Title: Demise of the CKM-paradigm and its aftermath

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Abstract: TBA

Demise of CKM & its aftermath

Amarjit Soni
BNL, HET
(adlersoni@gmail.com)
Perimeter Intstitue, 2/18/11

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 '07-08 accumulated data indicated measured value of sin2beta smaller than theory prediction by ~2 sigma but...
- CKM'10 updates (more data + important lattice developments) -> heightened discrepancy with the SM
- Taking it seriously, candidate NP scenarios at work
- Implications for LHC,LHCb,(S)BF...
- Summary & Oulook

1. WEXD
2 SM4

Inputs used

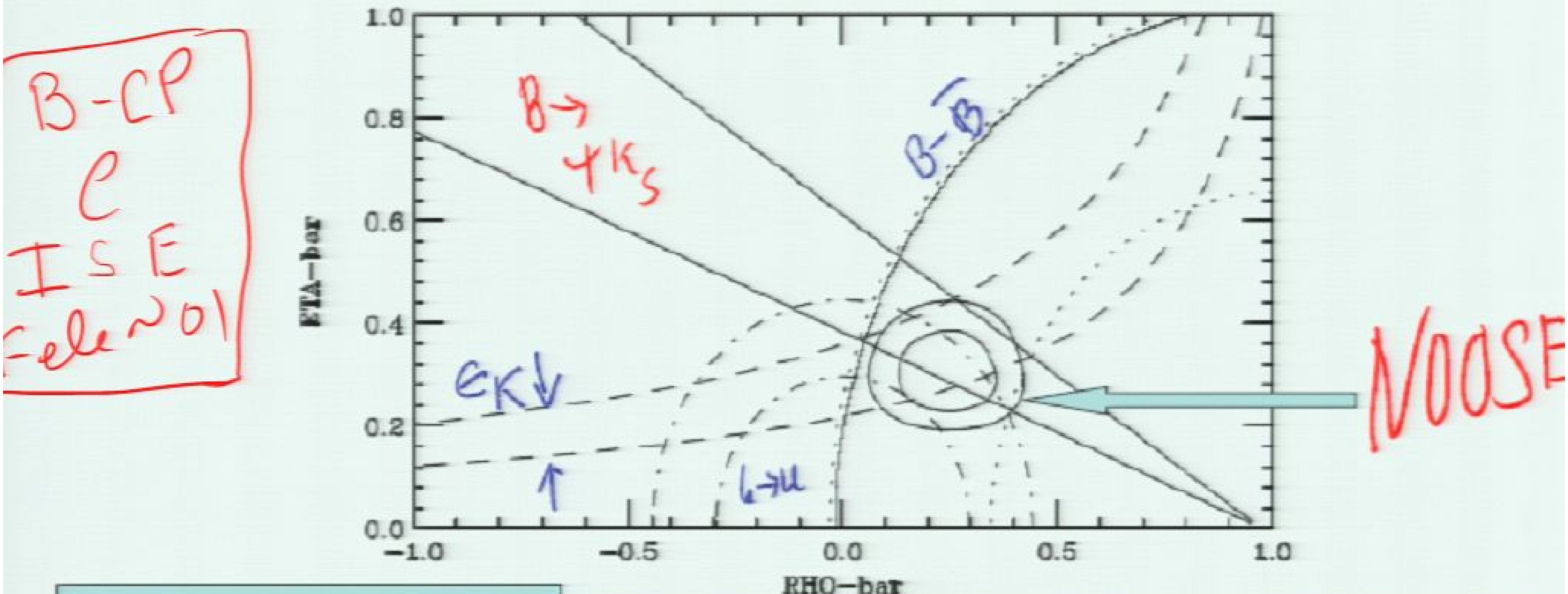
- From Expt.. Only confirmed and established inputs: S(ψ Ks), ΔMs, ΔMd, Br (B-> tau nu) used
- From the lattice, inputs used extensively studied and confirmed by different collabs.
- and are in full 2+1 QCD

I. Glorious Successes

1st Hint of confirmation of CKM CP description

Atwood &AS, hepph/0103197

Case−A1

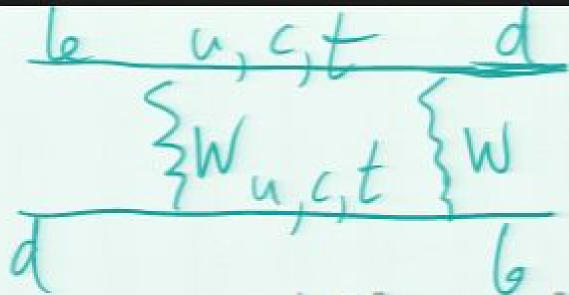


Most bands due
To theory errors

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

ALL EXPERIMENTAL DATA MUST REQUIRE ONLY UNIQUE ρ,η

5



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

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

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

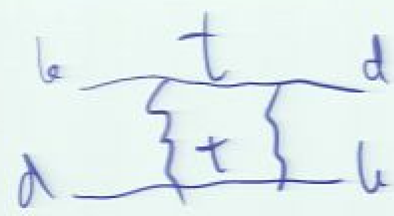
$$|\varepsilon_K| = \frac{G_F^2 m_W^2 f_K^2 m_K}{12\sqrt{2}\pi^2 \Delta m_K^{\rm exp}} \hat{B}_K \kappa_\varepsilon \, {\rm Im}\Big(\eta_1 S_0(x_c)\,(V_{cs}V_{cd}^*)^2 + 2\eta_3 S_0(x_c,x_t) V_{cs}V_{cd}^* V_{ts}V_{td}^*$$

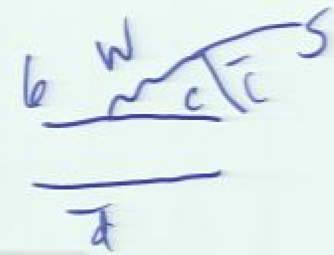
$$+\eta_2 S_0(x_t)\,(V_{ts}V_{td}^*)^2\Big) . \quad (2.3)$$

$$\langle 0 | [\bar{b}\gamma_{\mu L} d]^2 | B_d \rangle \equiv B_{B_d} / \tfrac{8}{3} f_{B_d}^2 m_{B_d}^2$$

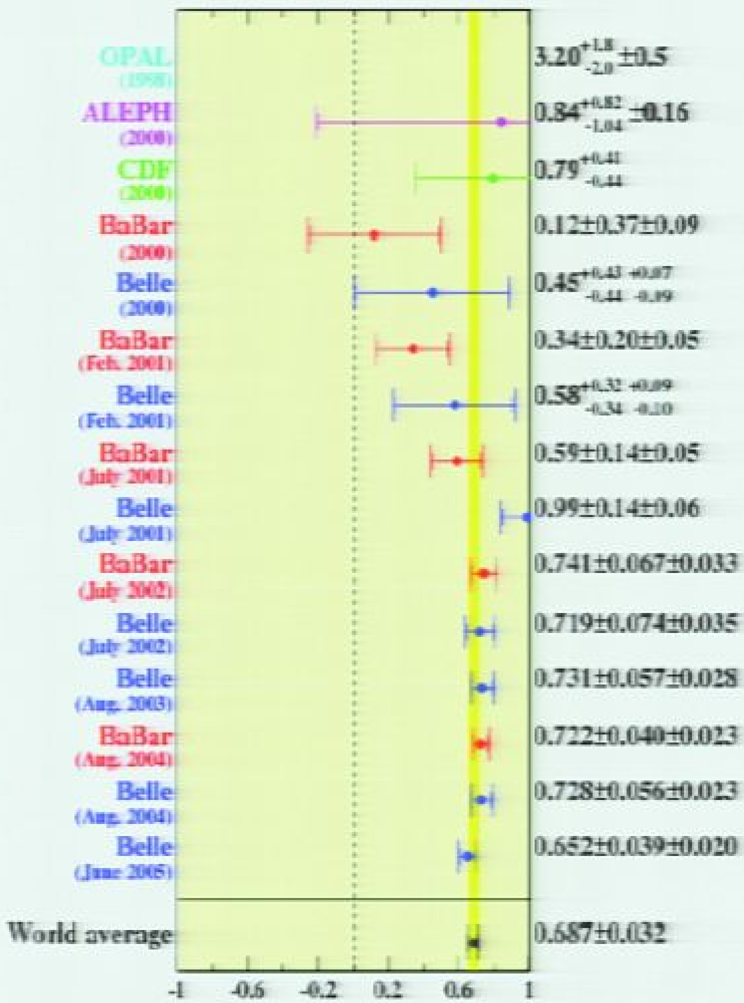
CIRCA ~ 2006

MEASUREMENT of $\beta(\phi_1)$





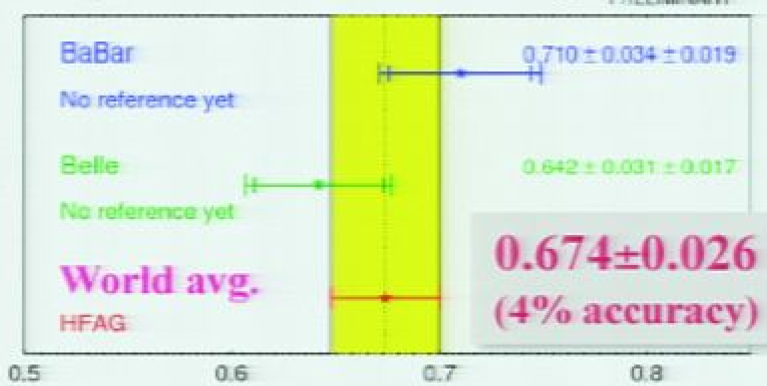
$\sin 2\beta$ history (1998-2005)



2006 BaBar + Belle

$S_{CP} = \sin(2\beta) \equiv \sin(2\phi_1)$

HFAG ICHEP 2006 PRELIMINARY



$b \to c\bar{c}s$ C_{CP}

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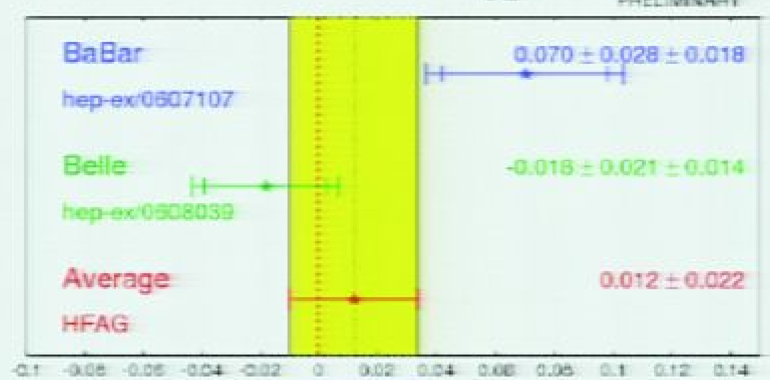


SM $\sin 2\beta = .79 \pm .10$

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. 8

Role of the lattice weak matrix elements in the rise & in 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.

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

ϵ_K = (KNOWN Constant) $B_K \, \eta$

BROWN

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 Lunghi+AS

0707.0212; 0803.4340;
0903.5059;0912.0002
1010.6069

Accentuated need for precise tests of the CKM-paradigm

- Since we are looking for small deviations, it should be clear that we need to sharpen our tests; use of ambiguous input or one that is theoretically not under good control defeats the purpose.
- Therefore in collaboration with E. Lunghi we have been trying systematically to improve the tests since ~07

Lunghi+AS,arXiv.0707.0212

(Sin 2 β = 0.78+-.04)

rectly measured via
(gold-plated)
B->ψ K_s ,
sin 2β = 0.68+-.026

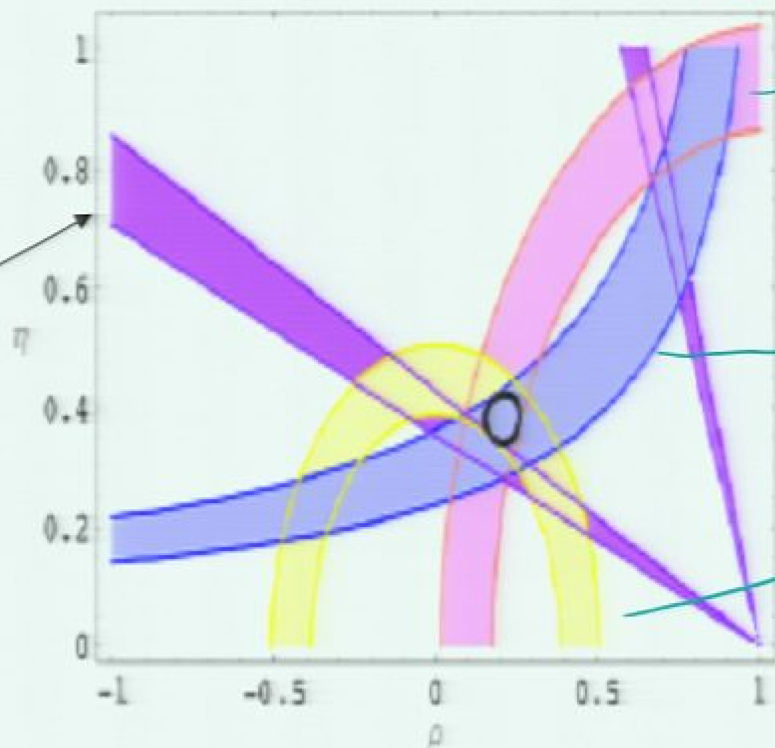


Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

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
continuum
$B \to X_u l \nu$
e.g. $B \to \pi l \nu$

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

ONLY BECAME VIABLE DUE TO SIGNIFICANT BETTER

Use Short-Distance Physics observables as much as possible

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

SU(3) Breaking only

- Needed lattice info:EXCELLENT PROSPECTS FOR PRECISE DETERMINATION

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

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

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

(became possible only due significantly reduced error in B_K)

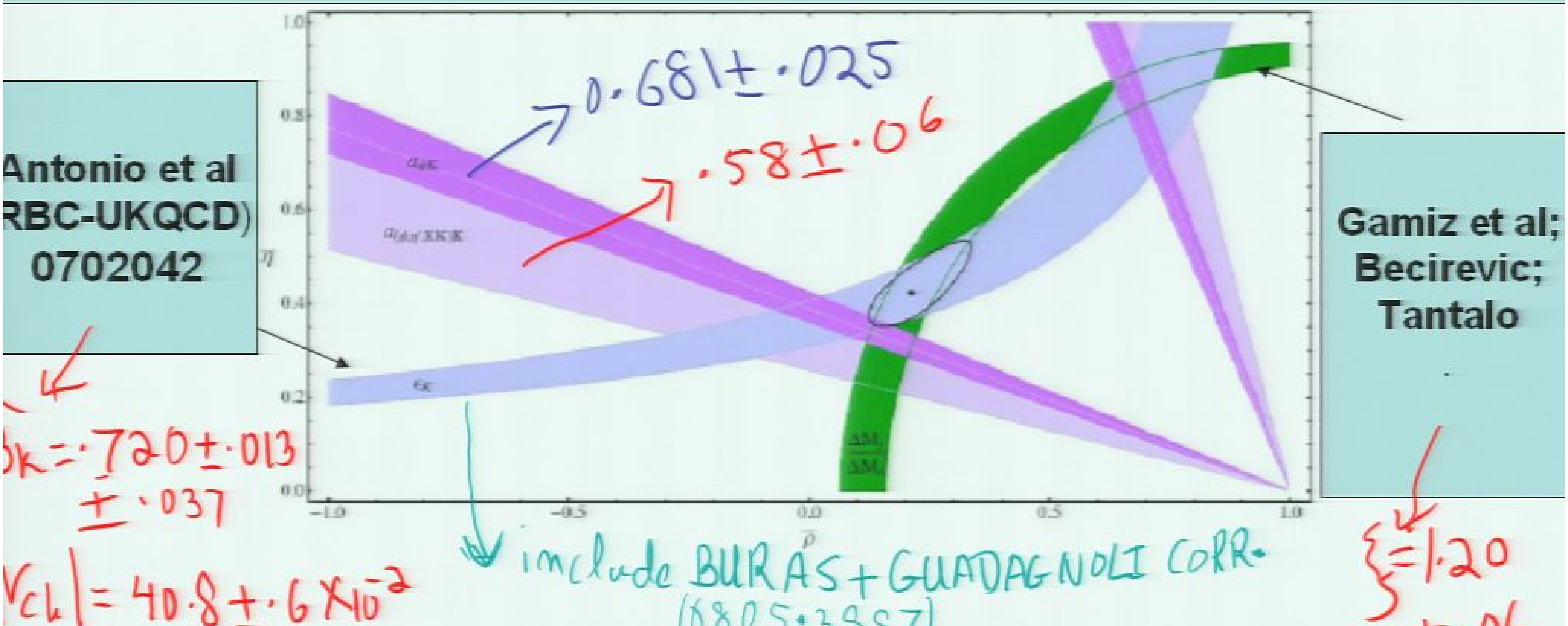


FIG. 1: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.. The solid contour is obtained using the constraints from ε_K and $\Delta M_{B_s}/\Delta M_{B_d}$. The regions allowed by $a_{\psi K}$ and $a_{(\phi+\eta'+2K_s)K_s}$ are superimposed.

$B_K = .720 \pm .013 \pm .037$

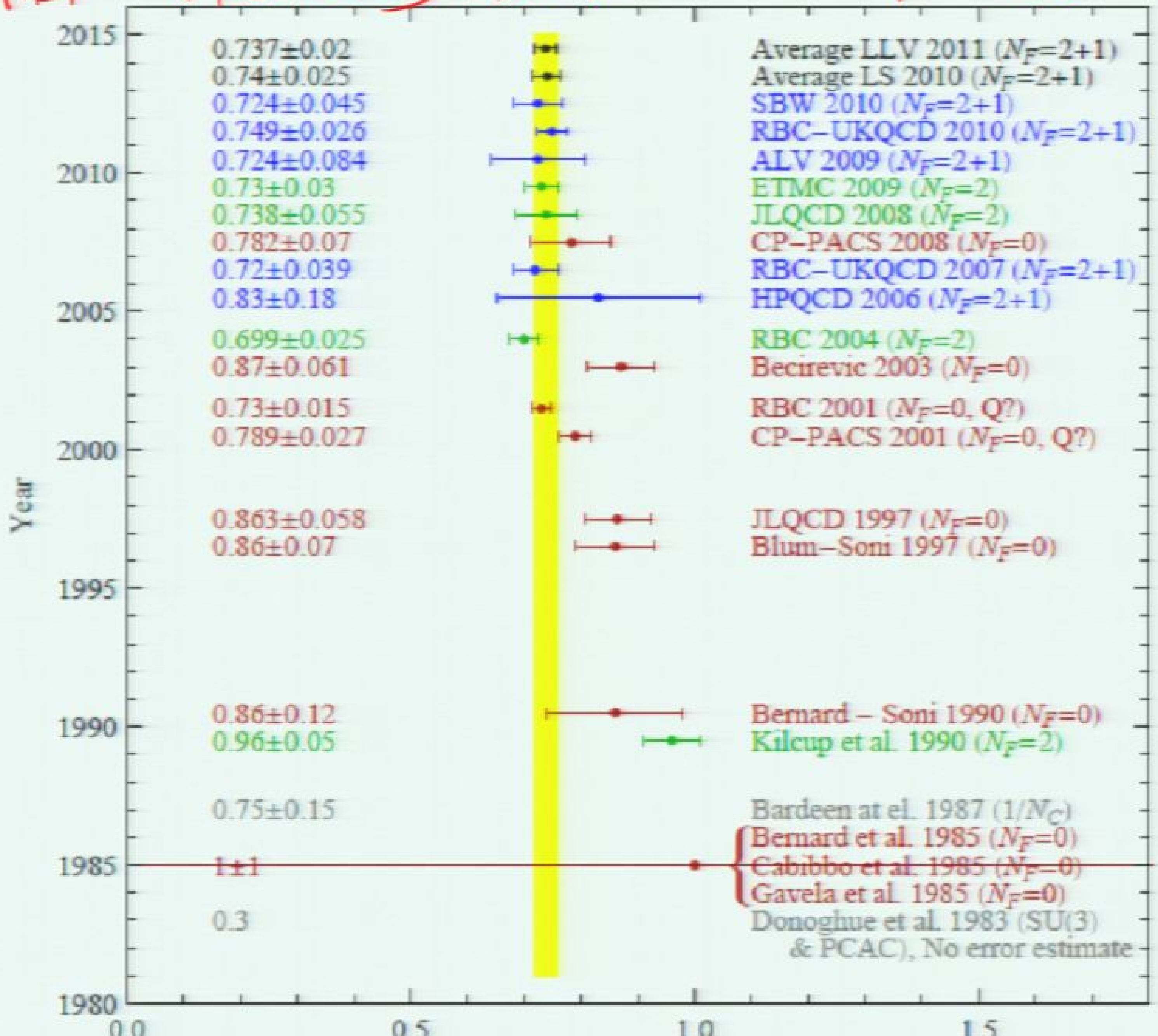
$|V_{cb}| = 40.8 \pm .6 \times 10^{-3}$

$\xi = 1.20 \pm .06$

2.1-2.7 σ- deviation from the directly measured values of sin 2 β

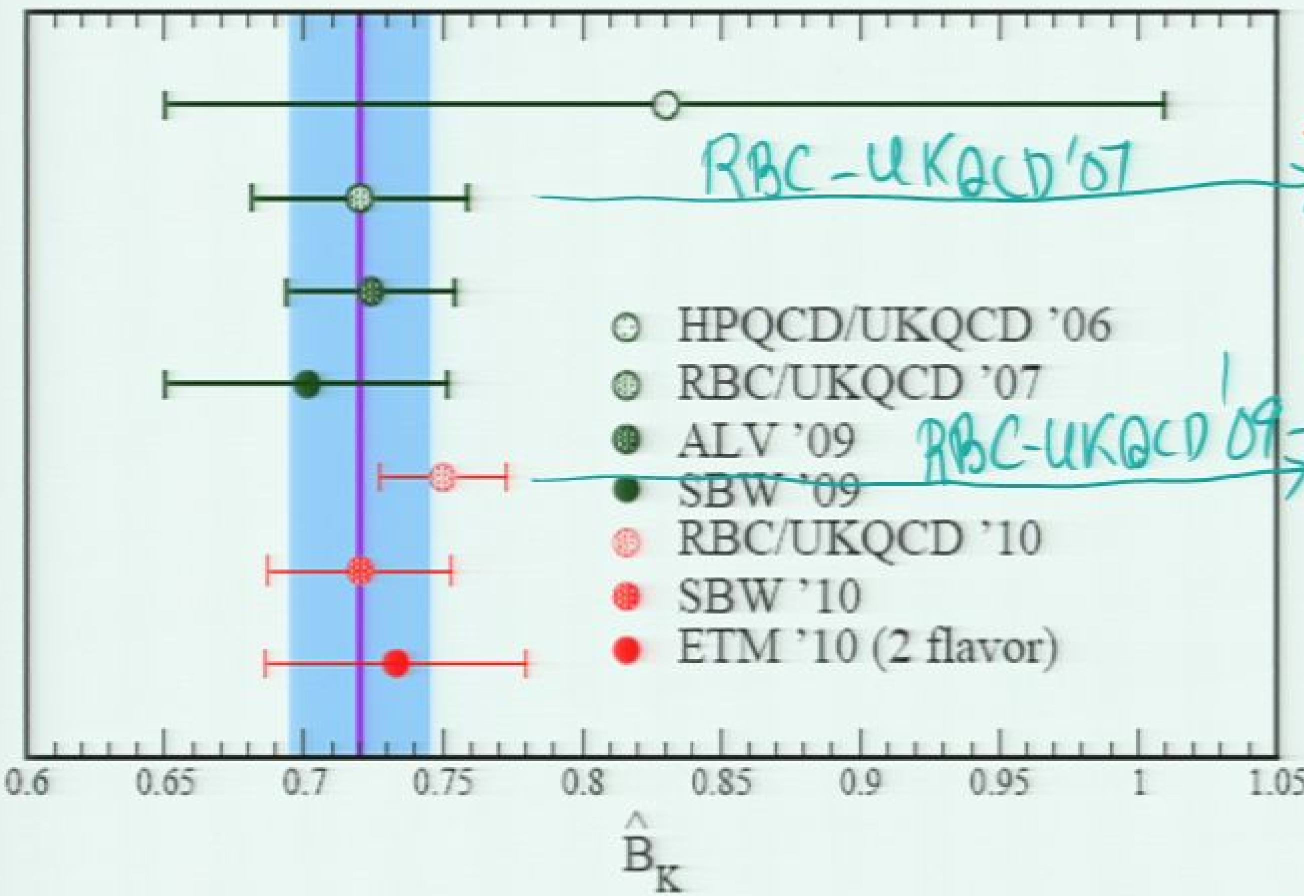
2010 UPDATE

A BRIEF (≃ 25 yrs) HISTORY OF B_K



B_K

Jack LAIHO @ LATTICE '10



USED by L&S '08

RBC-UKQCD '07 → 0.720 ± .013 ± .037

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

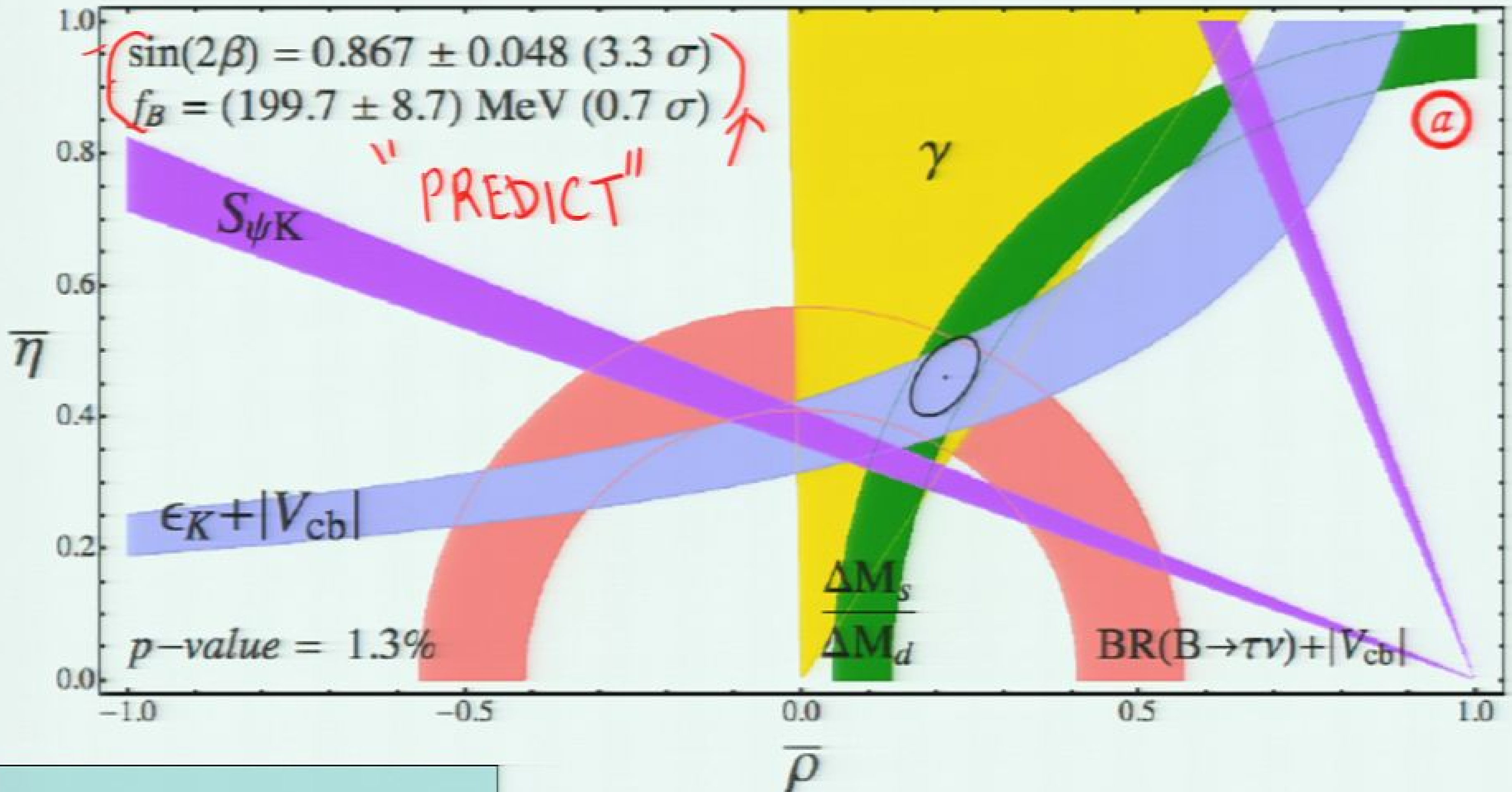
Total ERROR ~3.6%

NOW USE 0.740 ± .025

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

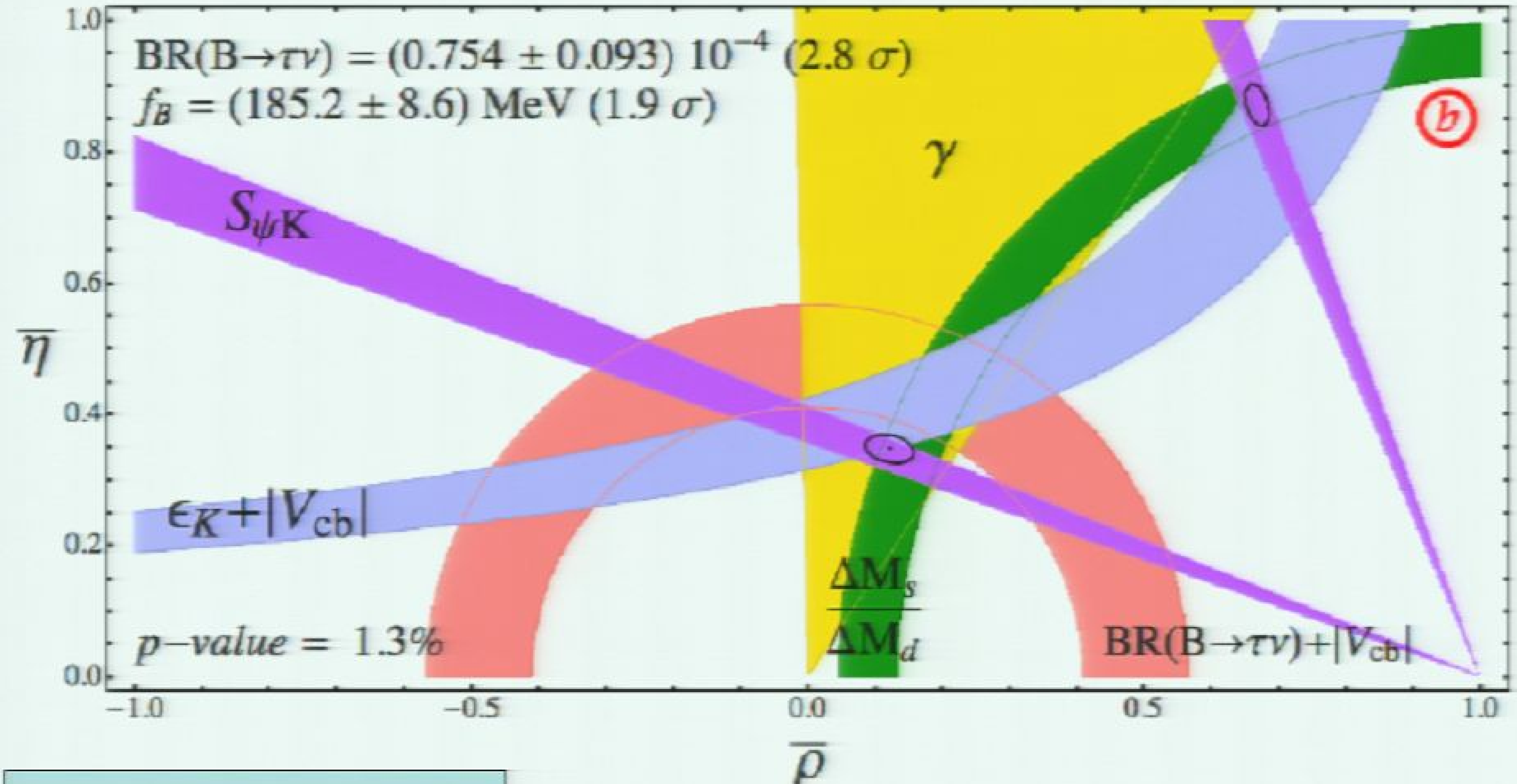
[a] Our value of f_B reflects the change in the overall scale (r_1) recently adopted by the Fermilab/MILC and HPQCD collaborations [29]

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



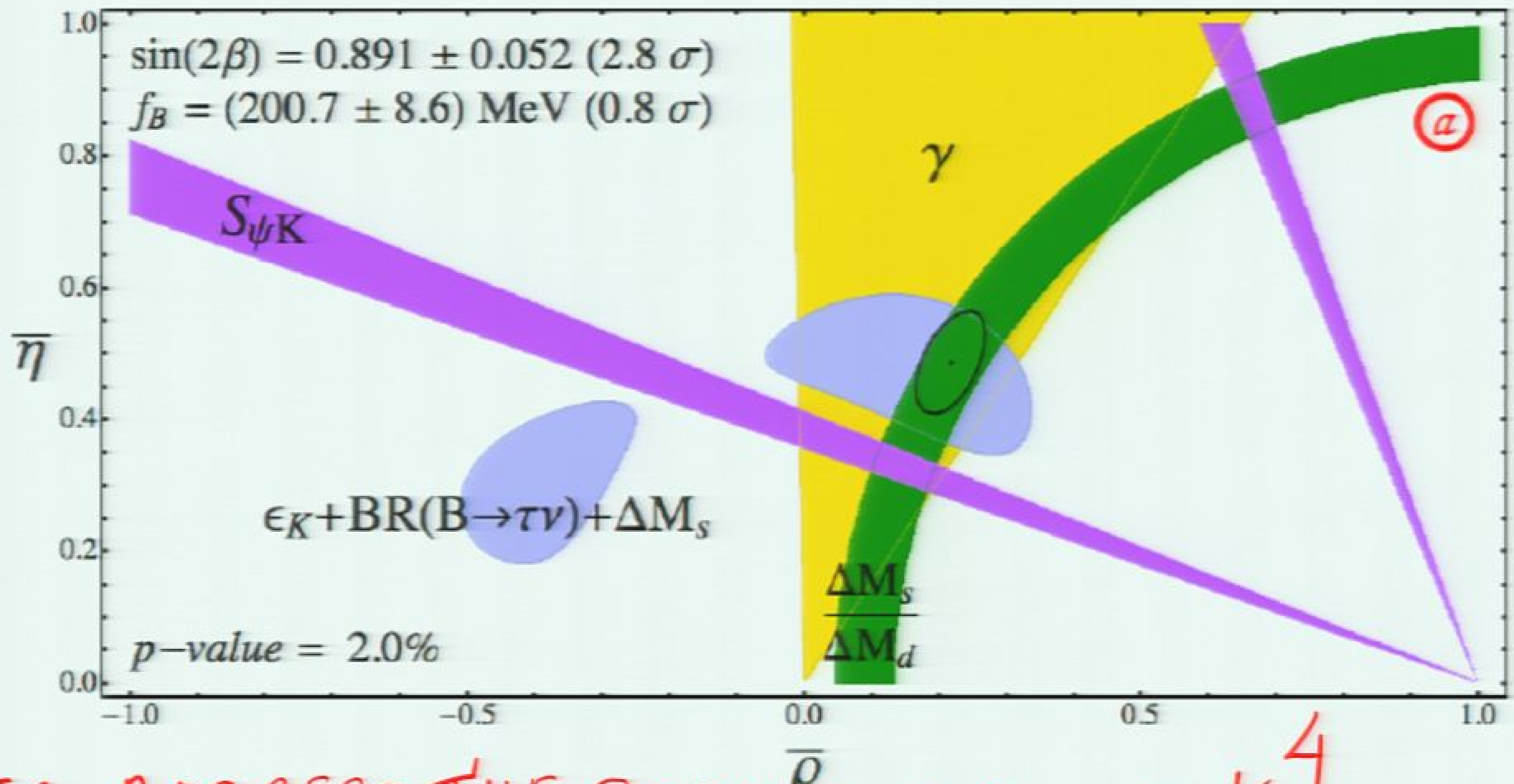
Predict sin2β & fB

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

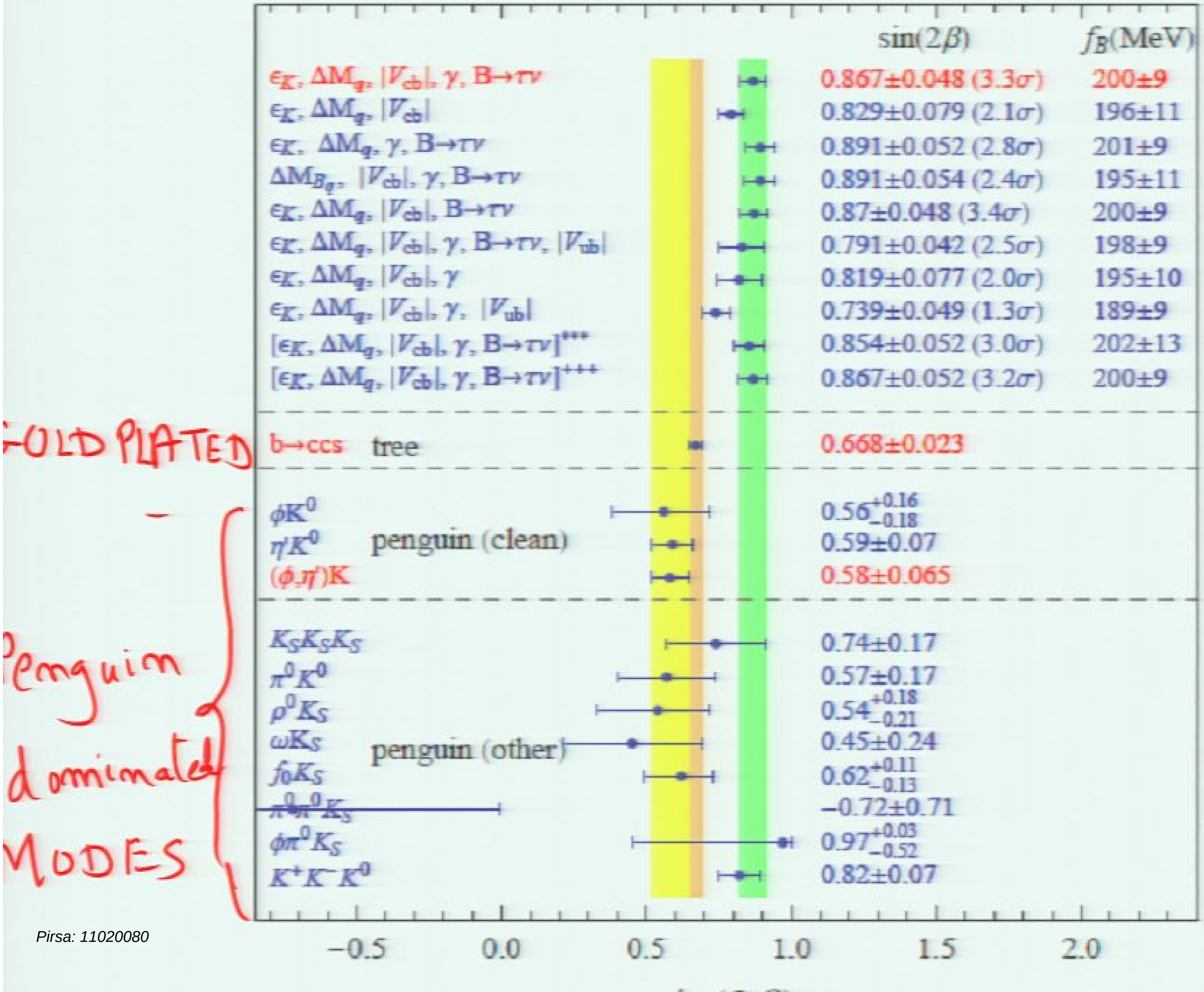


TO ADDRESS THE CONCERN: $\epsilon_K \sim V_{cb}^4$

DEVISE Method

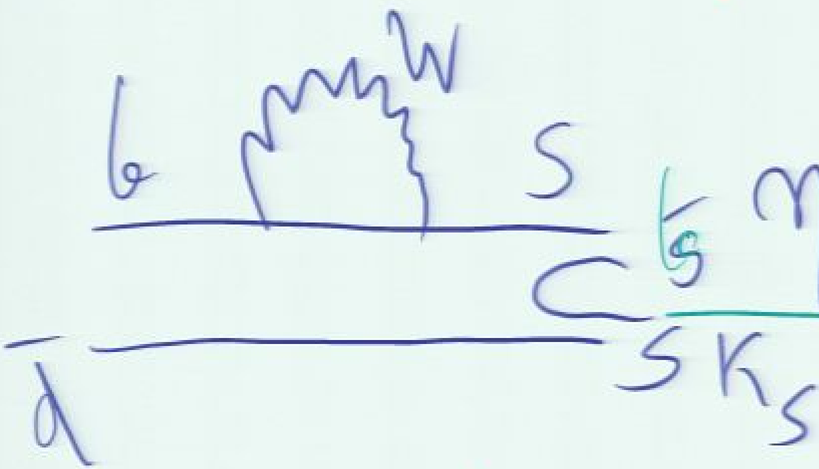
In a nutshell

- Bulk of NP effects in Bd,Bs mixing & in $\sin 2\beta$ {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

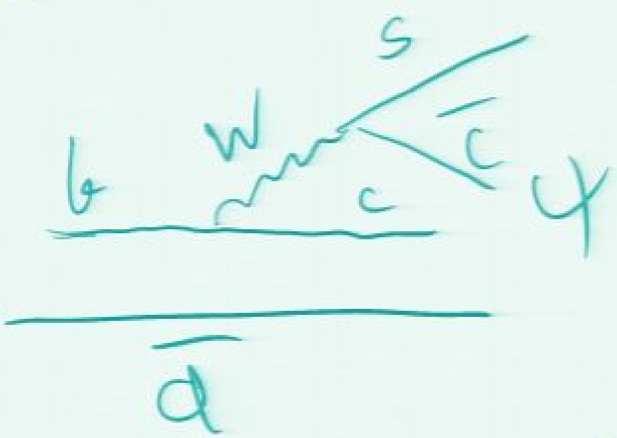


sin(2β)
f_B(MeV)
ϵ_K, ΔM_q, $|V_{cb}|$, γ, $B\to\tau\nu$ 0.867±0.048 (3.3σ) 200±9
ϵ_K, ΔM_q, $|V_{cb}|$ 0.829±0.079 (2.1σ) 196±11
ϵ_K, ΔM_q, γ, $B\to\tau\nu$ 0.891±0.052 (2.8σ) 201±9
ΔM_{B_q}, $|V_{cb}|$, γ, $B\to\tau\nu$ 0.891±0.054 (2.4σ) 195±11
ϵ_K, ΔM_q, $|V_{cb}|$, $B\to\tau\nu$ 0.87±0.048 (3.4σ) 200±9
ϵ_K, ΔM_q, $|V_{cb}|$, γ, $B\to\tau\nu$, $|V_{ub}|$ 0.791±0.042 (2.5σ) 198±9
ϵ_K, ΔM_q, $|V_{cb}|$, γ 0.819±0.077 (2.0σ) 195±10
ϵ_K, ΔM_q, $|V_{cb}|$, γ, $|V_{ub}|$ 0.739±0.049 (1.3σ) 189±9
$[\epsilon_K, \Delta M_q, |V_{cb}|, \gamma, B\to\tau\nu]^{***}$ 0.854±0.052 (3.0σ) 202±13
$[\epsilon_K, \Delta M_q, |V_{cb}|, \gamma, B\to\tau\nu]^{+++}$ 0.867±0.052 (3.2σ) 200±9
GOLD PLATED
b→ccs tree 0.668±0.023
ϕK^0 $0.56^{+0.16}_{-0.18}$
$\eta' K^0$ penguin (clean) 0.59±0.07
$(\phi,\eta')K$ 0.58±0.065
$K_S K_S K_S$ 0.74±0.17
$\pi^0 K^0$ 0.57±0.17
$\rho^0 K_S$ $0.54^{+0.18}_{-0.21}$
ωK_S penguin (other) 0.45±0.24
$f_0 K_S$ $0.62^{+0.11}_{-0.13}$
$\pi^0\pi^0 K_S$ −0.72±0.71
$\phi\pi^0 K_S$ $0.97^{+0.03}_{-0.52}$
$K^+K^-K^0$ 0.82±0.07
Penguin dominated MODES
−0.5 0.0 0.5 1.0 1.5 2.0

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



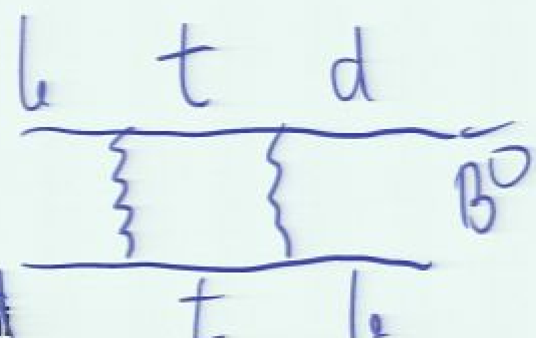
$$S^{Decay}_{peng} \simeq O(\lambda^2) \sim few\,\%$$



$$S^{Decay}_{\psi K_s} = 0$$

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

OSC is B^0



Main Conclusion (I) of '10 analysis

- Measured value of sin2 beta via S(ψKs) is smaller than SM expectations by ~3.3 sigma

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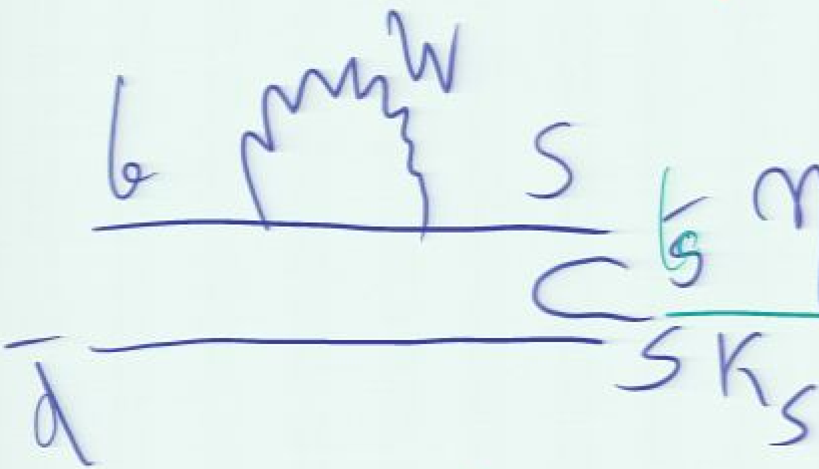

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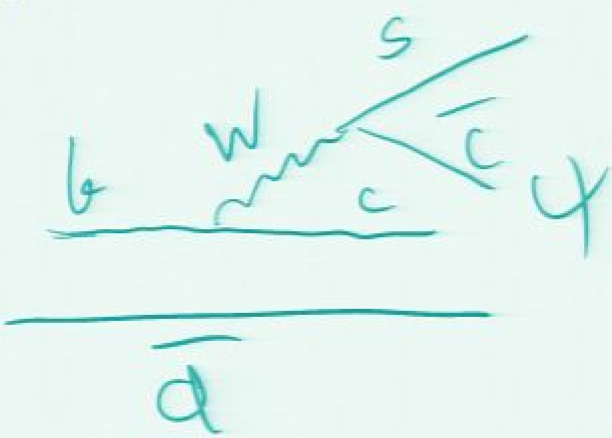

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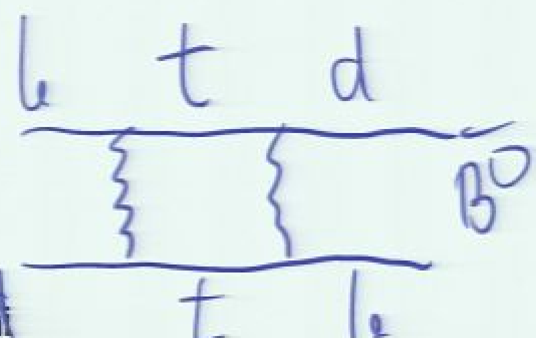

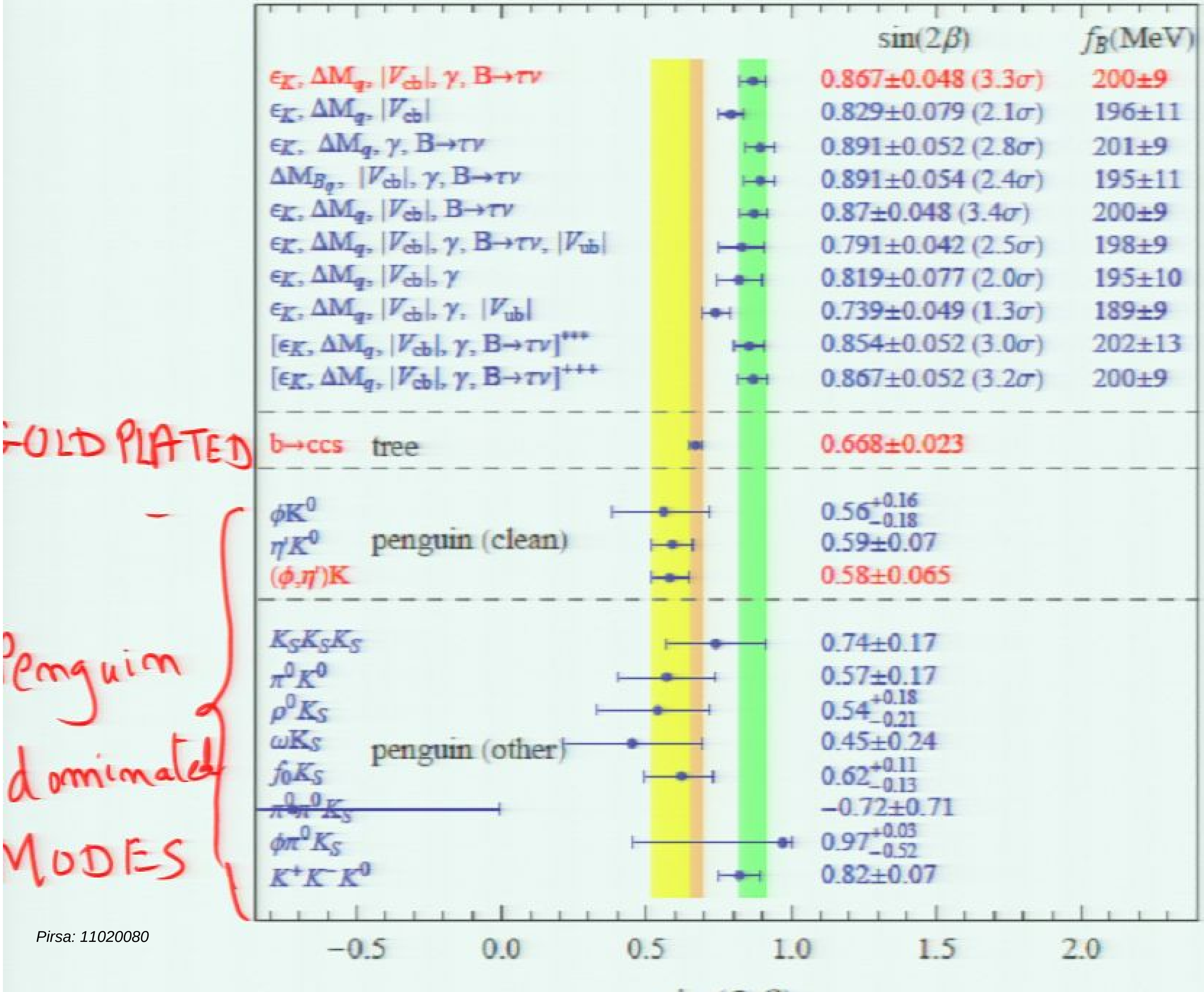
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K^+ K^− K^0 0.82±0.07
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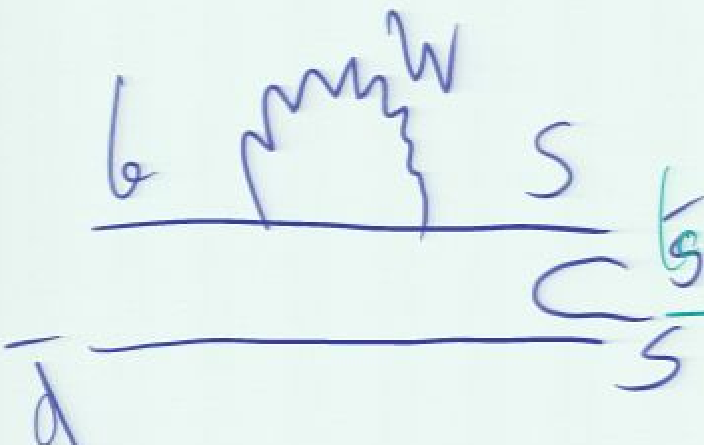
0.0
0.5
1.0
1.5
2.0

25

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



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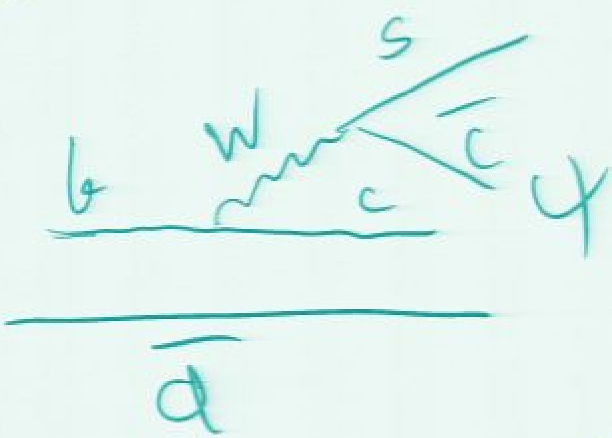

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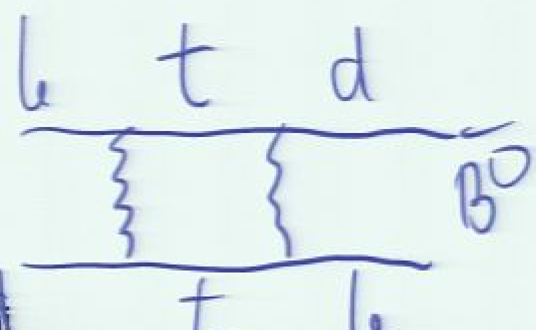

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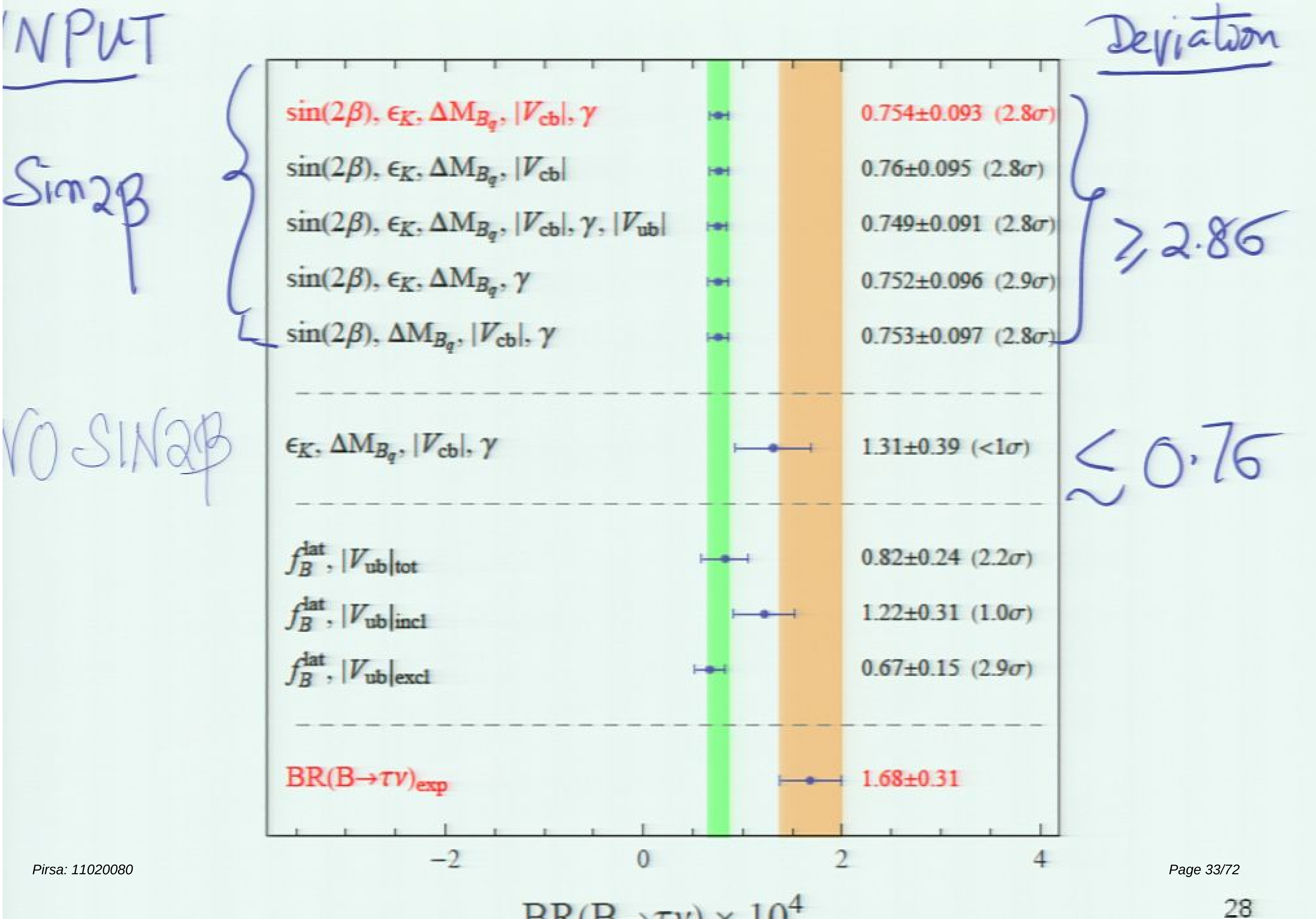
- Measured value of sin2 beta via S(ψKs) is smaller than SM expectations by ~3.3 sigma


INPUT
Deviation
Sin2β
sin(2β), ϵK, ΔMBq, |Vcb|, γ
0.754±0.093 (2.8σ)
sin(2β), ϵK, ΔMBq, |Vcb|
0.76±0.095 (2.8σ)
sin(2β), ϵK, ΔMBq, |Vcb|, γ, |Vub|
0.749±0.091 (2.8σ)
sin(2β), ϵK, ΔMBq, γ
0.752±0.096 (2.9σ)
sin(2β), ΔMBq, |Vcb|, γ
0.753±0.097 (2.8σ)
≳ 2.86
NO SIN2β
ϵK, ΔMBq, |Vcb|, γ
1.31±0.39 (<1σ)
≲ 0.76
fB lat, |Vub|tot
0.82±0.24 (2.2σ)
fB lat, |Vub|incl
1.22±0.31 (1.0σ)
fB lat, |Vub|excl
0.67±0.15 (2.9σ)
BR(B→τν)exp
1.68±0.31
−2
0
2
4
BR(B→τν) × 10^4
28

Conclusions (II)

- 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

III. IMPLICATIONS

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 $K_L \to \pi^+ \pi^-$ 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 ?

Christenson, Cronin, FITCH + TURLAY BNL '64

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!!

LESSON FROM HISTORY

DRELL-YAN @ its INFANCY!

The BIGGEST MISNOMER

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

Lederman Reaction

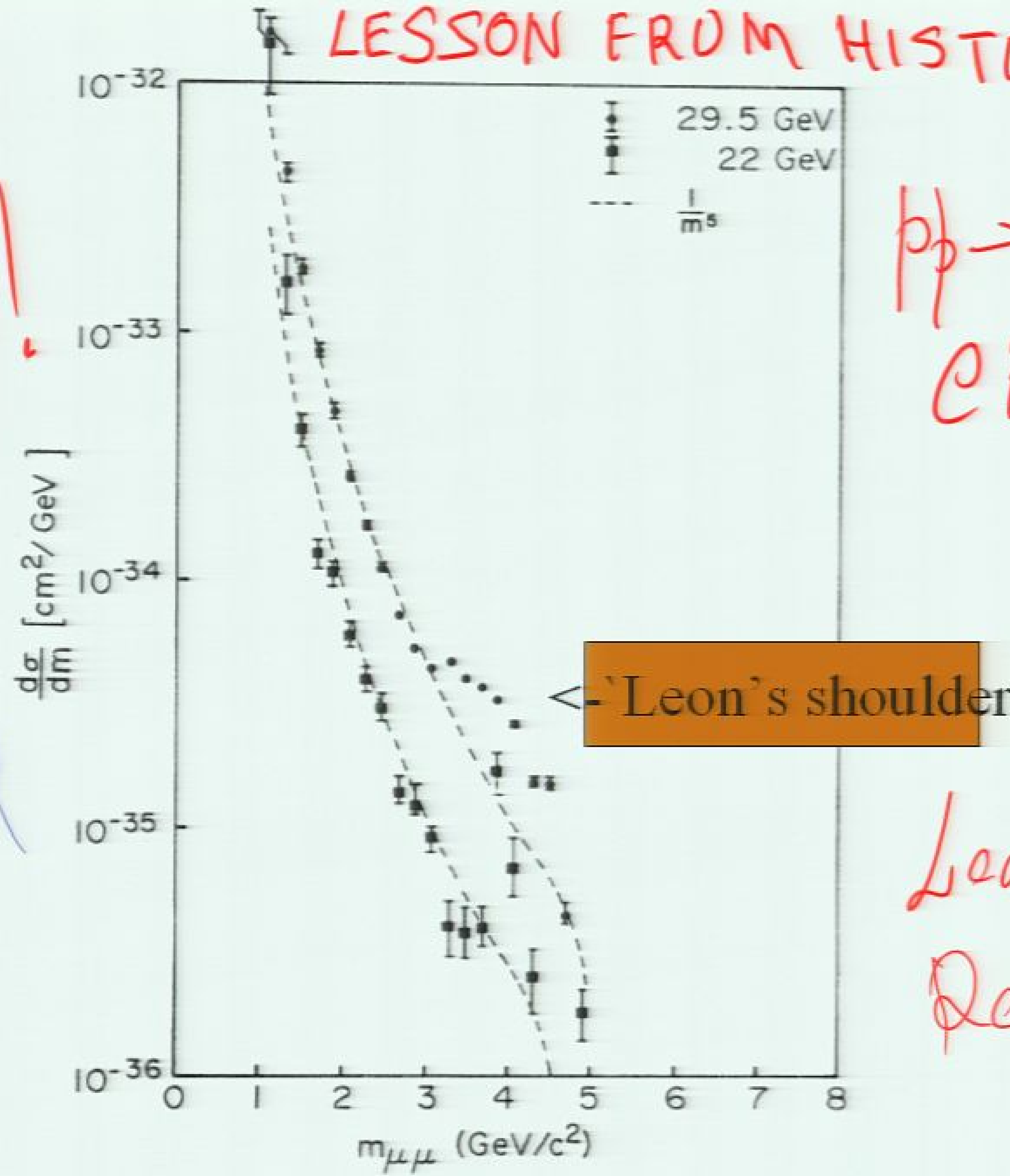


FIG. 15. Experimental cross sections at two energies compared with a simple $1/m^5$ continuum.

Leon Lederman

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2nd

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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

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

GREAT NEWS 4 LHC, LHCb & for SBF!

C also UTFit:0707.0636

For LR case enhancement noted long ago, See Beall, Bander and A.S.

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 ...?

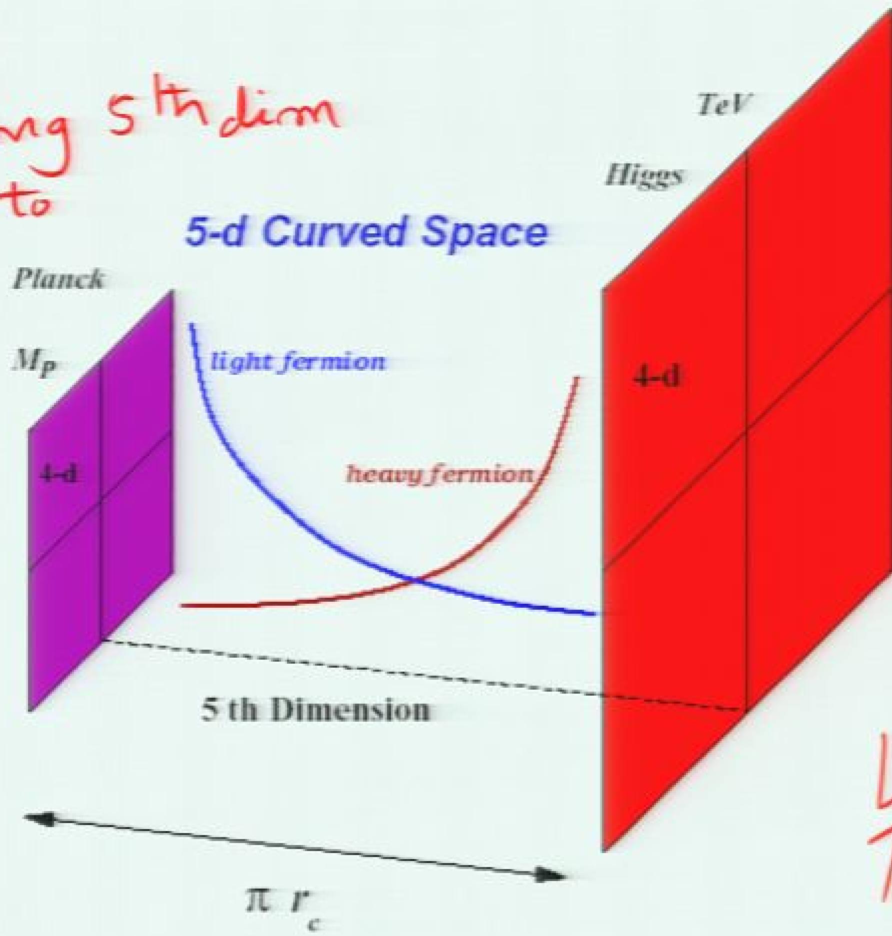
SM4

MAY B LINKED DUE DUALITY

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 ← $\langle H_4\rangle$; $\langle H_5\rangle$ → M_P

$$\sigma = k r_c \pi$$

$k r_c \sim 12$

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

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

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

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

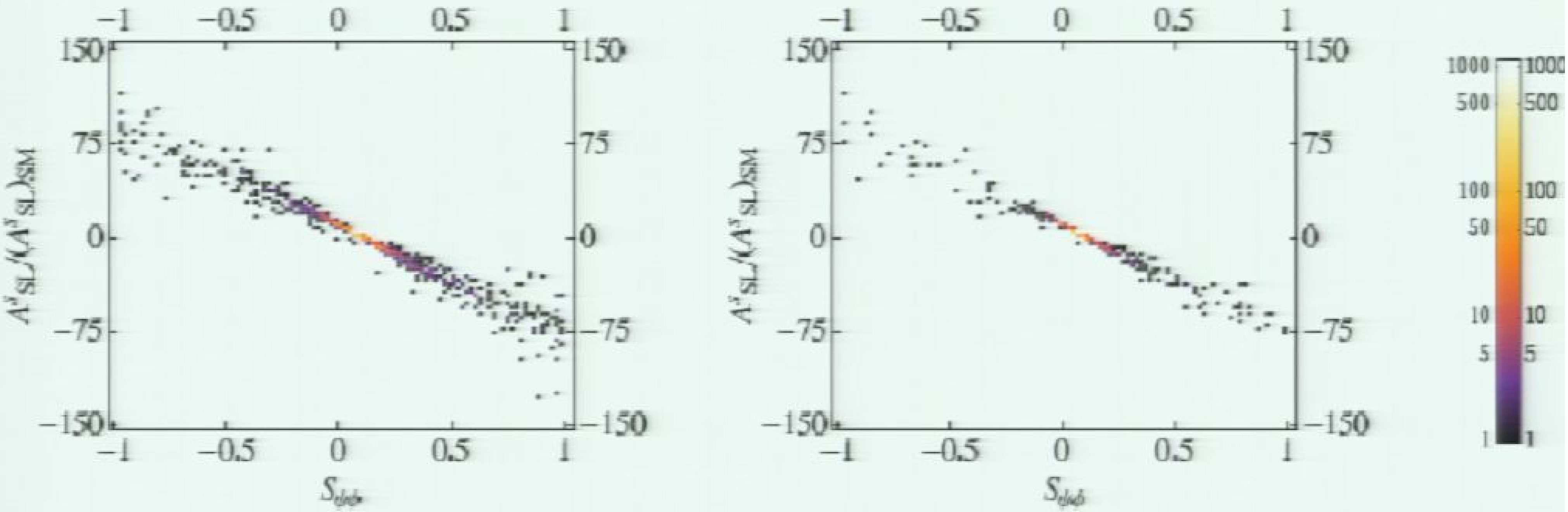


Figure 7: *left:* A^s_{SL}, *normalised to its SM value, as a function of* $S_{\psi\phi}$. *In addition t the requirement of correct quark masses and CKM mixings, also the available* $\Delta F = $ *constraints are imposed. right: The same, but in addition the condition* $\Delta_{BG}(\varepsilon_K) <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

DØ ANOMALY

COMPARISONS

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

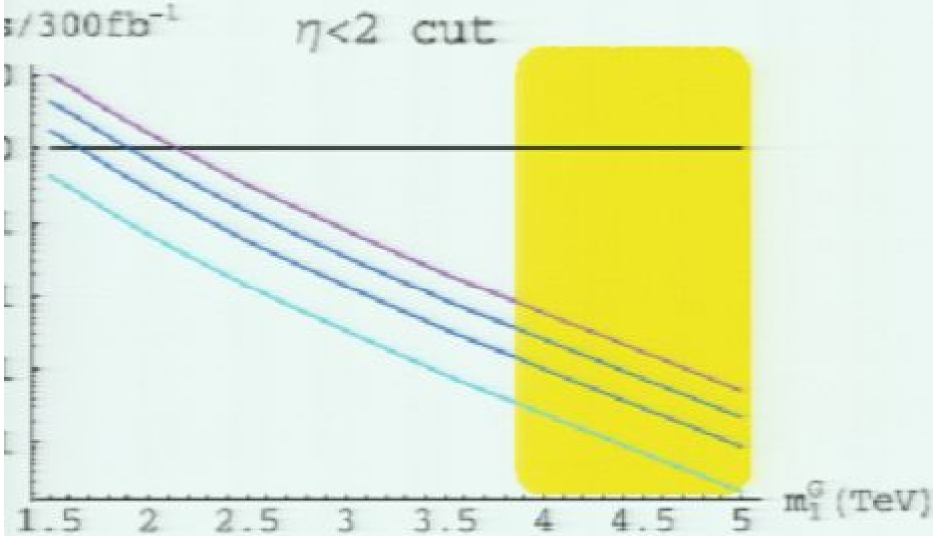
SIGNIFICANT DIFFERENCES

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

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

... EILAM, MELIC, TRAMPETIC '0909.3227

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



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

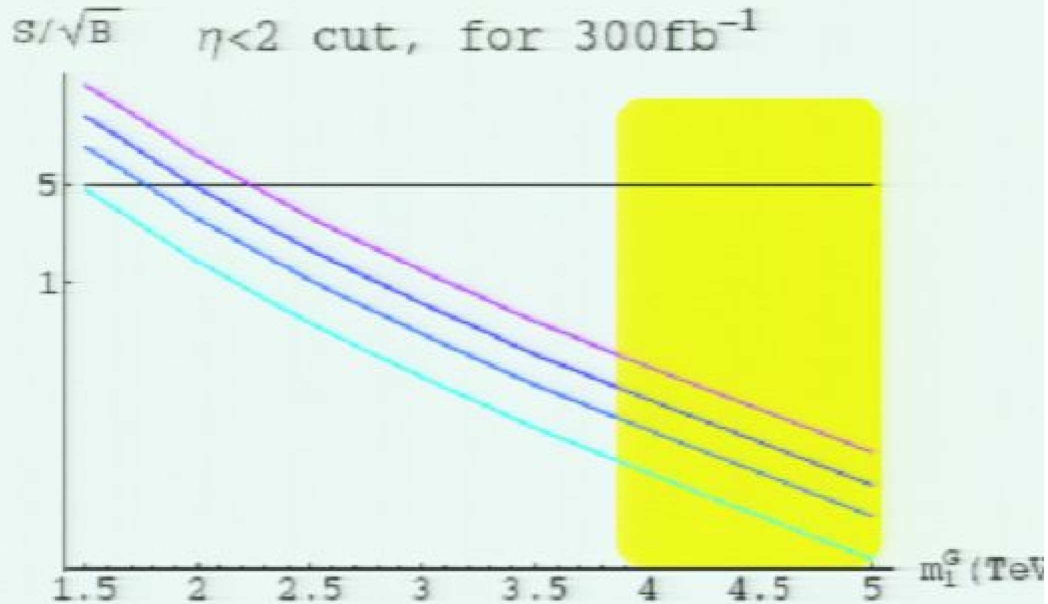


FIG. 5 (color online). Same as Fig. 4, but with $\eta < 2$.

GRAVITON @ LHC

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?

Let's B Modest

Perimeter, 2/18/1

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

Little Radian Signals

- Effective Langrangian:

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

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

(No brane kinetic terms) Csáki, Hubisz, Lee, 2007 ⇒ 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

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

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

SM4: 4 Gen. standard model

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

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

CIRCA 1989 (UCLA)

1st ~1987

Motivation

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

SM4 significantly facilitates baryogenesis compared to SM3

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

$$(m_t^2/m_c^2)(m_t'^4/m_t^4)(m_b^2/m_s^2)(m_b'^4/m_b^4) \approx 10^{16}$$

May be the best reason

- My license plate: udcstbgz (since '89 NY)

- Used to be OSCILL8 (before '89 in CA)

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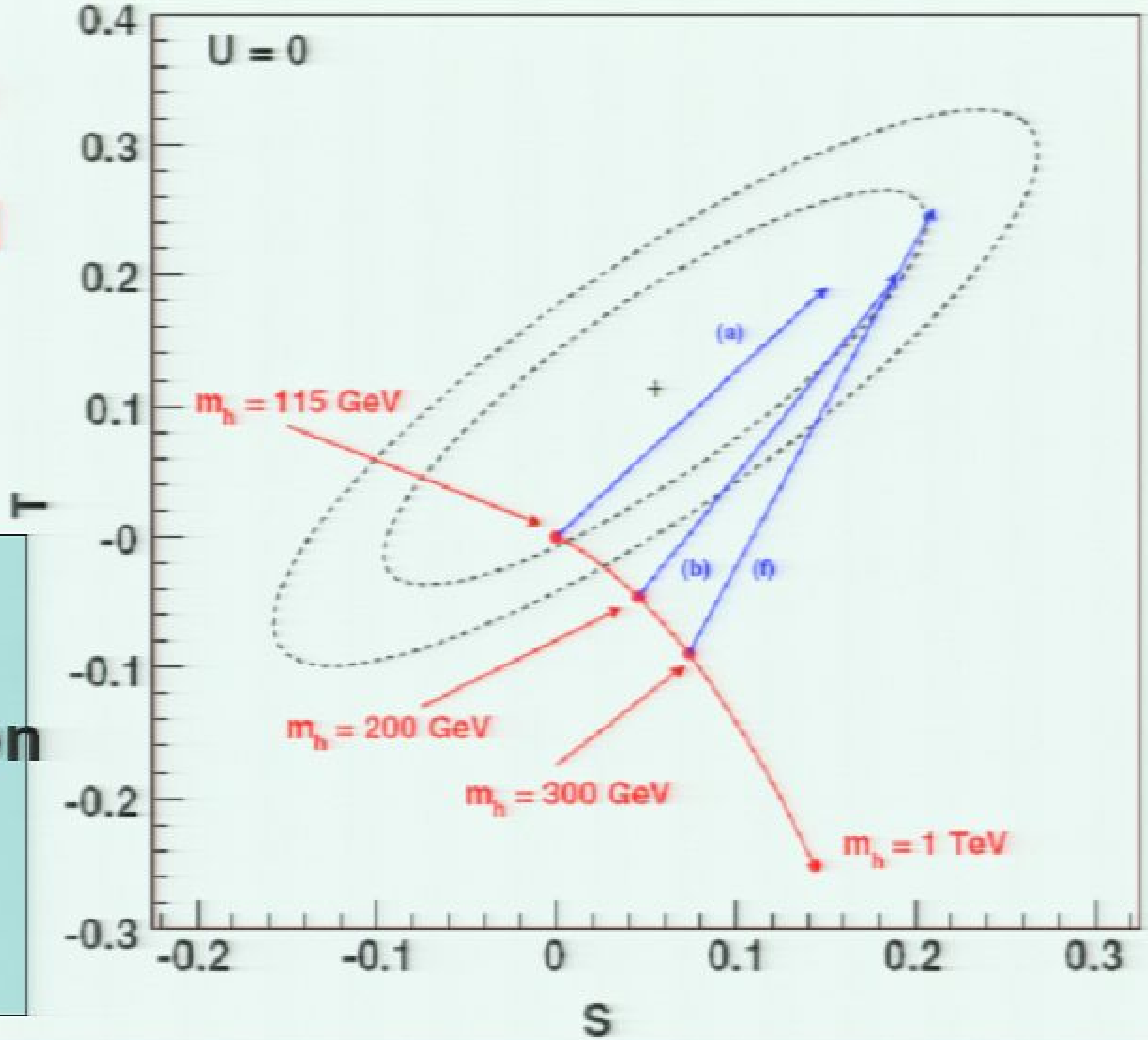
Knibs, Plehn, Spannowsky & Tait, PRD '07

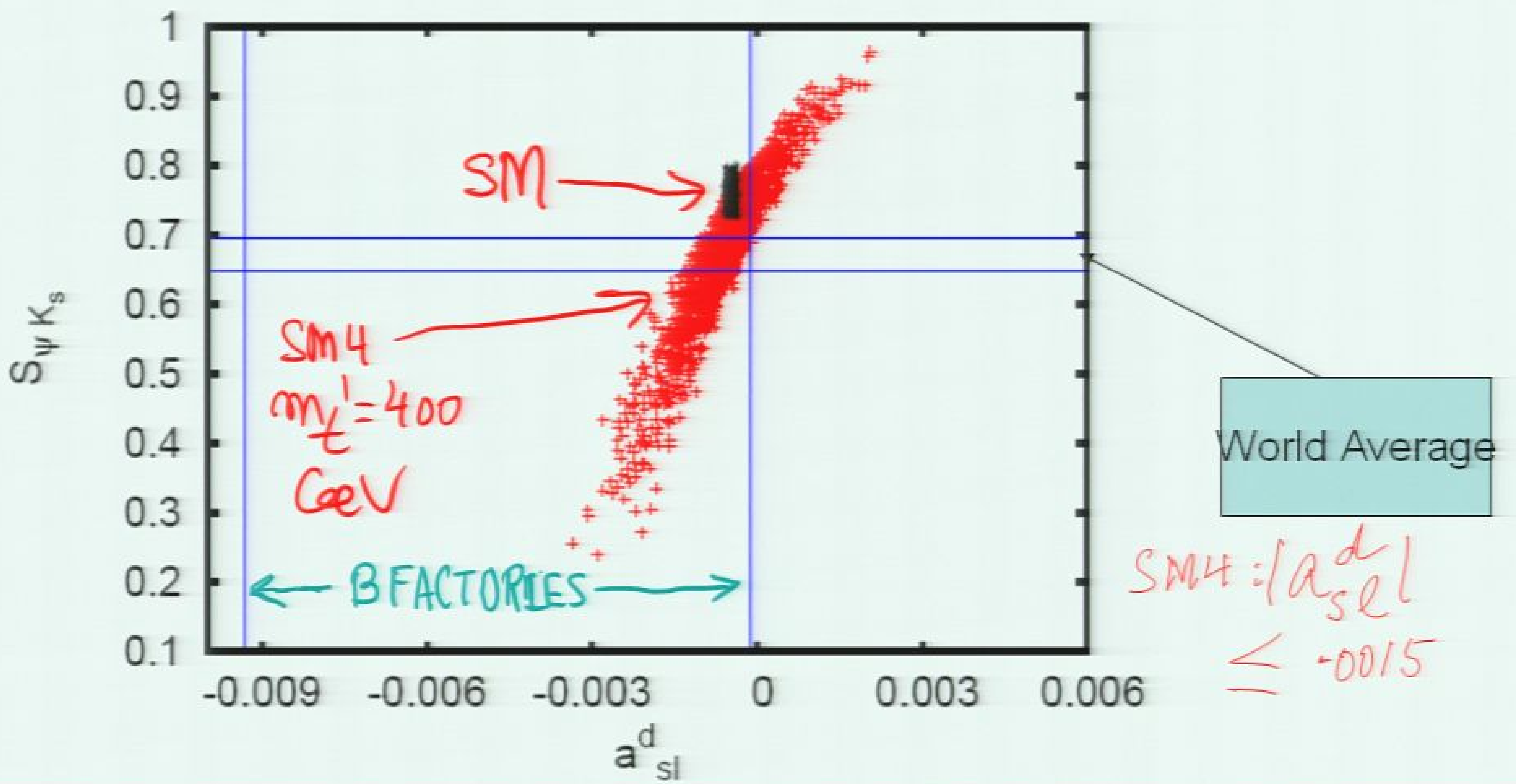
LEP EW constraints on $m_{t'}$, $m_{b'}$, m_H



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

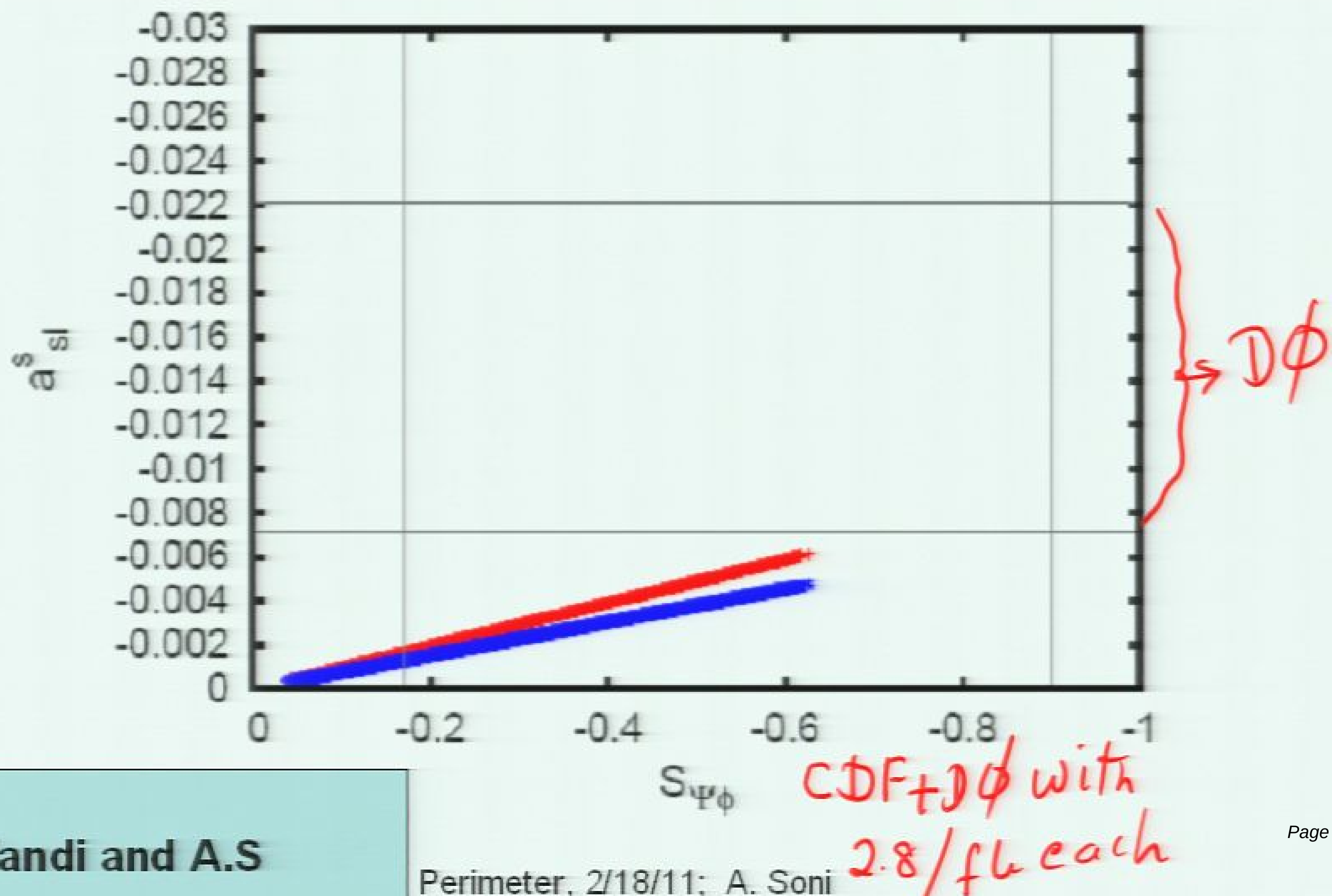
4^{th} family is not inconsistent with LEP EWPC
See also M. Chanowitz, arXiv:0903.3570; 1007.0043; Erler abd Langacker 1003.3211

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



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

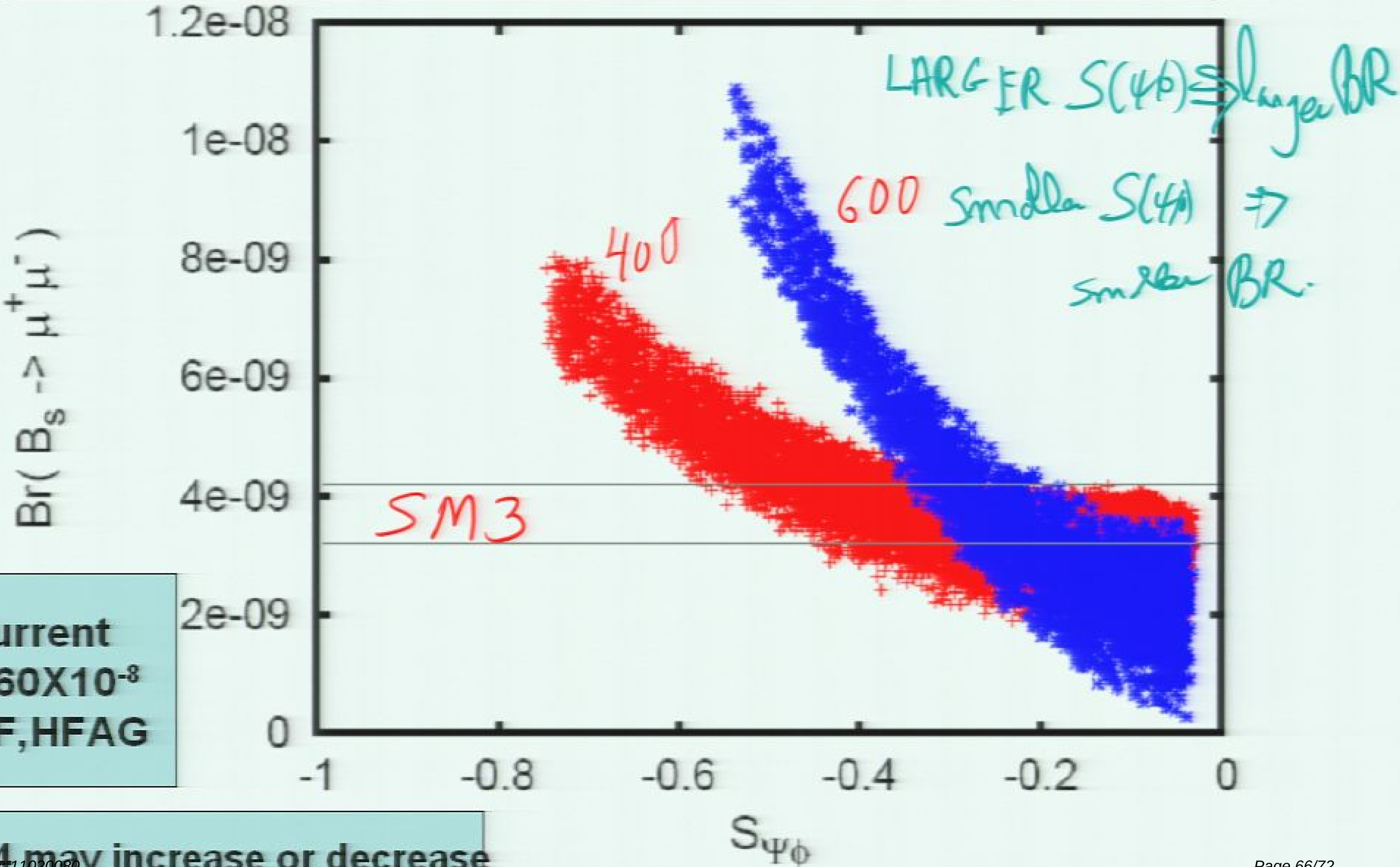
Recent D0 result is vertical axis and combined D0, CDF each For SM4 error on Delta_Gamma_s is increased by a factor of two resulting in ~50% increase in a_sl^s



S.Nandi and A.S

Perimeter, 2/18/11; A. Soni

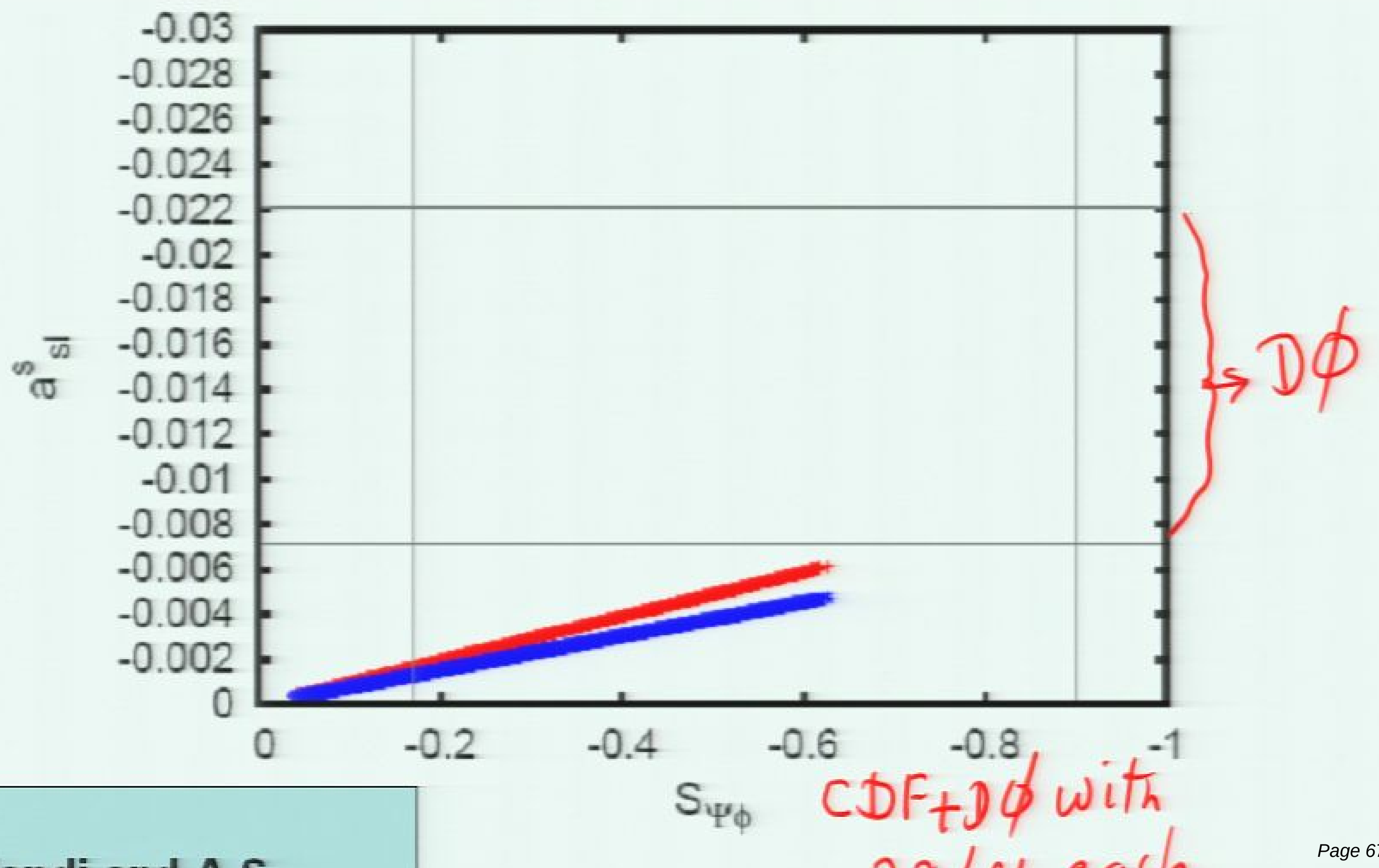
Br(Bs->μμ): a very clean process



Current
$<3.60 \times 10^{-8}$
CDF,HFAG

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

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

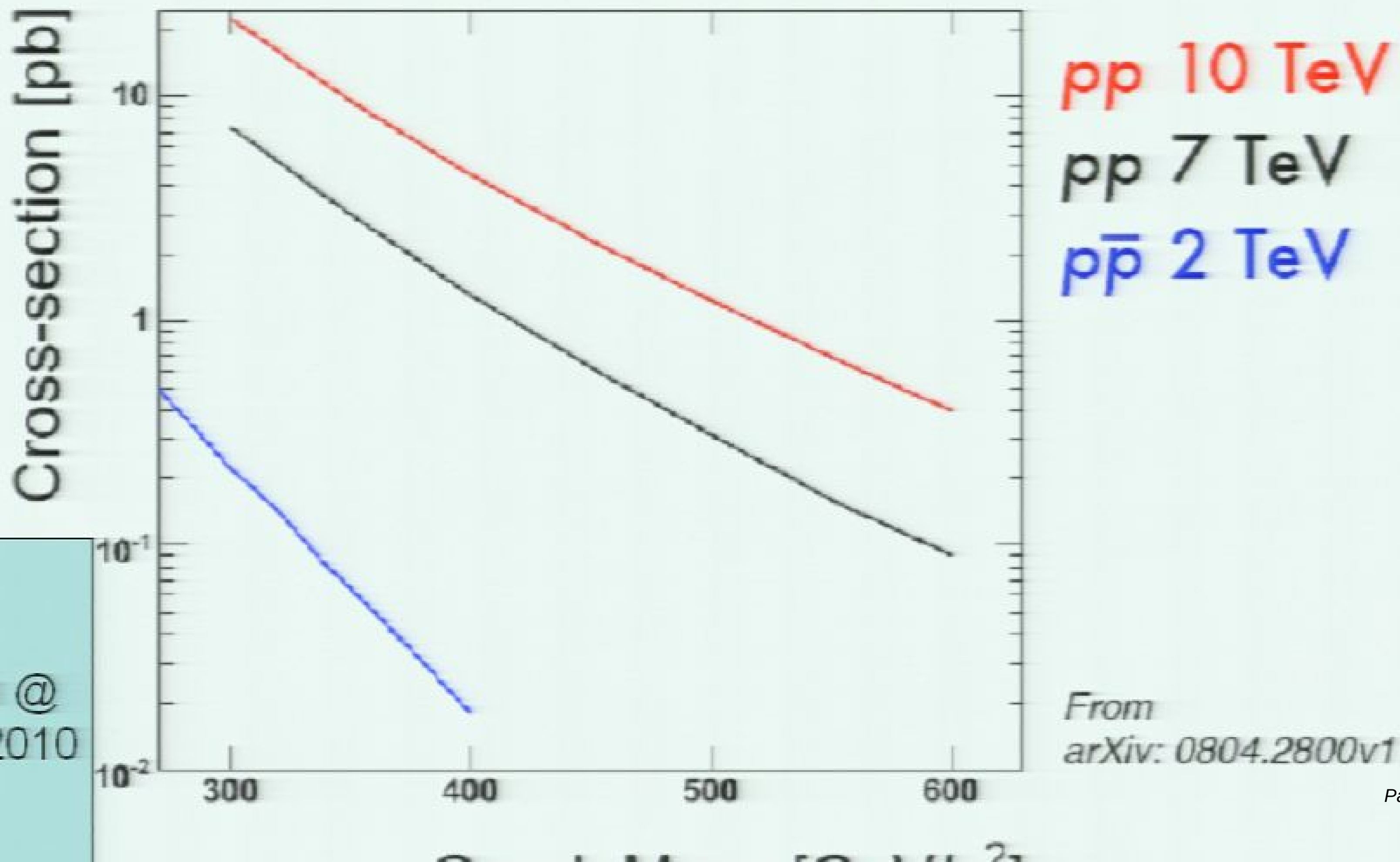


S.Nandi and A.S

Perimeter, 2/18/11; A. Soni

Cross-sections

LHC has much larger rates for heavy quarks

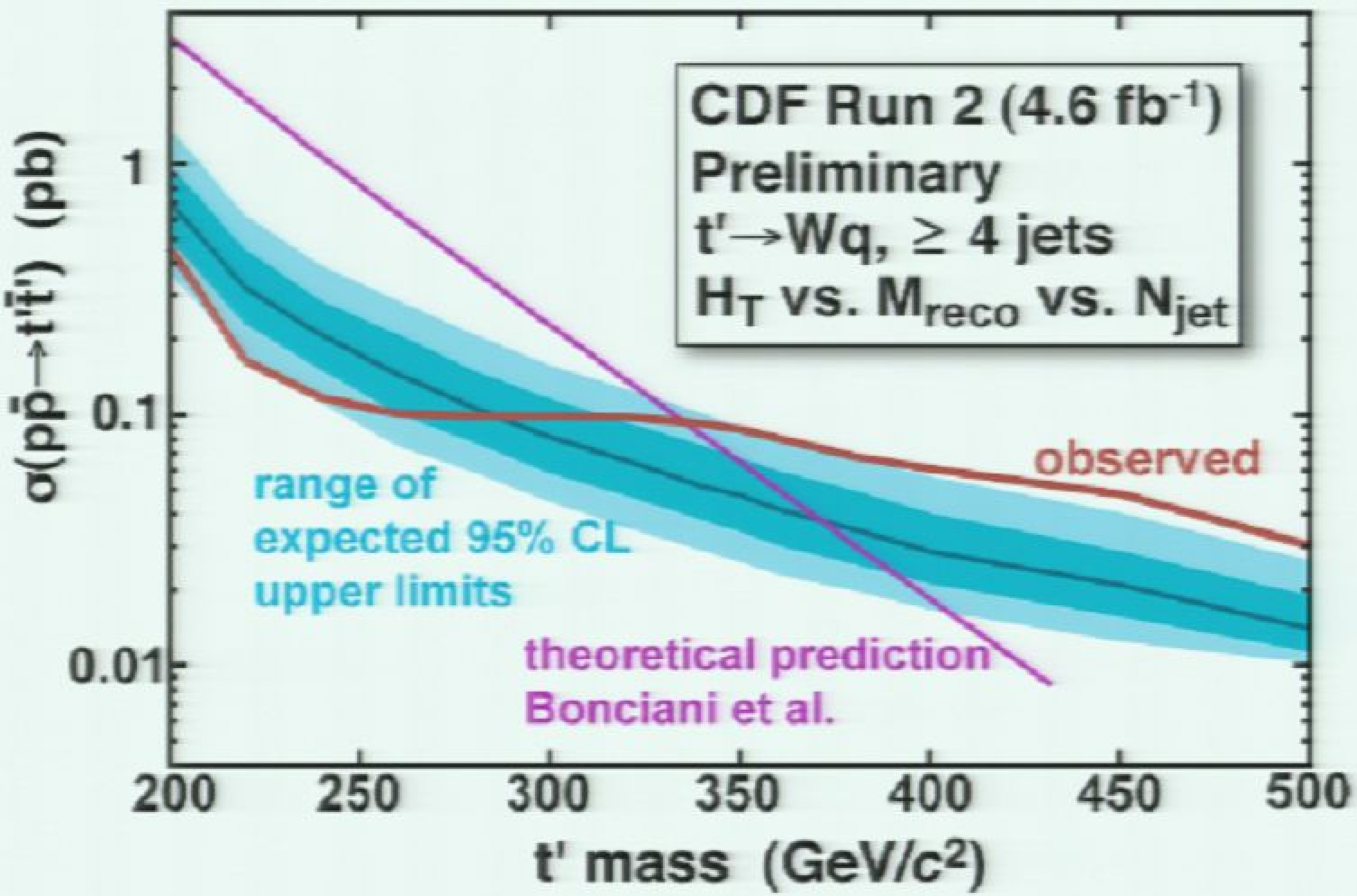


From
arXiv: 0804.2800v1

Whiteson @
NTU Jan2010

t′ limit curve

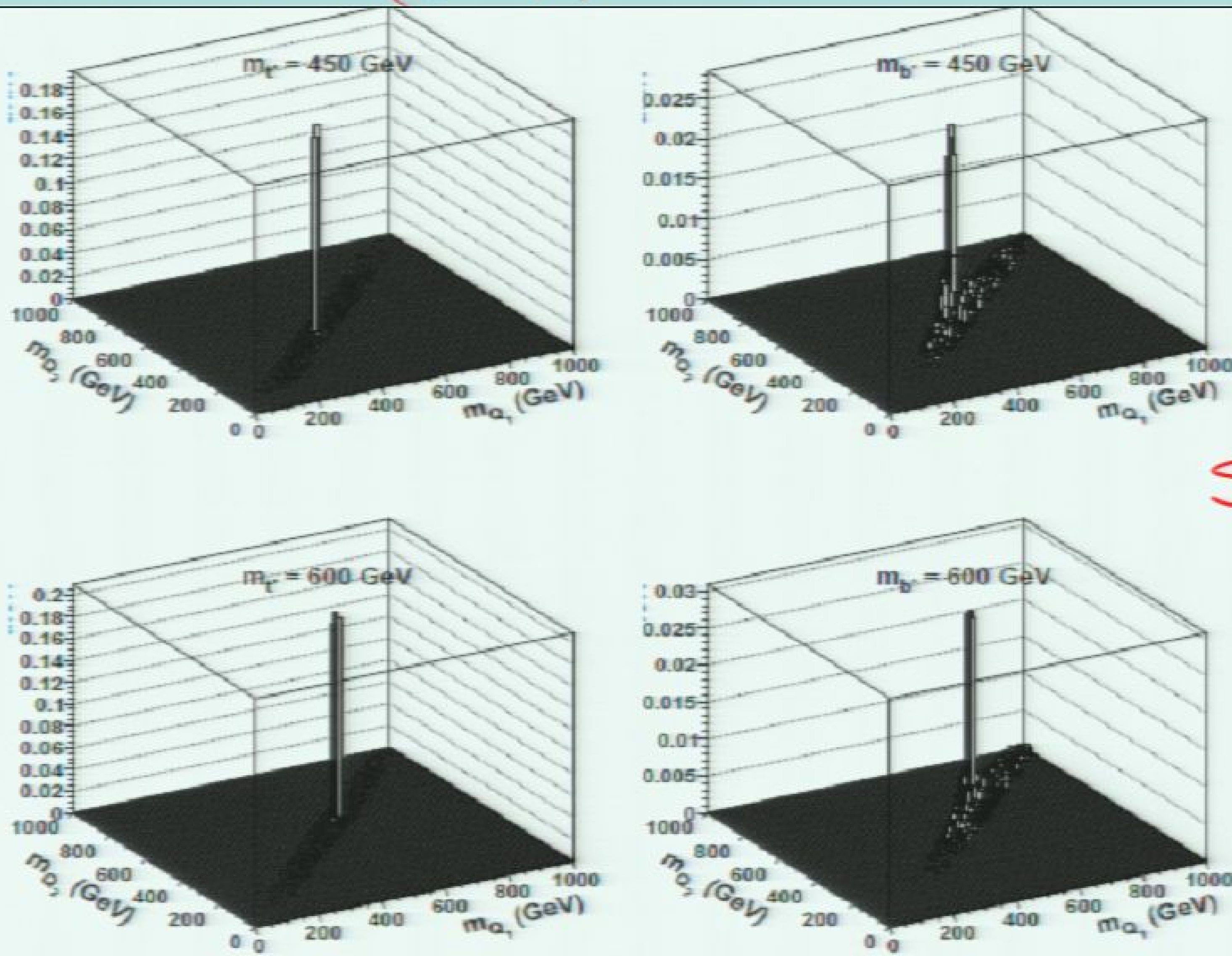
Conway@BF2010: CDF with 4.6 /fb now



m(t′) > 335 GeV at 95% CL

Detection of 4gen quarks at hadron colliders: David Atwood, Sudhir Gupta &A. Soni

(WIP)

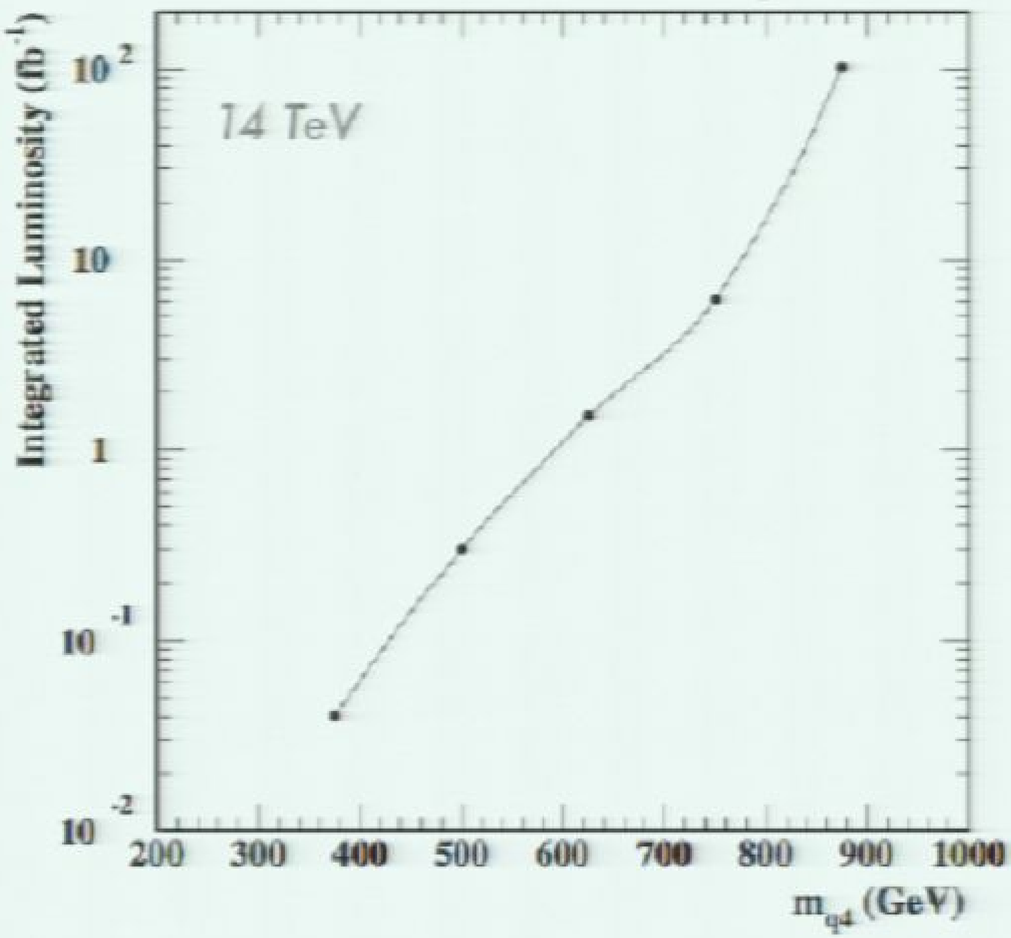


SINGLE Lepton Sample

FIG. 4: 2D histogram for reconstructed $Q_h(Q_2)$ and $Q_\ell(Q_1)$ from single lepton signal after selecting events. Left plot is for t' and

Sensitivity

5σ discovery



Whiteson@NTU,Jan2010

From ATLAS SN-ATLAS-2008-069

Summary & Outlook

- Though CKM works ~O(20%) accuracy, directly measured sin2β is small compared to SM prediction by ~ 3 σ. dev..
- DOMINANT deviation seems to originate in Bd,Bs mixing, Bd->psi Ks, and NOT in ε_K or B->tau nu
- 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, though SM4 offers a rather simple explanation…
- More accurate results from Tevatron, LHCb, SBFs should be very valuable.
- Direct searches at LHC should clarify matter significantly POSSIBLE EARLY NEW PHYSICS if mt';mb' ~500 GeV