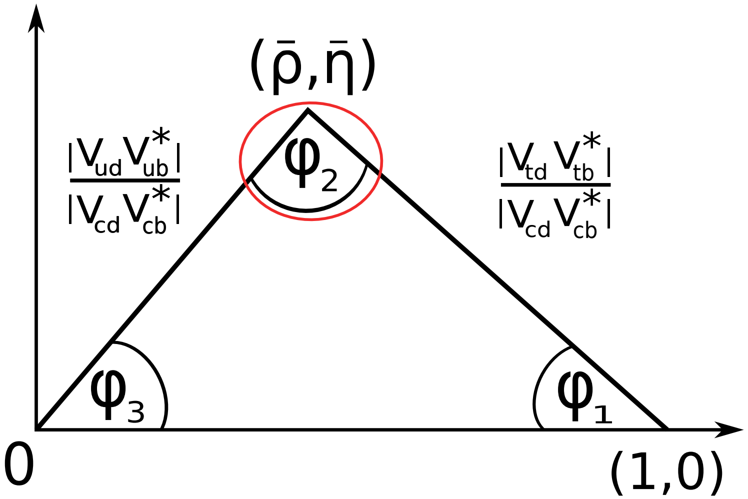
Results On ϕ_2 From e^+e^- Colliders

Pit Vanhoefer on behalf of the

Belle Collaboration

Max-Planck-Institut für Physik, München

pvanhoef *at* mpp.mpg.de



ϕ_2/α: Decays covered in this talk

a) $B \to \pi\pi$

b) $B \to \rho\rho$

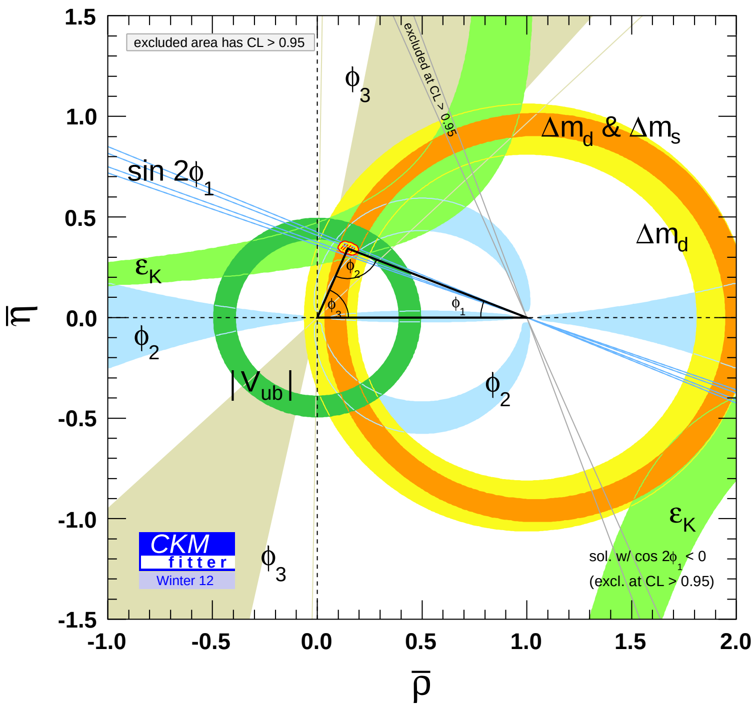
c) $B^0 \to (\rho\pi)^0$

d) $B^0 \to a_1^\pm \pi^\mp$

Introduction

- Measure properties of unitarity triangle to test CKM mechanism: 2 sides, 3 angles
- Time-dependent decay rate of a B or a $\bar{B}$ meson decaying into common CP eigenstate

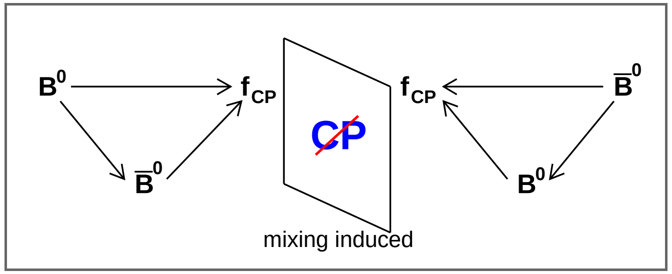
$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left\{ 1 + q \left[\mathcal{S}_{CP} \sin(\Delta m_d \Delta t) + \mathcal{A}_{CP} \cos(\Delta m_d \Delta t) \right] \right\}$$



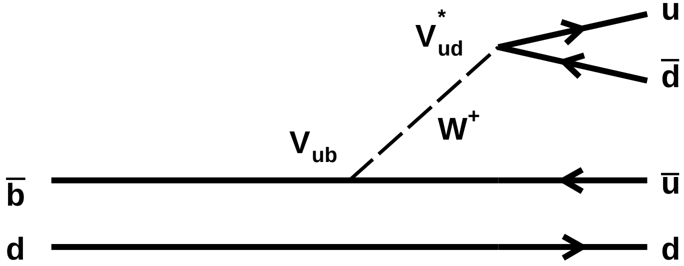
- $\mathcal{A}_{CP}$: direct CP violation ($= -\mathcal{C}_{CP}$)
- $\mathcal{S}_{CP}$: mixing induced CP violation
- q: flavor of B_{tag}, $q = +1$ for $B_{tag} = B^0$
- τ_{B^0}: B life time
- Δm_d: mass difference of B_H and B_L
- Δt: decay time difference of B_{CP} and B_{tag}

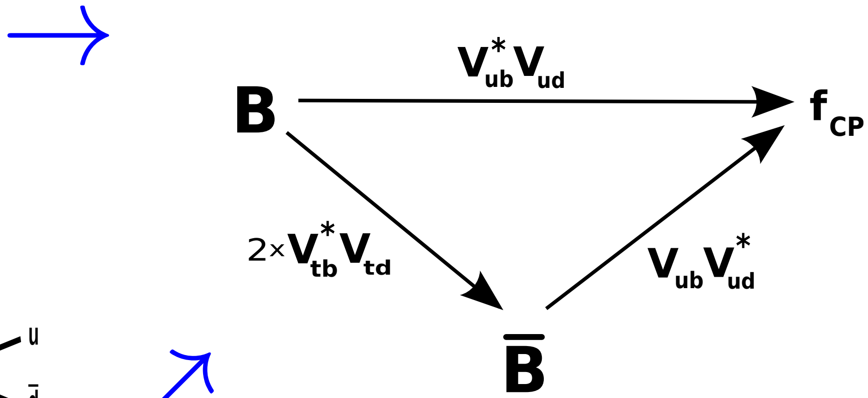
ϕ_2 Mixing Induced $\not{CP}$

- $\boxed{\phi_2 = arg\left(\frac{V_{td}V_{tb}^*}{V_{ub}V_{ud}^*}\right)}$ accesible through mixing induced $\not{CP}$ in $b \to u$ transitions,



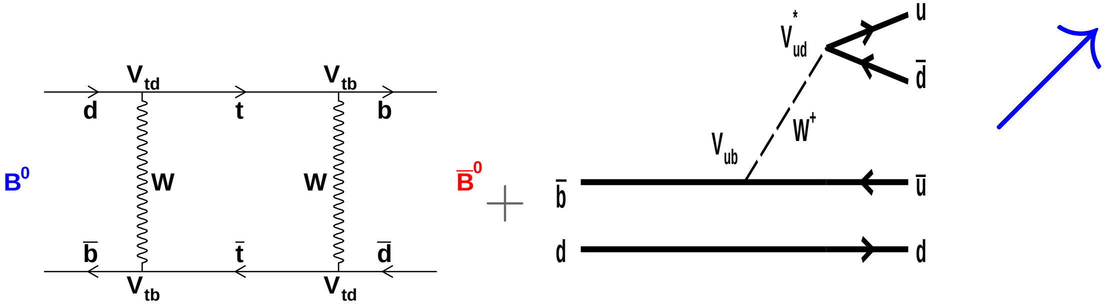
e.g. interference between $B \to \pi^+\pi^-$





$f_{CP} =$ ππ, ρρ

and $B \to \bar{B} \to \pi^+\pi^-$



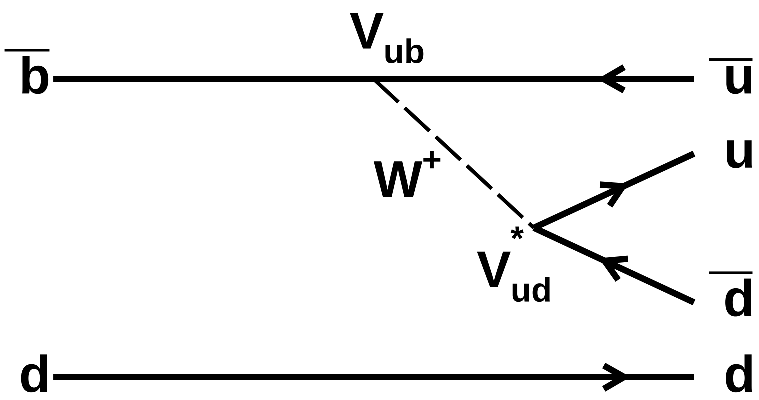
$\Rightarrow$ at tree level:

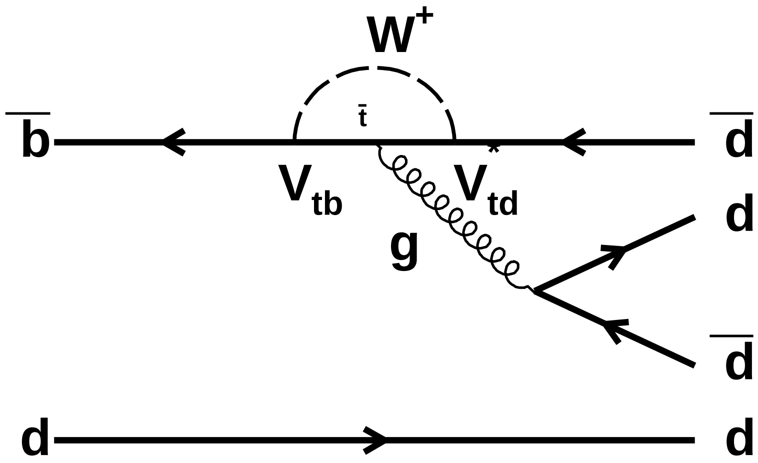
$$\boxed{\mathcal{S}_{CP} = \sin(2\phi_2), \quad \mathcal{A}_{CP} = 0}$$

ϕ_2 Living With Pollution

$b \to u$ (ρ, π, ...) at Tree level: $\mathcal{S}_{CP} = \sin(2\phi_2)$ and no direct $\not{C}\!\!\not{P}$ ($\mathcal{A}_{CP} = 0$)

BUT more amplitudes (penguins) can contribute with different weak/strong phases





$\Rightarrow \phi_2$

penguin pollution $\Rightarrow \Delta\phi_2, \mathcal{A}_{CP}$

$\Rightarrow$ measured observable $\phi_2^{eff} = \phi_2 + \Delta\phi_2$

$\to$ extraction of $\Delta\phi_2$ with isospin analysis is possible

$\mathcal{S}_{CP} = \sqrt{1 - \mathcal{A}_{CP}^2}\sin(2\phi_2^{eff})$

with $\mathcal{A}_{CP} \neq 0$ possible

Recover ϕ_2

- **extraction of $\Delta\phi_2$ with isospin analysis** (remove penguin pollution)

  for unflavored isospin triplets, e.g. ρ, π

  Bose statistics:$\Rightarrow$ I=0,2 (final states);

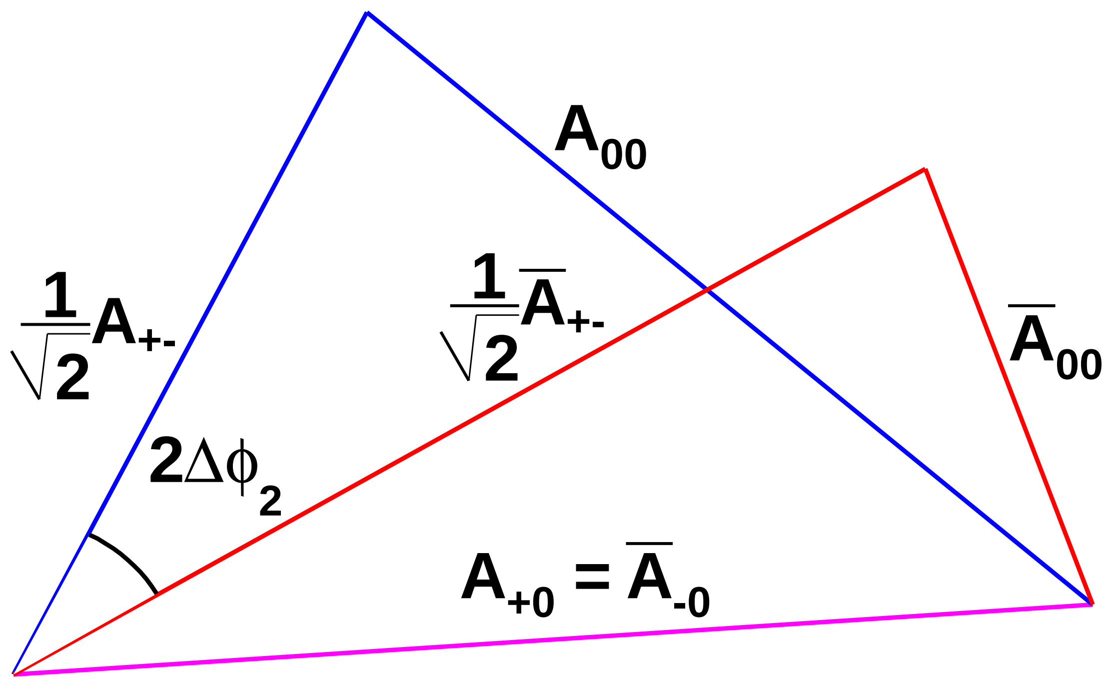
  tree I=0,2;

  penguin: I=0 only (gluon)

  allows to formulate relations of the

  decay amplitudes A

  e.g. $\bar{A}^{+-} = \mathcal{A}(\bar{B} \to \rho^+\rho^-)$



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

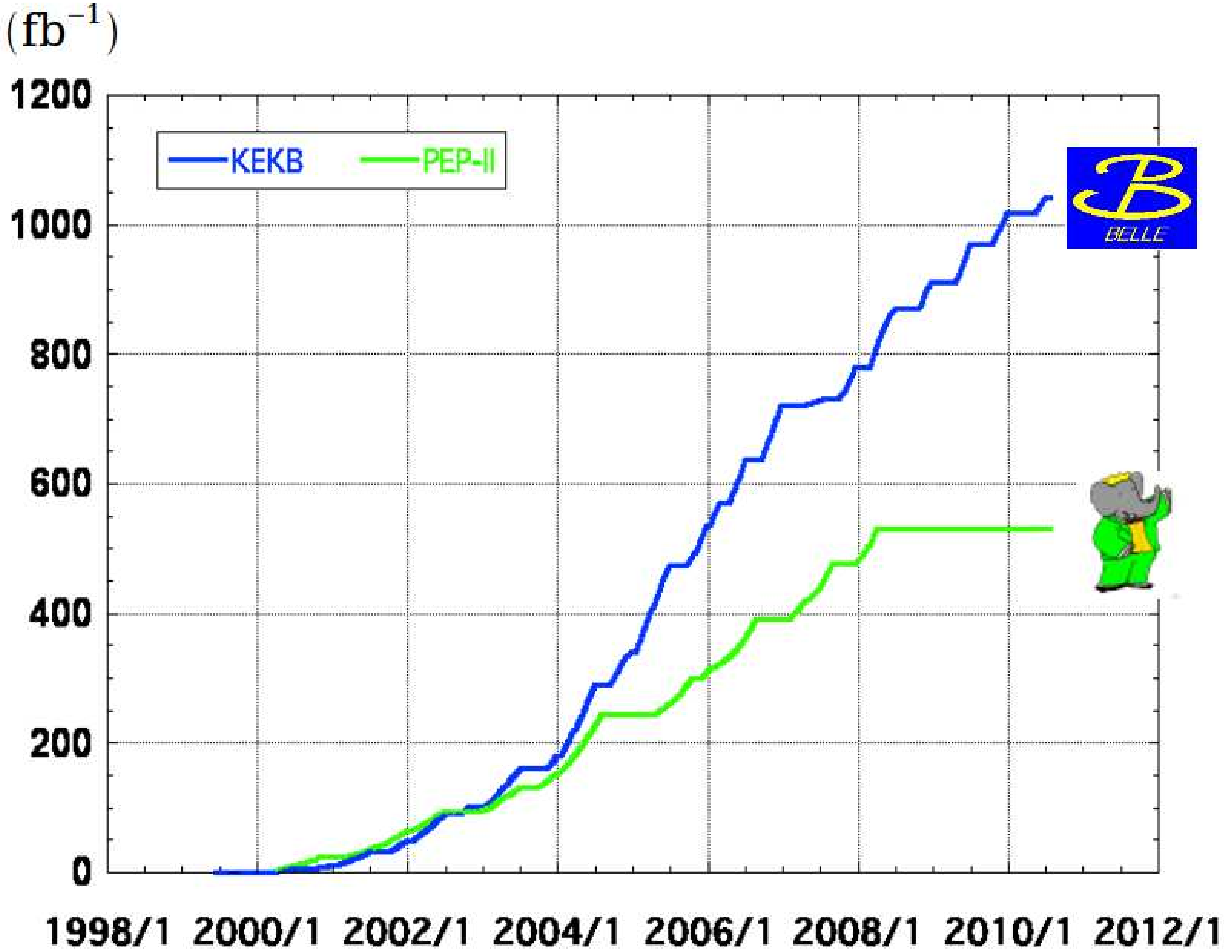
M. Gronau and D. London, PRL 65 3381 (1990)

- $A^{+0} = \bar{A}^{-0}$ (no penguin)

$\Rightarrow$ geometrical considerations reveal $\Delta\phi_2$

Data Samples

Integrated luminosity of B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

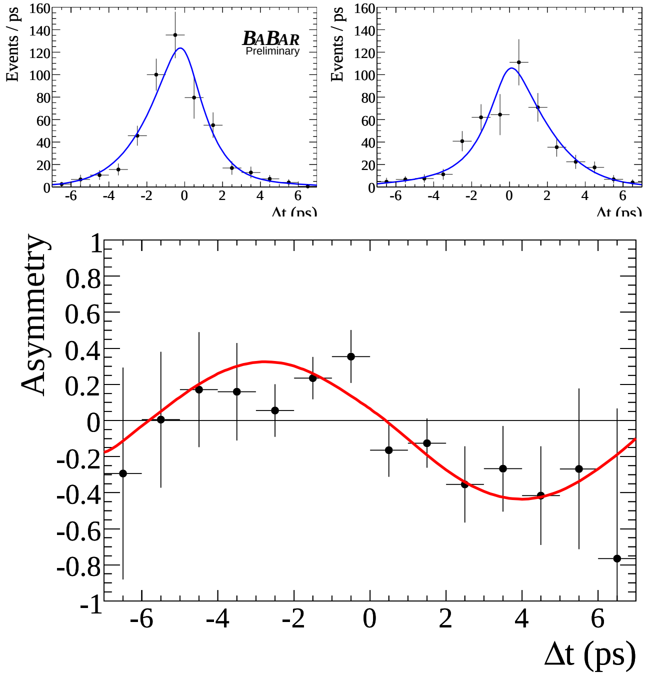
Off resonance:

~ 54 fb^{-1}

$B \to \pi^+\pi^-$

BaBar PRD **87** 052009(2013)

$467 \times 10^6 B\bar{B}$ pairs

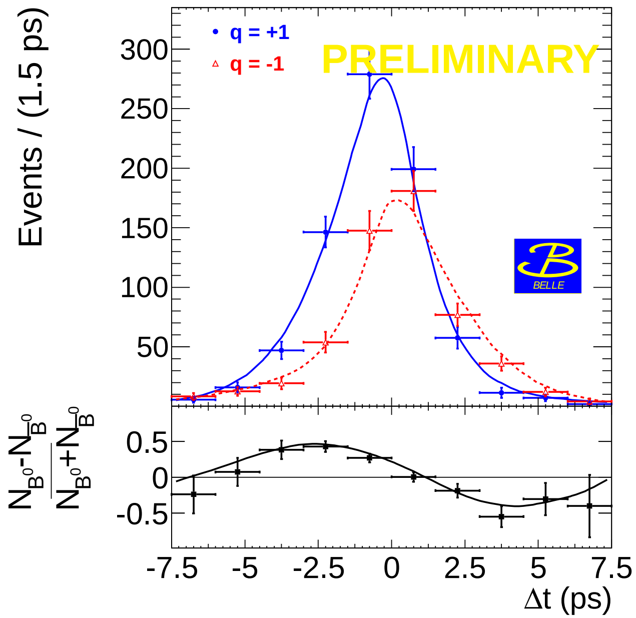


$$\mathcal{S}_{CP}^{\pi^+\pi^-} = -0.68 \pm 0.10 \pm 0.03$$

$$\mathcal{A}_{CP}^{\pi^+\pi^-} = +0.25 \pm 0.08 \pm 0.02$$

Belle arXiv:1302.0551

$772 \times 10^6 B\bar{B}$ pairs



$$\mathcal{S}_{CP}^{\pi^+\pi^-} = -0.636 \pm 0.082 \pm 0.027$$

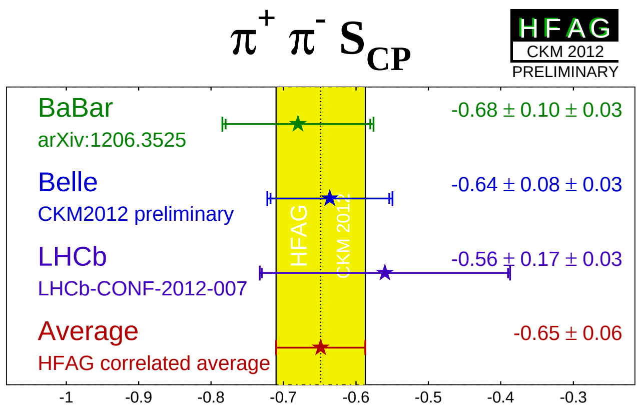
$$\mathcal{A}_{CP}^{\pi^+\pi^-} = +0.328 \pm 0.061 \pm 0.027$$

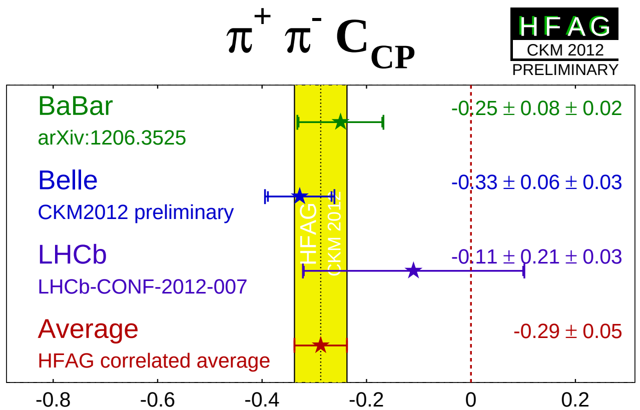
$\Rightarrow$ clear mixing induced $\not{CP}$ and presence of penguins

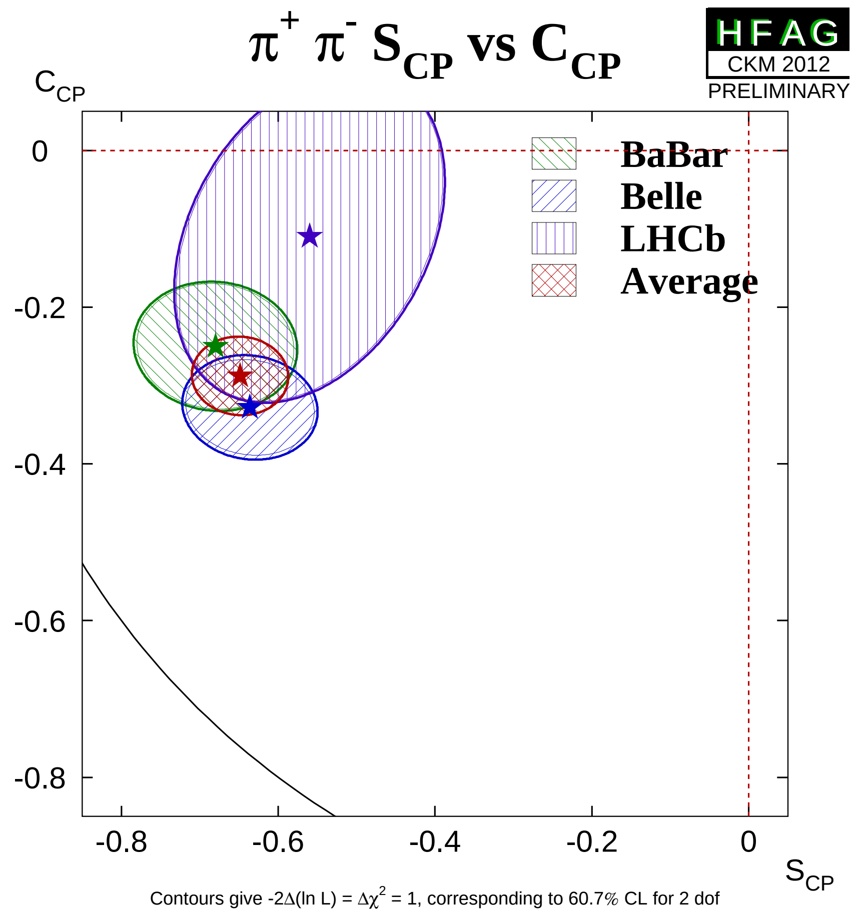
$B \to \pi^+\pi^-$

World averages

$$\mathcal{C}_{CP} = -\mathcal{A}_{CP}$$







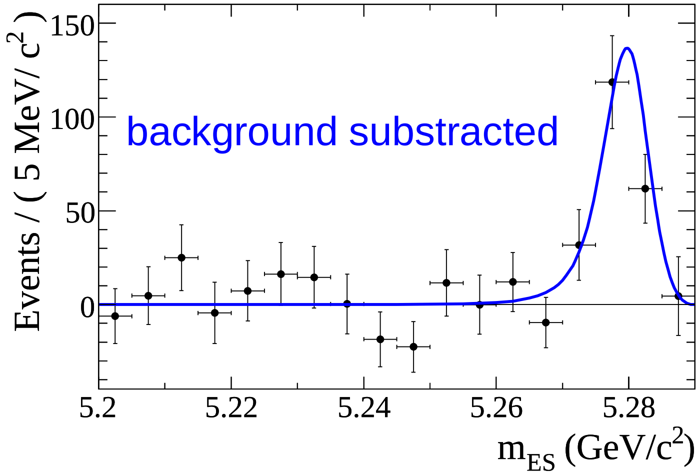
$\Rightarrow$ good agreements between experiments (prev. tension removed)

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

BaBar

PRD **87** 052009(2013)

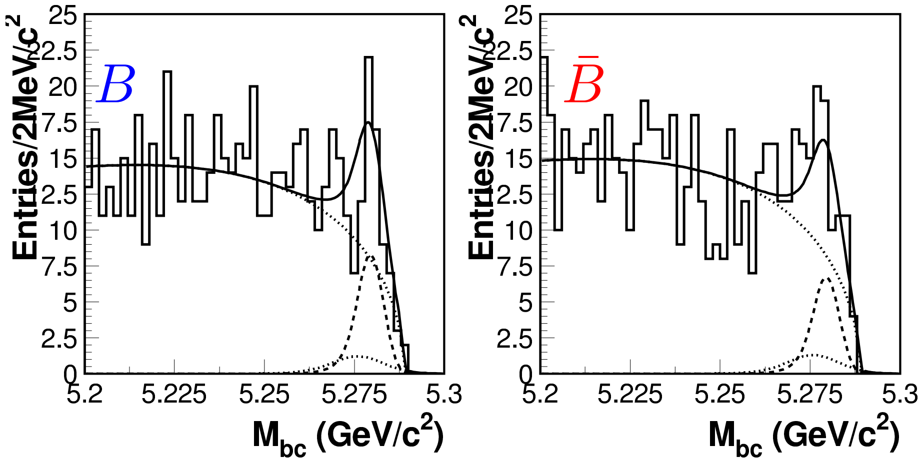
$467 \times 10^6 B\bar{B}$ pairs



Belle

PRL **94** 181803 (2005)

$275 \times 10^6 B\bar{B}$ pairs



$$m_{ES} = M_{bc} = \sqrt{E^2_{\rm beam} - p^2_B}$$

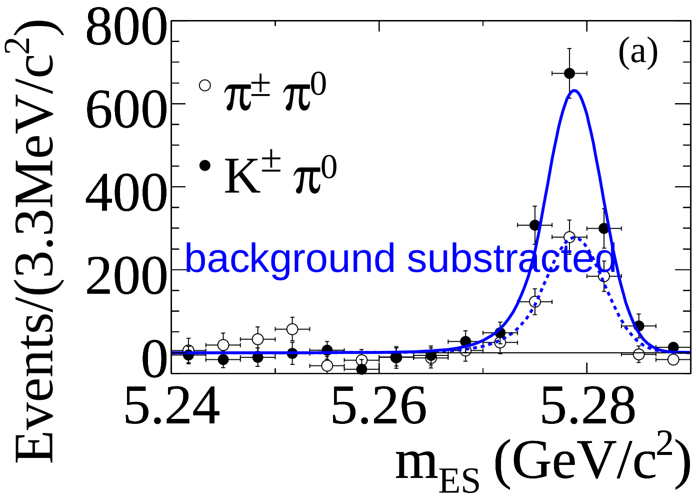
	BaBar	Belle
$\mathcal{B}(B^0 \to \pi^0\pi^0) \times 10^6$	$1.83 \pm 0.21 \pm 0.13$	$2.3^{+0.4\ +0.2}_{-0.5\ -0.3}$
$\mathcal{A}^{\pi^0\pi^0}_{CP}$	$0.43 \pm 0.26 \pm 0.05$	$0.44^{+0.53}_{-0.52} \pm 0.17$

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

BaBar

PRD **76** 091102 (2007)

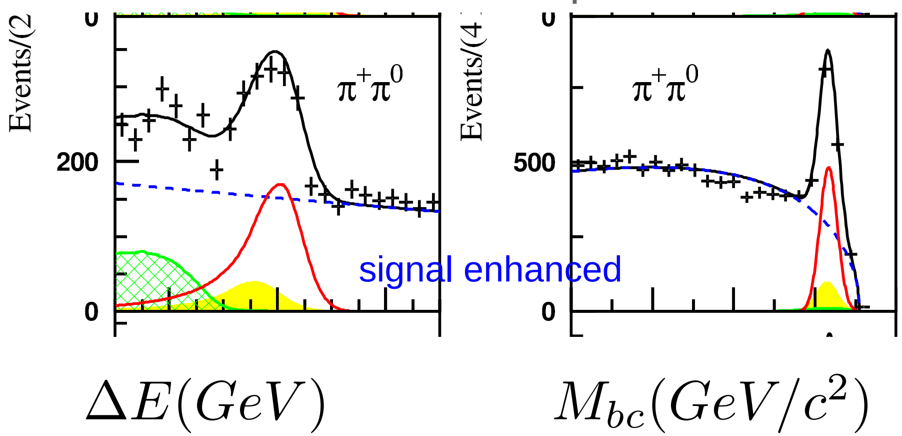
$383 \times 10^{6} B\bar{B}$ pairs



Belle

arxiv:1210.1348 (2012)

$772 \times 10^{6} B\bar{B}$ pairs

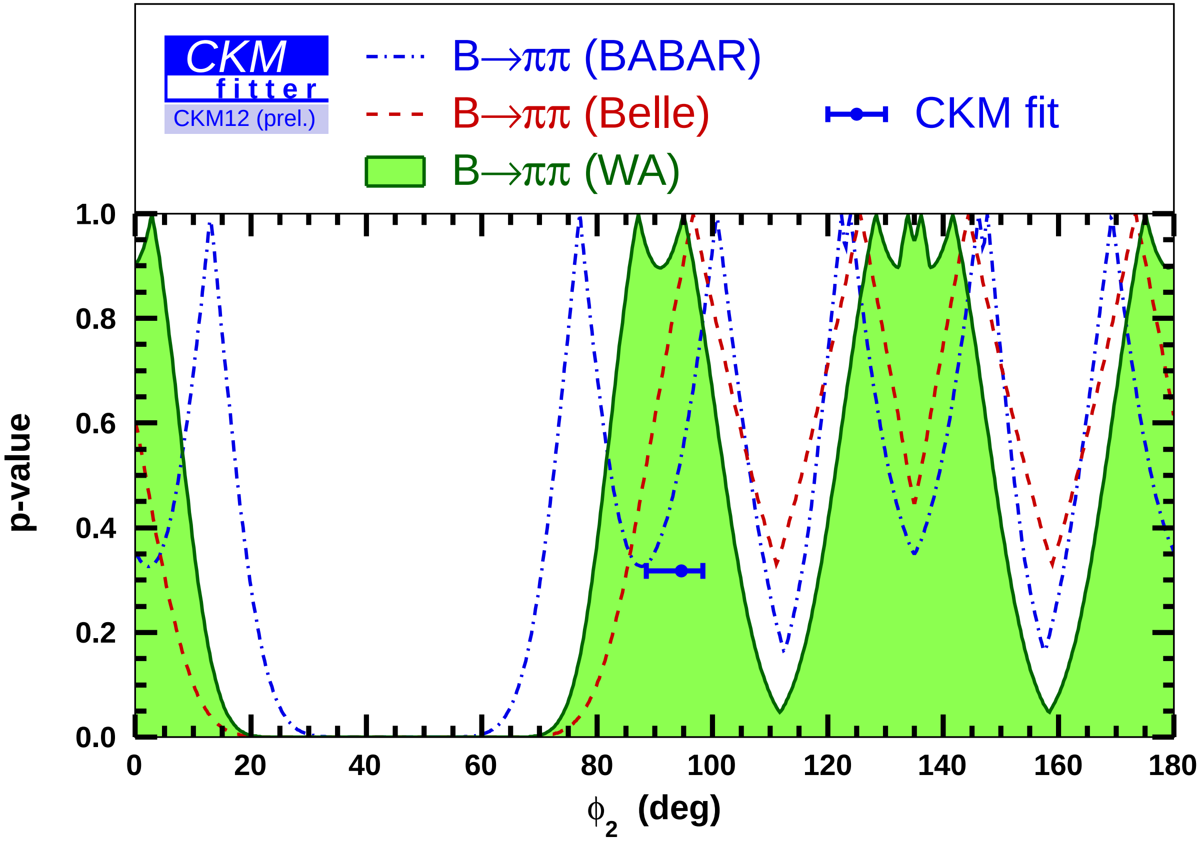


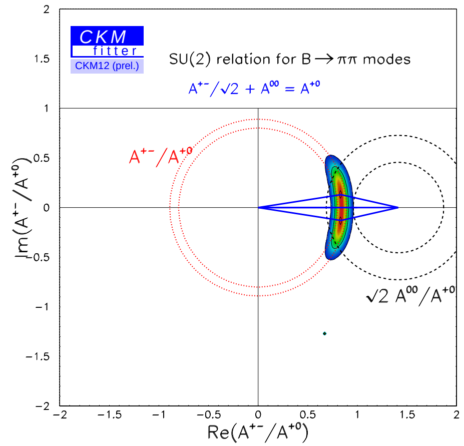
$$\Delta E = E_{B_{\mathrm{rec}}} - E_{\mathrm{beam}}$$

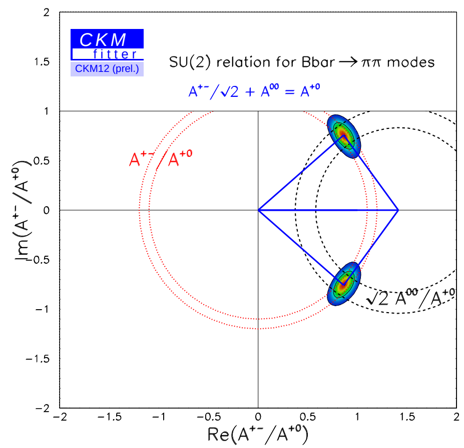
	BaBar	Belle
$\mathcal{B}(B^{\pm} \to \pi^{\pm}\pi^{0}) \times 10^{6}$	$5.02 \pm 0.46 \pm 0.29$	$5.86 \pm 0.26 \pm 0.38$
$\mathcal{A}_{CP}^{\pi^{\pm}\pi^{0}}$	$0.03 \pm 0.08 \pm 0.01$	$0.043 \pm 0.043 \pm 0.007$

$B \to \pi\pi$

ϕ_2/α constraints







Belle: $\phi_2 \in [85.0°, 148.0°]$, Babar: $\alpha \in [71°, 109°]$, WA: $\phi_2/\alpha = (87.1^{+17.5}_{-7.8})°$

$B \to \rho\rho$

- $B \to \rho\rho$

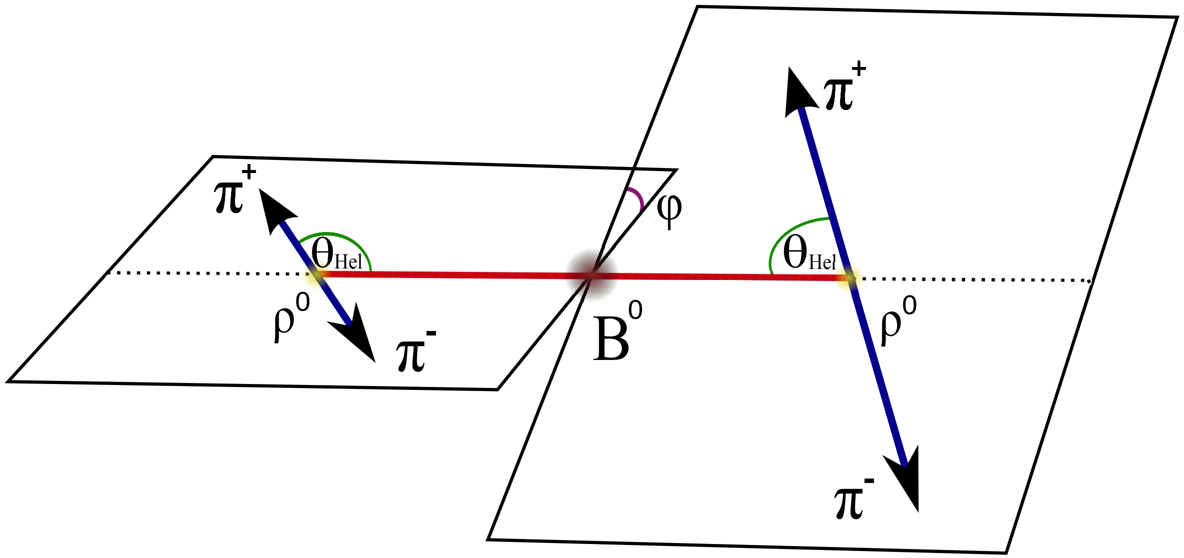
  $\rho \to \pi\pi$

- S $\to$ VV decay

  $\hookrightarrow$ superposition of CP even and odd states

  $\hookrightarrow$ separation through helicity analysis

helicity basis:



- f_L: fraction of longitudinal polarization(LP, pure CP even final states)

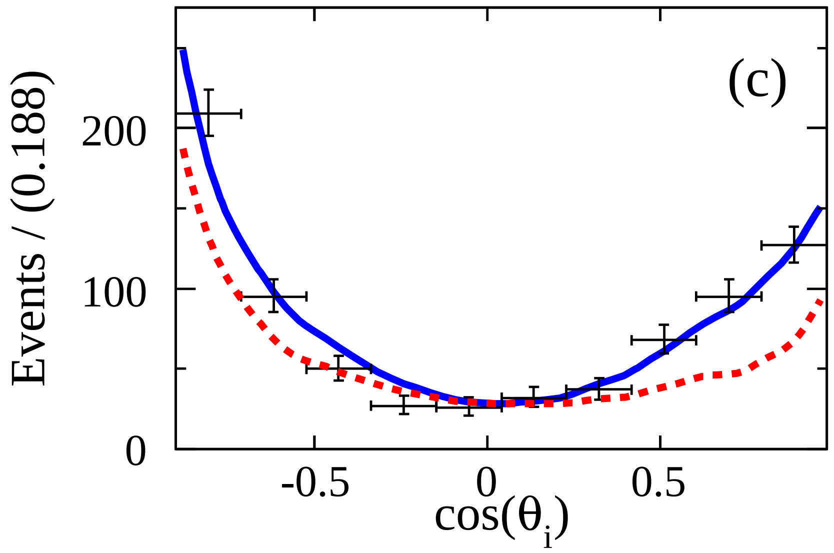
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta^1_{\rm Hel}\, d\cos\theta^2_{\rm Hel}} = \frac{9}{4}\left(f_L\cos^2\theta^1_{\rm Hel}\cos^2\theta^2_{\rm Hel} + \frac{1}{4}(1-f_L)\sin^2\theta^1_{\rm Hel}\sin^2\theta^2_{\rm Hel}\right)$$

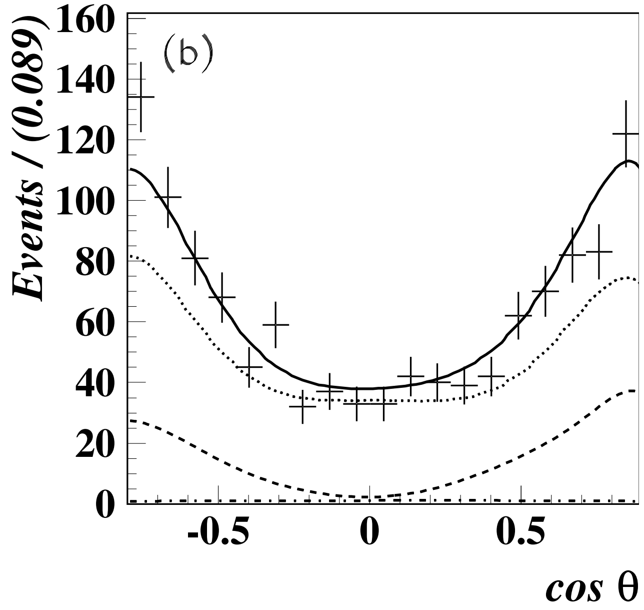
naiv SM expectation: $f_L \sim 1 - \frac{m_V^2}{m_B^2} \sim 1$ difficult to predict for color-suppressed mode $B^0 \to \rho^0\rho^0$

- smaller statistics(exp.) less penguin pollution compared to $B \to \pi\pi$

$B^0 \to \rho^+ \rho^-$ Helicity

BaBar	Belle
PRD **76** 052007 (2007)	PRL **96** 171801 (2006)
384 million $B\bar{B}$ pairs	275 million $B\bar{B}$ pairs





	BaBar	Belle
$\mathcal{B}(B^0 \to \rho^+\rho^-) \times 10^6$	$(25.5 \pm 2.1^{+3.6}_{-3.9})$	$(22.8 \pm 3.8^{+2.3}_{-2.6})$
f_L	$0.992 \pm 0.024^{+0.026}_{-0.013}$	$0.941^{+0.034}_{-0.040} \pm 0.030$

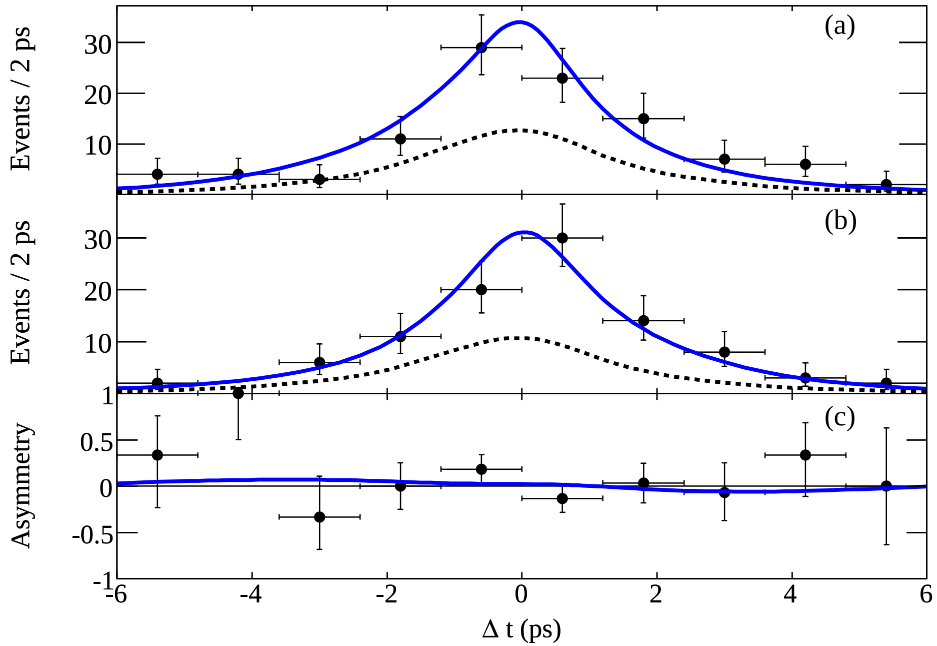
$B^0 \to \rho^+ \rho^-$

BaBar

PRD **76** 052007 (2007)

384 million $B\bar{B}$ pairs

Δt distribution and asymmetry



$$\mathcal{S}_{CP} = -0.17 \pm 0.20^{+0.05}_{-0.06}$$

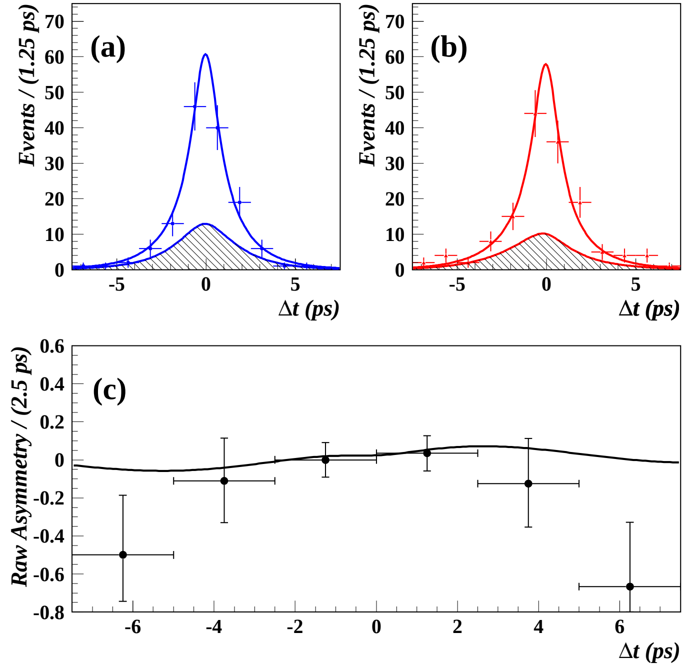
$$\mathcal{A}_{CP} = -0.01 \pm 0.15 \pm 0.06$$

Belle

PRD **76** 011104 (2007)

Update to 535 million $B\bar{B}$ pairs

Δt distribution and asymmetry

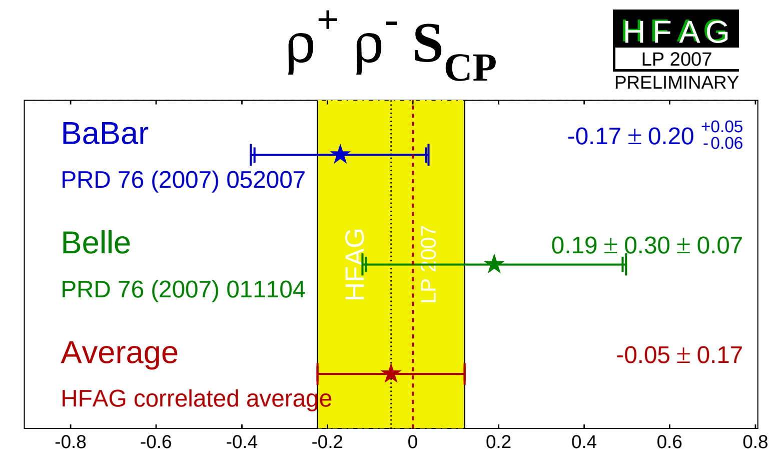


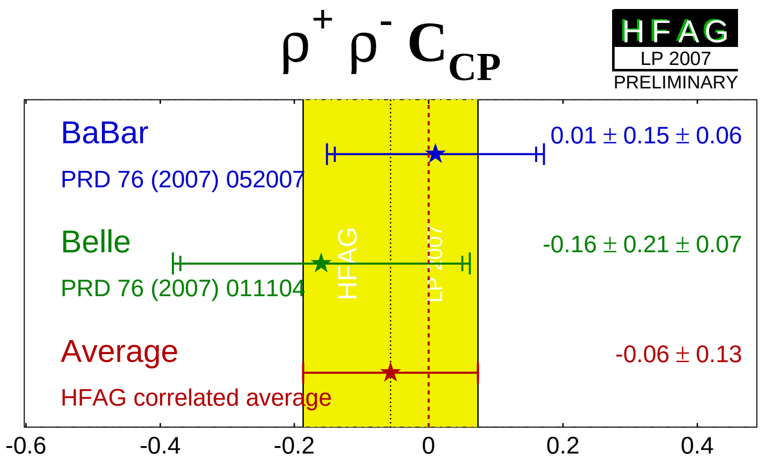
$$\mathcal{S}_{CP} = +0.19 \pm 0.30 \pm 0.07$$

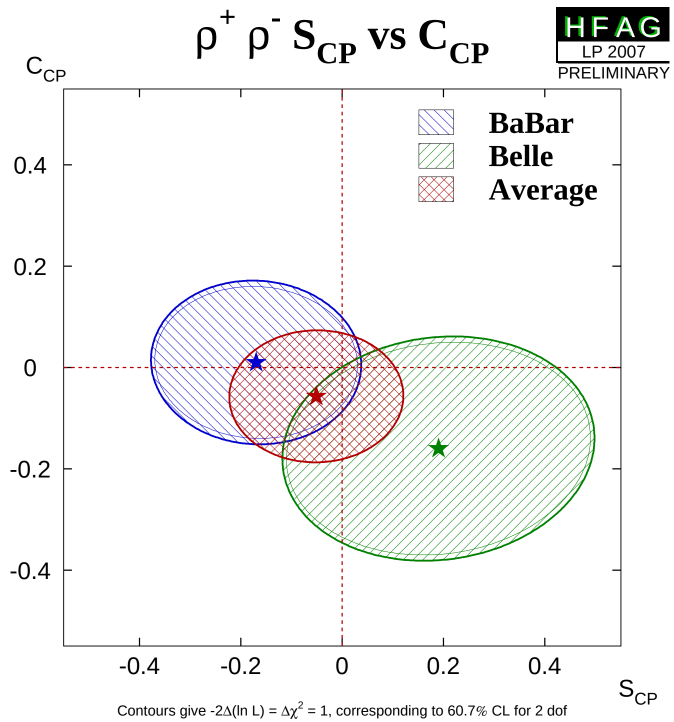
$$\mathcal{A}_{CP} = +0.16 \pm 0.21 \pm 0.07$$

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

World average







Good agreements between experiments

$\mathcal{A}_{CP}(= -\mathcal{C}_{CP}) \approx 0$

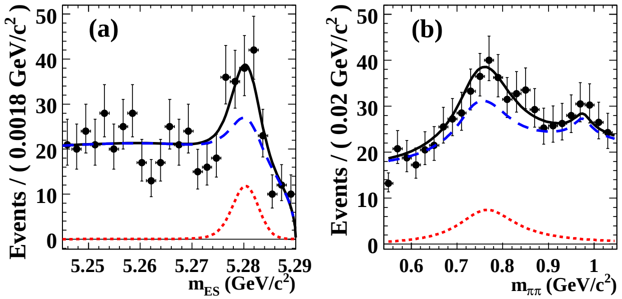
$\rightarrow$ small penguin contribution

$B^0 \to \rho^0 \rho^0$

BaBar

PRD **78**, 071104 (2008)

465 million $B\bar{B}$ pairs



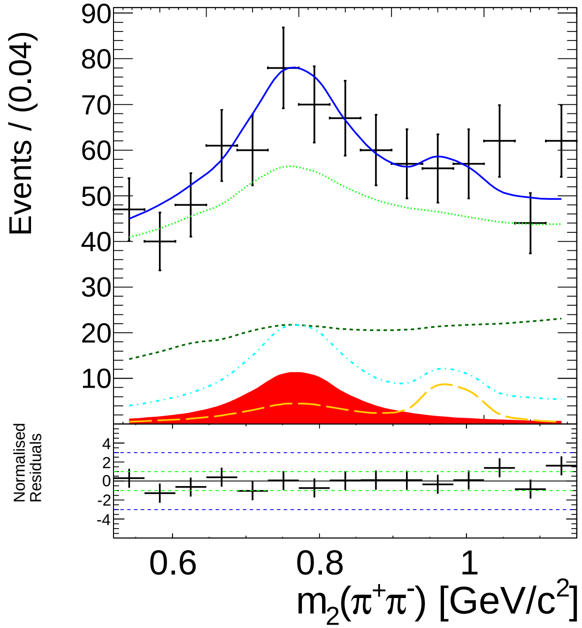
$$S_{CP}^{00LP} = 0.3 \pm 0.7 \pm 0.2$$

$$\mathcal{A}_{CP}^{00LP} = -0.2 \pm 0.8 \pm 0.3$$

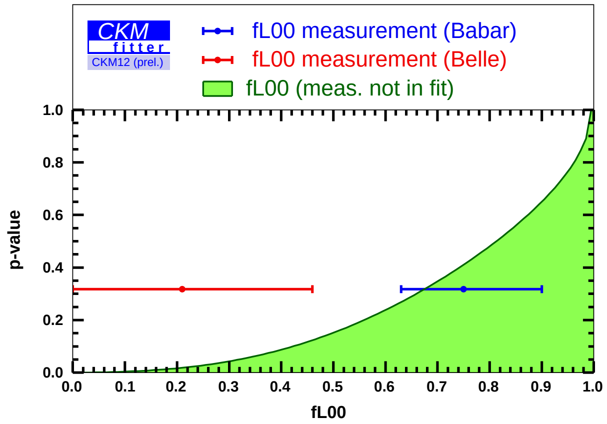
Belle

arXiv:1212.4015

772 million $B\bar{B}$ pairs



f_L: Belle vs BaBar

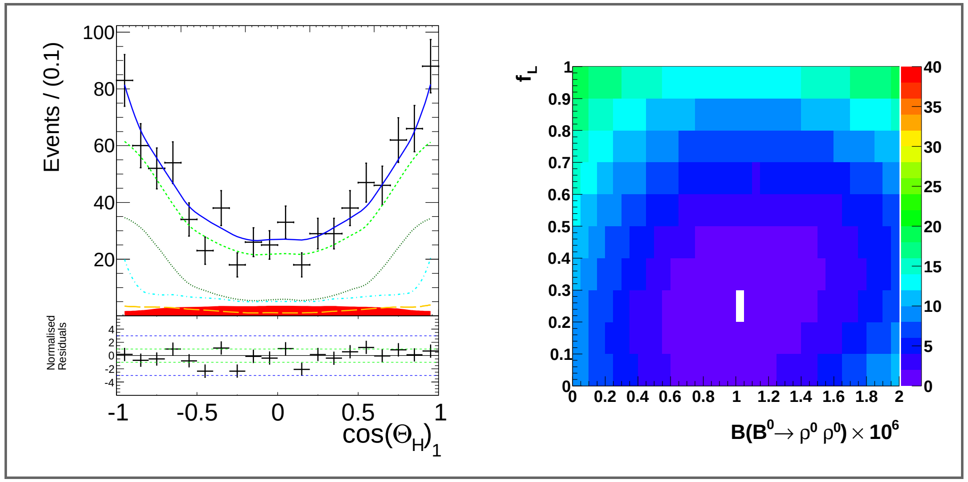


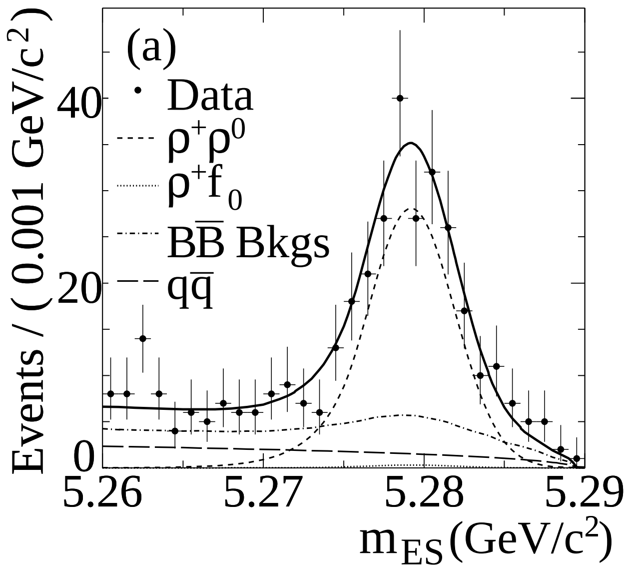
2.1σ tension

	BaBar	Belle (preliminary)
$\mathcal{B}(B^0 \to \rho^0 \rho^0) \times 10^6$	$0.92 \pm 0.32 \pm 0.14$	$1.02 \pm 0.30 \pm 0.22$
f_L	$0.75^{+0.11}_{-0.14} \pm 0.04$	$0.21^{+0.18}_{-0.22} \pm 0.11$

$B^0 \to \rho^{0(\pm)}\rho^0$

$B^0 \to \rho^0\rho^0$ from Belle

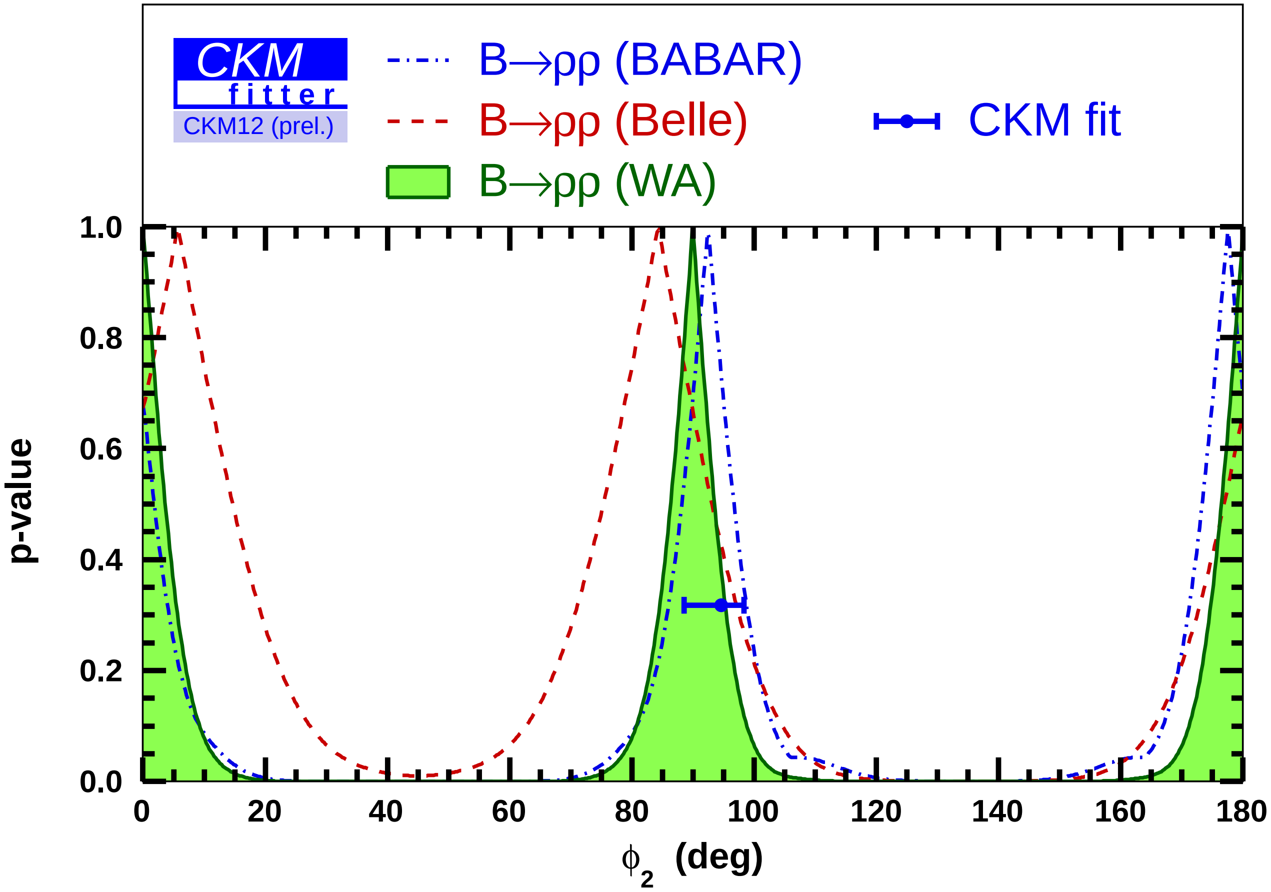




$B^0 \to \rho^{\pm}\rho^0$	BaBar	Belle
journal	PRL **102** 141802 (2009)	PRL **91** 221801 (2003)
N($B\bar{B}$) $\times 10^6$	465	85
$\mathcal{B}(B^0 \to \rho^{\pm}\rho^0) \times 10^6$	$23.7 \pm 1.4 \pm 1.4$	$31.7 \pm 7.1^{+3.8}_{-6.7}$
f_L	$0.950 \pm 0.015 \pm 0.006$	$0.948 \pm 0.106 \pm 0.021$
$\mathcal{A}_{CP}^{\pm 0}$	$0.054 \pm 0.055 \pm 0.010$	$0.00 \pm 0.22 \pm 0.03$

$B \to \rho\rho$

ϕ_2/α constraints



- small penguin contribution
- best environment for constraining ϕ_2 with 1st generation B-factories

Belle: $\phi_2 = (84 \pm 13)^\circ$, Babar: $\alpha = (92.4 \pm 6.4)^\circ$, WA: $\phi_2/\alpha = (89.9^{+5.4}_{-5.3})^\circ$

$B^0 \to (\rho\pi)^0$

Not a CP eigenstate, need to consider the 4 flavour-charge configurations

Corresponding isospin analysis has 12 unknowns compared to 6 for CP eigenstates

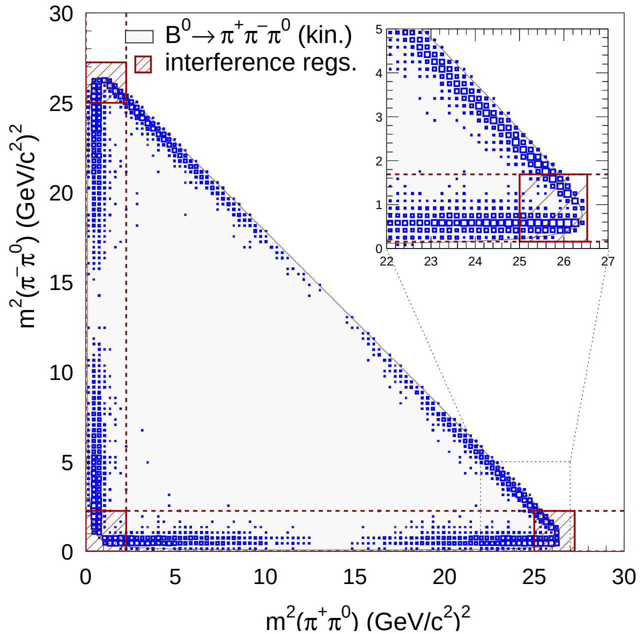
- U/I fomalism instead of quasi-two-body(Q2B)

  $\rightarrow$ 27 real free parameters

  can be related to $\mathcal{A}_{CP}$ and $\mathcal{S}_{CP}$ parameters

- Dalitz plot sensitive to strong and weak phases of the interfering ρ resonances

  (A. Snyder and H. Quinn, PRD **48** 2139 (1993))



$\Rightarrow$ possible to constrain ϕ_2 without ambiguity explicitly in the analysis !

$B^0 \to (\rho\pi)^0$

NEW BaBar

arXiv:1304.3503 (2013)

471 million $B\bar{B}$ pairs

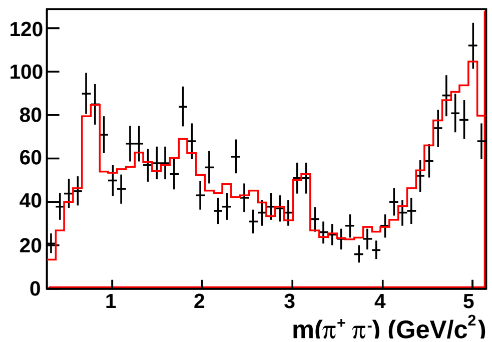
Mass projections

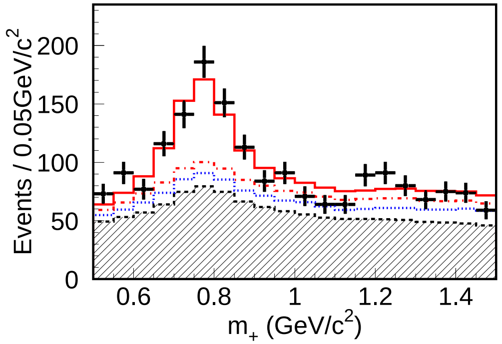
Belle

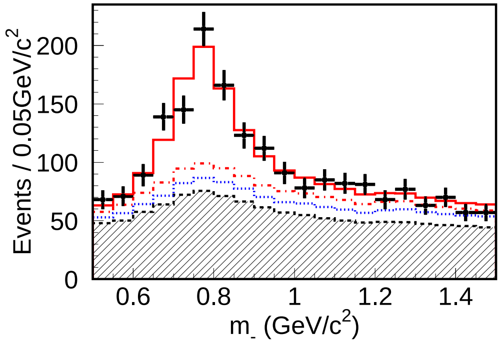
PRL **98** 221602 (2007)

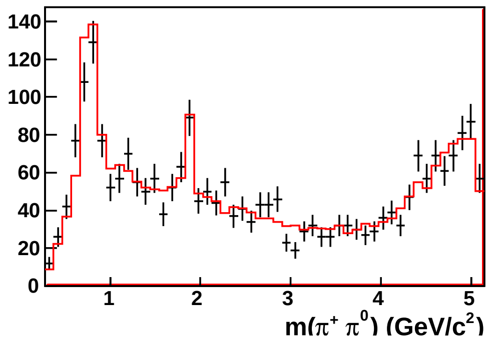
449 million $B\bar{B}$ pairs

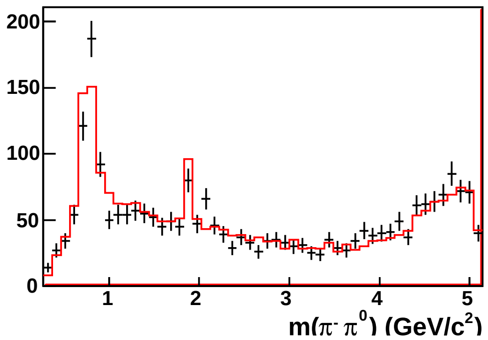
Mass projections

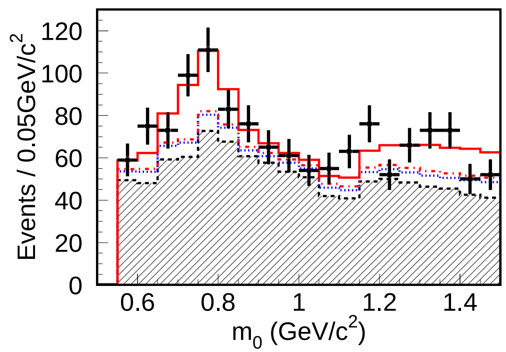








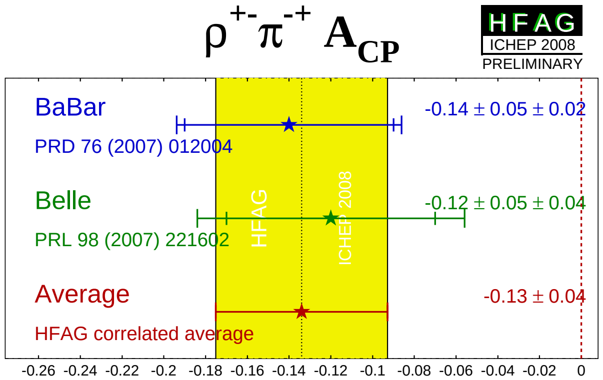




$B^0 \to (\rho\pi)^0$

World averages for $B^0 \to \rho^\pm\pi^\mp$

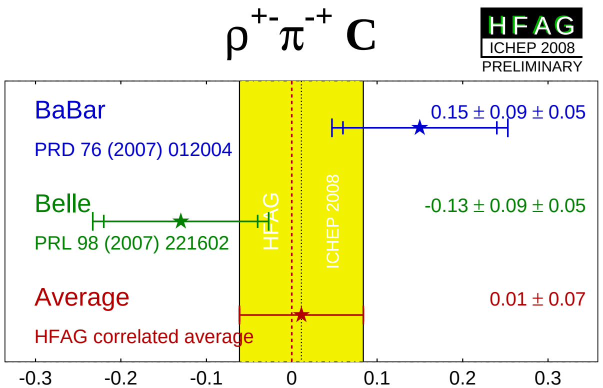
$\mathcal{A}_{CP}$ is time and flavour-integrated CP asymmetry

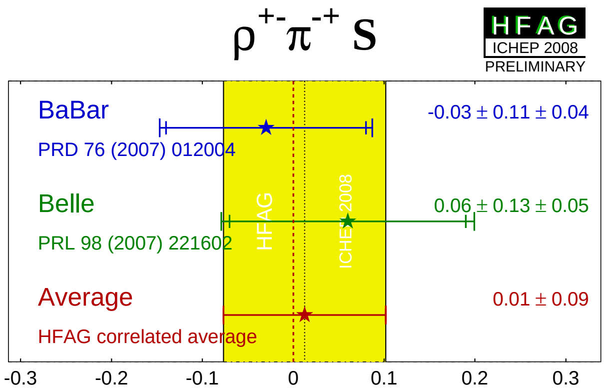


NEW Babar Result

arXiv:1304.3503 (2013)

Param	Value ± stat ± syst
$\mathcal{A}_{CP}$	$-0.100 \pm 0.029 \pm 0.021$
$\mathcal{C}$	$0.016 \pm 0.059 \pm 0.036$
$\mathcal{S}$	$0.053 \pm 0.081 \pm 0.034$
$\mathcal{A}_{CP}^{+-}$	$0.09^{+0.05}_{-0.06} \pm 0.04$
$\mathcal{A}_{CP}^{-+}$	$-0.10 \pm 0.08^{+0.04}_{-0.05}$





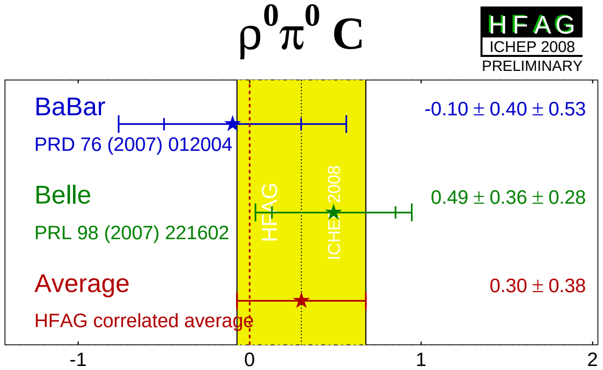
$$\mathcal{A}_{CP}^{+-} = -\frac{\mathcal{A}_{CP}+\mathcal{C}+\mathcal{A}_{CP}\Delta\mathcal{C}}{1+\Delta\mathcal{C}+\mathcal{A}_{CP}\mathcal{C}}$$

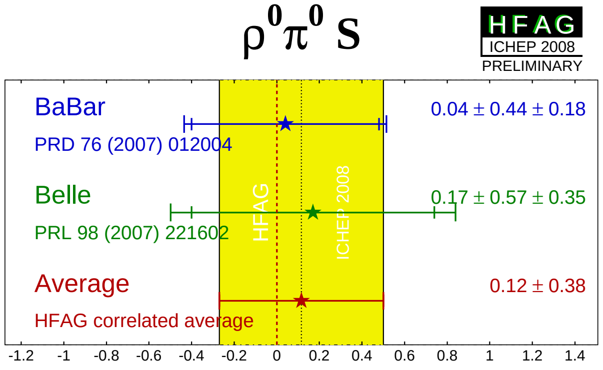
$$\mathcal{A}_{CP}^{-+} = \frac{\mathcal{A}_{CP}-\mathcal{C}-\mathcal{A}_{CP}\Delta\mathcal{C}}{1-\Delta\mathcal{C}-\mathcal{A}_{CP}\mathcal{C}}$$

$\Delta\mathcal{C}$: rate asymmetry if $\rho^\pm$ formed from spectator or not

$B^0 \to (\rho\pi)^0$

World averages for $B^0 \to \rho^0\pi^0$





NEW Babar Result

arXiv:1304.3503 (2013)

Param	Value
$\mathcal{C}_{00}$	$0.19 \pm 0.23 \pm 0.15$
$\mathcal{S}_{00}$	$-0.37 \pm 0.34 \pm 0.20$
f_{00}	$0.092 \pm 0.011 \pm 0.009$

f_{00} fraction of $\rho^0\pi^0$ in $(\rho\pi)^0$

Babar's result submitted to PRD

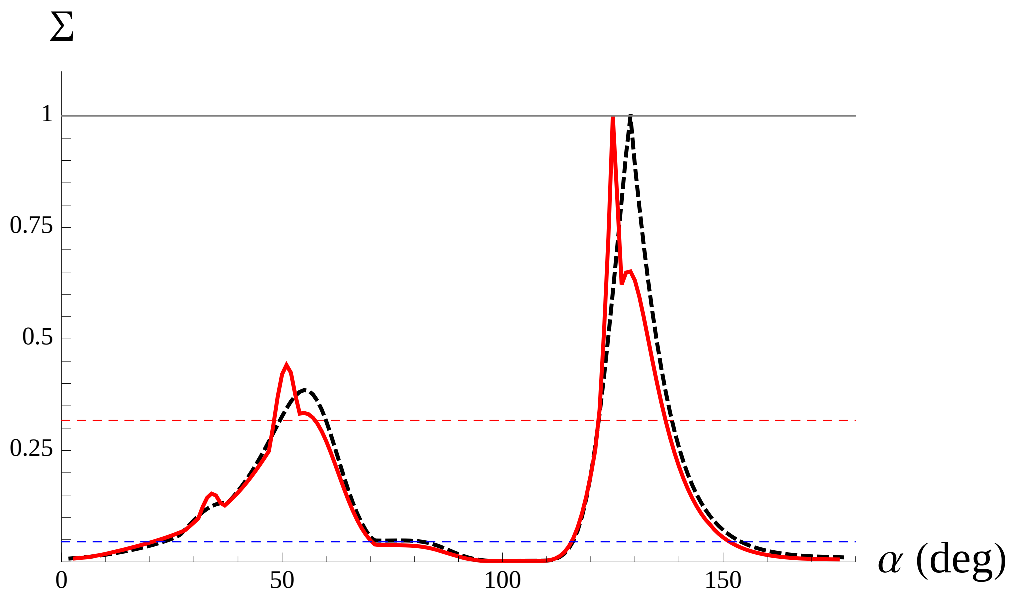
Belle is working on final update

Good agreement between experiments but difficult mode with current statistics

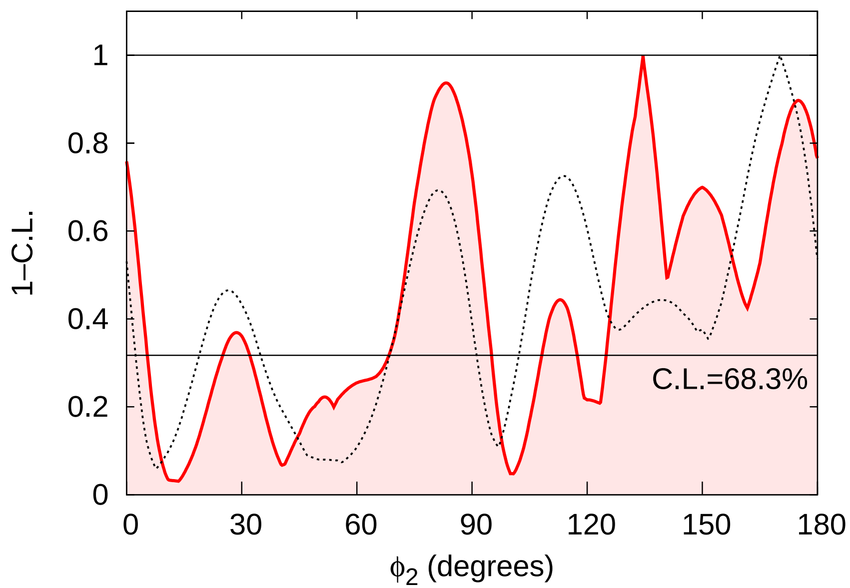
ϕ_2 scan

- Solid line: incl. isospin constraints ($\mathcal{B}$ and $\mathcal{A}_{CP}$ of $B^+ \to \rho^+\pi^0$, $\rho^0\pi^+$)
- Dotted line: Use $B^0 \to (\rho\pi)^0$ results only

BaBar



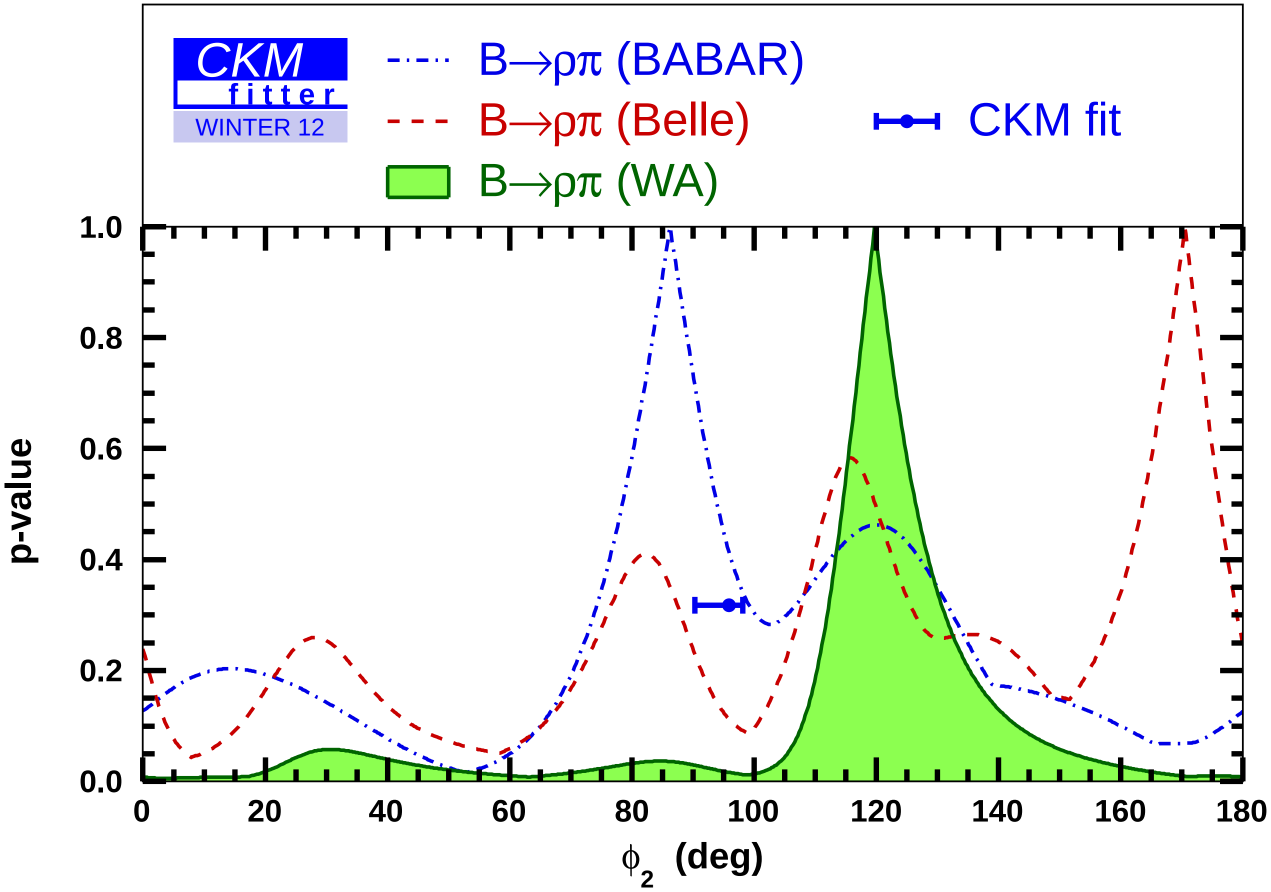
Belle



scan not robust with current statistic

$B^0 \to (\rho\pi)^0$

ϕ_2/α constraints (not incl. NEW Babar result)



- difficult to pin down ϕ_2 with $B^0 \to (\rho\pi)^0$ now

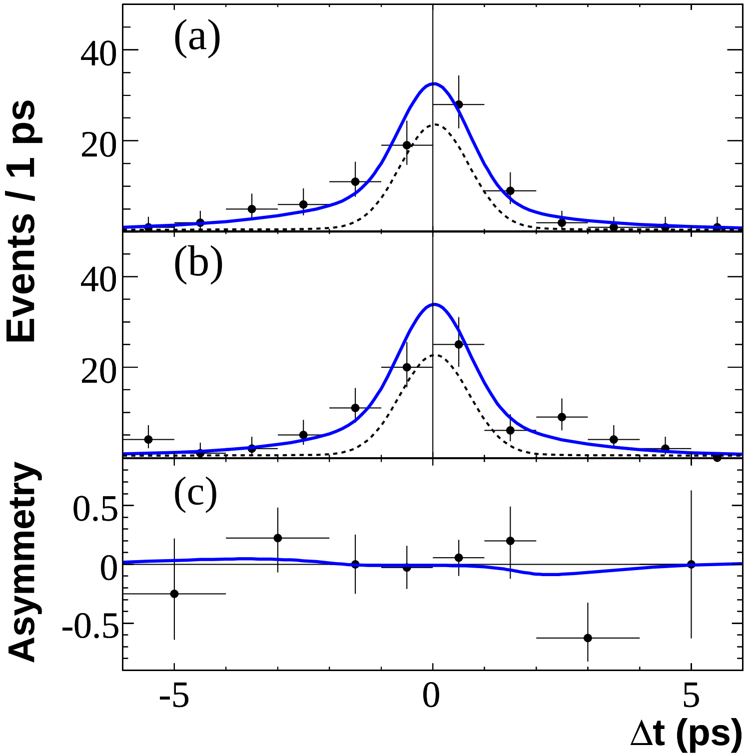
one solution for ϕ_2 with higher statistics possible, $\to$ higher luminosity experiments

$B^0 \to a_1(1260)^{\pm}\pi^{\mp}$

Flavour non-specific final state

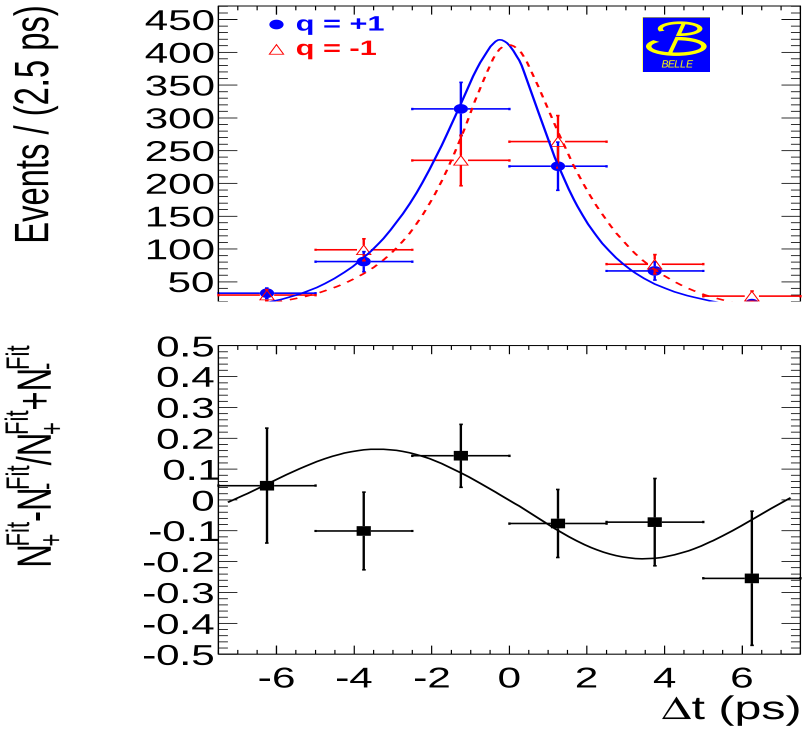
$\Rightarrow 5CP$ parameters

Babar, PRL **97**, 051802 (2006).



$$\mathcal{S}_{CP} = +0.37 \pm 0.21(stat) \pm 0.07(syst)$$

Belle, PRD **86**, 092012 (2012).



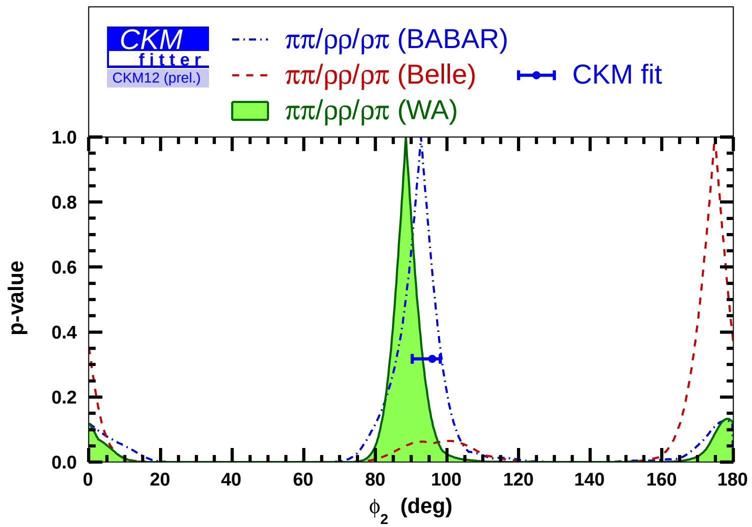
$$\mathcal{S}_{CP} = -0.51 \pm 0.14 \text{ (stat)} \pm 0.08 \text{ (syst)}$$

First evidence of mixing induced CP violation in $B^0 \to a_1(1260)^{\pm}\pi^{\mp}$ decays(3.1σ)

Summary

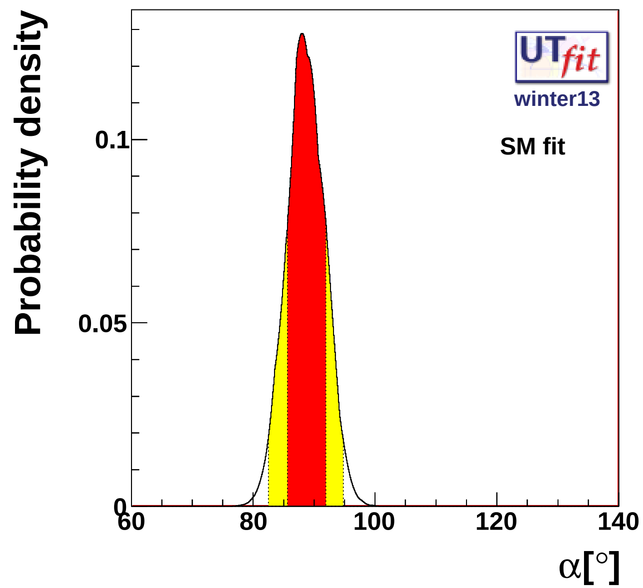
- recent results on $B \to \pi^+\pi^-$ and $B \to \rho^0\rho^0$ from Belle and on $B \to (\rho\pi)^0$ from Babar
- tightest constraint from $B \to \rho\rho$, best potential in $B \to (\rho\pi)^0$

(frequentist)



$$\phi_2/\alpha = (88.5^{+4.7}_{-4.4})^\circ$$

(bayesian)



$$\phi_2/\alpha = (88.7 \pm 3.1)^\circ$$

- some final results still anticipated
- LHCb entered the game, Belle2 under construction

Summary

BACKUP

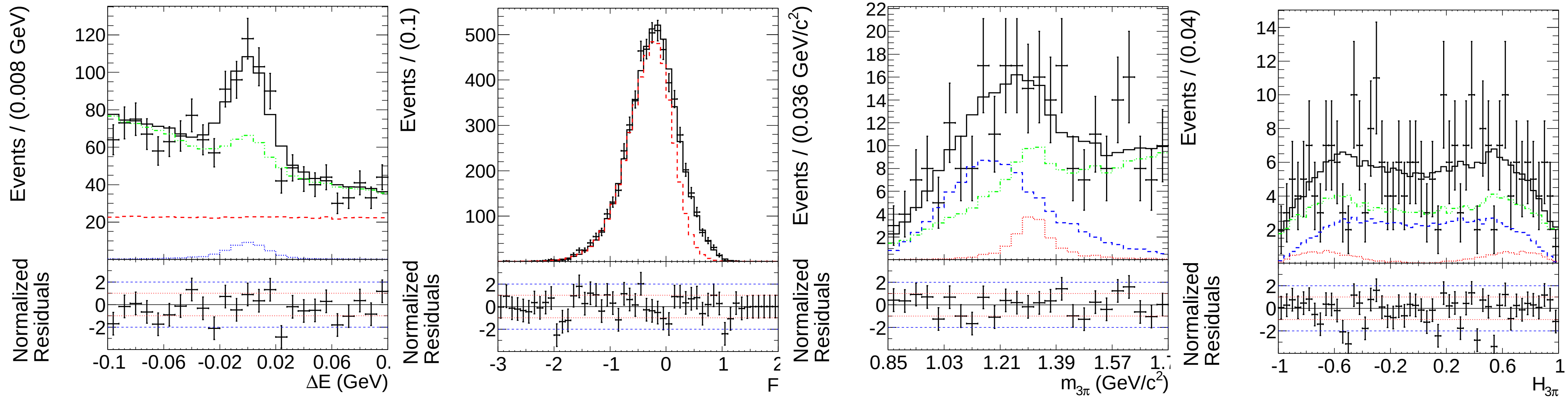
$B^0 \to a_1(1260)^{\pm}\,\pi^{\mp}$

reconstructed in 4 charged pion final state *arXiv:1205.5957* **PRELIMINARY**

Difficulties from huge continuum background and other 4 pion backgrounds

Extract branching fraction from 4 discriminating variables

ΔE Fisher discriminant 3π mass 3π helicity



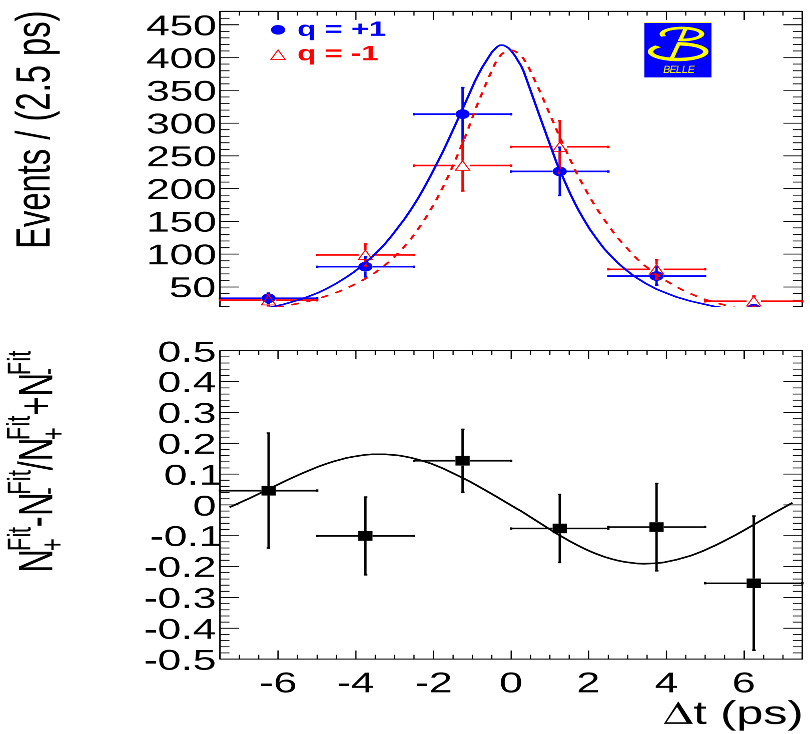
Blue: 4π background Red: Continuum Blue: a_1, Red: a_2 Blue: a_1, Red: a_2

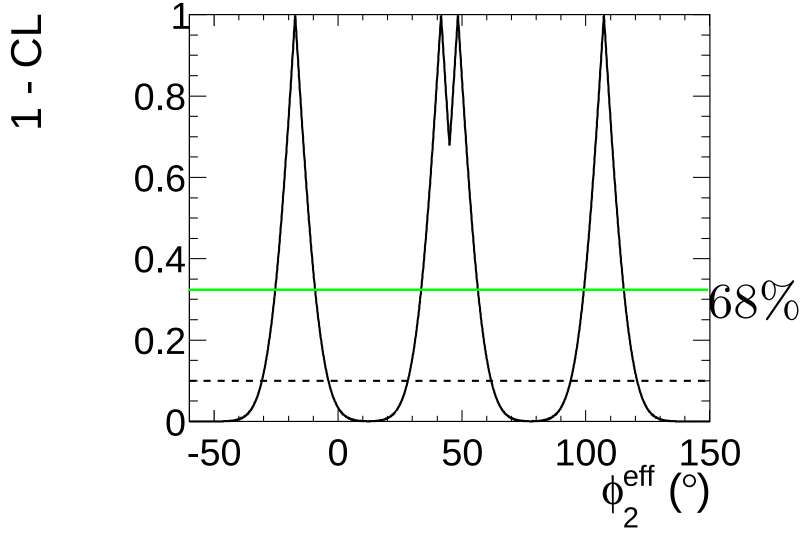
$$\mathcal{B}(B^0 \to a_1(1260)^{\pm}\,\pi^{\mp}) \times \mathcal{B}(a_1^{\pm}(1260) \to \pi^{\pm}\pi^{\mp}\pi^{\pm}) = (11.1 \pm 1.0\,(\mathrm{stat}) \pm 1.4\,(\mathrm{syst})) \times 10^{-6}$$

$B^0 \to a_1(1260)^\pm \pi^\mp$

Flavour non-specific final state $\Rightarrow$ 5CP parameters

arXiv:1205.5957, **PRELIMINARY**





$$\phi_2^{eff} = \frac{1}{4}\left[\arcsin\left(\frac{\mathcal{S}_{CP}+\Delta\mathcal{S}}{\sqrt{1-(\mathcal{C}_{CP}+\Delta\mathcal{C})^2}}\right) + \arcsin\left(\frac{\mathcal{S}_{CP}-\Delta\mathcal{S}}{\sqrt{1-(\mathcal{C}_{CP}-\Delta\mathcal{C})^2}}\right)\right]$$

$\mathcal{S}_{CP} = -0.51 \pm 0.14$ (stat) $\pm\, 0.08$ (syst)

First evidence of mixing induced CP violation in $B^0 \to a_1(1260)^\pm \pi^\mp$ decays(3.1σ)

ϕ_2^{eff} scan: 4 solutions at 1σ level,

$\phi_2^{eff} = [-25.5^\circ, -9.1^\circ], \quad [34.7^\circ, 55.3^\circ], [99.1^\circ, 115.5^\circ]$

$B^0 \to a_1(1260)^{\pm} \pi^{\mp}$

non CP eigenstate - final state, need to consider 4 flavour-charge configurations (q, c)

$$\mathcal{P}(\Delta t, q, c) = (1 + c\mathcal{A}_{CP}) \frac{e^{-|\Delta t|/\tau_{B^0}}}{8\tau_{B^0}} \left\{ 1 + q \left[(\mathcal{S}_{CP} + c\Delta\mathcal{S}) \sin \Delta m_d \Delta t - (\mathcal{C}_{CP} + c\Delta\mathcal{C}) \cos \Delta m_d \Delta t \right] \right\}$$

$\mathcal{A}_{CP}$: Time and flavour-integrated direct CP violation

$\mathcal{C}_{CP}$: Flavour-dependent direct CP violation

$\mathcal{S}_{CP}$: Mixing-induced CP violation

$\Delta\mathcal{C}$: Rate asymmetry between configurations where a_1 does not and does contain the spectator quark

$\Delta\mathcal{S}$: Strong phase difference between configurations where a_1 does not and does contain the spectator quark

$B^0 \to (\rho\pi)^0$

Time and amplitude differential decay rate,

$$\frac{d^3\Gamma}{d\Delta t ds_+ ds_-} \propto e^{-|\Delta t|/\tau_{B^0}} \Big\{ (|A_{3\pi}|^2 + |\bar{A}_{3\pi}|^2) - q(|A_{3\pi}|^2 - |\bar{A}_{3\pi}|^2)\cos\Delta m_d \Delta t + 2q\Im\left[\frac{q}{p}A^*_{3\pi}\bar{A}_{3\pi}\right]\sin\Delta m_d\Delta t \Big\}$$

$$|A_{3\pi}|^2 \pm |\bar{A}_{3\pi}|^2 = \sum_{\kappa\in\{+,-,0\}} |f_\kappa|^2 U_\kappa^\pm + \sum_{\kappa<\sigma\in\{+,-,0\}} 2(\Re[f_\kappa f_\sigma^*]U_{\kappa\sigma}^{\pm,\Re} - \Im[f_\kappa f_\sigma^*]U_{\kappa\sigma}^{\pm,\Im})$$

$$\Im\left[\frac{q}{p}A^*_{3\pi}\bar{A}_{3\pi}\right] = \sum_{\kappa\in\{+,-,0\}} |f_\kappa|^2 I_\kappa + \sum_{\kappa<\sigma\in\{+,-,0\}} (\Re[f_\kappa f_\sigma^*]I_{\kappa\sigma}^{\Im} + \Im[f_\kappa f_\sigma^*]I_{\kappa\sigma}^{\Re})$$

27 coefficients U, I determined from a fit to data

f: Form factors and line shapes

$B^0 \to (\rho\pi)^0$

$$U_\kappa^\pm = |A_\kappa|^2 \pm |\bar{A}_\kappa|^2$$
$$U_{\kappa\sigma}^{\pm,\Re} = \Re[A_\kappa A_\sigma^* \pm \bar{A}_\kappa \bar{A}_\sigma^*]$$
$$U_{\kappa\sigma}^{\pm,\Im} = \Im[A_\kappa A_\sigma^* \pm \bar{A}_\kappa \bar{A}_\sigma^*]$$
$$I_\kappa = \Im[\bar{A}_\kappa A_\kappa^*]$$
$$I_{\kappa\sigma}^{\Re} = \Re[\bar{A}_\kappa A_\sigma^* - \bar{A}_\sigma A_\kappa^*]$$
$$I_{\kappa\sigma}^{\Im} = \Im[\bar{A}_\kappa A_\sigma^* + \bar{A}_\sigma A_\kappa^*]$$

$$e^{+2i\phi_2} = \frac{\bar{A}_+ + \bar{A}_- + 2\bar{A}_0}{A_+ + A_- + 2A_0}$$

Convert to Quasi-two-body parameters

For $B^0 \to \rho^\pm \pi^\mp$

$$\mathcal{A}_{CP} = \frac{U_+^+ - U_-^+}{U_+^+ + U_-^+}$$
$$\mathcal{C}_{CP} = \frac{1}{2}\left(\frac{U_+^-}{U_+^+} + \frac{U_-^-}{U_-^+}\right), \quad \mathcal{S}_{CP} = \frac{I_+}{U_+^+} + \frac{I_-}{U_-^+}$$
$$\Delta\mathcal{C} = \frac{1}{2}\left(\frac{U_+^-}{U_+^+} - \frac{U_-^-}{U_-^+}\right), \quad \Delta\mathcal{S} = \frac{I_+}{U_+^+} - \frac{I_-}{U_-^+}$$

For $B^0 \to \rho^0 \pi^0$

$$\mathcal{A}_{CP} = -\frac{U_0^-}{U_0^+}, \quad \mathcal{S}_{CP} = \frac{2I_0}{U_0^+}$$

$B \to K_{1A}\pi$

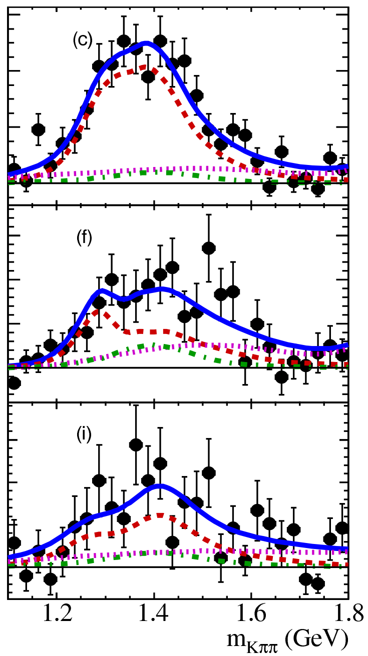
4-fold ambiguity for $\phi_2^{\rm eff}$

$$\phi_2^{\rm eff} = \frac{1}{4}\left[\arcsin\left(\frac{\mathcal{S}_{CP}+\Delta\mathcal{S}}{\sqrt{1-(\mathcal{C}_{CP}+\Delta\mathcal{C})^2}}\right)+\arcsin\left(\frac{\mathcal{S}_{CP}-\Delta\mathcal{S}}{\sqrt{1-(\mathcal{C}_{CP}-\Delta\mathcal{C})^2}}\right)\right]$$

Can measure $|\Delta\phi_2|$ using $SU(3)$ symmetry involving $B^0 \to a_1 K$, $B \to K_{1A}\pi$ decays

M. Gronau and J. Zupan, PRD **73** 057502 (2006)

PRD **81** 052009 (2010)



BaBar, 454 million $B\bar{B}$ pairs

Amplitude analysis of WA3 data taken by ACCMOR collaboration

Needed to determine $K\pi\pi$ model

First measurement!

$$\mathcal{B}(B^0 \to K_1(1270)^+\pi^- + K_1(1400)^+\pi^-) = 3.1^{+0.8}_{-0.7}\times 10^{-5}\ (7.5\sigma)$$
$$\mathcal{B}(B^+ \to K_1(1270)^0\pi^+ + K_1(1400)^0\pi^+) = 2.9^{+2.9}_{-1.7}\times 10^{-5}\ (3.2\sigma)$$

Relative contributions also determined

$B \to K_{1A}\pi$

Solve system of inequalities,

$$\cos 2(\phi^{\pm}_{2,\,\mathrm{eff}} - \phi_2) \geq \frac{1 - 2R^0_{\pm}}{\sqrt{1 - \mathcal{A}^{\pm\,2}_{CP}}}$$

$$\cos 2(\phi^{\pm}_{2,\,\mathrm{eff}} - \phi_2) \geq \frac{1 - 2R^+_{\pm}}{\sqrt{1 - \mathcal{A}^{\pm\,2}_{CP}}}$$

$$R^0_+ \equiv \frac{\bar{\lambda}^2 f^2_{a_1} \bar{\Gamma}(K^+_{1A}\pi^-)}{f^2_{K_{1A}} \bar{\Gamma}(a^+_1\pi^-)}, \quad R^0_- \equiv \frac{\bar{\lambda}^2 f^2_{\pi} \bar{\Gamma}(a^-_1 K^+)}{f^2_{K} \bar{\Gamma}(a^-_1\pi^+)}$$

$$R^+_+ \equiv \frac{\bar{\lambda}^2 f^2_{a_1} \bar{\Gamma}(K^0_{1A}\pi^+)}{f^2_{K_{1A}} \bar{\Gamma}(a^+_1\pi^-)}, \quad R^+_- \equiv \frac{\bar{\lambda}^2 f^2_{\pi} \bar{\Gamma}(a^+_1 K^0)}{f^2_{K} \bar{\Gamma}(a^-_1\pi^+)}$$

$$\lambda^2 = |V_{us}|/|V_{ud}| = |V_{cd}|/|V_{cs}|$$

$\bar{\Gamma}$: averaged decay rates, f_i: decay constants

Calculate bound on $|\Delta\phi_2| \equiv |\phi^{\mathrm{eff}}_2 - \phi_2|$ from

$$|\phi^{\mathrm{eff}}_2 - \phi_2| \leq (|\phi^{+}_{2,\,\mathrm{eff}} - \phi_2| + |\phi^{-}_{2,\,\mathrm{eff}} - \phi_2|)/2$$

$|\Delta\phi_2| < 11^\circ(13^\circ)$ at 68% (90%) CL

Solution nearest SM expectation, $\phi^{\mathrm{eff}}_2 = (79 \pm 7 \pm 11)^\circ$

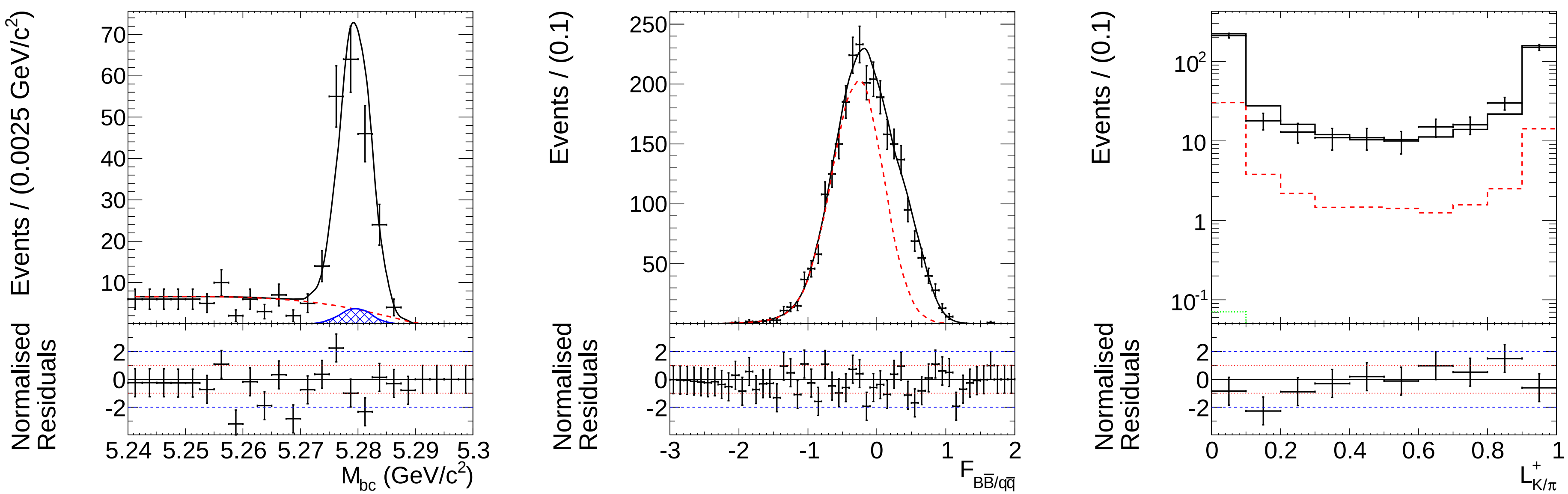
$B \to \pi^+\pi^-$

New results

- S→SS, simultanious fit including $B^0 \to \pi^+\pi^-, K^{\pm}\pi^{\mp}, K^+K^-$
- 6D fitter: ΔE, $M_{\rm bc}$, $L^+_{K/\pi}$, $L^-_{K/\pi}$, $\mathcal{F}_{s/b}$ and Δt

$L^{\pm}_{K/\pi}$: likelihood to be a K for a π mass hypothesis for pos./neg. charged tracks

$\mathcal{F}_{s/b}$: event shape dependent variable



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

Downward fluktuation within the last 240 million $B\bar{B}$ pairs

Belle result for the last 236.995e+06 BBbar pairs.

$\mathcal{A}_{CP}(B^0 \to \pi^+\pi^-) = 0.06 \pm 0.10$

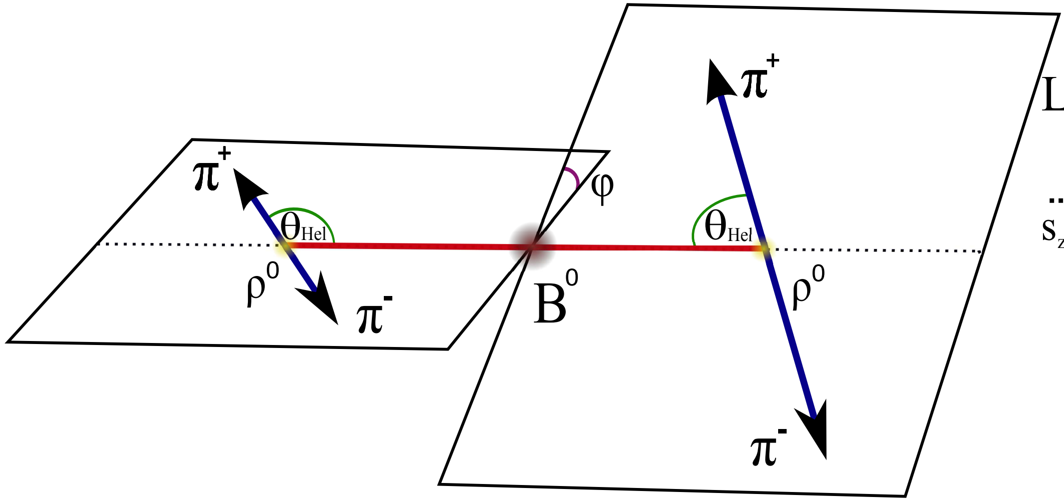
$\mathcal{S}_{CP}(B^0 \to \pi^+\pi^-) = -0.62 \pm 0.13$

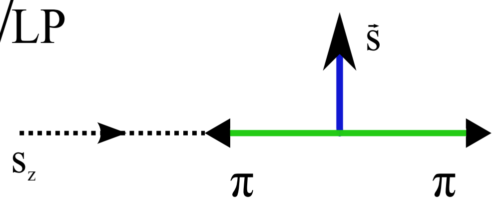
Polarization: Helicity Basis

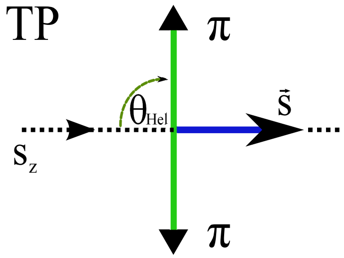
2 different polarizations, longitudinal(LP, CP even) and transversal(TP, CP even & odd)

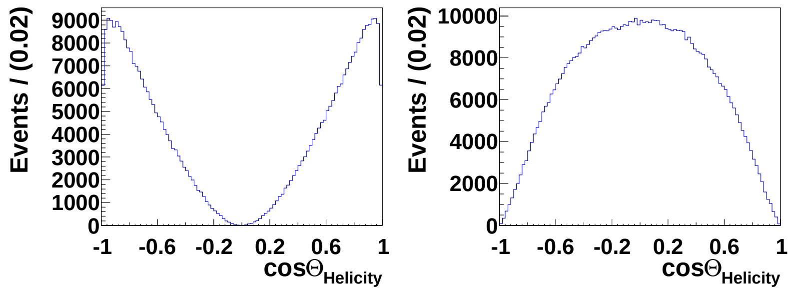
f_L: fraction of L pol,through helicity analysis (SM: $f_L \sim 1$)

θ_{Hel}: angle between the B^0 and the π^+ flight directions in the ρ frame









$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta^1_{\rm Hel}\, d\cos\theta^2_{\rm Hel}} = \frac{9}{4}\left(f_L \cos^2\theta^1_{\rm Hel}\cos^2\theta^2_{\rm Hel} + \frac{1}{4}(1-f_L)\sin^2\theta^1_{\rm Hel}\sin^2\theta^2_{\rm Hel}\right)$$

$B \to \pi^+\pi^-$

PRELIMINARY *New results* on full data set

- simultanious fit of branching ratios and CP asymmetries

$$N_{B^0\to\pi^+\pi^-} = 2886 \pm 82\ (\mathrm{stat})$$

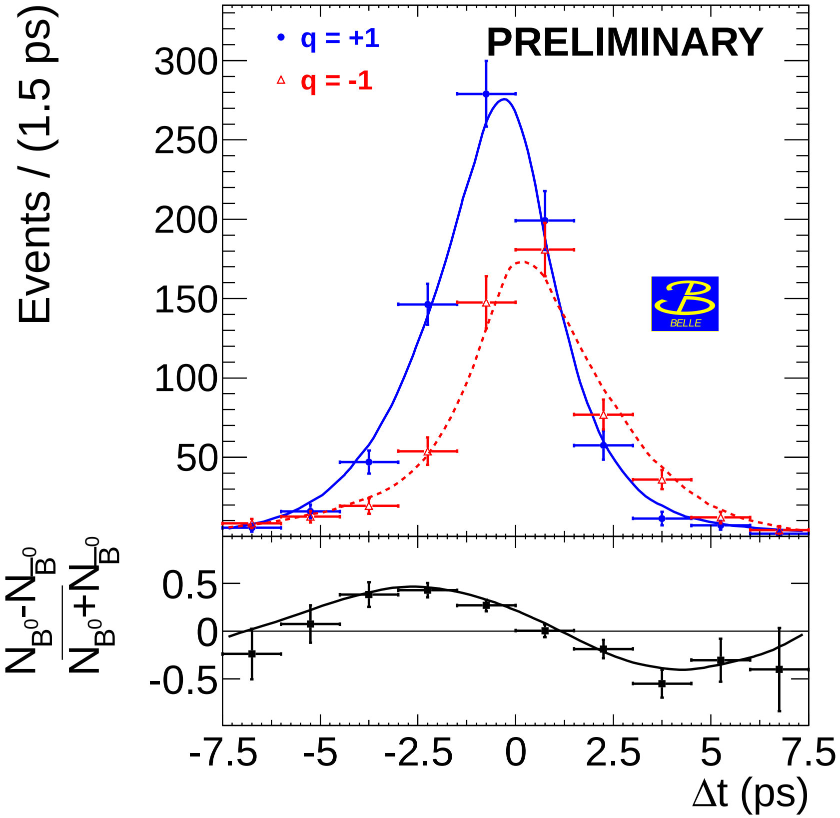
- previous Belle result: $(450 \times 10^6 B\bar{B}$ pairs)

$$\mathcal{S}^{\pi^+\pi^-}_{CP,prev.} = -0.61 \pm 0.10 \pm 0.04$$

$$\mathcal{A}^{\pi^+\pi^-}_{CP,prev.} = +0.55 \pm 0.08 \pm 0.05$$

new analysis is consistent on same dataset

'downward fluctuation' with last 200×10^6 $B\bar{B}$ pairs

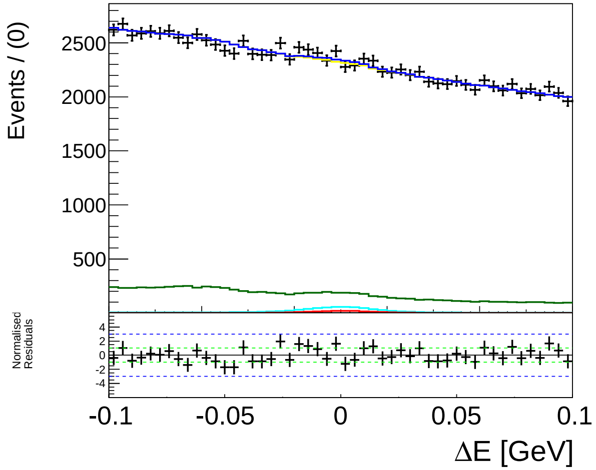


$$\mathcal{S}^{\pi^+\pi^-}_{CP} = -0.636 \pm 0.082 \pm 0.027$$

$$\mathcal{A}^{\pi^+\pi^-}_{CP} = +0.328 \pm 0.061 \pm 0.027$$

$B^0 \to \rho^0 \rho^0$

Full Projection



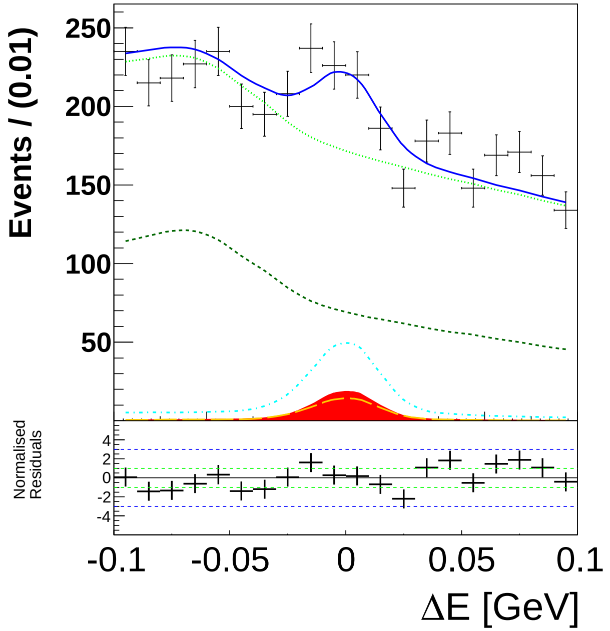
PRELIMINARY

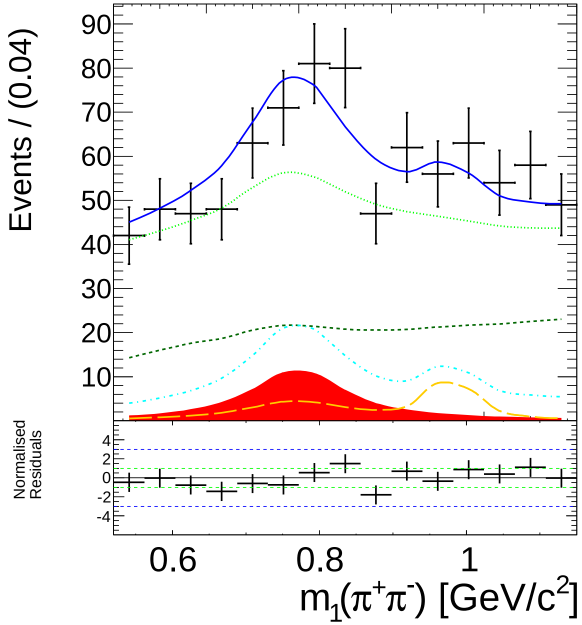
New results

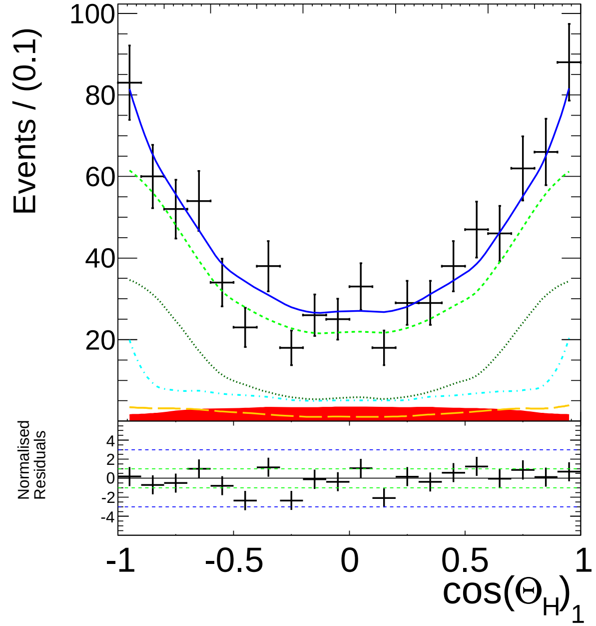
Signal enhanced projections

$B^0 \to \rho^0\rho^0$, $B^0 \to f_0\rho^0$, 4π final states,

$B\bar{B}$ bkg, total non-peaking bkg, total



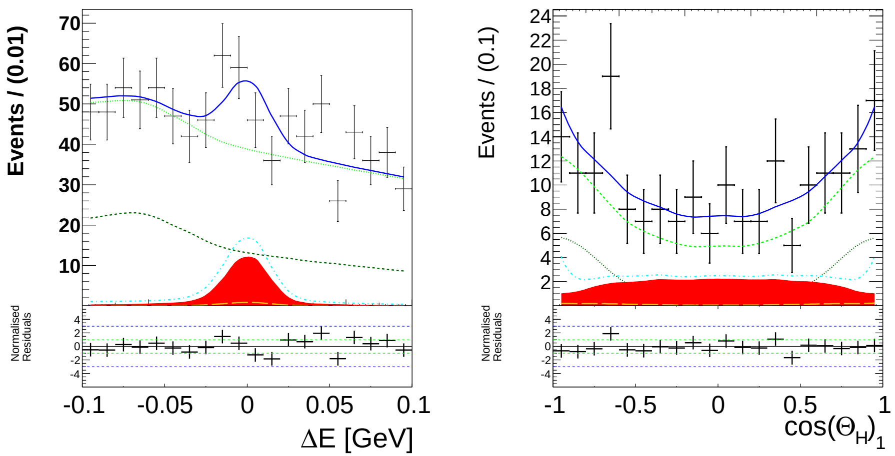




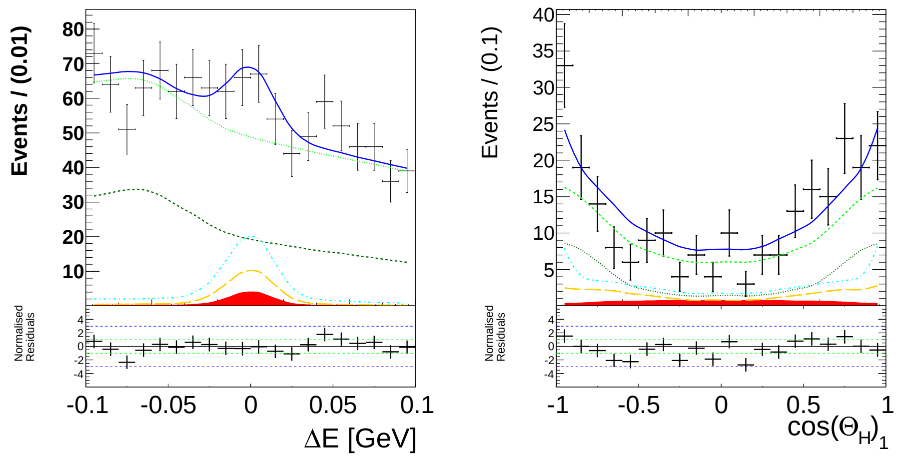
$B^0 \rightarrow \rho^0 \rho^0$

visually seperate $B^0 \rightarrow \rho^0 \rho^0$ from $B^0 \rightarrow f_0 \rho^0$ with projections into

$\rho^0 \rho^0$window



$f_0 \rho^0$ window



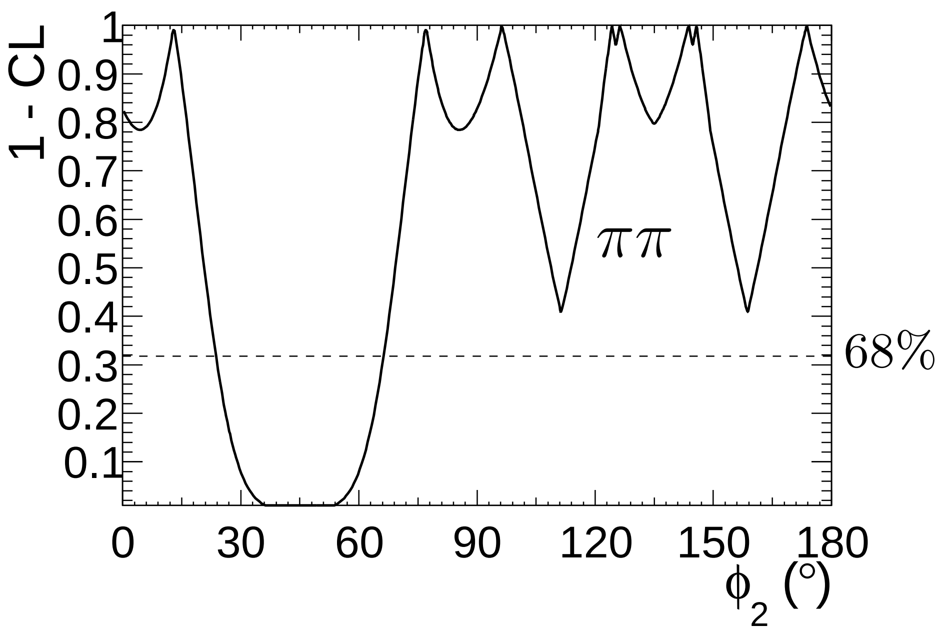
- $\rho^0 \rho^0$, $f_0 \rho^0$, 4π fs, $B\bar{B}$ bkg

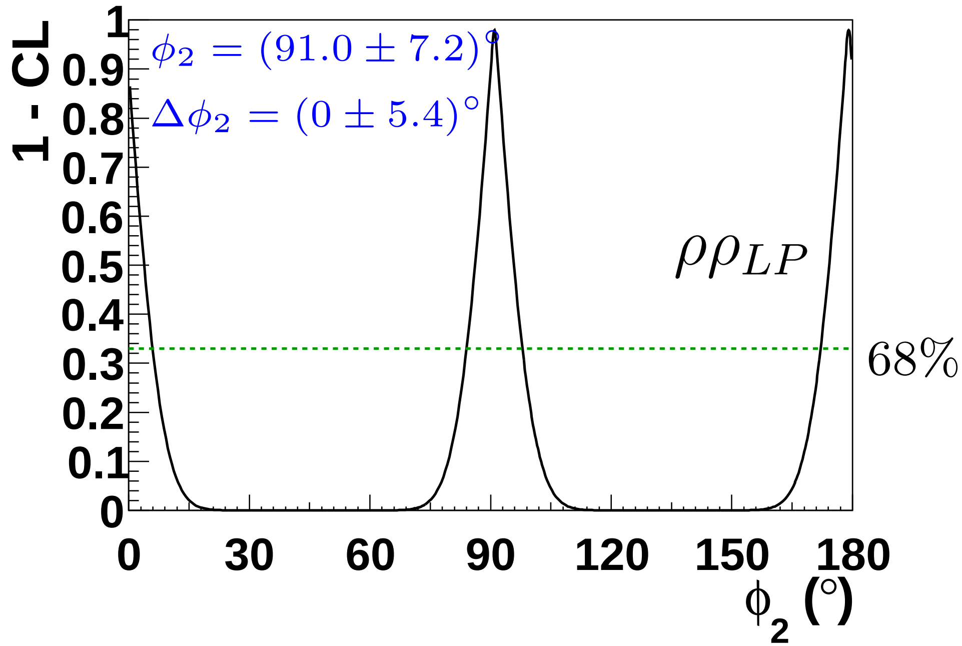
Interference is treated as a systematic uncertainty, dominant source for $B^0 \rightarrow \rho^0 \rho^0$.

PRELIMINARY

New results

ϕ_2 scan from isospin analysis in the $\pi\pi$ and the $\rho\rho$(LP) system





- $B \to \pi\pi$, using Belle results only
- exclude: $23.8^\circ < \phi_2 < 66.8^\circ$ (at 1σ)
- exclude: $|\Delta\phi_2| > 44.25^\circ$

- $B \to \rho\rho$, using the LP fraction of $\mathcal{B}(B^0 \to \rho^0\rho^0)|_{LP} = (0.21 \pm 0.36) \times 10^{-6}$ from this measurement, world averages otherwise