CKM Unitarity angles
α (ϕ_2) and γ(ϕ_3)
(Recent results from the B factories.)

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Outline

- **Introduction & definitions**
- **Experimental observables related to α and γ**
- **Experimental results, some discussion of implications for SM & constraints on α and γ**

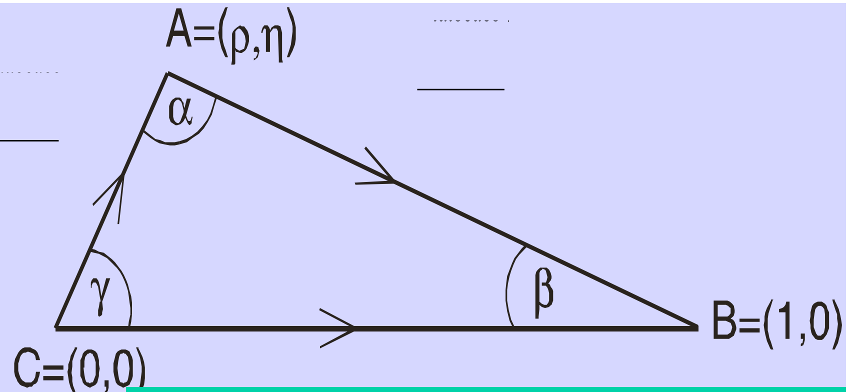
Definitions

~~C~~P

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

The Unitarity Test

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



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

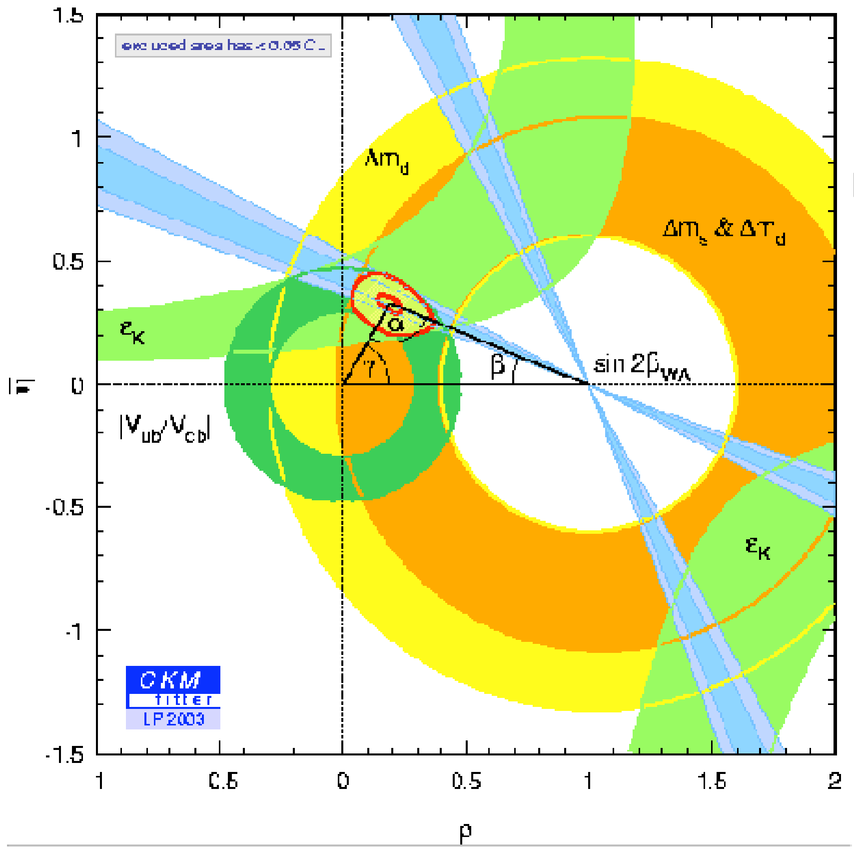
$$\alpha = \arg\left(-\frac{V_{tb}^* V_{td}}{V_{ub}^* V_{ud}}\right)$$

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

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

Both involve V_{ub}

Constraints from the CKM fit $|V_{ub}|$, $|V_{cb}|$, ϵ_K, Δm_d , Δm_s



At 95% C.L.

Indirect info on angles

$$19.4^o < \beta < 26.5^o$$

$$77^o < \alpha < 122^o$$

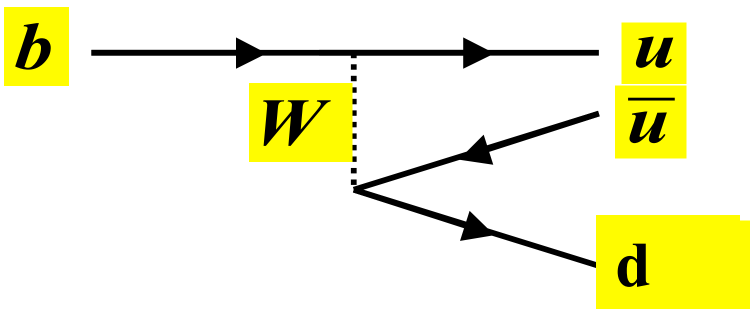
$$37^o < \gamma < 80^o$$

A. Hoecker et al, Eur. Phys. Jour. C21 (2001) 225, [hep-ph/0104062]

- **Unitarity Tests : Search for deviation from SM**
  - Using direct measurements of angles check: $\alpha + \beta + \gamma = \pi$
  - Check if B Decays are consistent with the range of angles from the CKM fit?

Main source of info on □ and □:
Decays involving b→u transitions

I- Charmless B Decays

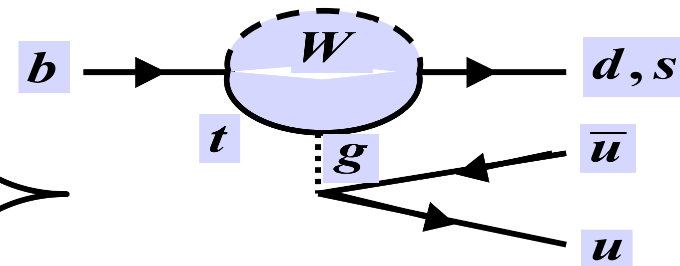


□→□ □: (□$^+$ □$^□$, □$^+$ □^{0}, □^{0} □^{0})

□→□□, □→ □□, a_1□,….

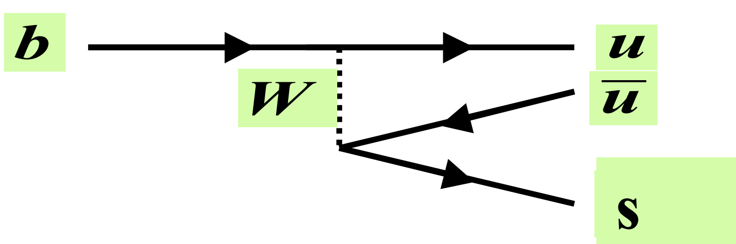
Tree diagrams are not alone:

Penguins (gluonic & E.W) can also lead to the same decays:



Data indicate gluonic penguins are large & complicate extraction of □

Interference of T & P results in Direct CP violation & sensitivity to □



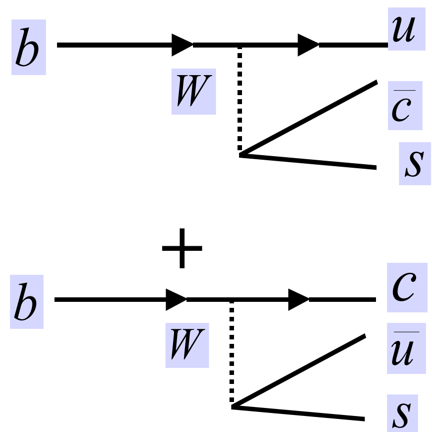
□→□ □: (□$^+$ □$^□$, □^{0} □$^+$, □^{0} □^{0}, ..)

CKM suppressed

II- Decays involving interference of b→u W^- & b→c W^- Processes

(Penguin Free)

B→DK:



$B^{□}□> \bar{D}^0 K^{□}$

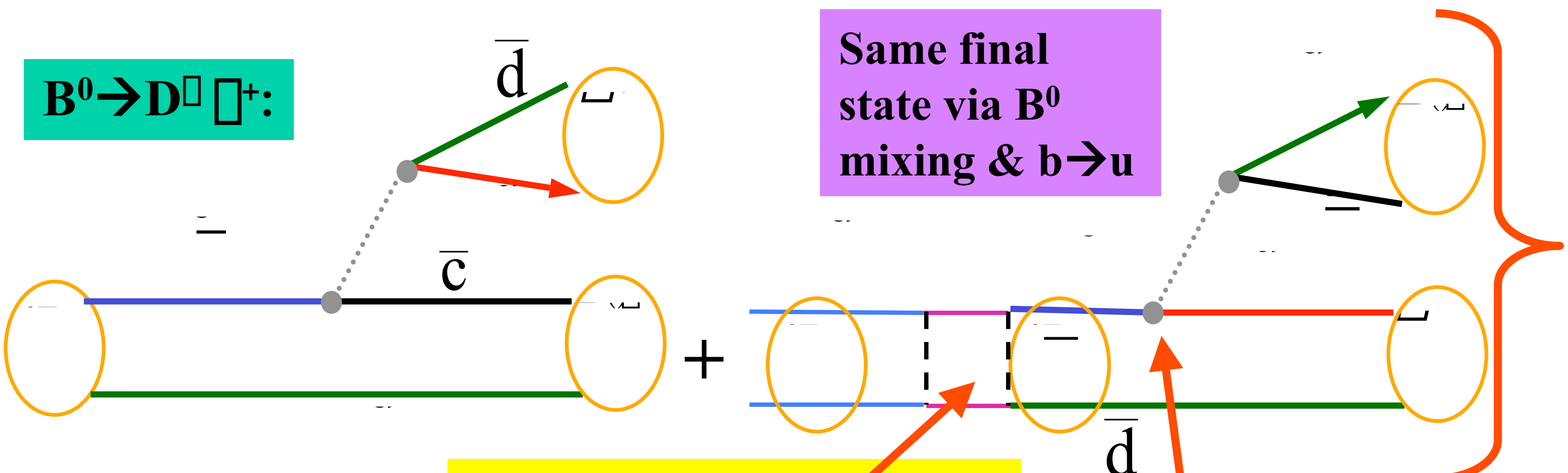
Involves arg(V_{ub})=□

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

$B^{□}□> D^0 K^{□}$

□dependence of rate and direct asymmetry

B^0→D□ □$^+$:



Same final state via B^0 mixing & b→u

Direct CP asymmetry sensitive to sin(2□+□)

arg(V_{ub})=□

Experimental Observables

- **Branching fractions for various non-charm B decays**
- **Time Integrated (Direct) CP asymmerties**

$$\mathrm{Acp} = \frac{\tilde{A}(\overline{\hat{A}} \,\square\, \bar{f}) \,\square\, \tilde{A}(\hat{A} \,\square\, f)}{\tilde{A}(\hat{A} \,\square\, f) + \tilde{A}(\overline{\hat{A}} \,\square\, \bar{f})}$$

With Tree and Penguins both in action:

$$A = \square(|T|e^{i\tilde{a}} + |P|e^{i\ddot{a}}) \qquad \overline{A} = \square(|T|e^{\square i\tilde{a}} + |P|e^{i\ddot{a}})$$

$$Br \quad 1 + 2\left|\frac{P}{T}\right| \cos\ddot{a} \cos\tilde{a} + \left|\frac{P}{T}\right|^2$$

$$A_{cp} = \square 2\left|\frac{P}{T}\right| \sin\ddot{a} \sin\tilde{a}$$

To constrain □requires estimates of:

$|P_{\square\square}/T_{\square\square}|$ & relative strong phase □

More observables: Time – Dependent CP Asymmetries

- **Time evolution of tagged B^0 decays, e.g. in the case of $B^0 \to \pi^+\pi^-$**

$$f_{\pm}(\Delta t) = \frac{e^{(-|\Delta t|/\tau)}}{4\tau}\left[1 \pm S_f \sin(\Delta m_d \Delta t) \mp C_f \cos(\Delta m_d \Delta t)\right]$$

$$S_f = \frac{2\,\mathrm{Im}(\lambda)}{1+|\lambda|^2}$$

CPV due to mixing and decay interference

$$\lambda = \frac{q}{p}\frac{\bar{A}(\bar{B}^0 \to f)}{A(B^0 \to f)}$$

$$C_f = \frac{1-|\lambda|^2}{1+|\lambda|^2}$$

Direct CPV in Decay

Belle: **A_f = - C_f (*BaBar*)**

With Tree alone

$$\lambda = -\frac{V_{tb}^*V_{td}V_{ub}V_{ud}^*}{V_{tb}V_{td}^*V_{ub}^*V_{ud}} = e^{i2\alpha} \qquad C = 0 \qquad \& \qquad S = \sin(2\alpha)$$

With Penguin and Tree

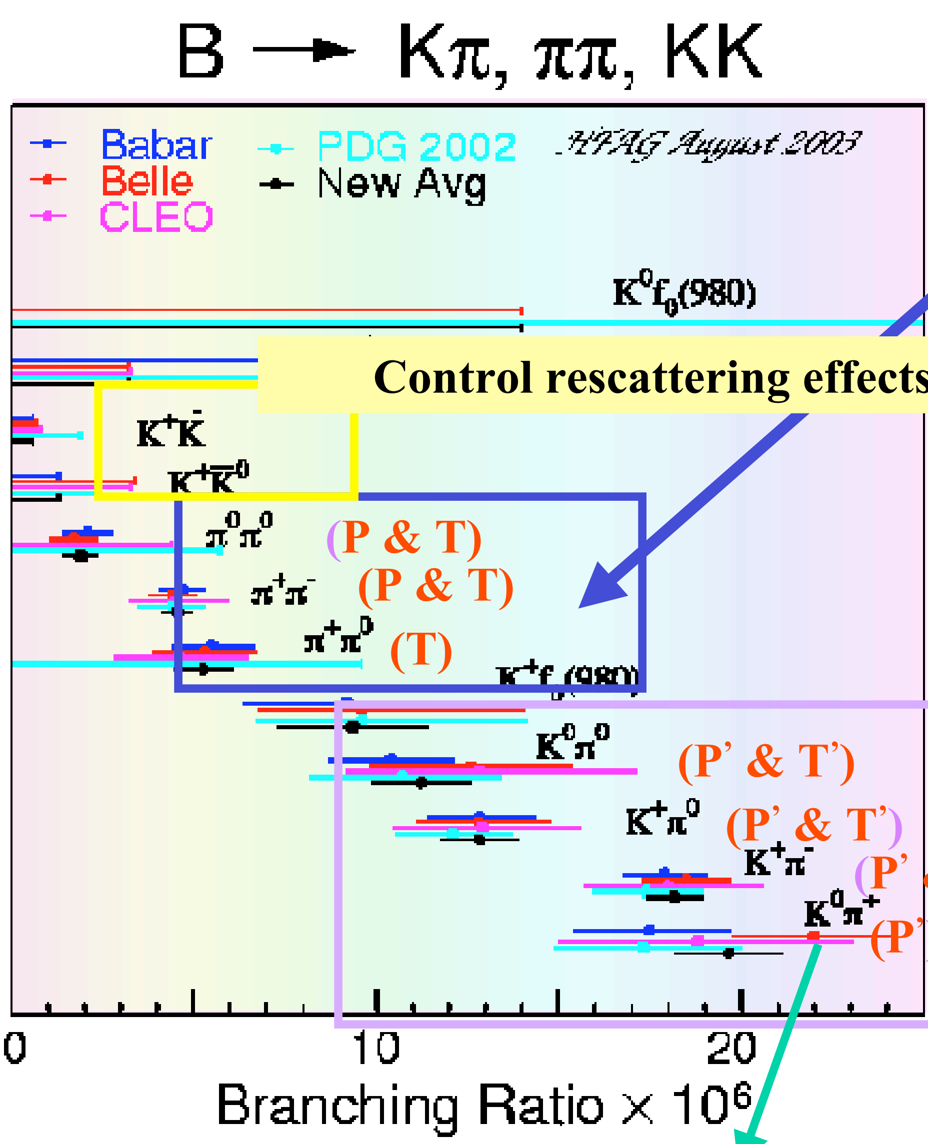
$$\lambda = e^{2i\alpha}\frac{1+|\frac{P}{T}|e^{i\delta}e^{i\gamma}}{1+|\frac{P}{T}|e^{i\delta}e^{-i\gamma}}$$

$S = \sin 2\alpha_{eff}$

$\Delta\alpha = \alpha_{eff} - \alpha$

$C \neq 0$

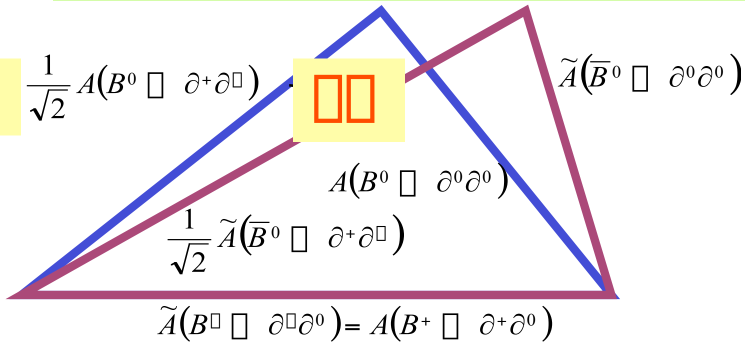
A few comments on the already established pattern from charmless 2-body decays



Control rescattering effects

Connected via Isospin symmetry *(Gronau &London)* (Isospin engineering)

Constructing these triangles is a major goal of the experiments



With Tree alone,expect:

$\frac{B\ \square\ K\square}{\square\ \square\ \square\square}\ \square\ 5\%$

Measurements:

$\frac{B\ \square\ K\square}{\square\ \square\ \square\square}\ \square\ 4$

➔Penguins are significant players

P' & use SU(3)connections to estimate P

Goals and Issues on the Measurement Side

- **Search for CP violation: Direct (C≠ 0) & Indirect (S≠0) deviating from (sin2□): [*i.e.* indirect CPV outside of mixing phase.]**
- **Measure/Constrain □ & □using many different modes and exploit the redundancy to resolve the ambiguities.**

- **<u>The reality</u> (Considering the presences of large Penguin effects)**
  - **No single measurement is expected to lead to determination of □ & □**
  - **Need info from many decay modes and the emerging pattern & connections via symmetries, [isospin, SU(3)], and eventually more predictive theories [perhaps QCD factorization or perturbative QCD- *when verified]* to constrain various components of the problem.**

The job description

Keep finding the pieces of the charmless puzzle → **Eventually □ & □**

Experiments and Data

Asymmetric e^+e^- B Factories:

The focus of this talk

Physics coverage : $\overline{B}_d$ & B_u Decays

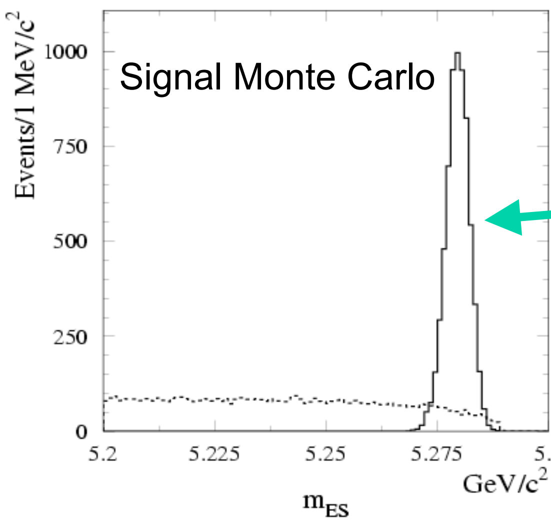
BaBar at SLAC PEP-II Machine	Belle at KEK-B Machine
113 fb^{-1} on Υ(4s) (126 fb^{-1} total)	140 fb^{-1} on Υ(4s) (158 fb^{-1} total)
124×10^6 B $\overline{B}$ events	152×10^6 B $\overline{B}$ events

CLEO at the CESR Machine – Some results on Br & direct Asymmetries.
The pioneer of the field and the first source of information on B decays,
Including observation of charmless decays. [~13 fb^{-1} on peak]

The B physics reach of hadron machines & current status covered by Kevin Pitts . Next Talk

Analysis Issues for Rare B Charmless decays

-Looking for modes with Br~10^{-6} to 10^{-5}
-Continuum qq(bar) background at 10^3 larger than the signal
BKG Suppression using event shape & topology, kinematics, particle ID,..

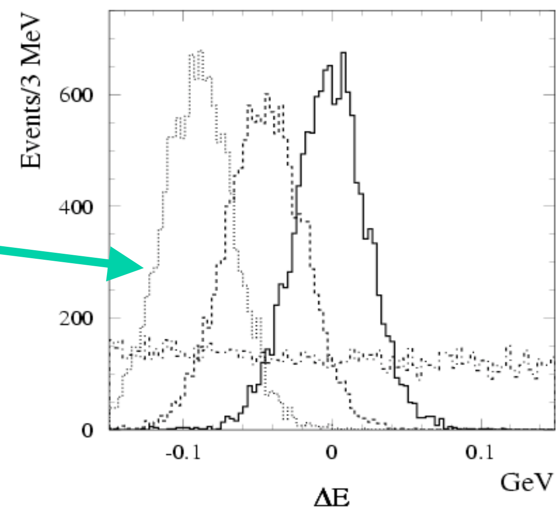


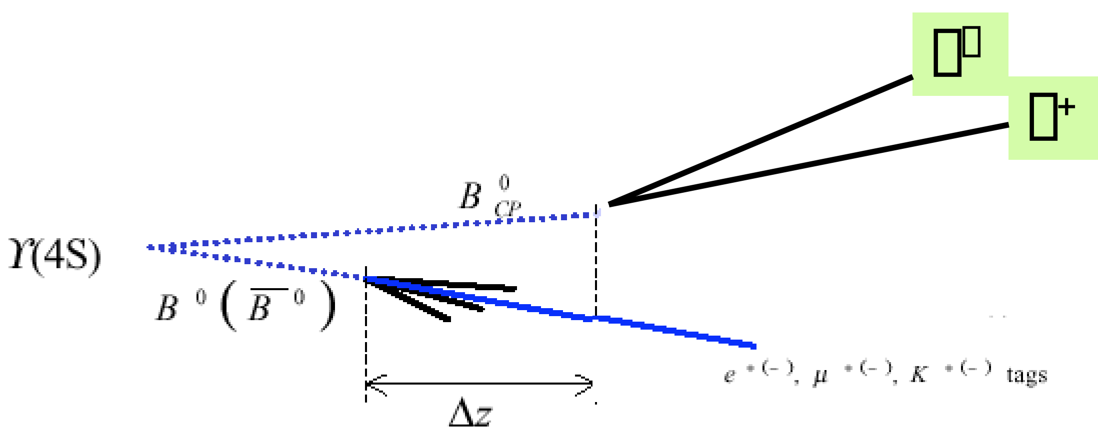
Kinematic variables:

$$Mes = \sqrt{E_{beam}^2 - p_B^2}$$

$\Delta E = E_{beam} - E_B$

provides separation of KK, Kπ, ππ decays





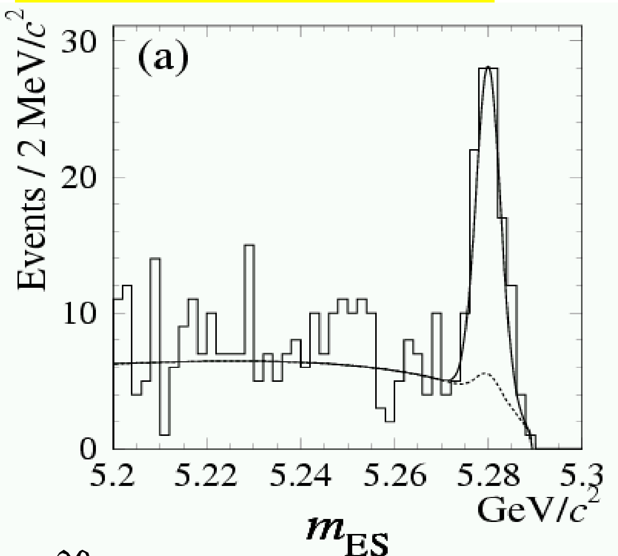
Other info into analysis:

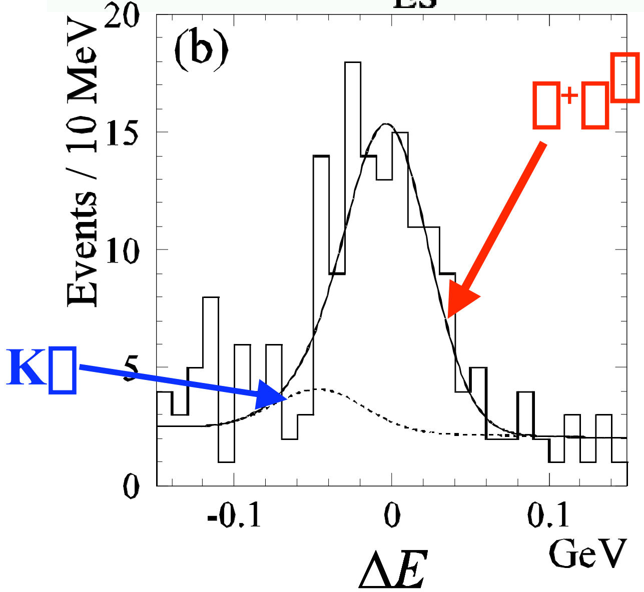
- $\Delta t = \Delta z / \langle c\beta\gamma \rangle$
- **Flavor tag of other side**
- **Particle ID, event shape,..**

The road to □: Measurement of CPV in B→□+ □□

Isolation of Signals

BaBar: 81 *fb*$^{-1}$

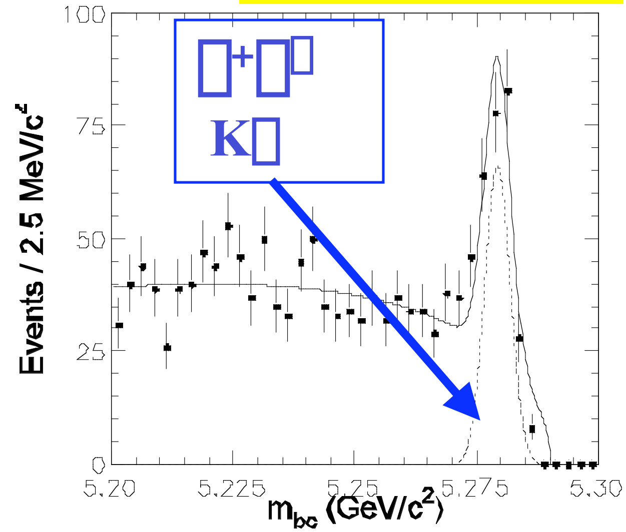


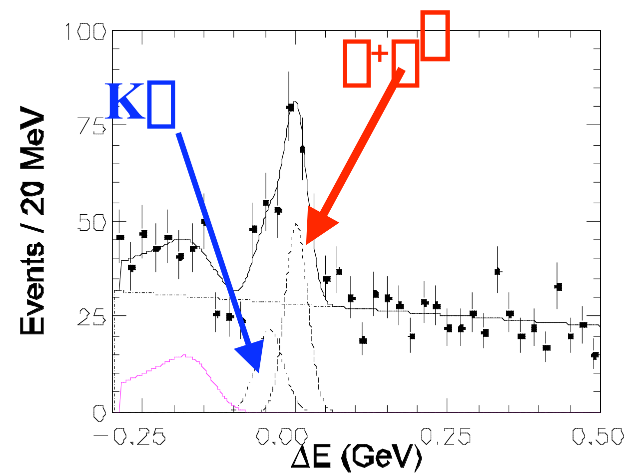


□200 B→□+ □□

Per experiment

Belle 78 fb^{-1}



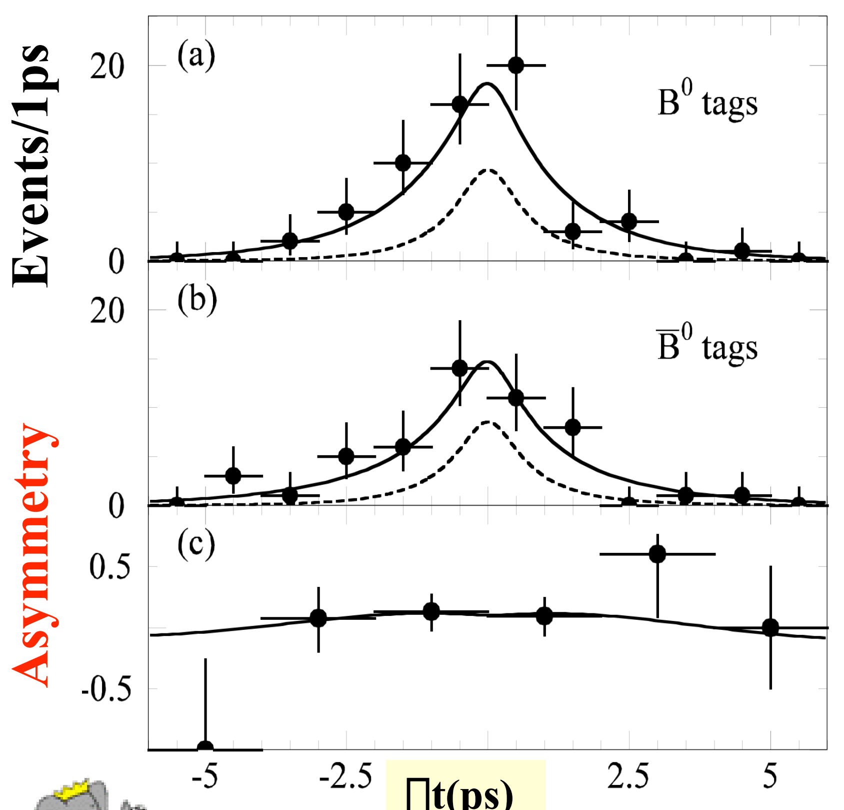


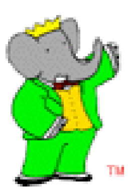
Time Dependent CPV in $B \to \pi^+ \pi^-$

Fits to:

$$f_\pm(\Delta t) = \frac{e^{(-|\Delta t|/\tau)}}{4\tau}[1 \pm S_f \sin(\Delta m_d \Delta t) \mp C_f \cos(\Delta m_d \Delta t)]$$

(BaBar) ***81 fb⁻¹***

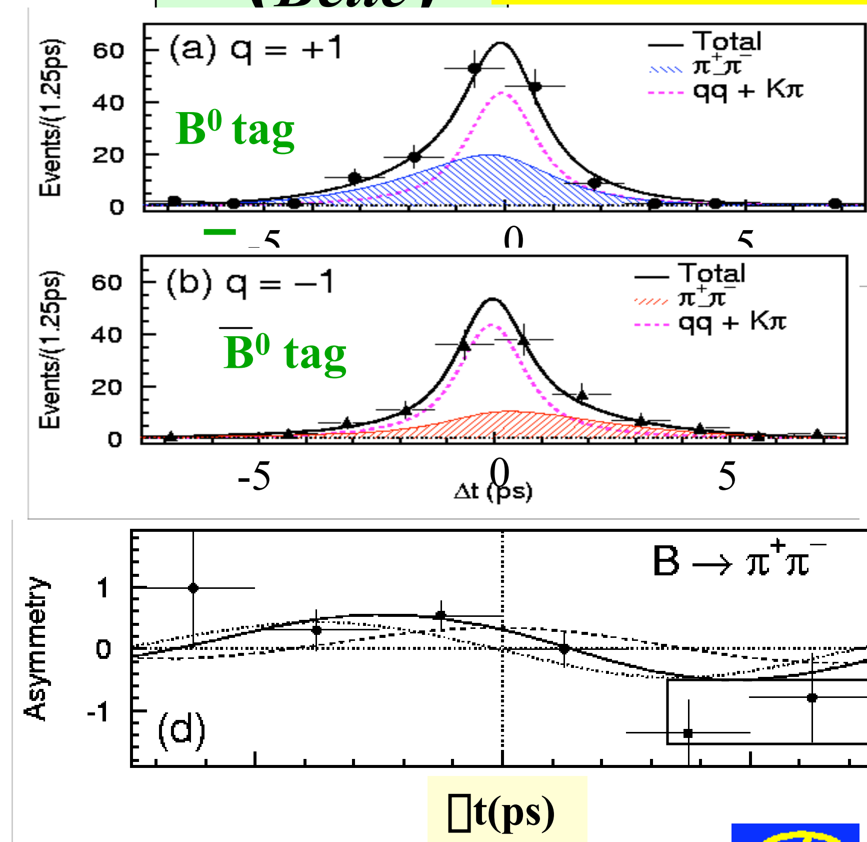




$S_{\pi\pi} = 0.02 \pm 0.34 \pm 0.05$

$C_{\pi\pi} = -0.30 \pm 0.25 \pm 0.04$

(Belle) ***78 fb⁻¹***



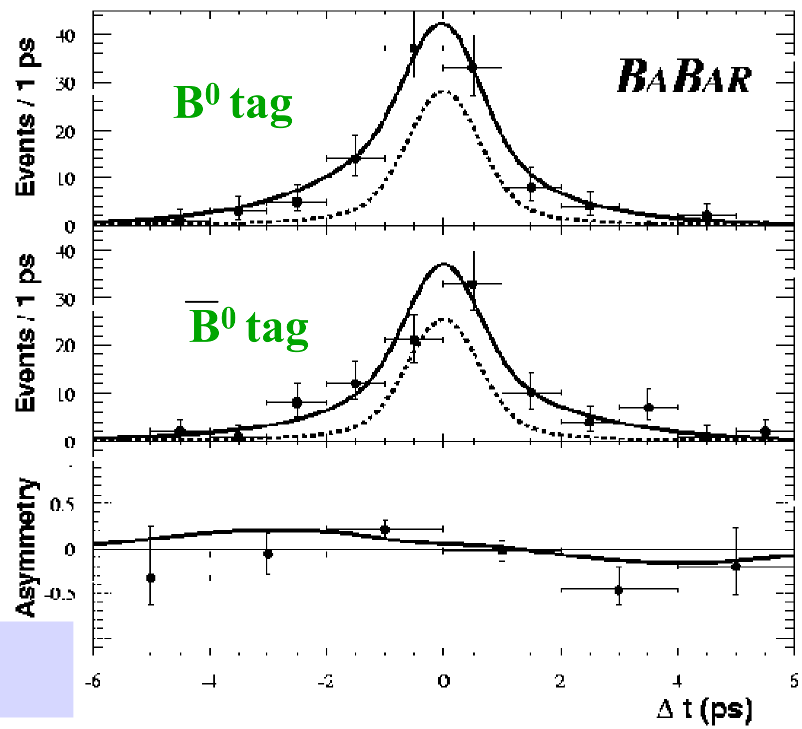
$S_{\pi\pi} = -1.23 \pm 0.41^{+0.08}_{-0.07}$

$C_{\pi\pi} = -0.77 \pm 0.27 \pm 0.08 \quad (-A_{\pi\pi})$

New Results: BaBar Update of CPV measurements with full data sample (Run 1+2+3): 113 fb^{-1} on Peak data

- Reprocessed Run1+2 (82 fb^{-1})
- Added Run 3 ((31 fb^{-1})

$$N_{\pi\pi} = 265.9 \pm 24.0$$
$$N_{K\pi} = 873.3 \pm 37.5$$
$$N_{KK} = 12.5 \pm 10.4$$



New CPV Results

Run1+2(reprocessed)

S=-0.252±0.27 C=-0.166 ±0.22

Run 3

S=-0.67±0.35 C=-0.33 ±0.34

$$S_{\pi\pi} = -0.40 \pm 0.22 \pm 0.03$$
$$C_{\pi\pi} = -0.19 \pm 0.19 \pm 0.05$$
$$A_{K\pi} = -0.107 \pm 0.041 \pm 0.013$$

Summary of CPV in $B \rightarrow \pi^+ \pi^-$:

Belle's update with their full data set awaited

Current world average (with BaBar new results)

S=-0.58±0.20 **C=-0.38 ±0.16**

Ignoring the large $\chi^2 \approx 6.3$ (~2 σ)

Too early to claim observation of CPV in $B \rightarrow \pi^+ \pi^-$:
Direct (in decay) or Indirect(mixing & decay)

S & C not enough to measure α:

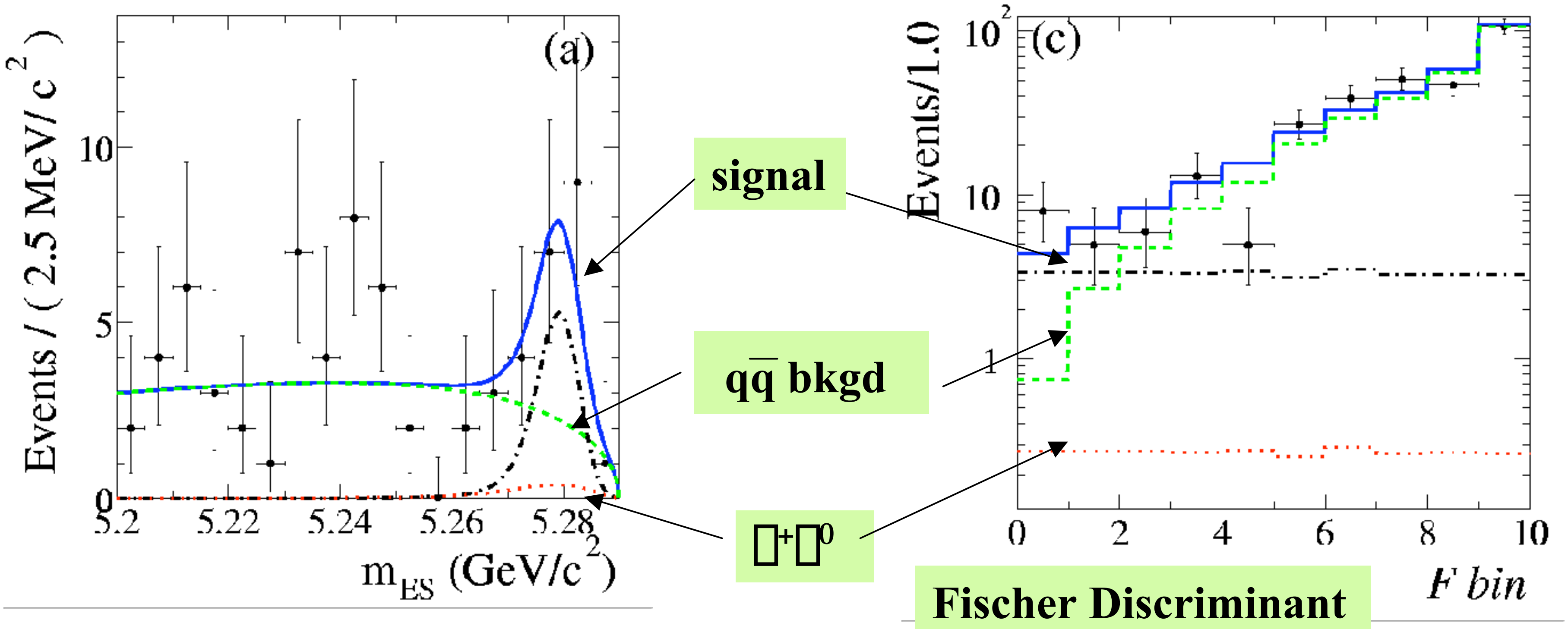
$$C \neq 0 \quad \& \quad S = \sqrt{1 - C^2}\,\sin(2\alpha_{eff})$$

Need $\Delta\alpha = \alpha_{eff} - \alpha$, which requires the other pieces of the isospin analysis.

BaBar: The decay B→□0 □0

- ➢Used their full data set (113 fb^{-1})
- ➢ Measured Br(B→□+□0) [Br(B→□+□0) =(11±2.7)x10^{-6}]

Control over a major background source. Br about half of previous assumed value

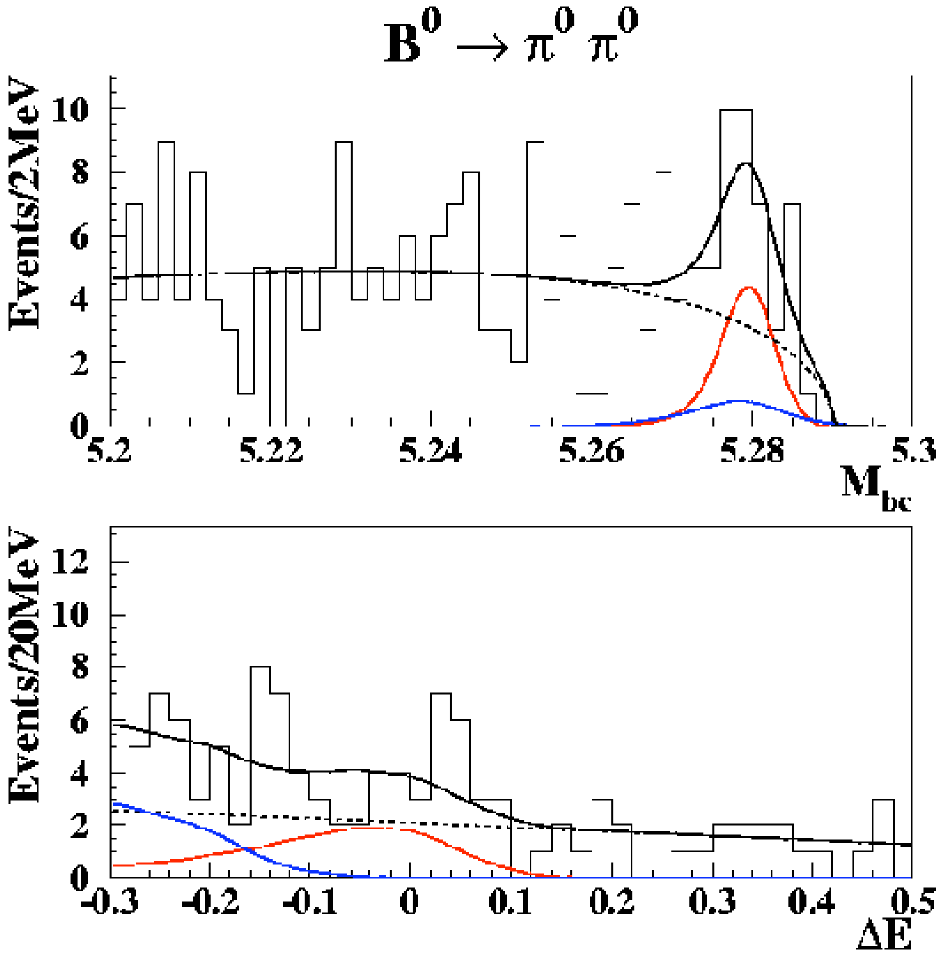


$$N(□^0□^0) = 46^{+14+2}_{□13□3}$$

$$\overline{B}(B^0 □ □^0□^0) = 2.1 \pm 0.6 \pm 0.3 □ 10^{□6}$$

Significance: 4.2 □ **→Observation**

Belle: The decay B→$\pi^0\pi^0$



Analyzed full data set of 140 fb^{-1}

From a fit to 2-dimensional distribution of Mes and ΔE

Find:

$$N(\pi^0\pi^0) = 25.6^{+9.3}_{-8.4}$$

Significance:3.4 σ

→Evidence

$$\overline{B}(B^0 \to \pi^0\pi^0) = 1.7 \pm 0.6 \pm 0.3 \times 10^{-6}$$

What about □□: All but one piece is in place

Branching ratios (x10^{-6})

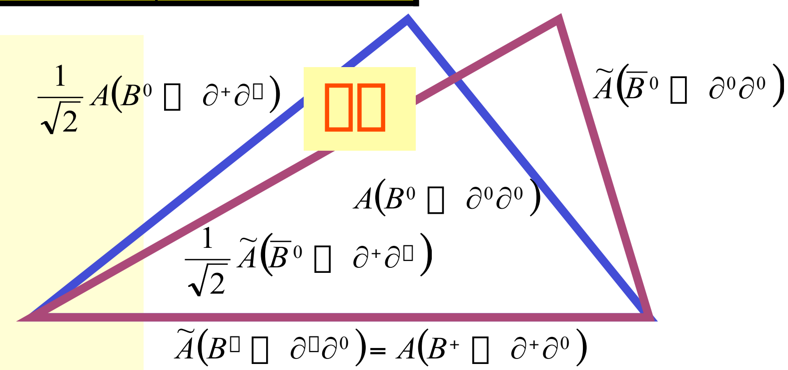
Mode	CLEO	Belle	BaBar	Average
$\pi^+\pi^-$	$4.5 \pm^{1.4}_{1.2} \pm^{0.5}_{0.4}$	$4.4 \pm 0.6 \pm 0.3$	$4.7 \pm 0.6 \pm 0.2$	4.6 ± 0.4
$\pi^+\pi^0$	$4.6 \pm^{1.8}_{1.6} \pm^{0.7}_{0.6}$	$5.3 \pm 1.3 \pm 0.5$	$5.5 \pm^{1.0}_{0.9} \pm 0.6$	5.2 ± 0.8
$\pi^0\pi^0$	<4.4	1.7±0.6 ±0.3	2.1 ±0.6 ±0.3	1.97 ±0.47

For a full Isospin analysis need: $C_{\pi^0\pi^0}$ (direct CPV)

$B(\overline{B}^0 \to \pi^0\pi^0)$ **&** $B(B^0 \to \pi^0\pi^0)$

Still some constraint can be set using the measured average Branching fraction:

(Quinn- Grossman), $\sin^2 \Delta\alpha \le \dfrac{\overline{B}(B^0 \to \pi^0\pi^0)}{\overline{B}(B^\pm \to \pi^\pm\pi^0)}$



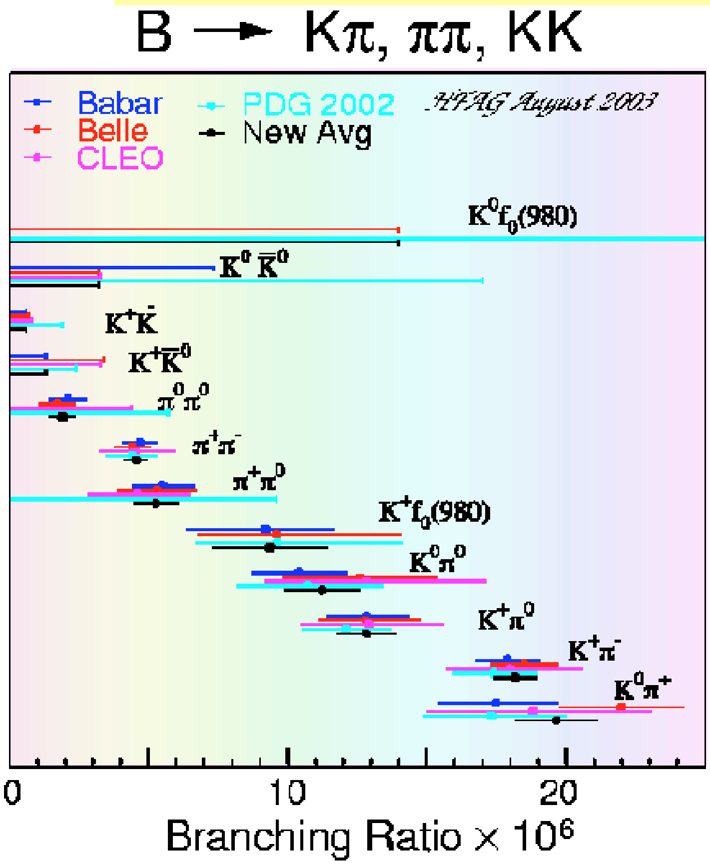
With WA Br(B→ $\pi^0\pi^0$)

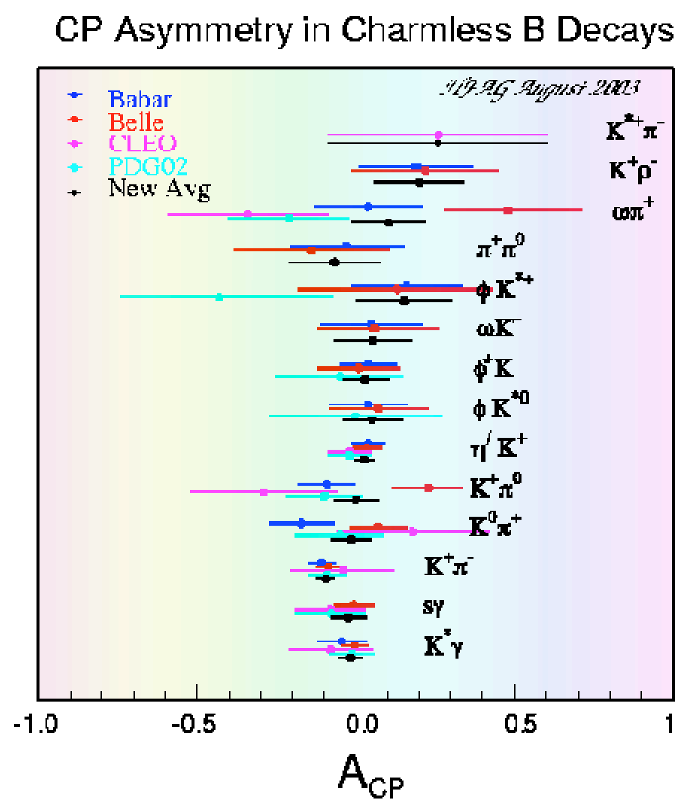
$|\alpha - \alpha_{eff}| < 48^\circ$ at 90% c.l.

Not a very useful limit & don't expect more than ~10º improvement in future.

Summary of measurements of B→□□ & □□ Decays

See John Fry's talk this morning for more detail &comparison with Theory





Thanks to Heavy flavor averaging group(HFAG): Rare decays: J. Smith (colorado), J. Alexander(Cornell), P.Chang (KEK)

$A_{K\square} = \square 0.086 \pm 0.035 \pm 0.014 (Belle)$

$= \square 0.107 \pm 0.041 \pm 0.012 (BaBar)$

$= \square 0.04 \pm 0.16 \pm 0.02 (CLEO)$

Evidence Direct CPV ?

$Average = \square 0.09 \pm 0.03$

What did we learn about □ & □?

□s this all consistent with

Standard Model?

Does it accommodate the range of UT angles from the global CKM fit?

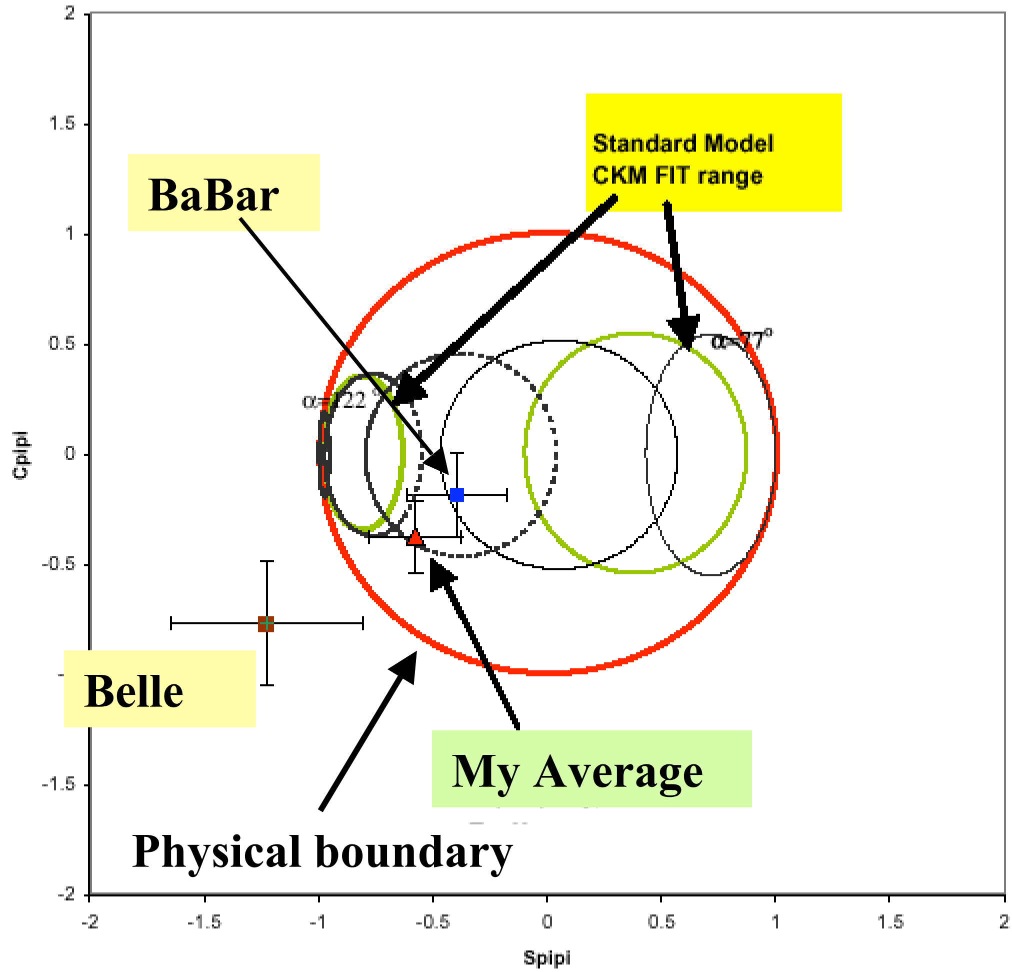
$C_{\pi\pi}$ vs $S_{\pi\pi}$:
Allowed range & comparison with SM (CKM fit)

Gronau and Rosner approach (PRD 093012)
$|P_{\pi\pi} / T_{\pi\pi}|$ estimated using
$B \to K^0\pi^+$ & $B \to \pi l \nu$, $B \to \pi^0\pi^+$
(with use of SU(3) & factorization)

Here calculate S & C for |P/T|~0.3
Unconstrained strong phase δ

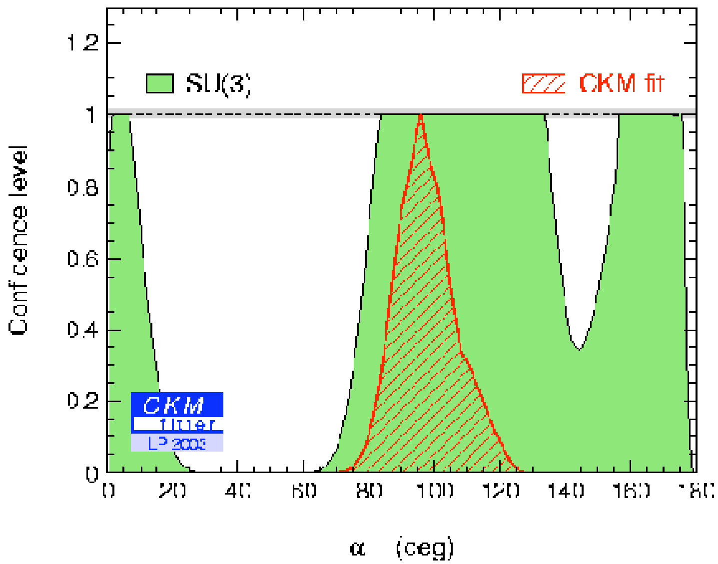
$$\lambda = e^{2i\alpha} \frac{1 + |\frac{P}{T}| e^{i\delta} e^{i\gamma}}{1 + |\frac{P}{T}| e^{i\delta} e^{-i\gamma}}$$

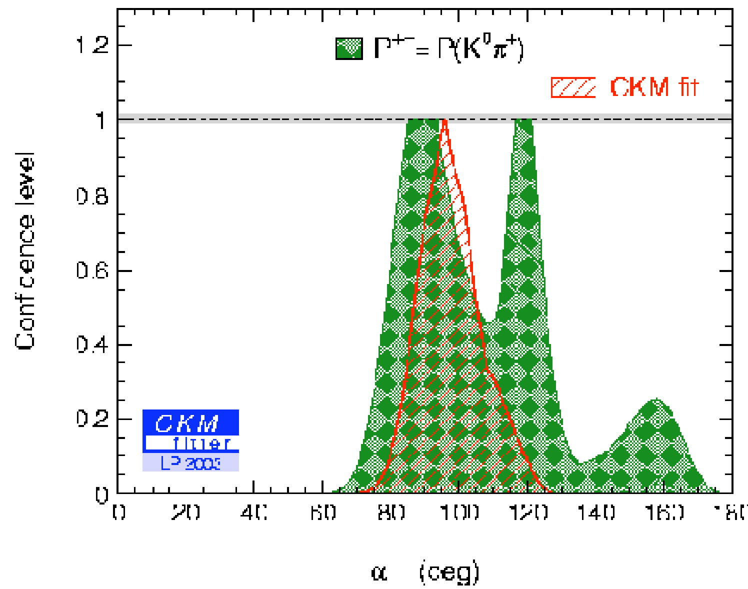
$$S_f = \frac{2\,\mathrm{Im}(\lambda)}{1 + |\lambda|^2} \qquad C_f = \frac{1 - |\lambda|^2}{1 + |\lambda|^2}$$

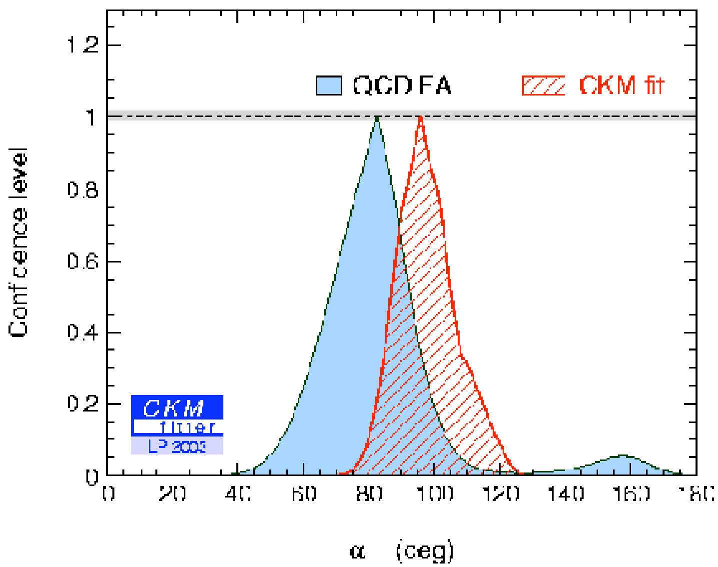


Data consistent with SM (CKM fit)

A more optimal use of information using the CKMfitter tools with various assumptions *(LAL 02-103: Authors Hoecker, Lacker, Pivak, Roos).*







SU(3) & some use of QCD Factorization to estimate SU(3) breaking effects

In all scenarios data can accommodate the range of α from the SM CKM fit

Constraints on γ: Connecting the B→Kπ data via symmetries

Useful ratios of branching fractions and ps-asymmetries with sensitivity to γ:

$$\begin{bmatrix} R \\ A_0 \end{bmatrix} = \left[\frac{Br(B^0 \to K^+\pi^-) \pm Br(\overline{B}^0 \to K^-\pi^+)}{Br(B^+ \to K^+\pi^0) + Br(B^- \to \overline{K}^0\pi^-)}\right]\frac{t_{B+}}{t_{B0}}$$

$$\begin{bmatrix} R_n \\ A_0^n \end{bmatrix} = \frac{1}{2}\left[\frac{Br(B^0 \to K^+\pi^-) \pm Br(\overline{B}^0 \to K^-\pi^+)}{Br(B^0 \to K^0\pi^0) + Br(\overline{B}^0 \to \overline{K}^0\pi^0)}\right]$$

$$\begin{bmatrix} R_c \\ A_0^c \end{bmatrix} = 2\left[\frac{Br(B^+ \to K^+\pi^0) \pm Br(B^- \to K^-\pi^0)}{Br(B^+ \to K^0\pi^+) + Br(B^- \to \overline{K}^0\pi^-)}\right]$$

Rosner, Gronau, Neubert, Fleischer, Mannel, ..

$$R_{c,n} = 1 - 2r_{c,n}(\cos\gamma - q)\cos\delta_{c,n} + (1 - 2q\cos\gamma + q^2)r_{c,n}^2$$

$$A_0^{c,n} = 2r_{c,n}\sin\delta_{c,n}\sin\gamma$$

|T/P| **Size of EW penguins**

Ratios using HFAG averages:

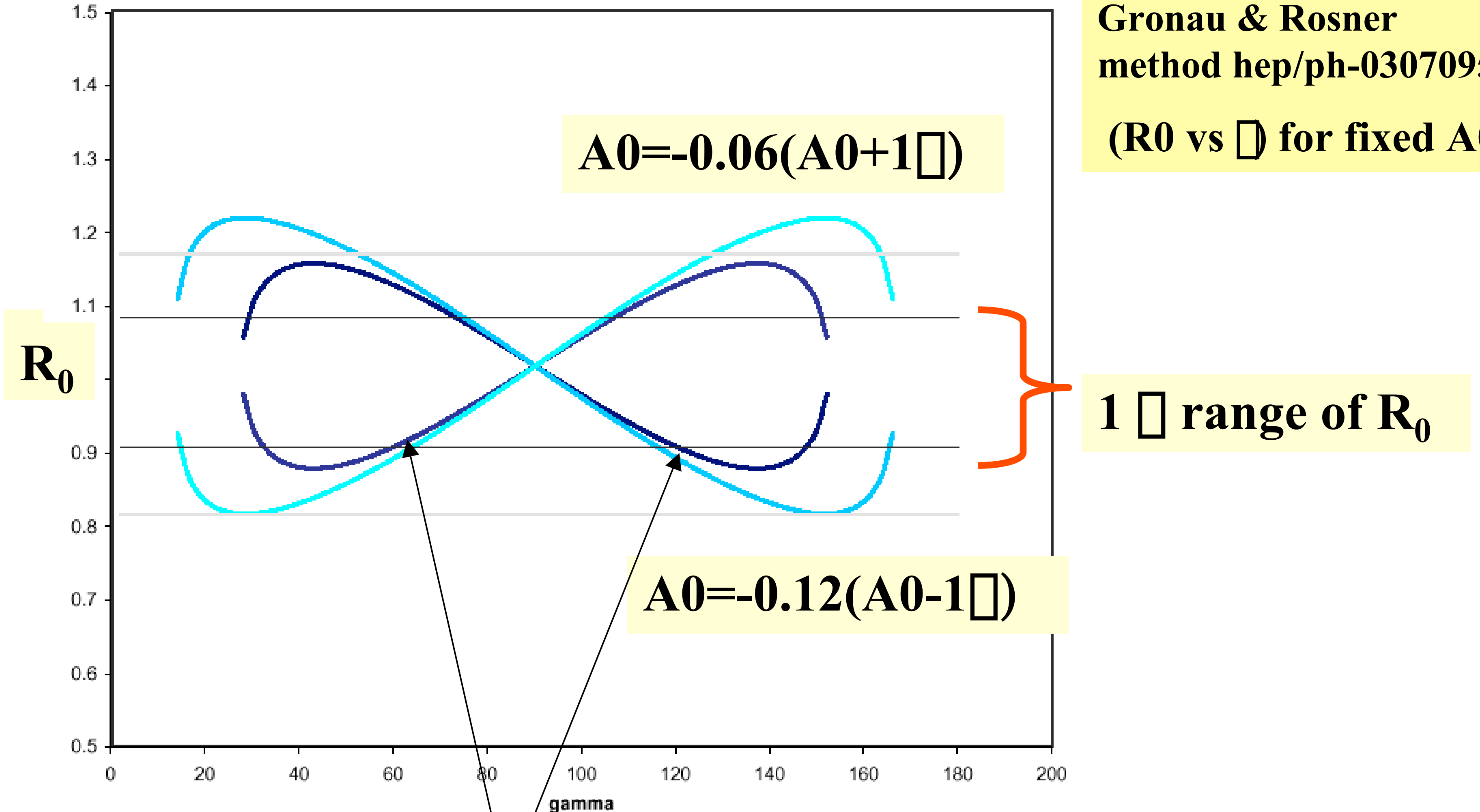
R0=0.99±0.09	A0= - 0.09 ±0.03
Rc=1.30±0.15	Ac=0.0 ± 0.06
Rn=0.8 ±0.11	An=-0.07 ± 0.03

All shown to accommodate range of γ from CKM fit

(Fleischer), (Gronau, Rosner),…

Gronau & Rosner method hep/ph-0307095

(R0 vs γ) for fixed A0



60 < γ<120 at 1 σ level

No useful limit at 2 σ level

Consistent with CKM range: $37^o < \gamma < 80^o$

Other channels of reaching □:

<u>**B→ (□□□):**</u> **CPV studies require isolation of states with specific CP parity: e.g. B→ (□$^+$□$^□$+ □$^□$□$^+$) using Dalitz plot analysis.**

Interference between (□$^+$□$^□$+ □$^□$□$^+$) can be used to determine □ even in the presence of penguins [*Quinn-Snyder*]

- **BaBar has presented CPV results based on quasi 2-body decays B^0→"□$^+$ "□$^□$, B^0→"□$^□$"□$^+$ □□ updated for this conference with their full data sample.**
- **1st Belle results on CPV with these modes expected soon.**
- **Components of the Isospin analysis (pentagon) are also being measured.** (*J. Fry's talk today*)

B→(□□□□): e.g. B→□□ has been measured and shown to be dominated by the CP even component – good news for CPV studies.

CPV Studies with the decay $B^0 \to \rho\pi$

Not a CP eigenstate & involves more observables:

$$f_{B^0}^{\rho^\pm h^\mp}(\Delta t) = (1 \pm A_{CP}(\rho h))e^{-|\Delta t|/\tau}(1 + [(S_{\rho h} \pm \Delta S_{\rho h})\sin(\Delta m \Delta t) - (C_{\rho h} \pm \Delta C_{\rho h})\cos(\Delta m \Delta t)])$$

$$f_{\overline{B}^0}^{\rho^\pm h^\mp}(\Delta t) = (1 \pm A_{CP}(\rho h))e^{-|\Delta t|/\tau}(1 - [(S_{\rho h} \pm \Delta S_{\rho h})\sin(\Delta m \Delta t) - (C_{\rho h} \pm \Delta C_{\rho h})\cos(\Delta m \Delta t)])$$

Summing over the ρ charge:

$$A_{\rho\pi}(B^0/\overline{B}^0) = S_{\rho\pi}\sin(\Delta m \Delta t) - C_{\rho\pi}\cos(\Delta m \Delta t)$$

Direct CP violation: $C_{\rho\pi}$

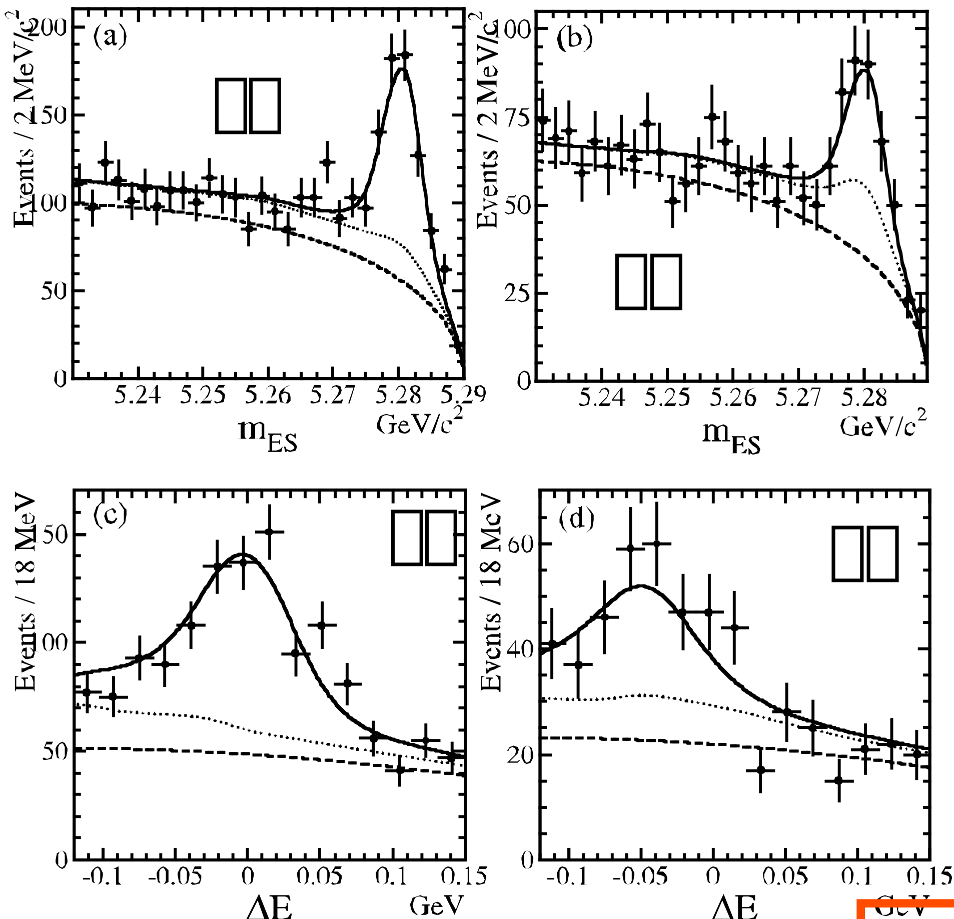
Indirect CP (mixing and decay): $S_{\rho\pi}$

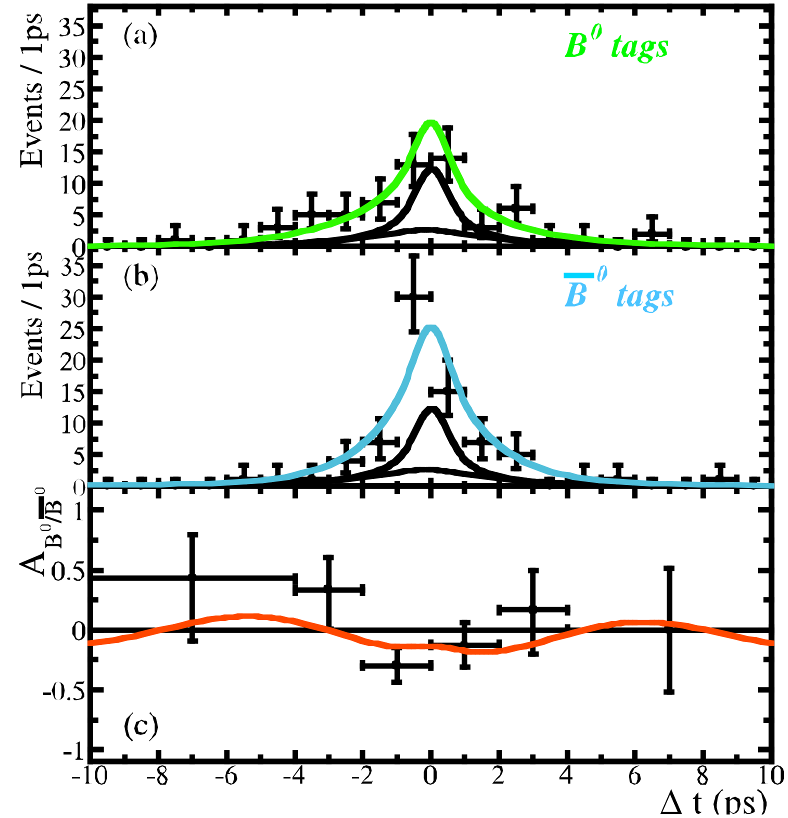
Charge Asymmetry:

$$A_{CP}^{\rho h} = \frac{N(\rho^+ h^-) - N(\rho^- h^+)}{N(\rho^+ h^-) + N(\rho^- h^+)}$$

Dilution (Non CP parameters): $\Delta C_{\rho\pi}$ & $\Delta S_{\rho\pi}$

BaBar results on CPV in B→□□: 113 fb^{-1}





$$A_{□□}(B^0/\overline{B}^0) □ S_{□□}\,\mathbf{sin}(□m□t) □ C_{□□}\,\mathbf{cos}(□m□t)$$

N(□□)	N(□□)	C	□C	S	□S	A_{CP}(□□)	A_{CP}(□□)
804.2 ±49.2	260.4 ±31.4	0.35 ±0.13 ±0.05	0.20 ±0.13 ±0.05	-0.13±0.18 ±0.04	0.33 ±0.18 ±0.03	-0.11±0.06 ±0.03	0.18 ± 0.12 ± 0.08

Test Of Direct CPV

Define two asymmetries:

$$A_{-+} = \frac{N(\overline{B}^0 \to \rho^+\pi^-) - N(B^0 \to \rho^-\pi^+)}{\Sigma} = \frac{A_{CP}^{\rho\pi} - C - A_{CP}^{\rho\pi}\cdot\Delta C}{1 - \Delta C - A_{CP}^{\rho\pi}\cdot C}$$

$$A_{+-} = \frac{N(\overline{B}^0 \to \rho^-\pi^+) - N(B^0 \to \rho^+\pi^-)}{\Sigma} = \frac{A_{CP}^{\rho\pi} + C + A_{CP}^{\rho\pi}\cdot\Delta C}{1 + \Delta C + A_{CP}^{\rho\pi}\cdot C}$$

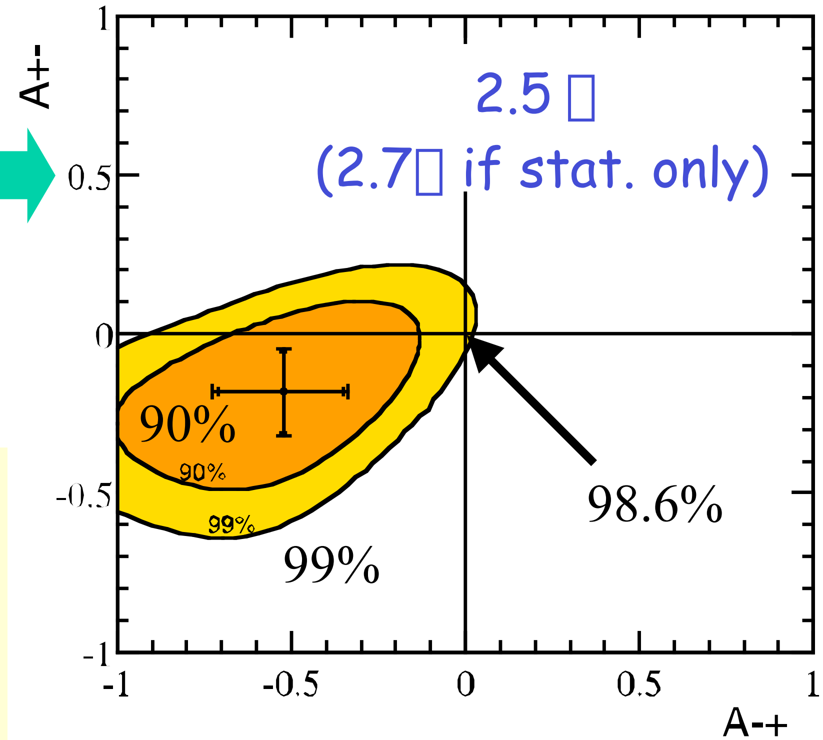
New Results

$$A_{-+} = -0.52\,^{+0.17}_{-0.19} \pm 0.07,\quad A_{+-} = -0.18\,^{+0.13}_{-0.13} \pm 0.05$$

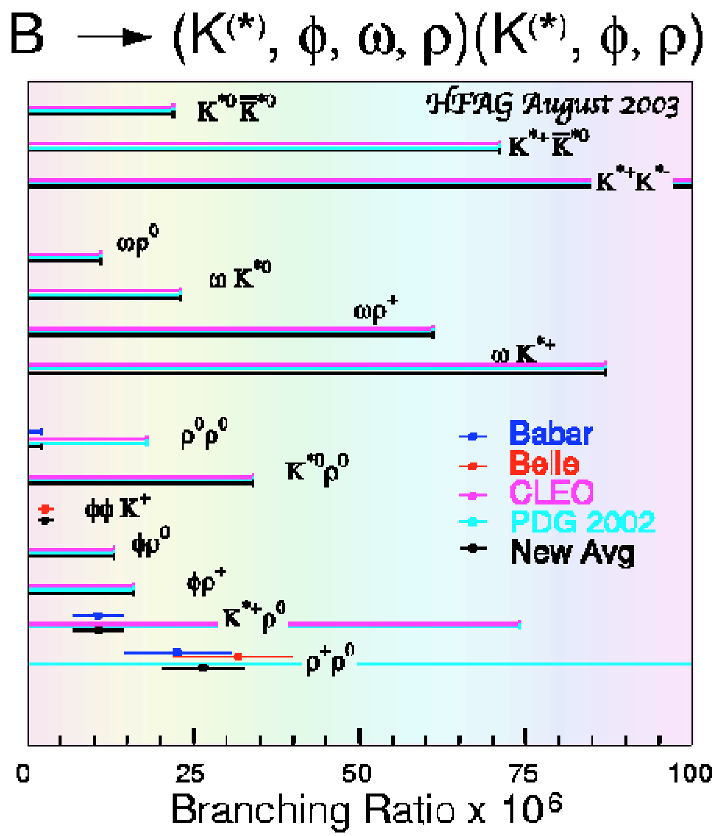
PRL

$$A_{-+} = -0.62\,^{+0.24}_{-0.28} \pm 0.06,\quad A_{+-} = -0.11\,^{+0.16}_{-0.17} \pm 0.04$$

2.3σ (Stat. only)



A promising channel:the B→ρρ system



The components of B→ρρ are identifeid: $B^0 \to \rho^+\rho^-$ (BaBar), $B^+ \to \rho^+\rho^0$ (Belle & BaBar)

Decays nealy 100% longitudinally polarized [CP-even]

Limit has been set on $B^0 \to \rho^0\rho^0$.

See John Fry's talk this morning for more detail

Quinn-Grossman bound applied to the longitudenal polarization component of the rates:

$$\sin^2(\alpha_{eff} - \alpha) \le (f_L^{\rho 0\rho 0} \times B^{\rho 0\rho 0})/(f_L^{\rho +\rho 0} \times B^{\rho +\rho 0}) < 0.10 \quad @90\ \%\ c.l.$$

$$|\alpha_{eff} - \alpha| < 19^o$$

>2 times more restrictive than B→ππ system

The Channel to watch in Future

Reaching □

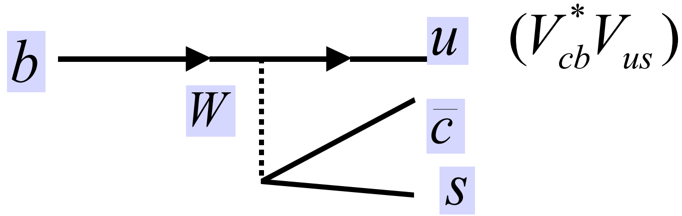
via

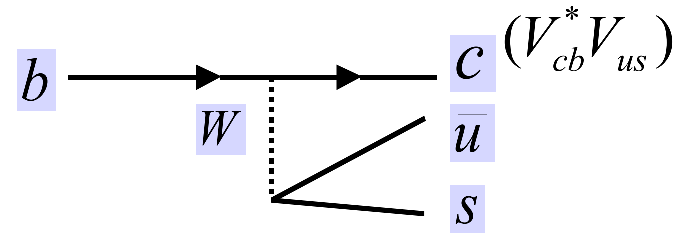
(b$\rightarrow$u($\bar{c}$s) & b$\rightarrow$c($\bar{u}$s) interference:

B$\rightarrow$DK Decays

Method and observables suggested by Gronau, Wyler,Atwood,Dunietz, Soni,Quinn, Sanda

B→DK Modes- No penguins





$A(B^{-} -> \overline{D}^{0}K^{-}) = |A_1|\, e^{i\delta_2} e^{i\gamma}$

$A(B^{-} -> D^{0}K^{-}) = |A_2|\, e^{i\delta_1}$

In $B^- \to D_{CP}K^-$, the diagrams interfere & provide the sensitivity to γ:

[$D_{CP}=(1/\sqrt{2})(D^{0} \pm \bar{D}^{0})$] $D_{CP\ even} = \pi^{+}\pi^{-}, K^{+}K^{-}$ $D_{CP\ odd} = K_s\pi^{0}, K_s\phi,..$

DK triangle

Observables

$$R_{cp} = \frac{B(B^{-} \to D_{cp}^{0}K^{-}) + B(B^{+} \to \overline{D}_{cp}^{0}K+)}{B(B^{+} \to D^{0}K^{-}) + B(B^{+} \to \overline{D}^{0}K+)} = 1 + r_{DK}^{2} \pm 2r_{DK}\cos\delta_{DK}\cos\gamma$$

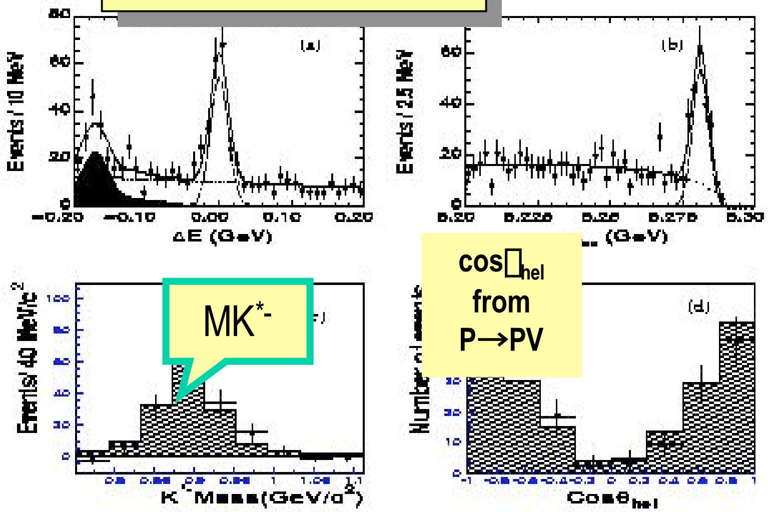
$$A_{cp} = \frac{B(B \to D_{cp}^{0}K^{-}) - B(B \to \overline{D}_{cp}^{0}K+)}{B(B \to D_{cp}^{0}K^{-}) + B(B \to \overline{D}_{cp}^{0}K+)} = \frac{\pm 2r_{DK}\sin\delta_{DK}\sin\gamma}{1 + r_{DK}^{2} \pm 2r_{DK}\cos\delta_{DK}\cos\gamma}$$

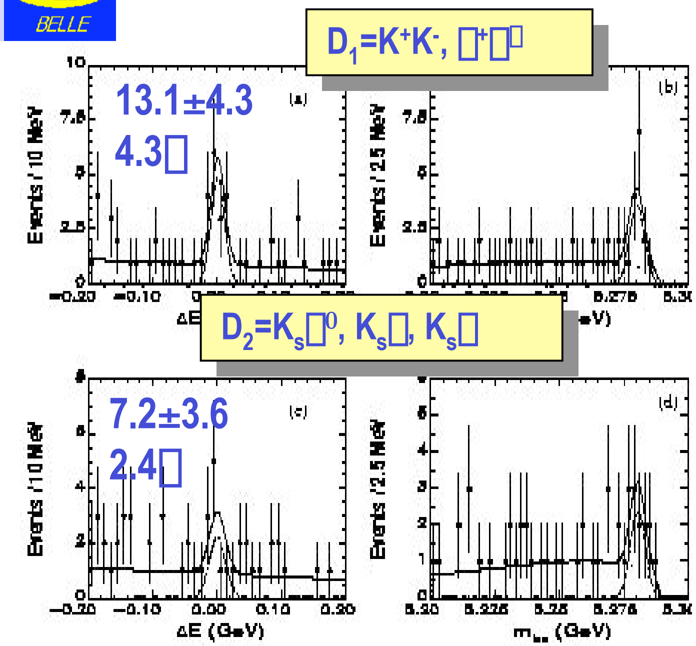
Also unknown

r_{DK} (~0.1 –0.2)
& δ_{DK}

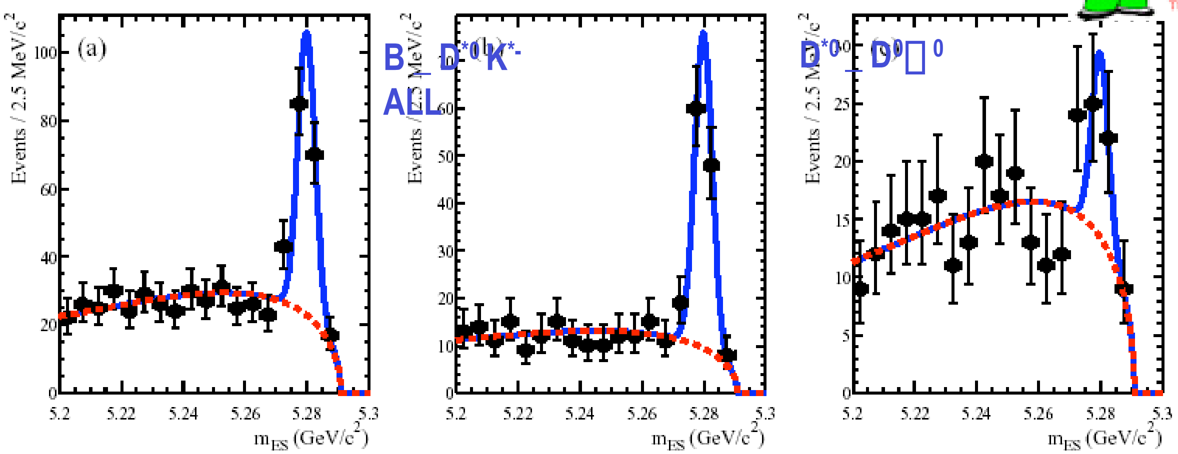
Experimenters are very active in constructing the DK puzzle

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

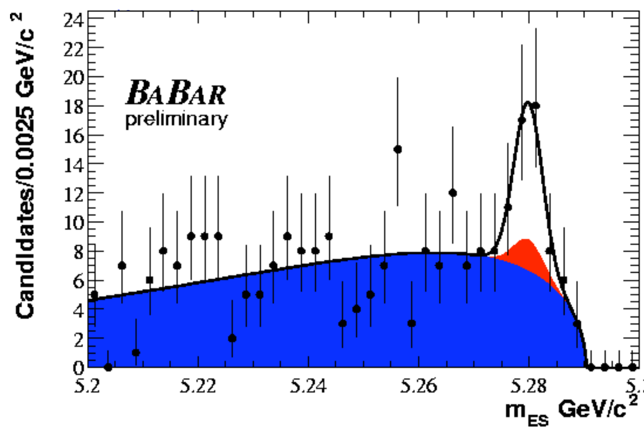




$B^- \to D^{*0} K^{*-}$



$B^0 \to D K^0$



The B→DK puzzle under construction

V_{ub}

$B \to D^0 K^-$	R1(CP=+1)	A1 (CP=+1)	R2(CP=-1)	A2 (CP=-1)
BaBar	1.06 ±0.26 ±0.17	0.17 ±0.23 ±0.08		
Belle	1.21 ±0.25 ±0.14	0.06 ±0.19 ±0.04	1.41 ±0.27 ±0.15	-0.19 ±0.17 ±0.05
Average				

$B \to D^0 K^{*-}$	$Br(\times 10^{-4})$	R1(CP=+1)	A1 (CP=+1)	R2(CP=-1)	A2 (CP=-1)
BaBar	6.3 ±0.7 ±0.4				
Belle	5.2 ±0.5 ±0.6		-0.06 ±0.33 ±0.07		0.19 ±0.50 ±0.04
CLEO	6.1 ±1.6 ±1.7				
Average					

Mode	$Br(\times 10^{-5})$ Belle	$Br(\times 10^{-5})$ BaBar	$Br(\times 10^{-5})$ Average
$B^0 \to \bar{D}^0 K^{*0}$	4.8 ±1.1 ±0.5	3.0 ±1.3 ±0.6	
$B^0 \to \bar{D}^0 K^0$	5.0 ±1.3 ±0.6	3.4 ±1.3 ±0.6	

$B^0 \to \bar{D}^{*0} K^0$	<6.6 (90% c.l.)
$B^0 \to \bar{D}^{*0} K^{*0}$	<6.9 (90% c.l.)
$B^0 \to D^0 K^{*0}$	<1.8 (90% c.l.)
$B^0 \to D^{*0} K^{*0}$	<4.0 (90% c.l.)

V_{ub}

$\mathcal{B}(\bar{B}^0 \to D^{*0} K^{*0}) =$ $(8.3 \pm 1.1(stat) \pm 1.0(sys)) \times 10^{-4}$ & $\Gamma_L/\Gamma = 0.86 \pm 0.06 \pm 0.03$ (BaBar)

$(7.7 \pm 2.2(stat) \pm 2.6(sys)) \times 10^{-4}$ CLEO

What about □: Current errors are still too large to allow for simultaneous extraction of □& ratio of (b→c) and (b→u) amplitudes (r_{dk}) and the strong phase. Need many fold more data. (□□□20 may be possible with 500 fb^{-1})

With assumptions on (r_{dk}): mild limits can be extracted. ***e.g M. Gronau (hep-ph/0306308):*** □>72□ **at 1 sigma level.**

Reaching $\sin(2\beta+\gamma)$

via

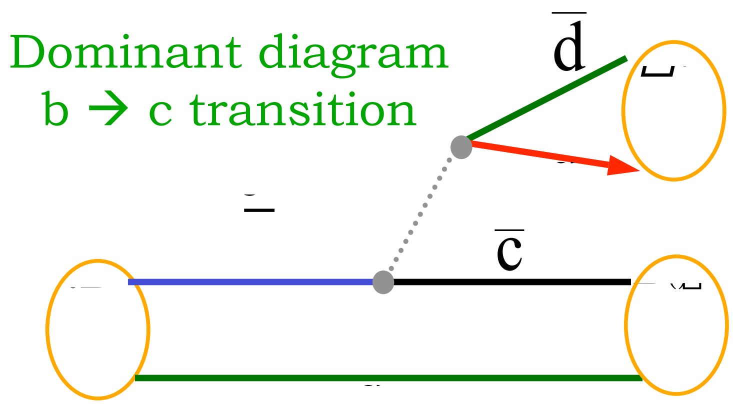
$(b \rightarrow u(\bar{c}d)$ & $b \rightarrow c(\bar{u}d))$ interference

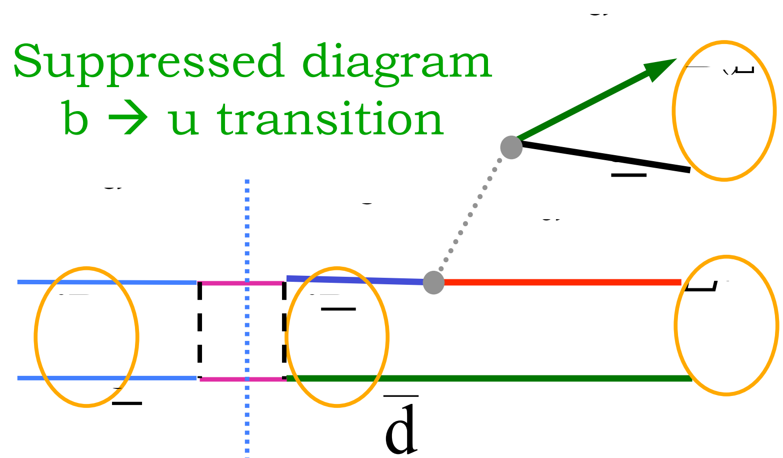
(& B^0 mixing)

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

Method and observables first suggested by Sachs,Dunietz

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





$$A(B^0 \to D^+\pi^-) \approx |A_1|\, e^{i\delta_2} V_{cb} V_{ud}^*$$

$$A(\bar{B}^0 \to D^+\pi^-) \approx |A_2|\, e^{i\delta_2} V_{cd}^* |V_{ub}|\, e^{i\gamma}$$

$$r = \frac{A(\bar{B}^0 \to D^-\pi^+)}{A(B^0 \to D^-\pi^+)} \approx 0.02$$

Small asymmetry expected

Time evolution:

$$P(B^0 \to D^\mp\pi^\pm, \Delta t) = N e^{-\Gamma|\Delta t|}\{1 \pm C\cos(\Delta m_d \Delta t) + S^\mp \sin(\Delta m_d \Delta t)\}$$

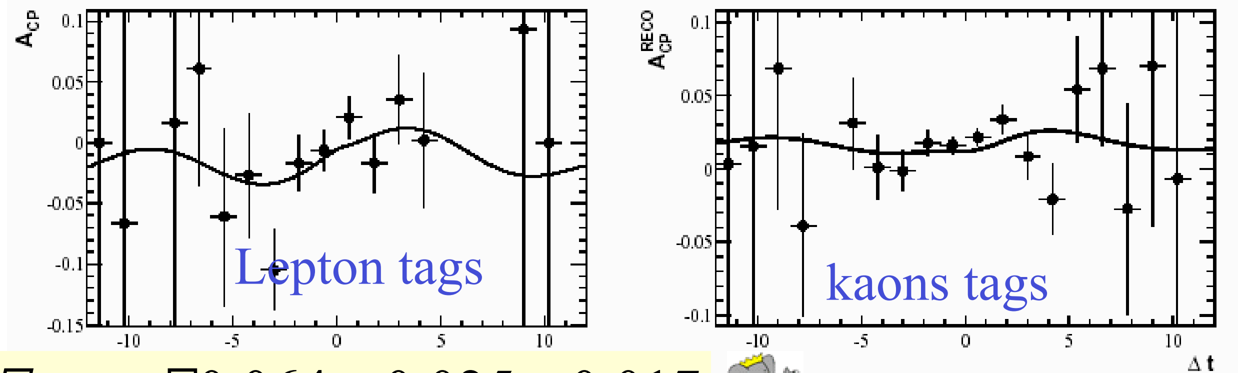
$$P(\bar{B}^0 \to D^\mp\pi^\pm, \Delta t) = N e^{-\Gamma|\Delta t|}\{1 \mp C\cos(\Delta m_d \Delta t) - S^\mp \sin(\Delta m_d \Delta t)\}$$

$$S^\pm = \frac{2r}{1+r^2}\sin(2\beta + \gamma \pm \delta)$$

$2\square+\square$

BaBar

I- Partially reconstructed $B^0 \rightarrow D^{*+}\square^-$ Decays: (number of events)



$$2r_{D^*\square}\sin(2\square+\square)\cos\square_{D^*\square} = \square 0.064 \pm 0.025 \pm 0.017$$

II - Fully reconstructed $B^0 \rightarrow D^{(*+)}\square^-$ Decays

$$2r_{D^*\square}\sin(2\square+\square)\cos\square_{D^*\square} = \square 0.068 \pm 0.038 \pm 0.021$$

$$2r_{D^*\square}\cos(2\square+\square)\sin\square_{D^*\square} = \square 0.031 \pm 0.070 \pm 0.035$$

$$2r_{D\square}\sin(2\square+\square)\cos\square_{D\square} = \square 0.022 \pm 0.038 \pm 0.021$$

$$2r_{D\square}\cos(2\square+\square)\sin\square_{D\square} = \square 0.025 \pm 0.068 \pm 0.035$$

Belle

Fully reconstructed $B^0 \rightarrow D^{(*+)}\square^-$ Decays

$$2r_{D^*\square}\sin(2\square+\square+\square_{D^*\square}) = 0.092 \pm 0.059 \pm 0.016 \pm 0.036(D^*l\square)$$

$$2r_{D^*\square}\sin(2\square+\square\square\square_{D^*\square}) = 0.033 \pm 0.056 \pm 0.016 \pm 0.036(D^*l\square)$$

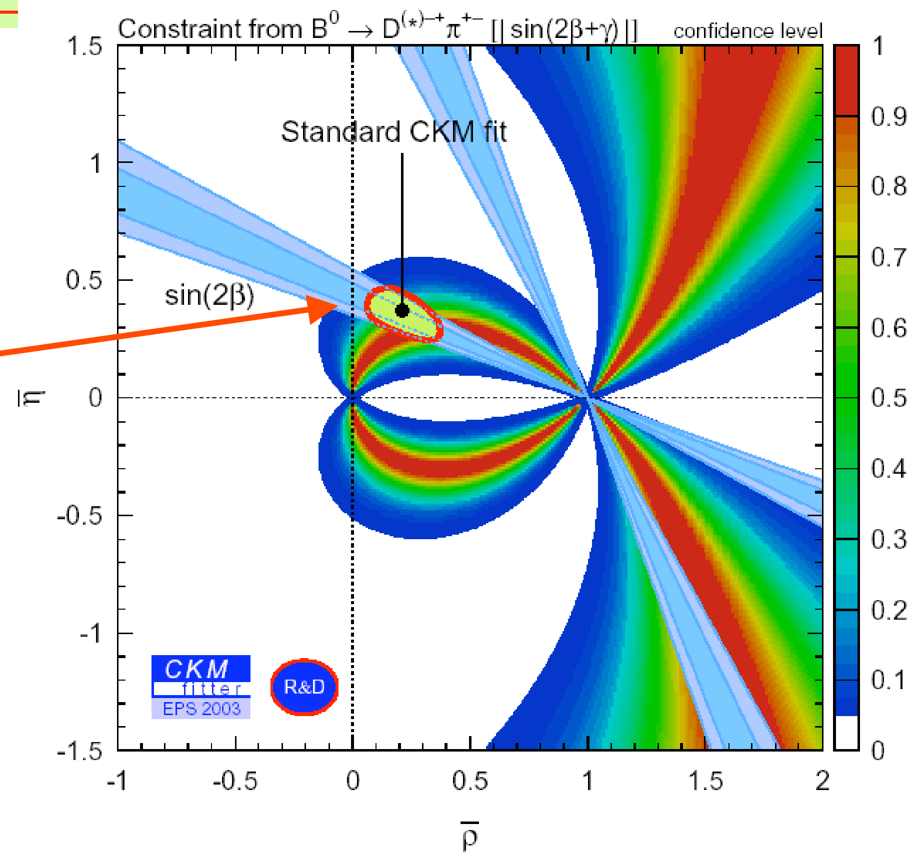
$$2r_{D\square}\sin(2\square+\square+\square_{D\square}) = 0.094 \pm 0.059 \pm 0.013 \pm 0.036(D^*l\square)$$

$$2r_{D^*\square}\sin(2\square+\square\square\square_{D^*\square}) = 0.022 \pm 0.056 \pm 0.013 \pm 0.036(D^*l\square)$$

Interpretation:BaBar's attempt

Use measurements of $B^0 \rightarrow D^{(*+)}_s \pi^+$ to estimate $r^{(*)}$ (Factorization & SU3 correction)

Favors the CKM favored solution to sin2β



Summary & Conclusions

- **Major progress made in probing the charmless sector of B decays for information on unitarity angles □ & □:**
  - **New updated measurements of CPV in B→ $\square^{+}\square^{\square}$ still show no significant evidence for CP violation in this mode.**
  - **Observation of B→ $\square^{0}\square^{0}$ – a missing component of Tree/Penguin disentanglement plan.**
  - **CPV studies in B→□□ shows hints of direct CP violation.**
  - **The decay □→□□ is now measured and looks promising for CPV studies and constraining □. Indications that penguins are smaller.**
  - **Indication of direct CPV in B→ $\square^{\square}\square^{+}$ (WA: Belle, BaBar, CLEO) No indication for large direct CP yet.**
  - **The emerging constraints on the angles from the pattern of data are consistent with the favored range from the CKM picture in the Standard Model.**
- **Penguin free modes (B→DK & D*□) are beginning to contribute to constraints on CKM parameters & many new B→DK modes identified.**
- **Much more data & major progress in theoretical understanding of hadronic B decays needed to complete the picture and conclusively perform the CKM unitarity test.**