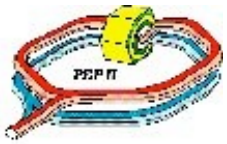


BaBar α measurement from $B^0 \to \rho\pi$ Dalitz plot analysis and β from $B^0 \to D^{*+}D^{*-}$ with partial reconstruction

CKM 2014 Workshop - Vienna, Austria

Tomo Miyashita
Caltech

Representing
The BaBar Collaboration
September 11, 2014

Overview

α

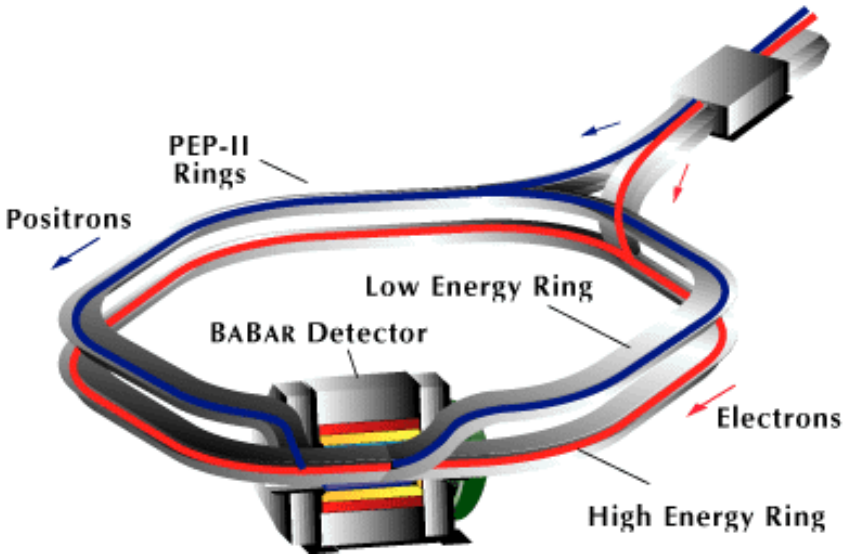
- "Measurement of *CP*-violating asymmetries in $B^0 \to (\rho\pi)^0$ decays using a time-dependent Dalitz plot analysis"

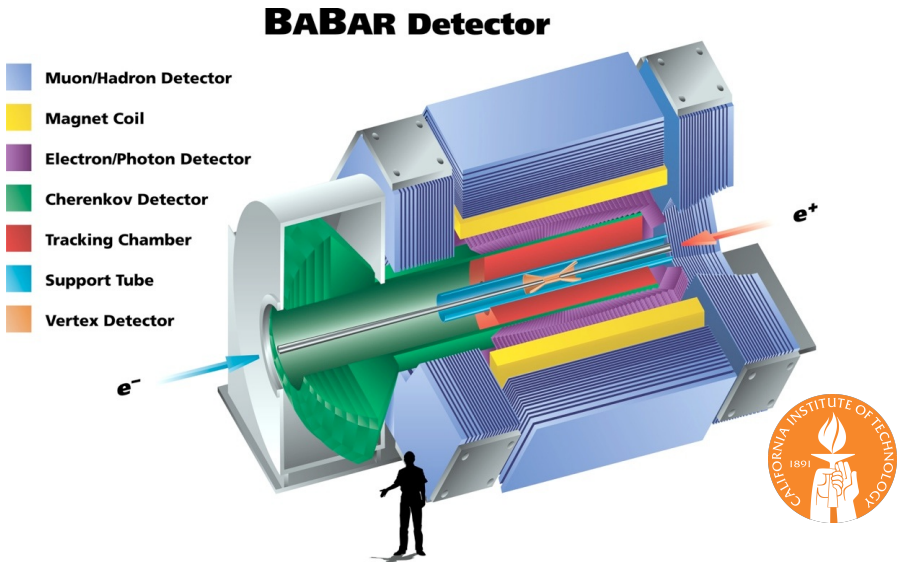
Phys. Rev. D 88, 012003 (2013)

β

- "Measurement of the time-dependent *CP* asymmetry of partially reconstructed $B^0 \to D^{*+}D^{*-}$ decays" **Phys. Rev. D 86, 112006 (2012)**

- Both analyses use the full BaBar dataset collected at the $\Upsilon(4s)$ resonance ($\sim 470 \times 10^6$ $B\overline{B}$ pairs)

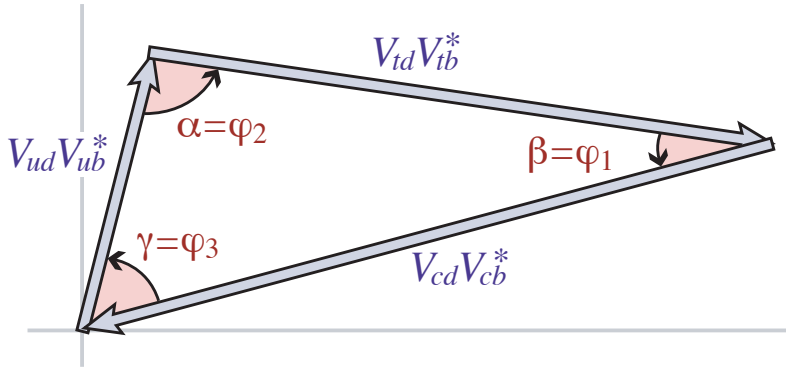




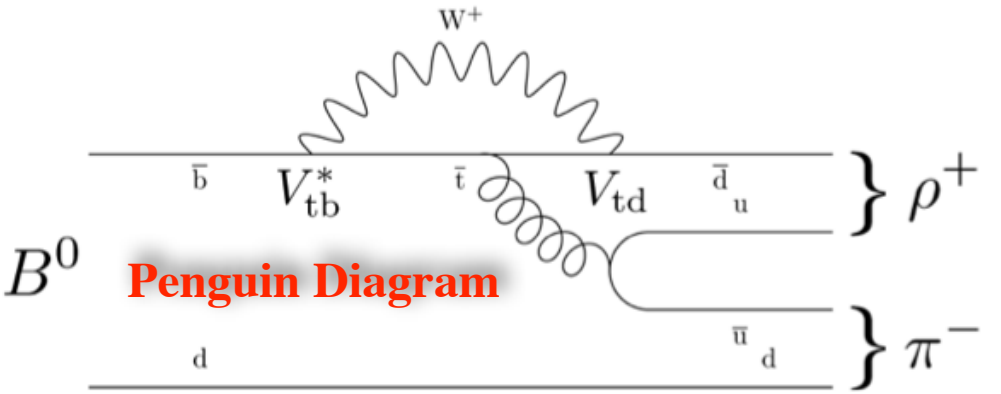
$B^0 \to \rho\pi$ CP Violation Analysis I

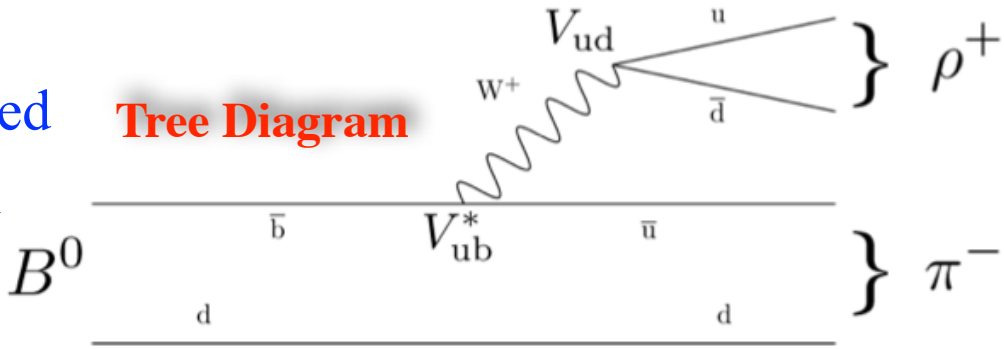
- $B^0 \to \pi^+\pi^-\pi^0$ time-dep *CPV* measurement

Phys. Rev. D 88, 012003 (2013)



- Dominated by $B^0 \to \rho^{\pm}\pi^{\mp}$
- Extensive update and reoptimization of a 2007 BaBar analysis*
- Extracts information about alpha, and other parameters
  - Interference between tree and penguin modes and decays w/ and w/o mixing provides sensitivity to alpha
- The use of a full Dalitz plot analysis reduces ambiguities found in analyses that ignore the interference regions
- Isospin relations allow info from charged B decays to be used in alpha extraction





*Phys. Rev. D 76, 012004 (2007)

$B^0 \to \rho\pi$ CP Violation Analysis II

- Time-Dependent Probability Distribution

$$|\mathcal{A}^{\pm}_{3\pi}(\Delta t)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big[|A_{3\pi}|^2 + |\overline{A}_{3\pi}|^2 \mp \left(|A_{3\pi}|^2 - |\overline{A}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t) \pm 2\mathrm{Im}\left[\frac{q}{p}\overline{A}_{3\pi}A^*_{3\pi}\right]\sin(\Delta m_d \Delta t)\Big]$$

$$A_{3\pi} = f_+ A^+ + f_- A^- + f_0 A^0 \quad \text{for} \quad B^0 \to \pi^+\pi^-\pi^0$$
$$\overline{A}_{3\pi} = f_+ \overline{A}^+ + f_- \overline{A}^- + f_0 \overline{A}^0 \quad \text{for} \quad \overline{B}^0 \to \pi^+\pi^-\pi^0$$

$$f_\kappa(m,\theta_\kappa) \propto F_{\rho(770)}(m,\theta_\kappa) + a_{\rho'} e^{i\phi_{\rho'}} F_{\rho(1450)}(m,\theta_\kappa)$$

- In the final fit, this distribution is parameterized using 26 "U and I" parameters calculated from resonance amplitudes:

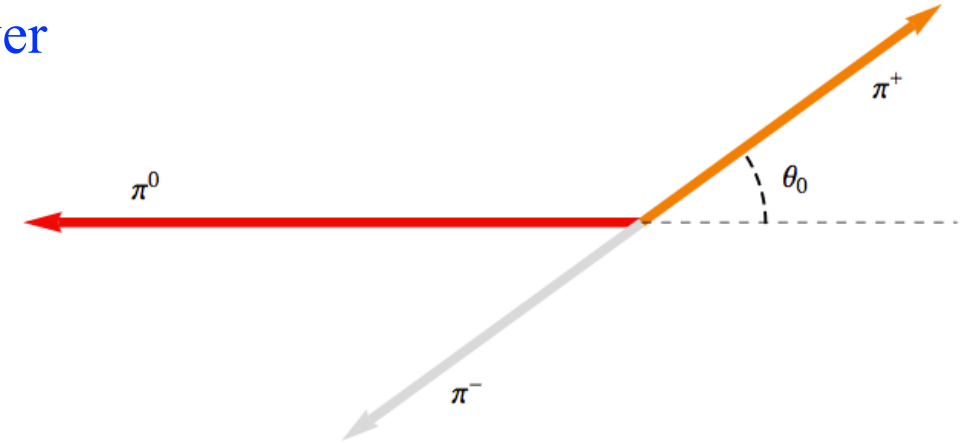
$$U^{\pm}_{\kappa} = |A^\kappa|^2 \pm |\overline{A}^\kappa|^2$$
$$U^{\pm,\mathrm{Re(Im)}}_{\kappa\sigma} = \mathrm{Re(Im)}\left[A^\kappa A^{\sigma *} \pm \overline{A}^\kappa \overline{A}^{\sigma *}\right]$$
$$I_\kappa = \mathrm{Im}\left[\overline{A}^\kappa A^{\kappa *}\right]$$
$$I^{\mathrm{Re}}_{\kappa\sigma} = \mathrm{Re}\left[\overline{A}^\kappa A^{\sigma *} - \overline{A}^\sigma A^{\kappa *}\right]$$
$$I^{\mathrm{Im}}_{\kappa\sigma} = \mathrm{Im}\left[\overline{A}^\kappa A^{\sigma *} + \overline{A}^\sigma A^{\kappa *}\right]$$

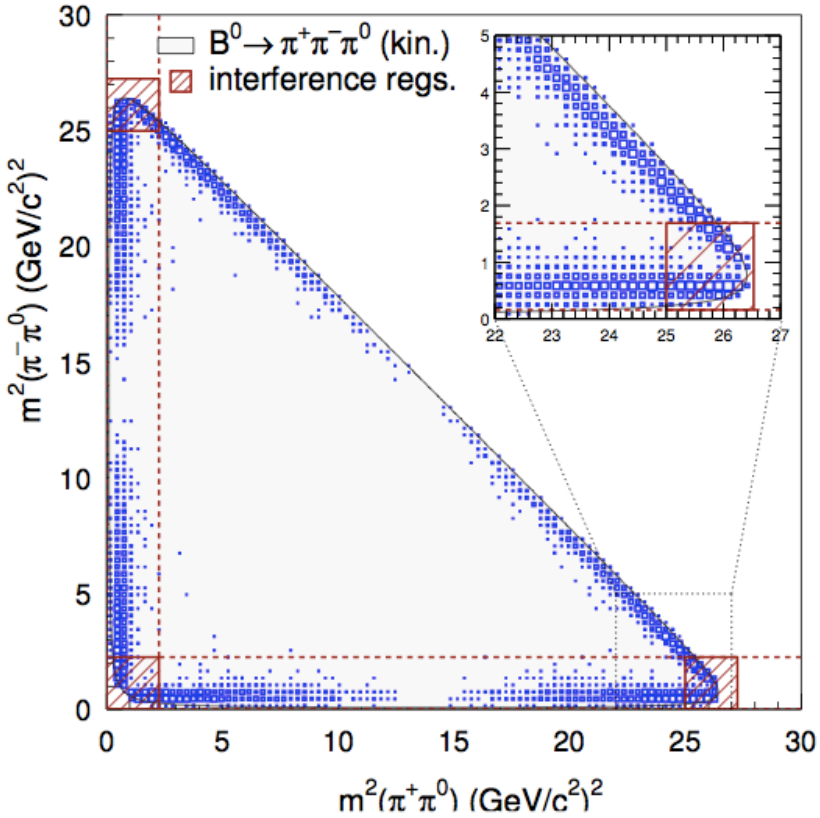
$B^0 \to \rho\pi$ CP Violation Analysis III

- The Dalitz plot is transformed to cover a unit square before fitting

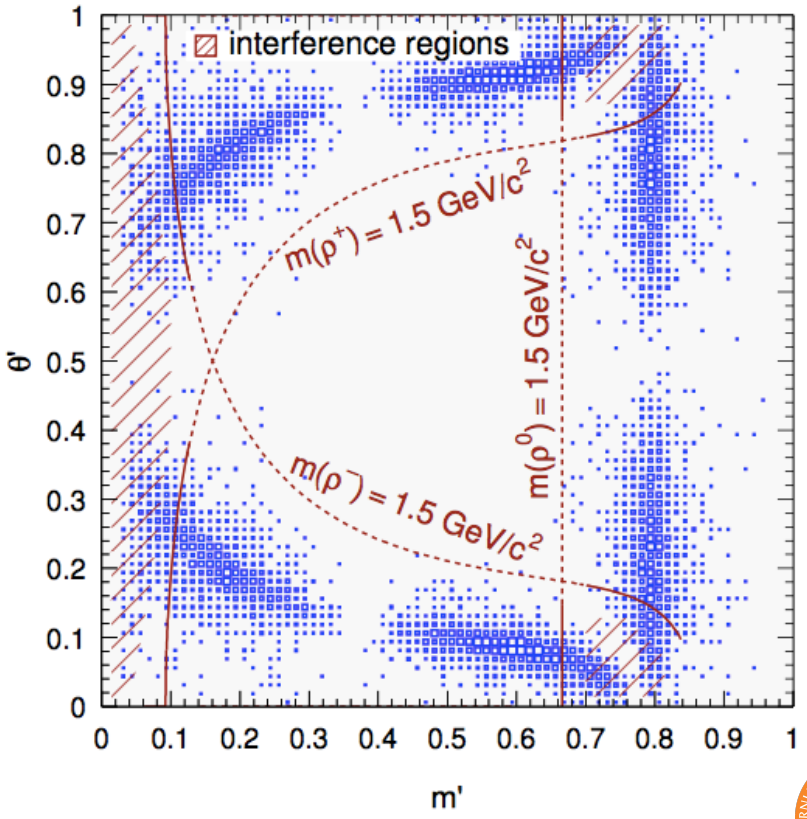
$$m' \equiv \frac{1}{\pi} \arccos\left(2\frac{m_0 - m_0^{\min}}{m_0^{\max} - m_0^{\min}} - 1\right)$$

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





$\rho\pi$ Toy Dalitz Plot



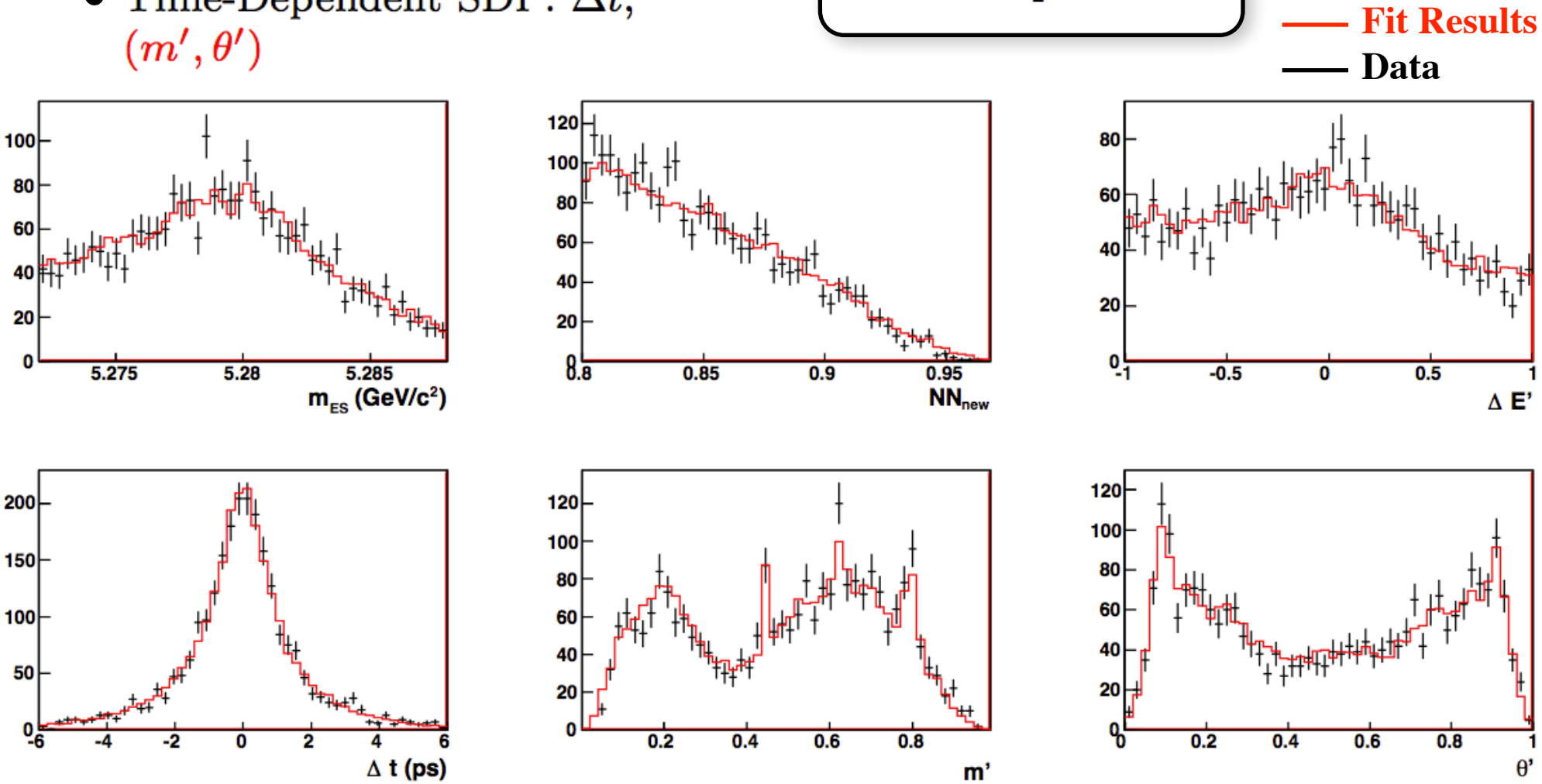
Square Dalitz Plot (SDP)

$B^0 \to \rho\pi$ CP Violation Analysis IV

- Data is fit using a multi-dimensional extended maximum likelihood fit with 6 input variables:
  - $m_{\rm ES}$, ΔE, NN output
  - Time-Dependent SDP: Δt, (m', θ')

$$m_{ES} = \sqrt{\left(\frac{\sqrt{s}}{2}\right)^2 - (p_B^*)^2}$$

$$\Delta E = E_B^* - \tfrac{1}{2}\sqrt{s}$$



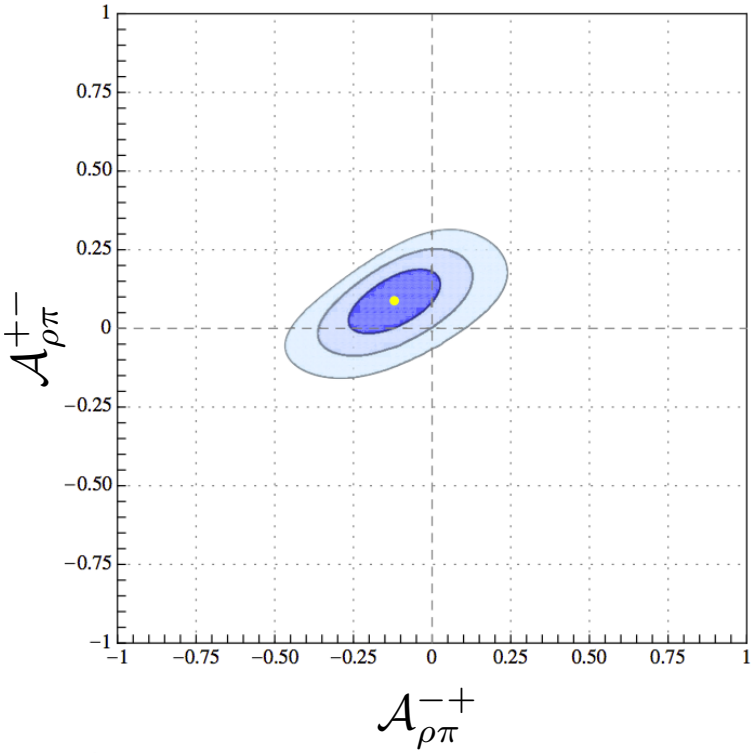
Signal-Enhanced Agreement Between Data and Fit

$B^0 \to \rho\pi$ CP Violation Analysis V

- Direct *CPV* asymmetries extracted in 2D scan:

$$\mathcal{A}_{\rho\pi}^{+-} \equiv \frac{\Gamma(\bar{B}^0 \to \rho^- \pi^+) - \Gamma(B^0 \to \rho^+ \pi^-)}{\Gamma(\bar{B}^0 \to \rho^- \pi^+) + \Gamma(B^0 \to \rho^+ \pi^-)} = 0.09^{+0.05}_{-0.06} \pm 0.04$$

$$\mathcal{A}_{\rho\pi}^{-+} \equiv \frac{\Gamma(\bar{B}^0 \to \rho^+ \pi^-) - \Gamma(B^0 \to \rho^- \pi^+)}{\Gamma(\bar{B}^0 \to \rho^+ \pi^-) + \Gamma(B^0 \to \rho^- \pi^+)} = -0.12 \pm 0.08^{+0.04}_{-0.05}$$



  - Origin (no direct *CPV*) is ~2σ from central value
  - Previous results:

BaBar 2007

$$\mathcal{A}_{\rho\pi}^{+-} = 0.03 \pm 0.07 \pm 0.04$$
$$\mathcal{A}_{\rho\pi}^{-+} = -0.32 \pm 0.16^{+0.09}_{-0.10}$$

Belle 2008

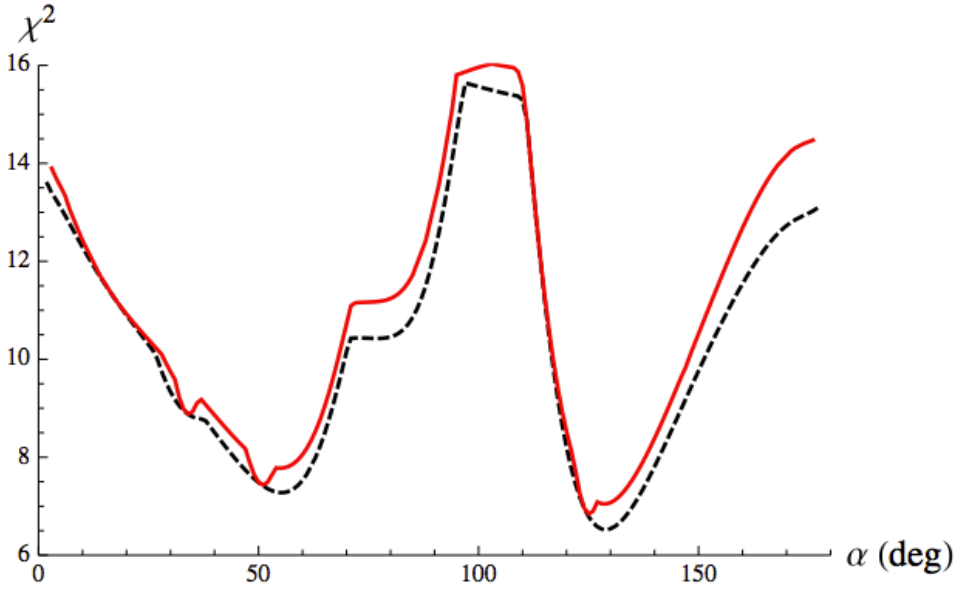
$$\mathcal{A}_{\rho\pi}^{+-} = 0.21 \pm 0.08 \pm 0.04$$
$$\mathcal{A}_{\rho\pi}^{-+} = 0.08 \pm 0.16 \pm 0.11$$

- The 26 physics parameters describing the $B^0 \to \rho\pi$ decay are extracted with, on average, 0.47 times the statistical uncertainties from the previous BaBar measurement

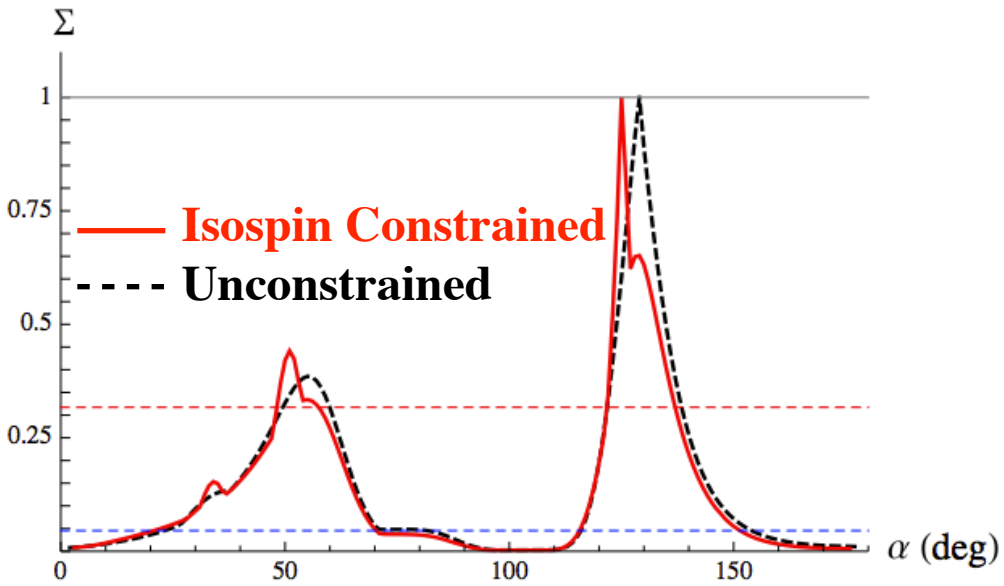
- Studies find that the 26 physics parameters are robustly extracted with our current statistical sensitivity

$B^0 \to \rho\pi$ CP Violation Analysis VI

- We extract information about α from a χ^2 scan
  - For each step in α between 0° and 180°, we perform a χ^2 minimization using the U and I parameter values from our nominal fit along with their full covariance matrix



χ^2 Scan



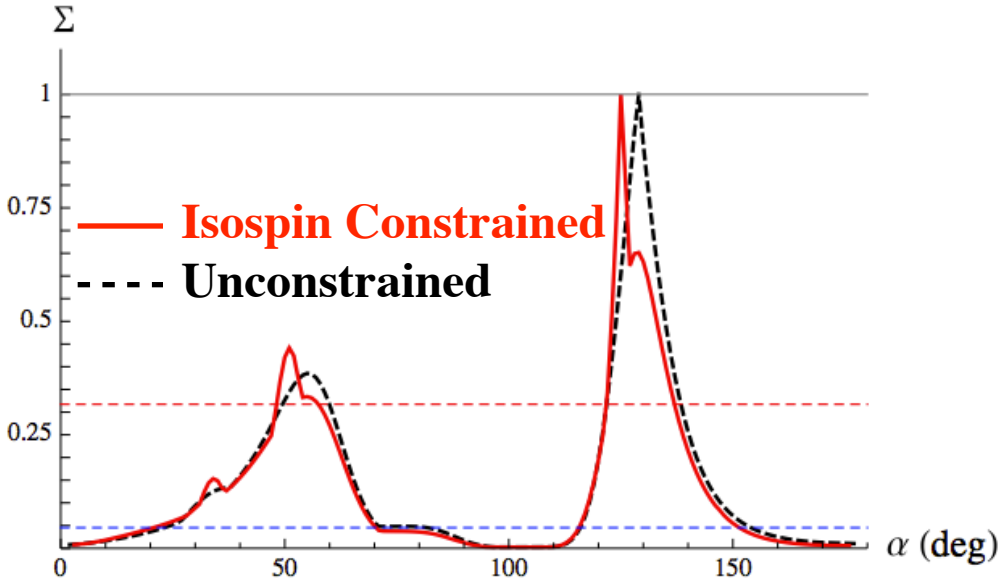
Σ Scan

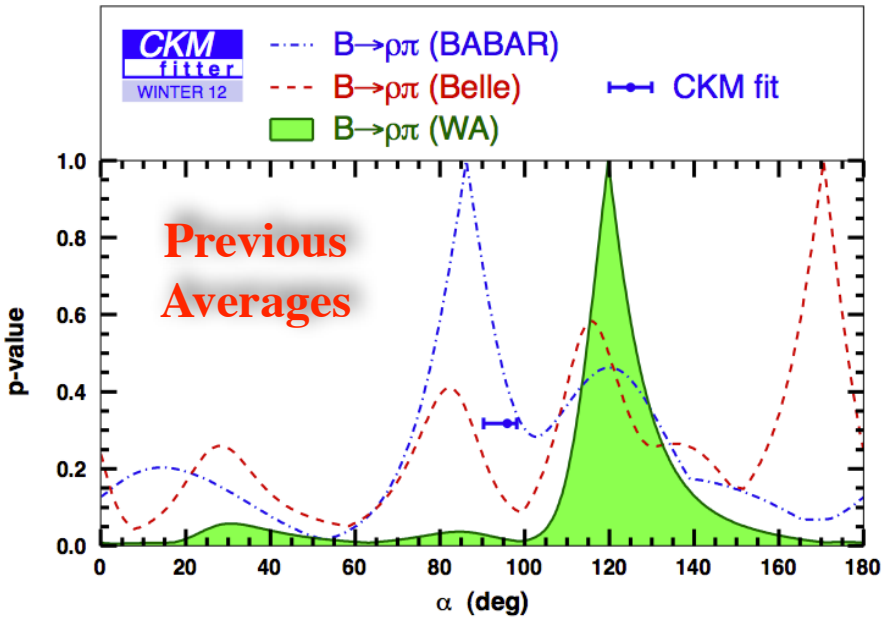
(Commonly called "1-CL")

- Notably, studies reveal that the alpha scan is not robust with current statistics

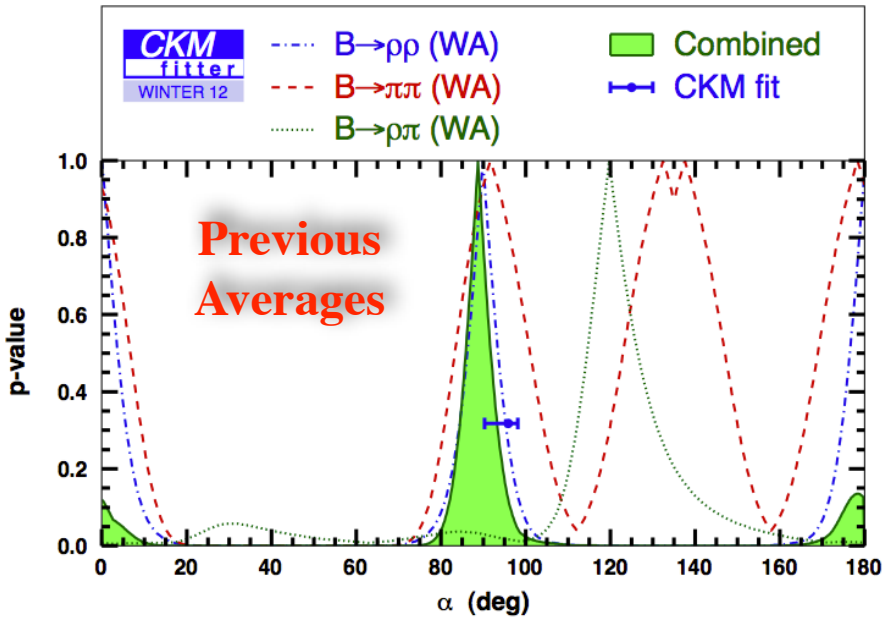
$B^0 \to \rho\pi$ CP Violation Analysis VII

- Comparison with previous CKMFitter world averages





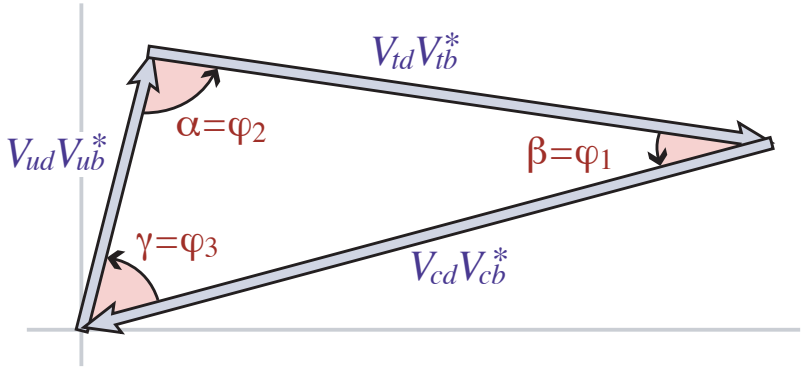
$\rho\pi$ Only



All Modes

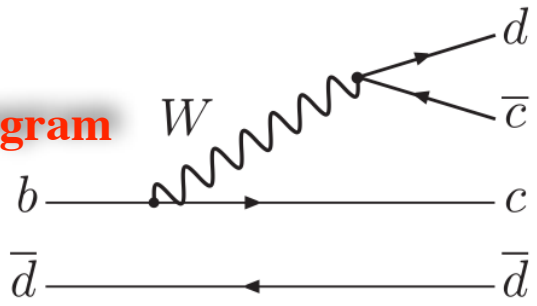
$B^0 \to D^{*+} D^{*-}$ CP Violation Analysis I

- $b \to c\bar{c}d$ time-dependent *CPV* measurement
- In the absence of penguin contributions, this mode should yield the same measured value for $\sin 2\beta$ as $b \to c\bar{c}s$ $(J/\psi K)$

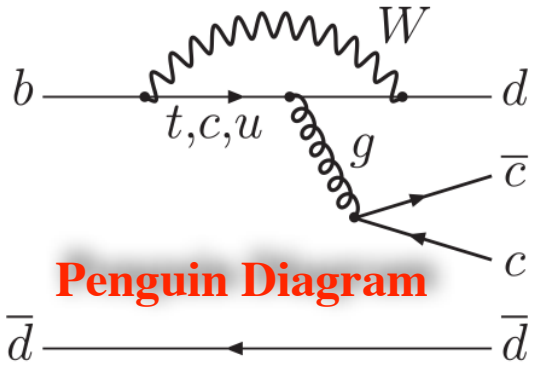


- Only expect correction of a few % due to penguin contributions in the standard model
- A large discrepancy between $\sin 2\beta$ in the two modes could indicate new physics

Tree Diagram



Penguin Diagram



$B^0 \to D^{*+} D^{*-}$ CP Violation Analysis II

- The Vector-Vector final state is a mixture of *CP*-odd and *CP*-even states
  - Need an angular analysis to separate *CP* states
  - Using fully reconstructed events, BaBar and Belle have both measured the *CP*-odd fraction $R_\perp$ and the time-dep *CP* asymmetry

$$R_\perp = \frac{|A_\perp^0|^2}{|A_0^0|^2 + |A_\parallel^0|^2 + |A_\perp^0|^2}$$

CP=+1 for $A_\parallel$,A_0
CP=–1 for $A_\perp$

BaBar Full Reco

$$R_\perp = 0.158 \pm 0.028 \pm 0.006$$

Phys. Rev. D 79, 032002 (2009)

- The previously measured CP-odd fraction reveals that the final state is dominated by the CP = +1 amplitude
- We can forego the angular analysis and use the previously measured CP-odd fraction to separate the CP-odd and CP-even S and C components

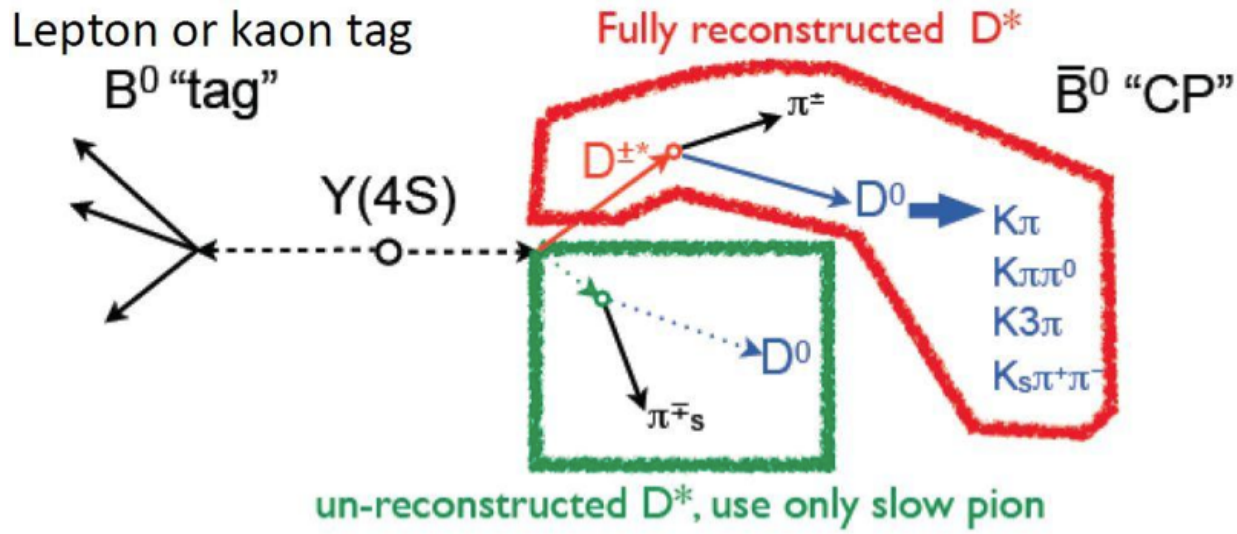
$B^0 \to D^{*+} D^{*-}$ CP Violation Analysis III

- Use partial reconstruction
  - One D^* is fully reconstructed from $D^* \to D^0 \pi$ where the D^0 decays to one of 4 modes
  - The fully reconstructed D^* is matched with a slow pion of opposite charge
  - The D^* candidate is selected if the kinematics are consistent with $B^0 \to D^* D^0 \pi$ where the D^0 is missing

$m_{\rm rec}$ = Mass of recoiling D^0 reconstructed from the D^* and slow pion momenta

  - Partial reconstruction provides ~5x the sig evts from a full reco, but with higher background and larger systematic errors

- The flavor of the other B meson is determined by either "lepton" or "kaon" tagging



$B^0 \to D^{*+} D^{*-}$ CP Violation Analysis IV

- PDF for final fit is composed of three components

$$P = f_{B\bar{B}} \underbrace{[\overbrace{f_{\rm sig} P_{\rm sig}}^{\text{signal}} + \overbrace{(1 - f_{\rm sig}) P_{\rm comb}}^{\text{B}\bar{\text{B}}\text{ combinatoric}}]}_{\text{B}\bar{\text{B}}} + \underbrace{(1 - f_{B\bar{B}}) P_{q\bar{q}}}_{\text{continuum}}$$

(Peaking background was found to be negligible)

- Each component of the PDF is a product of a kinematic element and a Δt element

$$P_i(m_{\rm rec}, F, \Delta t, \sigma_{\Delta t}, S_{\rm tag}) =$$

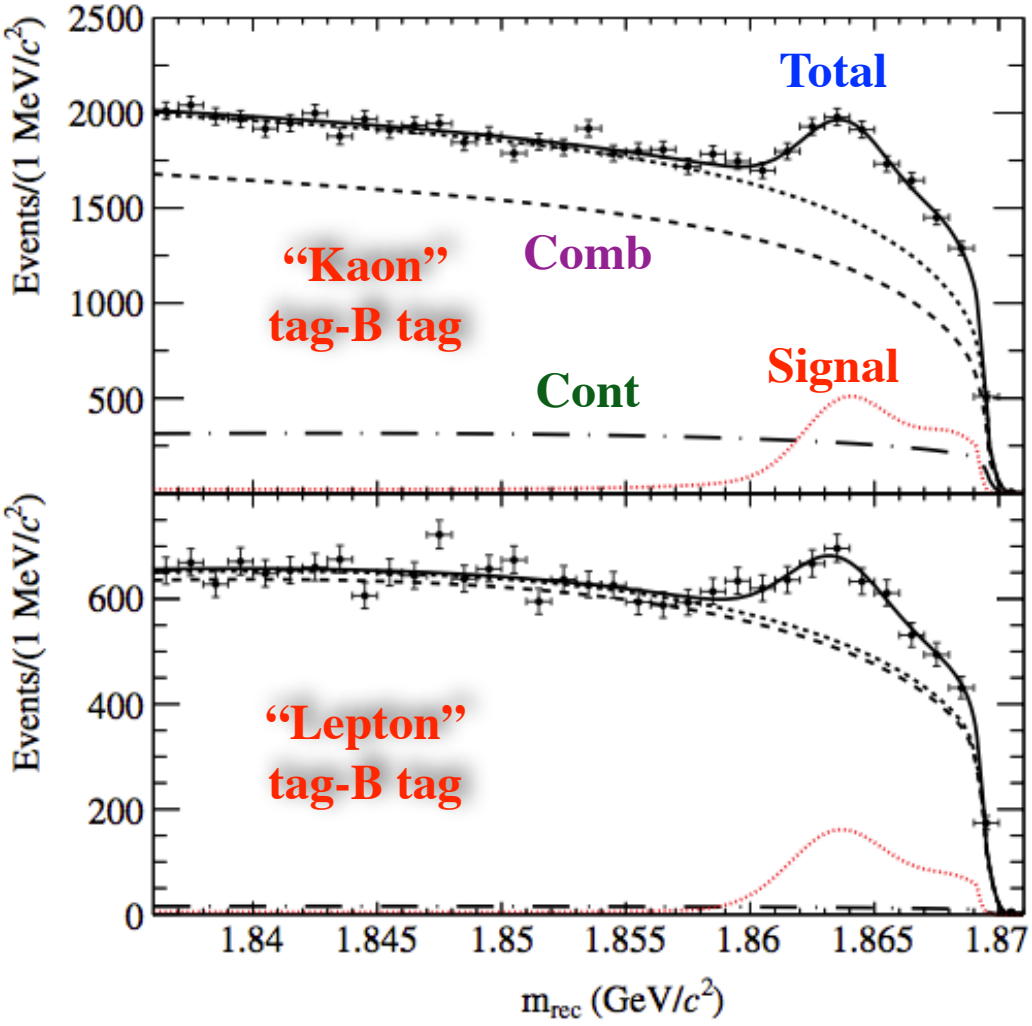
$$\underbrace{\mathcal{M}_i(m_{\rm rec})\, \mathcal{F}_i(F)}_{\text{“KIN”}}\, \underbrace{T_i'(\Delta t, \sigma_{\Delta t}, S_{\rm tag})}_{\text{“Δt”}}$$

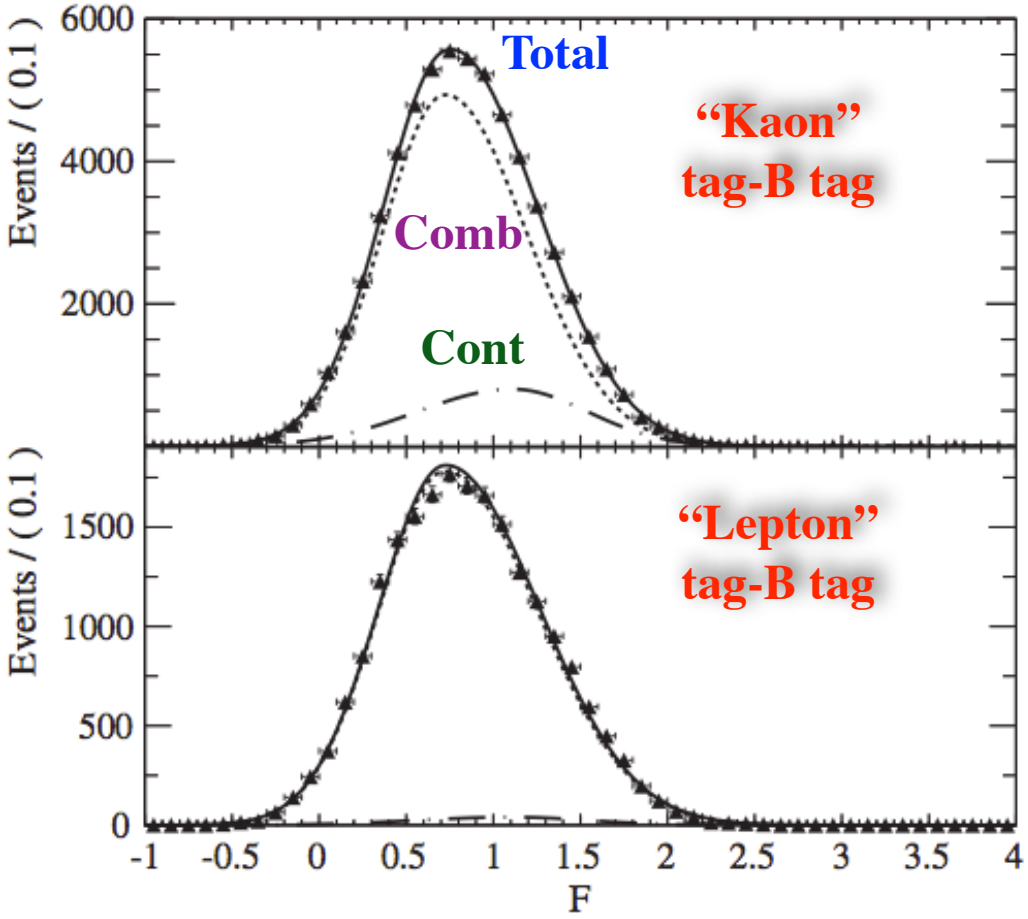
  - A Fisher discriminant is used to help distinguish jet-like continuum events from more spherically distributed signal events

$B^0 \to D^{*+} D^{*-}$ CP Violation Analysis V

- Kinematic fit distributions

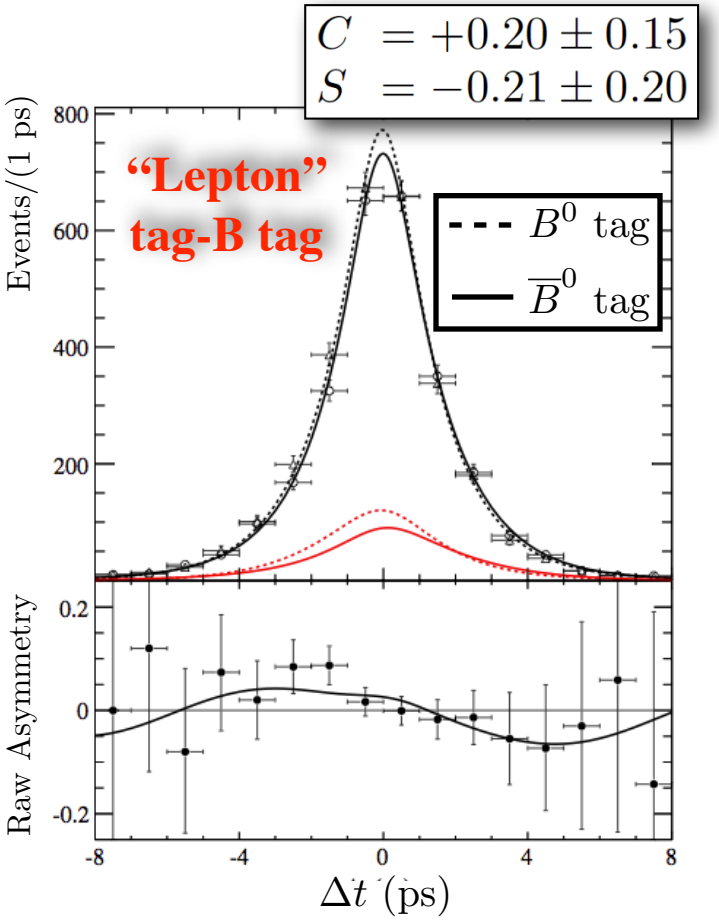
Phys. Rev. D 86, 112006 (2012)

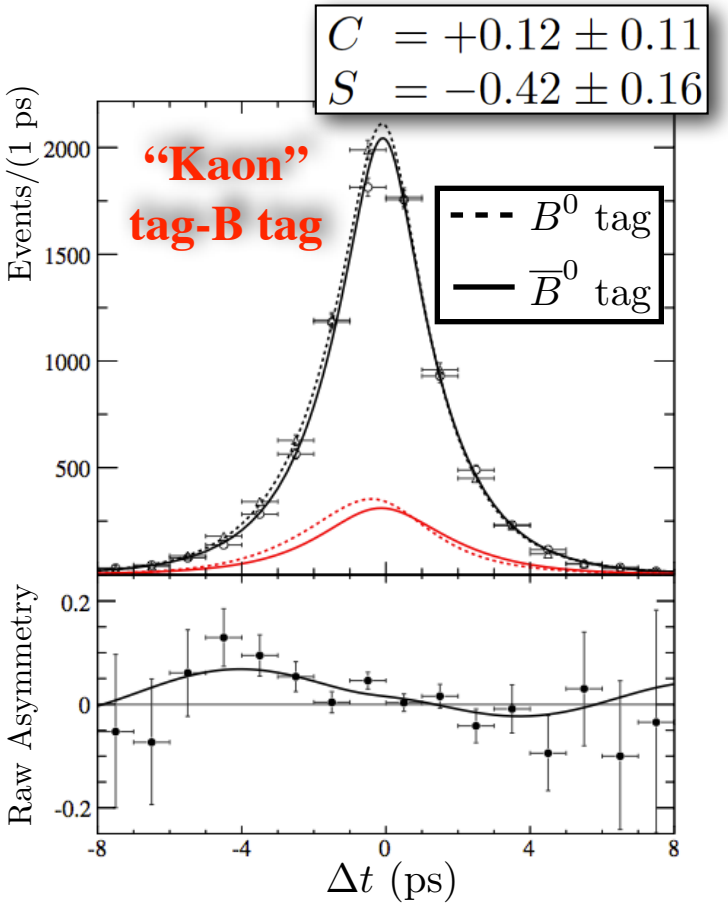




$B^0 \to D^{*+} D^{*-}$ CP Violation Analysis VI

- Time-dependent fit results:





- Combined parameters:

$$C = +0.15 \pm 0.09 \pm 0.05$$
$$S = -0.34 \pm 0.12 \pm 0.09$$

for $R_\perp = 0.158 \pm 0.029^*$

*Phys. Rev. D 79, 032002 (2009)

- Neglecting penguin amplitudes:

$$S_+ = -S_-, \; C_+ = -C_-$$
$$C = C_+ \qquad S = S_+(1 - 2R_\perp)$$

$$\Longrightarrow$$

$$C_+ = +0.15 \pm 0.09 \pm 0.04$$
$$S_+ = -0.49 \pm 0.18 \pm 0.07 \pm 0.04$$

$B^0 \to D^{*+} D^{*-}$ CP Violation Analysis VII

- Time-dependent fit result comparison:

  - BaBar Partial Reconstruction:

$$\begin{aligned} C &= +0.15 \pm 0.09 \pm 0.05 \\ S &= -0.34 \pm 0.12 \pm 0.09 \end{aligned}$$

$$\begin{aligned} C_+ &= +0.15 \pm 0.09 \pm 0.04 \\ S_+ &= -0.49 \pm 0.18 \pm 0.07 \pm 0.04 \end{aligned}$$

$S_+ \approx -\sin 2\beta$

  - Our measured value of $\sin 2\beta$ is consistent with the PDG world average calculated from a variety of modes:

PDG 2012 WA

$\sin 2\beta = 0.679 \pm 0.020$

  - Out results are also consistent with the previous Belle and BaBar measurements performed using full reconstruction:

Belle Full Reco*

$C = 0.15 \pm 0.13 \pm 0.04$

$S = -0.96 \pm 0.25^{+0.13}_{-0.16}$

*Phys. Rev. D 80, 111104 (2009)

BaBar Full Reco**

$C_+ = +0.00 \pm 0.12 \pm 0.02$

$S_+ = -0.76 \pm 0.16 \pm 0.04$

**Phys. Rev. D 79, 032002 (2009)

Conclusions

- We have performed an update of our alpha measurement in $B^0 \to (\rho\pi)^0$ decays using the full BaBar dataset
  - Significantly, studies reveal that alpha is not robustly extracted with current statistical significance, though other physics parameters are robust
- A CPV analysis in the mode $B^0 \to D^{*+} D^{*-}$ using partial reconstruction has obtained results consistent with the previous BaBar and Belle measurements
  - Our result for $\sin 2\beta$ is consistent with the PDG world average of previous measurements performed in a variety of modes