



New Physics CP Violation in $b \rightarrow s$ & $bs \leftrightarrow sb$ Transitions

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National Taiwan University

September 5, 2008, Beyond 3SM @ CERN





Outline



- I. $\Delta A_{K\pi} = A_{B \rightarrow K^+ \pi^0} - A_{B \rightarrow K^+ \pi^-} \neq 0$
- II. Consistence and 4×4 CKM
- III. $\sin 2\Phi_{B_s} < 0$ and Large
- IV. $A_{FB}(B \rightarrow K^* l^+ l^-)$ and Other Predictions
- V. Conclusion



$$\text{I. } \Delta A_{K\pi} = A_{B \rightarrow K^+ \pi^0} - A_{B \rightarrow K^+ \pi^-} \neq 0$$



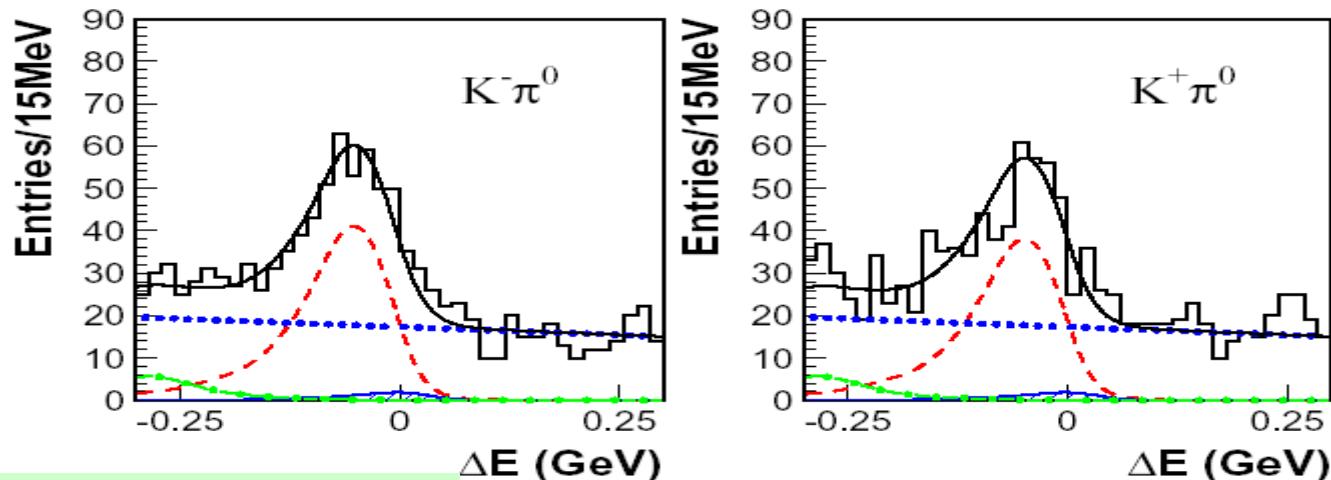
$A_{CP}(B^- \rightarrow K^+ \pi^0)$

Sakai



275M BB
New

$K^\pm \pi^0: 728 \pm 53$

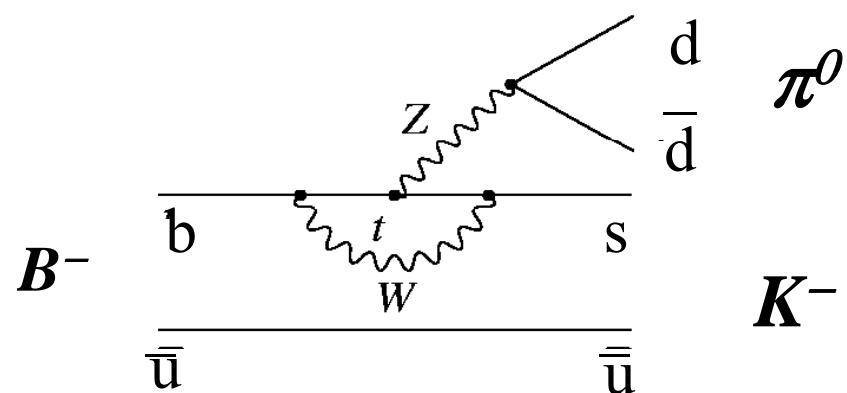


$$A_{CP}(K^\pm \pi^0) = 0.04 \pm 0.05 \pm 0.02$$

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 ?



ICHEP 2004, Beijing



Belle 2004 PRL: Seed



Y. Chao, P. Chang et al.



The partial rate asymmetry $\mathcal{A}_{CP}(K^+ \pi^-)$ is found to be $-0.101 \pm 0.025 \pm 0.005$, which is 3.9σ from zero. The significance calculation includes the effects of systematic uncertainties. Our result is consistent with the value reported by *BABAR*, $\mathcal{A}_{CP}(K^+ \pi^-) = -0.133 \pm 0.030 \pm 0.009$ [7]. The combined experimental result has a significance greater than 5σ , indicating that direct CP violation in the B meson system is established. Our measurement of $\mathcal{A}_{CP}(K^+ \pi^0)$ is consistent with no asymmetry; the central value is 2.4σ away from $\mathcal{A}_{CP}(K^+ \pi^-)$. If this result is confirmed with higher statistics, the difference may be due to the contribution of the electroweak penguin diagram or other mechanisms [16]. No evidence of

- [16] A. J. Buras, R. Fleischer, S. Recksiegel, and F. Schwab, hep-ph/0402112; V. Barger, C.W. Chiang, P. Langacker, and H.S. Lee, Phys. Lett. B **598**, 218 (2004).

P_{EW}
Z'



Belle 2008 Nature: Simple Bean Count

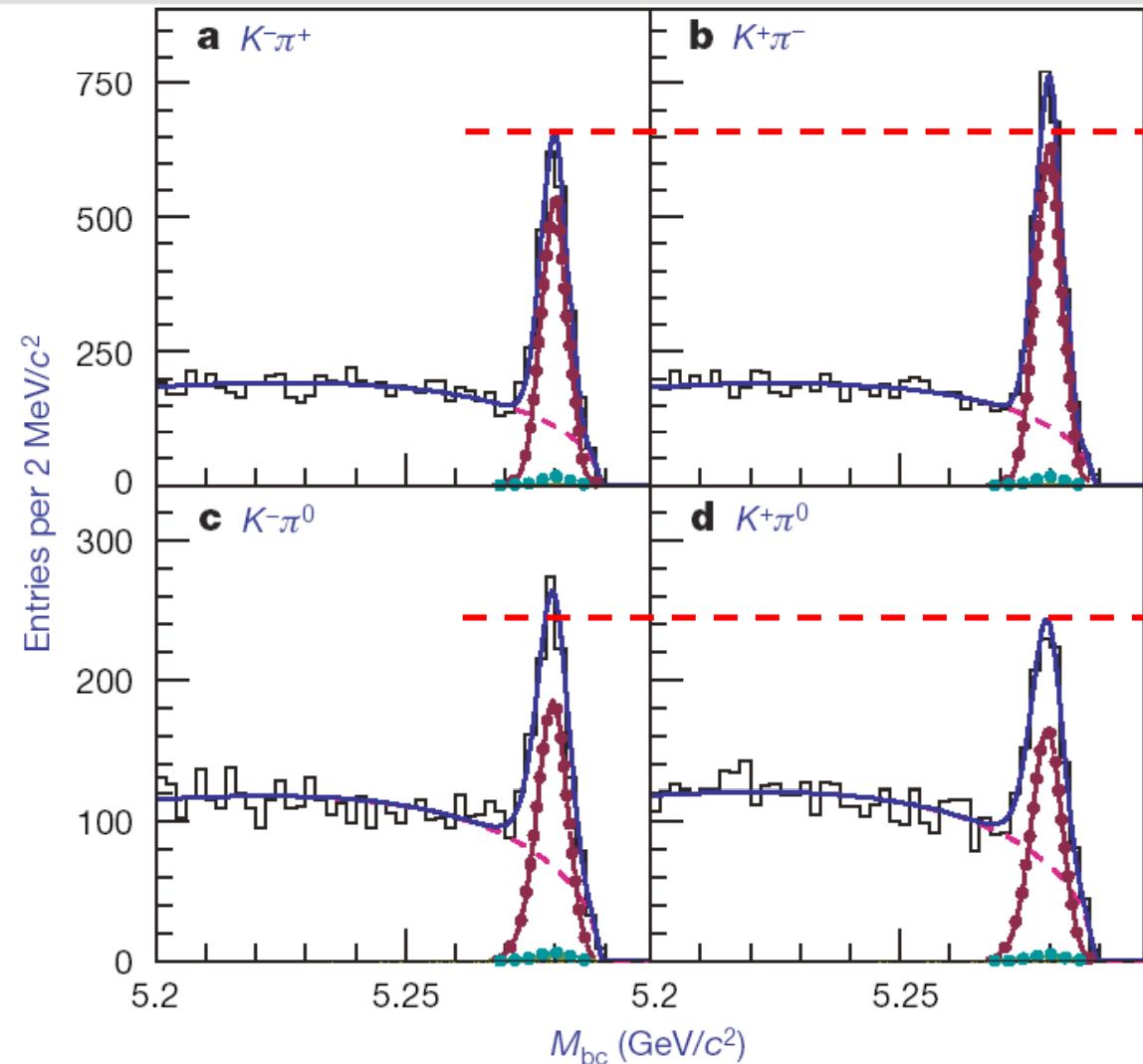


$$\Delta A = A_{K^+\pi^0} - A_{K^+\pi^-} = +0.164 \pm 0.037 \quad 4.4\sigma$$

+0.07 \pm 0.03 \text{ vs } -0.094 \pm 0.020

LETTERS

NATURE | Vol 452 | 20 March 2008





$$\Delta A_{K\pi} = A_{B \rightarrow K^+ \pi^0} - A_{B \rightarrow K^+ \pi^-} \stackrel{+0.050 \pm 0.025}{=} \stackrel{-0.097 \pm 0.012}{\neq} 0$$

World



Difference is Large!

$$= +0.147 \pm 0.028 > 5\sigma$$

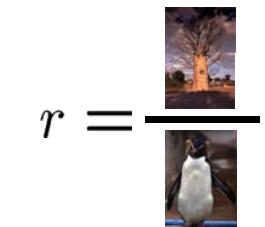
Experiment is Firm

Why a Puzzle ?

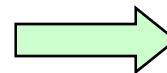
 $\Delta A_{K\pi} \sim 0$ expected

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

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



Large C ?

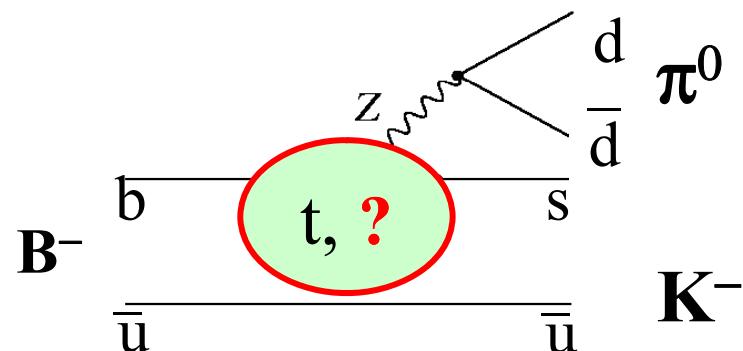


A lot of (hadronic) finesse

Baek, London, PLB653, 249 (2007)

Large EW Penguin ?

Need NP CPV Phase

 P_{EW} has practically no weak phase in SM



My first B (and 4th gen.) paper



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PHYSICAL REVIEW LETTERS

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

$$\mathcal{L}_{\text{eff}}^{b\bar{s} \rightarrow l^+l^-} = 2\sqrt{2}G_F\chi v_i\{\bar{C}_i(\bar{s}\gamma_\mu Lb)(\bar{l}\gamma_\mu Ll) - s_W^2(F_1^l + 2\bar{C}_i^Z)(\bar{s}\gamma_\mu Lb)(\bar{l}\gamma_\mu l) - s_W^4F_2^l[\bar{s}i\sigma_{\mu\nu}(q_\nu/q^2)(m_sL + m_bR)b](\bar{l}\gamma_\mu l)\}, \quad (1)$$

$$\mathcal{L}_{\text{eff}}^{b\bar{s} \rightarrow \nu\bar{\nu}} = -2\sqrt{2}G_F\chi v_i\bar{D}_i(\bar{s}\gamma_\mu Lb)(\bar{\nu}\gamma_\mu Lv), \quad (2)$$

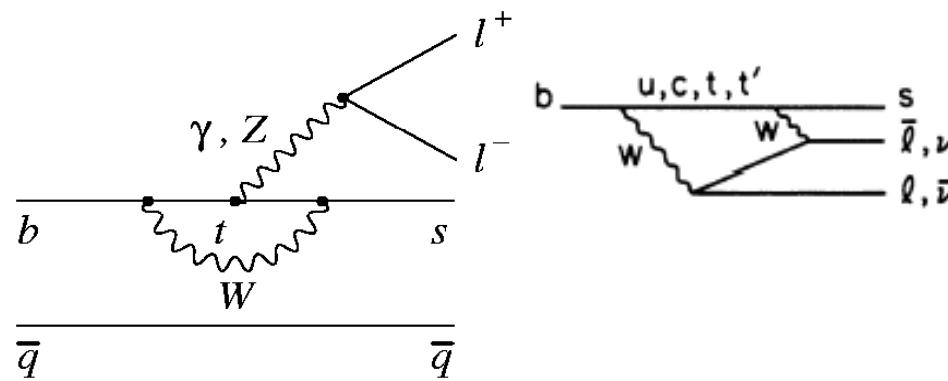
where $\chi = g^2/16\pi^2$, $v_i \equiv V_{is}^* V_{ib}$, i is summed from 2 to n (where n is the number of generations),¹⁰ s_W is the sine of the Weinberg angle, and we exhibit¹¹

dimensions

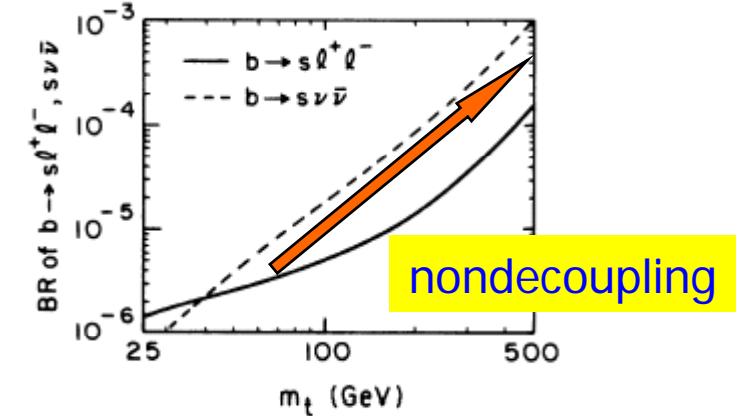
$$\bar{C}_i \equiv \bar{C}_i^Z + \bar{C}_i^{\text{box}} = \frac{1}{4}x_i + \frac{3}{4}\left(\frac{x_i}{x_i-1}\right)^2 \ln x_i - \frac{3}{4}\frac{x_i}{x_i-1}, \quad (3)$$

$$\bar{D}_i \equiv \bar{D}_i^Z + \bar{D}_i^{\text{box}} = \frac{1}{4}x_i + \frac{3}{4}\frac{x_i(x_i-2)}{(x_i-1)^2} \ln x_i + \frac{3}{4}\frac{x_i}{x_i-1}, \quad (4)$$

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



γ	Z
αG_F	$G_F^2 m_t^2$





$$\Delta A_{K\pi} = A_{B \rightarrow K^+ \pi^0} - A_{B \rightarrow K^+ \pi^-} \stackrel{+0.050 \pm 0.025}{-0.097 \pm 0.012} \neq 0$$

World



$$= +0.147 \pm 0.028 > 5\sigma$$

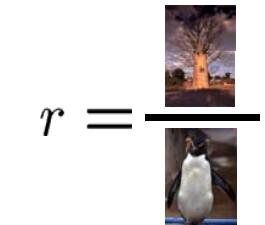
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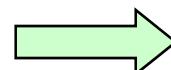
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$$\mathcal{M}(B^0 \rightarrow K^+ \pi^-) \propto (\textcolor{blue}{T} + \textcolor{red}{P}) = \boxed{re^{i\phi_3} + e^{i\delta}}$$

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



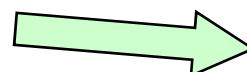
Large C ?



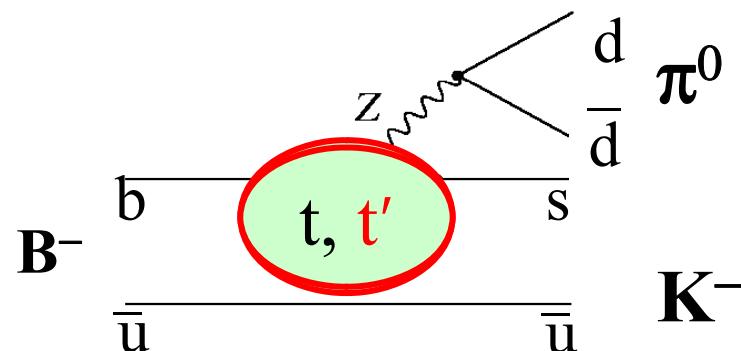
A lot of (hadronic) finesse

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

nondecoupling



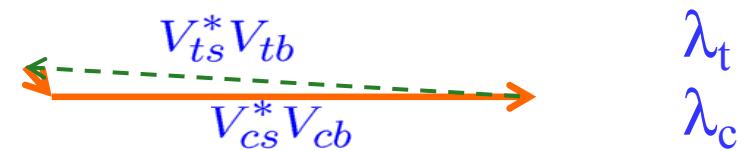
Effective $b \rightarrow s$ Hamiltonian: t and t' Effect



$$\left. \begin{array}{l} \lambda_u + \lambda_c + \lambda_t = 0 \\ |\lambda_u| \sim 10^{-3} \end{array} \right\} \Rightarrow \boxed{\lambda_t \cong -\lambda_c}$$

SM 3

$$H_{\text{eff}}^3 = \frac{G_F}{\sqrt{2}} \left[\lambda_u (C_1 O_1 + C_2 O_2) + \sum_{i=3}^{10} \lambda_c C_i^t O_i \right]$$

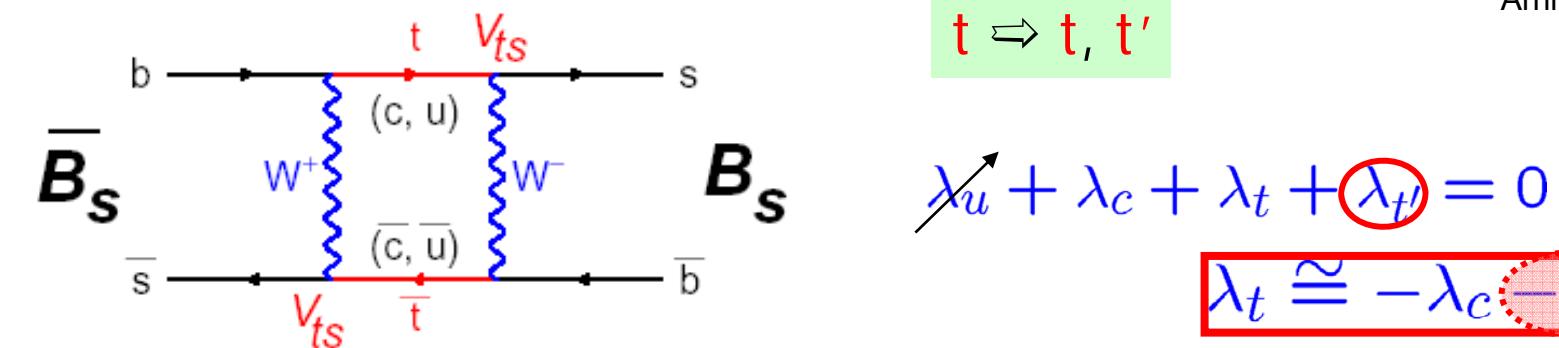




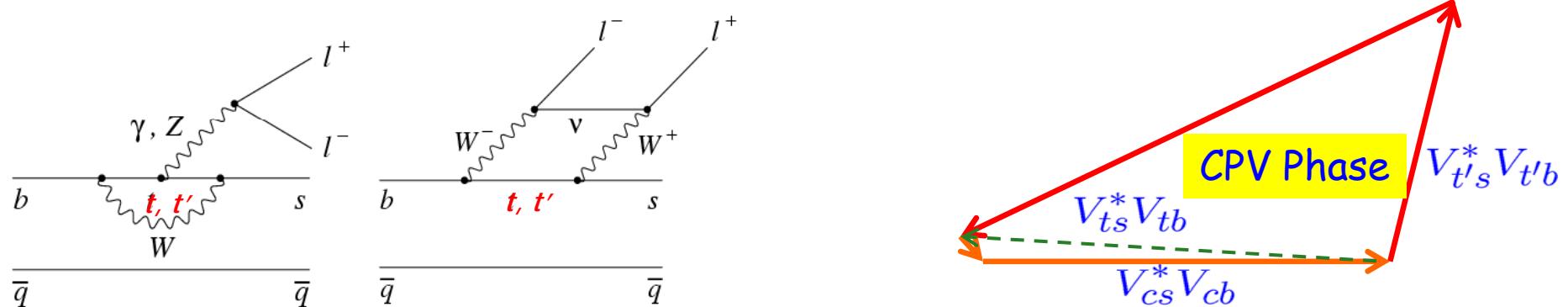
$$\lambda_{t'} \equiv V_{t's}^* V_{t'b} \equiv r_{sb} e^{i\phi_{sb}}$$



Arhrib and WSH, EPJC'03



SM 4



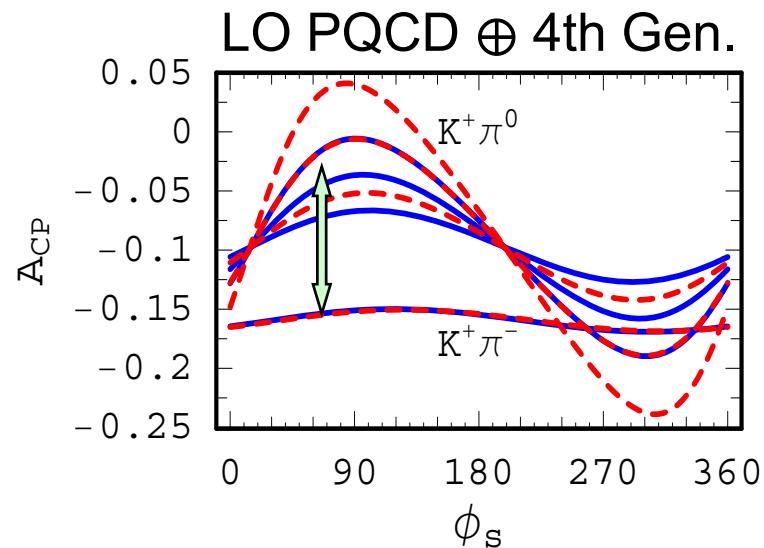
$$M_{12} \propto f_{B_s}^2 B_{B_s} \left\{ \lambda_c^2 S_0(t, t) + 2 \lambda_c \lambda_{t'} [S_0(t, t) - S_0(t, t')] \right. \\ \left. + \lambda_{t'}^2 [S_0(t, t) - 2 S_0(t, t') + S_0(t', t')] \right\}$$

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

GIM Respecting



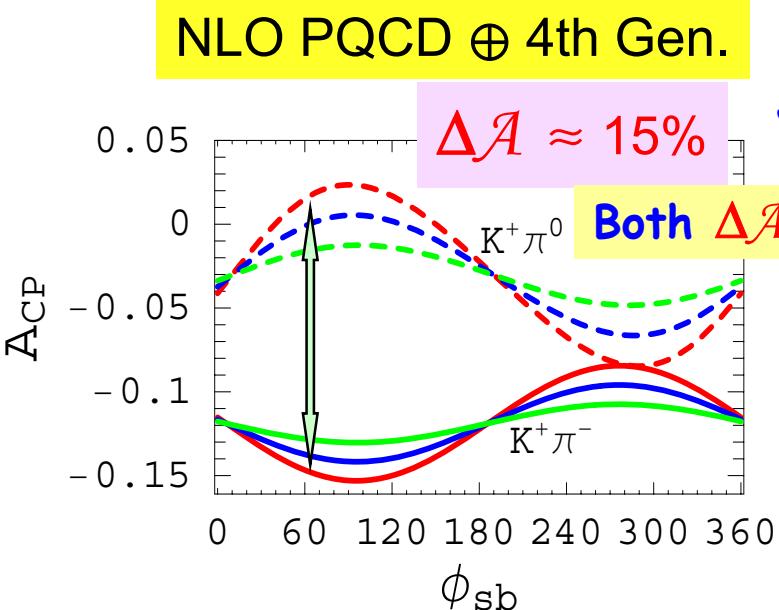
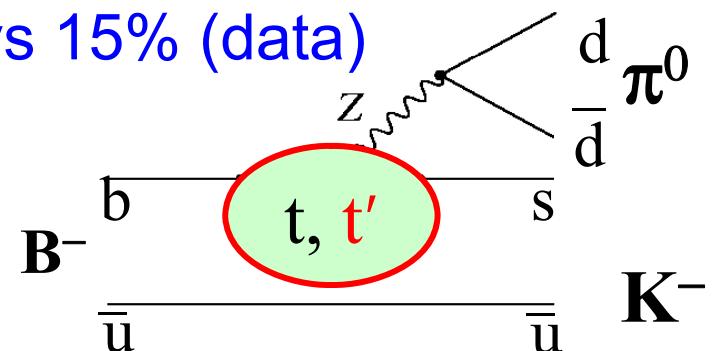
$$\Delta A = A_{K^+\pi^0} - A_{K^+\pi^-} \sim 15\% \text{ and } P_{EW}^{b \rightarrow s}$$



WSH, Nagashima, Soddu, PRL'05

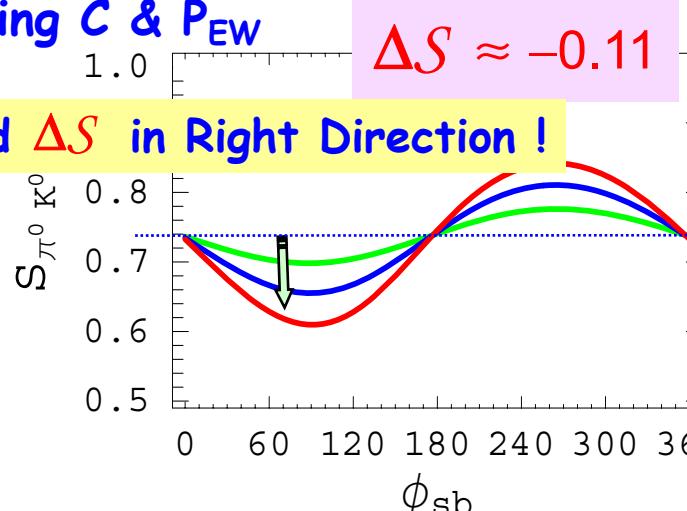
$\Delta A \approx 12\%$ vs 15% (data)

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



WSH, Li, Mishima, Nagashima, PRL'07

Joining C & P_{EW}



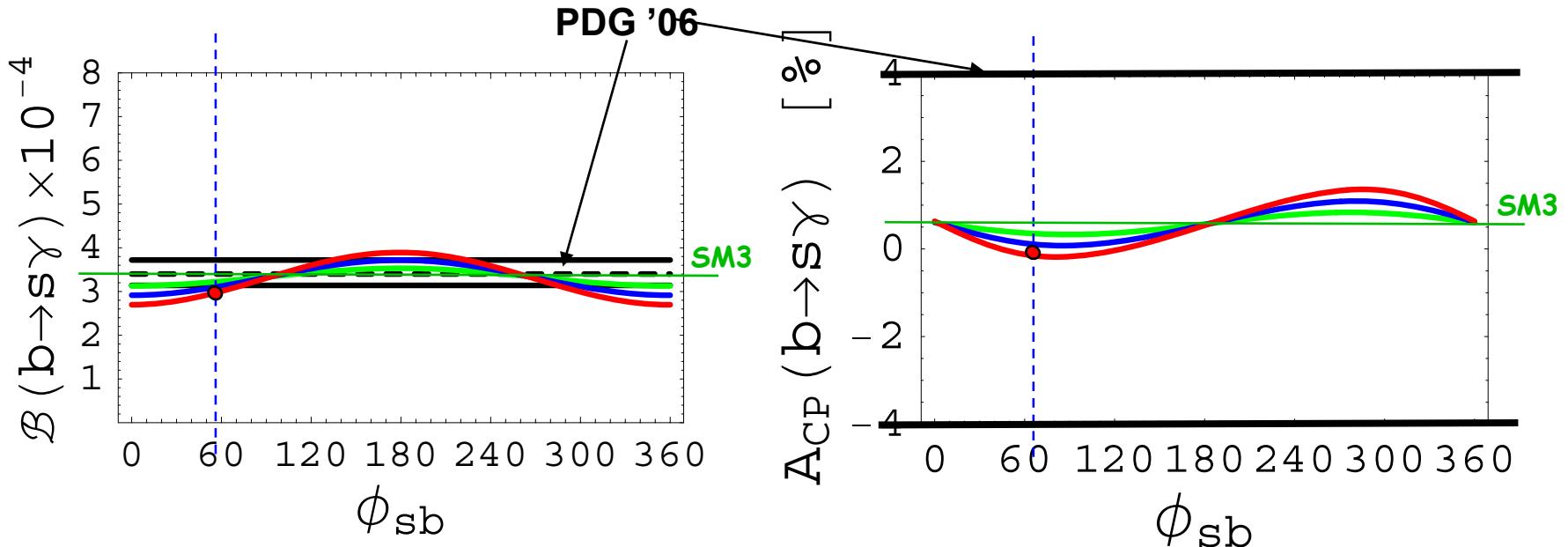
$r_{sb} = 0.03$: red, dash
0.02: blue, solid
0.01: green, dot-dash
weakened
vs $-0.34 \pm 0.2x$
(data)
@ ICHEP
SM3 input



II. Consistence and 4×4 CKM

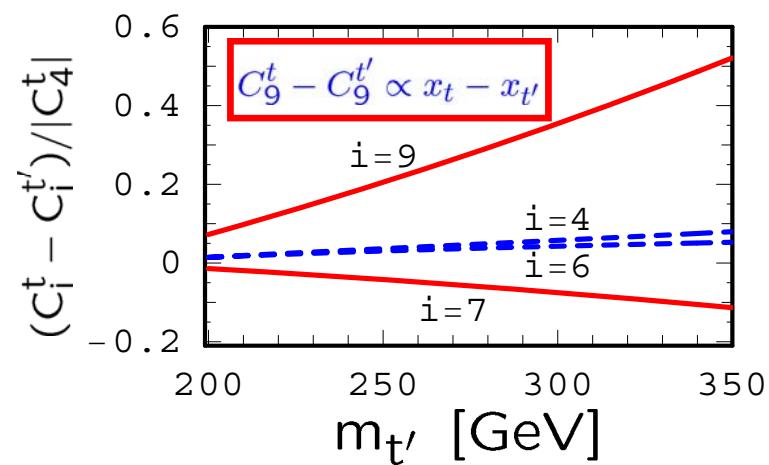


Consistency and $b \rightarrow s\gamma$ Predictions



BR OK

Heavy t' effect
decoupled
for $b \rightarrow s\gamma$



$A_{CP} \sim 0$ far away

beyond SuperB



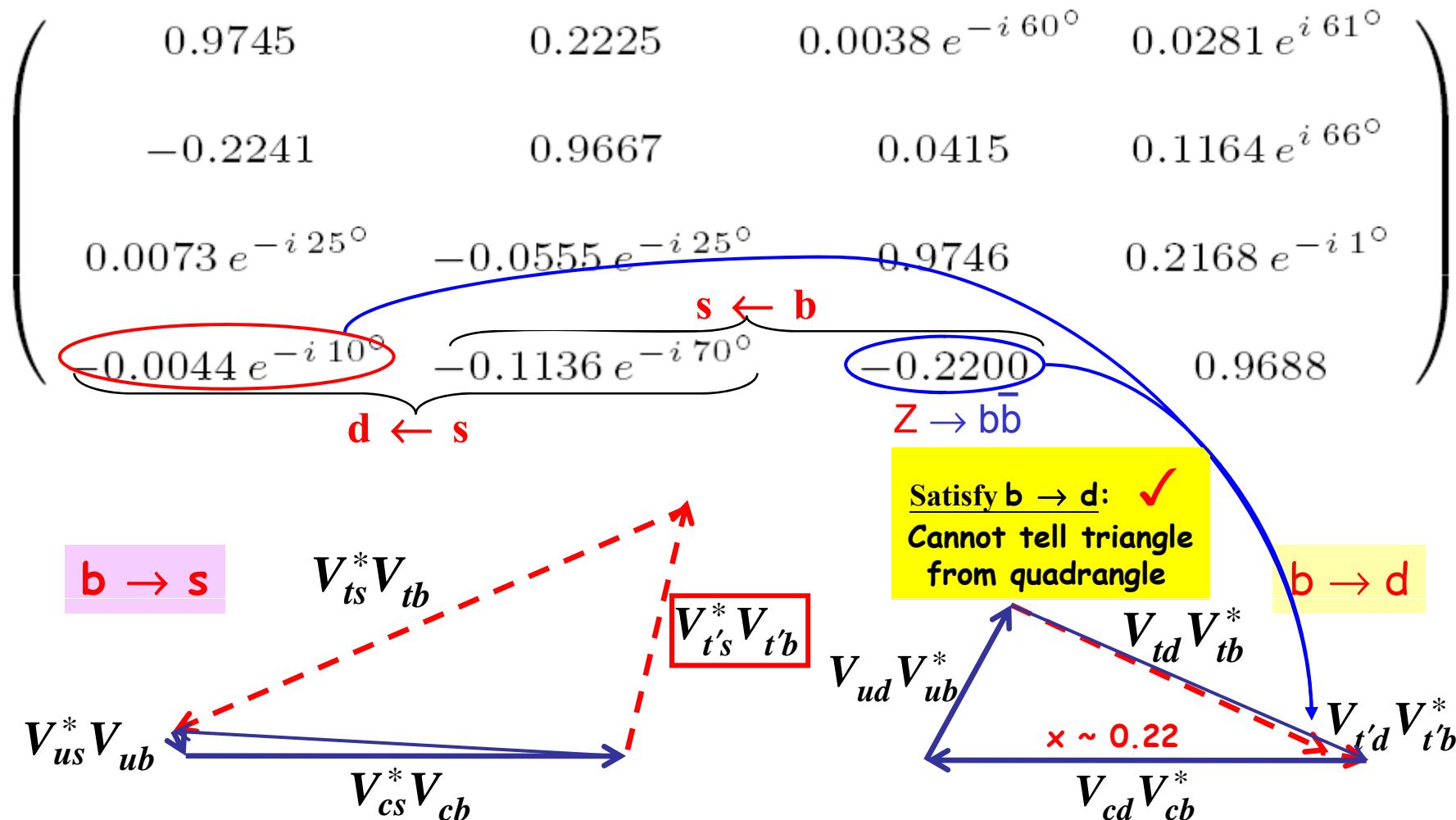
4 x 4 Unitarity \Rightarrow Z/K Constraints



$$V_{CKM}^4 =$$

“Typical” CKM Matrix

WSH, Nagashima, Soddu, PRD'05

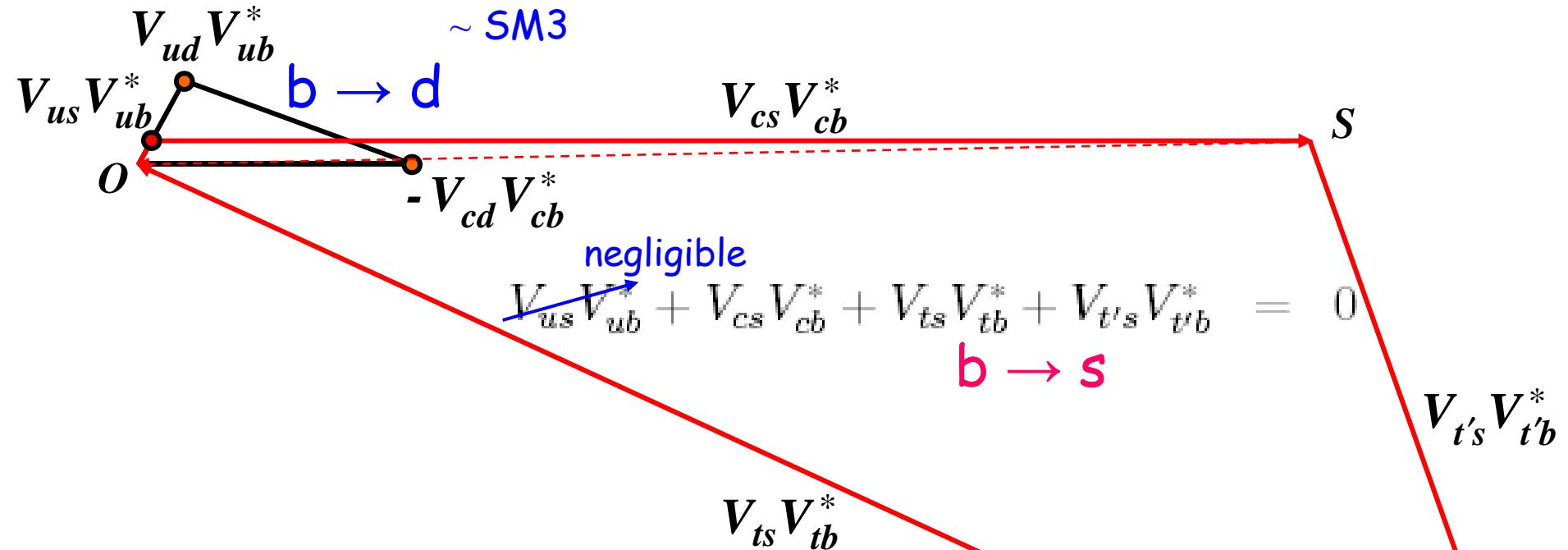




b → d "Triangle" and b → s Quadrangle

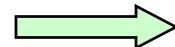


$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + \underbrace{V_{td}V_{tb}^* + V_{t'd}V_{t'b}^*}_{\sim \text{SM3}} = 0$$



b → s Quadrangle(almost Triangle)

Area $\sim (-)30 \times$ b → d Triangle

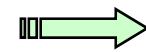
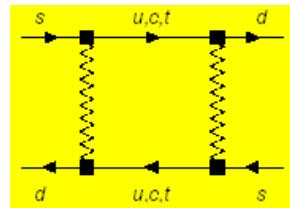


Strength and Size of $\sin 2\Phi_B$

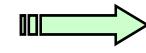
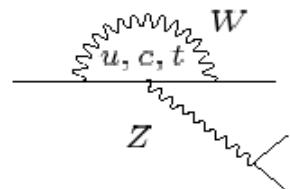
Q



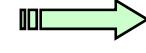
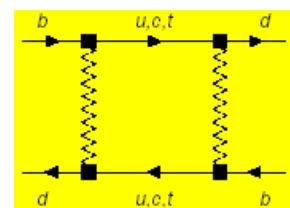
On Boxes and Z Penguins



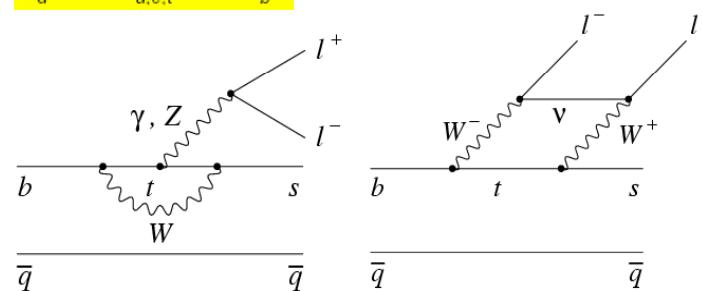
GIM, charm, ε_K



small ε'/ε , $K \rightarrow \pi\nu\bar{\nu}$ (still waiting)



heavy top, $\sin^2\phi_1/\beta$



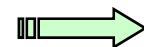
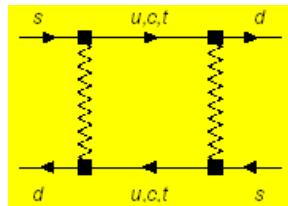
Z dominance for heavy top

1986 → 2002

Most Flavor/CPV learned from these diagrams/processes



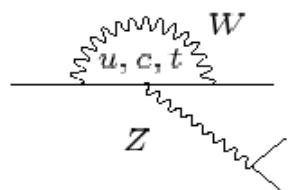
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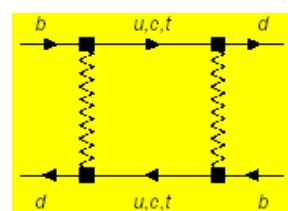
GIM, charm, ε_K

Nondecoupling

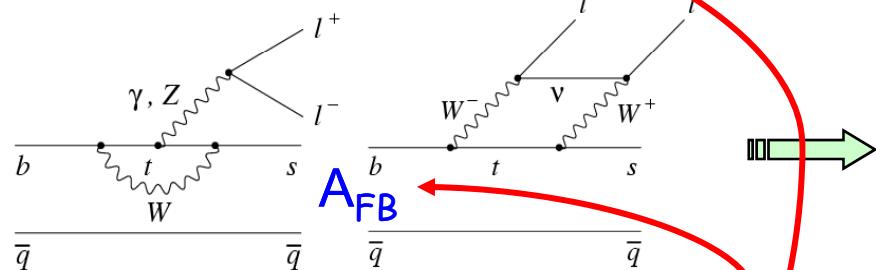
:: Large Yukawa!



small ε'/ε , $K \rightarrow \pi\nu\bar{\nu}$ (still waiting)



heavy top, $\sin 2\phi_1/\beta$



Z dominance for heavy top

1986 → 2002

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



D !

b', t' @ LHC



II. $\sin 2\Phi_{B_s} < 0$ and Large

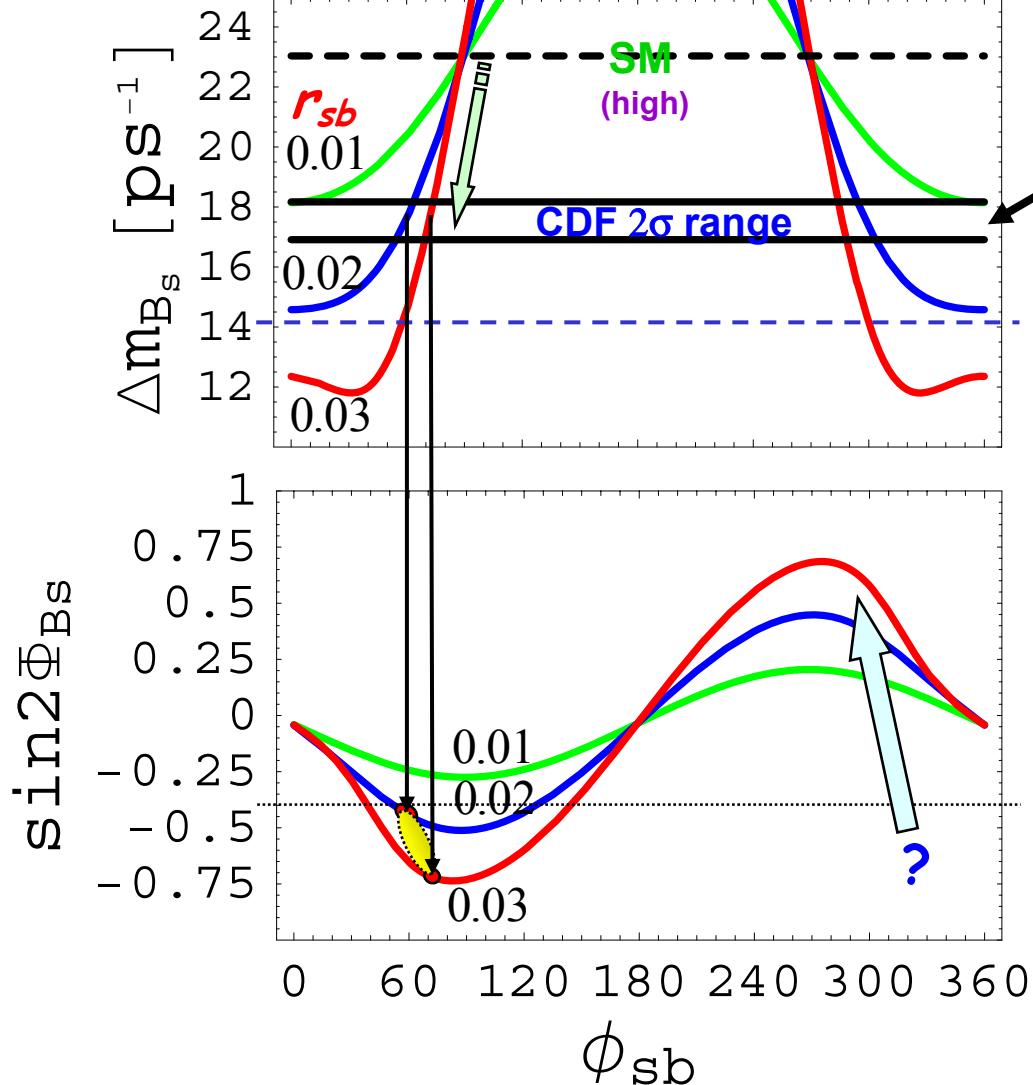


Large CPV in B_s Mixing



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 $r_{sb} \sim 0.02 - 0.03$, $[V_{cb} \sim 0.04]$
 ϕ_{sb} Range $\sim 60^\circ - 70^\circ$
Finite CPV Phase

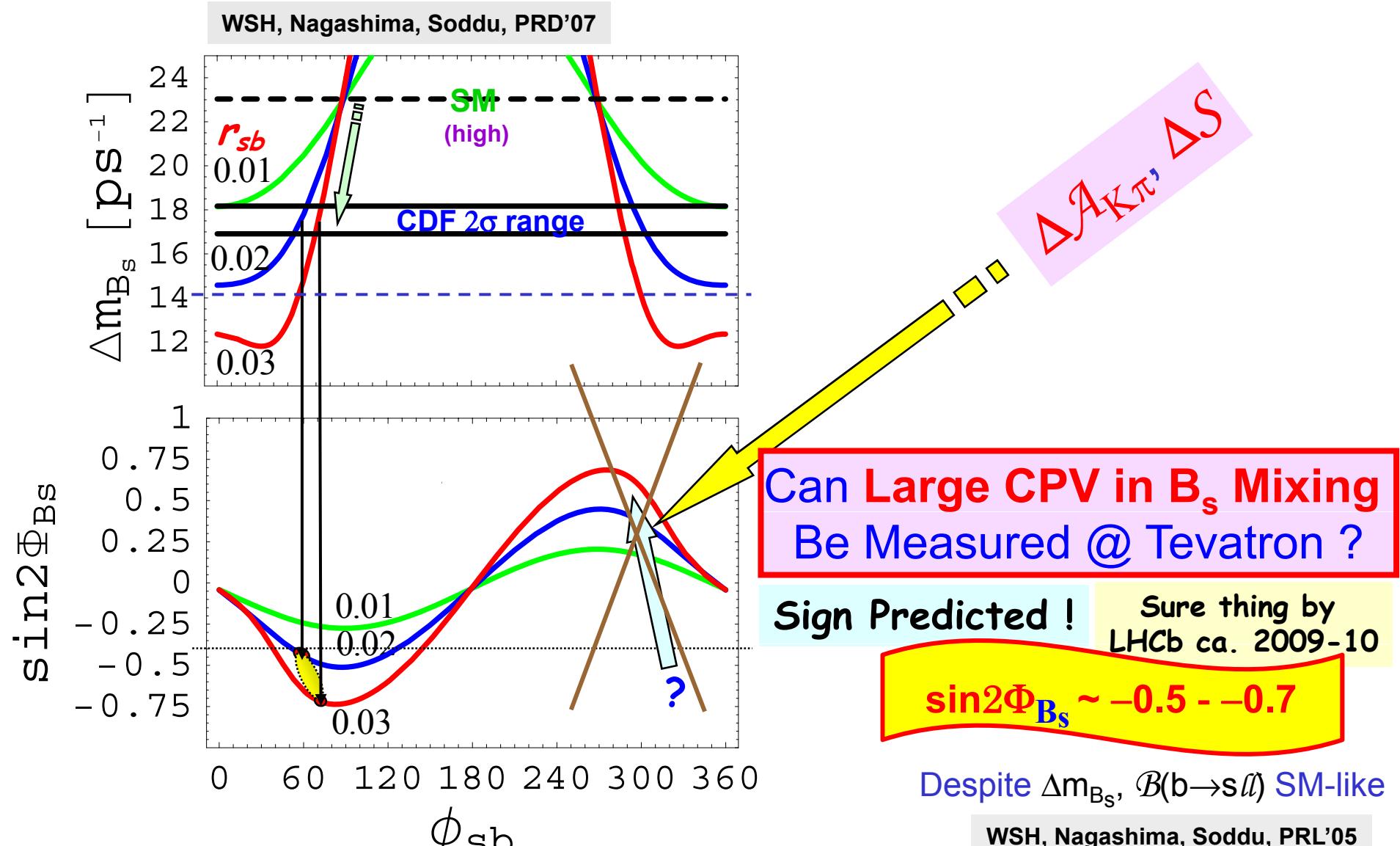
$$\sin 2\Phi_{B_s} \sim -0.5 - -0.7$$

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

WSH, Nagashima, Soddu, PRL'05



Large CPV in B_s Mixing



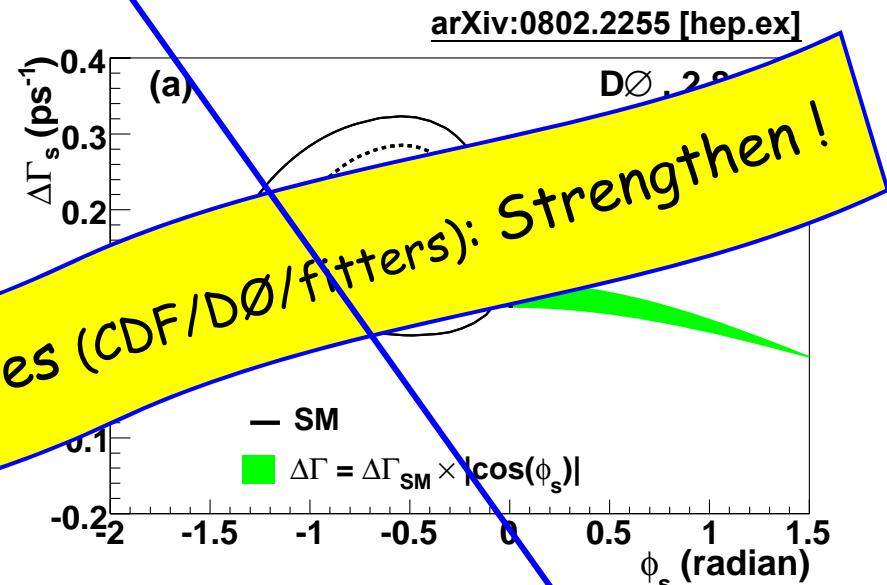
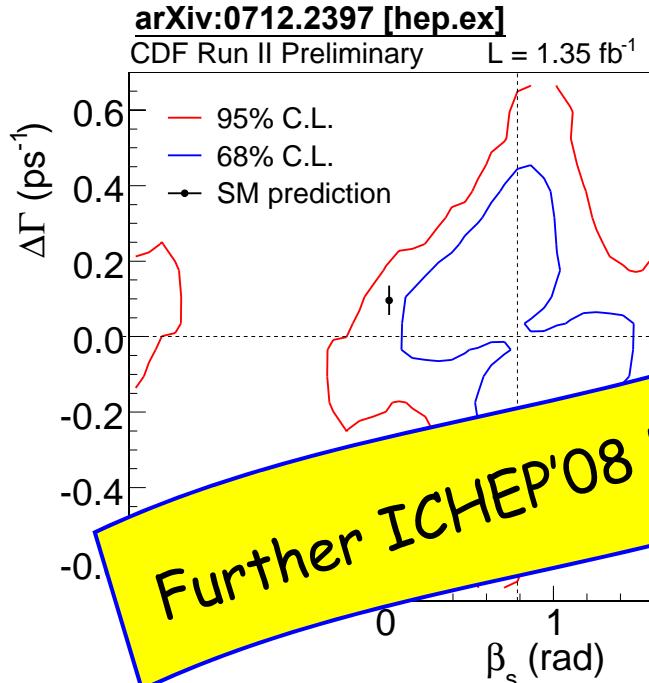


$\sin 2\Phi_{B_s} \sim -0.5 - -0.7$



talk by Juan Fernandez (CDF)

WSH, Nagashima, Soddu, PRD'07



Observable 68% Prob. 95% Prob.

ϕ_{B_s} [°]	-19.9 ± 5.6	$[-30.45, 0.29]$
UTfit	-68.2 ± 4.9	$[-78.45, -58.2]$

arXiv:0803.0659 [hep.ph]

$\sim 2.5\sigma$
 $\sin 2\Phi_{B_s} = -0.64 \pm ?$

Incredible !!!



Results with Flavor Tagging



4th Generation ?

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

D0^[1]

D0^[2]

CDF^[3]

CDF^[4]

SM

-0.57^{+0.25}
-0.30

-0.46 ± 0.29

-1.36 ↔ -0.24

-1.20 ↔ -0.40

-0.0038 ± 0.002

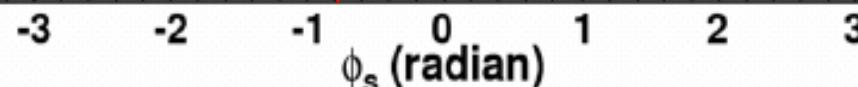
Tevatron can compete w/ LHCb
iff $|\sin 2\Phi_{B_s}| > 0.4$

Did not ask for this!

$$[1] \Delta\Gamma_s = 2 \Delta\Gamma_{12}^{\text{SM}} |\cos\phi_s|$$

$$[2] \Delta\Gamma_s = 2 \Delta\Gamma_{12}^{\text{SM}} |\cos\phi_s|$$

$$[3] \Delta\Gamma_s = 2 \Delta\Gamma_{12}^{\text{SM}} |\cos\phi_s| \text{ and } \delta_i = (\delta_i)_{B_d \rightarrow J/\psi K} \text{ and } \tau(B_s) = \tau(B_d)$$



ICHEP update

Increased dataset still hints at larger than SM values!

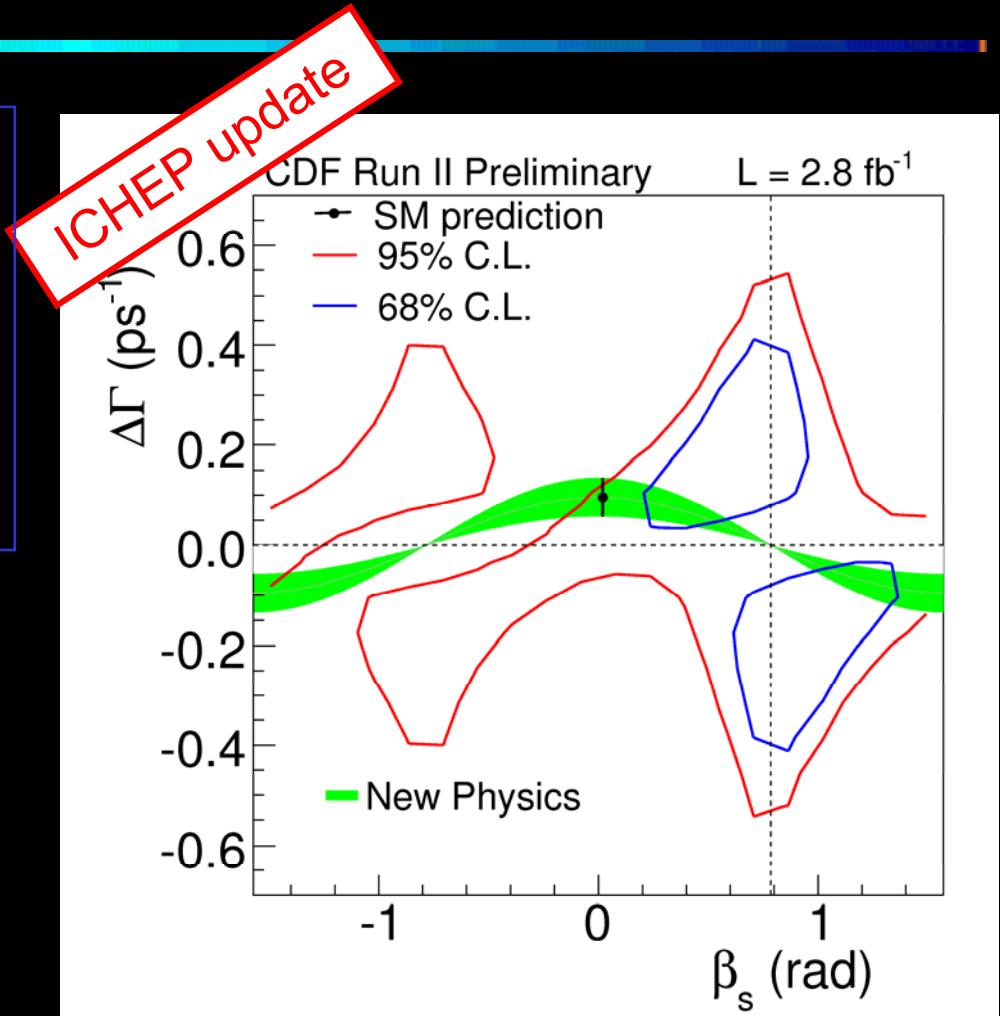
Consistency with SM decreased 15% \rightarrow 7% ($\sim 1.8\sigma$)

$0.28 < \beta_s < 1.29$ at 68% CL

$-\pi/2 < \beta_s < -1.45$ OR

$-1.01 < \beta_s < -0.57$ OR

$-0.13 < \beta_s < \pi/2$ at 95% CL



www-cdf.fnal.gov/physics/new/bottom/080724.blessed-tagged_BsJPsiPhi_update_prelim/

Will shrink further with PID in the whole dataset



Φ_{B_s} Prospect (short term)

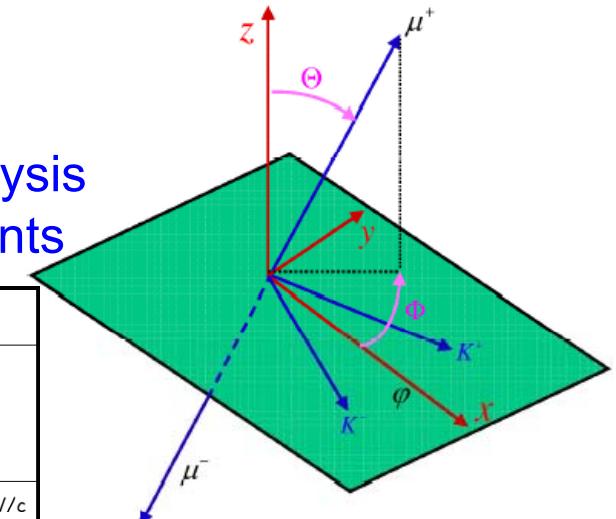
$B_s \rightarrow J/\psi \phi$ analogous to $B_d \rightarrow J/\psi K_S$

VV \Rightarrow Angular & Vertex Resolved Analysis
to disentangle CP \pm components

- CDF/DØ: 8 fb⁻¹ projected

$$\sigma(\sin 2\Phi_{B_s}) \approx 0.2 \text{ (?)}/\exp \text{ similar}$$

Trigger	CDF	DØ
2-Track	$p_T > 2.0 \text{ GeV}/c$ $p_{T1} + p_{T2} > 5.5 \text{ GeV}/c$ $100 \mu\text{m} < d_{1,2} < 1 \text{ mm}$	—
1-Muon	—	$p_T(\mu) > 3.4, 5 \text{ GeV}/c$
2-Muon	$p_T(\mu's) > 1.5 \text{ GeV}/c$	$p_T(\mu's) > 2.0 \text{ GeV}/c$



- LHCb: 0.5 fb⁻¹ (2008 ?)

$$\sigma(\sin 2\Phi_{B_s}) \approx 0.04$$

- ATLAS: 2.5 fb⁻¹ (2008 ?)

$$\sigma(\sin 2\Phi_{B_s}) \approx 0.16$$

CMS ?

Nakada @ fLHC 3/07

€ LHCb the winner if \sim SM

$$\sin 2\Phi_{B_s} \sim -0.04 \text{ in SM}$$

But 2009 looks interesting !

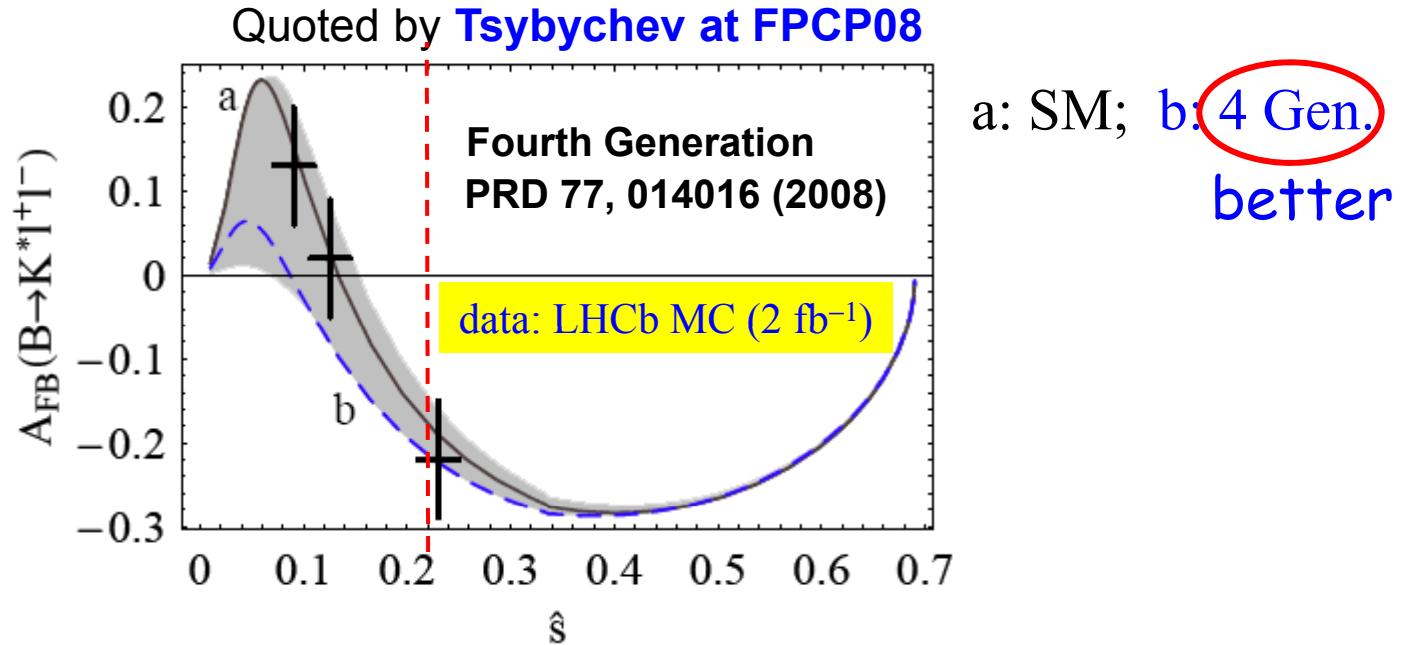
\$ Tevatron could get lucky

if $\sin 2\Phi_{B_s}$ large \longleftrightarrow New Physics !

Could Tevatron run beyond 2008 ?

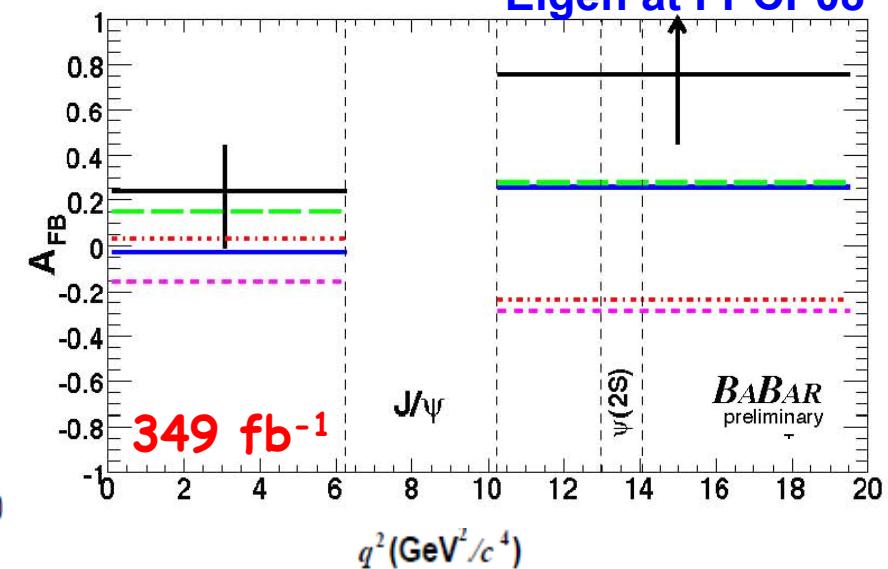
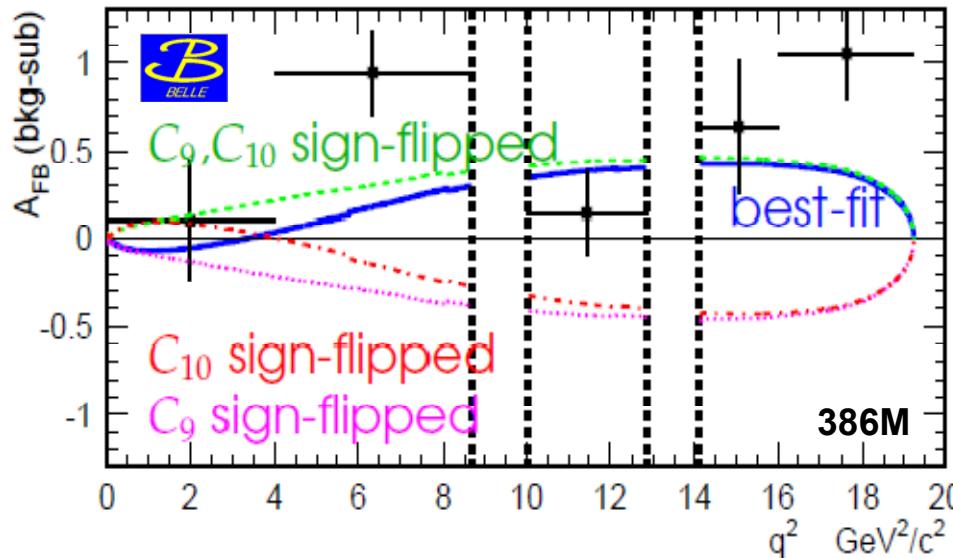


IV. $A_{FB}(B \rightarrow K^* l^+ l^-)$ and Other Predictions



• (F_L and) A_{FB} (and A_I) favor the "opposite-sign C_7 model"

Eigen at FPCP08



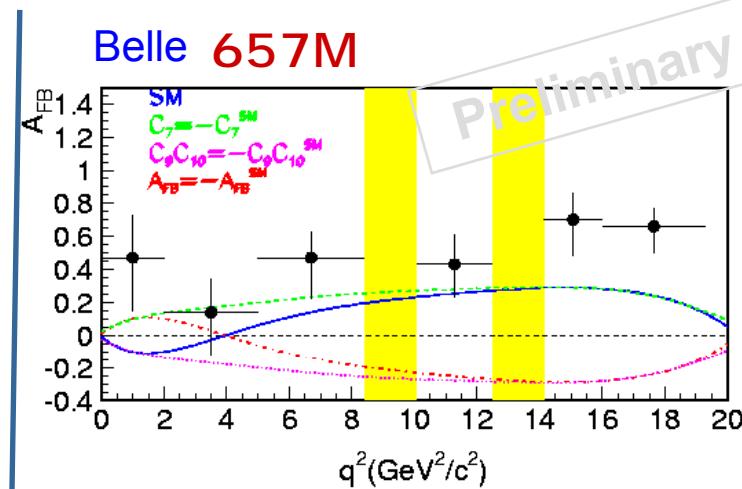
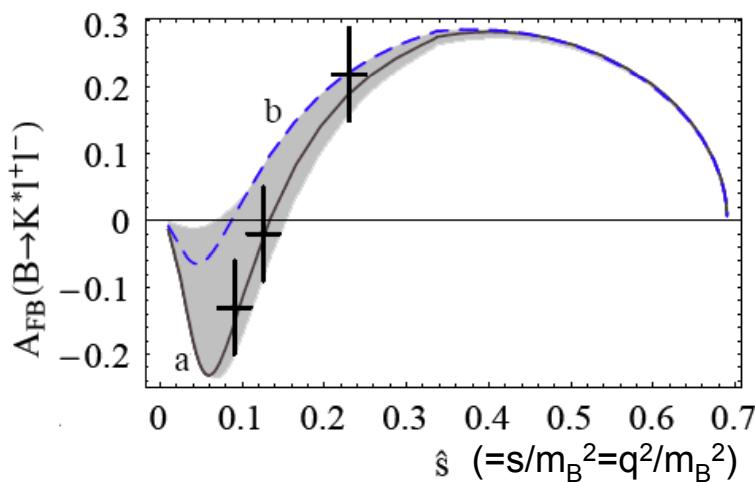
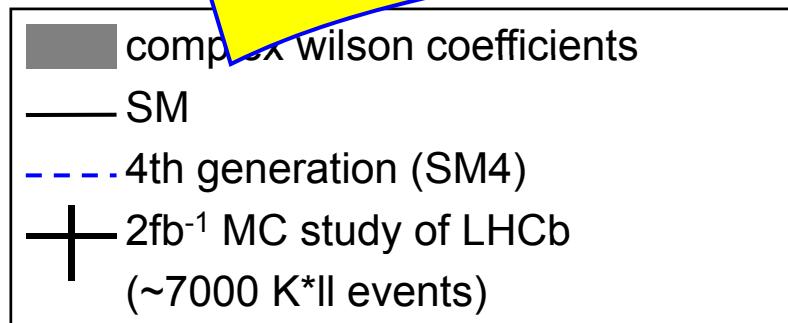


Instead flipped C_7

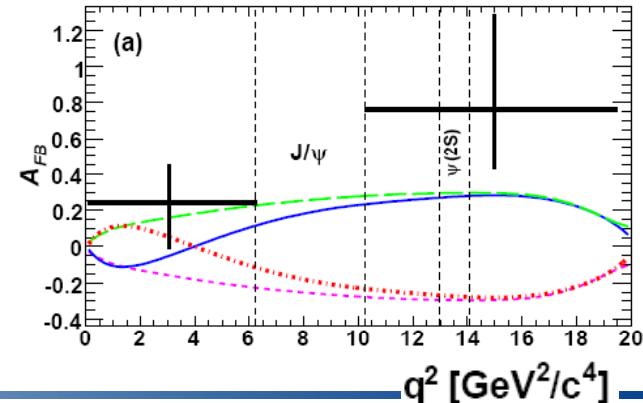


$$\frac{dA_{FB}}{ds} \propto -\left\{ \text{Re}(C_9^{\text{eff}} C_{10}) V A_4 + \hat{m}_{K^*} [A_2 (1 + \hat{m}_{K^*}) + A_1 T_1 (1 + \hat{m}_{K^*})] \right\}$$

W.-S. Hou, J. N. Ng, and N. Mahajan, arXiv:0804.4016 (2008)

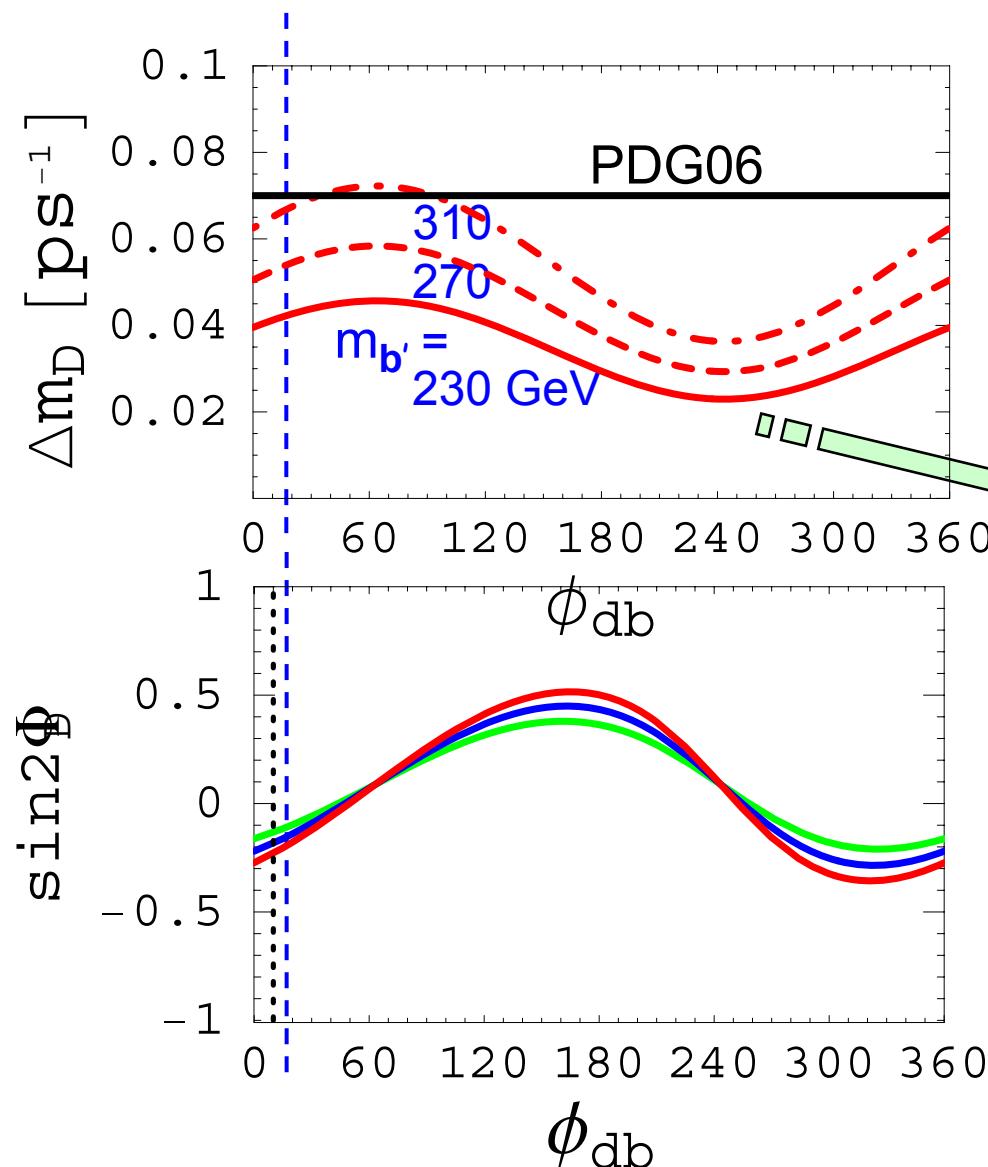


BABAR, arXiv:0804.4412 386M





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

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

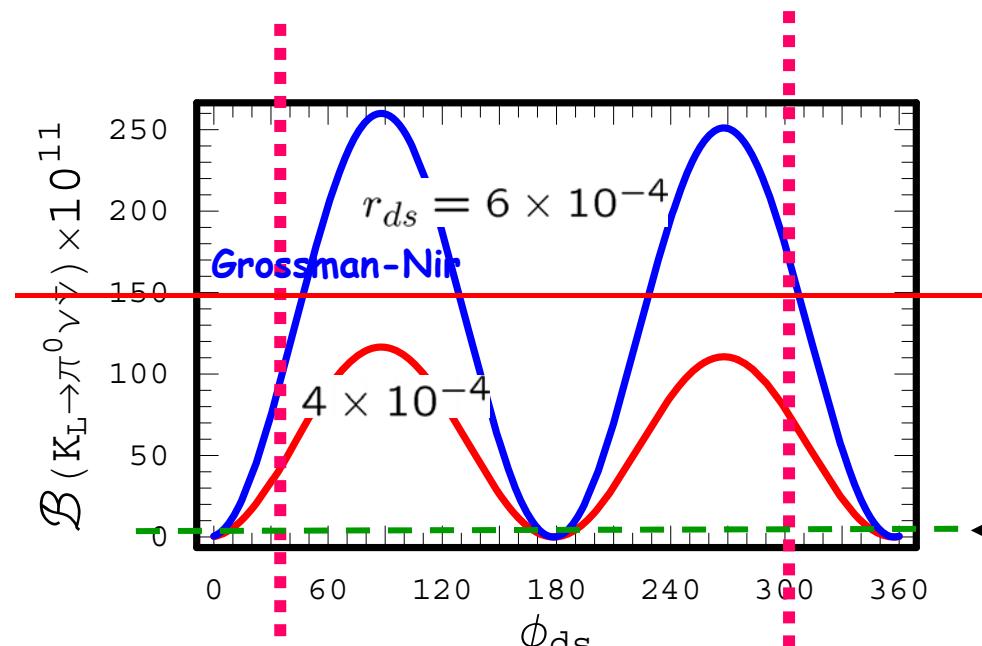
$x = \Delta m / \Gamma \sim 1 - 3$ plausible

w/ Sizable (but not huge)
CPV in Mixing $\sim -15\%$

N.B. SM LD could generate
 $y \sim 1\%$, $x \approx y$
[Falk, Grossman, Ligeti, (Nir,) Petrov]



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



Current E391A U.L.

2.86×10^{-7} (90% c.l.)

Very hard to measure

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

SM 3

Rate could be enhanced up to almost two orders !!

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

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

\therefore Large CPV Phase



VI. Conclusion



$$\begin{aligned} J_{(2,3,4)}^{sb} &\simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2) A_{234}^{sb} \\ &\sim \underbrace{\frac{m_{t'}^2}{m_c^2} \left(\frac{m_{t'}^2}{m_t^2} - 1 \right) \frac{m_{b'}^4}{m_b^2 m_s^2}}_{m_{b'}, m_{t'} \approx 300 \text{ GeV } 10^{+13}} \underbrace{\frac{A_{234}^{sb}}{A} J}_{\sim 10^{+15} \text{ Gain}} \end{aligned}$$

Even if $O(1)$

Enough CPV
for B.A.U.

Maybe there is a 4th Generation !



V. Conclusion



$$\begin{aligned} J_{(2,3,4)}^{sb} &\simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_b^2 - m_s^2)(m_{b'}^2 - m_s^2)(m_b^2 - m_s^2) A_{234}^{sb} \\ &\sim \underbrace{\frac{m_{t'}^2}{m_c^2} \left(\frac{m_{t'}^2}{m_t^2} - 1 \right)}_{m_b, m_t \approx 300 \text{ GeV}} \frac{m_{b'}^4}{m_b^2 m_s^2} \frac{A_{234}^{sb}}{A} J \quad \textcolor{red}{\sim 10^{+15} \text{ Gain}} \end{aligned}$$

Even if $O(1)$

$m_b, m_t \approx 300 \text{ GeV}$ 10^{+13}
 $\sim 600 \text{ GeV}$ 10^{+15}

Enough CPV
for B.A.U.

CDF/D0
↓
LHCb

- I. $\Delta A_{K\pi} = A_{B \rightarrow K^+\pi^0} - A_{B \rightarrow K^+\pi^-} \neq 0$
- II. Consistence and 4×4 CKM
- III. $\sin 2\Phi_{B_s} < 0$ and Large
- IV. $A_{FB}(B \rightarrow K^* l^+ l^-)$ and Other Predictions

D mixing, $K_L \rightarrow \pi^0 \nu \bar{\nu}$



Backup

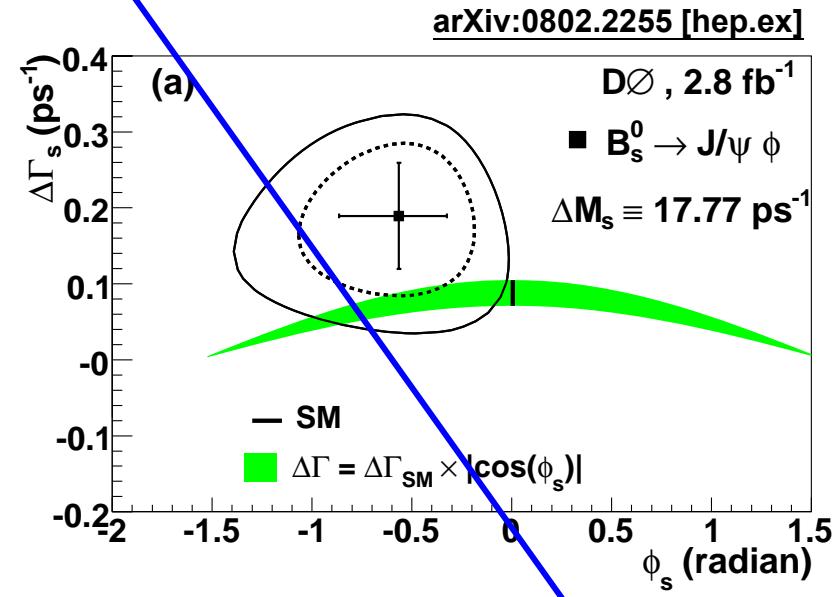
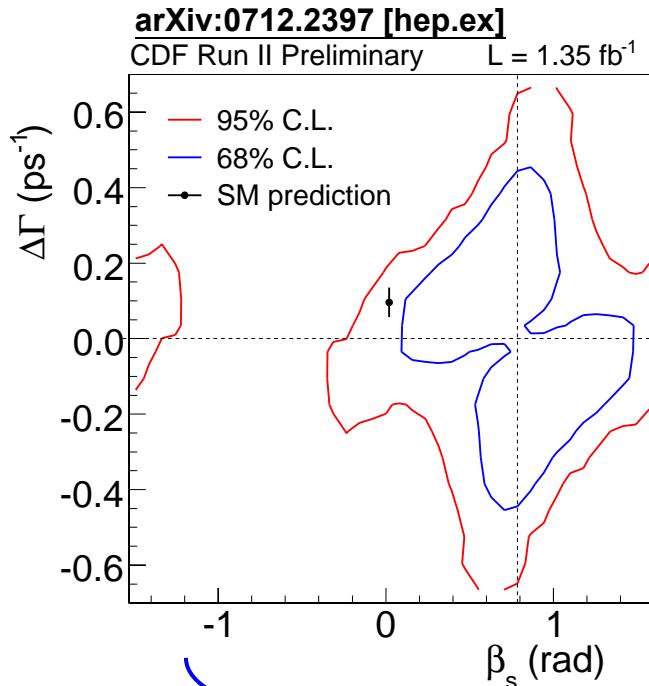


$$\sin 2\Phi_{B_s} \sim -0.5 - -0.7$$

Added 4/2008



WSH, Nagashima, Soddu, PRD'07



Observable 68% Prob. 95% Prob.

$\phi_{B_s} [\circ]$	-19.9 ± 5.6	$[30.45, 0.29]$
UTfit	-68.2 ± 4.9	$[-78.45, -58.2]$

arXiv:0803.0659 [hep.ph]

3.7σ

$$\sin 2\Phi_{B_s} = -0.64^{+0.16}_{-0.14}$$

Incredible !!!



B.A.U. from Electroweak Baryogenesis ?



CPV

$$\frac{n_B}{n_\gamma} = (5.1^{+0.3}_{-0.2}) \times 10^{-10}$$

WMAP

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

Too Small in SM

Why? Jarlskog Invariant in SM3

(need 3 generation in KM)

$$J_3 = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2) A_3$$

Normalize by $T \sim 100$ GeV

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

masses too small !

$A_3 \sim 3 \times 10^{-5}$ in SM
is common (unique) area of triangle





B.A.U. from Electroweak Baryogenesis ?



CPV

$$\frac{n_B}{n_\gamma} = (5.1^{+0.3}_{-0.2}) \times 10^{-10}$$

WMAP

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

Too Small in SM

If shift by One Generation in SM4

(need 3 generation in KM)

$$J_3 = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2) A_3$$

$$J_4^{sb} = (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2) A_4^{sb}$$

$$\sim \left(\frac{m_{t'}^2}{m_c^2} \left(\frac{m_{t'}^2}{m_t^2} - 1 \right) \frac{m_{b'}^4}{m_b^2 m_s^2} \frac{A_4^{sb}}{A_3} \right) J_3$$

$\sim 10^{+15}$ Gain

Only fac. 30 in CPV per se

Gain mostly in Large Yukawa Couplings !



B.A.U. from Electroweak Baryogenesis ?



Order of Phase Transition

Too much equilibration in SM washes away B.A. at high T

$$\mathcal{F}_{\text{SM3}} = -\frac{\pi^2}{90} g_* T^4 + D(T^2 - T_0^2) \phi^2 - \underbrace{ET\phi^3}_{\text{Cubic term too small}} + \frac{\lambda}{4} \phi^4$$

→ Extra Heavy Bosons (usual approach)

“similar effect by fermions strongly coupled to Higg, even if in high-temperature regime do not contribute to cubic term...”

Carena, Megevand, Quirós, Wagner, NPB’05

Fermion

- Couple Strongly to Higgs → Can “Boil” Higgs Soup
- m_F/T Not small → Cannot use above m/T expansion
- Not too large → Does not decouple too early

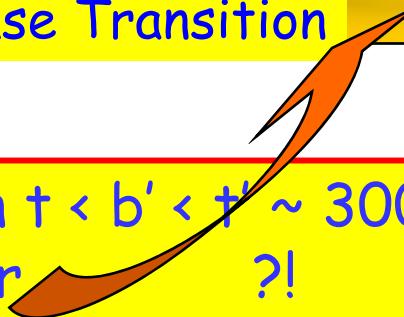
Upshot: relativistic d.o.f. g^* become $g_*(\phi)$, effective reheating by F decoupling around T_c → Stronger Transition



B.A.U. from Electroweak Baryogenesis ?



Order of Phase Transition

Observation: \exists 4th Generation, then $t < b' < t' \sim 300$ GeV
may be sufficient for  ?!

If numerics of CMQW can be used

Used Higgsino/Wino Model w/ 12 d.o.f. $\lambda > 2.1$

Comment that top (also 12 d.o.f.) w/ $\lambda \approx 1$ is too small

Carena, Megevand, Quirós,
Wagner, NPB'05

Fermion

- Couple Strongly to Higgs \rightarrow Can "Boil" Higgs Soup
- m_F/T Not small \rightarrow Cannot use above m/T expansion
- Not too large \rightarrow Does not decouple too early

Upshot: relativistic d.o.f. g^* become $g_*(\phi)$, effective reheating by
F decoupling around T_c \rightarrow Stronger Transition



B.A.U. from Electroweak Baryogenesis ?

CPV Order of Phase Transition



Can 4th Generation Restore Electroweak Baryogenesis ?

Can we use this to *Demand* to see NP $b \rightarrow s$ CPV ?



V. Discussion and Conclusion

- 4th generation not in such great conflict with EWPrT
Kribs, Plehn, Spannowsky, Tait, PRD'07
- Issue of "UV completion" for EWBG picture (vacuum stability)
- Heavy 4th generation above 600 GeV (unitarity limit)
could lead to EWSB \rightarrow No Higgs ? Holdom, JHEP'06
- t' & b' can be discovered at LHC !



Conclusion on New Physics $b \rightarrow s$ CPV



I. Intro: BAU \Rightarrow Need New Physics CPV

II. *Hints* in $b \rightarrow s$

- * $\Delta A_{K\pi} = A_{B \rightarrow K^+ \pi^0} - A_{B \rightarrow K^+ \pi^-} \neq 0$
- * Δm_{B_s} vs f_{B_s}

Experiment is Firm

III. New Large Yukawa Couplings: CPV in $P_{EW}^{b \rightarrow s}$ and $M_{box}^{b \leftrightarrow s}$

4th Generation

- * kaon constraint
- * Δm_{B_s} refinement

$\sin 2\Phi_{B_s} < 0$
and Large

IV. *Proof:* (near) Future and (distant) Past

- * $\sin 2\Phi_{B_s}$ @ Tevatron & LHC(b)
- * BAU from Electroweak Baryogenesis

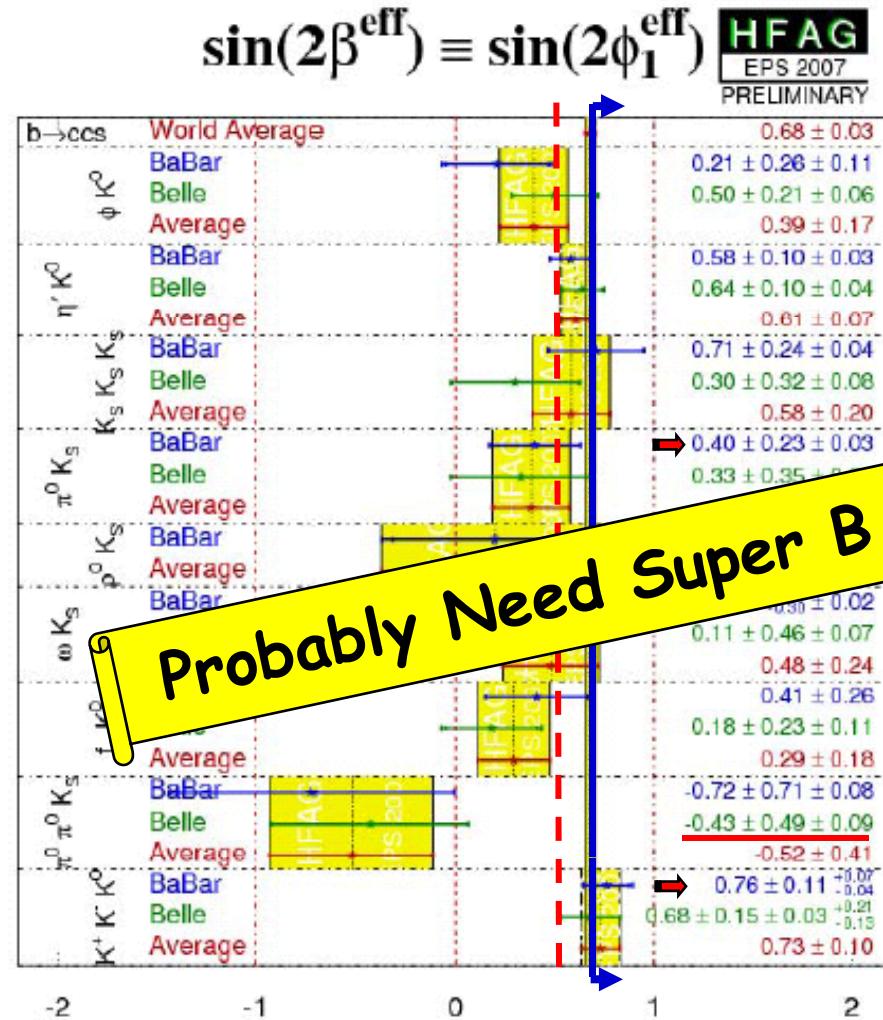
Soon !



Backup



$$\Delta S = S_{\text{sqq}} - S_{\text{ccs}} < 0 \text{ "Problem"}$$

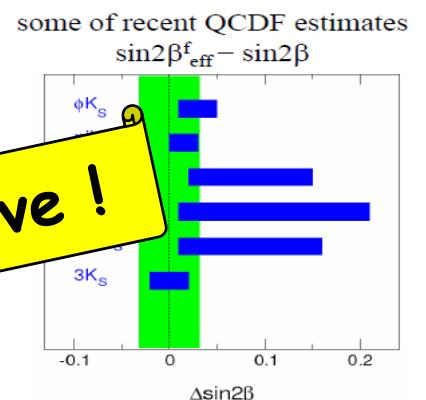


Probably Need Super B Factory to Resolve !

Smaller than $b \rightarrow c\bar{c}s$
in almost all modes

Theory Expect

$\sin 2\phi$ s-pen



Naïve average of all $b \rightarrow s$ modes

$$\sin 2\beta^{\text{eff}} = 0.56 \pm 0.05$$

2.1σ deviation (was 2.6) btwn
 $b \rightarrow \text{sqq}$ and $b \rightarrow \text{ccs}$

New Physics !?

Even deviation of ~ few deg indicate NP

Sinha, Misra, WSH, PRL 97, 131802 (2006)

Need More Data !



Box/EWP Sensitivity to 4th Gen. γ, g less sensitive (No New Operators)

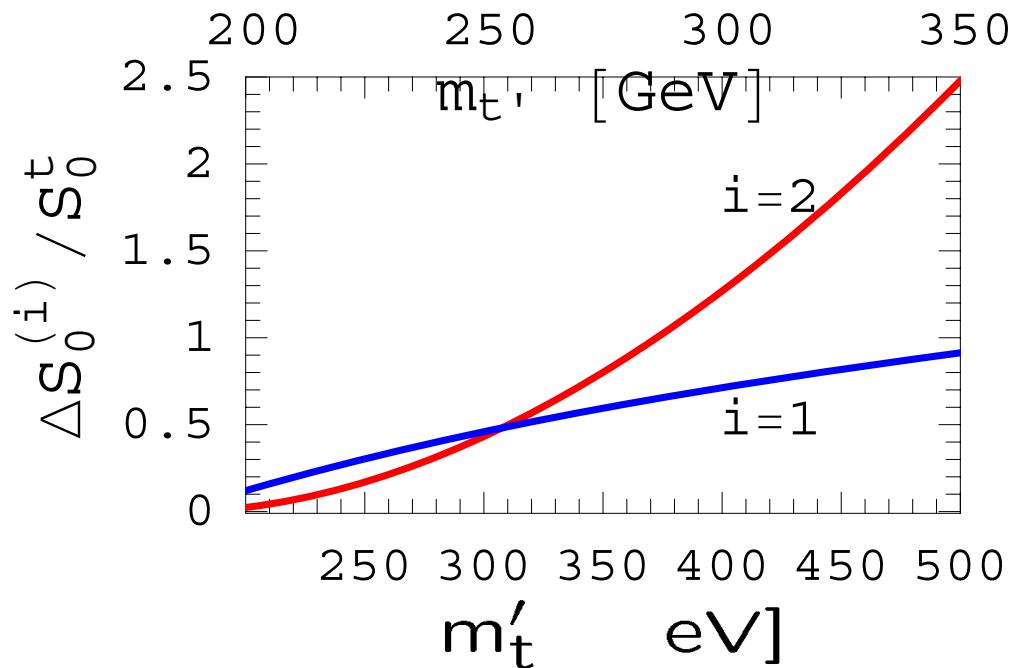
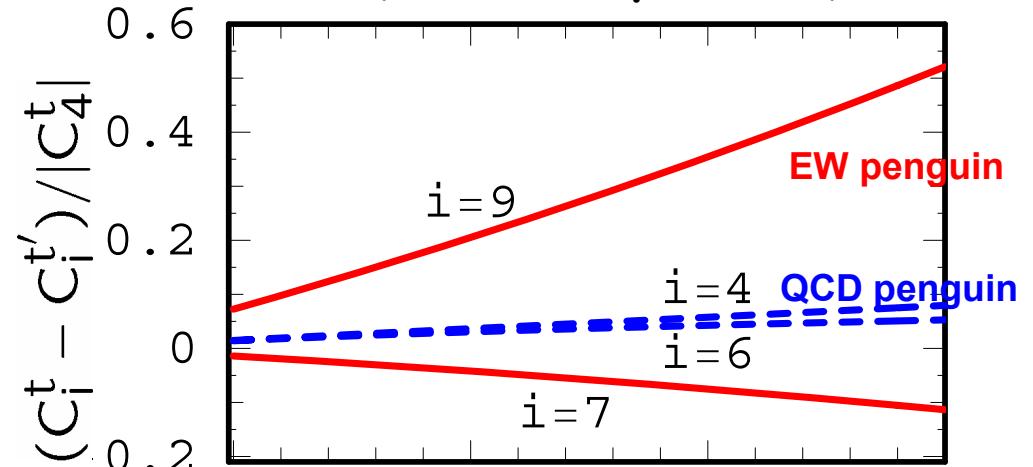


$$C_9^t - C_9^{t'} \propto x_t - x_{t'}$$

nondecoupling

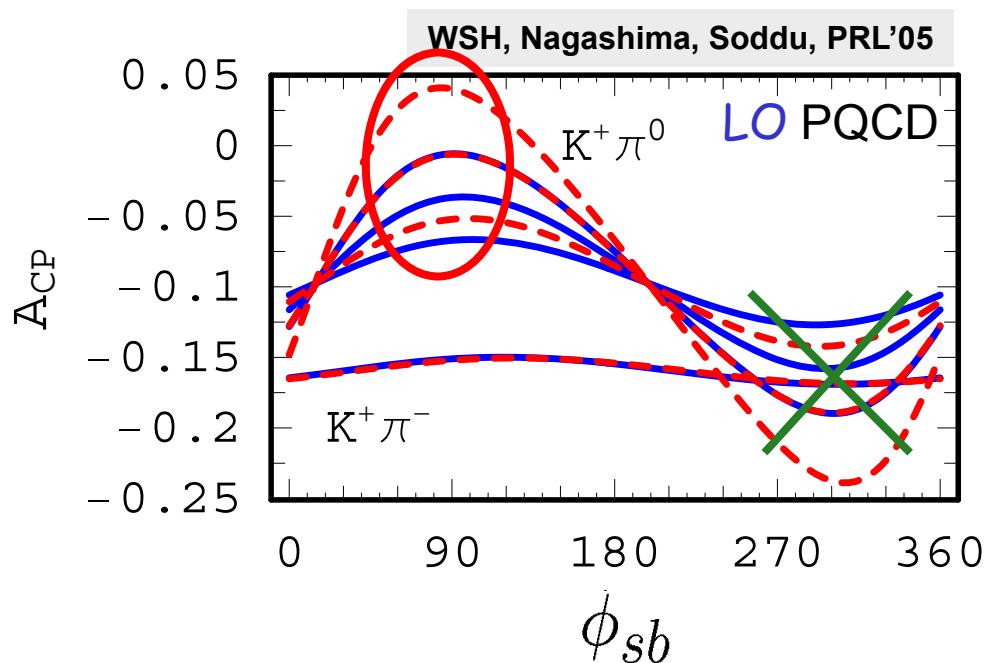
$$\Delta S_0^{(1)} = S_0(t, t') - S_0(t, t)$$

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





$\mathcal{A}_{CP}(K^+\pi^-) \sim -0.12, \quad \mathcal{A}_{CP}(K^+\pi^0) \sim +0.04 ?$



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

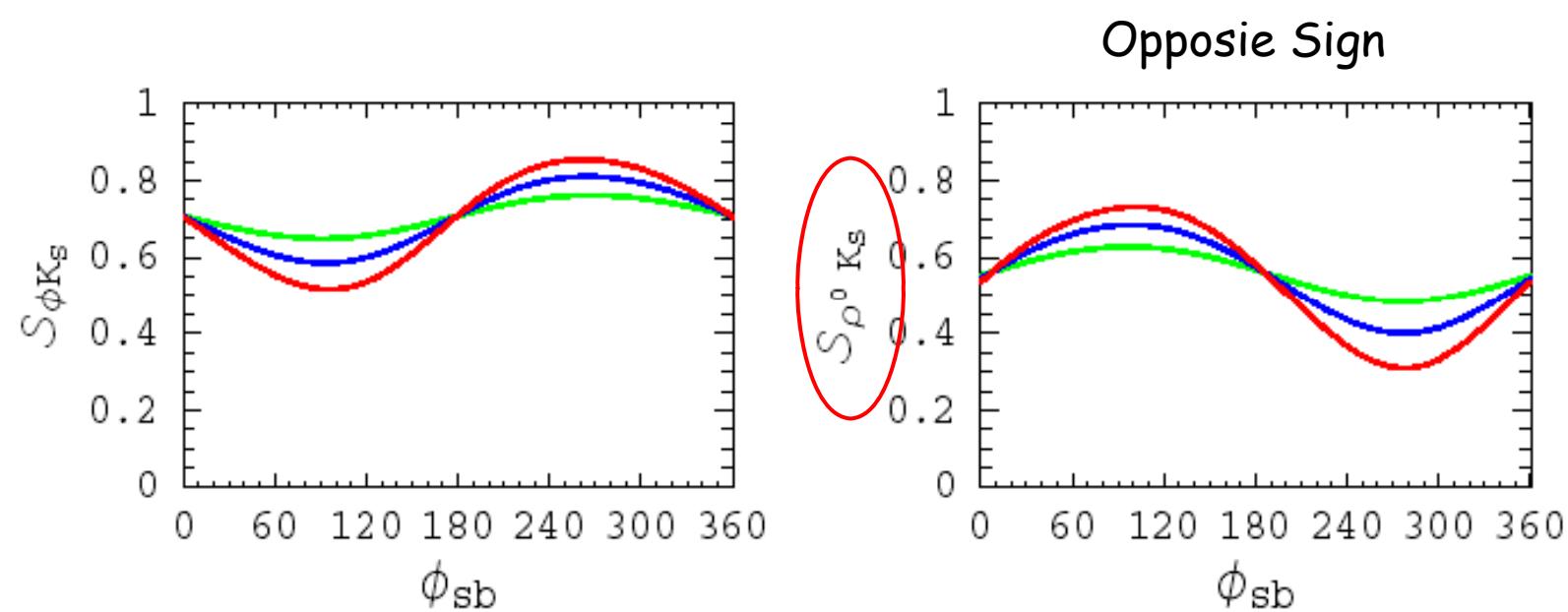
r_{sb}

$- \cdots - \quad m_{t'} = 350 \text{ GeV}$	0.03
$- \quad m_{t'} = 300 \text{ GeV}$	0.02
$- \quad m_{t'} = 300 \text{ GeV}$	0.01

$$V_{cs}^* V_{cb} \sim 0.04$$

- ☞ $\mathcal{A}_{CP}(K^+\pi^-)$ almost independent of t'
- ☞ $\mathcal{A}_{CP}(K\pi^0) - \mathcal{A}_{CP}(K\pi) > 0.1$ demands
 - $\phi_{sb} \sim +\pi/2$
 - Large $m_{t'}$ and r_{sb}

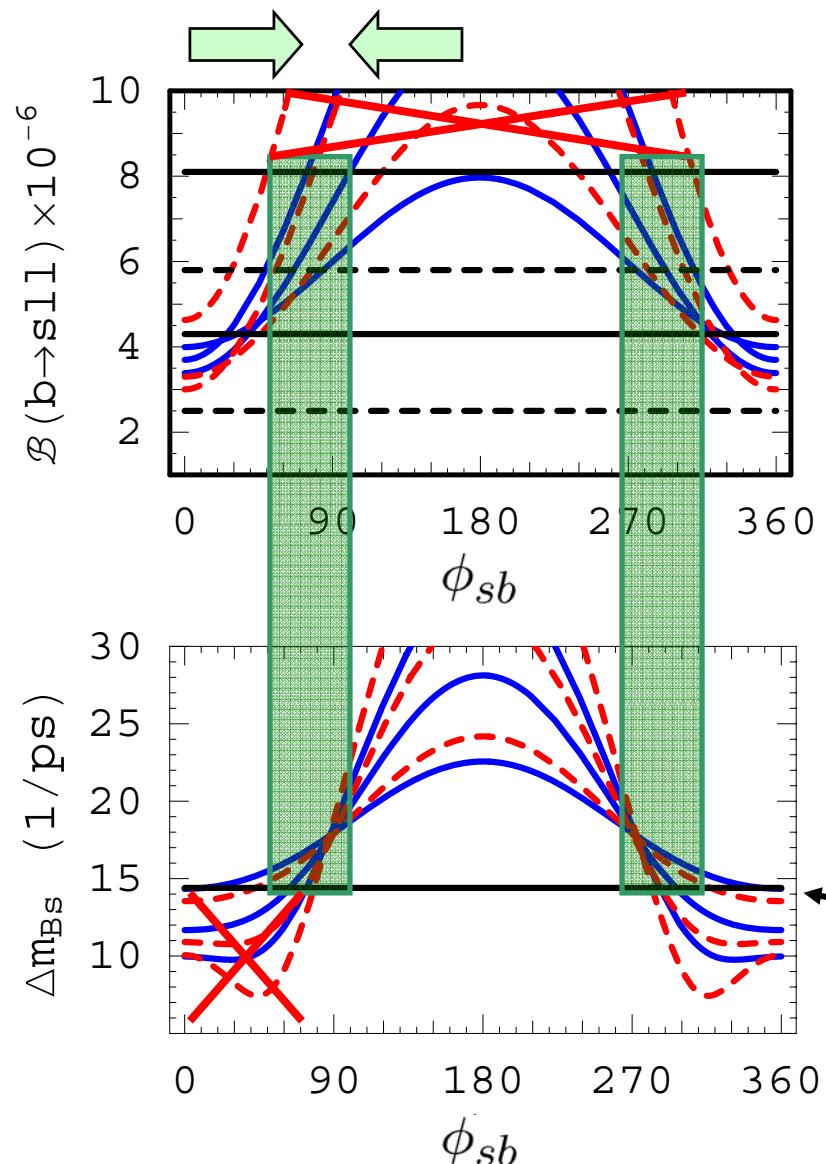
Large Effect





$B \rightarrow X_s l^+ l^-$

Δm_{B_s}



r_{sb}

$m_{t'} = 350\text{GeV}$	0.03
$m_{t'} = 300\text{GeV}$	0.02
	0.01

PDG04 $(6.1 \pm 2.0) \cdot 10^{-6}$

Belle04 $(4.11 \pm 0.83) \cdot 10^{-6}$
 2σ

4th generation not excluded

$\phi_{sb} = 90^\circ$

$m_{t'} = 300\text{GeV}$
 $r_{sb} = 0.03$

Independently favored

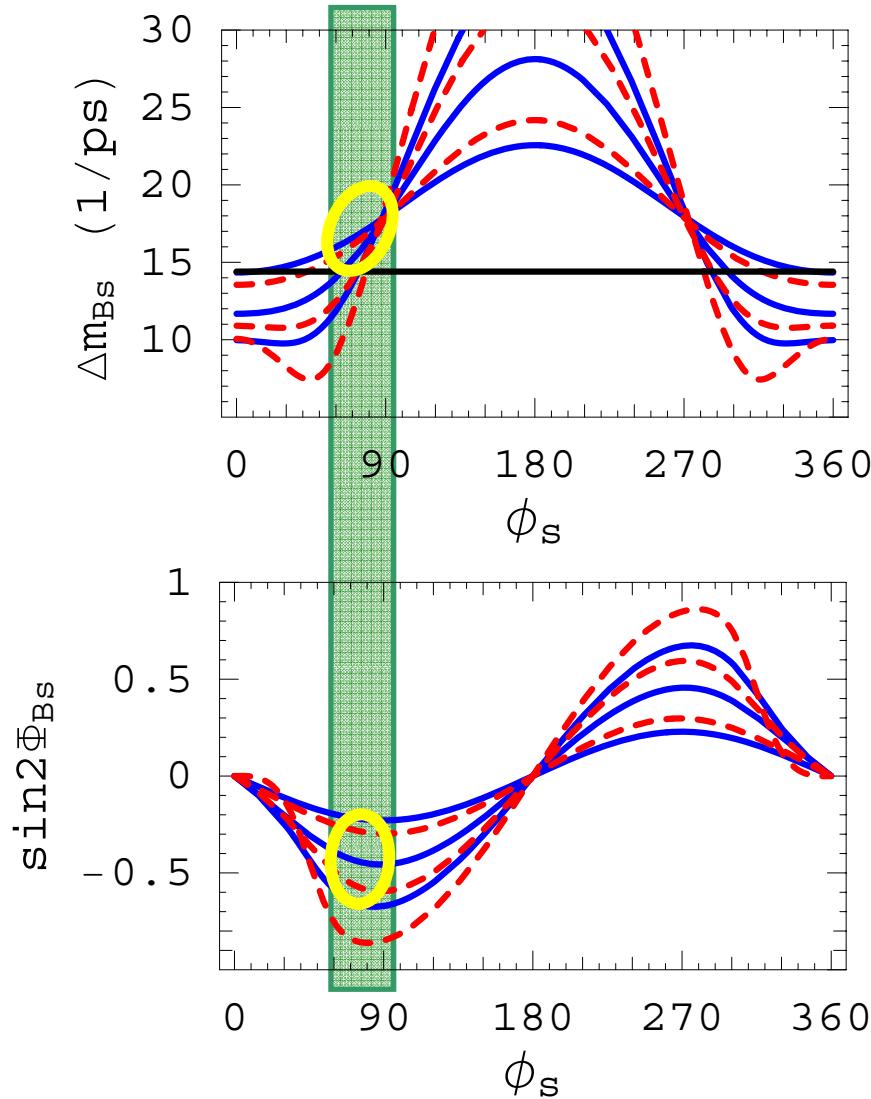
allowed

PDG04 (14.4ps^{-1})

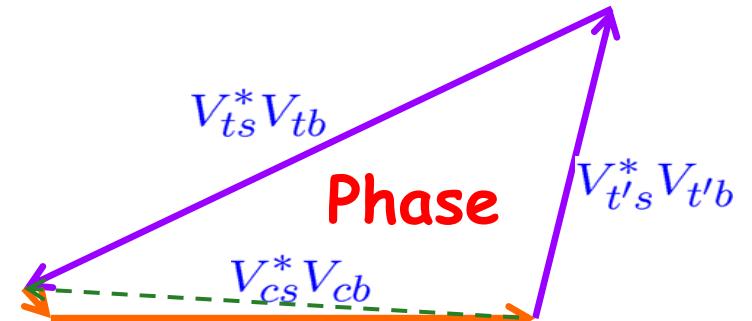
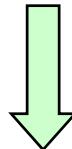
Arhrib and WSH
Hattori, Hasuike and Wakaizumi
Yanir



Δm_{B_s} and $\sin 2\Phi_{B_s}$ Prospects



Δm_{B_s} Just Around Corner!
(SM3-like)



$\sin 2\Phi_{B_s}$ ~ -0.2 to -0.7!
Definitely BSM if measured!



4 x 4 Unitarity \Rightarrow Constraints



	d	s	b	b'
u	$c_{12} c_{13} c_{14}$ $-c_{13} s_{12} s_{14} s_{24} \exp[-i(\phi_{db} - \phi_{sb})]$ $-c_{24} s_{13} s_{14} s_{34} \exp[-i(\phi_{db} + \phi_{ub})]$	$c_{13} c_{24} s_{12}$ $-s_{13} s_{24} s_{34} \exp[-i(\phi_{sb} + \phi_{ub})]$	$c_{34} s_{13} \exp[-i\phi_{ub}]$	$c_{12} c_{13} s_{14} \exp[i\phi_{db}]$ $+c_{13} c_{14} s_{12} s_{24} \exp[i\phi_{sb}]$ $+c_{14} c_{24} s_{13} s_{34} \exp[-i\phi_{ub}]$
	$-c_{14} c_{23} s_{12}$ $-c_{12} c_{14} s_{13} s_{23} \exp[i\phi_{ub}]$ $-c_{12} c_{23} s_{14} s_{24} \exp[-i(\phi_{db} - \phi_{sb})]$ $+s_{12} s_{13} s_{14} s_{23} s_{24} \exp[-i(\phi_{db} - \phi_{sb} - i\phi_{ub})]$ $-c_{13} c_{24} s_{14} s_{23} s_{34} \exp[-i\phi_{db}]$	$c_{12} c_{23} c_{24}$ $-c_{24} s_{12} s_{13} s_{23} \exp[i\phi_{ub}]$ $-c_{13} s_{23} s_{24} s_{34} \exp[-i\phi_{sb}]$	$c_{13} c_{34} s_{23}$	$-c_{23} s_{12} s_{14} \exp[i\phi_{db}]$ $-c_{12} s_{13} s_{14} s_{23} \exp[i(\phi_{db} + \phi_{ub})]$ $+c_{12} c_{14} c_{23} s_{24} \exp[i\phi_{sb}]$ $-c_{14} s_{12} s_{13} s_{23} s_{24} \exp[i(\phi_{sb} + \phi_{ub})]$ $+c_{13} c_{14} c_{24} s_{23} s_{34}$
	$-c_{12} c_{14} c_{23} s_{13} \exp[i\phi_{ub}]$ $+c_{14} s_{12} s_{23}$ $+c_{23} s_{12} s_{13} s_{14} s_{24} \exp[-i(\phi_{db} - \phi_{sb} - i\phi_{ub})]$ $+c_{12} s_{14} s_{23} s_{24} \exp[-i(\phi_{db} - \phi_{sb})]$ $-c_{13} c_{23} c_{24} s_{14} s_{34} \exp[-i\phi_{db}]$	$-c_{23} c_{24} s_{12} s_{13} \exp[i\phi_{ub}]$ $-c_{12} c_{24} s_{23}$ $-c_{13} c_{23} s_{24} s_{34} \exp[i\phi_{sb}]$	$c_{13} c_{23} c_{34}$	$-c_{12} c_{23} s_{13} s_{14} \exp[i(\phi_{db} + \phi_{ub})]$ $+s_{12} s_{14} s_{23} \exp[i\phi_{db}]$ $-c_{14} c_{23} s_{12} s_{13} s_{24} \exp[i(\phi_{sb} + \phi_{ub})]$ $-c_{12} c_{14} s_{23} s_{24} \exp[i\phi_{sb}]$ $+c_{13} c_{14} c_{23} c_{24} s_{34}$
t'	$-c_{24} c_{34} s_{14} \exp[-i\phi_{db}]$	$-c_{34} s_{24} \exp[-i\phi_{sb}]$	$-s_{34}$	$c_{14} c_{24} c_{34}$

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

$$V_{t's}^* V_{t'd} = c_{24} c_{34}^2 s_{14} s_{24} e^{i(\phi_{sb} - \phi_{db})}$$

Kaon $\equiv r_{ds} \phi_{ds}$

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

$b \rightarrow s \equiv r_{sb}$

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

$b \rightarrow d$

Cross Check!

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

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

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

From $b \rightarrow s$ study

$$r_{sb} e^{i\phi_{sb}} \simeq 0.025 e^{i70^\circ}$$



Constrain $s \leftrightarrow d$ from K Physics



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

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

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

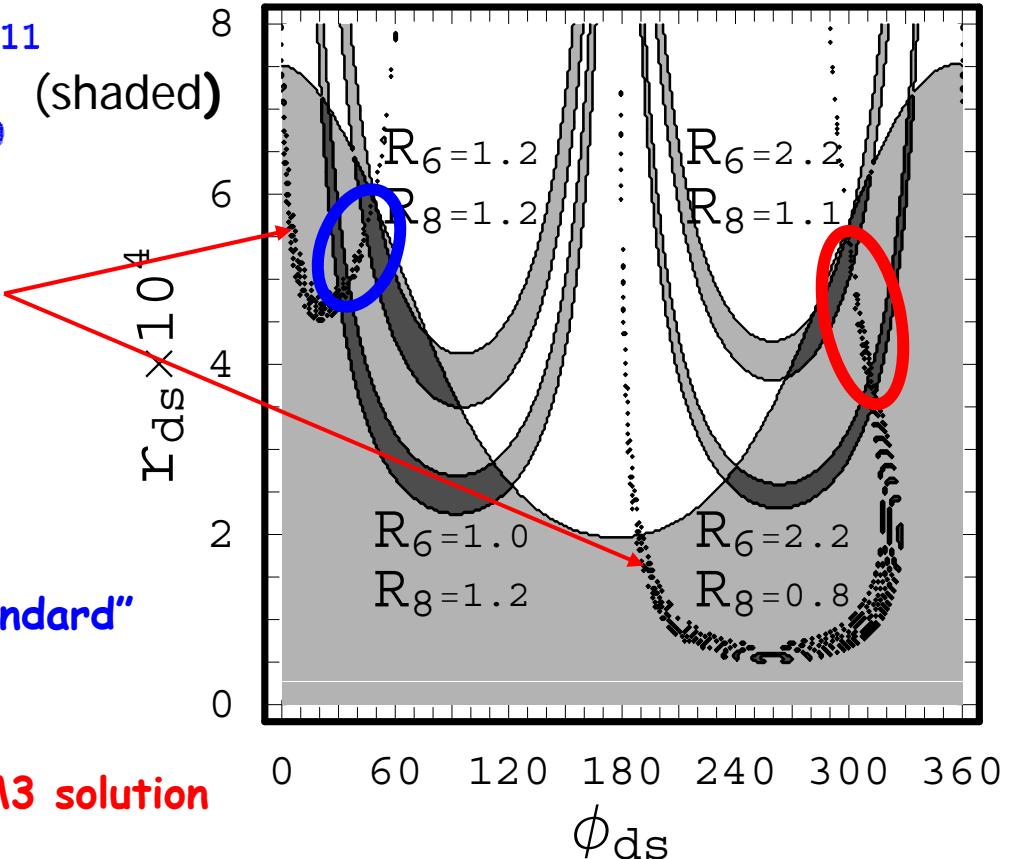
$$\frac{\epsilon'}{\epsilon} = (16.6 \pm 2 \times 1.6) \cdot 10^{-4}$$

$R_6 = 1.2$ (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 $\sin 2\phi_1$!

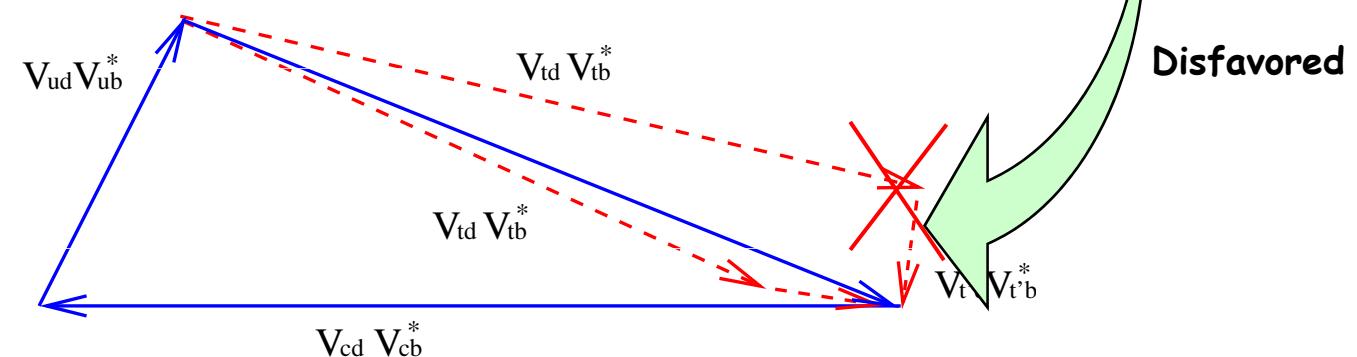
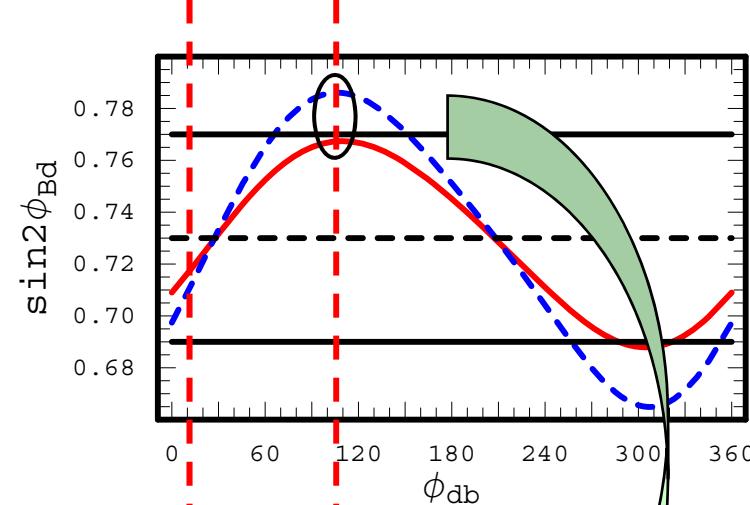
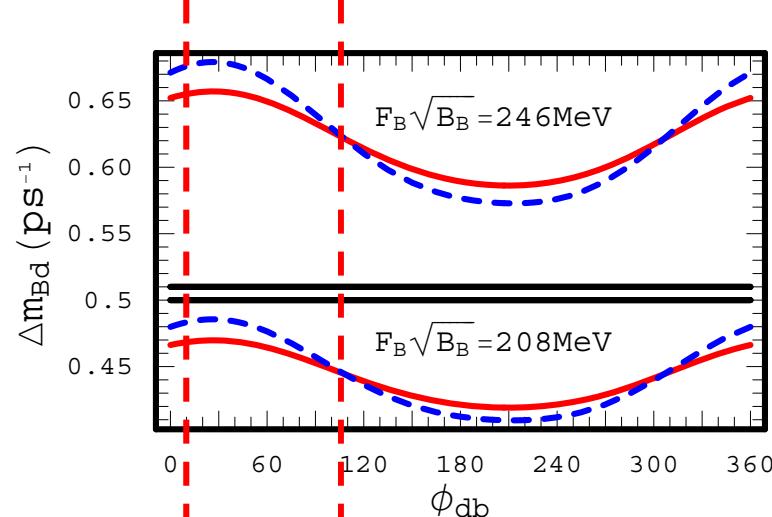


$$r_{ds} \sim 5 \times 10^{-4}, \quad \phi_{ds} \sim -60^\circ \text{ or } +35^\circ$$

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



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
 \therefore stringent $s \rightarrow d$