Summary: Highlights & Prospects

Amarjit Soni

HET, BNL

"Second Workshop on Beyond 3 Generation Standard Model --- New Fermions at the Crossroads of Tevatron and LHC "

NTU,Taipei(Jan14-16,2010)

Scope of the NTU Wrkshp

- **Highlights of CERN Wrkshp: Unel**
- **DEWSB& barogenesis: Holdom, PQ, Gerhard,Kikukawa,Hashimoto, Bar-Shalom**
- **Possible cracks in CKM(SM): Punzi,Zieminska,Nandi, Lacker, Nakao,CYMa,Musy, FFLee**
- **EWPConstraints:Plehn, Ozcan, Antipin**
- **CKM constraints: Lenz, Lacker,CYMa,Nandi**
- **FCNC &CP: Arhrib, CHShen, Nebot, Bashiry**
- **Direct Searches (quarks):Whiteson,Bose,Plehn,Ozcan**
- **Direct Searches: Leptons:Antipin, Ozcan**
- **Dark Matter: Alwall**
- **Vector-like /isosinglet quarks: Branco, Nebot**
- **4^{th} Gen @SuperB/BelleII: Paoloni,PChang**

Sincere apologies for omissions, likely to be many despite considerable efforts

Outline

- The scope
- Prologue
- A Renaissance: may be joyous?
- Possible cracks in CKM?
- Prospects for settling the cracks.
- How much room is there?
- Indirect searches
- Direct searches
- DEWSB/Composite Higgs
- The Epilogue:Challenging Yogi

UNEL

Four Statements about the Fourth Generation

1)The fourth generation (SM4) is not excluded by EW precision data.
2)The SM4 addresses some of the currently open questions.
3)The SM4 can accommodate emerging possible hints of new physics.
4)LHC has the potential to discover or fully exclude the SM4.

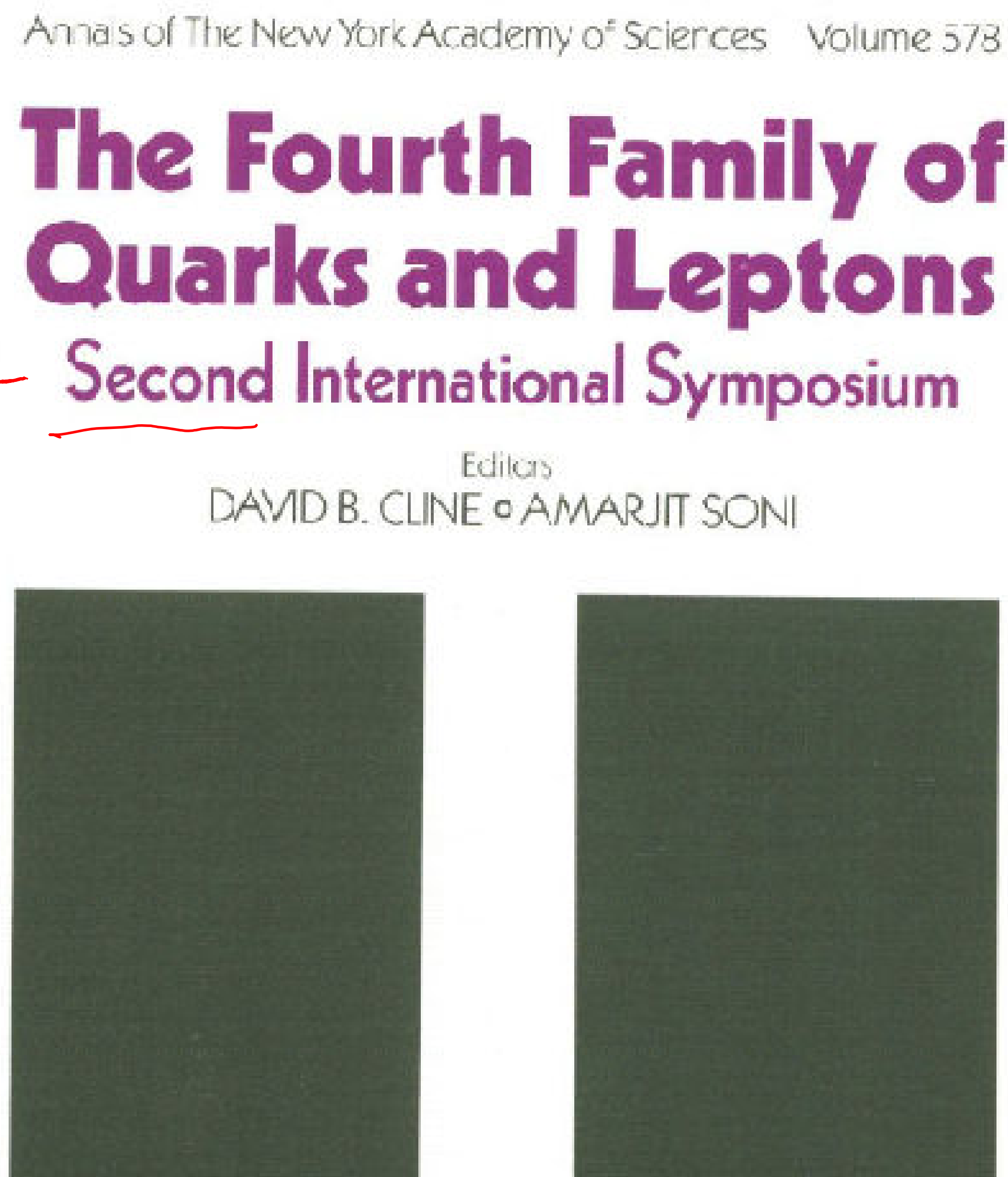
arXiv:0904.4698 PMC Phys

B. Holdom,[a] W.S. Hou,[b] T. Hurth,[c] M. Mangano,[c] S. Sultansoy,[d] G. Ünel[e]

- Once popular, an additional 4th generation was no longer "a la mode". Last workshop around late 1980s

➡misinformation disseminated by PDG contributed to this omission.

CIRCA 1989
(UCLA)



1st
~1987

VOLUME 65, NUMBER 2 PHYSICAL REVIEW LETTERS 9 JULY 1990

Properties of a Composite Higgs Particle in a Dynamically Broken Formulation of the Standard Model

J. Carpenter, R. Norton, and S. Siegemund-Broka
Department of Physics, University of California, Los Angeles, California 90024

A. Soni
Brookhaven National Laboratory, Upton, New York 11973
(Received 1 September 1989)

$m_H \sim \sqrt{2}\, m_Q$

We suggest that dynamical breakdown of electroweak symmetry in an SU(3)×SU(2)×U(1) model of a single fermion family without fundamental scalars can reproduce the entire scalar sector of the standard model through fermion bound states and loop-induced couplings. The physical Higgs boson is essentially a $t\bar{t}$ bound state. The top-quark and Higgs-boson masses are approximately 300 and 400 GeV, respectively. The strengths of the induced couplings among the scalars do not indicate a strongly interacting scalar sector.

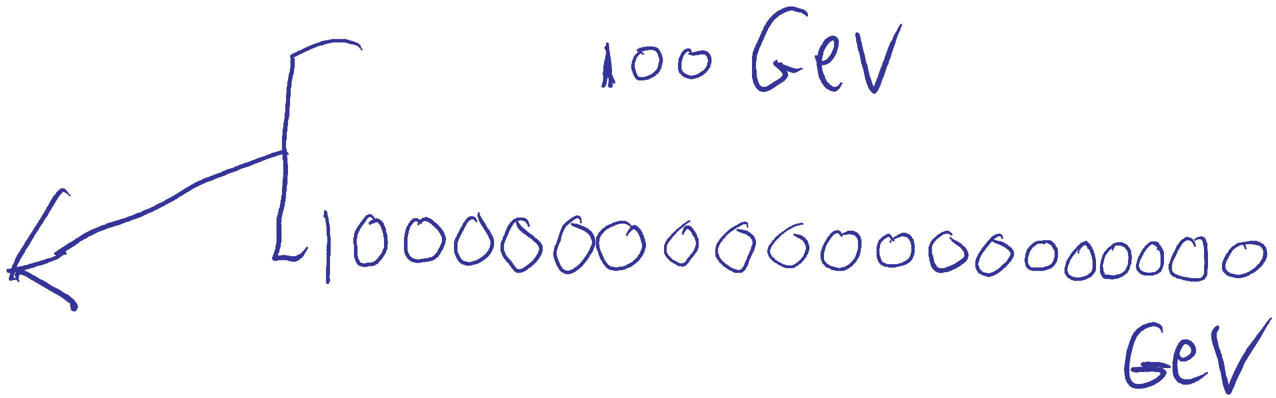
$(300)^2 \sim (m_{t'} - m_{b'})(m_{t'} + m_{b'})$

$70 \sim$

$m_{t'} \sim 500$ GeV

Origin of EWSB:Possibly a glorious renaissance

I. **SUSY**



II. **Strong dynamics {WEXD, TC, WTC….}**

Quarks/Leptons with O(500 GeV) masses make strong dynamics unavoidable….

The natural mass scale for Higgs like object becomes >>m_Z ~ susy higgs mass scale

Top ~10 reasons

- #1: udcstbgz
- Instead of ~121 can do with 7
- Another 4 reasons:1234
- Another 3 reasons: e mu tau

89 →

OSCILL8

~80 – 89

Possible cracks in CKM?

Related talks here by:

Punzi,Zieminska,Nandi, Lacker, Nakao,CYMa,Bashiry,Musy

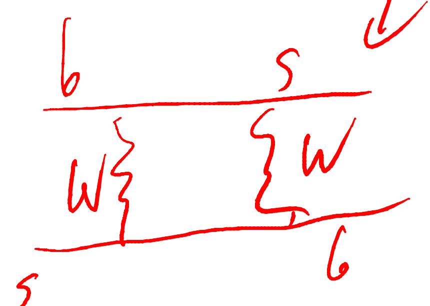
Based also on Lunghi+AS

Summary of B-CP Anomalies (~'07-'09)

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

- **Dir CP in K+π- vs K+ π0**
- **Bs->ψφ (esp. significant since 1. Its theoretically very clean(Gold plated) II. It essentially follows from others…Consequently very important that Fermilab follows it up & clarifies it with very high priority).**
- **Each ~2 to 3.5 σ**

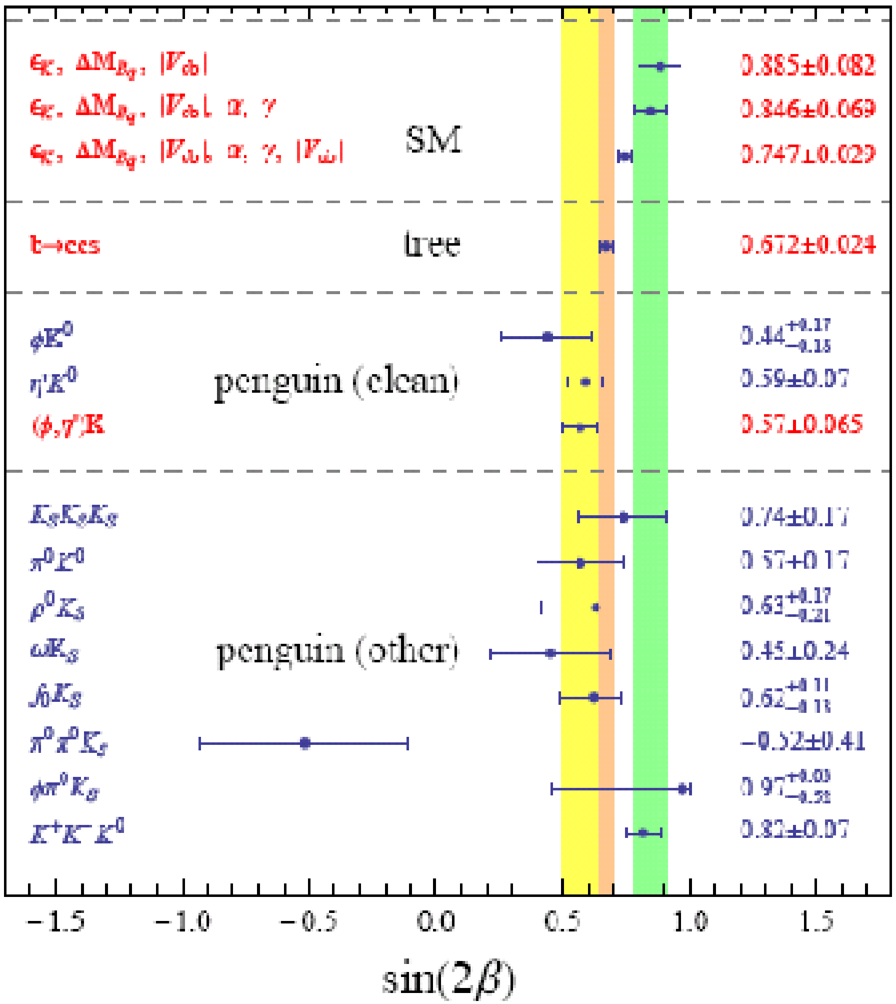
also Bona fide



Should also bear in mind

- Br (B -> $\tau \nu_\tau$) $\sim 1.5\sigma$ weakest
- AFB (B ->K^* l l) $\sim 2.5\sigma$ just BELLE + BABAR + CDF
- $(g – 2)_\mu$ $\sim 3\sigma$

Lunghi + AS, arXiv:0903.5059



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

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

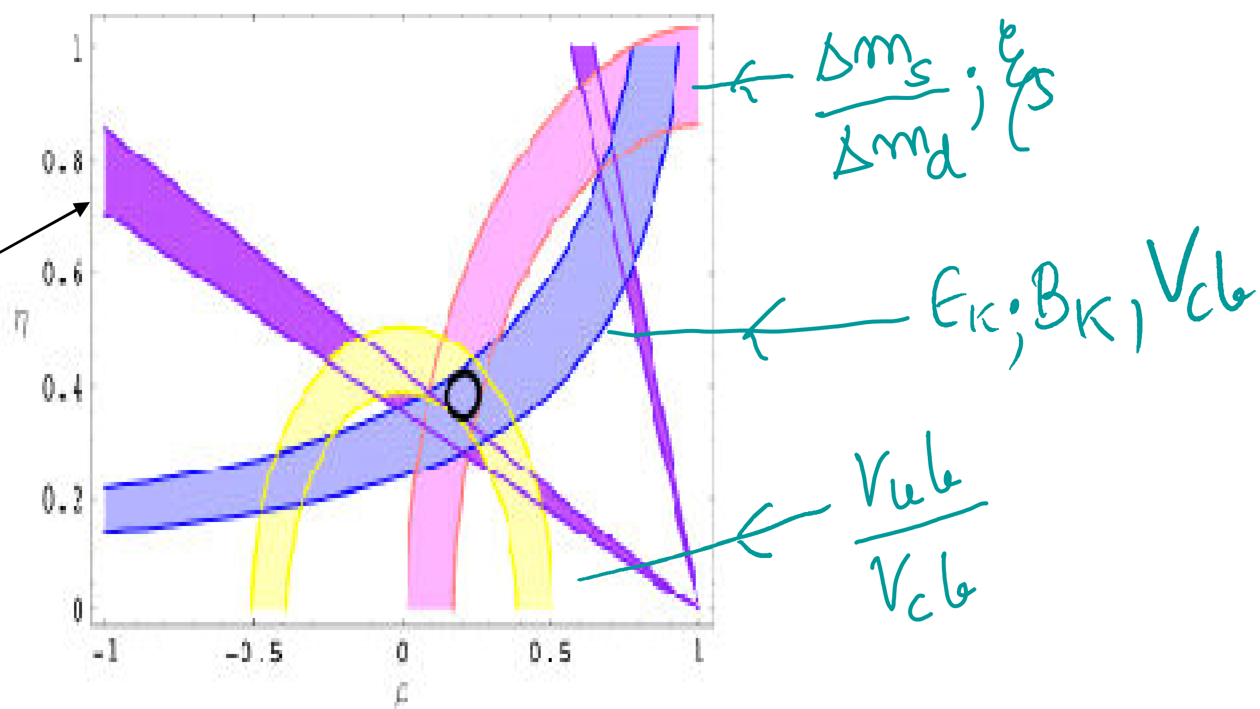


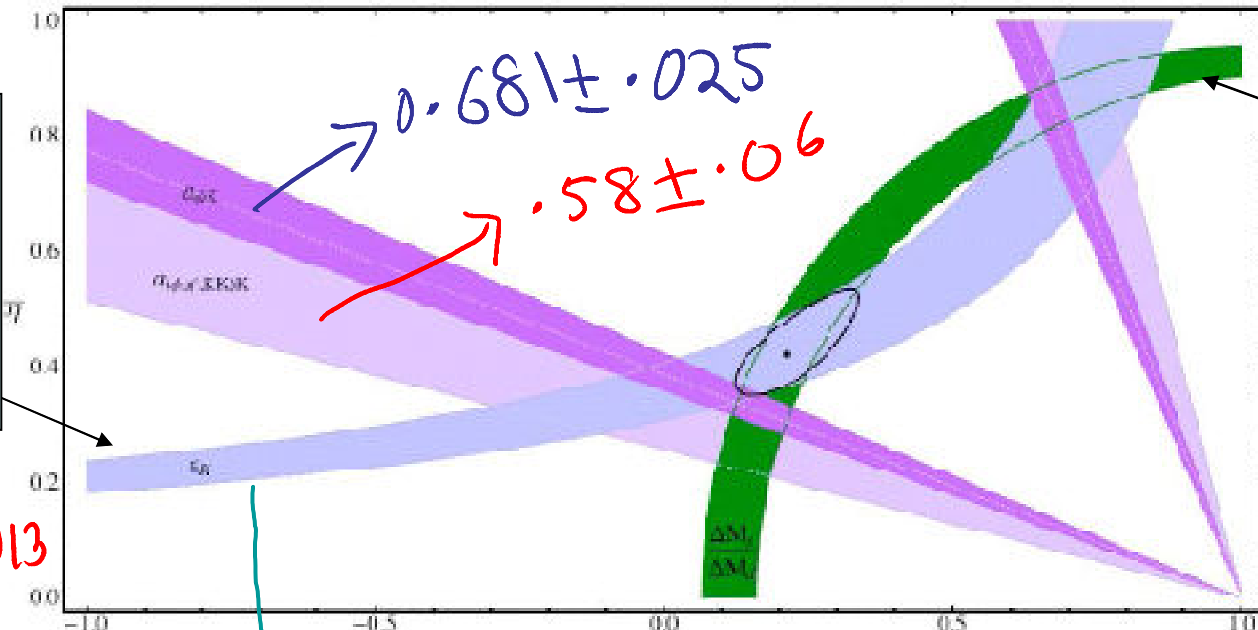
Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

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

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

(became possible only due significantly reduced error in B_K)

Antonio et al (RBC-UKQCD) 0702042



Gamiz et al; Becirevic; Tantalo

.

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

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

include BURAS + GUADAGNOLI CORR. (0805.3887)

$\xi = 1.20 \pm .06$

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

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

B_K - Preliminary Results

C.Kelly for RBC-UKQCD @ LATTICE'09
Beijing, 7/26/09

- 24^3 paper value (*Phys. Rev. Lett.* 100:032001,2008): → RBC

$$B_K^{\overline{\rm MS}}(2\,{\rm GeV}) = 0.524(30)$$

OLD (USED By LUNGHI + AS)

- New value:

$$B_K^{\overline{\rm MS}}(2\,{\rm GeV}) = 0.537(19)$$

NEW (PRELIMINARY)

Source	24^3 Mag	New Mag.	%	Comment
stat	0.010	0.006	1.1	Stat err. from sim. fit
ChPT	0.010	0.013	2.4	analytic expansion $\sim NLO^2$ est.
FV	0.005	??	??	NLO ChPT FV corrections
NPR	0.013	0.013	2.4	Comb. stat + sys err. (mult. ex + non-ex MOM schemes)
Scaling	0.021	0	0	Scaling inc. in fits
Unphys. m_K	0.005	0	0	Reweighting
Total	0.030	0.019	3.5	Preliminary

Aubin, Laiho, VandeWater
arXiv:0905.3947

$$B_K^{\overline{\rm MS},{\rm NDR}}(2{\rm GeV}) = 0.527(6)(20)$$

DIFF METHOD

BROOKHAVEN NATIONAL LABORATORY

HEP office of high energy physics

Brief (~25 years) History of B_K

, ~'83 DGH use K^+ lifetime + LOChPT + SU(3)->
B_K ~0.33… no error estimate, no scale dependence….

UNCONTROLLABLE APPROXIMATION ⇒

~'84 Lattice method for WME born…many attempts & improvements for B_K evaluations

~'98 JLQCDstaggered B_K (2GeV)= 0.628(42)quenched(~110).
~'97 1st B_K with DWQ(T.Blum&A.S),0.628(47) quenched.
~'01 RBC B_K with DWQ, quenched=0.532(11) quenched

~'05 RBC , nf=2, dyn. DWQ, B_K =0.563(21)(39)(30)
~'06 Gimnez et al (HPQCD; stagg.) 2+1, B_K =0.618(18)(19)(30)(130)
~07,RBC-UKQCD DWQ 2+1 …..0.524(10)(28)
DWQ lower B_K -> requiring larger CKM-phase

BBG LgN PLB'88 .70±.07

~'08 Target 2+1 dyn. DWQ, B_K with total error 5%
~'09 : error below ~4%
NO LONGER THE LIMITING ERROR!!

.720(13)(37)

$$B_K \equiv \langle K | [\bar{s}\gamma_\mu(1-\gamma_5)d]^2 | \bar{K} \rangle / \tfrac{8}{3} f_K^2 m_K^2$$

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

time has constrained KM parameters well enough that a knowledge of the B parameter can be used to put a nontrivial bound on the mass of the top quark. Thus, for example, with B = .33 the standard model with three generations requires $m_{top} \gtrsim 40$ GeV for it to successfully account for the experimentally observed value of ϵ.[6)]

Left-right symmetric theories constitute a popular means for extending the standard model. The $K^o\bar{K}^o$ mass difference can be used to learn about the lower bound on the mass scale of such theories. These bounds depend linearly on $M_{LR} \equiv \langle K^o|\bar{s}\gamma_\mu(1-\gamma_5)d\ \bar{s}\gamma^\mu(1+\gamma_5)d|\bar{K}^o\rangle$, and the current bound (1.6 TeV for the mass of the right handed gauge bosons) was deduced by assuming vacuum saturation.[7)] It will therefore be useful to calculate M_{LR} on the lattice.

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.

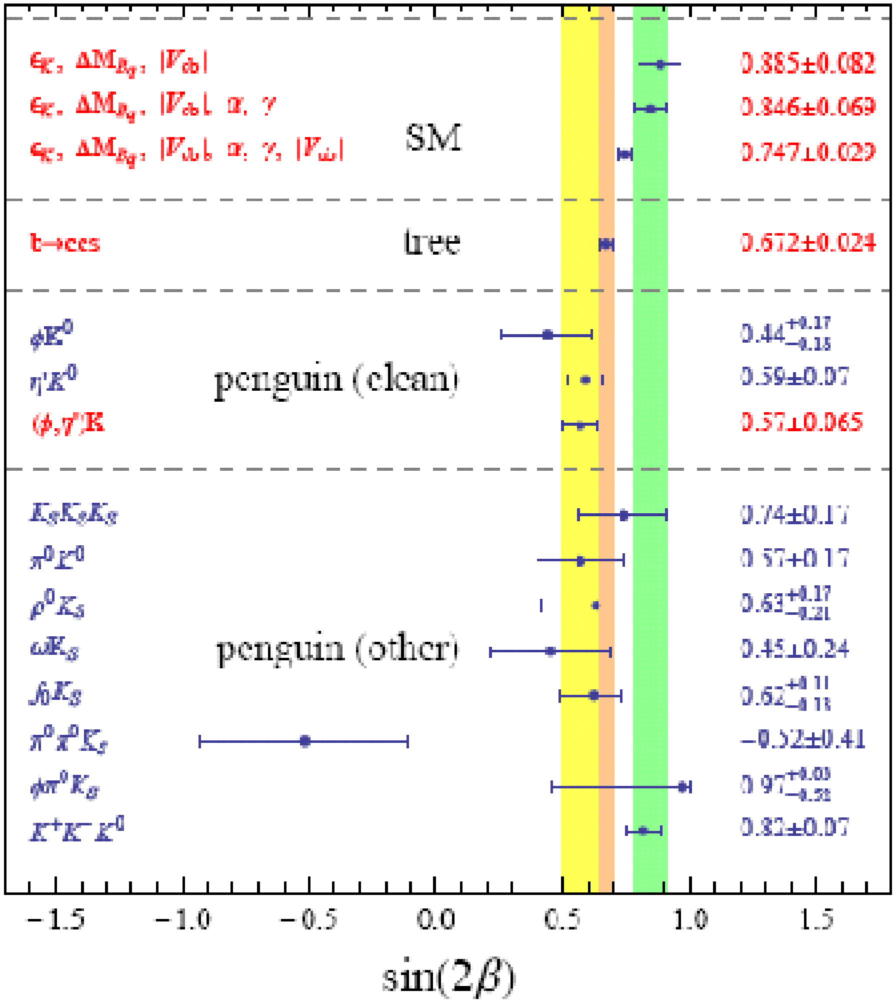
Courtesy: Tom Browder

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.

Lunghi + AS, arXiv:0903.5059



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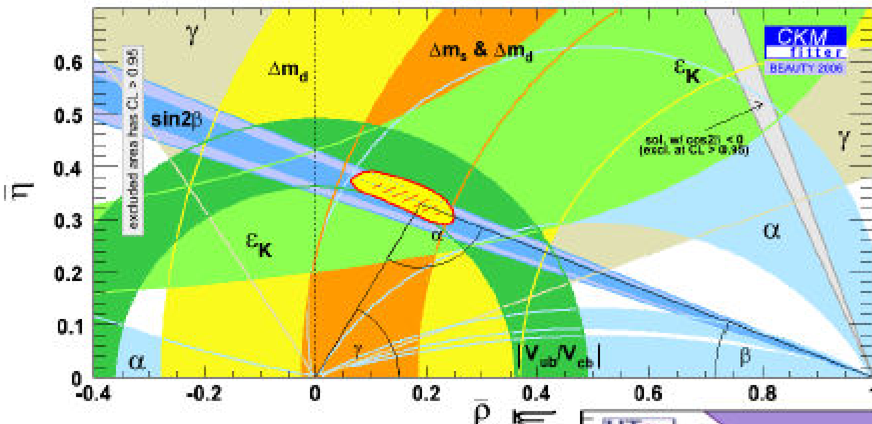
$S_{\phi K_S}$	$2.2\ \sigma$	$1.8\ \sigma$
$S_{\eta' K_S}$	$2.6\ \sigma$	$2.1\ \sigma$
$S_{(\phi-\eta')K_S}$	$2.9\ \sigma$	$2.5\ \sigma$

Overall CKM agreement

$S(t)(B^0 \to \psi K_S) \sim 70\%$

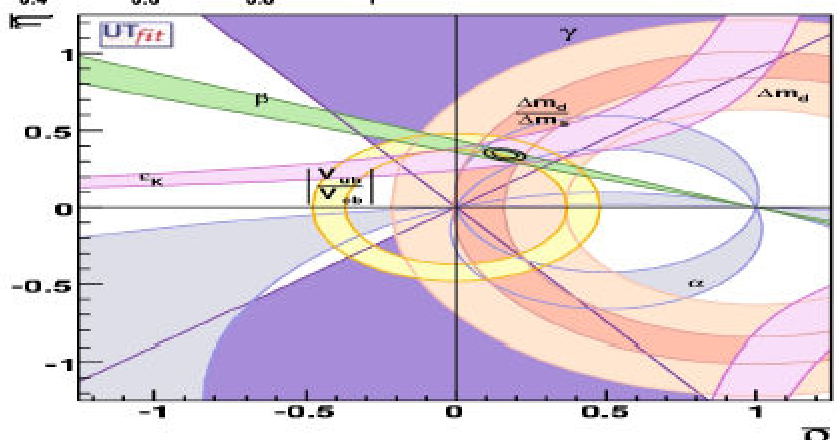
Frequentist



$\epsilon_K (K_L \to \pi\pi) \sim 10^{-3}$

BOTH Accounted by the KM phase!!

Bayesian



Conclusion is the same:

All measurements agree with SM picture of CKM matrix within errors

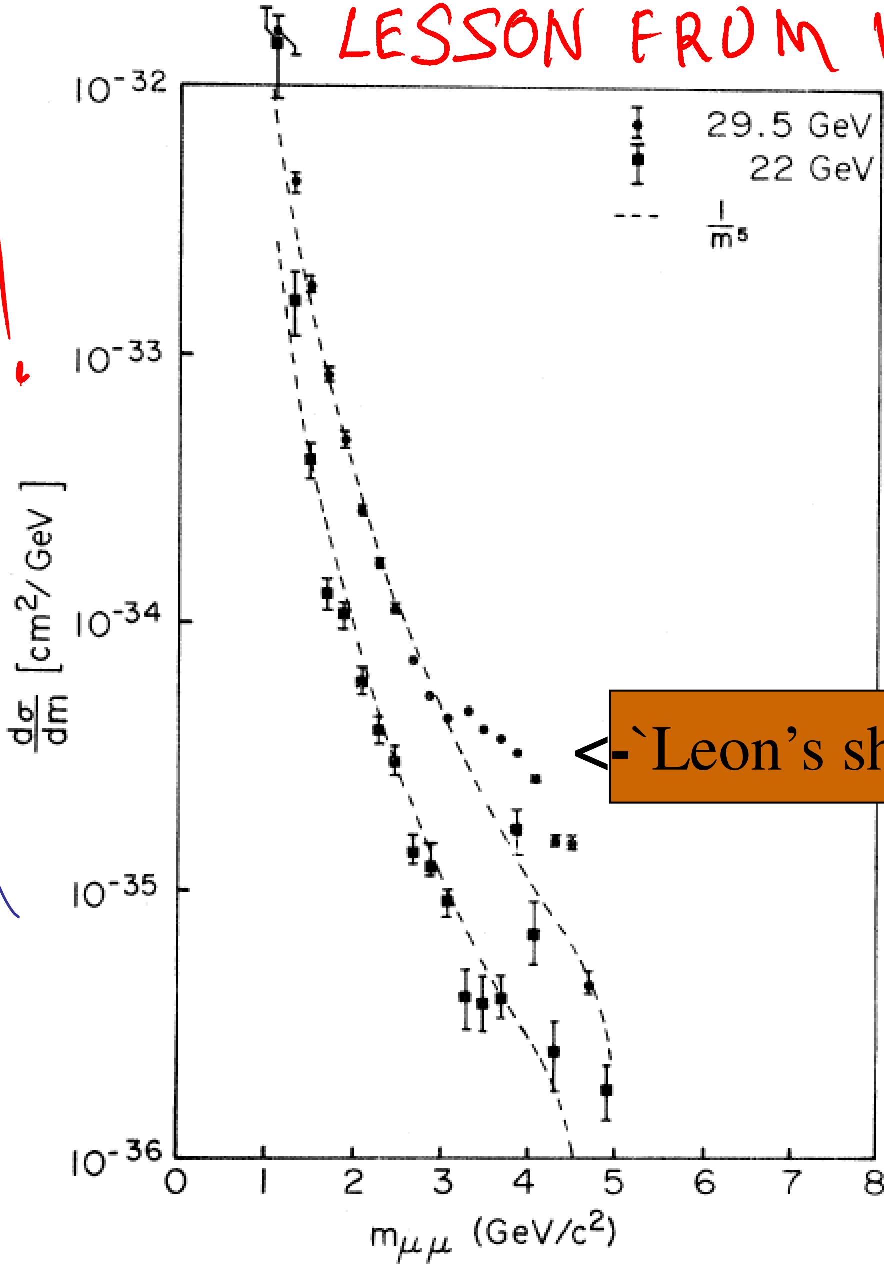
WAY too much read from ~ 20% agreement

LESSON FROM HISTORY

DRELL-YAN @ its INFANCY!

The BIGGEST MISNOMER

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



<-`Leon's shoulder

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

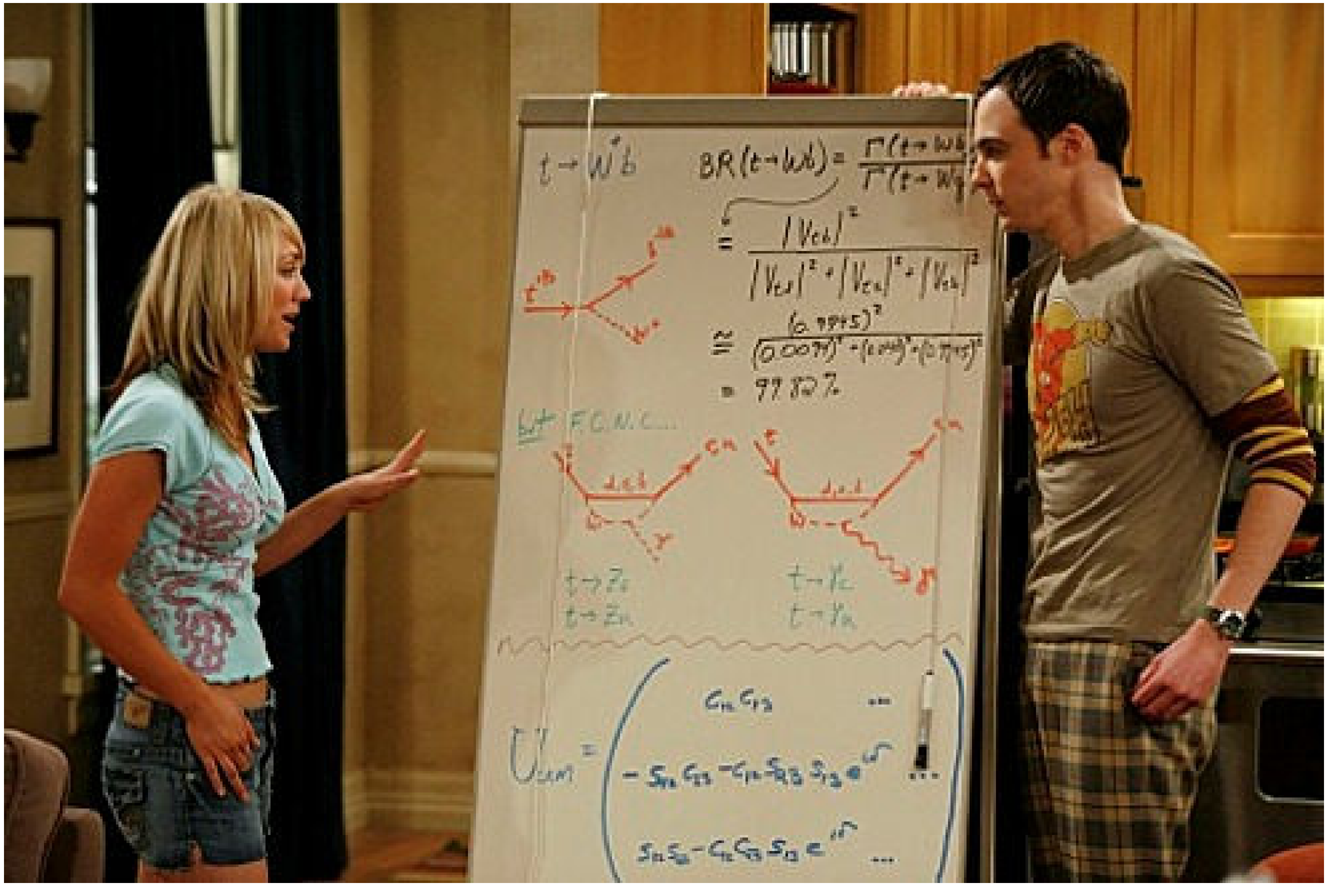
Lederman Reaction

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!!

LHC/Super B factory synergy discussion on US TV comedy

D. Saltzberg, Science Advisor



CBS, “Big Bang Theory” averages 9 million viewers per episode.

Courtesy Tom Browder

.

2nd

Adapted from Browder

A lesson from history (I)

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

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

1964: BF= 2×10^{-3}

A failure of imagination ? Lack of patience ?

Christenson, Cronin, FITCH + TURLAY BNL '64

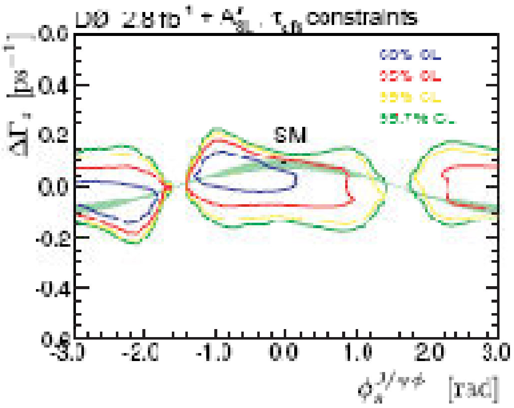
ZIEMINSKA

$\Delta\Gamma_s$ vs $\phi_s^{J/\psi\phi}$ with Additional Constraints

$B_s^0 \rightarrow J/\psi\phi$ (DØ)

$+A_{SL}^s + \tau_s(SL)$ (World Average)

SM p-value = 12%

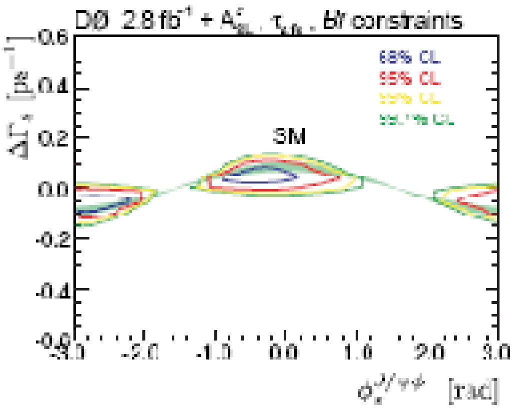


$B_s^0 \rightarrow J/\psi\phi$

$+A_{SL}^s + \tau_s(SL) +$

$\mathcal{B}(B_s \rightarrow D_s^{(*)+} D_s^{(*)-})$ (DØ)

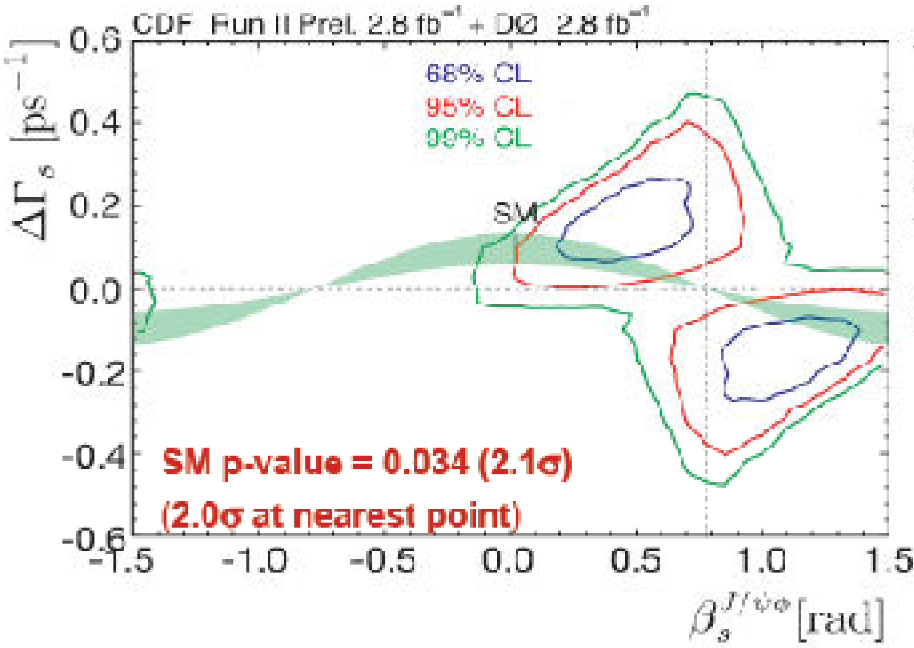
SM p-value = 10%

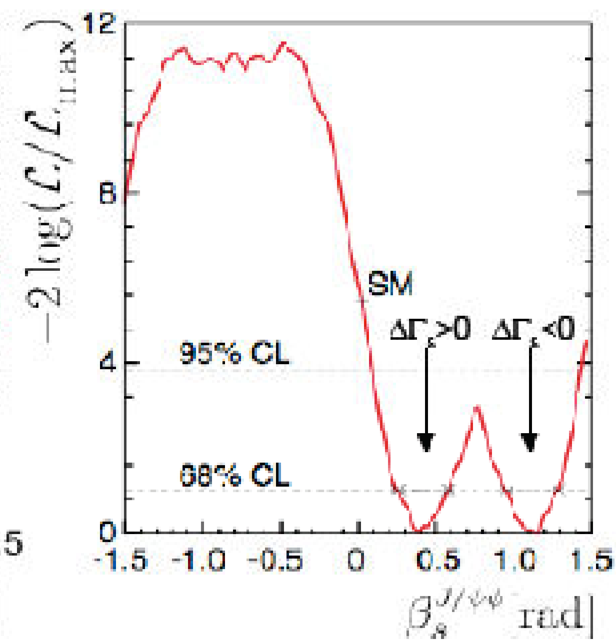


PUNZI

Combined Tevatron result

[http://tevbwg.fnal.gov]





- Full inclusion of systematics and non-Gaussian effects. No external constraints.
- Compared to HFAG 2008: Larger CDF sample + Better accounting for tails → same level of SM agreement.

$\beta_s^{J/\psi\phi}$ range:
[0.27,0.59] U [0.97,1.30] @68%
[0.10,1.42] @95%
1-D p-value for SM= 0.020 (2.3σ)

Settling the fate of the cracks

Highest priority item in the particle physics community for now(at least for flavor physics)

$S(B_s \to \psi\phi)$

Other items needing priority

- **From the lattice B_K with other (than DWQ) methods such as overlap and/or other groups**
- **ξ_s SU3 breaking ratio for $\Delta m_s / \Delta m_d$ with DWQ/overlap**
- $f_B \sqrt{B}$ **with DWQ/overlap** Δm_d
- **MORE ACCURATE A_{FB} from Expt**
- **More accurate Br**(B->$\tau \nu_\tau$) from expt.

WHODUNIT?

Honest answer &

- Don't really know (too many possibilities…)
- But theoretically the most interesting possibility is that we may be witnessing Dawning of the age of

"Warped Flavordynamics"

RANDALL-SANDRUM '99

(Gives a simultaneous resoltution to Planck-EW hierarchy AND the flavor puzzle [through fermion "geography"]).

Tree level FCNC are severely suppressed through "RS-GIM" mechanism (Agashe, Perez & AS'04)

Thus remarkably RS-leads to lowering of Λ_{flavor} from ~1000 TeV to < 20 TeV (possibly just a few TeV if you allow small amount of tuning)

NEUBERT et al '08
BURAS et al '08

GROSSMAN-NEUBERT, '99
GHERGHETTA-POMAROL '00

RANDALL+SUNDRUM '99

[FIG BY H DAVOUDIASL]

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

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

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

$\langle H_4\rangle \to$ TeV, $\langle H_5\rangle \to M_P$

$$\sigma = k r_c \pi, \quad k r_c \sim 12$$

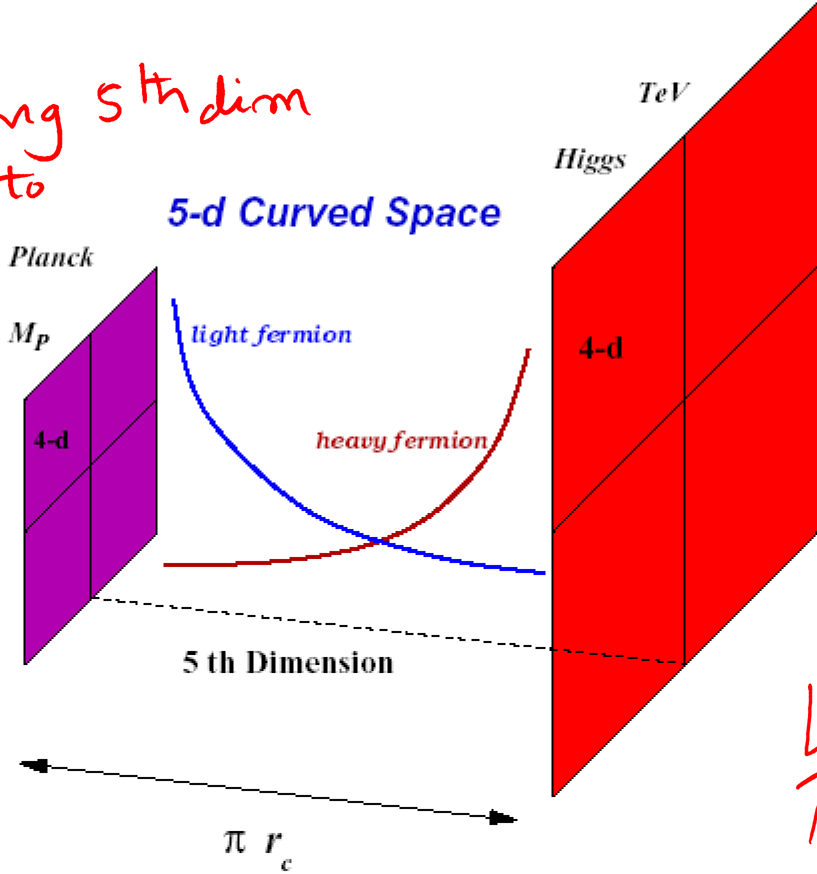


Figure 1: Warped geometry with flavor from fermion localization. The Higgs field resides on the TeV-brane. The size of the extra dimension is $\pi r_c \sim M_P^{-1}$.

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**
- **Most flavor violations are driven by the top**

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

$m_{KK} \gtrsim 3$ TeV

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

EXTREMELY INTERESTING SUBTELTY of warped models

- Maldacena conjecture
- ***"Warped Flavordynamics" is DUAL to strong dynamics->***

SIMPLEST 4d Explanation of B,Bs CP anomalies is SM4: SM with 4 generations

Burdman & Rold arXiv: 0710.0623

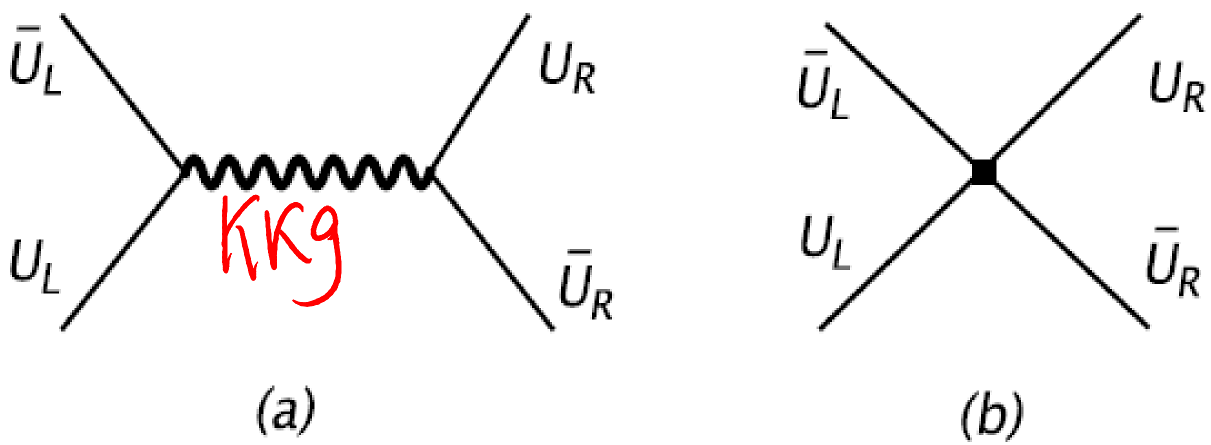


Figure 1: Two contributions to four-fermion interactions of the up-type fourth-generation quark: (a) from the interactions with a KK gluon; (b) from the four-fermion interactions induced by the bulk operators of (2.11).

$\langle \bar{u}_L u_R \rangle \neq 0$

$m_u \sim 600\text{–}700\ \mathrm{GeV}$

$m_H \sim 2 m_u$

HEAVY fourth family cannot co-exist with light Higgs

Higgs description loses meaning

- $m_{t',b'} \approx 600$ GeV close to the unitarity upper bound
- Goldstone bosons of electroweak symmetry breaking couple strongly to t', b', so strong interactions unitarize WW scattering

Higgs is no longer needed

- strong interactions can also be responsible for the Goldstone bosons
- a fermion condensate replaces the Higgs vev

- so where do quark and lepton masses come from?

$$\langle \overline{\Psi}\Psi \rangle = \Lambda_{ew}^3 \qquad \frac{1}{\Lambda_{fl}^2}\overline{\Psi}\Psi\overline{\psi}\psi \qquad m_\psi = \frac{\Lambda_{ew}^3}{\Lambda_{fl}^2}$$

BOB HOLDOM

what causes $\langle\overline{\Psi}\Psi\rangle = \Lambda_{ew}^3$?

- new strong UNBROKEN gauge interaction—technicolor

  or

- new strong BROKEN gauge interaction—similar to original NJL model

- for the latter we can identify Ψ with the fourth family

$$\frac{1}{\Lambda_{fl}^2}\overline{\Psi}\Psi\overline{\psi}\psi \qquad\qquad \frac{1}{{\Lambda'_{fl}}^2}\overline{\Psi}\Psi\overline{\Psi}\Psi$$

$$\Lambda_{fl} \gg \Lambda'_{fl} \approx \Lambda_{ew} \approx 1\ \text{TeV}$$

BOB HOLDOM

- flavor gauge interactions, partially broken at Λ_{fl}, with a remnant broken at Λ'_{fl}

Heavy 4th Generation's scenario

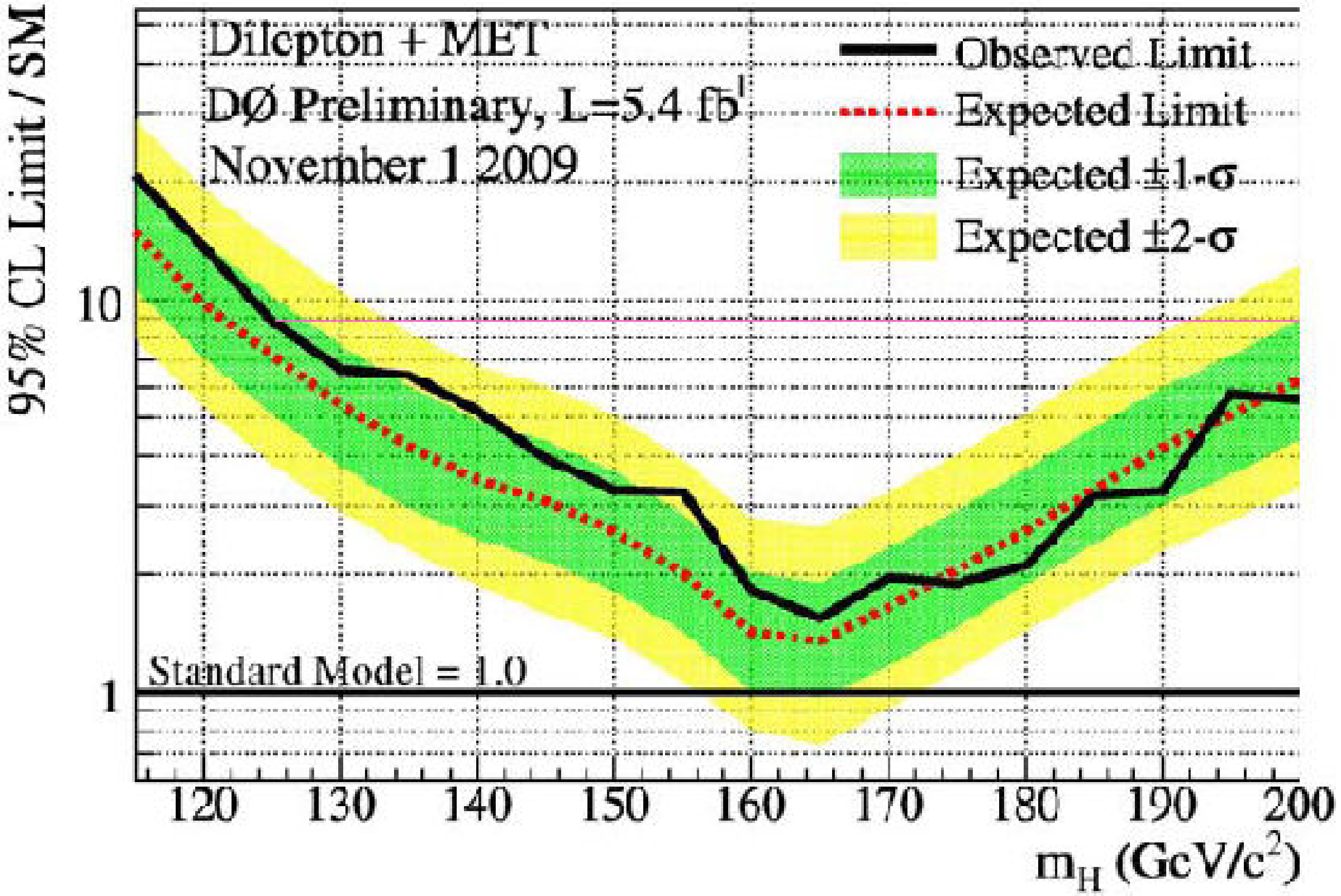
PQ Hung

What can a heavy 4th generation do?

- A **heavy Higgs-4th Yukawa** system can give rise to **condensates** and **bound states** of 4th generation fermions ⇒ Implications on the **vacuum structure** of the SM and the **number of Higgs doublets** (a mixture of fundamental and composites)
- The appearance of **quasi-fixed points** in the **2-loop approximation** at a scale $\Lambda_{FP} \sim O(TeV)$ hints at a possible **scale-invariant** theory above Λ_{FP}.

Tulika Bose, D0

In SM4 mH > 200 GeV



The "3-prong composite solution" to the SM4

(figure taken from: Chanowitz, Phys.Rev.D79:113008,2009)

BAR-SHALOM

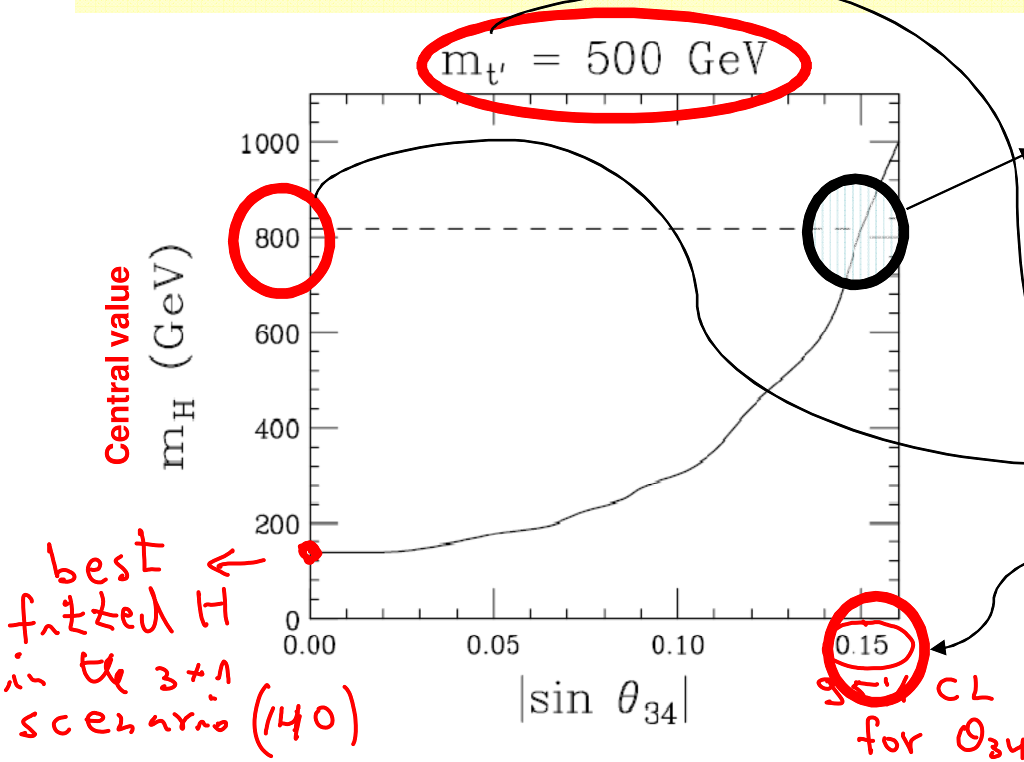


Figure 2: Higgs boson mass as a function of $|\sin\theta_{34}|$ for the global fit to the four family
with $m_{t'} = 500$ GeV. The horizontal line indicates the 95% confidence interval for |sir

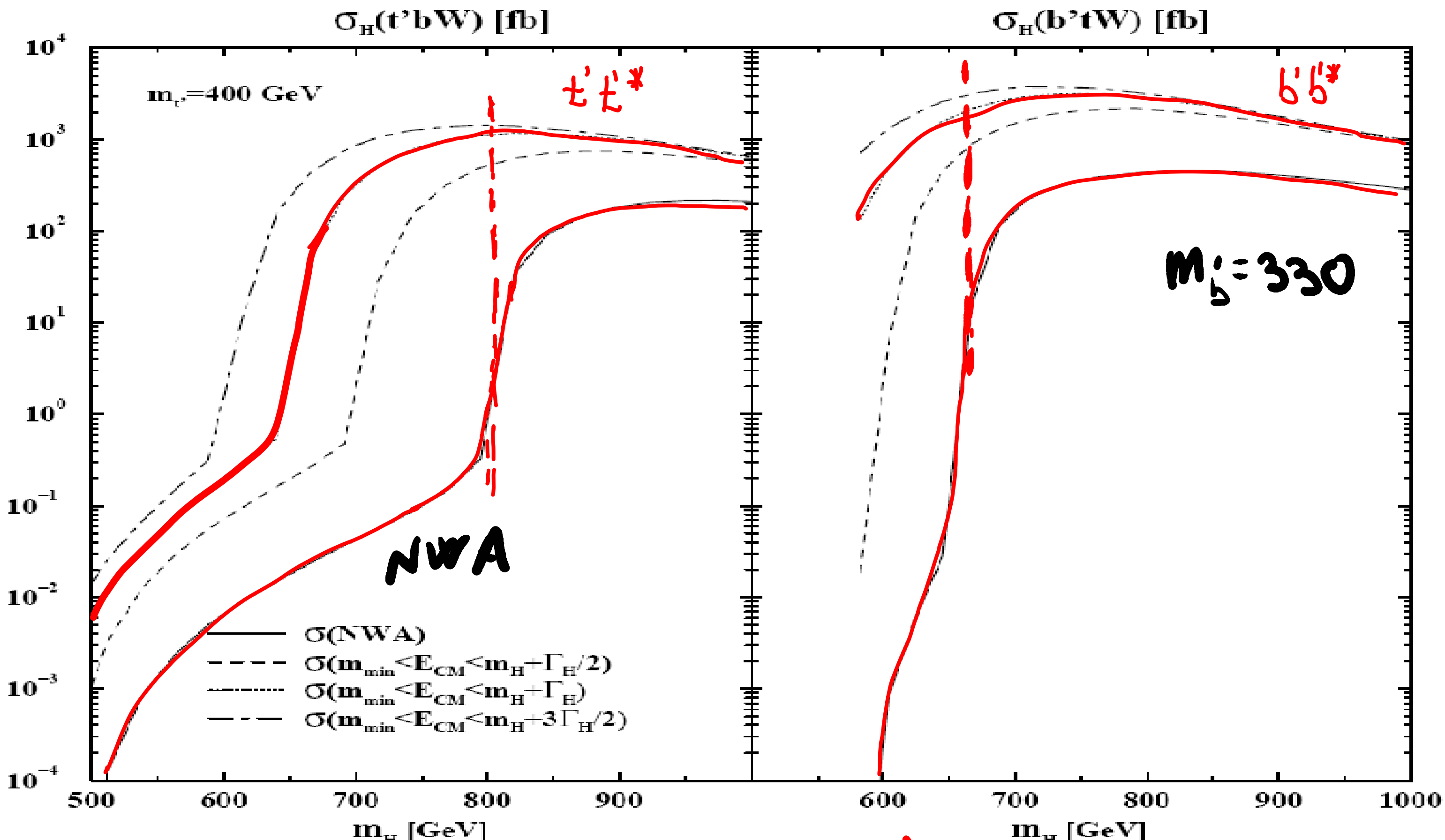
The compositeness SM4 "spot"?

$m_H \sim O(1)$ TeV < $2m_{t'b'}$

$\theta_{34} \sim O(0.1)$ — $m_{t',b'} \sim O(500)$ GeV

$$m_{t'} - m_{b'} \approx \left(1 + \frac{\ln \frac{m_H}{115\ \text{GeV}}}{5}\right) \times 50\ \text{GeV}$$

Further hints from:
- compositeness
- Flavor data
- Direct searches



e.g. $\sigma_H(pp \to H \to t'bW) \sim 300$ fb at $m_H \sim 700$ GeV, $m_{t'} \sim 400$ GeV

(where $\sigma_H(\text{NWA}) \sim 0.03$ fb)

BAR-SHALOM

LENZ, LACKER, CYMA, NANDI ...

(Chanowitz)

HOW much room is there?

UT angles: "γ"

LACKER

- Problem within 4[th] generation scenario:

$\gamma = Arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$ but the following CKM element combinations appear in

weak decay or also $K\text{-}\bar{K}$ mixing

1) GLW

a) $D^0 \to K^+ K^-$ $\quad -Arg\left(\frac{V_{us}V_{cb}^*}{V_{cs}V_{ub}^*}\frac{V_{cs}V_{us}^*}{V_{us}V_{cs}^*}\right) = \gamma - \pi - Arg\left(\frac{V_{ud}V_{us}^*}{V_{cd}V_{cs}^*}\right)$

b) $D^0 \to \pi^+ \pi^-$ $\quad -Arg\left(\frac{V_{us}V_{cb}^*}{V_{cs}V_{ub}^*}\frac{V_{cd}V_{ud}^*}{V_{ud}V_{cd}^*}\right) = \gamma - \pi + Arg\left(\frac{V_{ud}V_{us}^*}{V_{cd}V_{cs}^*}\right)$

c) $D^0 \to K_S \pi^0$ etc. $\quad -Arg\left(\frac{V_{us}V_{cb}^*}{V_{cs}V_{ub}^*}\frac{V_{cs}V_{us}^*}{V_{us}V_{cs}^*}\right) = \gamma - \pi - Arg\left(\frac{V_{ud}V_{us}^*}{V_{cd}V_{cs}^*}\right)$

3SM: π to very good approximation

4 SM: ? (next slide)

2) ADS: $D^0 \to K^+ \pi^-$ $\quad -Arg\left(\frac{V_{us}V_{cb}^*V_{cd}V_{us}^*}{V_{cd}V_{ub}^*V_{ud}V_{cs}^*}\right) = \gamma - \pi$

WORK in progress

3) Dalitz

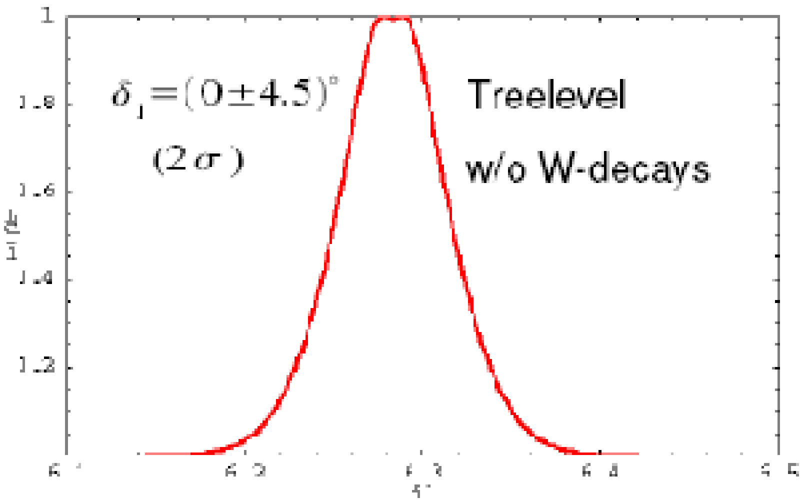
Analogous possibilities depending on final state in Dalitz plane

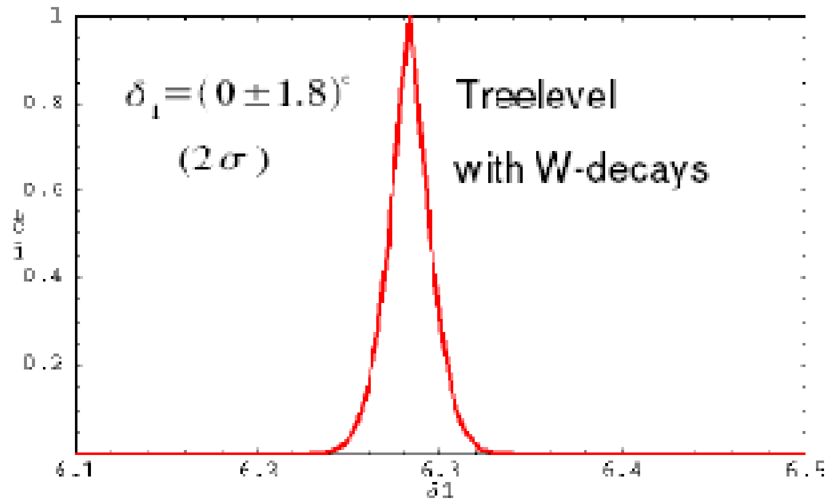
UT angles: "γ"

LACKER

Define $\delta_1 = Arg\left(\frac{V_{ud} V_{us}^*}{V_{cd} V_{cs}^*}\right) + \pi$ => Fit for deviation from 2π≙0 within 4[th] generation scenario

(Already considered in Kurimoto & Tomita, Prog.Theor.Phys. 98 (1997) 967; sign error in eq. (18))





=> γ-extraction in ADS and GLW within 4[th] generation scenario

like in 3-generation scenario to a very good approximation (1° systematics @ 1σ)

Should be analogous in Dalitz plot analysis but not thought through in detail yet

In Progress

Mixing with the 4th Family XIV

LENZ

Result:

- **As expected:** most points belong to SM3 like parameters
- **Unexpected:** large mixing not yet excluded
  V_{td}, V_{ts}, V_{tb} can differ considerably from SM3-fit values

Ultraconservative allowed ranges

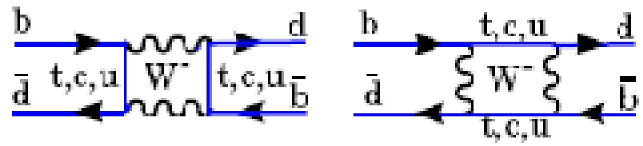
$$
\begin{aligned}
\theta_{14} &\leq 0.04 \approx 1.27\lambda^2 \\
\theta_{24} &\leq 0.25 \approx 0.9\lambda^1 \\
\theta_{34} &< 0.8 \approx 0.8\lambda^0 \\
\delta_{14}, \delta_{24} &\leq 2\pi
\end{aligned}
$$

No “nice” Wolfenstein expansion possible

Mixing with the 4th Family VII

LENZ

Bounds from FCNC:



$$\Delta_X := \frac{X_{SM4}}{X_{SM3}}$$

- K-Mixing: $Re(\Delta_K) = 1 \pm 0.5\,(0.25)$ $\quad Im(\Delta_K) = 0 \pm 0.3\,(0.15)$
- B_d-Mixing: $|\Delta_{B_d}| = 1 \pm 0.3\,(0.1)$ $\quad Arg(\Delta_{B_d}) = 0 \pm 10^\circ\,(5^\circ)$
- B_s-Mixing: $|\Delta_{B_s}| = 1 \pm 0.3\,(0.1)$ $\quad Arg(\Delta_{B_s}) = $ free
- $b \to s\gamma$ $\quad \Delta_{b\to s\gamma} = 1 \pm 0.15\,(0.07)$

classic examples of evasion of decoupling ie

$A\,\alpha\, m^2_{t'}$!!

Highly Counterintuitive

WORK IN PROGRESS

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

- Hou, Willey and AS, PRL (88)..b->s l l…
- Hou, AS, Steger, PRL 87……b-> s g
- Hou, AS, Steger, PLB 87

  4X4 mixing matrix and b -> s gamma

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

CYMA (+ Hou)

Use parametrization matrix

[Hou, Soni and Steger PLB **192** (1987)]

1st Row

$$V_{ud} = -c_{13}\, s_{14}\, s_{12}\, s_{24}\, e^{i\Phi_{sb}-i\Phi_d} - s_{13}\, c_{24}\, s_{14}\, s_{34}\, e^{-i\Phi_d - i\phi_3} + c_{14}\, c_{13}\, c_{12}$$

$$V_{us} = c_{13}\, c_{24}\, s_{12} - s_{13}\, s_{34}\, s_{24}\, e^{-i\Phi_{sb}-i\phi_3}$$

$$V_{ub} = s_{13}\, c_{34}\, e^{-i\phi_3}$$

$$V_{ub'} = s_{14}\, c_{13}\, s_{12}\, s_{24}\, e^{i\Phi_{sb}} + c_{13}\, c_{12}\, s_{14}\, e^{i\Phi_d} + s_{13}\, c_{14}\, c_{24}\, e^{-i\phi_3}\, s_{34}$$

4th Row

$$V_{t'd} = -c_{34}\, c_{24}\, s_{14}\, e^{-i\Phi_d}$$

$$V_{t's} = -c_{34}\, s_{24}\, e^{-i\Phi_{sb}}$$

$$V_{t'b} = -s_{34}$$

$$V_{t'b'} = c_{14}\, c_{34}\, c_{24}$$

2nd Row

$$V_{cd} = s_{14}\, s_{13}\, s_{12}\, s_{24}\, s_{23}\, e^{i\Phi_{sb}-i\Phi_d+i\phi_3} - c_{12}\, c_{23}\, s_{14}\, s_{24}\, e^{i\Phi_{sb}-i\Phi_d} - c_{13}\, c_{24}\, s_{14}\, s_{34}\, s_{23}\, e^{-i\Phi_d} - c_{14}\, c_{12}\, e^{i\phi_3}\, s_{13}\, s_{23} - c_{14}\, c_{23}\, s_{12}$$

$$V_{cs} = -c_{13}\, s_{34}\, s_{24}\, s_{23}\, e^{-i\Phi_{sb}} - c_{24}\, e^{i\phi_3}\, s_{13}\, s_{12}\, s_{23} + c_{12}\, c_{24}\, c_{23}$$

$$V_{cb} = c_{13}\, c_{34}\, s_{23}$$

$$V_{cb'} = -c_{14}\, s_{13}\, s_{12}\, s_{24}\, s_{23}\, e^{i\Phi_{sb}+i\phi_3} + c_{14}\, c_{12}\, c_{23}\, s_{24}\, e^{i\Phi_{sb}} - c_{12}\, s_{14}\, s_{13}\, s_{23}\, e^{i\Phi_d+i\phi_3} - c_{23}\, s_{14}\, s_{12}\, e^{i\Phi_d} + c_{14}\, c_{13}\, c_{24}\, s_{34}\, s_{23}$$

3rd Row

$$V_{td} = c_{23}\, s_{14}\, s_{13}\, s_{12}\, s_{24}\, e^{i\Phi_{sb}-i\Phi_d+i\phi_3} + c_{12}\, s_{14}\, s_{24}\, s_{23}\, e^{i\Phi_{sb}-i\Phi_d} - c_{13}\, c_{24}\, c_{23}\, s_{14}\, s_{34}\, e^{-i\Phi_d} + c_{14}\, s_{12}\, s_{23} - c_{14}\, c_{12}\, c_{23}\, e^{i\phi_3}\, s_{13}$$

$$V_{ts} = -c_{13}\, c_{23}\, s_{34}\, s_{24}\, e^{i\Phi_{sb}} - c_{12}\, c_{24}\, s_{23} - c_{24}\, c_{23}\, e^{i\phi_3}\, s_{13}\, s_{12}$$

$$V_{tb} = c_{13}\, c_{34}\, c_{23}$$

$$V_{tb'} = -c_{14}\, c_{23}\, s_{13}\, s_{12}\, s_{24}\, e^{i\Phi_{sb}-i\phi_3} - c_{14}\, c_{12}\, s_{24}\, s_{23}\, e^{i\Phi_{sb}} - c_{12}\, c_{23}\, s_{14}\, s_{13}\, e^{i\Phi_d+i\phi_3} + s_{14}\, s_{12}\, s_{23}\, e^{i\Phi_d} - c_{14}\, c_{13}\, c_{24}\, c_{23}\, s_{34}$$

сума (+ нои)

Conclusion

For $f_{Bs}\sqrt{B_{Bs}}$ = 266(18) MEV, $m_{t'}$=500 GEV

I. For $V^*_{t's}V_{t'b}=0.006\, e^{i\,75^{\circ}}$, $|V_{t'b}|<0.13$ on $Z \to bb$, $|V_{t'b}|>0.06$ on D-D mixing , best global fit at $|V_{t'b}|=0.08$

II. $\sin 2\Phi_{Bs} \sim -0.33 \in [0.00, -0.40]$,

Larger $m_{t'}$ implies larger $\sin 2\Phi_{Bs}$

III. Future measurement $\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu})$ and $\sin 2\Phi_{Bd}$ can determine $V_{t'd}$.

NANDI

Allowed ranges for the parameters, $\lambda^s_{t'} = V_{t'b}V^*_{t's}$, phase of $V_{t's} = \phi^s_{t'}$ and upper limit for $\lambda^d_{t'} - V_{t'b}V^*_{t'd}$

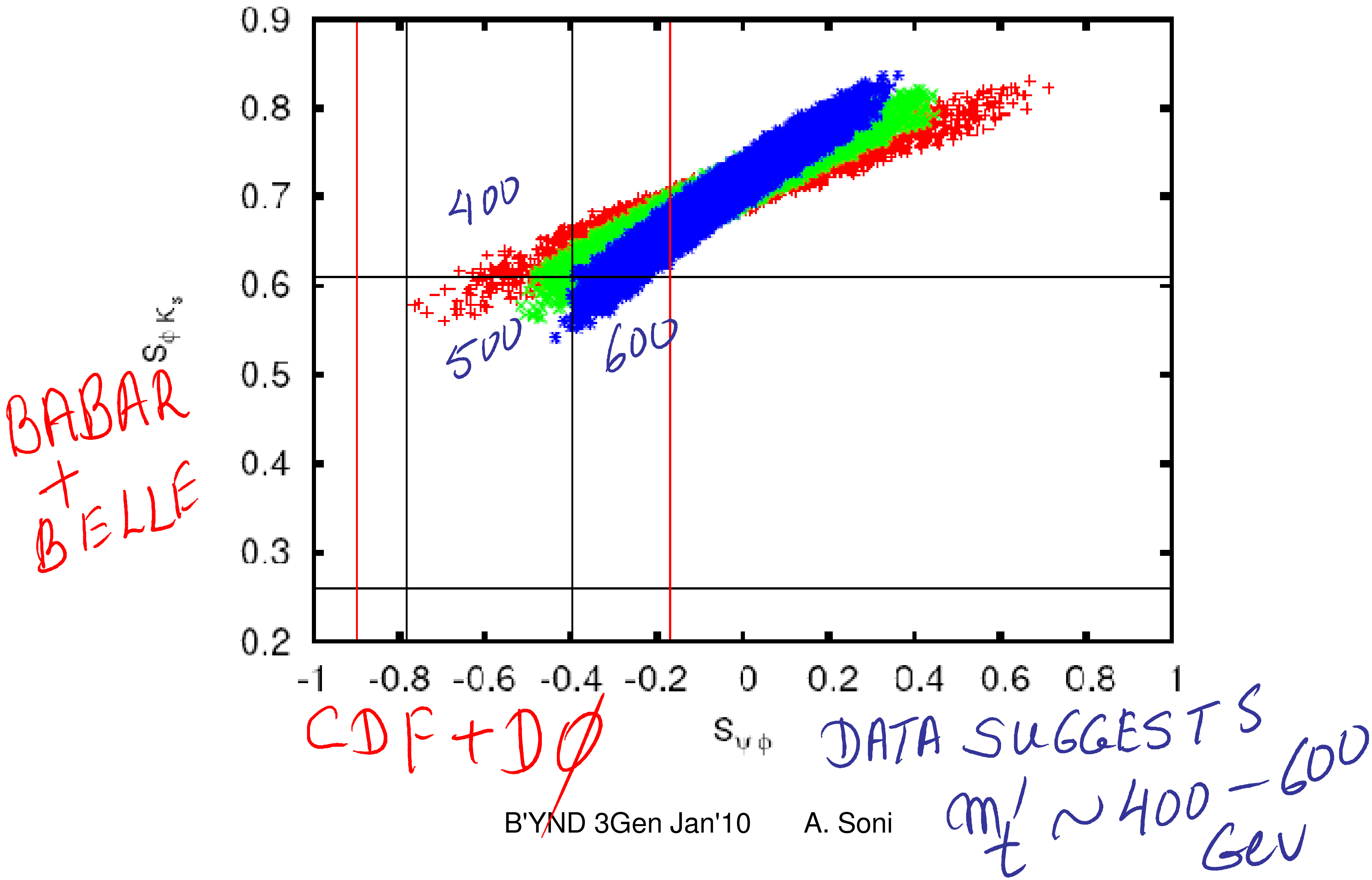
$m_{t'}\ (GeV)$	400	600
$\lambda^s_{t'} \times 10^2$	(0.08 - 1.4)	(0.05 - 0.6)
$\phi^s_{t'}$	-80 $\rightarrow$ 80	-80 $\rightarrow$ 80
$\lambda^d_{t'} \times 10^3$	< 2.0	< 1.6

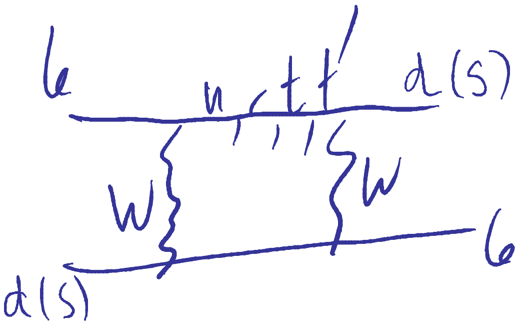
Upper bound on the SM4 coupling reducing with the mass of fourth family...

Constrain used $\Rightarrow$ *CKM* unitarity + Oblique corrections + $Br(B \rightarrow X_s\gamma)$ + ϵ_k + ΔM_d + $\frac{\Delta M_d}{\Delta M_s}$ + $Br(B \rightarrow X_s\ell^+\ell^-)$ + $\mathcal{BR}(K^+ \rightarrow \pi^+\nu\nu)$

Nandi

arXiv:0807.1971, and to be submitted





THUS

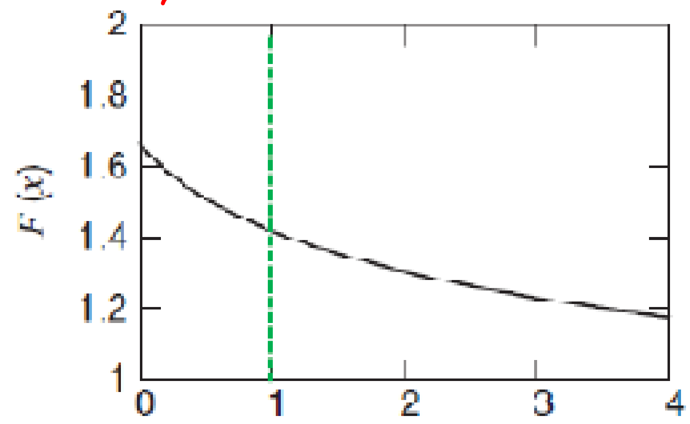
by construction

- The CKM-paradigm of CP violation accounts for the observed CP patterns to an accuracy of about 15%!
- SM3-CKM predicted value of sin2β tends to be high compared to direct (ψ K) measurements by about 15-20%...t is dominant
- Hierarchical structure [in sin2β] of SM4 mixing matrix NATURALLY lets t' be subdominant here but due to its large mass (and decoupling theorem) not negligible Leads to small ~15% deviations
- Dynamics of EW gauge interactions (evasion of decoupling theorem) by EWpenguins and the large mt' plays an important role in the large "isospin" violating ΔA_{CP} (K π)
- SM3 says B_s mixing has negligible CP-odd phase therein t' plays a dominant role (& t is subdominant) due to t

HOU, MA & LEE, PRD'09

$(g-2)_\mu$ in SM4 FFLEE

- $F(x)$, an Inami-Lim loopfunction, is well-behaved and bounded
- $F(1) = 17/12$: not singular
  Incorrectly rendered in W. Huo and T. F. Feng arXiv:0301153 and K. R. Lynch arXiv:0108081
- Since $F(x) \sim 1.4$, $|V_{N\mu}|$ needs to be ≥ 0.7 to reach within 2σ of Δa_μ



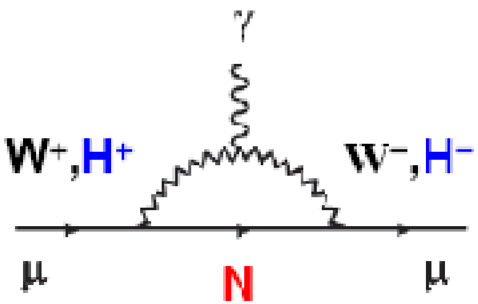
$x \left(= \frac{m_N^2}{M_W^2}\right)$

- On the other hand,

$$\mathcal{B}_{\mu\to e\gamma}(W^\pm W^\pm N) = \frac{3\alpha|V^*_{Ne}V_{N\mu}|^2}{8\pi}F^2(x)$$

$$\approx 1.2\times10^{-11}\left(\frac{|V_{N\mu}|}{0.7}\right)^2\left(\frac{|V_{Ne}|}{10^{-4}}\right)^2\left(\frac{F(x)}{1.6}\right)^2$$

upper bound



II $|V_{N\mu}| \gtrsim 0.7$ ➡ $|V_{Ne}| \lesssim 10^{-4}$ ➡ **Unrealistic!**

Δa_μ unlikely from W^+W^-N

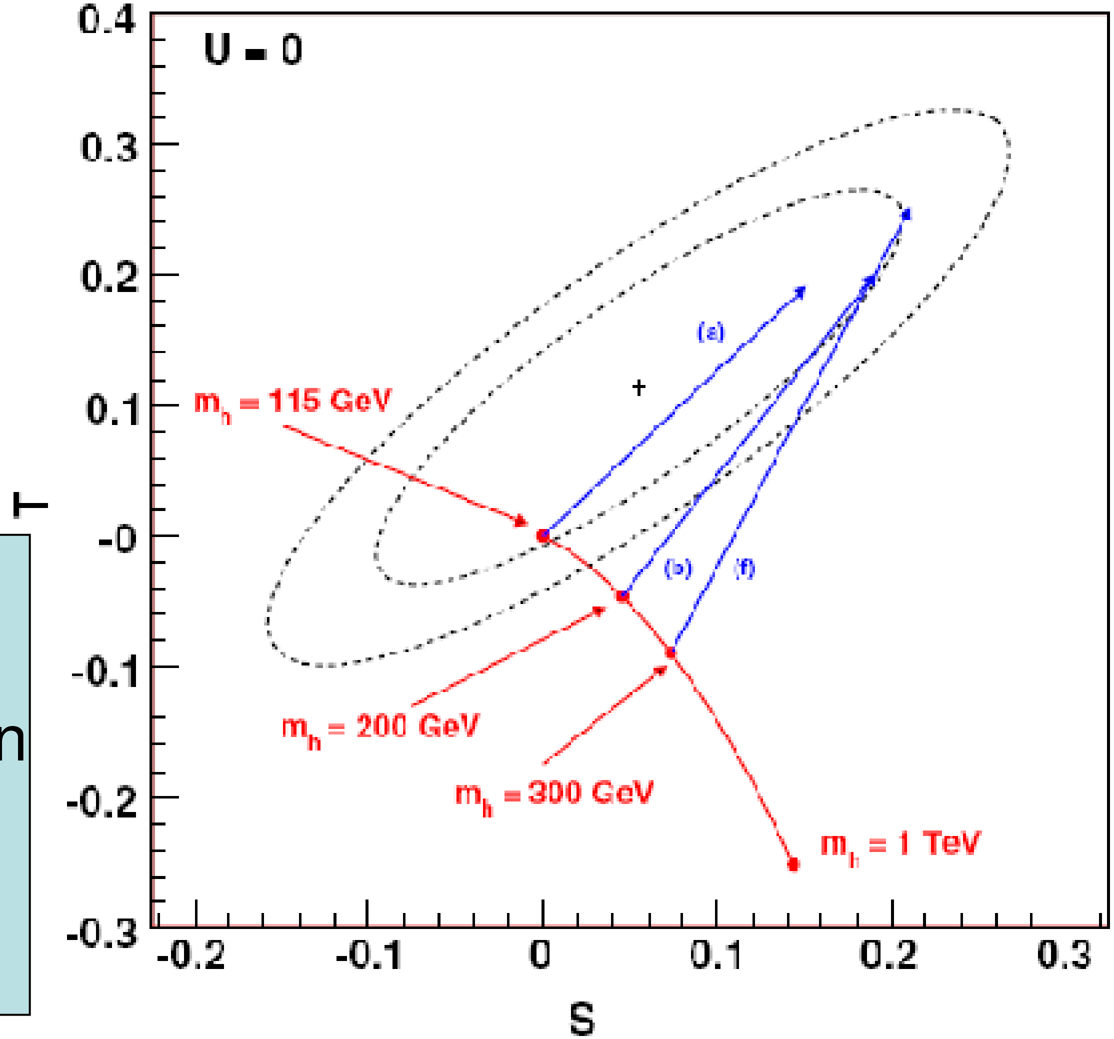
because of $\mu \to e\gamma$

① MAJORANA N?

② By-W like 2 loop diagram?

Kribs, Plehn, Spannowsky & Tait, PRD '07

TILMAN



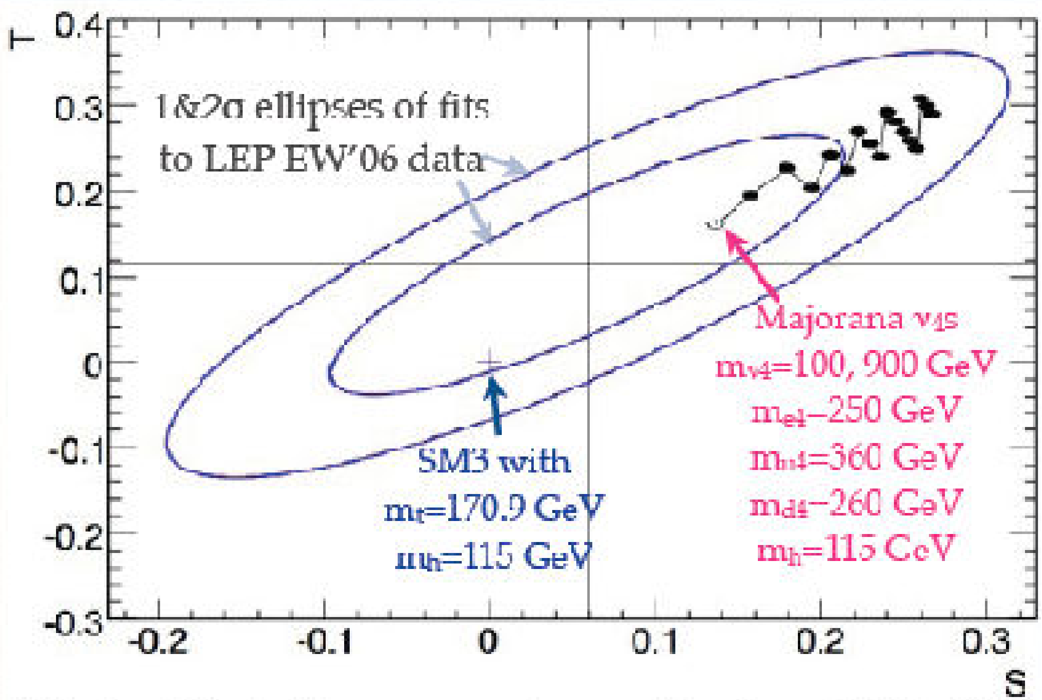
LEP EW Constraints on $m_{t'}$, $m_{b'}$, m_H

4^{th} family is not inconsistent with LEP EWPC (despite perhaps wishful thinking of some Influential PDG authors)

OZCAN

STU on L±L⁰

$m_{L^\pm} = 250$ GeV
$m_{L^0} = 100$



Black solid circles represent m_h going from 150 to 900 GeV in steps of 50 GeV, while the best value of m_{u4} goes slowly up to 390 GeV.

Implemented exact one-loop calculations from:

- B.A.Kniehl & H.G.Khors, PRD48(1993)225.
- H.J.He, N.Polonsky & S.F.Su, PRD64(2001)053004.

=> Referance scenario can easily be accomodated for light or heavy Higgs alike.

After all cuts, 1 fb^{-1} @ 14 TeV:

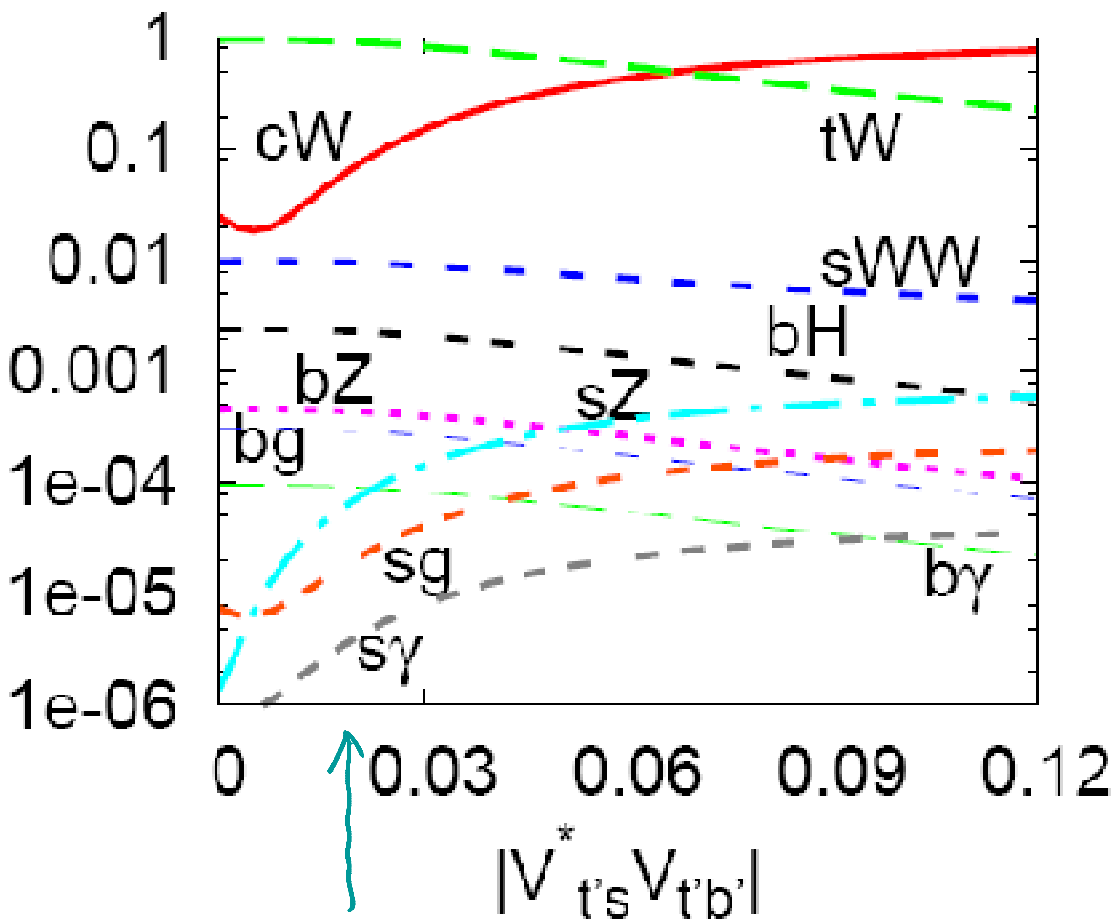
- 7 signal events
- Rudimentary background estimate = 0.22 events

Further details in: V. E. Özcan, S. Sultansoy, G. Ünel, **A Possible Discovery Channel for New Charged Leptons at the LHC**, *J. Phys.* **G** 36 (2009) 095002.

C ALSO ANTIPIN

Indirect effects: Ahrib,CHShen,Bashiry,CYMa, Nandi,(Eilam M T)…

ARHRIB (+HOU)



$m'_t \sim 400$
$m'_b \sim 340$
GeV

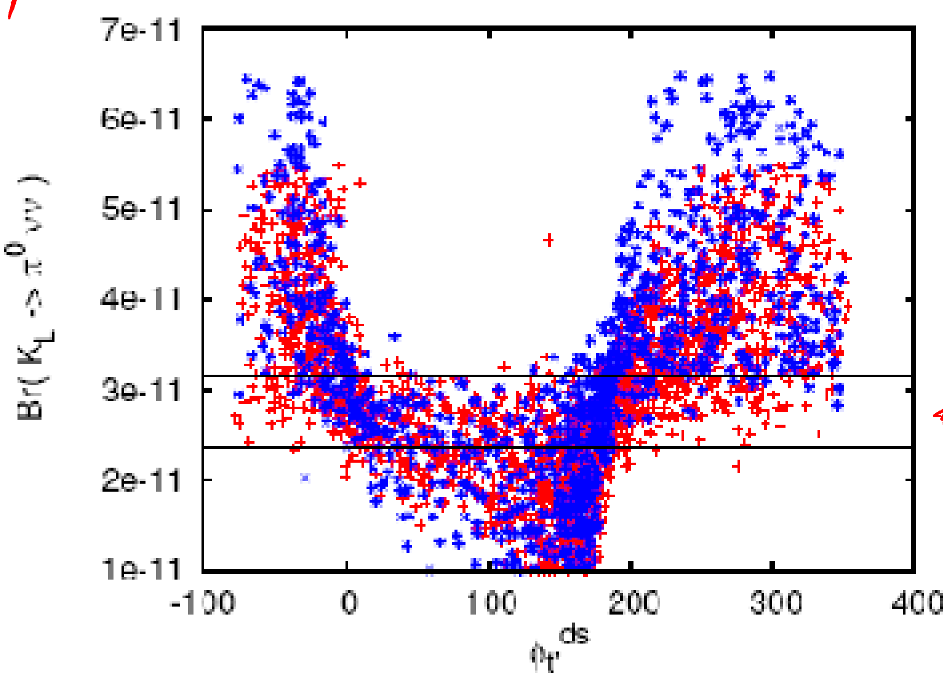
Figure 6: $m_{b'}$ = 340 GeV, $m_{t'} - m_{b'} = 50$ GeV, $V_{ts}V_{tb'} = 0.01\, e^{-i\,10^\circ}$ and $\arg(V^*_{t's}V_{t'b'}) = 70^\circ$

(ALSO EILAM, MELIC, TRAMPETIC

NANDI

Variation of $\mathbf{Br(K_L \to \pi^0 \nu \bar{\nu})}$ with $\phi^{ds}_{t'} = \phi^{d}_{t'} - \phi^{s}_{t'}$, black horizontal lines correspond to SM limit

GOLD



Red $m_{t'}$ 400

BLUE 600 GeV

SM3

$$Br(K_L \to \pi^0 \nu \bar{\nu}) \propto \left[\left(\frac{Im\lambda_t}{\lambda^5} X(x_t) + \frac{Im\lambda_{t'}}{\lambda^5} X(x_{t'}) \right)^2 \right]$$

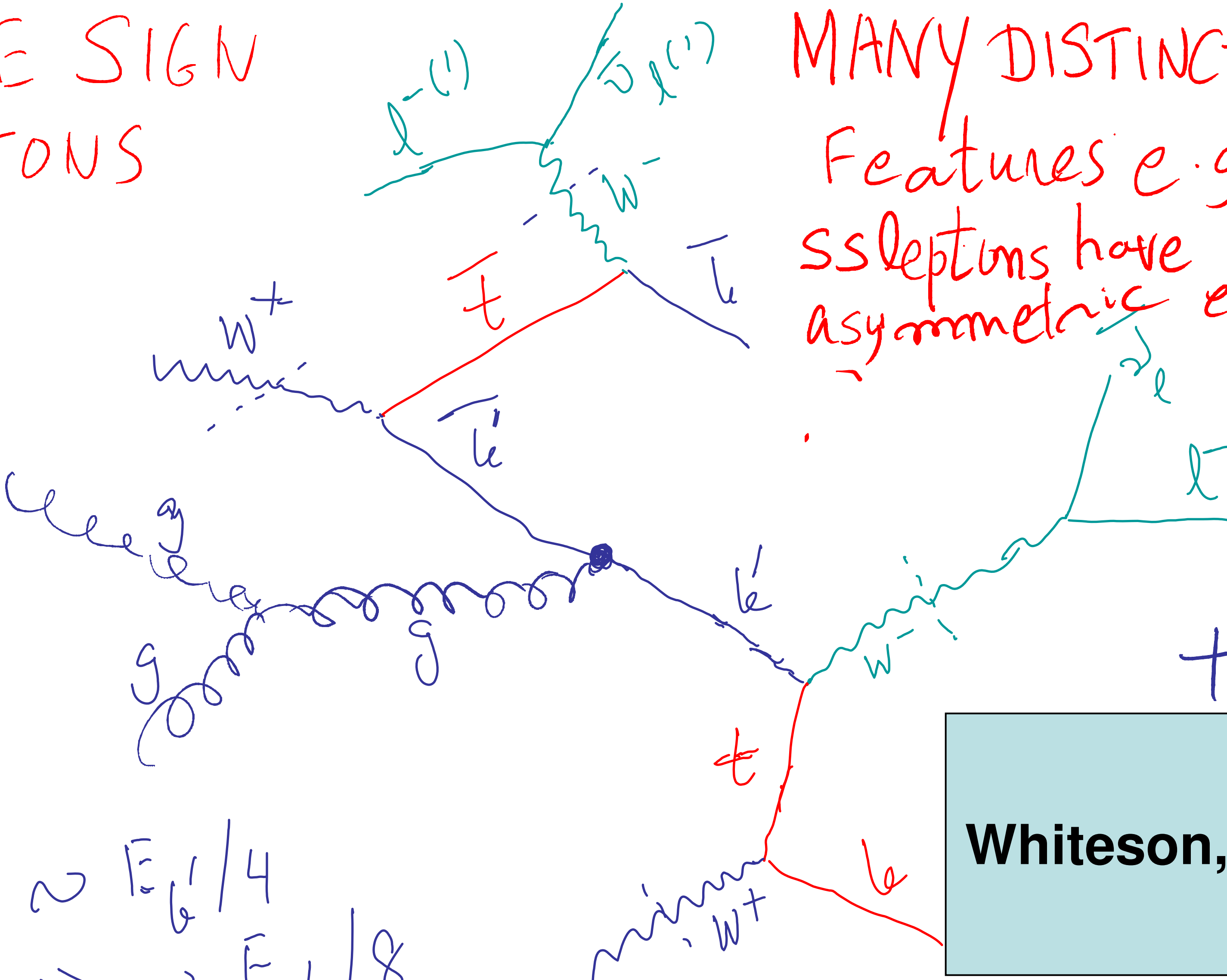
$Br(K_L \to \pi^0 \nu \bar{\nu}) = (1.0 \to 5.2) \times 10^{-11} \Rightarrow 1\,\sigma$ range in SM4

DIRECT SEARCHES

Whiteson,Bose, Ozcan,Antipin..

SAME SIGN LEPTONS

MANY DISTINCTIVE Features e.g ssleptons have asymmetric energies



$\langle E_{\ell^-} \rangle \sim E_{b'}/4$

$\langle E_{\ell^-(')} \rangle \sim E_{b'}/8$

Whiteson, Bose..

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

Limits

WHITESON

Limit

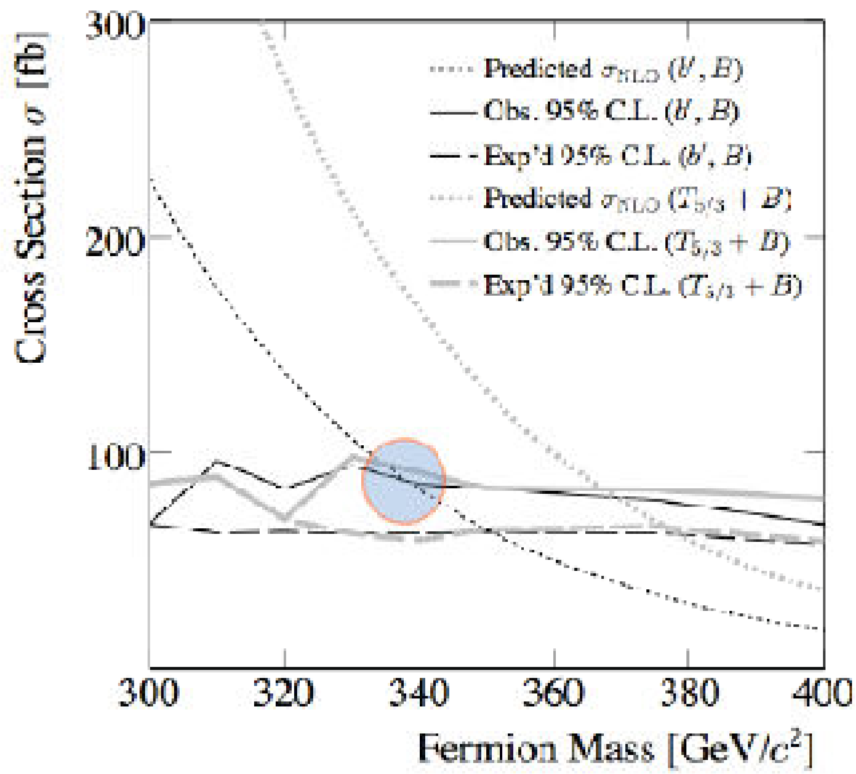
$m_{b'} > 338$ GeV

$m_{t'} > 311$

TEVATRON '11

$\sim$ 400GeV

arxiv:0912.1057



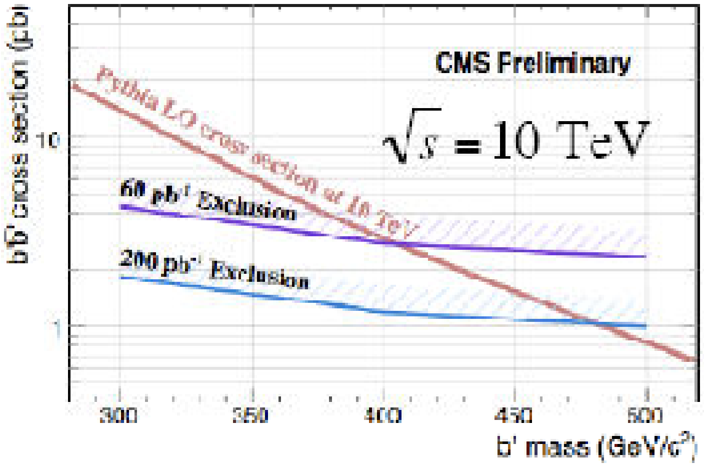
BOSE

Heavy b' limits

CMS

m(b') @ 200pb^{-1}	300 GeV	400 GeV	500 GeV
Cross-section	13.6 pb	2.8 pb	0.78 pb
Expected Yields	34.08	10.58	3.52
Background	1.08	1.08	1.08
Significance	9.0 σ	3.7 σ	1.4 σ

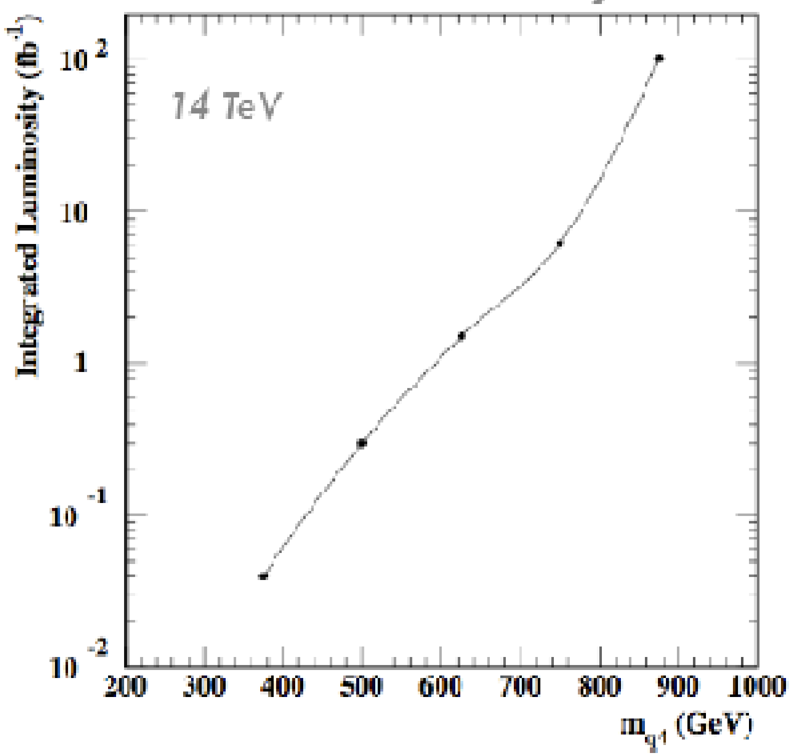
Exclude b' masses less than 485 (405) GeV with 200 (60) pb^{-1}



Stringent limits can be set at the LHC with early data

Sensitivity

5σ discovery



WHITESON

LHC should be able to cover the entire Expected mass range

From ATLAS SN-ATLAS-2008-069

ANTIPIN

We focus on the $\ell^{\pm}\ell^{\pm}$ and $\ell^{\pm}\ell^{\mp}\ell^{\mp}$ final states arising from $Z^* \to \chi\chi$ and $W^* \to \ell^{\pm}\chi$ production channels.

LHC Phenomenology II

Production and decay of new heavy leptons :

Table 1: Signal cross-sections σ (in fb) with the corresponding leading SM background for three scenarios described in the text. Pre-selection and selection criteria are also described in the text.

$\mu^{\pm}\mu^{\pm}$ X (M_{χ_1}=100 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	$S/\sqrt{B}$
$\mu^{\pm}\chi_1 : \mu^{\pm}\mu^{\pm}$ + 2 jets	1.11	0.6	6	7.25
$\chi_1\chi_1 : \mu^{\pm}\mu^{\pm}$ + 4 jets	2.5	1.32	13.2	
SM background	10.25	0.7	7	
$\mu^{\pm}\mu^{\pm}$ X (M_{χ_1}=90 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	$S/\sqrt{B}$
$\mu^{+}\chi_1 : \mu^{+}\mu^{+}$ + 2 jets	0.21	0.113	1.1	1.89
$\chi_1\chi_1 : \mu^{+}\mu^{+}$ + 4 jets	0.73	0.39	3.9	
SM background	10.25	0.7	7	
$\mu^{\pm}\mu^{\pm}$ X (M_{χ_2}=135 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	$S/\sqrt{B}$
$\mu^{\pm}\chi_1 : \mu^{\pm}\mu^{\pm}$ + 2 jets	2.1	1.1	11	6.95
$\chi_1\chi_1 : \mu^{\pm}\mu^{\pm}$ + 4 jets	1.4	0.74	7.4	
SM background	10.25	0.7	7	
$\ell^{+}\ell^{+}\ell^{\mp}$ X (M_{χ_1}=100 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	$S/\sqrt{B}$

- In the most optimistic cases early discoveries at the LHC might be expected.

C ALSO OZCAN

The Epilogue: Challenging Yogi

The Legendary American philosopher

The Future

- Yogi Berra: “Its difficult to make predictions, especially about the future”*

Yogi Berra

Catcher / Manager/ Outfielder

Born: May 12, 1925
St. Louis, Missouri

Batted: Left	**Threw:** Right

MLB debut

September 22, 1946 for the New York Yankees

Last MLB appearance

May 9, 1965 for the New York Mets

- New York Yankees (1964, 1984-1985)
- New York Mets (1972-1975)

Career highlights and awards

- 15× All-Star selection (1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962)
- 13× World Series champion (1947, 1949, 1950, 1951, 1952, 1953, 1956, 1958, 1961, 1962, 1969, 1977, 1978)
- 3× AL MVP (1951, 1954, 1955)
- New York Yankees #8 retired
- Major League Baseball All-Century Team

Member of the National

☆ ☆ ☆ Baseball Hall of Fame ☆ ☆ ☆

Induction	1972
Vote	85.61% (second ballot)

* Lifted from Sheldon Stone

Prospects: (why not?)Glorious

- By late 2010-mid'11: S($B_s \to \psi\phi$) non-vanishing to ~4 σ through combined efforts of CDF/D0/possibly LHCb!
- '11-12: Gold-plated H->ZZ!! (heavy, possibly broad)
- 12-13: Excess of same sign dileptons signaling mb'~450-500GeV!!!

BORING REPETITION?

- If the mt' is heavy ~(400-600) GeV, then for sure it will have serious role to play in EWSB .(NOTE CDF+D0 latest bound $m_{t'} > 350$ GeV).
- It will clearly have significant impact on CP violation phenomena, given that now we will have 2 additional CP-odd phases
- It may play an interesting role in baryogenesis (W.-S. Hou, 0803.1234)
- CANNOT BE A CONVENTIONAL 4th Gen..mv4>mZ/2
- Possible DMC (if no mixing with lighter 3 nu's)..see e.g. Volovik'03
- It may open up possibilty of unification (PQ Hung,'98)
- Can be observed or ruled out at LHC

Cons: "Cancellations"

- Extra contributions to EWP observables due mt',mb' need to be cancelled by the heavier "higgs"
- Similarly, |mt'-mb'| < ~ 60 GeV for mt' O(500 GeV) O(10%) degeneracy
- So how much of a concern should one give to these cons?
- Let's just remember Δ(mn-mp)<O(0.1%) We understand this now as due ISOSPIN

Summary & Conclusions (I)

- While for now no compelling evidence against CKM-picture, several fairly sizeable effects (~2 - ~3.5 σ) in B,Bs CP asymmetries are difficult to understand in SM3.

Being careful,``conservative" in such instances means hunting down seriously the underlying cause…..

- CDF/D0 finding of Bs->psi phi "anomaly" is especially interesting since, 1) it is essentially predicted by the ones from BFs, 2) unlike the other effects, this is theoretically very clean i.e. GOLD-PLATED

  Consequently, it is extremely important that FERMILAB follows it up & clarifies it with a very high priority.

Summary & Conclusions (II)

- **SM4 opens up important new avenues for baryogenesis, DMC, unification, and most likely also crucial for EWSB…thereby it may well lead to a possible resolution to the hierarchy puzzle**
- **Underlying nature of "4^{th} gen." has to be significantly diff**
- **If the effects stand further scrutiny, SM4 with mt', mb' (400-600 GeV) provides a v. simple explanation.**
- **Direct verification at LHC should be relatively easy.**
- **Suggestive also of a HEAVY (therefore most likely composite), likely broad HIGGS**
- **Dynamical EW symm breaking, strong dynamics, the lattice & high intensity facilities (e.g. SBF) may well have a crucial role to play even in the era of the LHC**

THANK YOU very much . .

Local Organizing Committee:
Paoti Chang (National Taiwan University)
Yuan-Hann Chang (National Central University)
Chuan-Hung Chen (National Cheng Kung University)
Kai-Feng Chen (National Taiwan University)
Kingman Cheung (National Tsing Hua University)
Cheng-Wei Chiang (National Central University)
Xiao-Gang He (National Taiwan University)
George Hou (National Taiwan University, Chair)
Song-Ming Wang (Academia Sinica)
Kwei-Chou Yang (Chung Yuan Christian University)
Tzu-Chiang Yuan (Academia Sinica)

for a fantastic meeting !!