# *CP* violations from *B* decays

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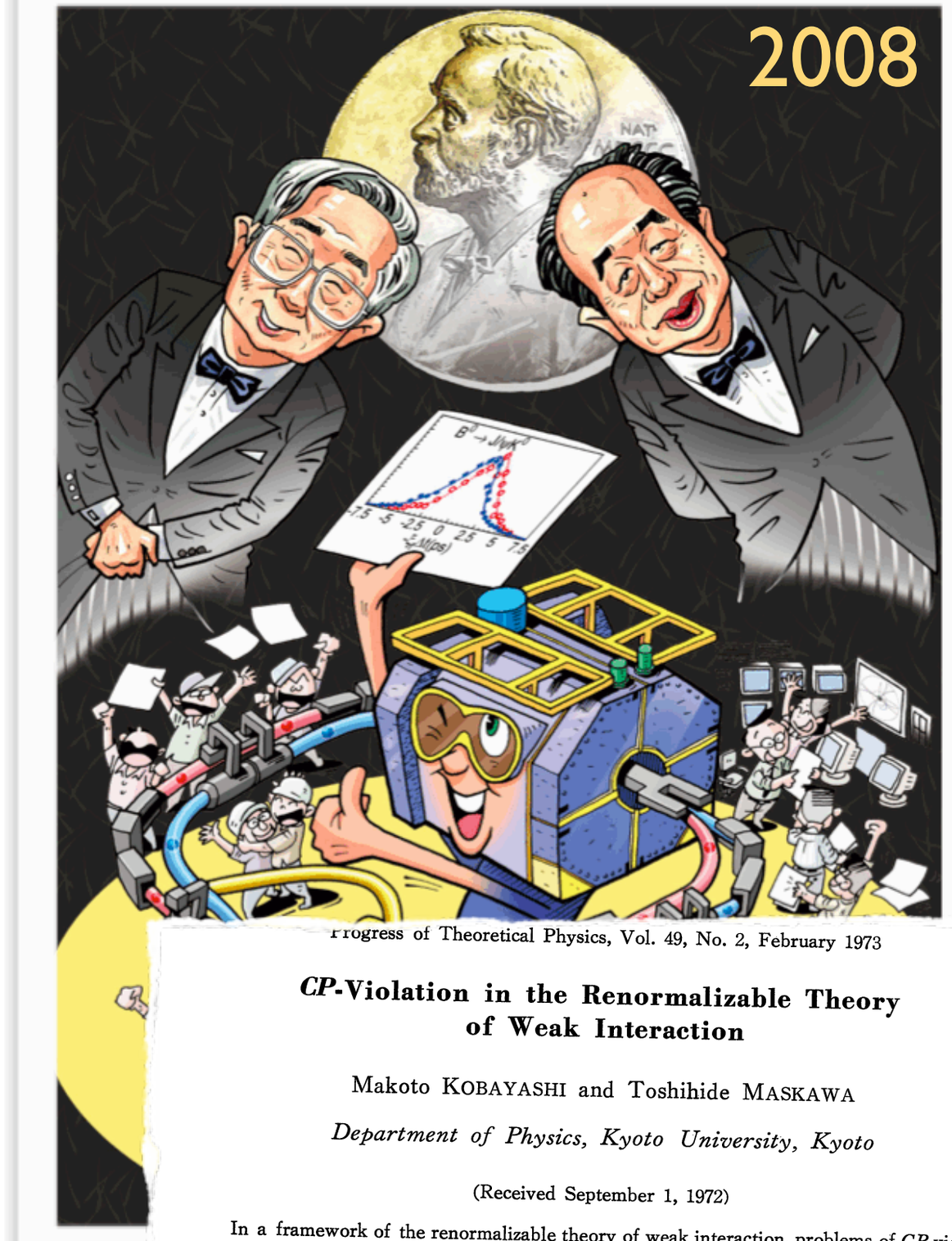
Physics in Collision, KIT, Sep.1-4, 2010

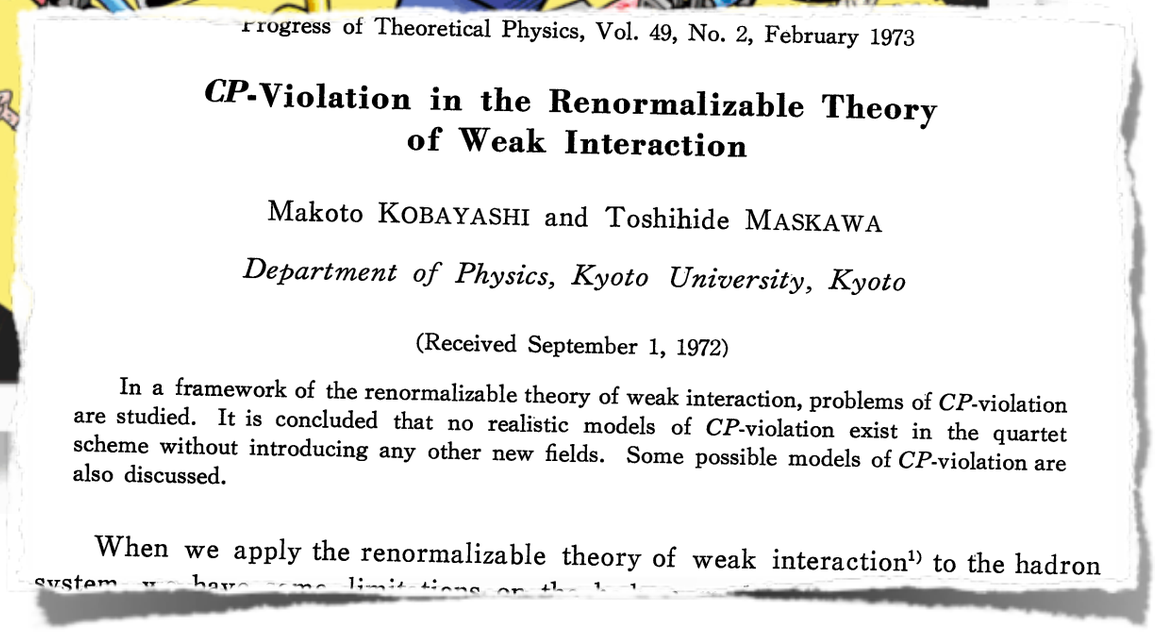
# Outline

- Introduction -- *key concepts & experimental methods*
- *CPV* in *B*
  - *t-CPV for CKM UT angles:* $\phi_1$, $\phi_2$, $\phi_3$
  - *some non-UT subjects**
    - Search for Direct CPV in $B^+ \to J/\psi\, K^+$ (--> *poster by K. Sakai*)
    - $A_{CP}$ of inclusive $B \to X_s\, \eta$
- Summary & Prospects

** no update of "Kπ puzzle" today…*

*CPV is due to an irreducible phase in the unitary quark mixing matrix in 3 generations*



Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

**CP-Violation in the Renormalizable Theory of Weak Interaction**

Makoto KOBAYASHI and Toshihide MASKAWA

*Department of Physics, Kyoto University, Kyoto*

(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of *CP*-violation are studied. It is concluded that no realistic models of *CP*-violation exist in the quartet scheme without introducing any other new fields. Some possible models of *CP*-violation are also discussed.

When we apply the renormalizable theory of weak interaction[1] to the hadron system

- Critical role of the *B*-factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation
- A single irreducible phase in the weak int. matrix accounts for most of the *CP* violation observed in the *K*'s and in the *B*'s
- *CP*-violating effects in the B sector are $\mathcal{O}(1)$ rather than $\mathcal{O}(10^{-3})$ as in the $K^0$ system.

# Historical Milestones

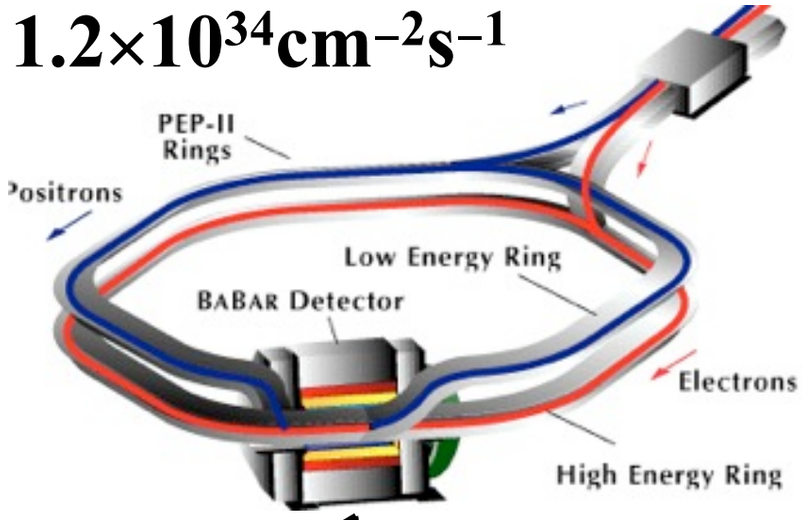
- 1957 Parity violation in $^{60}Co$
- 1963 Cabibbo angle
- 1964 CP violation in $K^0$
- 1967 Sakharov's 3 conditions
- 1973 KM mechanism
- 1977 Discovery of b quark
- 1983 1st recon. of B meson
- 1987 $B^0$ mixing
- 1999 B-factories (Belle, BaBar) started
- 2001 CP violation in $B^0$
- 2004 Direct CP violation in $B^0$
- 2006 $B_s$ mixing
- 2008 (1/2) Nobel Physics prize to K & M

N. Cabibbo
(1935-2010)

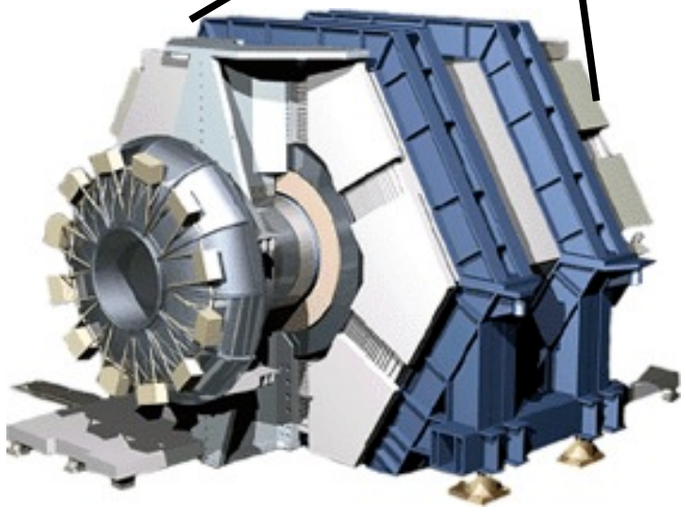
# Two asymmetric B-factories

## PEP-II at SLAC

9GeV ($e^-$) × 3.1GeV ($e^+$)
peak luminosity:
**$1.2\times10^{34}cm^{-2}s^{-1}$**

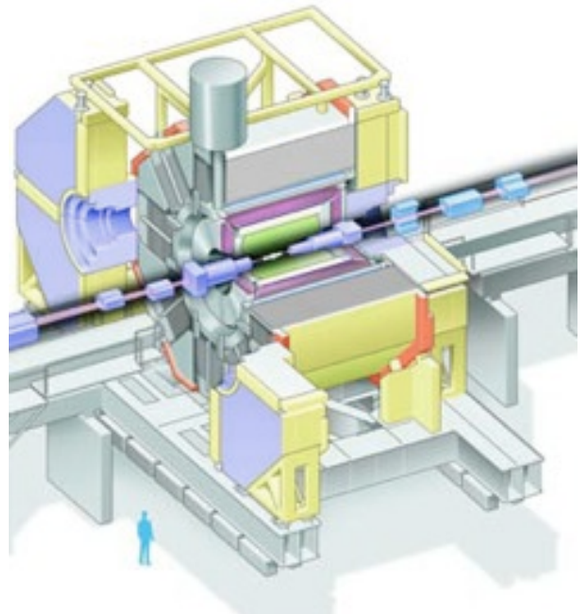


BaBar

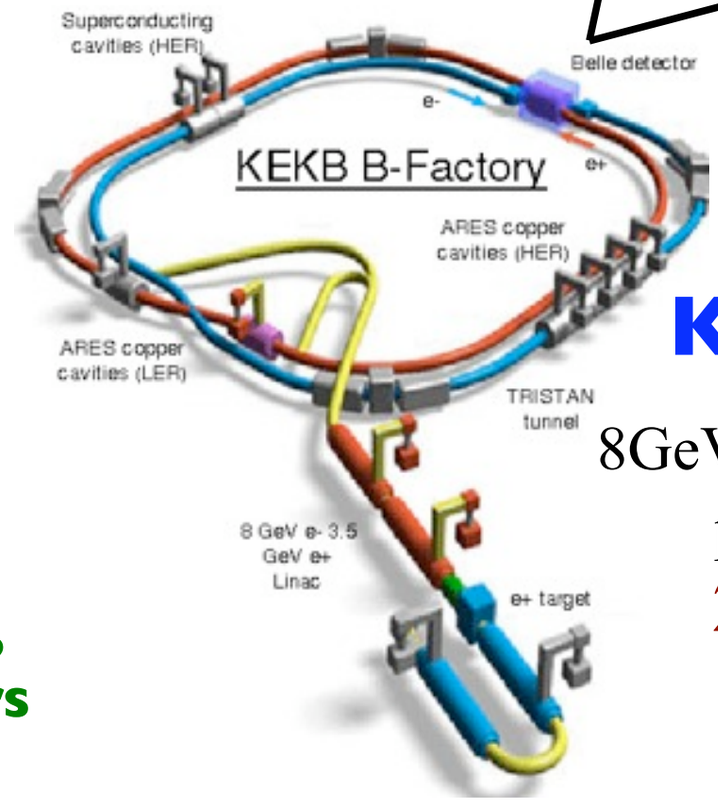


**11 nations,
80 institutes,
~600 members**

**13 countries,
57 institutes,
~400 members**



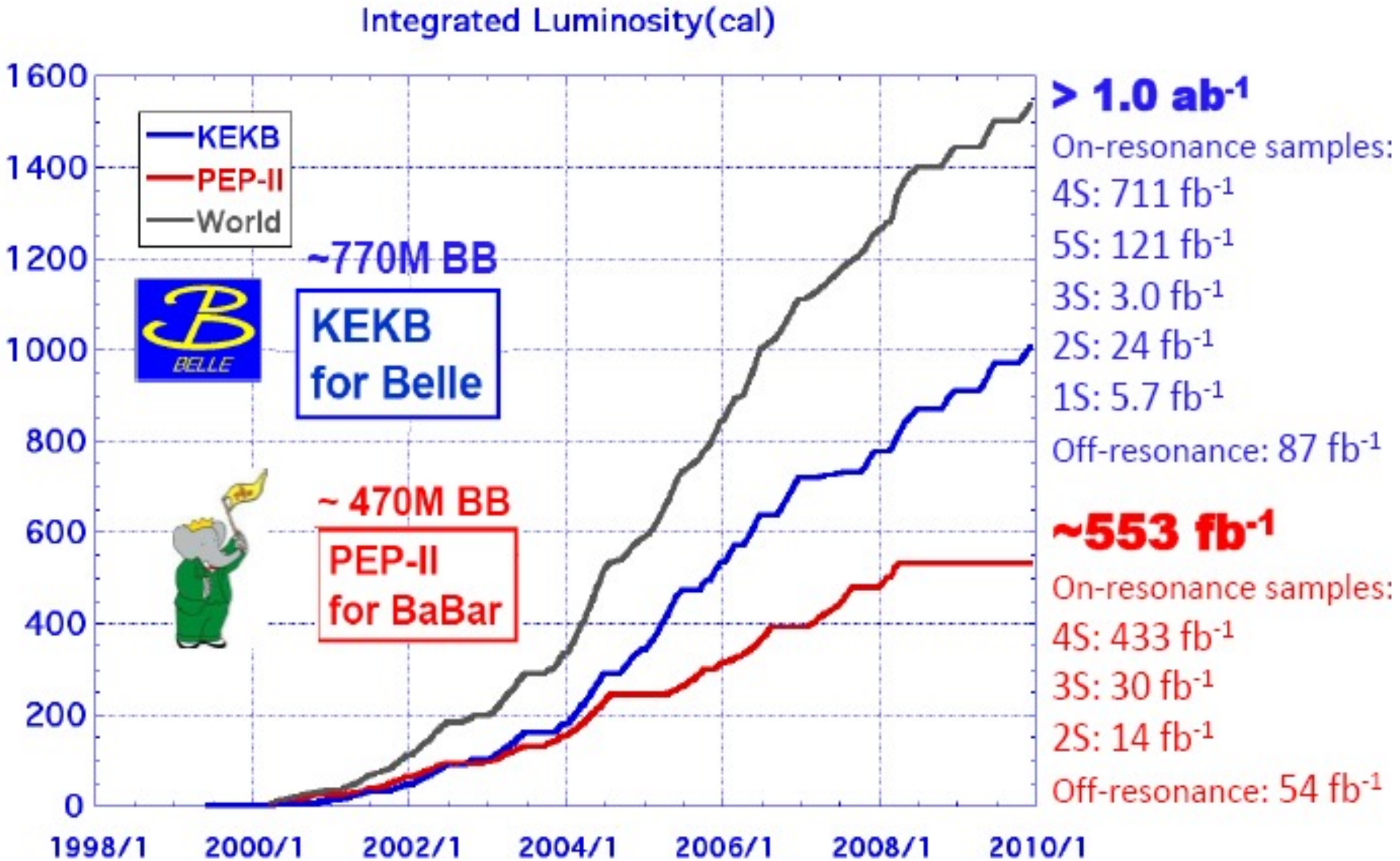
Belle



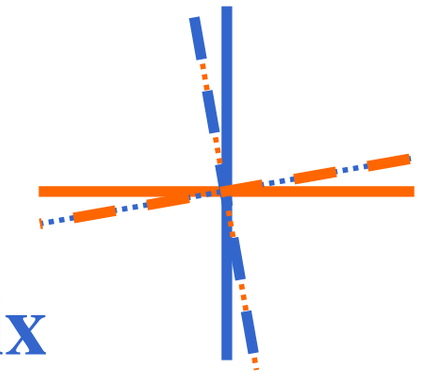

## KEKB at KEK

8GeV ($e^-$) × 3.5GeV ($e^+$)
peak luminosity:
**$2.1\times10^{34}cm^{-2}s^{-1}$**
***world record***

# B-factory Luminosities



# Flavor mixing and CKM matrix



- For quarks,
  - weak interaction eigenstates ≠ mass eigenstates
  - mixing of quark flavors through a **unitary matrix**

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \left(\mathrm{V_{CKM}}\right) \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} \mathrm{V}_{ud} & \mathrm{V}_{us} & \mathrm{V}_{ub} \\ \mathrm{V}_{cd} & \mathrm{V}_{cs} & \mathrm{V}_{cb} \\ \mathrm{V}_{td} & \mathrm{V}_{ts} & \mathrm{V}_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

**Wolfenstein parametrization**

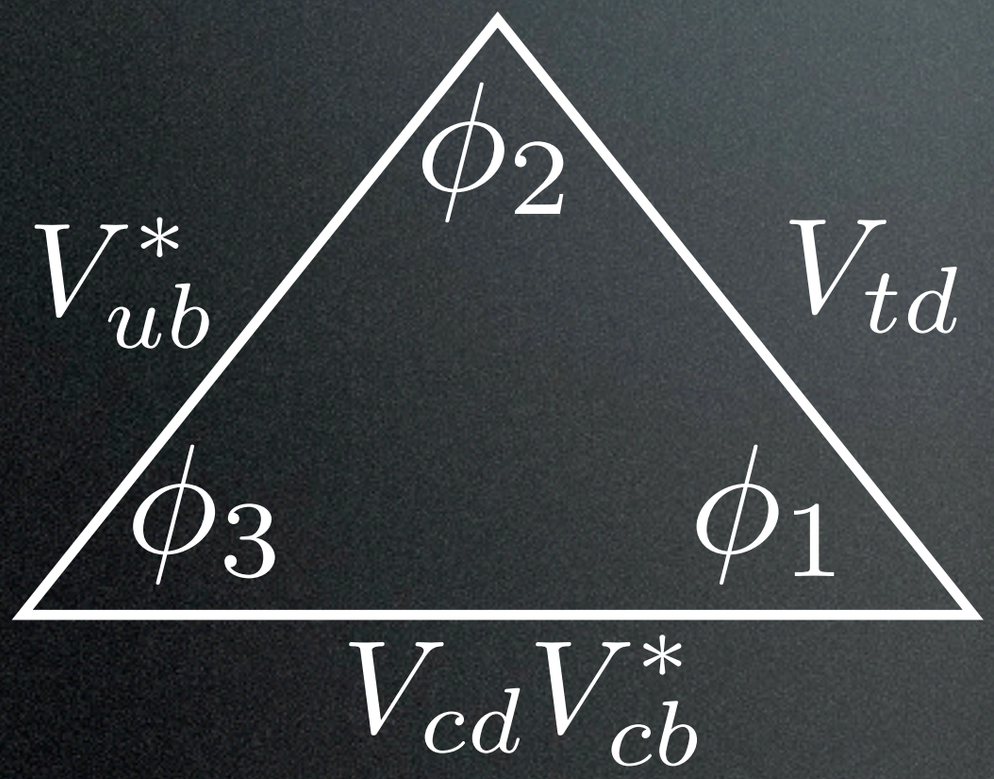
$$\mathbf{V}_{\mathrm{CKM}} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & \underline{A\lambda^3(\rho - i\eta)} \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ \underline{A\lambda^3(1-\rho-i\eta)} & -A\lambda^2 & 1 \end{pmatrix}$$

$$|\lambda| \approx O(0.1)$$

3 real parameters $(\lambda, A, \rho)$ and 1 phase $(\eta)$

# the CKM UT angles

- Extract the UT angles through time-dependent $A_{CP}$ measurement.



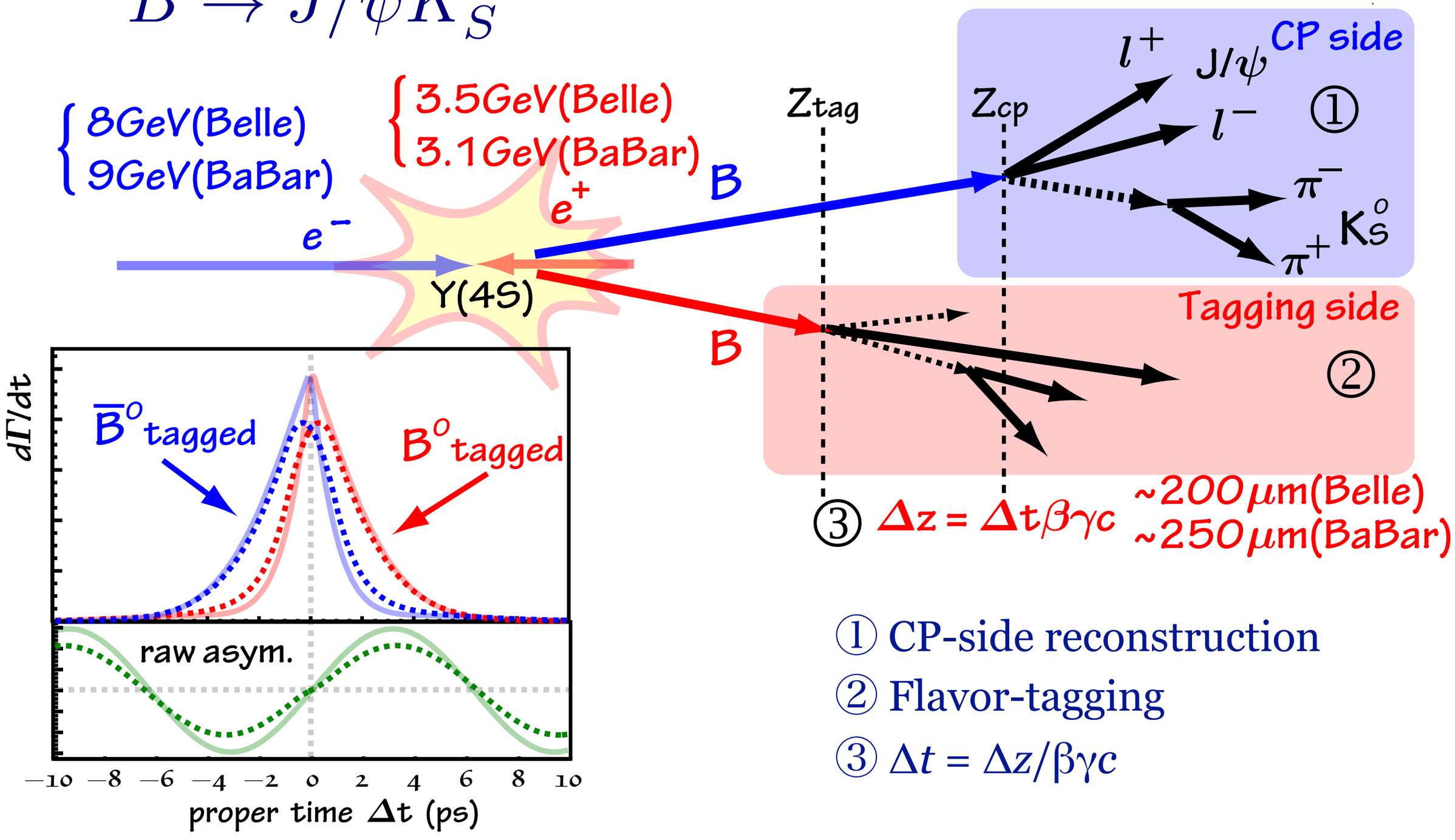

| Unitarity triangle angles | | | |
|---|---|---|---|
| BABAR: | $\beta$ | $\alpha$ | $\gamma$ |
| BELLE: | $\phi_1$ | $\phi_2$ | $\phi_3$ |
| | 易 | 難 | 魔 |

Z. Ligeti, ICHEP 2004

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$
$$V_{ud} \simeq V_{tb} \simeq 1$$

# to measure the angles

$$B \to J/\psi K^0_S$$

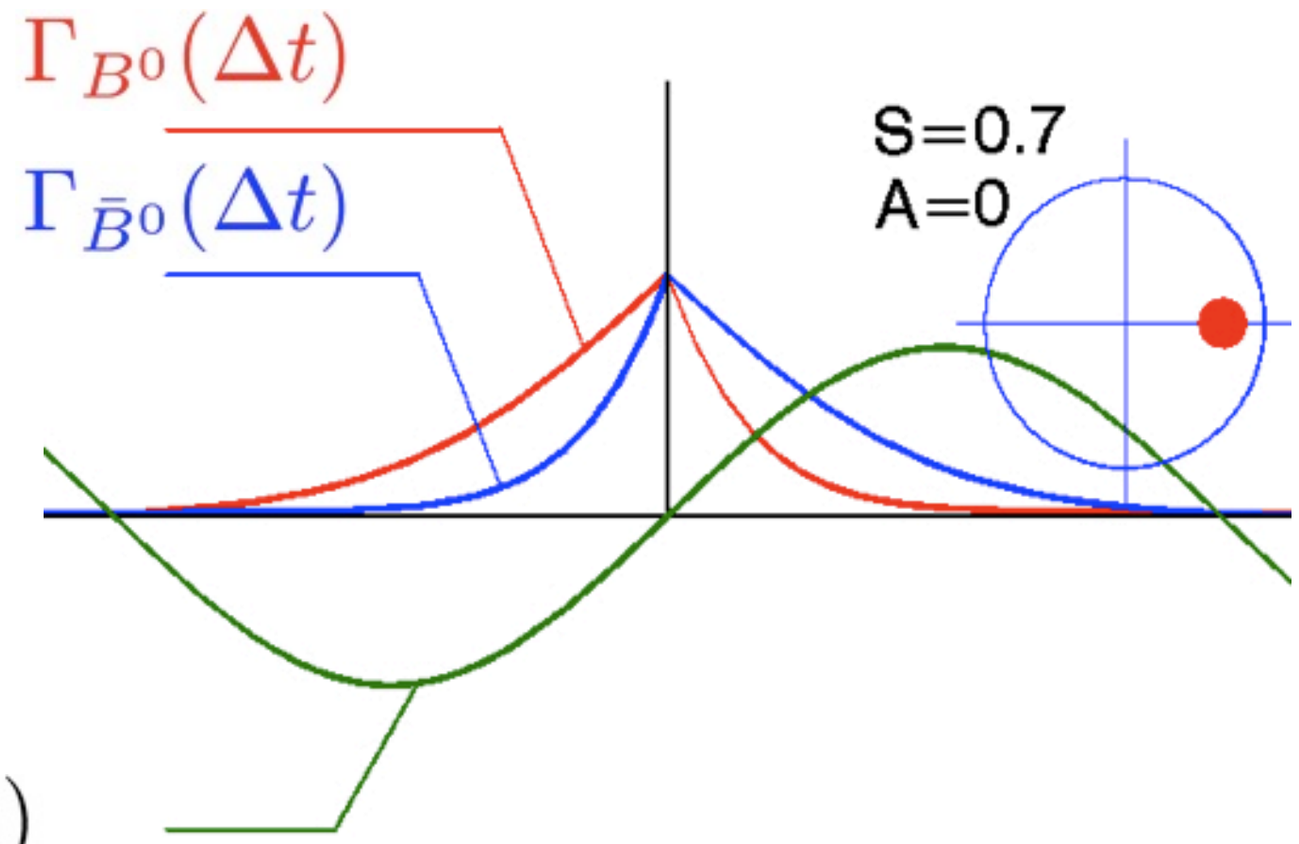



① CP-side reconstruction

② Flavor-tagging

③ $\Delta t = \Delta z/\beta\gamma c$

# to measure the angles




$$\equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)}$$

$$= \mathcal{S}\sin\Delta m\Delta t + \mathcal{A}\cos\Delta m\Delta t$$

Mixing-induced CPV

Direct CPV

($\mathcal{A} = -C$ a la BaBar)

e.g. for $B \to J/\psi K^0$,

$\mathcal{S} \approx -\xi_{CP}\sin 2\phi_1$

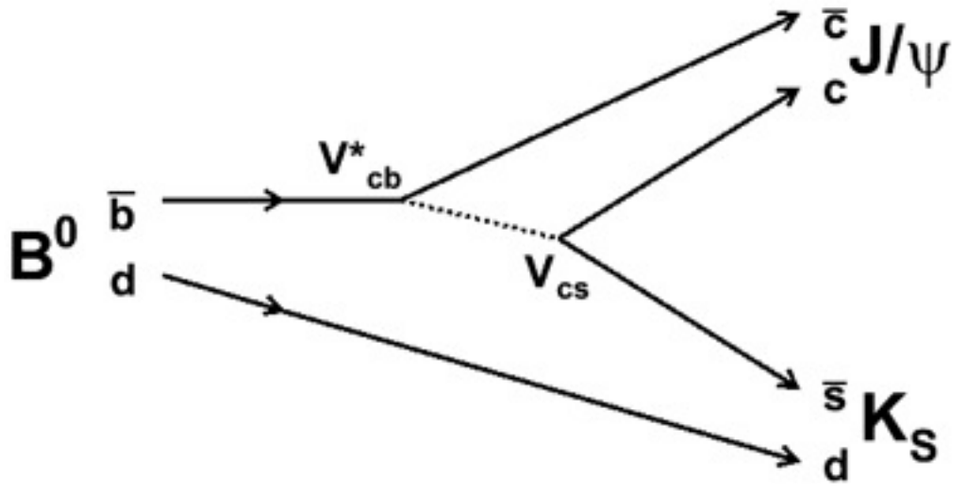
$\mathcal{A} \approx 0$

($\xi_{CP}$: $CP$ eigenvalue)

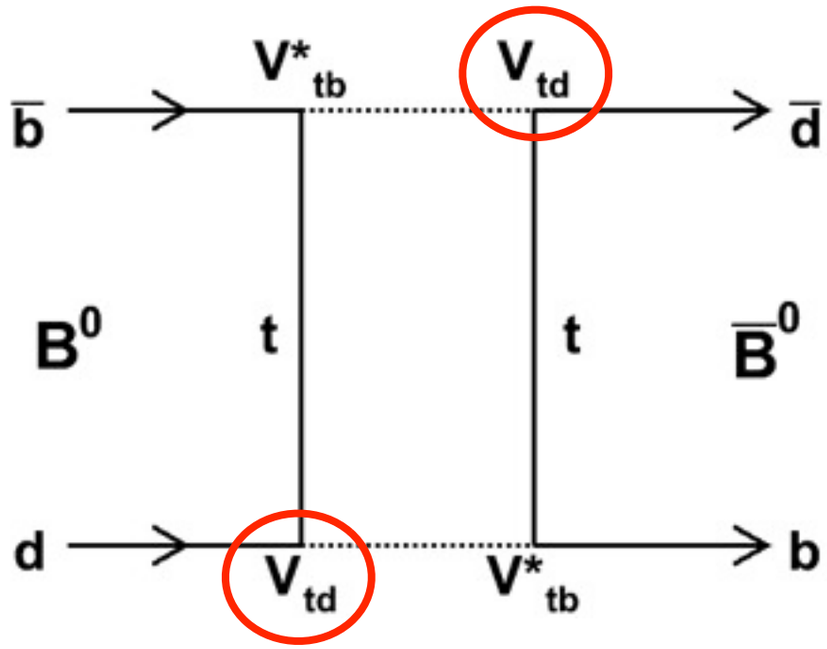
# The Golden mode for $\phi_1$

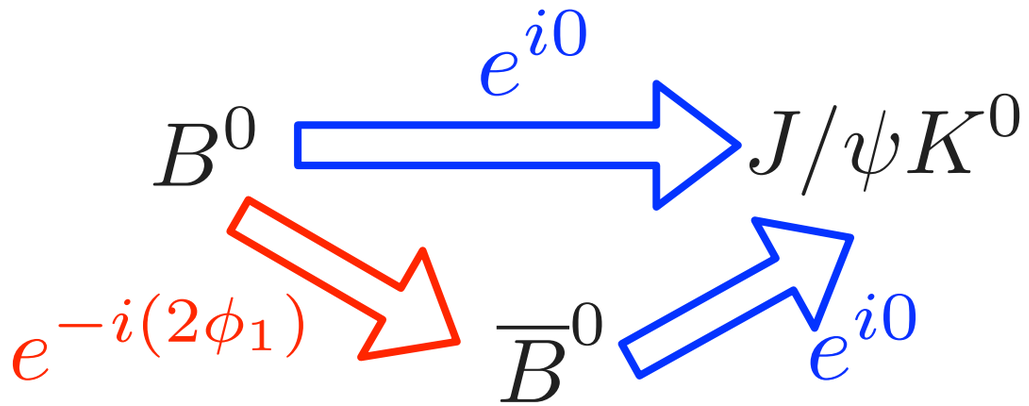
$B^0 \to J/\psi K^0$ : high rate, theoretically clean

No CKM phase $e^{i0}$

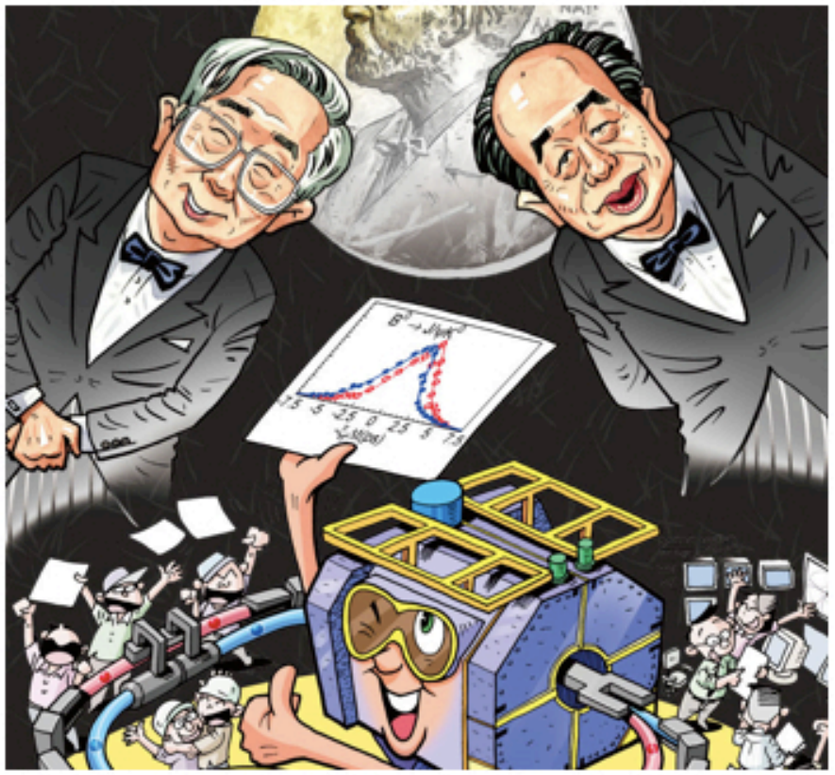


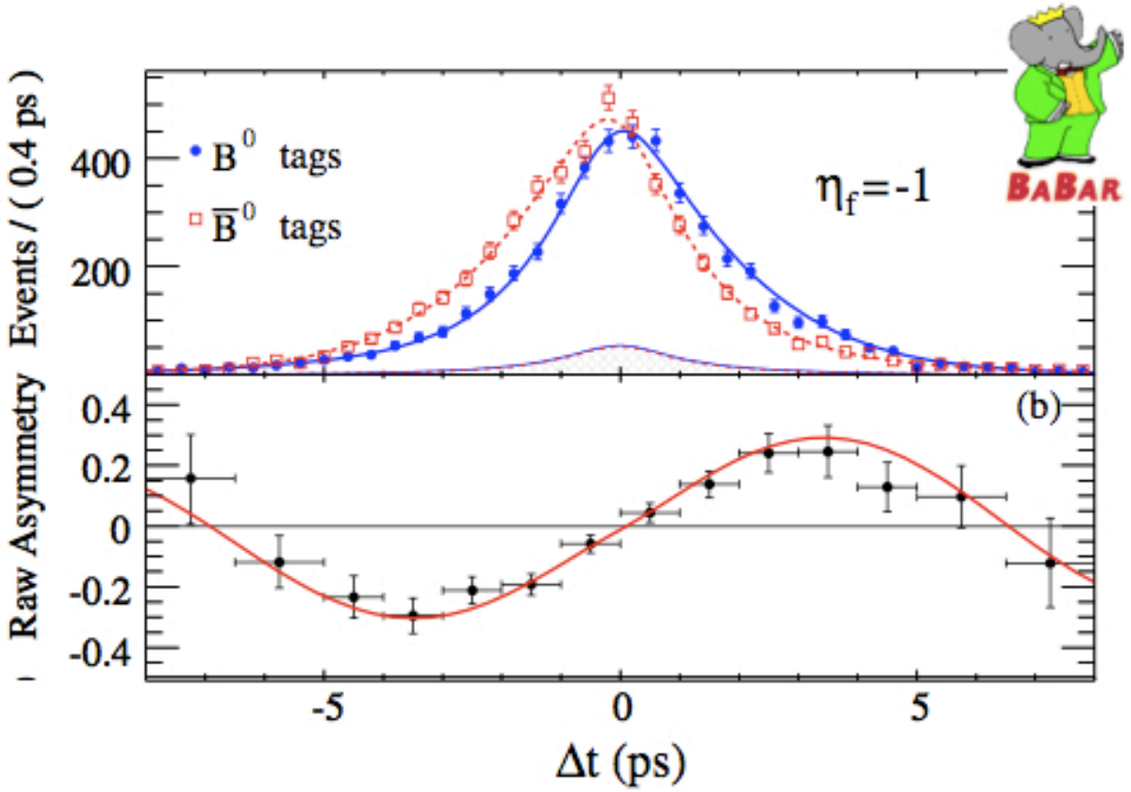

Two $V_{td}$ vertices $e^{-i(2\phi_1)}$



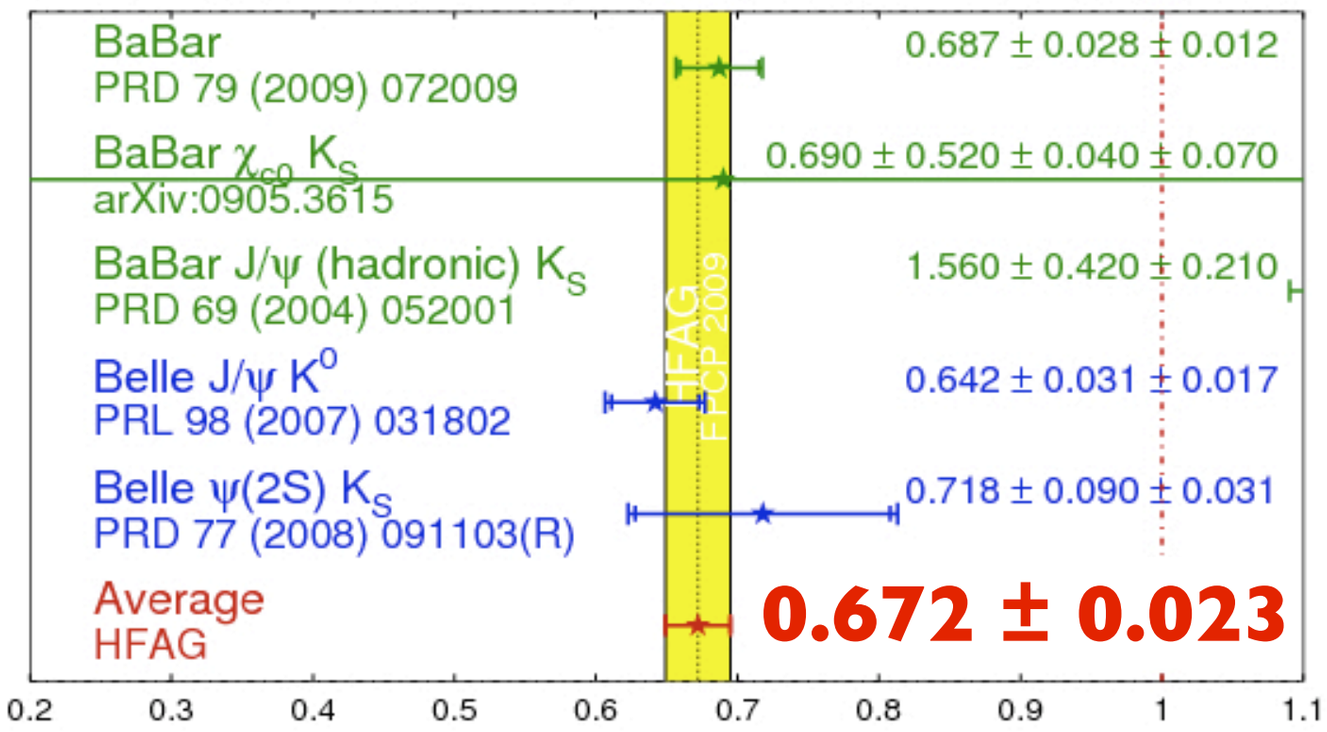

Note: true for any $B^0$ decay with no phase from decay amplitude

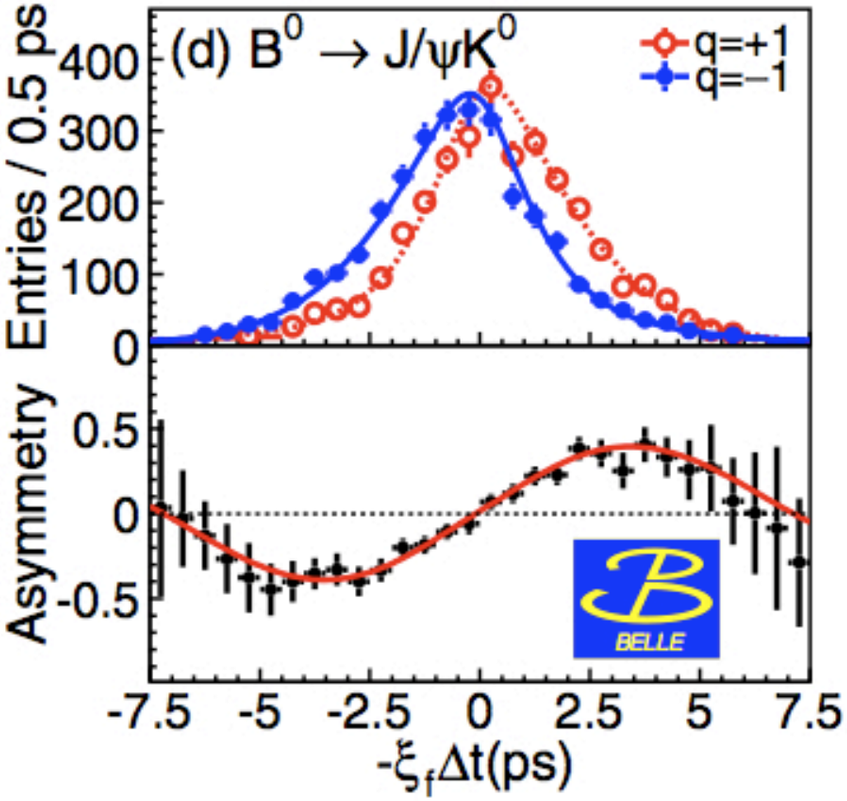


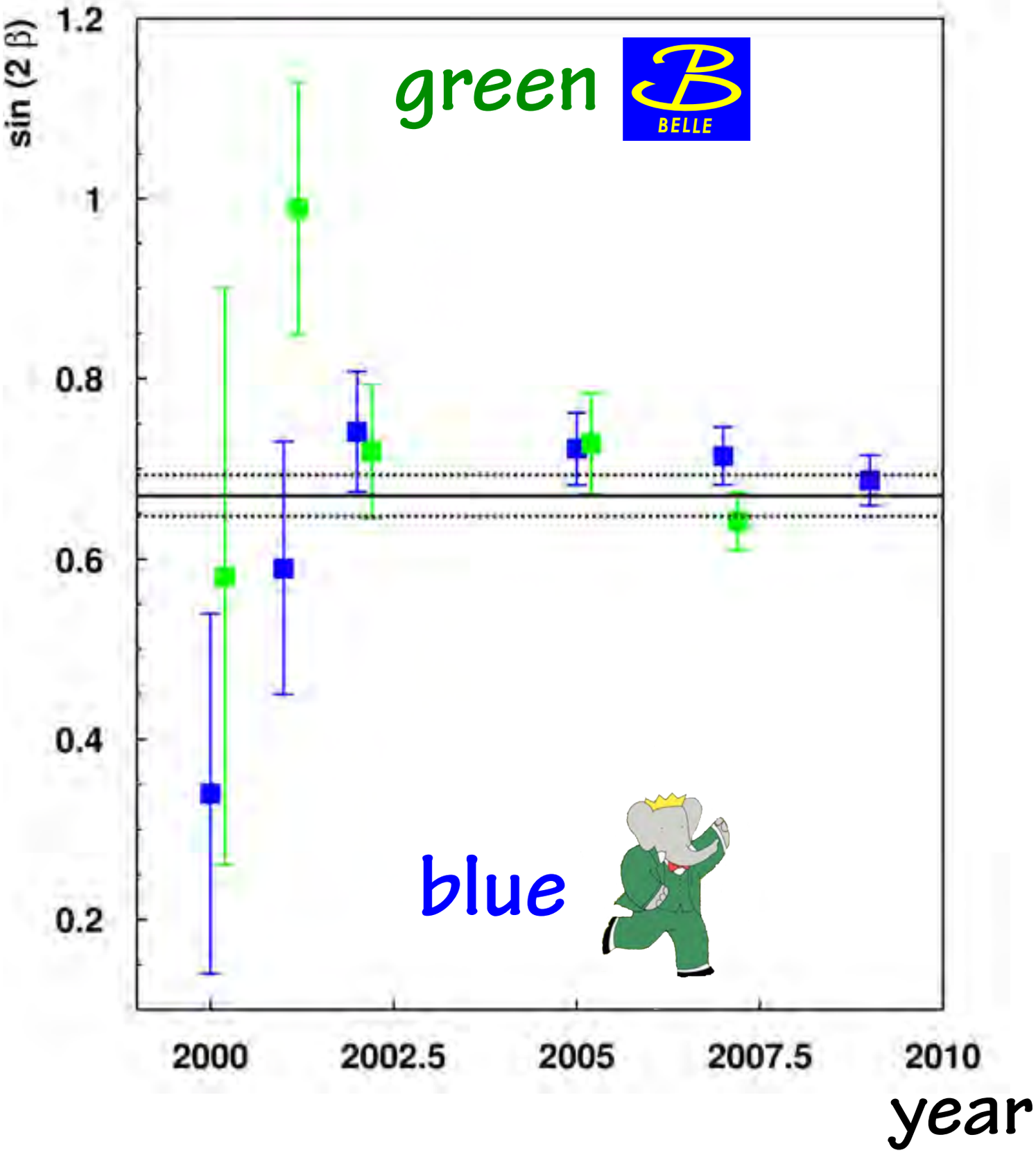



# $\sin(2\beta) \equiv \sin(2\phi_1)$

HFAG
FPCP 2009
PRELIMINARY



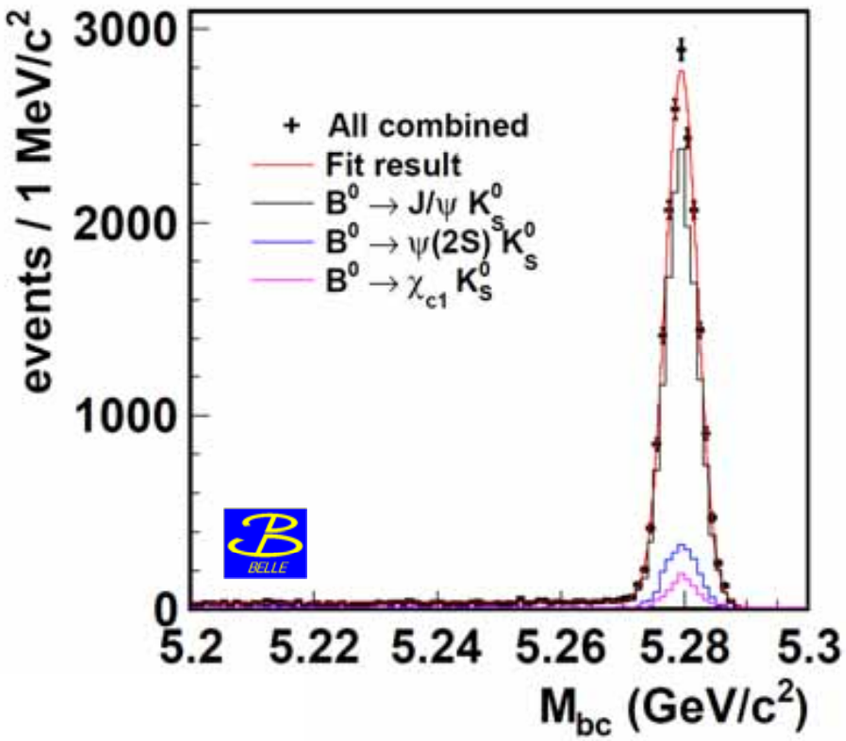



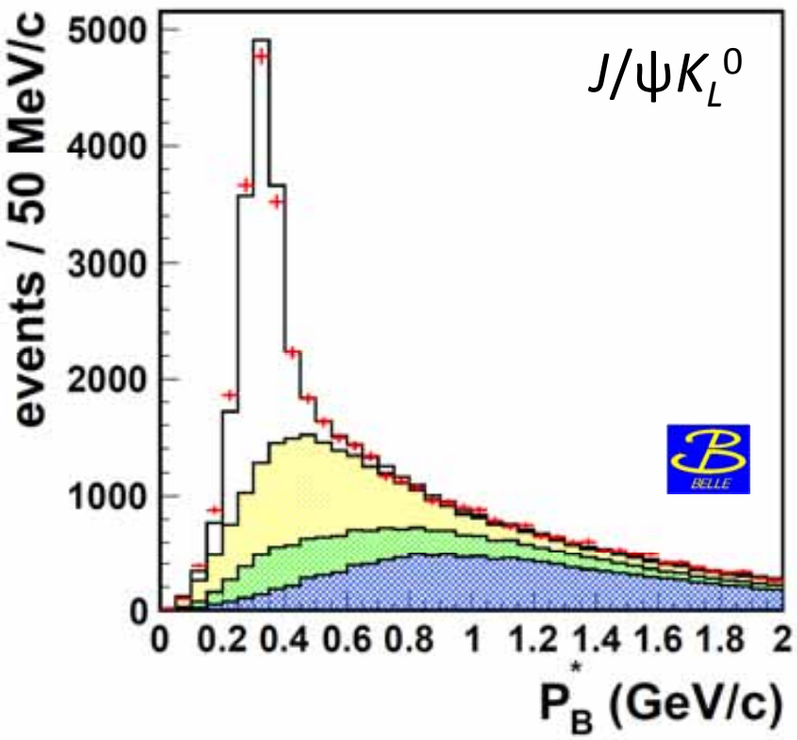



$\sin(2\phi_1)$ now became precision measurement!

# *Belle's up-coming update...*

from $N_{BB} = 772 \times 10^6$
final Belle data sample



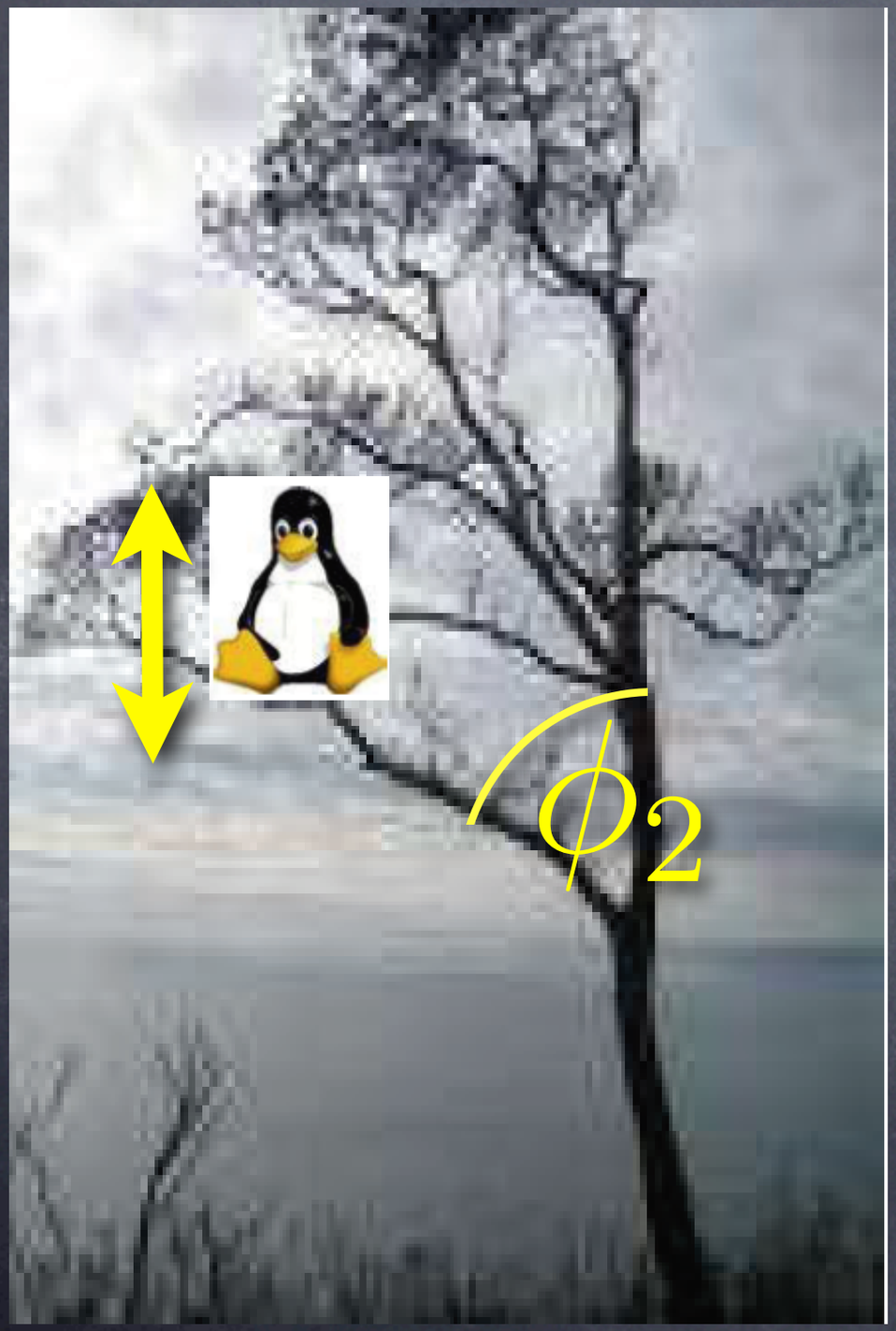

*With reprocessing for improved track-finding, we have more yields than the simple $N_{BB}$ scaling.*

| | $N(J/\psi K_S^0)$ | $N(J/\psi K_L^0)$ | $N_{B\bar{B}}$ $(\times 10^6)$ |
|---|---|---|---|
| Belle ($'10$) | $12727 \pm 115$ | $10087 \pm 154$ | 772 |
| purity | 0.97 | 0.63 | |
| Belle ($'06$) | $7484 \pm 87$ | $6512 \pm 123$ | 535 |
| purity | 0.97 | 0.59 | |

We will soon finalize the results. The expected stat. uncertainties are:

$$\sigma(\sin 2\phi_1) \approx 0.024, \quad \sigma(A_{CP}) \approx 0.016$$

# Other angles?

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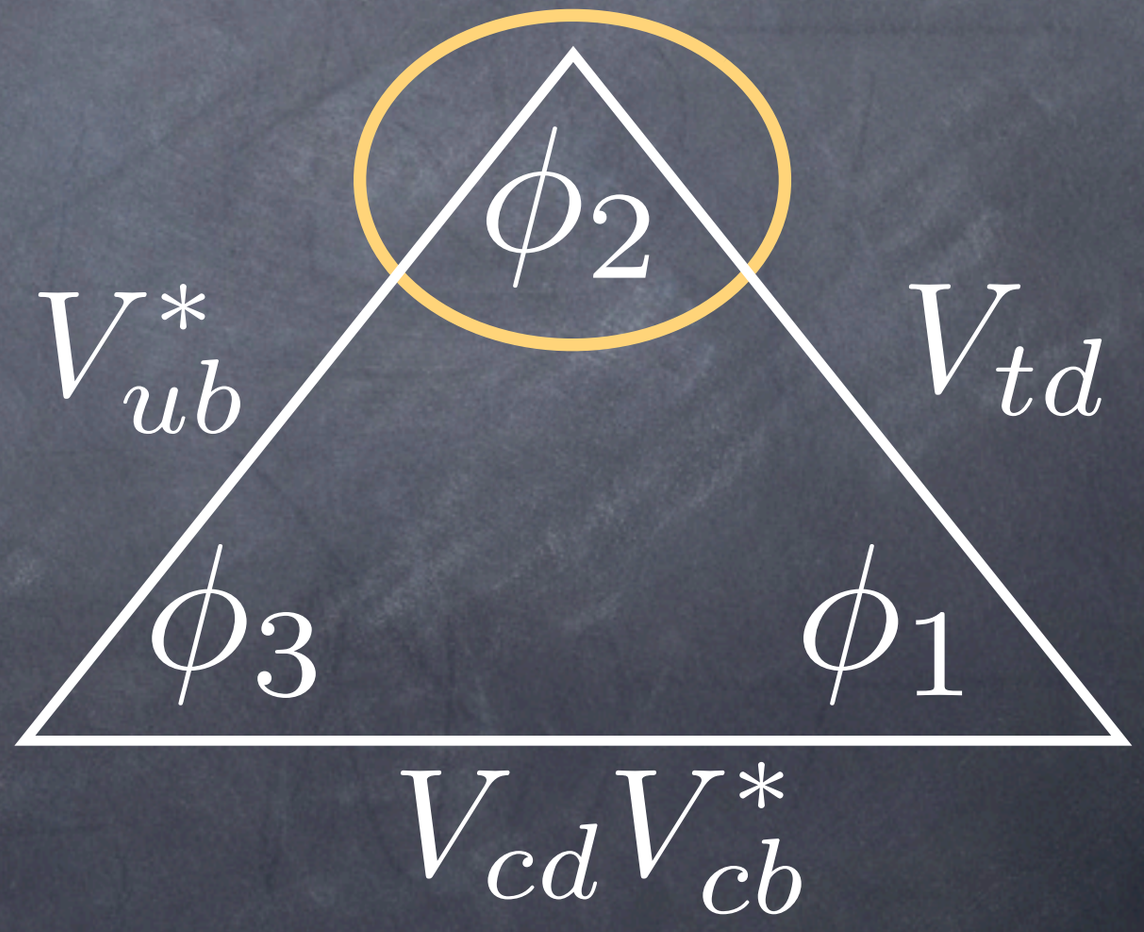


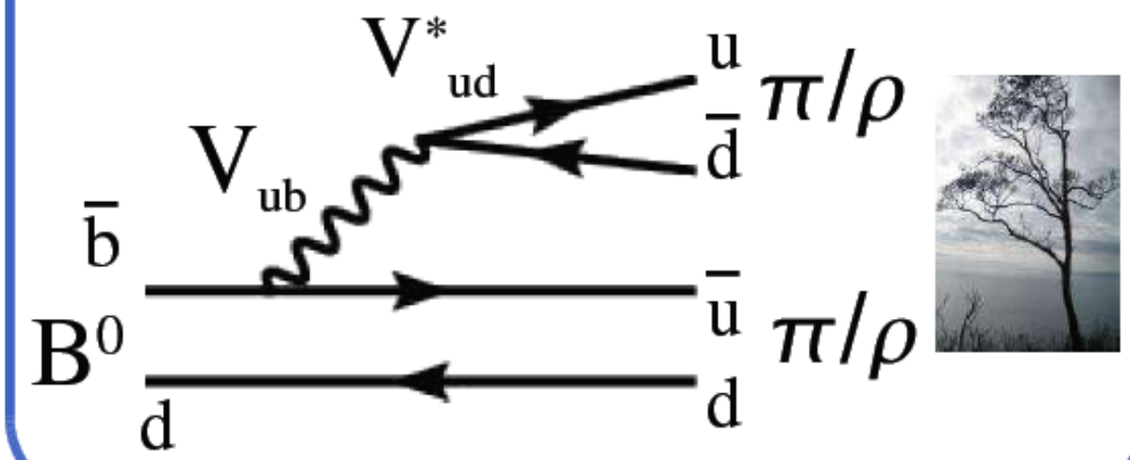
# to measure $\phi_2$

$B^0 \to \rho^+\rho^-$

$B^0 \to \rho^\pm\pi^\mp$

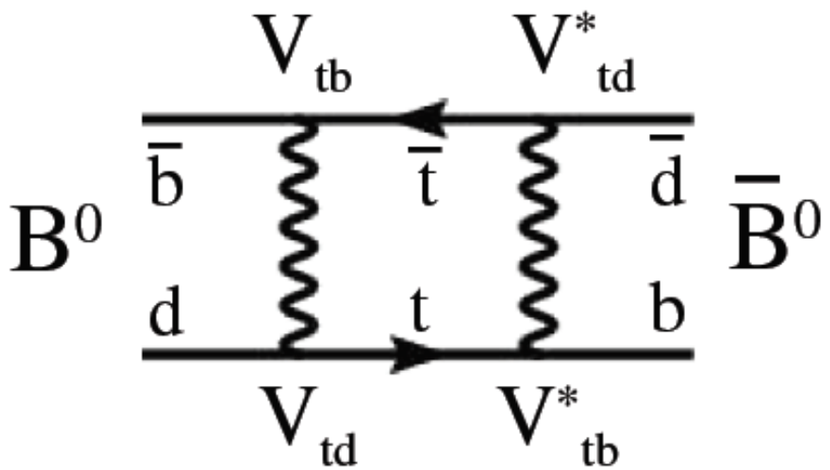
$B^0 \to \pi^+\pi^-$

Tree diagram




$\phi_2$

Mixing




Two phases

- mixing: $V_{td}$ --> $\phi_1$
- tree: $V_{ub}$ --> $\phi_3$

$180^\circ - (\phi_1 + \phi_3) \Rightarrow \phi_2$

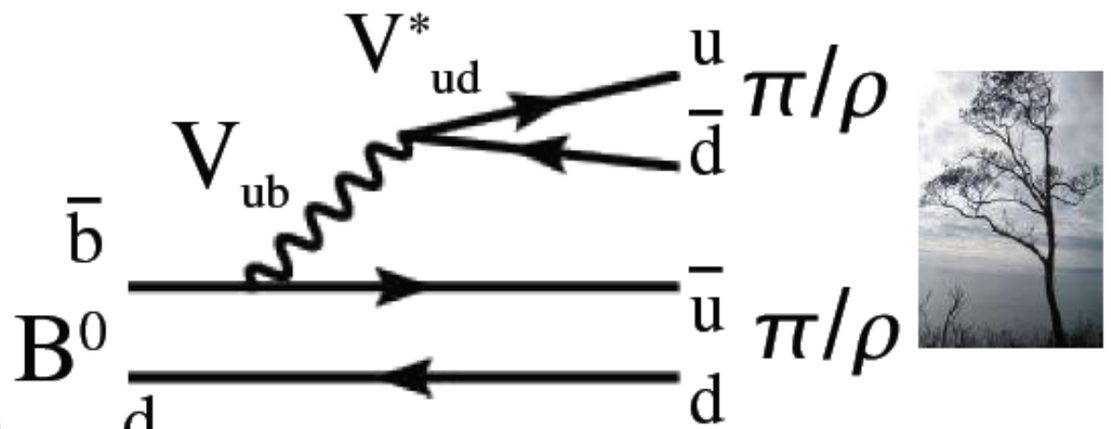
# penguin's shaking a tree...

$B^0 \to \rho^+ \rho^-$

$B^0 \to \rho^\pm \pi^\mp$

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

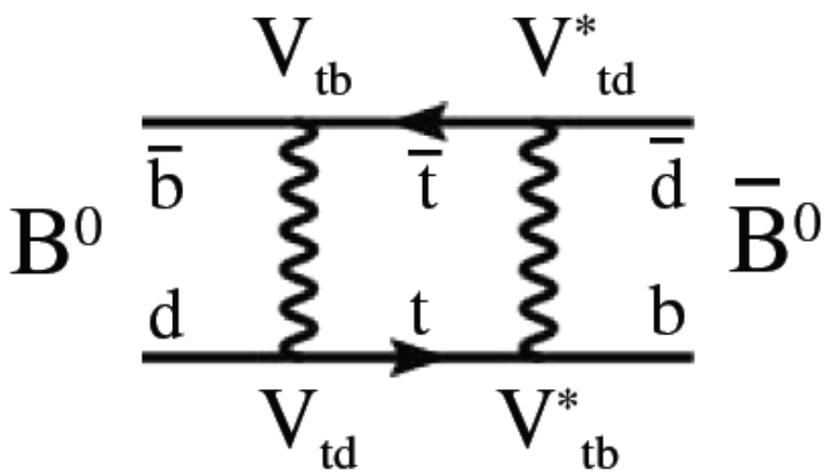
Tree diagram



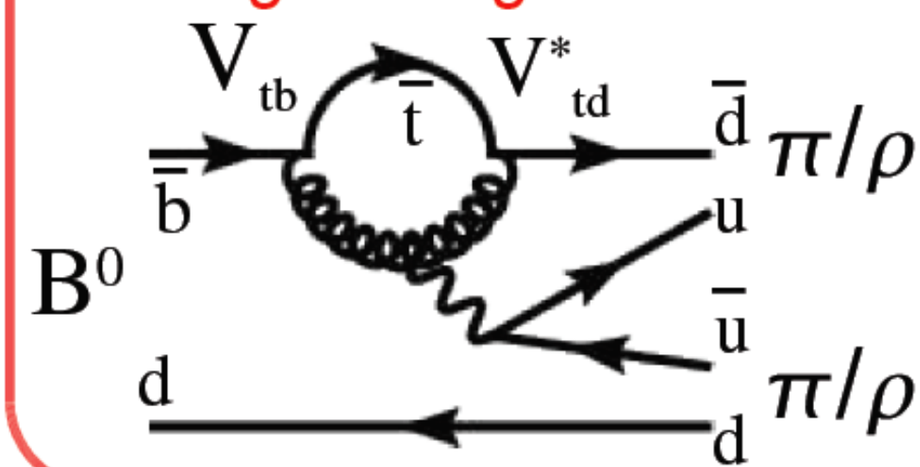



$\phi_2$

Mixing




Penguin diagram



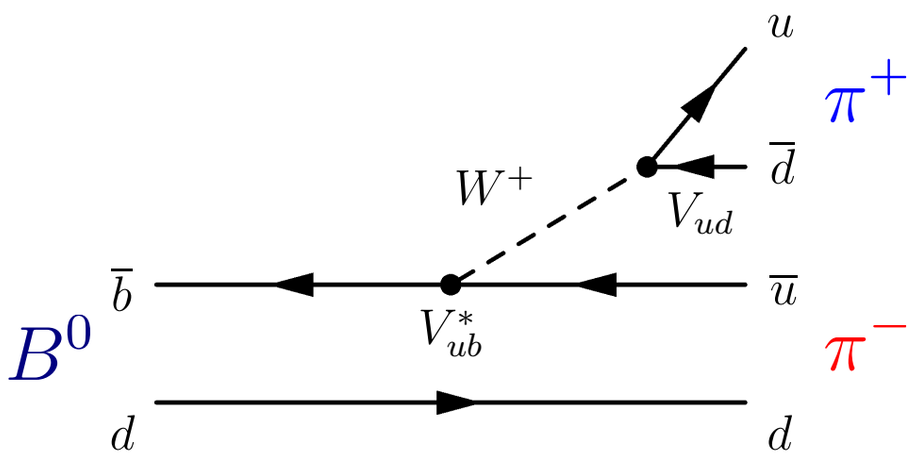
0

***What shall we do?***

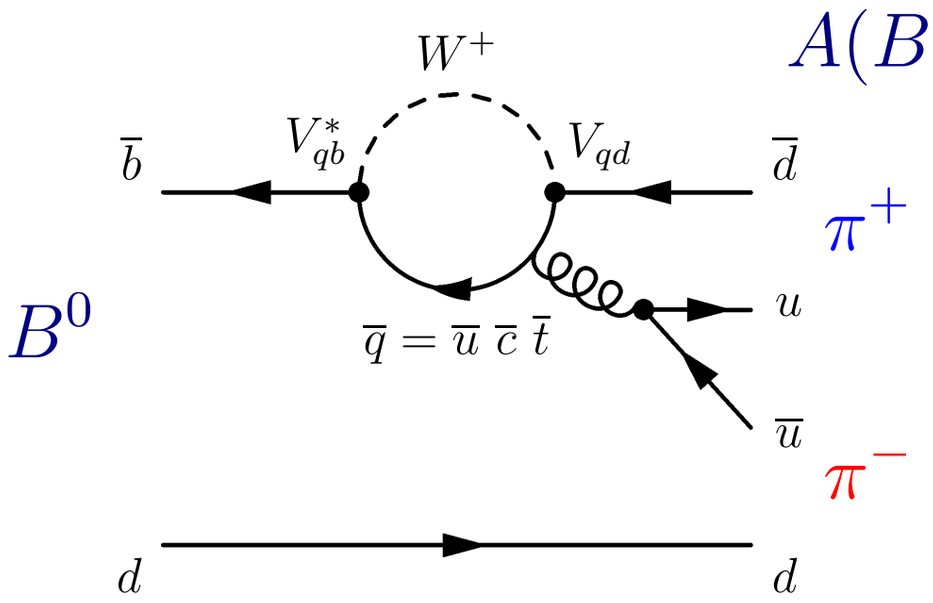
Gronau & London, PRL 65, 3381 (1990)

# Isospin Analysis

## "Penguin pollution" can be removed




$I(B^0) = (½, -½)$
$I(\pi^+) = (1, +1)$
$I(\pi^-) = (1, -1)$




$$A(B^0 \to \pi^+\pi^-) \propto A_{\frac{3}{2},2} \oplus A_{\frac{1}{2},0}$$

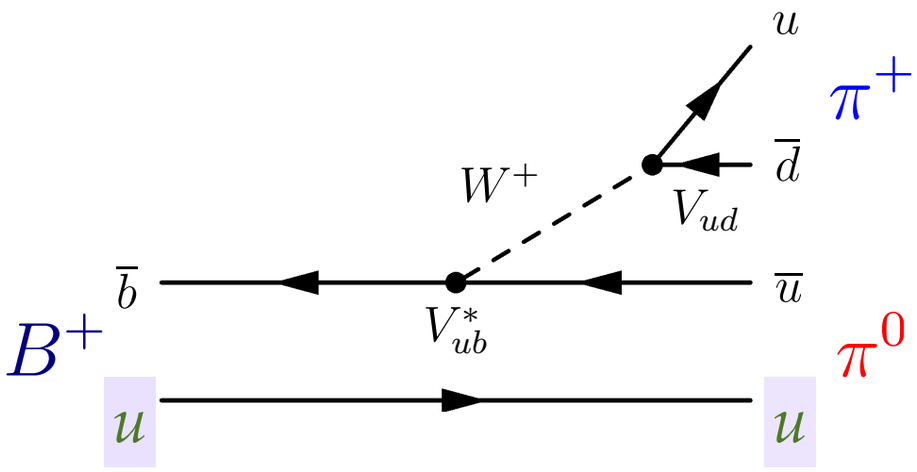
due to bosonic symmetry,
I ≠ 1 in the B -> π π final state

for gluonic transition, ΔI = 0.
∴ I ≠ 2 for gluonic penguins.

Gronau & London, PRL 65, 3381 (1990)

# Isospin Analysis

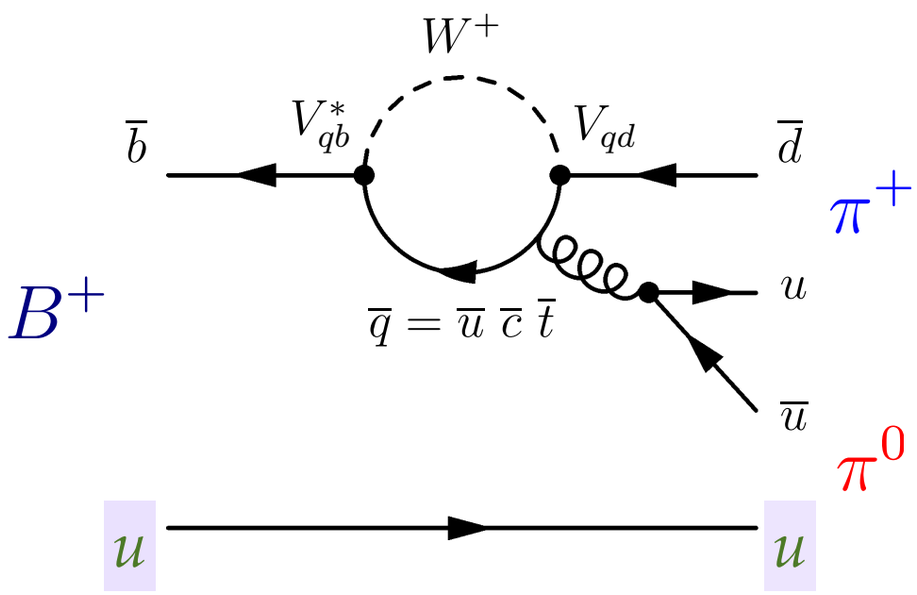
## "Penguin pollution" can be removed




$I(B^+) = (½, ½)$
$I(\pi^+) = (1, +1)$
$I(\pi^0) = (1, 0)$

***no penguin!***

$$A(B^+ \to \pi^+\pi^0) \propto A_{\frac{3}{2},2}$$



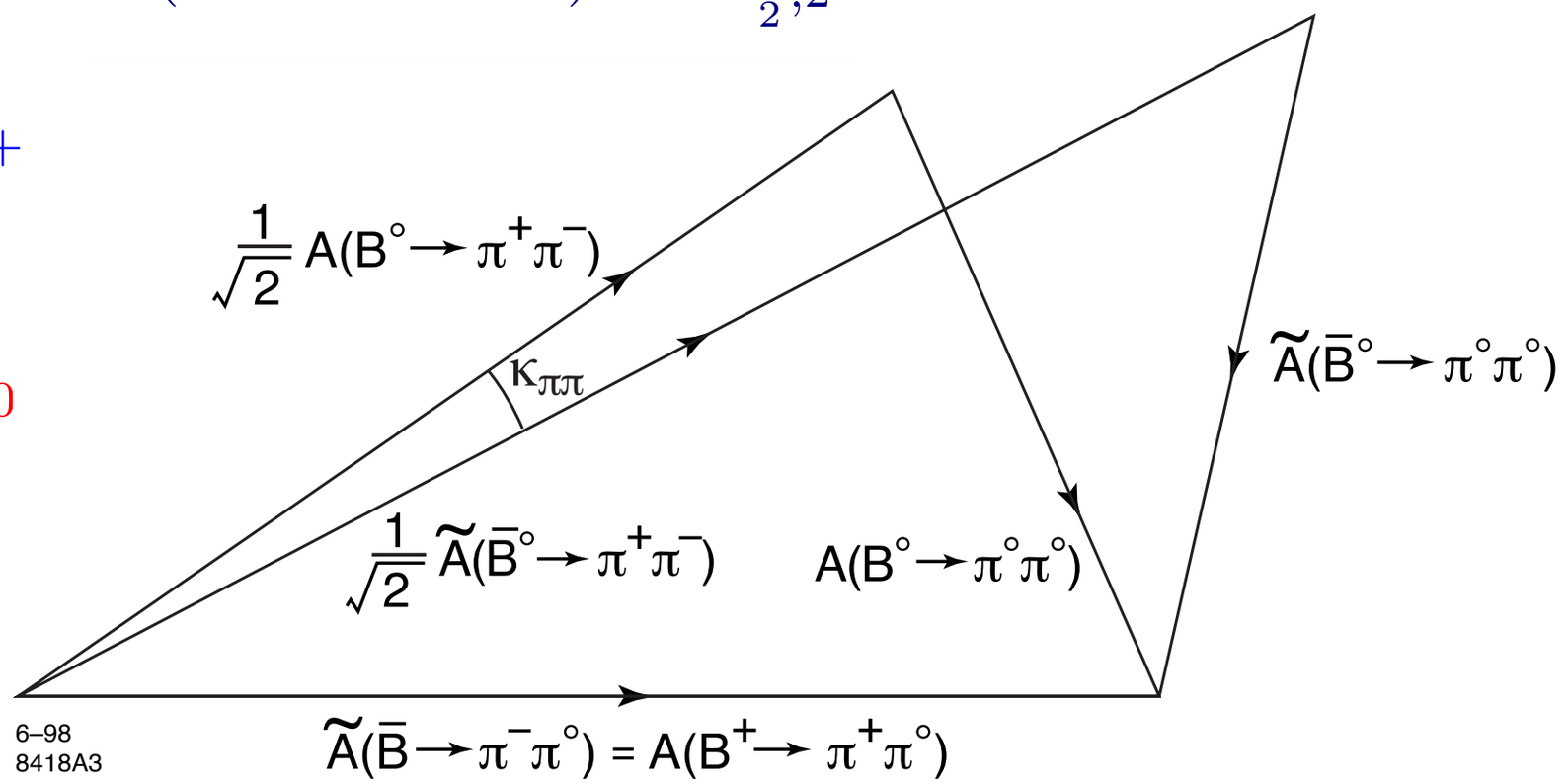
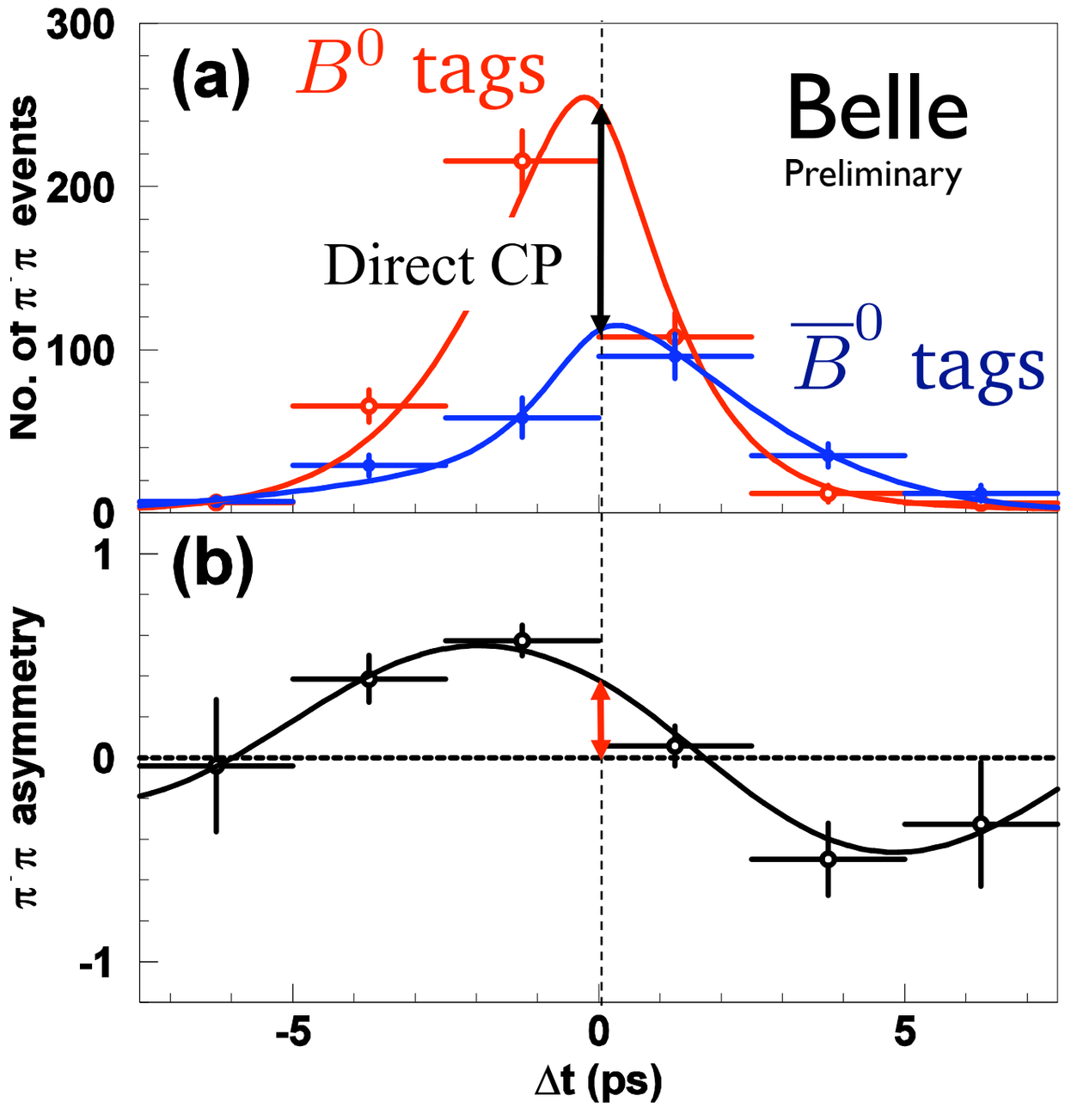



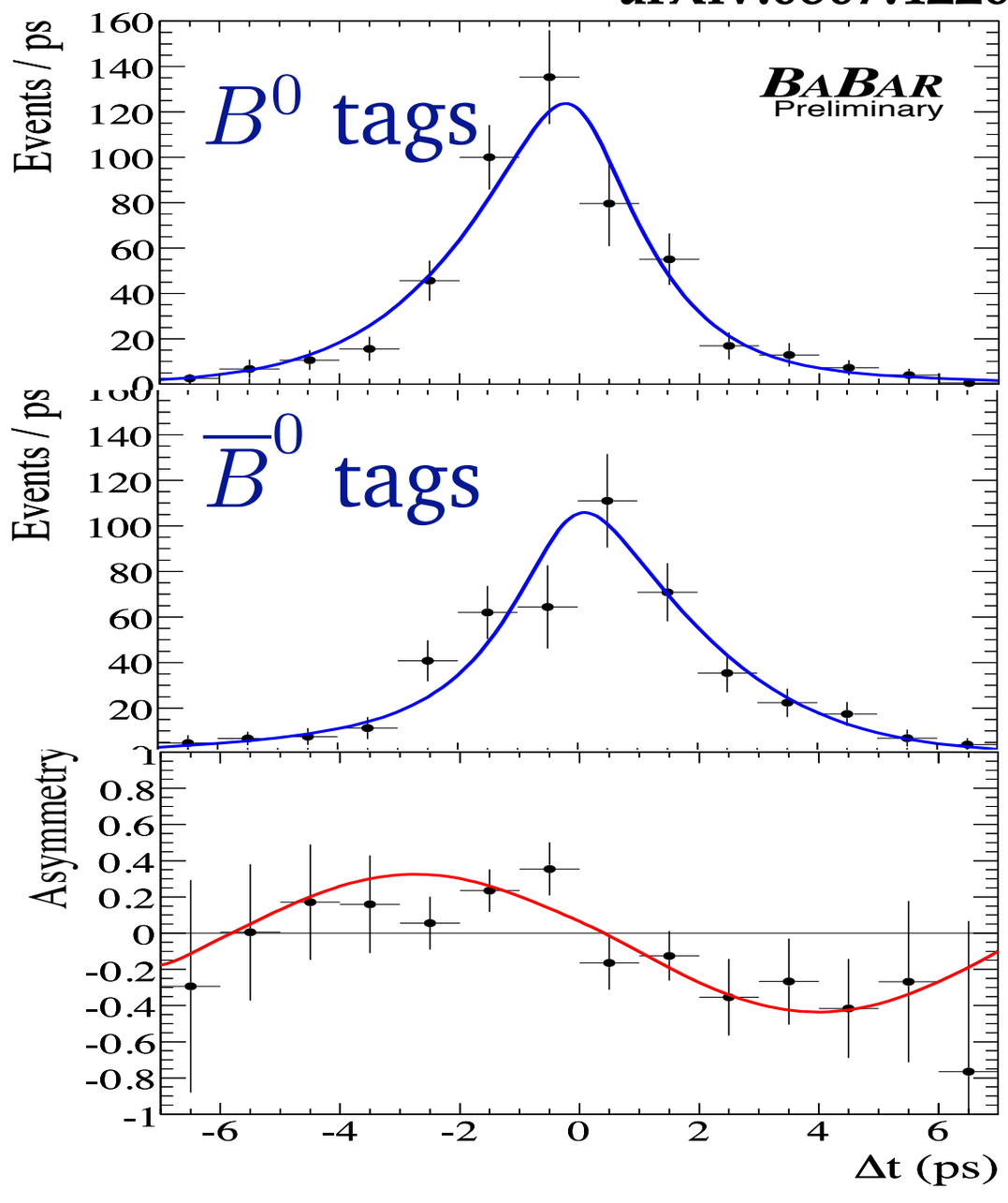

**Figure 6-1.** *Isospin analysis of $B \to \pi\pi$ decays.*

# $A_{CP}(\Delta t)$ from $B^0 \to \pi^+\pi^-$

PRL 98, 211801 (2007)



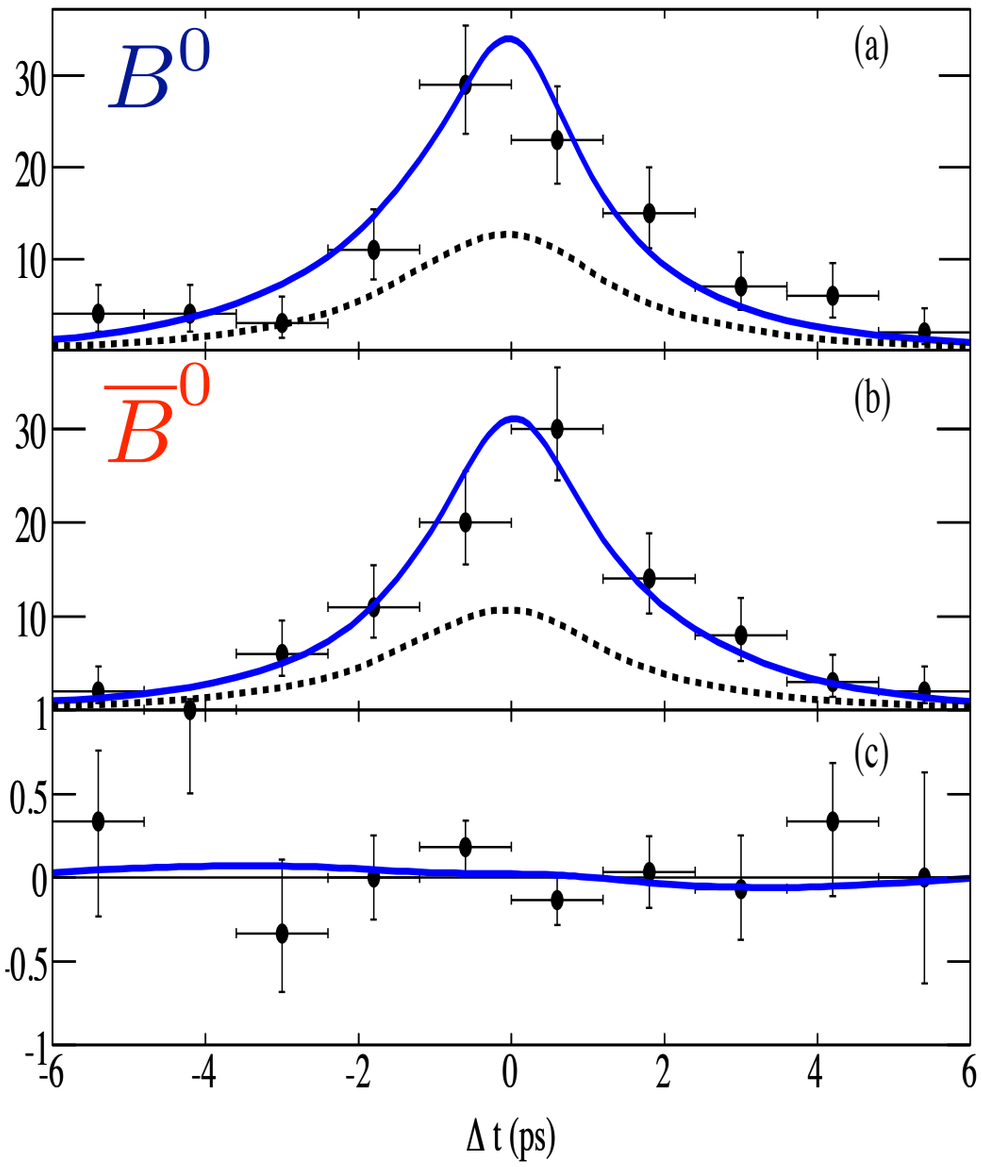

arXiv:0807.4226




$$C_{\rm CP} \neq 0 \Rightarrow S_{\rm CP} = \sqrt{1 - C_{\rm CP}^2}\sin(2\phi_2^{\rm eff})$$

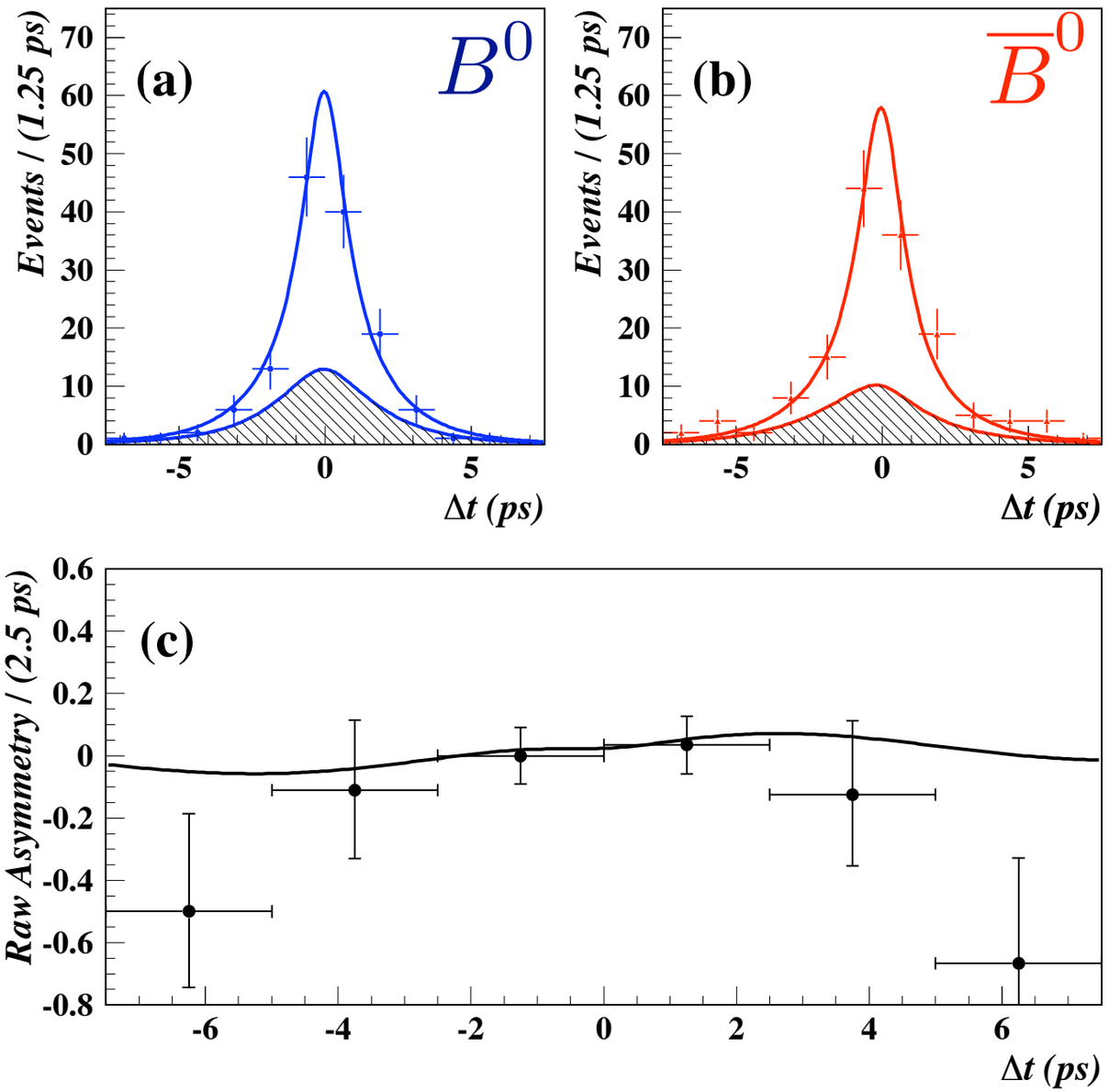
# $A_{CP}(\Delta t)$ from $B^0 \to \rho^+\rho^-$

**BABAR, PRD 76, 052007 (2007)**



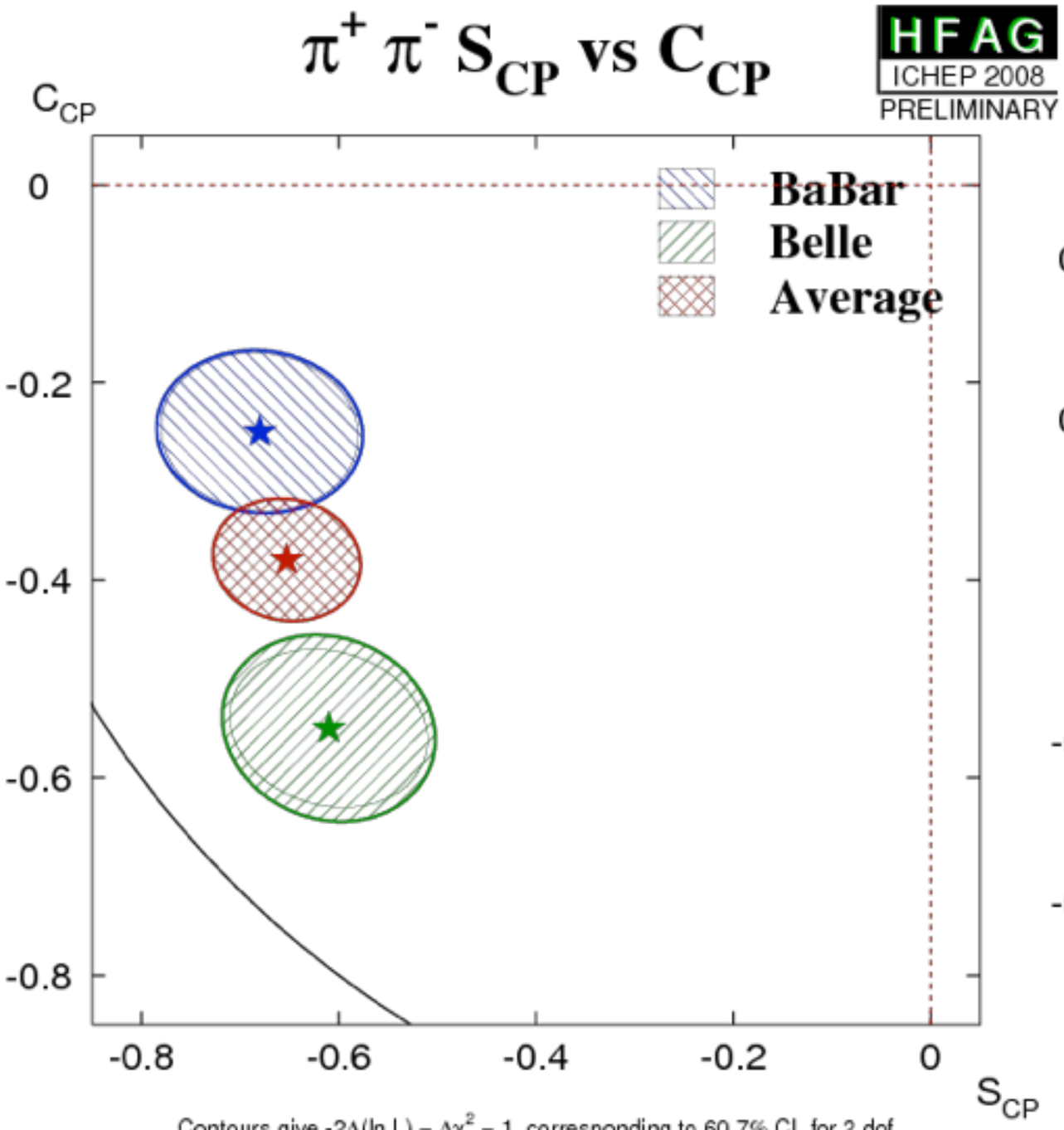

$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (25.5 \pm 2.1(\text{stat})^{+3.6}_{-3.9}(\text{syst})) \times 10^{-6},$$
$$f_L = 0.992 \pm 0.024(\text{stat})^{+0.026}_{-0.013}(\text{syst}),$$
$$S_{\text{long}} = -0.17 \pm 0.20(\text{stat})^{+0.05}_{-0.06}(\text{syst}),$$
$$C_{\text{long}} = 0.01 \pm 0.15(\text{stat}) \pm 0.06(\text{syst}).$$

**Belle, PRD 76, 011104 (2007)**

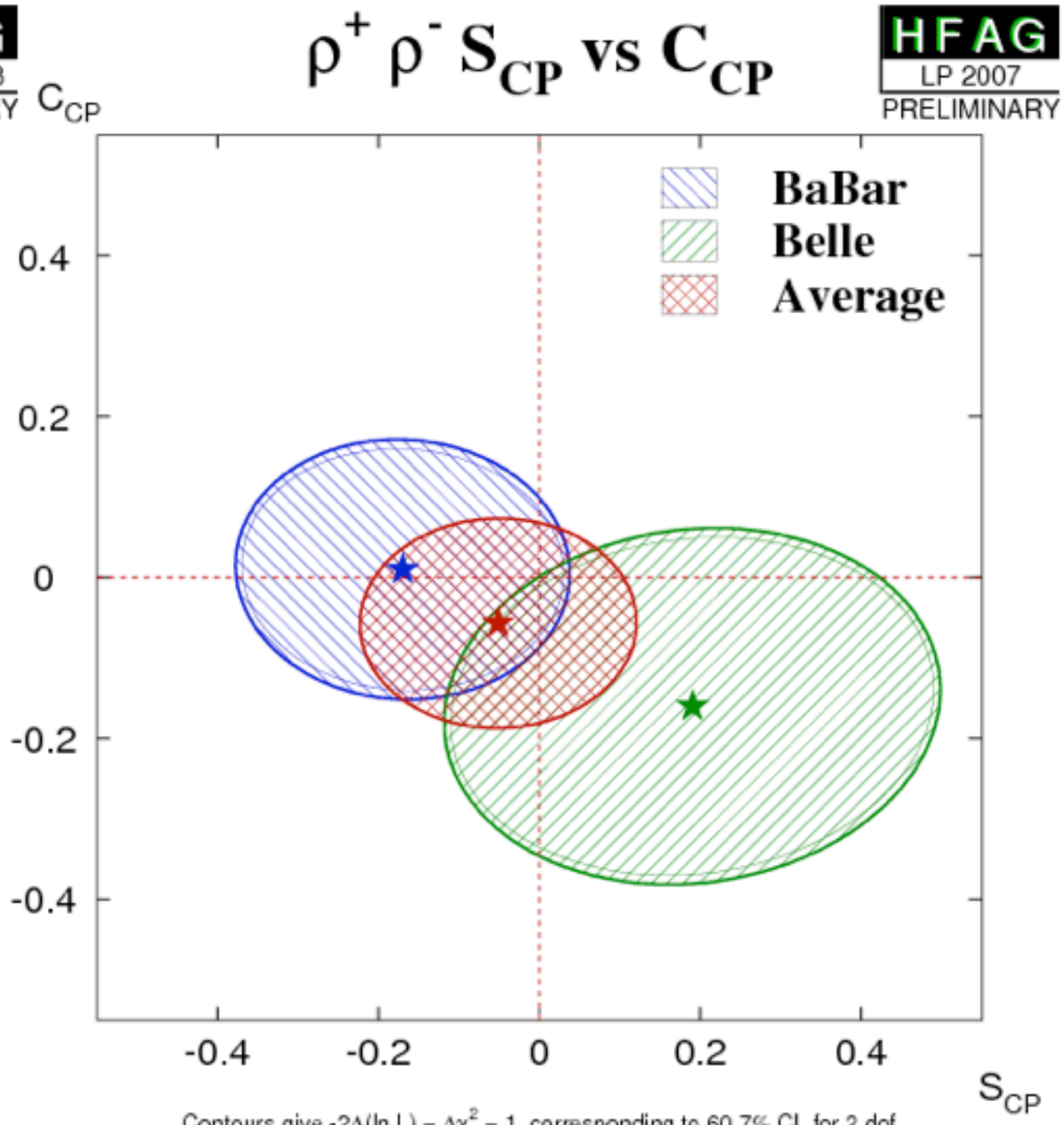



$$\mathcal{A}_L = 0.16 \pm 0.21\,(\text{stat}) \pm 0.07\,(\text{syst})$$
$$\mathcal{S}_L = 0.19 \pm 0.30\,(\text{stat}) \pm 0.07\,(\text{syst})$$

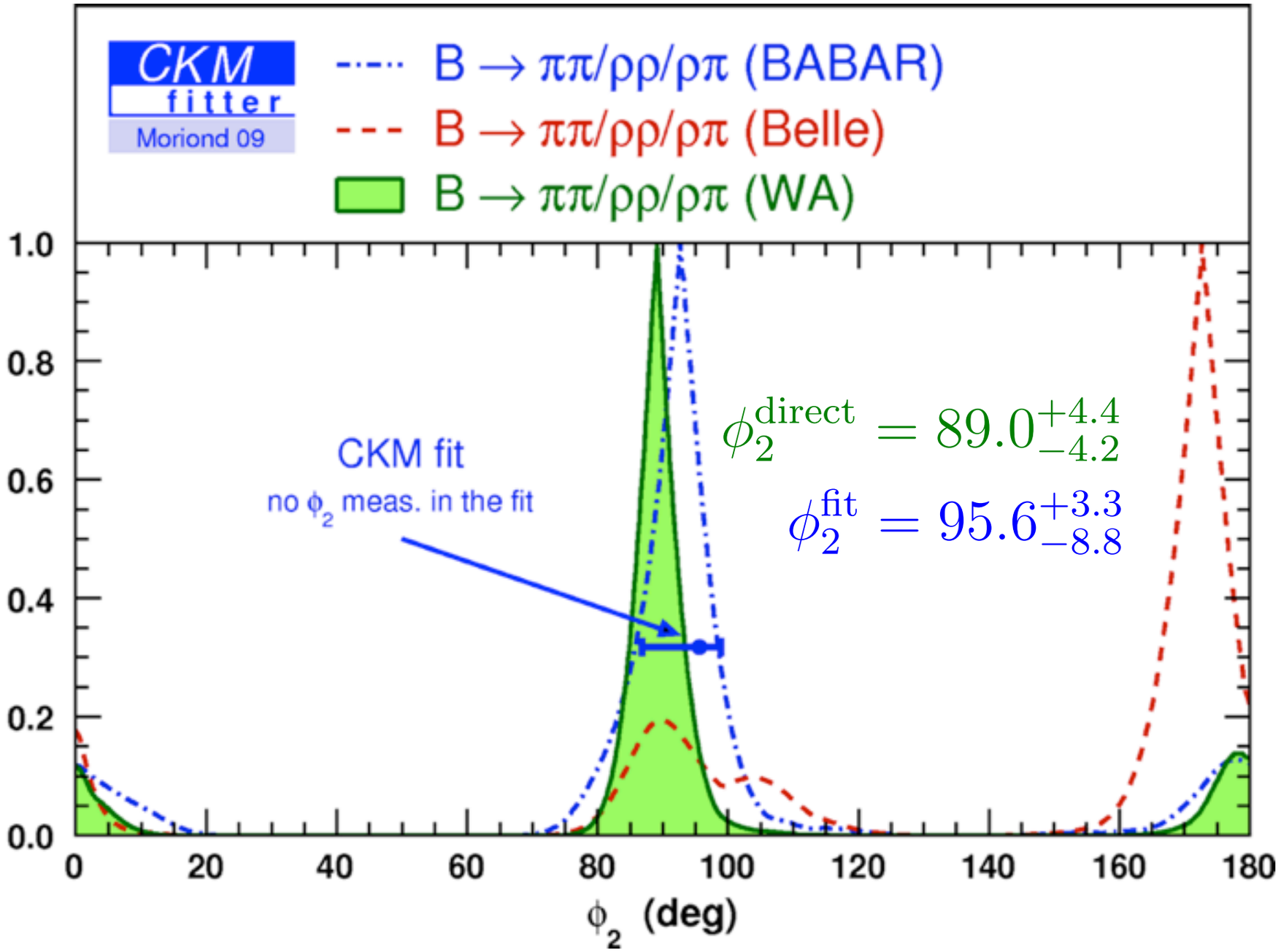
A, S : both consistent with 0




Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof




Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof




- $\phi_2$ is dominated by $B \to \rho^+\rho^-$ (with isospin relation)

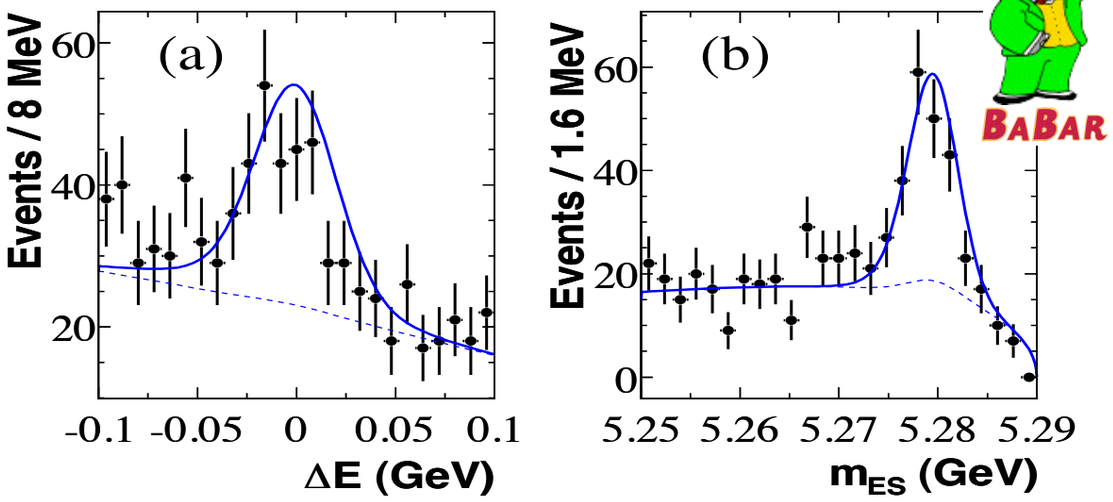
  $\because$ The isospin triangle for $\rho\rho$ is almost flat
  - $\mathcal{B}(B^0 \to \rho^0\rho^0) \sim \mathcal{O}(10^{-6})$, much smaller than the others
  - New BaBar measurement (PRL 102, 141802 (2009)) of

    $$\mathcal{B}(B^+ \to \rho^+\rho^0) = (23.7 \pm 1.4 \pm 1.4) \times 10^{-6}$$

    much improved the precision of the isospin triangle

# $\phi_2$ from $B \to a_1^{\pm}(1260)\pi^{\mp}$

PRL 98, 181803 (2007)




- $a_1\,\pi$ is not a CP eigenstate
- 4 flavor-charge configurations

$$B^0(\overline{B}^0) \to a_1^{\pm}\pi^{\mp}$$

$$\mathcal{B}(\overline{B}^0 \to a_1^-\pi^+) = (24.2 \pm 5.8) \times 10^{-6}$$

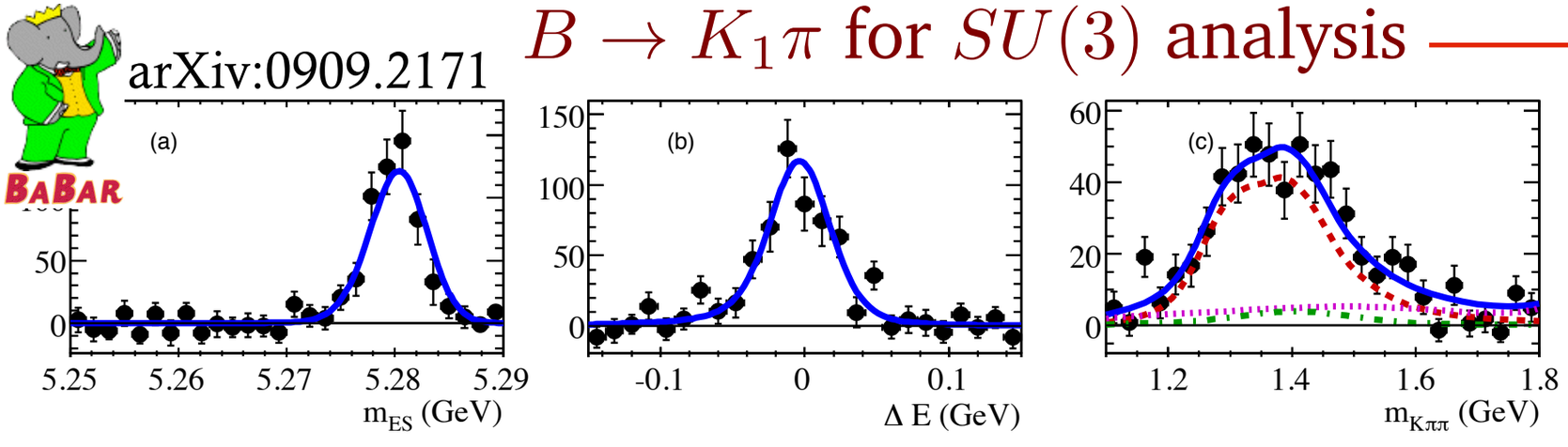
other BF's are smaller ~ O($10^{-5}$)

$$\alpha_{\rm eff} = \frac{1}{4}\left[\arcsin\left(\frac{S_{a_1\pi} + \Delta S_{a_1\pi}}{\sqrt{1-(C_{a_1\pi}+\Delta C_{a_1\pi})^2}}\right) + \arcsin\left(\frac{S_{a_1\pi} - \Delta S_{a_1\pi}}{\sqrt{1-(C_{a_1\pi}-\Delta C_{a_1\pi})^2}}\right)\right]$$

$$\alpha(=\phi_2) = 79 \pm 7 \pm 11(^\circ)$$

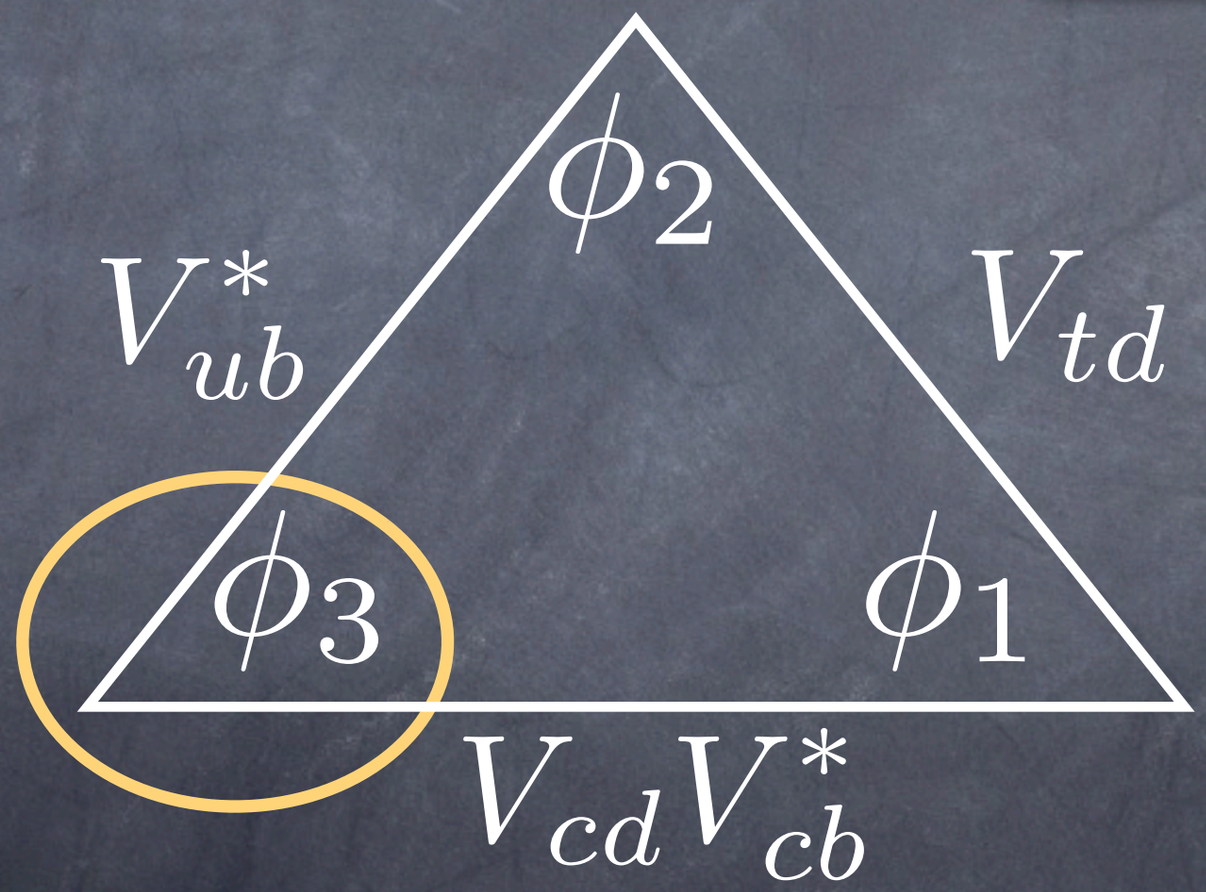
$B \to K_1\pi$ for $SU(3)$ analysis

arXiv:0909.2171



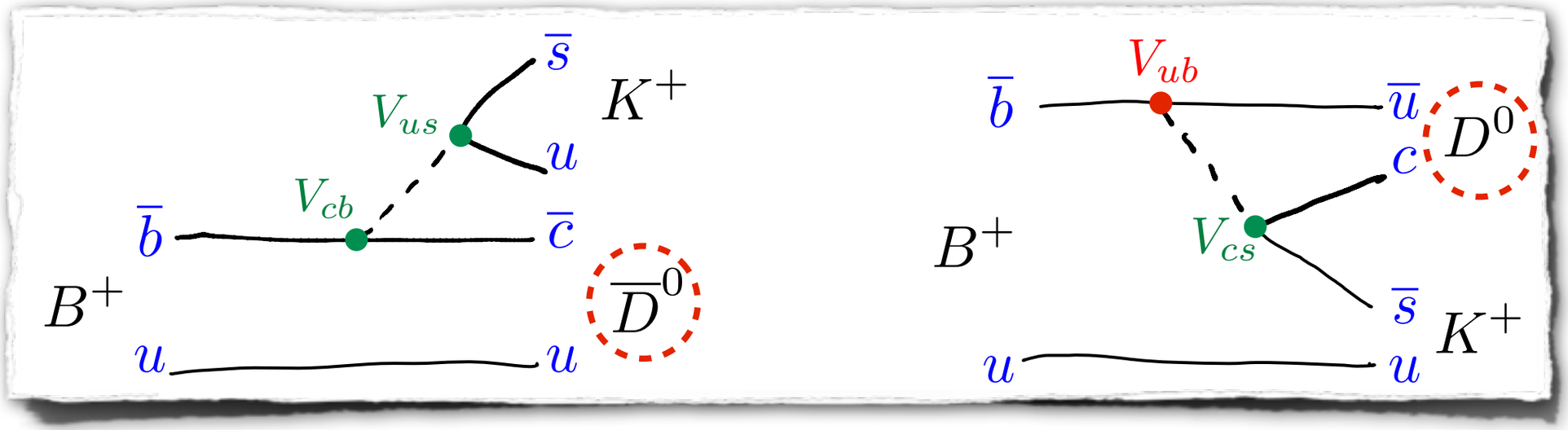
# Other angles?

| Unitarity triangle angles | | | |
|---|---|---|---|
| BABAR: | $\beta$ | $\alpha$ | $\gamma$ |
| BELLE: | $\phi_1$ | $\phi_2$ | $\phi_3$ |
| | 易 | 難 | 魔 |




**GLW: Gronau, London, Wyler (2001)**
**ADS: Atwood, Dunietz, Soni (1997)**
**GGSZ: Giri, Grossman, Soffer, Zupan (2003)**

# $\phi_3$ from CPV in $B^+ \to D^{(*)}K^{(*)}$ (GGSZ)




- IF both $D^0$ and $\overline{D}^0$ decay into a common final state (e.g. $K_S\pi^+\pi^-$), then $B^+ \to D^0K^+$ and $B^+ \to \overline{D}^0K^+$ amplitudes interfere.

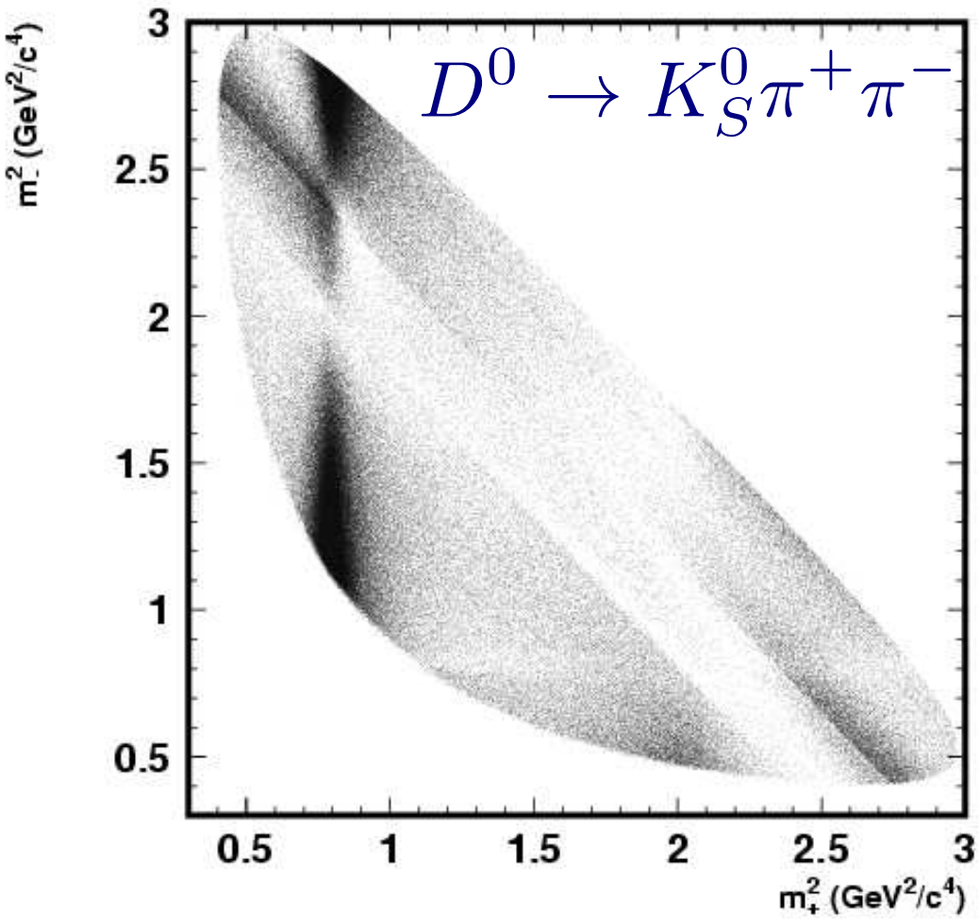
  Let $|\tilde{D}\rangle = |D^0\rangle + re^{i(\delta+\phi_3)}\,|\overline{D}^0\rangle$ be the mixed state.

- The matrix element for the Dalitz plots are:
  - $\mathcal{M}_+ = f(m_+^2, m_-^2) + re^{i(\delta+\phi_3)} f(m_-^2, m_+^2)$ for $B^+ \to \tilde{D}K^+$
  - $\mathcal{M}_- = f(m_-^2, m_+^2) + re^{i(\delta-\phi_3)} f(m_+^2, m_-^2)$ for $B^- \to \overline{\tilde{D}}K^-$

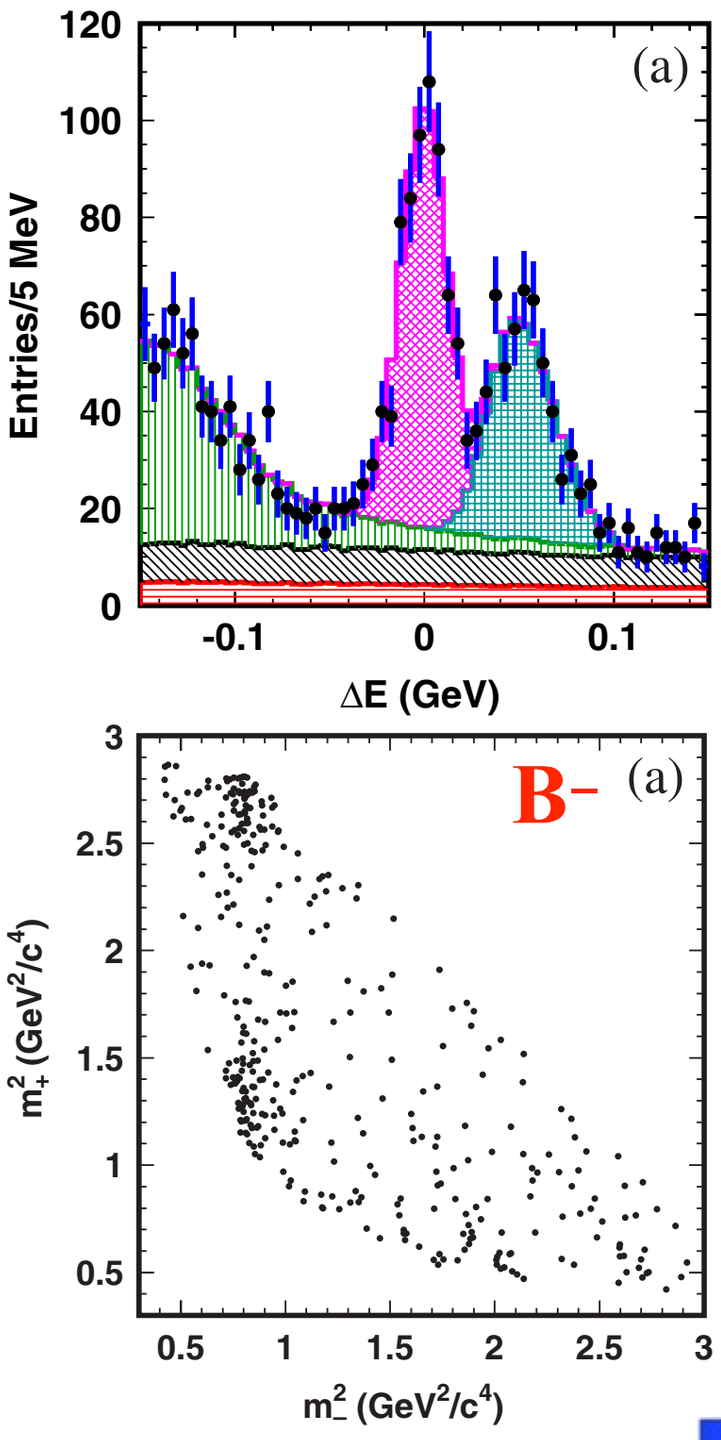
$$m_\pm = m(K_S\pi^\pm)$$

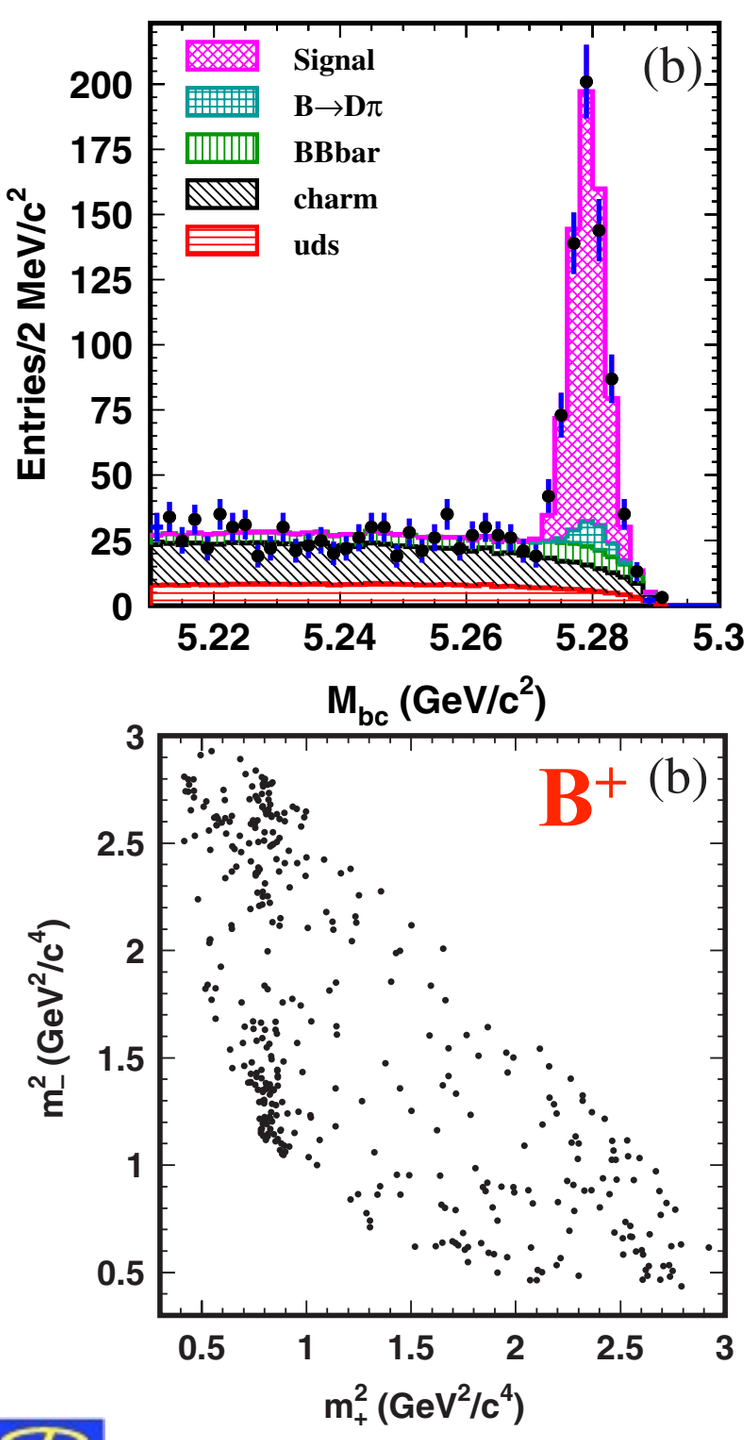
# $\phi_3$ from CPV in $B^+ \to D^{(*)}K^{(*)}$ (GGSZ)

Map out the Dalitz plot from all $D^0$ decays




Look for differences in $B^{\pm} \to D^0 K^{\pm}$ plots




PRD 81, 112002 (2010)

# $\phi_3$ from CPV in $B^+ \to D^{(*)}K^{(*)}$ (GGSZ)

in terms of measurables from $B^{\pm}$

$$x_{\pm} = r\cos(\delta_B \pm \phi_3)$$

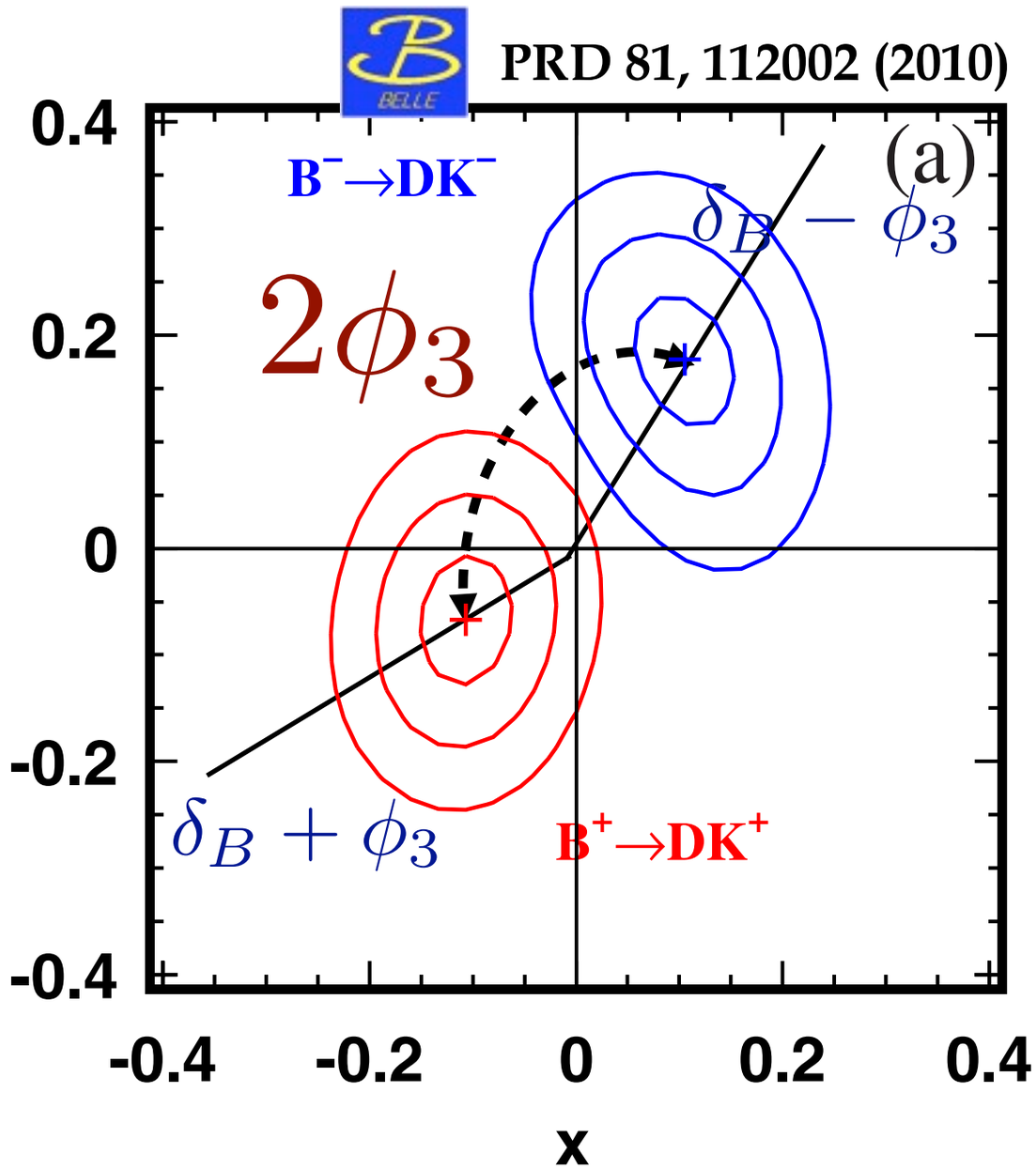
$$y_{\pm} = r\sin(\delta_B \pm \phi_3)$$

$r$ : ratio of $D/\overline{D}$ ampl.

$\delta_B$ : $D/\overline{D}$ relative phase

Different $r$, $\delta_B$ for each mode $D^{(*)}K^{(*)}$

$$r_{DK} = 0.160^{+0.040}_{-0.038} \pm 0.011^{+0.050}_{-0.010}$$

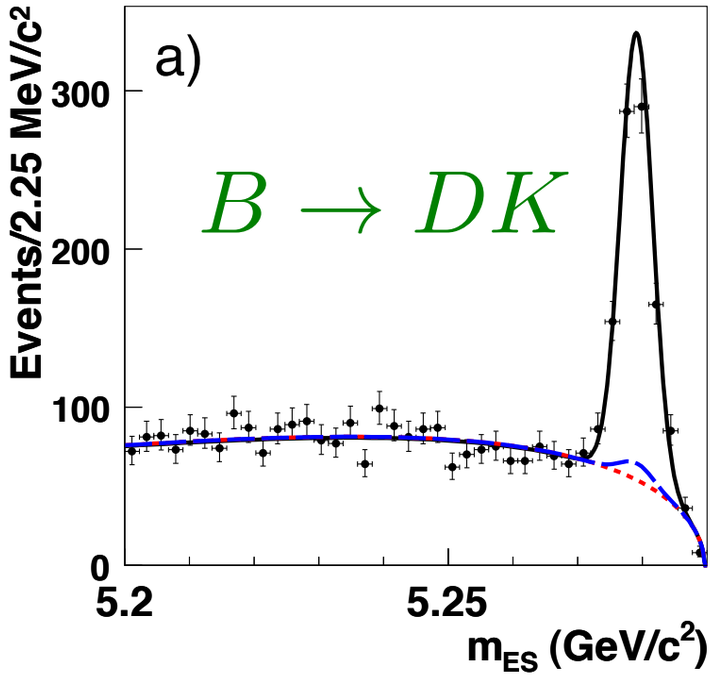


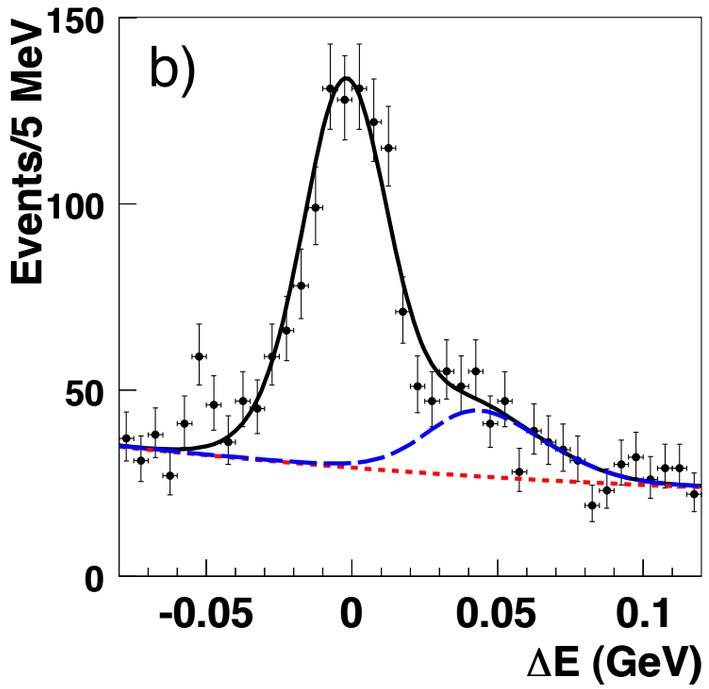

$$\phi_3 = 78.4^{+10.8}_{-11.6} \pm 3.6 \pm 8.9\,(^\circ)$$

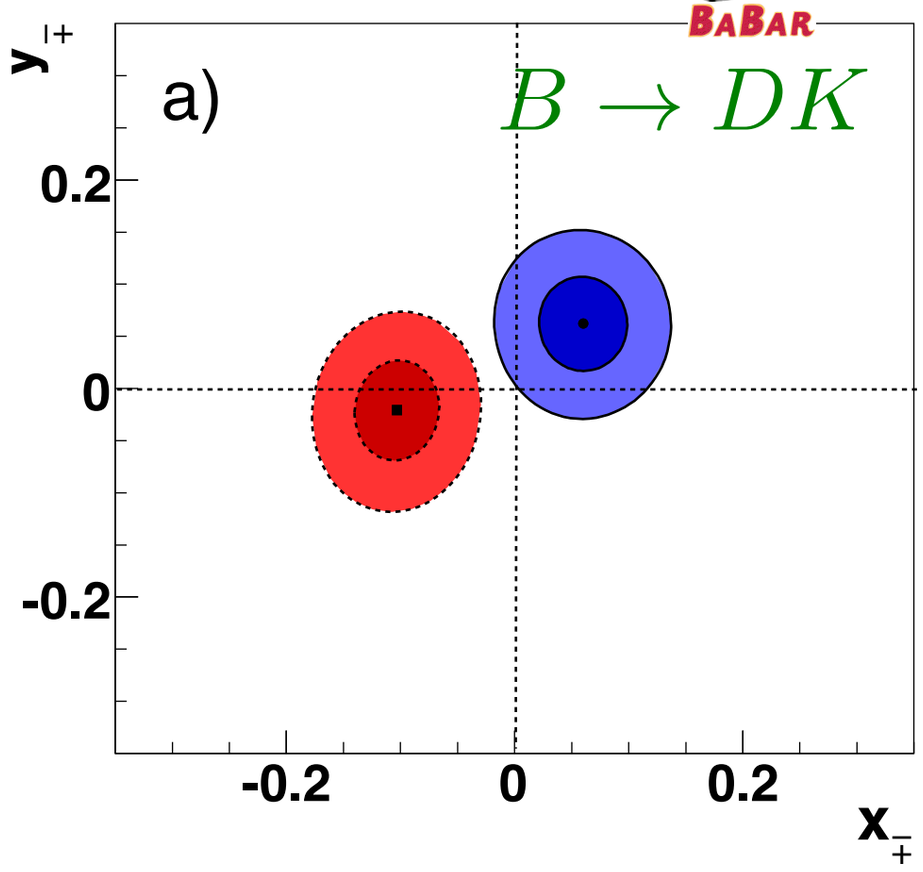
*Evidence of direct CPV !!*

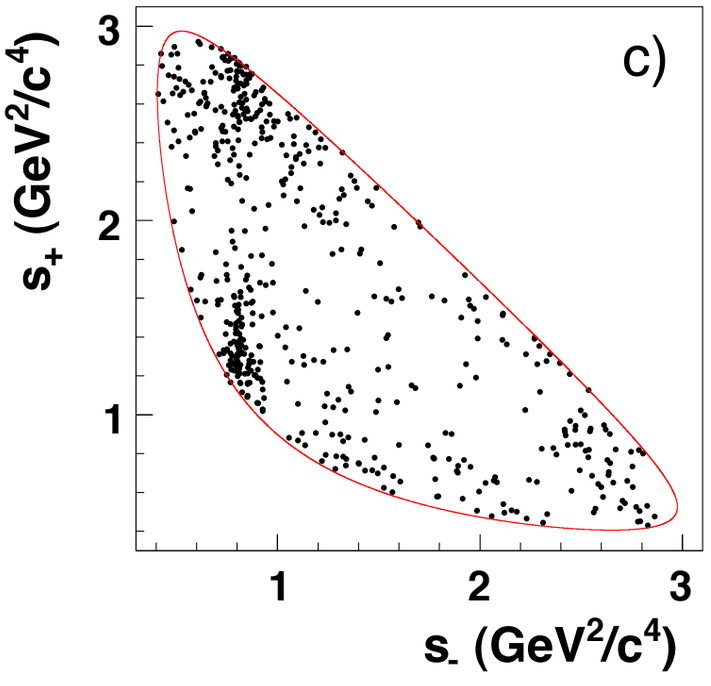
# $\phi_3$ from CPV in $B^+ \to D^{(*)}K^{(*)}$ (GGSZ)

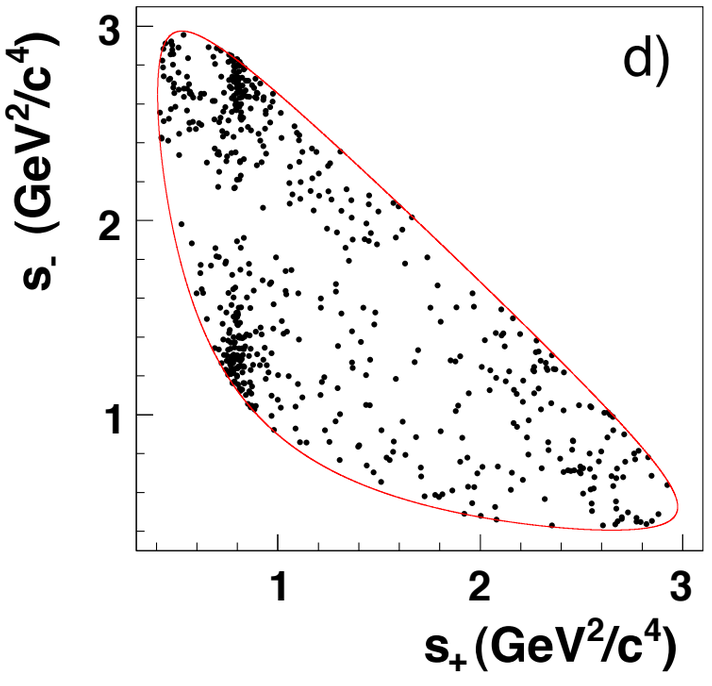
arXiv:1005.1096




$$\phi_3 = 68 \pm 14 \pm 4 \pm 3\,(^\circ)$$

*Evidence of direct CPV !!*

both $D^0 \to K^0_S\pi^+\pi^-$ and $K^0_S K^+ K^-$ Dalitz plots are used for $\phi_3$

# $\phi_3$ from GLW

arXiv:1007.0504

- measure two asymmetries $A_{CP\pm}$ and two ratios $R_{CP\pm}$

$$A_{CP\pm} \equiv \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}$$

$$R_{CP\pm} \equiv 2\,\frac{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \overline{D}^0K^+)}$$

  - for CP=+1 states: $K^0_S\pi^0, K^0_S\omega, K^0_S\phi$
  - for CP=-1 states: $K^+K^-, \pi^+\pi^-$
  - for flavor eigenstate: $D^0 \to K^-\,\pi^+$

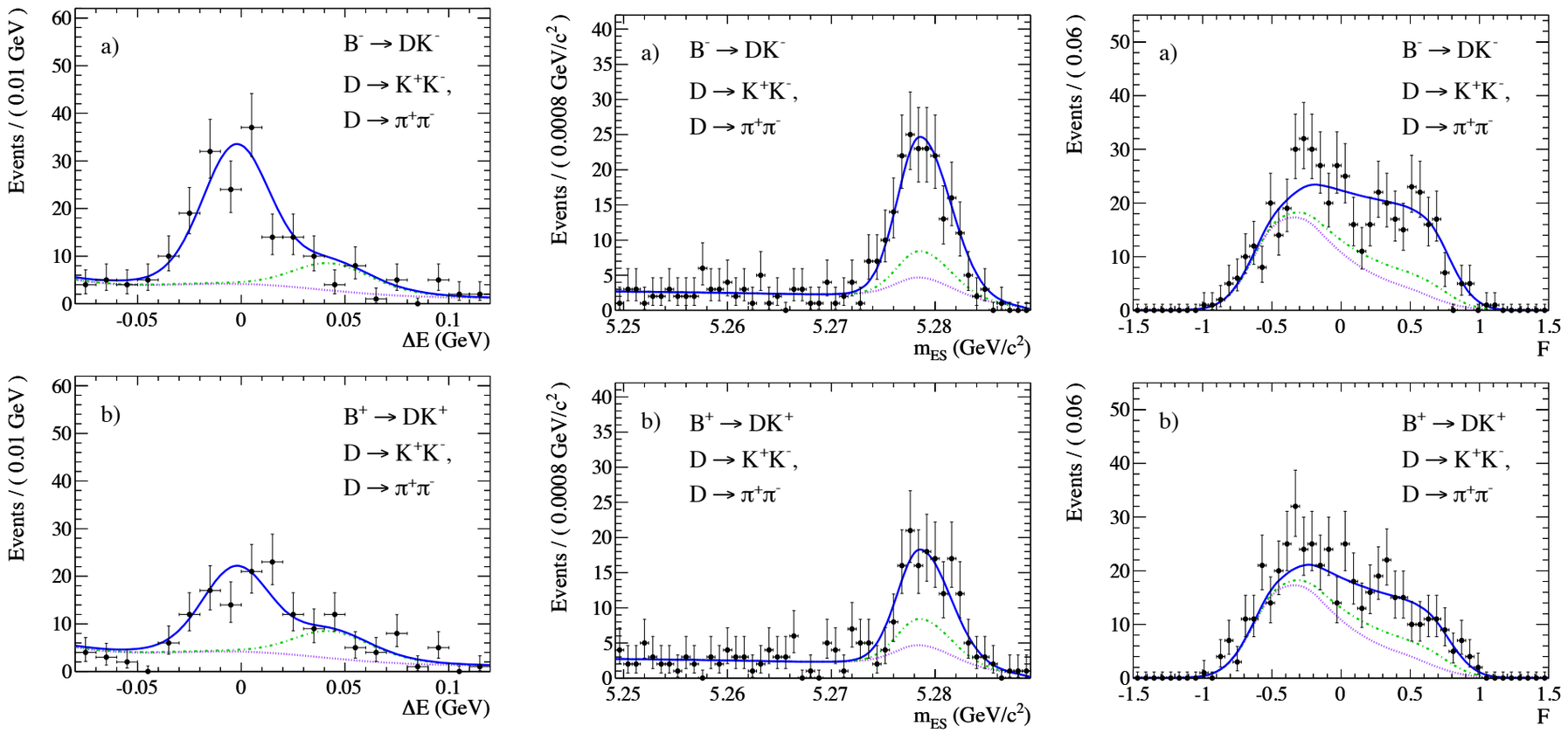
- then, extract γ (=$\phi_3$) using the relations

$$\begin{aligned} R_{CP\pm} &= 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma\,, \\ A_{CP\pm} &= \frac{\pm 2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma}. \end{aligned}$$

arXiv:1007.0504

# $\phi_3$ from GLW

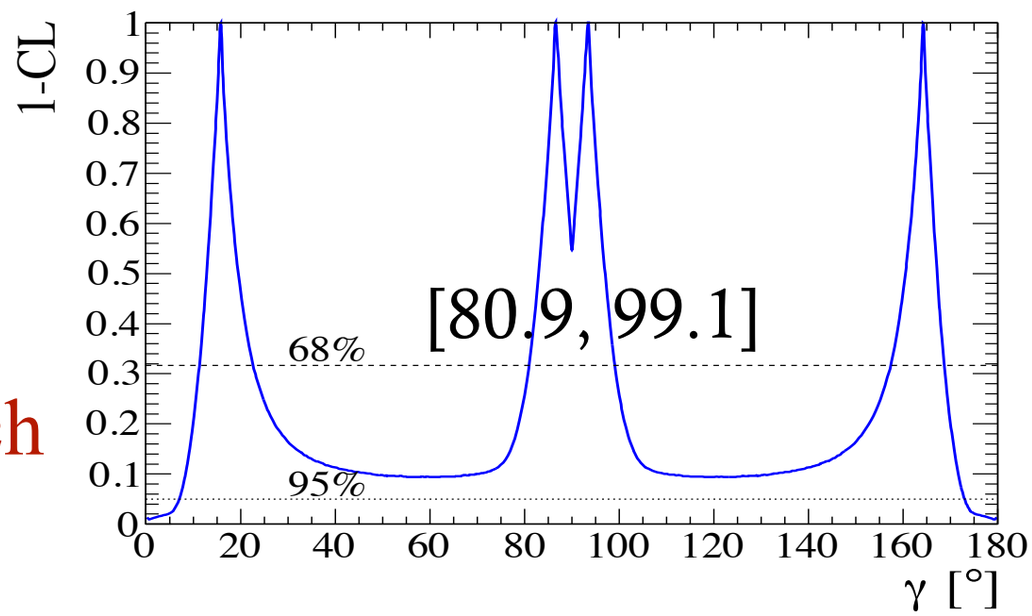
## fitting for max. $\mathcal{L}(m_{ES}, \Delta E, \mathcal{F})$



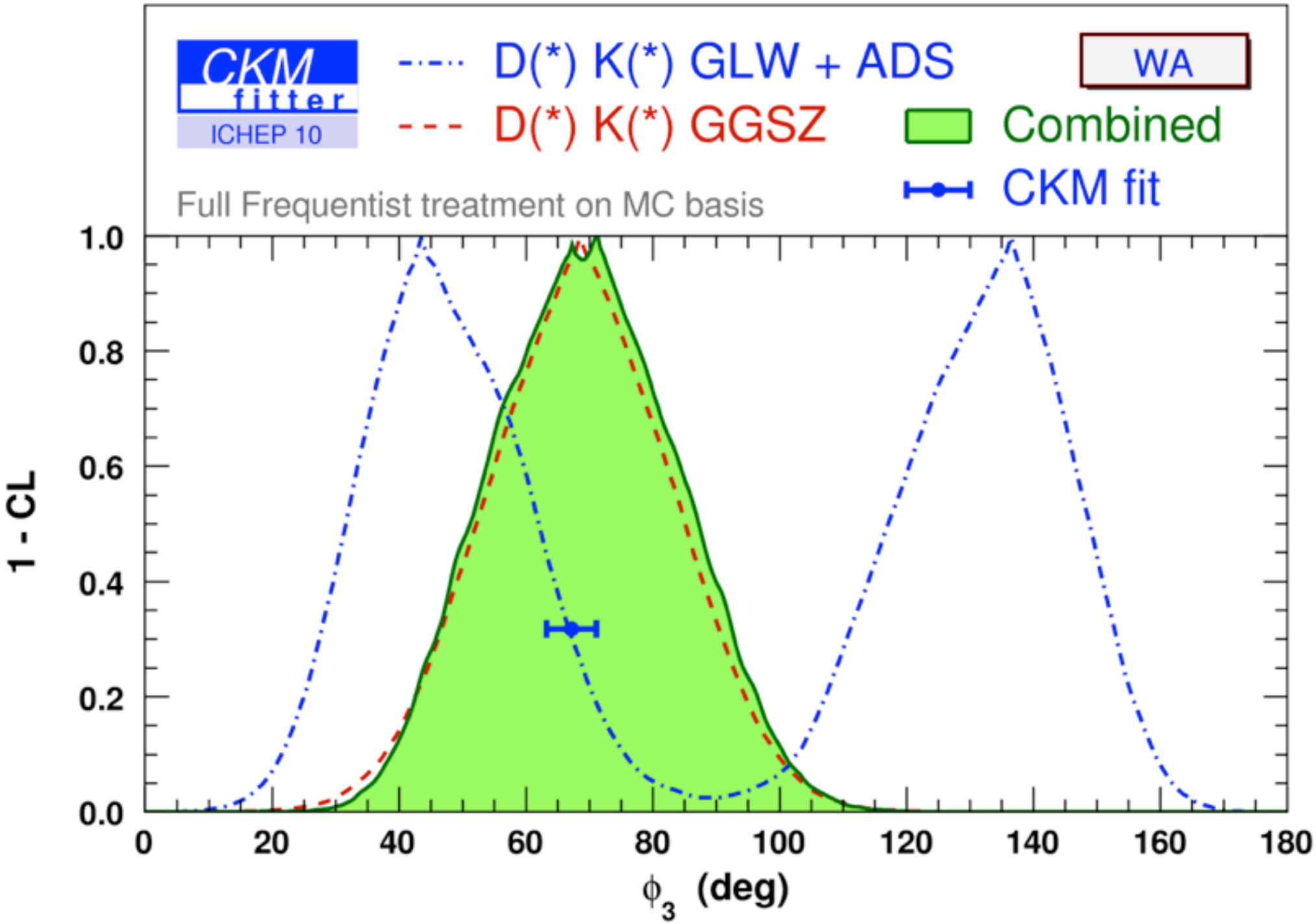

$B^- \to D_{CP+}K^-$

$B^+ \to D_{CP+}K^+$

$$
\begin{aligned}
A_{CP+} &= \phantom{-}0.25 \pm 0.06(\text{stat}) \pm 0.02(\text{syst}) \\
A_{CP-} &= -0.09 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}) \\
R_{CP+} &= \phantom{-}1.18 \pm 0.09(\text{stat}) \pm 0.05(\text{syst}) \\
R_{CP-} &= \phantom{-}1.07 \pm 0.08(\text{stat}) \pm 0.04(\text{syst})
\end{aligned}
$$

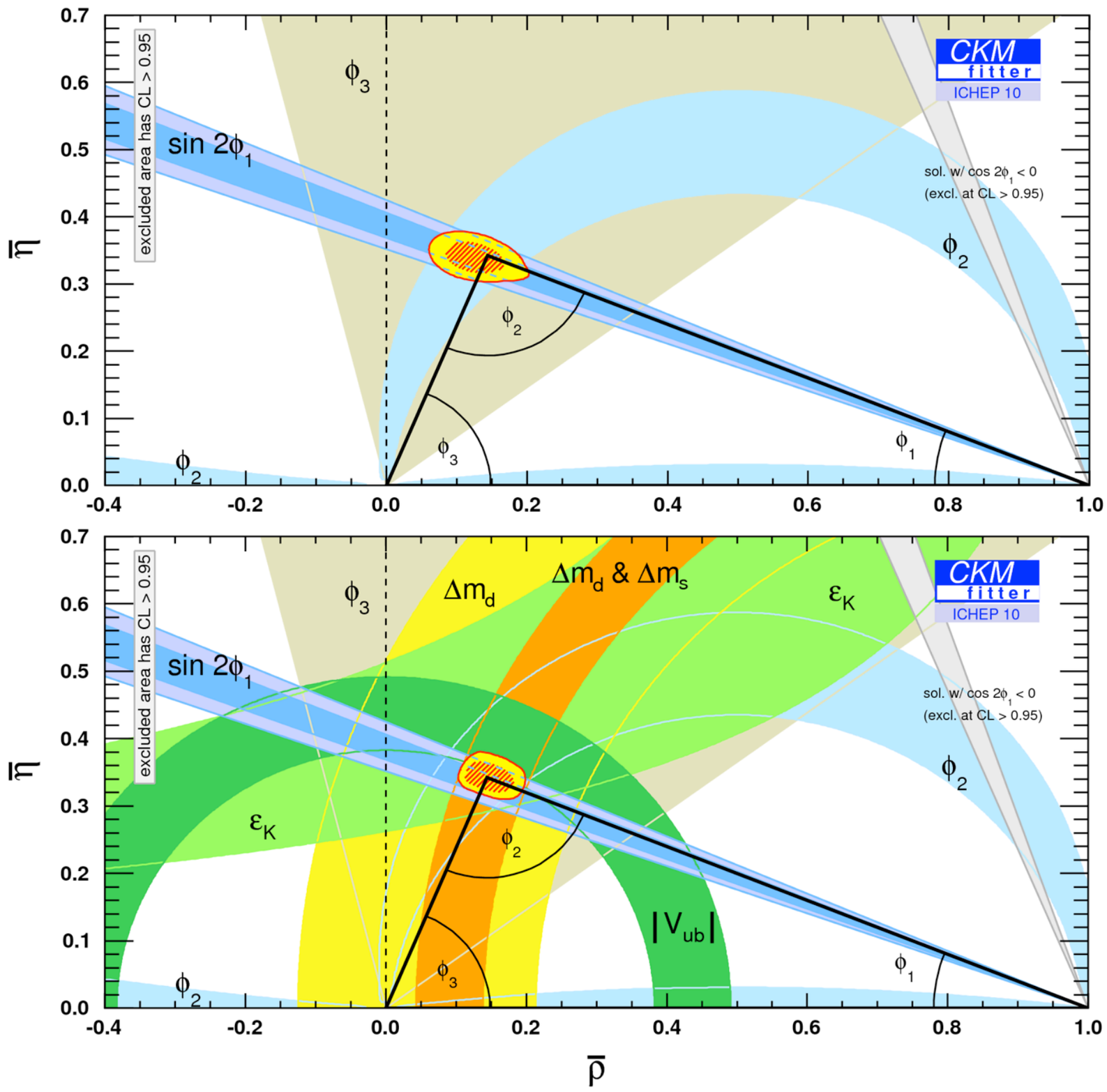



- extract γ (=$\phi_3$) using frequentist approach (e.g. by an ensemble of toy MC)




Indirect: $\phi_3 = 67.2 \pm 3.9(^\circ)$ Direct: $\phi_3 = 71^{+21}_{-25}\,(^\circ)$

# UT: current status

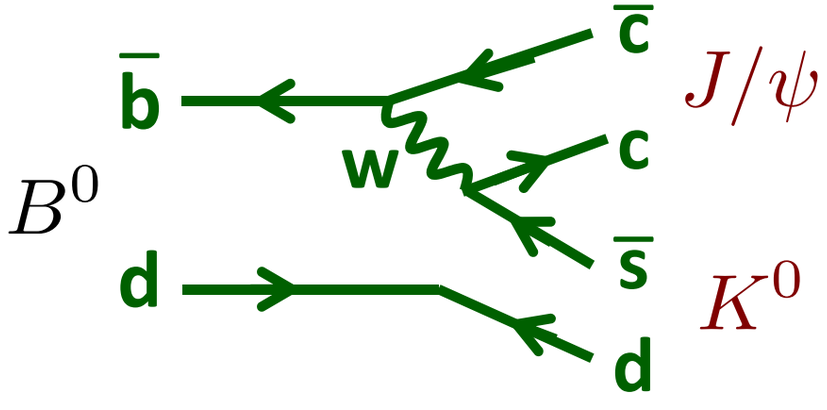


# Any Tensions?

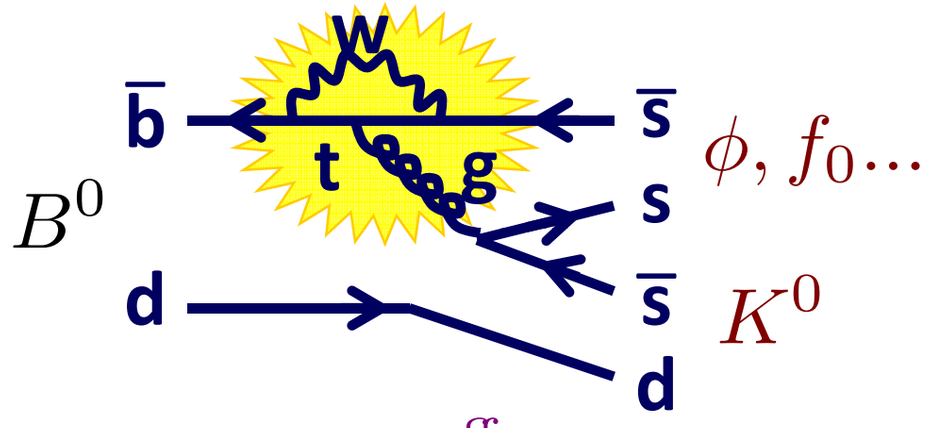
- "$\Delta S$ puzzle"
  - $\phi_1$ from $b \to s$ Penguin
- "$V_{ub}$ tension" (→ *talk by S. Robertson*)
  - with $B^+ \to \tau^+ \nu$

*If confirmed, these could be potential hints for NP…*

# $t$-dep. $CPV$ in $b \to s\bar{s}s$



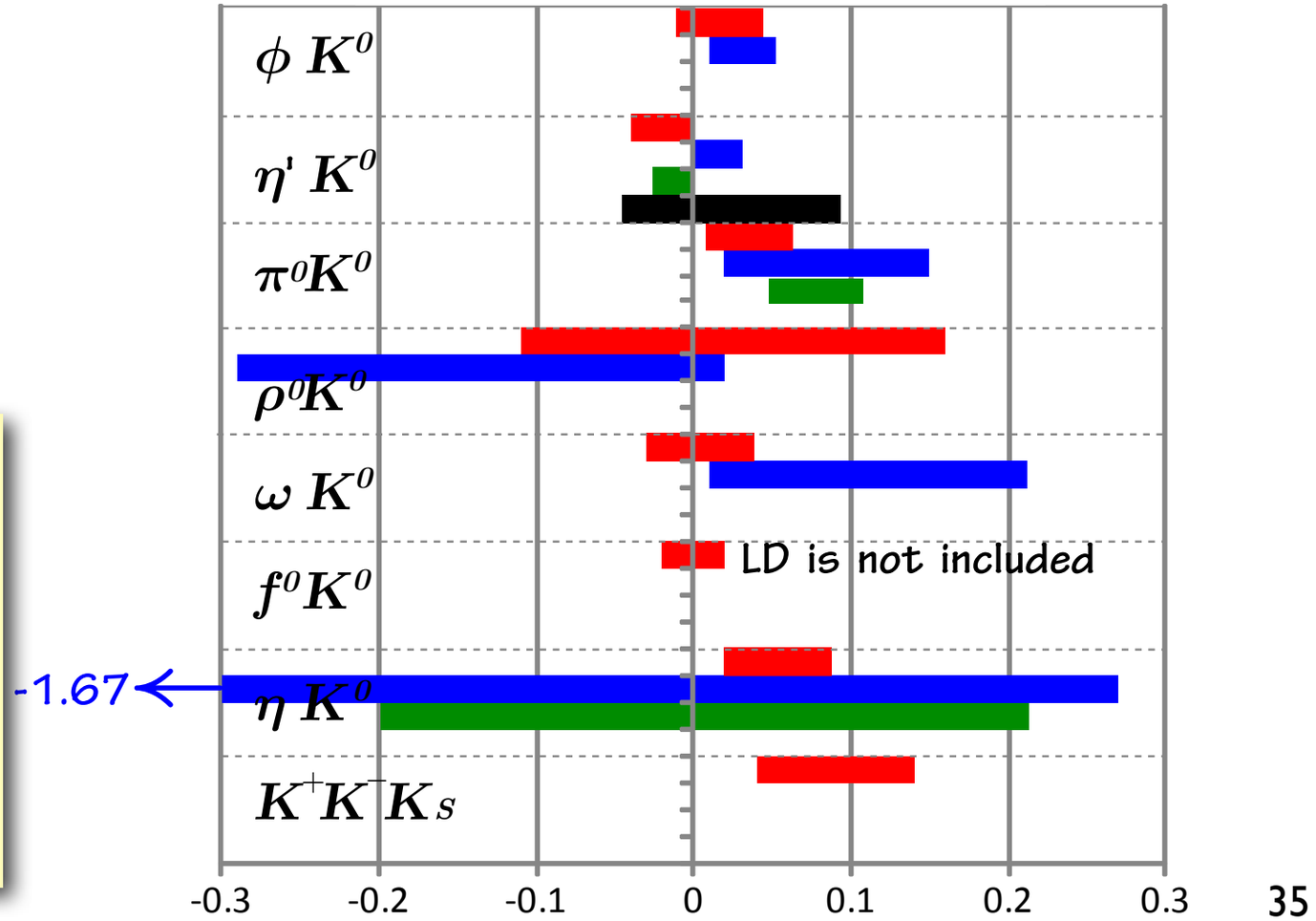

$\mathcal{S} = \sin 2\phi_1, \mathcal{A} \approx 0$




$\mathcal{S} = \sin 2\phi_1^{\rm eff}, \mathcal{A} \approx 0$

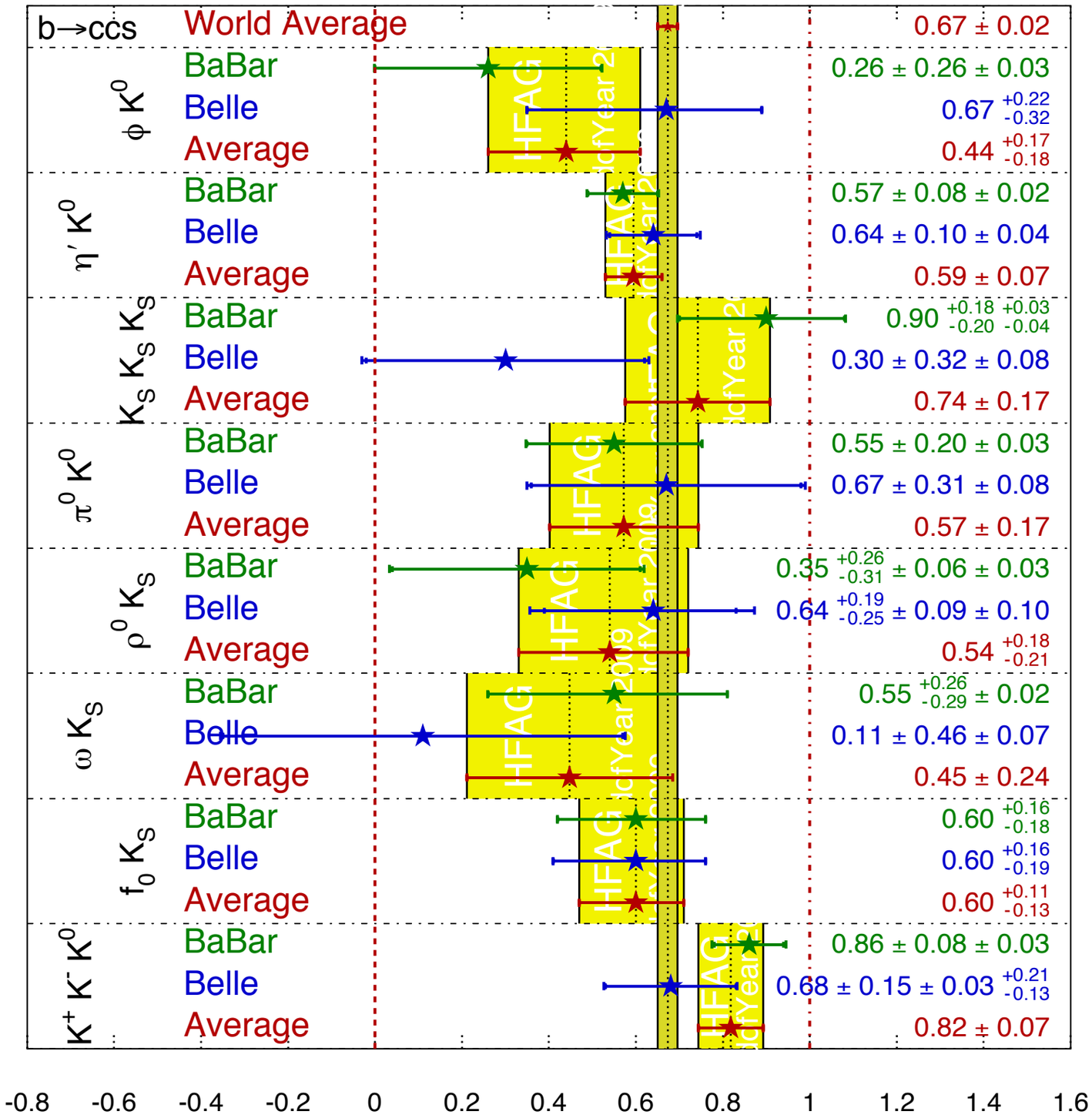
- In the SM,
  $\Delta\mathcal{S}(\equiv \sin 2\phi_1^{\rm eff} - \sin 2\phi_1) \simeq 0$
- With extra *CP* phase from NP, (in the penguin loop)
  $\Delta\mathcal{S} \neq 0$

QCDF: Cheng, Chua, Soni
PRD 72, 014006 (2005),
PRD 72, 094003 (2005)
QCDF: Beneke
PLB 620, 143 (2005),
SCET/QCDF: Williamson, Zupan
PRD 74, 014003 (2006)
SU(3): Gronau, Rosner, Zupan
PRD 74, 093003 (2006)



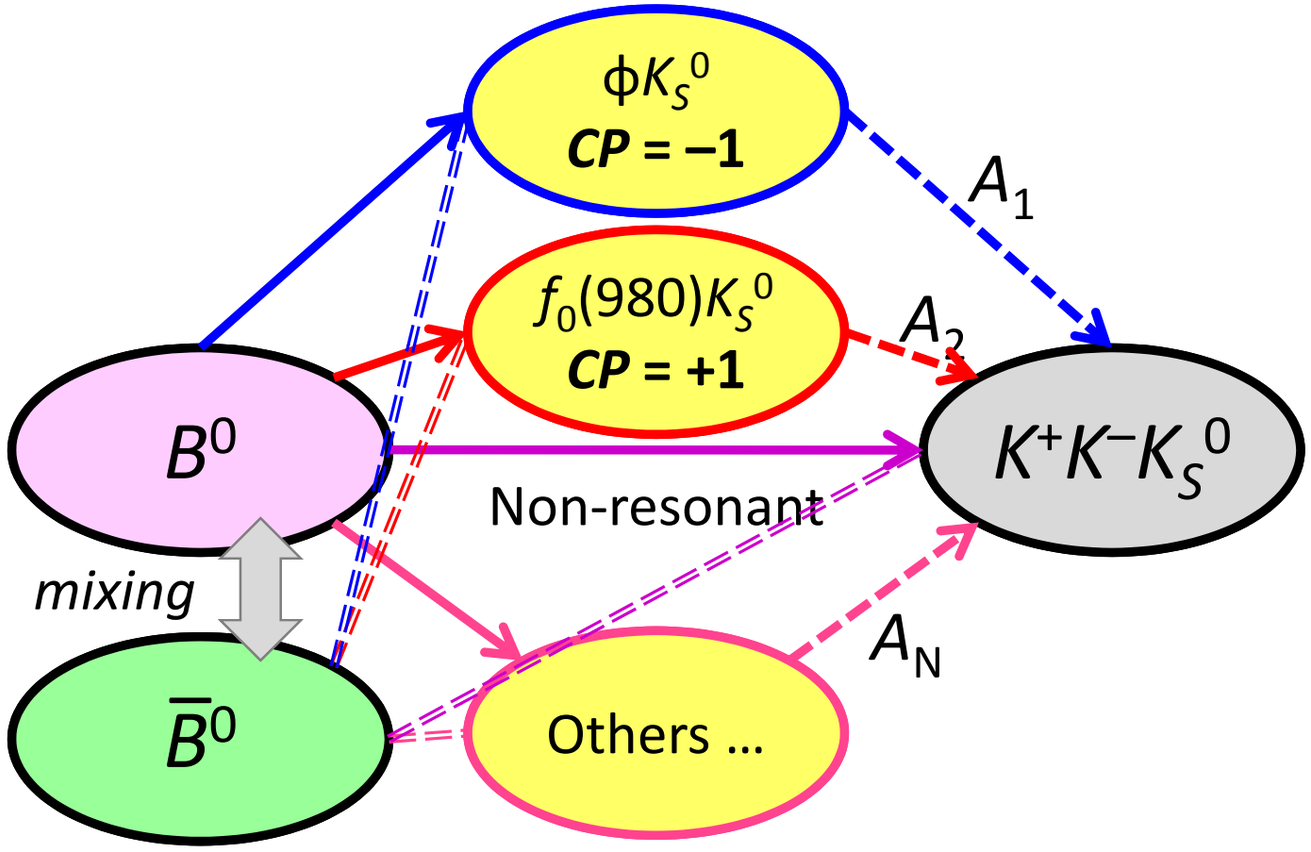
# $\sin(2\beta^{\rm eff}) \equiv \sin(2\phi_1^{\rm eff})$

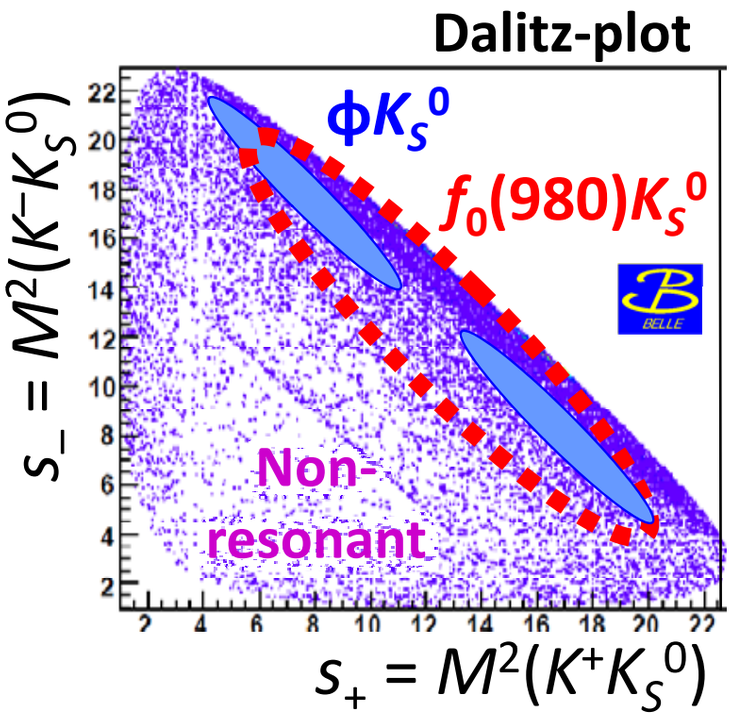
HFAG
EndofYear 2009
PRELIMINARY



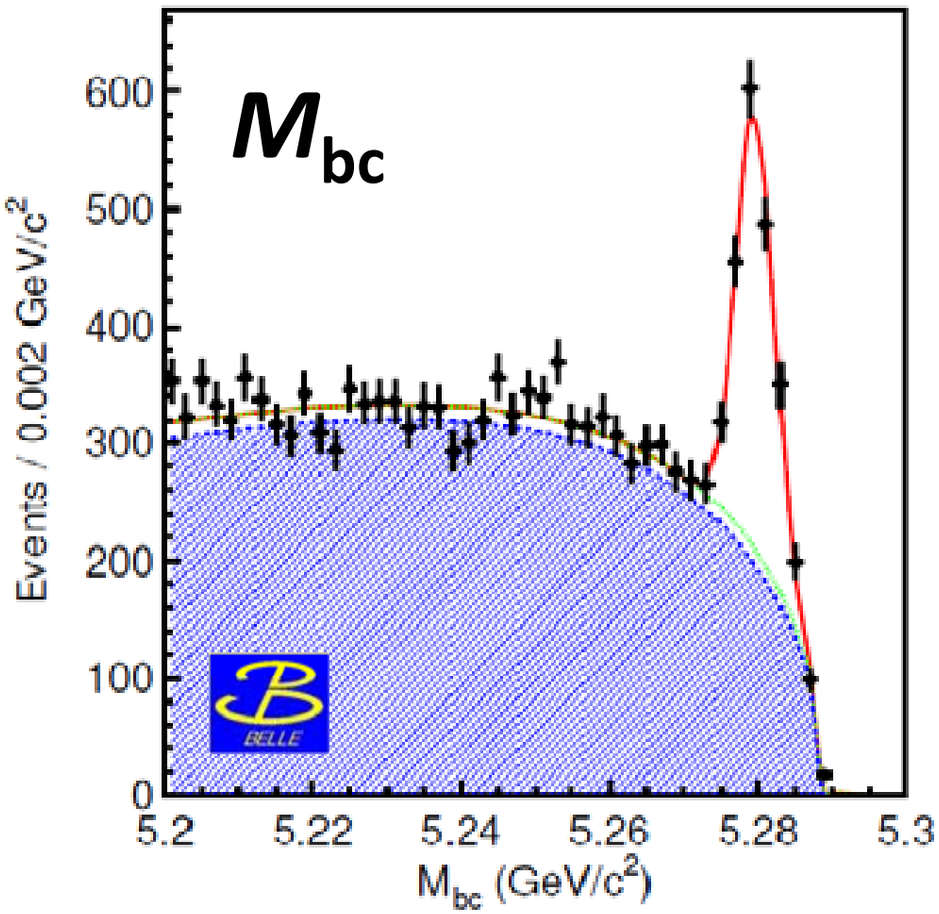
# $\Delta S$ puzzle, old & new

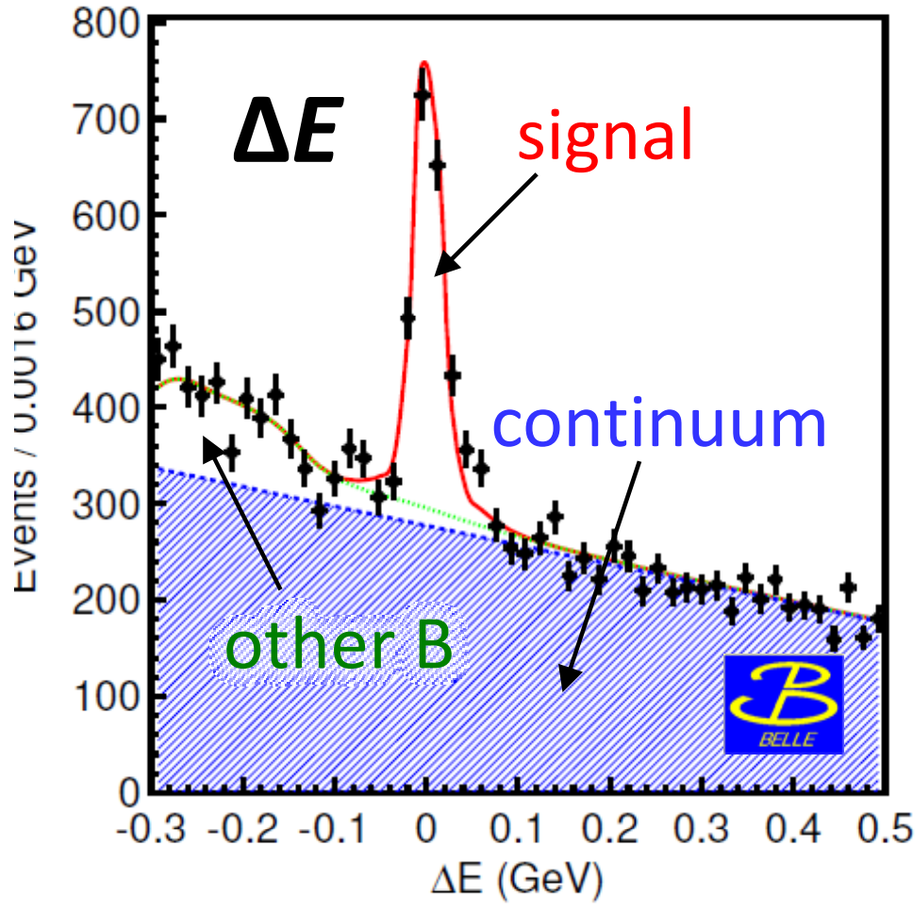
- In 2003, $> 3\sigma$ effect seen in $B \to \phi K^0_S$ with low stats and '*slide-and-dice*' analysis $\Longrightarrow$ " $\Delta\mathcal{S}$ puzzle"
- Now, we have more data and advanced 3-body analysis
  Fit to the Dalitz plot for $t$-dep. *CPV* analysis



# $t$-dep. $CPV$ in $B^0 \to K^0_S K^+ K^-$




- signal-enhanced projections

$$N(B^0 \to K^0_S K^+ K^-) = 1176 \pm 51$$
$$\text{eff.} \sim 16\%$$

$N_{BB} = 657 \text{ x } 10^6$

- background is mostly $q\bar{q}$ continuum

# $t$-dep. $CPV$ in $B^0 \to K^0_S K^+ K^-$

- multiple solutions in *ext. max-L fitting*

| | Solution #1 | Solution #2 | Solution #3 | Solution #4 |
|---|---|---|---|---|
| $\mathcal{A}_{CP}(f_0(980)K^0_S)$ | $-0.30 \pm 0.29 \pm 0.11 \pm 0.09$ | $-0.20 \pm 0.15 \pm 0.08 \pm 0.05$ | $+0.02 \pm 0.21 \pm 0.09 \pm 0.09$ | $-0.18 \pm 0.14 \pm 0.08 \pm 0.06$ |
| $\phi_1^{\rm eff}(f_0(980)K^0_S)$ | $(31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$ | $(26.1 \pm 7.0 \pm 2.4 \pm 2.5)^\circ$ | $(25.6 \pm 7.6 \pm 2.9 \pm 0.8)^\circ$ | $(26.3 \pm 5.7 \pm 2.4 \pm 5.8)^\circ$ |
| $\mathcal{A}_{CP}(\phi(1020)K^0_S)$ | $+0.04 \pm 0.20 \pm 0.10 \pm 0.02$ | $+0.08 \pm 0.18 \pm 0.10 \pm 0.03$ | $-0.01 \pm 0.20 \pm 0.11 \pm 0.02$ | $+0.21 \pm 0.18 \pm 0.11 \pm 0.05$ |
| $\phi_1^{\rm eff}(\phi(1020)K^0_S)$ | $(32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$ | $(26.2 \pm 8.8 \pm 2.7 \pm 1.2)^\circ$ | $(27.3 \pm 8.6 \pm 2.8 \pm 1.3)^\circ$ | $(24.3 \pm 8.0 \pm 2.9 \pm 5.2)^\circ$ |
| $\Delta(\ln \mathcal{L})$ | $-1.568$ | $0$ | $-2.956$ | $-5.155$ |

- any external conditions to consider?
  - $\mathcal{B}(f_0(980) \to \pi^+\pi^-)$ vs. $\mathcal{B}(f_0(980) \to K^+K^-)$
  - $\mathcal{B}(f_0(1500) \to \pi^+\pi^-)$ vs. $\mathcal{B}(f_0(1500) \to K^+K^-)$

# $t$-dep. $CPV$ in $B^0 \to K^0_S K^+ K^-$

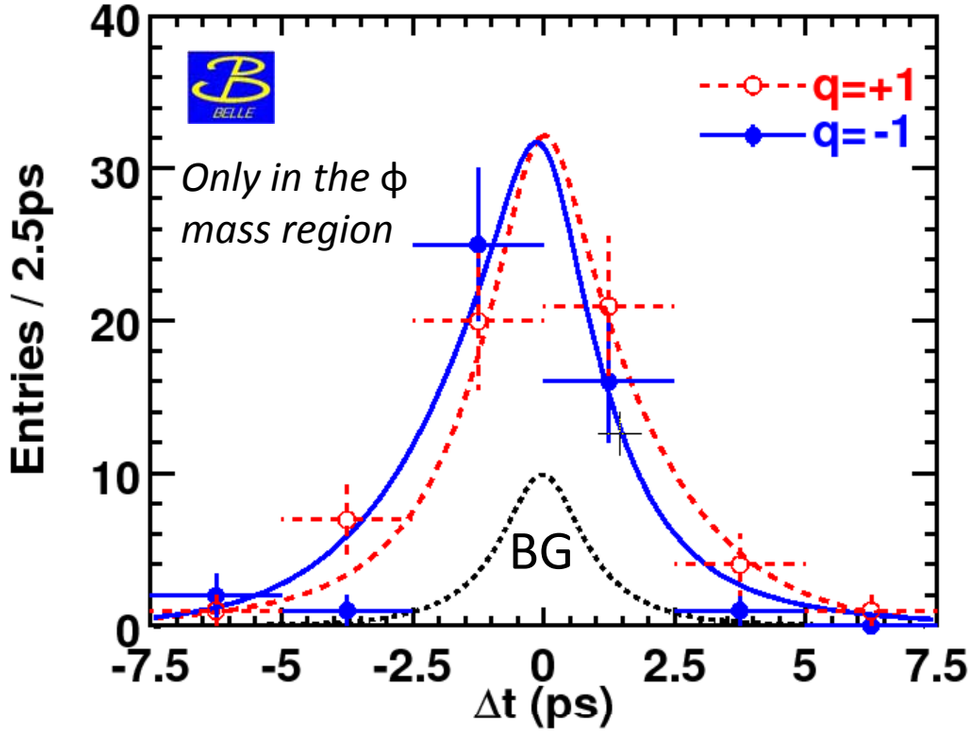
| Parameter | Solution 1 | Solution 2 | Solution 3 | Solution 4 |
|---|---|---|---|---|
| $f_{f_0(980)K^0_S}$ | $26.0 \pm 7.4$ | $54.0 \pm 9.6$ | $26.4 \pm 7.8$ | $68.1 \pm 12.3$ |
| $f_{\phi(1020)K^0_S}$ | $14.2 \pm 1.2$ | $14.5 \pm 1.2$ | $14.2 \pm 1.2$ | $14.4 \pm 1.2$ |
| $f_{f_X K^0_S}$ | $5.10 \pm 1.39$ | $5.89 \pm 1.86$ | $39.6 \pm 2.6$ | $59.0 \pm 3.0$ |
| $f_{\chi_{c0}K^0_S}$ | $3.73 \pm 0.74$ | $3.71 \pm 0.73$ | $3.68 \pm 0.73$ | $4.15 \pm 0.79$ |
| $f_{(K^+K^-)_{\rm NR}K^0_S}$ | $138.4 \pm 44.8$ | $175.0 \pm 52.6$ | $157.4 \pm 29.5$ | $48.1 \pm 11.7$ |
| $f_{(K^0_S K^+)_{\rm NR}K^-}$ | $1.65 \pm 4.17$ | $21.0 \pm 17.3$ | $4.63 \pm 6.76$ | $7.87 \pm 4.78$ |
| $f_{(K^0_S K^-)_{\rm NR}K^+}$ | $26.0 \pm 12.9$ | $78.0 \pm 36.2$ | $38.6 \pm 18.1$ | $6.27 \pm 3.81$ |
| $F_{\rm tot}$ | $215.2 \pm 47.5$ | $352.0 \pm 66.8$ | $284.5 \pm 36.3$ | $207.9 \pm 18.4$ |

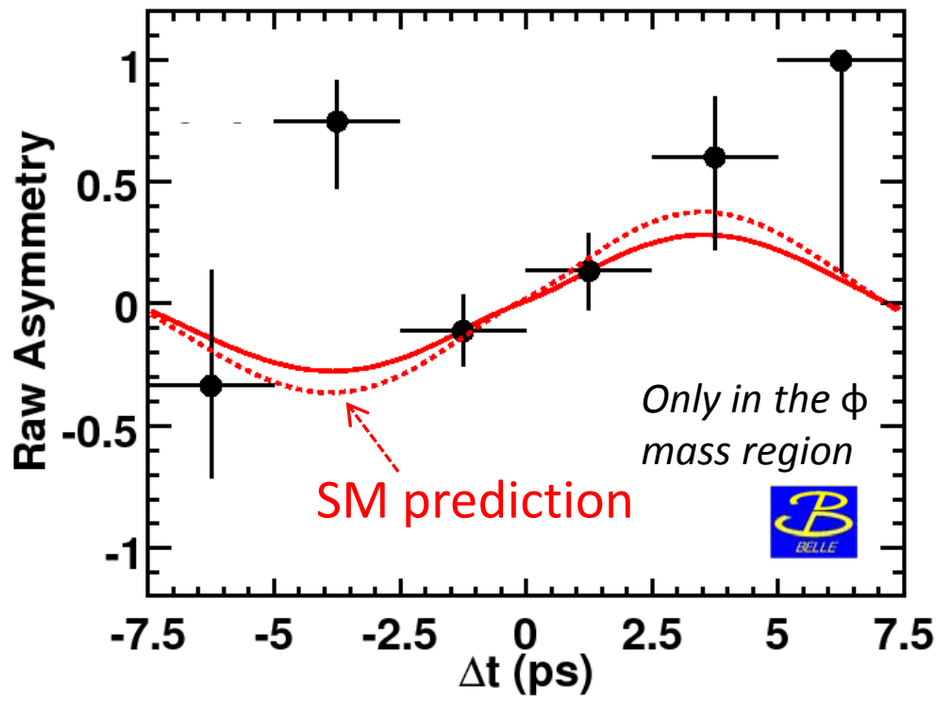
- any external conditions to consider?
  - $\mathcal{B}(f_0(980) \to \pi^+\pi^-)$ vs. $\mathcal{B}(f_0(980) \to K^+K^-)$
    $\Rightarrow$ prefer low value of $f_0(980)K^0_S$ fraction
  - $\mathcal{B}(f_0(1500) \to \pi^+\pi^-)$ vs. $\mathcal{B}(f_0(1500) \to K^+K^-)$
    $\Rightarrow$ prefer low value of $f_0(1500)K^0_S$ fraction

# $t$-dep. $CPV$ in $B^0 \to K^0_S K^+ K^-$

**[solution #1]**

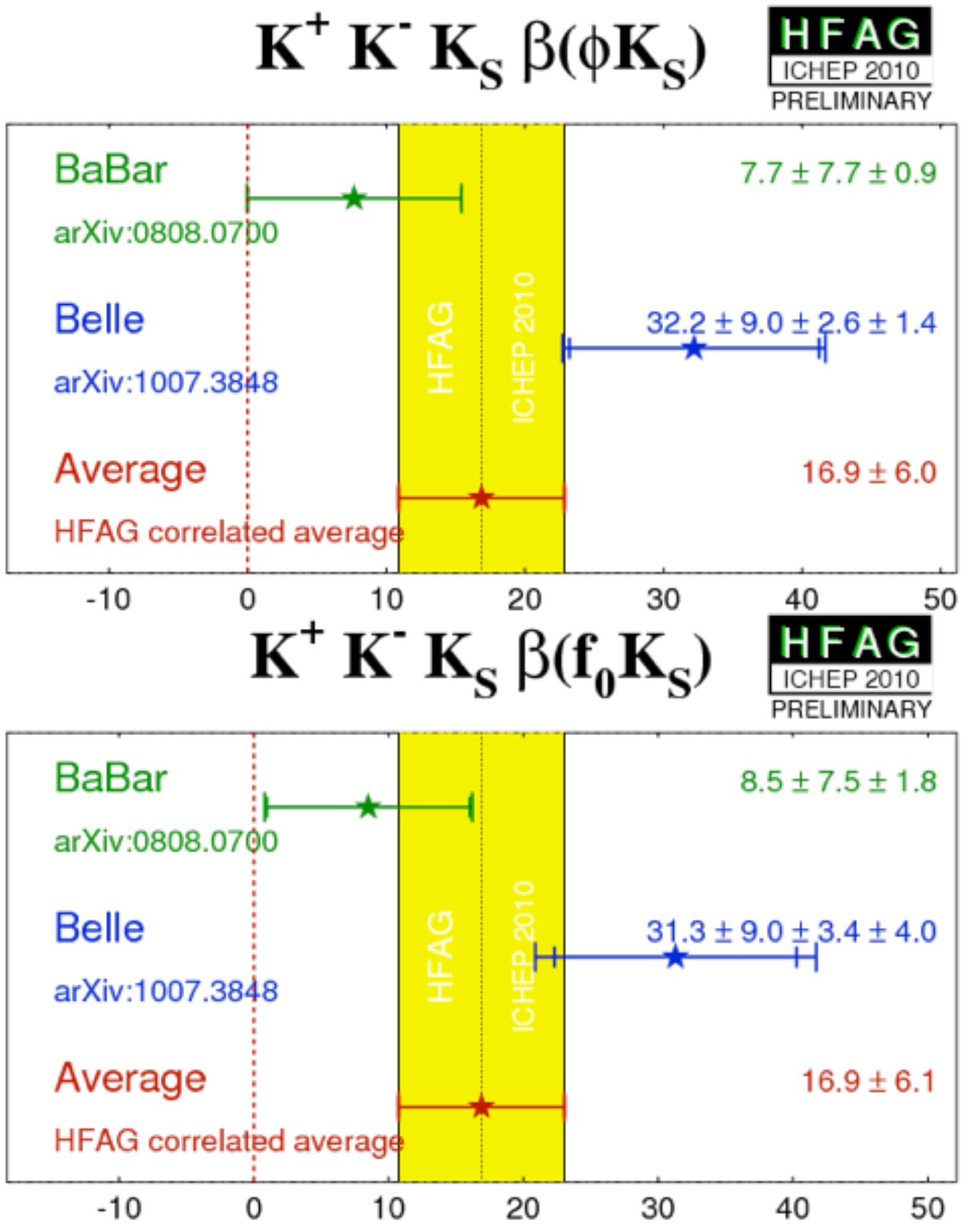
submitted to PRD;
hep-ex/1007.3848 (2010)

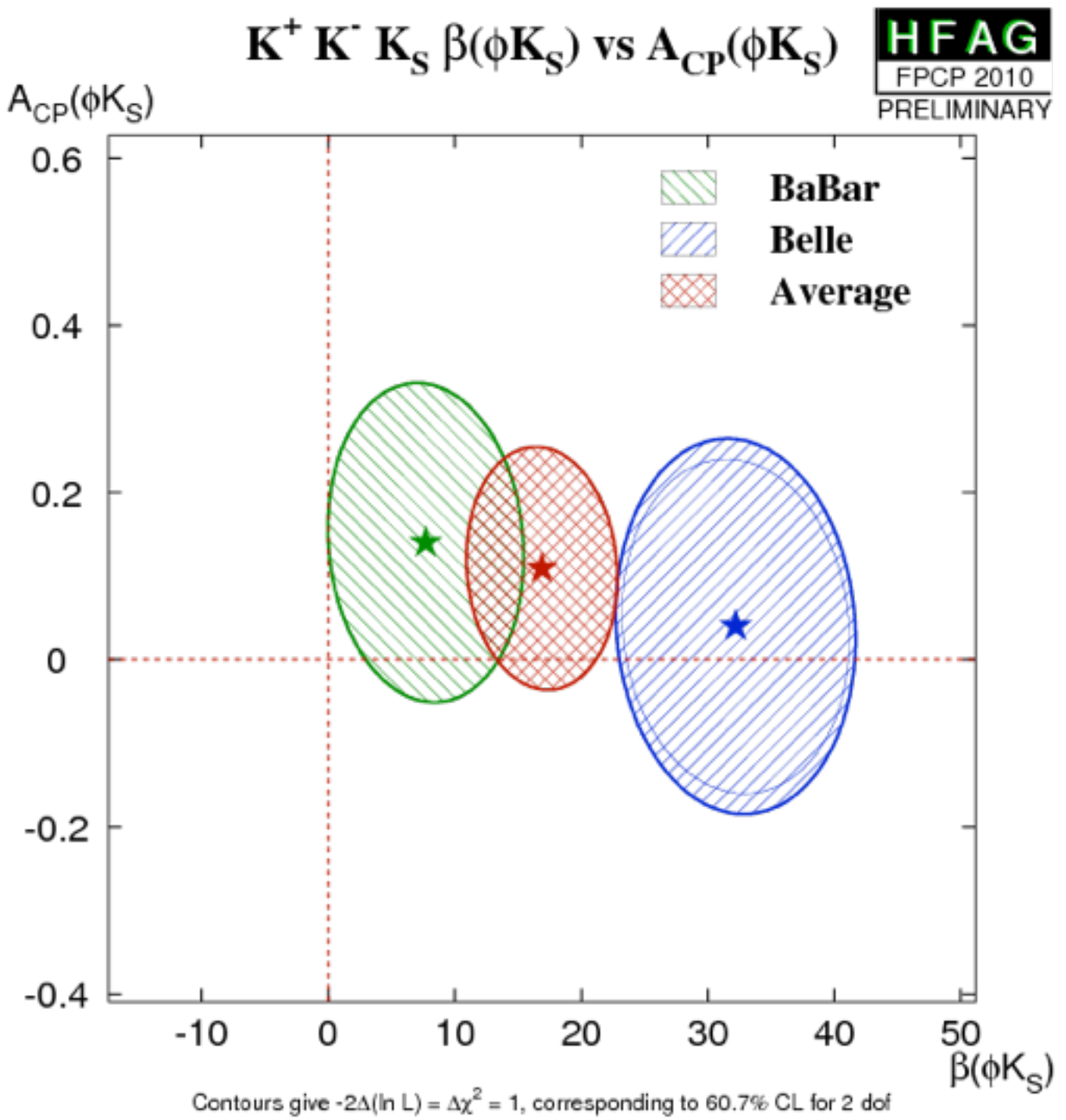



| mode | $\phi_1^{\rm eff}$ | $A_{CP}$ |
|---|---|---|
| $\phi K^0_S$ | $32.2 \pm 9.0 \pm 2.6 \pm 1.4\ (^\circ)$ | $+0.04 \pm 0.20 \pm 0.10 \pm 0.02$ |
| $f_0(980) K^0_S$ | $31.3 \pm 9.0 \pm 3.4 \pm 4.0\ (^\circ)$ | $-0.30 \pm 0.29 \pm 0.11 \pm 0.09$ |

# $t$-dep. $CPV$ in $B^0 \to K^0_S K^+ K^-$

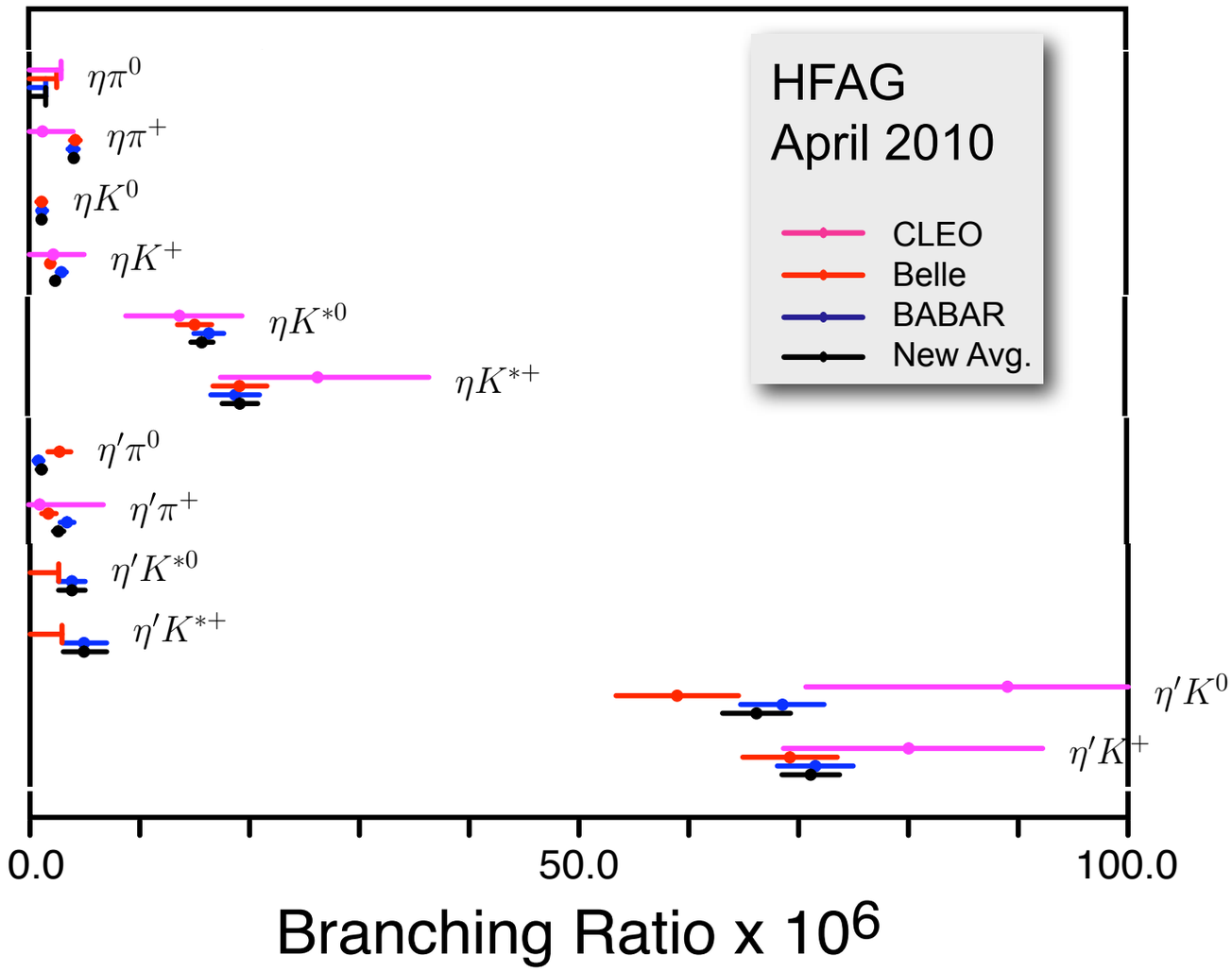


# $B \to X\,\eta^{(\prime)}$ decays

- points of interest
  - unexpectedly large BF for some modes and unexpected patterns of BF's for others
  - sensitive to interference b.w. flavor singlet & octet components
  - many studies using pQCD, QCDF, SCET, etc.
- It will be valuable for QCD studies to have results in more related decay modes

$B \to \eta^{(\prime)} K^{(*)}$



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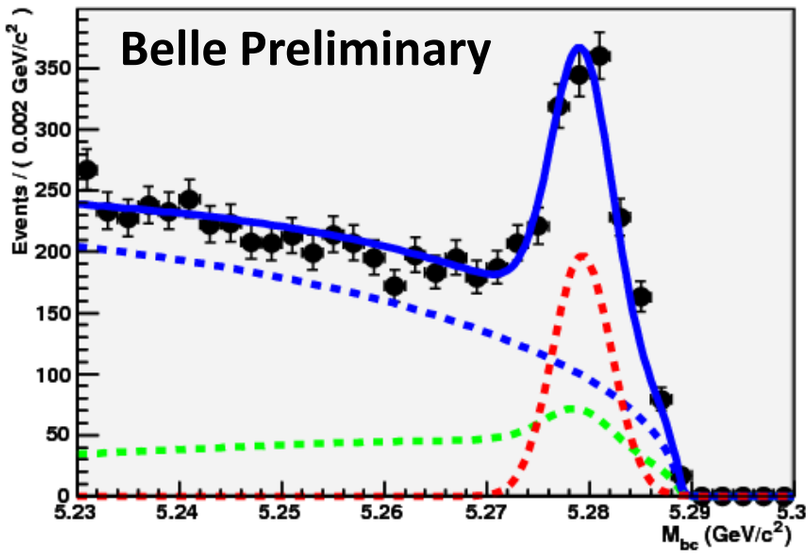
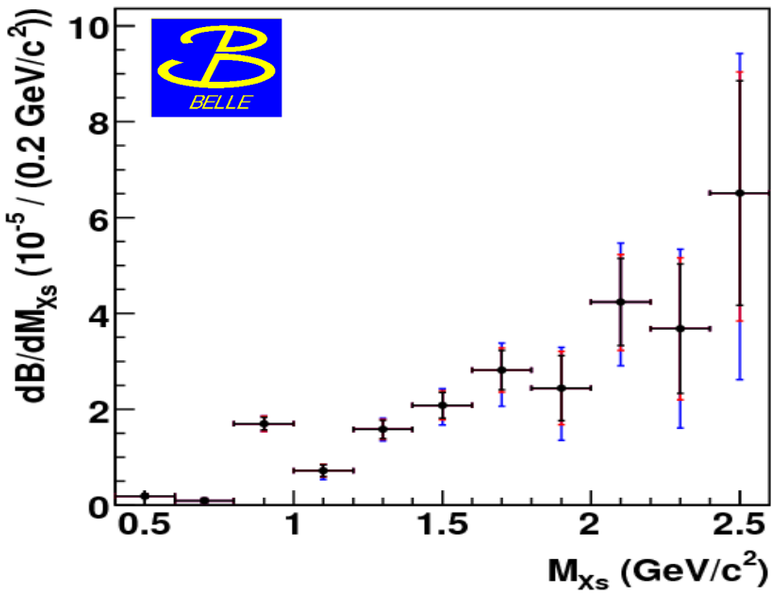
# $B \to X_s \eta$ inclusive

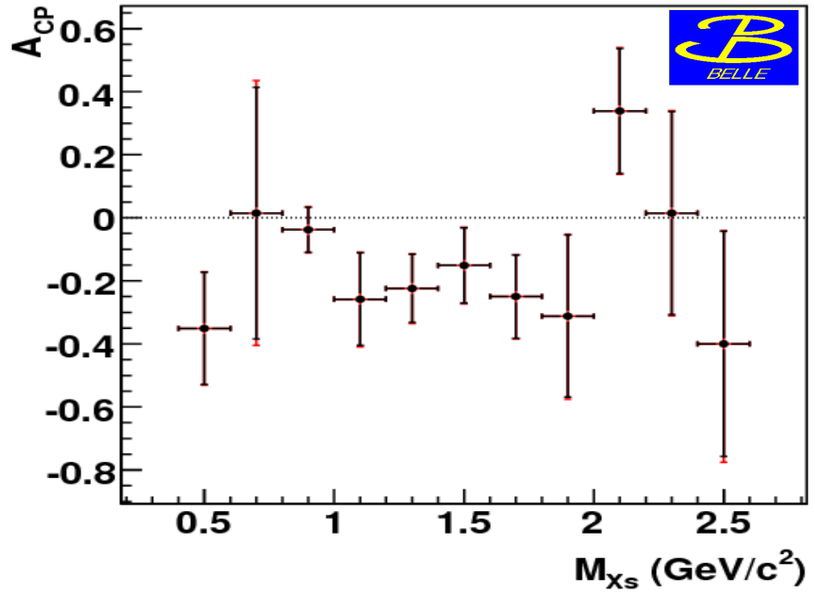



----- : signal

----- : BB background

----- : combinatorial background




- $N_{B\bar{B}} = 657$ M
- pseudo-inclusive
  - sum of exclusive modes
    - $B \to X_s \eta$ ($p^*_\eta > 2.0$ GeV/$c$)
      $\eta \to \gamma\gamma$
      $X_s \to Kn\pi$ ($n \leq 4$, $n_{\pi^0} \leq 1$)
- signal yield
  $N_{\rm sig} = 749 \pm 48 \pm 7$
  for $1.0 < M_{X_s} < 2.6$ GeV/$c^2$

$$\mathcal{B}(B \to X_s \eta) = (26.1 \pm 3.0^{+1.9+4.0}_{-2.1-7.1}) \times 10^{-5}$$

partial BF in $0.4 < M(X_s) < 2.6$ GeV/$c^2$

$$A_{CP}(B \to X_s \eta) = -0.13 \pm 0.04^{+0.02}_{-0.03}$$

for $M(X_s) < 2.6$ GeV/$c^2$

signif. $= 2.6\sigma$ (incl. syst.)

# Concluding Remarks

- B physics experiments have taught us a lot
  - success of CKM paradigm for CPV (--> Physics Nobel 2008)
  - many interesting Rare B decay study ( --> *next two talks*)
  - Yet, there are a few "tension"s

- What's ahead
  - (*although I didn't say a word about it…*) The case for flavor physics in the LHC era is still compelling
  - LHC, esp. LHCb experiment will be great tools for heavy-flavor physics
  - But some aspects, e.g. modes with neutrino(s), will require next-generation B-factory (i.e. **Belle-II**)

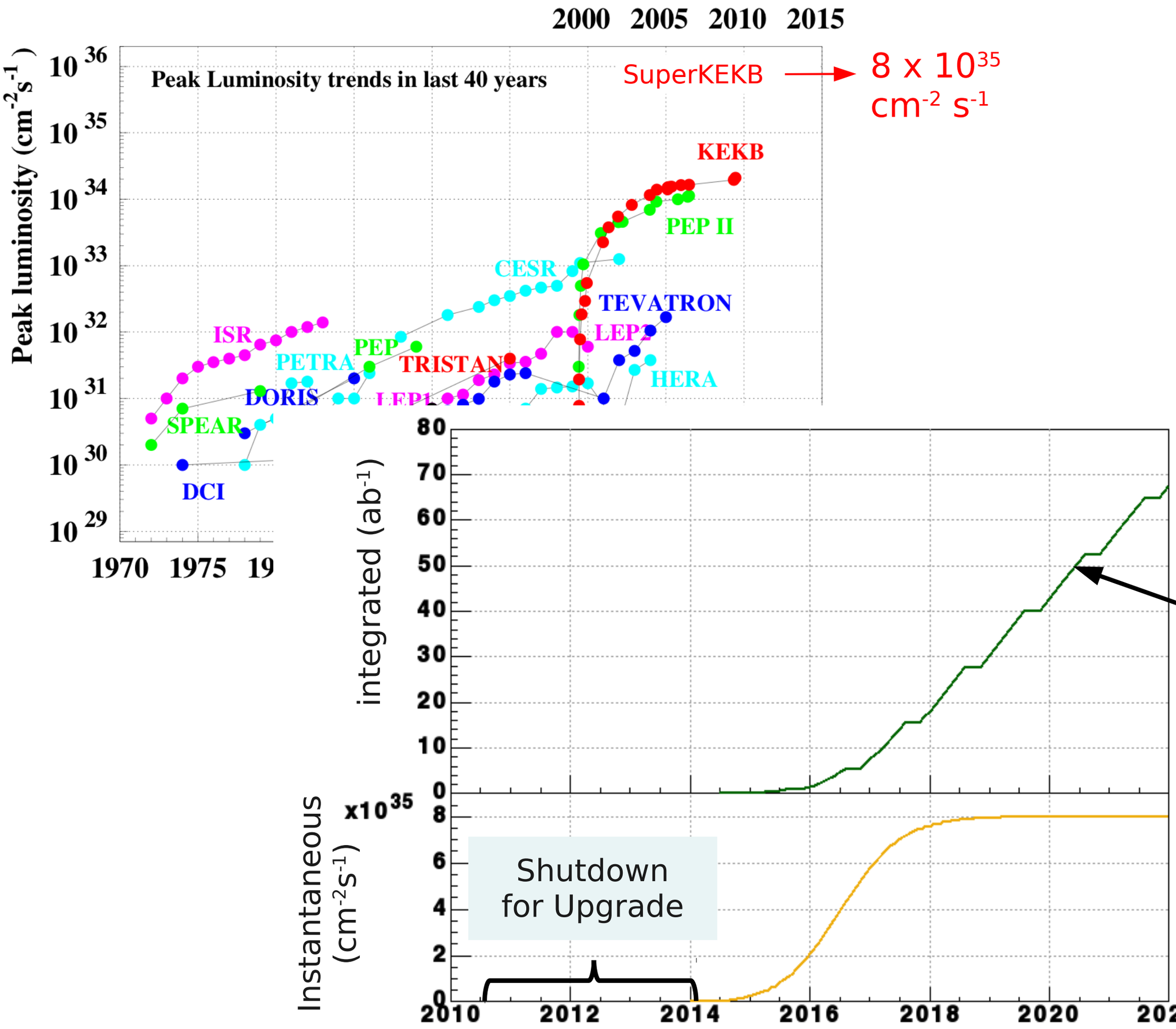
# Future prospects

Dear colleagues,

I am writing this to inform you that MEXT has just announced that it will appropriate 100 oku-yen ($100M) over the next three years starting this Japanese Fiscal Year (JFY) to the KEKB upgrade from a special fund called the "Very Advanced Research Support Program". KEK will, of course, continue its efforts to obtain additional funds from the regular budget to complete SuperKEKB as scheduled.

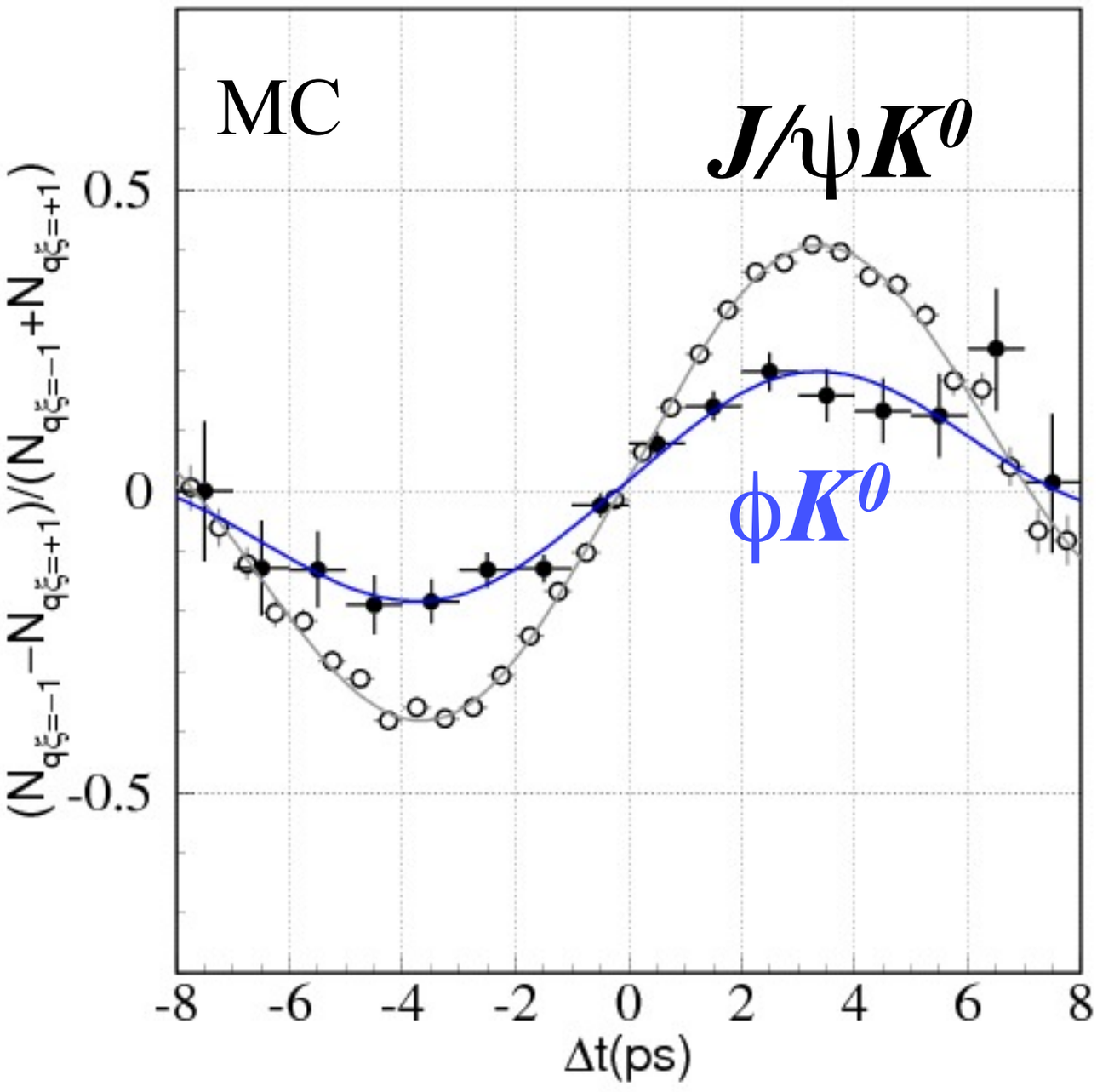
Many congratulations to you all !

news on Jun.22, 2010


Peak Luminosity trends in last 40 years
Peak luminosity (cm-2s-1)
SuperKEKB
8 x 10^35 cm-2 s-1
KEKB
PEP II
CESR
TEVATRON
LEP2
HERA
ISR
PETRA
PEP
TRISTAN
DORIS
SPEAR
DCI
integrated (ab-1)
50 ab-1 in 2020
Instantaneous (cm-2s-1)
x10^35
Shutdown for Upgrade

# *Extrapolation:* $B \to \phi K^0$ at 50/ab

## with present WA values




This would establish the existence of a NP phase

**Compelling measurement in a clean mode**

# Epilogue

*"Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed"*

–A. Soni@Super KEKB proto-collaboration meeting

## *A lesson from history*

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

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

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$$(1964)\ \mathcal{B} = 2 \times 10^{-3}$$

A failure of imagination, or lack of patience?