Bs mixing & interpertation

Amarjit Soni
HET, BNL

FPCP09
Lake Placid, NY

Outline

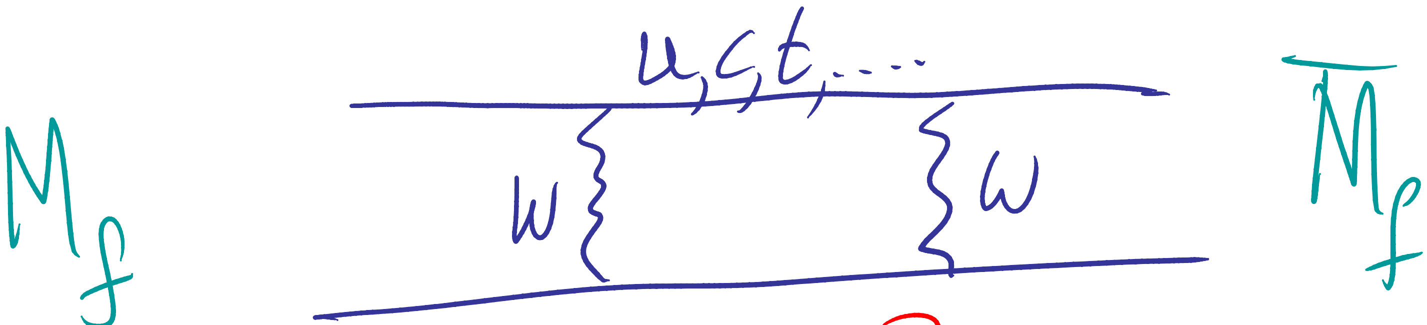
- **Introduction, Motivation, Basics**
- **Theoretical underpinnings of SM predictions**
- **Possible Hints: Bs & relation with others**
- **Sample BSM scenarios**
- **Summary & Outlook**

ΔFlavor=2 processes extremely powerful test

- 2^{nd} order –> severe suppresion-> FLAVOR PUZZLE ->extraordinary opportunity to further our understanding of basic physics at short distances & test alignment->FLAVOR PROBLEM for many if not most BSMs
- Kaon Mixing -> GIM, CHARM, CPV
- Bd Mixing -> Large m_t, O(1) CP asy, precision test of UT & CKM paradigm,

  possible anomalies…..
- Bs MIXING STUDIES EXPECTED TO BE EXTREMELY RICH -> POSSIBILTY OF NEW DISCOVERIES IS A SUPERB BET!

A UNIQUE GIFT: EVASION of the decoupling theorem



MIXING Amp $\propto$ $m^2_{\text{virtual fermion}}$

HIGHLY counter intuitive!

Importance of being Bs: NULL TESTS GALORE!

- **Because of limitations of theory viability**

of CP-conserving observables is limited

- **Much more precious are CP violating observables:**
- **CKM predicts: ~0 phase in b->s (penguin)**

~.004

- **(related) ~0 phase in Bs box-> zilch time-dependent/mixing-induced CP Asyms** ~.02
- **Semi-leptonic asy ..TINY** $\sim 10^{-5}$

Bs mixing preliminaries

- Time evolution:

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle\\|\bar{B}_s^0(t)\rangle\end{pmatrix}=\left(M-\frac{i}{2}\Gamma\right)\begin{pmatrix}|B_s^0(t)\rangle\\|\bar{B}_s^0(t)\rangle\end{pmatrix}$$

MASS Eigenstates $B_L^s(m_L^s)$, $B_H^s(m_H^s)$

OBSERVABLES

Mean mass $m_s = (m_L^s + m_H^s)/2$

" lifetime $\tau_s = \frac{1}{\Gamma_s} = 2/(\Gamma_H^s + \Gamma_L^s)$

CPV phase $\phi_s \equiv \arg(-M_{12}/\Gamma_{12})$

I. $\Delta m_s = 2|M_{12}|$; II. $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\phi_s$

III $a_{fs}^s = \mathrm{Im}(\Gamma_{12}/M_{12}) = (\Delta\Gamma_s/\Delta m_s)\tan\phi_s$

$$\Delta M_{B_q} = 2\left|M_{12}^q\right| = \frac{\left|\langle \bar{B}_q^0|\mathcal{H}_{\text{eff}}|B_q^0\rangle\right|}{m_{B_q}} = \frac{G_F^2}{12\pi^2} m_W^2 m_{B_q} f_{B_q}^2 \hat{B}_{B_q} \eta_B S_0(x_t) \left|V_{tb}V_{tq}^*\right|^2$$

CDF+DØ ... WA

$\Delta m_s = 17.78 \pm .12/ps$

O(.7%)

$\langle B_s | [\bar{b}\gamma_\mu(1-\gamma_5)s]^2 | \bar{B}_s\rangle$

$\sim O(30\%)$

THEORY CONSISTENT BUT LAGS SIGNIFICANTLY

$$\frac{\Delta M_{B_s}}{\Delta M_{B_d}} = \xi^2 \frac{m_{B_s}}{m_{B_d}} \left|\frac{V_{ts}}{V_{td}}\right|^2$$

ξ → Non perturbative SU(3) breaking ratio

$\sim 1.21 \pm .05$

$\Rightarrow \left|\frac{V_{td}}{V_{ts}}\right| = .206 \pm .001 {}^{+.008}_{-.007}$

$\Rightarrow$ PROVIDES STRINGEST TEST OF UT & CKM (c later)

MORE PROGRESS underway; RUTH VDW

Width Diff

Buchalla,Beneke, Lenz, & Nierste '98

$$\Gamma_{21} = \frac{1}{2M_{B_s}} \langle \bar{B}_s | \mathcal{T} | B_s \rangle$$

$$\mathcal{T} = \mathrm{Im}\, i \int d^4x \; T\, \mathcal{H}_{eff}(x) \mathcal{H}_{eff}(0)$$

$$\left(\frac{\Delta\Gamma}{\Gamma}\right)_{B_s} = \left(\frac{f_{B_s}}{210\ \mathrm{MeV}}\right)^2 \left[0.006\, B(m_b) + 0.150\, B_S(m_b) - 0.063\right]$$

$(\bar{b}\gamma_\mu(1-\gamma_5)s)^2$

$[\bar{b}(1+\gamma_5)s]^2$

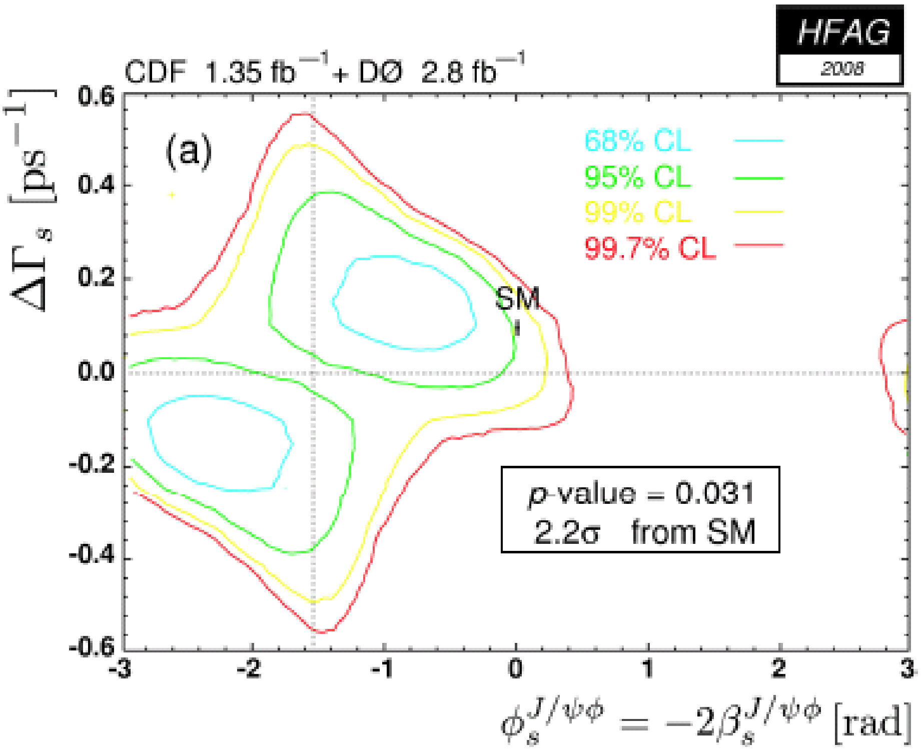
Lenz&Nierste'07

$\bar{b}_\alpha(1+\gamma_5)s_\beta\, \bar{b}_\beta(1+\gamma_5)s_\alpha$

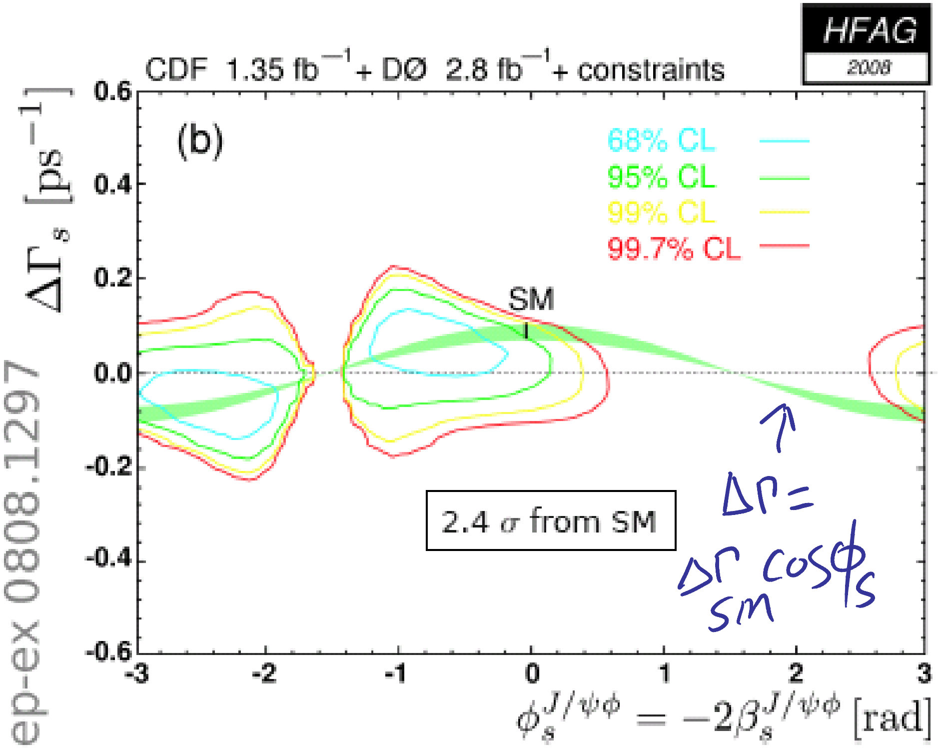
$$\Delta\Gamma_s^{SM} = \left(\frac{f_{B_s}}{240\,\mathrm{MeV}}\right)^2 \Big[(0.105 \pm 0.016)B + (0.024 \pm 0.004)\tilde{B}_S' \text{ - - - -}$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} \simeq 0.15 \pm .07$$

Combination



hep-ex 0808.1297



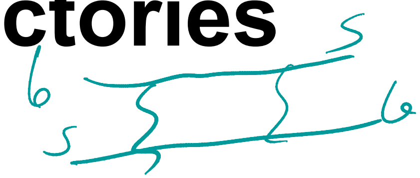
- Old CDF result
- No constraint on strong phases

- Constraints on B_s lifetime and a^s_{SL}

→ Hint for new physics?

Summary of B-CP Anomalies

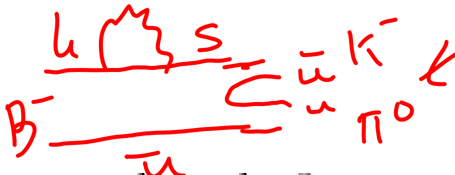
- **CDF+D0 HINTS of New Physics in $B_s \to \psi\phi$ esp. intriguing as nicely fits with indications from B-Factories**



- **Dir CP in $K^+\pi^-$ vs $K^+\pi^0$**
- **Fitted ("SM-predicted") value of sin 2β vs directly measured a) via tree decays**
- LUNGHI + AS 108 **b) via loop decays**

EACH ~2 to ~3.5σ

ΔACP(Kπ) (Lunghi +AS,'07)



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

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

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

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

$(3^{+1}_{-3})\%$ CCS '04

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

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

$\gtrsim 3.5\sigma$

BENEKE+NEUBERT 0308039 based on BBNS

yields a 3.5σ effect.

For an alternate explanation See Gronau & Rosner(PLB,'07)

Lunghi+AS,arXiv.0707.0212
(Sin 2 β = 0.78+-.04)

Directly measured via (gold-plated) B->ψ K_S , sin 2β = 0.68+-.026

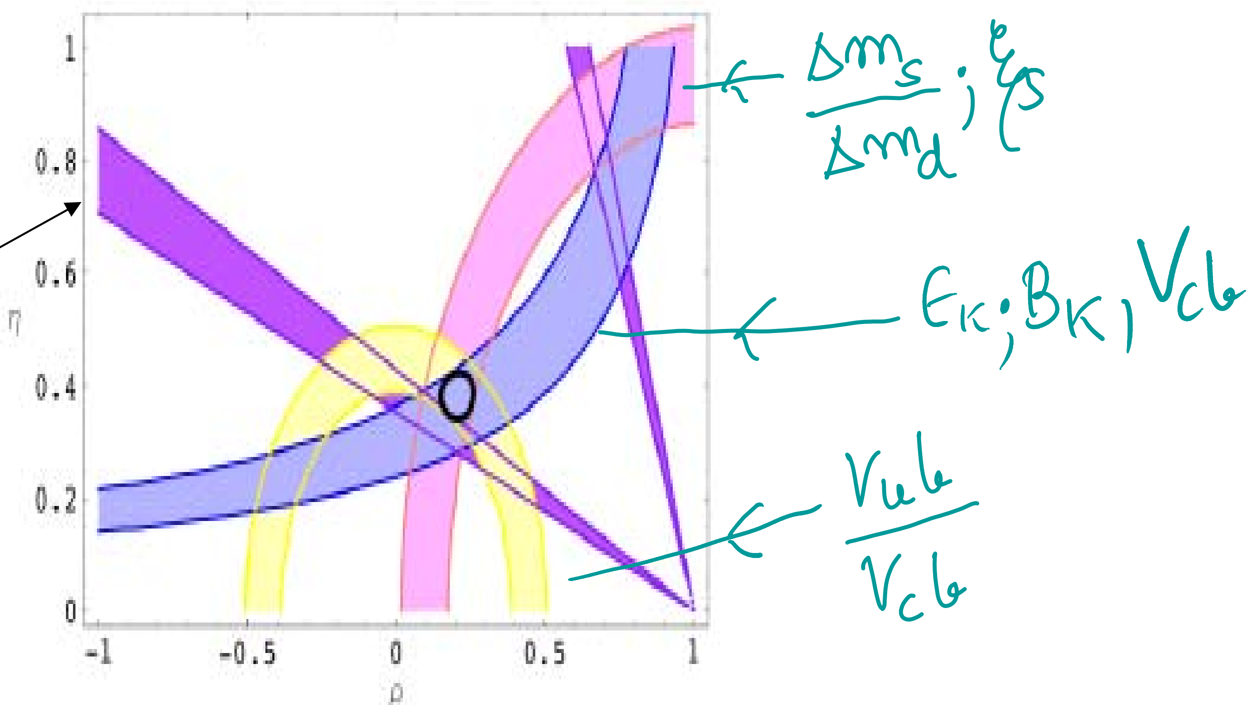


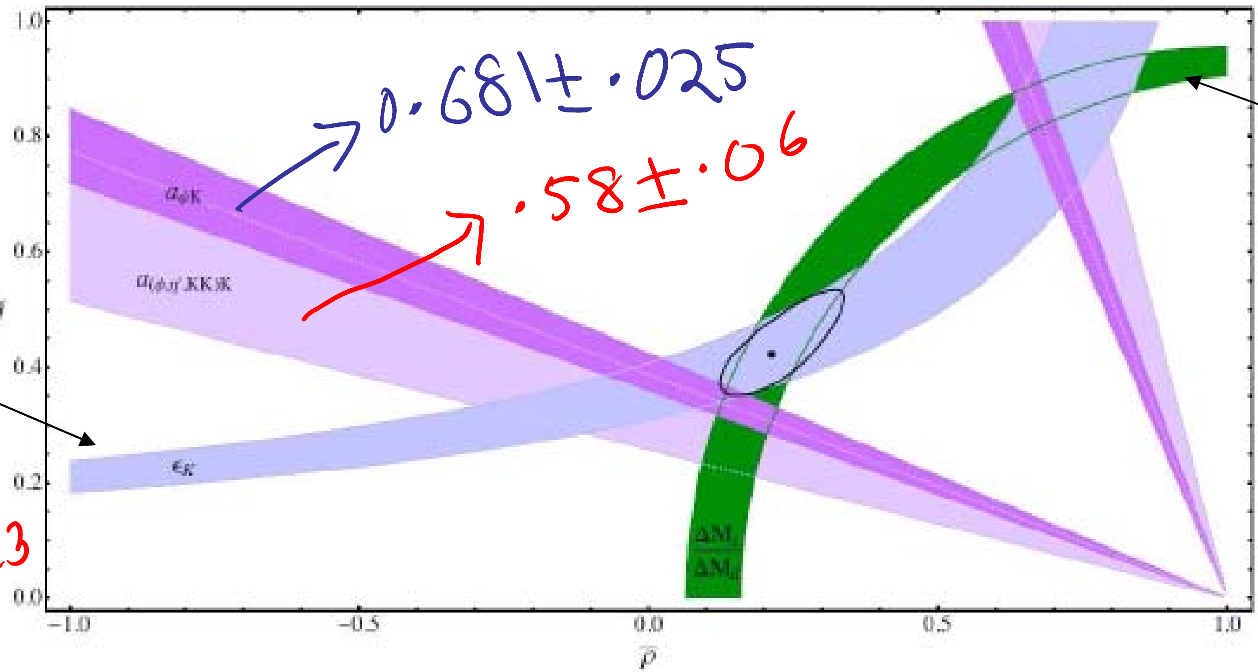
Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

Important to Examine only DeltaF=2 observables: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



Gamiz et al; Becirevic; Tantalo

.

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

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

$\xi = 1.20 \pm .06$

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 ε_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 requires careful follow-up

Anomalies in $B(B_s)$-CP asymmetries

MORE RECENTLY

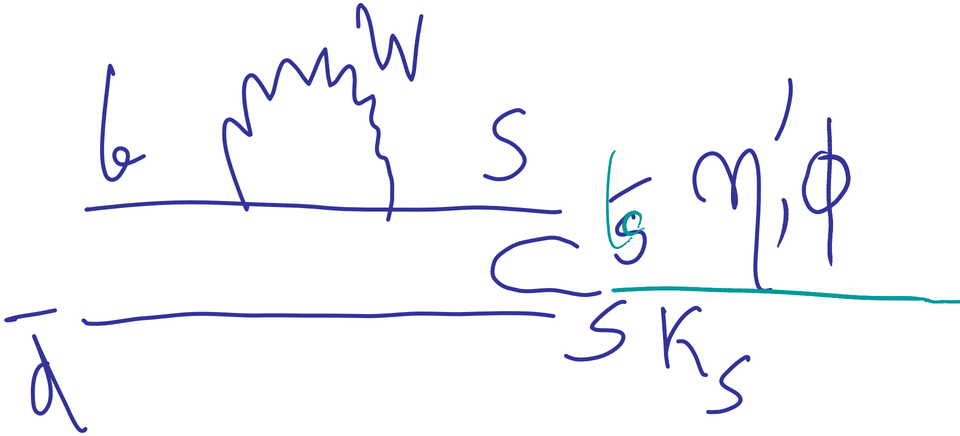
- Increased accuracy in B_K from the lattice(+ important correction from Buras & Guadagnoli), along

  with ξ_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}

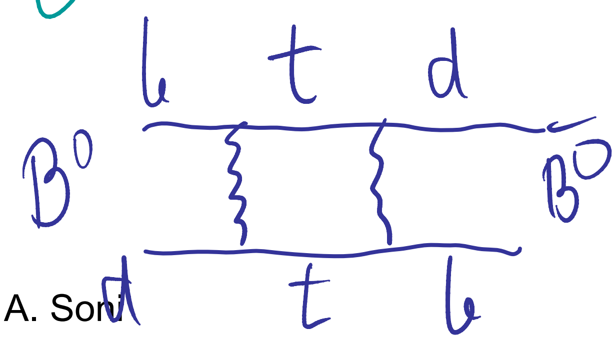
$$\Delta S \equiv S_{penguin} - S_{\psi K_S} = O(\lambda^2)$$

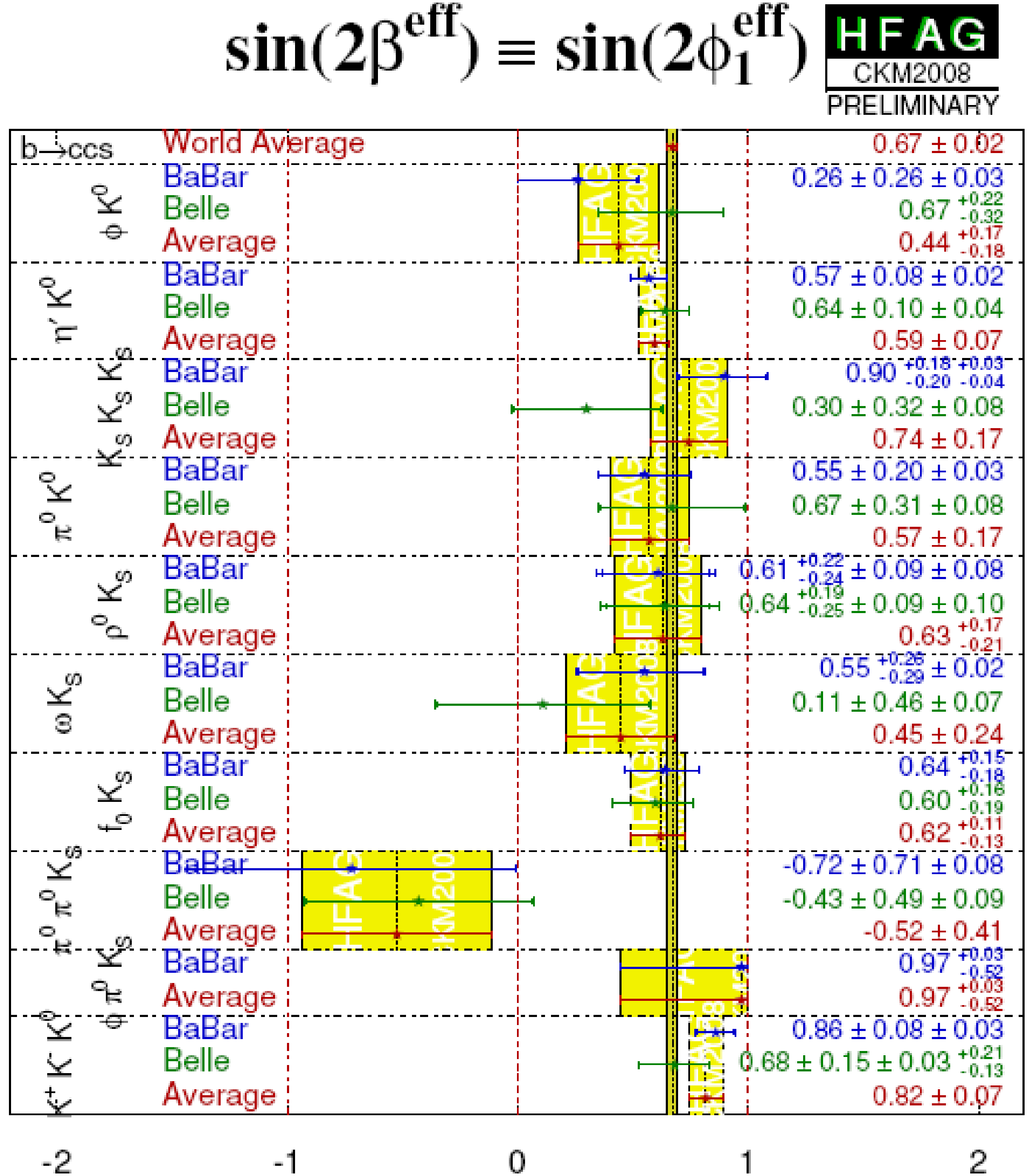


$S^{Decay}_{peng} \simeq O(\lambda^2) \sim$ few %

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

OSC is common





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

Cheng, Chua, AS '05 PRD

M. Beneke PLB '05

Buchalla, Hiller, Nir + RAZ JHEP '05

Williamson + Zupan PRD '06

TABLE I: Some expectations for ΔS 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 ± 0.01	0.01 ± 0.02	-0.019 ± 0.009 -0.010 ± 0.001
ϕK^0	$0.03^{+0.01}_{-0.04}$	0.02 ± 0.01	0.02 ± 0.01	
$K_S K_S K^0$	$0.02^{+0.00}_{-0.04}$			

CLEANEST MODES

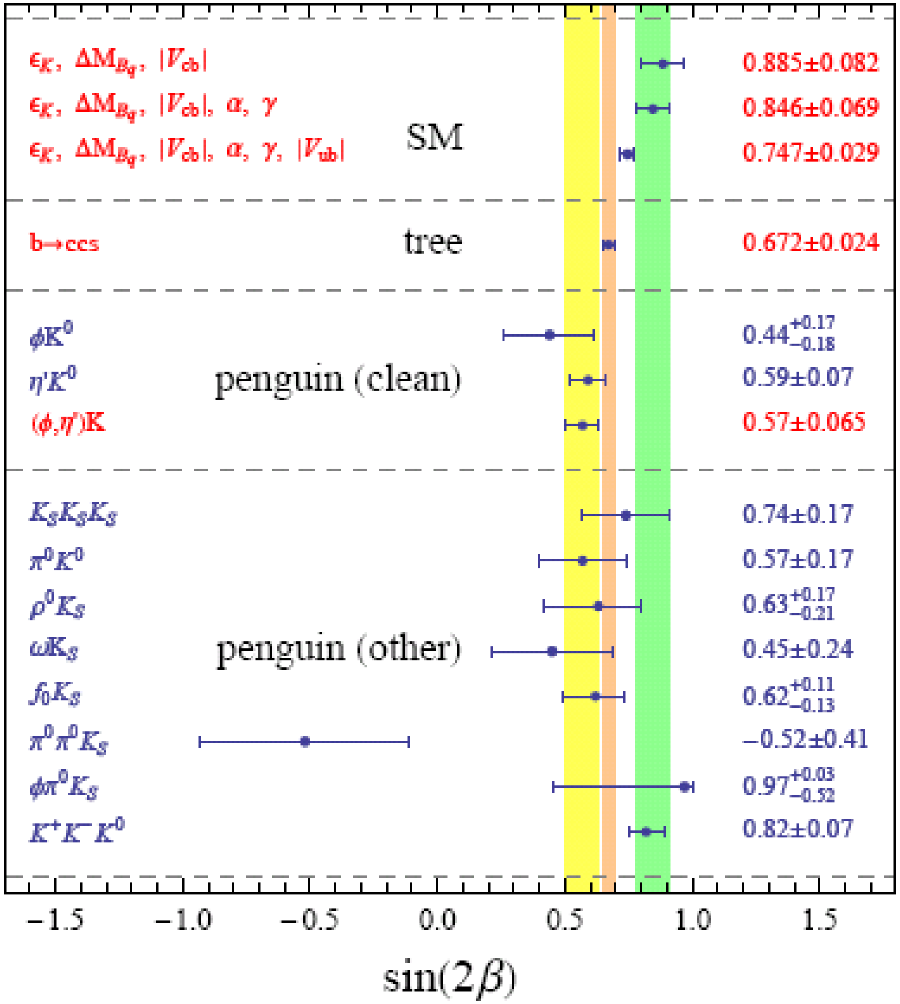
Courtesy: Tom Browder

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

Lunghi + AS, arXiv:0903.5059



mode	w/out V_{ub}	with V_{ub}
$S_{\psi K_S}$	$2.4\ \sigma$	$2.0\ \sigma$
$S_{\phi K_S}$	$2.2\ \sigma$	$1.8\ \sigma$
$S_{\eta' K_S}$	$2.6\ \sigma$	$2.1\ \sigma$
$S_{(\phi+\eta')K_S}$	$2.9\ \sigma$	$2.5\ \sigma$

YET ANOTHER!

Adapted from Browder

A lesson from history (I)

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

1964: BF= 2×10^{-3}

A failure of imagination ? Lack of patience ?

Model independent determination of scale of new physics with a non-standard CP phase needed to fix B-CP anomalies {Lunghi + AS '09}

Scenario	Operator	Λ (TeV)	φ (°)
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	$O_1^{(K)}$ $O_4^{(K)}$ LR	< 1.9 < 24	$130 \div 320$
$\mathcal{A}_{b\to s}$	$O_4^{b\to s}$ $O_{3Q}^{b\to s}$	$.25 \div .43$ $.09 \div .2$	$0 \div 70$ $0 \div 30$

GREAT NEWS for LHC & for SBF!

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"

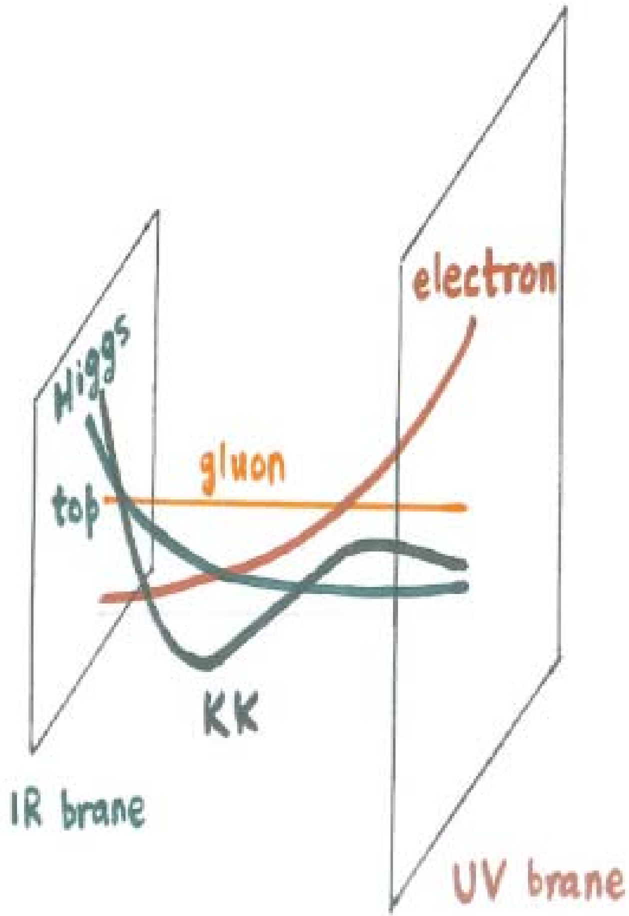
Many other possiblities

- **Susy[1]…**
- **Extra Higgs, Extra Z,…**
- **Extra gen….**
- **In past few years have studied few possibilities: WEXD,T2HDM & 4th gen**
- ***What's the simplest solution that "can do the job"***

[1] "Can do everything except make coffee" — [illegible] Physics Book

SM in bulk

(Davoudiasl, Hewett, Rizzo; Pomarol; Grossman, Neubert; Chang, Hisano, Nakano, Okada,Yamaguchi; Gherghetta, Pomarol)

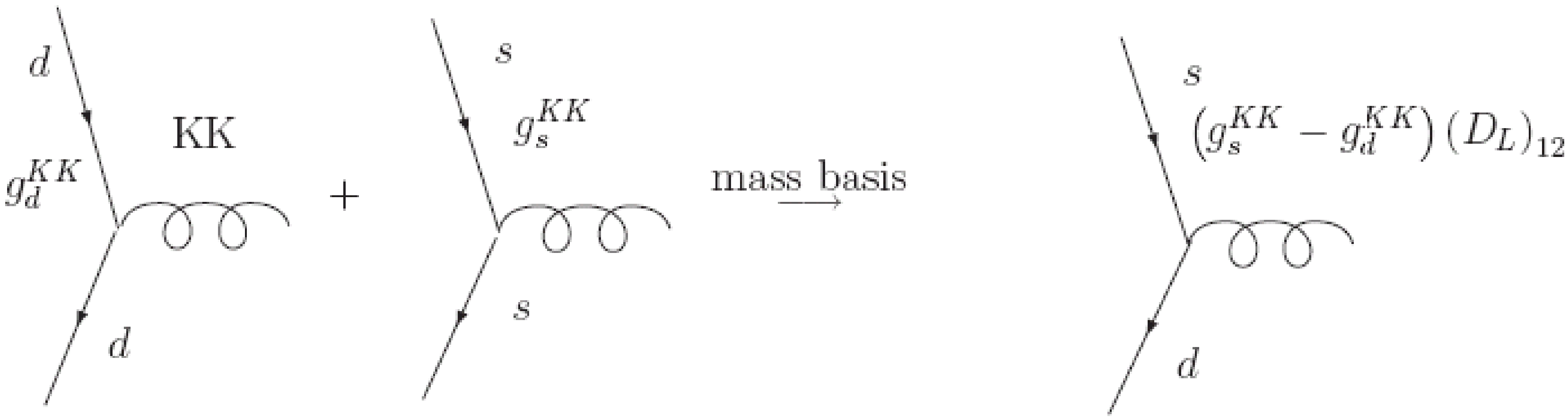


Agashe@Pheno09

Flavor hierarchy from profiles → flavor violation from KK's

- Non-universal, but diagonal coupling to gauge KK's in gauge/weak basis...

$$\left(\bar{d}_{L\,\text{weak}}\ \bar{s}_{L\,\text{weak}}\right)\begin{pmatrix} g_d^{KK} & 0 \\ 0 & g_s^{KK}\end{pmatrix}\gamma^\mu A_\mu^{(n)}\begin{pmatrix} d_{L\ \text{weak}} \\ s_{L\ \text{weak}}\end{pmatrix}$$



- off-diagonal in mass basis (in general):

$$\ldots D_L^\dagger\, \text{diag}\left(g_d^{KK}, g_s^{KK}\right) D_L \ldots \rightarrow \left(g_s^{KK}-g_d^{KK}\right)(D_L)_{12}\times$$
$$\bar{d}_{L\,\text{mass}}\gamma^\mu A_\mu^{(n)} s_{L\ \text{mass}}$$

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 & n edm]

	Δm_{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	$\Delta m_{B_s}^{SM}$	λ_c^2	$\sin 2\beta$	Br^{SM}	$\frac{m_s}{m_b}\left(\sin 2\beta, \lambda_c^2\right)$	$\frac{m_d}{m_b}\left(\lambda_c^2, \sin 2\beta\right)$

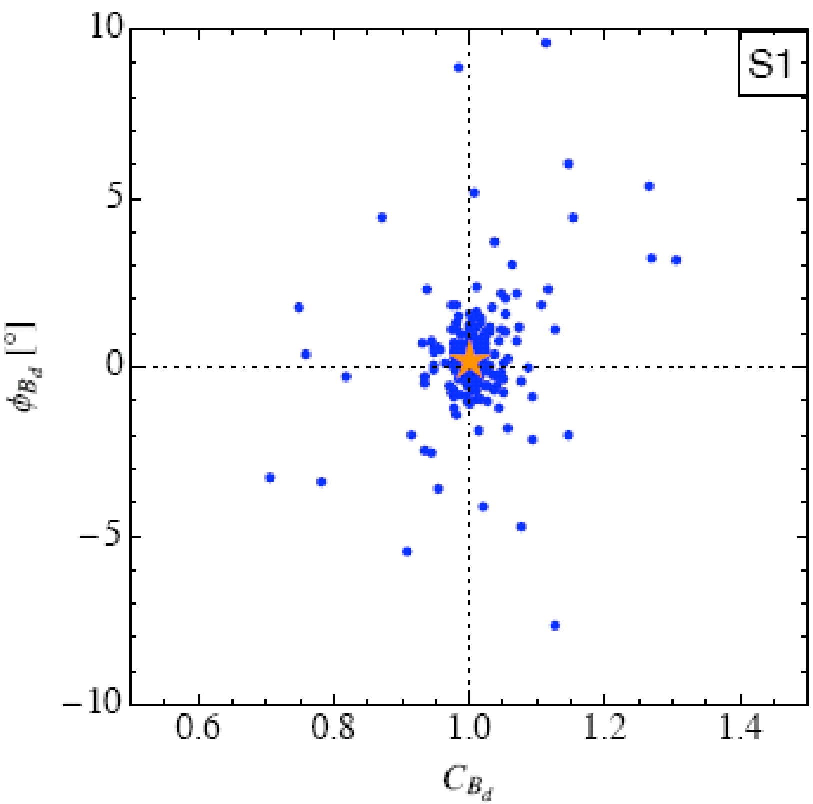
$m_{KK} \gtrsim 3$ TeV

Recently many very nice extensions (Buras,Falkowski, Perez,Weiler,Neubert)et al

Meson mixing: Neutral B_d mesons*

HAISCH
@ BF'08

- Even after imposing $|\varepsilon_K|$ constraint, sizable effects in magnitude and phase of B_d meson mixing amplitude possible



$$C_{B_d}\, e^{2i\phi_{B_d}} = \frac{\langle B_d | \mathcal{H}_{\rm eff,full}^{\Delta B=2} | \bar{B}_d \rangle}{\langle B_d | \mathcal{H}_{\rm eff,SM}^{\Delta B=2} | \bar{B}_d \rangle}$$

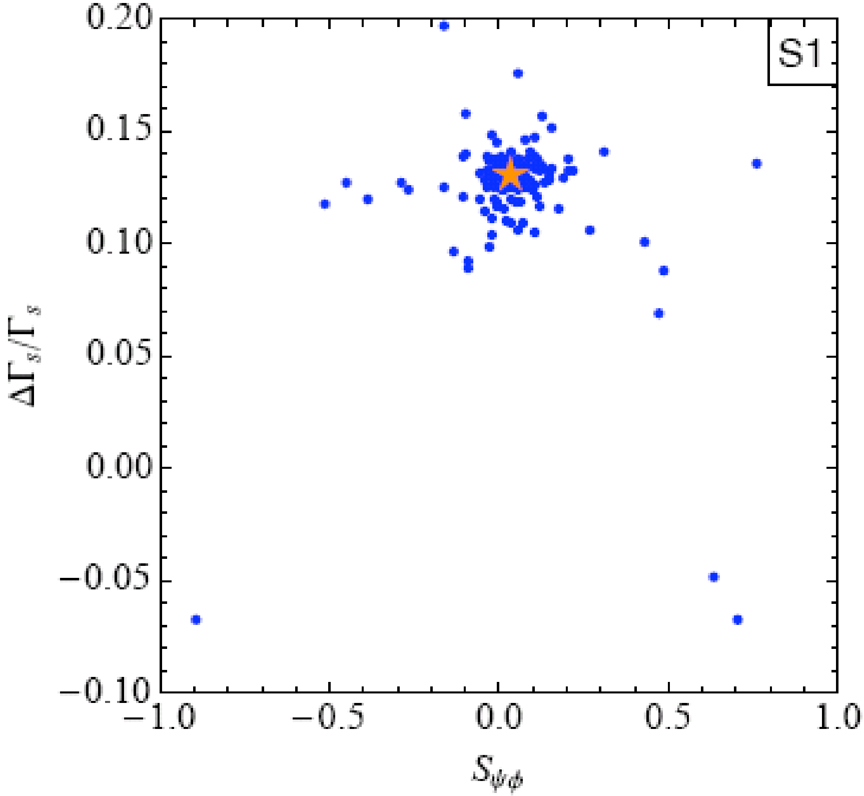
★ SM: $C_{B_d} = 1$, $\phi_{B_d} = 0^\circ$

● consistent with quark masses, CKM parameters, and 95% CL limit $|\varepsilon_K| \in [1.3, 3.3] \cdot 10^{-3}$

Meson mixing: Neutral B_s mesons*

Neubert@EWMoriond09

- Constraint from $|\varepsilon_K|$ does not exclude O(1) effects in width difference $\Delta\Gamma_s/\Gamma_s$ of B_s system



$$\Delta\Gamma_s = \Gamma_L^s - \Gamma_S^s$$
$$= 2\,|\Gamma_{12}^s|\cos(2|\beta_s| - 2\phi_{B_s})$$

★ SM: $\Delta\Gamma_s/\Gamma_s \approx 0.13$, $S_{\psi\phi} \approx 0.04$

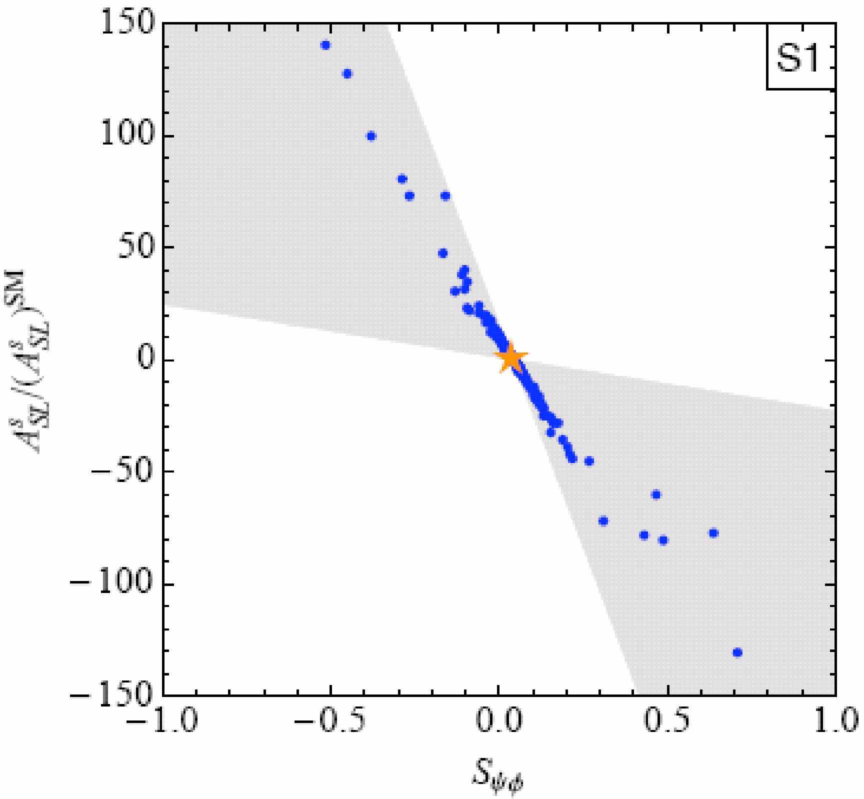
● consistent with quark masses, CKM parameters, and 95% CL limit $|\varepsilon_K| \in [1.3, 3.3] \cdot 10^{-3}$

*Blanke *et al.*, arXiv:0809.1073; Bauer *et al.*, paper in preparation

Meson mixing: Neutral B_s mesons*

Neubert@EWMORIOND09

- In RS model significant corrections to semileptonic CP asymmetry A^s_{SL} and $S_{\psi\phi} = \sin(2|\beta_s| - 2\phi_{B_s})$, consistent with $|\varepsilon_K|$, can arise



$$A^s_{SL} = \frac{\Gamma(\bar{B}_s \to l^+X) - \Gamma(B_s \to l^-X)}{\Gamma(\bar{B}_s \to l^+X) + \Gamma(B_s \to l^-X)}$$

$$= \mathrm{Im}\left(\frac{\Gamma^s_{12}}{M^s_{12}}\right)$$

★ SM: $A^s_{SL} \approx 2 \cdot 10^{-5}$, $S_{\psi\varphi} \approx 0.04$

model-independent prediction

● consistent with quark masses, CKM parameters, and 95% CL limit $|\varepsilon_K| \in [1.3, 3.3] \cdot 10^{-3}$

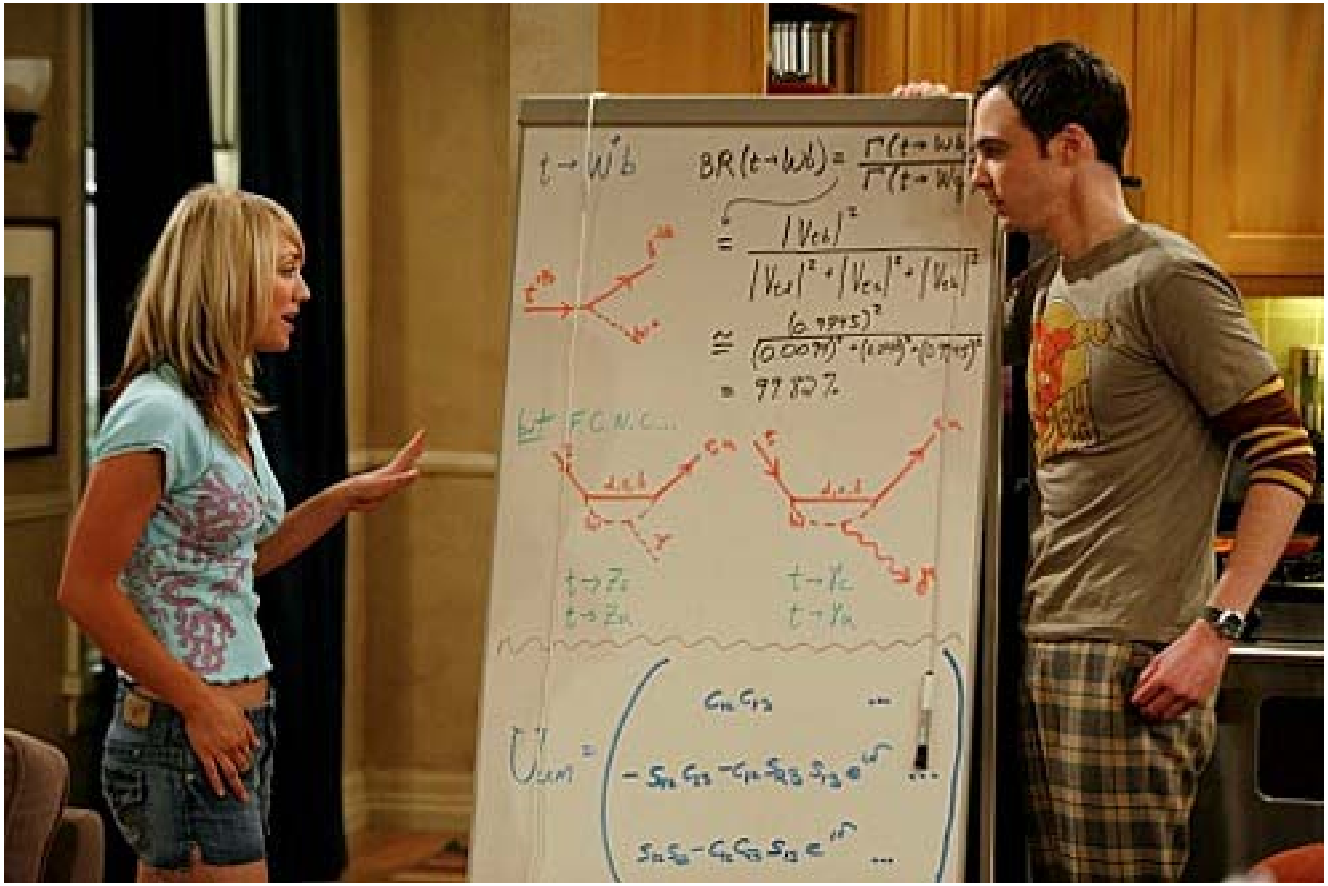
*Blanke *et al.*, arXiv:0809.1073; Bauer *et al.*, paper in preparation

TWO important subtleties:

I. The flavor puzzle

LHC/Super B factory synergy discussion on US TV comedy

D. Saltzberg, Science Advisor



CBS, “Big Bang Theory” averages 9 million viewers per episode.

Courtesy Tom Browder

.

II. EXTREMELY INTERESTING SUBTELTY of warped models

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

Focus for now on the SIMPLEST 4d Explanation(s): I T2HDM '07 II SM4 → Now

Thus by process of elimination one arrives at

More explicitly How does 4th family fit in?

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

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. NP seems to depend on b->d versus b->s (s->d is also a possibilty)

->This is suggestive of a "4th family"…PERHAPS THE SIMPLEST SOLUTION

-> 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…

-> 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 also made by Hou et al JHEP'06;PRL'05;PRL'07…. though their discussions seem 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

$B_K = 0.72 \pm 0.05$

$f_{bs}\sqrt{B_{bs}} = 0.281 \pm 0.021 \text{ GeV}$

$\Delta M_s = (17.77 \pm 0.12) ps^{-1}$

$\Delta M_d = (0.507 \pm 0.005) ps^{-1}$

$\xi_s = 1.2 \pm 0.06$

$\gamma = (75.0 \pm 22.0)^\circ$

$|\epsilon_k| \times 10^3 = 2.32 \pm 0.007$

$\sin 2\beta_{\psi K_s} = 0.672 \pm 0.024$

$\mathcal{BR}(K^+ \to \pi^+ \nu\nu) = (0.147^{+0.130}_{-0.089}) \times 10^{-9}$

$\mathcal{BR}(B \to X_c \ell\nu) = (10.61 \pm 0.17) \times 10^{-2}$

$\mathcal{BR}(B \to X_s \gamma) = (3.55 \pm 0.25) \times 10^{-4}$

$\mathcal{BR}(B \to X_s \ell^+ \ell^-) = (0.44 \pm 0.12) \times 10^{-6}$

(High q^2 region)

$R_{bb} = 0.216 \pm 0.001$

$|V_{ub}| = (37.2 \pm 2.7) \times 10^{-4}$

$|V_{cb}| = (40.8 \pm 0.6) \times 10^{-3}$

$\eta_c = 1.51 \pm 0.24$ [21]

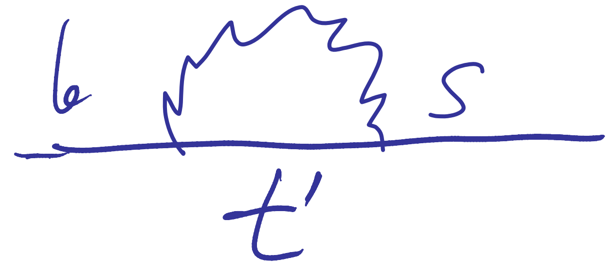
$\eta_t = 0.5765 \pm 0.0065$ [22]

$\eta_{ct} = 0.47 \pm 0.04$ [23]

$m_t = 172.5 \text{ GeV}$

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

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



$m_{t'}$	400	500	600	700
$\lambda^s_{t'}$	(0.08 - 1.4)	(0.06 - 0.9)	(0.05 - 0.7)	(0.04 - 0.55)
ϕ'_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 ϕ'_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 ϕK_s, $\eta' K_s$ ...

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

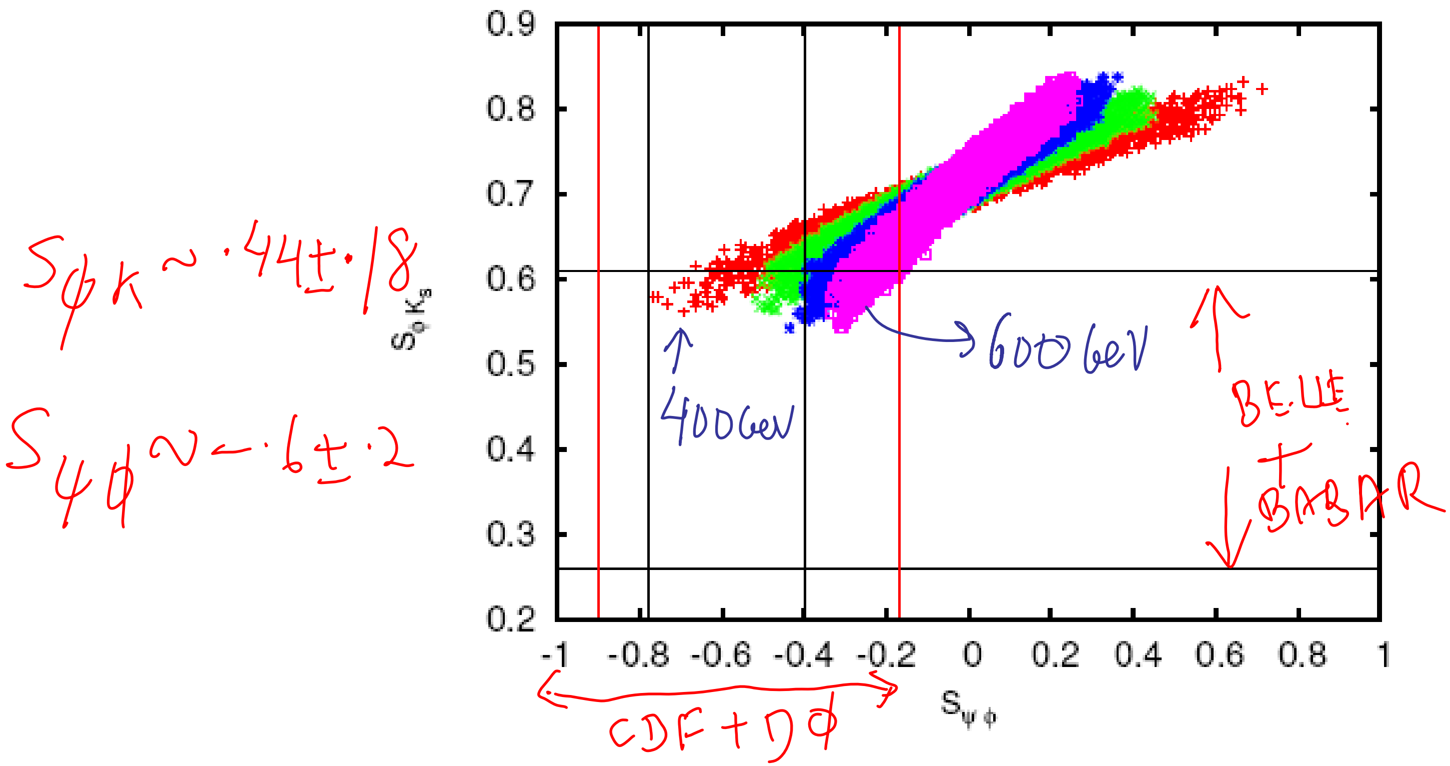


FIG. 3: Correlation between $S_{\phi K_s}$ and $S_{\psi\phi}$ for $m_{t'} = 400$ (red), 600 (green), 800 (magenta) and 1000 (blue) GeV respectively. The horizontal lines represent the experimental 1σ range for $S_{\phi K_s}$ whereas the vertical lines (Black 1-σ and red 2-σ) represent that for $S_{\psi\phi}$.

CURRENT DATA MILDLY FAVORS $m_{t'} \sim 4\text{–}500$

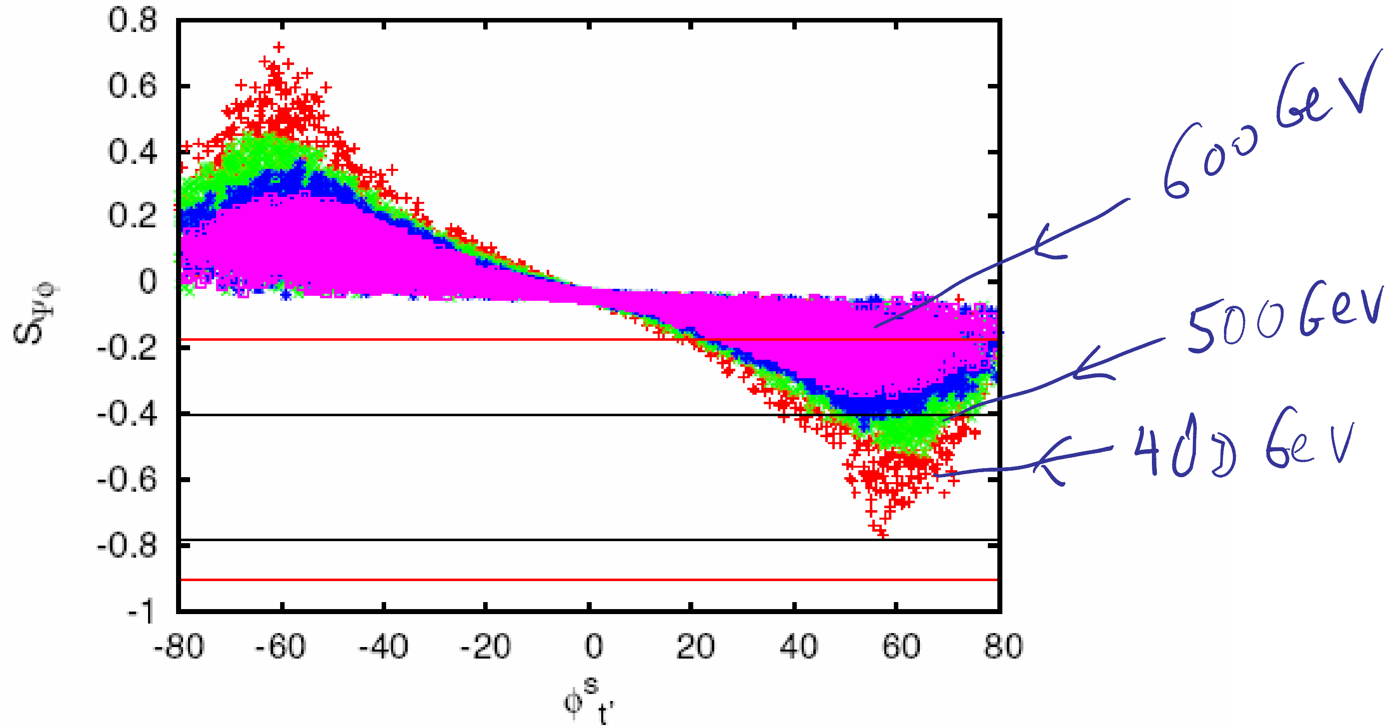
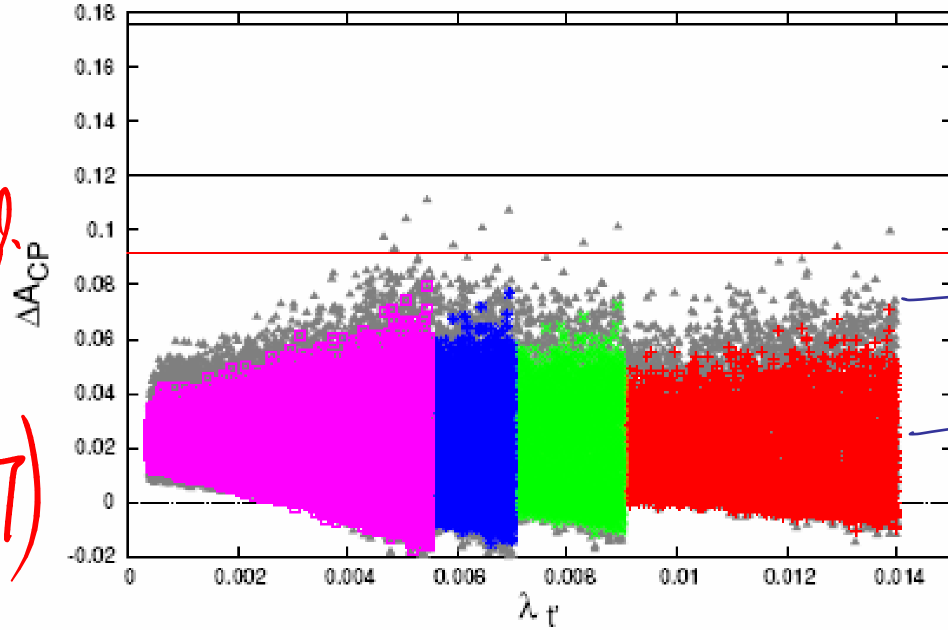


FIG. 2: The allowed range for $S_{\psi\phi}$ in the $(S_{\psi\phi} - \phi^s_{t'})$ plane for $m_{t'} = 400$ (red), 500 (green), 600 (magenta) and 700 (blue) GeV respectively. Black and red horizontal lines in the figure indicate 1-σ and 2-σ experimental ranges for $S_{\psi\phi}$ respectively.

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 (ΔA_{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-σ range respectively.

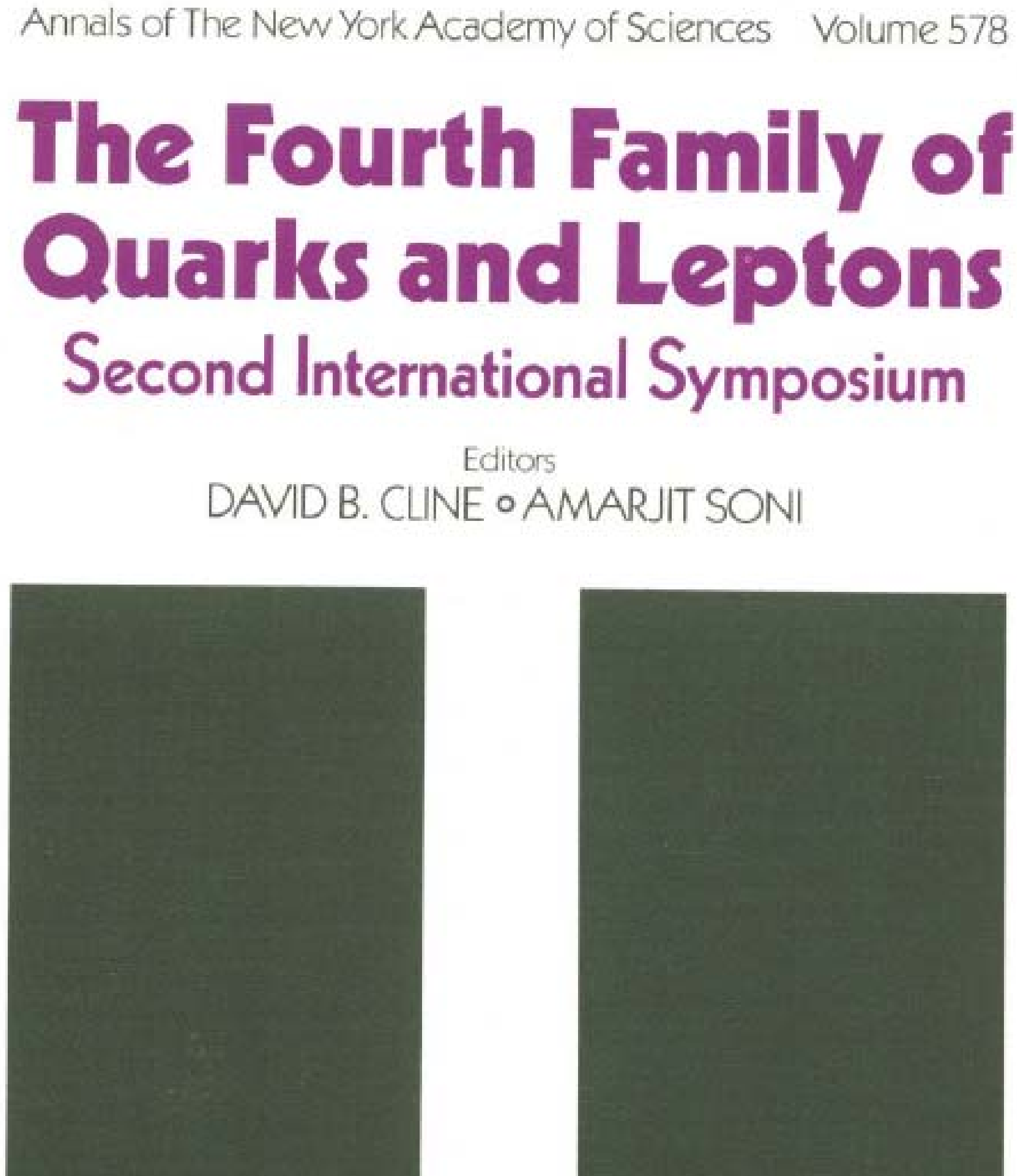
Possible relevance of SM4: This is a revisit

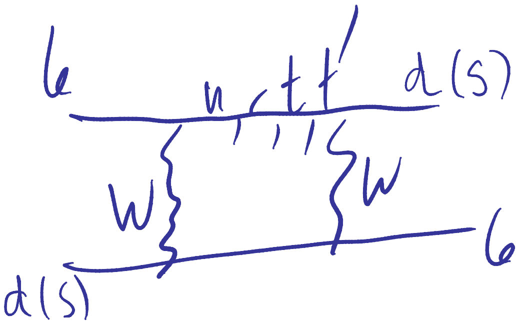
Early (~87-88) studies on 4^{th} gen.

- **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 4^{th} gen. due to non-decoup
emphasized long ago


Annals of The New York Academy of Sciences Volume 578
The Fourth Family of Quarks and Leptons
Second International Symposium
Editors
DAVID B. CLINE ◦ AMARJIT SONI



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 ΔA_{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

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 latest bound $m_{t'}$ > 350 GeV).
- It will clearly have significant impact on CP violation phenomena, given that now we will 2 additional CP-odd phases
- It may play an interesting role in baryogenesis (W.-S. Hou, 0803.1234; Fok & Kribs, 0803.4207)
- CANNOT BE A CONVENTIONAL 4th Gen..mv4>mZ/2
- Possible DMC (if no mixing with lighter 3 nu's)..see e.g. Volovik
- 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

SUMMARY & OUTLOOK

- **Bs mixing is an EXTREMELY VALUABLE TREASURE…most likely will enrichen our understanding significantly.**
- **SEVERAL ANOMALIES involving Bs,Bd mixings & decays should be scrutinized with the highest priority…Underlying cause may well be NP in a sub-TeV range…``4th Gen" seems to offer a simple solution**
- **These indications imply lots of accessible manifestations at LHC but also, for sure, means that LHC(b), SBF & (S)LHCb will have a very important role to play**

Backup slides

It is perhaps of some use to extract the values of $\hat{B}_K$, ξ_s and V_{cb} that are required to reduce to the 1-σ 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 $\hat{B}_K^{\rm new} = 0.96 \pm 0.04$, $\xi_s^{\rm new} = 1.37 \pm 0.06$ or $V_{cb} = (44.3 \pm 0.6) \times 10^{-3}$.

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

Continuing saga of Vub

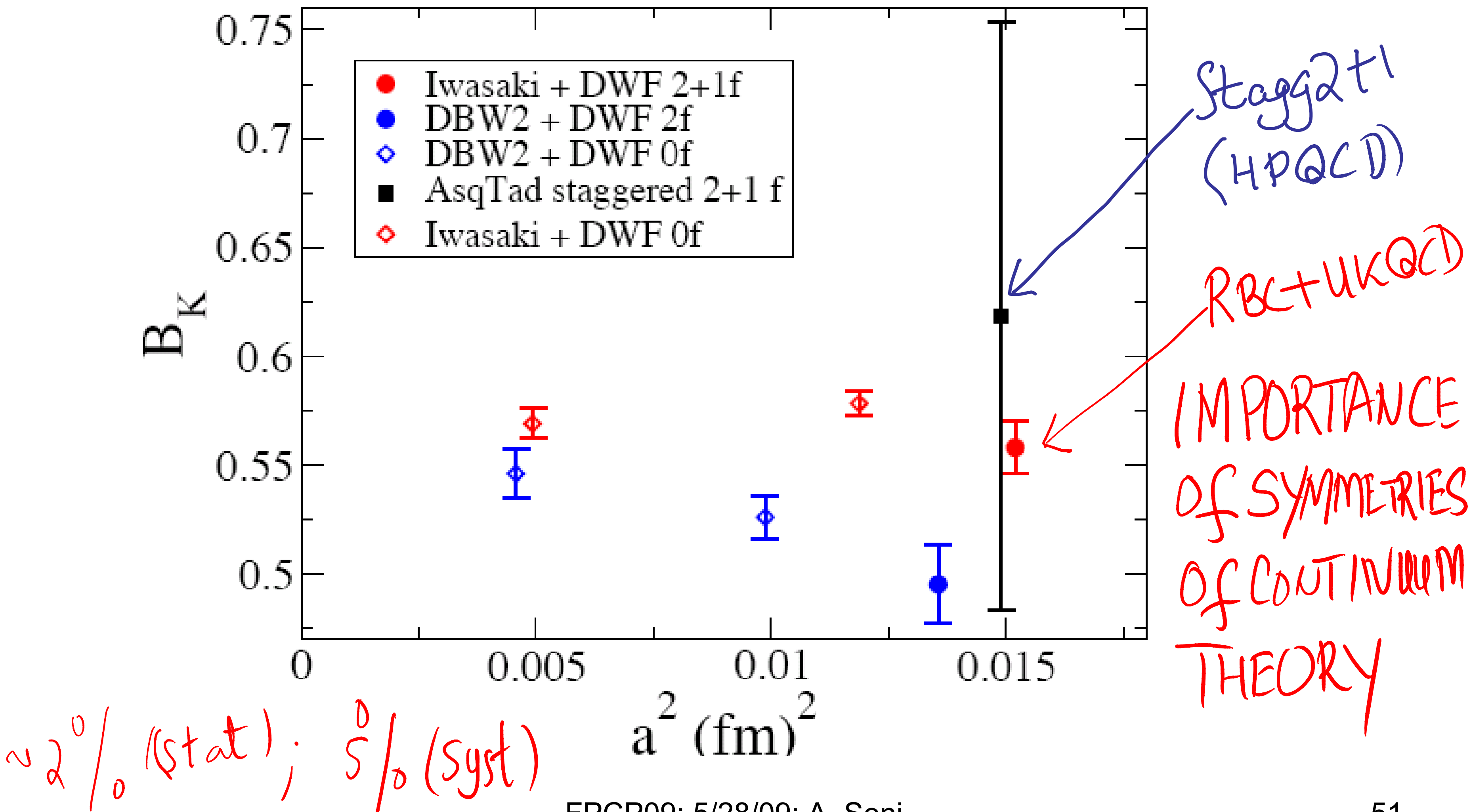
- For past 2 years or so exclusive & inclusive ~small discrepancy:
- Exc ~ (3.7 +-.2+-.5)X10^{-3}
- Inc ~ (4.3 +-.2+-.3)X10^{-3}

-> ***Let's try NOT use Vub***

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

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

PRL Jan25,08

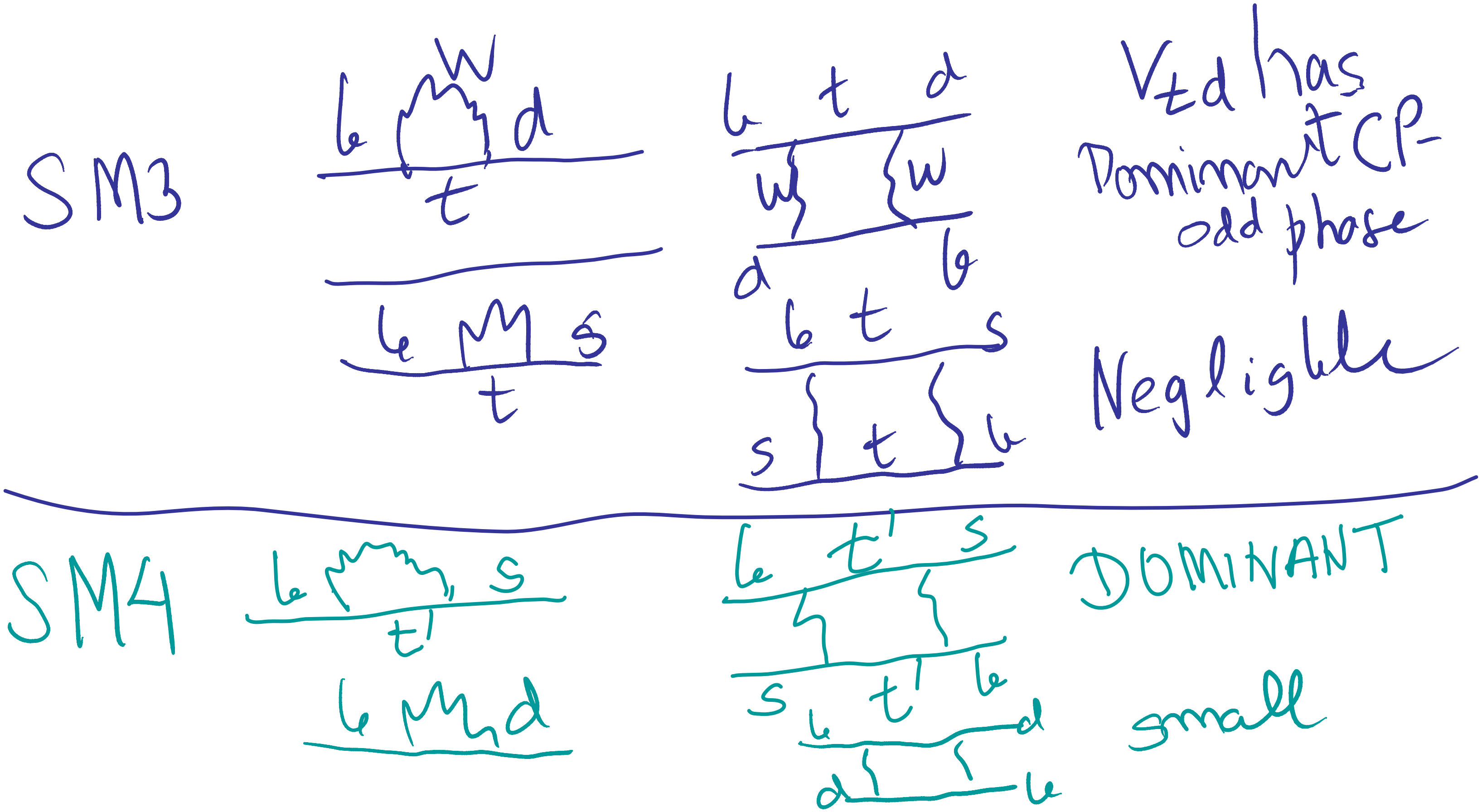


Cons: “Cancellations”

- Extra contributions to EWP observables due mt’,mb’ need to be cancelled by the heavier “higgs”
- Similarly, |mt’-mb’| < ~ 60 GeV for mt’ O(500 GeV)
- So how much of a concern should one give to these cons?
- Let’s just remember Δ(mn-mp)<O(0.1%)

We understand this now as due ISOSPIN

t & t' Role Reversals in Bd & Bs mixing



*Buras & Guadagnoli '08 correction

They stressed that due increased demands on precision, O(5%) (below) should not be ignored anymore

$$|\varepsilon_K| = \frac{G_F^2 m_W^2 f_K^2 m_K}{12\sqrt{2}\pi^2 \Delta m_K^{\rm exp}} \hat{B}_K \kappa_\varepsilon \, {\rm Im}\Big(\eta_1 S_0(x_c)\,(V_{cs}V_{cd}^*)^2 + 2\eta_3 S_0(x_c, x_t) V_{cs}V_{cd}^* V_{ts} V_{td}^* + \eta_2 S_0(x_t)\,(V_{ts}V_{td}^*)^2\Big) . \qquad (2.3)$$

LUNGHI+AS '08

$$\epsilon_K = \frac{\exp(i\pi/4)}{\sqrt{2}\Delta M_K}\left({\rm Im}(M_{12}^K) + 2\xi\, {\rm Re}(M_{12}^K)\right) ,$$

$$\xi = \frac{{\rm Im} A_0}{{\rm Re} A_0} , \qquad (9)$$

Increases discrepancy with SM

Kribs, Plehn, Spannowsky & Tait, PRD '07

LEP EW Constraints on $m_{t'}$

$m_{b'}$, m_H

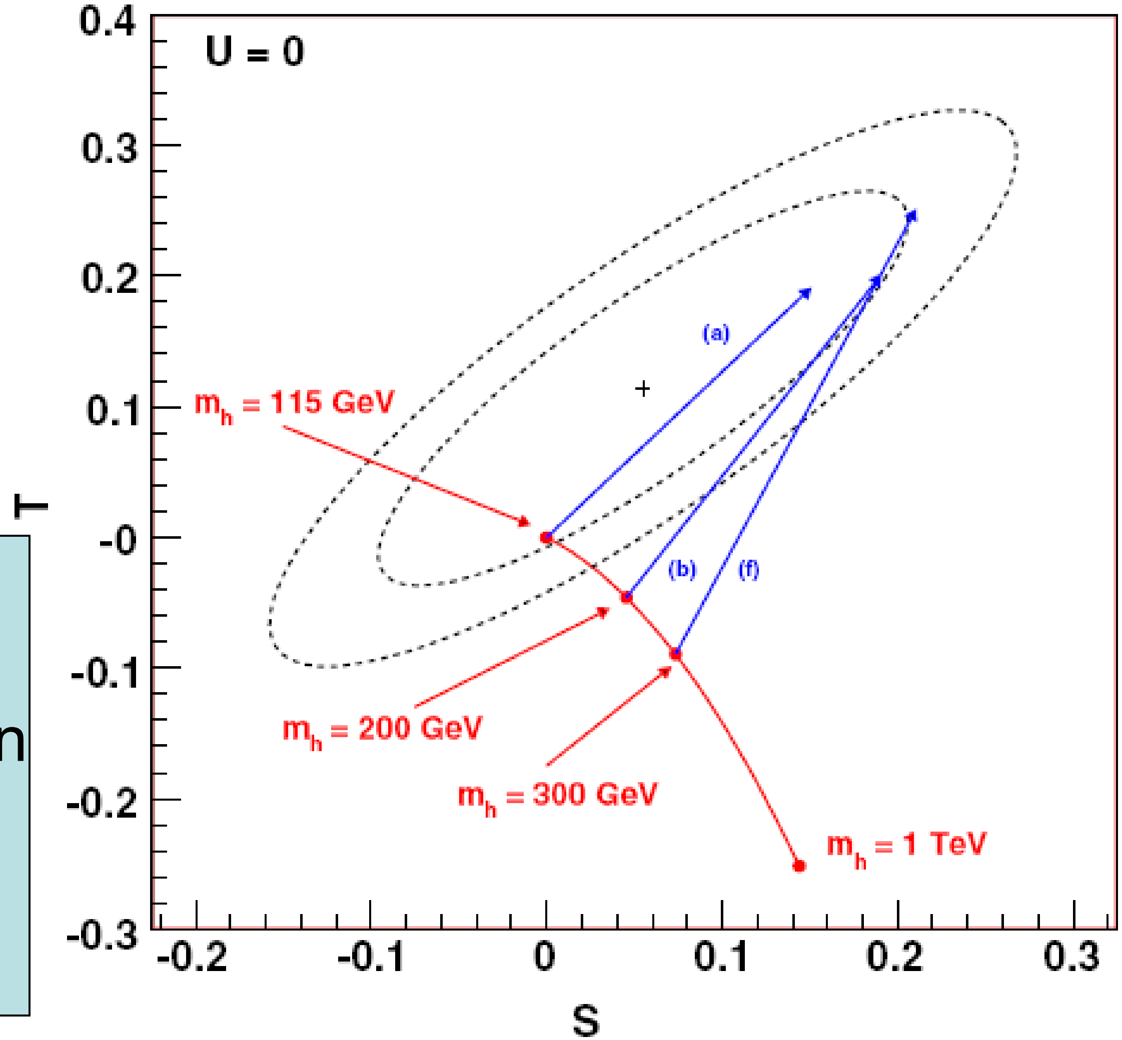


FIG. 2 (color online). The 68% and 95% C.L. constraints on the (S, T) parameters obtained by the LEP Electroweak Working Group [34,35]. The shift in (S, T) resulting from increasing the Higgs mass is shown in red (solid line). The shifts in ΔS and ΔT from a fourth generation with several of the parameter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

TABLE I. Examples of the total contributions to ΔS and ΔT 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

Improved prospects for baryogenesis in SM4

WMAP Data : $\frac{n_B}{n_\gamma} = \left(5.1 {}^{+.3}_{-.2}\right) 10^{-10}$

But $\frac{n_{\bar{B}}}{n_\gamma} \sim 0$

$$A_{BAU} = \frac{n_B - n_{\bar{B}}}{n_B + n_{\bar{B}}} \approx 100\%$$

$$J_3 = \frac{(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_t^2 - m_u^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)(m_b^2 - m_d^2)}{m_W^{12}} A$$

with $A \sim 6 \times 10^{-5}$

WITH 4 generations, there are 3 sets of 3 generations. One of them (w/o the 1st gen) has a huge enhancement over J_3.

$$J^{2,3,4} = (m_{t'}^2 - m_t^2)(m_{t'}^2 - m_c^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_b^2)(m_{b'}^2 - m_s^2) *$$
$$* (m_b^2 - m_s^2) A^{2,3,4}$$

$$\frac{J^{2,3,4}}{J_3} = \frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}\frac{A^{2,3,4}}{A} \sim 10^{14}\frac{A^{2,3,4}}{A} \text{ !!!}$$