

Constraints on α from $B \rightarrow \rho\rho$ Decays at *BaBar*

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For the *BaBar* Collaboration

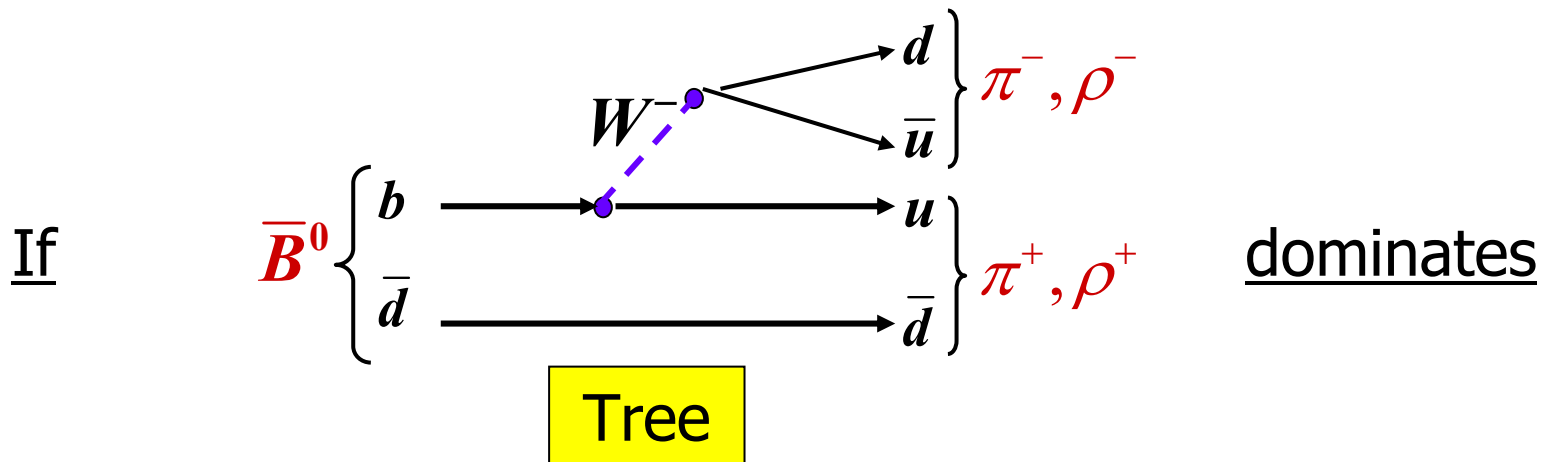
Outline

- Introduction and Motivation
- History of Measurements
- Time dependent CP Asymmetry in $B^0 \rightarrow \rho^+ \rho^-$
- Update of $B^0 \rightarrow \rho^0 \rho^0$ **NEW!**
- Constraint on Unitarity Triangle angle α

Motivation: Measuring α

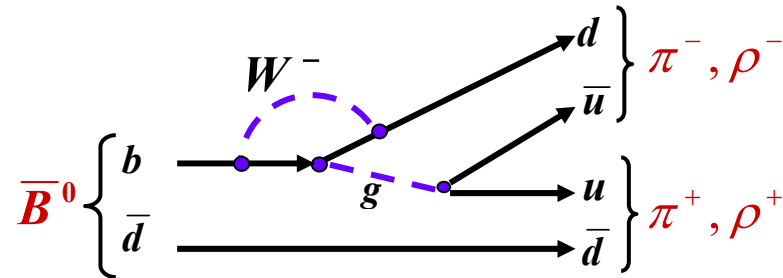
$\mathcal{A}_{CP}(t)$ in $b \rightarrow u\bar{u}d$ decay to CP eigenstate:


 Measure $\alpha \equiv \arg \left[\frac{-V_{td}V_{tb}^*}{V_{ud}V_{ub}^*} \right] = \pi - \beta - \gamma$ (SM)



Motivation: Measuring α

But...contribution from



Penguin

Interferes with Tree:

$$\mathcal{A}_{CP}(t) \Rightarrow \sin(2\alpha_{\text{eff}})$$

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

$$\text{direct } \mathcal{A}_{CP} \neq 0$$

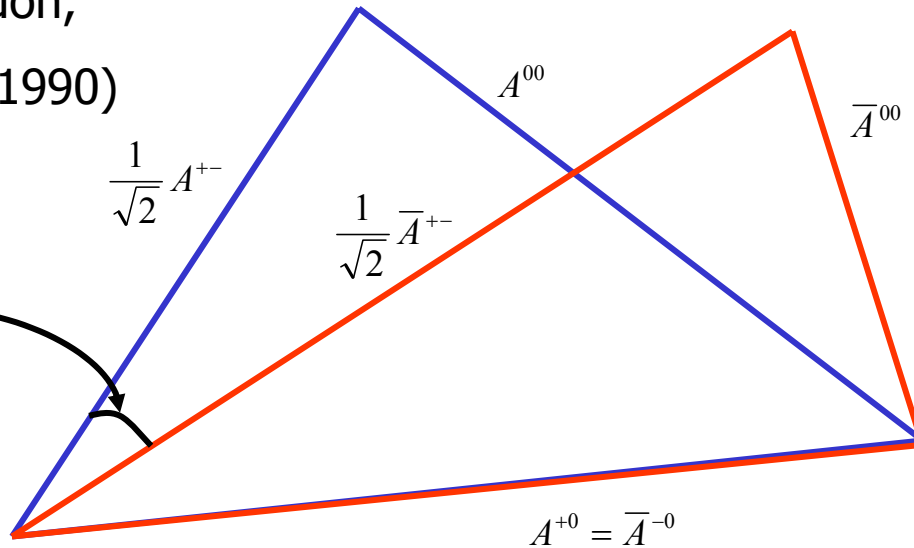
But can measure $\delta\alpha_{\text{peng}}$ using isospin relations...

Motivation: Isospin and $\rho\rho$

Gronau&London,

PRL 65, 3381 (1990)

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



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

3 such relations (one for each polarization)

Relative to experimentally simpler $B \rightarrow \pi\pi$:

$$\frac{|A^{00}|}{|A^{+0}|}, \frac{|A^{00}|}{|A^{+-}|} \text{ Much smaller in } \rho\rho \text{ system}$$



$\delta\alpha_{\text{peng}}$ much smaller!!

History: $\rho^+\rho^-$ Observation

But ρ is a vector \longrightarrow $\rho^+\rho^-$ not a CP eigenstate?

Transverse ($h=\pm 1$) and **longitudinal** ($h=0$) helicity states

Non- CP eigenstates

CP eigenstate

* Observation of $B^0 \rightarrow \rho^+\rho^-$ PRD 69, 031102 (2004) *

- Run1-2 data (89M $B\bar{B}$)

- Measure BF: $(25_{-6}^{+7} {}_{-6}^{+5}) \times 10^{-6} \Rightarrow$ 5 times larger than $\pi^+\pi^-$

- **Measure Polarization** $f_L \equiv \frac{\Gamma_L}{\Gamma} = 0.98_{-0.08}^{+0.02} \pm 0.03$

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

History: $\rho^+\rho^0$ and $\rho^0\rho^0$

- $B^+ \rightarrow \rho^+\rho^0$ and $B^0 \rightarrow \rho^0\rho^0$ 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)	
◆ $B^0 \rightarrow \rho^+\rho^-$	$30 \pm 4 \pm 5$	$0.99 \pm 0.03^{+0.04}_{-0.03}$

* PRL 91, 171802 (2003)

◆ hep-ex/0404029, submitted to PRL

} 89M $B\bar{B}$

- Update of $BF(B^0 \rightarrow \rho^0\rho^0)$ in this talk

$\mathcal{A}_{CP}(t)$ in $B^0 \rightarrow \rho^+ \rho^-$ Decays

- 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

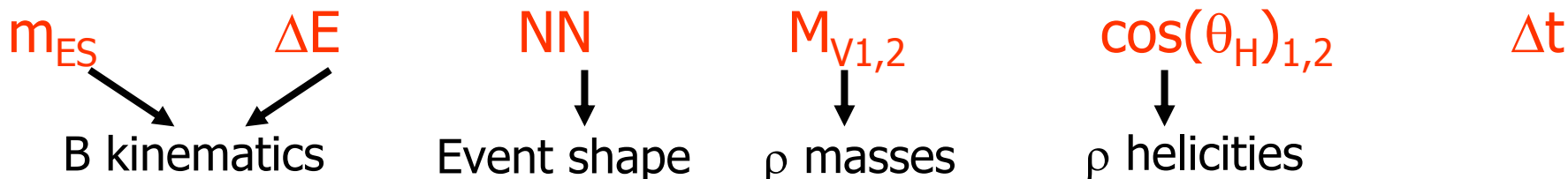
$$f_{B^0(\bar{B}^0)}^{Long}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} (1 \pm S_{Long} \sin(\Delta m \Delta t) \mp C_{Long} \cos(\Delta m \Delta t))$$

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

Set to 0 since $f_L \cong 1$

$\mathcal{A}_{\text{CP}}(\mathbf{t})$ in $B^0 \rightarrow \rho^+ \rho^-$ Decays

- Run1-3 data (122M $B\bar{B}$)
 - Max. Likelihood fit in 8 dimensional space



- Fit for signal yield, polarization, S_{long} and C_{long}
- Model: true signal, misreco. signal, continuum and 17 $B\bar{B}$ backgrounds

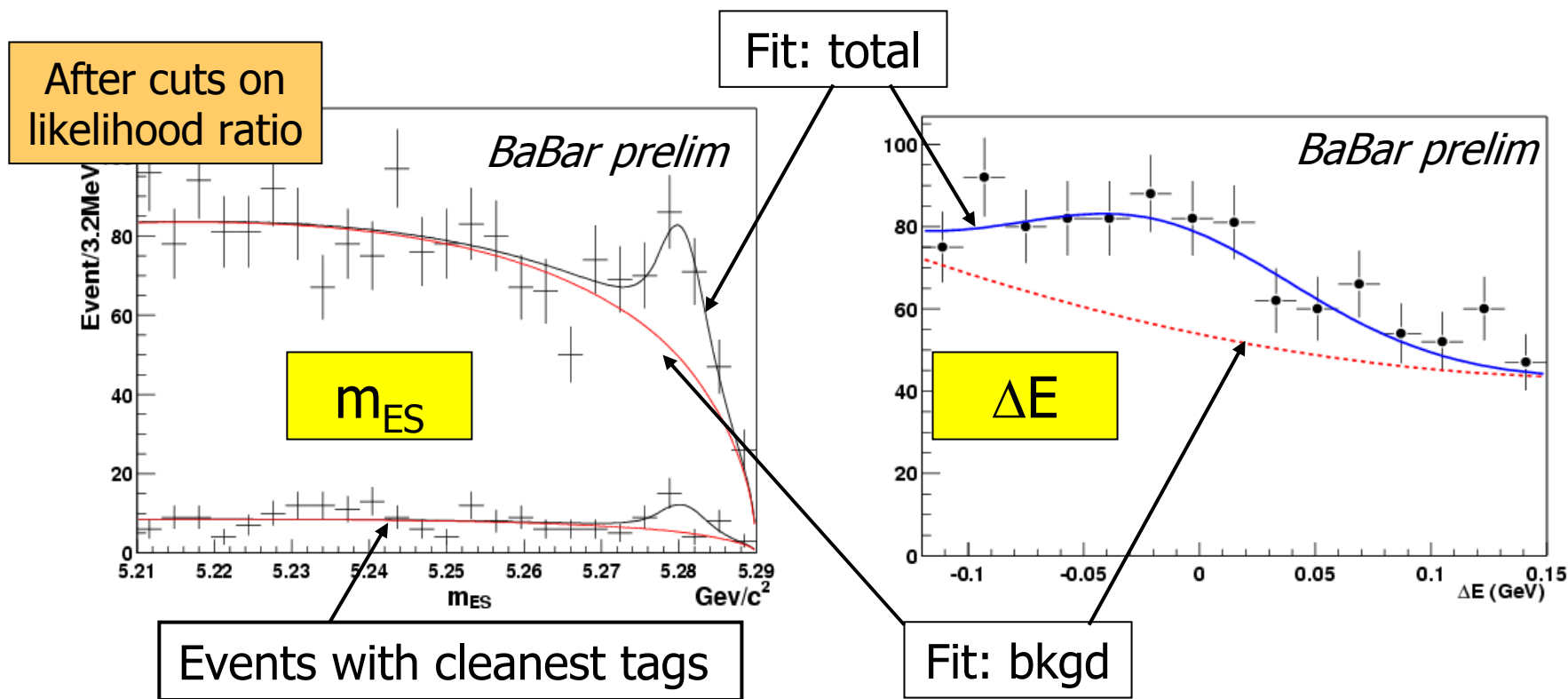
32133 events in fit sample:

- 87% of background is continuum, 13% B backgrounds

$\mathcal{A}_{CP}(t)$ in $B^0 \rightarrow \rho^+ \rho^-$ Decays

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

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



$\mathcal{A}_{CP}(t)$ in $B^0 \rightarrow \rho^+ \rho^-$ Decays

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

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

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

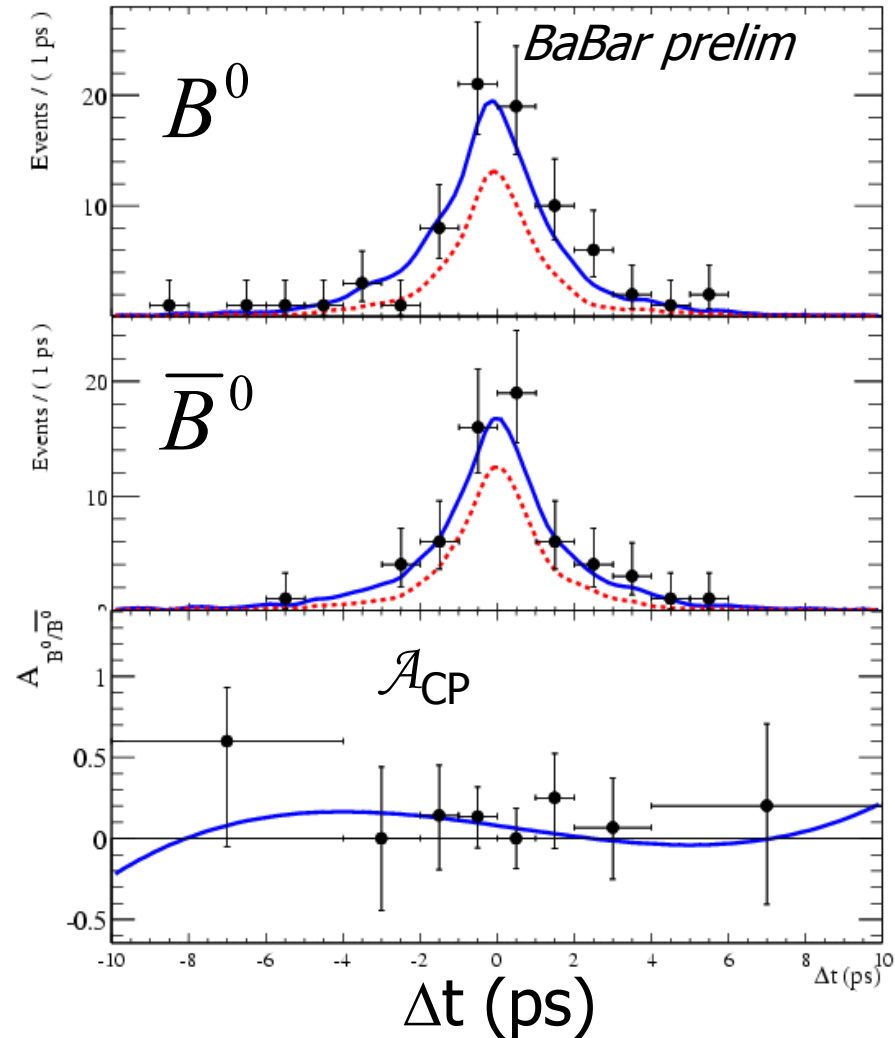
- BaBar Run1-2 (89M $B\bar{B}$)

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

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

Hep-ex/0404029, to PRL

$$\alpha_{eff} = \frac{1}{2} \arcsin \left(\frac{S_{long}}{\sqrt{1 - C_{long}^2}} \right)$$



$\mathcal{A}_{CP}(t)$ in $B^0 \rightarrow \rho^+ \rho^-$ Decays: Run4

- Run1-4 data (226.6M $B\bar{B}$) \Rightarrow Analysis in progress!
 - Add 86% more statistics
 - 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 $B^0 \rightarrow \rho^+ \rho^-$
- First result from Run1-2 (89M $B\bar{B}$)

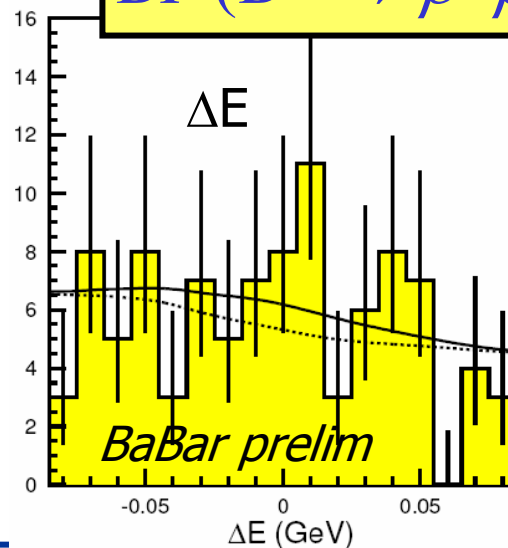
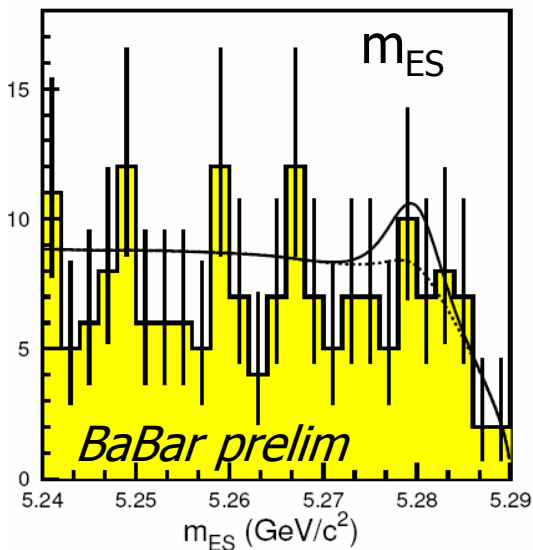
$BF(B^0 \rightarrow \rho^0 \rho^0) < 2.1 \times 10^{-6}$ (90% CL) *PRL 91, 171802 (2003)*

- Updated with Run1-4 data (226.6M $B\bar{B}$)

NEW!

- $33^{+22}_{-20} \pm 12$ signal observed

$BF(B^0 \rightarrow \rho^0 \rho^0) < 1.1 \times 10^{-6}$ (90% CL)



Dominant Syst

- $a_1\pi$ interfer: ± 7.5 events
- PDF variations: ± 6 events
- B bkgd: ± 5.8 events

Constraint on α

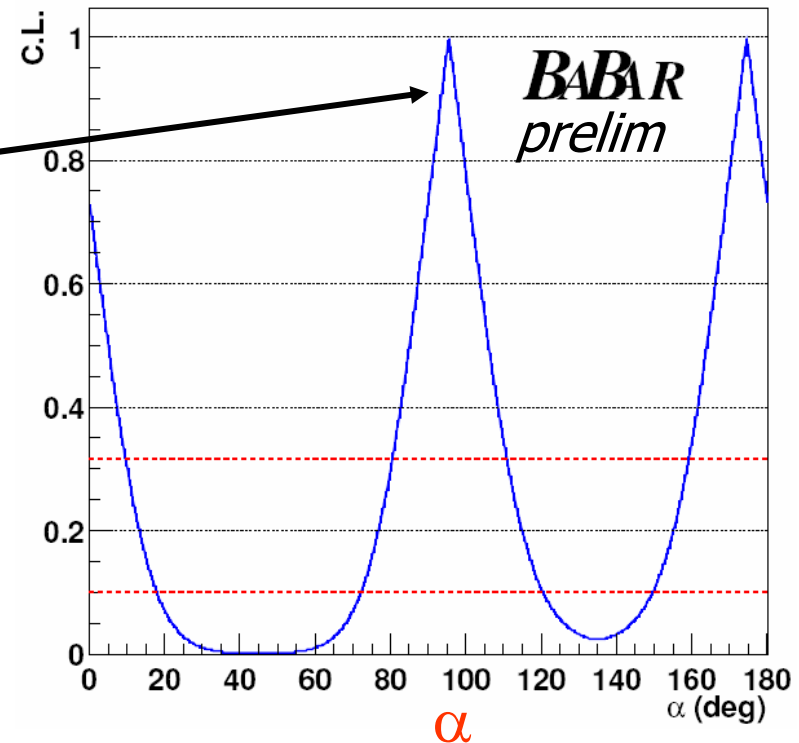
- Preliminary update on α constraint:
 - *BaBar* $\text{BF}(\rho^+\rho^-)$, $\text{BF}(\rho^0\rho^0)$ and S_{long} and C_{long}
 - World average $\text{BF}(\rho^+\rho^0) = (26.4^{+6.1}_{-6.4}) \times 10^{-6}$ (HFAG)

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

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


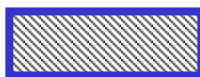
Run1-2 result:

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



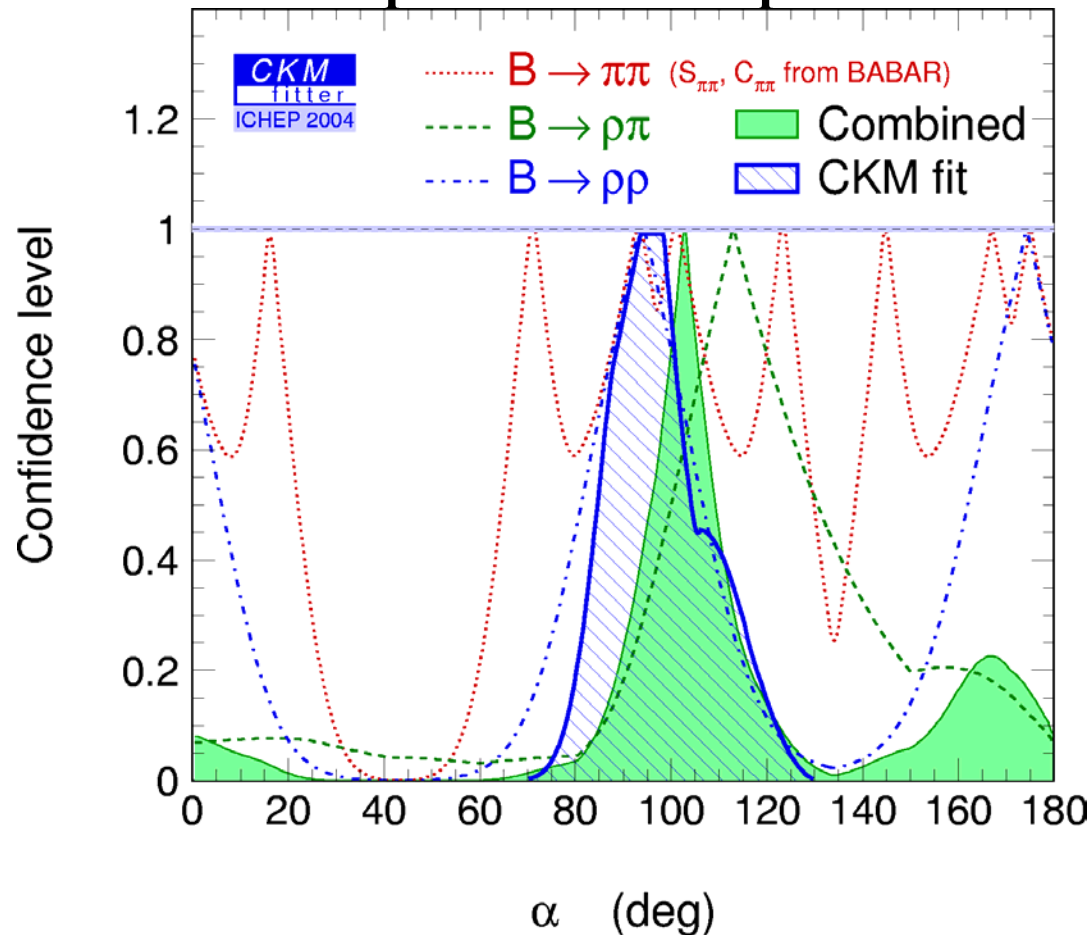
Constraints on α Using *BaBar* $\rho\rho$, $\rho\pi$, and $\pi\pi$ Measurements

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

 α from $\rho\rho$, $\rho\pi$, $\pi\pi$ only
 α from full CKM fit
 (ε_{K^L} , 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 $\mathcal{A}_{\text{CP}}(t)$ 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 α via isospin relations!
- Important milestone for B -Factories!

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

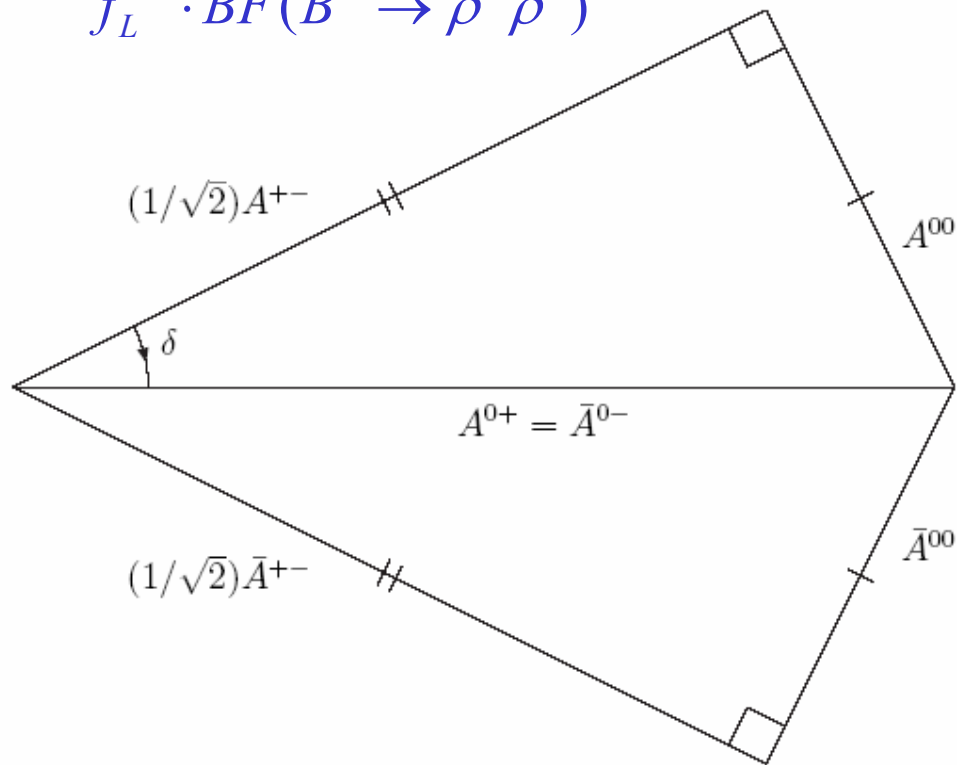
- Coming soon \Rightarrow update of $\mathcal{A}_{\text{CP}}(t)$ in $B^0 \rightarrow \rho^+ \rho^-$ with full Run1-4 data sample and improved analysis

Backup Slide

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

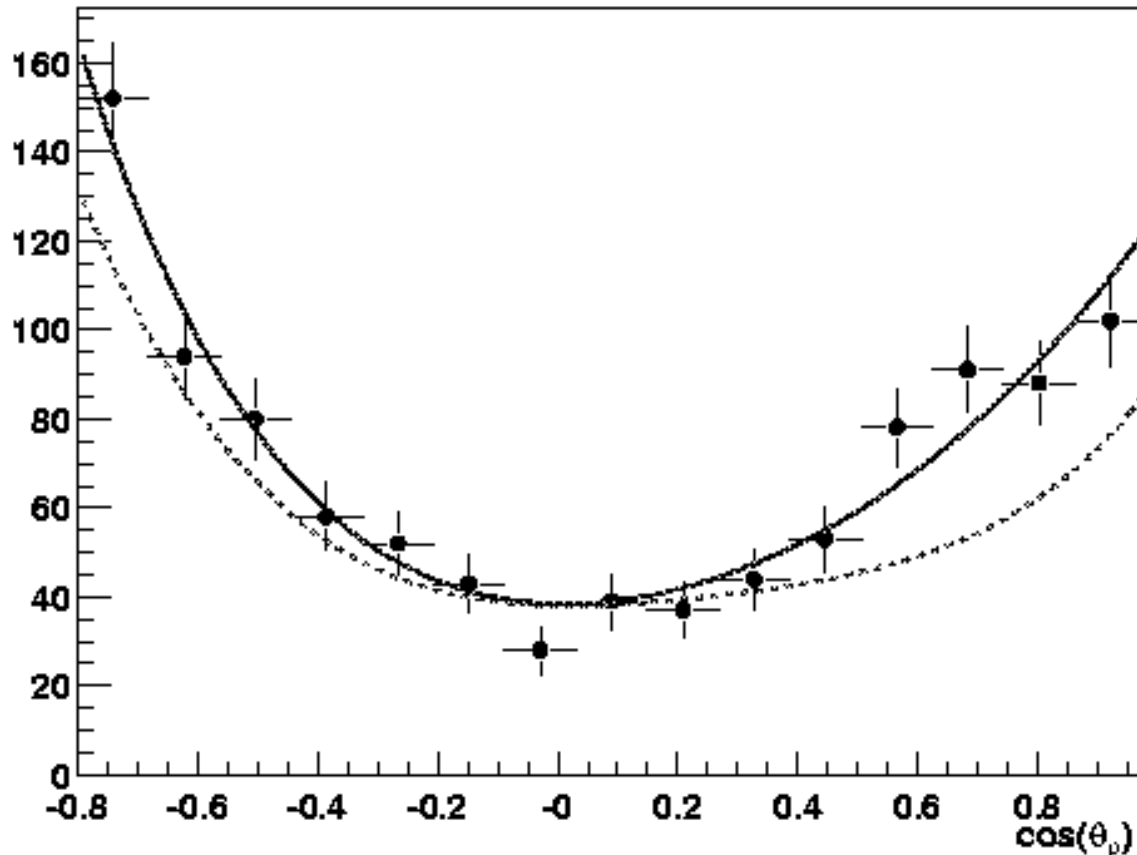
$$\sin^2(\delta\alpha_{peng}) \leq \frac{f_L^{00} \cdot BF(B^0 \rightarrow \rho^0 \rho^0)}{f_L^{+0} \cdot BF(B^+ \rightarrow \rho^+ \rho^0)}$$

➔ Use $f_L^{00} = 1$



Backup Slide

- Distribution of ρ^\pm helicity distributions for data
 - Clear demonstration of strong longitudinal polarization



Backup Slide

- Constraints in the ρ - η plane:

