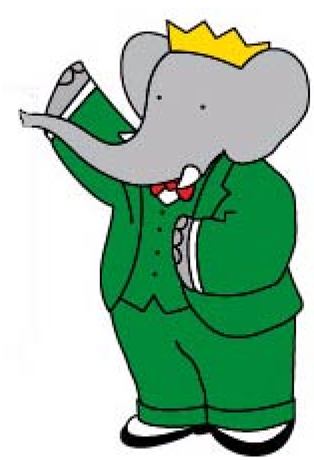
$\alpha(\varphi_2)$ from a time-dependent analysis of $B^0 \to (\rho\pi)^0$ Dalitz-plot



Gagan Mohanty

University of Warwick

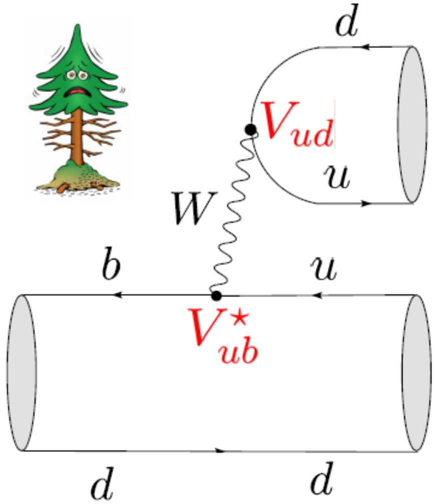
From BABAR Collaboration

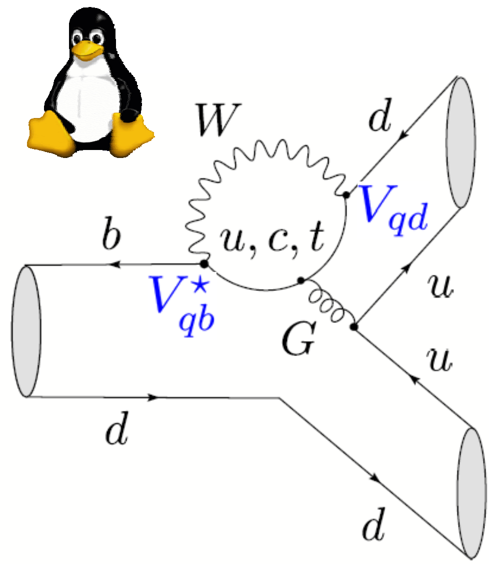
BELLE

Outline of the Talk

- Introduction
- Signal Model
- Reconstruction Effects
- Backgrounds
- Dalitz-plot Fit Results
- Q2B Interpretation
- Constraint on Angle α
- Conclusions and Outlook

Introduction





Issues in hand:

- Not a *CP* eigenstate
- Has four isospin (0, 1, 2) amplitudes
  - ➢ 12 unknowns in the isospin pentagon

Snyder-Quinn Approach: **PRD 48 (1993) 2139**

- Time-dependent Dalitz plot analysis (TDPA) to constrain α without any discrete ambiguity
  - – Variation of strong phase of interfering ρ resonances over the DP

TDPA Formulation

Three-body differential decay rate:

Decay amplitude

$$d\Gamma[B^0(\overline{B}^0) \to \pi^+\pi^-\pi^0] = \frac{1}{(2\pi)^3}\frac{|A_{3\pi}|^2}{32m_{B^0}^3}\,dm_+^2\,dm_-^2$$

DP variables

For a decay tagged as $B^0(+)$ or $\overline{B}^0(-)$:

$$\left|A_{3\pi}^{\pm}\right|^2 \propto \left[1 \mp \frac{|A_{3\pi}|^2-|\overline{A}_{3\pi}|^2}{|A_{3\pi}|^2+|\overline{A}_{3\pi}|^2}\cos(\Delta m_d \Delta t) \pm \frac{2\,\mathrm{Im}(\frac{q}{p}A_{3\pi}^*\overline{A}_{3\pi})}{|A_{3\pi}|^2+|\overline{A}_{3\pi}|^2}\sin(\Delta m_d \Delta t)\right]$$

$$A_{3\pi}(m_+^2, m_-^2) = \sum_\kappa f_\kappa(m_+^2, m_-^2)\,A_\kappa$$

27 Bilinear coefficients (U, I) – determine from the data fit:

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

PRD 62 (2000) 054002

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

Nominal Signal Model

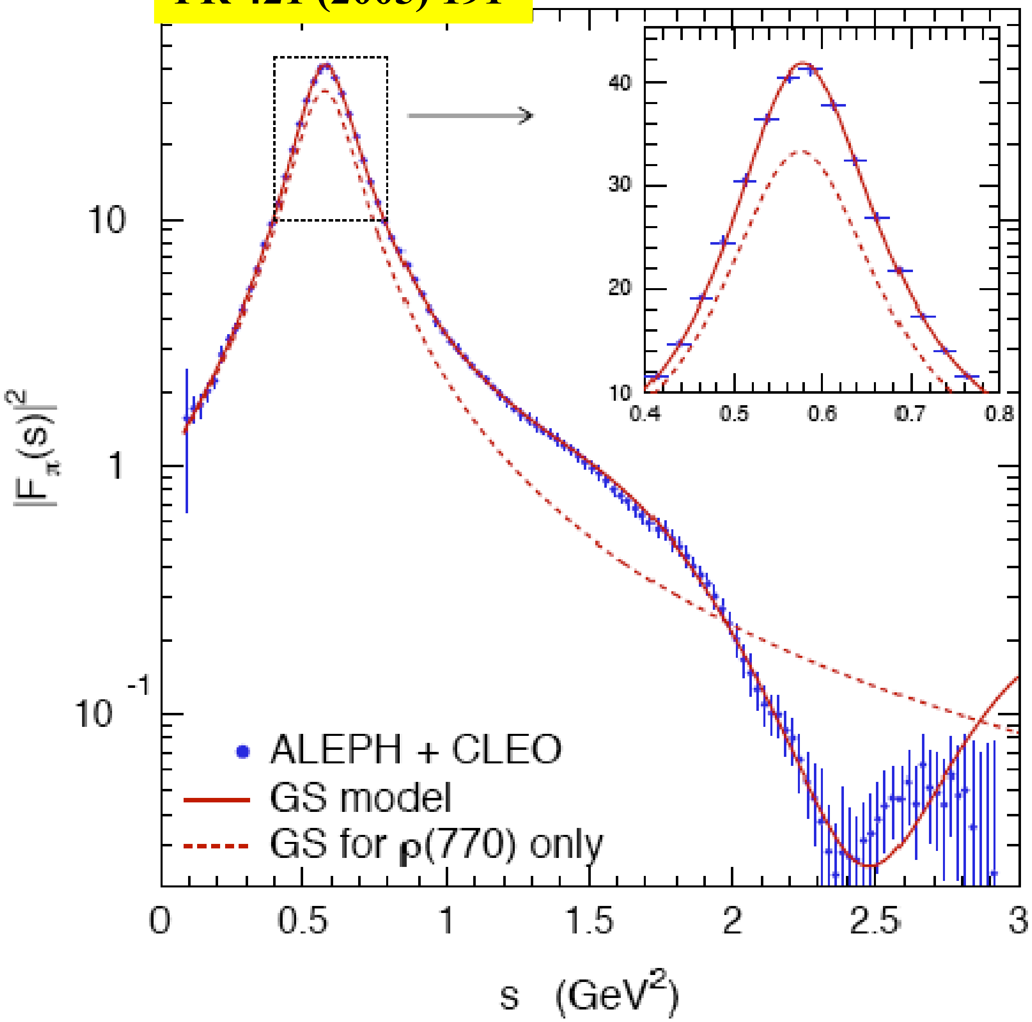
Isobar Approach:

- ρ dominated: $\rho^0(770)$, $\rho^0(1450)$ and $\rho^0(1700)$
- Gounaris-Sakurai (GS) lineshape for broad *P*-waves

PRL 21 (1968) 224

- Other resonances as a part of systematic
  - ❖ scalar, e.g. $f_0(980)$
  - ❖ tensor $f_2(1270)$

PR 421 (2005) 191



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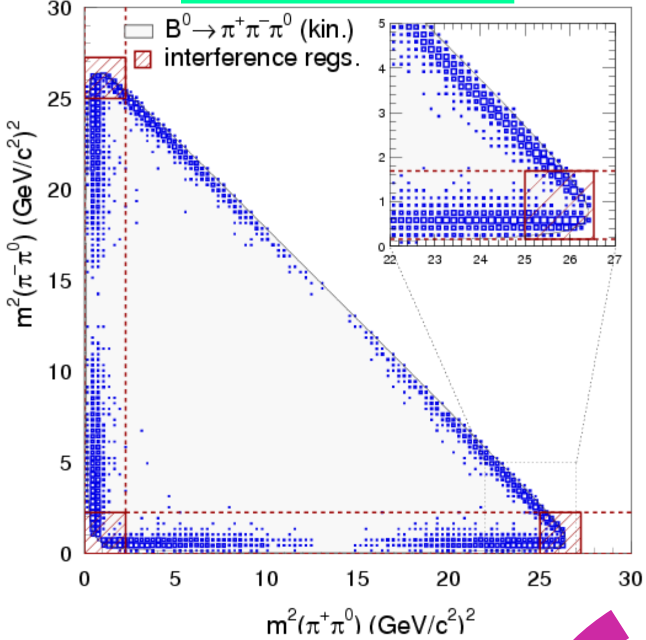
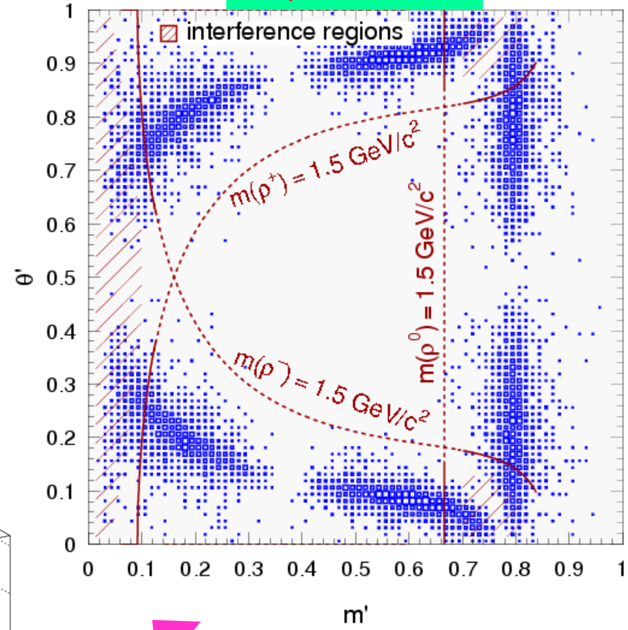
Square Dalitz Plot

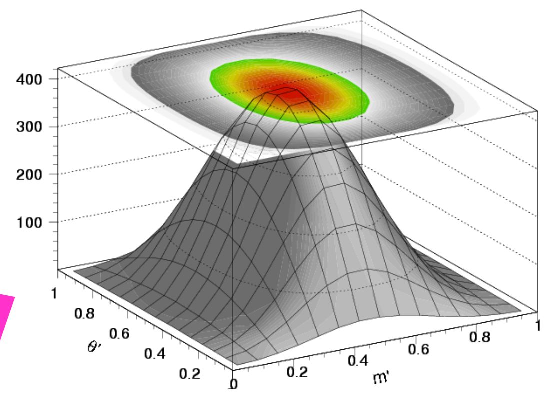
Traditional DP



Square DP



- Square DP zooms in regions of interest
- Plots from simulated signal events



$$m' \equiv \frac{1}{\pi} \arccos\left(2\frac{m_0 - m_0^{\min}}{m_0^{\max} - m_0^{\min}} - 1\right)$$

$$\theta' \equiv \frac{1}{\pi}\theta_0$$

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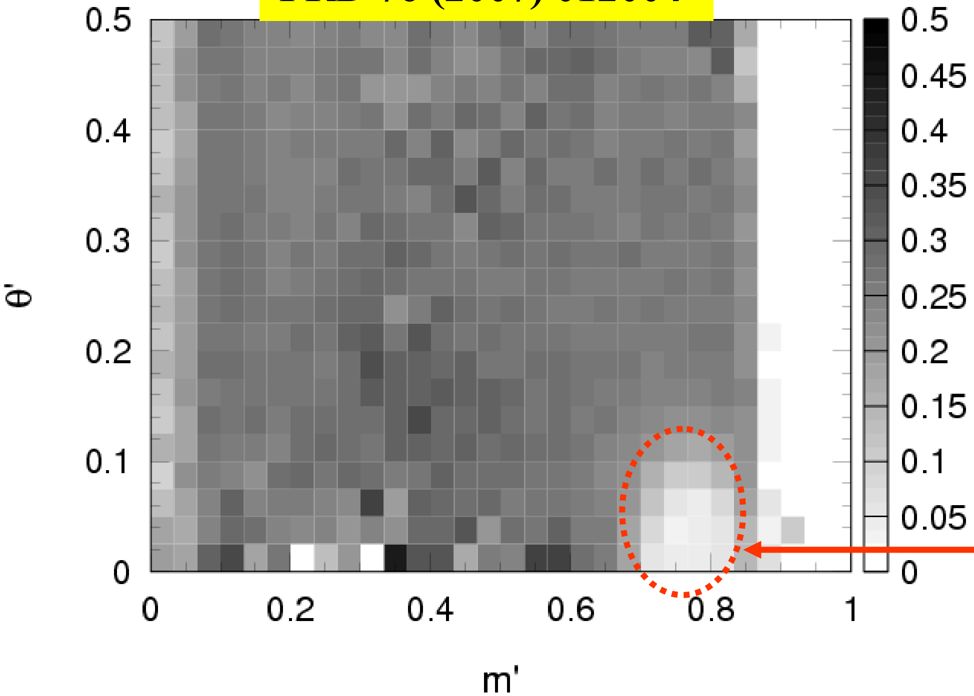
Reconstruction Effects

PRD 76 (2007) 012004



Efficiency variation over DP

- Smooth across major part of the DP
- Inefficiency because of low momentum tracks

- Explicit treatment of misreconstructed (SCF) events
  - BaBar: 22% $\rho^+\pi^-$, 13% $\rho^0\pi^0$ and 6% nonresonant
  - Belle: about 6% charged- and 14% neutral-type SCF
- Swapping of a track or neutral cluster with the tagged *B*

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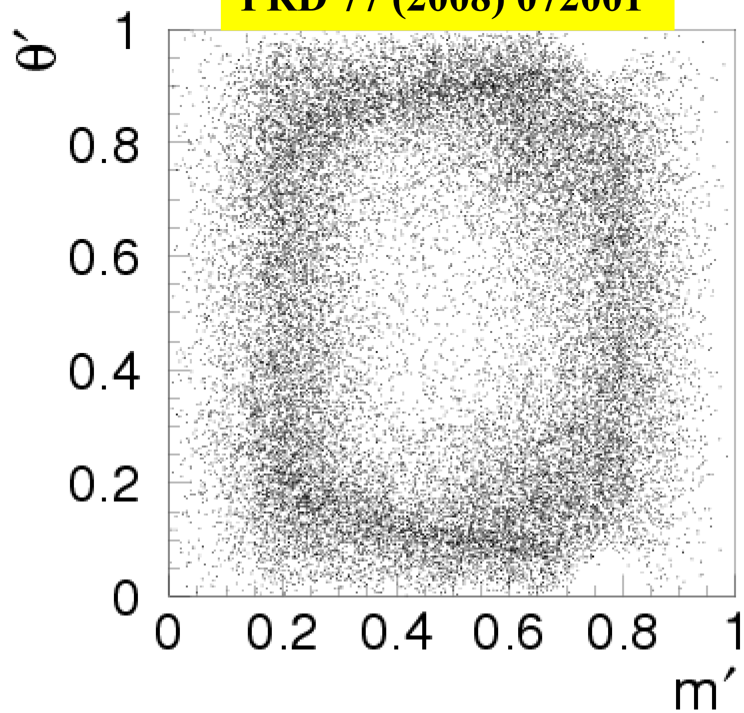
Backgrounds

- Dominant background from $q\bar{q}$ continuum events
- Topological variables are combined into
  - Neural network, NN (BABAR)
  - Likelihood ratio (LR) for Belle

PRD 77 (2008) 072001



Continuum background DP

- B-backgrounds mainly from:
  - Charmed B decays, such as $B^0 \to D^-(\to \pi^-\pi^0)\pi^+$
  - Three-body final state ($K^+\pi^-\pi^0$) and its Q2B decays

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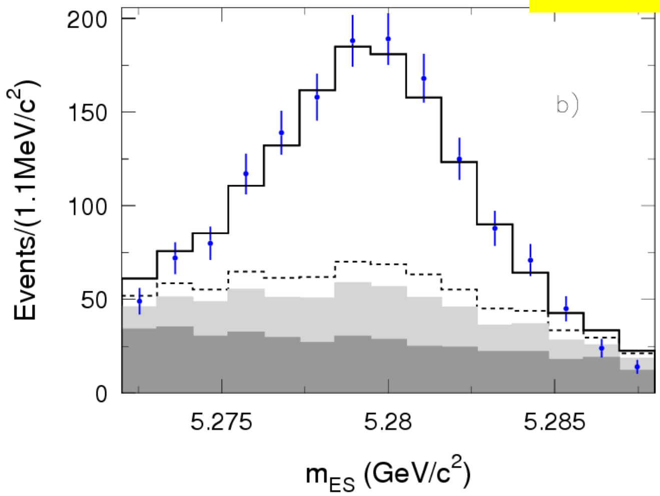
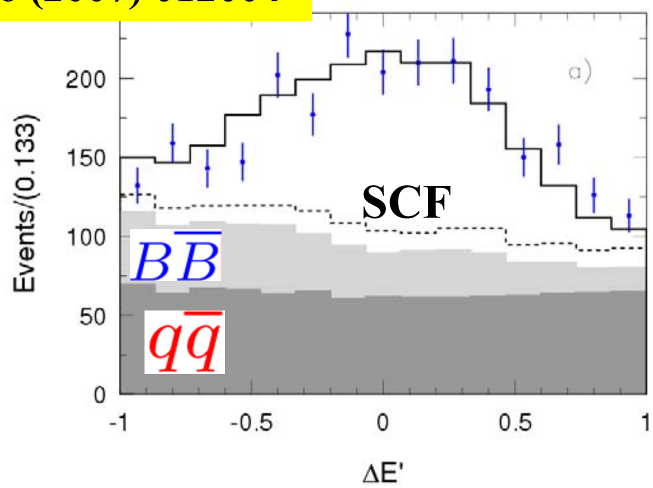
Signal Yield

PRD 76 (2007) 012004



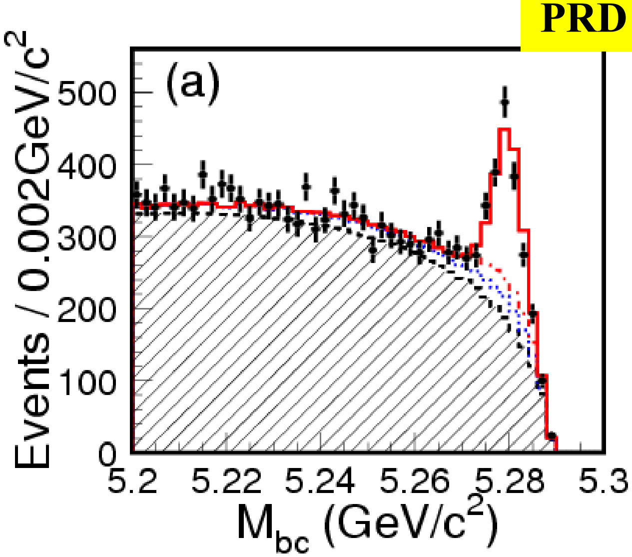


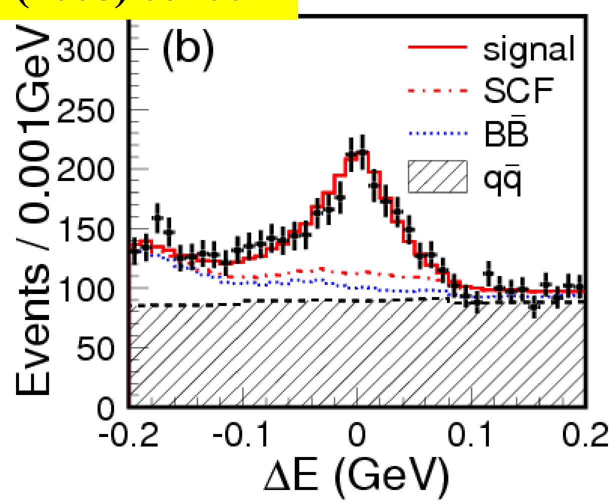
BABAR

$$N_{B\overline{B}} = 375 \times 10^6$$
$$N_{3\pi} = 2067 \pm 86$$

- ΔE→ ΔE' (remove dependence on the π^0 momentum)
- NN is a part of the ML fit

PRD 77 (2008) 072001





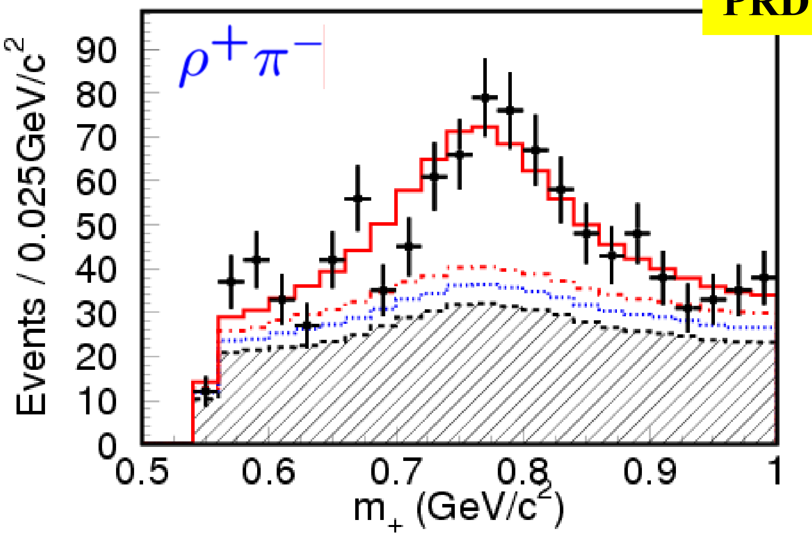
Belle

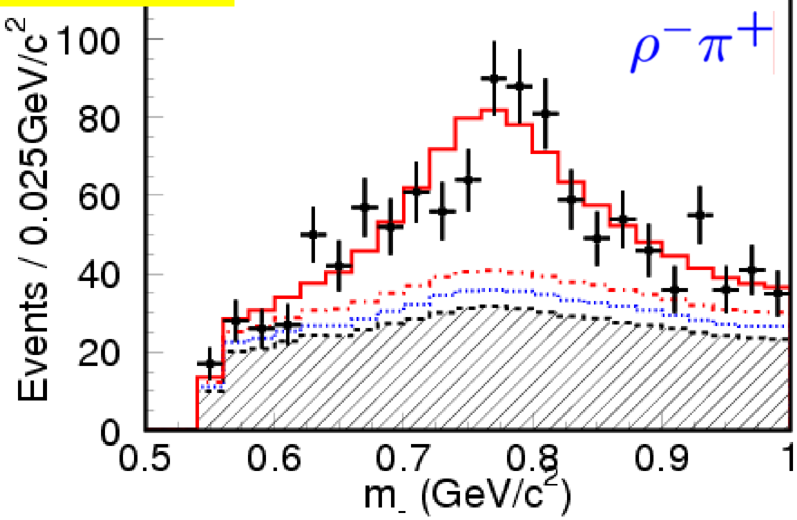
$$N_{B\overline{B}} = 449 \times 10^6$$
$$N_{3\pi} = 971 \pm 42$$

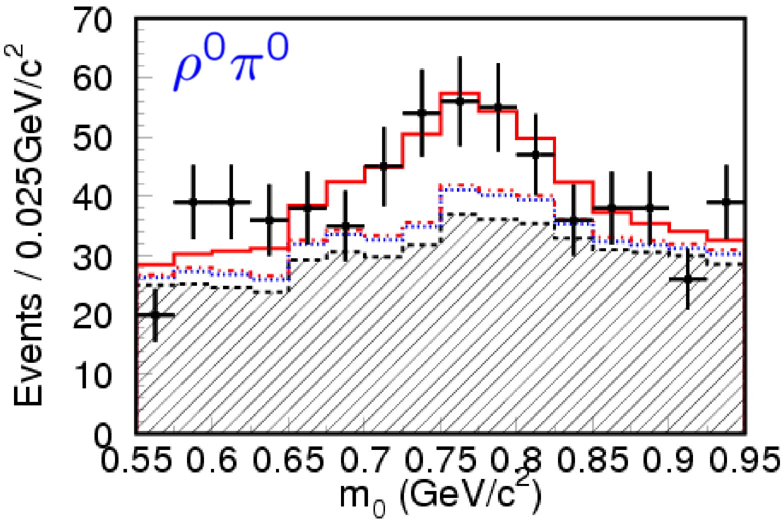
- Cut on LR and (M_{bc},ΔE) in the ML fit

Mass Distributions

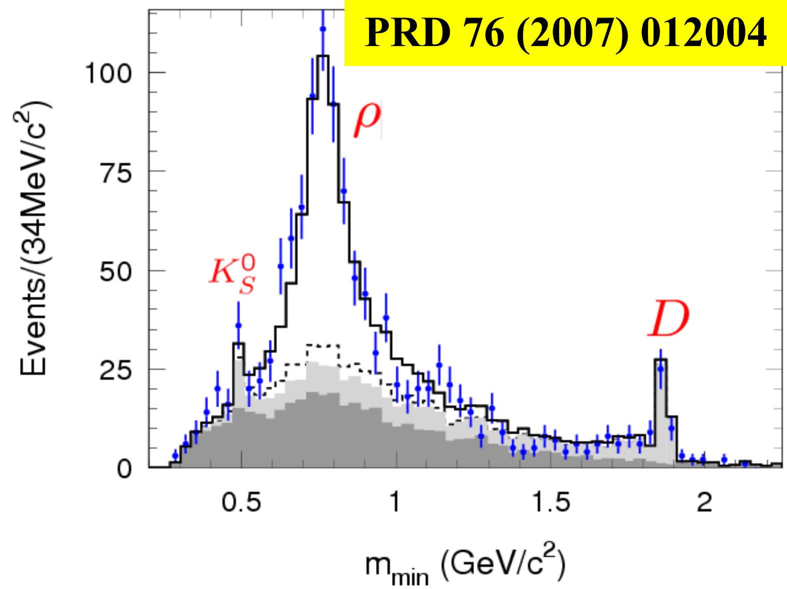
PRD 77 (2008) 072001







PRD 76 (2007) 012004



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Fit Results

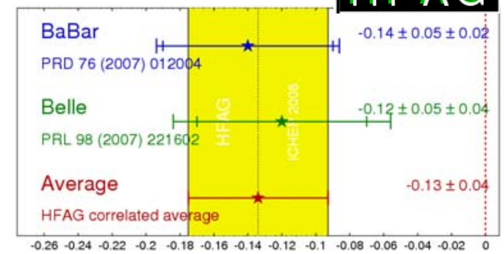
- Overall normalization fixed $[U_+^+ = 1.0]$
- Excellent agreement between two expts: χ^2=19.0 for 26 dof

  From HFAG
- We translate these seemingly complex bilinear coefficients to Q2B parameters
  - Easy to interpret

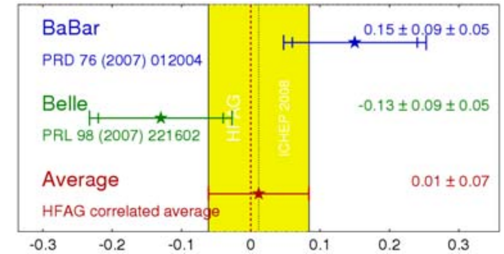
Parameter	BaBar	Belle
U_-^+	$+1.32 \pm 0.12 \pm 0.05$	$+1.27 \pm 0.13 \pm 0.09$
U_0^+	$+0.28 \pm 0.07 \pm 0.04$	$+0.29 \pm 0.05 \pm 0.04$
U_+^-	$+0.54 \pm 0.15 \pm 0.05$	$+0.23 \pm 0.15 \pm 0.07$
U_-^-	$-0.32 \pm 0.14 \pm 0.05$	$-0.62 \pm 0.16 \pm 0.08$
U_0^-	$-0.03 \pm 0.11 \pm 0.09$	$+0.15 \pm 0.11 \pm 0.08$
I_+	$-0.02 \pm 0.10 \pm 0.03$	$-0.01 \pm 0.11 \pm 0.04$
I_-	$-0.01 \pm 0.10 \pm 0.02$	$+0.09 \pm 0.10 \pm 0.04$
I_0	$+0.01 \pm 0.06 \pm 0.01$	$+0.02 \pm 0.09 \pm 0.05$
$U_{+-}^{+,\mathrm{Re}}$	$+0.17 \pm 0.49 \pm 0.31$	$+0.49 \pm 0.86 \pm 0.52$
$U_{+-}^{+,\mathrm{Im}}$	$-0.07 \pm 0.71 \pm 0.73$	$+1.18 \pm 0.86 \pm 0.34$
$U_{+-}^{-,\mathrm{Re}}$	$+2.23 \pm 1.00 \pm 0.43$	$-1.18 \pm 1.61 \pm 0.72$
$U_{+-}^{-,\mathrm{Im}}$	$-0.38 \pm 1.06 \pm 0.36$	$-2.32 \pm 1.74 \pm 0.91$
$U_{+0}^{+,\mathrm{Re}}$	$-1.08 \pm 0.48 \pm 0.20$	$+0.29 \pm 0.50 \pm 0.35$
$U_{+0}^{+,\mathrm{Im}}$	$-0.16 \pm 0.57 \pm 0.14$	$-0.57 \pm 0.35 \pm 0.51$
$U_{+0}^{-,\mathrm{Re}}$	$-0.18 \pm 0.88 \pm 0.35$	$-2.37 \pm 1.36 \pm 0.60$
$U_{+0}^{-,\mathrm{Im}}$	$-1.66 \pm 0.94 \pm 0.25$	$-0.41 \pm 1.00 \pm 0.47$
$U_{-0}^{+,\mathrm{Re}}$	$-0.36 \pm 0.38 \pm 0.08$	$+0.25 \pm 0.60 \pm 0.33$
$U_{-0}^{+,\mathrm{Im}}$	$-0.17 \pm 0.50 \pm 0.23$	$-1.34 \pm 0.60 \pm 0.47$
$U_{-0}^{-,\mathrm{Re}}$	$-0.63 \pm 0.72 \pm 0.32$	$-0.53 \pm 1.44 \pm 0.65$
$U_{-0}^{-,\mathrm{Im}}$	$+0.12 \pm 0.75 \pm 0.22$	$-0.02 \pm 1.31 \pm 0.83$
I_{+-}^{Re}	$+1.90 \pm 2.03 \pm 0.65$	$+1.21 \pm 2.59 \pm 0.98$
I_{+-}^{Im}	$-1.99 \pm 1.25 \pm 0.34$	$-1.93 \pm 2.39 \pm 0.89$
I_{+0}^{Re}	$+0.41 \pm 1.30 \pm 0.41$	$+1.15 \pm 2.26 \pm 0.92$
I_{+0}^{Im}	$-0.21 \pm 1.06 \pm 0.25$	$-0.40 \pm 1.86 \pm 0.85$
I_{-0}^{Re}	$+0.41 \pm 1.30 \pm 0.21$	$-0.92 \pm 1.34 \pm 0.80$
I_{-0}^{Im}	$+1.23 \pm 1.07 \pm 0.29$	$-2.03 \pm 1.62 \pm 0.81$

Q2B Parameters

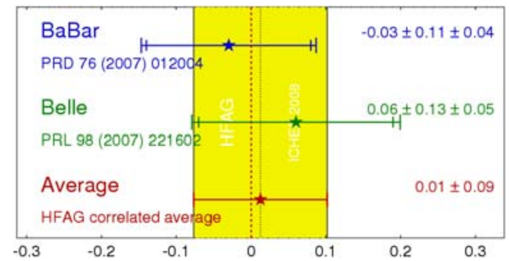
- Time- and flavor-integrated *CP* asymmetry: $$A_{\rho\pi}^{CP} = \frac{U_+^+ - U_-^+}{U_+^+ + U_-^+}$$



- Flavor-dependent direct *CP* violation (cos term): $$C = \frac{1}{2}\left(\frac{U_+^-}{U_+^+} + \frac{U_-^-}{U_-^+}\right)$$



- Mixing-induced indirect *CP* violation (sine term): $$S = \left(\frac{I_+}{U_+^+} + \frac{I_-}{U_-^+}\right)$$



- *CP*-conserving part of cos and sine terms:

$$\Delta C = \frac{1}{2}\left(\frac{U_+^-}{U_+^+} - \frac{U_-^-}{U_-^+}\right)$$

BABAR: $+0.39 \pm 0.09 \pm 0.09$

Belle: $+0.36 \pm 0.10 \pm 0.05$

$$\Delta S = \left(\frac{I_+}{U_+^+} - \frac{I_-}{U_-^+}\right)$$

BABAR: $-0.01 \pm 0.14 \pm 0.06$

Belle: $-0.08 \pm 0.13 \pm 0.05$

- Q2B parameters for the $\rho^0\pi^0$ mode also obtained

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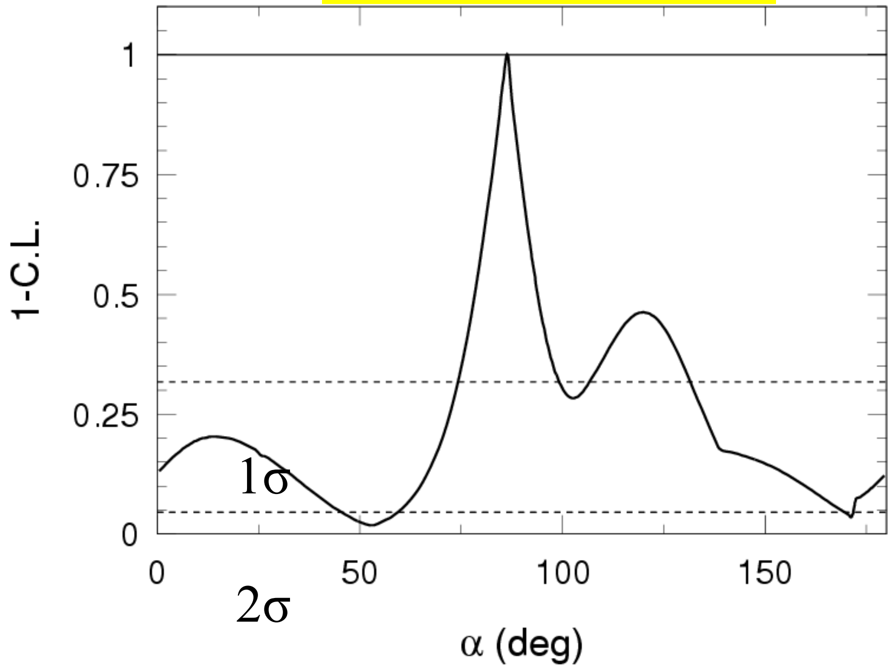
Constraint on Angle α

PRD 76 (2007) 012004

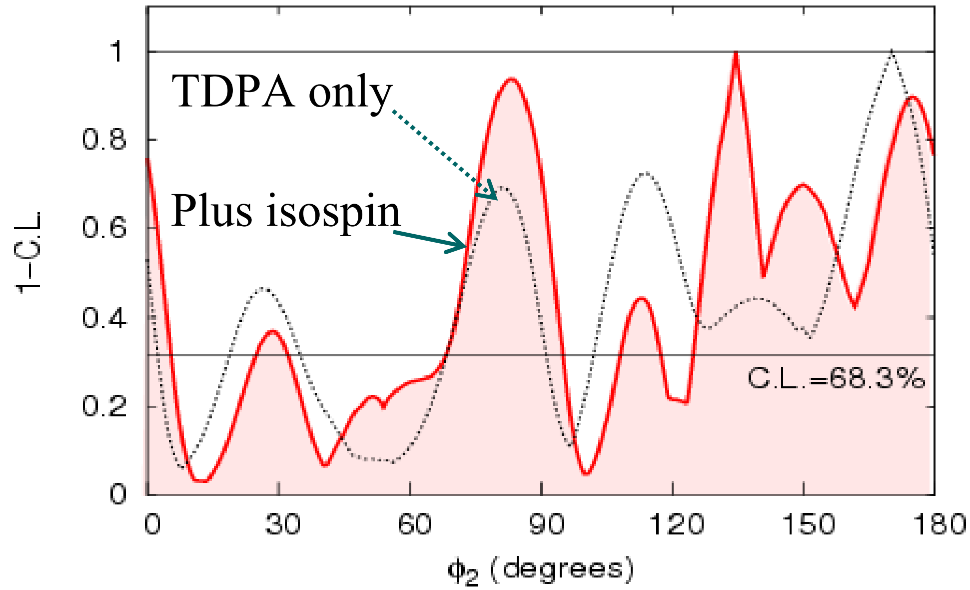


BaBar measures:

- $\alpha = \left(87\ ^{+45}_{-13}\right)^\circ$
- $\delta = (37 \pm 37)^o$

$$\delta = \arg\left(A^{-\star}A^{+}\right)$$

PRD 77 (2008) 072001

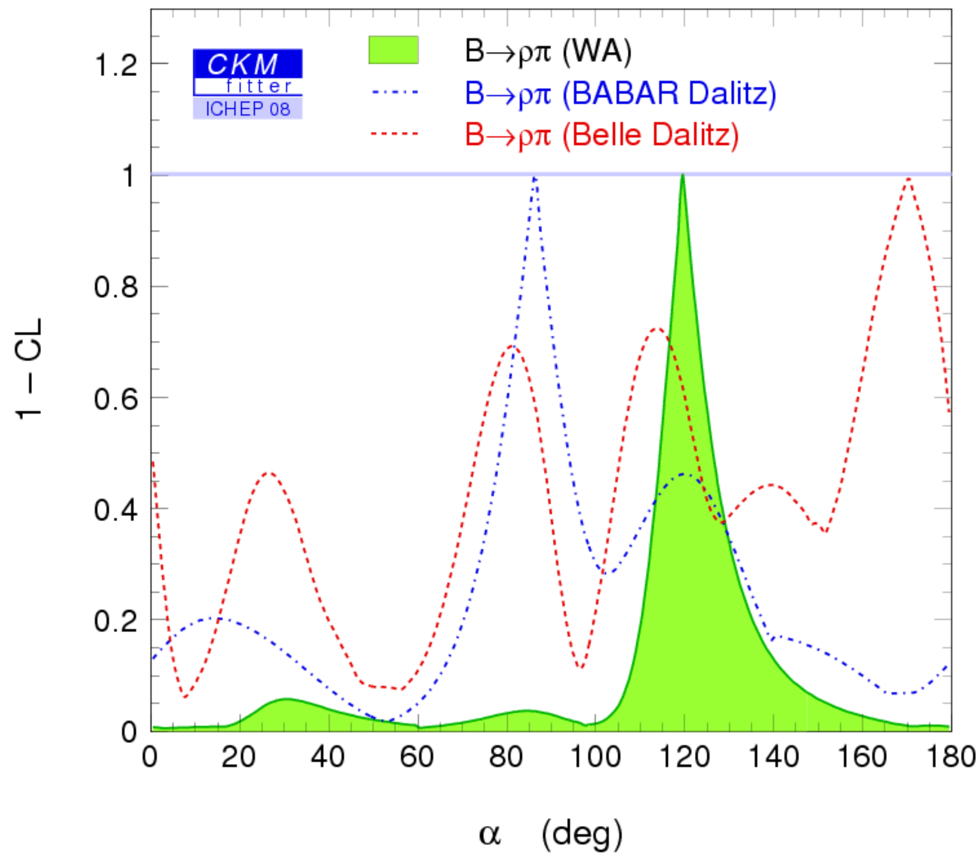


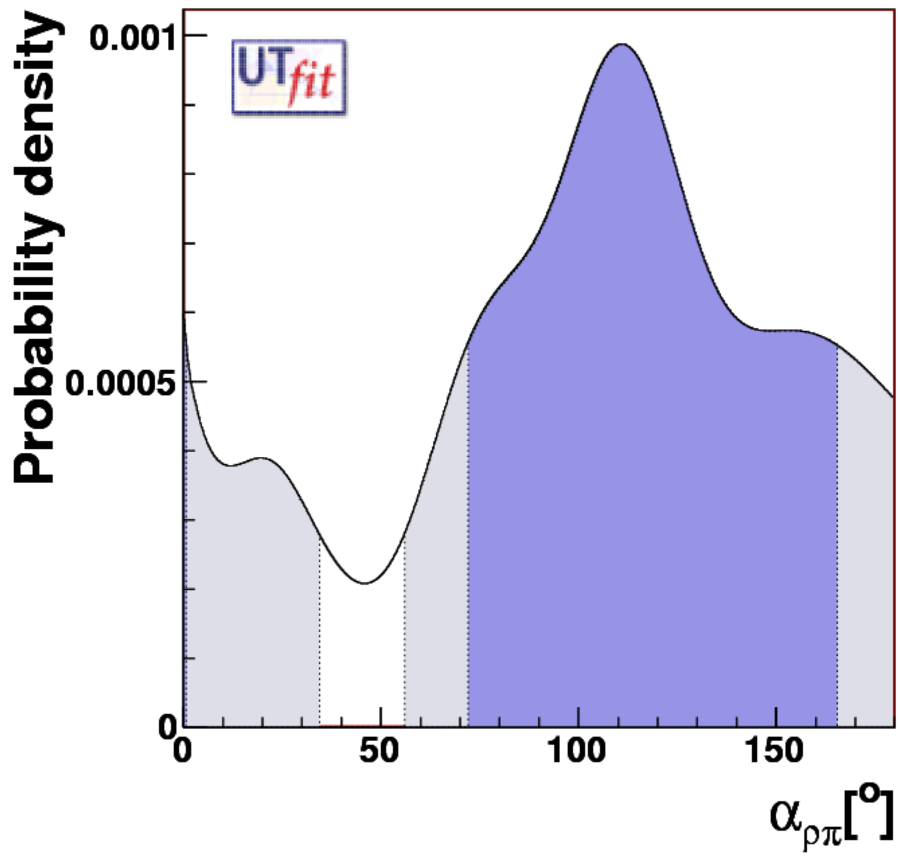
For Belle:

- $68^o < \varphi_2 < 95^o$ at 68.3% C.L.
- Using BF and A_{CP} values of $B^+ \rightarrow \rho^0\pi^+$ and $\rho^+\pi^0$

Global Picture

- Two statistical (frequentist vs. Bayesian) interpretations agree quite well





CKMfitter Group (J. Charles et al.)
Eur. Phys. J C41 (2005) 1-131

UTFit Collab. (M. Ciuchini et al.)
JHEP 0107 (2001) 013

See, http://ckmfitter.in2p3.fr

See, http://www.utfit.org

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Conclusions and Outlook

- Time-dependent Dalitz plot analysis performed by both BABAR and Belle
  - Model ρ mesons in an isobar approach
  - Interference effect correctly modeled
  - Extract strong and weak phases without any ambiguity
- Precision limited due to statistics at present
  - Look forward to updated results from both expts (~70% more $N_{B\bar{B}}$)
- Charged mode ($B^+ \to \pi^+\pi^+\pi^-$) would help to reduce model uncertainties
- Ignoring mirror solution
  - α is close to 90° (almost no constraint at 2σ)
- LHCb is projected to give a competitive limit (about 7° in 2 fb^{-1})

LHCb-2007-046

- Super flavor factory would really pin it down

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Appendix

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Event Selection

- Track selection and π^0 reconstruction
  - Interaction point, track momentum, and particle ID
  - Photon energy, π^0 momentum and invariant mass
- Background suppression (mostly topology)
- Kinematic selection: m_{ES} and ΔE
  - Signal region, where TDPA is performed
  - Sidebands – parameterize background shape
- Best *B* candidate selection
  - π^0 mass (and likelihood ratio – Belle)

Source of Systematic Error

- Dalitz plot model:
  - toyMC: Generate with alternative models:
    - Nonresonant (uniform) component
    - Scalar $\pi^+\pi^-$ component
      - » [low mass scalar, $f_0(980)$, $f_2(1270)$]
- ρ lineshape
    - Check relative amplitude assumption
  - Vary mass and width
- B-background
  - Assumption on CP contents
- And more
  - Fit bias (negligible)
  - Parameters other PDF (background Dalitz, f_{SCF})

Relevant for interference parameters

Relevant for Q-2b parameters

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