# CP violation in B decays
# Recent results from BABAR and BELLE

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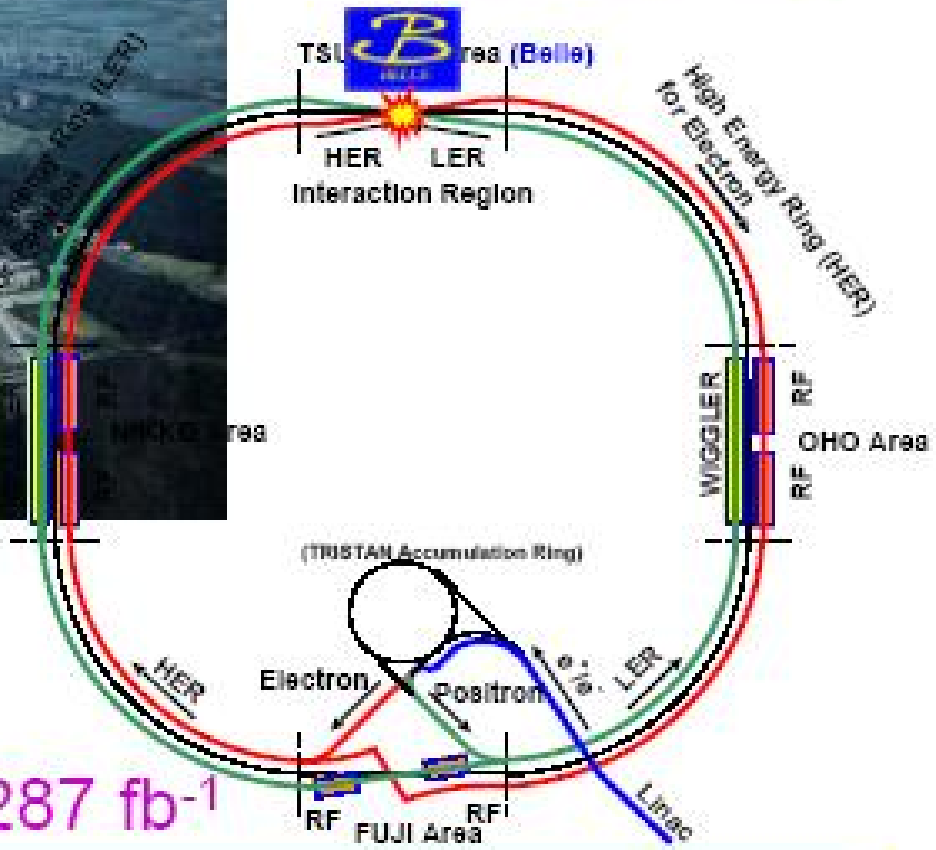
# Introduction

- *Very exciting harvest of results concerning CP violation*
  - 17 experimental talks at ICHEP in parallel and plenary sessions!
  - Made possible by superb performances of KEK-B and PEP-II
- *sin (2$\beta$) : Recent update using charmonium states*
- *Search for new physics in CPV thru s-penguins*
- *First measurement of sin(2$\alpha$)*
- *Many efforts concerning $\gamma$*
- *First significant constraints from sin(2$\beta$+ $\gamma$)*
- *First « consensual » direct CP violation in B decays*
- *Perspectives and conclusion*

# KEKB Collider


8 GeV $e^-$ x 3.5 GeV $e^+$

±11mrad crossing




$L_{peak} = 1.39 \times 10^{34}\ sec^{-1}cm^{-2}$

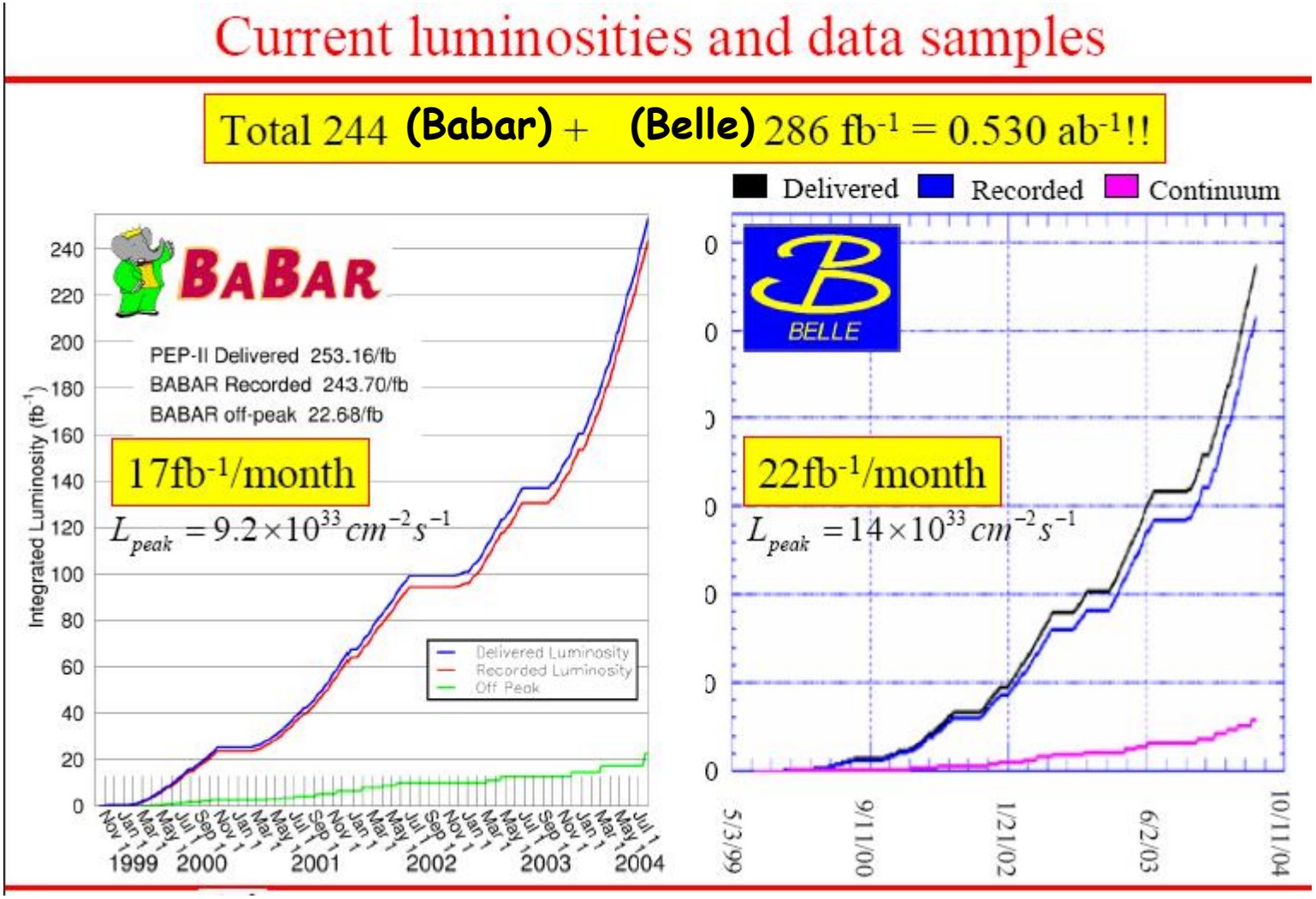
@ 1.2A x 1.6A

253 $fb^{-1}$ on Y(4S) 274M $B\bar{B}$

28 $fb^{-1}$ below Y(4S)

~287 $fb^{-1}$

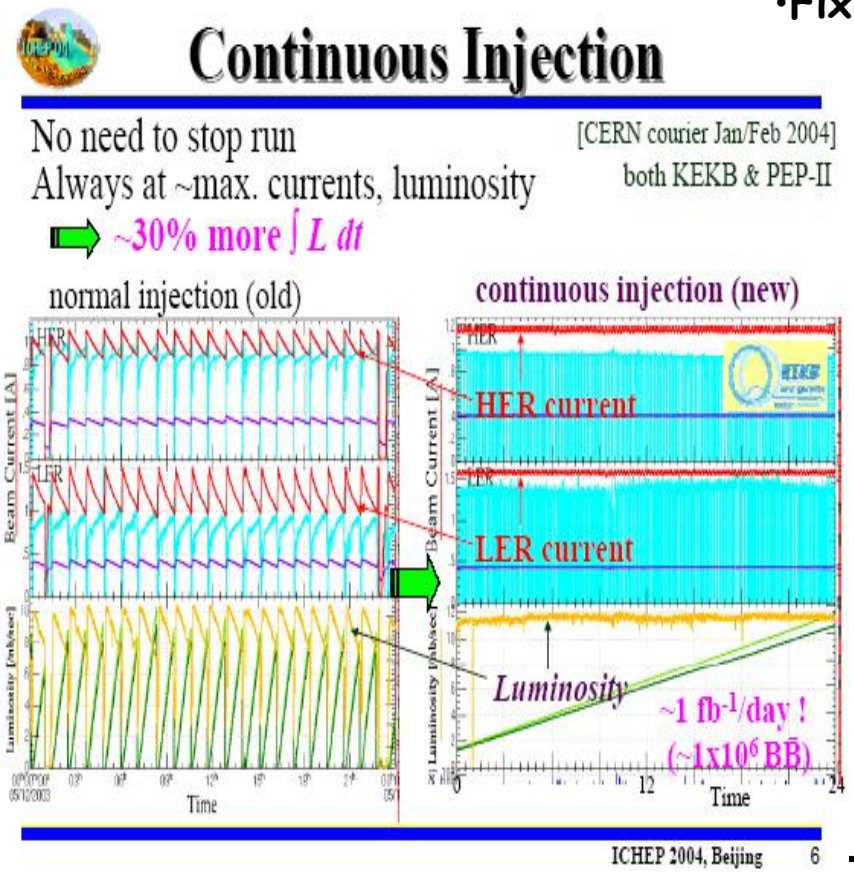
# BABAR and BELLE Integrated Lumi

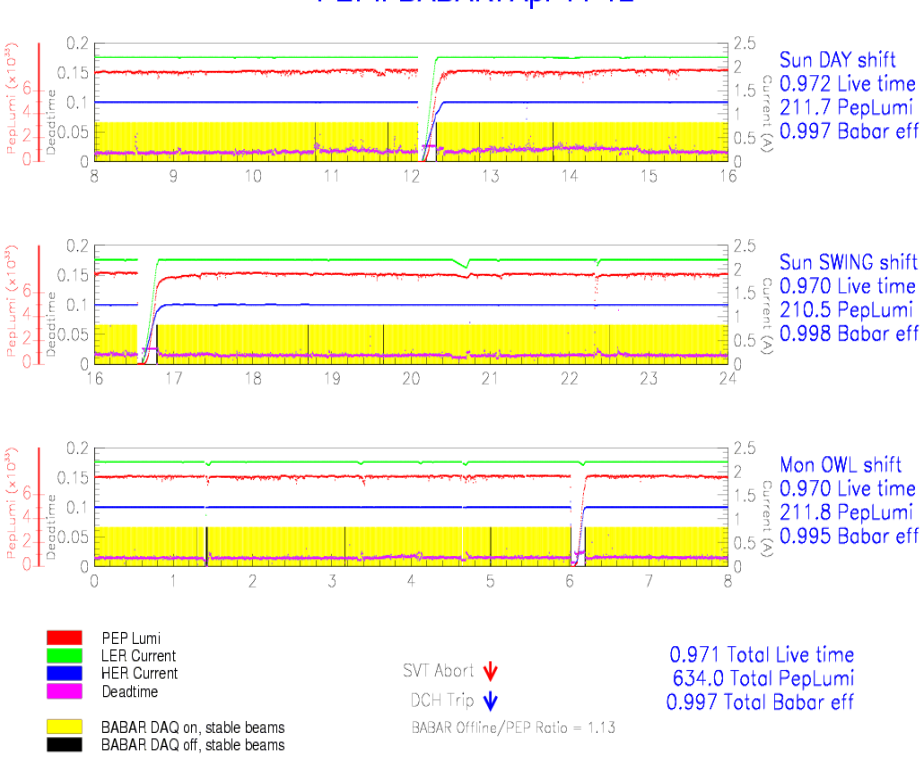


# The great success of continuous injection

**30% to 50% integrated lumi increase due to 4 combined factors:**

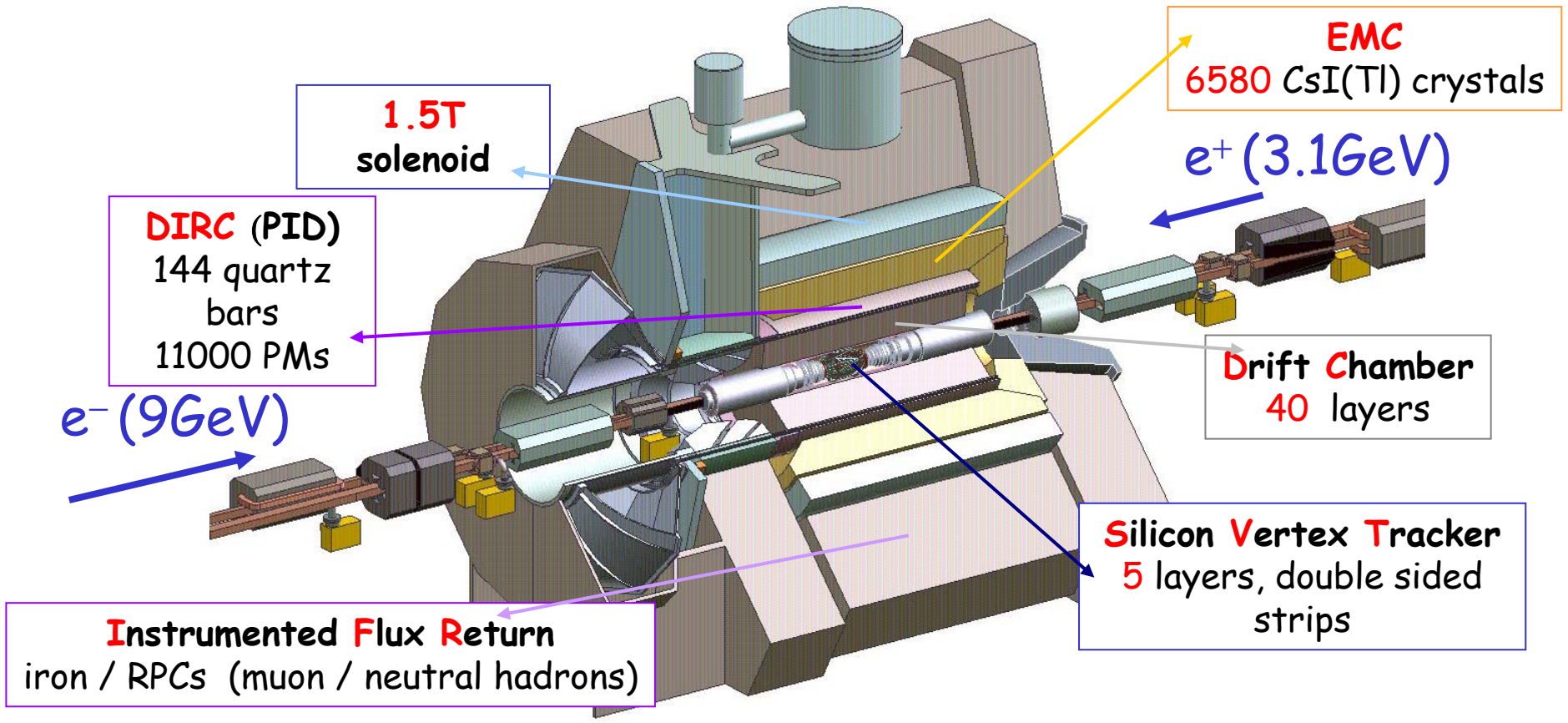
- **Higher average lumi**
- **Higher uptime fraction**
- **STABLE Temperatures**
- **Fixed Operating point in tune space**



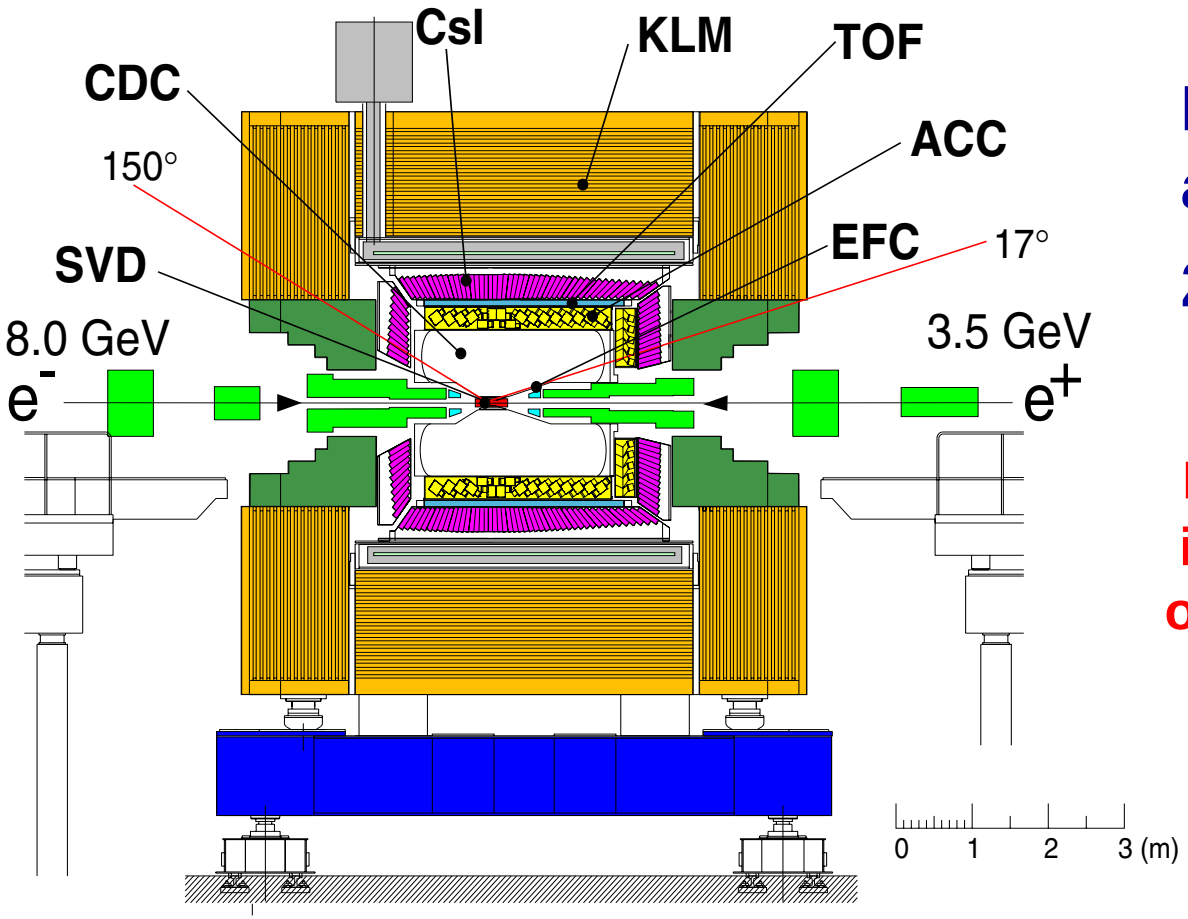




**BELLE** **BABAR**

# BABAR Detector



# Belle Detector




**Silicon Vertex Detector:**

3 layers

$\sigma \sim 55\mu$m for 1 GeV/c @ 90°

**Central Drift Chamber:**

50 layers

$\sigma_{Pt}/P_t \sim 0.35\%$ @ 1 GeV/c

$\sigma_{dE/dx} \sim 7\%$

**Calorimeter CsI:**

$\sigma/E = (1.3 \oplus 0.07/E \oplus 0.8/E^{1/4})\%$

(~1.8% @ 1 GeV)

**TOF:** $\sigma \sim 95ps$

**ACC (Cerenkov counters):**

n=1.01~1.03

**KLM (muons):** 14 layers

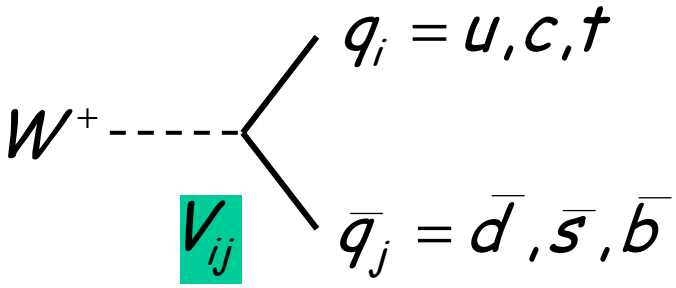
**Magnet :** 1.5 Tesla

$K/\pi$ sep. $dE/dx$ + TOF + ACC

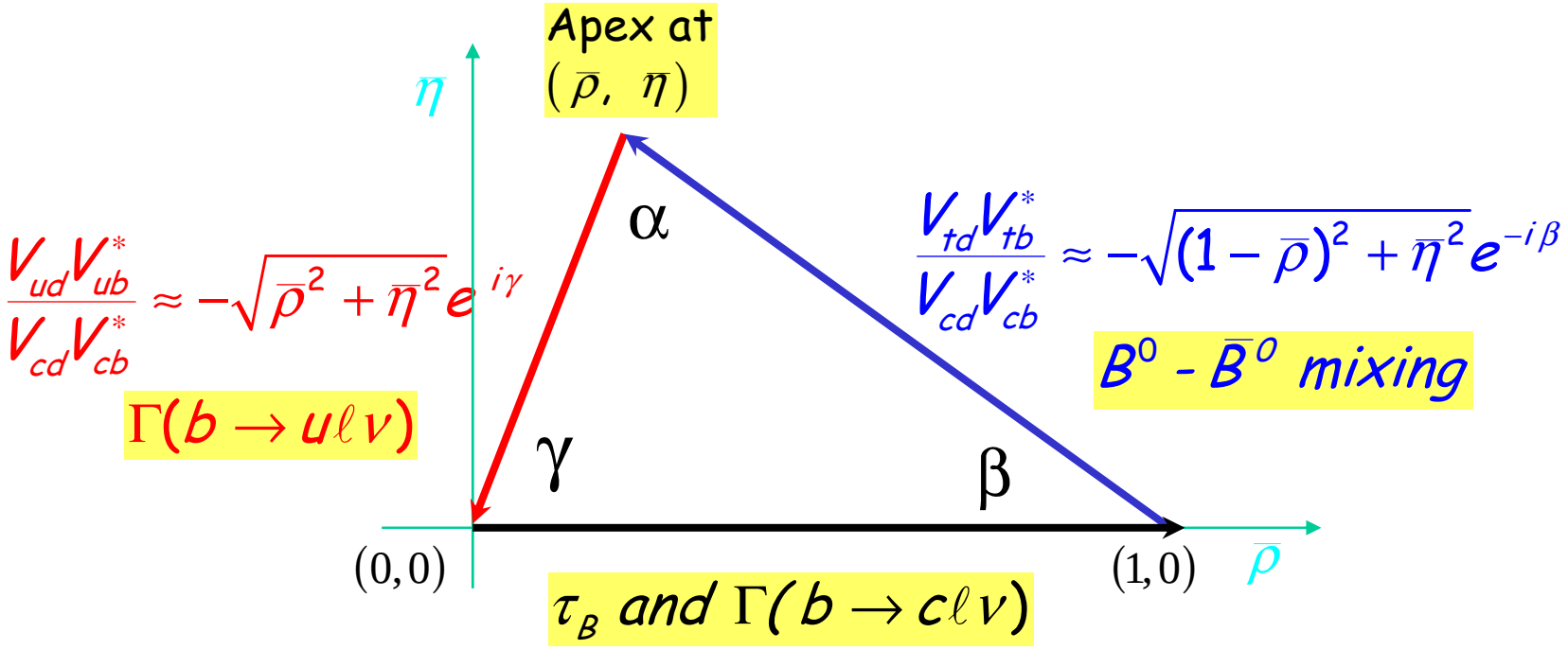
**Full statistics at Υ(4S) ~250 fb$^{-1}$ 274 x10$^6$ BB pairs**

**Partial statistics includes ~140 fb$^{-1}$ or 152 x10$^6$ BB pairs**

# CKM and unitarity conditions



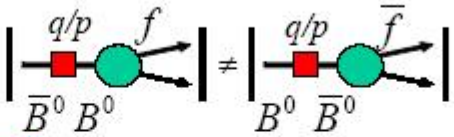

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$




$$\beta = -\arg V_{td};\ \gamma = \arg V_{ub}^*;\ \ \alpha = \pi - \gamma - \beta$$

# 3 ways for CP violation

## 1. CP violation in mixing



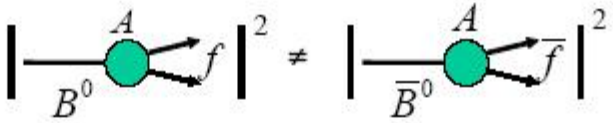

First mechanism observed historically in kaon decays

$$\left|\frac{q}{p}\right| = \sqrt{\frac{(M_{12}^* - i\frac{\Gamma_{12}^*}{2})}{(M_{12} - i\frac{\Gamma_{12}}{2})}} \neq 1$$

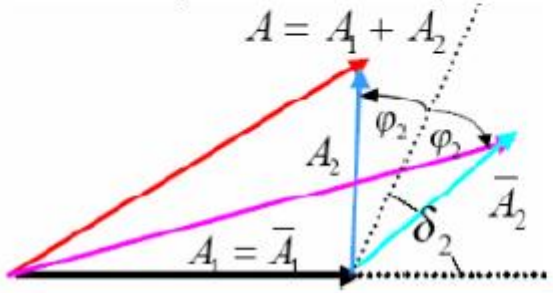
**SM predicts:**

$$\left|\frac{q}{p}\right| - 1 \approx 4\pi \frac{m_c^2}{m_t^2} \sin\beta \approx 5\times 10^{-4}$$

## 2. Direct CP violation in the decay



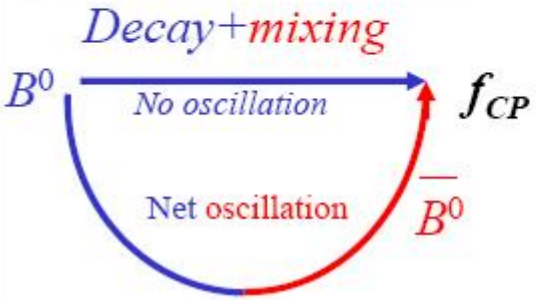

Occurs when $|\bar{A}/A| \neq 1$ where A is the amplitude for $B$ decays into a final state $f$ and $\bar{A}$ is the amplitude of $\bar{B}$ decays into the CP conjugate state $\bar{f}$.

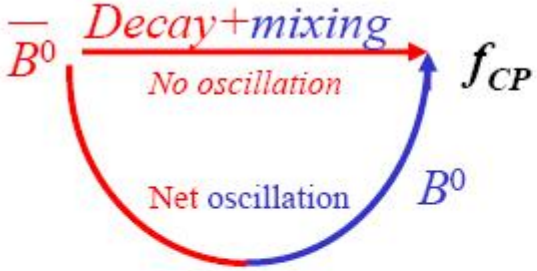



Two amplitudes $A_1$ and $A_2$ with a relative CP violating phase $\phi_2$ and a CP conserving phase $\delta$ :
CP violation and $|A| \neq |\bar{A}|$

# 3 ways for CP violation

**3. Time dependent**




$$\Gamma\left(B^0_{phys}(t) \to f_{CP}\right) \neq \Gamma\left(\overline{B}^0_{phys}(t) \to f_{CP}\right)$$

Define CP Asymmetry as:

$$A_{f_{CP}}(t) = \frac{\Gamma\left(\overline{B}^0_{phys}(t) \to f_{CP}\right) - \Gamma\left(B^0_{phys}(t) \to f_{CP}\right)}{\Gamma\left(B^0_{phys}(t) \to f_{CP}\right) + \Gamma\left(\overline{B}^0_{phys}(t) \to f_{CP}\right)}$$

$$A_{f_{CP}} = -C_{f_{CP}}\cos(\Delta m t) + S_{f_{CP}}\sin(\Delta m t)$$

$$\lambda_{f_{CP}} = \frac{q}{p}\frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} \approx e^{-2i\beta}$$

Amplitude ratio

*CP* parameter

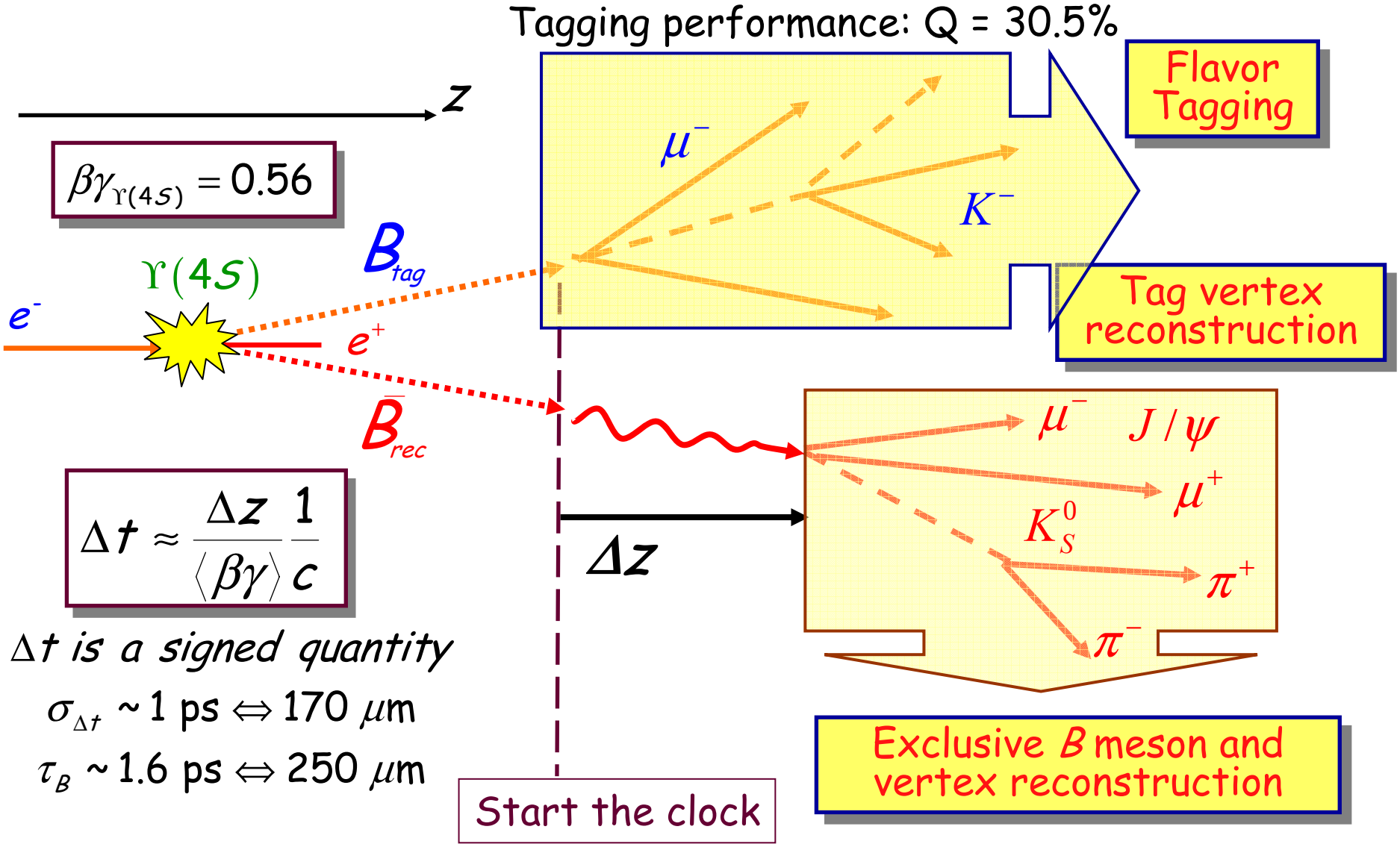
$$C_{f_{CP}} = \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2}$$

For single amplitude $= 0$

$$S_{f_{CP}} = \frac{-2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1+|\lambda_{f_{CP}}|^2} = -\,\mathrm{Im}\,\lambda_{f_{CP}}$$

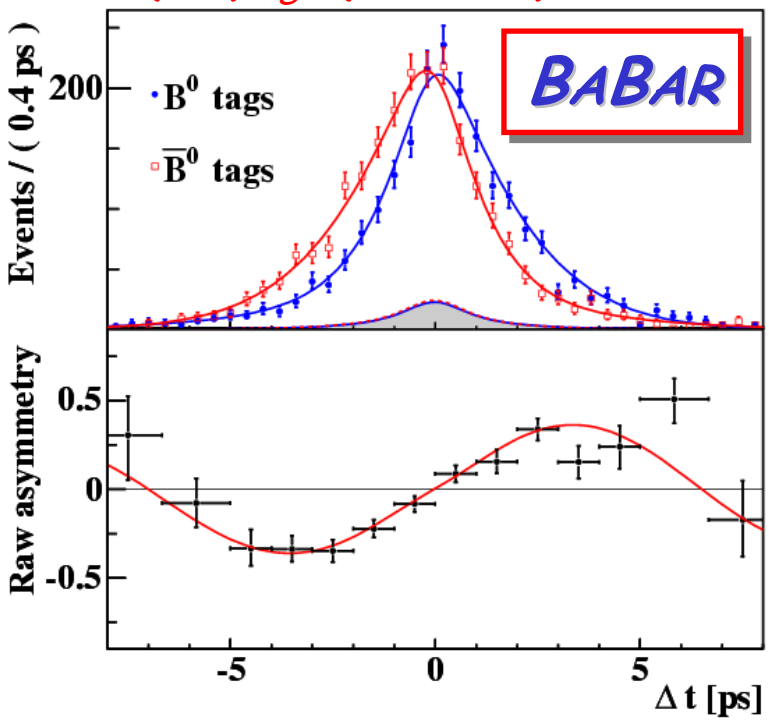
$C_{f_{CP}} \neq 0$ implies Direct *CP* Violation

# Measuring time-dependent CP asymmetries

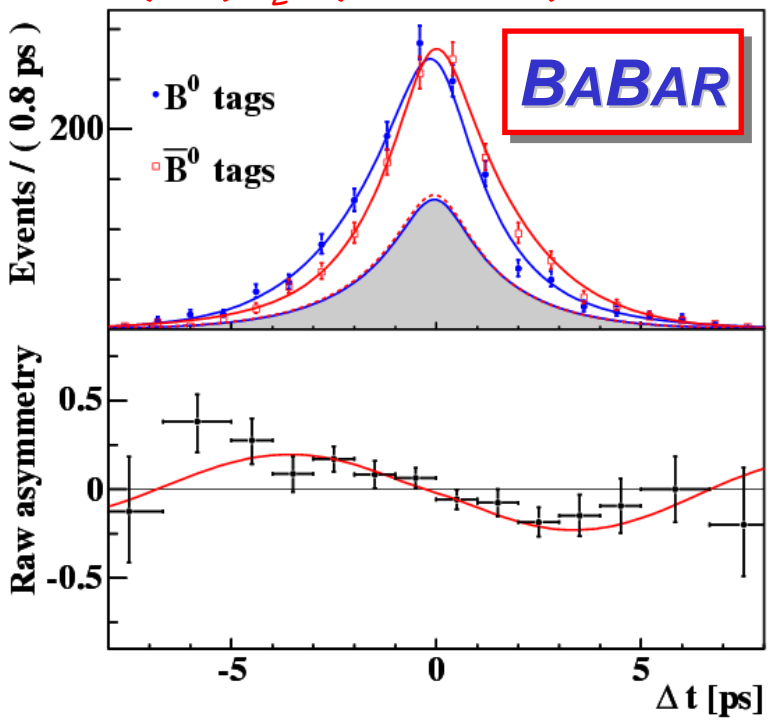


# sin2β_results from charmonium modes

$(c\bar{c})K^0_S$ (CP odd) modes




$(c\bar{c})K^0_L$ (CP even) modes




**Update for ICHEP04** *BABAR PUB-04/038*

$$\sin 2\beta = +0.722 \pm 0.040 \pm 0.023$$
$$|\lambda| = |\bar{A}/A| = 0.950 \pm 0.031 \pm 0.013$$

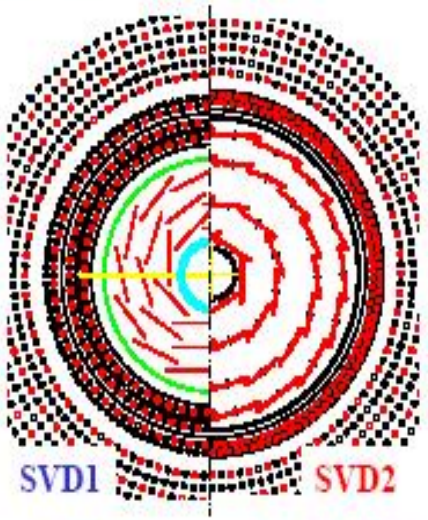
$205 fb^{-1}$ on peak or 227M $B\bar{B}$ pairs
7730 CP events (tagged signal)

$(c\bar{c})K^0_S +$
$(c\bar{c})K^0_L$

Updates previous result (2002) *PRL 89 (2002) 201802*

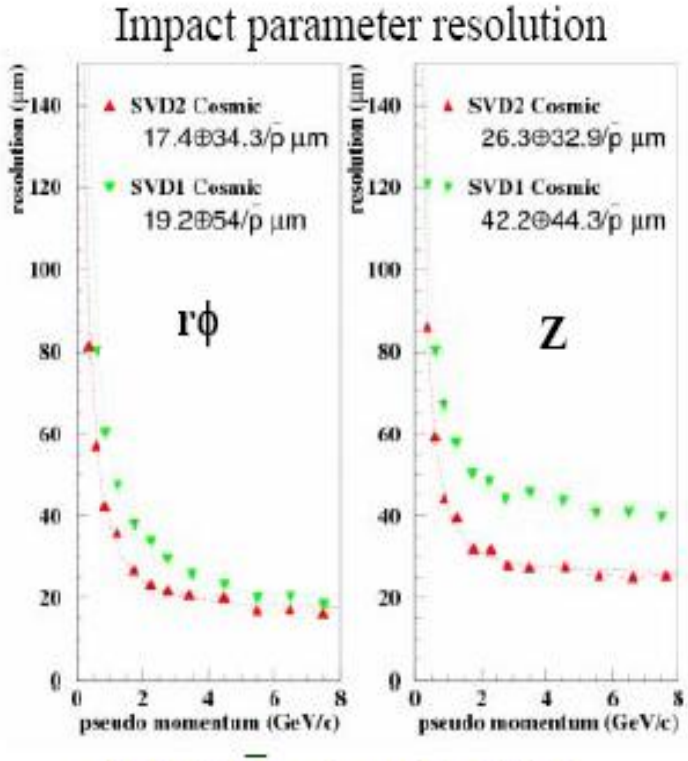
# BELLE Update on sin2β ($\phi_2$)

## SVD Upgrade 2003 summer




- 1 MRad → >20 MRad
- 3 layers → 4 layers
- 23°<θ<139° → 17°<θ<150°
- $R_{bp}$ = 2.0 cm → 1.5 cm

➡ Better I.P. resolutions




152M $B\bar{B}$ pairs with SVD1
+ 122M $B\bar{B}$ pairs with SVD2

ICHEP 2004, Beijing 8

Significant update of BELLE SVD in summer 2003 (~50% of total stat)

# Checks: sin2$\phi_1$ ($B^0 \to J/\psi K_{S/L}$)

Validation of new data sample (SVD2)

SVD1

SVD1: 152M $B\bar{B}$

$S = 0.696 \pm 0.061$ (stat)
$A = 0.011 \pm 0.043$ (stat)

Good tags

SVD2: 122M $B\bar{B}$

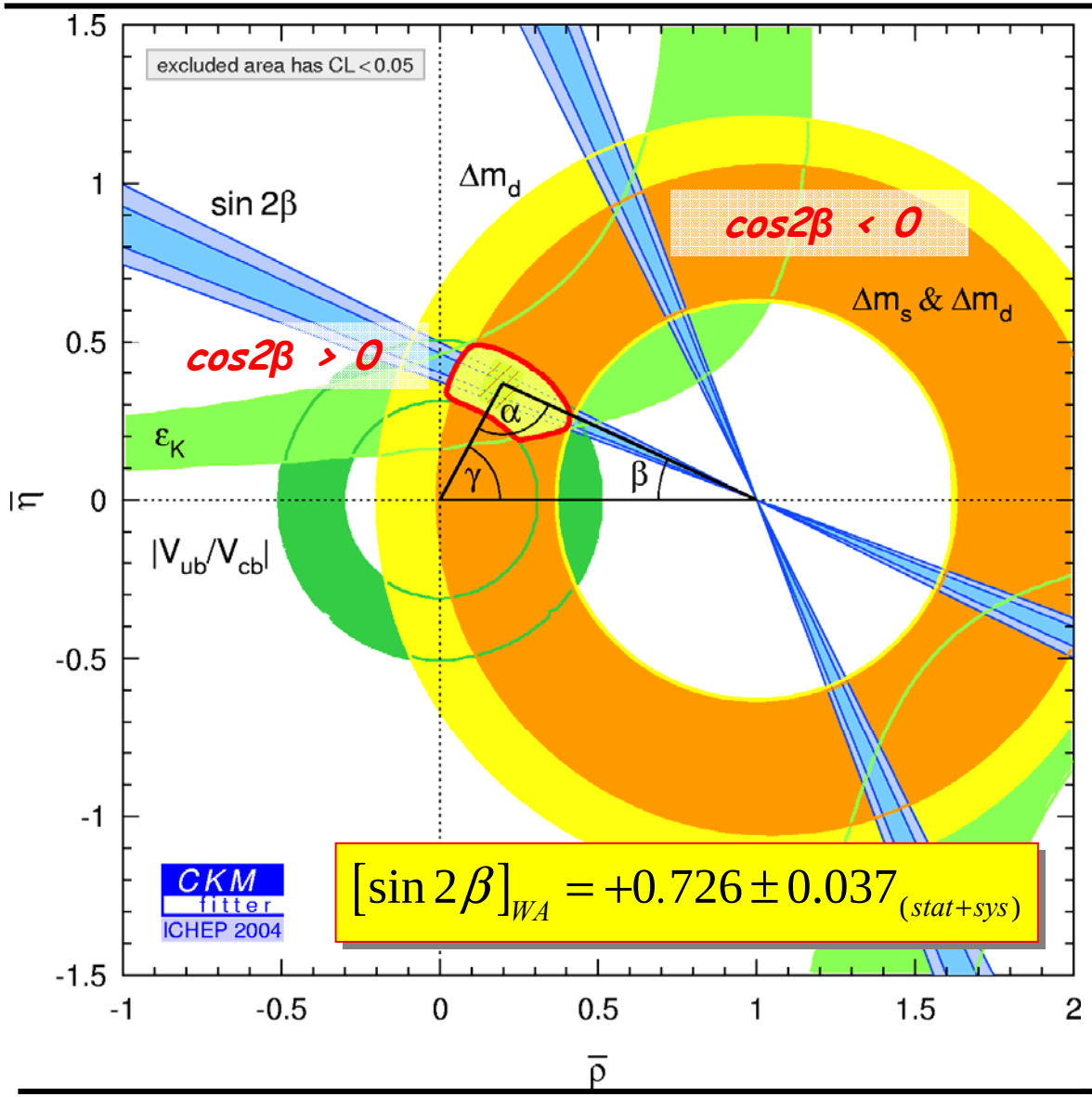
SVD2

$S = 0.629 \pm 0.069$ (stat)
$A = 0.035 \pm 0.044$ (stat)

Good tags

$\Delta t$ (ps)

# sin2β, cos2β and CKM constraints




**BABAR**

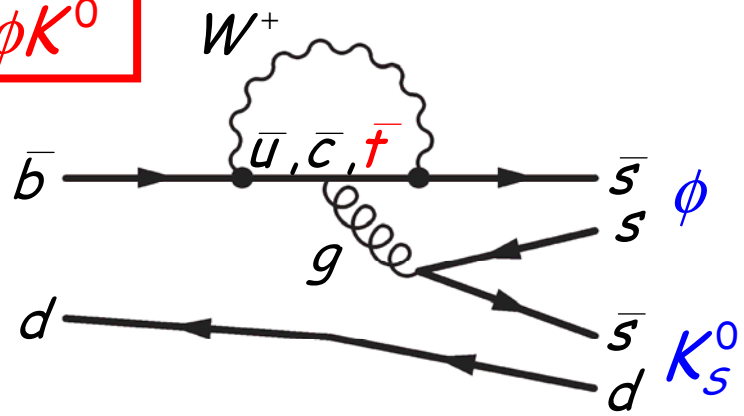
cos2$\beta$ < 0 ruled out at 87% CL by s- and p-wave interference in angular analysis of $B\ J/\psi K^{*0}$ ($K_S\pi^0$)

*M.Bruinsma, CP-3*

CKM fit to indirect constraints overlaid with $\sin 2\beta_{WA}$ measurement

# Asymmetries for $b \to s\bar{s}s$ Penguins

$B^0 \to \phi K^0$




*u-penguin CKM suppressed by ~0.02*

**Expectation**

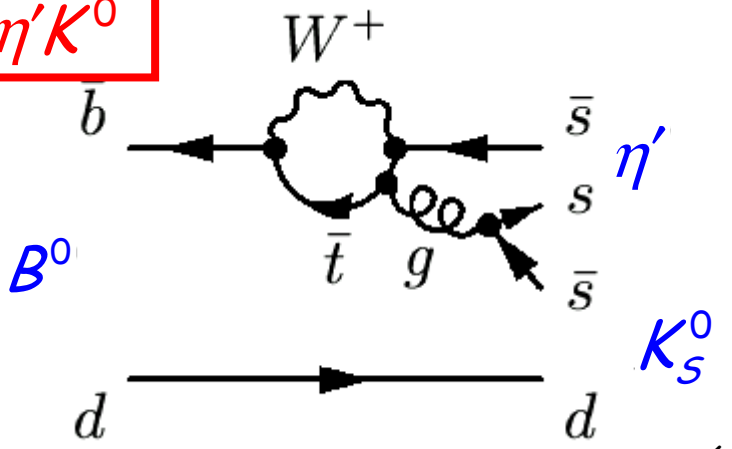
$$S_{\phi K_S^0} = \sin 2\beta, C_{\phi K_S^0} = 0$$

**Challenge**

$$BF = \left(7.6^{+1.3}_{-1.2} \pm 0.5\right) \times 10^{-6}$$

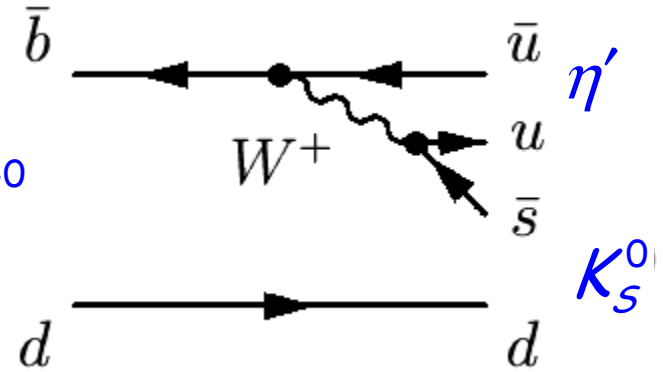
"Internal Penguin"

$B^0 \to \eta' K^0$




$$BF = (55.4 \pm 5.2 \pm 4.0) \times 10^{-6}$$

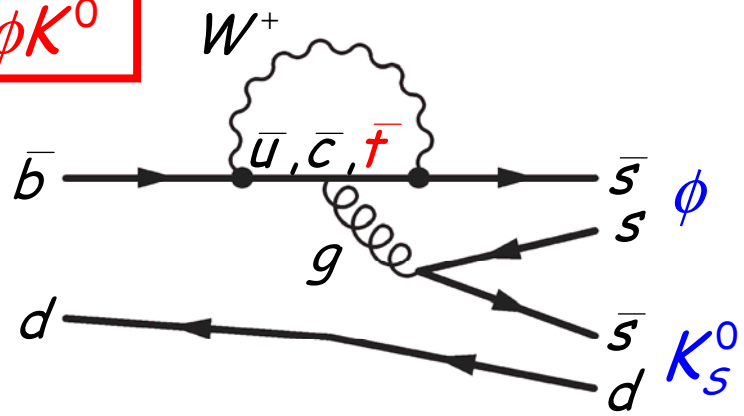
"Tree-level $b \to u$"




*u-tree CKM suppressed T/P < 0.1*

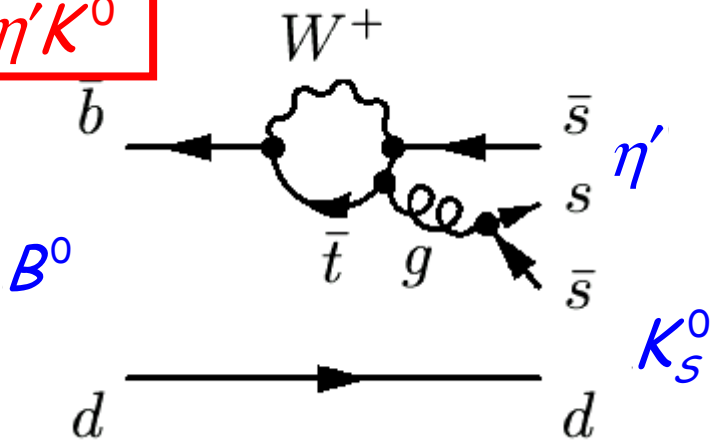
# Asymmetries for $b \to s\bar{s}s$ Penguins

$B^0 \to \phi K^0$

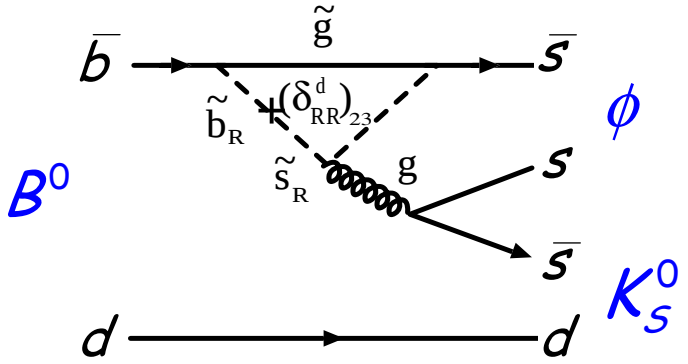



"Internal Penguin"

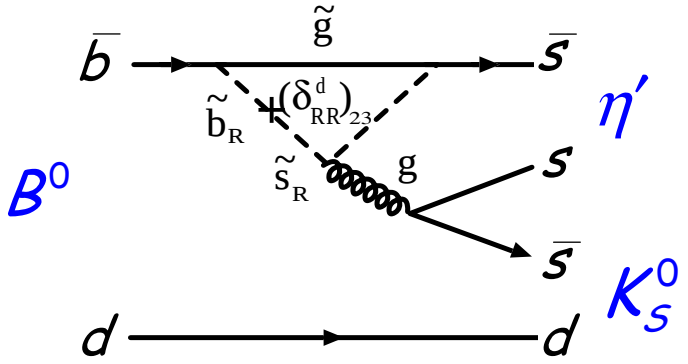
$B^0 \to \eta' K^0$




**New physics in loops?**




**SUSY contribution with new phases**

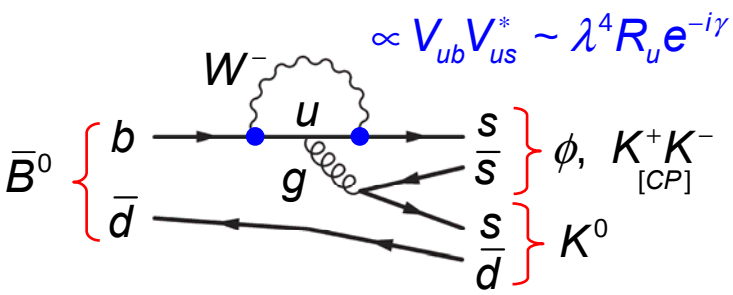


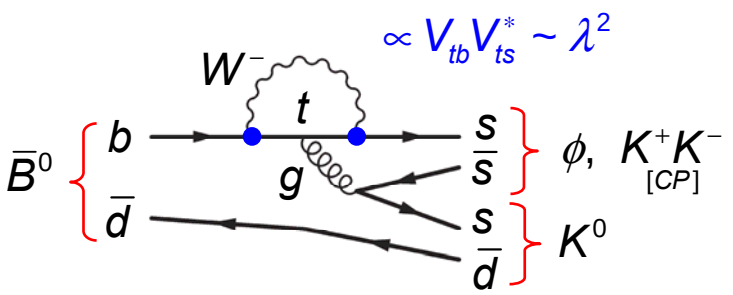
# Penguin Olympia

One may identify golden, silver and bronze-plated *s*-penguin modes:

Naive (dimensional) uncertainties on sin2β

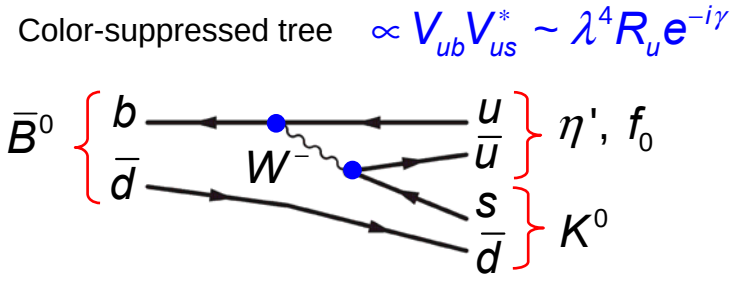
**Gold**

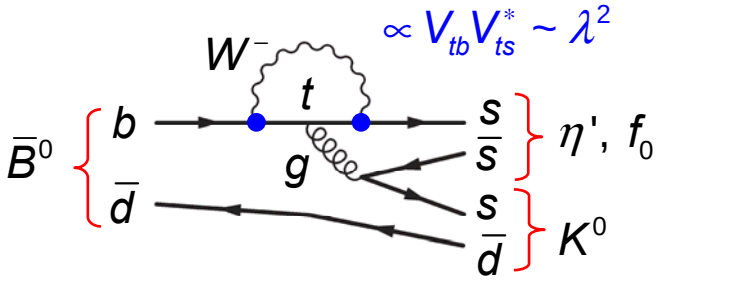



$O(\lambda^2)$
~ 5%

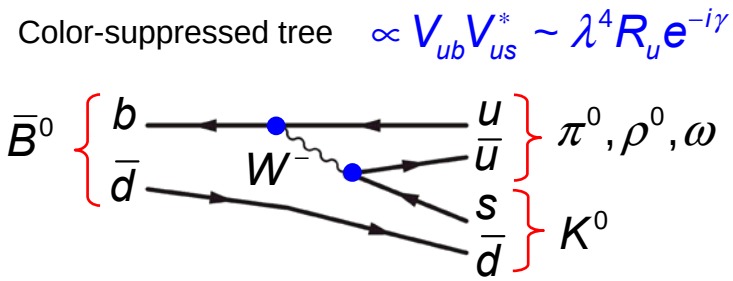
**Silver**

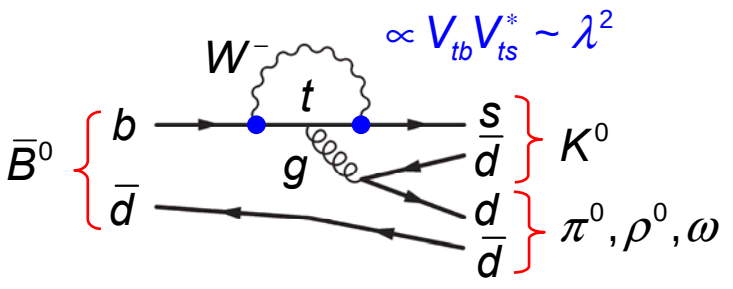



$O(\lambda^2(1+f_{q\bar{q}}/\bar{\lambda}))$
~ 10%

**Bronze**



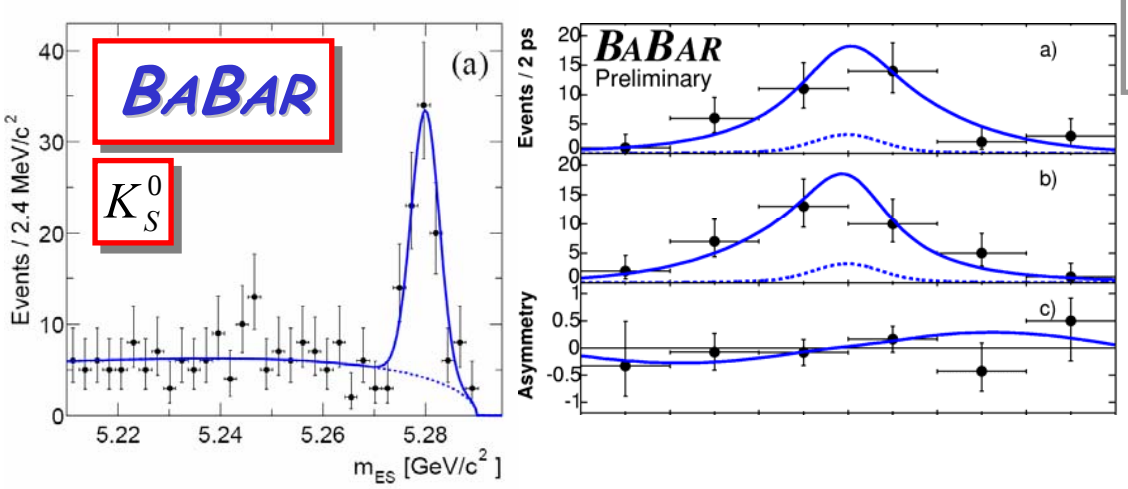



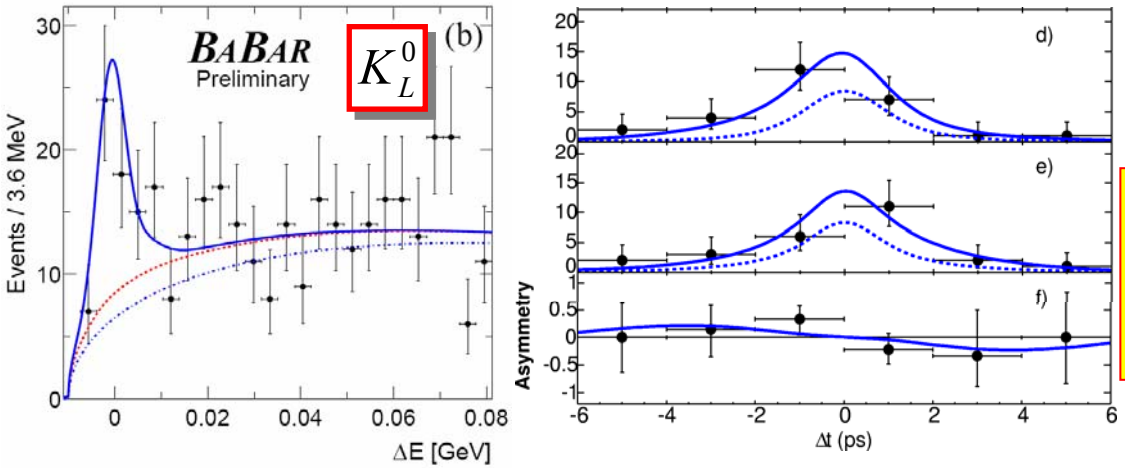

$O(\lambda^2/\bar{\lambda})$
~ 20%

Note that within QCD Factorization these uncertainties are much smaller !

# BABAR results for $B^0 \to \phi K^0$

2004 = 227M $B\bar{B}$ pairs
(2003 = 120M pairs)




2003 result

$$-\eta_{CP} \cdot S_{\phi K^0} = +0.47 \pm 0.34 \,^{+0.08}_{-0.06}$$
$$C_{\phi K^0} = +0.10 \pm 0.33 \pm 0.10$$

**Update for ICHEP04**

$B^0 \to \phi K^0_S$ $114 \pm 12$ events

$$S_{\phi K^0_S} = +0.29 \pm 0.31$$

$B^0 \to \phi K^0_L$ $98 \pm 18$ events

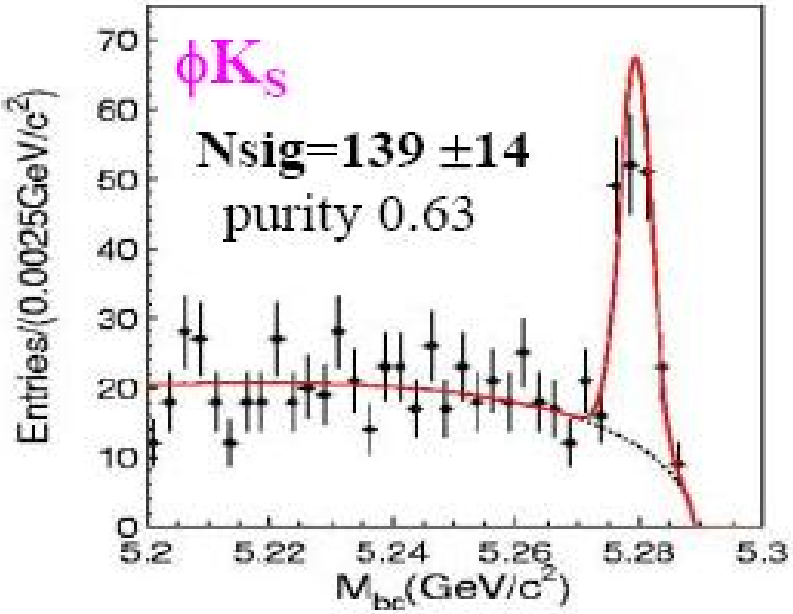
$$S_{\phi K^0_L} = -1.05 \pm 0.51$$

$$-\eta_{CP} \cdot S_{\phi K^0} = +0.50 \pm 0.25 \,^{+0.07}_{-0.04}$$
$$C_{\phi K^0} = +0.00 \pm 0.23 \pm 0.05$$

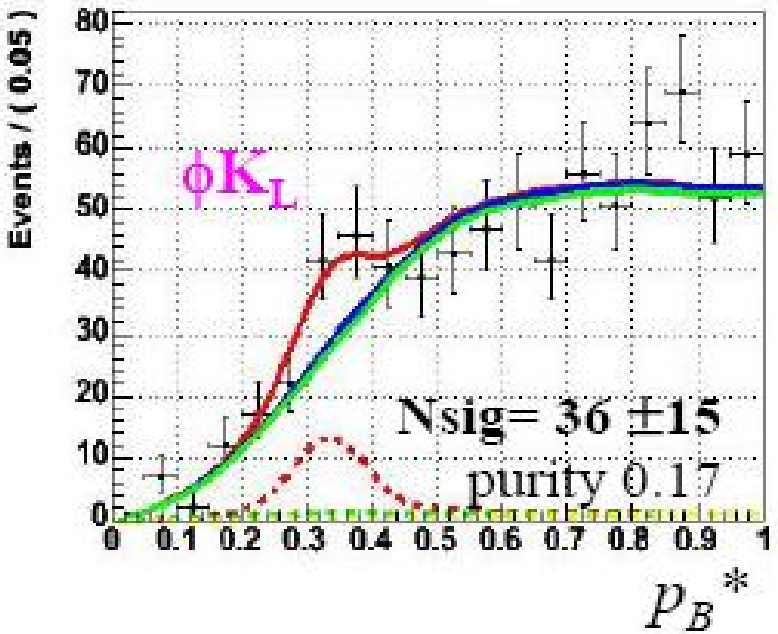
*BABAR-CONF 04/033*

# $B^0 \to \phi K^0$

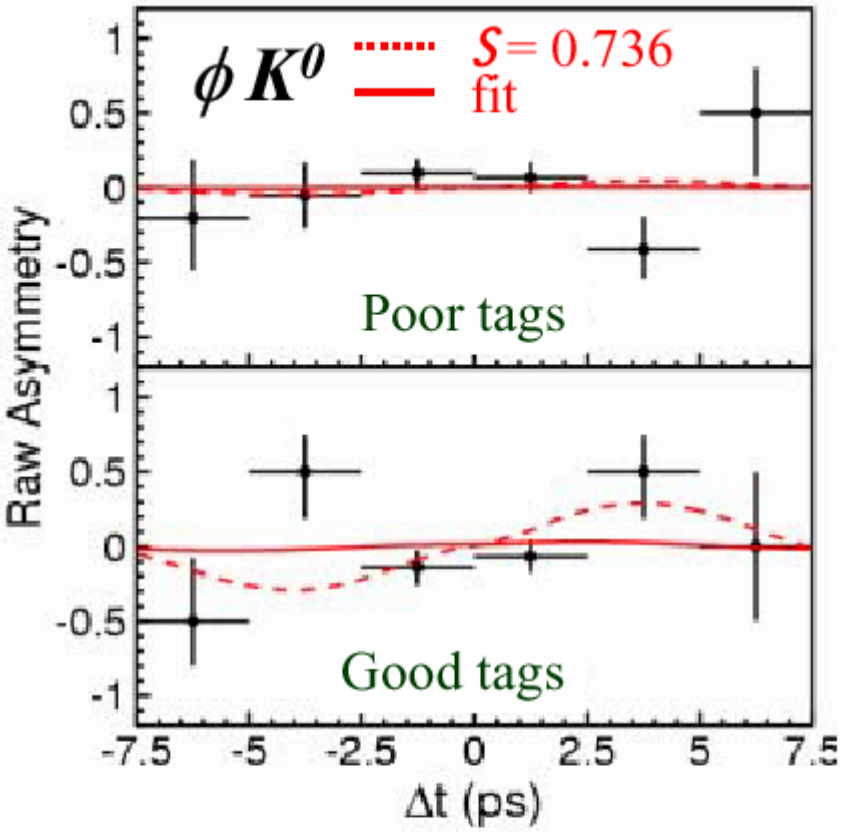
**274M $B\bar{B}$**

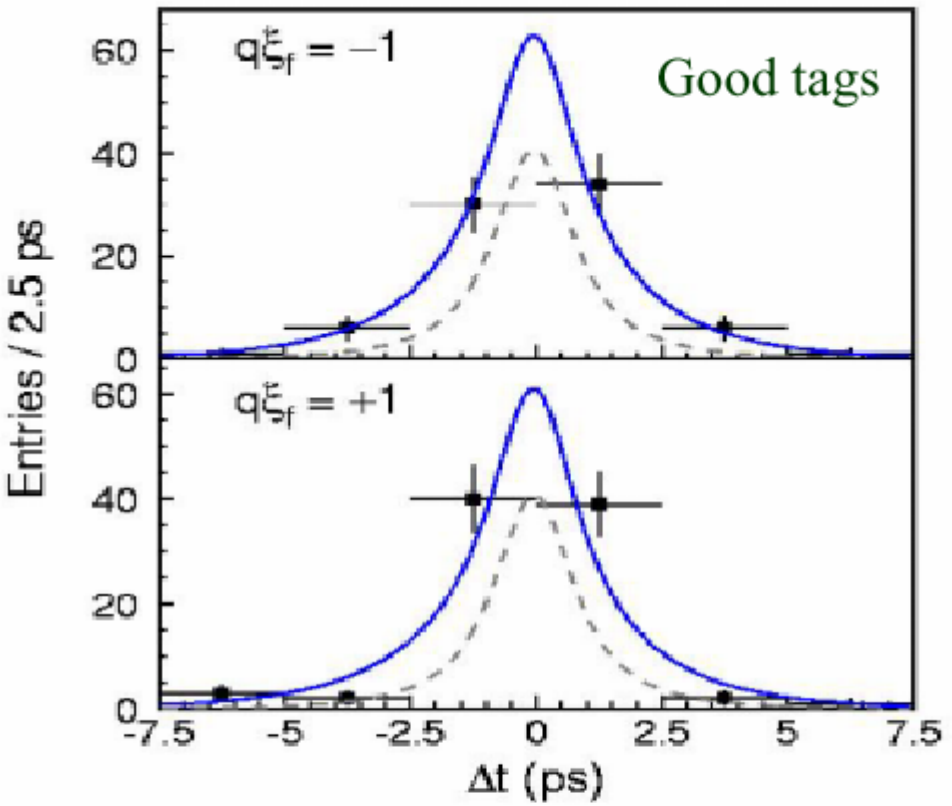



includes Ks $\to \pi^0\pi^0$
(Nsig=13 ±5)




Similar to $J/\psi K_L$ recon.
+ sophisticated continuum suppression




$\phi K_S + \phi K_L$ : $S(\phi K^0) = +0.06 \pm 0.33 \pm 0.09$

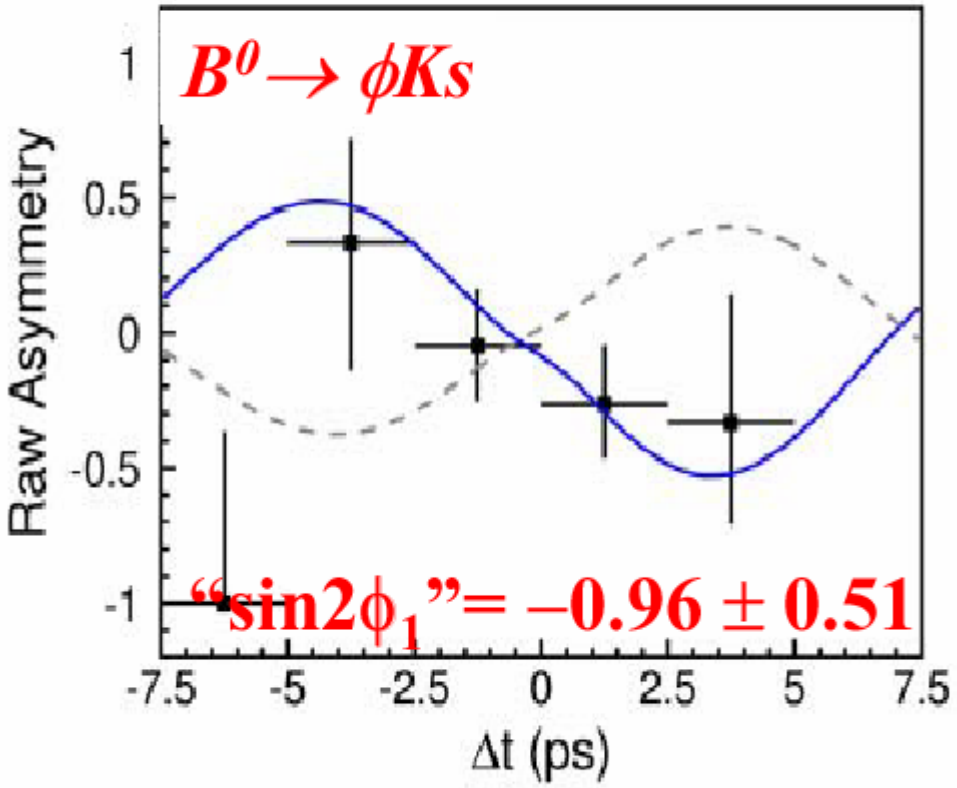
$A(\phi K^0) = +0.08 \pm 0.22 \pm 0.09$

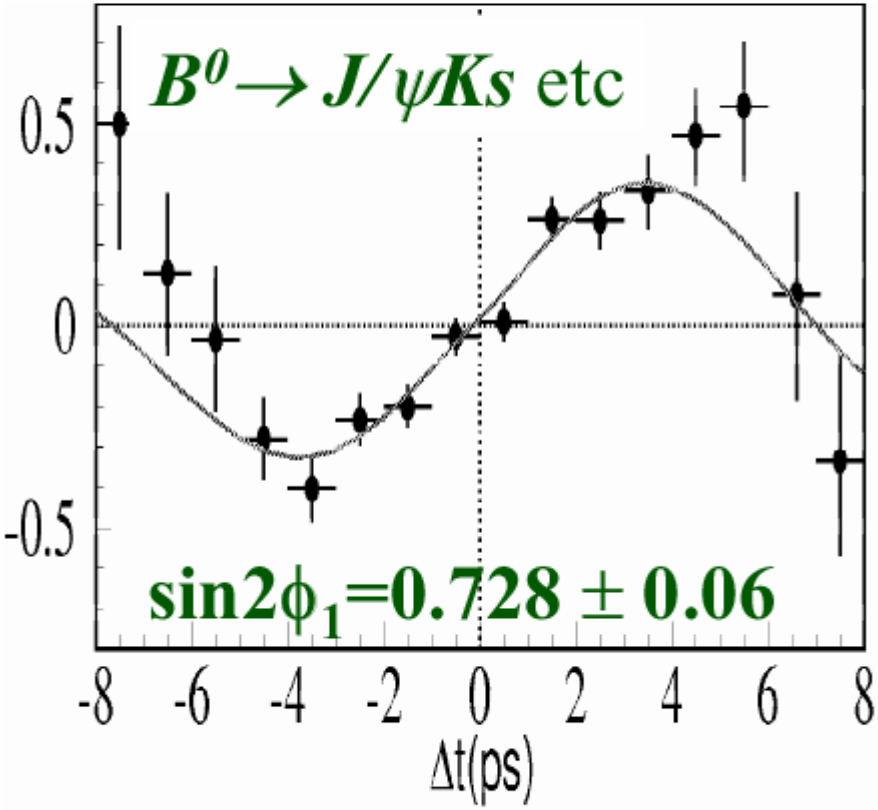
~2.2σ away from SM

**274M $B\bar{B}$**

# $b \to s\bar{q}q$ Penguin CPV

*Belle @LP03 (140 fb$^{-1}$)* [PRL 91, 261602 (2003)]

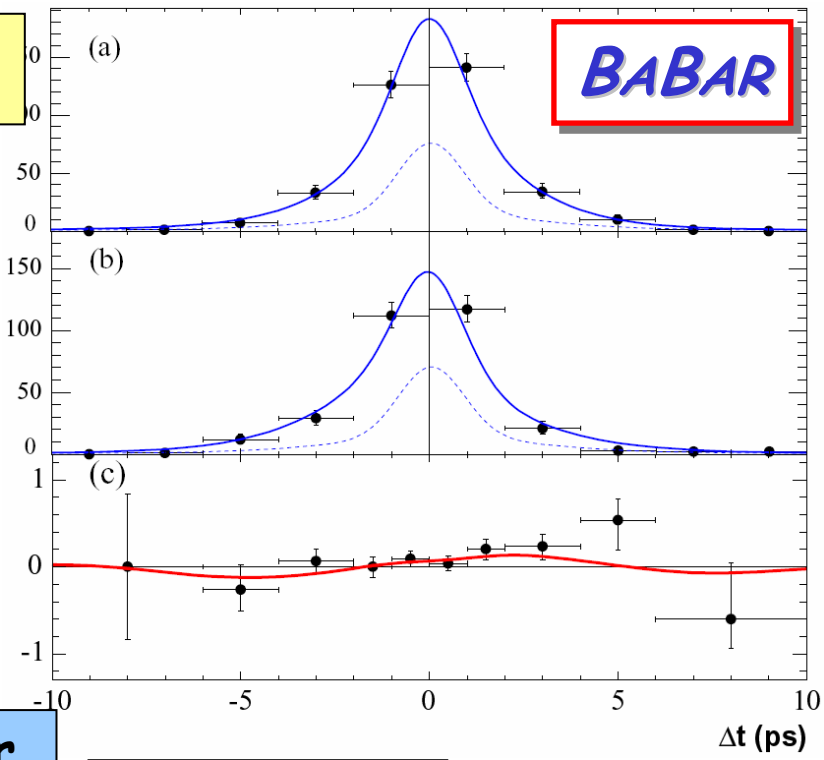


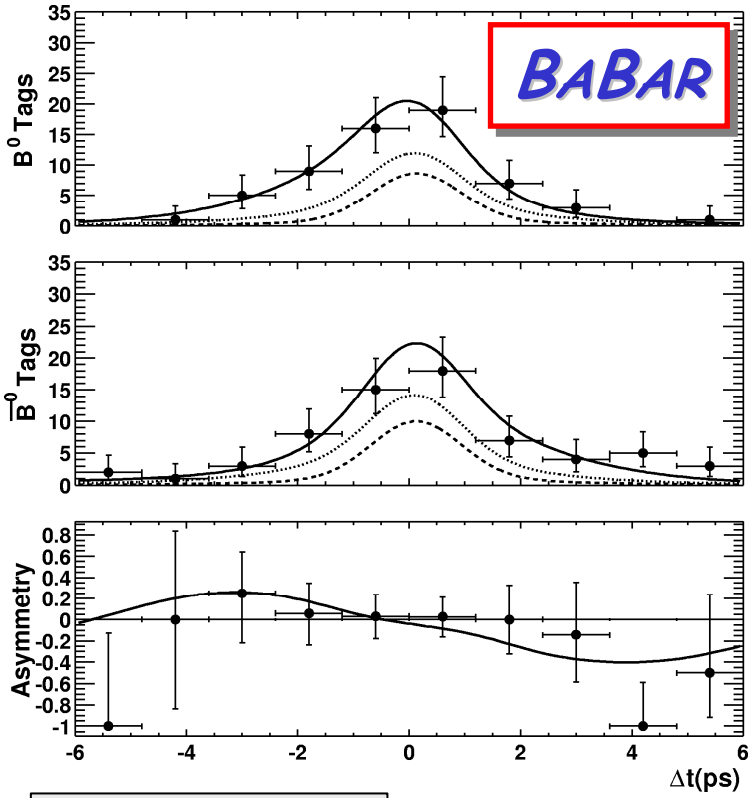




**3.5σ deviation from the SM !**

# More BABAR results from $b \to s\bar{s}s$ penguins

CONF 04/040
CONF 04/019




**Updates for ICHEP04**

208M $B\bar{B}$ pairs

$\eta' \to \rho^0\gamma, \eta\pi^+\pi^-$
$\eta \to \gamma\gamma, \pi^+\pi^-\pi^0$
$K^0_S \to \pi^+\pi^-, \pi^0\pi^0$

$B^0 \to \eta' K^0_S$ Signal: $819 \pm 38$

$\neq \sin 2\beta[c\bar{c}]$@3.0$\sigma$

$-\eta_{CP} \cdot S_{\eta' K^0_S} = +0.27 \pm 0.14 \pm 0.03$

$C_{\eta' K^0_S} = -0.21 \pm 0.10 \pm 0.03$

$B^0 \to f_0 K^0_S$ Signal: $152 \pm 19$

$-\eta_{CP} \cdot S_{f_0 K^0_S} = +0.95\,^{+0.32}_{-0.23} \pm 0.10$

$C_{f_0 K^0_S} = -0.24 \pm 0.31 \pm 0.15$

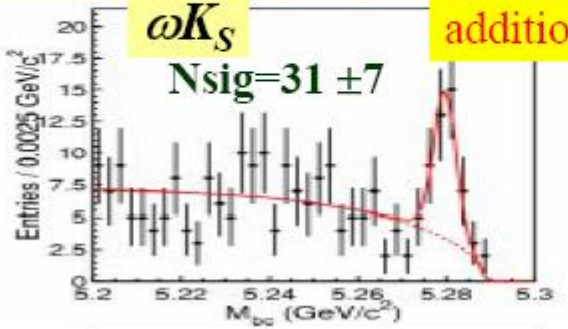
# $B^0 \to \omega K_S$ & $f_0(980)K_S$

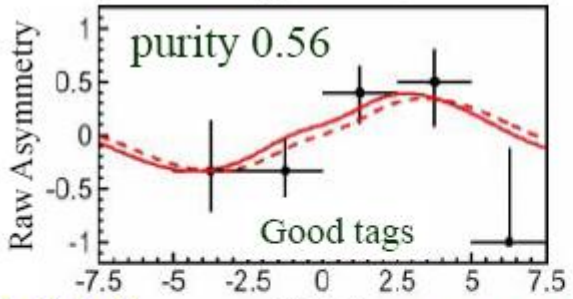
274M $B\bar{B}$

additional modes

## $\omega K_S$

Nsig=31 ±7



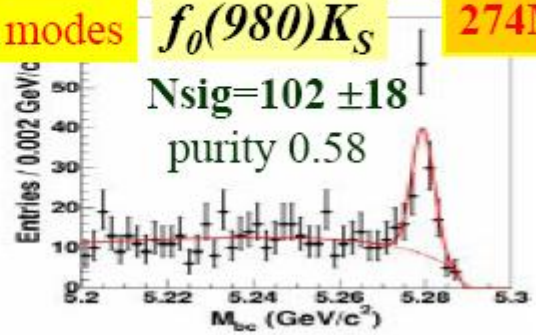



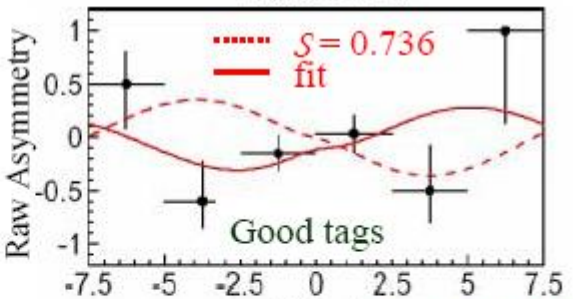

(~0σ @SM)

## $f_0(980)K_S$

Nsig=102 ±18

purity 0.58




(~2.9σ @SM)

"$\sin 2\phi_1$"

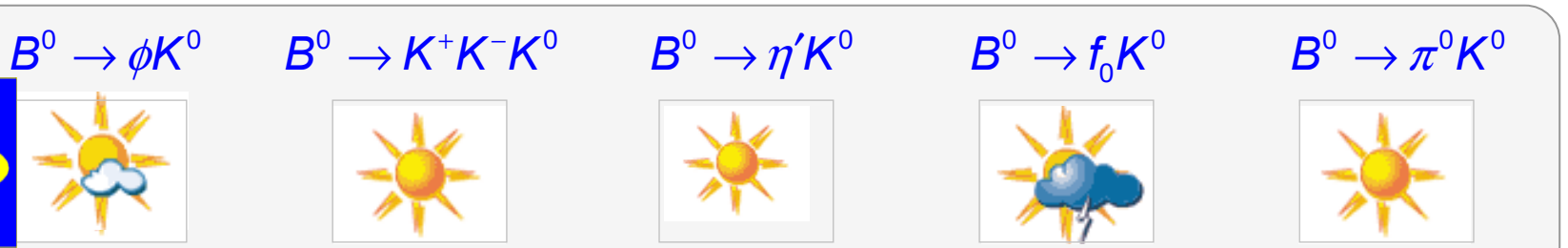
$\mathcal{S} = +0.75 \pm 0.64 \pm {}^{0.13}_{0.16}$ $\quad -\mathcal{S} = -0.47 \pm 0.41 \pm 0.08$

$\mathcal{A} = +0.26 \pm 0.48 \pm 0.15$ $\quad \mathcal{A} = -0.39 \pm 0.27 \pm 0.08$

# Conclusion

- BABAR has new sin2$\beta_{(eff)}$ results for all *s*-penguin analyses, most using 227×10$^6$ $B$ pairs
- Introduced and observed new silver-plated *s*-penguin mode $B^0 \to f_0(980)K^0_S$
- Sophisticated vertexing allows time-dependent measurement of CPV in $B^0 \to \pi^0 K^0_S$


BELLE

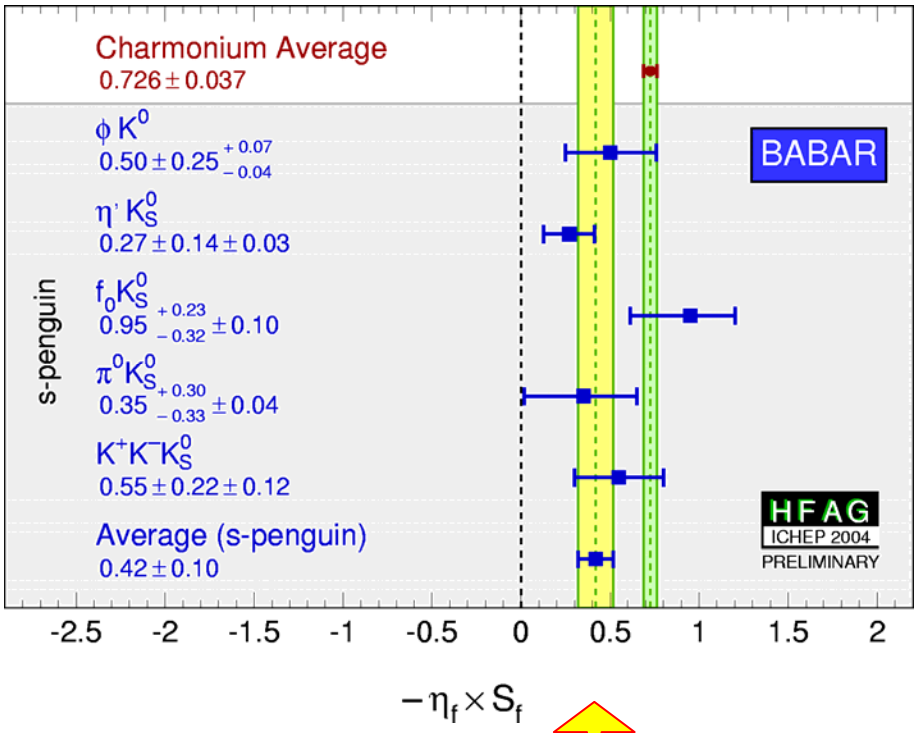



- ... and overall:

**s-penguins**

# Results on sin2β from s-penguin modes

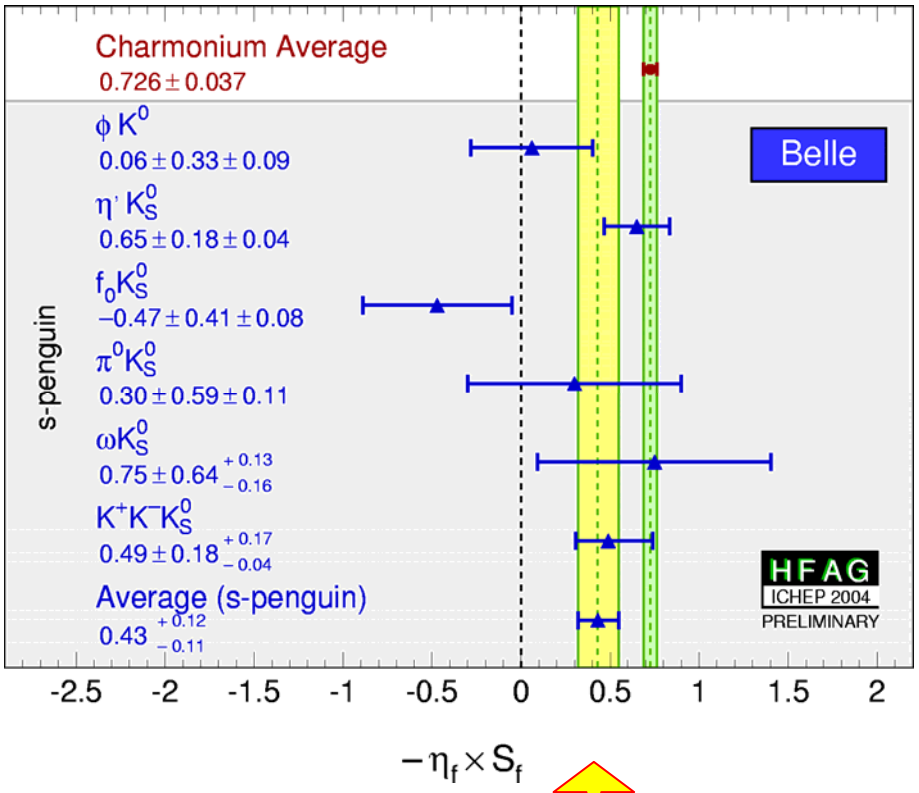
All new!




2.7σ from s-penguin to sin2β (cc̄)

BELLE

All new!




2.4σ from s-penguin to sin2β (cc̄)

# Great News on sin(2α) front
## (Mostly from BABAR)

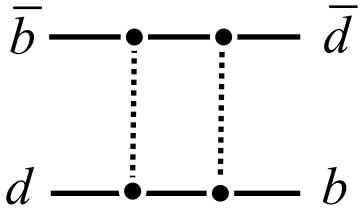
- *Update available on ππ mode, still « plagued » by penguins*
- *3 key measurements now available lead to First measurement on α, regardless of the penguin « pollution »*
  - Dalitz analysis in the ρπ mode
  - Precise BR AND asymmetry in $\pi^0\pi^0$
  - More precise measurement in ρρ mode
- *Direct measurement more precise than indirect estimation from CKM fit !*

# sin2α from $B \to \pi\pi,\ \rho\pi,\ \rho\rho$

Interference of suppressed $b \to u$ "tree" decay with mixing

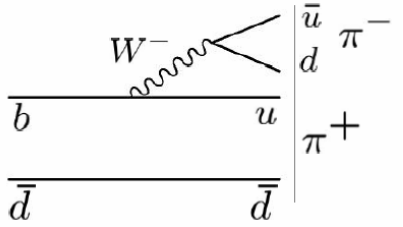
but: "penguin" is sizeable!

$B^0$ mixing



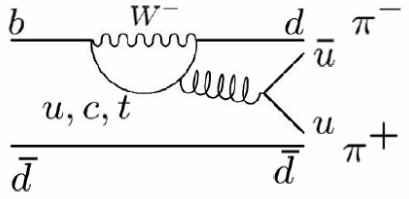

$\oplus$

$B^0$ decay: tree




$\oplus$

$B^0$ decay: penguin




$q/p \propto V_{tb}^* V_{td} / V_{tb} V_{td}^*$ $\quad A \propto V_{ub}^* V_{ud}$ $\quad \propto \lambda^3$

$A \propto V_{td}^* V_{tb}$ $\quad \propto \lambda^3$

$$\lambda_{\pi\pi} = \frac{q}{p}\frac{\bar{A}_{\pi\pi}}{A_{\pi\pi}} = e^{-i2\beta} e^{-i2\gamma} = e^{i2\alpha}$$

$$\lambda_{\pi\pi} = e^{i2\alpha} \frac{T + Pe^{+i\gamma} e^{i\delta}}{T + Pe^{-i\gamma} e^{i\delta}}$$

**Coefficients of time-dependent CP Asymmetry**

With no penguins $S_{\pi\pi} = \sin 2\alpha$, $C_{\pi\pi} = 0$

With large penguins and |P/T| ~ 0.3 $S_{\pi\pi} = \sqrt{1 - C_{\pi\pi}^2}\, \sin 2\alpha_{eff}$, $C_{\pi\pi} \propto \sin\delta$

# Results for $\sin 2\alpha_{eff}$ from $B \to \pi\pi$ decays

**BABAR: Updated for ICHEP04**

$B^0 \to \pi^+\pi^-$ (227 M pairs)

$$S_{\pi\pi} = -0.30 \pm 0.17 \pm 0.03$$
$$C_{\pi\pi} = -0.09 \pm 0.15 \pm 0.04$$

$B^\pm \to \pi^\pm\pi^0$ (227 M pairs)

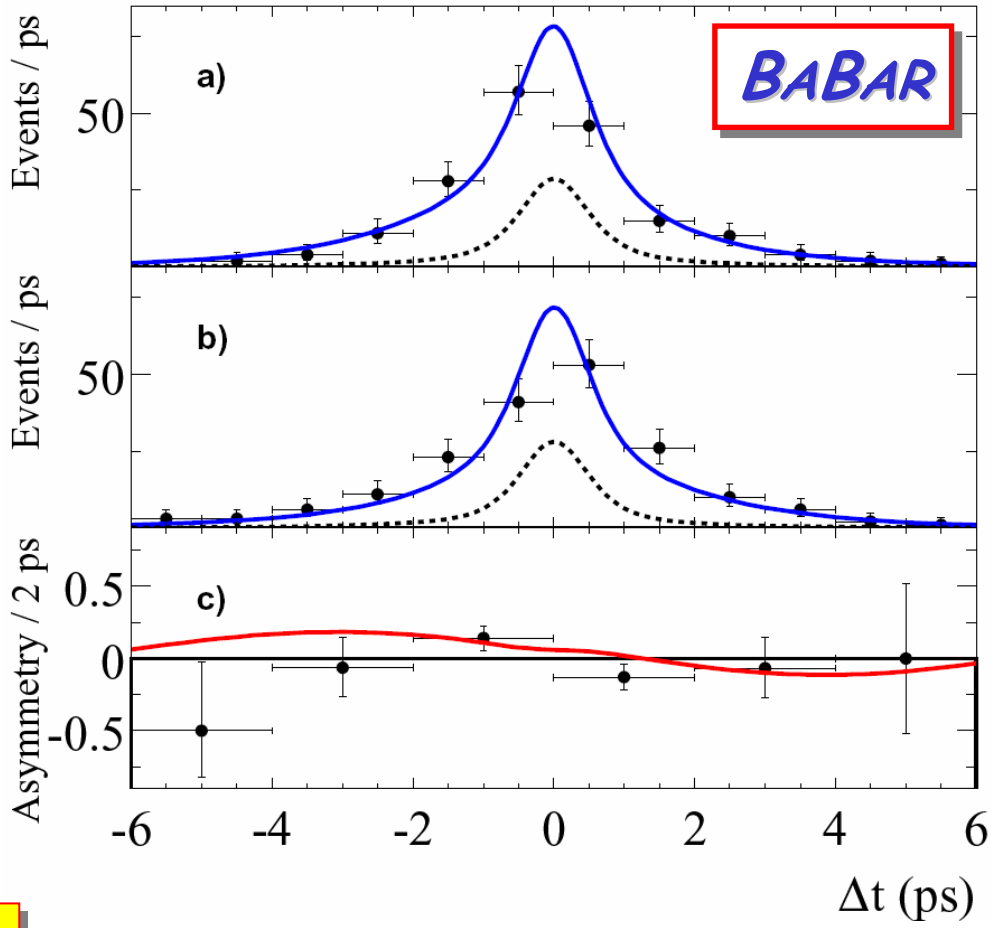
$$A_{\pi^\pm\pi^0} = -0.01 \pm 0.10 \pm 0.02$$
$$BF_{\pi^\pm\pi^0} = (5.8 \pm 0.6 \pm 0.4) \times 10^{-6}$$

**Belle: PRL 93 (2004) 021601**

BELLE

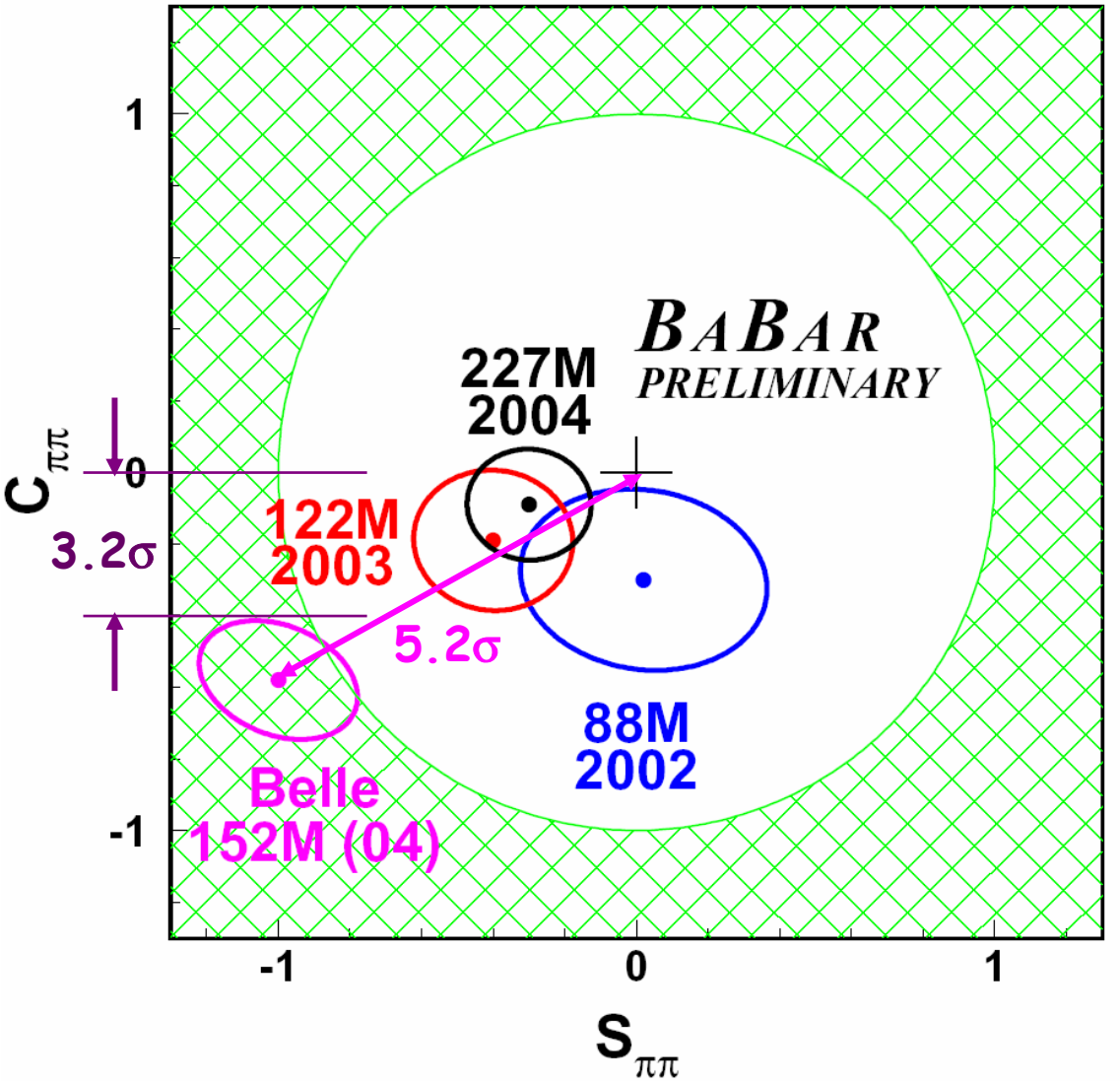
152 M pairs

$$S_{\pi\pi} = -1.00 \pm 0.21 \pm 0.07$$
$$C_{\pi\pi} = -0.58 \pm 0.15 \pm 0.07$$




BABAR CONF-04/047, 04/035

# Comparison of $B \to \pi\pi$ results



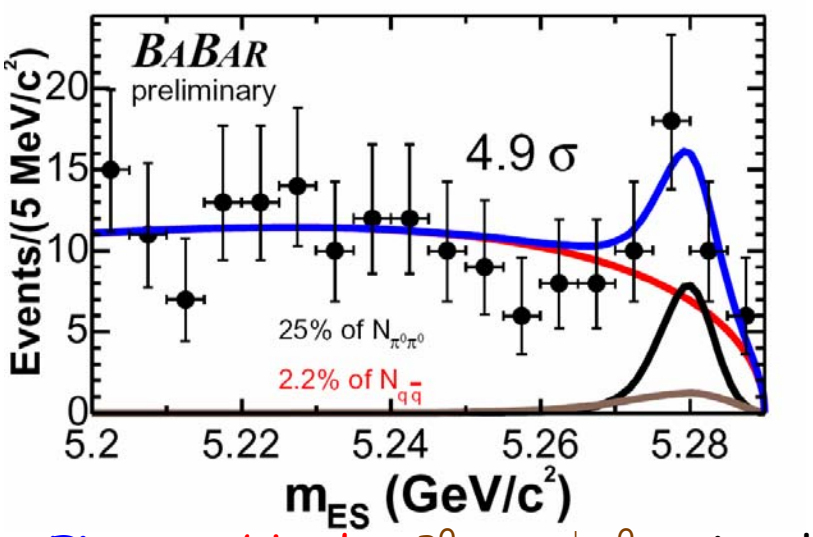

>3σ discrepancy between *BABAR* & Belle

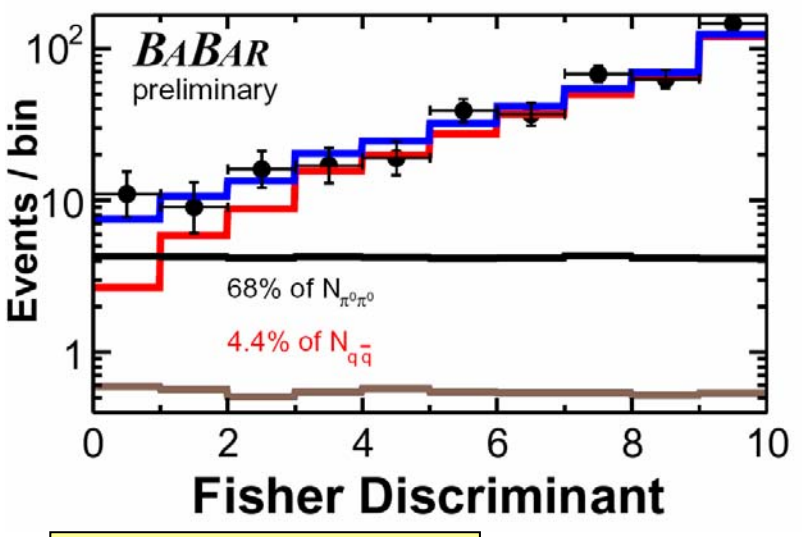
**Belle evidence for Direct *CP* violation not supported by *BABAR* measurements**

Caution averaging!

# Result for $B \to \pi^0\pi^0$

**Updated for ICHEP04**




Fit = $q\bar{q}$ bkgd + $B^0 \to \rho^{\pm}\pi^0$ + signal

*BABAR CONF-04/035*

Improved understanding of $\pi^0$ efficiency:

$\varepsilon_{data} / \varepsilon_{MC} = 0.99 \pm 0.03$ vs $0.88 \pm 0.08$

| *BABAR* | $B\bar{B}$ pairs | $N(\pi^0\pi^0)$ |
|---|---|---|
| *Run 1-3* | *122M* | *44 ±13* |
| *Run 4* | *105M* | *17 ±11* |
| *Run 1-4* | *227M* | *61 ±17* |

Consistent at 1.3σ level

4.9σ

$$BF_{\pi^0\pi^0} = (1.17 \pm 0.32 \pm 0.10) \times 10^{-6}$$

$$C_{\pi^0\pi^0} = -0.12 \pm 0.56 \pm 0.06$$

First measurements

$\alpha - \alpha_{eff} \leq 35°$ at 90% CL

6.0σ

$$BF_{\pi^0\pi^0} = (2.32^{+0.41}_{-0.48} {}^{+0.22}_{-0.18}) \times 10^{-6}$$

$$C_{\pi^0\pi^0} = -0.43 \pm 0.51^{+0.16}_{-0.17}$$

First measurements

- ***3 key measurements now available***
  - Dalitz analysis in the $\rho\pi$ mode
  - Precise BR AND asymmetry in $\pi^0\pi^0$
  - More precise measurement in $\rho\rho$ mode
- ***First measurement on $\alpha$, regardless of the penguin « pollution »***
- ***Direct measurement more precise than indirect estimation from CKM fit !***

# Results for $\sin 2\alpha_{eff}$ from $B \to \rho\rho$ decays

Extraction of $\alpha$ similar to $\pi\pi$, but with advantage of smaller Penguin pollution:

$\frac{|A^{00}|}{|A^{+0}|}, \frac{|A^{00}|}{|A^{+-}|}$ much smaller: $\alpha - \alpha_{eff}$ smaller

Potentially $\rho^+\rho^-$ could be mixed $CP$, but is observed to be almost pure $CP = +1$

**Moriond QCD04**

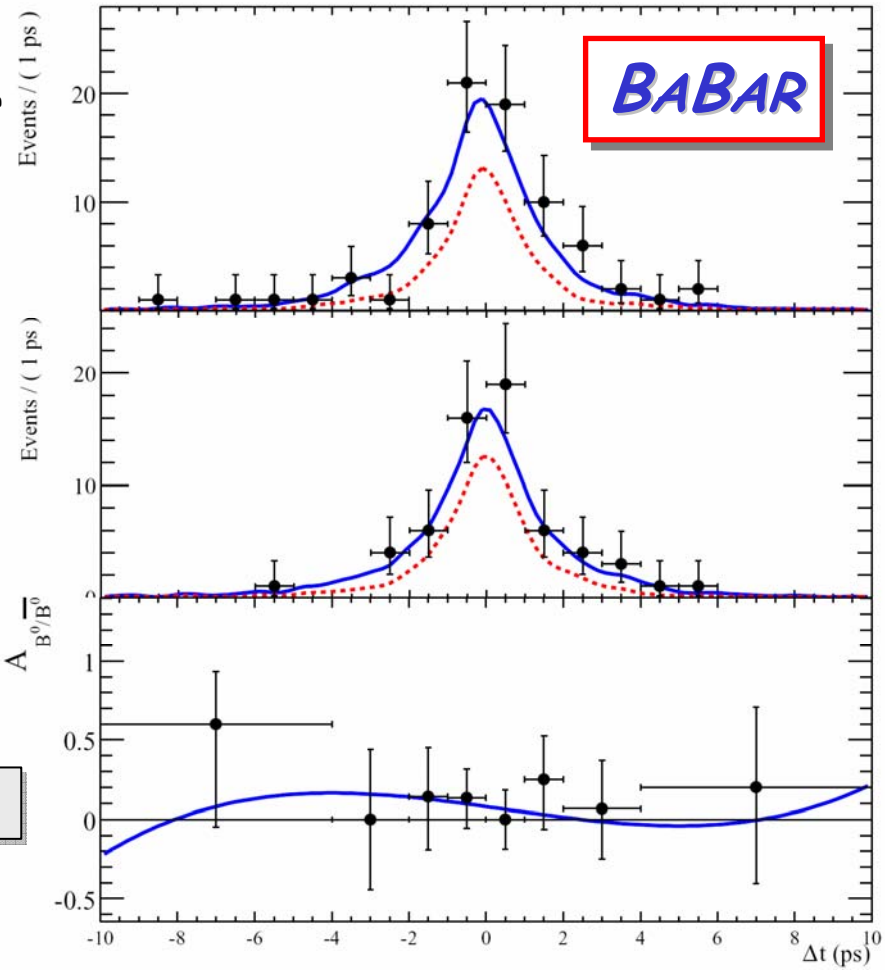
$B^0 \to \rho^+\rho^-$ (122M $B\bar{B}$ pairs)

Signal: $314 \pm 34$ events

$f_{long} = 1.00 \pm 0.02$

$S_{long} = -0.19 \pm 0.33 \pm 0.11$

$C_{long} = -0.23 \pm 0.24 \pm 0.14$




*hep-ex/0404029 to PRL* (89M $B\bar{B}$ pairs)

$S_{long} = -0.42 \pm 0.42 \pm 0.14$

$C_{long} = -0.17 \pm 0.27 \pm 0.14$

# Isospin Corrections for $\alpha$

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

PRL 91 (2003) 171802

First result from Run 1-2 (89M $B\bar{B}$ pairs)

$$BF(B^+ \to \rho^+ \rho^0) = (22.5^{+5.7}_{-5.4} \pm 5.8) \times 10^{-6}$$

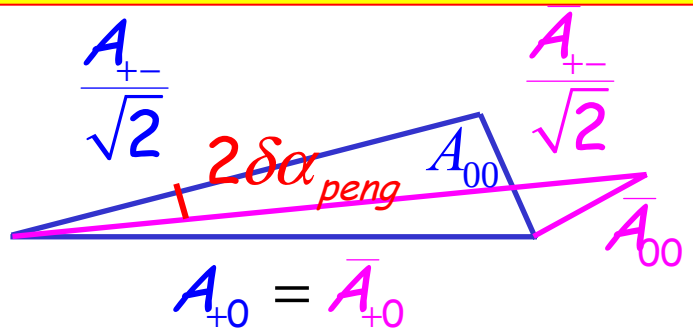
$B^0 \to \rho^0 \rho^0$

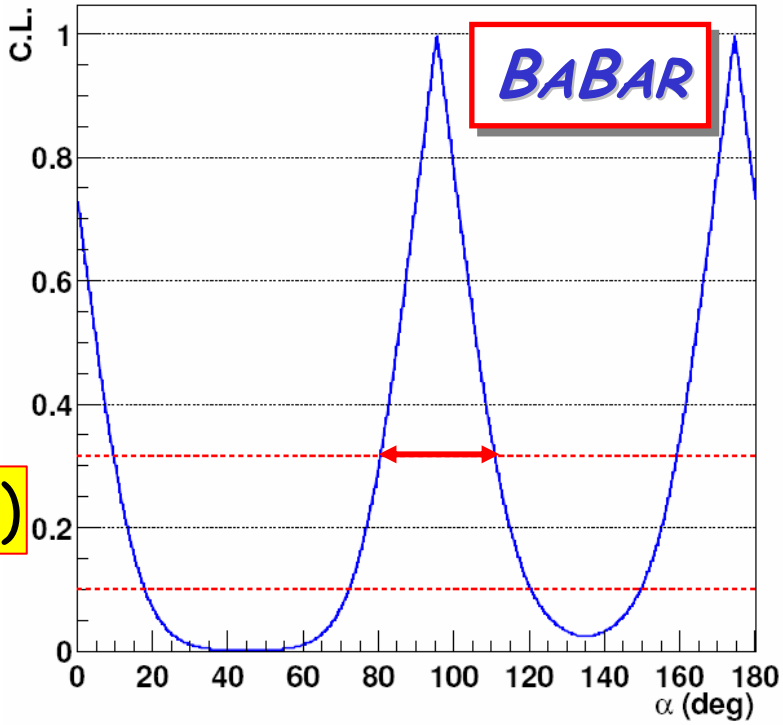
**Updated for ICHEP04**

BABAR CONF-04/037

Updated result from Run 1-4 (227M $B\bar{B}$ pairs)

$$BF(B^0 \to \rho^0 \rho^0) < 1.1 \times 10^{-6} \ (90\% \ CL)$$




$$\alpha = \left[ 96 \pm 10_{(stat)} \pm 4_{(sys)} \pm 11_{(peng)} \right]^\circ$$

Geometric limit on $2\delta\alpha_{peng}$: Grossman-Quinn bound

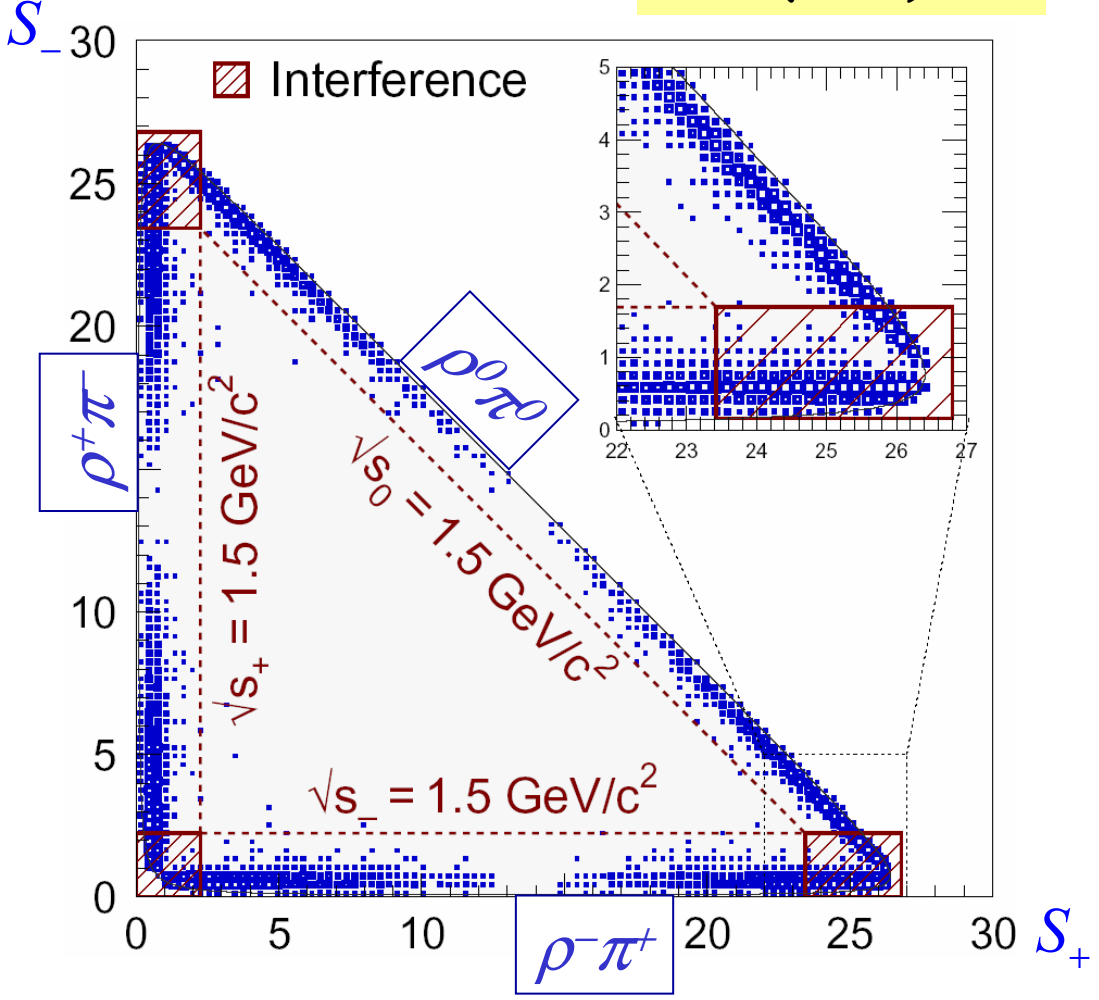
Compare with 35° for $\pi\pi$

# Basis for Dalitz plot analysis of $B^0 \to (\rho\pi)^0$

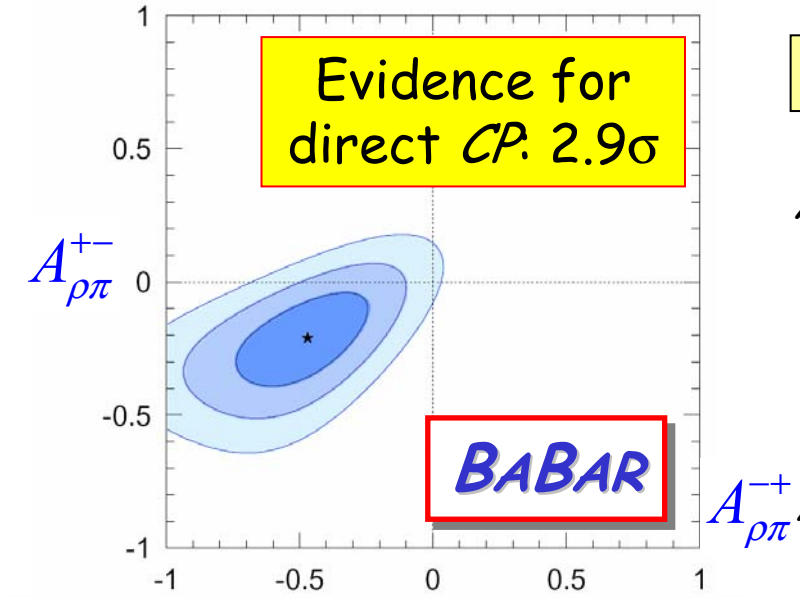
Quasi-two-body approach to Snyder-Quinn method

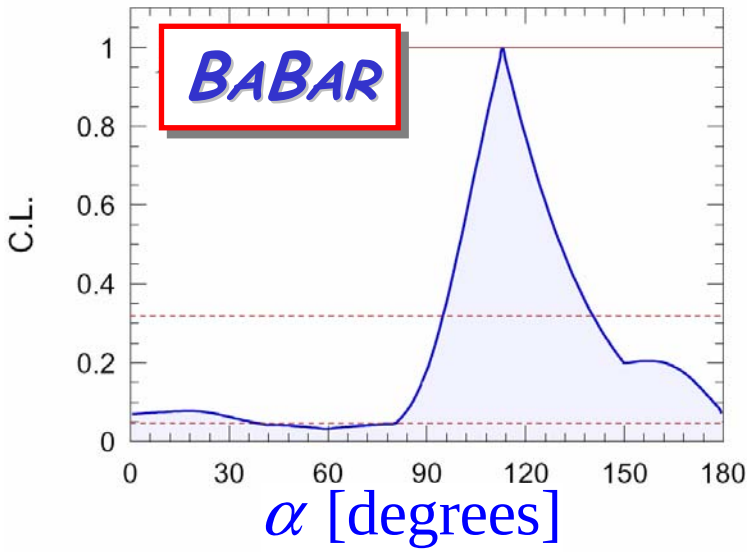
*Phys.Rev. D 48, 2139 (1993)*

- Extract $\alpha$ and strong phases using interference between amplitudes
- Amplitude $A_{3\pi}$ dominated by $\rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$ and radial excitations
- Form time-dependent decay rate coefficients of $\cos(\Delta m_d \Delta t)$ and $\sin(\Delta m_d \Delta t)$ on this basis



# Results from Dalitz analysis of $B^0 \to (\rho\pi)^0$




| | *Belle* [152M] | *BABAR* [213M] |
|---|---|---|
| $A_{CP}^{\rho\pi}$ | $-0.16\,^{+0.09}_{-0.10}$ | $-0.088 \pm 0.049 \pm 0.013$ |
| $S$ | $-0.28 \pm 0.23\,^{+0.10}_{-0.08}$ | $-0.10 \pm 0.14 \pm 0.04$ |
| $C$ | $0.25 \pm 0.17\,^{+0.02}_{-0.06}$ | $0.34 \pm 0.11 \pm 0.05$ |
| $A^{+-}$ | $-0.02 \pm 0.16\,^{+0.05}_{-0.02}$ | $-0.21 \pm 0.11 \pm 0.04$ |
| $A^{-+}$ | $-0.53 \pm 0.29\,^{+0.09}_{-0.04}$ | $-0.47 \pm 0.15 \pm 0.06$ |

combined $3.6\sigma$

$\alpha = (102 \pm 11 \pm 15)^\circ$

$\alpha = (113\,^{+27}_{-17} \pm 6)^\circ$

[Based on factorization & SU(3); Gronau & Zupan]

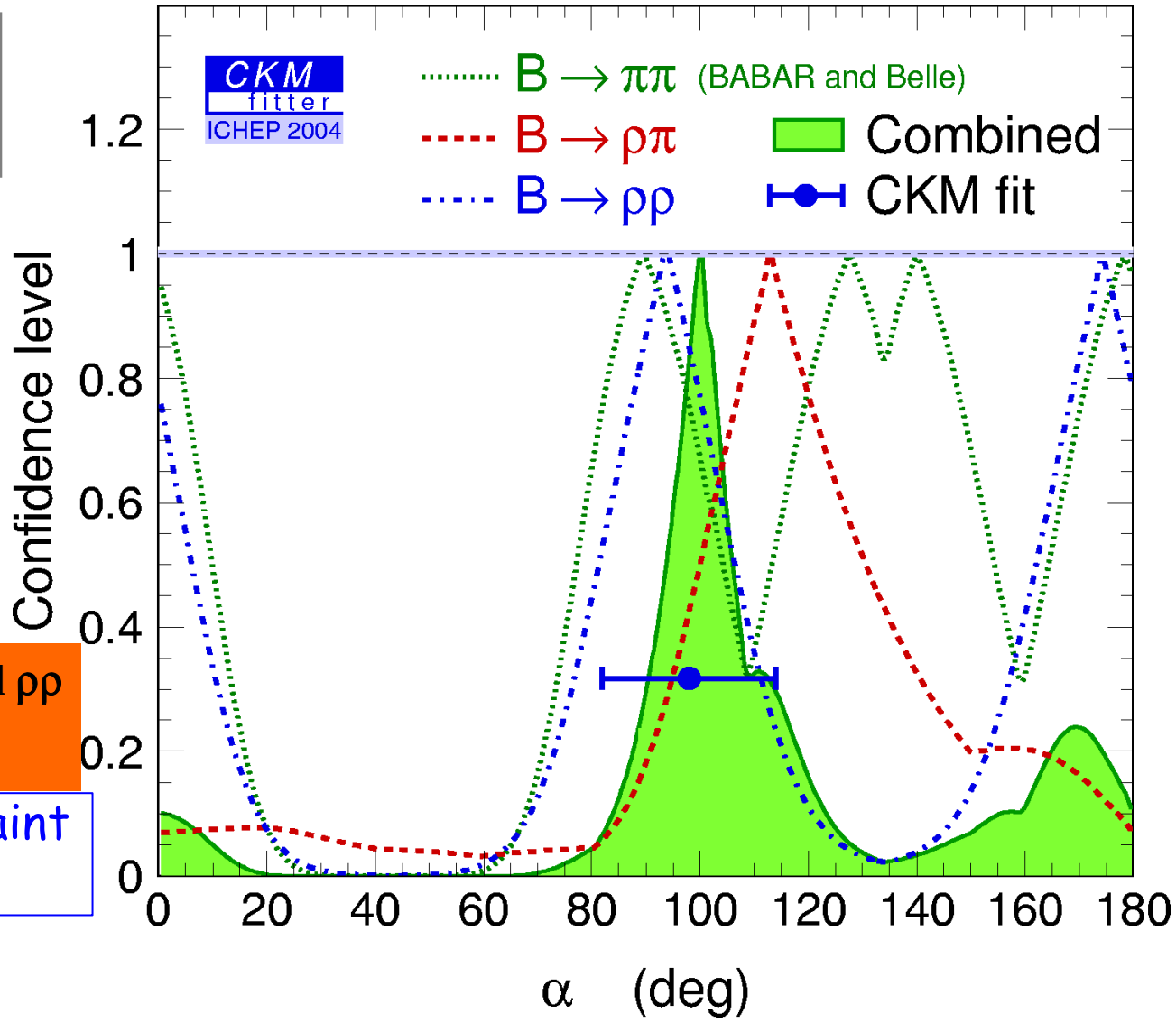
*hep-ex/0408003*

*BABAR CONF-04/038*

# Summary of constraints on $\alpha$

**BABAR & Belle combined**

Mirror solutions disfavored

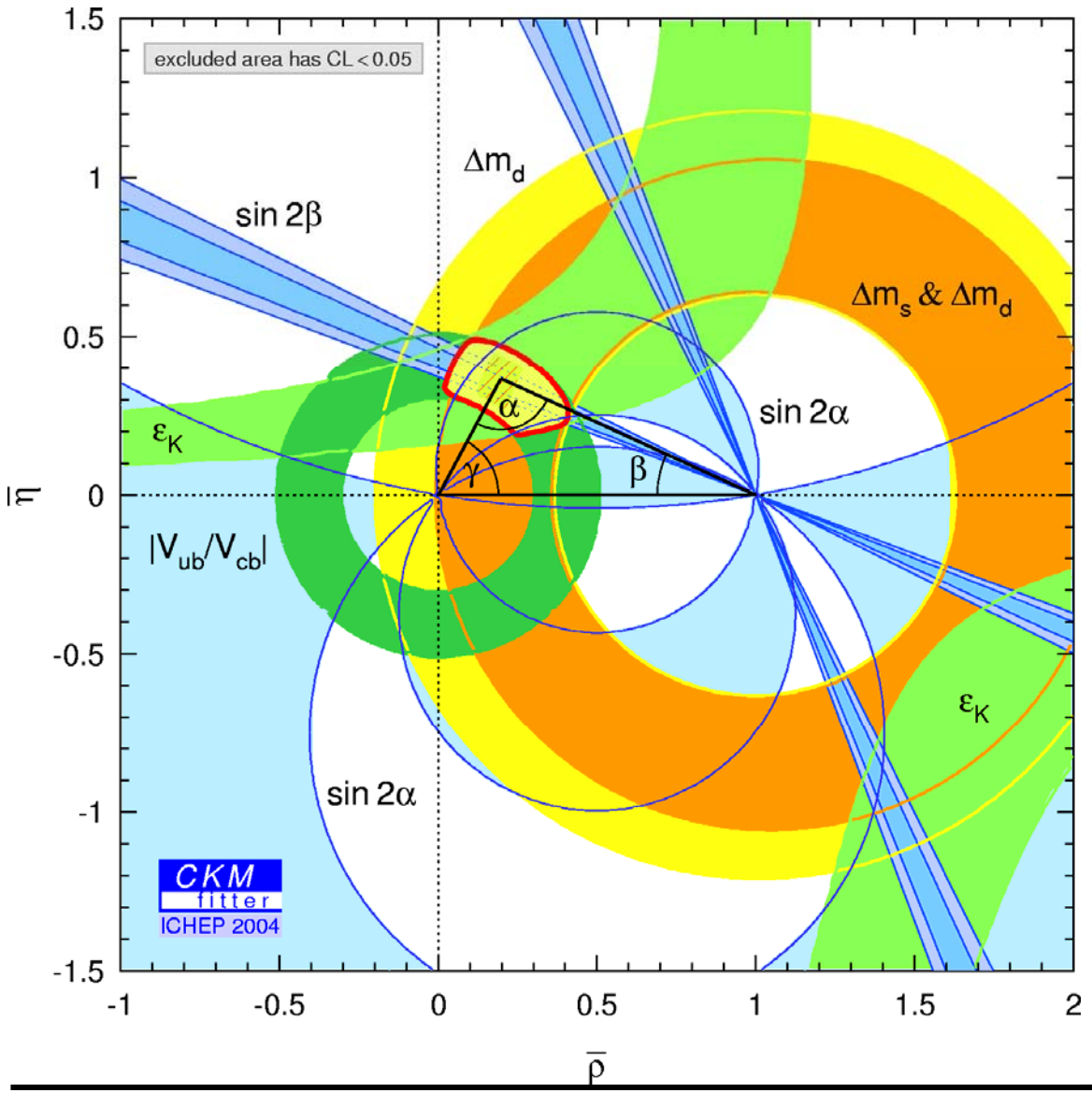



**From combined ππ, ρπ and ρρ**

**$\alpha$=100 +9 -10 degrees**

*CKM* indirect constraint fit: $\alpha = 98 \pm 16^{\circ}$

# CKM constraints and sin2β and α measurements




CKM fit to indirect constraints overlaid with $\sin 2\beta_{WA}$ and $\alpha$ measurements

# First observation of Direct CPV in B decays

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

**BABAR** *hep-ex/0408057, to appear in PRL*

$A_{CP} = -0.133 \pm 0.030 \pm 0.009$

$4.2\sigma$

**Belle** **Confirmation at ICHEP04**

Signal (274*M* $B\bar{B}$ pairs): $2140 \pm 53$

$A_{CP} = -0.101 \pm 0.025 \pm 0.005$

$3.9\sigma$

**Average** $A_{CP} = -0.114 \pm 0.020$

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

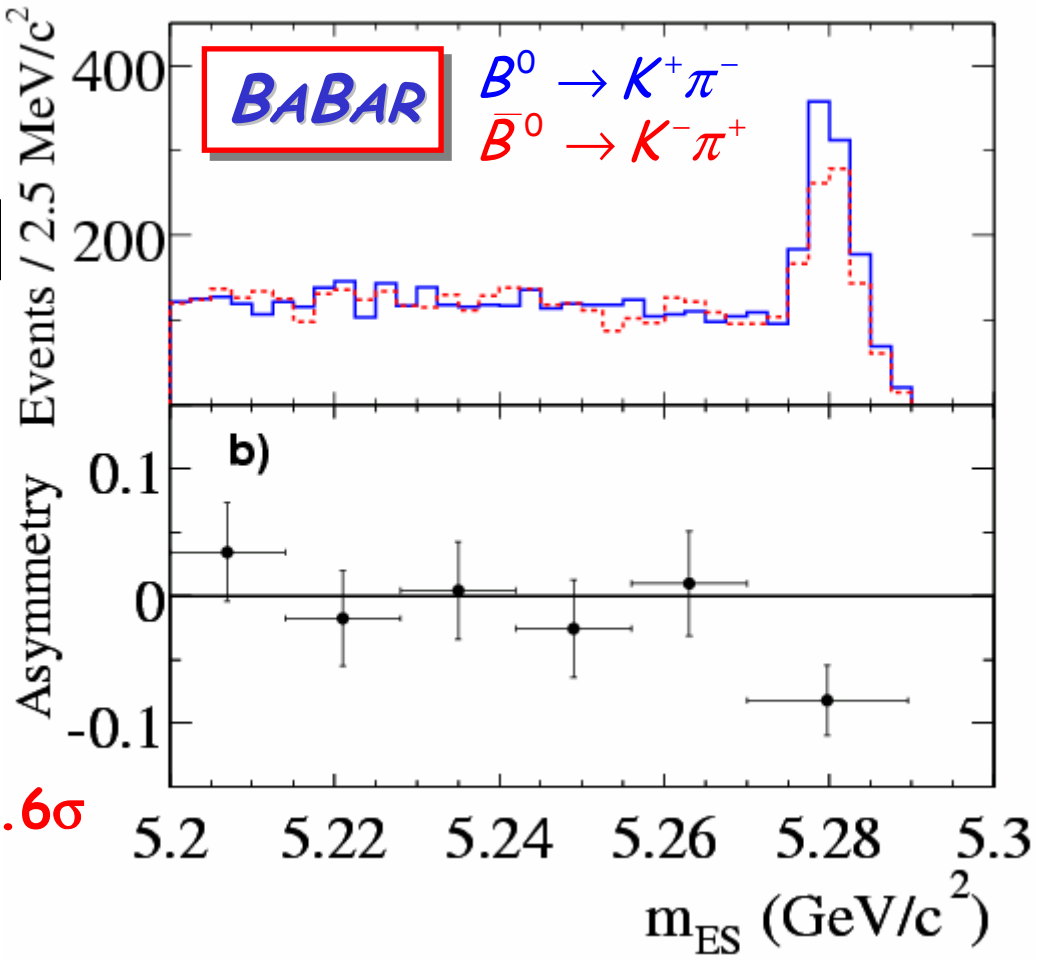
$A_{CP} = +0.06 \pm 0.06 \pm 0.01$ *BABAR*

$A_{CP} = +0.04 \pm 0.05 \pm 0.02$ Belle

$3.6\sigma$

**Average** $A_{CP} = +0.049 \pm 0.040$

Signal (227*M* $B\bar{B}$ pairs): $1606 \pm 51$

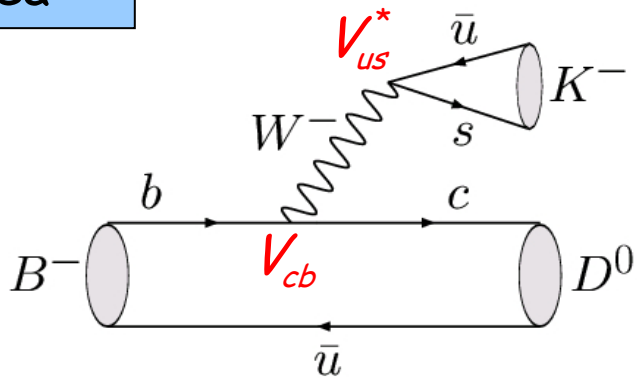


# Methods for extraction of $\gamma$

$\gamma$ is phase between $b \to u$ ($\propto V_{ub}$) and $b \to c$ ($\propto V_{cb}$) amplitudes

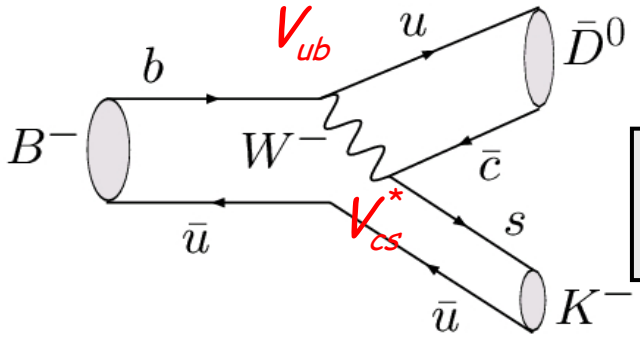
**Basic Idea**

Use interference between $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$ decays where the $D^0(\bar{D}^0)$ decay to a common final state $f$




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

$A \propto V_{ub}V_{cs}^* \quad \propto \lambda^3\sqrt{\rho^2+\eta^2}\,e^{i\gamma}$




Color suppressed

**GLW** *Gronau-London-Wyler, 1991*
Use $B^- \to D^0_{CP\pm} K^-$ decays

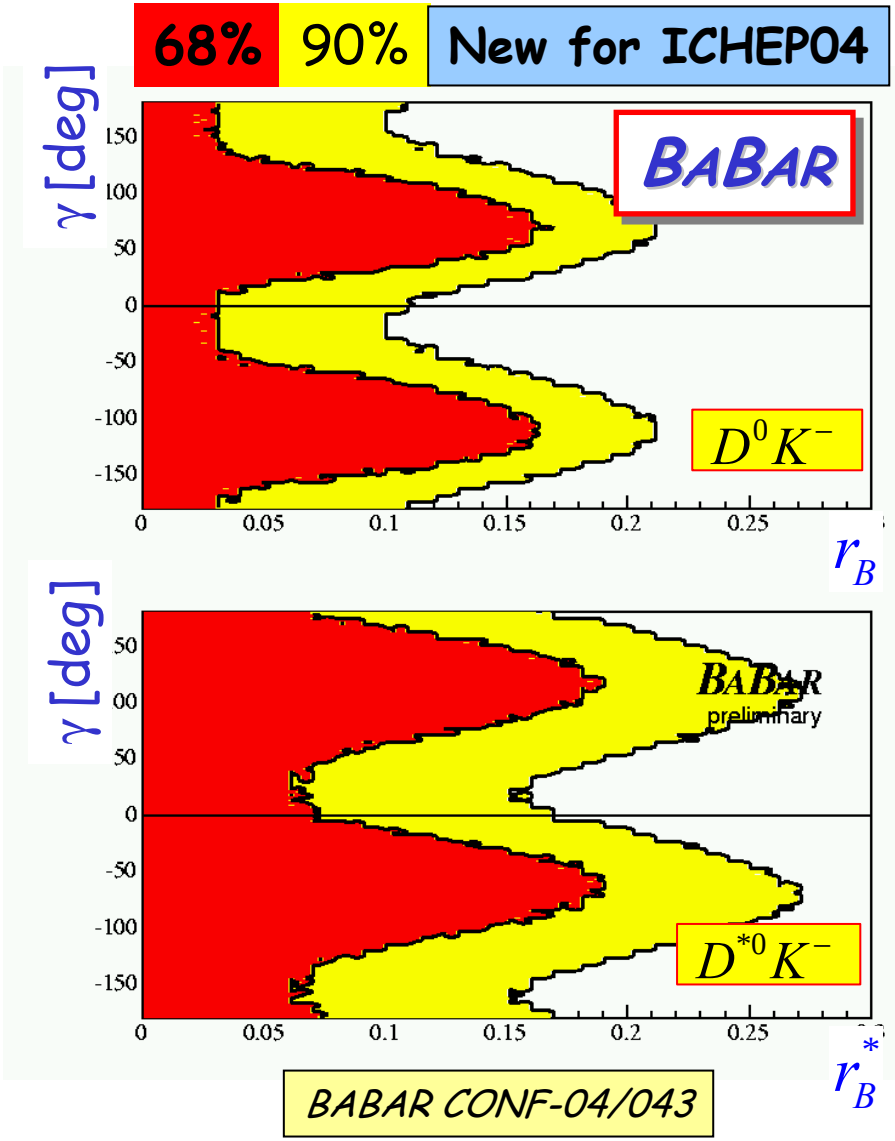
**ADS** *Atwood-Dunietz-Soni, 2001*
Use $B^- \to D^{(*)0}\left[K^+\pi^-\right]K^-$ decays

**D⁰ Dalitz plot** Use $B^- \to D^{(*)0}\left[K^0_S\pi^+\pi^-\right]K^-$ decays

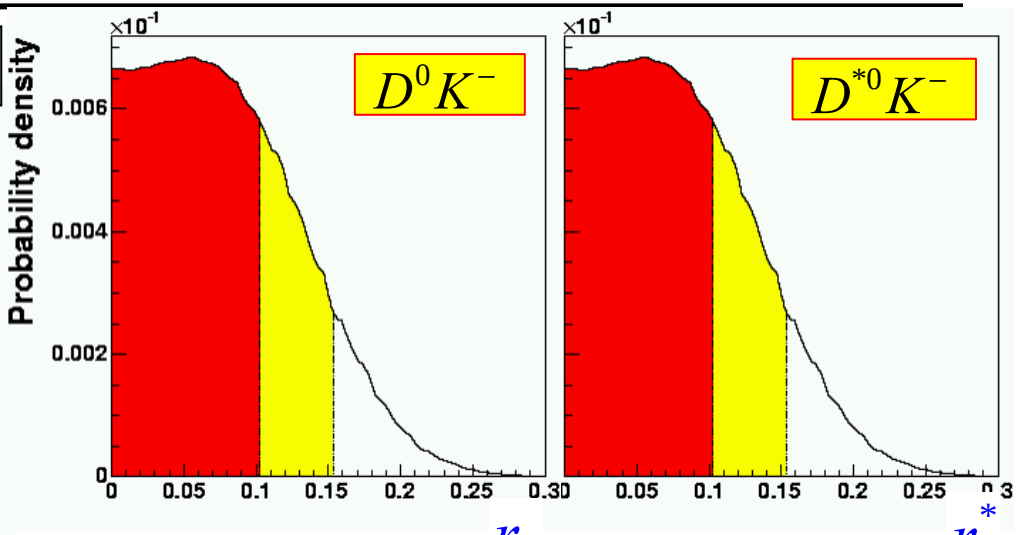
Size of CP asymmetry depends on

$$r_B^{(*)} \equiv \frac{|A(B^- \to \bar{D}^{(*)0}K^-)|}{|A(B^- \to D^{(*)0}K^-)|} \sim 0.1-0.3$$

# BABAR analysis of $B^- \to D^{(*)0}[K_S\pi^+\pi^-]K^-$




BABAR CONF-04/043




$r_B < 0.17$ (90% CL)

$r_B^* < 0.23$ (90% CL)

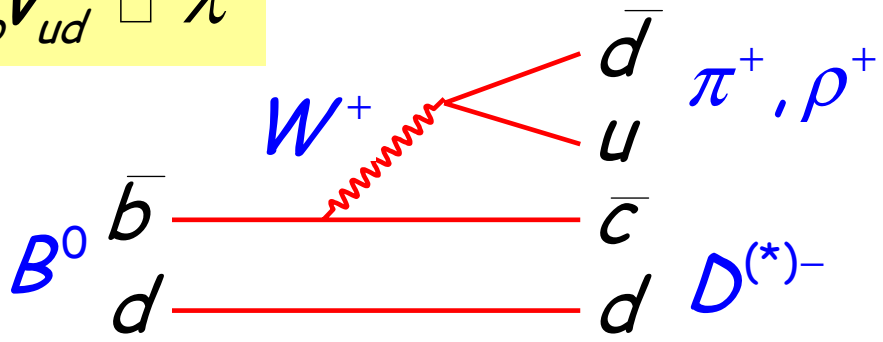
[No sensitivity to $r_B < 0.1$]

$$\delta_B = (130 \pm 45 \pm 8 \pm 10_{(model)})^\circ$$
$$\delta_B^* = (311 \pm 52 \pm 23 \pm 10_{(model)})^\circ$$
$$\gamma = (88 \pm 41 \pm 19 \pm 10_{(model)})^\circ$$

Poor constraints on $\gamma$ as yet

# Decays to common final states

$V_{cb}^{*}V_{ud} \sim \lambda^2$



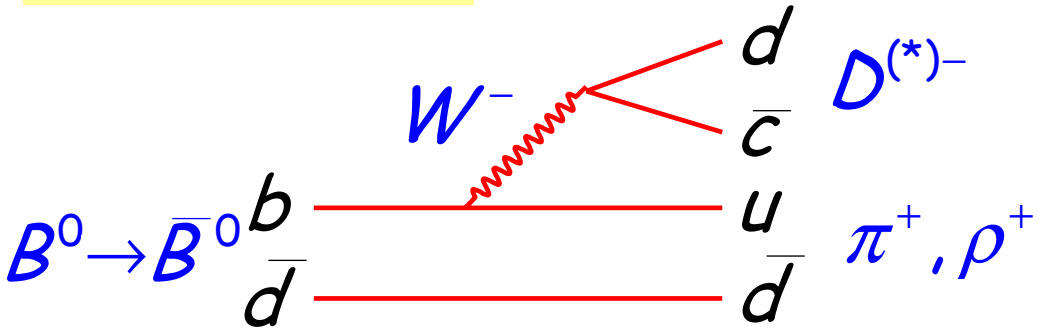

**Ingredients**

Both $B^0$ and $\bar{B}^0$ decay to $D^{(*)+}\pi^-$ and $D^{(*)-}\pi^+$

Sensitivity to $\gamma$ enters via amplitude $\propto V_{ub}$

Mixing induced time-dependent asymmetries

$V_{ub}^{*}V_{cd} \sim \lambda^4 e^{i\gamma}$




**Current status**

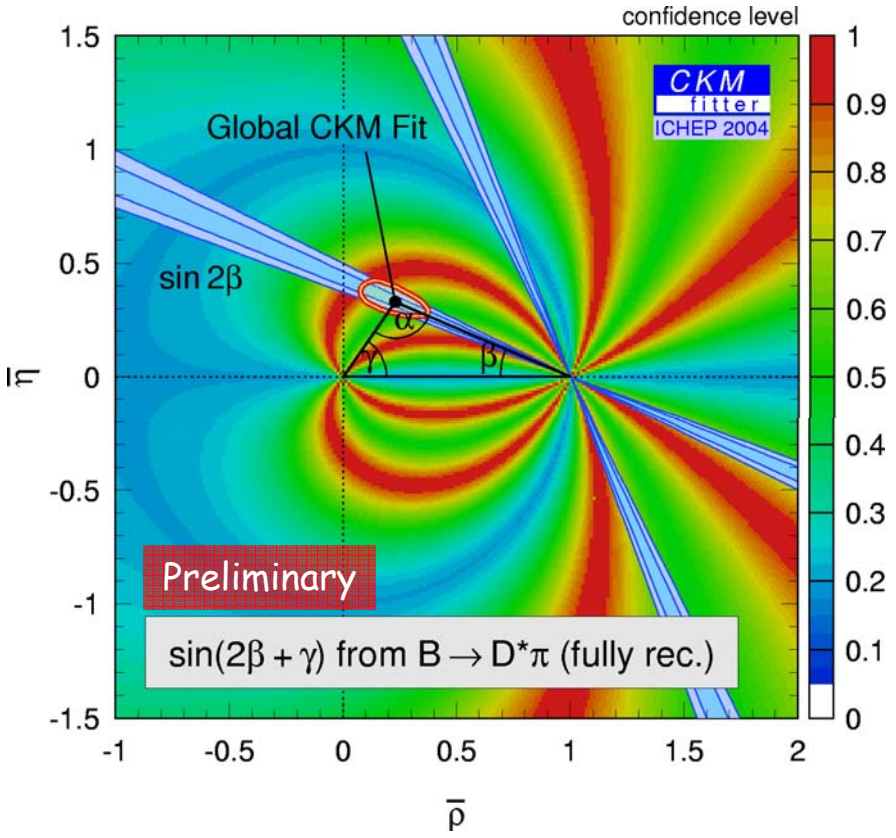
$$\left|r_B^{(*)}\right| = \frac{\left|A\left(\bar{B}^0 \to D^{(*)-}\pi^+\right)\right|}{\left|A\left(B^0 \to D^{(*)-}\pi^+\right)\right|} \sim 0.02$$

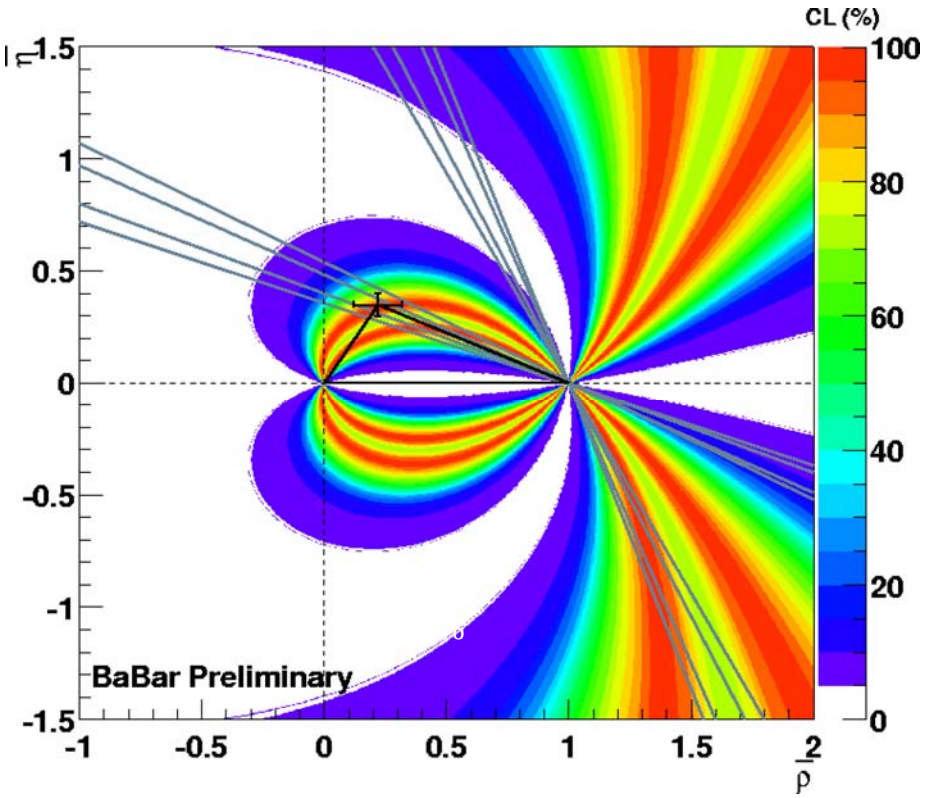
from $BF\left(B^0 \to D_S^+\pi^-\right)$ and SU(3) symmetry

# Constraints on Unitarity Triangle

Exclusive reconstruction of $B^0 \to D^{(*)}\pi$

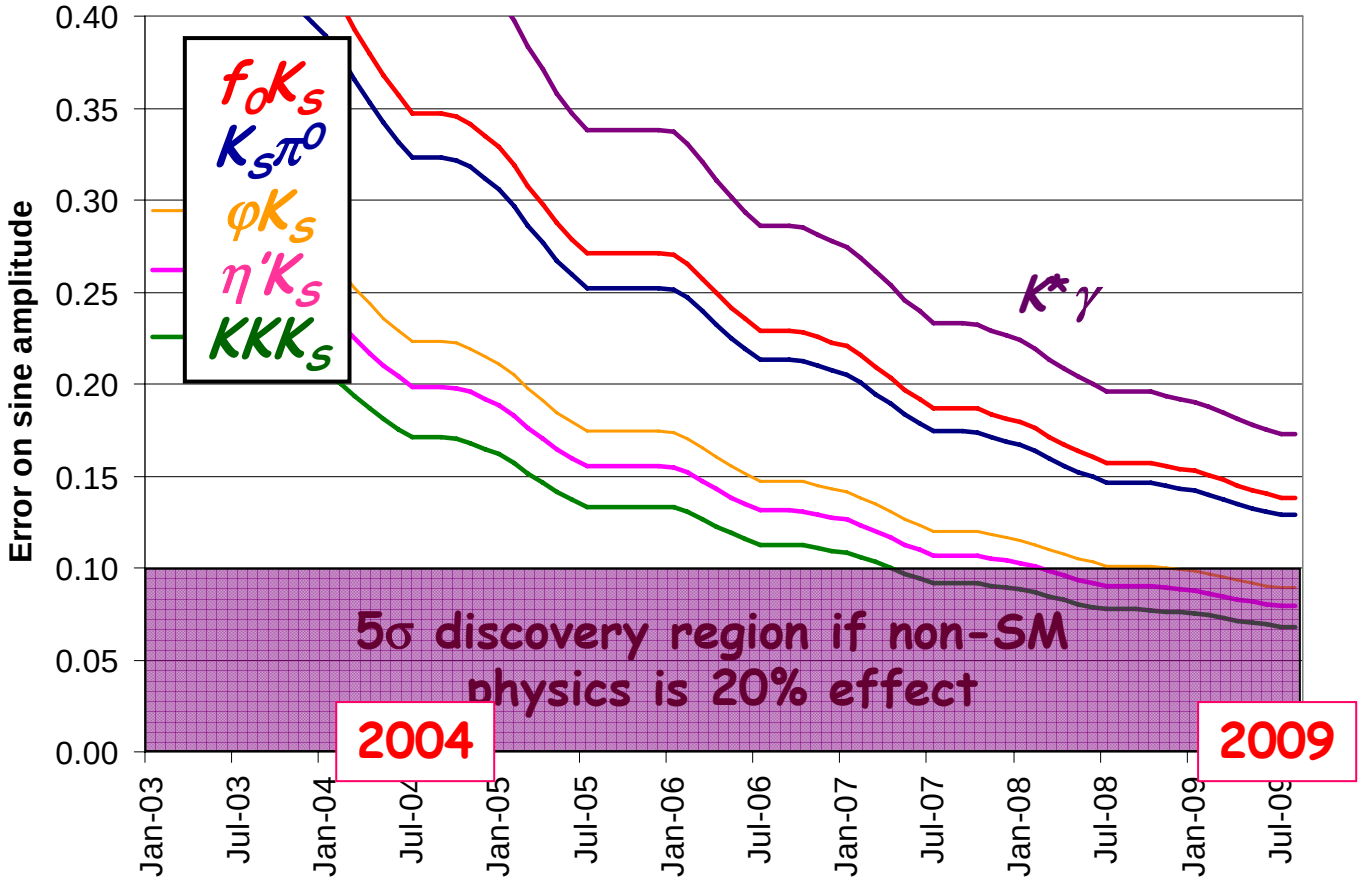
Partial reconstruction of $B^0 \to D^*\pi$




Updated estimate of $r_B^* = 0.015^{+0.004}_{-0.006}$ from improved $BF(D_S^+ \to \phi\pi^+)$

# Projections for Penguin Modes




Luminosity expectations :

2004=240 $fb^{-1}$
2009=1.5 $ab^{-1}$

**Similar projections for Belle as well**

Projections are statistical errors only;
but systematic errors at few percent level

# Perspectives and conclusion

- Precision measurements of *CP* violation in charmonium $b \to c\bar{c}s$ modes (new *BABAR* result $\sin 2\beta = 0.726 \pm 037$)
- Good agreement between *BABAR* and Belle CP violation in $b \to s\bar{s}s$ penguin modes, with both experiments showing a combined discrepancy with charmonium at the $3.7\sigma$ level. However, SM can allow such things to happen in certain modes.
  - *BABAR* and Belle should double dataset again by summer 2006, reaching statistically interesting levels of precision on these rare modes
- Measurement by *BABAR* of direct *CP* violation in $K^+\pi^-$ decays confirmed by Belle (average value -0.114 $\pm$0.024)
- Quantitative measurements of $\alpha(\phi_2)$ are now available
  - $\alpha(\phi 2)$ = 100 +9 -10 degrees
- Constraints on $\gamma(\phi_3)$ are still poor with present statistics (signs that $r_B$ may be small)

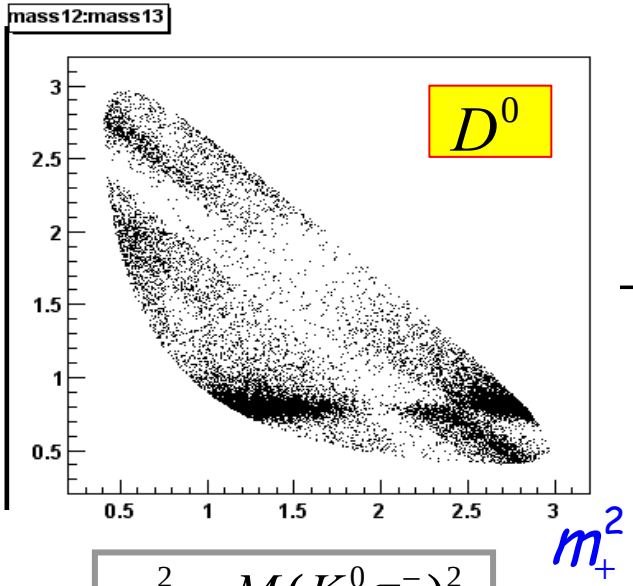
# Backup slides

# Dalitz analysis of $B^- \to D^{(*)0}[K_S\pi^+\pi^-]K^-$

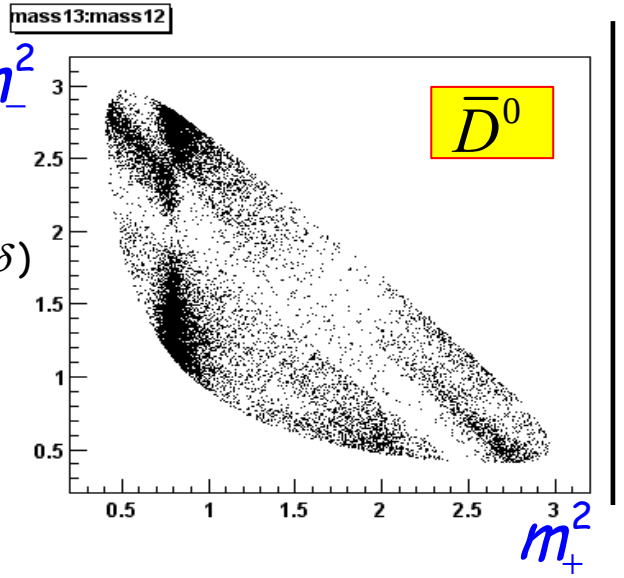
For $B^-$: $|A_-|^2 = |f(m_-^2, m_+^2) + r_b e^{i(\delta-\gamma)} f(m_+^2, m_-^2)|^2$

Schematic view of the interference

$$|A_-|^2 = \left| \right.$$




$$+ r_b e^{i(\gamma+\delta)}$$




$$\left. \right|^2$$

$$m_-^2 = M(K_S^0\pi^-)^2$$
$$m_+^2 = M(K_S^0\pi^+)^2$$

For $B^+$: $|A_+|^2 = |f(m_+^2, m_-^2) + r_b e^{i(\delta+\gamma)} f(m_-^2, m_+^2)|^2$

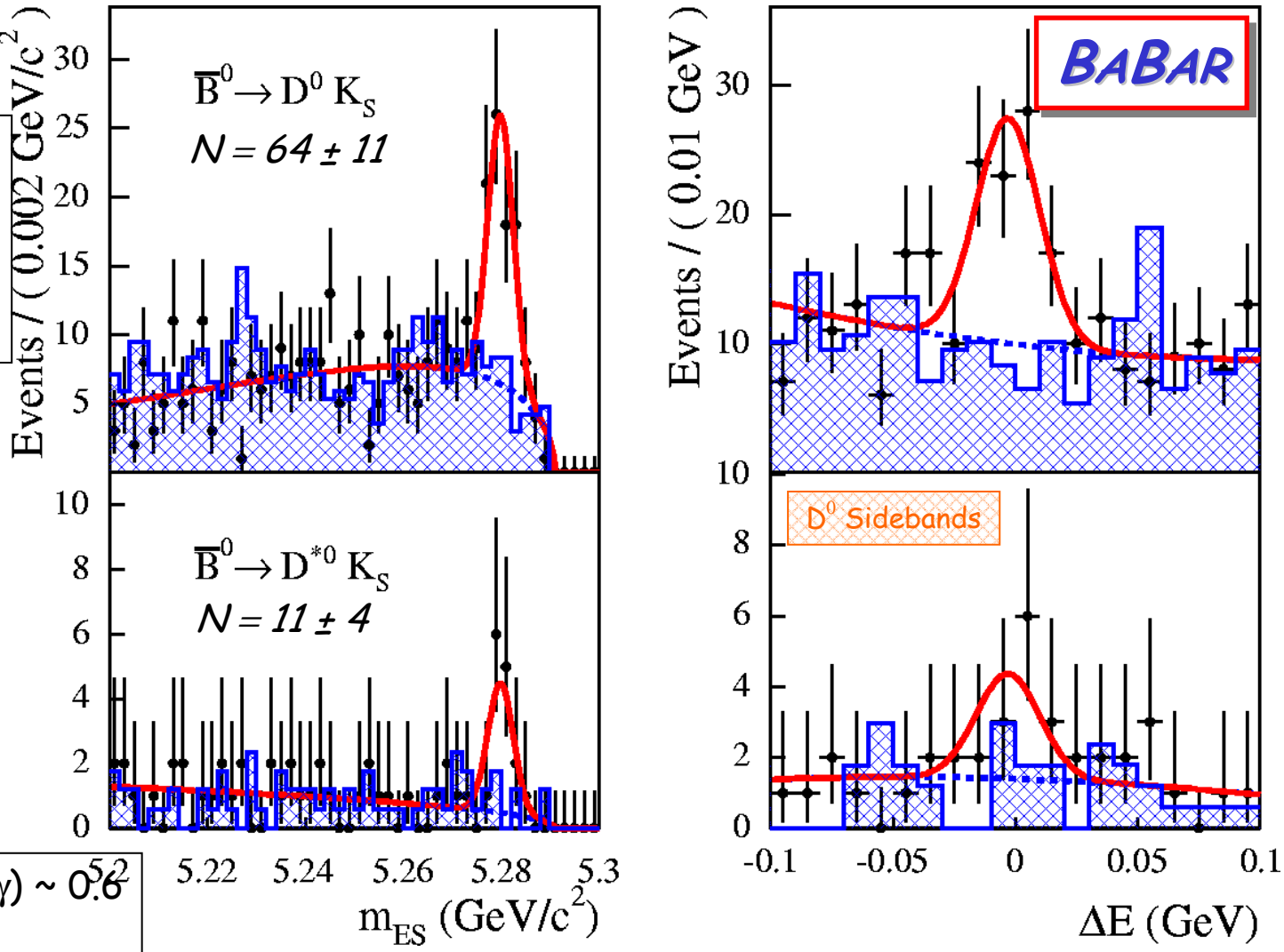
Two-fold ambiguity remains in extraction of $\gamma$ ($\gamma \to \gamma + \pi$)

# Study of $B^0 \to D^{(*)0} K_S$ decays

hep-ex/0408052

Cannot distinguish $B^0$ from $\bar{B}^0$

Hidden strangeness with $K_S$ in final state




Uncertainty on $\sin(2\beta+\gamma)$ ~ 0.6 with $D^0 K_s$ in 500 fb$^{-1}$

Caveat: assuming r ~ 0.4

# Self-tagging mode $\bar{B}^0 \to D^0 \bar{K}^{*0}$

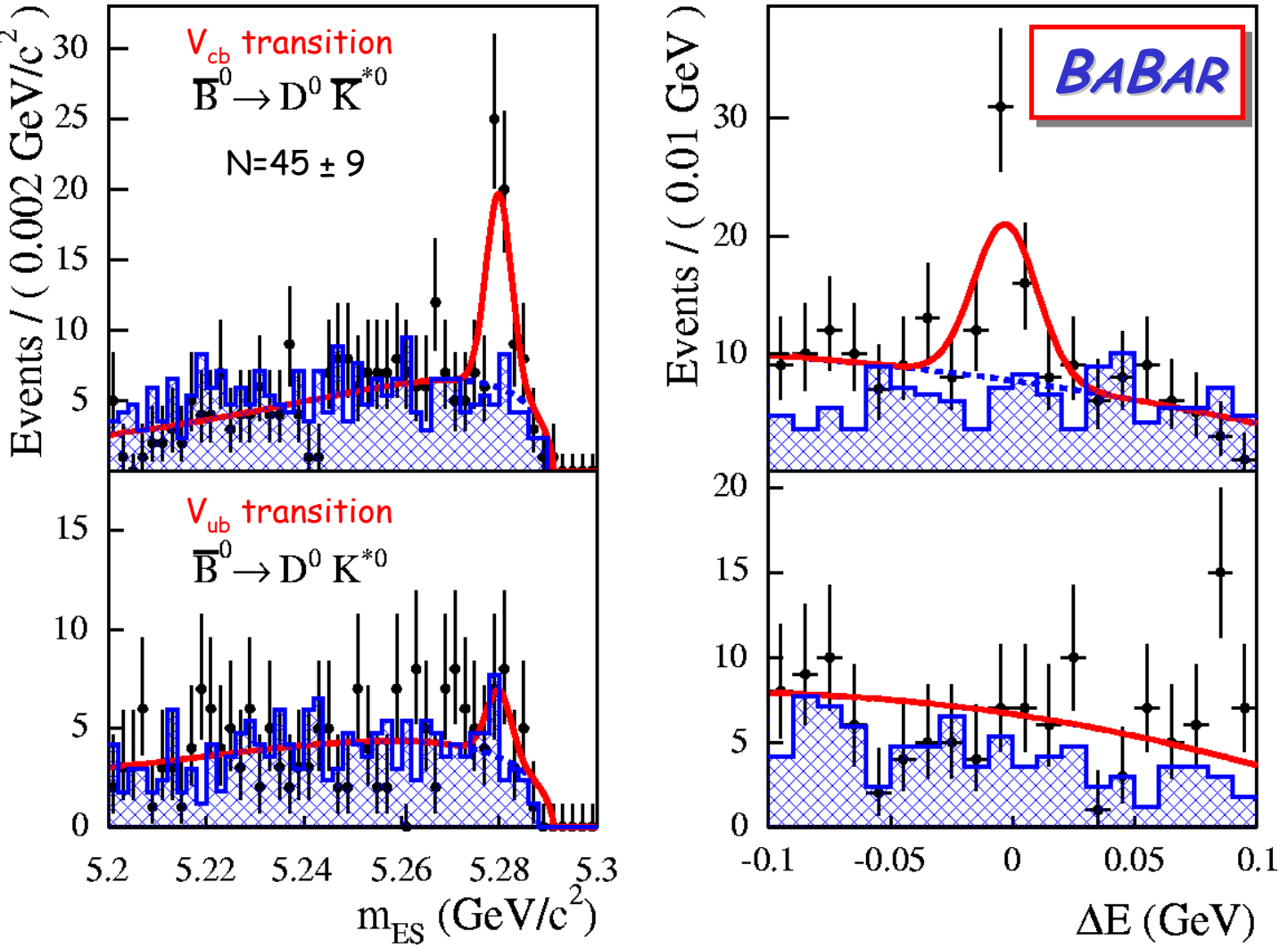
124M $B\bar{B}$ pairs

Charge correlation to separate $B^0$ from $\bar{B}^0$

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

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

No Signal in $V_{ub}$ mediated Decay

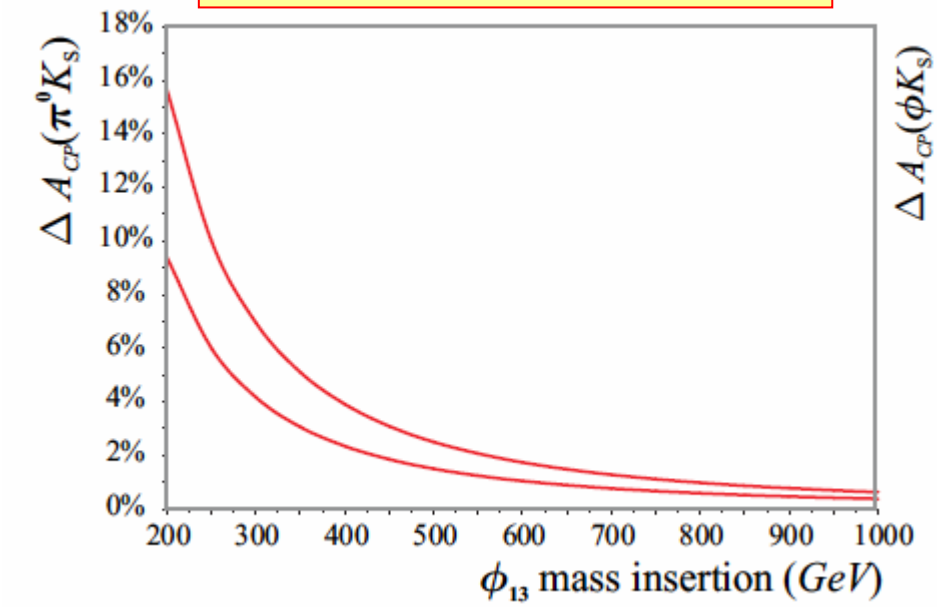



$V_{ub}$ contribution necessary for measurement of $\gamma$!

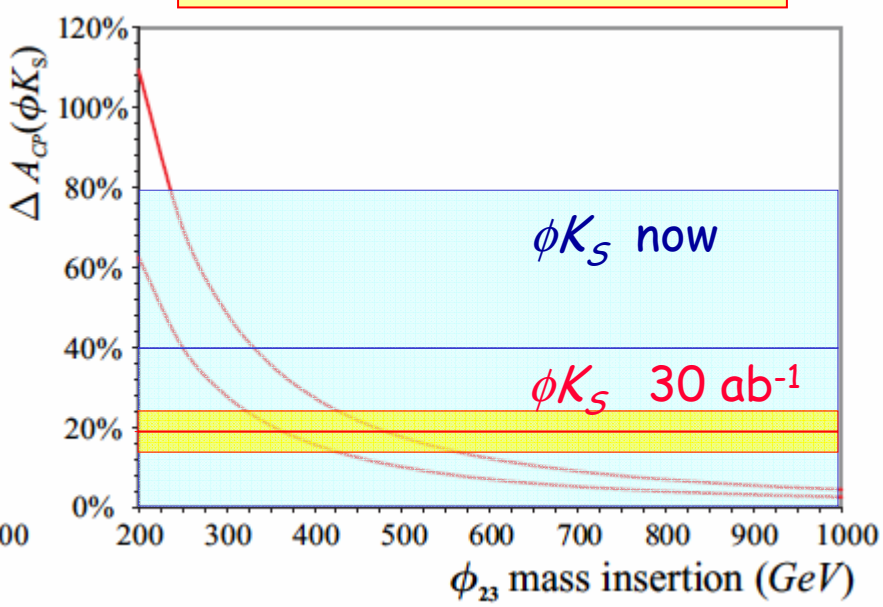
$r_B < 0.8$ @ 90% C.L.

# New Physics Sensitivity

$\Delta A_{CP}(J/\psi K_S - \pi^0 K_S)$

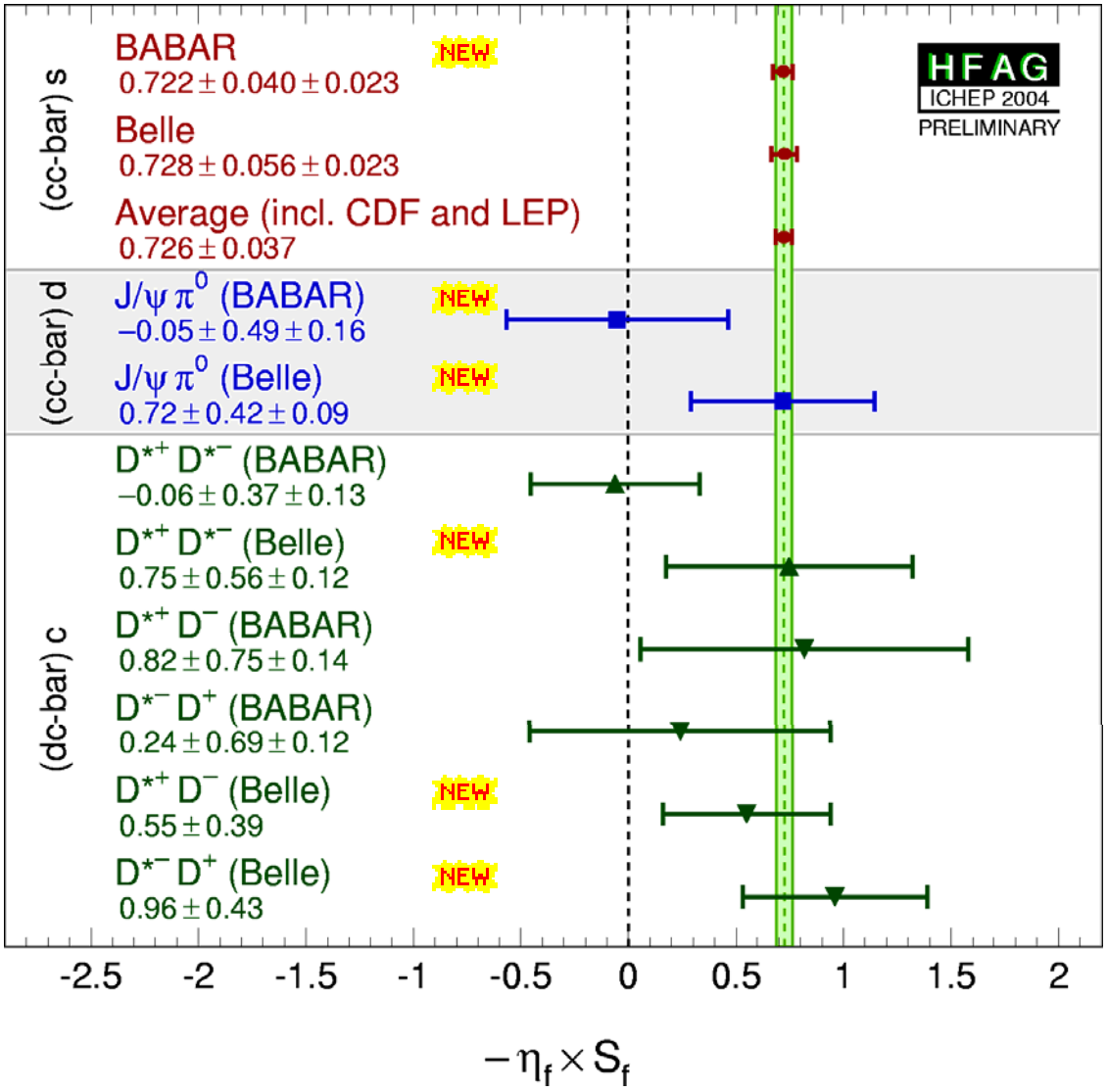



$\Delta A_{CP}(J/\psi K_S - \phi K_S)$



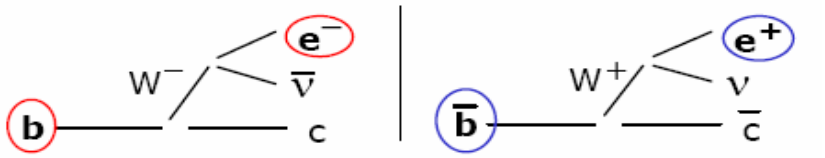

Ciuchini, Franco, Martinelli, Masiero, & Silvestrini

# Results on sin2β from $c\bar{c}s$, $d\bar{c}c$ modes

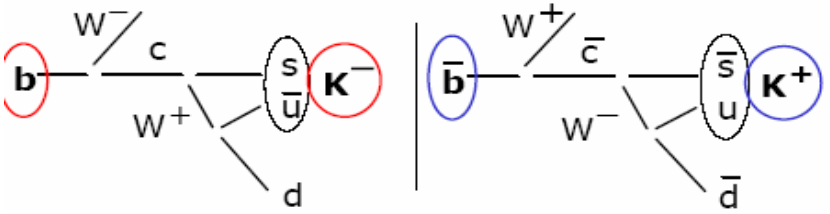


# B *flavor tagging and Δt measurement*

- **Leptons :** Cleanest tag. Correct >95%



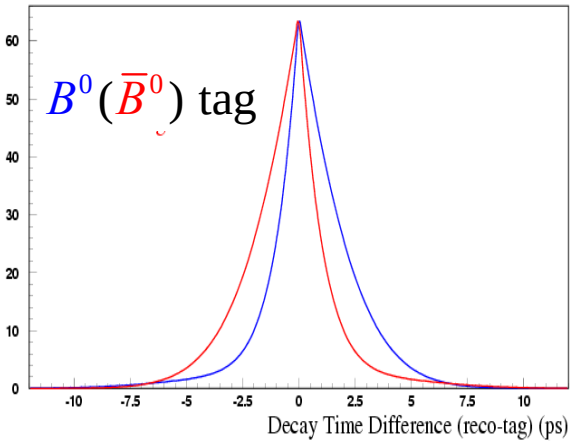

**Kaons :** Second best. Correct 80-90%



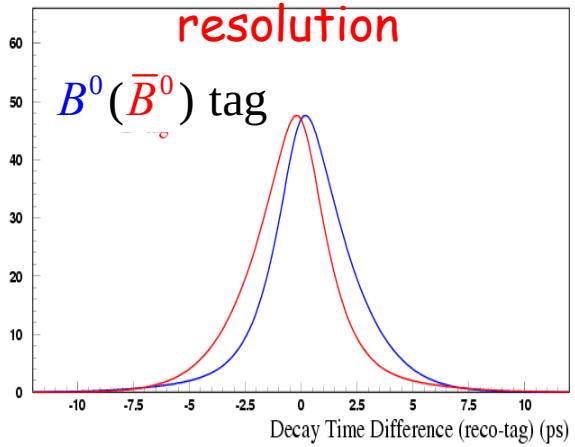

$$Q_T = \sum_i \varepsilon_i (1-2\omega_i)^2 \qquad \sigma(S_{f_{CP}}) \propto \frac{1}{\sqrt{N \times Q_T}}$$

Tagging performance
$Q_T$=30.5% (6 categories)
from full Neural Network
including these & other
physics processes to
identify b quark state

perfect resolution




smeared resolution




Δt resolution dominated
by tag side:
σ(Δt) ~ 1 ps ⇔ 170 μm

$\tau_B$ ~ 1.6 ps ⇔ 250 μm

CP asymmetry

# $\cos 2\beta$ from $B^0 \to J/\psi K^{*0}(K_S\pi^0)$

- $J/\psi K^{*0}$ ($K_S\pi^0$) final state can be $\eta_F = +1$ or $\eta_F = -1$, depending on L = 0, 1, 2
- Full angular analysis allows for the separation of CP even ($A_{||} = |A_{//}| e^{i\delta_{//}}$, $A_0 = |A_0| e^{i\delta_0}$) and CP odd ($A_\perp = |A_\perp| e^{i\delta_\perp}$)
- Many terms in time-dependent decay rate, but two are proportional to $\cos 2\beta$

$$\cos 2\beta = \pm 2.72 \pm {}^{+0.50}_{-0.79} \pm 0.027$$

*(with sin(2β) fixed to 0.731)*

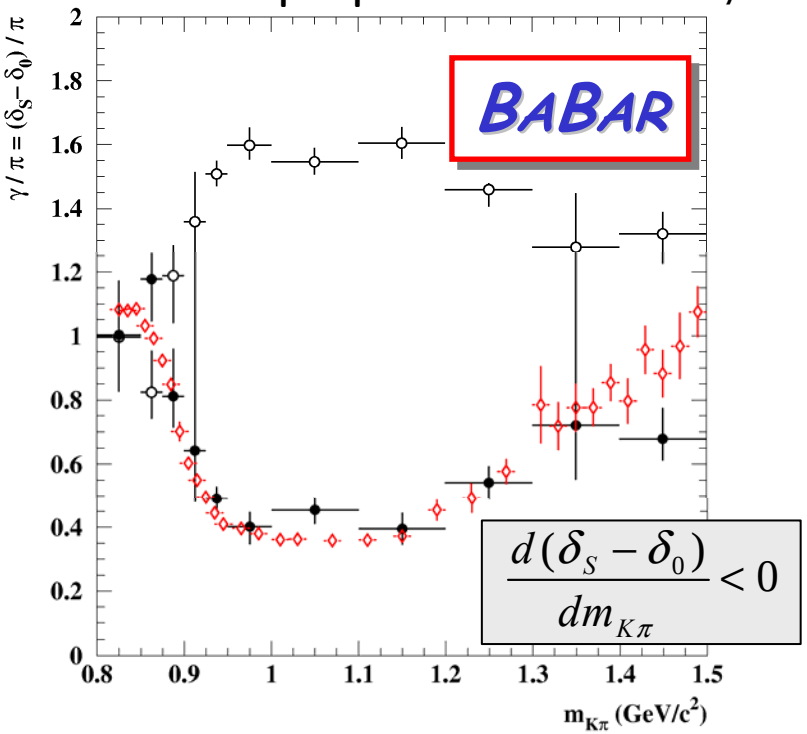
Sign ambiguity is related to the sign of strong phase difference

- Use interference of s-wave and p-wave contributions to Kπ final state to resolve sign ambiguity for strong phases

Assuming:

$$\cos 2\beta = \pm\sqrt{1-\sin^2 2\beta}$$

$\cos 2\beta = -0.68$ excluded at 86% CL




○ *solution 1: unphysical solution*

● *solution 2: physical solution*

*~ 466 data*

# $B^- \to D^{(*)0}[K^+\pi^-]K^-$ decays: ADS method

favored $B^- \to D^0 K^-$ suppressed $D^0 \to K^+\pi^-$

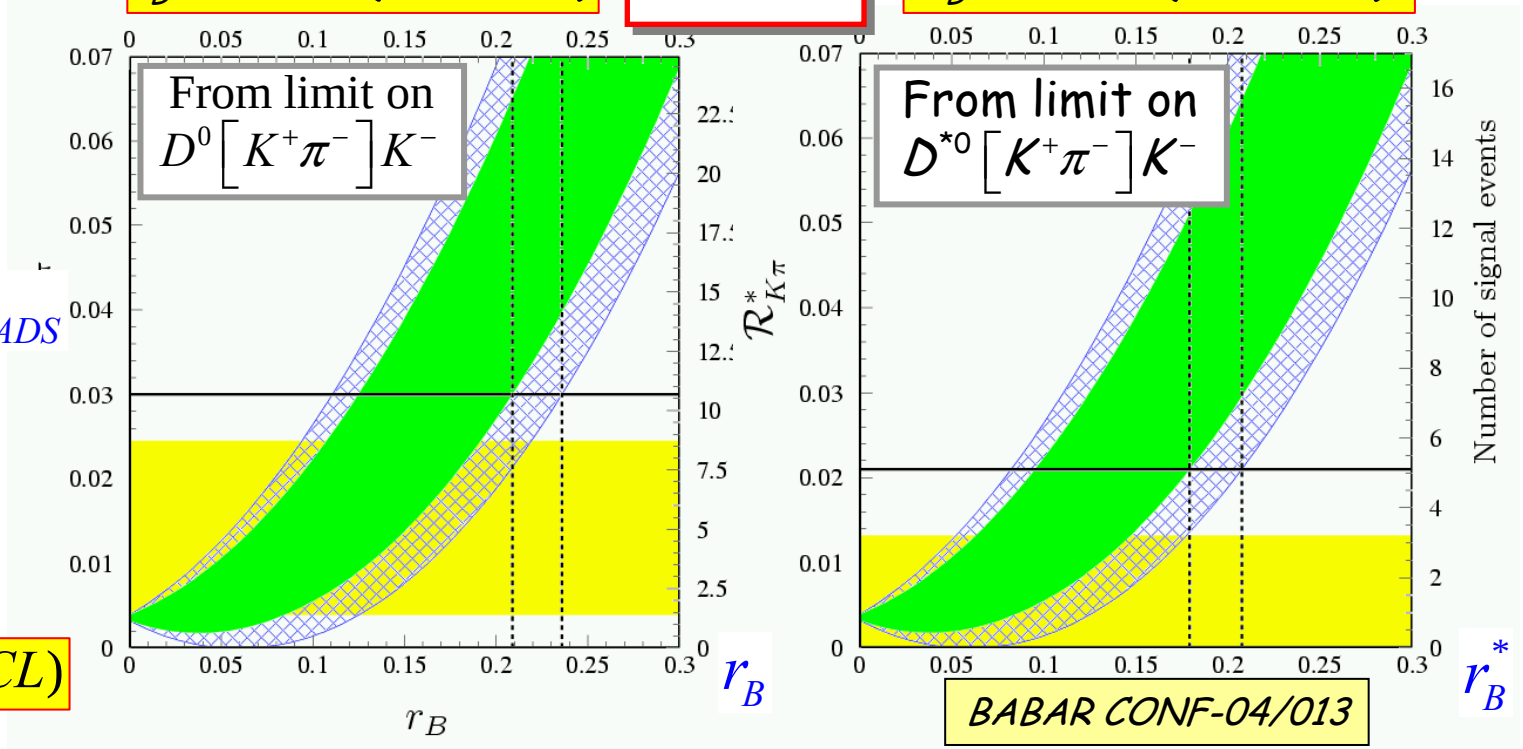
suppressed $B^- \to \overline{D}^0 K^-$ favored $\overline{D}^0 \to K^+\pi^-$

$$R_{ADS} = \frac{BF([K^+\pi^-]K^-) + BF([K^-\pi^+]K^+)}{BF([K^-\pi^+]K^-) + BF([K^+\pi^-]K^+)} \sim r_B^2$$

$[K^+\pi^-]_D K^-$

**Update for ICHEP04**

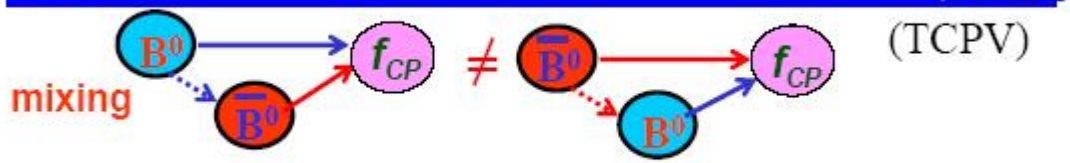
$r_B < 0.23$ (90% CL) **BABAR** $r_B^* < 0.21$ (90% CL)




**Belle**

$r_B < 0.28$ (90% CL)

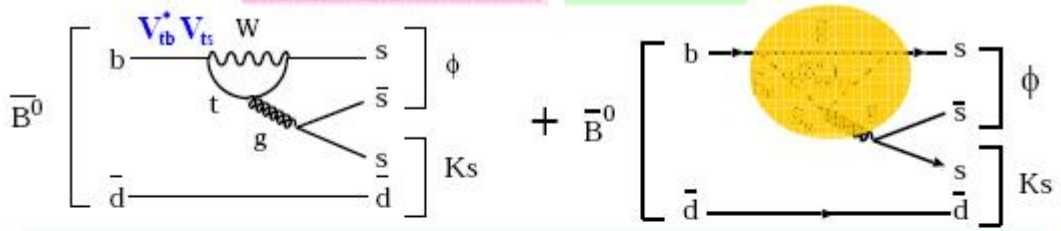
# Time-dependent CP Violation




(TCPV)

$$A_{CP}(\Delta t) = S \sin(\Delta m \Delta t) + \mathcal{A} \cos(\Delta m \Delta t)$$

**Mixing induced CPV** **Direct CPV**



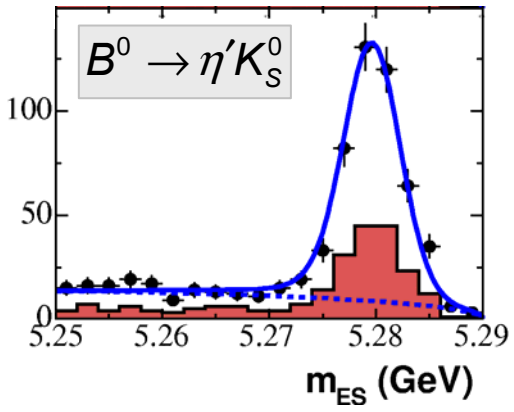

**SM: $b \to s$ Penguin**
phase = $J/\psi K_S$ $(b \to c)$
$S_{b\to s}$ = **sin2$\phi_1$**, $\mathcal{A}$=0

**+ New Physics**
**with New Phase**
$S_{b\to s} \neq$ **sin2$\phi_1$**, $\mathcal{A}$ **can** $\neq 0$

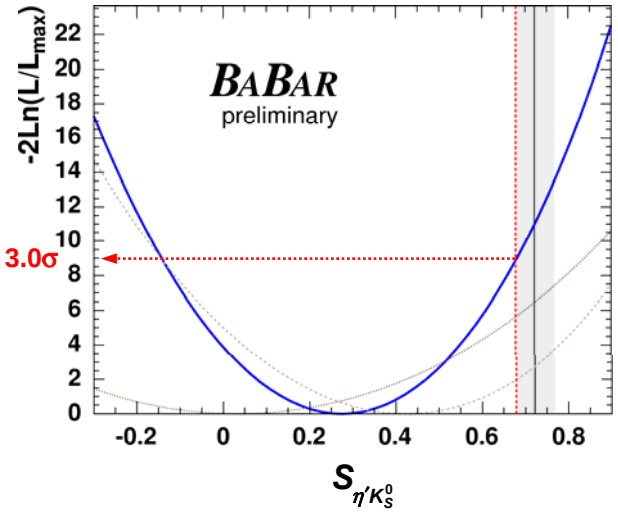
# Analysis of $B^0 \to \eta' K_S$

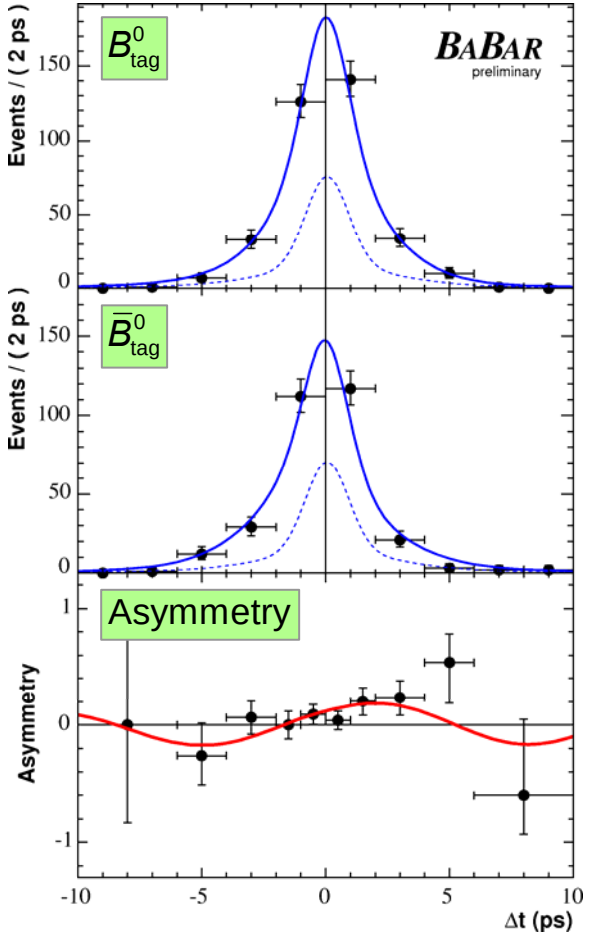
227×10⁶ *B* pairs

- Large statistics mode: BR($B^0 \to \eta' K^0$) ~ 65.2×10⁻⁶, we exploit: BR($B^0 \to \eta'_{rec} K^0_S$) ~ 14.9×10⁻⁶
- Reconstruct in multiple final states: $\eta' \to \eta\pi^+\pi^-$, $\rho^0\gamma$ and $\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$ and $K_S \to \pi^+\pi^-, \pi^0\pi^0$




Fit finds 819 ± 38 events




ML fit :

$$S_{\eta' K^0_S} = +0.27 \pm 0.14 \pm 0.03$$
$$C_{\eta' K^0_S} = -0.21 \pm 0.10 \pm 0.03$$

sin2$\beta$ [$c\bar{c}$] @ 3.0σ

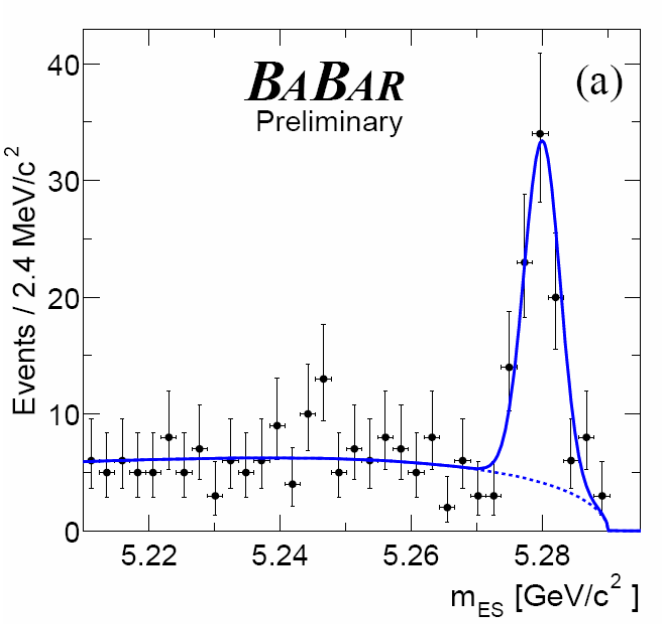
No CPV found in $B^+ \to \eta' K^+$ control sample

Systematic errors dominated by: Fit bias (MC statistics)

# Analysis of $B^0 \to \phi K^0$

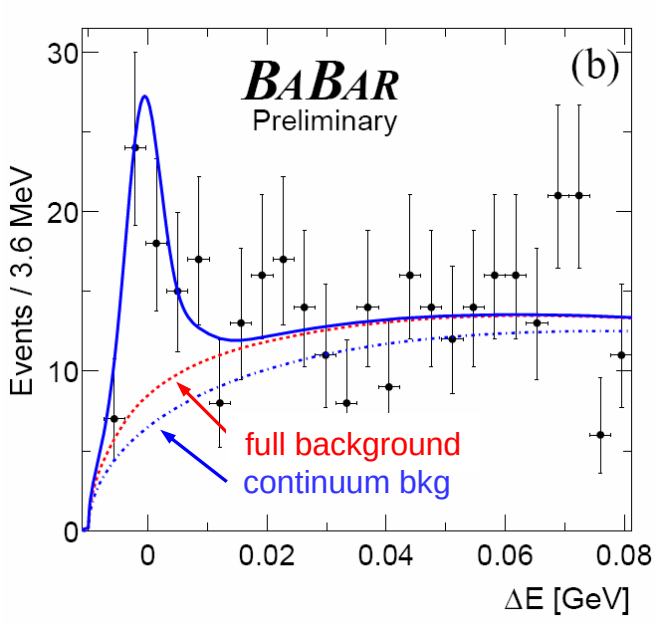
227×10⁶ *B* pairs

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




ML fit finds 114 ± 12 signal events

$B^0 \to \phi K^0_L \quad \left(\eta_{\phi K^0_L} = -\eta_{\phi K^0_S}\right)$




98 ± 18 signal events

combined fit :

$$S_{\phi K^0} = +0.50 \pm 0.25\ ^{+\,0.07}_{-\,0.04}$$

$$C_{\phi K^0} = +0.00 \pm 0.23 \pm 0.05$$

sin2$\beta$ [c$\bar{c}$] @ 0.9σ

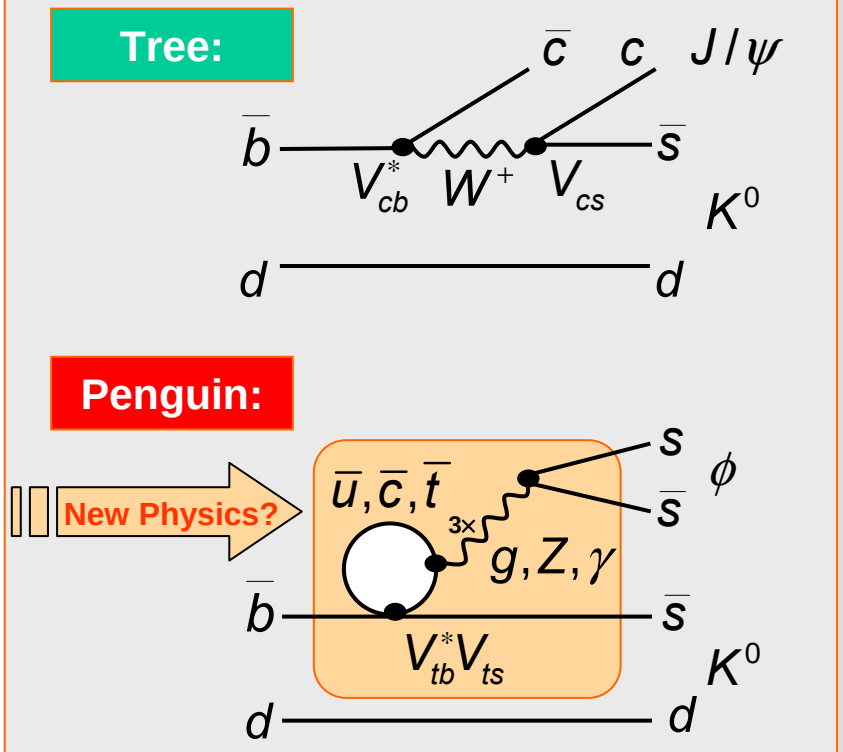
Systematic errors dominated by

- opposite-*CP* background
- PDF modeling
- Tag-side *CP* violation

# Confronting Loop Decays with Tree Dominance

- $b \to c\bar{c}s$ decays are tree and penguin diagrams, with equal dominant weak phases
- $b \to s\bar{s}s$ decays are pure "internal" and "flavor-singlet" penguin diagrams
- ➡ High virtual mass scales involved: believed to be sensitive to New Physics

Both decays dominated by single weak phase




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

$$\lambda_{J/\psi K^0_{S,L}} = \eta_{J/\psi K^0_{S,L}} \left(\frac{q}{p}\right)_B \cdot \left(\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}}\right) \cdot \left(\frac{q}{p}\right)_K = \eta_{J/\psi K^0_{S,L}} e^{-2i\beta}$$

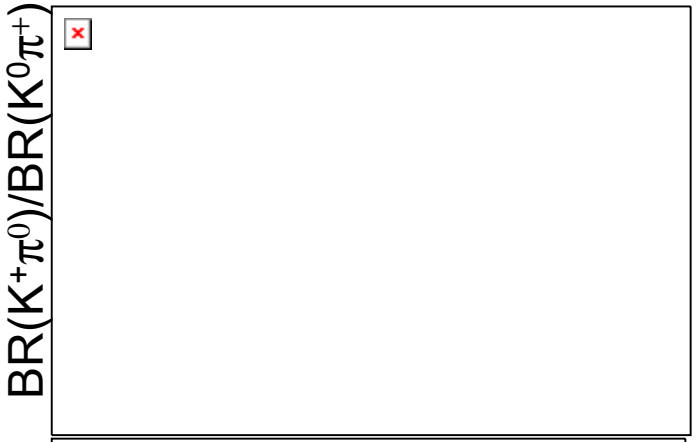
$b \to s\bar{s}s$

$$\lambda_{\phi K^0_{S,L}} = \eta_{\phi K^0_{S,L}} \left(\frac{q}{p}\right)_B \cdot \left(\frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}}\right) \cdot \left(\frac{q}{p}\right)_K \sim \eta_{\phi K^0_{S,L}} e^{-2i\beta}$$

$$\sin 2\beta \text{ [charmonium]} \stackrel{?}{=} \sin 2\beta \text{ [s-penguin]}$$

# Une anomalie dans $B \to K\pi$ ?

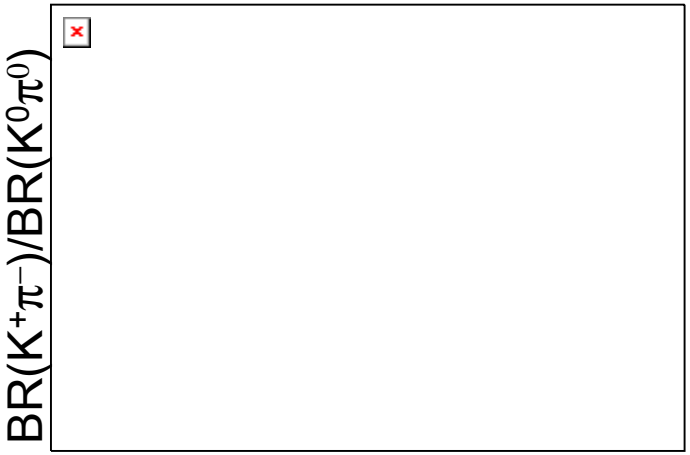
SU(3) : *prédiction* des observables $B \to K\pi$
d'après les mesures dans $B \to \pi\pi$ :
(annihilation et échange négligés)





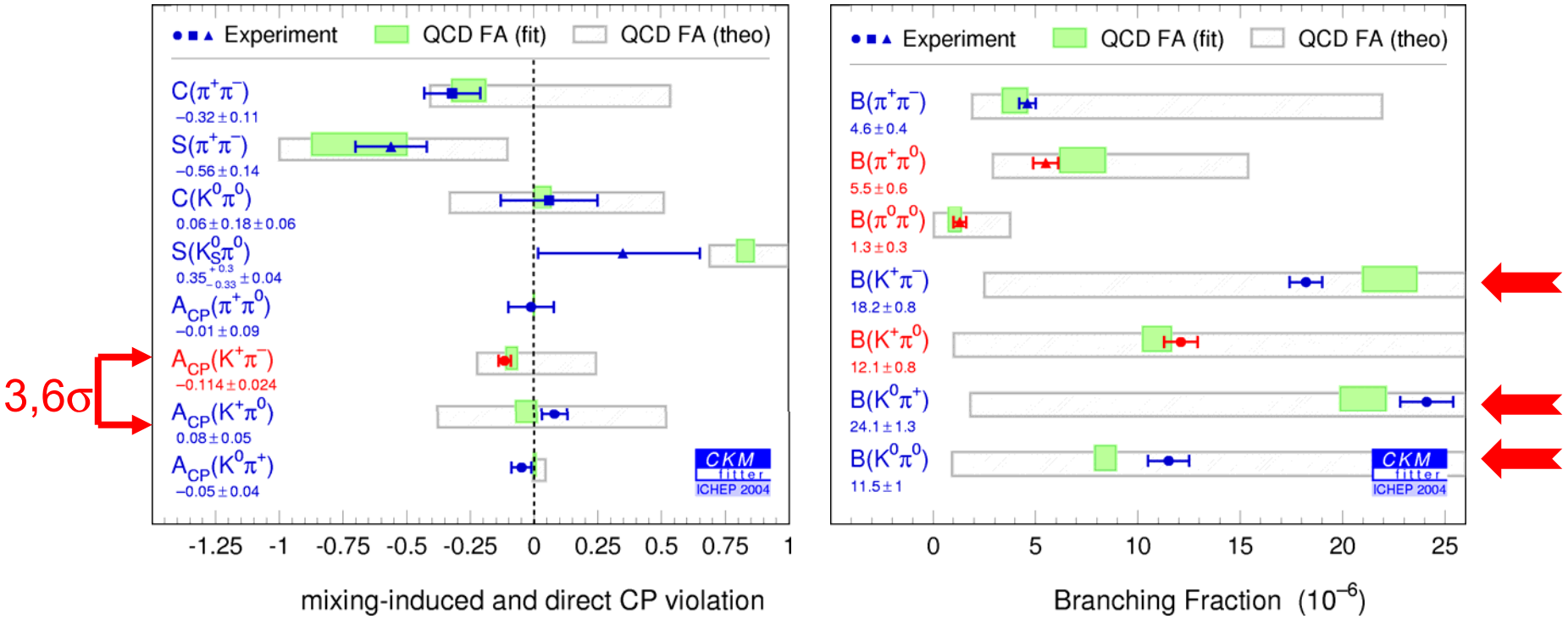
Ajustement global $\pi\pi$/ $K\pi$ : probabilité = 1 % !!
(précision accrue de $BR(\pi^0\pi^0)$)

Contribution au $\chi^2$ : 1) $BR(K^+\pi^-)$; 2) $BR(K^0\pi^+)$;
3) $BR(K^0\pi^0)$



# Une anomalie dans $B \to K\pi$ ?

Calcul de factorisation QCD : probabilité de 1,5% !




Prédiction pour $C(\pi^0\pi^0) = 0,06^{+0,10}_{-0,12}$, mesure : $C(\pi^0\pi^0) = -0,28 \pm 0,24$

Mais “corrections” non factorisables >>100%

Problème du modèle ou présence de nouvelle physique ?

# General CP formalism

## Decay distributions $f_+(f_-)$ when tag = $\bar{B}^0(B^0)$

$$f_{CP,\pm}(\Delta t) = \frac{\Gamma}{4} e^{-\Gamma \Delta t}\left[1 \pm S_{f_{CP}} \sin \Delta m_d \Delta t \mp C_{f_{CP}} \cos \Delta m_d \Delta t\right]$$

## Asymmetry

$$A_{f_{CP}}(\Delta t) = \frac{f_+ - f_-}{f_+ + f_-} = C_{f_{CP}} \cos(\Delta m_d \Delta t) - S_{f_{CP}} \sin(\Delta m_d \Delta t)$$

## CP parameter

$$\lambda_{f_{CP}} = \frac{q}{p}\frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}}$$

Amplitude ratio

$\approx e^{-2i\beta}$ from mixing

For single amplitude

$$C_{f_{CP}} = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2} = 0$$

$$S_{f_{CP}} = \frac{-2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2} = -\mathrm{Im}\,\lambda_{f_{CP}}$$

# More results from $b \to sss$ penguins

**Update for ICHEP04** | *BABAR CONF-04/025*

## $B^0 \to (K^+K^-)_{CP} K^0_S$ (208M pairs)

- Independent sample with ($K^+K^-$) mass outside $\phi$ region
- CP content can be determined experimentally with an angular moment analysis through the helicity angle distribution

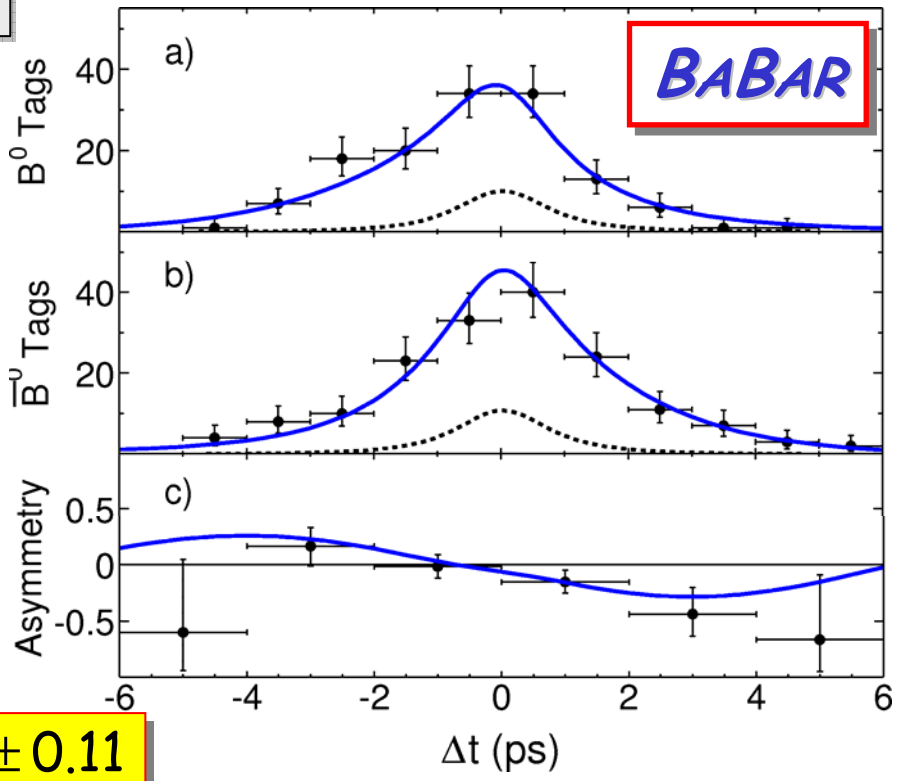
Signal: $481 \pm 29$ events

$$f_{even} = 0.89 \pm 0.08 \pm 0.04$$

$$S_{KKK^0_S} = -0.42 \pm 0.17 \pm 0.04$$

$$-(2f_{even} - 1) \cdot S_{KKK^0_S} = +0.55 \pm 0.22 \pm 0.04 \pm 0.11$$

$$C_{KKK^0_S} = +0.10 \pm 0.14 \pm 0.06$$



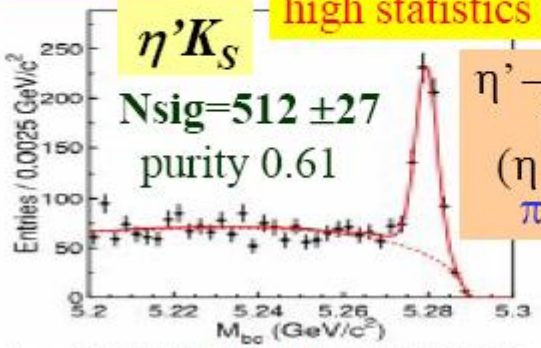
# $B^0 \to \eta' K_S$ & $K^+K^-K_S$

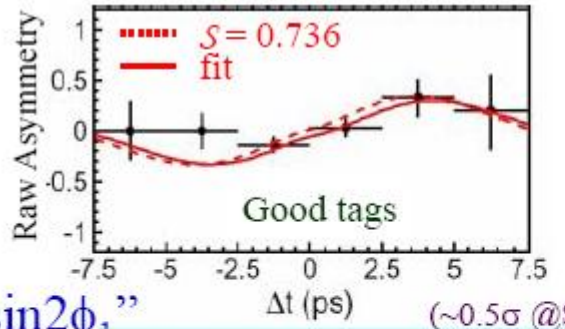
high statistics modes

## $\eta' K_S$

Nsig=512 ±27
purity 0.61

$\eta' \to \rho\gamma$, $\eta\pi^+\pi^-$ ($\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$)

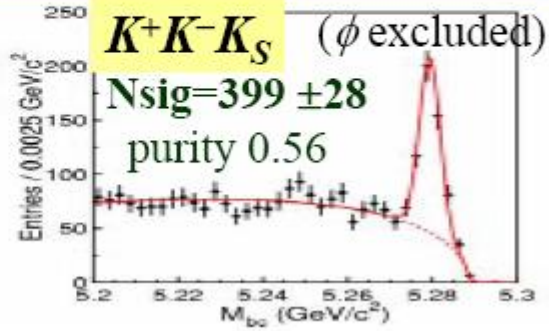


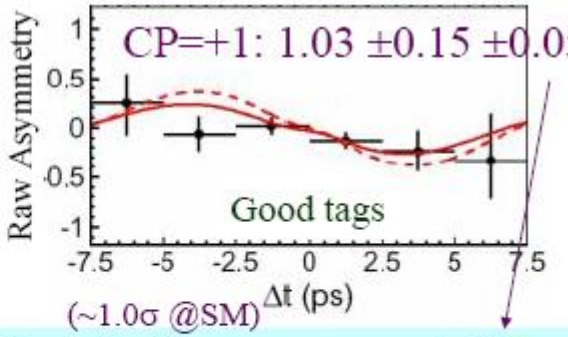




"sin2$\phi_1$"

## $K^+K^-K_S$ ($\phi$ excluded)

Nsig=399 ±28
purity 0.56



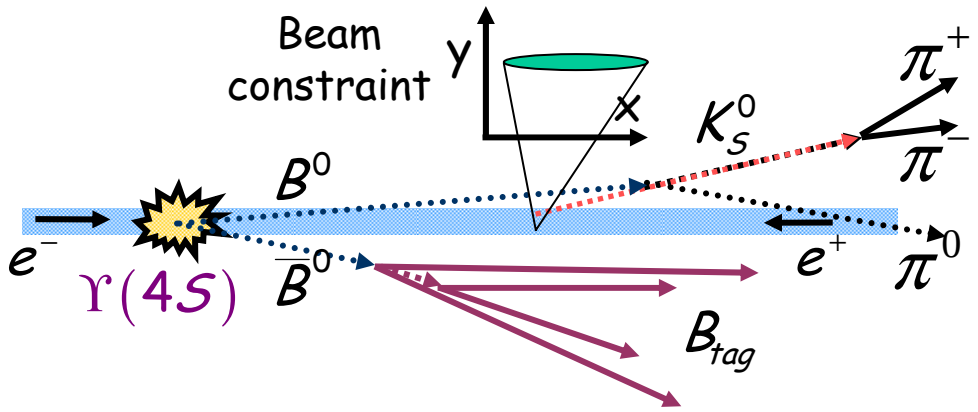




$\mathcal{S} = +0.65 \pm 0.18 \pm 0.04$ (~0.5σ @SM)
$\mathcal{A} = -0.19 \pm 0.11 \pm 0.05$

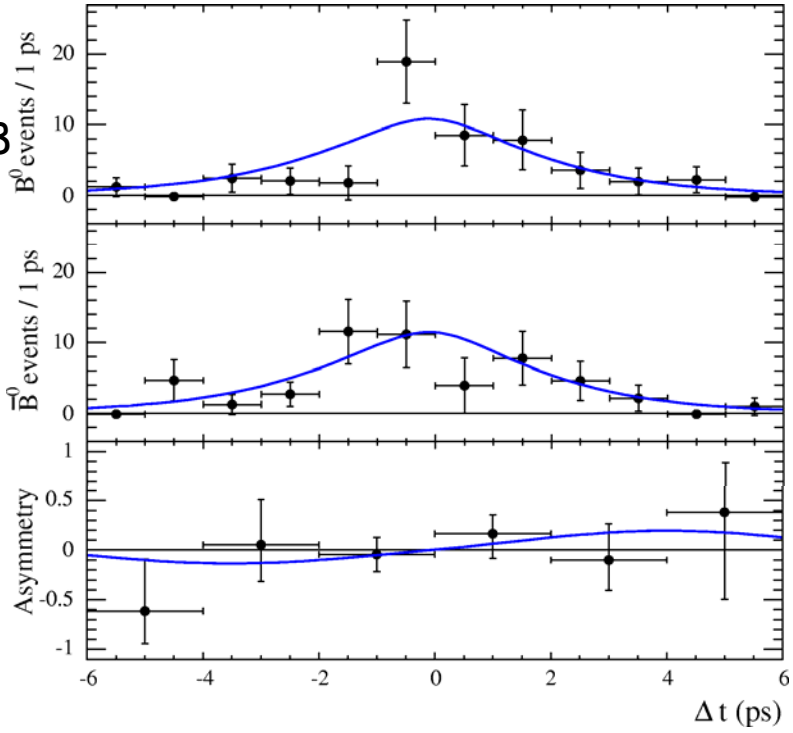
$-\mathcal{S} = +0.49 \pm 0.18 \pm 0.04 \left(\pm^{0.17}_{0.0}\right)$ (~1.0σ @SM)
$\mathcal{A} = -0.08 \pm 0.12 \pm 0.07$

274M $B\bar{B}$

# Still another penguin mode: $B^0 \to \pi^0 K_S$




[sPlots: Pivk, Le Diberder, physics/0402083]




**BABAR**

BABAR technique from 2003

Updated for ICHEP04

**BABAR** — *BABAR CONF-04/030*

227M $B\bar{B}$ pairs

Signal: 192 w/vertex, 108 w/o

$$-\eta_{CP} \cdot S_{\pi^0 K^0_S} = +0.35\,^{+0.30}_{-0.33} \pm 0.04$$
$$C_{\pi^0 K^0_S} = +0.06 \pm 0.18 \pm 0.06$$

**Belle** — 274M $B\bar{B}$ pairs

Signal: 77 w/vertex, 173 w/o

$$-\eta_{CP} \cdot S_{\pi^0 K^0_S} = +0.30 \pm 0.59 \pm 0.11$$
$$C_{\pi^0 K^0_S} = -0.12 \pm 0.20 \pm 0.07$$