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CP violation in hadronic penguin modes

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We present recent results from the BABAR experiment on *CP* violation in hadronic penguin modes. Included are results from the time-dependent amplitude analysis of $B^0 \to K^0_S\pi^+\pi^-$ and from updated measurements of the direct and mixing-induced *CP* violation in the B^0 decay modes ωK^0_S, $\eta' K^0$, and $\pi^0 K^0_S$. The Dalitz plot analysis uses a sample of approximately 383 million $B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance by the BABAR detector at the PEP-II asymmetric energy B factory at SLAC National Laboratory. The other measurements use the full BABAR dataset, of approximately 467 million $B\bar{B}$ pairs.

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1. Introduction

The Cabibbo-Kobayashi-Maskawa (CKM) mechanism [1, 2] for quark mixing describes transitions between quarks in terms of only four parameters: three rotation angles and one irreducible phase. Consequently, the flavor sector of the Standard Model (SM) is highly predictive. One particularly interesting prediction is that mixing-induced *CP* asymmetries in decays governed by $b \to q\bar{q}s$ ($q = u, d, s$) transitions are, to a good approximation, the same as those found in $b \to c\bar{c}s$ transitions. Since flavor changing neutral currents are forbidden at tree-level in the Standard Model, the $b \to s$ transition proceeds via loop diagrams (penguins), which are affected by new particles in many extensions of the SM.

Various $b \to s$ dominated charmless hadronic B decays have been studied in order to probe this prediction. The values of the mixing-induced *CP* asymmetry measured for each (quasi-)two-body mode can be compared to that measured in $b \to c\bar{c}s$ transitions. A recent compilation of results [3] shows that they tend to have central values below that for $b \to c\bar{c}s$. Recent theoretical evaluations (a list of references is given elsewhere [4]) suggest that SM corrections to the $b \to q\bar{q}s$ mixing-induced *CP* violation parameters should be small and tend to *increase* the values, i.e. the opposite trend to that seen in the data. However, there is currently no convincing evidence for new physics effects in these transitions. Clearly, more precise experimental results are required.

2. Time Dependent *CP* Asymmetry in B^0 meson decays to $\omega K^0_S, \eta' K^0$ and $\pi^0 K^0_S$

These updated analyses, which are presented in detail in Ref. [5], supersede our previous measurements (see the same Ref. for a detailed list). Significant changes to the previous analyses include twice as much data for ωK^0_S, 20% more data for $\eta' K^0$ and $\pi^0 K^0_S$, improved track reconstruction, and an additional decay channel in $\eta' K^0_L$. Despite the modest increase in data, the uncertainties on $S_{\eta' K^0}$ and $C_{\eta' K^0}$ decrease by 20% and 25%, respectively.

We have used samples of 121 ± 13 $B^0 \to \omega K^0_S$, 1457 ± 43 $B^0 \to \eta' K^0_S$, 416 ± 29 $B^0 \to \eta' K^0_L$, and 411 ± 24 $B^0 \to \pi^0 K^0_S$ flavor-tagged events to measure the time-dependent *CP* violation parameters

	$B^0 \to \omega K^0_S$	$B^0 \to \eta' K^0$	$B^0 \to \pi^0 K^0_S$
S	$0.55^{+0.26}_{-0.29} \pm 0.02$	$0.57 \pm 0.08 \pm 0.02$	$0.55 \pm 0.20 \pm 0.03$
C	$-0.52^{+0.22}_{-0.20} \pm 0.03$	$-0.08 \pm 0.06 \pm 0.02$	$0.13 \pm 0.13 \pm 0.03$

where the first errors are statistical and the second systematic. These results are consistent with our previous measurements; they are also consistent with the world average of $\sin 2\beta$ measured in $B^0 \to J/\psi K^0_S$ [6].

3. Time-dependent amplitude analysis of $B^0 \to K^0_S \pi^+ \pi^-$

The compilation given in [3] includes quasi-two-body (Q2B) modes, such as $f_0(980)K^0_S$ and $\rho^0(770)K^0_S$, which are reconstructed via their three-body final states ($K^0_S \pi^+ \pi^-$ for these modes). The precision of the Q2B approach is limited as other structures in phase space may cause interference with the resonances considered as signal. Therefore, more precise results can be obtained using a time-dependent amplitude analysis covering the complete phase space, or Dalitz plot (DP), of $B^0 \to K_S^0\pi^+\pi^-$. Furthermore the interference terms allow the cosine of the effective weak phase difference in mixing and decay to be determined, helping to resolve ambiguities which arise from the Q2B analysis.

Our time-dependent amplitude analysis of $B^0 \to K_S^0\pi^+\pi^-$ decays is described in detail in Ref. [4]. In this analysis we perform an unbinned extended maximum-likelihood fit to directly extract the inclusive $B^0 \to K_S^0\pi^+\pi^-$ event yield and the resonant amplitudes. The likelihood function comprises different variables to discriminate signal from background; two of these variables are invariant masses of the final-state particles (i.e. the DP). We describe the distribution of signal events in the DP using an isobar approximation, with 8 components: $f_0(980)K_S^0$, $\rho^0(770)K_S^0$, $K^{*+}(892)\pi^-$, the 0^+ component of the $K\pi$ spectrum (dubbed $(K\pi)_0^{*\pm}$), $f_2(1270)K_S^0$, $f_X(1300)K_S^0$, $\chi_{c0}K_S^0$, and a nonresonant contribution. Contributions to the DP from other components (e.g. $K^*(1680)\pi$) were determined to be small and included as a systematic uncertainty. The fit of 22525 candidates results in a signal event yield of 2182 ± 64, where the uncertainty is statistical only. Thanks to the rich DP structure of our signal, we measure 15 pairs of relative magnitudes and phases for the different resonances, taking advantage of the interference between them. From the measured decay amplitudes, we derive the Q2B parameters of the resonant decay modes. In particular, we extract the *CP* violation parameters of $f_0(980)K_S^0$ and $\rho^0(770)K_S^0$ and the direct *CP* asymmetry of $K^{*+}(892)\pi^-$. Two solutions, with equivalent goodness-of-fit, were found. Figures 1 and 2 show distributions of the invariant masses $m_{\pi^+\pi^-}$ and $m_{K_S^0\pi}$, respectively. They illustrate the good quality of the fit.

The measurements of time-dependent *CP*-violation in the $f_0(980)K_S^0$ and $\rho^0(770)K_S^0$ modes are presented as two-dimensional likelihood scans in the (β_{eff}, C) plane, shown in Fig. 3. The scans are displayed as confidence level contours after two-dimensional convolution with the covariance matrix of systematic uncertainties. Including systematic uncertainties, the combined confidence interval for the measured values of β_{eff} in B^0 decays to $f_0(980)K_S^0$ is $18^\circ < \beta_{\text{eff}} < 76^\circ$ at 95% confidence level (C.L.) *CP* conservation in B^0 decays to $f_0(980)K_S^0$ is excluded at 3.5 standard deviations, including systematics. For B^0 decays to $\rho^0(770)K_S^0$, the combined confidence interval is $-9^\circ < \beta_{\text{eff}} < 57^\circ$ at 95% C.L. These results are both consistent with the measurements in $b \to c\bar{c}s$ modes.

In decays to $K^{*+}(892)\pi^-$, we find $A_{CP} = -0.20 \pm 0.10$. For the relative phase between decay amplitudes of $B^0 \to K^{*+}(892)\pi^-$ and $\bar{B}^0 \to K^{*-}(892)\pi^+$ ($\Delta\Phi(K^*(892)\pi)$), we exclude the interval $-137^\circ < \Delta\Phi(K^*(892)\pi) < -5^\circ$ at 95% C.L. This last result, combined with measurements of branching ratios, direct *CP* asymmetries, and relative phases in $K^{*+}(892)\pi^-$ and $K^{*0}(892)\pi^0$, plus a theoretical hypothesis on the contributions of electroweak penguins to the decay amplitudes, can be used to set non-trivial constraints on the CKM parameters $(\overline{\rho}, \overline{\eta})$ by following the methods proposed in Refs. [7, 8, 9, 10]. The measurement of the phase $\Delta\Phi(K^*(892)\pi)$ is presented as a one-dimensional likelihood scan in Fig. 4 that also shows the measurement of the similar phase difference for the $(K\pi)_0^*$ component.

References

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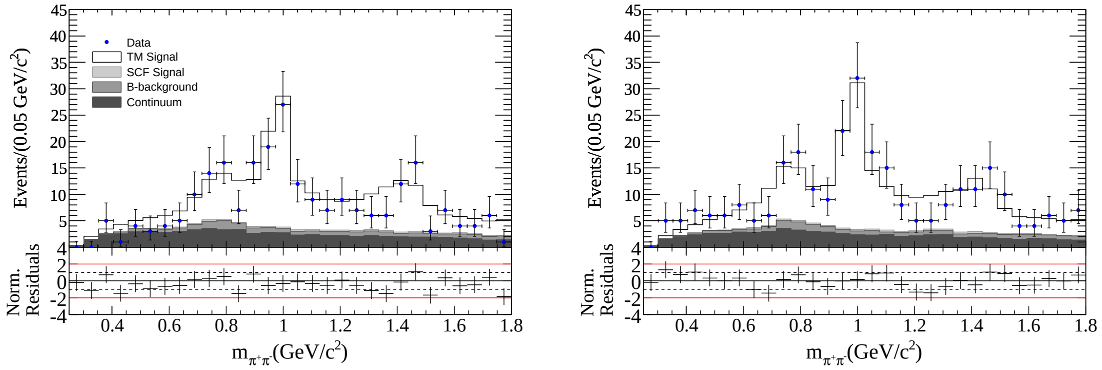

Figure 1: Distribution of $m_{\pi^+\pi^-}$ for a sample enhanced in $B^0 \to K^0_S\pi^+\pi^-$ signal, showing the $f_0(980)K^0_S$ and $\rho^0(770)K^0_S$ signal region for positive (left) and negative (right) $\pi^+\pi^-$ helicity. The contributions from $f_X(1300)K^0_S$ and $f_2(1270)K^0_S$ are also visible.

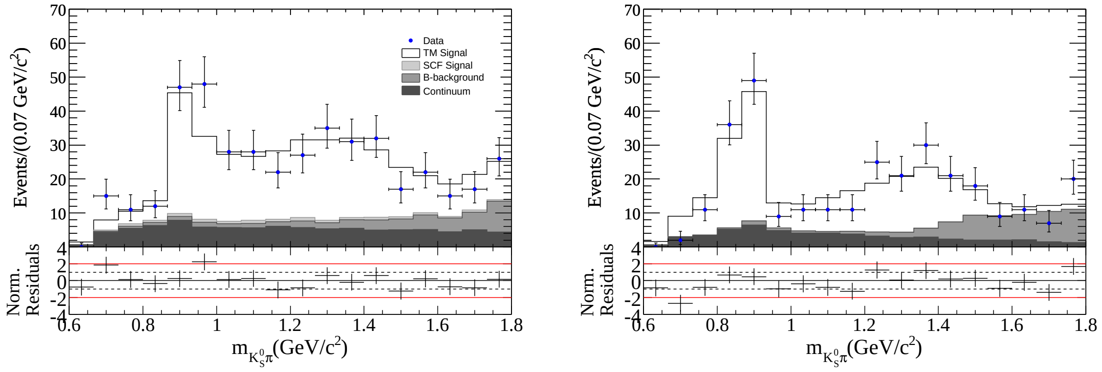

Figure 2: Distributions of $m_{K^0_S\pi}$ for a sample enhanced in $B^0 \to K^0_S\pi^+\pi^-$ signal, showing the $K^*(892)\pi$ and $K^*(1430)\pi$ signal region for positive (left) and negative (right) $K^0_S\pi$ helicity. An interference between the vector and scalar K^{*+} is apparent through a positive (negative) forward-backward asymmetry below (above) the $K^*(892)$.

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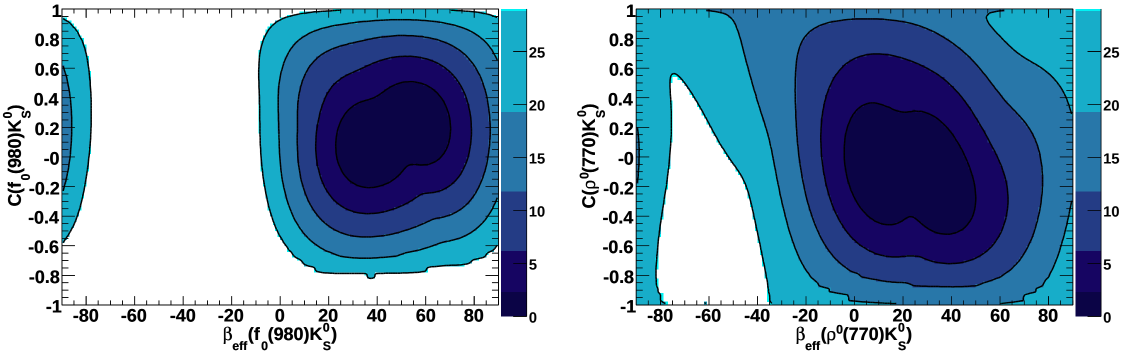

Figure 3: Two-dimensional scans of $-2\Delta\log\mathscr{L}$ (where $\mathscr{L}$ is the value of the likelihood) as a function of $\beta_{\rm eff}$ and C for the $f_0(980)K^0_S$ (left) and $\rho^0(770)K^0_S$ (right) isobar components. The value $-2\Delta\log\mathscr{L}$ is computed including systematic uncertainties. The shaded areas, from the darkest to the lightest, represent the one to five standard deviations contours.

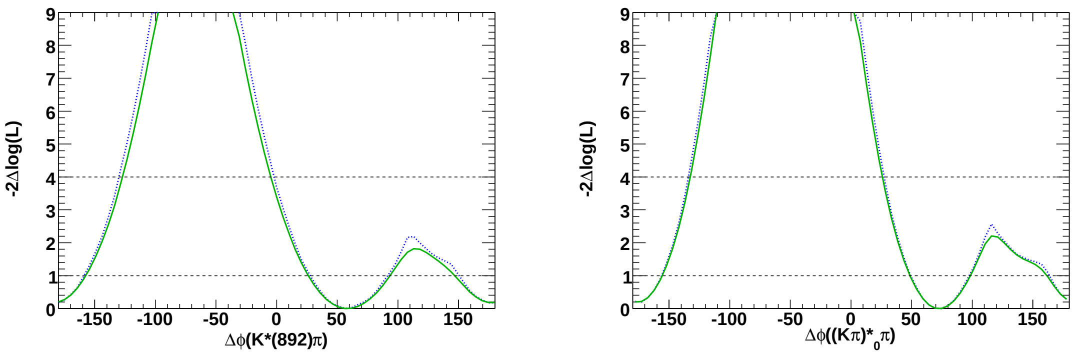

Figure 4: Statistical (dashed line) and total (solid line) scans of $-2\Delta\log\mathscr{L}$ (where $\mathscr{L}$ is the value of the likelihood) as a function of the relative phases $\Delta\Phi(K^*(892)\pi)$ (left) and $\Delta\Phi((K\pi)^*_0)$ (right). Horizontal dotted lines mark the one and two standard deviation levels.

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