Studies of CP violation in B meson decays

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NEW TRENDS IN HIGH-ENERGY PHYSICS,
Sep. 4, 2011, Yalta, Crimea, Ukraine

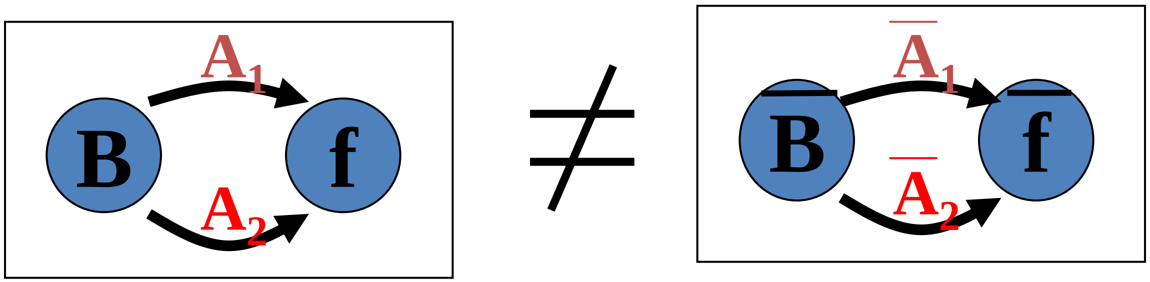
- Introduction of CP violation in B meson decays
- ϕ_1 measurements
- ϕ_3 measurements
- $\Delta A_{K\pi}$ puzzle

CP violation

CP violation(CPV): the difference of partial decay width between B and anti-B.

$$\Gamma(B \to f) \neq \Gamma(\overline{B} \to \overline{f})$$

interference between 2 amplitude with different complex phase make CPV



different complex phases for two path are needed.

$$A_1 = A_i e^{i\delta_i} e^{i\phi_i} \qquad \overline{A}_1 = A_i e^{i\delta_i} e^{-i\phi_i}$$

$$A_2 = A_j e^{i\delta_j} e^{i\phi_j} \qquad \overline{A}_2 = A_j e^{i\delta_j} e^{-i\phi_j}$$

CP transformation

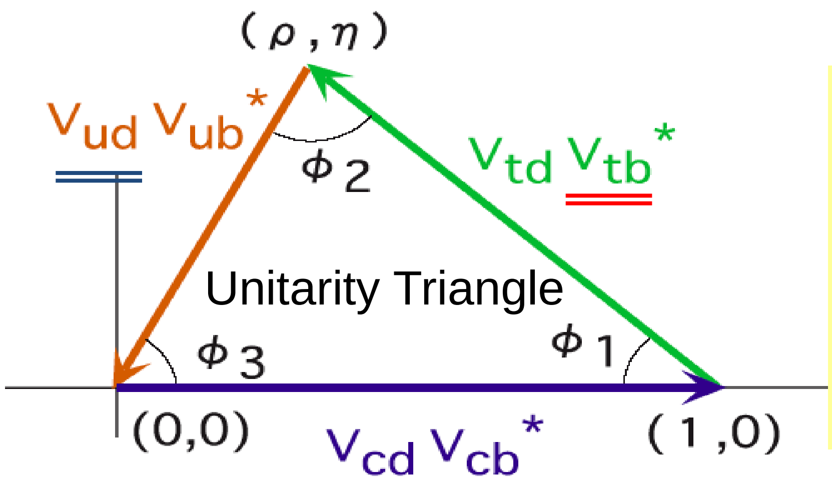
$$\mathcal{A}_{CP}(B \to f) = \frac{|\overline{A}|^2 - |A|^2}{|\overline{A}|^2 + |A|^2} \propto \sum_{i,j} A_i A_j \sin(\delta_i - \delta_j) \sin(\phi_i - \phi_j) \Big/ \sum_i |A_i|^2$$

$A_{CP} \sim 0$, when $A_i \gg A_j$ or $\delta_i \approx \delta_j$

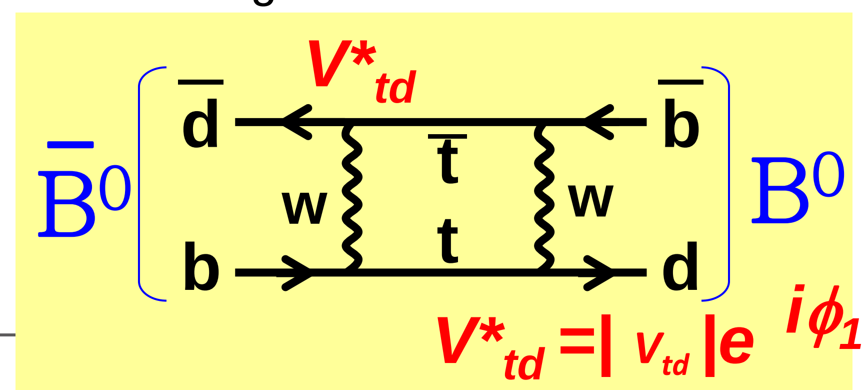
CP Violation in B^0 decays

KM ansatz: CPV is due to a complex phase in the quark mixing matrix

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



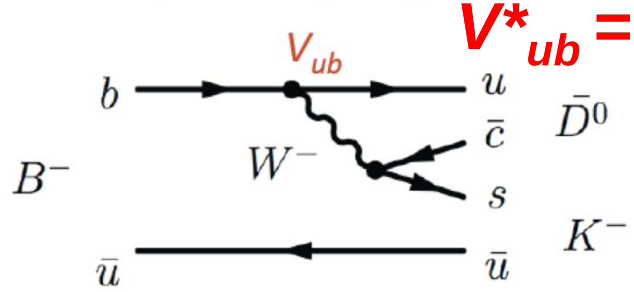
B-B̄ mixing



$V^*_{td} = |V_{td}| e^{i\phi_1}$

$$B^- \to \bar{D}^0 K^-$$

$V^*_{ub} = |V_{ub}| e^{i\phi_3}$



$$\phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

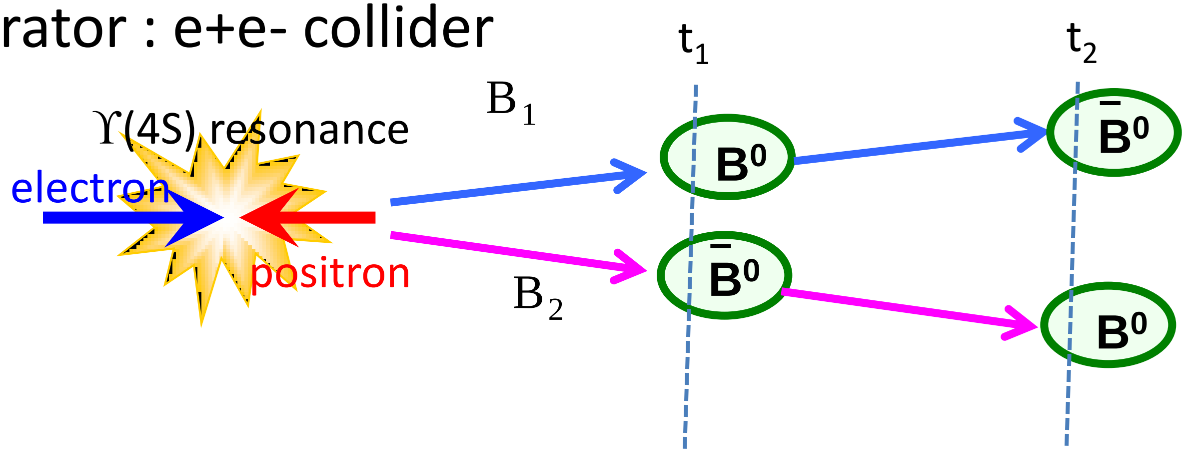
$$\phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

$\beta = \phi_1$
$\alpha = \phi_2$
$\gamma = \phi_3$

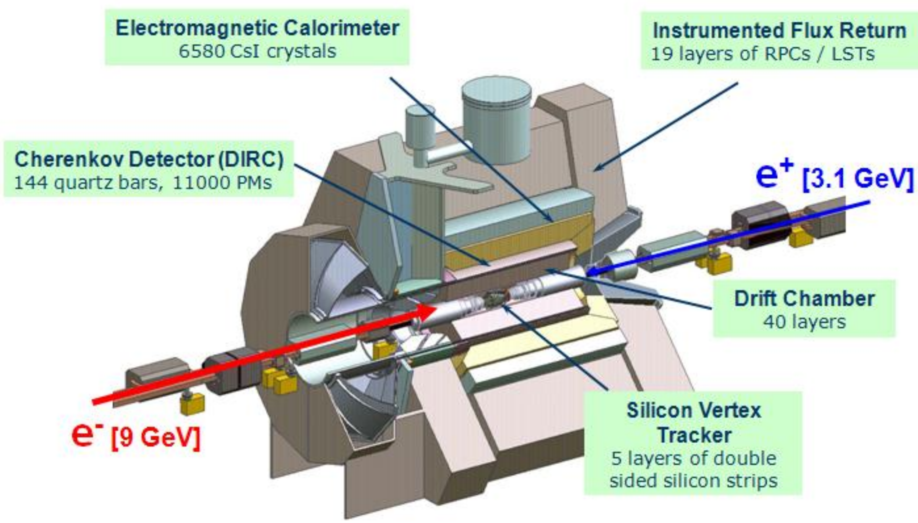
2 B-factories

accelerator : e+e- collider



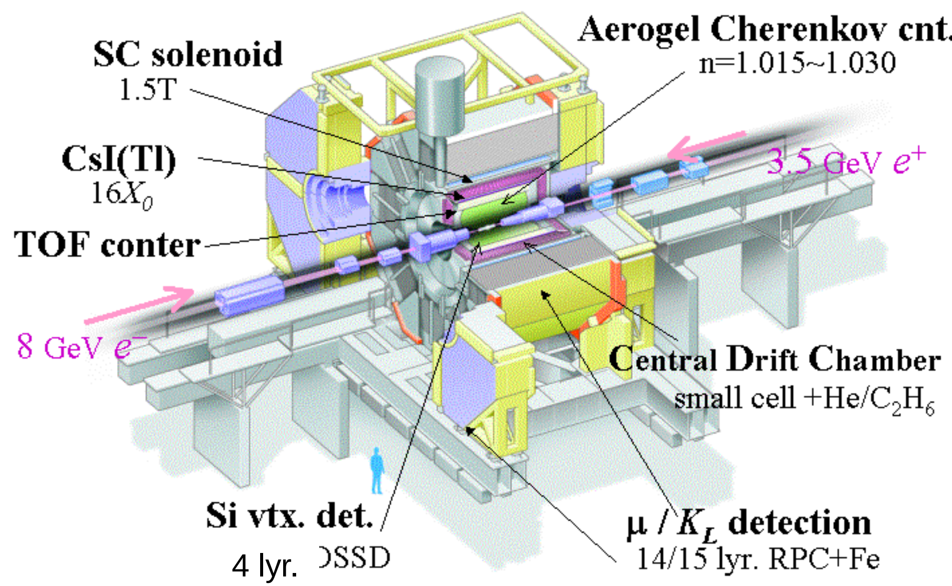
KEKB 8×3.5GeV
$2.1\times10^{34}cm^{-2}s^{-1}$

PEP-II 9GeV(e^-),3.1GeV(e^+)
$1.2\times10^{34}cm^{-1}s^{-1}$

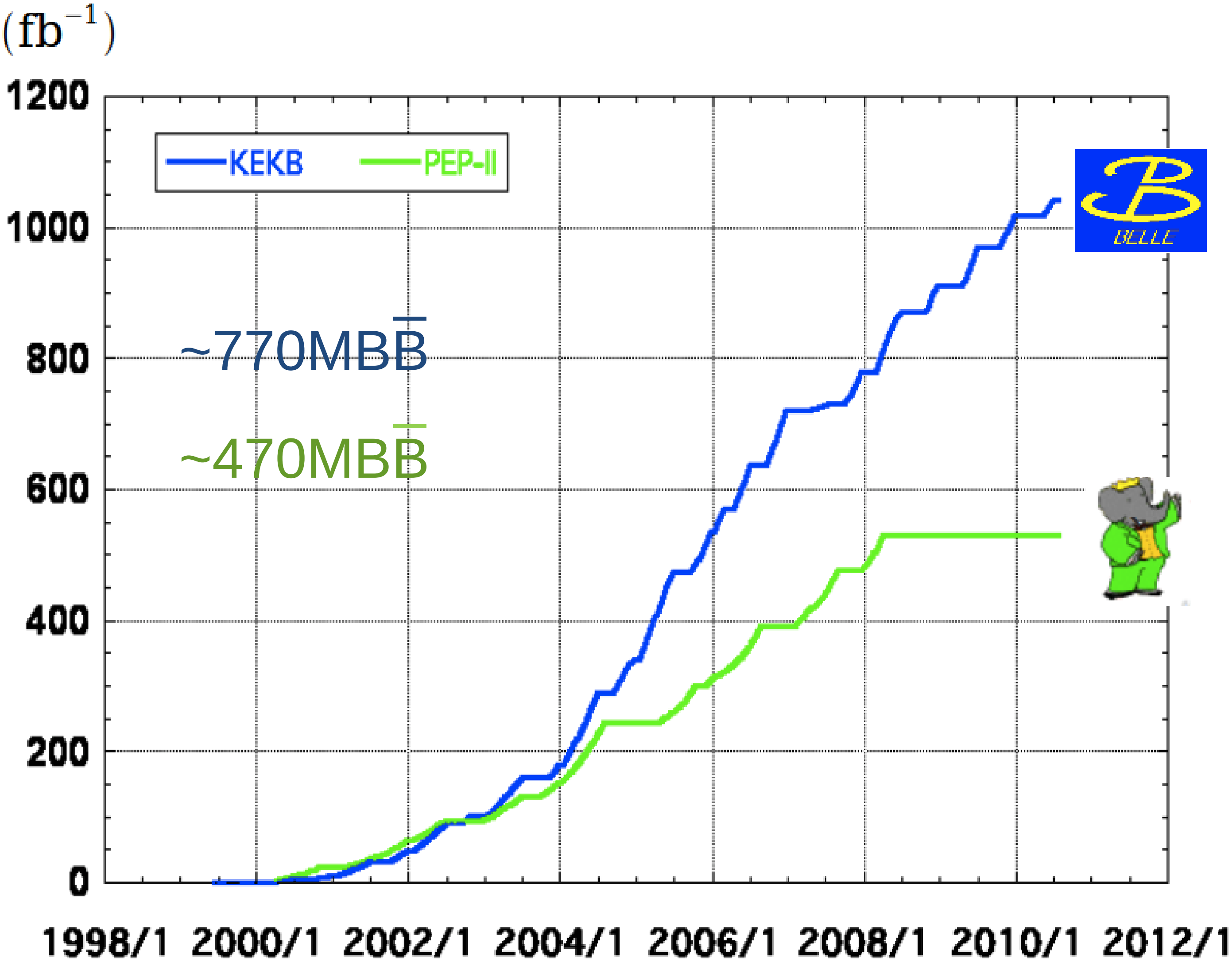


BABAR Detector

Belle Detector



Integrated luminosity of B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

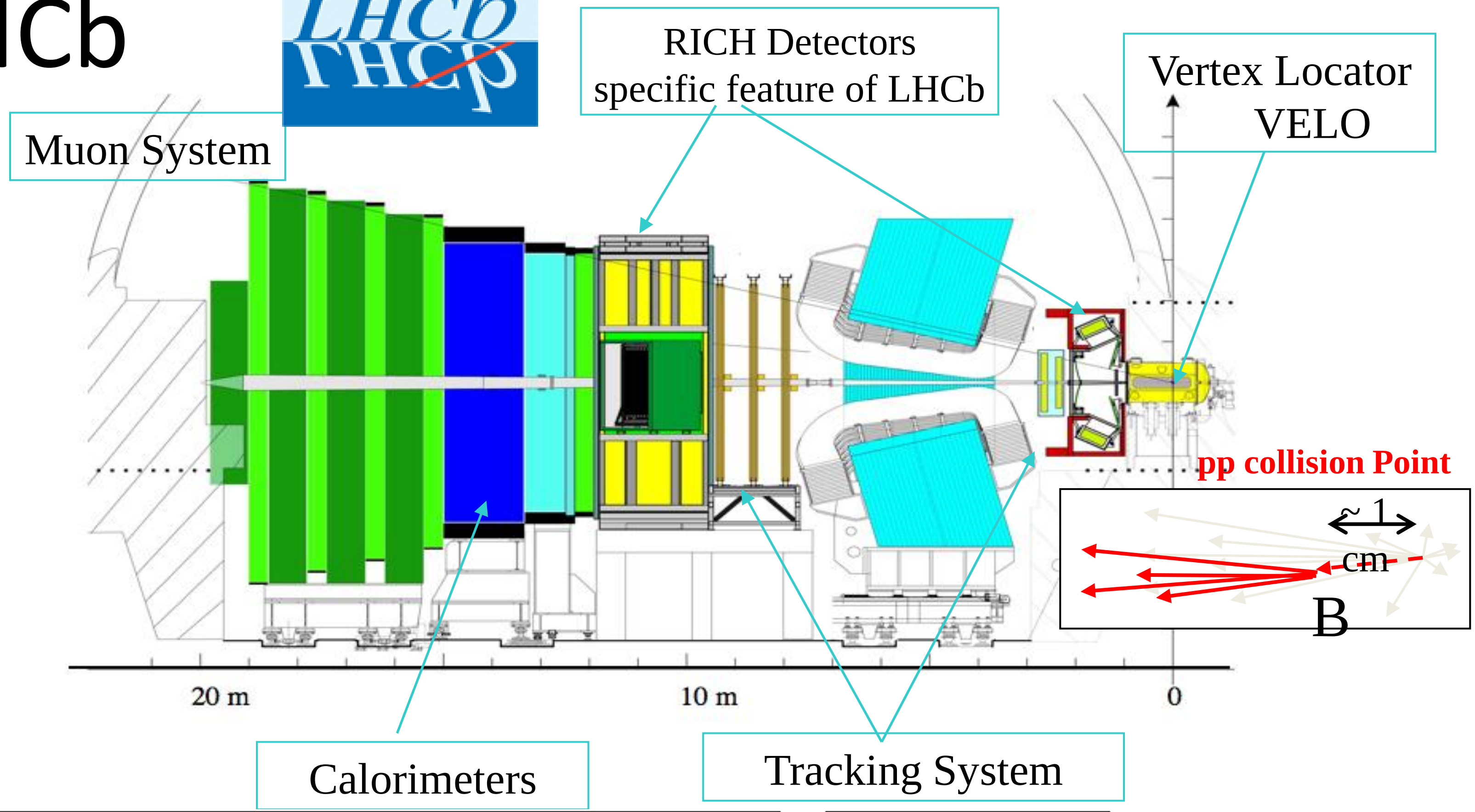
$\Upsilon(3S)$: 30 fb^{-1}

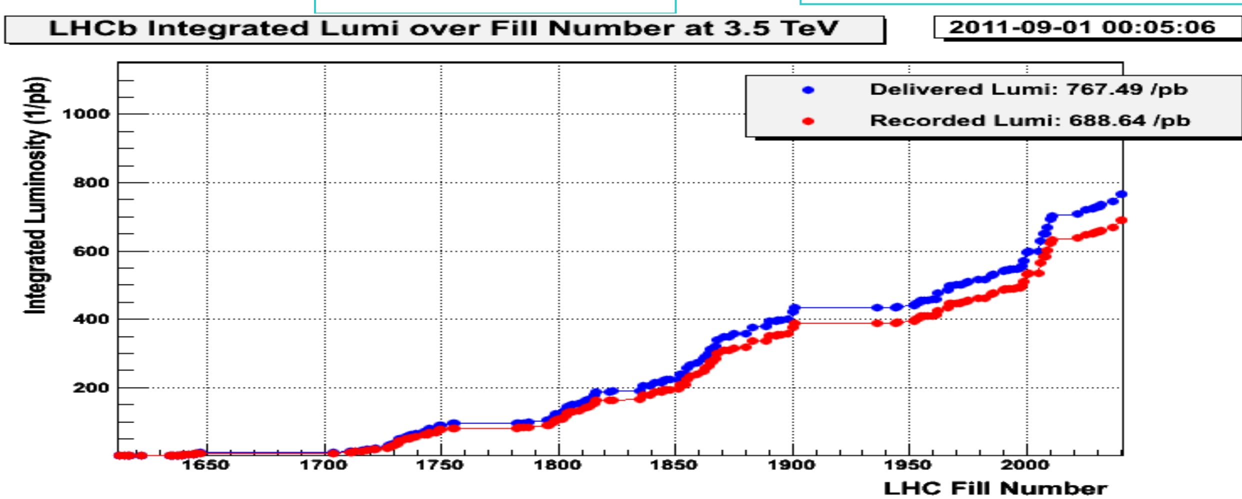
$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim$ 54 fb^{-1}

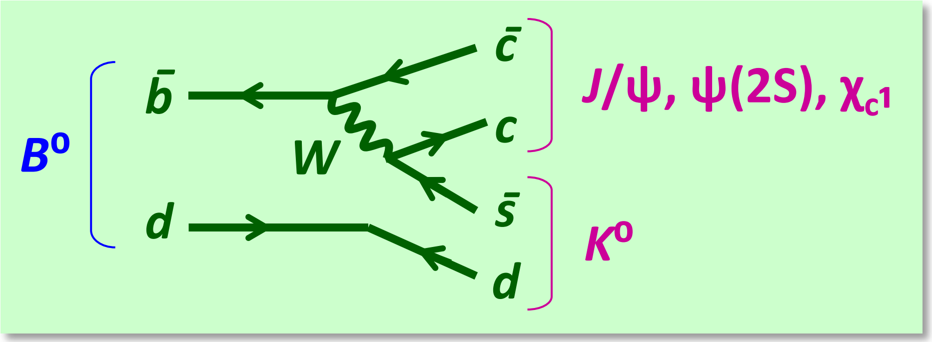
LHCb





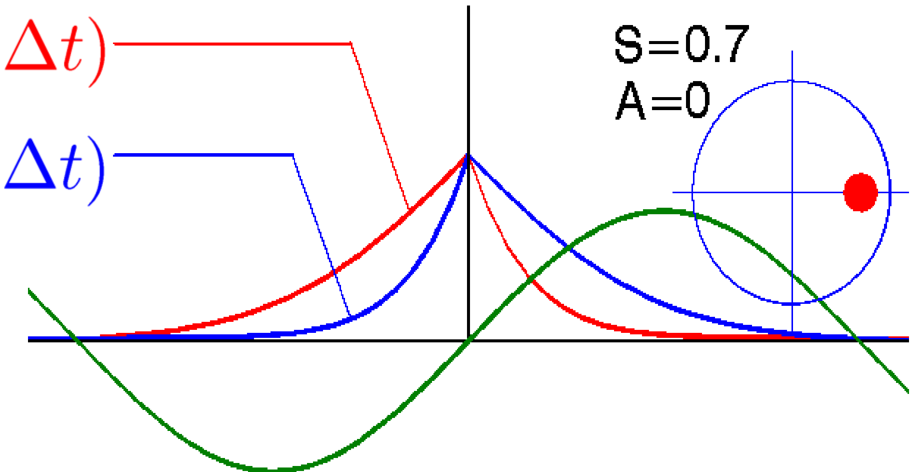
- pp collider
- B meson flight very forward or very backward.

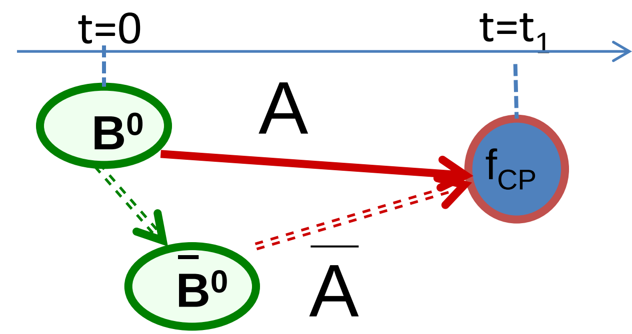
ϕ_1 in b→ccs



Time-dependent CP Violation in B^0 decays

We can measure CPV (asym.) as a function of proper time diff (Δt).





Decay time difference between B meson pairs

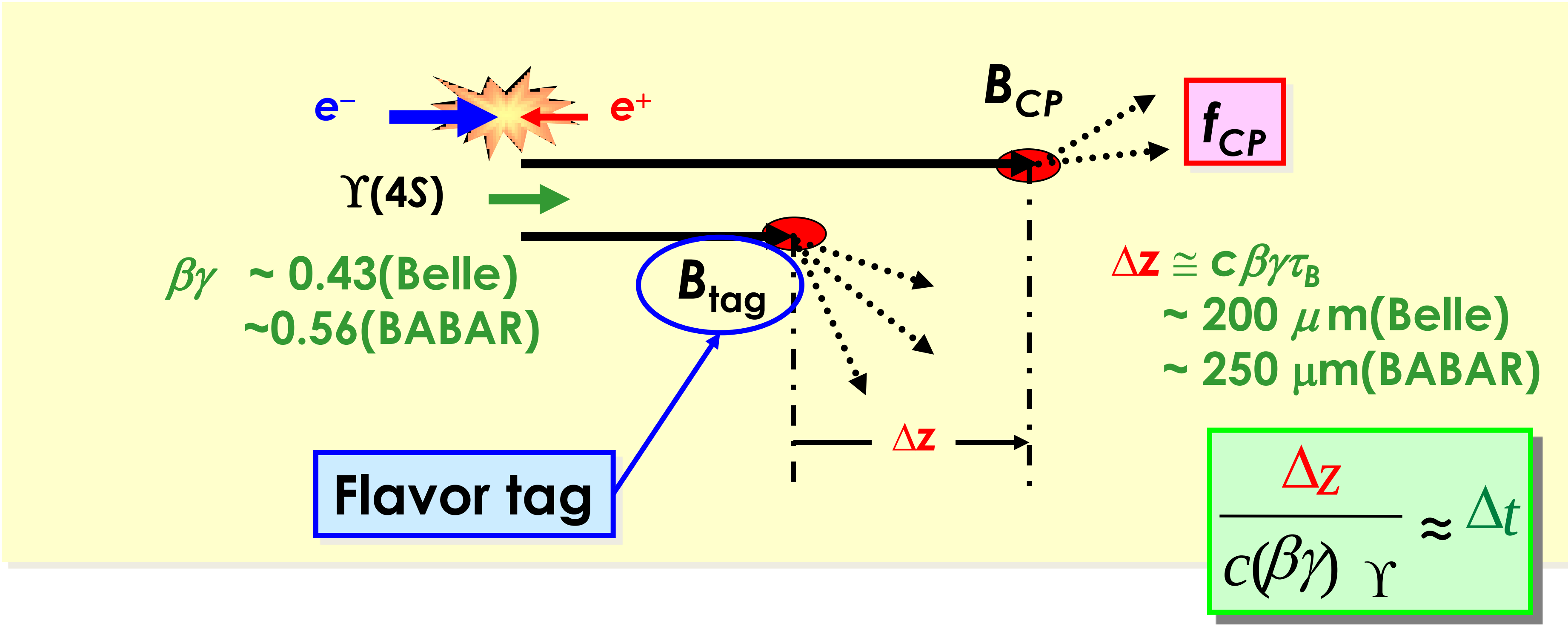
$$A_{CP}(\Delta t)$$
$$\equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)}$$
$$= \mathcal{S} \sin \Delta m \Delta t + \mathcal{A} \cos \Delta m \Delta t$$

Mixing-induced CPV | Direct CPV

e.g. for $B^0 \to J/\psi\ Ks$
$S = -\xi_{CP} \sin 2\phi_1 = +\sin 2\phi_1$
$A \sim 0$ (A= -C)
(ξ_{CP} : CP eigenvalue ±1)

$$S = \frac{2\,\mathrm{Im}\left(q/p\,\bar{A}A^*\right)}{|\bar{A}|^2 + |A|^2}, \quad A = \frac{|\bar{A}|^2 - |A|^2}{|\bar{A}|^2 + |A|^2}$$

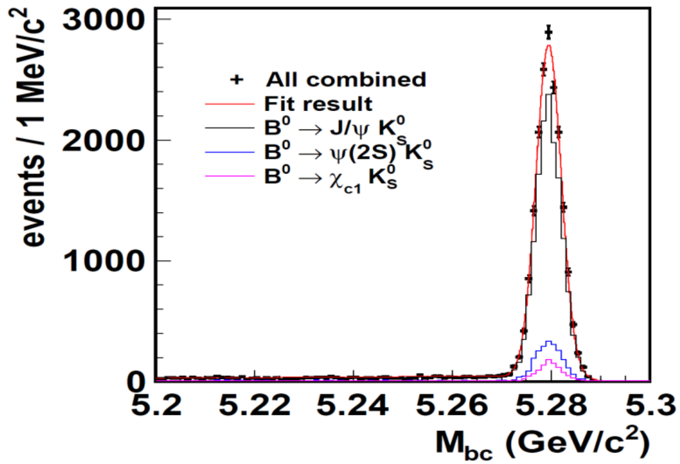
Principle of Measurement in B-factories

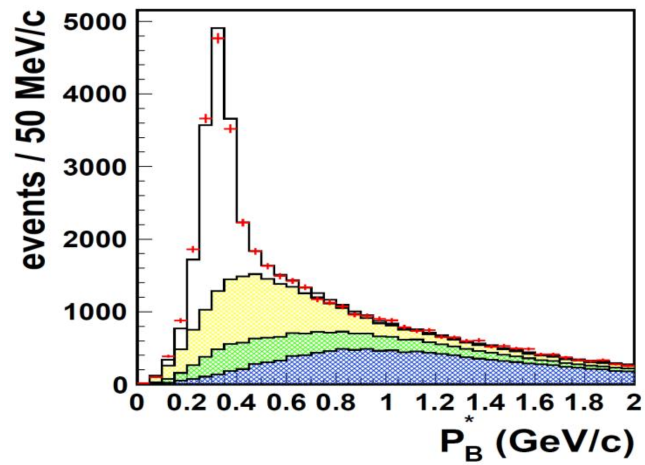


- Reconstruct $B \rightarrow f_{CP}$ decays
- Measure proper-time difference: Δt
- Determine flavor of B_{tag}
- Evaluate *CP* asymmetry from Δt and flavor of B_{tag}

$\sin 2\phi_1$ with charmonium K^0 modes

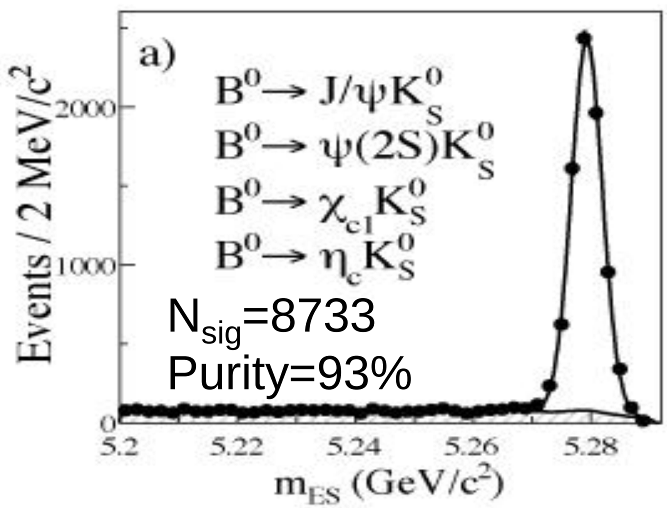
772MB$\bar{B}$

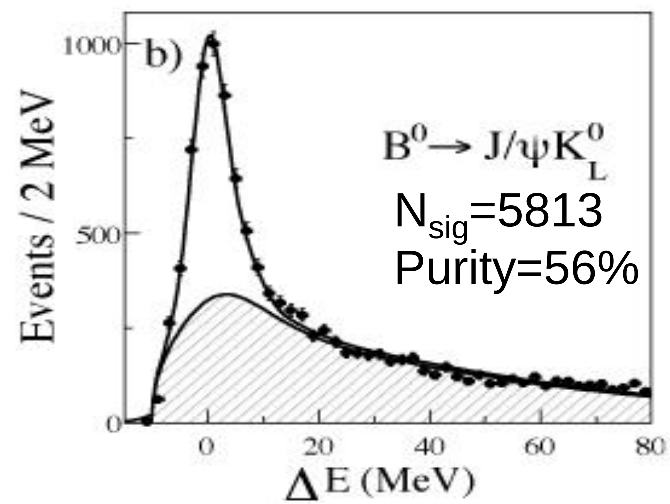




	$J/\psi K_S^0$	$J/\psi K_L^0$	$\psi(2S)K_S^0$	$\chi_{c1}K_S^0$	$N_{B\bar{B}}$ (x 10^6)
Signal yield	12727±115	10087±154	1981±46	943±33	772
Purity [%]	97	63	93	89	

465MB$\bar{B}$





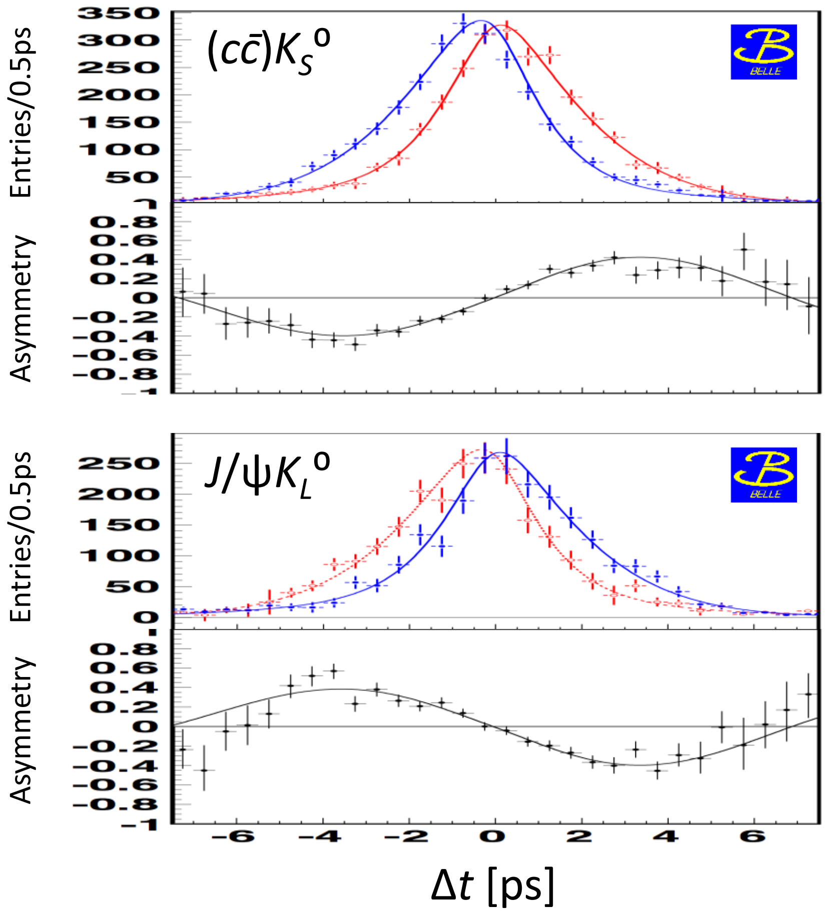
$E_B - E_{CM}/2$

$\sin2\phi_1$ with charmonium K^0 modes

Belle preliminary

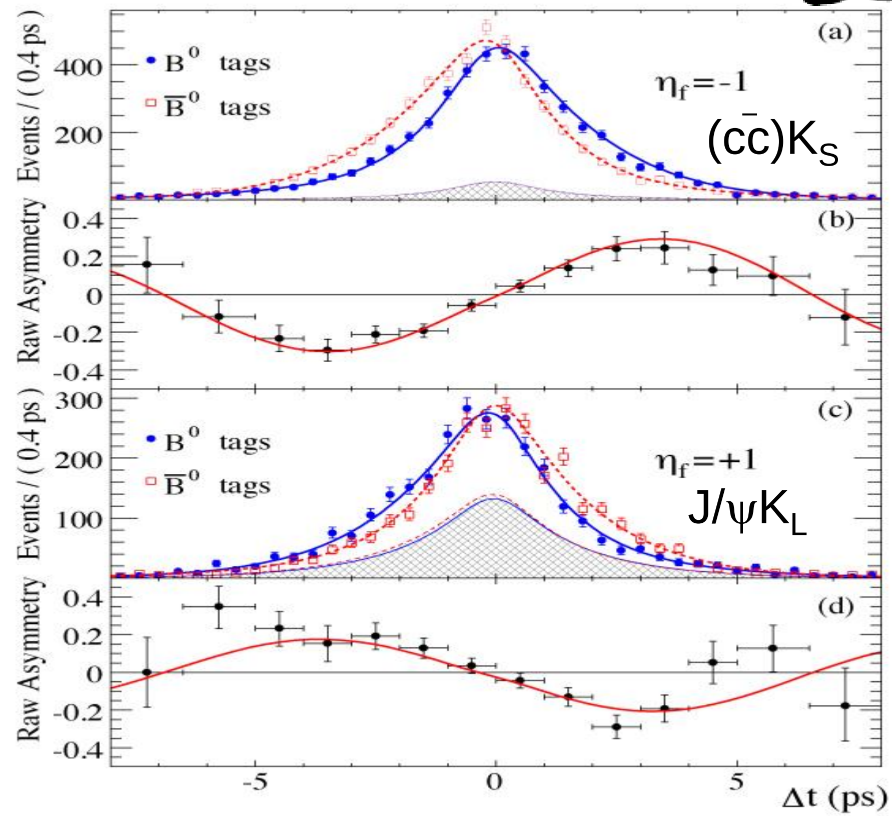
$B_{tag} = B^0$

$B_{tag} = \bar{B}^0$



$$\sin 2\phi_1 = +0.668 \pm 0.023 \pm 0.013$$

$$A = +0.007 \pm 0.016 \pm 0.013$$



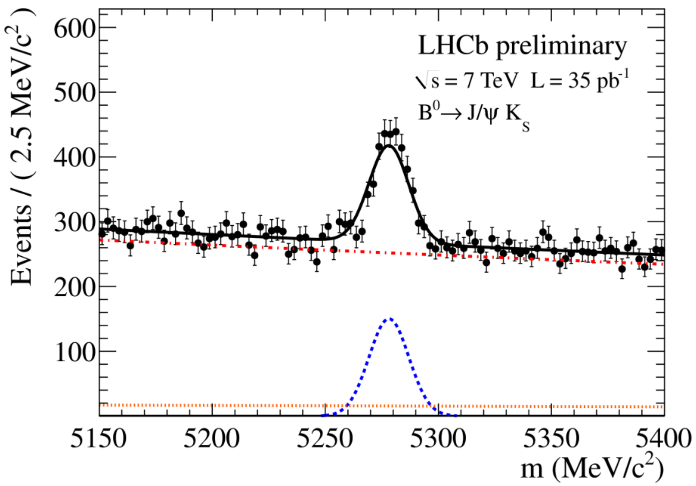
$\sin2\phi_1 = 0.687 \pm 0.028 \pm 0.012$

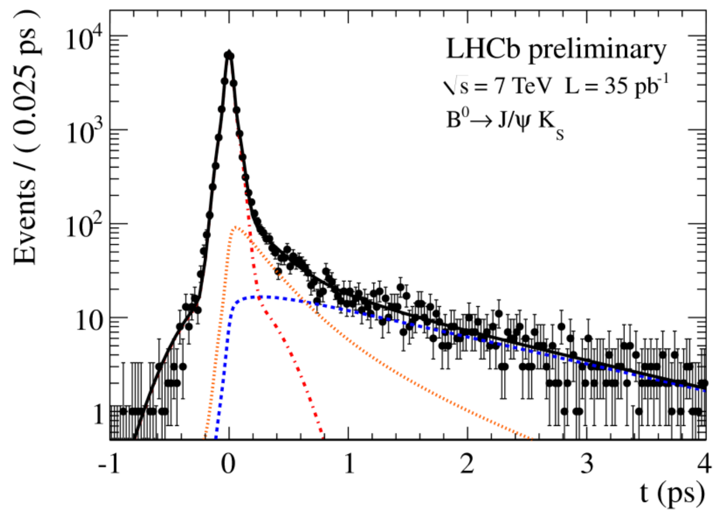
$A_f = -0.024 \pm 0.020 \pm 0.016$

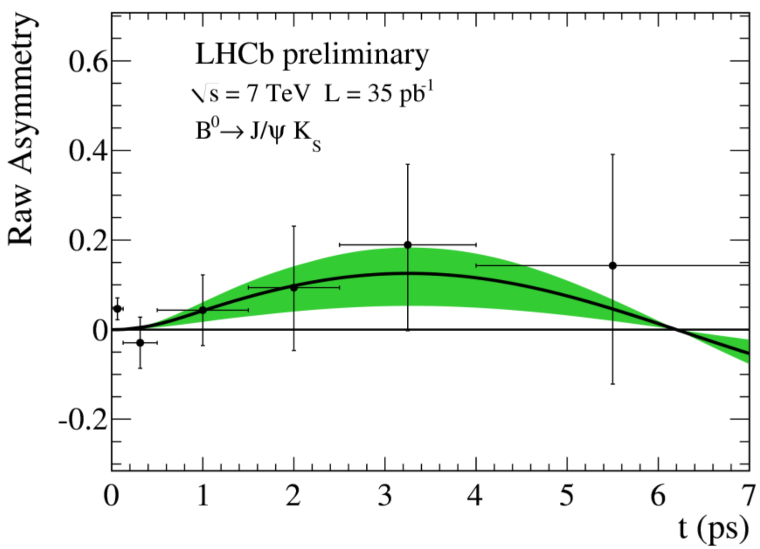
PRD79,072009(2009)

$\sin 2\phi_1$ in LHCb

$L=35pb^{-1}$







LHCb Preliminary

$\sin 2\phi_1 = 0.53^{+0.28}_{-0.29} \pm 0.05$

LHCb-CONF-2011-004

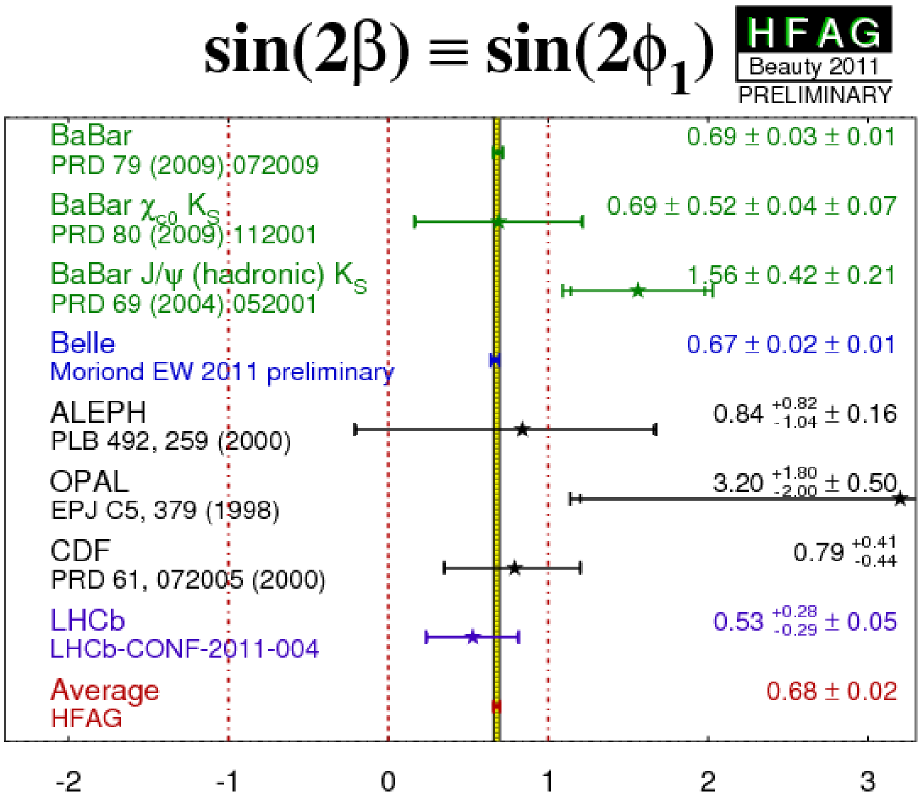
when A is floated

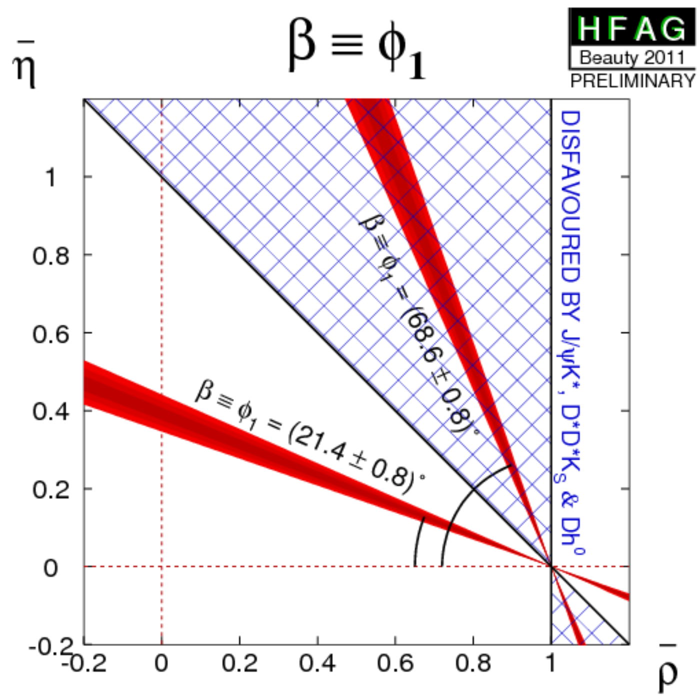
$S = +0.38 \pm 0.35$

$A = -0.28 \pm 0.32$

correlation coefficient $\rho = 0.53$

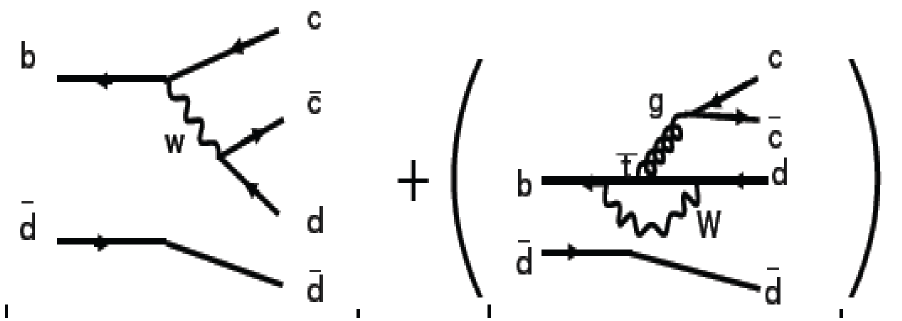
ϕ_1 in b→ccs





$\phi_1=(21.4\pm0.8)^\circ$

ϕ_1 in b→ccd



tree + (penguin)

J/ψ π^0 :
constrain penguin contribution in Golden mode(J/ψK^0) without model dependence.

$D^{(*)+}$ $D^{(*)-}$:
penguin contribution is expected to be small.

CPV in $B^0 \to D^+ D^-$

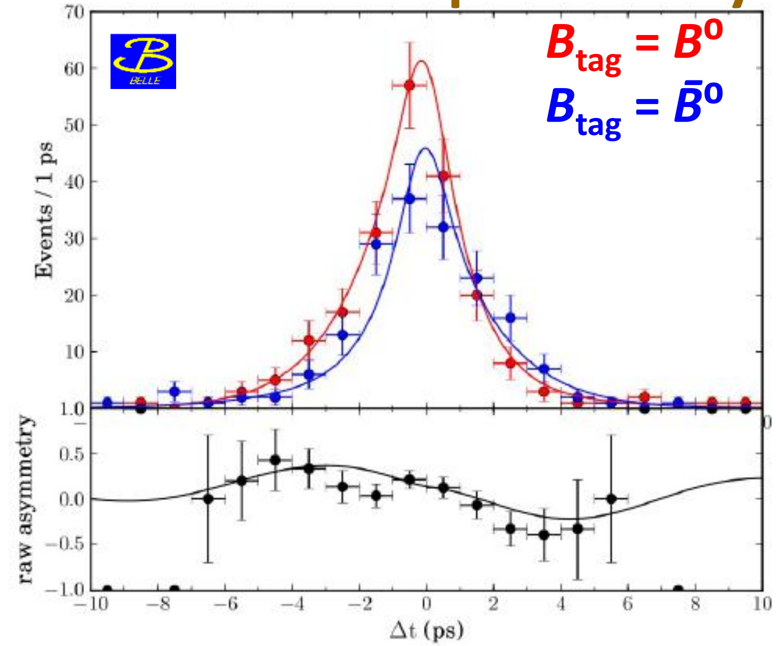
772 x 10^6 $B\bar{B}$ pairs

$B^0 \to (K^-\pi^+\pi^+)(K^+\pi^-\pi^-)$, $(K^-\pi^+\pi^+)(K_S\pi^-)$+c.c.

$$S = -1.06 \pm 0.21 \pm 0.07$$

$$A = +0.43 \pm 0.17 \pm 0.04$$

Belle preliminary

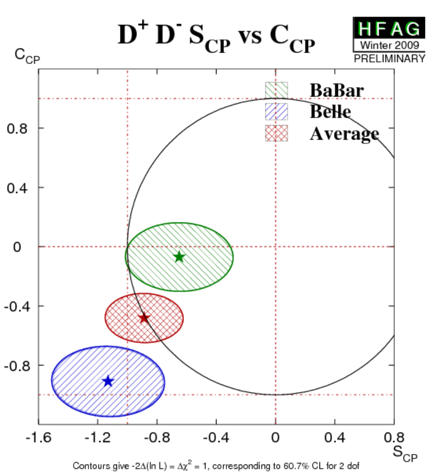


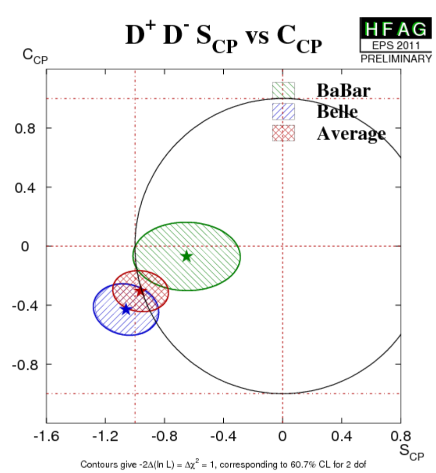
Previous measurement (535x10^6 $B\bar{B}$ pairs):

$$S = -1.13 \pm 0.37 \pm 0.09,$$

$$A = +0.91 \pm 0.23 \pm 0.06$$

Unexpectedly large *A* come closer to zero with more statistics.

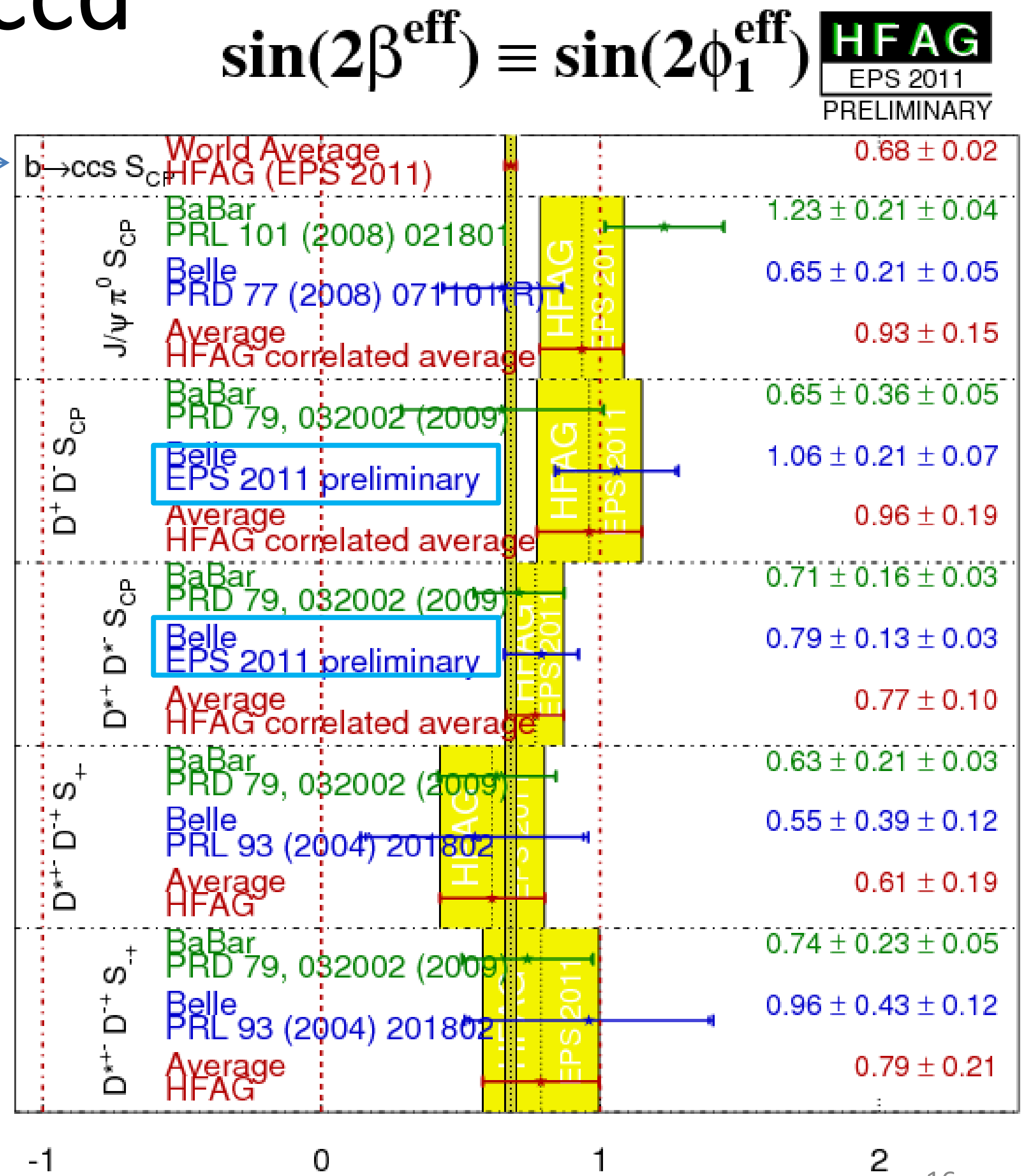




$C_{CP} = -A$

ϕ_1 in b→ccd

reference point →



CPV in $B^0 \to D^{*+}D^{*-}$

Belle preliminary

772 x 10^6 $B\bar{B}$ pairs

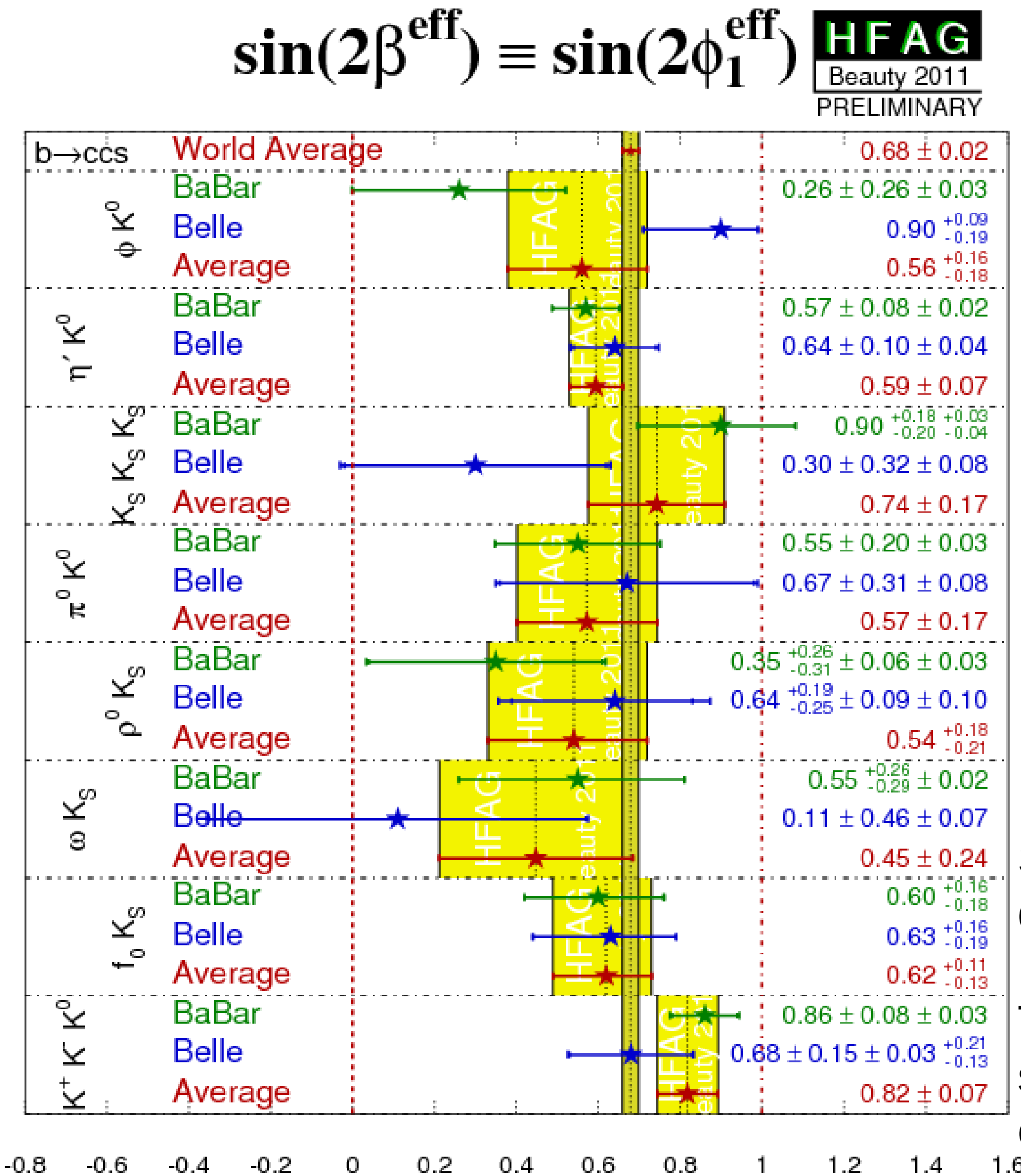
$$S = -0.79 \pm 0.13 \pm 0.03$$

$$A = +0.15 \pm 0.08 \pm 0.02$$

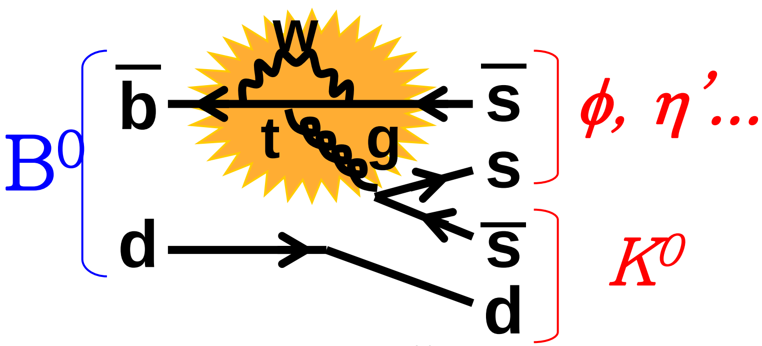
$$R_0 = 0.62 \pm 0.03 \pm 0.01$$

$$R_\perp = 0.14 \pm 0.02 \pm 0.01$$

ϕ_1 in b→sqq



$b \to s\bar{q}q$ penguin



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

Extra CPV phase

"$\sin 2\phi_1^{eff}$"$\neq \sin 2\phi_1$

Hint of New Physics

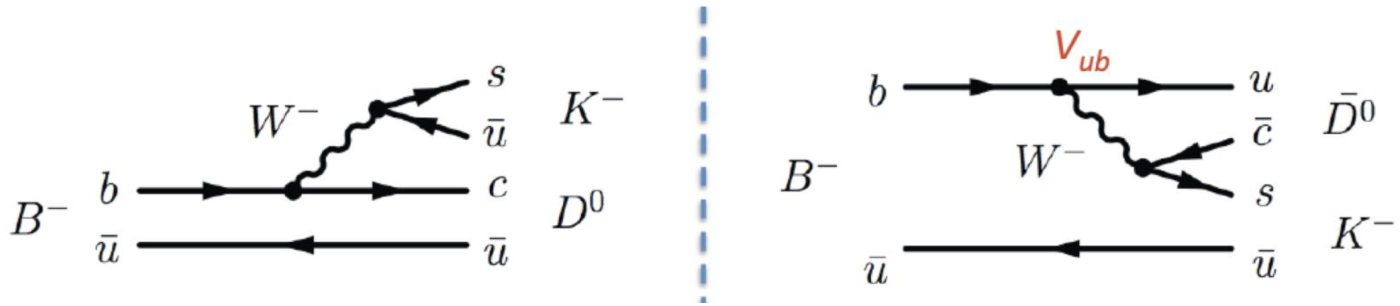
Still precision is statistically dominated.

↓

To obtain sensitivity in effective $\sin 2\phi_1$ of $O(10^{-2})$, we need $O(10\text{ab}^{-1})$ of integrated luminosity.

ϕ_3 measurement

Measurements using interference between V_{ub} contribution and another weak vertex.



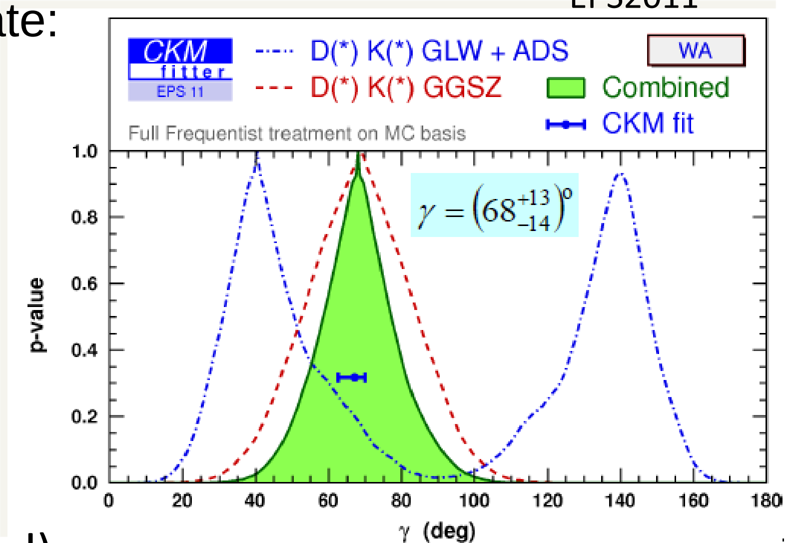
where, D^0 and $\overline{D^0}$ decay to the same final state:

$$\left|\tilde{D}\right\rangle = \left|D^0\right\rangle + r_B e^{i\theta}\left|\overline{D}^0\right\rangle$$

phase difference $\theta=\delta_B \pm \phi_3$

amplitude ratio: $r_B \equiv \dfrac{A(B^- \to \overline{D}^0 K^-)}{A(B^- \to D^0 K^-)}$

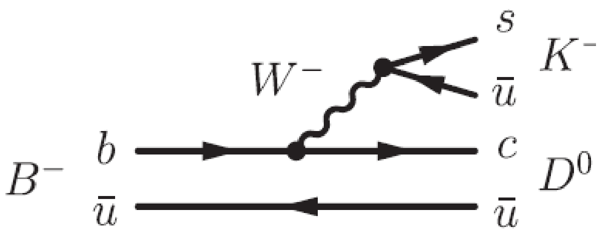
EPS2011



3 methods

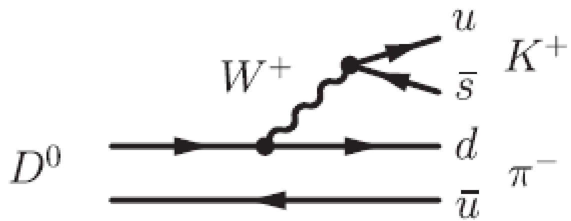
- ADS: doubly Cabibbo suppressed
- GLW: CP eigenstates (Cabibbo suppressed)
- GGSZ: Cabibbo favored multibody decays with Dalitz plane

ADS Analyses of $B^- \to D^{(*)} K^{(*)-}$



Color favored

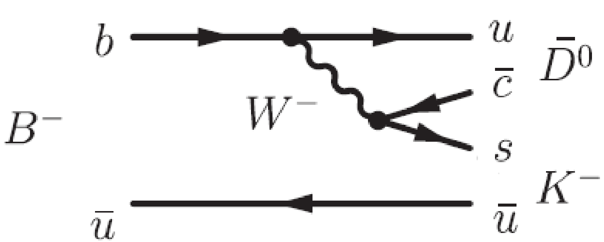
$V_{cb}V_{us}^* \sim A\lambda^3$



Doubly Cabibbo suppressed

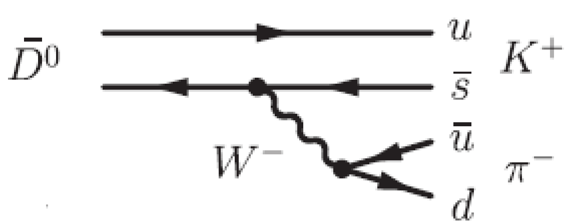
D. Atwood, I. Dunietz, and A. Soni, PRL. 78,3257 (1997); PRD 63, 036005 (2001).

Choosing both contributing decay amplitudes are of comparable size.



Color suppressed

$V_{ub}V_{cs}^* \sim A\lambda^3(\rho + i\eta)$



Cabibbo favored

r_D, δ_D : from other measurements

$$\mathcal{R}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^-\pi^+]_D K^-) + \mathcal{B}([K^+\pi^-]_D K^+)}$$

suppressed

favored

$$= r_B^2 + r_D^2 + 2 r_B r_D \cos\delta \cos\phi_3$$

$$r_B \equiv \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)}$$

$$r_D \equiv \frac{A(D^0 \to K^+\pi^-)}{A(D^0 \to K^-\pi^+)}$$

$$\delta = \delta_B + \delta_D$$

$$\mathcal{A}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) - \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}$$

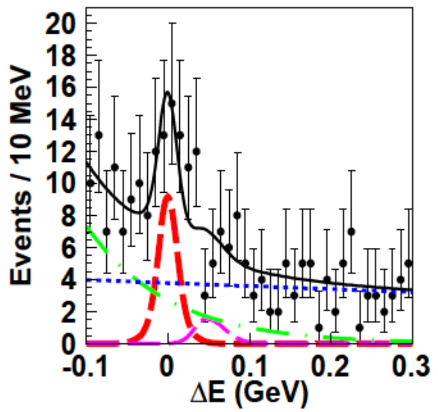
$$= 2 r_B r_D \sin\delta \sin\phi_3 / R_{DK}$$

$\delta_{B,D}$: Strong phase difference

results in $B^- \rightarrow D^0 K^-$

Suppressed mode $D \rightarrow K^+\pi^-$

772MB$\bar{B}$

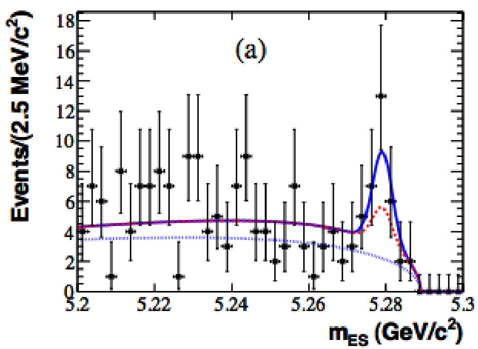


PRL 106, 231803 (2011)
first evidence with a significance of 4.1σ

$$\mathcal{R}_{DK} = [1.63^{+0.44}_{-0.41}(\text{stat})^{+0.07}_{-0.13}(\text{syst})] \times 10^{-2}$$

$$\mathcal{A}_{DK} = -0.39^{+0.26+0.04}_{-0.28-0.03}$$

467MB$\bar{B}$

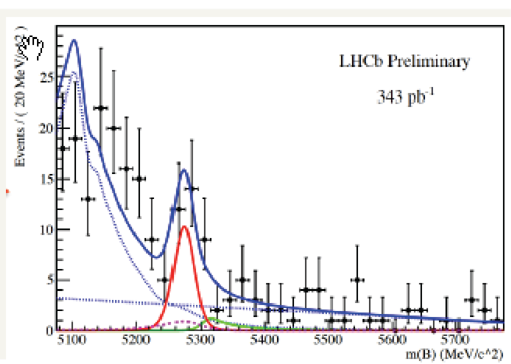


PRD82,072006(2010)

$$\mathcal{R}_{DK} = (1.1 \pm 0.6 \pm 0.2) \times 10^{-2}.$$

$$\mathcal{A}_{DK} = -0.86 \pm 0.47^{+0.12}_{-0.16}.$$

L=343pb^{-1}



LHCb Preliminary

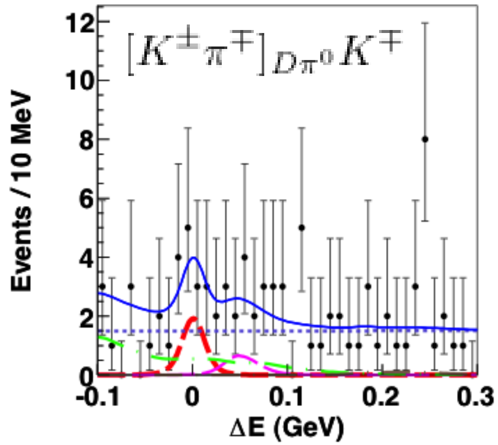
4σ significance

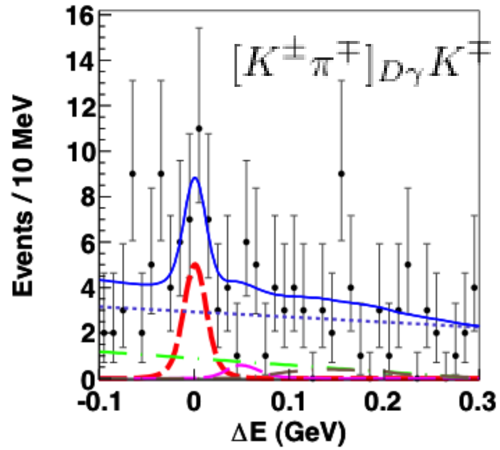
$$\mathcal{R}_{DK} = (1.66 \pm 0.39 \pm 0.24) \times 10^{-2}$$

$$\mathcal{A}_{DK} = -0.39 \pm 0.17 \pm 0.02$$

results in $B^- \rightarrow D^{*0}(D^0\pi^0, D^0\gamma)K^-$,

Suppressed mode $D \rightarrow K^+\pi^-$





Belle preliminary

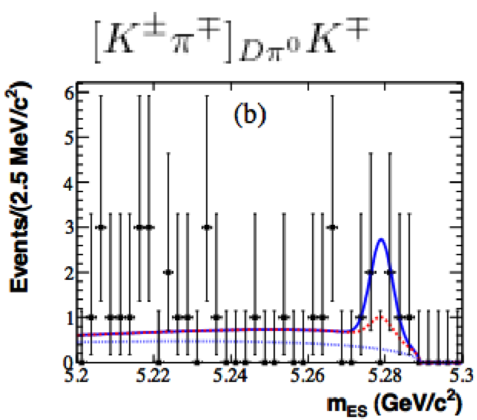
772MB$\bar{B}$

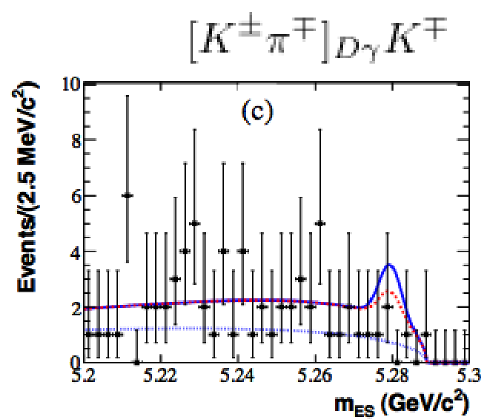
$$\mathcal{R}_{D\pi^0} = [1.0^{+0.8}_{-0.7}(\text{stat})^{+0.1}_{-0.2}(\text{syst})] \times 10^{-2}$$

$$\mathcal{R}_{D\gamma} = [3.6^{+1.4}_{-1.2}(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-2}$$

$$\mathcal{A}_{D\pi^0} = 0.4^{+1.1}_{-0.7}(\text{stat})^{+0.2}_{-0.1}(\text{syst})$$

$$\mathcal{A}_{D\gamma} = -0.51^{+0.33}_{-0.29}(\text{stat}) \pm 0.08(\text{syst})$$





PRD82,072006(2010)

467MB$\bar{B}$

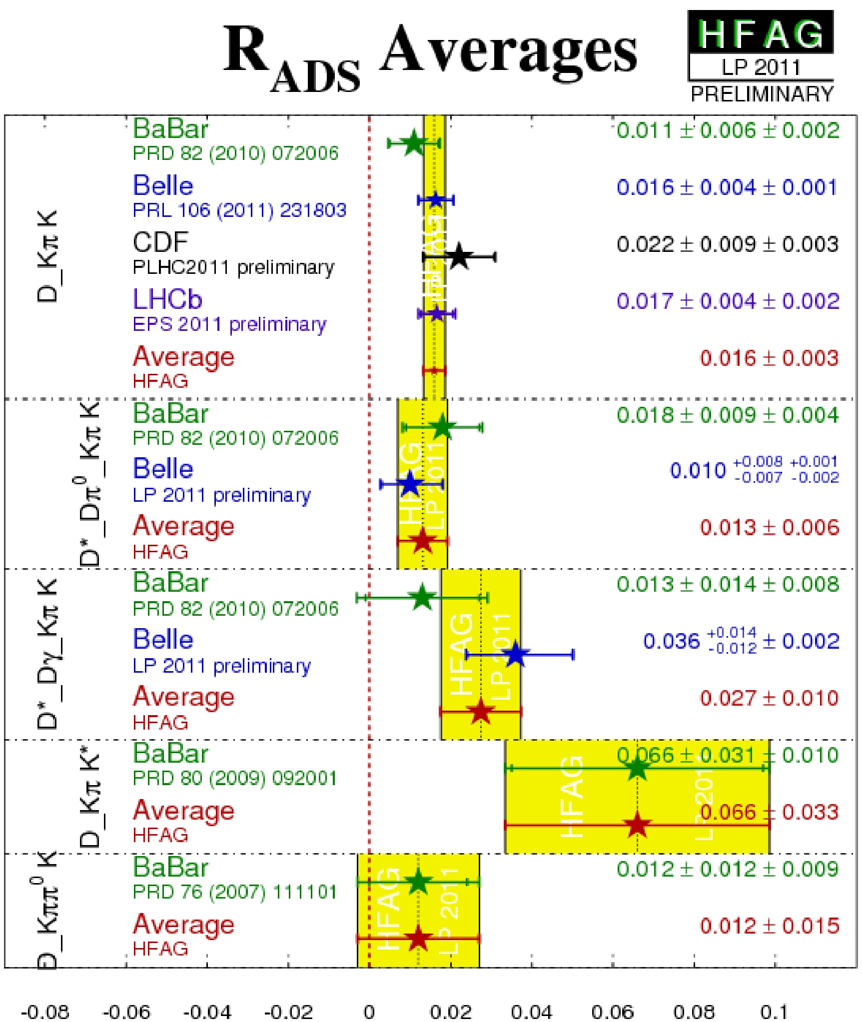
$$\mathcal{R}^*_{(D\pi^0)K} = (1.8 \pm 0.9 \pm 0.4) \times 10^{-2}.$$

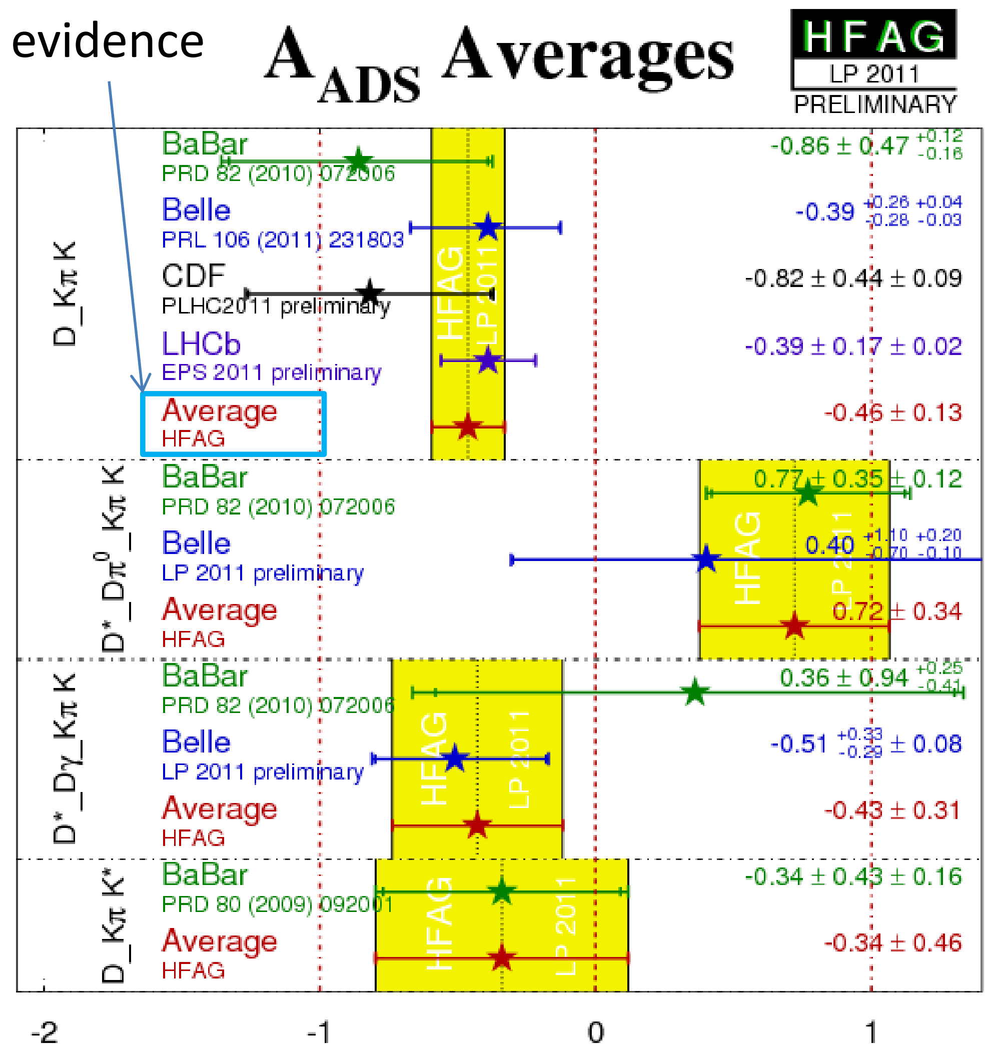
$$\mathcal{R}^*_{(D\gamma)K} = (1.3 \pm 1.4 \pm 0.8) \times 10^{-2}.$$

$$\mathcal{A}^*_{(D\pi^0)K} = +0.77 \pm 0.35 \pm 0.12.$$

$$\mathcal{A}^*_{(D\gamma)K} = +0.36 \pm 0.94^{+0.25}_{-0.41}.$$

ADS analysis





GLW Analyses of $B^- \to D^{(*)}K^{(*)-}$

M. Gronau and D. London, Phys. Lett. B **253**, 483 (1991);
M. Gronau and D. Wyler, Phys. Lett. B **265**, 172 (1991).

Defining the two CP eigenstates

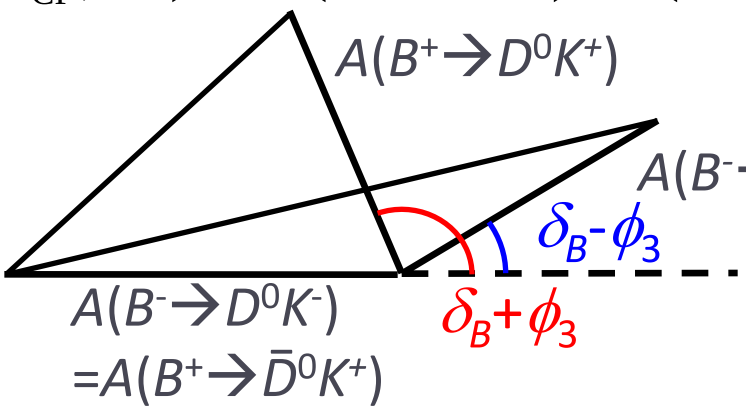
$$|D_{CP\pm}^0\rangle = \frac{1}{\sqrt{2}}(|D^0\rangle \pm |\bar{D}^0\rangle)$$

where D_{CP+}:
KK, $\pi\pi$,...(CP even)

where D_{CP-}:
$K_S\pi^0$, $K_S\omega$, $K_S\phi$,..(CP odd)

one can write $B \to D_{CP+}$ decays as

$$\begin{cases} \sqrt{2}A(B^+\to D_{CP+}^0K^+) = A(B^+\to D^0K^+) + A(B^+\to \bar{D}^0K^+) \\ \sqrt{2}A(B^-\to D_{CP+}^0K^-) = A(B^-\to D^0K^-) + A(B^-\to \bar{D}^0K^-) \end{cases}$$



$$\mathcal{A}_{CP\pm} \equiv \frac{\mathcal{B}(B^-\to D_{CP\pm}^0K^-) - \mathcal{B}(B^+\to D_{CP\pm}^0K^+)}{\mathcal{B}(B^-\to D_{CP\pm}^0K^-) + \mathcal{B}(B^+\to D_{CP\pm}^0K^+)} = \frac{\pm 2r_B \sin\delta_B \sin\phi_3}{\mathcal{R}_{CP\pm}}$$

r_D, δ_D is not needed

$$\mathcal{R}_{CP\pm} \equiv \frac{\mathcal{B}(B^-\to D_{CP\pm}^0K^-) + \mathcal{B}(B^+\to D_{CP\pm}^0K^+)}{\mathcal{B}(B^-\to D^0K^-) + \mathcal{B}(B^+\to \bar{D}^0K^+)} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\phi_3$$

where $r_B \equiv \frac{A(B^-\to \bar{D}^0K^-)}{A(B^-\to D^0K^-)}$, δ_B: strong phase difference

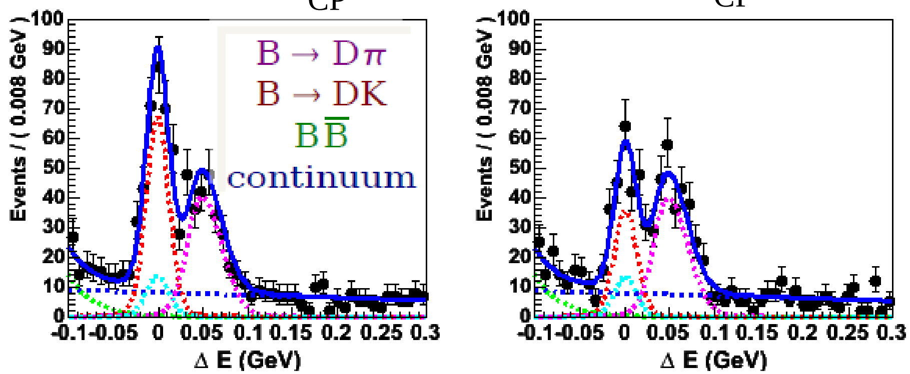
results in $B \rightarrow D_{CP+}K$

D_{CP+}:
KK, $\pi\pi$,...(CP even)

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

BELLE

772M$B\bar{B}$



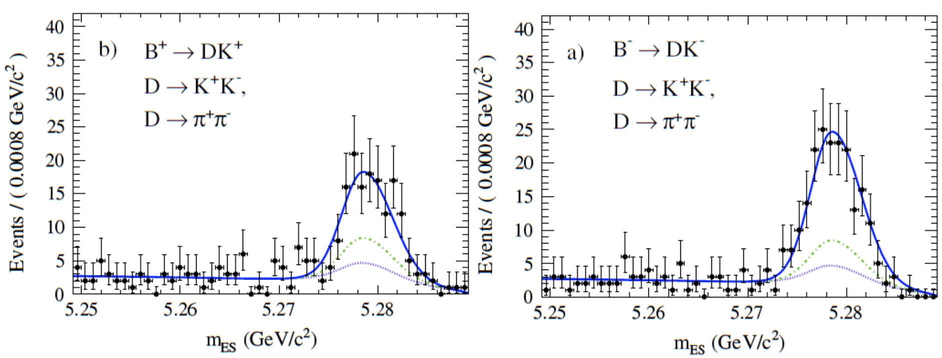
Belle preliminary

$$R_{CP+} = 1.03 \pm 0.07 \pm 0.03$$

$$A_{CP+} = 0.29 \pm 0.06 \pm 0.02$$

large CPV

467M$B\bar{B}$

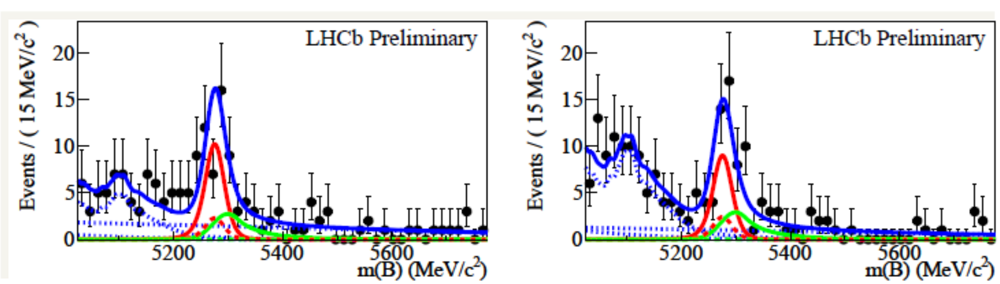


PRD82,072004(2010)

$$R_{CP+} = 1.18 \pm 0.09(\text{stat}) \pm 0.05(\text{syst}),$$

$$A_{CP+} = 0.25 \pm 0.06(\text{stat}) \pm 0.02(\text{syst}),$$

L=36pb^{-1}



LHCb Preliminary

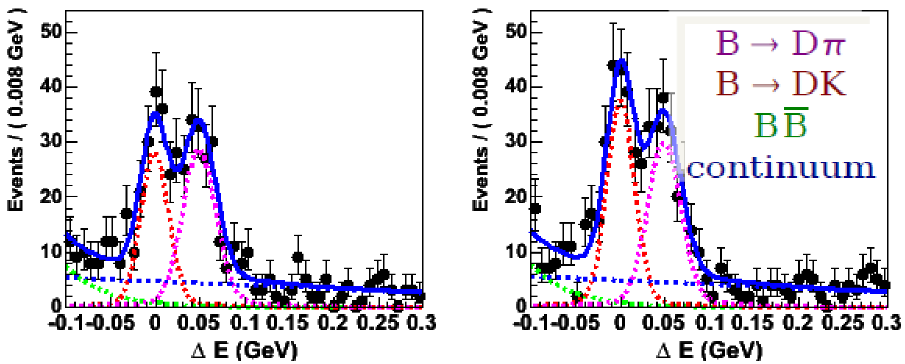
$$R_{CP+} = 1.48 \pm 0.31 \pm 0.12$$

$$A^{DK}_{CP+} = 0.07 \pm 0.18 \pm 0.07$$

results in $B \rightarrow D_{CP-}K$

D_{CP-}:
$K_S\pi^0$, $K_S\omega$, $K_S\phi$,..(CP odd)

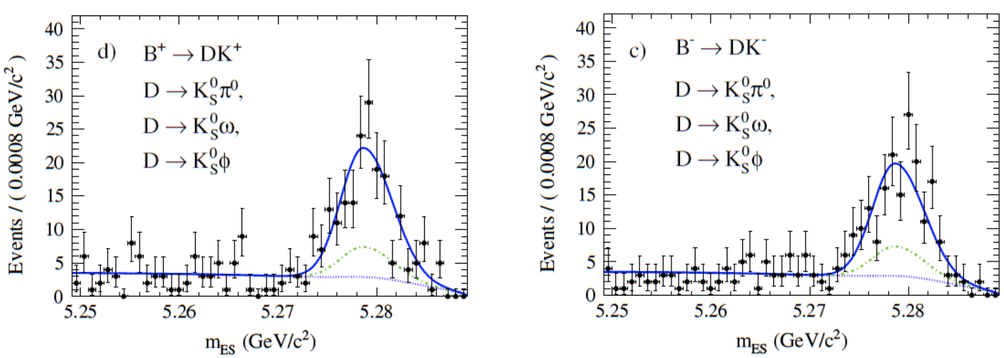
$B^- \rightarrow D_{CP}K^-$ $\quad$ $B^+ \rightarrow D_{CP}K^+$



Belle preliminary $\quad$ $772\text{M}B\bar{B}$

$$R_{CP-} = 1.13 \pm 0.09 \pm 0.05$$

$$A_{CP-} = -0.12 \pm 0.06 \pm 0.01$$

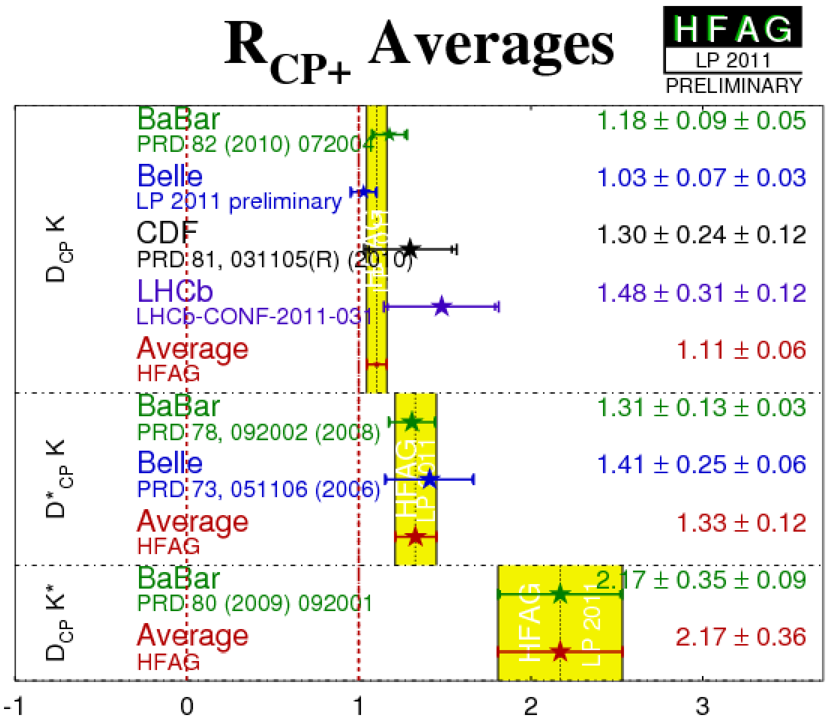


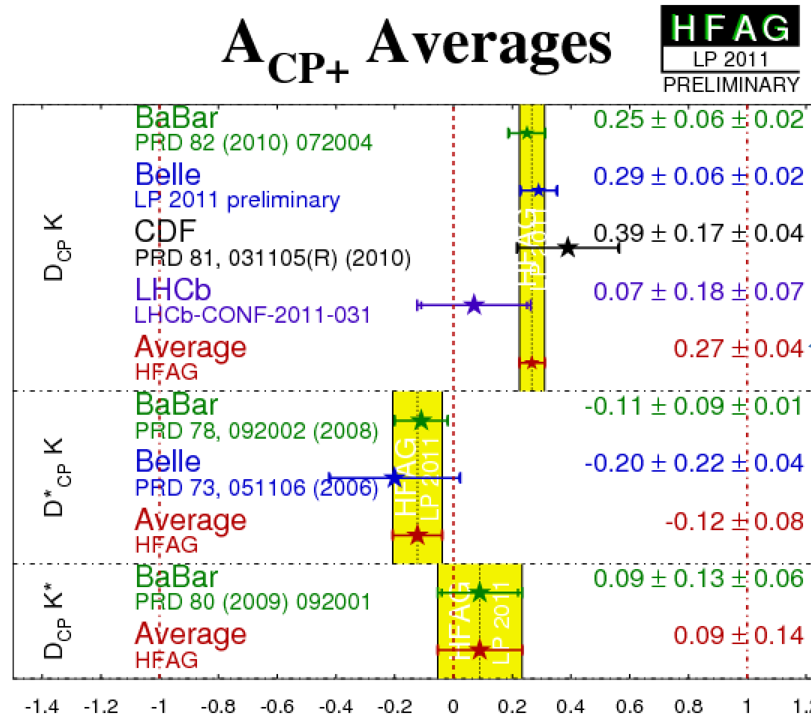
PRD82,072004(2010) $\quad$ $467\text{M}B\bar{B}$

$$R_{CP-} = 1.07 \pm 0.08(\text{stat}) \pm 0.04(\text{syst}).$$

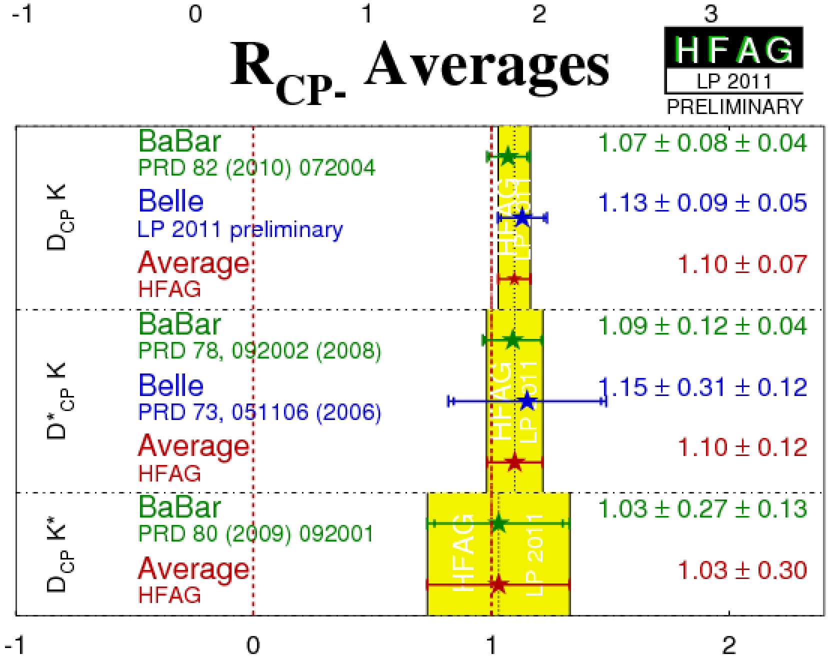
$$A_{CP-} = -0.09 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}),$$

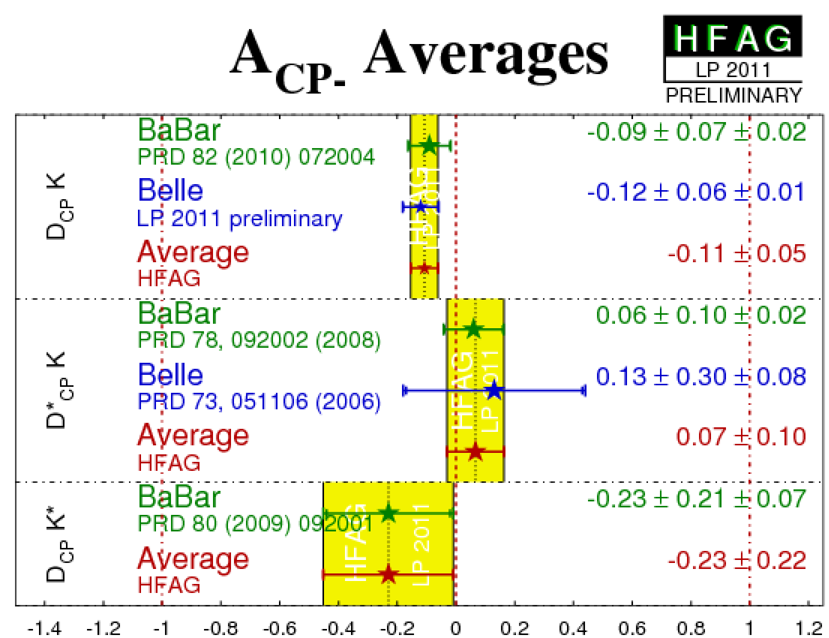
(sign of A_{CP-}) $\neq$ (sign of A_{CP+})





observation





ϕ_3 with GSSZ analysis

A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD 68, 054018 (2003)

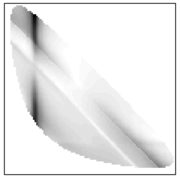
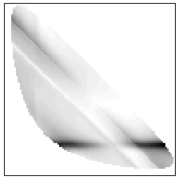
Dalitz plot(DP) analysis using $D \to K_S^0 \pi^+ \pi^-$ 3-body decay

$$\left|\tilde{D}\right\rangle = \left|D^0\right\rangle + r_B e^{i\theta} \left|\overline{D}^0\right\rangle \qquad \theta = \delta_B \pm \phi_3$$

$m_+ \equiv M_{Ksh+}, \quad m_- \equiv M_{Ksh-}$

Dalitz plot amp. $M_\pm(m_+, m_-)$:

$$M_\pm(m_+^2, m_-^2) = f(m_+^2, m_-^2) + r_B e^{\pm i\phi 3 + i\delta_B} f(m_-^2, m_+^2)$$

$=$  $+ r_B e^{\pm i\phi 3 + i\delta_B}$ 

$f(m_+^2, m_-^2)$ …consists of summing over the intermediate resonance amplitudes of $K_S h^+ (K_S h^-)$ at each fraction.

(Phase term $\delta_D(m_+, m_-)$ is based on model assumption)

PRD 81,112002(2010) 657M$B\overline{B}$

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

Combining the results for $B \to D^{(*)}K$

PRL 105, 121801(2010) 468M$B\overline{B}$

$\phi_3 = (68 \pm 14 \pm 4 \pm 3(\text{model}))^\circ$

Combining the results for $B \to D^{(*)}K^{(*)}$

At present, best measurements of ϕ_3.

Model-independent binned DP analysis

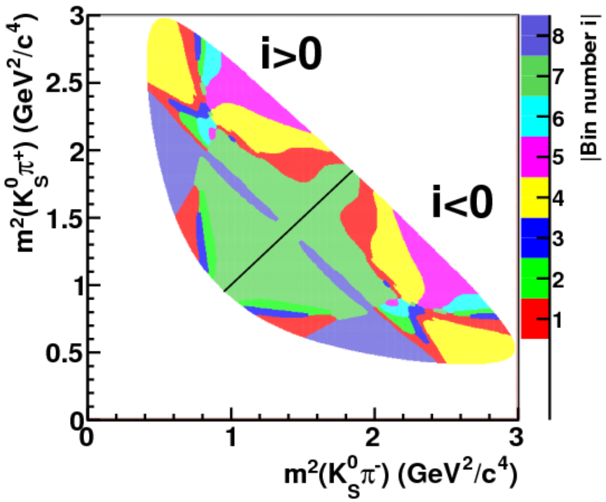
new

772M

Belle Preliminary

Model-independent optimal binned DP analysis

A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD 68, 054018 (2003)
A. Bondar, A.Poluektov, EPJ C 47, 347 (2006); EPJ C 55, 51 (2008)



$$M_i^{\pm} \equiv \iint_{Area_i} |M_{\pm}(m_+, m_-)|^2 dm_+ dm_+$$

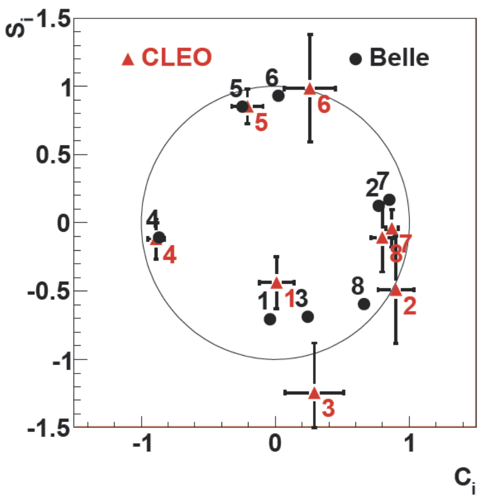
$$M_{\pm}(m_+^2, m_-^2) = f(m_+^2, m_-^2) + r_B e^{\pm i\phi 3 + i\delta B} f(m_-^2, m_+^2)$$

$$M_i^{\pm} = h\{K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_{\pm} c_i + y_{\pm} s_i)\}$$

$M_i^{\pm}$: numbers of events in $D \to K_S^0 \pi^+ \pi^-$ bins from $B^{\pm} \to DK^{\pm}$

$x_{\pm} = r_B \cos(\delta_B \pm \phi_3) \quad y_{\pm} = r_B \sin(\delta_B \pm \phi_3)$

K_i: numbers of events in bins of flavor $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ from $D^* \to D\pi$.



ci, si contain information about strong phase difference between symmetric Dalitz plots (m_+, m_-) and (m_-, m_+)

$$c_i = \langle \cos\Delta\delta_D \rangle, s_i = \langle \sin\Delta\delta_D \rangle$$

→ estimated from quantum correlations between D^0 and $\overline{D}^0$ in $\psi(3770) \to D^0\overline{D}^0$ decays
CLEO collaboration, PRD 82, 112006 (2010)

⇒ No model uncertainty

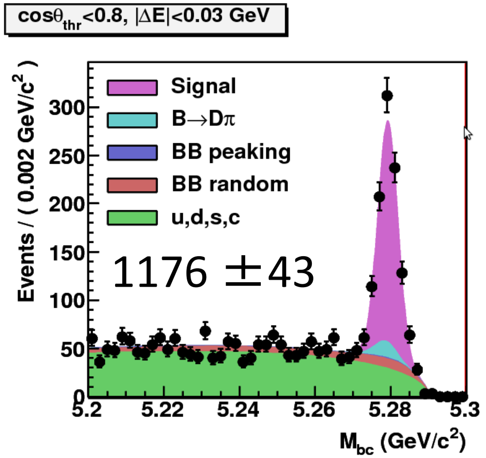
Model-independent Binned DP yield and plot

new

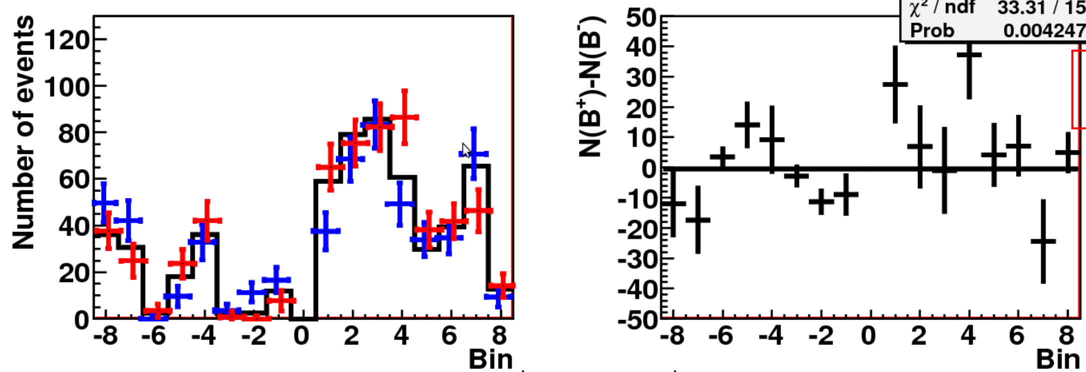
772MB$\overline{\text{B}}$

Belle Preliminary

$B^{\mp}\to D^0K^{\mp}$,$D^0\to K_S\pi\pi$



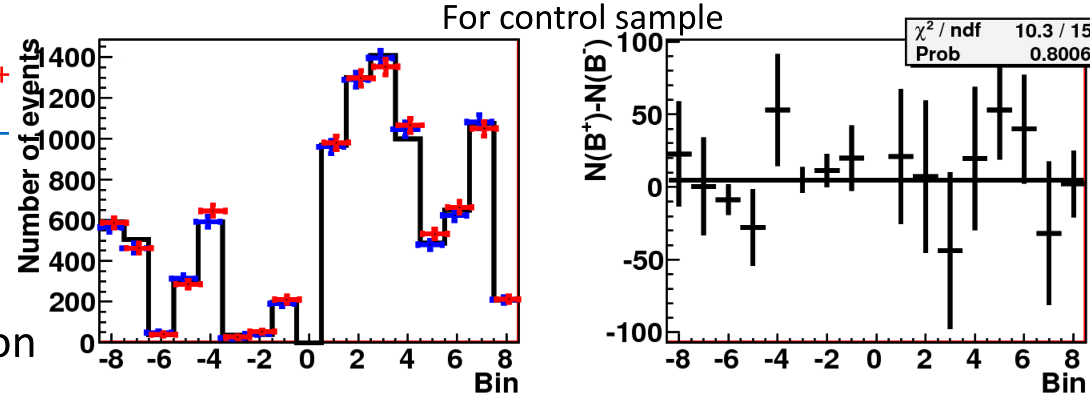
$B^{\pm}\to DK^{\pm}$



not flat

$B^{\pm}\to D\pi^{\pm}$

For control sample



- Using reprocessed data.
- Signal selection optimization

→Eff. increased ~55%

$\phi_3=(77.3^{+15.1}_{-14.9}\pm4.2\pm4.3(c_i,s_i))^\circ$

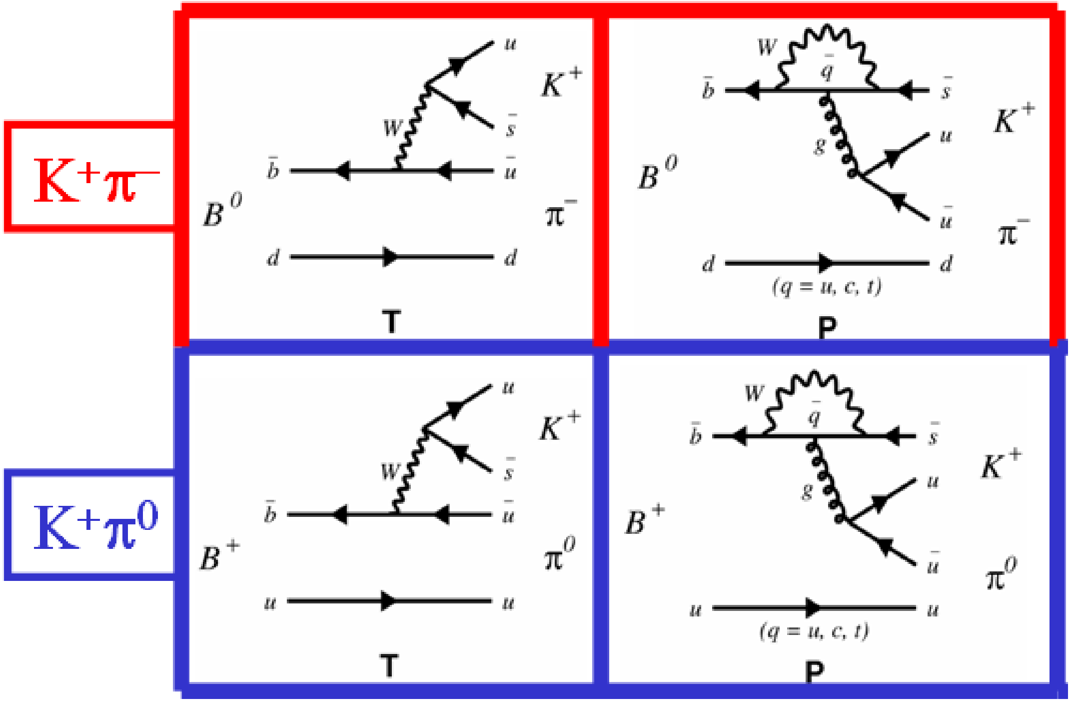
$r_B=0.145\pm0.030\pm0.011\pm0.011$

$\delta_B=(129.9\pm15.0\pm3.9\pm4.7)^\circ$

3rd errors are came from uncertainty of c_i and s_i

→ improved by charm-factory results

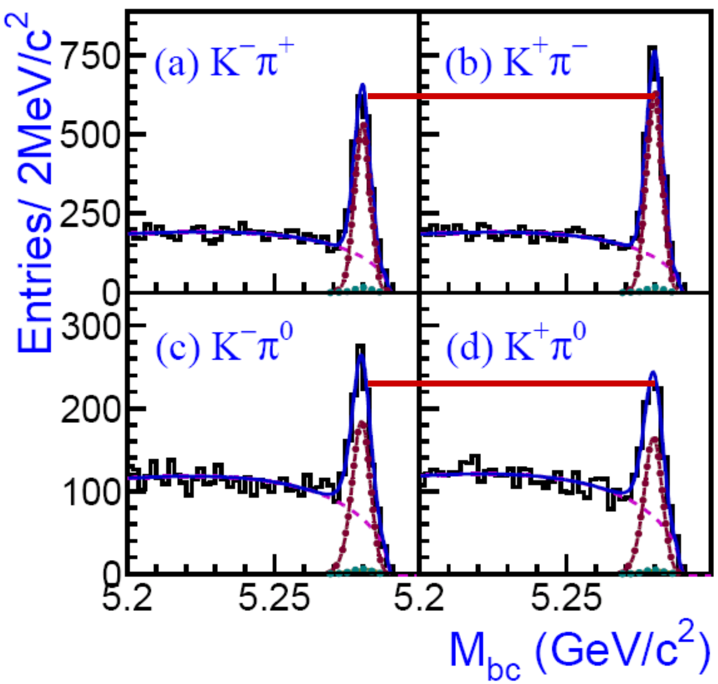
$\Delta A_{K\pi}$ puzzle



$$\Delta A_{K\pi} = A_{cp}(K^+\pi^-) - A_{cp}(K^+\pi^0) = 0?$$

$\Delta A_{K\pi}$ Puzzle in 2010

Belle Results: Nature 452, 332 (2008)



$A_{cp}(K^+\pi^-) =$

$-0.107 \pm 0.016 ^{+0.006}_{-0.004}$	BaBar
$-0.094 \pm 0.018 \pm 0.008$	Belle
$-0.086 \pm 0.023 \pm 0.009$	CDF
$-0.04 \pm 0.16 \pm 0.02$	CLEO

$\Rightarrow -0.098^{+0.012}_{-0.011}$ @ 8.1σ AVG

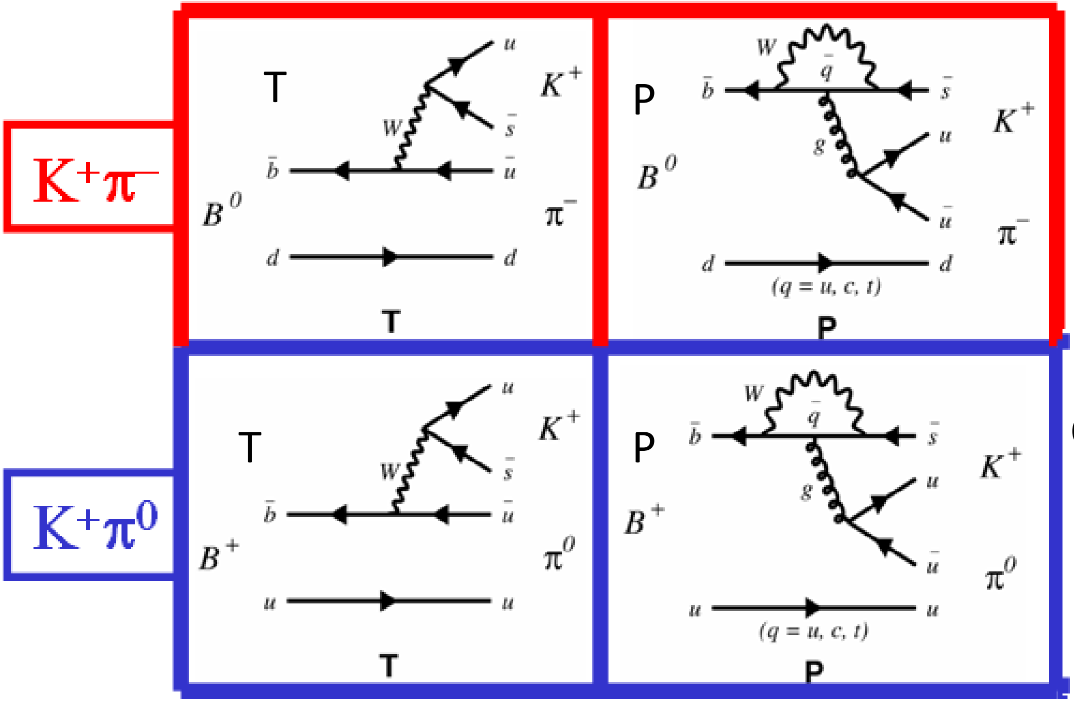
$A_{cp}(K^+\pi^0) =$

$+0.030 \pm 0.039 \pm 0.010$	BaBar
$+0.07 \pm 0.03 \pm 0.01$	Belle
$-0.29 \pm 0.23 \pm 0.02$	CLEO

$\Rightarrow +0.050 \pm 0.025$ @2.0σ AVG

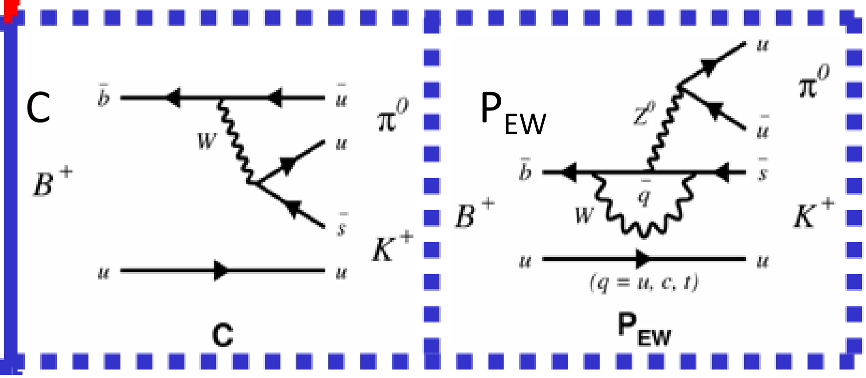
$\Delta A_{K\pi} = A_{cp}(K^+\pi^-) - A_{cp}(K^+\pi^0)$
$= -0.147 \pm 0.028$ @ 5.3σ

Solutions to the $\Delta A_{K\pi}$ Puzzle



Expectation from current theory

T & P are dominant $\Rightarrow \Delta A_{K\pi} \sim 0$

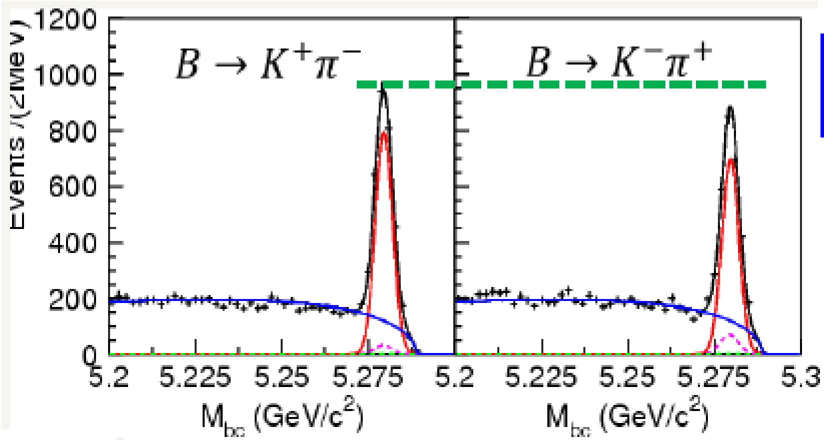


- Enhancement of large C with large strong phase to T
$\Rightarrow$ strong interaction !?

Chiang et. al. 2004
Li, Mishima & Sanda 2005

- Enhancement of large P_{EW}
$\Rightarrow$ New physics

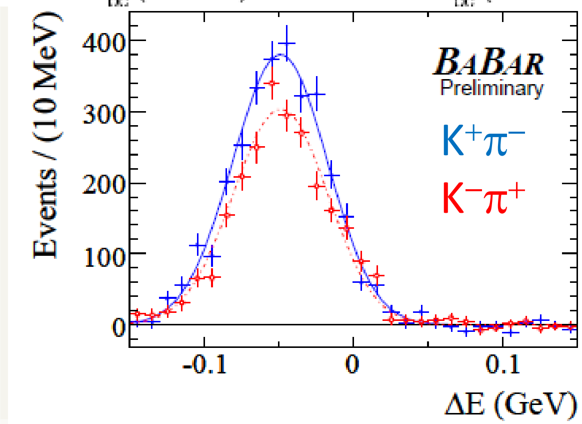
Yoshikawa 2003; Mishima & Yoshikawa 2004;
Buras et. al. 2004, 2006; Baek & London 2007;
Hou et. al. 2007; Feldmann, Jung & Mannel 2008



Belle preliminary

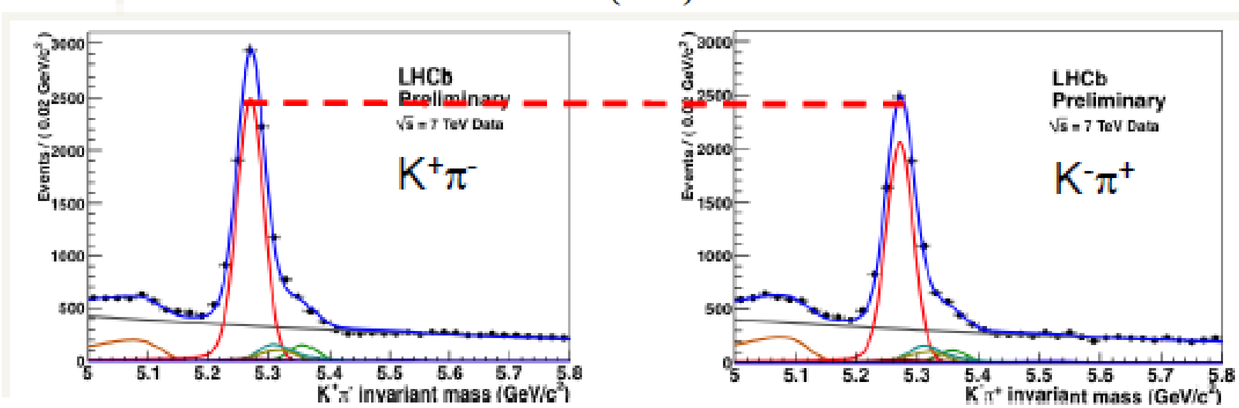
772MB$\bar{B}$

$A_{CP}(K^+\pi^-) = -0.069 \pm 0.014 \pm 0.007$



arXiv:0807.4226 467MB$\bar{B}$

$A_{CP}(K^+\pi^-) = -0.107 \pm 0.016^{+0.006}_{-0.004}$

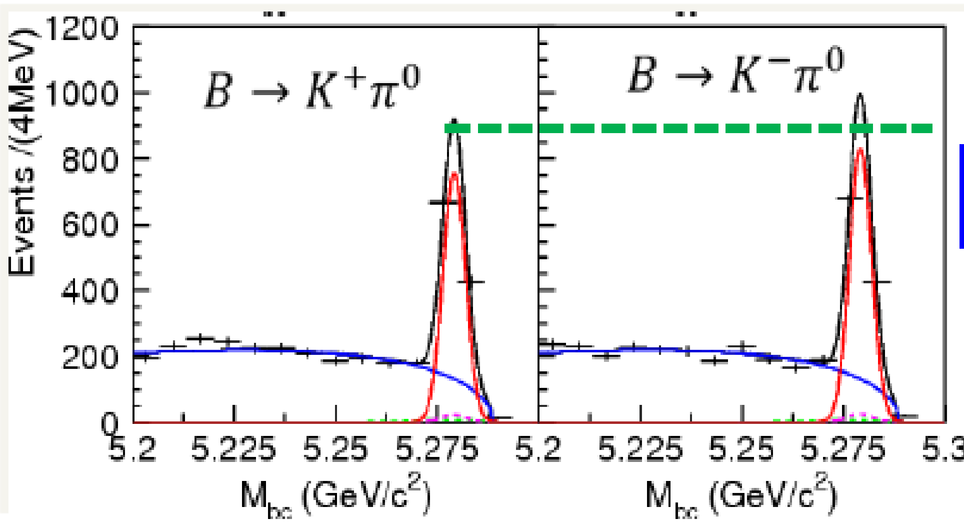


L=320pb^{-1}

LHCb Preliminary

$$A_{CP}(B^0 \to K^+\pi^-) = -0.088 \pm 0.011(\text{stat}) \pm 0.008(\text{syst})$$

$A_{cp}(K^+\pi^0)$ results



Belle preliminary 772MB$\bar{B}$

$A_{CP}(K^+\pi^0)=+0.043\pm0.024\pm0.002$

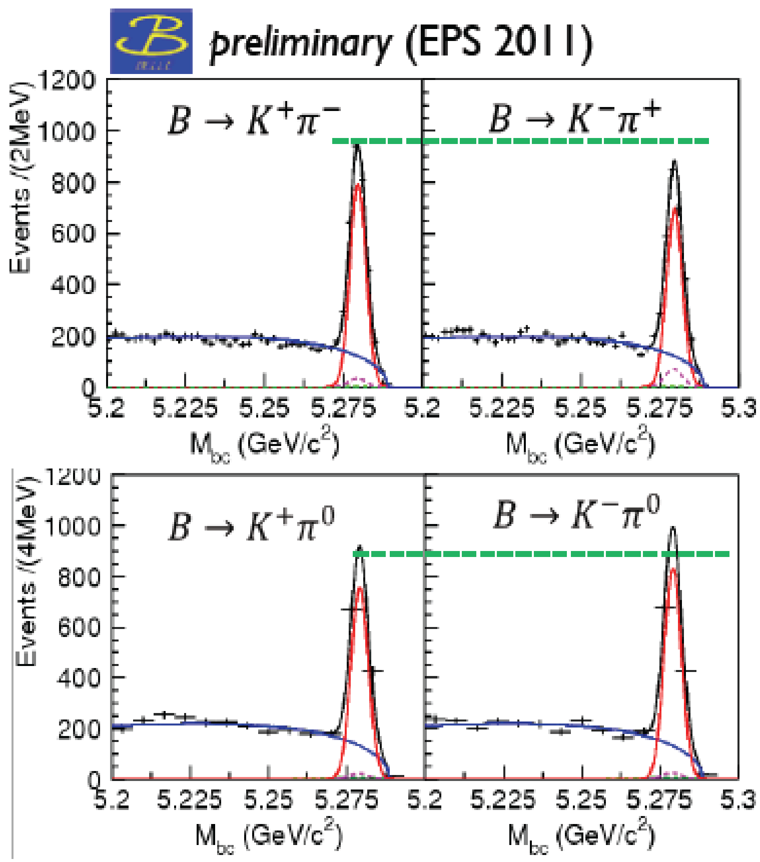
Phys.Rev. D76 (2007) 091102

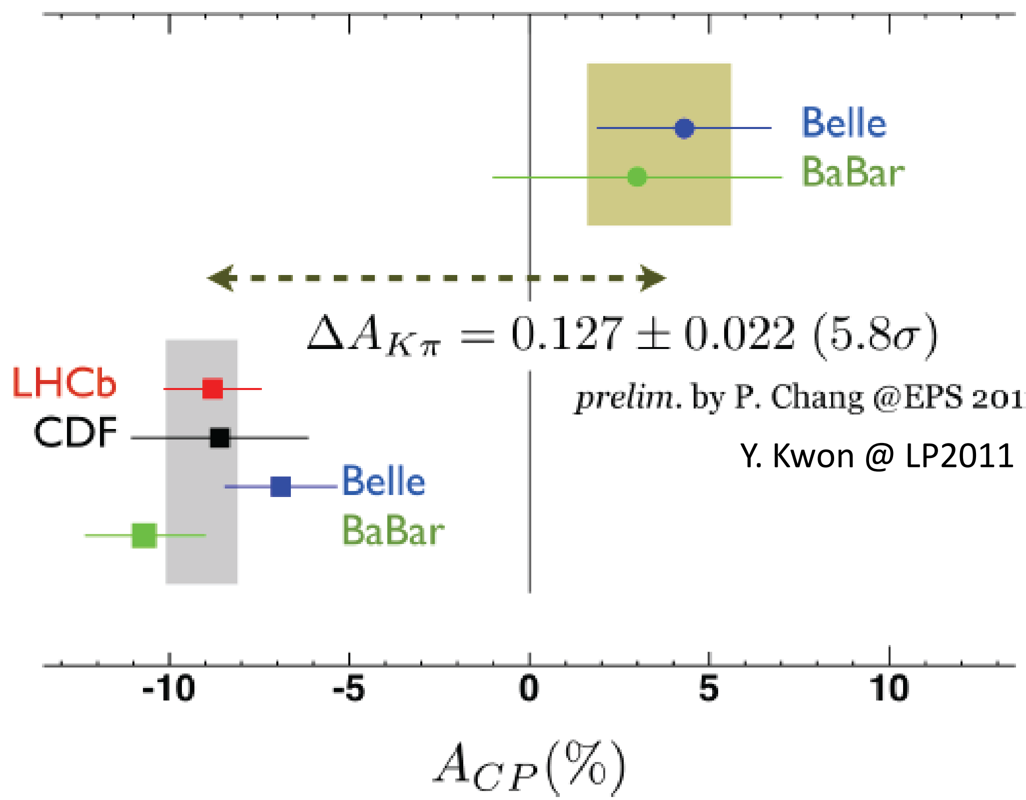
383MB$\bar{B}$

$A_{cp}(K^+\pi^0) = +0.030\pm 0.039\pm 0.010$

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

updated $\Delta A_{K\pi}$

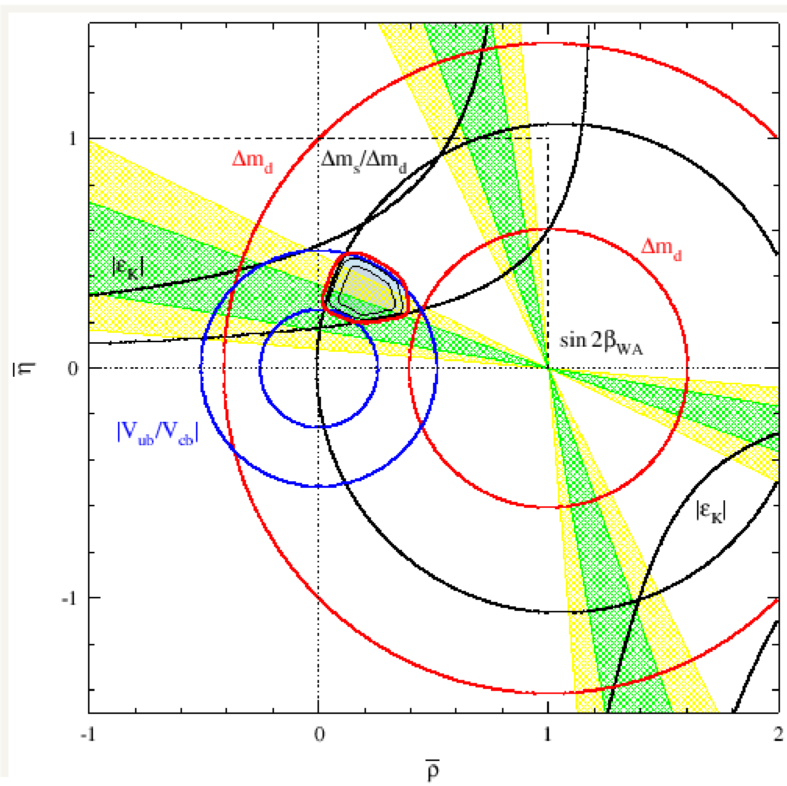




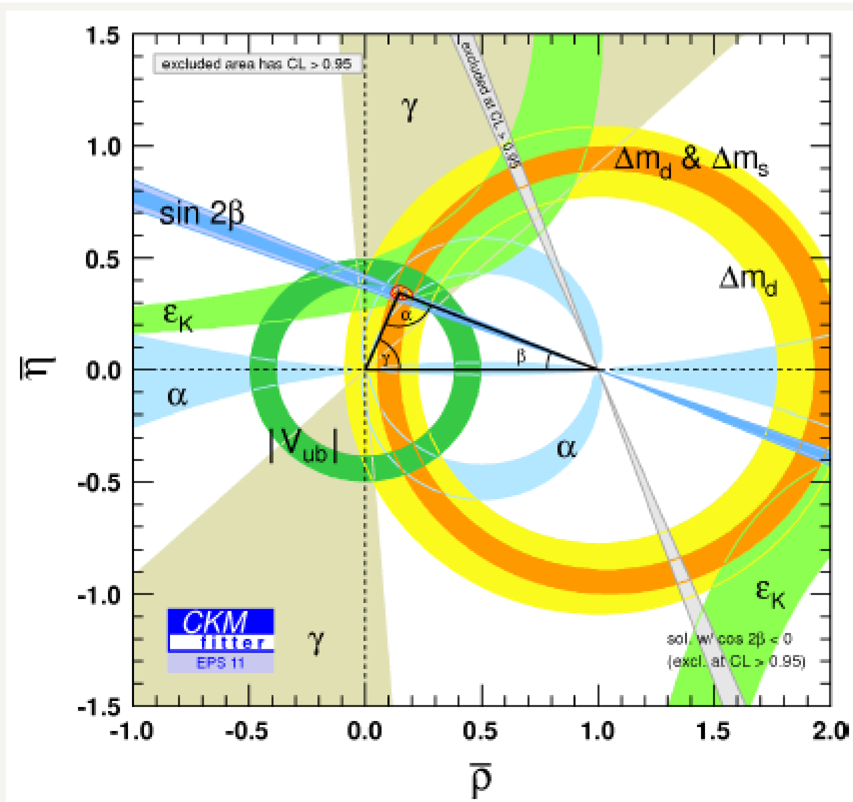
summary

- B-factory experiments played a critical role to verify SM.

2001 May



EPS2011 (not update ϕ_3/γ)



summary

- We measured various CP parameters, BRs for rare decays, etc.
  There are some puzzles and hints.
  CPV in $b \rightarrow sqq$, $\Delta A_{K\pi}$ puzzle, BR of $B \rightarrow \tau\nu$, …

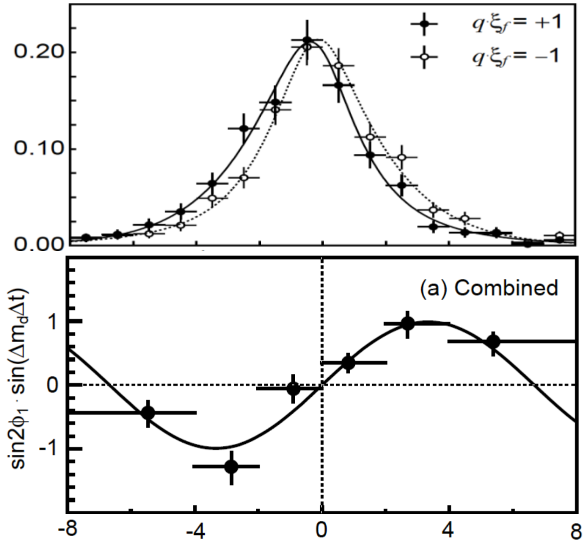
- We need much more luminosity to clearly see the effects of new physics; O(0.1) correction to SM.

backup

Bs meson

$\sin 2\phi_1$ measurement in 2001

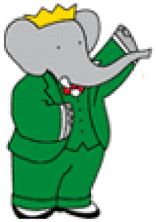
Belle

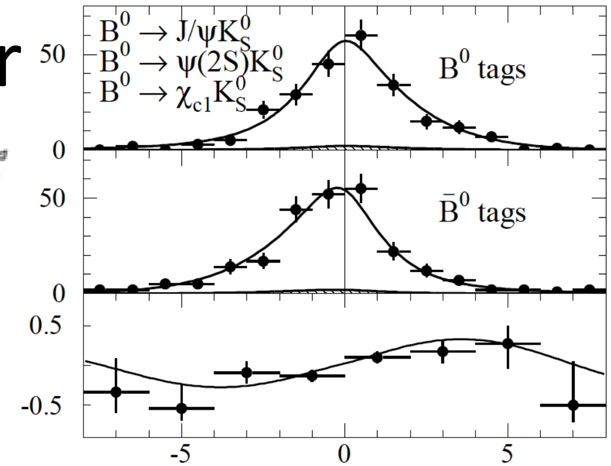


$$\sin 2\phi_1 = +0.99 \pm 0.14 \pm 0.06$$

@29.1 fb^{-1}

BaBar





$$\sin 2\phi_1 = +0.59 \pm 0.14 \pm 0.05$$

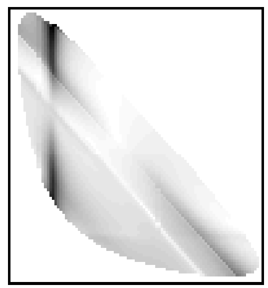
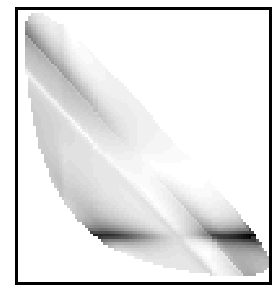
@23M $B\bar{B}$ pairs

Critical Role of the B factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation

Determination of ϕ_3/γ via CP asymmetries in Dalitz plots of $B \to D\,K$ modes, with $D \to K_S \pi^+ \pi^-$

Use $B^\pm \to D^{(*)}K^{(*)\pm}$ modes with 3-body decay $D \to K_S\pi^+\pi^-$.
Dalitz plot density: $d\sigma_\pm(m_+^2, m_-^2) \sim |M_\pm|^2 dm_+^2 dm_-^2$

$$|M_\pm(m_+^2, m_-^2)|^2 = |f_D(m_+^2, m_-^2) + re^{i\delta_B \pm i\phi_3} f_D(m_-^2, m_+^2)|^2$$

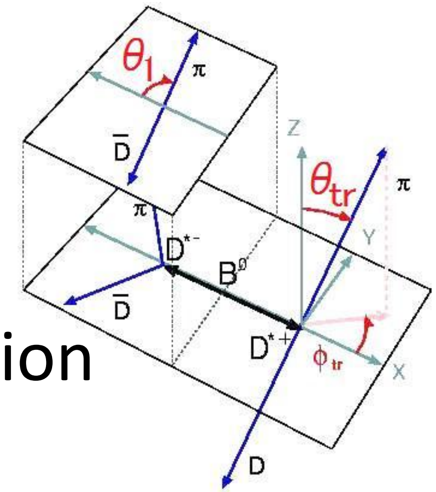
$= \Big|$  $+ re^{i\delta_B \pm i\phi_3}$  $\Big|^2$

$\overline{D}^0 \to K_S^0\pi^+\pi^-$ amplitude f_D is extracted from continuum ($D^{*\pm} \to D\pi^\pm$), parametrized as a set of two-body amplitudes.

Only $|f_D|^2$ is observable $\Rightarrow$ Model dependence as a result.

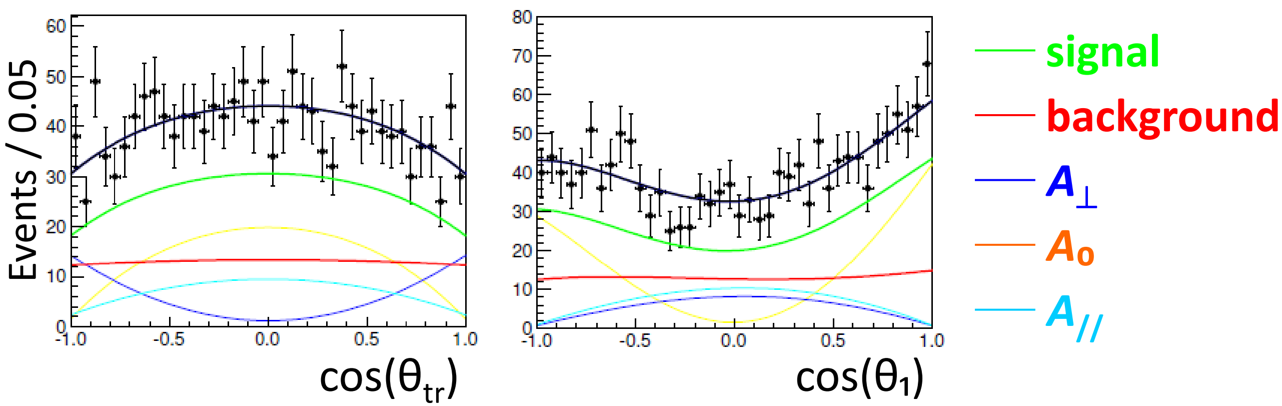
Fit variables: $x_\pm = r\cos(\delta_B \pm \phi_3)$, $y_\pm = r\sin(\delta_B \pm \phi_3)$.

CPV in $B^0 \to D^{*+}D^{*-}$



- Angular analysis is needed to access the CPV in the $P \to VV$ decay
  - Distributions of θ_{tr} and θ_1 give polarization amplitude ratios, R_0 and $R_\perp$.
  - We determine S, A, R_0, and $R_\perp$ simultaneously by a fit to 5-dimensional (Δt, $\cos(\theta_{tr})$, $\cos(\theta_1)$, ΔE, M_{bc}) distribution.

MC simulation



MC-simulated $\cos(\theta_{tr})$ and $\cos(\theta_1)$ distributions with input values of R_0=0.55 and $R_\perp$=0.16 together with fitted curves.

CPV in $B^0 \to D^{*+}D^{*-}$

- Fit result of S, A, R_0, and $R_\perp$

$$S = -0.79 \pm 0.13 \pm 0.03$$

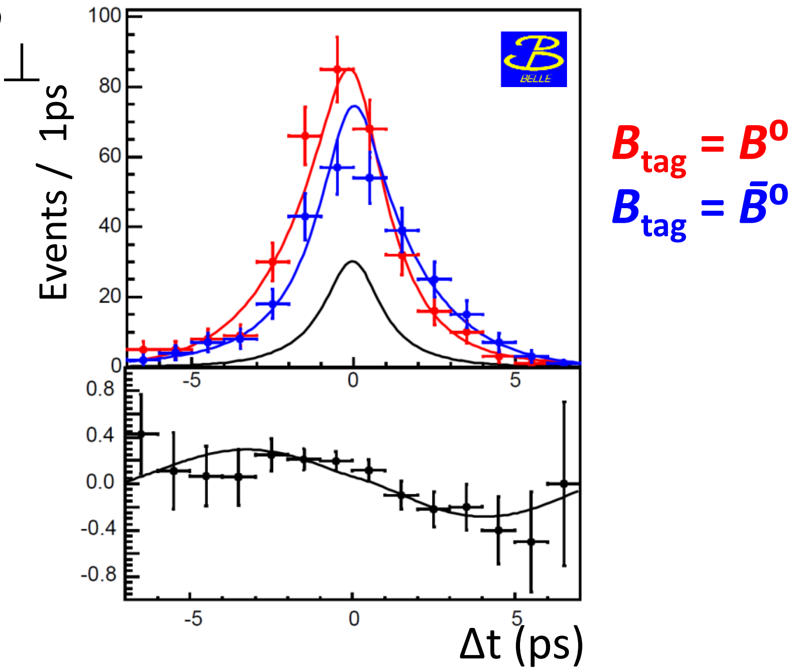
$$A = +0.15 \pm 0.08 \pm 0.02$$

$$R_0 = 0.62 \pm 0.03 \pm 0.01$$

$$R_\perp = 0.14 \pm 0.02 \pm 0.01$$

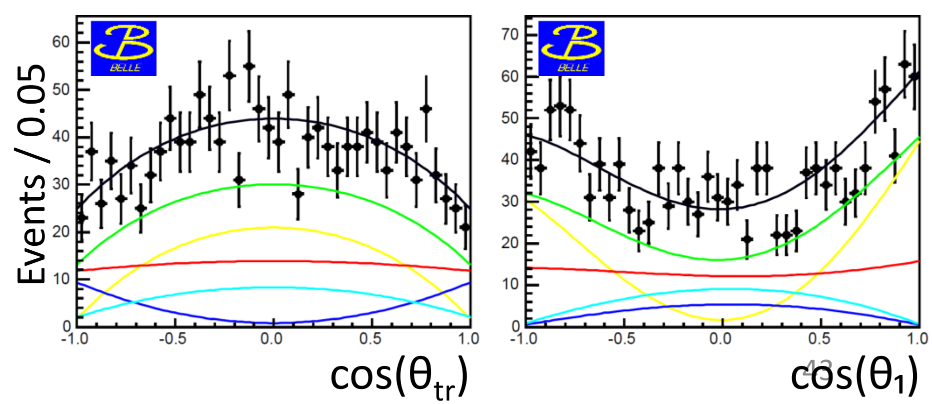
772 x 10^6 $B\bar{B}$ pairs

Belle preliminary



Sources of systematic errors

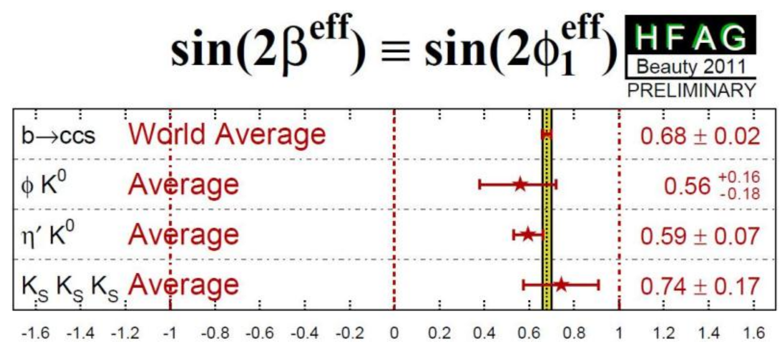
Category	δS	δA	$\delta(R_0)$	$\delta(R_\perp)$
Vertexing	±0.019	±0.021	±0.004	±0.004
Flavor tagging	±0.004	±0.003	< 0.001	< 0.001
Vertex resolution	±0.020	±0.004	±0.001	±0.001
Physics parameters	±0.004	±0.001	±0.001	< 0.001
Fit model	±0.002	< 0.001	±0.005	±0.002
Tag-side interference	±0.001	±0.008	< 0.001	< 0.001
Polarization recon. eff.	< 0.001	< 0.001	±0.002	±0.001
Total	±0.028	±0.023	±0.007	±0.005



Toward SuperKEKB / Belle II

- We are to start SuperKEKB from 2014.
  - x40 luminosity accelerator ($8 \times 10^{35}/cm^2s$), SuperKEKB.
  - More hermetic, granular, and faster signal detector, Belle II.
  - The final integrated luminosity will be $50ab^{-1}$.
- We hunt for new physics at the luminosity-frontier.
  - So far we have found several hints of NP.
  - These hints will be investigated further at SuperKEKB/Belle II.

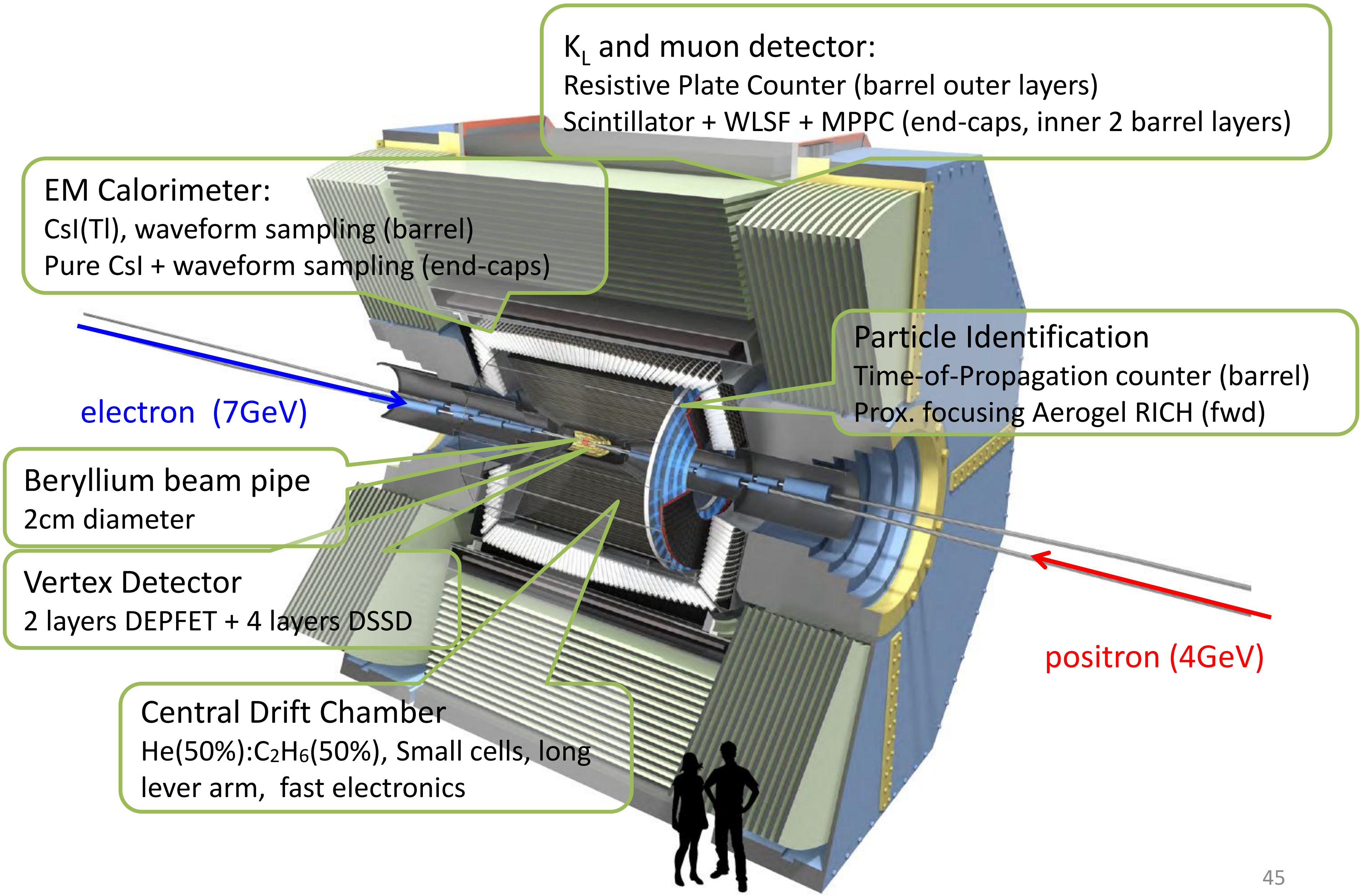
Present status



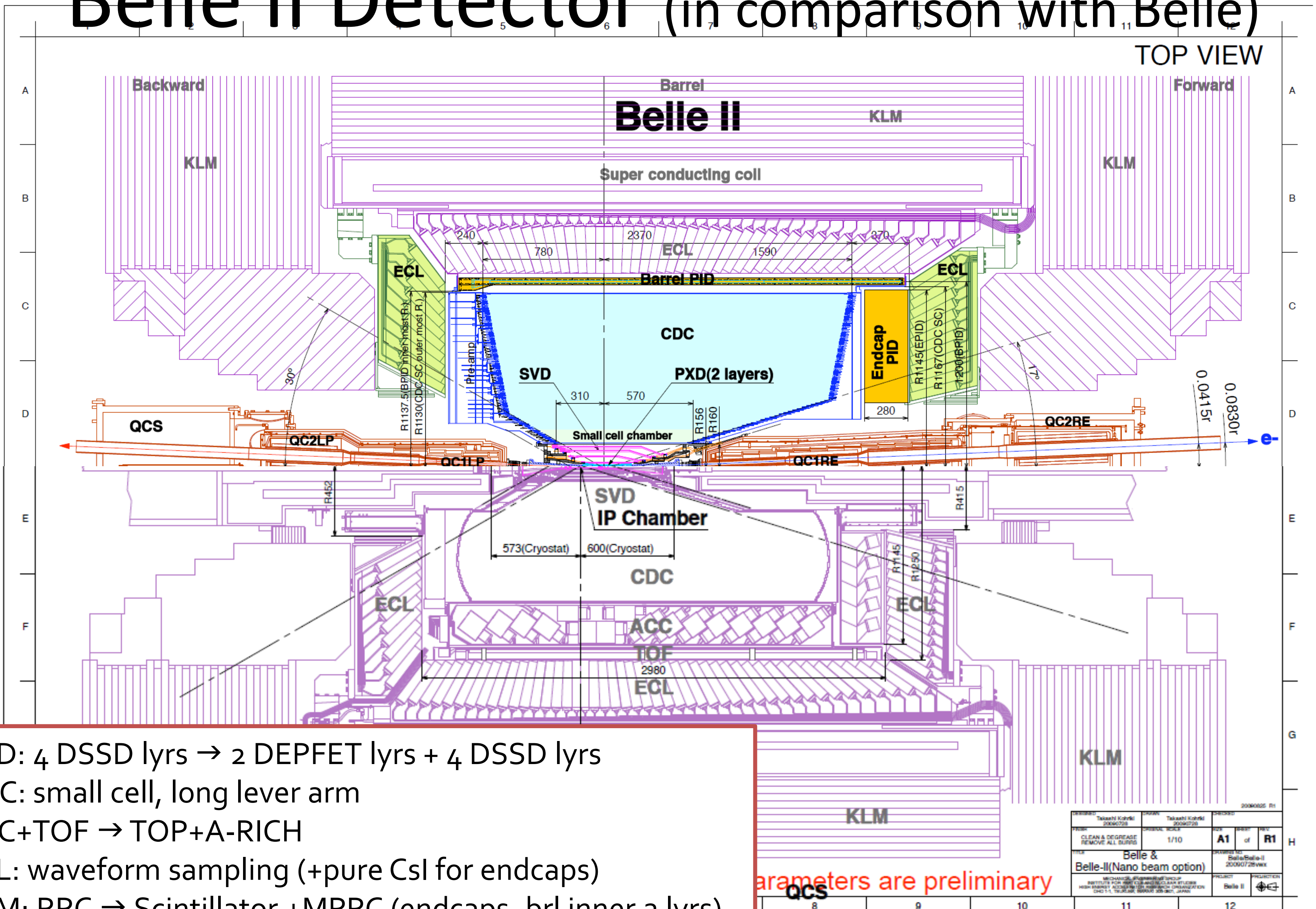
Future prospects of Belle II

Mode	$5\ ab^{-1}$		$50\ ab^{-1}$	
	δS	δA	δS	δA
$B^0 \to \phi K_S^0$	0.073	0.049	0.029	0.018
$B^0 \to \eta' K_S^0$	0.038	0.026	0.020	0.012
$B^0 \to K_S^0 K_S^0 K_S^0$	0.105	0.067	0.037	0.024

Belle II Detector



Belle II Detector (in comparison with Belle)



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, brl inner 2 lyrs)