Recent results on CP violation in B decays

Marcello A. Giorgi
Università di Pisa and INFN Pisa

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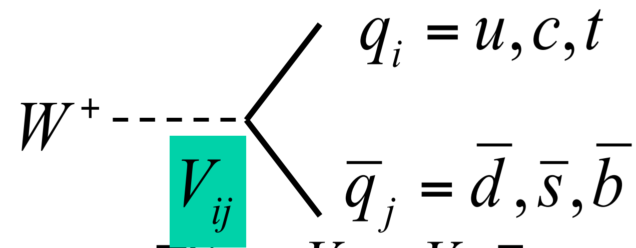
Mini Workshop on B-Factories

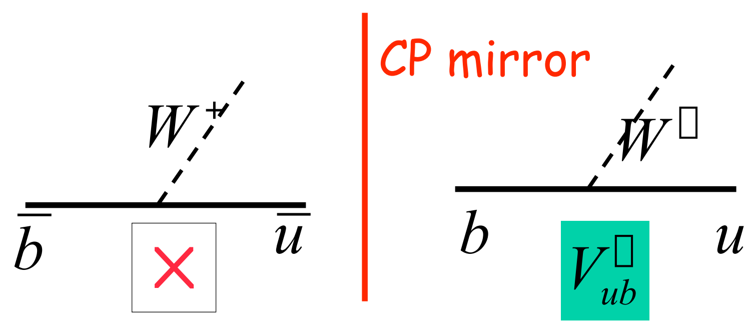
The CKM picture with 3 quark doublets

Cabibbo-Kobayashi-Maskawa matrix

- *quark charged currents <=> W±*
- *left-handed (q_j=d,s,b) quark mass eigenstates connected to weak eigenstates;*
- *Unitary (FCNC suppressed)=>4 independent parameters (e.g., 3 angles and 1 phase)*
- *Phase changes sign under CP*
- *Interfering amplitudes can give CP-violating asymmetries*



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



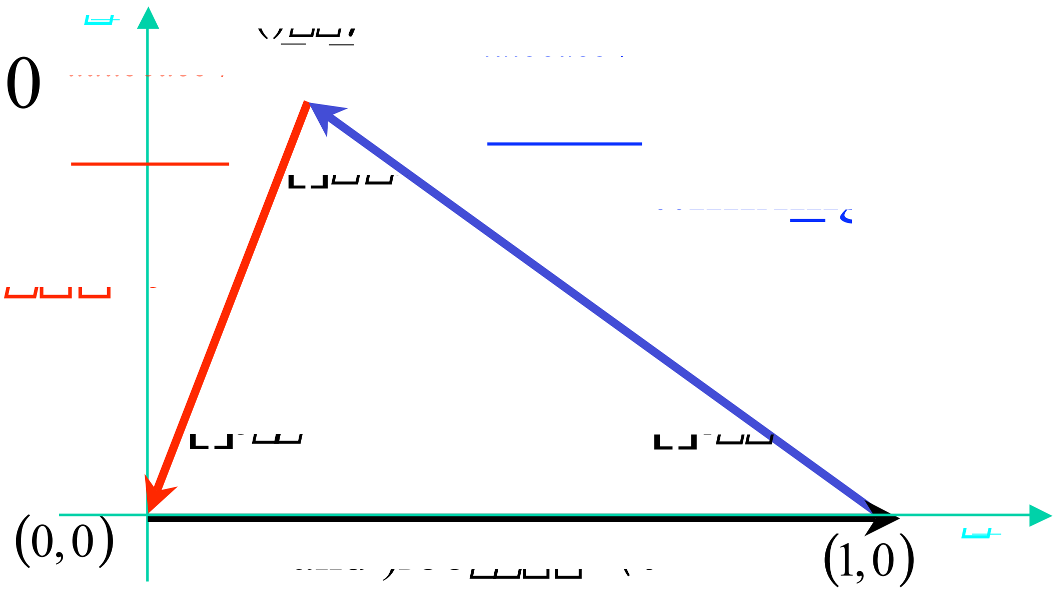
From Unitary CKM matrix to Unitarity Triangles

From unitarity condition .

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

$$\frac{V_{ub}^{*}}{\square V_{cb}^{*}}+1+\frac{V_{td}}{\square V_{cb}^{*}}\ \square\ 0$$

$$V_{cd}=\square,\qquad V_{ud}\ \square\ V_{tb}\ \square\ 1$$



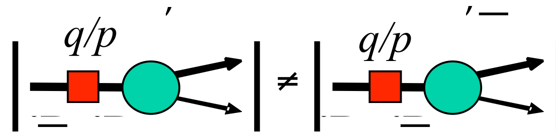
$$\square\ \square\ \square \arg V_{td}$$

$$\square\ \square \arg V_{ub}^{\square}$$

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

3 ways for CP violation

1. CP violation in mixing

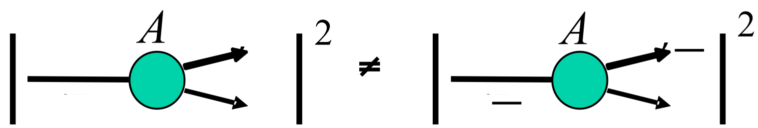


First mechanism observed historically in kaon decays

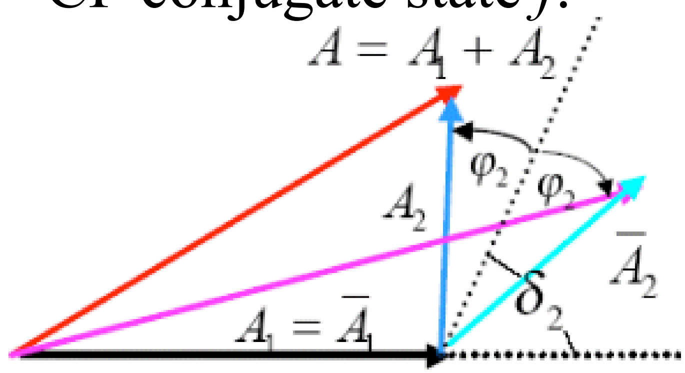
$$\left|\frac{q}{p}\right| = \left|\sqrt{\frac{(M_{12}^* - i\frac{\Gamma_{12}^*}{2})}{(M_{12} - i\frac{\Gamma_{12}}{2})}}\right| \neq 1$$

SM predicts:

2. Direct CP violation in the decay



Occurs when $\left| \quad \right|$ where A is the amplitude for *B* decays into a final state *f* and *A* is the amplitude of *B* decays into the CP conjugate state *f*.



Two amplitudes A_1 and A_2 with a relative CP violating phase ϕ_2 and a CP conserving phase δ:

CP violation and $|A| \neq |\bar{A}|$

First observation of Direct CPV in *B* decays

BABAR

hep-ex/0408057, submitted to PRL

4.2

Belle

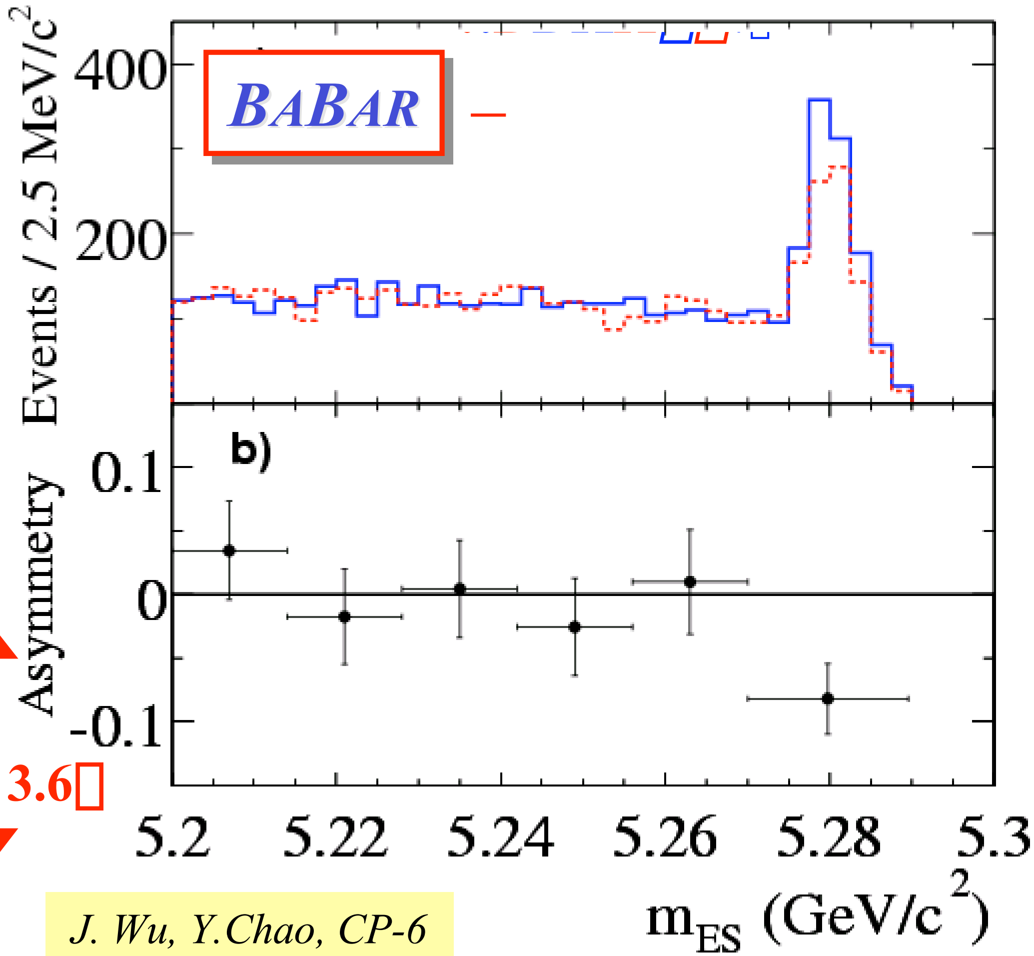
Confirmation at ICHEP04

3.9

Average

Average

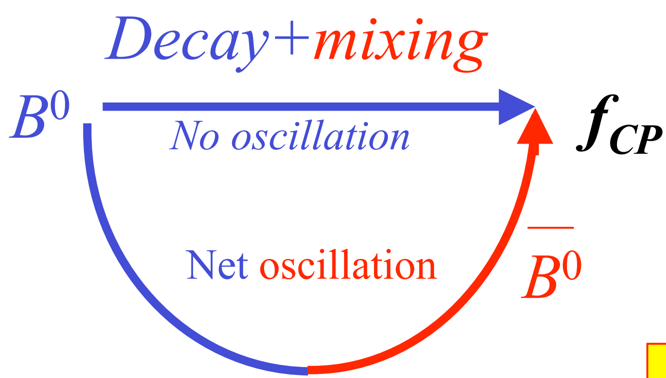
3.6

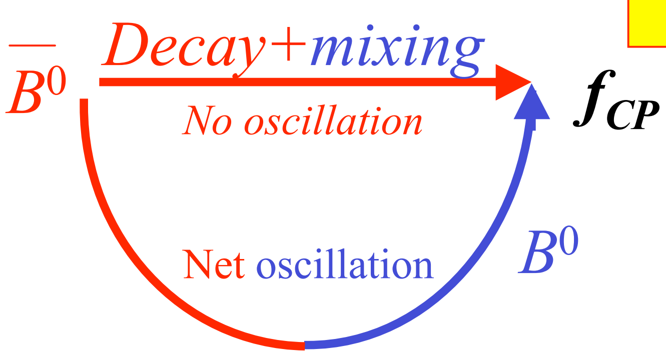


J. Wu, Y.Chao, CP-6

3 ways for CP violation

3.Time dependent





Decay rates of B^0 ad $\overline{B}^0$ are:

$$\left|B_0(t)\right\rangle_{phys} = e^{-imt}e^{-\frac{\Gamma}{2}t}\left(\cos\Delta mt\left|B^0\right\rangle \square\, i\frac{q}{p}\sin\Delta mt\left|\overline{B}^0\right\rangle\right)$$

$$\left|\overline{B}_0(t)\right\rangle_{phys} = e^{-imt}e^{-\frac{\Gamma}{2}t}\left(\cos\Delta mt\left|\overline{B}^0\right\rangle \square\, i\frac{p}{q}\sin\Delta mt\left|B^0\right\rangle\right)$$

Define CP Asymmetry as:

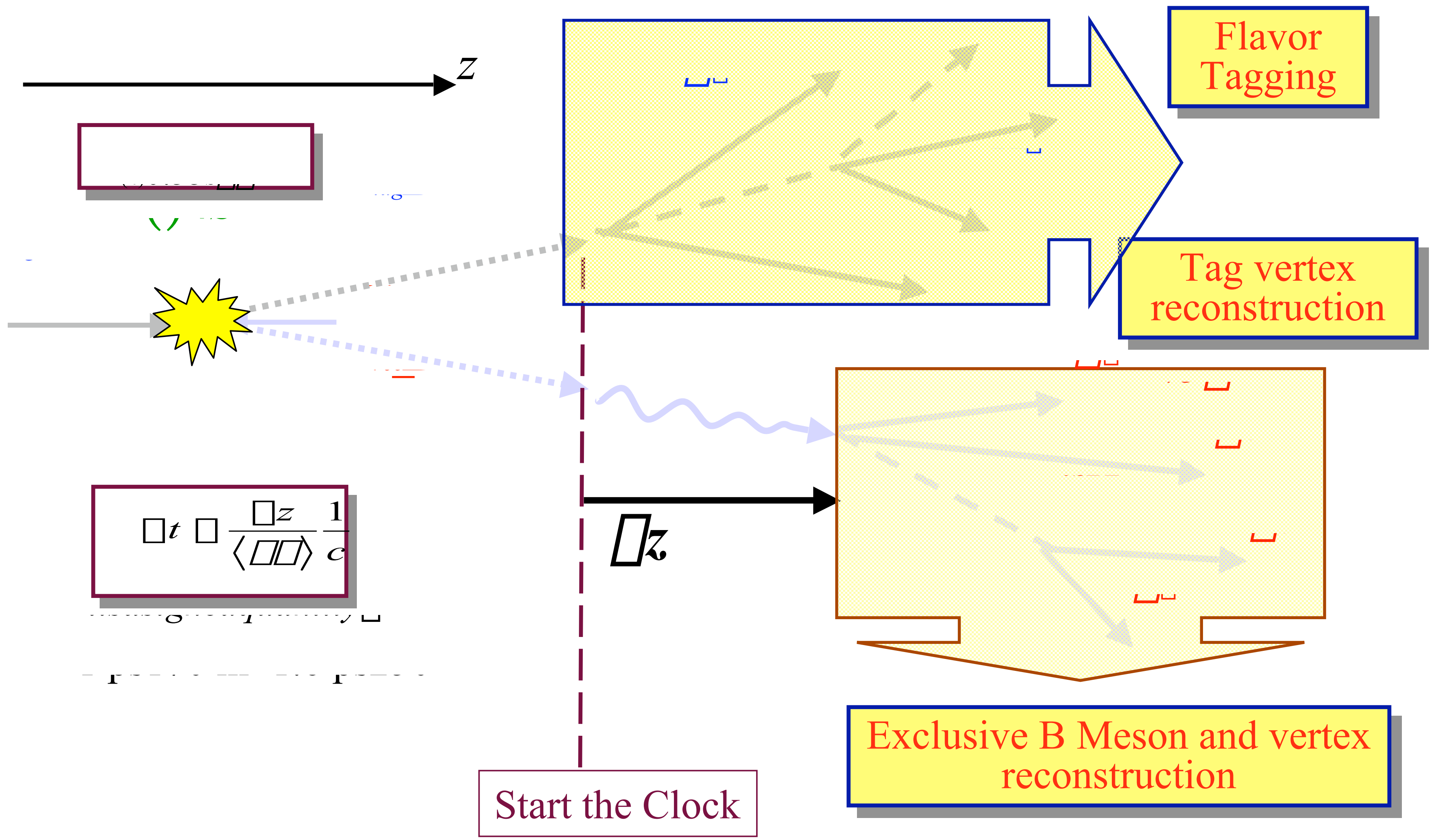
Amplitude ratio

For single amplitude

CP parameter

Measuring time-dependent CP asymmetries

Tagging performance: Q = 30.5%



Tools to measure time dependent Asymmetries

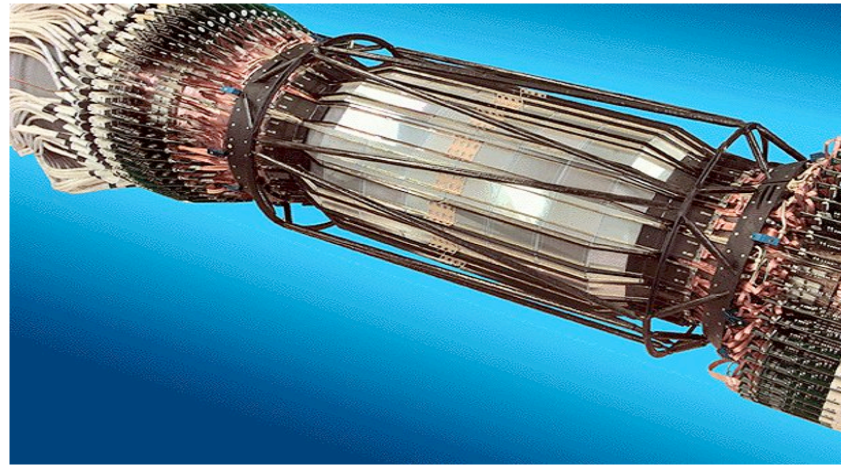
1) Precise measurement of decay points of boosted B^0B^0 system.

First projects of precise vertexing method:

vertex separation decay time measurement in

boosted heavy mesons and first Si strip detectors

before any industrial development in 1980



SILICON 'MULTIWIRE PROPORTIONAL CHAMBERS' AND THEIR APPLICATIONS IN HIGH-ENERGY PHYSICS EXPERIMENTS.

.By MAG. 1980. Published in *Pisa 1980, Proceedings, Miniaturization Of High Energy Physics Detectors*, 25-39.

SEMICONDUCTOR DETECTORS FOR LIFETIME MEASUREMENTS AND HIGH SPACE RESOLUTION.

By G.Bellini,L.Foa,M.A.G 1982. 30pp. Phys.Rept.83:9-38,1982

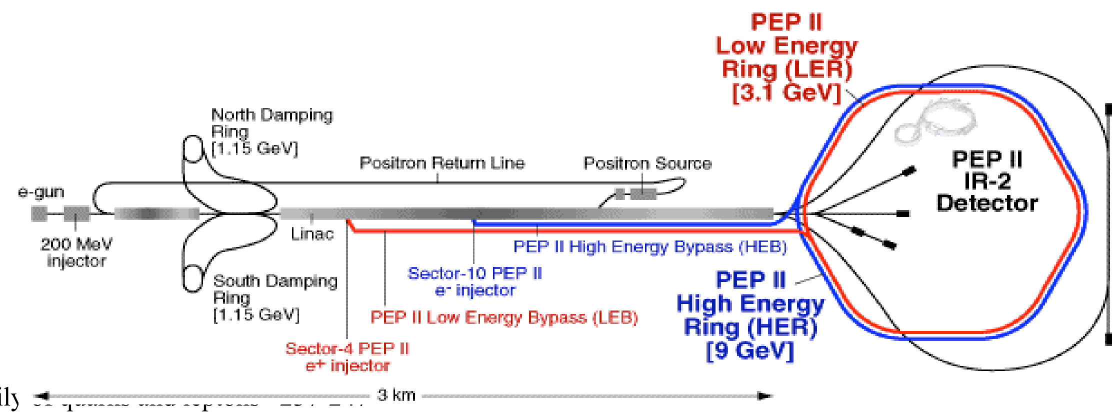
MICRODETECTORS FOR HIGH-ENERGY PHYSICS. .By M.A.G.,. 1981. In *Villars-sur-ollon 1981, Proceedings, General Meeting On Lep*, 179-211

1) Boosting system

First idea of an asymmetric B Factory to

boost the B^0B^0 system and allow the time

measurement in 1989

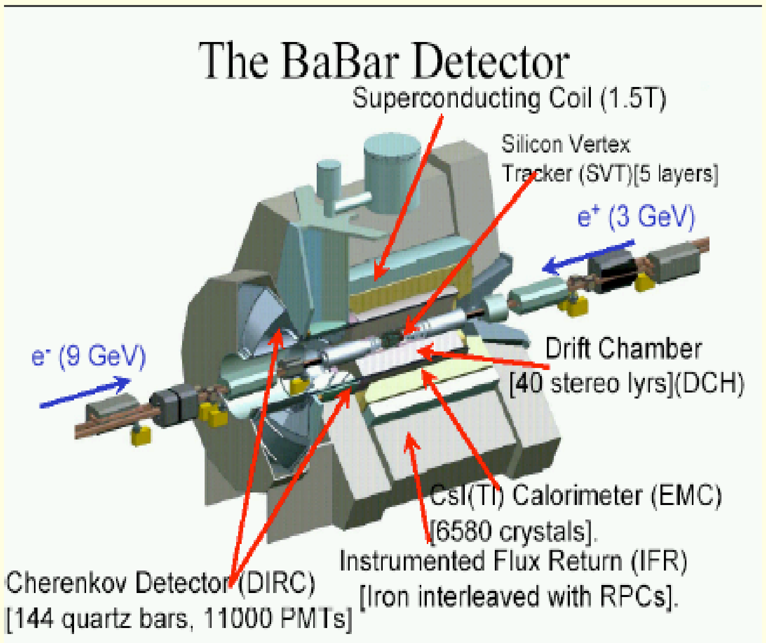


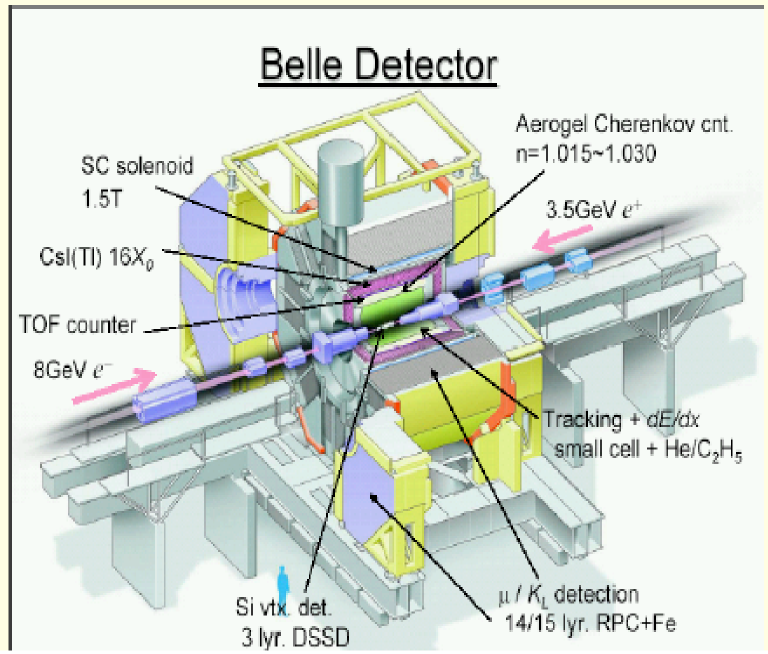
AN ASYMMETRIC B FACTORY BASED ON PEP.

By PP.Oddone,. Feb 1989. In*Santa Monica 1989, The fourth family

B-FACTORIES: A PERSONAL OVERVIEW. By P.Oddone 1989. In *Blois 1989, CP violation and beauty factories and related issues in physics* 299-304.

Asymmetric Bfactories PEPII and KEKB

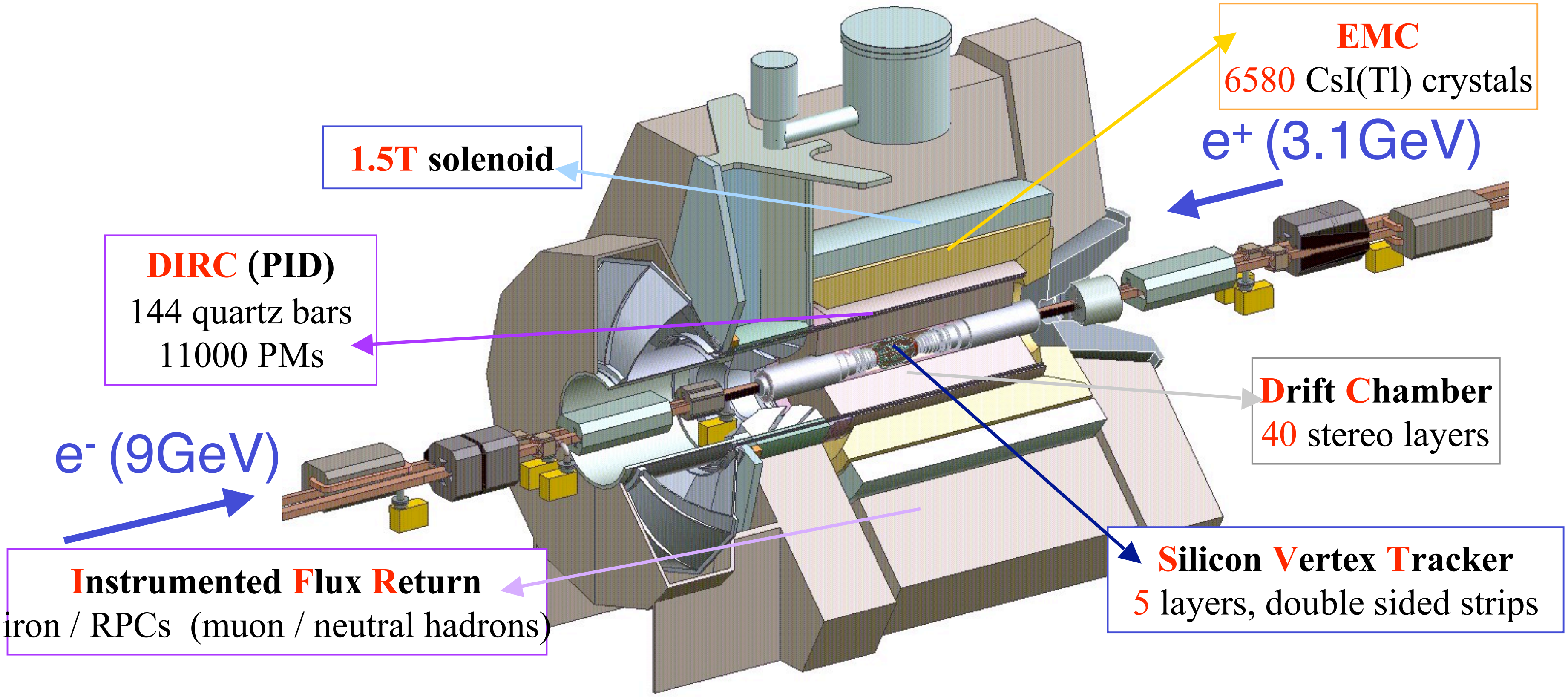




e- (9GeV)
e+(3Gev)

e- (8GeV)
e+(3.5Gev)

BaBar Detector



SVT: vertexing and tracking: crucial for Δt and low p_T tracks

DCH: main tracking device, also dE/dx for particle ID

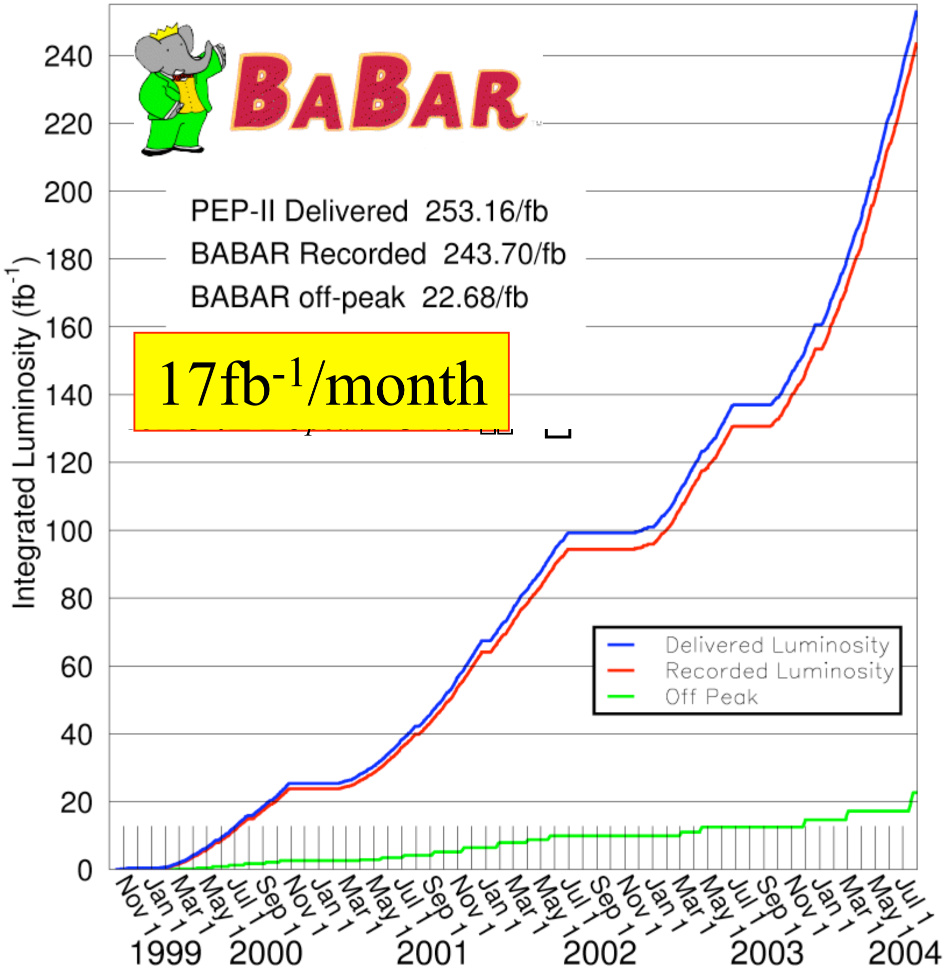
DIRC: K-π separation > 3.4σ for P < 3.5GeV/c

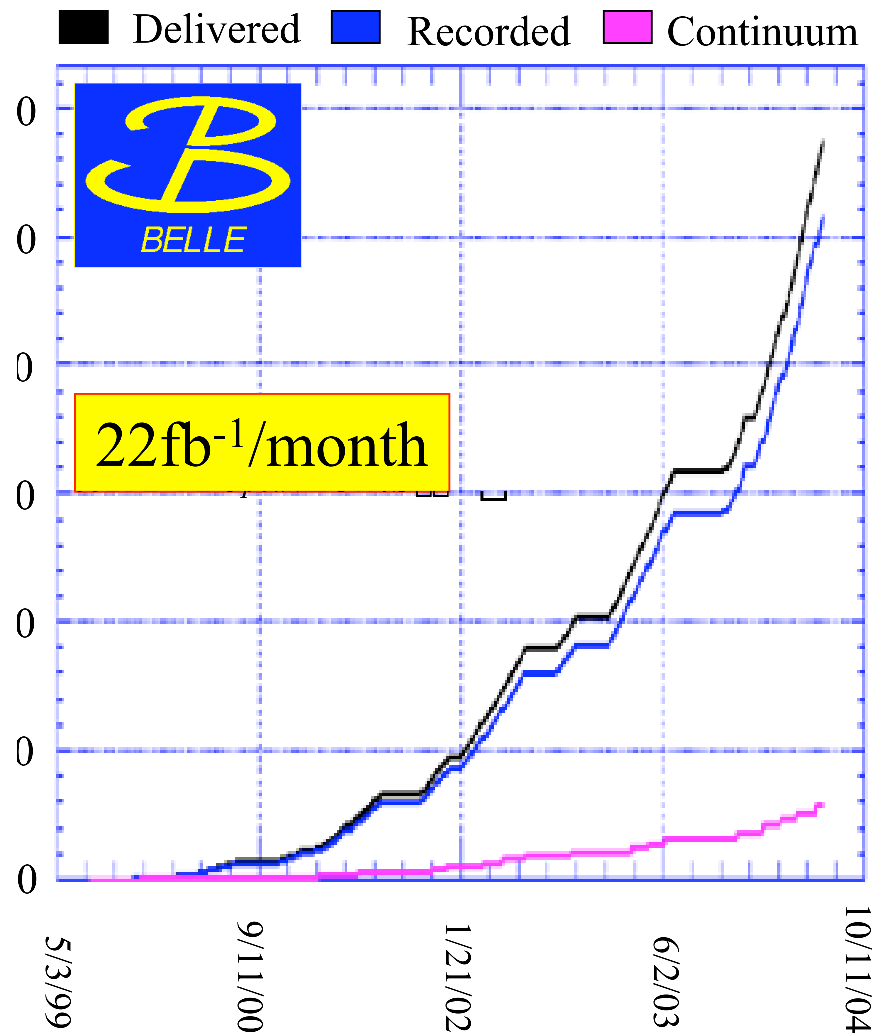
EMC: very good energy resolution; electron ID, π^0 and γ reco.

IFR: Muon and neutral hadrons (K^0_L) ID

Current luminosities and data samples

Total 244 + 286 fb^{-1} = 0.530 ab^{-1}!!





Exclusive B decay reconstruction

- Kinematic signature for B decays:

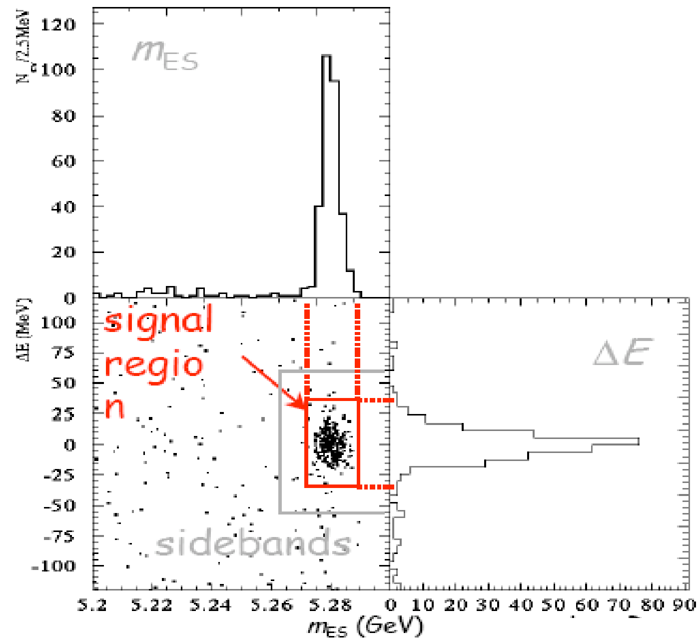
$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$

$$\Delta E = E^{*}_{B} - E^{*}_{beam}$$

Typical resolutions:

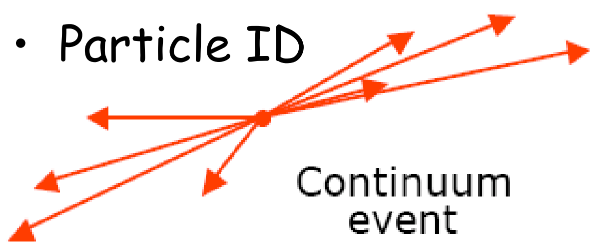
$\sigma(m_{ES}) \approx$ 2.5 MeV

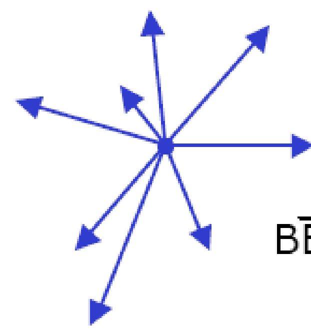
$\sigma(\Delta E) \approx$ 15 - 30 MeV



Typical reconstruction efficiency 15-40%
Purity: 97% for J/□K^0_s ; lower for:

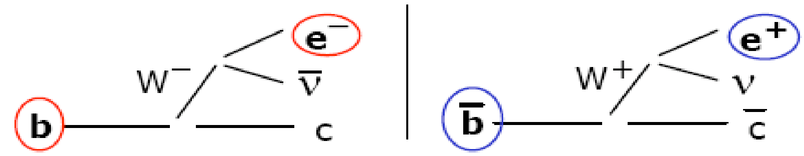
- Charmless hadronic B decays:
  - Use discriminating variables in maximum likelihood PDF
    - ΔE and m_{es} (standard variables)
    - Event shape information.
    - Particle ID



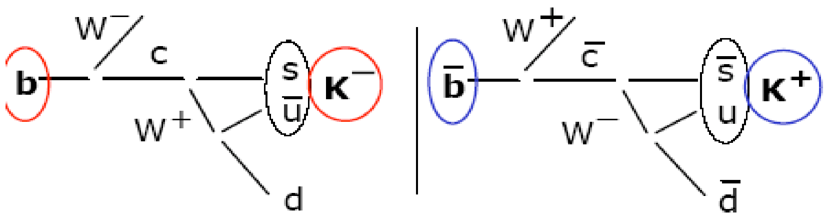


B Flavour Tagging

Leptons : Cleanest tag. Correct >95%



Kaons : Second best. Correct 80-90%



Soft and hard pion tagging

$\overline{B}^0 \rightarrow D^{*+}\pi^-$

$\hookrightarrow D^0\pi^+$

$\overline{B}^0$: fast π^-, soft π^+

B^0: fast π^+, soft π^-

Tag Performance:

$Q_T = \sum_i \varepsilon_i(1-2w_i)^2$

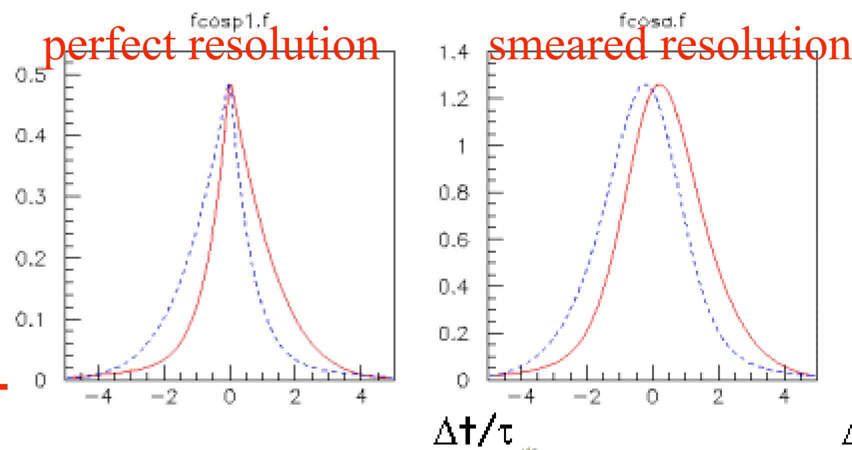
and

$\sigma(S_{f_{CP}}) \propto \frac{1}{\sqrt{N \cdot Q_T}}$

Full Tagging algorithm combines all in Neural Network, Tag categories based on particle content and NN output.

Q_T=30.5% *(6 tag categories) , it was* **28%** *(4 categories) in **2002** analysis*

Δt dependences and resolutions



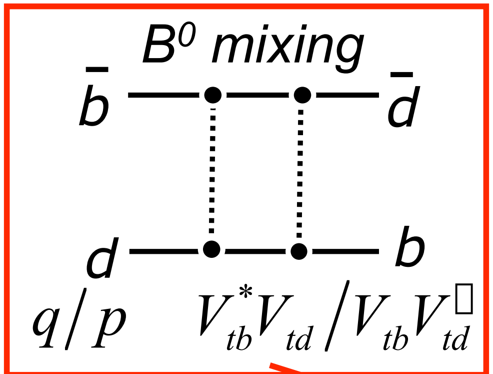
CP asymmetry

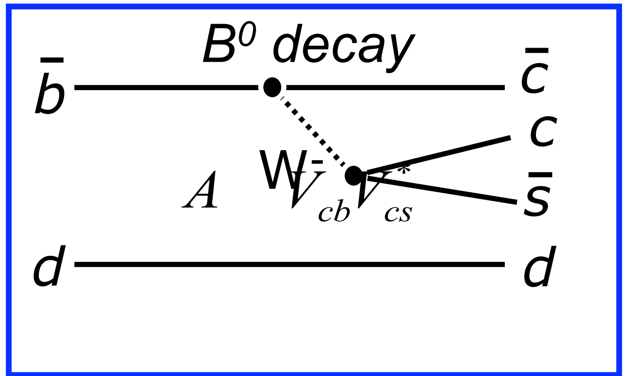
Δt resolution dominated by tag side:

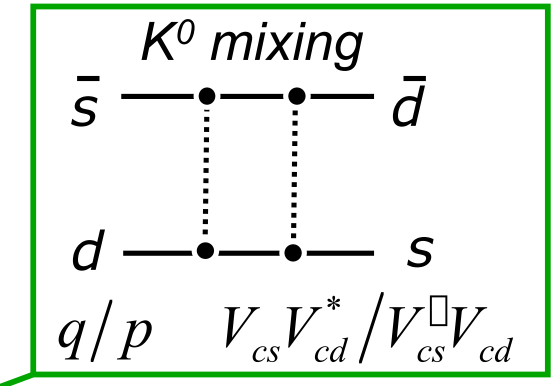
σ1 ps $\leftrightarrow$ 170 μm

$\tau_B \approx$ 1.6 ps $\leftrightarrow$ 250 μm

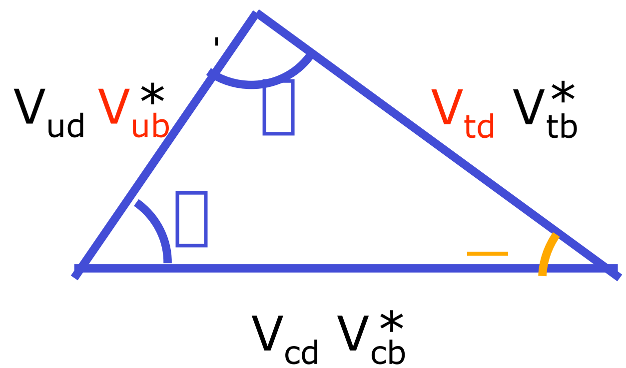
sin2β from mixing & b→ cc̄s "tree" amplitudes







$$\lambda_{\psi K_S} = \frac{q}{p}\frac{\bar{A}_{\psi K_S}}{A_{\psi K_S}} = \frac{V_{tb}^*V_{td}}{V_{tb}V_{td}^*}\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}}\frac{V_{cs}V_{cd}^*}{V_{cs}^*V_{cd}} = \eta e^{-2i\beta}$$

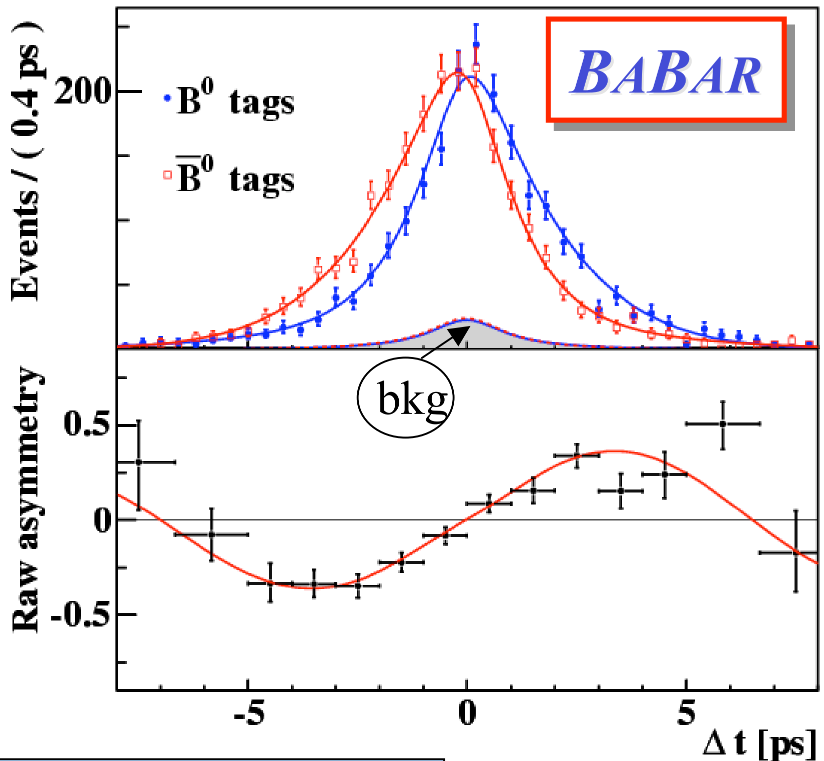


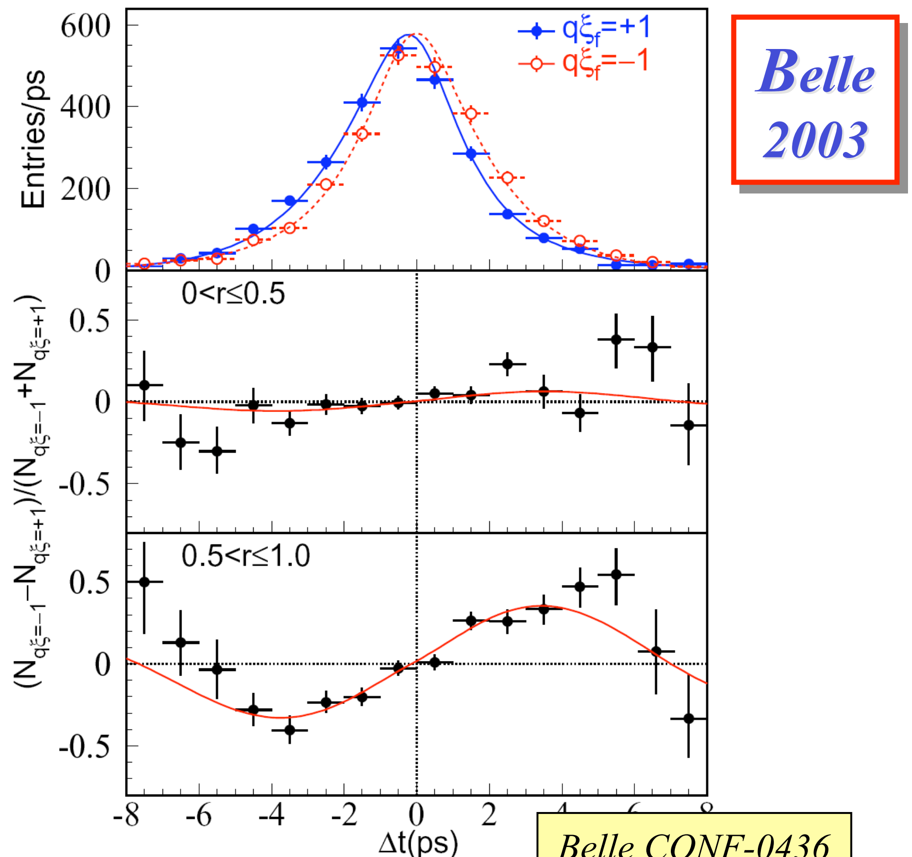
- *all decay amplitudes (tree and penguin) have same weak phase:*
- *no direct CP violation, no CP violation in mixing expected*

Clean!

- *BF(J/ψ(l⁺l⁻)K$_S$(π⁺π⁻)) = 3.5 × 10^{-4} ("large")*
- *Selection: purity 97%*
- *Similarly: χ$_{c1}$K$_S$, ψ(2s)K$_S$, …*

sin2β results from charmonium modes





Update for ICHEP04

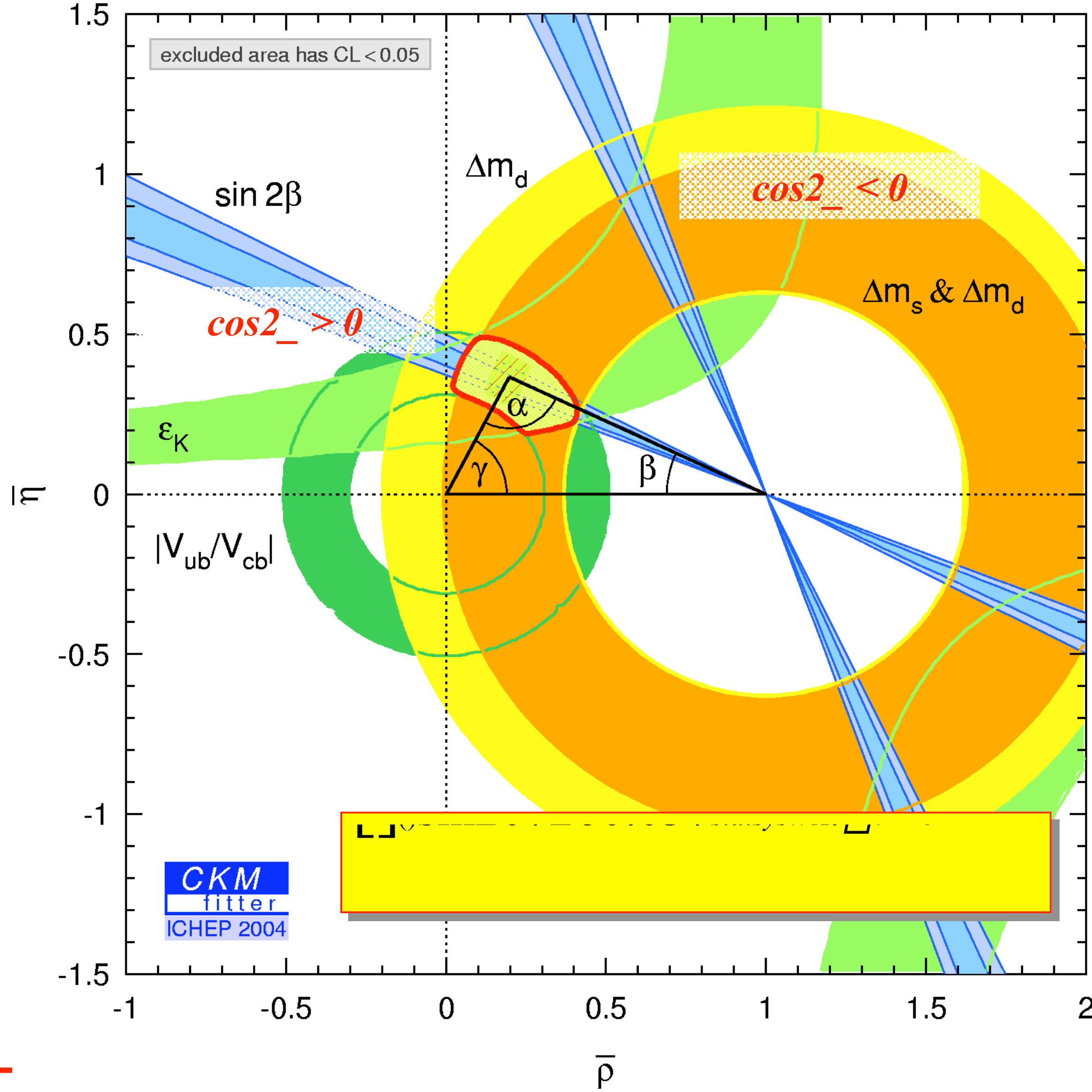
BABAR PUB-04/038

Belle CONF-0436

Limit on direct CPV

M.Bruinsma, T. Higuchi, CP-3

sin2_, cos2_ and CKM constraints



BABAR

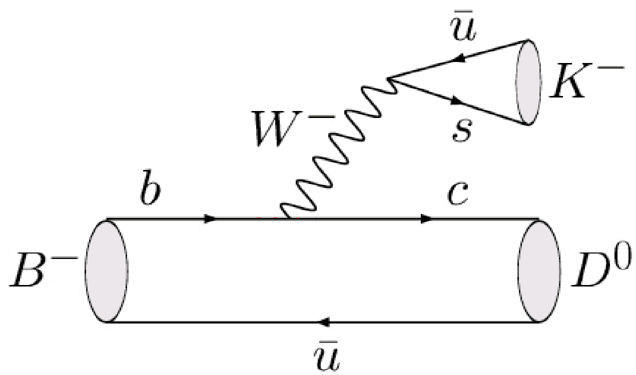
cos2□< 0 ruled out at 87% CL by s- and p-wave interference analysis in angular analysis of *B* *J/□K*^{*0} (*K*$_S$□^{0})

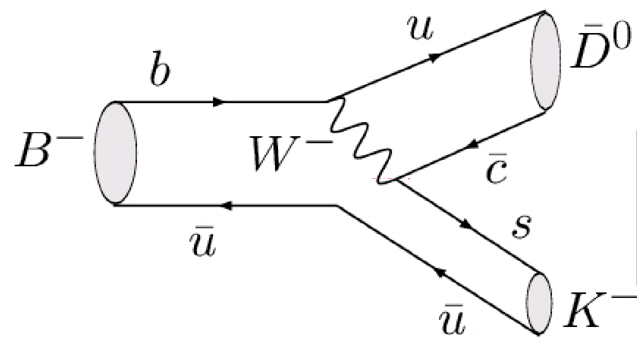
M.Bruinsma, CP-3

CKM fit to indirect constraints overlaid with sin2_$_{WA}$ measurement

Methods for extraction of

Basic Idea





Color suppressed

GLW *Gronau-London-Wyler, 1991*

ADS *Atwood-Dunietz-Soni, 2001*

D^0 Dalitz plot

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

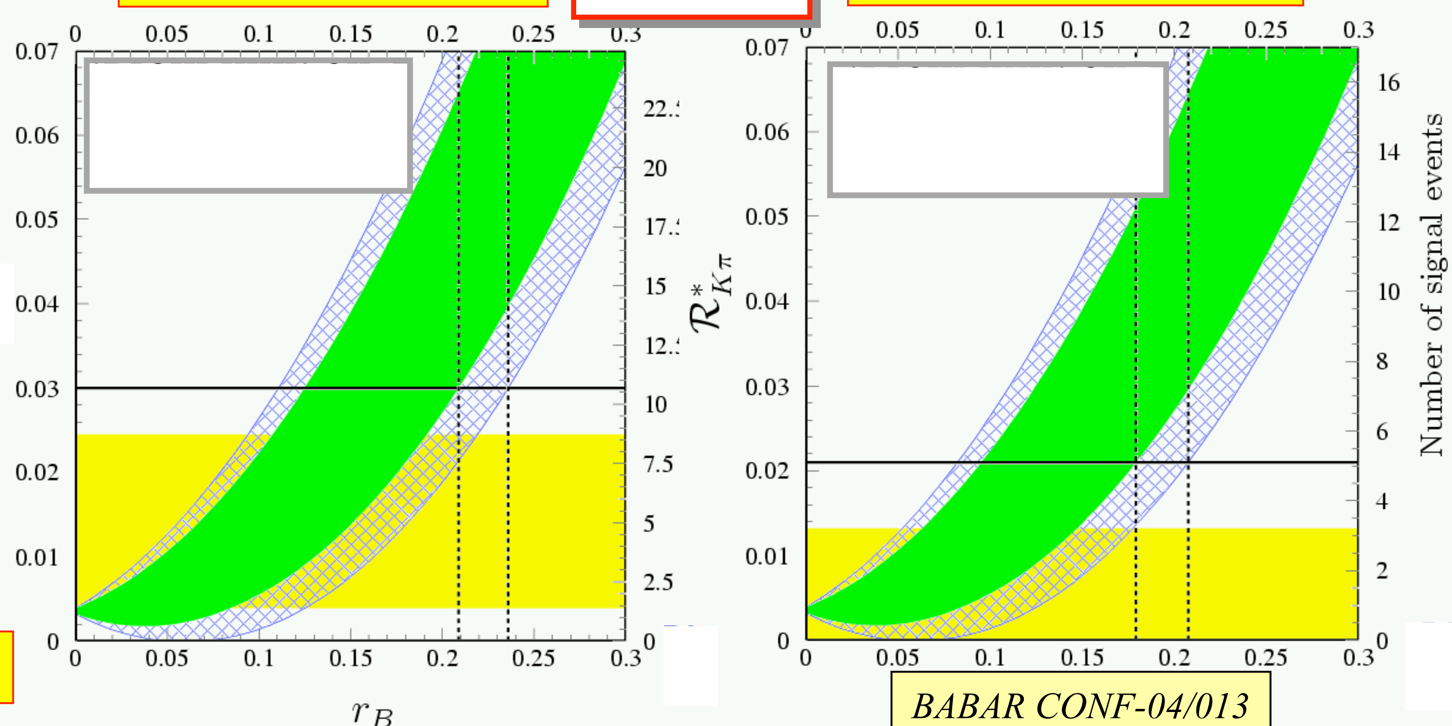
favored **suppressed**

suppressed **favored**

Update for ICHEP04

BABAR

Belle



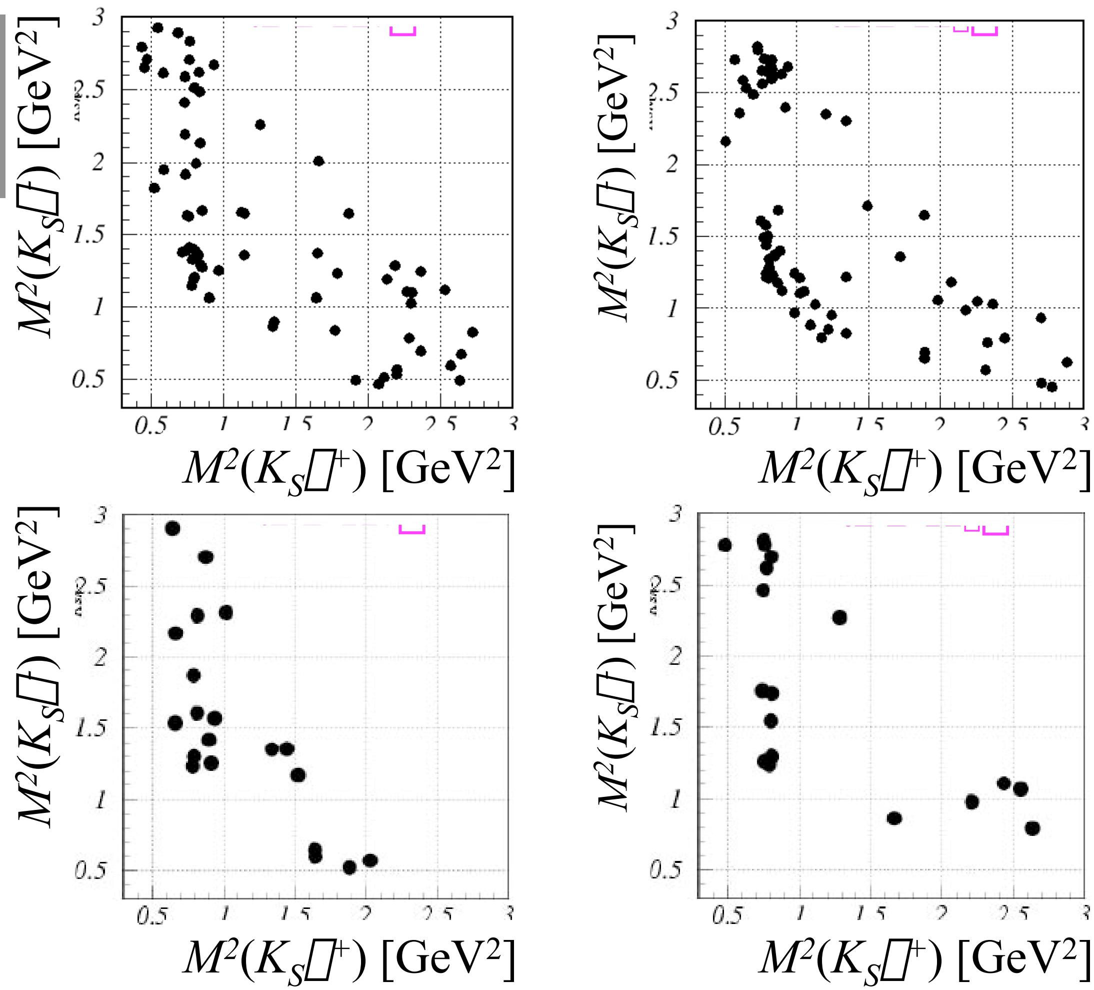
G.Cavoto, A.Bozek, CP-4

First look at $B^{\mp} \to D^{(*)0}[K_S\pi^+\pi^-]K^{\mp}$ sample by Belle

New: Winter 04

Belle
140 fb^{-1}

Visible asymmetry in Dalitz plots



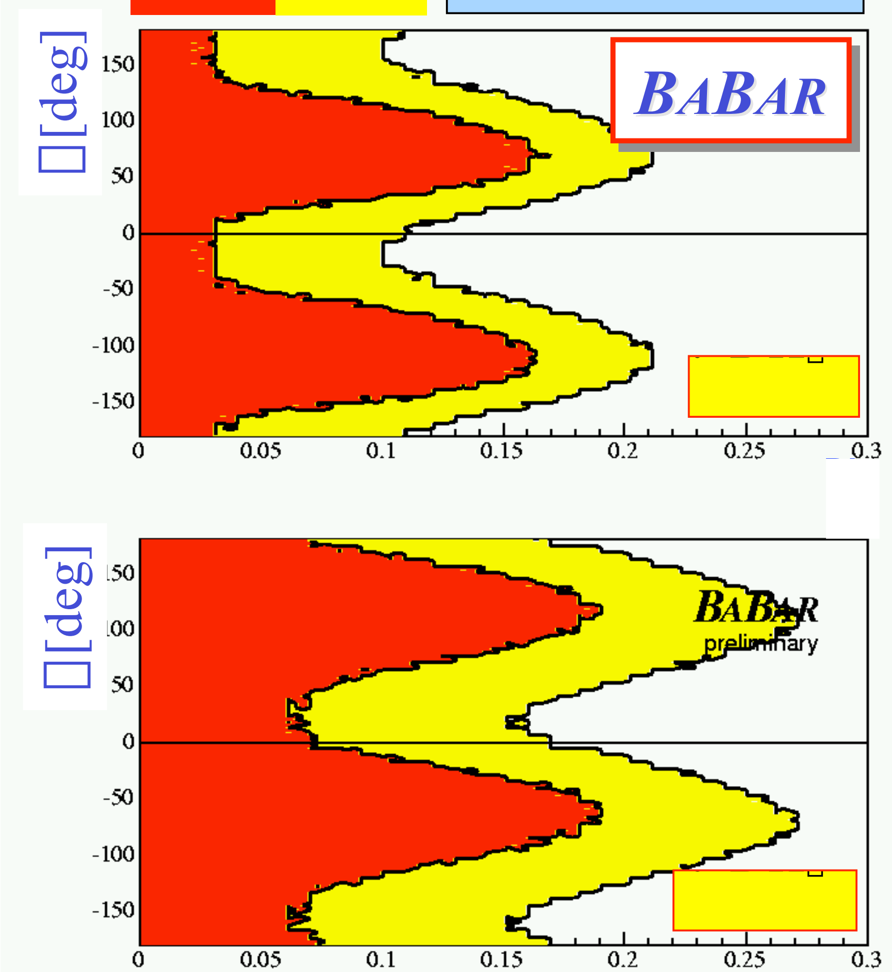
A.Bozek, CP-4

hep-ex/0406067

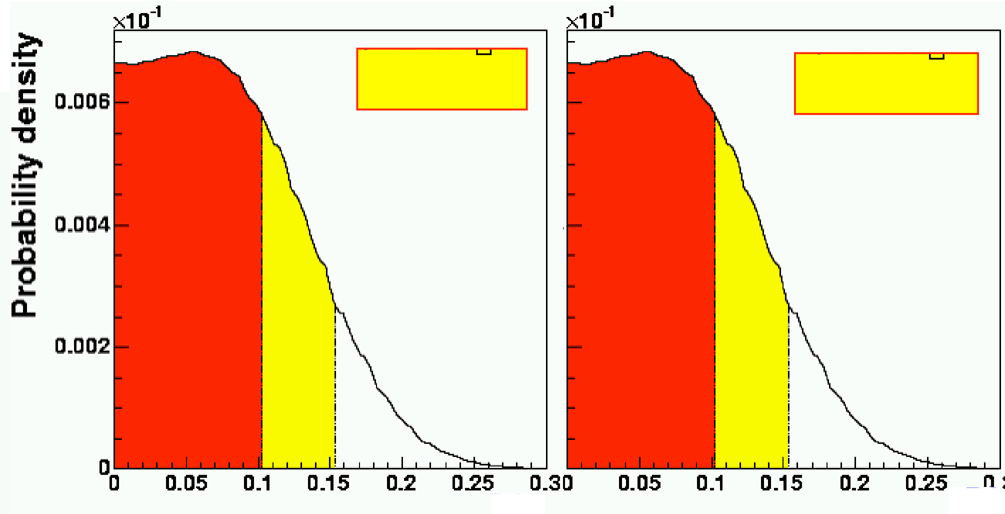
BABAR analysis of $B^{\mp} \to D^{(*)0}[K_S\pi^+\pi^-]K^{\mp}$

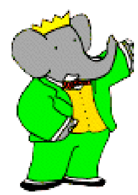
68% 90%

New for ICHEP04



BABAR CONF-04/043





[No sensitivity to $r_B < 0.1$]

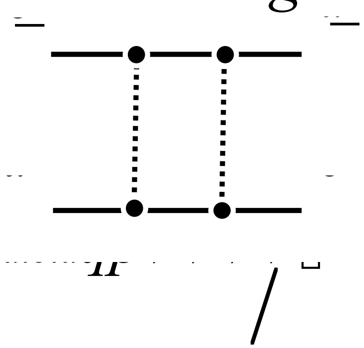
Poor constraints on γ as yet

sin2□ from *B* □ □□, □□, □□

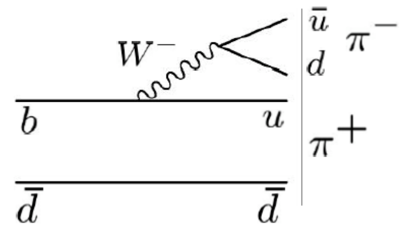
Interference of suppressed
b □ u "tree" decay with mixing

but: "penguin"
is sizeable!

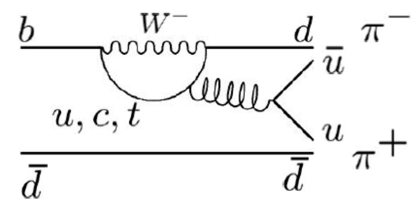
B⁰ mixing



B⁰ decay: tree



B⁰ decay: penguin



$$\ddot{e}_{\Box\Box} = \frac{q}{p}\frac{\overline{A}_{\Box\Box}}{A_{\Box\Box}} = e^{\Box i2\Box}e^{\Box i2\Box} = e^{i2\Box}$$

$$\ddot{e}_{\Box\Box} = e^{i2\Box}\frac{T + Pe^{+i\Box}e^{i\Box}}{T + Pe^{\Box i\Box}e^{i\Box}}$$

Coefficients of time-dependent CP Asymmetry

With no penguins

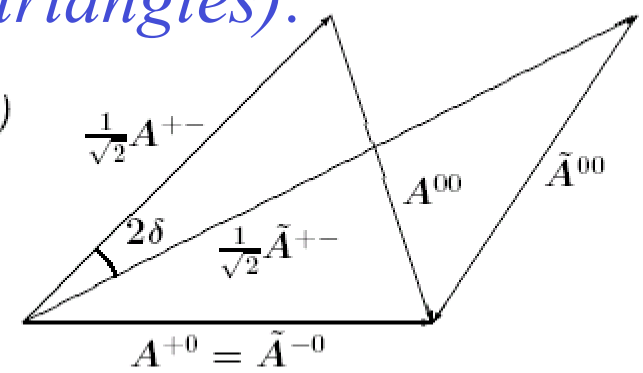
With large penguins
and |P/T| ~ 0.3

Gronau-London method (isospin triangles):

Gronau and London, *Phys. Rev. Lett. 65, 3381 (1990)*

$$2\alpha_{eff} = 2\alpha + 2\delta$$

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



BF of

If BF (00) is small then the Grossman-Quinn bound can be applied:

$$\sin^2(\alpha-\alpha_{\rm eff}) \leq \frac{\mathcal{B}(B^0 \to \pi^0\pi^0) + \mathcal{B}(\overline{B}^0 \to \pi^0\pi^0)}{\mathcal{B}(B^+ \to \pi^+\pi^0) + \mathcal{B}(B^- \to \pi^-\pi^0)}$$

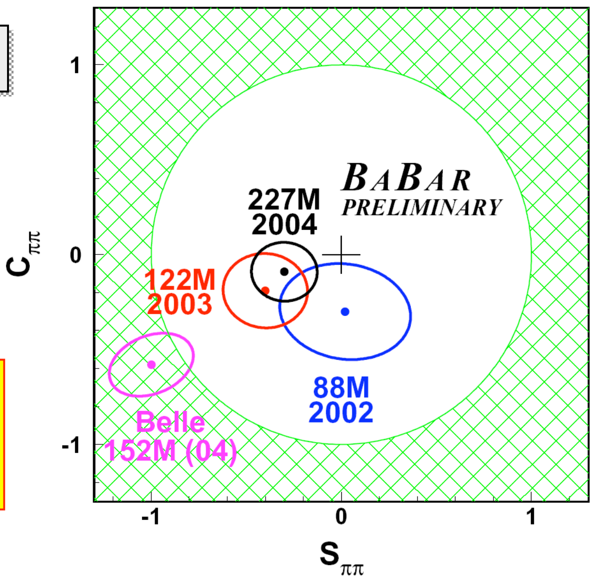
Results for sin2□$_{eff}$ from *B* □ □□ decays

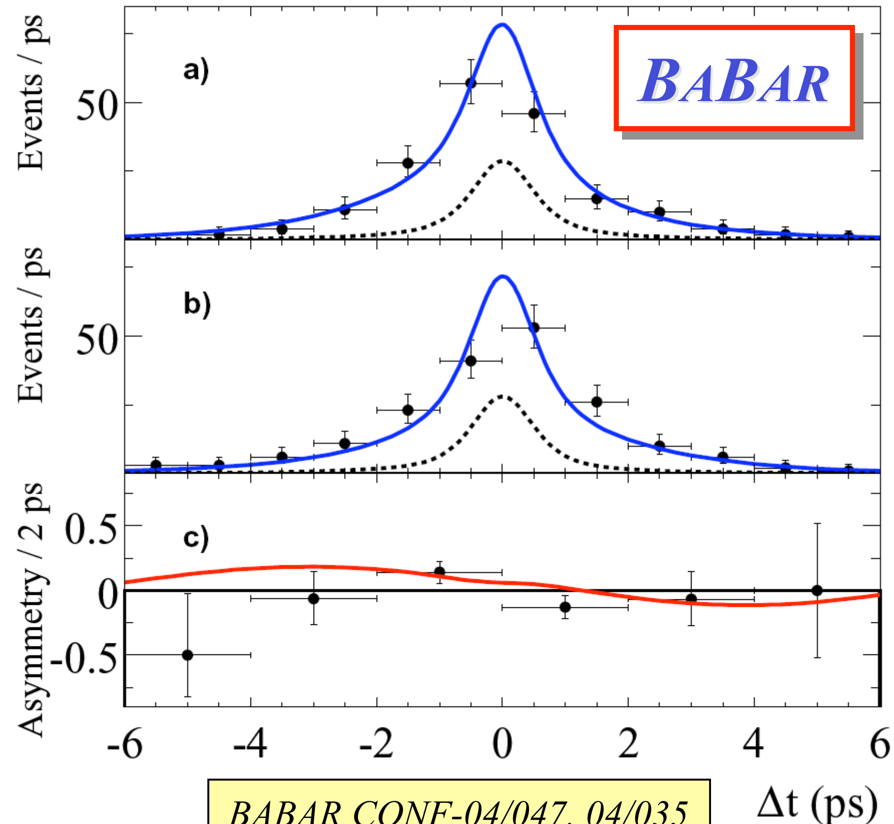
BABAR: Updated for ICHEP04

Belle: PRL 93 (2004) 021601

Comparison

Caution averaging!

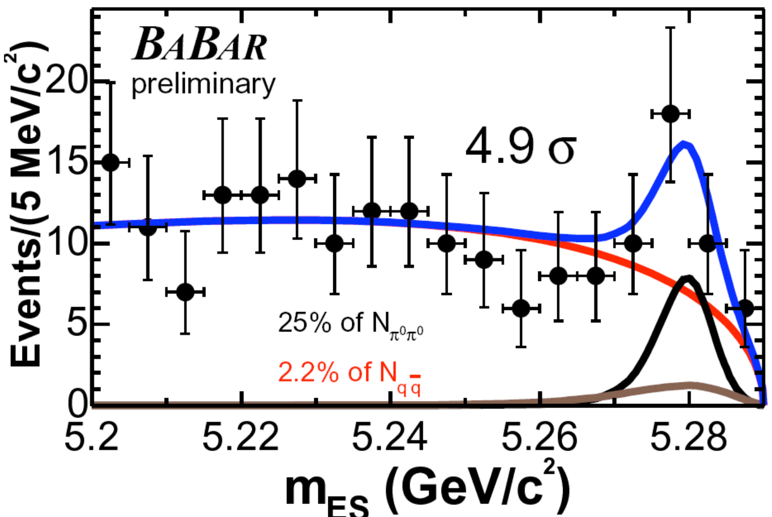


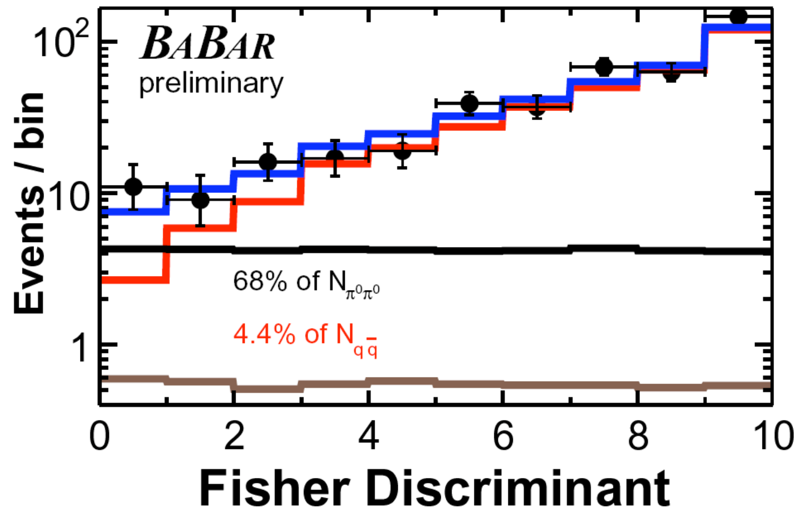


BABAR CONF-04/047, 04/035

Updated for ICHEP04

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





Improved understanding of π^0 efficiency:

BABAR CONF-04/035

Run 1-3	122*M*	44±13
Run 4	105*M*	17±11
Run 1-4	227*M*	61±17

Consistent at 1.3 level

4.9
First measurements

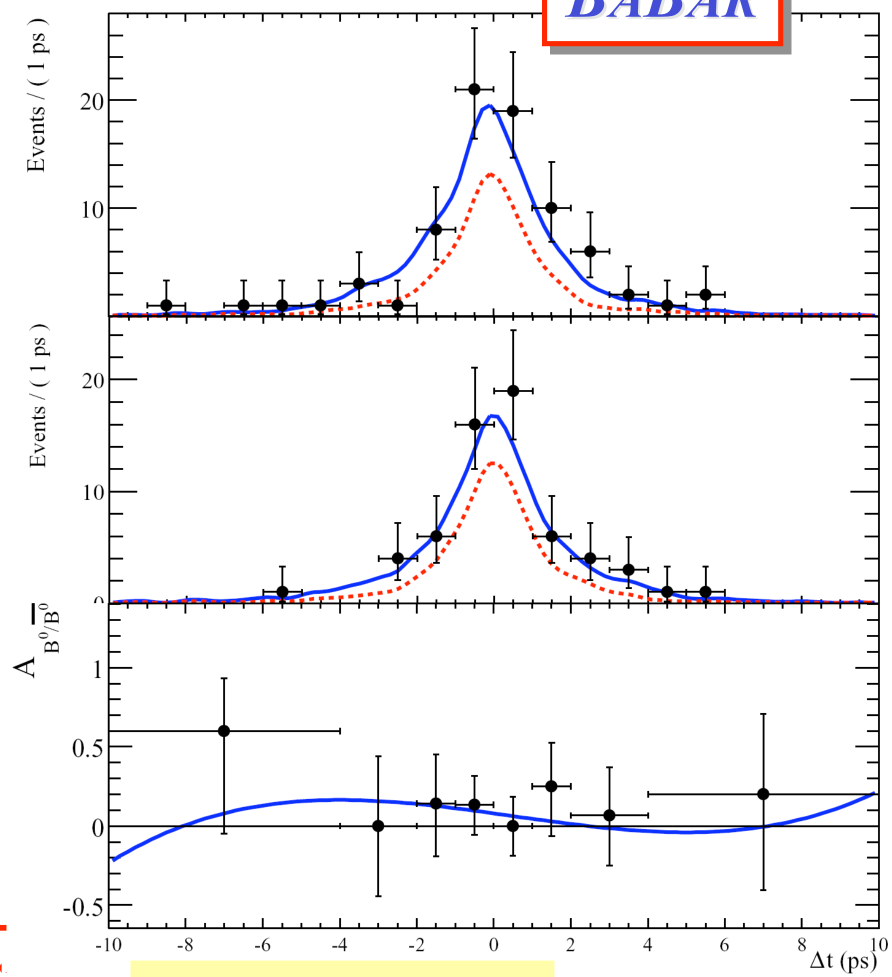
6.0
First measurements

M.Cristinziani, CP-4; Y.Chao, CP-6

Results for sin2□$_{eff}$ from *B* □ □□ decays

Extraction of □ similar to □□, but with advantage of smaller Penguin pollution:

Moriond QCD04



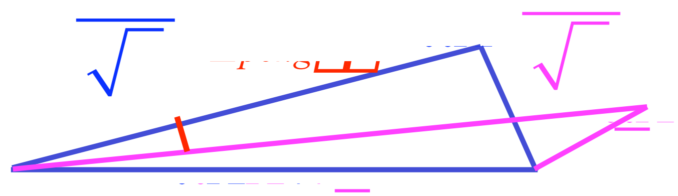
C.Dallapiccola, CP-6

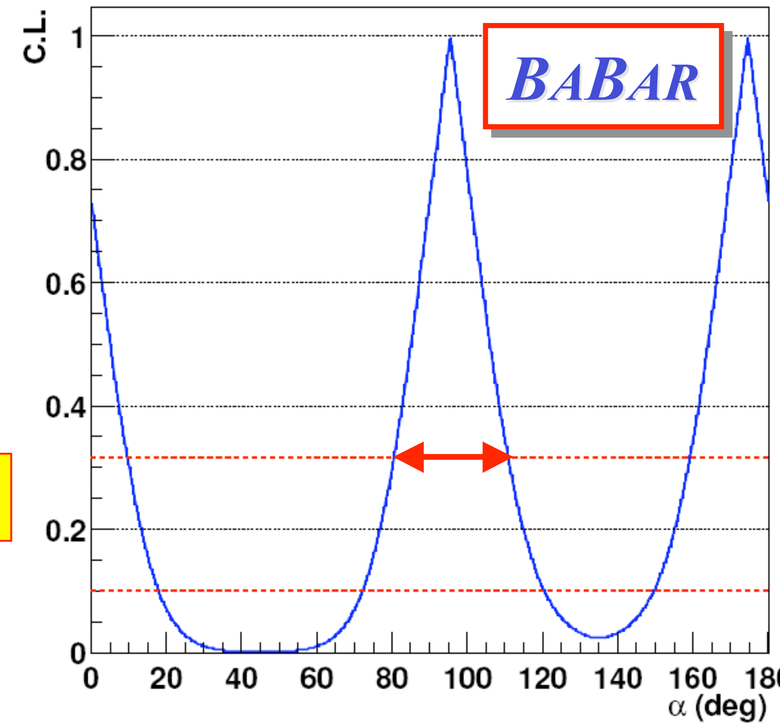
Isospin Corrections for

PRL 91 (2003) 171802

Updated for ICHEP04

BABAR CONF-04/037





Geometric limit on 2$_{peng}$: Grossman-Quinn bound

Compare with 35° for

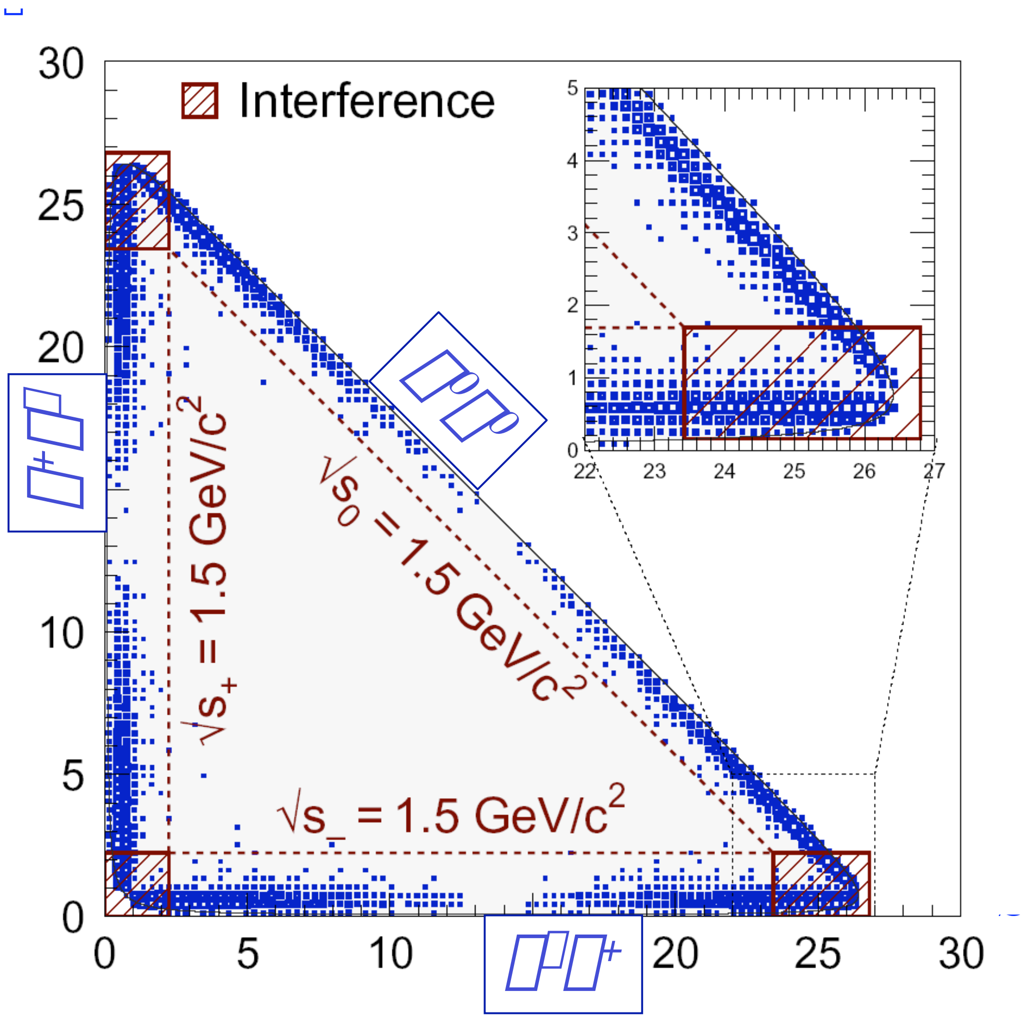
C.Dallapiccola, CP-6

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

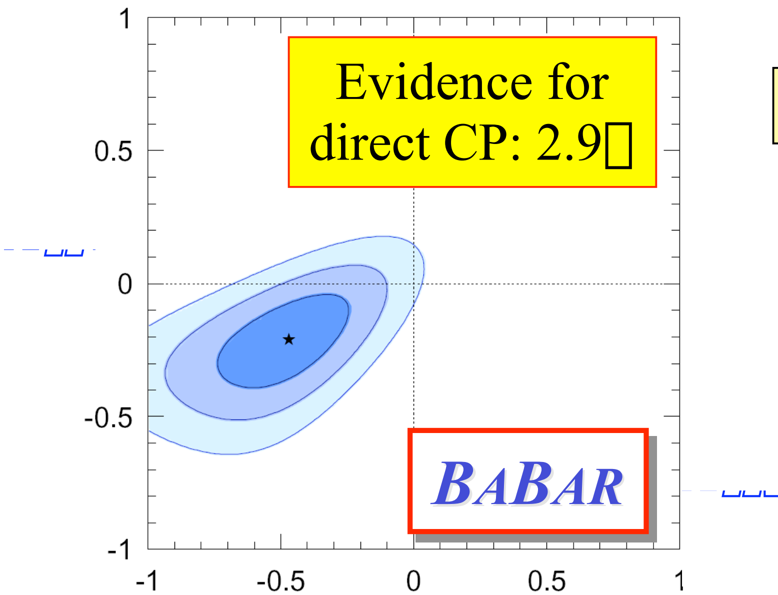
Quasi-two-body approach to Snyder-Quinn method

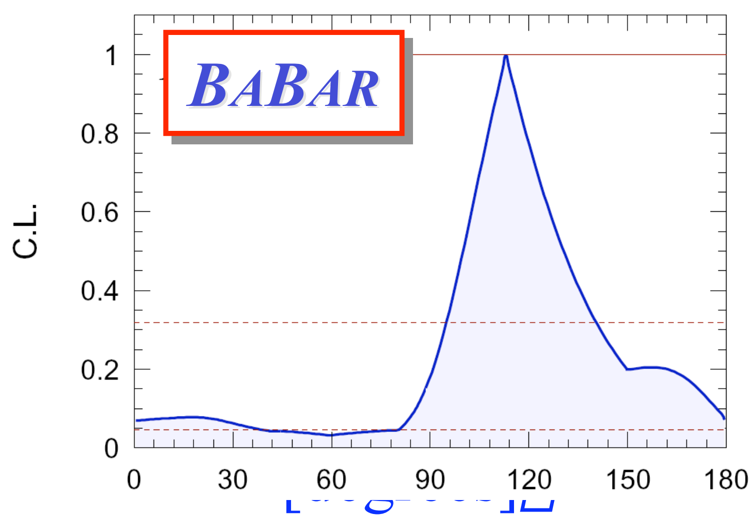
Phys.Rev. D 48, 2139 (1993)

- Extract α 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 □ (□□)^0





combined 3.6□

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

hep-ex/0408003

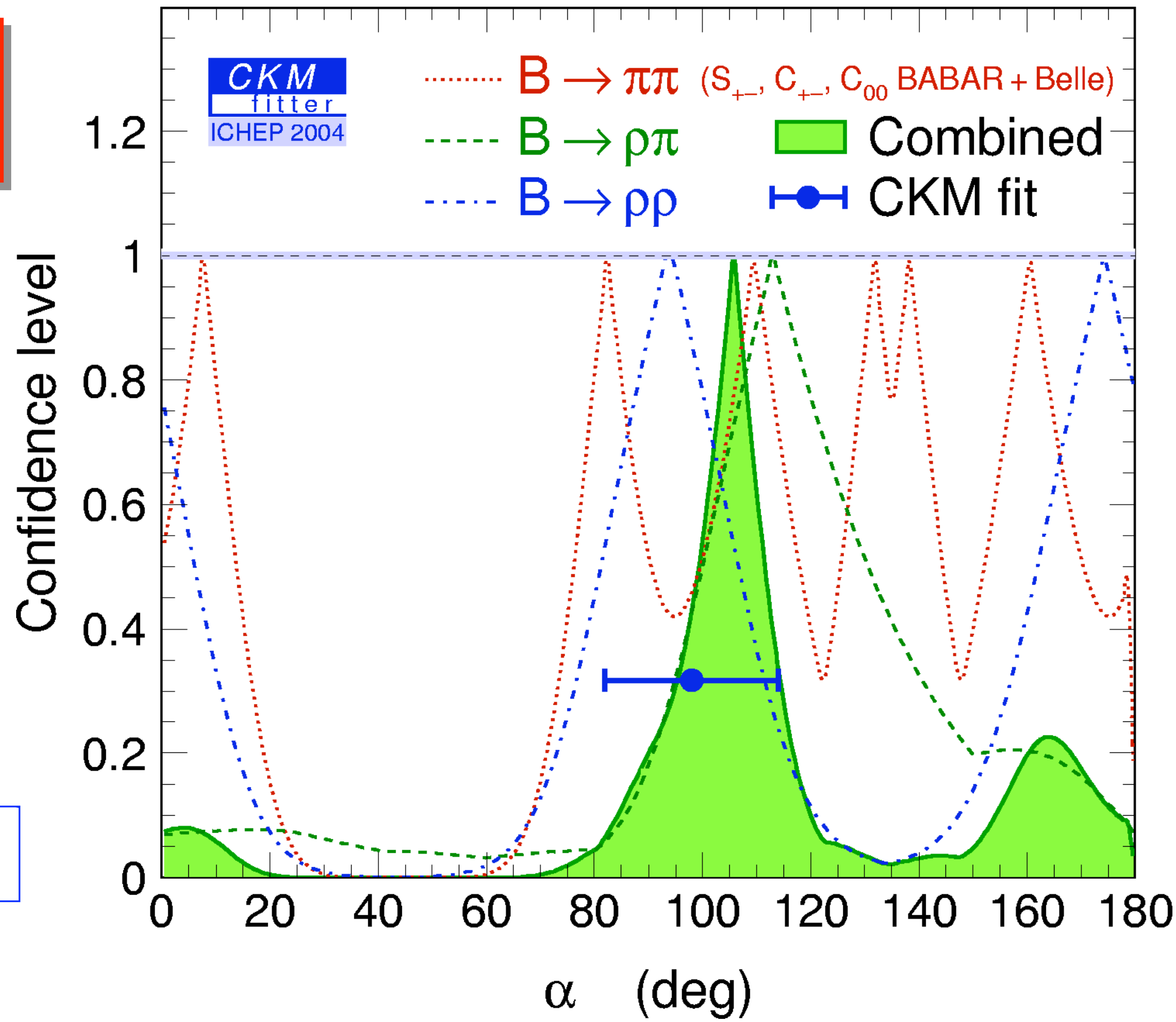
BABAR CONF-04/038

M.Cristinziani, CP-5; A.Somov, CP-6

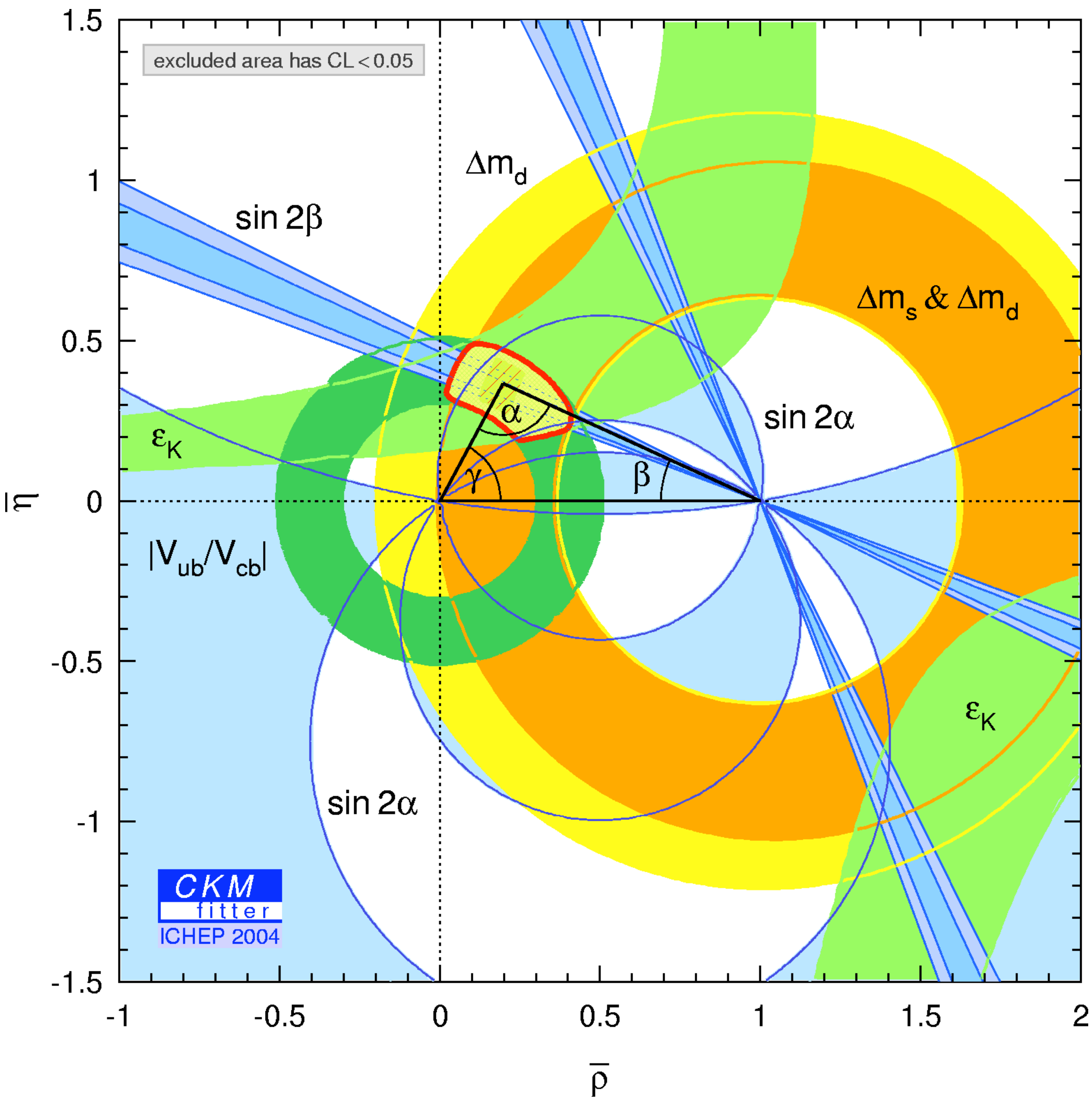
Summary of constraints on □

BABAR & Belle combined

Mirror solutions disfavored



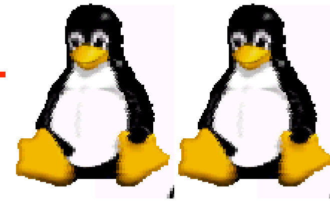
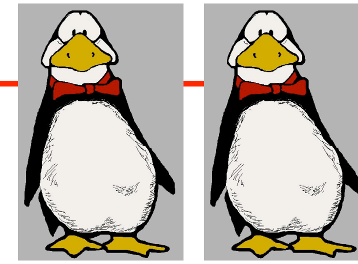
CKM constraints and sin2 and measurements



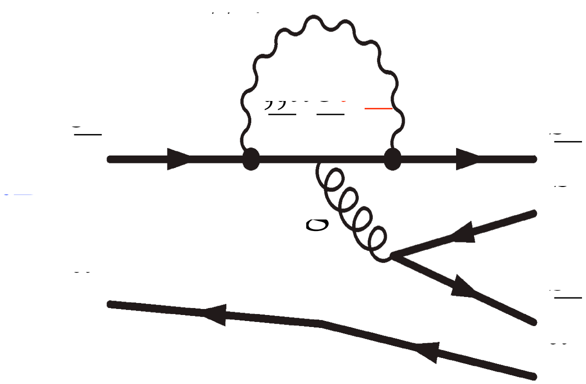
CKM fit to indirect constraints overlaid with sin2_$_{WA}$ and measurements

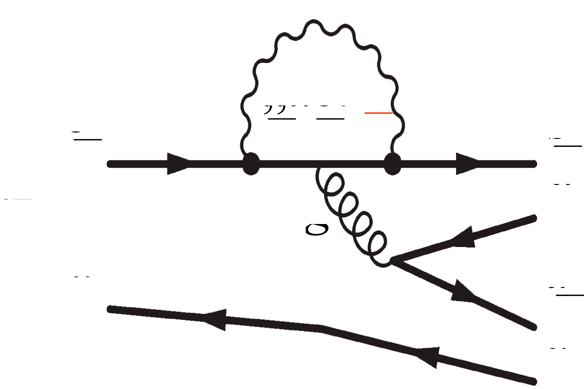
Beyond the Standard Model?

Do  and  yield the same $\sin 2\beta$?

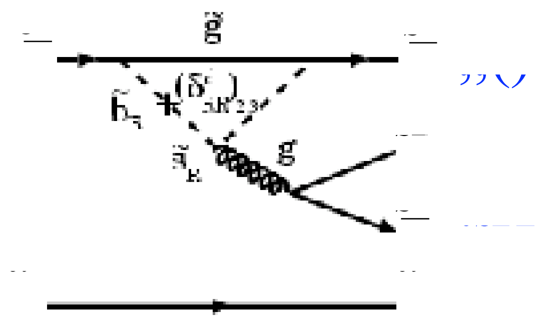
sin2β and..  and.... 

In SM interference between *B* mixing, *K* mixing and Penguin $b \to s\bar{s}s$ or $b \to s\bar{d}d$ gives the same $e^{-2i\beta}$ as in tree process $b \to c\bar{c}s$. However loops can also be sensitive to New Physics!

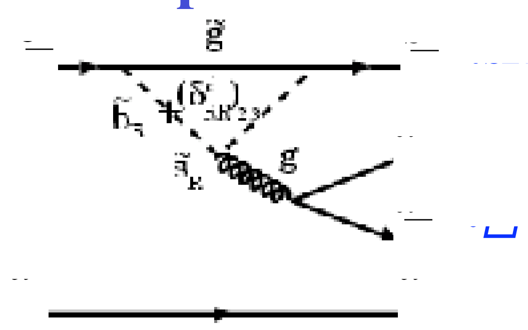




Purely dimensional estimate



New phases from SUSY?

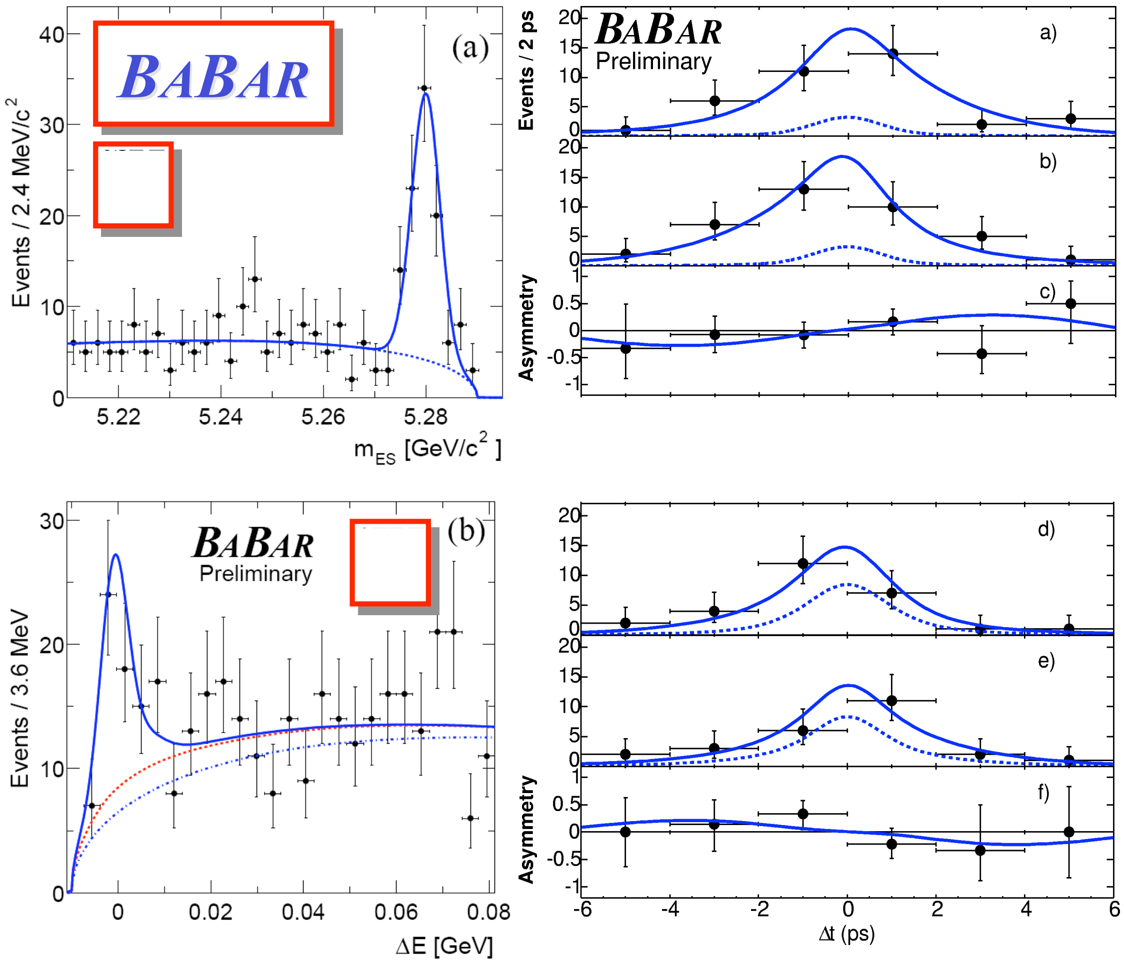


Note that within QCD these uncertainties turn out to be smaller !

A.Hoecker ICHEP04

BABAR results for B^0 □ □K^0

2004 = 227*M BB* pairs (2003 = 120M pairs)



2003 result

Update for ICHEP04

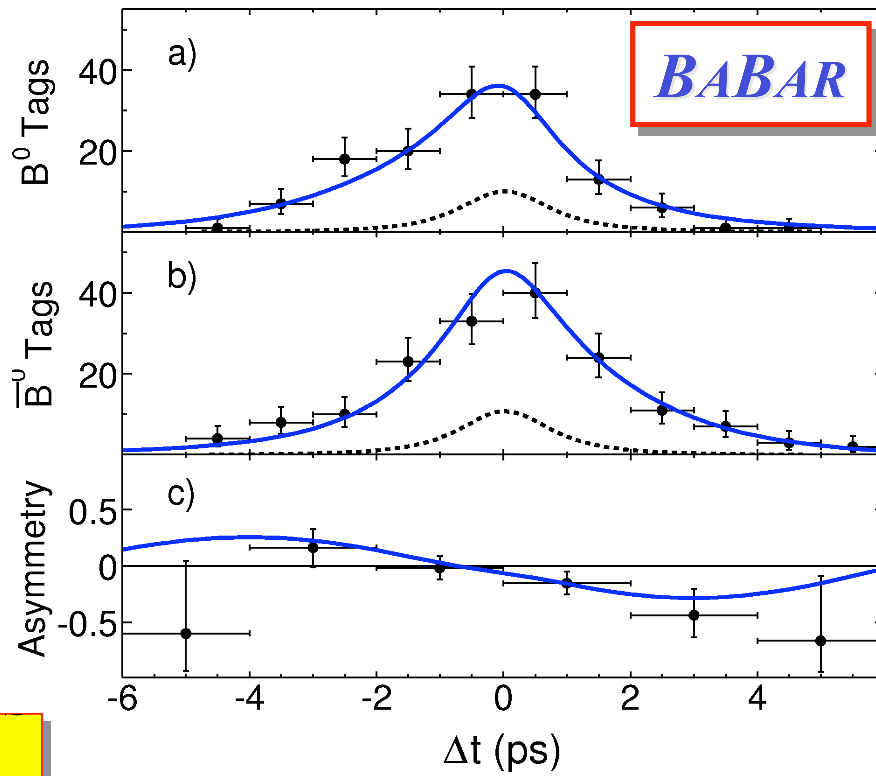
BABAR-CONF 04/033

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

Update for ICHEP04

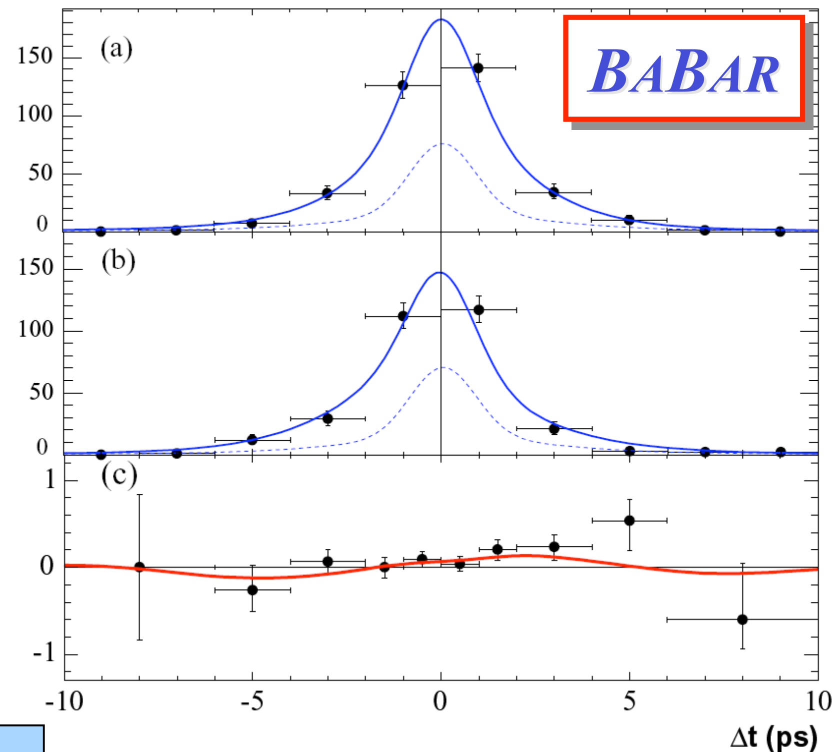
BABAR CONF-04/025

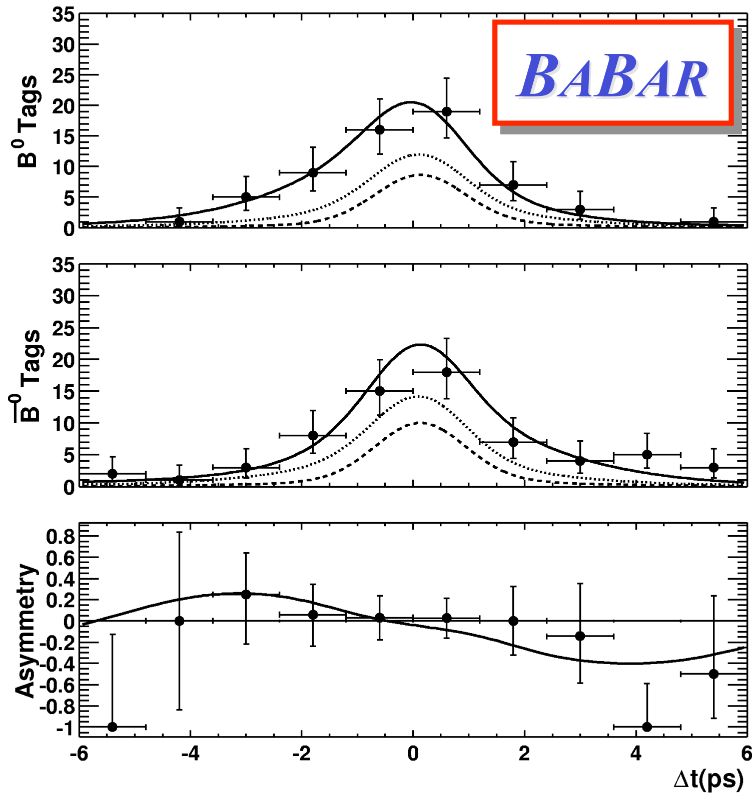
- Independent sample with (K^+K^-) mass outside ϕ region
- CP content can be determined experimentally with an angular moment analysis through the helicity angle distribution



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

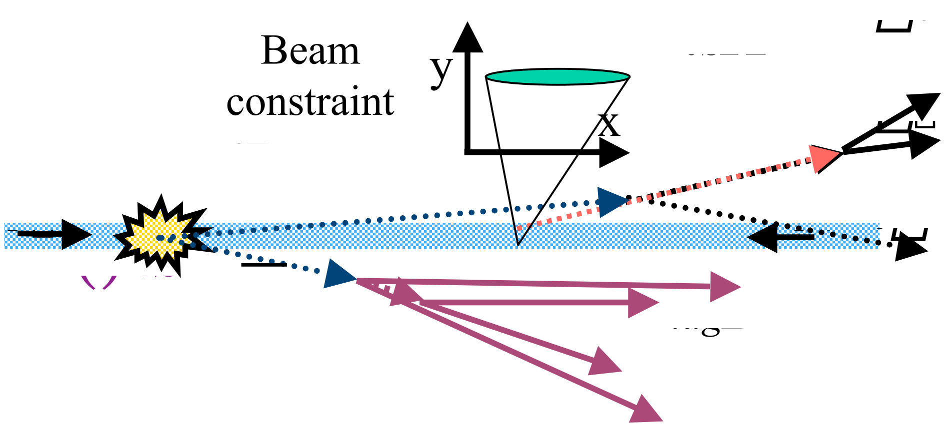
CONF 04/040
CONF 04/019





Updates for ICHEP04

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



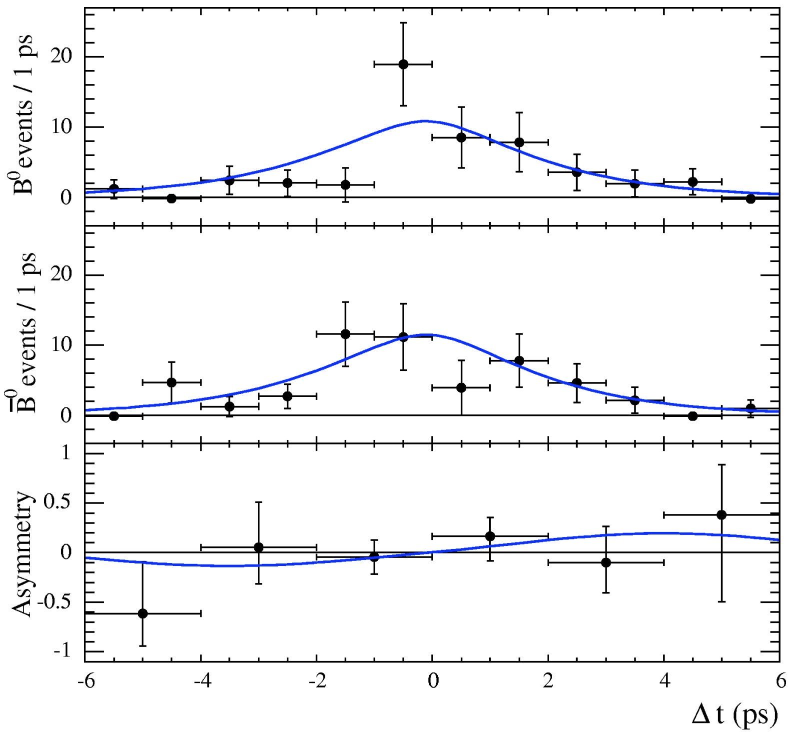
BABAR technique from 2003

Updated for ICHEP04

BABAR

BABAR CONF-04/030

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



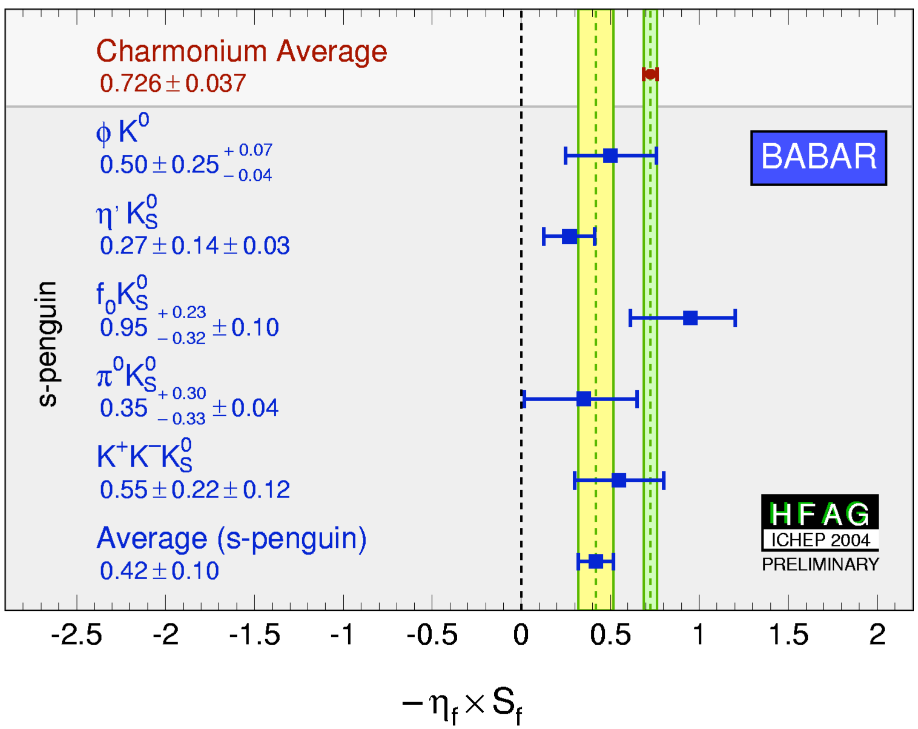
Belle

BABAR

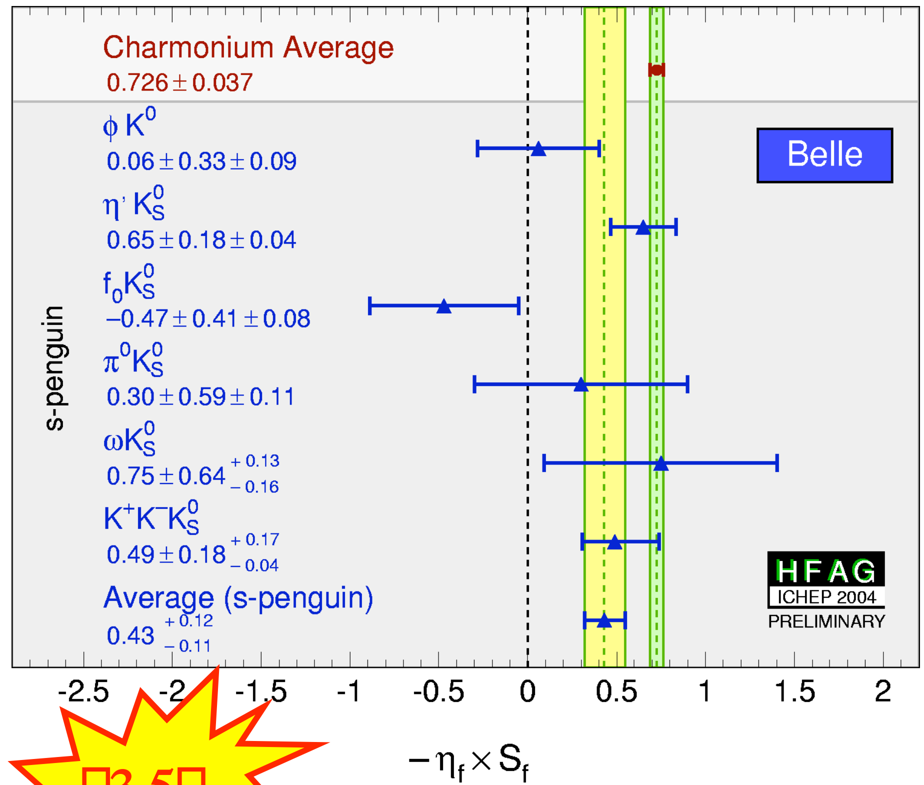
A.Hoecker, CP-4; C.F. Chen, CP-3

Results on sin2β from s-penguin modes

All new!



All new!

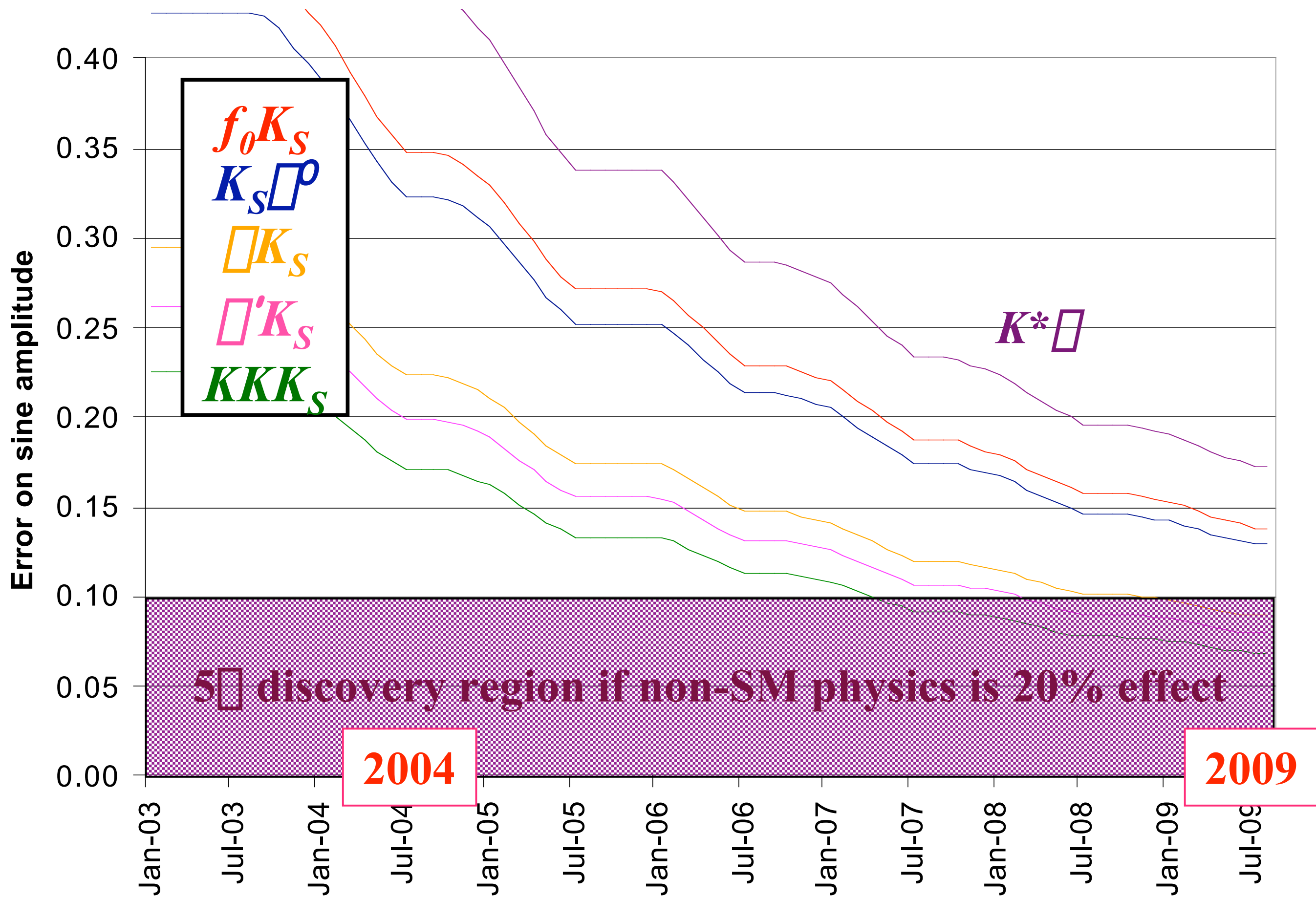


~3.5σ

2.7σ from s-penguin to sin2β (cc̄)

2.4σ from s-penguin to sin2β (cc̄)

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

Conclusions and outlook

- Success of *B* Factory experiments BaBar and Belle of b□ $c\bar{c}s$ (new sin2□ value from charmonium 0.726 ± 037)
- Good agreement between BaBar and Belle results on b□ $s\bar{s}s$ penguin, but both experiments still show discrepancies (2.7 and 2.4□) with charmonium!!
- Observation by BaBar of the direct CP violation in charmless *B* decay confirmed by Belle (average value)
- Quantitative measurements of □ (□$_2$) are emerging (new value)
- Constraints on □(□$_3$) are still poor with present statistics (low values for r_B).

- A statistical increase on these modes in the next few years could well provide initial evidence for new physics in the unitarity triangle beyond the SM.
- Modes dominated by penguin amplitudes as *B*0 □ *f**K*0 seem to be promising benchmarks for New Physics at a mass scale < 1 TeV. However unravelling the full flavour impact of this new physics will require a very high luminosity *B* Factory – a Super-*B* Factory – *(luminosity higher by a factor 50-100 than in the present machines).*