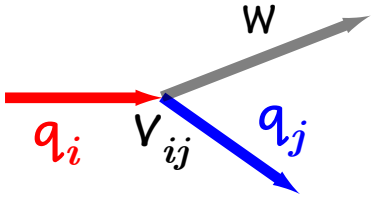
Searching for Physics Beyond the Standard Model in Precision CKM Measurements at the B-factories

Outline

- Introduction
- $b \to c\bar{c}d$
- $b \to s$ penguin
- ϕ_2 measurements
- Super B Factories
- Summary

Takanori Hara (KEK)
for Belle collaboration

Cabibbo-Kobayashi-Maskawa Matrix

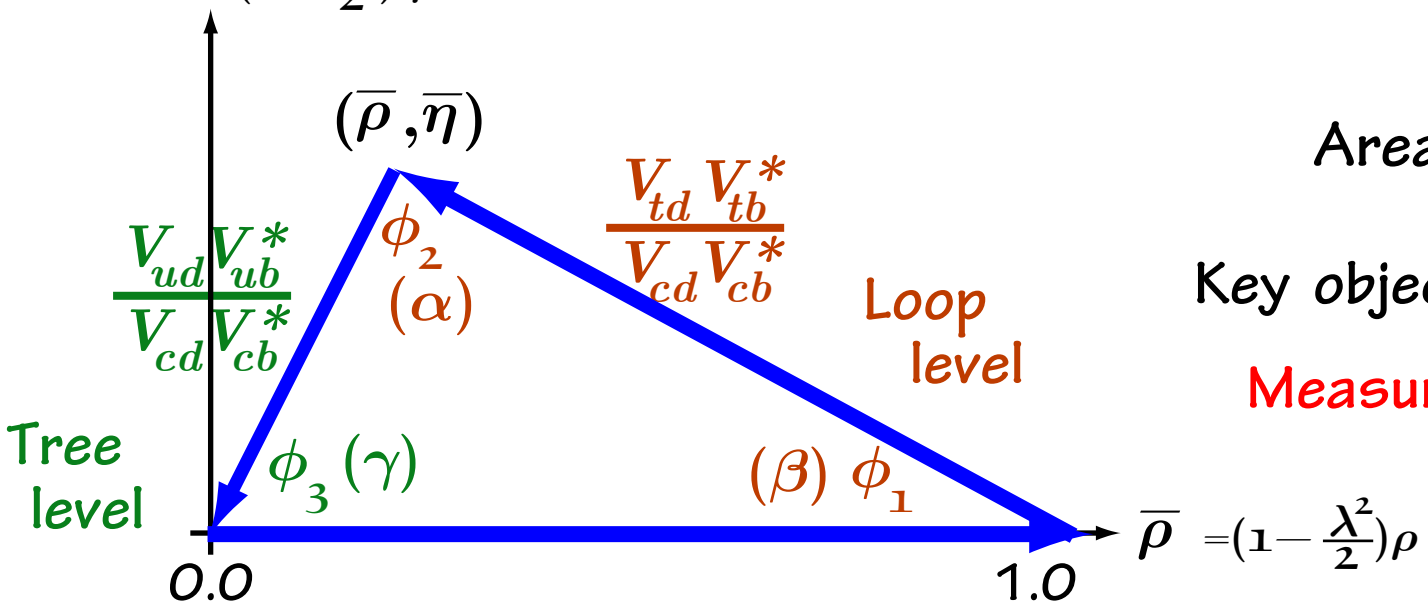


$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix}$$

Wolfenstein Parameterization

3 real parameters
+ 1 irreducible complex phase

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



Area ≠ 0 implies ~~CP~~

Key objective of B-factories :

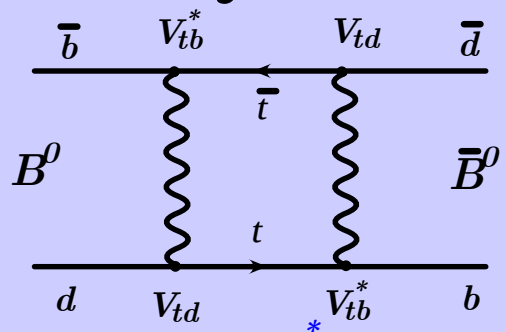
Measurement of the { 3 sides / 3 angles

Time-dependent CP asymmetry

Interference between $B^0 \to f_{cp}$ and $B^0 \to \bar{B}^0 \to f_{cp}$ leads to $\sin 2\phi_1$

B^0

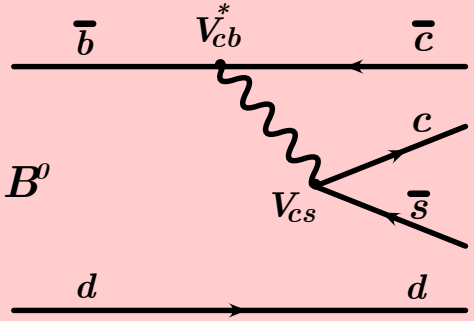
$B^0\bar{B}^0$ mixing



$$\frac{q}{p} \propto \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

+

Tree decay



$A \propto V_{cb}^* V_{cs}$

$$\mathcal{A}(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \to f_{cp}) - \Gamma(B^0(\Delta t) \to f_{cp})}{\Gamma(\bar{B}^0(\Delta t) \to f_{cp}) + \Gamma(B^0(\Delta t) \to f_{cp})}$$

$$= \underbrace{\frac{2Im\lambda}{1+|\lambda|^2}}_{\mathcal{S}} \sin(\Delta m \cdot \Delta t) - \underbrace{\frac{1-|\lambda|^2}{1+|\lambda|^2}}_{\mathcal{A}} \cos(\Delta m \cdot \Delta t)$$

Mixing-induced CPV Direct CPV

$$\lambda = \frac{q}{p} \frac{A(\bar{B}^0 \to f)}{A(B^0 \to f)}$$

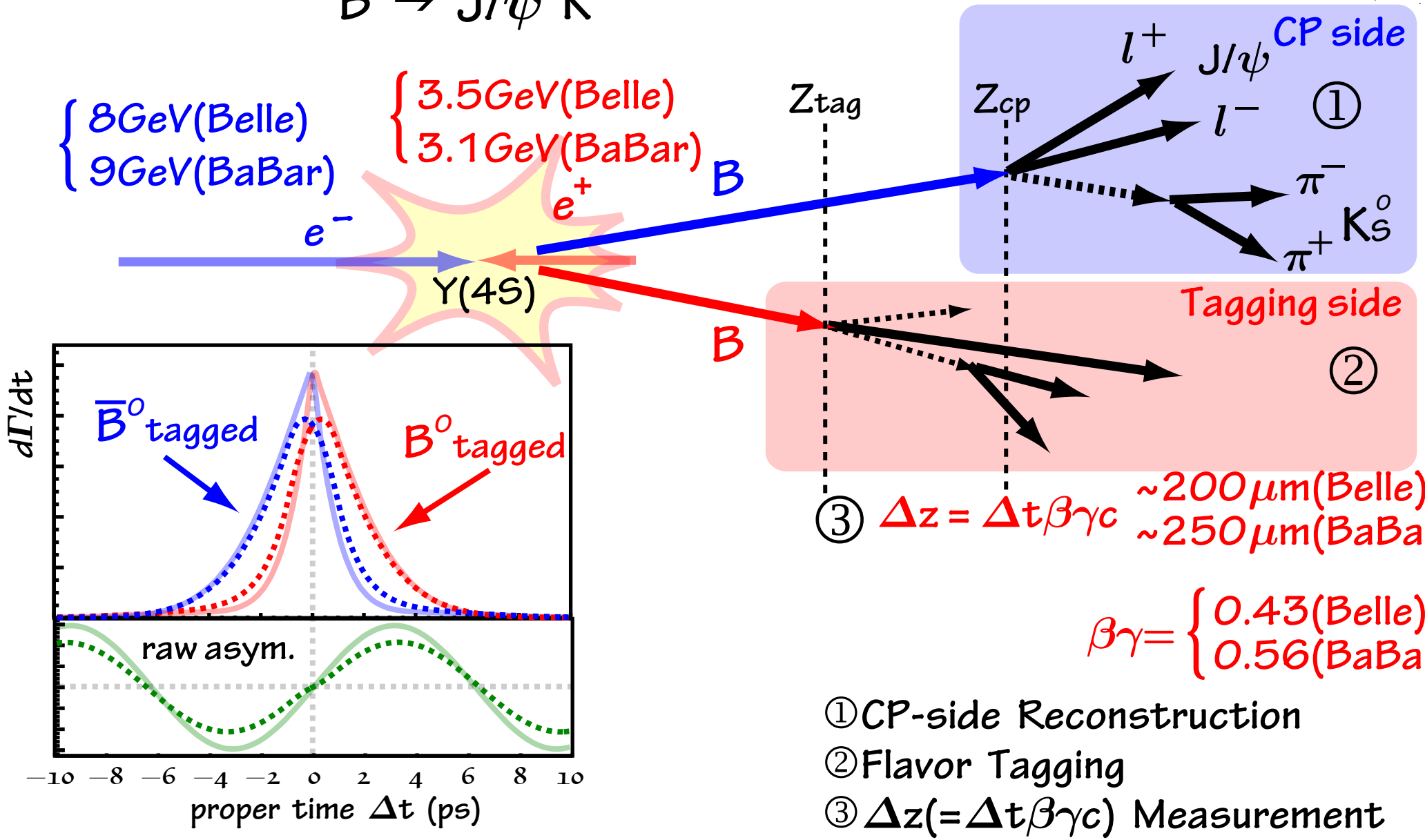
$$\lambda = \frac{q}{p} \frac{\bar{A}}{A} = \eta_{cp} e^{-i2\phi_1} \to \begin{matrix} \mathcal{S} = -\eta_{cp} \sin 2\phi_1 \\ \mathcal{A} = 0 \end{matrix}$$

$$\mathcal{A}(\Delta t) = -\eta_{cp} \sin 2\phi_1 \sin(\Delta m \cdot \Delta t)$$

η_{cp} : CP eigenvalue

Measurement of sin2ϕ_1

$B \rightarrow J/\psi\ K^0$

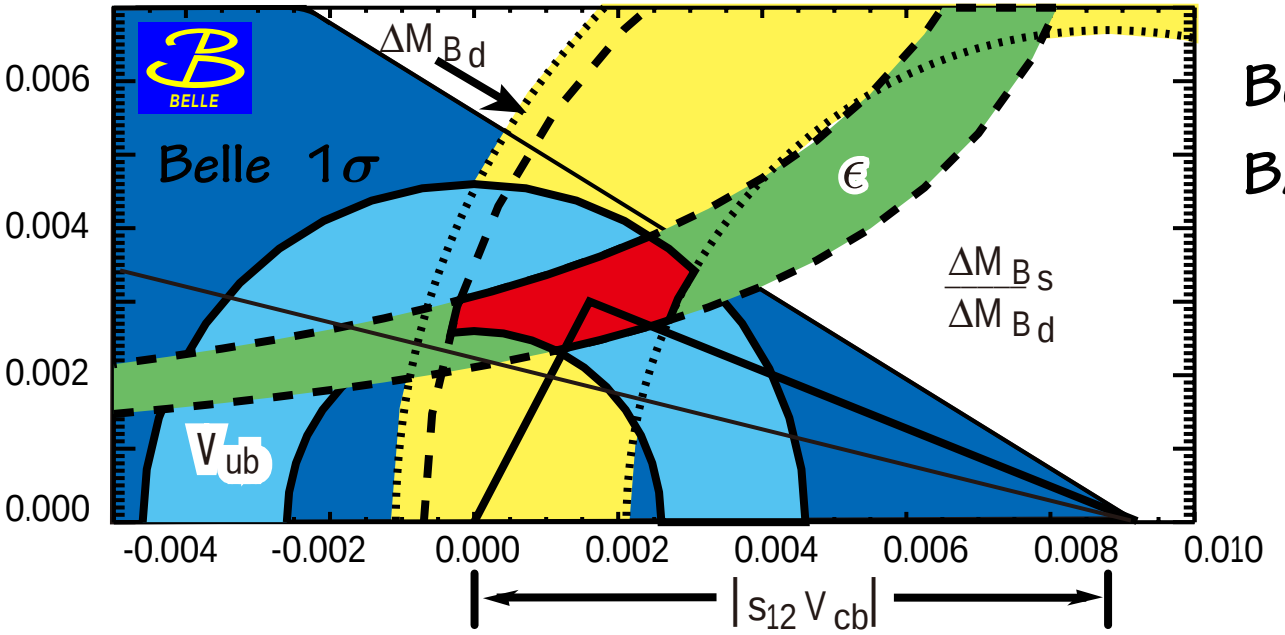


①CP-side Reconstruction
②Flavor Tagging
③$\Delta z(=\Delta t\beta\gamma c)$ Measurement

Back to 2000

B-Factories (BABAR/PEP-II, Belle/KEKB) started taking data from 1999

To confirm the large *CP* violation in B meson system as predicted in Kabayashi-Maskawa theory.



$\sin 2\phi_1 (=\sin 2\beta)$

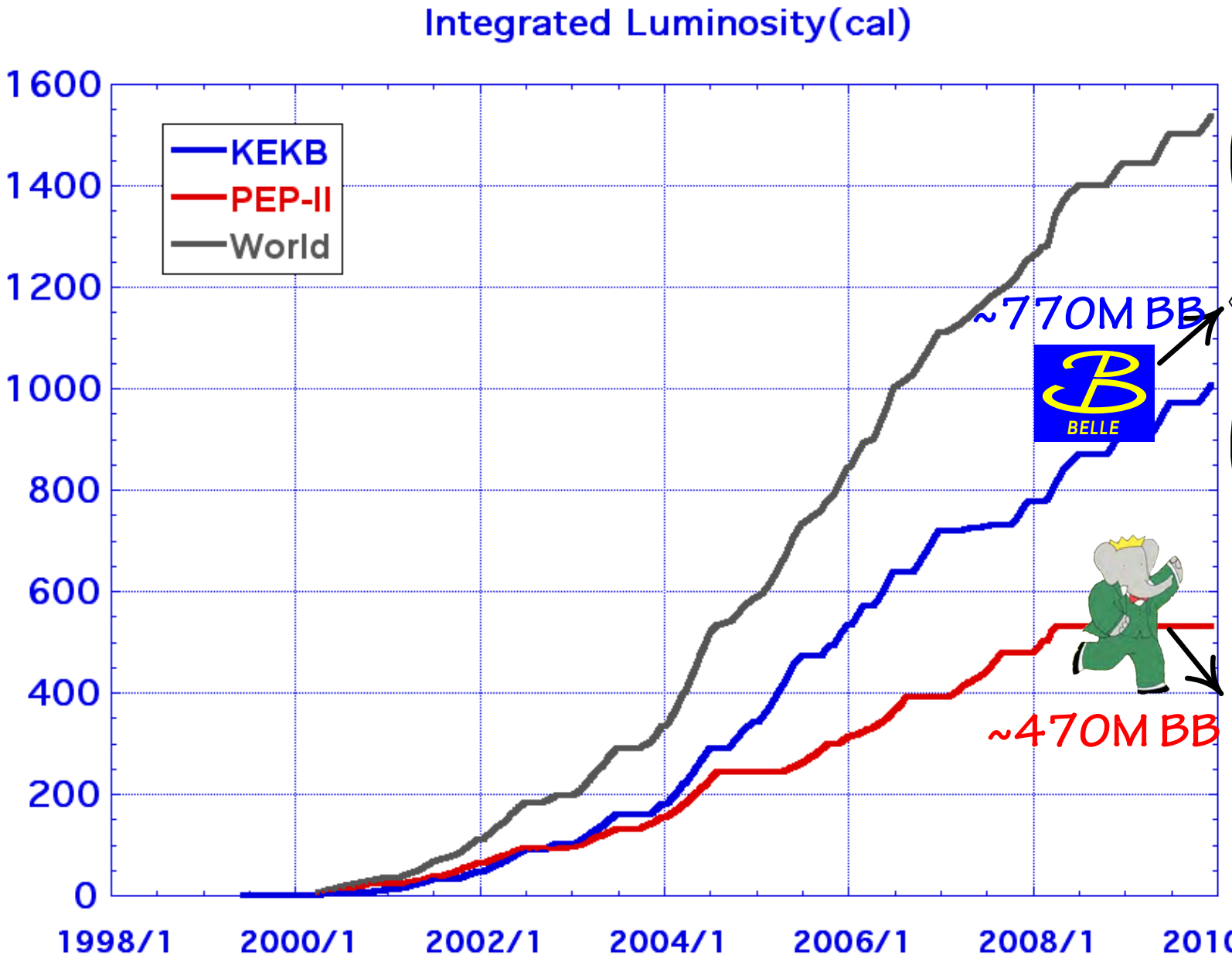
Belle (6 /fb) : $0.45^{+0.43}_{-0.44}{}^{+0.07}_{-0.09}$

BABAR (9 /fb) : $0.12 \pm 0.37 \pm 0.09$

$\phi_2 (=\alpha)$, $\phi_3 (=\gamma)$:

not measured

Luminosity at B factories



> 1.0 ab^{-1}

Y(1S) : 6 fb^{-1}
Y(2S) : 24 fb^{-1}
Y(3S) : 3 fb^{-1}
Y(4S) : 711 fb^{-1}
Y(5S) : 121 fb^{-1}
off-reso. : 87 fb^{-1}

0.553 ab^{-1}

Y(2S) : 14 fb^{-1}
Y(3S) : 30 fb^{-1}
Y(4S) : 433 fb^{-1}
off-reso. : 54 fb^{-1}

Now...

B-Factories have confirmed the large CP violation

in particular, $B \to c\bar{c}K^0$ modes : $\sin 2\phi_1 = 0.672 \pm 0.023$

high precision!

Now, the reference for the new physics search

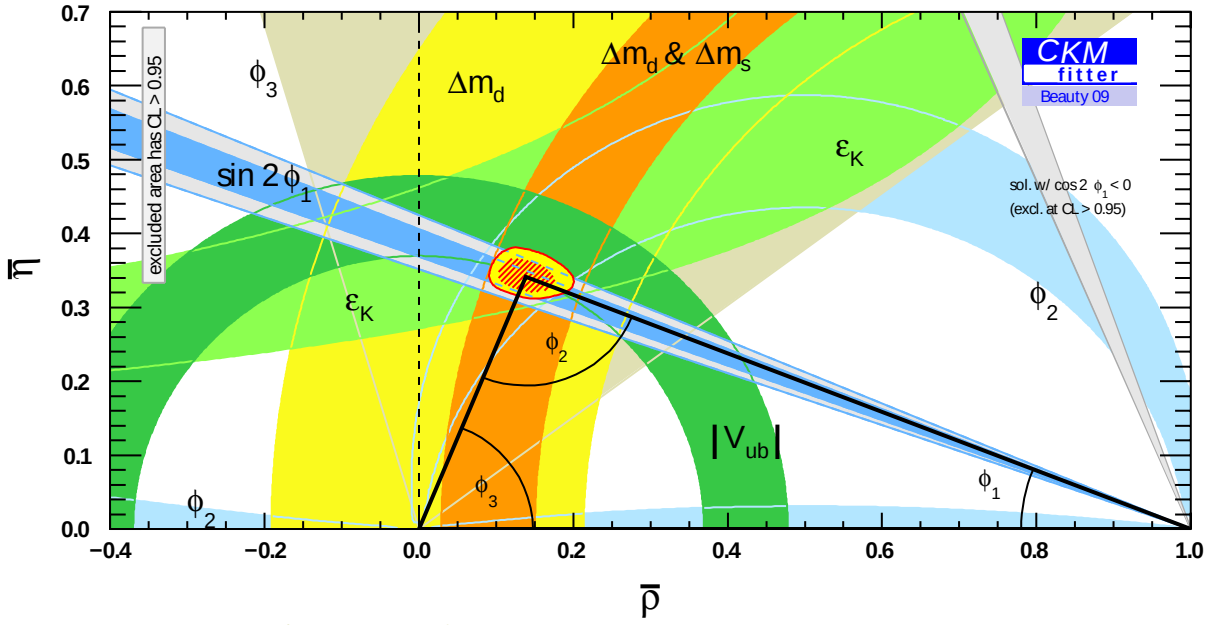
http://ckmfitter.in2p3.fr/

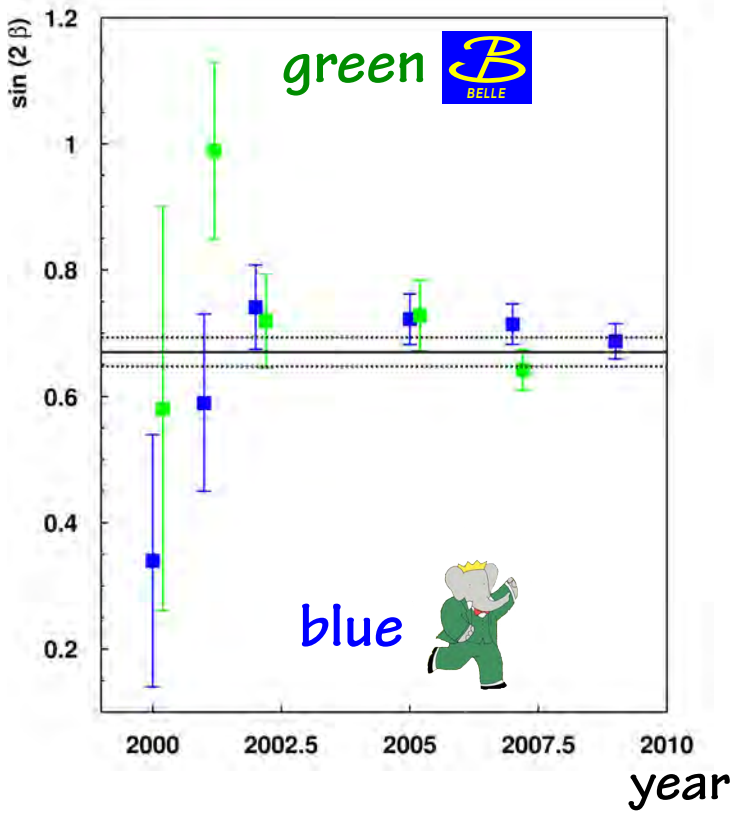
O.Long @ Moriond, EW, 2010

$$\phi_1 = 21.15^{+0.90}_{-0.88}{}^\circ$$

$$\phi_2 = 89.0^{+4.4}_{-4.2}{}^\circ$$

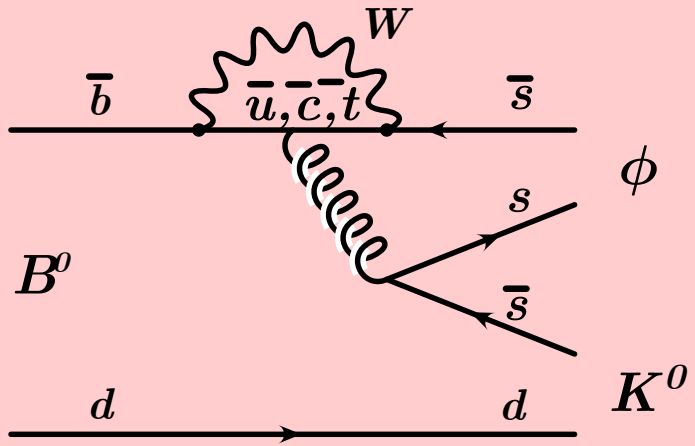
$$\phi_3 = 69^{+19}_{-21}{}^\circ$$





New Phsyics in penguin decay

penguin decay

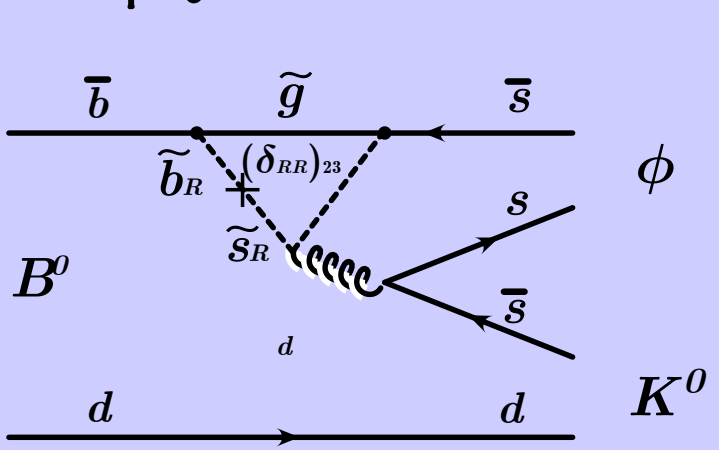


$$A \propto V_{cb}^{*}V_{cs}(P^{c}\text{-}P^{t}) + V_{ub}^{*}V_{us}(P^{u}\text{-}P^{t})$$

$$V_{cb}^{*}V_{cs}(P^{c}\text{-}P^{t}) \propto \lambda^{2}$$
$$V_{ub}^{*}V_{us}(P^{u}\text{-}P^{t}) \propto \lambda^{4}(\rho - i\eta)$$

$$\rightarrow \mathcal{A}(\Delta t) = -\eta_{cp}\sin 2\phi_{1}\ \sin(\Delta m \cdot \Delta t)$$

New physics



$$= -\eta_{cp}\sin 2(\phi_{1} + \phi_{NP})\ \sin(\Delta m \cdot \Delta t)$$

b → d penguin

$J/\psi\ \pi^{0}$, $D^{+}D^{-}$, $D^{*+}D^{*-}$

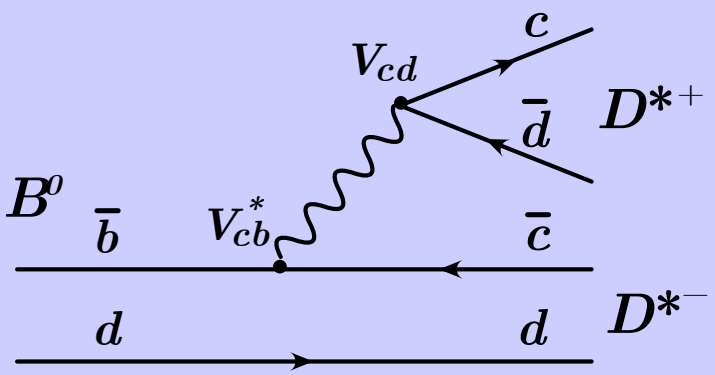
b → s penguin

ϕK^{0}, $\eta' K^{0}$, $K_{S}K_{S}K_{S}$,
$\pi^{0}K^{0}$, $\rho^{0}K_{S}$, ωK_{S}, $f_{0,1,x}K_{S}$,
$\pi^{+}\pi^{-}K_{S}$, $K^{+}K^{-}K^{0}$

NP

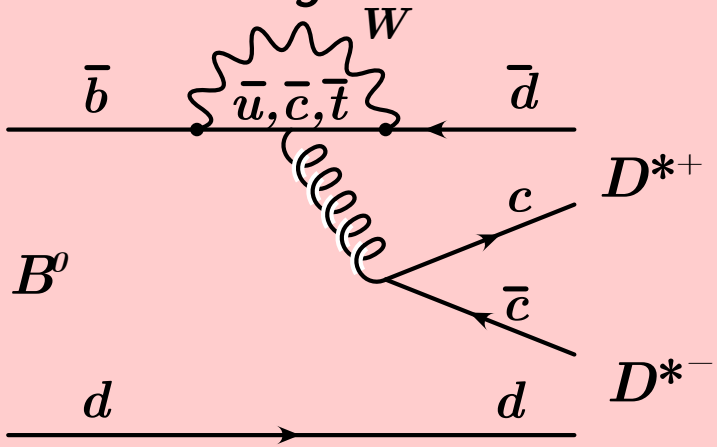
$D^{*+}D^{*-}$: $b \to c\bar{c}d$

Tree



$V_{cb}^* V_{cd}\, T$

Gluonic Penguin



$V_{cb}^* V_{cd}\,(P^c\text{-}P^u)$
$+V_{tb}^* V_{td}\,(P^t\text{-}P^u)$

no significant penguin amplitude

(=Same as $b \to c\bar{c}s$ CPV phase)

$J/\psi\ \pi^0$, D^+D^- , $D^{*+}D^{*-}$

$\mathcal{S} = -\sin 2\phi_1$
$\mathcal{C}(= -\mathcal{A}) = 0$

But if not, or NP

$\mathcal{S} \neq -\sin 2\phi_1$
$\mathcal{C}(= -\mathcal{A}) \neq 0$

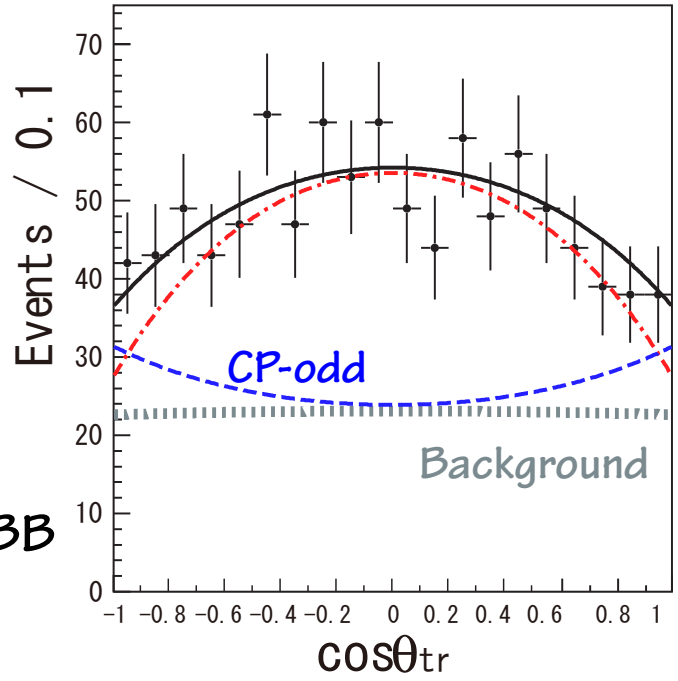
Different Weak Phase

$D^{*+}D^{*-}: b \to c\bar{c}d$

BaBar : PRD 79 (2009), 032002 : 467M BB
Belle : PRD 80 (2009), 111104 : 657M BB

2 vector mesons in the final state
: admixture of CP-odd and CP-even states

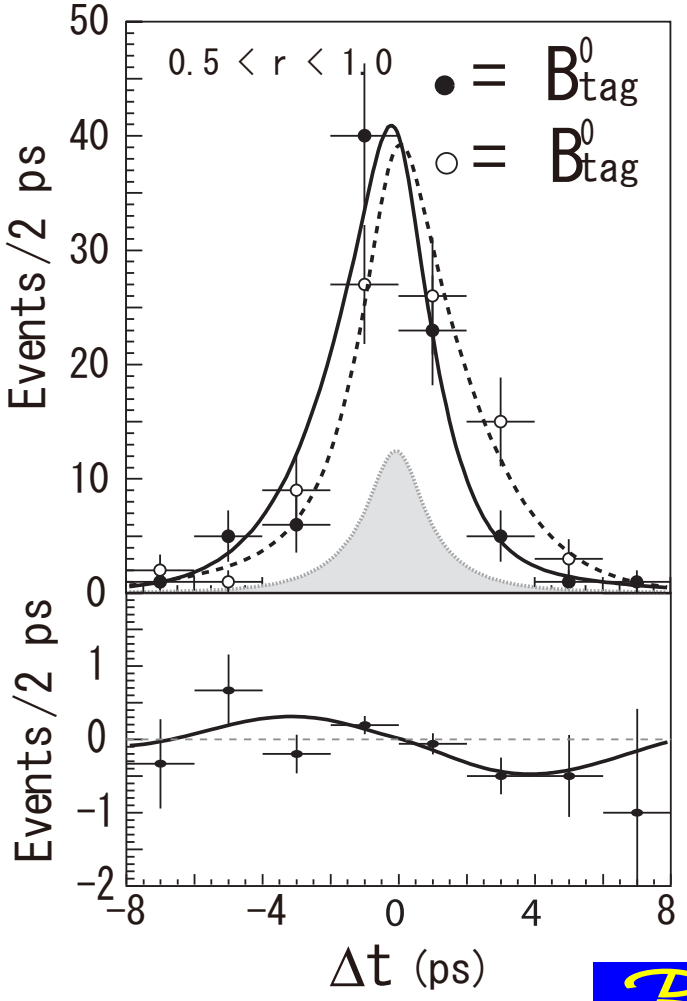
Time-integrated angular analysis



657M BB

CP-odd fraction

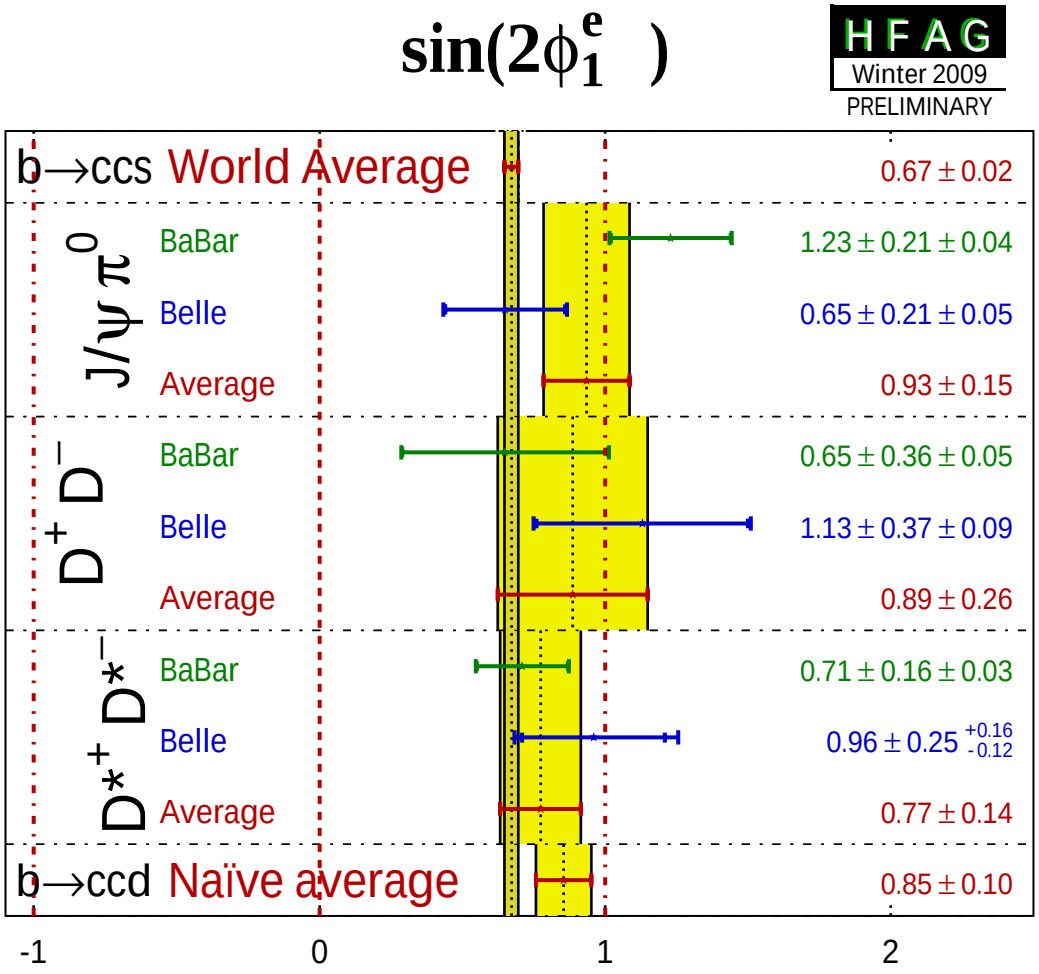
$R_\perp = 0.125 \pm 0.043 \pm 0.023$

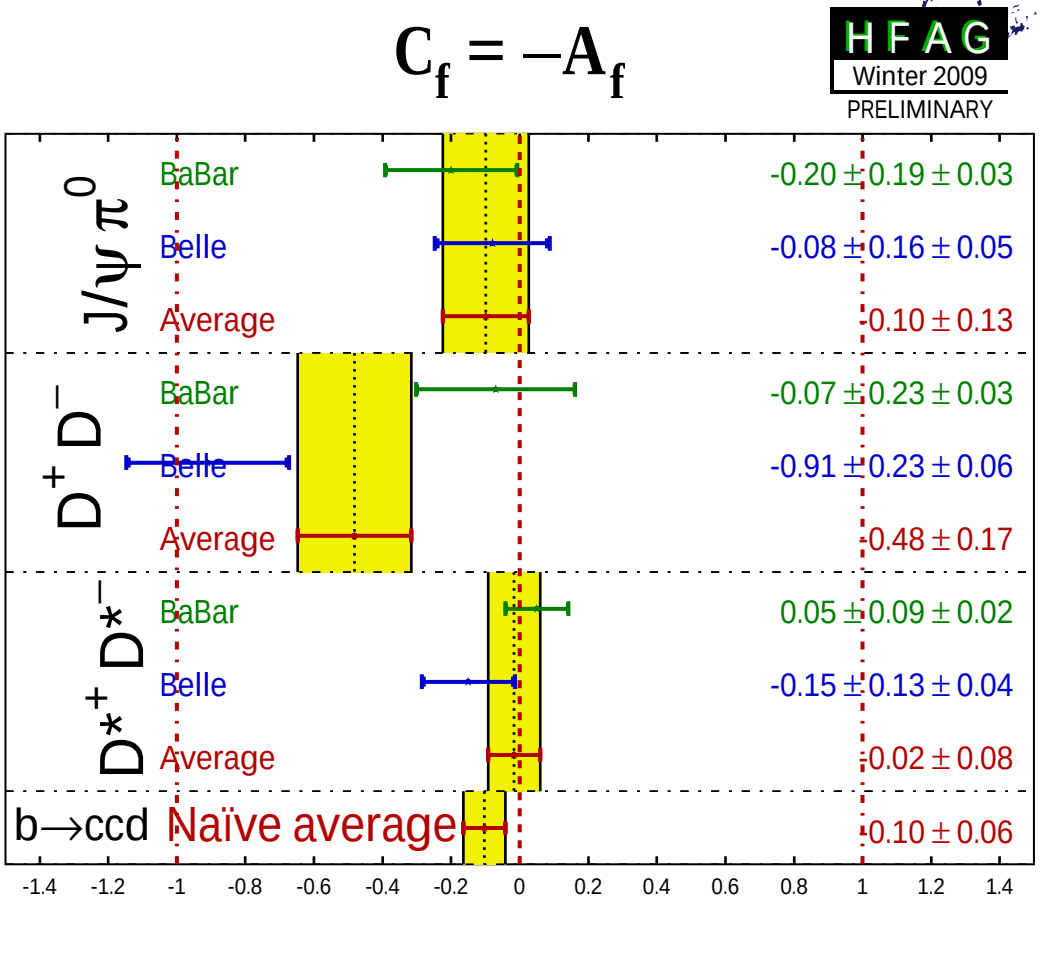


$\mathcal{S}_{D^*D^*} = -0.96 \pm 0.25 \pm {}^{0.12}_{0.16}$

$\mathcal{C}_{D^*D^*} (= -\mathcal{A}) = -0.15 \pm 0.13 \pm 0.04$

$b \to c\bar{c}d$



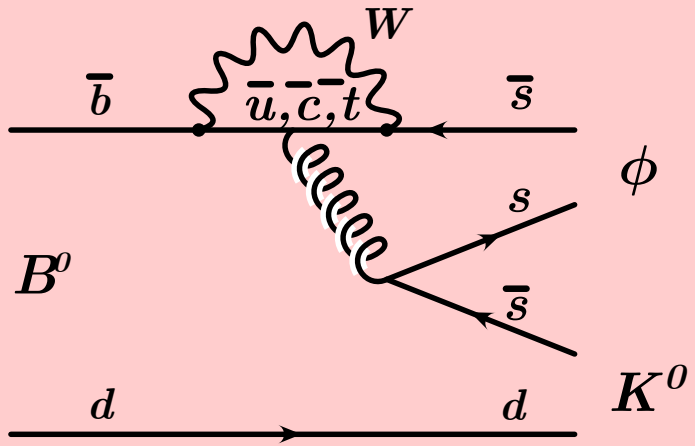


Good agreement with the CP observed in $b \to c\bar{c}s$ modes

Need more statistics

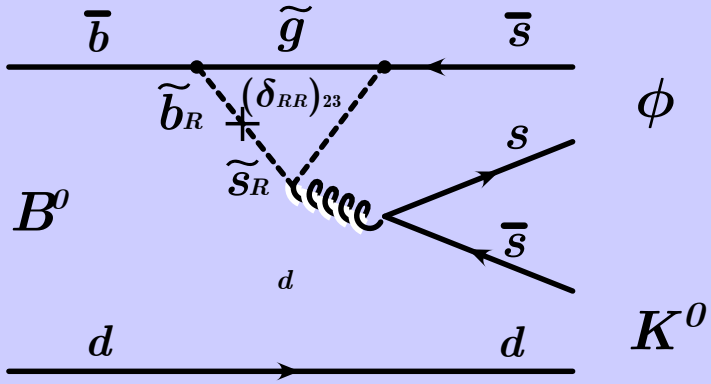
b → s penguin

penguin decay



$$A \propto V_{cb}^{*}V_{cs}(P^{c}\text{-}P^{t}) + V_{ub}^{*}V_{us}(P^{u}\text{-}P^{t})$$

New physics



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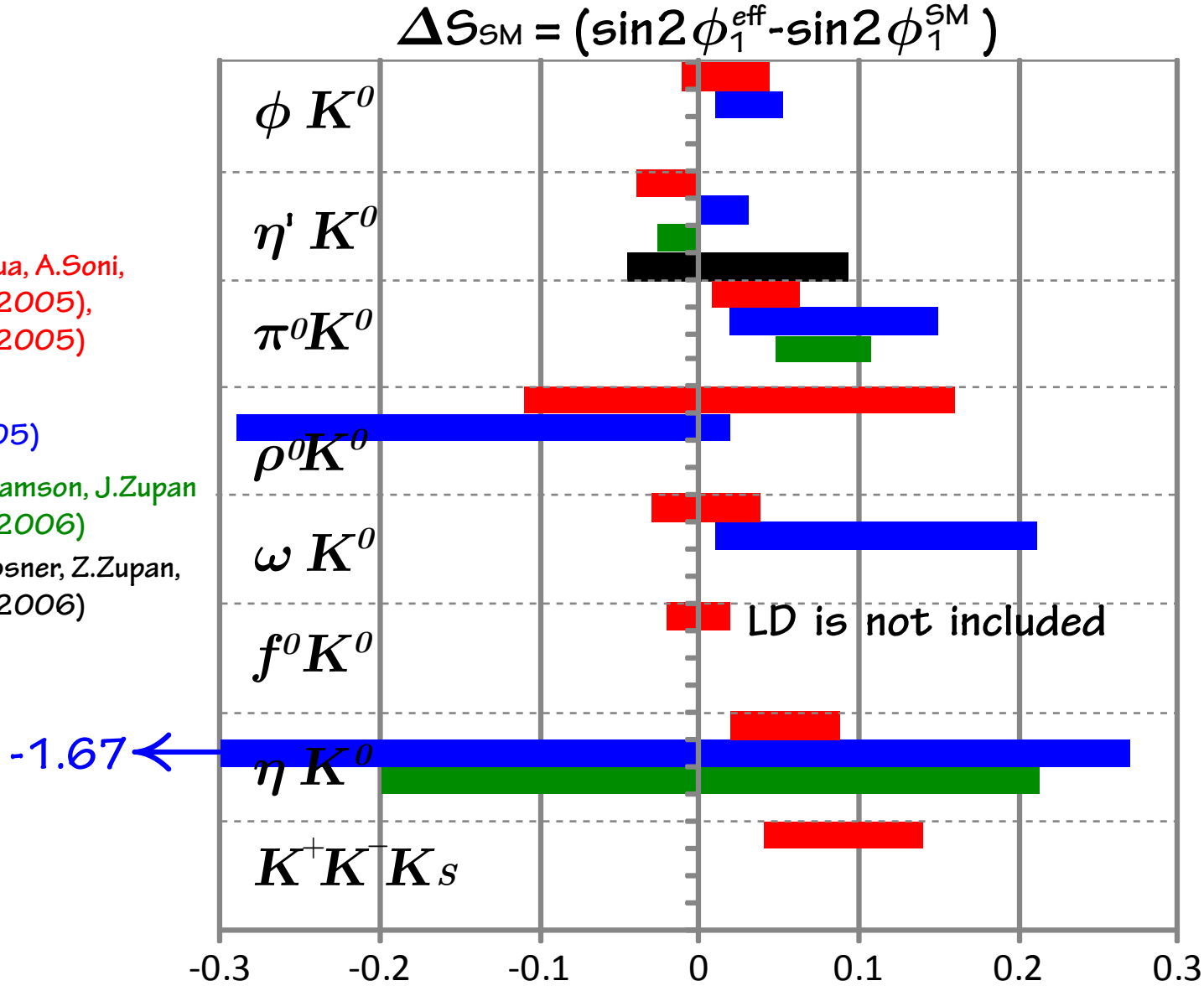
$$= -\eta_{cp}\sin 2(\phi_{1}+\phi_{NP})\ \sin(\Delta m \cdot \Delta t)$$

ϕK^{0}, $\eta' K^{0}$, $KsKsKs$,
$\pi^{0}K^{0}$, $\rho^{0}Ks$, ωKs, $f_{0,1,x}Ks$,
$\pi^{+}\pi^{-}Ks$, $K^{+}K^{-}K^{0}$

$b \to s$ penguin



QCDF:H.Cheng, CK.Chua, A.Soni,
PRD72, 014006 (2005),
PRD72, 094003 (2005)

QCDF:M.Beneke,
PLB620, 143 (2005)

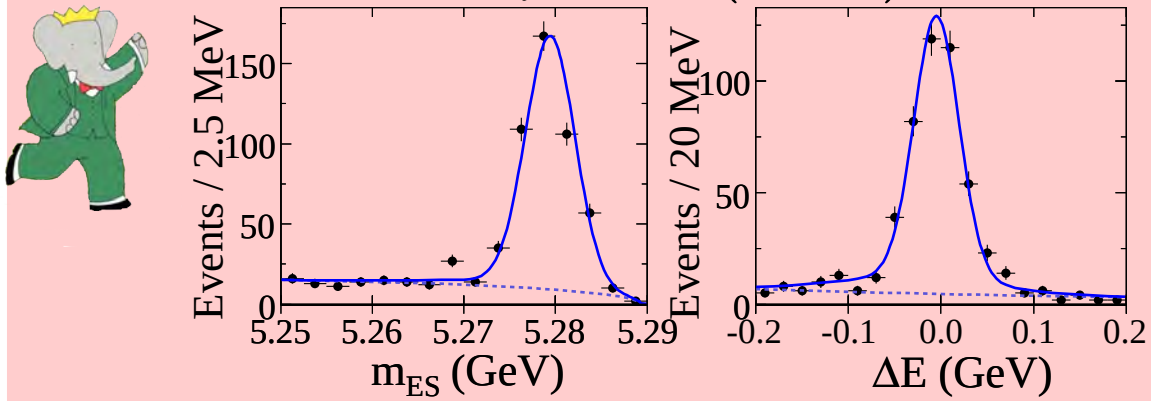
SCET/QCDF : A.R.Williamson, J.Zupan
PRD74, 014003 (2006)

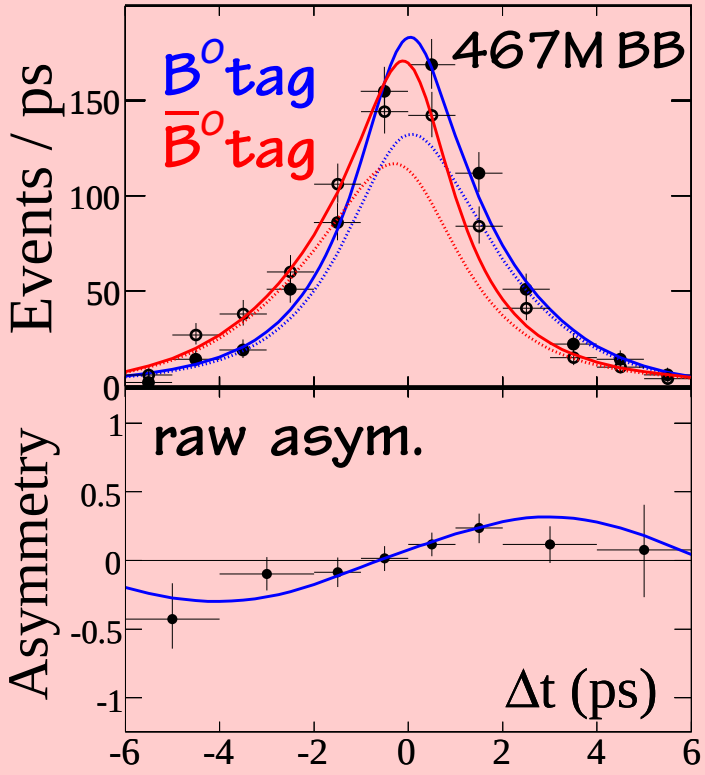
SU(3):M.Gronau, J.Rosner, Z.Zupan,
PRD74, 093003 (2006)

tend to be higher than the observed $\not{CP}$ in $b \to c\bar{c}s$ transitions

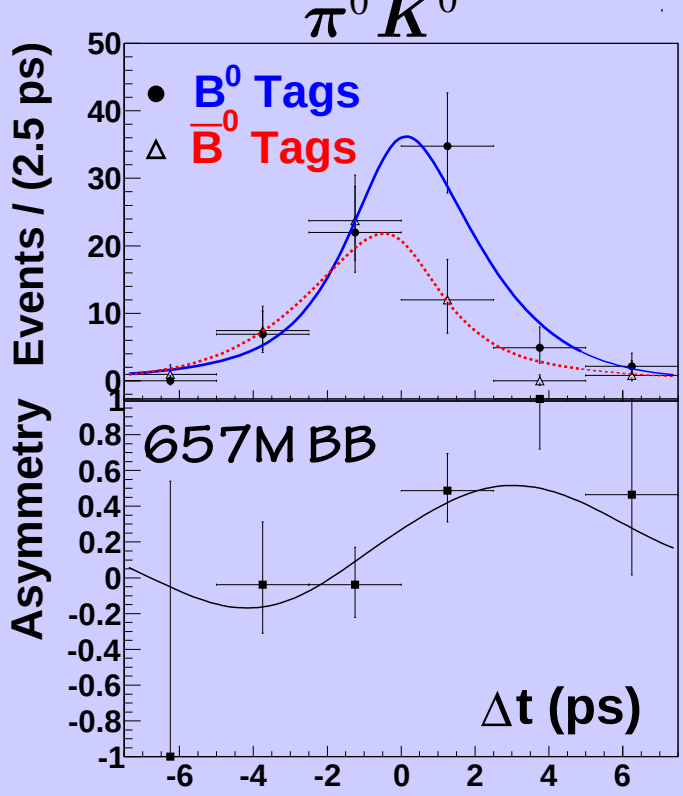
2-Body Decays ($\eta'K_S$, ωK_S, $\pi^0 K^0$)

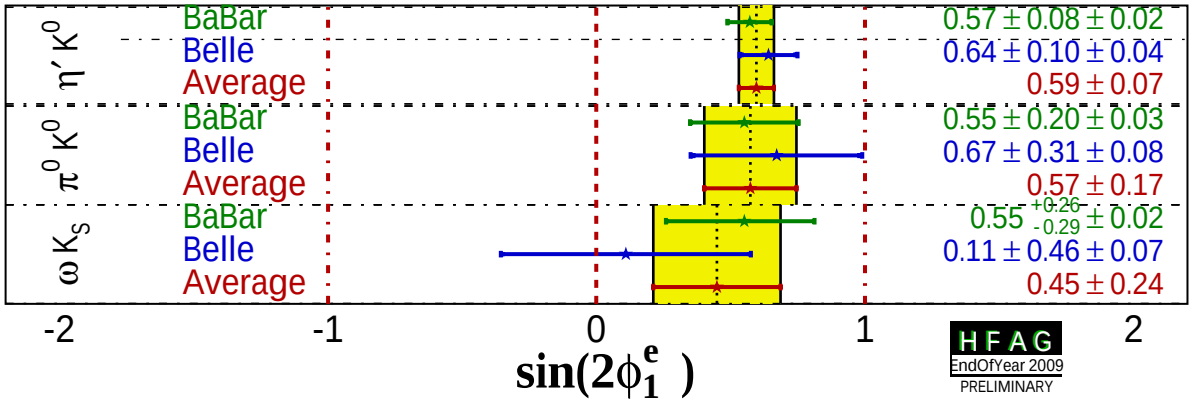
PRD 79 (2009), 052003 $\eta'_{(\gamma\gamma)} K_S(\pi^+\pi^-)$





PRD 81 (2010), 011101 $\pi^0 K^0$





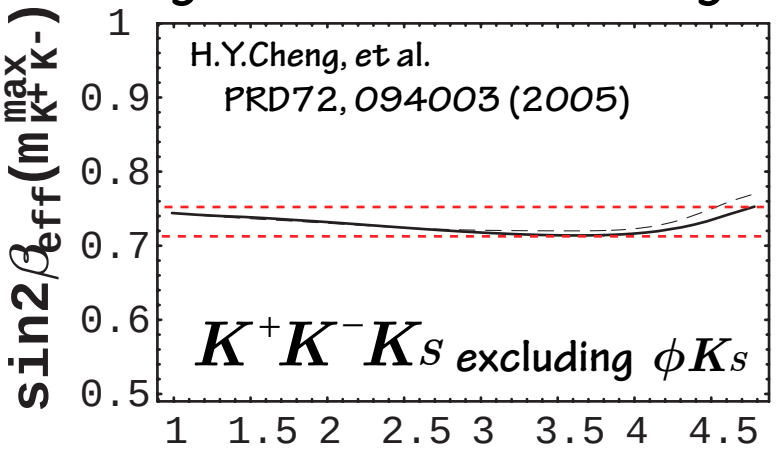
Time-dependent Dalitz plot analysis

$K^+K^-K_S$

$b \to u\bar{q}q$ tree amplitudes may depend on the position in the Dalitz plot

SM correction $\phi(\to K^+K^-)K_S$: O(0,01)

Higher K^+K^- mass region : O(0,1)



ϕK_S	$\phi_1^{eff} = 7.7 \pm 7.7 \pm 0.1^\circ$
$f(980)K_S$	$\phi_1^{eff} = 8.5 \pm 7.5 \pm 1.8^\circ$
$K^+K^-K_S$ (high mass)	$\phi_1^{eff} = 29.5 \pm 4.5 \pm 1.5^\circ$

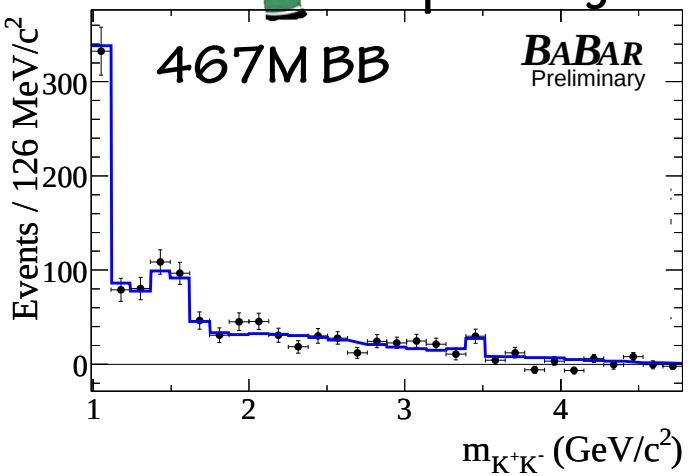
657M BB

ϕK_S	$\phi_1^{eff} = 21.1 \pm {}^{9.8}_{10.4} \pm 2.0 \pm 2.0^\circ$
$f(980)K_S$	$\phi_1^{eff} = 28.2 \pm {}^{9.9}_{9.8} \pm 2.0 \pm 2.0^\circ$

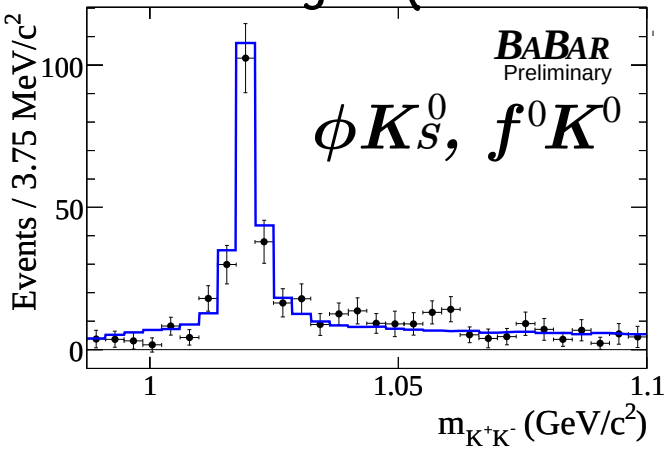
but suffer from 2- or 4-fold ambiguity

arXiv:0808.0700v2

whole Dalitz plot region



low mass region (<1.1GeV/c2)



Time-dependent Dalitz plot analysis

arXiv:0808.0700v2

$\pi^+\pi^- K_S$

2-body approach to $\rho^0 K_S$, $f(980) K_S$

interference with other resonances and non-resonant decays

657M BB

$\rho^0 K_S$ $\phi_1^{eff} = 20.0 \pm {}^{8.6}_{8.5} \pm 3.2 \pm 3.5°$

$f(980) K_S$ $\phi_1^{eff} = 12.7 \pm {}^{6.9}_{6.5} \pm 2.8 \pm 3.3°$

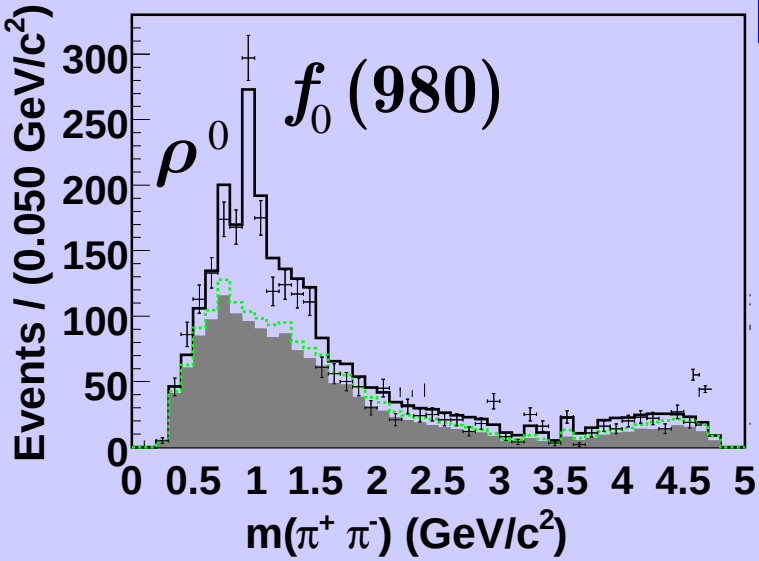
383M BB

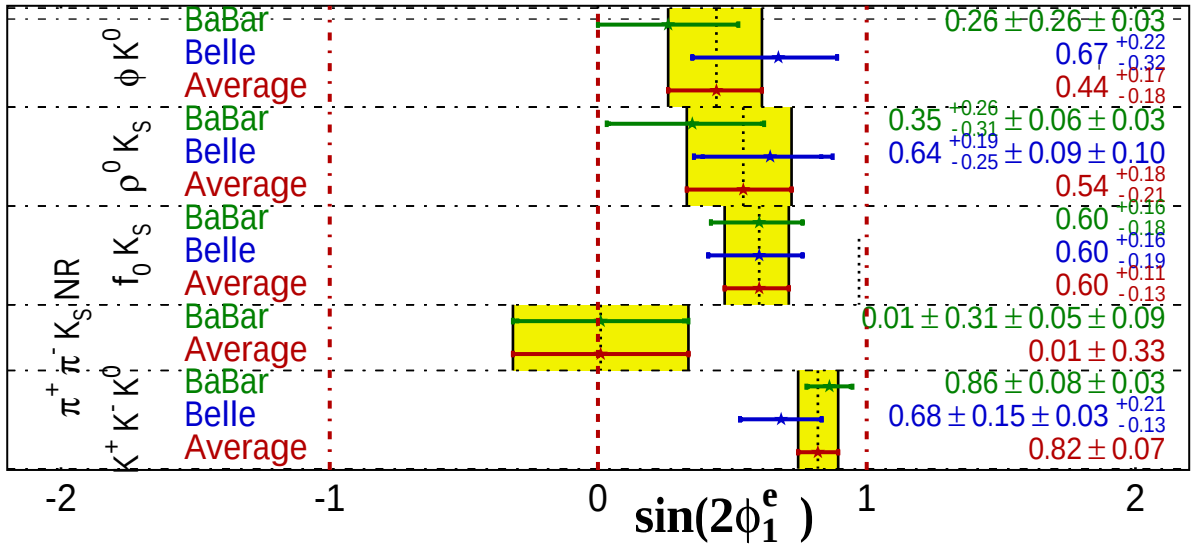
$\rho^0 K_S$ $\phi_1^{eff} = 10.2 \pm 8.9 \pm 3.0 \pm 1.9°$

$f(980) K_S$ $\phi_1^{eff} = 36.0 \pm 9.8 \pm 2.1 \pm 2.1°$

arXiv:0811.3665v2

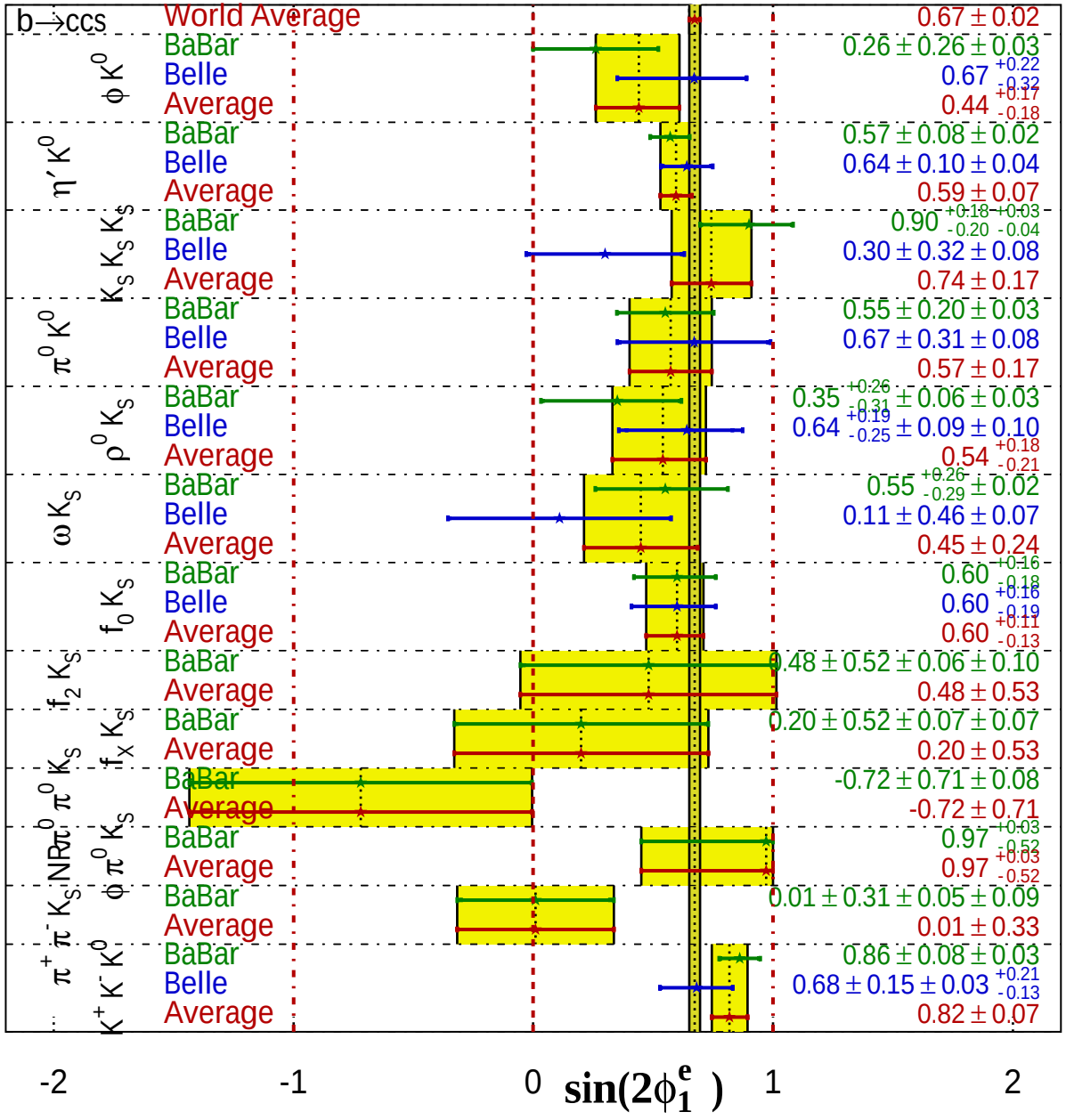
657M BB





HFAG EndOfYear 2009 PRELIMINARY

$\sin 2\phi_1^{eff}$ from $b \to s$ penguin



$\sin 2\phi_1^{eff}$ from $b \to s$ penguin

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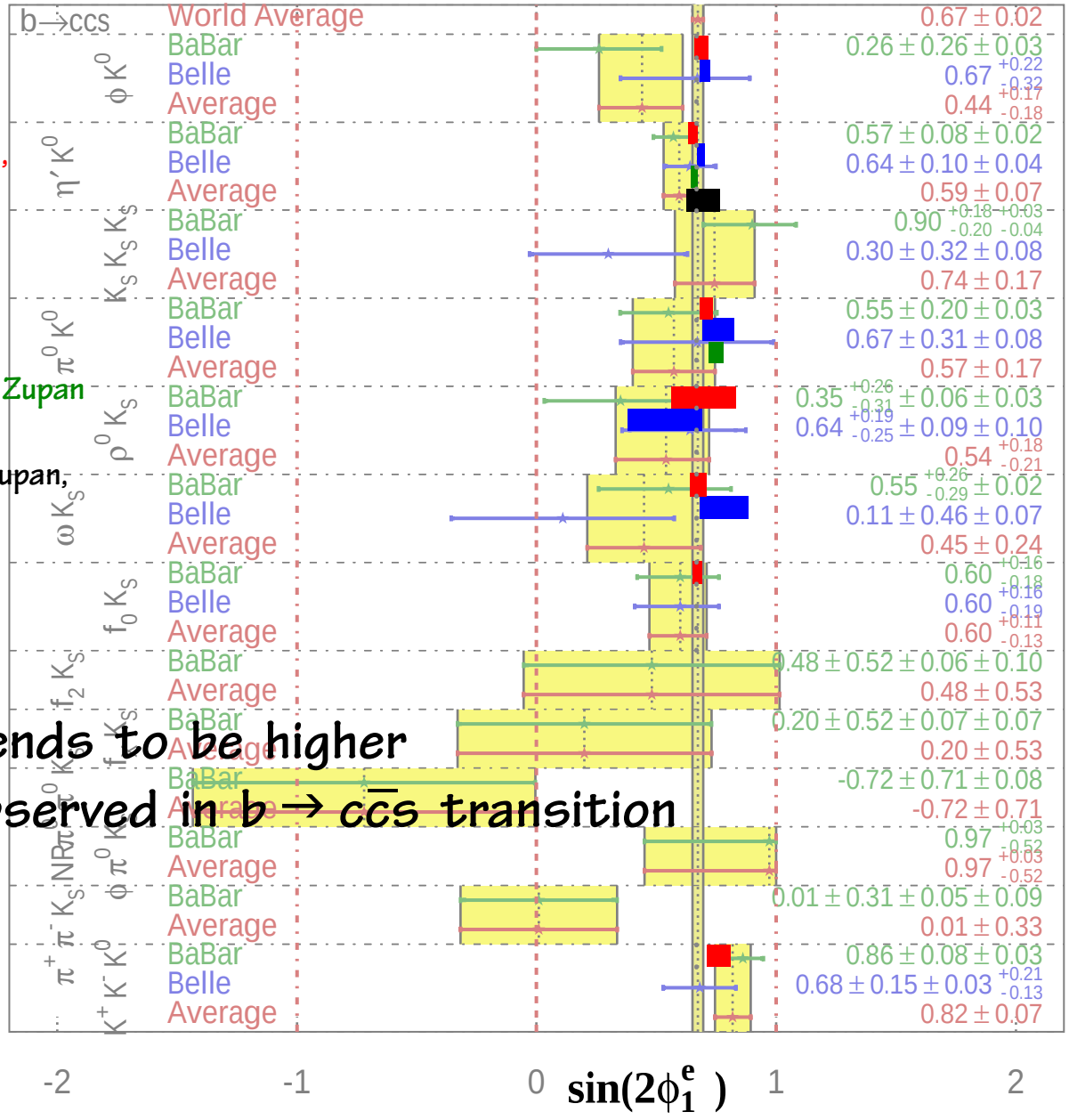


HFAG EndOfYear 2009 PRELIMINARY

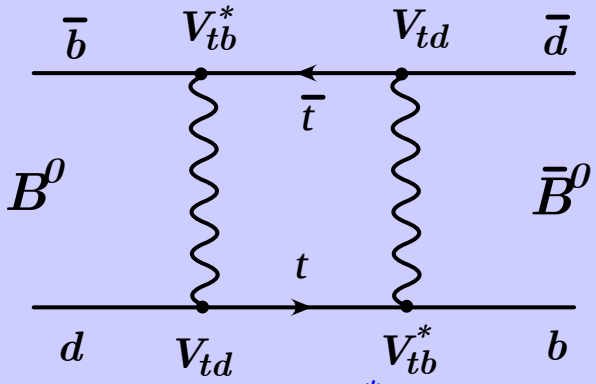
SM correction tends to be higher than the CP observed in $b \to c\bar{c}s$ transition

No convincing evidence for new physics...

more statistics is needed!

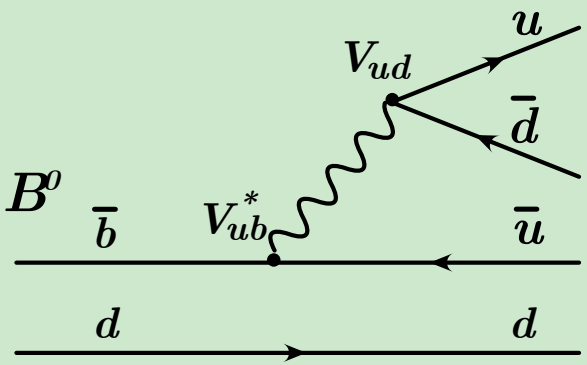
ϕ_2 measurement

$B^0\bar{B}^0$ mixing



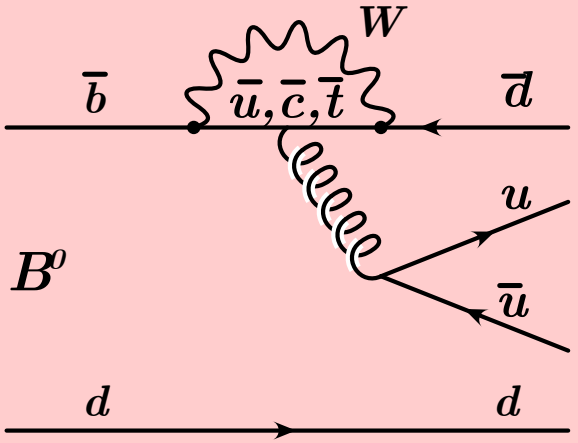
$$\frac{q}{p} \propto \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

Tree decay



$$A \propto V_{ub}^* V_{ud}$$

Penguin decay



$$A \propto V_{tb}^* V_{td}$$

If there is no penguin polution

$$\lambda = e^{i2\phi_2}$$

$$\mathcal{S}_{\pi\pi} = \sin 2\phi_2$$
$$\mathcal{A}_{\pi\pi} = 0$$

$\rightarrow$

but actually...

$$\lambda = e^{i2\phi_2} \frac{1 - R_{PT} e^{-i\phi_2}}{1 - R_{PT} e^{i\phi_2}} \quad , R_{PT} = \frac{|V_{tb}^* V_{td}| P}{|V_{ub}^* V_{ud}| T}$$

$$\mathcal{S}_{\pi\pi} = \sqrt{1 - \mathcal{A}_{\pi\pi}^2}\, \sin 2\phi_2^{\text{eff}} \neq \sin 2\phi_2$$
$$\mathcal{A}_{\pi\pi} \neq 0$$

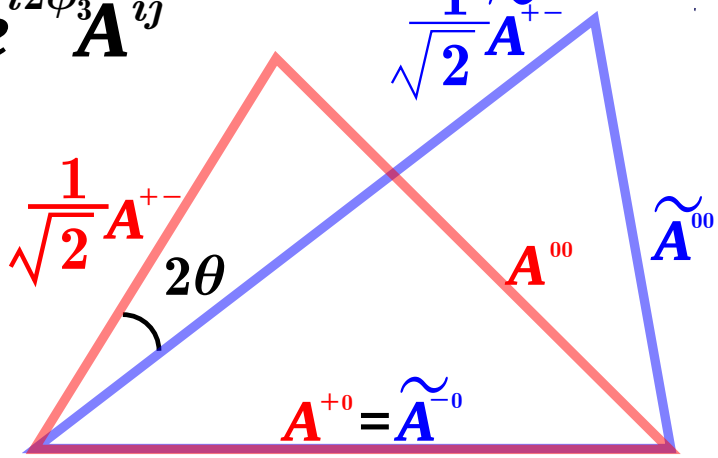
To extract ϕ_2 : isospin analysis

ϕ_2 measurement : isospin analysis

PRL 65,3381(1990)

	Amplitude
$A^{+-}(\overline{A}^{+-})$	$B^0(\overline{B}^0)\to\rho^+\rho^-$
$A^{00}(\overline{A}^{00})$	$B^0(\overline{B}^0)\to\rho^0\rho^0$
$A^{+0}(\overline{A}^{-0})$	$B^+(B^-)\to\rho^+\rho^0(\rho^-\rho^0)$

$$\widetilde{A}^{ij} = e^{i2\phi_3}\overline{A}^{ij}$$



admixture of CP-even and CP-odd states
a separation is possible (angular analysis)

$$\mathcal{S}_{\pi\pi}=\sqrt{1-\mathcal{A}_{\pi\pi}^2}\,\sin(2\phi_2+2\theta)$$

Belle : 275M BB $\quad \phi_2 = 91.7 \pm 14.9^\circ$ arXiv:0808.2576v3

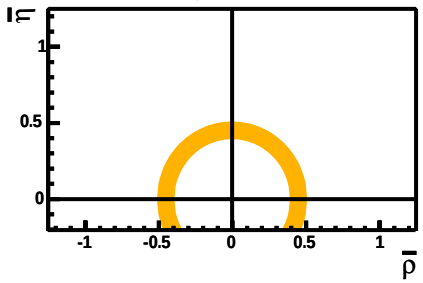
using upper limit on Br($B^0\to\rho^0\rho^0$) w/ 657M BB
assuming longitudinal polarization fraction : 1

BaBar : 465M BB $\quad \phi_2 = 92.4^{+6.0}_{-6.5}{}^\circ$ (68% C.L.) arXiv:0901.3522v4

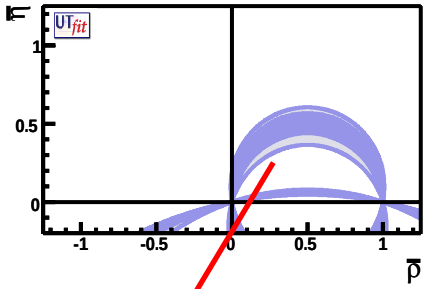
CKM fit : $\phi_2 = 89.0^{+4.4}_{-4.2}{}^\circ$

Other CKM measurements

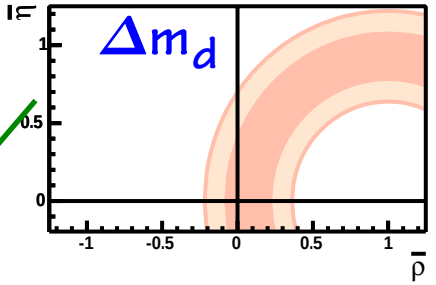
$b \to u\, l\, \nu$



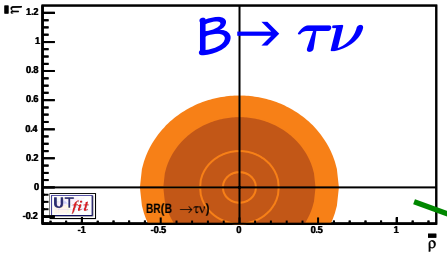
$B \to \pi\pi, \rho\rho, \rho\pi$



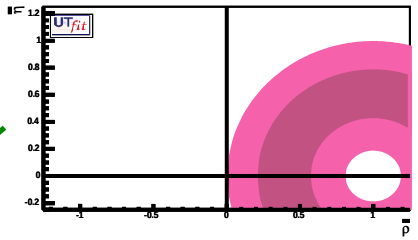
Δm_d



$B \to \tau\nu$



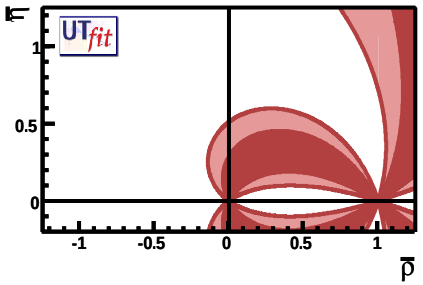
$B \to \rho\gamma$ / $B \to K^*\gamma$

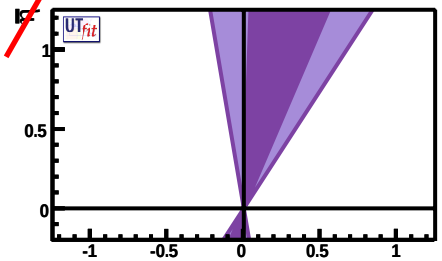


$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$ ϕ_2 $\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}$

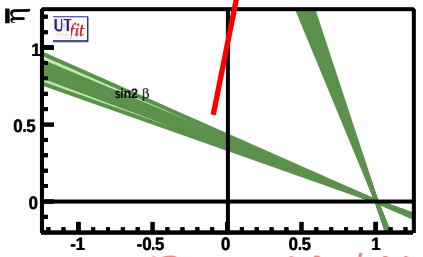
ϕ_3 ϕ_1

$2\phi_1 + \phi_3$

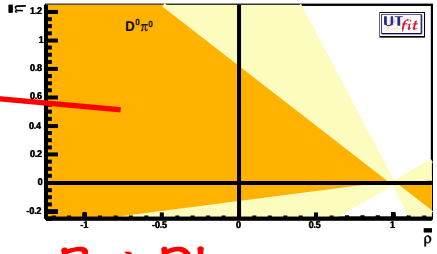




$B \to DK$ (Dalitz, GLW)



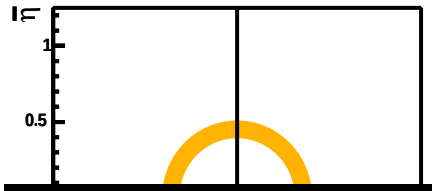
$B \to J/\psi K_S$



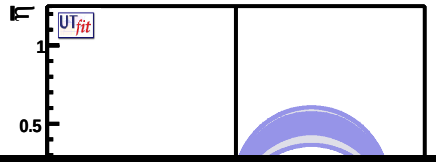
$B \to Dh$
time-dep. Dalitz

Other CKM measurements

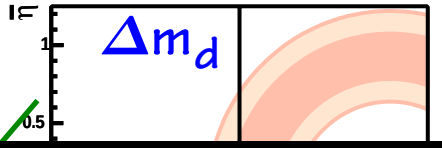
$b \to u\, l\, \nu$



$B \to \pi\pi, \rho\rho, \rho\pi$



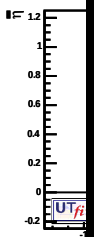
Δm_d

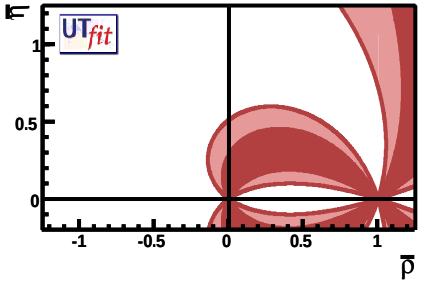


- Data reprocess w/ new tracking + θ-dep. γ threshold
  signal yield $B \to \eta' K_S$ $D^{(*)}\pi$
  : $48 \pm 10\%$ increase eff : 20~40% increase
- Full statistics (~770M BB)

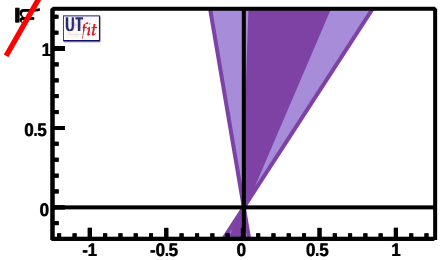
New results will be provided soon

BELLE

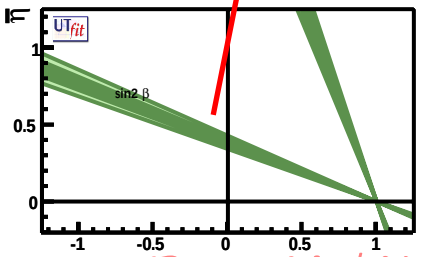




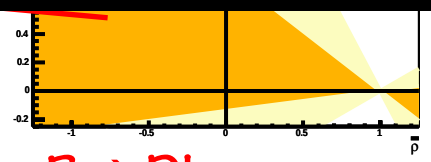
$B \to DK$ (Dalitz, GLW)



$B \to J/\psi K_S$



$B \to Dh$
time-dep. Dalitz

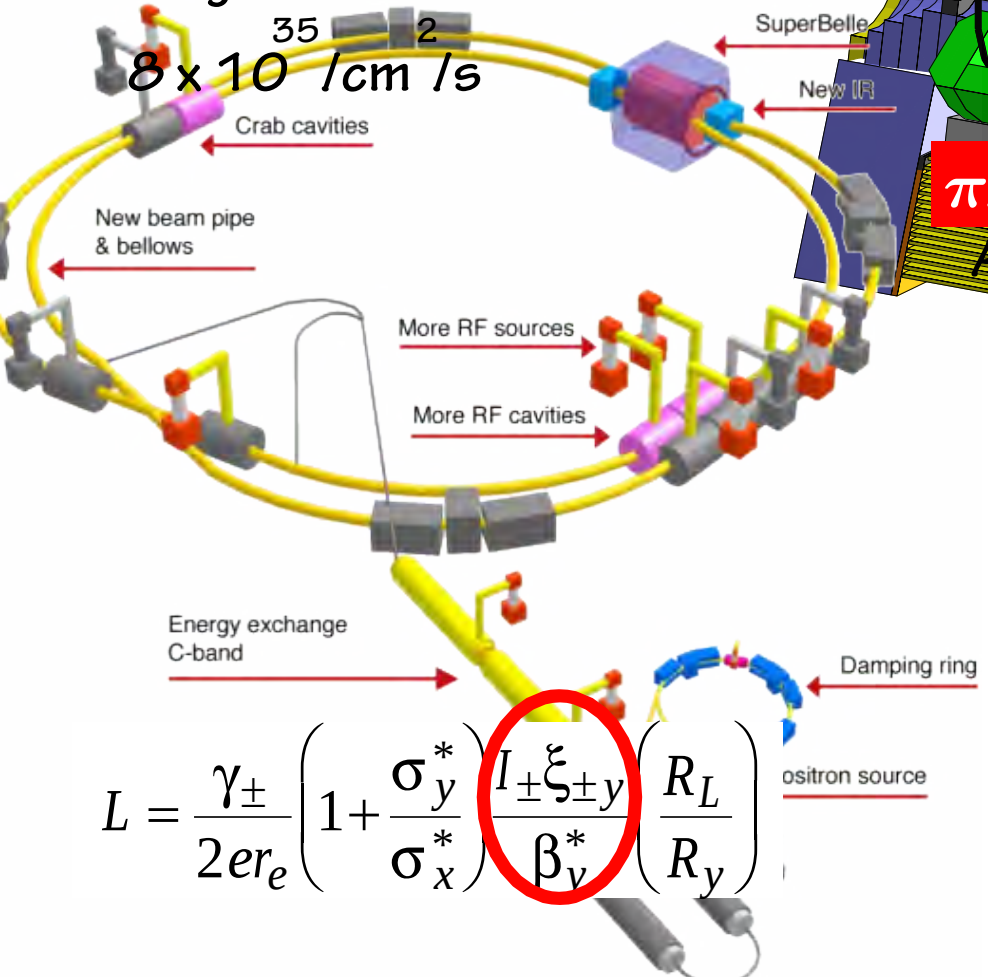


Super B factories

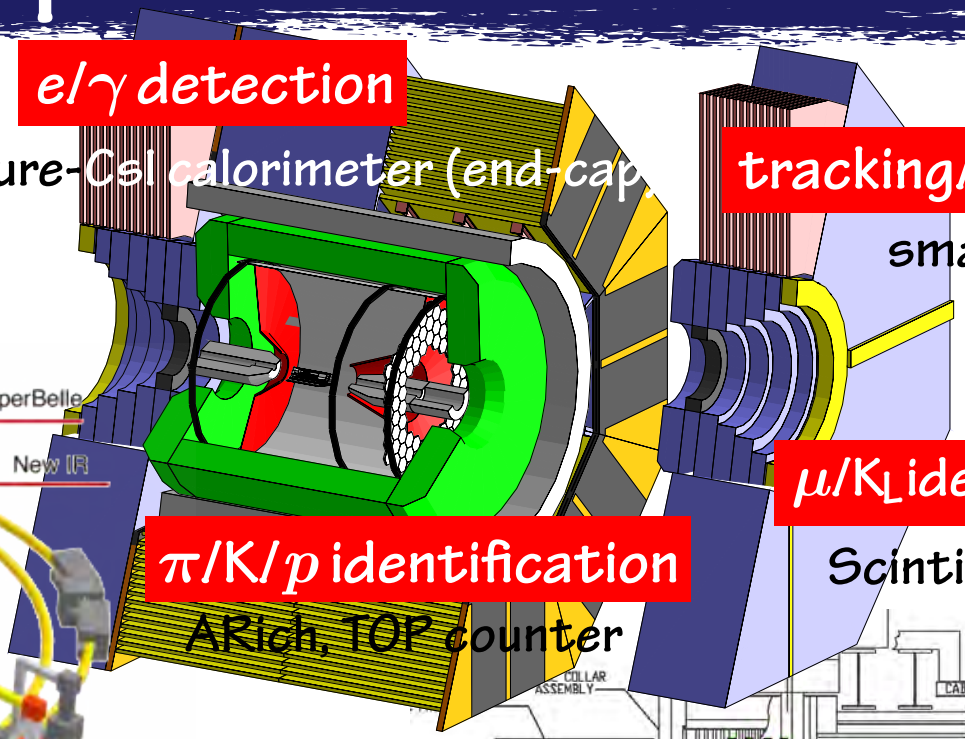
Super KEKB
uest for BSM

E_{cm} = 10.58 GeV
= @Υ(4S)

aiming for
8×10^{35} /cm^2/s

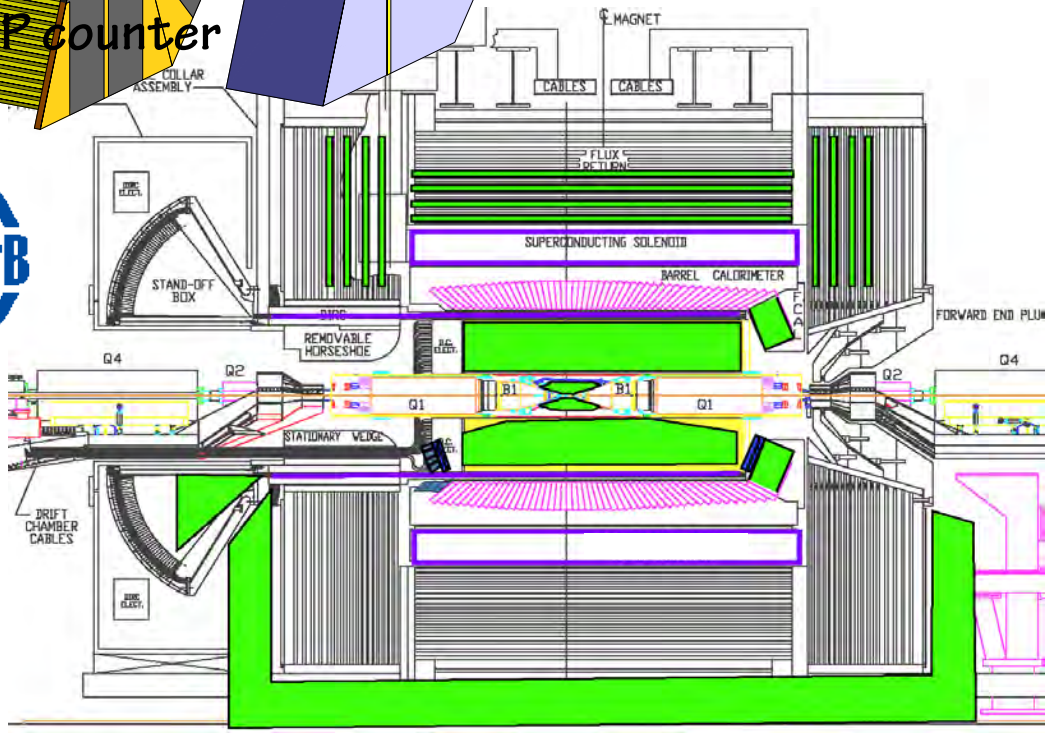


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$



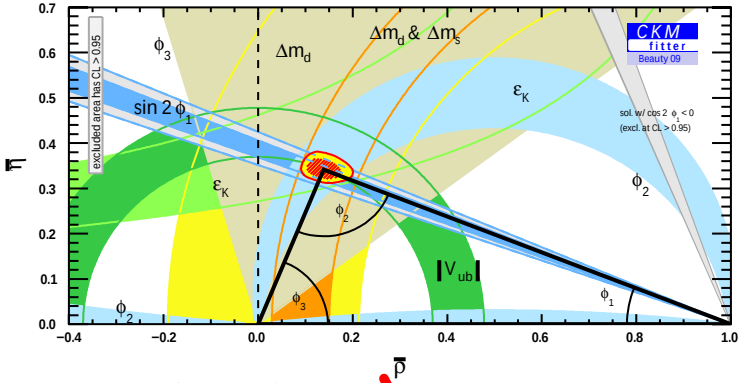
Belle II

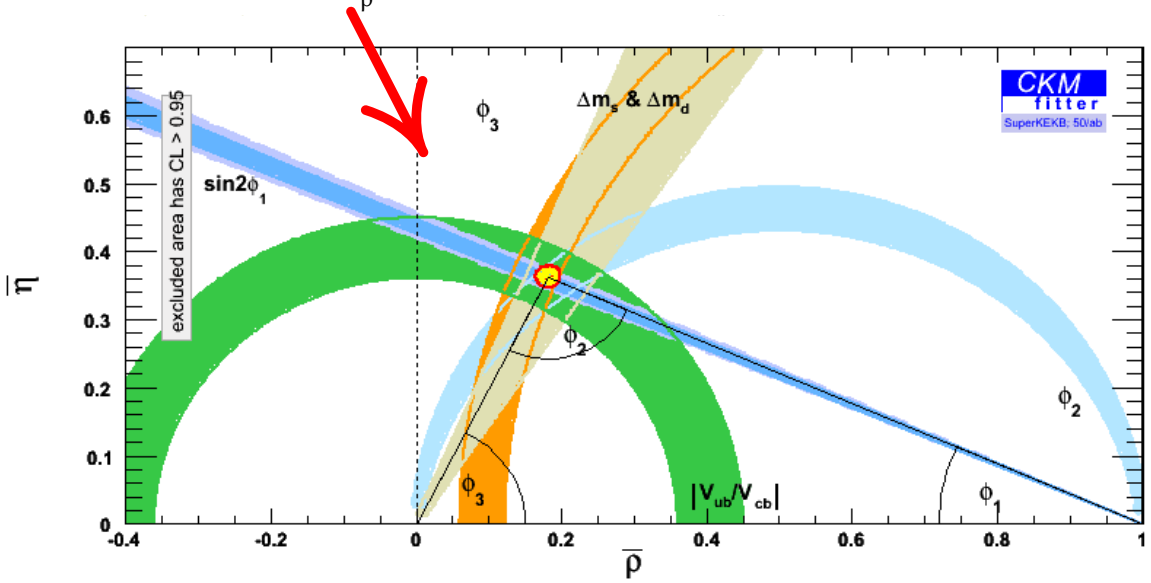
SuperB



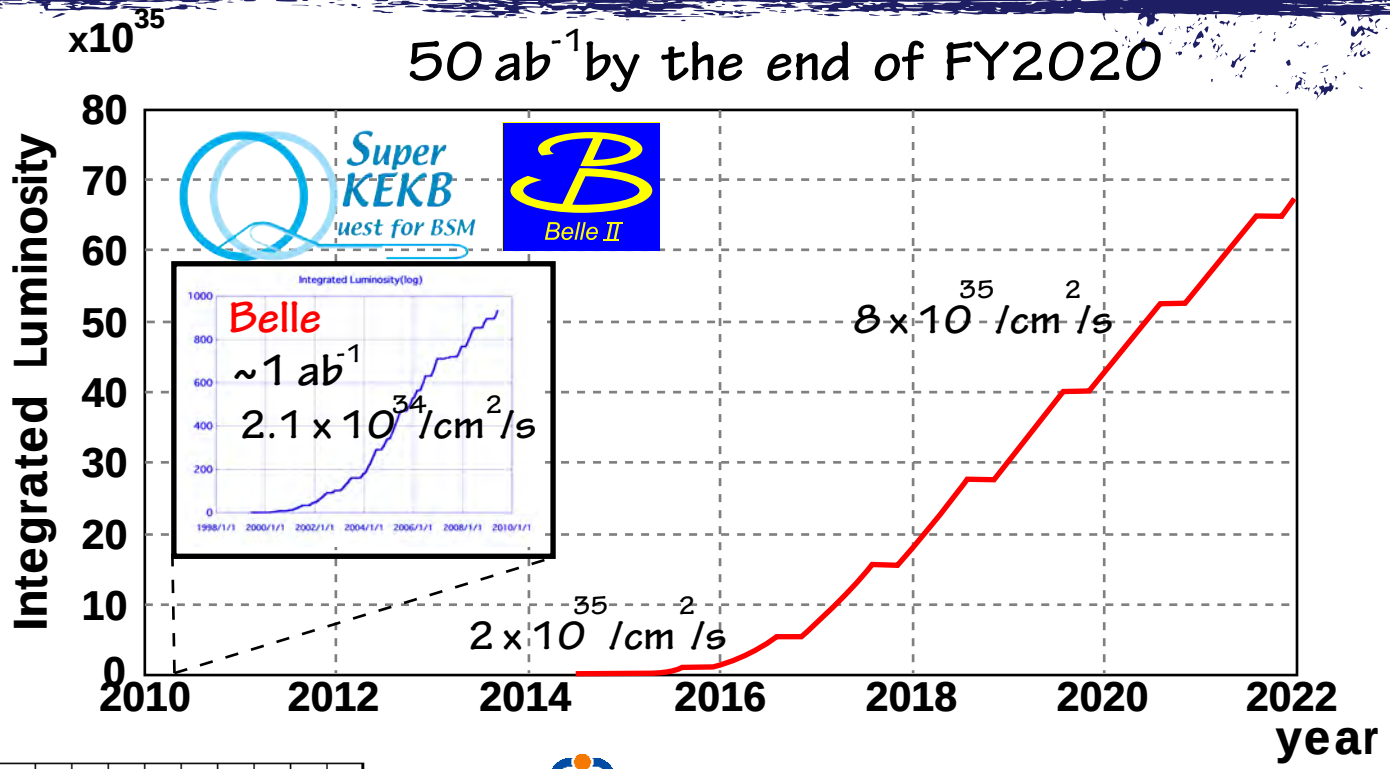
in 2020

Super B-Factories bring the NP searches to a new level of sensitivity





50 ab^{-1} by the end of FY2020



SuperB : 80 ab^{-1} in 7th year

Error	~0.5 ab^{-1}	50ab^{-1}
ϕ1	4%	1.6%
ϕ2	11°	2°
ϕ3	19°	3°

Summary

B-Factories have achieved the primary goal :

Confirmation of the large CP violation in B meson system

Now B-Factories have started to search for New Physics beyond the SM

$B \to c\bar{c}K^0$ modes : $\sin 2\phi_1 = 0.672 \pm 0.023$

$\phi_1 = 21.15^{+0.90}_{-0.88}{}^\circ$ 4% precision

$\phi_2 = 89.0^{+4.4}_{-4.2}{}^\circ$

$\phi_3 = 69^{+19}_{-21}{}^\circ$

the reference for the new physics search

penguin modes (esp. $b \to s$ penguin e.g. $\eta'K$) are senstive to New Physics

Currently, the results are consistent with the SM expectation

more statistics is needed

Next generations of B-factory are being proposed,

and these bring the New Physics searchs to the new level of sensitivity

B factories

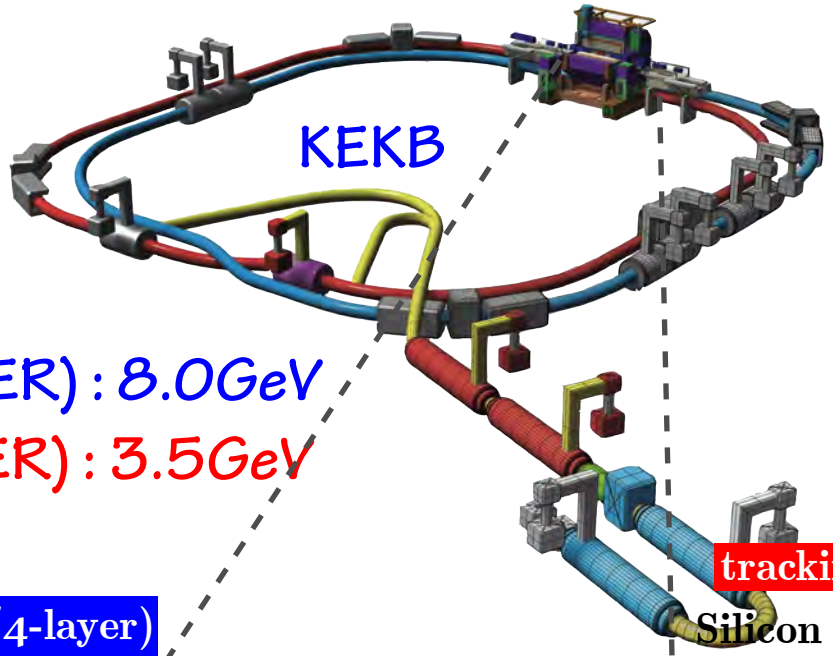
E_{cm}=10.58GeV
(=@ Y(4S))

KEKB

e−(HER) : 8.0GeV
e+(LER) : 3.5GeV

PEP-II

e−(HER) : 9.0GeV
e+(LER) : 3.1GeV



tracking/vertexing
Silicon Strip Detector
Drift Chamber

SVD(3/4-layer)
CDC(50-layer)

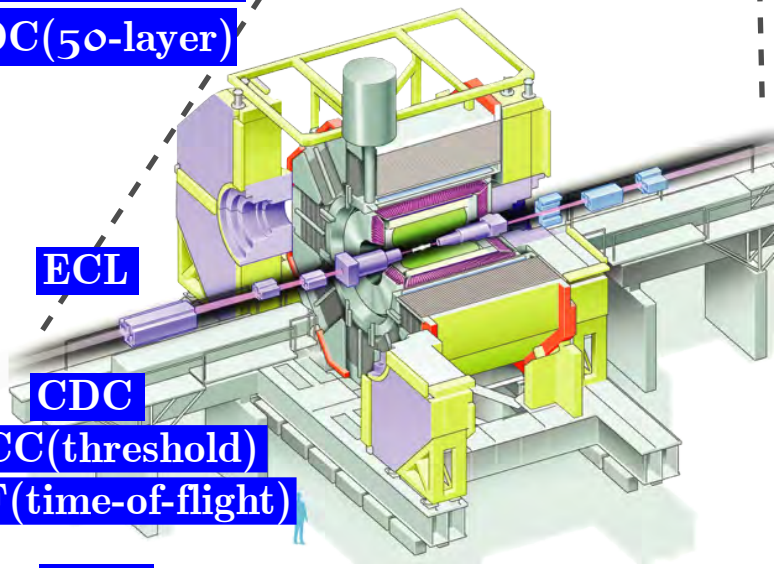
SVT(5-layer)
DCH(40-layer)

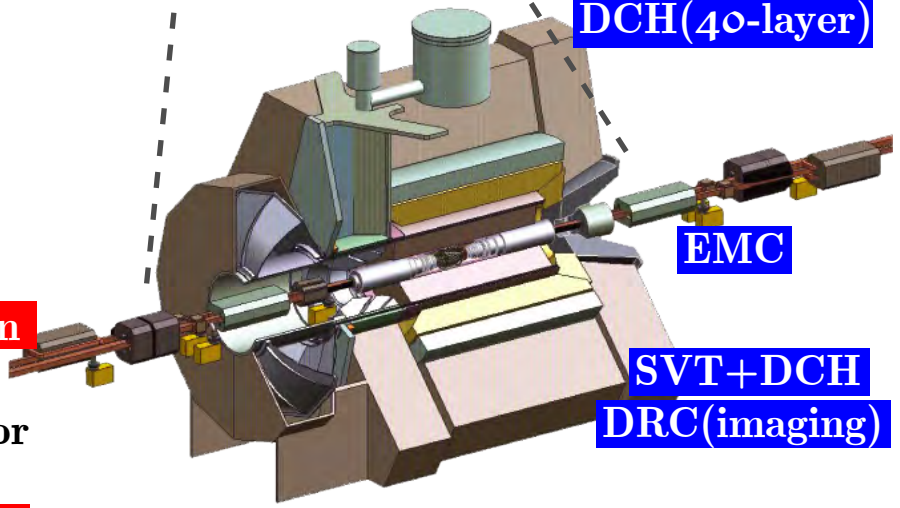
1.5T Solenoid

e/γ detection
CsI calorimeter

ECL

EMC





π/K/p identification
dE/dx
Cherenkov detector

CDC
ACC(threshold)
TOF(time-of-flight)

SVT+DCH
DRC(imaging)

μ/K_L identification
Resistive Plate Chamber

KLM

IFR