Demise of CKM & its aftermath

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EW Moriond, 3/17/11

Outline

- B-factories data upto ~'06 or so showed CKM-CP works to O(20%) 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 '08, careful analysis 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
- Taking it seriously model independent Implications
- Candidate NP scenarios at work
- Implications for LHC,LHCb,(S)BF…
- Summary & Oulook

1. WEXD
2 SM4

"COMPOSITE" MODELS

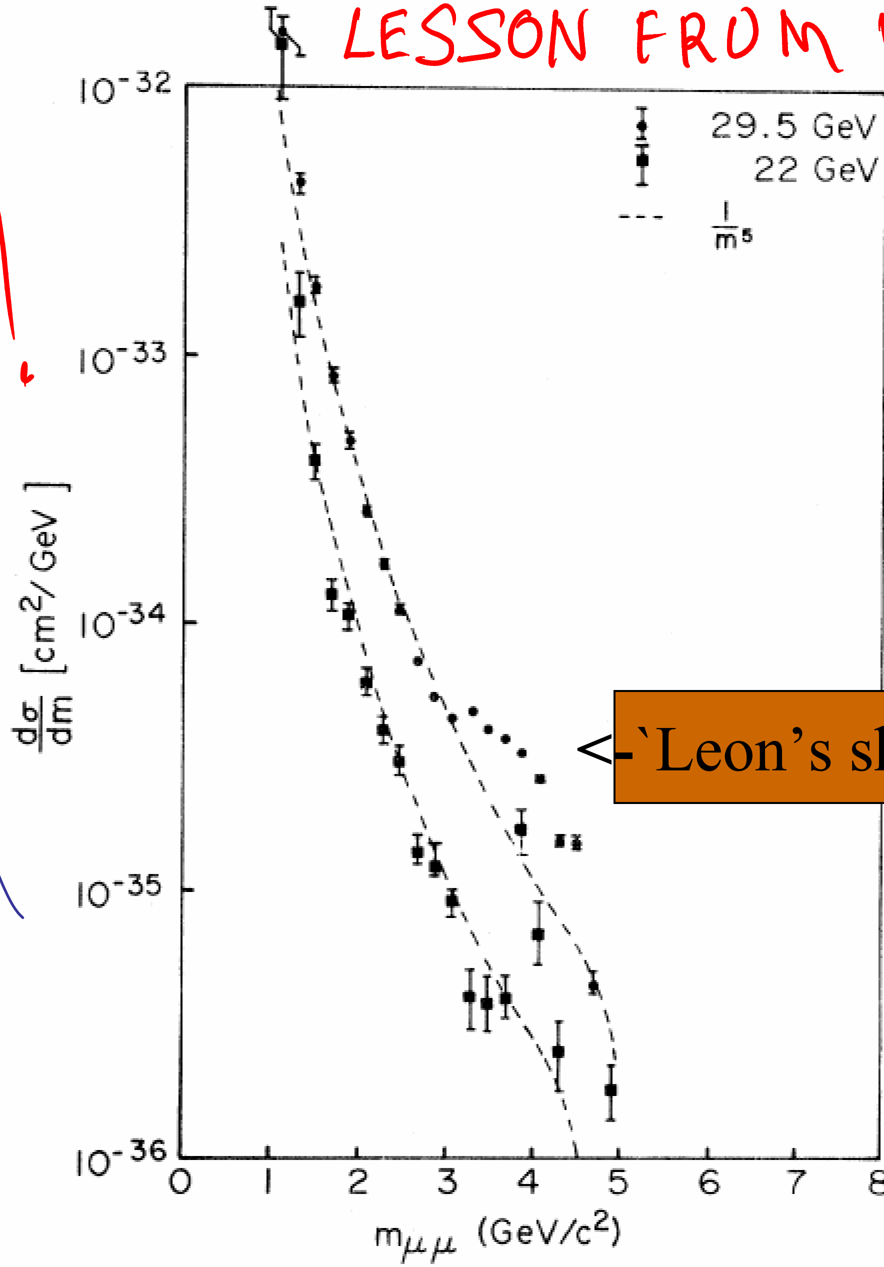
20% is far far from 0!

- Given our history you have to be extremely bold (may be even reckless?) to speculate from 20% accuracy that no need to probe deeper
- **Remember KL -> ππ , CP ~10^{-3} <<<20%!**
- If we had stopped searching after even 1% accuracy, history of our field would have been completely different.
- **Neutrino osc and neutrino mass is another example**

LESSON FROM HISTORY

DRELL-YAN @ its INFANCY!

The BIGGEST MISNOMER



<-`Leon's shoulder

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

Lederman Reaction

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

Leon
Lederman

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!!

STRESS: Inputs used

- From Expt.. Only established inputs: S(ψ Ks), ΔMs, ΔMd, Br (B-> tau nu) used
- From the lattice, inputs used extensively studied and are in full 2+1 QCD

$m_u = m_d$ m_s

- Lattice crucial development: RBC-UKQCD '07-'08 BK error dramatically reduced from 15% to ~5.5%!

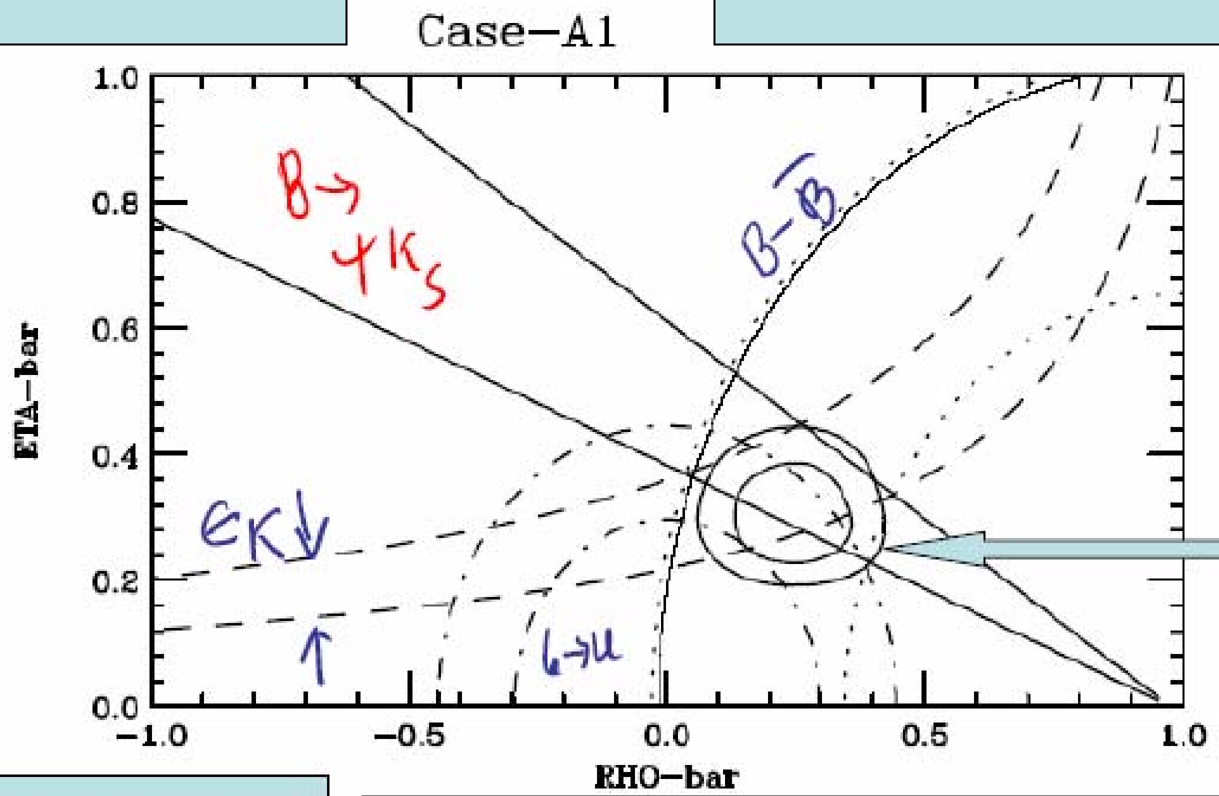
ESTIMATED error in quench Approx

error found in full QCD

1st Hint of confirmation of CKM CP description

Atwood &AS, hepph/0103197

B-CP
@
ISE
Feb ~01



NOOSE

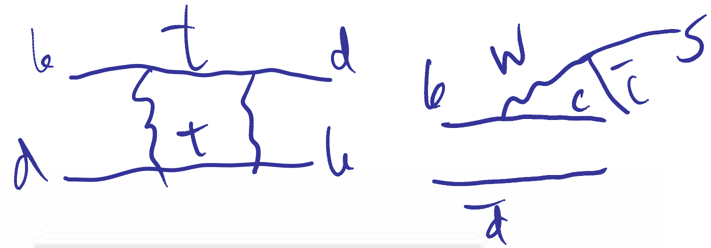
Most bands due
To theory errors

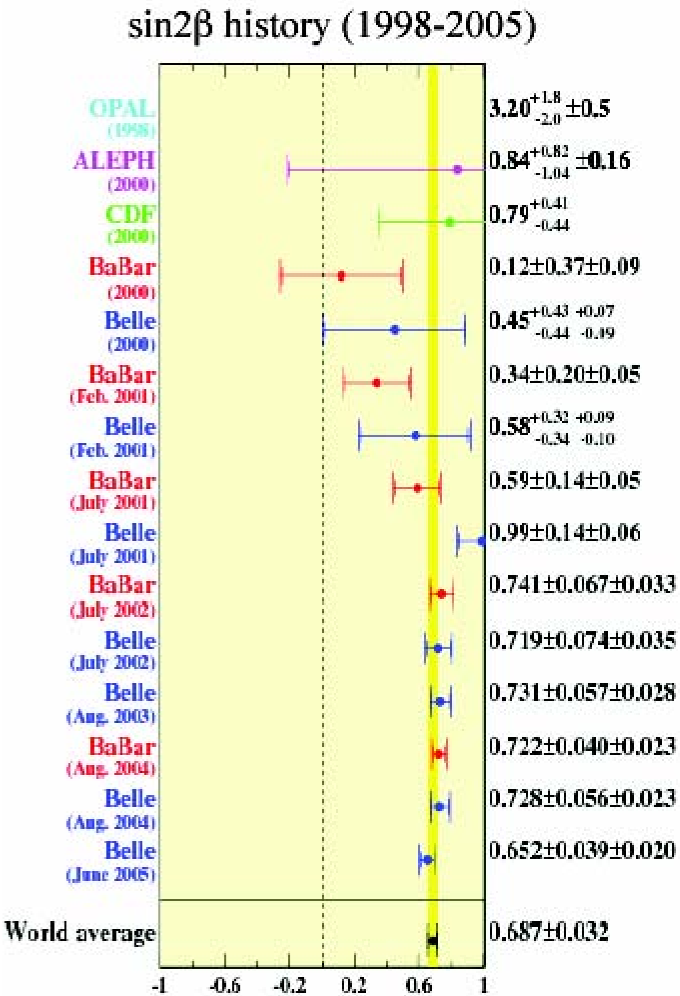
New physics will be a perturbation, important to use clean theory and lots of statistics.

ALL EXPERIMENTAL DATA MUST REQUIRE ONLY UNIQUE ρ,η

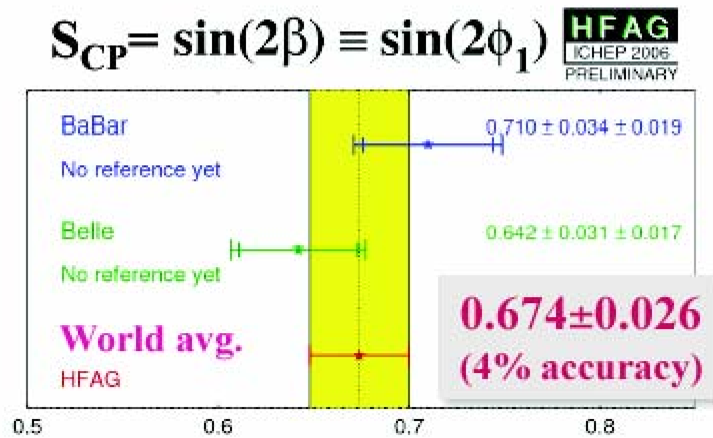
CIRCA ~ 2006

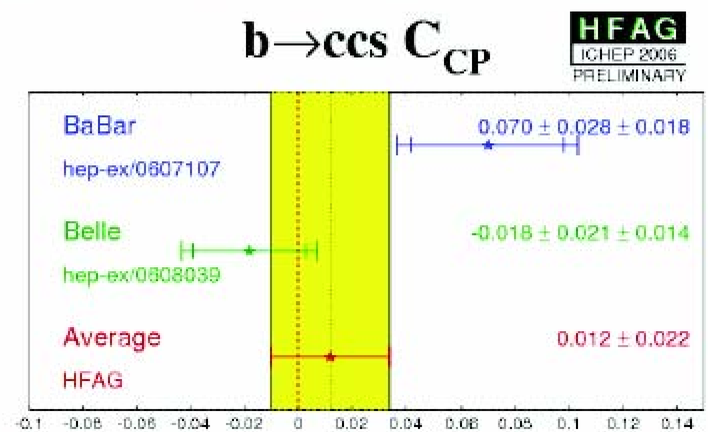
MEASUREMENT of $\beta(\phi_1)$





2006 BaBar + Belle





SM $\sin 2\beta = .79 \pm .10$

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.

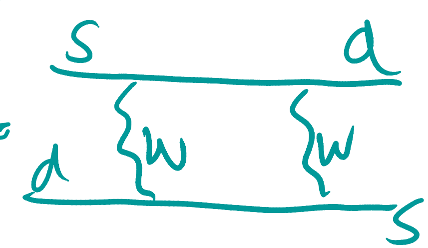
Role of the lattice weak matrix elements in the rise & in the demise of CKM

- 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.

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

$$\epsilon_K \sim (\text{Known Const}) * B_K * \eta$$



BROWN MUCK

gem

A. S : Proceedings of LATTICE '85 (FSU)…1st lattice meeting ever attended

The matrix elements of some penguin operators control in the standard model another CP violation parameter, namely ϵ'/ϵ.[6,8] Indeed efforts are now underway for an improved measurement of this important parameter.[10] In the absence of a reliable calculation for these parameters, the experimental measurements, often achieved at tremendous effort, cannot be used effectively for constraining the theory. It is therefore clearly important to see how far one can go with MC techniques in alleviating this old but very difficult problem of non-leptonic weak decays.

II. Possible cracks in CKM?

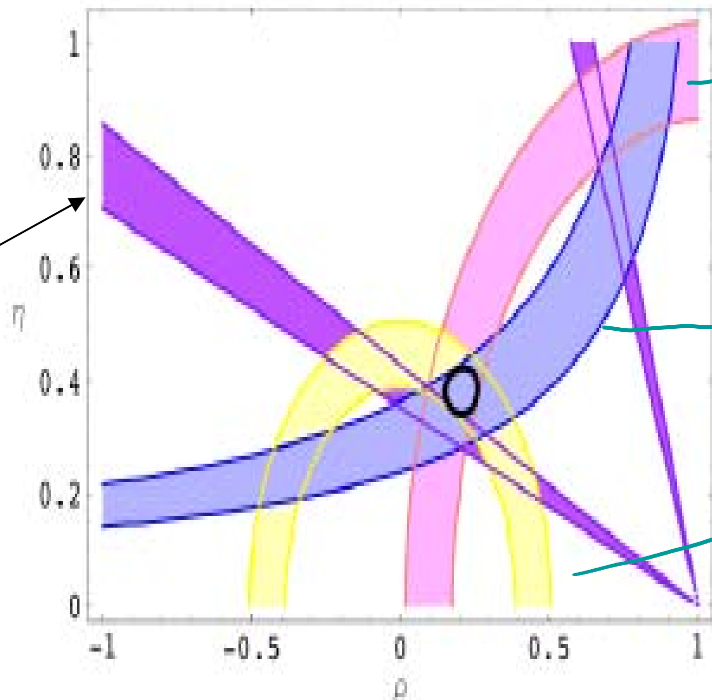
Based on Enrico Lunghi+AS

0707.0212; 0803.4340;
0903.5059;0912.0002
1010.6069

JHEP
JHEP
PLB
PRL
PLB

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



$\frac{\Delta m_s}{\Delta m_d}$; ξ_s

ϵ_K ; B_K, V_{cb}

$\frac{V_{ub}}{V_{cb}}$

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

(ALSO UTFITS '07

Continuing saga of Vub

- For past many years exclusive & inclusive show discrepancy (Latest; ~~gotten~~ worse)

lattice

continuum

- Exc ~ (29.7 +-3.1)X10^{-4}
- Inc ~ (40.1+-2.7+-4.0)X10^{-4}

e.g. $B \to \pi \ell \nu$

$B \to X_u \ell \nu$

-> ***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

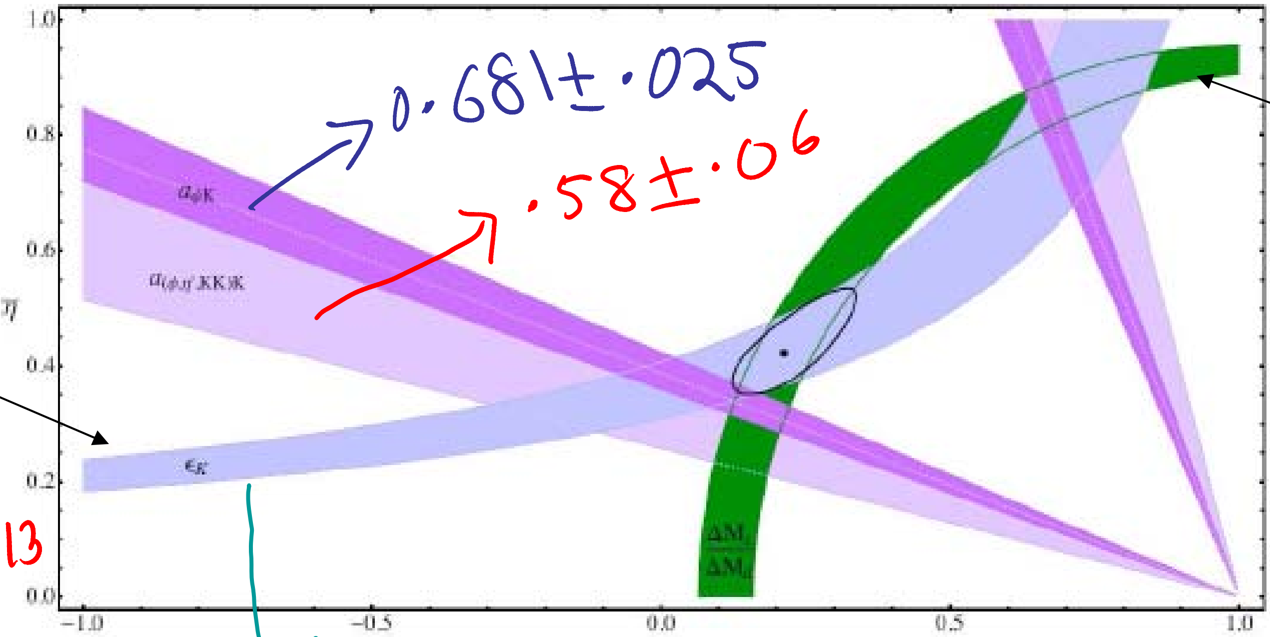
sin 2 β = 0.87+-.09{Lunghi+AS,hep-ph/08034340}

(became possible only due significantly reduced error in B_K)

Antonio et al (RBC-UKQCD) 0702042

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

$|V_{cb}| = 40.8 \pm .6 \times 10^{-2}$



include BURAS+GUADAGNOLI CORR.
(0805.3887)

Gamiz et al; Becirevic; Tantalo

.

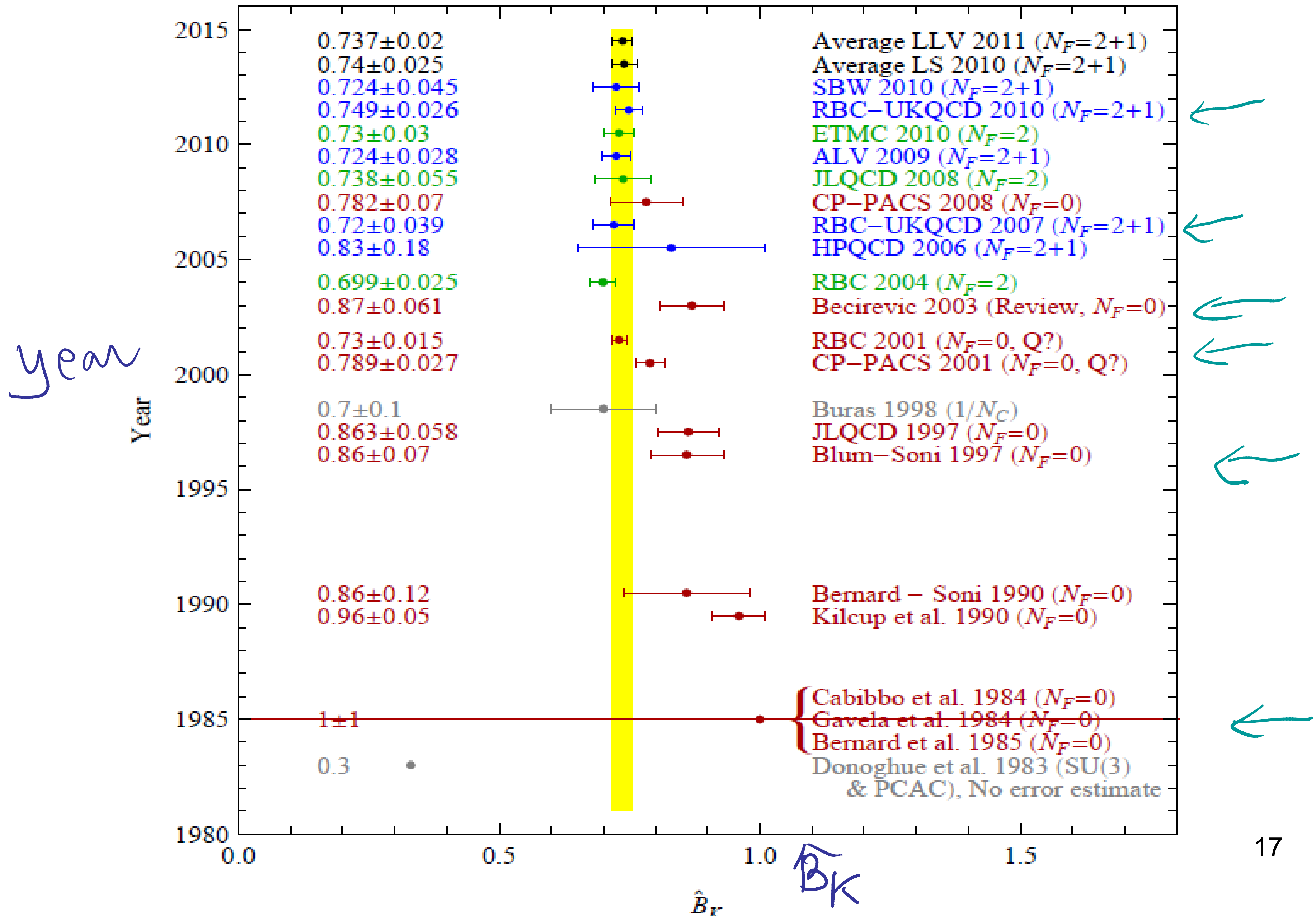
$\xi = 1.20 \pm .06$

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

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

2010 UPDATE

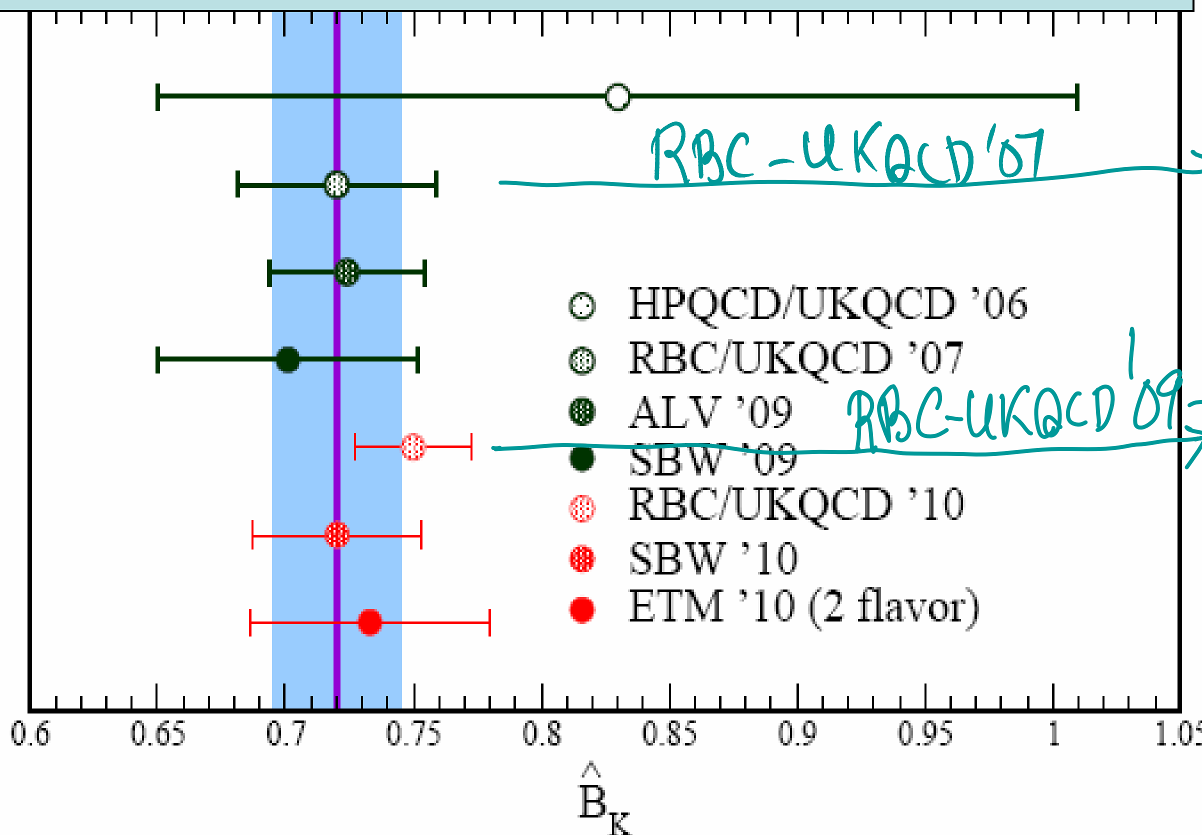
A BRIEF (~25 years) history of B_K



B_K

Jack LAIHO @ LATTICE '10

Several diff, collabs; diff discretizations, systematics…



RBC-UKQCD '07 → 0.720 ± .013 ± .037 → USED by L & S '08

RBC-UKQCD '09-'10 → 0.750 ± .007 ± .026

Total ERROR ~3.6%

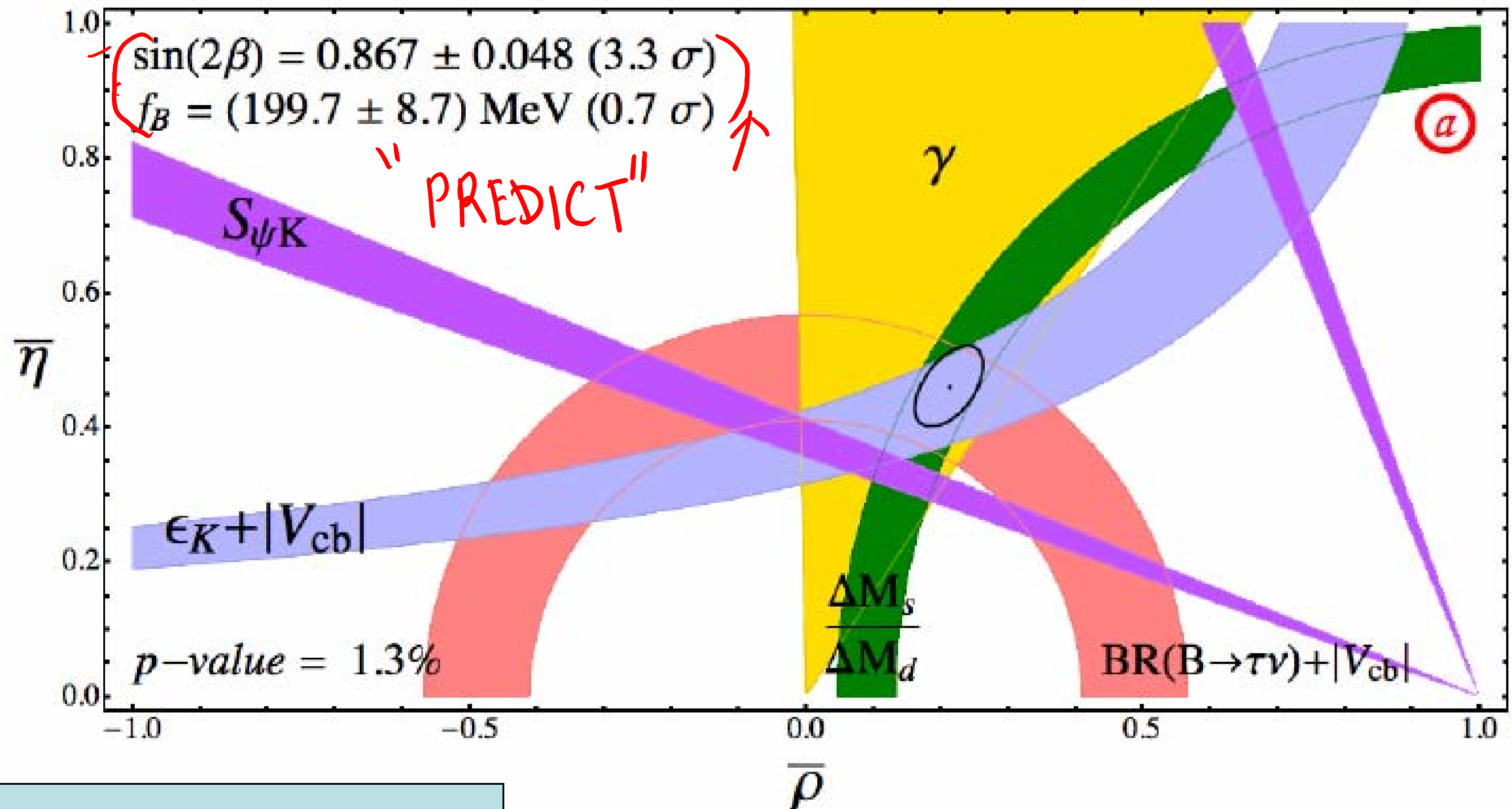
USE 0.740 ± 0.025

CKMFITTER 2010 USE

δStat ~ 5.9%; δsyst ~ 9.3% !!

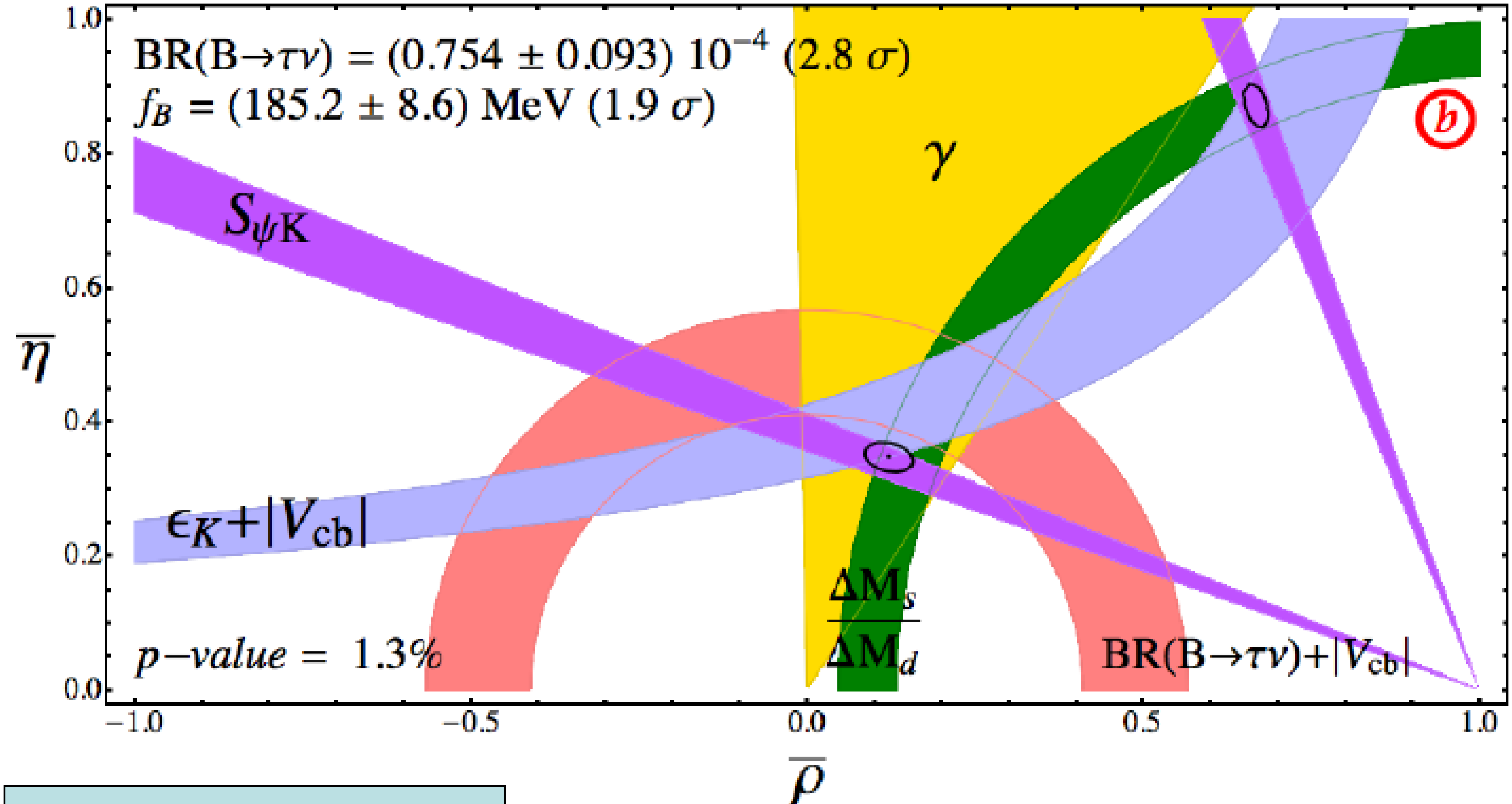
INPUTS ⇒ ε_K - $\Delta M_{Bs}/\Delta M_{Bd}$ - $|V_{cb}|$ - γ $B\to\tau\nu$

$\cancel{+}$ ΔM_{Bd}



Predict sin2β & fB

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

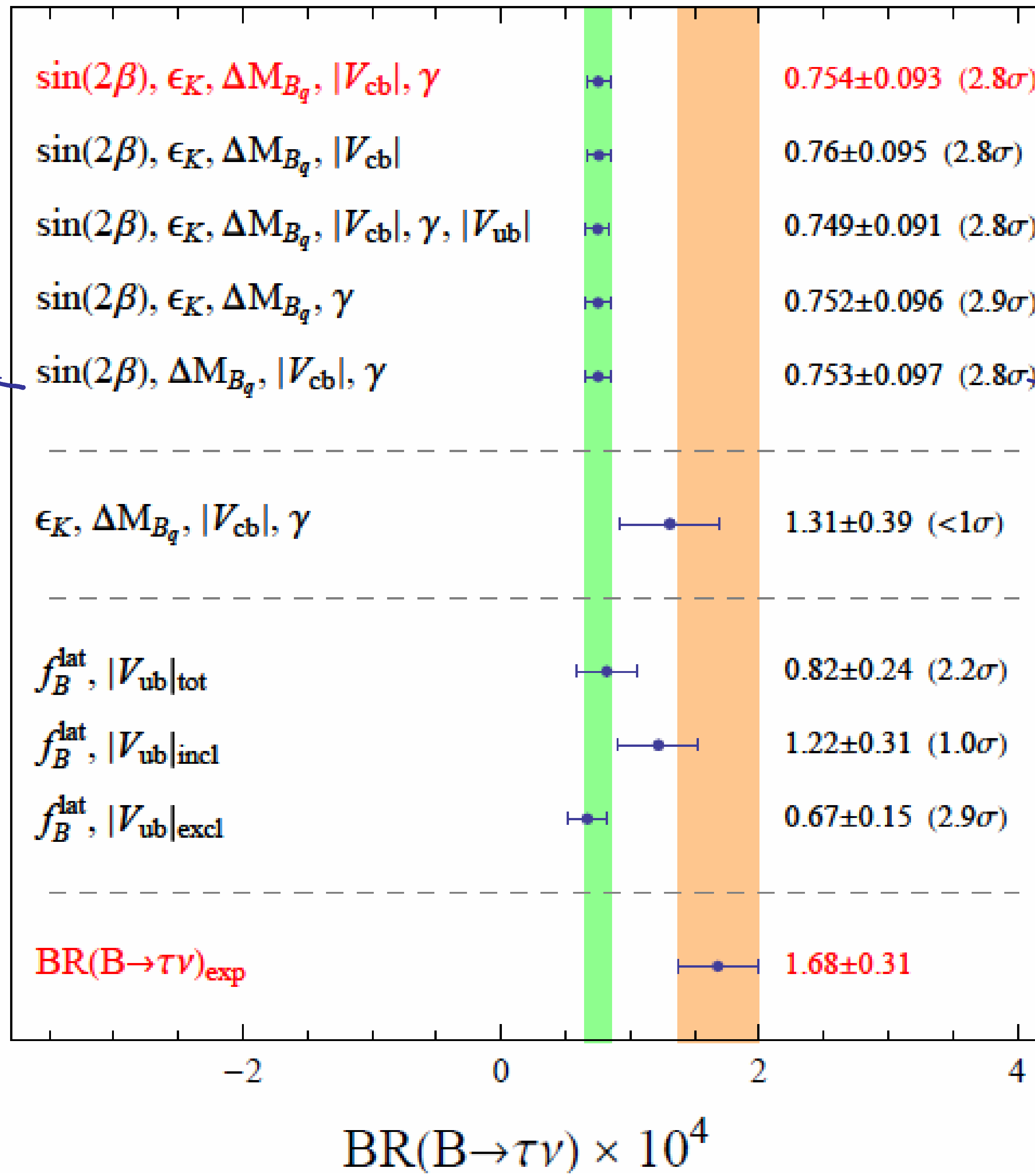


Predict: Br(B->τν) & fB

INPUT

Deviation

Sin2β



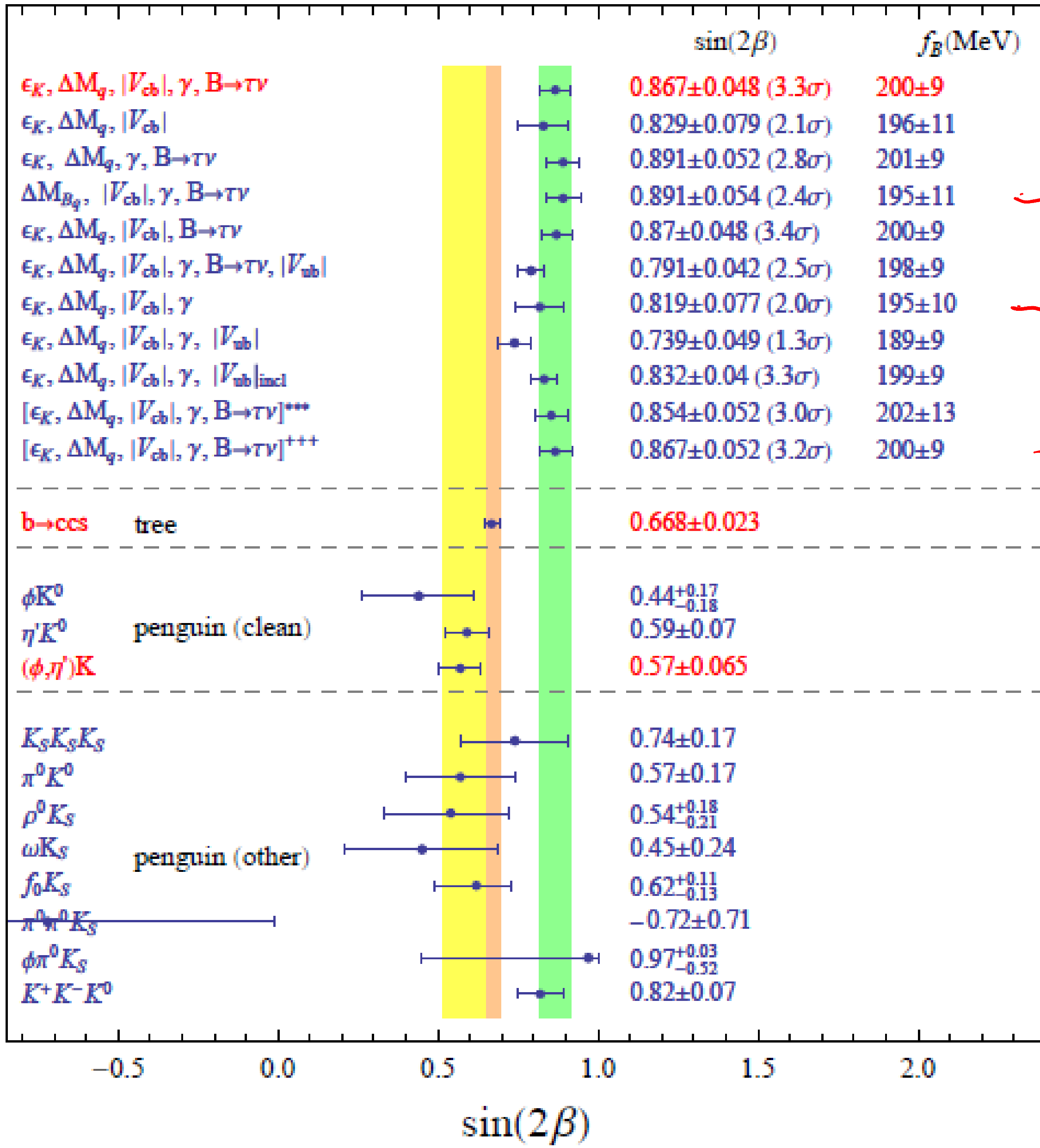
$\gtrsim 2.8\sigma$

NO SIN2β

$\lesssim 0.7\sigma$

"GOLD"

penguin dominated



In a nutshell

- **Bulk of NP effects is 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 for robustness of the conclusions**
- **VERY DIFFICULT to RECONCILE RESULTS with CKM-SM**

Overall perspective

[NONE of the FOLL. ARE USED IN OUR FITS]

- Sin 2 β from "penguin" dominated modes (ΦK_S, ηK_S, …..) tends to be even smaller than from "gold-plated" mode
- $\Delta A_{CP} (K\pi) = A_{CP} (K^+ \pi^0) - A_{CP} (K^+ \pi^-)$ is nowhere near zero (~14.4%) and rather difficult to understand.

. Also CDF, D0: S(ψΦ) mild indication….unsettled

. D0, dimuon asymmetry exptal analysis extremely difficult -> NEEDS confirmation

Implications of our analysis is that such nonSM effects requiring the presence of NP with a new CP-odd phase should persist

"Natural"

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 ($^\circ$)
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 Bona et al UTFit:0707.0636
Lenz et al, CKMFit: 1008.1593

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

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 …?

SM4

MAY B LINKED DUE DUALITY

Grojean; Weiler; Westhoff

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?
- 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

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

† CAVEAT: IN SIMPLE Models $K-\bar{K}$ PROBLEM
A. WEILER

LHC signals studied:

- g_{KK} -> tt
- G ->ZZ,WW; tt…
- Z' -> tt, WW…
- W'-> ZW,…..
- **CONCLUSION: Unless KK-masses are less than ~2TeV, very hard to find these at LHC; at least SLHC needed**

LRS@LHC

(Davoudiasl,Perez,AS,0802.0203)

- **LRS=Little Randall-Sundrum – a WARPED THEORY Of FLAVOR**
- **While the RS construction has a compelling appeal, as it allows a simultaneous resolution of SM (EW-Planck) and (EW-Flavor) puzzles, it is premised on a very strong assumption:**
- **Warping extends over many orders of magnitude w/o any basic change in physics, from the weak scale all the way to the Planck scale. Surely this assumption, no matter how appealing needs to be put to an experimental test.**
- **Is it possible, e.g. that the basic warped idea is used only for understanding EW-Flavor (>10^3 TeV) hierarchy via fermion localization, leaving open avenues for UV completion to Planck?**

$$y \equiv \frac{kr_c\pi\,|_{\mathrm{RS}}}{kr_c\pi\,|_{\mathrm{LRS}}} \approx 6$$

Let’s B Modest

Significant differences in phenomenology result in switching from RS as a theory of flavor to LRS as theory of flavor

LRS Phenomenology and Golden Modes

Courtesy HD

- $g_{KK}|_{UV} \sim g_4/\sqrt{kr_c\pi}, \quad g_{KK}|_{IR} \sim g_4\sqrt{kr_c\pi}.$

(i) Broad KK states become narrower by y.

(ii) Width into light states $(e^+e^-, u\bar{u}, \ldots)$ enhanced by $y \to$ BR$\sim y^2$.

(iii) $\sigma(f_i\bar{f}_j \to KK \to f_k\bar{f}_l) \propto \Gamma(KK \to f_i\bar{f}_j)\mathrm{BR}(KK \to f_k\bar{f}_l)$

(i) $\oplus$ (ii) $\oplus$ (iii) $\Rightarrow \mathcal{S} \sim y^3$ and $\mathcal{B} \sim 1/y$ (over the width); $\mathcal{S}/\mathcal{B} \sim y^4$.

LRS, $y \approx 6 \Rightarrow \mathcal{S} \to \mathcal{O}(100)\mathcal{S}$; $\mathcal{S}/\mathcal{B} \to \mathcal{O}(1000)\mathcal{S}/\mathcal{B}$!

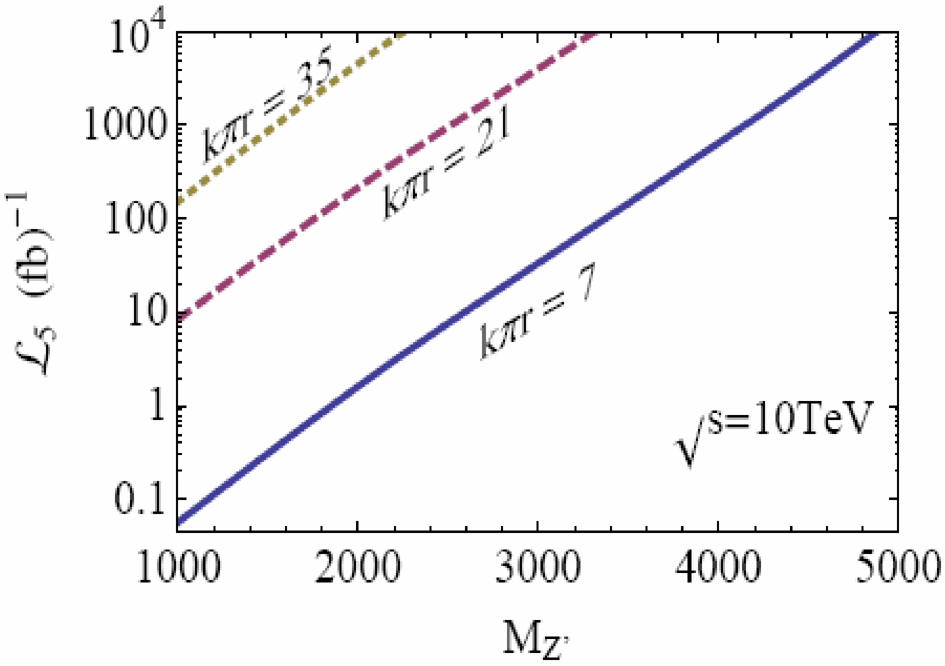
$M_{Z'} \sim 4$ TeV and L = 100 fb^{-1}: $Z' \to \ell^+\ell^-$, $\ell = e, \mu$.

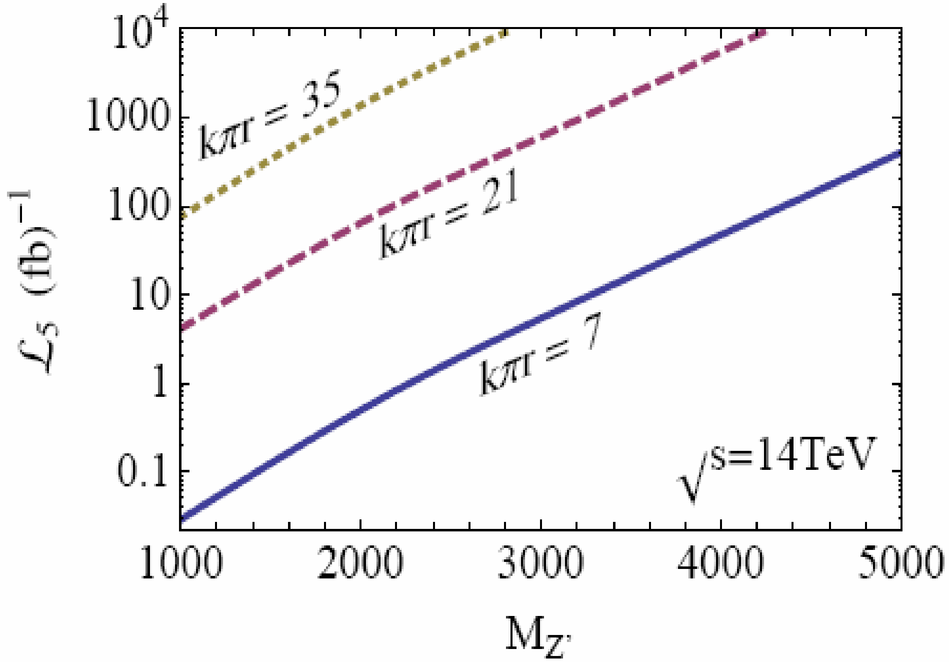
Compare with RS: $\underline{M_{Z'} \sim 2 \text{ TeV}}$ and L = $\underline{1000 \text{ fb}^{-1}}$. Agashe *et al.*, 2007

Revived prospects for golden modes!

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 ($\geq$ 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, <u>300 fb^{-1}</u>.

Agashe *et al.*, 2007

A Light Little Radion

Radian is rather unique prediction of RS

With Davoudiasl and McElmurry arXiv:1009.0764

- Radion ϕ: fluctuations of πr_c, coupling $\frac{\phi}{\Lambda_\phi}\theta^\mu_\mu$.

- Realistic phenomenology: $V(\phi) \Rightarrow m_\phi \neq 0$.

Goldberger, Wise, 1999

De Wolfe, Freedman, Gubser, Karch, 1999

Csáki, Graesser, Kribs, 2000

E.g., Golberger-Wise (GW) mechanism:

Bulk scalar with mass m and brane-localized potentials.

- Typically, lightest warped state $m_\phi \ll m_{KK}$.

GW: $\epsilon = m^2/(4k^2)$; $k\pi r_c \sim 1/\epsilon$; $m_\phi \sim \epsilon\, k\, e^{-k\pi r_c}$

$\Rightarrow\ m_\phi \sim k\, e^{-k\pi r_c}/(k\pi r_c)$; $k\, e^{-k\pi r_c} \sim 1$ **TeV (RS, LRS)**

- $k\pi r_c \sim 7$ **(LRS):** $m_\phi \sim 100$ **GeV.**

LITTLE RADIAN MAY BE ESPECIALLY INTERESTING FOR EARLY RUN @ 7 TeV

BR($\phi \to \gamma\gamma$) ~ 1-2% for $m_\phi \lesssim$ 200 GeV, $\gg$ BR($H \to \gamma\gamma$)

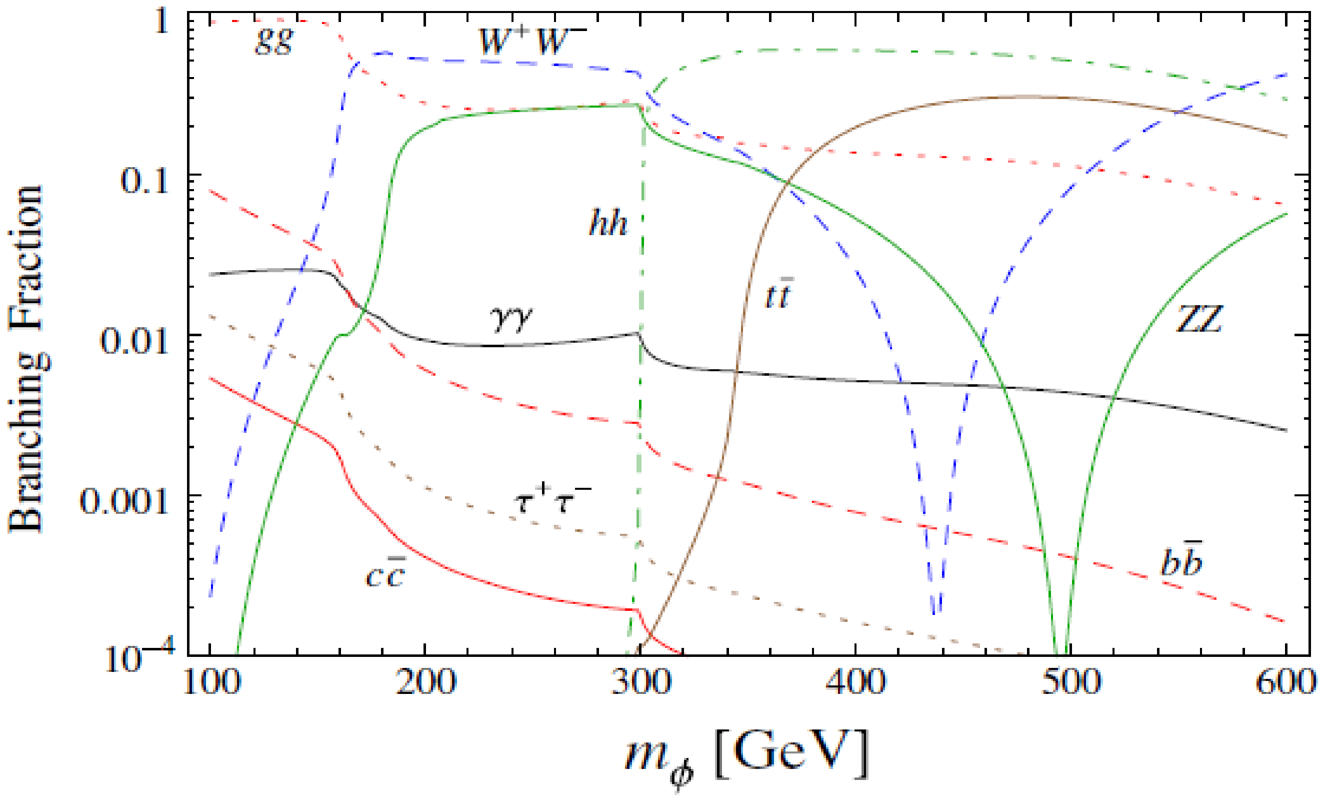
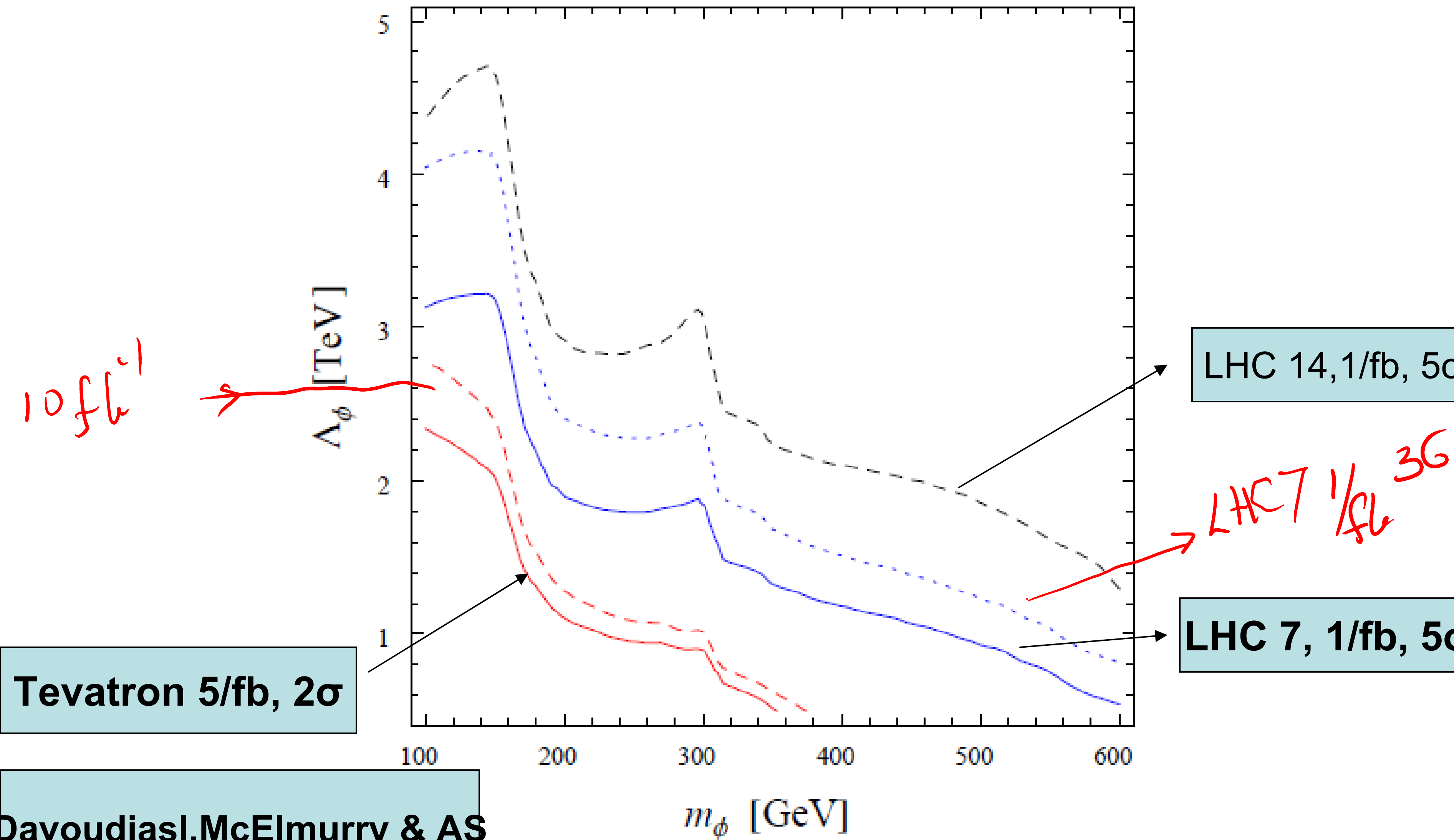


FIG. 1 (color online). Little radion branching fractions, for $kL = 7$ and $\Lambda_\star = 3$ TeV.

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

SM4: 4 Gen. standard model

- **Provides a rather simple explanation to the observed CP anomalies in B-decays**
- **It's a revisit: potential of B-physics forSM4 studied extensively with George Hou~86-88 [2 PRLs, 1 PLB] and others..**

Annals of The New York Academy of Sciences Volume 578

The Fourth Family of Quarks and Leptons

Second International Symposium

CIRCA 1989 (UCLA)

1st ~1987

Editors
DAVID B. CLINE • AMARJIT SONI

Motivation

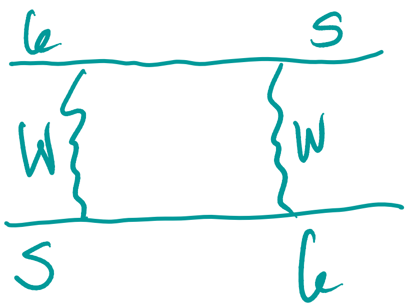
- 1,2,3, why not 4?
- Heavy quarks may trigger condensation -> STRONG DYNAMICS/ DEWSB ,no need 4 fundamental Higgs,SUSY
- SM4 has significant advantage for baryogenesis over SM3
- Gives a natural explanation why CP-Cons observable show miniscule deviations; in sharp contrast to CPV obs.
- Natural m_H ~2 $m_{b'}$ > 700 GeV due CDF -> H ->ZZ!!!
- From SM4perspective, hierarchy problem may well be an accident of history!
- CONS(?)….4th neutral lepton must be very heavy in stark contrast to the known 3
- 7 new parameters (in the quark sector): 2 masses, 3 real angles, 2 CP-odd (new) phases ⇒ HIGHLY CONSTRAINED

Where to look for deviations from SM3 (Examples)

SM3 SM4

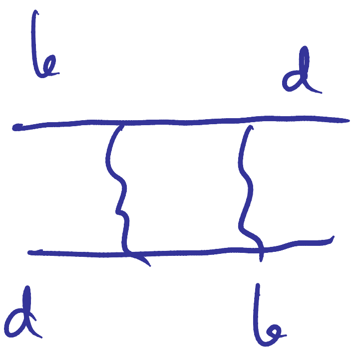
$\arg(V_{tb}^* V_{ts}) \simeq 0$ $\arg(V_{t'b}^* V_{t's}) \neq 0$

LOOK $S(B_d \to \phi K_s, \eta' K_s \ldots)$ $a_{cp}(B \to X_s \gamma) \ldots$



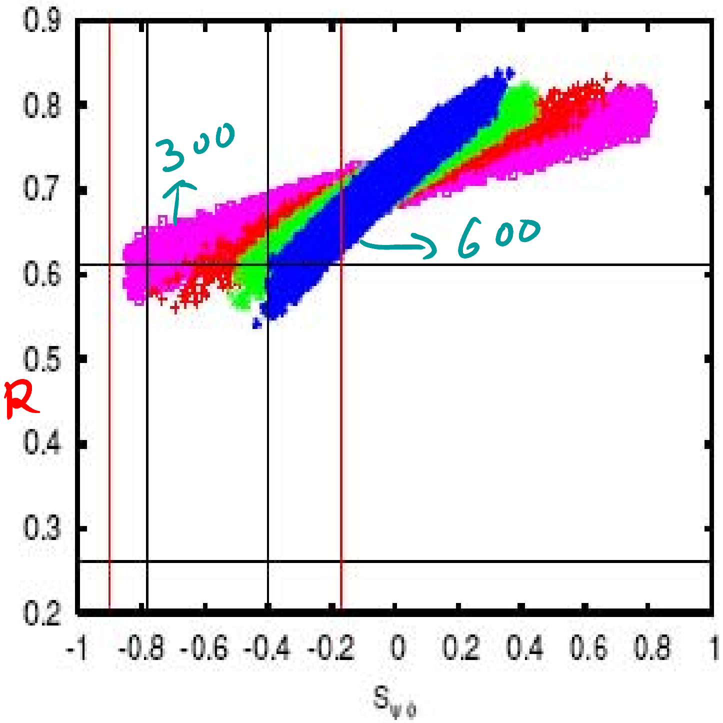
$\arg(V_{tb}^* V_{ts})^2 \simeq 0$ $\arg(V_{t'b}^* V_{t's})^2 \neq 0$

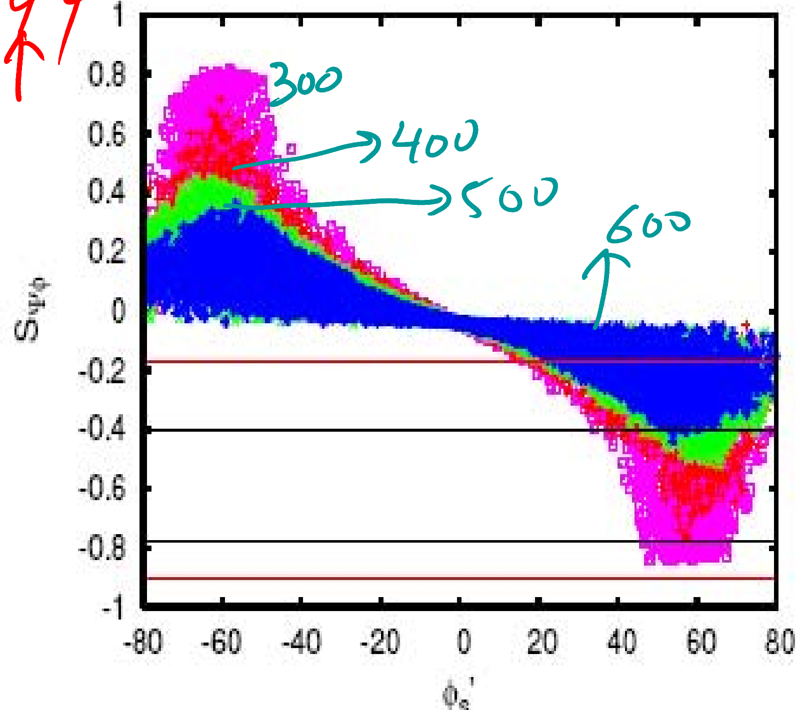
$S(B_s \to \psi\phi)$; $a_{sl}^s \ldots$



$\arg(V_{tb}^* V_{td})^2 \simeq \sin 2\beta$ $\arg(V_{t'b}^* V_{t'd})^2 \neq 0$

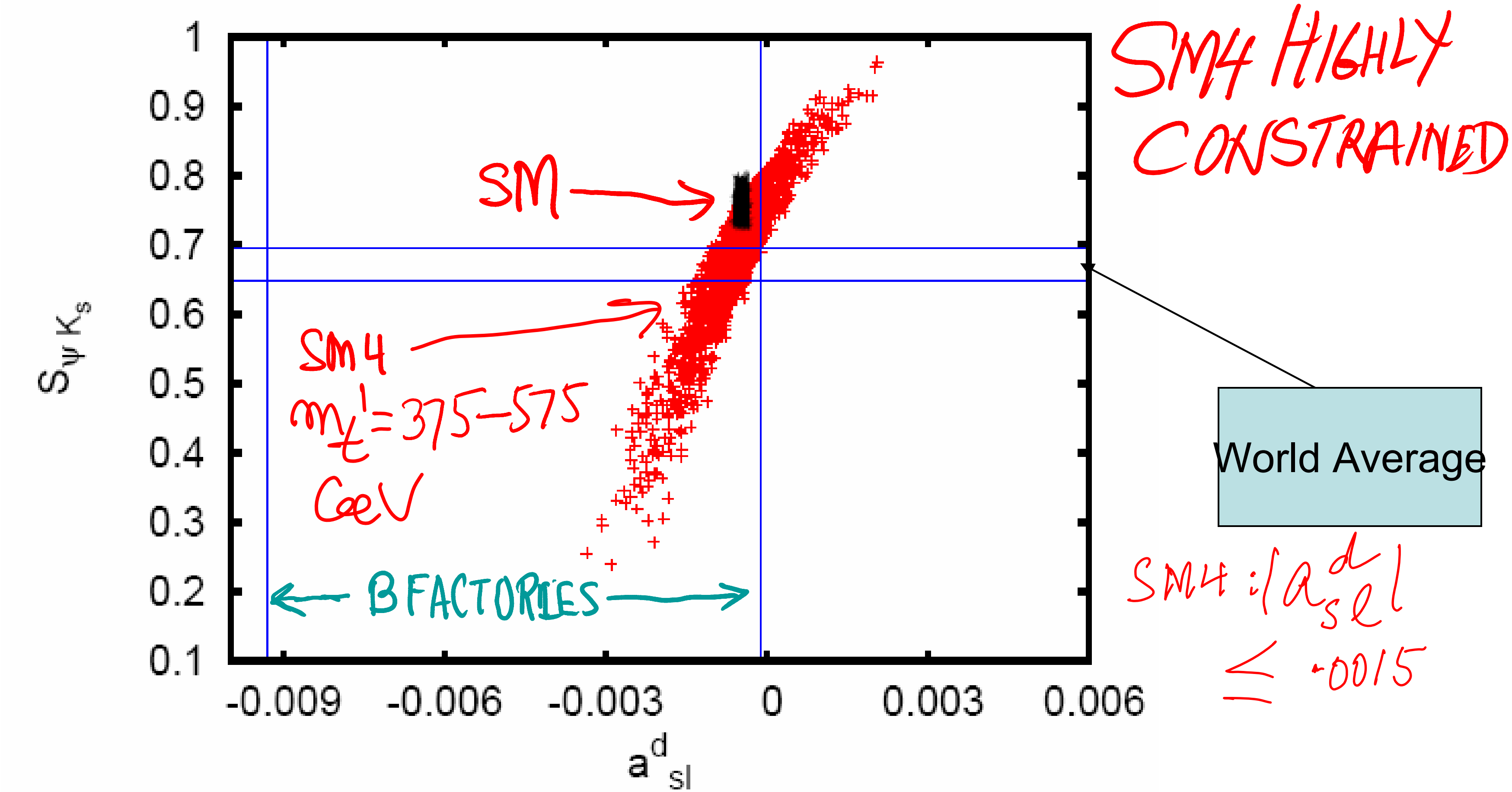
A. S et al 0807.1971; 1002.0595 {Note constraints from S,T, b -> s gamma, K-> pi nu nu ….are all included}
C ALSO A.Buras et al 1002.2126





DATA tends to favor $m_{t'} \sim 400 - 600$ GeV

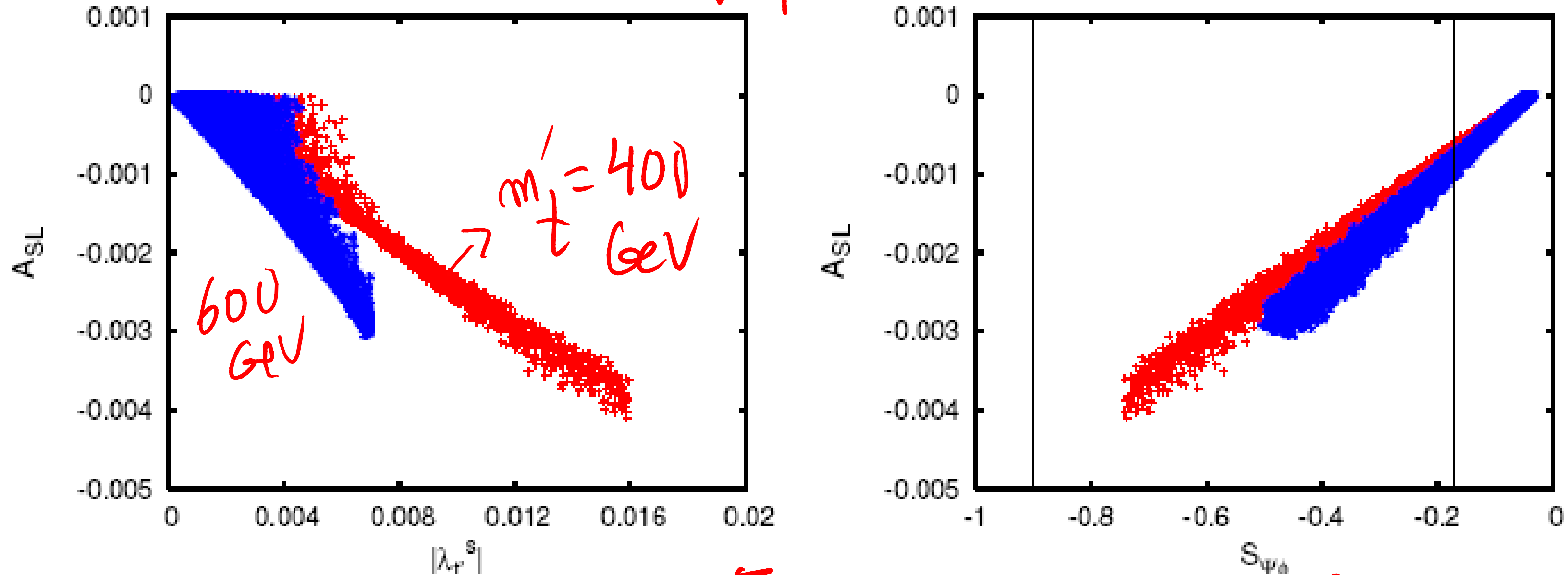
Predicted range of S(psiKs) in SM4 (with mt'=400 GeV) is (shown in red) compared with the experimentally measured value via the psi Ks mode (1 sigma error) and with the SM (1 sigma)



SM4 seems to predict sin2 beta around 0.70 with an error of about 0.06; S. Nandi and A.S, 1011.6091

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



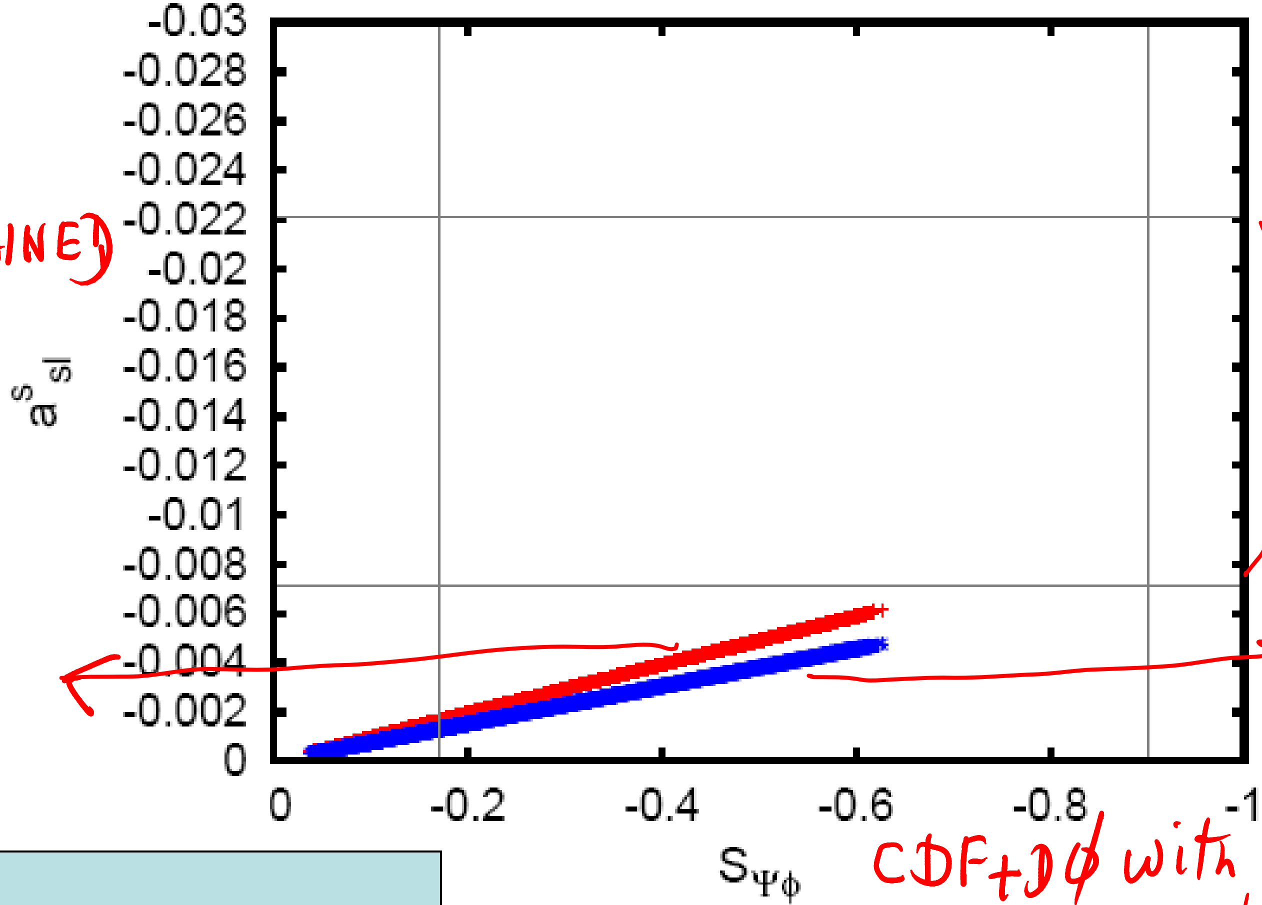
$SM3 \sim A^s_{sl} \sim 2 \times 10^{-5}$; $SM4 \lesssim 4 \times 10^{-3}$

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

SM4 is HIGHLY CONSTRAINED

VARY $m_{t'}$ 375–575 GeV



$\delta\Delta\Gamma_s \sim 2\sigma$

$D\phi$

$\delta\Delta\Gamma_s \sim 1\sigma$

CDF+Dϕ with 2.8/fb each

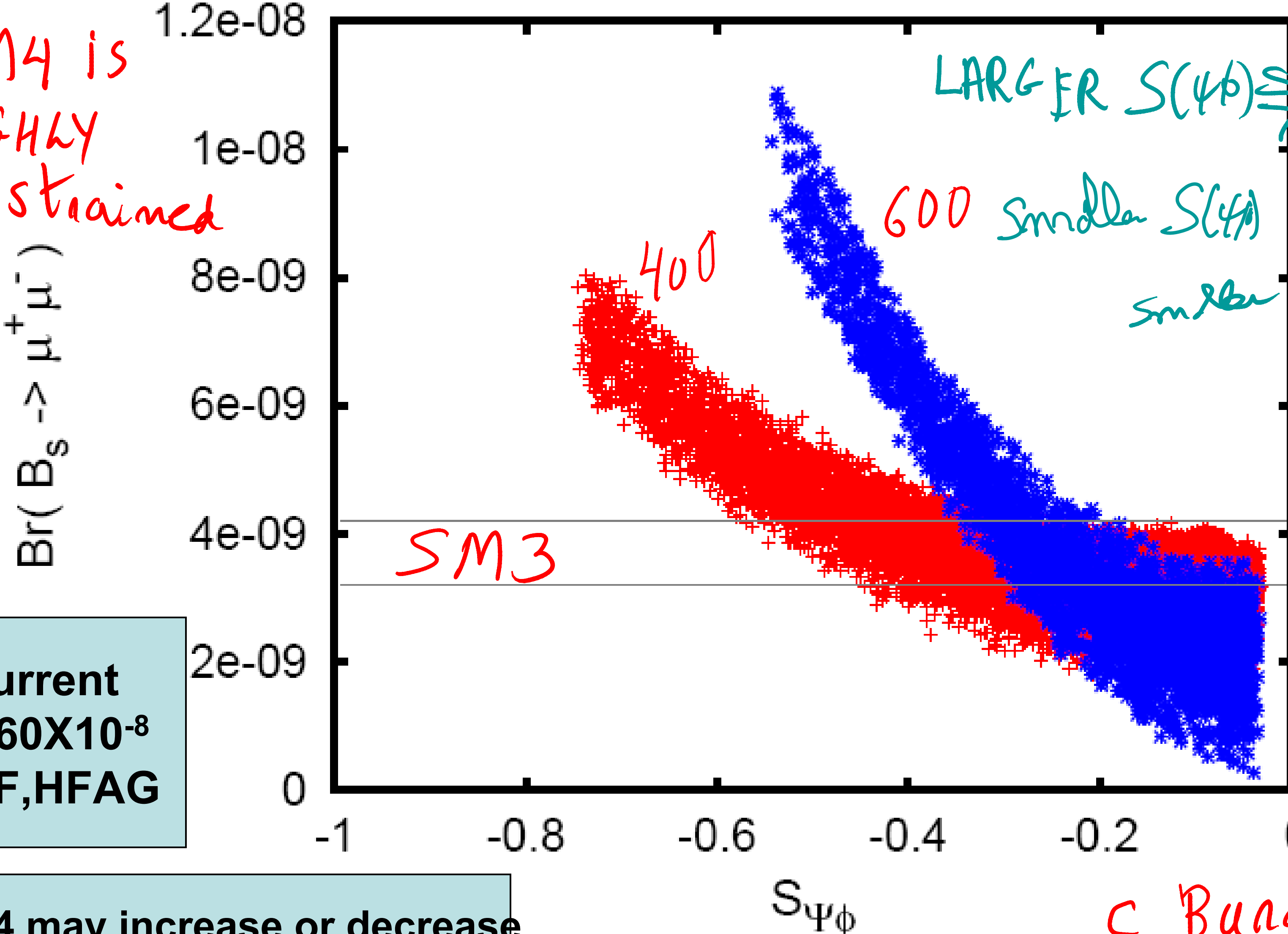
S.Nandi and A.S,1011.6091

Br(Bs->μμ): a very clean process

SM4 is HIGHLY constrained

LARGER S(ψφ) ⇒ larger BR

Smaller S(ψφ) ⇒ smaller BR.

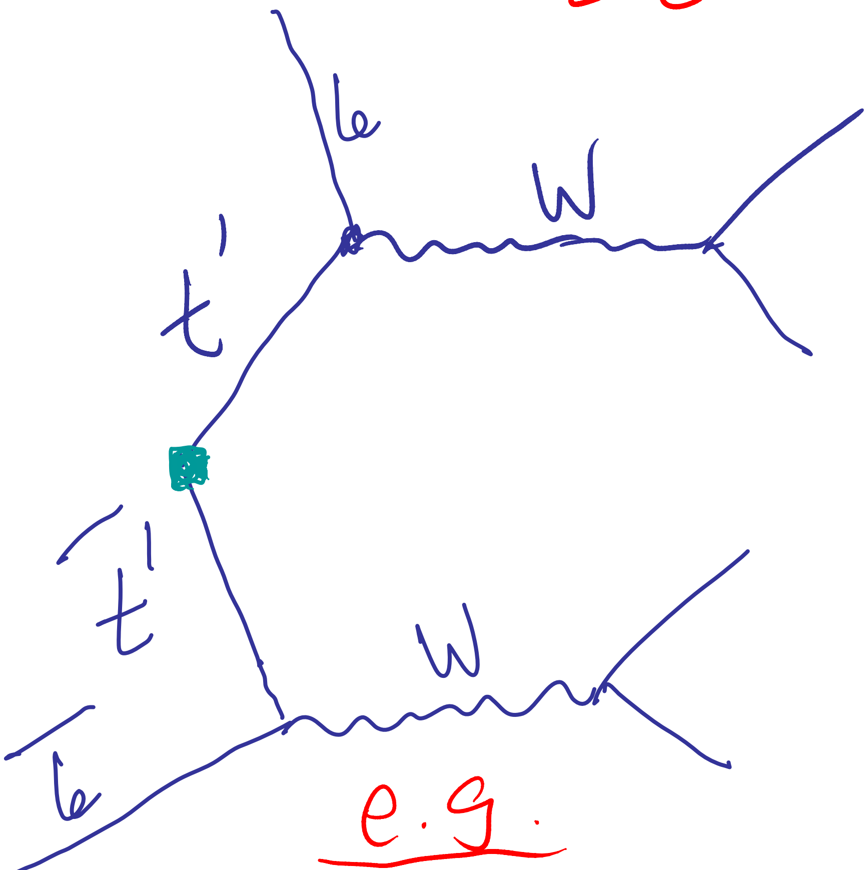


Current $<3.60X10^{-8}$ CDF,HFAG

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

c Buras et al; A.S. et al

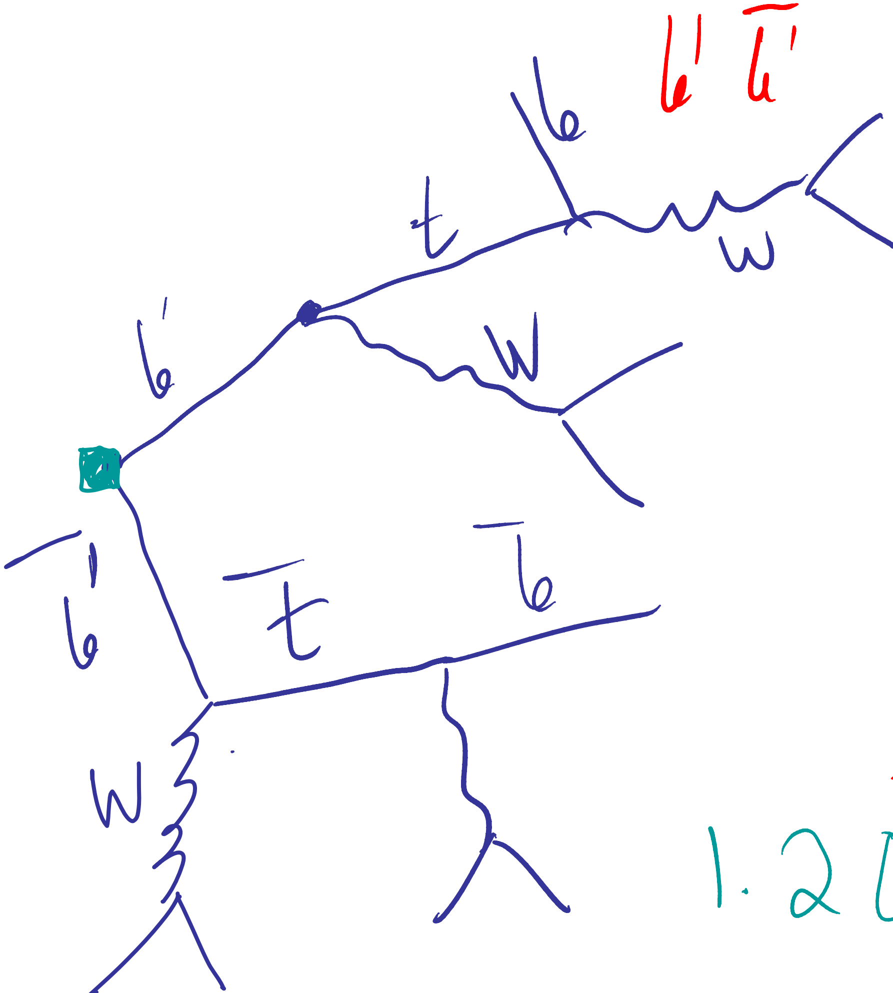
$t'\bar{t}'$



e.g.

I 2 OS l, 2 b_j, MET

II 1 l, 2 b_j, MET, W_{jj} → CDF current bound(s)

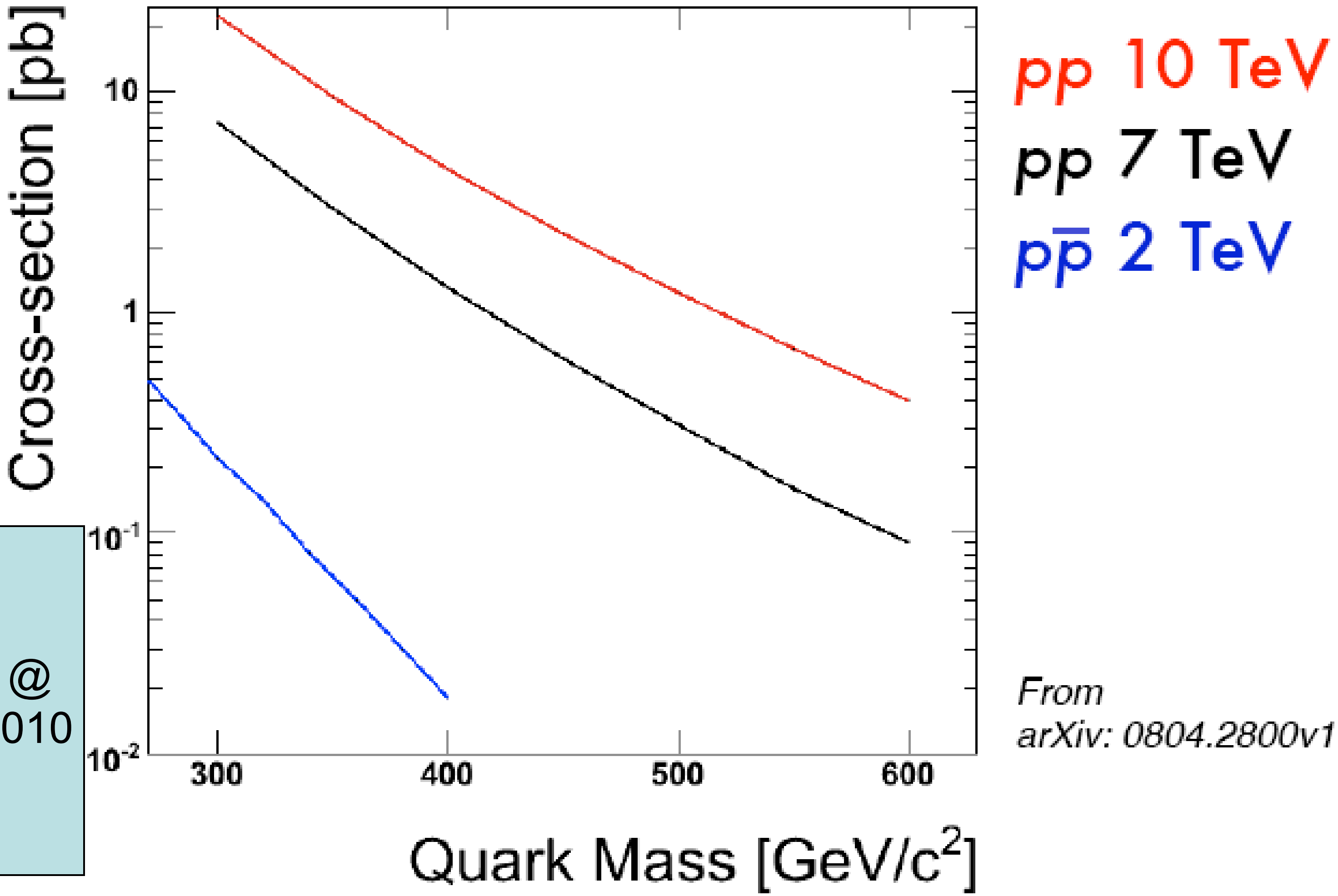


e.g.

1. 2 OS ℓ, $2b_j$, $W_{jj} W_{jj}$, MET
2. 2 SS ℓ, $2b_j$, $W_{jj} W_{jj}$, MET
3. 1 ℓ, $2b_j$, $W_{jj} W_{jj} W_{jj}$, MET

Cross-sections

LHC has much larger rates for heavy quarks

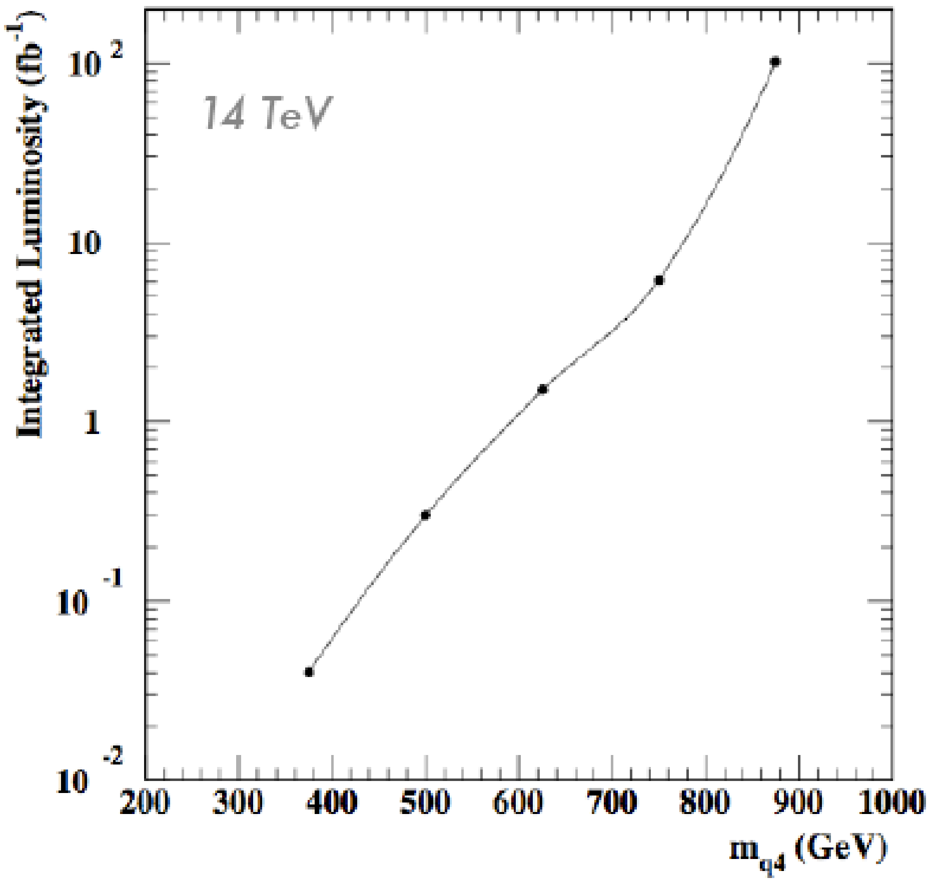


From arXiv: 0804.2800v1

Whiteson @ NTU Jan2010

Sensitivity

5σ discovery



Whiteson@NTU,Jan2010

From ATLAS SN-ATLAS-2008-069

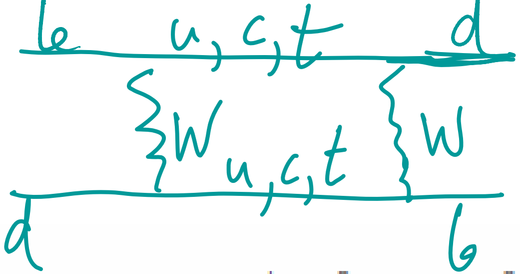
Urgent questions for experiments

- ATLAS,CMS: Φ, W',Z',G; t', b' exist?
- LHCb [CDF,D0]: S(Bs->$\psi\varphi$), a^s_{sl} ; a^d_{sl} ; S(Φ K_S), A_{FB}(K*ll) ....
- BABAR,BELLE updates for a^d_{sl} very useful
- BELLE (UPS5S run and nearby): a^s_{sl} and linear combination
- BELLEII; SBF: S(η'K_S, φK_S, $K_S K_S K_S$), Br(B->$\tau\nu$), a^d_{sl}, a^s_{sl} (?); S($B_{d(s)}$->K* γ; …); S(D^0); $a_{sl}(D^0)$…

Summary & Outlook

- Measured sin2β is off from SM prediction by ~ 3 σ. dev..
- DOMINANT deviation seems to originate in Bd,Bs mixing, Bd->ψ Ks, and NOT in ε_K or B->τν
- Model independent analysis suggests new physics with CP-odd phase with scale below ~few TeV (perhaps even O(few hundreds GeV))
- WARPED space ideas on flavor perhaps most interesting explanation, SM4 offers a rather simple explanation also…
- More accurate results from LHCb, Tevatron, BF, SBFs should be very valuable.
- Direct searches at LHC should clarify matter significantly POSSIBLE EARLY NEW PHYSICS if e.g Φ mass O(100 GeV) &/or Z' mass below 2 TeV or if mt';mb' ~500 GeV

XTRAS



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

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

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

$$|\varepsilon_K| = \frac{G_F^2 m_W^2 f_K^2 m_K}{12\sqrt{2}\pi^2 \Delta m_K^{\text{exp}}} \hat{B}_K \kappa_\varepsilon \,\mathrm{Im}\Big(\eta_1 S_0(x_c)\,(V_{cs}V_{cd}^*)^2 + 2\eta_3 S_0(x_c, x_t) V_{cs} V_{cd}^* V_{ts} V_{td}^*$$
$$+ \eta_2 S_0(x_t)\,(V_{ts}V_{td}^*)^2\Big) . \quad (2.3)$$

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

It is perhaps of some use to extract the values of $\hat{B}_K$, ξ_s and V_{cb} that are required to reduce to the 1-σ level the discrepancy between the prediction given in Eq. (5) and $a_{(\psi+\phi+\eta'+K_S K_S)K_S} = 0.66 \pm 0.024$. We find that one has to choose either $\hat{B}_K^{\text{new}} = 0.96 \pm 0.04$, $\xi_s^{\text{new}} = 1.37 \pm 0.06$ or $V_{cb} = (44.3 \pm 0.6) \times 10^{-3}$.

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

$B_K = 0.740 \pm 0.025$ [39–41]	$R_{bb} = 0.216 \pm 0.001$
$f_{bd}\sqrt{B_{bd}} = 0.224 \pm 0.015\ GeV$ [42, 43]	$\lvert V_{ub}\rvert = (32.8 \pm 2.6) \times 10^{-4}$ [a]
$\xi = 1.232 \pm 0.042$ [42, 43]	$\lvert V_{cb}\rvert = (40.86 \pm 1.0) \times 10^{-3}$
$\eta_c = 1.51 \pm 0.24$ [44]	$\gamma = (73.0 \pm 13.0)^\circ$
$\eta_t = 0.5765 \pm 0.0065$ [45]	$\mathcal{BR}(B \to X_s\gamma) = (3.55 \pm 0.25) \times 10^{-4}$
$\eta_{ct} = 0.494 \pm 0.046$ [46]	$\mathcal{BR}(B \to X_s\ell^+\ell^-) = (0.44 \pm 0.12) \times 10^{-6}$
$\Delta M_s = (17.77 \pm 0.12)ps^{-1}$	$\mathcal{BR}(K^+ \to \pi^+\nu\nu) = (0.147^{+0.130}_{-0.089}) \times 10^{-9}$
$\Delta M_d = (0.507 \pm 0.005)ps^{-1}$	$\mathcal{BR}(B \to X_c\ell\nu) = (10.61 \pm 0.17) \times 10^{-2}$
$\lvert\epsilon_k\rvert \times 10^3 = 2.32 \pm 0.007$	$T_4 = 0.11 \pm 0.14$
$\kappa_\epsilon = 0.94 \pm 0.02$ [47] [b]	$m_t(m_t) = (163.5 \pm 1.7)$ GeV

SM4 significantly facilitates baryogenesis [compared to SM3]

$$Q_B \approx A_{UT-SM3}[(m_c^2 - m_u^2)(m_t^2 - m_c^2)(m_t^2 - m_u^2)(m_s^2 - m_d^2)(m_b^2 - m_s^2)(m_b^2 - m_d^2)/m_W^{12}$$

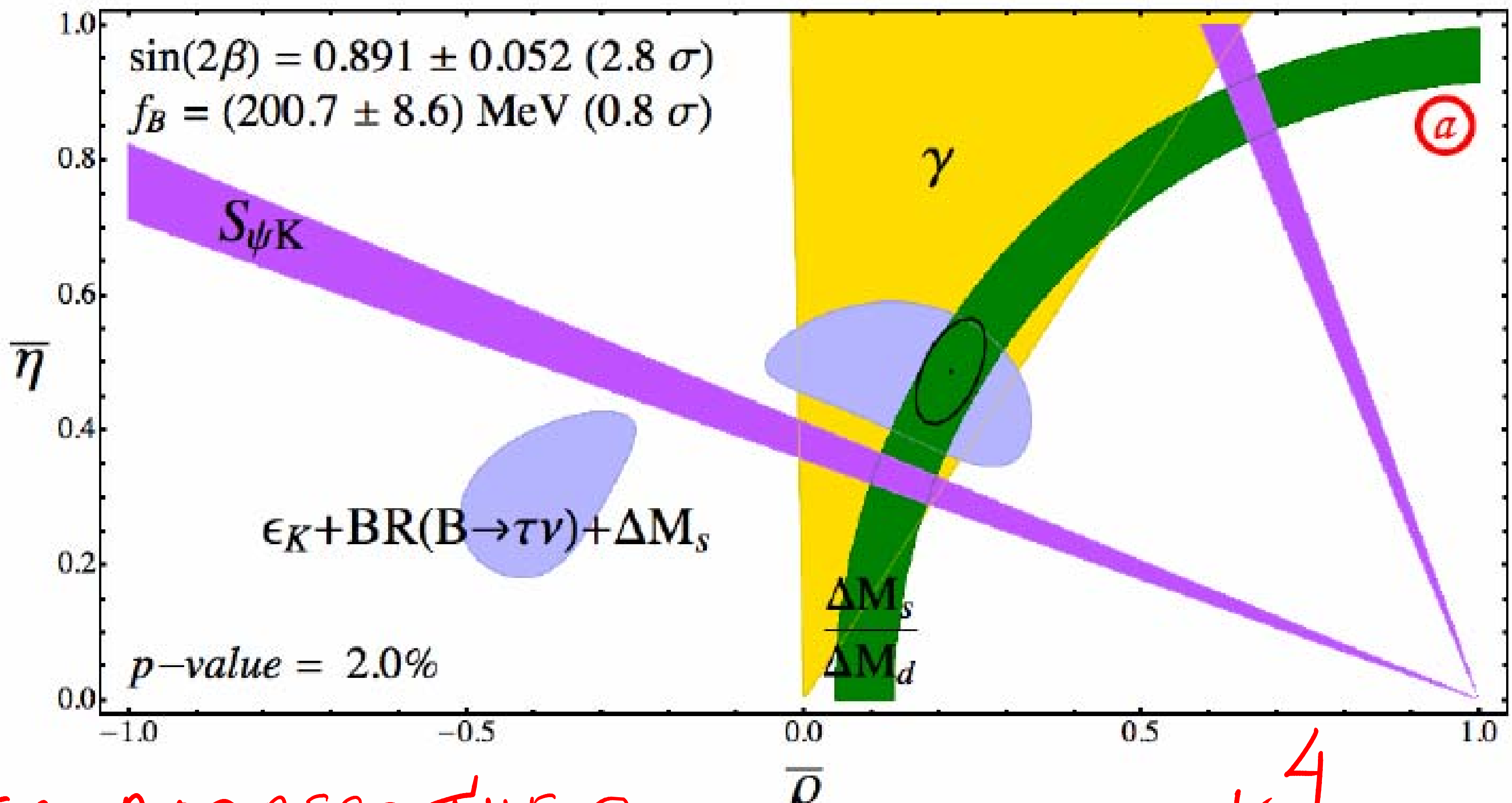
$$(m_t^2/m_c^2)(m_{t}'^4/m_t^4)(m_b^2/m_s^2)(m_{b}'^4/m_b^4) \approx 10^{16}$$

Disecting B->tau nu

- So long as S(sin2β) measured via ψKs is used, the predicted value of the Br(B->tau nu) is about 2.8 σ smaller compared to the directly measured Br (B->tau nu).
- Inclusive Vub leads to consistent prediction for Br(B->tau nu); most likely exclusive Vub has a problem.
- Cause of this may be lattice and/or physics

See: A.Crivellin (2010); Buras,Gemmler & Isidori (2011)

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}

LRS Alleviates confrontation with S, T

$$S_{\text{tree}} \approx 2\pi (v/\kappa)^2 \left[1 - \frac{1}{kr_c\pi} + \xi(c)\right], \tag{1}$$

$$T_{\text{tree}} \approx \frac{\pi}{2\cos\theta_W^2} (v/\kappa)^2 \left[kr_c\pi - \frac{1}{kr_c\pi} + \xi(c)\right], \tag{2}$$

where

$$\xi(c) \equiv \frac{(2c-1)/(3-2c)}{1 - e^{kr_c\pi(2c-1)}} \left(2kr_c\pi - \frac{5-2c}{3-2c}\right) \tag{3}$$

encodes fermion localization; $\cos^2\theta_W \simeq 0.77$. For all realistic warped fermion profiles of interest in this work, $\xi(c) \ll 1$.

[4,5] and $x_{KK}^{LRS} = 2.70, 5.87, \ldots$. Then, for $m_{KK} \approx 5$ TeV, the RS model yields $(S,T)_{\text{tree}} \approx (0.1, 1.1)$, whereas for the LRS model $(S,T)_{\text{tree}} \approx (0.1, 0.2)$, from Eqs. (1) and (2).

DATA: $|S|, |T| \sim 0.1 - 0.3$

Dual picture

- **LRS model is holographically dual to dynamics with number of colors larger by the truncation factor (y)**

  -> enhancment of "golden" modes follows from the larger "ρ-γ" mixing and a weaker inter-composite coupling (each by a factor of y)

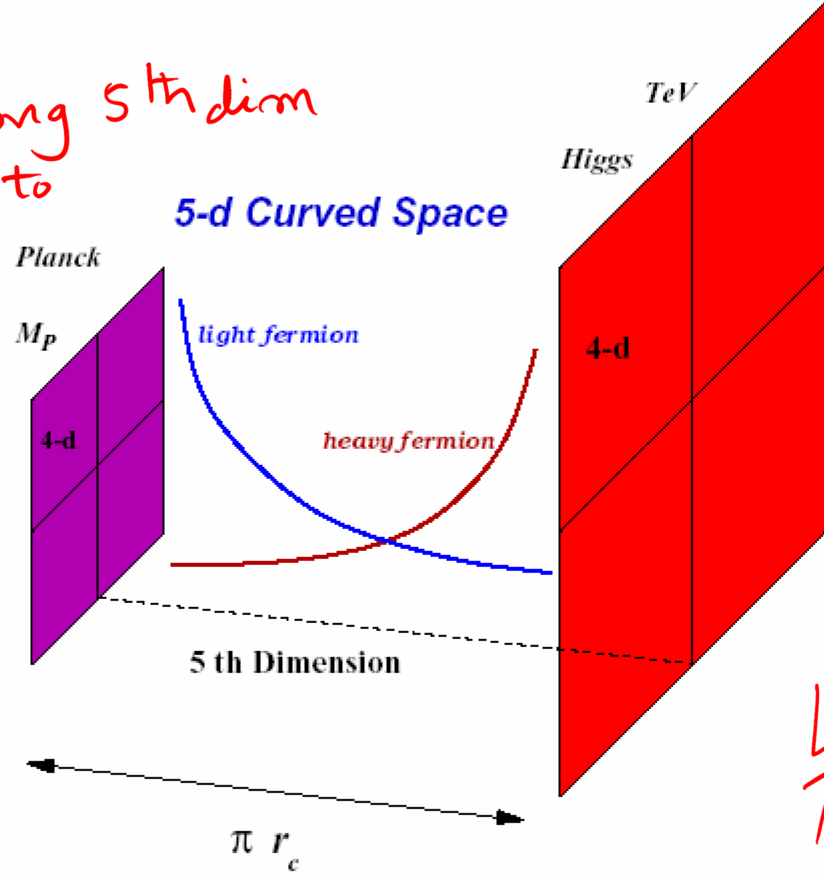
Experimental handle on truncation

- **Clean signals into the golden modes are thus very sensitive to truncation factor**
- **Endowing us with an experimental handle on $kr_c\pi$ (M_5) in simple models**
- **Thus in case a TeV scale KK mode is discovered, we can quantitatively address whether it is relevant to the Planck-weak hierarchy or to some other large scale, such as flavor or in fact something else**

RANDALL+SUNDRUM '99

[FIG BY H DAVOUDIASL]

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



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

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

TeV

M_P

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

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**
- **O(1) CP;…..in fact for neutron a (mild) CP problem**
- **Most flavor violations are driven by the top**

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

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**

May be the best reason

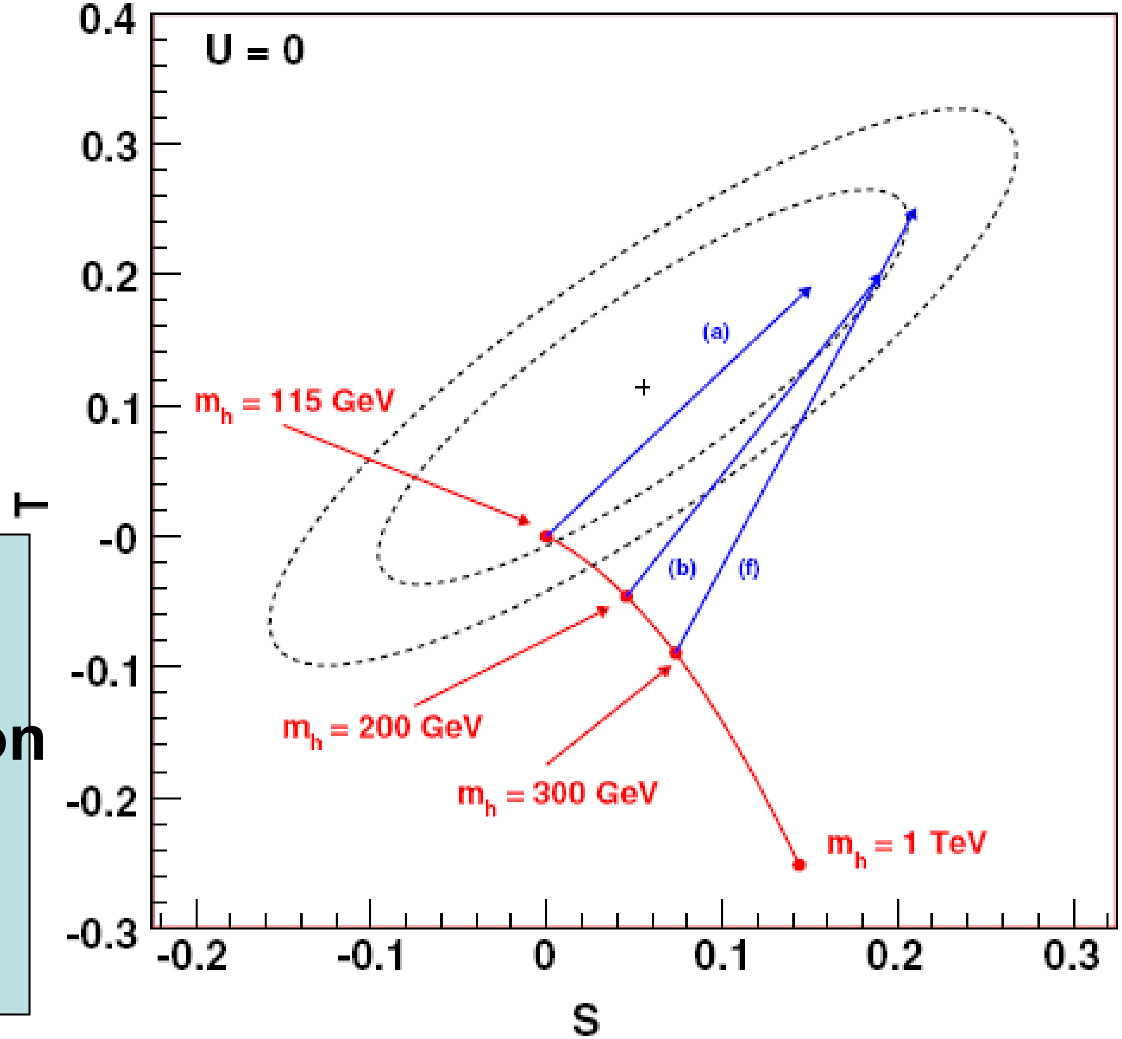
- **My license plate: udcstbgz   (since ‘89 NY)**

- **Used to be OSCILL8   (before ‘89 in CA)**

AVFAQ

- **Hasn't it already been ruled out?**
- **PDG (like all BIBLES) has its shares of "errors"**

Kribs, 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	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

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

CAVEAT K-$\bar{K}$ LR
c Beall Bander AS '82
BONA et al '07

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

$m_{KK} \gtrsim 3$ TeV

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

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

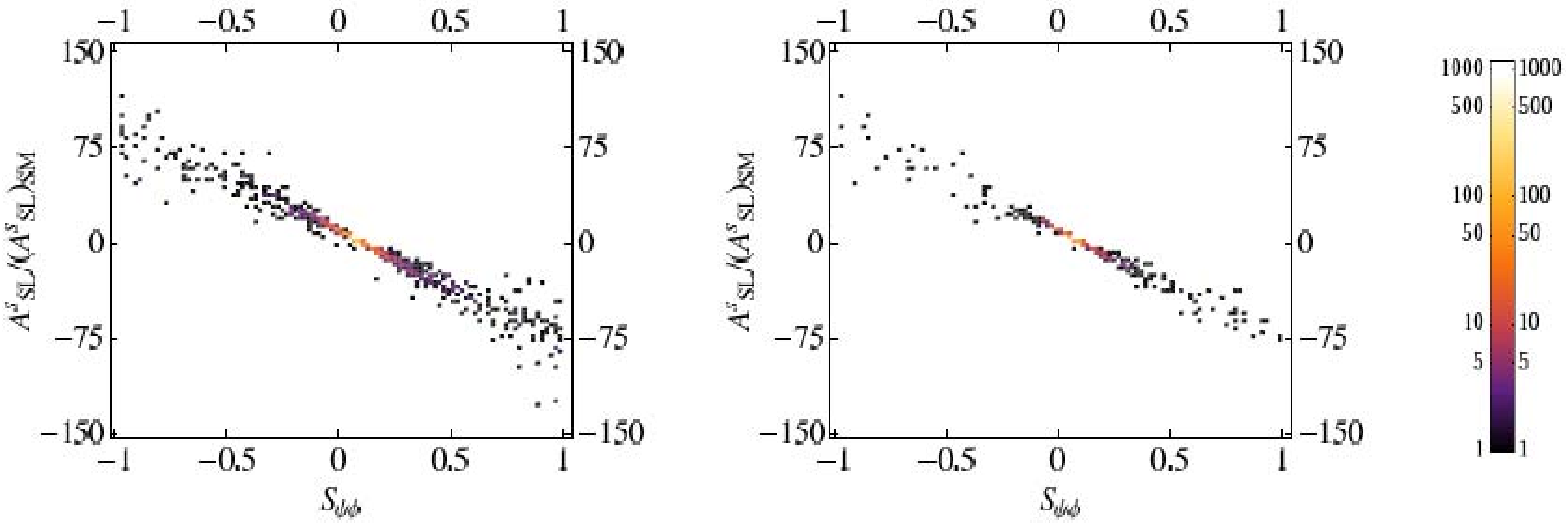


Figure 7: *left:* A^s_{SL}, *normalised to its SM value, as a function of* $S_{\psi\phi}$. *In addition to the requirement of correct quark masses and CKM mixings, also the available* $\Delta F = 2$ *constraints are imposed. right: The same, but in addition the condition* $\Delta_{BG}(\varepsilon_K)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

DØ ANOMALY

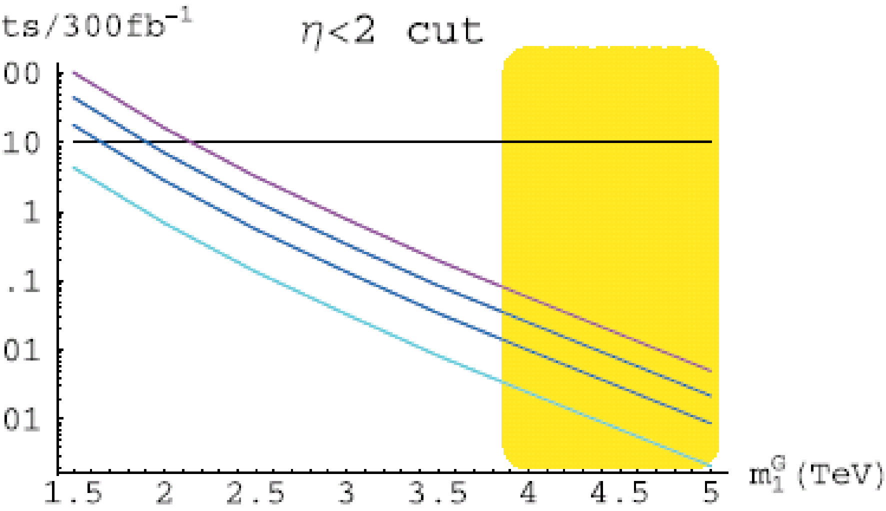
COMPARISONS

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

SIGNIFICANT DIFFERENCES

1) APS hep-ph 0606293. 2) EILAM, Hewett + AS '91
4) LIU, LI, YANG, JIN: "UNCONSTRAINED MSSM" 040155
3) AHRIB + HOU JHEP '06, EILAM, MELIC, TRAMPETIC '0909.3227

G->ZZ: Agashe et al,hep-ph/0701186



(color online). The total number of expected events for rely leptonic decay mode for Z pairs from KK graviton using 300 fb^{-1} with $\eta < 2$. See also Fig. (1).

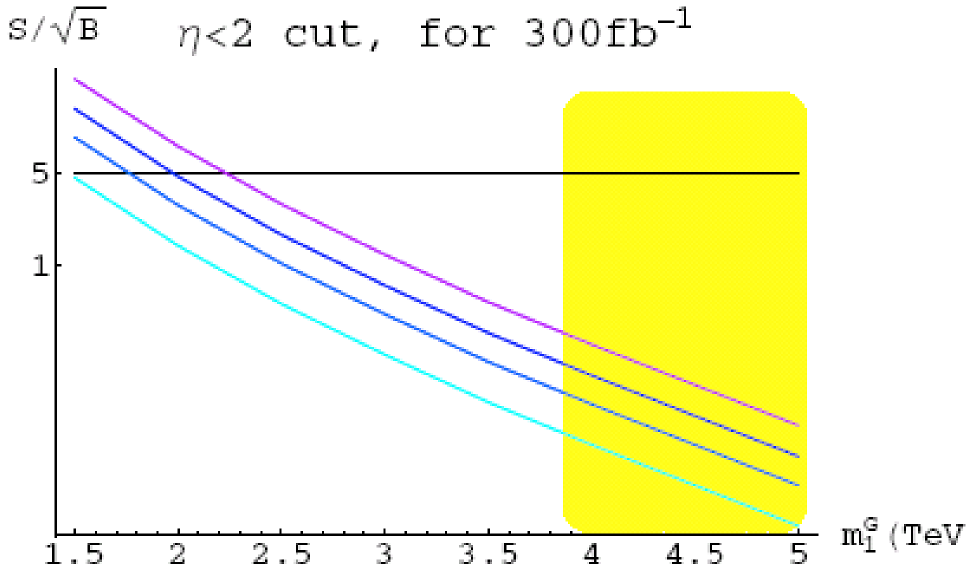
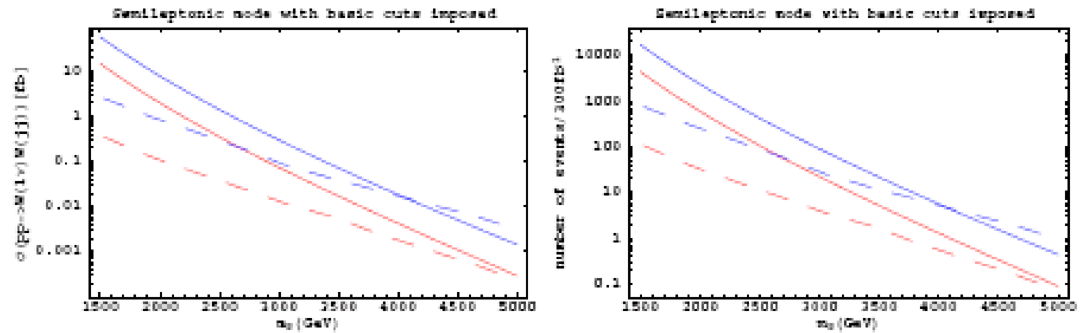


FIG. 5 (color online). Same as Fig. 4, but with $\eta < 2$.

GRAVITON @ LHC



Antipin, Atwood+A.S 0711.3175

FIG. 5: (Color online) (a) The total signal (solid) and SM background (dashed) cross-section (integrated in $m_G \pm \Gamma_G$ window) for $pp \to W(l\nu)W(jj)$ after $|\eta_W| < 1$ cuts were applied for c=1 (red) and c=2 (blue) values, (b) Corresponding number of events for 300 fb^{-1}.

$G \to WW$
$\hookrightarrow l\nu$
$\hookrightarrow q\bar{q}$

TABLE III: Semileptonic mode signal cross-sections [in fb] and S/B ratios along with W + 1 jet and WW SM backgrounds. Signal 1 and the corresponding W + 1 jet background results were obtained after cuts in Eqs.7,8 were imposed and $m_G \pm \Gamma_G/2$ integration region was chosen. Signal 2 and corresponding WW background results were obtained after $|\eta_W|$ <1 cut and integrated in $m_G \pm \Gamma_G$ window.

2 TeV	Cuts	# of events/300 fb^{-1}	S/B	S/$\sqrt{B}$
Signal 1 [c=1]	1.7	510	1.04	23
W + 1 jet background [c=1]	1.64	492		
Signal 2 [c=1]	2.0	600	13.3	90
WW background [c=1]	0.15	45		
Signal 2 [c=2]	7.8	2340	7.8	135
WW background [c=2]	1.0	300		
3.5 TeV	**Cuts**	**# of events/300 fb^{-1}**	**S/B**	**S/$\sqrt{B}$**
Signal 1 [c=1]	0.01	3	0.33	1
W + 1 jet background [c=1]	0.03	9		
Signal 2 [c=1]	0.02	6	2.9	4.1
WW background [c=1]	0.007	2.1		
Signal 2 [c=2]	0.07	21	1.4	5.4
WW background [c=2]	0.05	15		

$$\frac{\sigma B_{W\to jj} B_{W\to l\nu}}{\sigma B_{Z\to ll} B_{Z\to ll}} \sim 150$$

"Semileptonic"

HIGHLY COLLIMATED Jets.

MAY REACH 3.5 TeV with WW

"Semileptonic" Decays of KKZ $\hookrightarrow W\ W$ $\hookrightarrow \ell\nu$

$\hookrightarrow$ jets.

$\Rightarrow$ HIGHLY COLLIMATED jets.

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 $\mathcal{L} = 100$ 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		

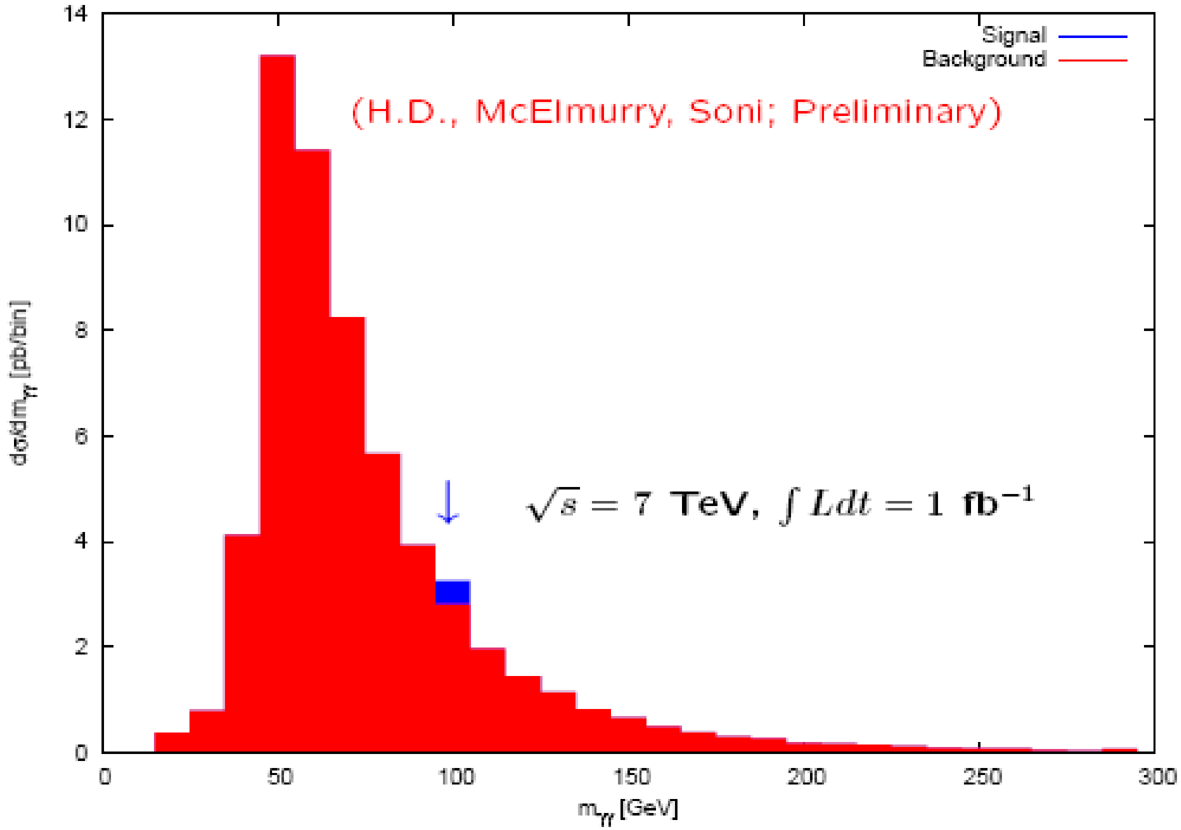
Shrihari Gopalakrishina et al;arXiv:0709.0007

KKZ @ LHC

General light dilatons

- In theories where the EW symmetry breaking originates from a spontaneously broken,nearly conformal sector, there is also a narrow scalar resonance, the pseudo-GB (pseudo-dilaton) of conformal symm breaking, properies much like Higgs.
- For collider signatures & distinction from Higgs, see: Goldberger,Grinstein,Skiba'07;Fan, Goldberger,Ross,Skiba'08
- Relation to walking technicolor, Applequist & Bai '10

$pp \to \phi \to \gamma\gamma$



- $m_\phi = 100$ GeV, $\Lambda_\phi = 3$ TeV, $kr_c\pi = 7$ ($M_5 \sim 10^4$ TeV).
- $\mathrm{Br}(\phi \to gg, b\bar{b}, \gamma\gamma) = 89.6\%, 8.0\%, 2.4\%$.
- $p_T(\gamma) > 20$ GeV, $|\eta| < 2.5$, isolation (0.4, 10 GeV):

$S \approx 460$ fb, $B \approx 60 \times 10^3$ fb (NLO).

- 90 GeV $< M_{\gamma\gamma} <$ 110 GeV $\Rightarrow S/B \approx 0.08$, $S/\sqrt{B} \approx 6$.

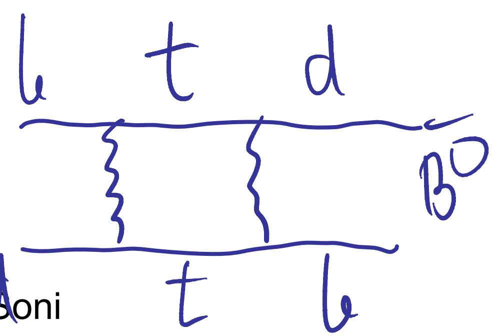
$$\Delta S \equiv S_{\text{penguin}} - S_{\psi K_S} = O(\lambda^2)$$

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

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

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

OSC is B^0 common



Little Radian Signals

- Effective Langrangian:

$$\mathcal{L} = -\frac{\phi}{\Lambda_\phi}\left(C_{gg}G_{\mu\nu}G^{\mu\nu} + C_{\gamma\gamma}F_{\mu\nu}F^{\mu\nu}\right)$$

$$C_{gg} = \frac{1}{4}\left[\frac{1}{k\pi r_c} + \frac{\alpha_s}{2\pi}b^s_{\text{light}}\right]; \qquad C_{\gamma\gamma} = \frac{1}{4}\left[\frac{1}{k\pi r_c} - \frac{\alpha}{2\pi}b^{EM}_{\text{light}}\right]$$

(No brane kinetic terms) Csáki, Hubisz, Lee, 2007 $\Rightarrow$ PHENO. USUAL RS

For LRS couplings C's enhanced due $k\pi r_c$

Assume m_Φ < 140 GeV, then gg -> Φ -> γγ important signal

LITTLE RADIAN MAY BE ESPECIALLY INTERESTING FOR EARLY RUN @ 7 TeV

$\lvert V_{cb}\rvert_{\rm excl} = (39.0 \pm 1.2)10^{-3}$	$\eta_1 = 1.51 \pm 0.24$ [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]
14.4% ← $\lvert V_{ub}\rvert_{\rm tot} = (32.7 \pm 4.7)10^{-4}$	$\lambda = 0.2255 \pm 0.0007$
$\Delta m_{B_d} = (0.507 \pm 0.005)\ \mathrm{ps}^{-1}$	$\alpha = (89.5 \pm 4.3)^\circ$
$\Delta m_{B_s} = (17.77 \pm 0.12)\ \mathrm{ps}^{-1}$	$\kappa_\varepsilon = 0.94 \pm 0.02$ [25–27]
$S_{\psi K_S} = 0.668 \pm 0.023$ [28]	$\gamma = (74 \pm 11)^\circ$
$m_c(m_c) = (1.268 \pm 0.009)\ \mathrm{GeV}$	$\hat{B}_K = 0.740 \pm 0.025$
$m_{t,pole} = (172.4 \pm 1.2)\ \mathrm{GeV}$	$f_K = (155.8 \pm 1.7)\ \mathrm{MeV}$
$f_{B_s}\sqrt{\hat{B}_s} = (276 \pm 19)\ \mathrm{MeV}$ [23]	$\varepsilon_K = (2.229 \pm 0.012)10^{-3}$
$f_B = (208 \pm 8)\ \mathrm{MeV}$ [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!

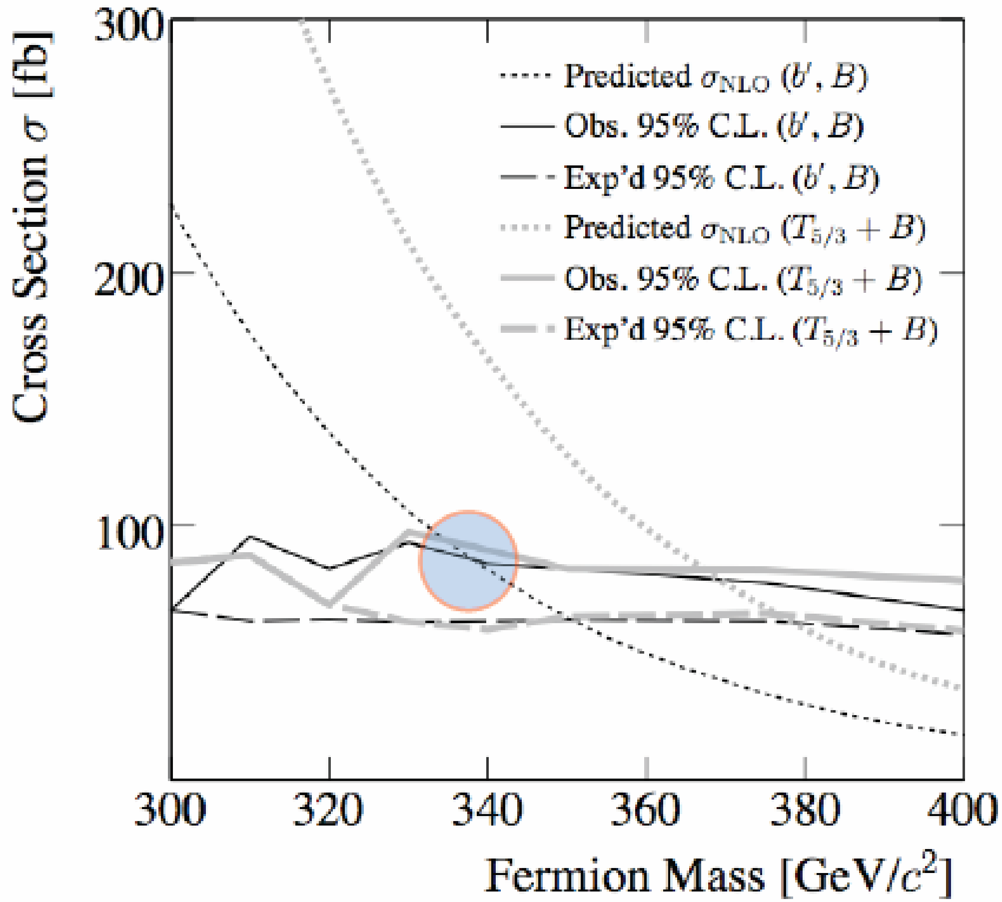
Limits

arxiv:0912.1057

CDF:Whiteson @NTU Jan 2010

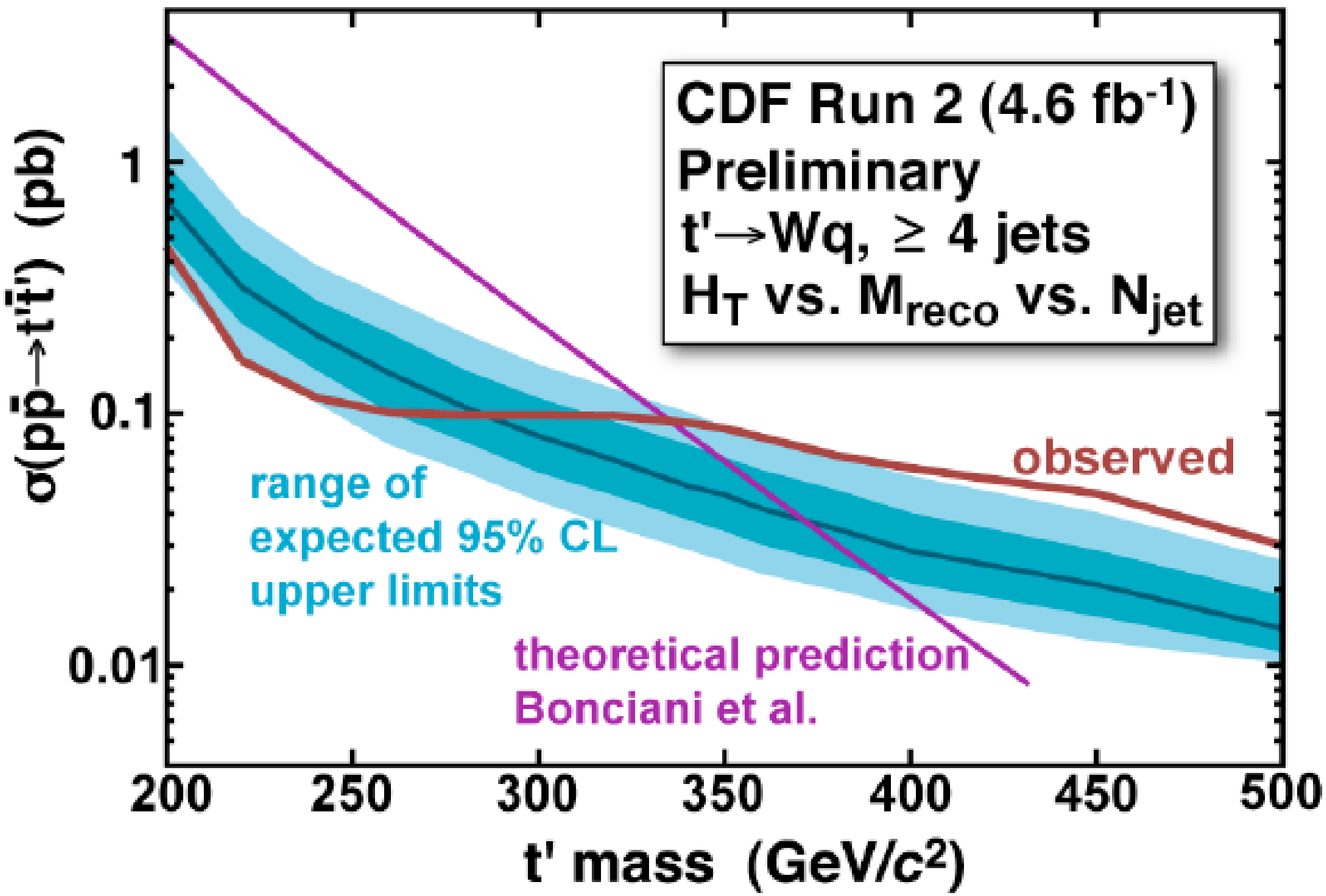
Limit

$m_{b'} > 338$ GeV



t′ limit curve

Conway@BF2010: CDF with 4.6 /fb now



m(t′) > 335 GeV at 95% CL