The rise & demise of the CKM-paradigm

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CKM2010

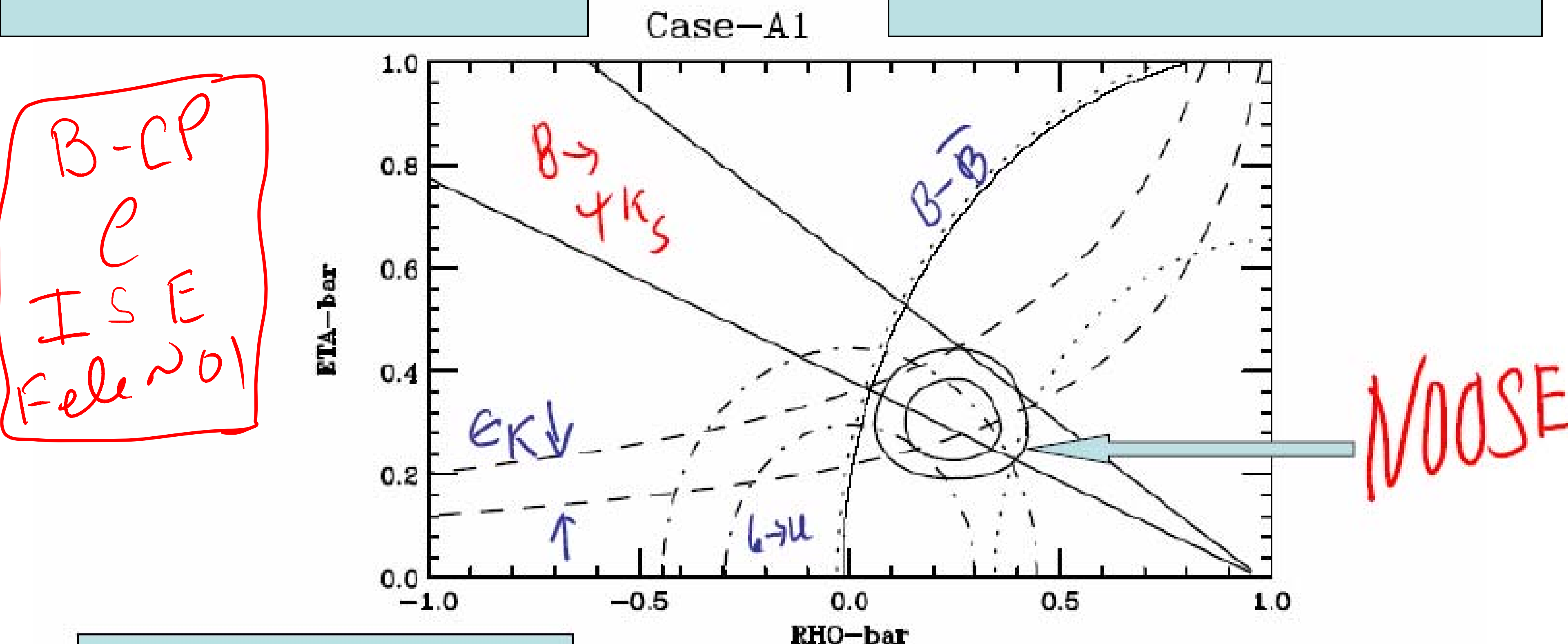
Outline

- **B-factories data upto ~'06 or so showed CKM-CP works to O(15%) accuracy**
- **Despite many warnings that 15-20% is huge for contamination from BSM, the degree to which CKM-CP works may have been oversold having serious adverse effect, at least on some experimental programs.**
- **Around '07-08 accumulated data upto then indicated measured value of sin2beta smaller than theory prediction by ~2 sigma**
- **CKM'10 updates (more data + important lattice developments) -> heightened discrepancy with the SM**
- **A simple NP scenario at work**
- **Summary & Outlook**

Glorious Successes

1st Hint of confirmation of CKM CP description

Atwood &AS, hepph/0103197



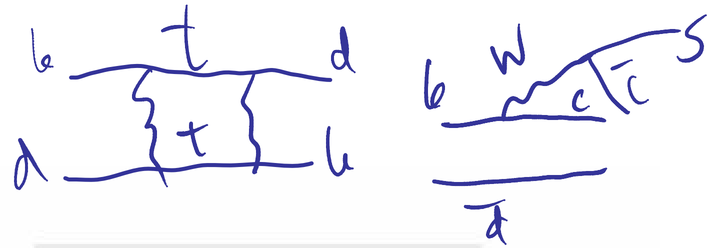
Most bands due
To theory errors

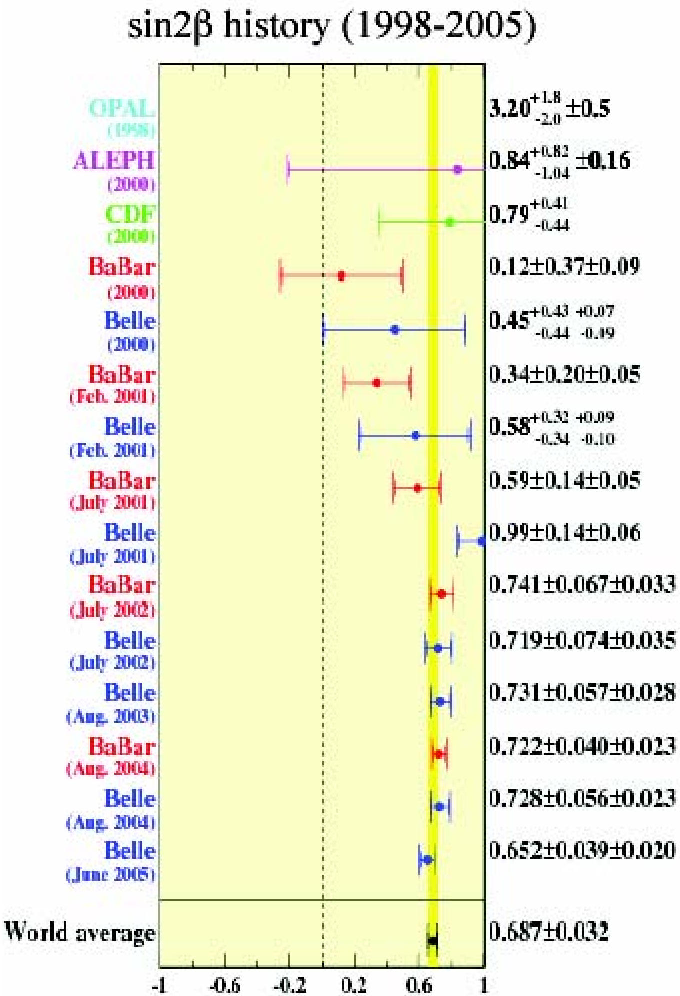
New physics will be a perturbation, important to use clean theory and lots of statistics.

ALL EXPERIMENTAL DATA MUST REQUIRE ONLY UNIQUE ρ,η

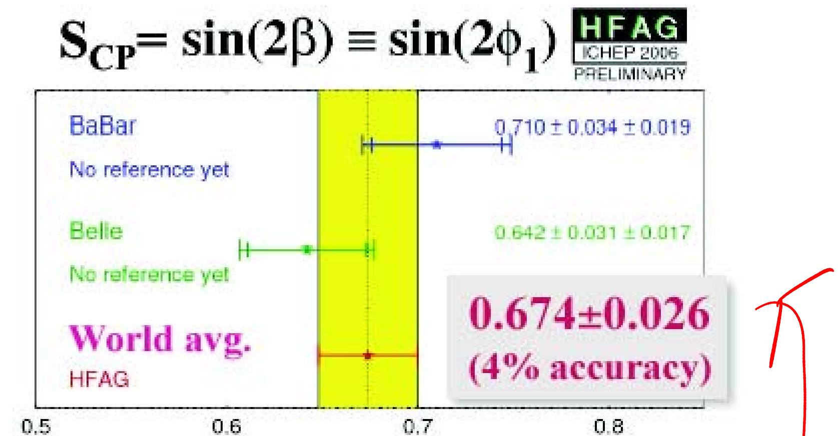
CIRCA ~2006

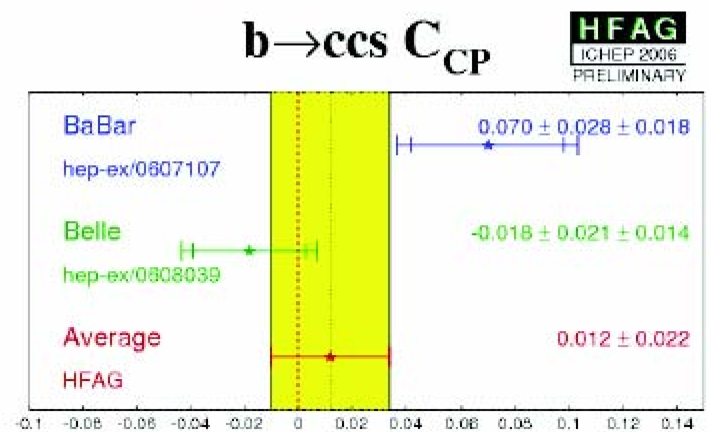
MEASUREMENT of β(φ1)





2006 BaBar + Belle





SM sin2β = .79 ± .10

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.

Role of the lattice weak matrix elements in the KM prize

- B_K is indispensible to demonstrate that the CKM phase SIMULTANEOUSLY accounts for Kaon CP as well as B-CP.

. Argueably lattice WME role in the Nobel Prize is as essential as BFs.

Actually there is much more to it then even that.

$$B_K \equiv \langle K | (\bar{s}\gamma_\mu L d)^2 | \bar{K} \rangle / \tfrac{8}{3} f_K^2 m_K^2$$

$$\epsilon_K = (\text{KNOWN Constant})\, B_K\, \eta$$

BROWN MUCK

gem

Possible cracks in CKM?

Based on Lunghi+AS

0707.0212; 0803.4340; 0903.5059;0912.0002

& Work in progress (WIP)

Accentuated need for precise tests of the CKM-paradigm

- It has been clear for quite a while that CKM paradigm accounts for the experimental results on sin2beta dominantly. There seems to be about 15-20% room for new physics. It is a serious mistake to assume that this degree of consistency rules out new physics as even ~ few % contribution can be pretty significant.
- This reasoning suggests that we need to sharpen and improve our tests.
- Therefore in collaboration with E. Lunghi we have been trying systematically improve the tests since ~07

Summary of B-CP Anomalies (~'07-'10)

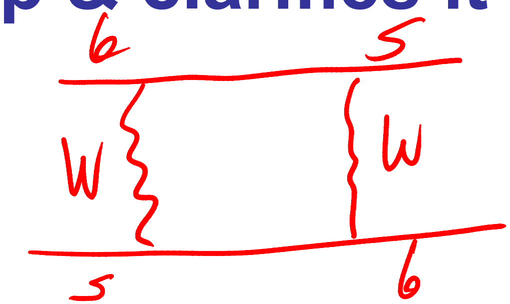
- Fitted ("SM-predicted") value of sin 2β(φ_1) vs directly measured, a) via golden tree decays
- b) via penguin-dominated loop decays

$\eta' K_S$, ϕK_S, $3K_S$ .....

- Dir CP in K+π- vs K+ π0
- Bs->ψφ (esp. significant since 1. Its theoretically very clean(Gold plated) II. It essentially follows from others…Consequently very important that Fermilab follows it up & clarifies it with very high priority).

c also UTFIT '08
LENZ+NIERSTE '06

- D0-dimuon SSA



~2—~3σ effects

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

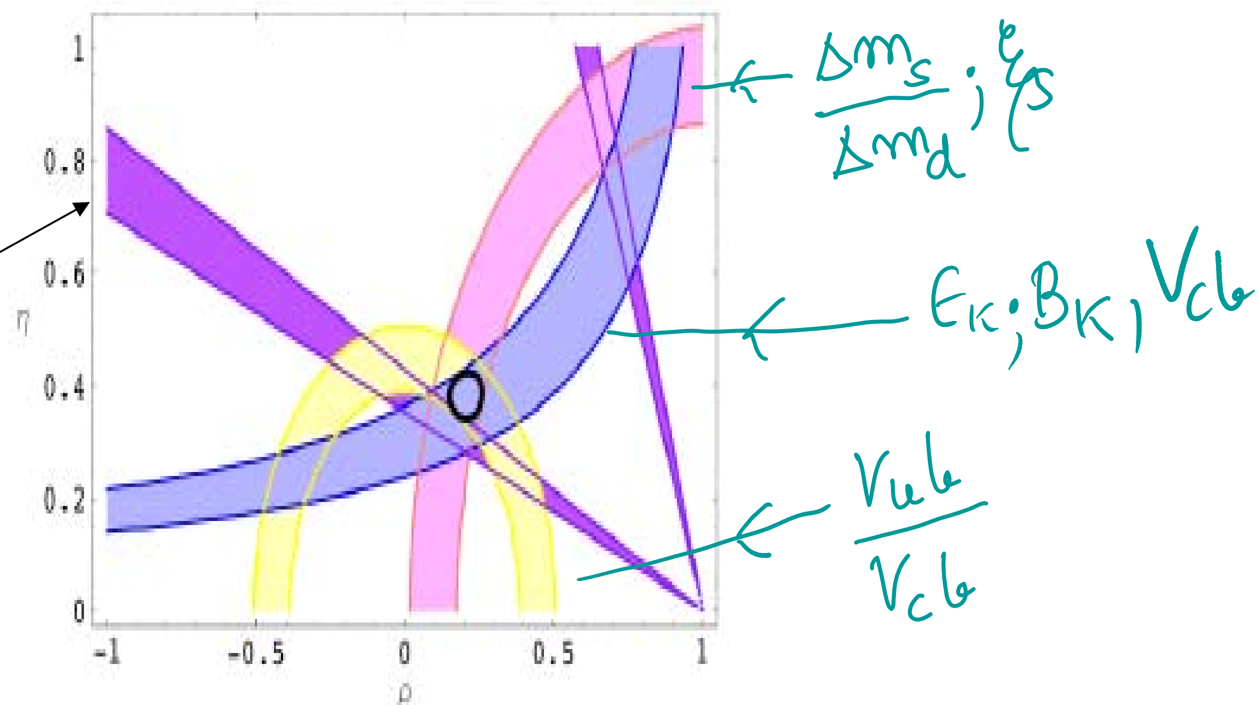


Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

CALSO UTFITS '07

Continuing saga of Vub

- For past many years exclusive & inclusive show discrepancy (Latest; gotten worse)
- Exc ~ (29.7 +-3.1)X10^{-4}
- Inc ~ (40.1+-2.7+-4.0)X10^{-4}

lattice e.g. $B \to \pi l \nu$

Continuum $B \to X_u l \nu$

-> ***Let's try NOT use Vub: initiated in '08 (EL&AS'08)…Not just for the above reason***

ONLY BECAME VIABLE DUE TO SIGNIFICANT BETTER B_K

Use Short-Distance Physics observables as much as possible

- **Vub is not under good control**
- **Vub is tree**
- **Use only ε_K & $\Delta m_s/\Delta m_d$ …so only DeltaF=2 Boxes & SD physics is involved [sooner or later its got to reveal NP]**

SU(3) Breaking only

- **Needed lattice info:EXCELLENT PROSPECTS FOR PRECISE DETERMINATION**

  no momentum inj. , chiral fermions, no or negligible issues with op. mixing
- **Became possible only due major strides in lattice accuracy**
- (Fine foot print Vcb)….addressed later …Lunghi & A.S, '09

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

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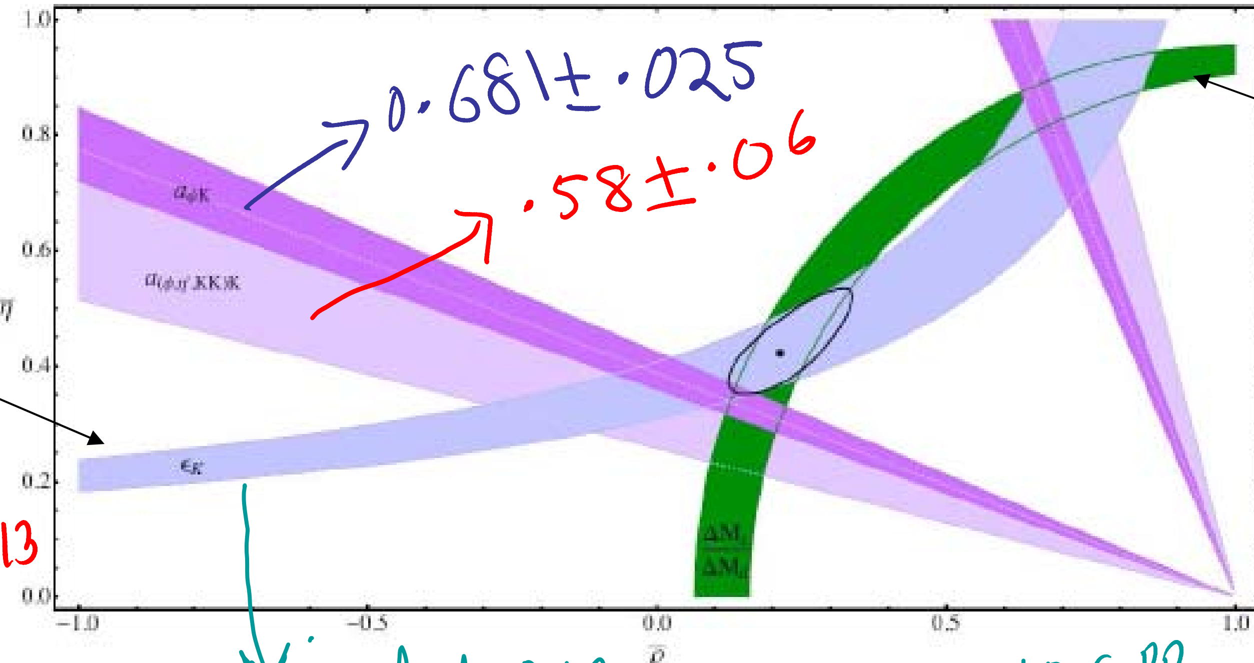


$\hat{B}_K = .720 \pm .013 \pm .037$

$|V_{cb}| = 40.8 \pm .6 \times 10^{-3}$

include BURAS+GUADAGNOLI CORR. (0805.3887)

$\xi = 1.20 \pm .06$

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

A BRIEF (≈ 25 years) HISTORY OF $\hat{B}_K$

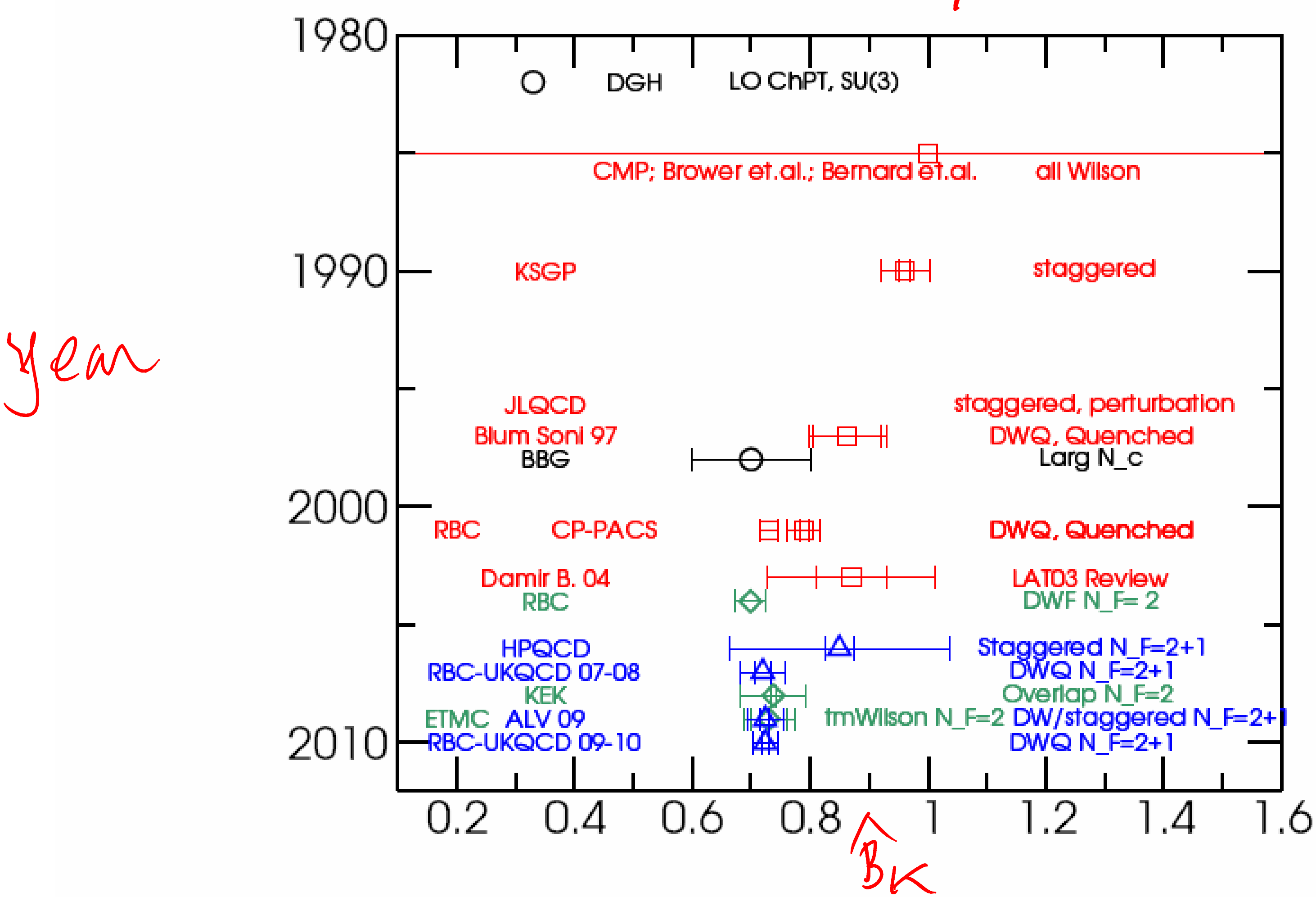
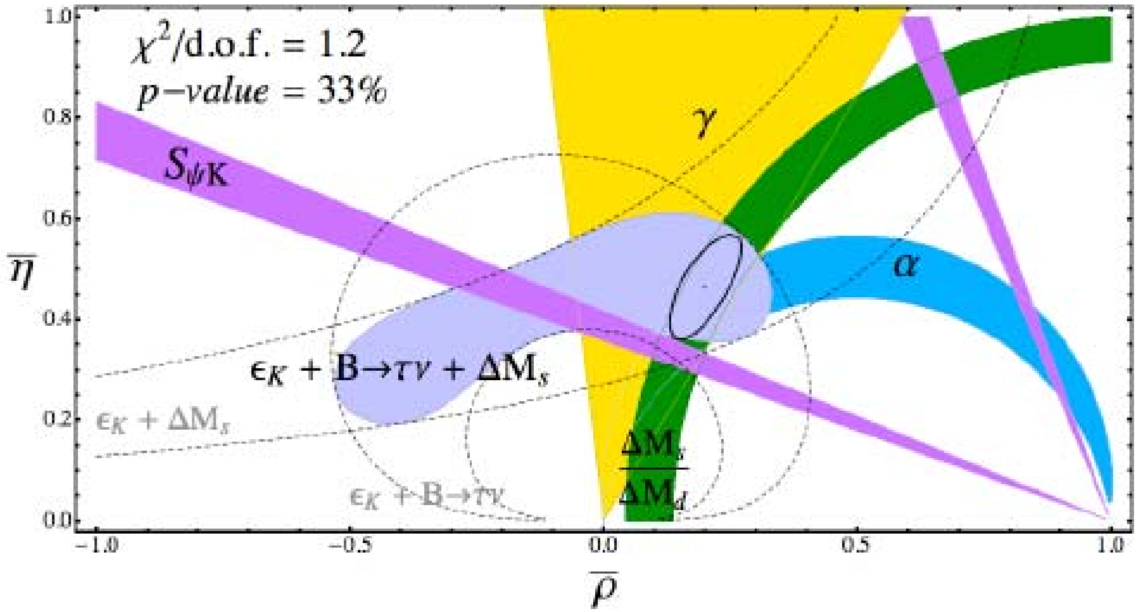


FIG. 20: A brief (≈ 25 years) history of $\hat{B}_K$; from continuum models (black), quenched lattice (red), $N_F = 2$ lattice (green), and $N_F = 2 + 1$ lattice (blue).

Different APPROACH: UT WITHOUT SEMI-LEPTONIC DECAYS
Lunghi+ AS, 0912.0002



sin2β
~1.86

FIG. 2: Unitarity triangle fit without semileptonic decays. The solid contour is obtained using ε_K, $B \to \tau\nu$, γ, ΔM_{B_s} and ΔM_{B_d}. The dashed contours show the interplay of the ε_K, ΔM_{B_s} and $\mathrm{BR}(B \to \tau\nu)$ constraints.

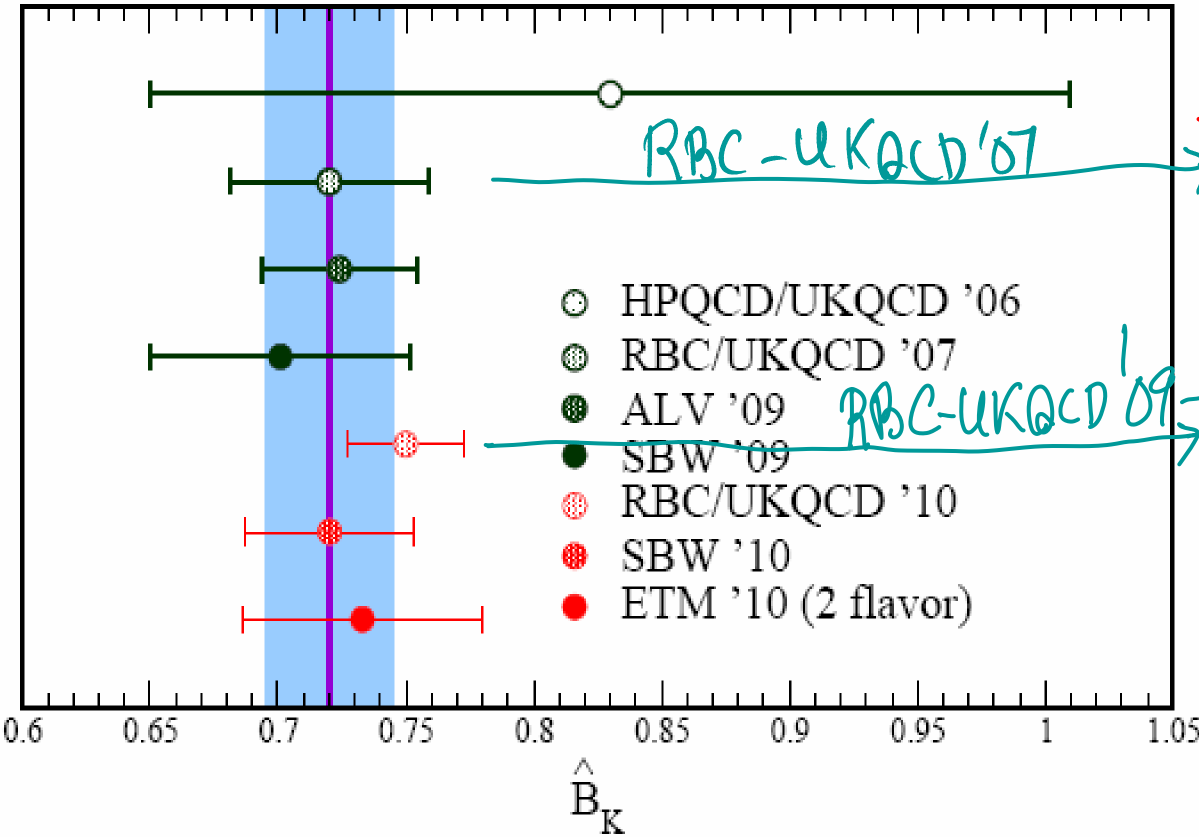
NEED IMPROVED BR $B \to \tau\nu$
(4 "f_B")

UPDATES for CKM'10

B_K

Jack Laiho @ Lattice '10

Used by L&S '08



RBC-UKQCD '07 → 0.720 ± .013 ± .037

RBC-UKQCD '09-'10 → 0.750 ± .010 ± .030

Now use 0.740 ± .025

Inputs to the UT fit

$\|V_{cb}\|_{excl} = (39.0 \pm 1.2)10^{-3}$	$\eta_1 = 1.51 \pm 0.24$
$\|V_{cb}\|_{incl} = (41.31 \pm 0.76)10^{-3}$	$\eta_2 = 0.5765 \pm 0.0065$
$\|V_{cb}\|_{incl+excl} = (40.43 \pm 0.86)10^{-3}$	$\eta_3 = 0.494 \pm 0.046$
$\|V_{ub}\|_{excl} = (29.7 \pm 3.1)10^{-4}$	$\eta_B = 0.551 \pm 0.007$
$\|V_{ub}\|_{incl} = (40.1 \pm 2.7 \pm 4.0)10^{-4}$	$\xi = 1.23 \pm 0.04$
$\|V_{ub}\|_{incl+excl} = (32.7 \pm 4.7)10^{-4}$	$\lambda = 0.2255 \pm 0.0007$
$\Delta m_{B_d} = (0.507 \pm 0.005)\ \mathrm{ps}^{-1}$	$\alpha = (89.5 \pm 4.3)^o$
$\Delta m_{B_s} = (17.77 \pm 0.12)\ \mathrm{ps}^{-1}$	$S_{\psi K_S} = 0.668 \pm 0.023$
$\varepsilon_K = (2.229 \pm 0.012) \times 10^{-3}$	$\gamma = (74 \pm 11)^o$
$m_c(m_c) = (1.268 \pm 0.009)\ \mathrm{GeV}$	$\hat{B}_K = 0.740 \pm 0.025$
$m_{t,pole} = (172.4 \pm 1.2)\ \mathrm{GeV}$	$\hat{B}_d = 1.26 \pm 0.11$
$f_{B_s}\sqrt{\hat{B}_s} = (276 \pm 19)\ \mathrm{MeV}$	$f_{B_d} = (208 \pm 8)\ \mathrm{MeV}$
$\mathcal{B}_{B\to\tau\nu} = (1.68 \pm 0.31)10^{-4}$	$\kappa_\varepsilon = 0.94 \pm 0.02$
$f_K = (155.8 \pm 1.7)\ \mathrm{MeV}$	

Table 1: Inputs used in the fit. Statistical and systematic errors are combined in quadrature.

14.4%

NNLO GORBAHN & JAGER '10

NEW

FERMI/MILC & HPQCD

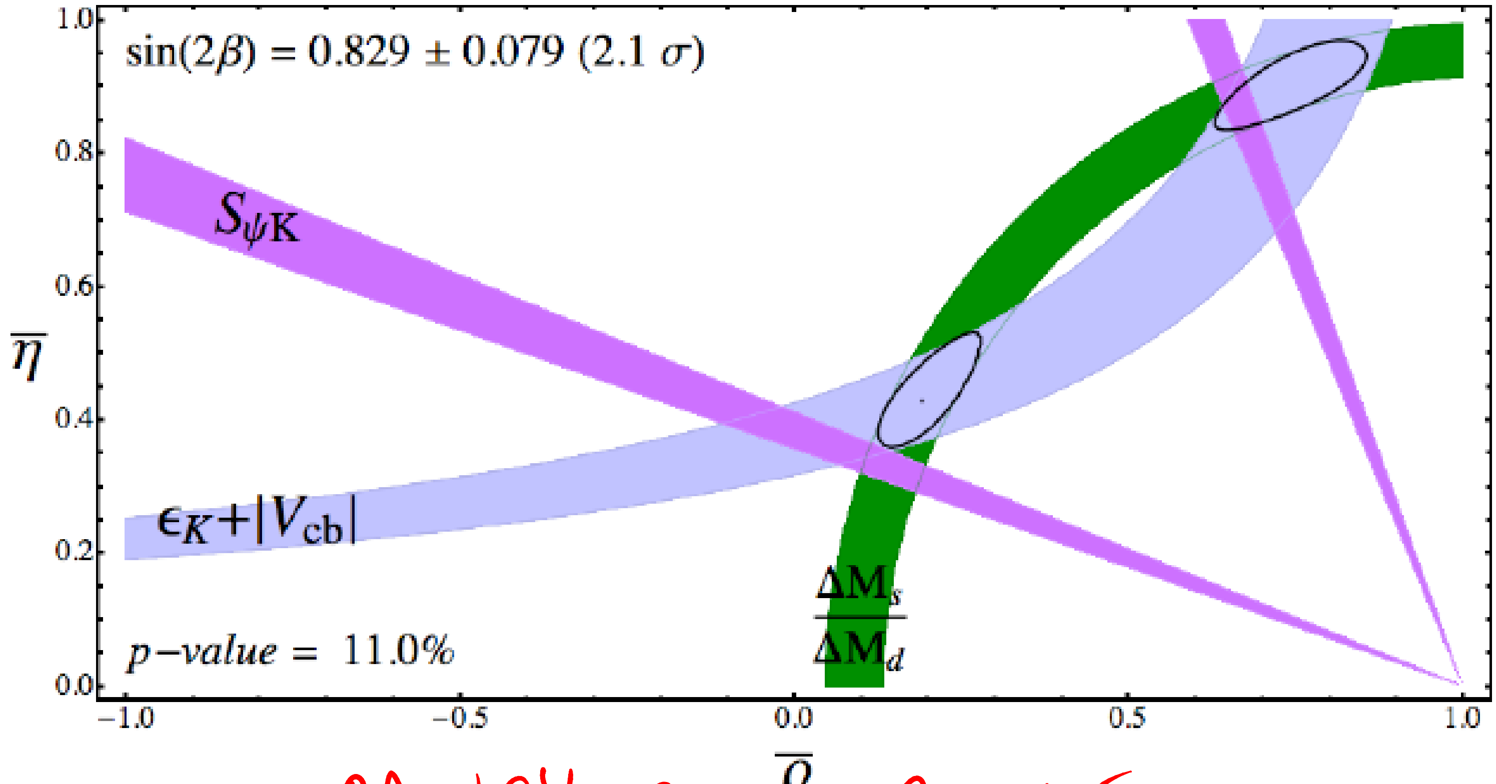
BURAS GUADAGNOLI ISIDORI

V_{ub} now even less Reliable: We'll leave it out again

Several inputs from Laiho,Lunghi & Van de Water

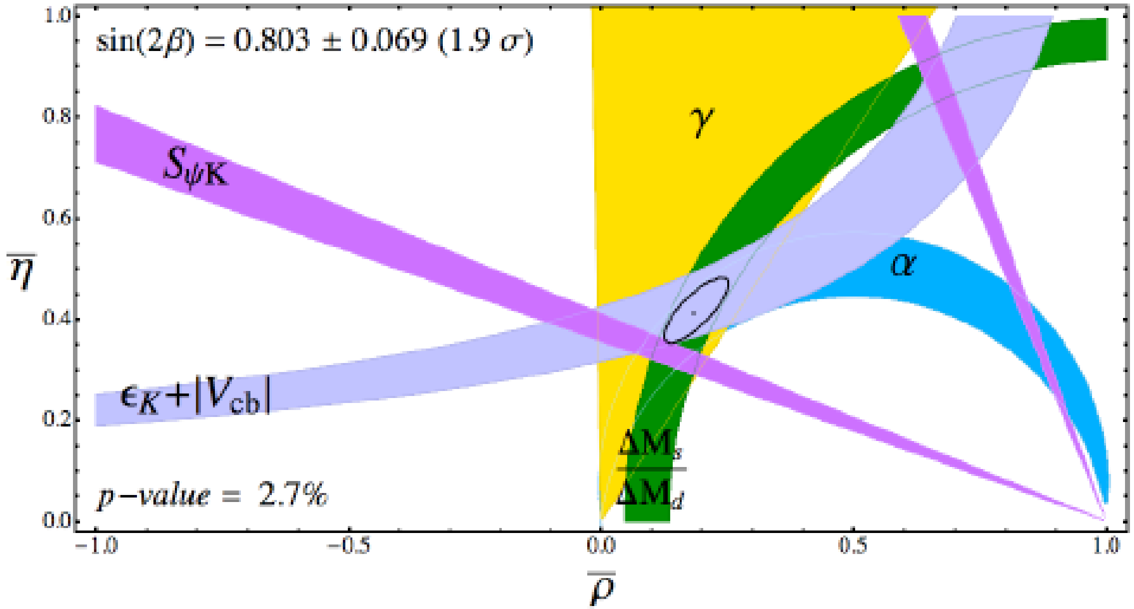
UPDATE of '08

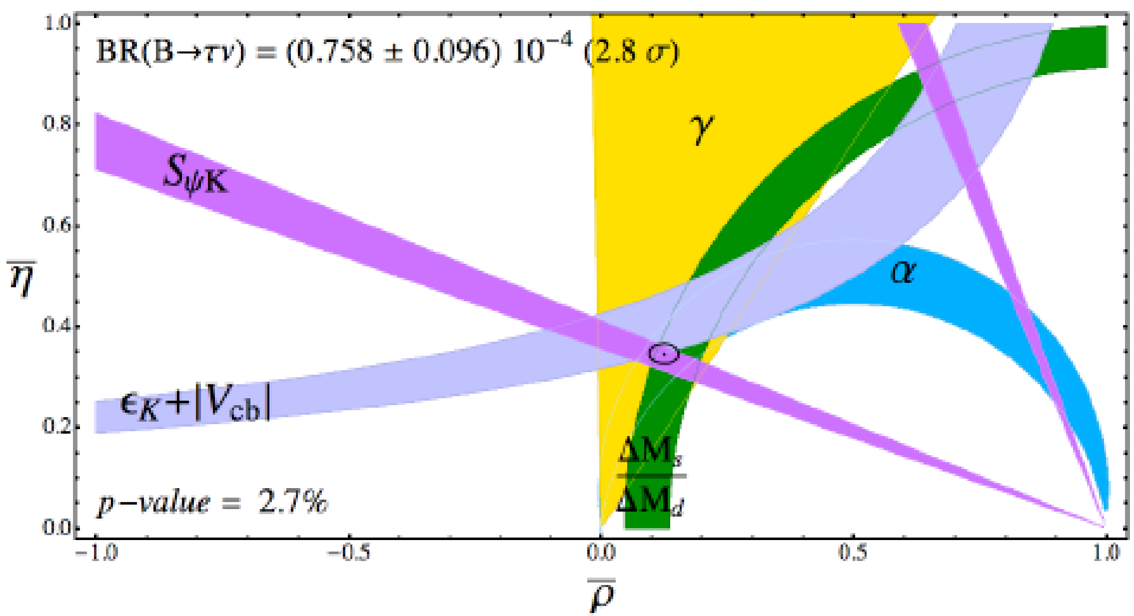
$\sin(2\beta)$ - ε_K - $\Delta M_{Bs}/\Delta M_{Bd}$ - $|V_{cb}|$



DISCREPANCY STAYS @ 2.1 σ

sin(2β) - ε_K - $\Delta M_{Bs}/\Delta M_{Bd}$ - $|V_{cb}|$ - α - γ

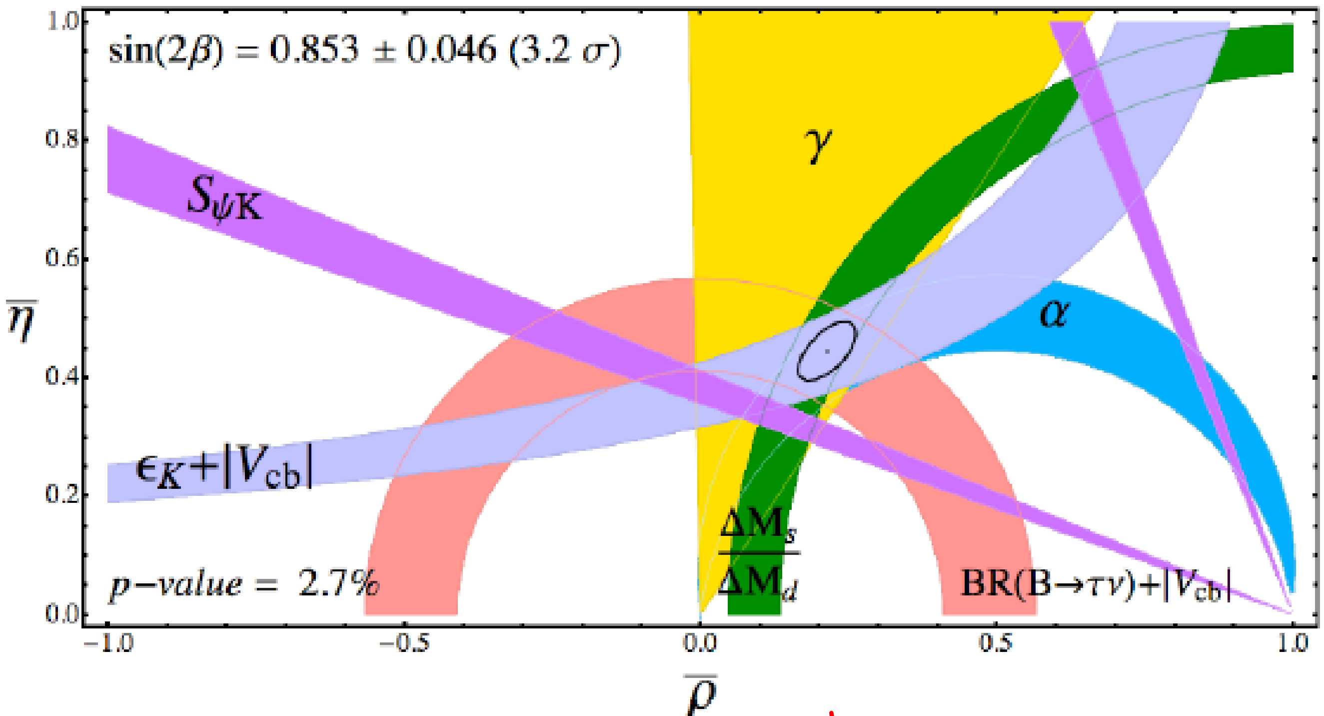




USE $S(\psi K_S)$ to
predict
$B_r(B\to\tau\nu)$

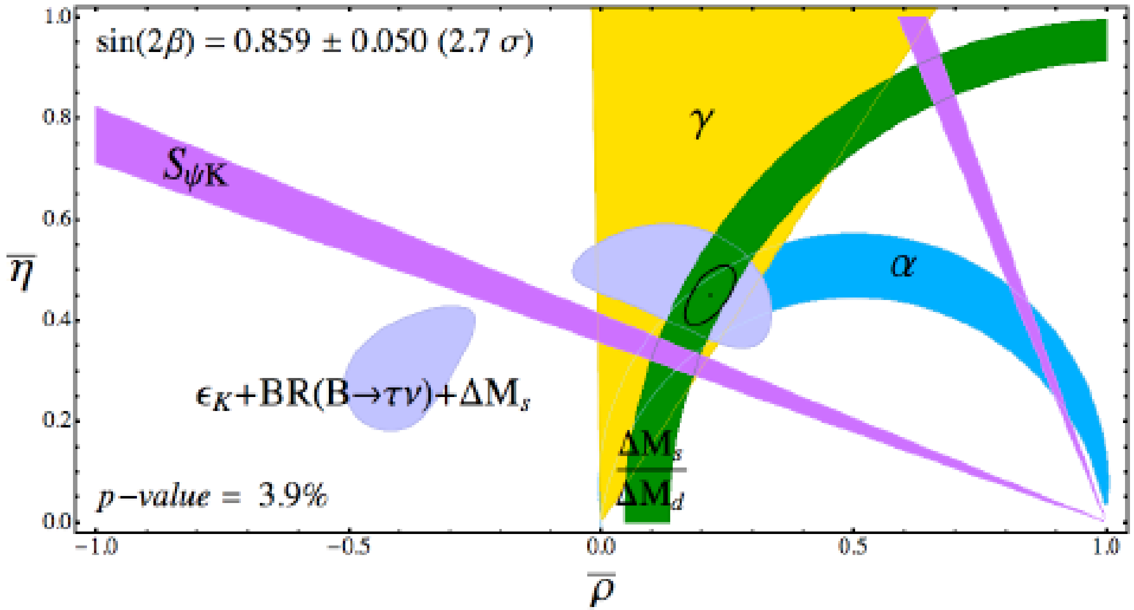
sin(2β) - ε_K - $\Delta M_{Bs}/\Delta M_{Bd}$ - $|V_{cb}|$ - $B \to \tau\nu$ - α - γ

- ΔM_{Bs}

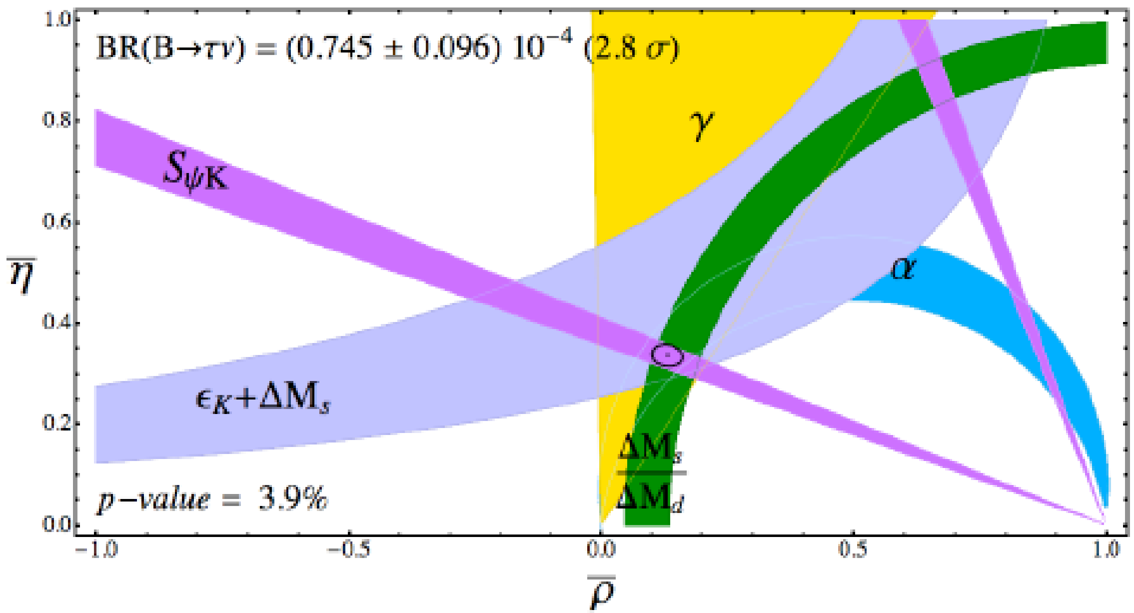


INCLUDE τ to predict sin2β

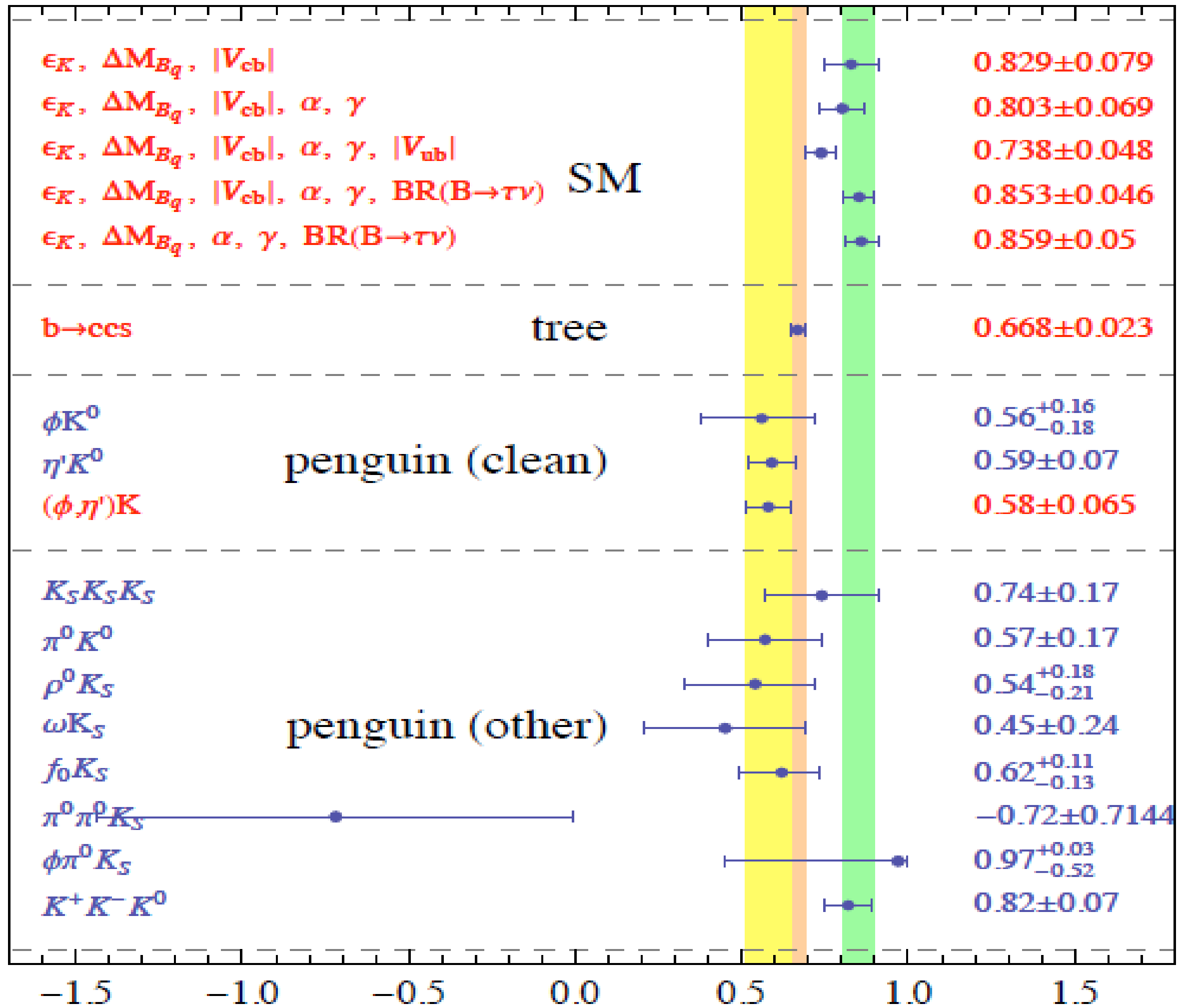
sin(2β) - ε_K - $\Delta M_{Bs}/\Delta M_{Bd}$ - B→τν - α - γ - ΔM_{Bs}



NO V_{cb}
(& of course NO V_{ub})



Summary (sin2β)

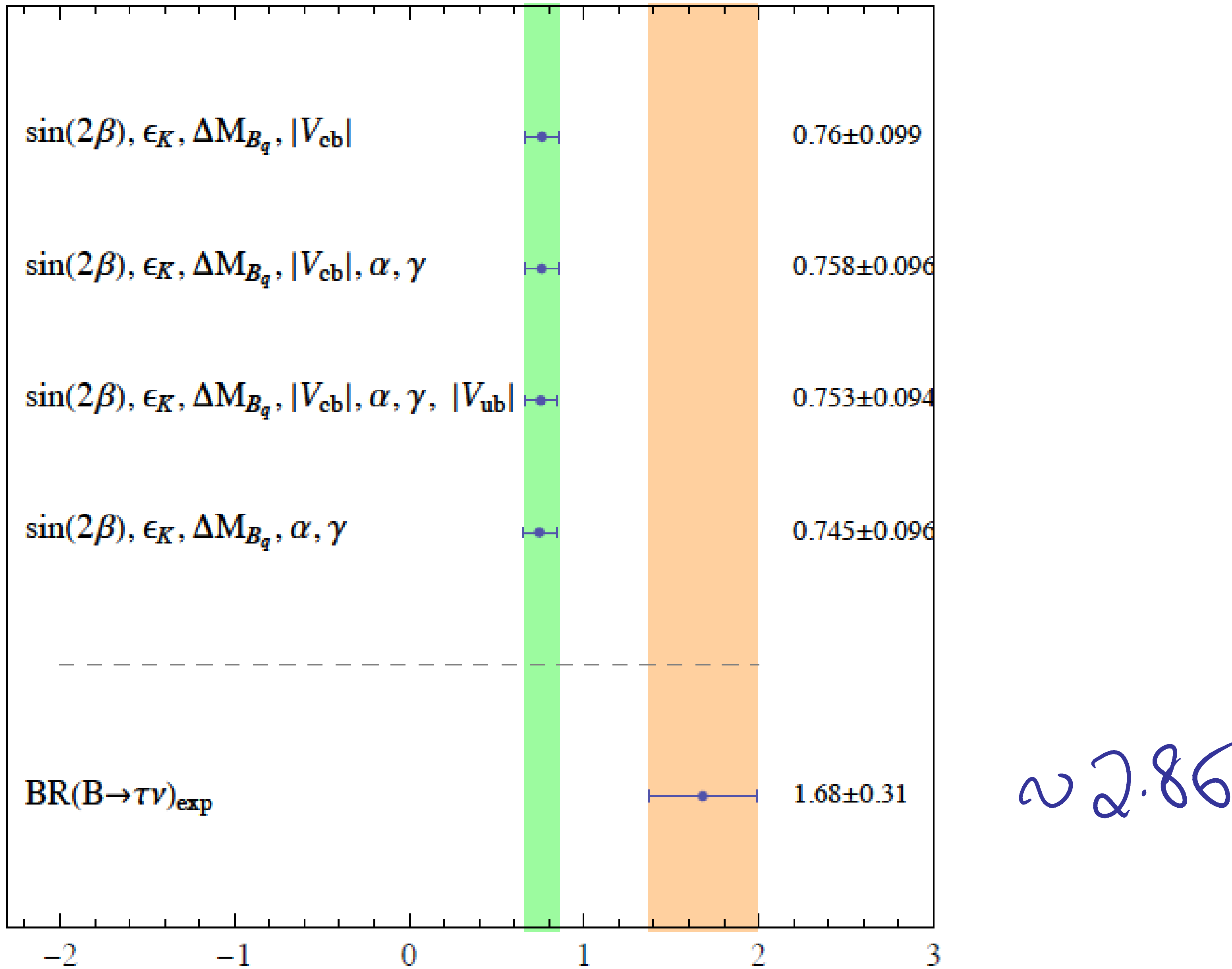


~ 2.6σ

~ 2.8σ

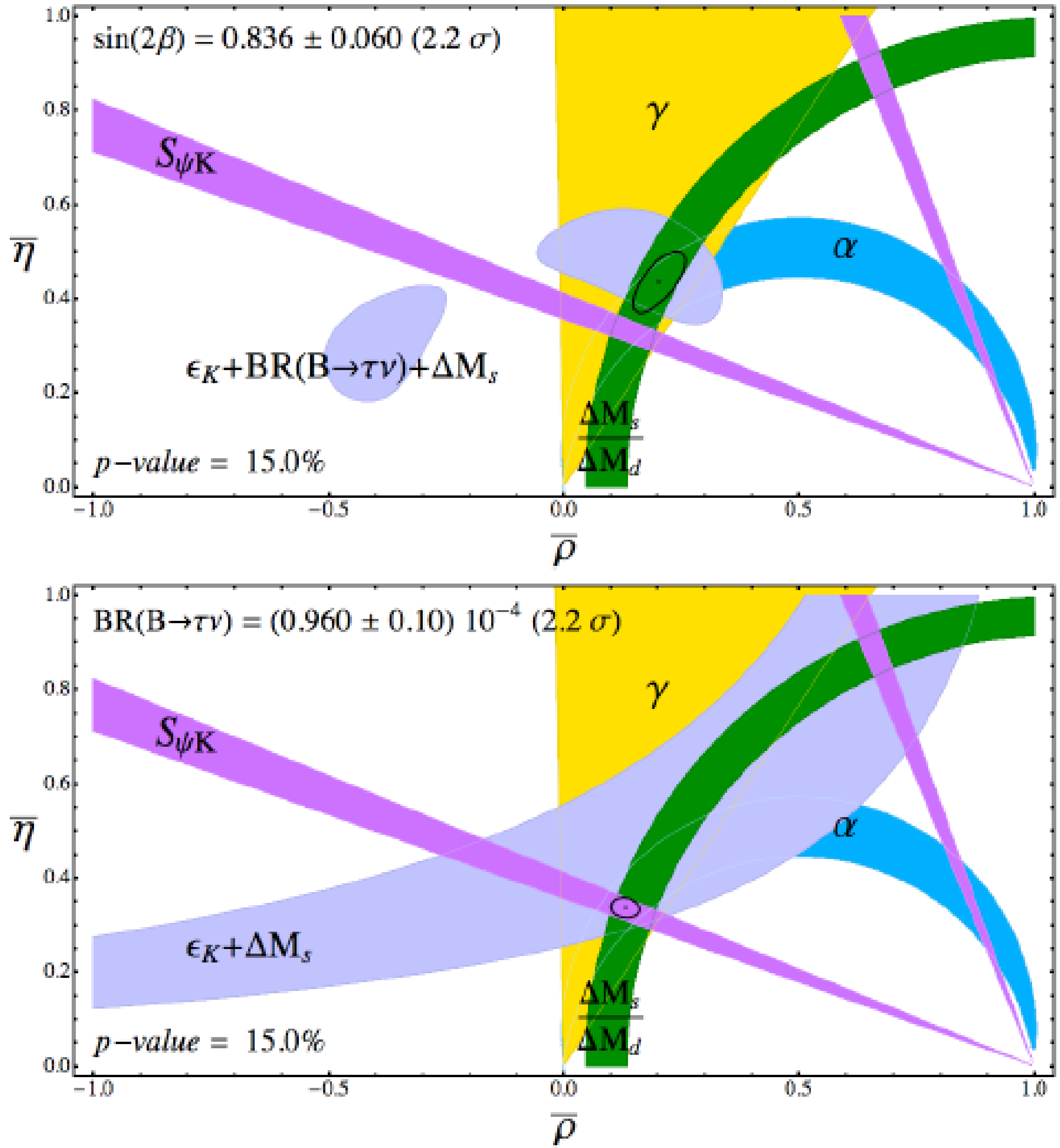
"CONSISTENCY" Bet. $\sin 2\beta^{tree}$ & $\sin 2\beta^{pengin}$ DOES NOT NECESSARILY MEAN NO NP

Summary (B→τν)



sin(2β), ε_K, ΔM_Bq, |V_cb|
0.76±0.099
sin(2β), ε_K, ΔM_Bq, |V_cb|, α, γ
0.758±0.096
sin(2β), ε_K, ΔM_Bq, |V_cb|, α, γ, |V_ub|
0.753±0.094
sin(2β), ε_K, ΔM_Bq, α, γ
0.745±0.096
BR(B→τν)_exp
1.68±0.31
−2
−1
0
1
2
3
∼2.86

sin(2β) - ε_K - $\Delta M_{Bs}/\Delta M_{Bd}$ - B→τν - α - γ



HERE USE direct f_{B_d} from lattice

Interpretation

- **Analysis suggests (AGAIN) sin2 beta likely off appreciably (may be ~ 3 sigma)**
- **Also Br B->tau nu MAY BE off quite a bit unless lattice and/or expt. seriously off**
- **Theoretical prejudice ("reluctance to believe NP in tree graph") suggests the latter option may well be at work; both relevant lattice calculations and experiments deserve a critical scrutiny** (BESIDES - - -

Interpretation(2)

- **Measured value of sin2beta continues to be persistently lower than SM "prediction" since our 2008 analysis…indicating (most likely) that Delta F=2 box graphs (Bd, Bs or K^0; some combo) are seeing effects of NP.**
- **For a long time b->s penguins also indicate S(eta'Ks,phiKs….) systematically smaller than sin2β_expt and even more from "SM"**
- **Large delta A_CP(K pi) likely due NP (at least in part) in b->s penguins**

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	$130 \div 320$
$\mathcal{A}_{b \to s}$	$O_4^{b \to s}$ $O_{3Q}^{b \to s}$	$.25 \div .43$ $.09 \div .2$	$0 \div 70$ $0 \div 30$

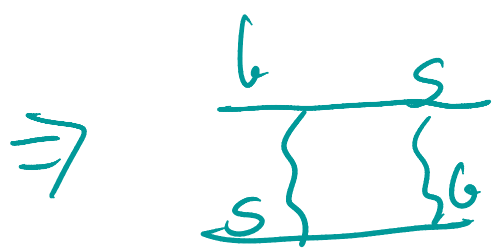
GREAT NEWS 4 LHC, LHCb & for SBF!

C also UTFit:0707.0636
CKMFit: 1008.1593

For LR case enhancement noted long ago, See Beall, Bander and A.S. PRL 48:848,1982

If hint of new CP-odd physics in b->s (penuin modes),Delta Flavor=1 is taken seriously then it becomes unnatural not to have new CP-violating phase in Bs mixings, since these are Delta Flavor=2

pictures



SM4: 4 Gen. standard model

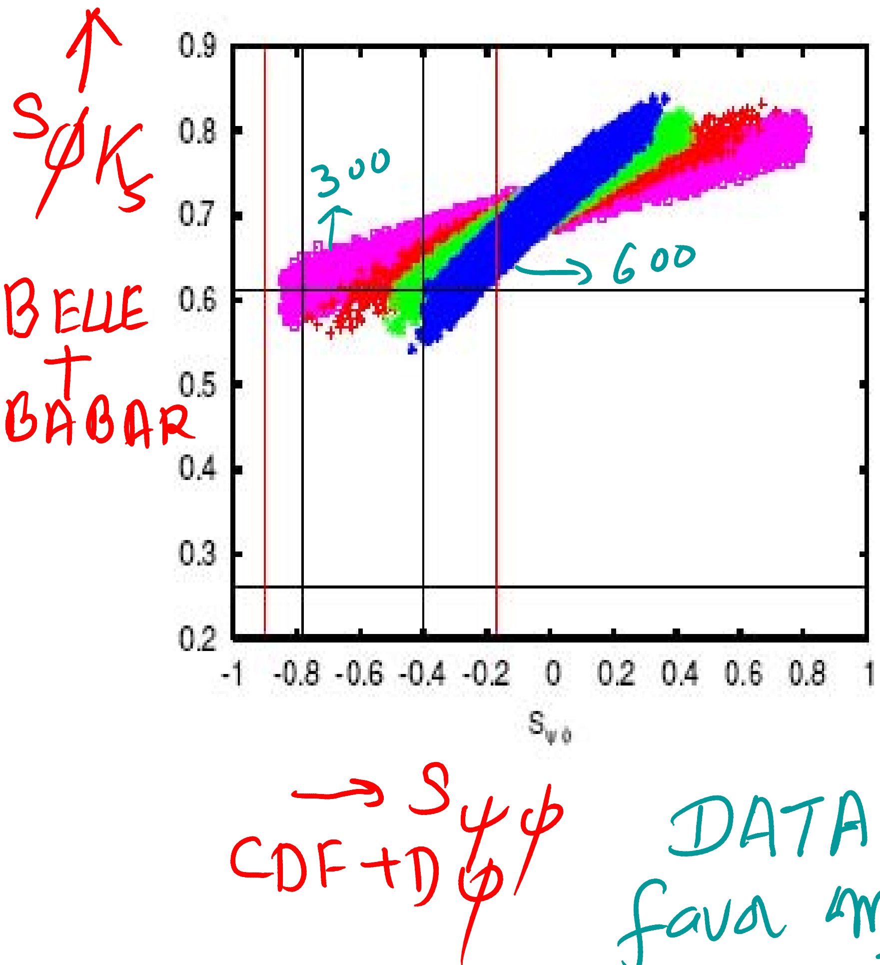
- Provides a rather simple explanation
- It's a revisit: potential of B-physics forSM4 studied extensively with George Hou~86-88.

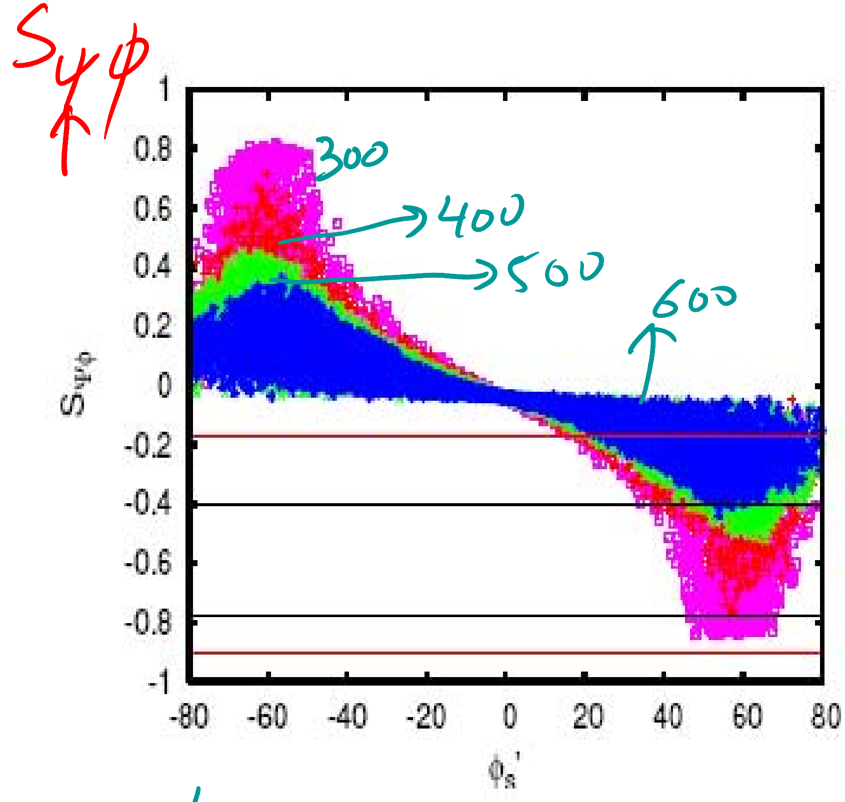
See also talk by Tilmann Heidsieck

Motivation

- 1,2,3, why not 4?
- Heavy quarks could be relevant to formation of condensates and may be instrumental for STRONG DYNAMICS/ DEWSB as an alternate to fundamental Higgs and the need for SUSY
- SM4 has significant advantage for baryogenesis over SM3 [HOU; Jarlskog+Stora; Branco etal]
- 7 new parameters (in the quark sector): 2 masses, 3 real angles, 2 CP-odd (new) phases
- CONS….4th neutral lepton must be very heavy in stark contrast to the known 3

A. S et al 0807.1971, 1002.0595 [C also Buras et al 1002.2186;Hou & Ma,1004.2186

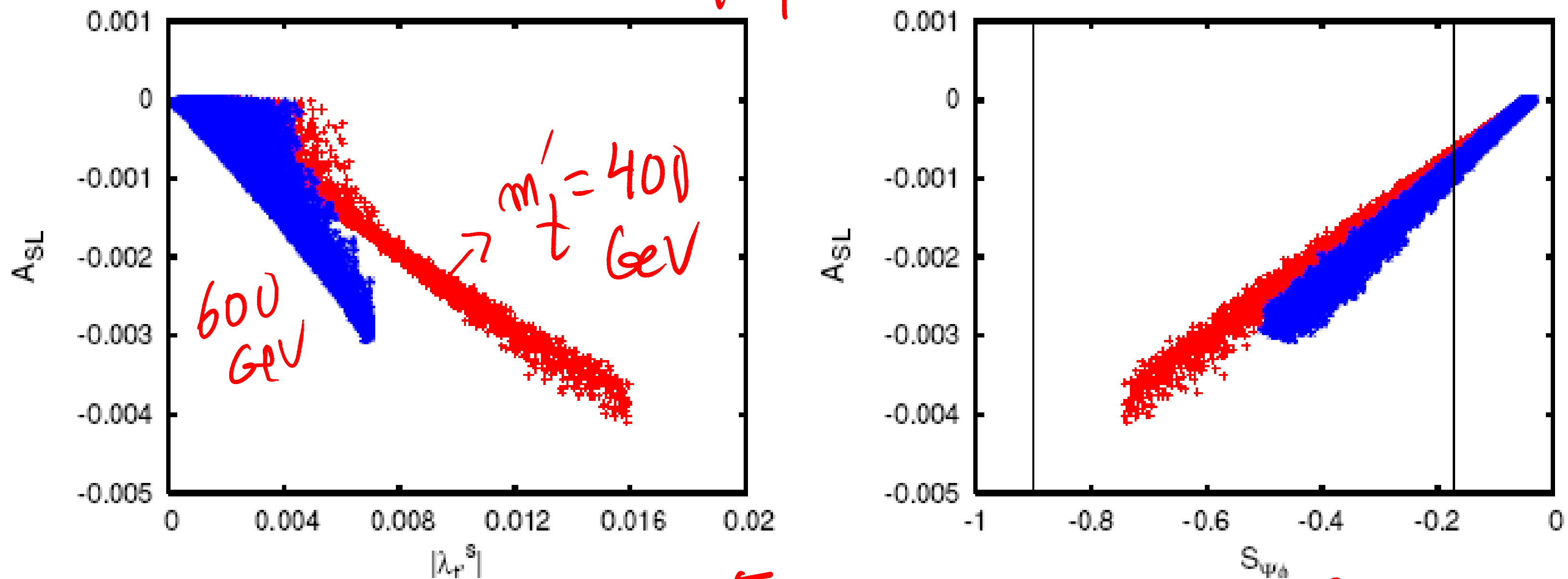




DATA tends to favor $m'_t \sim 400 - 600$ GeV

Semi-leptonic asymmetry (Bs-> Xs l nu) PREDICTION given in arXiv: 1002.0595 [Used here Delta_Gamma_s=0.096 +-.039 from Lenz and Nierste'07]

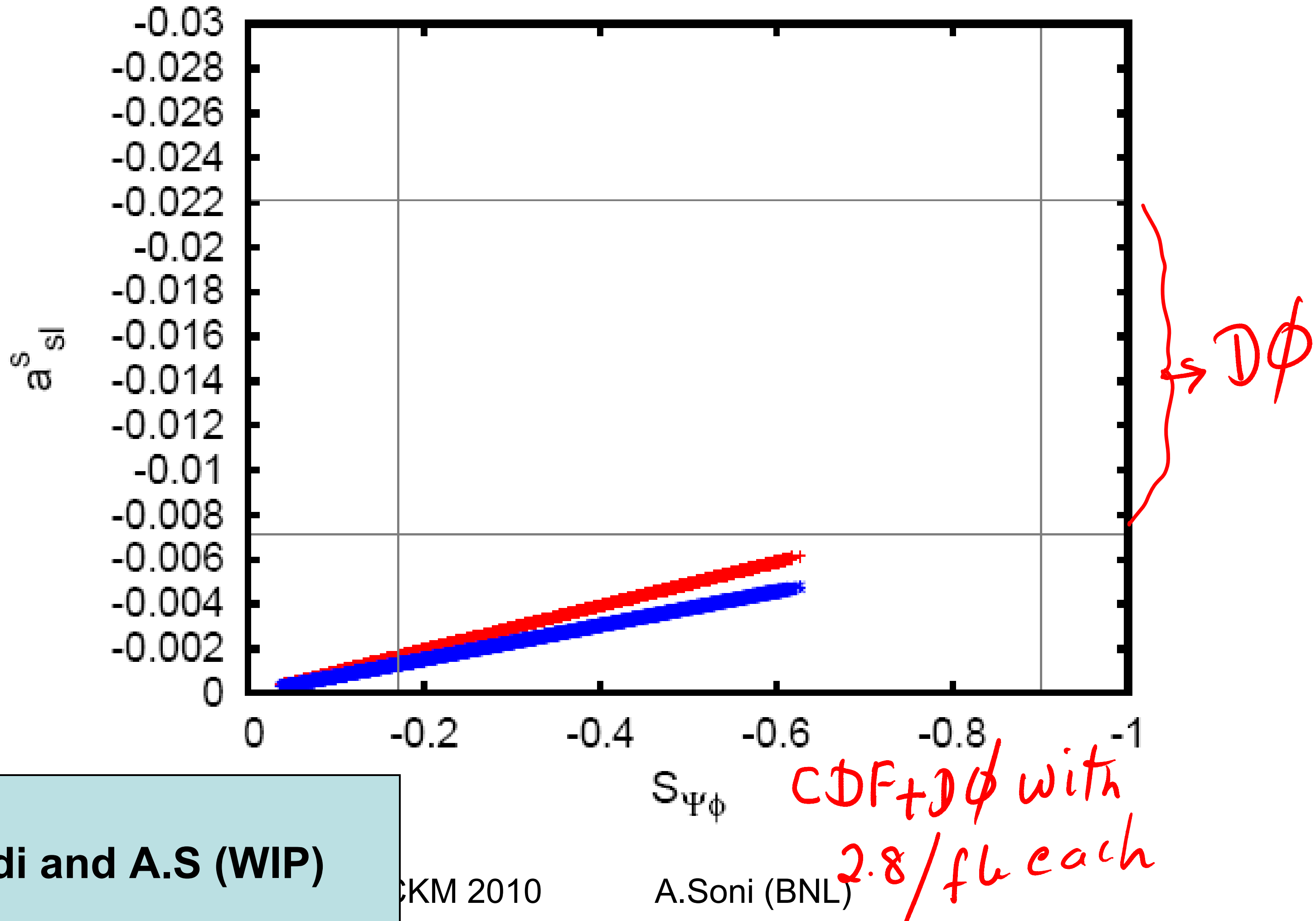
SM4 PREDICTIONS



SM3 ~ $A^s_{sl} \sim 2 \times 10^{-5}$; SM4 $\lesssim 4 \times 10^{-3}$

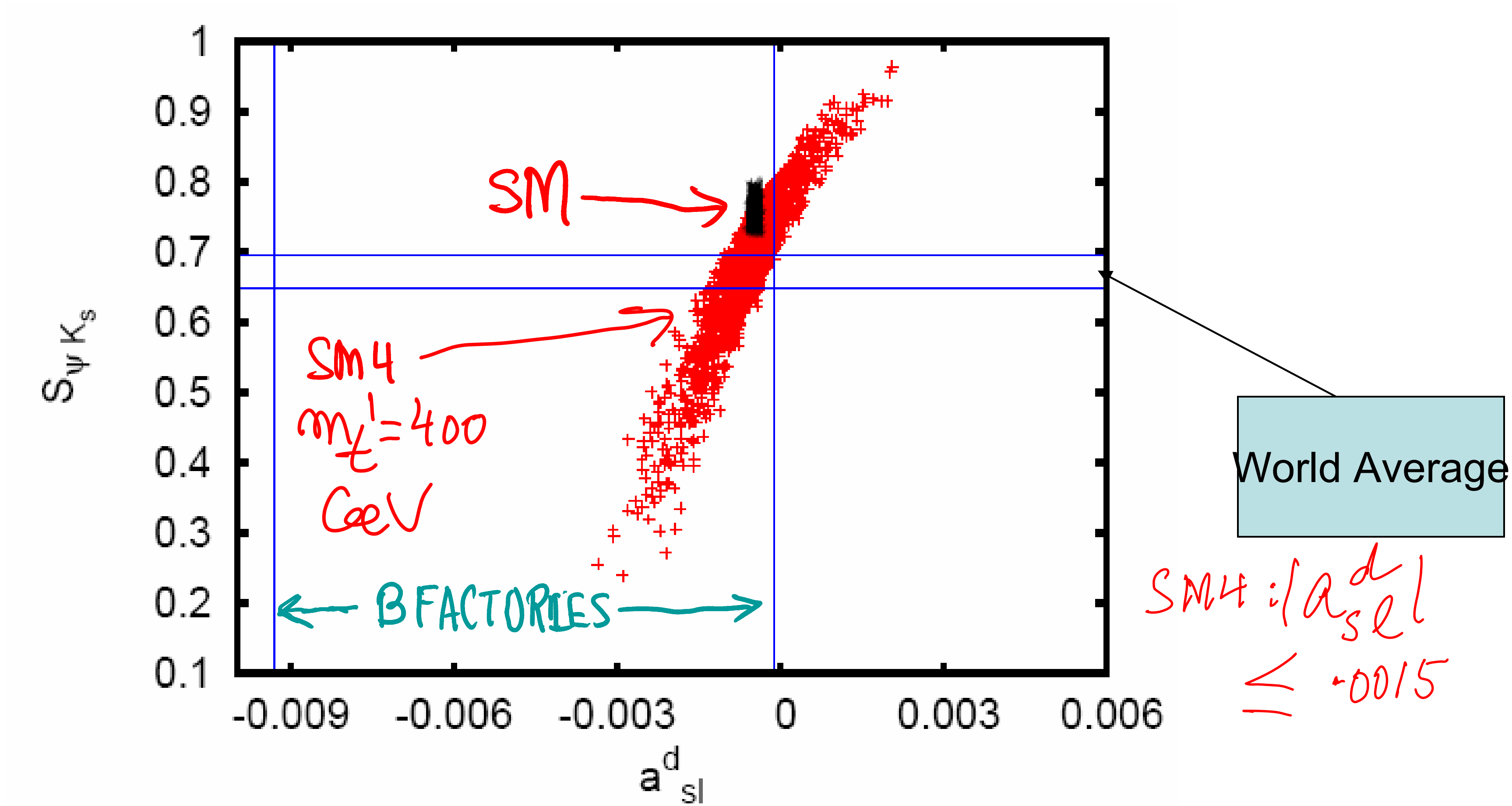
Recently D0 (V M Abazov et al, arXiv: 1005.2757) reported a_sl^s = -0.0146 +- 0.0075)

Recent D0 result is vertical axis and combined D0, CDF each
For SM4 error on Delta_Gamma_s is increased
by a factor of two resulting in ~50% increase in a_sl^s



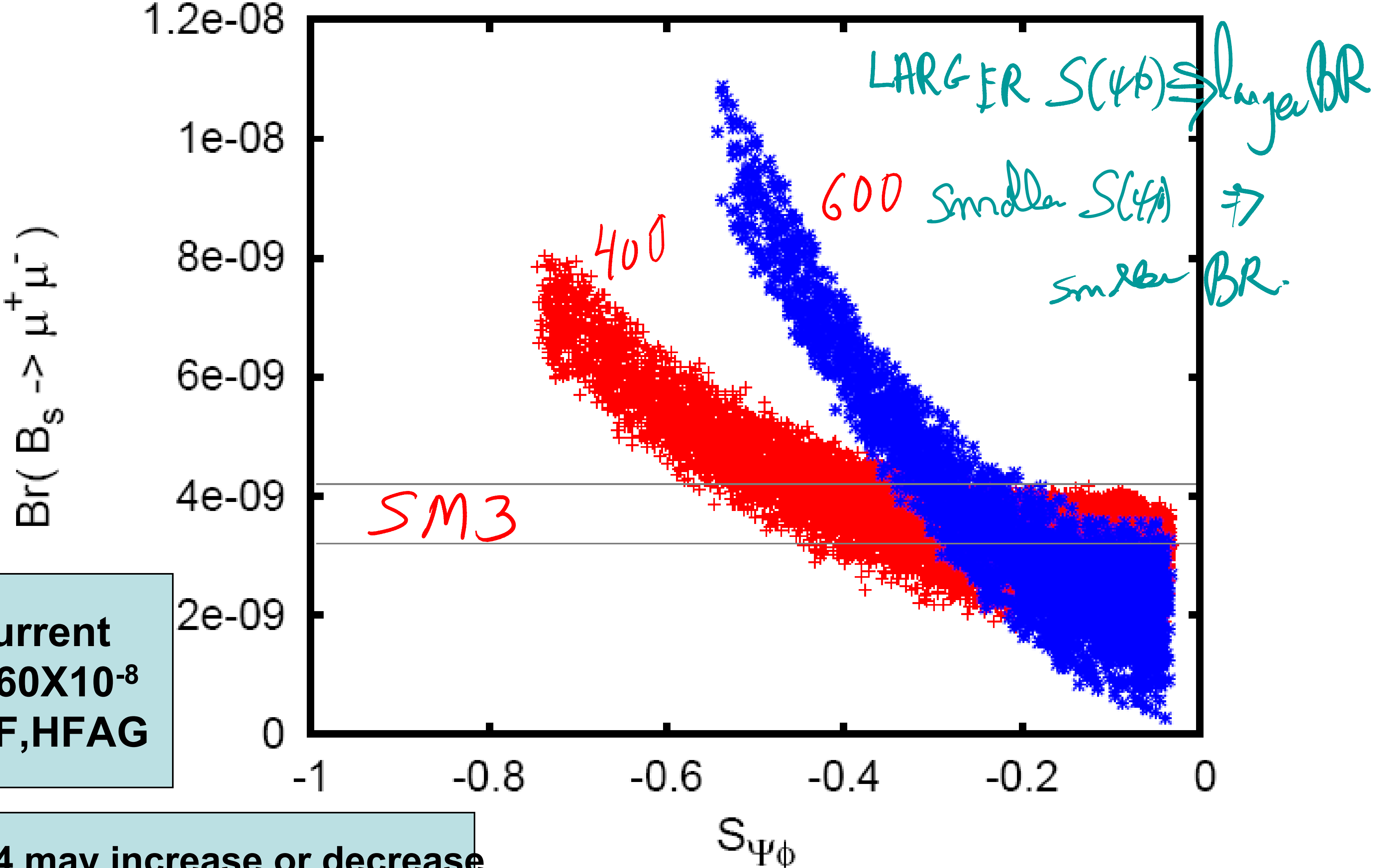
S.Nandi and A.S (WIP)

Predicted range of S(psiKs) in SM4 (with mt'=400 GeV) is (shown in red) compared with the experimentally measured value via the psi Ks mode (1 sigma error) and with the SM (1 sigma)



SM4 seems to predict sin2 beta around 0.70 with an error of about 0.06;
S. Nandi and A.S (work in progress)

Br(Bs->μμ): a very clean process



Current <$3.60X10^{-8}$ CDF,HFAG

SM4 may increase or decrease Br by ~ O(3)

Summary & Outlook

- Though CKM works ~15-20% accuracy,
  several ~2-3 σ deviations have been revealed..These need to be vigorously pursued.
- Taking these hints seriously, model independent analysis suggests new physics with CP-odd phase with scale below ~few TeV is most likely needed.
- SM4 offers a rather simple explanation…
- More accurate results from Tevatron, LHCb, SBFs
  should be very valuable.
- Direct searches at LHC should clarify matter significantly
- POSSIBLE EARLY NEW PHYSICS if mt';mb' ~500 GeV

Backups

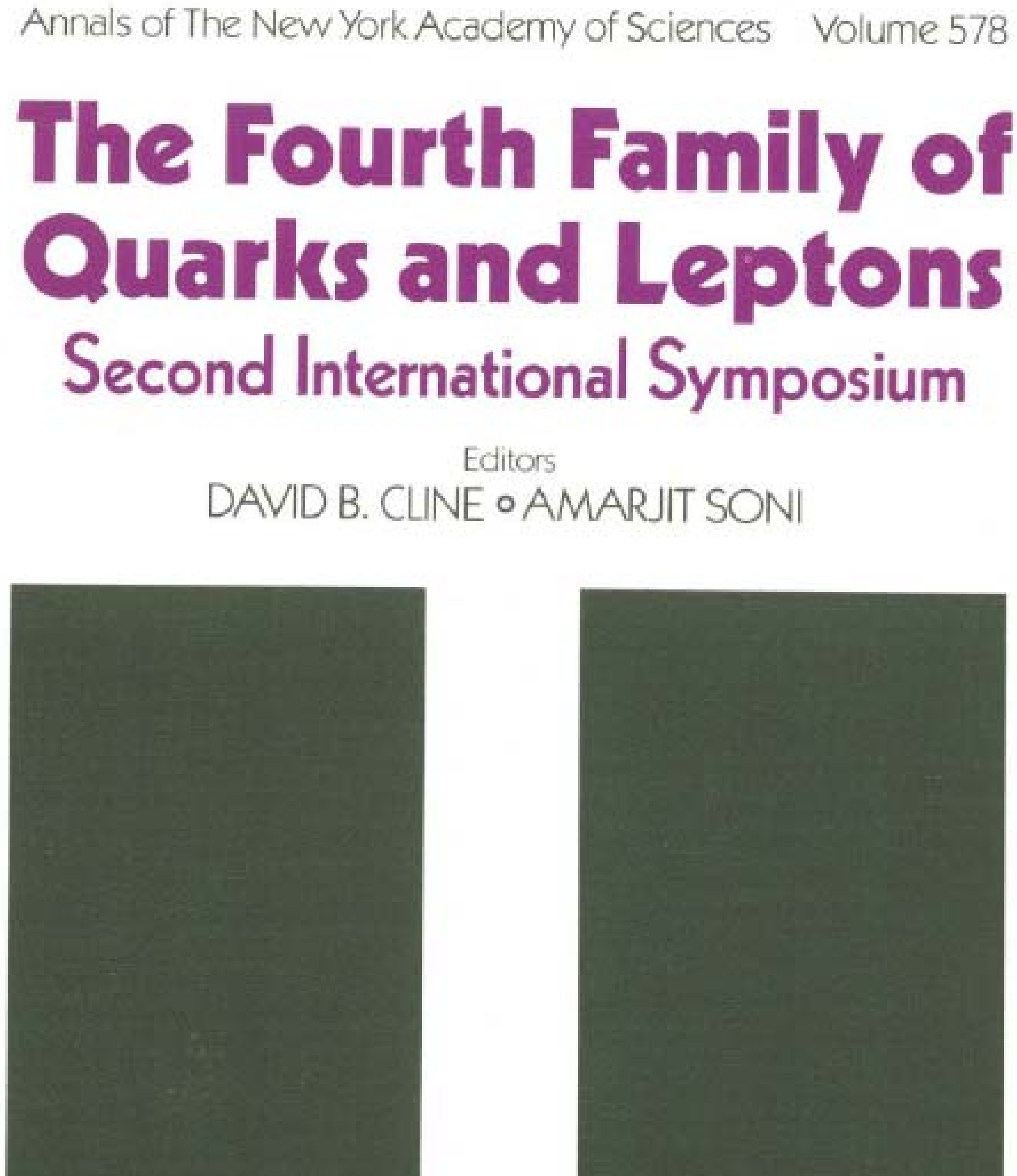
Early (~87-88) studies on 4^{th} gen.

- **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

mportance of B-decays for searching 4^{th} gen. due to non-decou emphasized long ago

CIRCA 1988
(UCLA)



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

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].

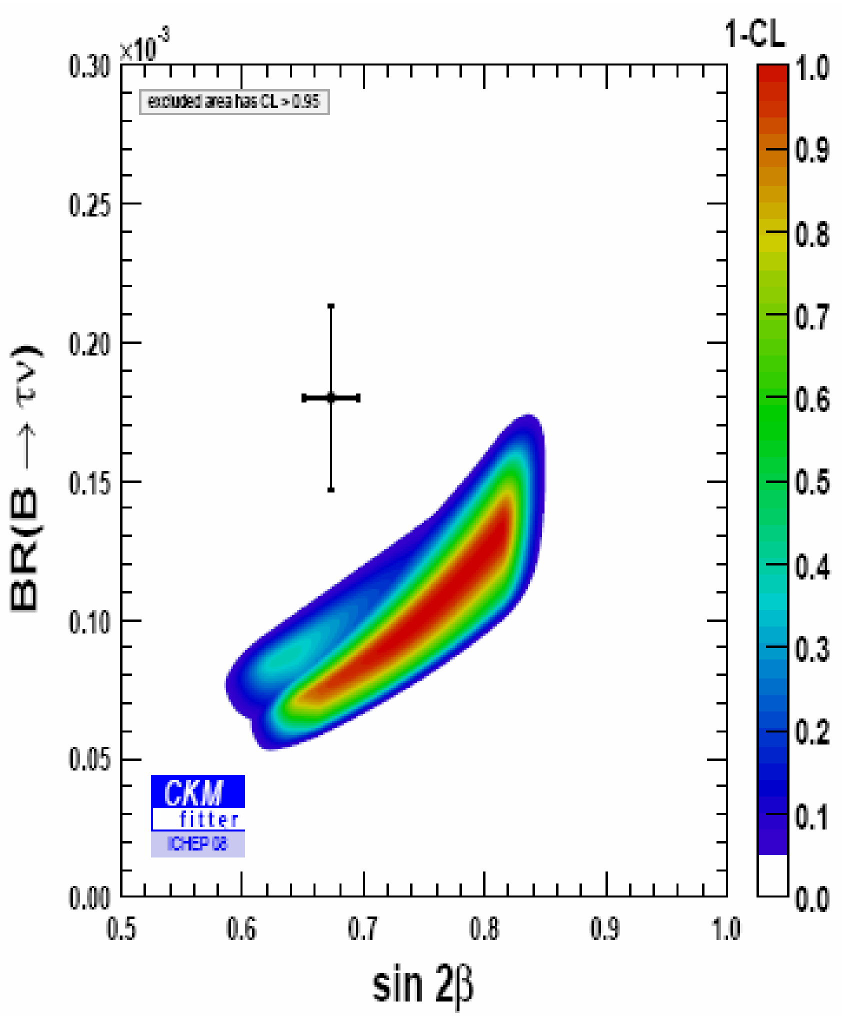
Parameter set	m_{u_4}	m_{d_4}	m_H	ΔS_{tot}	ΔT_{tot}
(a)	310	260	115	0.15	0.19
(b)	320	260	200	0.19	0.20
(c)	330	260	300	0.21	0.22
(d)	400	350	115	0.15	0.19
(e)	400	340	200	0.19	0.20
(f)	400	325	300	0.21	0.25

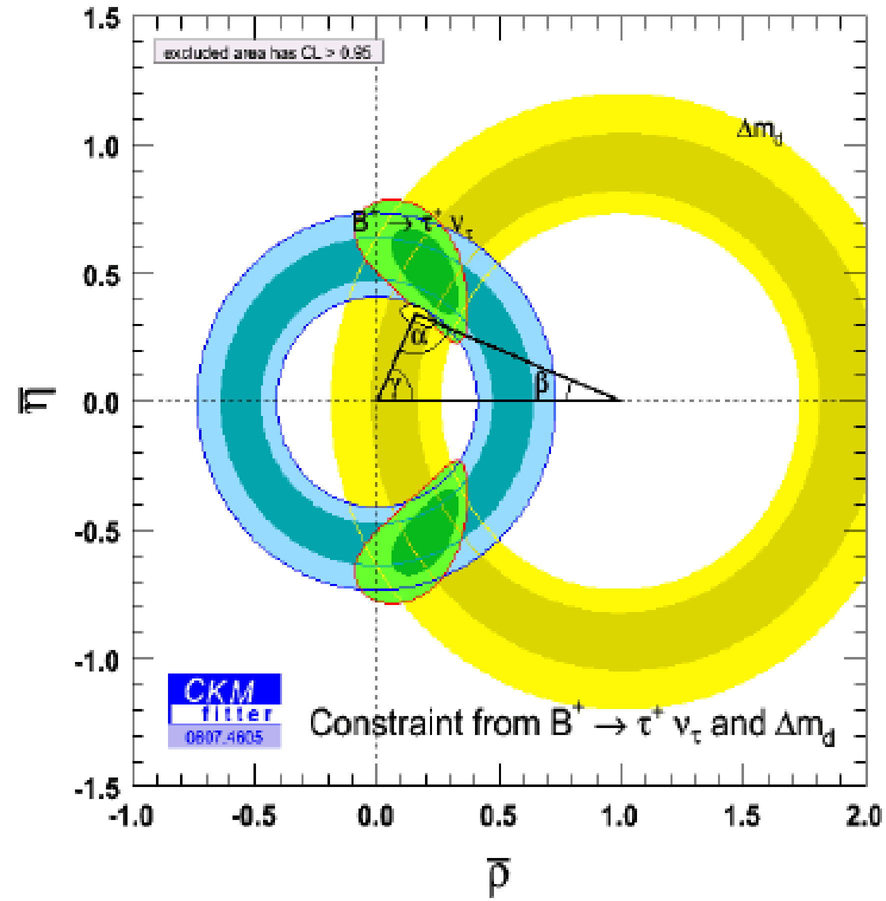
Possible indications of new physics in *Bd*-mixing and in sin*(2β)* determinations

E. Lunghi + A. S. '08

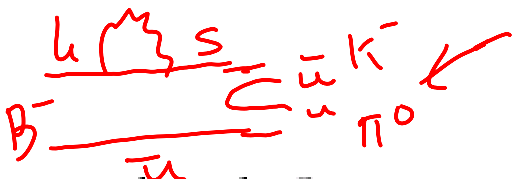
- Using K0, Bd, Bs mixings , along with Vcb only, "predicted" value of sin2 beta in SM comes out to be ~0.87 (see fig)
- The worrysome Vub is NOT used
- Through use of the Delta Flavor=2 box graphs one is searching for new physics where it is most likely to show up…
- Even if current tension goes away, as data and lattice continually improve it should capture new physics some day

DESCHAMPS (CKMFitter) '08





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:

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

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

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

$\gtrsim 3.5\sigma$

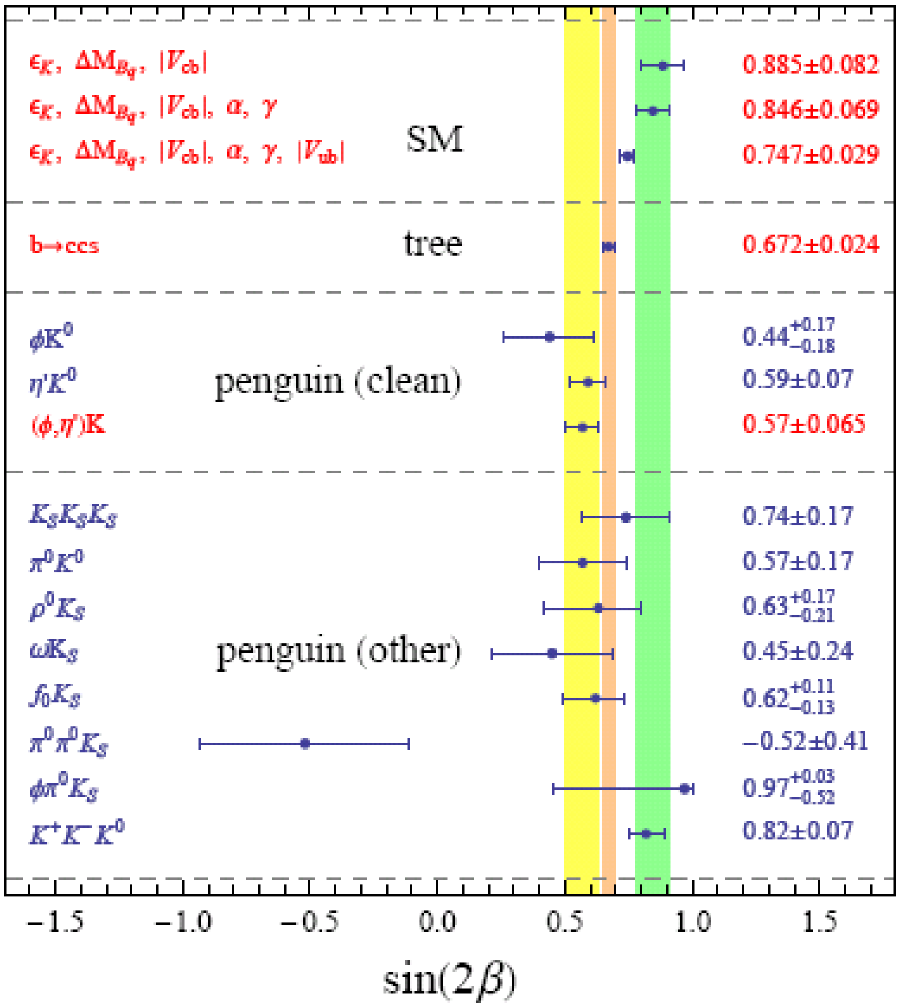
yields a 3.5σ effect.

BENEKE+NEUBERT 0308039 based on BBNS

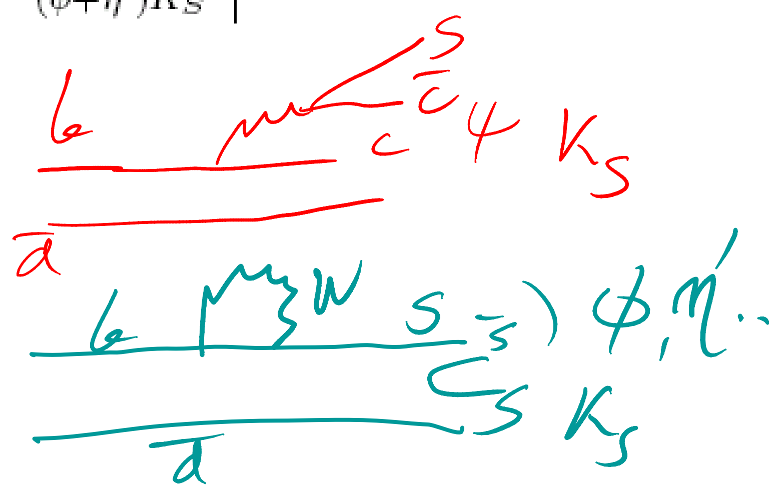
For alternate explanations see: M.Gronau;HS Li; M. Ciuchini ……

L)

Lunghi + AS, arXiv:0903.5059



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



SM4: Standard Model with 4-generations

- **SM4 provides simplest explanation of these deviations, if they are taken seriously.The heavy t' quark carries a new CP-phase in Vt'd as well as in Vt's which contributes new CP violating amplitudes relevant for epsilonK (and of course also for epsilon'), for sin2beta from trees or from penguins (due to t' contribution in B-box graphs as well as in the penguin graph) and infact imply non vanishing CP-asymmetries in Bs->psi phi as well as in semi-leptonic asymmetry in Bs-> l nu Xs**

Note these amplitudes typically evade the decoupling theorem and grow as $(mt')^2$

Note also that despite this large growth with mass of t', SM4 makes little contributions to CP conserving processes (such as B->Xs gamma, B->Xs l l) since the magnitudes of mixing angles such as Vt's are quite severely constrained by unitarity.

See arXiv: 0807.1971; 1002.0595

At Least in one aspect 4th gen fecilitates baryogenesis dramatically

$J_{SM3} \sim A^3 \lambda^6 \eta$

CPV in SM3 is driven by

$$(m_c^2 - m_u^2)(m_t^2 - m_c^2)(m_t^2 - m_u^2)(m_s^2 - m_d^2)(m_b^2 - m_s^2)(m_b^2 - m_d^2)/m_W^{12} J_{SM3}$$

IN SM4 the prefactor gains a gigantic enhancement

$$(m_t^2/m_c^2)(m_{t}'^4/m_t^4)(m_b^2/m_s^2)(m_{b}'^4/m_b^4) \approx 10^{16}$$

W. S. Hou, arxiv:0803.1234.

For earlier related works see, C. Jarlskog and R. Stora, Phys. Lett. **B208**, 288 (198

Aguila and J. A. Aguilar-Saavedra, Phys. Lett. **B386**, 241 (1996); F. del Aguila a

Aguilar-Saavedra and G. C. Branco Nucl. Phys. **B510** 39 1998