CP violation in the B system

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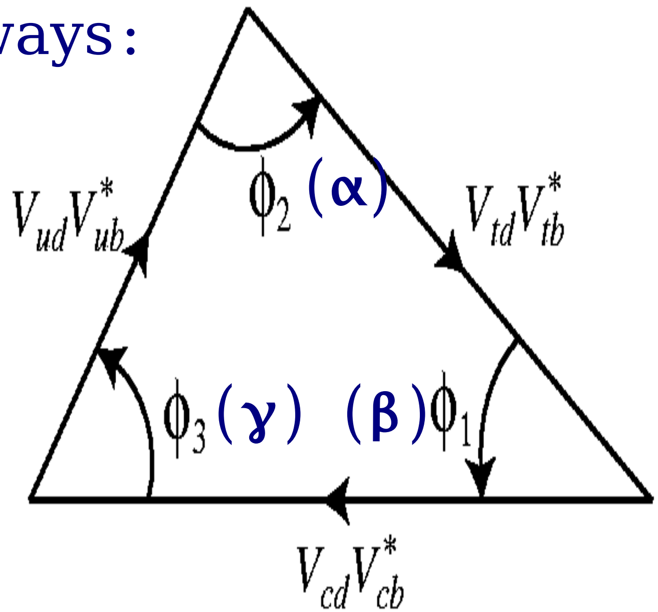
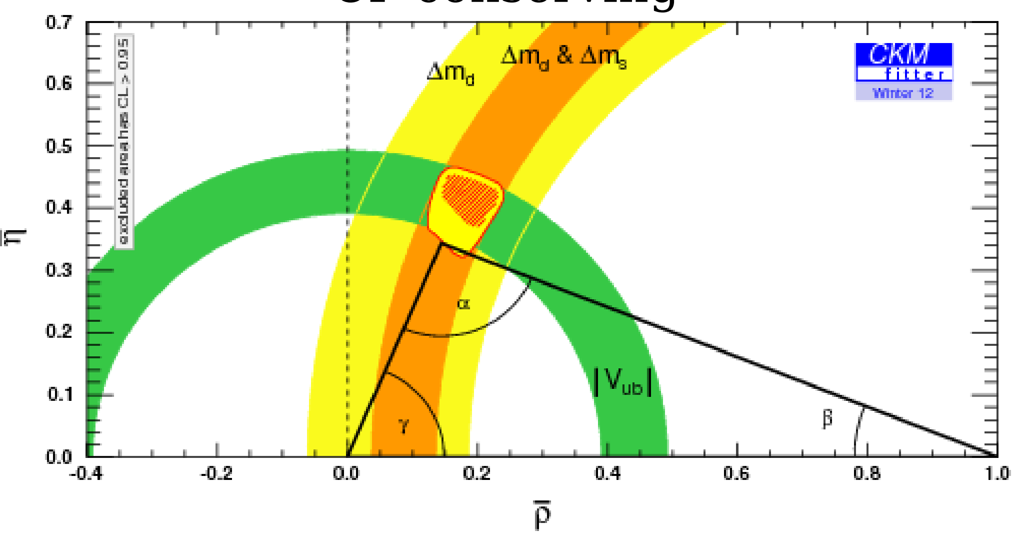
Flavor Physics and CP Violation, May 22, 2012

Main motivation…

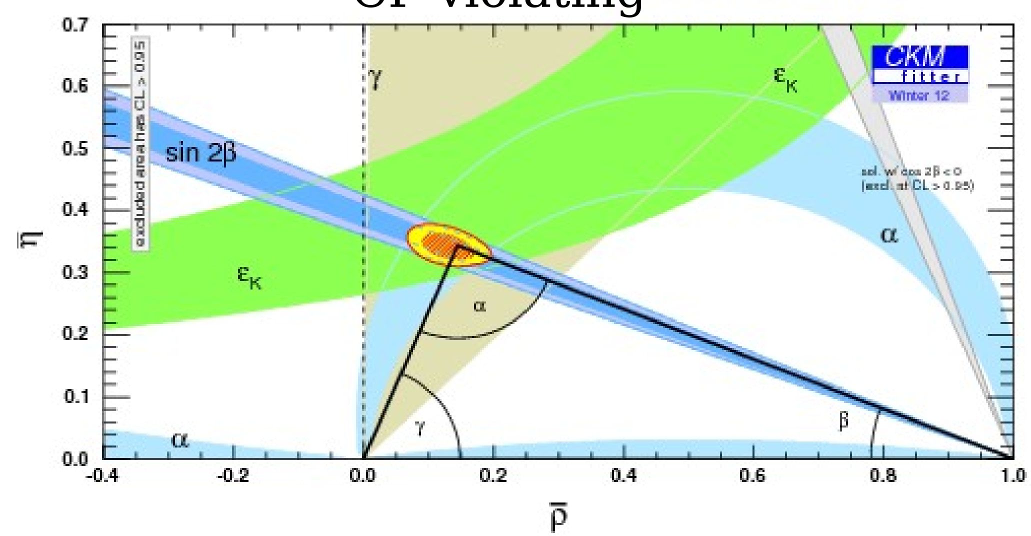
- Overconstrain the CKM matrix: measure fundamental parameters, constrain new physics effects
- Measure the 4 free paremeters in various ways:
  - CP conserving $\{|V_{us}|, |V_{cb}|, |V_{td}|, |V_{ub}|\}$
  - CP violating $\{\epsilon_K, \phi_s, \beta, \gamma\}$
  - Tree level $\{\ldots, \ldots, |V_{ub}|, \gamma\}$
  - Loop level $\{\ldots, \ldots, |V_{td}|, \beta\}$
  - …



CP conserving

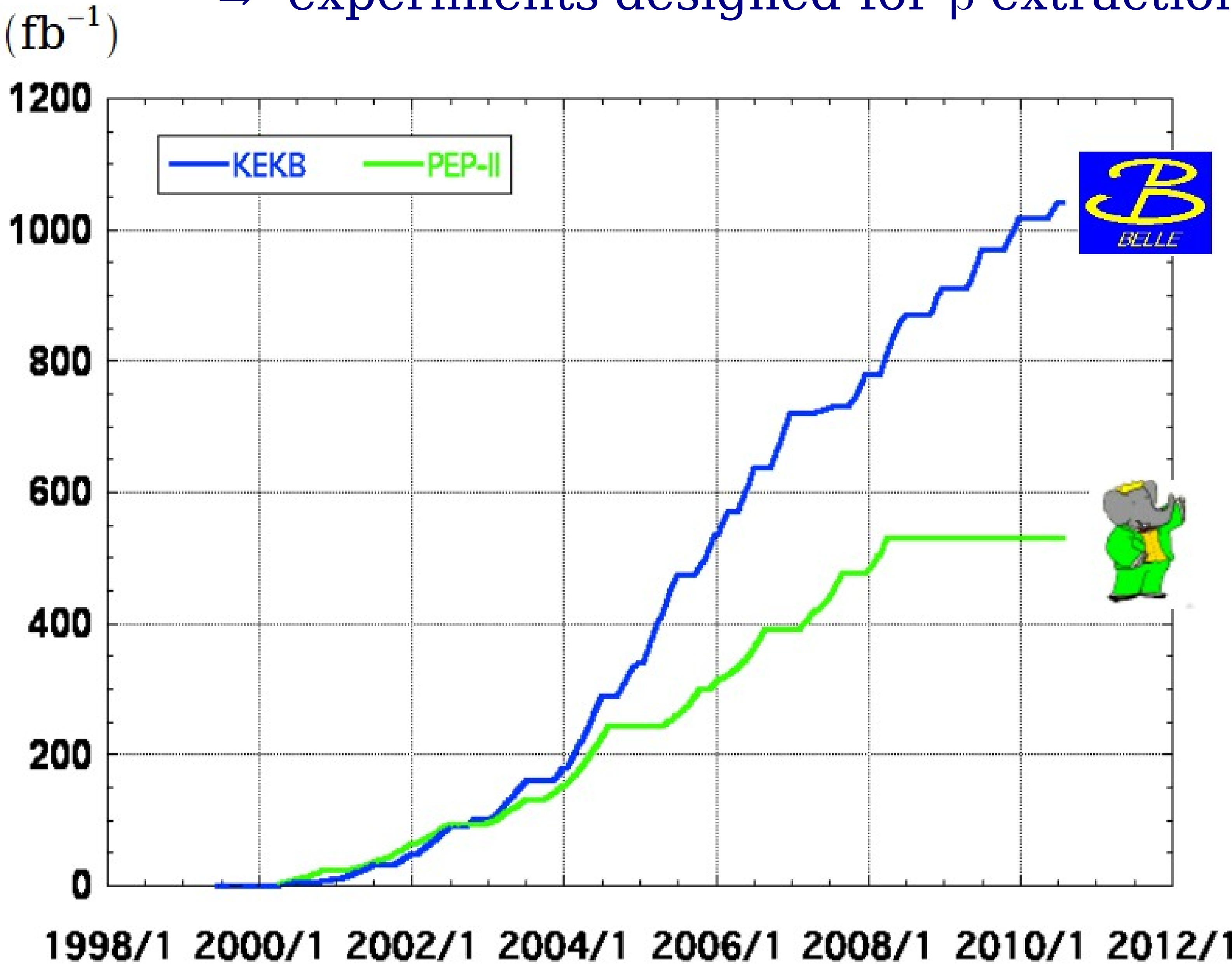


CP violating



B factories: BaBar and Belle

$\Rightarrow$ experiments designed for β extraction !



$> 1\ \mathrm{ab}^{-1}$

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:

~ 100 fb^{-1}

$\sim 550\ \mathrm{fb}^{-1}$

On resonance:

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

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

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

Off resonance:

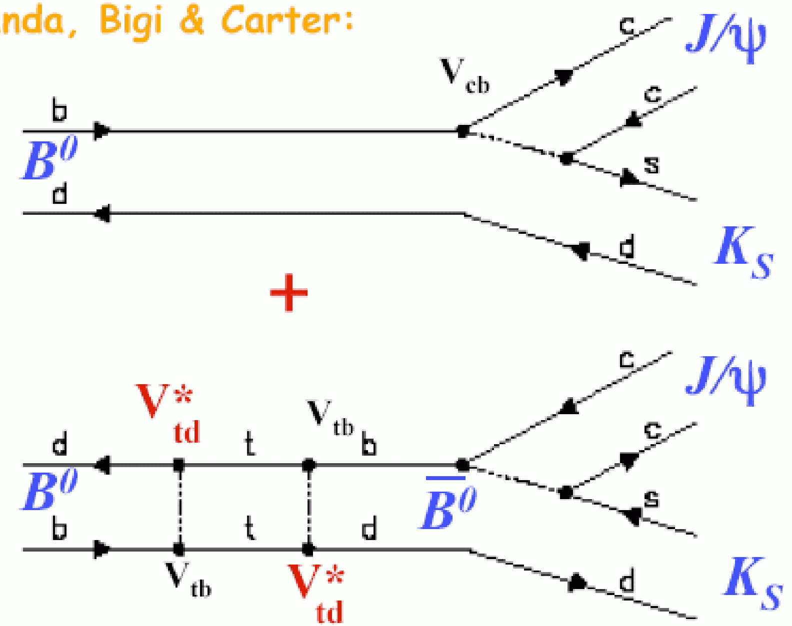
~ 54 fb^{-1}

final samples $\begin{cases} \textbf{BaBar: } 467 \times 10^6\, B\bar{B} \textbf{ pairs} \\ \textbf{Belle: } 772 \times 10^6\, B\bar{B} \textbf{ pairs} \end{cases}$

Time−dependent CP asymmetries in decays to CP eigenstates

$\sin 2\phi_1$ from $B \to f_{CP} + B \leftrightarrow \overline{B} \to f_{CP}$ interf.

Sanda, Bigi & Carter:



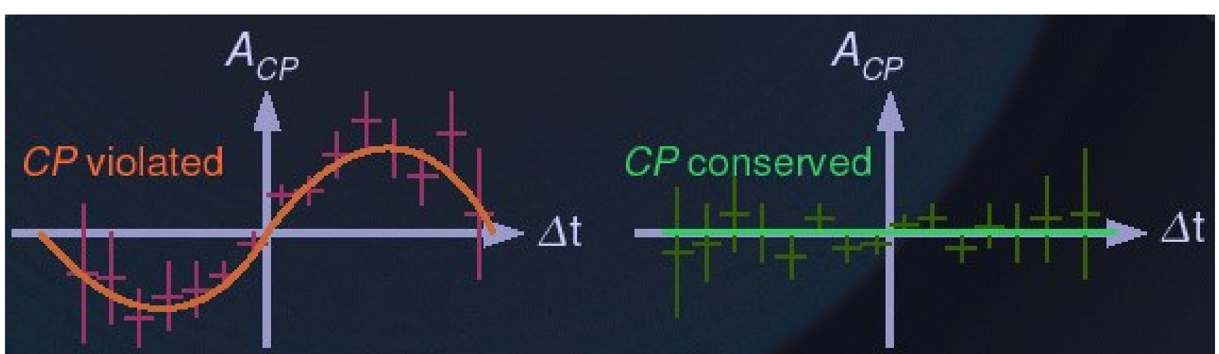
$$A_{CP}(f;t) = \frac{N(\overline{B}^0(t)\to f) - N(B^0(t)\to f)}{N(\overline{B}^0(t)\to f) + N(B^0(t)\to f)}$$

$$= \mathbf{S} \sin\Delta m_d t + \mathbf{A} \cos\Delta m_d t$$

$$= \frac{2\,\mathrm{Im}\,\lambda}{|\lambda|^2+1} \sin\Delta m_d t + \frac{|\lambda|^2-1}{|\lambda|^2+1} \cos\Delta m_d t$$

$$\lambda = \frac{q}{p}\,\frac{A(\overline{B}^0 \to f)}{A(B^0 \to f)} = e^{-i2\phi_i}\frac{\overline{A}_f}{A_f}$$

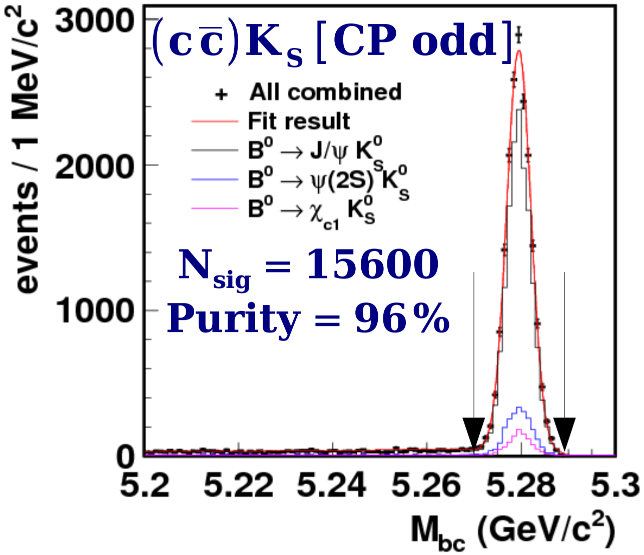
- $\mathbf{A} = 0$ and $\mathbf{S} = -\xi_f \sin 2\beta$ for $(c\bar{c})K_{S/L}$ $(\xi_f = \mp 1)$
- $\mathbf{A} = 0$ and $\mathbf{S} = \sin 2\alpha$ for $\pi^+\pi^-$ (if tree only)

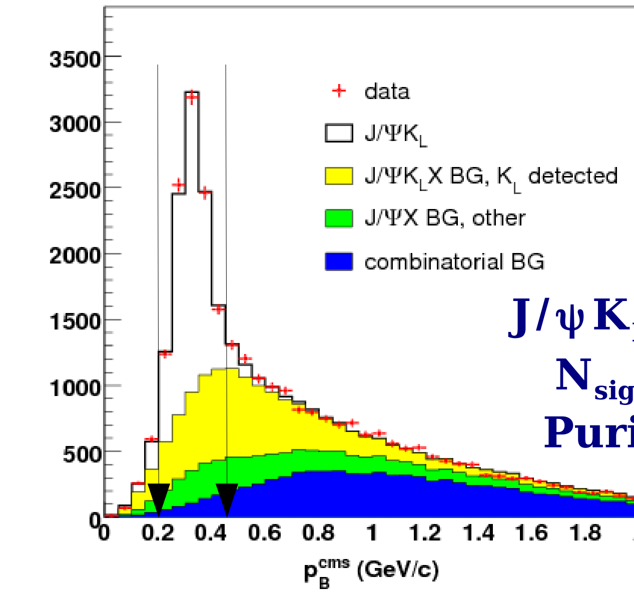


$$\mathbf{C = -A}$$

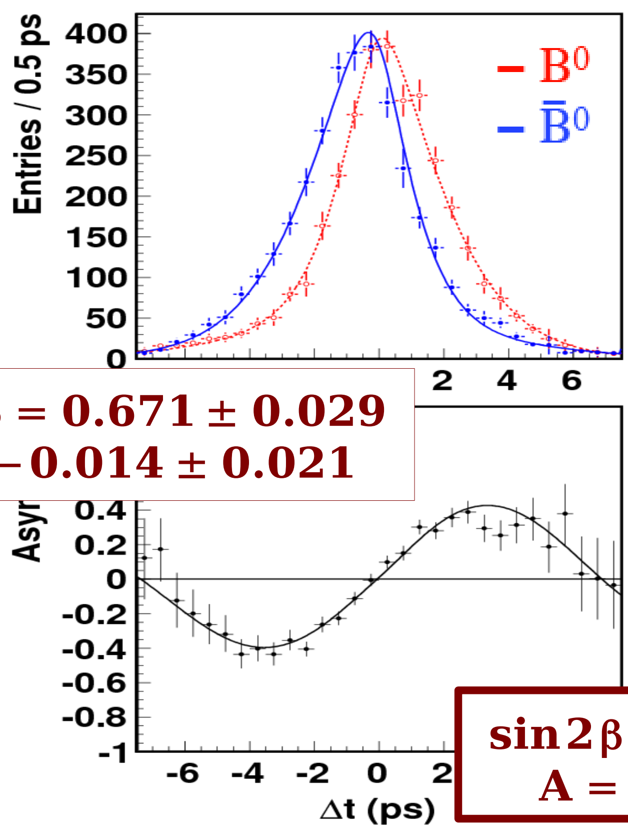
$\sin 2\beta$ in $(c\bar{c})K^0$ ...

772×10^6 $B\bar{B}$ pairs
[PRL 108 (2012) 171802, arXiv:1201.4643]

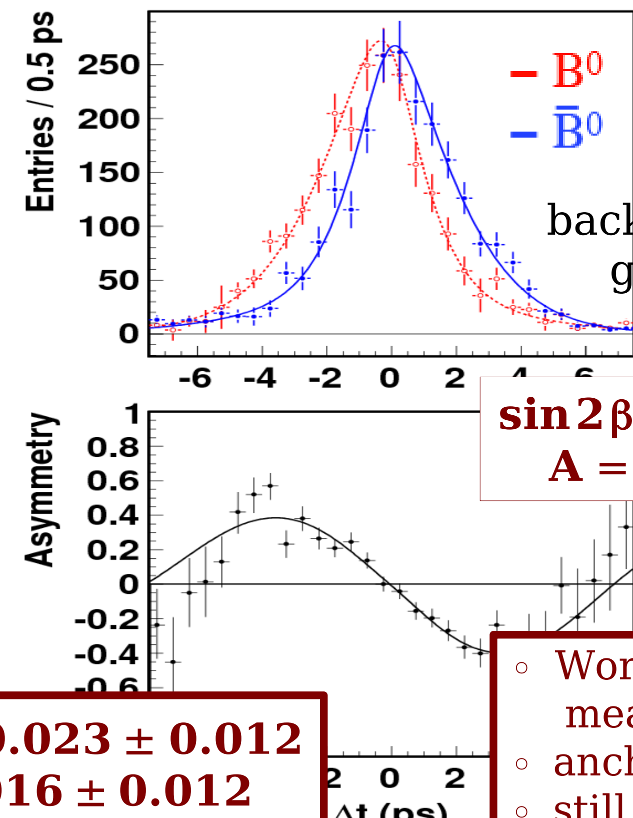




$J/\psi K_L$ [CP even]
N_{sig} = 10041
Purity = 63%



$\sin 2\beta = 0.671 \pm 0.029$
$A = -0.014 \pm 0.021$



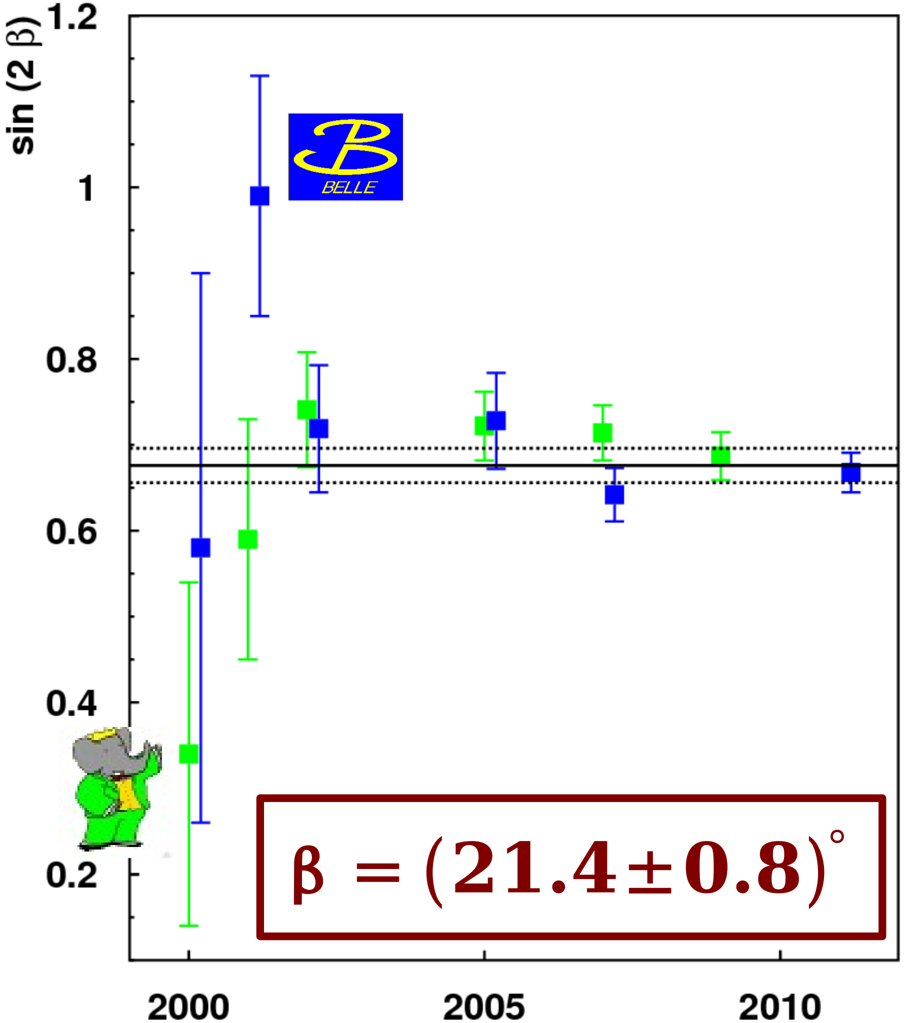
background subtracted
good tagged only

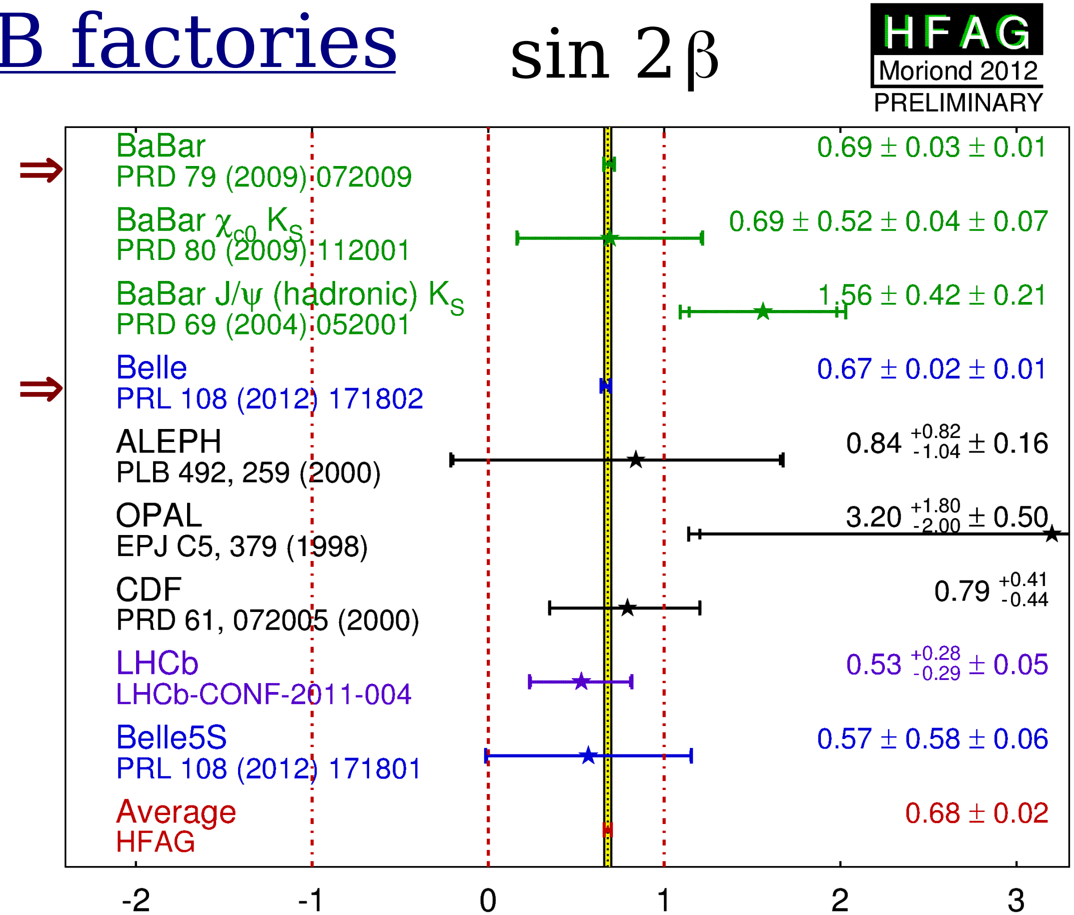
$\sin 2\beta = 0.642 \pm 0.047$
$A = 0.019 \pm 0.026$

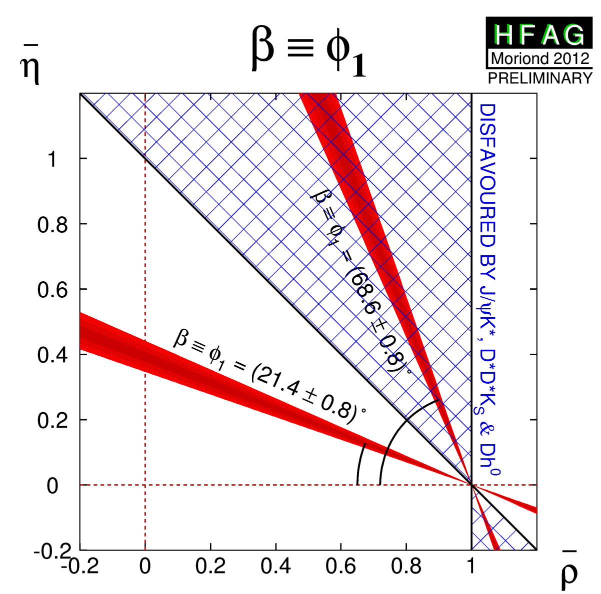
$\sin 2\beta = 0.667 \pm 0.023 \pm 0.012$
$A = 0.006 \pm 0.016 \pm 0.012$

- World's most precise measurements
- anchor point of the SM
- still statistically limited !

La raison d'être of the B factories



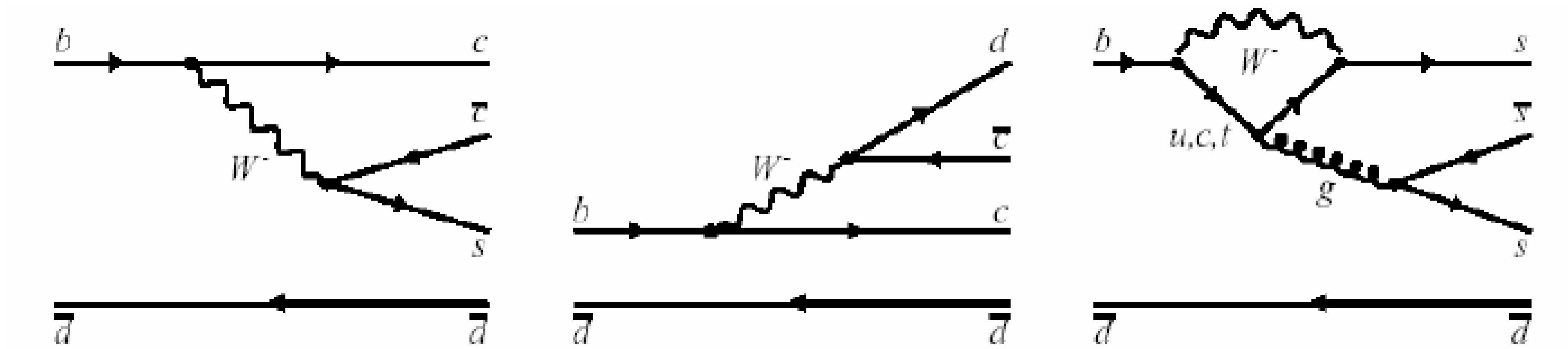




what is the source of CP violation ?

the **Kobayashi-Maskawa phase** is the source

β in other modes



$J/\psi K^0_S, \psi(2S)K^0_S, \chi_{c1}K^0_S,$ $\eta_c K^0_S, J/\psi K^0_L,$ $J/\psi K^{*0}(K^{*0} \to K^0_S\pi^0)$	$D^{*+}D^-, D^+D^-$ $J/\psi\pi^0, D^{*+}D^{*-}$	$\phi K^0, K^+K^-K^0_S,$ $K^0_S K^0_S K^0_S, \eta' K^0, K^0_S\pi^0,$ $\omega K^0_S, f_0(980)K^0_S$

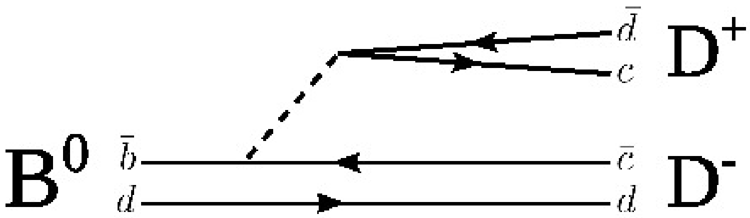
see G.Marchiori's talk

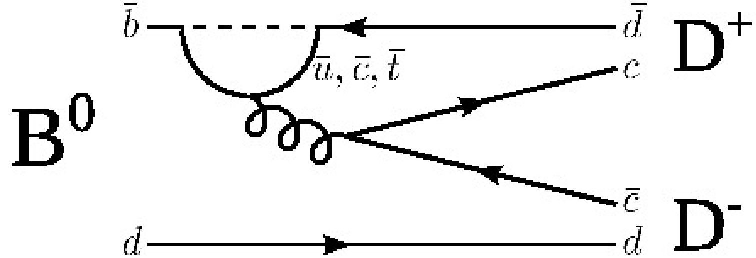
increasing tree diagram amplitude

increasing sensitivity to new physics

possible new sources of CPV ?

Update of $B^0 \to D^+ D^-$ mode





772×10^6 **$B\bar{B}$ pairs**
[arXiv: 1203.6647]

SM prediction: $S = -\sin 2\beta$ and $A \approx 0$ [Z.Z Xing, PRD61, 014010 (1999)]

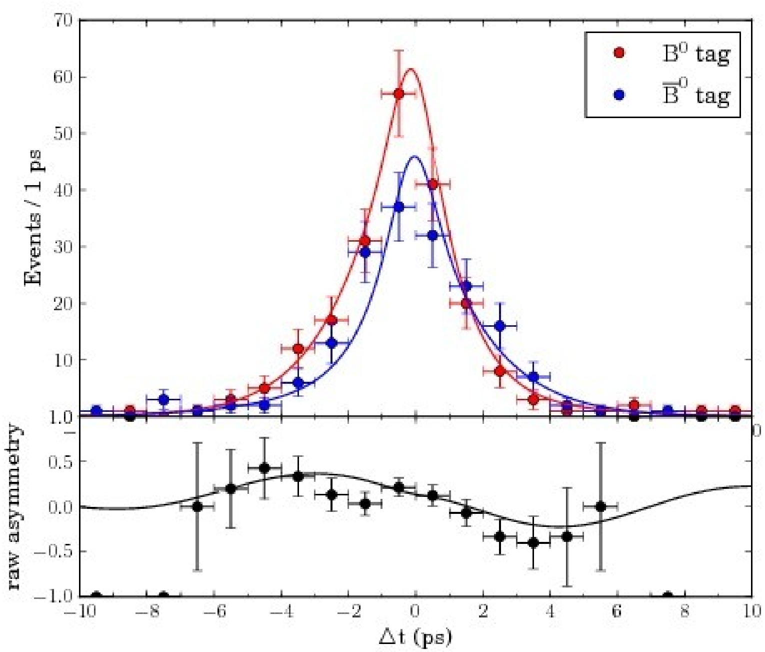
$B^0 \to D^+ D^- \to (K^- \pi^+ \pi^+)(K^+ \pi^- \pi^-)$
$\to (K^- \pi^+ \pi^+)(K^0_S \pi^-)$

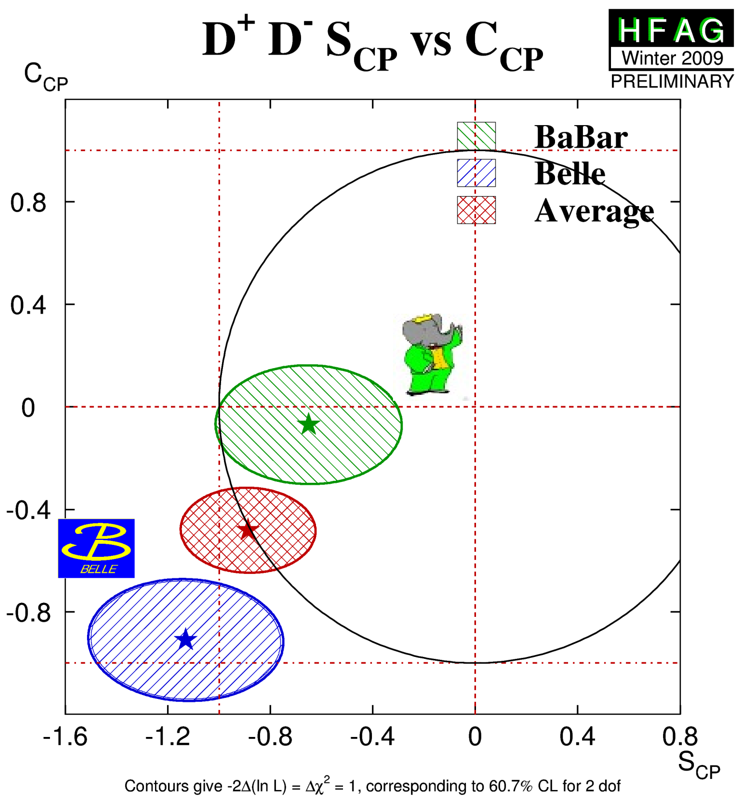
[> × 2 signal yield compared to previous analysis (535 MBB)]

Signal events = 269 ± 21

$Br(B^0 \to D^+ D^-) = (2.12 \pm 0.16 \pm 0.18) \times 10^{-4}$

[PDG: $(2.11 \pm 0.31) \times 10^{-4}$]





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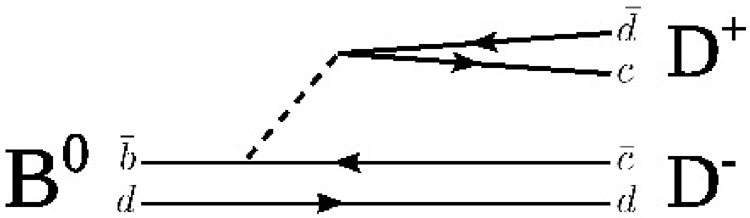

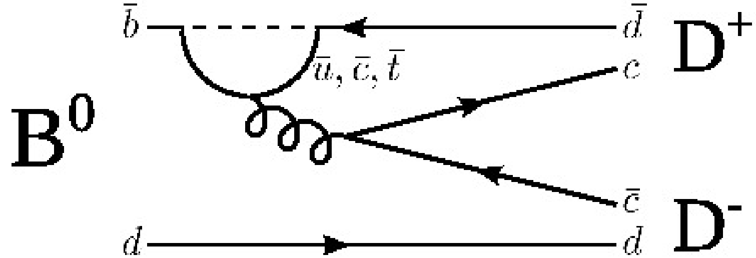

772×10^6 $B\bar{B}$ pairs

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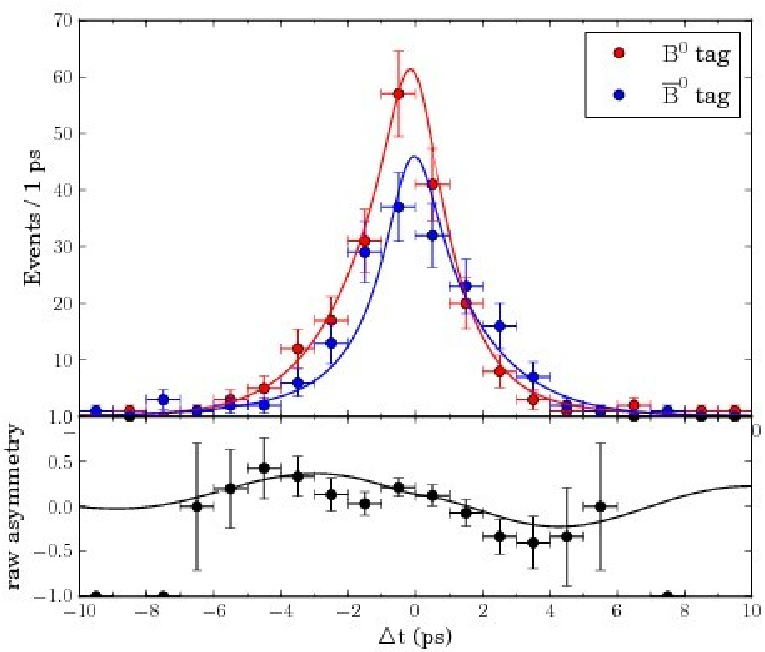
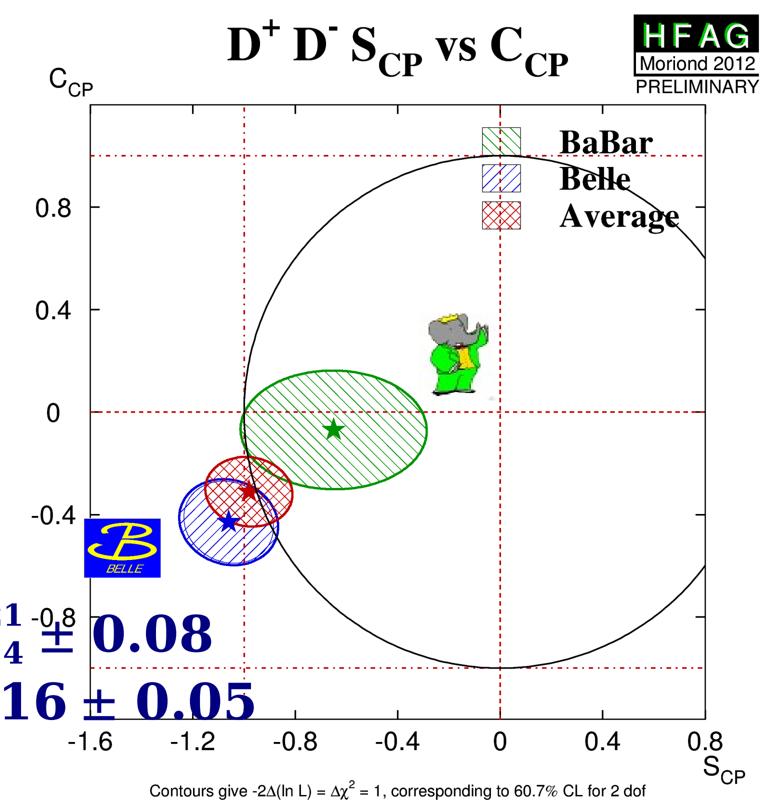




$S = -1.06 \,^{+0.21}_{-0.14} \pm 0.08$

$A = +0.43 \pm 0.16 \pm 0.05$

Update of $B^0 \to D^{*+} D^{*-}$ mode

Final state is a mixture of CP eigenstates

772×10^6 $B\bar{B}$ pairs
[preliminary]

B decay channels:

- $B \to D^{*+} D^{*-} \to (D^0 \pi^+)(\overline{D^0} \pi^-)$
- $B \to D^{*+} D^{*-} \to (D^+ \pi^0)(\overline{D^0} \pi^-)$

D decay channels:

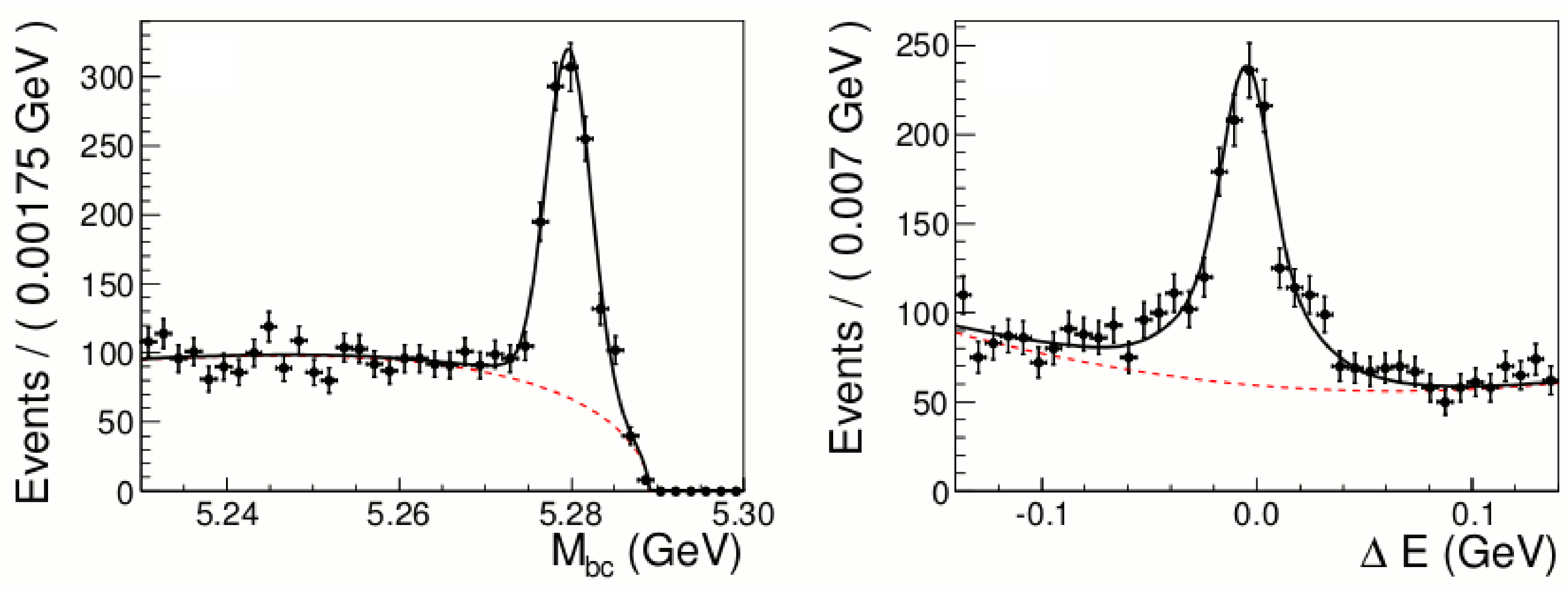
$D^+ \to K^- \pi^+ \pi^+$, $\quad D^+ \to K_S \pi^+$,
$D^+ \to K_S \pi^+ \pi^0$, $\quad D^+ \to K^- K^+ \pi^+$,
$D^0 \to K^- \pi^+$, $\quad D^0 \to K^- \pi^+ \pi^0$,
$D^0 \to K^- \pi^+ \pi^+ \pi^-$, $\quad D^0 \to K_S \pi^+ \pi^-$,
$D^0 \to K^- K^+$

Signal events = 1225 ± 59

$Br(B^0 \to D^{*+} D^{*-}) = (7.82 \pm 0.38 \pm 0.60) \times 10^{-4}$

[PDG: $(8.2 \pm 0.9) \times 10^{-4}$]

[take full advantage of the reprocessing of Belle data]

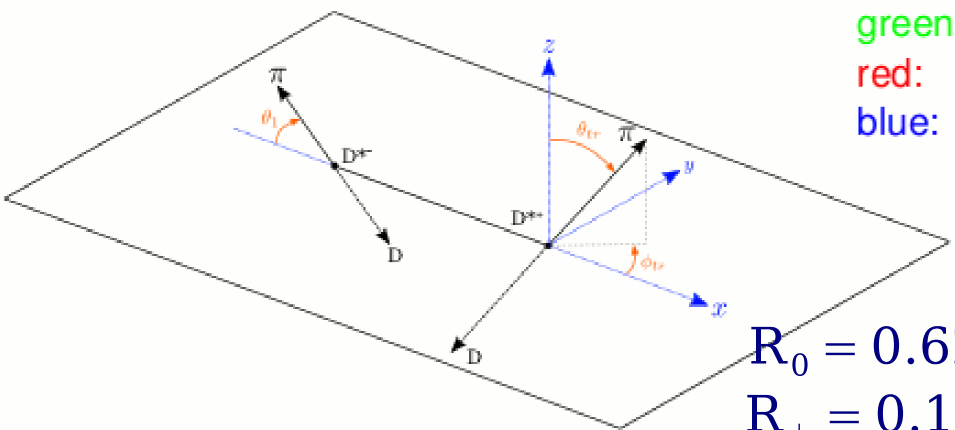


Update of $B^0 \to D^{*+} D^{*-}$ mode

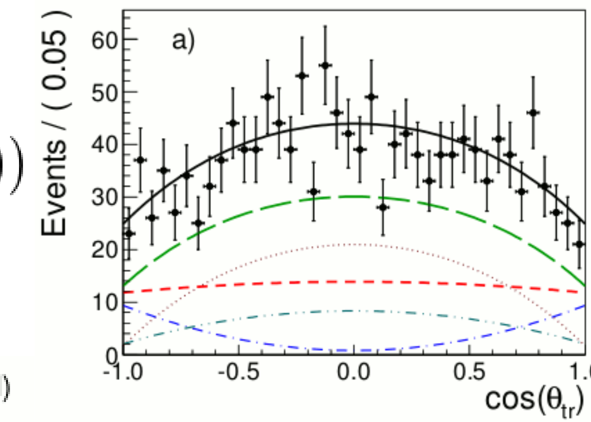
$$\mathcal{P}(t) = \frac{1}{4\tau_{B^0}} e^{-|t|/\tau_{B^0}} \left(1 + q\left((1 - 2P_{\rm odd}) S \sin(\Delta m \cdot t) + A\cos(\Delta m \cdot t)\right)\right)$$

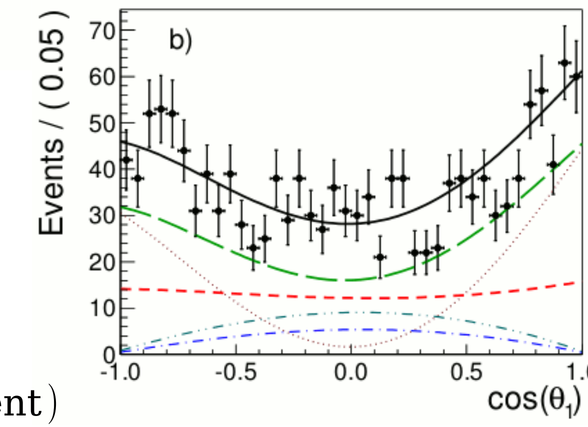
angular analysis to decompose CP-even and odd:

Transversity base



green: signal (*CP*-even + *CP*-odd)
red: background
blue: *CP*-odd

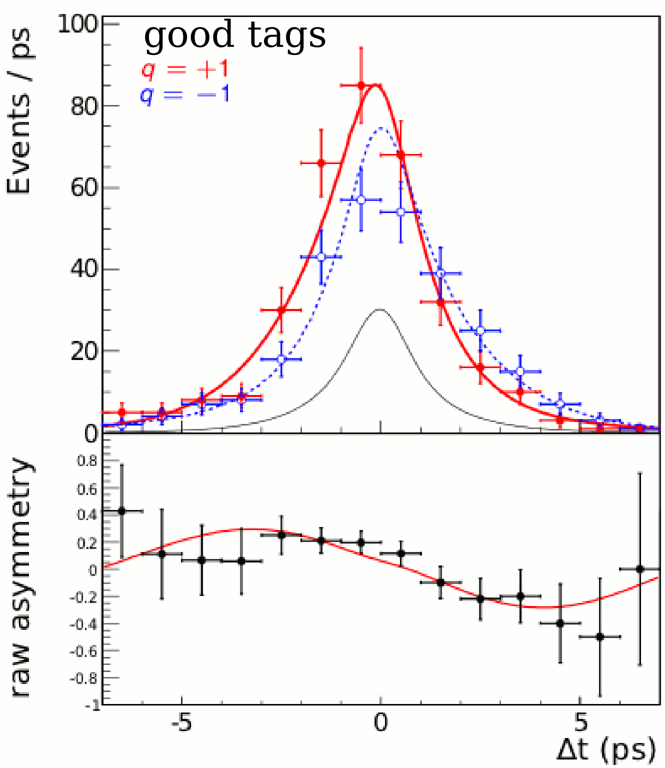


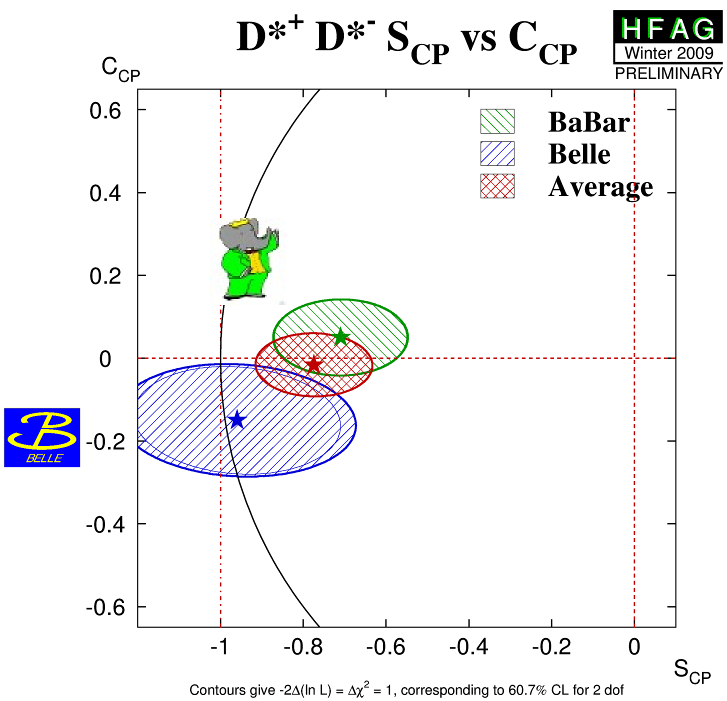


$R_0 = 0.62 \pm 0.03 \pm 0.01$

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

($R_\perp$ corresponds to CP-odd component)





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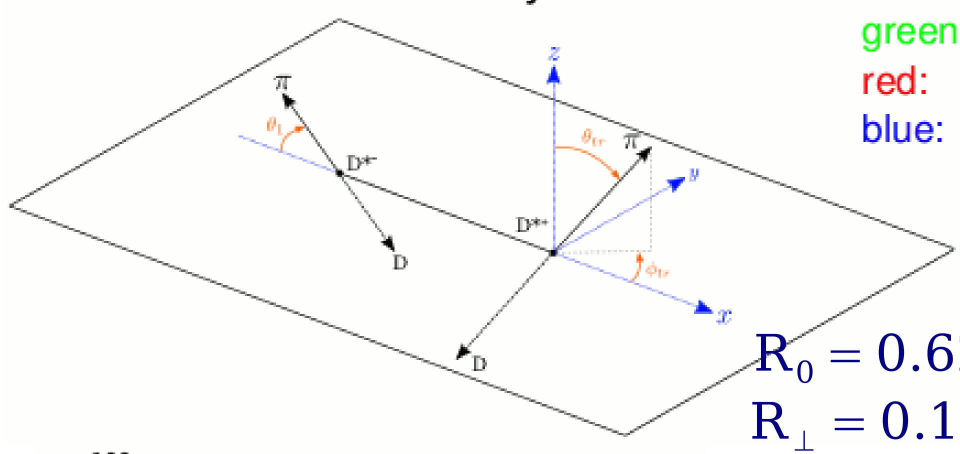
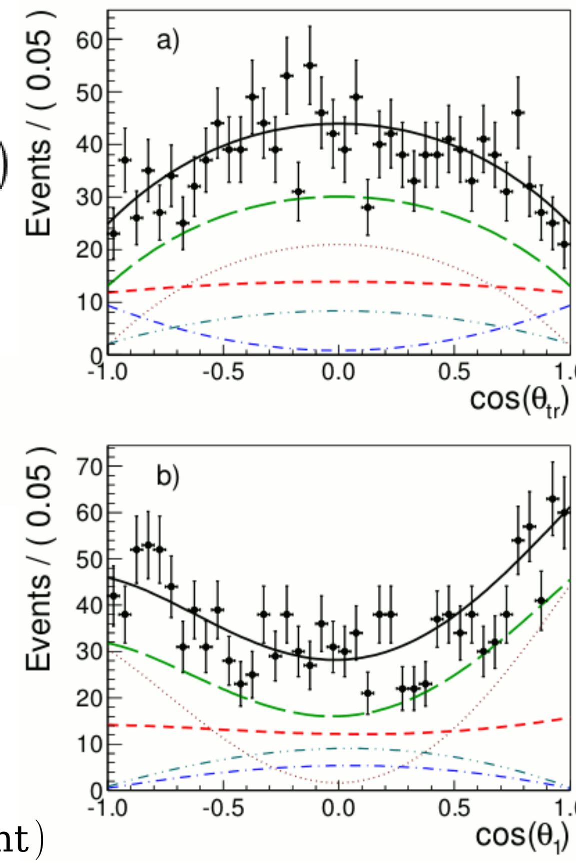


green: signal (CP-even + CP-odd)
red: background
blue: CP-odd



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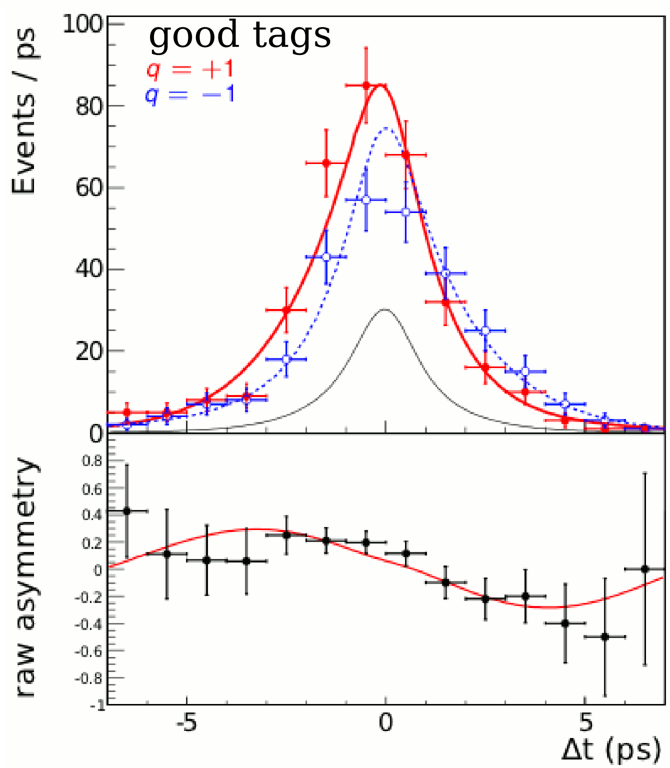
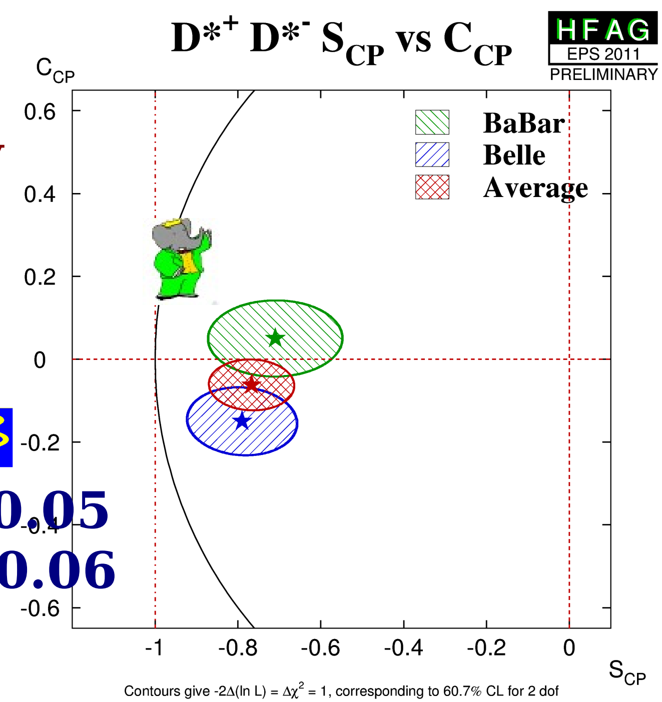
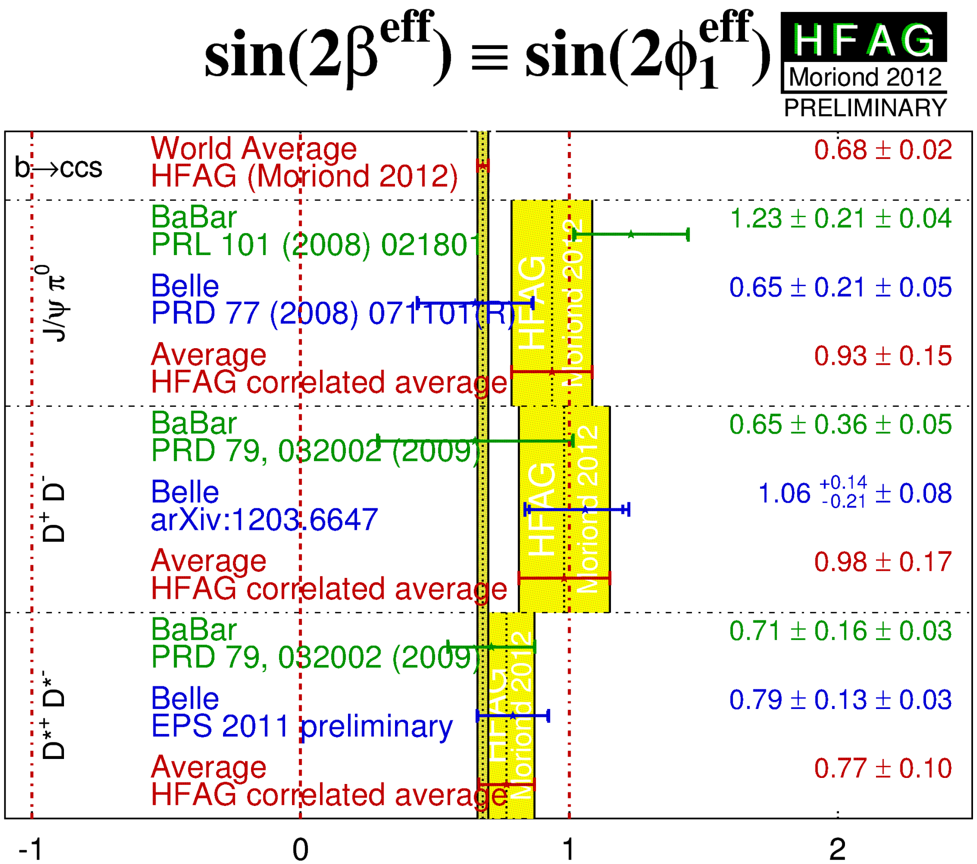


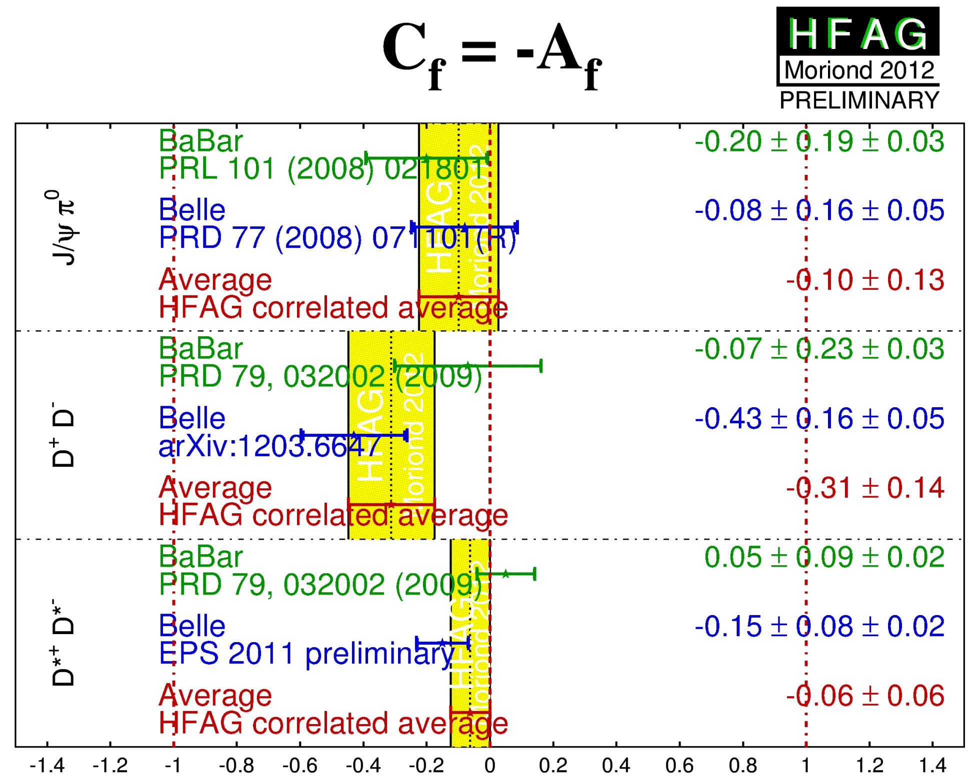
First observation of CPV in double charm decays



$S = -0.79 \pm 0.13 \pm 0.05$
$A = +0.15 \pm 0.08 \pm 0.06$

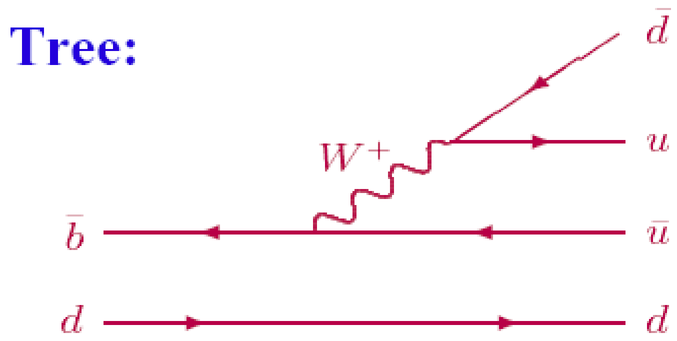
S and A in $b \to c\bar{c}d$ modes

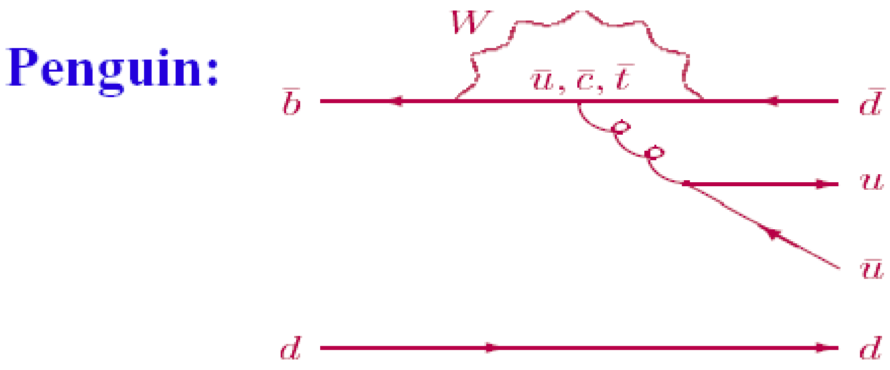




good agreement with $b \to c\bar{c}s$ modes result
$S = -\sin 2\beta, \quad A = 0$

α determination





$$A(B^0 \to \pi^+\pi^-) = T^{+-}\, e^{i\gamma} + P$$

$$\begin{aligned} A(t) &= S_{\pi^+\pi^-} \sin(\Delta m\, t) + A_{\pi^+\pi^-} \cos(\Delta m\, t) \\ &= \sqrt{1 - A^2_{\pi^+\pi^-}}\, \sin 2\alpha_{\mathrm{eff}}\, \sin(\Delta m\, t) + A_{\pi^+\pi^-} \cos(\Delta m\, t) \end{aligned}$$

from time dependent CP, we can measure α^{eff}, but we want α !

$$\mathbf{S}_{\pi^+\pi^-} = \mathbf{sin\, 2\alpha} + 2r \cos\delta\, \sin(\beta+\alpha) \cos 2\alpha + O(r^2)$$

$$r = |P|/|T|$$

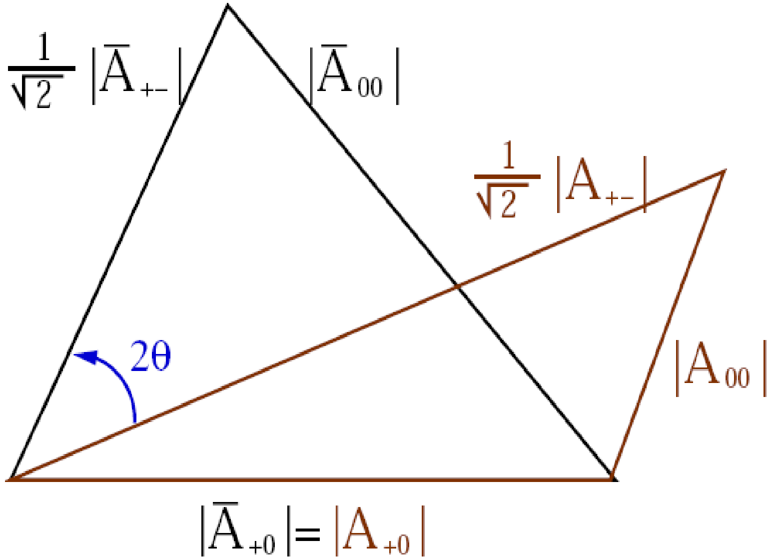
$\to$ additional inputs required to determine the penguin pollution

α determination with isospin analysis

[Gronau-London, PRL65, 3381 (1990)]

$$A_{+-} = A(B^0 \to \pi^+\pi^-) = e^{-i\alpha}\, T^{+-} + P$$
$$\sqrt{2}\, A_{00} = \sqrt{2}\, A(B^0 \to \pi^0\pi^0) = e^{-i\alpha}\, T^{00} + P$$
$$\sqrt{2}\, A_{+0} = \sqrt{2}\, A(B^+ \to \pi^+\pi^0) = e^{-i\alpha}\, (T^{00} + T^{+-})$$

$$A_{+-} + \sqrt{2}\, A_{00} = \sqrt{2}\, A_{+0}$$
$$\bar{A}_{+-} + \sqrt{2}\, \bar{A}_{00} = \sqrt{2}\, \bar{A}_{+0}$$



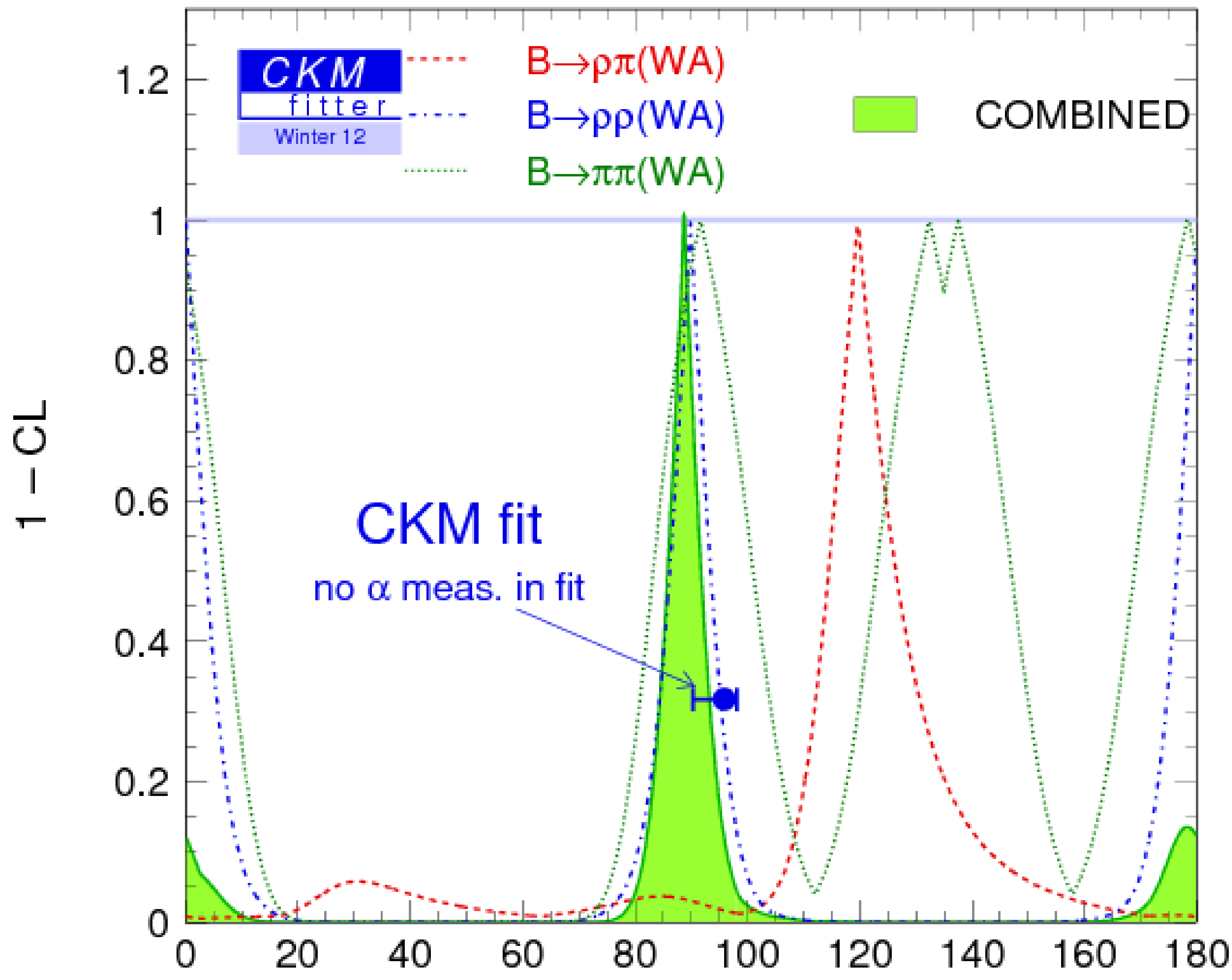
- neglecting EWP $\Rightarrow$ A_{+0} pure tree
  $|A_{+0}| = |\bar{A}_{+0}|$
- Isospin breaking (d and u charges different, $m_u \neq m_d$)
- $\pi - \eta - \eta'$ and $\rho - \omega$ mixing

[J.Zupan, hep-ph/0701004]

α can be resolved up to an 8-fold ambiguity ($\alpha \in [0, \pi]$)

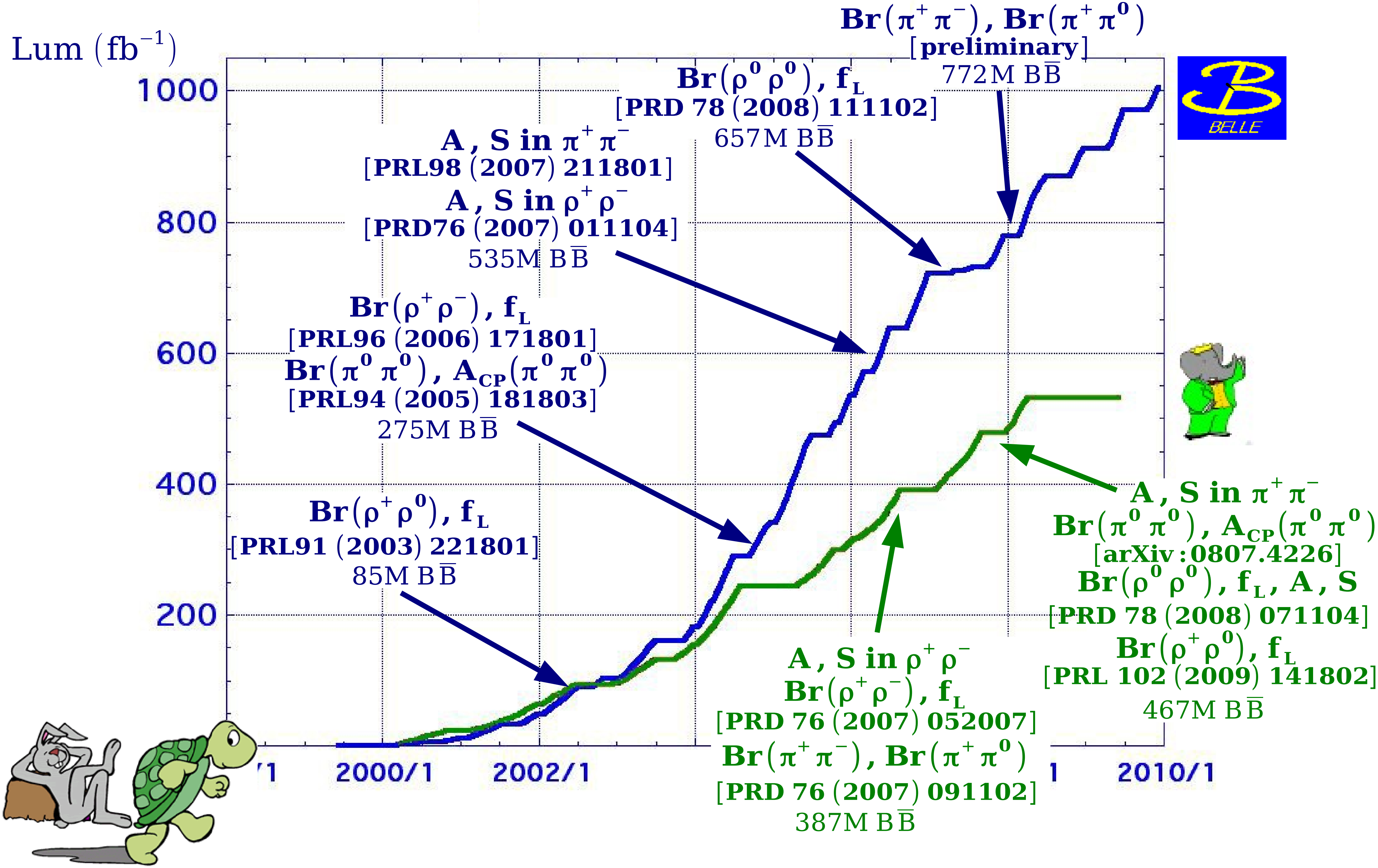
Combined ($\pi\pi$, $\rho\pi$, $\rho\rho$) measurements for α determination

dominated by the $B\to\rho\rho$ measurements (though flat isospin triangles)



$$\alpha = (88.7\,^{+4.6}_{-4.2})^{\circ}$$

$(\pi\pi, \rho\rho)$ measurements related to α determination

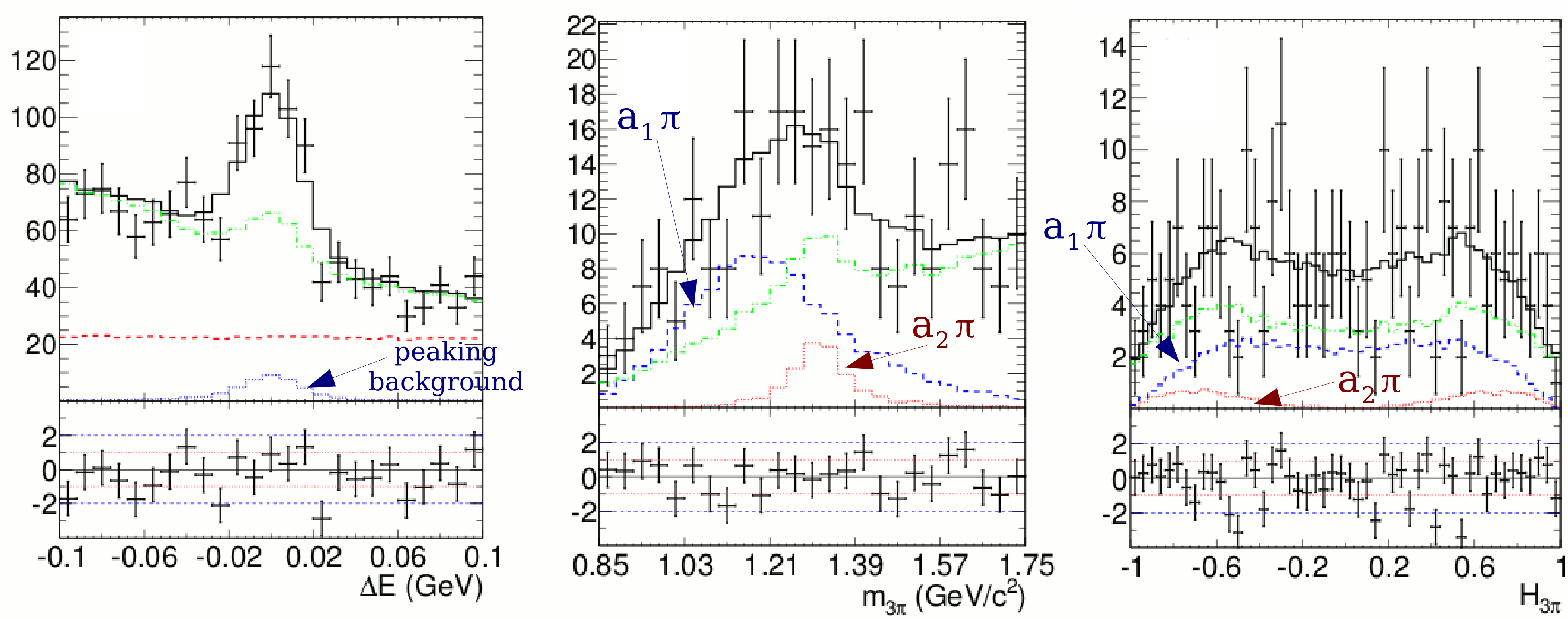


coming important updates from Belle: $B \to \rho^+\rho^0, \rho^0\rho^0, \pi^0\pi^0 \ldots$

$B \to a_1^{\pm}\pi^{\mp}$, $a_1^{\pm} \to (\pi^+\pi^-)\pi^{\pm}$

772×10^6 $B\bar{B}$ pairs
[NEW]

Signal extracted from a 4D $(\Delta E, F, m_{3\pi}, H_{3\pi})$ fit



$N_S = 1445 \pm 101$ events

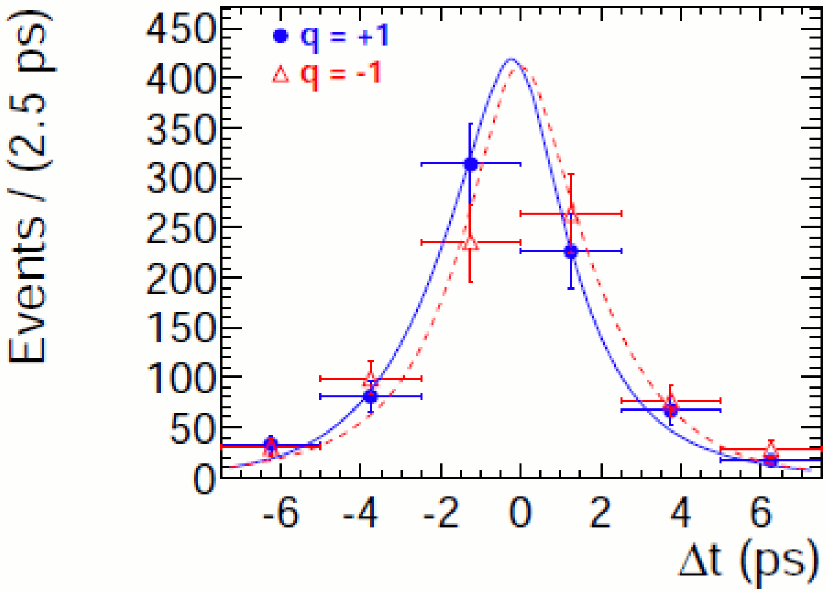
$Br(B^0 \to a_1^{\pm}(1260)\pi^{\mp}) \times Br(a_1^{\pm}(1260) \to \pi^+\pi^-\pi^{\pm}) = (11.1 \pm 1.0(\text{stat}) \pm 1.4(\text{syst})) \times 10^{-6}$

$B \to a_1^{\pm}\pi^{\mp}$, $a_1^{\pm} \to (\pi^+\pi^-)\pi^{\pm}$

772×10^6 $B\bar{B}$ pairs [NEW]

$$A_{CP} = -0.06 \pm 0.05(\text{stat}) \pm 0.07(\text{syst})$$
$$C_{CP} = -0.01 \pm 0.11(\text{stat}) \pm 0.09(\text{syst})$$
$$S_{CP} = -0.51 \pm 0.14(\text{stat}) \pm 0.08(\text{syst})$$

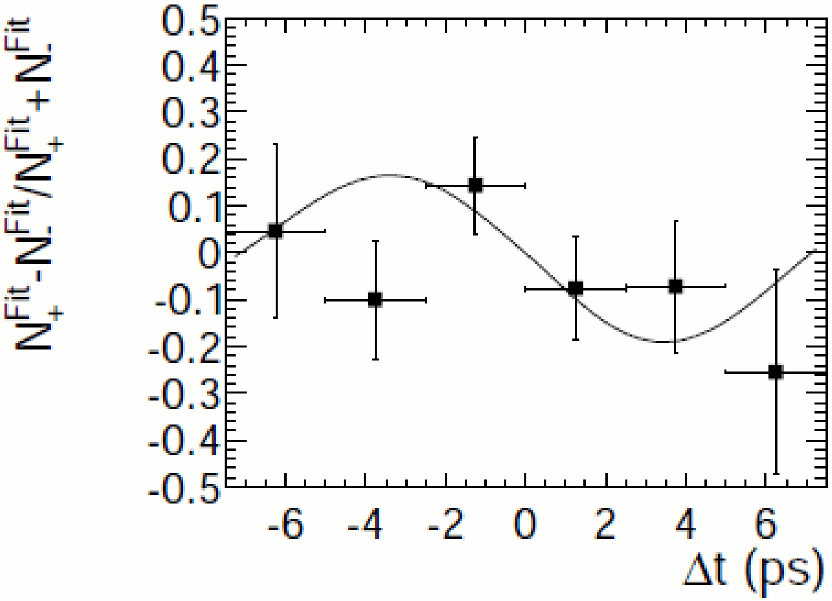
$$\Delta C = +0.54 \pm 0.11(\text{stat}) \pm 0.07(\text{syst})$$
$$\Delta S = -0.09 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$$

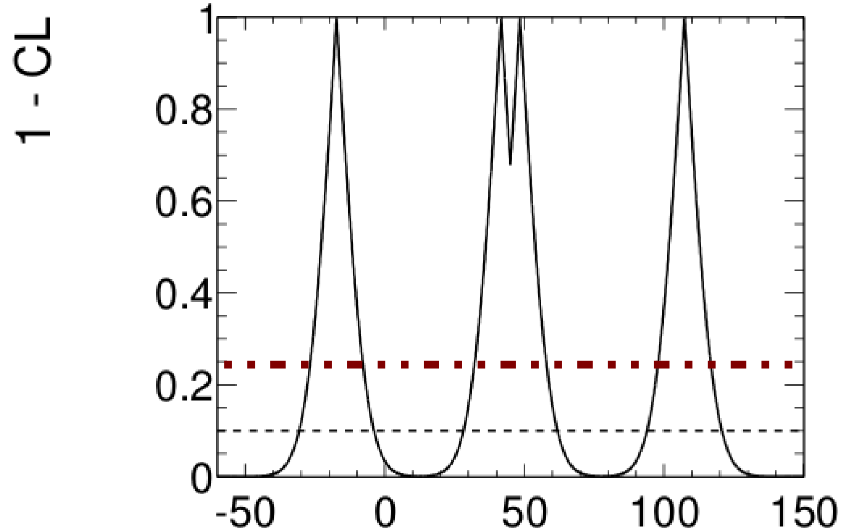


first evidence of mixing-induced CP violation with 3.1σ

α_{eff} determined with a four-fold ambiguity:

$$\alpha^{eff} = \frac{1}{4}\left[\arcsin\left(\frac{S_{CP} + \Delta S}{\sqrt{1-(C_{CP} + \Delta C)^2}}\right) + \arcsin\left(\frac{S_{CP} - \Delta S}{\sqrt{1-(C_{CP} - \Delta C)^2}}\right)\right]$$





$$\alpha^{eff} = \begin{array}{c} [34.7^\circ, 55.3^\circ] \\ [-25.5^\circ, -9.1^\circ] \quad [99.1^\circ, 115.5^\circ] \end{array}$$

$\to \alpha$ using isospin analysis

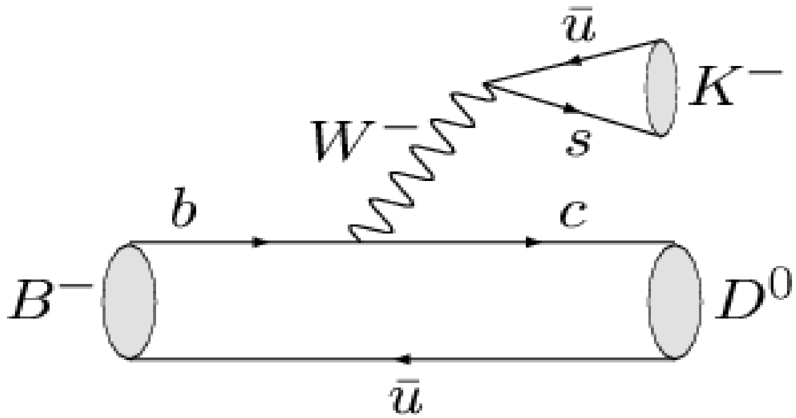
[M.Gronau and D.London, PRL 65 (1990) 3381]

using SU(3) flavour symmetry

[M.Gronau and J.Zupan, PRD 73 (2006) 057502]

γ measurements from $B^{\pm} \to DK^{\pm}$

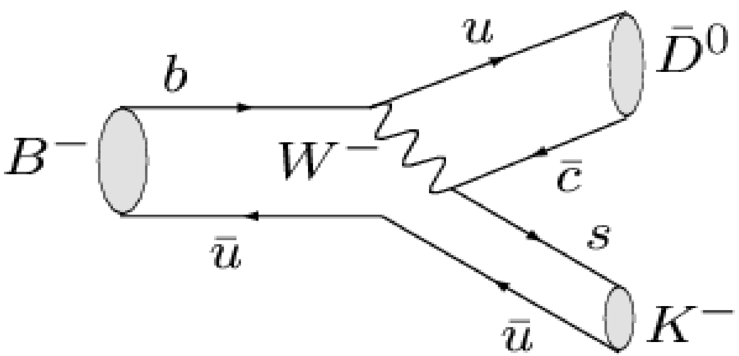
- Theoretically pristine $B \to DK$ approach
- Access γ via interference between $B^- \to D^0 K^-$ and $B^- \to \overline{D}^0 K^-$



color allowed

$B^- \to D^0 K^- \sim V_{cb} V_{us}^*$

$\sim \mathbf{A\lambda^3}$



color suppressed

$B^- \to \overline{D}^0 K^- \sim V_{ub} V_{cs}^*$

$\sim \mathbf{A\lambda^3(\rho + i\eta)}$

relative magnitude of suppressed amplitude is r_B

$$\boxed{r_B = \frac{|A_{\text{suppressed}}|}{|A_{\text{favoured}}|} \sim \frac{|V_{ub} V_{cs}^*|}{|V_{cb} V_{us}^*|} \times [\text{color supp}] = 0.1\text{-}0.2}$$

relative weak phase is γ, relative strong phase is δ_B

γ measurements from $B^{\pm} \to DK^{\pm}$

- Reconstruct D in final states accessible to both D^0 and $\overline{D}^0$
  - $D = D_{CP}$, CP eigenstates as K^+K^-, $\pi^+\pi^-$, $K_S\pi^0$

    GLW method (Gronau-London-Wyler)
  - $D = D_{sup}$, Doubly-Cabbibo suppressed decays as $K\pi$

    ADS method (Atwood-Dunietz-Soni)
  - Three-body decays as $D \to K_S\pi^+\pi^-$, $K_S K^+ K^-$

    GGSZ (Dalitz) method (Giri-Grossman-Soffer-Zupan)

- Largest effects due to
  - charm mixing
  - charm CP violation

  negligible

  Y.Grossman, A.Soffer, J.Zupan [PRD 72, 031501 (2005)]

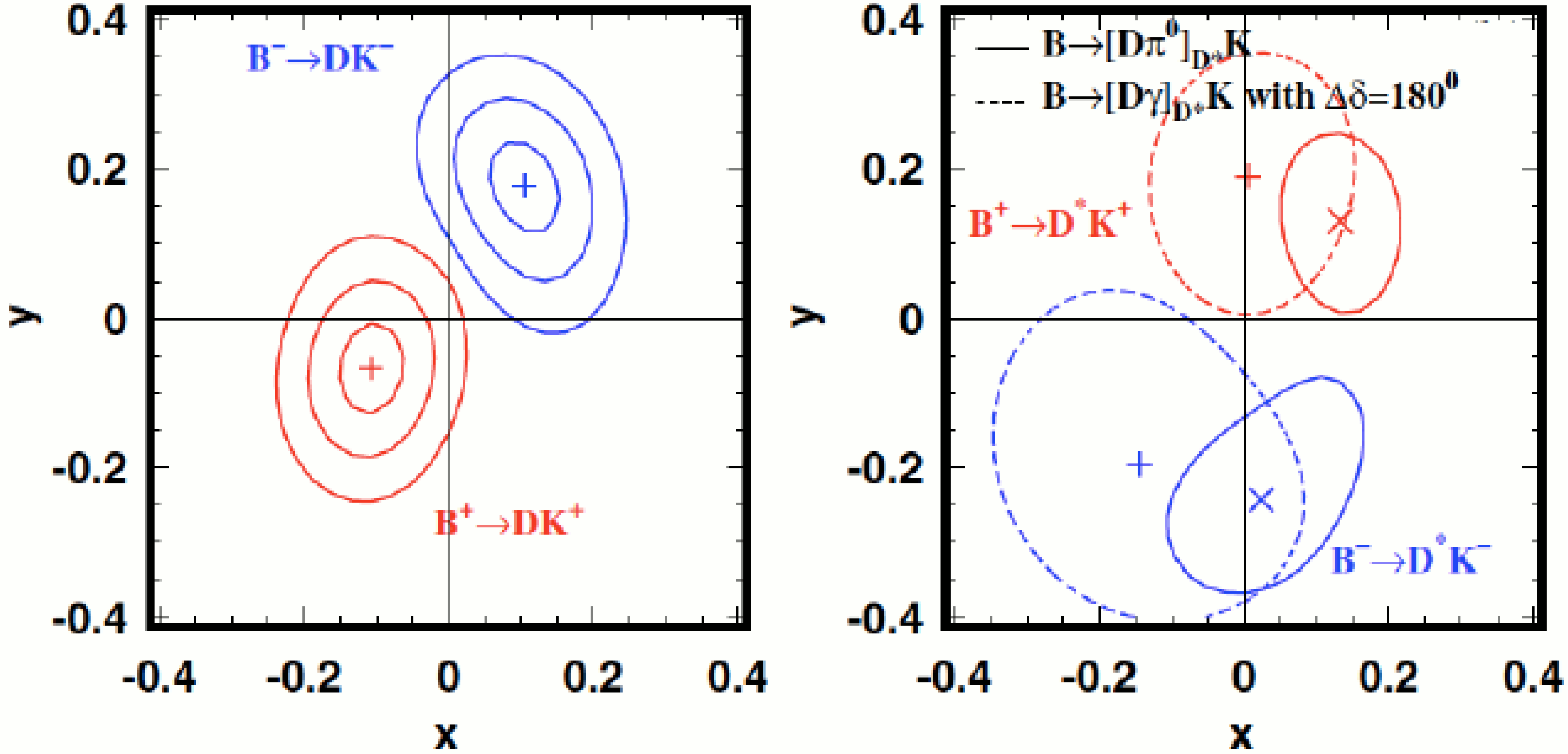
- **Different B decays (DK, D^*K, DK^*)**
  - **different hadronic factors (r_B, δ_B) for each**

γ measurement with $B \to D(K_S \pi\pi)K$

PRD 81, 112002 (2010)
657×10^6 $B\bar{B}$ pairs

$$x_\pm = r_B \cos(\delta_B \pm \gamma),\ \ y_\pm = r_B \sin(\delta_B \pm \gamma)$$

(similarly PRL 105 (2010) 121801)
(467×10^6 $B\bar{B}$ pairs)



$$\gamma = (80.8\ ^{+13.1}_{-14.8} \pm 5.0 \pm 8.9)^\circ$$
$$r_B = 0.161\ ^{+0.040}_{-0.038} \pm 0.011\ ^{+0.050}_{-0.010}$$
$$\delta_B = (137.4\ ^{+13.0}_{-15.7} \pm 4.0 \pm 22.9)^\circ$$

$$\gamma = (73.9\ ^{+18.9}_{-20.2} \pm 4.2 \pm 8.9)^\circ$$
$$r_B = 0.196\ ^{+0.073}_{-0.072} \pm 0.013\ ^{+0.062}_{-0.012}$$
$$\delta_B = (341.7\ ^{+18.6}_{-20.9} \pm 3.2 \pm 22.9)^\circ$$

combining both B modes (Dalitz): $\boldsymbol{\gamma = (78.4^{+10.8}_{-11.6} \pm 3.6 \pm 8.9)^\circ}$

CPV significance is 3.5 standard deviations

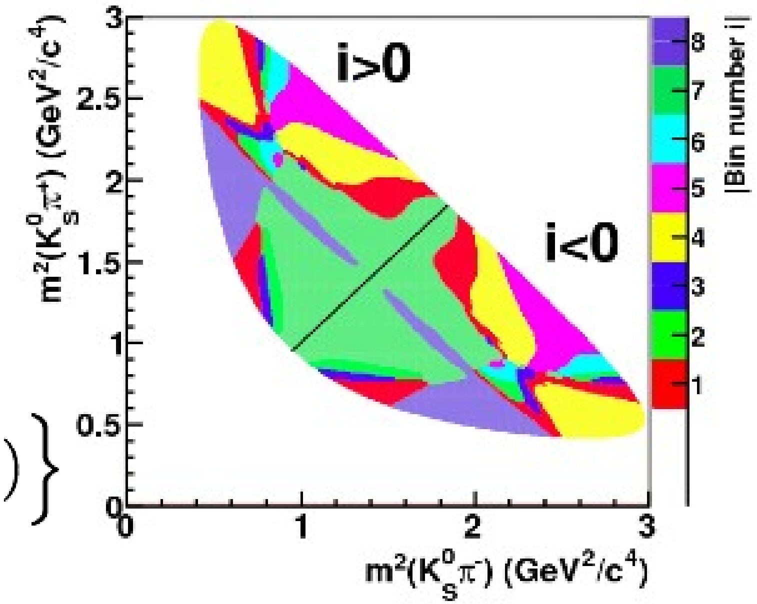
(model-dependent error will limit viability of this approach)

Binned Dalitz method: avoid the modeling error by ''optimal'' binning of the Dalitz plot

Bondar and Poluektov
EPJ C55, 51 (2008)

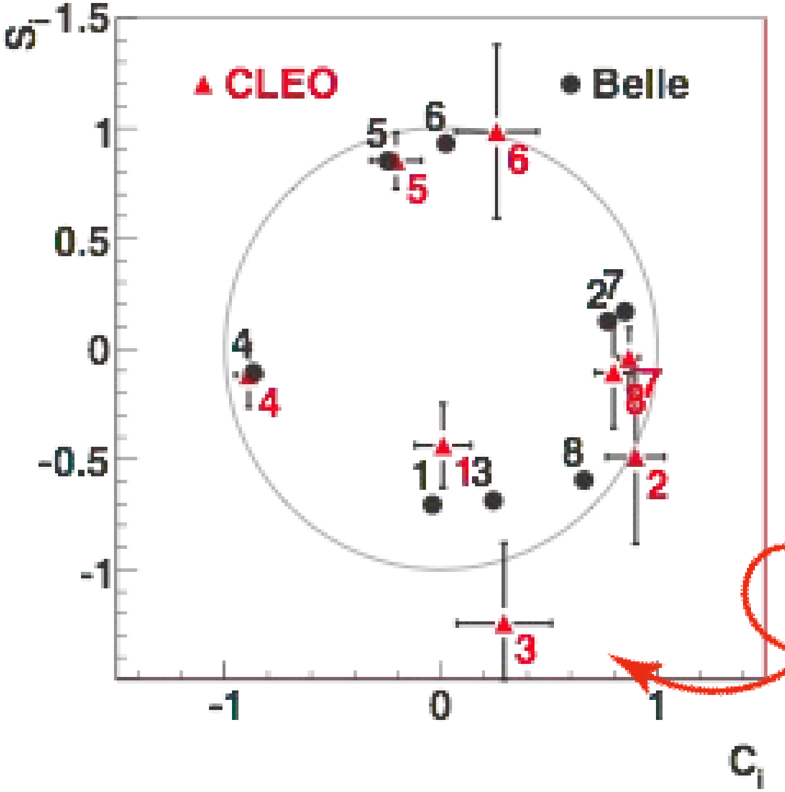
[choice of bins guided by model, but extraction of γ is not biased by this choice]

minimize χ^2 in fit to all bins for each mode



Expected number of $B^\pm \to D K^\pm$ events in bin i is:

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



K_i is the # of events in bin i from a flavour-tagged sample ($D^{*\pm} \to D\pi^\pm$)

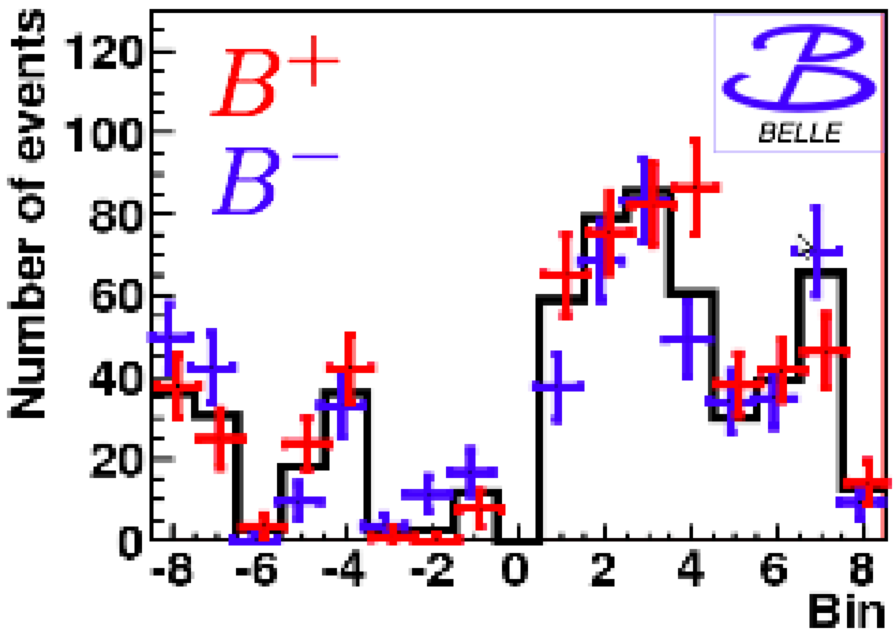
c_i and s_i contain information about the strong-phase difference in bin i

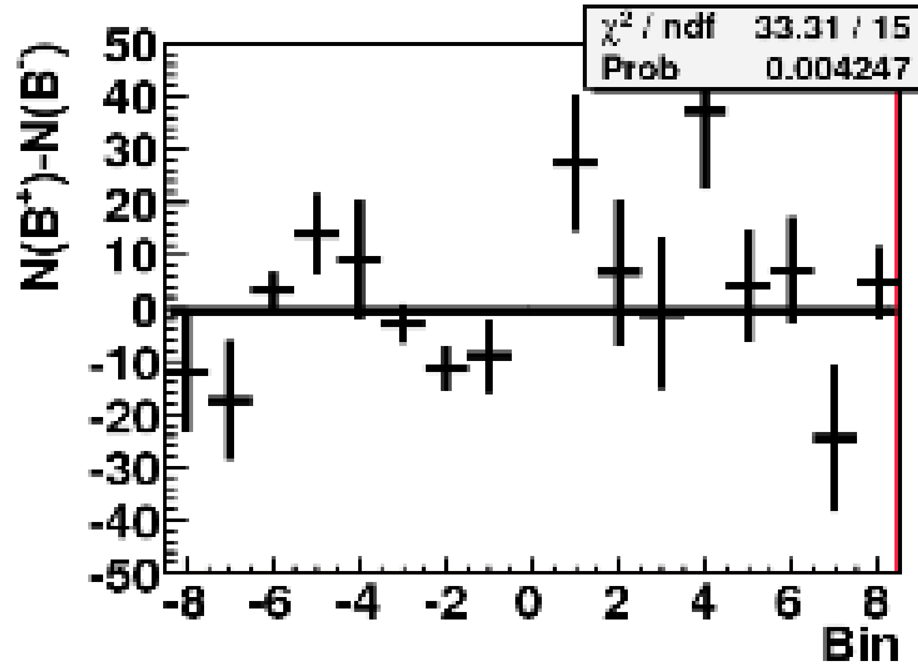
(use CLEO data for $\psi(3770) \to D^0 \overline{D}^0$ here; can be measured by BES-III too)

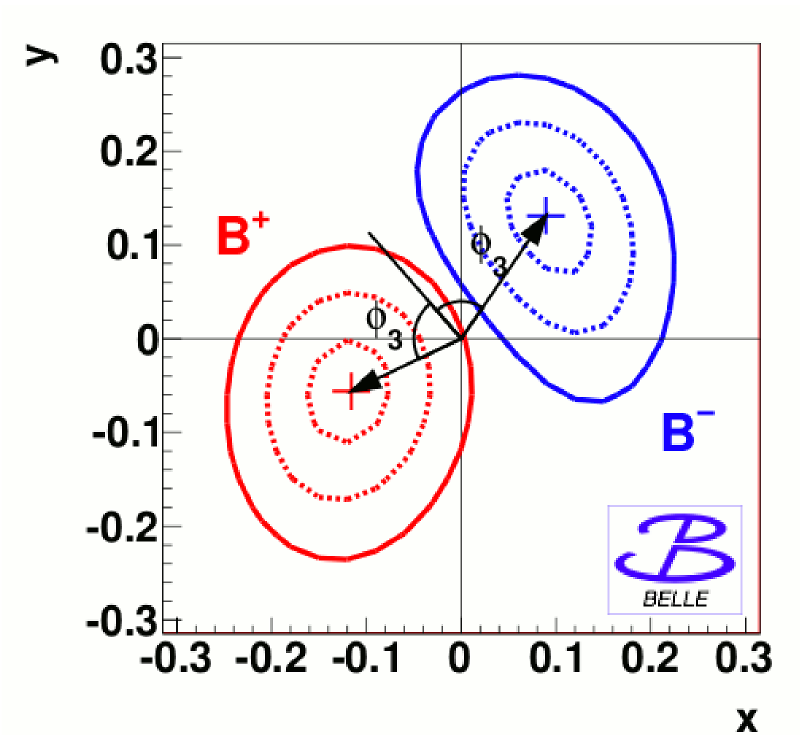
Binned Dalitz method result in $B \to DK$

772M $B\bar{B}$

arXiv:1204.6561, submitted to PRD







$$\gamma = \left(77.3\,^{+15.1}_{-14.9} \pm 4.1 \pm 4.3\right)^\circ$$

$$r_B = 0.145 \pm 0.030 \pm 0.010 \pm 0.011$$

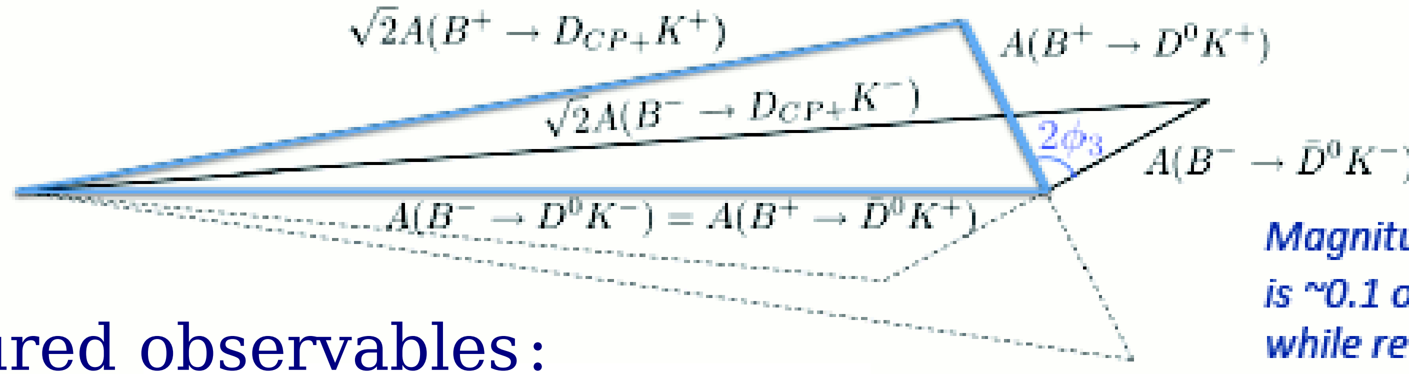
$$\delta_B = \left(129.9 \pm 15.0 \pm 3.8 \pm 4.7\right)^\circ$$

uncertainty in c_i, s_i
from CLEO data size
(can be reduced using
future BES-III data)

GLW with $D_{CP}^{(*)}K$

D decays to CP eigenstates

- Amplitude triangle:



Magnitude of one side is ~0.1 of the others while relative magnitude of the others help ϕ_3 constraint.

measured observables:

$$R_{CP\pm} \equiv \frac{Br(B^- \to D_{CP\pm}K^-) + Br(B^+ \to D_{CP\pm}K^+)}{Br(B^- \to D^0 K^-) + Br(B^+ \to \bar{D}^0 K^+)}$$

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

Relation between $(A_{CP+}, A_{CP-}, R_{CP+}, R_{CP-})$ and (γ, r_B, δ_B)

$$A_{CP+} = \frac{2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 + 2r_B\cos\delta_B\cos\gamma} \qquad A_{CP-} = \frac{-2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 - 2r_B\cos\delta_B\cos\gamma}$$

$$R_{CP+} = 1 + r_B^2 + 2r_B\cos\delta_B\cos\gamma \qquad R_{CP-} = 1 + r_B^2 - 2r_B\cos\delta_B\cos\gamma$$

$\Rightarrow$ look for $R_{CP\pm} \neq 1$ and $A_{CP\pm} \neq 0$

$\Rightarrow$ $\neq$ CP, $\neq$ sign of asymmetry

$B \to Dh,\ D \to K^+K^-, \pi^+\pi^- \ \to\ R_+$

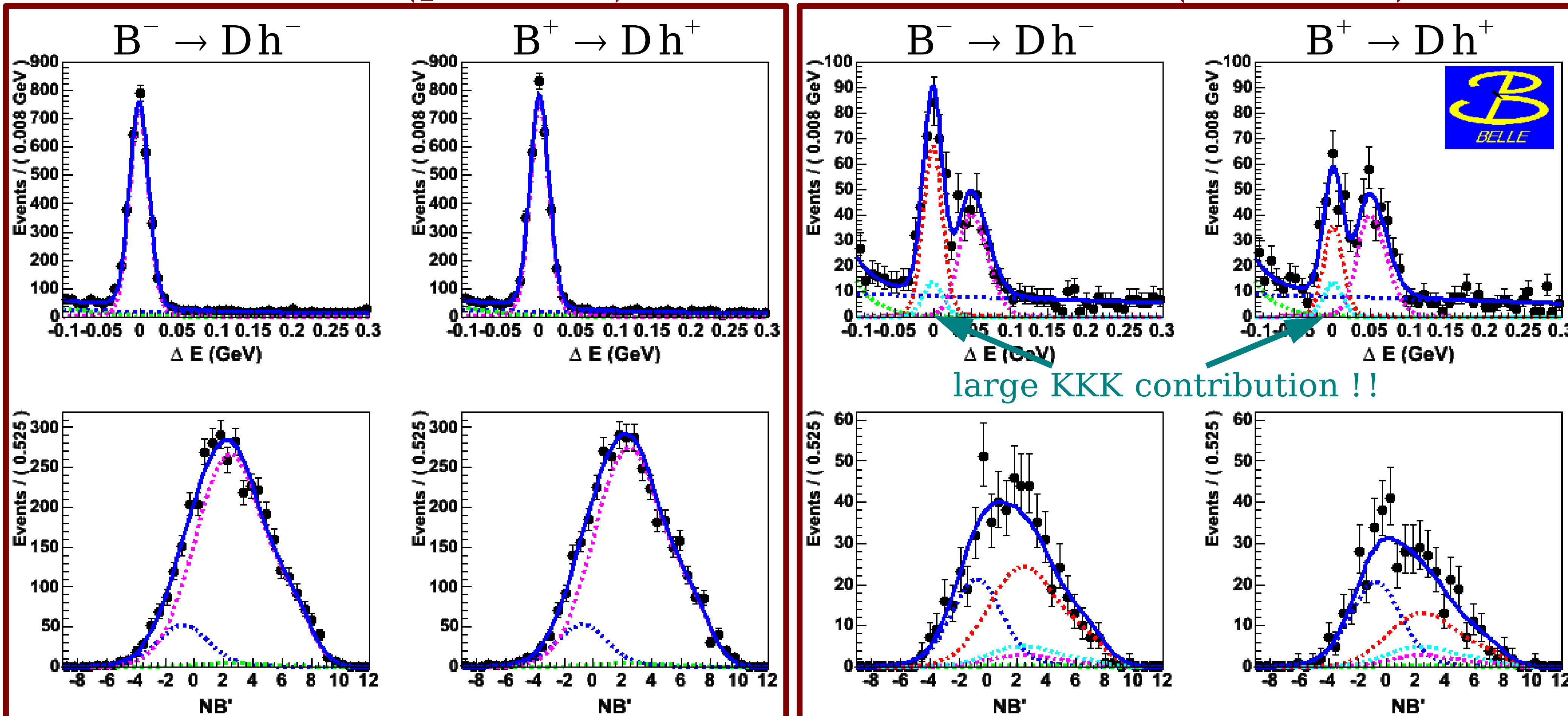
Preliminary
LP 2011

$(772\ \mathrm{M}B\bar{B})$
$B \to D\pi$
$B \to DK$
$B\bar{B}$
continuum

Yields	$\mathbf{B \to D\pi}$	$\mathbf{B \to DK}$
$\mathbf{D \to K\pi}$	50432 ± 243	3692 ± 83
$\mathbf{D \to KK, \pi\pi}$	7696 ± 106	582 ± 40

$\Rightarrow\ R_{D_{fav}} = (7.32 \pm 0.16)\%$
$A(DK) = (1.4 \pm 2.0)\%$

KID<0.6 (pion-like) **KID>0.6 (kaon-like)**



$$\Rightarrow\ R_{D_{CP+}} = (7.56 \pm 0.51)\%,\ \ A_{D_{CP+}} = (28.7 \pm 6.0)\%$$

large asymmetry !!

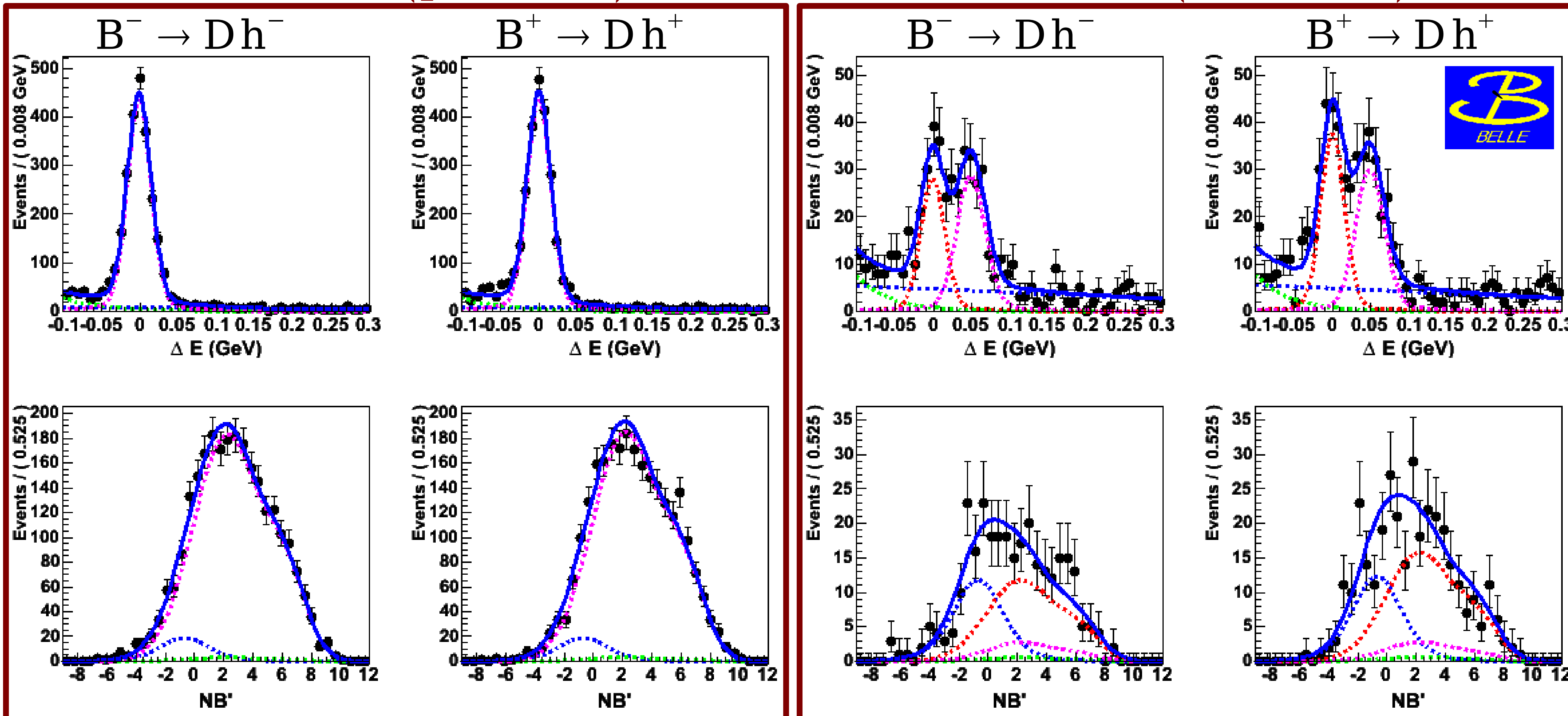
$B \to Dh,\ D \to K_S\pi^0,\ K_S\eta \ \to\ R_-$

Preliminary
LP 2011

$(772\ \mathrm{M}B\overline{B})$
$B \to D\pi$
$B \to DK$
$B\overline{B}$
continuum

Yields	$B \to D\pi$	$B \to DK$
$D \to K_S\pi^0,\ K_S\eta$	5745 ± 91	476 ± 37

KID<0.6 (pion-like) **KID>0.6 (kaon-like)**



$\Rightarrow\ R_{D_{CP-}} = (8.29 \pm 0.63)\%,\ \ A_{D_{CP-}} = (-12.4 \pm 6.4)\%$

opposite asymmetry !!

GLW Results

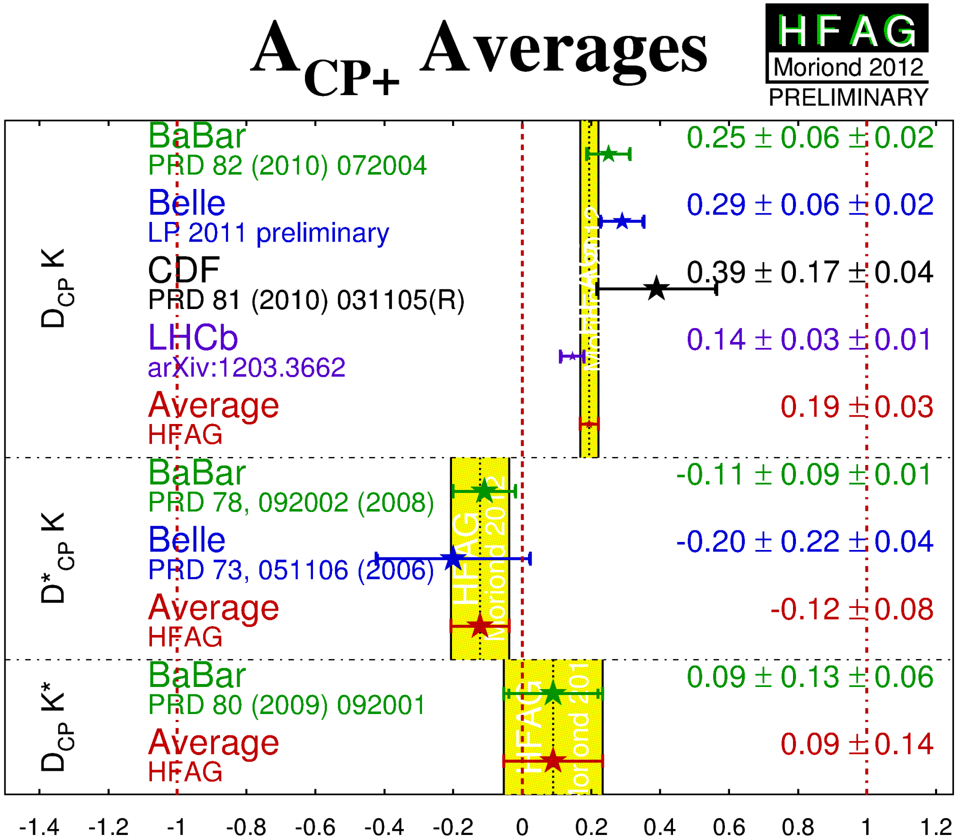
Preliminary (LP 2011)

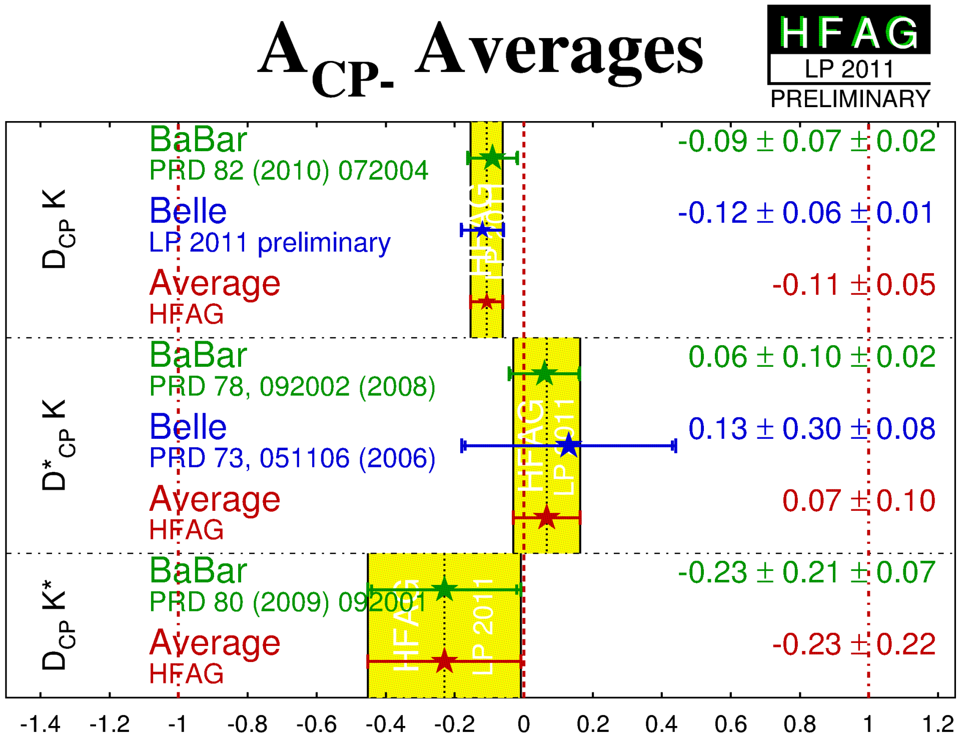
$$R_{CP+} = 1.03 \pm 0.07 \pm 0.03$$
$$R_{CP-} = 1.13 \pm 0.09 \pm 0.05$$

$$A_{CP+} = +0.29 \pm 0.06 \pm 0.02$$
$$A_{CP-} = -0.12 \pm 0.06 \pm 0.01$$

CP-odd observables
only available at B-factories

(systematics dominated by peaking background, double ratio approximation)

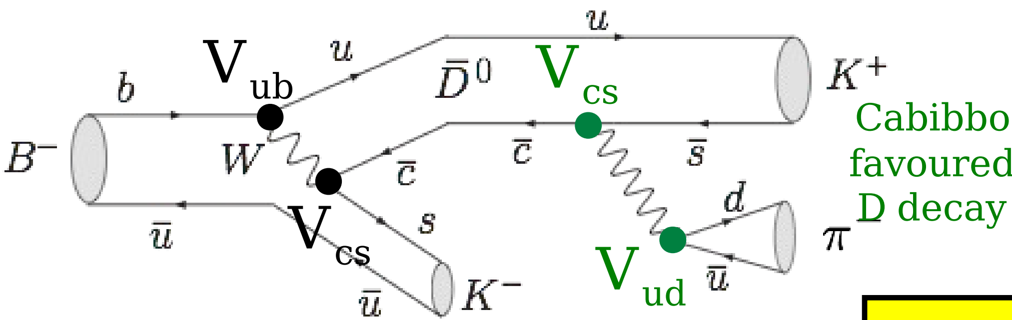


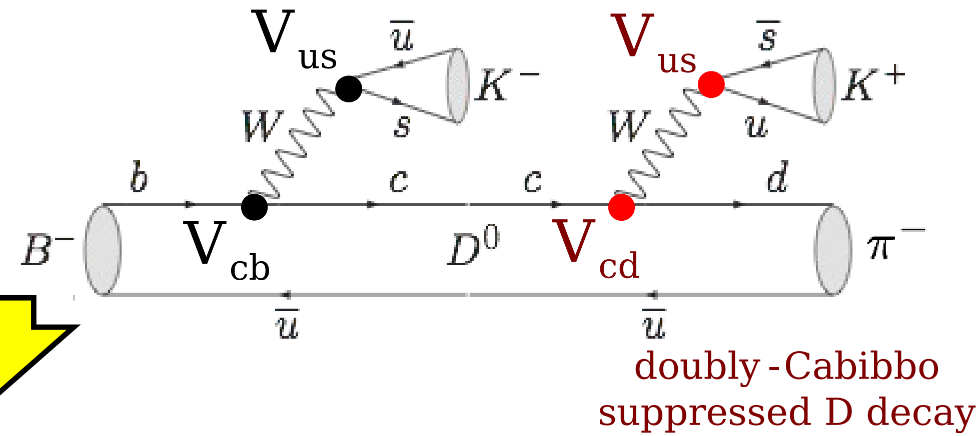


(see also M.T.Schiller's talk)

ADS method: γ via the interference in rare $B^- \to [K^+\pi^-]_D K^-$ decays

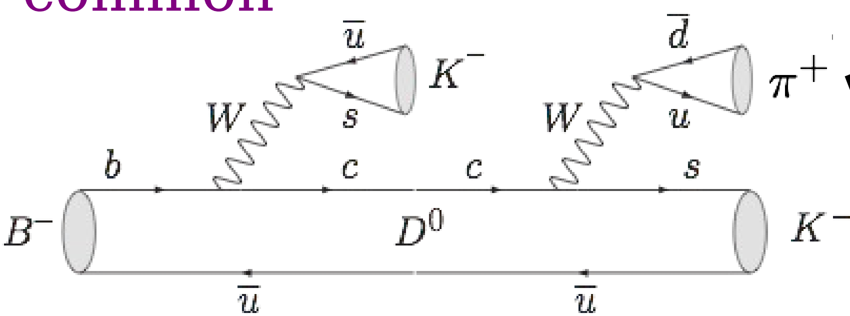
rate and asymmetry (relative to the common decay):





$$\mathcal{R}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) + \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)}$$

common



$$= r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma$$

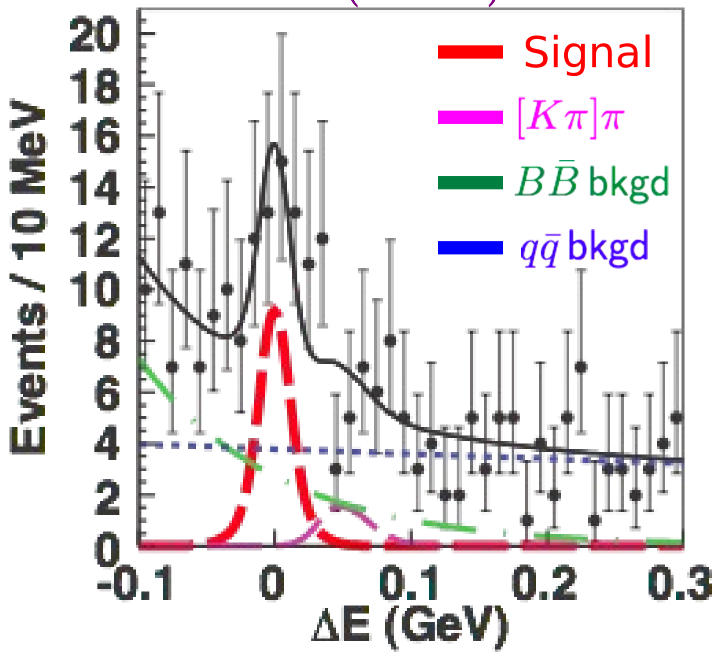
$$\mathcal{A}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) - \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)}$$

$$= 2 r_B r_D \sin(\delta_B + \delta_D) \sin\gamma \;\; / \mathcal{R}_{DK}$$

where $r_D = \left| \frac{\mathcal{A}(D^0 \to K^+\pi^-)}{\mathcal{A}(\bar{D}^0 \to K^+\pi^-)} \right| = 0.0613 \pm 0.0010$

ADS results

PRL 106 (2011) 231803



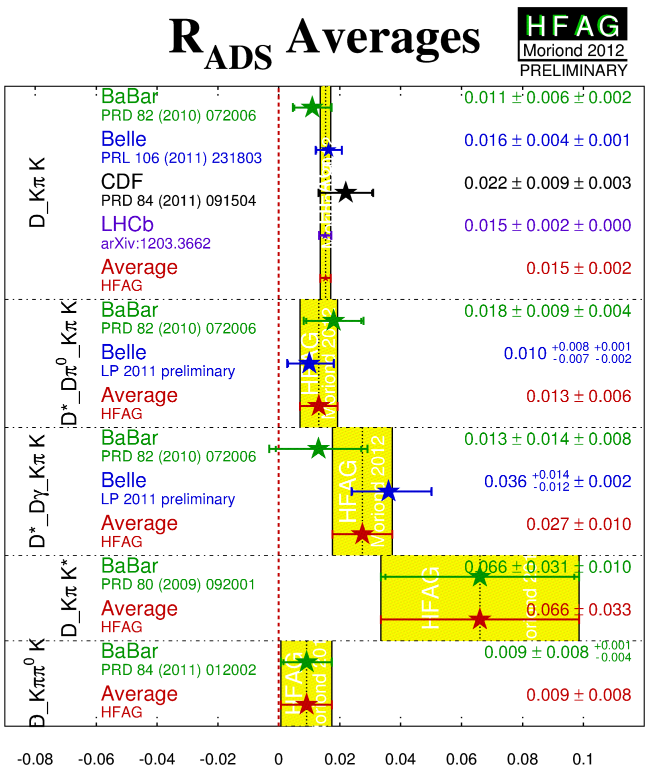
First evidence obtained with a significance of 4.1σ (including syst.)

$$56.0^{+15.1}_{-14.2}\ \text{events}$$

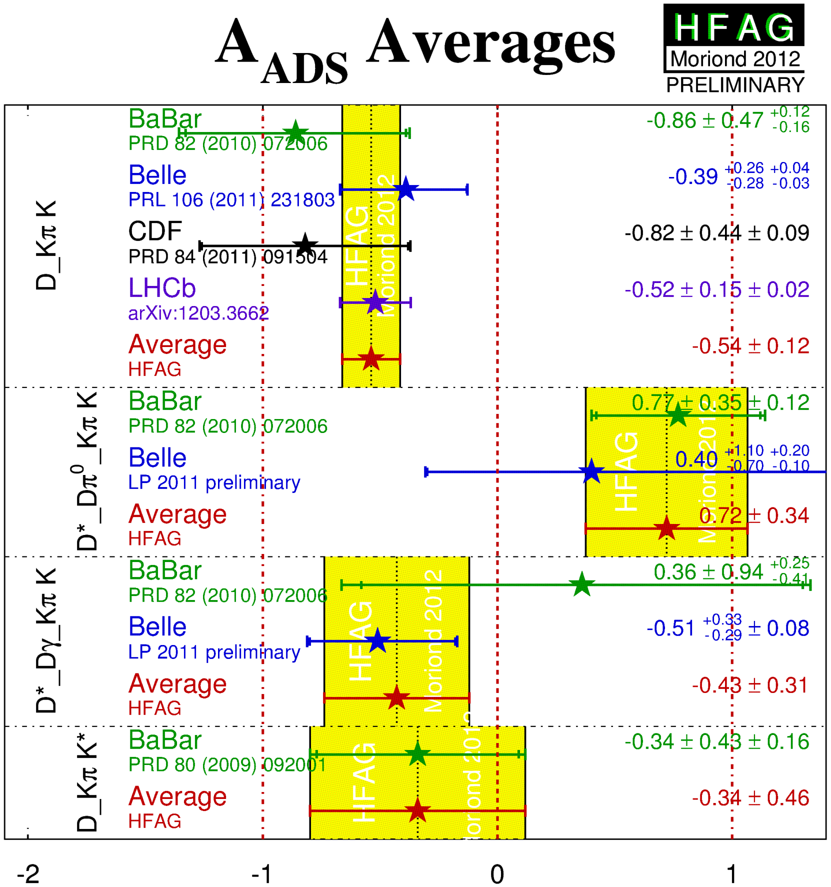
$$R_{DK} = (1.63\,^{+0.44}_{-0.41}\,^{+0.07}_{-0.13}) \times 10^{-2}$$

$$A_{DK} = -0.39\,^{+0.26}_{-0.28}\,^{+0.04}_{-0.03}$$

R_{ADS} Averages



A_{ADS} Averages



First evidence for the ADS mode $B^- \to [K^+\pi^-]_{D^*}K^-$

Preliminary
LP 2011

study both modes: $D^* \to D\pi^0$, $D\gamma$:

Signal seen
with a significance of 3.5σ
for $D^* \to D\gamma$ mode

Ratio to favored mode:

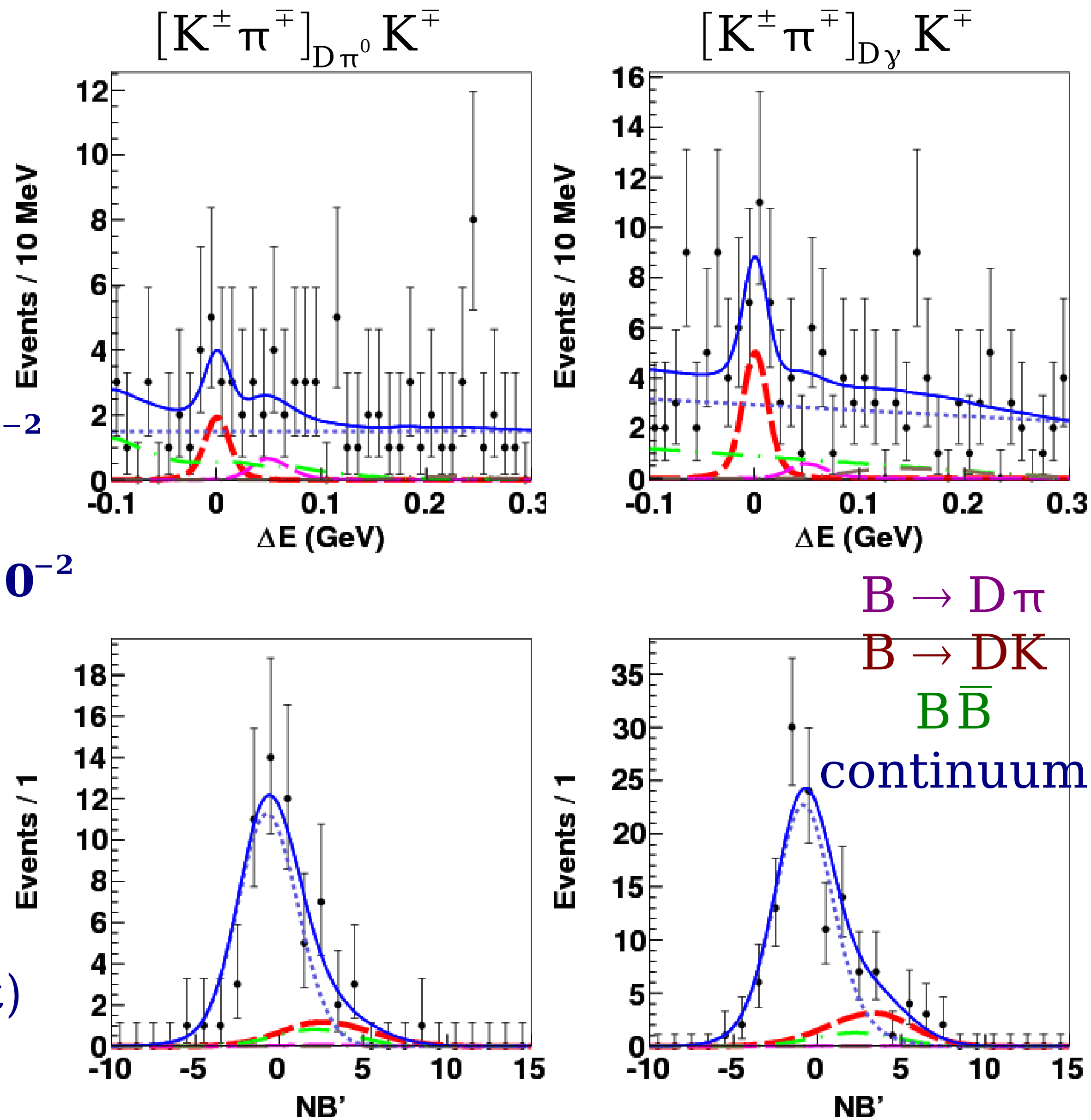
$$R_{D\pi^0} = (1.0\,^{+0.8}_{-0.7}(\text{stat})\,^{+0.1}_{-0.2}(\text{syst})) \times 10^{-2}$$

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

asymmetry:

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

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

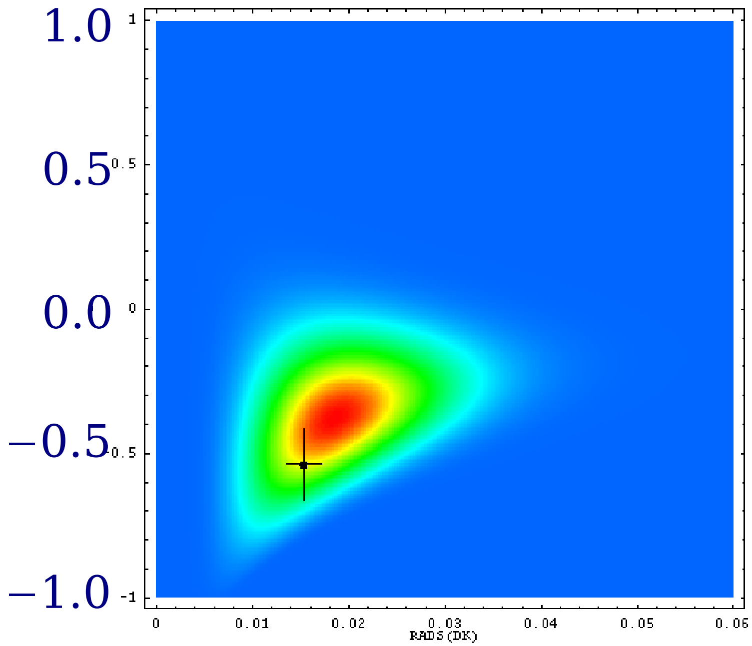


Comparison of the results obtained for $D^{(*)}K$ with expectations

(where ''expectations'' are derived from the GGSZ observables, δ_D)

DK

A_{ADS}



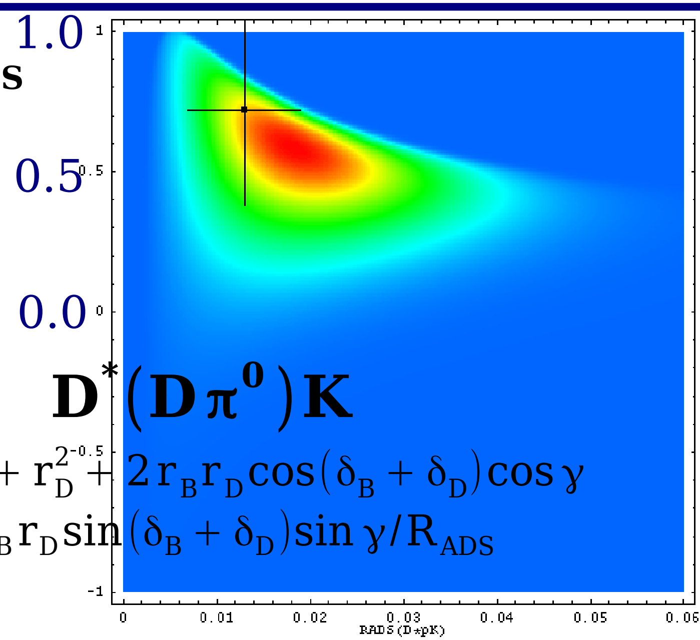
R_{ADS}

$$R_{ADS} = r_B^2 + r_D^2 + 2\,r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$$
$$A_{ADS} = 2\,r_B r_D \sin(\delta_B + \delta_D)\sin\gamma / R_{ADS}$$

D^*K

$D^*(D\pi^0)K$

A_{ADS}

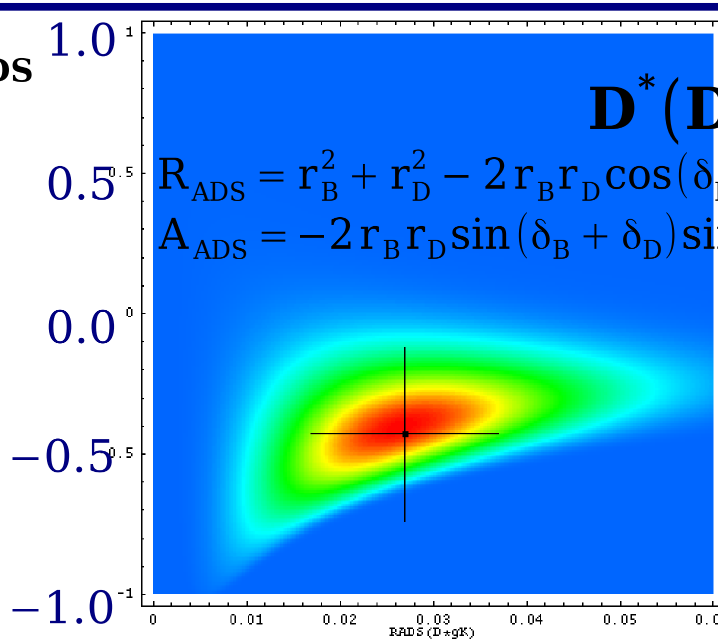


R_{ADS}

$$R_{ADS} = r_B^2 + r_D^2 + 2\,r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$$
$$A_{ADS} = 2\,r_B r_D \sin(\delta_B + \delta_D)\sin\gamma / R_{ADS}$$

$D^*(D\gamma)K$

A_{ADS}

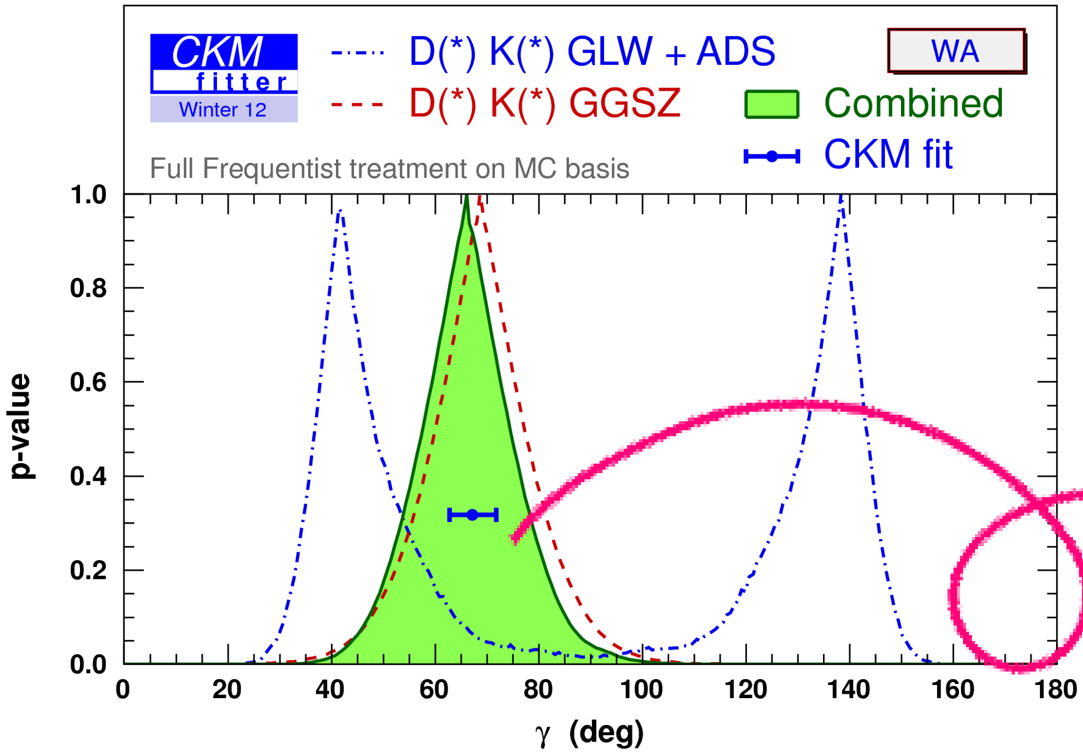


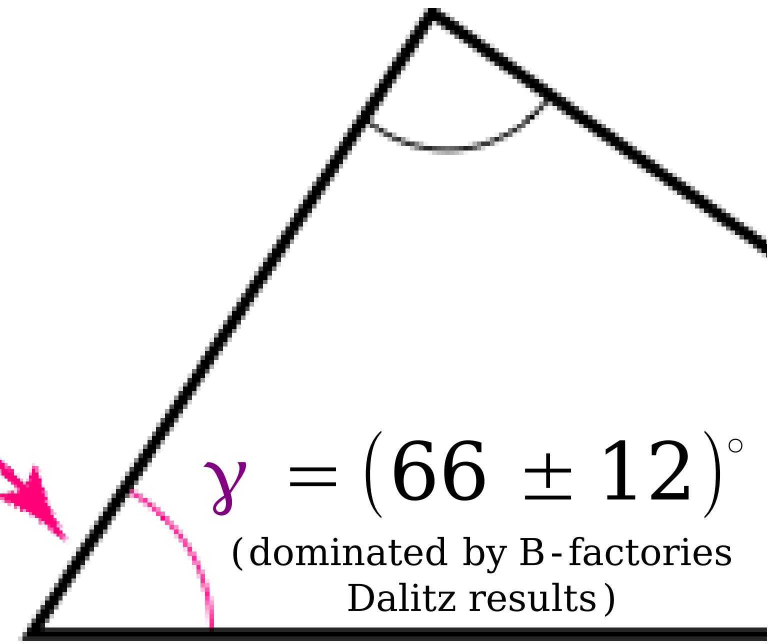
R_{ADS}

$$R_{ADS} = r_B^2 + r_D^2 - 2\,r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$$
$$A_{ADS} = -2\,r_B r_D \sin(\delta_B + \delta_D)\sin\gamma / R_{ADS}$$

Combined measurements for γ from all methods

http://ckmfitter.in2p3.fr/

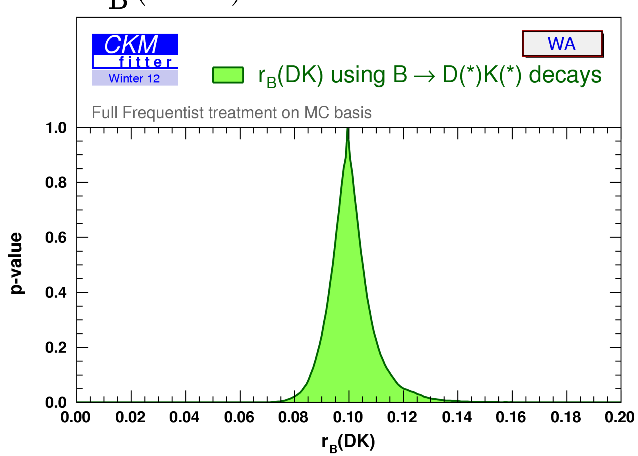




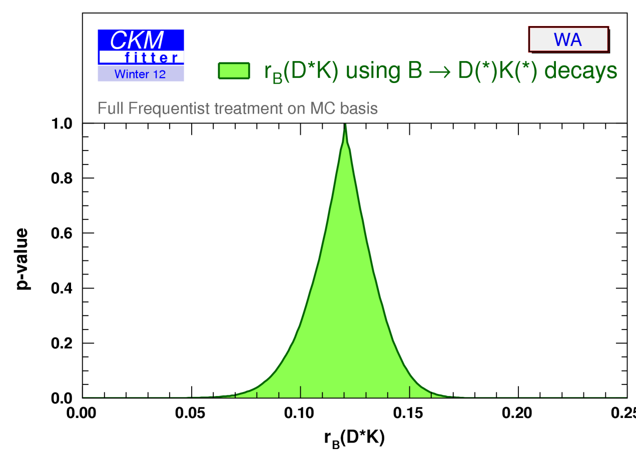
$$\gamma = (66 \pm 12)^{\circ}$$

(dominated by B-factories Dalitz results)

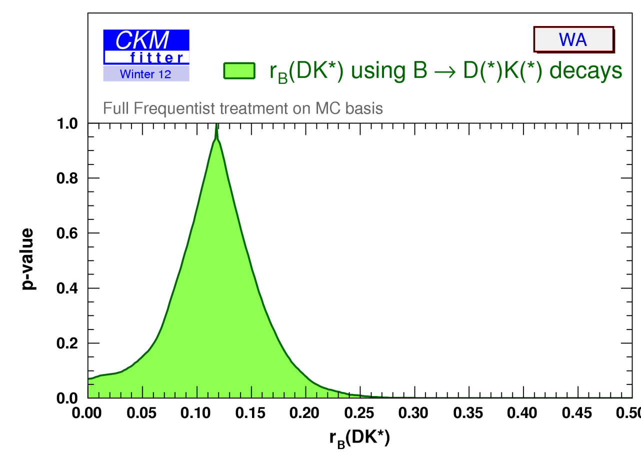
$$r_B(DK) = 0.099 \pm 0.008$$



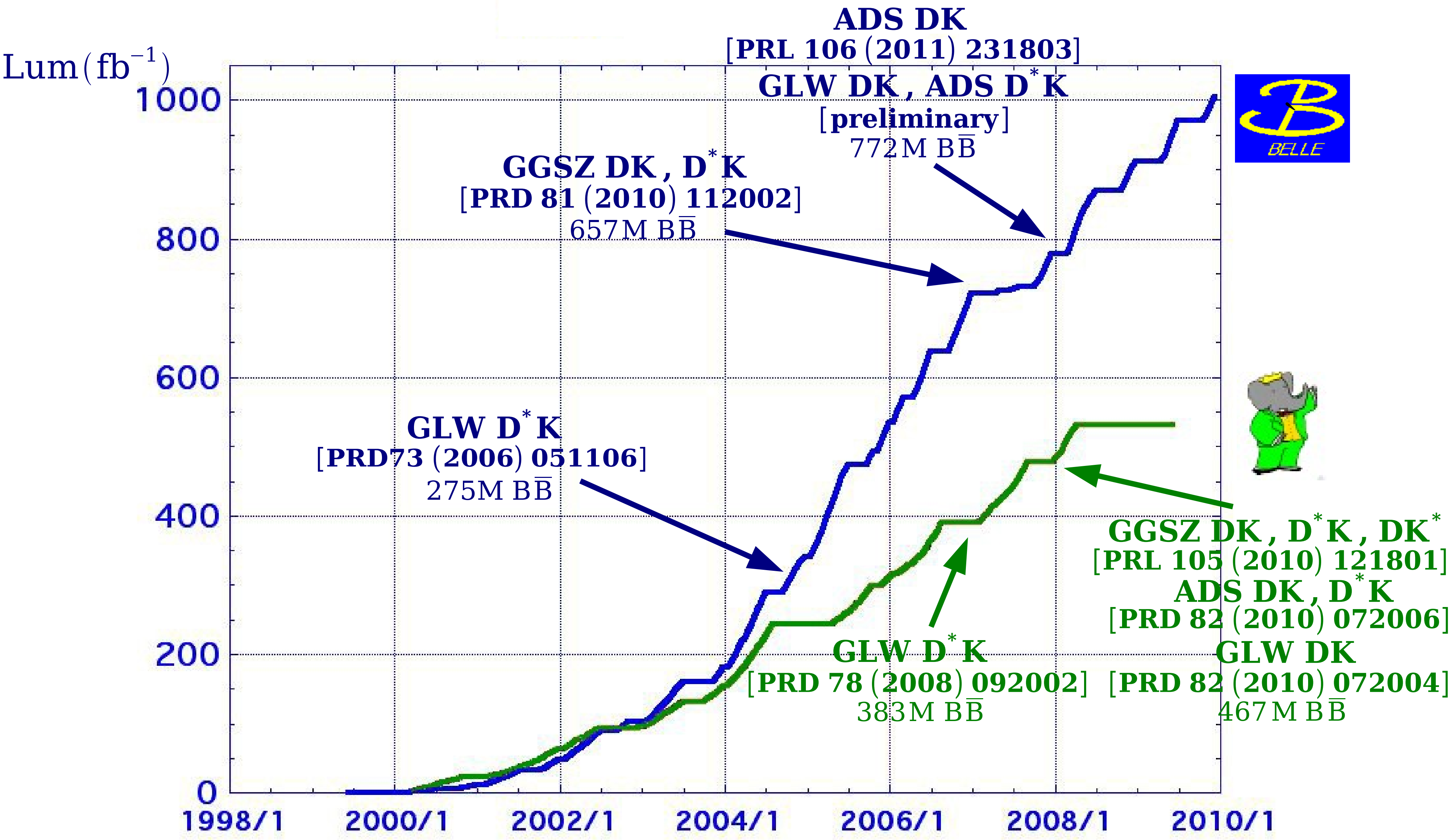
$$r_B(D^*K) = 0.121\,^{+0.018}_{-0.019}$$



$$r_B(DK^*) = 0.118 \pm 0.045$$



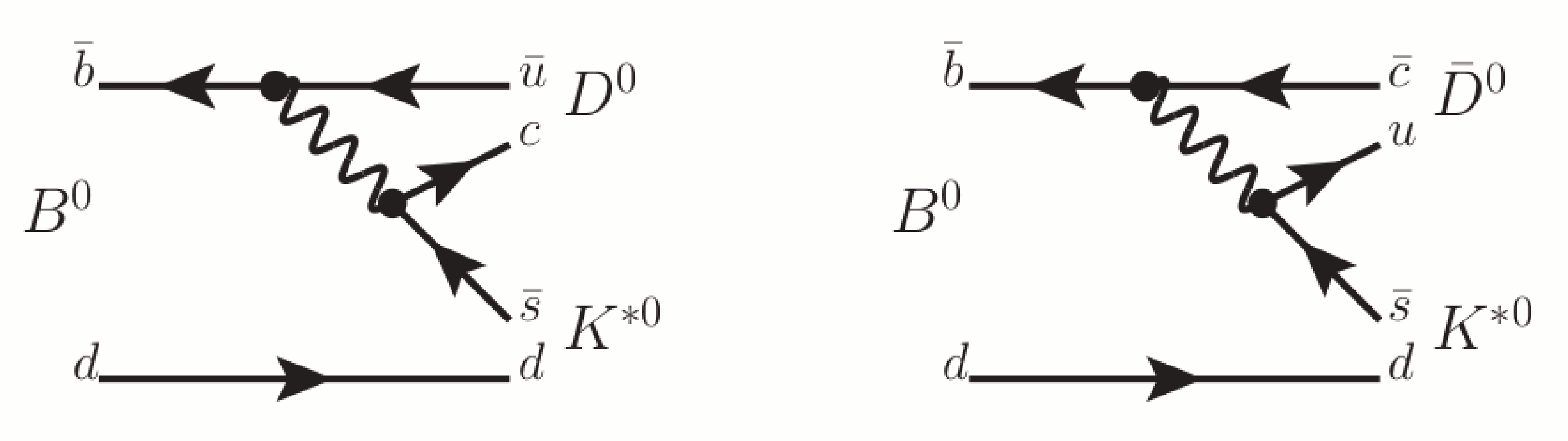
$D^{(*)}K^{(*)\pm}$ measurements related to γ determination



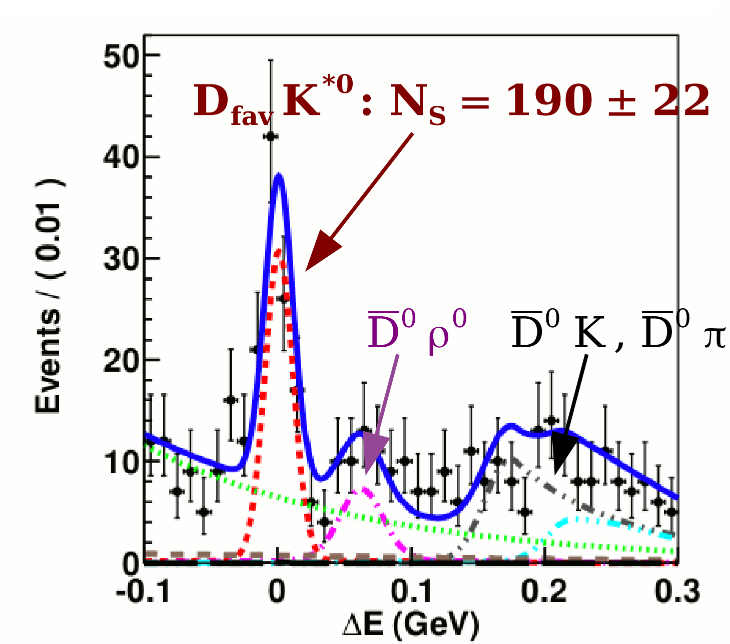
Coming relevant updates from Belle: GLW D^*K, GGSZ $D(K_S KK)K$...

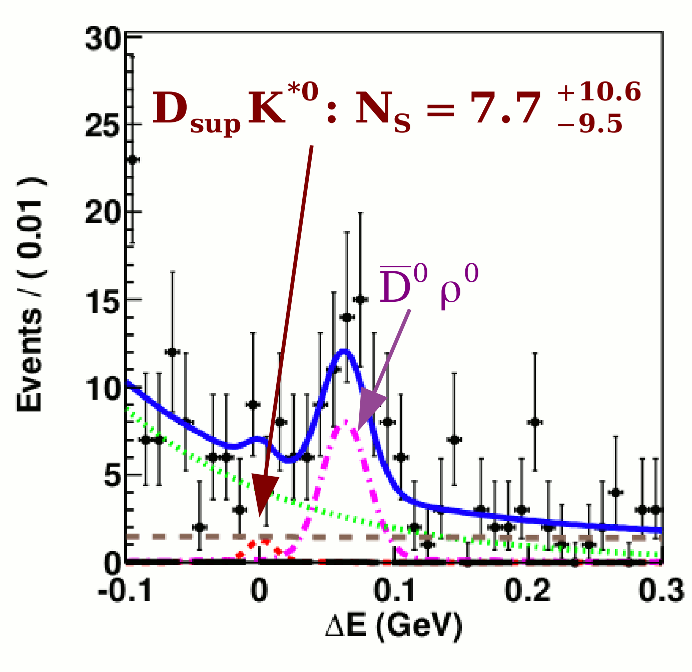
Search for $B^0 \to DK^{*0}$, $D \to K^- \pi^+$

772M $B\bar{B}$
arXiv:1205.0422



$$R_{DK^{*0}} = \frac{\Gamma(B^0 \to [K^- \pi^+]_D K^+ \pi^-)}{\Gamma(B^0 \to [K^+ \pi^-]_D K^+ \pi^-)} = r_S^2 + r_D^2 + 2\,k\,r_S\,r_D \cos(\delta_S + \delta_D)\cos\gamma$$





$R_{DK^{*0}} < 0.16$ @ 95% C.L.

$r_S < 0.4$ @ 95% C.L.

465M $B\bar{B}$
[PRD 80 (2009) 031102]

$R_{DK^{*0}} < 0.24$ @ 95% C.L.

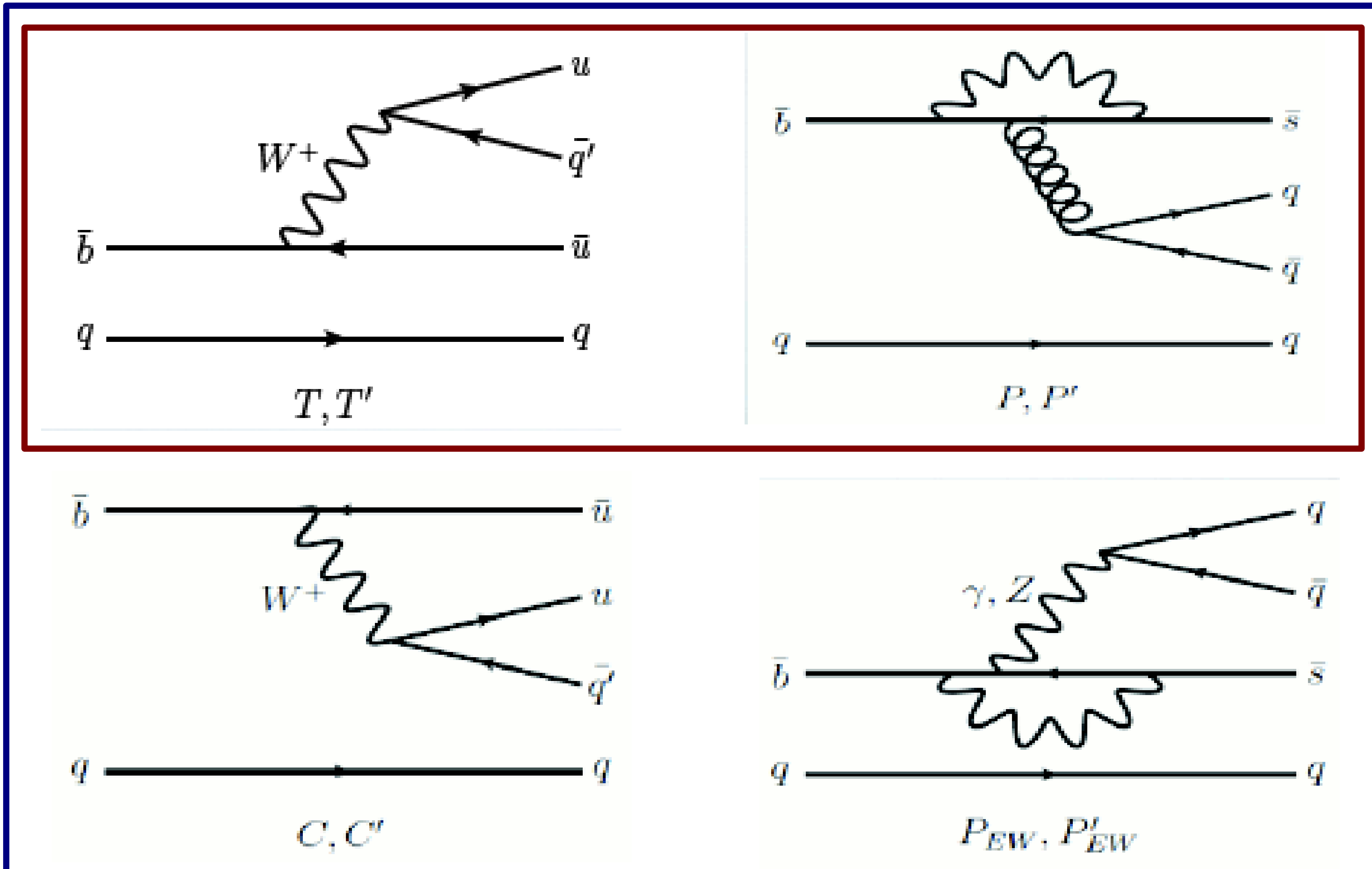
$r_S < 0.41$ @ 95% C.L.

Measuring direct CPV with $B \to K\pi$

$$A_{CP} \equiv \frac{\Gamma(\overline{B}\to\bar{f}) - \Gamma(B\to f)}{\Gamma(\overline{B}\to\bar{f}) + \Gamma(B\to f)} \propto \sin\Delta\phi \ \sin\Delta\delta$$

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

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

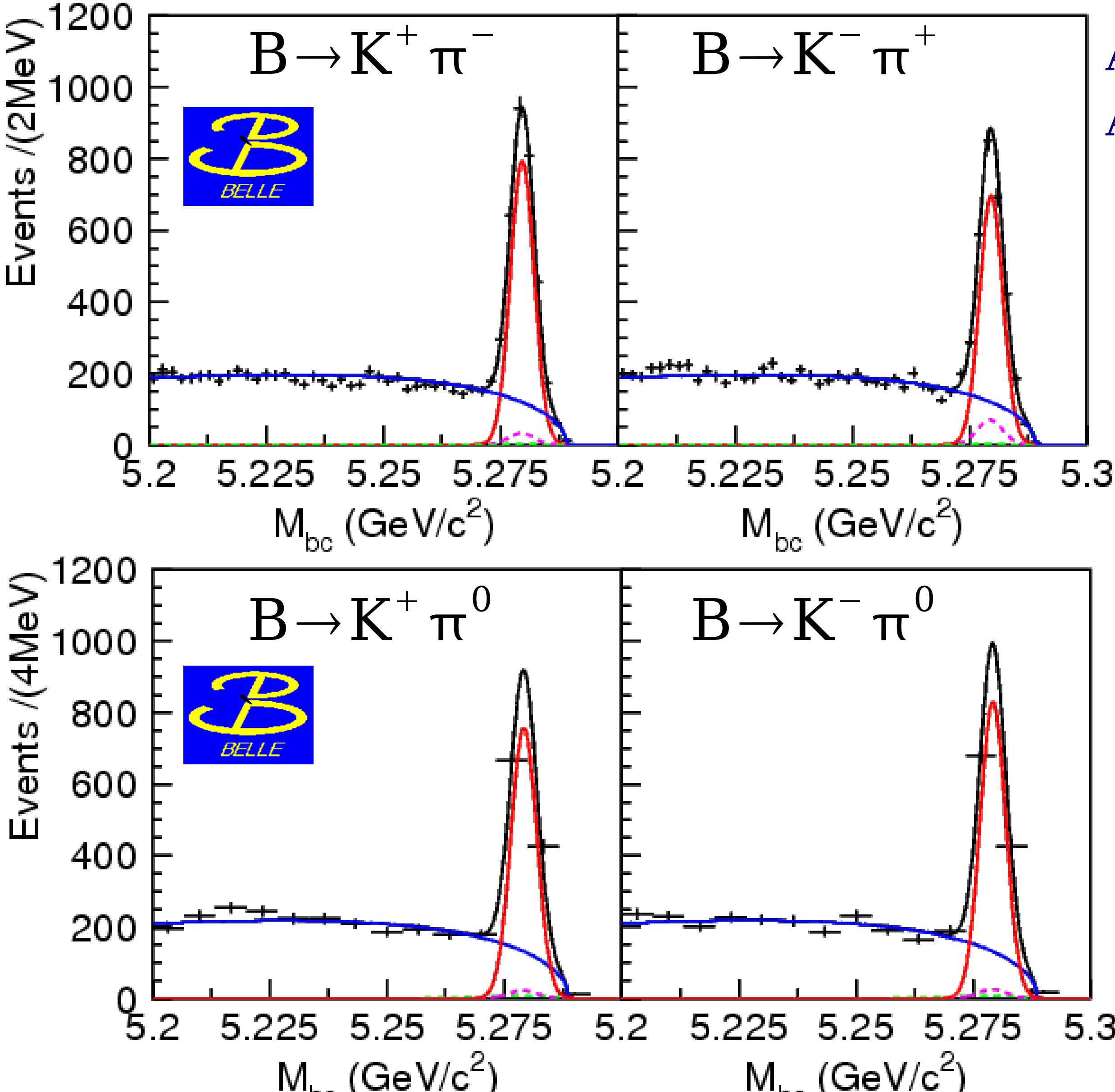


Diagrams identical except for spectator quark ?

$\Rightarrow$ strong and weak phases are the same, A_{CP} should be the same ?

$B \to K\pi$ measurements at B-factories…

$K\pi$ puzzle: $\Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi)$

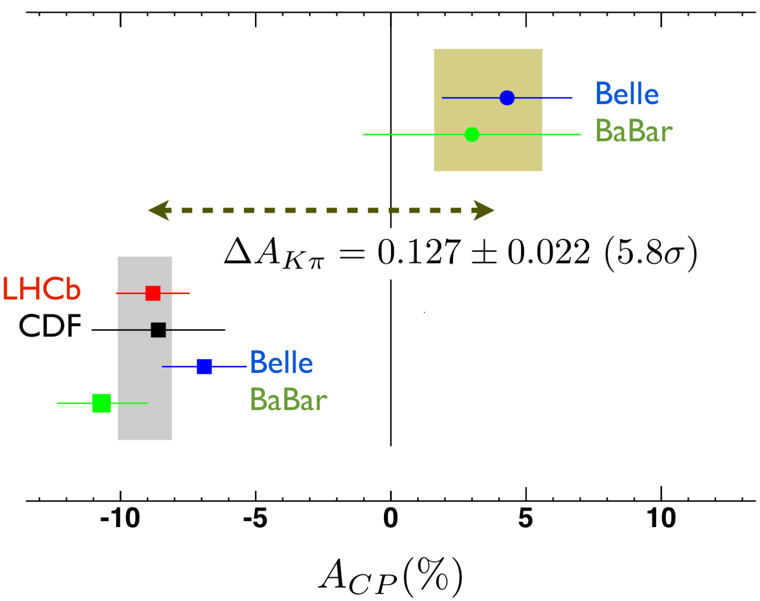


$A_{CP}(K^\pm\pi^0) = +0.043 \pm 0.024 \pm 0.002$

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

Belle preliminary:

$\Delta A_{K\pi} = +0.112 \pm 0.028$ @4.0σ



$\Delta A_{K\pi} = +0.121 \pm 0.022$ @5.5σ

$\Rightarrow$ NEW PHYSICS !!?

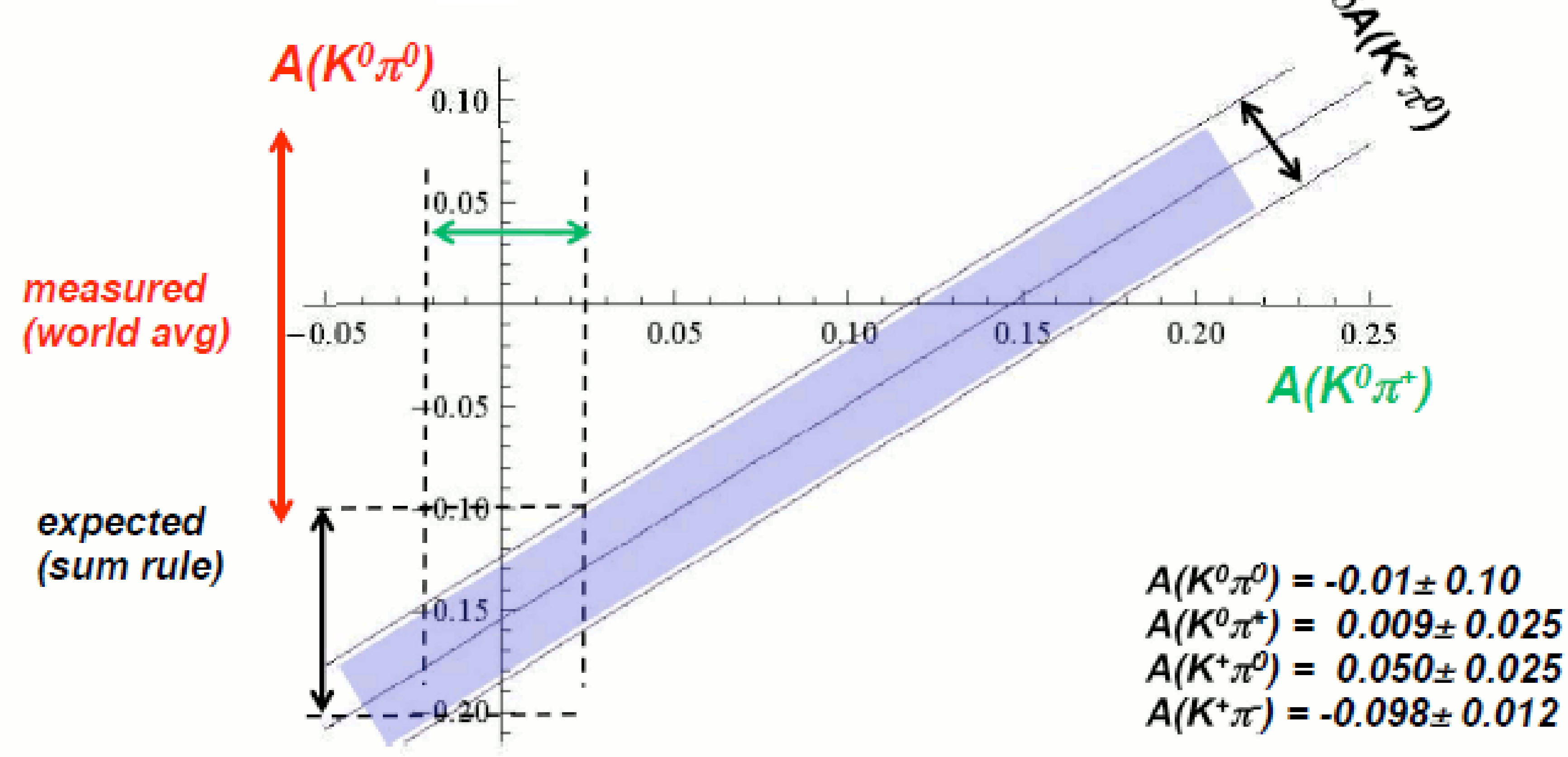
Measuring direct CPV

''Model independent'' sum rule for all four modes:

[Gronau, PLB 627, 82 (2005), Atwood & Soni, PRD 58, 036005 (1998)]

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{Br(K^0\pi^+)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2\,Br(K^+\pi^0)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2\,Br(K^0\pi^0)}{Br(K^+\pi^-)}$$

B factories now (~1.4 ab^{-1}):



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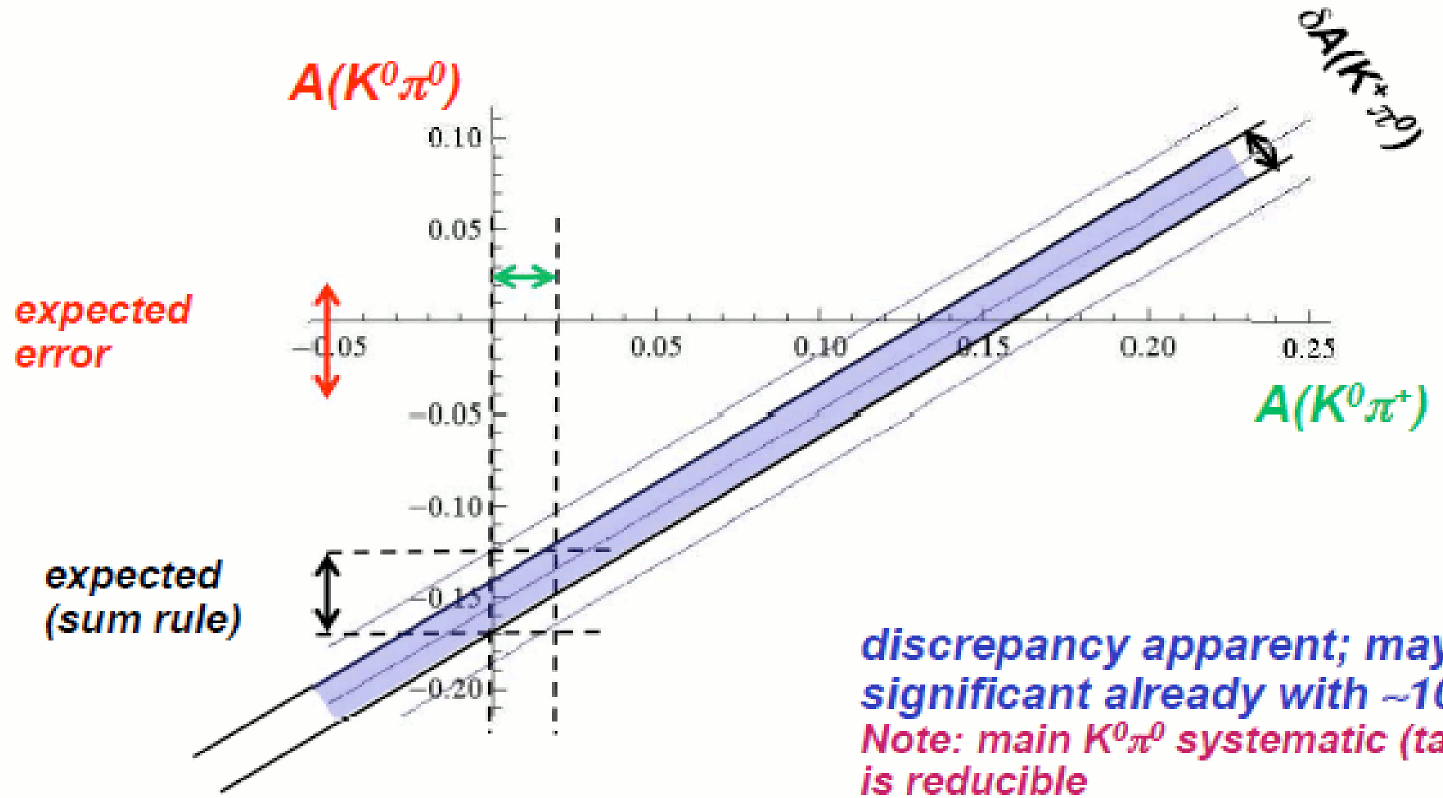
B factory at 50 ab^{-1}, with today's central values:



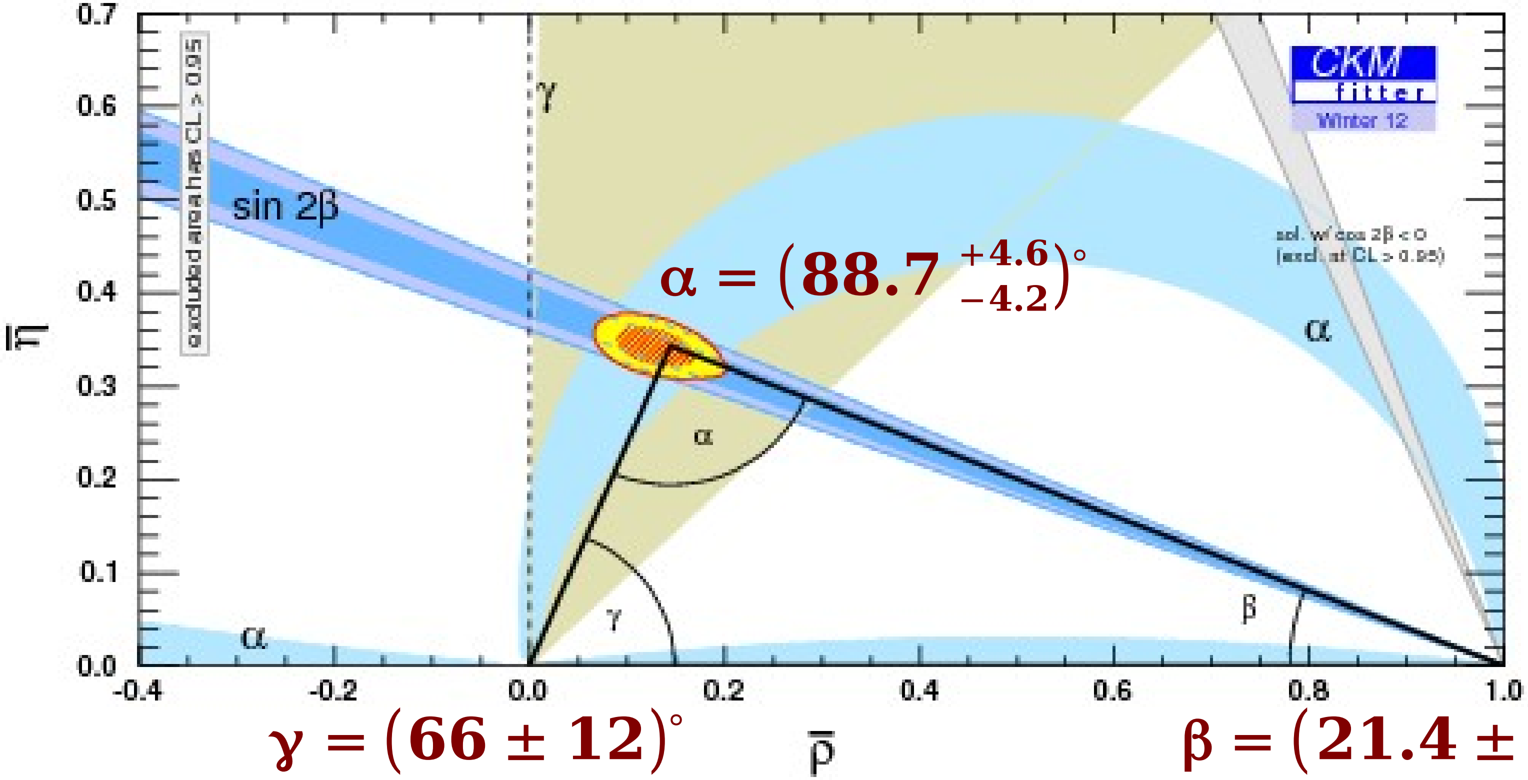
discrepancy apparent; may be significant already with ~10 ab^{-1}

Note: main $K^0\pi^0$ systematic (tag-side interference) is reducible

⇒ ideal for a super B-factory...

Summary

- B-factories have provided (most of) the current picture:



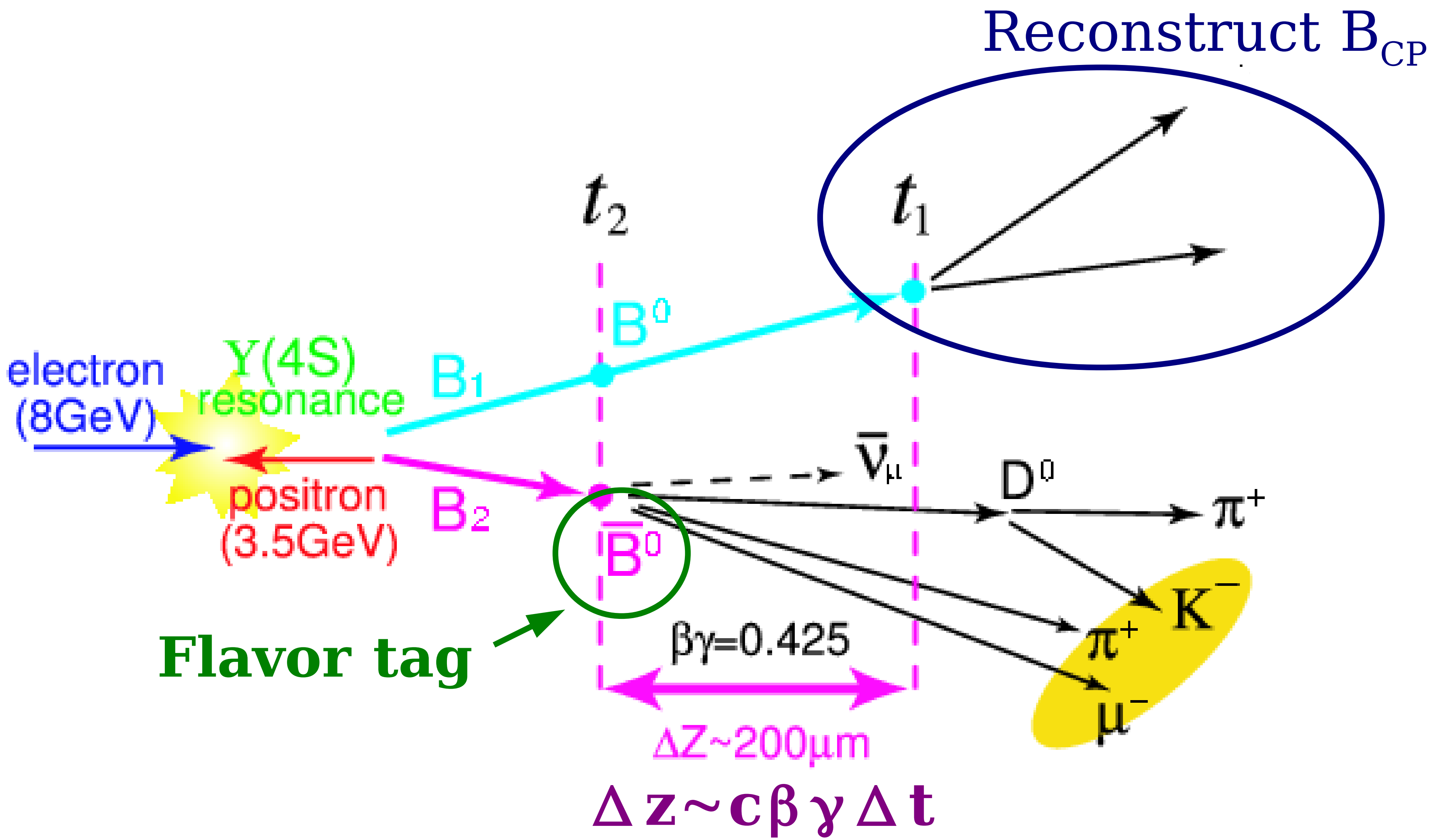
$\alpha = (88.7\,^{+4.6}_{-4.2})^\circ$

$\gamma = (66 \pm 12)^\circ$ $\beta = (21.4 \pm 0.8)^\circ$

- still few interesting updates in the pipeline (especially on α and γ)
  - new Belle result shown today on $B \to a_1^\pm \pi^\mp$
- B-factories $\to$ LHCb, Super B-factories

Backup slides

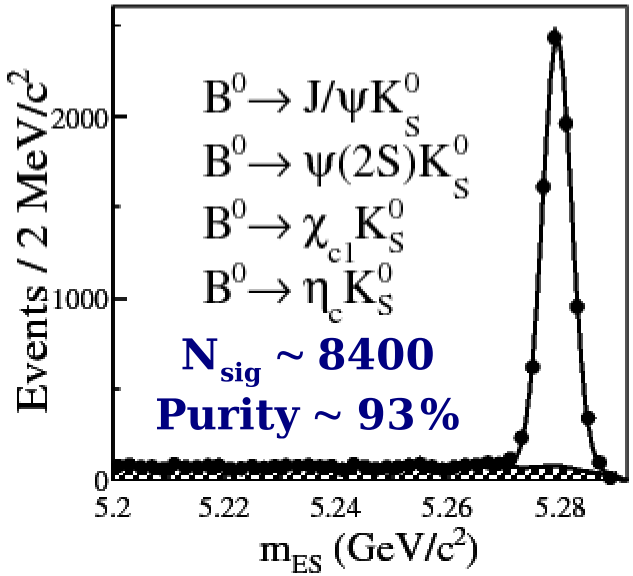
Measuring the CP parameters **S** and **A**

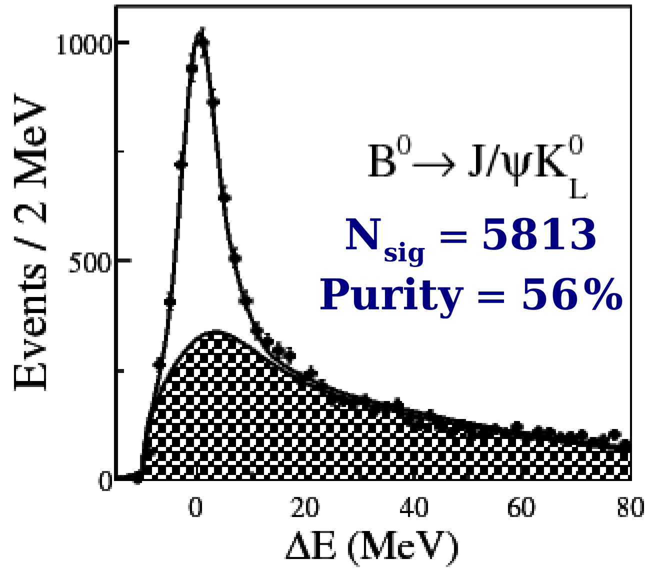


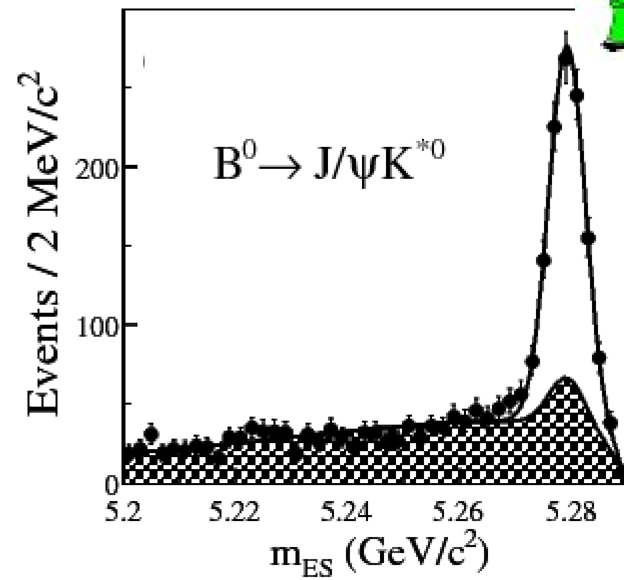
$$\frac{dP_{sig}}{dt}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left(1 + q\left(S \sin(\Delta m_d \Delta t) + A \cos(\Delta m_d \Delta t)\right)\right)$$

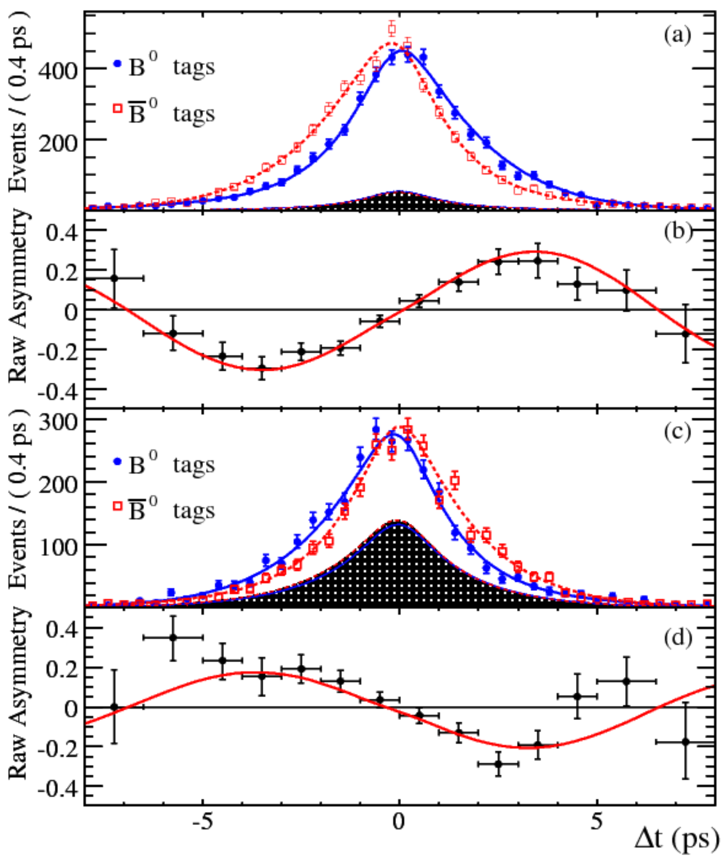
$\sin 2\beta$ in $(c\bar{c})\,K^{(*)0}$

$465 \times 10^6\ B\bar{B}$ pairs
[PRD 79 (2009) 072009, arXiv:0902.1708]









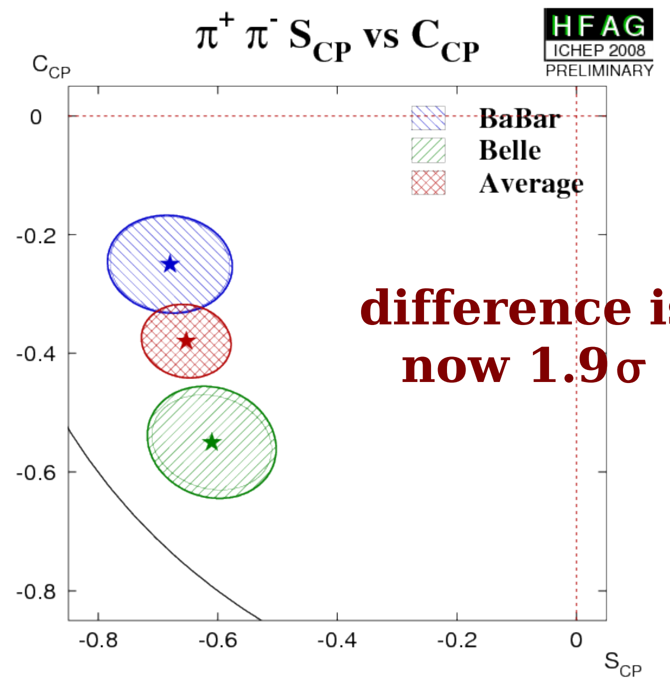
Mode	$\sin 2\beta$
$J/\psi K_S$	$0.657 \pm 0.036 \pm 0.012$
$J/\psi K_L$	$0.694 \pm 0.061 \pm 0.031$
$J/\psi K^0$	**$0.666 \pm 0.031 \pm 0.013$**
$\psi(2S) K_S$	$0.897 \pm 0.100 \pm 0.036$
$\chi_{c1} K_S$	$0.614 \pm 0.160 \pm 0.040$
$\eta_c K_S$	$0.925 \pm 0.160 \pm 0.057$
$J/\psi K^{*0}$	$0.601 \pm 0.239 \pm 0.087$
$c\bar{c}K^{(*)0}$	**$0.687 \pm 0.028 \pm 0.012$**

ϕ_2: $\pi\pi$ system

$535 \times 10^6\ B\bar{B}$ **pairs**
PRL 98, 221801(2007)

$C = -0.55 \pm 0.08 \pm 0.05$
$S = -0.61 \pm 0.10 \pm 0.04$

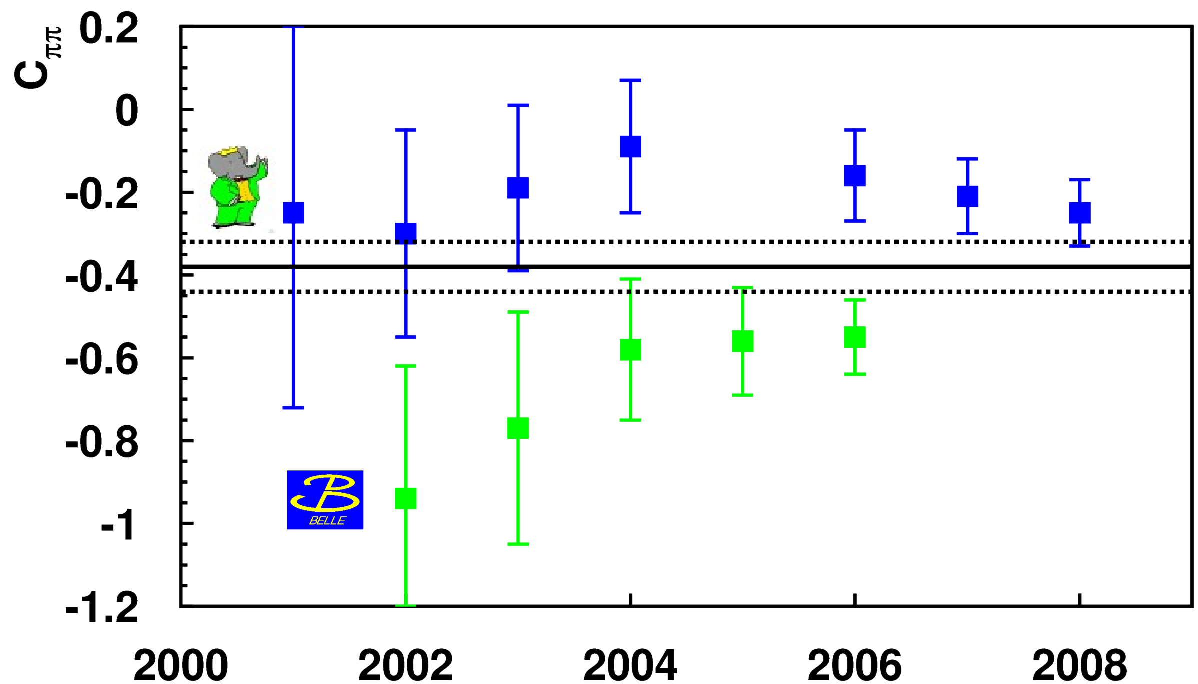
direct CPV @ 5.5σ



difference is now 1.9σ

$467 \times 10^6\ B\bar{B}$ **pairs**
ArXiv:0807.4226

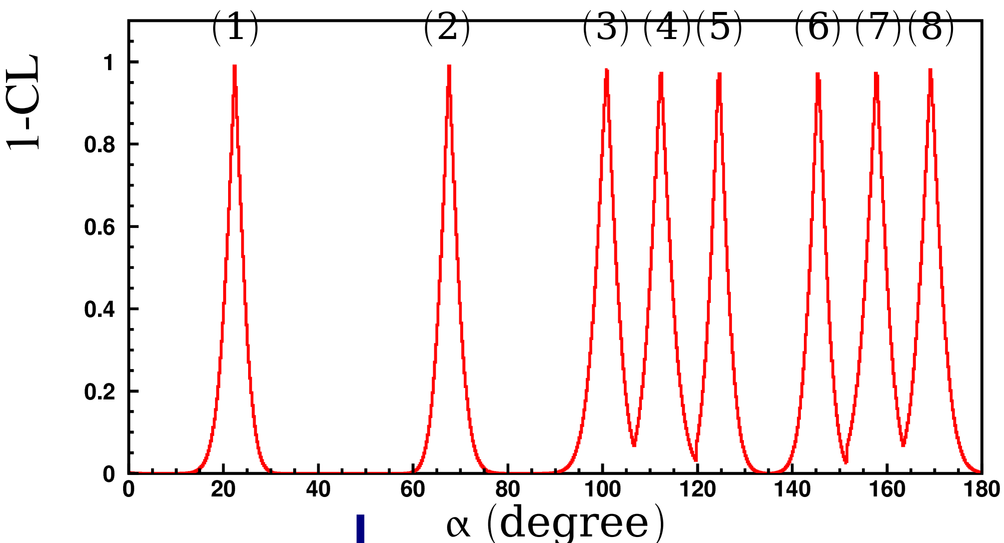
$C = -0.25 \pm 0.08 \pm 0.02$
$S = -0.68 \pm 0.10 \pm 0.03$

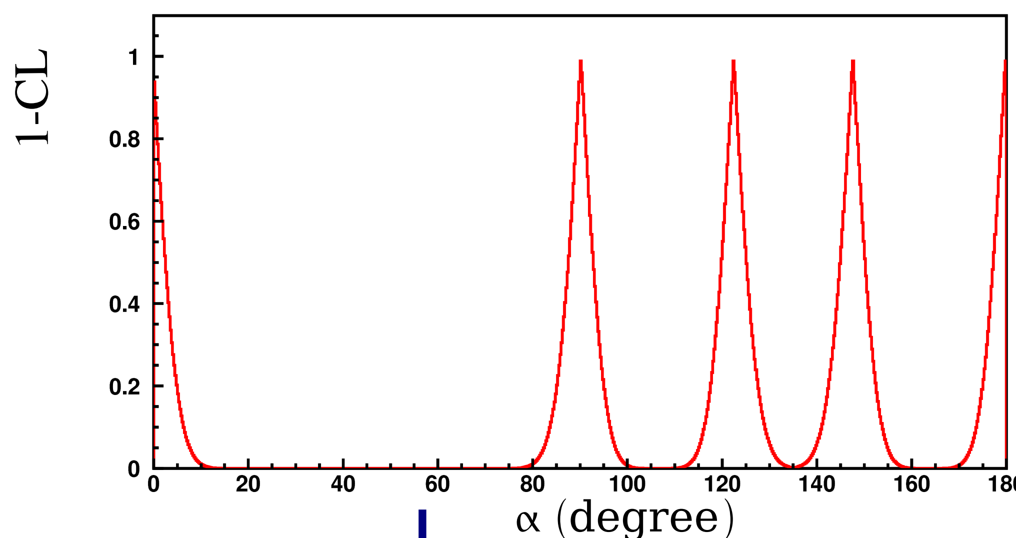


Some examples to illustrate ϕ_2 extraction

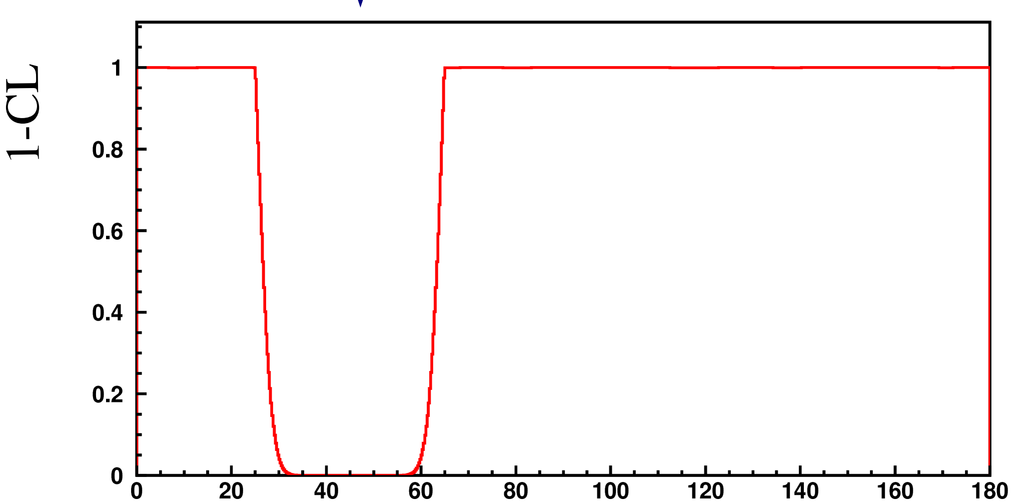
$Br(\pi^+\pi^-) = (5.0 \pm 0.2)\times10^{-6}$
$Br(\pi^0\pi^0) = (1.5 \pm 0.1)\times10^{-6}$
$Br(\pi^+\pi^0) = (3.5 \pm 0.2)\times10^{-6}$
$C(\pi^+\pi^-) = -0.40 \pm 0.03$
$S(\pi^+\pi^-) = -0.50 \pm 0.04$
$C(\pi^0\pi^0) = -0.30 \pm 0.10$

$\boxed{\begin{array}{l} Br(\pi^+\pi^-) = (2.0 \pm 0.2)\times10^{-6} \\ Br(\pi^0\pi^0) = (0.5 \pm 0.1)\times10^{-6} \end{array}}$
$Br(\pi^+\pi^0) = (3.5 \pm 0.2)\times10^{-6}$
$C(\pi^+\pi^-) = -0.40 \pm 0.03$
$S(\pi^+\pi^-) = -0.50 \pm 0.04$
$C(\pi^0\pi^0) = -0.30 \pm 0.10$

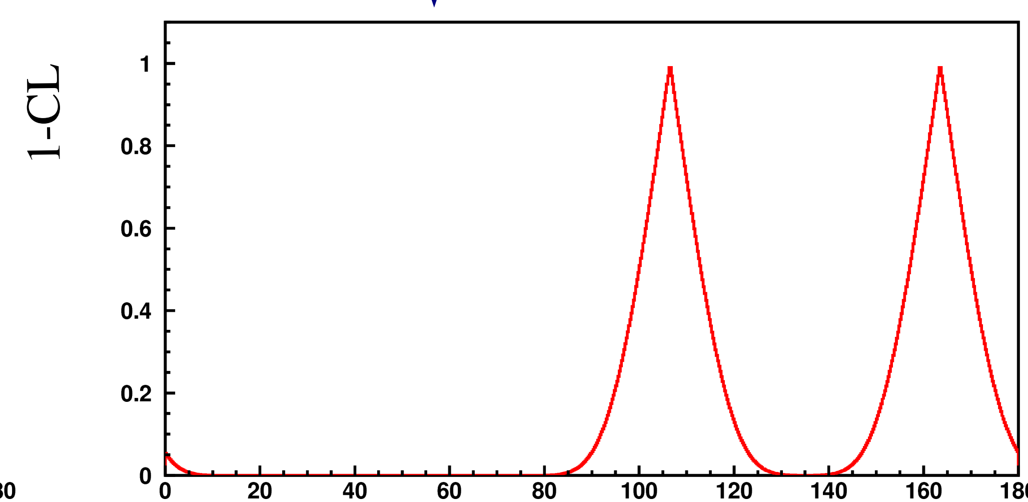




no $C(\pi^0\pi^0)$

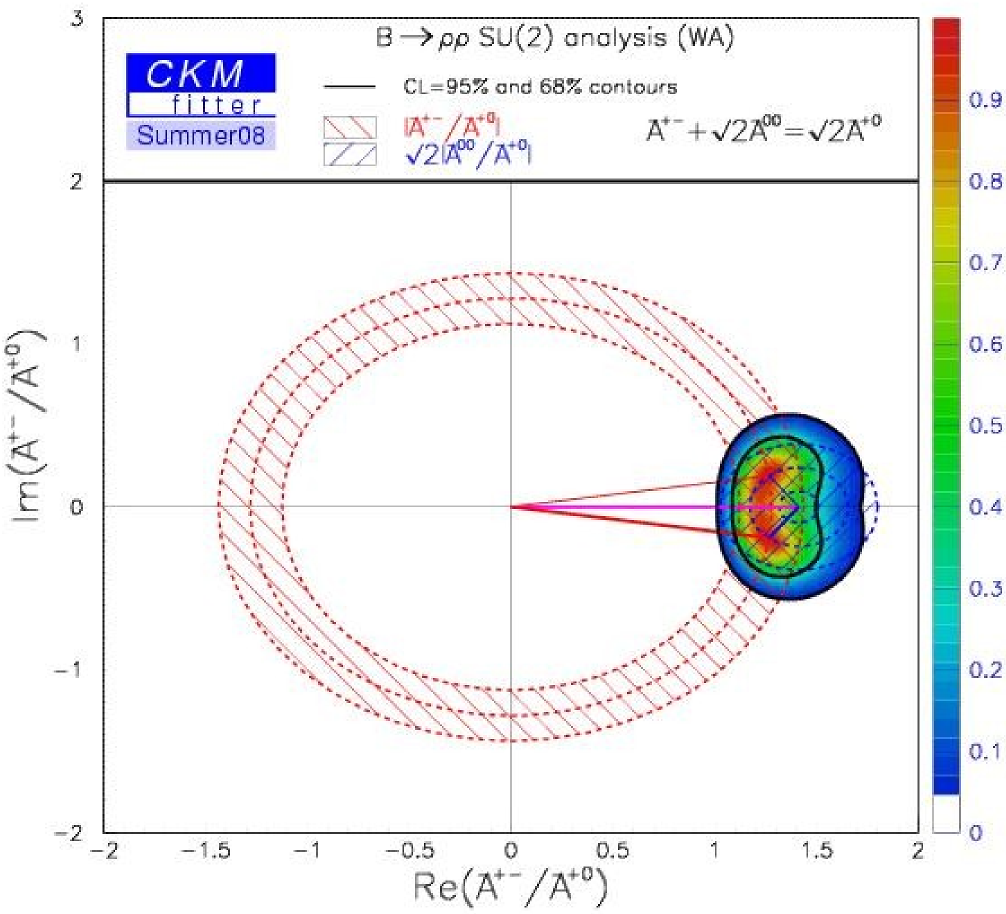


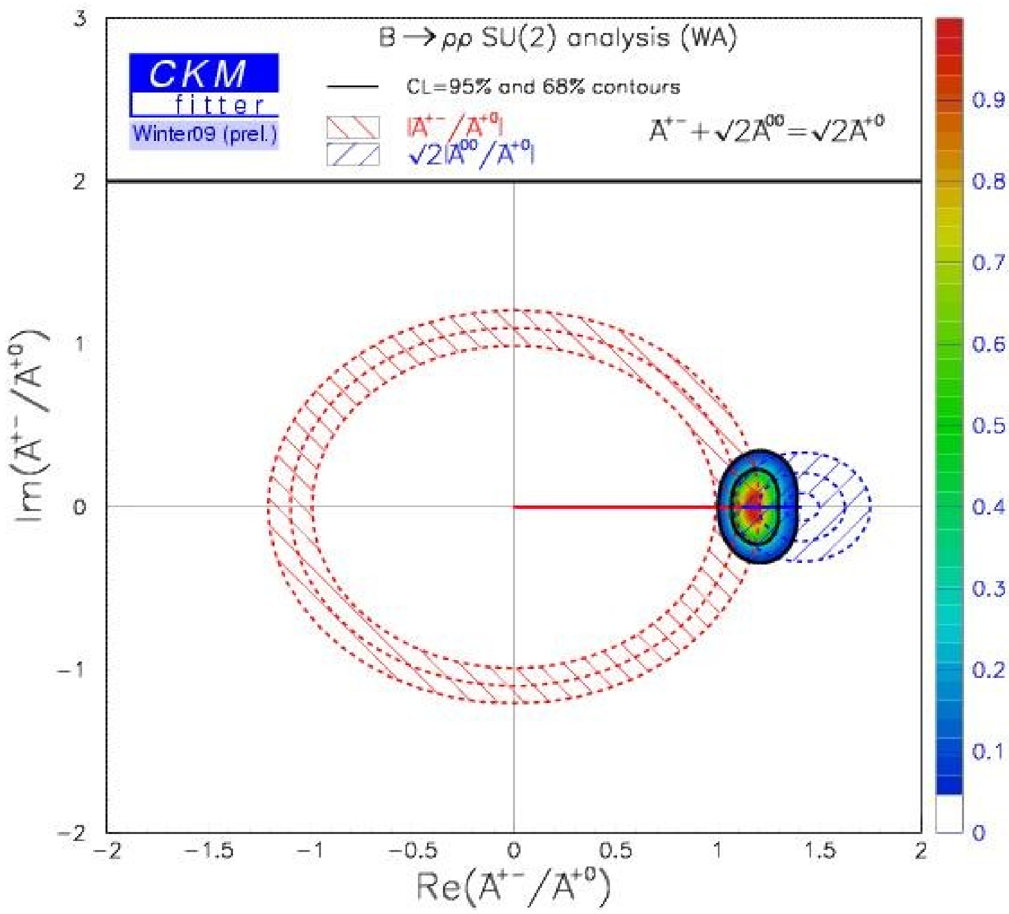
no $C(\pi^0\pi^0)$



Isospin triangles (Summer 08 to Winter 09)

$B \to \rho\,\rho$ case

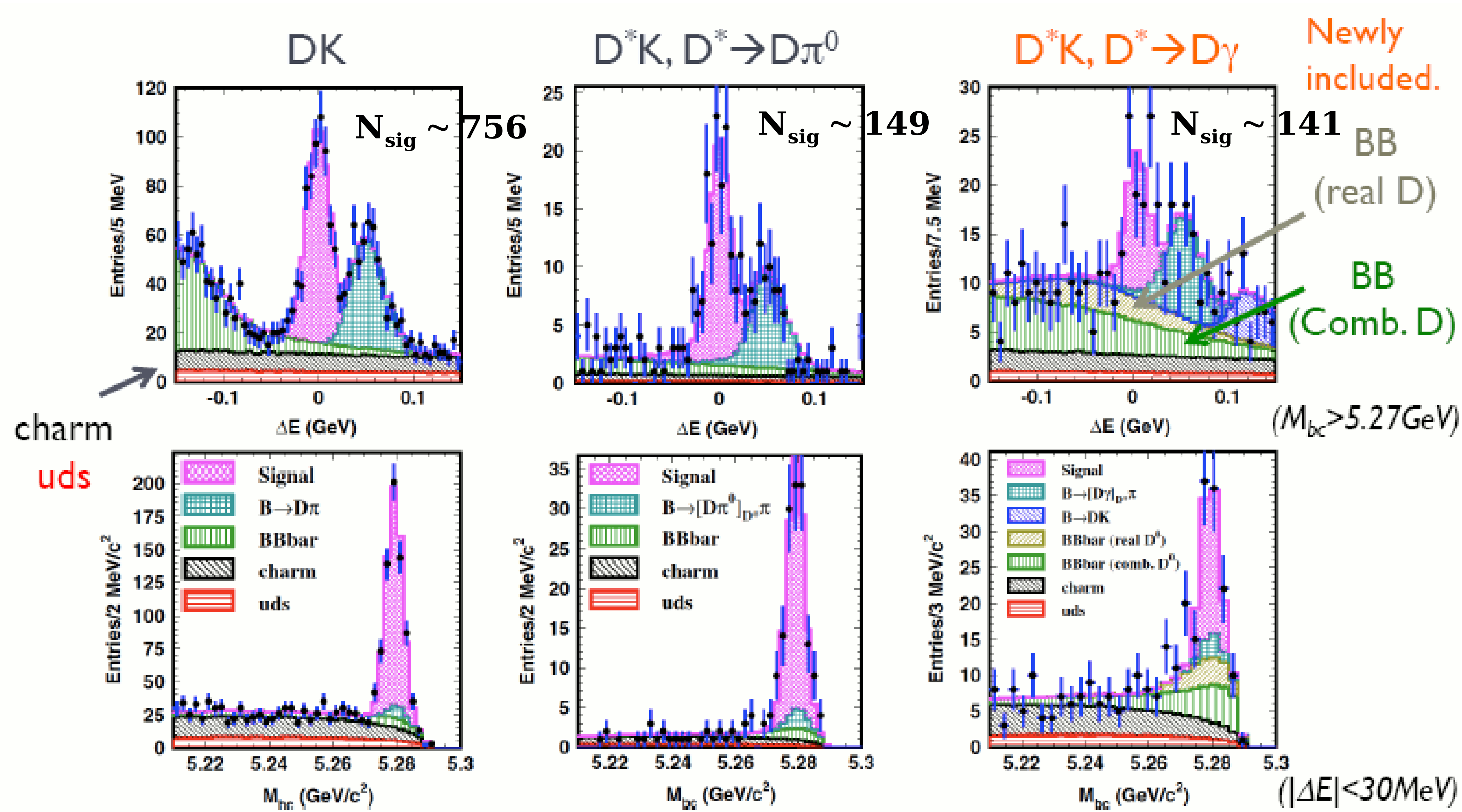




$B^- \to D^{(*)}(K_S \pi\pi) K^-$ Dalitz, ΔE and M_{bc} projections

$|\cos\theta_{thr}| < 0.8$ and $F > -0.7$

PRD 81, 112002 (2010)
657×10^6 $B\bar{B}$ pairs



$B \to Dh$, $D \to K\pi \;\to\; R_{D_{fav}}$

$$\boxed{\begin{aligned}
N^{DK}_{\eta,\,KID>0.6} &= \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\; R_{K/\pi}\;\epsilon \\
N^{DK}_{\eta,\,KID<0.6} &= \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\; R_{K/\pi}\;(1-\epsilon) \\
N^{D\pi}_{\eta,KID>0.6} &= \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\;\kappa \\
N^{D\pi}_{\eta,KID<0.6} &= \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\;(1-\kappa)
\end{aligned}}$$

	kaon fake (1-ϵ)	kaon eff ϵ	pion eff (1-κ)	pion fake κ	
MC	14.70 ± 0.06	85.41 ± 0.06	95.42 ± 0.03	4.47 ± 0.03	⇐
data	15.86 ± 0.40	84.32 ± 0.39	92.13 ± 0.46	7.94 ± 0.31	

Table 5: Efficiency and fake rate (in %) for kaon and pion, for data and MC. ϵ will be fixed in the fit but κ will be floated (see text for further explanations). These numbers are obtained after properly weighting the values provided by PID group for SVD1 and SVD2.

$\Rightarrow\ \kappa = (4.58 \pm 0.10)\%$ in the MC fit

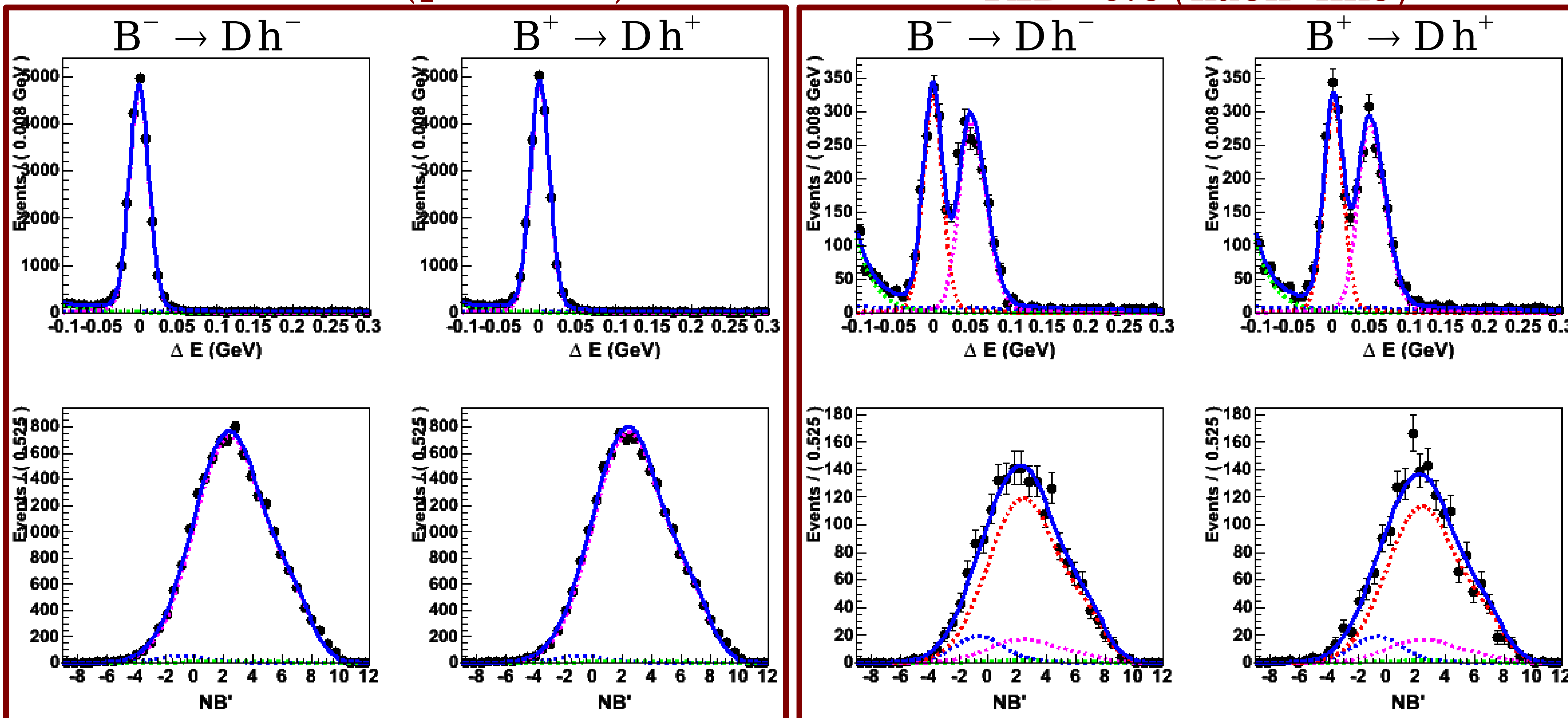
$B \to Dh,\ D \to K\pi \ \to \ R_{D_{fav}}$

Preliminary
LP 2011

$(772\ \mathrm{M} B\bar{B})$
$B \to D\pi$
$B \to DK$
$B\bar{B}$
continuum

Yields	$\mathbf{B \to D\pi}$	$\mathbf{B \to DK}$
$\mathbf{D \to K\pi}$	50432 ± 243	3692 ± 83

KID<0.6 (pion-like) **KID>0.6 (kaon-like)**



$\Rightarrow\ R_{D_{fav}} = (7.32 \pm 0.16)\%,\ \ A(DK) = (1.4 \pm 2.0)\%$

$B^- \to DK^-,\ D \to K^+\pi^-$ ADS

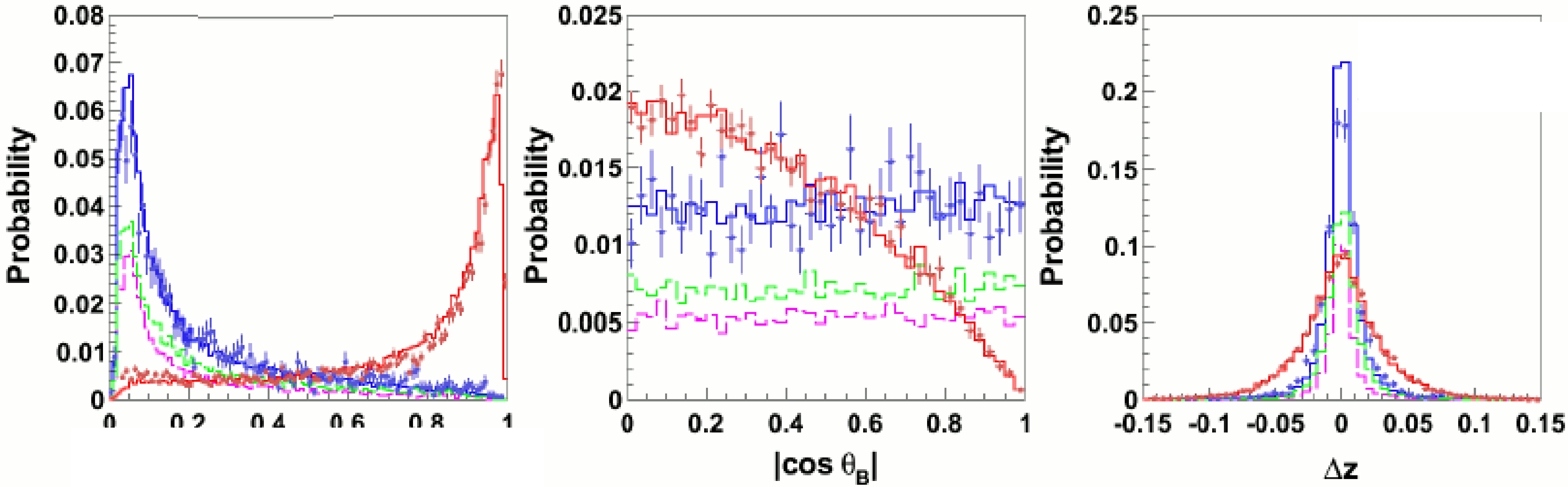
Main background is $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) continuum

combine 10 variables with neural network:

- Variables which have different distributions for signal and $q\bar{q}$ background are used.

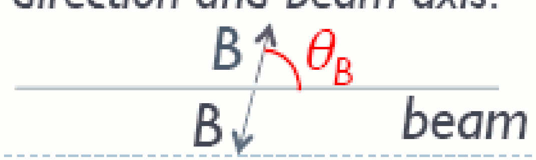
$B^- \to D\pi^-$
$\to K^-\pi^+$
M_{bc}-sideband

histogram: MC, dots: data
signal
qq = charm + uds

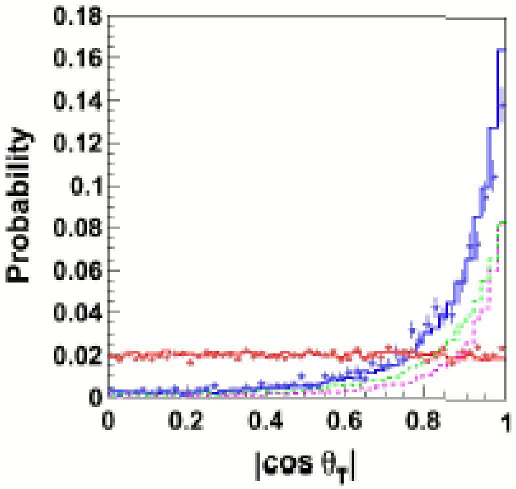


(Here, we use "old" package.)
(RooKSFW is also possible.)
Most powerful.

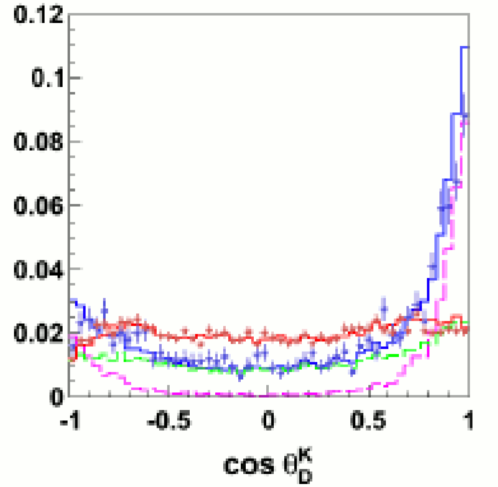
θ_B is angle between B-flight direction and beam axis.



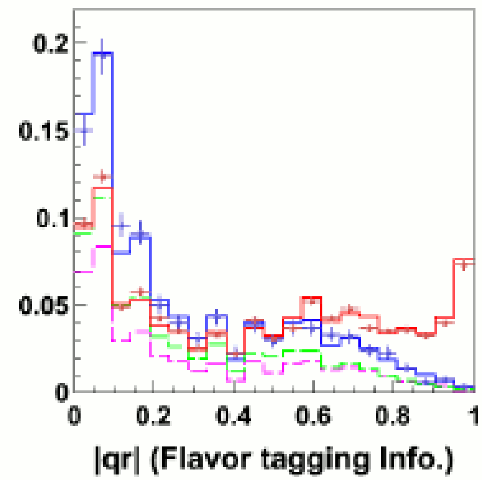
If tag is not possible, Δz = -999.
NB deals with as a δ-function.



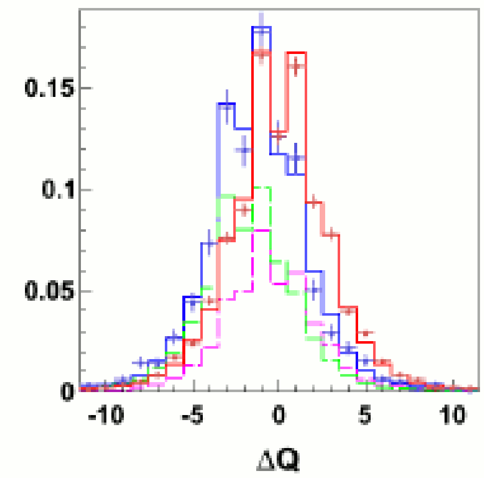
Angle between thrust axes of B decay and remainder.
No full correlation to LR(KSFW).



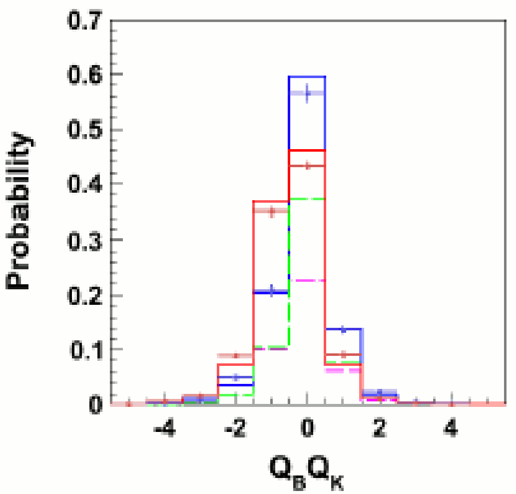
Decay angle of $D \rightarrow k\pi$.



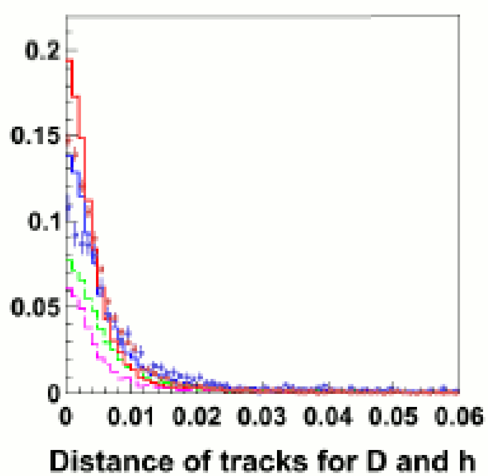
Flavor tagging Info. by MDLH. (NB possible.)



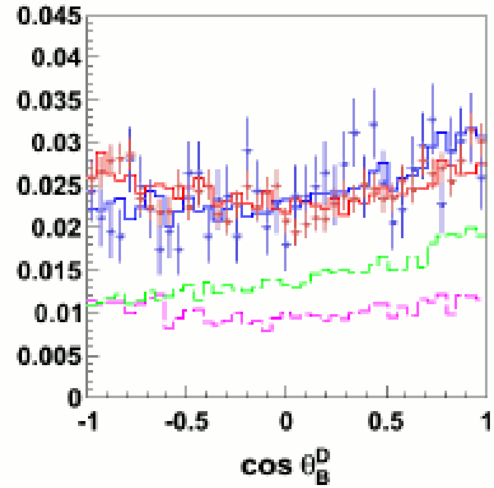
Difference of charges in D hemisphere and opposite hemisphere.



Product of charge of B and sum of charges for K not used in B reconstruction.



Distance of tracks for D and K.



Decay angle of $B \rightarrow DK$.

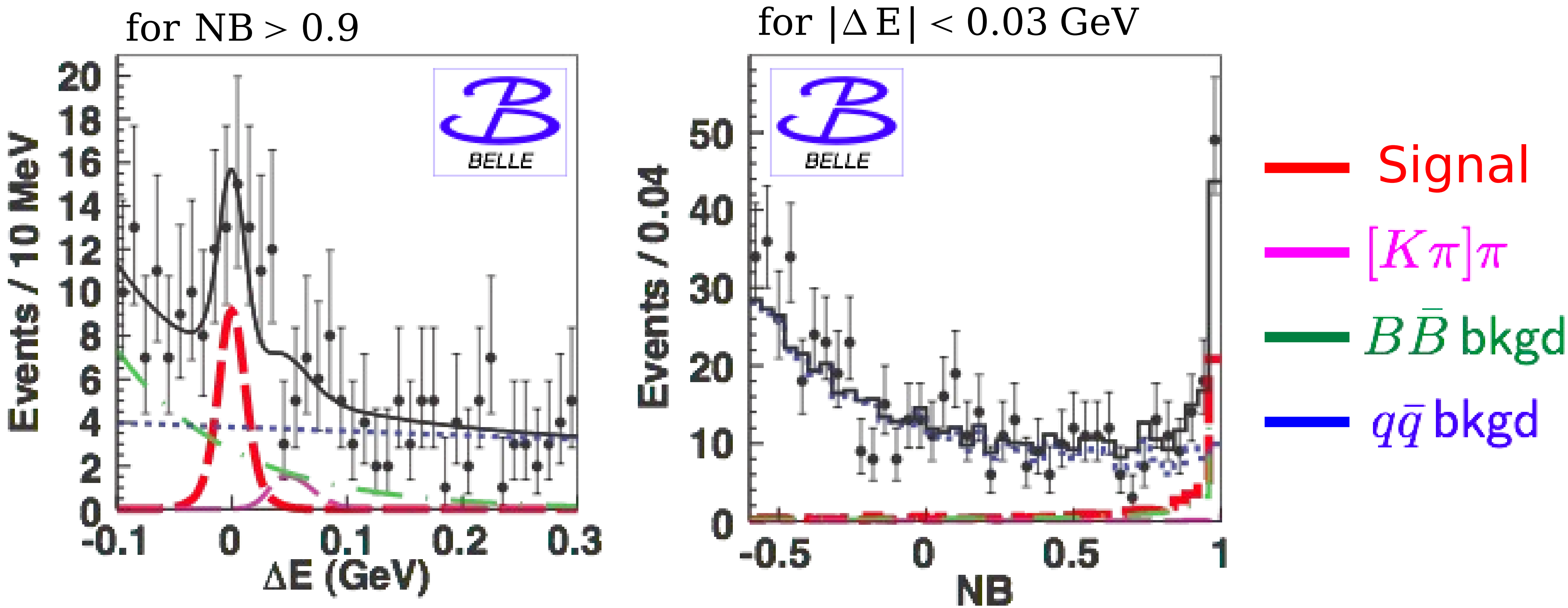
10 variables combined to obtain a single NN output (NB)

for example, at 99% bckg rej. signal eff. = 42% now becomes 60%

Yields for the ADS mode $B^- \to [K^+\pi^-]_D K^-$ from 772 million $B\bar{B}$ events

PRL 106, 231803 (2011)

Fit ΔE and NB distributions together to extract signal



$56.0^{+15.1}_{-14.2}$ events

First evidence obtained with a significance of 4.1σ (including syst.)

$$\mathbf{R_{DK} = (1.63\,^{+0.44}_{-0.41}\,^{+0.07}_{-0.13}) \times 10^{-2}}$$

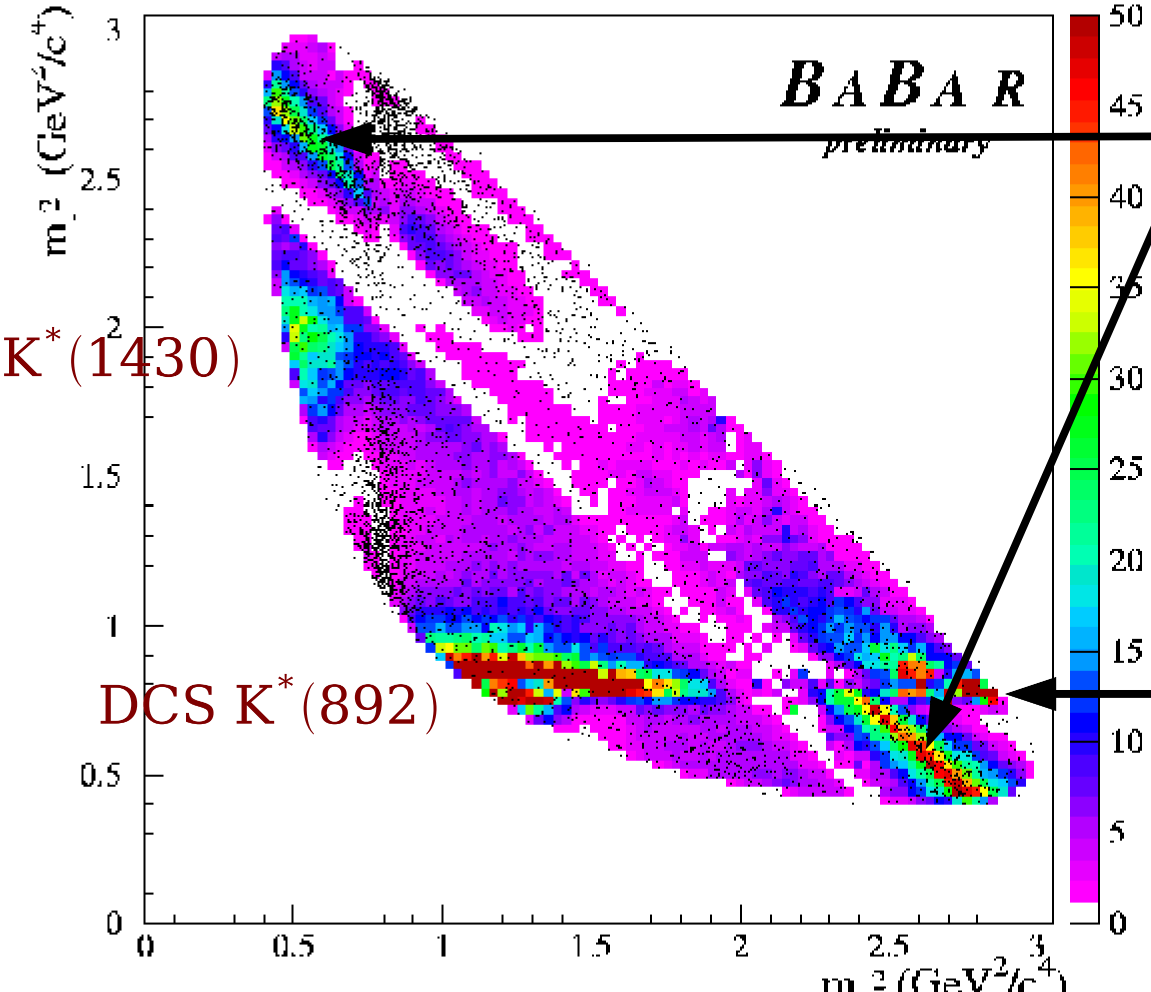
$$\mathbf{A_{DK} = -0.39\,^{+0.26}_{-0.28}\,^{+0.04}_{-0.03}}$$

Sensitivity to γ

sensitivity to γ/ϕ_3 varies across the Dalitz plot

$\gamma=75^\circ$, $\delta=180^\circ$, $r_B=0.125$

$w=1/(d^2L/d\gamma^2)$



DCS $K^*(1430)$

DCS $K^*(892)$

<u>GLW like</u>

Interference of

$B^- \to D^0 K^-$, $D^0 \to K_S^0 \rho^0$

with

$B^- \to \overline{D}^0 K^-$, $\overline{D}^0 \to K_S^0 \rho^0$

<u>ADS like</u>

Interference of

$B^- \to D^0 K^-$, $D^0 \to K^{*+} \pi^-$

with

$B^- \to \overline{D}^0 K^-$, $\overline{D}^0 \to K^{*+} \pi^-$

γ measurements from $B^{\pm} \to DK^{\pm}$

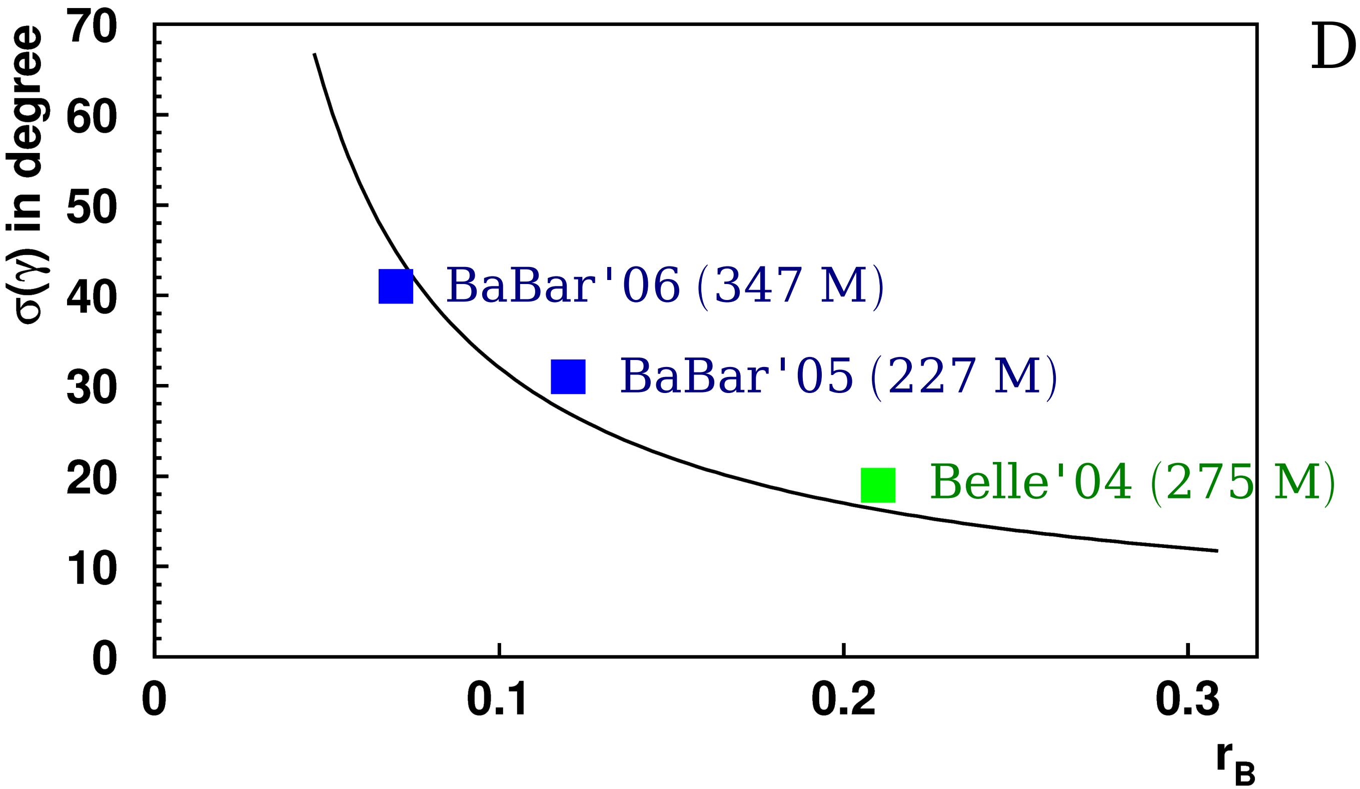
r_B dependence

Dalitz $B \to D(K_S\pi\pi)K$

experimental inputs:

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

uncertainty on γ scales as $1/r_B$!

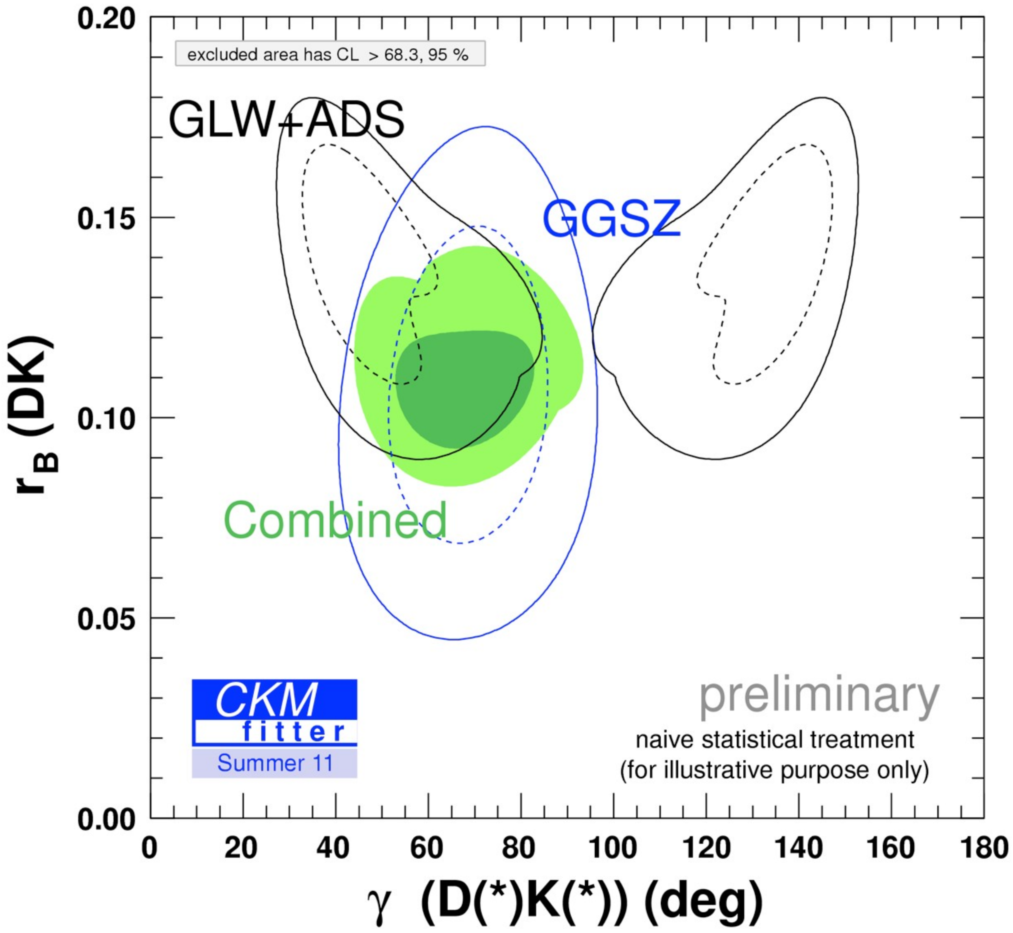


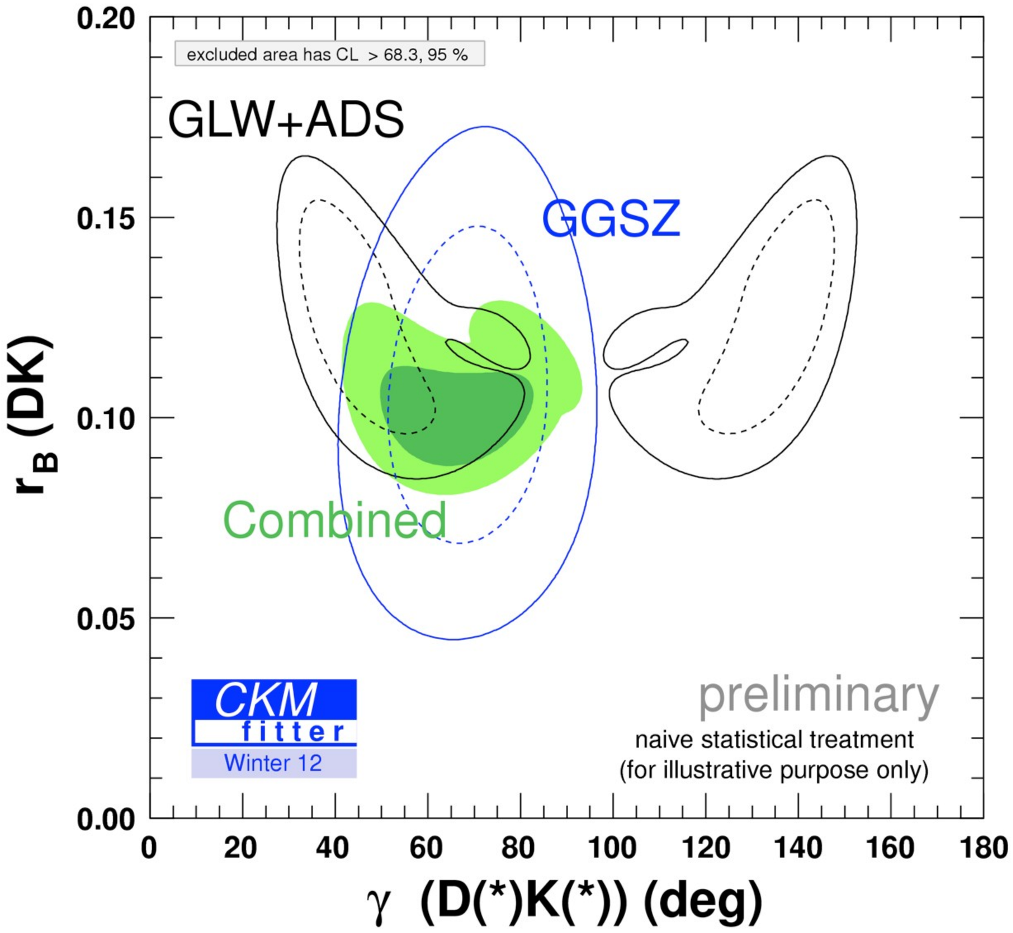
DK (stat only)

$\sigma(x_{\pm}) \sim 0.07$

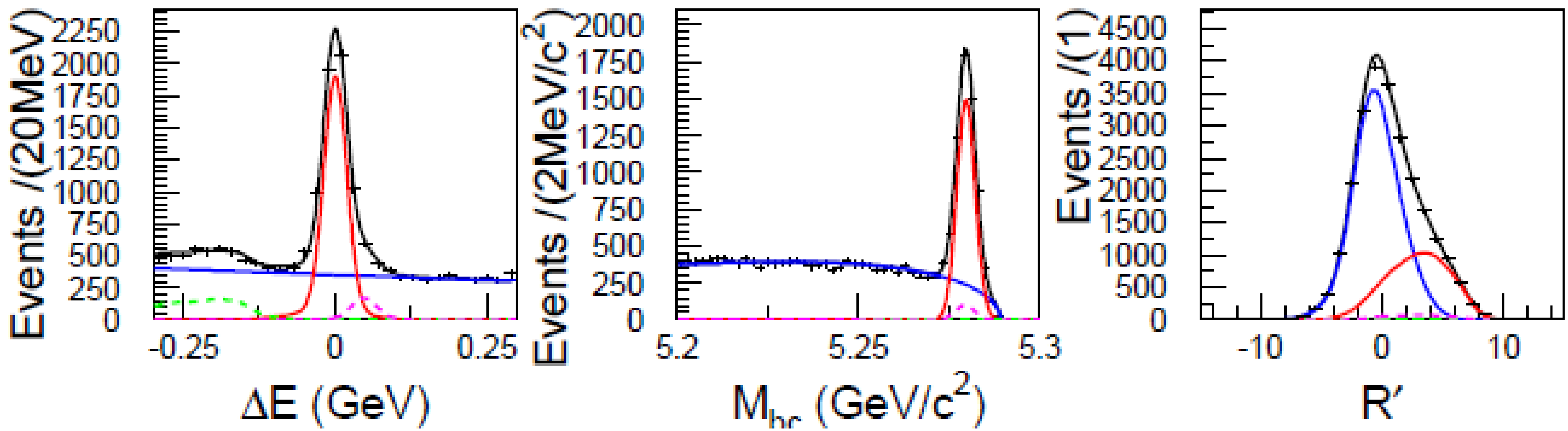
$\sigma(y_{\pm}) \sim 0.08$

New inputs (Winter 2012) ⇐ LHCb





$K^{\pm}\pi^{\mp}$



$K^{\pm}\pi^{0}$