天 地

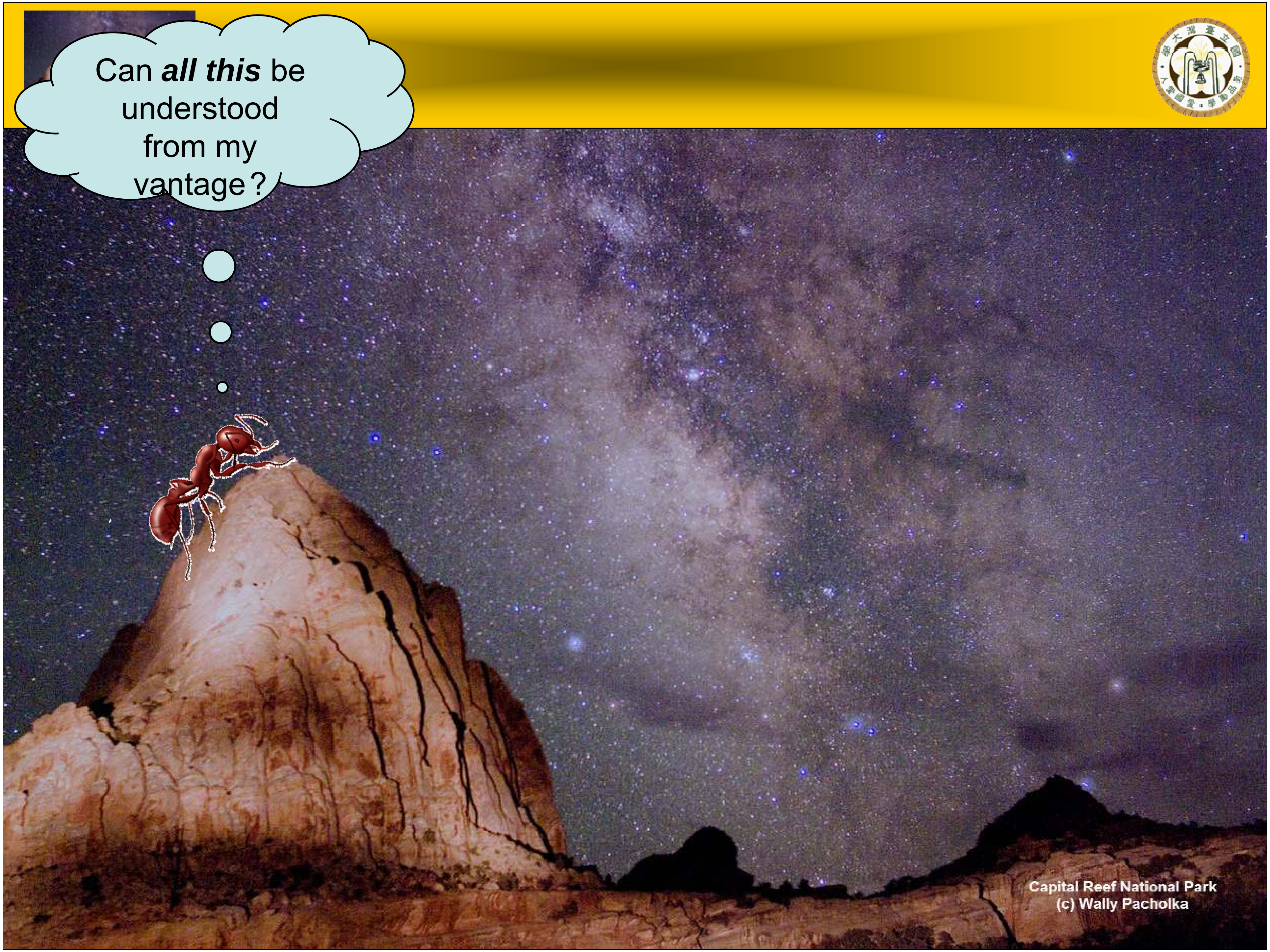
CP Violation for the Heaven and the Earth

— Sighting the 4th Generation ?

George W.S. Hou (侯維恕)
National Taiwan University

February 13, 2009, WG4/LHC2FC @ CERN

National Taiwan University


Can *all this* be understood from my vantage?
Capital Reef National Park
(c) Wally Pacholka

天 地

CP Violation for the Heaven and the Earth

— Sighting the 4th Generation ?

George W.S. Hou (侯維恕)
National Taiwan University

February 6, 2009, Wine & Cheese Seminar, Fermilab

see: http://theory.fnal.gov/jetp/

臺灣大學

National Taiwan University

BELLE

Outline

I. Intro

II. $\Delta A_{K\pi}$ & Nondecoupling: t′ in Z Penguin

1st Prediction for $\sin 2\Phi_{B_s}$

III. Δm_{B_s} & $\mathcal{B}(B \to X_s \ell^+ \ell^-)$: 2nd Prediction for $\sin 2\Phi_{B_s}$

[CKM Consistency & Implications

IV. A 10^{13}+ Enhancement of CPV for BAU ?

[V. (In)Direct Sighting: Tevatron vs LHC]

VI. Discussion/Conclusion: Know in 3-5 Years

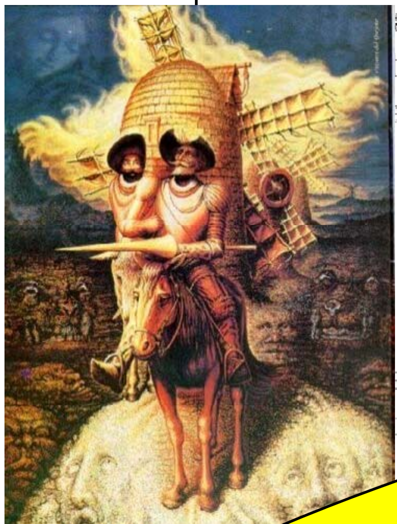
WSH, Nagashima, Soddu,
PRL'05; PRD'05; PRD'07; PRD'08
Belle, Nature, 452, 20 (2008)
WSH, arXiv:0803.1234 [hep/ph]

I. Intro

4th Generation Still?

- N_ν counting? 4th "neutral lepton" heavy
  Massive neutrinos call for new Physics

- Disfavored by EW Precision (see e.g. **J. Erler hep-ph/0604035; PDG06**



An extra generation of ordinary fermions is excluded at the 99.999% CL on the basis ... arameter alone, corresponding to $N_F = 2.81 \pm 0.24$ for the number of fa... assumes that there are no new contributions to T or U and th... amilies are degenerate. In principle this restriction can b...

July 14, 2006 10:...

10. Electroweak mode... ...ts on new physics **37**

...s well, since $T > 0$ ... a non-degenerate extra family. However, ...urrently fa... ...gthening the exclusion limits. A more detailed ... re... ...utrino (or the extra down-type quark) is close to ... This can drive S to small or even negative values but at ... ...rge contributions to T. These results are in agreement with a fit ... ...er of light neutrinos, $N_\nu = 2.986 \pm 0.007$ (which favors a larger value for ... $_Z) = 0.1231 \pm 0.0020$ mainly from R_ℓ and τ_τ). However, the S parameter fits are valid even for a very heavy fourth family neutrino.

Friday the 13th (before Valentines!!) Punishment !

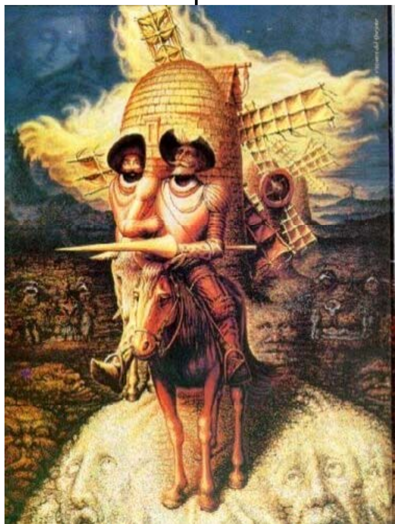
4th Generation Still?

- N_ν counting? 4th "neutral lepton" heavy
  Massive neutrinos call for new Physics

~ Tao Han's talk

- Disfavored by EW Precision (see e.g. **J. Erler hep-ph/0604035; PDG06**

An extra generation of ordinary fermions is excluded at the 99.999% CL on the basis
arameter alone, corresponding to $N_F = 2.81 \pm 0.24$ for the number of families.
assumes that there are no new contributions to T or U and therefore that
amilies are degenerate. In principle this restriction can be relaxed by allowing



July 14, 2006 10:37

10. Electroweak model and constraints on new physics **37**

as well, since $T > 0$ is expected from a non-degenerate extra family. However,
urrently favor $T < 0$, thus strengthening the exclusion limits. A more detailed
required if the extra neutrino (or the extra down-type quark) is close to
nass limit [208]. This can drive S to small or even negative values but at
the expense of too-large contributions to T. These results are in agreement with a fit to the number of light neutrinos, $N_\nu = 2.986 \pm 0.007$ (which favors a larger value for $\alpha_s(M_Z) = 0.1231 \pm 0.0020$ mainly from R_ℓ and τ_τ). However, the S parameter fits are valid even for a very heavy fourth family neutrino.

- 4th generation **not** in such great conflict with EWPrT
  Kribs, Plehn, Spannowsky, Tait, PRD'07

Emi Kou's talk

In fact, well presented !

General: Emi Kou (plenary)
[Heavy Lepton: Tao Han (plenary); could be related

ATLAS: Saleh Sultansoy (also on Higgs in WG1)
CMS: Kai-Feng Chen

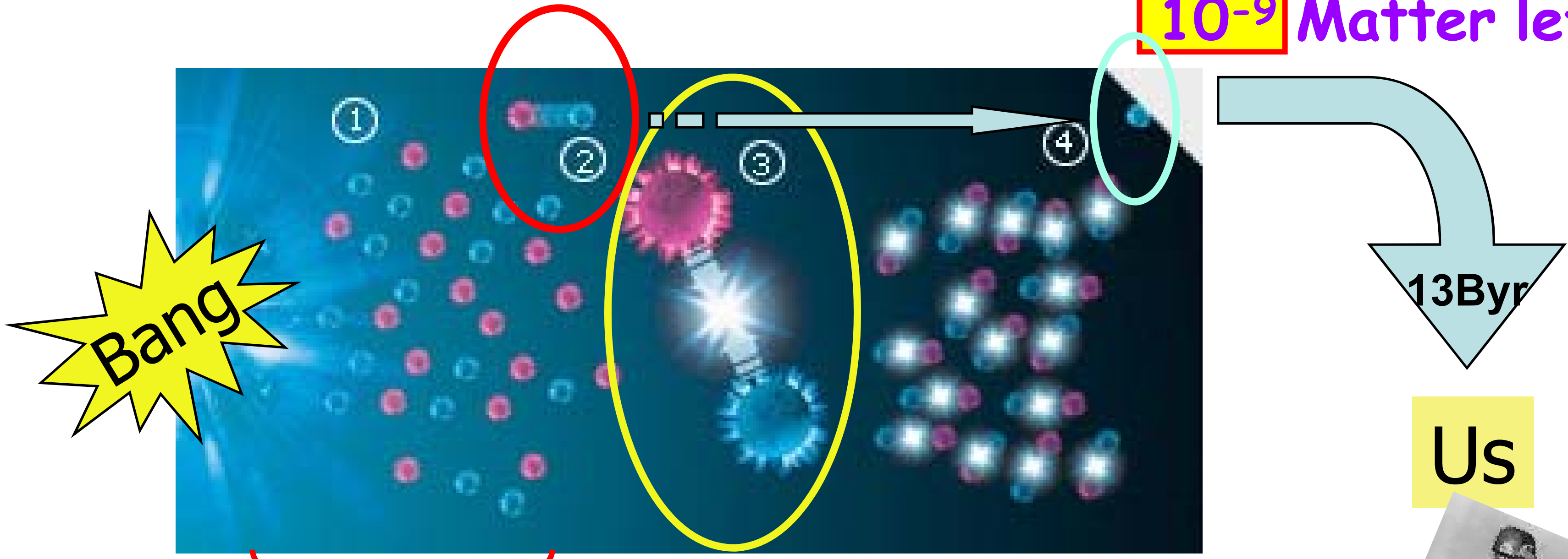
CPV: this talk

(1967)

CPV & BAU (& U): The Sakharov View

- *Baryon Number Violation*
- *CP Violation*
- Deviation from Equilibrium

10^{-9} Matter left !



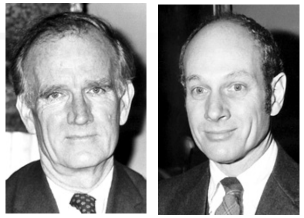
Equal Matter -Antimatter

Pair Annihilation

Us

Sakharov Stimulated by …
Discovery of CP Violation

- Phys. Rev. Lett. 13, 138 (1964)



1980 Nobel

VOLUME 13, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JULY 1964

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey

(Received 10 July 1964)

This Letter reports the results of experimental studies designed to search for the 2π decay of the K_2^0 meson. Several previous experiments have served[1,2] to set an upper limit of 1/300 for the fraction of K_2^0's which decay into two charged pions. The present experiment, using spark chamber techniques, proposed to extend this limit.

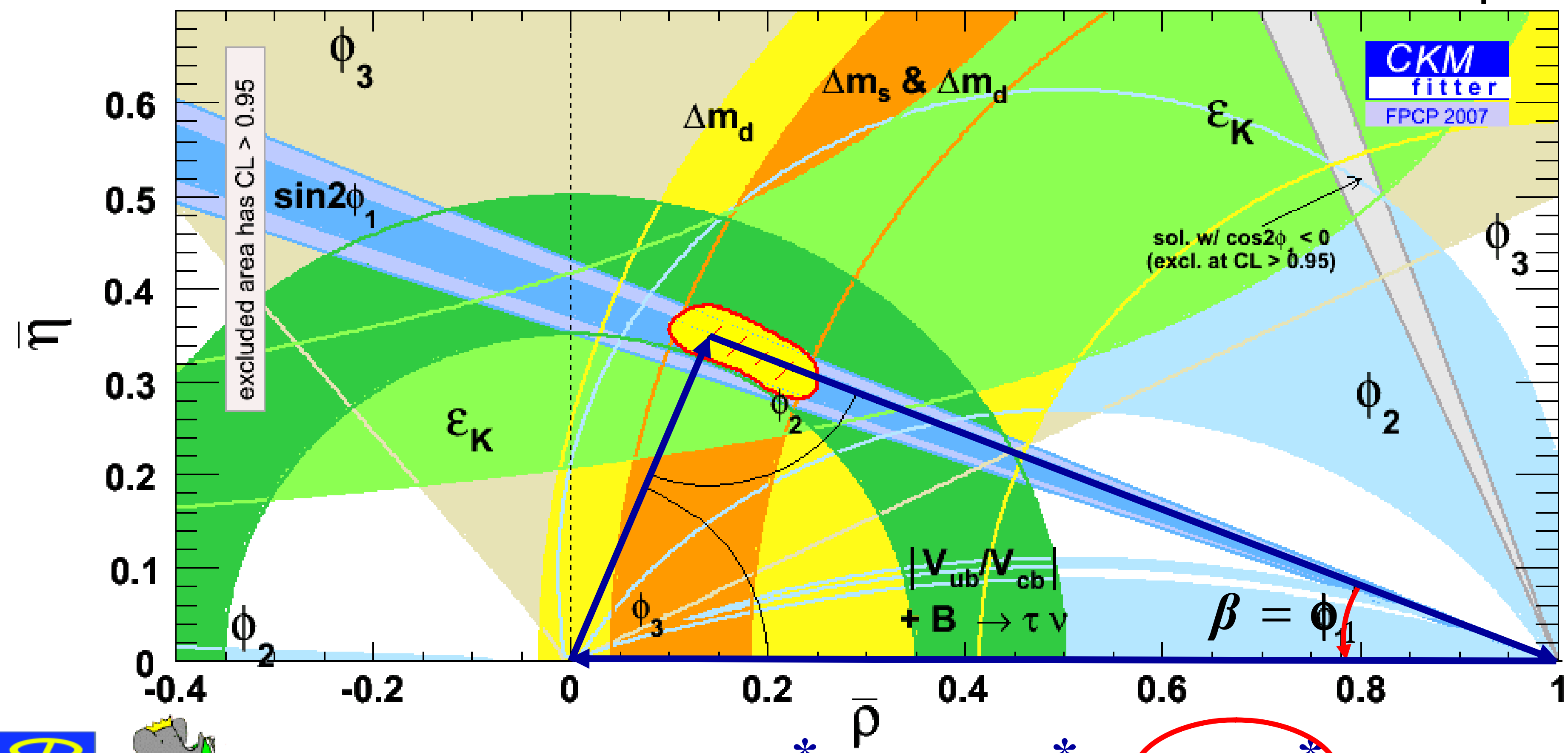
In this measurement, K_2^0 mesons were produced at the Brookhaven AGS in an internal Be target bombarded by 30-BeV protons. A neutral beam was defined at 30 degrees relative to the circulating protons by a $1\frac{1}{2}$-in.$\times 1\frac{1}{2}$-in.$\times$ 48-in. collimator at an average distance of 14.5 ft. from

The analysis program computed the vector momentum of each charged particle observed in the decay and the invariant mass, m^*, assuming each charged particle had the mass of the charged pion. In this detector the K_{e3} decay leads to a distribution in m^* ranging from 280 MeV to ~536 MeV; the $K_{\mu 3}$, from 280 to ~516; and the $K_{\pi 3}$, from 280 to 363 MeV. We emphasize that m^* equal to the K^0 mass is not a preferred result when the three-body decays are analyzed in this way. In addition, the vector sum of the two momenta and the angle, θ, between it and the direction of the K_2^0 beam were determined. This

2×10^{-3} : *Too Small .... for Sakharov !*

KM CPV Confirmed ~ 2001

the MOMA plot



"Nontrivial" $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

The Nobel Prize in Physics 2008

"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"

Photo: Universtity of Chicago

Yoichiro Nambu

1/2 of the prize

USA

Enrico Fermi Institute,
University of Chicago
Chicago, IL, USA

b. 1921
(in Tokyo, Japan)

Photo: KEK

Makoto Kobayashi

1/4 of the prize

Japan

High Energy Accelerator Research Organization (KEK)
Tsukuba, Japan

b. 1944

Photo: Kyoto University

Toshihide Maskawa

1/4 of the prize

Japan

Kyoto Sangyo University;
Yukawa Institute for Theoretical Physics (YITP),
Kyoto University
Kyoto, Japan

b. 1940

CP Violation in SM

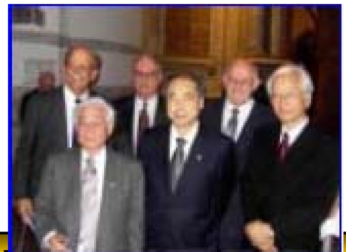
BELLE

naturenews
7 October 2008

The Belle detector in Japan helped to confirm the symmetry breaking effects predicted by theoretical physicists.

KEK

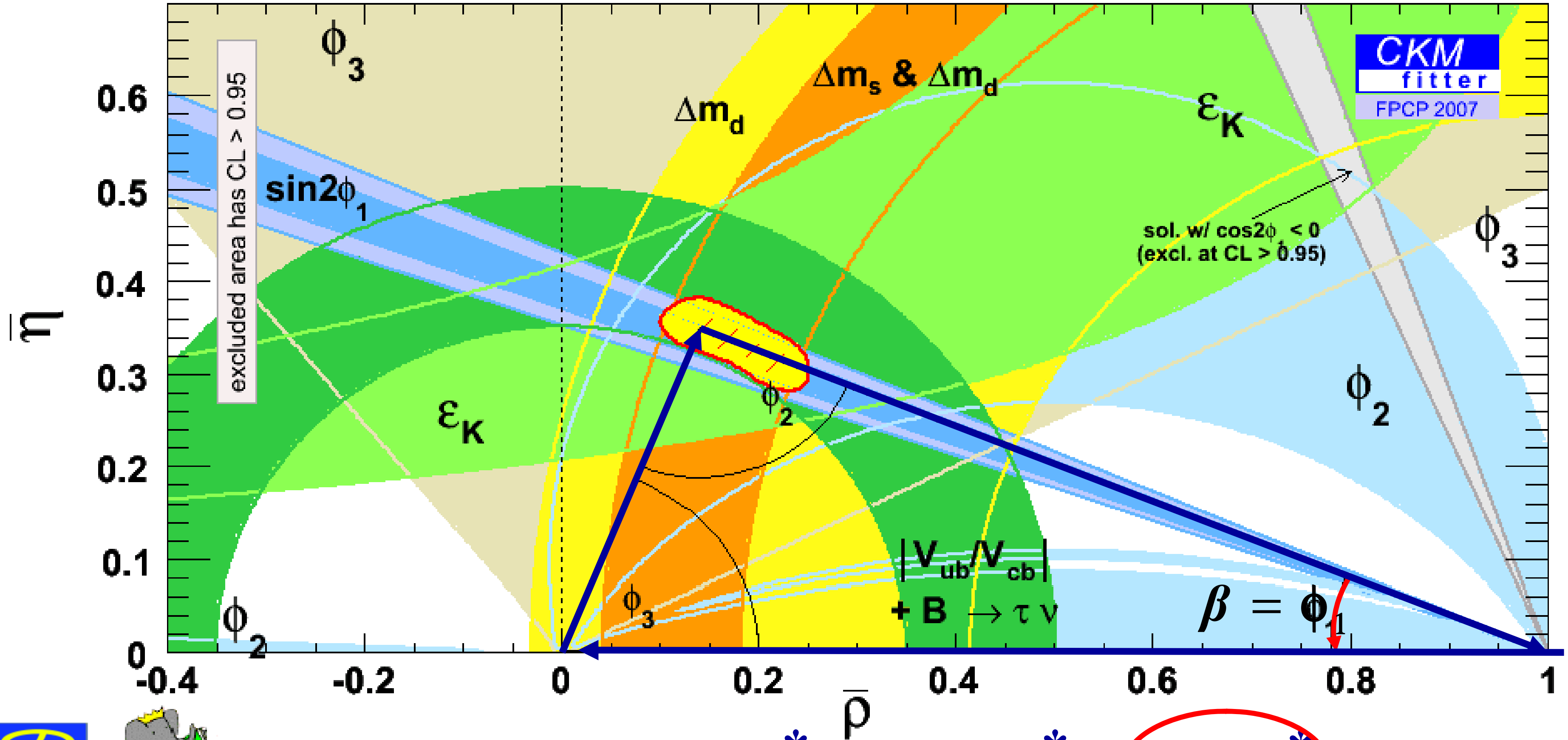
B Factories (BaBar & Belle)



b → d transitions consistent with SM

b → s: the Current Frontier

the MOMA plot



"Nontrivial"

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$

A Real Hint , ... or Not !?

II. $\Delta\mathcal{A}_{K\pi}$ & Nondecoupling: t′ in Z Penguin

1st Prediction for $\sin 2\Phi_{B_s}$

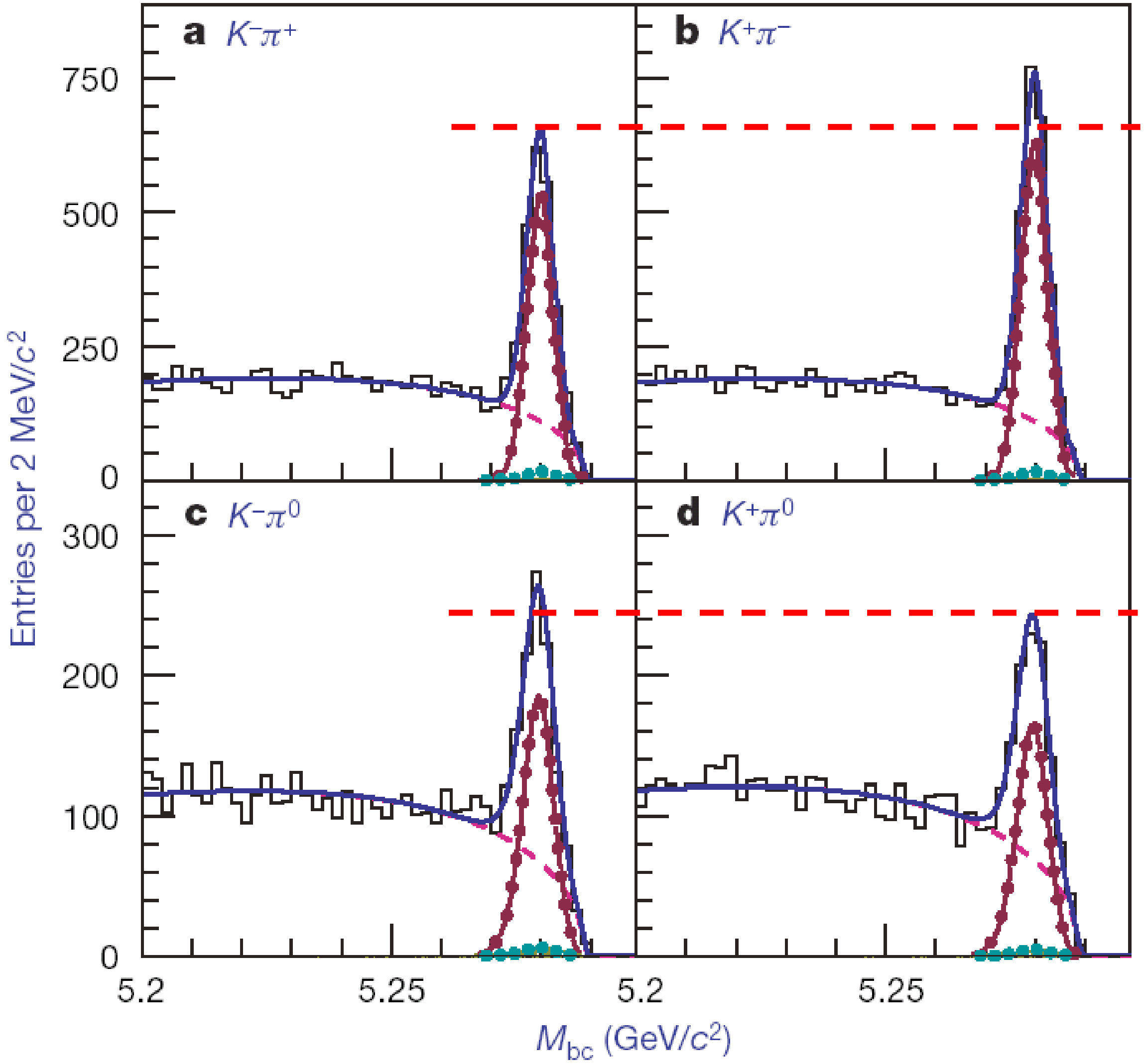
Belle 2008 Nature: Simple Bean Count

$\Delta A_{K\pi} = A_{K^+\pi^0} - A_{K^+\pi^-} = +0.164 \pm 0.037 \quad 4.4\sigma$

$+0.07 \pm 0.03$ vs -0.094 ± 0.020

LETTERS

NATURE| Vol 452| 20 March 2008



$b \to s$ CPV

Not Predicted !

Difference Is Large !

And Established

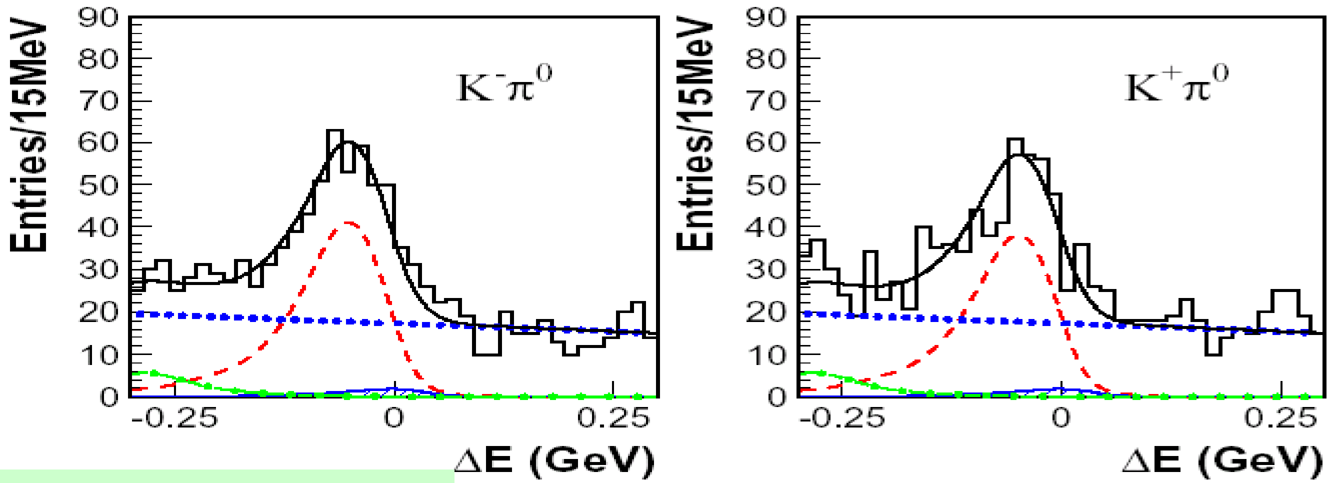
Belle + BaBar (+ CDF)

$A_{CP}(B \to K^+\pi^0)$

Sakai

275M $B\bar{B}$ New

$K^{\pm}\pi^0$: 728 ±53

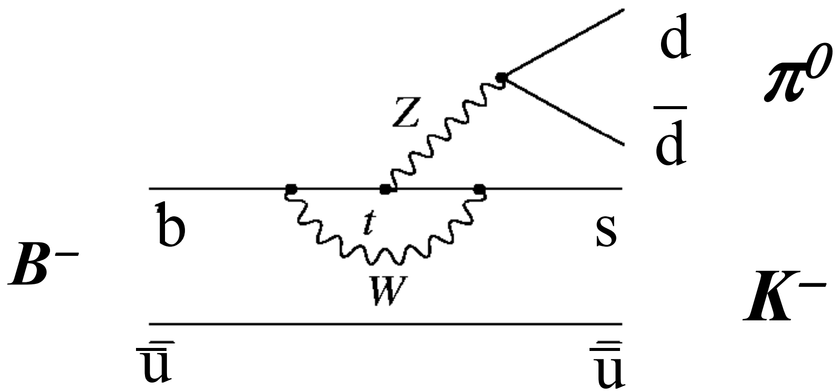


$$A_{CP}(K^{\pm}\pi^0) = 0.04 \pm 0.05 \pm 0.02$$

hint that $A_{CP}(K^+\pi^-) \neq A_{CP}(K^{\pm}\pi^0)$? (2.4σ) [also seen by BaBar]

Large EW penguin (Z^0) ?

New Physics ?

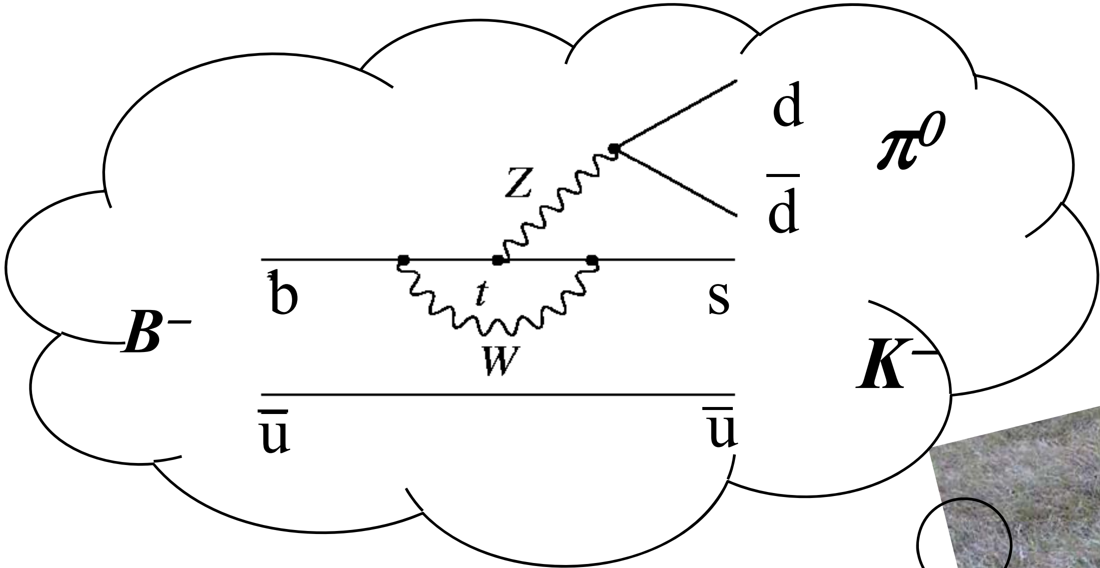


It would seem that we are well on the way to understanding the basis of particle–antiparticle asymmetry in the early Universe.

In fact, we are not. The KM predictions depend crucially on the masses of the intermediate-mass s and c quarks. But the high temperature of the Universe just after the Big Bang makes these masses irrelevant in calculations of the cosmic-matter excess. The degree of asymmetry predicted by the KM model is ten orders of magnitude too small.

the experimentalist

The Crawlin' of one Ant



Going Up a Hill ...

My first B paper

WSH, Willey, Soni

VOLUME 58, NUMBER 16 PHYSICAL REVIEW LETTERS 20 APRIL 1987

an by Inami and Lim,[9] and we follow their notation. The effective Lagrangean arising from Fig. 1 is

$$\mathcal{L}_{\rm eff}^{b\bar s\to l^+l^-} = 2\sqrt{2}G_F\chi v_i\{\bar C_i(\bar s\gamma_\mu L b)(\bar l\gamma_\mu L l) - s_W^2(F_1^i + 2\bar C_i^Z)(\bar s\gamma_\mu L b)(\bar l\gamma_\mu l) - s_W^4 F_2^i[\bar s i\sigma_{\mu\nu}(q_\nu/q^2)(m_s L + m_b R)b](\bar l\gamma_\mu l)\}, \quad (1)$$

$$\mathcal{L}_{\rm eff}^{b\bar s\to\nu\bar\nu} = -2\sqrt{2}G_F\chi v_i\bar D_i(\bar s\gamma_\mu L b)(\bar\nu\gamma_\mu L\nu), \quad (2)$$

where $\chi = g^2/16\pi^2$, $v_i \equiv V_{is}^* V_{ib}$, i is summed from 2 to n (where n is the number of generations),[10] s_W is the sine of the Weinberg angle, and we exhibit[11]

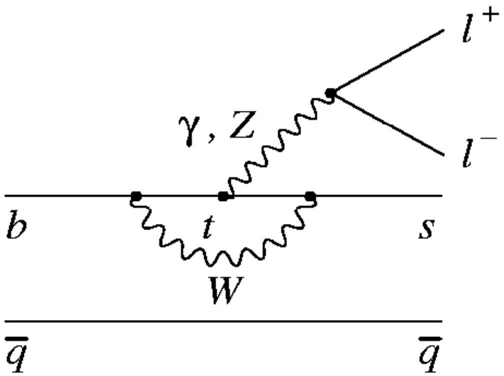
$$\bar C_i \equiv \bar C_i^Z + \bar C_i^{\rm box} = \tfrac{1}{4}x_i + \frac{3}{4}\left[\frac{x_i}{x_i-1}\right]^2 \ln x_i - \frac{3}{4}\frac{x_i}{x_i-1}, \quad (3)$$

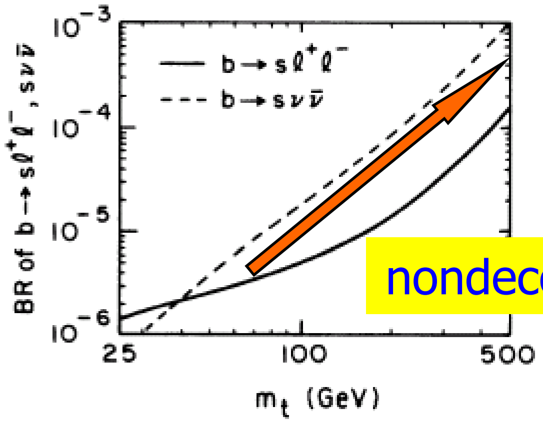
$$\bar D_i \equiv \bar D_i^Z + \bar D_i^{\rm box} = \tfrac{1}{4}x_i + \frac{3}{4}\frac{x_i(x_i-2)}{(x_i-1)^2}\ln x_i + \frac{3}{4}\frac{x_i}{x_i-1}, \quad (4)$$

dimensions

γ		Z
αG_F	<	$G_F^2 m_t^2$

where $x_i = m_i^2/M_W^2$, and m_i is the internal quark mass. The important feature of Eqs. (3) and (4) is the term $x_i/4$,[8]





nondecoupling

Nondecoupling

Decoupling Thm: Heavy Masses are decoupled in QED/QCD

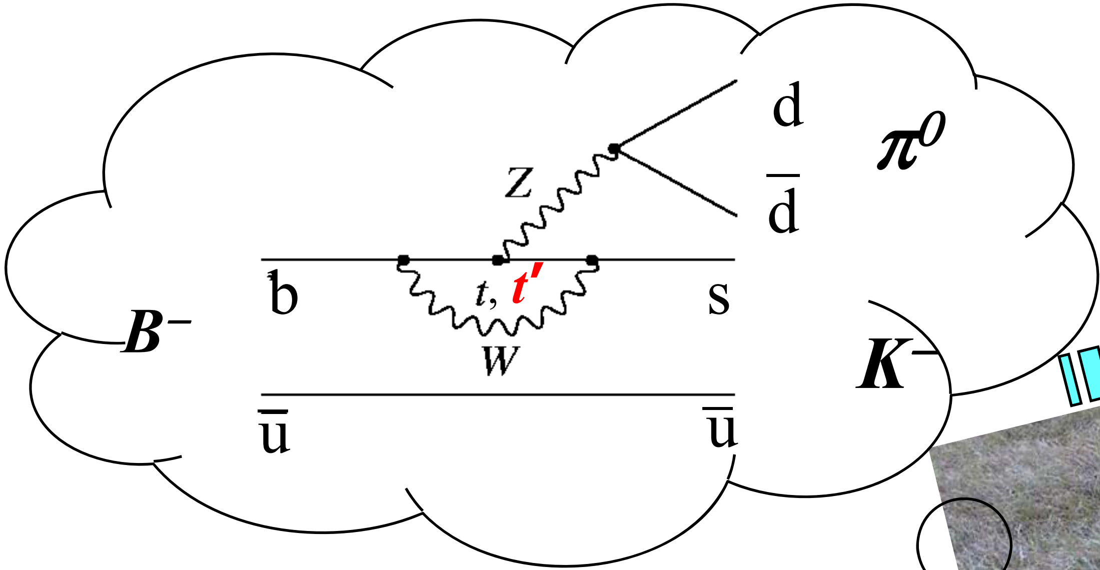
∵ Appear in Propagator

Nondecoupling: Yukawa Couplings λ_Q Appear in Numerator

dynamical

Subtlety of Spont. Broken Gauge Theory

The Crawlin' of one Ant



Going Up a Hill* ...

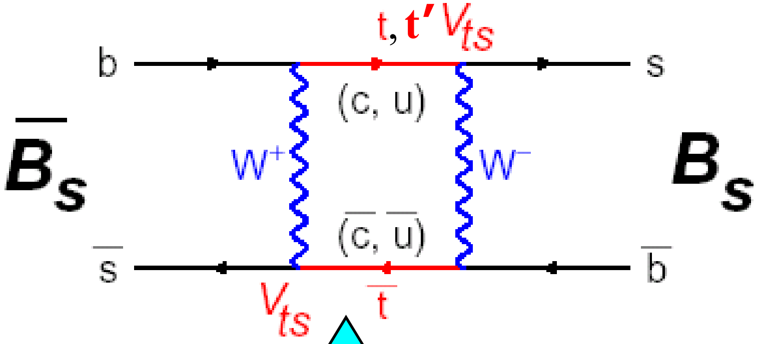
* I am aware of hadronic (color-suppressed C) complications

This is Still the Standard Model

$$\lambda_{t'} \equiv V^*_{t's} V_{t'b} \equiv r_{sb}\, e^{i\phi_{sb}}$$

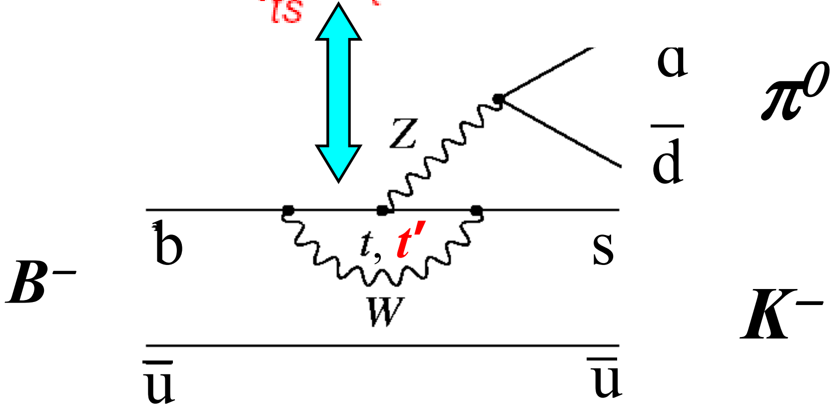
Arhrib and WSH, EPJC'03

t ⇨ t, t'

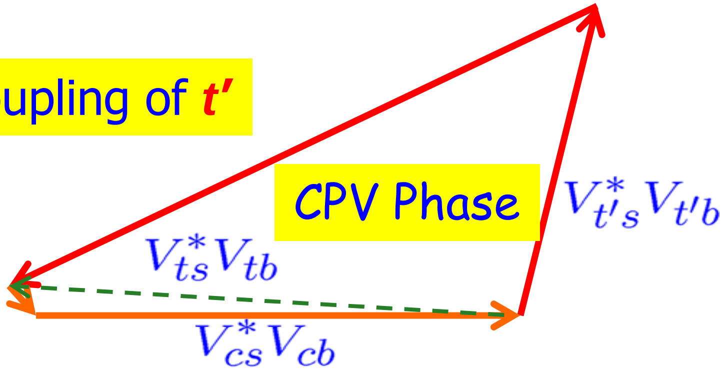


$$\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0$$

$$\lambda_t \cong -\lambda_c - \lambda_{t'}$$



Nondecoupling of *t'*



$$M_{12} \propto f^2_{B_s} B_{B_s} \{ \lambda_c^2 S_0(t,t) + 2\lambda_c \lambda_{t'} [S_0(t,t) - S_0(t,t')] + \lambda_{t'}^2 [S_0(t,t) - 2S_0(t,t') + S_0(t',t')] \}$$

GIM Respecting

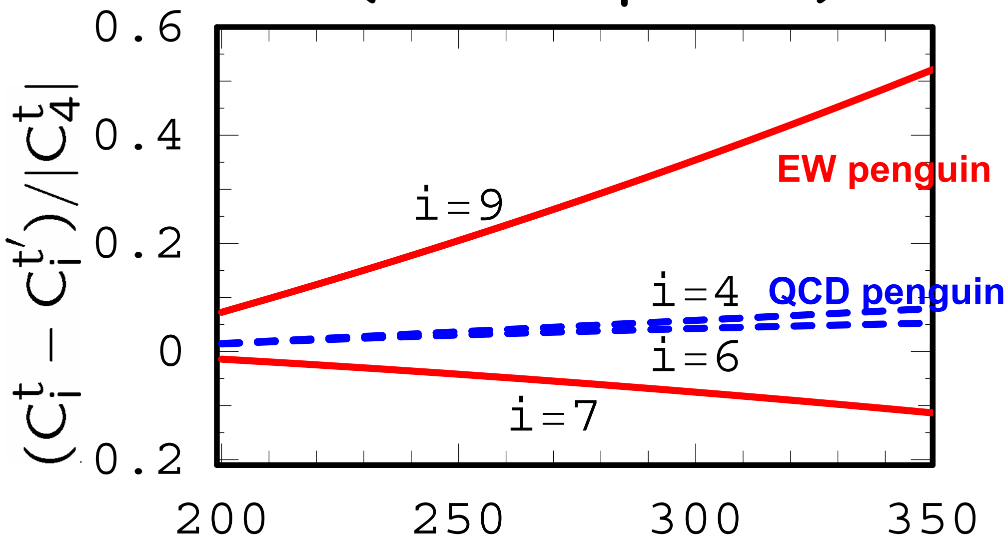
$$H^4_{\rm eff} = \frac{G_F}{\sqrt{2}} \left[\lambda_u (C_1 O_1 + C_2 O_2) + \sum_{i=3}^{10} (\lambda_c C_i^t - \lambda_{t'} (C_i^{t'} - C_i^t)) O_i \right]$$

EWP/Box Sensitivity to 4th Gen.

γ, g less sensitive

(No New Operators)

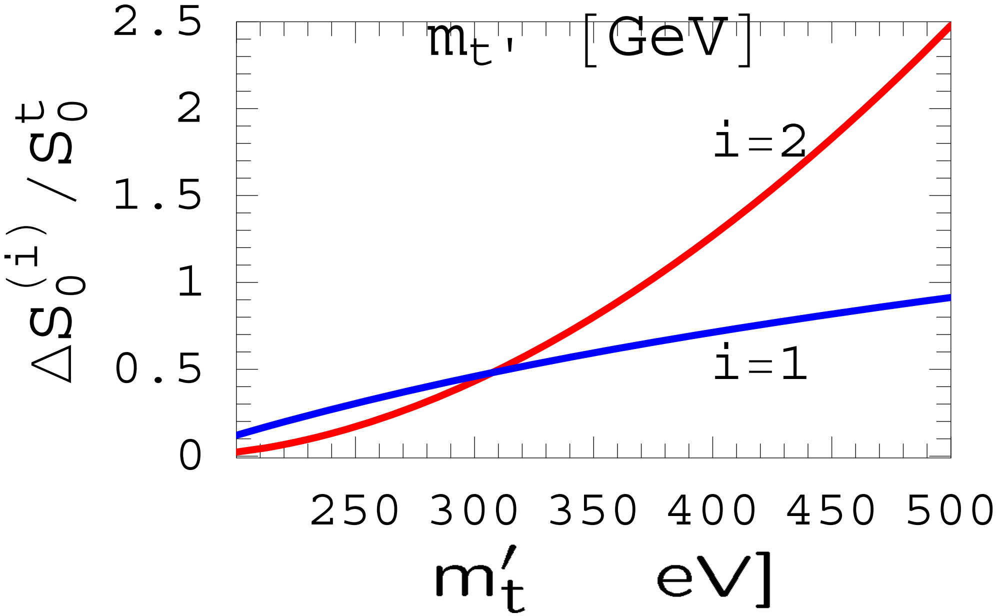
$$C_9^t - C_9^{t'} \propto x_t - x_{t'}$$



nondecoupling

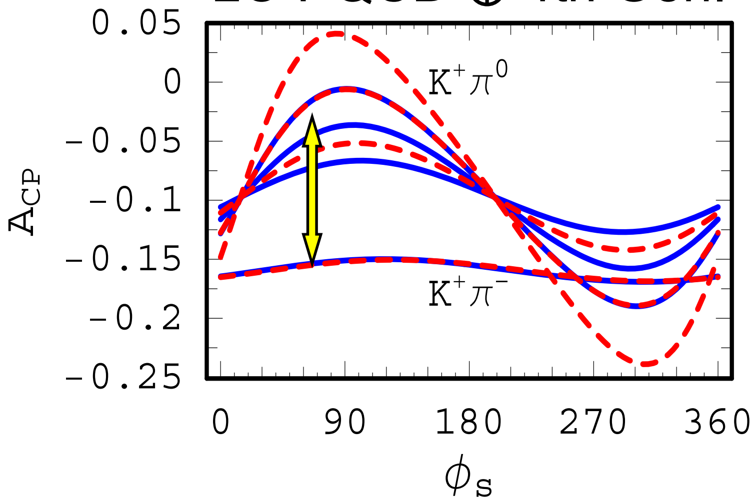
$$\Delta S_0^{(1)} = S_0(t,t') - S_0(t,t)$$

$$\Delta S_0^{(2)} = S_0(t',t') + S_0(t,t) - 2S_0(t,t')$$



$\Delta A = A_{K^+\pi^0} - A_{K^+\pi^-} \sim 15\%$ and $P_{EW}^{b\to s}$

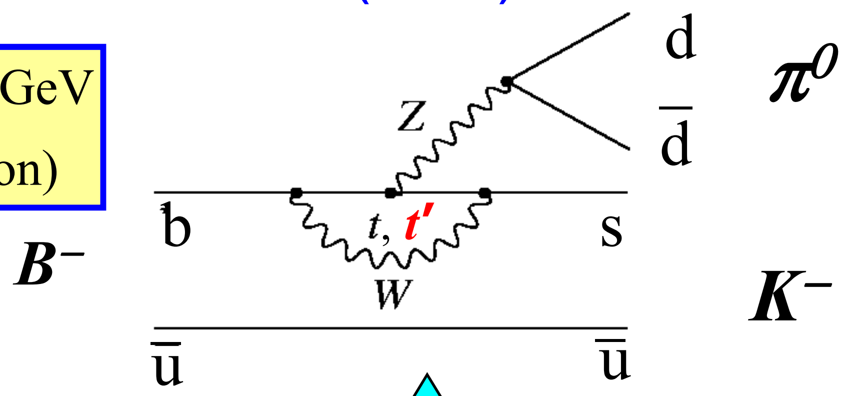
LO PQCD ⊕ 4th Gen.

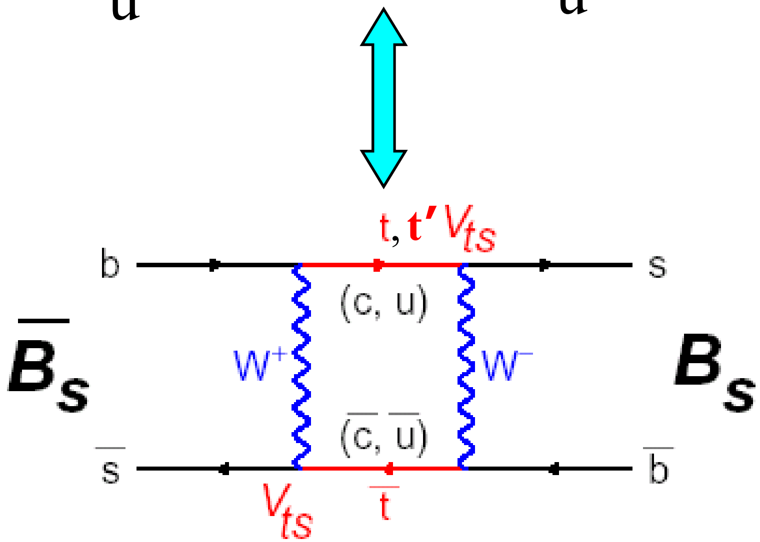


WSH, Nagashima, Soddu, PRL'05

$\Delta A \approx 12\%$ vs 15% (data)

$m_{t'} = 300$ GeV
(illustration)





PRL **95,** 141601 (2005) PHYSICAL REVIEW LETTERS week ending 30 SEPTEMBER 2005

Difference in B^+ and B^0 Direct CP Asymmetry as an Effect of a Fourth Generation

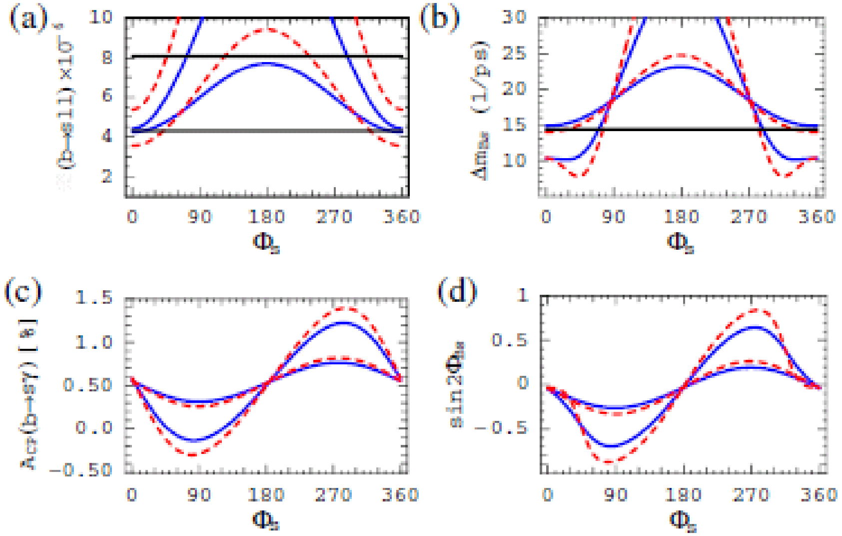
Wei-Shu Hou, Makiko Nagashima, and Andrea Soddu

Department of Physics, National Taiwan University, Taipei, Taiwan 106, Republic of China

(Received 8 March 2005; revised manuscript received 20 June 2005; published 30 September 2005)

Direct CP violation in $B^0 \to K^+\pi^-$ decay has emerged at the -10% level, but the asymmetry in $B^+ \to K^+\pi^0$ mode is consistent with zero. This difference points towards possible new physics in the electroweak penguin operator. We point out that a sequential fourth generation, with sizable $V^*_{t's}V_{t'b}$ and near maximal phase, could be a natural cause. We use the perturbative QCD factorization approach for $B \to K\pi$ amplitudes. While the $B^0 \to K^+\pi^-$ mode is insensitive to t', we critically compare t' effects on direct CP violation in $B^+ \to K^+\pi^0$ with $b \to s\ell^+\ell^-$ and B_s mixing. If the $K^+\pi^0 - K^+\pi^-$ asymmetry difference persists, we predict $\sin 2\Phi_{B_s}$ to be negative.

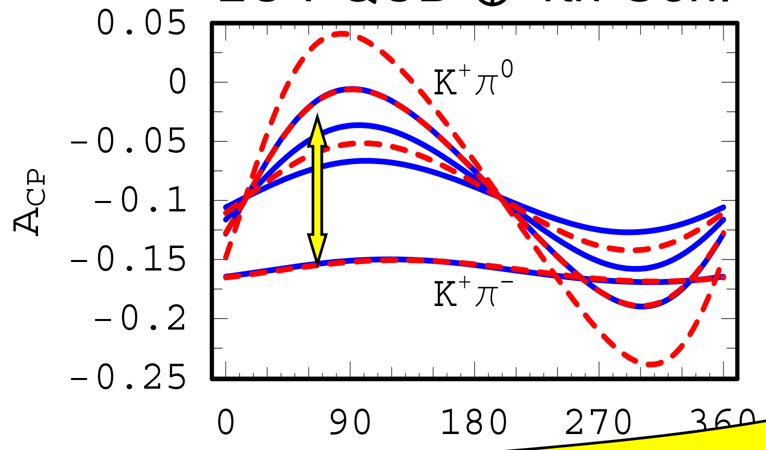
As prediction, we find $\sin 2\Phi_{B_s} < 0$ for CPV in B_s mixing, which is plotted versus ϕ_s in Fig. 3(d). We find $\sin 2\Phi_{B_s}$ in the range of -0.2 to -0.7 and correlating with $\mathcal{A}_{K\pi^0} - \mathcal{A}_{K\pi}$. Three generation SM predicts zero. Note that refined measurements of $\mathcal{B}(b \to s\ell\ell)$ and future measurements of Δm_{B_s} and $\sin 2\Phi_{B_s}$, together with theory improvements, can pinpoint $m_{t'}$, r_s, and ϕ_s. We note further that [6] $14.4\ \mathrm{ps}^{-1} < \Delta m_{B_s} < 21.8\ \mathrm{ps}^{-1}$ cannot yet be excluded because data are compatible with a signal in this region. We eagerly await B_s mixing and associated CPV measurement in the near future.



$\Delta A = A_{K^+\pi^0} - A_{K^+\pi^-} \sim 15\%$ and $P_{EW}^{b\to s}$

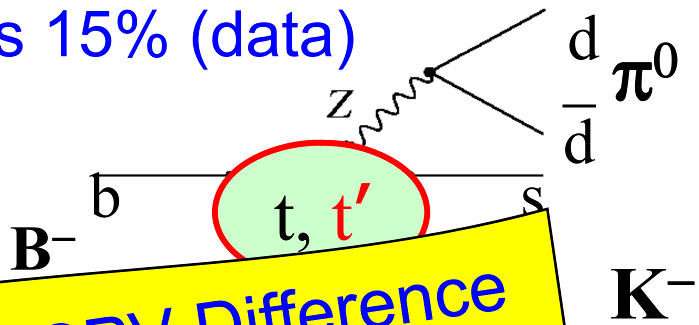
LO PQCD ⊕ 4th Gen.

WSH, Nagashima, Soddu, PRL'05



$\Delta A \approx 12\%$ vs 15% (data)

$m_{t'} = 300$ GeV (illustration)



$r_{sb} = $ 0.03: red, dash
0.02: blue, solid
0.01: green, dot-dash

Can Account for Belle/BaBar Direct CPV Difference

…, Li, Mishima, Nagashima, PRL'07

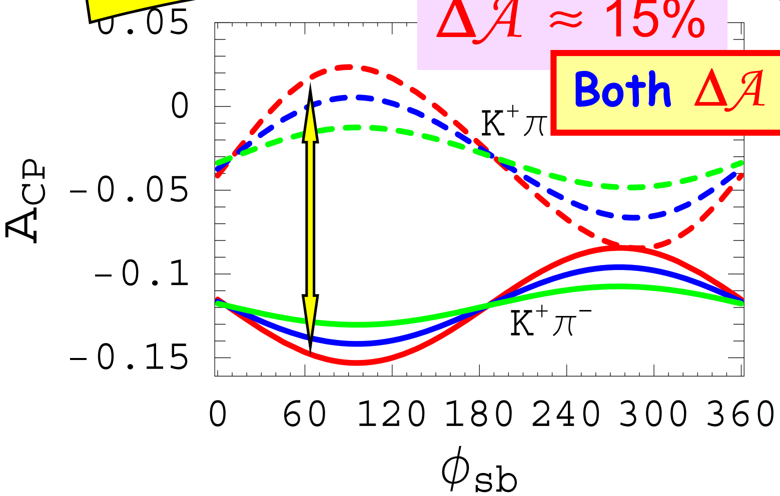
Joining C & P_{EW}

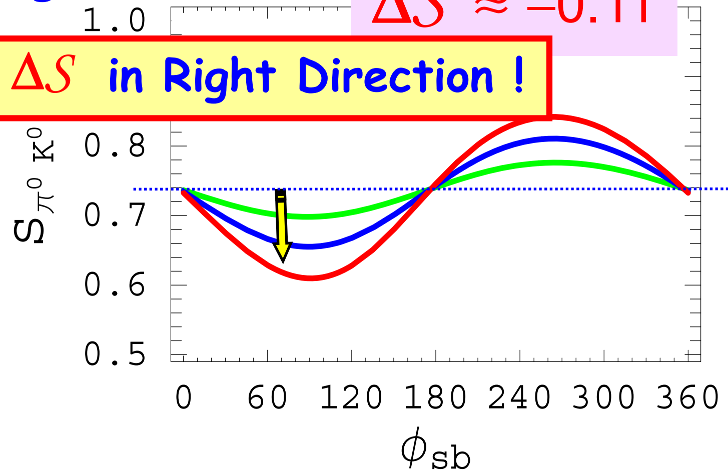
$\Delta\mathcal{A} \approx 15\%$

$\Delta\mathcal{S} \approx -0.11$

Both $\Delta\mathcal{A}$ and $\Delta\mathcal{S}$ in Right Direction !

consistent with data



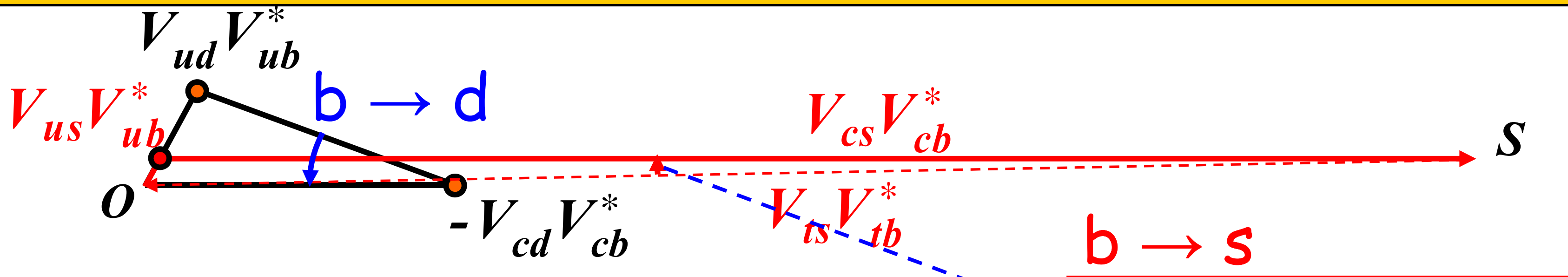


SM3 input

$b \leftrightarrow s$ *CPV*

III. Δm_{B_s} & $\mathcal{B}(B \to X_s \ell^+ \ell^-)$: 2nd Prediction for $\sin 2\Phi_{B_s}$

Mixing-dep. CPV in B_d and B_s in SM



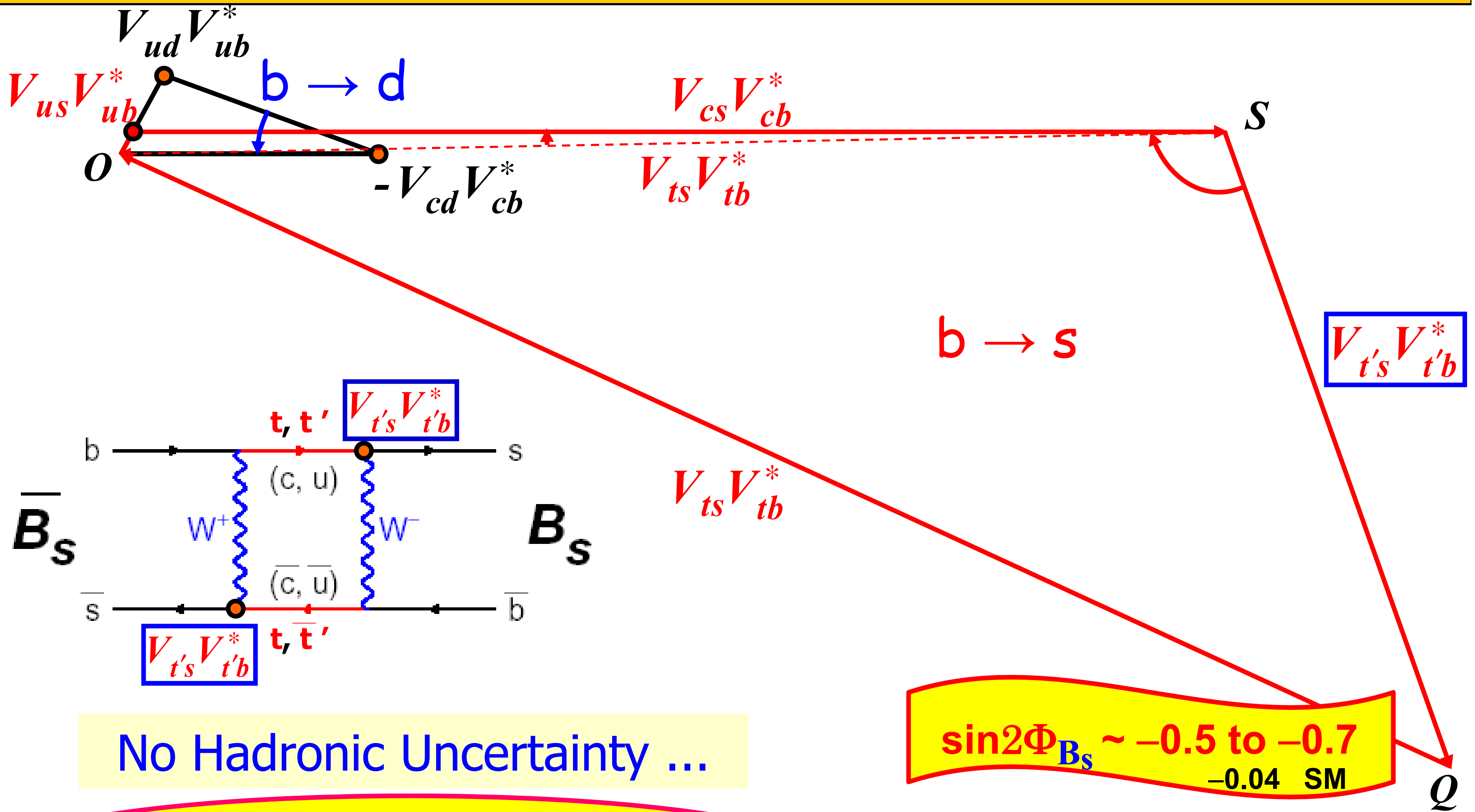
$\sin 2\phi_1 = \sin 2\beta$

Measured by Belle/BaBar
in $B_d \to J/\psi K_S$

$\sin 2\Phi_{B_s} \simeq -0.04$ in SM3

Measure in $B_s \to J/\psi\phi$

Prediction: Large CPV in B_s Mixing



$\sin 2\Phi_{B_s}$ ~ –0.5 to –0.7

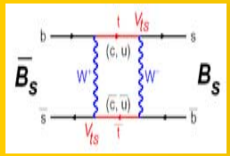
–0.04 SM

No Hadronic Uncertainty ...

Strength and Size of $\sin 2\Phi_{B_s}$

Despite Δm_{B_s}, $\mathcal{B}(b \to s\ell\ell)$ SM-like

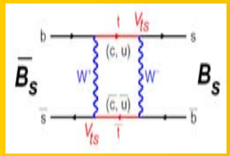
WSH, Nagashima, Soddu, PRD'07 PRL'05



B_s Mixing vs **$B \to X_s \ell^+ \ell^-$**

different nondecoupl. functions

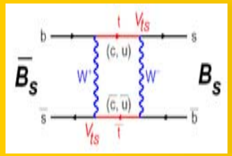
Large CPV in B_s Mixing



Use nominal $m_{t'}$ = 300 GeV
Change $m_{t'}$, Change parameter range
Effect the Same.

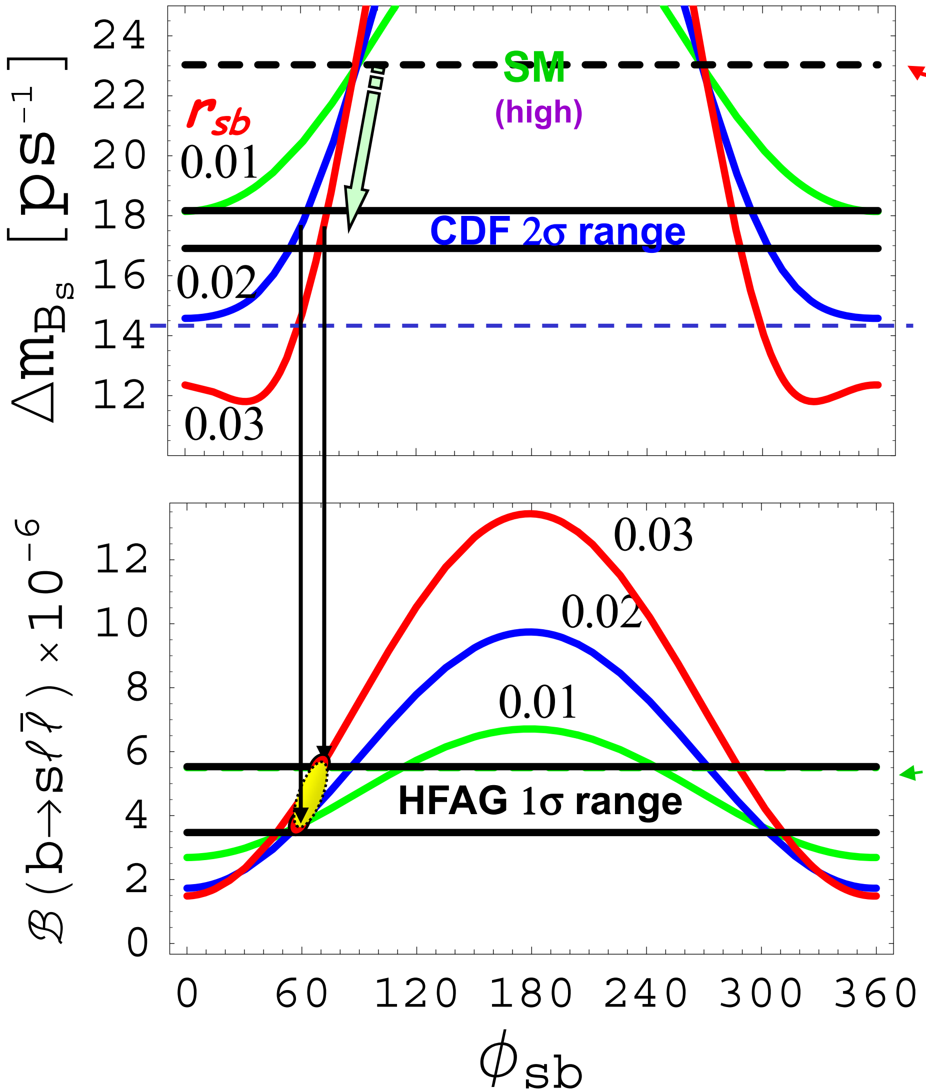
(Similar)

N.B. $\Delta A_{K\pi}$ suggest parameter space



$$\lambda_{t'} \equiv V^*_{t's} V_{t'b} \equiv r_{sb}\, e^{i\phi_{sb}}$$

WSH, Nagashima, Soddu, hep-ph/0610385 (PRD'07)



$$f_{B_s}\sqrt{B_{B_s}} = 295 \pm 32 \text{ MeV}$$

- Fixed r_{sb} ⇨ Narrow ϕ_{sb} Range
  destructive with top
- For r_{sb} ~ 0.02 – 0.03, [V_{cb} ~ 0.04

ϕ_{sb} Range ~ 60˚ - 70˚

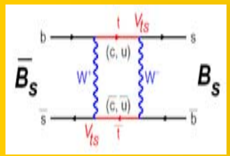
Finite CPV Phase

Consistent w/ $\mathcal{B}(b\to s\ell\ell)$

SM-like !

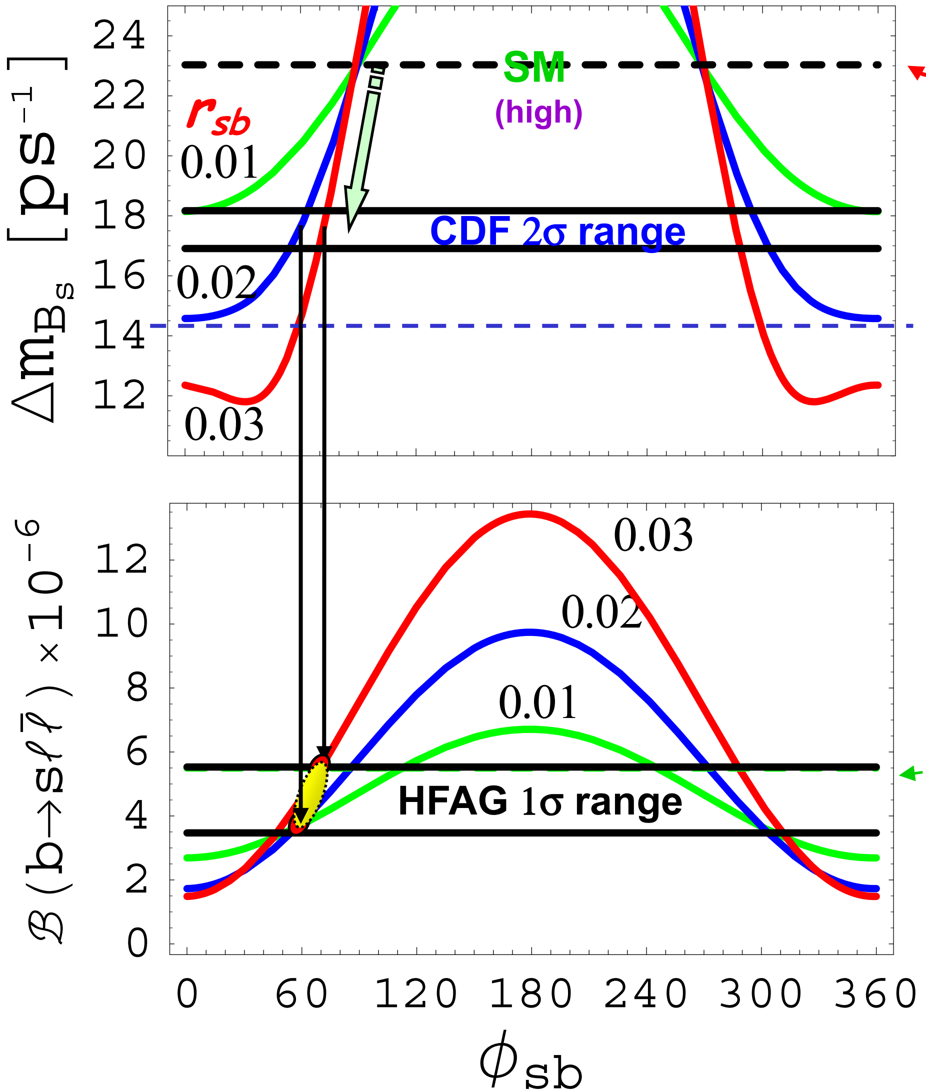
Large CPV Possible !

Despite Δm_{B_s}, $\mathcal{B}(b\to s\ell\ell)$ SM-like



$$\lambda_{t'} \equiv V^*_{t's} V_{t'b} \equiv r_{sb}\, e^{i\phi_{sb}}$$

WSH, Nagashima, Soddu, hep-ph/0610385 (PRD'07)



$$f_{B_s}\sqrt{B_{B_s}} = 295 \pm 32 \text{ MeV}$$

- Fixed r_{sb} ⇨ Narrow ϕ_{sb} Range destructive with top
- For r_{sb} ~ 0.02 – 0.03, [$V_{cb} \sim 0.04$]

ϕ_{sb} Range ~ 60° - 70°

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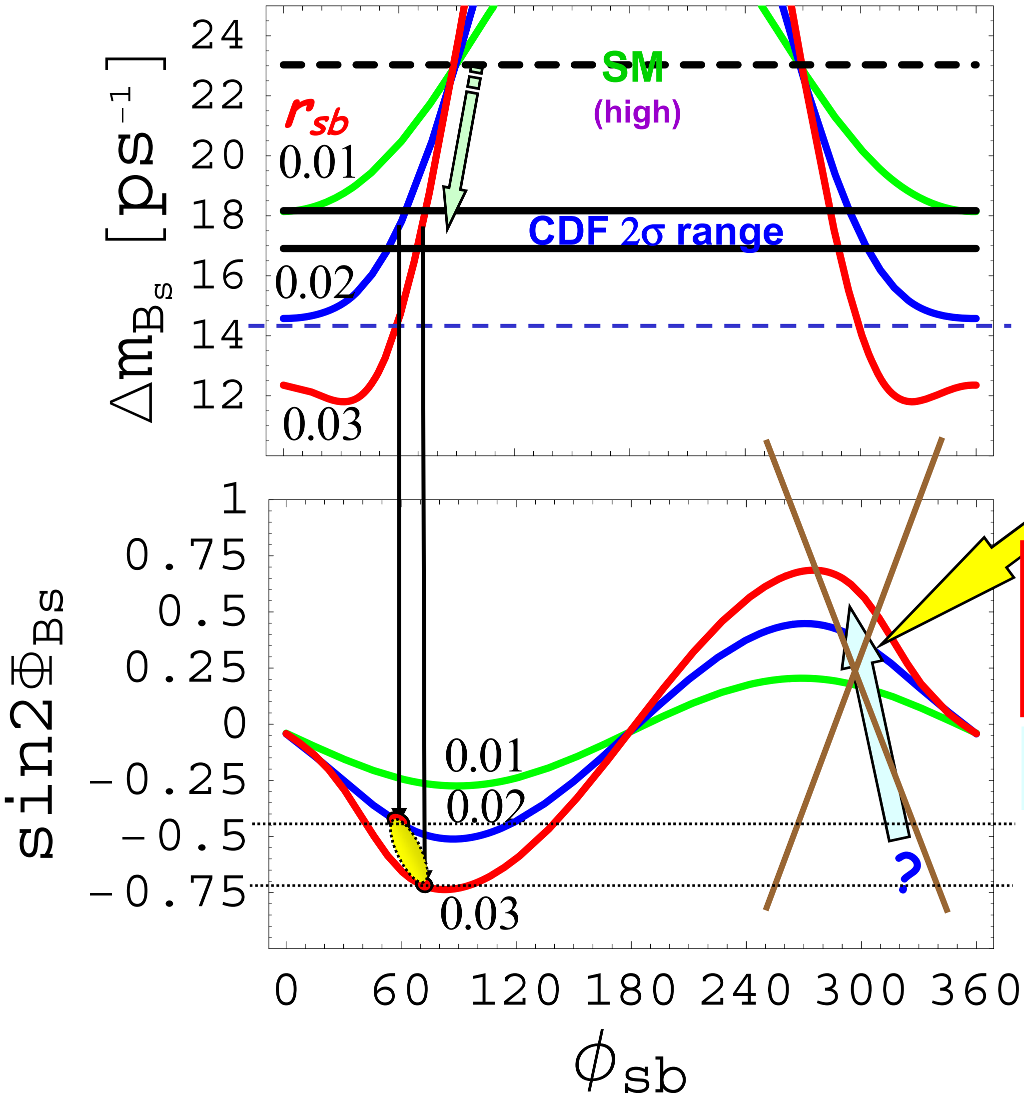
Large CPV in B_s Mixing

WSH, Nagashima, Soddu, hep-ph/0610385



Can Large CPV in B_s Mixing Be Measured @ Tevatron ?

Sign Predicted !

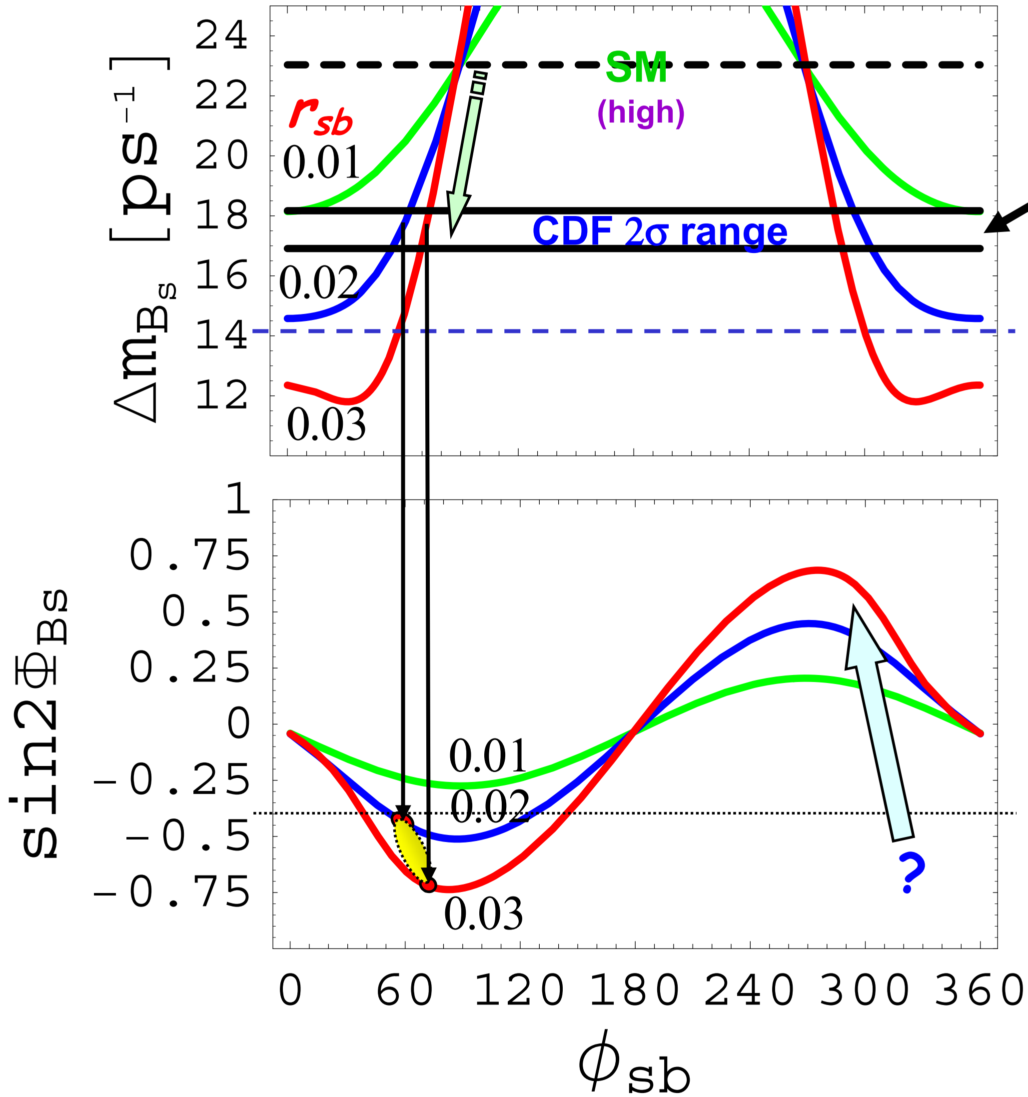
Sure thing by LHCb ca. 2008

$\sin 2\Phi_{B_s} \sim \pm 0.5$ - ± 0.7

Despite Δm_{B_s}, $\mathcal{B}(b \to s \ell\ell)$ SM-like

Prediction: Large CPV in B_s Mixing

WSH, Nagashima, Soddu, PRD'07



$$f_{B_s}\sqrt{B_{B_s}} = 295 \pm 32 \text{ MeV}$$

B_s Mixing Measured @ Tevatron in 4/2006

- For r_{sb} ~ 0.02 – 0.03, [$V_{cb} \sim 0.04$]

ϕ_{sb} Range ~ 60° - 70°

Finite CPV Phase

$\sin 2\Phi_{B_s}$ ~ –0.5 - –0.7

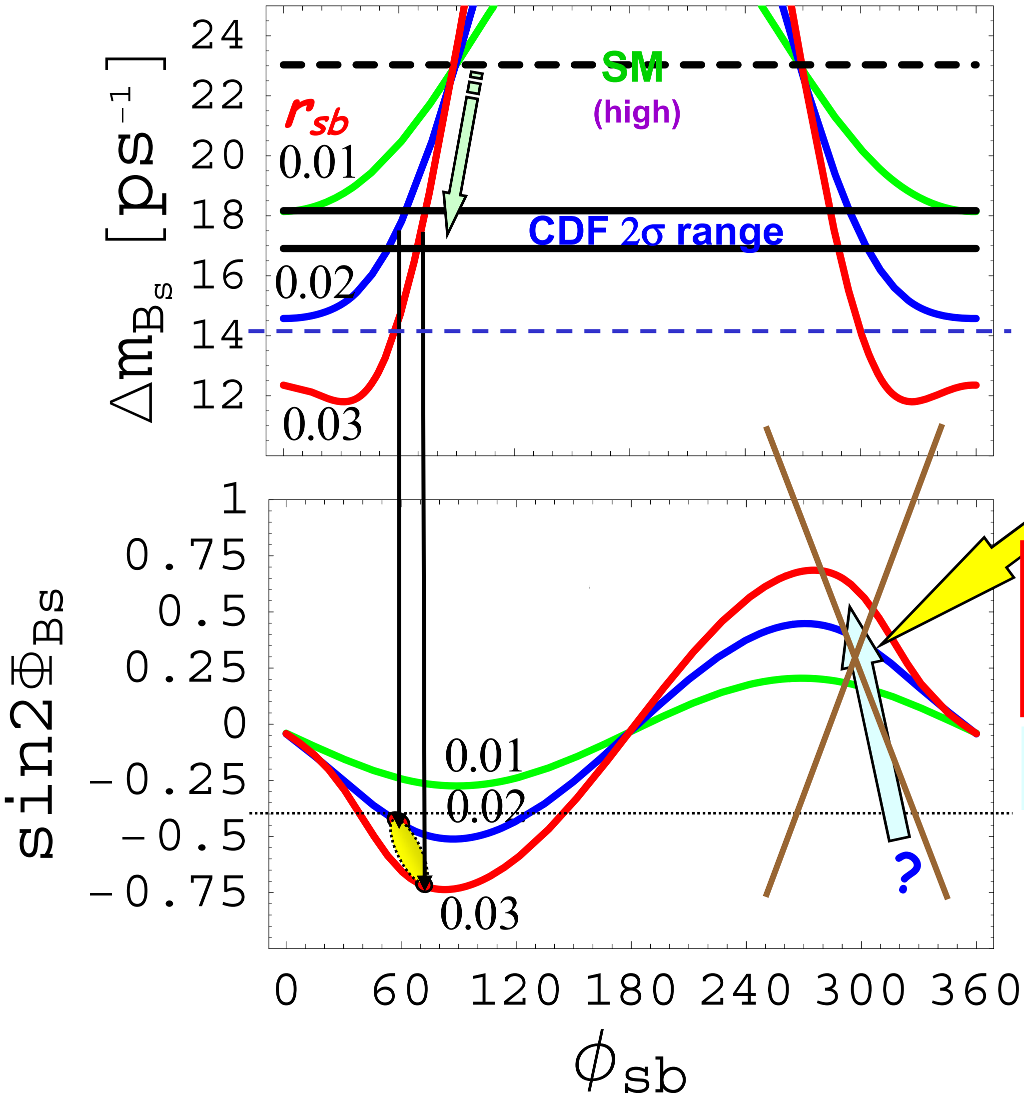
–0.04 SM

Despite Δm_{B_s}, $\mathcal{B}(b\to s\ell\ell)$ SM-like

WSH, Nagashima, Soddu, PRL'05

Prediction: Large CPV in B_s Mixing

WSH, Nagashima, Soddu, PRD'07



$\Delta\mathcal{A}_{K\pi}$, ΔS

Can Large CPV in B_s Mixing Be Measured @ Tevatron ?

Sign Predicted !

Sure thing by LHCb ca. 2010 (?)

$\sin 2\Phi_{B_s}$ ~ –0.5 - –0.7

–0.04 SM

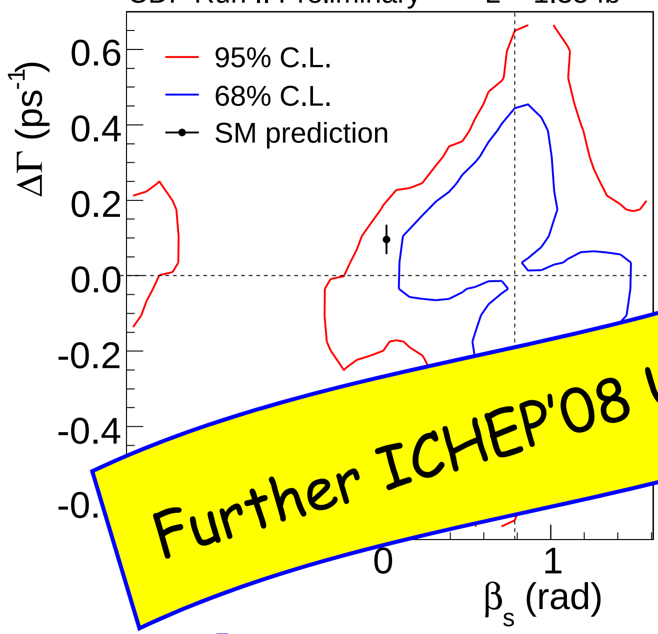
Despite Δm_{B_s}, $\mathcal{B}(b\to s\ell\ell)$ SM-like

WSH, Nagashima, Soddu, PRL'05

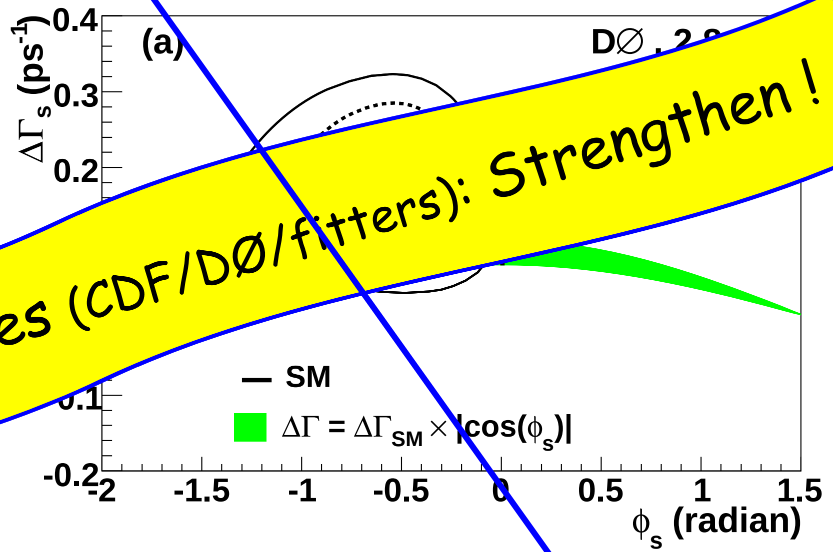
$\sin 2\Phi_{B_s} \sim -0.5 - -0.7$

WSH, Nagashima, Soddu, PRD'07 (already in 05)

PRL'08
arXiv:0712.2397 [hep.ex]



PRL'08
arXiv:0802.2255 [hep.ex]



Further ICHEP'08 Updates (CDF/DØ/fitters): Strengthen !

Observable	68% Prob.	95% Prob.
ϕ_{B_s} [°]	-19.9 ± 5.6	[-30.45,-9.29]
	-68.2 ± 4.9	[-78.45,-58.2]

UTfit

arXiv:0803.0659 [hep.ph]

$\sin 2\Phi_{B_s} = -0.64 \pm ?$

~2.8σ

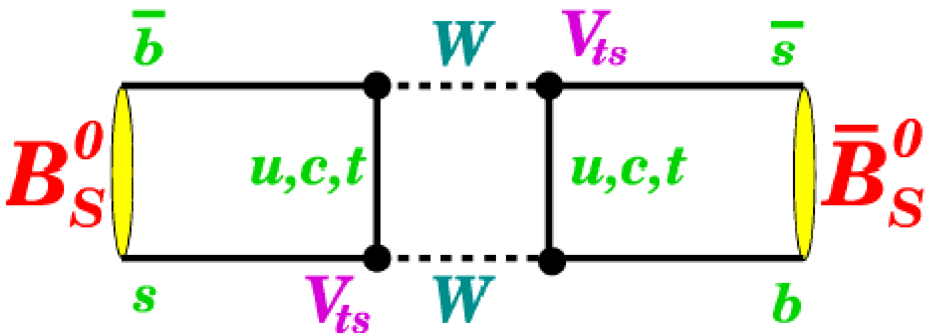
Incredible !!!

An Updated Measurement of the *CP* Violating Phase $\beta_s^{J/\psi\phi}$

The CDF Collaboration[1]

CDF/ANAL/BOTTOM/PUBLIC/9458
Version 1.0
August 7, 2008

It is interesting to note that the Belle and *BABAR* collaborations have observed an asymmetry between direct *CP* asymmetries of charged and neutral $B \to K\pi$ decays with 5σ significance [5, 6]. In the absence of an under-estimation of the contribution from color-suppressed tree decays, it is difficult to explain this discrepancy without some source of new physics contributing to the electroweak penguin which governs the $b \to s$ transition.In the standard model, this isospin-violating diagram should be highly suppressed, but if a new source of physics is indeed present in these transitions it may be enough to cause the different *CP* asymmetries that have been observed.. In the $B_s^0 \to J/\psi\,\phi$ decay, the $b \to s$ transition occurs through the mixing box diagram shown in Fig. 1. It is possible that new particles could enter this transition through the $b \to s$ quark transition. While there are surely a number of possible sources of new physics that might give rise to such discrepancies, George Hou predicted the presence of a t' quark with mass between ~ 300 and 1,000 GeV/c^2 in order to explain the Belle result and predicted *a priori* the observation of a large *CP*-violating phase in $B_s^0 \to J/\psi\,\phi$ decays [7, 8]. Another result of interest in the context of these measurements is the excess observed at ~ 350 GeV/c^2 in the recent t' search at CDF using 2.3 fb^{-1} of data [9]. In this direct search for a fourth generation up-type quark, a significance of less than 2σ is obtained for the discrepancy between the data and the predicted backgrounds, so that the effect, while intriguing, is presently consistent with a statistical fluctuation. A updated search with more data would also clearly be of interest, particularly if a large value of $\beta_s^{J/\psi\phi}$ persists with the addition of more data.



$\sin 2\Phi_{B_s} = -\sin\beta_s = \sin\phi_s$

(Conservative) outlook

% of CDF ‘clones’ that would observe a 5σ-effect, as a function of βs

Observation w/ 2010 Data if Central Value Stays !

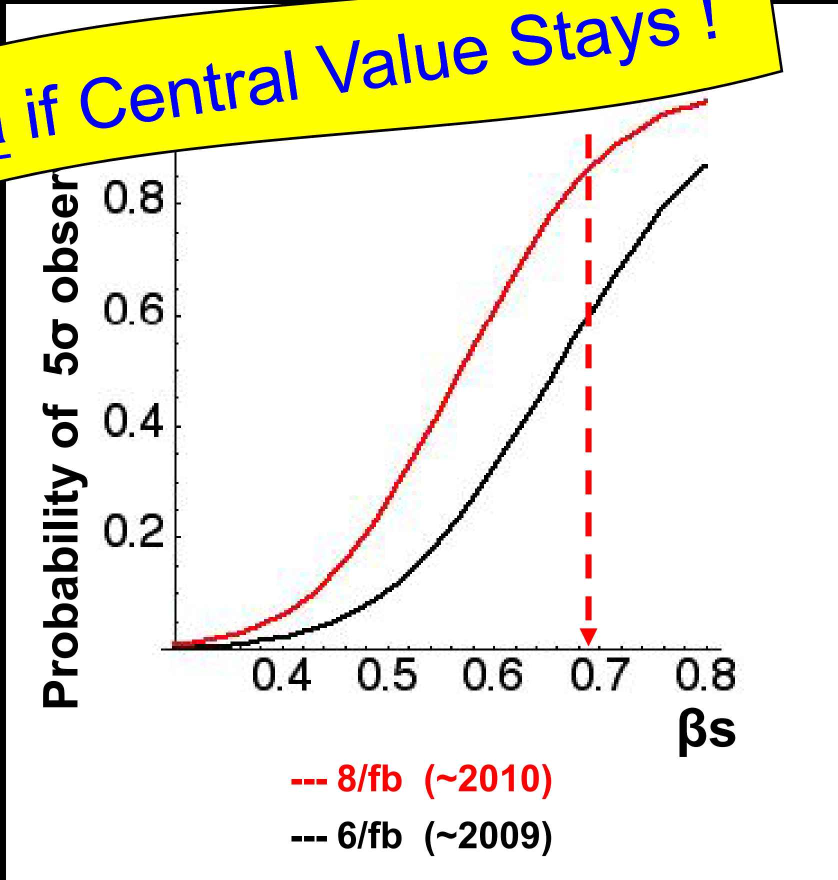
Assumptions

✓ $\Delta\Gamma_s = 0.1\ ps^{-1}$

✓ C… …ing efficiency

✓ No analysis improvements.

✓ No external constraints (A_{SL}, lifetimes) used.



CDF future will probably be better than that.

And DØ will contribute too.

4 x 4 Unitarity ⇨ Z/K Constraints

"Typical" CKM Matrix

WSH, Nagashima, Soddu, PRD'05

$V^4_{CKM} =$

$m_{t'} = 300\ \text{GeV}$

0.9745	0.2225	$0.0038\, e^{-i\, 60^\circ}$	… 61°
-0.2241…	…	…	$0.1164\, e^{i\, 66^\circ}$
0.0…	$-0.0555\, e^{-i\, 25^\circ}$	0.9746	$0.2168\, e^{-i\, 1^\circ}$
$-0.0044\, e^{-i\, 10^\circ}$	$-0.1136\, e^{-i\, 70^\circ}$	-0.2200	0.9688

Extract Information from Constraints

s ← b

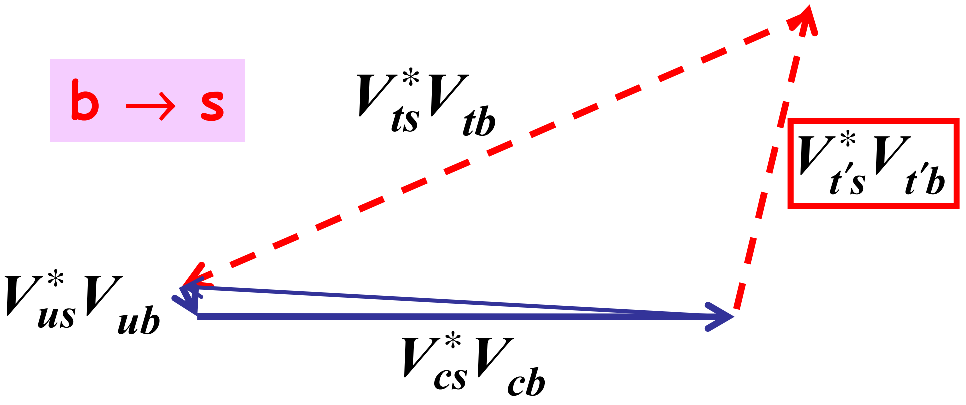
d ← s

Z → $b\bar{b}$

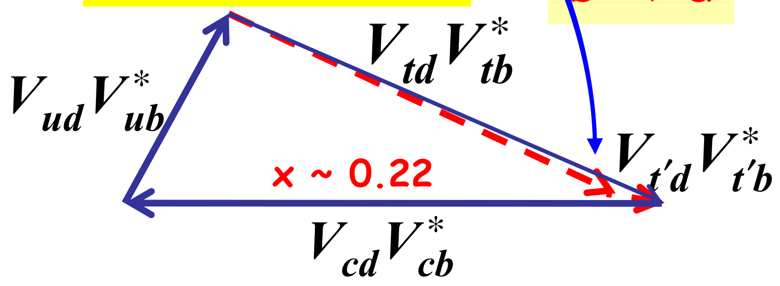
Nontrivial

Satisfy b → d: ✓
Cannot tell triangle from quadrangle

b → s



b → d



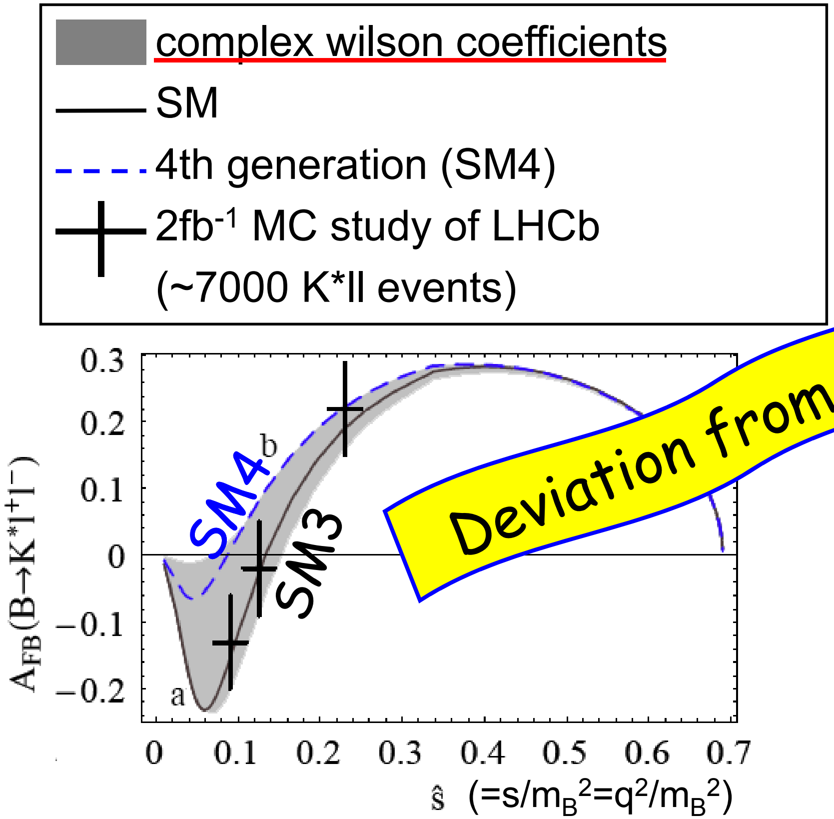
$A_{FB}(B \to K^* l^+ l^-)$ and Other Predictions

sent to Backup

Instead flipped C_7 ...

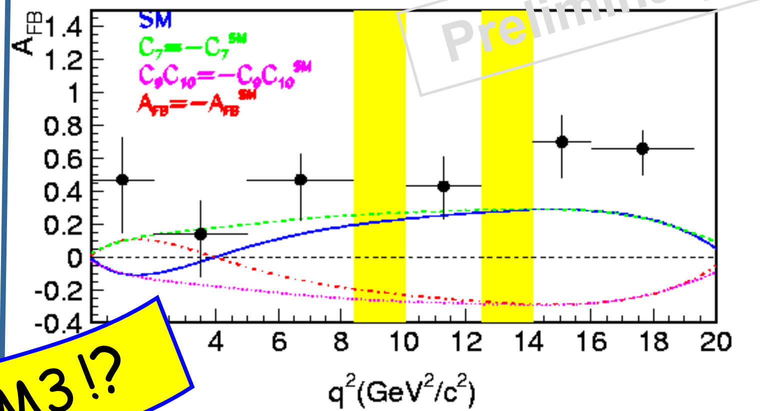
$$\frac{dA_{FB}}{d\hat{s}} \propto -\left\{ \mathrm{Re}(C_9^{eff} C_{10}) V A_1 + \frac{\hat{m}_b}{\hat{s}} \mathrm{Re}(C_7^{eff} C_{10}) \left[V T_2 (1-\hat{m}_{K^*}) + A_1 T_1 (1+\hat{m}_{K^*}) \right] \right\}$$

W.-S. Hou, A. Hovhannisyan, and N. Mahajan, PRD 77, 014016 (2008)

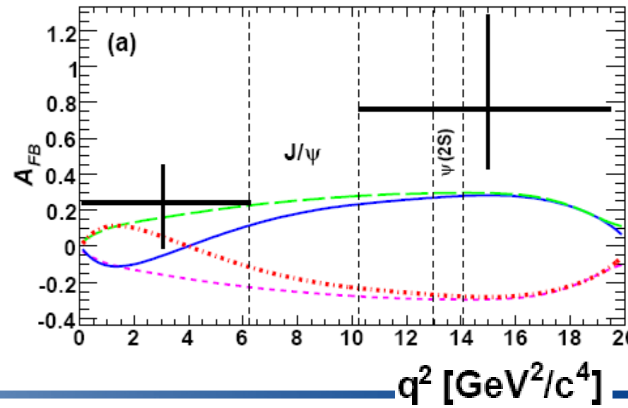


Deviation from SM3 !?

Belle **657M** arXiv:**0810.0335**



BABAR, arXiv:**0804.4412** **386M**



IV. A 10^{13}+ Enhancement of CPV for BAU?

If … KM4

The Abyss: CPV in KM and B.A.U.

The Lore

$$\frac{n_{\bar{\mathcal{B}}}}{n_\gamma} \cong 0$$

$$\frac{n_{\mathcal{B}}}{n_\gamma} = (6.2 \pm 0.2)\times 10^{-10}$$ WMAP

$$\text{KM} \sim 10^{-20}$$

Too Small in SM

Jarlskog Invariant in SM3 (need 3 generation in KM)

$$J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)A$$

Normalize by T ~ 100 GeV → $J/T^{12} \sim 10^{-20}$

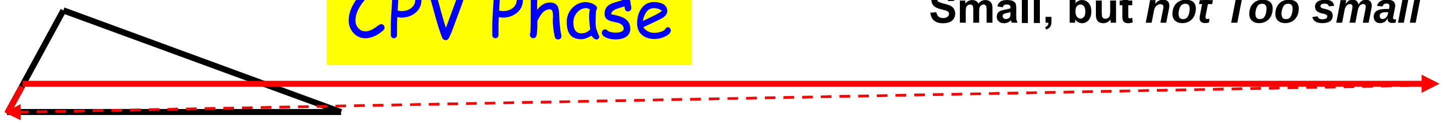
EW Phase Transition Temperature ~ v.e.v.

Masses too Small!

$A \sim 3\times 10^{-5}$ in SM is common (unique) area of triangle

CPV Phase

Small, but *not Too small*



B.A.U. from CPV in KM

$$\frac{n_{\bar{\mathcal{B}}}}{n_\gamma} \cong 0$$

$$\frac{n_{\mathcal{B}}}{n_\gamma} = (6.2 \pm 0.2)\times 10^{-10}$$

WMAP

KM ~ Enough CPV?

~~Too Small in SM~~

If shift by One Generation in SM4 (need 3 generation in KM)

$$J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)\,A$$

Providence

WSH, arXiv:0803.1234 [hep/ph]

$$J^{sb}_{(2,3,4)} \simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)\,A^{sb}_{234}$$

$$\sim \frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}\,\frac{A^{sb}_{234}}{A}\,J$$

~ 10^{+15} Gain

Order 1 ~ 30

CPV Phase

Gain mostly in Large Yukawa Couplings !

Nature would likely use this !?

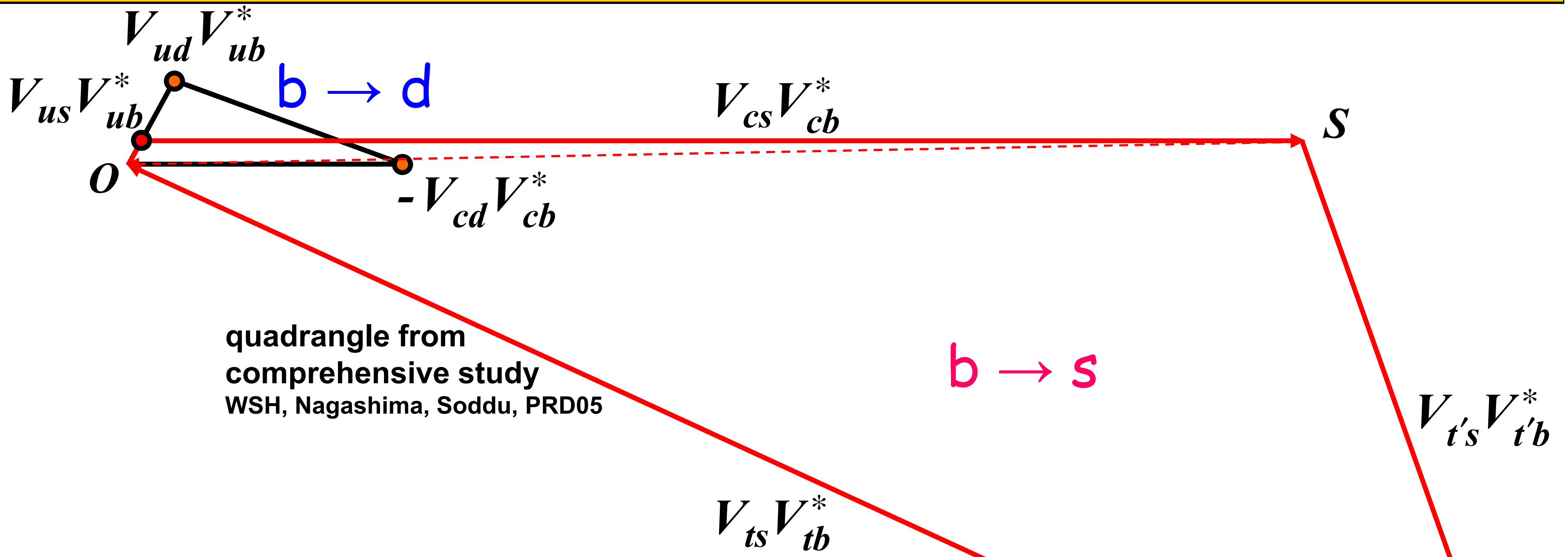
The Abyss between CPV in SM3 vs BAU

bridged in SM4 by *Heaviness of t′ and b′*

Why wasn't this clearly

pointed out in past 20 years?

Gain mostly in Large Yukawa Couplings !



$$J_{(2,3,4)}^{sb} \simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)\, A_{234}^{sb}$$

$$\sim \frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}\,\frac{A_{234}^{sb}}{A}\,J$$

~ 10^{+15} Gain

$m_{b'}, m_{t'} \cong 300\,\mathrm{GeV}$ 10^{+13}

$\sim 600\,\mathrm{GeV}$ 10^{+15}

Only fac. 30 in CPV per se

This part will shrink a bit.

V. Direct Sighting @ Tevatron vs LHC

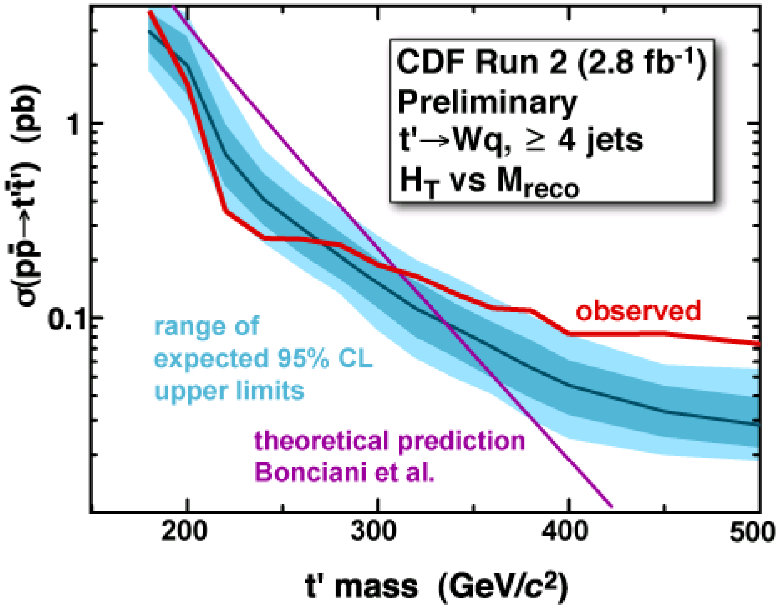
the Experimentalist

Tevatron/LHC Verification

Tevatron

Unequivocal BSM ... if true

- $\sin 2\Phi_{B_s}$ "Evidence" by 2009 ?
  "Observe" by 2010 ?
- t′ Search Ongoing:
  $m_{t'}$ > 311 GeV @ 95% CL



LHC

- $\sin 2\Phi_{B_s}$ "Confirmation" — "Easy" for LHCb

But when ?

- b′, t′ Discovery — Straightforward/full terrain

Glimpse of agenda at ATLAS/CMS

previous 2 talks

VI. Discussion/Conclusion: Know in 3-5 Years

CPV for BAU: 2-3-4 Dominance

Jarlskog'85, 3 generations

$$\mathrm{Im}\,\det\left[m_u m_u^\dagger,\ \ m_d m_d^\dagger\right]$$
$$\boldsymbol{S} \qquad\qquad \boldsymbol{S'}$$

Jarlskog'87, n generations

$$\mathrm{Im}\,\mathrm{tr}[\boldsymbol{S}, \boldsymbol{S'}]^3$$

"3 cycles"

also Gronau, Kfir, Loewy '87

4 generations: 3 indep. phases

long and short

d-*s* degenerate

(on v.e.v. scale)

2-3-4 generation only !

Effectively 3 generations

$$J^{sb}_{(2,3,4)} \simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)\, A^{sb}_{234}$$
$$\sim \frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}\frac{A^{sb}_{234}}{A} J$$

$\boldsymbol{J}$(1,2,3) very small

suppressed by m_s, m_c

1st Order EW Phase Trans. for BAU ?

0803.1234 will appear in Chin. J. Phys.

Ran out of time, and knowledge ...

(perturbative)

- Fok & Kribs: Not possible in 4th generation — PRD'08 arXiv:0803.4207 [hep-ph]
- Conjecture: Could Strong Yukawa's do it ?

Beyond Unitarity Limit

arXiv:0901.1962v1 [hep-ph]

The strongly coupled fourth family and a first-order electroweak phase transition (I) quark sector

Not quite conclusive (?)

Yoshio Kikukawa,[1,*] Masaya Kohda,[2,†] and Junichiro Yasuda[3,‡]
[1] *Institute of Physics, University of Tokyo Tokyo 153-8092, Japan*
[2] *Department of Physics, Nagoya University Nagoya 464-8602, Japan*
[3] *Center for the Studies of Higher Education, Nagoya University Nagoya 464-8601, Japan*
(Dated: January 14, 2009)

In models of dynamical electroweak symmetry breaking due to strongly coupled fourth-family quarks and leptons, their low-energy effective descriptions may involve multiple composite Higgs fields, leading to a possibility that the electroweak phase transition at finite temperature is first order due to the Coleman-Weinberg mechanism. We examine the behavior of the electroweak phase transition based on the effective renormalizable Yukawa theory which consists of the fourth-family quarks and two SU(2)-doublet Higgs fields corresponding to the bilinear operators of the fourth-family quarks with/without imposing the compositeness condition. The strength of the first order

Thoughts on the other 1/2 Nobel Prize

SSB

"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

Photo: Universtity of Chicago

Yoichiro Nambu

1/2 of the prize

USA

Enrico Fermi Institute,
University of Chicago
Chicago, IL, USA

b. 1921
(in Tokyo, Japan)

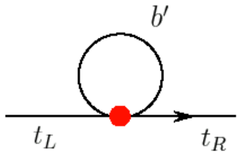
$\langle \bar{Q}Q \rangle$ can Condense

by Large Yukawa !

Could EWSB be
due to b′ and t′
above unitarity bound ~ 500-600 GeV ?

Bob Holdom: N–J-L

[Bardeen, Hill, Lindner



Gustavo Burdman: "Holographic" 4th gen.

VI. Conclusion: Know in 3-5 Years

$$J^{sb}_{(2,3,4)} \simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)\, A^{sb}_{234}$$

$$\sim \underbrace{\frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}}\, \frac{A^{sb}_{234}}{A}\, J$$

$\sim 10^{+15}$ Gain

Even if $O(1)$

$m_{b'}, m_{t'} \cong 300\,\text{GeV}$ 10^{+13}

$\sim 600\,\text{GeV}$ 10^{+15}

Enough CPV for B.A.U.

Maybe there is a 4th Generation !

$\sin 2\Phi_{B_s}$ @ Tevatron by 2010(1)

Will Really Know in ~ 3–5 years !

@ *LHC*

⇨ *Heaven on Earth?*

Backup

$$\Delta A_{K\pi} = \underset{+0.050\pm0.025}{A_{B\to K^+\pi^0}} - \underset{-0.097\pm0.012}{A_{B\to K^+\pi^-}} \neq 0$$

World

$= +0.147\pm0.028 \quad > 5\sigma$

Experiment is Firm

Why a Puzzle ?

$\Delta A_{K\pi} \sim 0$ expected

$$\mathcal{M}(B^0 \to K^+\pi^-) \propto (T + P) = \boxed{re^{i\phi_3} + e^{i\delta}}$$

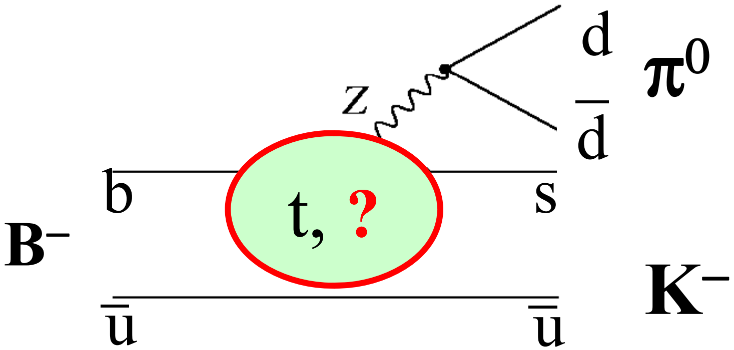
$$\sqrt{2}\mathcal{M}_{K^+\pi^0} - \mathcal{M}_{K^+\pi^-} \propto (P_{EW} + C)\ ?$$

$r =$ 

Large C ? ⇒ **A lot of (hadronic) finesse**

Baek, London, PLB653, 249 (2007)

Large EWPenguin ? ⇒ **Need NP CPV Phase**



P_{EW} has practically
no weak phase in SM

World

$$\Delta A_{K\pi} = \overset{+0.050\pm0.025}{A_{B\to K^+\pi^0}} - \overset{-0.097\pm0.012}{A_{B\to K^+\pi^-}} \neq 0$$

$= +0.147\pm0.028 \quad > 5\sigma$ Experiment is Firm

Why a Puzzle ?

$\Delta A_{K\pi} \sim 0$ expected

$$\mathcal{M}(B^0 \to K^+\pi^-) \propto (T+P) = re^{i\phi_3} + e^{i\delta}$$

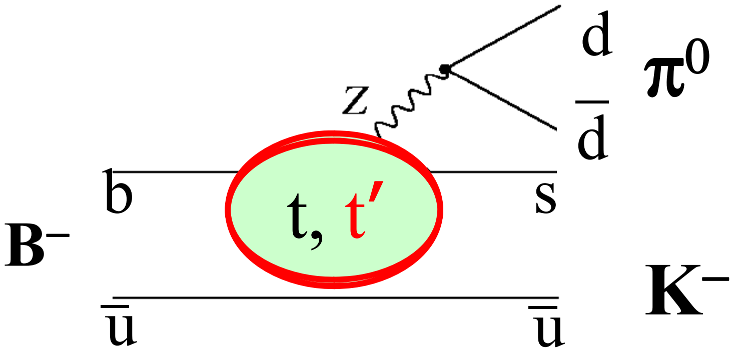
$$\sqrt{2}\mathcal{M}_{K^+\pi^0} - \mathcal{M}_{K^+\pi^-} \propto (P_{EW} + C) \; ?$$

$r =$  / 

Large C ? → *A lot of (hadronic) finesse*

Baek, London, PLB653, 249 (2007)

Large EWPenguin ? → **Need NP CPV Phase**

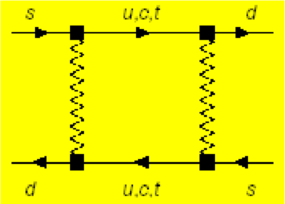


P_{EW} has practically no weak phase in SM

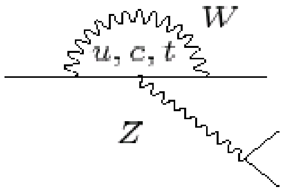
4th Gen. in EWP Natural

nondecouplin

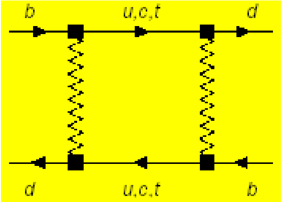
On Boxes and Z Penguins



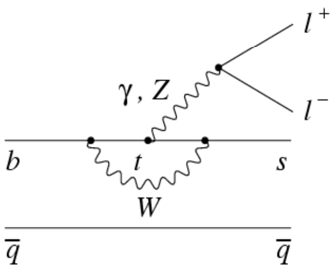
⟹ GIM, charm, ε_K

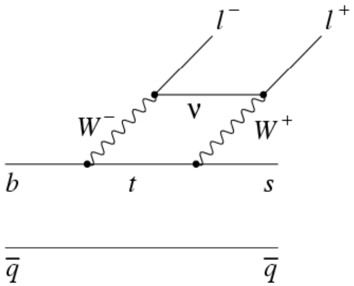


⟹ small ε'/ε, $K \to \pi\nu\nu$ (still waiting)



⟹ heavy top, $\sin 2\phi_1/\beta$



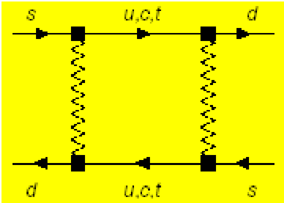


⟹ Z dominance for heavy top

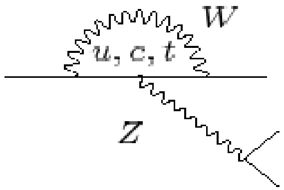
1986 $\to$ 2002

Most Flavor/CPV learned from these diagrams/processes

On Boxes and Z Penguins



⇒ GIM, charm, ε_K



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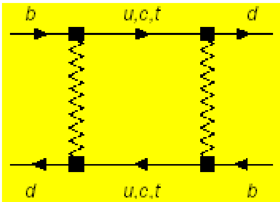
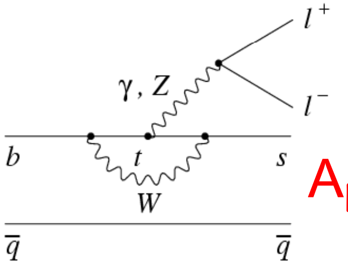
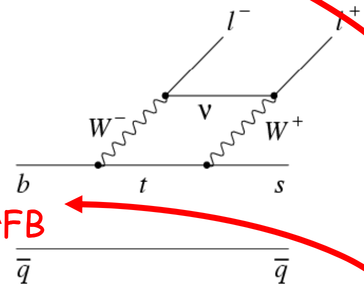


⇒ heavy top, $\sin 2\phi_1/\beta$

B_s



A_{FB}



⇒ Z dominance for heavy top

1986 → 2002

All w/ 3-generations,
Just wait if there's a 4th

→ D !

→ **b′**, **t′** @ LHC

4 x 4 Unitarity ⇒ Constraints

$$
\begin{array}{c|cccc}
 & d & s & b & b' \\
\hline
u & \begin{array}{l} c_{12}c_{13}c_{14} \\ -c_{13}s_{12}s_{14}s_{24}\exp[-i(\phi_{db}-\phi_{sb})] \\ -c_{24}s_{13}s_{14}s_{34}\exp[-i(\phi_{db}+\phi_{ub})] \end{array} & \begin{array}{l} c_{13}c_{24}s_{12} \\ -s_{13}s_{24}s_{34}\exp[-i(\phi_{sb}+\phi_{ub})] \end{array} & c_{34}s_{13}\exp[-i\phi_{ub}] & \begin{array}{l} c_{12}c_{13}s_{14}\exp[i\phi_{db}] \\ +c_{13}c_{14}s_{12}s_{24}\exp[i\phi_{sb}] \\ +c_{14}c_{24}s_{13}s_{34}\exp[-i\phi_{ub}] \end{array} \\
c & \begin{array}{l} -c_{14}c_{23}s_{12} \\ -c_{12}c_{14}s_{13}s_{23}\exp[i\phi_{ub}] \\ -c_{12}c_{23}s_{14}s_{24}\exp[-i(\phi_{db}-\phi_{sb})] \\ +s_{12}s_{13}s_{14}s_{23}s_{24}\exp[-i(\phi_{db}-\phi_{sb}-i\phi_{ub})] \\ -c_{13}c_{24}s_{14}s_{23}s_{34}\exp[-i\phi_{db}] \end{array} & \begin{array}{l} c_{12}c_{23}c_{24} \\ -c_{24}s_{12}s_{13}s_{23}\exp[i\phi_{ub}] \\ -c_{13}s_{23}s_{24}s_{34}\exp[-i\phi_{sb}] \end{array} & c_{13}c_{34}s_{23} & \begin{array}{l} -c_{23}s_{12}s_{14}\exp[i\phi_{db}] \\ -c_{12}s_{13}s_{14}s_{23}\exp[i(\phi_{db}+\phi_{ub})] \\ +c_{12}c_{14}c_{23}s_{24}\exp[i\phi_{sb}] \\ -c_{14}s_{12}s_{13}s_{23}s_{24}\exp[i(\phi_{sb}+\phi_{ub})] \\ +c_{13}c_{14}c_{24}s_{23}s_{34} \end{array} \\
t & \begin{array}{l} -c_{12}c_{14}c_{23}s_{13}\exp[i\phi_{ub}] \\ +c_{14}s_{12}s_{23} \\ +c_{23}s_{12}s_{13}s_{14}s_{24}\exp[-i(\phi_{db}-\phi_{sb}-i\phi_{ub})] \\ +c_{12}s_{14}s_{23}s_{24}\exp[-i(\phi_{db}-\phi_{sb})] \\ -c_{13}c_{23}c_{24}s_{14}s_{34}\exp[-i\phi_{db}] \end{array} & \begin{array}{l} -c_{23}c_{24}s_{12}s_{13}\exp[i\phi_{ub}] \\ -c_{12}c_{24}s_{23} \\ -c_{13}c_{23}s_{24}s_{34}\exp[i\phi_{sb}] \end{array} & c_{13}c_{23}c_{34} & \begin{array}{l} -c_{12}c_{23}s_{13}s_{14}\exp[i(\phi_{db}+\phi_{ub})] \\ +s_{12}s_{14}s_{23}\exp[i\phi_{db}] \\ -c_{14}c_{23}s_{12}s_{13}s_{24}\exp[i(\phi_{sb}+\phi_{ub})] \\ -c_{12}c_{14}s_{23}s_{24}\exp[i\phi_{sb}] \\ +c_{13}c_{14}c_{23}c_{24}s_{34} \end{array} \\
t' & -c_{24}c_{34}s_{14}\exp[-i\phi_{db}] & -c_{34}s_{24}\exp[-i\phi_{sb}] & s_{34} & c_{14}c_{24}c_{34}
\end{array}
$$

SM3

We need to deal with mixing matrix in detail to keep Unitarity

$$V^*_{t's}V_{t'd} = c_{24}c^2_{34}s_{14}s_{24}e^{i(\phi_{sb}-\phi_{db})} \equiv r_{ds} \quad \phi_{ds}$$

Kaon

$$V^*_{t's}V_{t'b} = c_{34}s_{24}s_{34}e^{i\phi_{sb}} \equiv r_{sb}$$

b → s

$$V^*_{t'd}V_{t'b} = c_{24}c_{34}s_{14}s_{34}e^{i\phi_{db}} = \frac{r_{ds}s^2_{34}}{r_{sb}}e^{i\phi_{db}}$$

b → d

Cross Check !

$\Gamma(Z \to \text{hadrons})$

impose $s_{34} = 0.22 \simeq V_{us}$

$|V_{tb}|^2 + 3.4|V_{t'b}|^2 < 1.14$ for $m_{t'} = 300$ GeV $\Rightarrow s_{34} < 0.25$

From b → s study $\quad r_{sb}\, e^{i\phi_{sb}} \simeq 0.025\, e^{i\,70^\circ}$

Constrain s ↔ d from K Physics

$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (14.7^{+13.0}_{-8.9}) \cdot 10^{-11}$ (shaded)

$BR(K_L \to \mu^+\mu^-)_{SD} < 3.75 \cdot 10^{-9}$

$\epsilon_K = (2.284 \pm 2 \times 0.014) \cdot 10^{-3}$

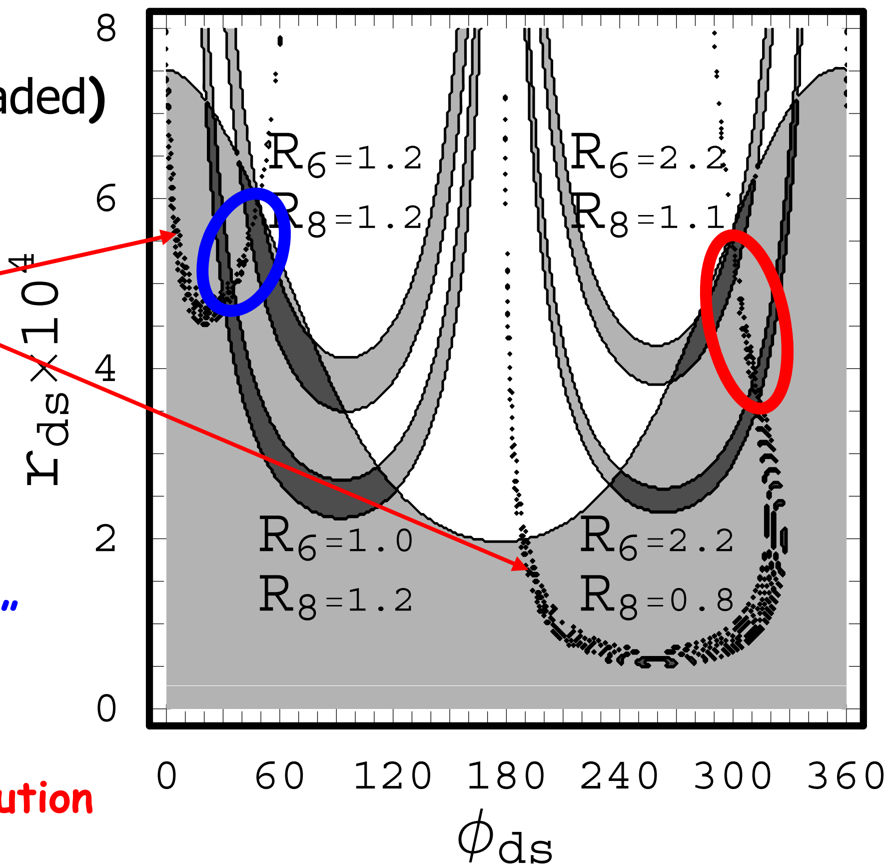
$\frac{\epsilon'}{\epsilon} = (16.6 \pm 2 \times 1.6) \cdot 10^{-4}$

$R_6 = 1.2$ (E. Pallante et al.)

$R_8 = 0.7 - 1.3$ "Standard"

$R_6 = 2.2$ (J. Bijnens et al.)

$R_8 = 0.8 - 1.4$ No SM3 solution



Therefore….

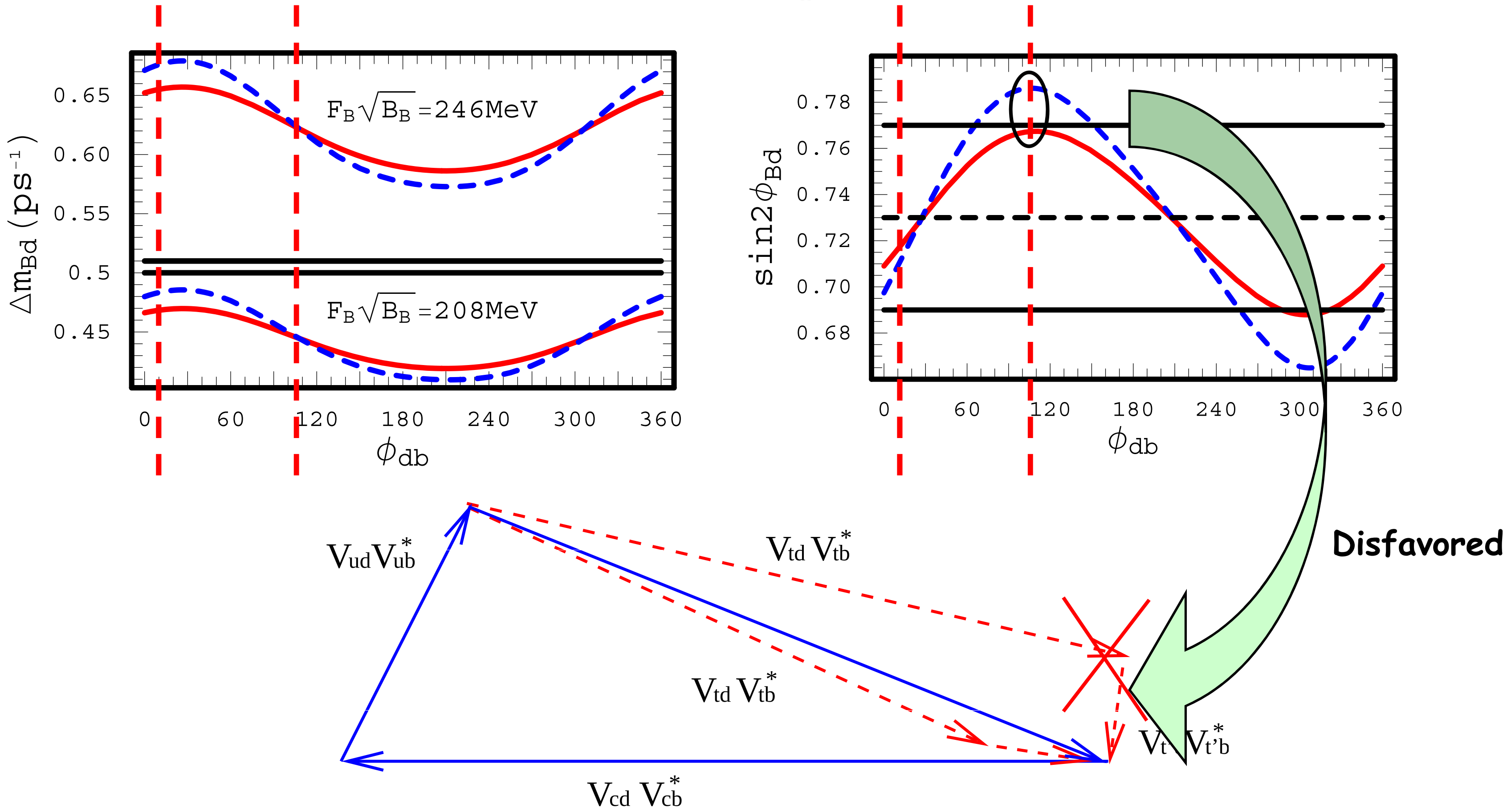
$$r_{ds} \sim 5 \times 10^{-4}, \quad \phi_{ds} \sim -60^\circ \text{ or } +35^\circ$$

well-satisfy Δm_{B_d} and $\sin 2\phi_1$ **!**

$$r_{ds} \sim 5 \times 10^{-4}, \quad \phi_{ds} \sim -60^\circ \text{ or } +35^\circ$$

$$r_{db} \sim 1 \times 10^{-3}, \quad \phi_{db} \sim 10^\circ \ (105^\circ)$$

well-satisfy Δm_{B_d} and $\sin 2\phi_1$ vs $V_{ub} \sim 0.01\, e^{-i\gamma}$



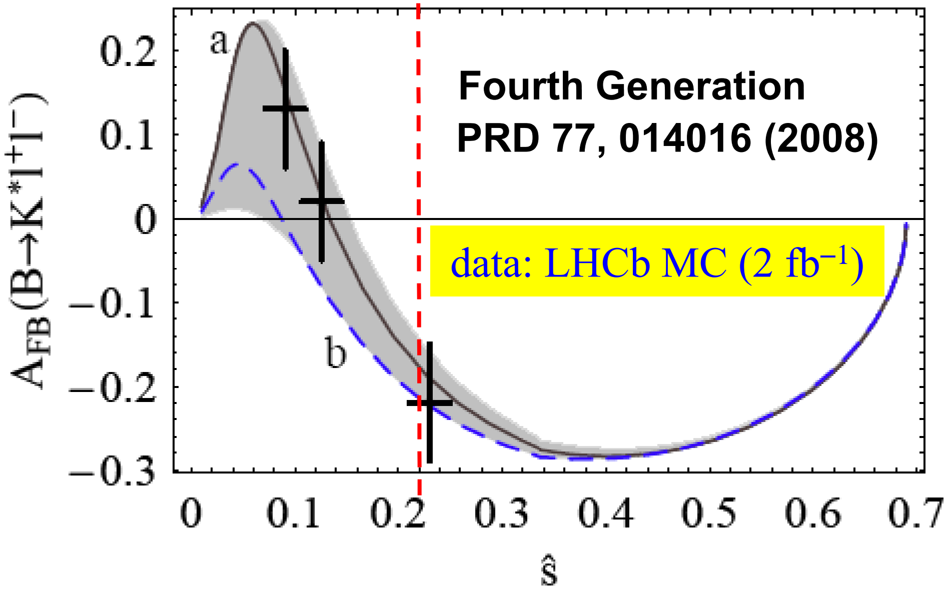
Hard to tell apart (non-trivial) with present precision

$\because$ stringent $s \to d$

$A_{FB}(B \to K^* l^+ l^-)$ and Other Predictions

sent to Backup

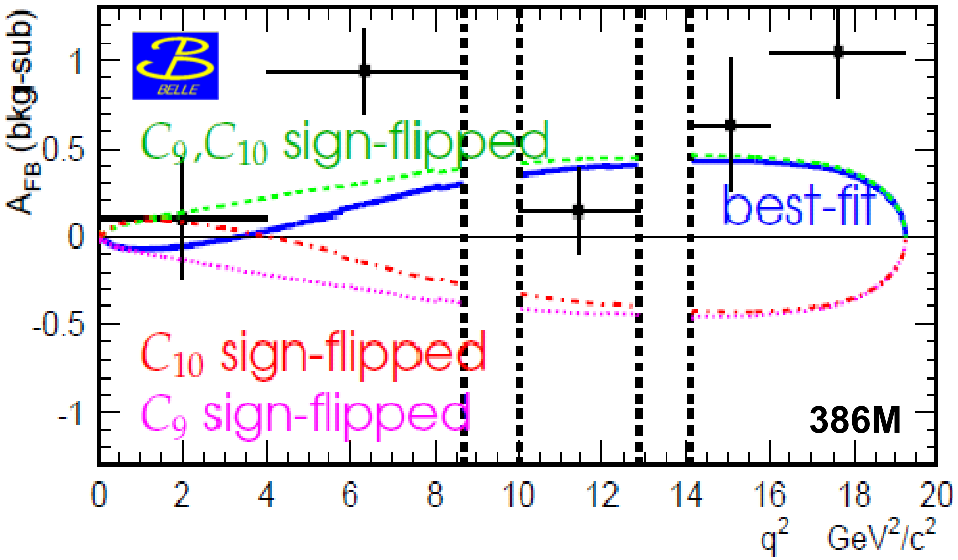
Quoted by **Tsybychev at FPCP08**

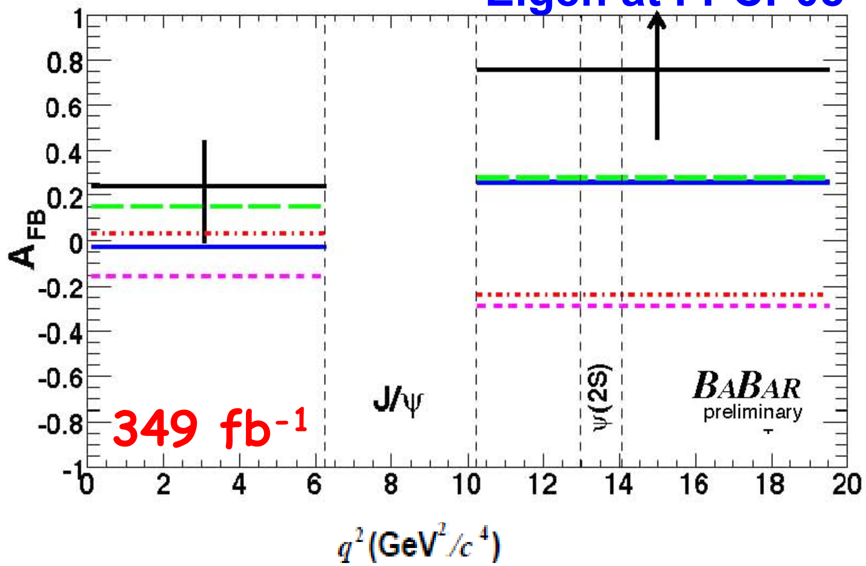


a: SM; b: 4 Gen. better

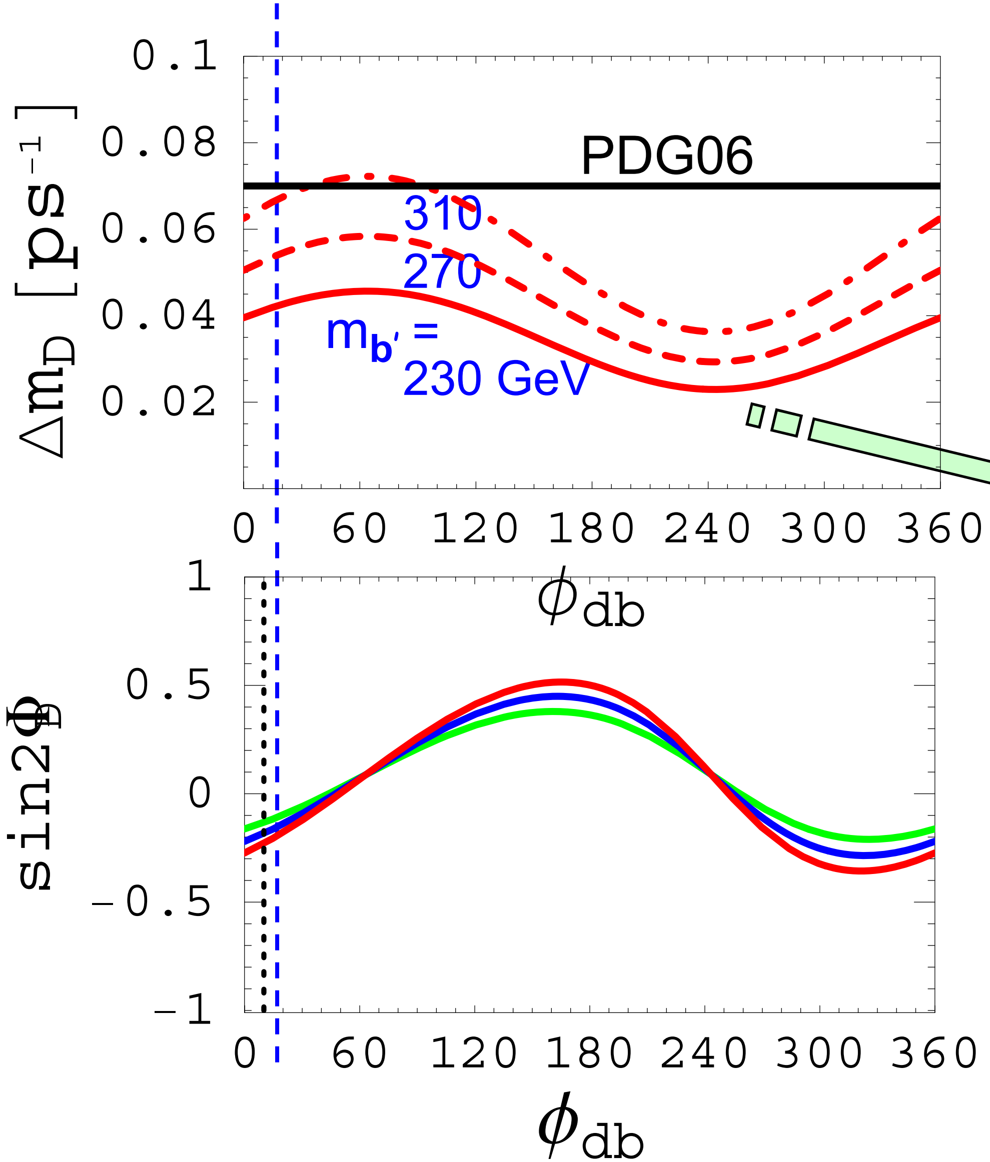
- (F$_L$ and) A_{FB} (and A_I) favor the "opposite-sign C_7 model"

Eigen at FPCP08





D Mixing (Short-distance Only)



$$f_D\sqrt{B_D} = 200\ \text{MeV}$$

$$V^*_{t'd}V_{t'b} \equiv r_{db}e^{i\phi_{db}}$$

⇕ From 4 x 4 Unitarity

$$V_{ub'}V^*_{cb'}$$

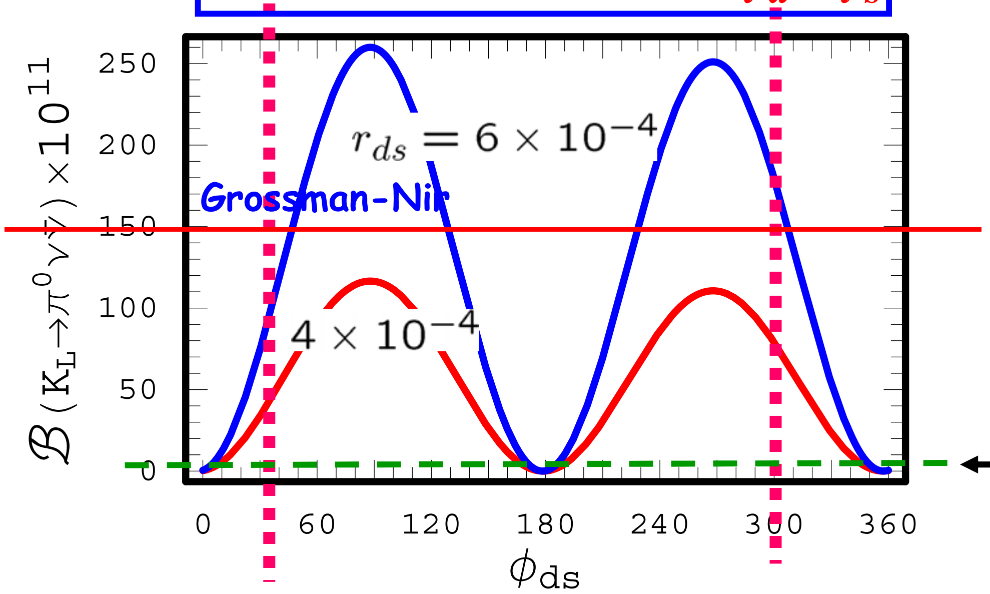
x = Δm/Γ ~ 1 - 3 plausible

w/ Sizable (but not huge) CPV in Mixing ~ –15%

N.B. SM LD could generate
y ~ 1%, x ≈ y
[Falk, Grossman, Ligeti, (Nir,) Petrov]

Implication for $\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu})$

Nontrivial (phase) $V^*_{t'd}V_{t's}$



Current E391A U.L.

2.86×10^{-7} (90% c.l.)

Very hard to measure

$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) \simeq 3 \times 10^{-11}$

SM3

Rate could be enhanced by up to almost two orders !!

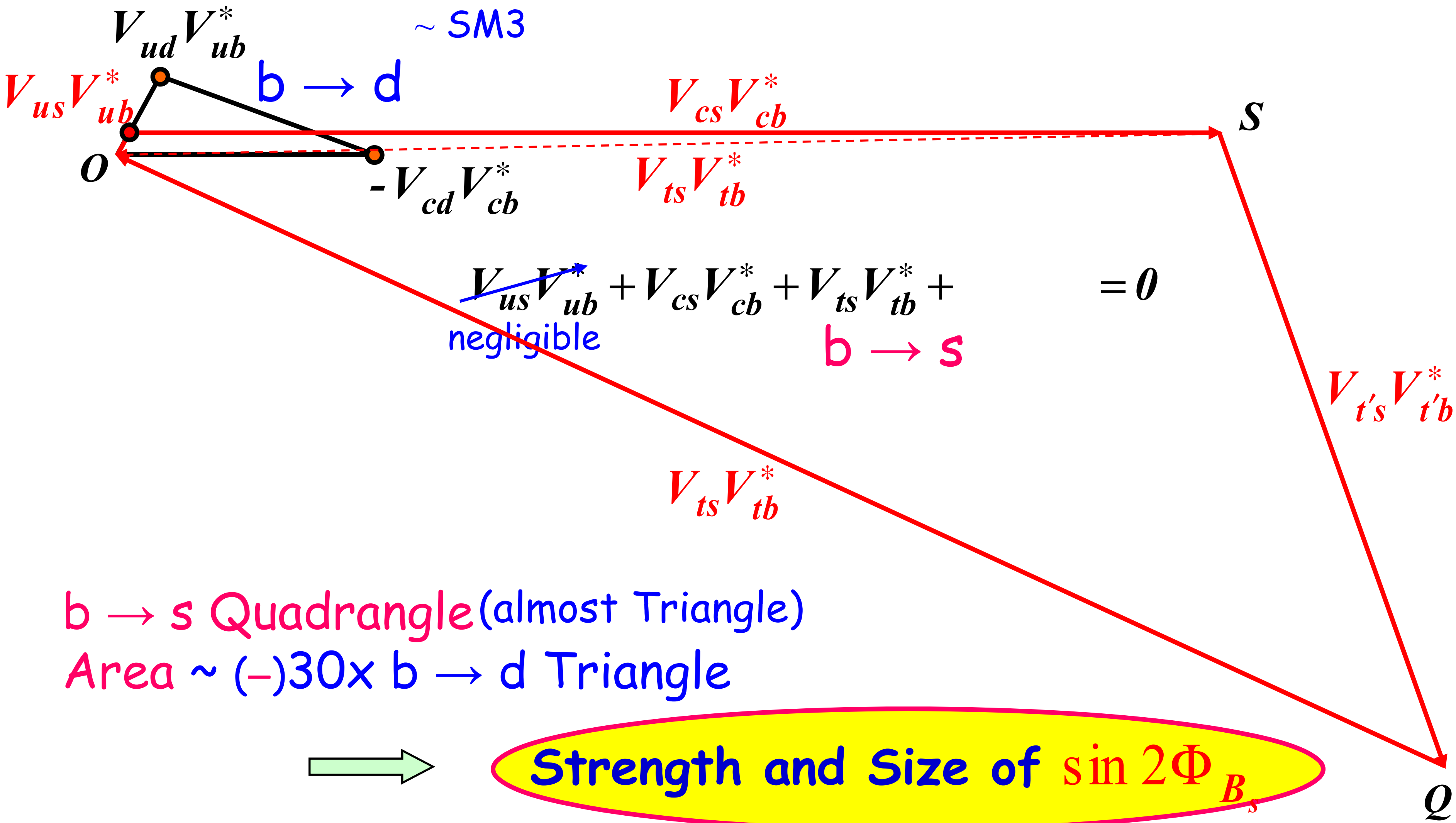
$K_L \to \pi^0 \nu\bar{\nu}$ **enhanced to** 5×10^{-10} **or even higher !!**

In general larger than $K^+ \to \pi^+ \nu\bar{\nu}$ $(2\text{–}3 \times 10^{-10})$

∵ Large CPV Phase

b → d "Triangle" and b → s Quadrangle

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + \underbrace{V_{td}V_{tb}^* + V_{t'd}V_{t'b}^*}_{\sim \text{SM3}} = 0$$



$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* + \qquad = 0$$

negligible

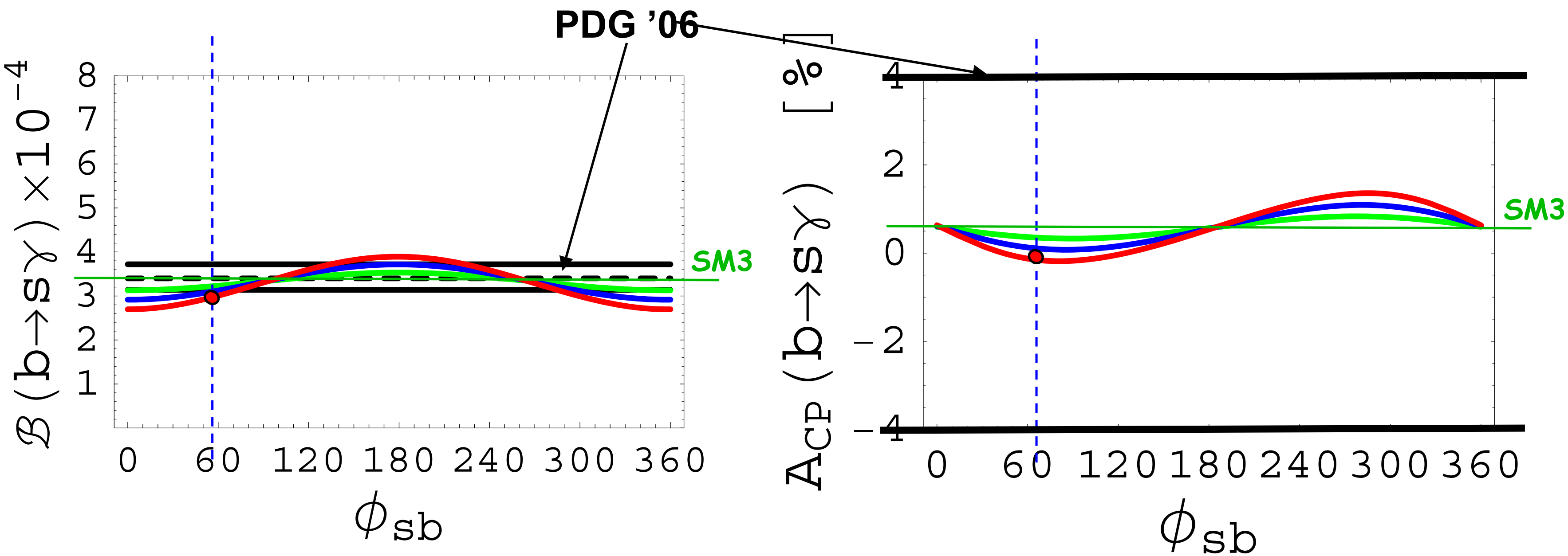
b → s

b → s Quadrangle (almost Triangle)

Area ~ (–)30x b → d Triangle

⇒ **Strength and Size of** $\sin 2\Phi_{B_s}$

Consistency and b → sγ Predictions

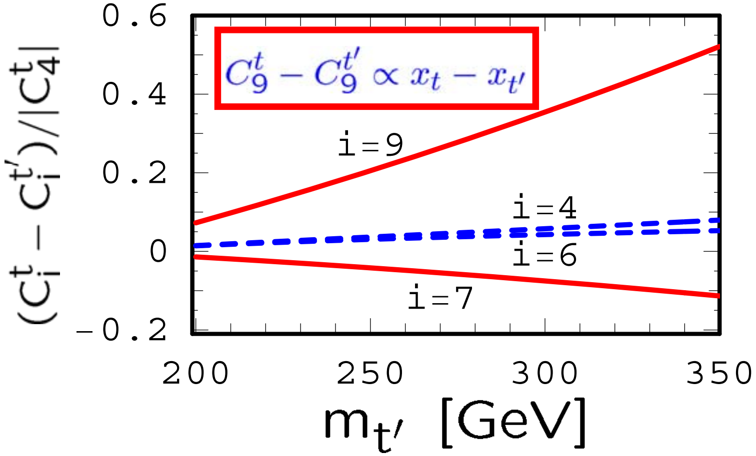


BR OK

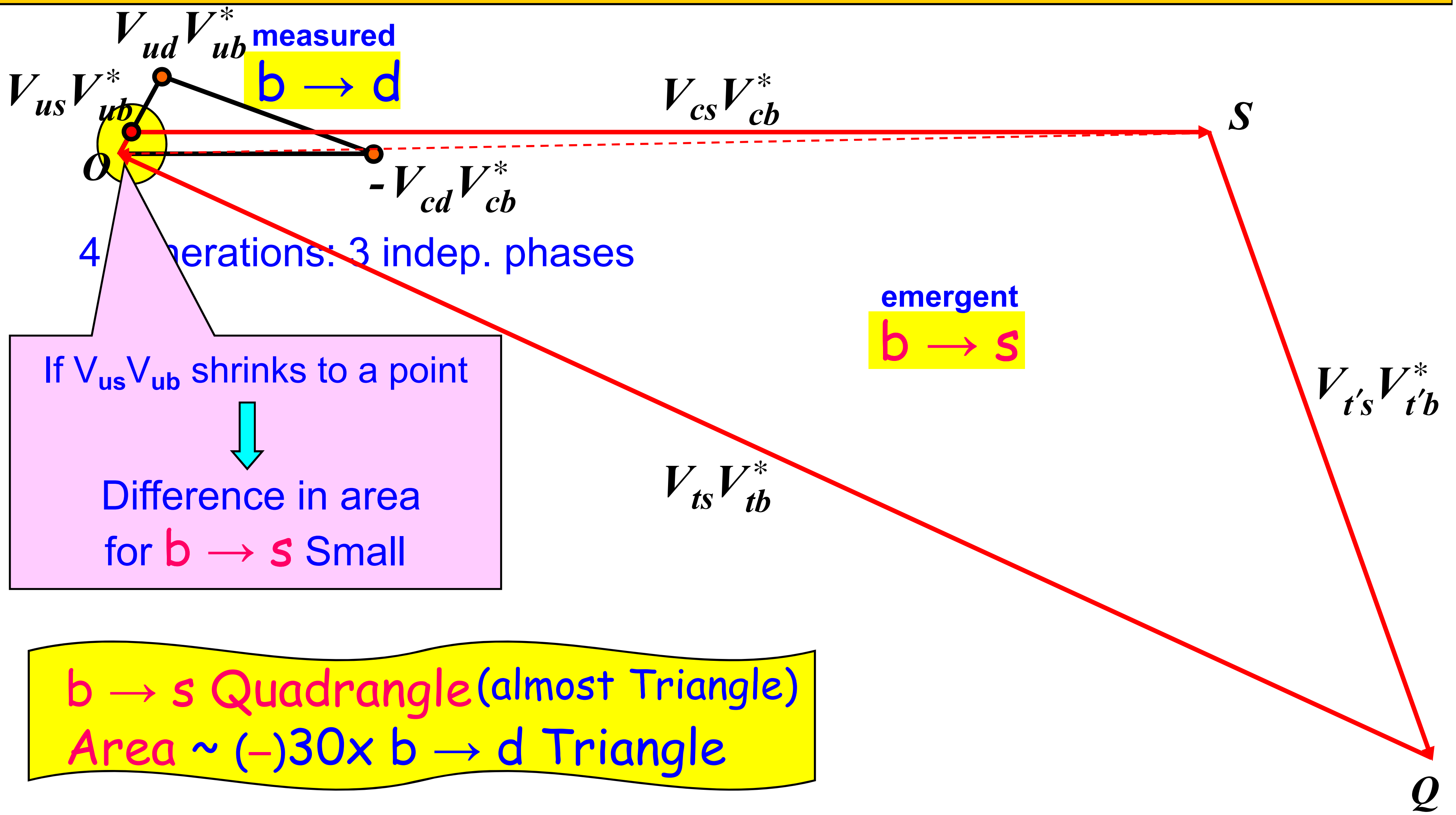
A_{CP} ~ 0 far away

beyond SuperB

Heavy t′ effect decoupled for b → sγ



4 generations: 3 indep. phases



2nd argument that $J^{sb}_{(2,3,4)}$ is predominant CPV

4^{th} generation? — The jury is out …

In era of LHC, can Directly Search for b′, t′
Once and For All !

Find b′, t′, or Rule Out @ LHC

It’s a Duty.

Strategy Considerations (漢中策略

- **Well shielded training ground — All Tools**
  - ☞ Move on to Greener Pastures ~ in 2 years
- **Publish early — Large Cross Section**
  - **- If “Limits”, then easy to publish**
  - **- If “Signal”, Lucked Out!**

b′ Signatures

For $m_{b'} < m_t + M_W = 255$ GeV

$b' \to cW$ dominance for sizable $V_{cb'}$
$b' \to tW^*$ dominance for suppressed $V_{cb'}$

Kinematic suppressed for $m_{b'} \lesssim 230$ GeV

Initial discovery should consider

$b' \to cW$ ~ $b' \to bZ, bH$ ~ $b' \to tW^*$

Rich Signature

cc(bar)WW; cWbZ; cWbH; ← Bonus !!
tc(bar)WW*;
tt(bar)W*W*; tW*bZ; tW*bH;

For $m_{b'} > m_t + M_W = 255$ GeV

$b' \to tW$ dominance; FCNC searchable

Heavy Q related To EWSB ?

$tt(bar)WW \to bb(bar)W^+W^-W^+W^-$ 4 W's + 2b's

Available on the CMS information server

CMS PAS EXO-08-09

CMS Physics Analysis Summary

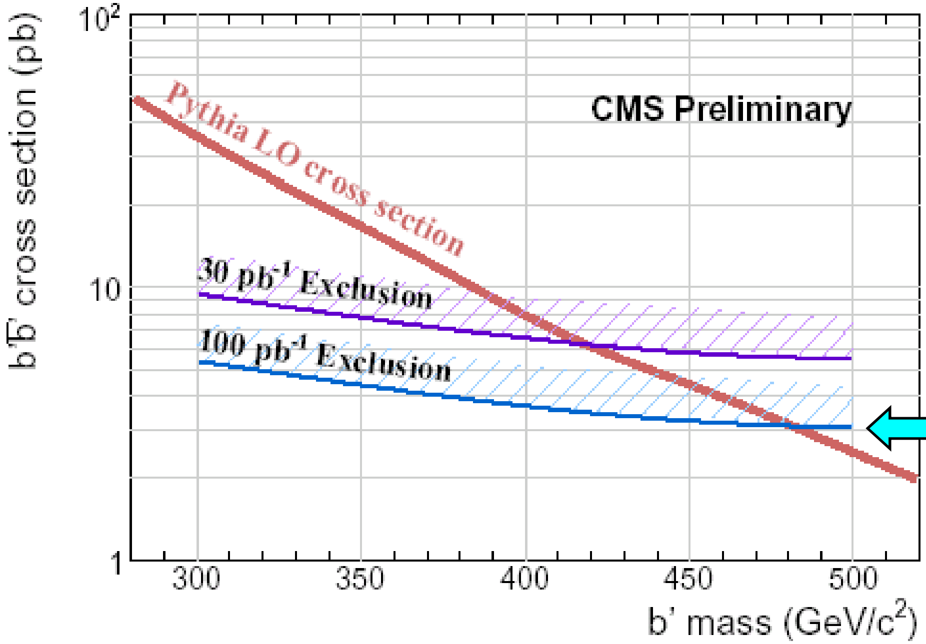
2008/08/29

Search for Heavy Bottom-like Fourth Generation Quark Pair at CMS in pp Collisions at $\sqrt{s} = 14$ TeV

The CMS collaboration

same-sign dilepton and trilepton

b' Mass	300 GeV/c^2	400 GeV/c^2	500 GeV/c^2
$b'\bar{b}'$ LO cross section	34.9 pb	8.05 pb	2.45 pb
Expected signal yield	68.2	22.2	8.0
Expected background yield		$7.3^{+10.5}_{-4.8}$	
S_{12}	7.5σ	2.0σ	0.0σ
S_{cP}	N/A	2.1σ	0.0σ



Limit to 480 GeV w/ $100\ \text{pb}^{-1}$