Visions of *New Physics* on Rare B Decays and CP Violation

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

May 24, 2007 @ NTHU

Outline

Δm_{B_s}, $\Delta\Gamma_{B_s}$

I Intro: $\Delta\mathcal{S}$, $\Delta\mathcal{A}_{K\pi}$

Z Penguins and Boxes

Why 4th Generation Revisit? $A_{CP}(K^+\pi^0) \neq A_{CP}(K^+\pi^-)$

II Accounting for $\Delta\mathcal{A}_{K\pi}$ and $\Delta\mathcal{S}$ (in NLO PQCD)

III B_s Mixing vs **$B \to X_s \ell^+\ell^-$** $\to$ **Large CPV in B_s Mixing**

Large CPV Phase (or Nil)

$\Delta\Gamma_{B_s}$ related effects; **A_{FB} in $B \to K^*\ell^+\ell^-$**

IV DCPV in $B^+ \to J/\psi K^+$?

IV Aside: **$K_L \to \pi^0\nu\nu$; D^0 Mixing**

V Conclusion

I. Intro: $\Delta\mathcal{S}$, $\Delta\mathcal{A}_{K\pi}$

$b \leftrightarrow s$ CPV Phenomena Is Current *NP* Frontier

Two Hints

- $\mathcal{S}_f$ in $\mathbf{b \to sqq}$ — TCPV Mixing-dep.
- $\mathcal{A}_{K^+\pi^-} - \mathcal{A}_{K^+\pi^0}$ Puzzle — DCPV Direct

⇕

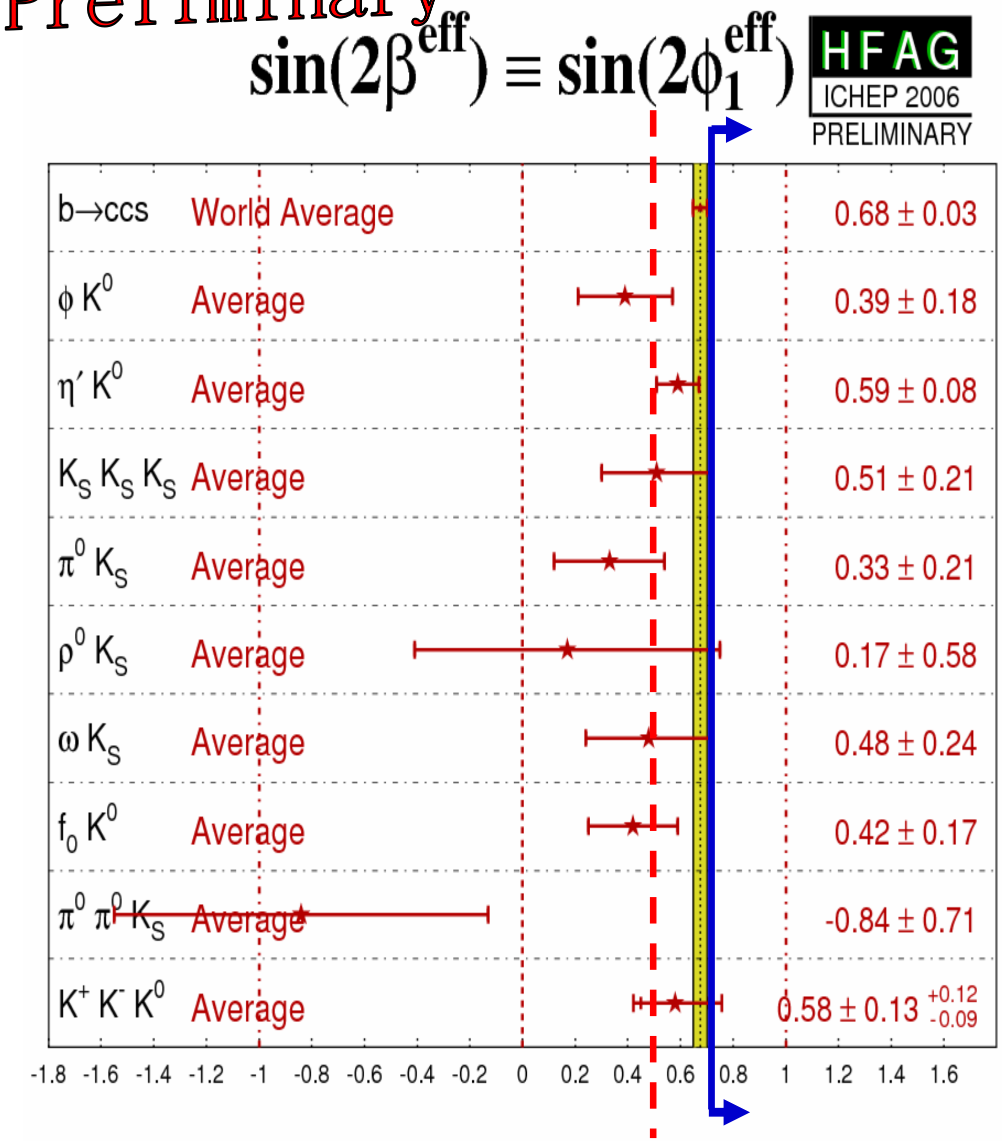
- Δm_{B_s}
- $\Delta\Gamma_{B_s}$

SM-like

2006 ... uins

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

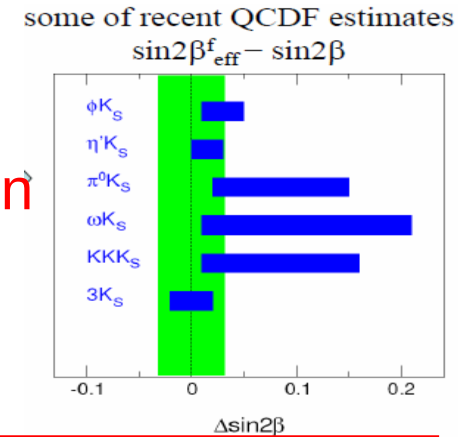
Preliminary



Smaller than $b \to c\bar{c}s$ in all 9 modes

Theory Expect

$\sin 2\phi_1^{\text{s-penguin}} > \sin 2\phi_1^{\text{cc(bar)s}}$



Naïve average of all $b \to s$ modes

$\sin 2\beta^{eff} = 0.52 \pm 0.05$

2.6σ deviation btwn

$b \to sqq$ and $b \to ccs$

New Physics !?

Need More Data !

PRL 97, 131802 (2006) PHYSICAL REVIEW LETTERS week ending 29 SEPTEMBER 2006

Has New Physics Already Been Seen in B_d Meson Decays?

Rahul Sinha,[1] Basudha Misra,[1] and Wei-Shu Hou[2]

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[2]*Department of Physics, National Taiwan University, Taipei, Taiwan 106, Republic of China*

(Received 5 June 2006; published 28 September 2006)

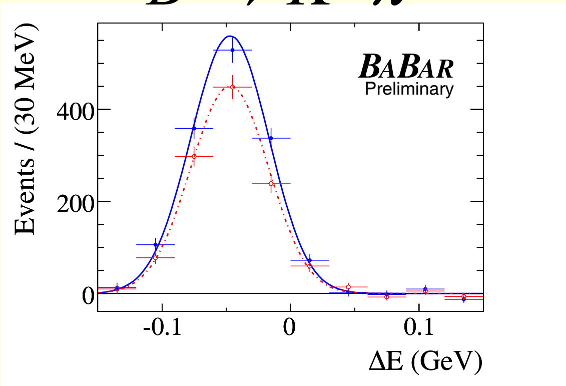
We show in a model independent way that, within the standard model, the deviation in the measured $B_d^0 - \bar{B}_d^0$ mixing phase caused by pollution from another amplitude is always less in magnitude, and has the same sign as, the weak phase of the polluting amplitude. The exception is to have large destructive interference between the two amplitudes: any deviation larger than a few degrees is only possible if the observed decay rate results from fine-tuned cancellations between significantly larger amplitudes. This is unlikely given our understanding of B decays. Even if the deviation reduces to a few degrees in the future, new physics would still likely be implied.

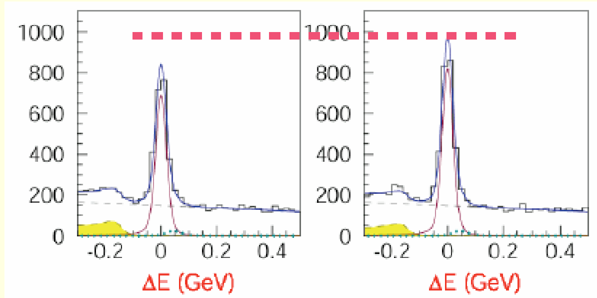
DOI: 10.1103/PhysRevLett.97.131802 PACS numbers: 13.25.Hw, 11.30.Er, 12.60.−i

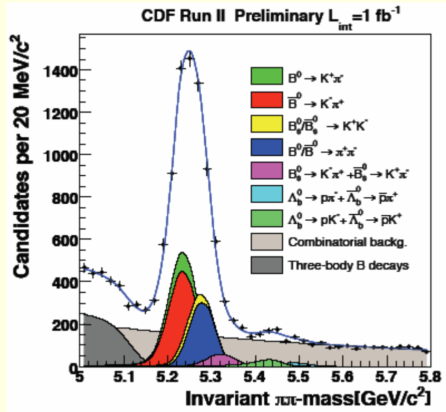
Acp on B → Kπ

$B \to K^{\pm}\pi^{\mu}$

Belle







Acp = $-0.107\pm0.018^{+0.007}_{-0.004}$ $-0.093\pm0.018\pm0.008$ $-0.086\pm0.023\pm0.009$

- World Average including CLEO: Acp($K^+\pi^-$) = -0.097 ± 0.01

$\Delta\mathcal{A}_{K\pi}$

- Acp($K^+\pi^0$) = $+0.047\pm0.026$ ⇒ $\Delta A(K\pi) = -0.144 \pm 0.029$ @5σ
- Need to explain the deviation. Hadronic effect or new physics?

⇓

- $A(K^0\pi^0) = -0.12\pm0.11$; $S(K^0\pi^0) = +0.33\pm0.21$ ⇒ Super B factory!

Why $\Delta\mathcal{A}_{K\pi} = \mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} > 0$ a Puzzle ?

−9.5±1.3 %   +4.7±2.6 %

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

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

$r =$  / 

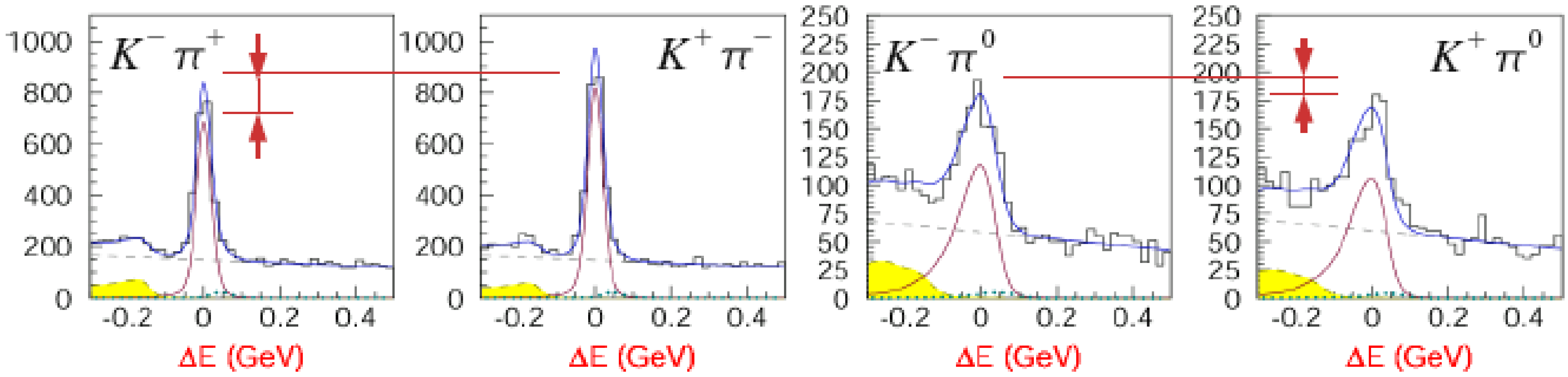
$\Delta\mathcal{A}_{K\pi}$ ~ 0 expected

C: color-suppressed tree (a_2)

$P_{\rm EW}$: EW penguin ($a_{7,9}$)

Large C ? → **Suppress Tree CPV Phase**

$K\pi$ *decays: direct CPV asymmetries* **Outlook/Golutvin/FPCP07**



World average (including CLEO, CDF): $A_{CP}(K^+\pi^-) = -0.093 \pm 0.015$
$A_{CP}(K^+\pi^0) = 0.047 \pm 0.026$

Direct CPV asymmetries in $K^-\pi^+$ and $K^-\pi^0$ channels differ by 4.4 σ

Various interpretations (unlikely to be a "puzzle") :

- *factorization in SCET*
- *Large color suppressed tree contribution*
- *pQCD NLO*

(see Mike Gronau, Iain Stewart, Hsiang-nan Li)

$A_{CP}(K^+\pi^0) \neq A_{CP}(K^+\pi^-)$ puzzle?

$A_{CP}(K^+\pi^-) = -0.097 \pm 0.012$ spectator d

difference $= 5\sigma$

$A_{CP}(K^+\pi^0) = 0.046 \pm 0.026$ spectator u

$A(K^+\pi^-) = P + T + ...$ $\sqrt{2}A(K^+\pi^0) = P + T + C + ...$ (next)

This would be a puzzle if $|C| \ll |T|$ but not if $|C| \sim |T|$

QCD calc. and SU(3) fits (excl. these asym.) find $|C| \sim |T|$

NO PUZZLE **Really?**

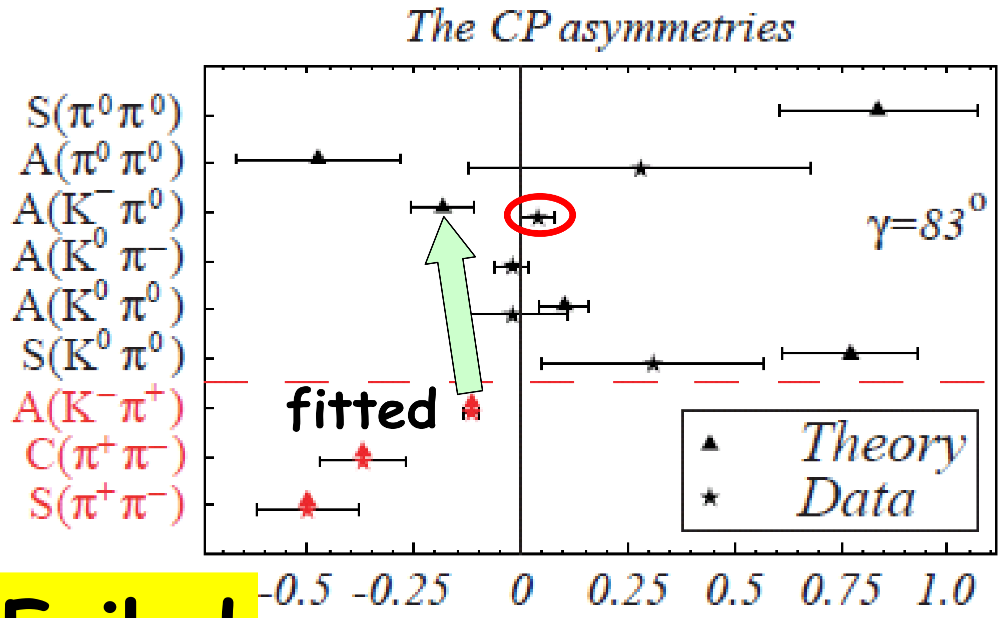
Implication of 2 different asymmetries: $\mathbf{Arg(C/T) < 0}$ large

seems like a difficulty for QCD-factorization/SCET

FPCP07 – p.12

SCET

	Expt.	Theory ($\gamma = 83°$)	Theory ($\gamma = 59°$)
Data in Fit			
$S(\pi^+\pi^-)$	-0.50 ± 0.12	-0.50 ± 0.10	-0.51 ± 0.10
$C(\pi^+\pi^-)$	-0.37 ± 0.10	-0.37 ± 0.07	-0.38 ± 0.07
$Br(\pi^+\pi^-)$	5.0 ± 0.4	5.0 ± 2.0	4.6 ± 1.8
$Br(\pi^+\pi^0)$	5.5 ± 0.6	5.5 ± 2.2	7.3 ± 2.9
$Br(\pi^0\pi^0)$	1.45 ± 0.29	1.45 ± 0.58	1.32 ± 0.53
$Br(\bar{K}^0\pi^-)$	24.1 ± 1.3	24.1 ± 1.2	24.1 ± 1.2
$A(K^-\pi^+)$	-0.115 ± 0.018	-0.115 ± 0.023	-0.115 ± 0.023
$Br(\bar{K}^0K^-)$	1.2 ± 0.3	1.2 ± 0.5	1.2 ± 0.5
Predictions			
$A(\pi^+\pi^0)$	0.01 ± 0.06	$\lesssim 0.05$	$\lesssim 0.05$
$A(\pi^0\pi^0)$	0.28 ± 0.40	-0.48 ± 0.19	-0.52 ± 0.27
$S(\pi^0\pi^0)$		0.84 ± 0.23	-0.14 ± 0.22
$Br(\pi^0\bar{K}^0)$	11.5 ± 1.0	10.4 ± 1.1	10.9 ± 1.2
$Br(\pi^+K^-)$	18.9 ± 0.7	24.0 ± 2.1	22.5 ± 2.1
$Br(\pi^0K^-)$	12.1 ± 0.8	14.3 ± 1.5	12.7 ± 1.4
$S(\pi^0K_S)$	0.31 ± 0.26	0.77 ± 0.16	0.76 ± 0.16
$A(\pi^0K^-)$	0.04 ± 0.04	-0.183 ± 0.075	-0.184 ± 0.076
$A(\bar{K}^0\pi^0)$	-0.02 ± 0.13	0.103 ± 0.058	0.083 ± 0.047
$A(\pi^-\bar{K}^0)$	-0.02 ± 0.04	< 0.1	< 0.1
$Br(K^0\bar{K}^0)$	0.96 ± 0.25	1.1 ± 0.3	1.1 ± 0.3
$Br(K^+K^-)$	0.06 ± 0.12	$\lesssim 0.1$	$\lesssim 0.1$
$A(\bar{K}^0K^-)$		$\lesssim 0.2$	$\lesssim 0.2$
$A(\bar{K}^0K^0)$		$\lesssim 0.2$	$\lesssim 0.2$



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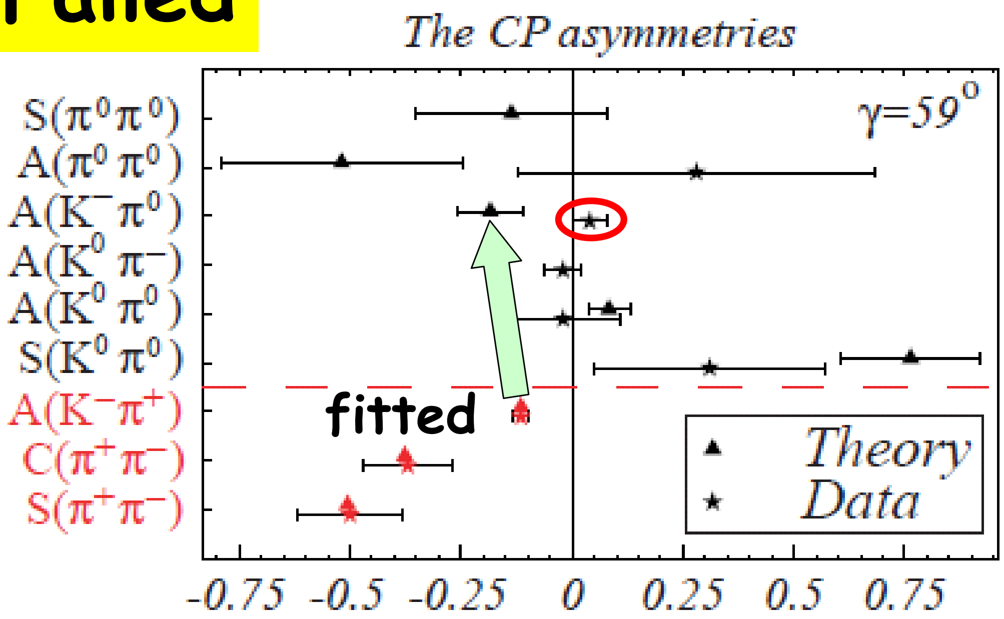

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FPCP07 – p.12

$$A_{CP}(0+) \approx -2\left|\frac{T'}{P'_{tc}}\right| \sin\delta_{T'} \sin\gamma \quad (10)$$

$$A_{CP}(-+) \approx -2\left|\frac{T'}{P'_{tc}}\right| \sin\delta_{T'} \sin\gamma - 2\left|\frac{C'}{P'_{tc}}\right| \sin\delta_{C'} \sin\gamma \ ,$$

where $\delta_{C'}$ is the strong-phase difference between C' and P'_{tc}, we see that a large value of $|C'|$ can give the correct sign for $A_{CP}(-+)$ when $\sin\delta_{C'}$ has a different sign from $\sin\delta_{T'}$. This is confirmed numerically. A good fit is obtained: $\chi^2_{min}/d.o.f. = 1.0/$ ... $|P'| = 47\pm1$ eV, $|T'| = 8.1\pm3.5$ eV, ... $\delta_{T'} = (154\pm10)^\circ$, $\delta_{C'} = (-154\pm7)^\circ$. ... $|C'/T'| = 1.6\pm0.3$ is required (we stre...

Baek-London, hep-ph/0701181v2

Thus, as expected, a good fit is found only if the NP is in the form of $\mathcal{A}'^{,comb} e^{i\Phi'}$.

This is the same conclusion as that found in Ref. [7]. Thus, not only is the $B \to \pi K$ puzzle still present, but it is still pointing towatds the same type of NP, $\mathcal{A}'^{,comb} e^{i\Phi'} \neq 0$ (this corresponds to NP in the electroweak penguin amplitude). For this (good) fit, we find $|T'/P'| = 0.09$, $|\mathcal{A}'^{,comb}/P'| = 0.24$, $\Phi' = 85^\circ$. We therefore find that the NP amplitude must be sizeable, with a large weak phase

Neubert@FPCP07:
Just a fit, cannot sustain from computation.

I'm in agreement with Baek-London.
And this is the start of our Vision Thing.

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

$r =$ 

$\Delta\mathcal{A}_{K\pi} \sim 0$ expected

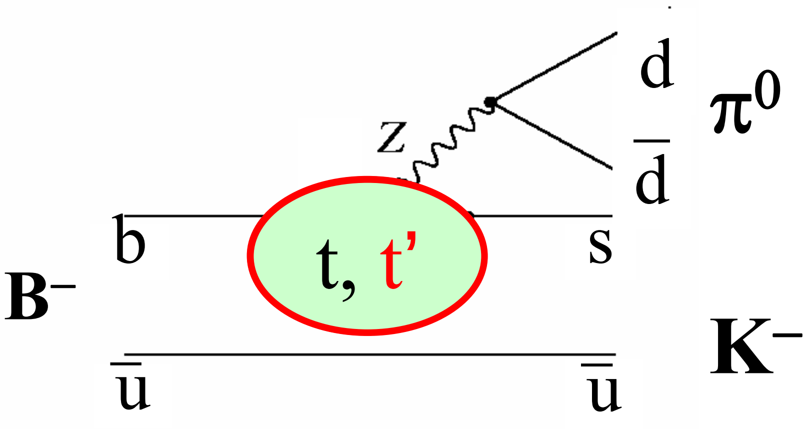
C: color-suppressed tree (a_2)

P_{EW}: EW penguin ($a_{7,9}$)

Large C ? ⟹ Suppress Tree CPV Phase

Large EWPenguin ? ⟹ Need NP CPV Phase

∵ T and P_{EW} ≈ same strong phase



4th Gen. in EWP Natural

Why ?

4th Generation !?

4th Generation Still?

- N_ν counting? 4th "neutrino" heavy

  Massive neutrinos call for new Physics

Despite MiniBooNE ruling out LSND.

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- 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 of the S parameter alone, corresponding to $N_F = 2.81 \pm 0.24$ for the number of families. This result assumes that there are no new contributions to T or U and therefore that any new families 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**

T to vary as well, since $T > 0$ is expected from a non-degenerate extra family. However, the data currently favor $T < 0$, thus strengthening the exclusion limits. A more detailed analysis is required if the extra neutrino (or the extra down-type quark) is close to its direct mass 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.

What can we exclude?

This should dictate some of the goals in this field.

For example:

1. Fourth generation?
   More generally, is the CKM unitary?

2. New CP violating interactions?
   Needed for lepto/baryo-genesis

3. Other new interactions?
   Particularly those related to EW-SB (TeV scale)

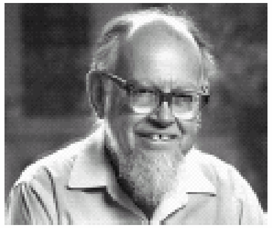
Answer: sadly, we cannot exclude much.

But we may be able to set useful constraints

Ben Grinstein @ CKM06

yardstick1:
Testing unitarity (or fourth generation) can give us an idea of what to aim for, as follows. (BTW, I know Z-width implies only 3 light neutrinos)

Wolfenstein reminds us of the texture of the CKM matrix



$$V_{\rm CKM}^{(3)} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

To see what to expect, guess what would go in fourth row and column.

Close to what we'll see !

Guess #1

$$V_{\rm CKM}^{(4)} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 & \lambda^5 \\ \lambda & 1 & \lambda^2 & \lambda^4 \\ \lambda^3 & \lambda^2 & 1 & \lambda^2 \\ \lambda^5 & \lambda^4 & \lambda^2 & 1 \end{pmatrix}$$

Guess #2

$$V_{\rm CKM}^{(4)} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 & \lambda^3 \\ \lambda & 1 & \lambda^2 & \lambda^2 \\ \lambda^3 & \lambda^2 & \cos\theta_G & \sin\theta_G \\ \lambda^3 & \lambda^2 & -\sin\theta_G & \cos\theta_G \end{pmatrix}$$

4th Generation Still?

- N_ν counting? 4th "neutrino" heavy

  Massive neutrinos call for new Physics

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

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- **Flavor physicists should not throw 4th Generation away !**

CDF Continues to Search

http://www-cdf.fnal.gov/physics/new/top/2005/ljets/tprime/gen6/public.html

Search for Heavy Top t'->Wq In Lepton Plus Jets Events in 760 pb^{-1}

J. Conway, R. Erbacher, A. Ivanov
University of California, Davis
A. Lath
Rutgers University
R. Roser
Fermilab
R. Hughes, K. Lannon, B. Winer
Ohio State University

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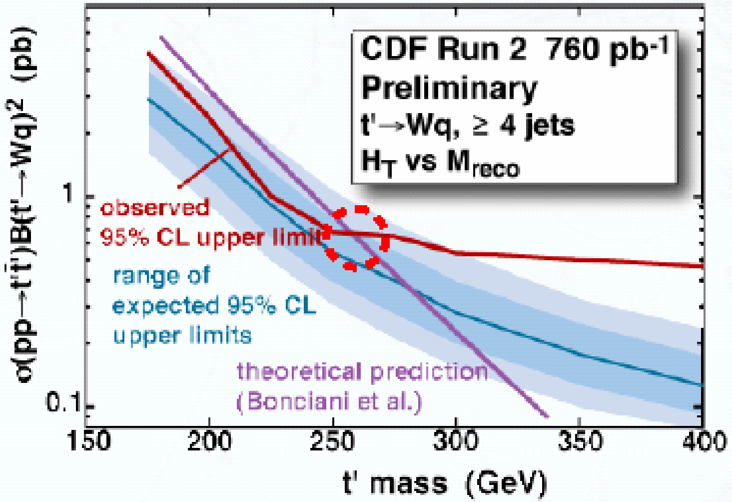
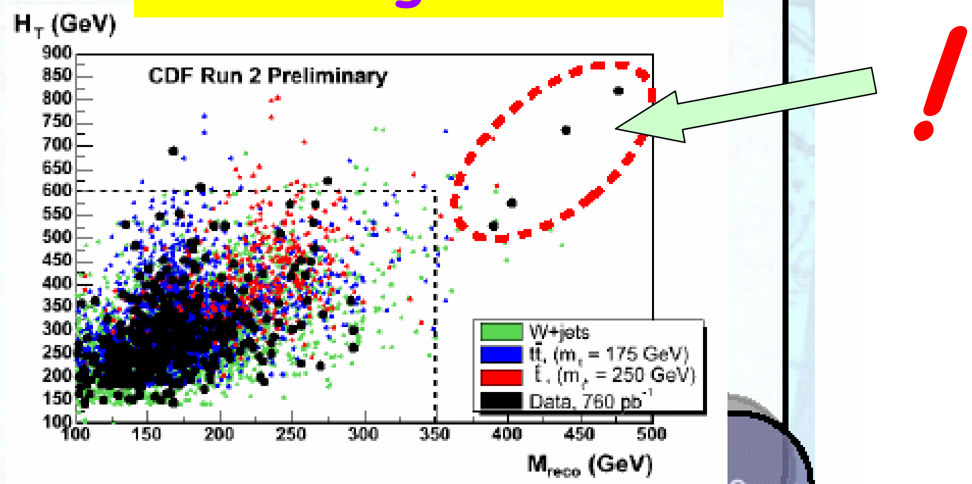
http://www-cdf.fnal.gov/physics/new/top/2005/ljets/tprime/gen6/public.html

Search for Heavy Top $t' \to Wq$ Events

- CDF Run II data, 760/pb
  - Decay channel: $t't' \to W(l'v)$+4-jets
  - Veto: cosmic ray, $Z \to ll$
- Template method for M_T recon. based on best χ^2-fit:
  - Observables: t' mass (M_{recon}) & total trans. energy (T_H)
  - t' mass > 258 GeV at 95% CL

Softening of Bound





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In era of LHC, can Directly Search for b', t'
Once and For All !

CMS/ATLAS Duty.

A set goal at NTUHEP

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- **EW Precision test is "old" ...; Overconstrain ourselves, or look forward to LHC ?**

Personal Reason for 4th Generation Revisit

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

First observation of Direct CPV in B decays

$B^0 \to K^+\pi^-$

BABAR *hep-ex/0408057, submitted to PRL*

$A_{CP} = -0.133 \pm 0.030 \pm 0.009$

4.2σ

Belle **Confirmation at ICHEP04**

Signal ($274M\ B\bar{B}$ pairs): 2140 ± 53

$A_{CP} = -0.101 \pm 0.025 \pm 0.005$

3.9σ

Average $A_{CP} = -0.114 \pm 0.020$

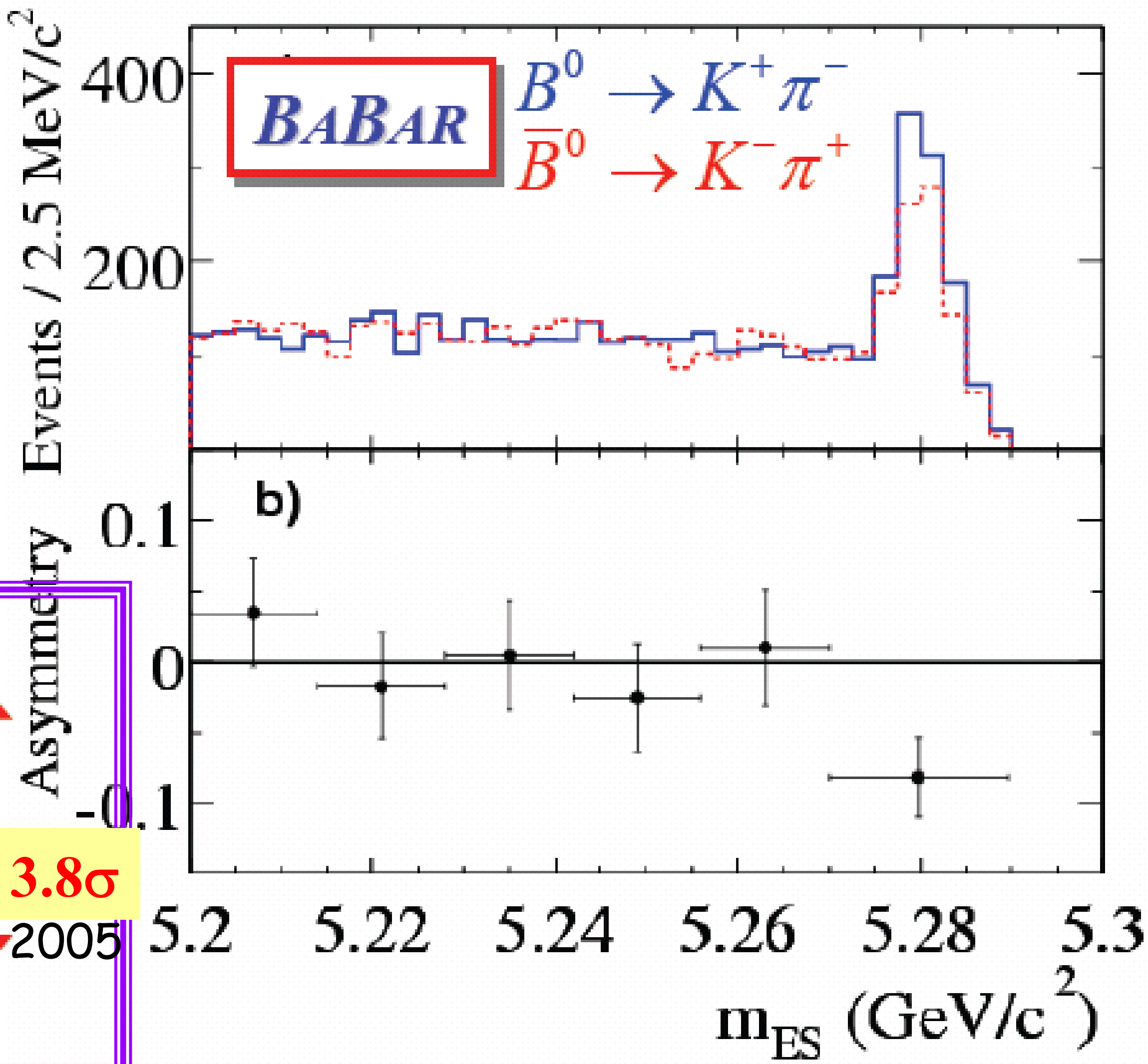
$B^+ \to K^+\pi^0$

$A_{CP} = +0.06 \pm 0.06 \pm 0.01$ *BABAR*
$A_{CP} = +0.04 \pm 0.05 \pm 0.02$ Belle

Average $A_{CP} = +0.049 \pm 0.040$

3.8σ
2005

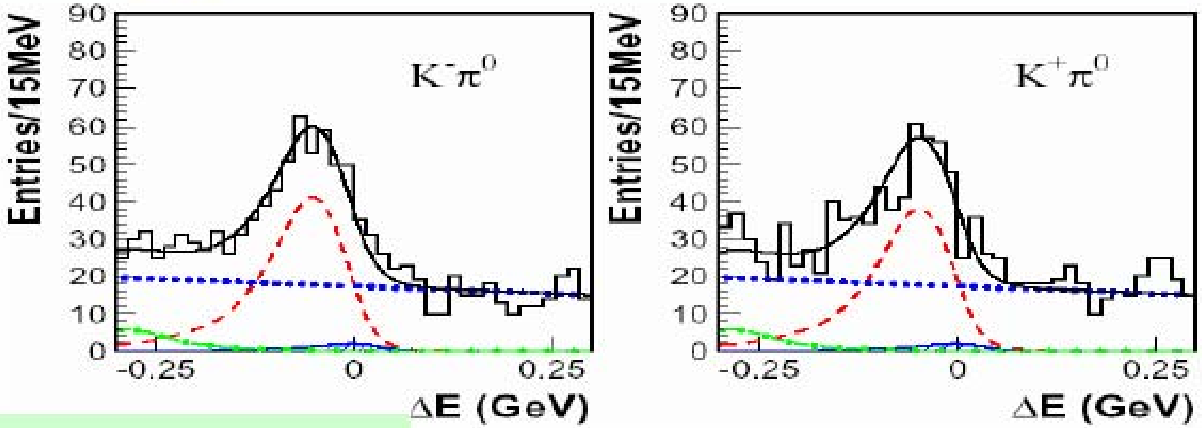
Signal ($227M\ B\bar{B}$ pairs): 1606 ± 51



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

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 ?

Sakai

ICHEP 2004, Beijing 14

VOLUME 93, NUMBER 19 PHYSICAL REVIEW LETTERS week ending 5 NOVEMBER 2004

Evidence for Direct CP Violation in $B^0 \to K^+\pi^-$ Decays

Y. Chao,[29] P. Chang,[29] K. Abe,[10] K. Abe,[46] N. Abe,[49] I. Adachi,[10] H. Aihara,[48] K. Akai,[10] M. Akatsu,[24] M. Akemoto,[10]

. . .

(Belle Collaboration)

We report evidence for direct CP violation in the decay $B^0 \to K^+\pi^-$ with 253 fb^{-1} of data collected with the Belle detector at the KEKB e^+e^- collider. Using 275×10^6 $B\overline{B}$ pairs we observe a $B \to K^\pm\pi^\mp$ signal with 2140 ± 53 events. The measured CP violating asymmetry is $\mathcal{A}_{CP}(K^+\pi^-) = -0.101 \pm 0.025(\text{stat}) \pm 0.005(\text{syst})$, corresponding to a significance of 3.9σ including systematics. We also search for CP violation in the decays $B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$. The measured CP violating asymmetries are $\mathcal{A}_{CP}(K^+\pi^0) = 0.04 \pm 0.05(\text{stat}) \pm 0.02(\text{syst})$ and $\mathcal{A}_{CP}(\pi^+\pi^0) = -0.02 \pm 0.10(\text{stat}) \pm 0.01(\text{syst})$, corresponding to the intervals $-0.05 < \mathcal{A}_{CP}(K^+\pi^0) < 0.13$ and $-0.18 < \mathcal{A}_{CP}(\pi^+\pi^0) < 0.14$ at 90% confidence level.

. . .

nificance 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 direct CP violation is observed in the decay $B^+ \to \pi^+\pi^0$. We set 90% C.L. intervals $-0.05 < \mathcal{A}_{CP}(K^+\pi^0) < 0.13$ and $-0.18 < \mathcal{A}_{CP}(\pi^+\pi^0) < 0.14$.

We thank the KEKB group for the excellent operation

[4] Belle Collaboration, K. Abe *et al.*, Phys. Rev. Lett. **93**, 021601 (2004).

[5] C.-K. Chua, W.-S. Hou, and K.-C. Yang, Mod. Phys. Lett. A **18**, 1763 (2003); S. Barshay, L. M. Sehgal, and J. van Leusen, Phys. Lett. B **591**, 97 (2004).

[6] Belle Collaboration, Y. Chao *et al.*, hep-ex/0407025 [Phys. Rev. D. (to be published)].

[7] *BABAR* Collaboration, B. Aubert *et al.*, hep-ex/0407057 [Phys. Rev. Lett. (to be published)].

[8] Y.-Y. Keum and A. I. Sanda, Phys. Rev. D **67**, 054009 (2003); M. Beneke *et al.*, Nucl. Phys. B **606**, 245 (2001).

It was the handiwork of "yours truly" ...

My first B paper

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

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

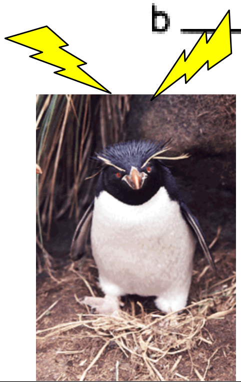
$$\mathcal{L}_{\rm eff}^{b\bar{s}\to \nu\bar{\nu}} = -2\sqrt{2}G_F\chi v_i\bar{D}_i(\bar{s}\gamma_\mu Lb)(\bar{\nu}\gamma_\mu L\nu), \quad (2)$$

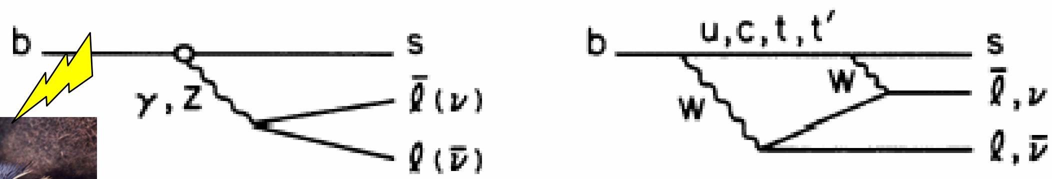
where $\chi = g^2/16\pi^2$, $v_i \equiv V_{is}^* V_{ib}$, i is summed from 2 to n (where n is the number of generations),[10] s_W is the sine of the Weinberg angle, and we exhibit[11]

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

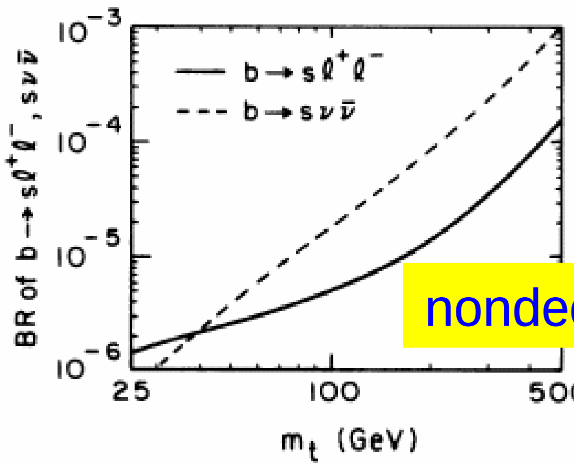
$$\bar{D}_i \equiv \bar{D}_i^Z + \bar{D}_i^{\rm box} = \tfrac{1}{4}x_i + \frac{3}{4}\frac{x_i(x_i - 2)}{(x_i - 1)^2}\ln x_i + \frac{3}{4}\frac{x_i}{x_i - 1}, \quad (4)$$

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]





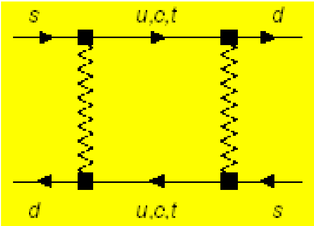
EW Penguin + Box



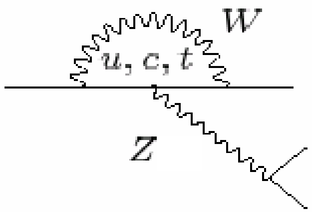
nondecoupling

On Boxes and Z Penguins

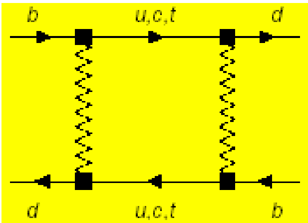
nondecoupling



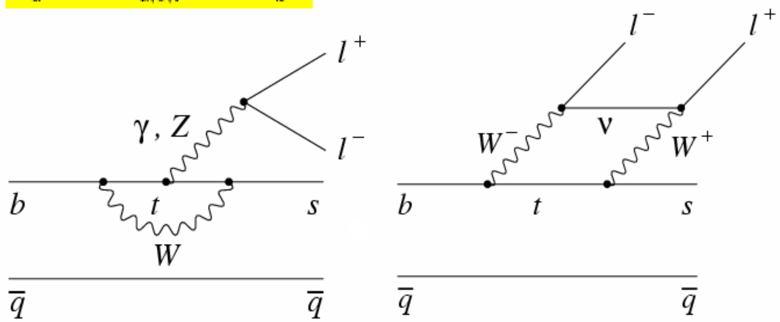
GIM, charm, ε_K



small ε'_K, K $\rightarrow \pi\nu\nu$ (still waiting)



heavy top, sin2ϕ_1/β

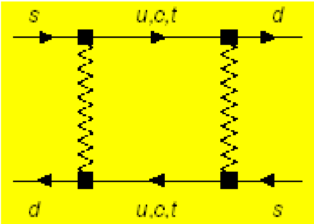


Z dominance for heavy top

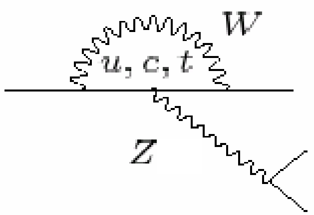
1986 $\rightarrow$ 2002

On Boxes and Z Penguins

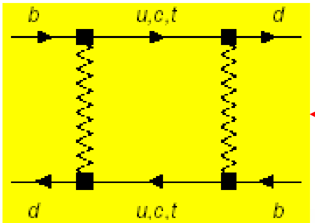
nondecoupling



GIM, charm, ε_K

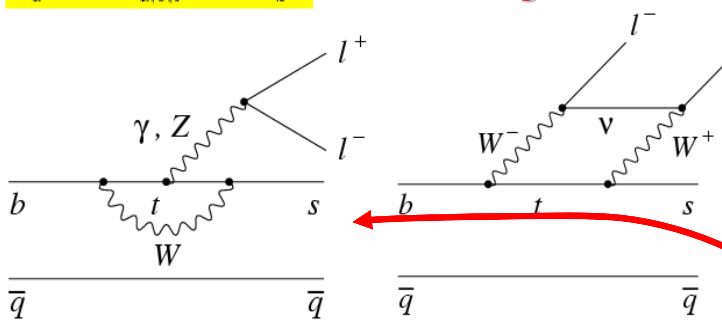


small ε'_K, $K \to \pi\nu\nu$ (still waiting)



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

***B*$_s$**



Z dominance for heavy top

1986 → 2002

All w/ 3-gen.,
Just wait if there's 4th

t, t'

D !

b', t' @ LHC

II. Accounting for $\Delta\mathcal{A}_{K\pi}$, $\Delta\mathcal{S}$

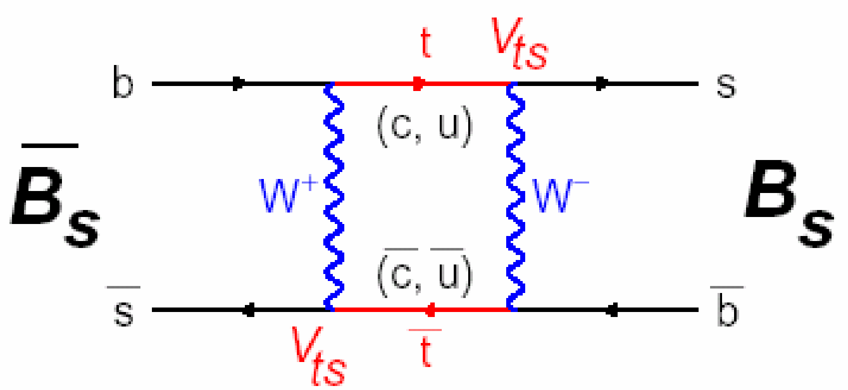
Effective b → s Hamiltonian and t' Effect

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

SM 3

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

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

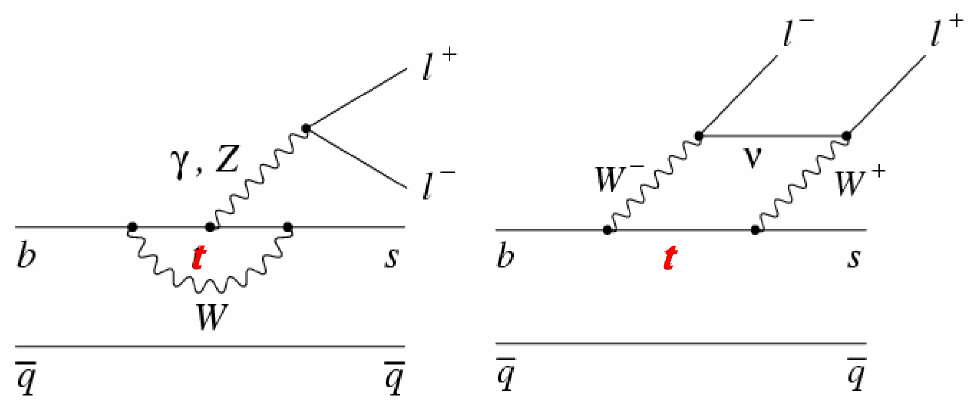


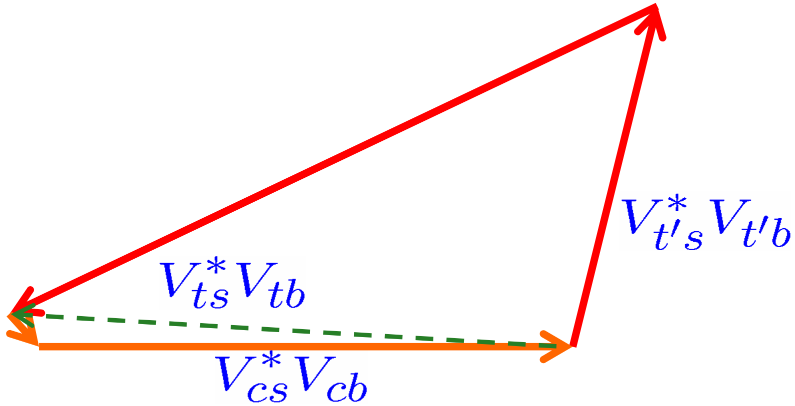
t ⇨ t, t’

SM 4

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

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





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

GIM Respecting

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

Box/EWP Sensitivity to 4th Gen.

γ, g less sensitive

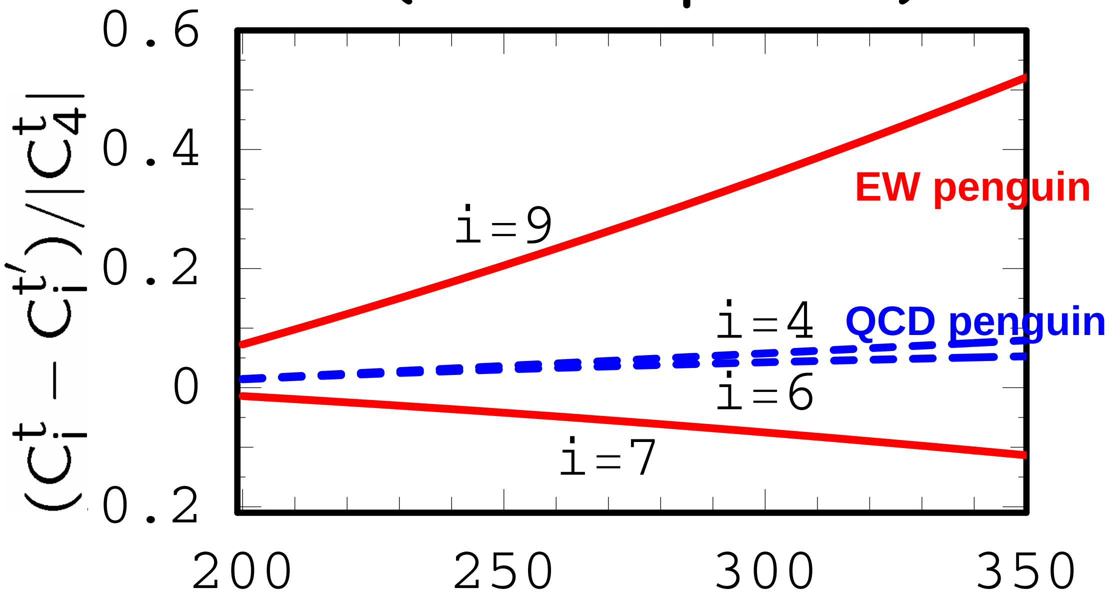
(No New Operators)

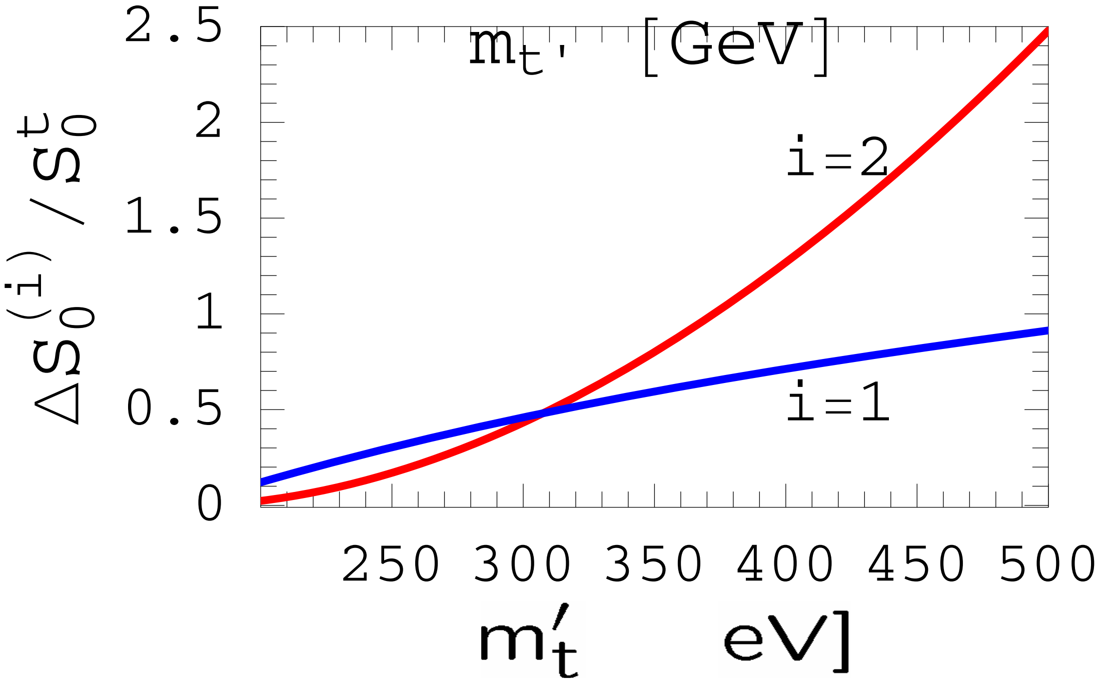
$$C_9^t - C_9^{t'} \propto x_t - x_{t'}$$

nondecoupling

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

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

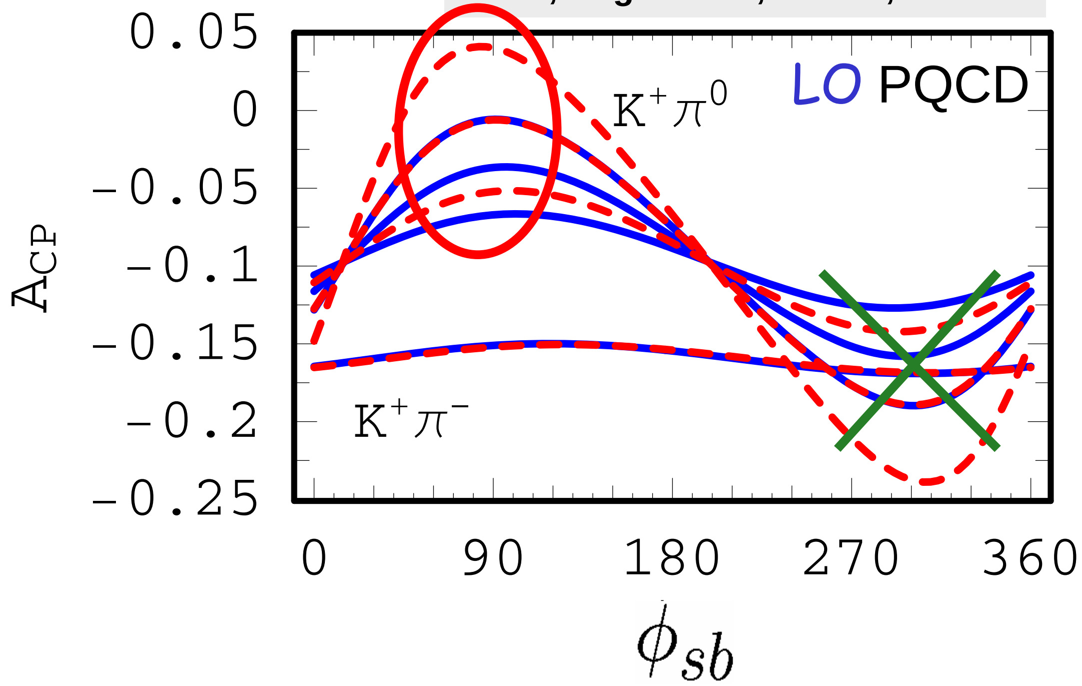




$\mathcal{A}_{CP}(K^+\pi^-) \sim -0.12, \quad \mathcal{A}_{CP}(K^+\pi^0) \sim +0.04$?

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

WSH, Nagashima, Soddu, PRL'05



r_{sb}

- - - $m_{t'} = 350\text{GeV}$ — 0.03

—— $m_{t'} = 300\text{GeV}$ — 0.02, 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**

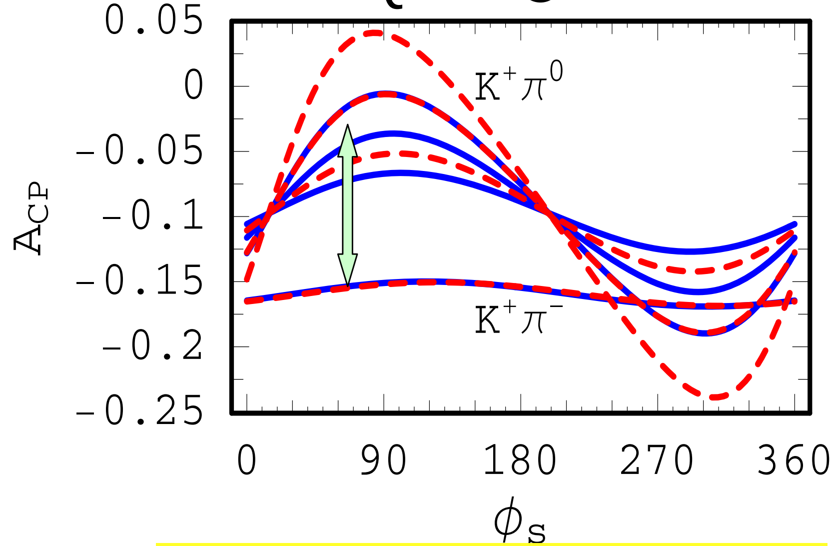
- $\phi_{sb} \sim +\pi/2$
- **Large** $m_{t'}$ **and** r_{sb}

Large Effect

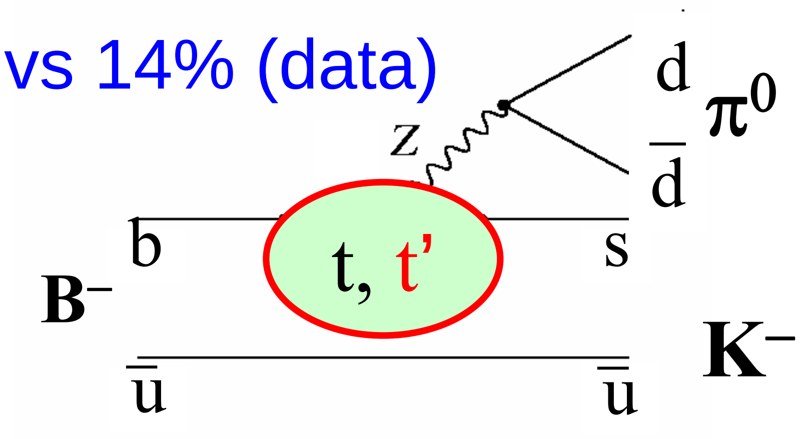
Use nominal $m_{t'}$ = 300 GeV
Change $m_{t'}$, Change parameter range
Effect the Same.

$\Delta\mathcal{A} = \mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} \sim 14\%$

LO PQCD ⊕ 4th Gen.



$\Delta\mathcal{A} \approx 12\%$ vs 14% (data)



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

NLO PQCD ⊕ 4th Gen.

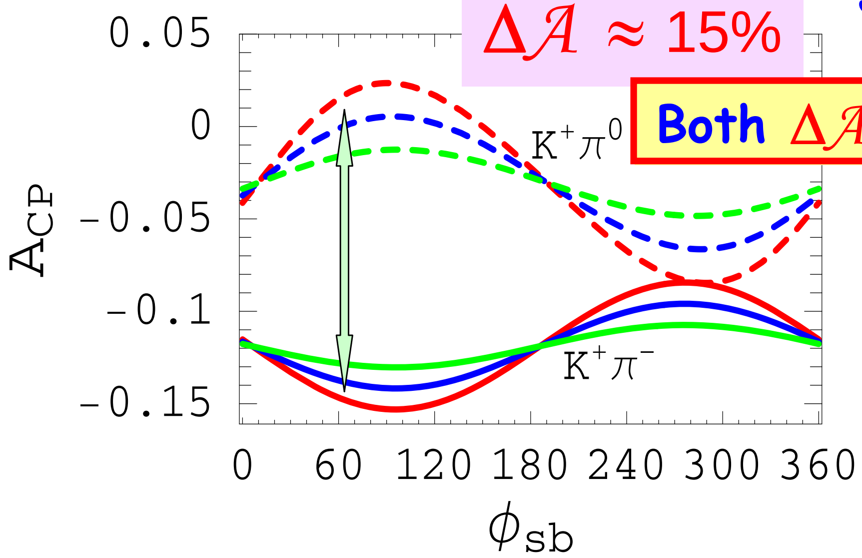
WSH, Li, Mishima, Nagashima, PRL'07

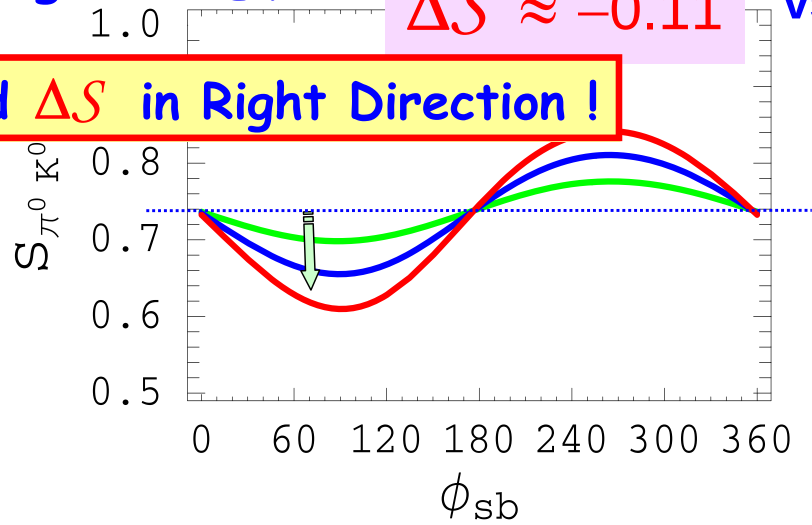
$\Delta\mathcal{A} \approx 15\%$

Joining C & P_{EW}

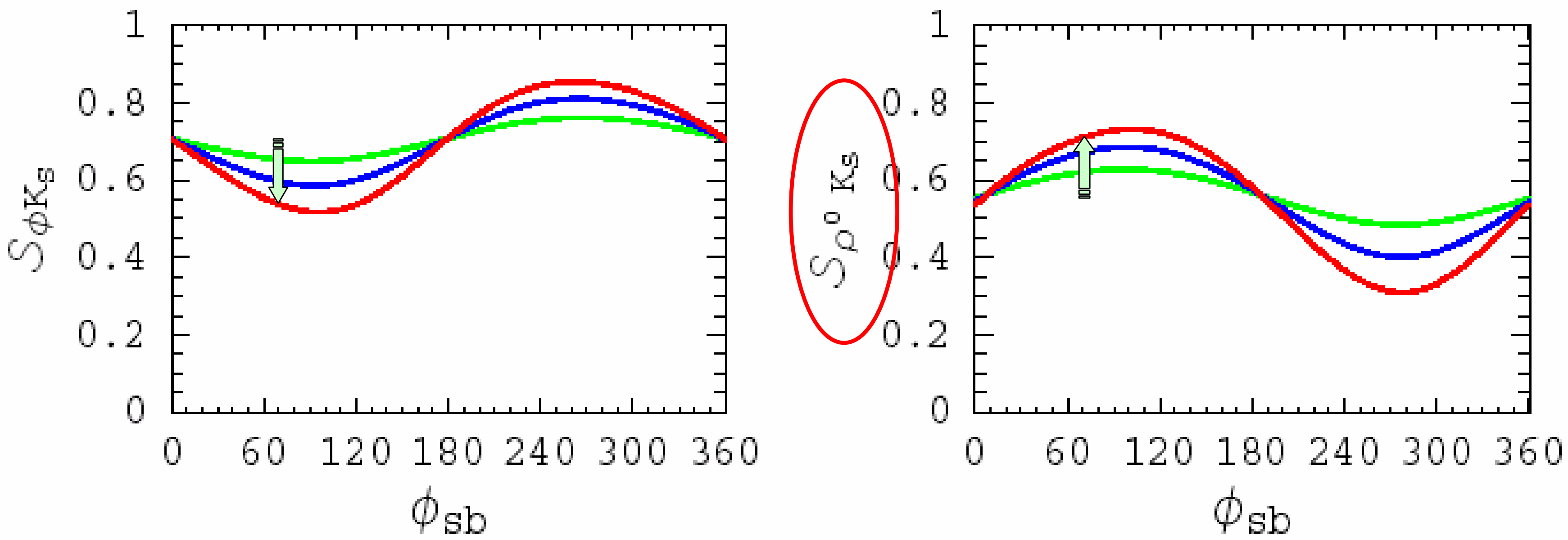
$\Delta S \approx -0.11$ vs **−0.34±0.2x (data)**

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





Opposite Sign

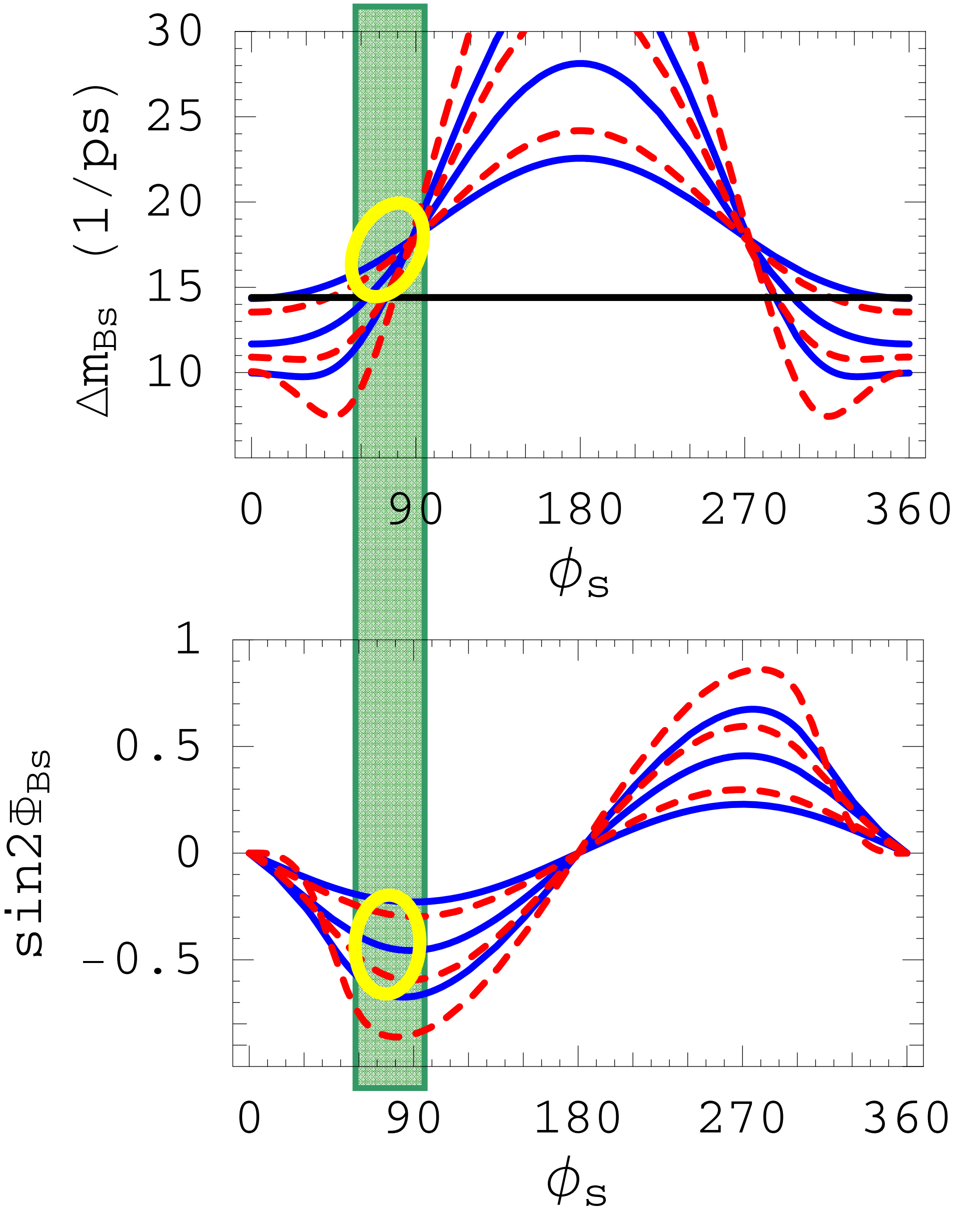


III. Prediction: Large CPV in B_s Mixing

Two Reasons

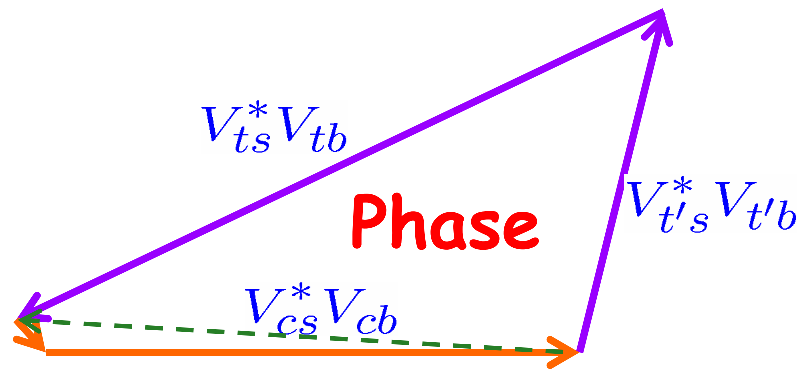
WSH, Nagashima, Soddu, hep-ph/0610385

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



WSH, Nagashima, Soddu, PRL'05

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



$\sin 2\Phi_{B_s}$ **~ –0.2 to –0.7 !**
Defintely BSM if measured !

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

↓

Large CPV in B_s Mixing

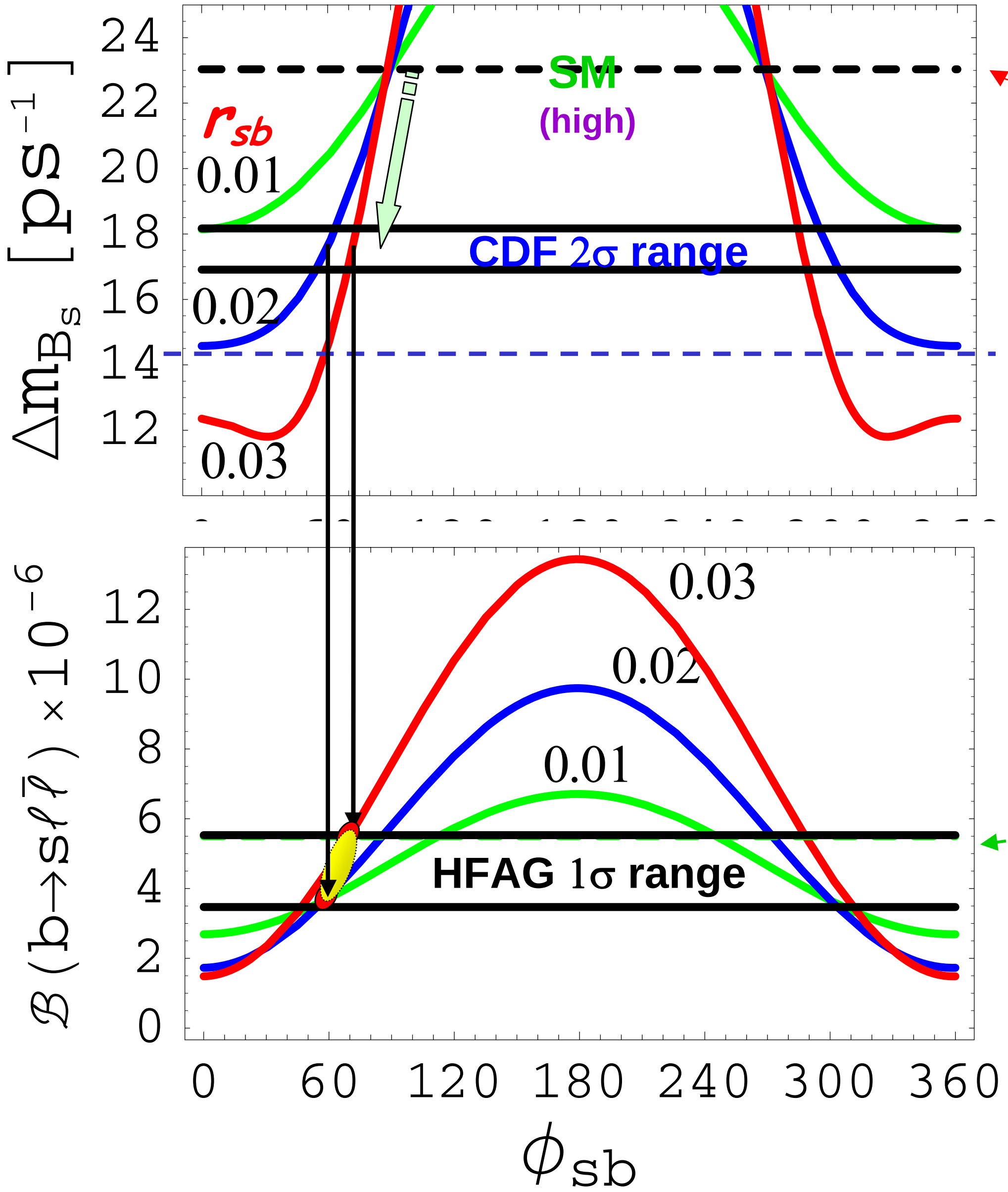
Use nominal $m_{t'}$ = 300 GeV

Change $m_{t'}$, Change parameter range

Effect the Same.

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

WSH, Nagashima, Soddu, hep-ph/0610385



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

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

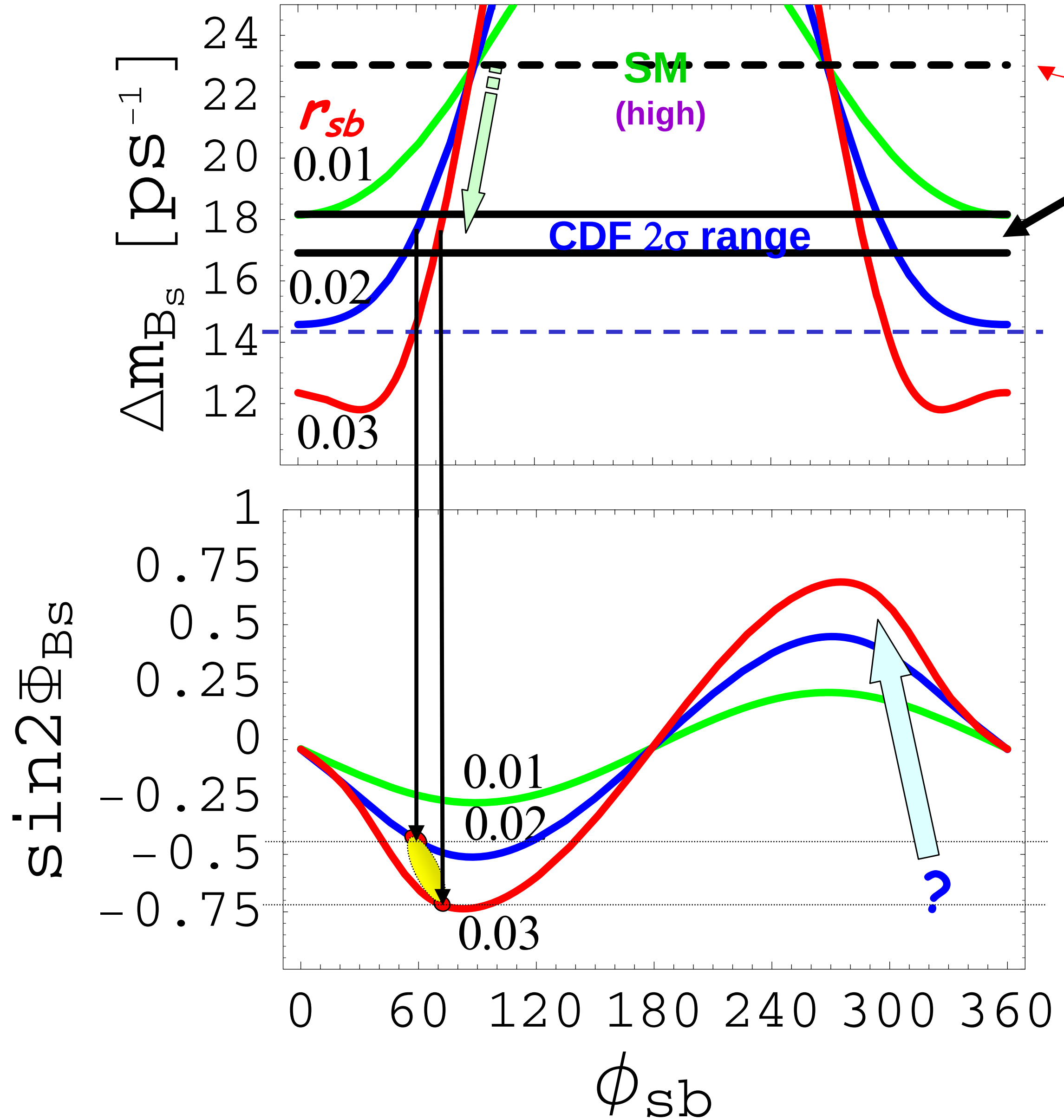
SM-like !

Large CPV Possible !

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

Large CPV in B_s Mixing

WSH, Nagashima, Soddu, hep-ph/0610385



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

B_s Mixing Measured @ Tevatron in 4/2006

- For r_{sb} ~ 0.02 – 0.03, [V_{cb} ~ 0.04

ϕ_{sb} Range ~ 60° - 70°

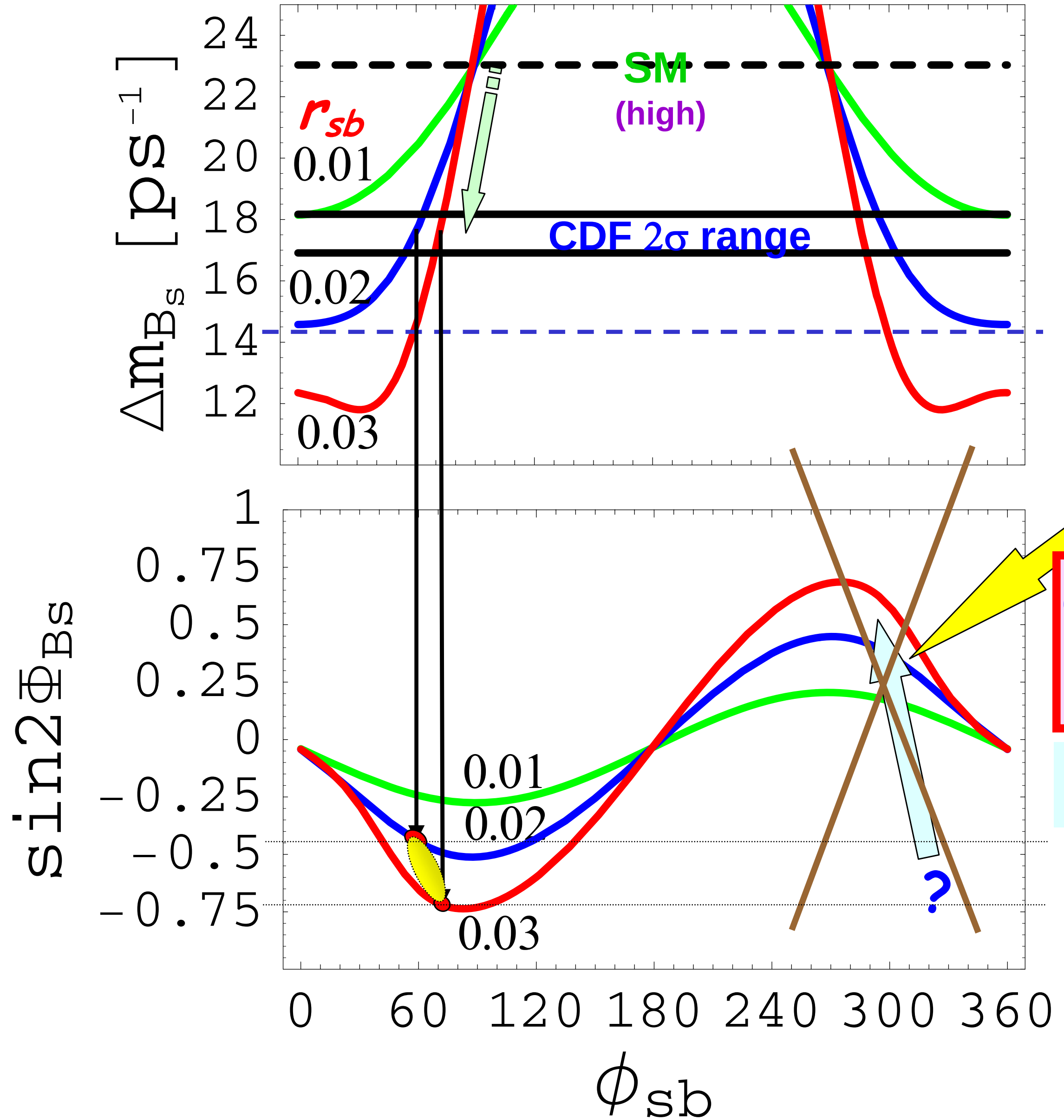
Finite CPV Phase

$\sin 2\Phi_{B_s}$ ~ ±0.5 - ± 0.7

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

Large CPV in B_s Mixing

WSH, Nagashima, Soddu, hep-ph/0610385



$\Delta\mathcal{A}_{K\pi}$, ΔS

Can Large CPV in B_s Mixing Be Measured @ Tevatron ?

Sign Predicted !

Sure thing by LHCb ca. 2008

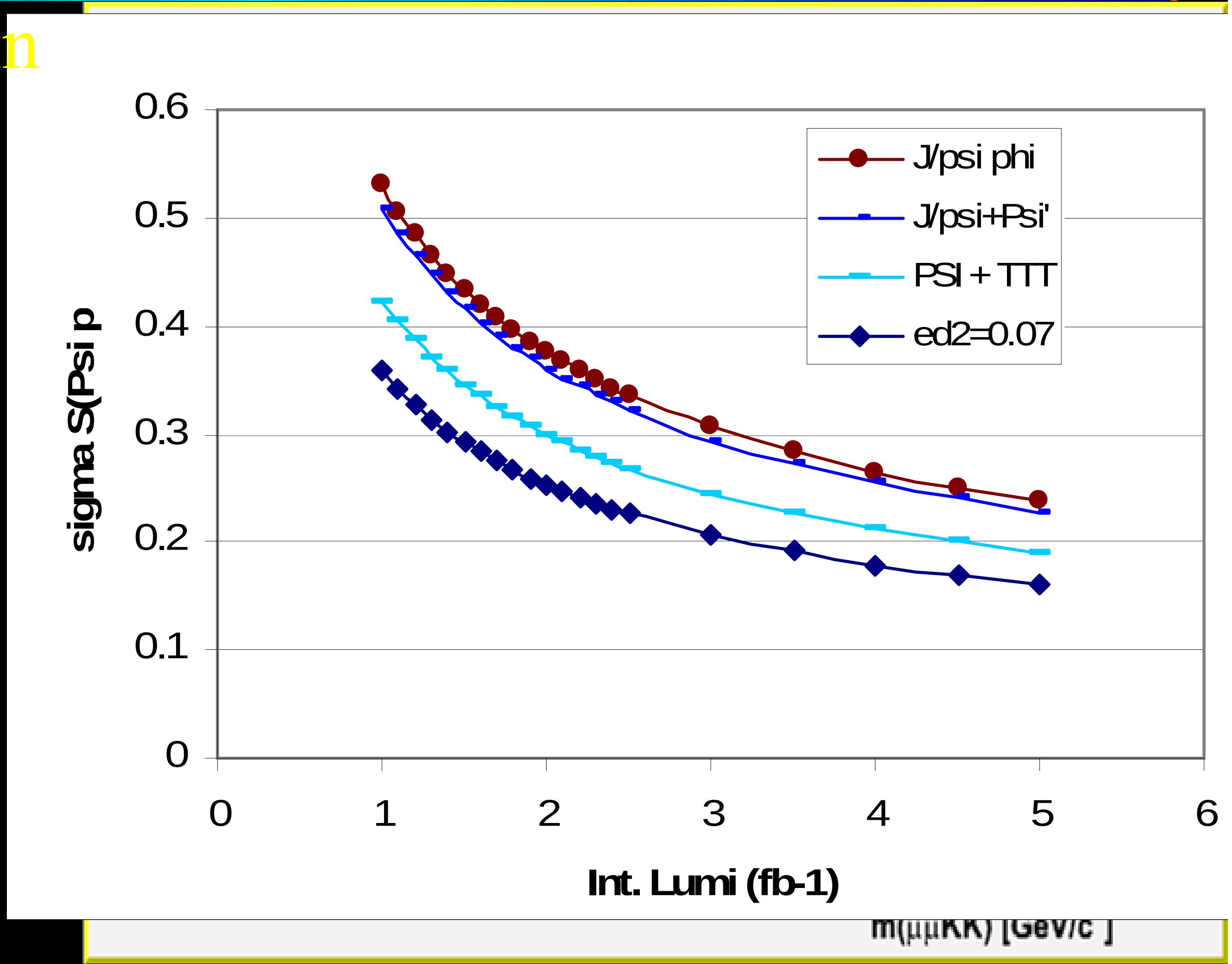
$\sin 2\Phi_{B_s}$ ~ ±0.5 - ± 0.7

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

Sin 2β_s expectations

- Use CP asymmetry in $B_s \to \psi\phi$
  - 80% CP-even
    - Reduced asymmetry
      - $S_{\psi\phi}$ = 60% sin 2β_s
  - Tevatron could reach **$\sigma(\sin 2\beta_s) < 0.2$/exp.**
  - ~ early LHC-B

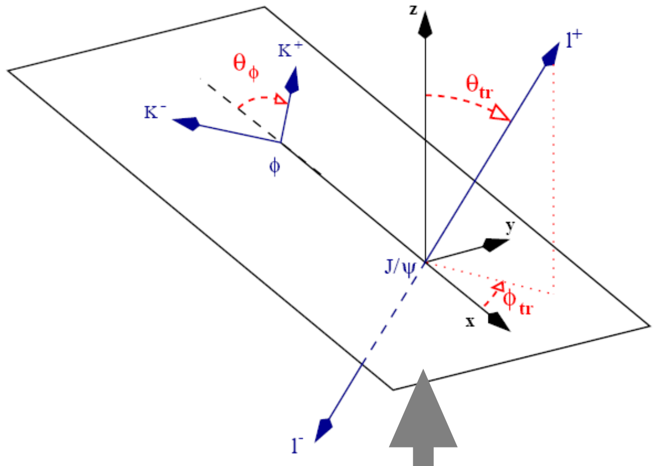
Also, K. Pitts private comm.



back

χ: Tevatron prospects (?) & LHC

Outlook/Golutvin/FPCP07



$B_s \to J/\psi\phi$ is the B_s counterpart of $B^0 \to J/\psi\ K_S$

- In SM $\phi_S = -2\arg(V_{ts}) = -2\Lambda^2\eta \sim -0.04$
- Sensitive to New Physics effects in the B_s-B_s system

  if NP in mixing $\longrightarrow$ $\phi_S = \phi_S(SM) + \phi_S(NP)$

- 2 CP-even, 1 CP-odd amplitudes, angular analysis needed to separate, then fit to ϕ_S, $\Delta\Gamma_S$, CP-odd fraction

LHCb

Channels	$\sigma(\phi_s)$ [rad]	Weight $(\sigma/\sigma_i)^2$ [%]
$B_s \to J/\psi\ \eta(\pi^+\ \pi^-\ \pi^0)$	0.142	2.3
$B_s \to D_sD_s$	0.133	2.6
$B_s \to J/\psi\ \eta(\gamma\ \gamma)$	0.109	3.9
$B_s \to \eta_c\phi$	0.108	3.9
Combined (pure CP eigenstates)	**0.060**	**12.7**
$B_s \to J/\psi\phi$	0.023	87.3
Combined (all CP eigenstates)	**0.022**	**100.0**

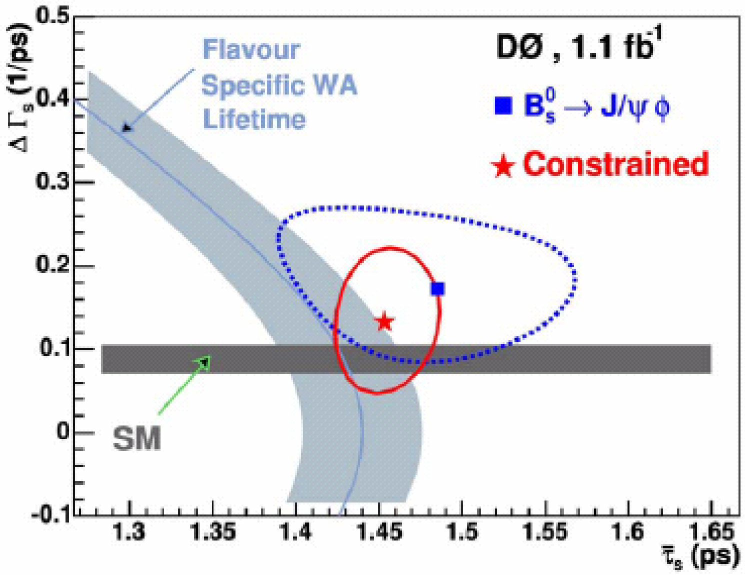
ATLAS **will reach s(ϕ_s) ~ 0.08 (10/fb, Δm_s=20/ps, 90k $J/\psi\phi$ evts)**

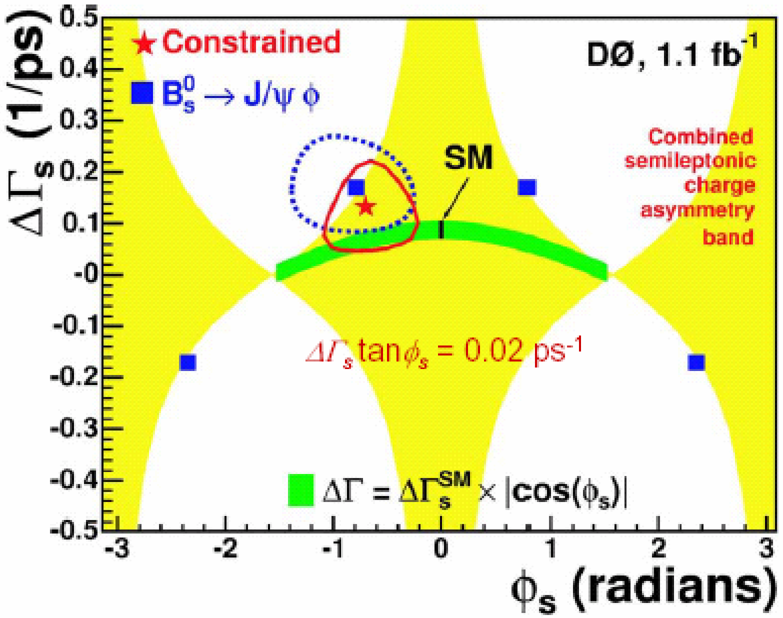
$\Delta\Gamma_{B_s}$ related effects: another avenue

$\Delta\Gamma_s$ and ϕ_s Results

hep-ex/0702030

- Repeat fit to $B_s \to J/\psi\,\phi$ (1 fb^{-1}) with
  - constraint from charge asymmetry
  - constraint from WA τ_{fs}
- The contours indicate error ellipses $\Delta ln(\mathcal{L}) = 0.5$ (39% CL)





- ϕ_s ambiguity remains unsolved
- For the solution with

  $\phi_s < 0$, $\cos\delta_1 > 0$ and $\cos\delta_2 < 0$

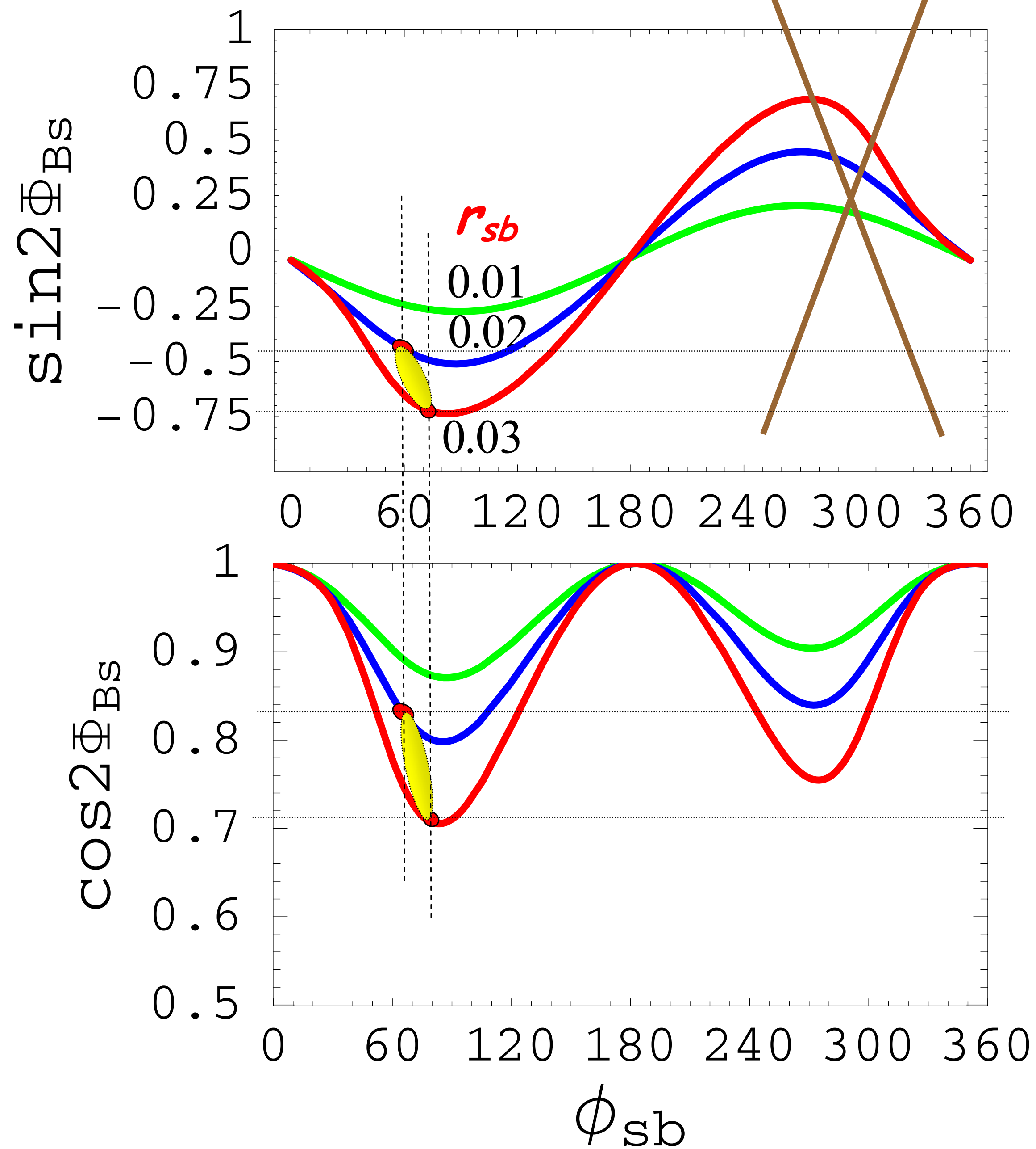
$$\Delta\Gamma_s = 0.13 \pm 0.09\ \text{ps}^{-1}$$
$$\phi_s = -0.70^{+0.47}_{-0.39}$$

WSH & Mahajan hep-ph/0702163

$$\phi_s^{\rm SM4} \sim -0.6$$

J. Piedra @ Flavour/LHC

Large CPV in B_s Mixing



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

Measure @ Tevatron ?

$\cos 2\Phi_{B_s} \sim 0.85$ - 0.7

A_{FB} in $B \to K^* \ell^+ \ell^-$

Probe Complexity w/o CPV

Hovhannisyan, WSH and Mahajan, hep-ph/0701046

A_{FB} in K*ll

C_7, C_9, C_{10} taken REAL

Why should they be ?

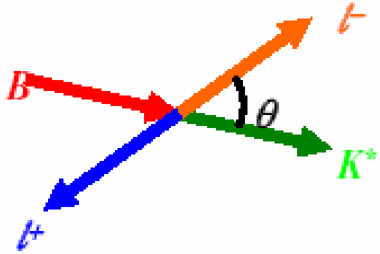
- Forward-backward asymmetry is induced by interference btw virtual photon and Z^0 contributions.
- Relative signs of C_7 to C_{10} and C_9 to C_{10} can be determined :

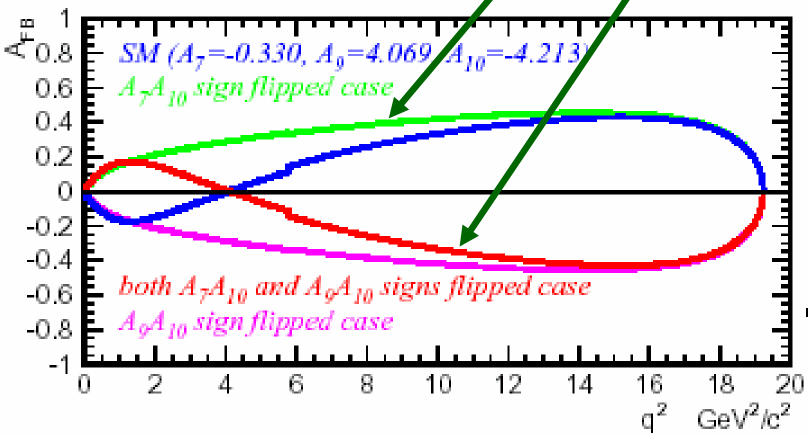
$$\frac{d}{d\hat{s}}(\Gamma_F^{K^*} - \Gamma_B^{K^*}) = -\frac{G_F^2 \alpha^2 m_B^5}{2^8 \pi^5} |V_{ts}^* V_{tb}|^2 \hat{s}\hat{u}(\hat{s})^2 \times \left[\mathrm{Re}(C_9^{\mathrm{eff}}) C_{10} V A_1 + \frac{\hat{m}_b}{\hat{s}} C_7^{\mathrm{eff}} C_{10} (V T_2 (1 - \hat{m}_{K^*}) + A_1 T_1 (1 + \hat{m}_{K^*})) \right] .$$

Definition of A_{FB}

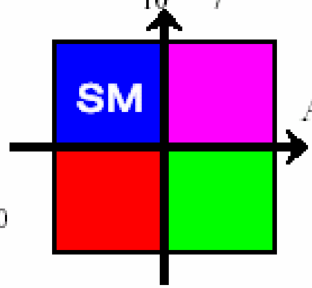
$$A_{FB}(q^2) = \frac{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) - \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) + \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}$$

θ_{Bl^-} : angle btw B and l^- in the dilepton rest frame





We can examine the sign of A_{10}/A_7 and A_9/A_7 with $A_{FB}(q^2)$



A_i : leading terms of the Wilson coefficients C_i

M. Iwasaki @ CKM06

Form factors induce some level of theoretical uncertainty

Use form factors calculated within LCSR – Ball & Zwicky

Forward-backward asymmetry

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

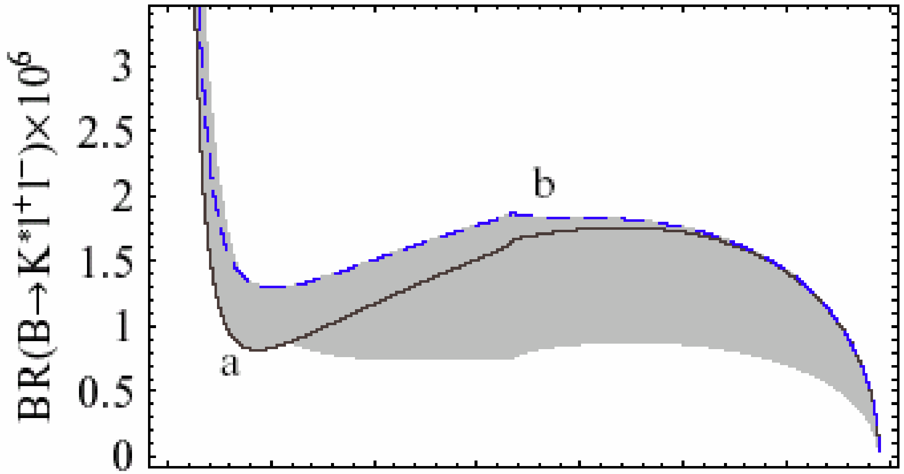
Form Factor Products

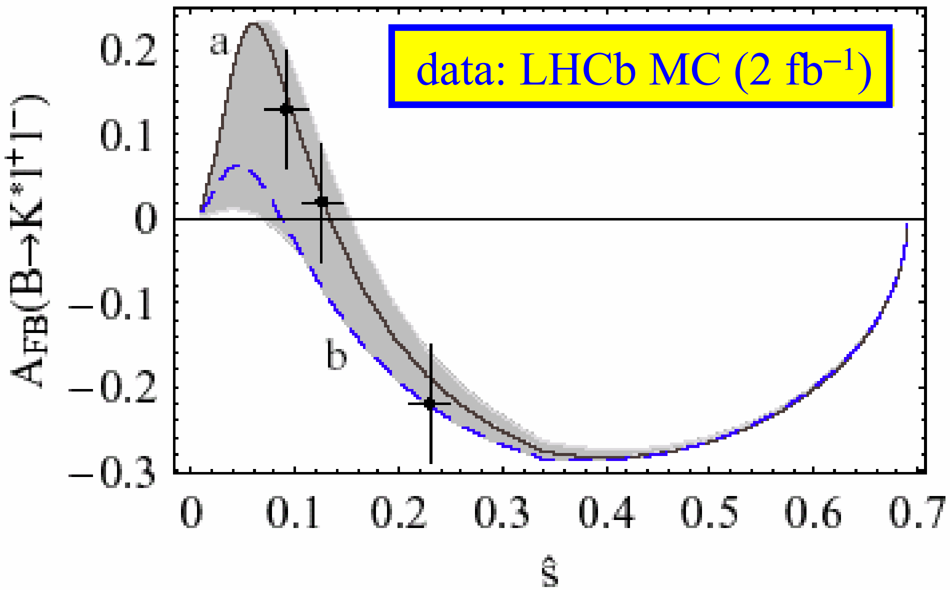
Richer Interference

SM like : $\Delta_9 \cong \Delta_{10}$ & $\phi_9 \cong \phi_{10}$

Hovhannisyan, WSH and Mahajan, hep-ph/0701046

$$
\begin{aligned}
C_7(M_W) &= C_7^{\rm SM}(M_W)\,(1+\Delta_7\, e^{i\phi_7}) \\
C_9(M_W) &= C_9^{\rm SM}(M_W)\,(1+\Delta_9\, e^{i\phi_9}) \\
C_{10}(M_W) &= C_{10}^{\rm SM}(M_W)\,(1+\Delta_{10}\, e^{i\phi_{10}})
\end{aligned}
$$





a: SM

b: 4 Gen.

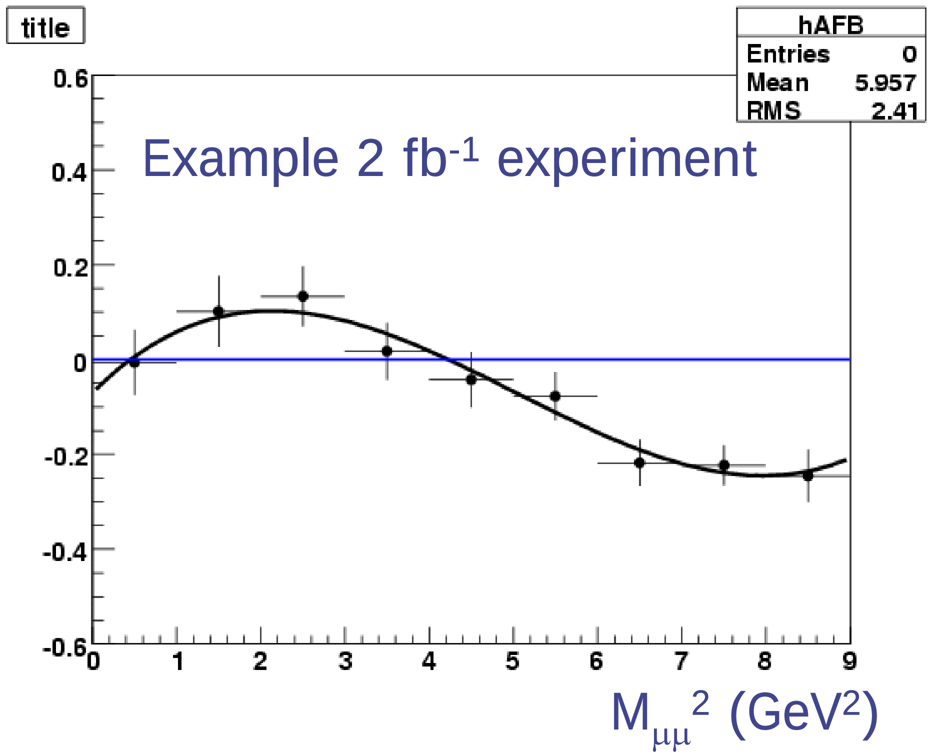
shaded: rough boundaries
(for illustration only)

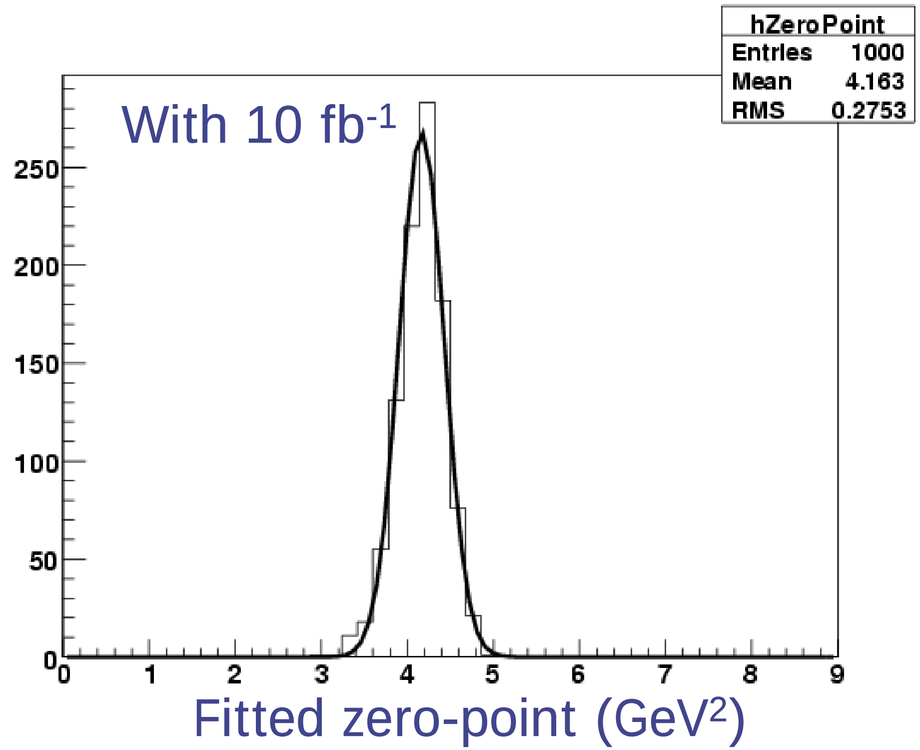
Constrained to 1σ experimental range for exclusive radiative and semi-leptonic rates

Probe Complexity w/o CPV
~ Early LHCb data

$B_d \to K^*\mu\mu$: FBA sensitivity

- Generator zero-crossing point: $s_0 = 4.10\ GeV^2$
- From 1000 experiments of 2 fb^{-1}:
  - No background $s_0 = 4.17 \pm 0.38\ GeV^2$
  - With background $s_0 = 4.11 \pm 0.52\ GeV^2$
- With 10 fb^{-1} (with background) $s_0 = 4.17 \pm 0.28\ GeV^2$





Demanded by Kevin Pitts

IV. DCPV in $B^+ \to J/\psi K^+$?

WSH, Nagashima, Soddu, hep-ph/0605080

Intriguing "Prediction": $\mathcal{A}_{J/\psi K^+} \neq 0$?

- B → J/ψK⁺ dominated by color suppressed b → ccs (a$_2$)
  - Inclusion of SM3 Penguin does not alter Weak Phase ~ 0 [hard to predict
- The amplitude above likely has **Strong Phase** δ
  - ALL "color-suppressed" processes turned out Enhanced
    ~ some effective strong phase

  Examples:

  * $B^0 \to D^+\pi^-$ and $D^0\pi^0$ ⇨ $\delta \sim 30^\circ$ in $D\pi$ system

  * $B^0 \to \pi^0\pi^0$ and $\pi^+\pi^-$ ⇨ $\delta \sim ??^\circ$ in $\pi\pi$ system (Belle vs BaBar)

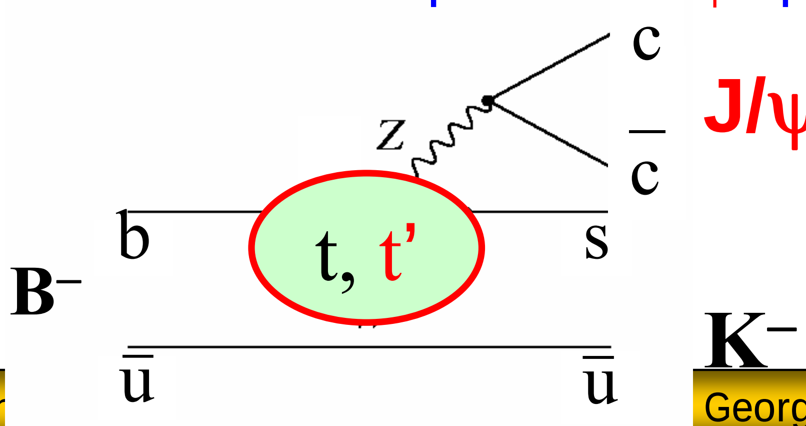
  Expt

  - B → J/ψK⁺ Rate is enhanced: "hadronic"

  Analogous to enhancement seen in B → J/ψK*

  ⇨ Strong Phase Diff. in Helicity Amplitudes: $\delta \sim 30^\circ$
- Enter t': **Weak Phase** $e^{i\phi_{sb}}$

  Factorized amplitude : J/ψ spits off from virtual Z



⇨ $\delta \sim 30^\circ$ Likely Retained

Interference

Making of DCPV !

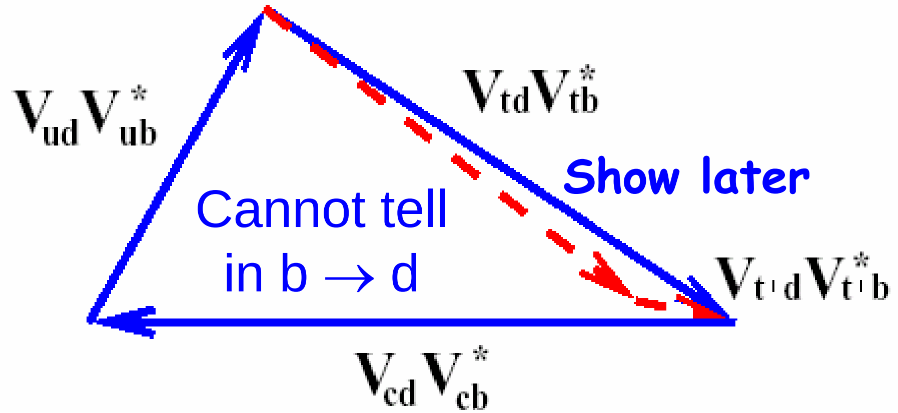
$\mathcal{A}_{J/\psi K^+} \neq 0$?

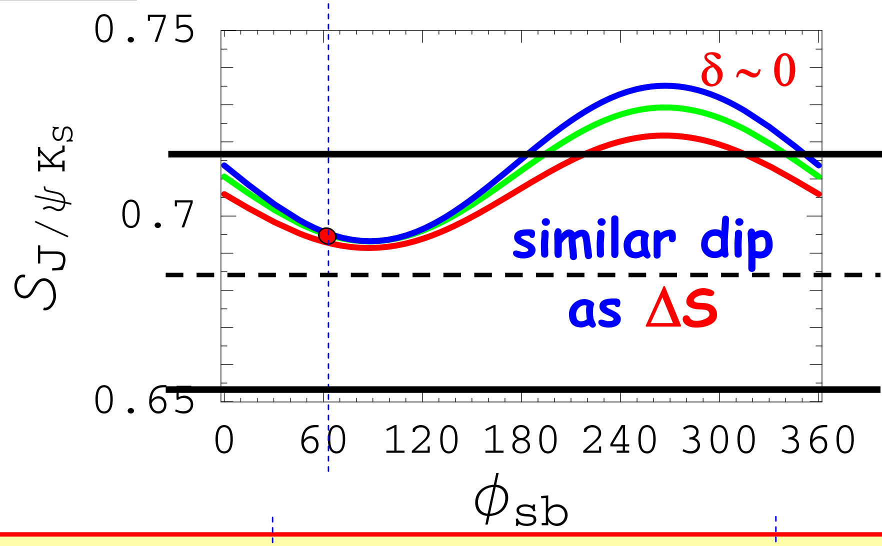
Another hint:

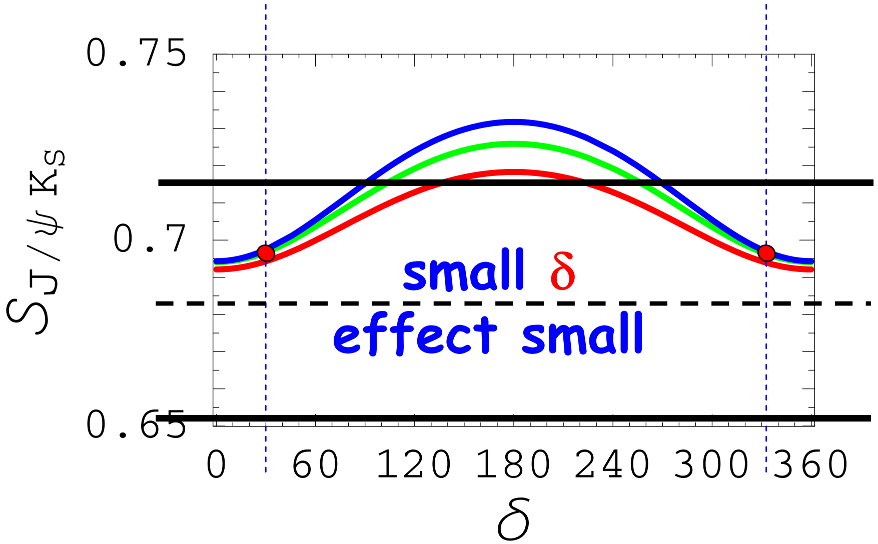
Low $\mathcal{S}_{J/\psi K}$?

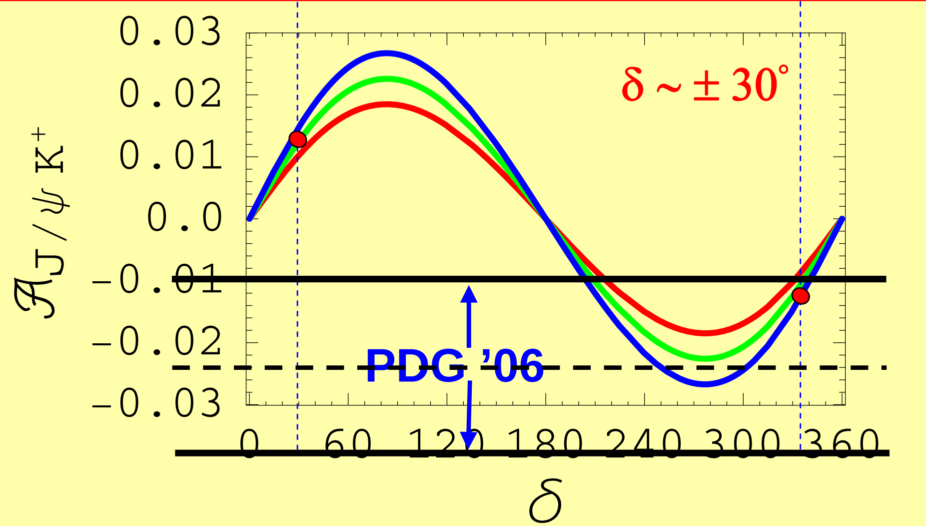
indirect	
$0.752^{+0.057}_{-0.035}$	CKMfit
0.790 ± 0.031	UTfit

vs. Belle/BaBar 0.685 ± 0.032 HFAG









Prognosis for $\mathcal{A}_{J/\psi K^+}$ Measurement

PDG ’06

ICHEP06: $\mathcal{A}_{J/\psi K^0}$ **0.018 ± 0.021 ± 0.014 Belle**
–0.07 ± 0.028 ± 0.018 BaBar

$A_{CP}(B^+ \to J/\psi(1S)K^+)$

VALUE			DOCUMENT ID		TECN
−0.024±0.014 OUR AVERAGE					
−0.030±0.014±0.010	124M		AUBERT	05J	BABR
−0.026±0.022±0.017	32M		ABE	03B	BELL
0.018±0.043±0.004	10M	577	BONVICINI	00	CLE2
• • • We do not use the following data for averages, fits, limits,					
0.03 ±0.015±0.006	89M		AUBERT	04P	BABR
0.003±0.030±0.004			AUBERT	02F	BABR

Sign flip

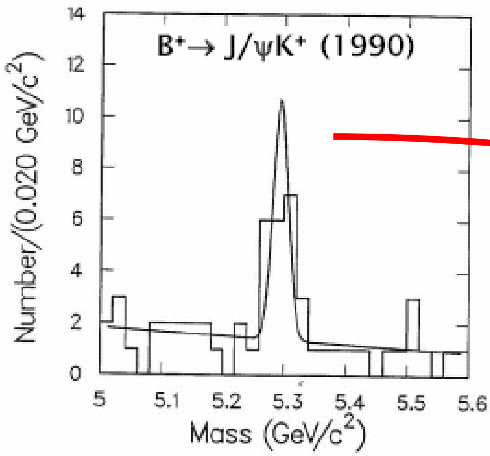
BaBar/Belle Should Update !

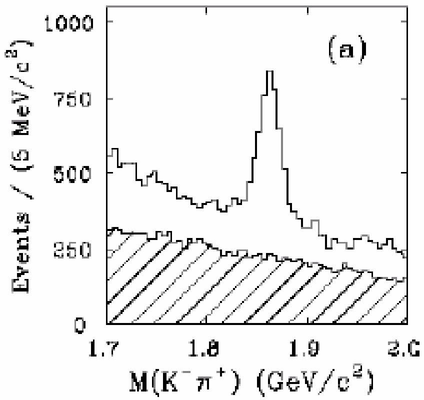
- $\mathcal{A}_{J/\psi K^+}$ is getting serious
- Systematics Control!
  — Needed towards SuperB !!

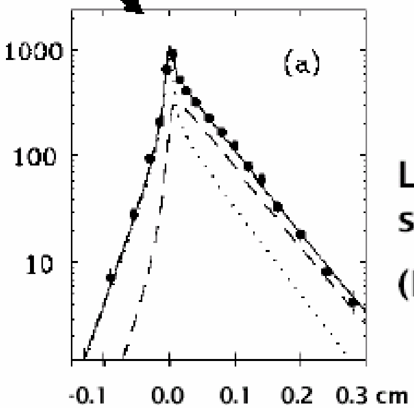
The White Horse

The early days…

- Before silicon
- After silicon



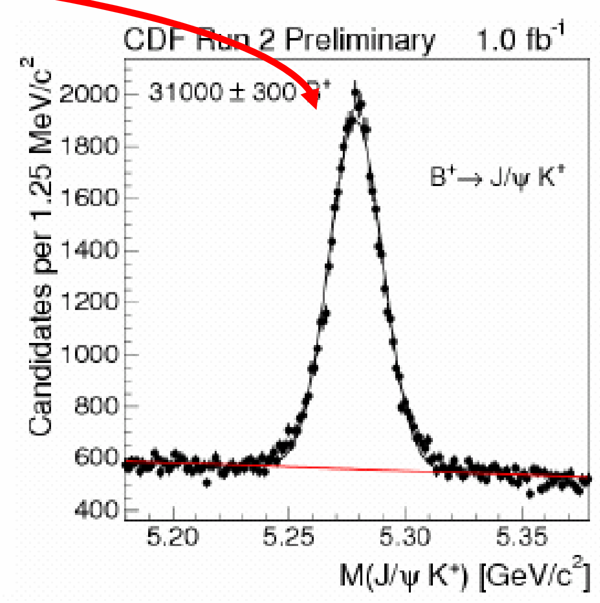




Lifetimes in semileptonic decays

(F. Ukegawa et al.)

6th KEK Topical Conference *February 8, 2007* *Kevin Pitts* *Page-10*



Much larger control sample ! ⟹ **Better Systematics !**

Prognosis for $\mathcal{A}_{J/\psi K^+}$ Measurement

PDG '06

$A_{CP}(B^+ \to J/\psi(1S) K^+)$

ICHEP06: $\mathcal{A}_{J/\psi K^0}$

$0.018 \pm 0.021 \pm 0.014$	Belle
$-0.07 \pm 0.028 \pm 0.018$	BaBar

VALUE			DOCUMENT ID		TECN
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$0.03 \pm 0.015 \pm 0.006$	89M		AUBERT	04P	BABR
$0.003 \pm 0.030 \pm 0.004$			AUBERT	02F	BABR

Sign flip

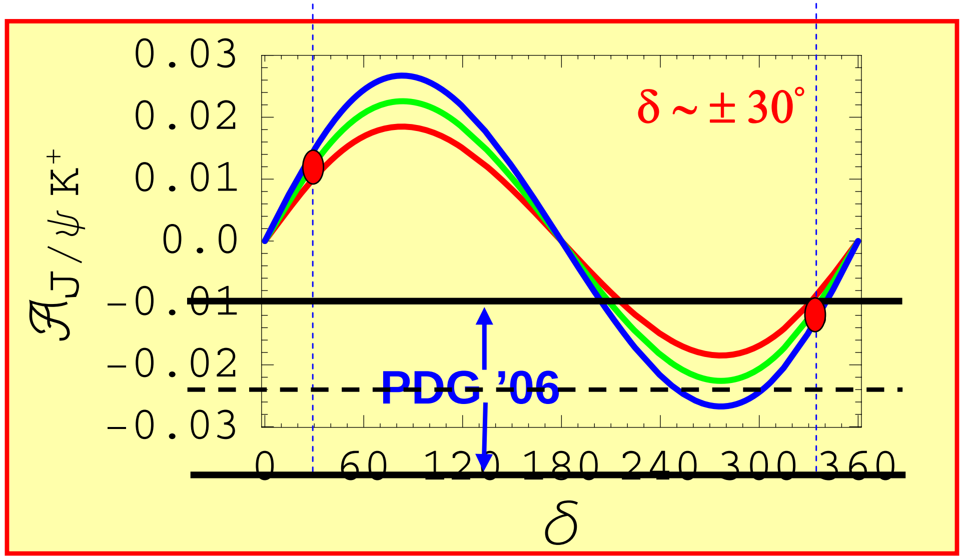
BaBar/Belle Should Update !

- $\mathcal{A}_{J/\psi K^+}$ is getting serious
- Systematics Control!
  - — Needed towards SuperB !!

K. Pitts

CDF could reach 0.3%

Could be seen by 2008 ?! Better than $\Delta\mathcal{A}$ and $\Delta\mathcal{S}$?



0.03
0.02
0.01
0.0
-0.01
-0.02
-0.03
0 60 120 180 240 300 360
δ
$\mathcal{A}_{J/\psi K^+}$
$\delta \sim \pm 30^\circ$
PDG '06

Abstract ID : 171

Search for anomalous direct and indirect CP violation in b to c transitions at Dzero

We search for anomalous charge asymmetries in the b to c transitions of both neutral and charged B mesons. Indirect CP violation in Bd and Bs mixing is studied using semileptonic decays. Direct CP violation in B+ decay is studied using exclusive decays to J/psi mesons. The results are based on a large data set of proton-antiproton collisions recorded by the Dzero detector operating at the Fermilab Tevatron Collider. Dzero contains independent spectrometers based on an inner solenoid and outer toroids. The magnet polarities are reversed on a regular basis allowing for unprecedented control of the systematic uncertainties associated with charge asymmetry measurements in B meson mixing and decay. The results presented can be used to limit new physics in both Delta Bd and Delta Bs = 2 operators as well as limit recent fourth generation models.

Abstract ID : 381

CP Violation Measurements at CDF

We present the latest results on CP violation measurement from CDF. These include:

- a measurment of sin(2beta) from B0 -> J/Psi K0s decays
- a high-precision measurement of the inclusive CP asymmetry in same sign dimuon events originating from two semileptonic B~hadron decays
- a search for a CP charge asymmetry in B+ -> J/Psi K+ decays

IV. Aside: $K_L \to \pi^0 \nu\nu$; D^0 Mixing

Full 4 x 4 Unitarity ⇨ Z/K Constraints

"Typical" CKM Matrix

WSH, Nagashima, Soddu, PRD'05

$$V^4_{CKM} = \begin{pmatrix} 0.9745 & 0.2225 & 0.0038\, e^{-i\,60^\circ} & 0.0281\, e^{i\,61^\circ} \\ -0.2241 & 0.9667 & 0.0415 & 0.1164\, e^{i\,66^\circ} \\ 0.0073\, e^{-i\,25^\circ} & -0.0555\, e^{-i\,25^\circ} & 0.9746 & 0.2168\, e^{-i\,1^\circ} \\ -0.0044\, e^{-i\,10^\circ} & -0.1136\, e^{-i\,70^\circ} & -0.2200 & 0.9688 \end{pmatrix}$$

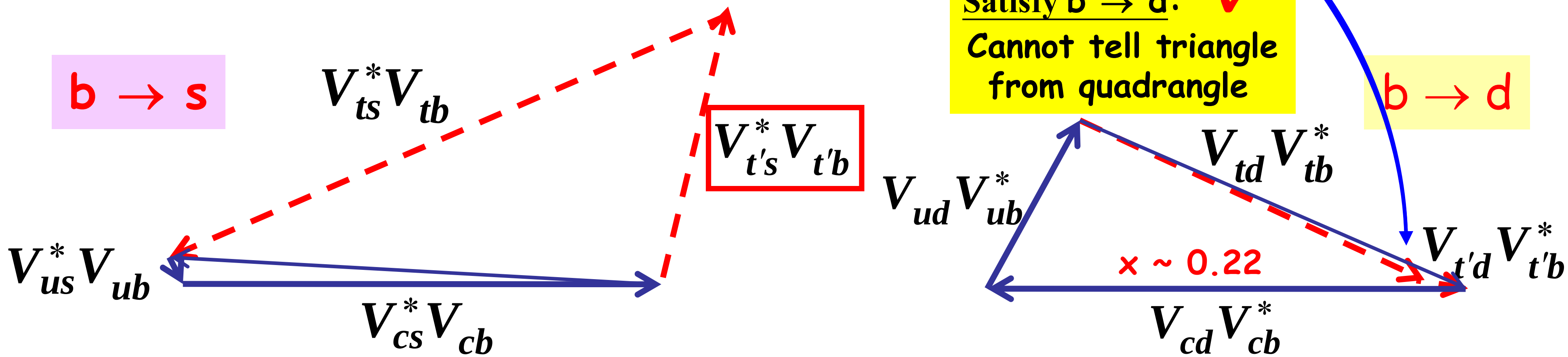
$s \leftarrow b$

$d \leftarrow s$

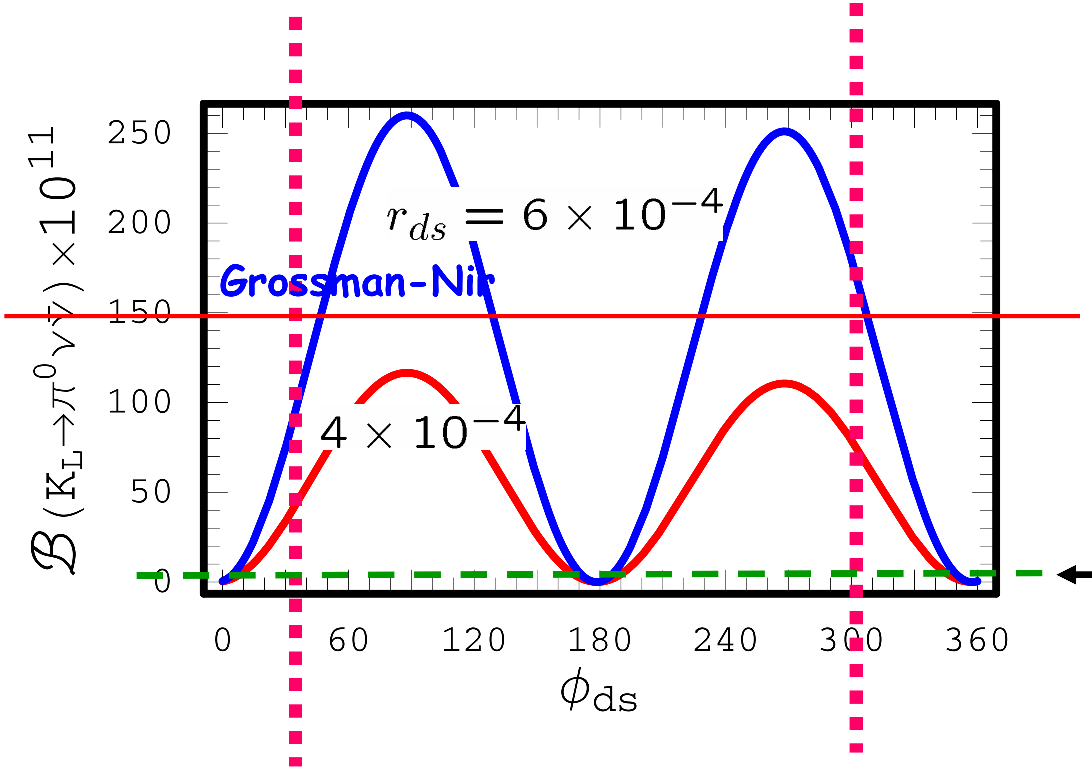
$Z \to b\bar{b}$

Satisfy $b \to d$: ✓

Cannot tell triangle from quadrangle



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



Current E391A U.L.

2.86×10^{-7} (90% c.l.)

Very hard to measure

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

SM 3

Rate could be enhanced 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 $K^+ \to \pi^+ \nu\bar{\nu}$ $(2\text{–}3 \times 10^{-10})$

$\because$ Large CPV Phase

WSH, Nagashima, Soddu, PRD'05

4 x 4 Unitarity ⇨ Z/K Connections

"Typical" CKM Matrix

(Too) Large/Imaginary

$$V^4_{CKM} = \begin{pmatrix} 0.9745 & 0.2225 & 0.0038\,e^{-i\,60^\circ} & 0.0281\,e^{i\,61^\circ} \\ -0.2241 & 0.9667 & 0.0415 & 0.1164\,e^{i\,66^\circ} \\ 0.0073\,e^{-i\,25^\circ} & -0.0555\,e^{-i\,25^\circ} & 0.9746 & 0.2168\,e^{-i\,1^\circ} \\ -0.0044\,e^{-i\,10^\circ} & -0.1136\,e^{-i\,70^\circ} & -0.2200 & 0.9688 \end{pmatrix}$$

Data Driven

Ben Grinstein @ CKM06

Guess #1

$$V^{(4)}_{\rm CKM} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 & \lambda^5 \\ \lambda & 1 & \lambda^2 & \lambda^4 \\ \lambda^3 & \lambda^2 & 1 & \lambda^2 \\ \lambda^5 & \lambda^4 & \lambda^2 & 1 \end{pmatrix}$$

Close to what we'll see !

Guess #2

$$V^{(4)}_{\rm CKM} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 & \lambda^3 \\ \lambda & 1 & \lambda^2 & \lambda^2 \\ \lambda^3 & \lambda^2 & \cos\theta_G & \sin\theta_G \\ \lambda^3 & \lambda^2 & -\sin\theta_G & \cos\theta_G \end{pmatrix}$$

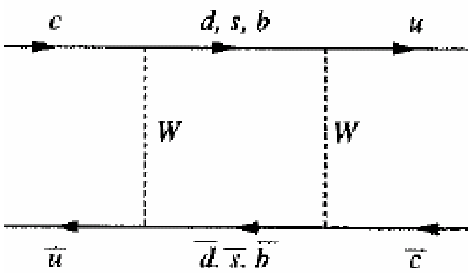
4 x 4 Unitarity ⇨ Z/K Connections

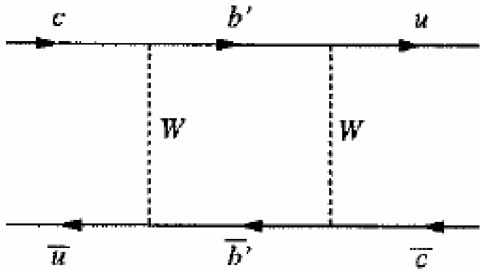
"Typical" CKM Matrix

(Too) Large/Imaginary

$$V^4_{CKM} = \begin{pmatrix} 0.9745 & 0.2225 & 0.0038\,e^{-i\,60^\circ} & 0.0281\,e^{i\,61^\circ} \\ -0.2241 & 0.9667 & 0.0415 & 0.1164\,e^{i\,66^\circ} \\ 0.0073\,e^{-i\,25^\circ} & -0.0555\,e^{-i\,25^\circ} & 0.9746 & 0.2168\,e^{-i\,1^\circ} \\ -0.0044\,e^{-i\,10^\circ} & -0.1136\,e^{-i\,70^\circ} & -0.2200 & 0.9688 \end{pmatrix}$$

Data Driven





SM LD | NP SD

$$V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub}V_{cb}^* + V_{ub'}V_{cb'}^* = 0$$

-0.218 | $+0.215$ | $+0.0033\,e^{-i5^\circ}$

"Evidence" for D Mixing: Only 2 results > 3σ

- Babar (384 fb^{-1}) $D^0 \to K\pi$
  - c.w. Belle (400 fb^{-1})
    $x'^2 = (0.18^{+0.21}_{-0.23}) \times 10^{-3}$ $y' = (0.6^{+4.0}_{-3.9}) \times 10^{-3}$

$$x'^2 = (-0.22 \pm 0.30 \pm 0.21) \times 10^{-3}$$
$$y' = (9.7 \pm 4.4 \pm 3.1) \times 10^{-3}$$

- Belle (540 fb^{-1}) $D^0 \to KK, \pi\pi$
  - c.w. W.A. (includes Belle '03)
    $y_{CP} = (0.90 \pm 0.42)\%$

$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$$

- Belle (540 fb^{-1}) $D^0 \to K_S\pi\pi$
  - c.w. CLEO (9 fb-1)
    $x = (1.8 \pm 3.4 \pm 0.6)\%$ $y = (-1.4 \pm 2.5 \pm 0.9)\%$

$$x = (0.80 \pm 0.29 \pm 0.17)\%$$
$$y = (0.33 \pm 0.24 \pm 0.15)\%$$

- CLEO-c (281 pb^{-1}) - new results expected soon
  - y, x^2 and cosδ

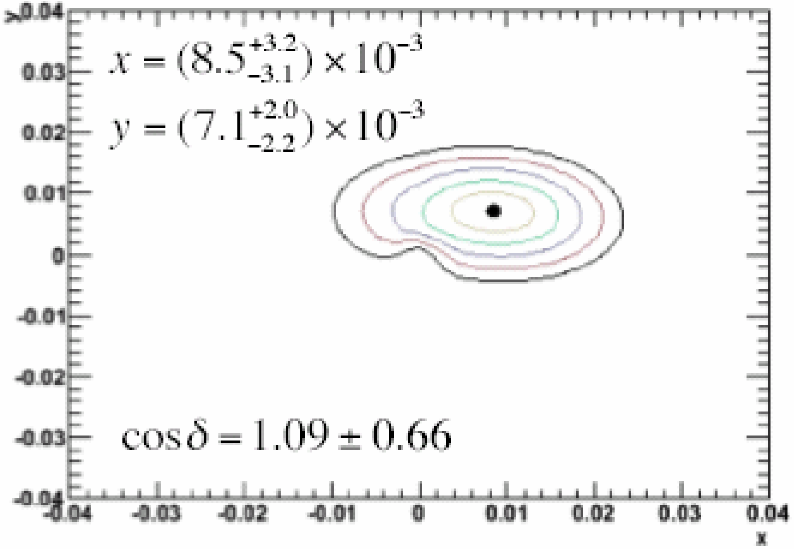
Before Moriond '07

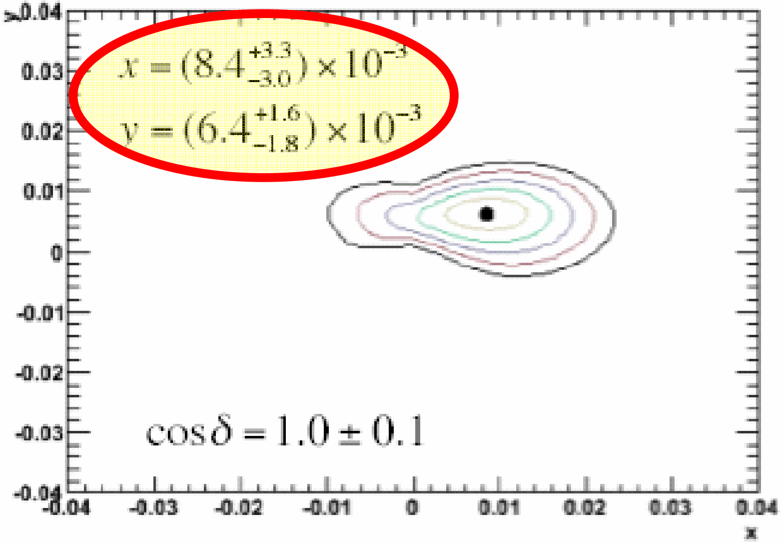
NO MIXING (x,y)=(0,0) excluded:
- ✓ ~2.1 σ Belle $D^0 \to K\pi$ (no CPV)
- ✓ ~2.3 σ BaBar $D^0 \to K2\pi/K3\pi$
- ✓ ~2.2 σ Average y_{CP}

After Moriond '07

NO MIXING (x,y)=(0,0) excluded:
- ✓ 3.9 σ BABAR $D^0 \to K\pi$ (no CPV)
- ✓ ~2.4 σ Belle $D^0 \to K_S\pi\pi$
- ✓ ~3.5 σ New Average y_{CP}=1.12±0.32

HFAG - VERY Preliminary

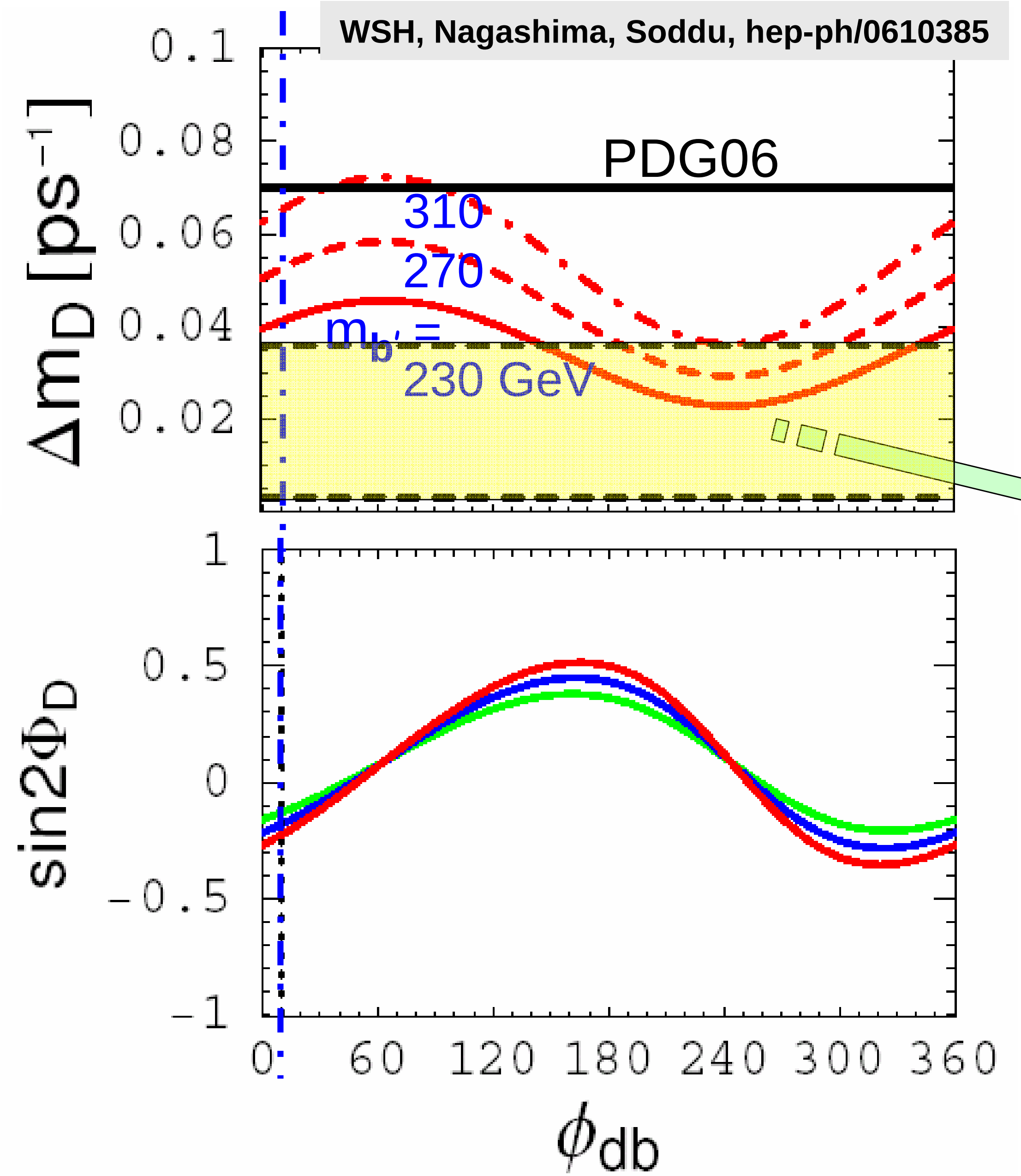




- With great trepidation average all results
  - Use likelihood contours where appropriate
- Consider two scenarios
  - Current results - with CLEO-c $\cos\delta = 1.09 \pm 0.66$
  - Current results + anticipating $\cos\delta = 1.0 \pm 0.1$

D. Asner March 26-28, 2007 Charm Report:Flavour in LHC Era 30

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

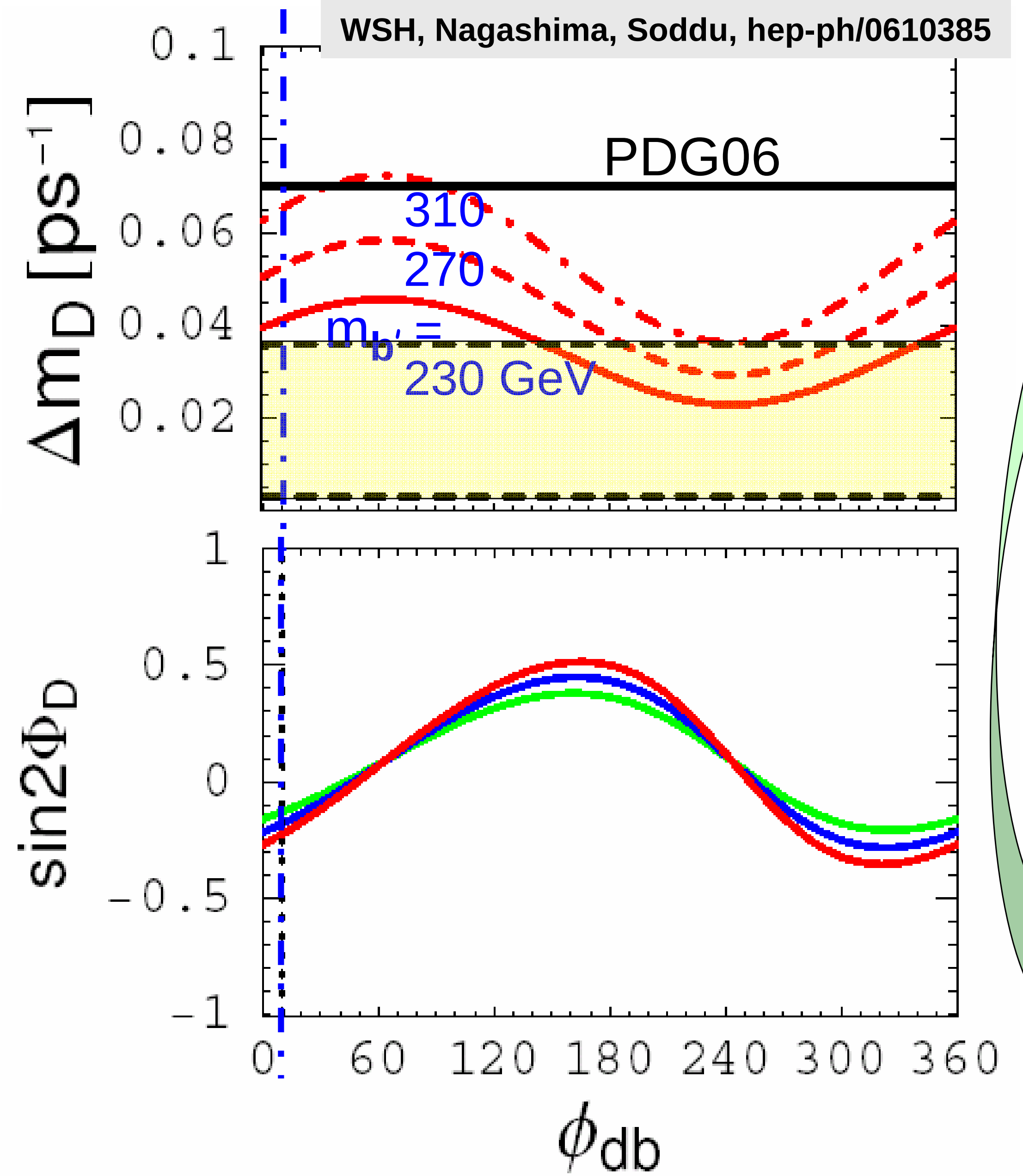
$$V_{ub'}V^*_{cb'}$$

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**]

Short-distance Only



Nir: x^{LD} opposite sign
to y (assumptions)

but x, y expt same sign

When can be tested ?

x^{SD} $x = \Delta m/\Gamma \sim 1$ - 3 plausible

Sizable (but not huge) **CPV in Mixing ~15% to 20%**

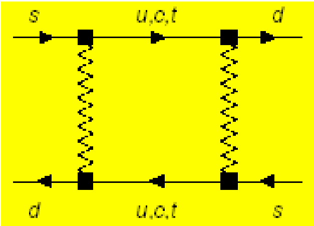
w/ Sizable (but not huge) CPV in Mixing ~15%

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

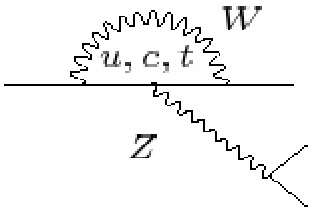
V. Conclusion

On Boxes and Z Penguins

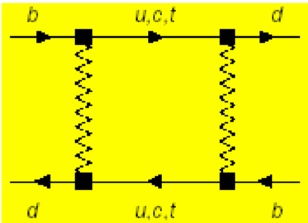
nondecoupling



GIM, charm, ε_K

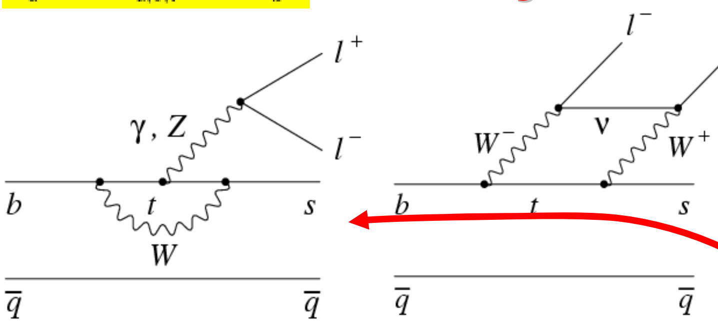


small ε'_K, $K \to \pi\nu\nu$ (still waiting)



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

B_s



Z dominance for heavy top

1986 $\to$ 2002

All w/ 3-gen.,
Just wait if there's 4th

D !

b', t' @ LHC

Outline

Δm_{B_s}, $\Delta\Gamma_{B_s}$

I Intro: $\Delta\mathcal{S}$, $\Delta\mathcal{A}_{K\pi}$

Z Penguins and Boxes

Why 4th Generation Revisit? $A_{CP}(K^+\pi^0) \neq A_{CP}(K^+\pi^-)$

II Accounting for $\Delta\mathcal{A}_{K\pi}$ and $\Delta\mathcal{S}$ (in NLO PQCD)

III B_s Mixing vs **$B \to X_s \ell^+\ell^-$** $\to$ **Large CPV in B_s Mixing**

Large CPV Phase (or Nil)

$\sin 2\Phi_{B_s}$ ~ –0.5 - – 0.7

$\cos 2\Phi_{B_s}$ ~ 0.85 - 0.7

$\Delta\Gamma_{B_s}$ related effects; **A_{FB} in $B \to K^*\ell^+\ell^-$**

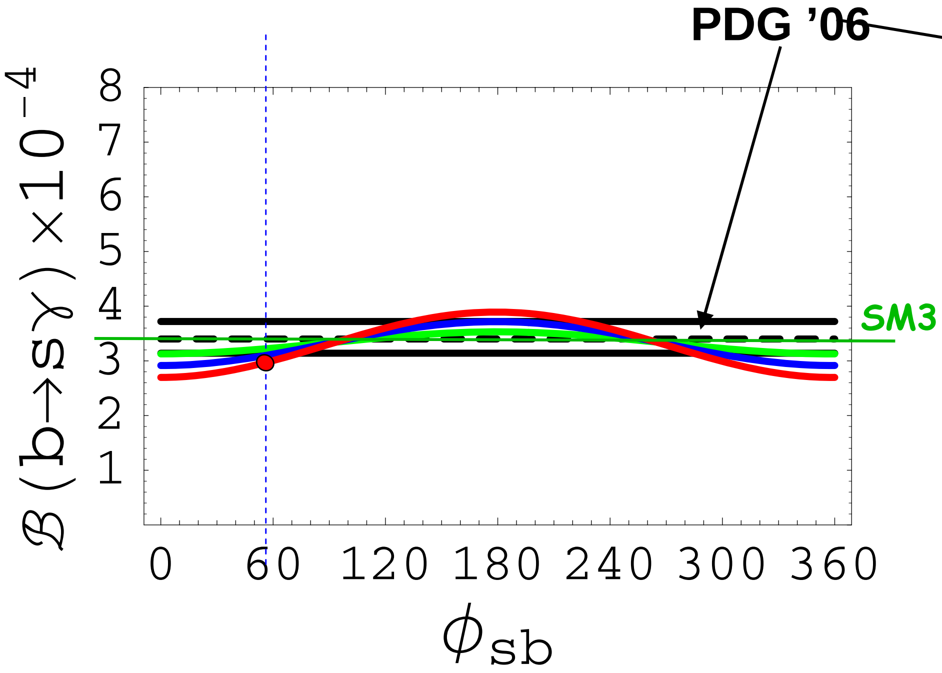
IV DCPV in $B^+ \to J/\psi K^+$? **% level**

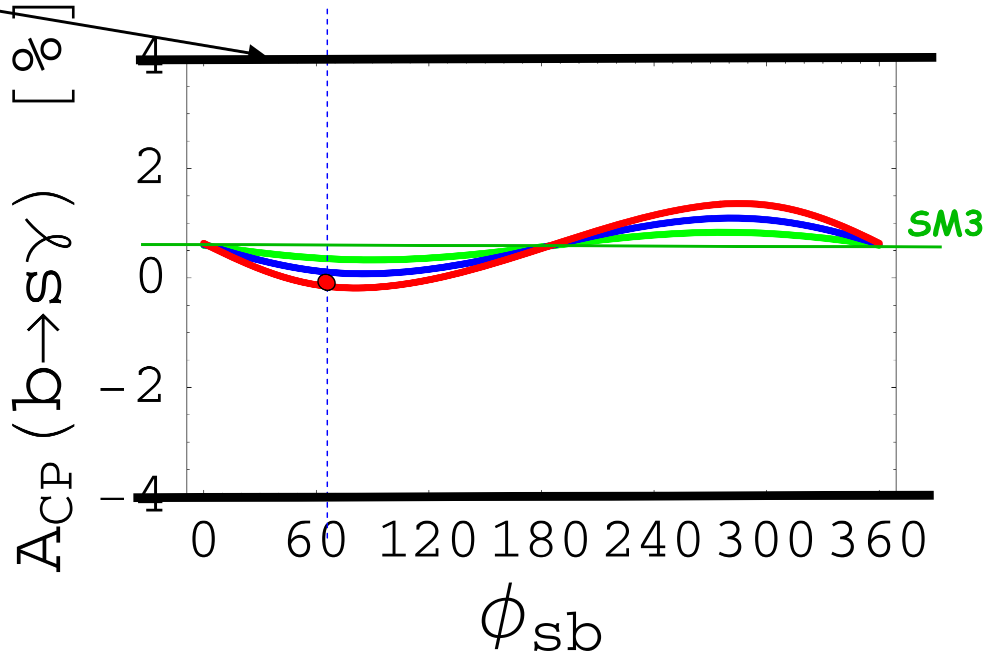
Will start to place bet if measured !

IV Aside: **$K_L \to \pi^0\nu\nu$; D^0 Mixing**

V Conclusion

Consistency and b → sγ Predictions



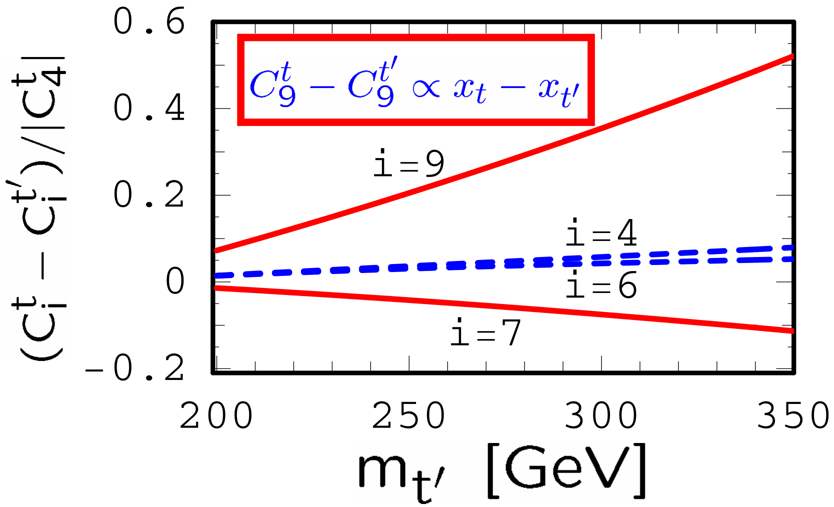


BR OK

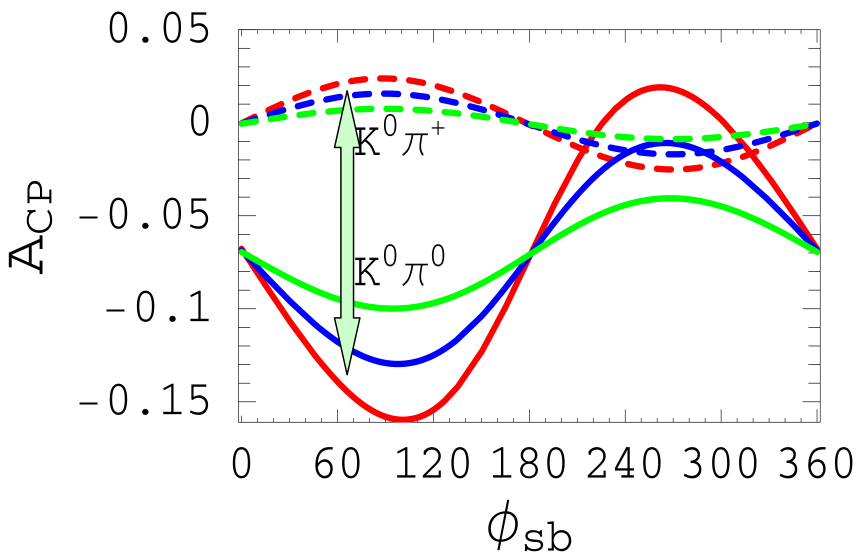
A_{CP} ~ 0 far away

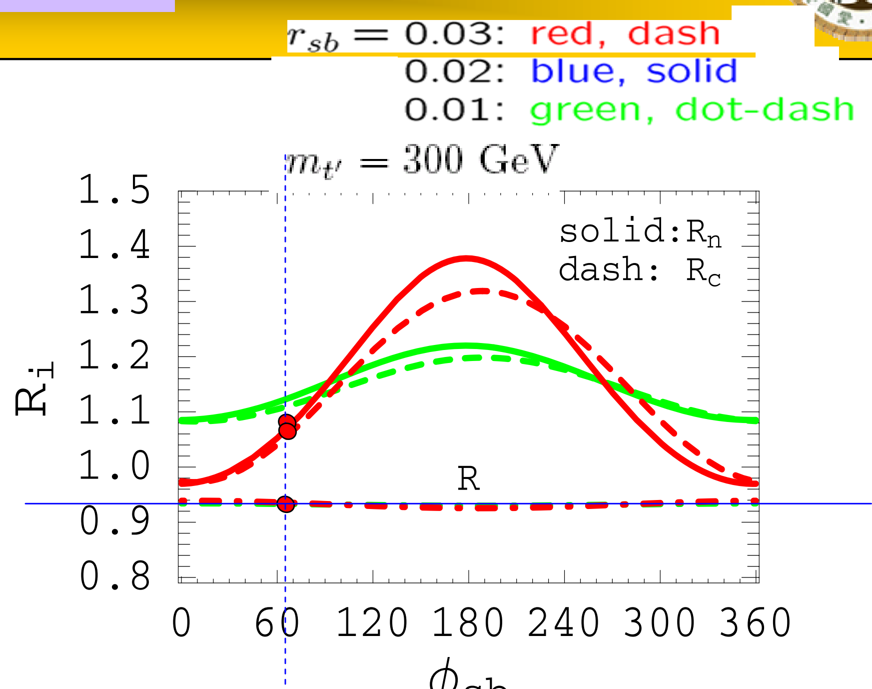
beyond SuperB

Heavy t' effect decoupled for b → sγ



$K^0\pi$ Predictions





ICHEP06: ~ 0 ~ –0.12

$$\mathcal{A}_{K^0\pi^+} - \mathcal{A}_{K^0\pi^0} \approx 14\%$$ ✓

–0.02±0.04 +0.02±0.13 HFAG

(+0.11 ± 0.18 ± 0.08) Belle

$R_c \lesssim R_n \approx 1.08$

$R \approx 0.94$ ✓

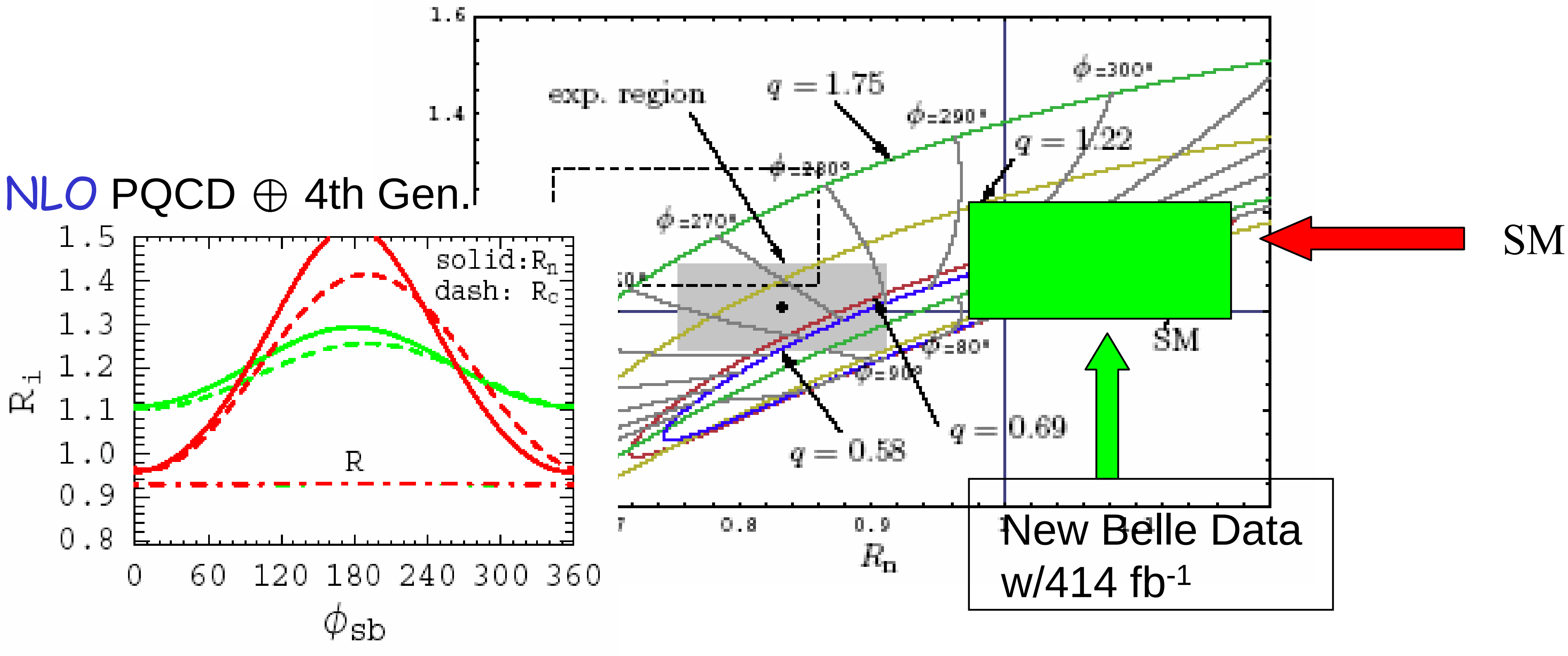
~~Not~~ in good agreement

— Await further test

New Electroweak Penguins in the Ratios R_n and R_c

q: measures the importance of the EW penguins with respect to the tree-diagram-like topologies

ϕ: CP-violating weak phase



Buras, Fleischer et al, APO B36(2005)2015-2050

4 x 4 Unitarity ⇨ Constraints

	d	s	b	b'
u	$c_{12}\,c_{13}\,c_{14}$ $-c_{13}\,s_{12}\,s_{14}\,s_{24}\exp[-i(\phi_{db}-\phi_{sb})]$ $-c_{24}\,s_{13}\,s_{14}\,s_{34}\exp[-i(\phi_{db}+\phi_{ub})]$	$c_{13}\,c_{24}\,s_{12}$ $-s_{13}\,s_{24}\,s_{34}\exp[-i(\phi_{sb}+\phi_{ub})]$	$c_{34}\,s_{13}\exp[-i\phi_{ub}]$ **SM3**	$c_{12}\,c_{13}\,s_{14}\exp[i\phi_{db}]$ $+c_{13}\,c_{14}\,s_{12}\,s_{24}\exp[i\phi_{sb}]$ $+c_{14}\,c_{24}\,s_{13}\,s_{34}\exp[-i\phi_{ub}]$
c	$-c_{14}\,c_{23}\,s_{12}$ $-c_{12}\,c_{14}\,s_{13}\,s_{23}\exp[i\phi_{ub}]$ $-c_{12}\,c_{23}\,s_{14}\,s_{24}\exp[-i(\phi_{db}-\phi_{sb})]$ $+s_{12}\,s_{13}\,s_{14}\,s_{23}\,s_{24}\exp[-i(\phi_{db}-\phi_{sb}-i\phi_{ub})]$ $-c_{13}\,c_{24}\,s_{14}\,s_{23}\,s_{34}\exp[-i\phi_{db}]$	$c_{12}\,c_{23}\,c_{24}$ $-c_{24}\,s_{12}\,s_{13}\,s_{23}\exp[i\phi_{ub}]$ $-c_{13}\,s_{23}\,s_{24}\,s_{34}\exp[-i\phi_{sb}]$	$c_{13}\,c_{34}\,s_{23}$	$-c_{23}\,s_{12}\,s_{14}\exp[i\phi_{db}]$ $-c_{12}\,s_{13}\,s_{14}\,s_{23}\exp[i(\phi_{db}+\phi_{ub})]$ $+c_{12}\,c_{14}\,c_{23}\,s_{24}\exp[i\phi_{sb}]$ $-c_{14}\,s_{12}\,s_{13}\,s_{23}\,s_{24}\exp[i(\phi_{sb}+\phi_{ub})]$ $+c_{13}\,c_{14}\,c_{24}\,s_{23}\,s_{34}$
t	$-c_{12}\,c_{14}\,c_{23}\,s_{13}\exp[i\phi_{ub}]$ $+c_{14}\,s_{12}\,s_{23}$ $+c_{23}\,s_{12}\,s_{13}\,s_{14}\,s_{24}\exp[-i(\phi_{db}-\phi_{sb}-i\phi_{ub})]$ $+c_{12}\,s_{14}\,s_{23}\,s_{24}\exp[-i(\phi_{db}-\phi_{sb})]$ $-c_{13}\,c_{23}\,c_{24}\,s_{14}\,s_{34}\exp[-i\phi_{db}]$	$-c_{23}\,c_{24}\,s_{12}\,s_{13}\exp[i\phi_{ub}]$ $-c_{12}\,c_{24}\,s_{23}$ $-c_{13}\,c_{23}\,s_{24}\,s_{34}\exp[i\phi_{sb}]$	$c_{13}\,c_{23}\,c_{34}$	$-c_{12}\,c_{23}\,s_{13}\,s_{14}\exp[i(\phi_{db}+\phi_{ub})]$ $+s_{12}\,s_{14}\,s_{23}\exp[i\phi_{db}]$ $-c_{14}\,c_{23}\,s_{12}\,s_{13}\,s_{24}\exp[i(\phi_{sb}+\phi_{ub})]$ $-c_{12}\,c_{14}\,s_{23}\,s_{24}\exp[i\phi_{sb}]$ $+c_{13}\,c_{14}\,c_{23}\,c_{24}\,s_{34}$
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

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

$\equiv r_{ds}$ ϕ_{ds}

Kaon

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

b → s $\equiv r_{sb}$

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

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 $s \leftrightarrow d$ from K Physics

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

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

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

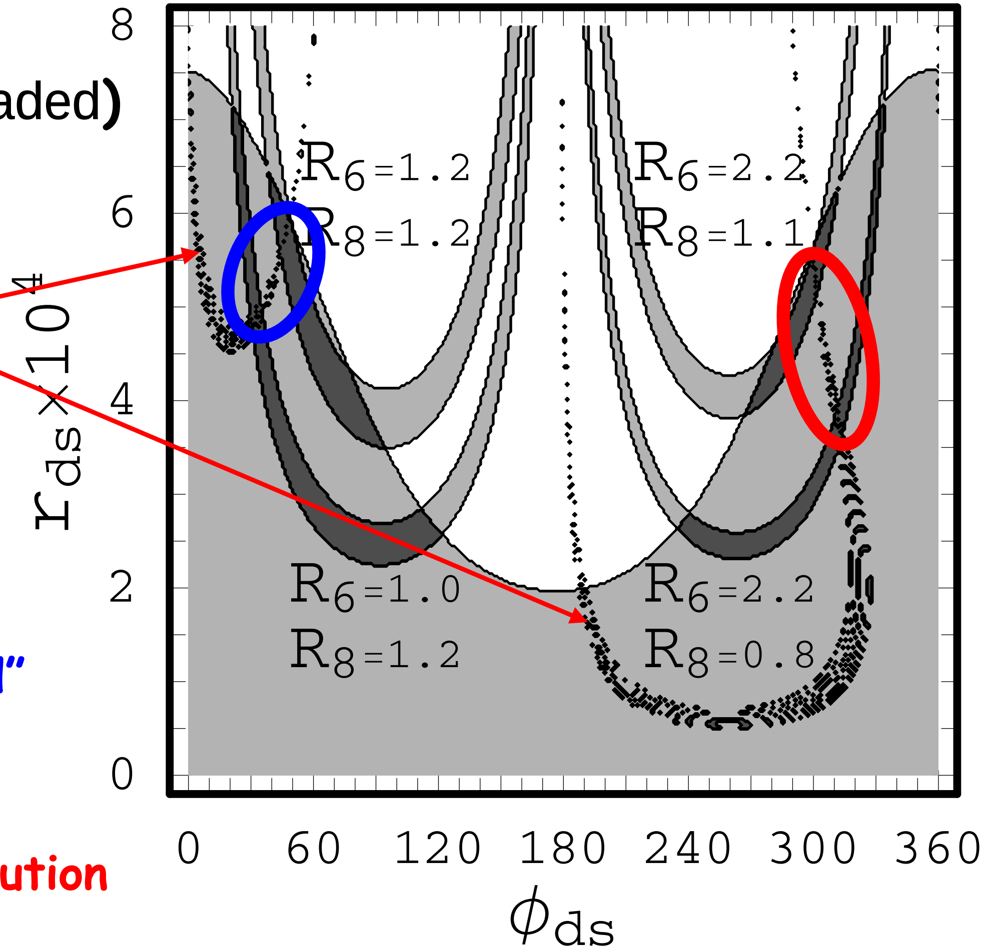
$\frac{\epsilon'}{\epsilon} = (16.6 \pm 2 \times 1.6) \cdot 10^{-4}$

$R_6 = 1.2$ **(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….

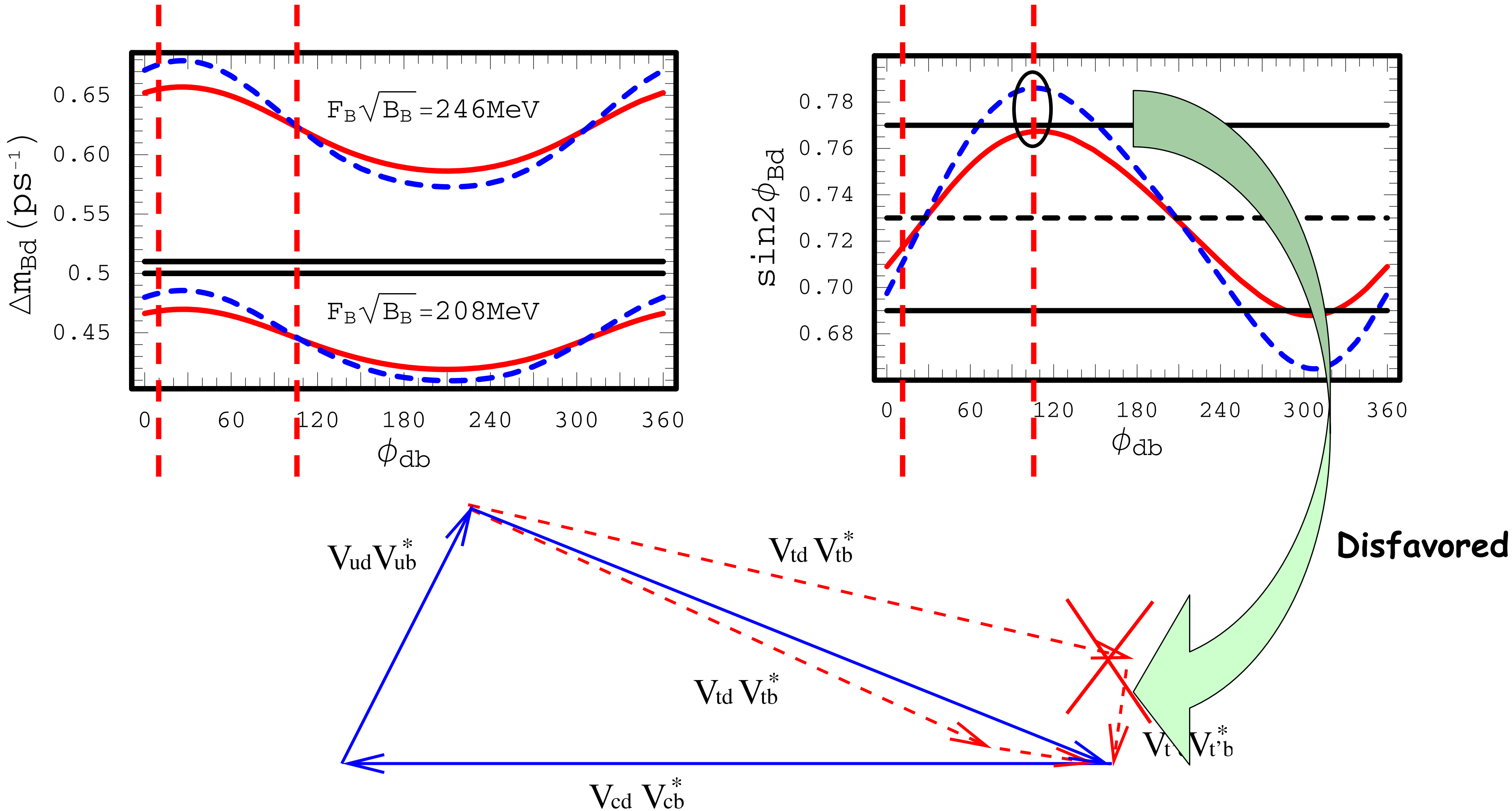
$$r_{ds} \sim 5 \times 10^{-4}, \quad \phi_{ds} \sim -60^\circ \text{ or } +35^\circ$$

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 $V_{ub} \sim 0.01\, e^{-i\gamma}$



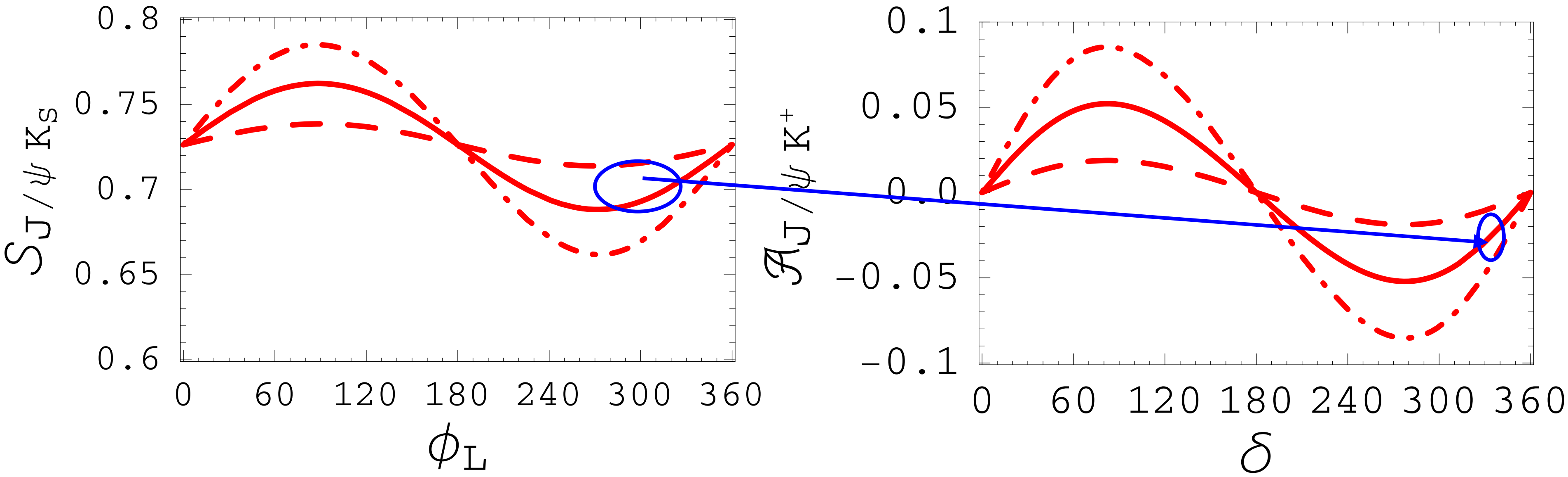
Hard to tell apart (non-trivial) with present precision

$\because$ stringent s $\to$ d

$\mathcal{A}_{J/\psi K^+} \neq 0$? Mechanism Generic

e.g. Z' model of **Barger, Chiang, Langacker, Lee, PLB'04**

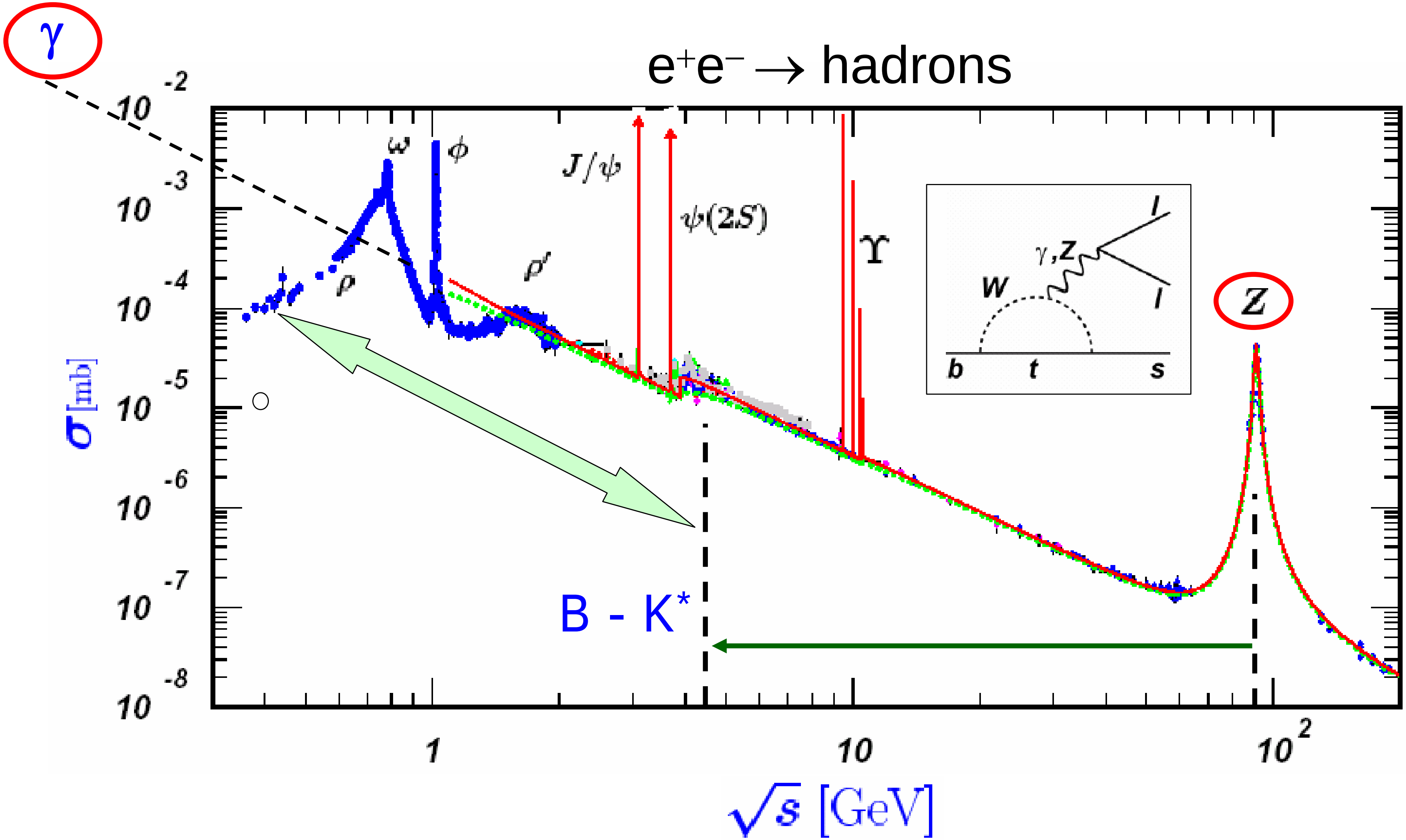
Less constrained !



$\mathcal{A}_{J/\psi K^+}$ **~ few % possible**

A_{FB} in $B \to K^* \ell^+ \ell^-$ made easy

γ - Z interference with M_Z brought low !



Quark level *Quantum* amplitude:

Real by convention

$$C_9^{eff} = C_9 + Y(s)$$

$$\mathcal{M}_{b\to s\ell^+\ell^-} = -\frac{G_F\alpha}{\sqrt{2}\pi} V_{cs}^* V_{cb} \left\{ C_9^{\rm eff} \, [\bar{s}\gamma_\mu L b] \, [\bar{\ell}\gamma^\mu \ell] + C_{10} \, [\bar{s}\gamma_\mu L b] \, [\bar{\ell}\gamma^\mu \gamma_5 \ell] - 2\frac{\hat{m}_b}{\hat{s}} C_7^{\rm eff} \, [\bar{s}\, i\sigma_{\mu\nu}\hat{q}^\nu R b] \, [\bar{\ell}\gamma^\mu \ell] \right\}$$

$$\hat{s} = s/m_B^2$$

$$C_7^{eff} = \xi_7 C_7 + \xi_8 C_8 + \sum_{j\neq 7,8} \xi_j C_j$$

No Reason *a priori* why C_7, C_9, C_{10} should be Real

To be Probed BY EXPERIMENT

Parameterization at weak scale

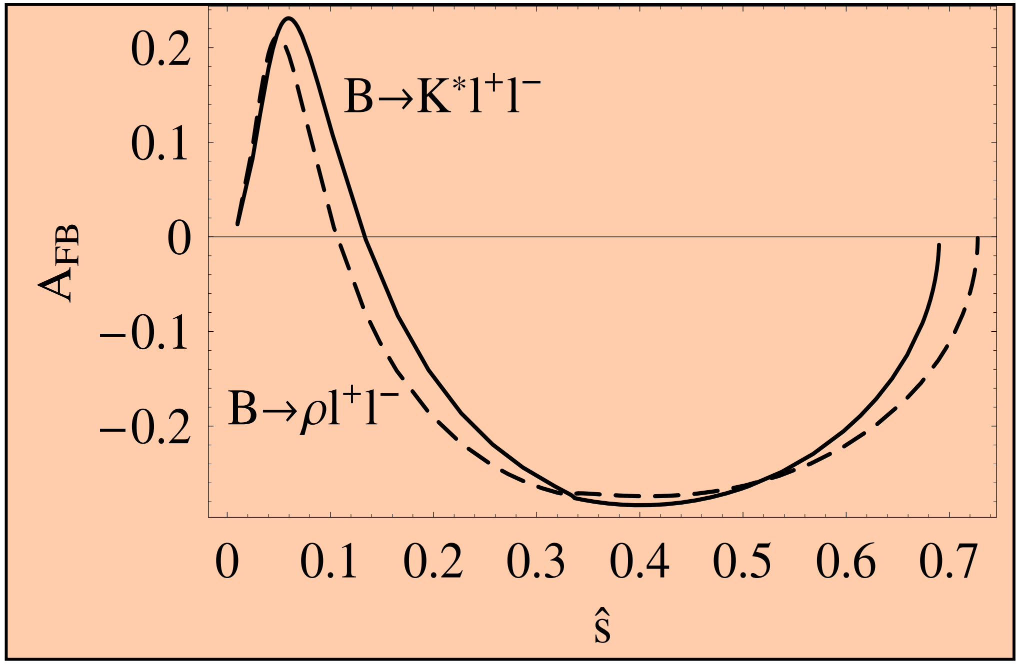
$$
\begin{aligned}
C_7(M_W) &= C_7^{\rm SM}(M_W)\,(1+\Delta_7\, e^{i\phi_7}) \\
C_9(M_W) &= C_9^{\rm SM}(M_W)\,(1+\Delta_9\, e^{i\phi_9}) \\
C_{10}(M_W) &= C_{10}^{\rm SM}(M_W)\,(1+\Delta_{10}\, e^{i\phi_{10}})
\end{aligned}
$$

Such an introduction of complexity is beyond MFV and may look very outrageous at first glance, though not impossible, e.g. in generic Z' models or more than 3 generations

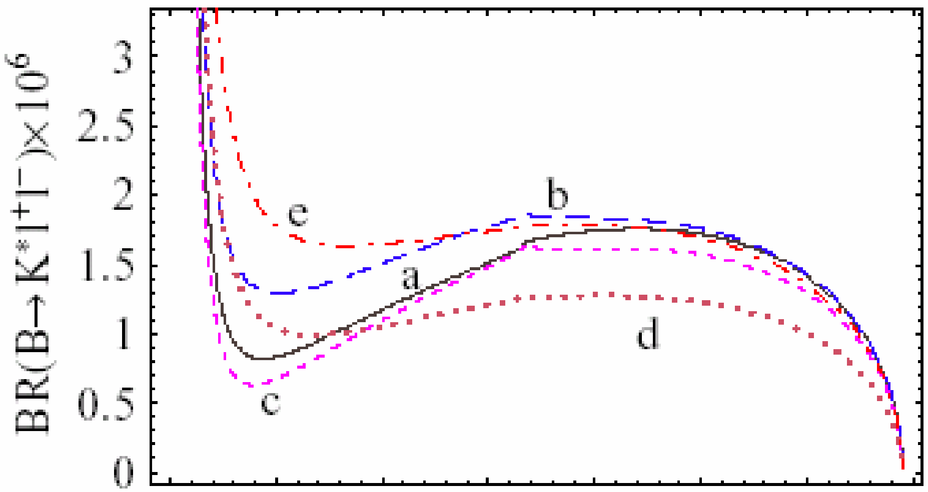
N.B. Wilson coeffs. becoming complex is already present in SM (not via New Phys corrections)

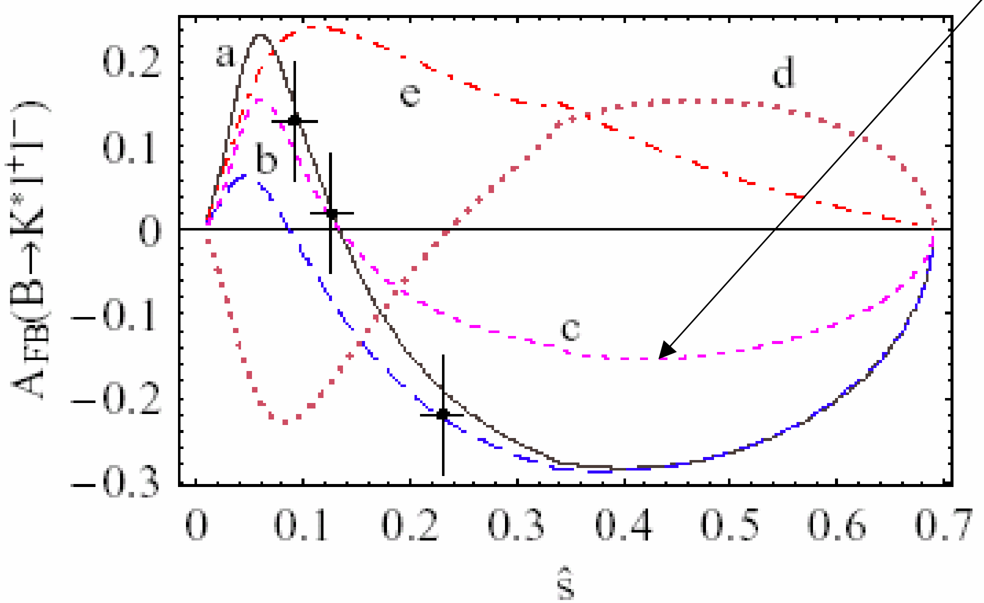
$$B \to \rho\lambda^+\lambda^- : \; V_{ud}^* V_{ub} \approx V_{td}^* V_{tb}$$

$$\Rightarrow \quad C_9 \to C_9 + \lambda_u \#$$



General: Both Zero & Shape Sensitive to NP



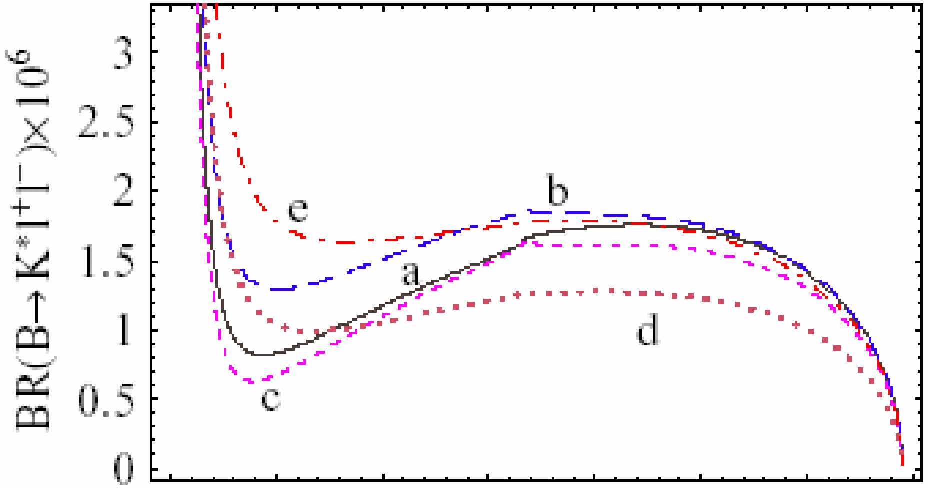


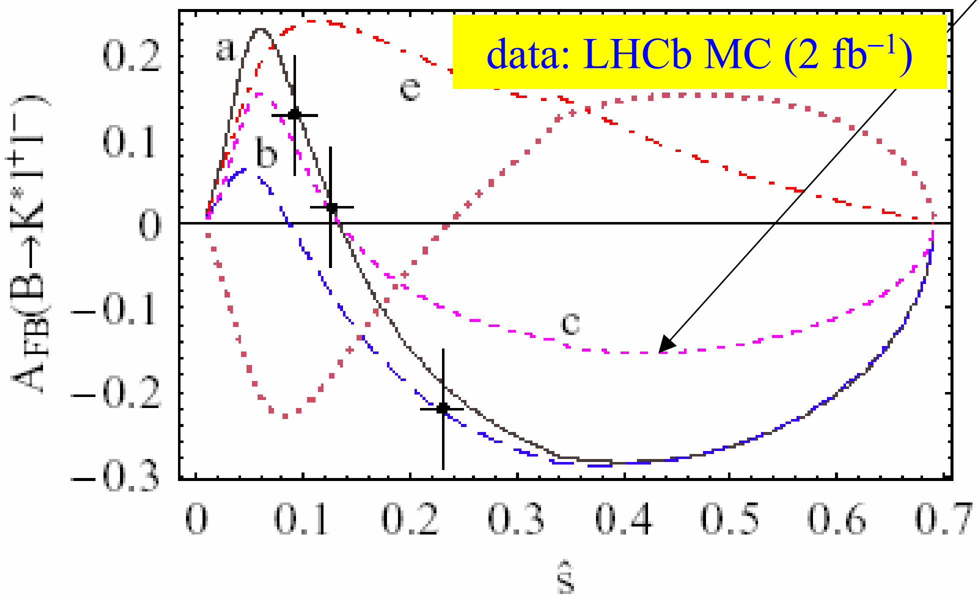
a: SM
b: 4 gen.
d: ruled out
e: disfavoured

c: ~ SM, even the zero, different for large q^2

Case	Δ_7	Δ_9	Δ_{10}	ϕ_7	ϕ_9	ϕ_{10}	$A_{CP}(b \to s\gamma)$
b	−0.2	−0.9	−0.9	65°	65°	65°	2%
c	−0.5	1	−0.5	90°	270°	0	5%
d	0	−1.5	−2.0	0	35°	0	–
e	−4.8	−1.2	−2.2	0	0	0	–

General: Both Zero & Shape Sensitive to NP





a: SM
b: 4 gen.
d: ruled out
e: disfavoured

$$C_7(M_W) = C_7^{\rm SM}(M_W)\left(1+\Delta_7 e^{i\phi_7}\right)$$
$$C_9(M_W) = C_9^{\rm SM}(M_W)\left(1+\Delta_9 e^{i\phi_9}\right)$$
$$C_{10}(M_W) = C_{10}^{\rm SM}(M_W)\left(1+\Delta_{10} e^{i\phi_{10}}\right)$$

c: ~ SM, even the zero,
different for large q^2

$b \to s\gamma$ DCPV can be tested at SuperB

Case	Δ_7	Δ_9	Δ_{10}	ϕ_7	ϕ_9	ϕ_{10}	$A_{CP}(b\to s\gamma)$
b	−0.2	−0.9	−0.9	65°	65°	65°	2%
c	−0.5	1	−0.5	90°	270°	0	5%
d	0	−1.5	−2.0	0	35°	0	–
e	−4.8	−1.2	−2.2	0	0	0	–

Early LHCb Data Can Tell

$$\mathcal{M}_{\rm new} = \frac{G_F\alpha}{\sqrt{2}\pi} V_{ts}^* V_{tb} [C_{LL}\ \bar{s}_L\gamma_\mu b_L\ \bar{l}_L\gamma^\mu l_L$$
$$+ C_{LR}\ \bar{s}_L\gamma_\mu b_L\ \bar{l}_R\gamma^\mu l_R + C_{RL}\ \bar{s}_R\gamma_\mu b_R\ \bar{l}_L\gamma^\mu l_L$$
$$+ C_{RR}\ \bar{s}_R\gamma_\mu b_R\ \bar{l}_R\gamma^\mu l_R + C_{LRLR}\ \bar{s}_L b_R\ \bar{l}_L l_R$$
$$+ C_{RLLR}\ \bar{s}_R b_L\ \bar{l}_L l_R + C_{LRRL}\ \bar{s}_L b_R\ \bar{l}_R l_L$$
$$+ C_{RLRL}\ \bar{s}_R b_L\ \bar{l}_R l_L + C_T\ \bar{s}\sigma_{\mu\nu} b\ \bar{l}\sigma^{\mu\nu} l$$
$$+ iC_{TE}\ \bar{s}\sigma_{\mu\nu} b\ \bar{l}\sigma_{\alpha\beta} l\ \epsilon^{\mu\nu\alpha\beta}]$$

In general 10 operators

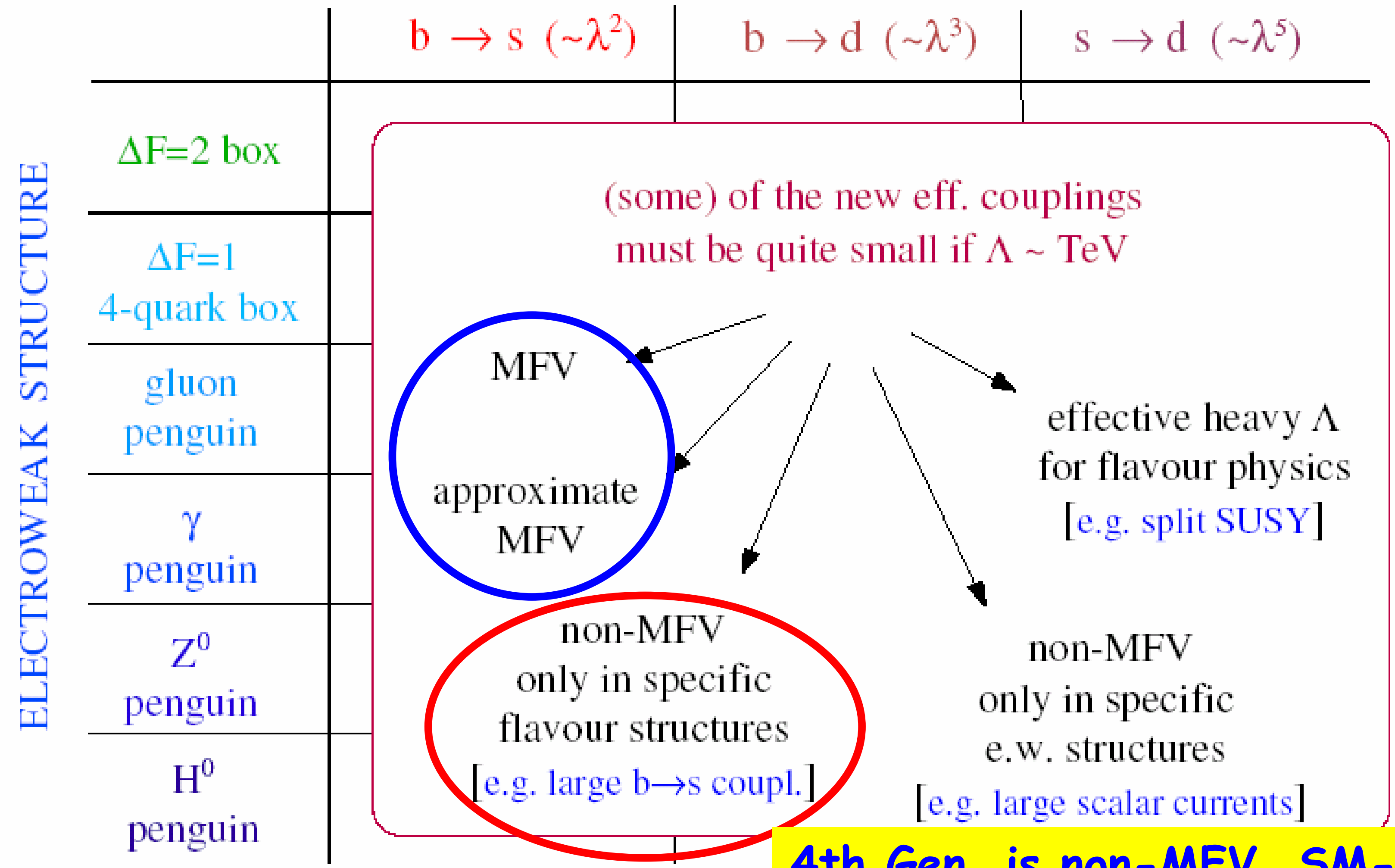
⇨ 20 parameters

Impractical for early fit;
Other measurables sought
(K* pol.)

$$\frac{d\mathcal{A}}{ds} = \frac{1}{2m_b^8}\mathcal{B}_0(A_3(s,1)\ \{|(C_9^{\rm eff} - C_{10})|^2 - |(C_9^{\rm eff} + C_{10})|^2\}$$
$$+ A_5(s,1)\ \{2{\rm Re}[-2C_7(C_9^{\rm eff*} - C_{10}^*)] - 2{\rm Re}[-2C_7(C_9^{\rm eff*} + C_{10}^*)]\}$$
$$+ A_3(s,1)\ \{2{\rm Re}[(C_9^{\rm eff} - C_{10})C_{LL}^*] - 2{\rm Re}[(C_9^{\rm eff} + C_{10})C_{LR}^*]\}$$
$$+ A_5(s,1)\ \{2{\rm Re}[-2C_7(C_{LL}^* - C_{LR}^*)]\}$$
$$+ A_7(s,1)\ \{2{\rm Re}[-2C_7(C_{RL}^* - C_{RR}^*)]\}$$
$$+ A_3(s,1)\ \{|C_{LL}|^2 - |C_{LR}|^2 - |C_{RL}|^2 + |C_{RR}|^2\}$$
$$+ A_3(s,1)\ \{-4{\rm Re}[C_{LRLR}(C_T^* - 2C_{TE}^*) + C_{RLRL}(C_T^* + 2C_{TE}^*)]\})$$

G. Isidori – *Rare K decays within & beyond the SM* KEKTC6 – Feb 2007

Our present knowledge is too limited to draw definite conclusions: only with the help of both high- and low-energy experiments we can hope to solve the puzzle...



4th Gen. is non-MFV, SM-like

Minimal Flavor Violation

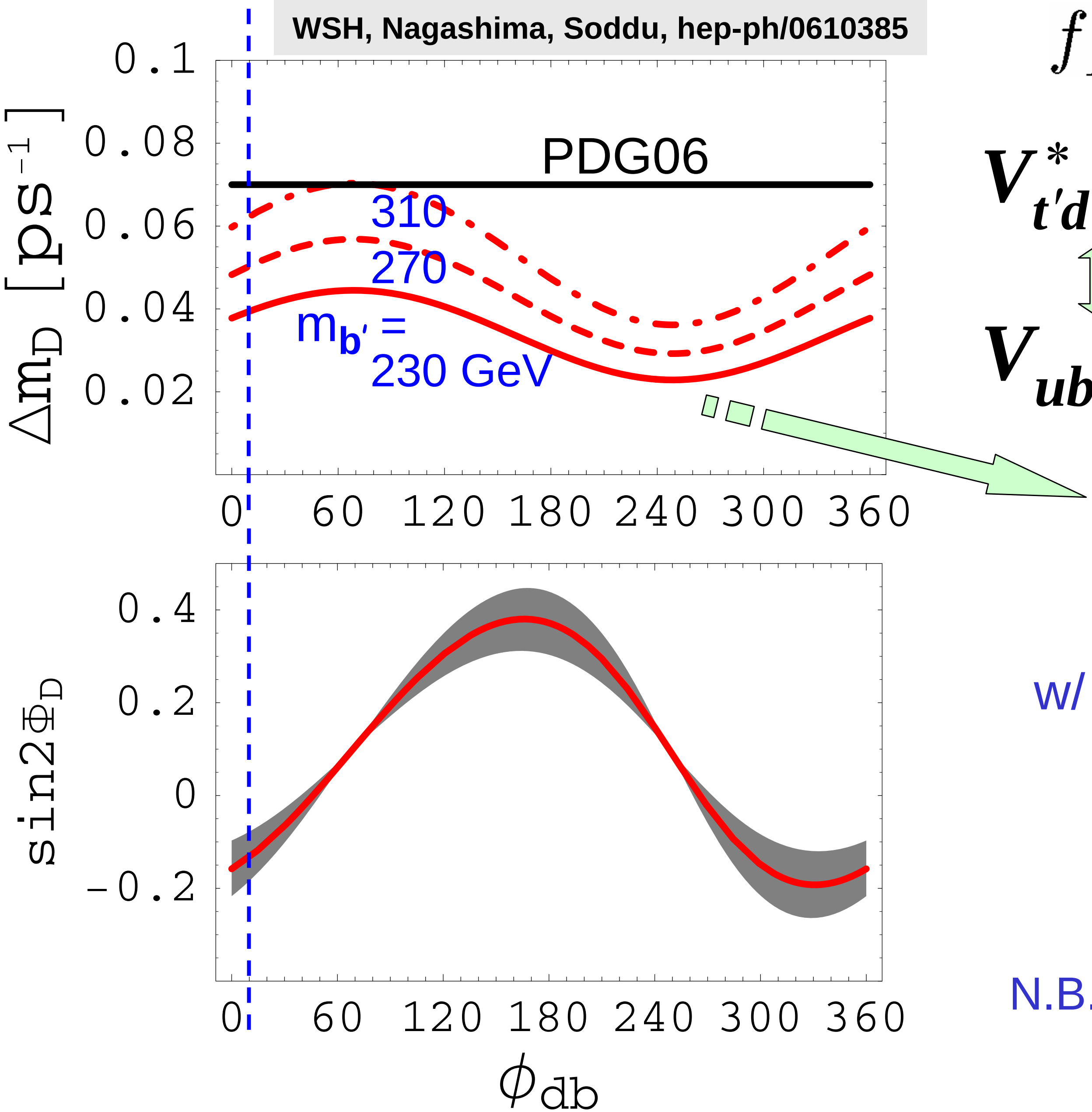
- Def MFV: New physics has exactly the same CKM structure as SM
  - Thus no effects will be seen in CPV
  - An example of such a model is the Universal Extra Dimensions model of Appelquist, Cheng & Dobrescu
- However, effects WILL be seen in the modification of decay rates
- MFV is not so much a model as a declaration. Lets ignore this paradigm for now and look at two examples of B decay processes

4th Generation the epitome

Flavour in the Era of the LHC, March, 2007 6

Sheldon Stone

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

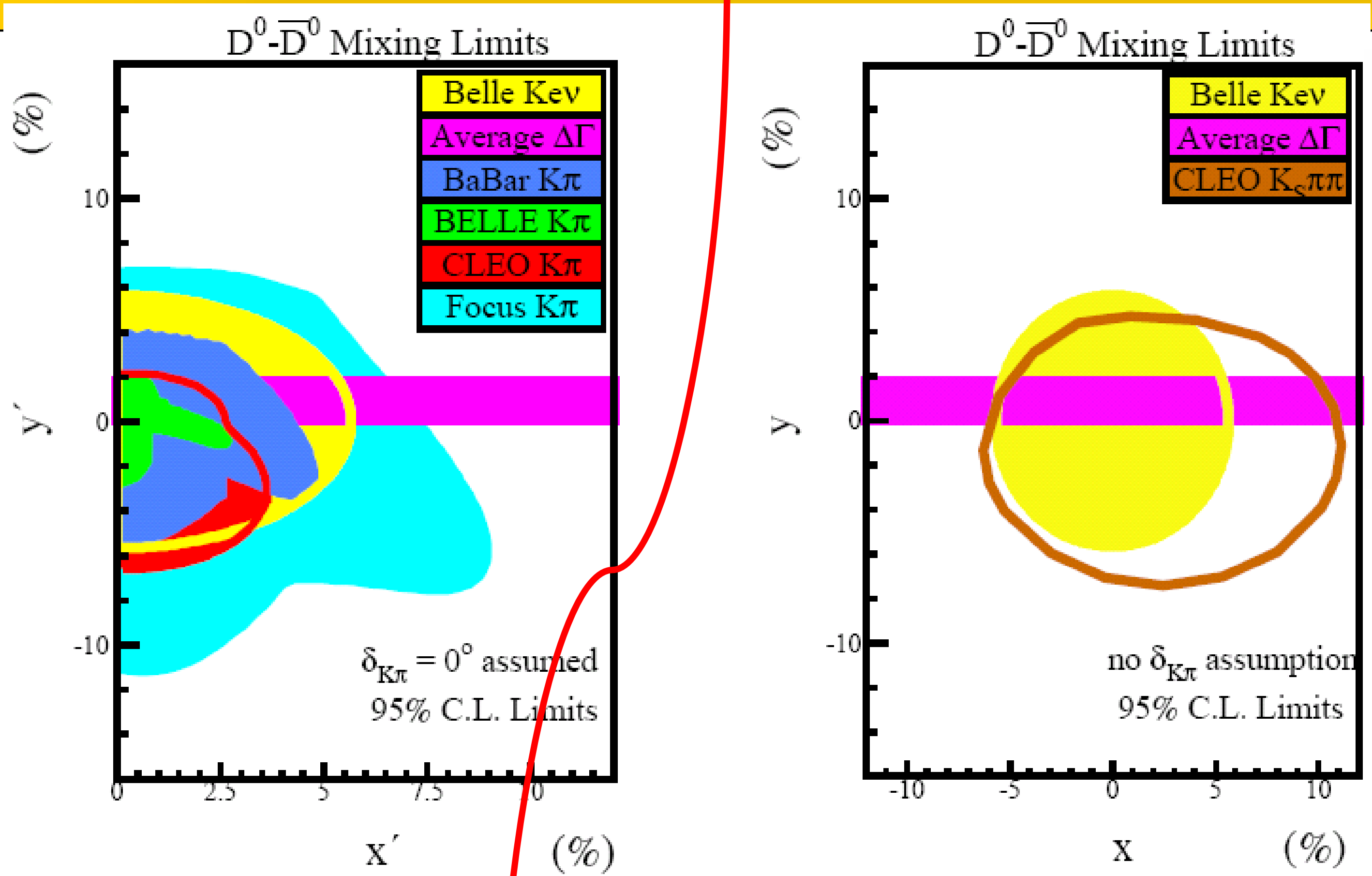
$$V_{ub'}V^*_{cb'}$$

x = Δm/Γ ~ 1 - 3 plausible

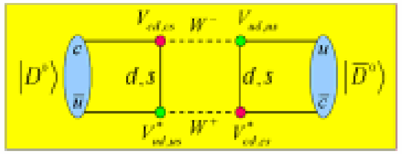
w/ Sizable (but not huge)
CPV in Mixing ~ –15%

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

Data (PDG06)

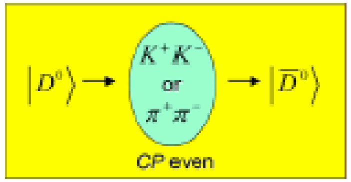


x mixing: Channel for New Physics.



$$x = \frac{\Delta M}{\Gamma}$$

y (long-range) mixing: SM background.



$$y = \frac{\Delta\Gamma}{2\Gamma}$$

- Hint for D mixing
- No evidence for CPV

Need more data !

Promising !

measurements. The average of the six y_{CP} measurements is $0.90 \pm 0.42\,\%$.

Real interest is x (probe New Physics)