Determination of the Unitarity-triangle Angle

α from $B \to \pi\pi$

(experimental aspects)

BABAR

A review talk on behalf of the Belle, BABAR and CDF Collaborations

5th International Workshop on the Unitarity Triangle

Università di Roma "La Sapienza"
September 9-13, 2008

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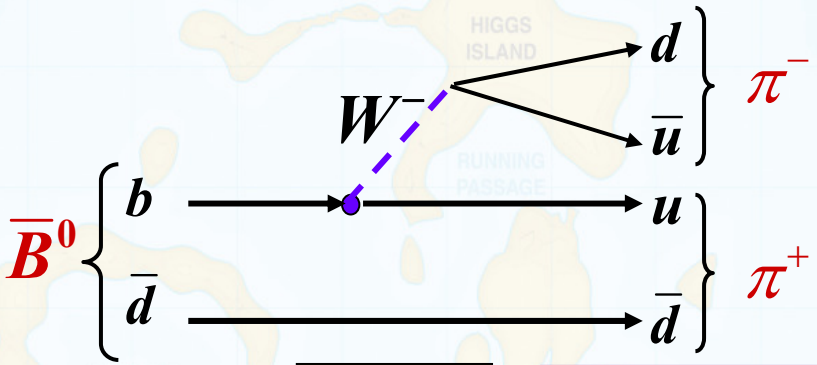
Measuring α with $B^0 \to \pi^+\pi^-$

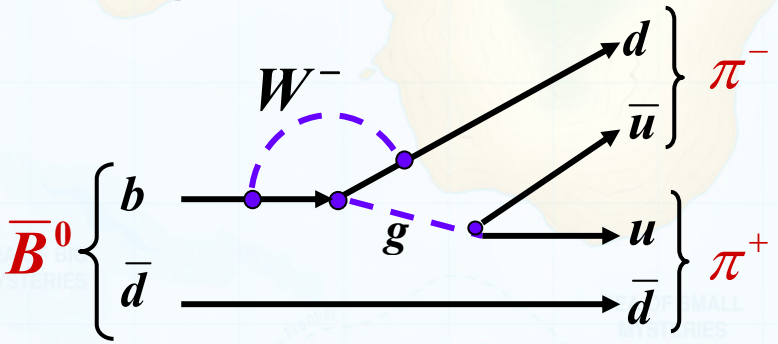
Discussed in greater detail in Enrico Franco's theory talk

At **tree level** in $b \to u\bar{u}d$, in SM, a time-dependent *CP* analysis measures phase

$$-2\beta - 2\gamma = 2\alpha - 2\pi \qquad \alpha \equiv \arg\left[\frac{-V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]$$

In the presence of penguins:





Tree

Tree and penguin amplitudes have different weak and strong phases

Penguin

Direct *CP* violation: $C_{\pi\pi} \neq 0$ allowed

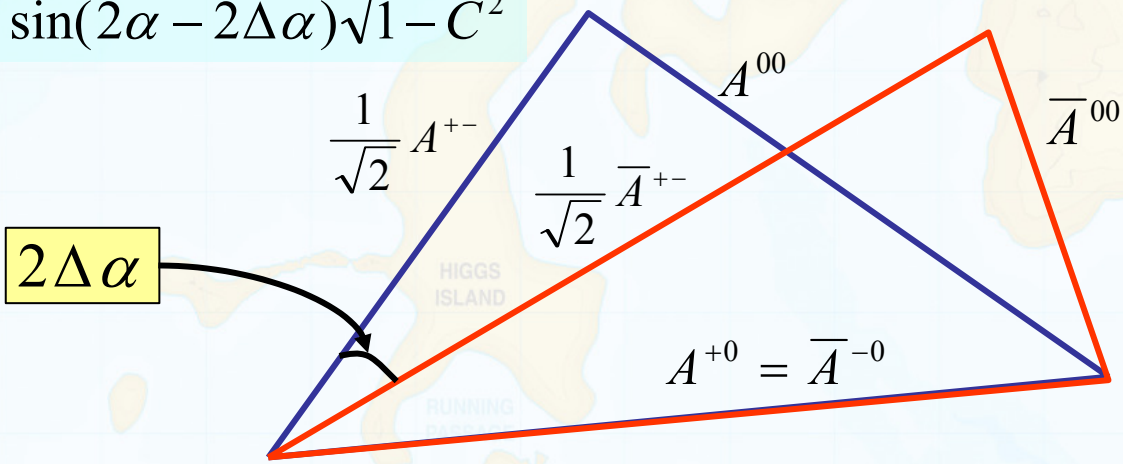
$$S_{\pi\pi} = \sqrt{1-C_{\pi\pi}^2}\,\sin(2\alpha - 2\Delta\alpha_{\pi\pi}) = \sqrt{1-C_{\pi\pi}^2}\,\sin 2\alpha_{\text{eff}}$$

SU(2) isospin analysis in $B \to \pi\pi$

Determines relative phase between B^0 mixing and the tree, independent of the EW model

M. Gronau, D. London, Phys. Rev. Lett. ***65****, 3381 (1990)*

$$S = \sin(2\alpha - 2\Delta\alpha)\sqrt{1-C^2}$$



$$A^{+-} = A(B^0 \to \pi^+\pi^-)$$
$$\overline{A}^{+-} = A(\overline{B}^0 \to \pi^+\pi^-)$$
$$A^{00} = A(B^0 \to \pi^0\pi^0)$$
$$\overline{A}^{00} = A(\overline{B}^0 \to \pi^0\pi^0)$$
$$A^{+0} = A(B^+ \to \pi^+\pi^0)$$
$$\overline{A}^{-0} = A(B^- \to \pi^-\pi^0)$$

4-fold ambiguity in $2\Delta\alpha$: either triangle can flip up or down

$$A_{\pi\pi} = e^{+i\gamma}T + e^{-i\beta}P$$
$$\overline{A}_{\pi\pi} = e^{-i\gamma}T + e^{+i\beta}P$$

Neglecting EW penguins, ± 0 is a pure tree mode, and so the two triangles share a common side:

$$A(B^+ \to \pi^+\pi^0) = \overline{A}(B^- \to \pi^-\pi^0)$$

$$A^{+0} = \frac{1}{\sqrt{2}} A^{+-} + A^{00}$$
$$\overline{A}^{-0} = \frac{1}{\sqrt{2}} \overline{A}^{+-} + \overline{A}^{00}$$

Other (small) issues: $\Delta I = 5/2$ and $\pi^0/\eta/\eta'$ mixing corrections

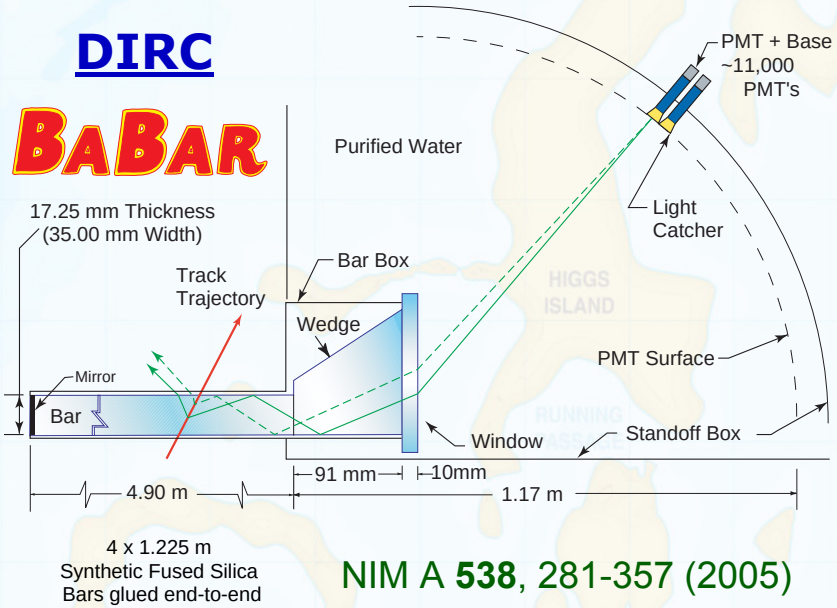
Discussed in greater detail in Enrico Franco's theory talk

The $B^0 \to h^+h^-$ analyses

Simultaneous Maximum-Likelihood fits to $B^0 \to \pi^+\pi^-,\ K^+\pi^-,\ \pi^+K^-,\ K^+K^-$

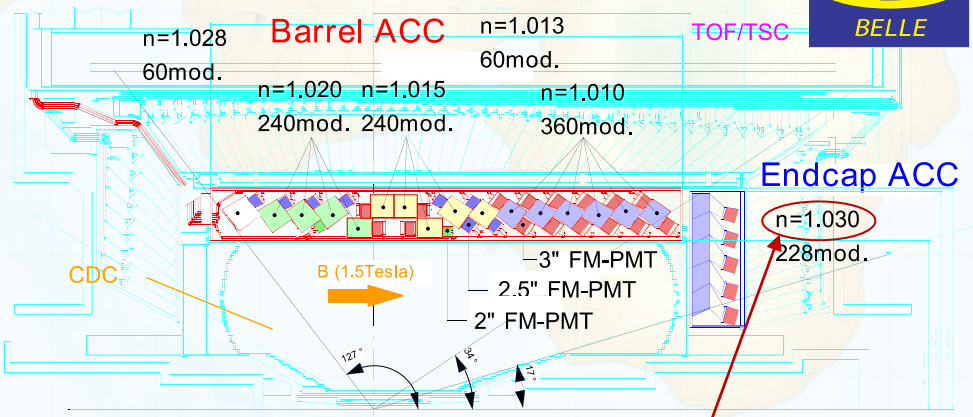
kaon-pion separation is essential; dedicated Cherenkov detectors in the barrel

DIRC



NIM A **538**, 281-357 (2005)

Aerogel (threshold Cherenkov)



NIM A **453**, 321-325 (2000)

Forward ACC not in threshold mode: kaon threshold 2.0 GeV/*c*, chosen for *B* flavor tagging

Calorimeter-based electron veto is also applied

Additional $\pi\pi/K\pi/KK$ separation from energy difference ΔE

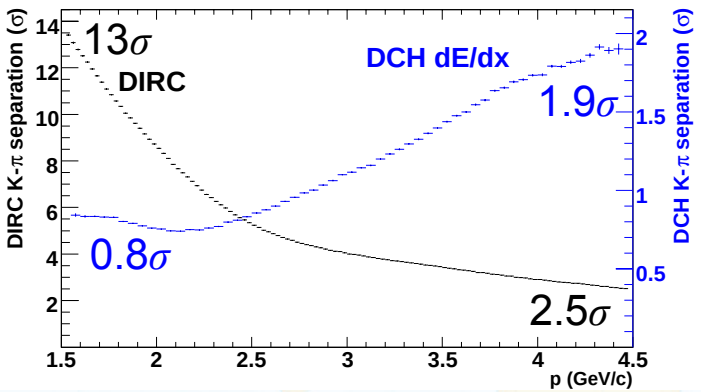
Thanks to better particle ID acceptance and use of drift chamber dE/dx, in 2006 Belle had x1.4 more h^+h^- per fb^{-1} than *BABAR*

dE/dx and B mass separate B^0, B_s, $\Lambda_b \to h^+h'^-$; cannot do absolute $\mathcal{B}r$

(CLEO measurements are no longer competitive)

π/K separation with Drift Chamber dE/dx

New in the BABAR $B^0 \to h^+h^-$ analysis since 2006



PRL 99, 021603 (2007) PHYSICAL REVIEW LETTERS week ending 13 JULY 2007

Observation of *CP* Violation in $B^0 \to K^+\pi^-$ and $B^0 \to \pi^+\pi^-$

2007 publication based on 383 million $B\bar{B}$ pairs

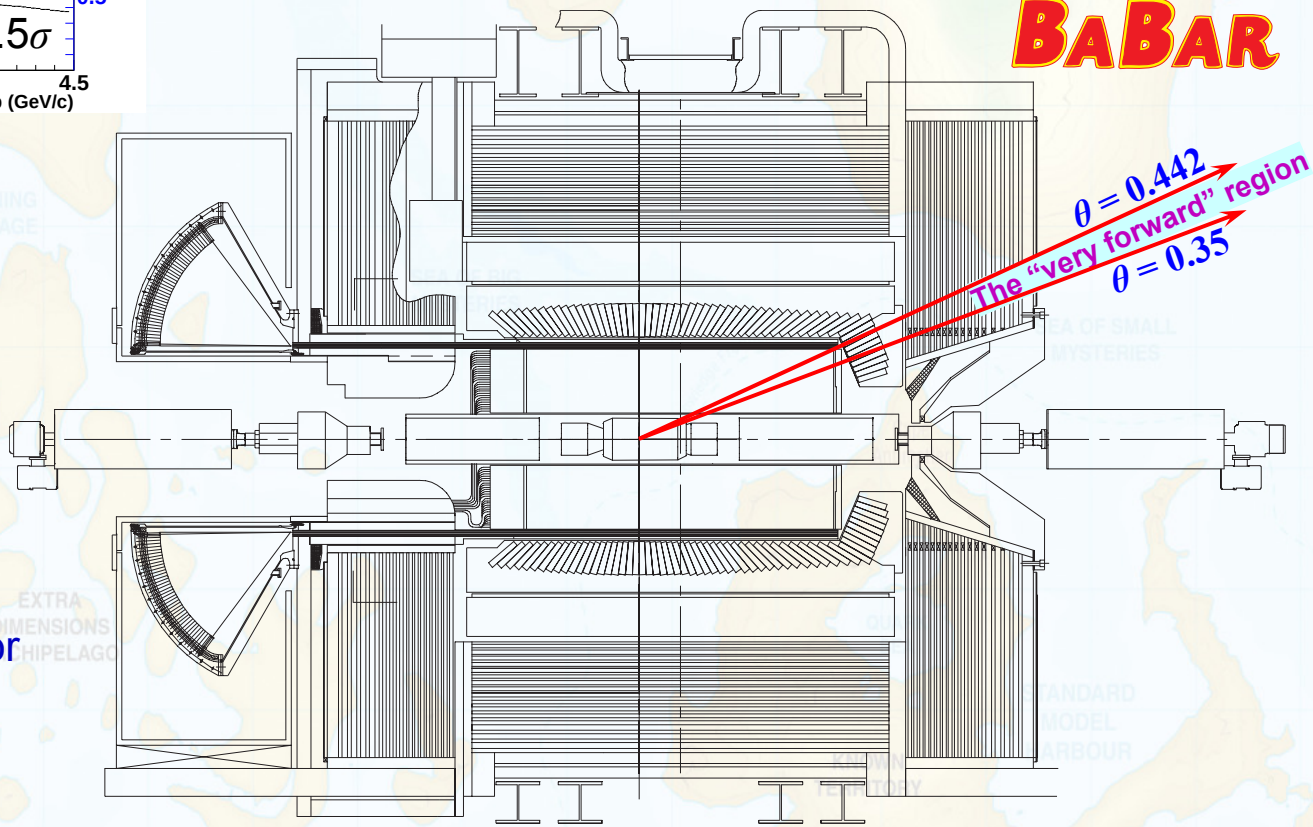
In the barrel (θ>0.442), the DIRC is ~9.3% inefficient (φ cracks, etc.)

Another ~12% of high-momentum tracks are outside the DIRC acceptance in θ.

We use Drift Chamber (DCH) tracks down to θ = 0.35 rad

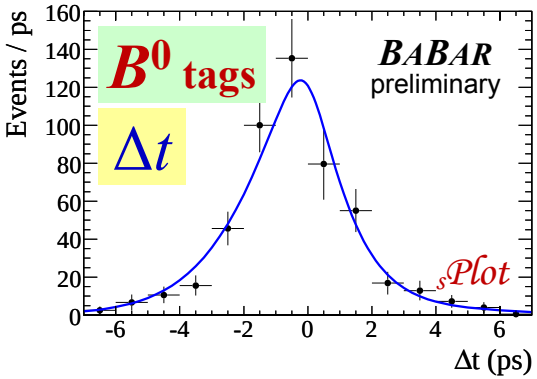
➔16% event-yield increase for $B \to Xh^{\pm}$, 35% for $B^0 \to h^+h^-$

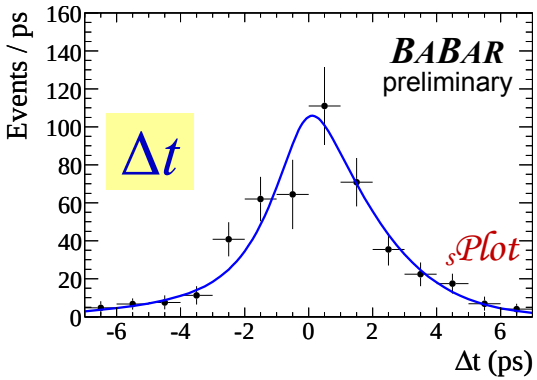
Total 52% eff increase compared to earlier versions of the analysis

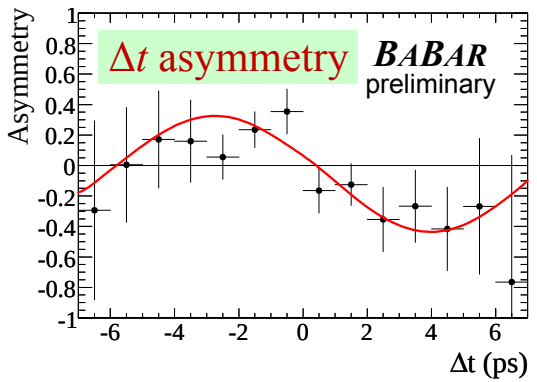


CP Violation in $B^0 \to \pi^+\pi^-$ (1)

A new preliminary result from BABAR







BABAR

467 million $B\bar{B}$ pairs

$N_{\pi^+\pi^-} = 1394 \pm 54$

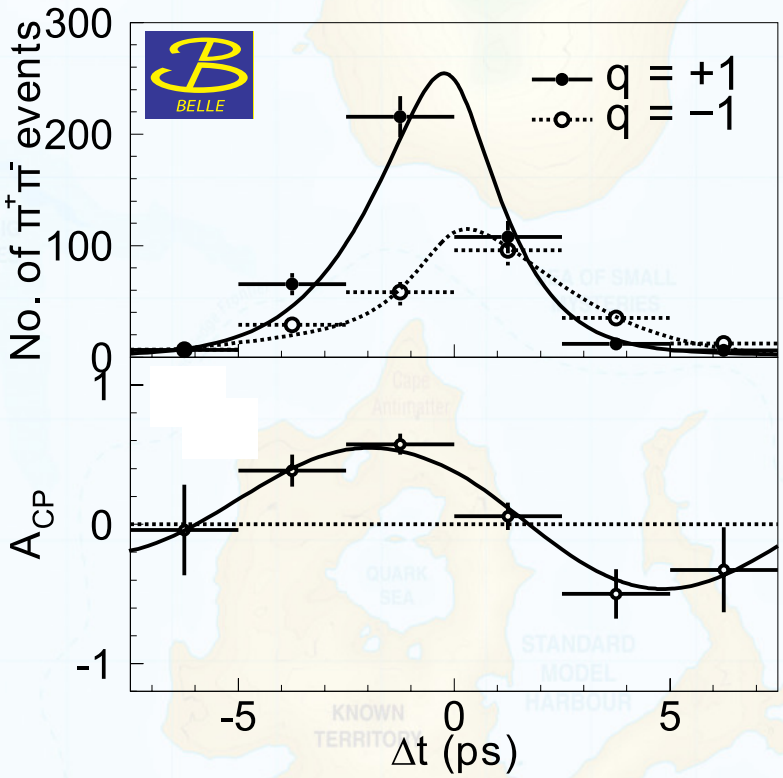
arXiv:0807.4226 [hep-ex]

BELLE

535 million $B\bar{B}$ pairs

$N_{\pi^+\pi^-} = 1464 \pm 65$

PRL 98, 211801 (2007)



sPlot:

Builds a histogram of x excluding it from the Maximum-Likelihood fit, assigning a weight to each event, keeping all signal events, getting rid of all background events, and keeping track of the statistical errors in each x bin

*M. Pivk and F. R. Le Diberder, "**sPlot: a statistical tool to unfold data distributions**," Nucl. Instrum. Meth. A **555**, 356 (2005) [arXiv:physics/0402083]*

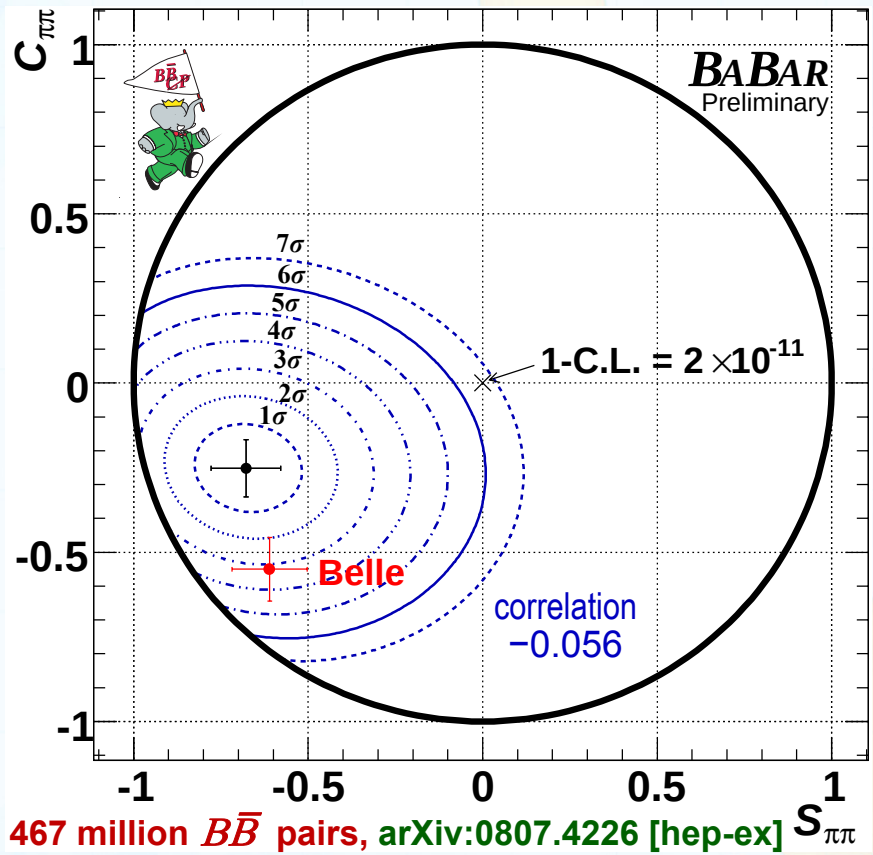
CP Violation in $B^0 \to \pi^+\pi^-$ (2)

A new preliminary result from BABAR (presented at ICHEP 2008)

$S_{\pi\pi} = -0.67 \pm 0.10 \pm 0.03\ (6.3\sigma)$

$C_{\pi\pi} = -0.25 \pm 0.08 \pm 0.02\ (3.0\sigma)$

CP violation observed with a 6.7σ significance

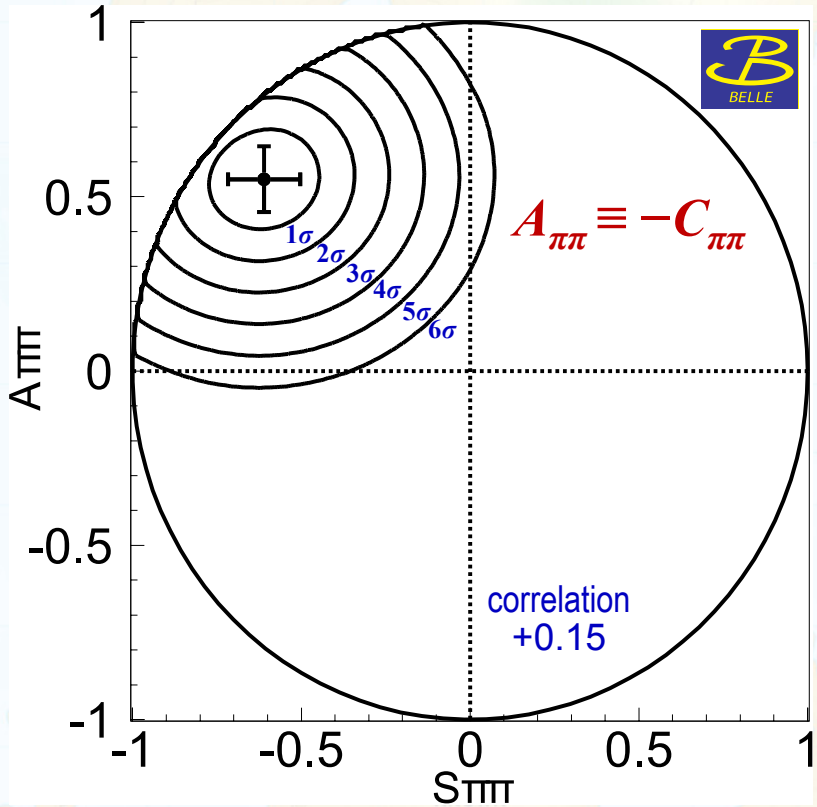


467 million $B\bar{B}$ pairs, arXiv:0807.4226 [hep-ex]

$S_{\pi\pi} = -0.61 \pm 0.10 \pm 0.04\ (5.3\sigma)$

$C_{\pi\pi} = -0.55 \pm 0.08 \pm 0.05\ (5.5\sigma)$

Both time-dependent and direct *CP* violation observed

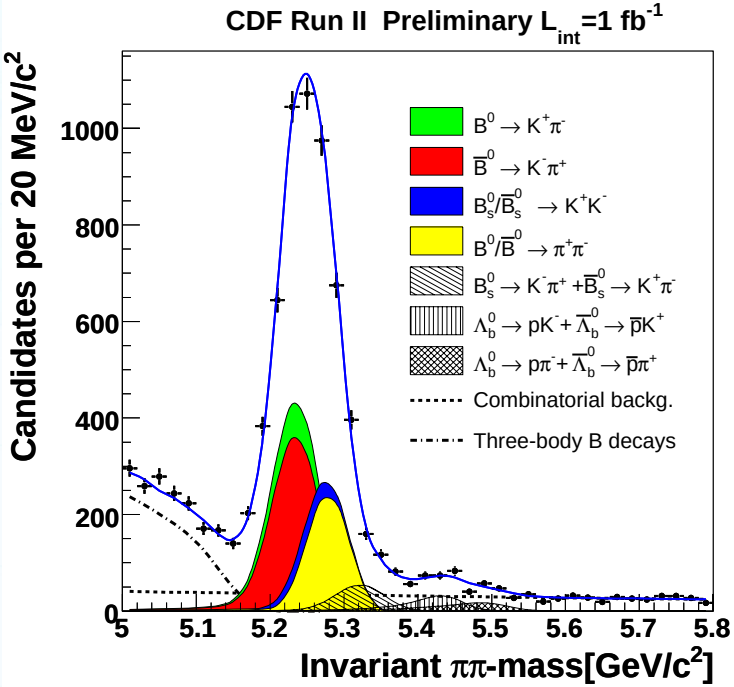


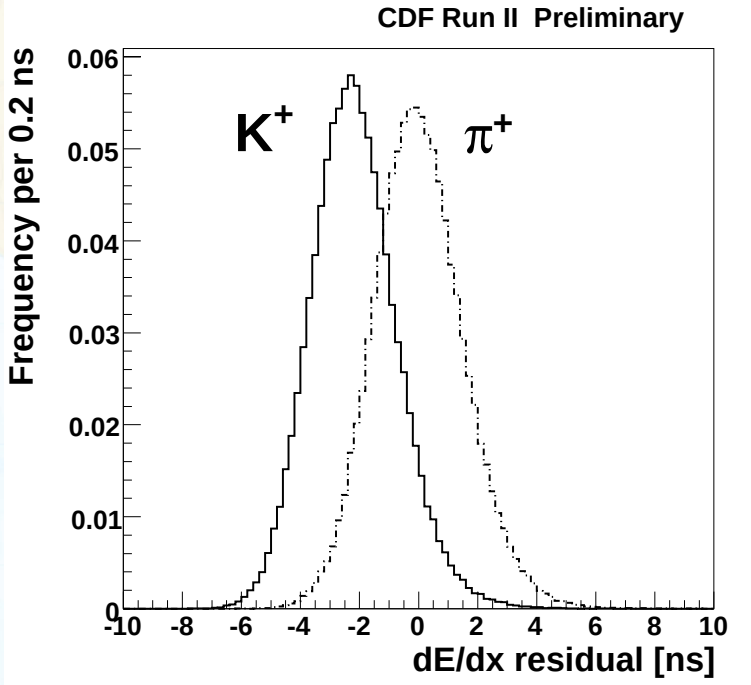
535 million $B\bar{B}$ pairs, PRL 98, 211801 (2007)

The $B^0 \to \pi^+\pi^-$ Branching Fraction from CDF

The same BF ratios as in 2006, based on 1 fb^{-1}; updated $K^+\pi^-$ BF WA

Many two-track final states overlap in the invariant mass **1.4σ K-π separation with dE/dx**





Using the Winter 2008 HFAG $\mathcal{B}(B^0 \to K^+\pi^-)$ world average,

$$\mathcal{B}r_{\pi^+\pi^-} = (5.02 \pm 0.33 \pm 0.35) \times 10^{-6}$$

2006: (5.10 ± 0.33 ± 0.36) x 10^{-6}

This CDF measurement is competitive with e^+e^- B-meson factories ($\mathcal{A}_{K\pi}$, too)

http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/ (updated April 10, 2008) **and hep-ex/0612018**

$\mathcal{B}r(B^0 \to \pi^+\pi^-)$

449 million $B\bar{B}$ pairs, PRL 99, 121601 (2007)

$$\mathcal{B}r_{\pi^+\pi^-} = (5.1 \pm 0.2 \pm 0.2) \times 10^{-6}$$

227 million $B\bar{B}$ pairs, PRD 75, 012008 (2007)

$$\mathcal{B}r_{\pi^+\pi^-} = (5.5 \pm 0.4 \pm 0.3) \times 10^{-6}$$

1 fb^{-1}, http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

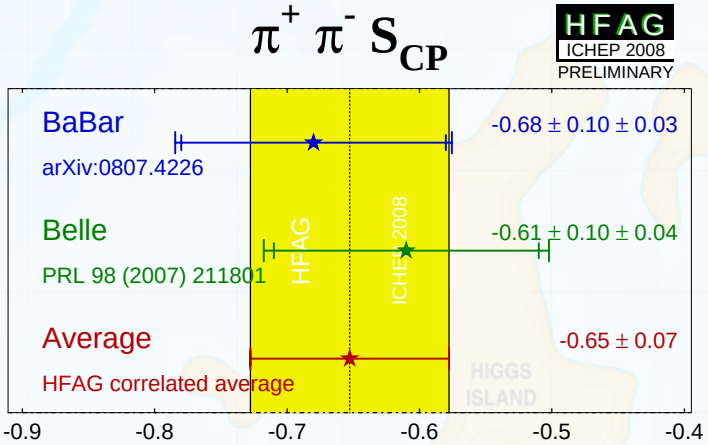
$$\mathcal{B}r_{\pi^+\pi^-} = (5.02 \pm 0.33 \pm 0.35) \times 10^{-6}$$

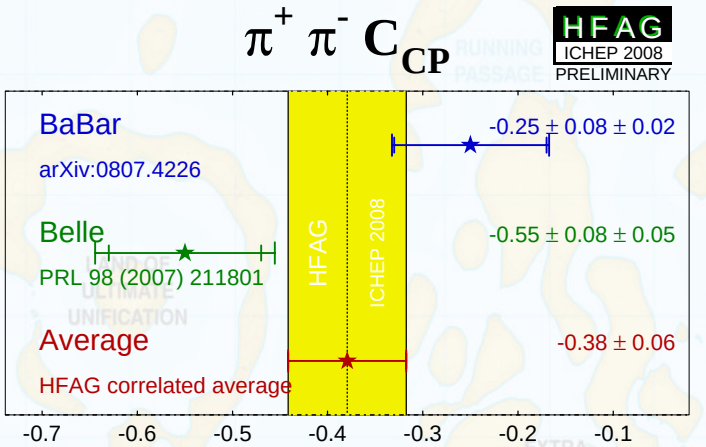
15.4 million $B\bar{B}$ pairs, PRD 68, 052002 (2003)

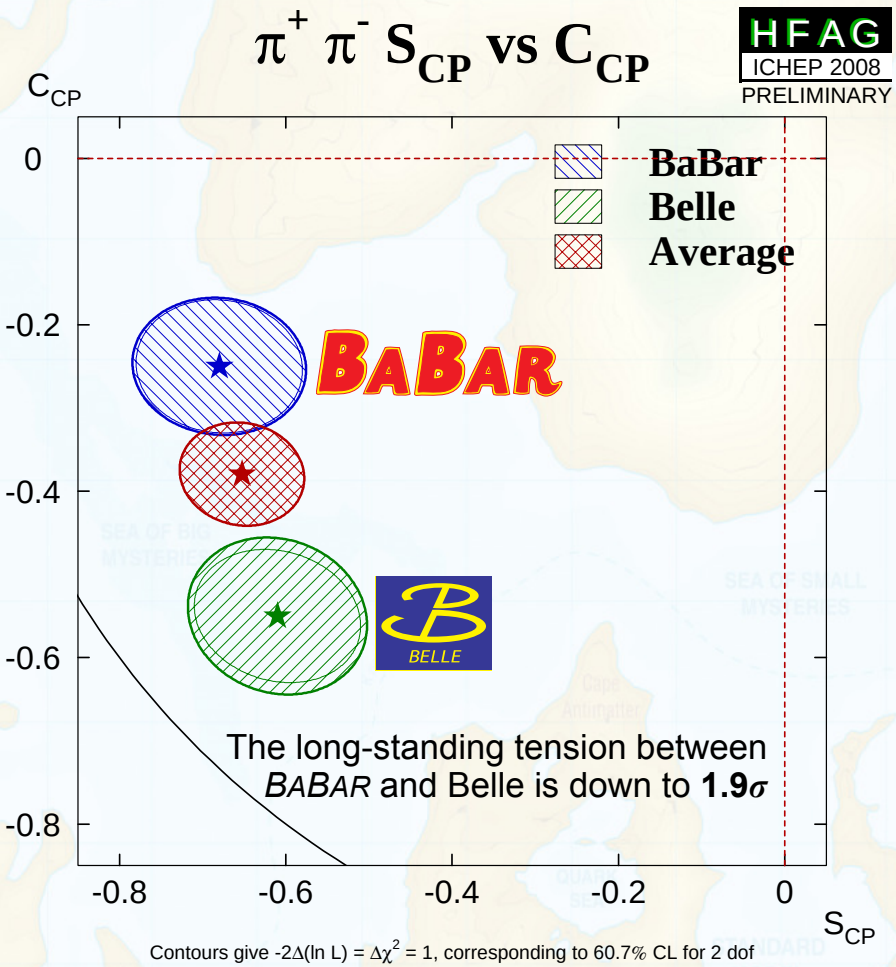
CLEO

$$\mathcal{B}r_{\pi^+\pi^-} = (4.5^{+1.4+0.5}_{-1.2-0.4}) \times 10^{-6}$$

World averages on $B^0 \to \pi^+\pi^-$ from HFAG







Contours give -2Δ(ln L) = $\Delta\chi^2$ = 1, corresponding to 60.7% CL for 2 dof

Official HFAG Winter 2008: $\mathcal{B}r_{\pi^+\pi^-} = (5.16 \pm 0.22) \times 10^{-6}$

With Apr 08 CDF update: $\mathcal{B}r_{\pi^+\pi^-} = (5.14 \pm 0.22) \times 10^{-6}$

http://www.slac.stanford.edu/xorg/hfag/rare/winter08/charmless/index.html
http://www.slac.stanford.edu/xorg/hfag/triangle/summer2008/#alphaeff_pipi

The $B \to \pi^{\pm}\pi^0$, $\pi^0\pi^0$ analyses

Common feature: $\pi^0 \to \gamma\gamma$ **reconstruction**

$\pi^{\pm}\pi^0$:

BABAR: Simultaneous fit to $B^0 \to \pi^+\pi^0$, $K^+\pi^0$ using DIRC Cherenkov angle PDFs

Belle: Cut on the kaon/pion likelihood ratio, fit with $K^+\pi^0$ as crossfeed

BABAR

A recent addition: in addition to $\pi^0 \to \gamma\gamma$, *use merged* π^0 *and* $\gamma \to e^+e^-$ *conversions*

$\Rightarrow$ ***10% efficiency increase per*** π^0 (4% from merged π^0, 6% from γ conversions)

At a Super *B-meson* factory, $\gamma \to e^+e^-$ conversions could make $S_{\pi^0\pi^0}$ determination possible! (hep-ex/0703039)

merged π^0 :

the two photons are too close to one another in the calorimeter to be reconstructed individually; can be recovered using

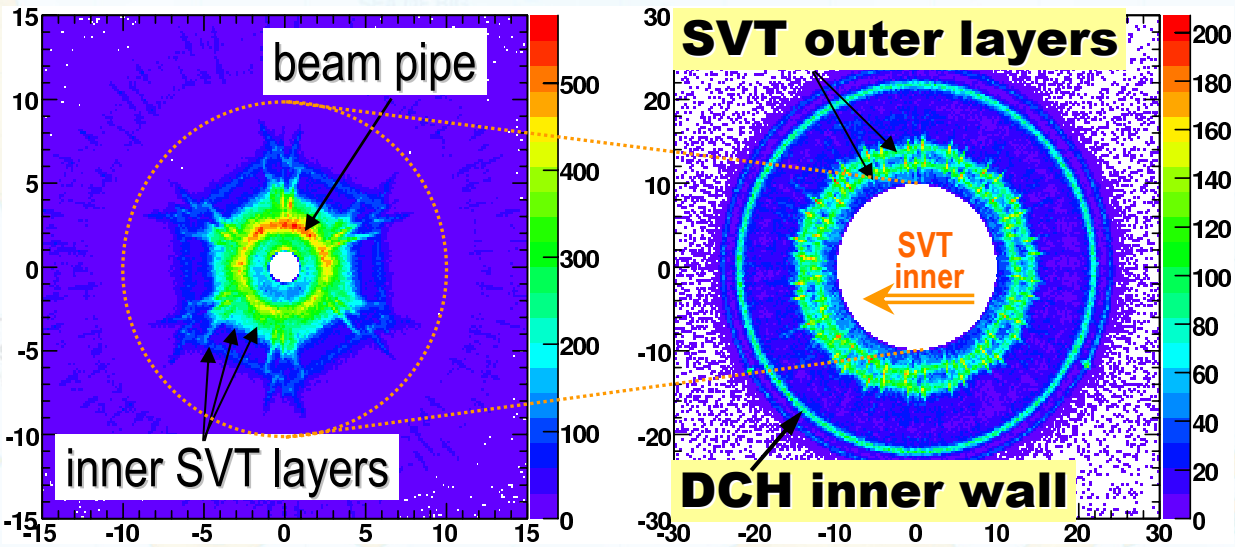
$$M^2_{\pi^0} \approx E^2_{\pi^0}(S_{\pi^0} - S_\gamma),$$

where S is the second EMC moment of the merged $\pi^0 \to \gamma\gamma$

The control sample: $\tau \to \rho\nu$

$\gamma \to e^+e^-$ conversions:

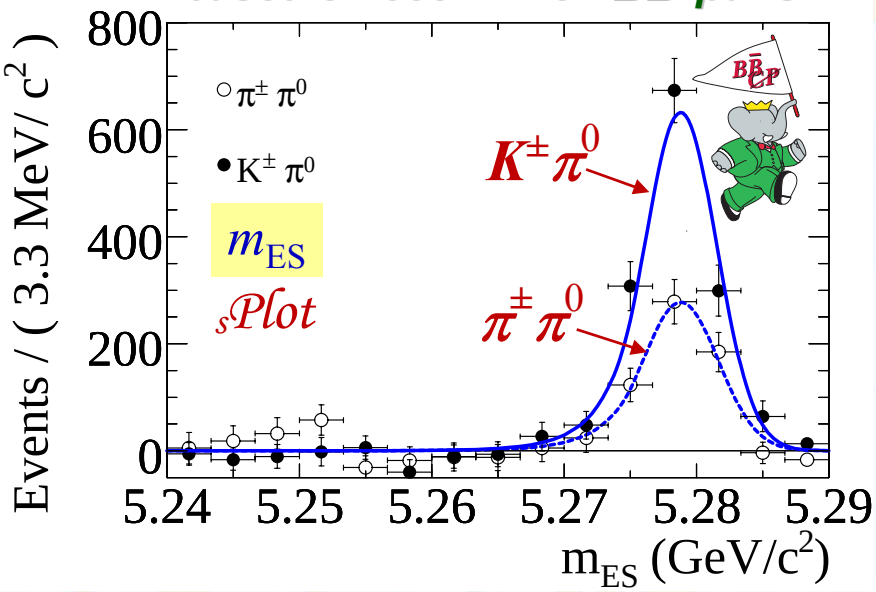
result from interactions with detector elements



$B^{\pm} \to \pi^{\pm}\pi^{0}$ results

BABAR $N_{\pi^{\pm}\pi^{0}} = 627 \pm 58$

based on 383 million $B\bar{B}$ pairs



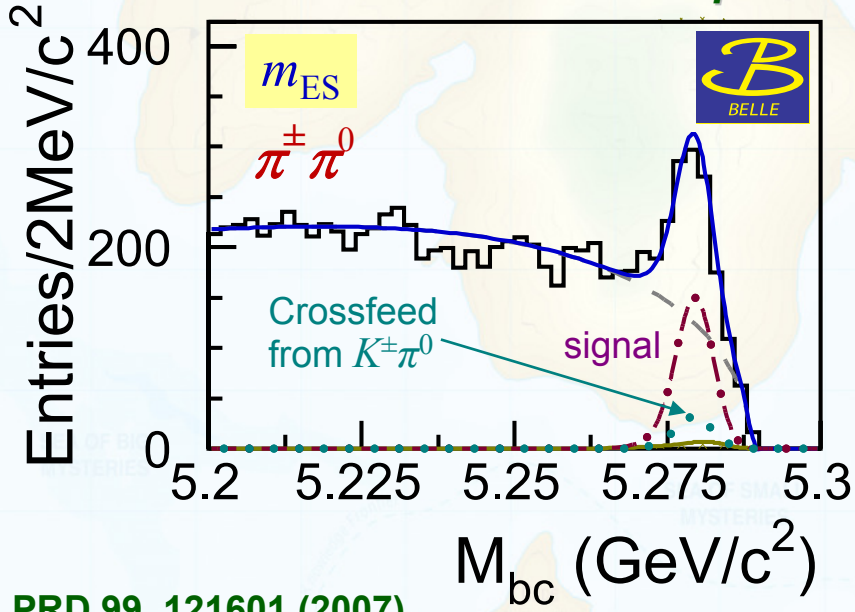
PRD 76, 091102 (2007)

$\mathcal{B}r_{\pi^{\pm}\pi^{0}} = (5.02 \pm 0.46 \pm 0.29) \times 10^{-6}$

$\mathcal{A}_{\pi^{\pm}\pi^{0}} = 0.03 \pm 0.08 \pm 0.01$

BELLE $N_{\pi^{\pm}\pi^{0}} = 693^{+46}_{-43}$

based on 449 million $B\bar{B}$ pairs



PRD 99, 121601 (2007)

$\mathcal{B}r_{\pi^{\pm}\pi^{0}} = (6.5 \pm 0.4 \pm 0.4) \times 10^{-6}$

$\mathcal{A}_{\pi^{\pm}\pi^{0}} = 0.07 \pm 0.06 \pm 0.01$

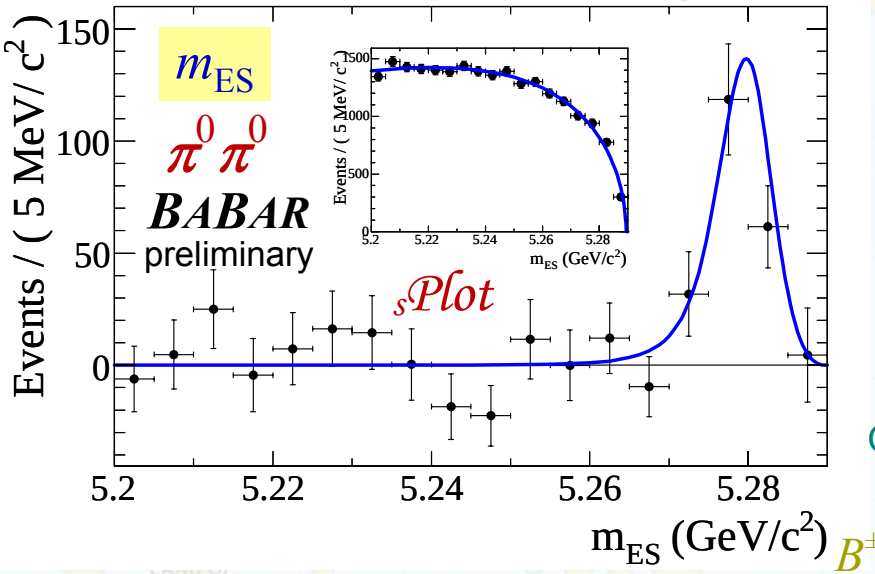
Nature 452, 332 (2008) – based on 535 million $B\bar{B}$ pairs

There is no gluonic penguin amplitude, so no measurable direct *CP* violation is expected

$B^0 \to \pi^0\pi^0$ results

BABAR $N_{\pi^0\pi^0} = 247 \pm 29$

based on 467 million $B\bar{B}$ pairs



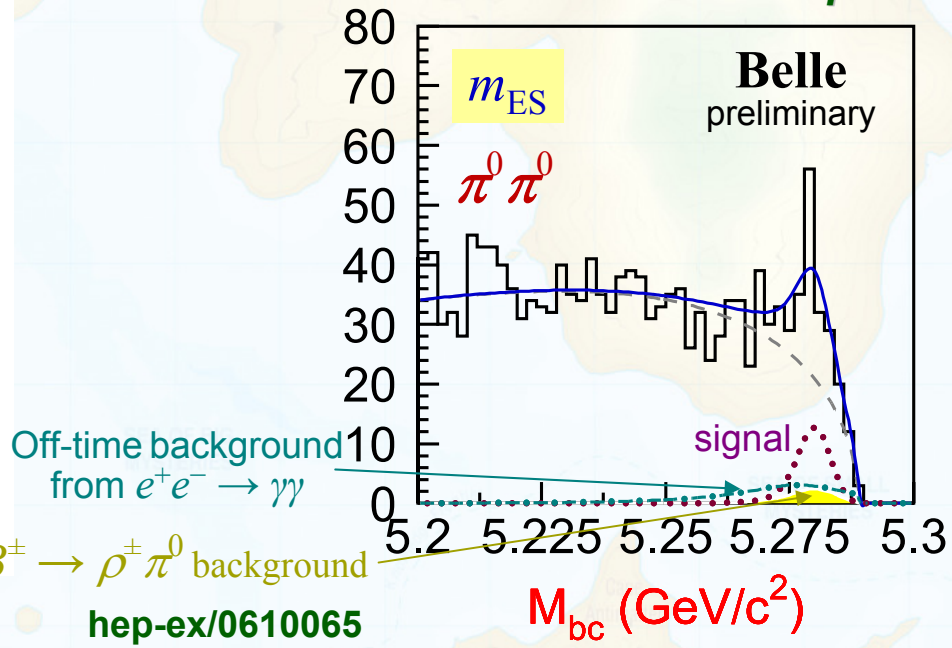
arXiv:0807.4226 [hep-ex]

$Br_{\pi^0\pi^0} = (1.83 \pm 0.21 \pm 0.13) \times 10^{-6}$

$C_{\pi^0\pi^0} = -0.43 \pm 0.26 \pm 0.05$

BELLE $N_{\pi^0\pi^0} = 74^{+20}_{-19}$

based on 535 million $B\bar{B}$ pairs



hep-ex/0610065

$Br_{\pi^0\pi^0} = (1.1 \pm 0.3 \pm 0.1) \times 10^{-6}$

$C_{\pi^0\pi^0} = -0.44^{+0.62+0.06}_{-0.73-0.04}$

$B \to \pi^{\pm}\pi^0, \pi^0\pi^0$: world averages

$B^+ \to \pi^+\pi^0$

$$\mathcal{B}r_{\pi^\pm\pi^0} = (5.59^{+0.41}_{-0.40}) \times 10^{-6}$$

$$\mathcal{A}_{\pi^\pm\pi^0} = 0.06 \pm 0.05$$

$B^0 \to \pi^0\pi^0$

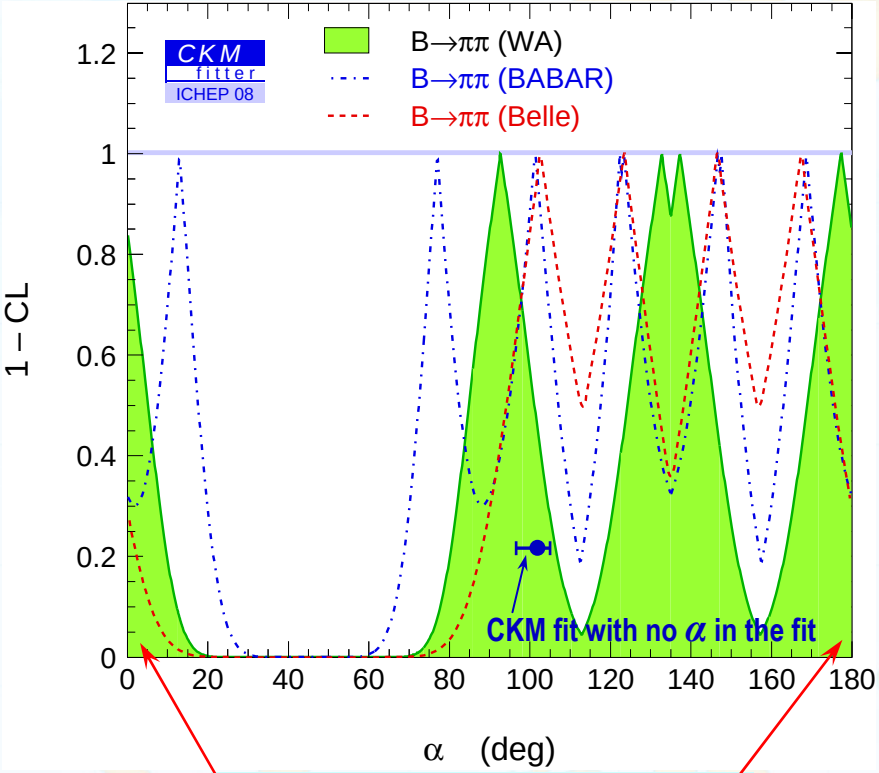
$$\mathcal{B}r_{\pi^0\pi^0} = (1.55 \pm 0.19) \times 10^{-6}$$

$$C_{\pi^0\pi^0} = -0.43^{+0.25}_{-0.24}$$

http://hep.physics.wayne.edu/~harr/hfags08/CHARMLESS/index.html
http://www.slac.stanford.edu/xorg/hfag/triangle/summer2008/#alphaeff_pipi

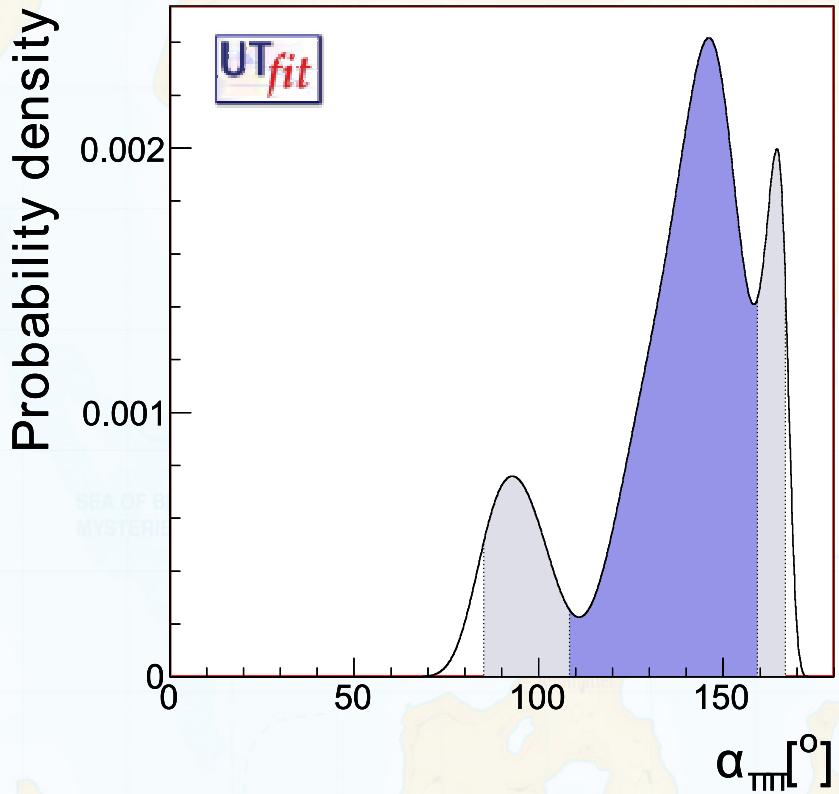
Interpretations of the latest $B \to \pi\pi$ results

A frequentist interpretation



α near 0 or π can be disfavored by additional experimental information

A Bayesian interpretation, with model-dependent choices of priors



Please see talk by Vincenzo Vagnoni (UTfit) tomorrow at 15:30

CKMfitter Group (J. Charles et al.), Eur. Phys. J. C**41**, 1-131 (2005) [hep-ph/0406184], updated results and plots available at http://ckmfitter.in2p3.fr

M. Ciuchini, G. D'Agostini, E. Franco, V. Lubicz, G. Martinelli, F. Parodi, P. Roudeau, A. Stocchi, JHEP **0107** (2001) 013 [hep-ph/0012308], updated results and plots posted at http://www.utfit.org

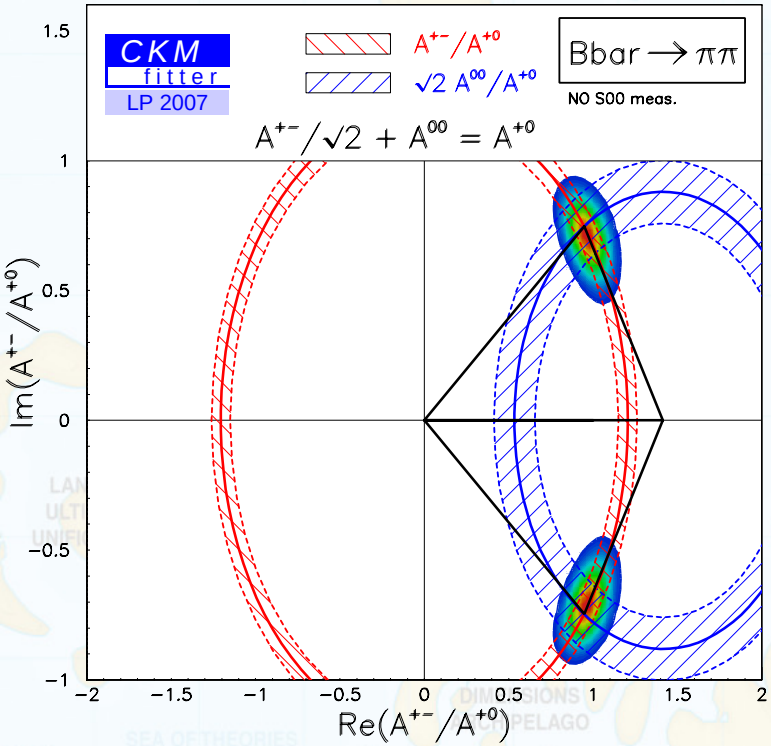
More on the status of $B \to \pi\pi$ isospin triangles

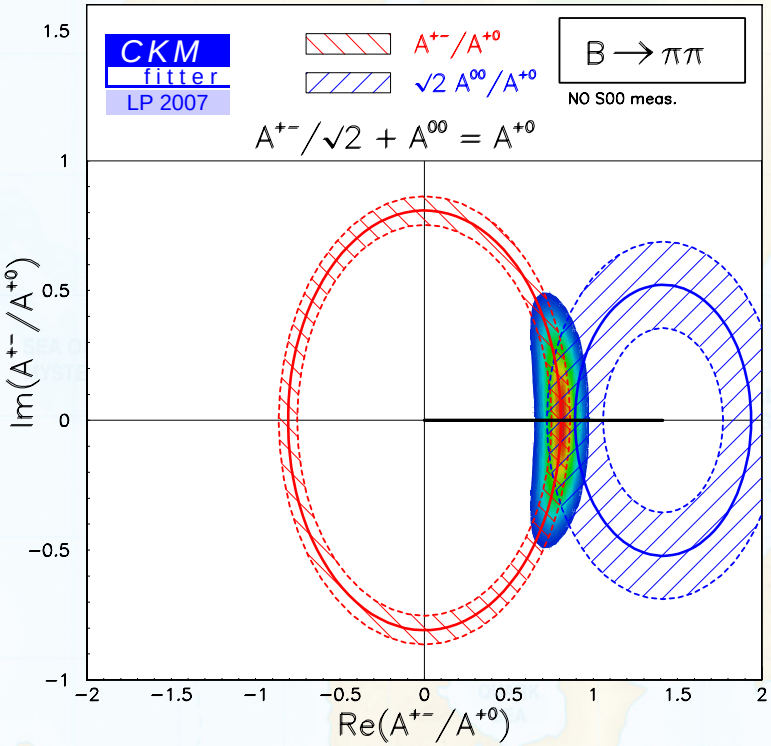
Why do we see a 4-fold ambiguity, not an 8-fold one?

One of the two triangles is degenerate

(in Belle data and in the WA, not *BABAR*)

*CKM*fitter WA circa Lepton-Photon 2007:





Changes of WA means since LP 2007 did help the degenerate *B* triangle a little:

$\mathcal{B}r_{\pi^0\pi^0} : (1.3 \to 1.55) \times 10^{-6}$

$C_{\pi^0\pi^0} : -0.48 \to -0.43$

$S_{\pi\pi} : -0.61 \to -0.65$

$C_{\pi\pi} : -0.38$ (unchanged)

Outlook

BABAR **has finished taking data**

Belle will roughly double its dataset, to 1.0 ab^{-1}

LHC*b* is starting soon:

will significantly contribute to α from $B \to (\rho\pi)^0, \rho\rho$

only marginally to $B \to \pi\pi$

SuperKEKB and Super*B* Super Flavor Factories

would be a very important addition to the arsenal of HEP in LHC era

would greatly enhance sensitivity of the $B \to \pi\pi$ analysis

It will be interesting to see how the degeneracy of the B isospin triangle gets resolved; not easy to make "2 ab^{-1}", "5 ab^{-1}", "10 ab^{-1}" plots without knowing it.