Measurement of the CKM angle α (ϕ_2) at Babar

- Physics motivation
- How to extract α
- Babar analysis of :
  - $B \rightarrow \pi\pi$
  - $B \rightarrow \rho\rho$
  - $B \rightarrow \pi\pi\pi$ Dalitz
- Summary on α

Woochun Park, University South Carolina
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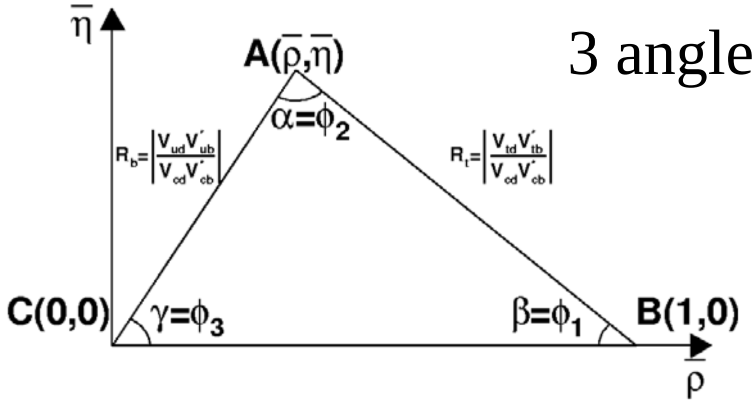
PHENO 2007 symposium, « Prelude to the LHC », may 7-9, 2007

The CKM matrix and the unitarity triangle

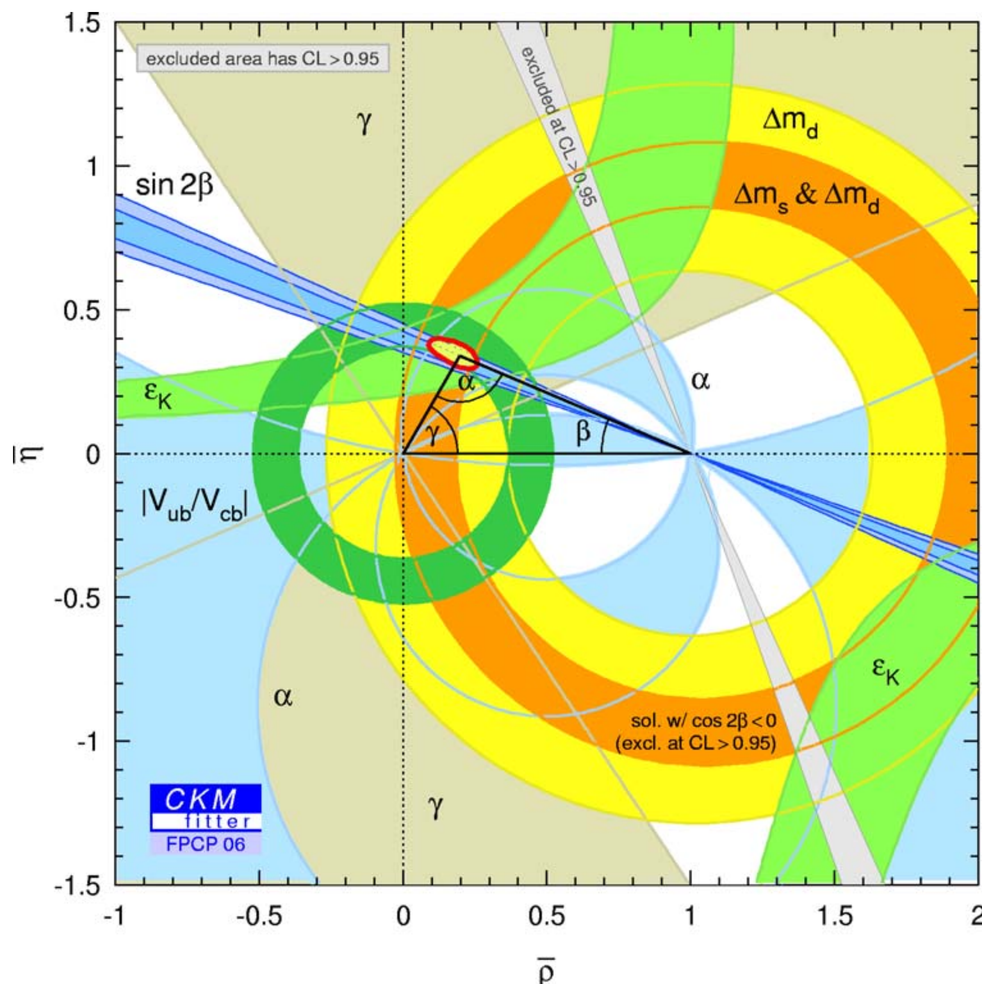
physics motivation

V_{CKM}, unitarity $\begin{cases} V^\dagger V = 1 & \rightarrow \text{unitarity triangle} \\ V V^\dagger = 1 & V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0 \end{cases}$



3 angles: α, β, γ

- $\alpha = 92.6^{+10.7}_{-9.3}$ °
- $\beta = 21.7^{+1.3}_{-1.2}$ ° $\longrightarrow$ precise
- $\gamma = 62^{+38}_{-24}$ °



β: precise: measure with ≠ methods
→new physics ?
γ & α: rare modes, (more stat)

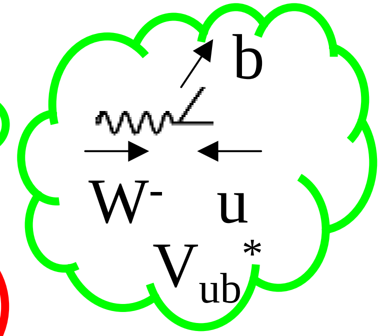
Extraction of α

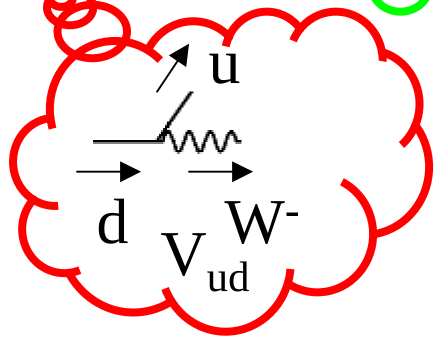
- $B^0/\bar{B}^0 \rightarrow \pi^+\pi^-$
- $B^0/\bar{B}^0 \rightarrow \rho^\pm\pi^{-+}$
- $B^0/\bar{B}^0 \rightarrow \rho^+\rho^-$

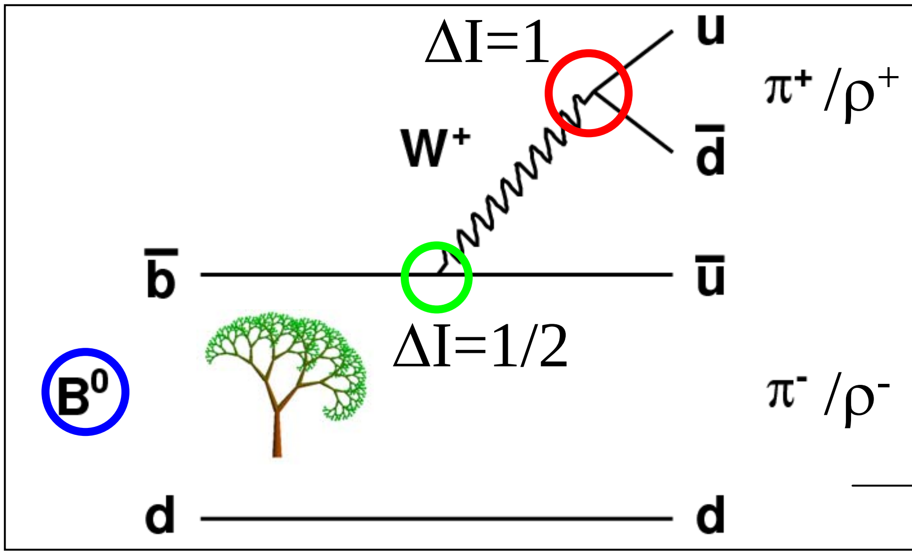
$$\alpha = arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\frac{V_{td}V_{tb}^*}{V_{tb}V_{td}^*}$$

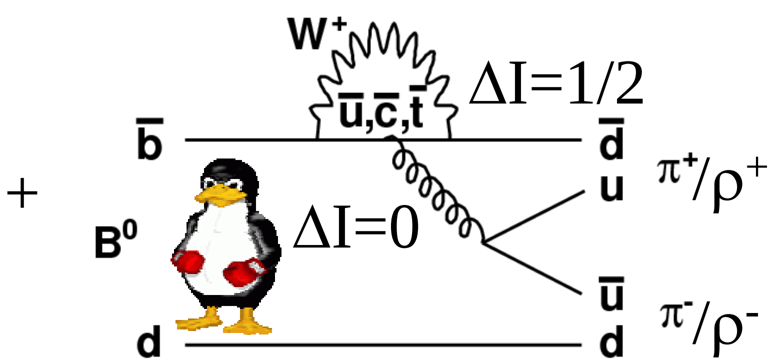
$B^0\bar{B}^0$ oscillation







tree: ΔI=1/2; 3/2



penguin: ΔI=1/2

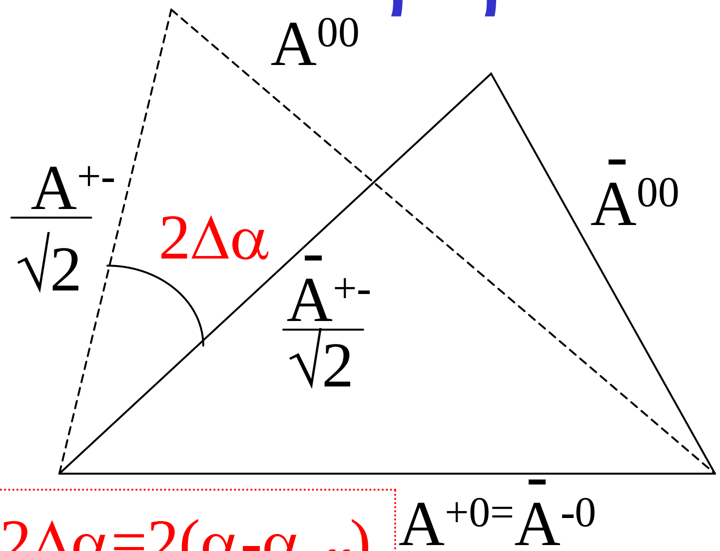
penguin $\rightarrow \alpha_{eff}$

strategy: use isospin relationship to remove penguin pollution

(Gronau, London (1990))

ρ ρ /ππ analysis

Gronau, London (1990)



$\boxed{2\Delta\alpha=2(\alpha-\alpha_{eff})}$

$A^{+-}=A(B^0 \rightarrow \rho^+\rho^-)$

$\bar{A}^{+-}=A(\bar{B}^0 \rightarrow \rho^+\rho^-)$

$A^{00}=A(B^0 \rightarrow \rho^0\rho^0)$

$\bar{A}^{00}=A(\bar{B}^0 \rightarrow \rho^0\rho^0)$

$\rightarrow \pi^+\pi^-\pi^+\pi^-$ (vertex $\neq \pi^0\pi^0$)

measure C^{00} & S^{00}

$A^{+0}=A(B^+ \rightarrow \rho^+\rho^0)$

$\bar{A}^{-0}=A(B^- \rightarrow \rho^-\rho^0)$

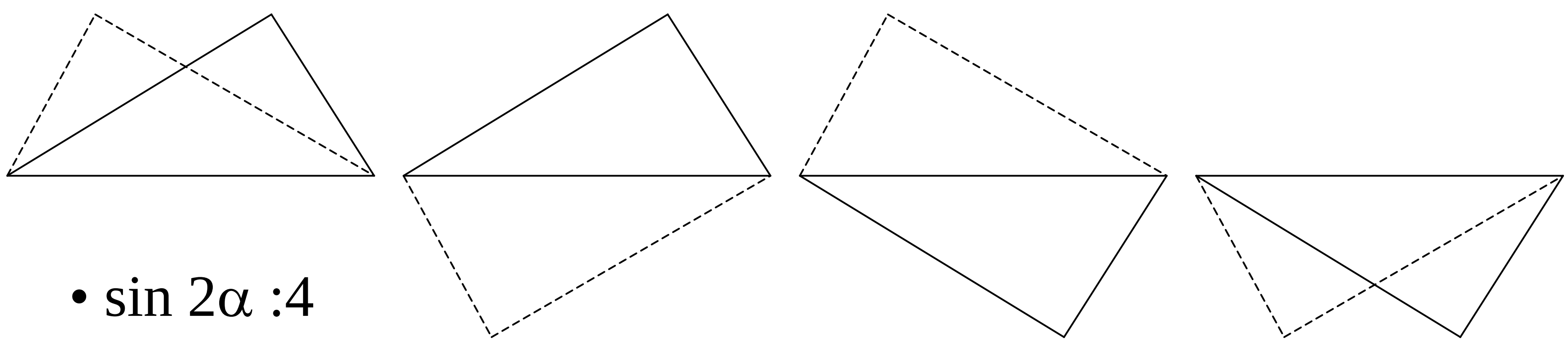
= because tree

(EW penguin<<1)

$$A_{\text{Long}}(B^+ \to \rho^+\rho^0) = 1/\sqrt{2}\cdot A_{\text{Long}}(B^0 \to \rho^-\rho^+) + A_{\text{Long}}(B^0 \to \rho^0\rho^0)$$

8-fold ambiguity

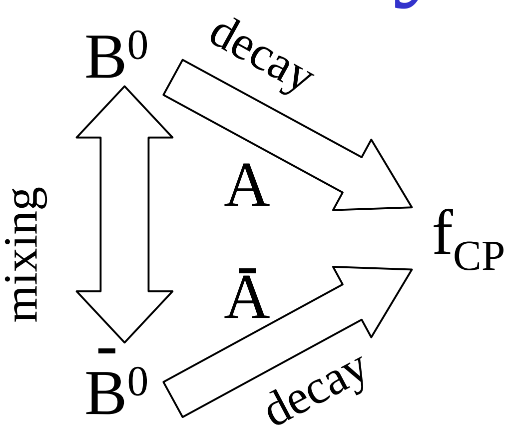
- triangles flip up/down:4



- sin 2α :4

$\phi=z$, $\phi=z+\pi$, $\phi=\pi/2-z$, $\phi=3\pi/2-z$

CP Violation in interference between decay with and without mixture

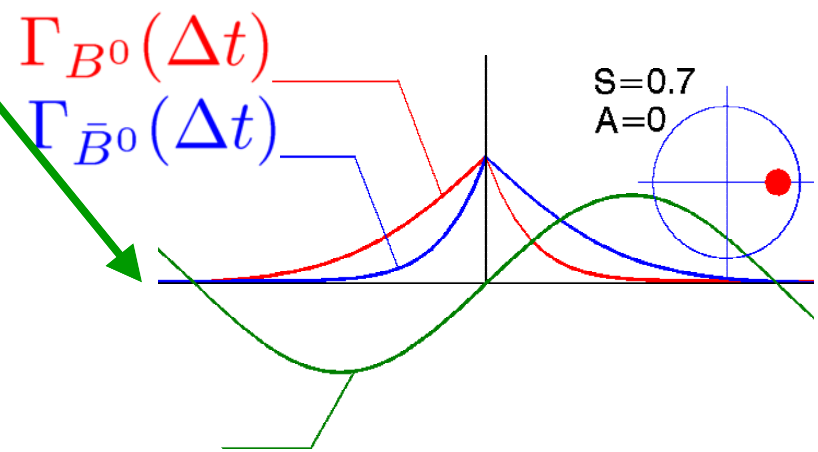


$$A_{CP}(\Delta t) \equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)} = \mathcal{S}\sin\Delta m\Delta t + \mathcal{A}\cos\Delta m\Delta t$$

$$a_{CP}(t) = \boxed{-C_f}\cos\Delta mt + \boxed{S_f}\sin\Delta mt$$

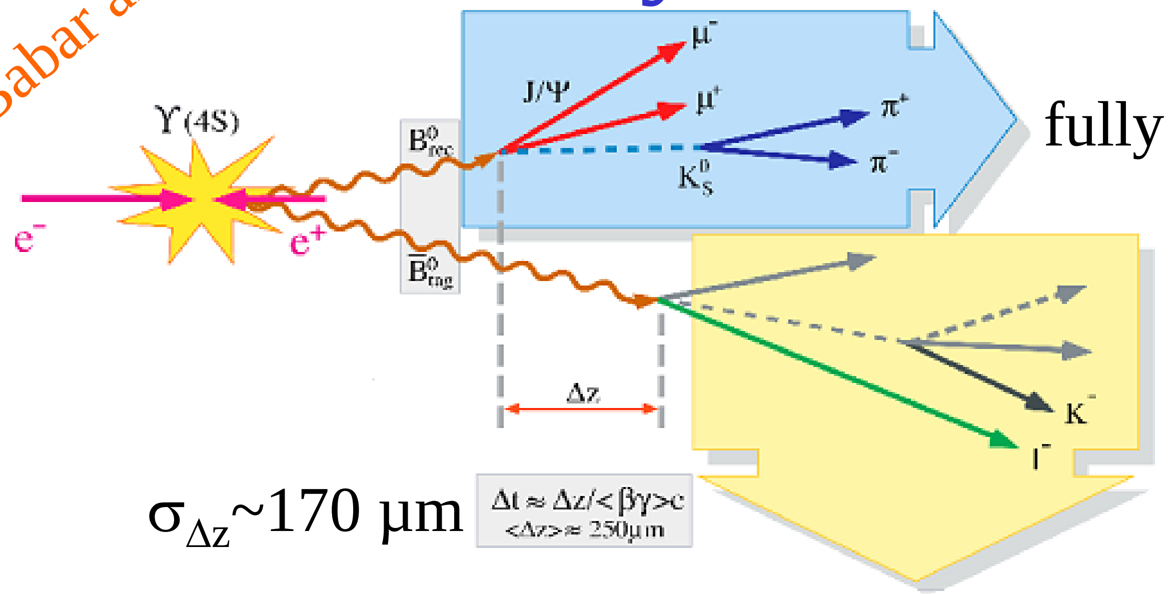
$\not{C}P$ direct $\quad$ $\not{C}P$ mixing

A=-C (Belle) $\quad$ $S = \sqrt{1 - C^2}\sin(2\alpha_{\text{eff}})$



Analysis method

Babar analysis



fully reconstructed

$\sigma_{\Delta z}$~170 μm

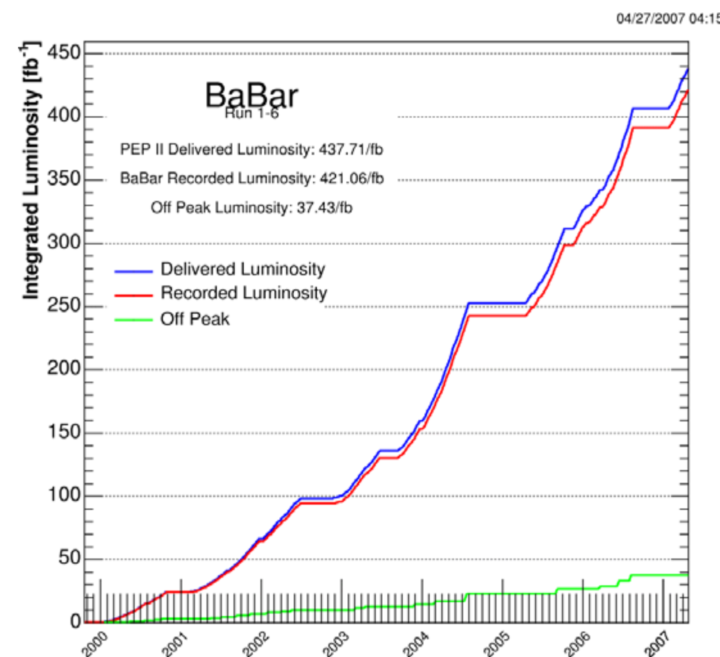
tagging→$B^0/\bar{B}^0$

B-flavor tagging:

$Q=\Sigma\varepsilon_i(1-2\omega_i)^2$~30 %

efficiency

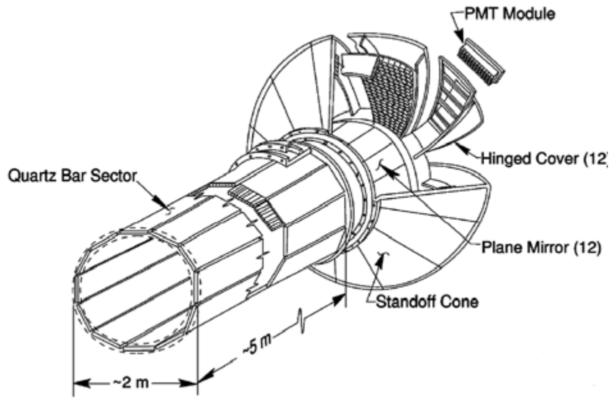
mistag rate

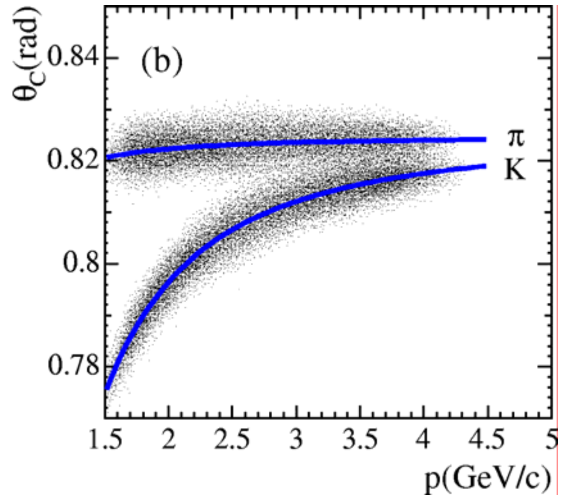


Signal selection

- Hadron ID→π/K separation

DIRC : Cherenkov angle





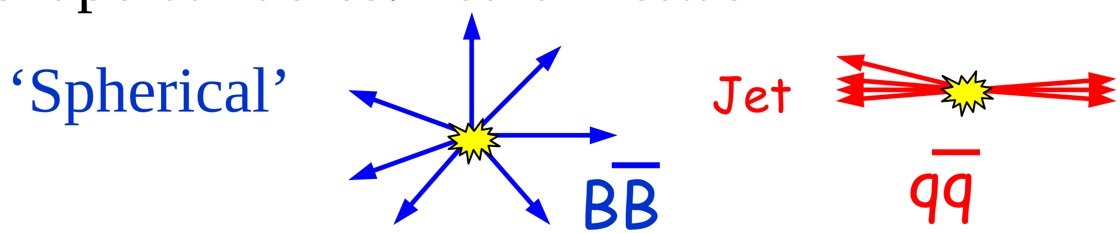
+dE/dx using DCH

- Kinematical identification with
  - -Beam energy substituted mass
  - -Energy difference

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

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

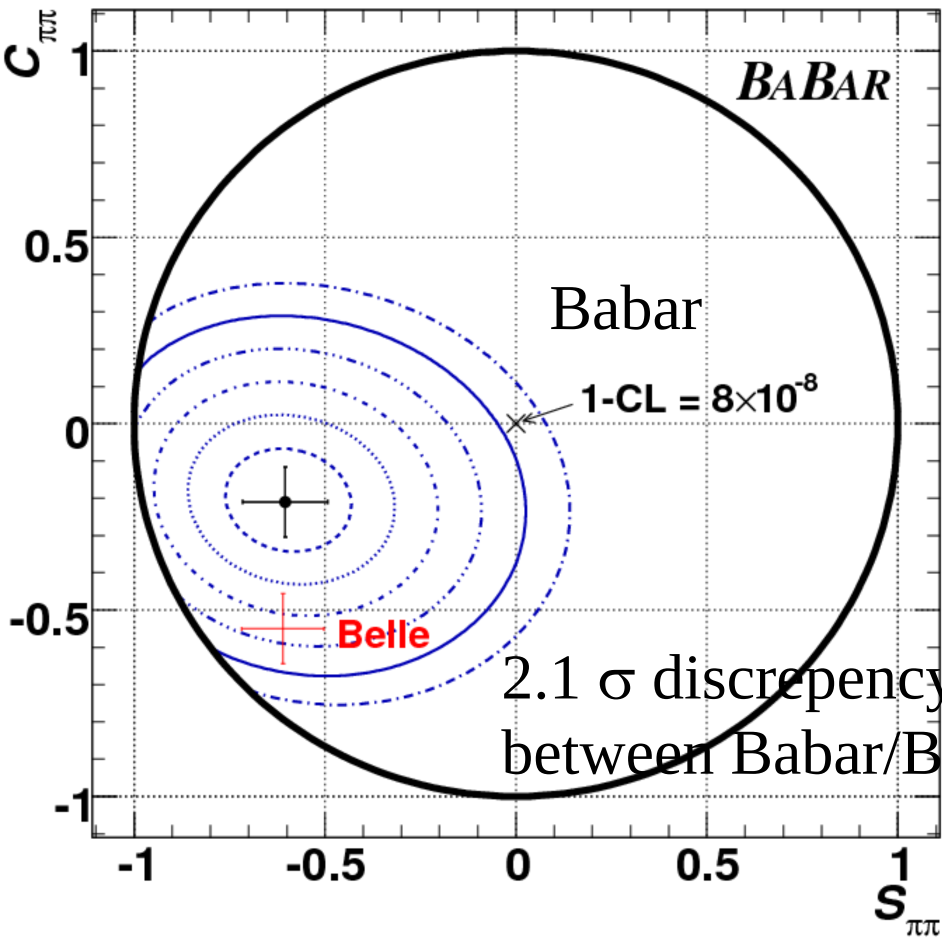
- Event-shape variables: neural network



+mass +helicities

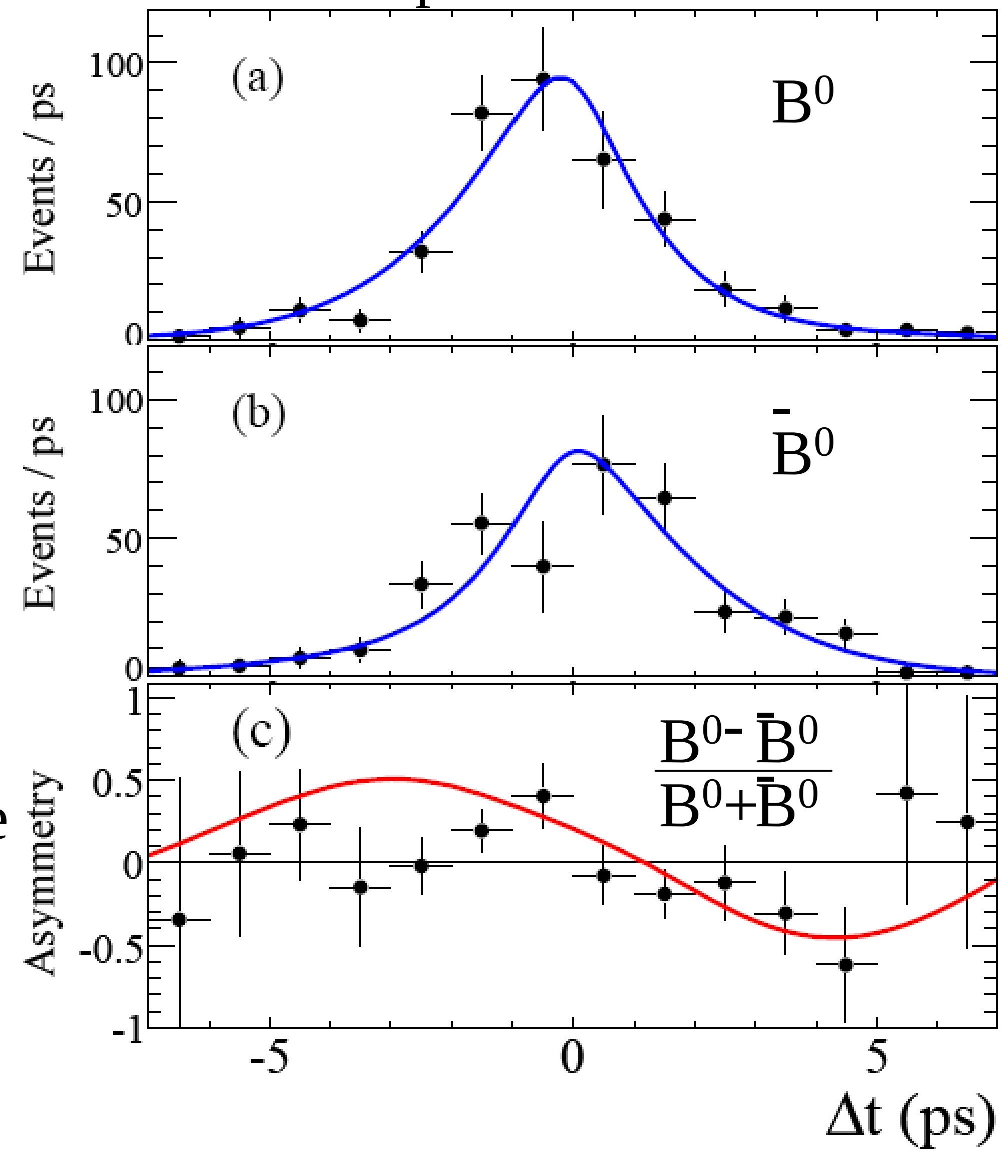
$B^0 \rightarrow \pi^+\pi^-$

383 Millions $B\bar{B}$



2.1 σ discrepency between Babar/Belle

hep-ex 0703016



S=-0.60±0.11 (stat) ±0.03 (syst)

C=-0.21±0.09 (stat) ±0.02 (syst)

S, C≠ 0 : 5.4 σ

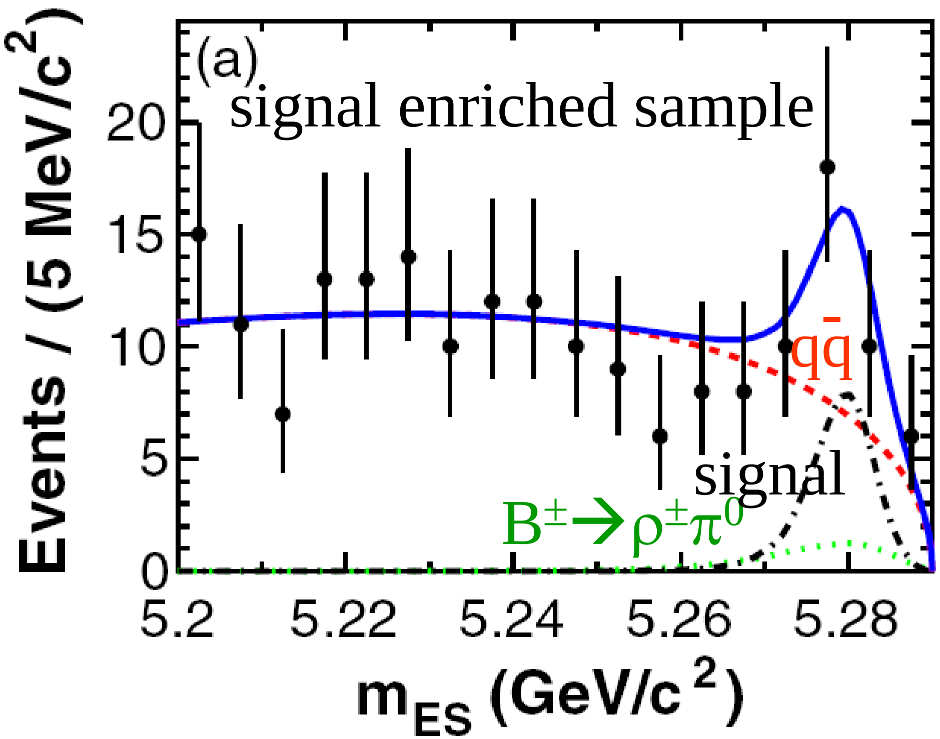
$\rightarrow \alpha_{eff}$

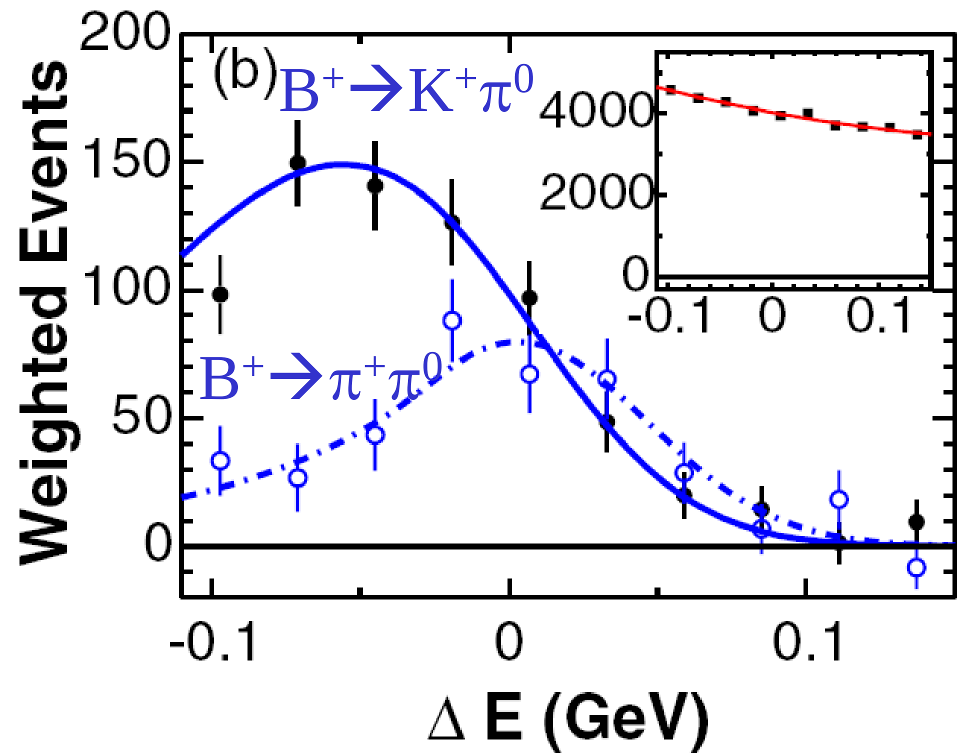
to go on α, need $\pi^0\pi^0$; $\pi^+\pi^0$

$B^0 \rightarrow \pi^0\pi^0$ 227 M $B\bar{B}$ $B^+ \rightarrow \pi^+\pi^0$

BR=$(1.17\pm0.32\pm0.10)10^{-6}$
C_{00}=$-0.12\pm0.56\pm0.06$
$61\pm17\pm5$ signal, 5.0 σ

BR=$(5.8\pm0.6\pm0.4)10^{-6}$
A_{CP}=$-0.01\pm0.10\pm0.02$
379 ± 41 signal





PRL 94, 181802 (2005)

$B \rightarrow \rho\rho$

π: J=0 (S)
ρ: J=1 (V)

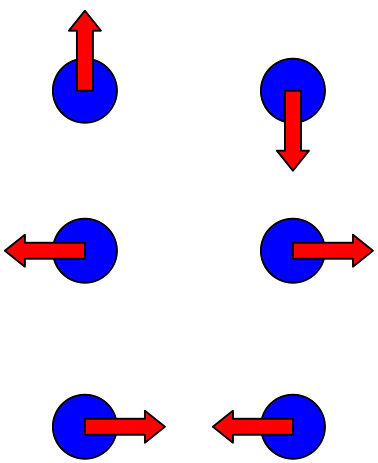
ρ: J=1 ➔ J=0, 1, 2

$\rho^+\rho^-$ more difficult:

- 2 π^0 in final state ($\rightarrow$vertex difficult)
- wide ρ resonance$\rightarrow$more background
- 3 polarization states w/ different CP eigenvalues

$\rightarrow$separate contrib to avoid dillution

ρ^+ ρ^-



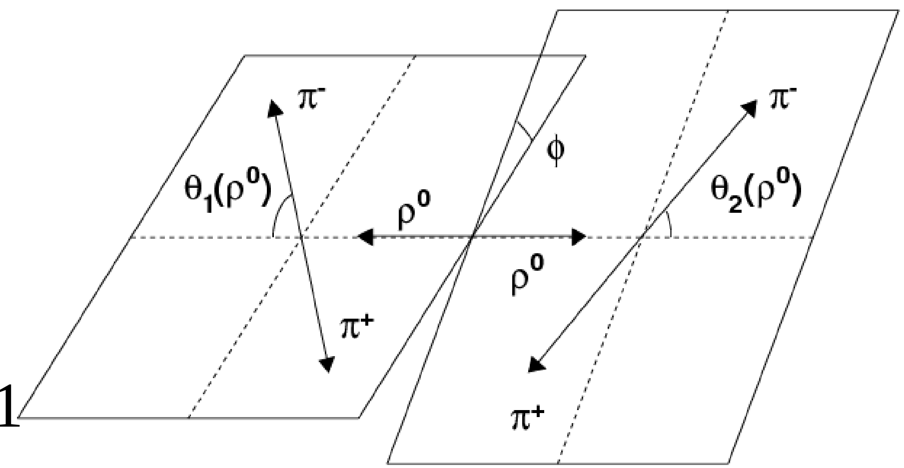
$A_0=H_0$ (long) CP=1

H^+

$A_{\parallel}=(H^++H^-)/\sqrt{2}$ CP=1

H^-

$A_{\perp}=(H^+-H^-)/\sqrt{2}$ CP=-1



$$\frac{1}{\Gamma}\,\frac{d^2\Gamma}{d\cos\theta_1\;d\cos\theta_2}=\frac{9}{4}\left[\cos^2\theta_1\cos^2\theta_2 f_L+\frac{1}{4}\sin^2\theta_1\sin^2\theta_2\,(1-f_L)\right]$$

eventually best mode:

- BR~6 x those from $B\rightarrow\pi\pi$
- Penguin pollution much small/$B\rightarrow\pi\pi$
- f_L~almost 100 % (pure CP-event state)

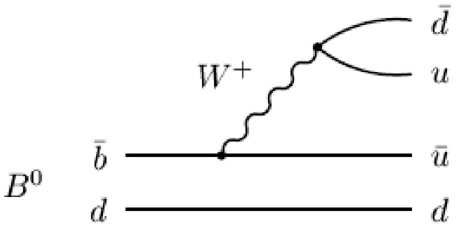
$B^0 \rightarrow \rho^+\rho^-$

hep-ex/0607098

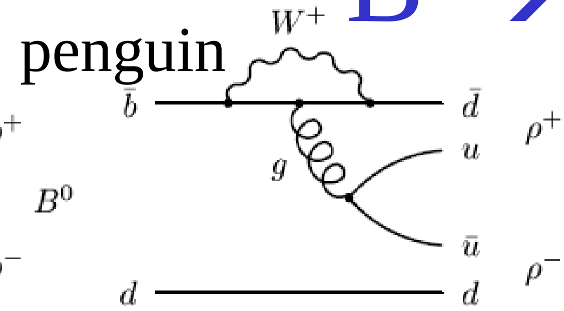
347 M $B\bar{B}$, 316 fb^{-1}

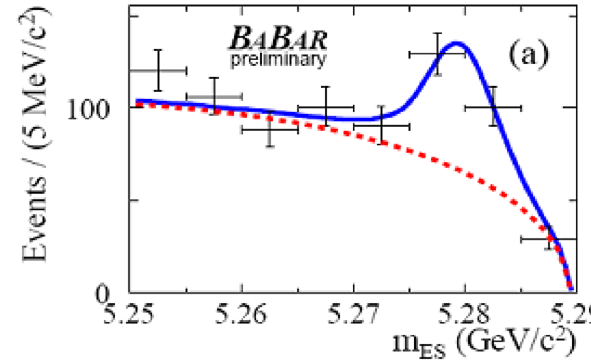
615±57 events

tree



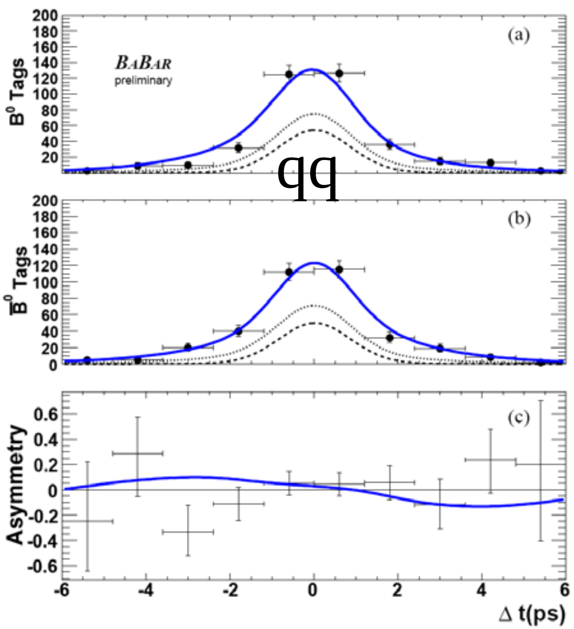
penguin





$$\mathcal{B}(B^0 \rightarrow \rho^+\rho^-) = (23.5 \pm 2.2(\mathrm{stat}) \pm 4.1(\mathrm{syst}))\times 10^{-6},$$
$$f_L = 0.977 \pm 0.024(\mathrm{stat})^{+0.015}_{-0.013}(\mathrm{syst}),$$
$$S_{\mathrm{long}} = -0.19 \pm 0.21(\mathrm{stat})^{+0.05}_{-0.07}(\mathrm{syst}),$$
$$C_{\mathrm{long}} = -0.07 \pm 0.15(\mathrm{stat}) \pm 0.06(\mathrm{syst}).$$

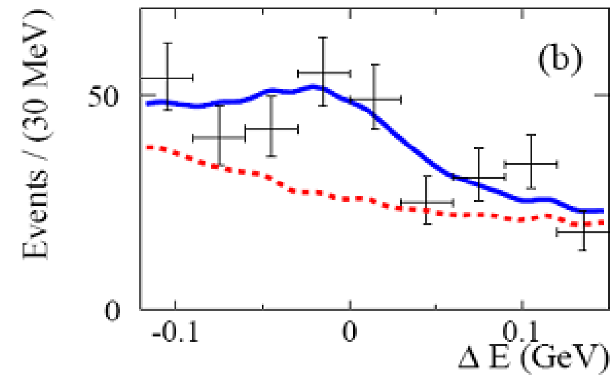
$$\alpha = [74, 117]^\circ \text{ at } 68\% \text{ CL}$$



qq

dominant systematic:
self cross feed

no CP violation



1 ab^{-1} projection:
f_L ±0.014±0.011 (statistically limited)
BF±1.3±3.8 (systematically limited)

$\rightarrow \alpha_{\mathrm{eff}}$, to go on α, need $\rho^0\rho^0$; $\rho^+\rho^0$

PRL 97 (2006) 261801

232 M $B\bar{B}$

$B^{\pm} \to \rho^{\pm}\rho^{0}$

Tree process

Observables	Fitted value
$B^{\pm} \to \rho^{\pm}\rho^{0}$ yield	390±49 events
Polarization f_L	0.897±0.042
Charge asymmetry A_{CP}	-0.12 ± 0.13
$B^{\pm} \to \rho^{\pm} f_0$ yield	51±30 events

$$\mathcal{B} = (16.8 \pm 2.2 \pm 2.3) \times 10^{-6}$$

$$A_{CP} = -0.12 \pm 0.13 \pm 0.10$$

$$f_L = 0.905 \pm 0.042^{+0.023}_{-0.027}$$

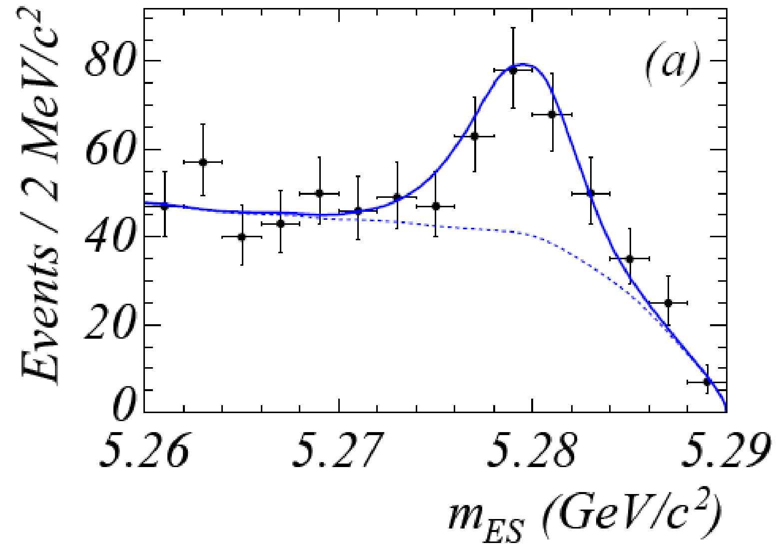
$$C = -0.12 \pm 0.13 \pm 0.10$$

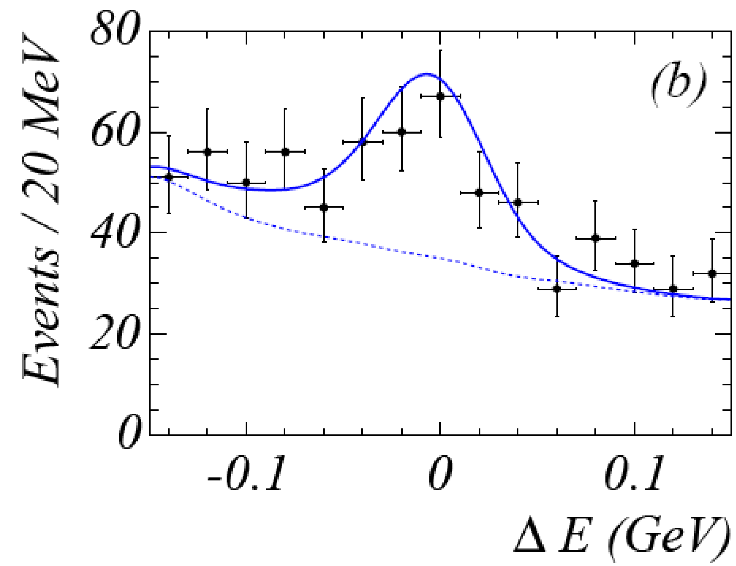
Dominant systematic: fit bias, Self cross feed

1 ab^{-1} projection:

f_L ±0.002±0.018 (statistically limited)

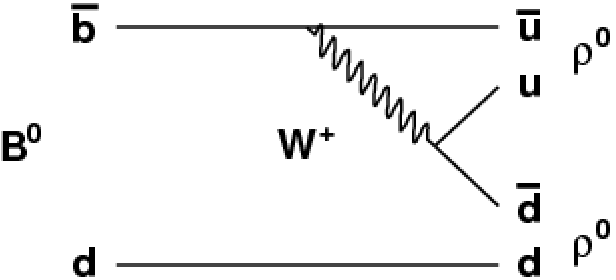
BF±1.0±2.0 (systematically limited)



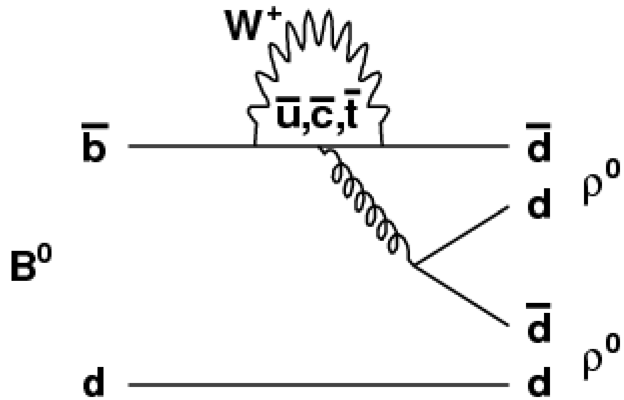


Search for $B^0 \rightarrow \rho^0\rho^0$

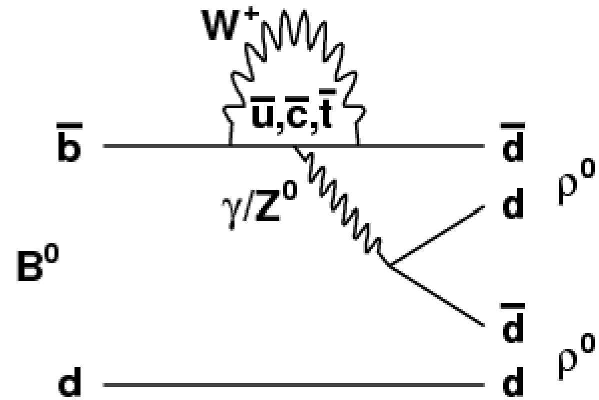
PRL 98 (2007) 111801



color suppressed



gluonic penguin

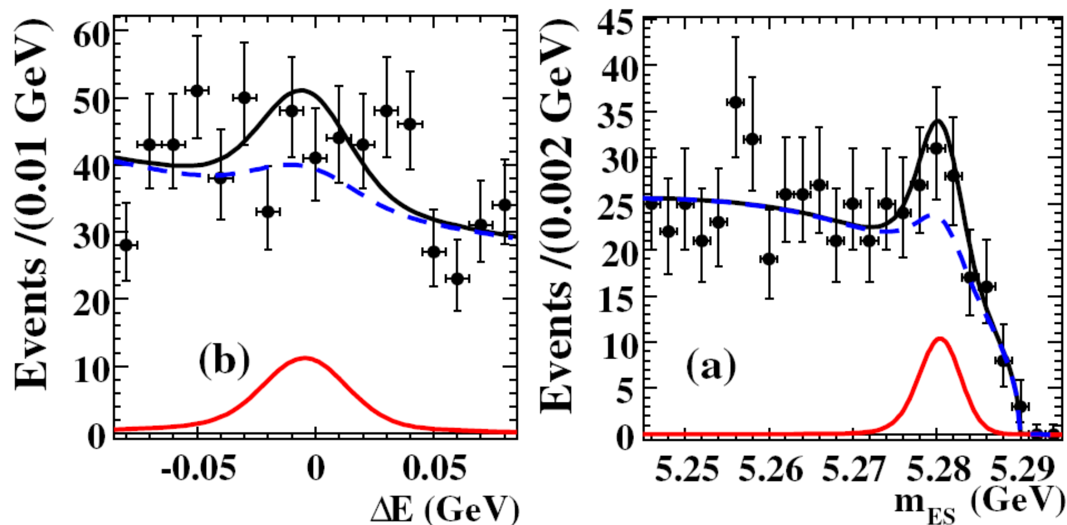


EW penguin: weak

383 M $B\bar{B}$

3,5 σ evidence, first time
$Br(\rho^0\rho^0)=(1.07\pm0.33\pm0.19)\ x10^{-6}$
$f_L=0.87\pm0.13\pm0.04$
$|\Delta\alpha|<18°$
100 $\pm32\pm17$ $\rho^0\rho^0$

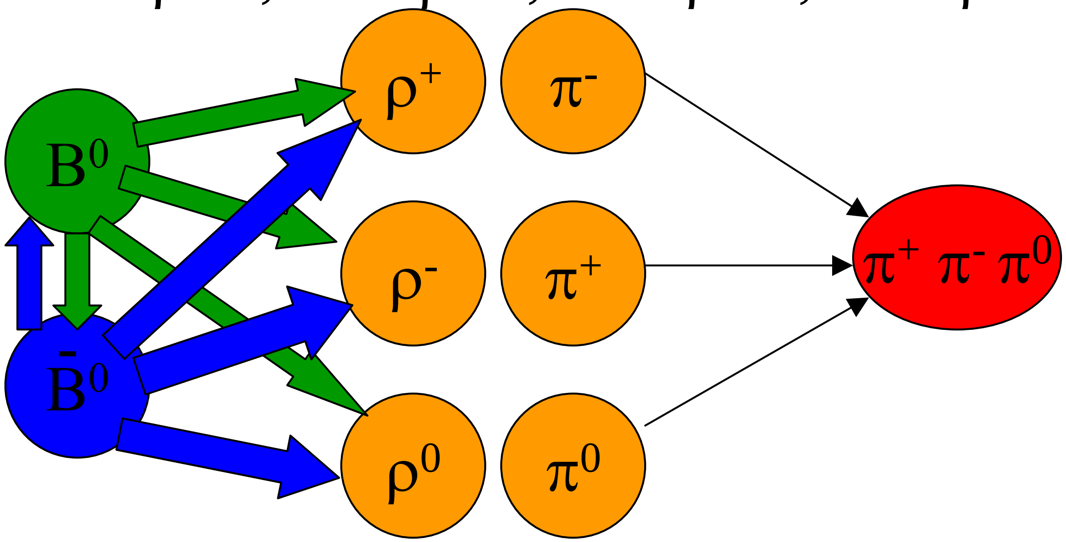
dominant systematic:
interference with $a_1\pi$



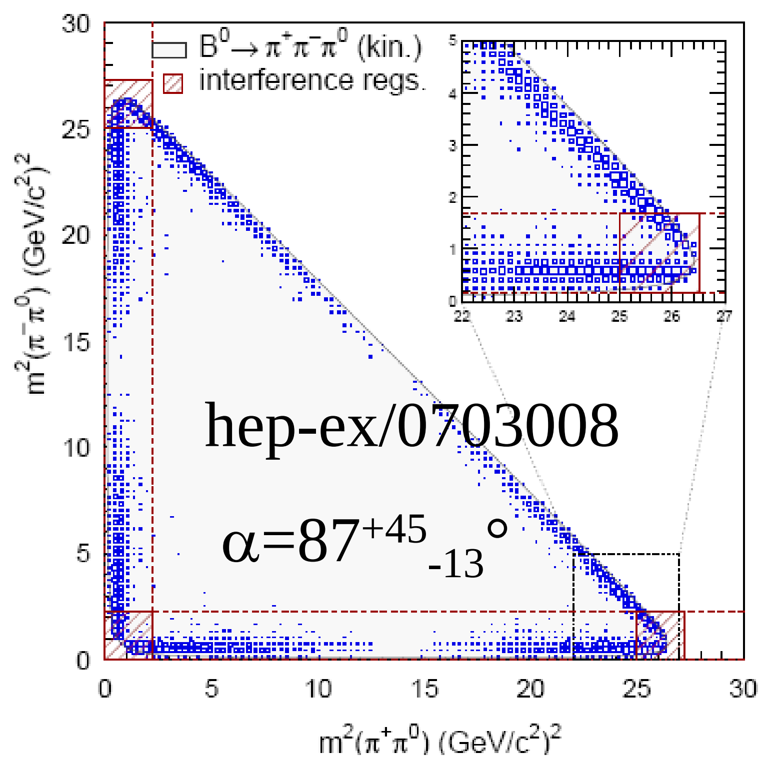
Dalitz analysis of $B^0 \rightarrow (\rho\pi)^0\ \pi^+\pi^-\pi^0$

Snyder-Quinn, PRD 48, 2139 (1993)

dominant decay $B^0 \rightarrow \rho^+\pi^-$: not a CP eigenstate
isospin analysis not viable: too many amplitudes:
$B^0 \rightarrow \rho^+\pi^-$, $B^0 \rightarrow \rho^-\pi^+$, $B^0 \rightarrow \rho^0\pi^0$, $B^+ \rightarrow \rho^+\pi^0$, $B^+ \rightarrow \rho^0\pi^+$ and charge conjugates



375 M BB



hep-ex/0703008

$\alpha = 87^{+45}_{-13}{}^{\circ}$

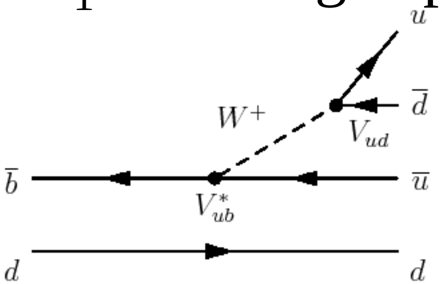
better approach: Time-dependent Dalitz analysis:
- simultaneous fit of α, T, P amplitudes
- no ambiguity on α (unlike isospin analysis)

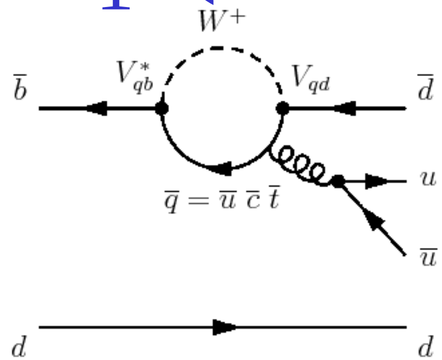
$$\mathcal{A}_{\rho\pi} = -0.14 \pm 0.05 \pm 0.02$$
$$C = 0.15 \pm 0.09 \pm 0.05 \qquad \Delta C = 0.39 \pm 0.09 \pm 0.09$$
$$S = -0.03 \pm 0.11 \pm 0.04 \qquad \Delta S = -0.01 \pm 0.14 \pm 0.06$$

$B^0 \rightarrow a_1^+(1260)\pi^-$

PRL 97, 051802 (2006)

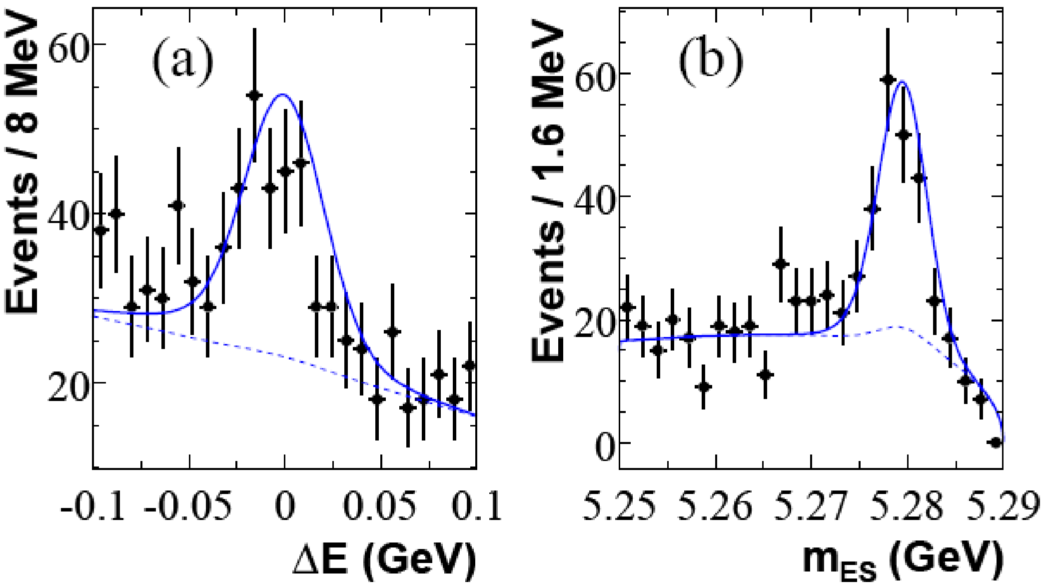
$a_1 \rightarrow$ 3 charged pions

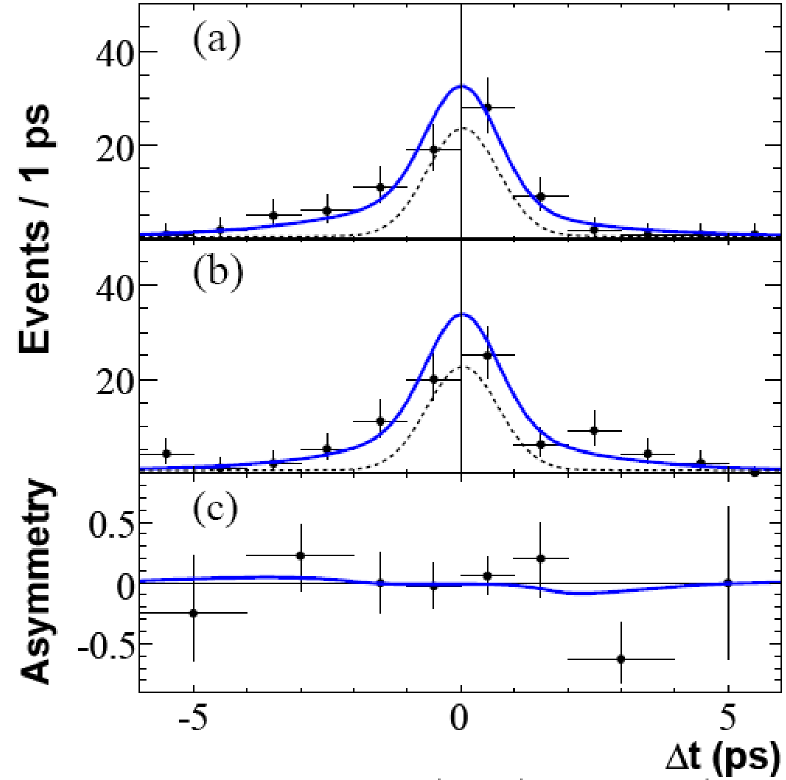




Br=(33.2±3.8±3.0) 10^{-6}

9.2 σ, first observation





$$C_{a1\pi} = -0.10 \pm 0.15\,(\text{stat}) \pm 0.09\,(\text{syst})$$
$$S_{a1\pi} = 0.37 \pm 0.21\,(\text{stat}) \pm 0.07\,(\text{syst})$$
$$\Delta C_{a1\pi} = 0.26 \pm 0.15(\text{stat}) \pm 0.07\,(\text{syst})$$
$$\Delta S_{a1\pi} = -0.14 \pm 0.21\,(\text{stat}) \pm 0.06\,(\text{syst})$$
$$\mathcal{A}_{CP}^{a_1\pi} = -0.07 \pm 0.07\,(\text{stat}) \pm 0.02\,(\text{syst})$$

α_{eff}=78.6±7.3°

need $B^0 \rightarrow a_1(1260)^+(K^-/K^0)$ (SU(3) to extract α)

Conclusion

- $B^0/\bar{B}^0 \rightarrow \pi^+\pi^-$
- $B^0/\bar{B}^0 \rightarrow \rho^\pm\pi^{-+}$
- $B^0/\bar{B}^0 \rightarrow \rho^+\rho^-$

→ best single measurement

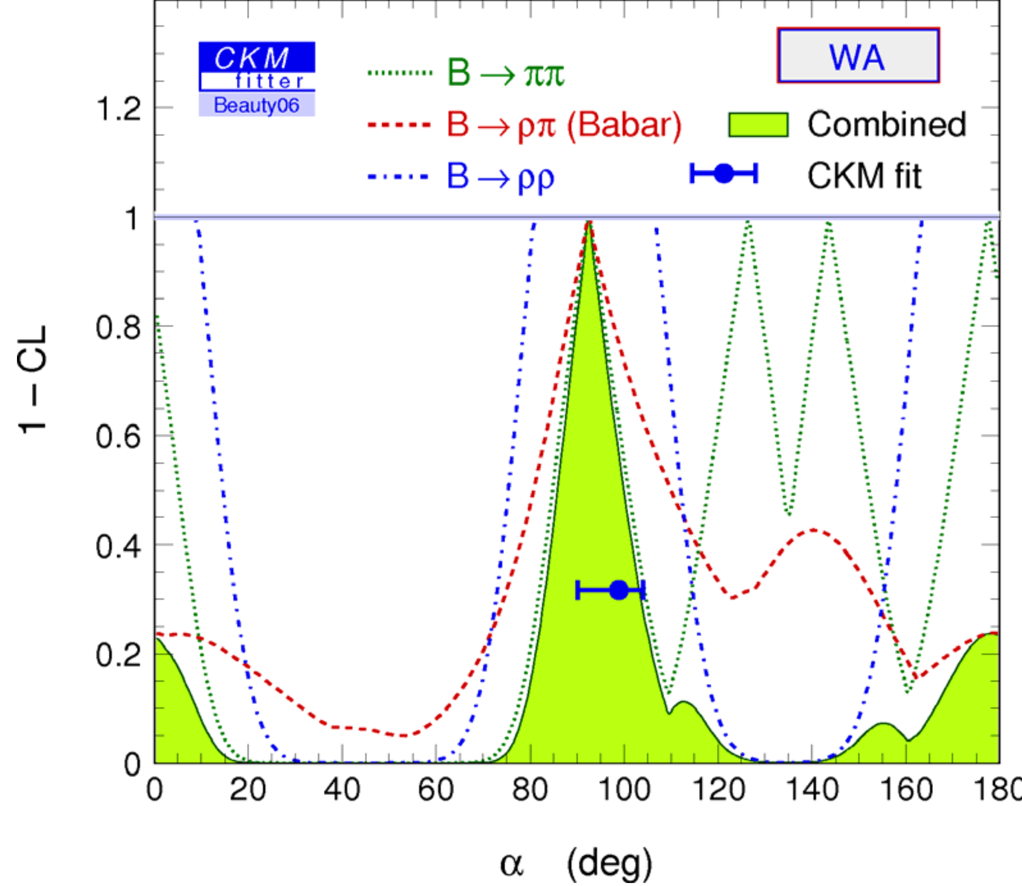
→ disfavors mirror solutions

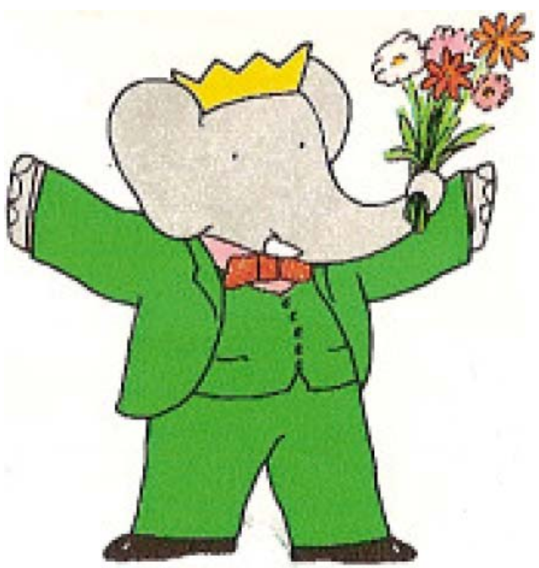
- $a_1\pi$

Beauty 2006

$\alpha = 92.6^{+10.7}_{-9.3}{}^\circ$

good agreement with global CKM fit





Babar is working fine

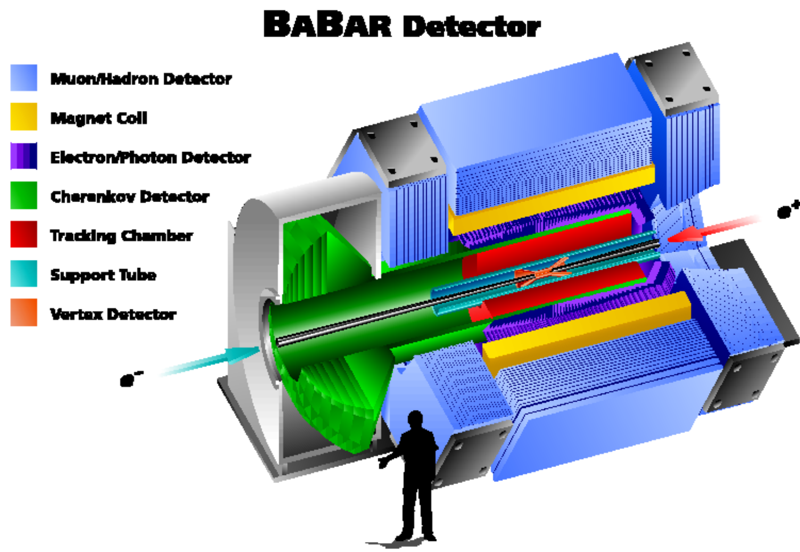
$\sim 400\ \mathrm{fb}^{-1}$

2008: expected $\sim 1\ \mathrm{ab}^{-1} = 1000\ \mathrm{fb}^{-1}$

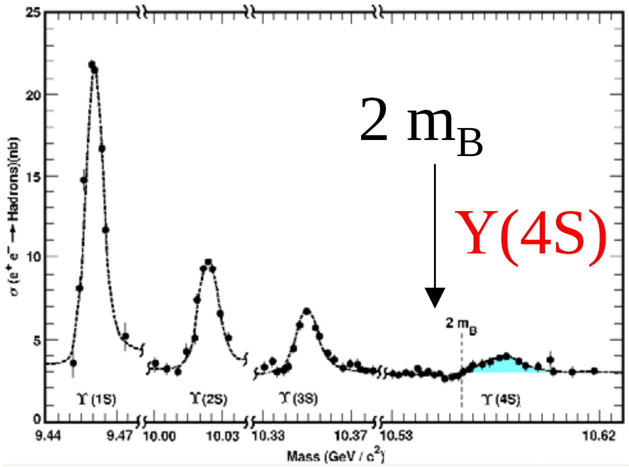
→many physics potential

appendix

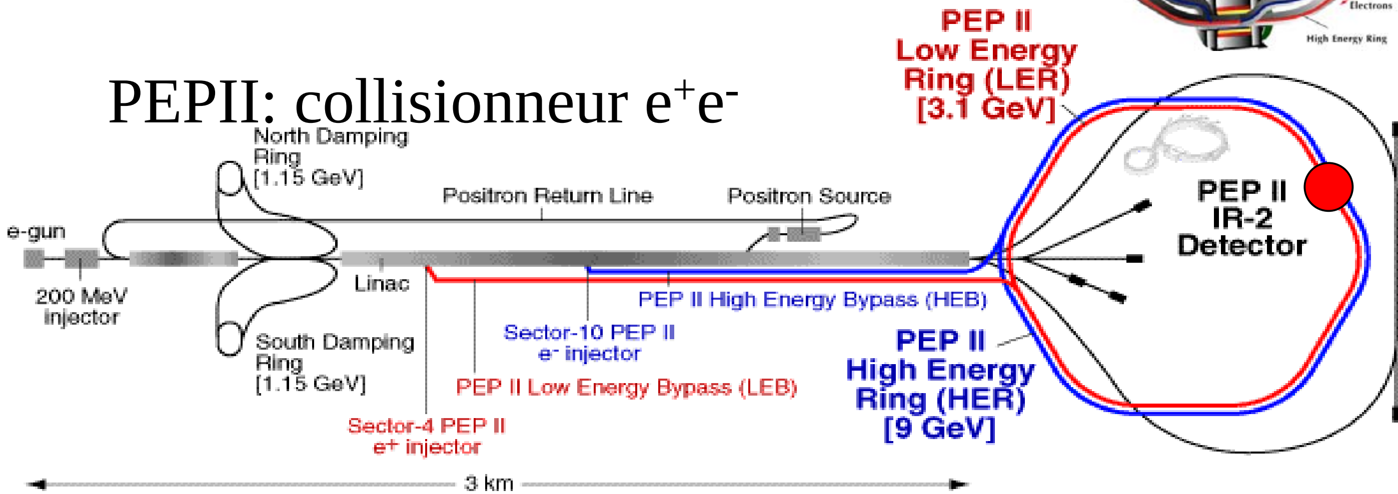
- vertex detector (SVT)
- Drift chamber (DCH)
- Cerenkov detector (DIRC)
- electromagnetic calorimeter (EMC)
- supraconductor magnet
- Instrumented Flux Return (IFR)

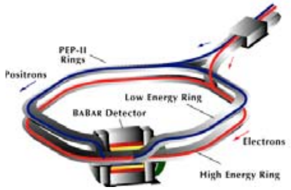


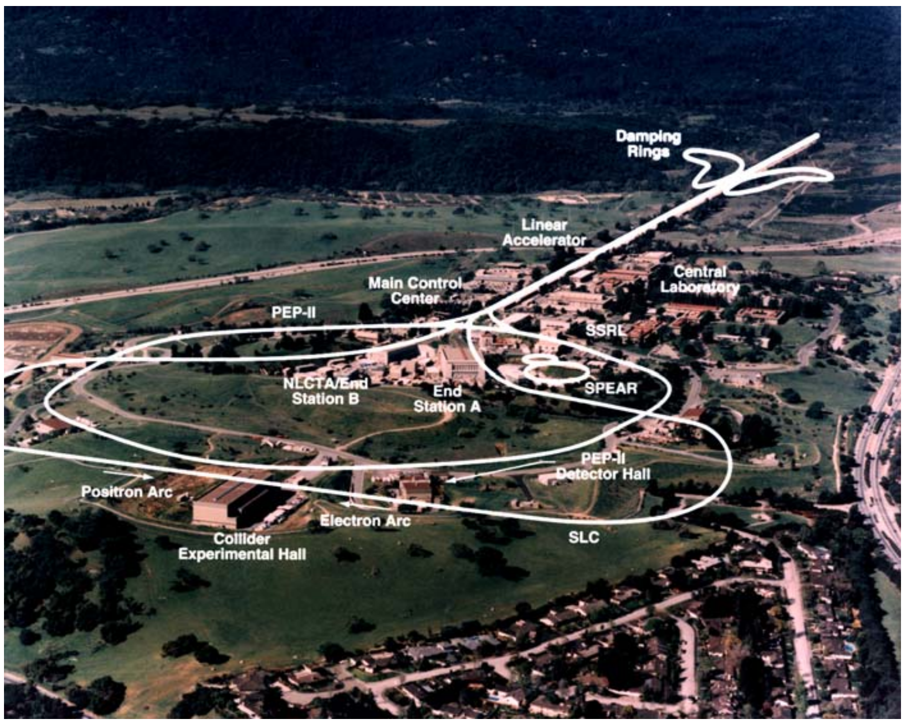
Babar experiment

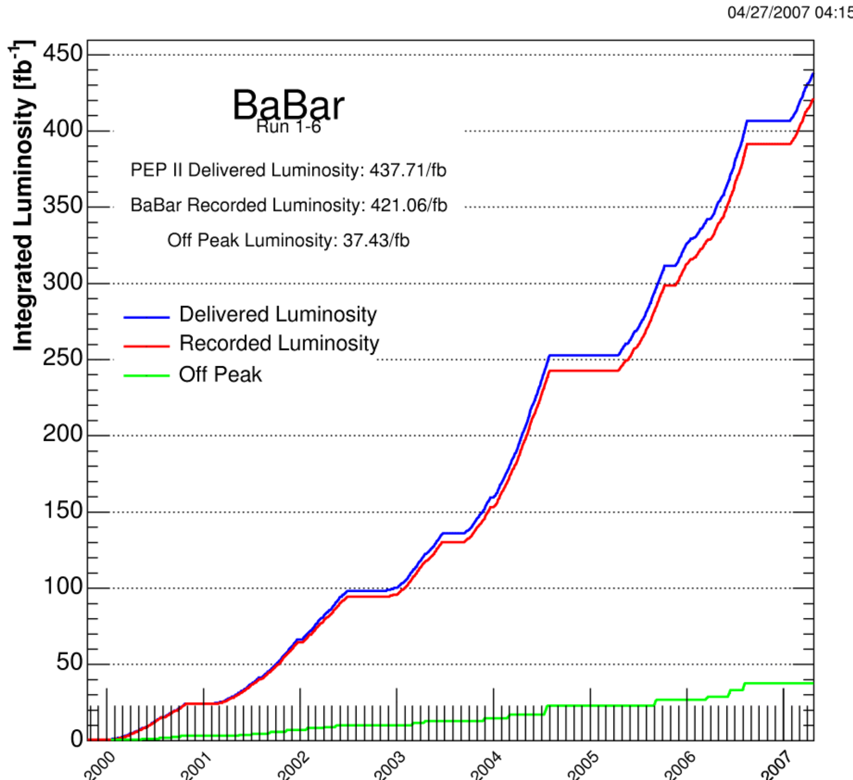


PEPII: collisionneur e^+e^-





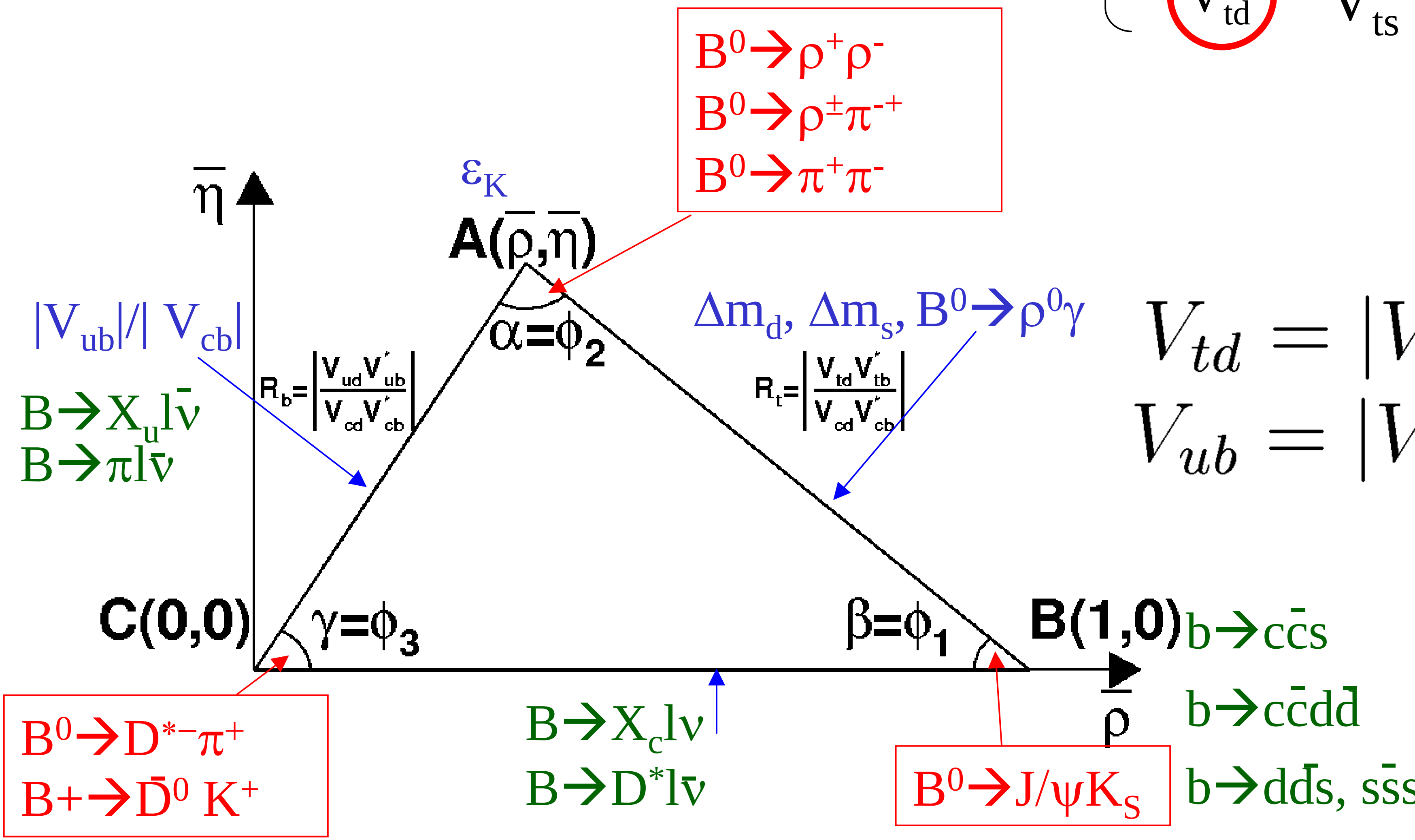




Extraction of α

Extraction of parameters

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



$$V_{td} = |V_{td}|e^{-i\beta}$$
$$V_{ub} = |V_{ub}|e^{-i\gamma}$$

$$\langle\pi^+\pi^-|H_W|B^0\rangle = -\sqrt{\tfrac{1}{3}}A_{1/2,0} + \sqrt{\tfrac{1}{6}}A_{3/2,2} - \sqrt{\tfrac{1}{6}}A_{5/2,2}$$

$$\langle\pi^0\pi^0|H_W|B^0\rangle = \sqrt{\tfrac{1}{6}}A_{1/2,0} + \sqrt{\tfrac{1}{3}}A_{3/2,2} - \sqrt{\tfrac{1}{3}}A_{5/2,2}$$

$$\langle\pi^+\pi^0|H_W|B^+\rangle = \tfrac{\sqrt{3}}{2}A_{3/2,2} + \sqrt{\tfrac{1}{3}}A_{5/2,2}$$

$$\boxed{\frac{1}{\sqrt{2}}\langle\pi^+\pi^-|H_W|B^0\rangle + \langle\pi^0\pi^0|H_W|B^0\rangle = \langle\pi^+\pi^0|H_W|B^+\rangle}$$

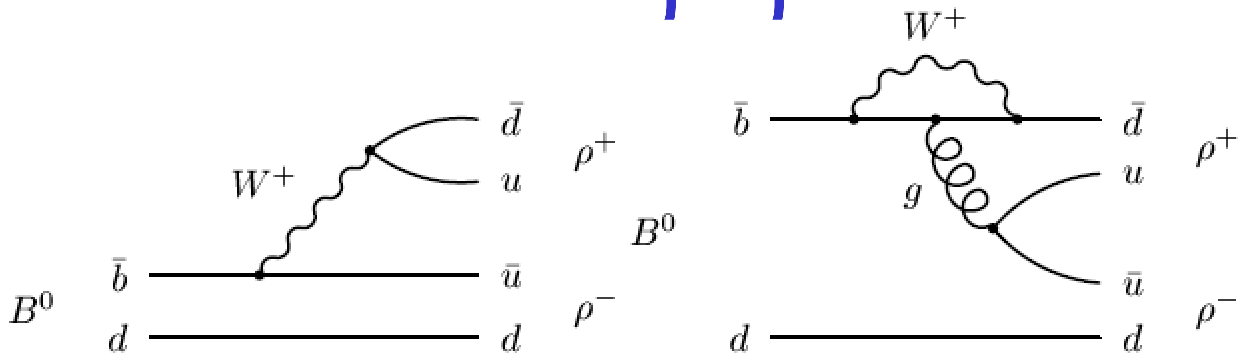
Idem for ρρ

($A_{1/2}$=penguin)

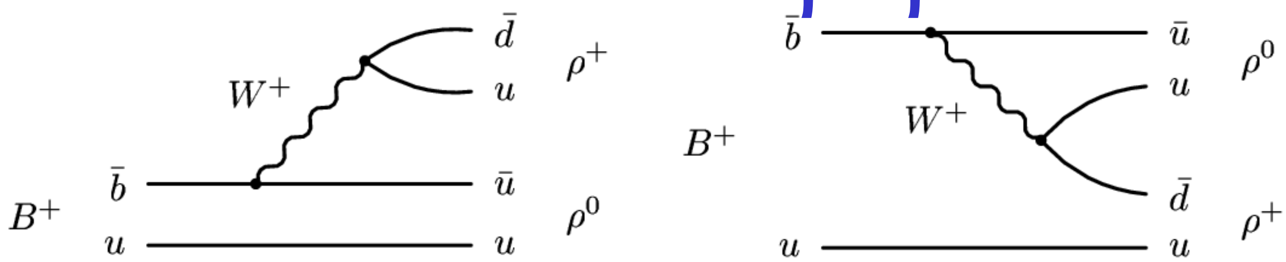
($A_{5/2}$=NP)

→triangle **only** if $A_{5/2}$=0

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



$B^\pm \rightarrow \rho^\pm\rho^0$



$B^0 \rightarrow \rho^0\rho^0$