CP violation in BaBar / Belle part II

Yosuke Yusa
Virginia Tech

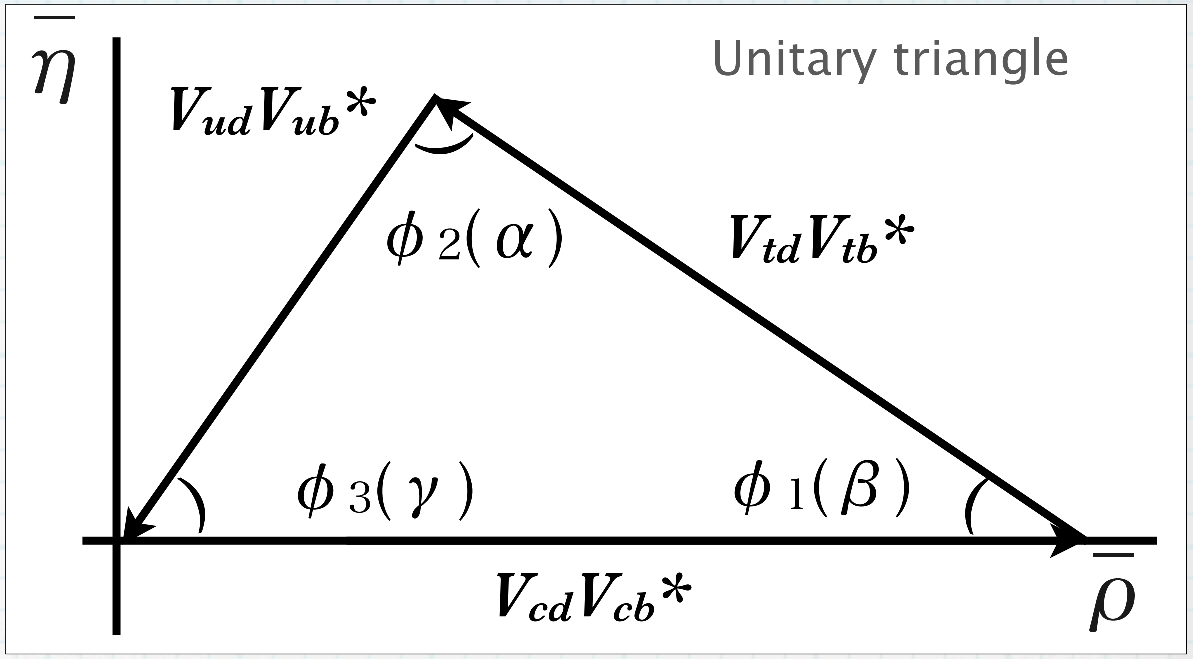
Recent Hot Topics

- ϕ_3/γ measurements

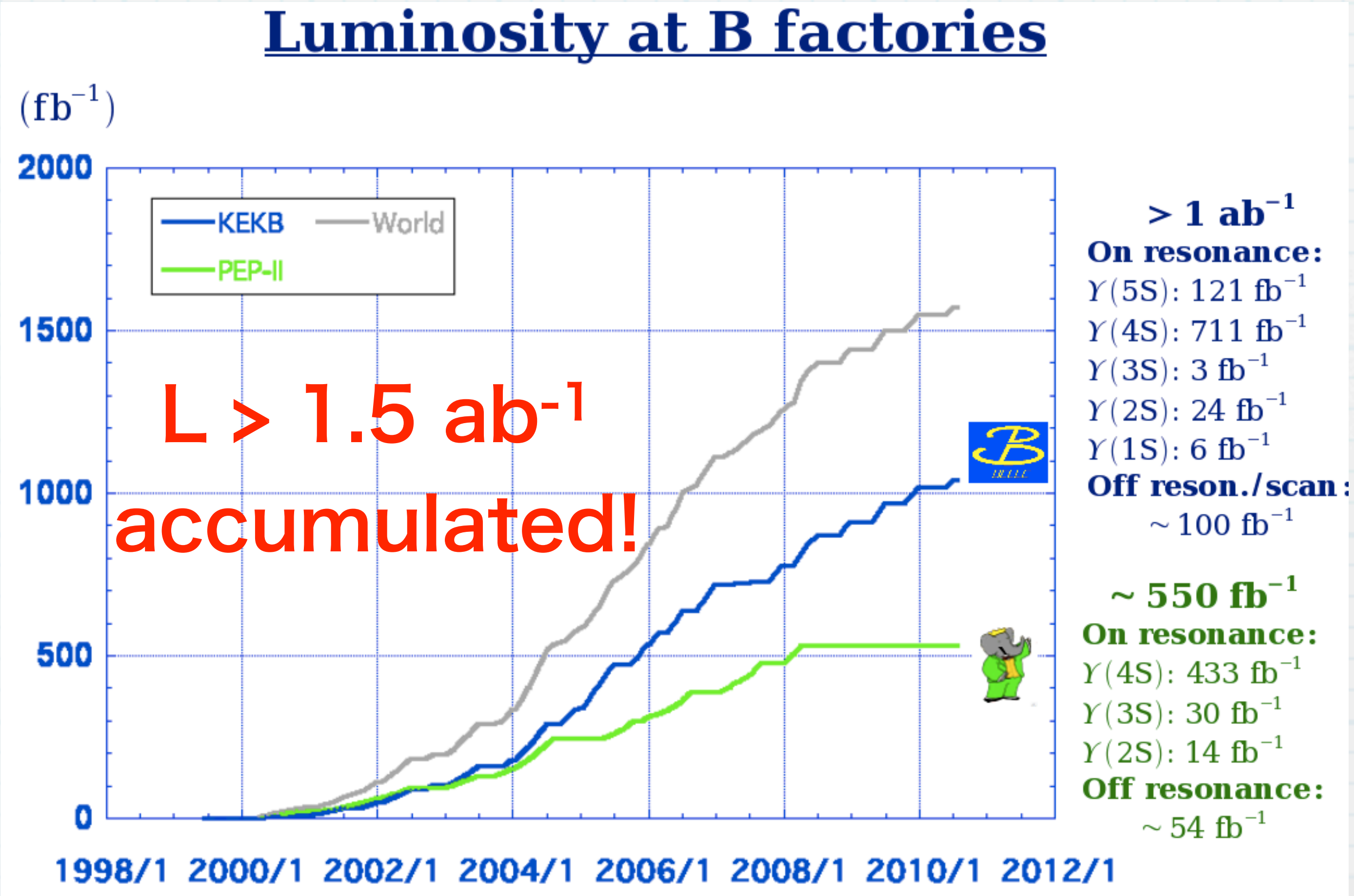
  ADS, Dalitz (GGSZ)

- Direct CP violation

  in B / non-B decays



- KEKB shutdown for upgrade to superKEKB



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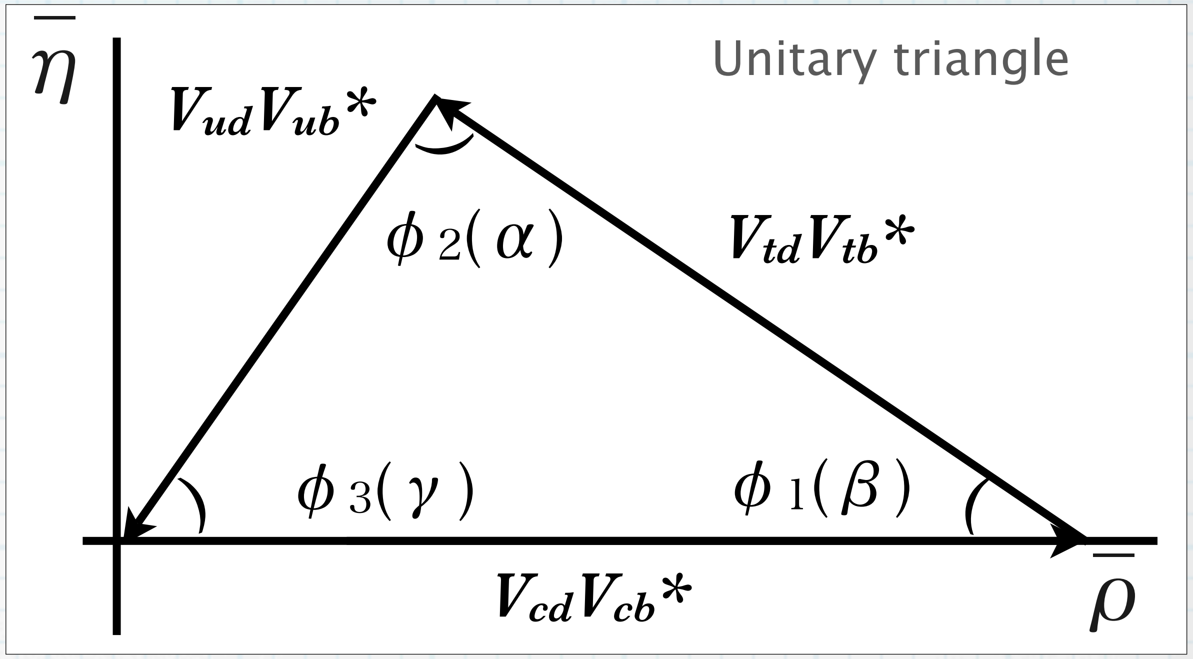


Contents of this talk

- Review of time-dependent CP violation measurement
- Recent results of CP violation measurement

Review of time-dependent CP violation measurement

Overview of Time-dependent CP asymmetry measurement

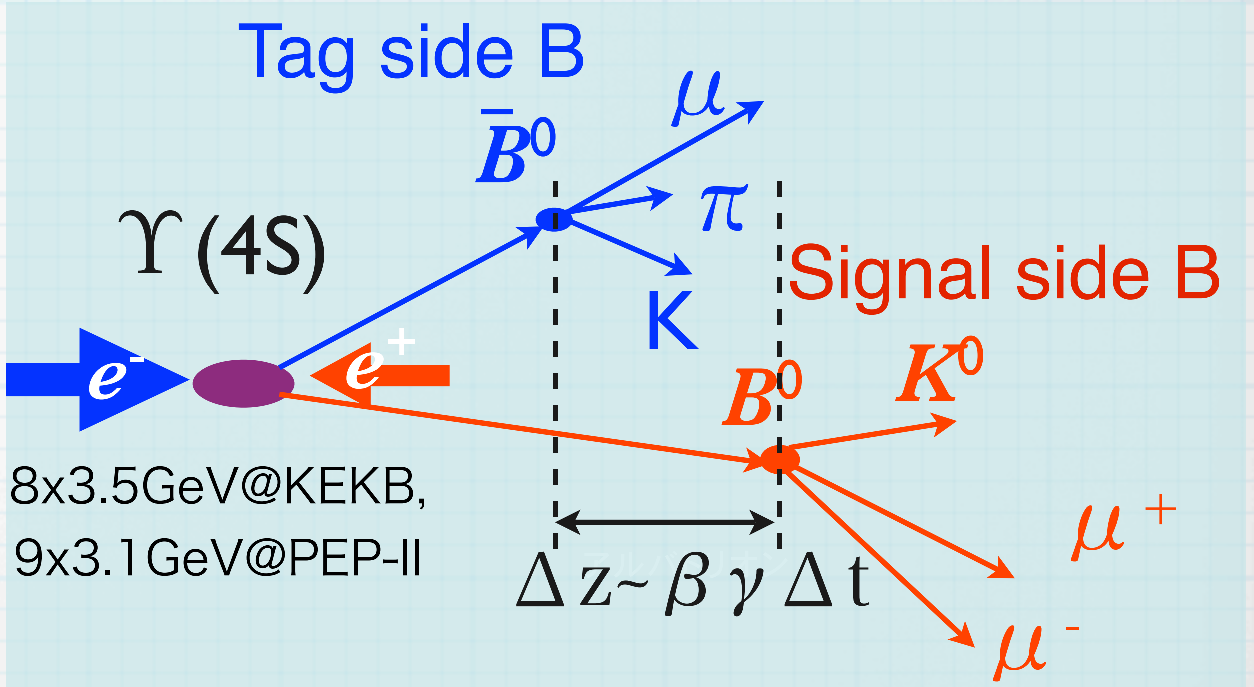
$$\mathcal{A}_{CP} = \frac{\mathcal{P}(\overline{B^0}(\Delta t) \to f_{CP}) - \mathcal{P}(B^0(\Delta t) \to f_{CP})}{\mathcal{P}(\overline{B^0}(\Delta t) \to f_{CP}) + \mathcal{P}(B^0(\Delta t) \to f_{CP})}$$

$$= S \sin\Delta m\Delta t \quad + \quad A \cos\Delta m\Delta t$$

mixing induced CPV — direct CPV

Δm: B-$\bar{B}$ mass difference

Δt: B-$\bar{B}$ decay time difference



Angles of unitary triangle can be measured in several CP-eigenstates:

ex. **$B^0 \to J/\psi K^0$ (b→ccs tree)**

$S = -\xi_f \sin 2\phi_1$

$B^0 \to \pi\pi$, $\rho\rho$ (b→uud tree)

$S = -\xi_f \sqrt{1-A^2} \sin 2\phi_2^{eff}$

$\phi_2^{eff} = \phi_2 - \Delta\phi_2$

(extra-CP phase from other diagram)

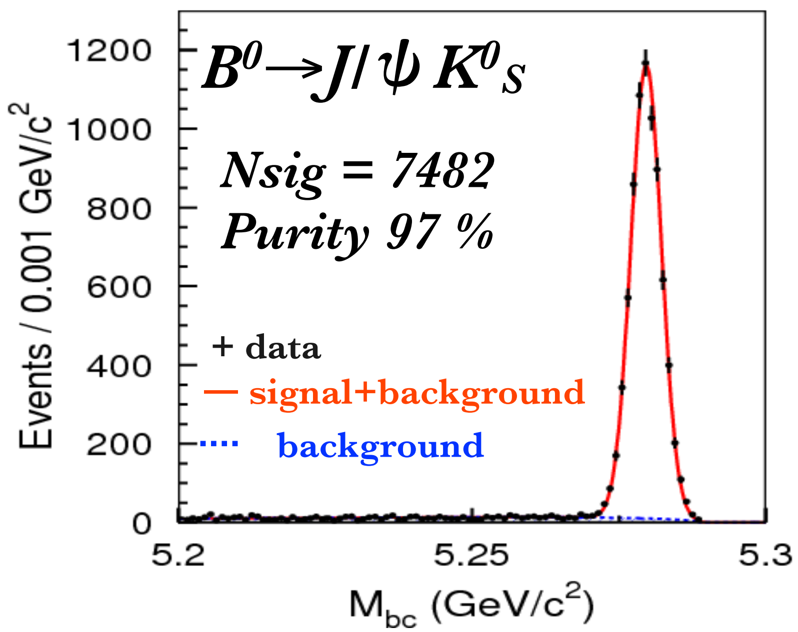
- Decay time is measured from difference of vertex position
- Flavor of B^0 is measured from information of daughter of companion B (high momentum lepton, kaon, etc.)

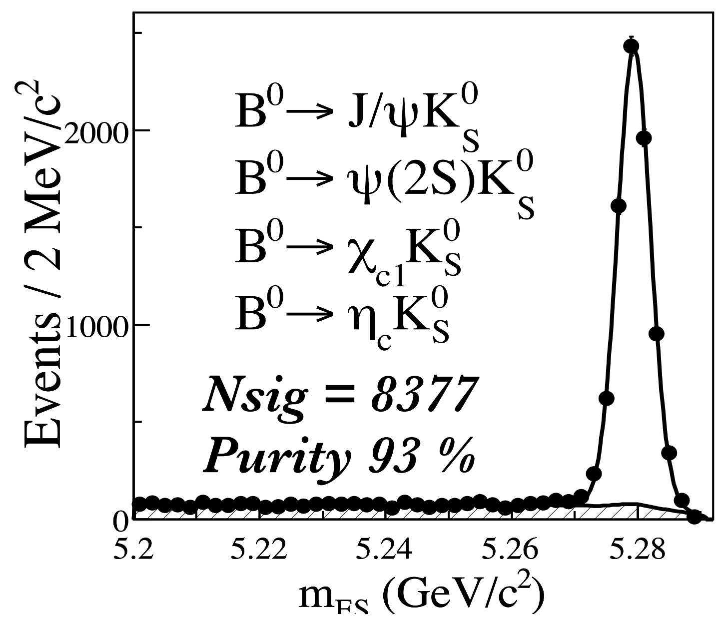
$\sin 2\phi_1 / \beta$ measurement

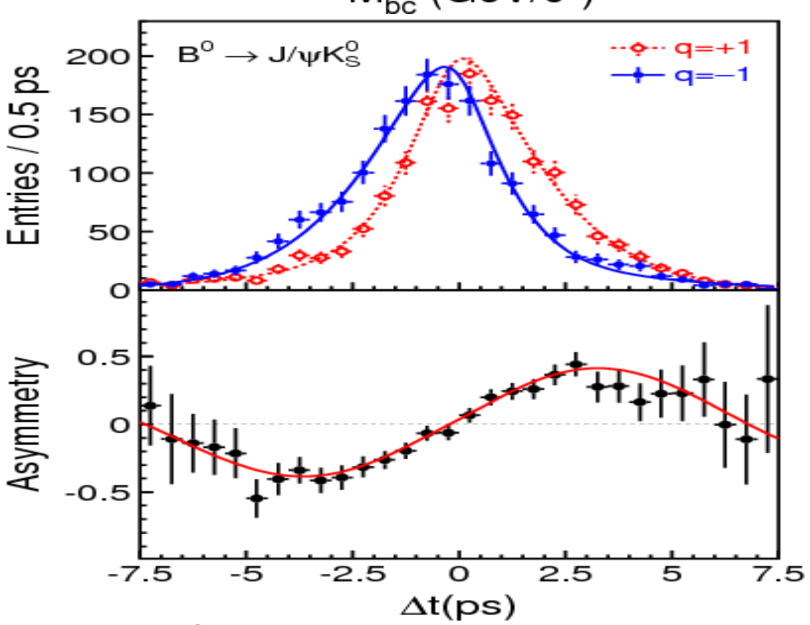
CP odd ($\xi_f = -1$)

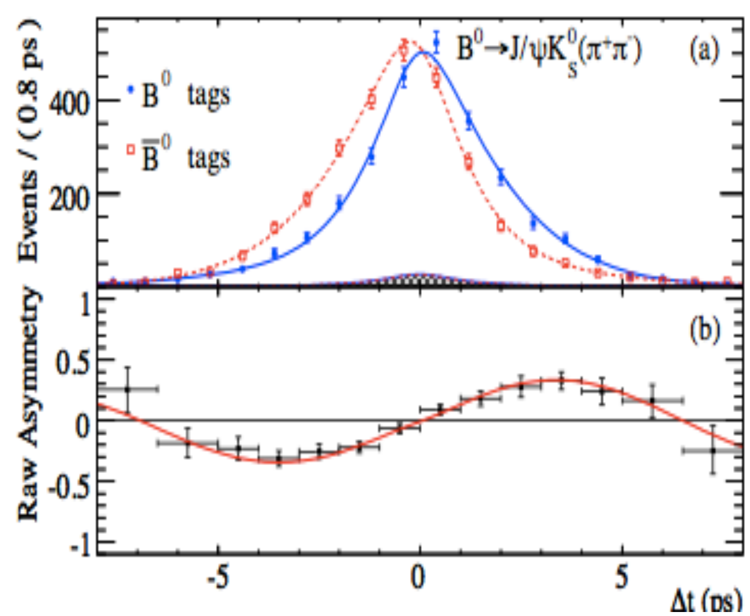
Belle 535M $B\bar{B}$
(PRL 98 (2007) 031802)

BABAR 465M $B\bar{B}$
(full data set)
(PRD 79 (2009) 072009)









$\sin 2\phi_1 = 0.642 \pm 0.031 \pm 0.017$

$A = -0.018 \pm 0.021 \pm 0.014$
($B^0 \to J/\psi K^0$ total)

$\sin 2\phi_1 = 0.666 \pm 0.031 \pm 0.013$

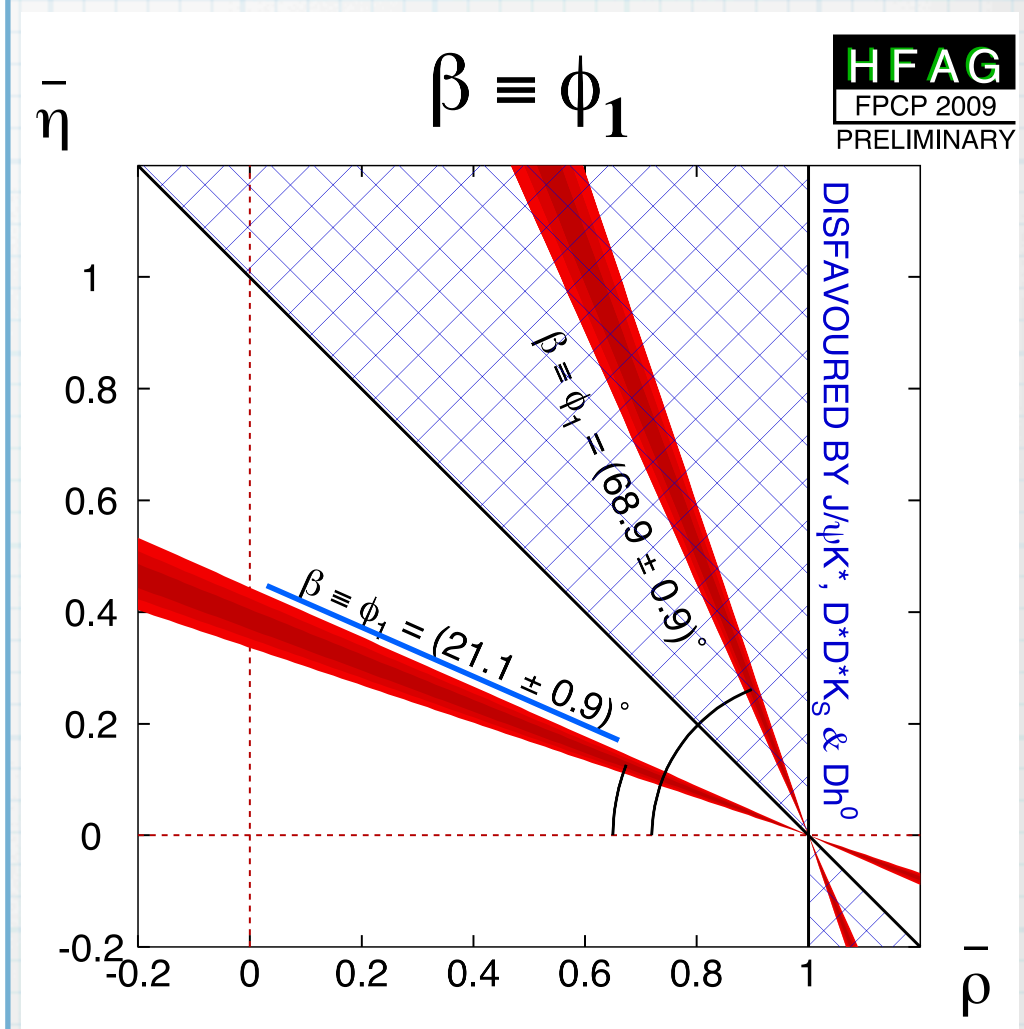
$A = -0.016 \pm 0.023 \pm 0.018$
($B^0 \to J/\psi K^0$ total)

beam constraint mass:

$M_{bc} = \sqrt{(E_{beam}/2)^2 - p_{rec}^2} = m_{ES}$

(signal: $= M_{B0}$)

Average of b→charmonium

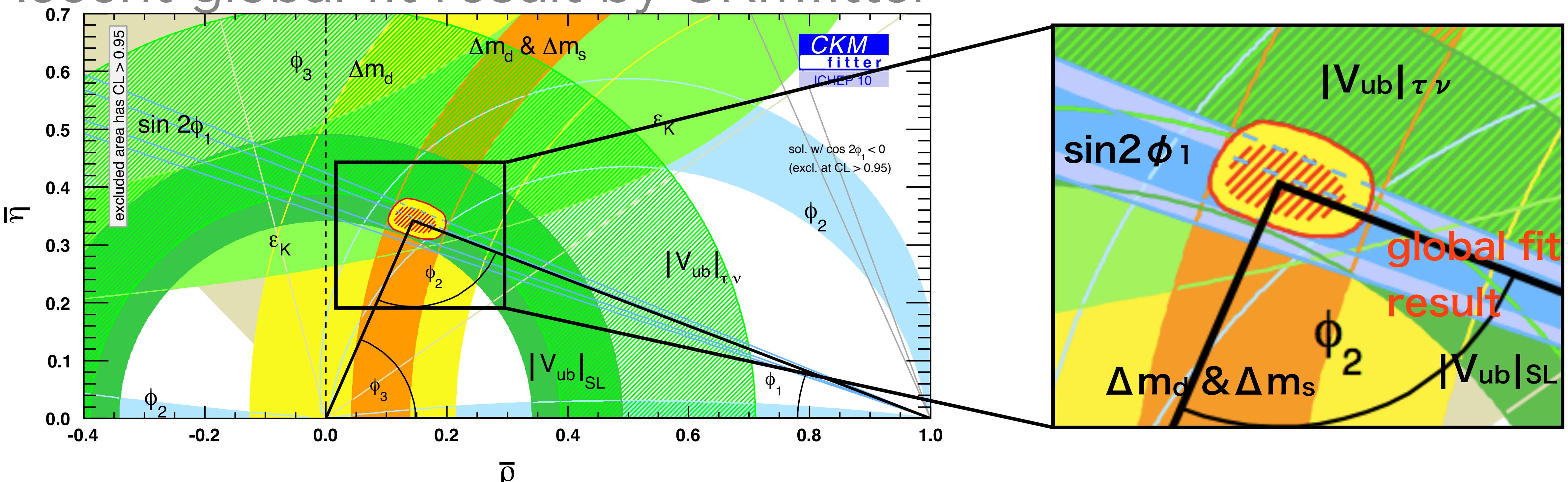


ϕ_1 is measured to <5% accuracy

Motivation of further $\sin 2\phi_1/\beta$ measurements

- $\sin 2\phi_1 \longleftrightarrow |V_{ub}|$ from $B^+ \to \tau^+ \nu$

Recent global fit result by CKMfitter



$B(B^+ \to \tau\,\nu) = (0.861^{+0.101}_{-0.095}) \times 10^{-4}$ (CKMFitter, ICHEP10)

Hints of new physics contribution?

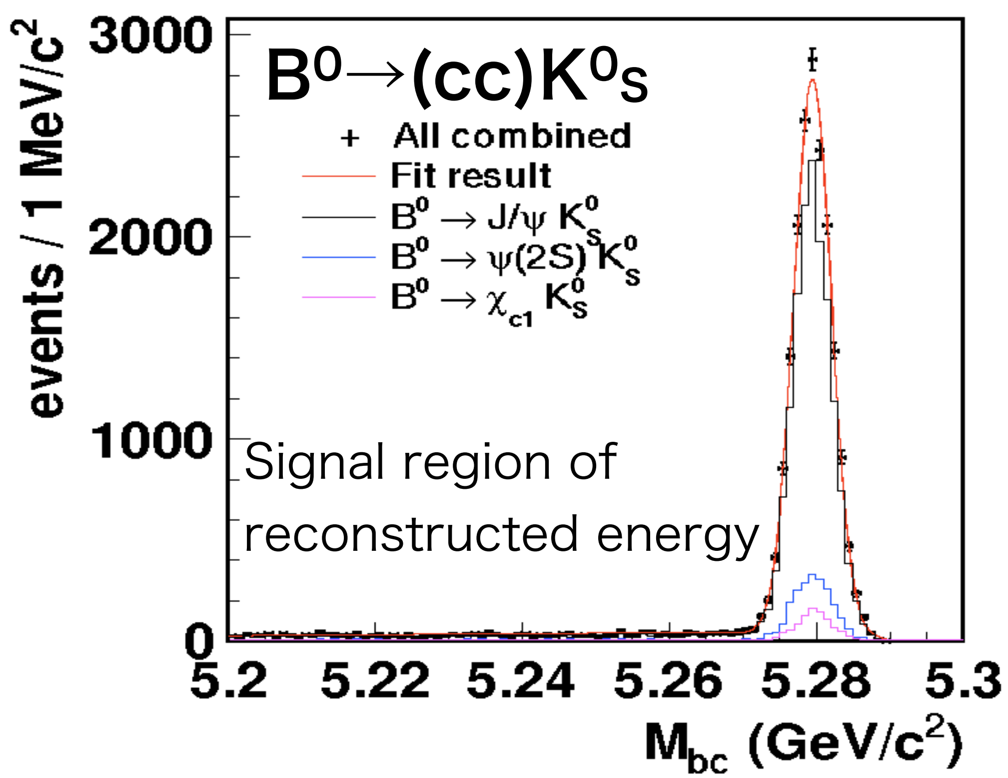
Belle preliminary	$(1.54\,^{+0.38}_{-0.37}\,^{+0.29}_{-0.31}) \times 10^{-4}$
BaBar preliminary	$(1.76 \pm 0.45) \times 10^{-4}$
Average	$(1.64 \pm 0.34) \times 10^{-4}$

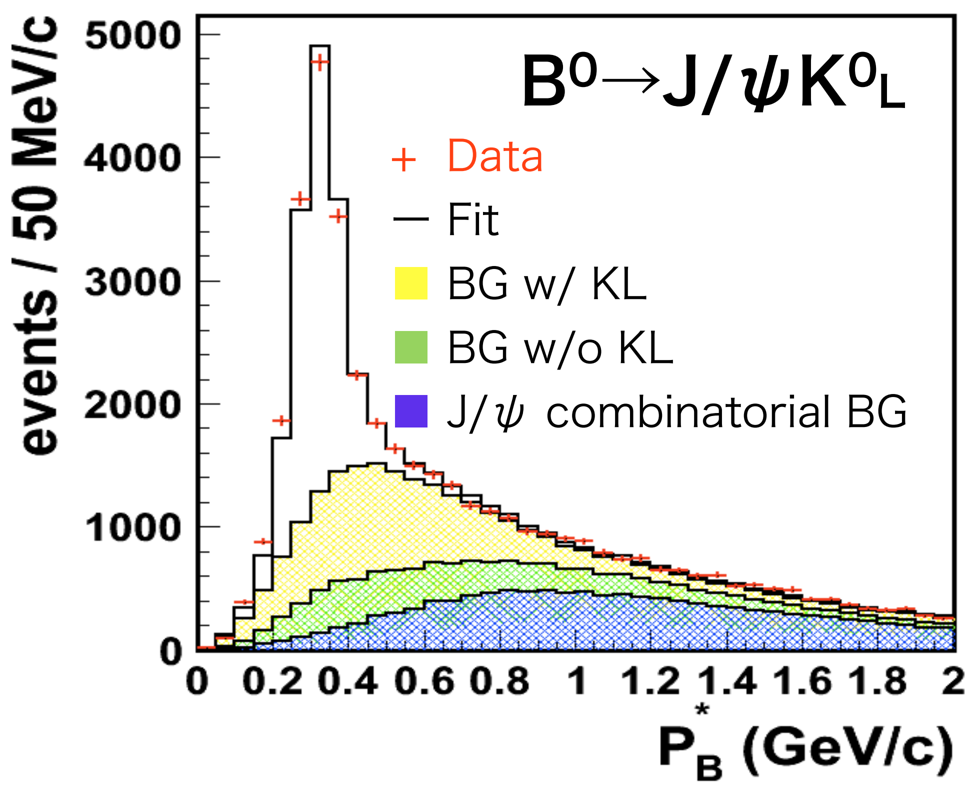
Precise $\sin 2\phi_1$ measurement contributes to reduce global fit error

Further sin2ϕ_1/β measurements

- Belle final result will be shown in near future

772M $B\bar{B}$, full data





	$J/\psi K^0_S$	$J/\psi K^0_L$	$\psi(2S)K^0_S$	$\chi_{c1}K^0_S$
Signal yield	12727±115	10087±154	1981±46	949±33
Purity (%)	97	63	93	89
Signal yield (535M $B\bar{B}$)	7484±87	6312±123	—	—
Purity (%) (535M $B\bar{B}$)	97	59	—	—

Expected statistical error on sin2ϕ_1 = 0.023

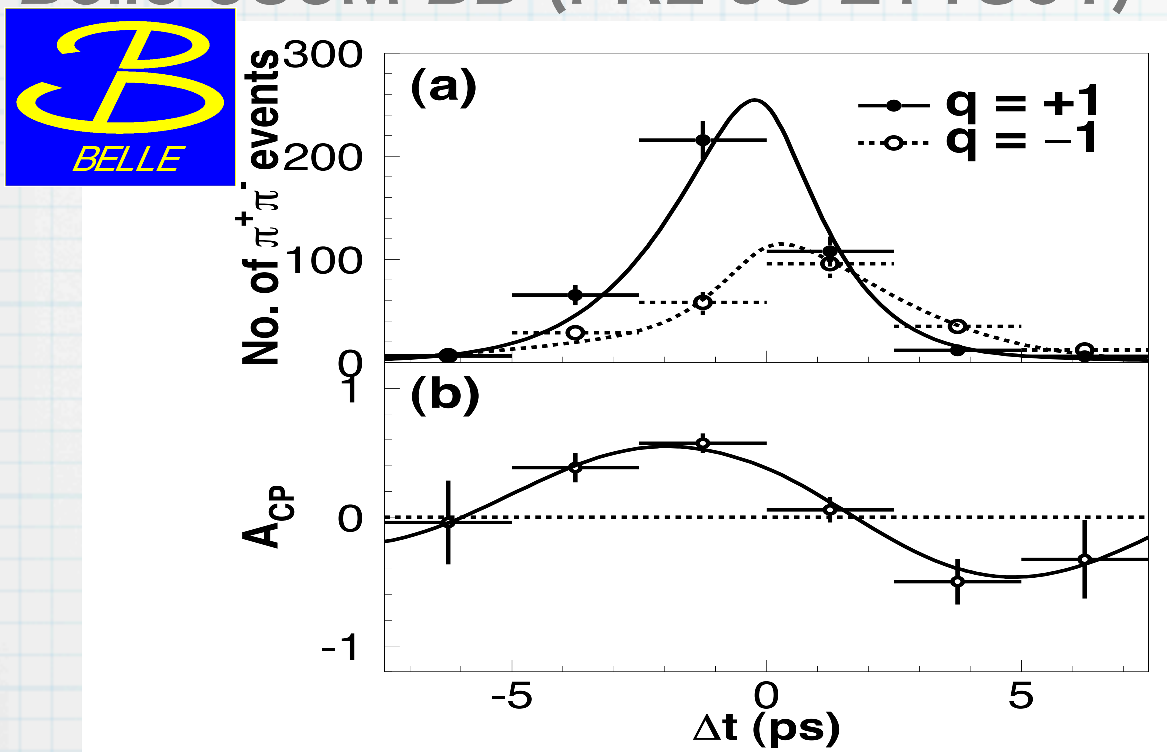
→ 30% smaller than previous result and close to systematic limit

(c.f. sin2ϕ_1 = 0.642±0.031(stat)±0.017(syst), Belle 535M $B\bar{B}$)

ϕ_2/α measurement

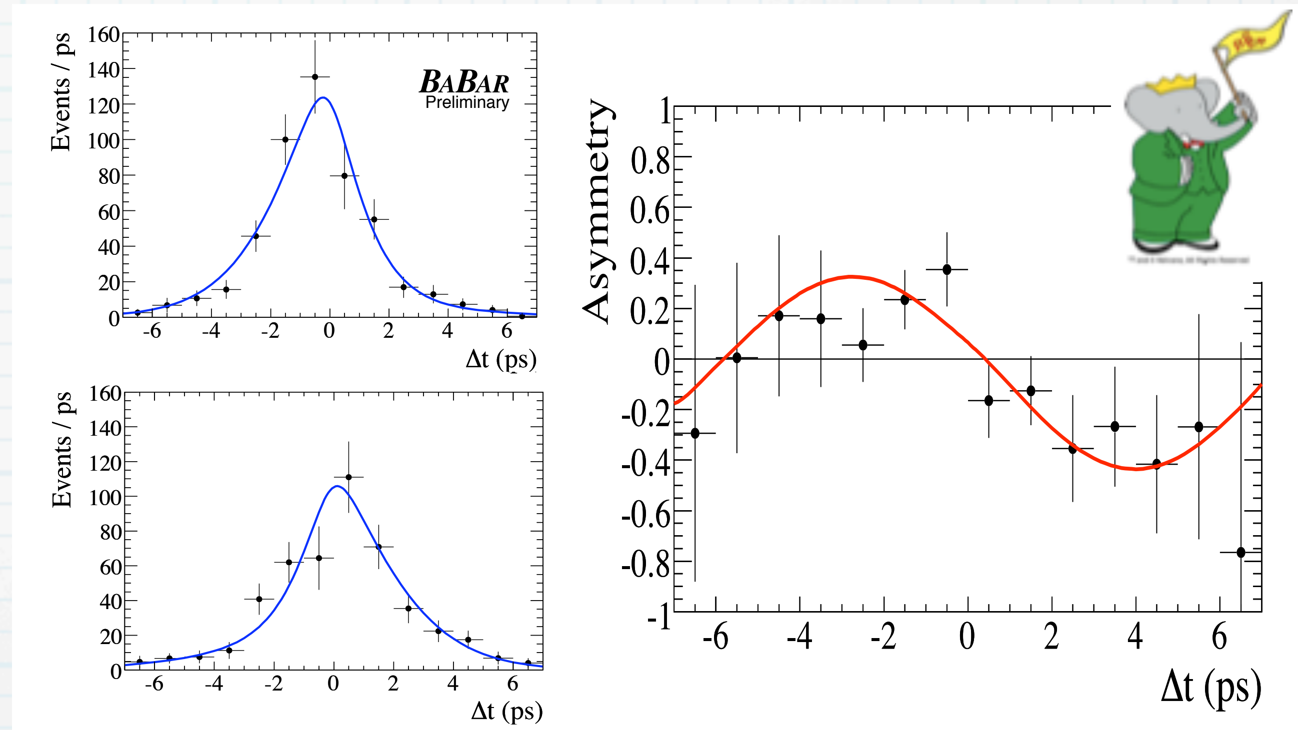
- $B^0 \to \pi^+\pi^-$

Belle 535M $B\bar{B}$ (PRL 98 211801)



S = -0.61±0.10±0.04
A = 0.55±0.08±0.05

BABAR 465M $B\bar{B}$ (arXiv:0807.4226)



S = -0.68±0.10±0.03
A = 0.25±0.08±0.02

→ Extra CP phase is determined using isospin relations (Gronau and London, PRL65 3381) with other measured values

$$A^{+0} = \frac{1}{\sqrt{2}} A^{+-} + A^{00}$$

$$\bar{A}^{-0} = \frac{1}{\sqrt{2}} \bar{A}^{+-} + \bar{A}^{00}$$

(A^{ij} : Decay amplitude of $B \to \pi^i \pi^j / \rho^i \rho^j$)

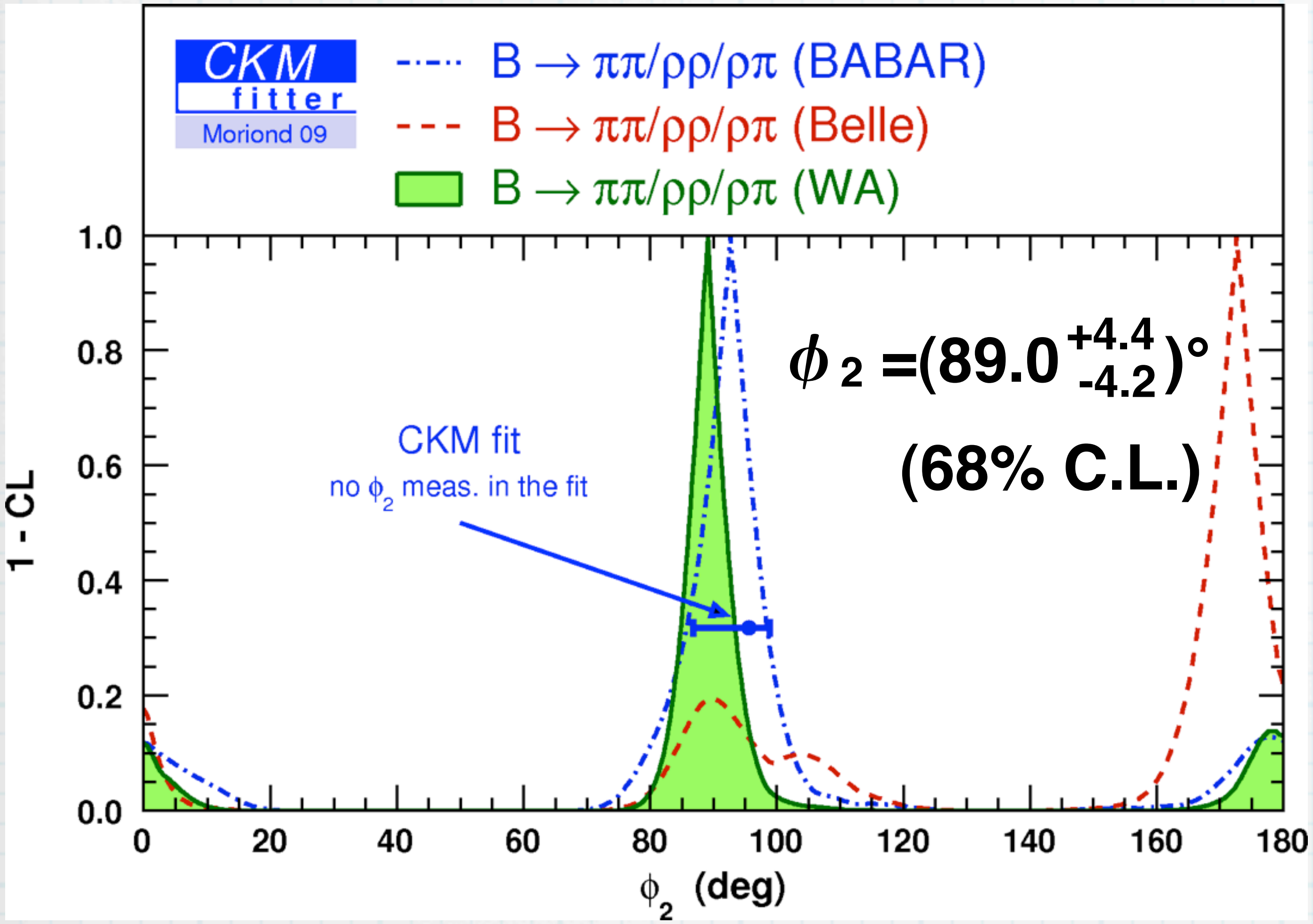
$BR(B^0 \to \pi^+\pi^-) = 5.16 \pm 0.22$	-
$BR(B^+ \to \pi^+\pi^0) = 5.59\ ^{+0.41}_{0.41}$	$A_{CP}(B^+ \to \pi^+\pi^0) = 0.06 \pm 0.05$
$BR(B^0 \to \pi^0\pi^0) = 1.55 \pm 0.19$	$A_{CP}(B^0 \to \pi^0\pi^0) = 0.43\ ^{+0.25}_{-0.24}$

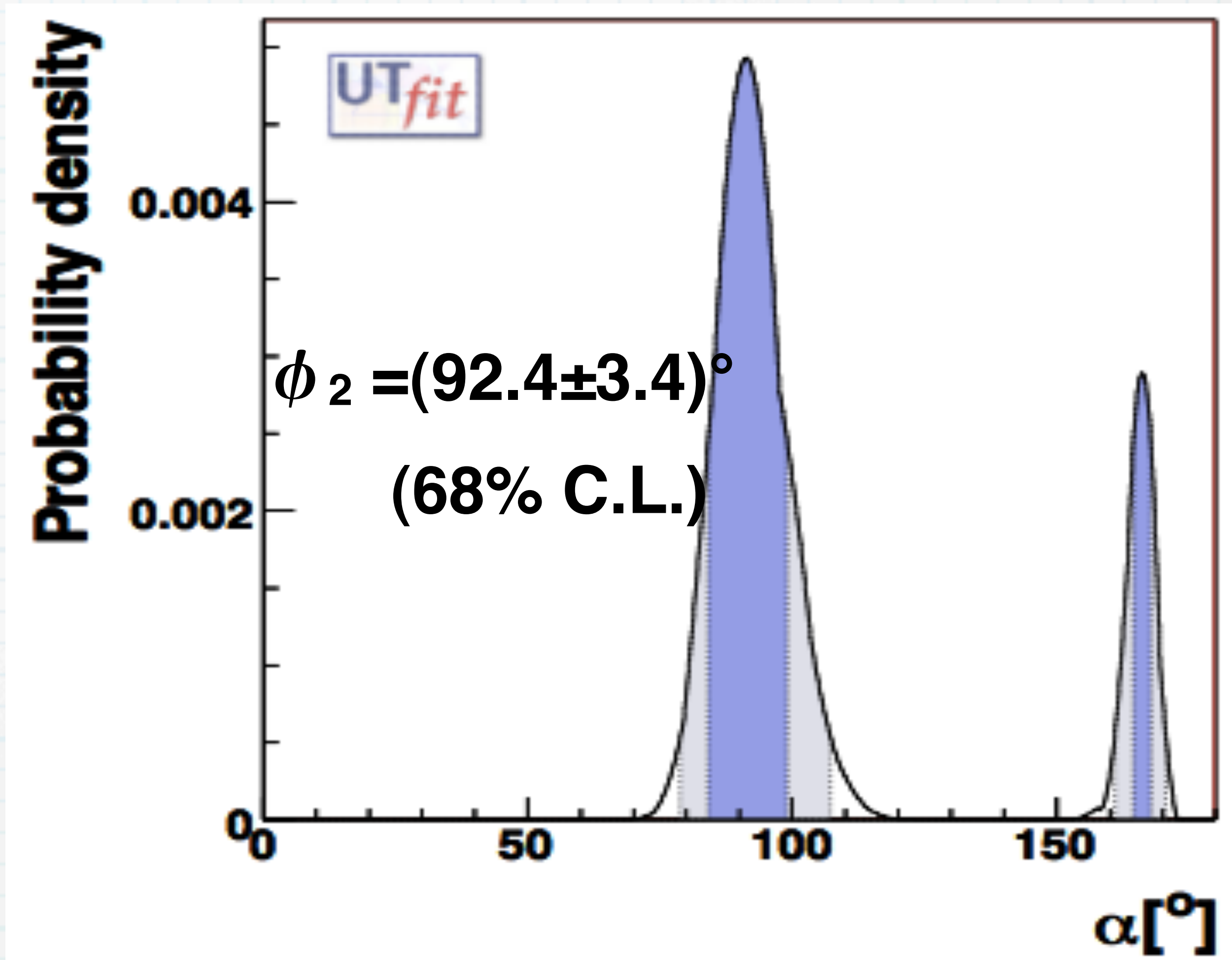
(units: 10^{-6})

⇒ exclude 9° < ϕ_2 < 81° (95.4% C.L.)

⇒ exclude 23° < ϕ_2 < 67° (90% C.L.)

ϕ_2/α measurement





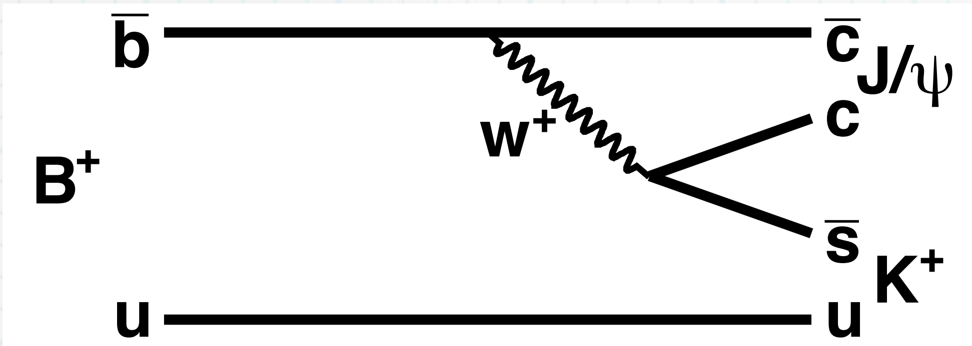
Both asymmetries and branching fractions will be updated with full data samples in Belle and BABAR.

$\phi 2$ will be measured with better accuracy in near future.

Recent results of CP violation measurement

$B^+ \to J/\psi K^+$ Direct CPV

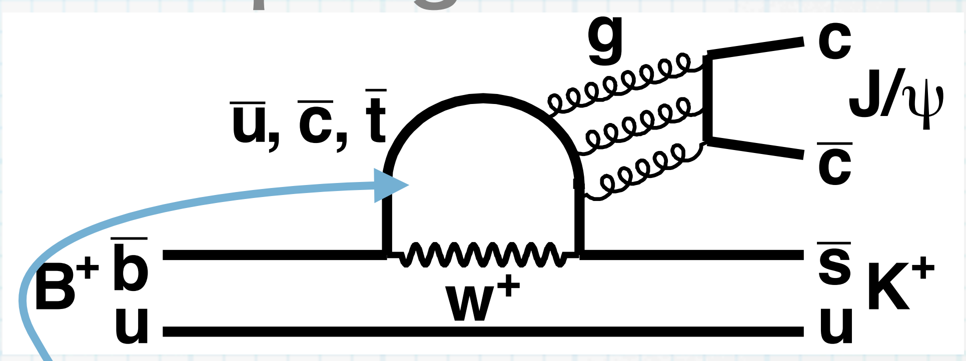
b→c tree



Direct CPV~0

\+

b→s penguin



New physics contribution?

Asymmetry :

$$A_{CP}(B^+ \to J/\psi K^+) = \frac{\mathcal{B}(B^- \to J/\psi K^-) - \mathcal{B}(B^+ \to J/\psi K^+)}{\mathcal{B}(B^- \to J/\psi K^-) + \mathcal{B}(B^+ \to J/\psi K^+)}$$

~ 0.3% in Standard Model

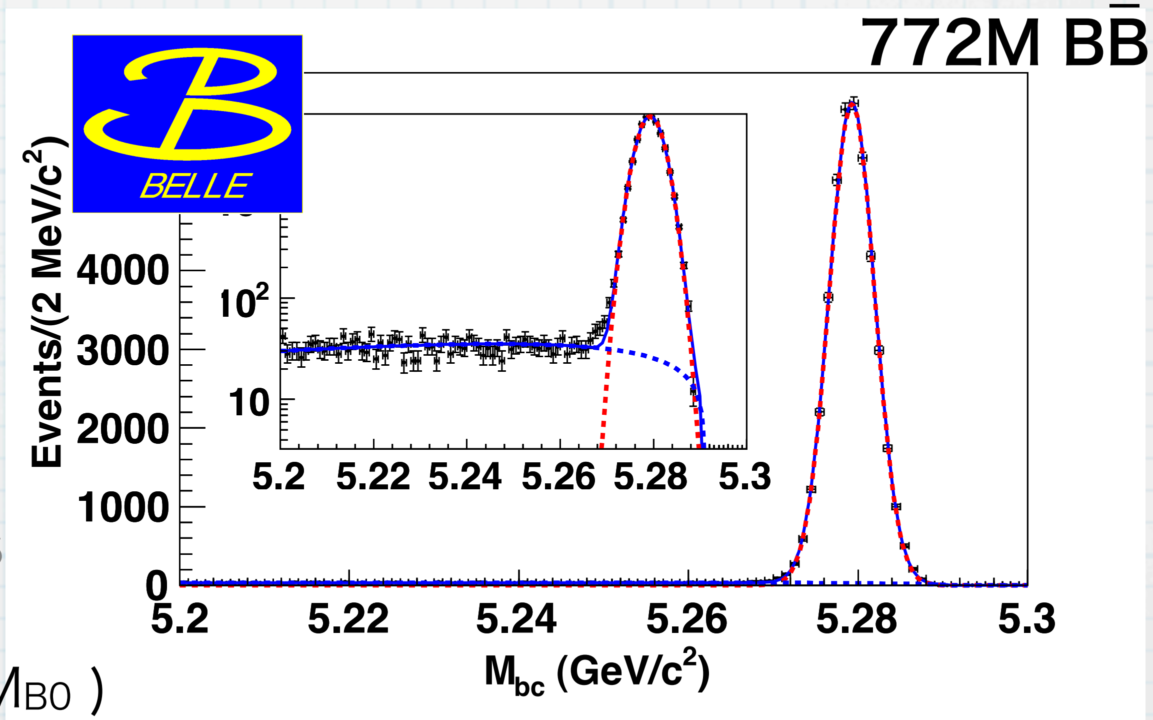
O(1%) extra U(1)' gauge boson

Phys. Lett. B. 598, 218 (2004)

O(10%) extra coupling to charged Higgs

Phys. Rev. D. 62, 056005 (2000)

Previous measurements	Asymmetry (%)
Belle (2003, 32M $B\bar{B}$)	$-2.6 \pm 2.2 \pm 1.7$
BABAR (2005, 124M $B\bar{B}$)	$+3.0 \pm 1.4 \pm 1.0$
D0 (2008, 40k signal)	$+0.75 \pm 0.61 \pm 0.30$
PDG (2009)	$+0.9 \pm 0.8$



Precise measurement using huge data samples

N_{signal} = 41315±205 events

beam constraint mass:

$M_{bc} = \sqrt{(E_{beam}/2)^2 - p_{rec}^2}$ (signal: = M_{B0})

$B^+ \to J/\psi K^+$ Direct CPV

Asymmetry from K^+/K^- detection efficiency should be considered (detector acceptance, interaction rate difference between K^+ and K^-)

→ estimate from control samples: $D_s \to \phi(\to KK)\pi^+$, $D^0 \to K\pi^+$

measured		forward-backward asymmetry of D		π detection efficiency		K detection efficiency
A_{rec}^{Ds}	=	A_{FB}^{Ds}	+	A_{ε}^{π}	+	A_{ε}^{K}
-) A_{rec}^{D}	=	A_{FB}^{D}	+	A_{ε}^{π}		

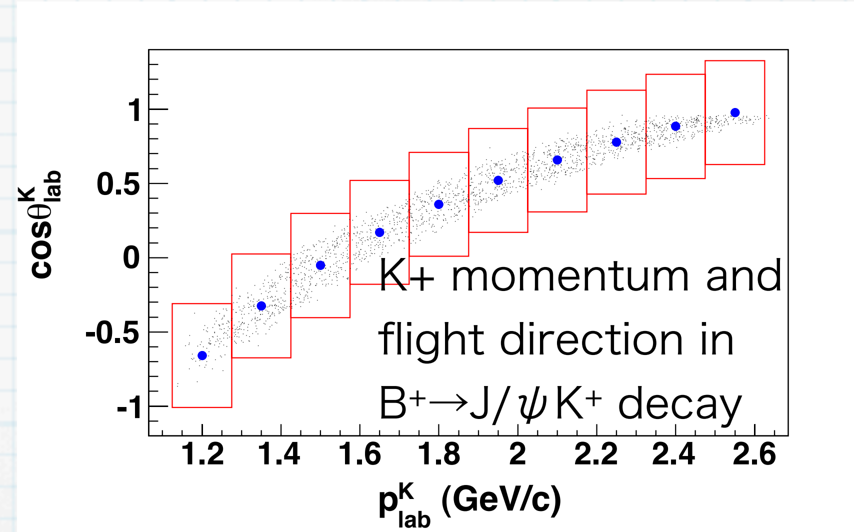
A_{ε}^{K} (Assume $A_{FB}^{Ds} = A_{FB}^{D}$)

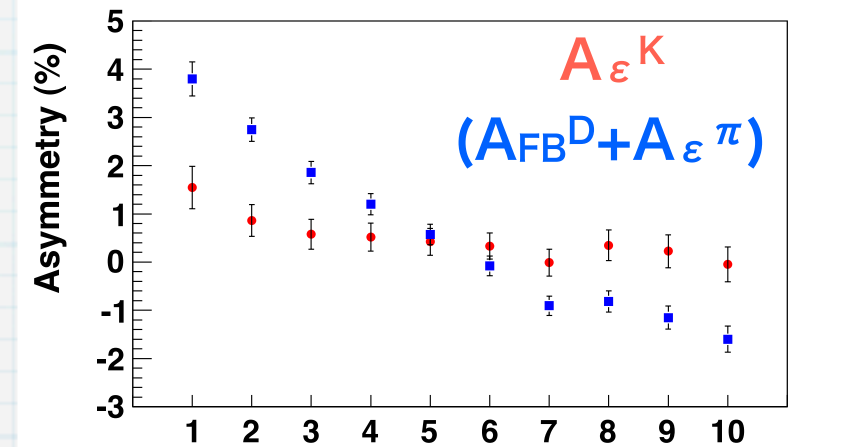
Consider K momentum/flight direction dependence on A_{ε}^{K}

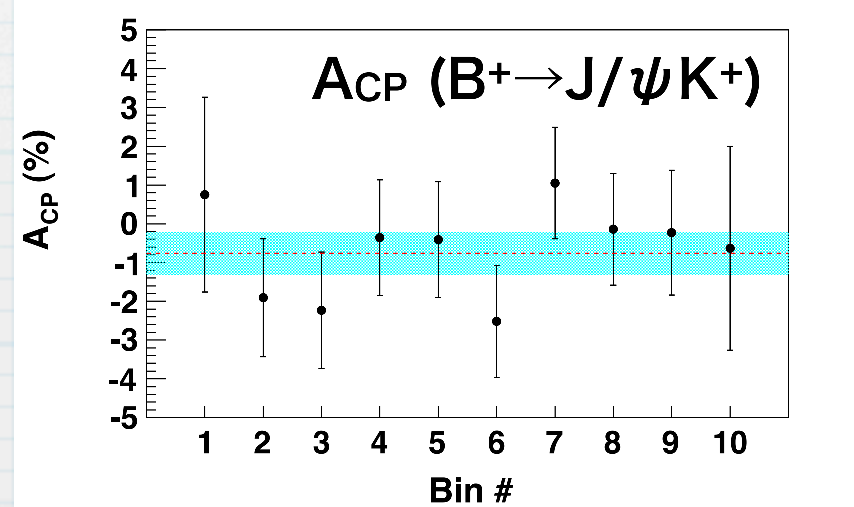
$$A_{CP}(B^+ \to J/\psi K^+) = \frac{\mathcal{B}(B^- \to J/\psi K^-) - \mathcal{B}(B^+ \to J/\psi K^+)}{\mathcal{B}(B^- \to J/\psi K^-) + \mathcal{B}(B^+ \to J/\psi K^+)}$$

$$= (-0.76 \pm 0.50 \pm 0.22)\%$$

BELLE







CP violation in b→s transition

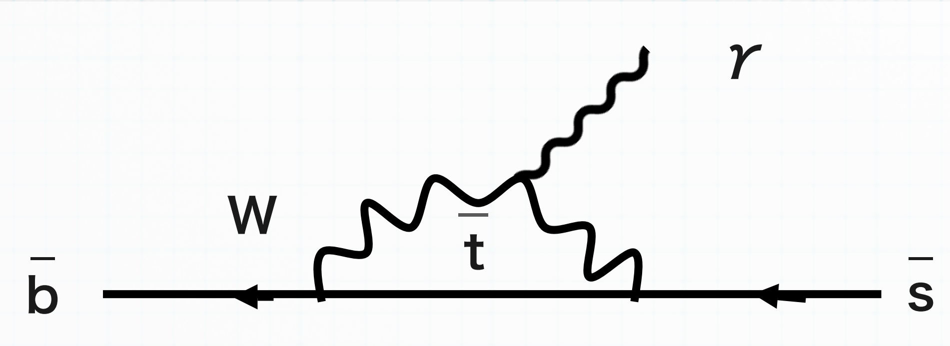
Loop appears in first order diagrams of

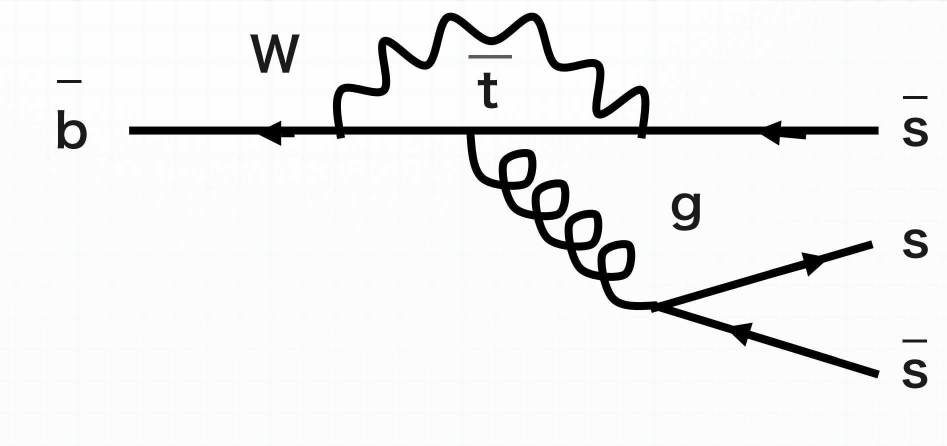
Flavor Changing Neutral Current transitions

b→sqq penguin, b→s γ

⇒ Sensitive to new physics contribution

→ Extra CP phase





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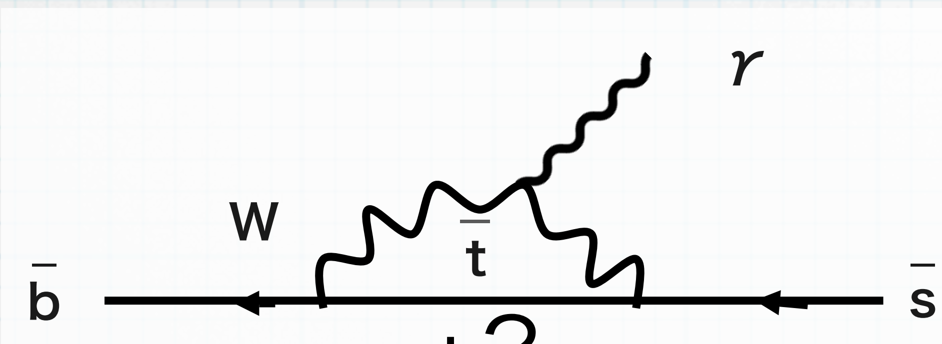
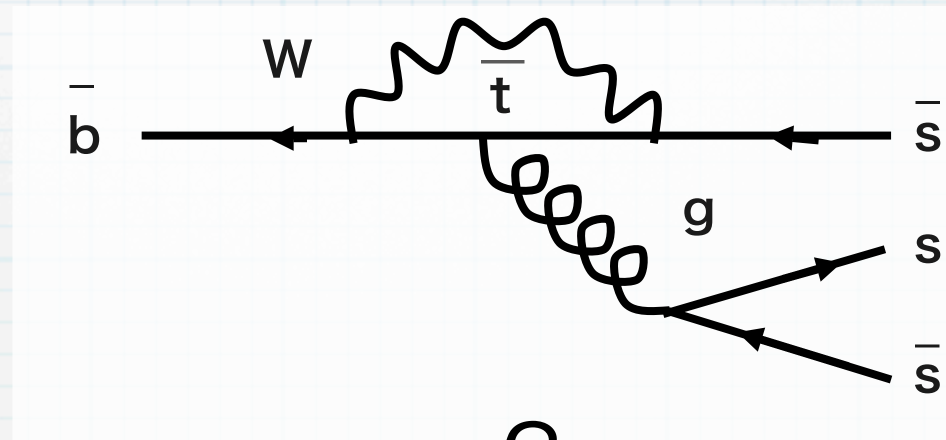
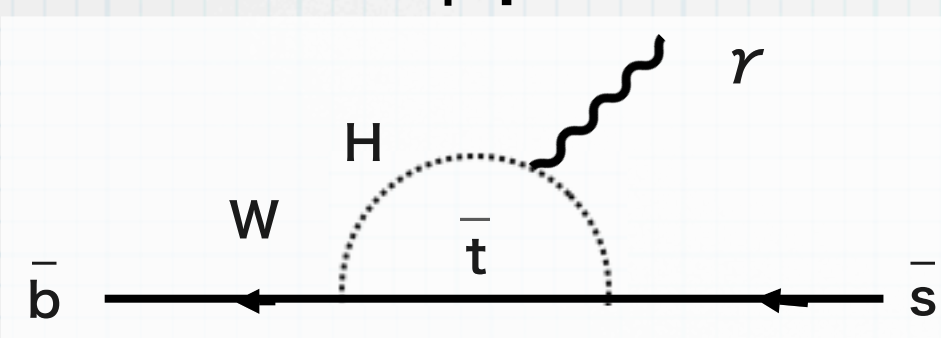
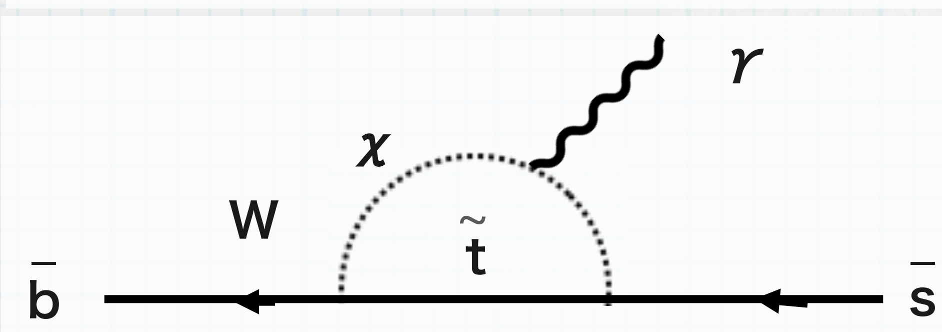


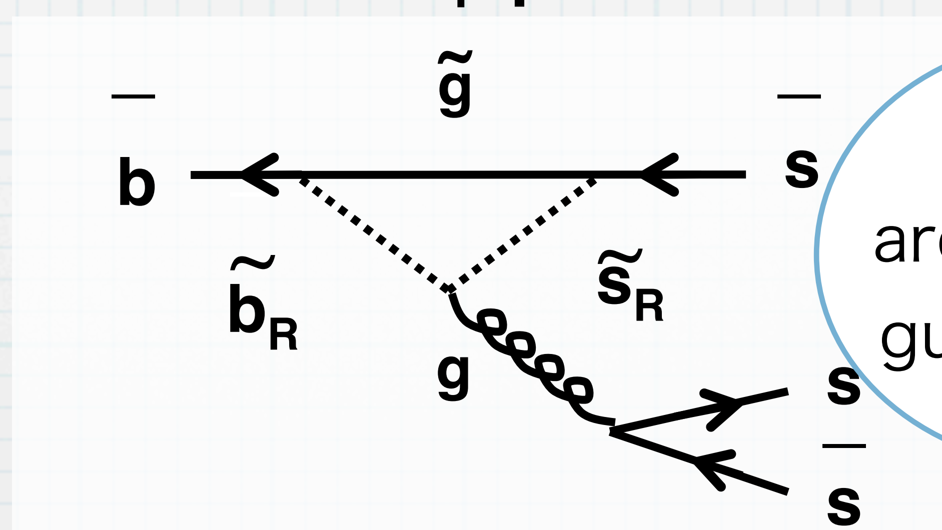
+?

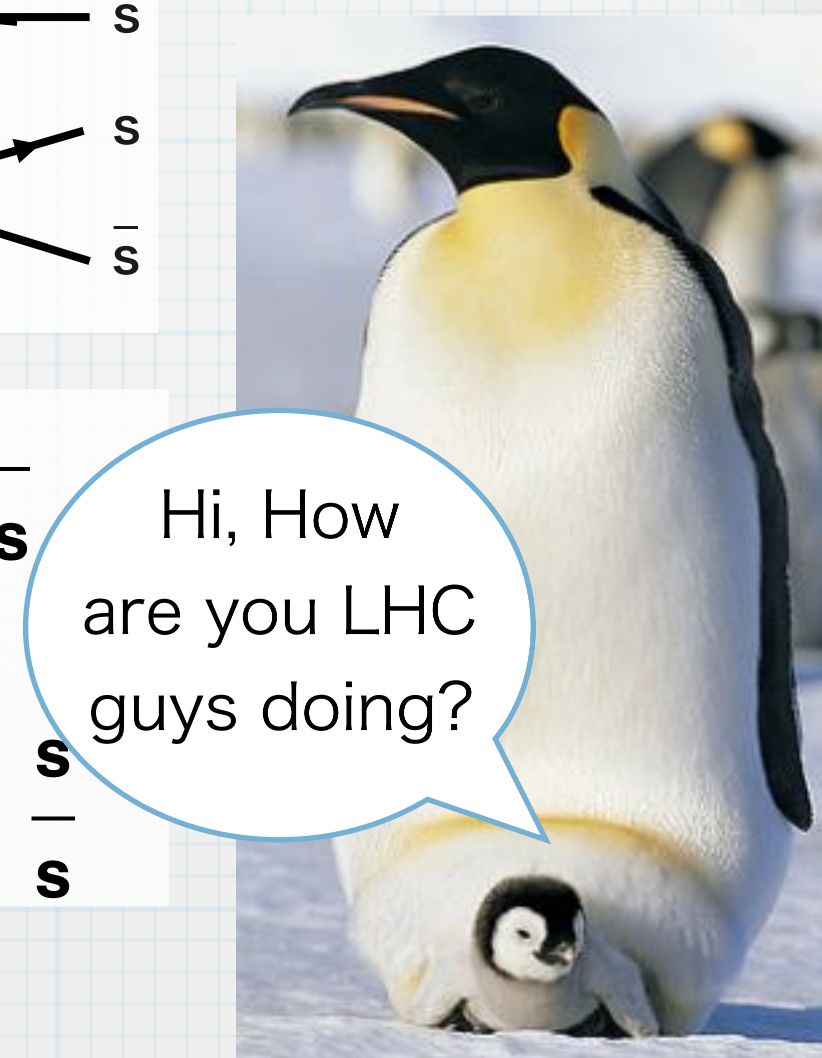


+?





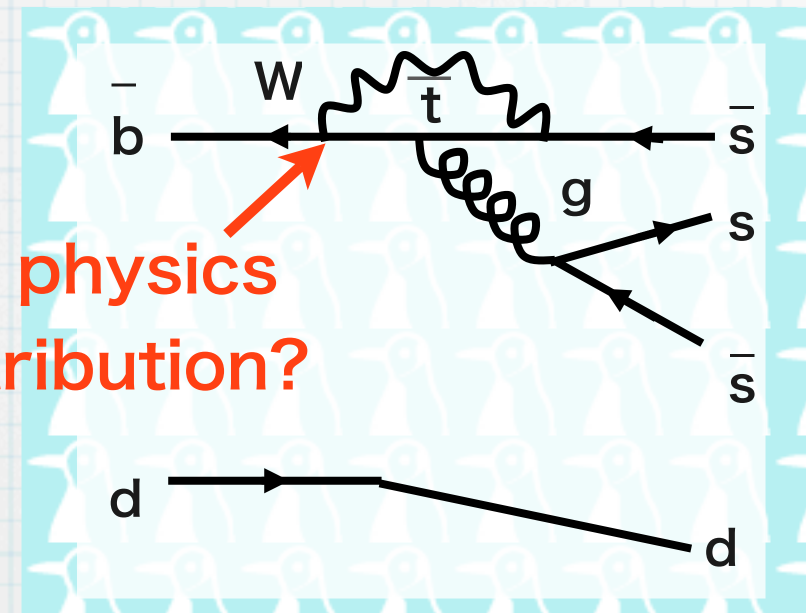




Indirect search for SUSY and Higgs

$(\sin 2\phi_1/\beta)^{eff}$ measurement

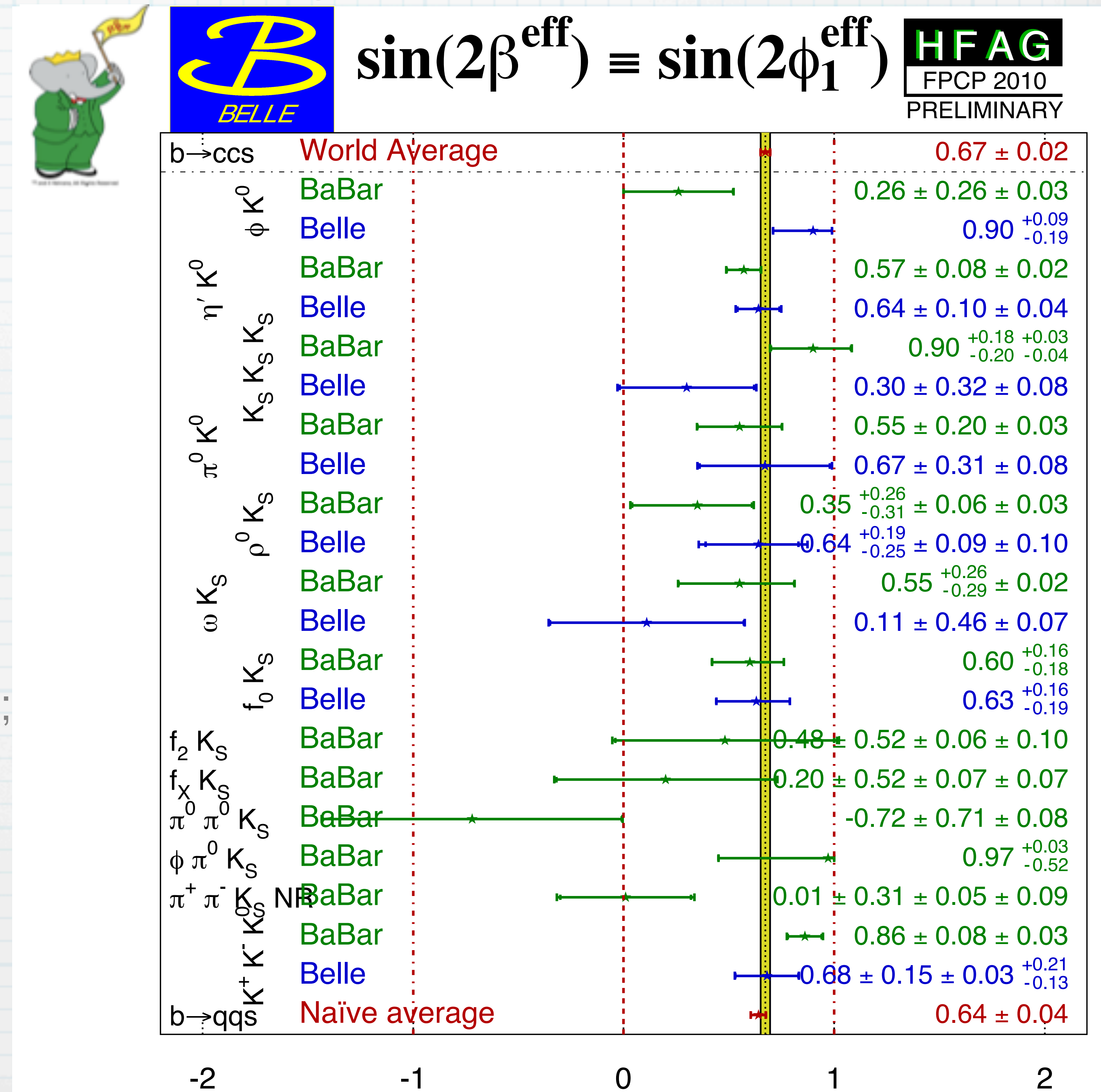
- $\sin 2\phi_1 \longleftrightarrow \sin 2\phi_1^{eff}$ (b→sqq penguin dominant modes)



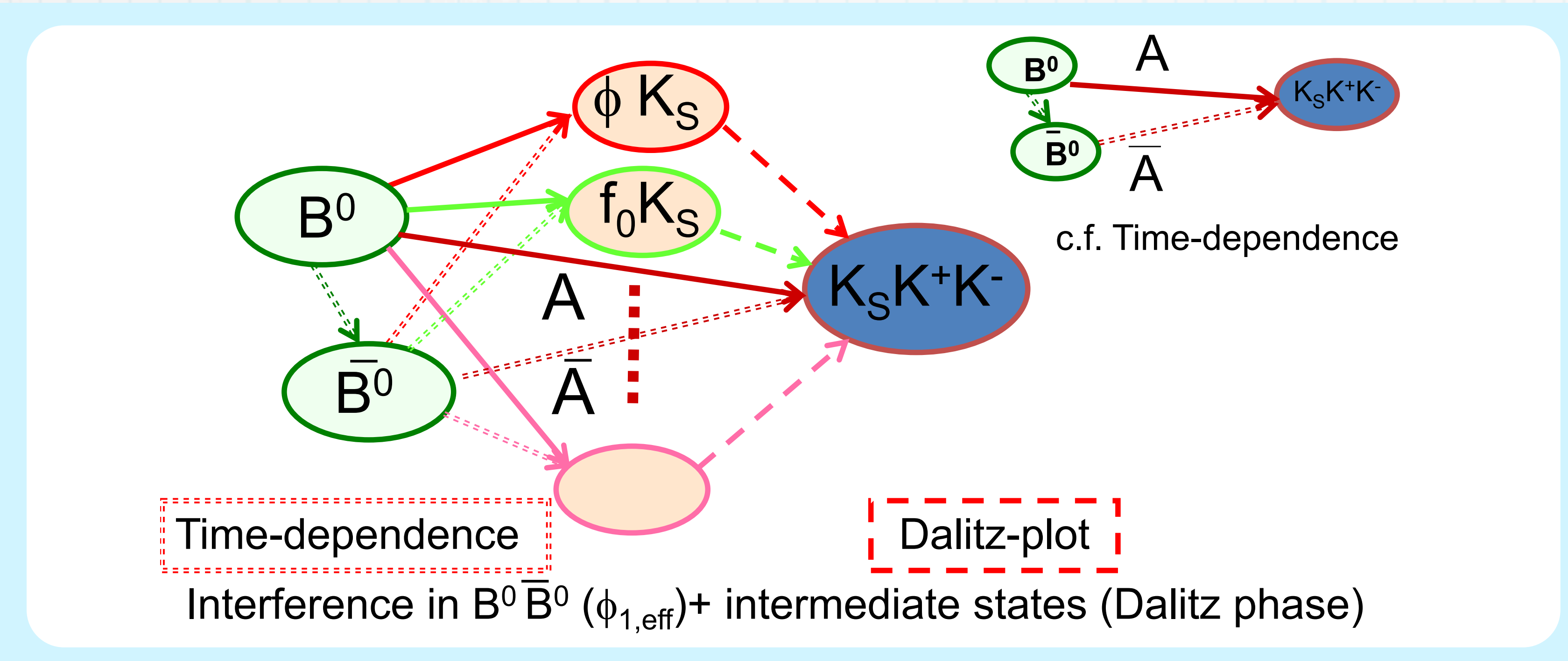
Slight positive shifts from $\sin 2\phi_1$ are expected by contribution from b→u tree and so on.

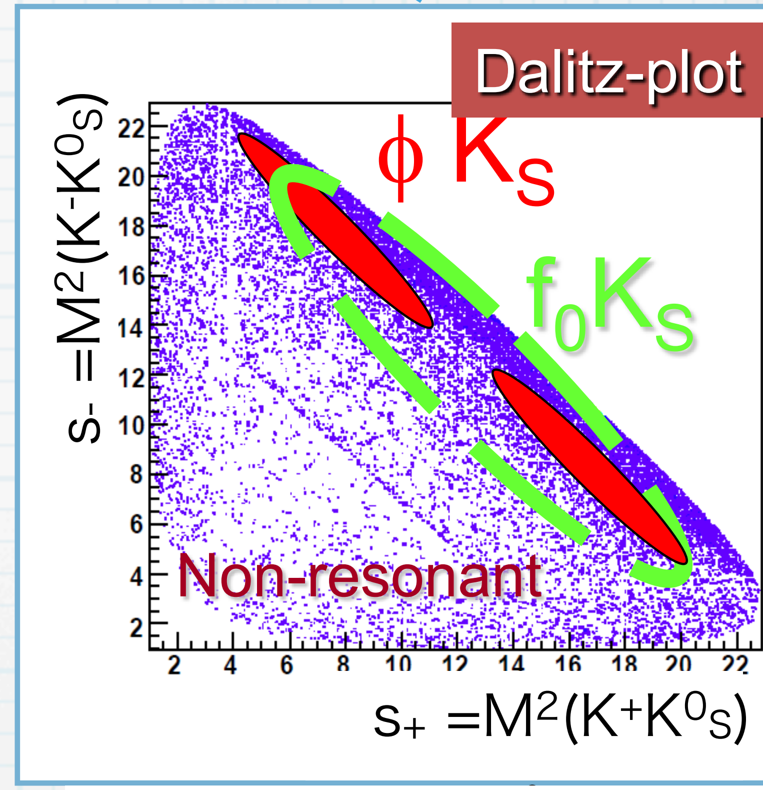
J. Zupan, ECONFC070512:012, 2007;
Hai-Yang Cheng, hep-ph/0702252

$\sin 2\phi_1$ is a reference point for this study

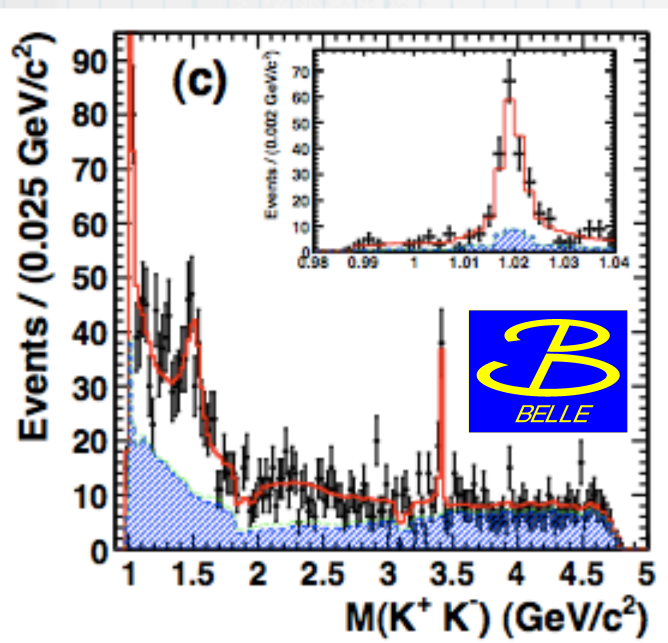


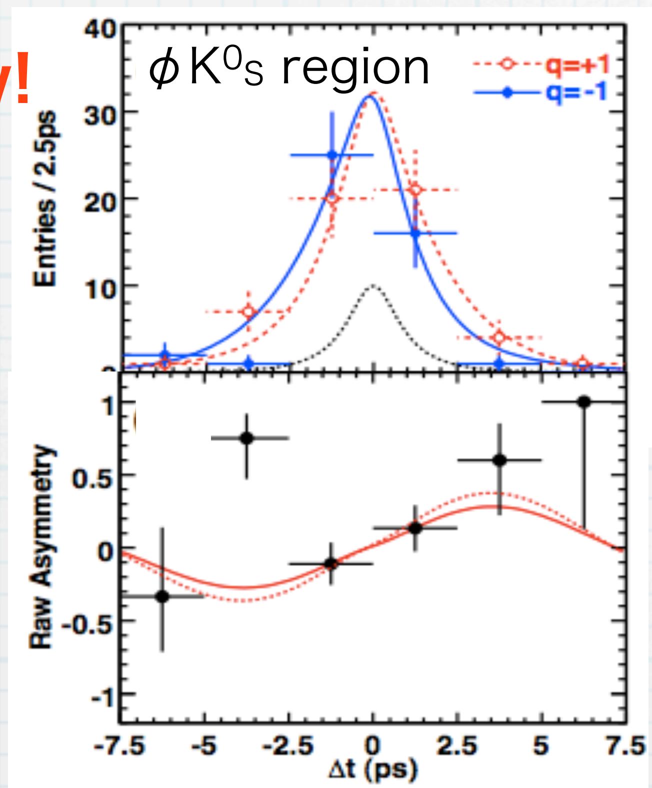
$B^0 \to K^+K^-K^0$ ($B^0 \to f_0K^0$, $B^0 \to \phi K^0$)



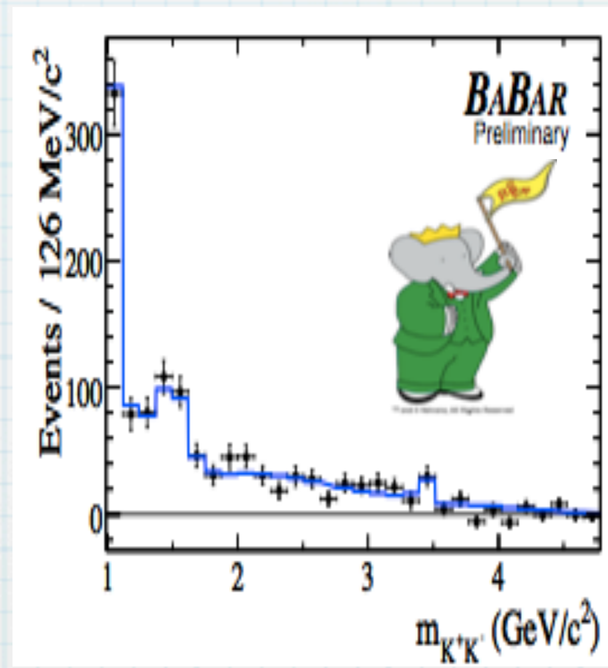


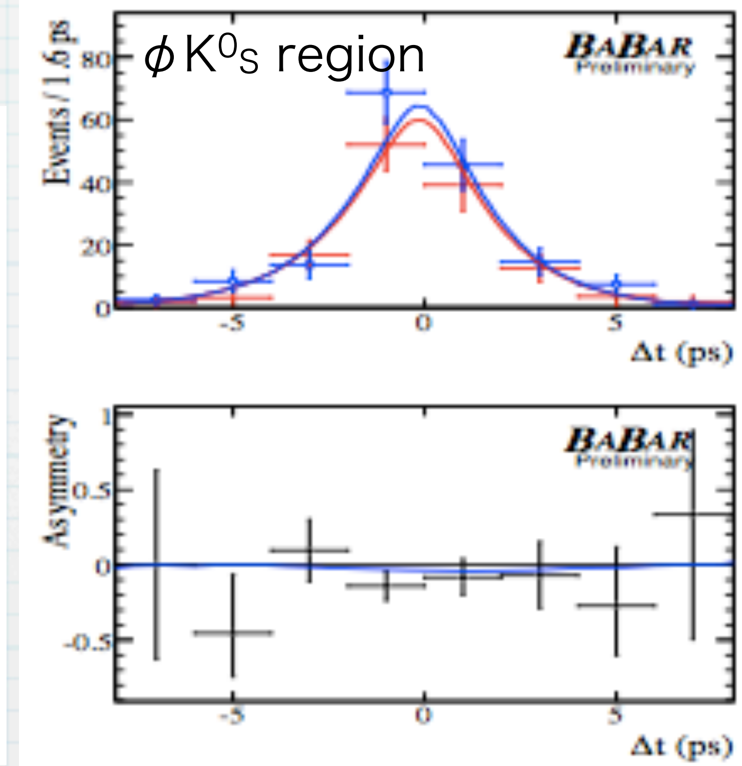
Belle 657M $B\bar{B}$ New!





BABAR 465M $B\bar{B}$





$\phi_1^{eff}\,(\phi K^0_S) = (32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$

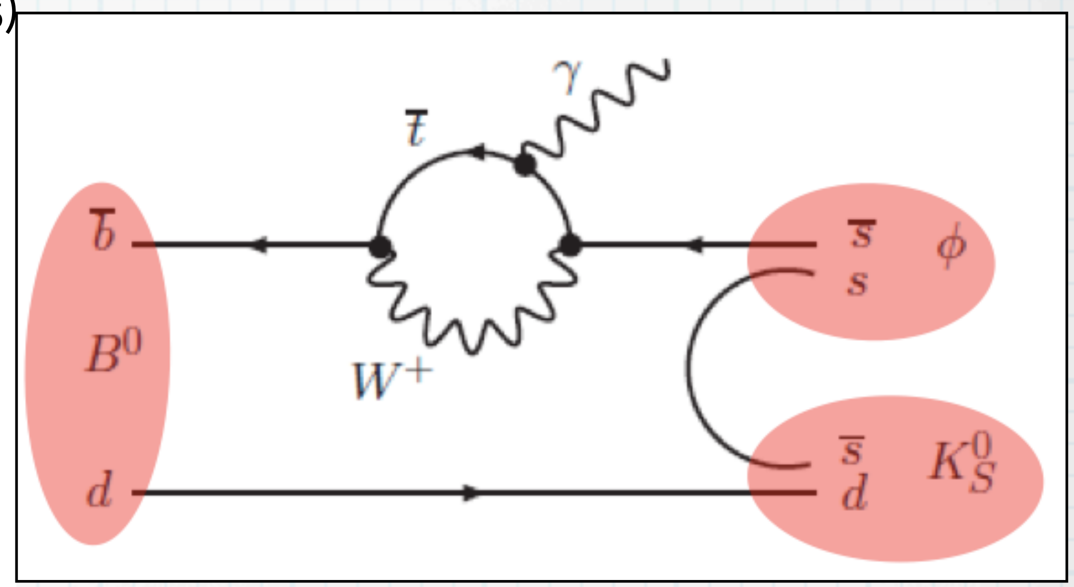
$\phi_1^{eff}\,(f_0 K^0_S) = (31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$

$\phi_1^{eff}\,(\phi K^0_S) = (7.7 \pm 7.7 \pm 0.9)^\circ$

$\phi_1^{eff}\,(f_0 K^0_S) = (8.5 \pm 7.5 \pm 1.8)^\circ$

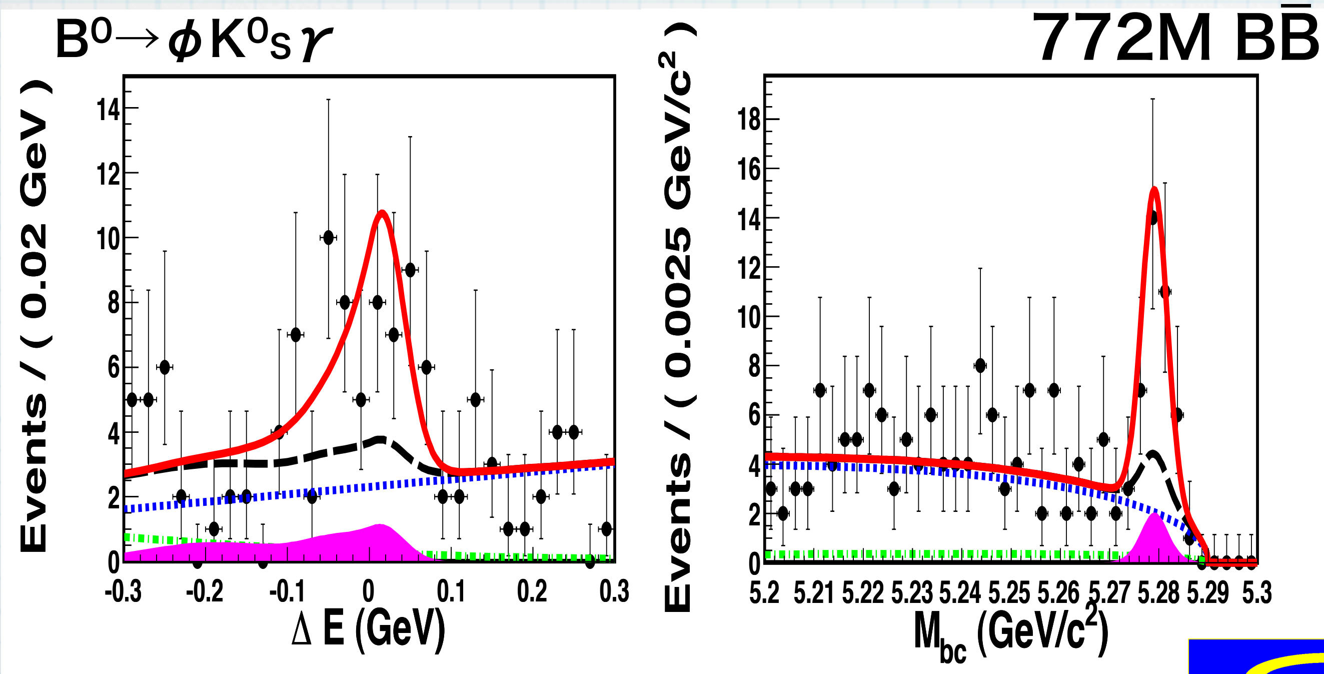
$B^0 \to \phi K_S^0 \gamma$

D. Atwood, M.Gronau, A.Soni,
PRL 79, 185 (1997)



- In SM, radiative photon from b→sγ transition is flavor-specific.
- $B^0 \leftrightarrow \overline{B^0}$ interference can occur only through a helicity flip.
- The CP asymmetry in SM is suppressed by the quark mass ratio.

$$S \approx -2(m_s/m_b)\sin(2\phi_1) \sim 0.03$$

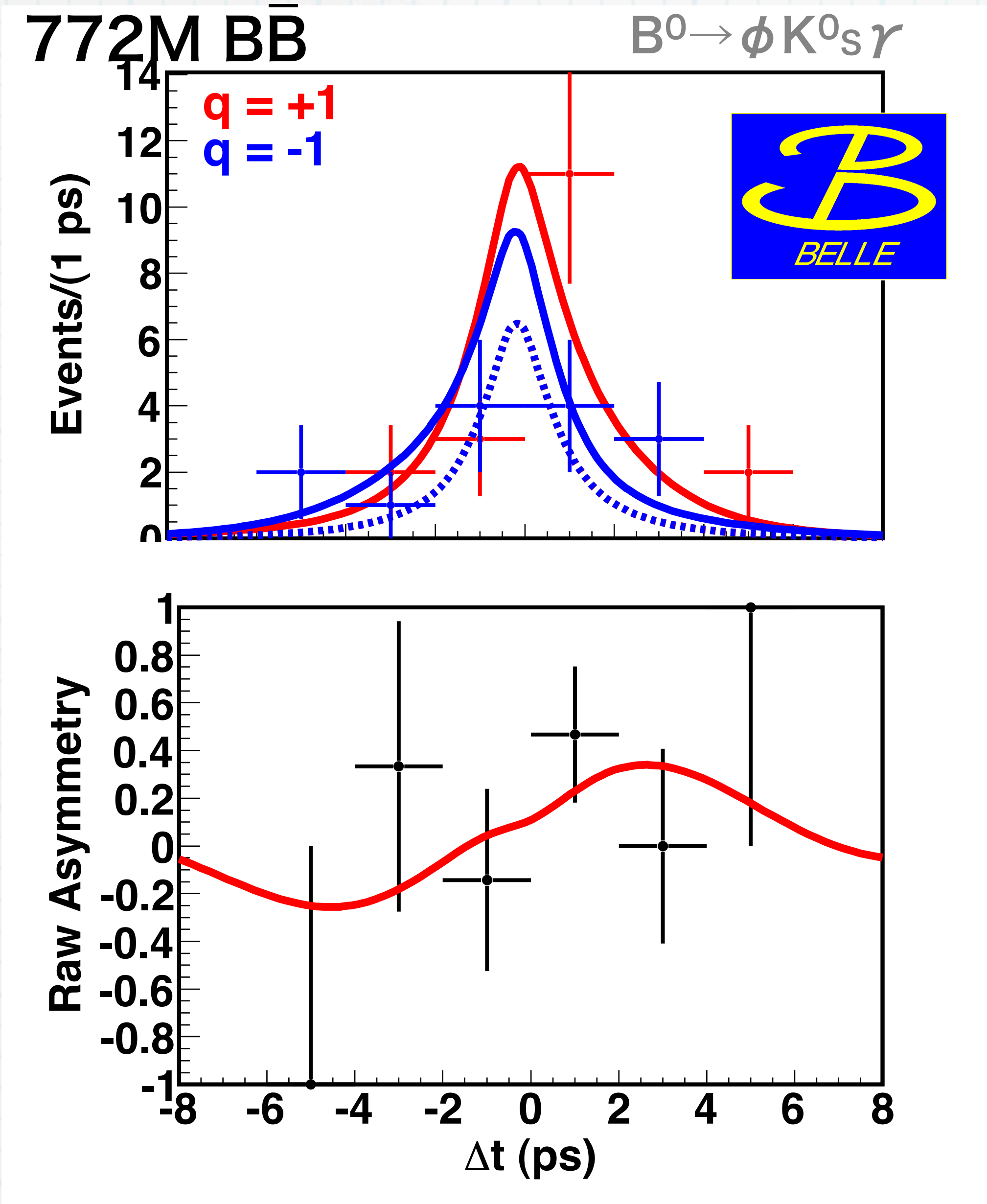


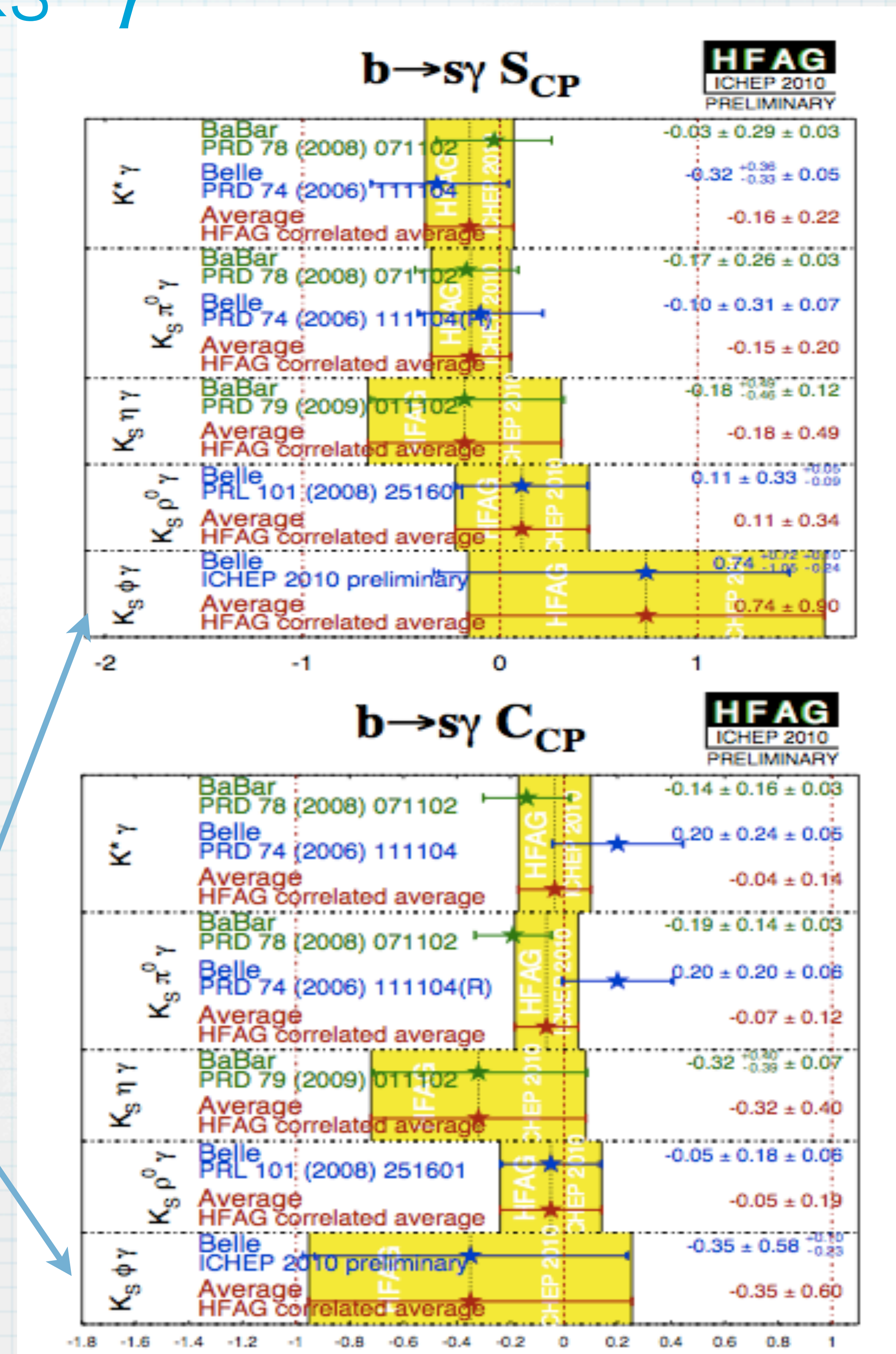
$Br(B^0 \to \phi K^0_S \gamma)$ =
$(2.66 \pm 0.60 \pm 0.32) \times 10^{-6}$
(5.4σ significance)
35±8 events → CP study

BELLE

beam constraint mass:
$M_{bc} = \sqrt{(E_{beam}/2)^2 - p_{rec}^2}$ (signal: = M_{B0})
energy difference:
$\Delta E = E_{rec}^{CM} - E_{beam}/2$ (signal: = 0)

$B^0 \to \phi K_S^0 \gamma$





$$S(B^0 \to \phi K^0_S \gamma) = 0.74\ ^{+0.72}_{-1.05}\ ^{+0.10}_{-0.24}$$

$$A(B^0 \to \phi K^0_S \gamma) = 0.35 \pm 0.58\ ^{+0.23}_{-0.10}$$

Belle preliminary

Consistent with SM expectation

Summary

- $\sin 2\phi_1$ study using full data will be finalized soon
- Further constraints on ϕ_2 are expected from asymmetries/branching fraction measurements

- New results using large data sets
  - $B^+ \to J/\psi K^+$ direct CP violation
  - $B \to KKK_S$ time-dependent Dalitz analysis
  - $B^0 \to \phi K^0_S \gamma$ time-dependent CP violation

  and other modes in backup slides

backup

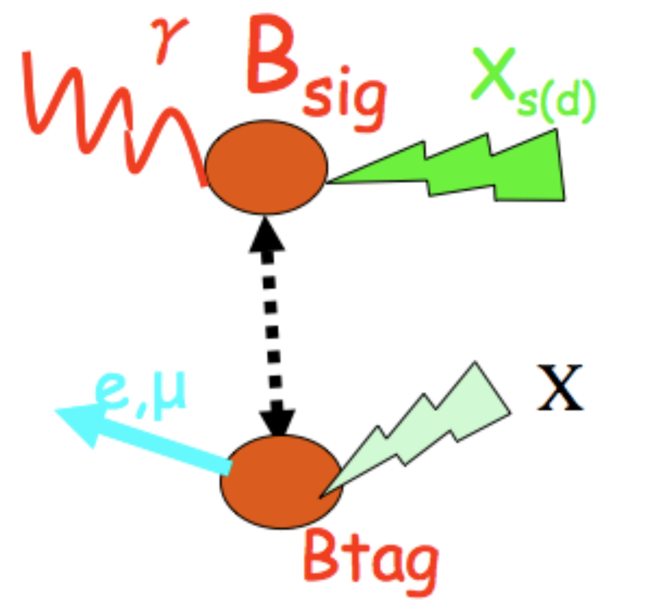
Fully inclusive B→Xs γ

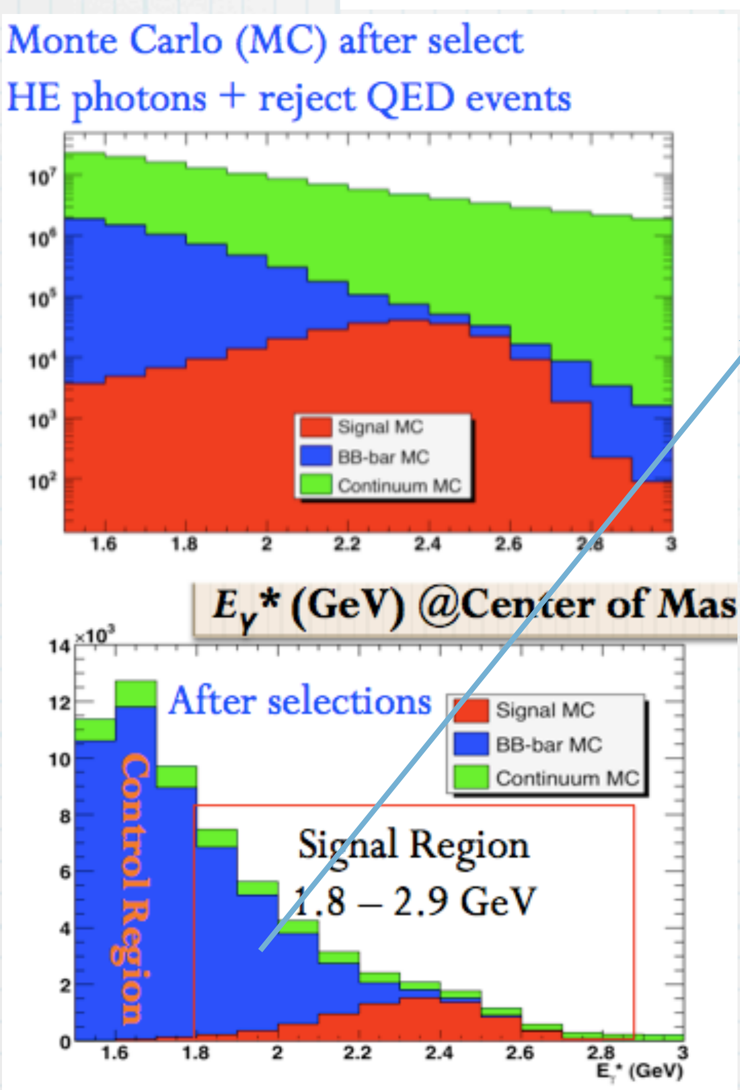
347 fb^{-1} Y(4S) Data and 36 fb^{-1} Off resonance Data

❖Signal signature:

One isolated High Energy photon (γ_{HE}), do not reconstruct the hadronic system. Veto γ_{HE} from π^0/η.

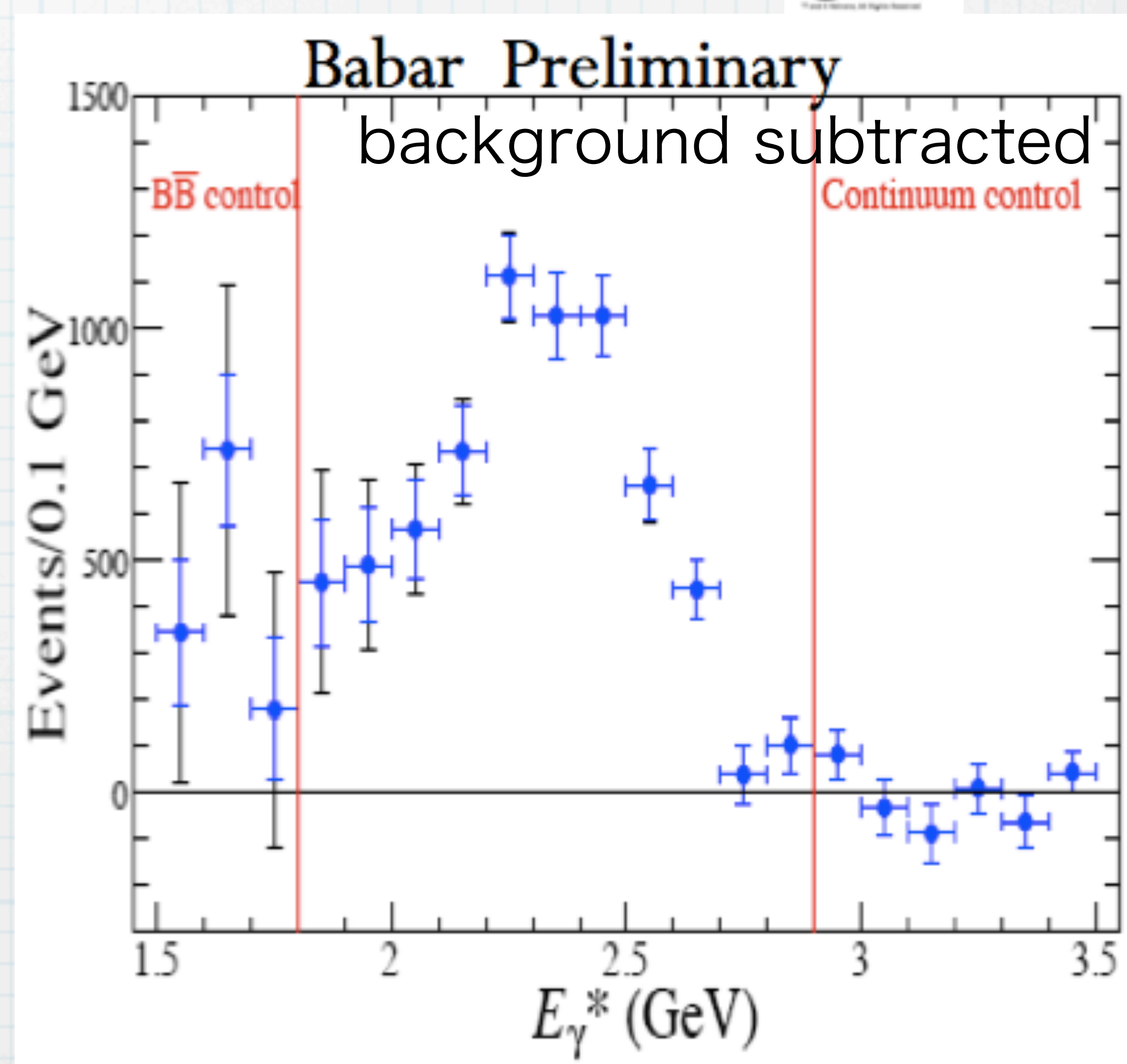
❖Lepton tag and event topology criteria used to suppress continuum.





Dominant BG components are photon from π^0/η, $e^{\pm}$ bremsstrahlung and fake photon.

MC BB-bar distribution is used after correction using control sample

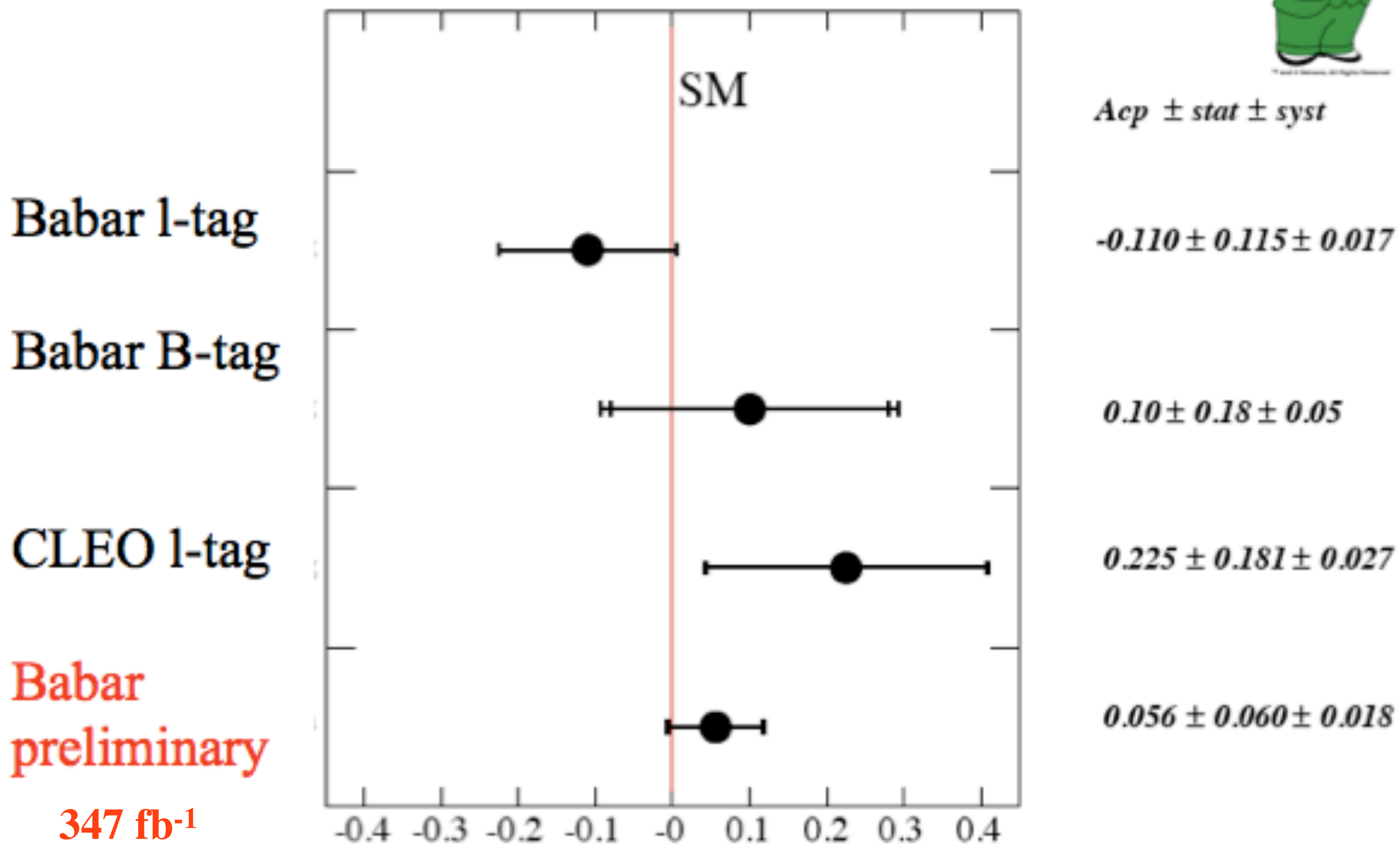


Fully inclusive B→Xs γ

$A_{CP}(B\to X_{s+d}\gamma)$ preliminary

$N(l^+) = 2623\pm158$
$N(l^-) = 2397\pm151$

Babar preliminary
$A_{CP} = 0.056\pm0.060\pm0.018$



Consistent with SM expectation:

$A_{CP}(B\to X_{s+d}\gamma)\sim10^{-6}$ (T.Hurth, et. al., Nucl. Phys. B704 (2005))

Statistical error dominant

Inclusive $B \to X_s \eta$

Unexpectedly large branching fraction observed in $B \to X_s \eta'$

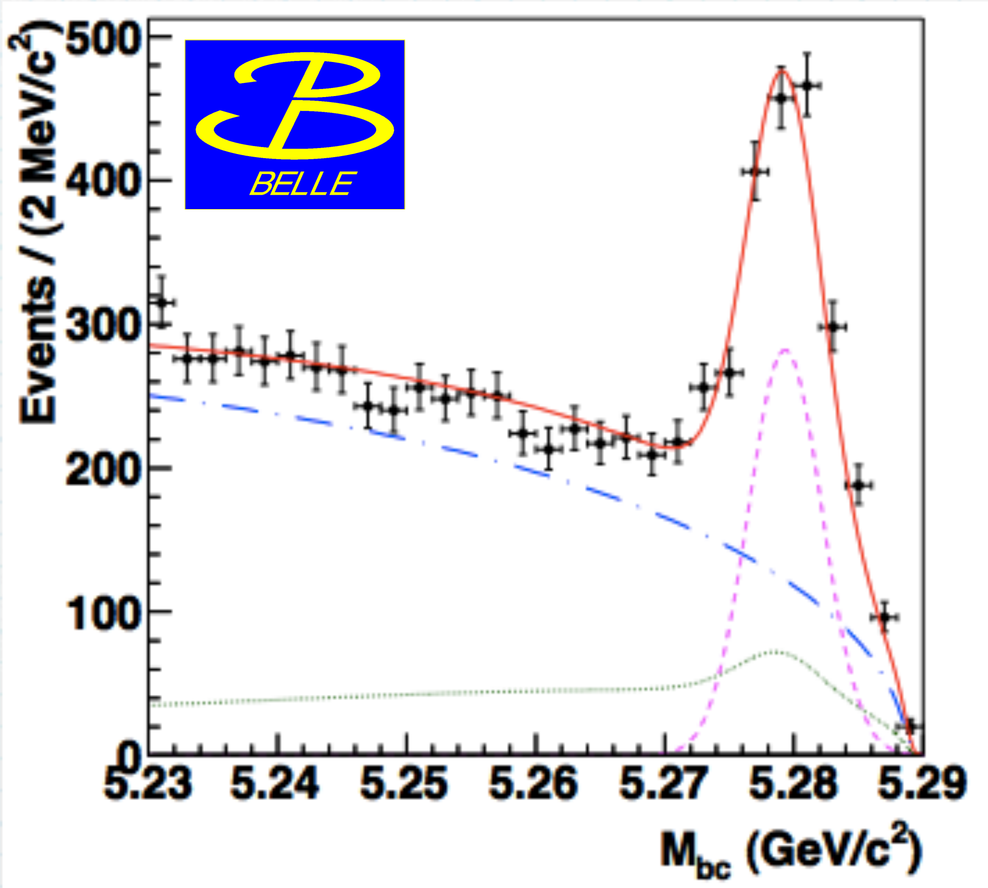
CLEO2003 (9.7M BB) $(4.6 \pm 1.1 \pm 0.4 \pm 0.5) \times 10^{-4}$

BABAR2004 (88.4M BB) $(3.9 \pm 0.8 \pm 0.5 \pm 0.8) \times 10^{-4}$

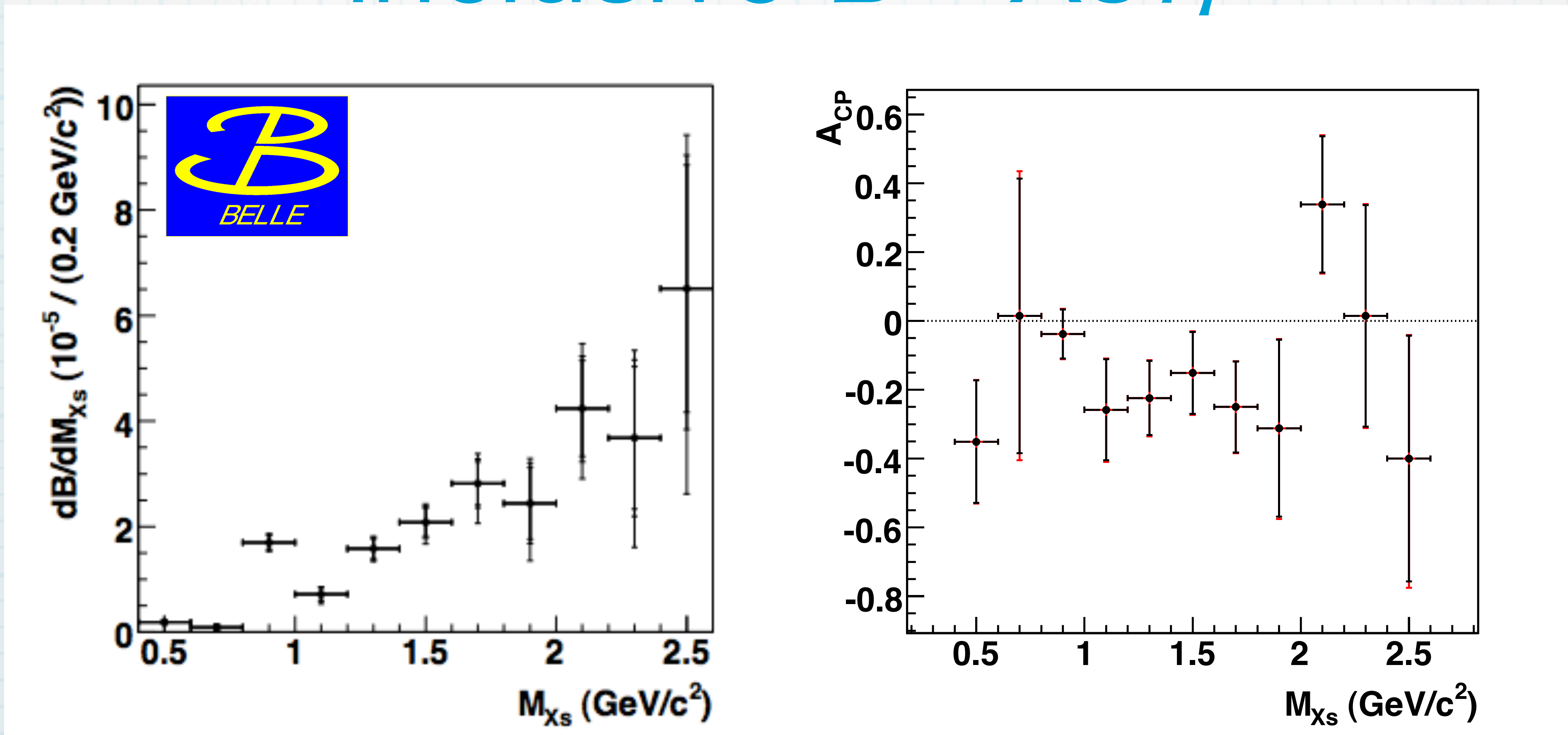
$(2.0\ \mathrm{GeV}/c < P_{\eta'} < 2.7\ \mathrm{GeV}/c)$

→ No explanation so far, comparison to $X_s \eta$ gives some hints

Xs: pseudo-inclusive reconstruction with $(K_0^S$ or $K^{\pm}) + n\pi$ (n=1-4)



Inclusive B→Xsη



$Br(B \to X_s \eta; M_{Xs} < 2.6\ GeV/c^2) = (26.1 \pm 3.0\ (stat) \pm {}^{+1.9}_{-2.1}\ (syst)\ {}^{+4.0}_{-7.1}\ (model)) \times 10^{-5}$

$Br(B \to X_s \eta; 1.8\ GeV/c^2 < M_{Xs} < 2.6\ GeV/c^2) = (16.9 \pm 2.9\ (stat) \pm {}^{+1.5}_{-1.8}\ (syst)\ {}^{+3.3}_{-5.9}\ (model)) \times 10^{-5}$

$ACP\ (B \to Xs\ \eta; MXs < 2.6\ GeV/c2) = -0.13 \pm 0.04\ (stat)\ {}^{+0.02}_{-0.03}\ (syst)$

(Belle preliminary arXiv:0910.4751v2 [hep-ex])

Lack of strong suppression / MXs spectrum shape

→ disfavors η´ specific mechanism

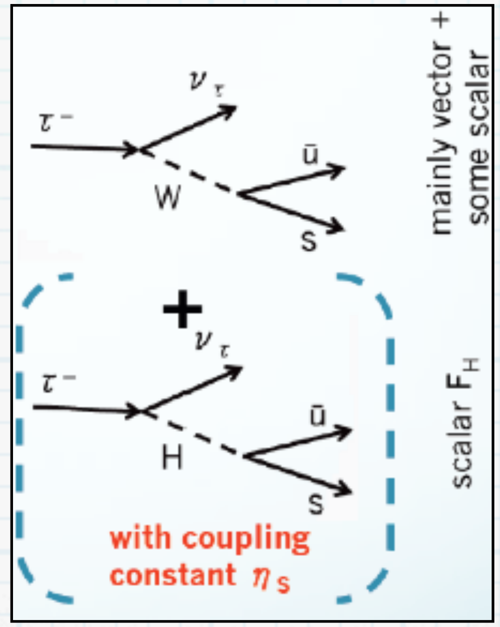
(I. E. Halperin and A. Zhitnitsky, Phys. Rev. Lett. 80;

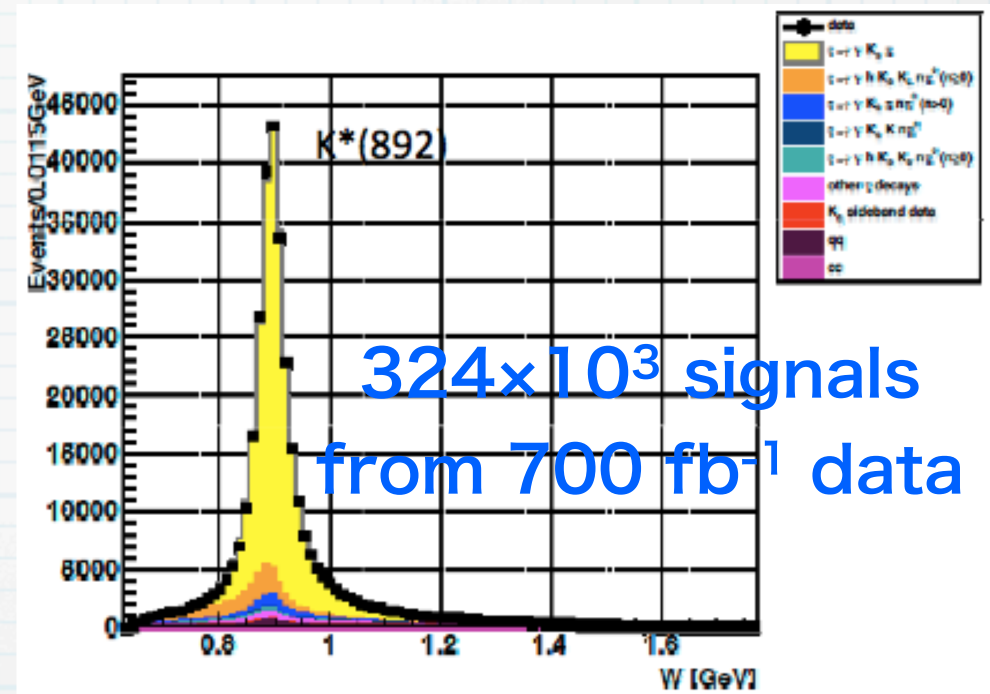
D. Atwood and A. Soni, Phys. Lett. B 405, 150 (1997) 438 (1998))

⇒ We still have puzzle

CP violation in $\tau \to K_S^0 \pi \nu$

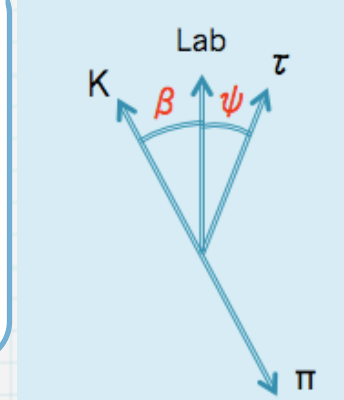
CP violating phase in
New physics
(ex. Multi-Higgs model)
Higgs coupling constant:
$-4.1 < \mathrm{Im}(\eta S) < 1.6$ (CLEO)





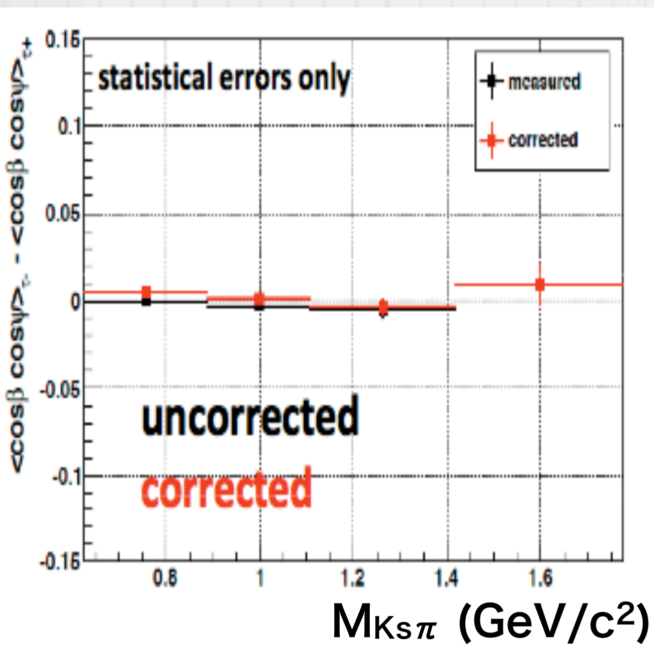
324×10³ signals
from 700 fb⁻¹ data

$$A^{CP}_{\psi\beta} \simeq \frac{1}{N^-}\sum_{i\in\tau^-}\cos\psi_i\cos\beta_i - \frac{1}{N^+}\sum_{j\in\tau^+}\cos\psi_j\cos\beta_j$$
$$\equiv \langle\cos\psi\cos\beta\rangle_- - \langle\cos\psi\cos\beta\rangle_+$$



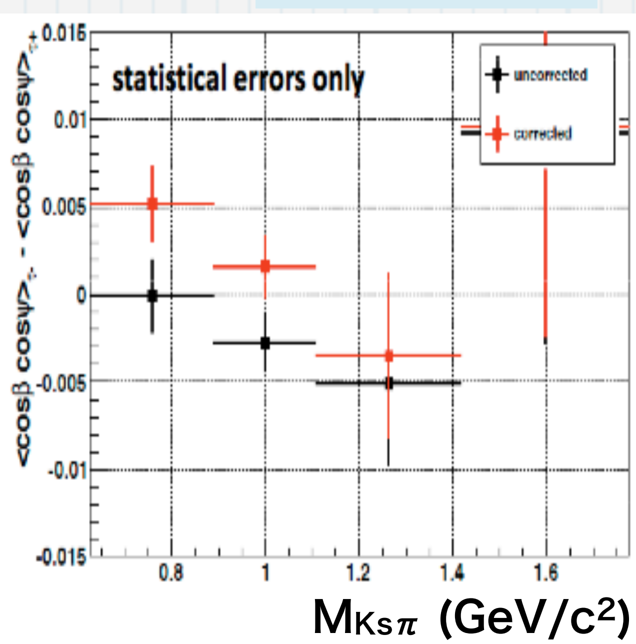
Results after background subtraction

$M_{K_s\pi}$ in (GeV)	$A^{CP}_{\psi\beta}$ (10^{-3})	σ_{stat}	σ_{syst}
0.625 – 0.890	7.97	3.35	2.85
0.890 – 1.110	1.74	2.19	1.40
1.110 – 1.420	4.92	8.02	1.62
1.420 – 1.775	-3.15	22.09	5.47



Zoom in:

before background subtraction

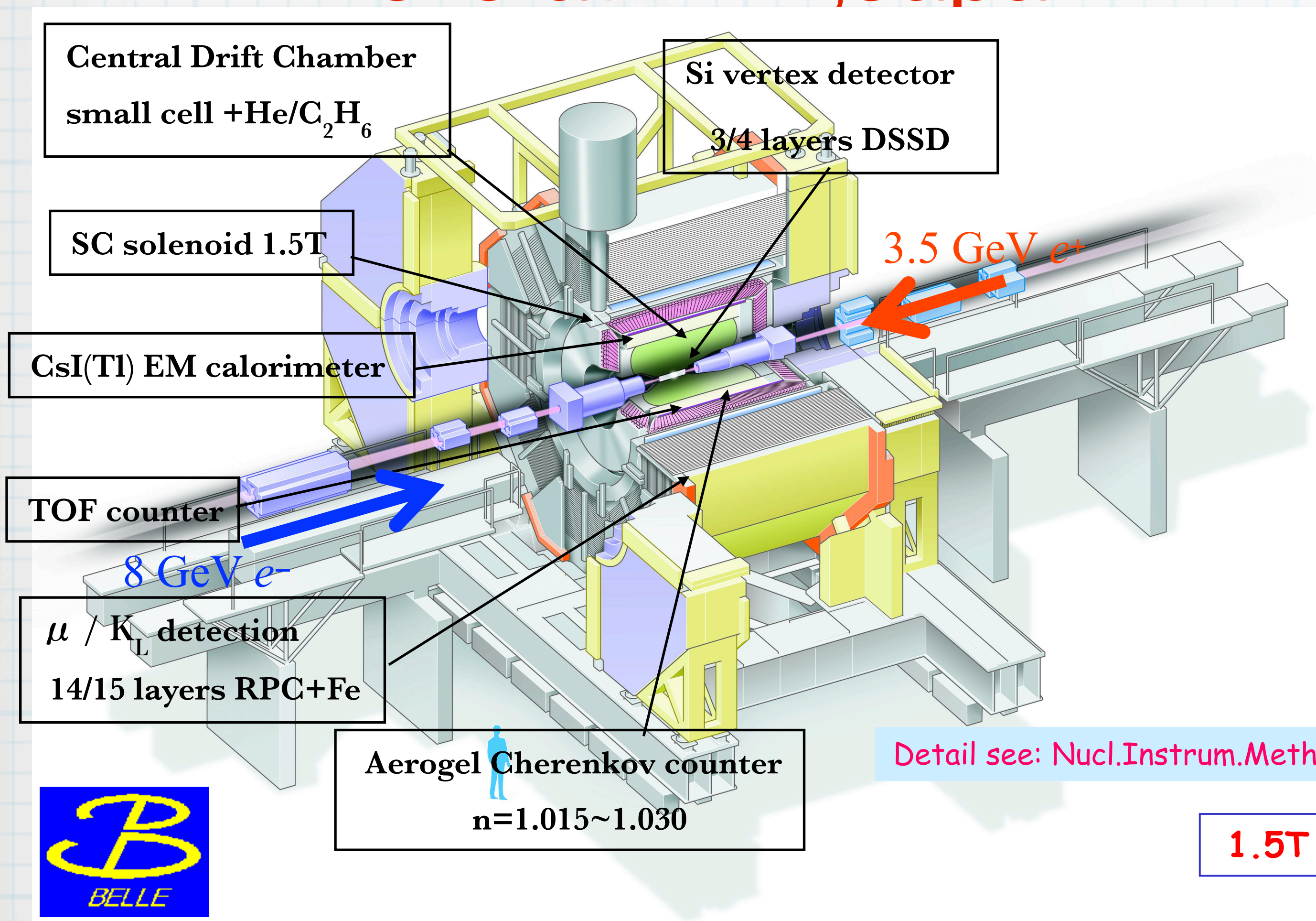


$|\mathrm{Im}(\eta_S)| < 0.05\text{-}0.2$ @90%CL

Belle preliminary

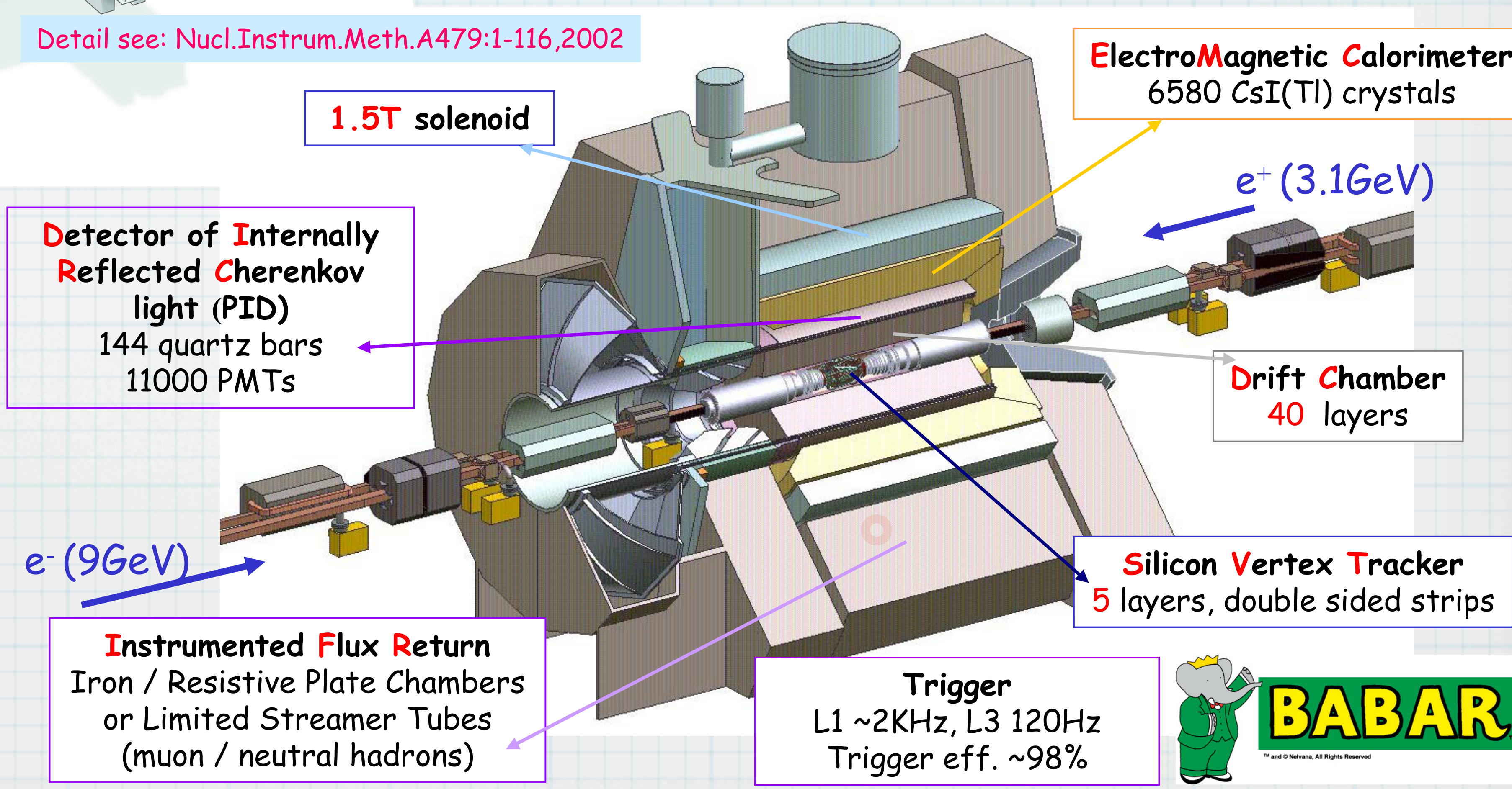
Experimental Apparatus

KEKB/Belle at KEK,Japan



- charged particle tracking
- momentum measurement
- particle identification
- e/γ energy measurement
- K_L cluster detection

PEP-II/BaBar at SLAC,USA



$\cos 2\phi_1/\beta$ measurement with Dalitz

$B^0 \to D[K^0_S \pi^+ \pi^-]\, h^0$ ($h^0 = \pi^0, \eta, \omega, \eta'$)

Time-dependent Dalitz plot density:

(A.Bonder, T.Gershon and P. Krokovny, PLB 624 1-10)

$$P(m_+^2, m_-^2, \Delta t, q_B) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{8\tau_{B^0}} \frac{F(m_+^2, m_-^2)}{2N} \left(1 + q_B \times \{\mathcal{A}(m_-^2, m_+^2)\cos(\Delta m \Delta t) + \mathcal{S}(m_-^2, m_+^2)\sin(\Delta m \Delta t)\}\right)$$

$$\mathcal{S} = \frac{-2\xi_{h^0}(-1)^l Im\{f(m_-^2, m_+^2) f^*(m_+^2, m_-^2) e^{2i\phi_1}\}}{F(m_+^2, m_-^2)}$$

$$Im(f(m_-^2, m_+^2) f^*(m_+^2, m_-^2))\cos 2\phi_1 + Re(f(m_-^2, m_+^2) f^*(m_+^2, m_-^2))\sin 2\phi_1$$

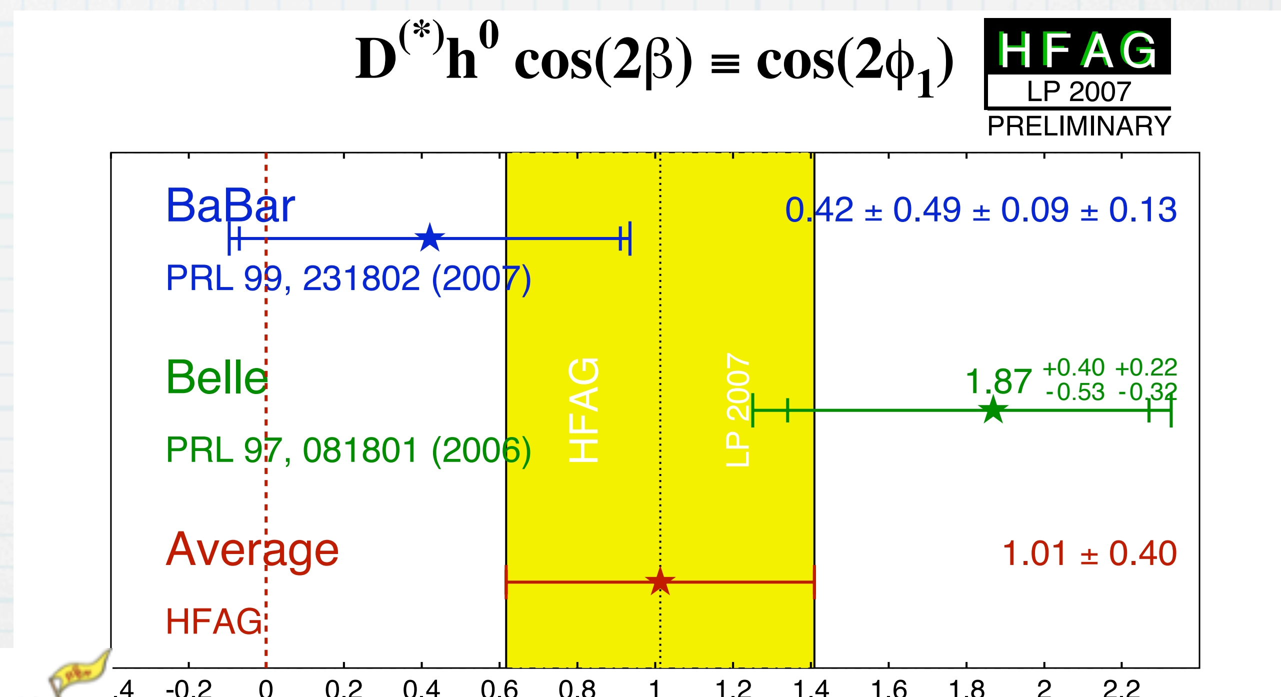
f : decay amplitude of $D^0 \to K^0_S \pi^+ \pi^-$

$m_\pm$: two-body invariant mass of $K^0_S \pi^\pm$

ξ_{h^0}: CP eigenvalue of h^0

$$F = |f(m_-^2, m_+^2)|^2 + |f(m_+^2, m_-^2)|^2$$

$$N = \int |f(m_-^2, m_+^2)|^2 dm_+^2 dm_-^2,$$



$\cos 2\phi_1 > 0$ at 86% C.L.

$\cos 2\phi_1 > 0$ at 98.3% C.L.

$\sin 2\phi_1/\beta$ systematic error

In future experiment, error of $\sin 2\phi_1$ measurement will be systematic dominant

Belle 535M BB

Categories	σ ($\sin 2\phi_1$)
Vertexing	0.012
Possible fit bias	0.007
Δt Resolution function	0.006
BG fractions ($J/\psi K_L$)	0.005
Wrong tag probability	0.004
BG fractions ($J/\psi K_S$)	0.003
Fixed Physics parameters: Δm_d ,τ_{B0}	0.001
BG Δt	0.001
Tag-Side interference	0.001
Total	**0.017**

Vertexing detail	σ(**$\sin 2\phi_1$**)
IP tube constraint vertex fit	0.0072
Poor-quality vertex rejection	0.0064
Imperfect SVD alignment	0.0056
Δz bias	0.0050
Track error estimation	0.0033
Track rejection in B_{tag} decay vertexing	0.0026
Δt fit range	0.0002
Total	0.012

Colored contents are independent of increase of data sample

→ Technical improvement is needed.

ex.

- select good quality tracks, reconstruct vertex without e^+e^- interaction point information
- Improve detector mis-alignment

ϕ_2/α measurements

$$\mathcal{A}_{CP} = \frac{\mathcal{P}(\overline{B^0}(\Delta t) \to f_{CP}) - \mathcal{P}(B^0(\Delta t) \to f_{CP})}{\mathcal{P}(\overline{B^0}(\Delta t) \to f_{CP}) + \mathcal{P}(B^0(\Delta t) \to f_{CP})}$$

$= S \sin\Delta m \Delta t \quad + \quad A \cos\Delta m \Delta t$

mixing induced CPV — direct CPV

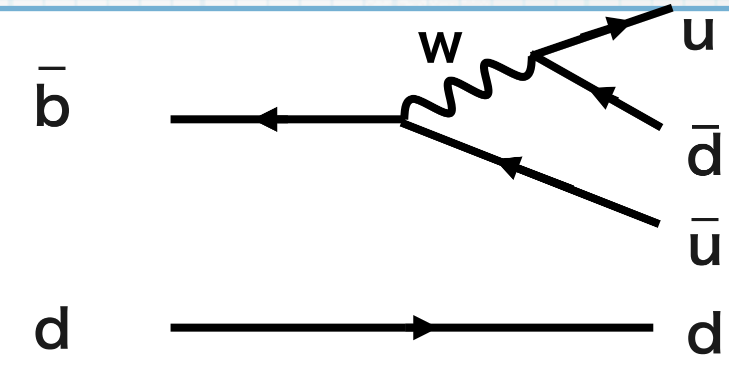
where $S = -\xi_f \sqrt{1-A^2} \sin 2\phi_2^{eff}$

ξ_f: *CP* eigenvalue

Δm: B-$\overline{B}$ mass difference

Δt: B-$\overline{B}$ decay time difference

$\phi_2^{eff} = \phi_2 - \Delta\phi_2$ ("effective" ϕ_2)



penguin contamination

- Isospin relations between $B \to \pi^i \pi^j / \rho^i \rho^j$ decay amplitudes

(Gronau and London, PRL65 3381)

$$A^{+0} = \frac{1}{\sqrt{2}} A^{+-} + A^{00}$$

$$\overline{A}^{-0} = \frac{1}{\sqrt{2}} \overline{A}^{+-} + \overline{A}^{00}$$

(A^{ij} : Decay amplitude of $B \to \pi^i \pi^j / \rho^i \rho^j$)

$\Rightarrow \Delta\phi_2$ is determined with four-fold ambiguity.

- Dalitz analysis for $\pi\pi\pi^0$ 3-body system

(A. Snyder and H. Quinn, PRD 48 2139 (1993))

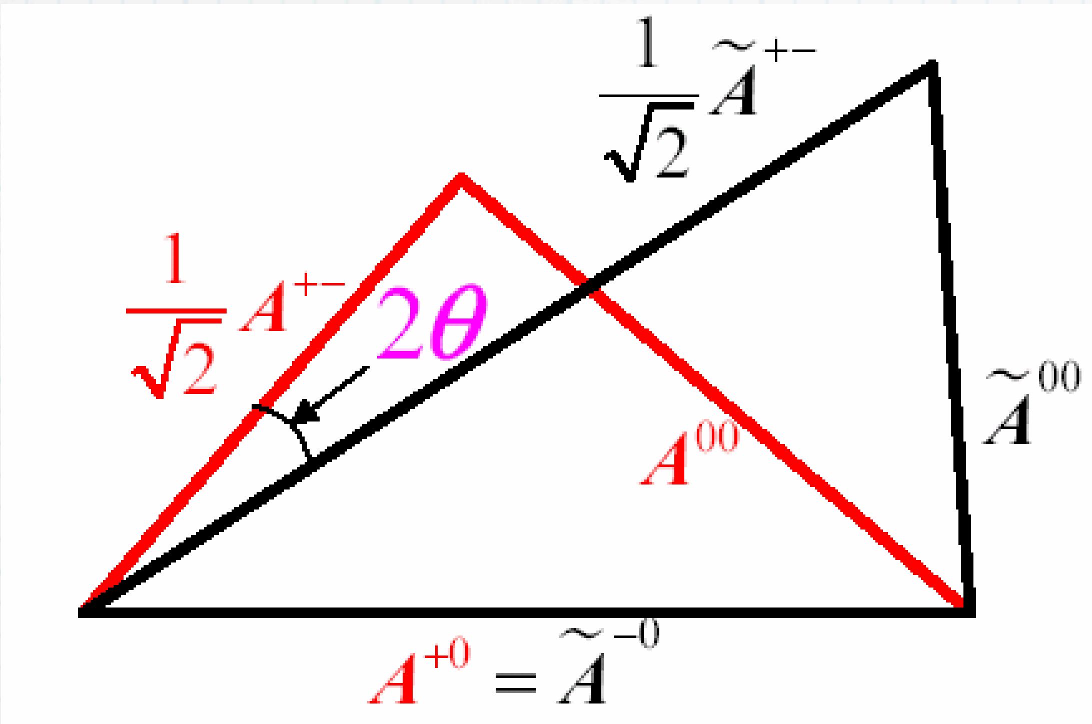
Interference between three $B \to \rho\pi$ states

Δt fit with coefficients of Dalitz plot functions

$\Rightarrow$ constrain ϕ_2 without ambiguity.

Interpretation: ϕ_2 constraint using isospin

M. Gronau and D. London, PRL 65, 3381 (1990)



	Amplitude for
$A^{+-}(\bar{A}^{+-})$	$B^0(\bar{B}^0) \to \pi^+\pi^-$
$A^{00}(\bar{A}^{00})$	$B^0(\bar{B}^0) \to \pi^0\pi^0$
$A^{+0}(\bar{A}^{-0})$	$B^+(B^-) \to \pi^+\pi^0(\pi^-\pi^0)$

$$\tilde{A}^{ij} = e^{2\phi_3}\bar{A}^{ij}$$

$$S_{\pi\pi} = \sqrt{1 - A_{\pi\pi}^2}\,\sin(2\phi_2 + 2\theta)$$

The cleanest method to extract ϕ_2

We use the statistical treatment of
J. Charles *et al.*, Eur. Phys. J. C 41, 1 (2005)

ϕ_2/α measurement $B \to \rho\rho$

$P \to VV$ decay $\Rightarrow \begin{cases} \text{longitudinal } (CP\text{-even}) \\ \text{transverse } (CP\text{-even and } CP\text{-odd}) \end{cases}$

From angular analysis, longitudinally polarized dominant for this decay.
(94.1% from Belle, 99.2% from BABAR)

Belle 535M $B\bar{B}$ (PRD76 011104)

S = 0.19±0.30±0.07
A = 0.16±0.21±0.07

BABAR 387M $B\bar{B}$ (PRD76 052007)

S = $-0.17\pm0.20^{+0.05}_{-0.06}$
A = 0.01±0.15±0.06

(small penguin contamination)

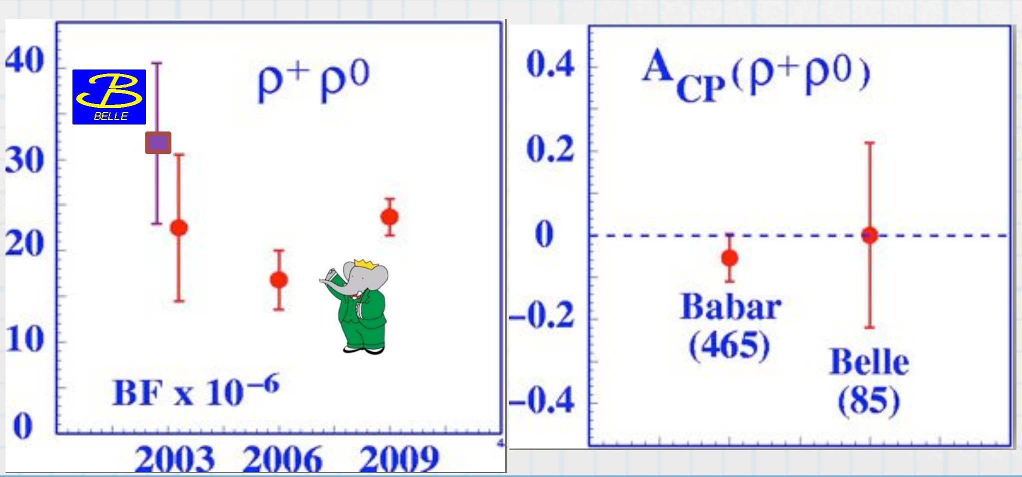
→ ϕ_2 constraint by isospin relations with other measured values

$BR(B^0 \to \rho^+\rho^-) = 24.2\,^{+3.1}_{-3.2}$	–
$BR(B^+ \to \rho^+\rho^0) = 24.0\,^{+1.9}_{-2.0}$	$A_{CP}(B^+ \to \rho^+\rho^0) = -0.051 \pm 0.054$
$BR(B^0 \to \rho^0\rho^0) = 0.73\,^{+0.27}_{-0.28}$	–

(units: 10^{-6})

$\Rightarrow 59° < \phi_2 < 117°$ **(90% C.L.)**

$\Rightarrow \phi_2 = [73.1, 117]°$ **(68% C.L.)**



$\rho^+\rho^0$ parameters are updated in BaBar

PRL **102** 141802 (2009)

$\Rightarrow \phi_2 = (92.4\,^{+6.0}_{-6.5})°$

$-1.8° < \Delta\phi_2 < 6.7°$ (68% C.L.)

ϕ_2/α measurement $B \to \pi\pi\pi^0$

Coefficients of Dalitz plot functions are interrupted to CPV parameters of quasi-2-body decays, $B \to \rho^+\pi^-$ and $B \to \rho^0\pi^0$

$$\mathcal{C}^+ = \frac{U_+^-}{U_+^+}, \quad \mathcal{C}^- = \frac{U_-^-}{U_-^+}, \quad \mathcal{S}^+ = \frac{2I_+}{U_+^+}, \quad \mathcal{S}^- = \frac{2I_-}{U_-^+}, \quad \mathcal{A}_{\rho\pi}^{CP} = \frac{U_+^+ - U_-^+}{U_+^+ + U_-^+}$$

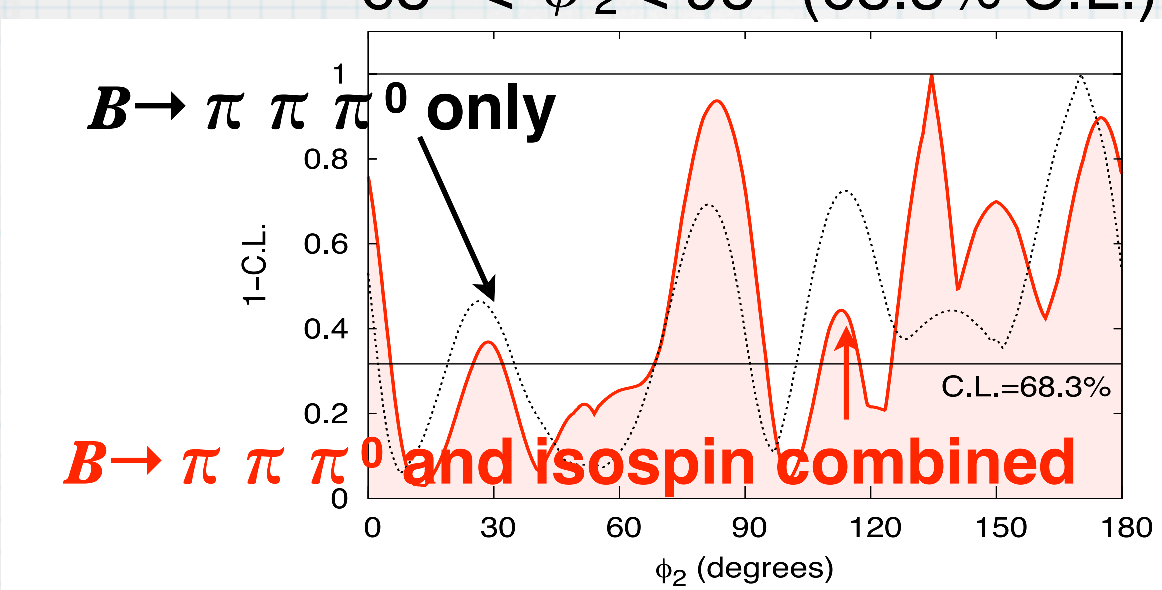
$$\mathcal{A}_{\rho^0\pi^0} = -\frac{U_0^-}{U_0^+}, \quad \text{and} \quad \mathcal{S}_{\rho^0\pi^0} = \frac{2I_0}{U_0^+}$$

$$\mathcal{C} \equiv \frac{\mathcal{C}^+ + \mathcal{C}^-}{2}, \quad \Delta\mathcal{C} \equiv \frac{\mathcal{C}^+ - \mathcal{C}^-}{2}, \quad \mathcal{S} \equiv \frac{\mathcal{S}^+ + \mathcal{S}^-}{2}, \quad \Delta\mathcal{S} \equiv \frac{\mathcal{S}^+ - \mathcal{S}^-}{2}$$

Belle 449M $B\bar{B}$ (PRL98 221602)

$$\mathcal{A}_{\rho\pi}^{CP} = -0.12 \pm 0.05 \pm 0.04$$
$$\mathcal{C} = -0.13 \pm 0.09 \pm 0.05$$
$$\Delta\mathcal{C} = +0.36 \pm 0.10 \pm 0.05$$
$$\mathcal{S} = +0.06 \pm 0.13 \pm 0.05$$
$$\Delta\mathcal{S} = -0.08 \pm 0.13 \pm 0.05$$
$$\mathcal{A}_{\rho^0\pi^0} = -0.49 \pm 0.36 \pm 0.28$$
$$\mathcal{S}_{\rho^0\pi^0} = +0.17 \pm 0.57 \pm 0.35$$

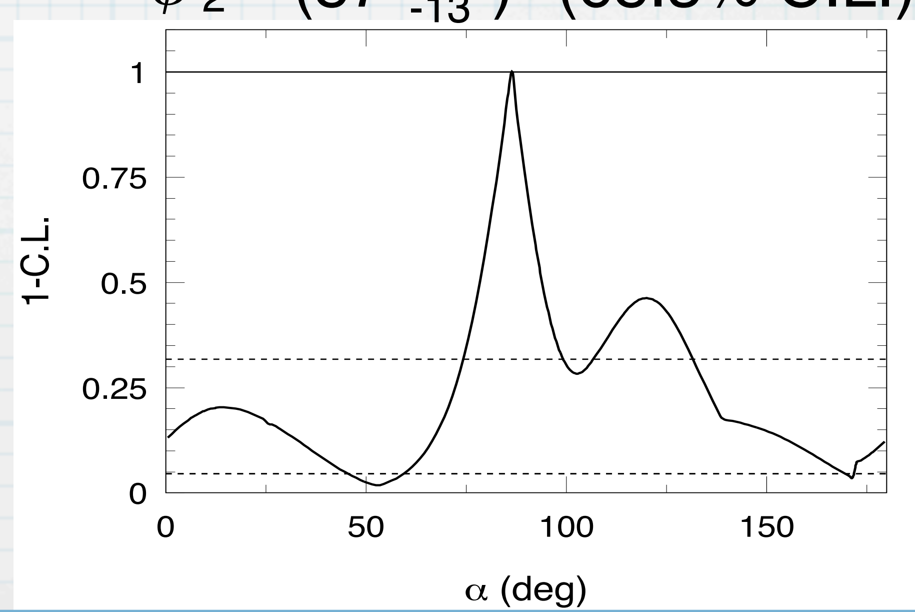
$68° < \phi_2 < 95°$ (68.3% C.L.)



BABAR 375M $B\bar{B}$ (PRD76 012004)

$$\mathcal{A}_{\rho\pi} = -0.14 \pm 0.05 \pm 0.02$$
$$C = 0.15 \pm 0.09 \pm 0.05$$
$$S = -0.03 \pm 0.11 \pm 0.04$$
$$\Delta C = 0.39 \pm 0.09 \pm 0.09$$
$$\Delta S = -0.01 \pm 0.14 \pm 0.06$$
$$C_{00} = \frac{U_0^-}{U_0^+} = -0.10 \pm 0.40 \pm 0.53$$
$$S_{00} = \frac{2\,I_0}{U_0^+} = 0.04 \pm 0.44 \pm 0.18$$

$\phi_2 = (87\,^{+45}_{-13})°$ (68.3% C.L.)



Dalitz analysis for $B^0 \to \rho\,\pi\,(\pi^+\pi^-\pi^0)$ 3-body decay.

$$\frac{d\Gamma}{d\Delta t\, ds_+ ds_-} \propto e^{-\Gamma|\Delta t|}\Big[|A_{3\pi}(s_+,s_-)|^2 + |\overline{A}_{3\pi}(s_+,s_-)|^2$$
$$- q_{\rm tag}\cdot(|A_{3\pi}(s_+,s_-)|^2 - |\overline{A}_{3\pi}(s_+,s_-)|^2)\cos(\Delta m_d \Delta t)$$
$$+ q_{\rm tag}\cdot 2{\rm Im}\left(\frac{q}{p}\overline{A}_{3\pi}(s_+,s_-)A_{3\pi}(s_+,s_-)^*\right)\sin(\Delta m_d \Delta t)\Big]$$

$$A_{3\pi}(s_+,s_-) = f_+(s_+,s_-)A^+ + f_-(s_+,s_-)A^- + f_0(s_+,s_-)A^0\,,$$
$$\frac{q}{p}\overline{A}_{3\pi}(s_+,s_-) = \overline{f}_+(s_+,s_-)\overline{A}^+ + \overline{f}_-(s_+,s_-)\overline{A}^- + \overline{f}_0(s_+,s_-)\overline{A}^0$$

Dalitz plot variables

$$s_+ \equiv (p_+ + p_0)^2$$
$$s_- \equiv (p_- + p_0)^2$$
$$s_0 \equiv (p_+ + p_-)^2$$

Decay amplitudes

$A^+ = T^{-+}\, V_{ub}V^*_{ud} + P^{-+}\, V_{tb}V^*_{td}$ — T : tree transition

$A^- = T^{+-}\, V_{ub}V^*_{ud} + P^{+-}\, V_{tb}V^*_{td}$ — P : penguin transition

$A^0 = C^{00}\, V_{ub}V^*_{ud} + P^{00}\, V_{tb}V^*_{td}$ — C : color-suppressed tree transition

$V_{ub}V^*_{ud} \to \phi_2$

$$|A_{3\pi}(s_+,s_-)|^2 \pm |\overline{A}_{3\pi}(s_+,s_-)|^2 = \sum_{\kappa\in\{+,-,0\}} |f_\kappa|^2(|A^\kappa|^2 \pm |\overline{A}^\kappa|^2)$$
$$+2\sum_{\kappa<\sigma\in\{+,-,0\}}\left({\rm Re}[f_\kappa f_\sigma^*]\,{\rm Re}[A^\kappa A^{\sigma *} \pm \overline{A}^\kappa\overline{A}^{\sigma *}] - {\rm Im}[f_\kappa f_\sigma^*]\,{\rm Im}[A^\kappa A^{\sigma *} \pm \overline{A}^\kappa\overline{A}^{\sigma *}]\right)$$

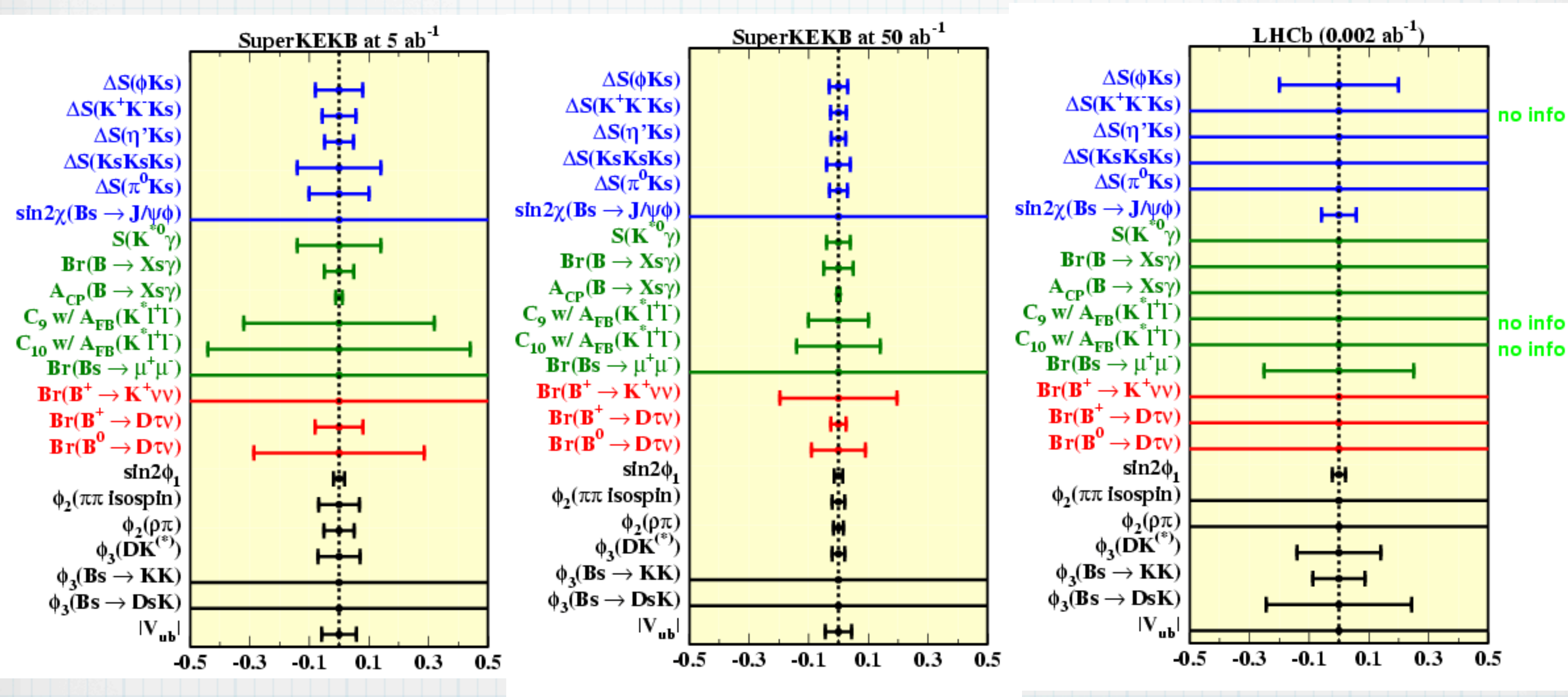
$${\rm Im}\left(\frac{q}{p}\overline{A}_{3\pi}(s_+,s_-)A_{3\pi}(s_+,s_-)^*\right) = \sum_{\kappa\in\{+,-,0\}} |f_\kappa|^2{\rm Im}[A^\kappa A^{\kappa *}]$$
$$+2\sum_{\kappa<\sigma\in\{+,-,0\}}\left({\rm Re}[f_\kappa f_\sigma^*]\,{\rm Im}[\overline{A}^\kappa A^{\sigma *} + \overline{A}^\sigma A^{\kappa *}] + {\rm Im}[f_\kappa f_\sigma^*]\,{\rm Re}[\overline{A}^\kappa A^{\sigma *} - \overline{A}^\sigma A^{\kappa *}]\right)$$

$f_{\kappa,\sigma}$: 9 Dalitz plot functions

×

3 types of distributions in Δt direction (lifetime, sine, cosine)

→ 27 coefficients measurable



(LoI for Belle II at superKEKB)