New ideas and directions in flavor physics/CP violation

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Daunting task of a BSM theorist

- # of BSMs ~ [# of theorists]$^{\text{Huge\#}}$!!

- Safer to cling closer to experiments and take cue from there => Rephrase my charge to

Possible new physics opportunities in the flavor sector

Somewhat optimistic interpretation of (some) existing deviations > 2 σ

HINTS & THENCE

- g – 2

- B-CP anomalies
- C-CP – anomaly
- AFB(t t)

$\sin 2\beta$

$\Delta \sin 2\beta$

ΔA_{CP}

$2-3\sigma$

- Outlook for possible resolution

- NP in Flavor needs only one to survive

- Taking these seriously, candidate NP scenarios at work

$(g-2)_\mu$ & SM

the complete SM prediction is given by

$$a_\mu^{SM} = 116591834(2)(41)(26) \times 10^{-11}$$

whereas the current experimentally measured value is [8]

$$a_\mu^{exp} = 116592089(54)(33) \times 10^{-11}\,.$$

BNL E821
'04; '06

The SM prediction, therefore, differs from the the experimentally measured value by (see also [9, 10]):

$$a_\mu^{\text{new}} = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (255 \pm 80) \cdot 10^{-11}\,,$$

$\sim 3.2\sigma$

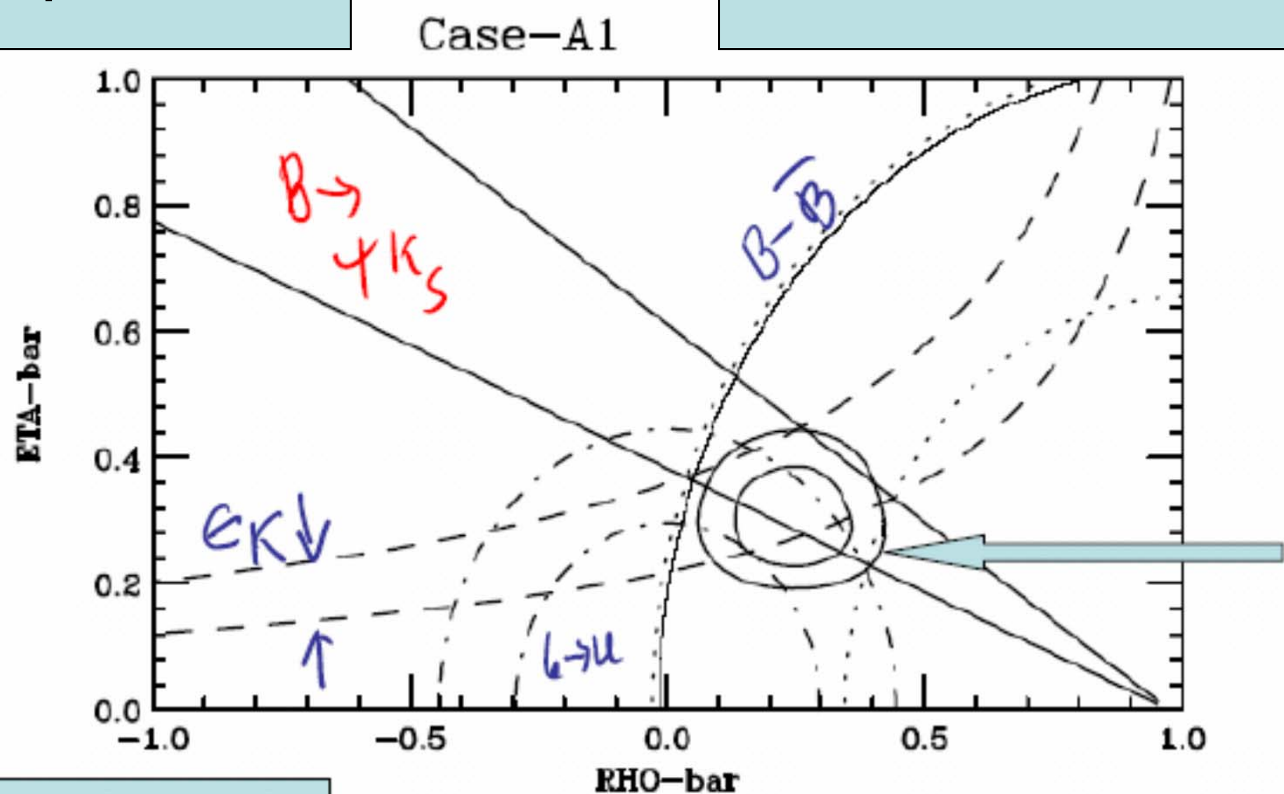
$\Rightarrow$ FNAL improved determination $\sim$ 5 yrs

Glorious successes
&
simmering limitations

1st Hint of confirmation of CKM CP description

Atwood &AS, hepph/0103197

B-CP
e
ISE
Feb~01



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

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 rise & in possible demise of CKM

[C. AIDA E-K]

- 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

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

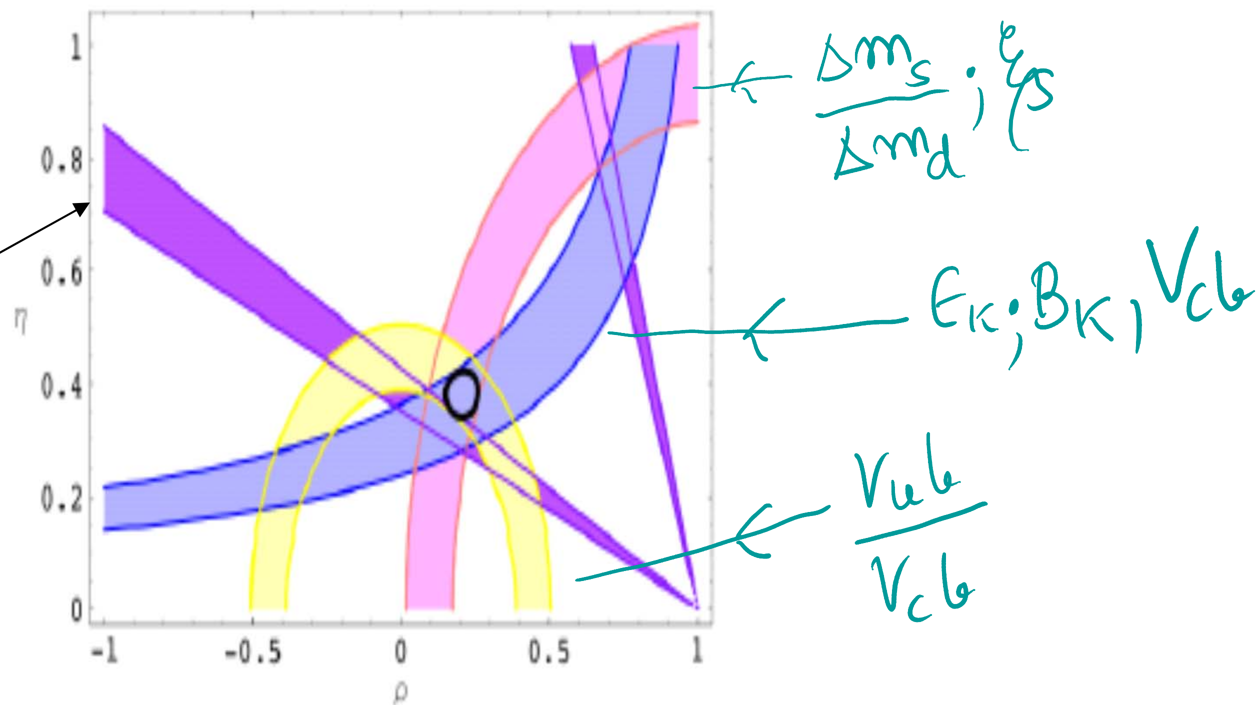


Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

Continuing saga of Vub

- For past 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. $B \to \pi \ell \nu$

continuum $B \to X_u \ell \nu$

-> ***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

Important to Examine only DeltaF=2 observables:Leave out Vub

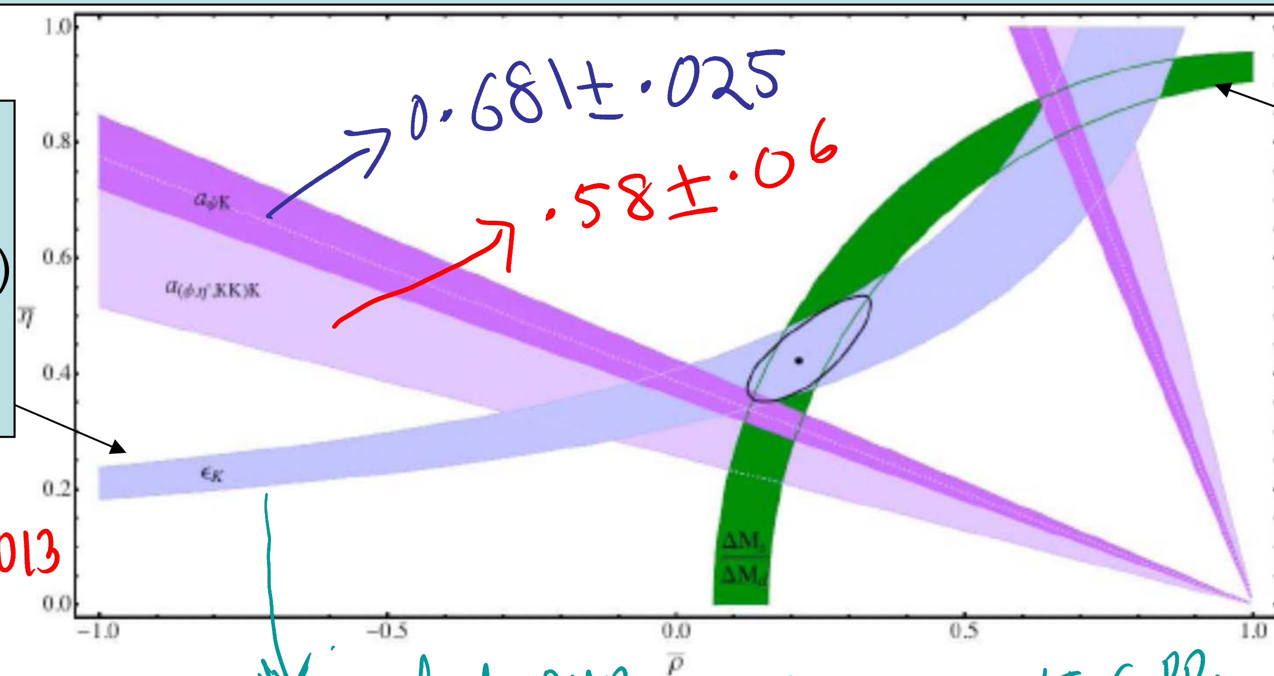
sin 2 β = 0.87+-.09{Lunghi+AS,hep-ph/08034340}

(became possible only due significantly reduced error in B_K)

Antonio et al (RBC-UKQCD) 0702042

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

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



$0.681 \pm .025$

$.58 \pm .06$

Gamiz et al; Becirevic; Tantalo

.

$\xi = 1.20 \pm .06$

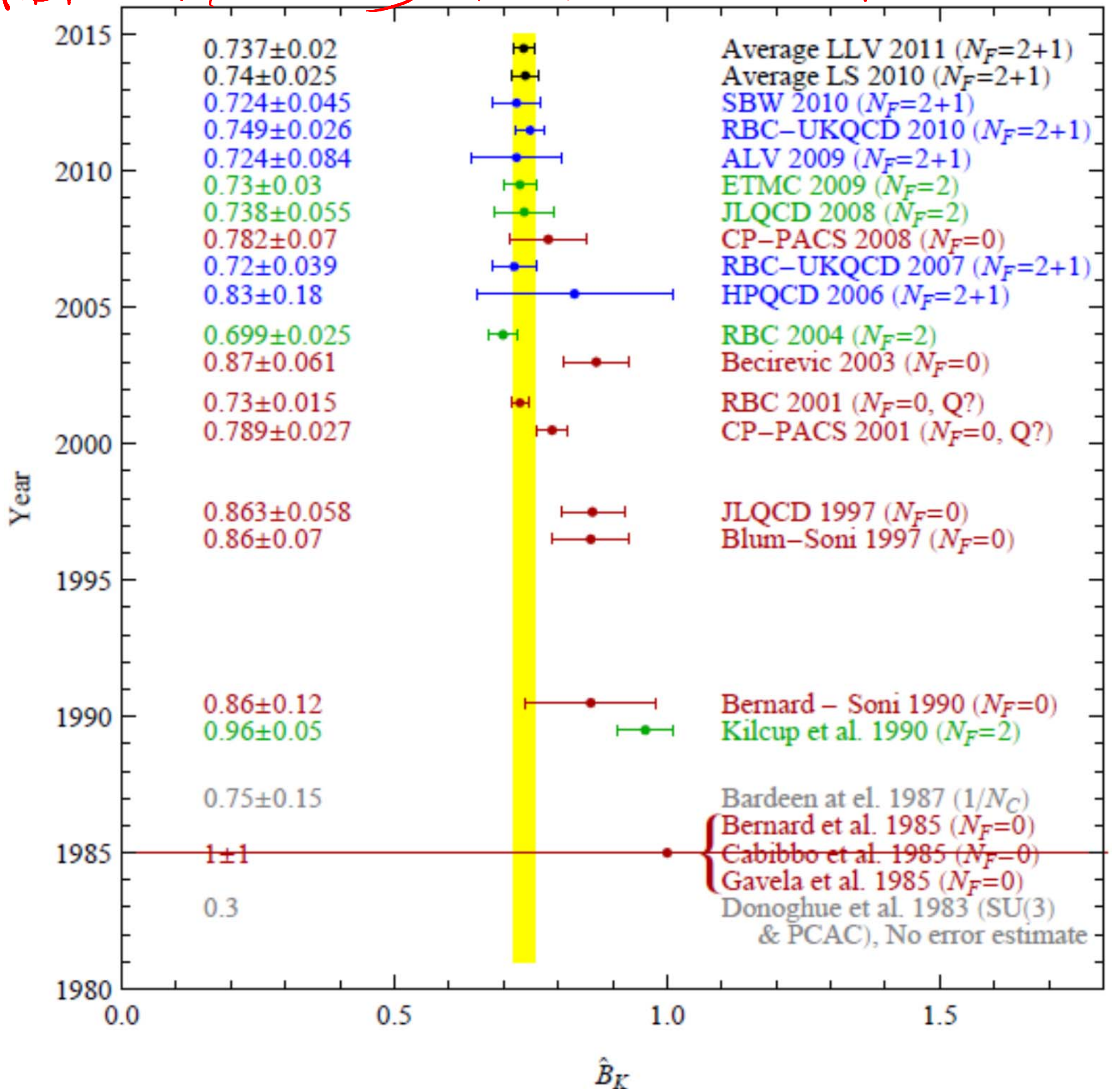
include BURAS+GUADAGNOLI CORR.
(0805.3887)

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

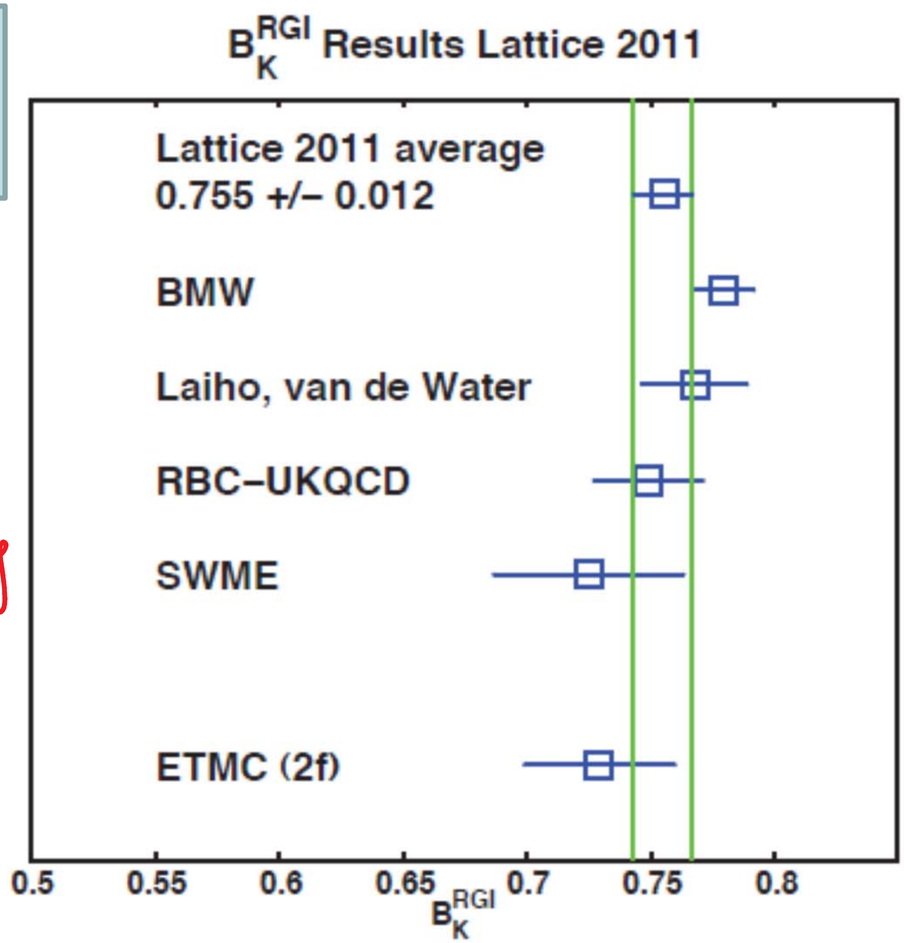
2010 UPDATE

A BRIEF (≈ 25 yrs) HISTORY OF B_K



Mawhinney, plenary LAT'11

Several Lattice groups using completely diff methods reporting B_K with total error $\leq 3\%$!

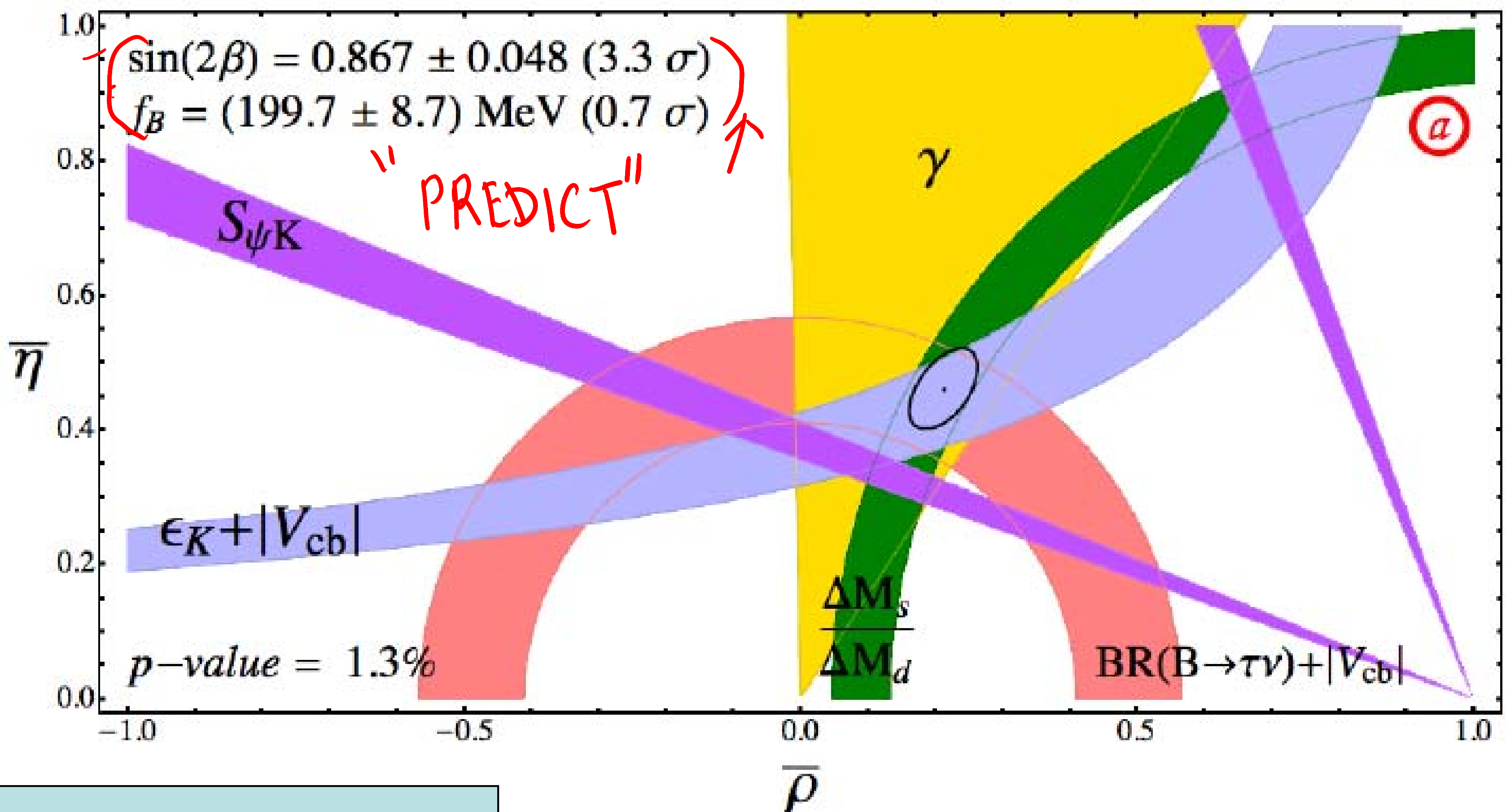


HUGE STRIDES IN LATTICE CALCULATION OF BK!

- Average the four 2+1 flavor calculations presented
- Except for BMW, all are preliminary, although all groups have recently published B_K results from earlier datasets, so preliminary work should be fairly reliable.

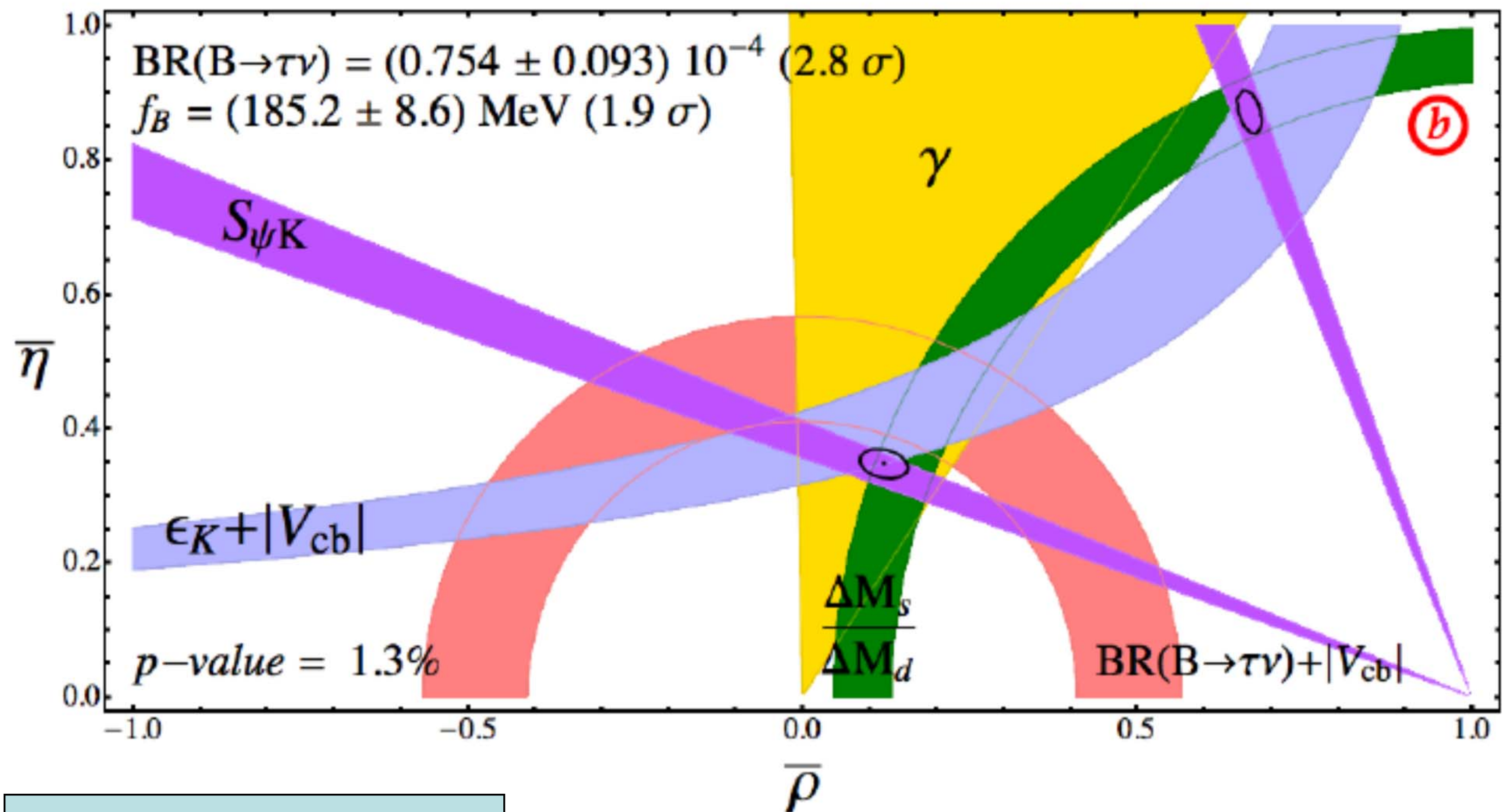
See also recent summary by FLAG working group of FLAVIANET (arXiv:1011.4408)
They quote $\hat{B}_K = 0.738(20)$ for $N_f = 2+1$

INPUTS ⇒ ε_K - $\Delta M_{Bs}/\Delta M_{Bd}$ - $|V_{cb}|$ - γ $B \to \tau\nu$



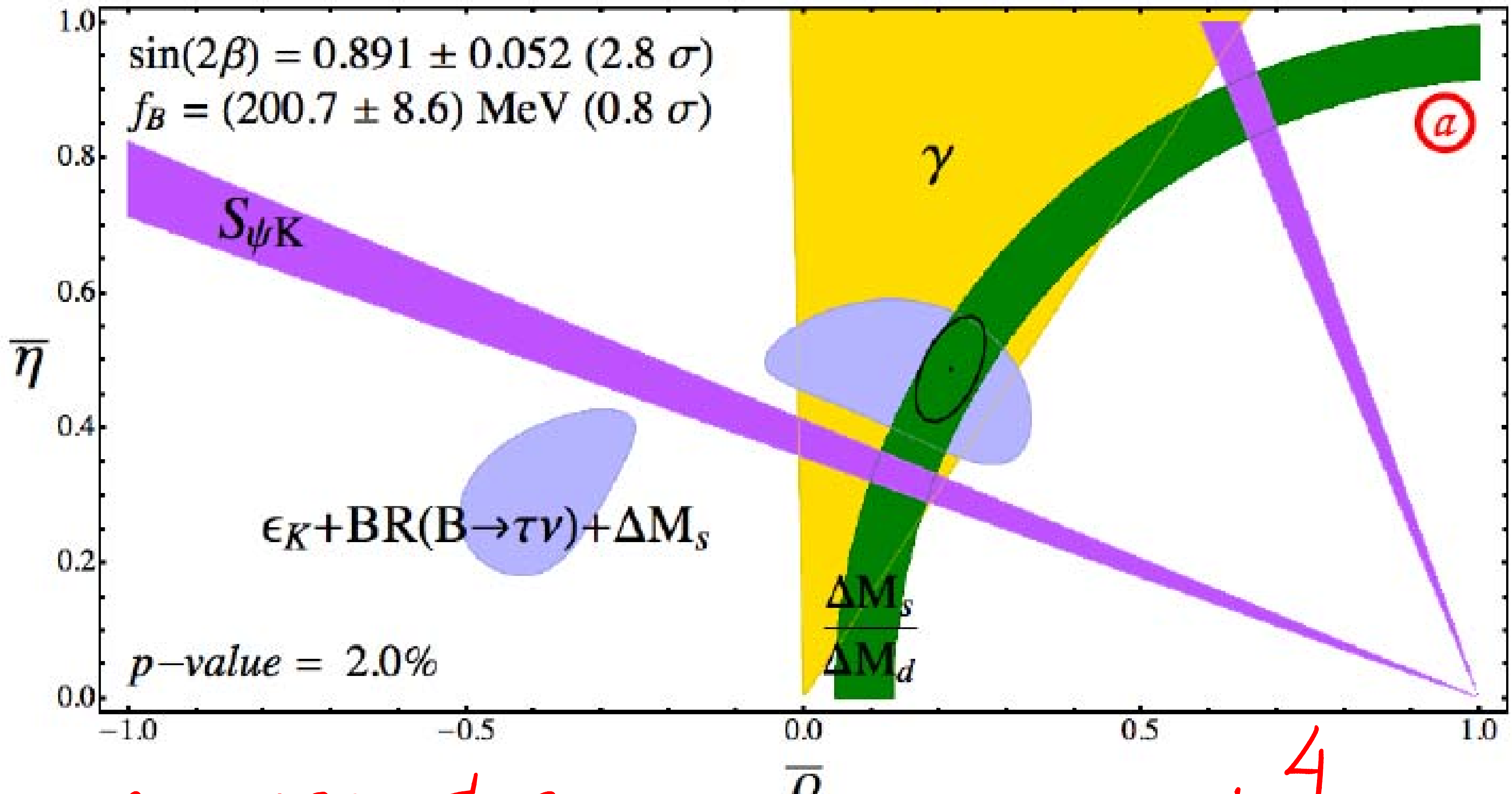
Predict sin2β & fB

Inputs: S(Bd->ψK), εK, ΔMs, ΔMd, Vcb, γ



Predict: Br(B->τν) & fB

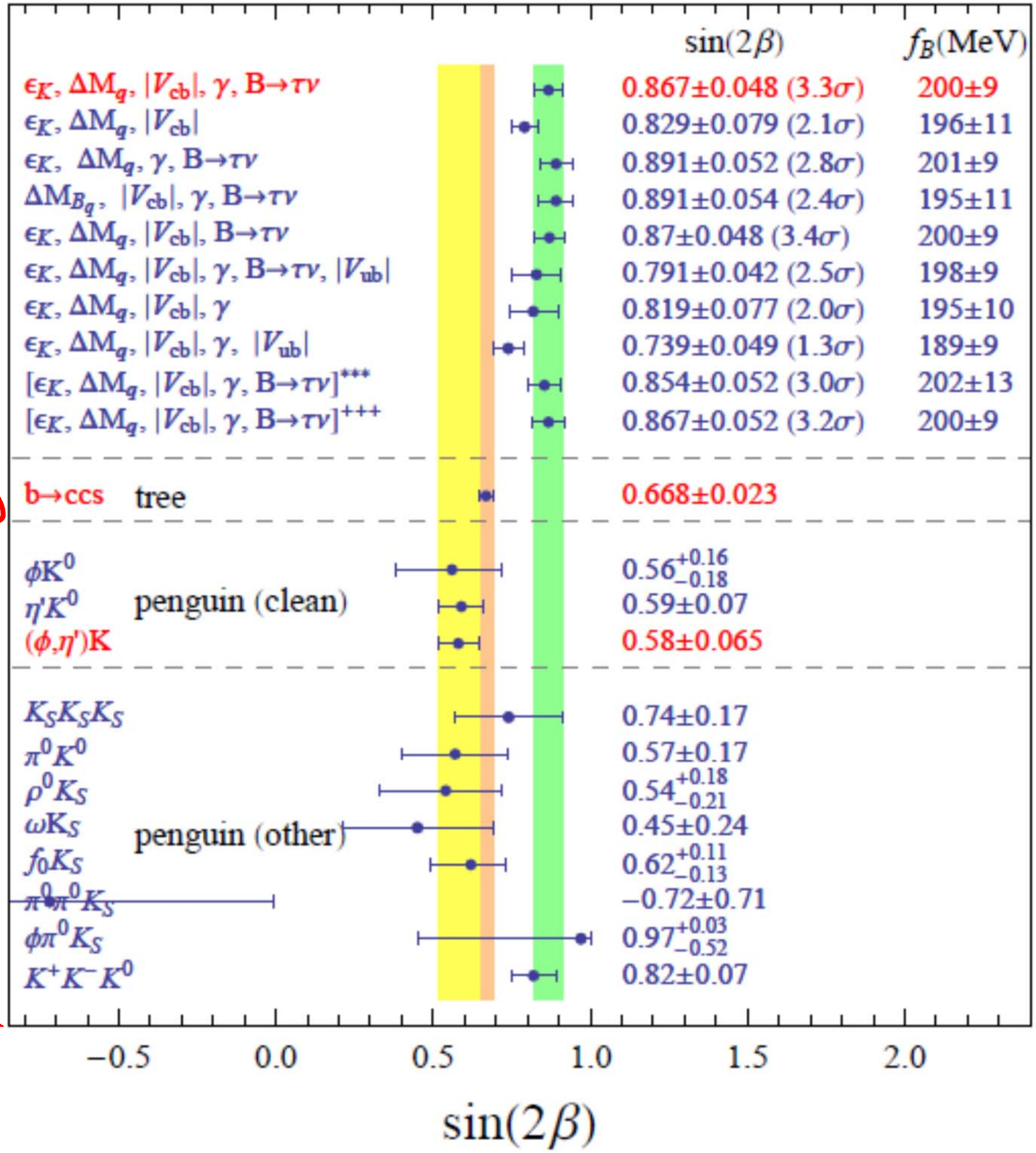
No semi-leptonic input, neither Vub or Vcb
Lunghi + AS PRL 2010



TO ADDRESS THE CONCERN : $\epsilon_K \sim V_{cb}^4$
DEVISE Method w/o use of V_{cb}

GOLD PLATED

Penguin dominated MODES

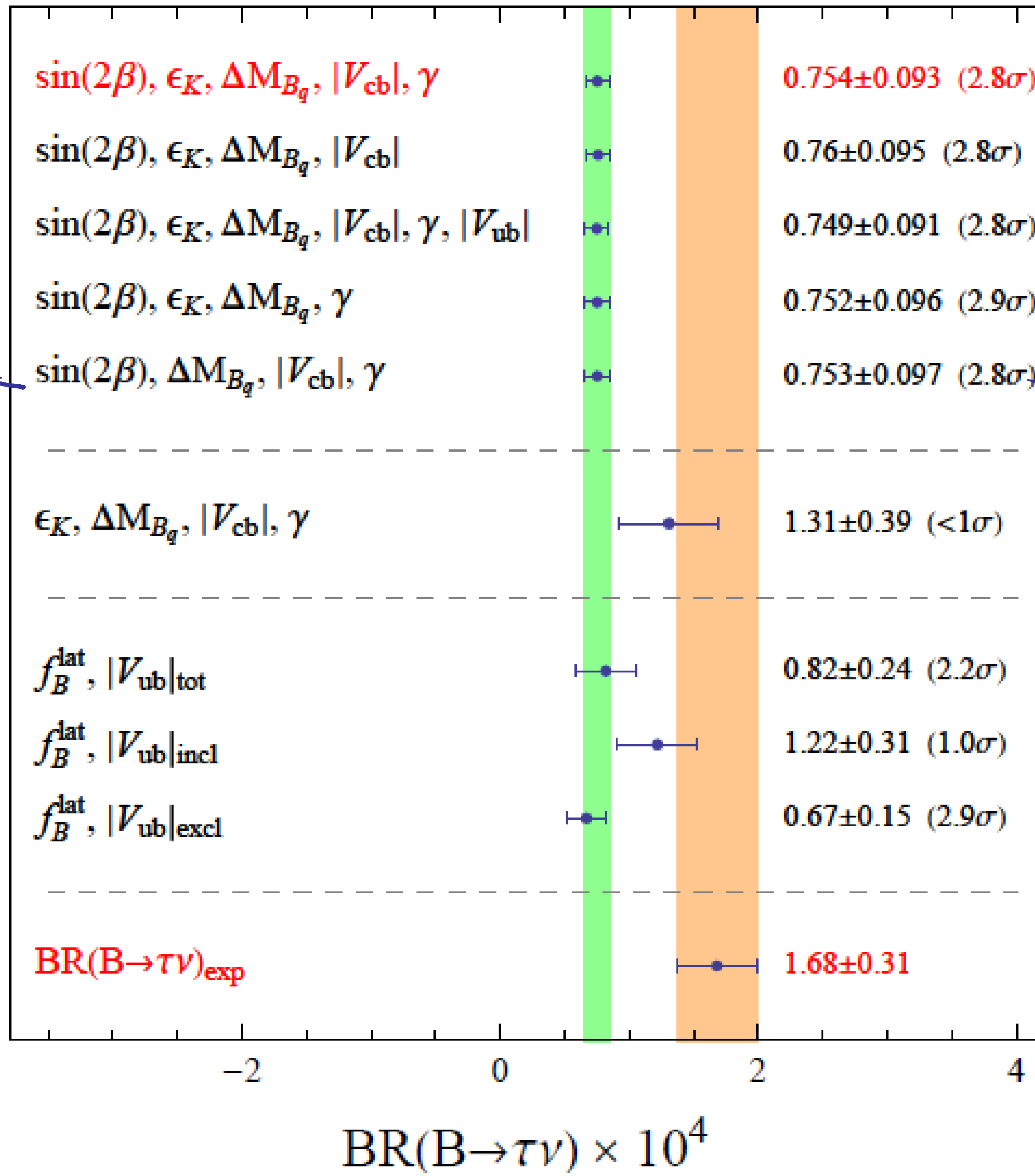


INPUT

Deviation

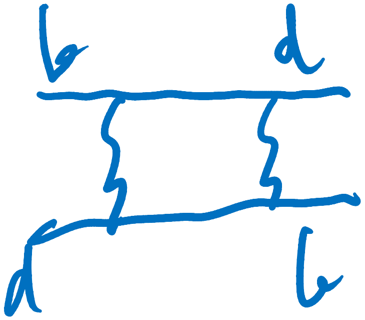
Sin2β

NO SIN2β



$\gtrsim 2.8\sigma$

$\lesssim 0.7\sigma$



(Sin2beta)tree vs (sin2beta)penguin

- The other hint is that b-> s penguin transitions have a non-vanishing BSM phase.
- Cleanest modes (eta' Ks, phi Ks) seem to show smaller value ~0.59 – 0.56
- Central value for several other modes is smaller than 0.68 [and of course practically all are well below the theory prediction ~0.85]

Note sin 42 deg = 0.67

sin 35 deg = 0.59 NEED TO TARGET such small deviation

~0.1 rad

P. Clarke [LHCb Collab] update @ EWMoriond 2012

$B_s \to J/\psi\Phi$ and $B_s \to J/\psi\pi\pi$ combined prelim.result

- Used a simultaneous fit to both datasets, taking all common parameters and correlations into account.
- Used largest syst. error.

c also Y. XIE talk here

$$\boxed{\phi_s = -0.002 \pm 0.083(\text{stat.}) \pm 0.027(\text{syst.})\ \text{rad}}$$

$\lesssim 0.2$ rad

Main Conclusion on B CP anomalies

- **Measured value of sin2 beta via S(ψKs) is smaller than SM expectations by ~3.3 sigma**
- **Also $\Delta ACP\ K\pi$ problem**
- ALSO $\sin 2\beta$ penguin smaller than from (ψK_S) tree .

Will assume this is HINT for NP (later)

RECENT CP STUDIES IN D DECAYS

c. M. GRONAU

Recent results from LHCb, CDF

LHCb

$$\Delta A_{CP}^{\rm dir} \equiv A_{CP}^{\rm dir}(K^+K^-) - A_{CP}^{\rm dir}(\pi^+\pi^-) = -(0.82 \pm 0.21 \pm 0.11)\%$$

U Spin $\Rightarrow$

$$A_{\rm CP}^{\rm dir}(K^+K^-) \simeq -A_{\rm CP}^{\rm dir}(\pi^+\pi^-)$$

$$A_{\rm CP}(K^+K^-) = (-0.24 \pm 0.22 \pm 0.09)\%$$

$$A_{\rm CP}(\pi^+\pi^-) = (+0.22 \pm 0.24 \pm 0.11)\%$$

CDF

$$\Delta A_{CP}^{\rm dir} = (-0.645 \pm 0.180)\%$$

Peek @ PDG: old results

$$\mathrm{BR}[D^0 \to K^-\pi^+] = (3.949 \pm 0.023 \pm 0.040 \pm 0.025)\% \,,$$

$$\mathrm{BR}[D^0 \to \pi^+\pi^-] = (0.1425 \pm 0.0019 \pm 0.0018 \pm 0.0014)\% \,,$$

$$\mathrm{BR}[D^0 \to K^+K^-] = (0.3941 \pm 0.0038 \pm 0.0050 \pm 0.0024)\% \,,$$

$$\frac{\mathrm{BR}[D^0 \to K^+\pi^-]}{\mathrm{BR}[D^0 \to K^-\pi^+]} = (0.331 \pm 0.008)\% \,,$$

$$\mathrm{obs}_1 \equiv \frac{\mathrm{BR}[D^0 \to K^+K^-]/|\vec{p}_K|}{\mathrm{BR}[D^0 \to \pi^+\pi^-]/|\vec{p}_\pi|} \simeq 3.22 \pm 0.09$$

$$\mathrm{obs}_2 \equiv \frac{\mathrm{Br}[D^0 \to K^-\pi^+]/|\vec{p}_{\pi K}|}{\mathrm{Br}[D^0 \to K^+K^-]/|\vec{p}_K|}\,\lambda^2 \simeq 0.47 \pm 0.01 \,,$$

$$\mathrm{obs}_3 \equiv \frac{\mathrm{Br}[D^0 \to K^+\pi^-]}{\mathrm{Br}[D^0 \to K^-\pi^+]}\,\lambda^{-4} \simeq 1.28 \pm 0.03 \,,$$

$\neq 1$

$\Rightarrow$ U Spin Badly Broken

EXACT U-SPIN LIMIT

$$H_{\rm eff}(c \to us\bar{d}) = -\,(V_{cs}^* V_{ud})\, H_{U=1}^{(U_3=-1)}\,,$$

$$H_{\rm eff}(c \to uq\bar{q}) = \left(\frac{V_{cd}^* V_{ud} - V_{cs}^* V_{us}}{\sqrt{2}}\right) H_{U=1}^{(U_3=0)} + (V_{cd}^* V_{ud} + V_{cs}^* V_{us})\, H_{U=0}\,,$$

$$H_{\rm eff}(c \to ud\bar{s}) = (V_{cd}^* V_{us})\, H_{U=1}^{(U_3=+1)}\,.$$

$\lambda_q \equiv V_{cq}^* V_{uq}$ $\quad q = d, s$

$$\mathcal{A}[D^0 \to K^- \pi^+] = 2\, V_{cs}^* V_{ud}\, B_{U=1}\,,$$

$$\mathcal{A}[D^0 \to \pi^+ \pi^-] = (\lambda_d + \lambda_s)\, A_{U=0} + (\lambda_d - \lambda_s)\, B_{U=1}\,,$$

$\to O(\lambda^5)$

$$\mathcal{A}[D^0 \to K^+ K^-] = (\lambda_d + \lambda_s)\, A_{U=0} - (\lambda_d - \lambda_s)\, B_{U=1}\,,$$

$\to O(\lambda)$

$$\mathcal{A}[D^0 \to K^+ \pi^-] = 2\, V_{cd}^* V_{us}\, B_{U=1}\,,$$

Taking U-spin breaking into a/c

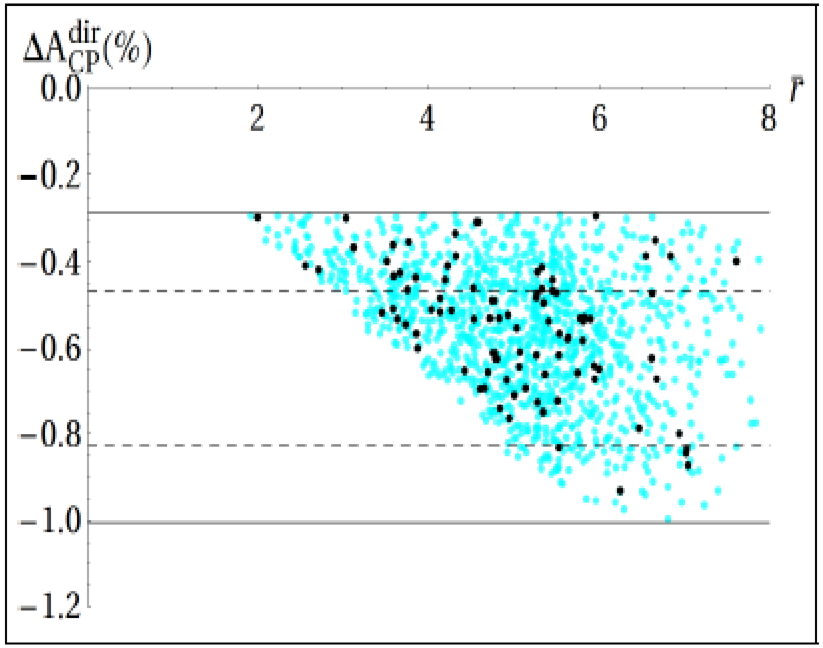
$$\mathcal{A}[D^0 \to K^-\pi^+] \equiv 2\,V_{cs}^* V_{ud}\left(B_{U=1} - \Delta B'_{U=1}\right) = 2\,V_{cs}^* V_{ud}\, B_{U=1}\left[1 - r'_1\, e^{i\,\phi'_1}\right],$$

$$\begin{aligned}\mathcal{A}[D^0 \to \pi^+\pi^-] &= (\lambda_d + \lambda_s)\,(A_{U=0} + \Delta B_{U=1}) + (\lambda_d - \lambda_s)\,(B_{U=1} + \Delta A_{U=0}) \\ &= B_{U=1}\left[(\lambda_d + \lambda_s)\,\left(r\,e^{i\,\phi} + r_1\,e^{i\,\phi_1}\right) + (\lambda_d - \lambda_s)\,\left(1 + r_0\,e^{i\,\phi_0}\right)\right],\end{aligned}$$

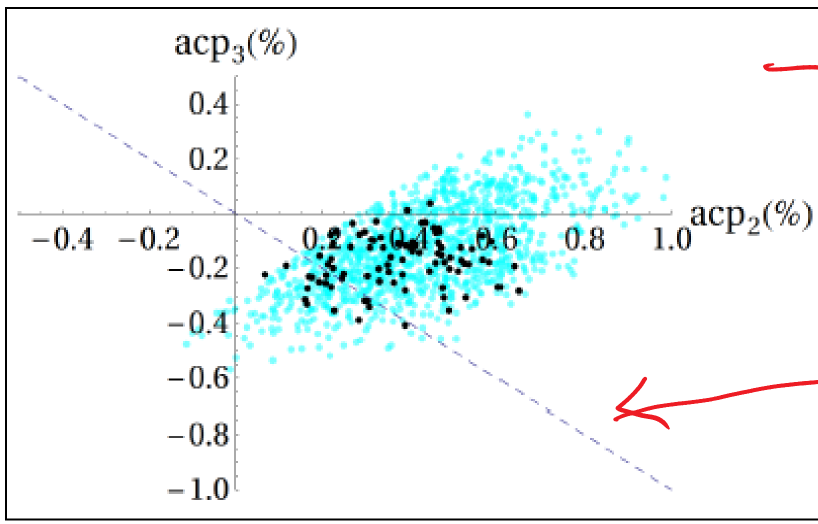
$$\begin{aligned}\mathcal{A}[D^0 \to K^+K^-] &= (\lambda_d + \lambda_s)\,(A_{U=0} - \Delta B_{U=1}) - (\lambda_d - \lambda_s)\,(B_{U=1} - \Delta A_{U=0}) \\ &= B_{U=1}\left[(\lambda_d + \lambda_s)\,\left(r\,e^{i\,\phi} - r_1\,e^{i\,\phi_1}\right) - (\lambda_d - \lambda_s)\,\left(1 - r_0\,e^{i\,\phi_0}\right)\right],\end{aligned}$$

$$\mathcal{A}[D^0 \to K^+\pi^-] = 2\,V_{cd}^* V_{us}\left(B_{U=1} + \Delta B'_{U=1}\right) = 2\,V_{cd}^* V_{us}\, B_{U=1}\left[1 + r'_1\, e^{i\,\phi'_1}\right].$$

Feldman, Nandi , A.S, arXiv: 1202.3795



ΔA_{CP} ~0.6% PLAUSIBLE



$A_{CP}(\pi\pi)$

$A_{CP}(KK)$

EXACT U SPIN

Conclusion on Recent D-CP results

- **Plausible contribution originates from SM**
- **Part from NP cannot be ruled out**
- ***Unless true result is , for sure, 1% or more , not a compelling sign of new physics***
- ***theory estimates plagued by large hadronic (non-perturbative) uncertainties; NO RIGOUROUS METHOD IN SIGHT; LONG-TERM WORRY => Ghost of ε'/ε***
- ***More exptal input crucial & could change SM vs NP; see arXiv:1202.3795 for suggested modes***

Outlook for future (~5 years) for resolution of anomalies

- Lattice …BG/Q's arrived late 2011…

  Computing power enhanced factor

O(20-50) more compared to past 5-7 years

- SUPER KEK-B O(20- 50) X BELLE/BABAR

- S(LHCb) ….~10 X LHCb

OPTIMISTIC THAT A BSM CP-odd PHASE will be seen

IMPLICATIONS of Hints From B,D-CP studies

Assume now problems with CKM-SM are serious

- What is the most interesting theoretical scenario for BSM? HIGHLY SUBJECTIVE

WARPED EXTRA-DIMENSION

- What is the simplest scenario …?

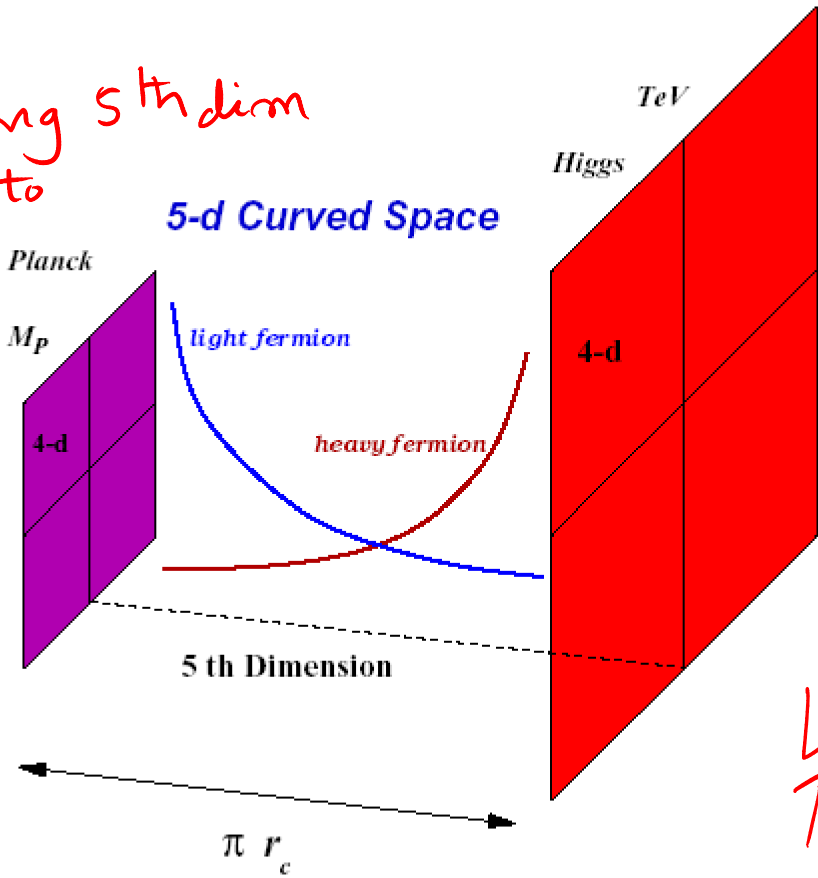
4th generation

MAY B LINKED DUE DUALITY

RANDALL+SUNDRUM '99

[FIG BY H DAVOUDIASL]

Points along 5th dim correspond to diff. eff. 4d scale!



$$ds^2 = e^{-2\sigma}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2\, d\phi^2$$

$$\langle H_4\rangle = e^{-\sigma}\langle H_5\rangle$$

$$\sigma = \underbrace{k r_c}_{\sim 12}\pi$$

TeV

M_P

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 interaction to mass basis)are suppressed roughly to the same level as loop in SM**
- **O(1) CP omnipresent;…..in fact for neutron a (mild) CP problem**
- **Most flavor violations are driven by the top quark**

-> ENHANCED t-> cZ, (alsoD^0)….A VERY IMPORTANT "GENERIC" PREDICTION..Agashe, Perez, AS'04;06

K-$\bar{K}$: 10^3 TeV $\longrightarrow$ ~10TeV (RS)

EXTENSIVE RECENT STUDIES by BURAS et al and NEUBERT et al

PROS & Cons

- The possibility to simultaneously address
EW-PI and EW-FI puzzles renders the basic warp idea extremely appealing

BUT

- Specific model(s) that can be used to make precise quantitative predictions are not yet there
- Therefore, SEEK GENERIC CLUES & TARGETS

WARPED SPACE: THEORY of Flavor

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 expected
- 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

PRECISE Quantitative predictions difficult at present

$(\Delta \sin 2\beta) \sim 0.2$

One Very Important Repercussion of RS.

Enhanced $t \to cZ$ . . . . possibly with CP

$D^0 - \bar{D}^0$ . . "

t -> c Z

Effective Lagrangian from WED

$$\mathcal{L}^t_{\rm FC} \ni \left(g_1 \bar{t}_R \gamma_\mu c_R + g_2 \bar{t}_L \gamma_\mu c_L\right) Z^\mu g_Z$$

with

$$g_{1,2} \sim \left[5\cdot 10^{-3}\frac{(U_R)_{23}}{0.1}, 4\cdot 10^{-4}\frac{(U_L)_{23}}{0.04}\right]\left(\frac{3\ \mathrm{TeV}}{m_{KK}}\right)^2 ;$$

expect $O(1)$

AGASHE et al
EWPT JHEP '03
$\Rightarrow m_{KK} \sim 3\,\mathrm{TeV}$

Experimental signals @ the LHC

$$\mathrm{BR}\,(t \to cZ) \;\sim\; 10^{-5} \left(\frac{3\ \mathrm{TeV}}{m_{KK}}\right)^4 \left(\frac{(U_R)_{23}}{0.1}\right)^2$$

≈ 1

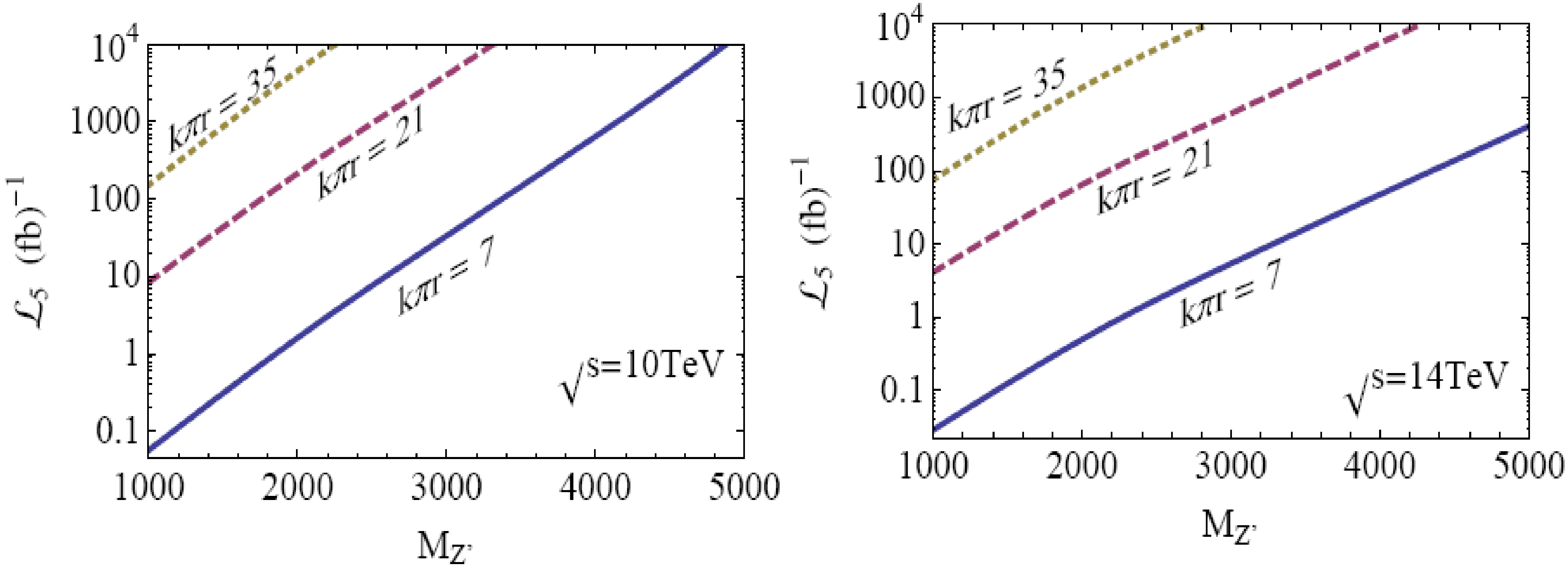
At the LHC expect 10^8 top pairs so should be accessible.
Specifically with 100 fb^{-1} ,upper limit on BR(t->cZ)~10^{-5} is feasible (ATLAS)
With enough statistics angular analysis would also be very informative.
SLHC
WED predicts predominantly RH couplings.

Though RS represents an extremely interesting framework for a theory of flavor, an explicit consruction is still lacking…generically expect a zoo of new particles (graviton, Z',W'…..) with masses > ~ 3 TeV, except for a light scalar (radion) should be considerably lighter

3 TeV may be too optimistic. . wishful thinking due LHC energy

LHC reach for the Little Z' via the clean dilepton channel

(Davoudiasl, Gopalakrishna and A.S. arXiv:0908.1131)



- $\mathcal{L}_5$: $\int L\, dt$ for 5σ signal (≥ 3 events) in $pp \to \ell^+\ell^-$ ($\ell = e$ or μ).

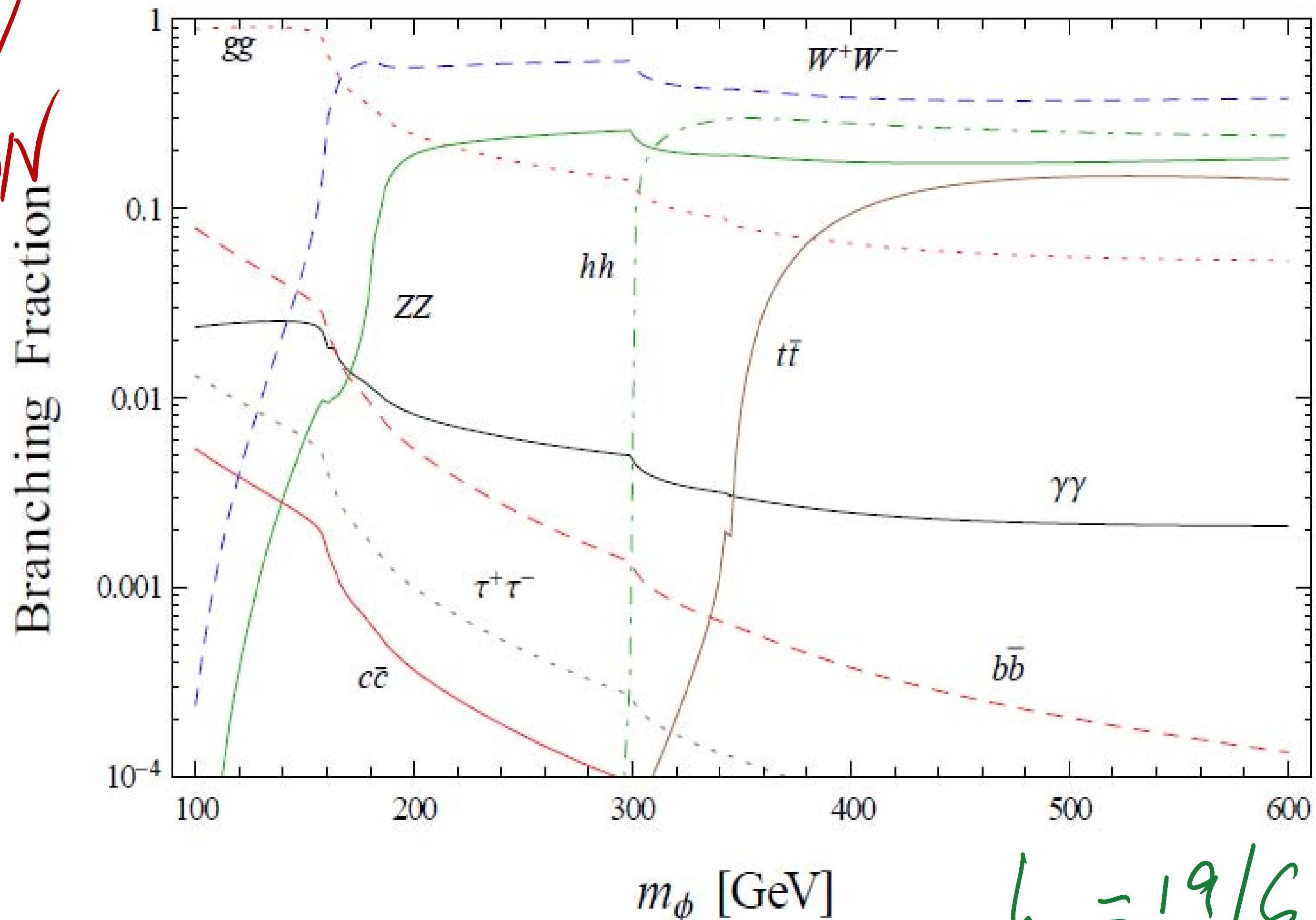
- For $kr_c\pi \approx 7$:

$M_{Z'} \approx 2(3)$ **TeV at** $\sqrt{s} = 10\,(14)$ **TeV with 1 (4) fb^{-1}.**

- $kr_c\pi \approx 35$ (RS), any channel: $M_{Z'} \approx 3$ TeV, $\sqrt{s} = 14$ TeV, 300 fb^{-1}.

Agashe *et al.*, 2007

RADION/
DILATON



$$\mathcal{L}_A = -\frac{\phi}{4\Lambda_\phi\, kL}\left[1 + \frac{\alpha_G}{2\pi}\, b_G\, kL\right] F_{\mu\nu}F^{\mu\nu},$$

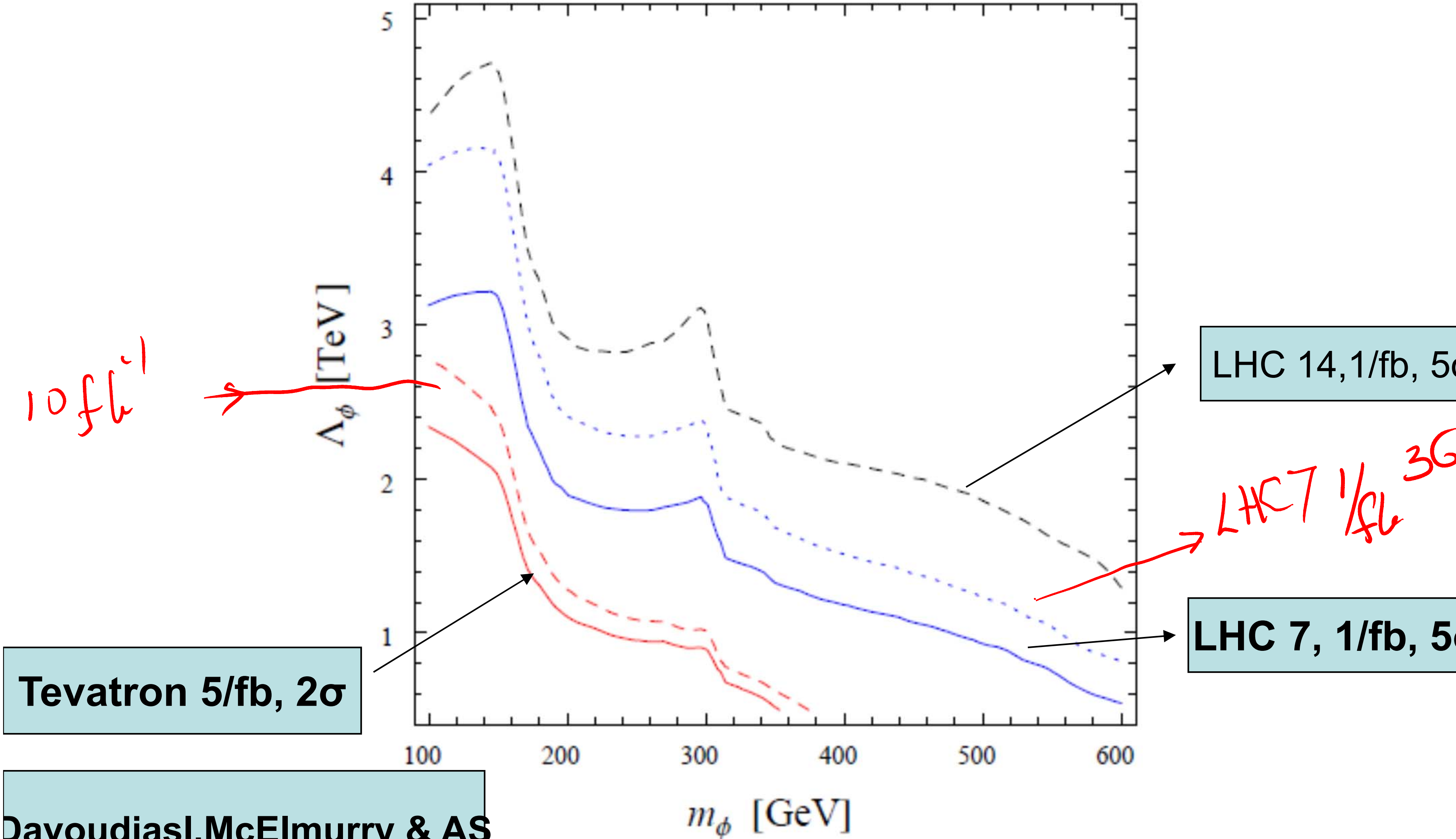
$$b_{\rm EM} = b_2 + b_Y - F_W - \frac{4}{3}F_t, \qquad b_{\rm QCD} = 11 - \frac{2}{3}N_F,$$

$b_2 = 19/6$; $b_Y = -41/6$

$F_W = 7$

$F_t = -4/3$

Tevatron & LHC Reach for the Radion



LHC 14,1/fb, 5σ

LHC 7, 1/fb, 5σ

Tevatron 5/fb, 2σ

Davoudiasl,McElmurry & AS
arXiv:1009.0764

KK-Particle Masses

$J_1(x_n) = 0$

$$m_n = x_n k e^{-k r_c \pi}, \tag{18}$$

where for gauge fields $x_n = 2.45, 5.56, 8.70, \ldots$ and for the graviton $x_n^G = 3.83, 7.02, 10.17, \ldots$.

EWPT $\Rightarrow m_{KK} \gtrsim 3$ TeV   AgasheDMS '03

$m_G \sim 1.6\, m_{glu}$, $m_{KKF} \sim 1.5\, m_{glu}$

$Z', W' \sim m_{glu}$

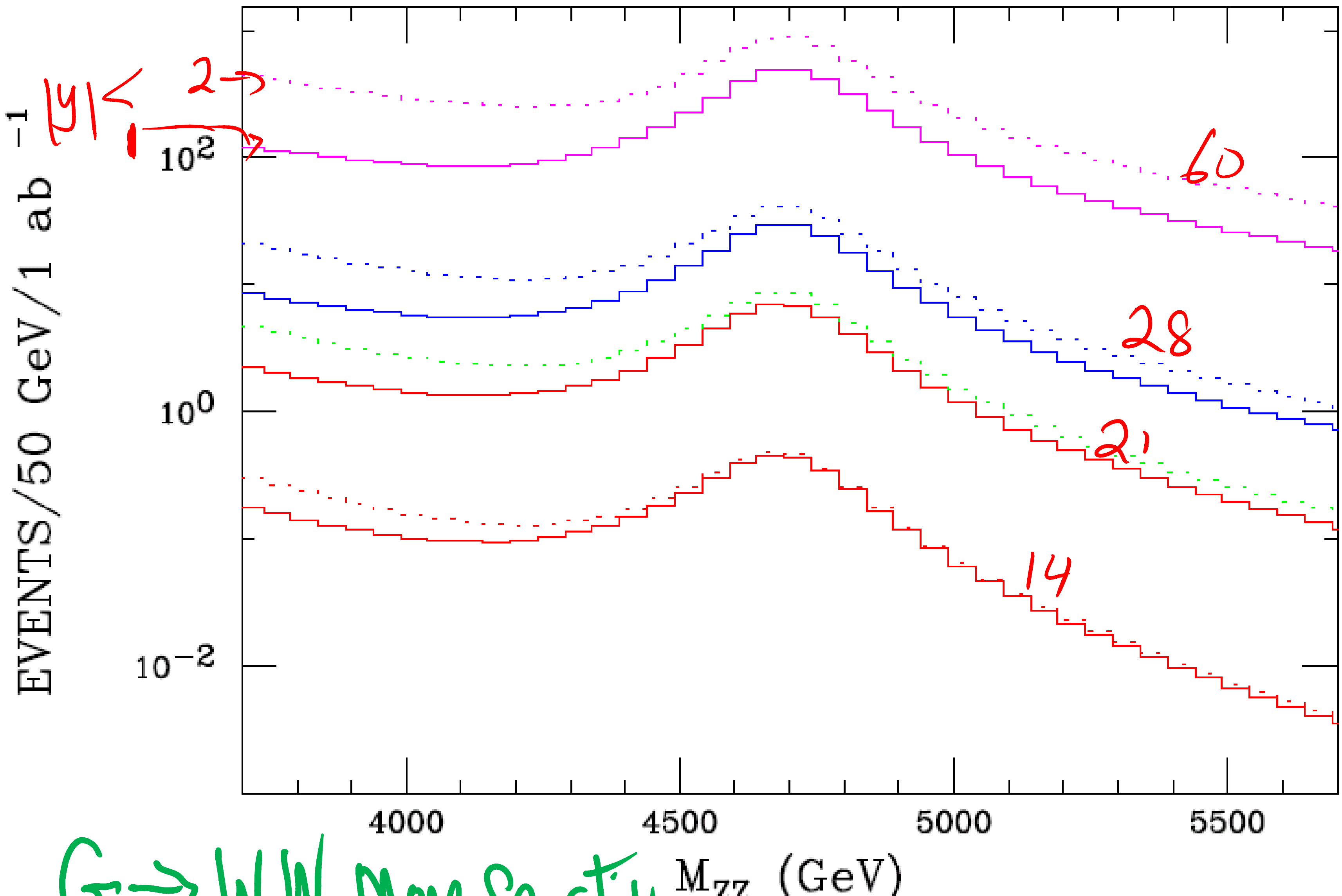
Prospects for Direct Verifiction of a warped nature

Davoudiasl, Rizzo, AS,'07

Brussels, 12/04/09

GOLD-Plated $G \to ZZ$

Z BR Not inc.



$G \to WW$ More Senstive

Associated Production of PAIR of KK Fermions

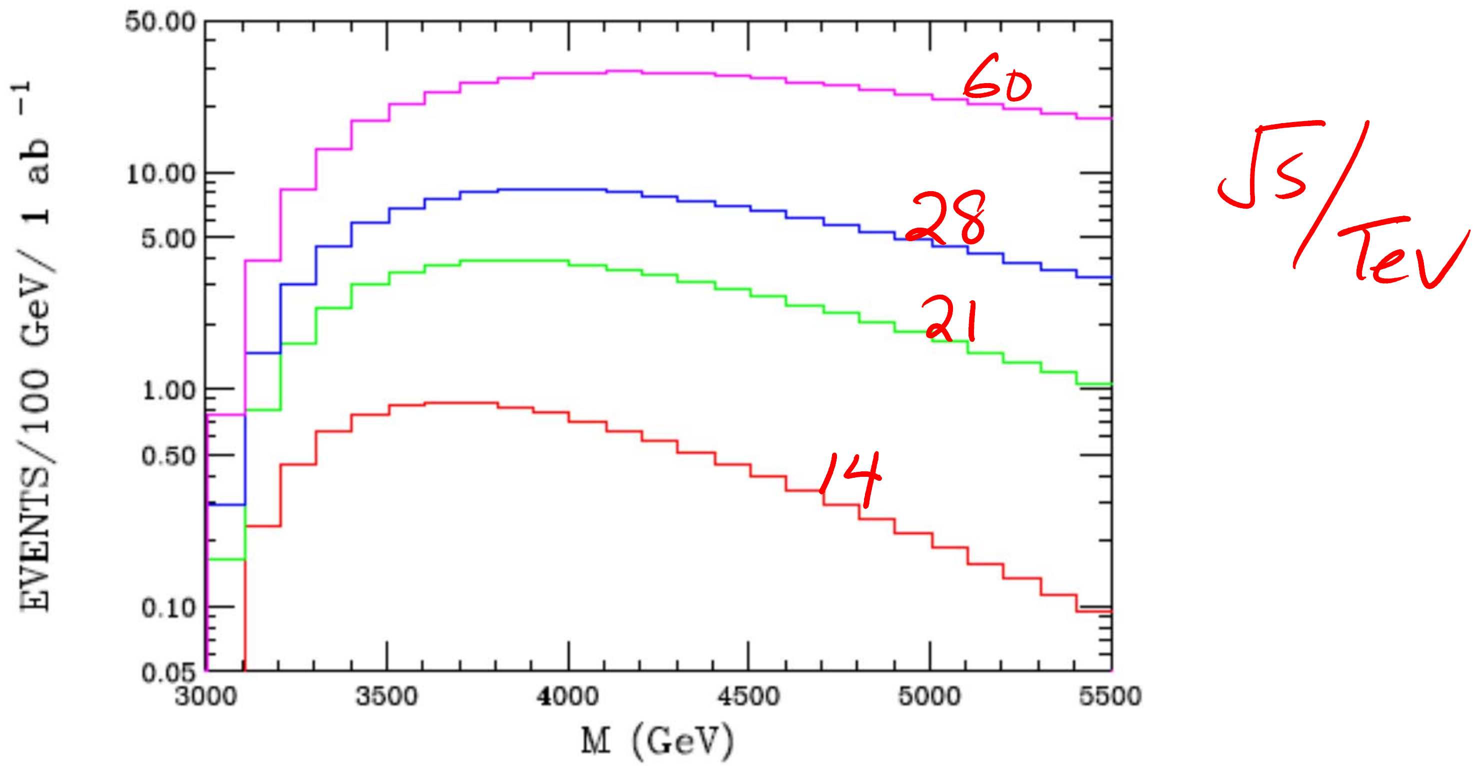


FIG. 2: Same as the last figure but now for different values of $\sqrt{s}$ and taking the first gluon KK and fermion KK masses to be degenerate at 3 TeV. From bottom to top the histograms correspond to $\sqrt{s} = 14$, 21, 28 and 60 TeV, respectively.

"Direct verification" (i.e. KK-graviton and/or KK-fermion) at LHC will be very difficult unless we can learn to lower m_{KK} appreciably

Motivation [1] for a 4th generation

- **Seen 3; why not 4?**

- **Enhanced prospects for DEWSB**
- **[Holdom('86); Bardeen et al ('90); Hung & Isidori('97); Hung & Xiong('11)]............**

- **Enhanced prospects for baryogenesis**

[Jarlskog & Stora('88); Branco et al('98); Hou('08)]

Motivation [II]

- **NFC: built in…..Recall this is a very serious problem for almost all BSMs**
- **Cannot be just simple SM4: DM link?**
  [See e.g. Volovik(‘03); Lee, Liu & AS (‘11)]
- **Readily accounts for B-CP-anomalies**
  [A.S et al (’08; ’10); Buras et al (‘10)]
- **Accounts also for AFB(tt)**
  [Davoudiasl,McElmurry & A S]

Cannot be simple SM4

- **Even if a 4th generation exists it is unlikely to be a simple replica of SM3:**
- **Neutrino mass provides a strong clue**
- **DM possibility and baryogenesis both strongly suggest 4G not in SM4**
- **Highly implausible that heavy quarks will not be used for DEWSB…..One Higgs tends to be heavy in these models**

4G2HDM:LEET for DEWSB

[Bar-Shalom,Nandi, A.S '11, arXiv:1105.6095]

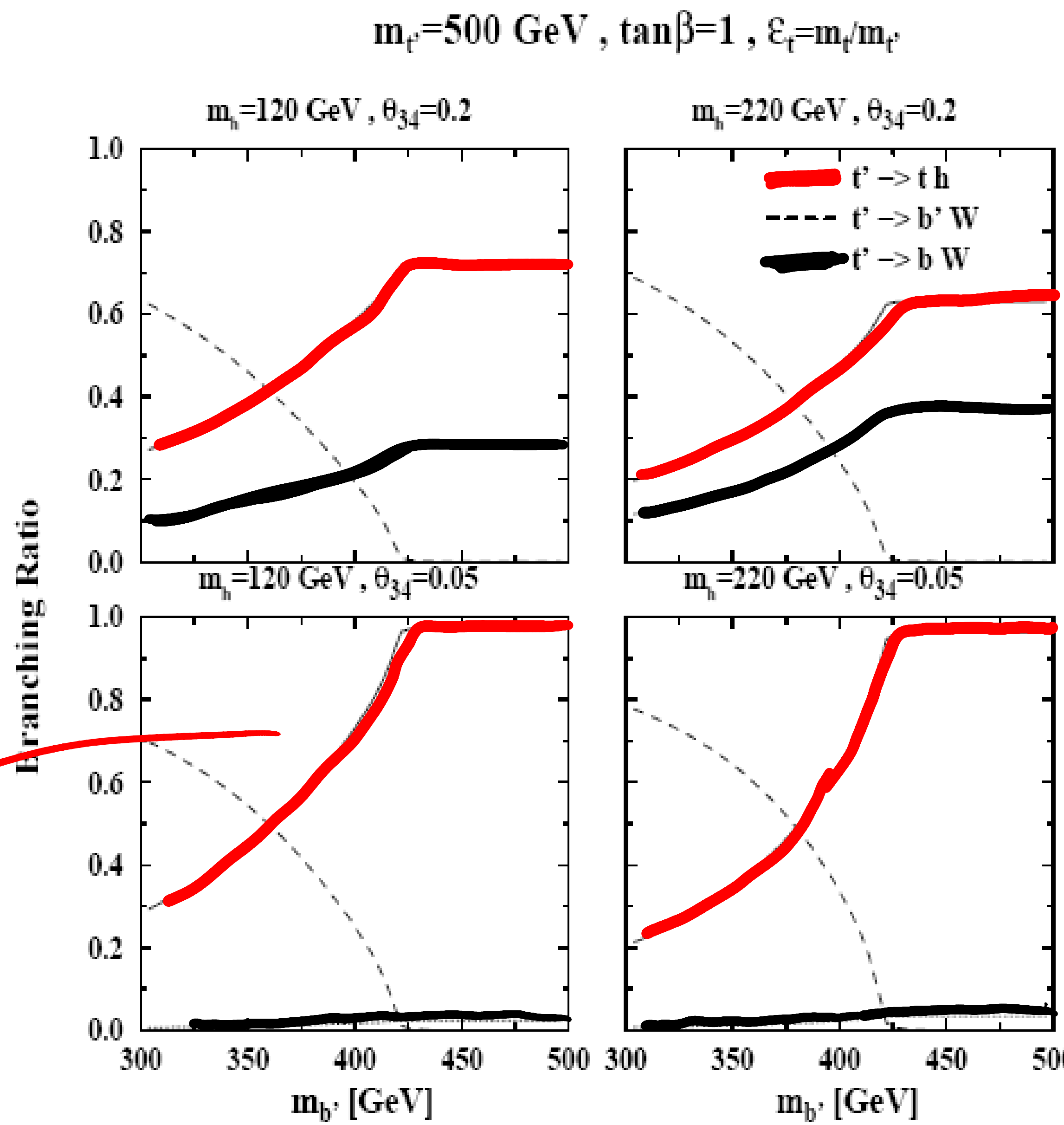
see also He & Valencia: arXiv:1108:0222

- **2 Higgs doublet model for the 4th ; 2nd doublet with v2/v1 >> 1 couples only to 4th gen**
- **FCNC only among 3rd and 4th gen.t'<->t**
- **Drastic modifications to t', b' search strategies; see Bar-Shalom,Eilam & Geller** '12
- **t'->t h, b h+ very large BR, similarly for b'**
- **Can account for tt FB asymmetry**

c also N. Chen & H.-J. He 1202.3072

t' decay pattern

t' decays:



$BR(t' \to th) \simeq 1$

4G2HDM: significantly alleviates EWPC on 4G

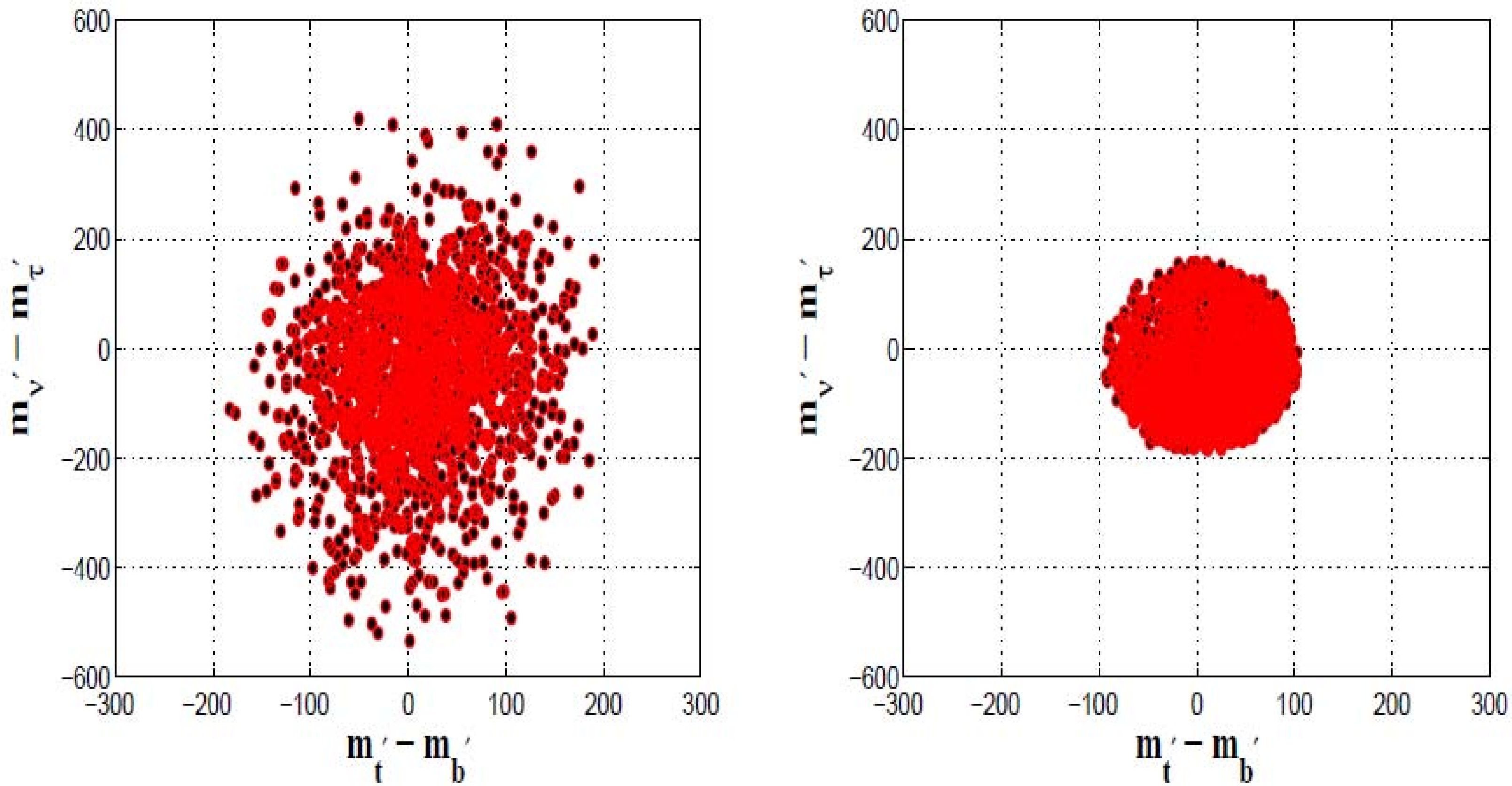


FIG. 13: *Allowed regions in the $\Delta m_{q'} - \Delta m_{\ell'}$ plane within the 95%CL contour in the S-T plane, for the 4G2HDMs (left) and for the SM4 (right). The data points are varied as in Fig. 11.*

Top pair FB asymmetry from strongly coupled 4G quarks

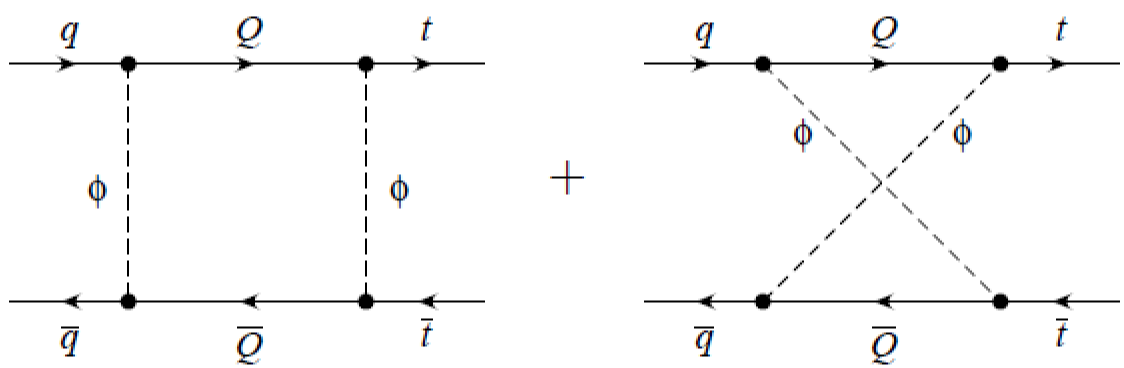
- [Davoudiasl, McElmurry and AS arXiv:1108.1173]
- CDF has been reporting ~2 sigma deviation from SM in the integrated asymm. And in the high invariant top pair mass about 3.5 sigma deviation from SM:
- 0.158 +- 0.075 vs 0.058+-0.009
- For high (>450 GeV), 0.475+-0.114 vs 0.088+-0.013
- NEW (EPS'11) D0 finds similar integrated asymmetery (a bit more significant than CDF); in the high mass region they see some increase but not so pronounced as CDF

We consider a simple toy 4G model with [FC] scalars

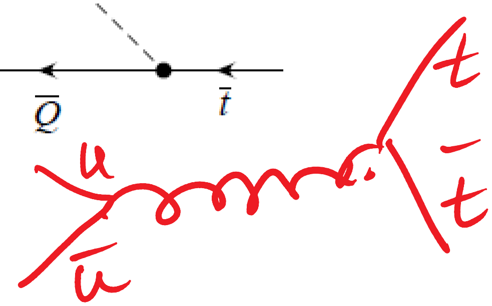
$$\mathcal{L} \supset \lambda_{ut'}\phi^0\bar{u}t' + \lambda_{ub'}\phi^+\bar{u}b' + \lambda_{dt'}\phi^-\bar{d}t'$$

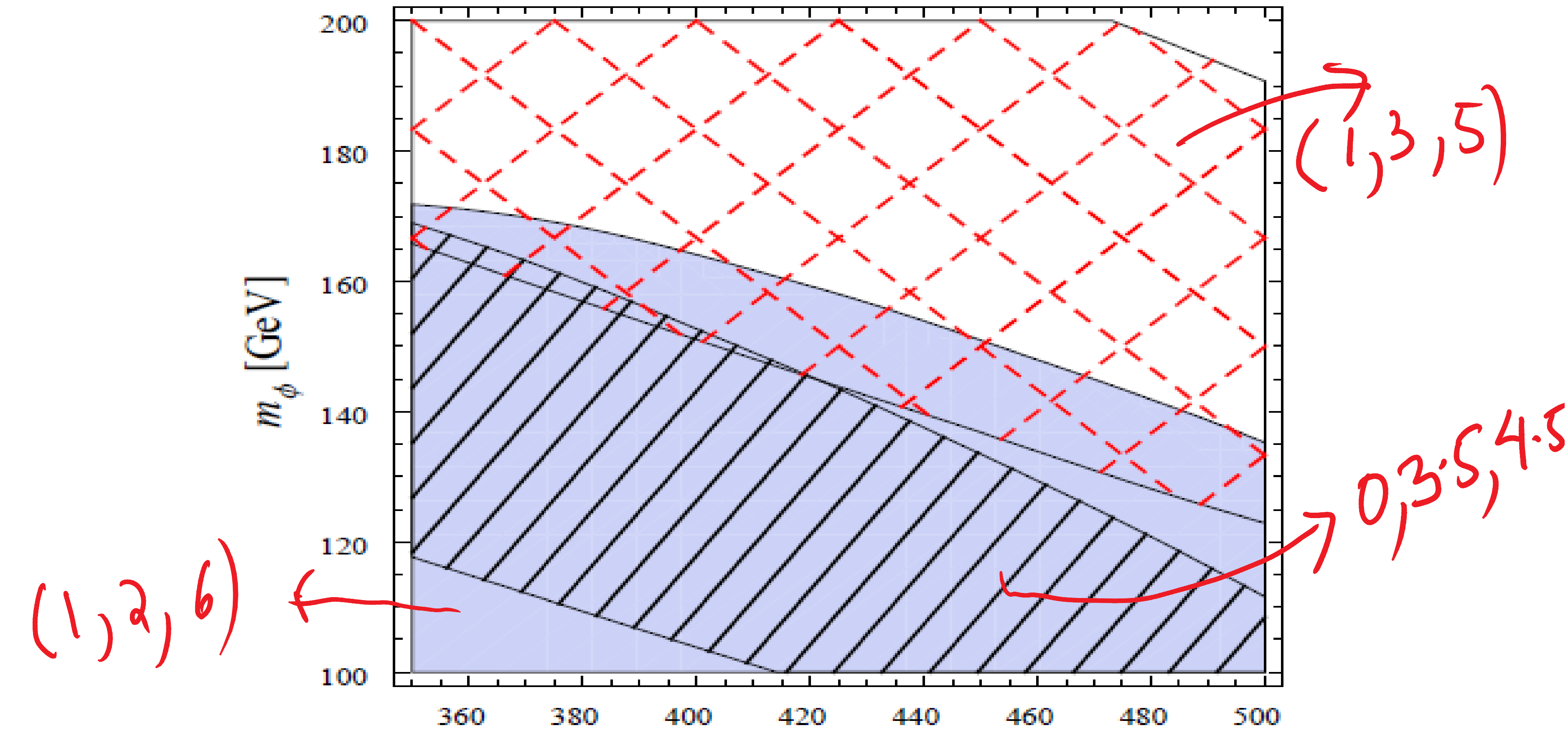
$$+\lambda_{db'}\phi^0\bar{d}b' + \lambda_{tt'}\phi^0\bar{t}t' + \lambda_{tb'}\phi^+\bar{t}b' + \text{H.C.},$$

NOTE $t' \to t\phi$ DOMINANT Not $t' \to bW$



ASYMMETRY from inteference with

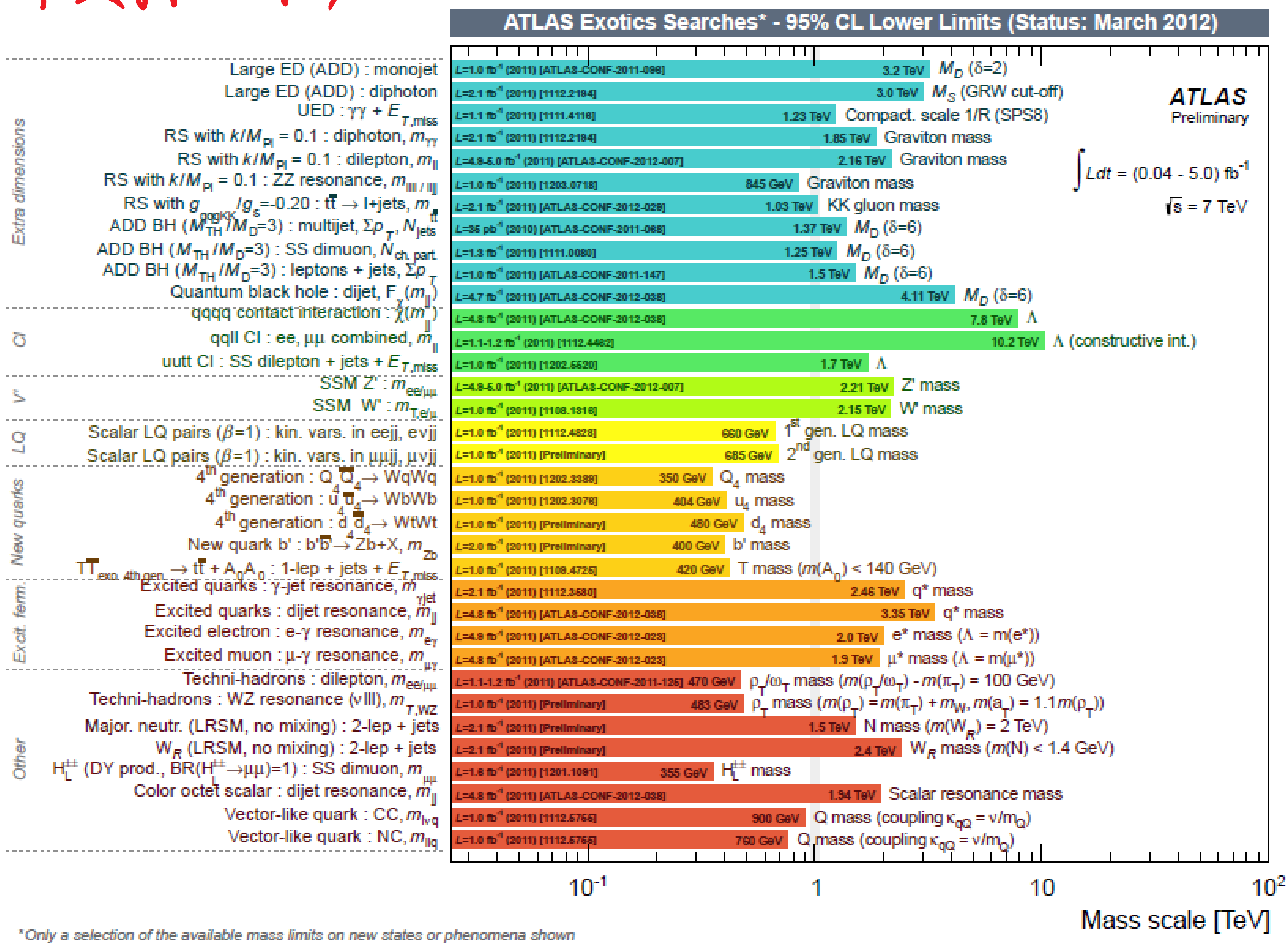




ALLOWED parameter [λ_u, λ_d, λ_t] space

FIG. 3: Regions of parameter space that yield 2σ agreement with the CDF results [1], as well as agreement with the $t\bar{t}$ total cross section within 30%, for $(\lambda_u, \lambda_d, \lambda_t) = (1, 2, 6)$ (shaded), for $(\lambda_u, \lambda_d, \lambda_t) = (0, 3.5, 4.5)$ (hatched) and for $(\lambda_u, \lambda_d, \lambda_t) = (1, 3, 5)$ (cross-hatched).

ATLAS EXOTICS LIMIT ~MAR. 2012



Lesson learnt from ν's

~ **Circa 1983, after long and arduous efforts, Δm^2 upper bound used to be around a few ev^2 but efforts to Search oscillations continued basically because there was no good theoretical reason for m_ν to be zero.**

- ***Recall it took more than a decade beyond '83*** **and Δm^2 had to be lowered by almost 4 orders of magnitude (!) before osc were discovered.**

JIANGLAI LIU [INPAC, SHANGHAI]; DAYA BAY

SSC 40 TeV ~ 1990

MAY WELL NEED SERIOUSLY THINKING of

GIGANTIC INTERNATIONAL HADRON COLLIDER ~ 100 TeV CM

Summary & Outlook

- **Thanks to the ABFs significant progress was achieved in confirming SM-CKM-CP**
- **However, basic understanding of flavor continues to represent an outstanding challenge**
- **Several interesting anomalies exist, possibly hinting at NP in flavor/CP**
- **Warped extra dimension ideas represent most interesting theoretical construct for flavor…it may manifest in LEET models with 4 families**
- **Direct signatures in collider physics may require higher cm energies not within reach of LHC**
- **Along with more powerful gadgets at the intensity frontier, may well need GIHC**

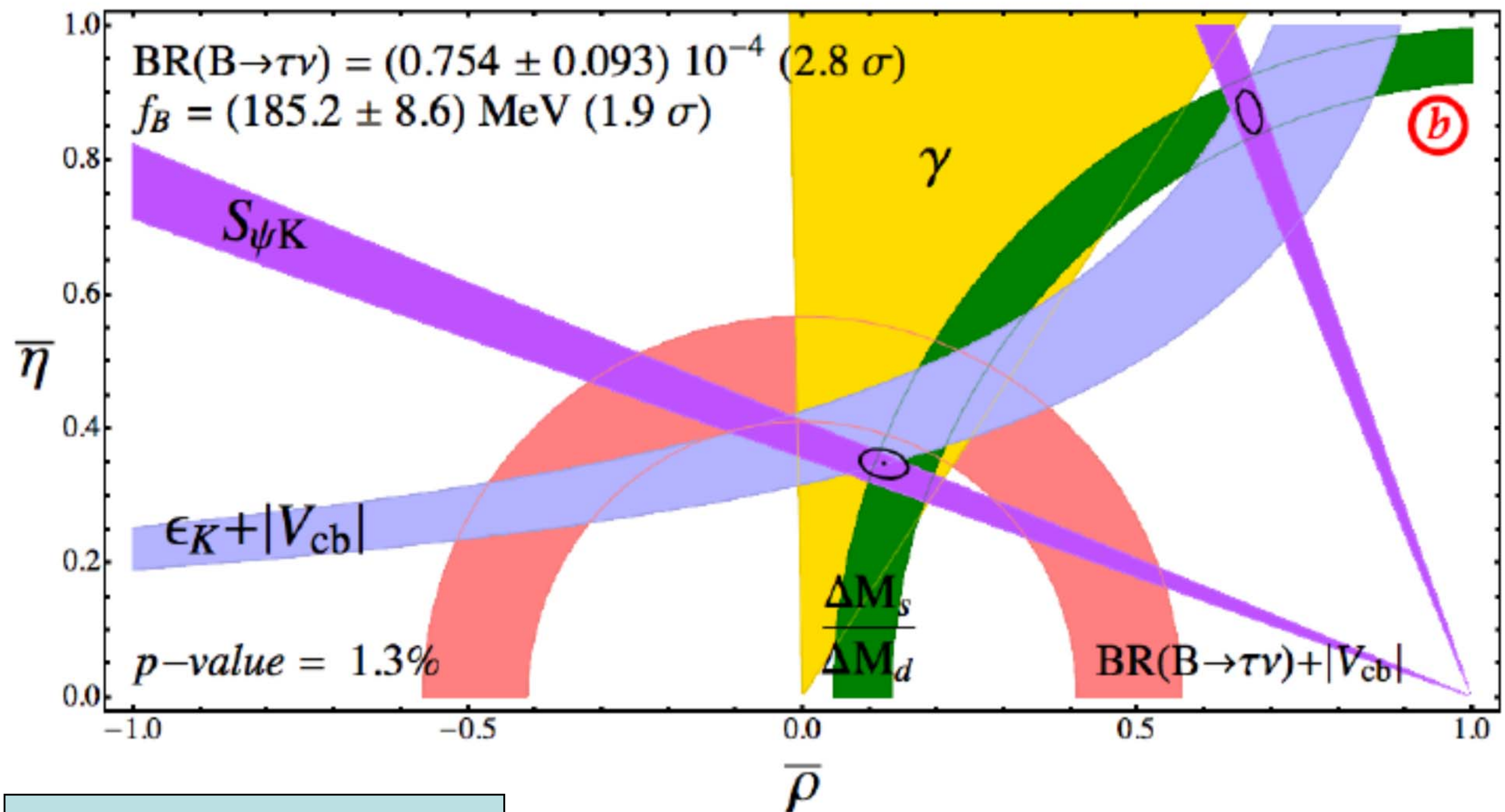
XTRAS

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 1σ 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 $V_{cb} = (44.3 \pm 0.6) \times 10^{-3}$.

Urgent questions for experiments

- **BABAR,BELLE updates for a_sl^d**
- **BELLE (UPS5S run and nearby): a_sl^s and linear combination**
- **CDF,D0, LHCb: S(Bs->psi phi), a_sl^s, a_sl^d; S(phi Ks), A_FB(K*ll)**
- **BELLEII; SBF: S(eta'Ks, phiKs,KsKsKs), Br(B->tau nu), a_sl^d, a_sl^s(?); S(B_d(s)->K* gamma rho(phi)); S(D0); a_sl(D0)…**

Inputs: S(Bd->ψK), εK, ΔMs, ΔMd, Vcb, γ



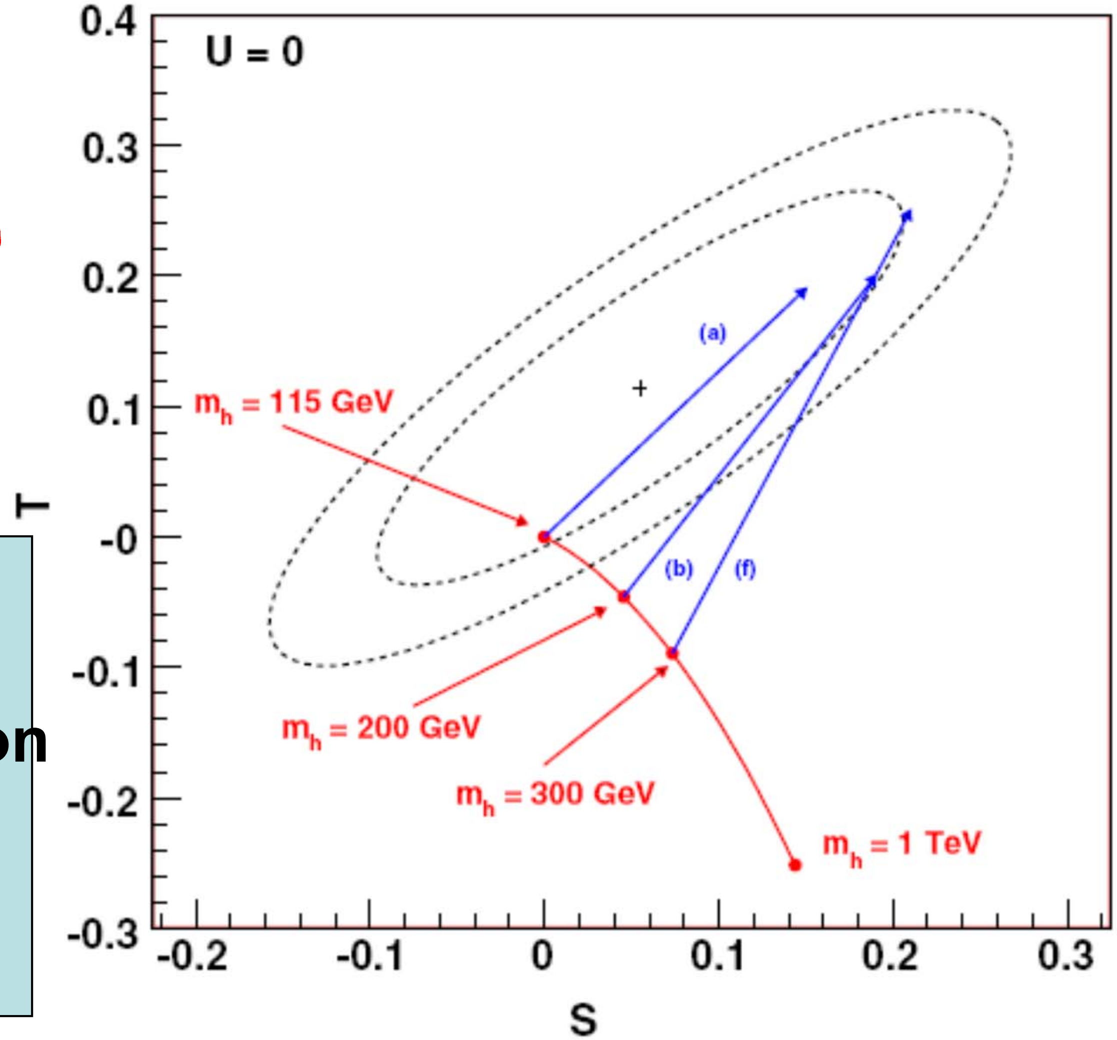
Predict: Br(B->τν) & fB

AVFAQ

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

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

Knibs, Plehn, Spannowsky & Tait, PRD '07



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

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

Baryogenesis

- For SM3, there is unique CP invariance [Jarlskog '87]

$$J = \mathrm{Im}\det[M_u M_u^\dagger M_d M_d^\dagger]$$
$$= 2(m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)$$
$$(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)A$$

Area of UT

⇒ exceeding<u>ly</u> small CP ∵ of small masses

$J/v^{12} \sim 10^{-20}$!

In 4G models

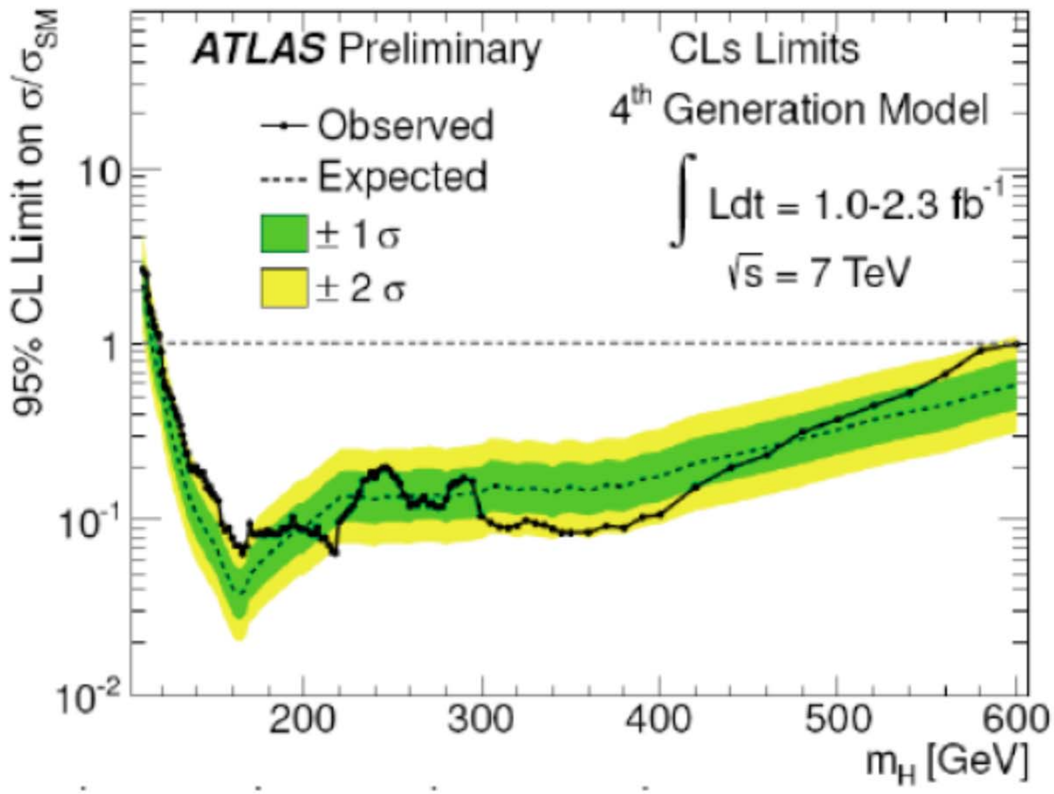
$$J_{234} = 2(m_{t'}^2 - m_t^2)(m_{t'}^2 - m_c^2)(m_t^2 - m_c^2)$$
$$(m_{b'}^2 - m_b^2)(m_{b'}^2 - m_s^2)(m_b^2 - m_s^2)A_{234}$$

$\frac{J_{234}}{J} \sim 10^{16}$!!

SHOULD FACILITATE SIGNIFICANTLY

But SM4 simple Higgs not good 4 phase transition; 2 HDM needed [c DINE + KUSENKO]

Higgs limits assuming a 4th generation of quarks and leptons:

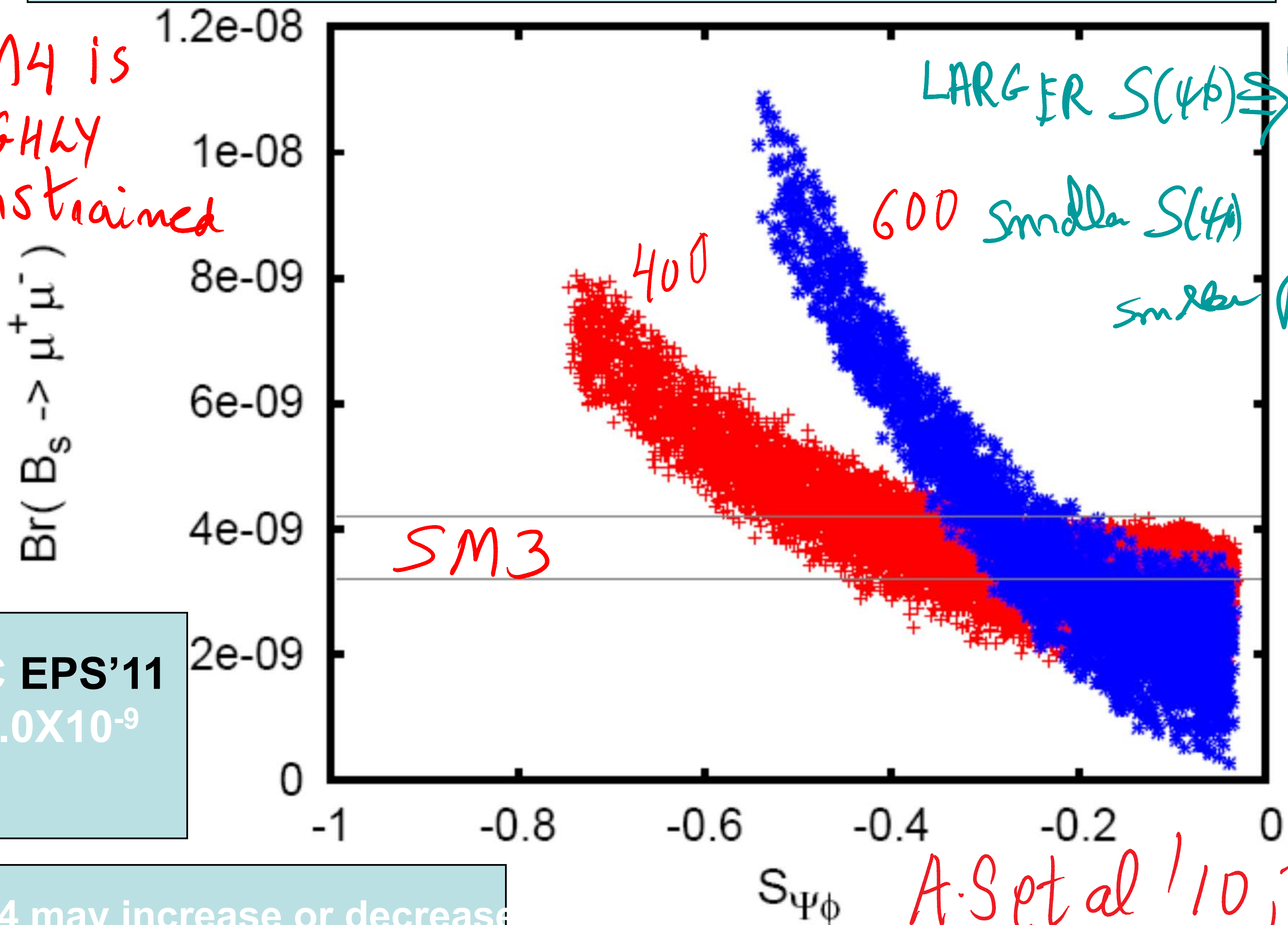


Other exotic fermions are still alive and interesting, but the sequential 4th generation is in deep troupble!

see Xiao-Gang He

Br(Bs->μμ): a very clean process
IMPORTANT Correlation with S(psi phi)

SM4 is HIGHLY constrained



LARGER S(ψφ) ⇒ larger BR

Smaller S(ψφ) ⇒ smaller BR.

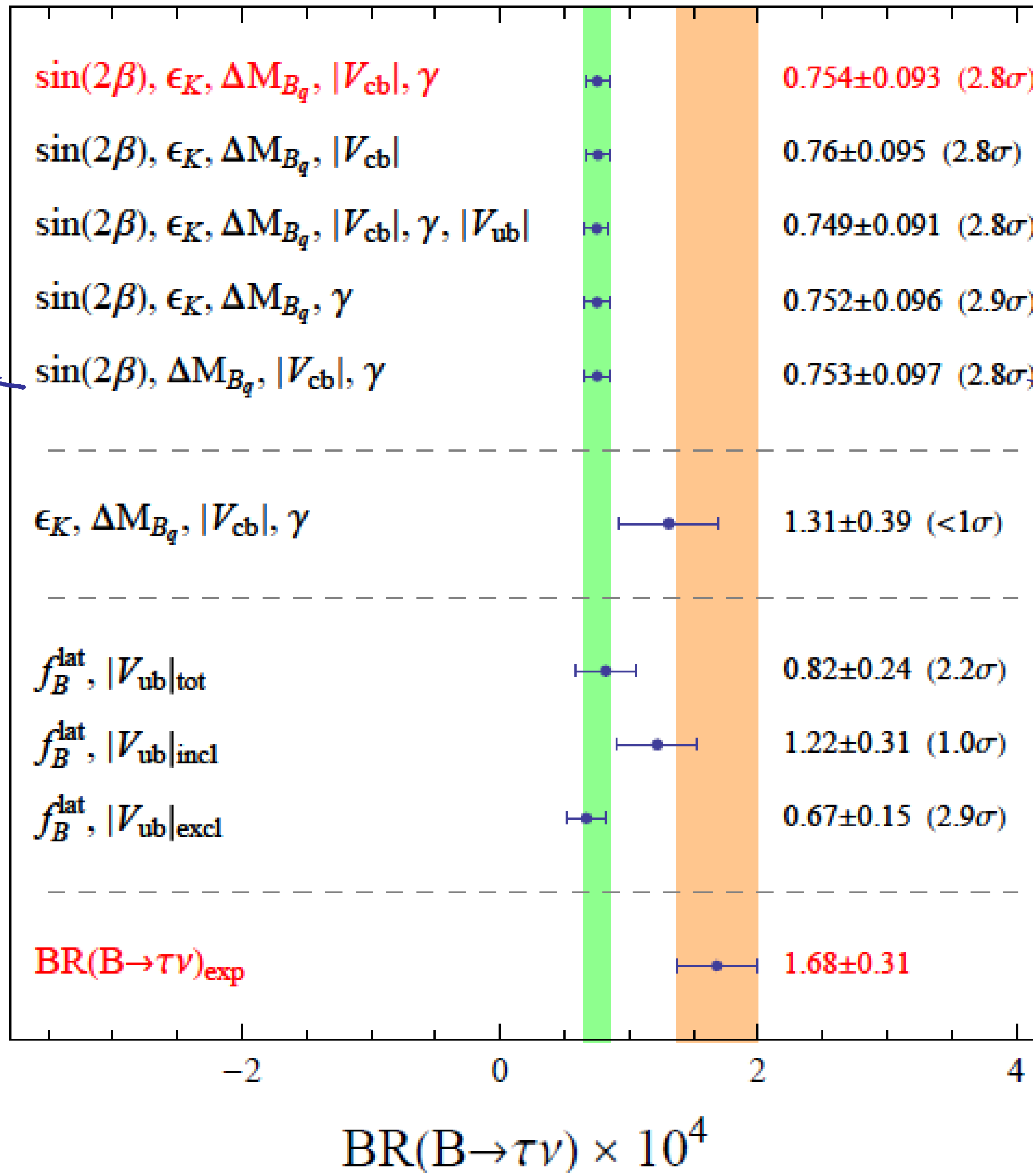
LHC EPS'11
<9.0X10^{-9}

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

A.S et al '10; BURAS et al '10

INPUT

Deviation



Sin2β

$\gtrsim 2.8\sigma$

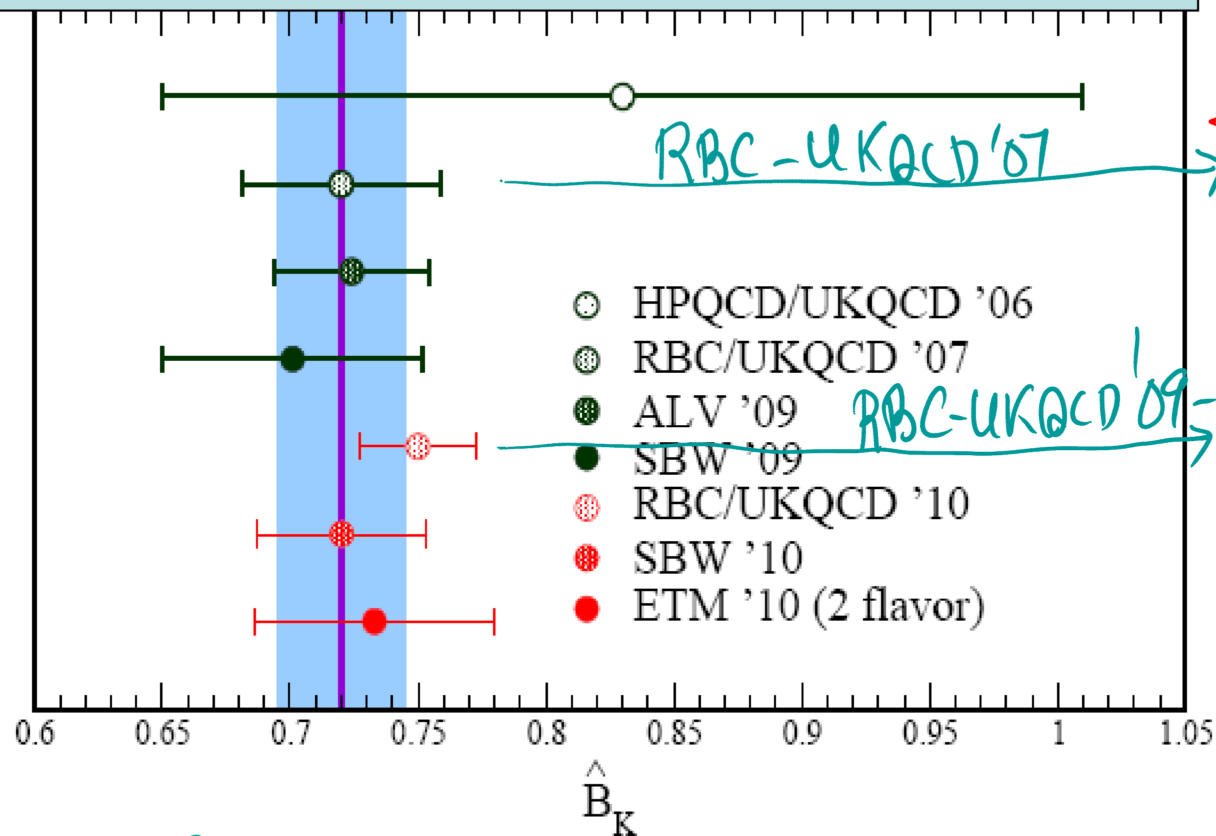
NO SIN2β

$\lesssim 0.7\sigma$

B_K

Jack LAIHO @ LATTICE '10

Several diff, collabs; diff discretizations, systematics…



USED by L & S '08

$0.720 \pm .013 \pm .037$

$0.750 \pm .007 \pm .026$

Total ERROR ~3.6%

USE 0.740 ± 0.025

CKMFITTER 2010 Use

δStat ~ 5.9%; δsyst ~ 9.3% !!

78

In the SM, the total contributions to the muon $g-2$ (a_μ^{SM}) can be divided into three parts: the QED, the electroweak (EW) and the hadronic contributions. While the QED [1] and EW [2] contributions are well under control, the main theoretical uncertainties lies with the hadronic part which are difficult to control [3]. The hadronic loop contributions cannot be calculated from first principles, so that one relies on a dispersion relation approach [4]. At present the available $\sigma(e^+e^- \to hadrons)$ data are used to calculate the leading-order (LO) and higher-order vacuum polarization contributions to a_μ^{SM}; the estimated contributions are given by [5, 6]

$$a_{LO}^{Had} = 6955(40)(7) \times 10^{-11}, \quad a_{NLO}^{Had,Disp} = -98(1) \times 10^{-11}. \tag{1}$$

On the other hand, the hadronic light-by-light contribution cannot be calculated from data, hence, its evaluation relies on specific models. The latest determination of this term is [7]

$$a_{lbl}^{Had} = 116(39) \times 10^{-11}. \tag{2}$$

Including all these corrections, the complete SM prediction is given by

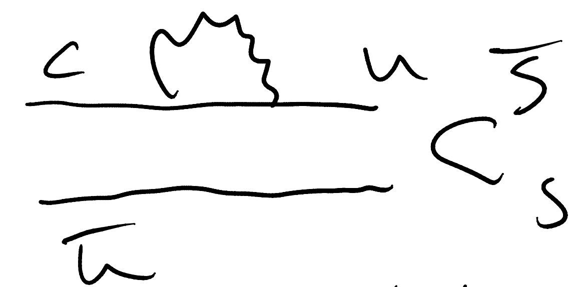
$$a_\mu^{SM} = 116591834(2)(41)(26) \times 10^{-11}\,, \tag{3}$$

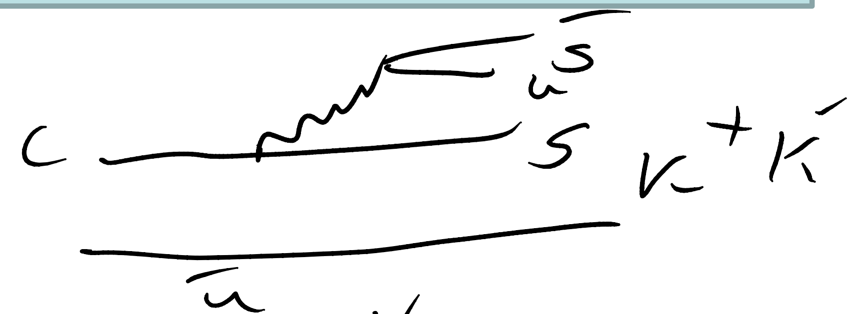
$\lvert V_{cb}\rvert_{\rm excl} = (39.0 \pm 1.2)10^{-3}$	$\eta_1 = 1.51 \pm 0.24$ [18]
$\lvert V_{cb}\rvert_{\rm incl} = (41.31 \pm 0.76)10^{-3}$	$\eta_2 = 0.5765 \pm 0.0065$ [19]
$\lvert V_{cb}\rvert_{\rm tot} = (40.43 \pm 0.86)10^{-3}$	$\eta_3 = 0.494 \pm 0.046$ [20, 21]
$\lvert V_{ub}\rvert_{\rm excl} = (29.7 \pm 3.1)10^{-4}$	$\eta_B = 0.551 \pm 0.007$ [22]
$\lvert V_{ub}\rvert_{\rm incl} = (40.1 \pm 2.7 \pm 4.0)10^{-4}$	$\xi = 1.23 \pm 0.04$ [23, 24]
$\lvert V_{ub}\rvert_{\rm tot} = (32.7 \pm 4.7)10^{-4}$	$\lambda = 0.2255 \pm 0.0007$
$\Delta m_{B_d} = (0.507 \pm 0.005)\ {\rm ps}^{-1}$	$\alpha = (89.5 \pm 4.3)^{\circ}$
$\Delta m_{B_s} = (17.77 \pm 0.12)\ {\rm ps}^{-1}$	$\kappa_{\varepsilon} = 0.94 \pm 0.02$ [25–27]
$S_{\psi K_S} = 0.668 \pm 0.023$ [28]	$\gamma = (74 \pm 11)^{\circ}$
$m_c(m_c) = (1.268 \pm 0.009)\ {\rm GeV}$	$\hat{B}_K = 0.740 \pm 0.025$
$m_{t,pole} = (172.4 \pm 1.2)\ {\rm GeV}$	$f_K = (155.8 \pm 1.7)\ {\rm MeV}$
$f_{B_s}\sqrt{\hat{B}_s} = (276 \pm 19)\ {\rm MeV}$ [23]	$\varepsilon_K = (2.229 \pm 0.012)10^{-3}$
$f_B = (208 \pm 8)\ {\rm MeV}$ [23, 24] [a]	$\hat{B}_d = 1.26 \pm 0.10$ [23, 24]
$\mathcal{B}_{B\to\tau\nu} = (1.68 \pm 0.31) \times 10^{-4}$ [30–32]	

[a] Our value of f_B reflects the change in the overall scale (r_1) recently adopted by the Fermilab/MILC and HPQCD collaborations [29]

→ As in 2008 we ASSERT again V_{ub} cannot be used!

Hand-waving estimates

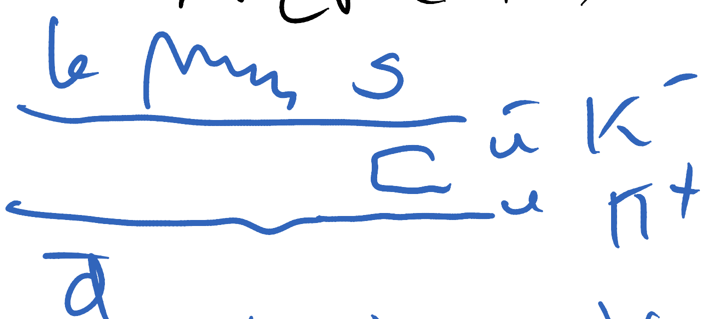


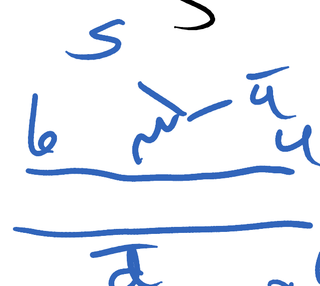


$V_{cb}\ V_{ub}$ $\qquad$ V_{us}

$$A_{CP}(D^0) \sim \frac{V_u\ V_{cb}}{V_{us}} \sim \lambda^4 \sim 1.6\times10^{-3}$$

$$(\sim 6\times10^{-3})$$





$$A_{CP}(B^0) \sim \frac{V_{ub}\ V_{us}}{V_{cb}\ V_{cs}} \sim \frac{\lambda^4}{\lambda^2} \sim 4\times10^{-2}$$

$$(\sim 9\times10^{-2})$$

arXiv:1202.3795

Repercussions of Flavor Symmetry Breaking on CP Violation in D Decays

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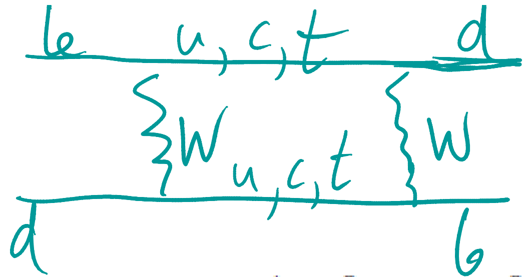


$$\Rightarrow [\bar{b}\,\gamma_{\mu L}\, d]^2$$

$$\Delta M_{B_q} = 2\left|M_{12}^q\right| = \frac{\left|\langle \bar{B}_q^0|\mathcal{H}_{\rm eff}|B_q^0\rangle\right|}{m_{B_q}} = \frac{G_F^2}{12\pi^2} m_W^2 m_{B_q} f_{B_q}^2 \hat{B}_{B_q} \eta_B S_0(x_t) \left|V_{tb}V_{tq}^*\right|^2 , \quad (2.1)$$

$$\frac{\Delta M_{B_s}}{\Delta M_{B_d}} = \xi^2 \frac{m_{B_s}}{m_{B_d}} \left|\frac{V_{ts}}{V_{td}}\right|^2 , \quad (2.2)$$

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

$$+\eta_2 S_0(x_t)\left(V_{ts}V_{td}^*\right)^2\Big) . \quad (2.3)$$

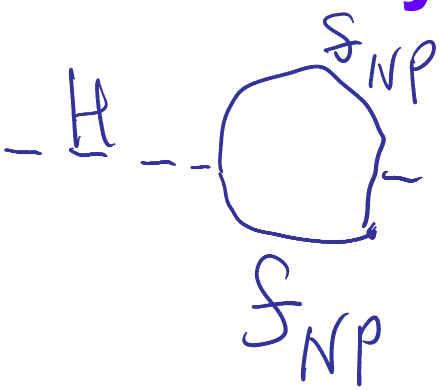
$$\langle \bar{B}_d | [\bar{b}\,\gamma_{\mu L}\, d]^2 | B_d \rangle \equiv B_{B_d} / \tfrac{8}{3} f_{B_d}^2 m_{B_d}^2$$

In a nutshell

- **Bulk of NP effects in Bd,Bs mixing & in sin2β {CONFIRMS our 2008 findings}**
- **Bulk of NP NOT in B->τν, or in ε_K [Presence of subdominant effects therein certainly possible]**
- **Many, many checks (some next page) for robustness of the conclusions**
- **EXTREMELY DIFFICULT to RECONCILE RESULTS with CKM-SM**

Outstanding Th.puzzles of our times

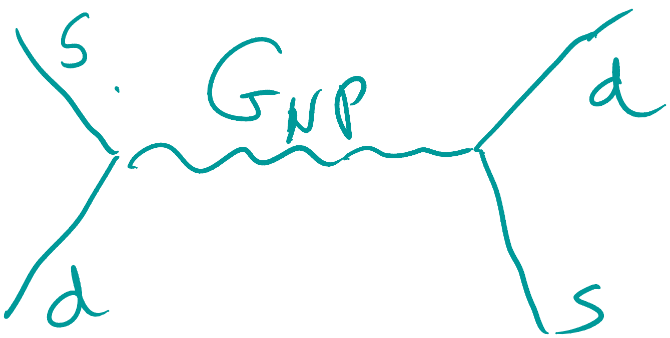
- **Hierarchy puzzle**



$$\sim \frac{g_{NP}^2}{16\pi^2}\Lambda_{NP}^2 \Rightarrow \Lambda_{NP} \lesssim \text{TeV}$$

to avoid fine tuning m_H

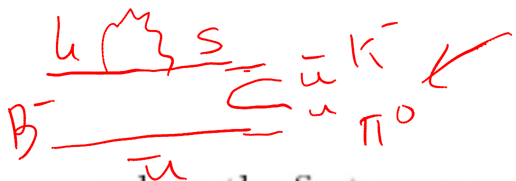
- **Flavor puzzle** Δ flavor $= 2$ e.g.



$$\sim \frac{g_{NP}^2}{\Lambda_{NP}^2} \Rightarrow \Lambda_{NP} \gtrsim 10^3 \text{ TeV}$$

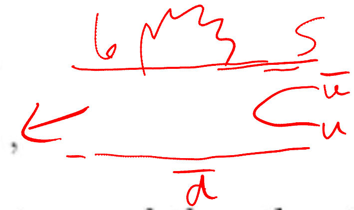
to avoid constraint from Δm_K

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:

JHEP/09
$(2.8 \pm 2.8)\%$

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

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]

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

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

yields a 3.5σ effect.

$\approx 3.5\sigma$

BENEKE+NEUBERT 0308039 based on BBNS

NOTE: Asl(b) from D0 Collab
is NOT being used despite the claimed deviation of over 3.2σ as I have serious reservation about the the expt.

Suggested charged modes

- Since at issue is direct CP, no good reason at all not to use charged modes D^+, Ds^+

SCS

$D^+ \to K^+ \bar{K}^{*0}, \; K^{*+} \bar{K}^0, \phi\pi^+, \pi^+\eta' \ldots$

$D_s \to K^+ \phi (\eta'), K^0 (K^{*0}) \pi^+$

CA

$D^+ \to \bar{K}^0 (\bar{K}^{*0}) \pi^+$

$D_s \to \phi\pi^+ (K^+)$

See also Table

EXISTING DATA: CHARGED MODES

Mode	BR	A_{CP} in %	5σ Reach
$D^+ \to K_S\pi^+$	1.47×10^{-2}	-0.80 ± 0.26 (-0.52 ± 0.14)	1×10^{-3}
$D^+ \to K^+K_0^*(1430)$ $\to K^+K^-\pi^+$	1.79×10^{-3}	43^{+20}_{-26} (0.39 ± 0.61)	3×10^{-3}
$D_s \to \eta'\pi^+$	3.94×10^{-2}	-6.1 ± 3.0 $(-5.5 \pm 3.7 \pm 1.2)$	0.7×10^{-3}
$D_s \to K_S\pi^+$	1.21×10^{-3}	6.6 ± 3.3 (6.53 ± 2.46)	4×10^{-3}

Table 1. Branching fractions and CP asymmetries in different charged D^+ and D_s decay modes [38] ([20]). The quoted (naive) 5σ reach for the sensitivity on A_{CP} refers to 10^9 produced D^+, D_s mesons at LHCb or future Super-B factories.

MORE EXPT INPUT MAY PROVE VERY USEFUL

SYNERGY with HE Colliders

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

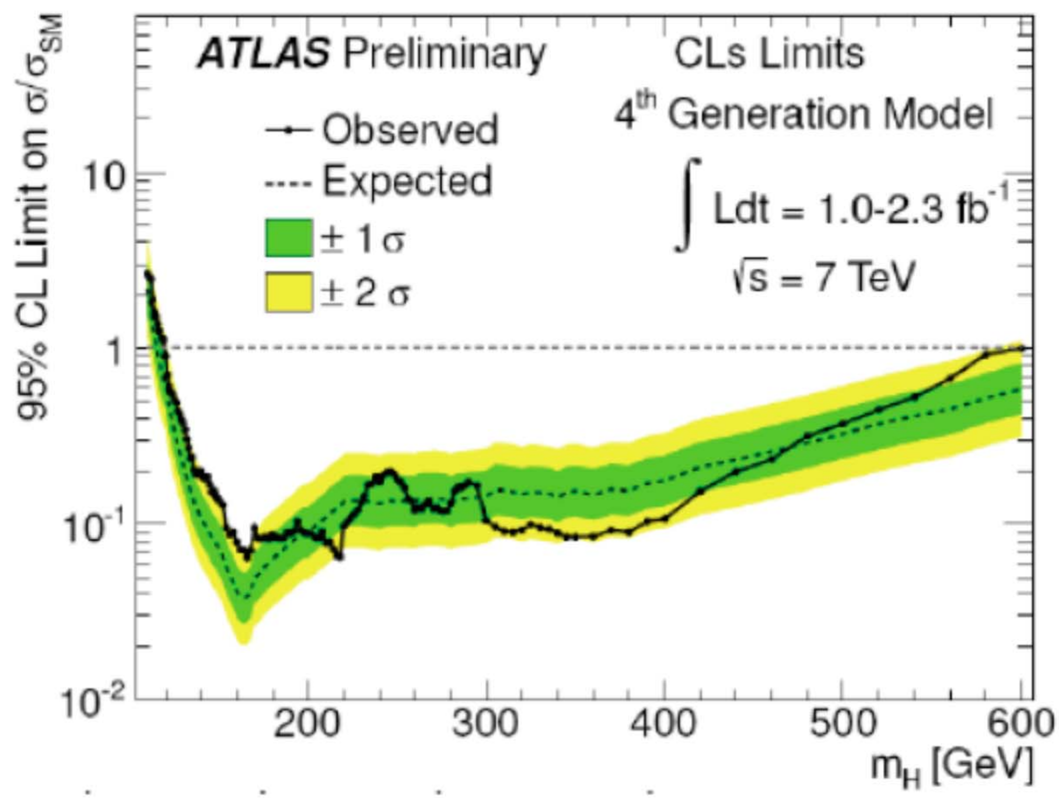
Scenario	Operator	Λ (TeV)	φ (°)
B_d mixing	$O_1^{(d)}$	$\begin{cases} 1.1 \div 2.1 & \text{no } V_{ub} \\ 1.4 \div 2.3 & \text{with } V_{ub} \end{cases}$	$\begin{cases} 15 \div 92 & \text{no } V_{ub} \\ 6 \div 60 & \text{with } V_{ub} \end{cases}$
$B_d = B_s$ mixing	$O_1^{(d)}$ & $O_1^{(s)}$	$\begin{cases} 1.0 \div 1.4 & \text{no } V_{ub} \\ 1.1 \div 2.0 & \text{with } V_{ub} \end{cases}$	$\begin{cases} 25 \div 73 & \text{no } V_{ub} \\ 9 \div 60 & \text{with } V_{ub} \end{cases}$
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

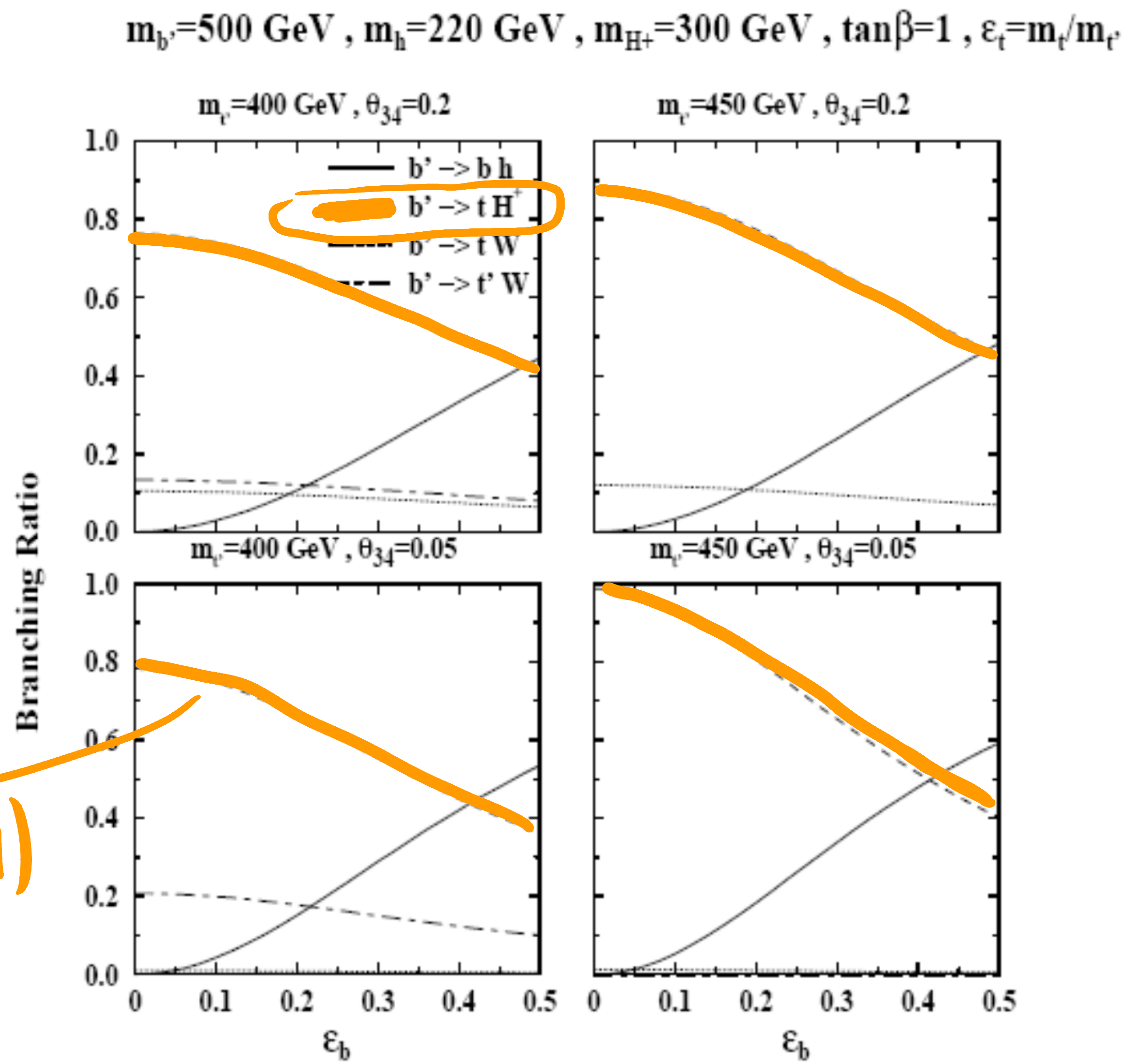
For LR case enhancement noted long ago,
See Beall, Bander and A.S.
PRL 48:848,1982

Higgs limits assuming a 4th generation of quarks and leptons:



Other exotic fermions are still alive and interesting, but the sequential 4th generation is in deep troupble!

b’ decay pattern



A. Soni

b’ decays:

$BR(b' \to tH^+) \sim \mathcal{O}(1)$

Bar-Shalom @ BNL

COMPARISONS

	WED(1)	SM3(2)	SM4(3)	SUSY(4)
$t \to cZ$	$\lesssim 10^{-5}$	$\sim 10^{-13}$	$\lesssim 10^{-6}$	$\lesssim 10^{-6}$
$t \to c\gamma$	$\lesssim 10^{-10}$	$\sim 10^{-12}$	$\lesssim 10^{-9}$	$\lesssim 10^{-6}$
$t \to cg$	$\lesssim 10^{-9}$	$\sim 10^{-10}$	$\lesssim 10^{-8}$	$\lesssim 10^{-4}$

SIGNIFICANT DIFFERENCES

1) APS hep-ph 0606293. 2) EILAM, Hewett + AS '91

4) LIU, LI, YANG, JIN: "UNCONSTRAINED MSSM" 0406155

3) AHRIB + HOU 'JHEP '06; EILAM, MELIC, TRAMPETIC '0909.3227

Phenomenology of type-I 4G2HDM

- **FCNC effects only in t' $\rightarrow$ t & b' $\rightarrow$ b transitions**

e.g., $$\mathcal{L}(ht't) = -\frac{g}{2}\frac{m_{t'}}{m_W}\epsilon_t\sqrt{1+t_\beta^2}\,\bar{t}'\left(R+\frac{m_t}{m_{t'}}L\right)th\ ,$$

-
  - **Enhanced htt Yukawa interaction while suppressed ht't' one:**

$$\mathcal{L}(htt) \approx \frac{g}{2}\frac{m_t}{m_W}\sqrt{1+t_\beta^2}\left(1-|\epsilon_t|^2\right)\ \bar{t}th \xrightarrow{|\epsilon_t|^2 \ll 1} \frac{g}{2}\frac{m_t}{m_W}\sqrt{1+t_\beta^2}\ \bar{t}th$$

$$\mathcal{L}(ht't') \approx \frac{g}{4}\frac{m_{t'}}{m_W}\sqrt{1+t_\beta^2}|\epsilon_t|^2\ \bar{t}'t'h$$

b->s γ, Z-> bb, oblique corrections …….etc See Bar-Shalom, Nandi, AS,arXiv:1105.6095