Fourth family: A natural explanation for the observed pattern of anomalies in B-CP asymmetries

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Beyond the 3SM generation at the LHC era Workshop

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Outline

- **Motivation**
- **Apparent difficulties for CKM-paradigm**
- **Crucial ingredients for a NP solution**
- **Why "4th family" is a NATURAL solution**
- **Broader repercussions**
- **Outlook & 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 strong) hints have emerged.
- Although, taking too seriously every little deviation

  is not desirable and may be counterproductive,

  disregarding or overlooking the hints can be painfully

  unwise and in fact can be more damaging; (arguably considerable damage has already been done by such mis-interpretations)

Following these up in flavor & collider physics and in theory may prove beneficial esp. in light of the LHC turning on

{ based in part on Enrico Lunghi + A. S. 0707.0212; 0803.4340 & in progress. Also AS et al (+Alok, Giri, Mohanta and Nandi) (WHEPP X):0807.1971 & in progress}
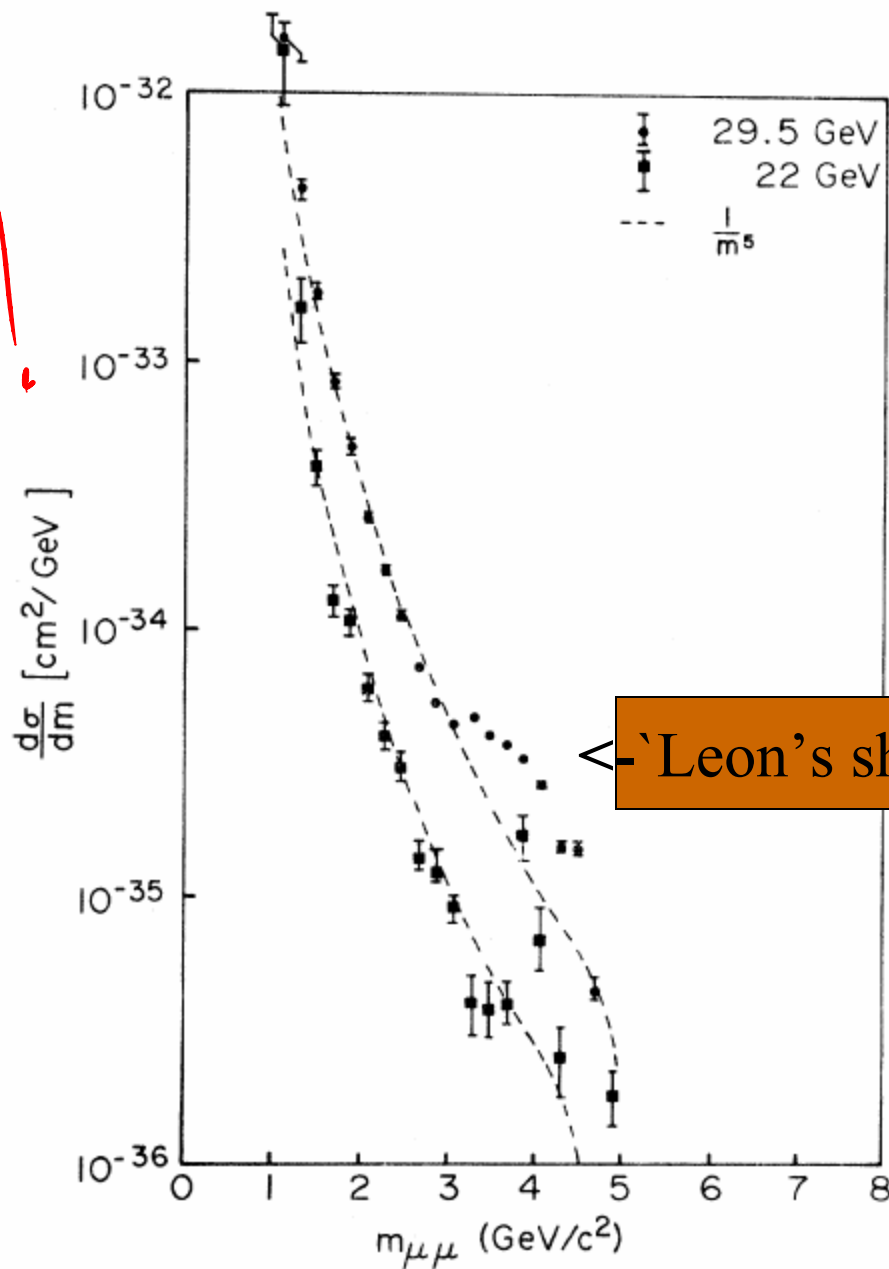
FIG. 15. Experimental cross sections at two energies compared with a simple $1/m^5$ continuum.

DRELL-YAN @ its INFANCY!

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

<-`Leon's shoulder

4

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

Anomalies in B(B$_s$)-CP asymmetries (I)

- **Using B$_K$ (& ε$_K$),ξ$_s$ (&Δm$_s$ /Δm$_d$),|V$_{ub}$|/|V$_{cb}$| and |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)) [CONCERN |V$_{ub}$|]**

- **Sin 2 β from penguin-dominated "clean"modes**

  is smaller than from the value obtained via B->ψ K$_S$ ~2.5 σ (in addition an intriguing trend of central values of almost all modes are low)

  . **Of no less importance is also the fact that sin2β from penguins is also well below SM (theory) prediction of 0.78 +-0.04 (more later)**

- **ACP(K$^+$ π$^-$)) – ACP(K$^+$ π^0) =14.4+-2.9% & not ~0**

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

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

$$\frac{\Delta m_s}{\Delta m_d}; \xi_s$$
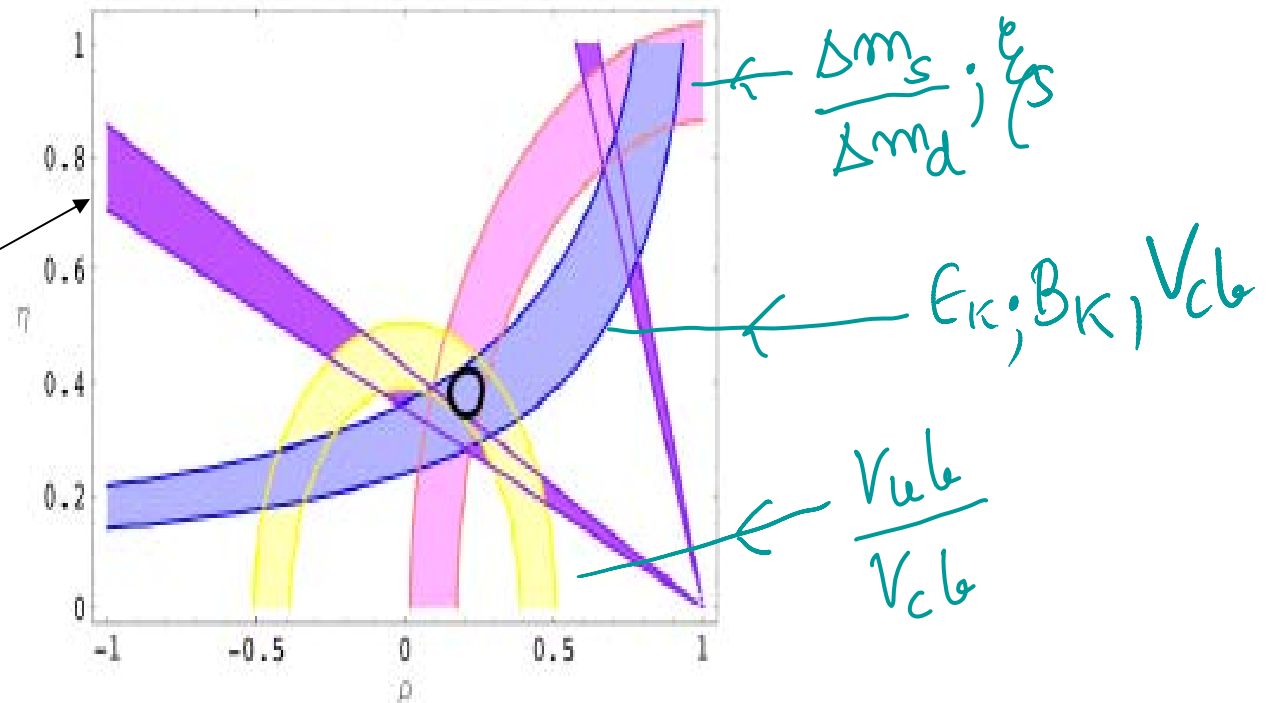
$$\epsilon_K; B_K, V_{cb}$$
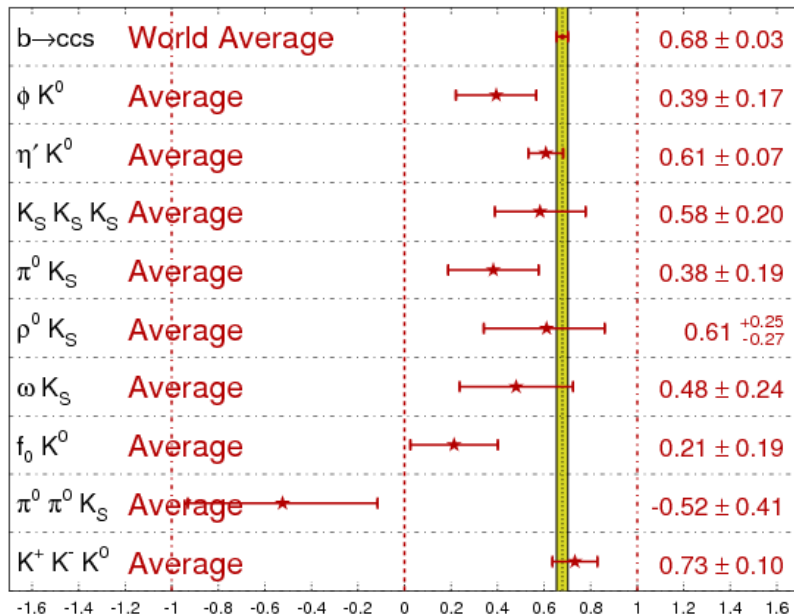
$$\frac{V_{ub}}{V_{cb}}$$

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.

ΔS results before ICHEP 2008

347M $B\bar{B}$ PRL 99, 161802 (2007)
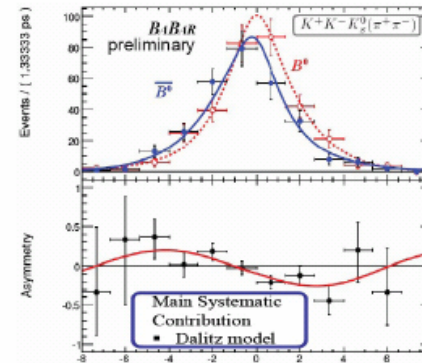
Based on KKK Dalitz analysis

ϕK^0: $\sin 2\beta_{eff} = +0.12 \pm 0.31 \text{(stat)} \pm 0.10 \text{ (syst)}$

$$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$$ **HFAG** LP 2007 PRELIMINARY

$b \to ccs$	World Average	0.68 ± 0.03
ϕK^0	Average	0.39 ± 0.17
$\eta' K^0$	Average	0.61 ± 0.07
$K_S K_S K_S$	Average	0.58 ± 0.20
$\pi^0 K_S$	Average	0.38 ± 0.19
$\rho^0 K_S$	Average	$0.61 ^{+0.25}_{-0.27}$
ωK_S	Average	0.48 ± 0.24
$f_0 K^0$	Average	0.21 ± 0.19
$\pi^0 \pi^0 K_S$	Average	-0.52 ± 0.41
$K^+ K^- K^0$	Average	0.73 ± 0.10

535 M PRL 98, 031802 (2007)

For most modes, $\Delta S(SM)$ is positive.
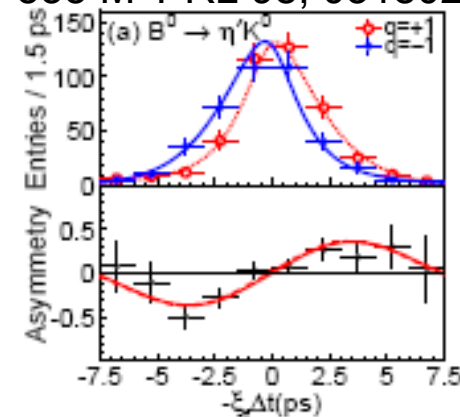
$\eta' K^0$: $\sin 2\phi_{1eff}$: $+0.64 \pm 0.10 \pm 0.04$

TCPV Results on $\bar{b} \to s\, qq$

Sorry official HFAG average is not ready yet!

$S(c\bar{c}s) = 0.67 \pm 0.02$
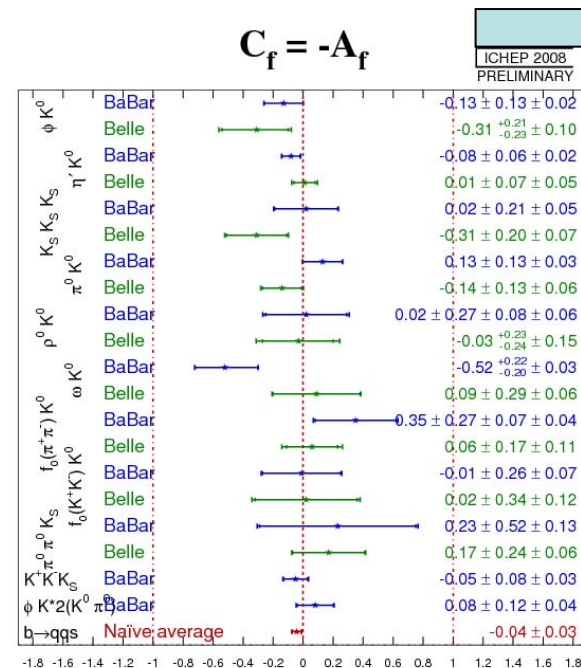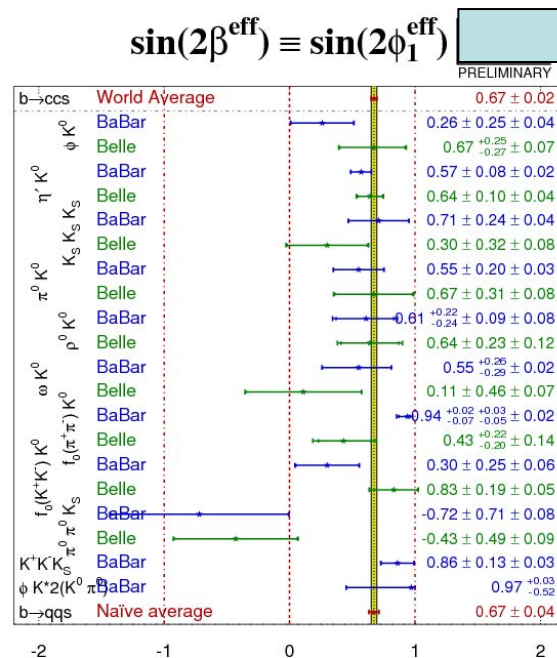
Naïve $S(q\bar{q}s) = 0.67 \pm 0.04$ $C = -0.04 \pm 0.03$

Average $S(q\bar{q}s) = 0.60 \pm 0.05$ after removing BaBar's $f_0(\pi\pi)K^0$ and $\phi K^0 \pi^0$

PaotiChang(ICHEP08)

TDCP studies in b->s penguins: two crucial messages NOT one

- **Focus has been just on comparison with B->ψ Ks**

- **In fact at least equally important and most likely, much more important, is that the sin2β from penguins is a lot less than the SM prediction (~0.78 +-0.04); more later on this**

- **Ignoring this 2nd point for last ~3 years has been a costly omission for the flavor community, adversely affecting its exptal program**
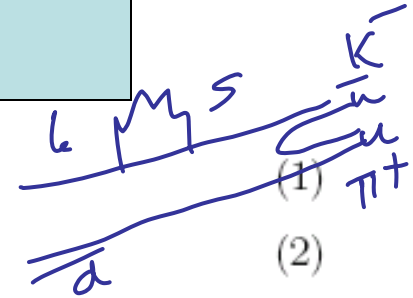
has not been adequately emphasized

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

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

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:

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

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]

$$\Delta A_{CP}^{\text{exp}} = (14.4 \pm 2.9)\% , \tag{4}$$

yields a 3.5σ effect.

(handwritten annotations) based on BENEKE+NEUBERT 0308039

Anomalies in B(B$_s$)-CP asymmetries(II)

→ next page

- **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}

- **Also interestingly: With input of trees only (γ and |Vub|), predicted value of sin 2 β = 0.68+-0.065 in good agreement with the directly measured one (ψ K$_s$)**
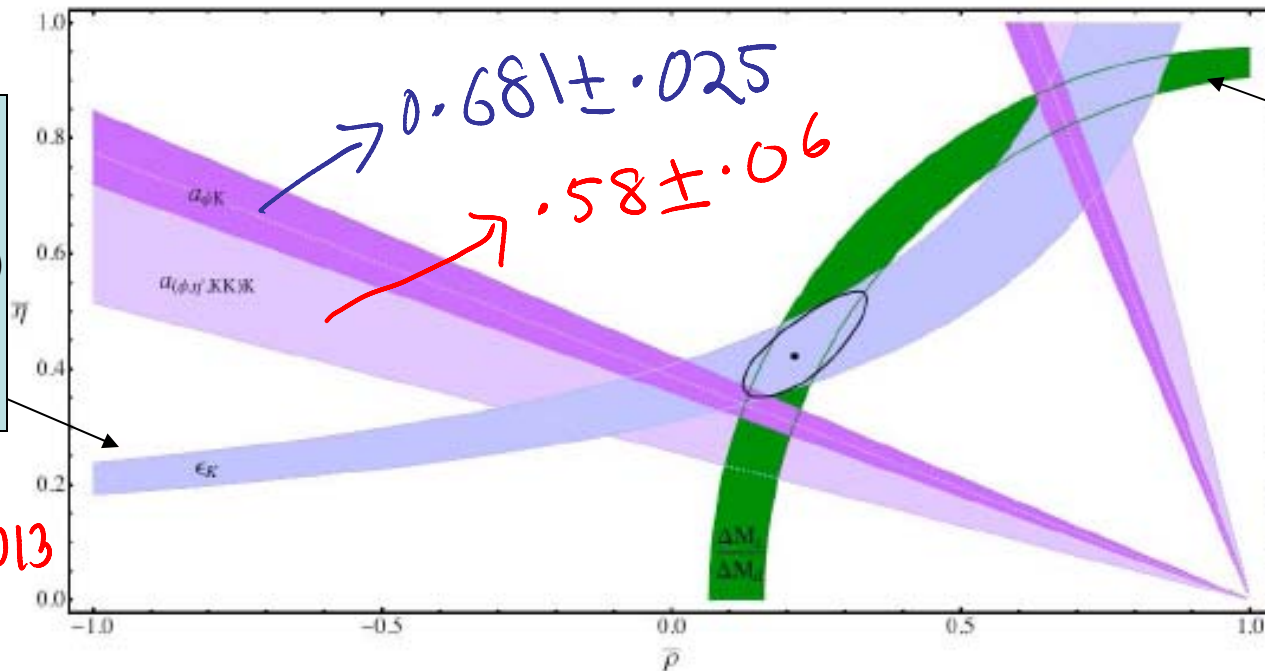
↓ DIRECTLY FROM EXPT

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

0.681±.025

.58±.06

$B_K = .720 ± .013 ± .037$

$|V_{cb}| = 40.8 ± .6 \times 10^{-2}$

{ = 1.20 ± .06
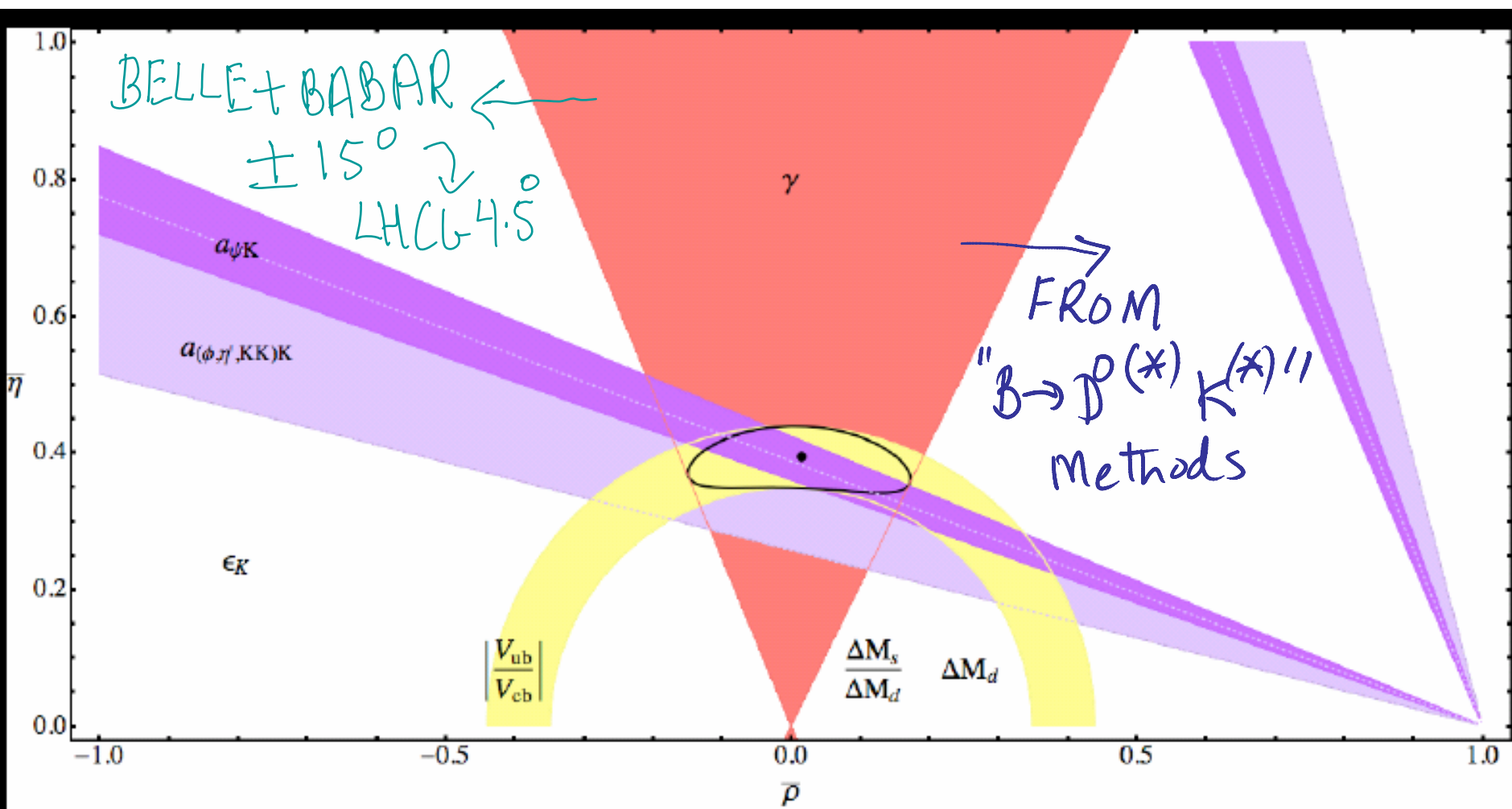
FIG. 1: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.. The solid contour is obtained using the constraints from ε_K and $\Delta M_{B_s}/\Delta M_{B_d}$. The regions allowed by $a_{\psi K}$ and $a_{(\phi+\eta'+2K_s)K_s}$ are superimposed.

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

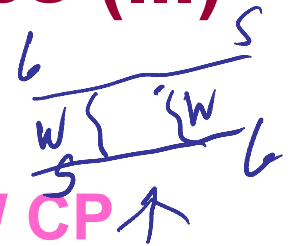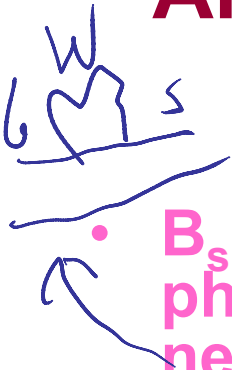# **Predict sin 2 β only from "trees"**

Lunghi + AS

(work in progress)

Anomalies in B(B$_s$)-CP asymmtries (III) & a possible resolution

- **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)**

- **-> 4th family with rather heavy t'(b'), perhaps ~TeV 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 in several nice papers: JHEP'06;PRL'05;PRL'07… though discussions confined to lighter mt' around 300 GeV}

NOTE Also FERMILAB (ICHEP08) m_t' > 311 GeV

-> IN OUR WORK mt' larger than ~600 GeV seems

necessary -> 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, Holdom; Burdman et al}

How does 4th family fit in?

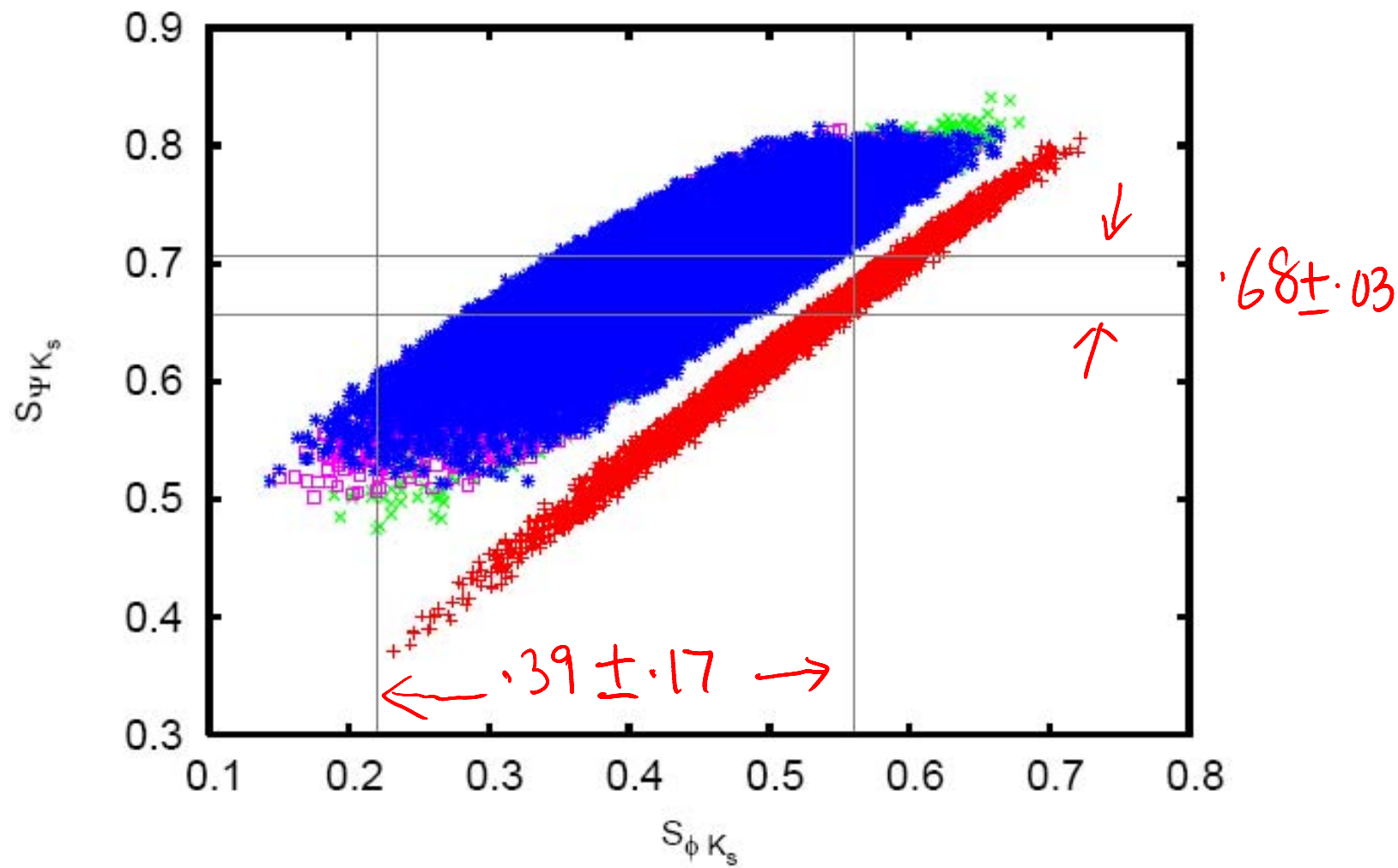$A \sim m_t'^2$

COLOR ALLOWED

EWP ↑   TIO

$14.4 \pm 2.9\%$

Evasion of decoupl.p Theorem

BANDS due 30% error

1000   800   600   400

$\lambda_{t'}^s \equiv |V_{t's}^* V_{t'b}|$

Recall $\lambda_t^s \simeq 0.04$

Byond_SM3_CERN_sept08(soni)   18
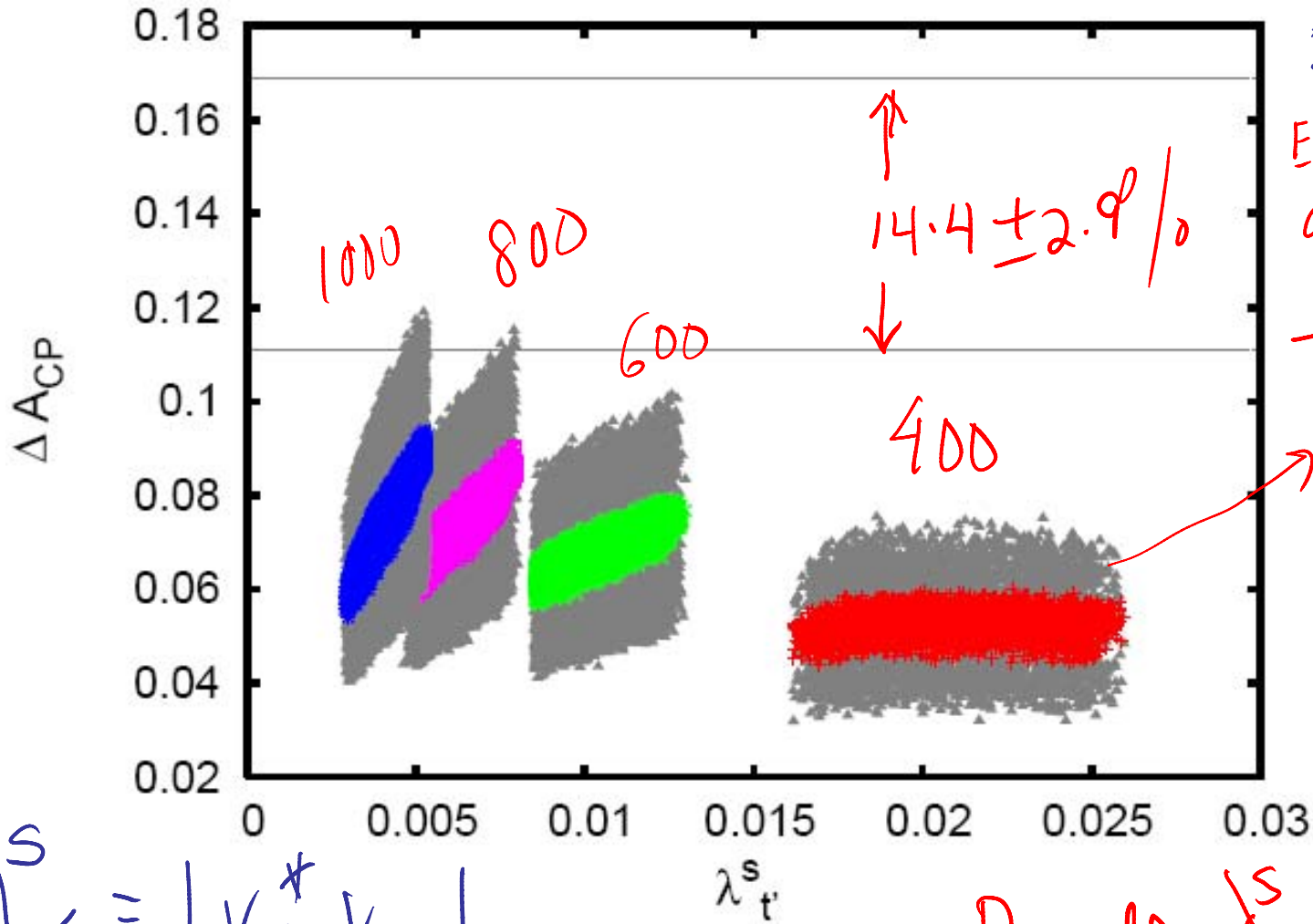
THUS

by cmstruction

- **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**

- **Dynamics of EW gauge interactions (evasion of decoupling theorem) by EWpenguins and the large mt' plays a crucial 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 heavier than ~600 GeV (perhaps O(TeV)) then for sure it will have a very serious role to play in EWSB

- It will clearly have significant impact on CP violation phenomena, given that now we will have 2 additional CP-odd phases

- It may play an interesting role in baryogenesis (W.-S. Hou, 0803.1234; Fok & Kribs, 0803.4207)

- An important CAVEAT…such heavy mass of t' means Yukawa couplings are rather large so perturbation theory calculations used in here are likely to have large corrections

- Of immediate interest is the 5-paramter space:

- m_t', Re & Im {lamda^d_t'} , Re & Im {lamda^s_t'} which is under intense study {AS + Alok, Giri, Rukmani and Nandi}

Boring Repetition (II)

- **Nature of this family may be quite different from 1st 3 since the corresponding neutral lepton has to be >m$_Z$ /2**
- **Relevant to EW flavor phenomenology is only that 3X3 CKM matrix is getting enlarged to 4X4**
- **However, this does NOT preclude the possibilty,**

   for example that new fermion generation is NOT a Kaluza-Klein excitation relevant to warped space interpertaition….This is to emphasize that new family may have significant, fundamental differences with the 1st three
- **In addition to baryogenesis, EWSB, also**

   important role possible as dark matter candidate (see e.g. Volovik, hep-ph/0310006)

Repercussions for LHC

- **Efforts should be put to devise strategies for searching 4th family quarks and leptons.**

- **Mass splitting between t' and b' has to quite small due to electroweak precision constraints…this provides important clues as to the decay properties of the new fermions**

Summary & Conclusions

- **While for now no compelling evidence against CKM-picture, several interesting and fairly sizeable effects in B,Bs CP asymmetries   are quite difficult to understand.**

- **Repercussions for MFV: such indications if confirmed would be difficult to reconcile with MFV**

- **Moreover, embedding of such low scale {O(TeV)}, NP scale in flavor physics is usually a very difficult challenge..(i.e. alignment problem)**

- **In this sense, if the effects stand further scrutiny, SM4**

   with rather heavy mt', mb' (O (TeV)) provides a natural explanation of the anomalies.

- **SM4 may have interesting role to play in baryogenesis and EWSB, DM….thereby it may well be a very economical resolution to the hierarchy problem & other important issues**

   in Particle Physics

Backup slides

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

Amarjit Soni,[1] Ashutosh Kumar Alok,[2] Anjan Giri,[3] Rukmani Mohanta,[4] and Soumitra Nandi[5]

[1] *Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA*
[2] *Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India*
[3] *Department of Physics, Punjabi University, Patiala-147002, India*
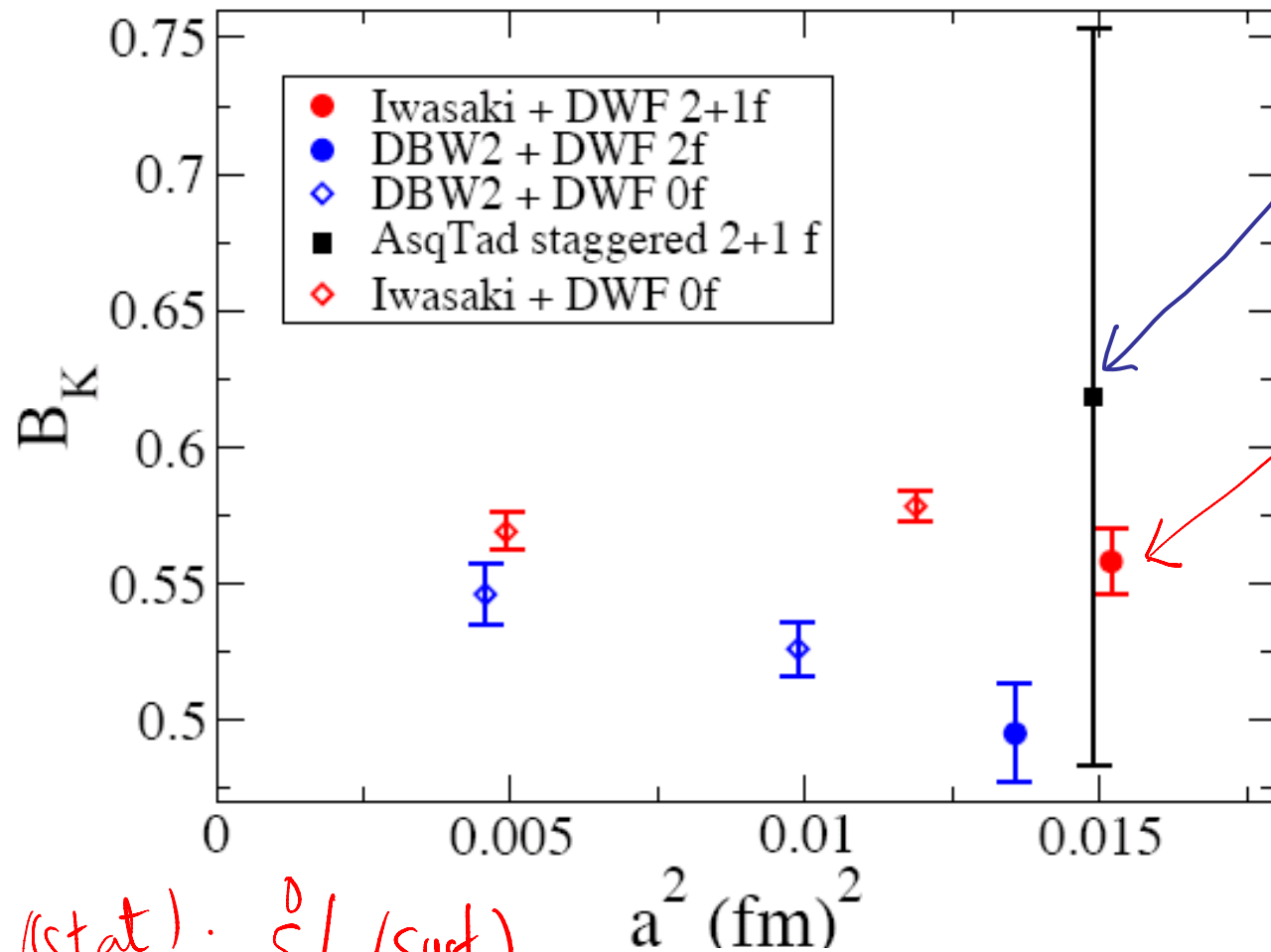[4] *School of Physics, University of Hyderabad, Hyderabad - 500046, India*
[5] *Harish Chandra Research Institute, Chhatnag Road, Jhusi, Allahabad- 211 019, India*

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.

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

PRL Jan25,08

Iwasaki + DWF 2+1f
DBW2 + DWF 2f
DBW2 + DWF 0f
AsqTad staggered 2+1 f
Iwasaki + DWF 0f

Stagg2+1 (HPQCD)

RBC+UKQCD

$\sim 2\%\ (Stat)$; $5\%\ (Syst)$

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 $\Delta m_s / \Delta m_d$ 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

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 $\hat{B}_K^{\text{new}} = 0.96 \pm 0.04$, $\xi_s^{\text{new}} = 1.37 \pm 0.06$ or $V_{cb} = (44.3 \pm 0.6) \times 10^{-3}$.

$$[\text{USED } \hat{B}_K = 0.72 \pm .04; \ \xi_s = 1.20 \pm .06;$$
$$V_{cb} = (40.8 \pm .6) \times 10^{-3}]$$
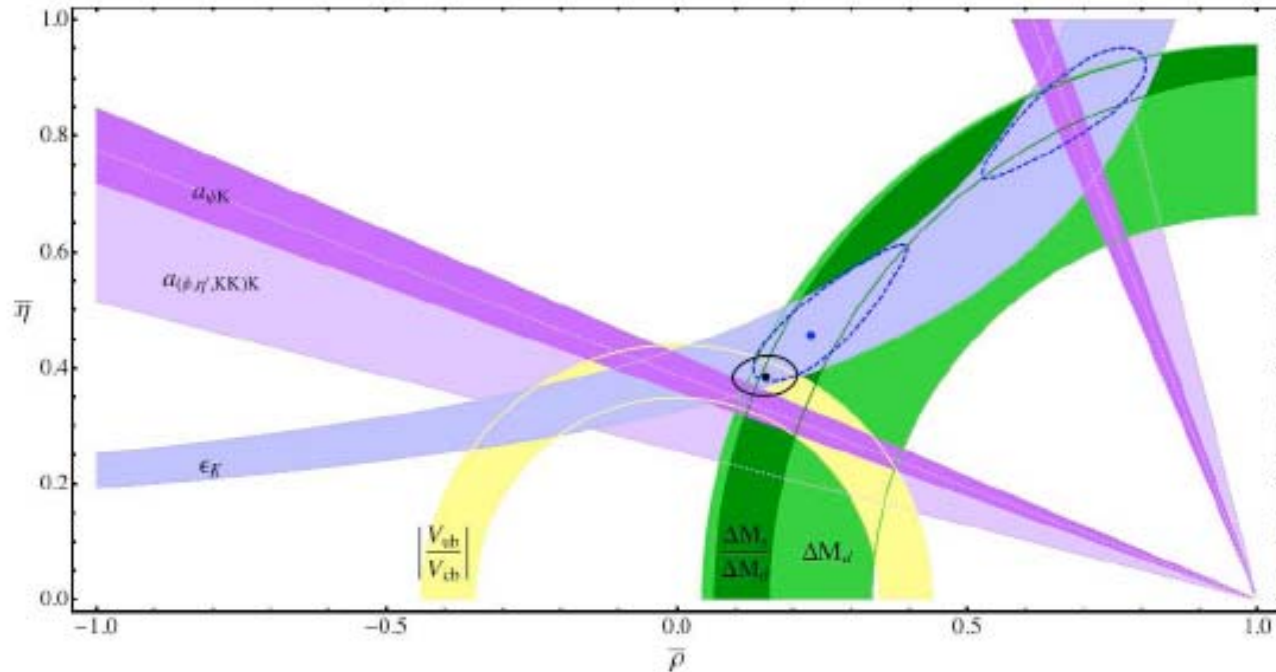
FIG. 2: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.. The solid contour is obtained using the constraints from ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ and $|V_{ub}/V_{cb}|$. The dashed contour shows the effect of excluding $|V_{ub}/V_{cb}|$ from the fit. The regions allowed by $a_{\psi K}$ and $a_{(\phi+\eta'+2K_s)K_s}$ are superimposed.
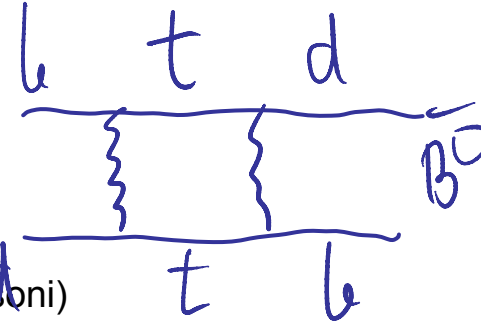
Continuing saga of Vub

- For past 2 years or so exclusive & inclusive ~small discrepancy:
- Exc ~ $(3.7 +-.2+-.5) \times 10^{-3}$
- Inc ~ $(4.3 +-.2+-.3) \times 10^{-3}$
- More recently (LP'07) Neubert suggests source is m_b extraction from b s gamma; disregarding that m_b shows incl. Vub quite consistent i.e. $3.98+-.15+-.30 \times 10^{-3}$

-> *Let's try NOT use Vub*

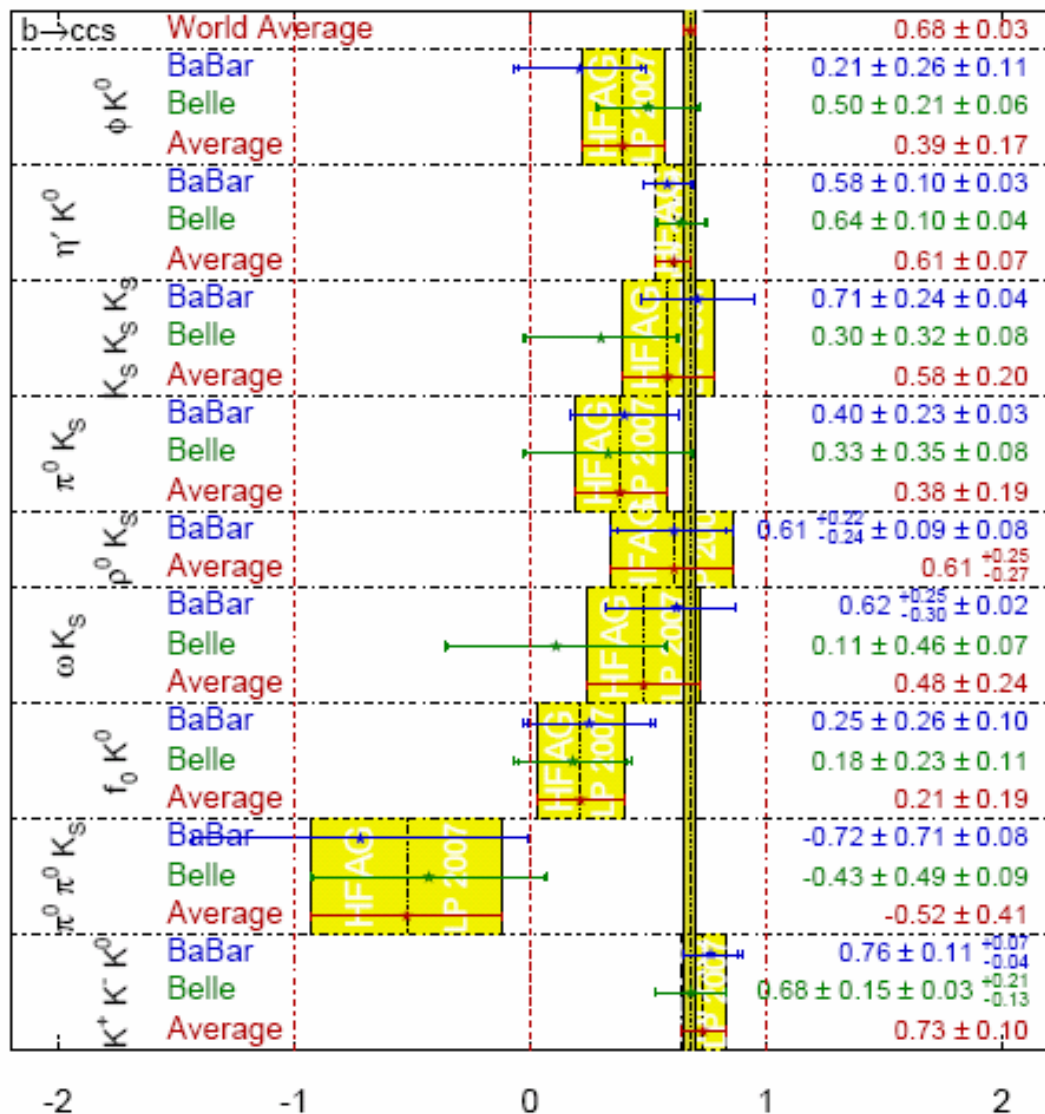$$\Delta S \equiv S_{penguin} - S_{\psi K_S} = O(\lambda^2)$$

$$S_{peng}^{Decay} \simeq O(\lambda^2) \sim \text{few}/_0$$

$$S_{\psi K_S}^{Decay} = 0$$
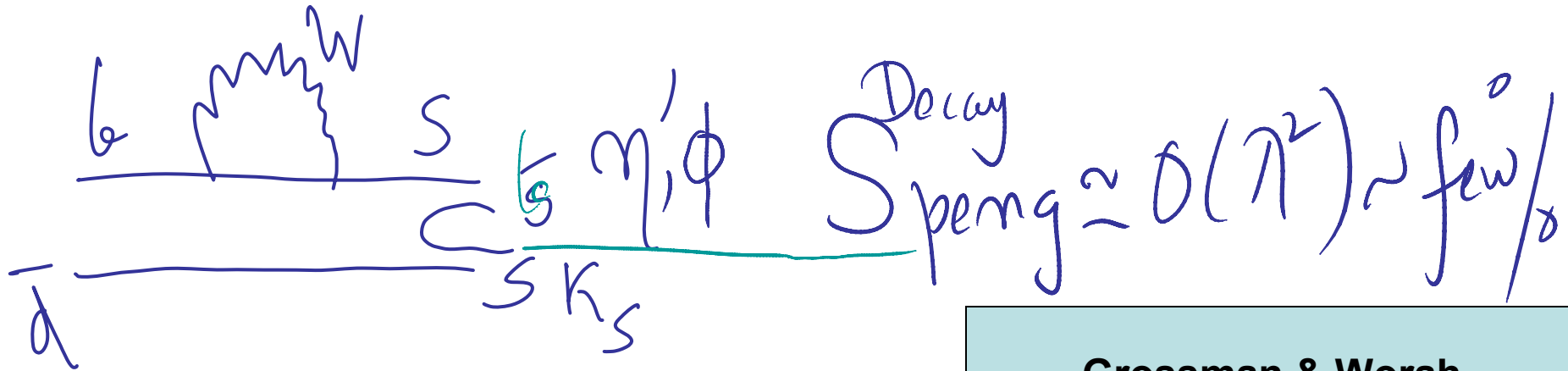
Grossman & Worah, hepph/9612269; London & AS, hepph/9704277
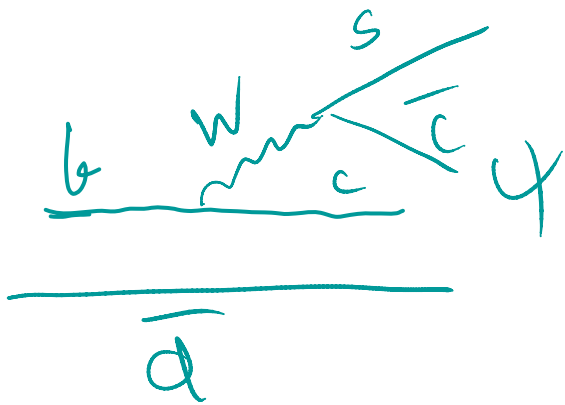
OSC is COMMON

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