“*4th generation” and B-CP anomalies*

EW MORIOND’09

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Outline

- **Motivation**
- **FOUR ANOMALIES**
- **A NATURAL solution that fits the pattern of anomalies**
- **Why not some other (simple) ones?**
- **Broader repercussions**
- **Conclusion & Summary**

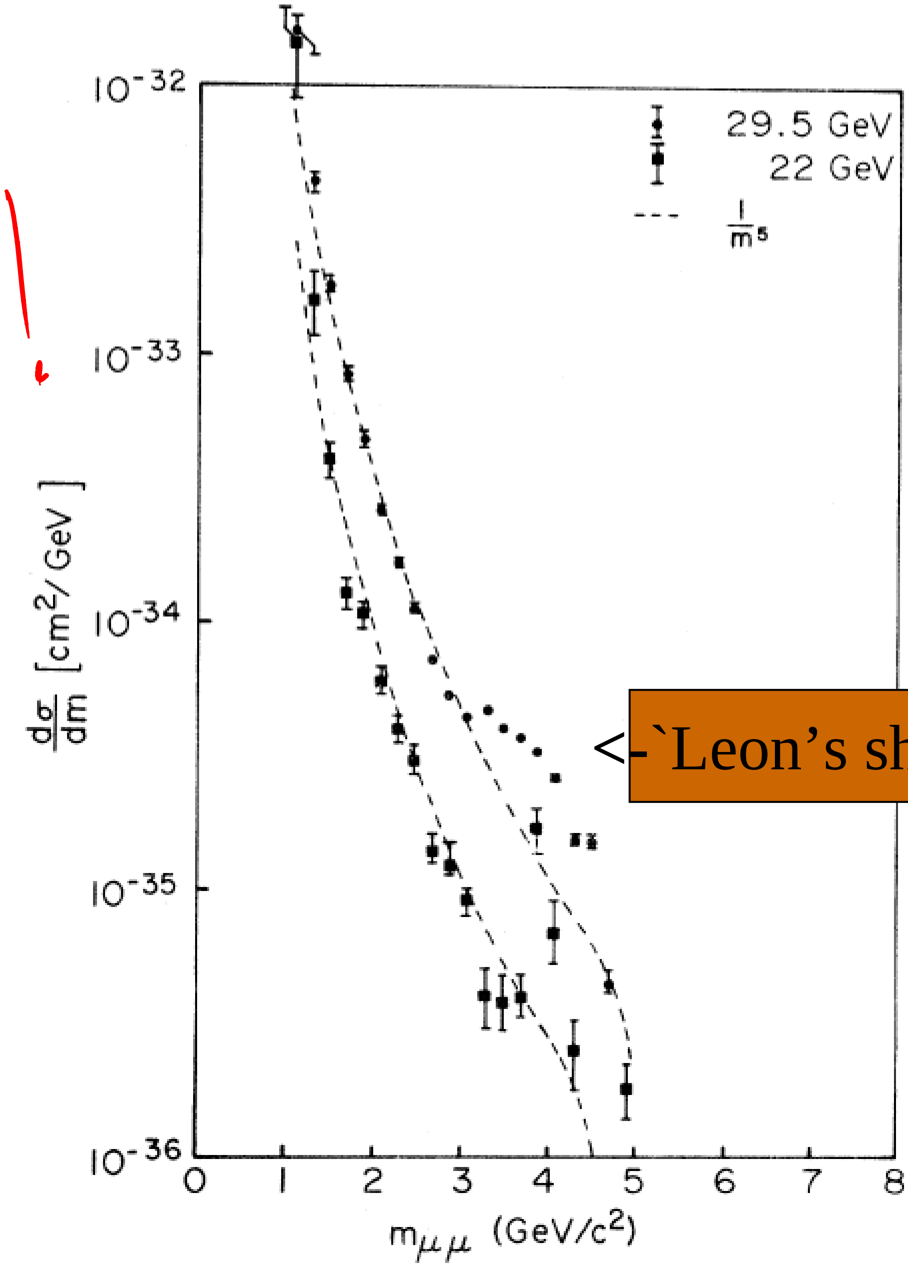
Motivation

- **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!



<-`Leon's shoulder

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

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

Christenson,Hicks,Lederman,Limon,Pope & Zavattini
PRD 8,2016 '72

mass range of 3–5 GeV/c^2, there is a distinct excess of the observed cross section over the reference curve. If this excess is assumed (certainly not required) to be the production of a resolution-broadened resonance, the cross-section–branching-ratio production σB would be approximately 6×10^{-35} cm^2, subject to the cross-section uncertainties discussed above. Alternatively the excess may be interpreted as merely a departure from the overly simplistic (and arbitrarily normalized) $1/m^5$ dependence. In this regard, we should remark that there may be two entirely different processes represented here: a low-Q^2 part which has to do with vector mesons, tail of the ρ, bremsstrahlung, etc., and a core yield with a slower mass dependence, which may be relevant to the scaling argument discussed below.

The "heavy photon" pole that has been postulated[32] to remove divergence difficulties in quan-

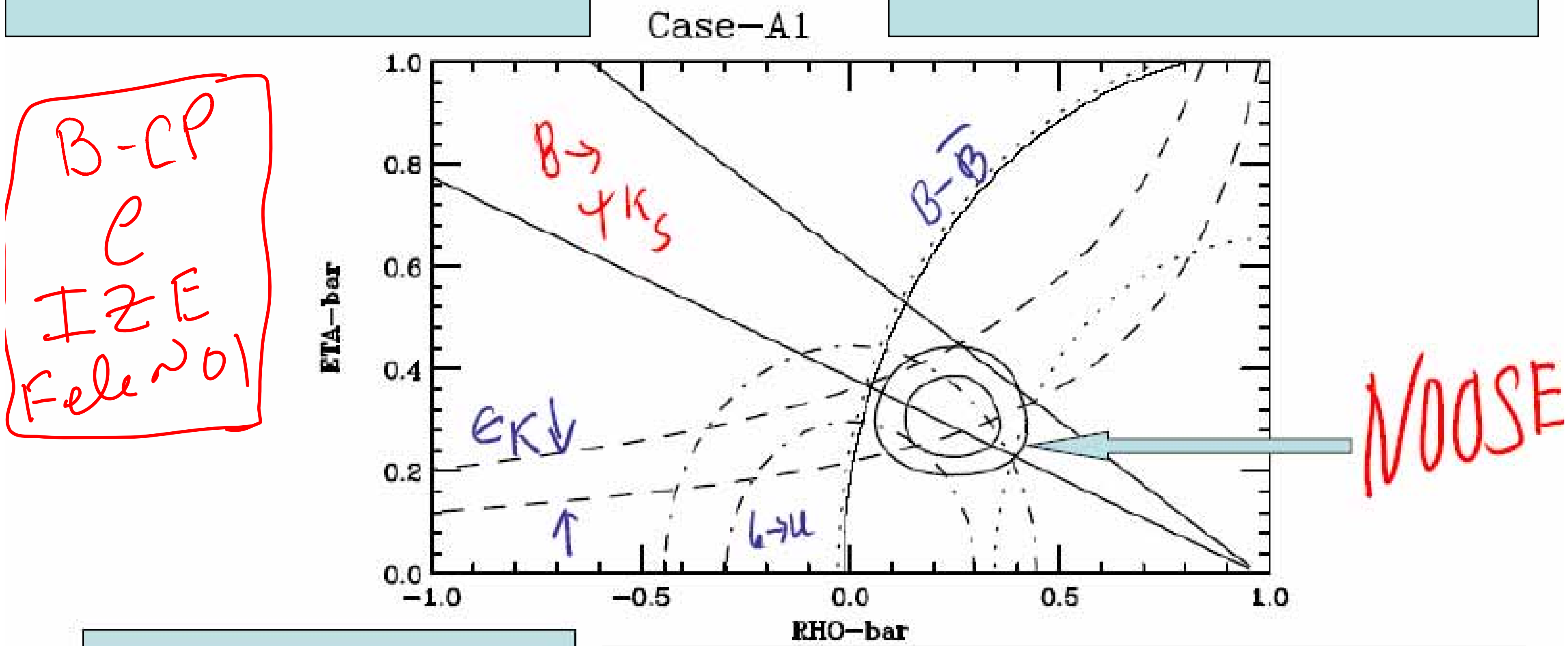
cles produced in the initial proton-uranium collision. In principle, these secondary particles could also create muon pairs. In this case, the observed spectrum would represent the inseparable product of the spectrum of the secondary particle and its own yield of muon pairs. In exploratory research of this kind this disadvantage is largely offset by the fact that the variety of initial states provides a more complete exploration of dimuon production in hadron collisions.

2. *Real Photons*

Real photons produced in the target (presumably from the decay of neutral pions) yield muon pairs by Bethe-Heitler or Compton processes. Estimates were made for the photon flux on the basis of pion-production models,[27,28] and this method of calculating the flux was checked against the experimental data of Fidecaro *et al.*[33] The argument

1st Hint of confirmation of CKM CP description

Atwood &AS, hepph/0103197



Most bands due To theory errors

New physics will be a perturbation, important to use clean theory and 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+pi- vs K+pi0**

- **Bs->ψφ ?**

EACH ~ 2 to 3.5 σ effects

Anomalies in $B(B_s)$-CP asymmtries (I)

- Using B_K (& ε_K),ξ_s (&Δm_s /Δm_d),$|V_{ub}|/|V_{cb}|$ &$|V_{cb}|$ yields sin2β ~ 0.78 +-0.04 to be compared to 0.681+-0.025 (ψK_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

-> 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

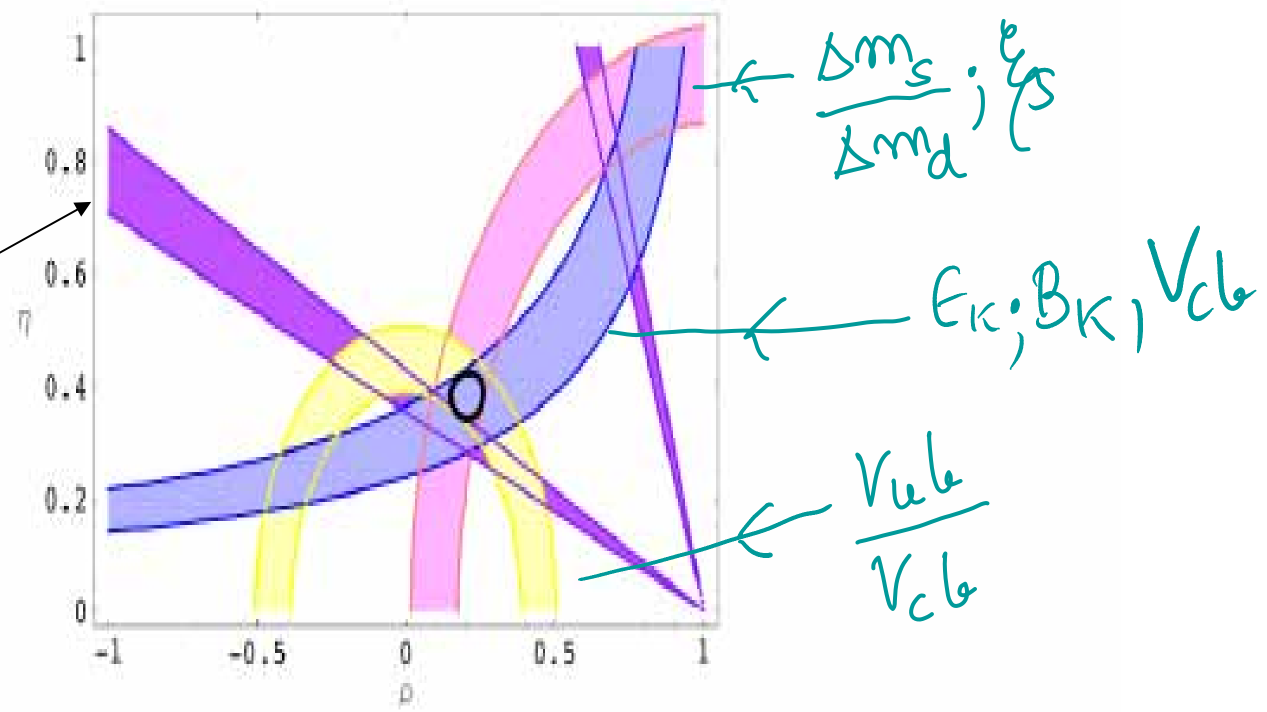


Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

Anomalies in B(B_s)-CP asymmetries(II)

MORE RECENTLY

- **Increased accuracy in B_K from the lattice, along with 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}

Leave out Vub

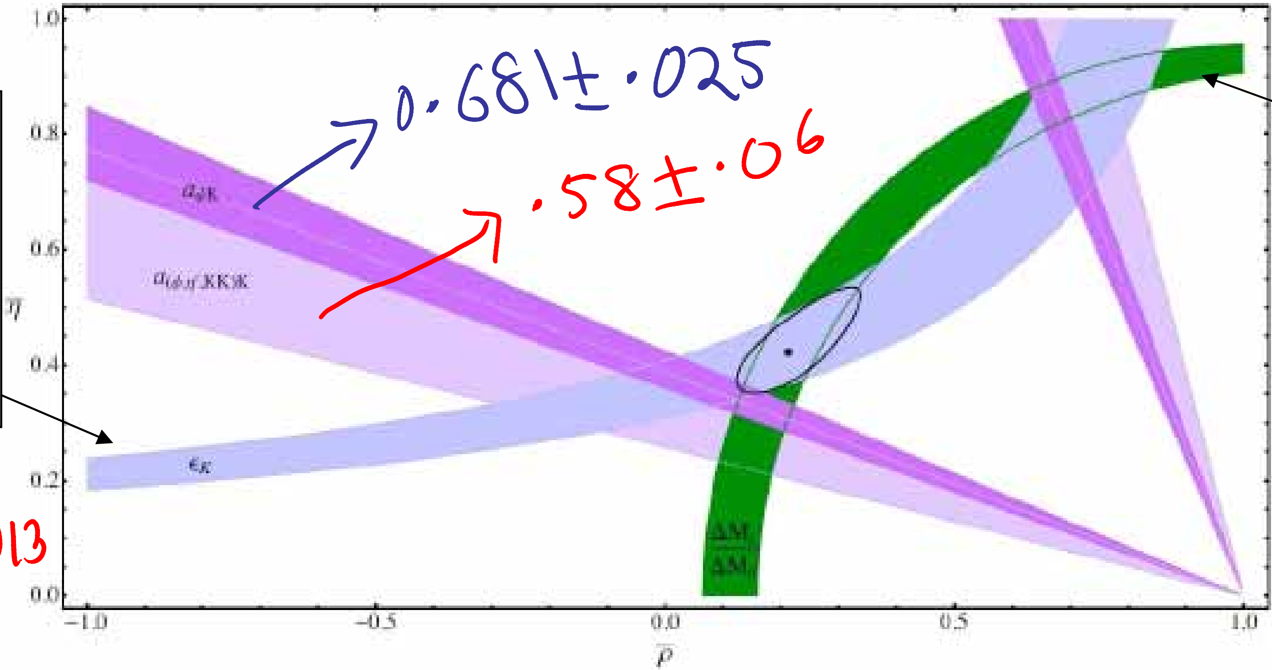
sin 2 β = 0.87+-.09{Lunghi+AS,hep-ph/08034340}

(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 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.

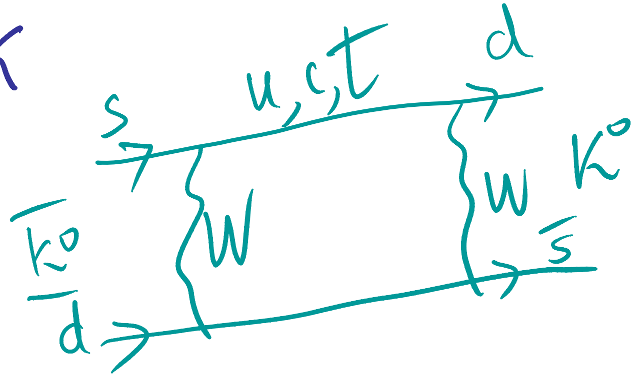
2.1-2.7 σ- deviation from the directly measured values of sin 2 β require careful follow-up

Important Developments in lattice QCD

- **Widespread use of chiral fermions (i.e. Domain wall or overlap) : respects important symmetries of the continuum theory.**
- **Dynamical (2+1) gauge configurations (no longer quenched)**
- **Use of SU(2)ChPT, (assume m_K too heavy) therefore based on isospin and significantly more accurate than SU(3), for chiral extrapolations (pioneered by RBC-UKQCD, hep-ph/0702042….): INCREASED PRECISION**

Define B_K

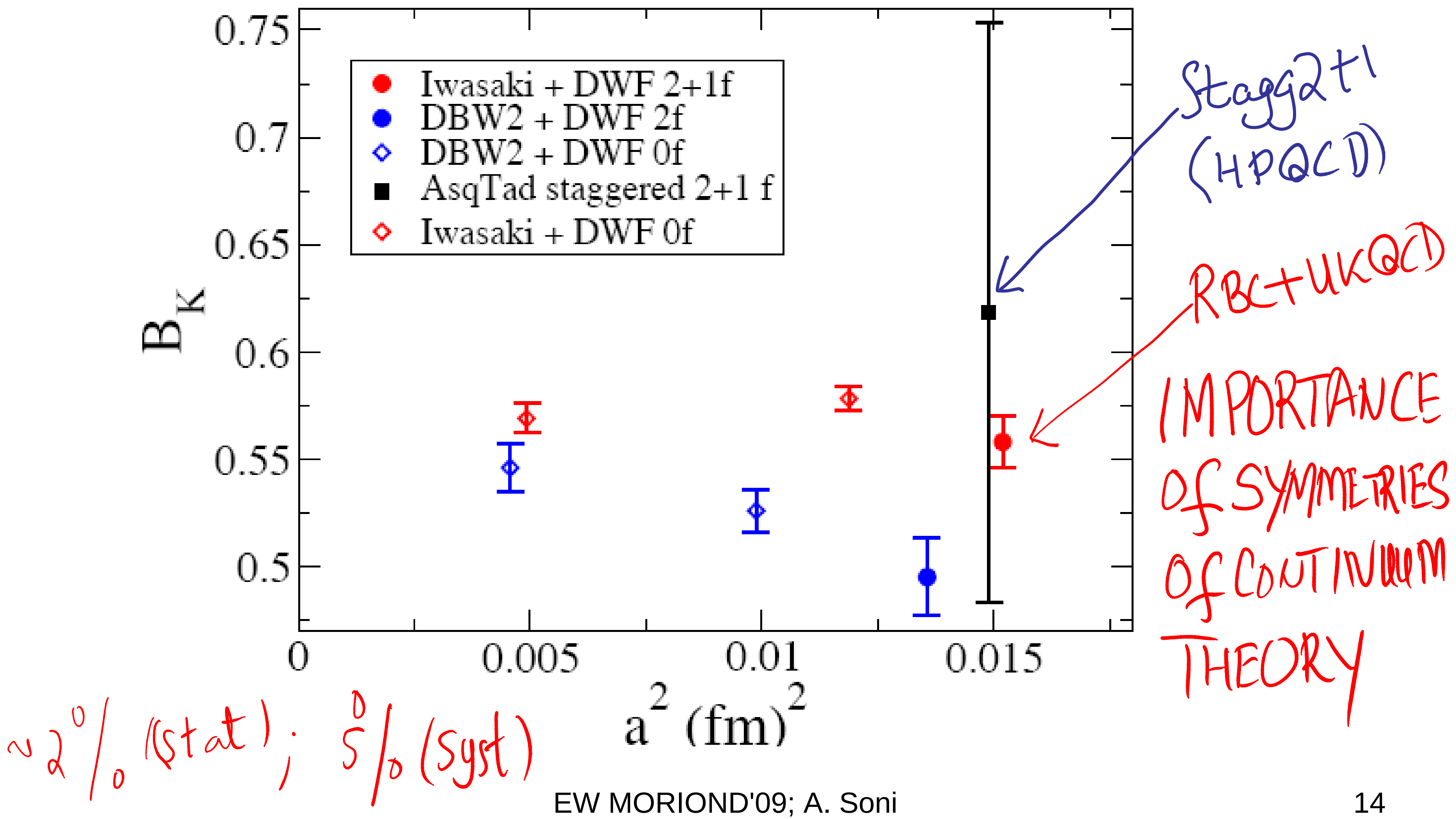
$$B_K \equiv \frac{\langle K | [\bar{s}\gamma_\mu(1-\gamma_5)d]^2 | \bar{K} \rangle}{\frac{8}{3} f_K^2 m_K^2}$$



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

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

PRL Jan25,08



Brief (~25 years) History of B_K

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

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

~'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

BBG LgN PLB '88 .70±.07

~'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%

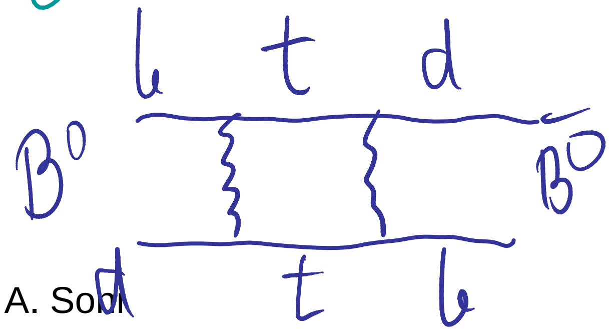
$$\Delta S \equiv S_{penguin} - S_{\psi K_S} = O(\lambda^2)$$

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

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

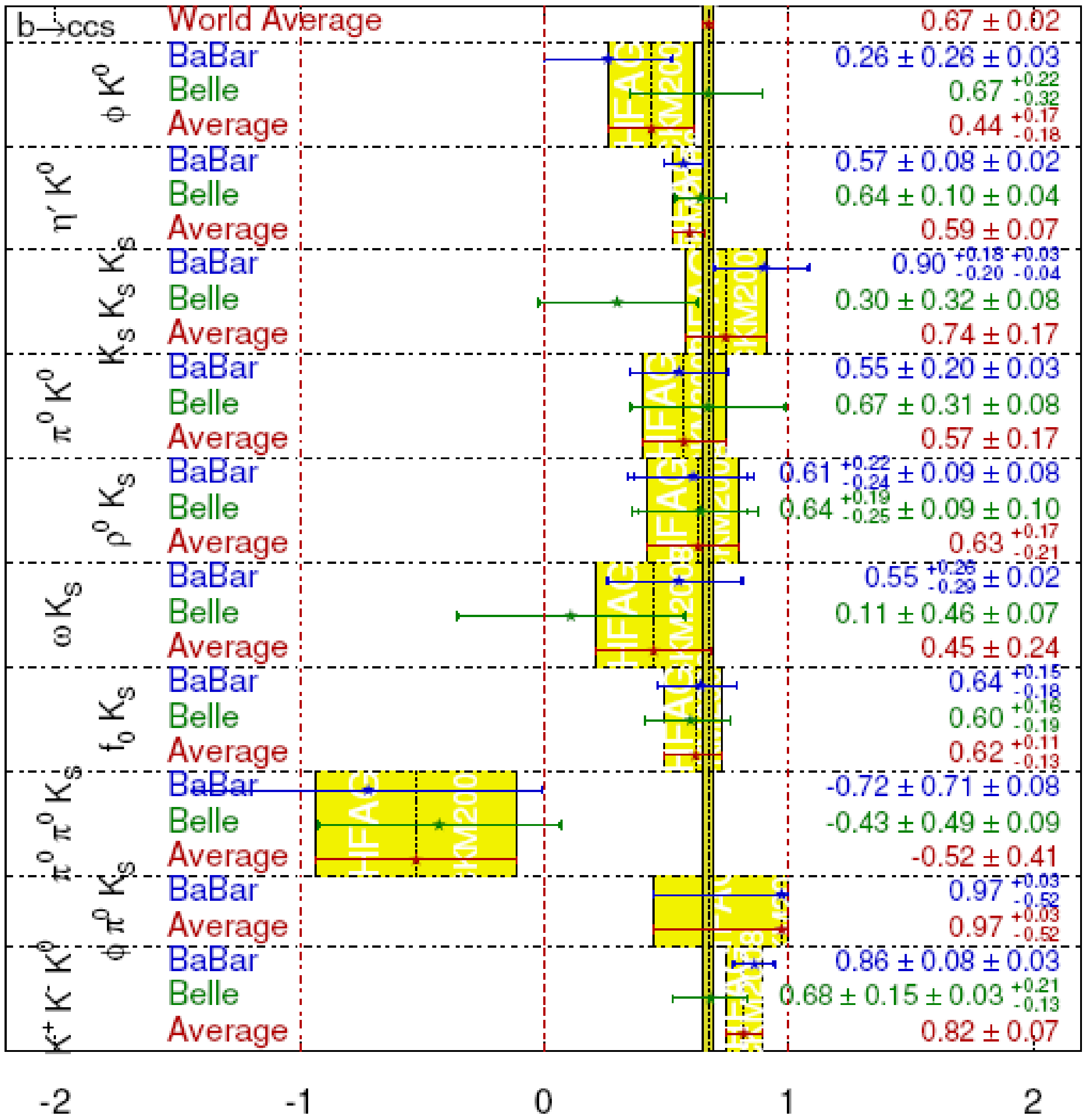
Grossman & Worah, hepph/9612269; London & AS,hepph/9704277

OSC is common



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

HFAG
CKM2008
PRELIMINARY



Intriguing:

Practically all have

$\sin 2\beta < (\sin 2\beta)_{SM}$!

Most have

$\sin 2\beta < (\sin 2\beta)_{\psi K_S}$

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

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

Mode	ΔS_f (Theory)	ΔS_f [Range]	Experiment [3] (BaBar/Belle)
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$[+0.02, 0.15]$	$-0.39^{+0.27}_{-0.29}$ $(-0.38^{+0.30}_{-0.33}/-0.43^{+0.60}_{-0.60})$
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$	$[-0.29, 0.02]$	—
$\eta' K_S$	$0.01^{+0.01}_{-0.01}$	$[+0.00, 0.03]$	$-0.30^{+0.11}_{-0.11}$ $(-0.43^{+0.14}_{-0.14}/-0.07^{+0.18}_{-0.18})$
ηK_S	$0.10^{+0.11}_{-0.07}$	$[-1.67, 0.27]$	—
ϕK_S	$0.02^{+0.01}_{-0.01}$	$[+0.01, 0.05]$	$-0.39^{+0.20}_{-0.20}$ $(-0.23^{+0.26}_{-0.25}/-0.67^{+0.34}_{-0.34})$
ωK_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 $\eta' K_S$ & ϕK_S are clean amongst 2-body

Table 1: Comparison of theoretical and experimental results for ΔS_f.

Similar conclusions from Cheng, Chua &AS PRD'05

∴ NAIVE AVERAGE OVER ALL MODES Should Not be done

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

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

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

$K^+\pi^0 = 4.7 \pm 2.6\%$

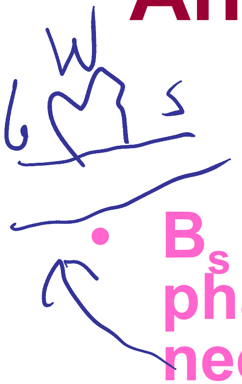
$$\Delta A^{\rm exp}_{CP} = (14.4 \pm 2.9)\%\,, \quad (4)$$

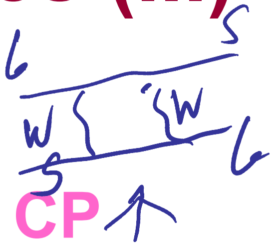
yields a 3.5σ effect.

$\sim 3.5\,G$

BENEKE + NEUBERT 0308039

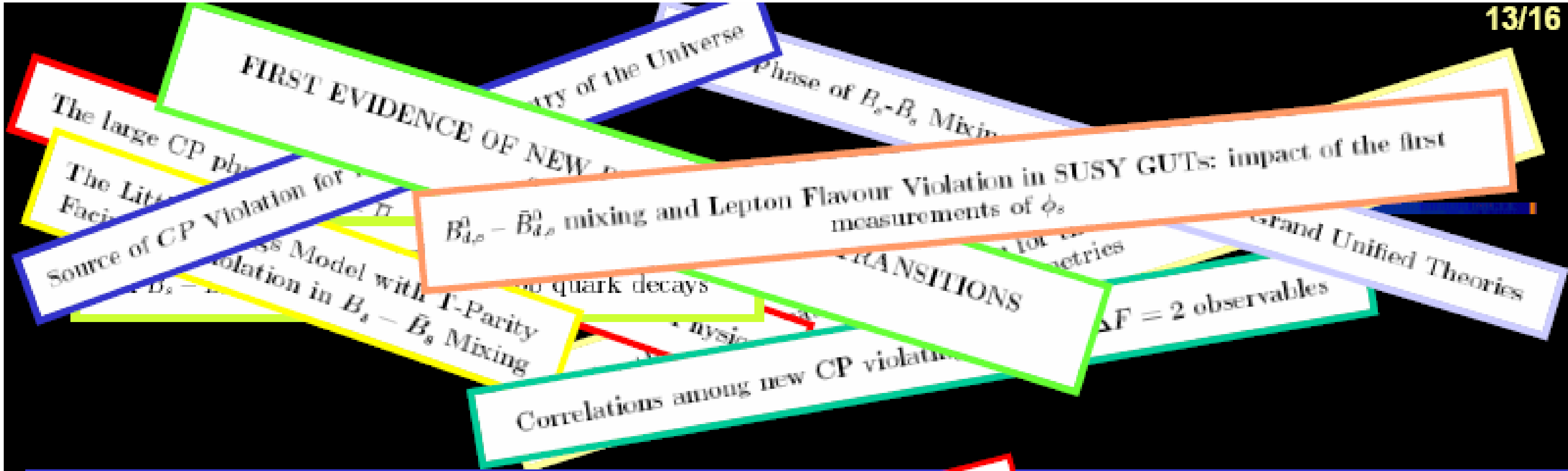
Anomalies in B(B_s)-CP asymmetries (III)





- 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



ICHEP update

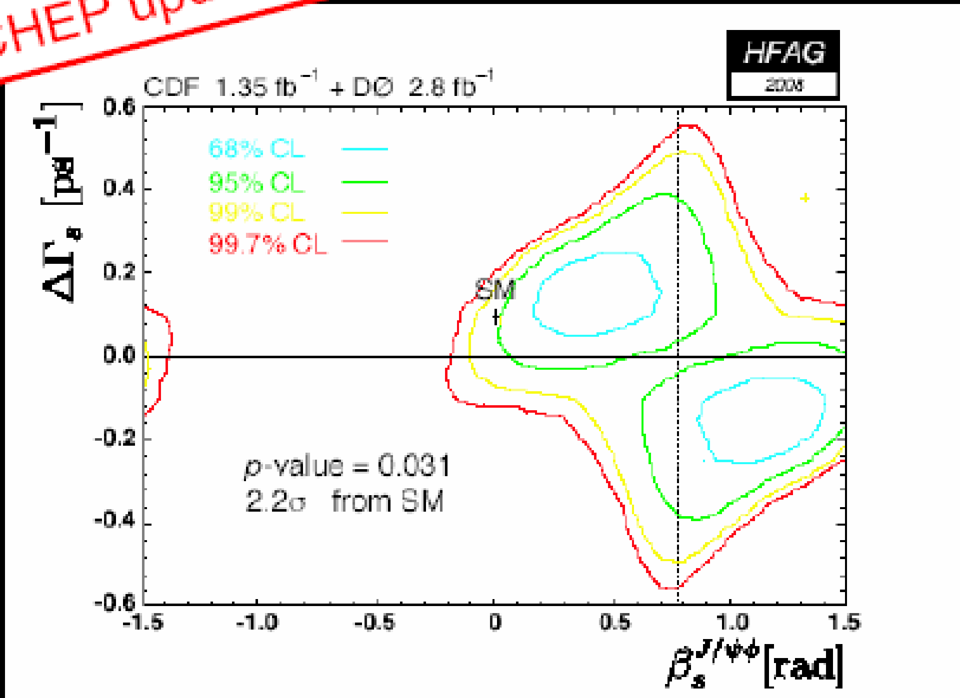
Tevatron combination

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**
- **->Hierarchy suggestive of 4th gens intervention**

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

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	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!

How does 4^{th} family fit in?

For details see A.S et al

arXiv:0807.1971

-> 4th family with rather heavy t'(b'), masses ~ 400-600 GeV provides a rather NATURAL 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'}

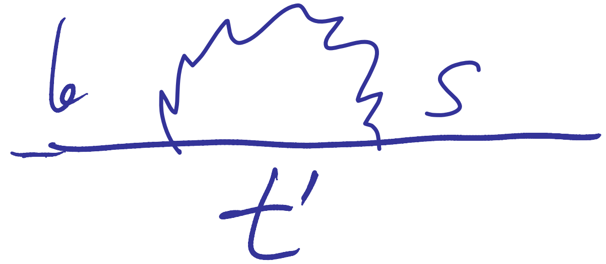
-> IN OUR WORK mt' 400-600GeV seems quite critical-> If true then it plays a CRUCIAL ROLE IN DYNAMICAL EWSB thereby providing a resolution to EW-Planck hierarchy{ see, e.g. He, Hill & Tait, hepph/0108041}

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 2σ range for V_{ub}.

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



$m_{t'}$	400	500	600	700
$\lambda_{t'}^{s}$	(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

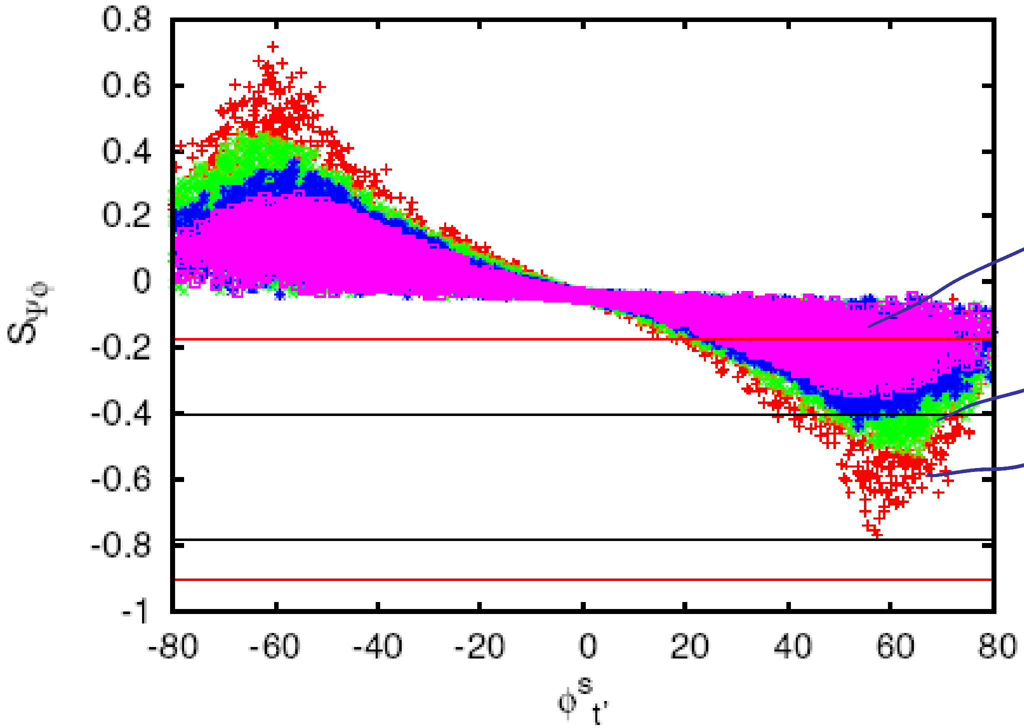
NOTE

TABLE II: Allowed ranges for the parameters, $\lambda_{t'}^{s}$ $(\times 10^{-2})$ 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 $\not\mathrm{C}\!\!\!\not\mathrm{P}$ $\phi K_s, \eta' K_s \ldots$

Recall $\lambda_t^s = 0.04$
arg $V_{ts} \sim 0$

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



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-σ and 2-σ experimental ranges for $S_{\psi\phi}$ respectively.

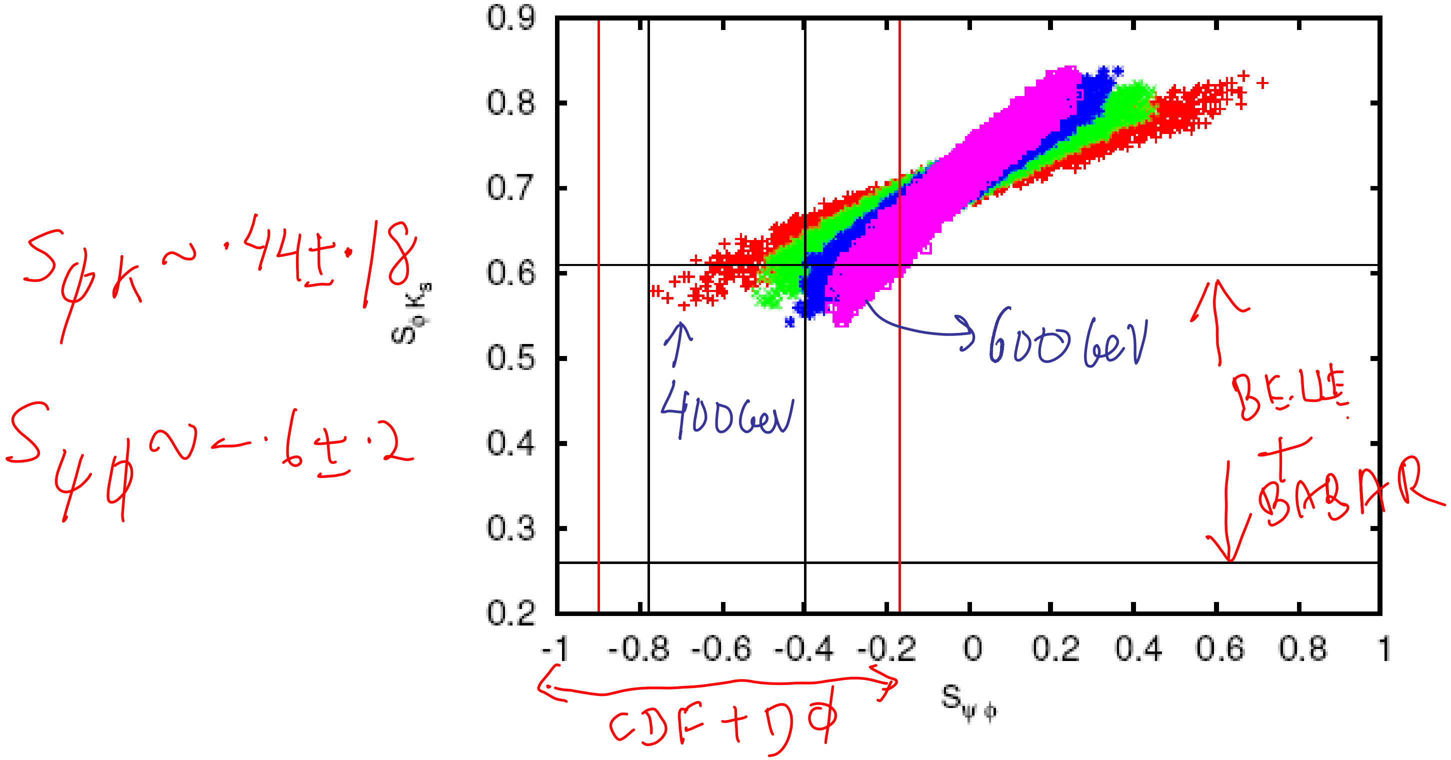


FIG. 3: Correlation between $S_{\phi K_s}$ and $S_{\psi\phi}$ for $m_{t'} = 400$ (red), 600 (green), 800 (magenta) and 1000 (blue) GeV respectively. The horizontal lines represent the experimental 1σ range for $S_{\phi K_s}$ whereas the vertical lines (Black 1-σ and red 2-σ) represent that for $S_{\psi\phi}$.

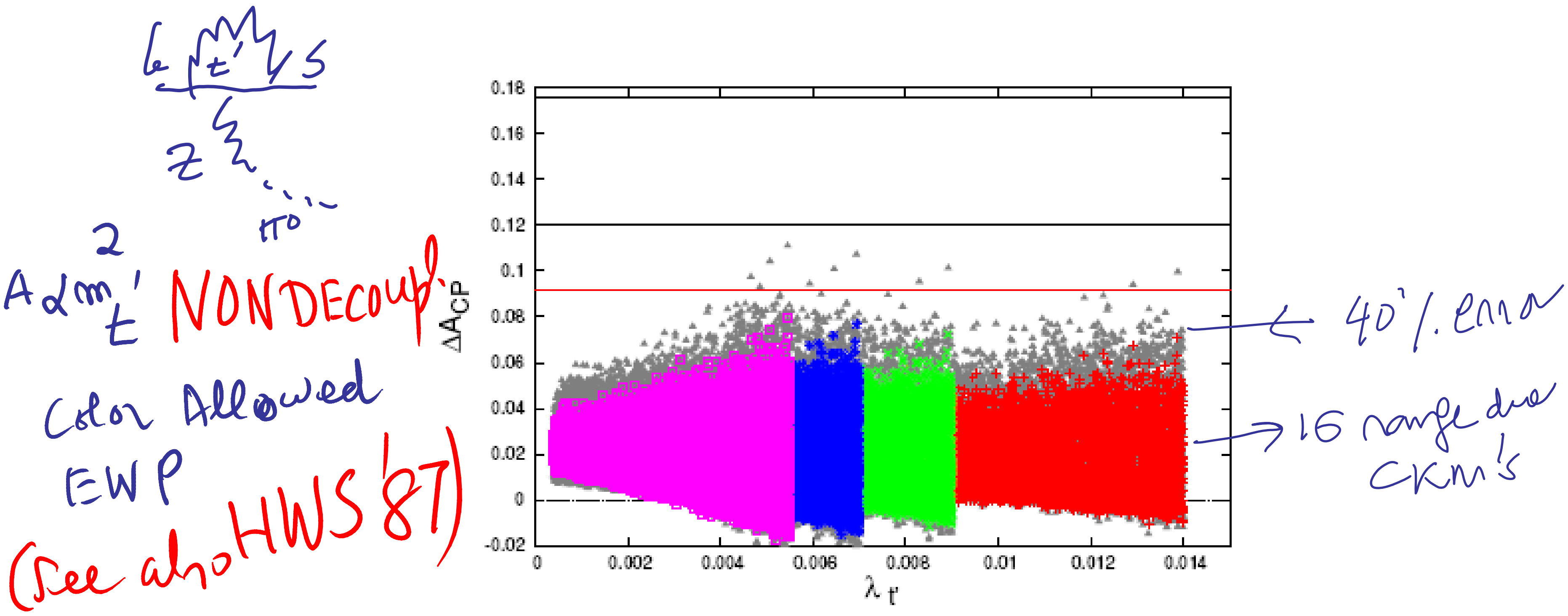


FIG. 1: The allowed range of the CP asymmetry difference (ΔA_{CP}) in the ($\Delta A_{CP} - \lambda^s_{t'}$) plane, where the red, green, magenta and blue regions correspond to $m_{t'} = 400$, 500, 600 and 700 GeV. The 30 % error bars due to hadronic uncertainties [5] are shown by grey bands. The balck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

NUMBER 16 PHYSICAL REVIEW LETTERS 20 APRIL

Implications of a Heavy Top Quark and a Fourth Generation on the Decays $B \to K l^+ l^-$, $K \nu \bar{\nu}$

Emphasized
non-decoupl

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and

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(Received 12 November 1986)

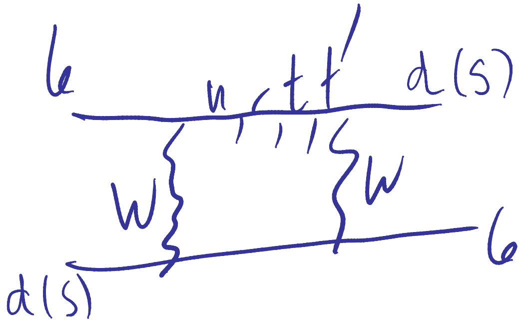
We point out the importance of the Z and box diagram to the decays $B \to K l^+ l^-$, $K \nu \bar{\nu}$. The rate for $B \to K l^+ l^-$ grows rapidly for internal quark masses >100 GeV. With three generations and 25 GeV $\lesssim m_t \lesssim$ 200 GeV the branching ratio ranges roughly from 10^{-6} to 10^{-5}. With four generations, this rate could go up another order of magnitude. The mode $B \to K \nu \bar{\nu}$ typically has a higher branching ratio, but is harder to detect experimentally. The rare B decays combined with information from $K \to \pi \nu \bar{\nu}$ studies may provide a test of the symmetry-breaking mechanism of the standard model and/or evidence for a fourth generation.

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
emphsized long ago



THUS

by construction

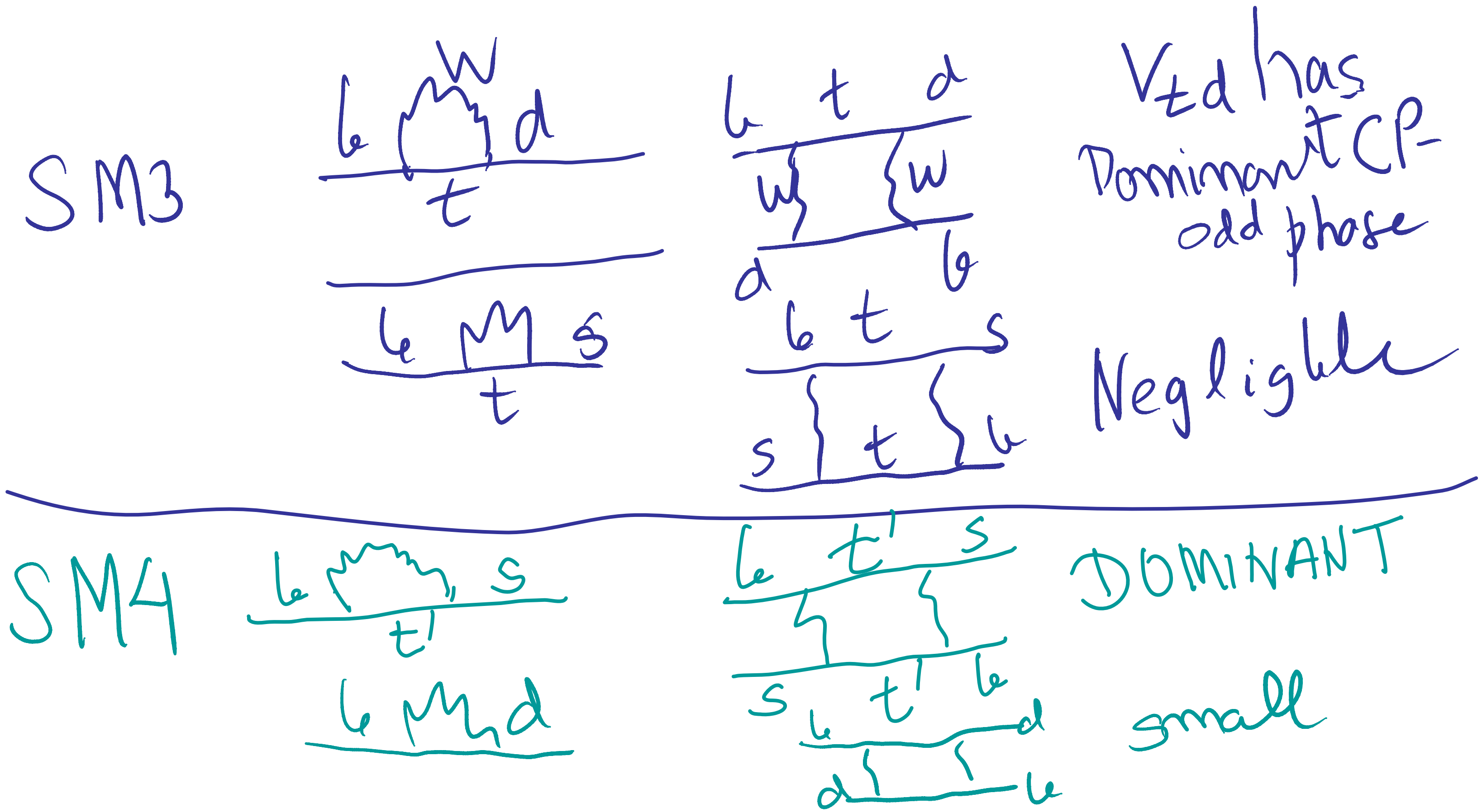
- The CKM-paradigm of CP violation accounts for the observed CP patterns to an accuracy of about 15%!
- SM3-CKM predicted value of sin2β tends to be high compared to direct (ψ K) measurements by about 15-20%...t is dominant

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 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

t & t' Role Reversals in Bd & Bs mixing



Knibs, Plehn, Spannowsky & Tait, PRD '07

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

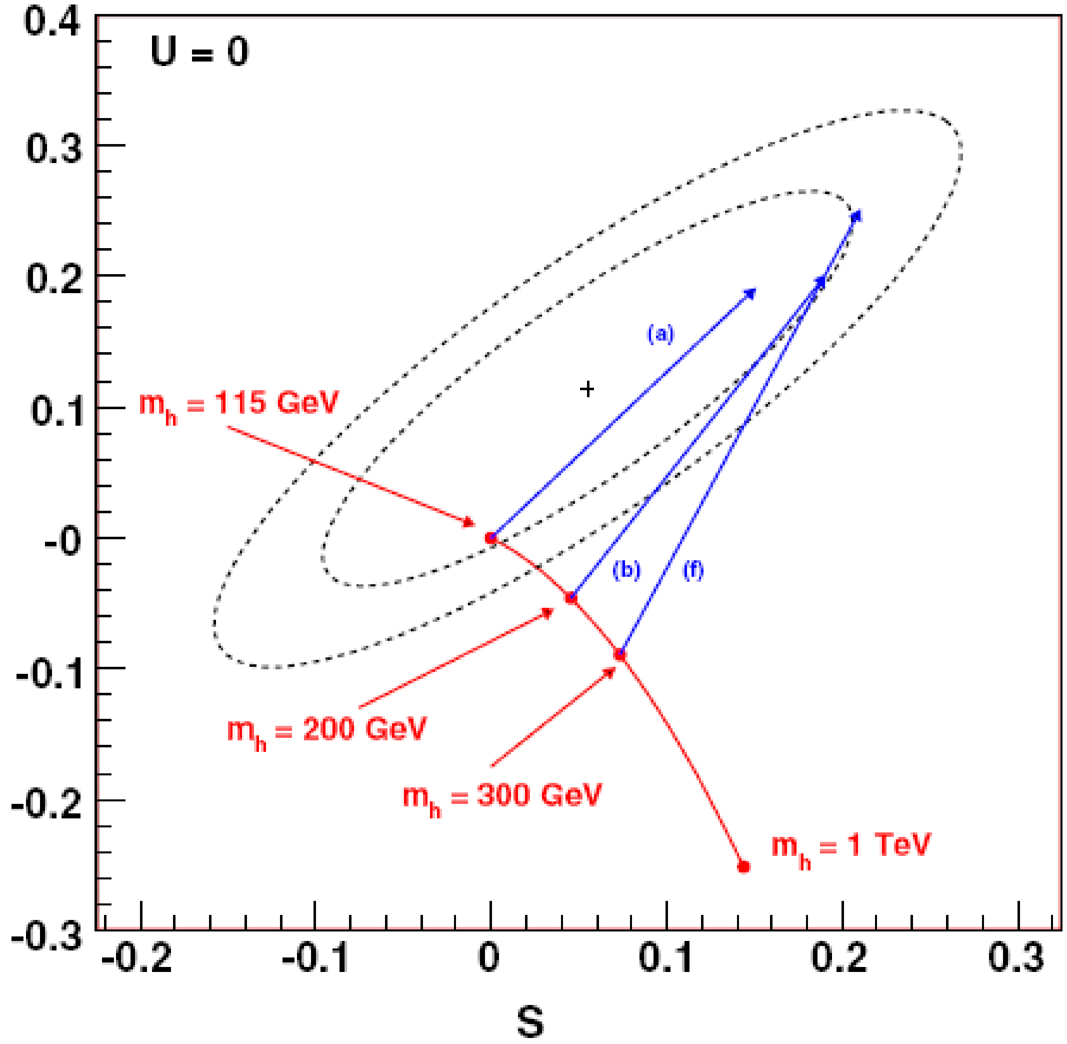


FIG. 2 (color online). The 68% and 95% C.L. constraints on the (S, T) parameters obtained by the LEP Electroweak Working Group [34,35]. The shift in (S, T) resulting from increasing the Higgs mass is shown in red (solid line). The shifts in ΔS and ΔT from a fourth generation with several of the parameter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

Why not some (simple) ones?

- **Z’……….Helps with K π CP asymmetry, and possibly with penguin dominated modes but DIFFICULT to affect Bs mixing…..So unless CDF/D0 signals go away, Z’ cannot fit the bill**
- **T2HDM a very nice simple extension (examined in Lunghi + AS, 0707.0212) has some difficulty in penguin dominated modes and serious difficulty again in Bs mixing**
- **Of course complicated setups such as SUSY or Warped Xtra Dims can accommodate such effects**

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
- 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

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

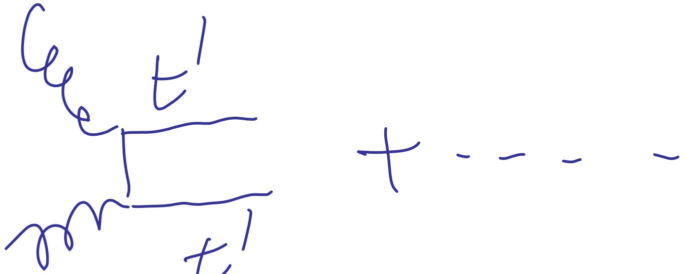
WITH 4 generations, there are 3 sets of 3 generations. One of them (w/o the 1st gen) has a huge enhancement over J_3.

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

$$* (m_b^2 - m_s^2)\ A^{2,3,4}$$

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

Repercussions for the LHC



(b' phase space suppressed so may need go via 3 body)

Possibly enhanced

Of course a lot more - -

Summary & Conclusions

- **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.**
- **If the effects stand further scrutiny, SM4 with mt', mb' (400-600 GeV) provides a natural explanation of the anomalies.**
- **SM4 opens up important new avenues for baryogenesis and most likely also crucial for EWSB…thereby it may well lead to a resolution to the hierarchy problem.**
- **Underlying nature of the "4th 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 SuperB Factories will have a very important role to play

Backup slides

BNL-HET-08/17, TIFR/TH/08-29, HRI-P-08-07-001

The fourth family: a natural explanation for the observed pattern of anomalies in B-CP asymmetries

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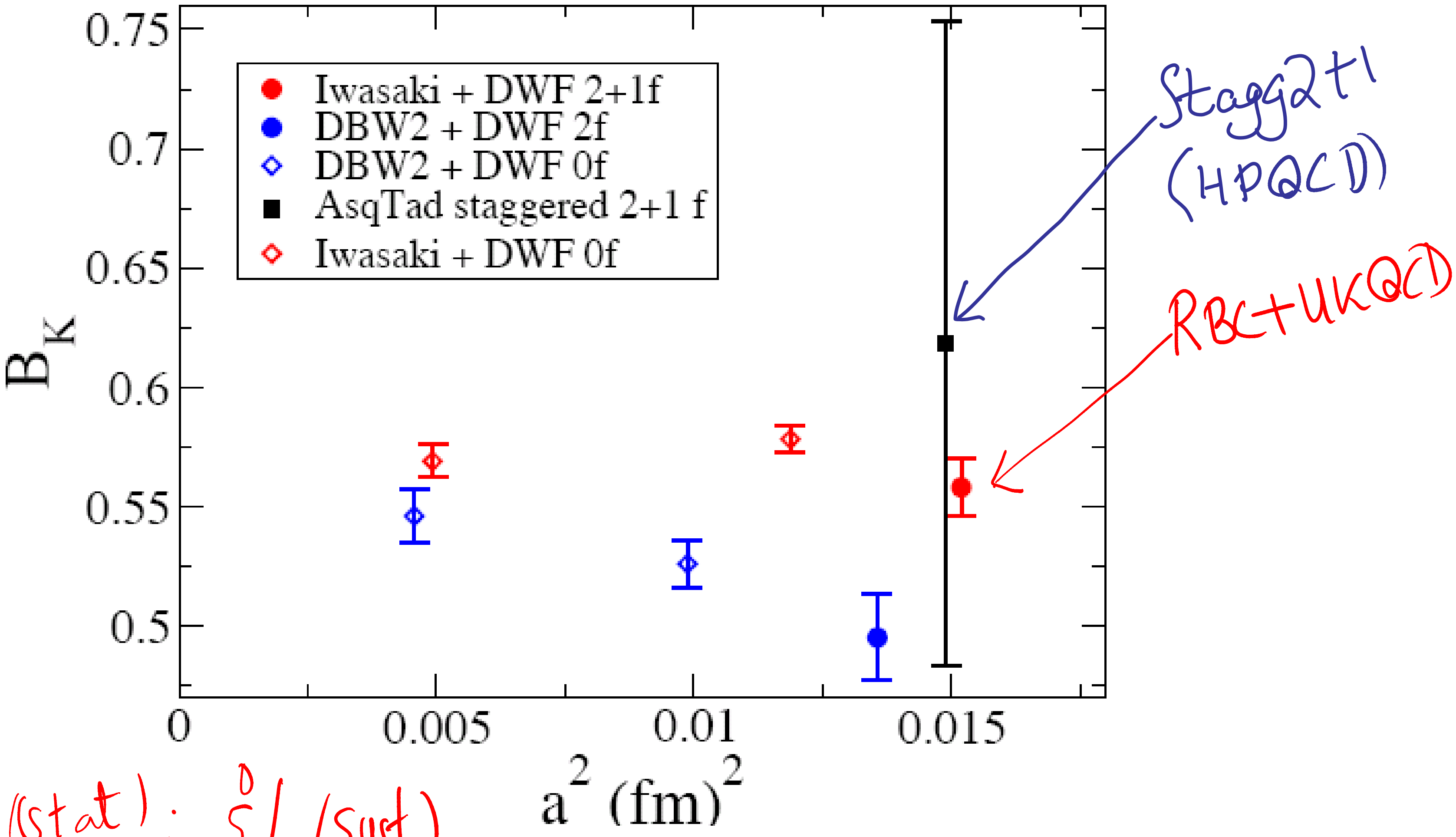
We show that a fourth family of quarks with $m_{t'} \gtrsim 700$ GeV provides a rather natural explanation for the several indications of new physics that have been observed involving CP asymmetries of the b-quark. The built in hierarchy of the 4×4 mixing matrix is such that the t' readily provides a needed *perturbation* ($\approx 15\%$) to $\sin 2\beta$ as measured in $B \to \psi K_s$ and simultaneously is the dominant source of CP asymmetry in $B_s \to \psi\phi$. The difference in direct CP asymmetries in $\bar{B}^0 \to K^-\pi^+$ versus $B^- \to K^-\pi^0$ requires $m_{t'} \gtrsim 600$ GeV. The correlation between CP asymmetries in $B_s \to \psi\phi$ and the difference [S($B_d \to \psi K_s$) - S($B_d \to \phi K_s$)] suggests $m_{t'} \gtrsim 700$ GeV. Such heavy masses point to the tantalizing possibility that the 4th family plays an important role in the electroweak symmetry breaking as the Pagels-Stokar relation in fact requires quarks of masses around 700 GeV for dynamical mass generation to take place.

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

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

PRL Jan25,08



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

SU(3) breaking ratio ξ_s

- It was noted (Bernard, Blum & AS,heplat/9801039; c also Lellouch et al, hepph/0011086) that once Δm_s gets measured then Δm_s / Δm_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

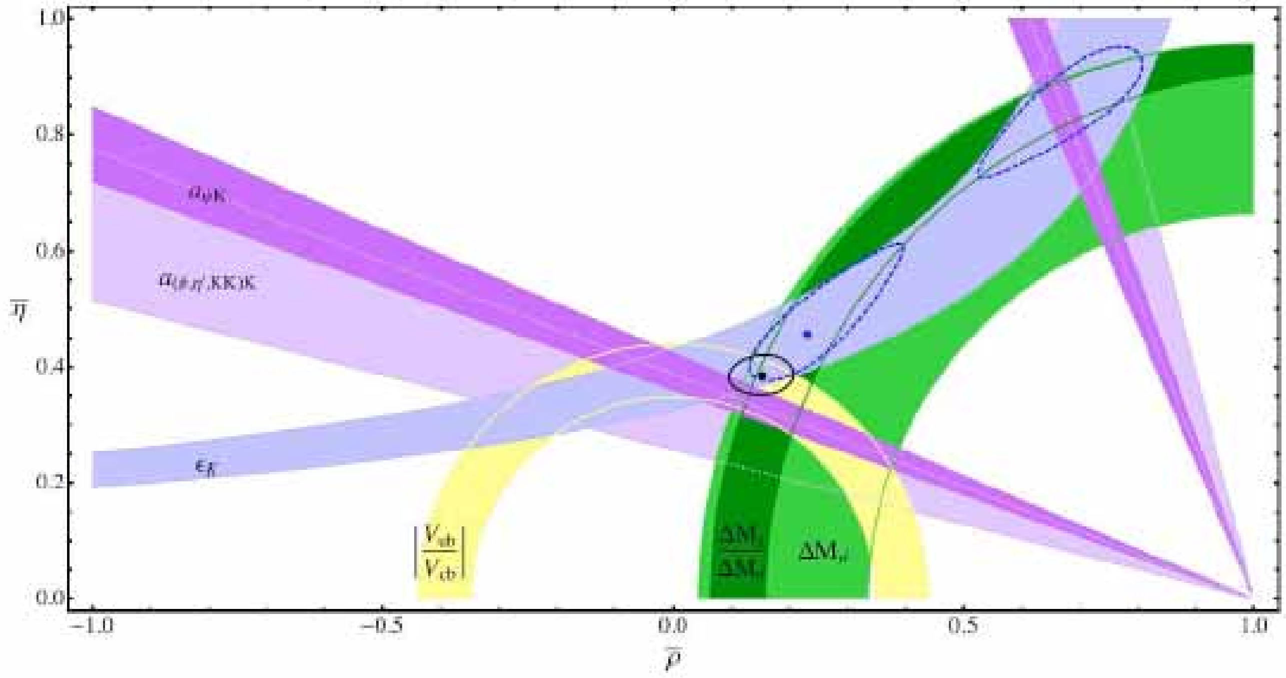


FIG. 2: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.. The solid contour is obtained using the constraints from ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ and $|V_{ub}/V_{cb}|$. The dashed contour shows the effect of excluding $|V_{ub}/V_{cb}|$ from the fit. The regions allowed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

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***