CP Violation and Flavour

Lecture 5

Dottorato in Fisica – XXI Ciclo

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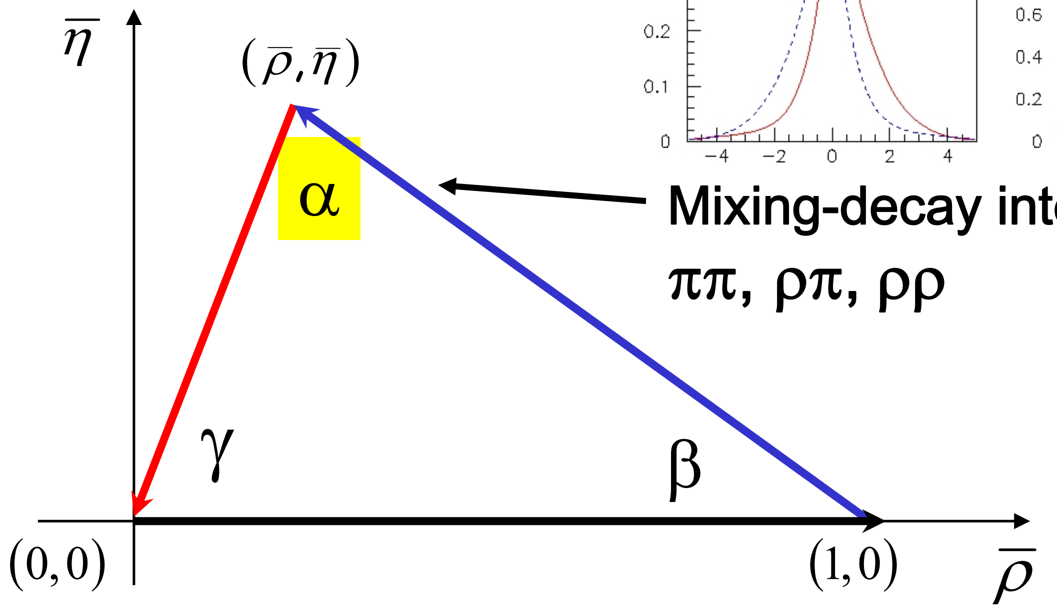
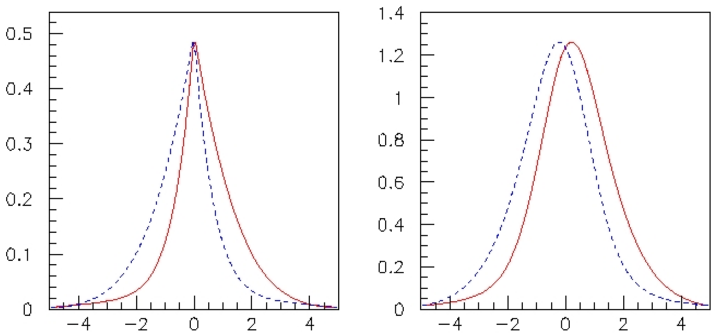
Recap and Outline

- sin2β measurements (Lecture 4):
  - $b \to c\bar{c}s$: very good agreement with SM (CKM) expectations
  - $b \to s\bar{s}s$: ϕK_S update from Belle now consistent with BaBar and compatible with the SM
  - $b \to s\bar{s}s$: all compatible with the SM within $\approx 1\sigma$, except $\eta' K_S$; all below the SM except $f_0 K_S$; more data needed to understand if there really is a non-SM effect

- Today:
  - Review of results on $\pi\pi$, $\rho\pi$, $\rho\rho$ and sin2α (ϕ_2)
  - Measurements of γ (ϕ_3)
  - Wrap-up on the Unitarity Triangle and CKM fits

sin2α (ϕ_2) from time-dependent CP asymmetries in b → uūd





Mixing-decay interference

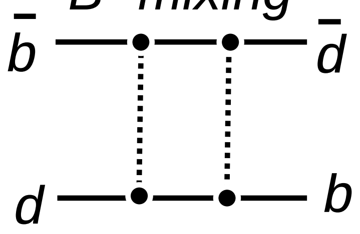
ππ, ρπ, ρρ

$\sin 2\alpha$ from $B \to \pi\pi, \rho\pi, \rho\rho$

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

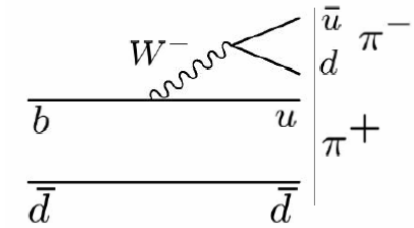
but: "penguin" is sizeable!

B^0 mixing



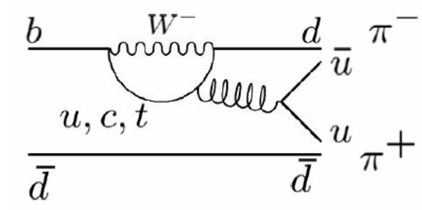
$$q/p \approx e^{-i2\beta}$$

B^0 decay: tree



$$A \propto V_{ub}^* V_{ud} \quad \propto \lambda^3$$

B^0 decay: penguin



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

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

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

→ Coefficients in time-dependent CP Asymmetry:

Neglecting penguins:

$$S_{\pi\pi} = \sin 2\alpha$$
$$C_{\pi\pi} = 0$$

But: large penguins expected !
|P/T| ~ 0.3 $\Rightarrow$

$$S_{\pi\pi} = \sqrt{1 - C_{\pi\pi}^2} \sin 2\alpha_{eff}$$
$$C_{\pi\pi} \propto \sin \delta$$

NB: Experimental challenge: BFs down to ~ 10^{-6} ; purities also are lower!

Isospin analysis for $\kappa = \alpha - \alpha_{eff}$

Use SU(2) (u and d quarks) to relate amplitudes of all ππ (ρρ) modes.

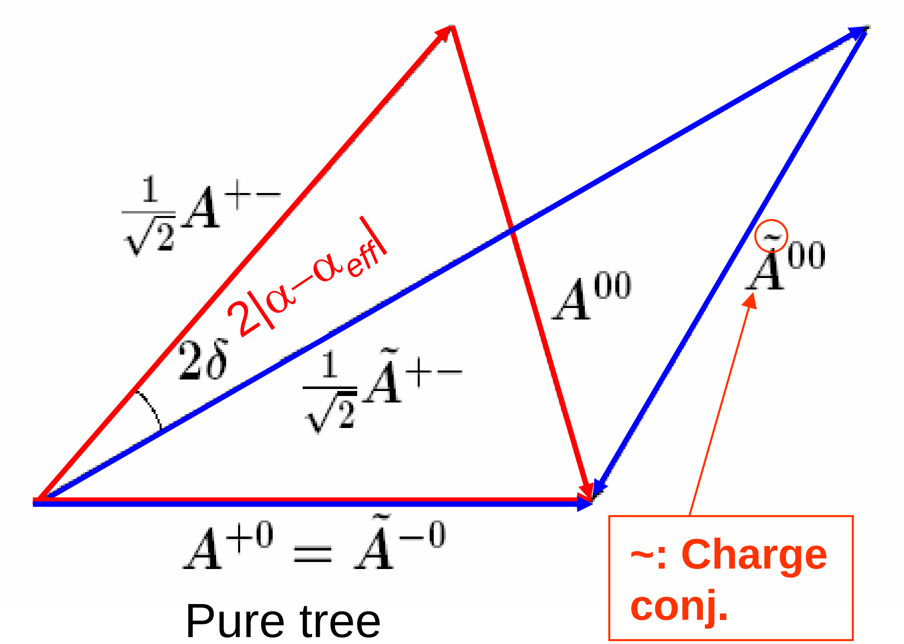
$$\mathbf{A}^{+-} = A(B^0 \to h^+ h^-)$$

$$\mathbf{A}^{+0} = A(B^+ \to h^+ h^0)$$

$$\mathbf{A}^{00} = A(B^0 \to h^0 h^0)$$

$$hh = \pi\pi, \rho\rho$$

Gronau, London : PRL**65**, 3381 (1990)



ππ favored for isospin analysis

- $\pi^0\pi^0$ measured: too small for isospin analysis, too large for limits

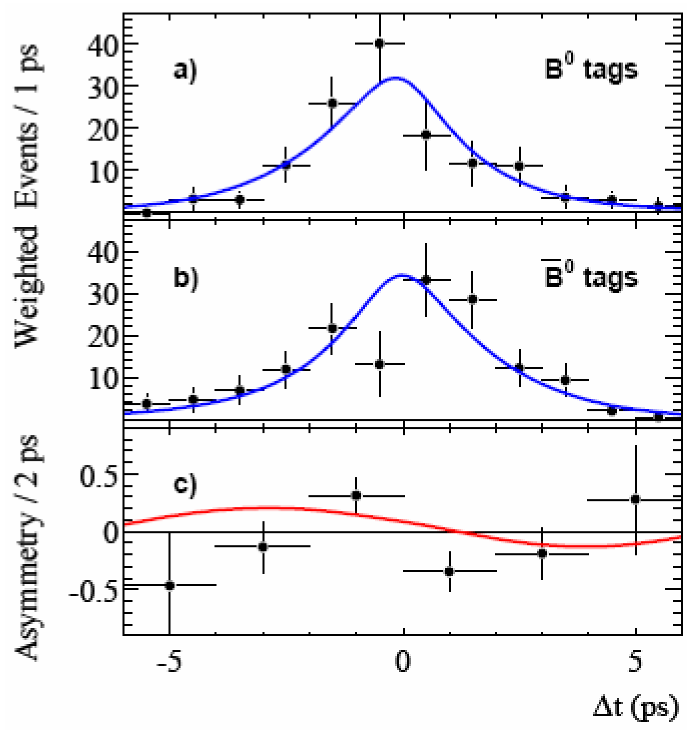
ρρ has 3 polarization amplitudes

- Expected dilution because of mixed CP, but instead…
- …almost 100% longitudinally polarized: pure CP-even state
- Larger branching fraction than ππ
- $\rho^0\rho^0$ not observerd yet (small)
- → good limit on $\alpha - \alpha_{eff}$

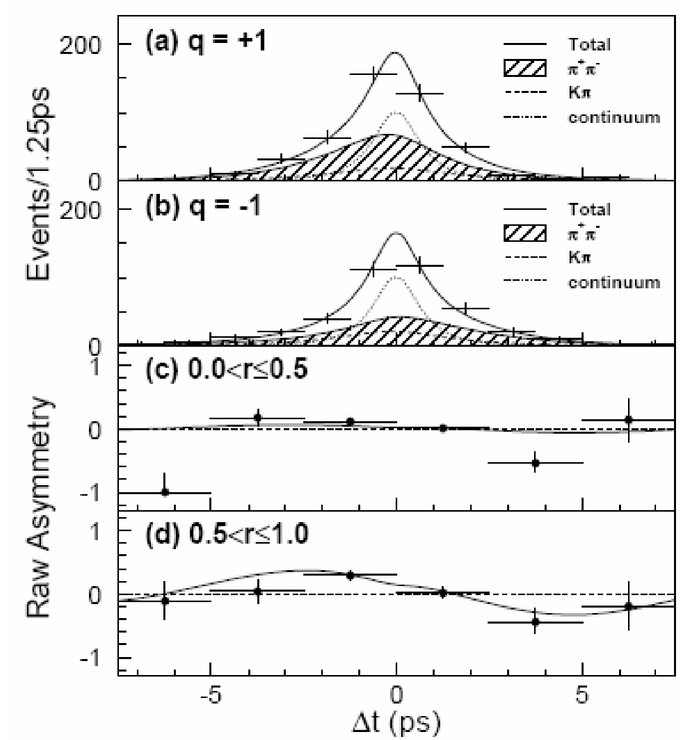
ρρ gives best determination of α

$B^0 \rightarrow \pi^+\pi^-$

BaBar (227 M B-pairs)

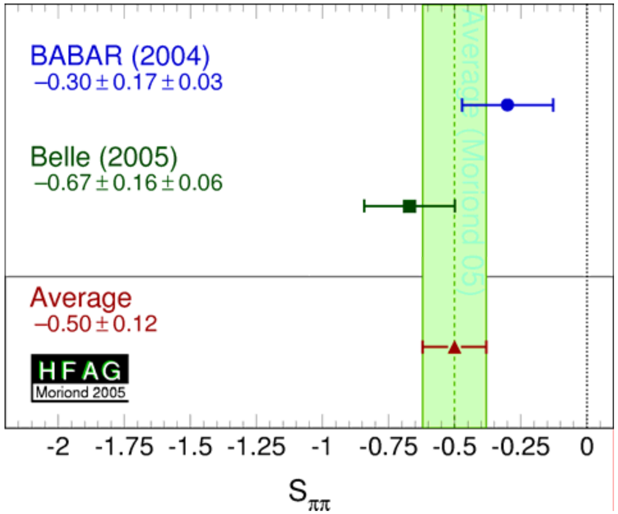


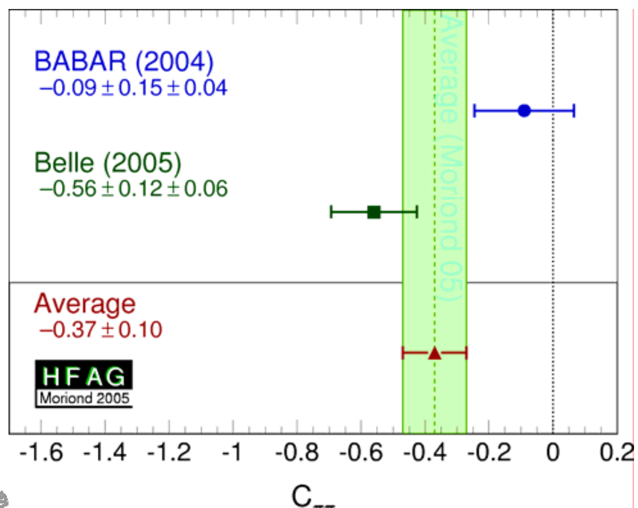
Belle (275 M B-pairs)



CP fit results: $S_{\pi\pi}$ and $C_{\pi\pi}$

Improved agreement (CL=0.019, 2.3σ)

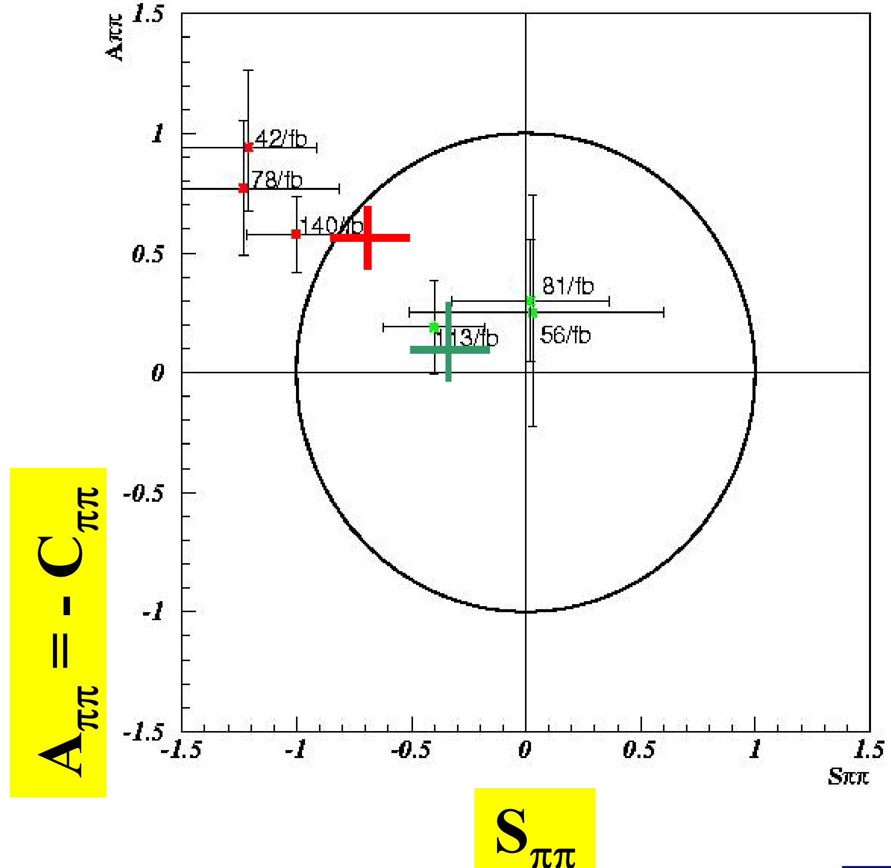




BaBar, hep-ex/0501071
Belle, hep-ex/0502035

- BaBar
- Belle

Belle claim: 4.0 σ evidence of direct CPV

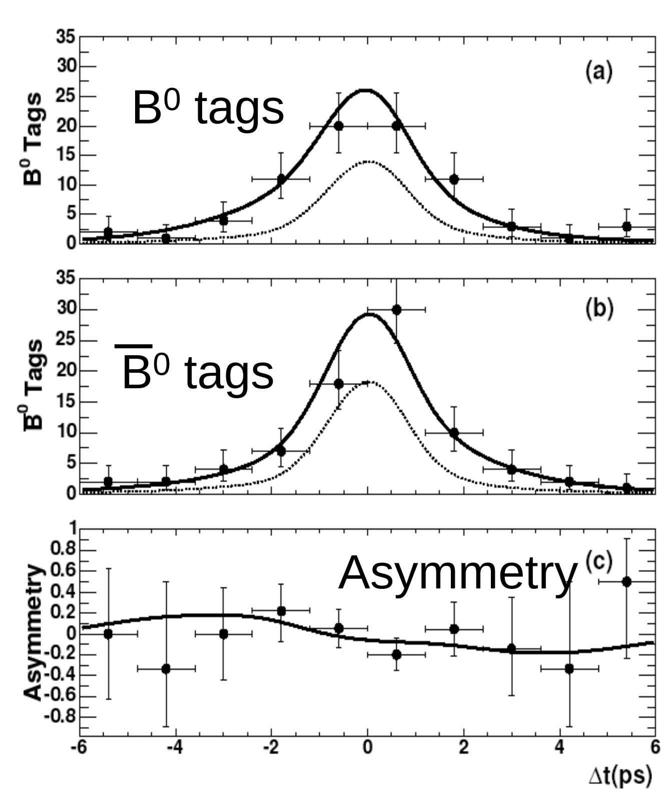


$B \to \pi\pi$: experimental issues

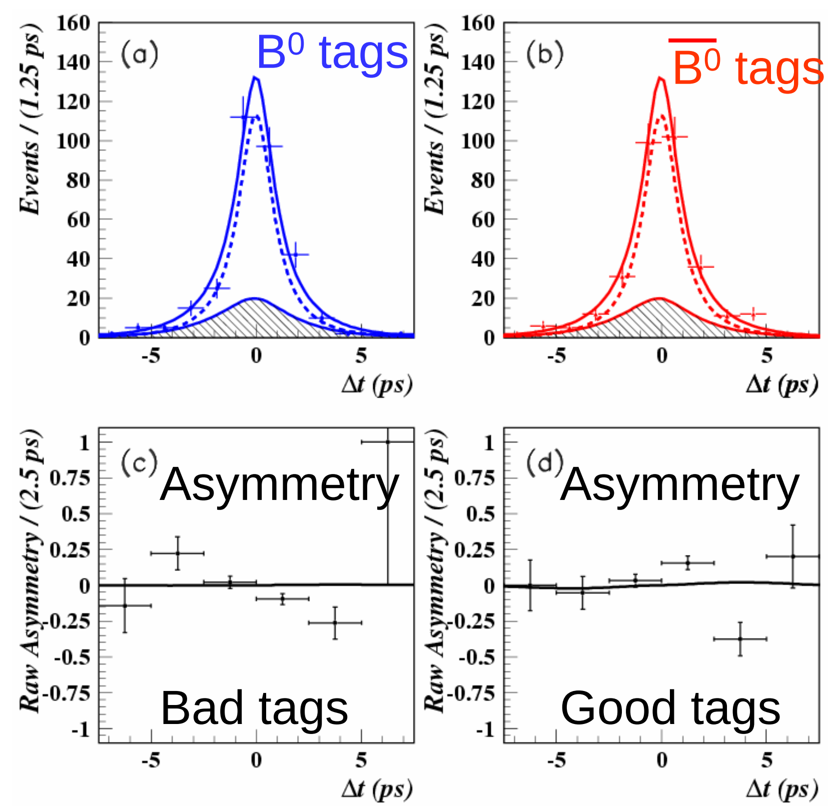
- Higher backgrounds than charmonium; K-π separation to distinguish $\pi\pi$ from $K\pi$; otherwise the analysis is *as "simple"*
  - m_{ES}, ΔE, "Fischer", θ_C^+, θ_C^- ; Δt , "tag"
- For the isospin analysis:
  - $B^0 \to \pi^0\pi^0$: BF = $(1.45 \pm 0.29) \times 10^{-6}$
  - Too small, not enough
- Direct CPV evidence from Belle (4.0σ), not seen by BaBar

$B^0 \to \rho\rho$

BaBar (232 M B-pairs)



Belle (275 M B-pairs)



$B \to \rho^+ \rho^-$

- Reconstruct the $\rho^{+(-)} \to \pi^{+(-)} \pi^0$

- As for $\pi\pi$, CP fit based on: kinematical signal identification + π/K separation + event shape variables; and Δt, tag

- From the polarization measurement (f_L): almost pure CP eigenstate

- It can be treated as a "two-body" decay, but: *larger backgrounds!* Not only continuum, also from other B decays, and "self-cross-feed" (SCF)

$B \to \rho^+\rho^-$

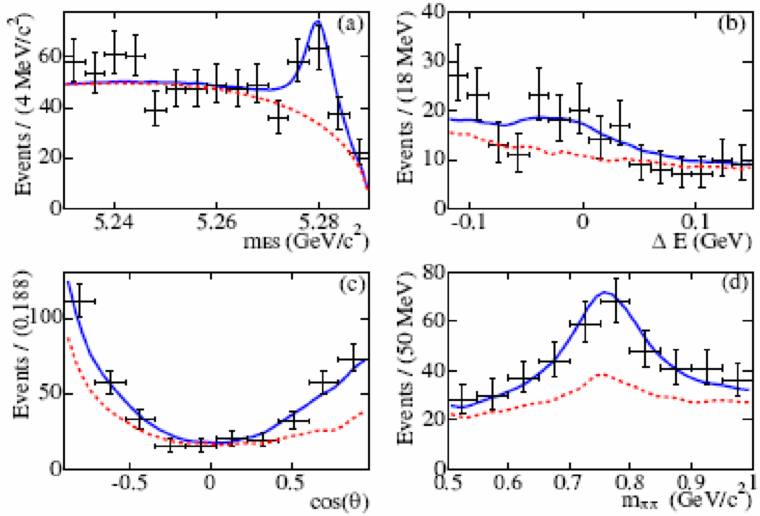


FIG. 1: The distributions for the highest purity tagged events for the variables m_{ES} (a), ΔE (b), cosine of the ρ helicity angle (c) and $m_{\pi^{\pm}\pi^{0}}$(d). The dotted lines are the sum of backgrounds and the solid lines are the full PDF.

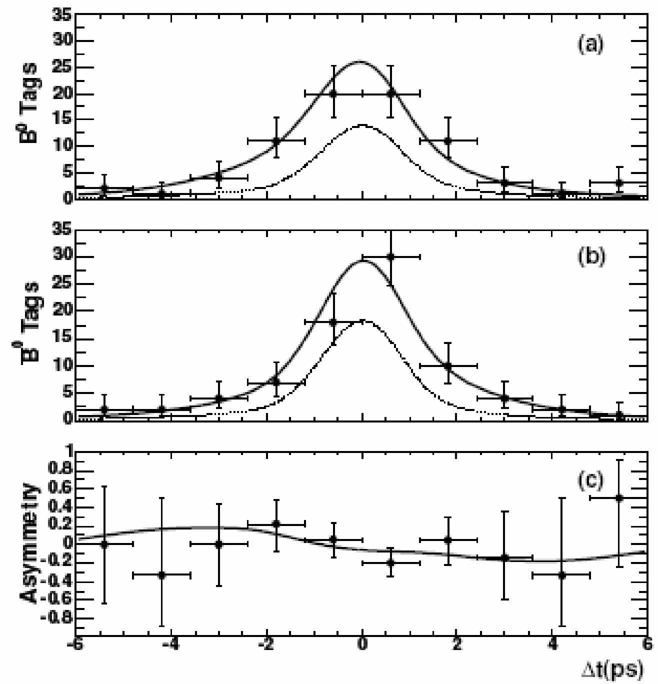


FIG. 2: The Δt distribution for a sample of events enriched in signal for B^0 (a) and $\overline{B}^0$ (b) tagged events. The dotted lines are the sum of backgrounds and the solid lines are the sum of signal and backgrounds. The time-dependent CP asymmetry (see text) is shown in (c), where the curve is the measured asymmetry.

F.Forti, LP05

Isospin analysis with $B \to \rho\rho$

Almost complete polarization f_L
$\Rightarrow \approx$ CP eigenstate

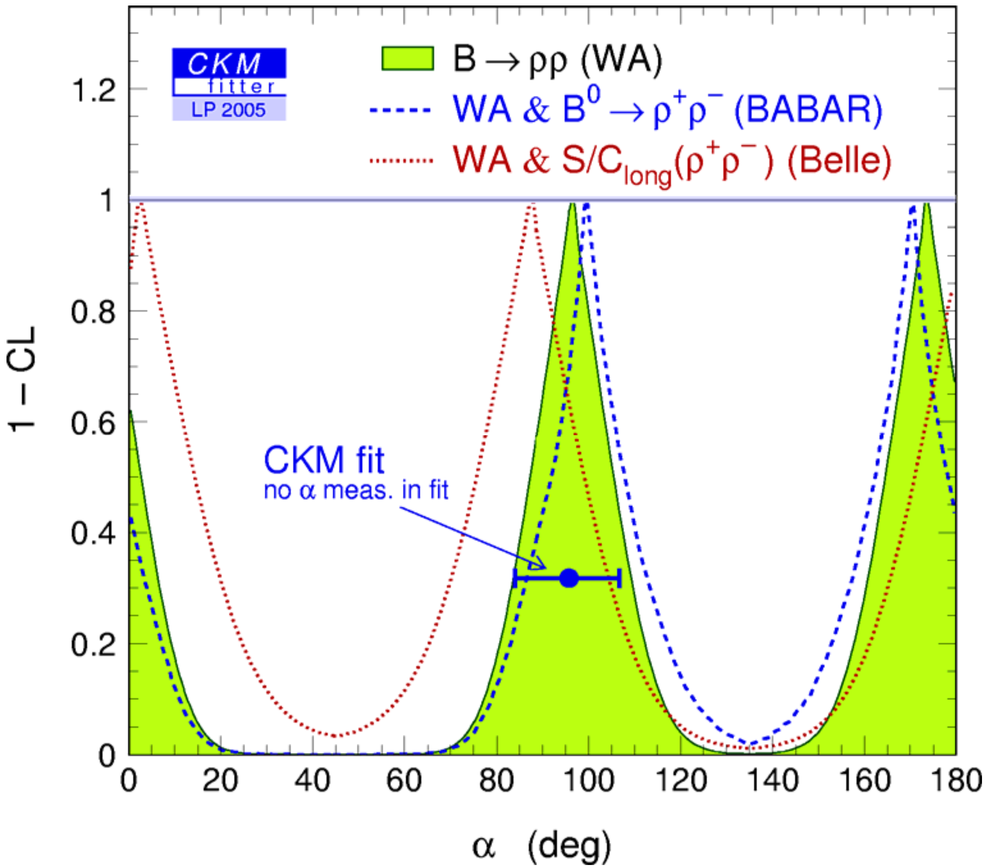
Time-dep. fit
$S_{\rho\rho, L}$, $C_{\rho\rho, L}$

Branching Fractions isospin-related channes

New	BABAR	BELLE
f_L	$0.978 \pm 0.014^{+0.021}_{-0.029}$	$0.951^{+0.033+0.029}_{-0.039-0.031}$
$S_{\rho\rho,L}$	$-0.33 \pm 0.24^{+0.08}_{-0.14}$	$0.09 \pm 0.42 \pm 0.08$
$C_{\rho\rho,L}$	$-0.03 \pm 0.18 \pm 0.09$	$0.00 \pm 0.30^{+0.09}_{-0.10}$
$B_{\rho+\rho-}$	$(30 \pm 4 \pm 5) \times 10^{-6}$	$(24.4 \pm 2.2^{+3.8}_{-4.1}) \times 10^{-6}$
$B_{\rho+\rho0}$	$(22.5^{+5.7}_{-5.4} \pm 5.8) \times 10^{-6}$	$(31.7 \pm 7.1^{+3.8}_{-6.7}) \times 10^{-6}$
$B_{\rho0\rho0}$	$< 1.1 \times 10^{-6}$	–

Use averages for BF and S/C coefficients
Use BABAR $\rho^0\rho^0$ limit, which dominates the error. $|\alpha - \alpha_{eff}| < 11°$

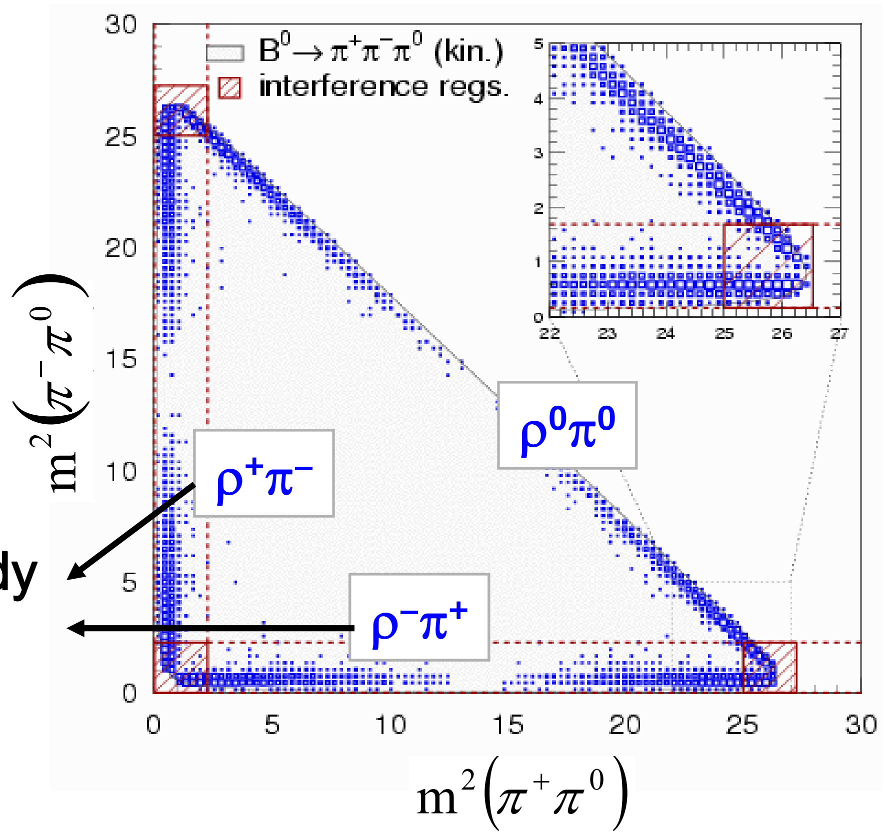
Isospin analysis with $B \to \rho\rho$



$$\alpha[\rho\rho] = 96 \pm 13°$$

$B^0 \to \rho\pi$

$B^0 \to \pi^+\pi^-\pi^0$ “Dalitz plot”



(1) Quasi-2-body analysis

(2) Full “Dalitz” analysis

(1) "Quasi 2-body" parameters

Not a CP eigenstate: time dependence is more complicated:
5 coefficients instead of just 2:

Fit parameters

$\overset{(-)}{B}{}^0 \to \rho^+\pi^-$: $\lambda_{\rho^+\pi^-}$

$\overset{(-)}{B}{}^0 \to \rho^-\pi^+$: $\lambda_{\rho^-\pi^+}$

→ λ_{CP}, λ_{tag}

→

- $\mathcal{A}_{\rho\pi}$ Global charge asymmetry
- $C_{\rho\pi}$ Direct CP-violating
- $S_{\rho\pi}$ Mixing/decay interference CP-violating
- $\Delta S_{\rho\pi}$ Dilution parameter
- $\Delta C_{\rho\pi}$ Linked to $B^0 \to \rho^-\pi^+$ vs $\overline{B}{}^0 \to \rho^-\pi^+$

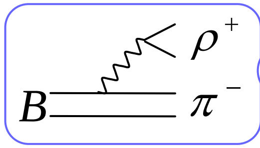
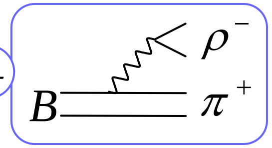
These coefficients are related to two more intuitive asymmetries:

$$A_{-+} \equiv \frac{\mathcal{N}(\overline{B}{}^0 \to \rho^+\pi^-) - \mathcal{N}(B^0 \to \rho^-\pi^+)}{\mathcal{N}(\overline{B}{}^0 \to \rho^+\pi^-) + \mathcal{N}(B^0 \to \rho^-\pi^+)} = \frac{\mathcal{A}_{\rho\pi} - C_{\rho\pi} - \mathcal{A}_{\rho\pi} \times \Delta C_{\rho\pi}}{1 - \Delta C_{\rho\pi} - \mathcal{A}_{\rho\pi} \times C_{\rho\pi}}$$

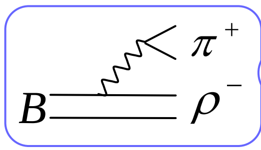
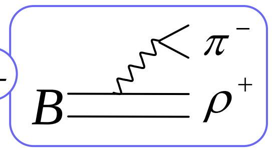
$$A_{+-} \equiv \frac{\mathcal{N}(\overline{B}{}^0 \to \rho^-\pi^+) - \mathcal{N}(B^0 \to \rho^+\pi^-)}{\mathcal{N}(\overline{B}{}^0 \to \rho^-\pi^+) + \mathcal{N}(B^0 \to \rho^+\pi^-)} = \frac{\mathcal{A}_{\rho\pi} + C_{\rho\pi} + \mathcal{A}_{\rho\pi} \times \Delta C_{\rho\pi}}{1 + \Delta C_{\rho\pi} + \mathcal{A}_{\rho\pi} \times C_{\rho\pi}}$$

"Quasi 2-body" parameters

F.Forti, LP05

$A^{+-}_{\rho\pi} \cong$  $-$ 

$= -0.21 \pm 0.11 \pm 0.04$

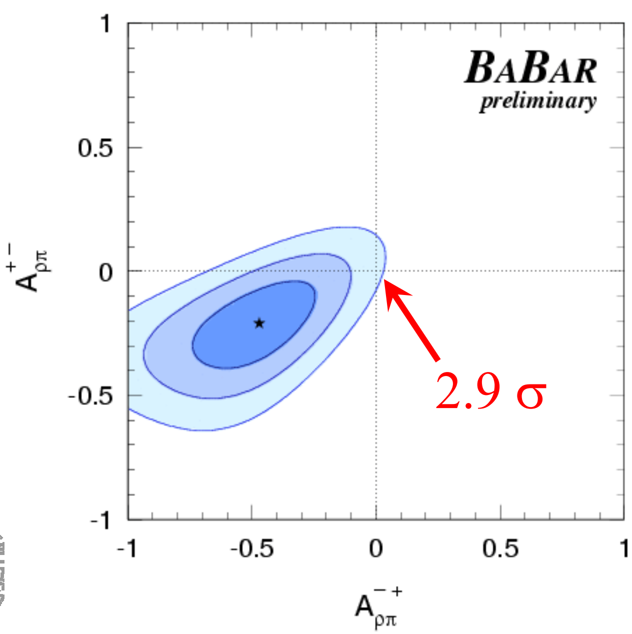
$A^{-+}_{\rho\pi} \cong$  $-$ 

$= -0.47^{+0.14}_{-0.15} \pm 0.06$

Hint of direct *CP*-violation →

	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 3.6σ



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

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

hep-ex/0408003

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

BABAR CONF-04/038

"Full Dalitz" analysis

A full time-dependent Dalitz plot analysis can constrain α.

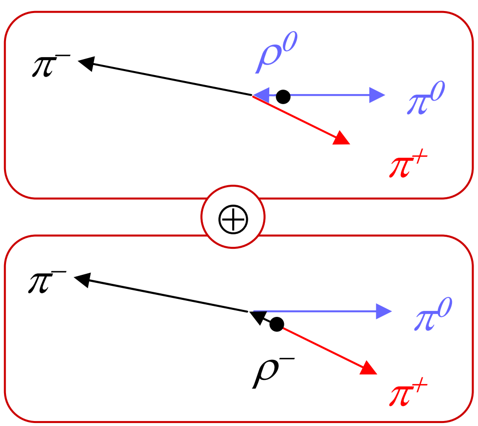
Time-dependent decay rate: Snyder, Quinn : PRD 48, 2139 (1993)

$$|\mathcal{A}_{3\pi}^{\pm}(\Delta t)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big[|\mathcal{A}_{3\pi}|^2 + |\overline{\mathcal{A}}_{3\pi}|^2 \mp \left(|\mathcal{A}_{3\pi}|^2 - |\overline{\mathcal{A}}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t)$$
$$\pm 2\mathrm{Im}\left[\overline{\mathcal{A}}_{3\pi}\mathcal{A}_{3\pi}^{*}\right]\sin(\Delta m_d \Delta t)\Big] ,$$

Interference at equal masses-squared gives information on strong phases between resonances

$$A_{3\pi} = f_+ A^+ + f_- A^- + f_0 A^0$$
$$\overline{A}_{3\pi} = f_+ \overline{A}^+ + f_- \overline{A}^- + f_0 \overline{A}^0$$

script {+,–,0} refers to {ρ^+,ρ^-,ρ^0}



The "f"s are functions of the Dalitz-plot and describe the kinematics of $B \to \rho\pi$ (S→VS).

The "A"s are the complex amplitudes containing weak and strong phases. They are independent of the Dalitz variables.

Experimental & analysis issues

- Signal and backgrounds: also here, not only continuum but also “other B” and “self-cross-feed”: keep migrations in the interference regions under control!

- Rather long path from fitted coefficients to the Unitarity Angle, through parametrizations of the tree and penguin amplitudes and their phases

F.Forti, LP05

α determination

ππ determination: limited power

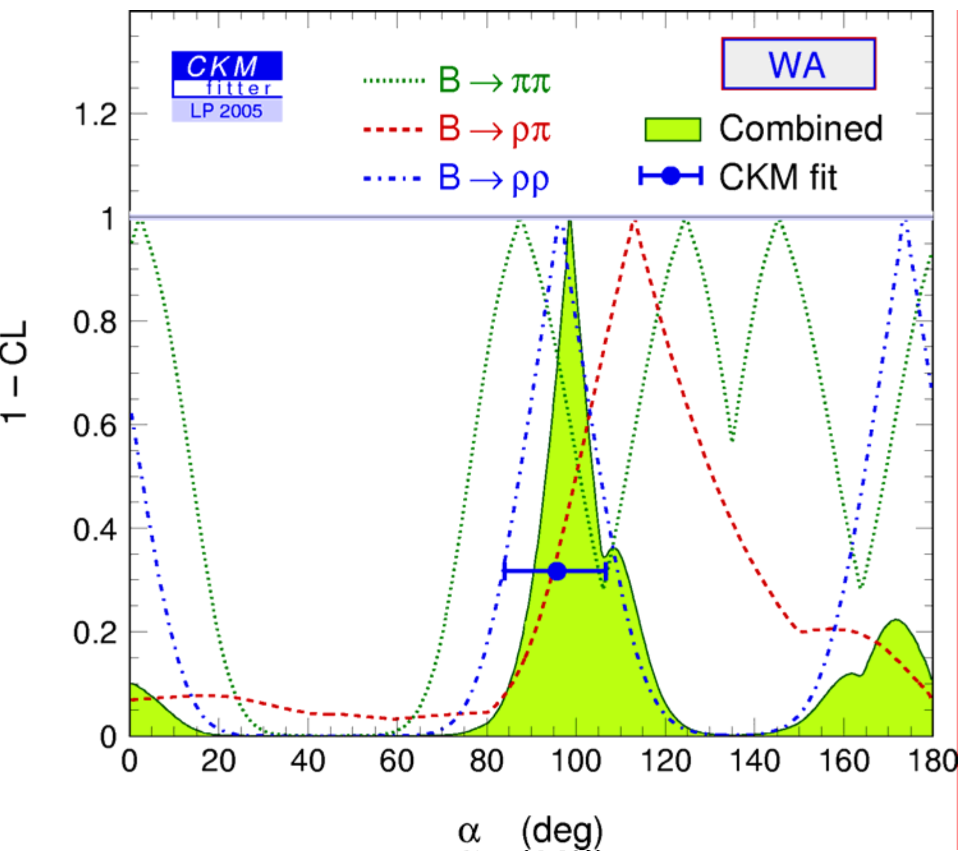
ρρ best individual measurement

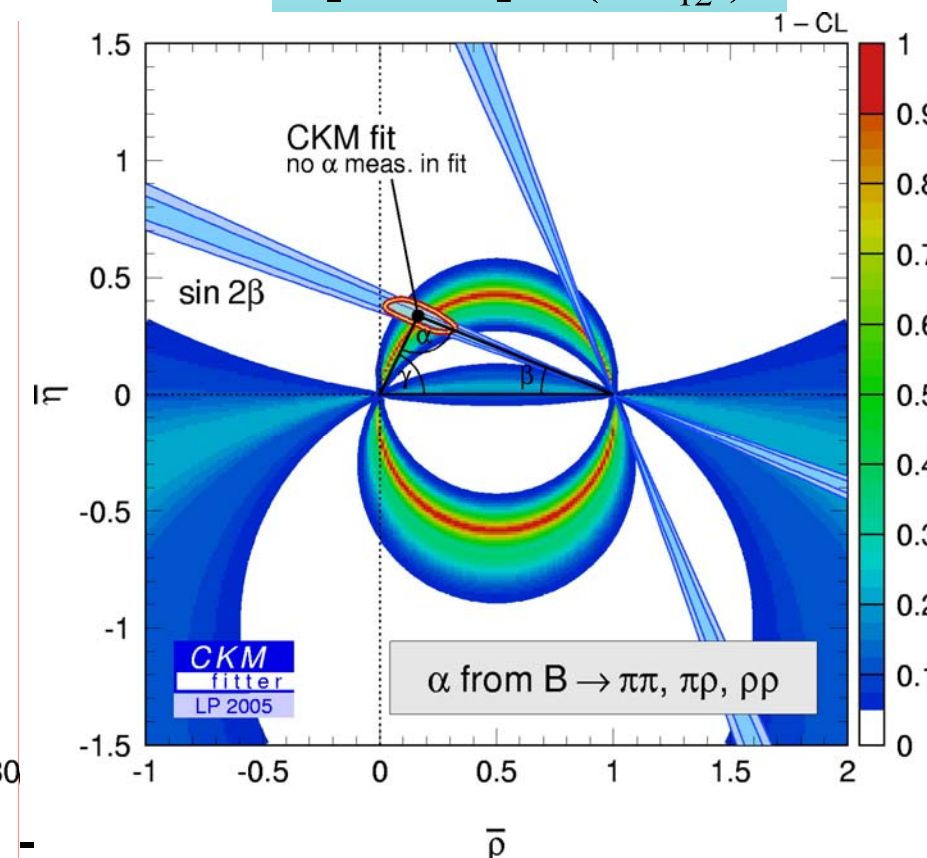
Mirror solution are disfavored, thanks to ρπ.

- **Same precision as global CKM fit.**

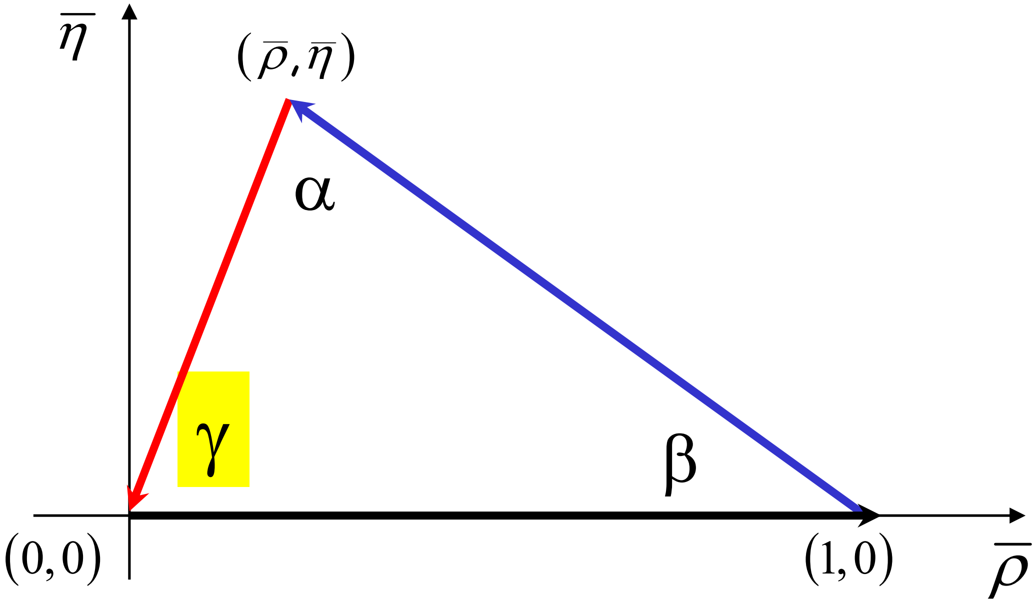
$$\alpha[\text{all}] = (99^{+12}_{-9})°$$

$$\alpha[\text{CKM}] = (96^{+11}_{-12})°$$





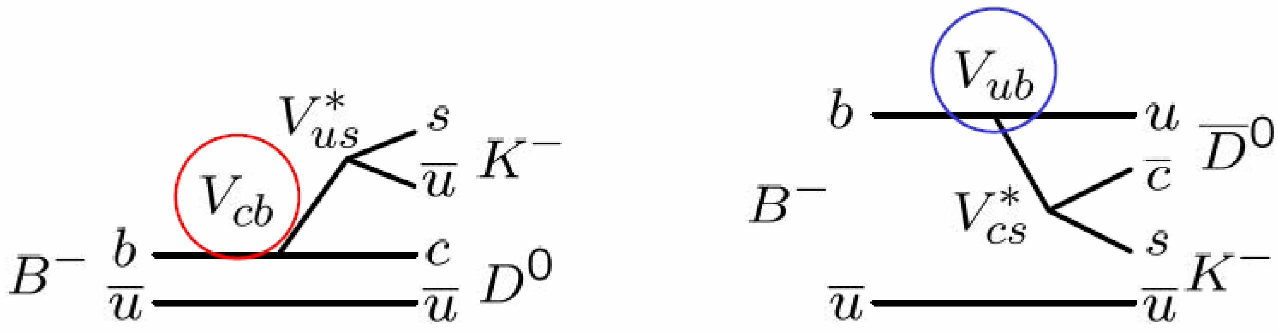
gamma (ϕ_3)



$\overline{\eta}$
$(\overline{\rho},\overline{\eta})$
α
γ
β
(0,0)
(1,0)
$\overline{\rho}$

Methods to measure γ

- *The challenge*: directly measure the $b \to u$ phase (γ) relative to the $b \to c$ phase (0).



- These amplitudes *interfere* for D final states that both D^0 and $\overline{D}^0$ can decay to.

$$r_b \equiv \frac{A(b \to u)}{A(b \to c)} = R_u \, F_{cs}$$

larger $r_b \Rightarrow$ larger interference term

$\Rightarrow$ more sensitivity to γ

F_{cs} is an *unknown* color-suppression factor. Expected to be in the range [0.2,0.5].

R_u is the left side of the Unitarity Triangle (~0.4).

$r_b \approx 0.1 \div 0.2$

Methods to measure γ

- $B^- \to D^{(*)0} K^{(*)-}$, $B^- \to \bar{D}^{(*)0} K^{(*)-}$
  - $D^{(*)0}$, $\bar{D}^{(*)0}$ decay to same final state.
    - D^0_{CP} Gronau-London-Wyler (*GLW*)
    - $D^0_{\text{Non-CP}}$ Atwood-Dunietz-Soni (*ADS*)
    - $D^0 \to K_s \pi^+ \pi^-$ Dalitz Giri-Grossman-Soffer-Zupan

The best results at present

Problems:
Squashed triangles
Small triangles
Model dependence

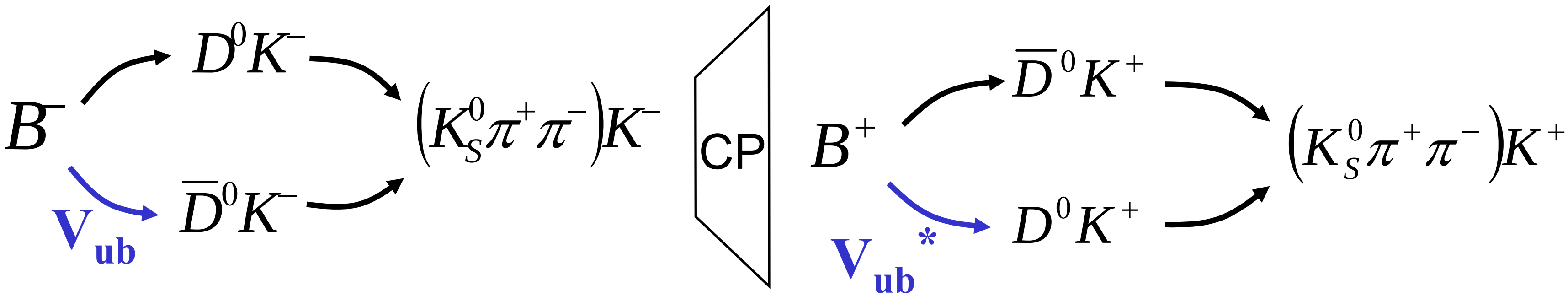
- $\sin(2\beta + \gamma)$ in $B^0 \to D^{(*)\pm} \pi^\mp$
  - Via $B\bar{B}$ mixing.

Alternative interference method:
2β from mixing (time-dependent!),
γ from suppressed $b \to u$ decays

Large number of events, but: small time-dependent asymmetry

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

- Interference since both $D^0 \to K^0_S\pi^+\pi^-$ and $\overline{D}^0 \to K^0_S\pi^+\pi^-$



- Sensitivity to γ enters via amplitude $\propto V_{ub}$; interference occurs in Dalitz plot for $D^0(\overline{D}^0) \to K^0_S\pi^+\pi^-$

$$M_+ = f\left(m_+^2, m_-^2\right) + re^{i(\delta+\gamma)} f\left(m_-^2, m_+^2\right)$$
$$M_- = f\left(m_-^2, m_+^2\right) + re^{i(\delta-\gamma)} f\left(m_+^2, m_-^2\right)$$

$$r = \frac{A(b \to u)}{A(b \to c)} = \frac{A\left(B^- \to \overline{D}^0K^-\right)}{A\left(B^- \to D^0K^-\right)}$$

Dalitz distributions

$\left|f(m_+^2, m_-^2) + re^{i(+\phi_3+\delta)} f(m_-^2, m_+^2)\right|^2$ and $\left|f(m_-^2, m_+^2) + re^{i(-\phi_3+\delta)} f(m_+^2, m_-^2)\right|^2$

These will have different patterns if $r \neq 0$ and $\phi_3 \neq 0$. r, ϕ_3, and δ can be extracted from the difference.

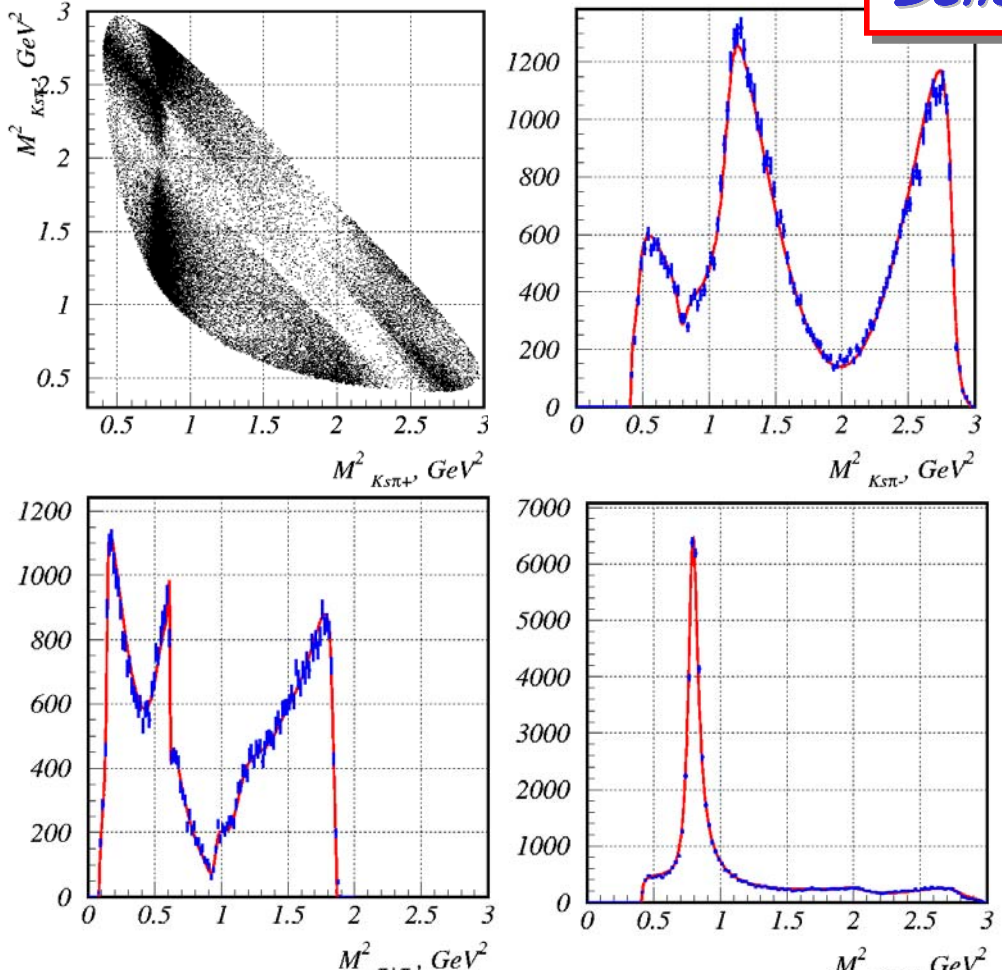
D^0 Dalitz Plot Model (old plots)

Select D^0 sample from

$$D^{*+} \to D^0\left[\to K_S^0\pi^+\pi^-\right]\pi^+$$

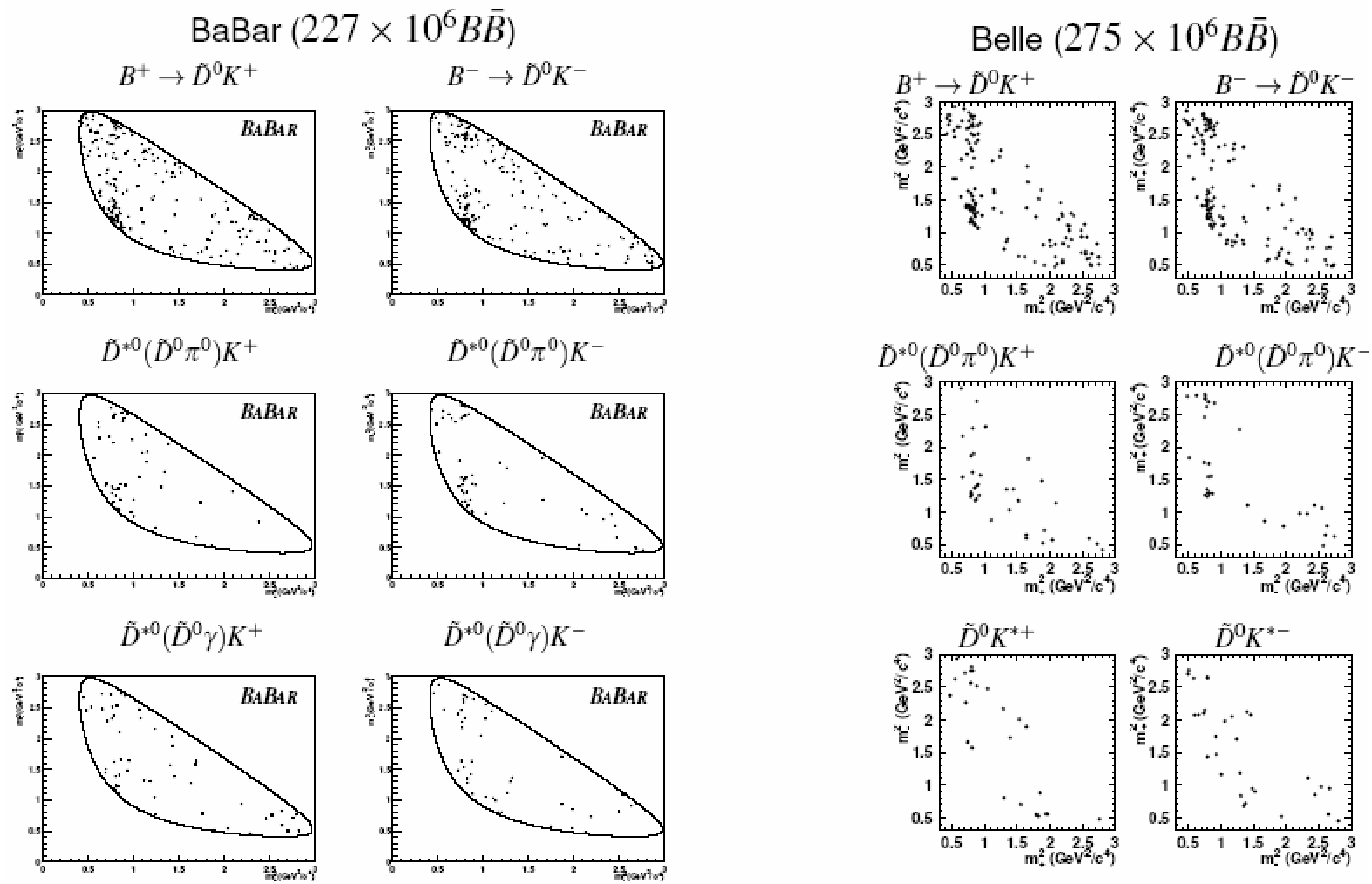
Resonance	Our fit		
	Amplitude	Phase, °	Fit fraction
$\sigma_1\ K_s$	1.66±0.11	218.0±3.8	11%
$\rho(770)\ K_S$	1	0	21%
$\omega\ K_s$	$(3.30\pm1.13)\cdot10^{-2}$	114.3±2.3	0.4%
$f_0(980)\ K_s$	0.405±0.008	212.9±2.3	4.8%
$\sigma_2\ K_s$	0.31±0.05	236±11	0.9%
$f_2(1270)\ K_s$	1.36±0.06	352±3	1.5%
$f_0(1370)\ K_s$	0.82±0.10	308±8	0.9%
$K^*(892)^-\pi^+$	1.656±0.012	137.6±0.6	60%
$K^*(892)^+\pi^-$	0.149±0.007	325.2±2.2	0.5%
$K^*_0(1430)^-\pi^+$	1.96±0.04	357.3±1.5	5.8%
$K^*_0(1430)^+\pi^-$	0.30±0.05	128±8	0.1%
$K^*_2(1430)^-\pi^+$	1.32±0.03	313.5±1.8	2.8%
$K^*_2(1430)^+\pi^-$	0.21±0.03	281.5±9	0.07%
$K^*(1680)^+\pi^-$	2.56±0.22	70±6	0.4%
$K^*(1680)^-\pi^+$	1.02±0.22	102±11	0.07%
Non resonant	6.1±0.3	146±3	24%

101800 events, 3% background



Dalitz distributions

K.Abe, LP05



Difference between B^+ and B^- signifies direct CP violation

Fitting for $Re(r_\pm e^{i(\pm\phi_3+\delta)})$ and $Im(r_\pm e^{i(\pm\phi_3+\delta)})$

- Dalitz distributions

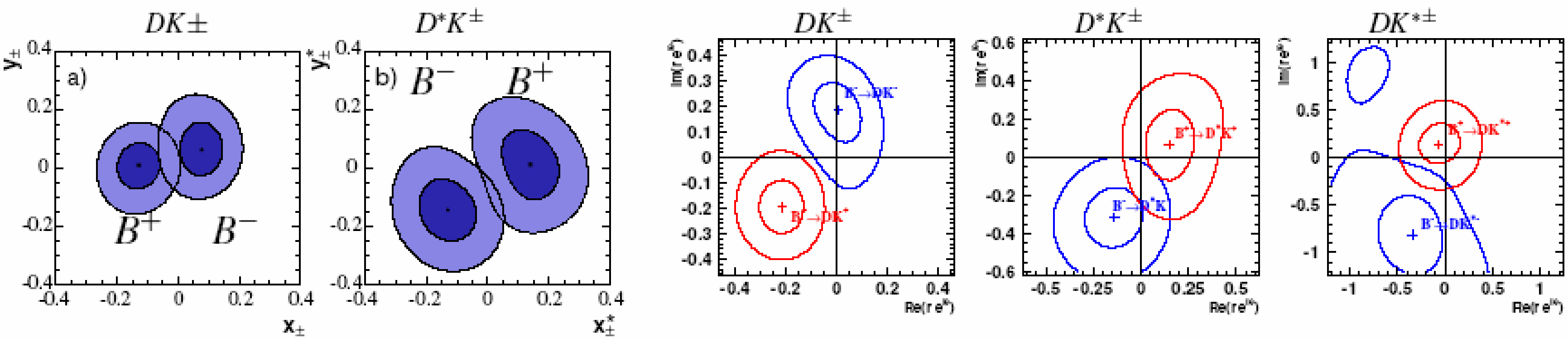
$$B^+: \quad \left|f(m_+^2, m_-^2) + r_+ e^{i(\phi_3+\delta)} f(m_-^2, m_+^2)\right|^2 \qquad B^-: \quad \left|f(m_-^2, m_+^2) + r_- e^{i(-\phi_3+\delta)} f(m_+^2, m_-^2)\right|^2$$

Physically $r_+ = r_-$, allow them to vary separately for better statistical behaviour

- Determine $x_\pm = Re(r_\pm e^{i(\pm\phi_3+\delta)})$, $y_\pm = Im(r_\pm e^{i(\pm\phi_3+\delta)})$ for each decay mode
- Perform pseudo-experiment technique (Toy Monte Carlo)

$$(x_\pm, y_\pm) \times \text{decay mode} \rightarrow (r, \delta) \times \text{decay modes and } \phi_3$$

BaBar　　　　　　　　　　Belle



γ (ϕ_3) Dalitz fit results

K.Abe, LP05

	Modes	r	δ (°)	ϕ_3 (°)
BaBar	DK	$0.118 \pm 0.079 \pm 0.034^{+0.036}_{-0.034}$	$104 \pm 45^{+17}_{-21}{}^{+16}_{-24}$	
	D^*K	$0.169 \pm 0.096^{+0.030}_{-0.028}{}^{+0.029}_{-0.026}$	$296 \pm 41^{+14}_{-12} \pm 15$	
	combined			$70 \pm 31^{+12}_{-10}{}^{+14}_{-11}$
Belle	DK	$0.21 \pm 0.08 \pm 0.03 \pm 0.04$	$157 \pm 19 \pm 11 \pm 21$	
	D^*K	$0.12^{+0.16}_{-0.11} \pm 0.02 \pm 0.04$	$321 \pm 57 \pm 11 \pm 21$	
	combined			$68^{+14}_{-15} \pm 13 \pm 11$
	DK^*	$0.25^{+0.17}_{-0.18} \pm 0.09 \pm 0.04 \pm 0.08$	$358 \pm 35 \pm 8 \pm 21 \pm 49$	$112 \pm 35 \pm 9 \pm 11 \pm 8$

Errors: statistical, detector systematic, $D \to K_S\pi\pi$ decay model, non-resonant $DK\pi$

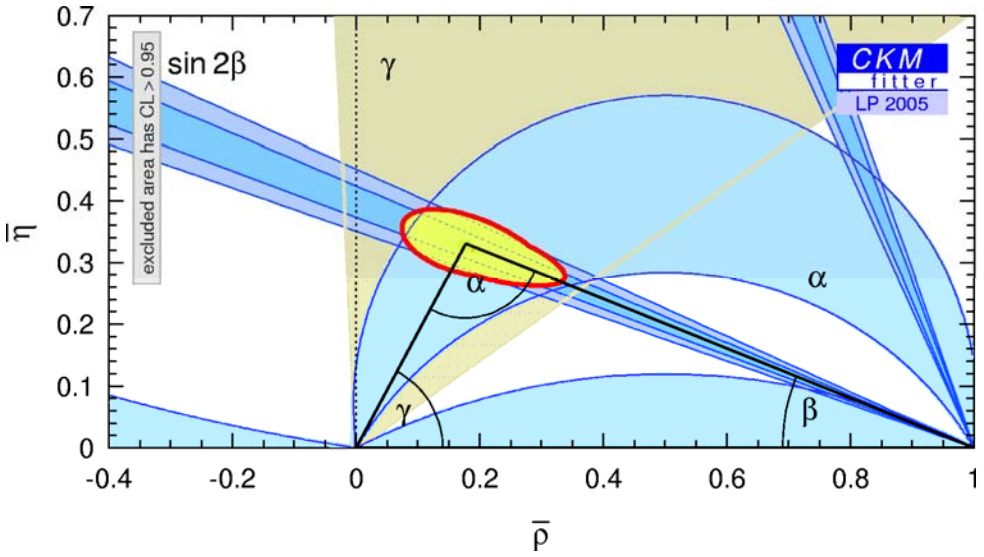
2σ allowed interval	
BaBar	12° - 137°
Belle	22° - 113°

Significance of direct CPV	
BaBar	2.4σ
Belle	2.3σ

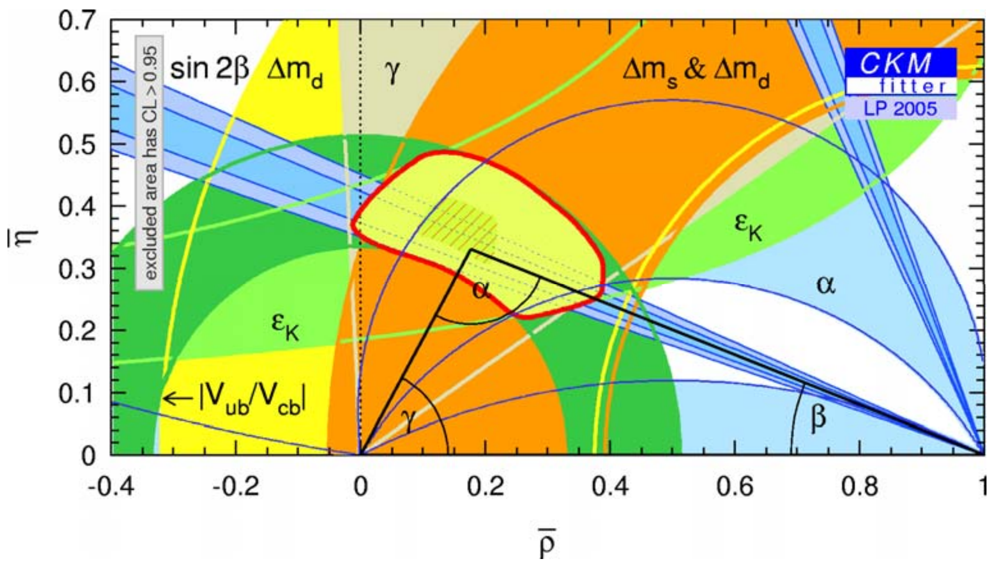
CKM fits

CKM fits (CKMfitter group)

Angles only

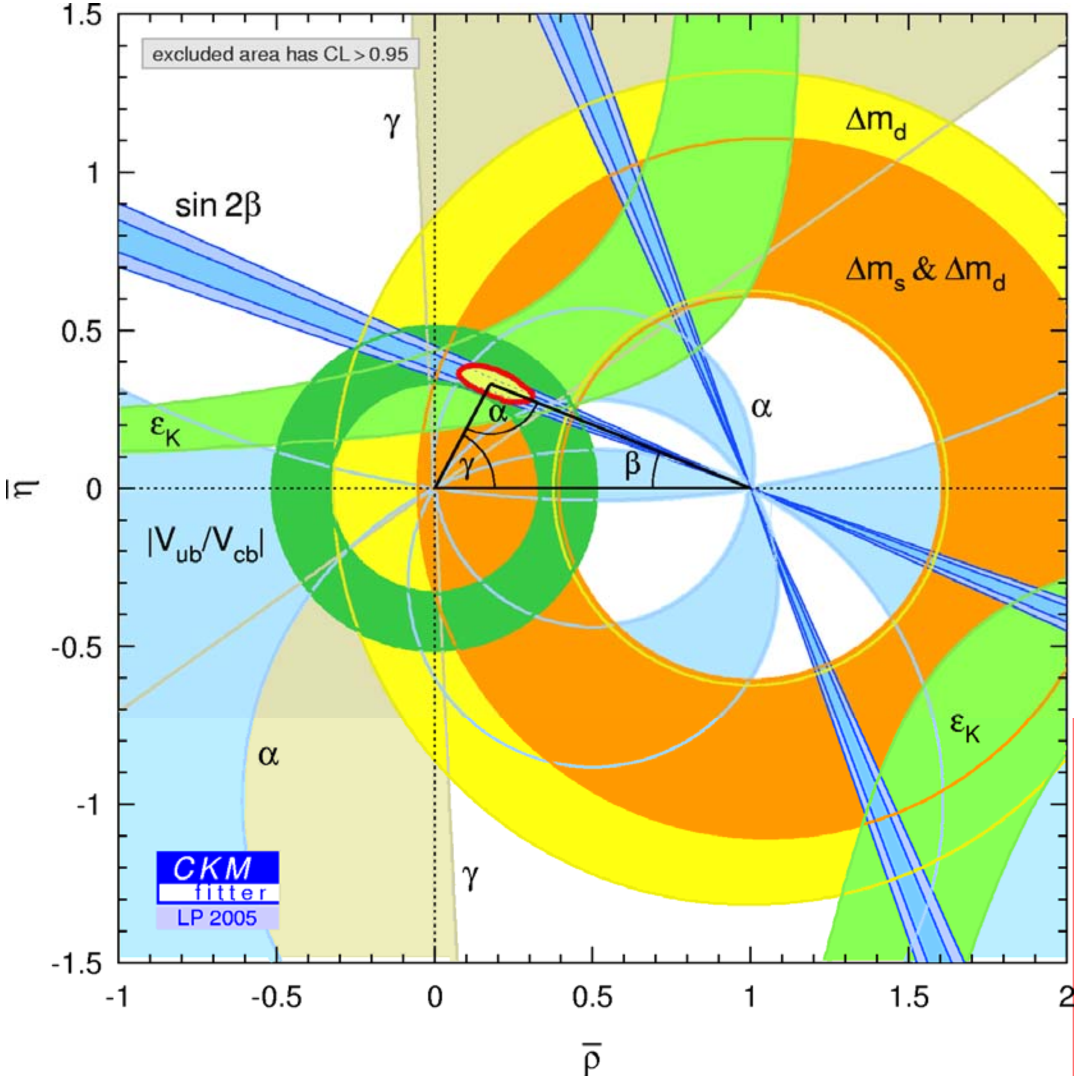


No angles



Putting it all together

All constraints



Conclusions on B mesons - 1

- "Direct" CPV
  - Observed by BaBar and Belle in $B \to K^+\pi^-$
  - Evidence by Belle in $B \to \pi^+\pi^-$, not seen by BaBar
- CPV in mixing
  - Expected to be small ($\approx 10^{-3}$), not seen yet
- $\sin 2\beta$
  - Precision measurement with charmonium modes dominate now CKM fits, in agreement with SM expectation
  - Looking at $b \to s$ penguins for non-SM effects : ϕK^0 from Belle now compatible with SM; if present, effects are not large $\Rightarrow$ more data required

Conclusions - 2

- $\sin 2\alpha$
  - $\pi^+\pi^-$ interesting, also penguins $\Rightarrow$ isospin analysis needed for $\sin 2\alpha$, too few $\pi^0\pi^0$…
  - $\rho^+\rho^-$ smaller corrections
  - $\rho^+\pi^-$ asymmetries measured in "quasi-two-body" approach; first results also from Dalitz analyses, work in progress
- γ
  - DK and Dπ methods: few events, sensitivities depend on r_b (CKM and color suppression factor of interfering amplitudes) $\Rightarrow$ Dalitz method is the best up to now: need more data…

- CKM fits are giving a consistent picture (SM works!) and also feedback on B decay mechanisms

Conclusions - 3

- Short term prospects for the B factories, very successful up to now:
  - Double the integrated luminosity at least twice with the present detectors:
    - ~ 500 fb^{-1} per experiment by 2006 (KEK-B is almost there!)
    - > 1 ab^{-1} per experiment by 2008-09
  - This will *not* exhaust the B physics program…

- Hadron collider experiments: B_s, γ, some rare decays
  - Tevatron, CDF/D0: upgrades and new triggers, preliminary results for B_s mixing: SEEN ! Compatible with SM
  - LHC-B at LHC: expected on line in ~2007; BTeV terminated

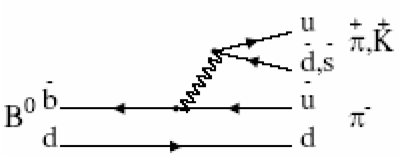
- Long term future of B-factories: physics case of a Super B-Factory
  - Prospects under discussion by the interested community

Backup slides

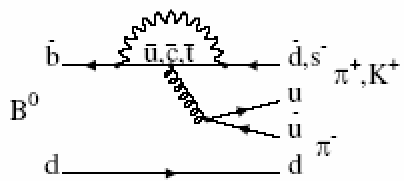
A_{CP} in charmless $B \to PP$

K.Abe, LP05

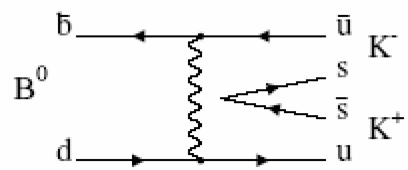
Decay Mode	BaBar	Belle	SM diagrams
$K^+\pi^-$	$-0.133 \pm 0.030 \pm 0.009$	$-0.113 \pm 0.021 \pm 0.008$	tree, penguin
$K^+\pi^0$	$+0.06 \pm 0.06 \pm 0.01$	$+0.04 \pm 0.04 \pm 0.02$	tree, penguin
$K^0_S\pi^+$	$-0.09 \pm 0.05 \pm 0.01$	$+0.05 \pm 0.05 \pm 0.01$	penguin
$K^0_S\pi^0$	$-0.06 \pm 0.18 \pm 0.03$	$+0.16 \pm 0.29 \pm 0.05$	penguin
$\pi^+\pi^-$	$+0.09 \pm 0.15 \pm 0.04$	$+0.52 \pm 0.14$	tree, penguin
$\pi^+\pi^0$	$-0.01 \pm 0.10 \pm 0.02$	$+0.02 \pm 0.08 \pm 0.01$	tree
$\pi^0\pi^0$	$+0.12 \pm 0.56 \pm 0.06$	$0.44^{+0.53}_{-0.52} \pm 0.17$	tree, penguin
K^+K^-	signal not seen	signal not seen	W-exchange
K^+K^0	seen	seen	penguin, annihilation
$K^0\bar{K}^0$	seen	seen	penguin



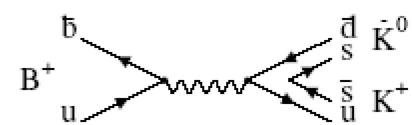
tree ($\phi_w = \phi_3$)



penguin ($\phi_w = 0$)



W-exchange ($\phi_w = \phi_3$)



annihilation ($\phi_w = \phi_3$)

Extraction of ϕ_3 may be difficult due to hadronic effects. Hope to learn about them from measurements.
(e.g. Why $A_{CP}(K^+\pi^0) \neq A_{CP}(K^+\pi^-)$? Expect the same based on naive factorization)