Measurements of sin2α from B-Factories

Masahiro Morii

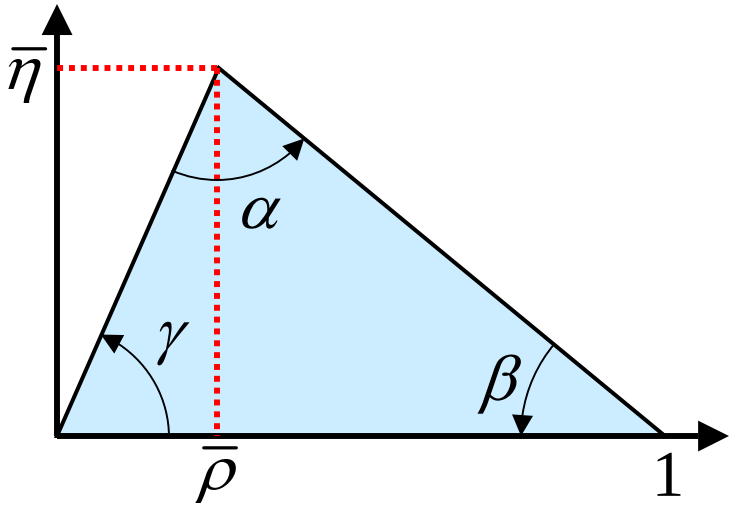
Harvard University

The BABAR Collaboration

BEACH 2002, Vancouver, June 25-29, 2002

Introduction

- *CP* violation in B^0 decays gives access to the angles of the Unitarity Triangle



$$\alpha = \phi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\beta = \phi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

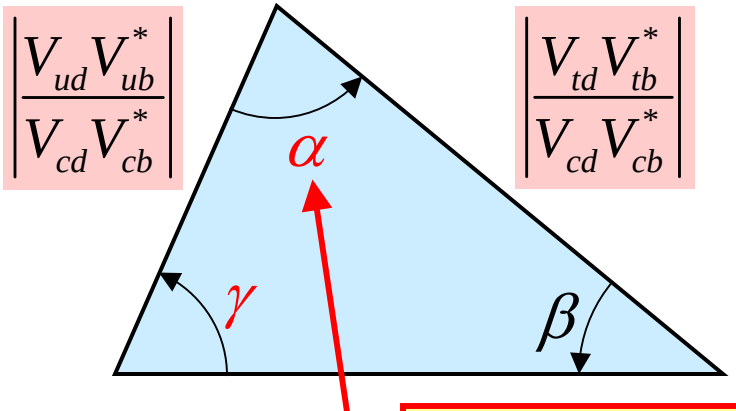
$$\gamma = \phi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

- $\sin 2\beta$ measured to ± 0.08 dominated by $B^0 \to J/\psi K_S$
- Where does this leave us?

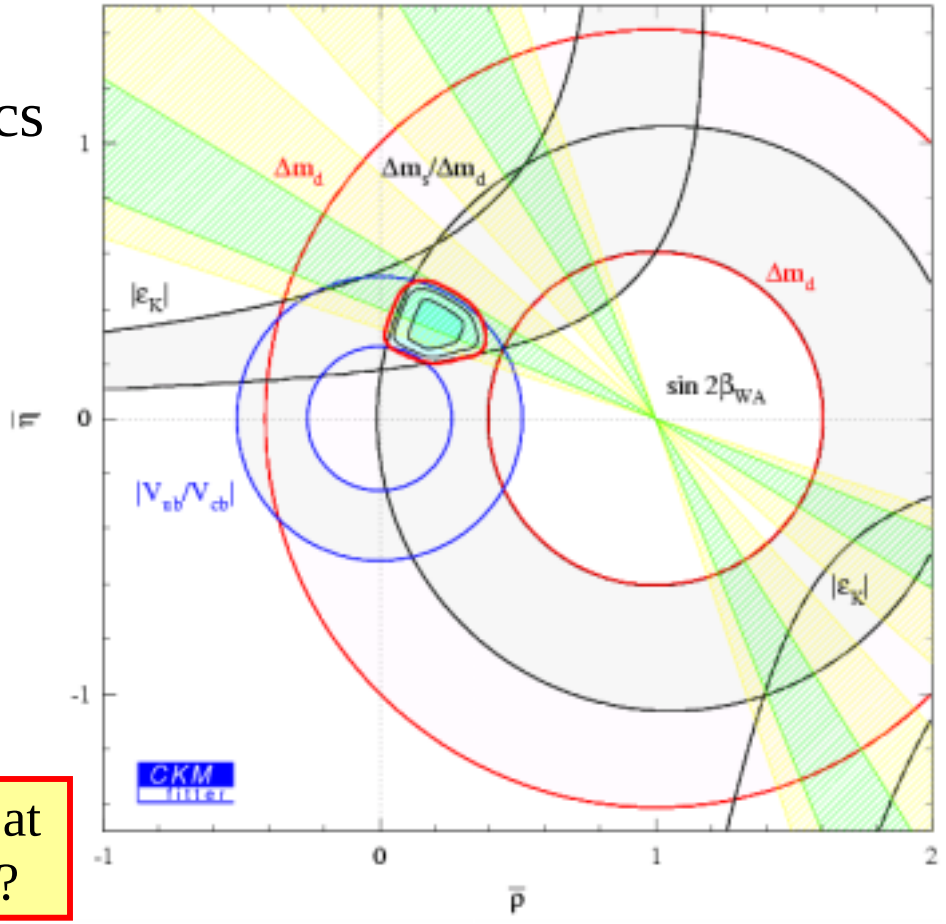
See D. Marlow's talk

Unitarity Triangle and sin2β

- Measured sin2β agrees with indirect constraints
  - Shrinking σ(sin2β) alone may not reveal new physics
- Must measure the sides and the other angles



Next possibility at the B Factories?



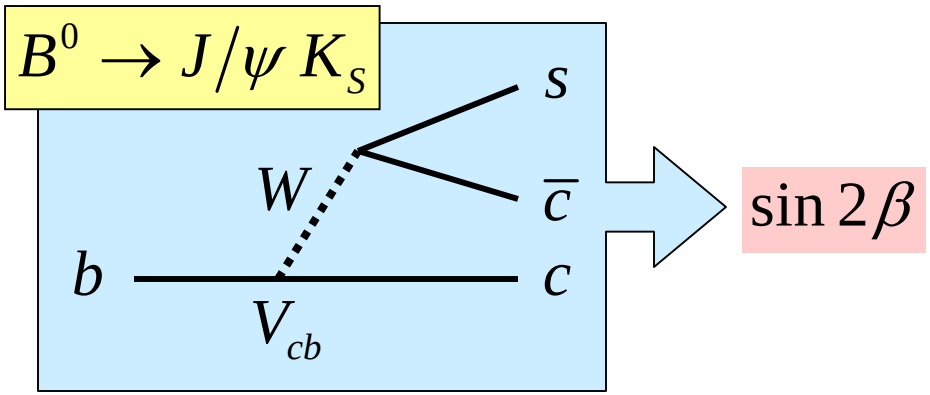
Measuring sin2α

- Time-dependent *CP* asymmetry in $B^0 \to f_{CP}$ is

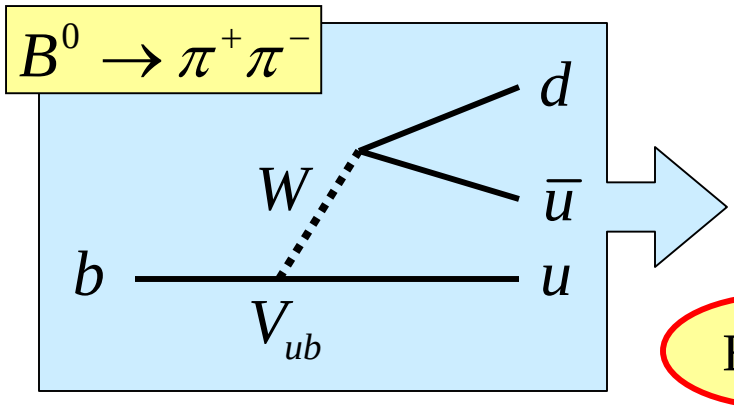
$$\frac{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) - \Gamma(B^0_{phys}(t) \to f_{CP})}{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) + \Gamma(B^0_{phys}(t) \to f_{CP})} = S_{f_{CP}} \sin(\Delta m_d t) + C_{f_{CP}} \cos(\Delta m_d t)$$

$$S_{f_{CP}} = -\frac{2\,\mathrm{Im}\,\lambda}{1+|\lambda|^2} \qquad C_{f_{CP}} = \frac{1-|\lambda|^2}{1+|\lambda|^2} \qquad \lambda = \frac{q}{p}\frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}}$$

CKM phase appears here



$\sin 2\beta$

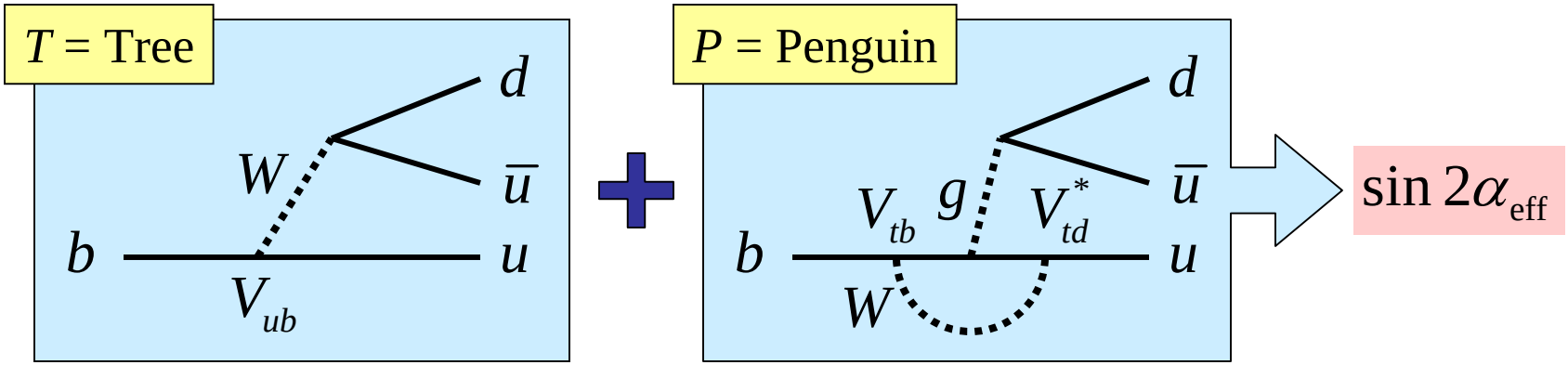


$\sin 2\alpha$

Easy!

Penguin Pollution

- Unlike $J/\psi K_S$, $\pi^+\pi^-$ mode suffers from significant pollution from the penguin diagrams with a different weak phase

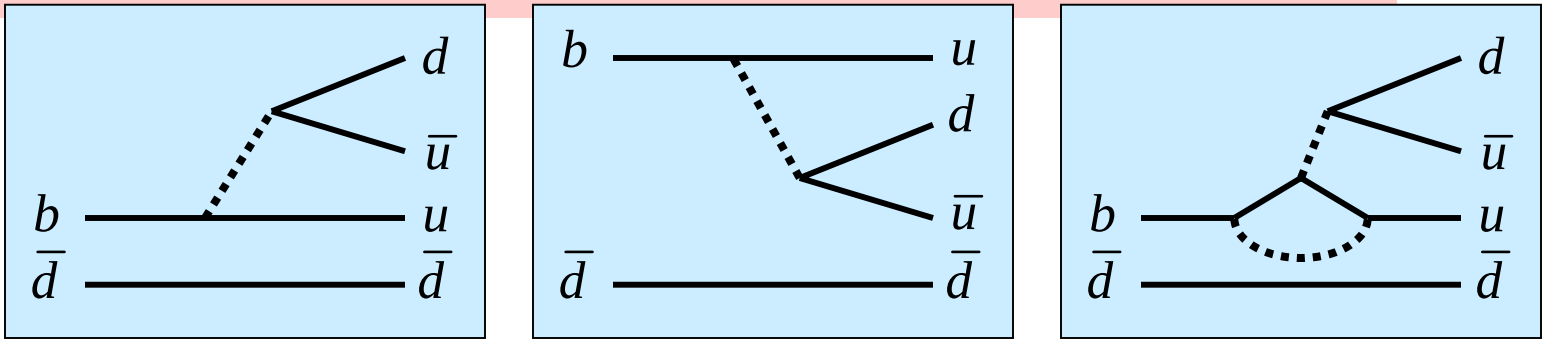


  - To estimate $\alpha_{\text{eff}} - \alpha$, we need:
    - P/T ratio – about 1/3 from $BR(B \to K\pi)/BR(B \to \pi\pi)$
    - δ = strong phase difference between P and T

Taming Penguins

- Take advantage of the isospin symmetry

$$\mathcal{A} = \alpha_T \cdot T + \alpha_C \cdot C + \alpha_P \cdot P$$

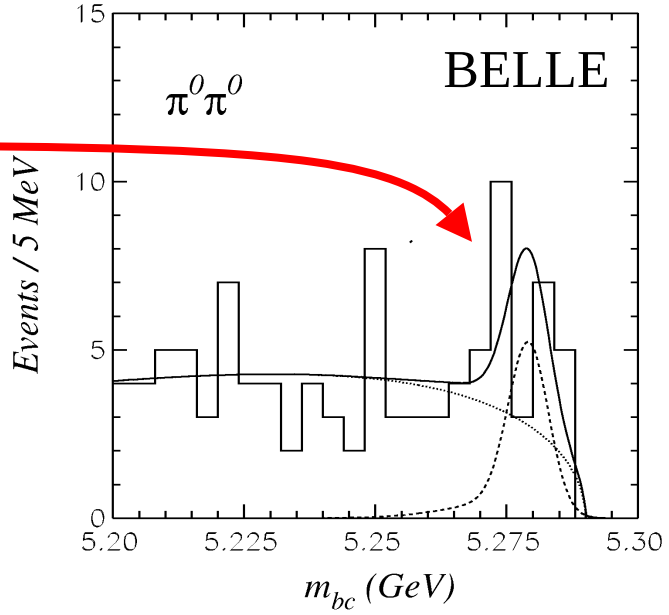


Mode	α_T	α_C	α_P	BABAR $BR\times10^6$	Belle $BR\times10^6$
$B^0 \to \pi^+\pi^-$	$\sqrt{2}$	0	$\sqrt{2}$	$5.4 \pm 0.7 \pm 0.5$	$5.1 \pm 1.1 \pm 0.4$
$B^+ \to \pi^+\pi^0$	1	1	0	$4.1^{+1.1}_{-1.0} \pm 0.8$	$7.0 \pm 2.2 \pm 0.8$
$B^0 \to \pi^0\pi^0$	0	1	−1	< 3.3	< 5.6

All preliminary

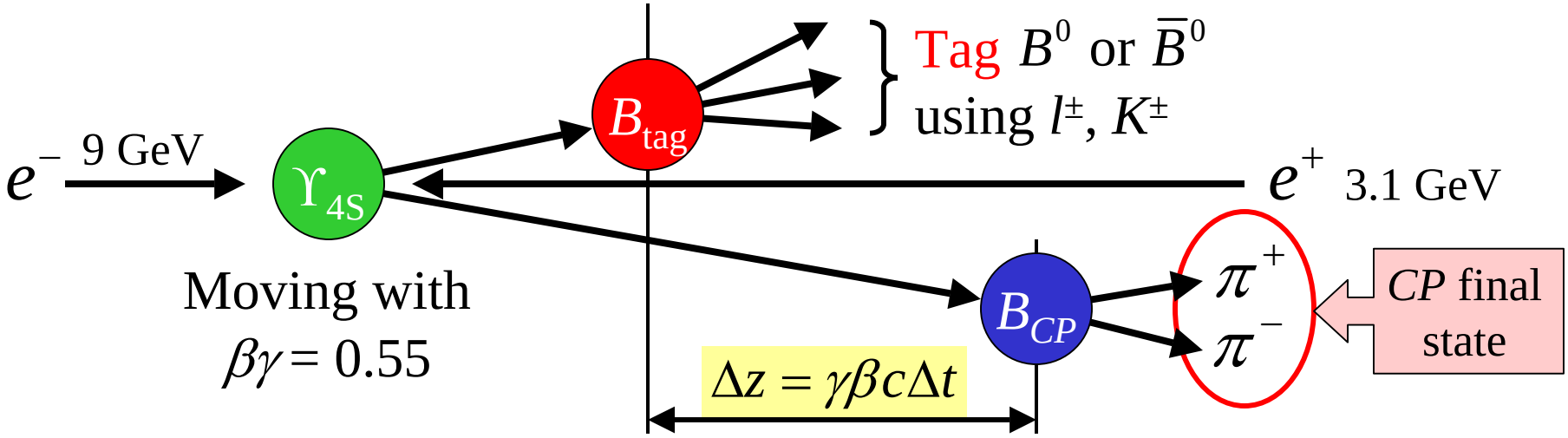
$B^0 \rightarrow \pi^0\pi^0$ Branching Ratio

- BABAR: Preliminary 54 fb^{-1}
  - $BR(\pi^0\pi^0) < 3.3\times10^{-6}$ (90% CL)
- Belle: Preliminary 31.7 M *BB*
  - 2.2σ "bump" in the signal
  - Fitted $BR = (2.9 \pm 1.5 \pm 0.6)\times10^{-6}$
  - $BR(\pi^0\pi^0) < 5.6\times10^{-6}$ (90% CL)
- CLEO: 9.13 fb^{-1}
  - $BR(\pi^0\pi^0) < 5.7\times10^{-6}$ (90% CL)



Expect first observation in the near future

CP Asymmetry in $B^0 \rightarrow \pi^+\pi^-$



- Same method as sin2β measurements
  - Difference: the direct *CP* term cannot be neglected

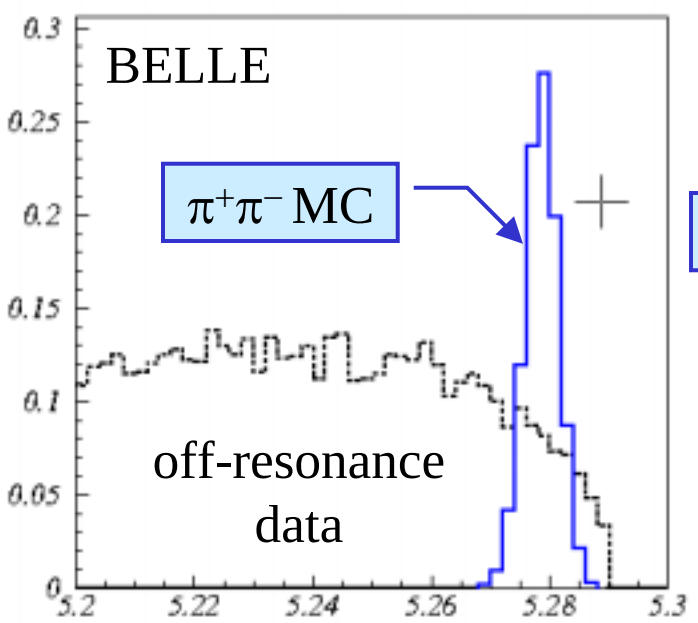
$$\frac{N(B^0_{tag}) - N(\bar{B}^0_{tag})}{N(B^0_{tag}) + N(\bar{B}^0_{tag})} = S_{\pi\pi}\sin(\Delta m_d \Delta t) - C_{\pi\pi}\cos(\Delta m_d \Delta t)$$

# of events with $B^0/\bar{B}^0$ tag

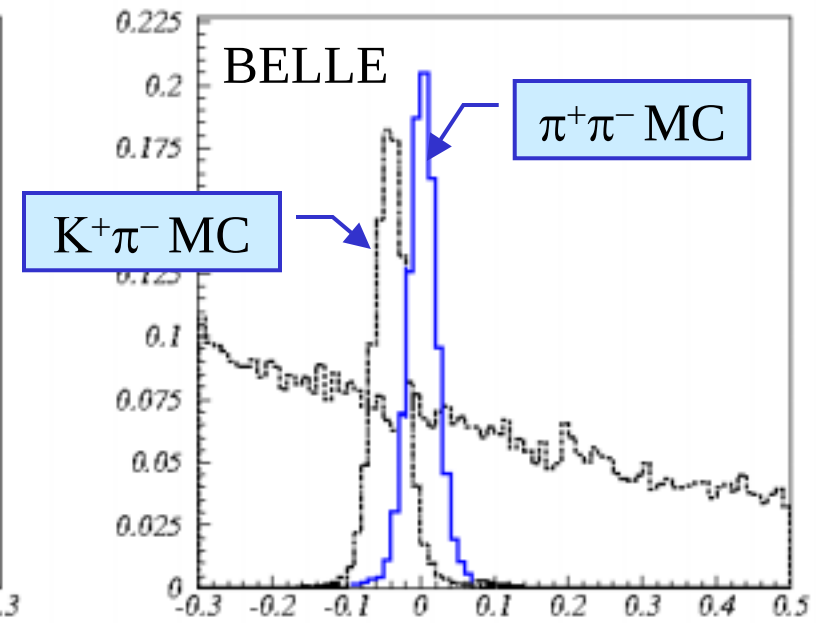
Challenges

- Specific to $B^0 \to \pi^+\pi^-$
  - Topology $B^0 \to h^+h^-$ simple to reconstruct
  - Particle ID must separate $\pi^\pm$ from $K^\pm$ $BR(\pi^+\pi^-) < BR(K^+\pi^-)$
    - DIRC (BABAR) and Aerogel (Belle)
  - Significant background from continuum
    - Event-shape variables → Fisher discriminant
- Common with other *CP* measurements
  - Flavor tagging
  - Vertex reconstruction
- And, of course, as much $\int \mathcal{L} dt$ as possible

B^0 Reconstruction



$$m_{bc} = \sqrt{(E_{CM}/2)^2 - (\mathbf{p}_{\pi^+} + \mathbf{p}_{\pi^-})^2}$$

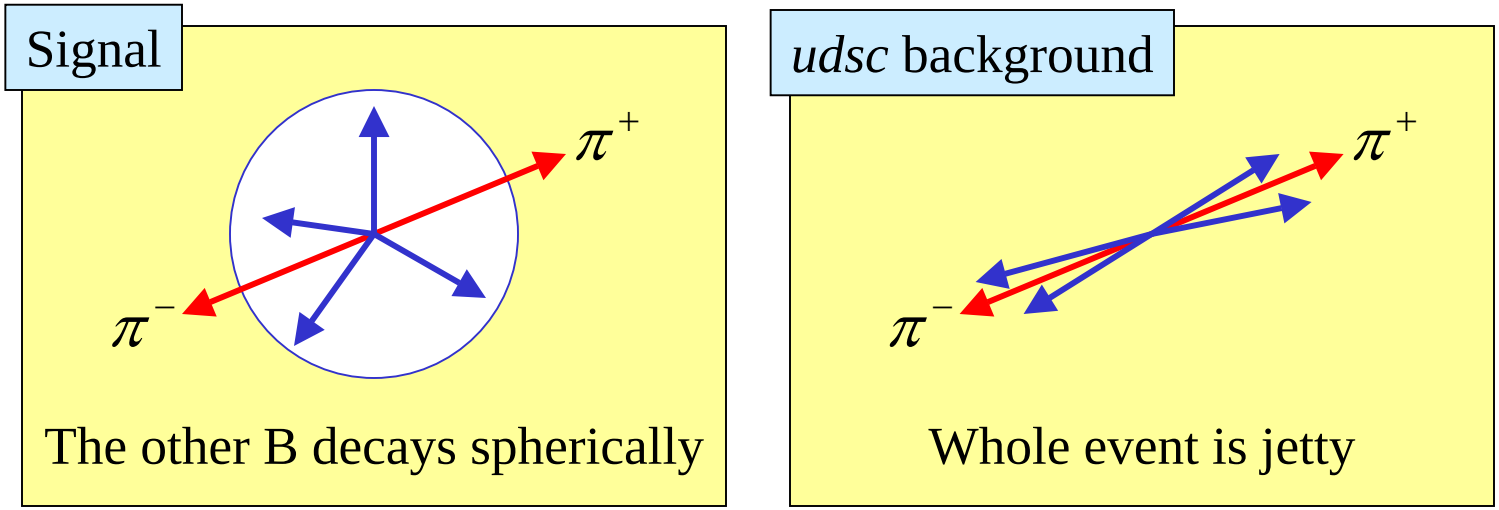


$$\Delta E = E_{\pi^+} + E_{\pi^-} - E_{CM}/2$$

- m_{bc} (or m_{ES}) and ΔE peak cleanly for the two-body signal
  - $K\pi$ and KK peaks shifted in ΔE → Additional discrimination

Continuum Background

- Most of the background come from continuum

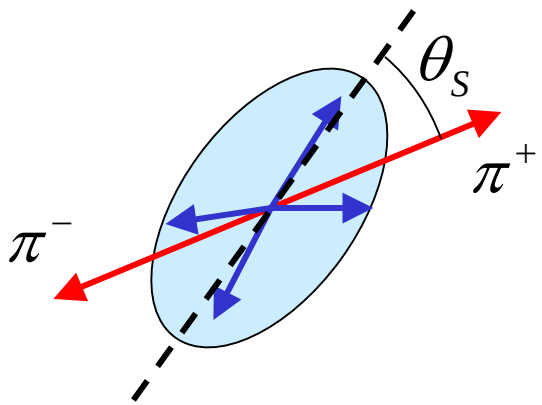


  - Use event shape variables that represent “jettiness” to suppress them

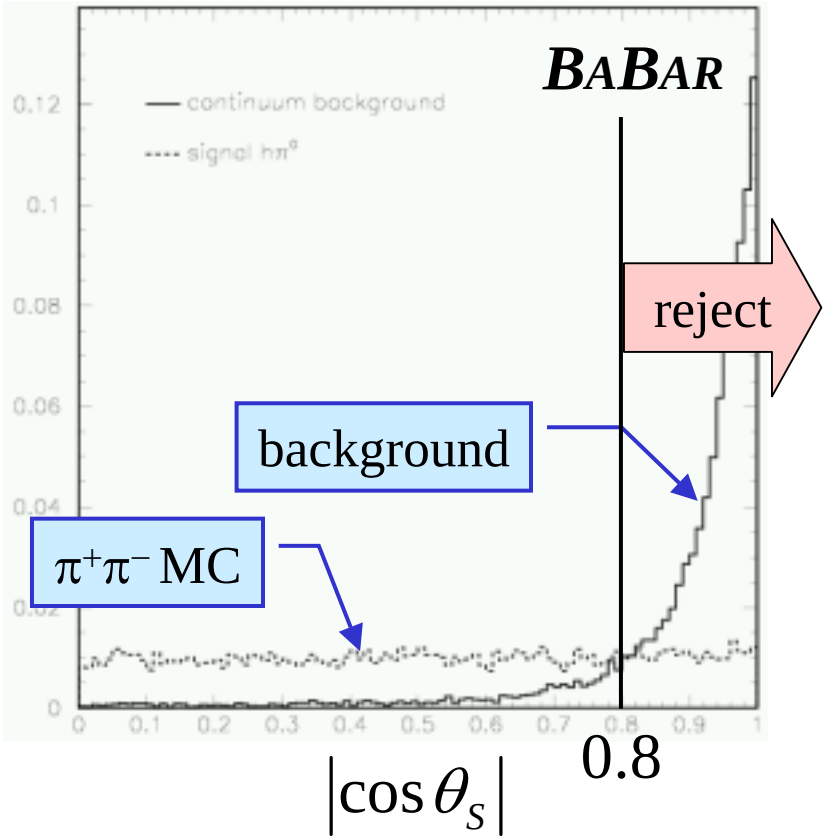
Examples

Sphericity Angle

- Angle θ_S between the sphericity axes of the B candidate and the rest of the event

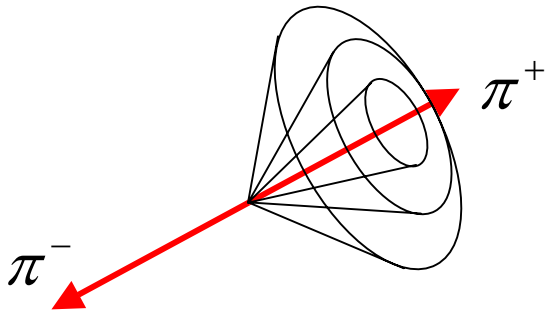


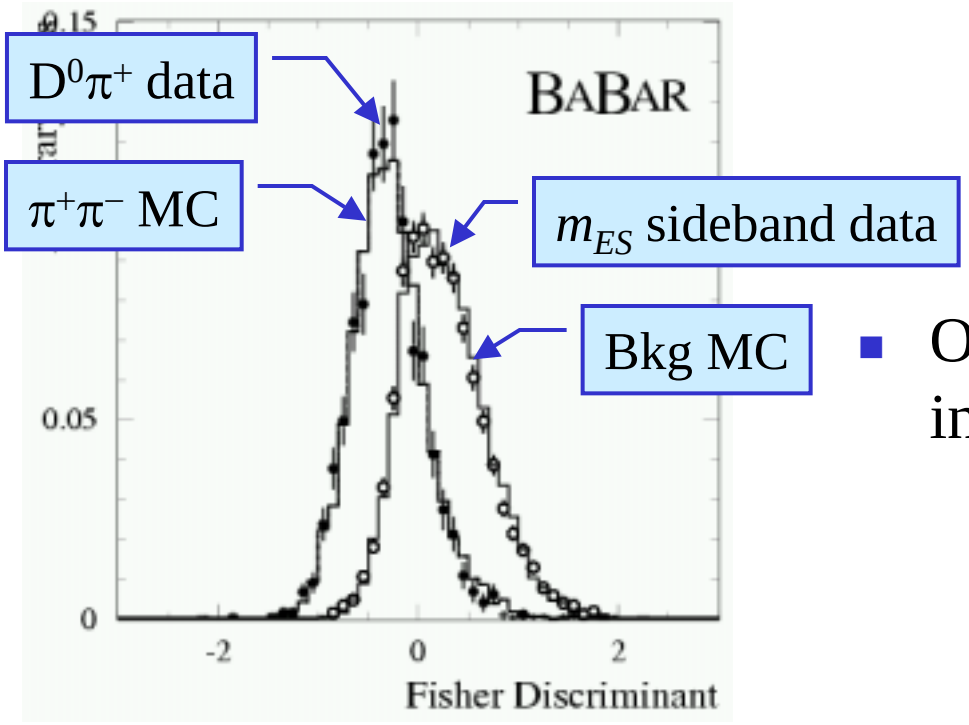
- Cut at 0.8 removes 83% of the continuum background



Fisher Discriminant

- BABAR uses the "CLEO" Fisher
  - Momentum flow in 9 cones around the candidate axis

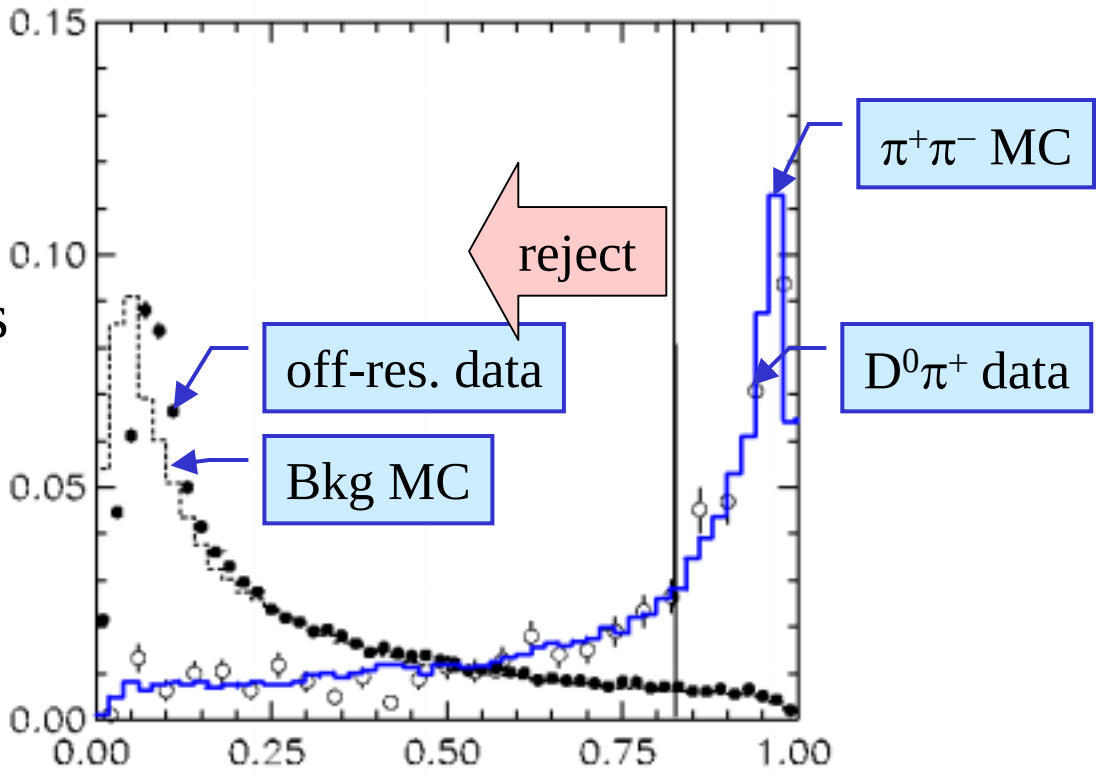




- Output of Fisher goes into the likelihood fit

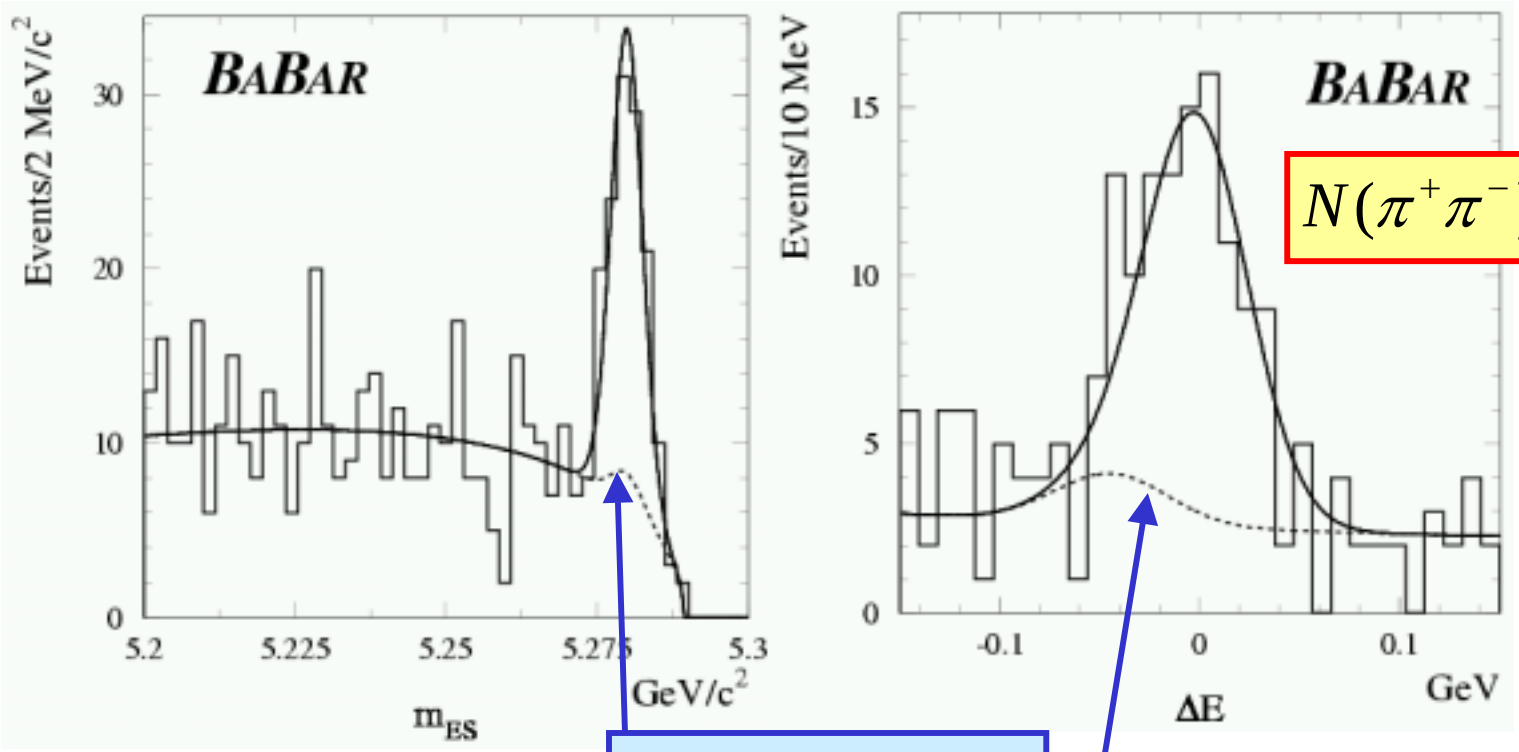
Fisher Discriminant

- Belle's Fisher discriminant uses:
  - Modified Fox-Wolfram moments
  - *B* flight direction
- Output is turned into a likelihood ratio *R*
  - Cut at 0.825 removes 95% of continuum background



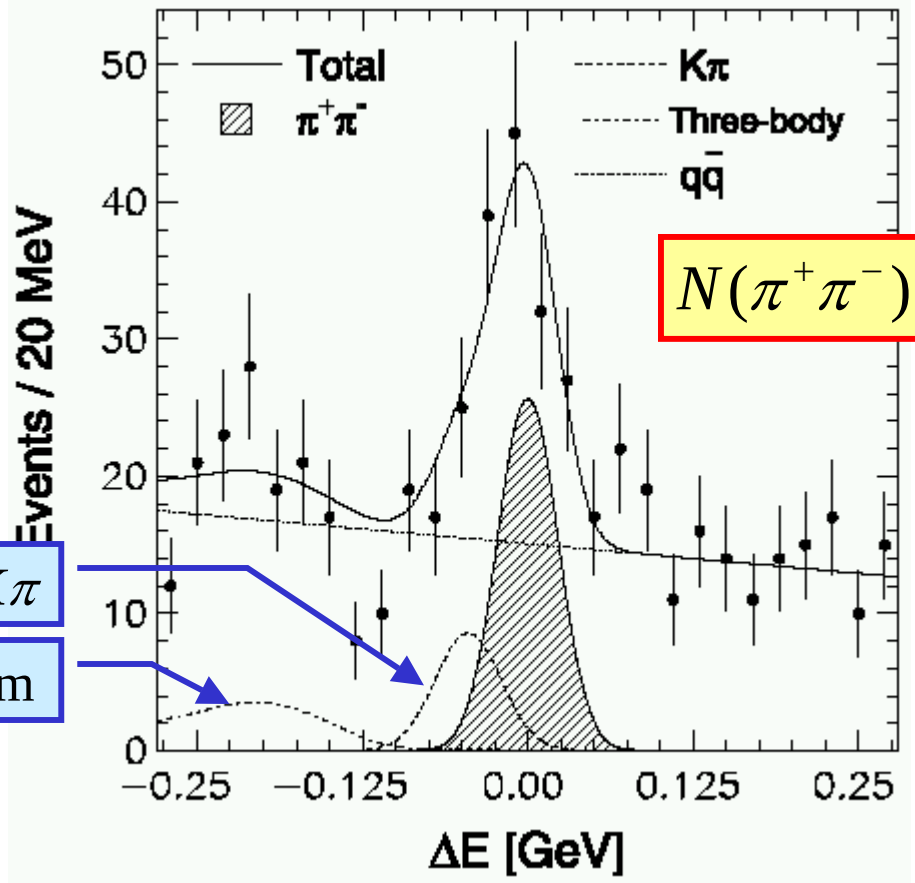
Event Sample – BABAR

- BABAR 55.6 fb^{-1} preliminary
  - $\pi^+\pi^-$ enhanced for these plots with a cut on Fisher



Event Sample – Belle

- Belle 41.8 fb^{-1}



$N(\pi^+\pi^-) = 78.5 \pm 13.8(\text{stat})$

$K\pi$

Continuum

Maximum Likelihood Fit

- Start from the physics function:

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left[1 \pm S_{\pi\pi}\sin(\Delta m_d \Delta t) \mp C_{\pi\pi}\cos(\Delta m_d \Delta t)\right]$$

$+$ B^0 tag

$-$ $\bar{B}^0$ tag

  - Fold in Δt resolution and mis-tag probabilities
  - Multiply by PDFs for m_{ES}, ΔE
  - BABAR uses particle ID and Fisher in the fit
    - Belle uses these variables in event selection
  - Add PDFs for background ($K\pi$, KK, continuum)
- Feed the candidates and turn the crank…

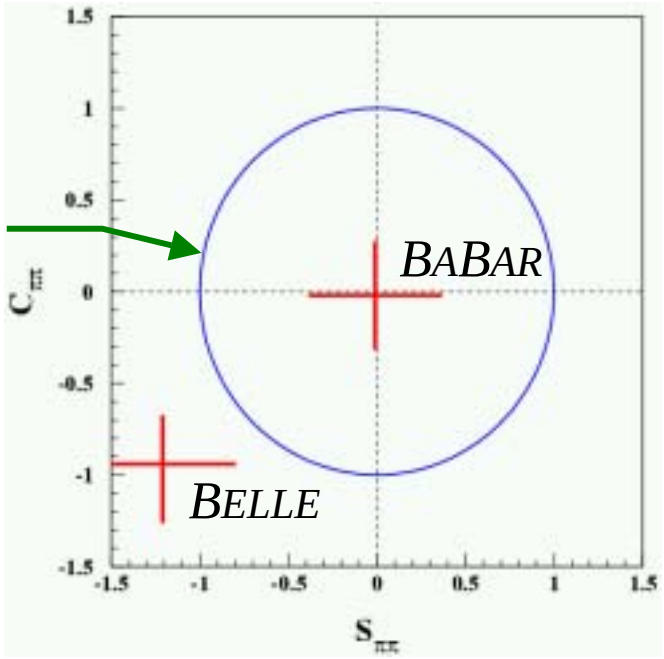
CP Fit Results

	BABAR (preliminary)	Belle (hep-ex/0204002)
$S_{\pi\pi}$	$-0.01 \pm 0.37 \pm 0.07$	$-1.21^{+0.38+0.16}_{-0.27-0.13}$
$C_{\pi\pi}$	$-0.02 \pm 0.29 \pm 0.07$	$-0.94^{+0.31}_{-0.25} \pm 0.09$

Belle uses $A_{\pi\pi} \equiv -C_{\pi\pi}$

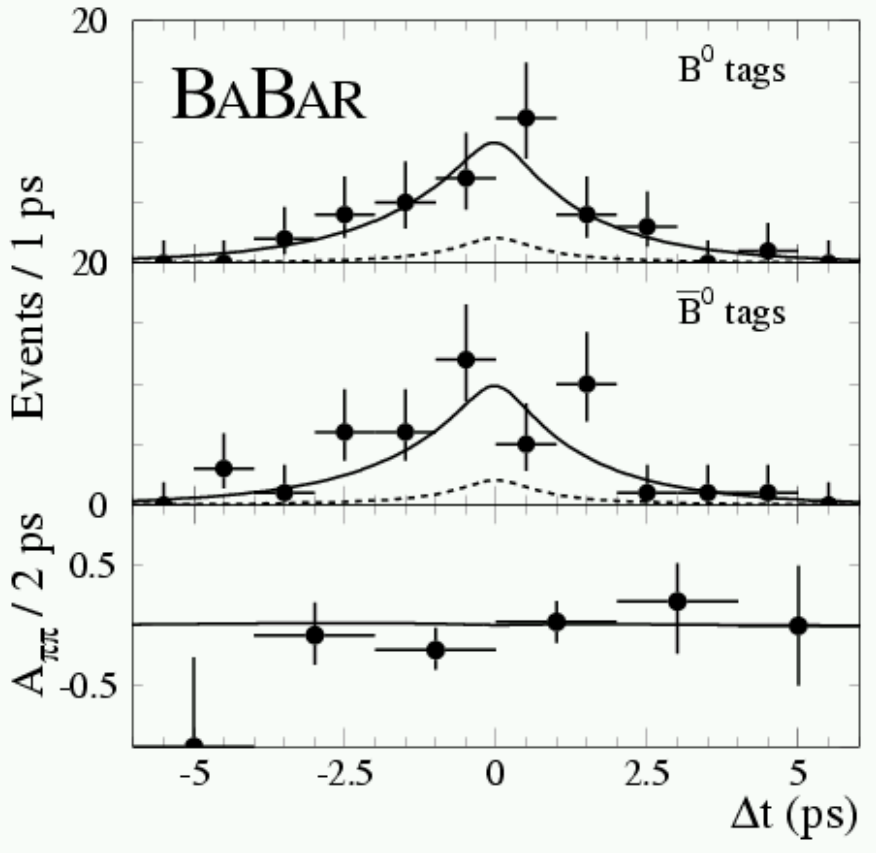
- BABAR and Belle disagree by $>2\sigma$
- Belle 1.2σ outside the physical boundary

$S_{\pi\pi}^2 + C_{\pi\pi}^2 = 1$



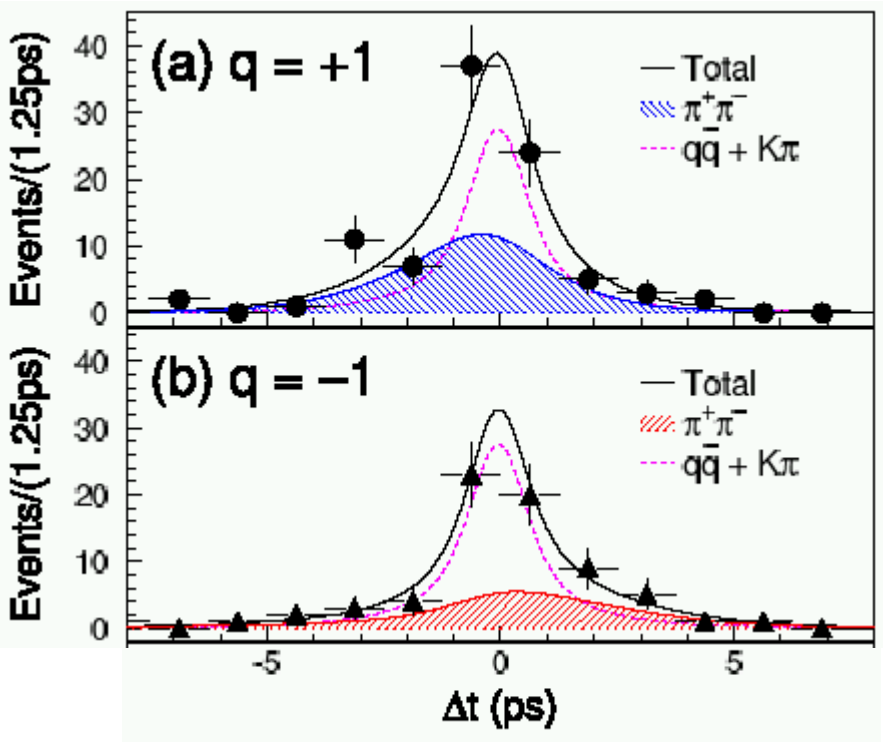
- Is there any problem?
  - Crosscheck systematics

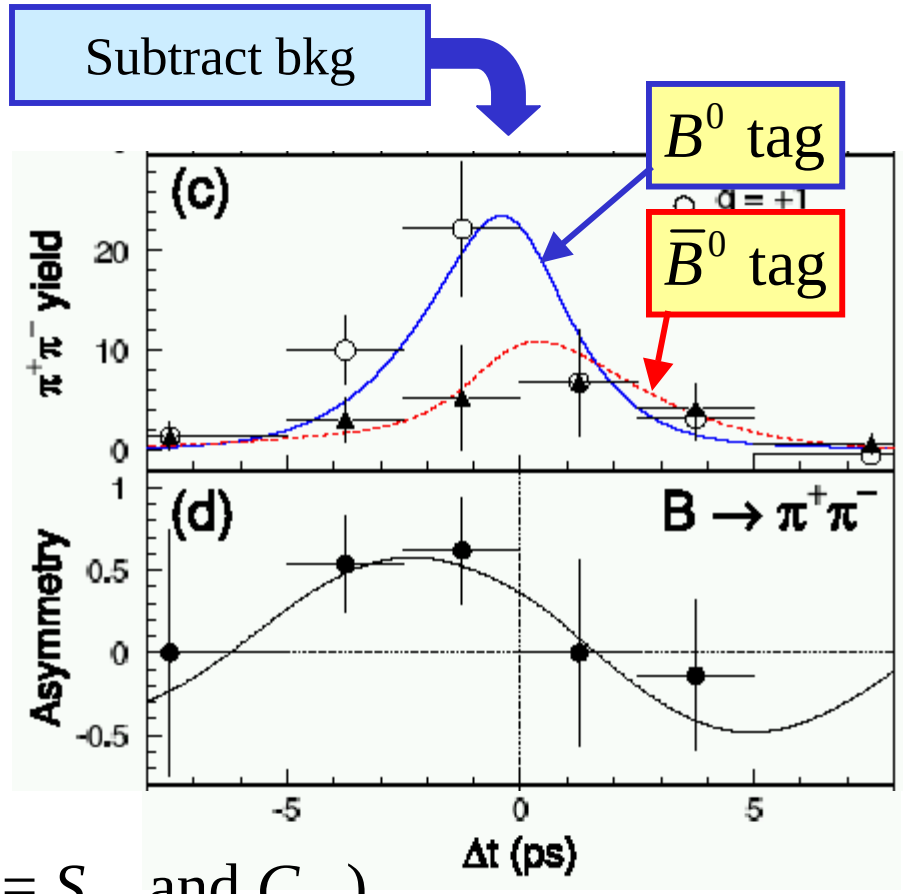
CP Asymmetries – BABAR



- $\pi^+\pi^-$ enhanced for these plots with a cut on Fisher
- No significant asymmetry

CP Asymmetries – Belle

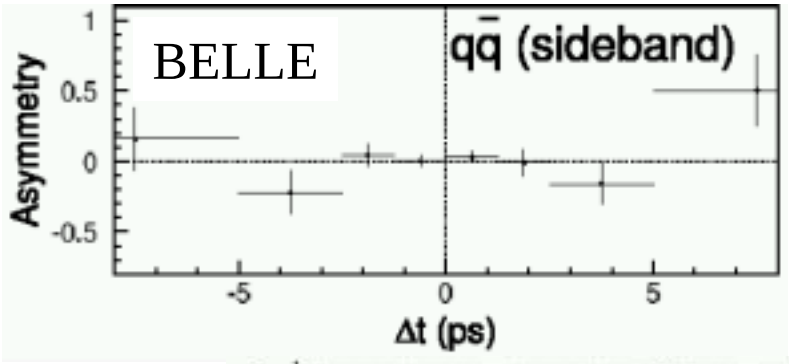


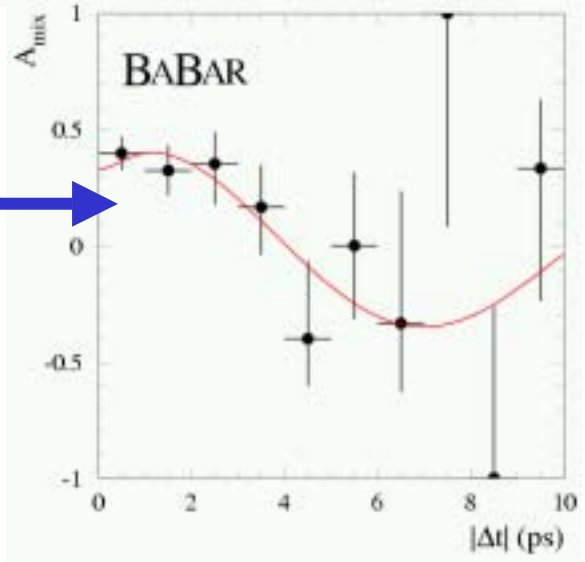


- Rate difference (= $C_{\pi\pi}$)
- Δt-dependent asymmetry (= $S_{\pi\pi}$ and $C_{\pi\pi}$)

Crosschecks

- Both experiment made extensive crosschecks, e.g.
  - Asymmetry in background?
    - Look for asymmetries in $K\pi$ or mass sideband
  - Vertex resolution of the 2-body decays?
    - Measure B lifetime with $\pi\pi$, $K\pi$
    - Measure mixing with $K\pi$
  - Likelihood values and errors?
    - Toy Monte Carlo studies

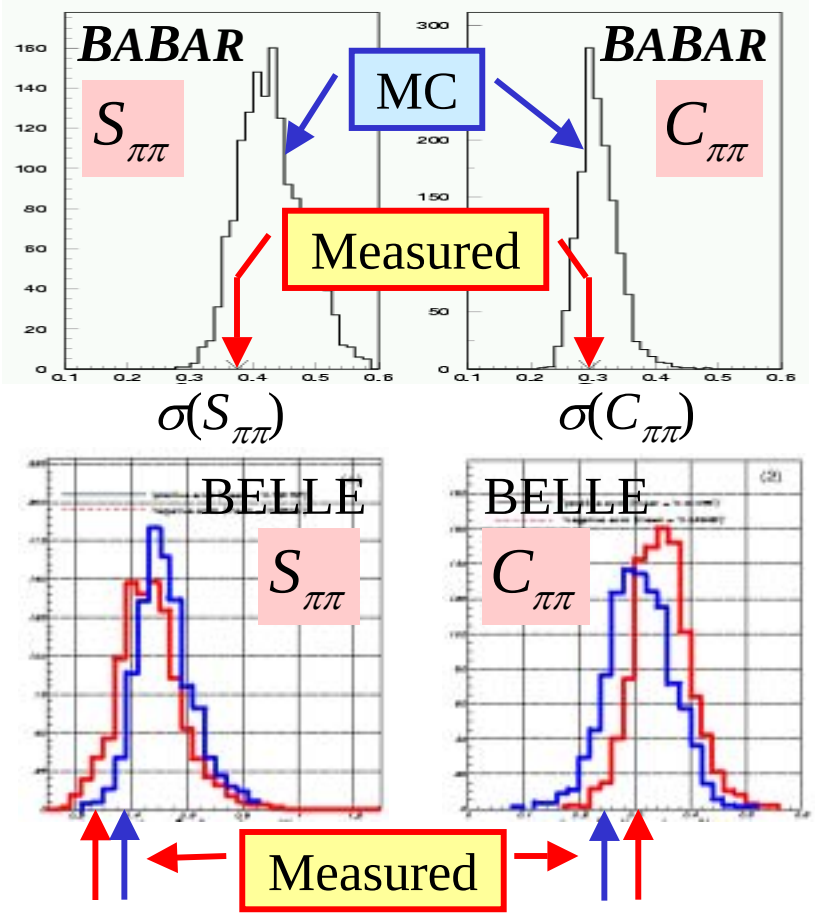




Monte Carlo Fit Test

- Generate ~1000 “toy” experiments
  - Belle used (–0.7, –0.7) for the central values
- Fit and compare:
  - Likelihood values
  - Pull distributions
  - Errors
- Lowest probability: 5.4%

Everything looks reasonable

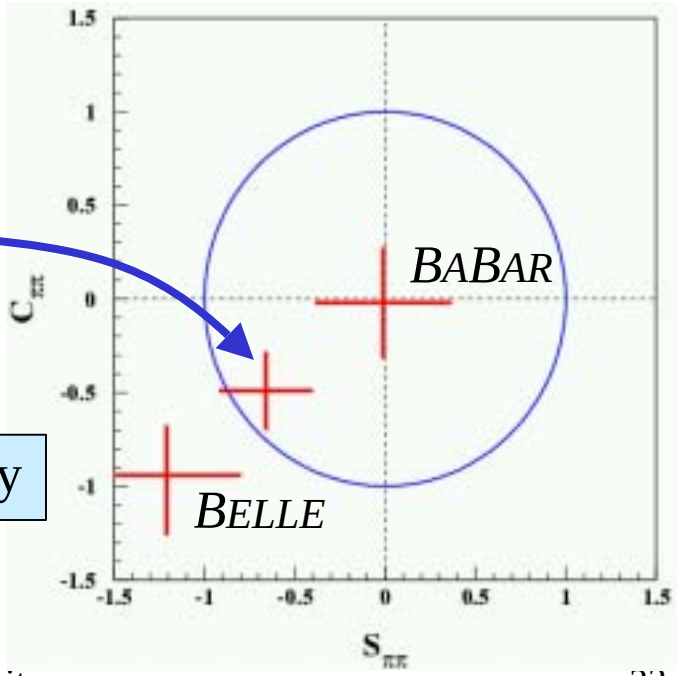


Interpretation

	BABAR (preliminary)	Belle (hep-ex/0204002)	Average*
$S_{\pi\pi}$	$-0.01 \pm 0.37 \pm 0.07$	$-1.21^{+0.38+0.16}_{-0.27-0.13}$	-0.66 ± 0.26
$C_{\pi\pi}$	$-0.02 \pm 0.29 \pm 0.07$	$-0.94^{+0.31}_{-0.25} \pm 0.09$	-0.49 ± 0.21

- How well do we know α?
  (*Gronau and Rosner, PRD65, 093012)
  - Average BABAR and Belle
  - Assume $\beta = 26°$, $P/T = 0.28$

NB: Large uncertainty



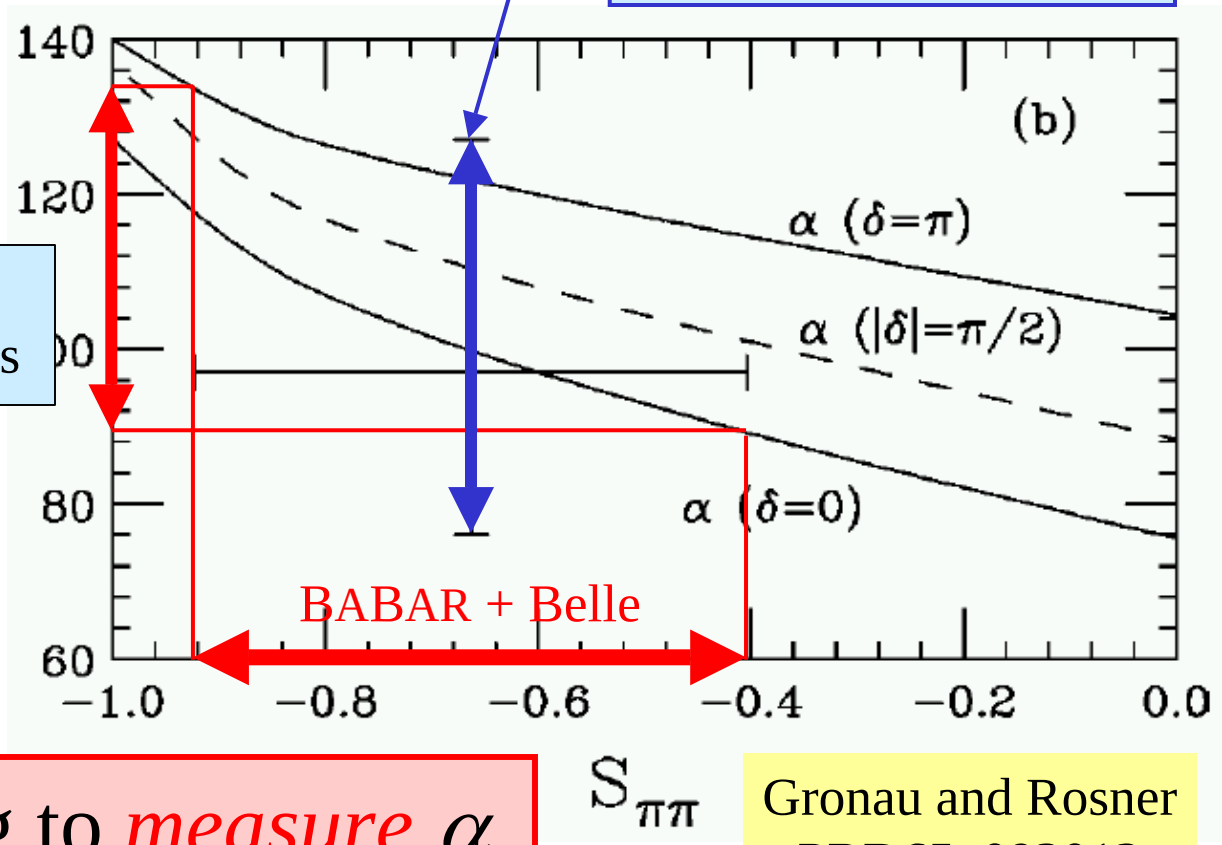
Interpretation

- Measured $S_{\pi\pi} \pm 1\sigma$ corresponds to

$\alpha \in [89°, 138°]$

Accuracy comparable to the indirect constraints

Indirect: $\alpha = (97^{+30}_{-21})°$



We are starting to *measure* α

Gronau and Rosner PRD65, 093012

Summary

- BABAR and Belle measured $\sin 2\alpha_{\text{eff}}$ using $B^0 \to \pi^+\pi^-$

	BABAR (preliminary)	Belle (hep-ex/0204002)
$S_{\pi\pi}$	$-0.01 \pm 0.37 \pm 0.07$	$-1.21^{+0.38+0.16}_{-0.27-0.13}$
$C_{\pi\pi}$	$-0.02 \pm 0.29 \pm 0.07$	$-0.94^{+0.31}_{-0.25} \pm 0.09$

  - Direct constraint on α is reaching useful accuracy
- Things to watch out for:
  - $\sin 2\alpha_{\text{eff}}$ with higher statistics → Resolve "discrepancy"
  - $BR(B^0 \to \pi^0\pi^0)$ → Better bound on $\alpha_{\text{eff}} - \alpha$