
Measurements related to the CKM angle α from *BABAR*

LYDIA ROOS

LPNHE-Paris

Rencontres de Moriond
EW04



will cover:

■ $B \rightarrow \pi\pi$

■ $B \rightarrow \rho\pi$

■ $B \rightarrow \rho\rho$

IN2P3

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α from $B \rightarrow hh$ ($h=\pi,\rho$)

In the usual phase convention:

$$\frac{q}{p} = e^{-2i\beta}$$

$$A = e^{+i\gamma}T + e^{-i\beta}P,$$

$$\bar{A} = e^{-i\gamma}T + e^{+i\beta}P$$

$$\lambda_{hh} = \frac{q}{p} \frac{\bar{A}}{A} = e^{2i\alpha} \frac{1 - \frac{P}{T} e^{-i\alpha}}{1 - \frac{P}{T} e^{+i\alpha}} = |\lambda| e^{i2\alpha_{\text{eff}}}$$

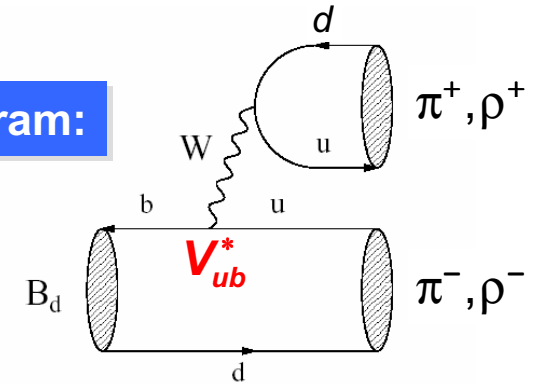
$$\alpha + \beta + \gamma = \pi$$

$$A_{CP}(t) = \frac{N(\bar{B}^0(t) \rightarrow h^+h^-) - N(B^0(t) \rightarrow h^+h^-)}{N(\bar{B}^0(t) \rightarrow h^+h^-) + N(B^0(t) \rightarrow h^+h^-)}$$

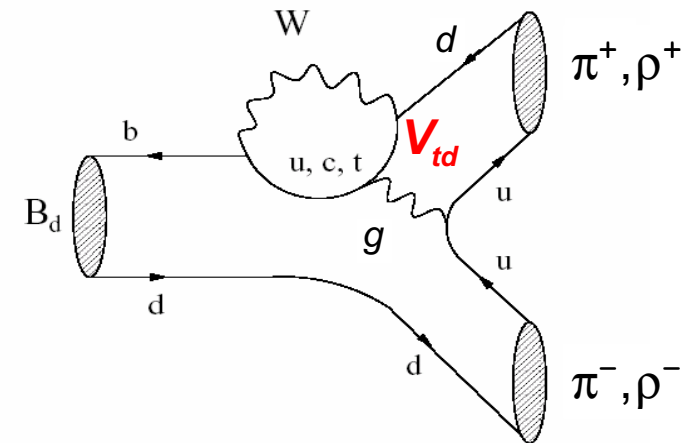
$$= S_{hh} \sin(\Delta mt) - C_{hh} \cos(\Delta mt)$$

$$S_{hh} = \frac{2 \text{Im} \lambda_{hh}}{1 + |\lambda_{hh}|^2} \quad C_{hh} = \frac{1 - |\lambda_{hh}|^2}{1 + |\lambda_{hh}|^2}$$

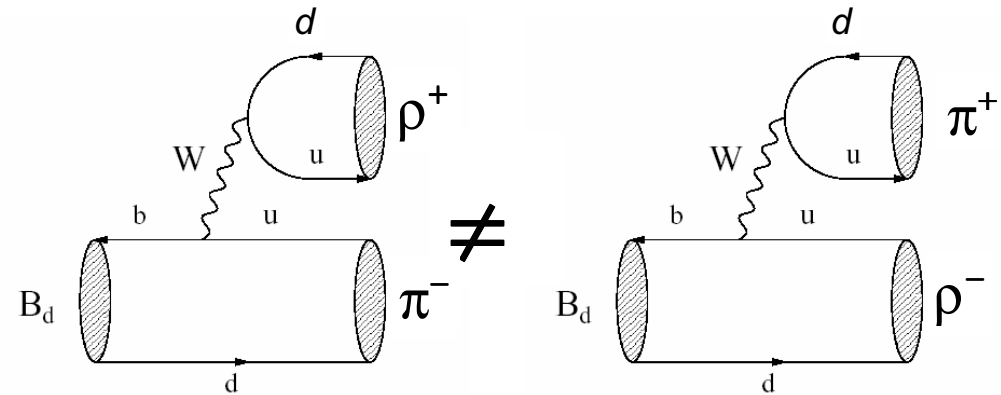
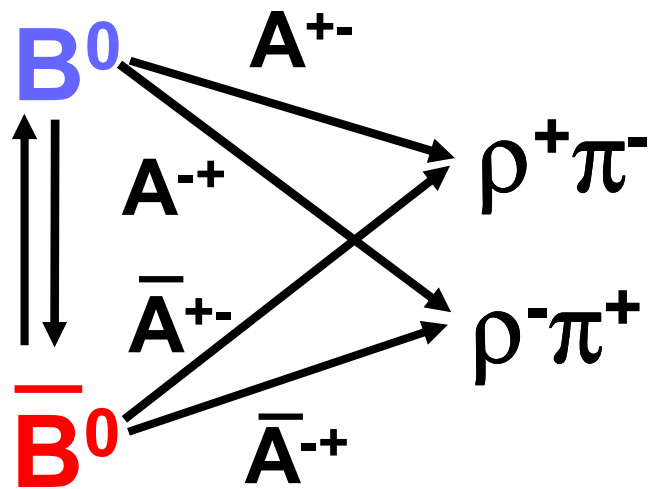
Tree diagram:



Penguin diagram:



Time-dependent CP asymmetries in $B \rightarrow \rho\pi$



$$\Gamma(B^0 \rightarrow \rho^\pm \pi^\mp) \propto (1 \pm A_{CP}) (1 - (S \pm \Delta S) \sin(\Delta m \Delta t) + (C \pm \Delta C) \cos(\Delta m \Delta t))$$

S: CPV in decay/mixing interferences

Usual CP parameters

C: direct CPV

A_{CP} : $\rho^+\pi^-$ vs. $\rho^-\pi^+$ asymmetry

Direct CPV

ΔS : from strong phase $\delta = \arg(A^{-+}/A^{+-})$

ΔC : $W \rightarrow \rho$ vs. *spectator* $\rightarrow \rho$ asymmetry

No CPV

DILUTION factors

Extraction of α : Isospin Analysis

B \rightarrow hh: 2 **triangular** relations [GL]

$$A^{+-} / \sqrt{2} + A^{00} = A^{+0}$$

$$\bar{A}^{+-} / \sqrt{2} + \bar{A}^{00} = \bar{A}^{+0}$$

with $\bar{A}^{+0} = A^{+0} + O(P_{EW})$

6 unknowns and 7 observables (or 6: no measure of S_{00} in B \rightarrow $\pi\pi$)

If C_{00} is not measured, one has the bound [GLSS]:

$$\cos(2\alpha - 2\alpha_{eff}) \geq \frac{1 - 2B^{00} / B^{+0}}{\sqrt{1 - C_{hh}^2}} + \frac{(B^{+-} - 2B^{+0} + 2B^{00})^2}{4B^{+-} B^{+0} \sqrt{1 - C_{hh}^2}}$$

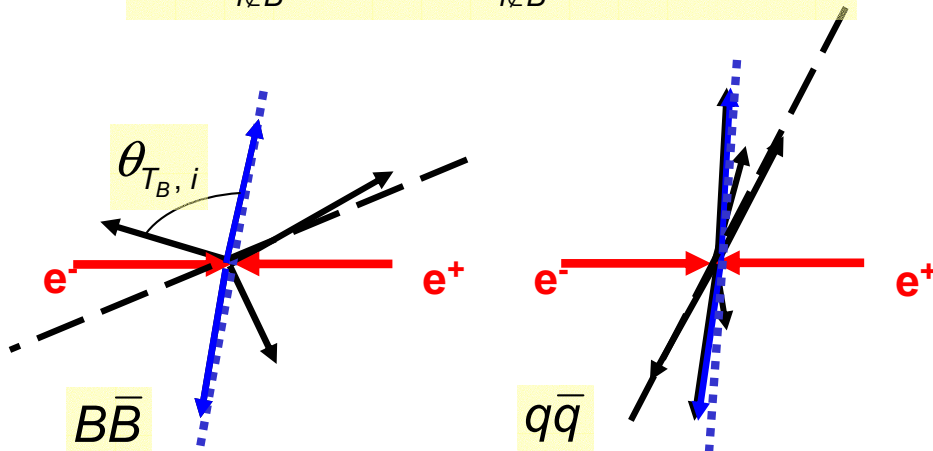
Common experimental aspects

■ continuum background

■ B candidate mass and energy

§ Topological variables in CMS, e.g.

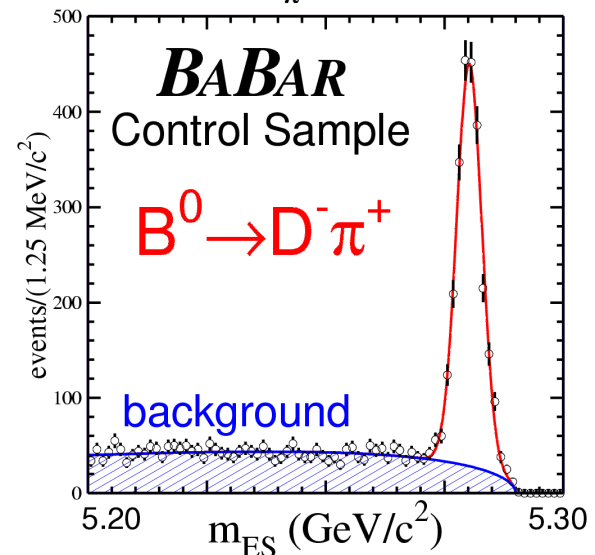
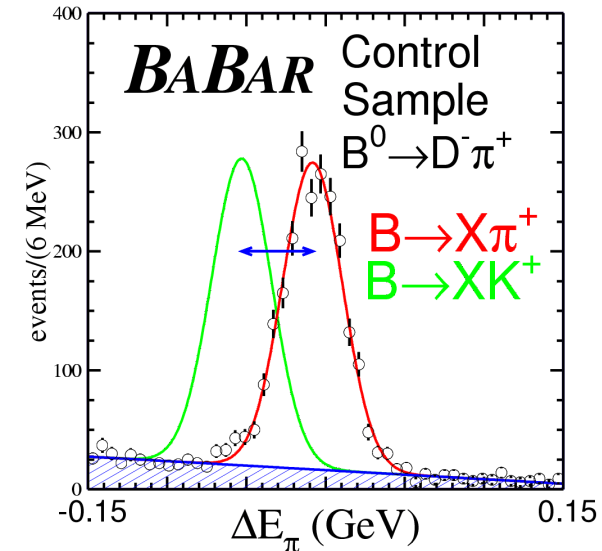
$$L_0 = \sum_{i \notin B} p_i, \quad L_2 = \sum_{i \notin B} p_i \left| \cos \theta_{T_B, i} \right|^2$$



§ Kinematical variables: $\cos(P_B, z)$, $\cos(T_B, z)$



Combined using Fisher or NN



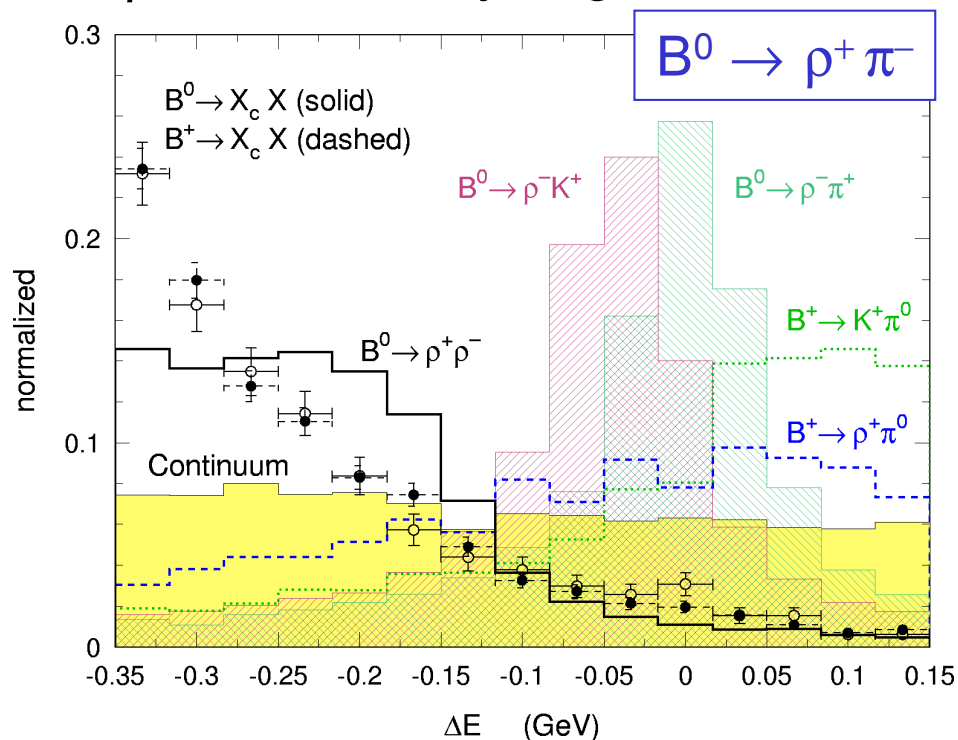
Common experimental aspects

- more rejection of B background
- Particle Identification

All channels but $\pi^+\pi^-$ suffer from B background. Useful variables are:

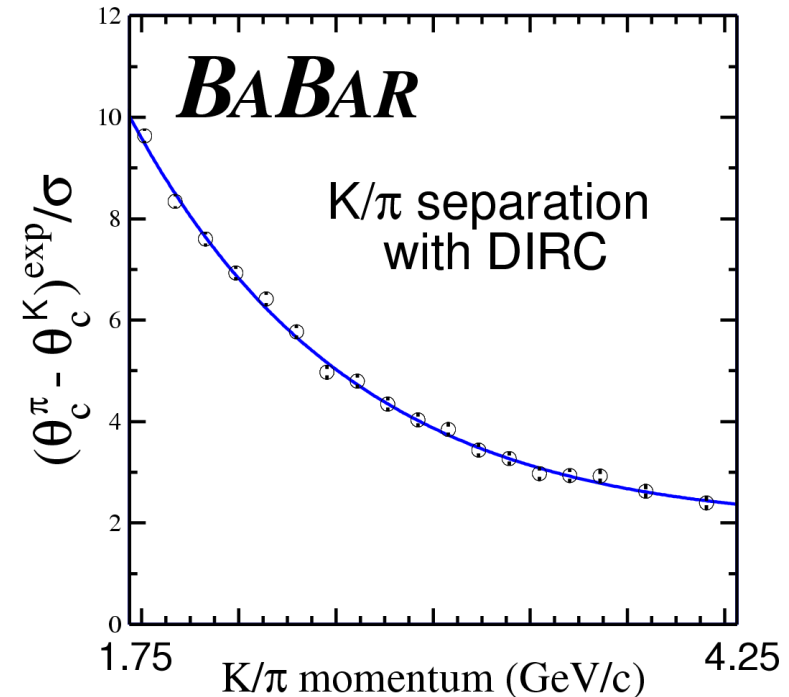
§ ΔE

§ ρ mass, helicity angle



Moriond EW04

LYDIA ROOS LPNHE-Paris



- Unbinned likelihood fit
- Likelihood function includes time dependence

$B^0 \rightarrow h^+ h^-$ ($h=\pi, K$)

81 fb⁻¹

$$Br(B^0 \rightarrow \pi^+ \pi^-) = (4.7 \pm 0.6 \pm 0.2) 10^{-6}$$

$$Br(B^0 \rightarrow K^+ \pi^-) = (17.9 \pm 0.9 \pm 0.6) 10^{-6}$$

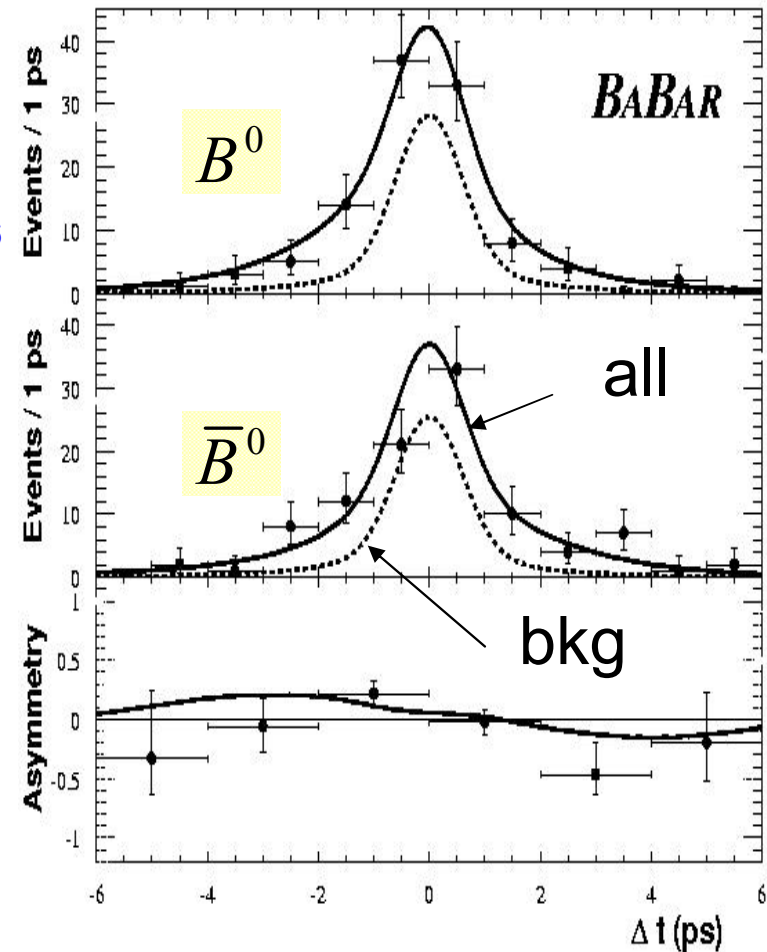
$$Br(B^0 \rightarrow K^+ K^-) < 0.6 10^{-6} (90\% \text{ CL})$$

113 fb⁻¹

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

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

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

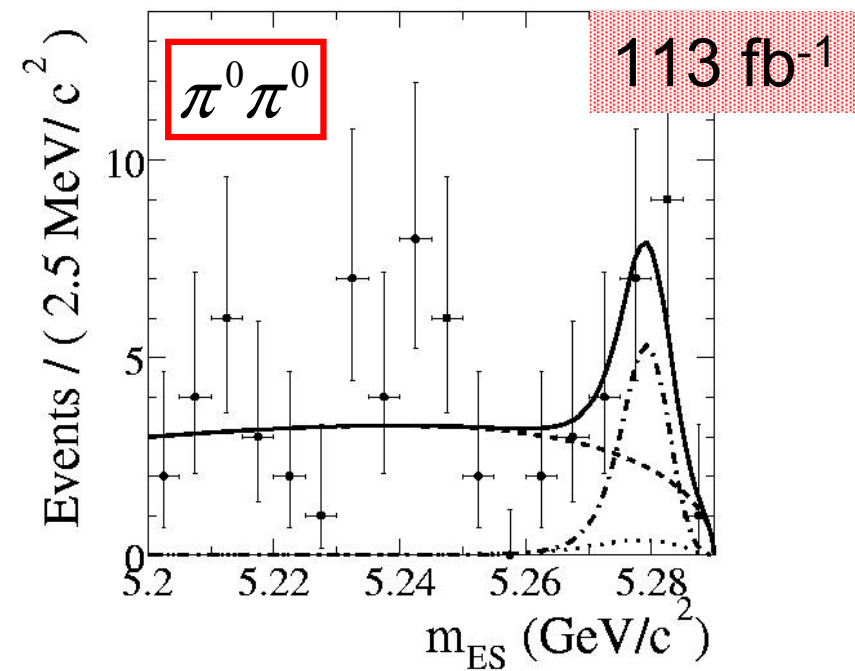
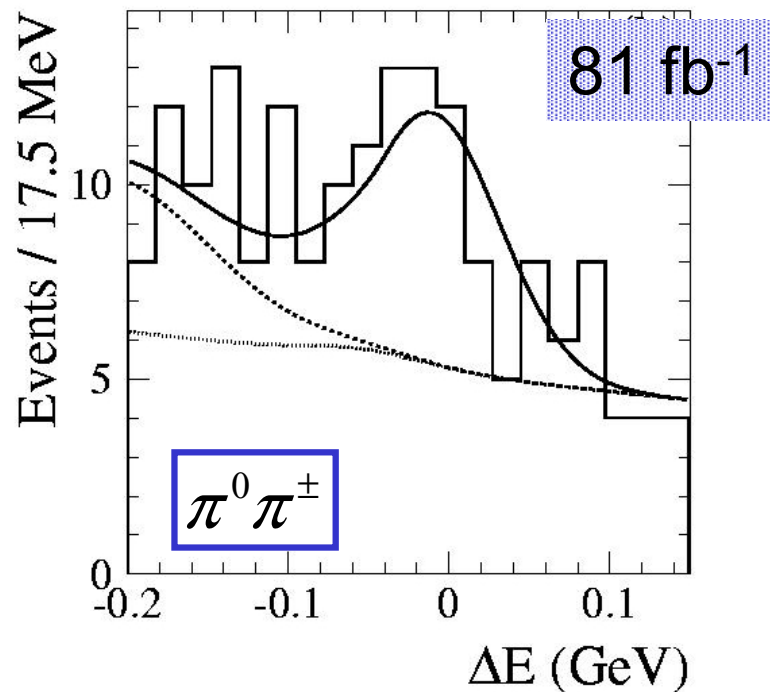


$B^\pm \rightarrow \pi^\pm \pi^0$ and $B^0 \rightarrow \pi^0 \pi^0$

$$\text{BR}(\pi^0 \pi^\pm) = (5.5^{+1.0}_{-0.9} \pm 0.6) 10^{-6}$$
$$\text{BR}(\pi^0 K^\pm) = (12.8^{+1.2}_{-1.1} \pm 1.0) 10^{-6}$$

Yield: $46 \pm 13 \pm 3$

$\text{BR}(\pi^0 \pi^0) = (2.1 \pm 0.6 \pm 0.3) 10^{-6}$
Significance: 4.2σ



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

Quasi two-body approach:

$$S_{\rho\pi} = -0.13 \pm 0.18 \pm 0.04$$

$$C_{\rho\pi} = 0.35 \pm 0.13 \pm 0.05$$

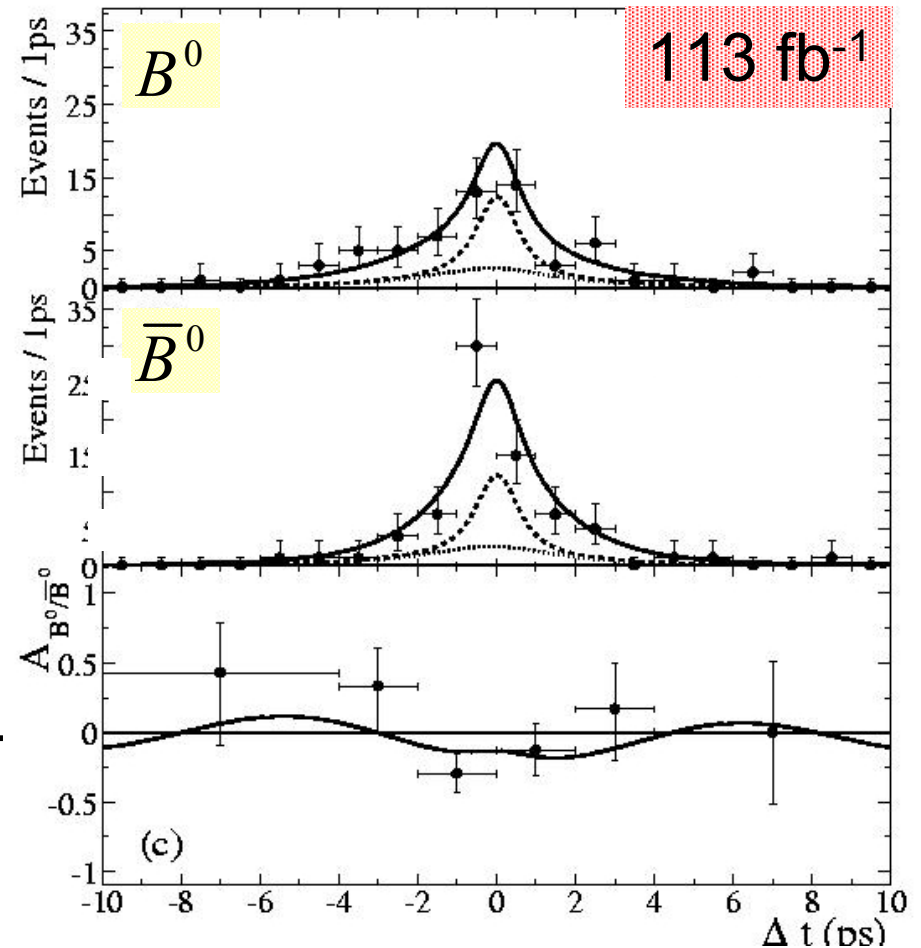
$$\Delta S_{\rho\pi} = 0.33 \pm 0.18 \pm 0.03$$

$$\Delta C_{\rho\pi} = 0.20 \pm 0.13 \pm 0.05$$

$$A_{CP}^{\rho\pi} = -0.114 \pm 0.062 \pm 0.027$$

Significance for direct CPV: 2.5σ

- Isospin analysis needs $\sim 10 \text{ ab}^{-1}$ to disentangle multiple solutions;
- More promising: perform full Dalitz plot analysis;
- Powerful but model-dependent constraint from QCD FA [BN]: $\sigma(\alpha) \sim 9^\circ$



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

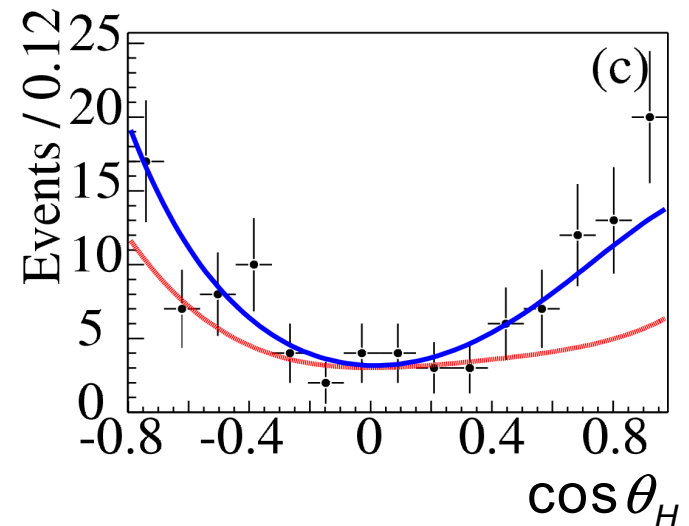
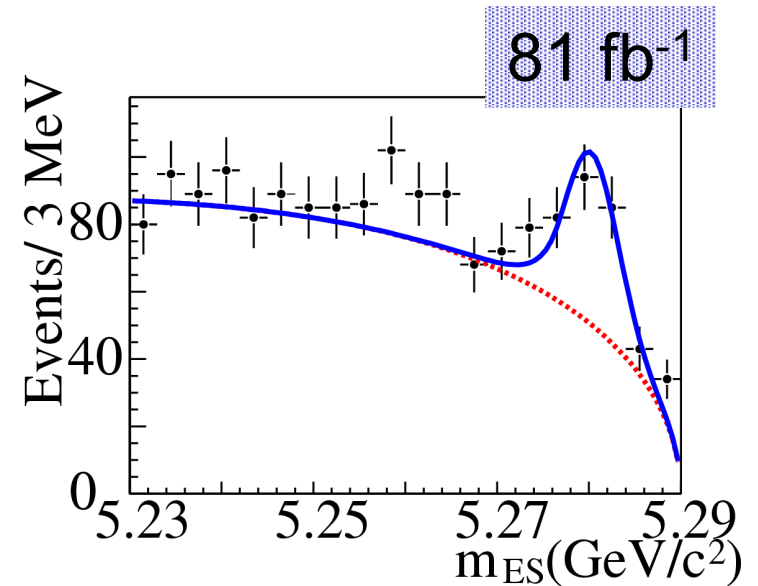
- Three helicity states:
longitudinal (CP+) and tranverse (CP+/-)
- Mis-reconstructed signal events:
39% (longitudinal), 16% (transverse)
- B background in signal region:
 - § $\sim 350 B^0, B^\pm \rightarrow$ charm;
 - § charmless B modes (~ 65 events), mainly:
 $\rho^+\pi^0, a_1\rho, a_1\pi, \rho^+\rho^0, (\text{higher K res})\pi$

$$BR(\rho^+ \rho^-) = (30 \pm 4_{stat} \pm 5_{syst}) 10^{-6}$$

$$f_{long} = 0.99 \pm 0.03(stat)_{-0.03}^{+0.04} (syst)$$

$$S_{long} = -0.42 \pm 0.42_{stat} \pm 0.14_{syst}$$

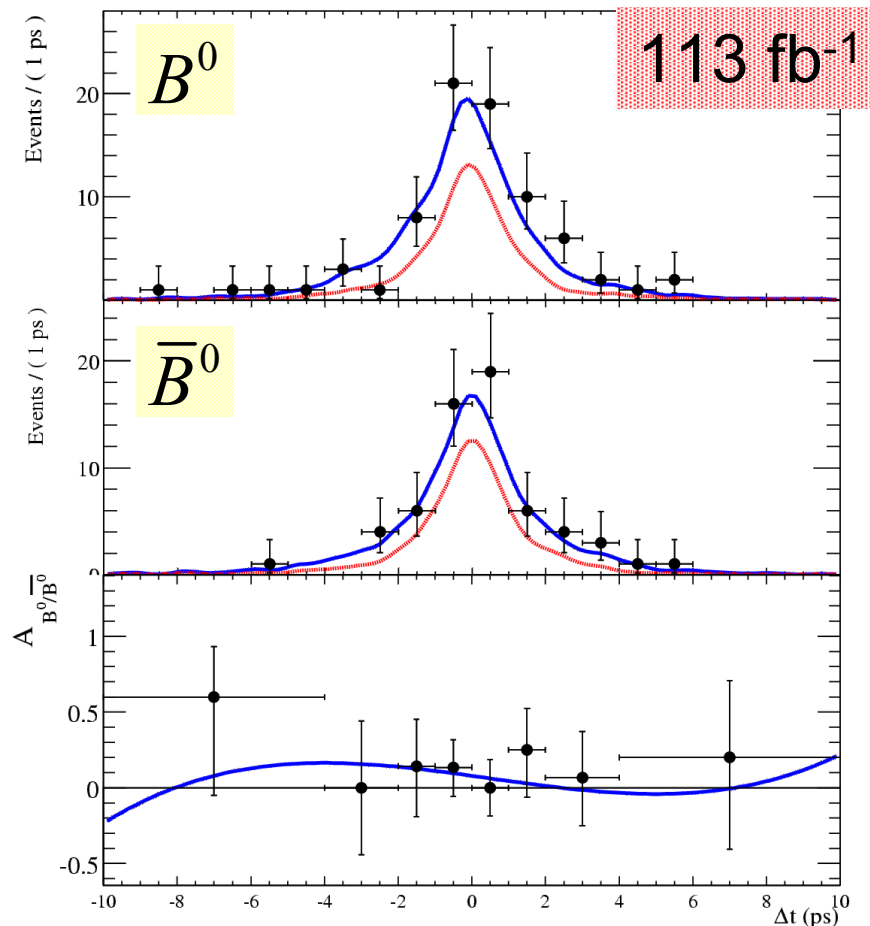
$$C_{long} = -0.17 \pm 0.27_{stat} \pm 0.14_{syst}$$



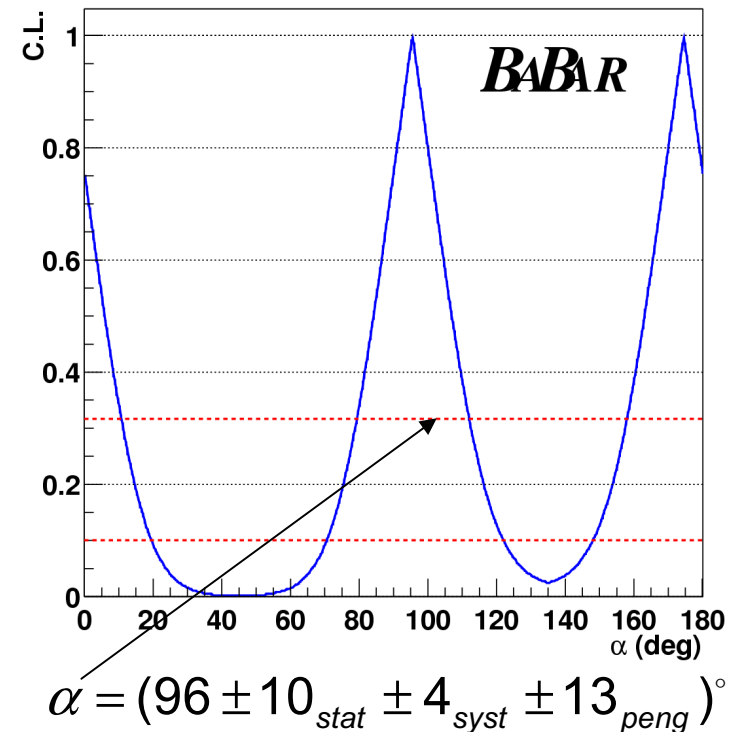
New result on $B^0 \rightarrow \rho^+ \rho^-$

$$S_{long} = -0.19 \pm 0.33_{stat} \pm 0.11_{syst}$$

$$C_{long} = -0.23 \pm 0.24_{stat} \pm 0.14_{syst}$$



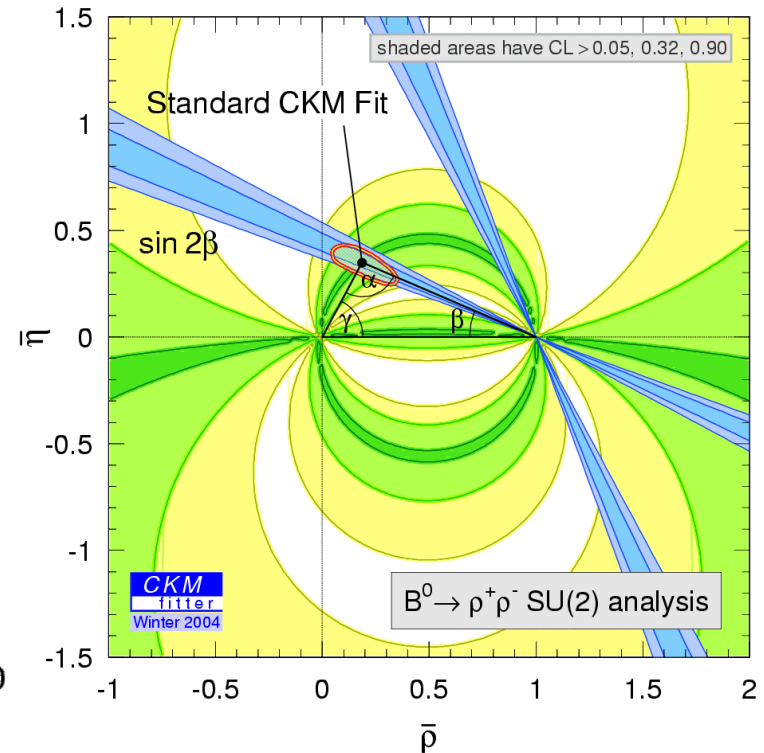
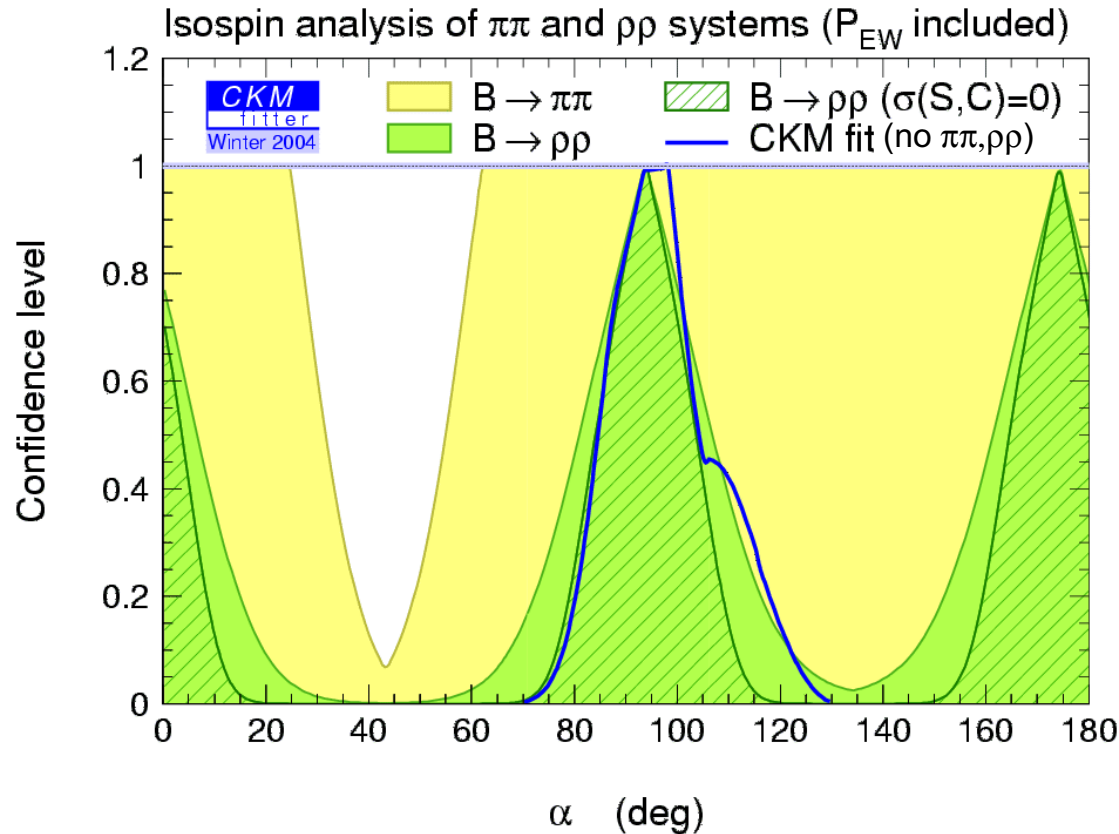
§ Main systematics: CPV in B bkg
 § Detailed study of B background:
 209 B decay modes simulated



§ Isospin analysis: interference,
 NR contributions, I=1 amplitudes
 neglected

PRELIMINARY

More on α from $B \rightarrow \pi\pi, \rho\rho$



Other ingredients in $\rho\rho$ isospin analysis:

$$BR(\rho^+ \rho^0) = (26.4 \pm 6.4)10^{-6} \text{ (BABAR \& Belle)}, BR(\rho^0 \rho^0) = (0.62_{-0.60}^{+0.72} \pm 0.12)10^{-6} \text{ (BABAR)}$$

$$f_{long}(\rho^+ \rho^0) = 0.962_{-0.065}^{+0.049} \text{ (BABAR \& Belle)}, f_{long}(\rho^0 \rho^0) = 1.0 \text{ (assumed)}$$

Conclusion

- $B \rightarrow \pi\pi$: evidence/observation of all decay modes.

No significant constraint on α with present data.

- $B \rightarrow \rho\pi$: quasi 2-body asymmetries measured.

Next step is the full Dalitz plot analysis.

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

81fb⁻¹ submitted

$$S_{long} = -0.42 \pm 0.42_{stat} \pm 0.14_{syst}$$

$$C_{long} = -0.17 \pm 0.27_{stat} \pm 0.14_{syst}$$

113 fb⁻¹ preliminary

$$S_{long} = -0.19 \pm 0.33_{stat} \pm 0.11_{syst}$$

$$C_{long} = -0.23 \pm 0.24_{stat} \pm 0.14_{syst}$$

§ Constraint on α in perfect agreement with the Standard Fit;

$$\alpha = (96 \pm 10_{stat} \pm 4_{syst} \pm 13_{peng})^\circ$$

§ low penguin pollution;

§ if $BR(\rho^0\rho^0)$ not too small, measure not only $C_{\rho^0\rho^0}$ but also $S_{\rho^0\rho^0}$