Recent BaBar Results on CP violation

A KEK seminar
October 24th 2003

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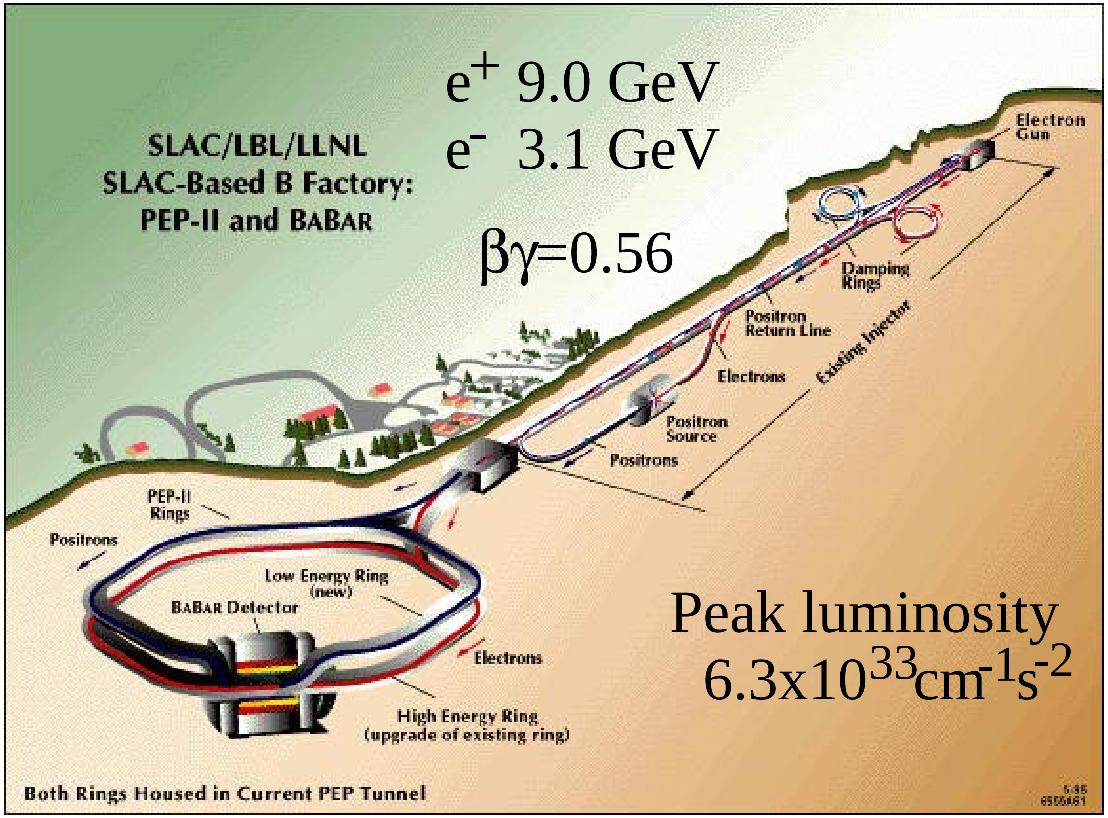
BaBar collaboration
The University of Iowa
Université Claude Bernard Lyon 1

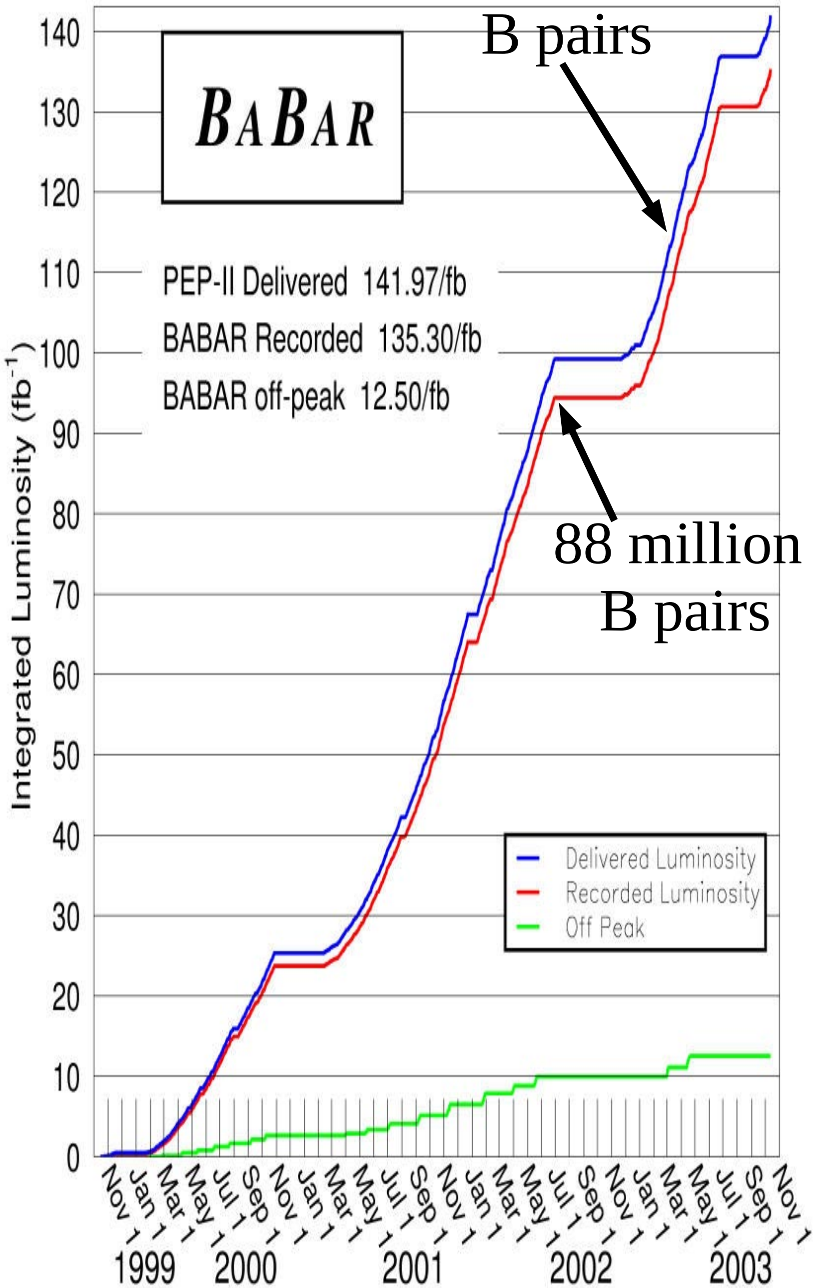
PEP-II and BaBar



e^+ 9.0 GeV
e^- 3.1 GeV

$\beta\gamma$=0.56

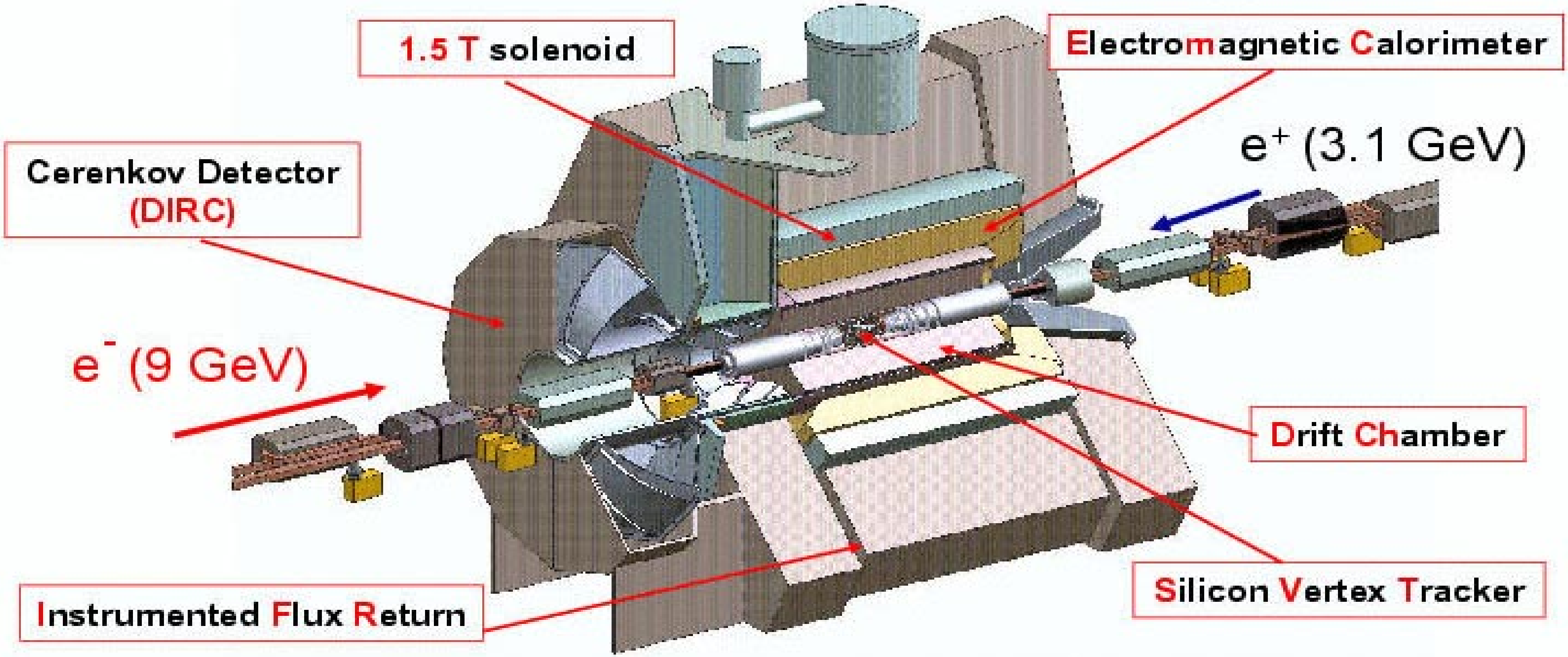
Peak luminosity
$6.3\times10^{33} cm^{-1} s^{-2}$



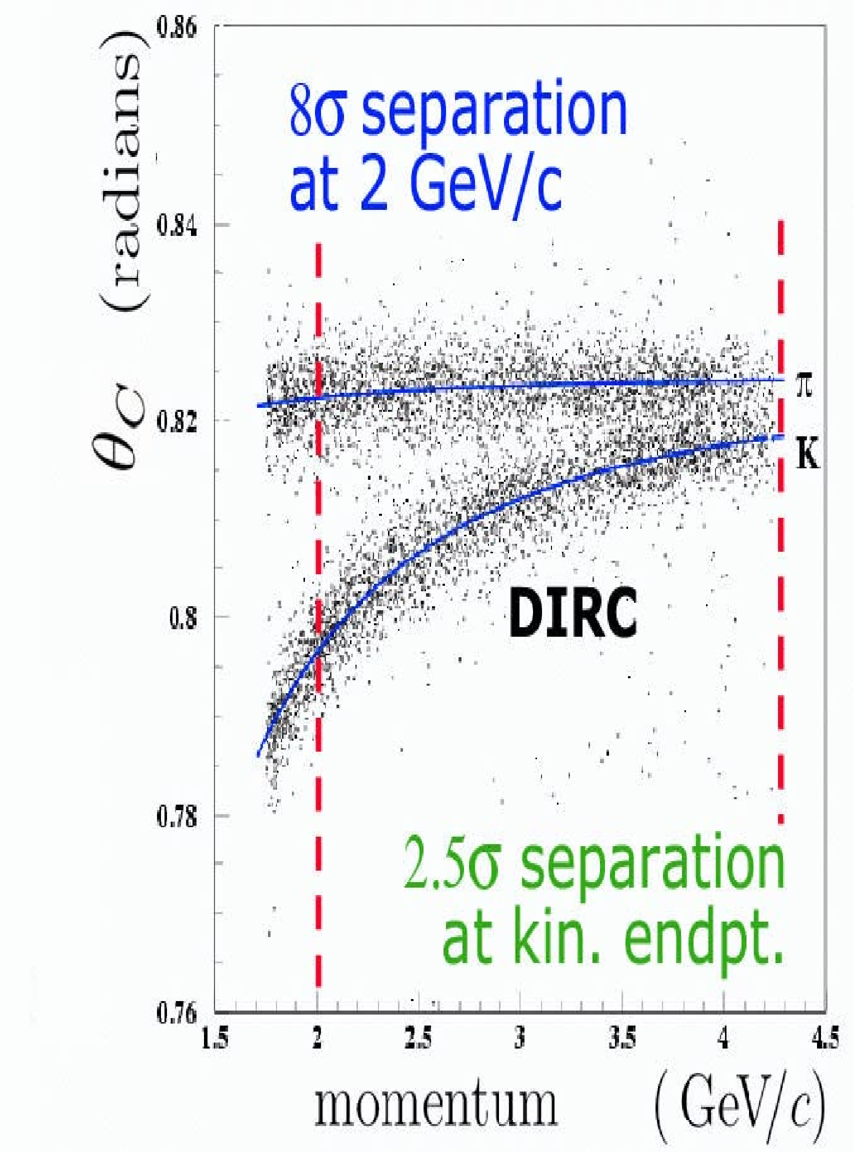
124 million
B pairs

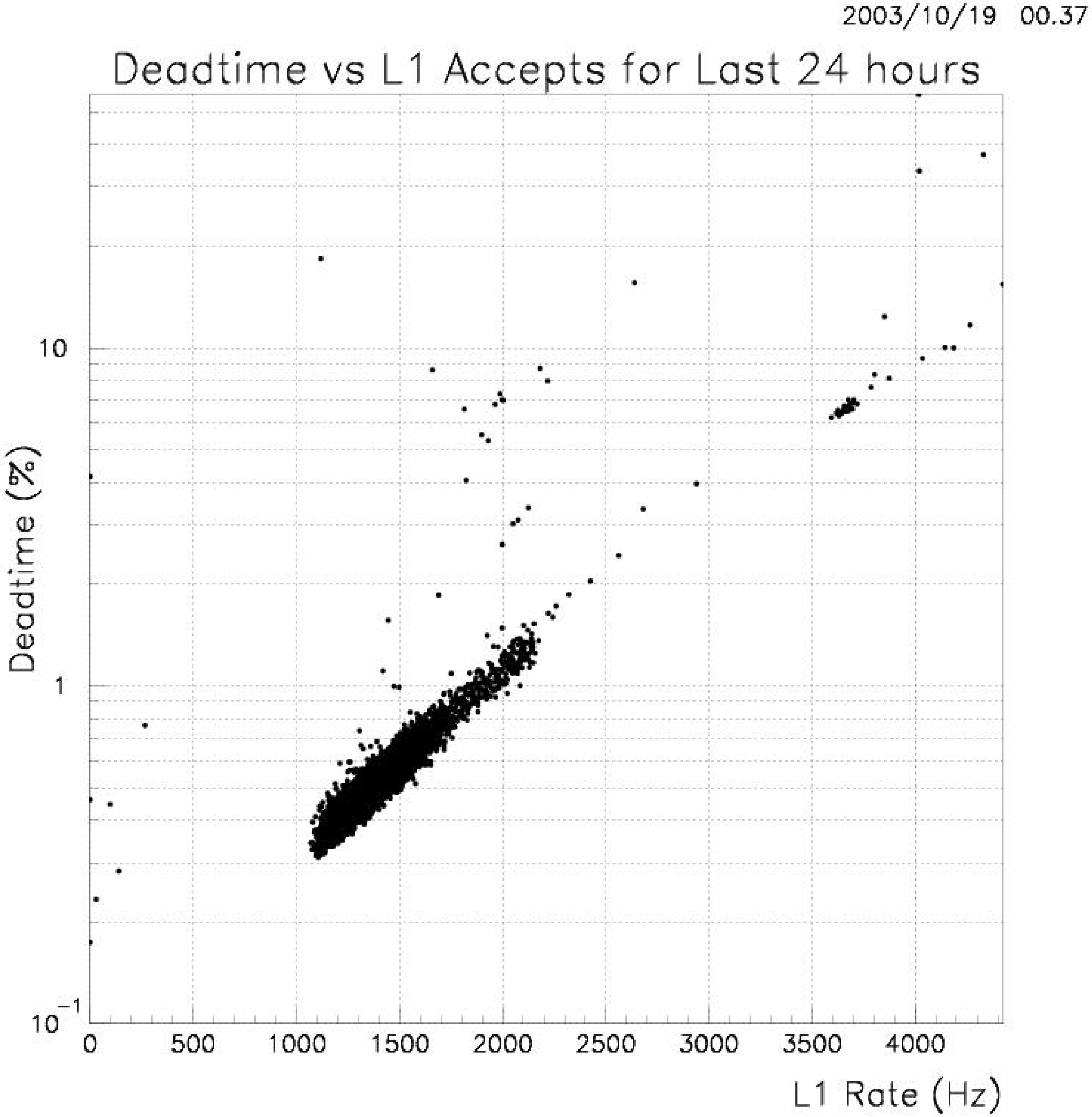
88 million
B pairs

The BaBar Detector



Some detector performances





Detector Upgrades

IFR replacement

Endcap RPC replaced by new ones: summer 2002

Barrel RPC replaced by LST: summer 2004: 2 sixths
summer 2005: 4 sixths

SVT

summer 2005: Extract SVT and replace damaged parts.
Install a rotation device to turn the SVT without removing it.

Drift Chamber Level 1 Trigger

Installation of a new trigger measuring the z coordinate of tracks.
Will reduce Level 1 Accept rate by a factor 2.
Commissioned in parallel with the current trigger.
Switch to new trigger around this February

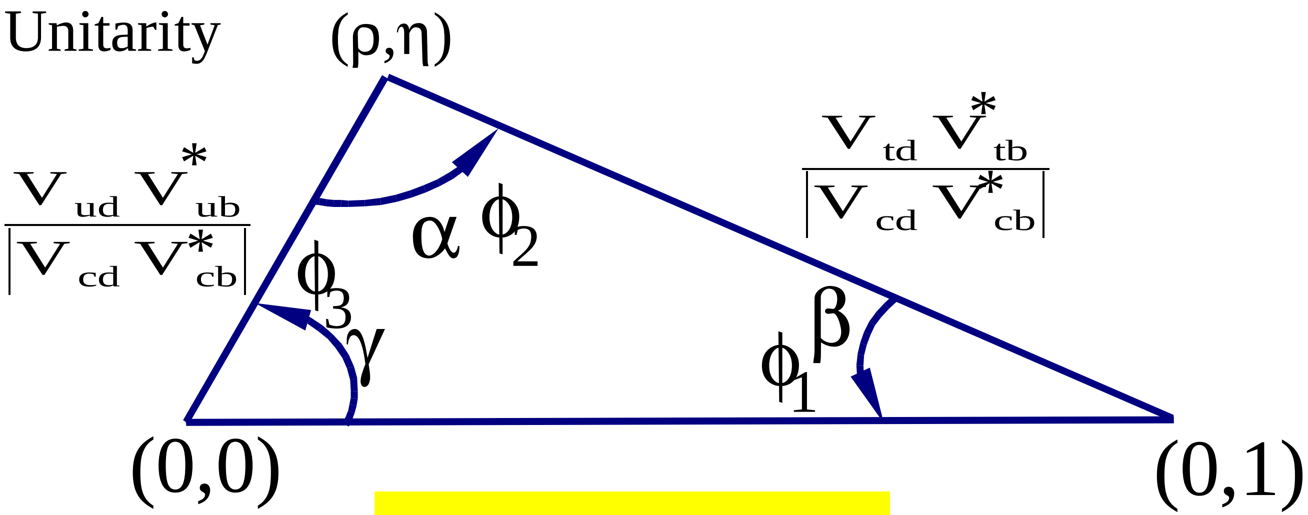
CKM Matrix

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

4 parameters (18 – 9 – 5)

3 mixing angles and a complex phase → ~~CP~~

- unitarity → 9
- 5 relative phases between the 6 quarks → 5



$$\alpha = \arg\left[-\frac{V_{td}V^*_{tb}}{V_{ud}V^*_{ub}}\right]$$

$$\beta = \arg\left[-\frac{V_{cd}V^*_{cb}}{V_{td}V^*_{tb}}\right]$$

$$\gamma = \arg\left[-\frac{V_{ud}V^*_{ub}}{V_{cd}V^*_{cb}}\right]$$

BELLE : $\phi_1\phi_2\phi_3$

BaBar's "bag" : βαγ

CPV in decays

All B's

Direct CPV asymmetries $A_f = \dfrac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \overline{f}) + \Gamma(B \to f)}$

Interference between at least 2 amplitudes

$$\Gamma(B \to f) = a_1 e^{i(\delta_1 + \phi_1)} + a_2 e^{i(\delta_2 + \phi_2)} + \ldots$$

$$\Gamma(\overline{B} \to \overline{f}) = a_1 e^{i(\delta_1 - \phi_1)} + a_2 e^{i(\delta_2 - \phi_2)} + \ldots$$

δ_i strong phase CP-even

ϕ_i weak phase CP-odd

$$A_f = \frac{\sum_{ij} a_i a_j \sin(\delta_i - \delta_j) \sin(\phi_i - \phi_j)}{\sum_{ij} a_i a_j \cos(\delta_i - \delta_j) \cos(\phi_i - \phi_j)}$$

Other manifestations of CPV

B^0 's only

CPV in mixing: $|B_L\rangle = p|B^0\rangle + q|\bar{B}^0\rangle$

$|B_H\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$

$|p| \neq |q|$

From BaBar di-lepton analysis:
$|q/p| = 0.998 \pm 0.006 \pm 0.007$
Phys. Rev. Lett. 88, 231801 (2002)

CPV in interference between mixing and decay:
interference between $B^0 \rightarrow f$ and $B^0 \rightarrow \bar{B}^0 \rightarrow f$

time dependent asymmetry :

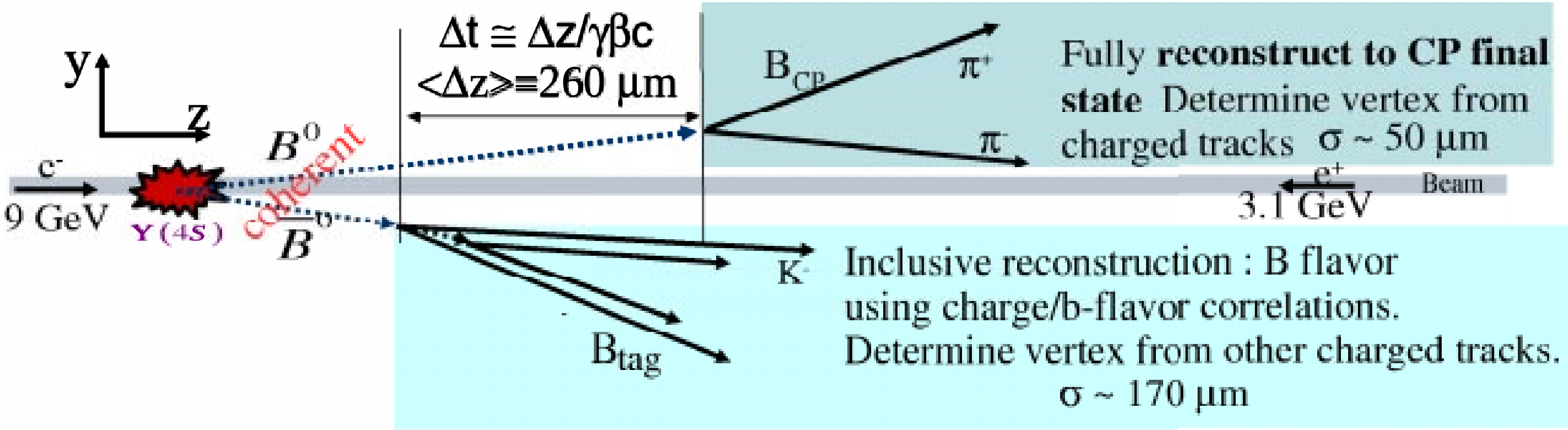
$$A_f(\Delta t) = S_f \sin(\Delta m_B \Delta t) - C_f \cos(\Delta m_B \Delta t) \quad \text{BaBar}$$

$$= S_f \sin(\Delta m_B \Delta t) + A_f \cos(\Delta m_B \Delta t) \quad \text{BELLE}$$

$$S_f = \frac{2\Im(\lambda_f)}{1 + |\lambda_f|^2} \qquad C_f = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2} \qquad \lambda_f = \frac{q}{p} \frac{a(\bar{B}^0 \rightarrow f)}{a(B^0 \rightarrow f)}$$

If only one amplitude and f is CP eigenstate:
$C_f = 0$
$S_f = \sin(2\beta), \sin(2\alpha), \ldots$

Time dependent asymmetries



Neural Network based tagging in 5 physics categories:

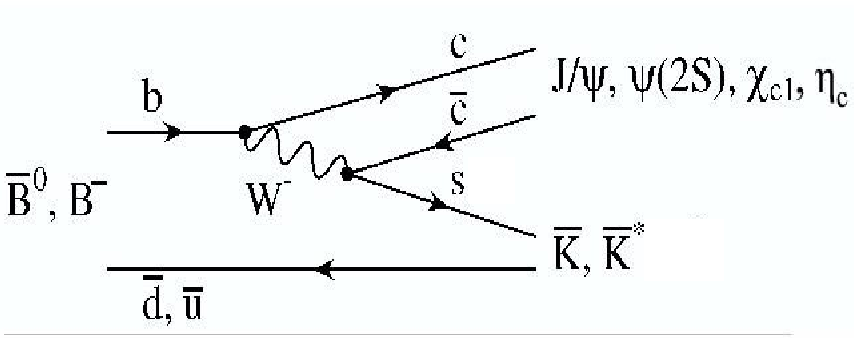
Category	ε (%)	ω(%)	Q(%)
Lepton	9.1± 0.2	3.3± 0.6	7.9± 0.3
Kaon+soft pion	16.7± 0.2	10.0± 0.7	10.7± 0.4
other Kaons	19.8± 0.3	20.9± 0.8	6.7± 0.4
other tags	20.0± 0.3	31.5± 0.9	2.7± 0.3
untagged	34.4± 0.5		
Total Q			28.1± 0.7

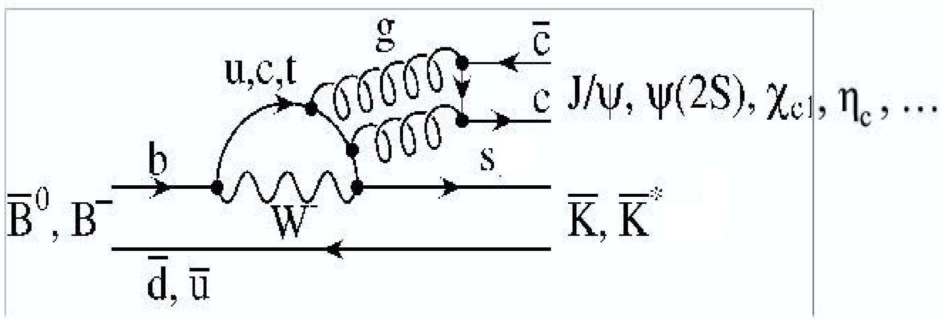
Coming next

$b \to c\bar{c}s$	$B \to J/\psi K, ...$	$\sin(2\beta)$
$b \to s\bar{s}s$	$B \to \phi K, ...$	$\sin(2\beta)$
$b \to s\bar{q}q$	$B \to \eta K, ...$	$\sin(2\beta)$
$b \to c\bar{c}d$	$B \to DD, ...$	$\sin(2\beta)$
$b \to u + b \to d$	$B \to \pi\pi, ...$	α
$b \to u + b \to c$	$B \to D\pi, ...$	$\gamma, 2\beta+\gamma$

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

"pure" Tree diagrams





same weak phase as Tree or suppressed

$B^0 \to$ charmonium

$B^0 \to \psi(2S) K_S^0$

$B^0 \to J/\psi\ K_S^0$

$B^0 \to \chi_{c1} K_S^0$

$$\sin(2\beta) = 0.741 \pm 0.067 \pm 0.034$$

$$|\lambda| = 0.948 \pm 0.051 \pm 0.030$$

88 million B pairs

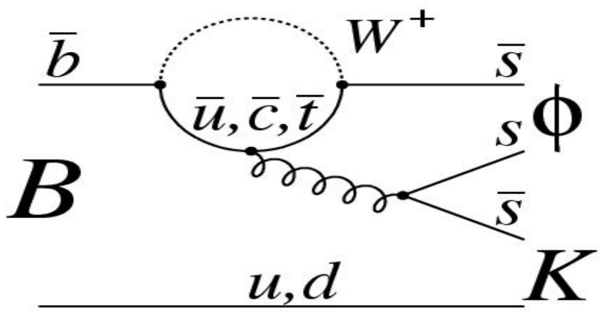
Phys Rev Lett 89 (2002) 201802

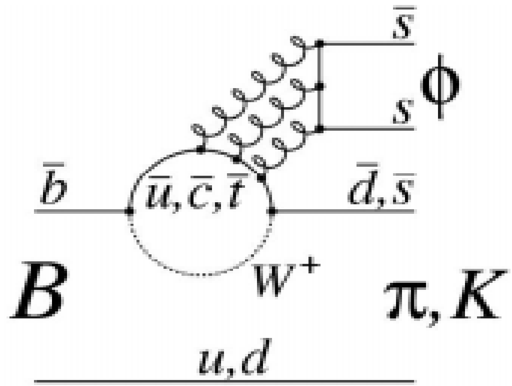
$B^0 \to \eta_c K_S^0$

$B^0 \to J/\psi\ K_L^0$

$B^0 \to J/\psi\ K^{*0}$

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





No Tree diagram
All other SM contributions suppressed.
In SM, direct CP violation small ~1% and measure sin(2β)

$B \to \phi K$, $B \to \phi\pi$

maximum likelihood fit for simultaneous extraction of signal yields and Direct CP asymmetries with $\phi \to K^+K^-$ and $K^0_S \to \pi^+\pi^-$

Measured B 4-momentum

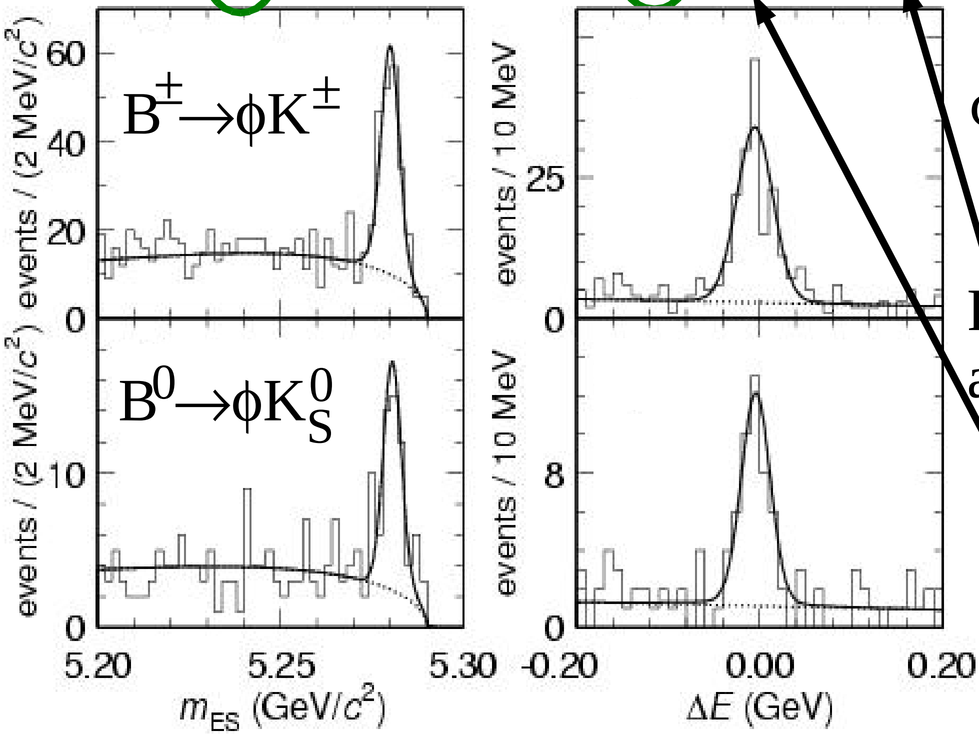
fitted distributions: $m_{ES} = \sqrt{E_b^2 - \vec{P}_B^2}$ $\Delta E = E_B - E_b$ F, $\cos(\theta_H)$, m_{KK}

$B = (10.0^{+0.9}_{-0.8} \pm 0.5) \times 10^{-6}$

$A = 0.04 \pm 0.09 \pm 0.01$

2 fits : neutrals and charged

$B = (8.4^{+1.5}_{-1.3} \pm 0.5) \times 10^{-6}$



ϕ helicity and mass

Fisher discriminant against continuum

B energy from center of mass boost

$B^\pm \to \phi\pi^\pm$: $B < 0.41 \times 10^{-6}$ (90% CL)

89 million B pairs

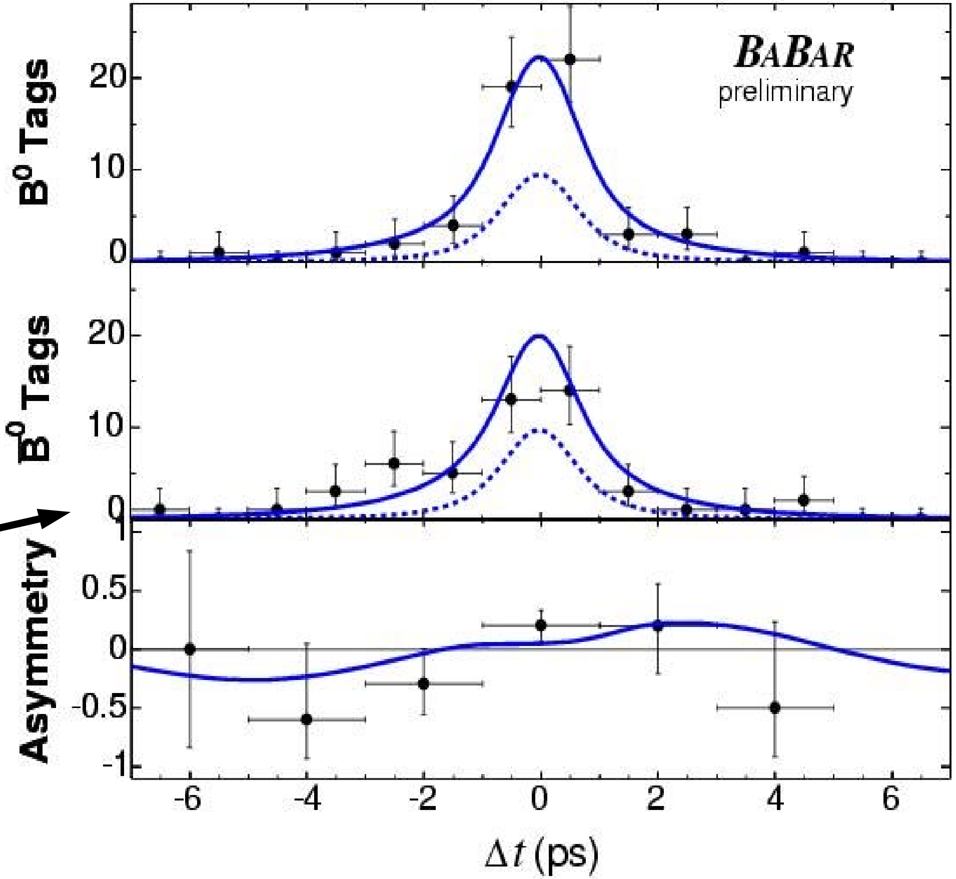
hep-ex/0309025

$B^0(t) \to \phi K_S$

Event yield maximum likelihood fit on distributions: $\Delta E, m_{ES}, \mathcal{F}, \cos(\theta_H)$

	signal	background
yield	70	2068

maximum likelihood CP fit on $\Delta E, m_{ES}, \mathcal{F}, \cos(\theta_H), \Delta t$ for CP B and $\Delta E, m_{ES}, \Delta t$ for flavor tag B



$C_{\phi K_S}$=-0.38±0.37±0.12

$S_{\phi K_S}$=sin(2β)=0.45±0.43±0.07

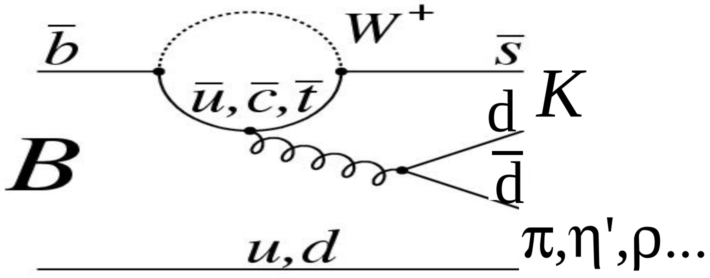
preliminary 110 fb^{-1}

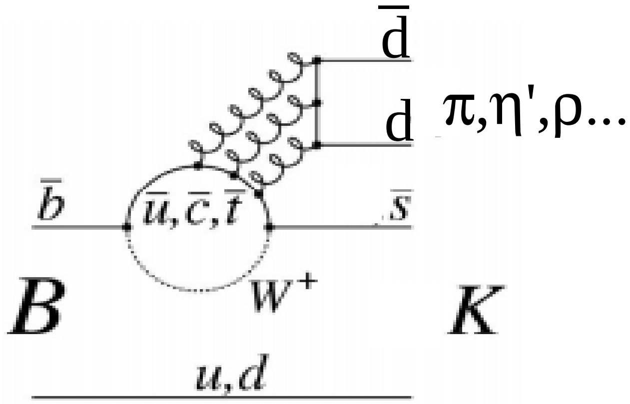
$B^0(t) \rightarrow \phi K_S$

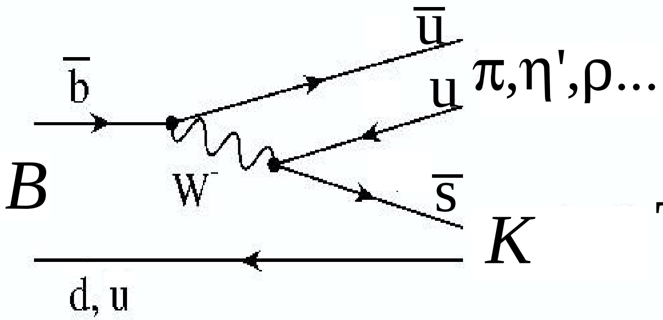
Systematic uncertainty due to	S	C
Fit bias	0.04	0.05
Event yield	0.01	0.05
Parametrization of Δt resolution	0.03	0.02
Background composition/CP asymmetry	0.03	0.05
m_{ES} background parametrization	0.02	0.05
Uncertainties in the SVT alignment	0.01	0.01
Beamspot position	0.01	0.01
PDFs for the event yield in signal and background	0.004	0.04
Potential S-wave contamination	0.002	0.015
$B^0/\overline{B}^0$ efficiency difference	0.002	0.02
Doubly-Cabbibo-suppressed decays	0.009	0.027
Total	0.07	0.12

Systematics are small and well understood from b to c cbar s studies

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





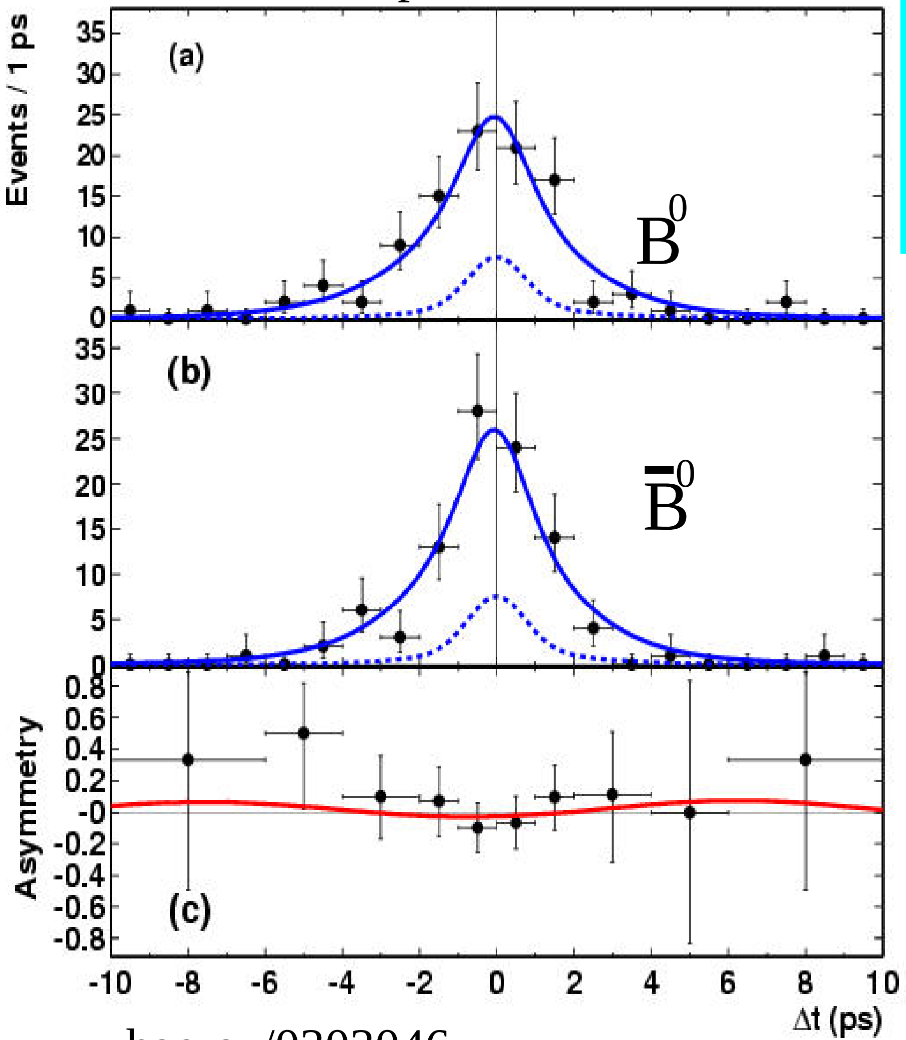


Penguin dominant

Tree Cabibbo and color suppressed

$B \to \eta' K$

88 million B pairs



hep-ex/0303046

$B^+ \to \eta' K^+$ $\quad B^0 \to \eta' K^0_S$

with $\eta' \to \eta \pi^+ \pi^-$, $\eta \to \gamma\gamma$ $\quad \eta' \to \rho^0 \gamma$, $\rho^0 \to \pi^+ \pi^-$

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

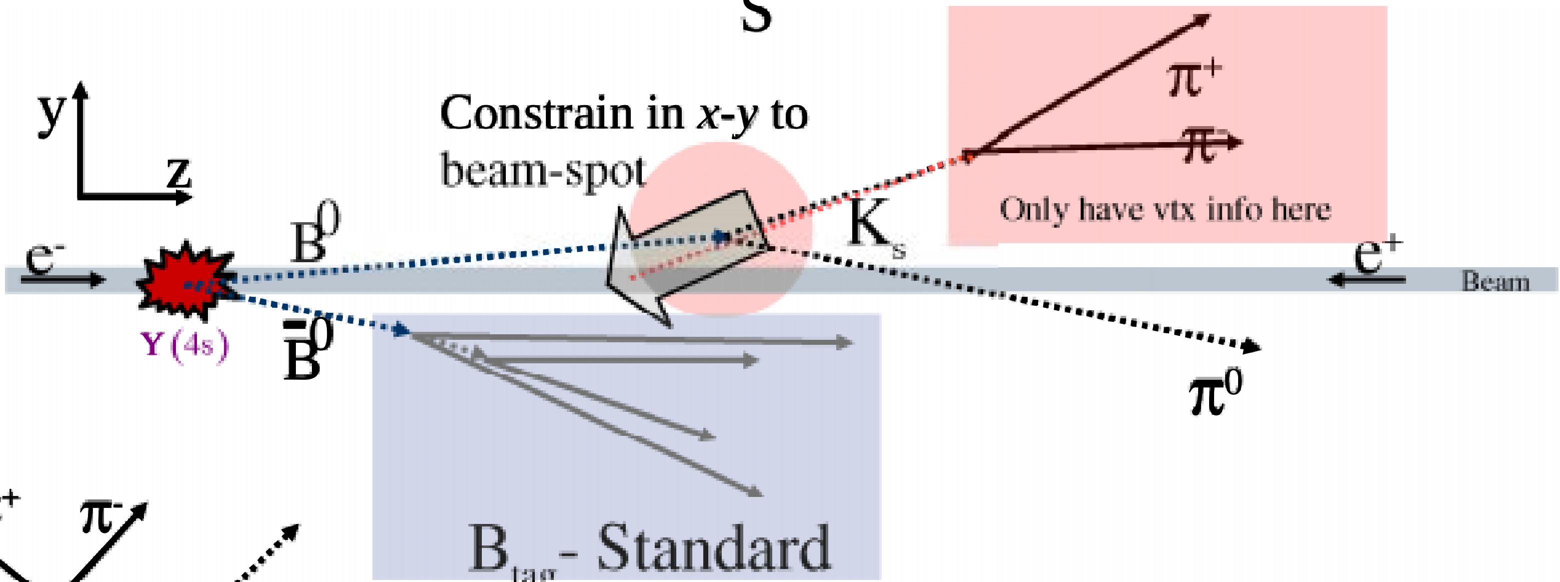
One step simultaneous fit gives yield and CP parameters

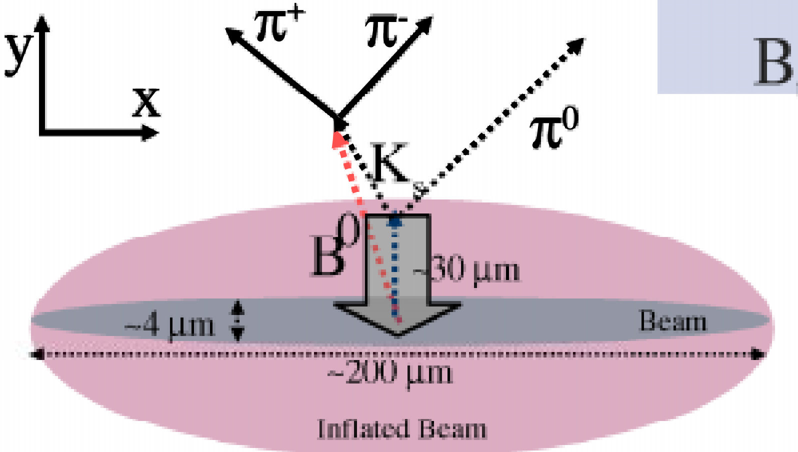
B^+ $\begin{cases} \mathcal{B} = (76.9 \pm 3.5 \pm 4.4) \times 10^{-6} \\ A = 0.037 \pm 0.045 \pm 0.011 \end{cases}$

B^0 $\begin{cases} \mathcal{B} = (60.6 \pm 5.6 \pm 4.6) \times 10^{-6} \\ C = 0.10 \pm 0.22 \pm 0.04 \\ S = 0.02 \pm 0.34 \pm 0.03 \end{cases}$

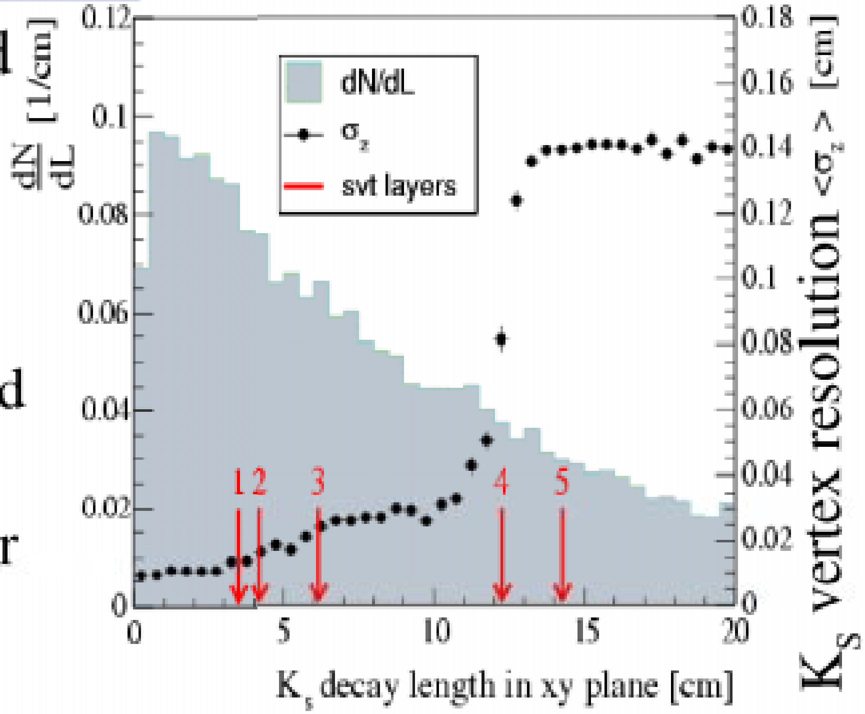
→ $\sin(2\beta)$

$B^0 \rightarrow K_S \pi^0$





B_{tag} - Standard Method



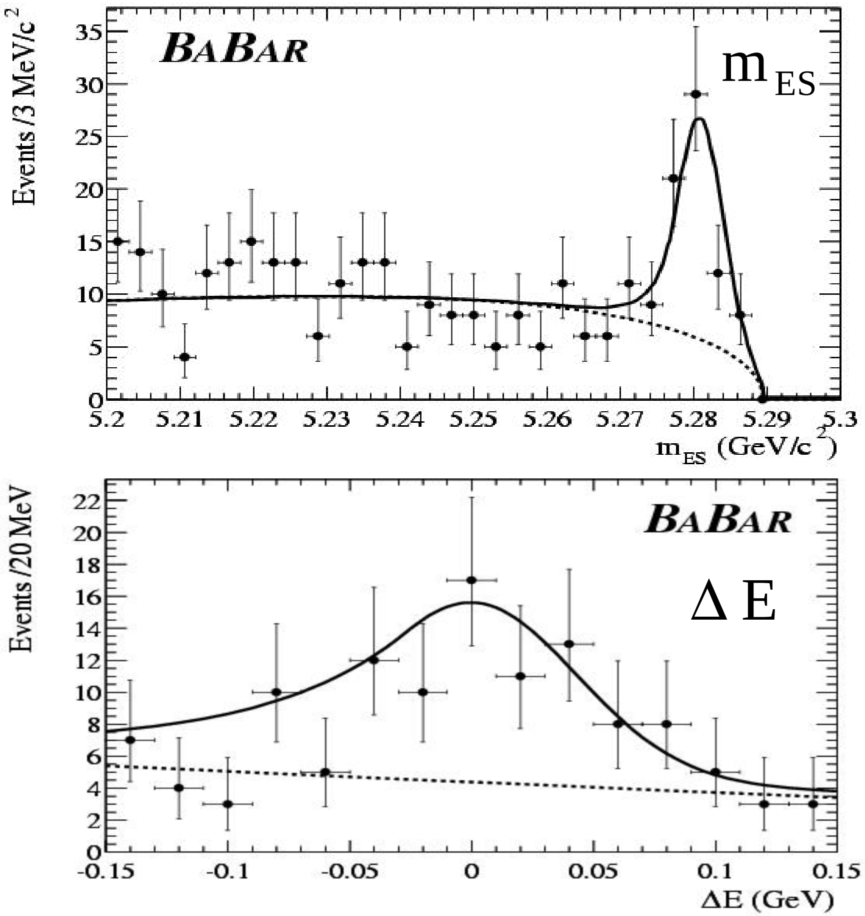
K_S reconstructed with a transverse extended

Beam spot constrained vertex fit

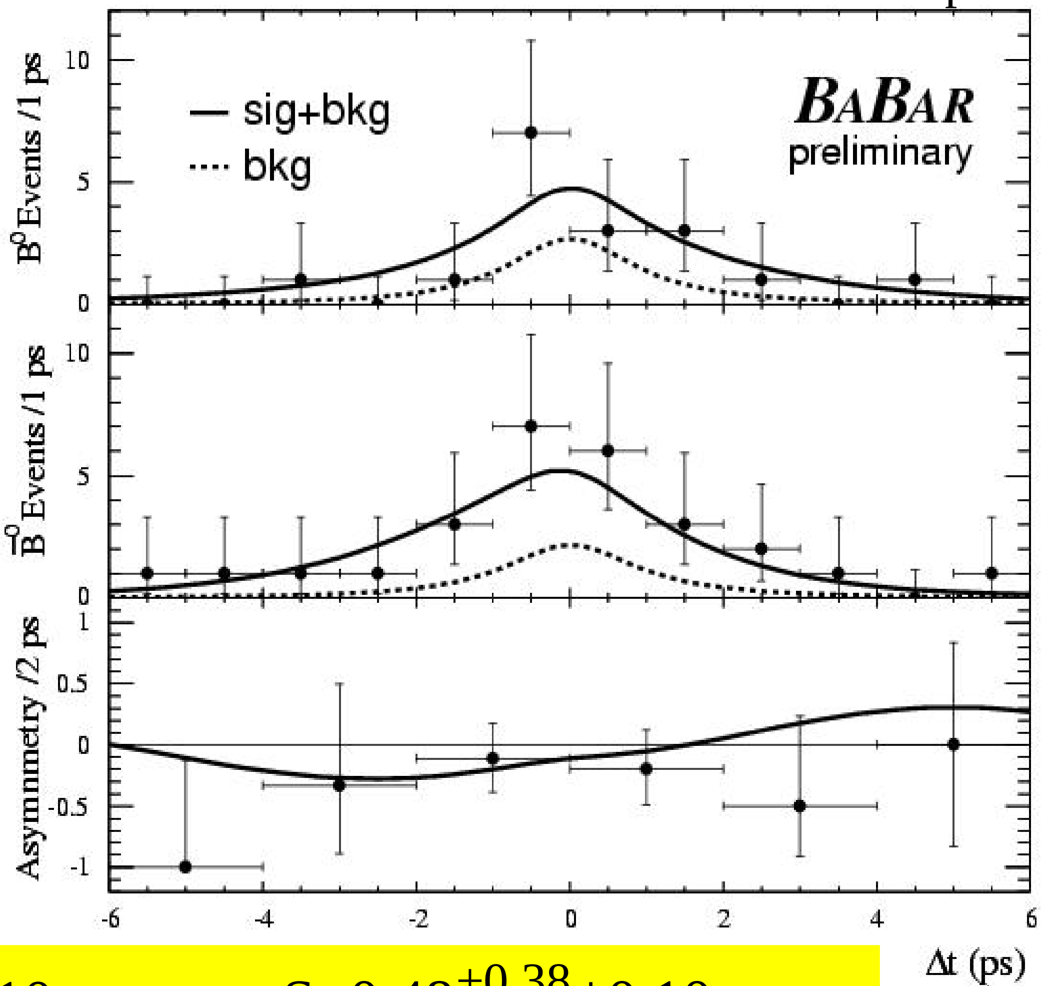
Δz resolution mostly depends on the number of π tracks hits in the SVT

$B^0 \rightarrow J/\Psi K_S$ used as control sample.

$B^0 \to K_S \pi^0$

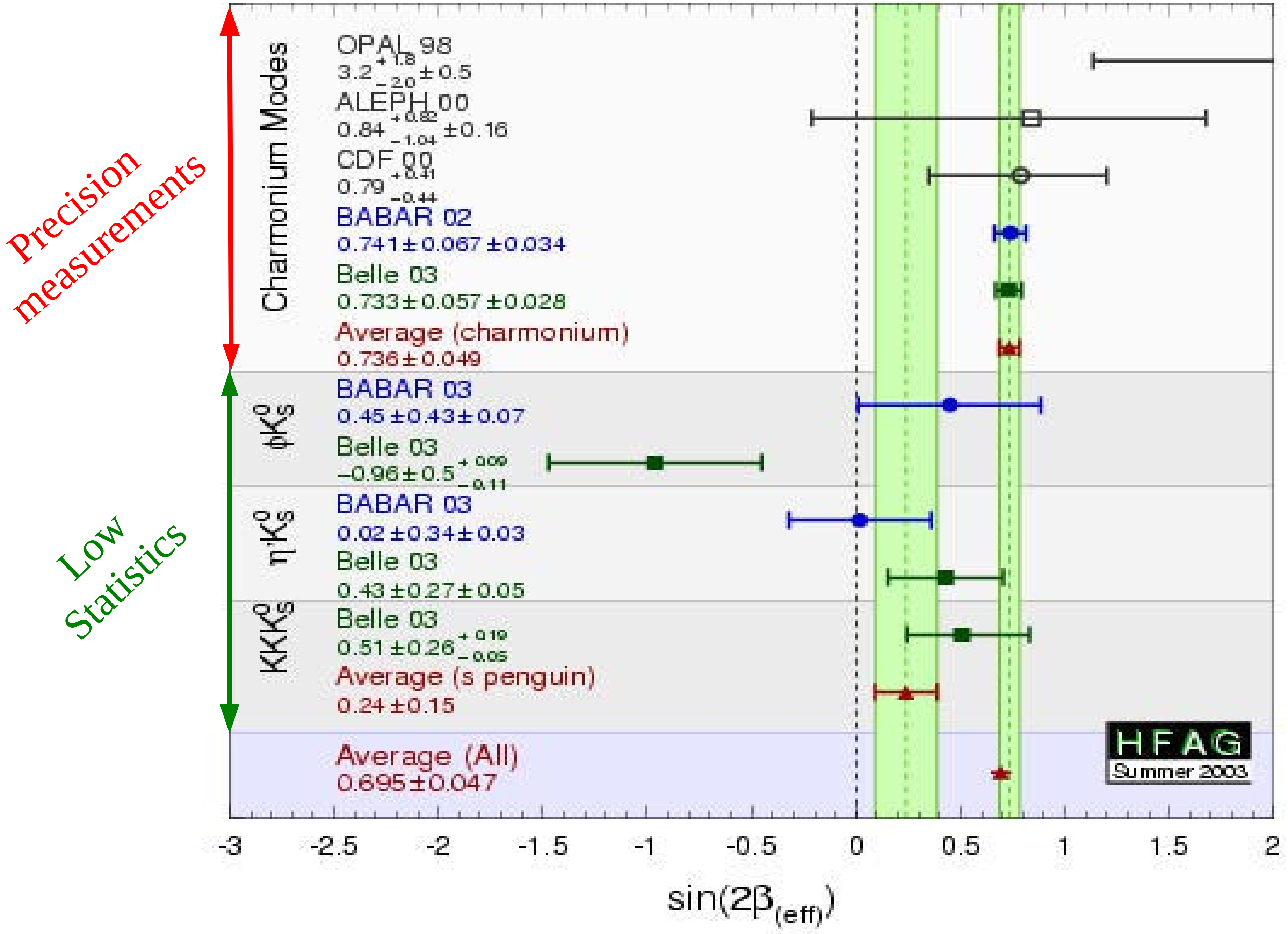


124 million B pairs



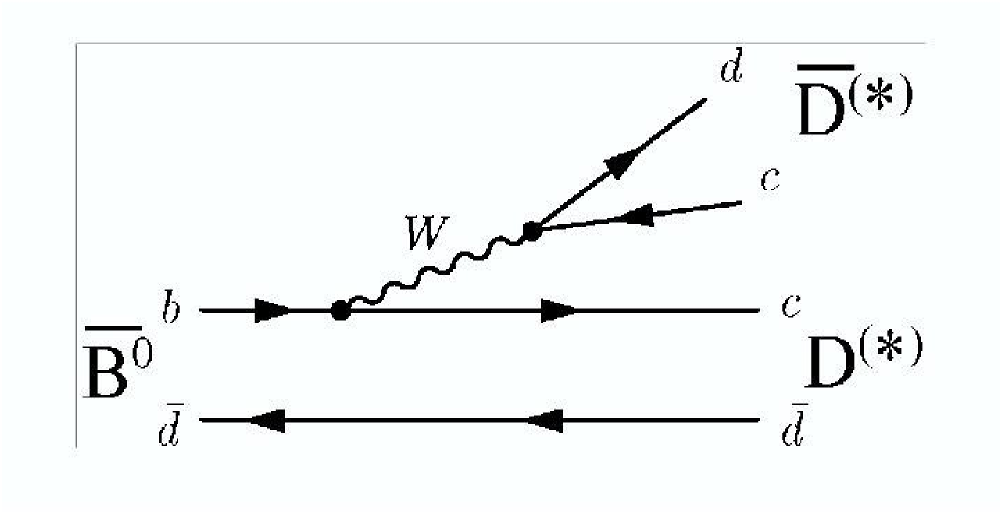
$C = 0.40^{+0.27}_{-0.28} \pm 0.10$ $\qquad$ $S = 0.48^{+0.38}_{-0.47} \pm 0.10$

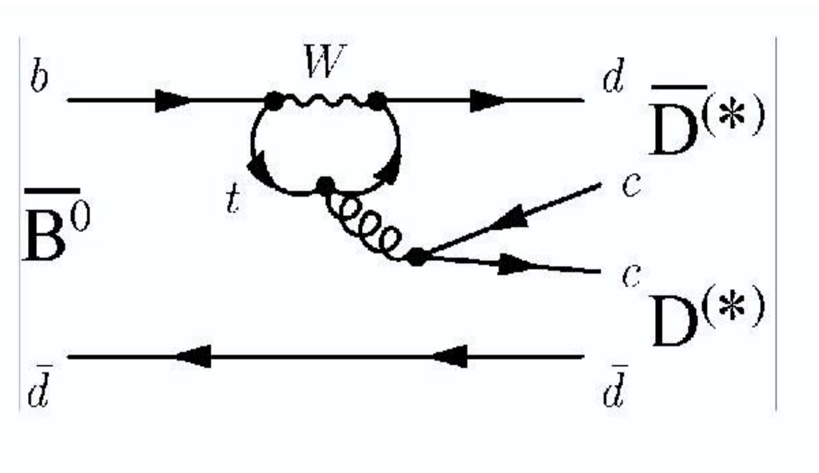
Fixing C=0 gives $\qquad$ $S = \sin(2\beta) = 0.41^{+0.41}_{-0.48} \pm 0.11$


Precision measurements
Low Statistics
Charmonium Modes
OPAL 98
3.2 +1.8 −2.0 ±0.5
ALEPH 00
0.84 +0.82 −1.04 ±0.16
CDF 00
0.79 +0.41 −0.44
BABAR 02
0.741±0.067±0.034
Belle 03
0.733±0.057±0.028
Average (charmonium)
0.736±0.049
φK0S
BABAR 03
0.45±0.43±0.07
Belle 03
−0.96±0.5 +0.09 −0.11
η'K0S
BABAR 03
0.02±0.34±0.03
Belle 03
0.43±0.27±0.05
KKK0S
Belle 03
0.51±0.26 +0.19 −0.05
Average (s penguin)
0.24±0.15
Average (All)
0.695±0.047
HFAG
Summer 2003
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
sin(2β(eff))

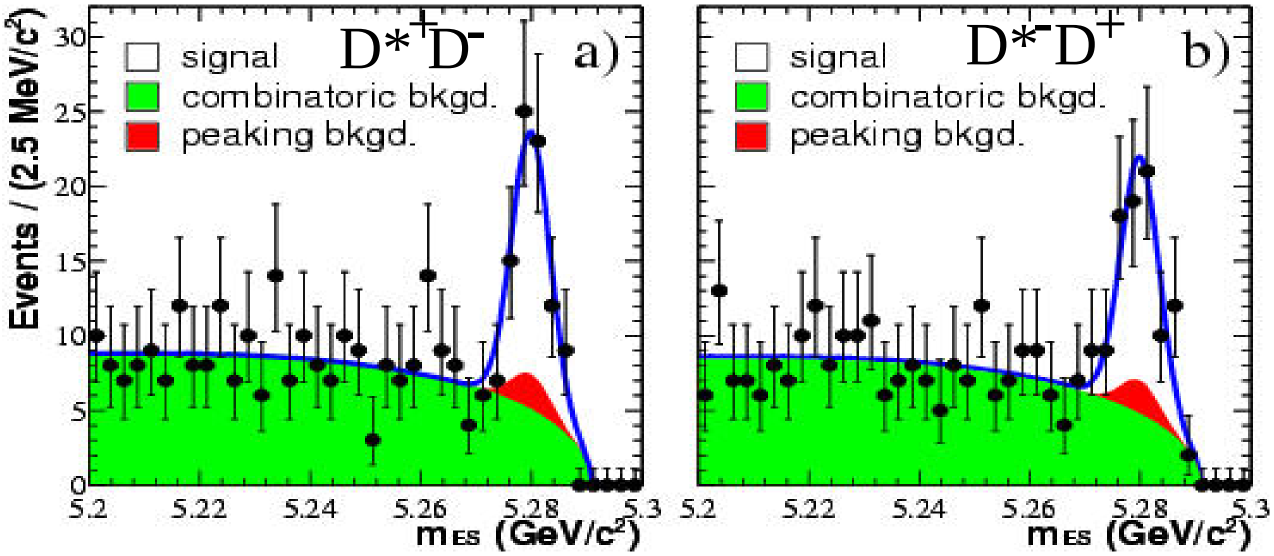
$b \rightarrow c\bar{c}d$

tree with small penguin contamination





$B^0 \rightarrow D^{*\pm} D^{\mp}$



SM penguin contribution to S expected to be small, measures sin(2β)

$\mathcal{B} = (8.8 \pm 1.0 \pm 1.3) \times 10^{-4}$; $A = -0.03 \pm 0.11 \pm 0.05$

D*-D+ $S_{D^{*-}D^{+}} = -0.24 \pm 0.69 \pm 0.12$; $C_{D^{*-}D^{+}} = -0.22 \pm 0.37 \pm 0.10$

D*+D- $S_{D^{*+}D^{-}} = -0.82 \pm 0.75 \pm 0.14$; $C_{D^{*+}D^{-}} = -0.47 \pm 0.40 \pm 0.12$

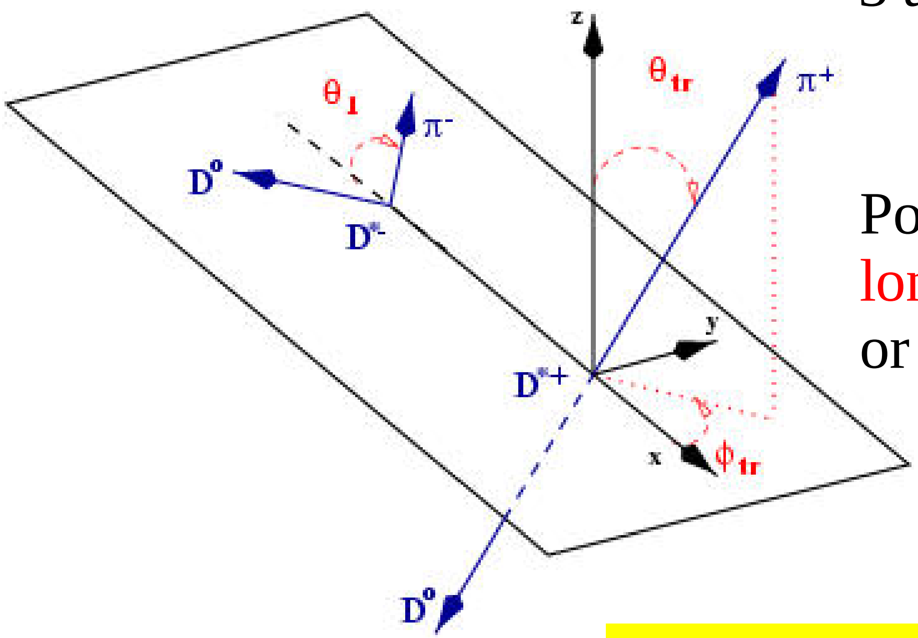
Phys Rev Lett 2003 (90) p221801

88 million B pairs

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

$D^{*+} D^{*-}$ is a mixture of CP even (S+D waves) and CP odd (P wave).

Transversity frame



$\cos(\theta_1), \cos(\theta_{tr}), \cos(\phi_{tr})$ distributions depend on 3 amplitudes: A_0, A_{par}, A_{perp}

Polarization: longitudinal or transverse

CP-even → $\sin(\theta_{tr})$

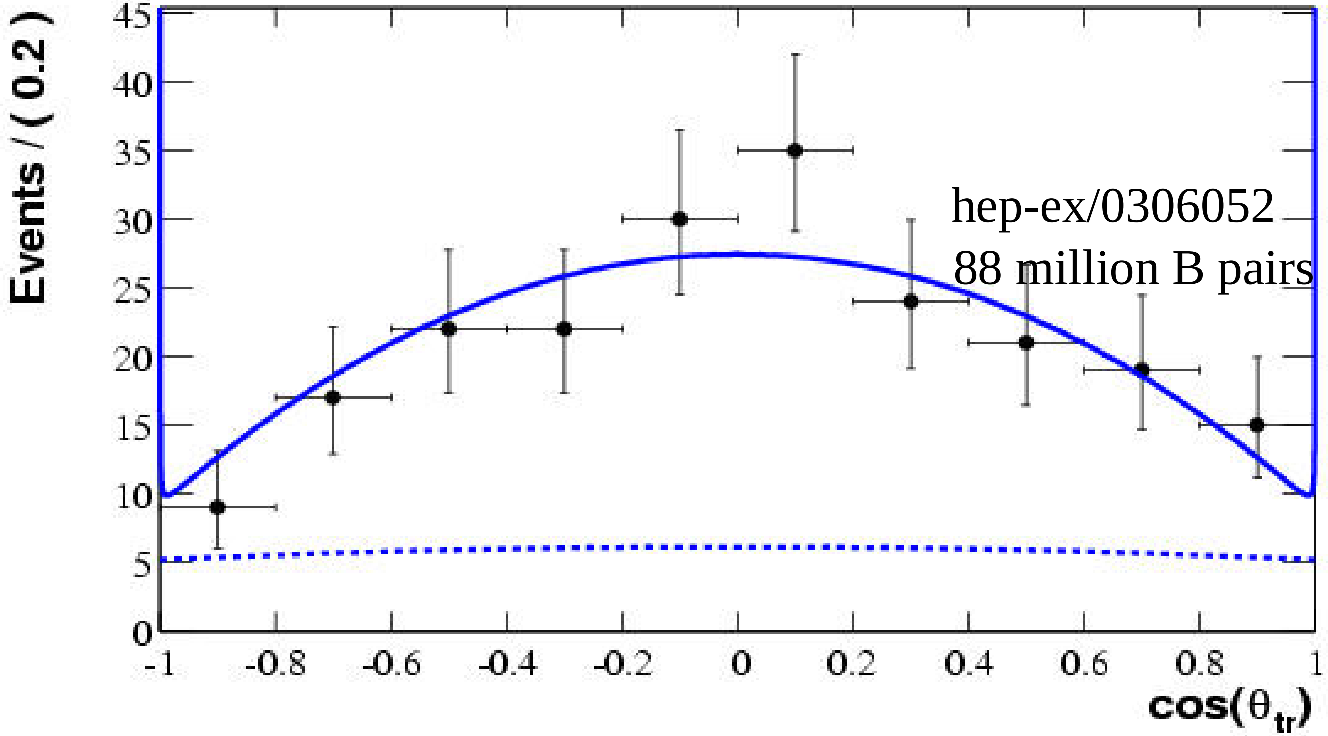
CP-odd → $\cos(\theta_{tr})$

$$R_{perp} = \frac{|A_{perp}|^2}{|A_0|^2 + |A_{par}|^2 + |A_{perp}|^2}$$

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

D*D* pairs reconstructed in $\left(D^0\pi^+, D^0\pi^-\right)\left(D^0\pi^+, D^-\pi^0\right)\left(D^+\pi^0, D^0\pi^-\right)$

time integrated fit on $\cos\left(\theta_{tr}\right)$



$R_{perp} = 0.063 \pm 0.055 \pm 0.009$

$B^0 \rightarrow D^{*+} D^{*-}$ is mostly CP-even (CP=+)

$B^0(t) \rightarrow D^{*+} D^{*-}$

fit on $\cos(\theta_{tr})$
and time distribution

$S_+ = \Im(\lambda_+) = 0.05 \pm 0.29 \pm 0.10$

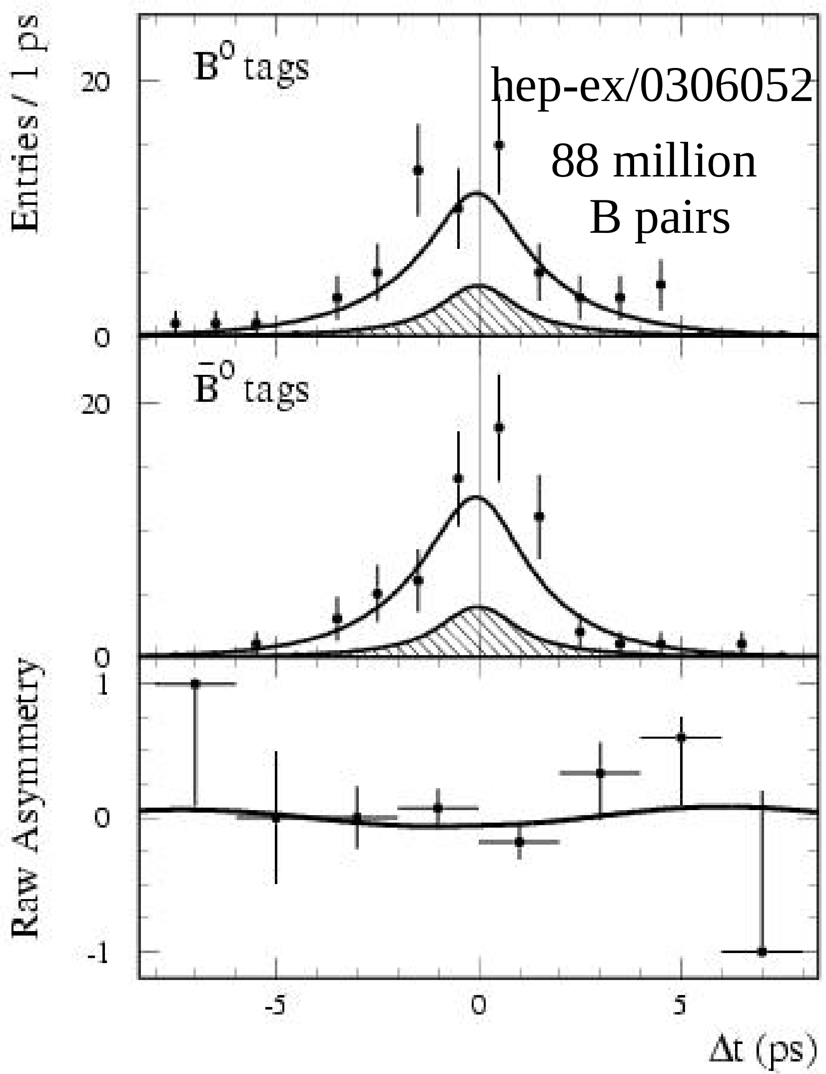
$|\lambda_+| = 0.75 \pm 0.19 \pm 0.02$

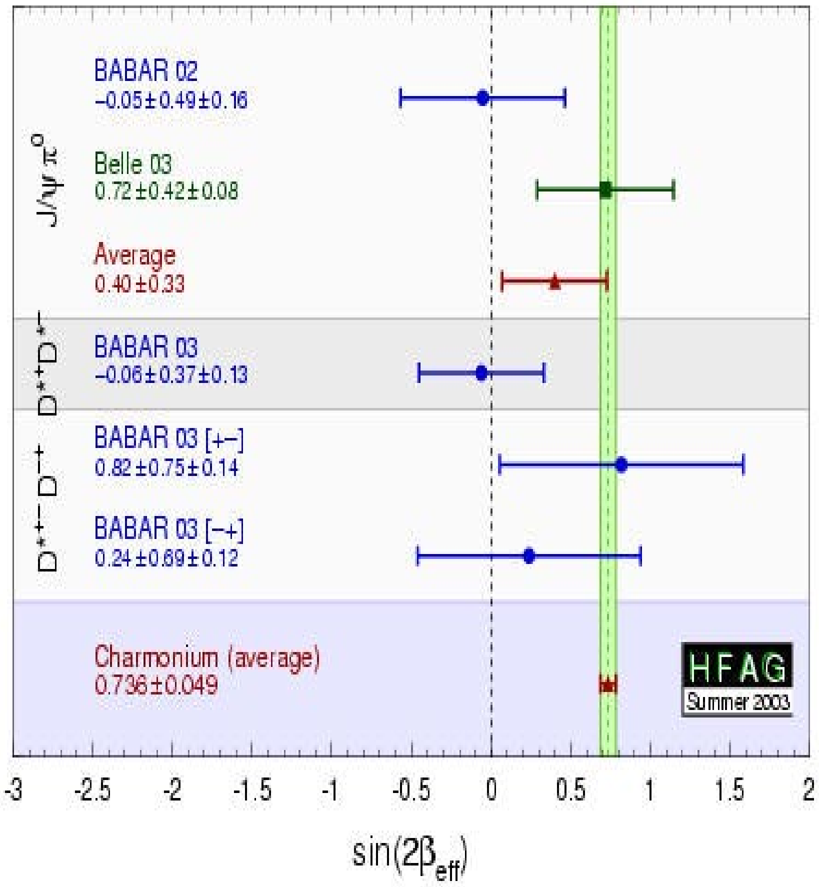
$+ \Leftrightarrow$ CP-even

SM with no penguin: $S_+ = \sin(2\beta)$

$C_+ = 0 \Rightarrow |\lambda_+| = 1$

Refit with this hypothesis
change likelihood by 2.5 σ

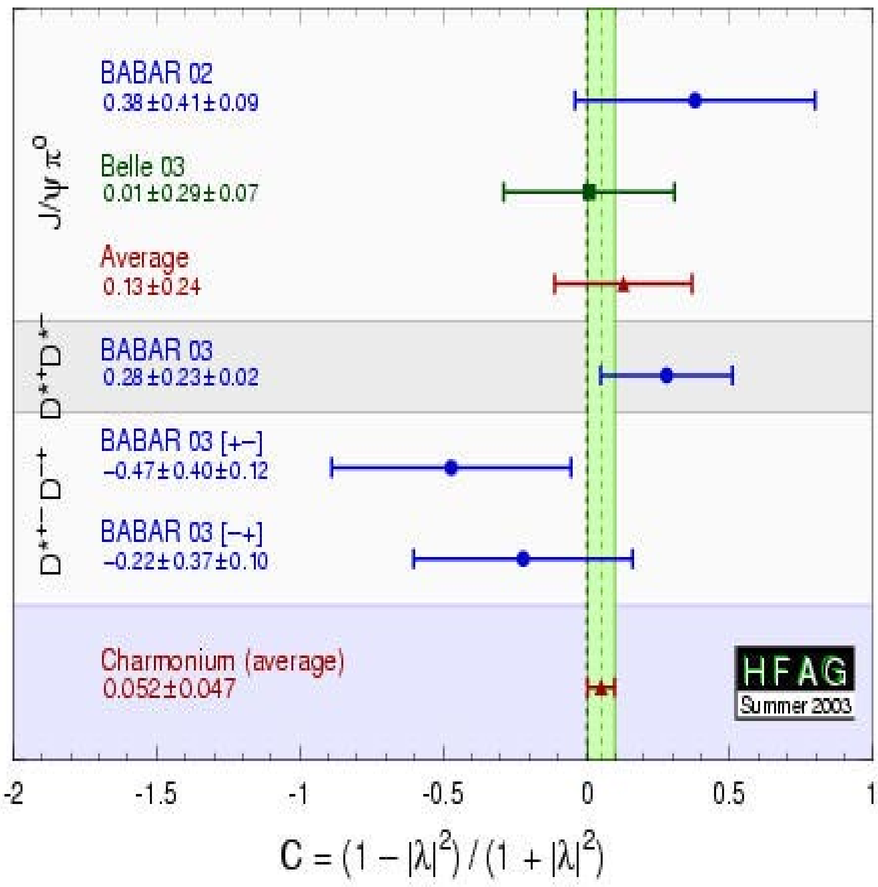



BABAR 02
−0.05±0.49±0.16
Belle 03
0.72±0.42±0.08
Average
0.40±0.33
BABAR 03
−0.06±0.37±0.13
BABAR 03 [+−]
0.82±0.75±0.14
BABAR 03 [−+]
0.24±0.69±0.12
Charmonium (average)
0.736±0.049
HFAG
Summer 2003
$J/\psi\,\pi^0$
$D^{*+}D^{*-}$
$D^{*\pm}D^{\mp}$
$\sin(2\beta_{eff})$

D^*D^*

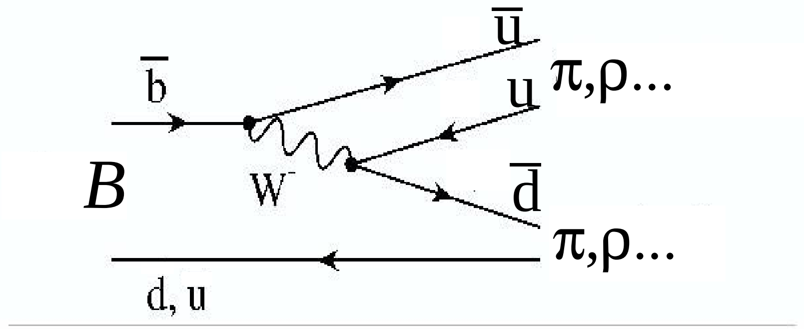
$D^{*+}D^-$

$D^{*-}D^+$


BABAR 02
0.38±0.41±0.09
Belle 03
0.01±0.29±0.07
Average
0.13±0.24
BABAR 03
0.28±0.23±0.02
BABAR 03 [+−]
−0.47±0.40±0.12
BABAR 03 [−+]
−0.22±0.37±0.10
Charmonium (average)
0.052±0.047
HFAG
Summer 2003
$J/\psi\,\pi^0$
$D^{*+}D^{*-}$
$D^{*\pm}D^{\mp}$
$C = (1-|\lambda|^2)/(1+|\lambda|^2)$

$\alpha=\phi_2$

$b \to u + b \to d$

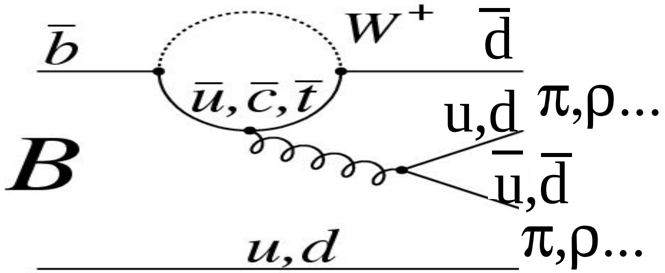


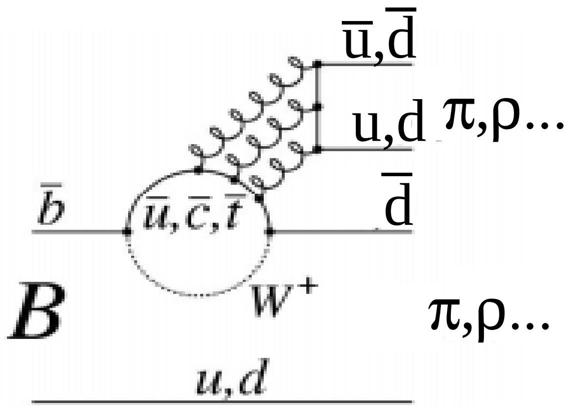
mixture of Tree and Penguin

Only Tree ⇒ C=0 and S=sin(2α)

With penguin:

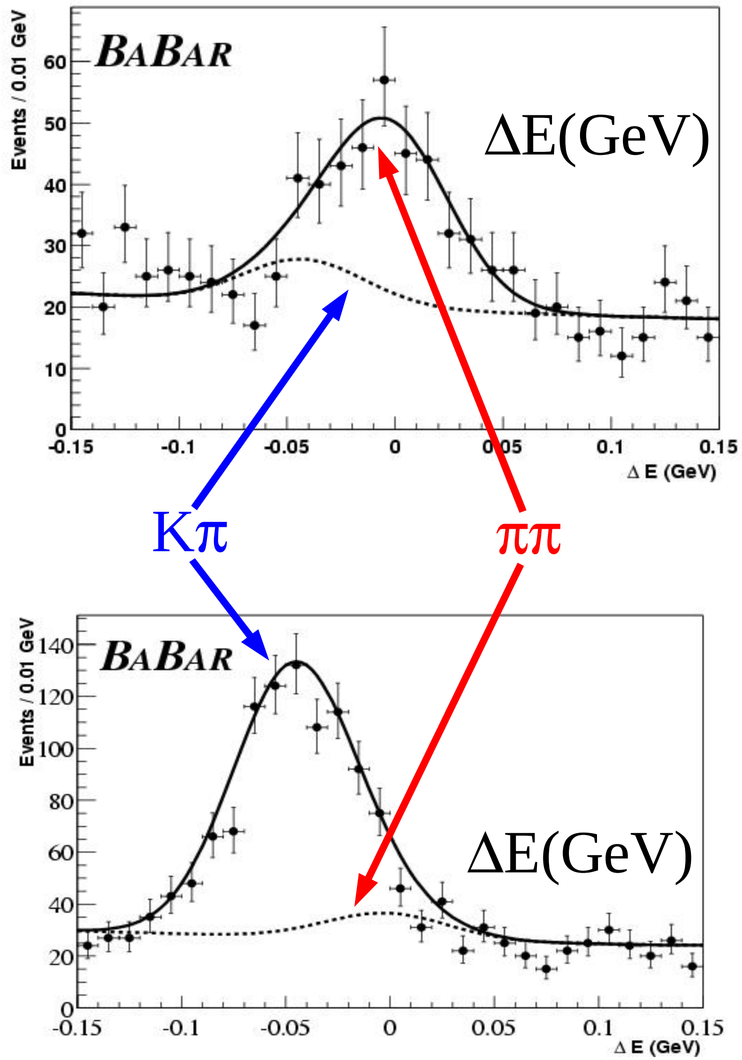
C≠0 and S= $\sqrt{1-C^2}\,\sin(2\alpha_{eff})$





$B^0 \to \pi^+ \pi^-$; $B^0 \to K^\pm \pi^\mp$; $B^0 \to K^+ K^-$

2 steps simultaneous likelihood fits of all channels (π-K mis-Id).



PRL 89, 281802 (2002) 88 million B pairs

$B_{K\pi} = (17.6 \pm 0.9 \pm 0.7) \times 10^{-6}$

$B_{\pi\pi} = (4.7 \pm 0.6 \pm 0.2) \times 10^{-6}$

$B_{KK} < 0.6 \times 10^{-6}$ (90% CL)

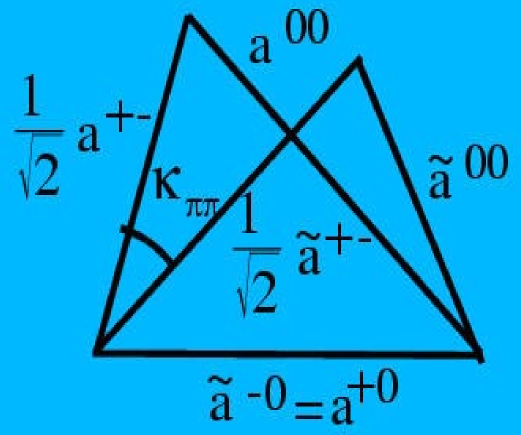
preliminary 124 million B pairs

$A_{K\pi} = -0.107 \pm 0.041 \pm 0.013$

$S_{\pi\pi} = -0.40 \pm 0.22 \pm 0.03$

$C_{\pi\pi} = -0.19 \pm 0.19 \pm 0.05$

$B\to\pi\pi$; $B\to K\pi$; $B\to KK$

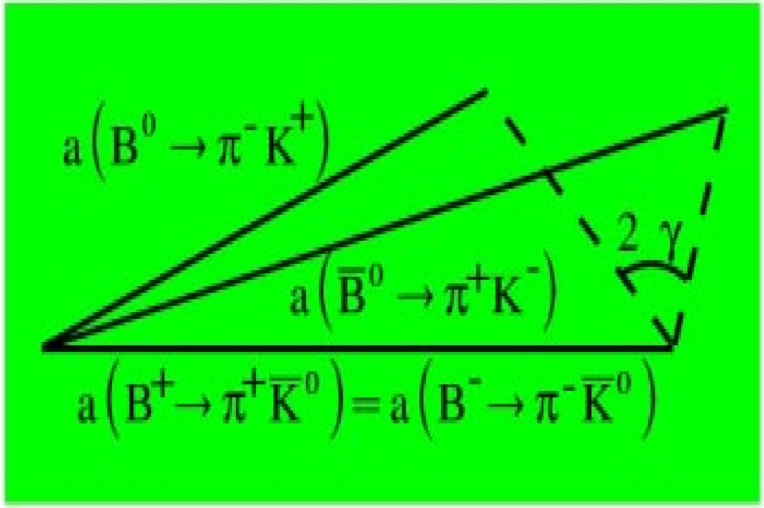


$a^{ij} \equiv a\left(B^{i+j} \to \pi^i \pi^j\right)$

$\tilde{a}^{ij} = e^{2i\phi_T}\,\bar{a}\left(\bar{B}^{i+j} \to \pi^i \pi^j\right)$

ϕ_T Tree weak phase

$S_{\pi^+\pi^-} = \sin\left(2\alpha + \kappa_{\pi\pi}\right)\left|\frac{\tilde{a}^{+-}}{a^{+-}}\right|$



$\pi^0\pi^0$ $B=(2.1 \pm 0.6 \pm 0.3)\times10^{-6}$ — discovery, 124 million B pairs, hep-ex/0308012

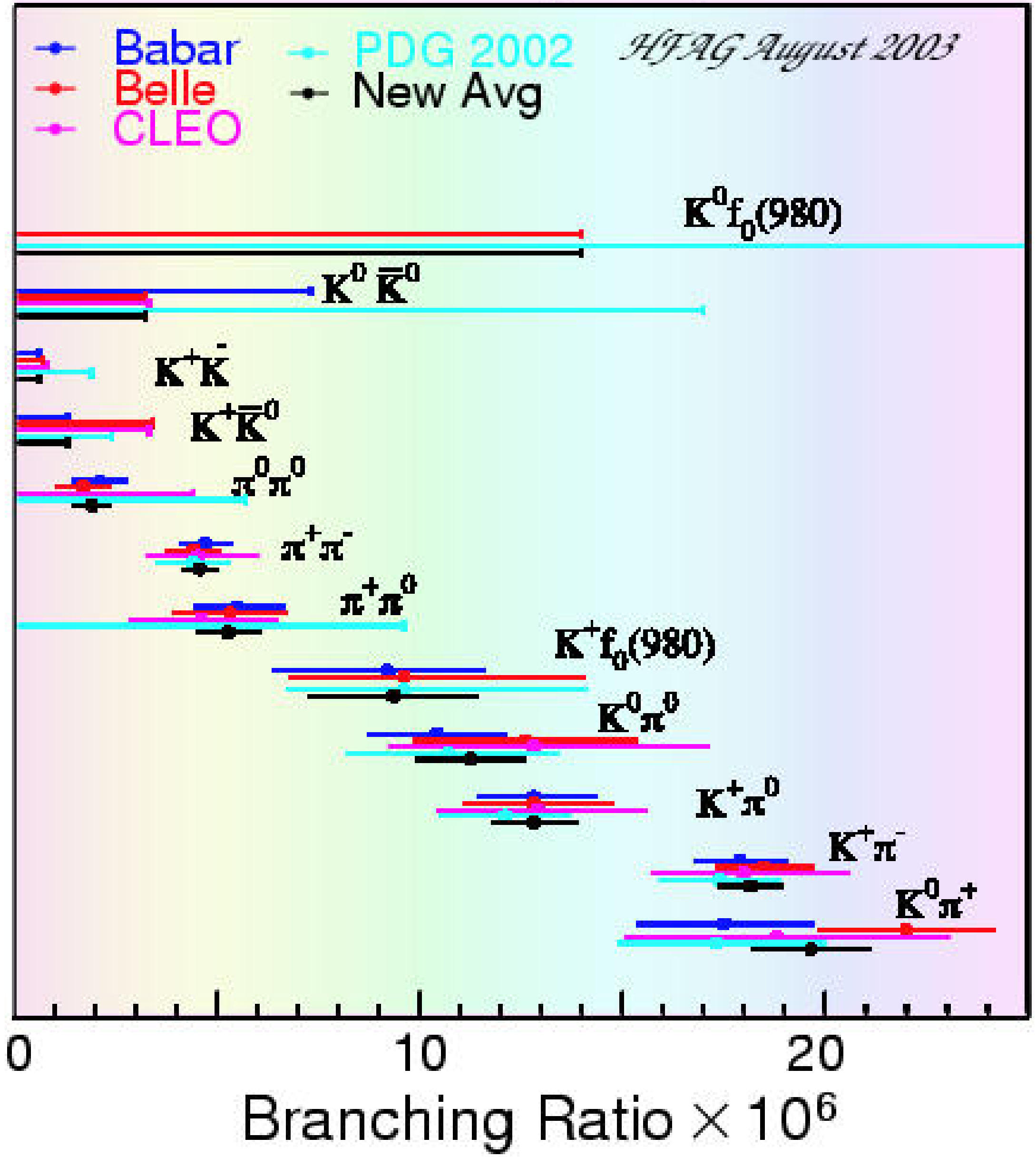
$K^+\pi^0$ $B=(12.8^{+1.2}_{-1.1} \pm 1.0)\times10^{-6}$, A= -0.09 ±0.09 ±0.01

$\pi^+\pi^0$ $B=(5.5^{+1.0}_{-0.9} \pm 0.6)\times10^{-6}$, A= $-0.03^{+0.18}_{-0.17} \pm 0.02$

88 million B pairs
hep-ex/0303028

$K^0\pi^+$ $B=(22.3 \pm 1.7 \pm 1.1)\times10^{-6}$ — 88 million B pairs, preliminary

B → Kπ, ππ, KK



Babar
Belle
CLEO
PDG 2002
New Avg
HFAG August 2003
K0f0(980)
K0 K̄0
K+K-
K+K̄0
π0π0
π+π-
π+π0
K+f0(980)
K0π0
K+π0
K+π-
K0π+
0
10
20
Branching Ratio × 10^6

$B^0 \rightarrow \rho^{\pm}\pi^{\mp};\ B^0 \rightarrow \rho^{\pm}K^{\mp}$

not CP eigenstate

$$f_{\rho\pi} = (1 \pm A_{\rho\pi})\, e^{-\frac{|\Delta t|}{\tau}} \times \left[1 \pm (S_{\rho\pi} \pm \Delta S_{\rho\pi}) \sin(\Delta m_B \Delta t) - (C_{\rho\pi} \pm \Delta C_{\rho\pi}) \cos(\Delta m_B \Delta t)\right]$$

A : flavor independent direct CPV

+ for B
− for $\overline{B}$

CKM asymmetry

Strong phase difference

ρ charge

flavor dependent direct CPV

Non CPV asymmetry

$$S_{\rho\pi} \pm \Delta S_{\rho\pi} = \sqrt{1 - (C_{\rho\pi} \pm \Delta C_{\rho\pi})^2}\, \sin(2\alpha_{eff} \pm \delta)$$

Summing over the charge : $A_{\rho\pi}(t) = S_{\rho\pi} \sin(\Delta m_B \Delta t) - C_{\rho\pi} \cos(\Delta m_B \Delta t)$

$B^0 \to \rho^{\pm}\pi^{\mp}$; $B^0 \to \rho^{\pm}K^{\mp}$

Simultaneous fit for yield and CP parameters

124 million B pairs
preliminary

$\rho\pi$

$\mathcal{B}$= $(22.6 \pm 1.8 \pm 2.2)\mathrm{x}10^{-6}$

A= $-0.114 \pm 0.062 \pm 0.027$

C= $0.35 \pm 0.18 \pm 0.05$

S= $-0.13 \pm 0.18 \pm 0.04$

ΔC = $0.20 \pm 0.13 \pm 0.05$

ΔS = $0.33 \pm 0.18 \pm 0.05$

ρK

$\mathcal{B}$= $(7.3^{+1.3}_{-1.2} \pm 1.3)\mathrm{x}10^{-6}$

A= $0.18 \pm 0.12 \pm 0.08$

$B^0 \to \rho^\pm \pi^\mp$; $B^0 \to \rho^\pm K^\mp$

Define asymmetries:

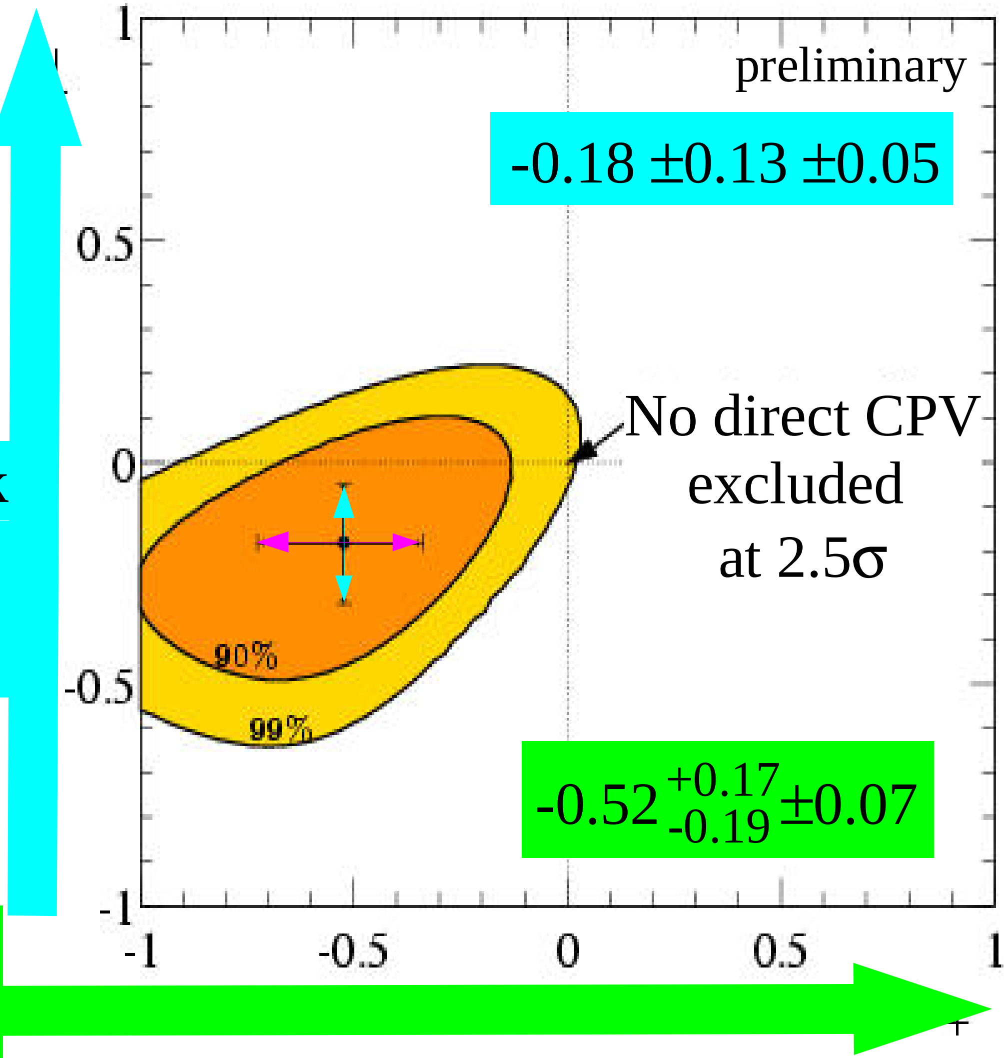
$$A_{ij} = \frac{N(\overline{B} \to \rho^j \pi^i) - N(B \to \rho^i \pi^j)}{N(\overline{B} \to \rho^j \pi^i) + N(B \to \rho^i \pi^j)}$$

Asymmetry for ρ from spectator quark

$$A_{+-} = \frac{A_{\rho\pi} + C_{\rho\pi} + A_{\rho\pi} C_{\rho\pi}}{A_{\rho\pi} + \Delta C_{\rho\pi} + A_{\rho\pi} C_{\rho\pi}}$$

Asymmetry for ρ from W

$$A_{-+} = \frac{A_{\rho\pi} - C_{\rho\pi} - A_{\rho\pi} C_{\rho\pi}}{A_{\rho\pi} - \Delta C_{\rho\pi} - A_{\rho\pi} C_{\rho\pi}}$$



charmless $B \to VV$

mode	$\mathcal{B}$ x10^{-6}	A
$B^+ \to \phi K^{*+}$	$12.7^{+2.2}_{-2.0} \pm 1.1$	$0.16 \pm 0.17 \pm 0.03$
$B^0 \to \phi K^{*0}$	$11.2 \pm 1.3 \pm 0.8$	$0.04 \pm 0.12 \pm 0.02$
$B^+ \to \rho^0 K^{*+}$	$10.6^{+3.0}_{-2.6} \pm 2.4$	$0.20^{+0.32}_{-0.29} \pm 0.04$
$B^+ \to \rho^0 \rho^+$	$22.5^{+5.7}_{-5.4} \pm 5.8$	$-0.19 \pm 0.23 \pm 0.03$
$B^0 \to \rho^0 \rho^0$	< 2.1 at 90% CL	
$B^0 \to \rho^+ \rho^-$	$25\ ^{+7+5}_{-8-8}$	

88 million B pairs
hep-ex/0307026

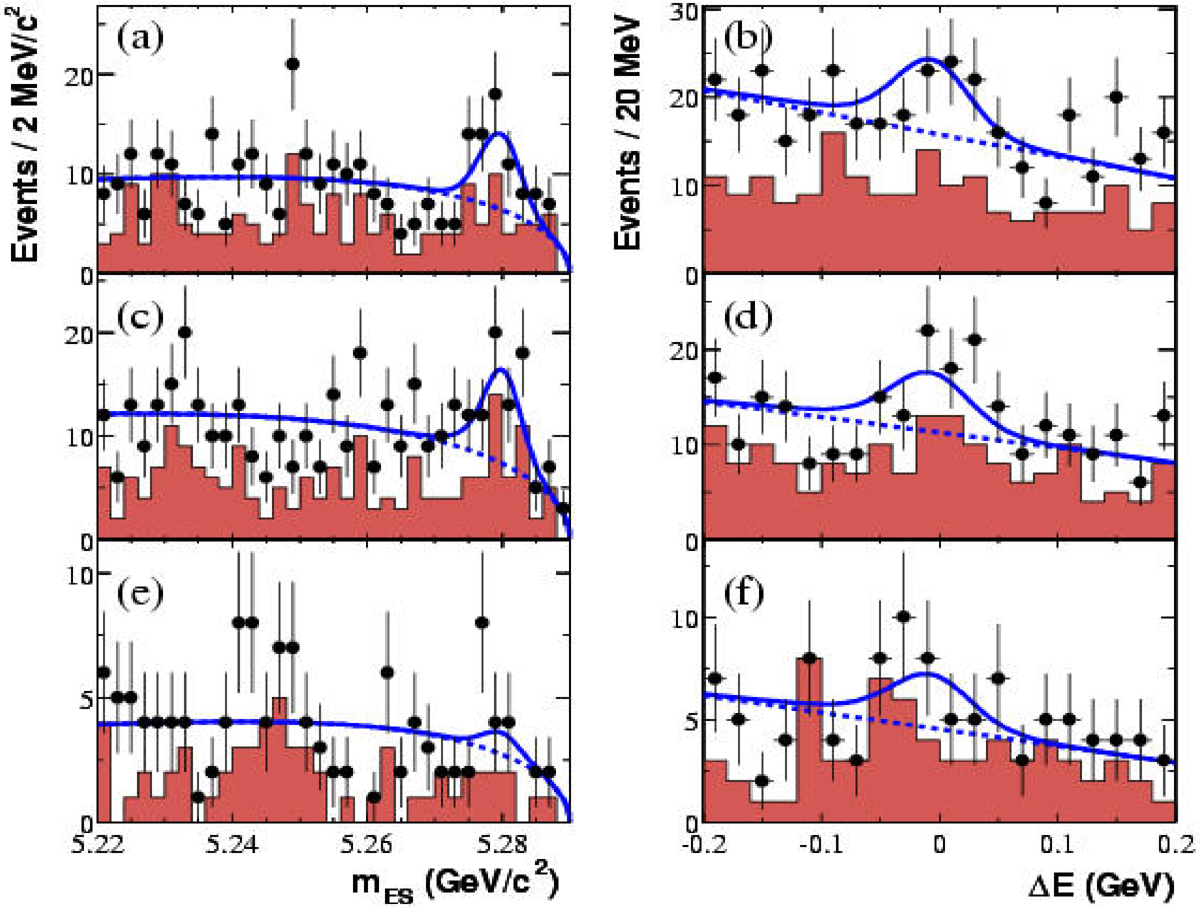
preliminary hep-ex/0308024
88 million B pairs

$\rho^+ \rho^-$ fraction of longitudinal polarization = $0.98^{+0.02}_{-0.08} \pm 0.03$

$\Rightarrow$is mostly CP-even

$B \to \eta K; B \to \eta \pi$

Large direct CPV theoretically possible:



$B^+ \to \eta \pi^+$

$B=(4.2^{+1.0}_{-0.9}\pm 0.3)\times 10^{-6}$

$A=-0.51^{+0.20}_{-0.18}\pm 0.01$

$B^+ \to \eta K^+$

$B=(2.8^{+0.8}_{-0.7}\pm 0.2)\times 10^{-6}$

$A=-0.32^{+0.22}_{-0.18}\pm 0.01$

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

$B<4.6\times 10^{-6}$ at 90% CL

88 million B pairs   hep-ex/0303039

$B \to \eta K^*$; $B \to \eta' K^*$; $B \to \eta \rho$; $B \to \eta' \rho$; $B \to \eta \pi$

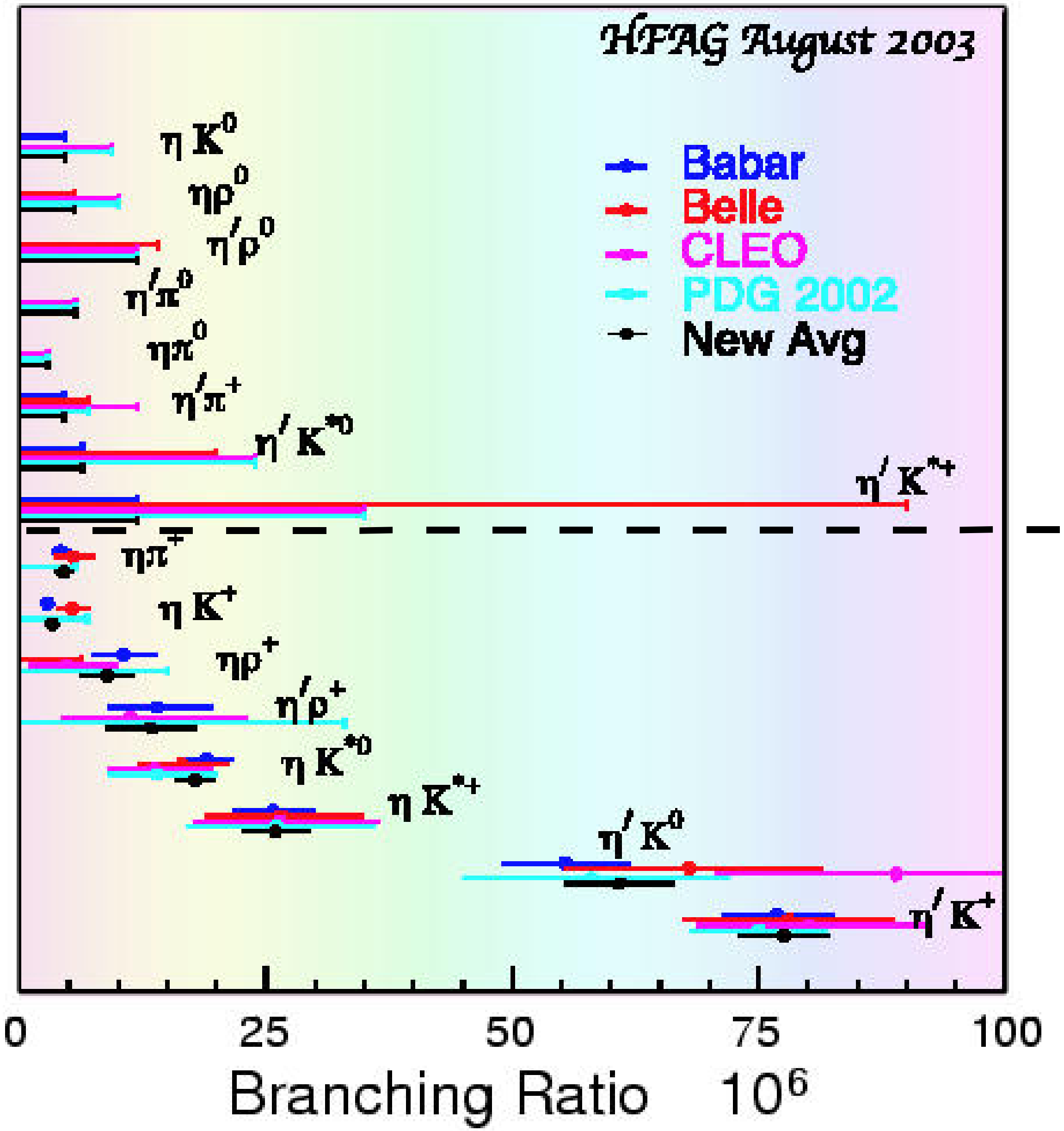
mode	$\mathcal{B} \times 10^{-6}$	A
$B^0 \to \eta K^{*0}$	$19.0^{+2.2}_{-2.1} \pm 1.3$	$0.03 \pm 0.11 \pm 0.02$
$B^+ \to \eta K^{*+}$	$25.7^{+3.8}_{-3.6} \pm 1.8$	$0.15 \pm 0.14 \pm 0.02$
$B^+ \to \eta \rho^+$	$10.5^{+3.1}_{-2.8} \pm 1.3$	$0.06 \pm 0.29 \pm 0.02$
$B^0 \to \eta' \pi^+$	< 4.5	
$B^0 \to \eta' K^{*0}$	< 6.4	90 % CL
$B^+ \to \eta' K^{*+}$	< 12	
$B^+ \to \eta' \rho^+$	< 22	

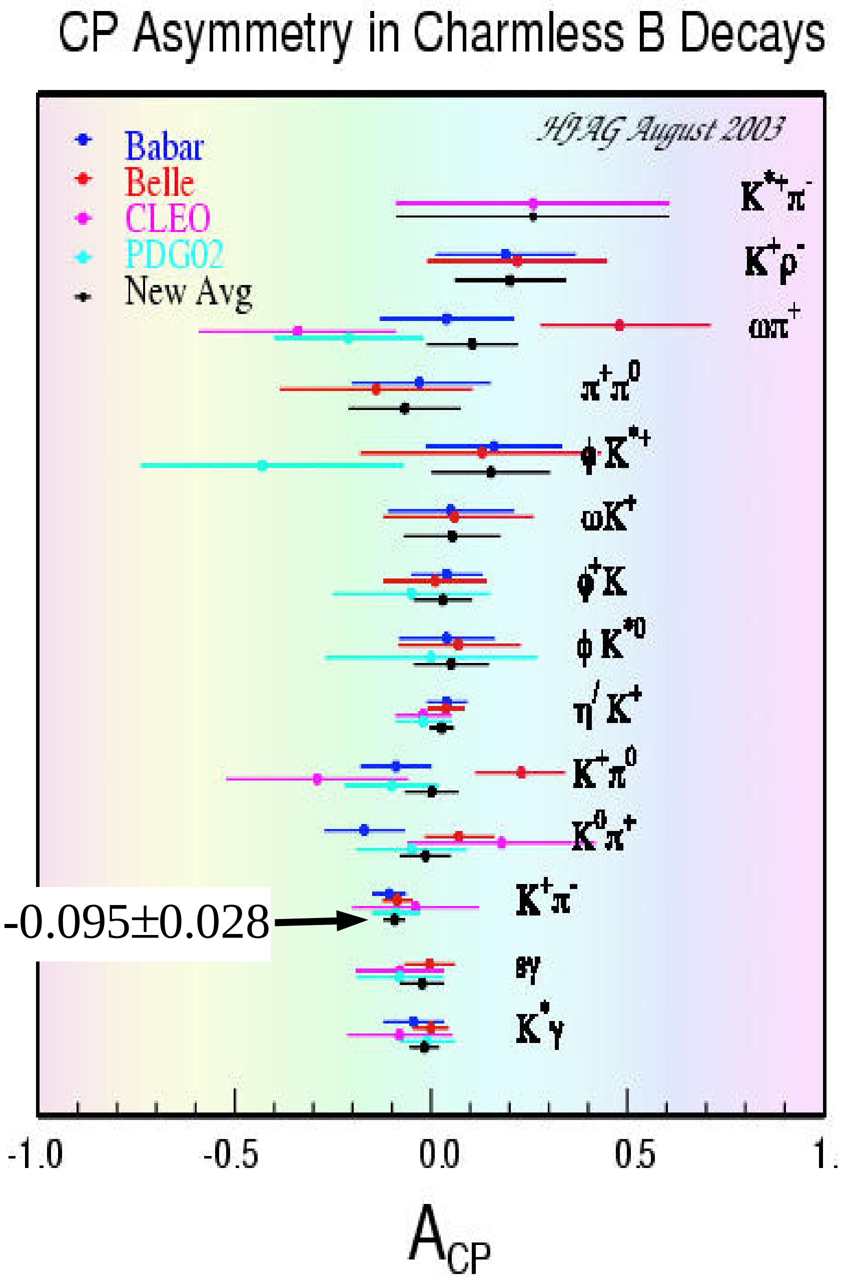
hep-ex/0308015
88 million B pairs

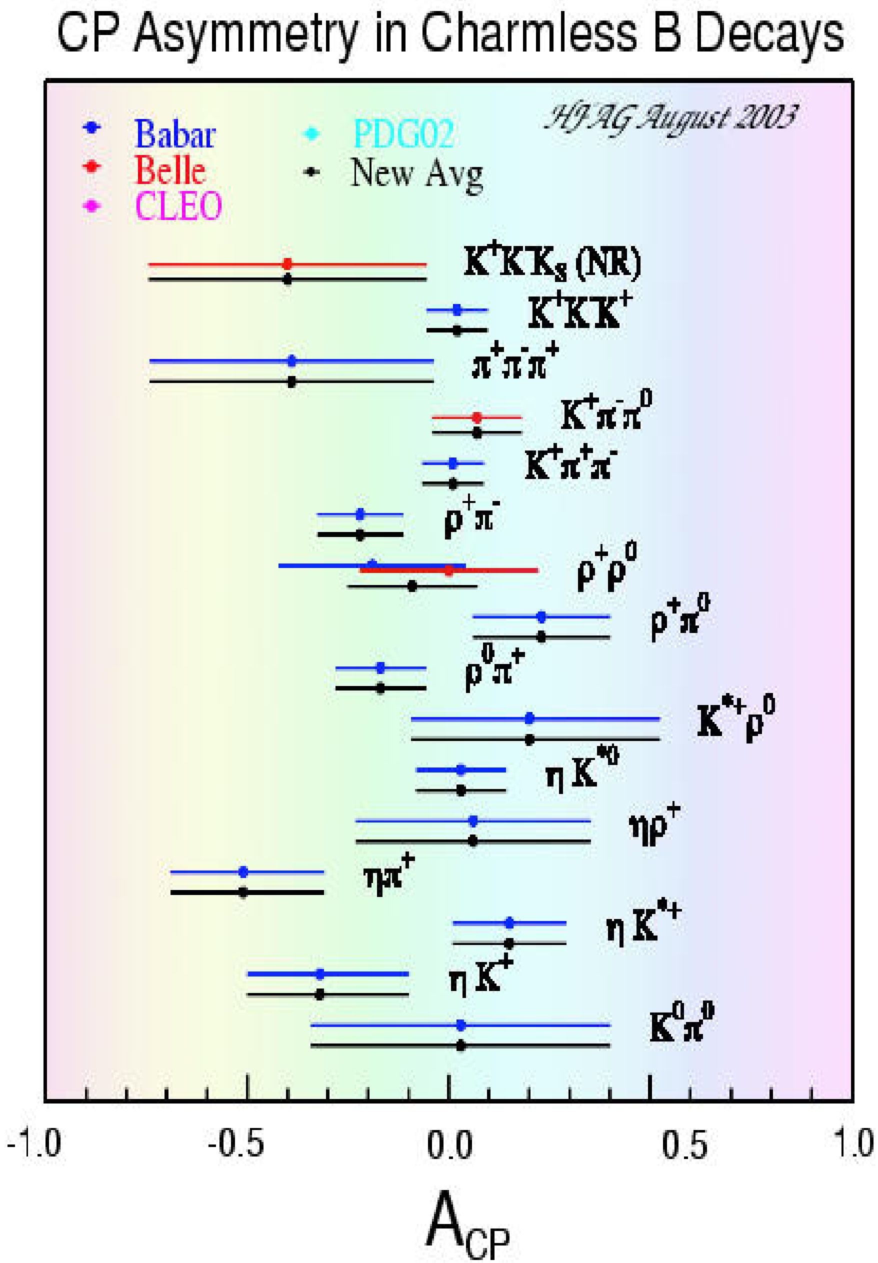
$B \rightarrow (\eta, \eta')(K^{(*)}, \pi, \rho)$

90% CL
Upper
Limits

Branching
Ratios
Measurements




CP Asymmetry in Charmless B Decays
HFAG August 2003
Babar
Belle
CLEO
PDG02
New Avg
$K^{*+}\pi^-$
$K^+\rho^-$
$\omega\pi^+$
$\pi^+\pi^0$
ϕK^{*+}
ωK^+
$\phi^+ K$
ϕK^{*0}
$\eta' K^+$
$K^+\pi^0$
$K^0\pi^+$
$K^+\pi^-$
-0.095±0.028
$s\gamma$
$K^*\gamma$
-1.0
-0.5
0.0
0.5
1.
A_{CP}

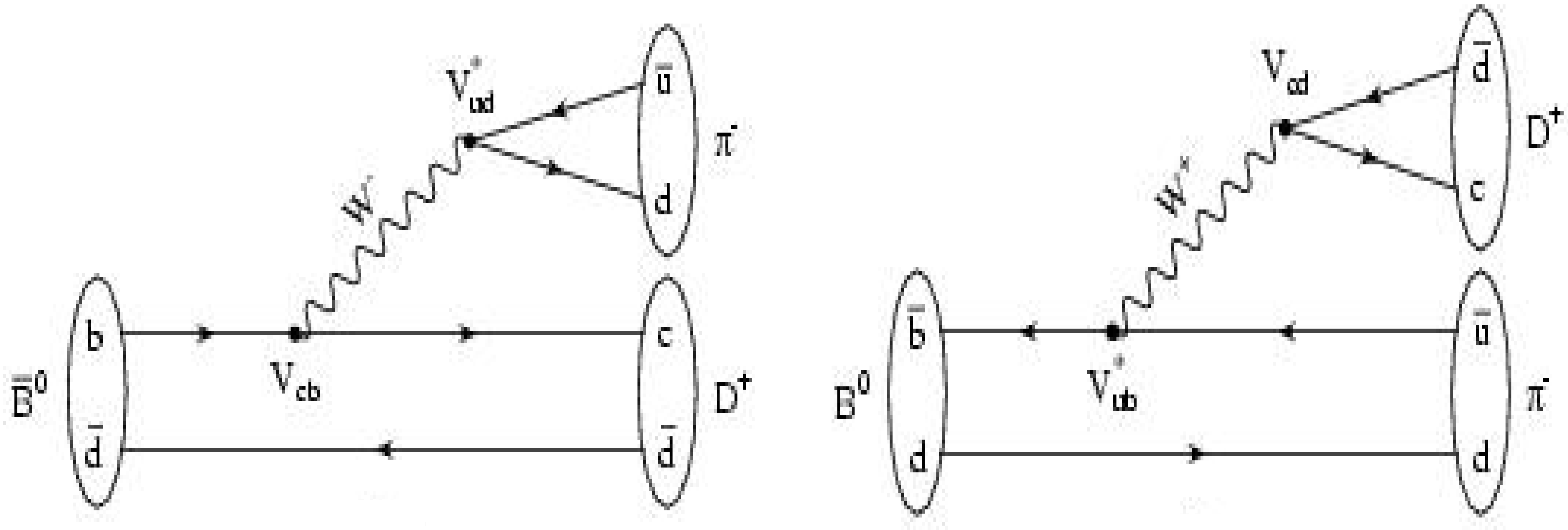

CP Asymmetry in Charmless B Decays
HFAG August 2003
Babar
Belle
CLEO
PDG02
New Avg
$K^+K^-K_s$ (NR)
K^+KK^+
$\pi^+\pi^-\pi^+$
$K^+\pi^-\pi^0$
$K^+\pi^+\pi^-$
$\rho^+\pi^-$
$\rho^+\rho^0$
$\rho^+\pi^0$
$\rho^0\pi^+$
$K^{*+}\rho^0$
ηK^{*0}
$\eta\rho^+$
$\eta\pi^+$
ηK^{*+}
ηK^+
$K^0\pi^0$
-1.0
-0.5
0.0
0.5
1.0
A_{CP}

$\gamma = \phi_3$

Interferences between

$b \to c$ and $b \to u$

sensitive to γ



$B^{\pm} \rightarrow D\,K^{\pm}$

interference between $B^- \rightarrow \overline{D}^0 K^-$ and $B^- \rightarrow D^0 K^-$

define:

$$R_X = \frac{\mathcal{B}(B^- \rightarrow D_X^0 K^-) + \mathcal{B}(B^+ \rightarrow \overline{D}_X^0 K^+)}{\mathcal{B}(B^- \rightarrow D_X^0 \pi^-) + \mathcal{B}(B^+ \rightarrow \overline{D}_X^0 \pi^+)} \equiv \begin{pmatrix} R \text{ for non-CP D decays} \\ R_+ \text{ for CP-even D decays} \\ R_- \text{ for CP-odd D decays} \end{pmatrix}$$

extract γ:

relative strong phase

$$\frac{R_\pm}{R} = 1 + r^2 \pm 2r\cos(\delta)\cos(\gamma)$$

$\overline{D}K^-/DK^-$ amplitude ratios

$$\frac{A_\pm R_\pm}{R} = \pm 2\,r\sin(\delta)\sin(\gamma)$$

Asymmetry

first step measurements:

$$\frac{\mathcal{B}(B^- \rightarrow D^0 K^-)}{\mathcal{B}(B^- \rightarrow D^0 \pi^-)} = 0.083 \pm 0.035 \pm 0.020$$

$R_+ = 0.088 \pm 0.016 \pm 0.005$

$A_+ = 0.07 \pm 0.17 \pm 0.06$

preliminary
88 million
B pairs

$B^0(t) \to D^{(*)\pm}\pi^{\mp}$

for $D^-\pi^+$, $A_+ = S_+ \sin(\Delta m_B \Delta t) - C\cos(\Delta m_B \Delta t)$

for $D^+\pi^-$, $A_- = S_- \sin(\Delta m_B \Delta t) + C\cos(\Delta m_B \Delta t)$

B flavor with lepton tag

$$r = \frac{\left|A\left(\overline{B}^0 \to D^-\pi^+\right)\right|}{\left|A\left(\overline{B}^0 \to D^+\pi^-\right)\right|} \quad \text{small}$$

$C \approx 1$

$S_\pm \approx \underbrace{2r\sin(2\beta+\gamma)\cos(\delta)}_{a} \pm \underbrace{2r\cos(2\beta+\gamma)\sin(\delta)}_{c}$

For hadronic tag, b→c + b→u interference in the flavor tag decay: r' δ'

$c \to c_i = c_{lep} - 2r_i'\cos(2\beta+\gamma)\sin(\delta_i')$ tag dependent

The sin term in the amplitude
has a CP-B independent term:

$b_i = 2r_i'\sin(2\beta+\gamma)\cos(\delta_i')$

Parameters for D : a , b, c, r ,δ
Parameters for D*: a*, b, c*,r*,δ*

$B^0(t) \to D^{*\pm}\pi^{\mp}$

$$B^0 \to D^{*\pm}(\to D^0 \pi^{\pm}_{soft})\pi^{\mp}_{hard}$$

Not reconstructed

hep-ex/0307036
hep-ex/0310037
82 million B pairs

Lepton tag

$S^*_+ = -0.078 \pm 0.052 \pm 0.021$

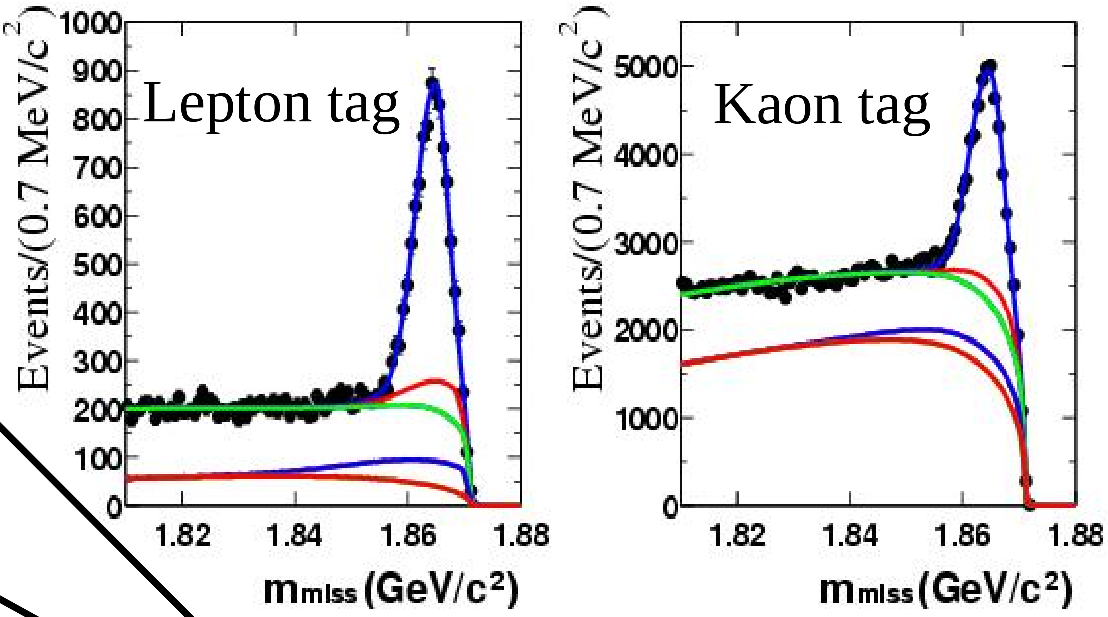
$S^*_- = -0.070 \pm 0.052 \pm 0.019$

Kaon tag

$a^* = -0.054 \pm 0.032 \pm 0.017$

$b_{Kaon} = -0.009 \pm 0.019 \pm 0.013$

$c^*_{Kaon} = +0.005 \pm 0.031 \pm 0.017$



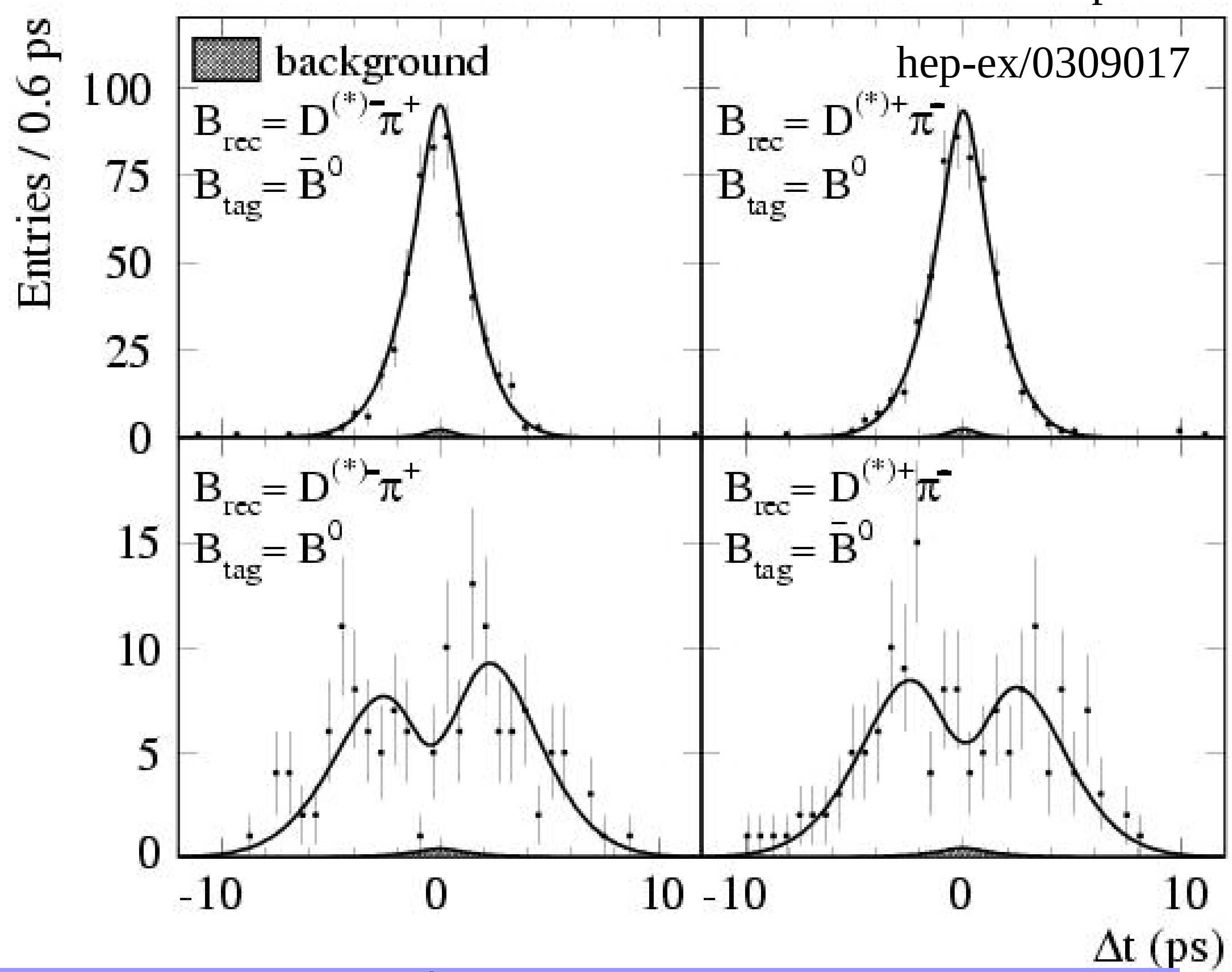
$a^* = -0.063 \pm 0.024 \pm 0.014$

$c^*_{lep} = -0.004 \pm 0.037 \pm 0.020$

$B^0(t) \to D^{(*)\pm}\pi^{\mp}$

Full CP B reconstruction in D and D*

88 million B pairs



$\underline{D^0 \text{ modes}}$

$K^-\pi^+$

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

$K^-\pi^+\pi^+\pi^-$

$K^0_S\pi^+\pi^-$

Simultaneous time dependent fit of all channels.

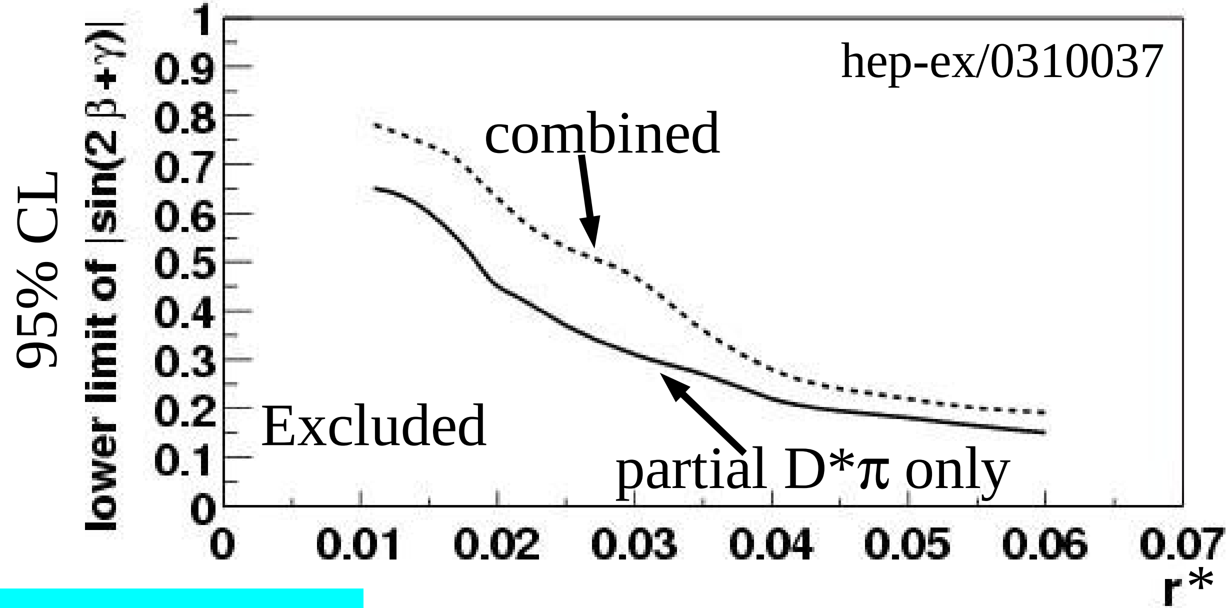
$a = -0.022 \pm 0.038 \pm 0.021$ $\quad a^* = -0.068 \pm 0.038 \pm 0.021$

$c_{lep} = +0.025 \pm 0.068 \pm 0.035$ $\quad c^*_{lep} = +0.031 \pm 0.070 \pm 0.035$

$B^0(t) \rightarrow D^{(*)\pm}\pi^{\mp}$

Interpretation from a*, S_+* and S_-* values

No assumption on r*



SU(3) symmetry relation

$$r = \tan(\theta_C)\sqrt{\frac{\mathcal{B}(B^0 \rightarrow D_s^+\pi^-)}{\mathcal{B}(B^0 \rightarrow D^-\pi^+)}}\frac{f_D}{f_{Ds}}$$

Cabibbo angle

decay constants

similar relation for r*

$$r = 0.021^{+0.004}_{-0.005}$$

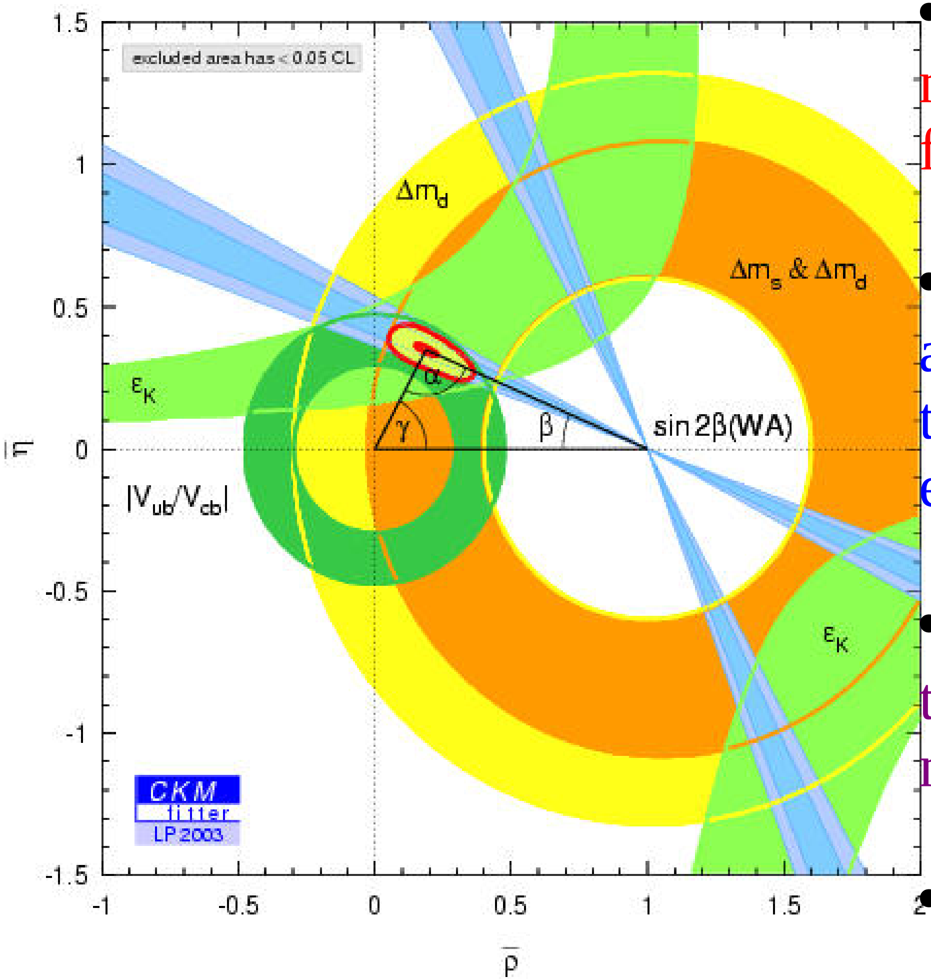
$$r^* = 0.017^{+0.005}_{-0.007}$$

Combined Dπ and D*π sample

$$|\sin(2\beta+\gamma)| > 0.87 \text{ (68\% CL)}$$

$$> 0.58 \text{ (95\% CL)}$$

Conclusion



- B factories have confirmed that CKM matrix provide an adequate explanation for CP violation in the Standard Model.
- Precision measurements are entering an era where they can test and measure theoretical model assumptions and even might hint at new physics.
- $|V_{ub}|$, $|V_{tb}|$, $b \to s\gamma$ will contribute to this precision testing of the CKM matrix.
- The coming data will be very exciting.