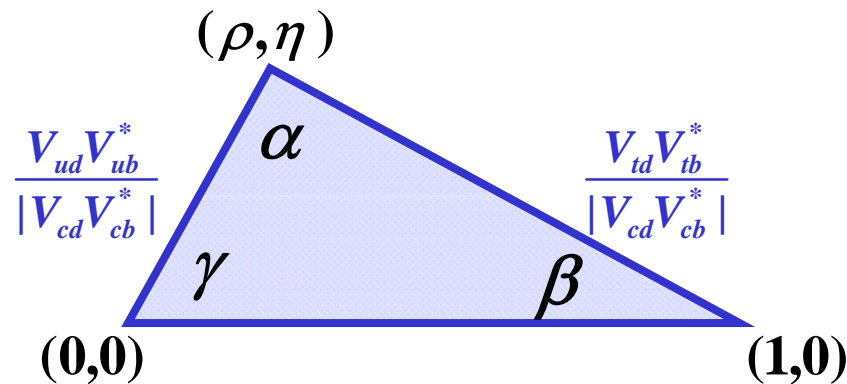


# Constraints on $\alpha$ from $B \rightarrow \rho\rho$ Decays at BaBar



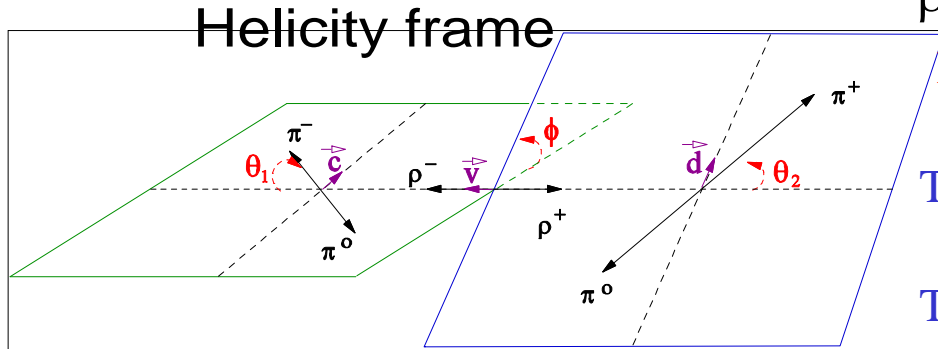
Haibo Li

University of Wisconsin, Madison  
For the BaBar Collaboration

# Out line

- Introduction and Motivation
- History of Measurements
- Time dependent CP Asymmetry in  $B^0 \rightarrow \rho^+ \rho^-$  (122M  $B\bar{B}$ )
- Update of  $B^0 \rightarrow \rho^0 \rho^0$  (227M  $B\bar{B}$ )
- Constraint on Unitarity Triangle angle  $\alpha$

# CP Study in $B^0 \rightarrow \rho^+\rho^-$ Decays



$\rho^+\rho^-$  is a mixture of CP even/ odd!

Longitudinal  $A_0 = -\frac{1}{\sqrt{3}}S + \sqrt{\frac{2}{3}}D$  Pure CP = +1

Transverse  $A_{+1} = \frac{1}{\sqrt{3}}S + \frac{1}{\sqrt{6}}D + \frac{1}{\sqrt{2}}P$  Transverse is Non-CP eigenstates

Transverse  $A_{-1} = \frac{1}{\sqrt{3}}S + \frac{1}{\sqrt{6}}D - \frac{1}{\sqrt{2}}P$

$$\text{BR}(B^0 \rightarrow \rho^+\rho^-) \times 10^{-6} = 30 \pm 4 \pm 5, \quad f_L = 0.99 \pm 0.03^{+0.04}_{-0.03}$$

( hep-ex/0404029, submitted to PRL )

It is almost a pure CP eigenstate (CP = +1)

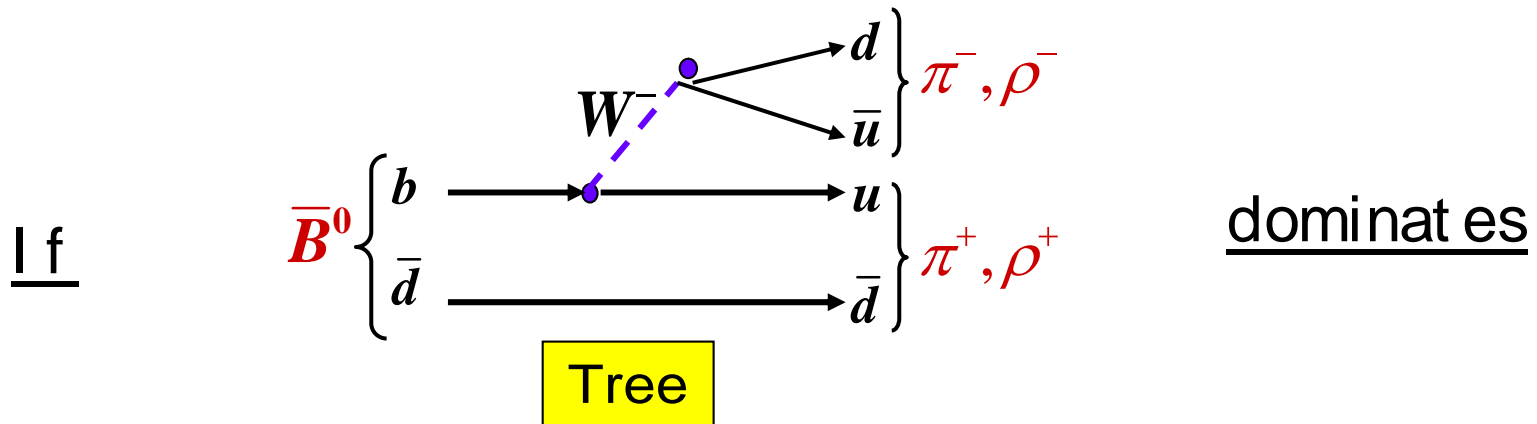
The branching fraction of  $\rho^+\rho^-$  is 5 times larger than  $B^0 \rightarrow \pi^+\pi^-$

# Motivation: Measuring $\alpha$

- Determine CKM angle  $\alpha \equiv \arg[-(V_{td} V_{tb}^*) / (V_{ud} V_{ub}^*)] = S_+$

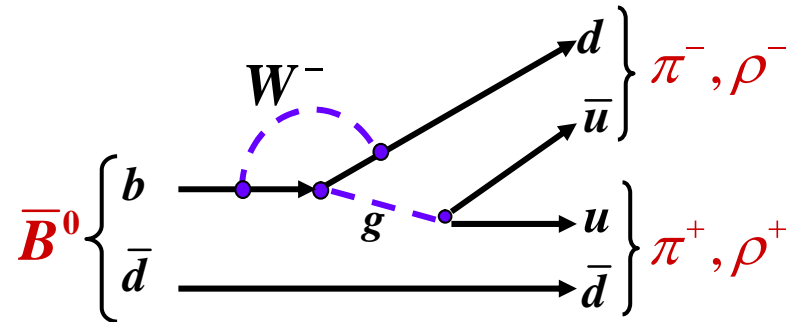
$$\frac{\Gamma(\bar{B}^0_{\text{phys}}(t) \rightarrow \rho^+ \rho^-) - \Gamma(B^0_{\text{phys}}(t) \rightarrow \rho^+ \rho^-)}{\Gamma(\bar{B}^0_{\text{phys}}(t) \rightarrow \rho^+ \rho^-) + \Gamma(B^0_{\text{phys}}(t) \rightarrow \rho^+ \rho^-)} = S_+ \sin(\Delta m t) - C_+ \cos(\Delta m t)$$

If the decay is dominated by tree amplitude, then  $S_+ = \sin(2\alpha)$



# Motivation: Measuring $\alpha$

But ...contribution from



Penguin

Interferes with Tree:

$$A_{CP}(t) \Rightarrow \sin(2\alpha_{\text{eff}})$$

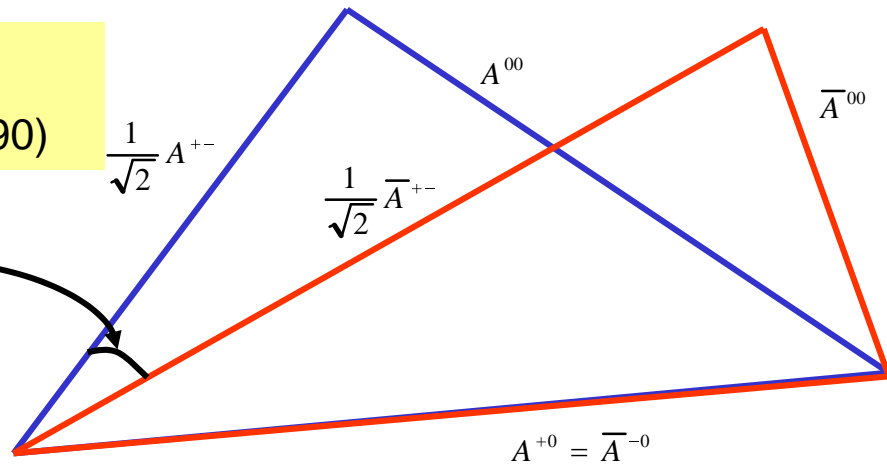
$$\alpha_{\text{eff}} = \alpha + \delta\alpha_{\text{peng}}$$

$$\text{direct } A_{CP} \neq 0$$

# Motivation: The Squashed Triangles in $B \rightarrow \rho\rho$

Gronau & London,  
PRL 65, 3381 (1990)

$2\delta\alpha_{\text{peng}}$



$$\begin{aligned} A^{+-} &= A(B^0 \rightarrow \rho^+ \rho^-) \\ \bar{A}^{+-} &= A(\bar{B}^0 \rightarrow \rho^+ \rho^-) \\ A^{00} &= A(B^0 \rightarrow \rho^0 \rho^0) \\ \bar{A}^{00} &= A(\bar{B}^0 \rightarrow \rho^0 \rho^0) \\ A^{+0} &= A(B^+ \rightarrow \rho^+ \rho^0) \\ \bar{A}^{-0} &= A(B^- \rightarrow \rho^- \rho^0) \end{aligned}$$

Advantage :

$$\text{BR}(B^0 \rightarrow \rho^0 \rho^0) / \text{BR}(B^0 \rightarrow \rho^+ \rho^-) < 0.07 \text{ (90 \% C.L.)}$$

$$\text{vs. } \text{BR}(B^0 \rightarrow \pi^0 \pi^0) / \text{BR}(B^0 \rightarrow \pi^+ \pi^-) \cong 0.33 \pm 0.07 \quad [\text{Z. Ligeti, ICHEP04}]$$

The triangles are squashed in  $B \rightarrow \rho\rho$  decays

- $A^{00}$  small  $\Rightarrow$  Grossman-Quinn bound [PRD 58, 017504 (1998)]

Gives same bound on  $\delta\alpha_{\text{peng}}$

$$\sin^2(\delta\alpha_{\text{peng}}) \leq \frac{f_L^{00} \cdot \text{BF}(B^0 \rightarrow \rho^0 \rho^0)}{f_L^{+0} \cdot \text{BF}(B^+ \rightarrow \rho^+ \rho^0)} \quad \longrightarrow \quad \text{Use } f_L^{00} = 1$$

## Challenges and Assumptions

### Experimental challenges:

- ⇒ Two  $\pi^0$  in the final state.
- ⇒  $\rho$  is broad ( $\sigma \sim 150$  MeV)!
- ⇒ Many sources of B backgrounds (charm and charmless decays).

### Theoretical limitations:

- Assume Isospin symmetry, neglect EW penguin [Z. Ligeti ICHEP04 ]
- We neglect interference with other decays to  $\pi^+\pi^-\pi^0\pi^0$  final states or other resonant modes ( $a_1^+\pi^-$ ,  $\rho^+\pi^-\pi^0$ ,  $\pi^-\pi^0\pi^-\pi^0$ )
- $l=1$  decay amplitudes are also neglected.  $l=1$  absent due to Bose statistics but reintroduced by the finite  $\Gamma_\rho$ .

(Falk, Ligeti, Nir, Quinn, Phys. Rev. D69:011502,2004)

# Review of $B \rightarrow \rho\rho$ measurements

- BR and  $f_L$  measurements:

Mode	BF ( $10^{-6}$ )	$f_L$
* $B^+ \rightarrow \rho^+ \rho^0$	$22.5^{+5.7}_{-5.4} \pm 5.8$	$0.97^{+0.03}_{-0.07} \pm 0.04$
* $B^0 \rightarrow \rho^0 \rho^0$	$< 2.1$ (90% CL)	$f_L = 1.0$
◆ $B^0 \rightarrow \rho^+ \rho^-$	$30 \pm 4 \pm 5$	$0.99 \pm 0.03^{+0.04}_{-0.03}$

\* PRL 91, 171802 (2003) (BaBar)

◆ hep-ex/0404029, submitted to PRL (BaBar)

} 89M  $B\bar{B}$

$$C_{\text{Long}} = -0.17 \pm 0.27 \pm 0.14$$

$$S_{\text{Long}} = -0.42 \pm 0.42 \pm 0.14$$

$S_{\text{Long}}$  and Isospin bound yield:

$$\alpha = \left[ 102^{+16}_{-12} (\text{stat})^{+5}_{-4} (\text{syst}) \pm 13 (\text{peng}) \right]^0$$

- Time dependent  $B^0 \rightarrow \rho^+ \rho^-$  from 123 M  $B\bar{B}$
- Update of  $BF(B^0 \rightarrow \rho^0 \rho^0)$  in this talk (227 M  $B\bar{B}$ )

# $A_{CP}(t)$ in $B^0 \rightarrow \rho^+ \rho^-$ Decay

- Reconstruct  $\rho^\pm \rightarrow \pi^\pm \pi^0$  candidates  $\Rightarrow$  combine  $\Rightarrow B_{CP}$
- Find **vertex** positions of  $B_{CP}$  and other B meson  $\Rightarrow B_{tag}$
- Tag **flavor** of  $B_{tag}$
- Compute  $\Delta t = t_{CP} - t_{tag}$

Fit params

$$f_{B^0(\bar{B}^0)}^{Long}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} (1 \pm S_{Long} \sin(\Delta m \Delta t) \mp C_{Long} \cos(\Delta m \Delta t))$$

$$f_{B^0(\bar{B}^0)}^{Tran}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} (1 \pm S_{Tran} \sin(\Delta m \Delta t) \mp C_{Tran} \cos(\Delta m \Delta t))$$

Set to 0 since  $f_L \cong 1$

# Maximum Likelihood Fit

## 8 discriminating variables

- $m_{ES}$ ,  $\Delta E$ , NN output and  $\Delta t$  ( $m_{\rho 1}$ ,  $m_{\rho 2}$ ,  $\cos(\theta_{\rho 1})$ ,  $\cos(\theta_{\rho 2})$ ).

- **4 types of events:**

⇒ **True Signal** and Misreconstructed signal

⇒ Longitudinal  $\rho\rho$  (fraction of misreconstruction: 42%),

⇒ Transverse  $\rho\rho$  (fraction of misreconstruction: 15%).

⇒ **Continuum.**

⇒ floating parameters to model PDFs

⇒ **B backgrounds:**

⇒ Charmless B background ( $B^0 \rightarrow \rho^+ \pi^-$ ,  $B^+ \rightarrow \rho^0 \rho^+ \dots$ ).

⇒ Charm B ( $b \rightarrow c$ ) background.

⇒ 17 distinct PDFs!!!

- **Likelihood:**

⇒ The likelihood is the sum over the types of events of the terms :

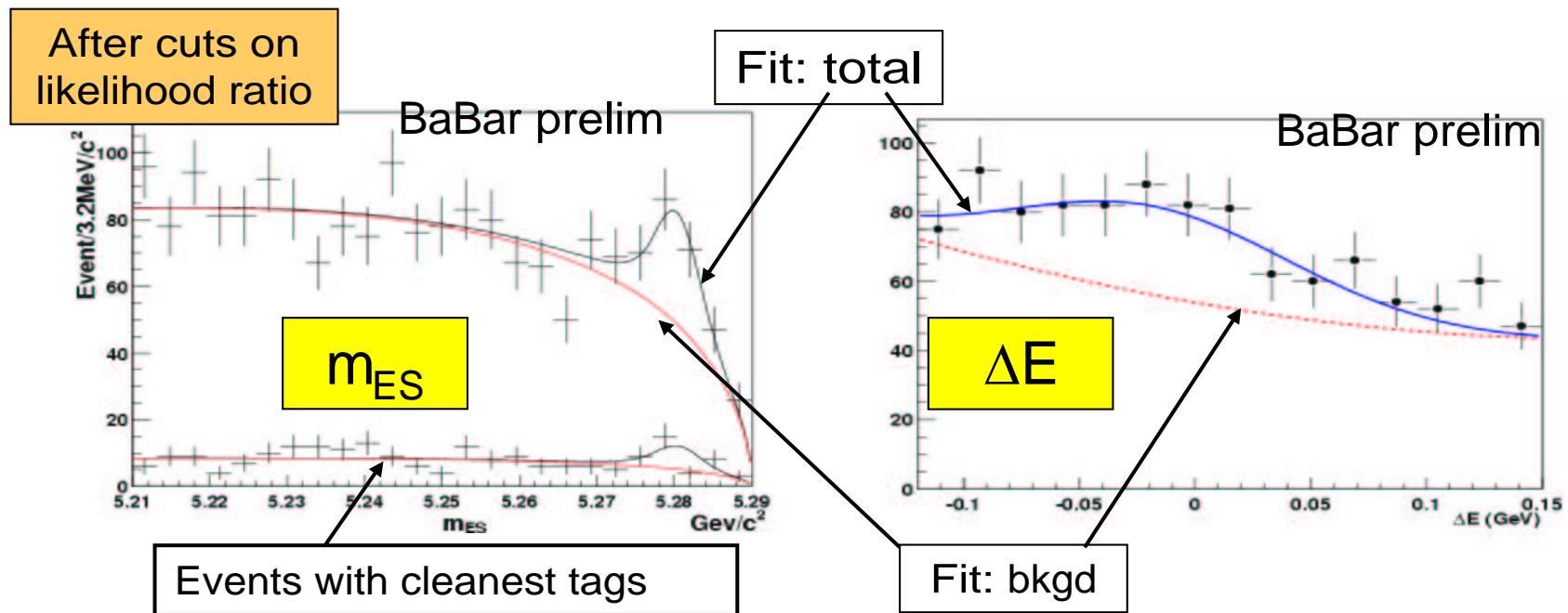
$\text{Pdf}(\text{NN}) \times \text{Pdf}(\Delta E) \times \text{Pdf}(m_B) \times \text{Pdf}(\Delta t) \times \text{Pdf}(m_{\rho 1}) \times \cos(\theta_{\rho 1}) \times \text{Pdf}(m_{\rho 2}) \times \cos(\theta_{\rho 2})$

⇒ In a simultaneous fit we measure: signal yield, polarization,  $C_{\text{long}}$  and  $S_{\text{long}}$ .

# Results in $B^0 \rightarrow \rho^+ \rho^-$ Decay

- Run1-3 data (122M  $B\bar{B}$ )  $\Rightarrow$  Preliminary  
32133 events in fit sample: 87% of background is continuum, 13% B backgrounds

$314 \pm 34$  Signal Events (205 tagged)  $f_L = 1.00 \pm 0.02$



# $A_{cp}(t)$ Results in $B^0 \rightarrow \rho^+ \rho^-$ Decay

- Run1-3 data (122M  $B\bar{B}$ )

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

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

- Main systematic: CPV in B bckground
- Detail study of B background :  
209 charmless B decay simulated.

$$B \rightarrow charm, B \rightarrow a_1 \rho, B \rightarrow a_1 \pi,$$

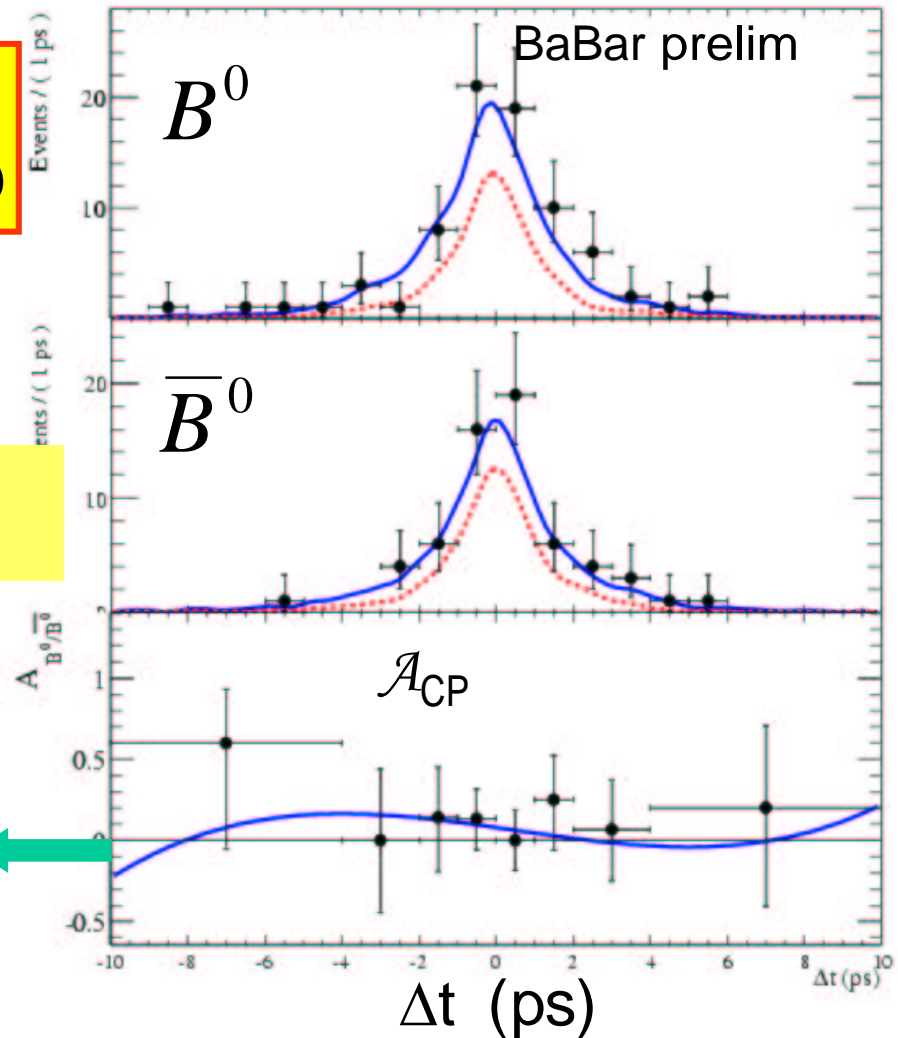
$$B^+ \rightarrow \rho^+ \pi^0, B^+ \rightarrow \rho^+ \rho^0$$

Comprehensive study of systematics due to interference of signal mode with other decays to  $\pi^+ \pi^- \pi^0 \pi^0$  final states

Prelim studies show it's not large

$$\sigma_s = \pm 0.023$$

$$\sigma_c = \pm 0.022$$



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

- Analysis description similar to that of  $B^0 \rightarrow \rho^+ \rho^-$
- Updated with Run1-4 data (227M BB)

$$N_{sig} = 33_{-20}^{+22} \pm 12; \varepsilon = (27 \pm 1.3)\%$$

$$f_L = 1.0(\text{fixed})$$

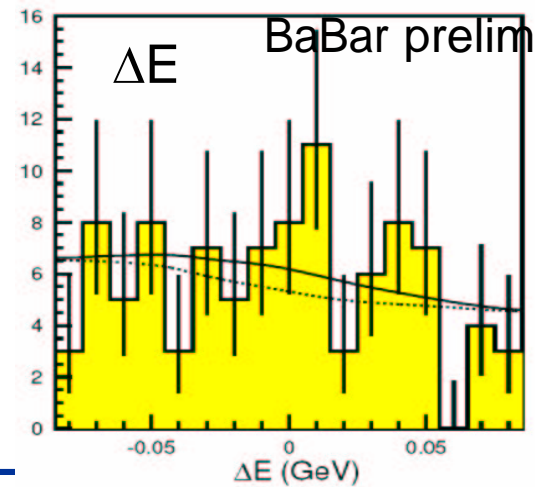
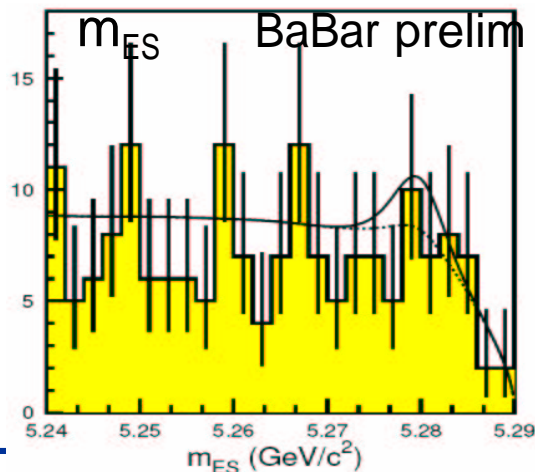
$$Br(B^0 \rightarrow \rho^0 \rho^0) < 1.1 \times 10^{-6} (90\% C.L.)$$

## BB background

Background Category	Yield
$q\bar{q}$	floated
$B \rightarrow \text{charm}$	floated
$B^0 \rightarrow a_1^\pm \pi^\mp$	floated
$B^0 \rightarrow \rho^0 K^{*\mp}$	$35 \pm 5 \pm 16$ [5]
$B^+ \rightarrow \rho^+ \rho^0$	$78 \pm 9 \pm 18$ [5]
$B \rightarrow \rho \pi \text{ modes}$	$34 \pm 6 \pm 4$ [13]
$B^0 \rightarrow \rho^+ \rho^-$	$14 \pm 4 \pm 3$ [ $\bar{7}$ ]
other charmless $B$ decays	floated

## Dominant Syst

- $a_1 \pi$  interfer:  $\pm 7.5$  events
- PDF variations:  $\pm 6$  events
- B bkgds:  $\pm 5.8$  events



# Constraint on $\alpha$

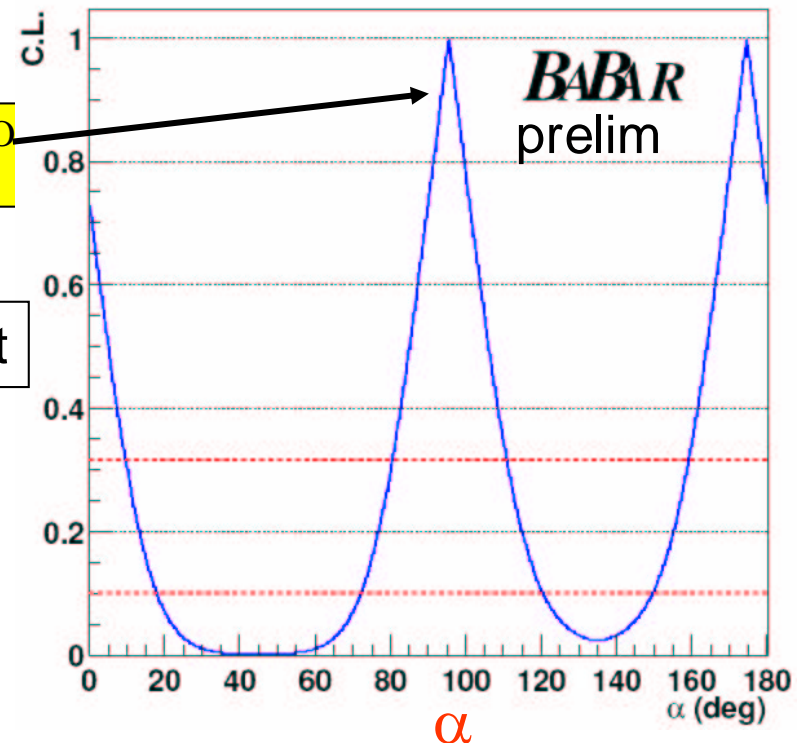
- Preliminary update on a constraint:
  - BaBar  $BF(\rho^+\rho^-)$ ,  $BF(\rho^0\rho^0)$  and  $S_{\text{long}}$  and  $C_{\text{long}}$
  - World average  $BF(\rho^+\rho^0) = (26.4^{+6.1}_{-6.4}) \times 10^{-6}$  (HFAG)

$$\alpha = [96 \pm 10(\text{stat}) \pm 4(\text{syst}) \pm 11(\text{peng})]^\circ$$

From  $\rho^0\rho^0$  measurement

Run1-2 result:

$$\alpha = [102^{+16}_{-12}(\text{stat})^{+5}_{-4}(\text{syst}) \pm 13(\text{peng})]^\circ$$



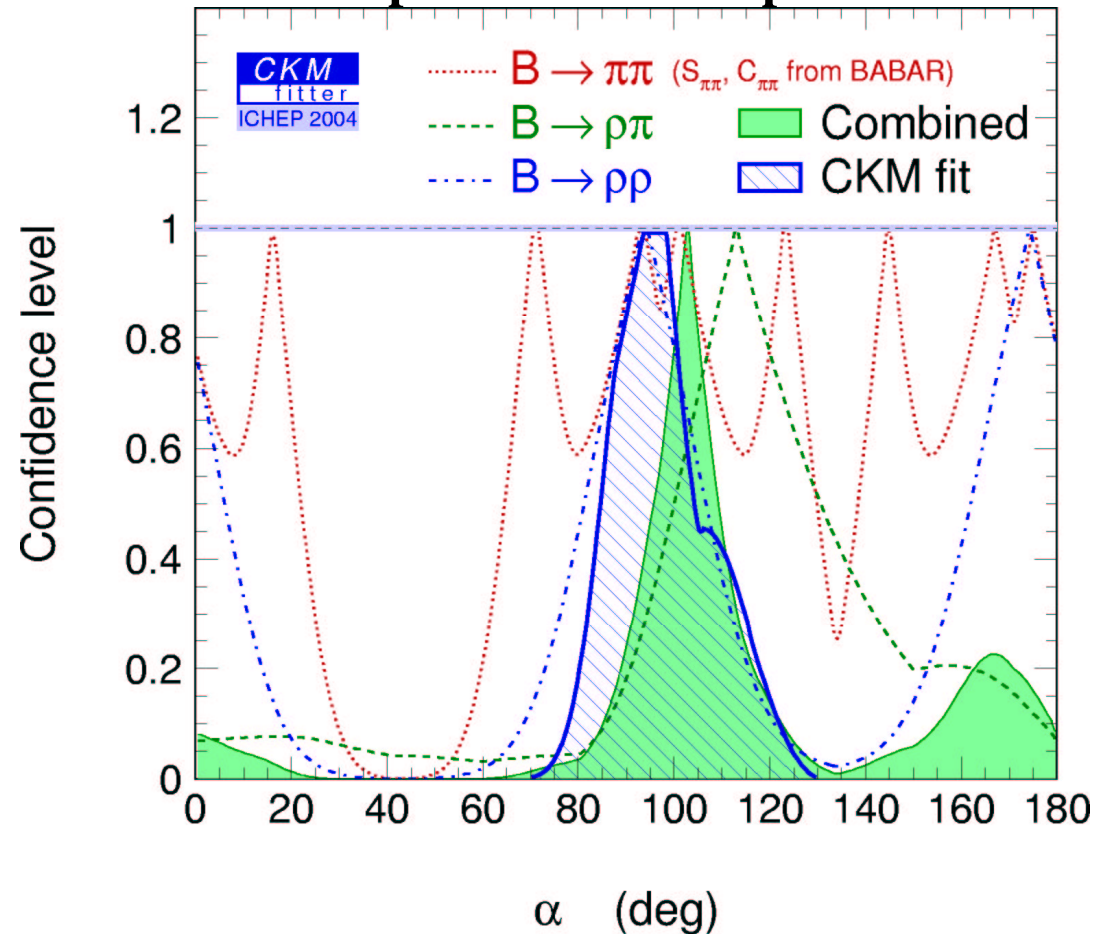
# Constraints on $\alpha$ Using BaBar $\rho\rho$ , $\rho\pi$ , and $\pi\pi$ Measurements

<http://ckmfitter.in2p3.fr/>

$\alpha$  from  $\rho\rho$ ,  $\rho\pi$ ,  $\pi\pi$  only  
  $\alpha$  from full CKM fit  
 $(\epsilon_K, V_{ub}, \Delta m_{d,s}, \sin(2\beta))$

- Mirror solutions being disfavored!
- From full CKM fit:

$$\alpha = (103^{+10}_{-11})^\circ$$



# Conclusion

- First measurement of  $A_{CP}(t)$  in  $B^0 \rightarrow \rho^+ \rho^-$  decays
  - Updated (2004) with Run1-3 data (122M  $B\bar{B}$ )
- Limit on  $BF(B^0 \rightarrow \rho^0 \rho^0)$ 
  - Updated with full Run1-4 sample (226.6M  $B\bar{B}$ )
  - Low BF allows for relatively clean measurement of  $\alpha$  via isospin relations!
- Important milestone for B-Factories!

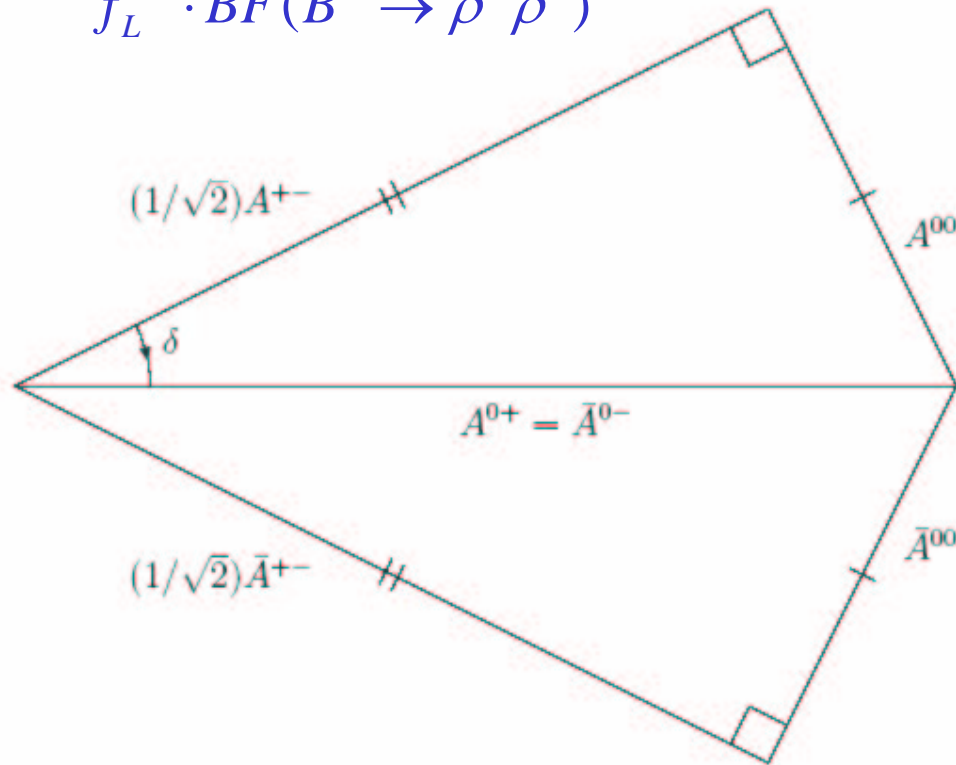
$$\alpha = [96 \pm 10(stat) \pm 4(syst) \pm 11(peng)]^{\circ}$$

- Coming soon  $\Rightarrow$  update of  $A_{CP}(t)$  in  $B^0 \rightarrow \rho^+ \rho^-$  with full Run1-4 data sample and improved analysis

# Backup Slide

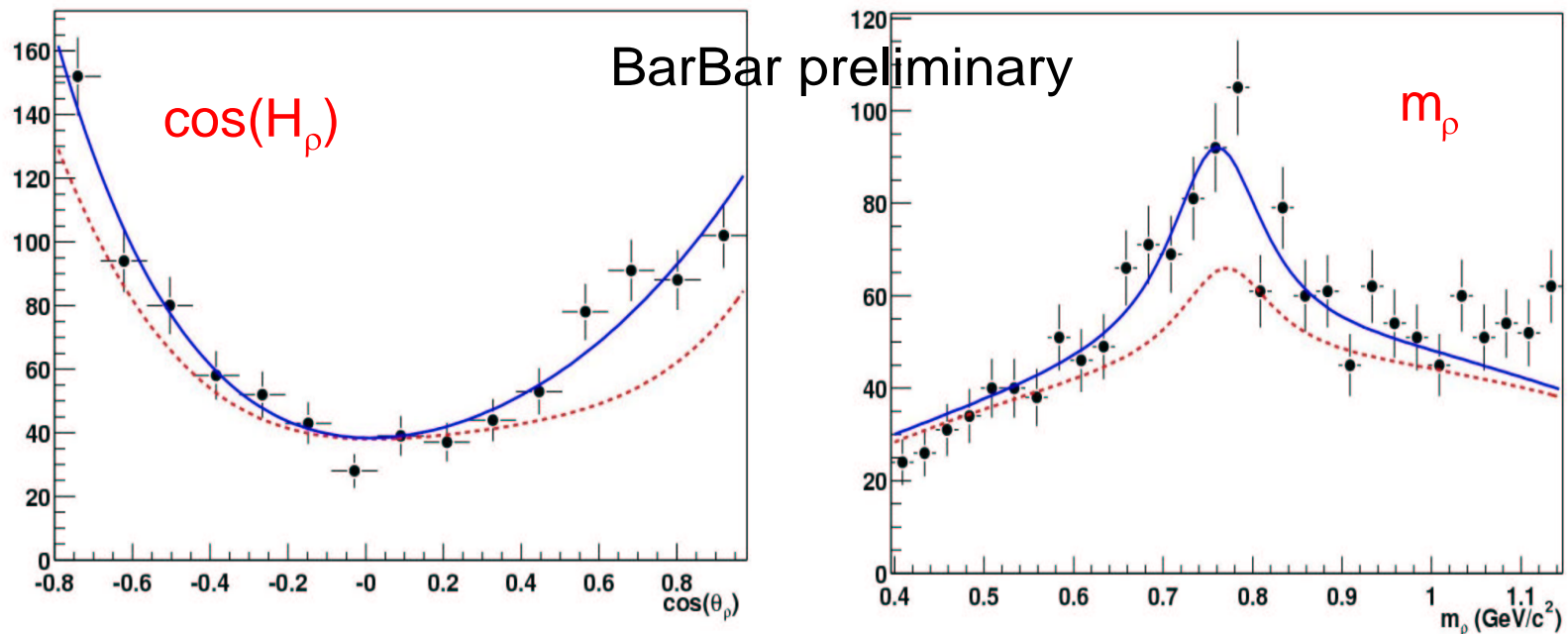
- $A^{00}$  small  $\Rightarrow$  Grossman-Quinn bound PRD 58, 017504 (1998). Gives same bound on  $\delta\alpha_{peng}$

$$\sin^2(\delta\alpha_{peng}) \leq \frac{f_L^{00} \cdot BF(B^0 \rightarrow \rho^0 \rho^0)}{f_L^{+0} \cdot BF(B^+ \rightarrow \rho^+ \rho^0)} \quad \longrightarrow \quad \text{Use } f_L^{00} = 1$$



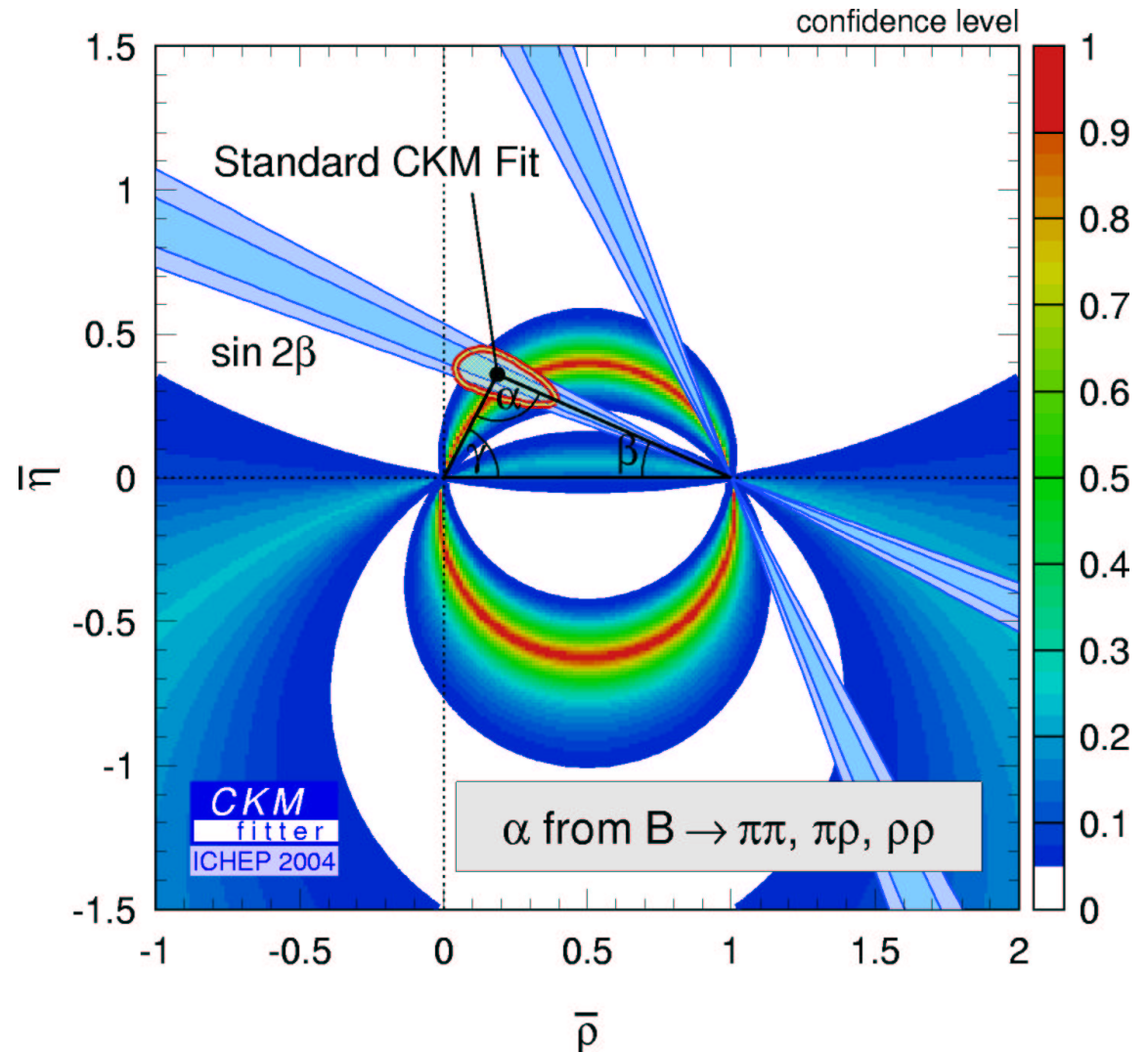
# Backup Slide

- Distributions of  $\rho^\pm$  helicity and mass for data
  - Clear demonstration of strong longitudinal polarization from helicity distribution.



# Backup Slide

- Constraints in the  $\rho$ - $\eta$  plane:



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