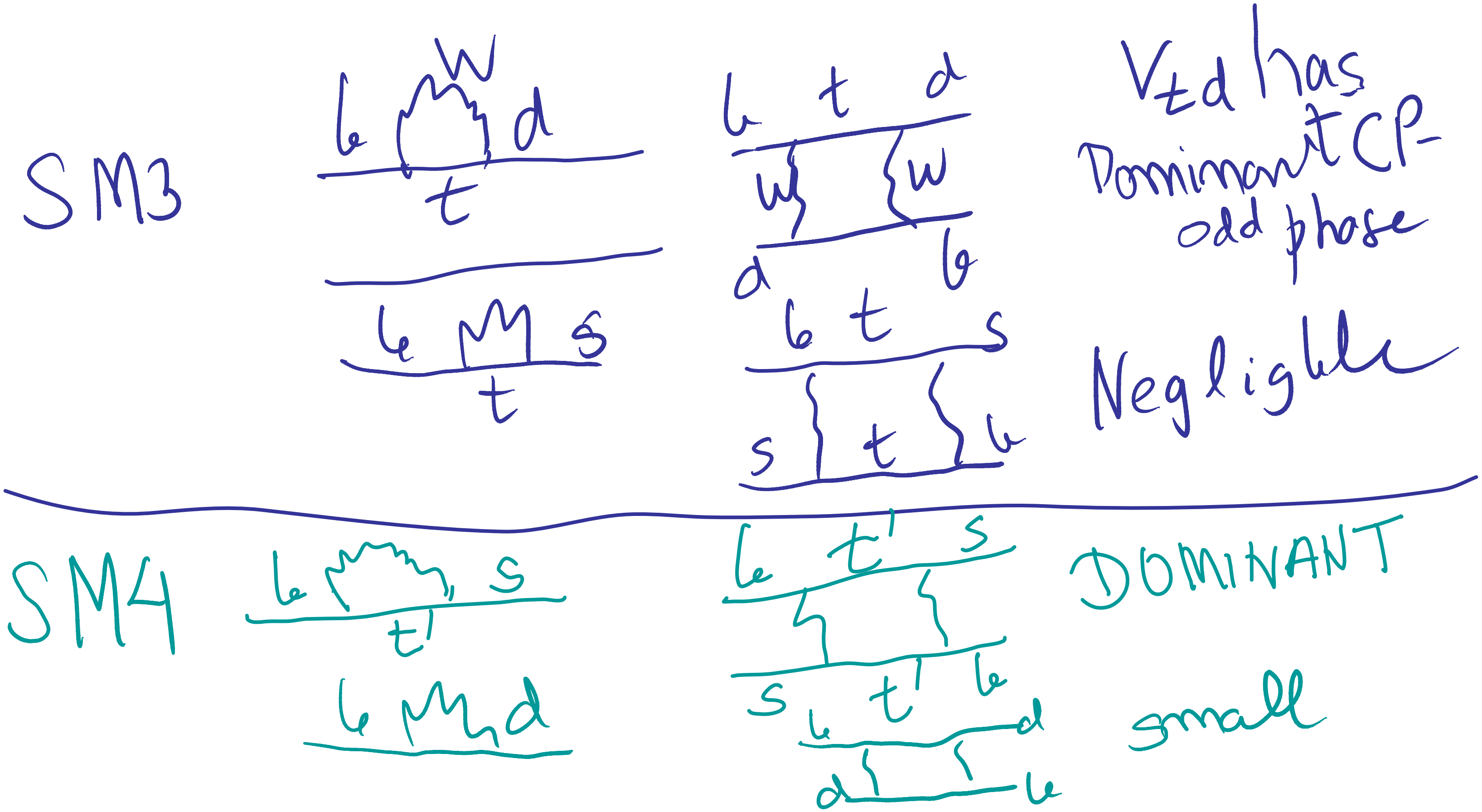
by construction

- The CKM-paradigm of CP violation accounts for the observed CP patterns to an accuracy of about 15%!
- SM3-CKM predicted value of sin2β tends to be high compared to direct (ψ K) measurements by about 15-20%...t is dominant

  in sin2β

- Hierarchical structure of SM4 mixing matrix NATURALLY lets t' be subdominant here but due to its large mass (and decoupling theorem) not negligible Leads to small ~ 15% deviations
- Dynamics of EW gauge interactions (evasion of decoupling theorem) by EWpenguins and the large mt' plays an important role in the large "isospin" violating $\Delta A_{CP}$ (K π)
- SM3 says $B_s$ mixing has negligible CP-odd phase therein t' plays a dominant role (& t is subdominant) due to t

# t & t' Role Reversals in Bd & Bs mixing



Kribs, Plehn, Spannowsky & Tait, PRD '07

LEP EW Constraints on $m_{t'}$
$m_{b'}$, $m_H$

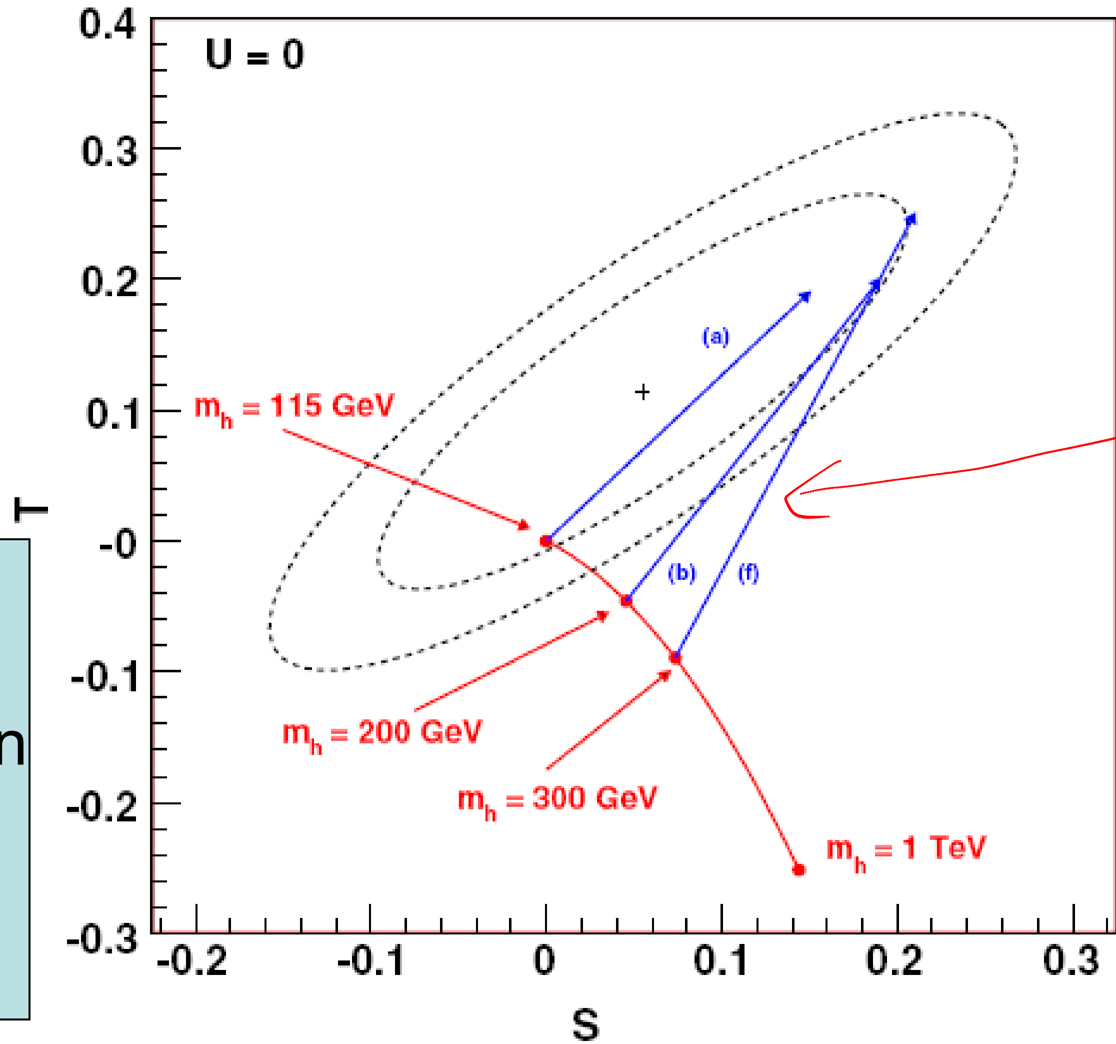



FIG. 2 (color online). The 68% and 95% C.L. constraints on the $(S, T)$ parameters obtained by the LEP Electroweak Working Group [34,35]. The shift in $(S, T)$ resulting from increasing the Higgs mass is shown in red (solid line). The shifts in $\Delta S$ and $\Delta T$ from a fourth generation with several of the parameter sets given in Table I are shown in blue (arrow lines).

$m_{t'} \sim 400$ GeV ✓

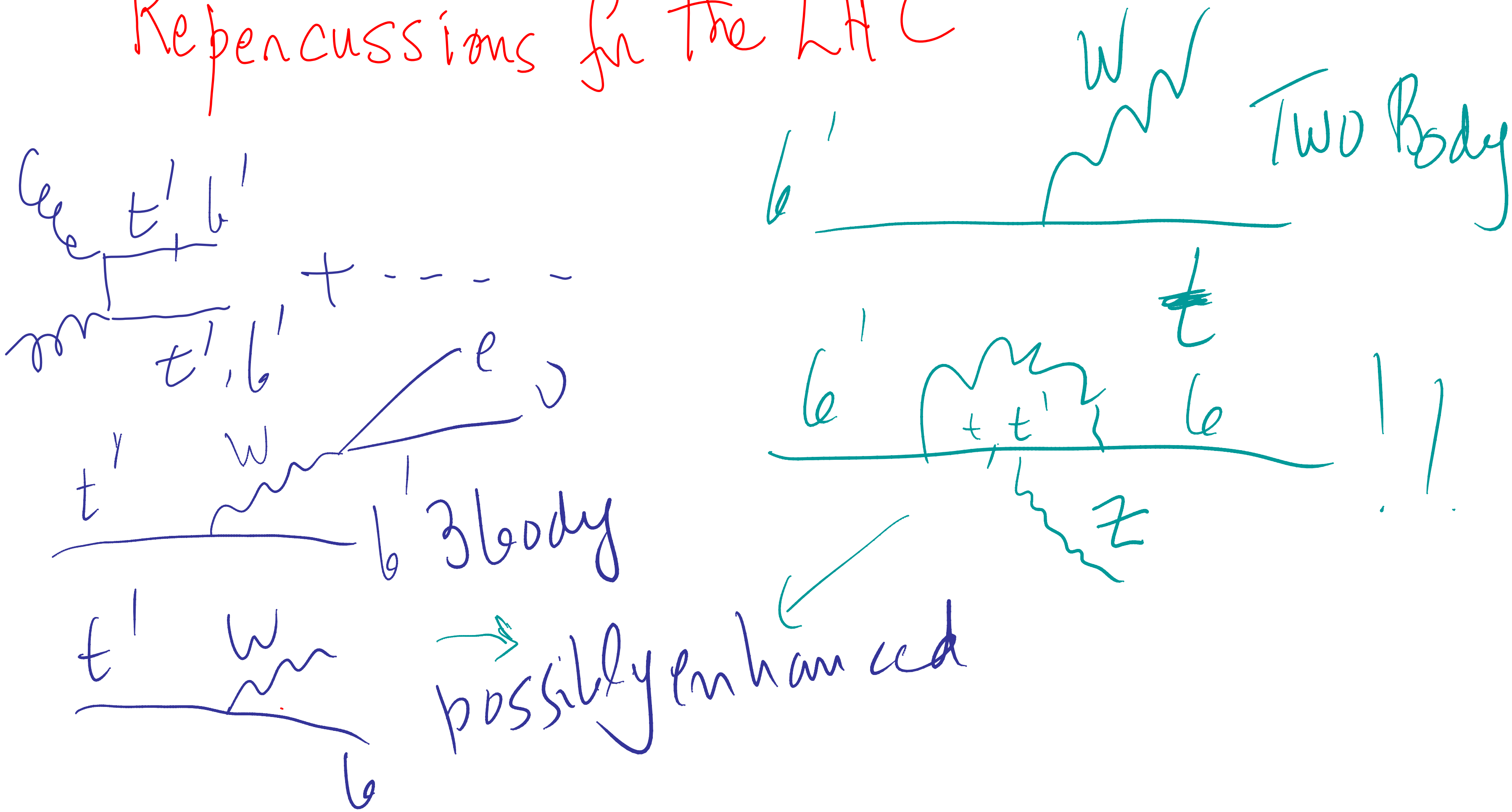
TABLE I. Examples of the total contributions to $\Delta S$ and $\Delta T$ from a fourth generation. The lepton masses are fixed to $m_{\nu_4} = 100$ GeV and $m_{\ell_4} = 155$ GeV, giving $\Delta S_{\nu\ell} = 0.00$ and $\Delta T_{\nu\ell} = 0.05$. The best fit to data is $(S, T) = (0.06, 0.11)$ [35]. The standard model is normalized to $(0, 0)$ for $m_t = 170.9$ GeV and $m_H = 115$ GeV. All points are within the 68% C.L. contour defined by the LEP EWWG [35].

| Parameter set | $m_{u_4}$ | $m_{d_4}$ | $m_H$ | $\Delta S_{\rm tot}$ | $\Delta T_{\rm tot}$ |
|---|---|---|---|---|---|
| (a) | 310 | 260 | 115 | 0.15 | 0.19 |
| (b) | 320 | 260 | 200 | 0.19 | 0.20 |
| (c) | 330 | 260 | 300 | 0.21 | 0.22 |
| (d) | 400 | 350 | 115 | 0.15 | 0.19 |
| (e) | 400 | 340 | 200 | 0.19 | 0.20 |
| (f) | 400 | 325 | 300 | 0.21 | 0.25 |

# *BORING REPETITION?*

- If the mt’ is heavy ~(400-600) GeV, then for sure it will have a very serious role to play in EWSB .(NOTE CDF+D0 now, $m_{t'}$ > 350 GeV).
- It will clearly have significant impact on CP violation phenomena, given that now 2 additional CP-odd phases
- It may play an interesting role in baryogenesis (Hou,0803.1234; Fok & Kribs, 0803.4207;c alsoAguila,Aguilar&Branco,hepph 9703410 )
- CANNOT BE A CONVENTIONAL 4$^{th}$ Gen..mv4>mZ/2
- Possibilty of DM candidate: M. Volovik, ‘03
- An important CAVEAT…such heavy mass of t’ means Yukawa couplings are somewhat large so perturbation theory calculations used in here are likely to have non-negligible corrections

# Repercussions for the LHC



# Summary & Conclusions (I)

- While for now no compelling evidence against CKM-picture, several fairly sizeable effects (~2 - ~3.5 σ) in B,Bs CP asymmetries are difficult to understand in SM3.
- Being careful,"conservative" & cautious in such instances means hunting down ferociously the underlying cause…..
- Effects sadly misinterpreted (downplayed, perhaps recklessly) rather widely in the US with detrimental implications to their own cause.

# *Summary & Conclusions (II)*

- **If the effects stand further scrutiny, SM4 with mt', mb' (400-600 GeV) provides simplest explanation of the anomalies.**
- **SM4 opens up important new avenues for baryogenesis, DMC and most likely also crucial for EWSB…thereby it may well lead to a possible resolution to the hierarchy problem.**
- **Underlying nature of the "4$^{th}$ gen." has to be significantly diff**

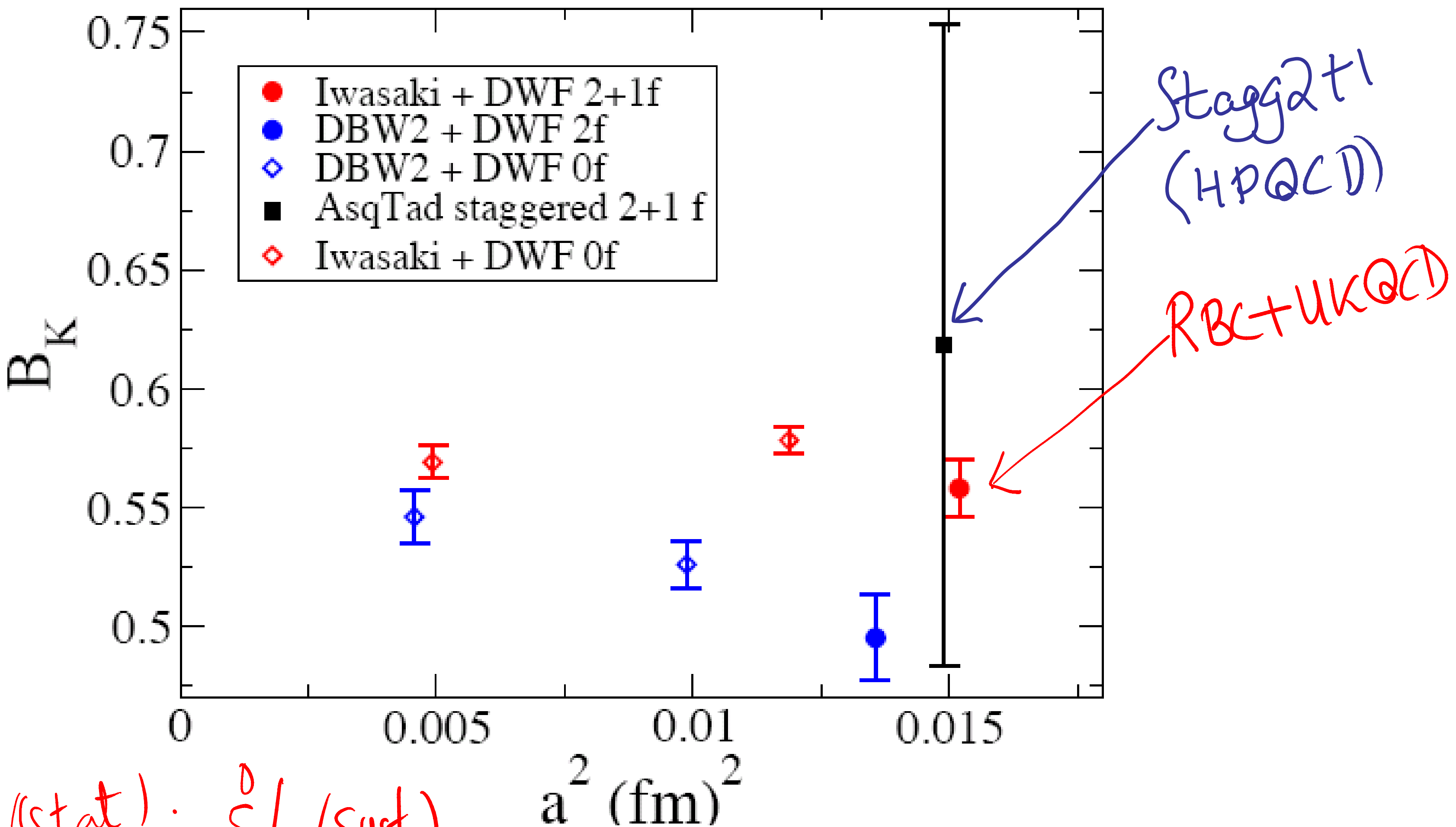
**On more general grounds BCP-anomalies means relative low scale for NEW PHYSICS with lots of accessible manifestations at LHC but also, for sure, means that SBF & (S)LHCb will have a very important role to play**

# Backup slides

# RBC-UKQCD 2+1 dynamical DWQ,hep-ph/0702042

$B_K^{\overline{\rm MS}}(2\ {\rm GeV}) = 0.524(10)(28)$

PRL Jan25,08




~2% (stat); 5% (syst)

Laurent @LAT08

| Ref. | publication | action, unit. | $N_f$ | mass extrap | $a \to 0$ | finite volume | renorm |
|---|---|---|---|---|---|---|---|
| JLQCD '08 | ⋆⋆⋆ | ⋆⋆⋆ | ⋆⋆ | ⋆⋆ | ⋆ | ⋆ | ⋆⋆ |
| ETM '08 | ⋆ | ⋆⋆ | ⋆⋆ | ⋆⋆ | ⋆⋆ | ⋆⋆ | ⋆⋆ |
| HPQCD/ UKQCD '06 | ⋆⋆⋆ | ⋆⋆ | ⋆⋆⋆ | ⋆ | ⋆ | ⋆⋆ | ⋆ |
| RBC/ UKQCD '07-08 | ⋆⋆⋆ | ⋆⋆⋆ | ⋆⋆⋆ | ⋆⋆ | ⋆ | ⋆⋆ | ⋆⋆ |

**Table 6:** *Starring of the simulations used to obtain $B_K$, according to the criteria put forth in Sec. 3.1. Th references are the same as in Table 5.*

LAT '08 PLENARY Review

*Kaon physics* Laurent Lellouch

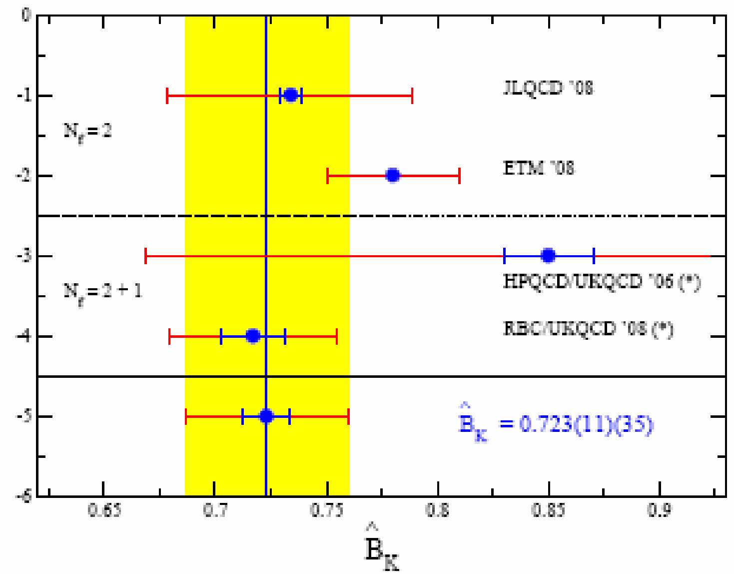



**Figure 9:** *Summary of unquenched lattice results for the renormalization group invariant $\hat{B}_K$, together with my average. The latter is obtained as described in Sec. 3.2 and in the text. The smallest error bar on each point is the statistical error and the larger one, the statistical and systematic errors combined in quadrature. The results marked with a "(*)" are those included in the average. The references are as in Table 5.*

# SU(3) breaking ratio $\xi_s$

- It was noted (Bernard, Blum & AS,heplat/9801039; c also Lellouch et al, hepph/0011086) that once $\Delta m_s$ gets measured then $\Delta m_s$ / $\Delta m_d$ from expt. along with SU(3) breaking ratio from the lattice would provide a powerful constraint on the η,ρ plar

$$\xi_s = \frac{f_{B_s}\sqrt{\hat{B}_s}}{f_{B_d}\sqrt{\hat{B}_d}}$$

- For now DWQs are quite behind this extremely important quantity and the best lattice numbers (1.20 +-0.06) come from Gamiz,Davies,Lepage, Shigemitsu and Wingate, arXiv:0710.0646; c also, Becirevic, hepph/0310072 and Tantalo, hepph/0703241

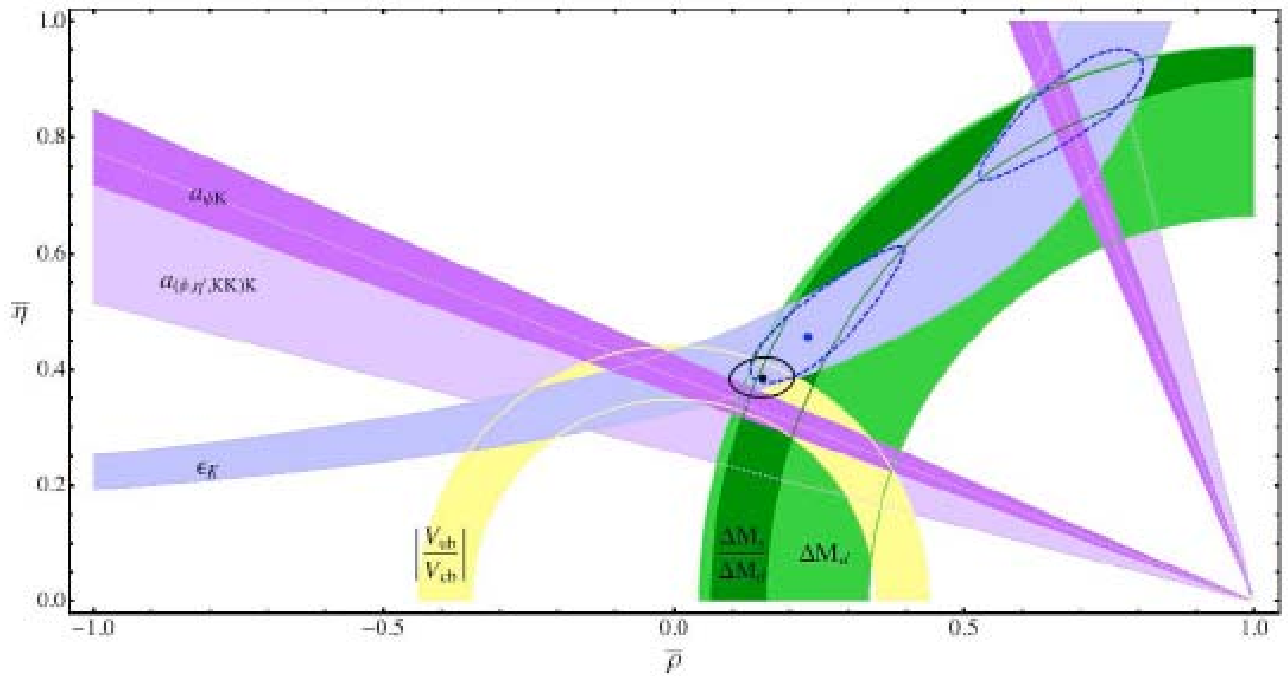



FIG. 2: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.. The solid contour is obtained using the constraints from $\varepsilon_K$, $\Delta M_{B_s}/\Delta M_{B_d}$ and $|V_{ub}/V_{cb}|$. The dashed contour shows the effect of excluding $|V_{ub}/V_{cb}|$ from the fit. The regions allowed by $a_{\psi K}$ and $a_{(\phi+\eta'+2K_s)K_s}$ are superimposed.

It is perhaps of some use to extract the values of $\hat{B}_K$, $\xi_s$ and $V_{cb}$ that are required to reduce to the 1-$\sigma$ level the discrepancy between the prediction given in Eq. (5) and $a_{(\psi+\phi+\eta'+K_S K_S)K_S} = 0.66 \pm 0.024$. We find that one has to choose either $\hat{B}_K^{\text{new}} = 0.96 \pm 0.04$, $\xi_s^{\text{new}} = 1.37 \pm 0.06$ or $V_{cb} = (44.3 \pm 0.6) \times 10^{-3}$.

[USED $\hat{B}_K = 0.72 \pm .04$; $\xi_s = 1.20 \pm .06$; $V_{cb} = (40.8 \pm .6) \times 10^{-3}$]

# DISREGARD Lattice for Vub

$$|V_{cb}| = \begin{cases} (41.67 \pm 0.68) \times 10^{-3} & \text{incl [15]} \\ (38.7 \pm 1.35) \times 10^{-3} & \text{excl [16]} \\ (41.0 \pm 0.63) \times 10^{-3} & \text{comb} \end{cases} \quad |V_{ub}| = \begin{cases} (39.6^{+2.5}_{-2.7}) \times 10^{-4} & \text{incl [15]} \\ (33.8 \pm 3.5) \times 10^{-4} & \text{excl [2]} \\ (37.4 \pm 2.1) \times 10^{-3} & \text{comb} \end{cases}$$

Used $\frac{V_{ub}}{V_{cb}} = (0.91 \pm .055) \times 10^{-1}$

using only inclusive: $(.95 \pm .067) \times 10^{-1}$

⟹ TENDS to MAKE IT WORSE!