Searches for New Physics in CP Violation from BABAR

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Abstract

Results of recent searches for new physics in CP violation in charm decays from the *BABAR* experiment are presented. These results include a measurement of D^0 - $\overline{D}^0$ mixing and searches for CP violation in two-body D^0 decays, a search for CP violation in the charm decays $D^{\pm} \to K^0_S K^{\pm}$ and $D^{\pm}_s \to K^0_S K^{\pm}$, $K^0_S \pi^{\pm}$, and a search for direct CP violation in the singly-Cabibbo suppressed $D^{\pm} \to K^+ K^- \pi^{\pm}$ decays. These studies are based on the final dataset collected by *BABAR* at the PEP-II B factory at SLAC in the period 1999-2008. No evidence of CP violation is found in these charm decays. The measured mixing parameter $y_{CP} = [0.72 \pm 0.18(stat) \pm 0.12(syst)]\%$ excludes the no-mixing null hypothesis with a significance of 3.3σ.

1 Introduction

The Cabibbo-Kobayashi-Maskawa (*CKM*) paradigm of CP violation (*CPV*) in the Standard Model (*SM*) has been tested by the *BABAR* and Belle experiments with high precision in many overconstrained measurements. Nevertheless *SM* leaves many unanswered questions. *CPV* is one of the three Sakharov necessary conditions to generate the asymmetry between matter-antimatter (baryogenesis) observed in the Universe. The measured *CKM* weak phase is unable to provide enough *CPV* to explain the observed baryon asymmetry. New *CPV* sources are needed from New Physics (*NP*) beyond the *SM*.

At the B-factories important areas of search for *NP* are processes which are expected at low level in *SM* and which could be enhanced by *NP*. In these *NP* searches at low energies, charm physics plays currently an important and increasing role. The *BABAR*, Belle and CDF measurements of flavor mixing in the neutral D meson system [1] show evidence of D^0 - $\overline{D}^0$ mixing at 1 % level. These results are in agreement with *SM* predictions [2, 3, 4] and sets constraints on possible contributions from many *NP* models [5].

Recently the LHCb collaboration has reported a first evidence of CP violation in D^0 decays to K^+K^- and $\pi^+\pi^-$ [6]. This evidence has been confirmed by the CDF Collaboration [7]. Given the *SM* expectation that *CPV* in charm sector should be at the level of 10^{-3} (or lower) [2, 4], this *CPV* evidence was rather unexpected at the present experimental sensitivity. Marginally compatible with the *SM* expectations, this *CPV* may be a manifestation of *NP* or of significant enhancements of penguin diagrams in charm decays [8, 9, 10, 11, 12].

In this talk I present recent *BABAR* measurements concerning mixing and CP violation in charm sector. All new results presented here are preliminary.

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2 D^0- $\overline{D}^0$ Mixing and CP Violation in Two-Body D^0 decays

Mixing in charm sector is unique because it involves virtual down type quarks. It arises from both short range and long range contributions. The short range contribution is expected to be very small because of *CKM* and GIM suppressions. The dominant long range contribution is non perturbative and hard to evaluate. This implies large theoretical uncertainties in the *SM* calculations of the mixing parameters x and y [3, 13, 14]. *SM* expectations values for x and y are $\leq 10^{-3}$ but higher values are predicted in some *NP* models [15, 16].

In a recent *BABAR* analysis [17] charm mixing and *CP* violation are measured using the ratio of lifetimes obtained in the D^0 decays to the two-body final states $K^{\mp}\pi^{\pm}$, K^-K^+, and $\pi^-\pi^+$. The analysis is based on an integrated luminosity of 468 fb^{-1} collected by the *BABAR* detector [18]. Five different signal channels are considered [19]: three flavor tagged channels $D^{*+} \to D^0\pi_s^+$ with $D^0 \to K^+K^-$, $D^0 \to \pi^+\pi^-$, and $D^0 \to K^-\pi^+, K^+\pi^-$ and two flavor untagged channels $D^0 \to K^+K^-$ and $D^0 \to K^-\pi^+$, $K^+\pi^-$, where π_s^+ is a slow pion track used in the tagging algorithm.

The experimental observables y_{CP} [20] , sensitive to mixing, and ΔY, sensitive to *CPV* , are measured. These observables are defined as:

$$y_{CP} \equiv \frac{\Gamma^+ + \bar{\Gamma}^+}{\Gamma} - 1 \qquad and \qquad \Delta Y \equiv \frac{\Gamma^+ - \bar{\Gamma}^+}{2\Gamma}, \tag{1}$$

where Γ^+ ($\bar{\Gamma}^+$) is the average width of the D^0 ($\overline{D}^0$) when reconstructed in the *CP*-even eigenstates (K^+K^-, $\pi^+\pi^-$). Γ is the average D^0 width describing the decays to the CP-mixed final states $K^{\mp}\pi^{\pm}$ [21].

Neglecting contribution of direct *CP* violation estimated at a level below our sensitivity [22] and taking into account that the *CP* violating weak phase ϕ in *SM* to a good approximation does not depend on the final states [23], the observables y_{CP} and ΔY in terms of the mixing parameters x and y can be written as:

$$\begin{aligned} y_{CP} &= y\cos\phi + \frac{\mathcal{A}_M}{2}x\sin\phi \\ \Delta Y &= -x\sin\phi + \frac{\mathcal{A}_M}{2}y\cos\phi\,, \end{aligned} \tag{2}$$

where $\mathcal{A}_M = (|q/p|^2 - |p/q|^2)/(|q/p|^2 + |p/q|^2)$ measures the *CP* asimmetry in mixing. The complex parameters p and q relate the mass eigenstates of neutral mesons , $|D_{1,2}>$, to the flavor eigenstates, $|D^0>$ and $|\overline{D}^0>$, through the relation $|D_{1,2}>= p|D^0> \pm q|\overline{D}^0>$. With no *CP* violation $y_{CP} = y$ and $\Delta Y = 0$.

A simultaneous extended unbinned Maximum Likelihood (ML) fit to the two-dimensional distribution of the proper time and proper time error in tagged and untagged modes is performed: the average D^0 lifetime τ is extracted from $K^{\mp}\pi^{\pm}$ final states and the effective lifetime τ^+ ($\bar{\tau}^+$) is extracted from D^0 ($\overline{D}^0$) decays to the final states K^-K^+ and $\pi^-\pi^+$. Main sources of background are misreconstructed charm events and the combinatorial background candidates consisting of random tracks. Using the reciprocals of the three measured lifetimes in Eq. 1 we obtain:

$$y_{CP} = (0.72 \pm 0.18 \pm 0.12)\% \qquad and \qquad \Delta Y = (0.09 \pm 0.26 \pm 0.09)\%\,,$$

where the first uncertainty is statistical and the second systematic. Projections of lifetime fit are in Fig. 1.

These results exclude no-mixing hypothesis at 3.3σ significance and show no evidence of *CPV*. The y_{CP} value is consistent with the mixing parameter y measured in the decays $D^0 \to K_S^0 h^+h^-$ (where $h = K, \pi$) [24] as expected in absence of *CPV*. This y_{CP} measurement is the most precise single measurement up to date. These results are in agreement with *SM* predictions.

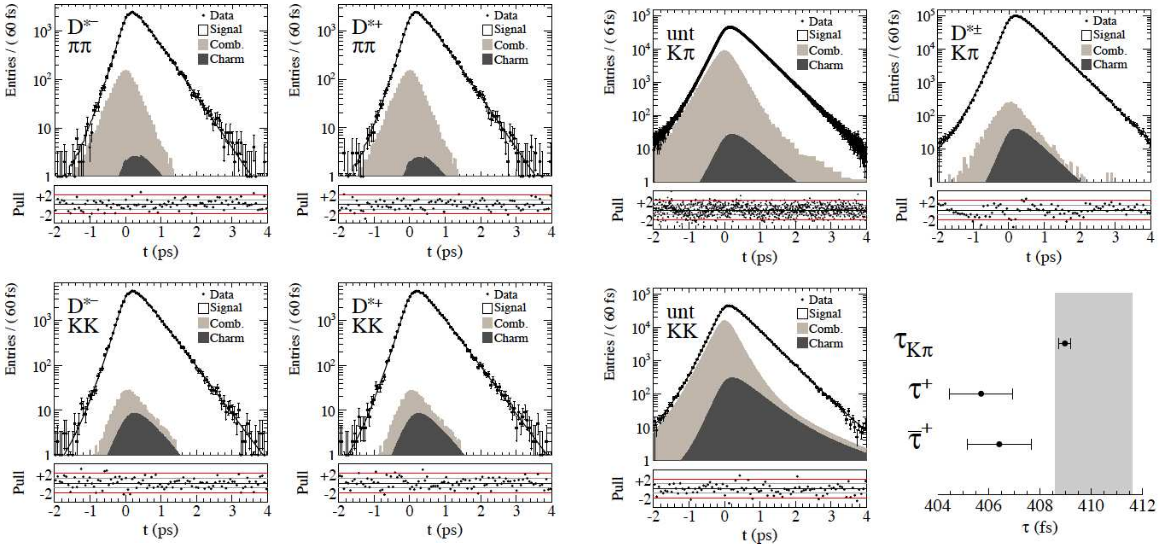

Figure 1: Proper time fit projections with the fit results overlaid. The combinatorial background distribution (Comb) is stacked on the top of the misreconstructed-charm background distribution (Charm). Under each plot are shown the normalized Poisson pulls; "unt" refers to the untagged dataset. The gray band is the PDG D^0 lifetime $\pm\sigma$[25].

3 *CP* Violation in $D^{\pm} \to K^0_S K^{\pm}$ and $D^{\pm}_s \to K^0_S K^{\pm}$, $K^0_S \pi^{\pm}$

The channels $D^{\pm} \to K^0_S K^{\pm}$ can proceed through Cabibbo-Favored (CF) and Doubly-Cabibbo-Suppressed (DCS) transitions. The CF transition is largely dominating and the *SM* expectation for direct *CP* is negligible. The channels $D^{\pm}_s \to K^0_S K^{\pm}$, $K^0_S \pi^{\pm}$ can proceed through two Singly-Cabibbo-Suppressed (SCS) transitions, both of comparable amplitudes. The relative weak phase between the two decay amplitudes can generate interference effects and induce direct *CPV*.

In these channels with a K^0 (or $\overline{K}^0$) in the final state a time-integrated *CPV* of $\approx (\pm 0.332 \pm 0.006)\,\%$ is induced by the $K^0\overline{K}^0$ mixing [25]. The sign of this asymmetry is positive (negative) in presence in the final state of a K^0 ($\overline{K}^0$). The exact value of this *CPV* asymmetry contribution depends on the requirements on the reconstructed $K^0_S \to \pi^+\pi^-$ decays and the decay kinematics [26].

Previous results of searches for direct *CP* violation in these decay modes by CLEO-c [27] and Belle [28] Collaborations are all in agreement with *SM* expectations.

Direct *CP* asymmetry in these charm decay modes has been recently searched for by *BABAR* [29] using a dataset of $469 fb^{-1}$. The following direct *CP*-violating parameter $\mathcal{A}_{CP}$ is measured for each decay channel:

$$\mathcal{A}_{CP} = \frac{\Gamma(D^+_{(s)} \to K^0_S(\pi^+, K^+)) - \Gamma(D^-(s) \to K^0_S(\pi^+, K^+))}{\Gamma(D^+_{(s)} \to K^0_S(\pi^+, K^+)) + \Gamma(D^+_{(s)} \to K^0_S(\pi^+, K^+))}\,, \tag{3}$$

where Γ is the partial width of the decay channel.

The measured *CP* asymmetry $\mathcal{A}$ an be written as $\mathcal{A} = \mathcal{A}_{CP} + \mathcal{A}_{\mathcal{FB}} + \mathcal{A}_{\epsilon}$, where $\mathcal{A}_{CP}$ is the direct *CP* asymmetry contribution, $\mathcal{A}_{FB}$ is a forward/backward asymmetry contribution in $c\bar{c}$ production from $\gamma - Z^0$ interference and higher order QED processes, and $\mathcal{A}_{\epsilon}$ is the asymmetry contribution induced by the detector in tracking, particle identification, and in material interactions. $\mathcal{A}_{FB}$ asymmetry is an odd function of the cosine of the polar angle of the $D^{\pm}_{(s)}$ meson momentum in the e^+e^- center of mass (CM) system, $\cos\theta^*_D$. $\mathcal{A}_{CP}$ and $\mathcal{A}_{FB}$ are both measured while data have been corrected for $\mathcal{A}_{\epsilon}$ with a control sample. The data-driven method used to correct for $\mathcal{A}_\epsilon$ is described in Ref.[30].

A simultaneous binned ML fit to the $D^+_{(s)}$ and $D^-_{(s)}$ mass distributions is performed in 10 equally spaced bins of $\cos\theta^*_D$ with bin 0 at [-1.0, -0.8]. Since $\mathcal{A}_{CP}$ is independent of the kinematic variable $\cos\theta^*_D$, the asymmetry $\mathcal{A}(+|\cos\theta^*_D|)$ measured in a positive $\cos\theta^*_D$ bin and the asymmetry $\mathcal{A}(-|\cos\theta^*_D|)$ measured in its symmetric (negative) counterpart $\cos\theta^*_D$ bin give the same contribution to $\mathcal{A}_{CP}$. On the other hand since $\mathcal{A}_{FB}$ is an odd function of $\cos\theta^*_D$, the contribution to $\mathcal{A}_{FB}$ from symmetric $\cos\theta^*_D$ bins have the same magnitude and opposte sign. So $\mathcal{A}_{CP}$ and $\mathcal{A}_{FB}$ as a function of $\cos\theta^*_D$ can be written in the form:

$$\begin{aligned}\mathcal{A}_{FB}(|\cos^*\theta_D|) &= \frac{\mathcal{A}(+|\cos\theta^*_D|) - \mathcal{A}(-|\cos\theta^*_D|)}{2}\\ \mathcal{A}_{CP}(|\cos^*\theta_D|) &= \frac{\mathcal{A}(+|\cos\theta^*_D|) + \mathcal{A}(-|\cos\theta^*_D|)}{2}\,,\end{aligned} \tag{4}$$

The values of $\mathcal{A}_{CP}$ and $\mathcal{A}_{FB}$ asymmetries are shown in Fig. 2.

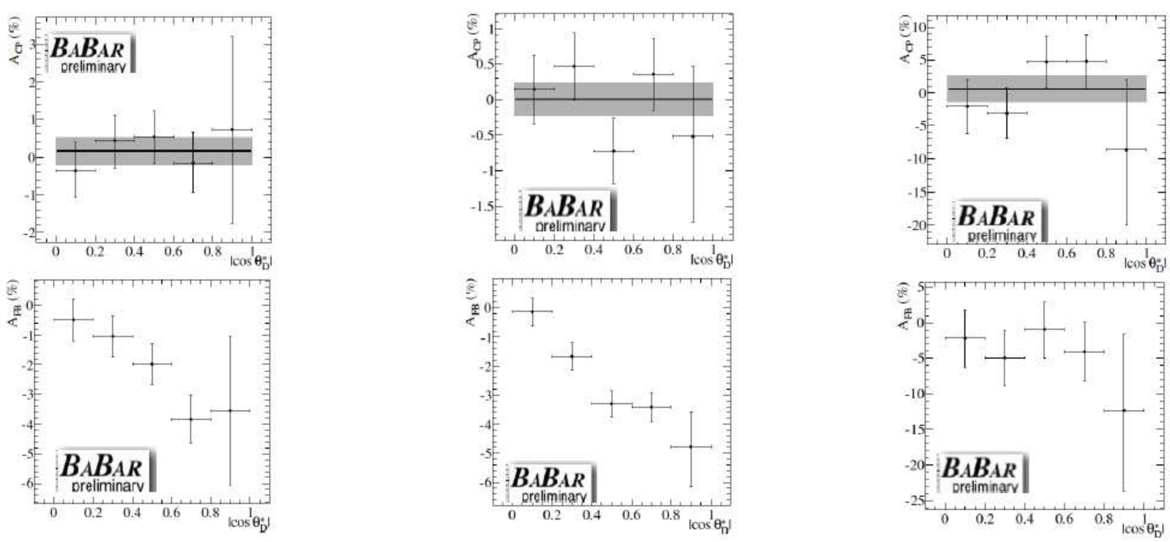

Figure 2: $\mathcal{A}_{CP}$ (top) and $\mathcal{A}_{FB}$ (bottom) asymmetries for $D^\pm \to K^0_S K^\pm$ (left), $D^\pm_s \to K^0_S K^\pm$ (center), and $D^\pm_s \to K^0_S \pi^\pm$ (right) as a function of $|\cos^*\theta_D|$ in the data sample. The solid line represents the central value of $\mathcal{A}_{CP}$ and the gray region is the $\pm\sigma$ interval, both from a χ^2 minimization assuming no dependence of $\mathcal{A}_{CP}$ on $|\cos^*\theta_D|$.

For each decay mode Table 1 shows the $\mathcal{A}_{CP}$ value from the fit, the bias corrected $\mathcal{A}_{CP}$ value and in the last raw the $\mathcal{A}_{CP}$ value after subtracting the expcted $\mathcal{A}_{CP}$ contribution due to K^0-$\overline{K}^0$ mixing. These results are consistent with zero and with the *SM* predictions within 1 σ.

4 CP Violation in the Decays $D^\pm \to K^+K^-\pi^\pm$

Searches for direct *CP* violation in the SCS decays $D^\pm \to K^+K^-\pi^\pm$ have been recently performed by *BABAR*, using a dataset of $476 fb^{-1}$ [31]. This sample contains enough 3-body SCS decays to probe *CP* at the level of *SM* predictions. The decay $D^+ \to K^+K^-\pi^+$ [19] is dominated by quasi-two body decays with resonant intermediate states, giving possibility to study direct *CPV* in a particular resonance or in different regions of the Dalitz plot (*DP*). In previous analyses of these 3-body decay modes performed by CLEO-c [32] and LHCb [33] Collaborations no evidence for *CPV* has been found in agreement with *SM* prediction.

Table 1: A_{CP} measurements. Uncertainties, where reported, are statistical the first and systematic the second (*BABAR* Preliminary).

	$D^{\pm} \to K_S^0 K^{\pm}$	$D_s^{\pm} \to K_S^0 K^{\pm}$	$D_s^{\pm} \to K_S^0 \pi^{\pm}$
A_{CP} value from the fit	$(+0.16 \pm 0.36)\%$	$(0.00 \pm 0.23)\%$	$(+0.6 \pm 2.0)\%$
Bias Corrections for:			
Toy MC experiments	$+0.013\%$	-0.01%	$-$
PID selectors	-0.05%	-0.05%	-0.05%
$K_S^0 - K_L^0$ interference	$+0.015\%$	$+0.014\%$	-0.008%
A_{CP} final value	$(+0.13 \pm 0.36 \pm 0.25)\%$	$(-0.05 \pm 0.23 \pm 0.24)\%$	$(+0.6 \pm 2.0 \pm 0.3)\%$
A_{CP} contribution from $K^0 - \overline{K}^0$ mixing	$(-0.332 \pm 0.006)\%$	$(-0.332 \pm 0.006)\%$	$(+0.332 \pm 0.006)\%$
A_{CP} final value (charm only)	$(+0.46 \pm 0.36 \pm 0.25)\%$	$(+0.28 \pm 0.23 \pm 0.24)\%$	$(+0.3 \pm 2.0 \pm 0.3)\%$

Signal reconstruction efficiency is determined with a sample of Monte Carlo (MC) simulated events from the distribution of reconstructed events as a function of the *CM* polar angle of the D meson ($\cos\theta_{CM}$) and of the $m^2(K^-\pi^+)$ vs $m^2(K^+K^-)$ *DP*. The ratio of efficiency-corrected signal yields, $R = \frac{N_{D^+}/\epsilon_{D^+}}{N_{D^-}/\epsilon_{D^-}} = 1.020 \pm 0.006$ is used to allow for asymmetries in the MC event production due to physics or detector induced effects.

Time-integrated *CP* asymmetry (charge asymmetry) is defined in a given bin as:

$$\mathcal{A} \equiv \frac{N_{D^+}/\epsilon_{D^+} - N_{D^-}/\epsilon_{D^-}}{N_{D^+}/\epsilon_{D^+} + N_{D^-}/\epsilon_{D^-}} \tag{5}$$

Selection efficiencies are corrected to account for differences between data and MC simulated events in the reconstruction asymmetry of charged pion tracks and in the production model of charm mesons. The charge asymmetry $\mathcal{A}$ contains contributions from both the forward/backward asymmetry $\mathcal{A}_{FB}$ and the direct *CP* asymmetry $\mathcal{A}_{CP}$. To remove the contribution $\mathcal{A}_{FB}$, the charge asymmetry is averaged over four symmetric bins in $\cos\theta_{CM}$. The averaged values of $\mathcal{A}_{CP}$ in the four bins are shown Fig. 3. The central value $\mathcal{A}_{CP} = (0.35 \pm 0.30 \pm 0.15)$ % is obtained with a χ^2 minimization. The probability that the asymmetries are null in all the four bins is 21%.

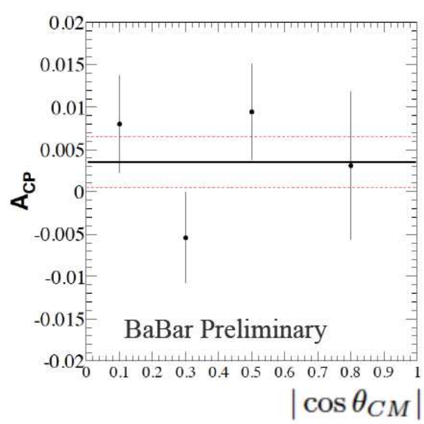

Figure 3: Charge asymmetry $\mathcal{A}_{CP}$ as a function of $|\cos\theta_{CM}|$ in data. The solid line represents the central value of $\mathcal{A}_{CP}$ and the dashed lines represent the $\pm\sigma$ interval, both determined from a χ^2 minimization assuming no dependence on $|\cos\theta_{CM}|$.

A model-independent technique to search for *CP* violation in *DP* is to compare *CP* asym-

Table 2: Yields, efficiencies,, and CP asymmetry in four different regions of the DP. First uncertainty in the CP asymmetry is statistical, the second is systematic (*BABAR* Preliminary).

Dalitz plot region	$N(D^+)$	$\epsilon(D^+)[\%]$	$N(D^-)$	$\epsilon(D^-)[\%]$	$A_{CP}[\%]$
Below $\bar{K}^*(892)^0$	1882 ± 70	7.00	1859 ± 90	6.97	-0.65 ± 1.64 ± 1.73
$\bar{K}^*(892)^0$	36770 ± 251	7.53	36262 ± 257	7.53	-0.28± 0.37 ± 0.21
$\phi(1020)$	48856 ± 289	8.57	48009 ± 289	8.54	-0.26 ± 0.32 ± 0.45
Above $\bar{K}^*(892)^0$ and $\phi(1020)$	25616 ± 244	8.01	24560 ± 242	8.00	1.05 ± 0.45 ± 0.31

metries in different regions of the *DP*. The results of $\mathcal{A}_{CP}$ asymmetry measured in four regions of *DP* are given in Table 2. Measured *CP* asymmetries are consistent with zero.

We also measure the normalized residuals Δ of efficiency-corrected and background subtracted *DP* for D^+ and D^- for equally populated bins. Δ is defined as

$$\Delta \equiv \frac{n(D^+) - R\,n(D^-)}{\sqrt{\sigma^2(D^+) + R^2\sigma^2(D^-)}}\,, \tag{6}$$

where n is the yield in a bin in the *DP* and σ its uncertainty.

Δ distribution is fitted to a Gaussian function. For 100 bins we obtain a Gaussian residual mean of 0.08 ± 0.15 and a width of 1.11 ± 0.15. The probability that the two *DP*'s are consistent with no *CP* asymmetry is 72%.

Angular moments of the cosine of the helicity angle θ_H of the D decay products reflect the spin and mass of intermediate resonant and non resonant states [34]. The helicity angle θ_H in the decay $D \to (r \to AB)C$ is defined as the angle between the momenta of B and parent D in the AB rest frame. We can search for *CP* in the *DP* in a model-independent way by comparing the angular moments between D^+ and D^- [35]. Angular moments of order l are defined as the efficiency-corrected and background-subtracted two-body invariant mass distributions ($m(K^+K^-)$, $m(K^-\pi^+)$) weighted by spherical harmonic moments $w^{(l)} = Y_l^0(\cos\theta_H)$. Weights in two-body invariant mass intervals are defined as:

$$W_i^{(l)} \equiv \frac{\left(\sum_j w_{ij}^{(l)S} - \sum_k w_{ik}^{(l)B}\right)}{< \epsilon_i >}\,, \tag{7}$$

where i is bin index, and j, k event indices. S and B refer to signal and background, and $< \epsilon_i >$ is the average efficiency in bin i.

Normalized moment residuals X_l for D^+ and D^- are calculated for l from 0 to 7:

$$X_l = \frac{\left(W_i^{(l)}(D^+) - RW_i^{(l)}(D^-)\right)}{\sqrt{\sigma_1^{(l)^2}(D^+) + R^2\sigma_1^{(l)^2}(D^-)}} \tag{8}$$

The χ^2 is calculated over all the mass bins in K^+K^- and $K^-\pi^+$ moments with

$$\chi^2 = \sum_i \sum_{l_1} \sum_{l_2} X_i^{(l_1)} \rho_i^{(l_1 l_2)} X_i^{(l_2)}\,, \tag{9}$$

where $\rho_i^{(l_1 l_2)}$ is the correlation coefficient between $X_i^{(l_1)}$ and $X_i^{(l_2)}$.

With a number of degrees of freedom NDF equal to 287 the χ^2/NDF in the K^+K^- and $K^-\pi^+$ moments is 1.10 and 1.09, consistent with no *CPV* at 11% and 13 %, respectively.

BABAR also searched for *CPV* in a model-dependent *DP* analysis of the $D^+ \to K^+K^-\pi^+$ decay [19]. The *DP* amplitude $\mathcal{A}$ in the isobar model is written as a set of two-body intermediate

Table 3: *CPV* parameters from the *DP* fit. First uncertainties are statistical, the second systematic (*BABAR* Preliminary).

Resonance	r (%)	$\Delta\phi$ (°)
$\bar{K}^*(892)^0$	0. (FIXED)	0. (FIXED)
$\bar{K}_0^*(1430)^0$	$-9.40^{+5.65}_{-5.36} \pm 4.42$	$-6.11^{+3.29}_{-3.24} \pm 1.39$
$\phi(1020)$	$0.35^{+0.82}_{-0.82} \pm 0.60$	$7.43^{+3.55}_{-3.50} \pm 2.35$
NR	$-14.30^{+11.67}_{-12.57} \pm 5.98$	$-2.56^{+7.01}_{-6.17} \pm 8.91$
$\kappa(800)$	$2.00^{+5.09}_{-4.96} \pm 1.85$	$2.10^{+2.42}_{-2.45} \pm 1.01$
$a_0(1450)^0$	$5.07^{+6.86}_{-6.54} \pm 9.39$	$4.00^{+4.04}_{-3.96} \pm 3.83$
	Δx	Δy
$f_0(980)$	$-0.199^{+0.106}_{-0.110} \pm 0.084$	$-0.231^{+0.100}_{-0.105} \pm 0.079$
$f_0(1370)$	$0.019^{+0.049}_{-0.048} \pm 0.022$	$-0.0045^{+0.037}_{-0.039} \pm 0.016$

states r : $\mathcal{A} = \sum_r \mathcal{M}_r e^{i\phi_r} F_r$, where $\mathcal{M}_r$ and ϕ_r are real and $F_r = F_r(m(K^+K^-), m(K^-\pi^+))$ are dynamical functions describing the intermediate states. In case of amplitudes with small contributions the complex coefficient has been parameterized in a Cartesian form: $x_r = \mathcal{M}_r \cos\phi_r$ and $y_r = \mathcal{M}_r \sin\phi_r$. The $K^*(892)^0$ has been chosen as the reference amplitude. Assuming no *CPV* the relative fractions of resonances and a constant non resonant amplitude over the entire *DP* contributing to the decay have been determined with an unbinned ML fit.

To allow for possible *CPV* in the decay, the resonances of the D^+ (D^-) decays contributing with a fit fraction of at least 1% have been parameterized with different amplitudes and phases in their decay amplitudes. A simultaneous fit to the D^+ and D^- samples have been performed, parameterizing each resonance with four parameters, $\mathcal{M}_r$, ϕ_r, r_{CP}, and $\Delta\phi_{CP}$. The *CPV* parameters are $r_{CP} = \frac{|\mathcal{M}_r|^2 - |\bar{\mathcal{M}}_r|^2}{|\mathcal{M}_r|^2 + |\bar{\mathcal{M}}_r|^2}$ and $\Delta\phi_{CP} = \phi_r - \bar{\phi}_r$.

The Cartesian form of the *CP* violating parameters are Δx_r and Δy_r with $x_r(D^\pm) = x_r \pm \Delta x_r/2$ and $y_r(D^\pm) = y_r \pm \Delta y_r/2$. Fit results are shown in Table 3.

All *CPV* parameters from *DP* fit are consistent with zero and with *SM* expectations.

5 Conclusions

I have presented recent improved *BABAR* measurement of mixing and a search of *CP* violation in two-body D^0 decays, a search for direct *CP* violation in $D^\pm \to K^0_S K^\pm$ and $D^\pm_s \to K^0_S K^\pm$, $K^0_S \pi^\pm$, and searches for *CP* violation in the decays $D^\pm \to K^+K^-\pi^\pm$ both using model-independent and model-dependent analysis techniques. All results in these analyses are well described within the *SM* and no effect related to *NP* has been found. The measured mixing parameter $y_{CP} = [0.72 \pm 0.18(stat) \pm 0.12(syst)]\%$ excludes the no-mixing null hypothesis with a significance of 3.3σ.

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