Theoretical Review of Heavy Flavor Physics

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22nd Rencontres de Blois

A New Clue to Explain Existence

By DENNIS OVERBYE
Published: May 17, 2010

Physicists at the Fermi National Accelerator Laboratory are reporting that they have discovered a new clue that could help unravel one of the biggest mysteries of cosmology: why the universe is composed of matter and not its evil-twin opposite, antimatter. If confirmed, the finding portends fundamental discoveries at the new Large Hadron Collider outside Geneva, as well as a possible explanation for our own existence.

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In a mathematically perfect universe, we would be less than dead; we would never have existed. According to the basic precepts of Einsteinian relativity and quantum mechanics, equal amounts of matter and antimatter

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EDITORIAL

The Being of Being

Published: May 20, 2010

Why is there something instead of nothing? That is a child's question, but it also haunts the imaginations of physicists and mathematicians. What they know is that the matter and antimatter created in the Big Bang should have canceled each other out, leaving nothing instead of the something we call the universe. Why that didn't happen may have been partially revealed in a recent experiment in the Tevatron — a particle accelerator — at Fermilab, in Batavia, Ill.

We proceed gingerly when interpreting the results of high-energy physics experiments. The way it has been explained is that it all comes down to a very slight bias, an asymmetry, in the behavior of a subatomic particle, the neutral B-meson. As it oscillates between its matter and antimatter states, it shows a slight predilection for matter, a result predicted by Andrei Sakharov.

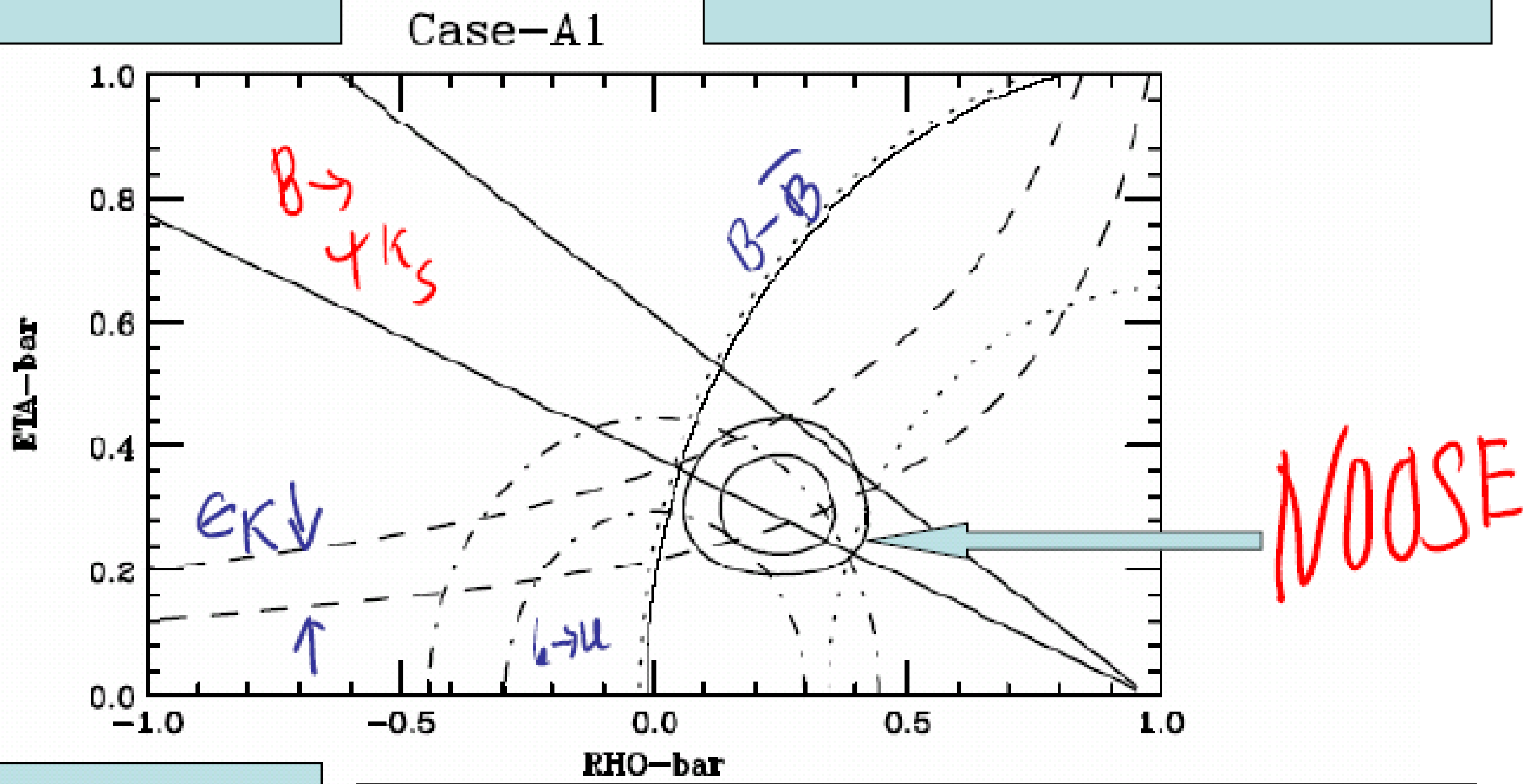
outline

- Expts confront CKM-paradigm: From Glorious successes(~01- 06) to Anomalies galore (~07- ~10)
- Possible theoretical interpretation of anomalies:
- 1) Most interesting
- 2) Simplest
- Implications for LHC,LHCb,(S)BF…
- Summary & Oulook

Glorious Successes

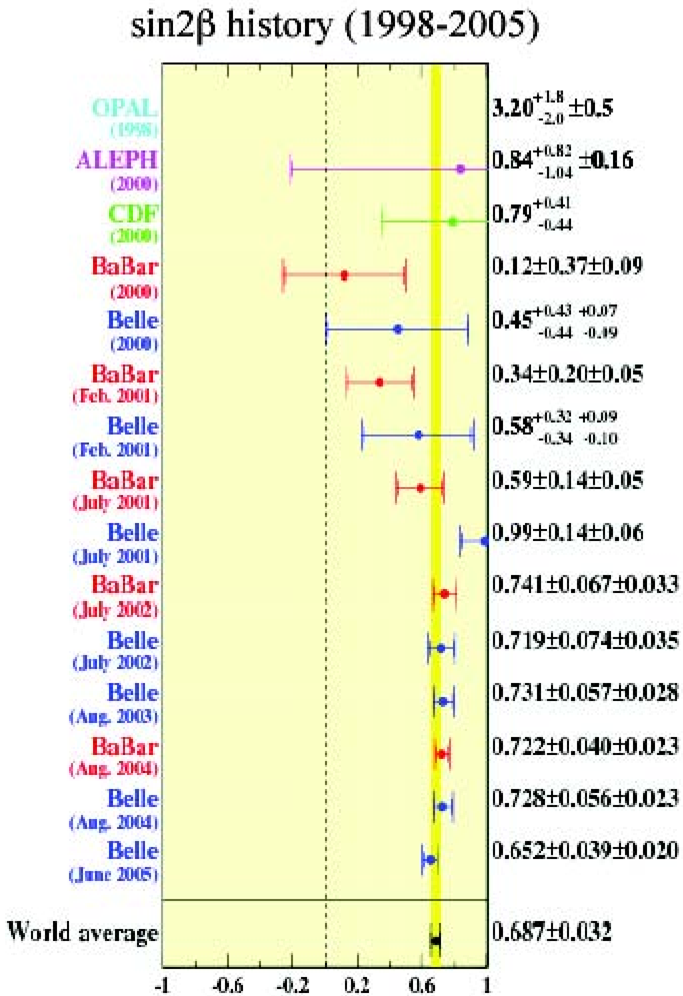
1st Hint of confirmation of CKM CP description

Atwood &AS, hepph/0103197

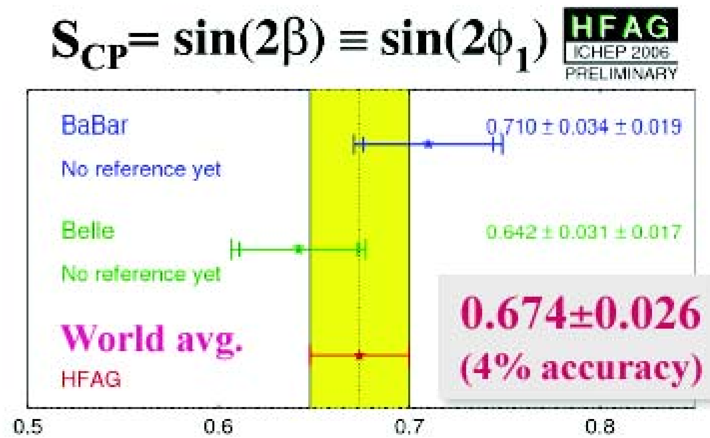


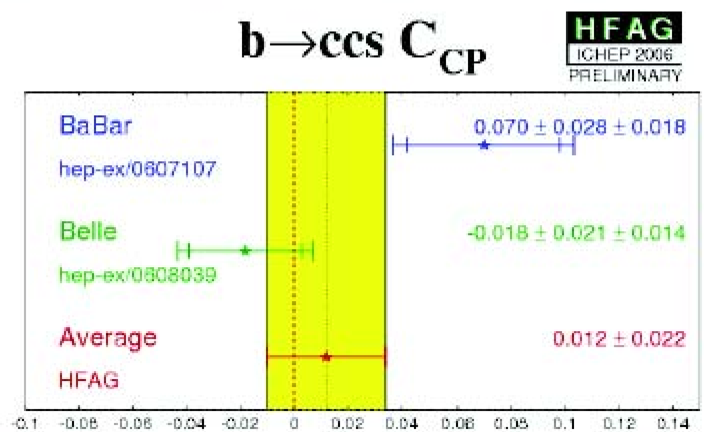
Most bands due
To theory errors

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

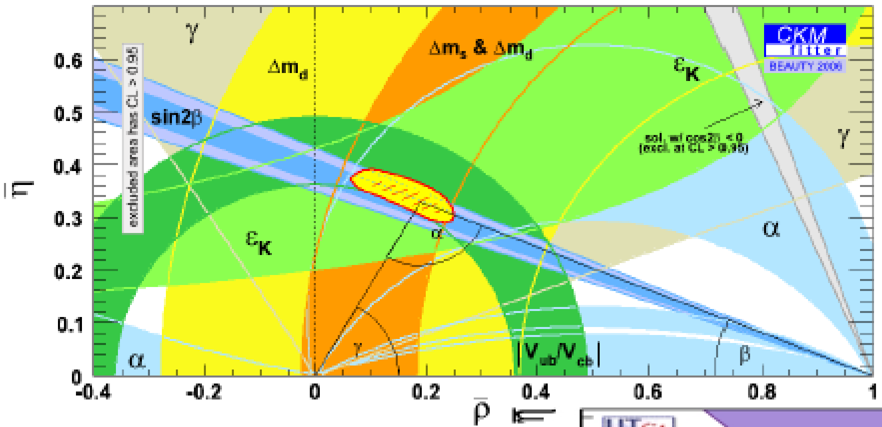


2006 BaBar + Belle



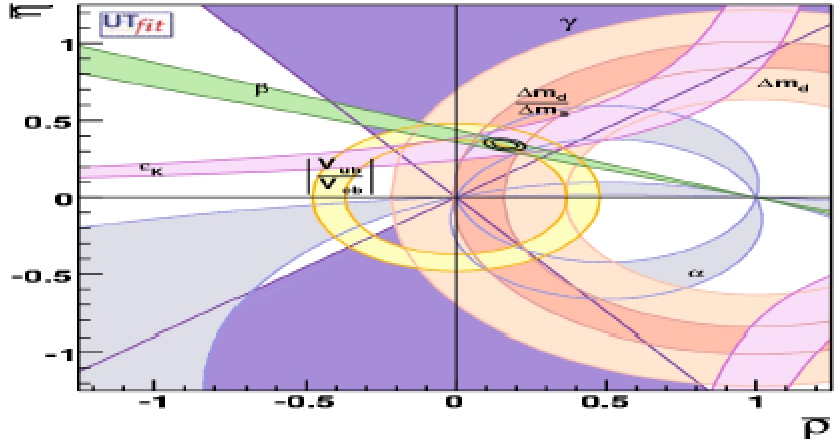


Overall CKM agreement



Frequentist

Bayesian



Conclusion is the same:

All measurements agree with SM picture of CKM matrix within errors

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.

Possible cracks in CKM?

Based on Lunghi+AS

0707.0212; 0803.4340; 0903.5059;0912.0002

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**
- **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).**
- **D0-dimuon SSA**

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

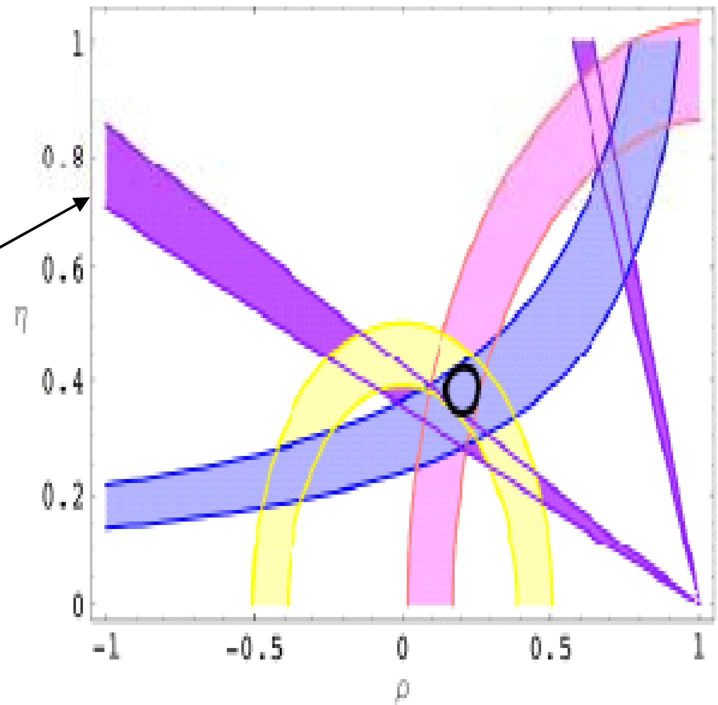


Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

Continuing saga of Vub

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

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

Use only SD Physics observables

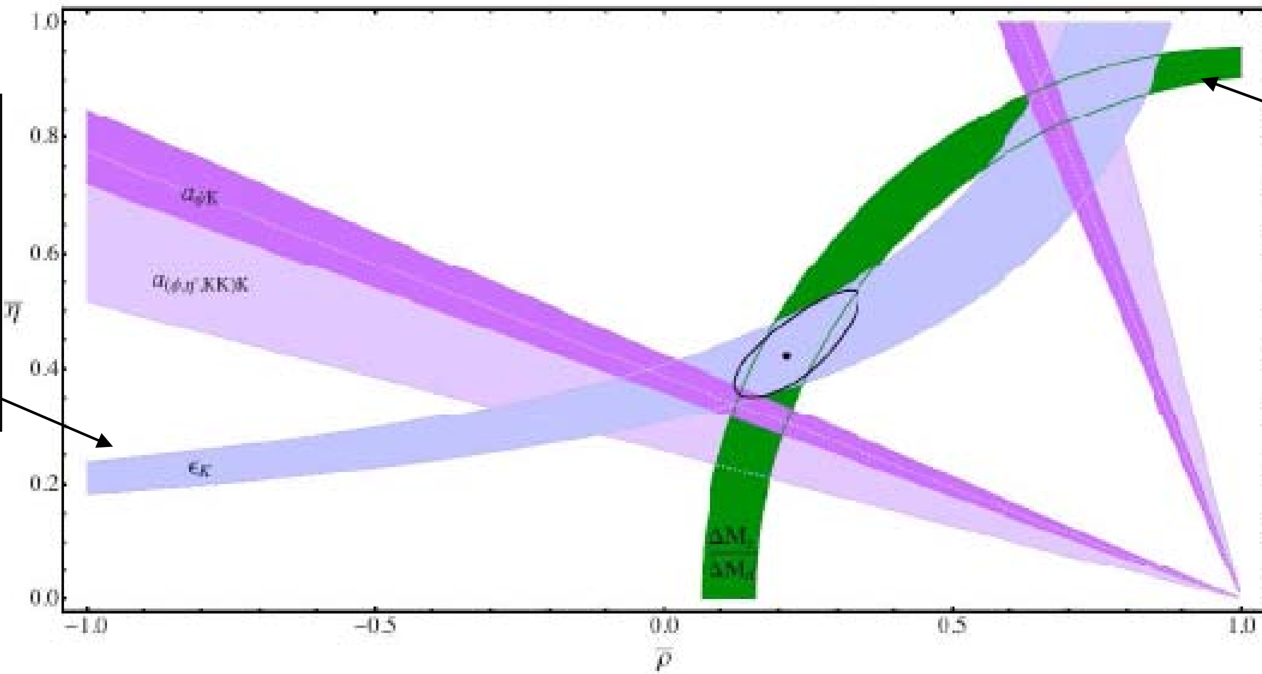
- **CP conserving tests almost never very "clean"**
- **Vub is not under good control**
- **Vub is tree**
- **Use only ε_K & $\Delta m_s/\Delta m_d$ …so only DeltaF=2 Boxes & SD physics is involved**
- **Became possible only due major strides in lattice accuracy**
- (Fine foot print Vcb)….addressed later …Lunghi & 's 2010

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

.

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

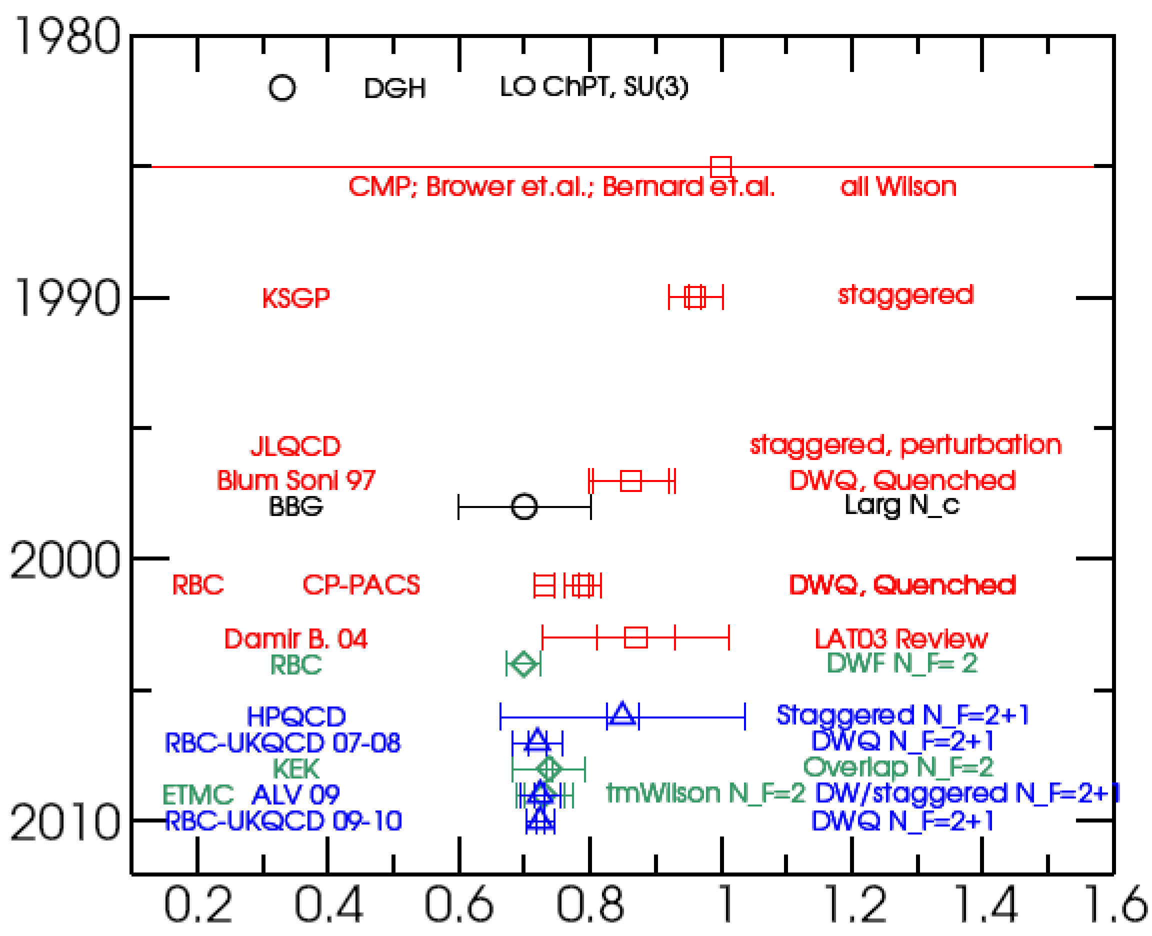
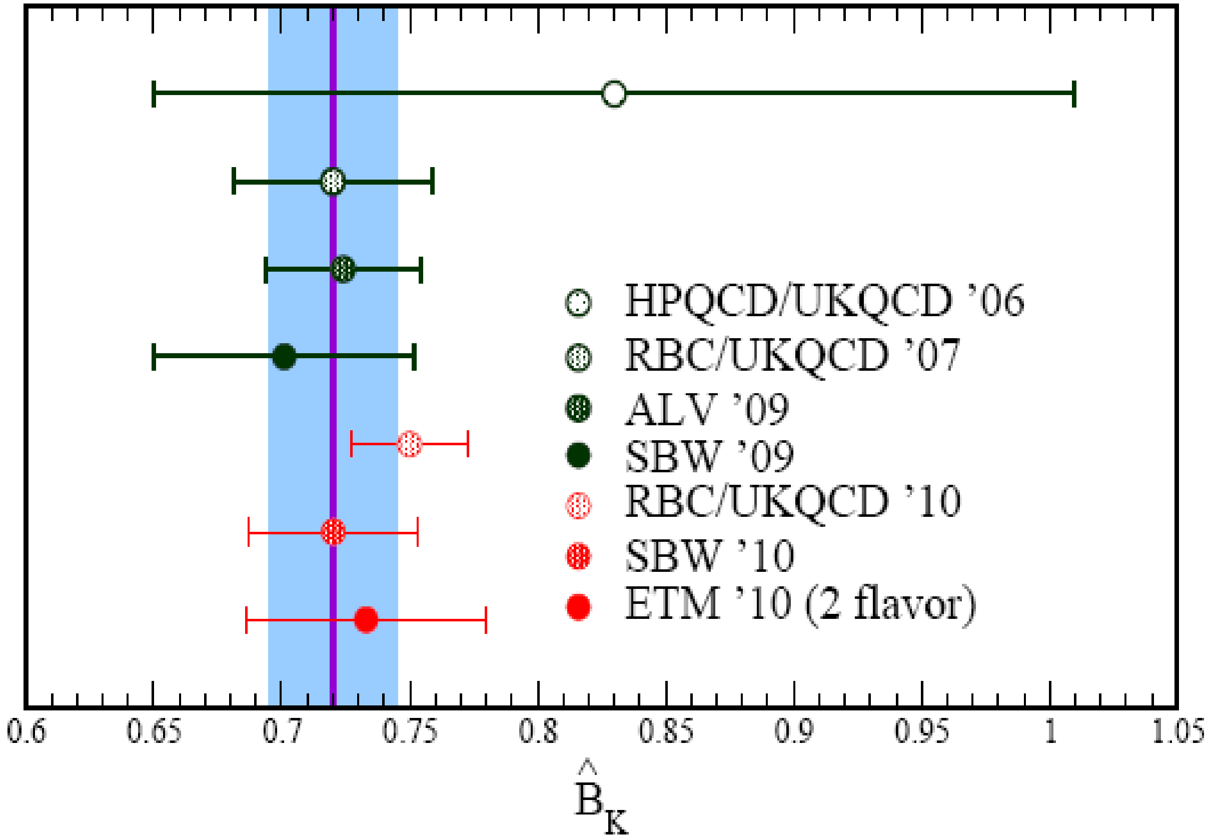


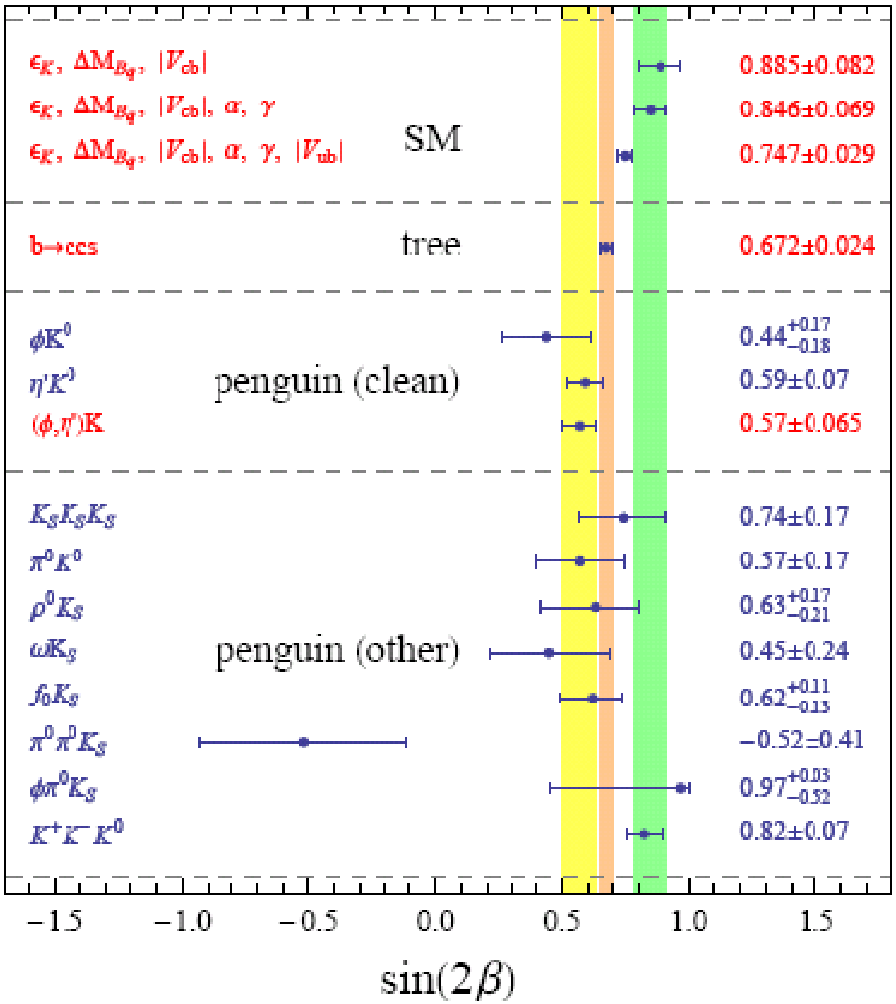
FIG. 20: A brief ($\approx$ 25 years) history of $\hat{B}_K$; from continuum models (black), quenched lattice (red), $N_F = 2$ lattice (green), and $N_F = 2 + 1$ lattice (blue).

B_K



HPQCD/UKQCD '06
RBC/UKQCD '07
ALV '09
SBW '09
RBC/UKQCD '10
SBW '10
ETM '10 (2 flavor)
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
$\hat{B}_K$

Lunghi + AS, arXiv:0903.5059



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

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:

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

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]

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

yields a 3.5σ effect.

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

ENTIRELY NEW APPROACH: UT WITHOUT SEMI-LEPTONIC DECAYS

Lunghi+ AS, 0912.0002

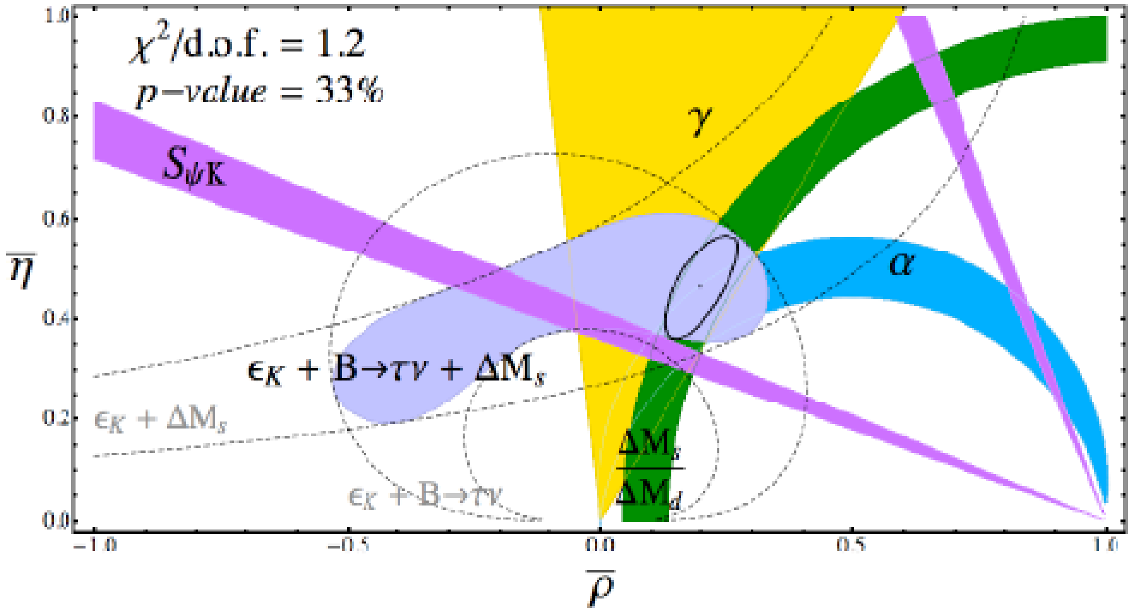
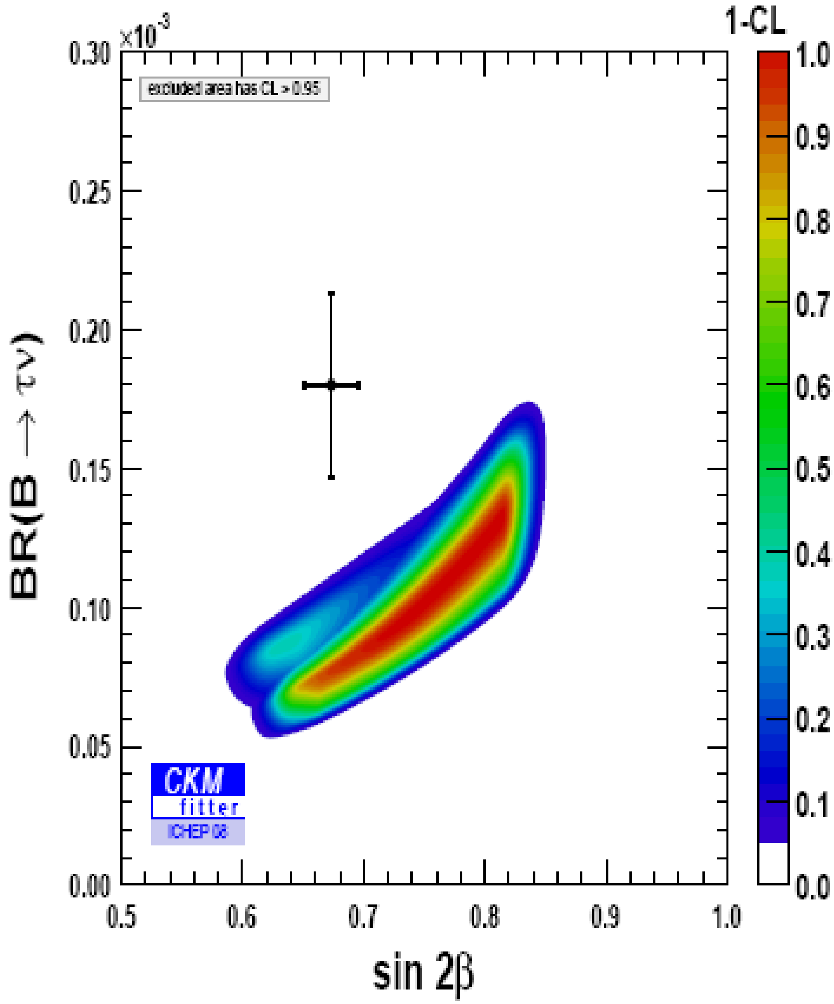
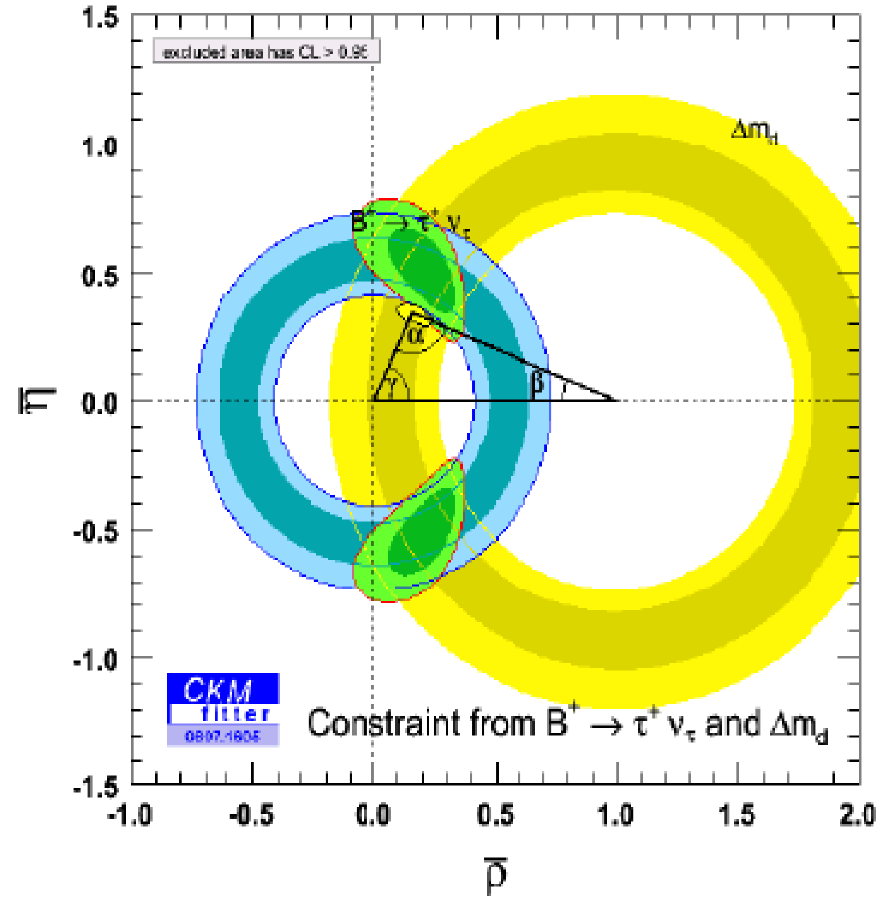


FIG. 2: Unitarity triangle fit without semileptonic decays. The solid contour is obtained using ε_K, $B \to \tau\nu$, γ, ΔM_{B_s} and ΔM_{B_d}. The dashed contours show the interplay of the ε_K, ΔM_{B_s} and BR($B \to \tau\nu$) constraints.



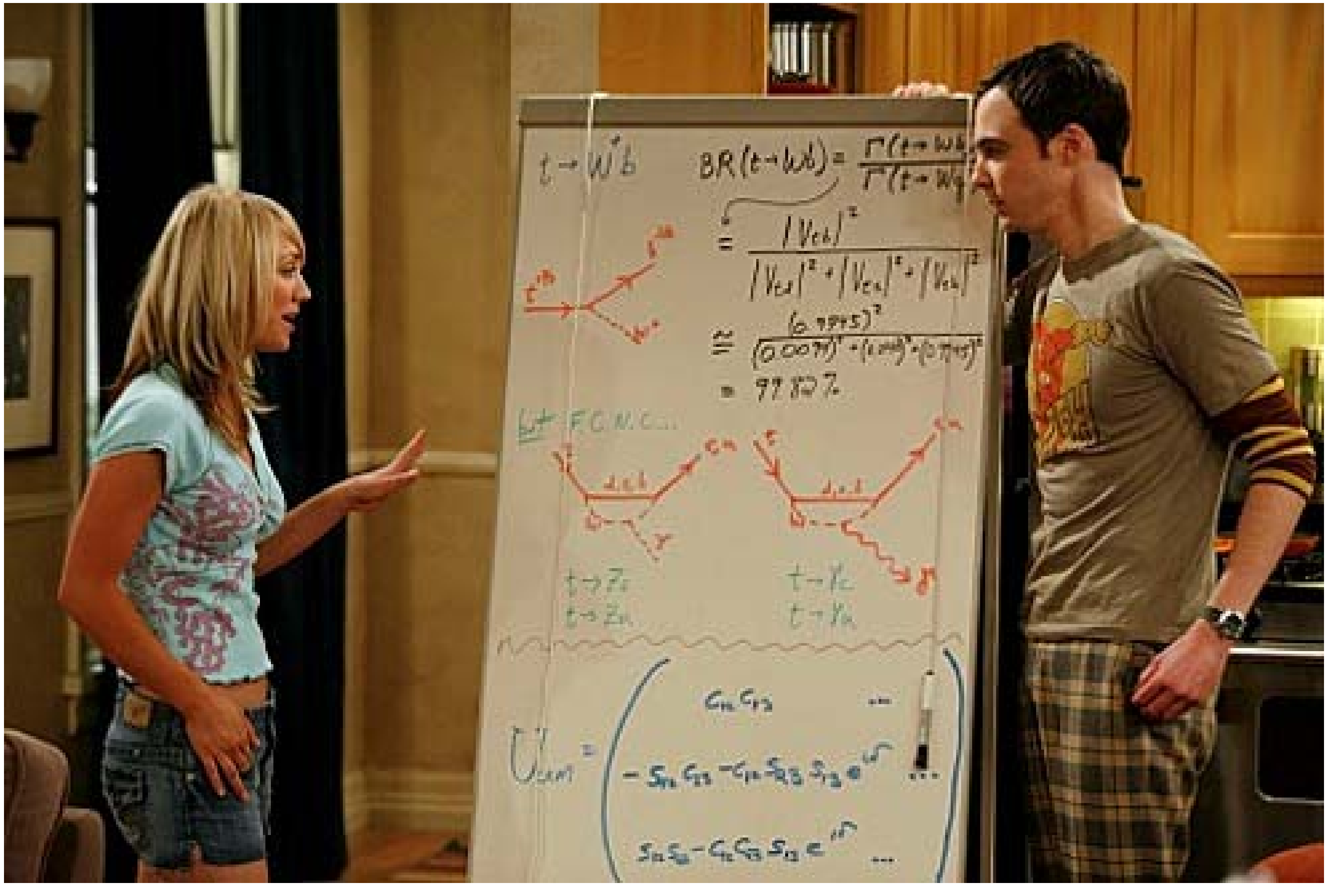
1-CL
excluded area has CL > 0.95
BR(B → τν)
sin 2β
×10^-3
CKM fitter
ICHEP 08



excluded area has CL > 0.95
Δm_d
B⁺ → τ⁺ ν_τ
α
β
γ
η̄
ρ̄
CKM fitter
Constraint from B⁺ → τ⁺ ν_τ and Δm_d

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

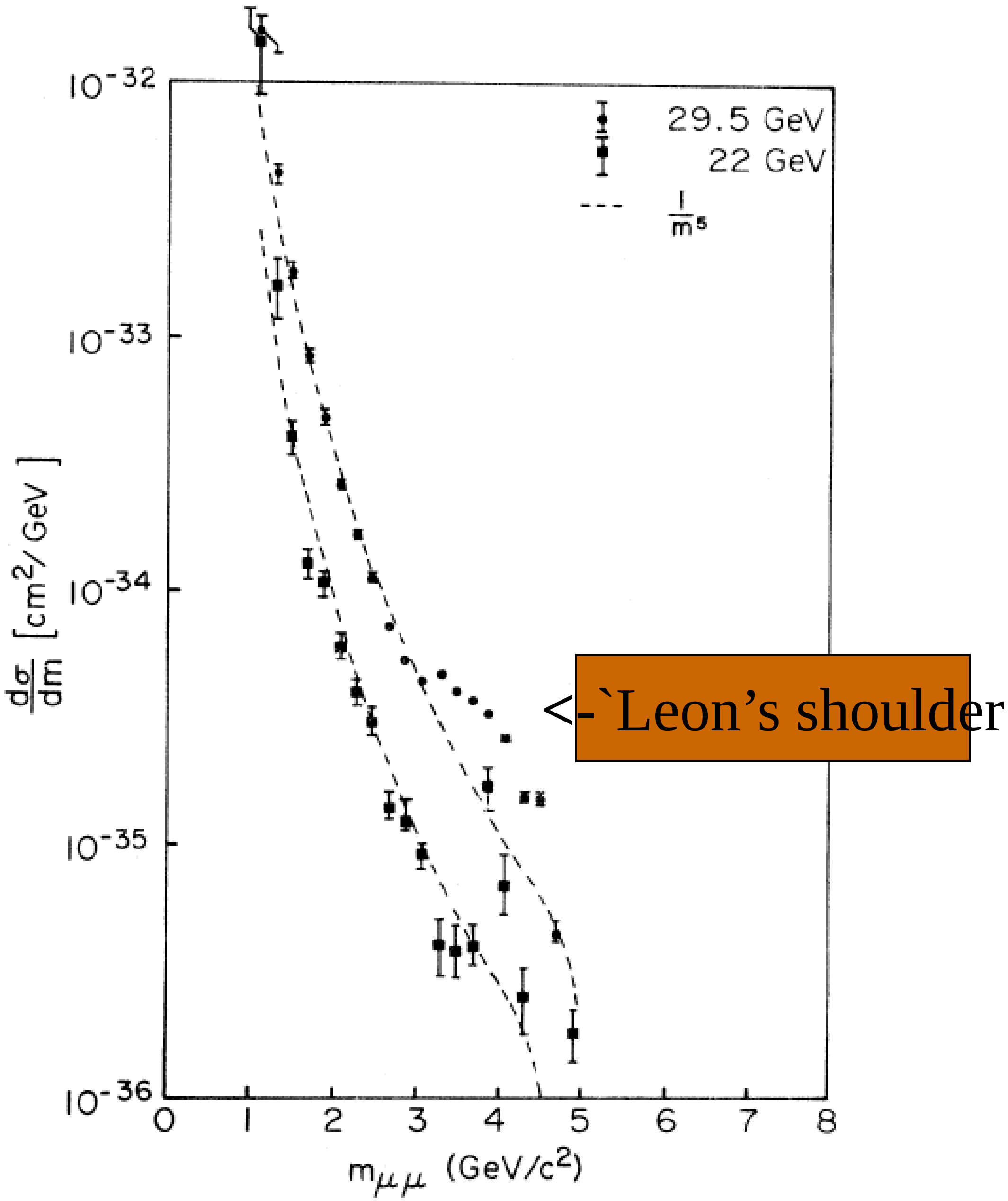


FIG. 15. Experimental cross sections at two energies compared with a simple $1/m^5$ continuum.

Deserves a 2nd NP for inventing the reaction: junk + junk -> gems +X which has led to the discoveries of J, Upsilon, W, Z , top,…and remains the most powerful exploratory tool in our arsenal!!

2nd

Adapted from Browder

A lesson from history (I)

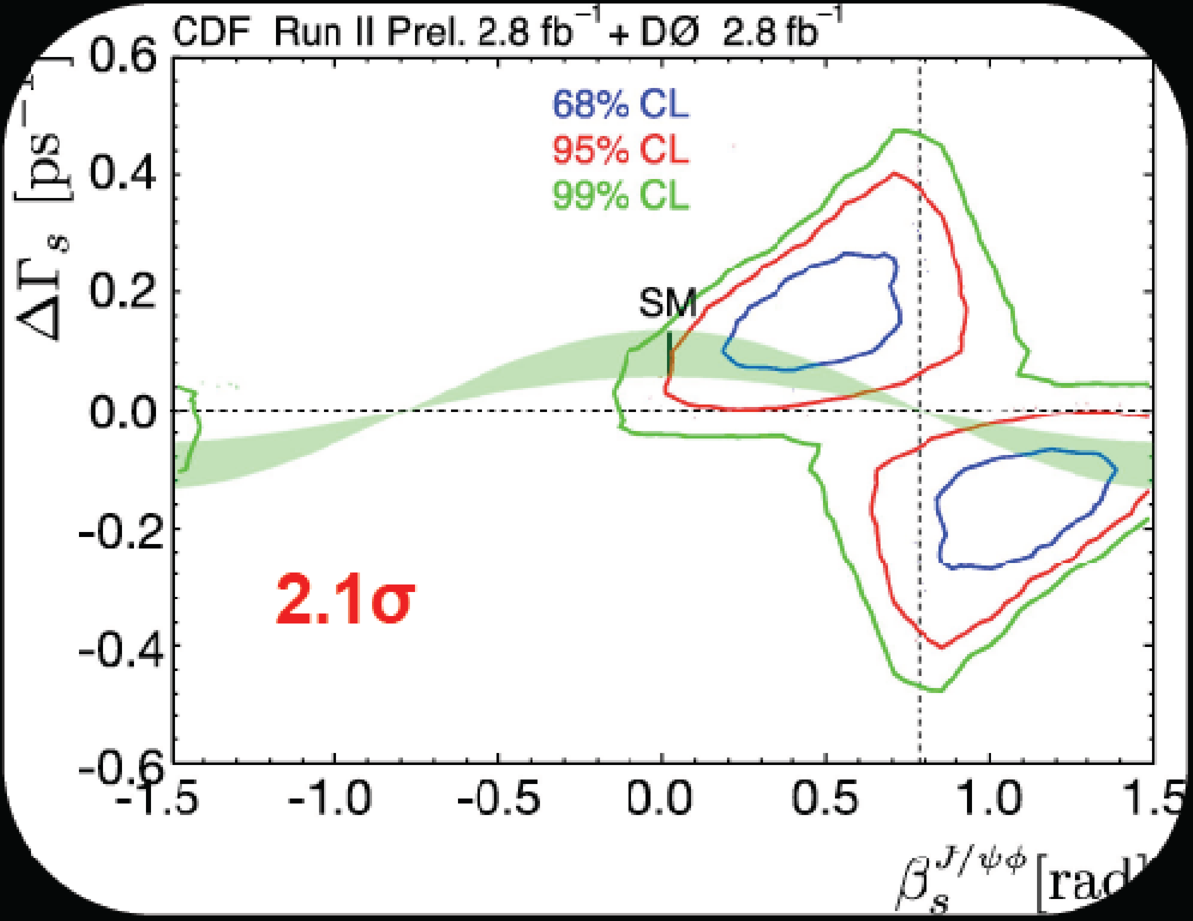
"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

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

1964: BF= 2×10^{-3}

A failure of imagination ? Lack of patience ?

DIEGO TONELLI @ BROOKHAVEN FORUM 2010 (May)



PRL101 161802 (2008) topcite100+
PRL101, 241801 (2008) topcite100+
http://tevbwg.fnal.gov/results/Summer2009_betas/

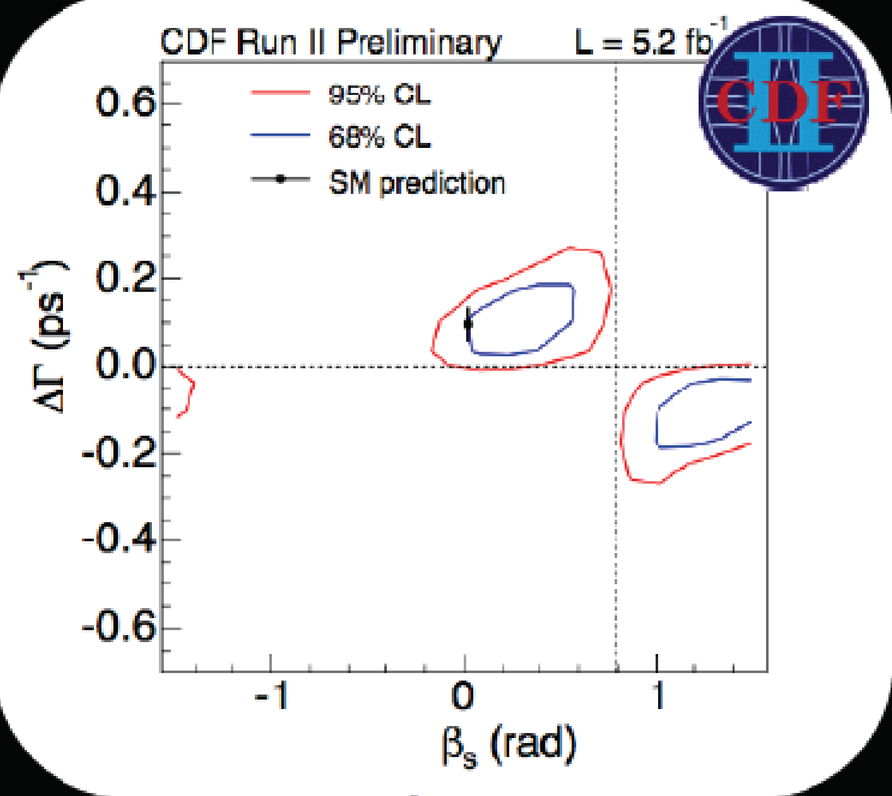
New for BF2010

Mixing phase

Allowed region for phase greatly reduced

Two solutions clearly separated.

Unfortunately the contour moved toward SM…



P-value = 44% wrt SM

βs in [0.0, 0.5] U [1.1, 1.5] at 68% CL (one-dimensional)

βs in [-0.1, 0.7] U [0.9, π/2] U [-π/2, -1.5] at 95% CL (one-dimensional)

Evidence for an anomalous like-sign dimuon charge asymmetry
V.M. Abazo et al (D0) arXiv:1005.2757

$$A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}},$$

$$A_{\rm sl}^{b} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}},$$

$$A_{\rm sl}^{b}(\mathrm{SM}) = \left(-2.3^{+0.5}_{-0.6}\right) \times 10^{-4},$$

$$A_{\rm sl}^b = (0.506 \pm 0.043) a_{\rm sl}^d + (0.494 \pm 0.043) a_{\rm sl}^s.$$

$$a_{\rm sl}^d = -0.0047 \pm 0.0046$$

$$a_{\rm sl}^s = -0.0146 \pm 0.0075.$$

$$a_{\rm sl}^b \equiv \frac{\Gamma(\bar{B} \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(\bar{B} \to \mu^+ X) + \Gamma(B \to \mu^- X)} = A_{\rm sl}^b.$$

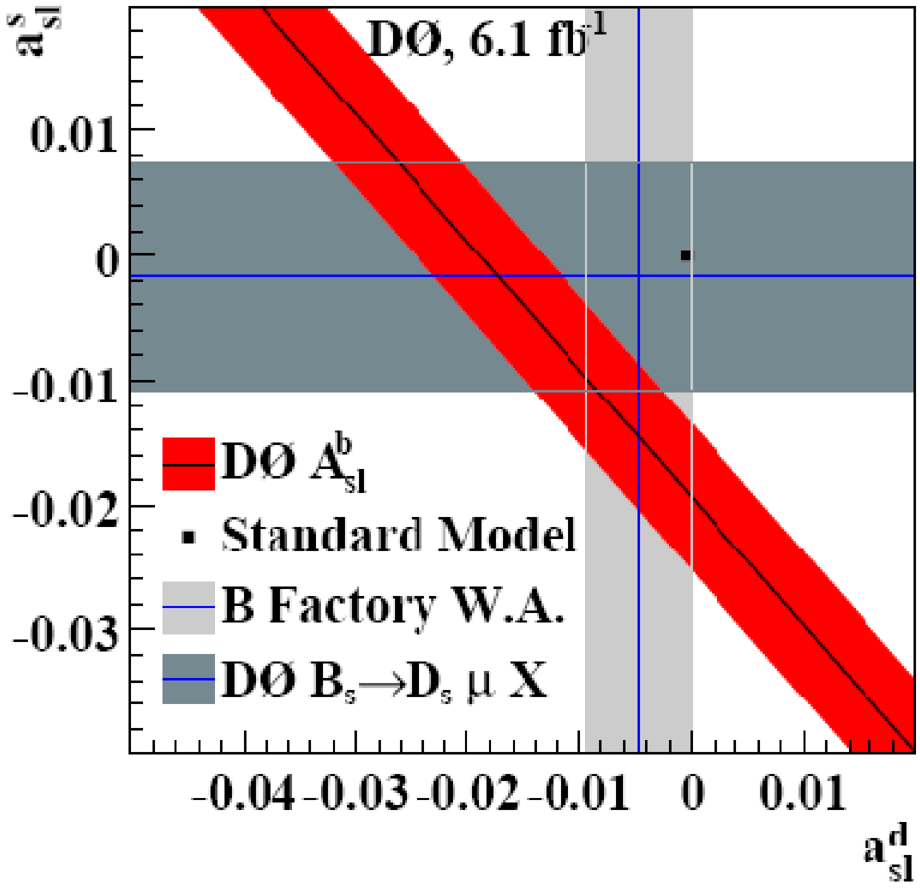


FIG. 17: (Color online) Comparison of A^b_{sl} in data with the standard model prediction for a^d_{sl} and a^s_{sl}. Also shown are the existing measurements of a^d_{sl} [23] and a^s_{sl} [24]. The error bands represent the ±1 standard deviation uncertainties on each individual measurement.

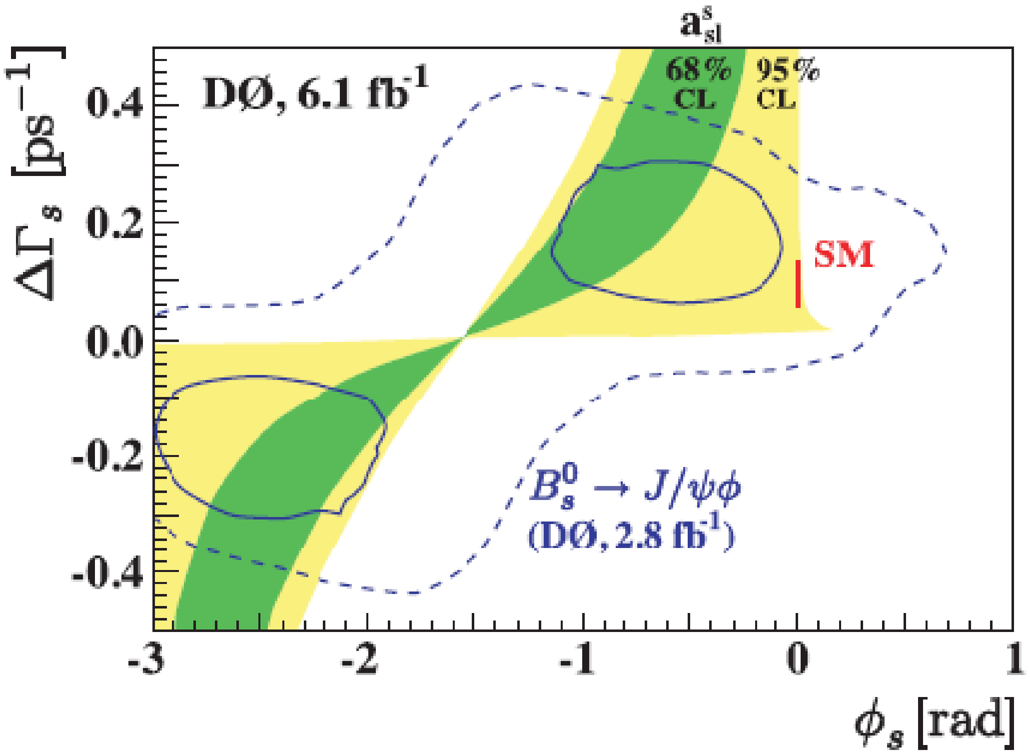


FIG. 18: (Color online) The 68% and 95% C.L. regions of probability for $\Delta\Gamma_s$ and ϕ_s values obtained from this measurement, considering the experimental constraints on a_{sl}^{d} [23]. The solid and dashed curves show respectively the 68% and 95% C.L. contours from the $B_s^0 \to J/\psi\phi$ measurement [25]. Also shown is the standard model (SM) prediction for ϕ_s and $\Delta\Gamma_s$.

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

FLAVOR PROBLEM (PUZZLE) is DUE TO FLAVOR POWER

Outstanding Th.puzzles of our times

- **Hierarchy puzzle**

- **Flavor puzzle**

A successful theory/model of flavor needs to address the flavor problem

1. Most interesting: Warped extra-dimension
2. Simplest: 4^{th} family

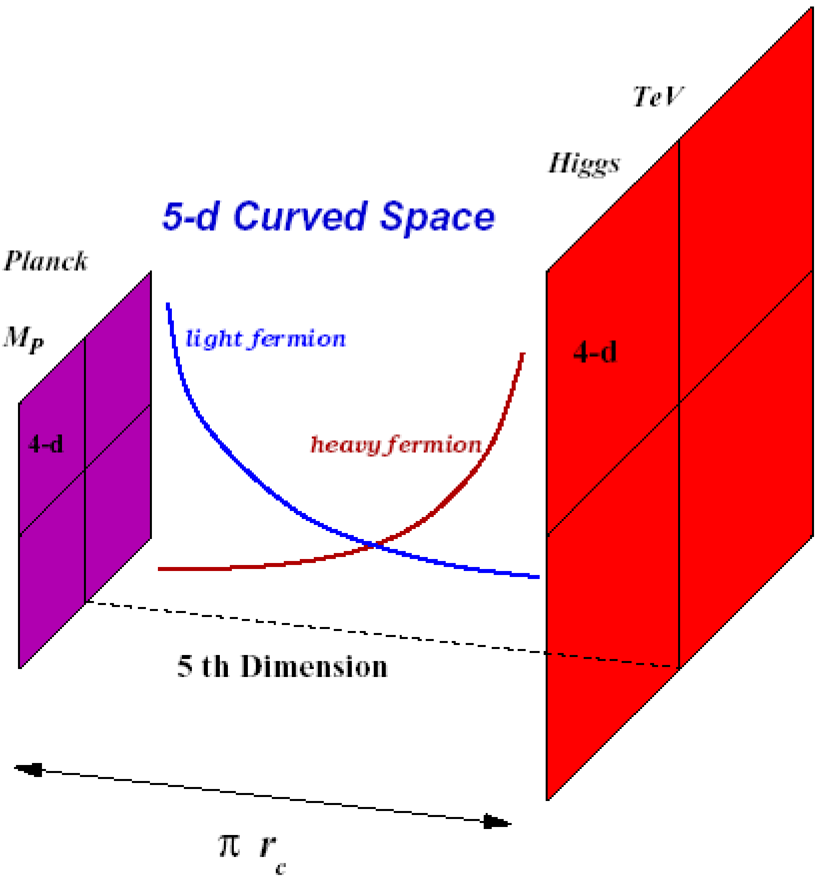


Figure 1: Warped geometry with flavor from fermion localization. The Higgs field resides on the TeV-brane. The size of the extra dimension is $\pi r_c \sim M_P^{-1}$.

Simultaneous resolution to hierarchy and flavor puzzles

Fermion "geography" (localization) naturally explains:

Grossman&Neubert; Gherghetta&Pomarol; Davoudiasl, Hewett & Rizzo

- **Why they are light (or heavy)**
- **FCNC for light quarks are severely suppressed**
- **RS-GIM MECHANISM (Agashe, Perez,AS'04) flavor changing transitions though at the *tree level* (resulting from rotation from interaction to mass basis)are suppressed roughly to the same level as the loop in SM**
- **Most flavor violations are driven by the top**

-> ENHANCED t-> cZ….A VERY IMPORTANT "GENERIC" PREDICTION..Agashe, Perez, AS'06

EXTENSIVE RECENT STUDIES by BURAS et al and NEUBERT et al

Contrasting B-Factory Signals from WEXD with those from SM

Agashe,Perez &AS, PRL'04
(Then for simplicity assumed Bd-mixing is SM)
O(1) uncertainties stressed. NOTE these are genuine PREDICTIONS

	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}	$\frac{m_s}{m_b}\left(\sin 2\beta, \lambda_c^2\right)$	$\frac{m_d}{m_b}\left(\lambda_c^2, \sin 2\beta\right)$

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

Comparison with the SM

- In SM & in 2HDM BR (t -> c V) with V= γ , G, Z

computed long ago (Eilam, Hewett, A.S, PRD'91)

In the SM 1-loop graph is extremely GIM suppressed as $\{(m_b , m_s , m_d)^2 / m_t^2) \to 0 \}$

SM4 changes the tc story

BLANKE,BURAS, DULING, GORI, WEILER,arXiv:0809.1073

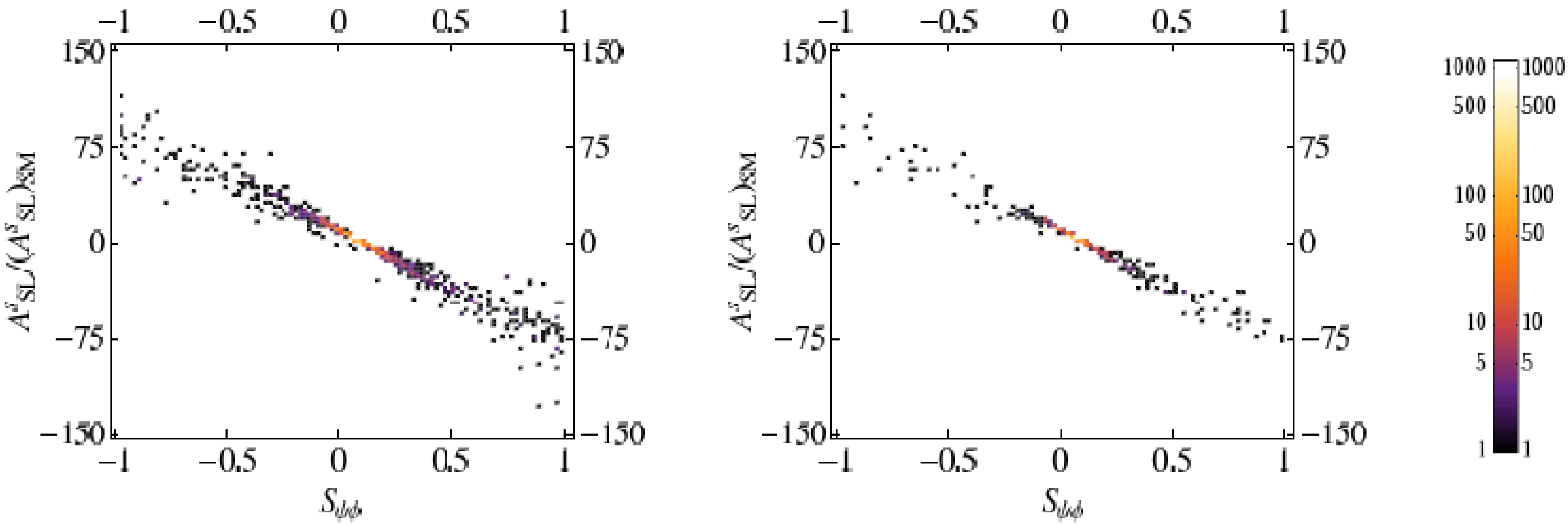


Figure 7: *left:* A^s_{SL}*, normalised to its SM value, as a function of* $S_{\psi\phi}$*. In addition to the requirement of correct quark masses and CKM mixings, also the available* $\Delta F = 2$ *constraints are imposed. right: The same, but in addition the condition* $\Delta_{BG}(\varepsilon_K) < 20$ *is imposed.*

Gold-mines@ H&L energies

- LHC:G->Z(ll) Z(l'l'), WW
- LHC et al: t \bar t due $(G,g,Z..)_{KK...}$BOOSTED TOPS
- LHC: Top polarization, FB-asym?
- LHC: t-> c Z…….
- t-edm
- N-edm
- D^0 mixing & CP (dir & TD)
- B_s (CP) ->ψφ,ψ η', φφ….
- B_d -> (φ,η'……)$K_{S,,}$ γ K^* ….TDCP

Table 3: $pp \to \ell^{\pm} \not{E}_T - 1$ jet cross-section (in fb) for $M_{Z'}$ =2 and 3 TeV, and background, with cuts applied successively. The number of events is shown for $\mathcal{L} = 100\ \text{fb}^{-1}$ for 2 TeV, and 1000 fb^{-1} for 3 TeV.

$M_{Z'} = 2$ TeV	p_T	$\eta_{\ell,j}$	M_{eff}	M_{TWW}	M_{jet}	# Evts	S/B	$S/\sqrt{B}$
Signal	4.5	2.40	2.37	1.6	1.25	125	0.39	6.9
W+1j	1.5×10^5	3.1×10^4	223.6	10.5	3.15	315		
WW	1.2×10^3	226	2.9	0.13	0.1	10		
$M_{Z'} = 3$ TeV								
Signal	0.37	0.24	0.24	0.12	-	120	0.17	4.6
W+1j	1.5×10^5	3.1×10^4	88.5	0.68	-	680		
WW	1.2×10^3	226	1.3	0.01	-	10		

Shrihari Gopalakrishina et al;arXiv:0709.0007

SM4: 4 Gen. standard model

- Provides a simple explanation to B-CP anomalies
- If true (unlike RS) excellent chance of direct discovery @ LHC [current Tevatron (CDF) bounds mt'>338 GeV; LHC can cover upto ~ 1TeV..see Meenakshi Narain talk…]
- It's a revisit: potential of B-physics forSM4 studied extensively with George Hou~86-88.

See also talks by Tilmann Heidsieck;Heiko Lacker..

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
- 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

At Least in one aspect 4th gen fecilitates baryogenesis dramatically

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 (1988

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

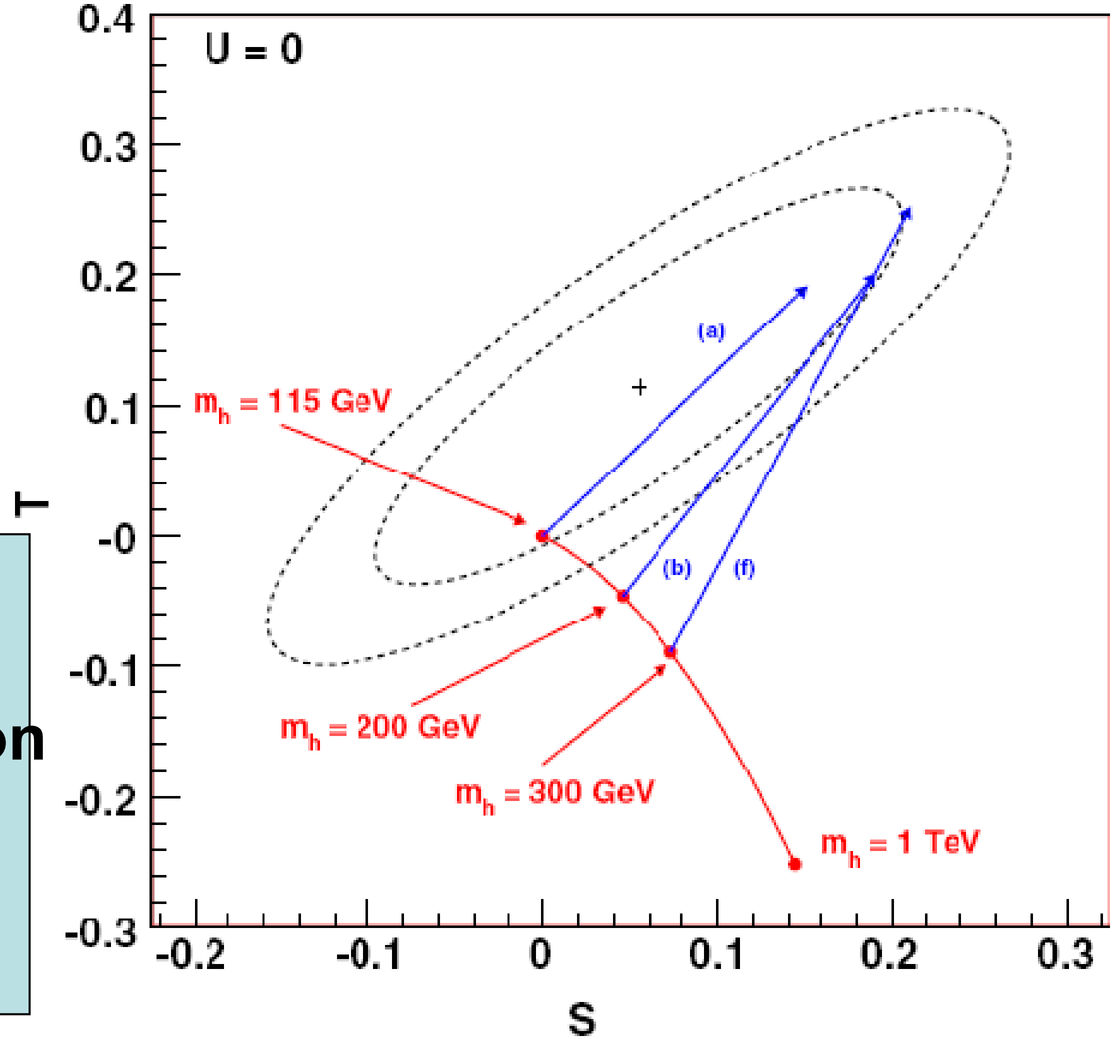
AVFAQ

- **Hasn't it already been ruled out?**

- **PDG (like all BIBLES) has its shares of errors**

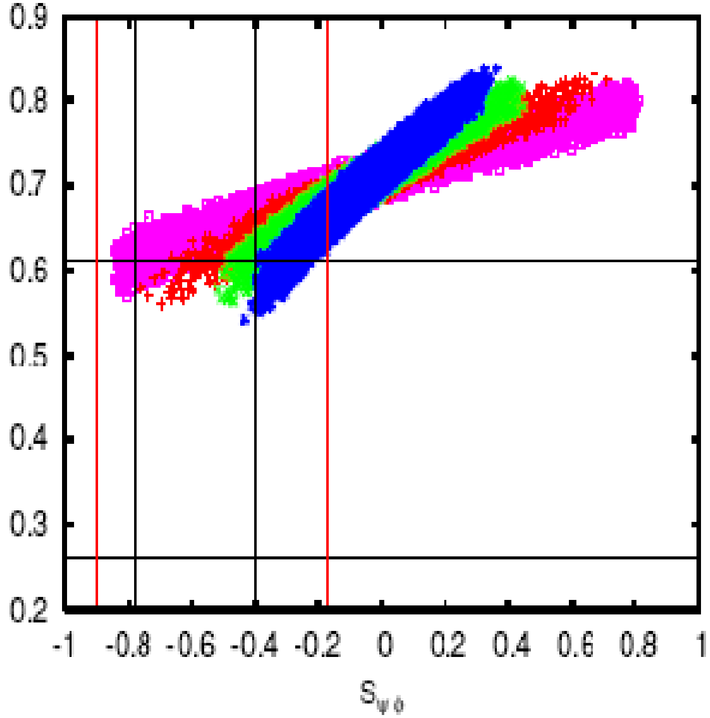
C also: Novikov, Rozanov, Vysotsky, 0904.4570 & earlier works

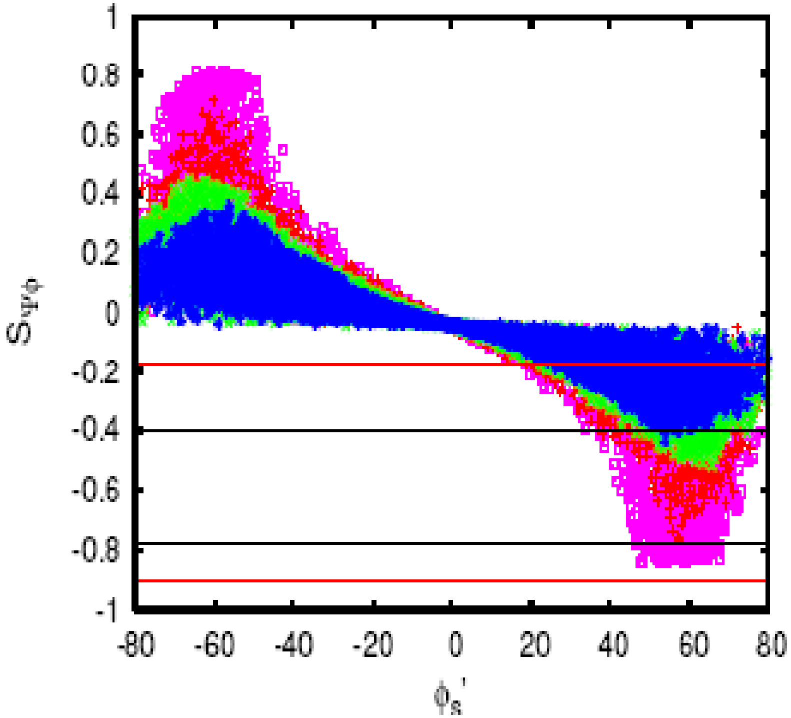
LEP EW Constraints on $m_{t'}$, $m_{b'}$, m_H



4th family is not inconsistent with LEP EWPC
See also M. Chanowitz, arXiv:0903.3570; 1007.0043; Erler abd Langacker 1003.3211

arXiv:0807.1971, 1002.0595

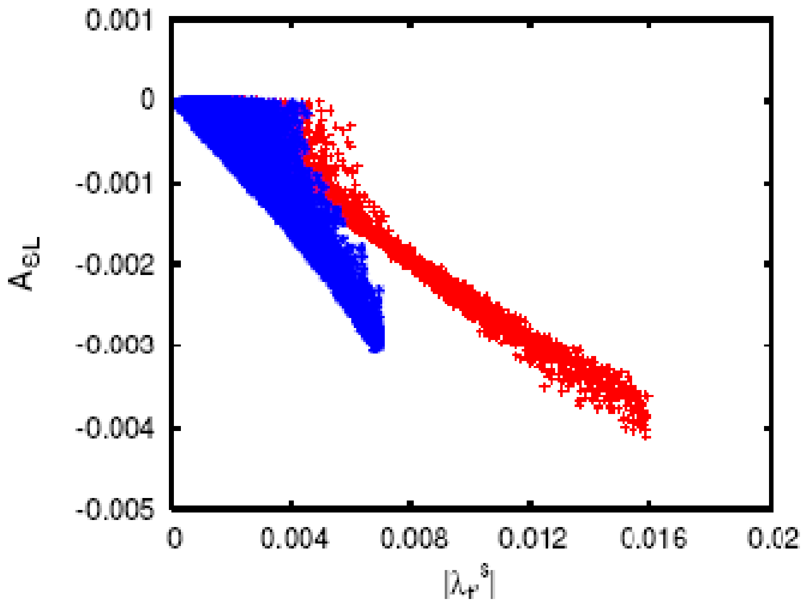


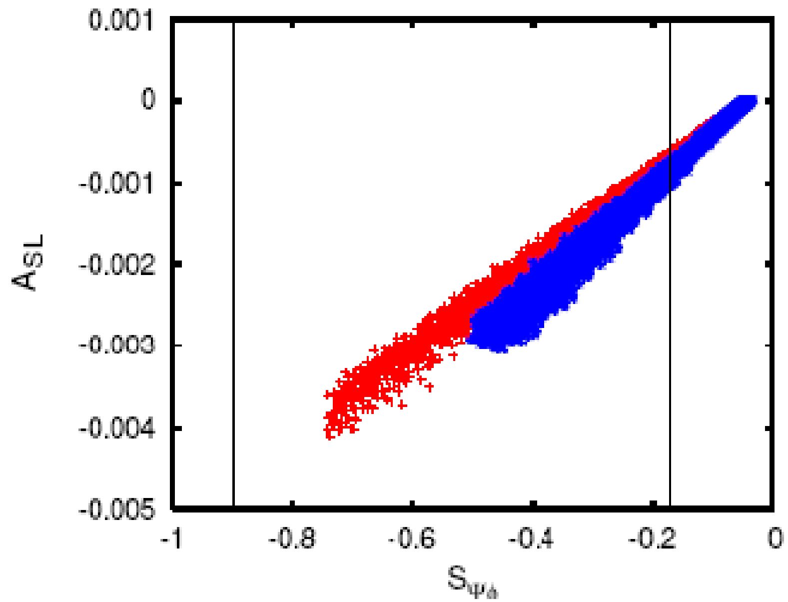


See also extensive studies by Hou et al, but they favored mt'~300 GeV & parameter spac disfavored by Chanowitz

Semi-leptonic asymmetry in Bs->Xs l nu

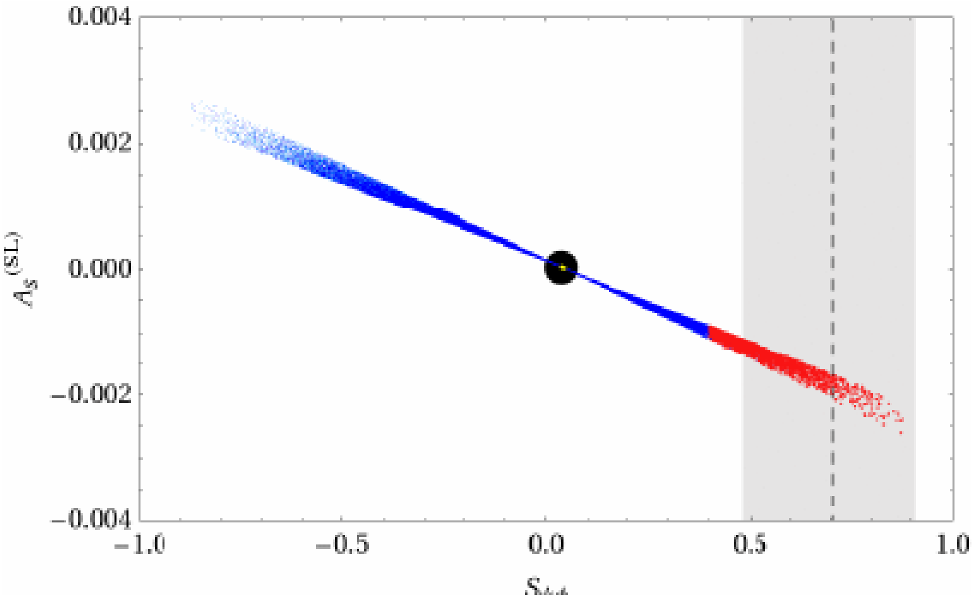
See arXiv:0807.1971, 1002.0595 A. S et al;
arXiv: 1002.2126 Buras et al





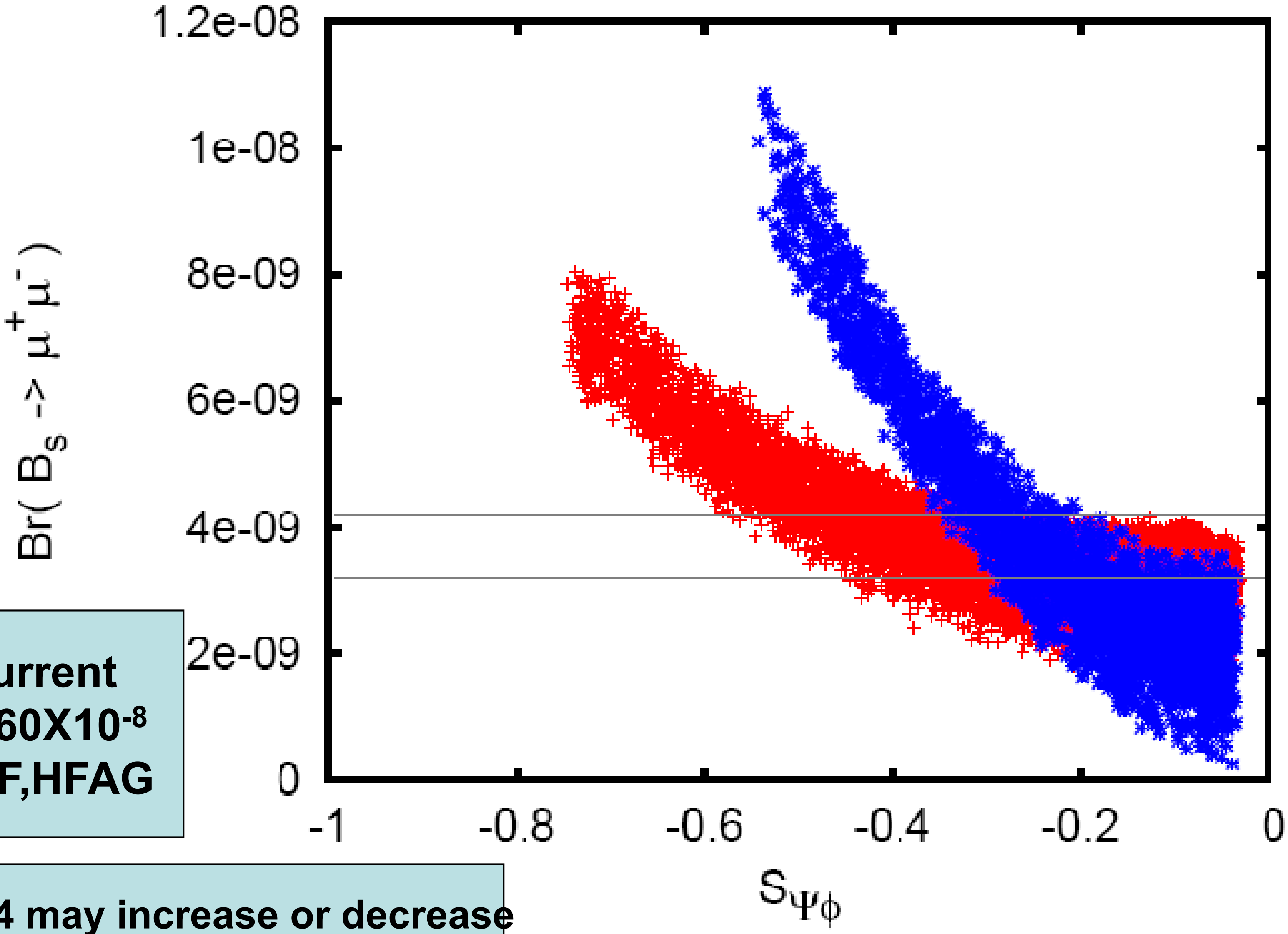
A_sl^s can readily reach ~ -0.004 ..genuine predictions contained in papers before D0 announcement…SM4 can give about 200 X SM3

xtensive recent studies in SM4 by Buras et al [arXiv: 1002.2126; 1004.4565; 1006.536



See Tilmann Heidsieck talk

Br(Bs->μμ): a very clean process



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

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

Collider SEARCHes FOR t', b' SHOULD BE GIVEN A HIGH PRIORITY

(See Meenakashi Narain talk.)

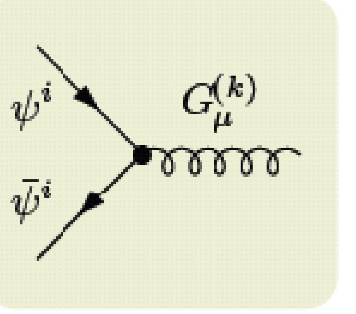
Summary & Outlook

- **B factories showed CKM works ~15-20% accuracy…It'd be a very serious mistake to interpret this to mean improved studies are not needed, given the reach of flavor studies.**
- **Although so far no compelling deviation from SM3 has been established, many ~2-3 σ deviations have been revelaled..These need to be vigorously pursued.**
- **Warp space ext. of SM may offer resolution; it represents perhaps most interesting candidate theory of flavor.**
- **SM4 offers simplest explanation…**
- **Direct searches at LHC should clarify matter significantly**
- **POSSIBLE EARLY NEW PHYSICS if mt';mb' ~500 GeV**
- **Flavor studies at (S)LHCb, (S)BF in the LHC-era would extend the reach of LHC extensively.**

Backups

RS-GIM mechanism*

- Quark-quark-gluon vertex in flavor eigenbasis:



$$\bar{\psi}^i G_\mu^{(k)} \psi^i \sim -i g_s^{4\mathrm{D}} \gamma_\mu \sqrt{L}\, F_{c_{\psi^i}}^2 \,, \quad F_{c_{\psi^i}} \sim \epsilon^{-c_{\psi^i}-1/2}$$

- Quark-quark-gluon vertex in mass eigenbasis:

$$\bar{q}_L^i G_\mu^{(k)} q_L^j \sim -i g_s^{4\mathrm{D}} \gamma_\mu \sqrt{L}\, F_{c_{Q_i}} F_{c_{Q_j}} \,, \quad \bar{q}_R^i G_\mu^{(k)} q_R^j \sim -i g_s^{4\mathrm{D}} \gamma_\mu \sqrt{L}\, F_{c_{q_i}} F_{c_{q_j}}$$

Important features:

- in flavor eigenbasis KK gluon couples to quarks flavor diagonally but non-universally, so that after rotation to mass eigenstates tree-level FCNCs arise
- since FCNCs are proportional to $F_{c_{A_i}} F_{c_{A_j}}$, exponential suppression of fermion profiles $F_{c_{A_i}}$ at IR brane guarantees **flavor protection (RS-GIM)**

*Agashe *et al.*, hep-ph/0406101, hep-ph/0408134

Quark masses and mixings in RS model*

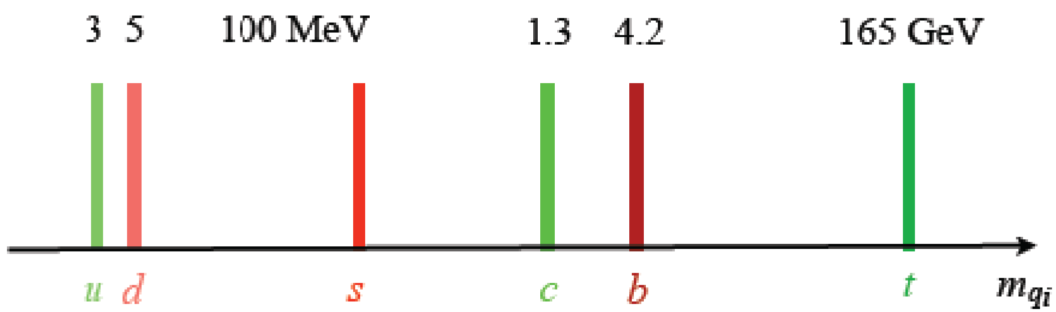
Scaling laws:

$$m_{q_i} = \mathcal{O}(1)\,\frac{v}{\sqrt{2}}\,F_{c_{Q_i}}F_{c_{q_i}}$$

$$\lambda = \mathcal{O}(1)\,\frac{F_{c_{Q_1}}}{F_{c_{Q_2}}}$$

$$A = \mathcal{O}(1)\,\frac{F^3_{c_{Q_2}}}{F^2_{c_{Q_1}}F_{c_{Q_3}}}$$

$$\bar\rho - i\bar\eta = \mathcal{O}(1)$$



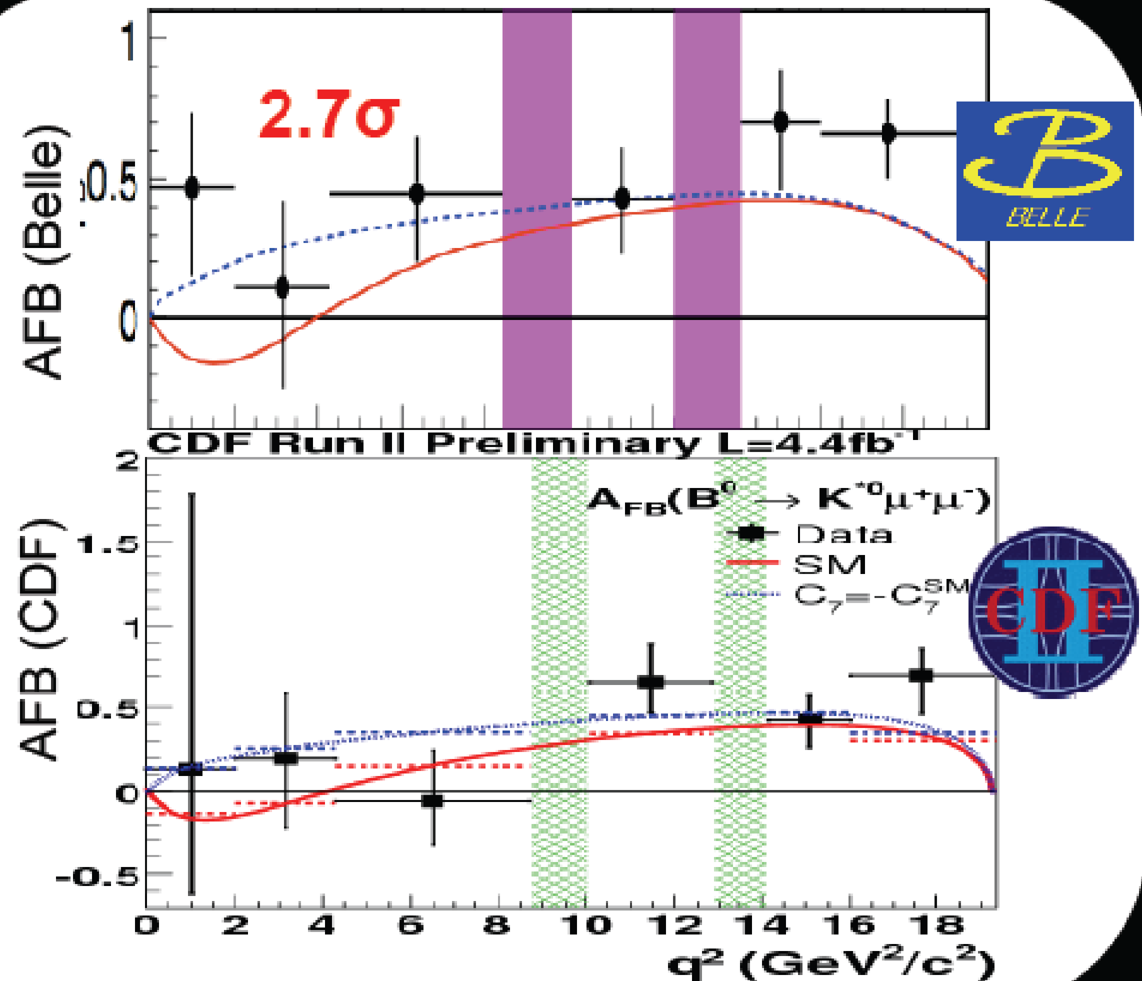
$c_{Q_1} = -0.579\,,$	$c_{Q_2} = -0.517\,,$	$c_{Q_3} = -0.473$
$c_{u_1} = -0.742\,,$	$c_{u_2} = -0.558\,,$	$c_{u_3} = +0.339$
$c_{d_1} = -0.711\,,$	$c_{d_2} = -0.666\,,$	$c_{d_3} = -0.553$

(+ anarchic Yukawa matrices)

- Hierarchy in quark masses and mixings can be naturally generated from anarchic complex 3×3 matrices $Y_q = \mathcal{O}(1)$ entering $Y_q^{\rm eff} = F_{c_{Q_i}}\,(Y_q)_{ij}\,F_{c_{q_j}}$

*Huber, hep-ph/0303183

$b \rightarrow s\mu^+\mu^-$ - current status



CDF Public Note 10047

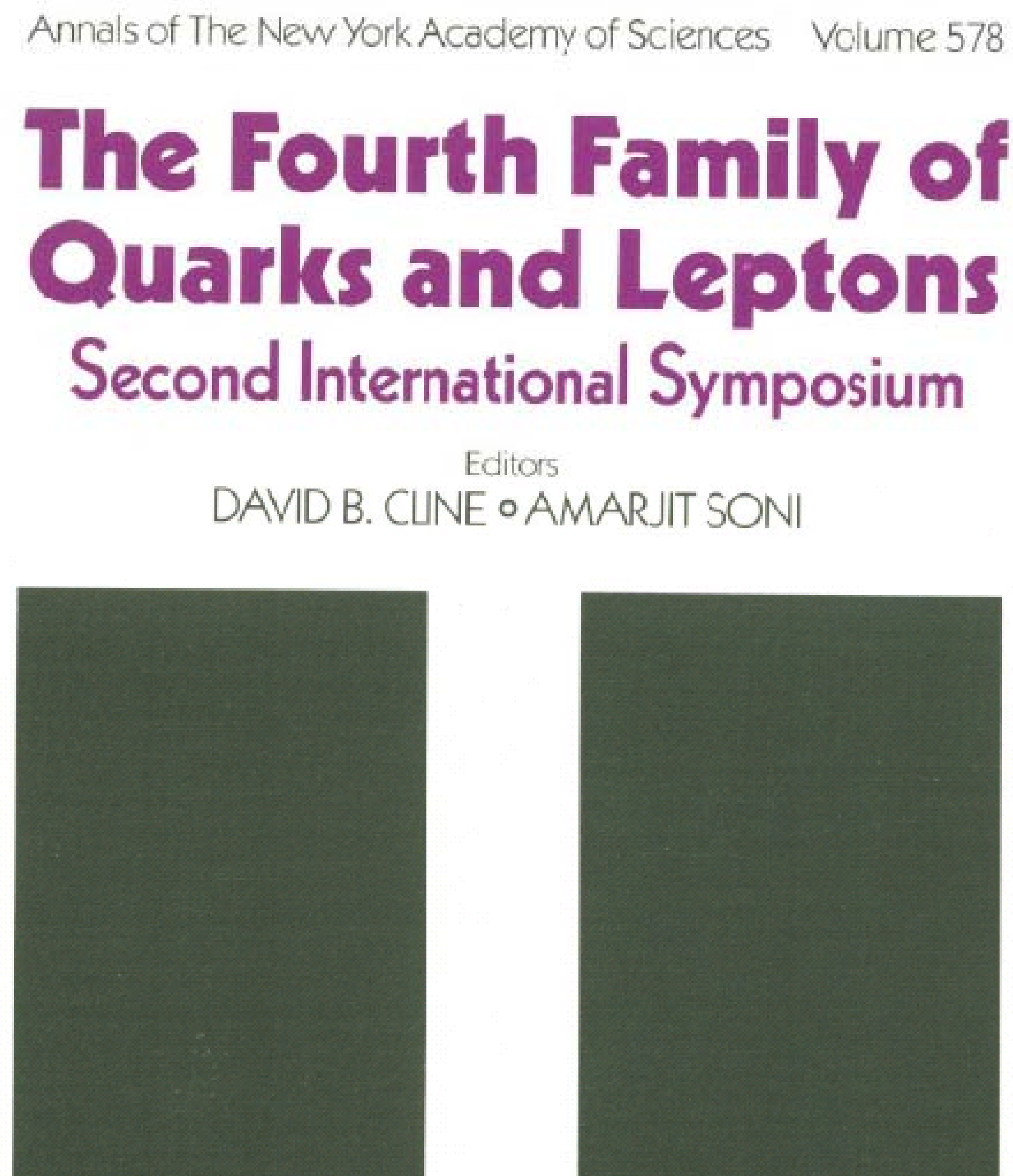
PRL103, 171801 (2009)

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


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

- 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

- 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 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)

$M_{ll'} \sim O(2\ m_{b'})$

BORING REPETITION?

- If the mt’ is heavy ~(400-600) GeV, then for sure it will have 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 have 2 additional CP-odd phases
- It may play an interesting role in baryogenesis (W.-S. Hou, 0803.1234; Fok & Kribs, 0803.4207; Jarlskog & Stora,’88; del Aguila & Aguilar-Saavedra’98)
- CANNOT BE A CONVENTIONAL 4^{th} Gen..mv4>mZ/2, thus,

  only for the purpose of interactions with W, CKM3 needs extension.
- Possible DMC (if no mixing with lighter 3 nu’s)..see e.g. Volovik’03
- It may open up possibilty of unification (PQ Hung,’98)
- Can be observed (with distinctive signatures) or ruled out at LHC

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	$\Delta S_{\rm tot}$	$\Delta T_{\rm tot}$
(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