

# Global fits to $D^0$ CPV parameters using an HFAG like fit

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## Abstract

The new  $D^0 \rightarrow K\pi$  result from LHCb provides a credibly powerful constraint on mixing parameters. This note describes a fit in the style of HFAG to combine our result with previous measurements.

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## 1 Introduction

To fully understand the global impact of the updated WS  $D^0 \rightarrow K\pi$  analysis, a combination of global results of the neutral  $D$  system is necessary. We present an HFAG-like fit for the underlying parameters  $|q/p|$ ,  $\phi$ ,  $x$  and  $y$  using the updated 2011+2012 LHCb  $D^0 \rightarrow K\pi$  results.

## 2 Chi-square calculation

The purpose of our fit is to combine the errors on several different measurements of the same parameters, where each measurement may have a different relation to the underlying true mixing parameters (eg measuring  $(x'^2, y')$  in place of  $(x, y)$ ), and where the numbers in each measurement may be strongly correlated. To do so we construct an overall  $\chi^2$  for all the results:

$$\chi^2 = \vec{\epsilon}^T \sigma^{-1} \vec{\epsilon} \quad (1)$$

where the elements of  $\vec{\epsilon}$  are given by  $\epsilon_i = m_i - p_i$ . Here  $\vec{m}$  is the list of measured values from experiments, and  $\vec{p}$  is a set of “proposed” values for the mixing parameters; we use MINUIT to vary  $\vec{p}$  so as to minimise  $\chi^2$ . Finally,  $\sigma$  is an  $N \times N$  matrix where  $N$  is the number of measurements, with  $\sigma_{ij} = e_i c_{ij} e_j$ . Here  $e_i$  is the reported error on measurement  $i$ , and  $c_{ij}$  is the correlation coefficient between measurements  $i$  and  $j$ .

Notice that, if the measurements are uncorrelated, then  $\sigma$  reduces to a diagonal matrix where the elements are the squares of the measurement errors. In this case  $\chi^2$  is simply the sum  $\sum_i \epsilon_i^2 / e_i^2$ , that is, each element is the difference between a measurement and the

corresponding prediction, divided by the error on the measurement, squared. In other words, if there are no correlations we recover the usual chi-square goodness-of-fit metric.

### 3 Fit variants

In full generality, we wish to fit for no less than seven underlying related mixing parameters:

- $x$  and  $y$ , the normalised mass and width differences
- $R_D^+$  and  $R_D^-$ , the ratios of rates
- $\delta$ , the strong phase difference
- $|q/p|$  and  $\phi$ , the magnitude and phase of the indirect CP violation.

The observed inputs, however, are not all direct measurements of these quantities. From  $D^0 \rightarrow K_S \pi \pi$  we get direct measurements of  $x$ ,  $y$ ,  $|q/p|$  and  $\phi$ ;  $D^0 \rightarrow K \pi$  results also yield  $R_D^\pm$  directly, although sometimes quoted as  $R_D = \frac{1}{2}(R_D^+ + R_D^-)$  and  $A_D = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-}$ . However, we also measure the derived parameters  $x'^{2(\pm)}$ ,  $y'^{(\pm)}$ ,  $y_{CP}$ , and  $A_\Gamma$ , defined as:

$$x' = x \cos \delta + y \sin \delta \quad (2)$$

$$y' = y \cos \delta - x \sin \delta \quad (3)$$

$$x'^{\pm} = \left( \frac{1 \pm A_M}{1 \mp A_M} \right)^{1/4} (x' \cos \phi \pm y' \sin \phi) \quad (4)$$

$$y'^{\pm} = \left( \frac{1 \pm A_M}{1 \mp A_M} \right)^{1/4} (y' \cos \phi \mp x' \sin \phi) \quad (5)$$

$$2y_{CP} = (|q/p| + |p/q|) y \cos \phi - (|q/p| - |p/q|) x \sin \phi \quad (6)$$

$$2A_\Gamma = (|q/p| - |p/q|) y \cos \phi - (|q/p| + |p/q|) x \sin \phi \quad (7)$$

$$(8)$$

where the helper quantity  $A_M$  is given by

$$A_M = \frac{|q/p|^2 - |p/q|^2}{|q/p|^2 + |p/q|^2}. \quad (9)$$

To calculate  $\vec{\epsilon}$ , then, we take in a vector of proposed mixing parameters from MINUIT, calculate the resulting observable parameters from the equations above, and subtract the actually observed numbers.

In addition to the fully-general fit allowing all these variables to float, there are some variants imposing different no-CPV constraints:

- No CP violation. In this fit we set  $|q/p| = 1$ ,  $\phi = 0$ , and  $R_D^+ = R_D^-$ , and fit only for  $x$ ,  $y$ ,  $\delta$ , and  $R_D$ .

- 40 • No direct CP violation. With no direct CP violation,  $R_D^+ = R_D^-$ ; in addition, the  
 41 four parameters  $x$ ,  $y$ ,  $\phi$  and  $|q/p|$  are related (in the limit that CPV is small) by the  
 42 constraint

$$|q/p| = 1 - \frac{y}{x} \tan \phi \quad (10)$$

$$\phi = \tan^{-1} \left( \frac{1 - |q/p|^2 x}{1 + |q/p|^2 y} \right) \quad (11)$$

43 Thus we have two variants on this fit:

44 **2a** Here we allow  $|q/p|$  to float and calculate  $\phi$  from the constraint.

45 **2b** We allow  $\phi$  to float and calculate  $|q/p|$  from the constraint.

- 46 • All CPV allowed. As  $A_D$  is quite small, the contribution of a new physics phase to  $\phi$   
 47 is far below our current sensitivity; consequently the constraint above is a reasonable  
 48 approximation. We therefore run three variants of the all-CPV-allowed scenario:

49 **3a** All parameters float, no constraint.

50 **3b**  $\phi$  is calculated from  $|q/p|$  as above, rather than allowed to float.  $R_D^+$  and  $R_D^-$  are  
 51 both free, as before.

52 **3c** As in 3b, but with  $|q/p|$  calculated from the constraint and  $\phi$  allowed to float.

53 In addition, we do a fit not allowing direct CP violation, in which the free parameters  
 54 are the underlying<sup>1</sup>  $x_{12}$ ,  $y_{12}$ , and  $\phi$ . These parameters are related (in the limit of no direct  
 55 CP violation) to  $|q/p|$ ,  $x$ ,  $y$  and  $\phi$  (no subscripts!) as follows:

$$x = \frac{1}{\sqrt{2}} \text{sg}(\cos \phi_{12}) \sqrt{x_{12}^2 - y_{12}^2 + |x_{12}^2 + y_{12}^2| - 4x_{12}^2 y_{12}^2 \sin^2(\phi_{12})} \quad (12)$$

$$y = \frac{1}{\sqrt{2}} \sqrt{y_{12}^2 - x_{12}^2 + |x_{12}^2 + y_{12}^2| - 4x_{12}^2 y_{12}^2 \sin^2(\phi_{12})} \quad (13)$$

$$|q/p| = \left( \frac{x_{12}^2 + y_{12}^2 + 2x_{12}y_{12}\sin(\phi_{12})}{x_{12}^2 + y_{12}^2 - 2x_{12}y_{12}\sin(\phi_{12})} \right)^{1/4} \quad (14)$$

$$\phi = -\frac{1}{2} \frac{\sin(2\phi_{12})}{\cos(2\phi_{12}) + \frac{y_{12}^2}{x_{12}^2}}. \quad (15)$$

56 Our approach in this fit is to allow MINUIT to believe that the parameters  $x_{12}$ ,  $y_{12}$ , and  
 57  $\phi_{12}$  are free, but interpret them internally as giving rise to the non-underlying parameters  
 58  $x$ ,  $y$ ,  $\phi$ , and  $|q/p|$ , and use these values in the calculation of  $\chi^2$ , as outlined for the other  
 59 fits.

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<sup>1</sup>See Kagan and Sokoloff, <http://arxiv.org/abs/0907.3917>.

## 4 Measurements Used

Of all of the current measurements available, only a few are resonable for certain fits. Table 1 lists all the possible measurements pertaining to fits excluding CP Violation. Table 2 corresponds to measurements allowing only direct CP violation, and Table 3 lists all measurments pertaining to both direct and indirect CP violation allowed.

Result	Value	Correlation Coefficients
HFAG $y_{CP}$	$0.00866 \pm 0.00155 \pm 0$	
LHCb $R_D$	$0.003568 \pm 5.8e-05 \pm 3.3e-05$	1 0.869 -0.953
LHCb $x'^2(K\pi)$	$5.5e-05 \pm 4.2e-05 \pm 2.6e-05$	1 -0.967
LHCb $y'(K\pi)$	$0.00481 \pm 0.00085 \pm 0.00053$	1
HFAG $x(K_S^0\pi\pi)$	$0.00419 \pm 0.00211 \pm 0$	
HFAG $y(K_S^0\pi\pi)$	$0.00456 \pm 0.00186 \pm 0$	
CLEO $\cos(\delta)(K\pi)$	$0.81 \pm 0.2 \pm 0.06$	
CLEO $\sin(\delta)(K\pi)$	$-0.01 \pm 0.41 \pm 0.04$	
CDF $R_D$	$0.00304 \pm 0.00055 \pm 0$	1 0.923 -0.87
CDF $x'^2(K\pi)$	$-0.00012 \pm 0.00035 \pm 0$	1 -0.984
CDF $y'(K\pi)$	$0.0085 \pm 0.0076 \pm 0$	1
Belle $R_D$	$0.00364 \pm 0.00017 \pm 0$	1 0.655 -0.834
Belle $x'^2(K\pi)$	$0.00018 \pm 0.00022 \pm 0$	1 -0.909
Belle $y'(K\pi)$	$0.0006 \pm 0.004 \pm 0$	
BaBar $R_D$	$0.00303 \pm 0.00016 \pm 0.0001$	1 0.77 -0.87
BaBar $x'^2(K\pi)$	$-0.00022 \pm 0.0003 \pm 0.00021$	1 -0.94
BaBar $y'(K\pi)$	$0.0097 \pm 0.0044 \pm 0.0031$	

Table 1: No CPV allowed inputs. Correlation coefficients follow the listing in the first column.

## 5 Results

The results are split into subsections depending on the type of CP Violation allowed. Additonally, results are presented using a variety of different combinations of the available data. Figure 1 shows all variations for the no CPV allowed fits. Figure 3 shows the results for a subset of variations on All CPV allowed fits.

### 5.1 No CP Violation Allowed

Table 4 lists the results from the No CP Violation allowed global fit. As  $A_\Gamma = 0$  in the the case of No CPV, the data is not included in this fit. Additionally, we take subsets of

Result	Value	Correlation Coefficients				
HFAG $y_{CP}$	$0.00866 \pm 0.00155 \pm 0$					
HFAG $A_\Gamma$	$-0.00022 \pm 0.00161 \pm 0$					
LHCb $A_\Gamma(KK)$	$-0.00035 \pm 0.00062 \pm 0.00012$					
LHCb $A_\Gamma(\pi\pi)$	$0.00033 \pm 0.00106 \pm 0.00014$					
LHCb $R_D$	$0.003568 \pm 5.8e-05 \pm 3.3e-05$	1	-0.902	0.773	-0.902	0.777
LHCb $y'^+(K\pi)$	$0.00446 \pm 0.00089 \pm 0.00057$		1	-0.948	0.795	-0.686
LHCb $x'^{2+}(K\pi)$	$7.7e-05 \pm 4.6e-05 \pm 2.9e-05$			1	-0.684	0.591
LHCb $y'^-(K\pi)$	$0.00517 \pm 0.00089 \pm 0.00058$				1	-0.950
LHCb $x'^{2-}(K\pi)$	$3.2e-05 \pm 4.7e-05 \pm 3e-05$					1
Belle $x(K_S^0\pi\pi)$	$0.00811 \pm 0.00334 \pm 0$					
Belle $y(K_S^0\pi\pi)$	$0.00309 \pm 0.00281 \pm 0$					
Belle $ q/p $	$0.95 \pm 0.22 \pm 0.1$					
Belle $\phi$	$-0.035 \pm 0.19 \pm 0.09$					
CLEO $R_D$	$0.00533 \pm 0.00107 \pm 0.00045$	1	0.000	0.000	-0.420	0.010
CLEO $x'^2(K\pi)$	$0.0006 \pm 0.0023 \pm 0.0011$		1	-0.730	0.390	0.020
CLEO $y'(K\pi)$	$0.042 \pm 0.02 \pm 0.01$			1	-0.530	-0.030
CLEO $\cos(\delta)(K\pi)$	$0.81 \pm 0.2 \pm 0.06$				1	0.040
CLEO $\sin(\delta)(K\pi)$	$-0.01 \pm 0.41 \pm 0.04$					1
CDF $R_D$	$0.00304 \pm 0.00055 \pm 0$		1	0.923	-0.971	
CDF $x'^2(K\pi)$	$-0.00012 \pm 0.00035 \pm 0$			1	-0.984	
CDF $y'(K\pi)$	$0.0085 \pm 0.0076 \pm 0$				1	
Belle $R_D$	$0.00364 \pm 0.00018 \pm 0$	1	0.655	-0.834	0.655	-0.834
Belle $x'^{2-}(K\pi)$	$6e-05 \pm 0.00034 \pm 0$		1	-0.909		
Belle $y'^-(K\pi)$	$0.002 \pm 0.0054 \pm 0$			1		
Belle $x'^{2+}(K\pi)$	$0.00032 \pm 0.00037 \pm 0$				1	-0.909
Belle $y'^+(K\pi)$	$-0.0012 \pm 0.0058 \pm 0$					1
BaBar $R_D$	$0.00303 \pm 0.000189 \pm 0$	1	0.77	-0.87	0.77	-0.87
BaBar $x'^{2-}(K\pi)$	$-0.0002 \pm 0.0005 \pm 0$		1	-0.94		
BaBar $y'^-(K\pi)$	$0.0096 \pm 0.0075 \pm 0$			1		
BaBar $x'^{2+}(K\pi)$	$-0.00024 \pm 0.00052 \pm 0$				1	-0.909
BaBar $y'^+(K\pi)$	$0.0098 \pm 0.0078 \pm 0$					1
BaBar $x(K_S^0\pi\pi)$	$0.0016 \pm 0.0023 \pm 0.0012$		1	0.0615		
BaBar $y(K_S^0\pi\pi)$	$0.0057 \pm 0.002 \pm 0.0013$			1		

Table 2: No Direct CPV allowed inputs. Correlation coefficients follow the order listed in the first column.

<sup>73</sup> the data which do not include results from Belle, BaBar and CDF in order to explore the  
<sup>74</sup> change in  $\chi^2/\text{ndf}$  of the global fit.

Result	Value	Correlation Coefficients					
HFAG $y_{CP}$	$(8.66 \pm 1.55) \times 10^{-3}$						
HFAG $A_{\Gamma}$	$(-0.22 \pm 1.61) \times 10^{-3}$						
LHCb $A_{\Gamma}(K\bar{K})$	$(-0.35 \pm 0.62 \pm 0.12) \times 10^{-3}$						
LHCb $A_{\Gamma}(\pi\pi)$	$(0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$						
LHCb $R_D^+$	$(3.523 \pm 0.081 \pm 0.047) \times 10^{-3}$	1	-0.947	0.866	-0.006	-0.007	0.006
LHCb $y'^+(K\pi)$	$(5.1 \pm 1.2 \pm 0.7) \times 10^{-3}$		1	-0.968	-0.007	0.007	-0.007
LHCb $x'^{2+}(K\pi)$	$(4.9 \pm 6.0 \pm 3.6) \times 10^{-5}$			1	0.006	-0.007	0.008
LHCb $R_D^-$	$(3.613 \pm 0.082 \pm 0.047) \times 10^{-3}$				1	-0.946	0.862
LHCb $y'^-(K\pi)$	$(4.5 \pm 1.2 \pm 0.7) \times 10^{-3}$					1	-0.966
LHCb $x'^{2-}(K\pi)$	$(6.0 \pm 5.8 \pm 3.6) \times 10^{-5}$						1
Belle $x(K_S^0\pi\pi)$	$(8.1 \pm 3.0 \pm 1.5) \times 10^{-3}$		1	-0.007	-0.510	0.216	
Belle $y(K_S^0\pi\pi)$	$(3.7 \pm 2.5 \pm 1.2) \times 10^{-3}$			1	-0.038	-0.280	
Belle $ q/p $	$0.86 \pm 0.3 \pm 0.1$				1	-0.266	
Belle $\phi$	$-0.244 \pm 0.31 \pm 0.09$					1	
CLEO $R_D$	$(5.33 \pm 1.07 \pm 0.45) \times 10^{-3}$		1	0.000	0.000	-0.420	0.010
CLEO $x^2(K\pi)$	$(0.6 \pm 2.3 \pm 1.1) \times 10^{-3}$			1	-0.730	0.390	0.020
CLEO $y(K\pi)$	$(4.2 \pm 2.0 \pm 1.0) \times 10^{-2}$				1	-0.530	-0.030
CLEO $\cos(\delta)(K\pi)$	$0.81 \pm 0.2 \pm 0.06$					1	0.040
CLEO $\sin(\delta)(K\pi)$	$-0.01 \pm 0.41 \pm 0.04$						1
CDF $R_D$	$(3.04 \pm 0.55) \times 10^{-3}$			1	0.923	-0.971	
CDF $x'^2(K\pi)$	$(-1.2 \pm 3.5) \times 10^{-4}$				1	-0.984	
CDF $y'(K\pi)$	$(8.5 \pm 7.6) \times 10^{-3}$					1	
Belle $R_D^-$	$0.0036 \pm 0.0002 \pm 0$		1	0.655	-0.834		
Belle $x'^{2-}(K\pi)$	$6e-05 \pm 0.00034 \pm 0$			1	-0.909		
Belle $y'^-(K\pi)$	$0.002 \pm 0.0054 \pm 0$				1		
Belle $R_D^+$	$0.00368 \pm 0.0002 \pm 0$					1	0.655
Belle $x'^{2+}(K\pi)$	$0.00032 \pm 0.00037 \pm 0$						1
Belle $y'^+(K\pi)$	$-0.0012 \pm 0.0058 \pm 0$						-0.909
BaBar $R_D^-$	$0.00303 \pm 0.0002 \pm 0.0001$		1	0.77	-0.87		
BaBar $x'^{2-}(K\pi)$	$-0.0002 \pm 0.00041 \pm 0.00029$			1	-0.94		
BaBar $y'^-(K\pi)$	$0.0096 \pm 0.0064 \pm 0.0045$				1		
BaBar $R_D^+$	$0.00303 \pm 0.0002 \pm 0.0001$					1	0.77
BaBar $x'^{2+}(K\pi)$	$-0.00024 \pm 0.00043 \pm 0.0003$						1
BaBar $y'^+(K\pi)$	$0.0098 \pm 0.0061 \pm 0.0043$						-0.87
BaBar $x(K_S^0\pi\pi)$	$0.0016 \pm 0.0023 \pm 0.0012$			1	0.0615		
BaBar $y(K_S^0\pi\pi)$	$0.0057 \pm 0.002 \pm 0.0013$				1		

Table 3: All CPV allowed inputs. Correlation coefficients follow the order listed in the first column.

## 5.2 No Direct CP Violation Allowed

Table 5 lists the results of the global fit of no direct CP violation. The final three columns of the table represent the effect of the inclusion of the preliminary LHCb  $A_\Gamma$  result in the global fit. The inclusion of this result does not change the central values or errors

	All Results	No Belle, BaBar	No Belle, BaBar, CDF
$x(\times 10^{-3})$	$3.677 \pm 1.815$	$4.497 \pm 1.912$	$4.515 \pm 1.919$
$y(\times 10^{-3})$	$6.504 \pm 1.006$	$6.856 \pm 1.040$	$6.876 \pm 1.041$
$\delta_{K\pi}(\times 10^{-1})$	$2.210 \pm 2.638$	$3.3407 \pm 2.131$	$3.253 \pm 2.141$
$R_D(\times 10^{-3})$	$3.497 \pm 0.041$	$3.552 \pm 0.046$	$3.552 \pm 0.047$
$\chi^2/ndf$	34.5065/13	14.8181/7	4.04354/4

Table 4: Output values of No CPV allowed global fit. Different columns list subsets of allowed data.

79 substantially.

	All Measurements	No Belle, BaBar	No Belle, BaBar, $A_{\Gamma \text{ LHCb}}$	No Belle, BaBar, CDF, $A_{\Gamma \text{ LHCb}}$
$x(\times 10^{-3})$	$5.191 \pm 1.746$	$4.843 \pm 1.782$	$4.845 \pm 1.782$	$4.844 \pm 1.787$
$y(\times 10^{-3})$	$6.343 \pm 0.905$	$6.797 \pm 1.029$	$6.797 \pm 1.030$	$6.809 \pm 1.031$
$\delta_{K\pi}(\times 10^{-1})[\text{rad}]$	$2.468 \pm 1.763$	$3.187 \pm 2.021$	$3.188 \pm 2.021$	$3.084 \pm 2.040$
$R_D(\times 10^{-3})$	$3.571 \pm 0.046$	$3.555 \pm 0.046$	$3.556 \pm 0.046$	$3.556 \pm 0.047$
$ q/p (\times 10^{-1})$	$9.931 \pm 0.125$	$9.935 \pm 0.135$	$9.929 \pm 0.131$	$9.930 \pm 0.130$
$\chi^2/ndf$	24.8569/28	19.0559/13	19.3925/15	8.61793/12

Table 5: Output values of No Direct CPV allowed global fit. Different columns list subsets of allowed data.

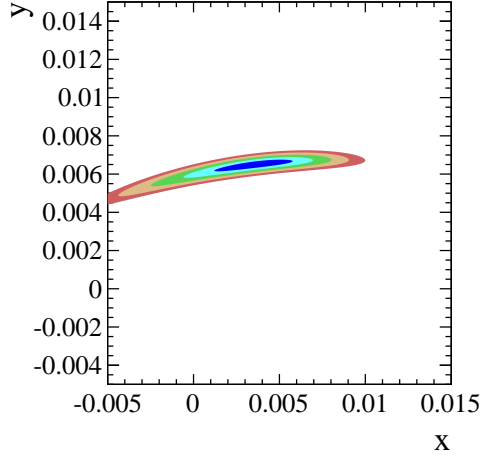
### 80 5.3 All CP Violation Allowed

81 Table 6 lists the results of the global All CP Violation allowed fit. Again, the latter  
82 columns list the differing subsets of the data to explore the variation in global  $\chi^2/ndf$ .  
83 The most noticable difference between all fits is the evaluation of  $x$ , which varies quite a  
84 bit with the inclusion of differing datasets.

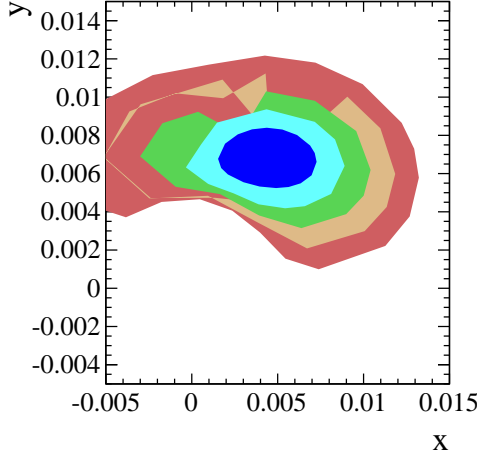
	All Measurements	No Belle, BaBar	No Belle, BaBar, $A_{\Gamma \text{ LHCb}}$	No Belle, BaBar, CDF, $A_{\Gamma \text{ LHCb}}$
$x(\times 10^{-3})$	$3.737 \pm 1.630$	$4.817 \pm 1.688$	$4.772 \pm 1.685$	$4.601 \pm 1.664$
$y(\times 10^{-3})$	$6.128 \pm 0.743$	$6.868 \pm 0.984$	$6.908 \pm 0.963$	$6.956 \pm 0.867$
$\delta_{K\pi}(\times 10^{-1})[\text{rad}]$	$1.146 \pm 2.127$	$3.246 \pm 1.935$	$3.329 \pm 1.891$	$3.250 \pm 1.756$
$\phi(\times 10^{-1})[\text{rad}]$	$-0.642 \pm 1.255$	$-0.623 \pm 1.055$	$-0.651 \pm 1.046$	$-1.534 \pm 1.712$
$R_D^-(\times 10^{-3})$	$3.501 \pm 0.040$	$3.568 \pm 0.049$	$3.567 \pm 0.049$	$3.582 \pm 0.055$
$R_D^+(\times 10^{-3})$	$3.496 \pm 0.036$	$3.547 \pm 0.044$	$3.548 \pm 0.043$	$3.533 \pm 0.046$
$ q/p (\times 10^{-1})$	$9.631 \pm 0.693$	$9.513 \pm 0.823$	$9.474 \pm 0.800$	$8.880 \pm 1.082$
$\chi^2/ndf$	59.9402/29	18.8317/11	19.1817/14	7.72181/9

Table 6: Output of the All CP Violation allowed global fit. Different Columns list differing subsets of data included in the fit.

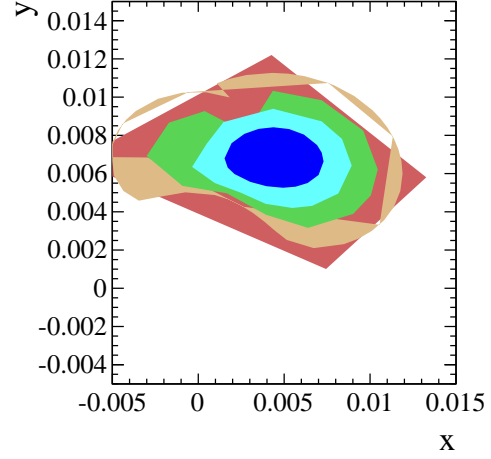




(a) Two dimensional error ellipses for  $x$  and  $y$  using all available measurements.



(b) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle and BaBar  $K\pi$  results.



(c) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle, BaBar and CDF measurements.

Figure 1: Two dimensional error ellipses of  $x$  and  $y$  from fit for No CPV. Exclusion of the Belle and BaBar results drastically change the slope of the error ellipses. The differing colors represent the 1-5 $\sigma$  contours.

#### 85 **5.4 All CP Violation Allowed, Fit for $x_{12}, y_{12}, \phi_{12}$**

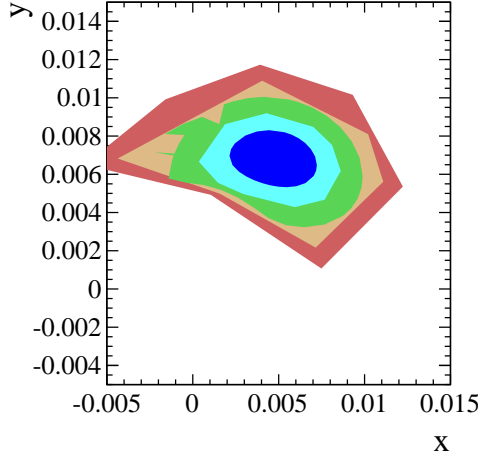
86 Table 7 lists the results for the All CPV allowed fit with the substitution of  $x$  and  $y$  for  
 87 the underlying parameters  $x_{12}, y_{12}$  and  $\phi_{12}$ .

	All Measurements	No Belle, BaBar	No Belle, BaBar, $A_{\Gamma}^{\text{LHCb}}$	No Belle, BaBar, CDF, $A_{\Gamma}^{\text{LHCb}}$
$x_{12}(\times 10^{-3})$	$3.789 \pm 1.627$	$4.842 \pm 1.693$	$4.842 \pm 1.693$	$4.853 \pm 1.694$
$y_{12}(\times 10^{-3})$	$6.365 \pm 0.953$	$6.851 \pm 0.099$	$6.851 \pm 0.994$	$6.863 \pm 0.994$
$\delta_{K\pi}(\times 10^{-1})[\text{rad}]$	$1.855 \pm 2.523$	$3.237 \pm 1.949$	$3.237 \pm 1.949$	$3.191 \pm 1.950$
$\phi_{12}(\times 10^{-2})[\text{rad}]$	$-0.304 \pm 4.277$	$-0.210 \pm 3.416$	$-0.210 \pm 3.416$	$-0.249 \pm 3.380$
$R_D^-(\times 10^{-3})$	$3.501 \pm 0.038$	$3.556 \pm 0.043$	$3.556 \pm 0.043$	$3.556 \pm 0.043$
$R_D^+(\times 10^{-3})$	$3.505 \pm 0.038$	$3.558 \pm 0.043$	$3.558 \pm 0.043$	$3.558 \pm 0.043$
$\chi^2/ndf$	50.73/27	19.5825/15	19.5825/15	8.62343/12

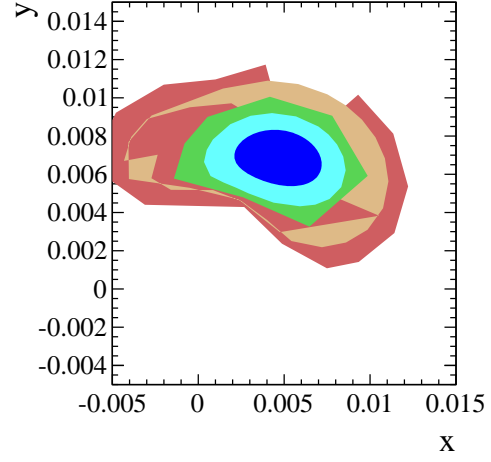
Table 7: Output of the All CP Violation allowed global fit when fitting for the underlying parameters  $x_{12}$  and  $y_{12}$ . Different Columns list differing subsets of data included in the fit.

## 6 Conclusion

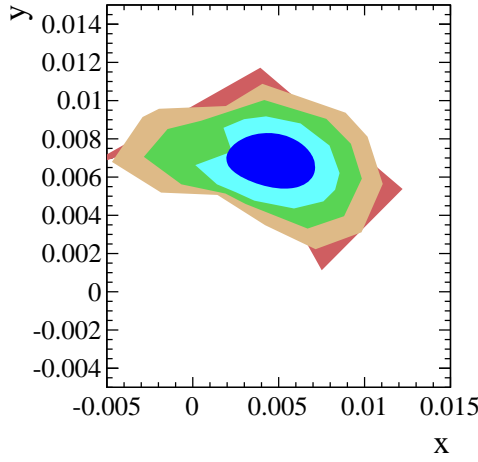
By utilizing a global, HFAG-like fit, we constrain to be  $|q/p| = xxxxx \pm yyyyy$  and  $\phi = zzzzzzz \pm qqqqqqqqqqqq$ , in the case of all CPV allowed. Allowing only direct CPV,  $|q/p| = xxxxx \pm yyyyy$  and  $\phi = zzzzzzz \pm qqqqqqqqqqqq$ . These measurements represent the most precise determination of the CP violating parameters of the natural  $D$  meson system



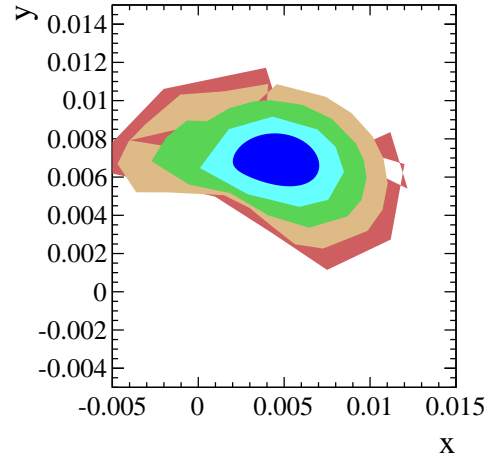
(a) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle and BaBar  $K\pi$  results. Does not include latest  $A_\Gamma$  result of LHCb.



(b) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle and BaBar  $K\pi$  results. Include latest  $A_\Gamma$  result of LHCb.

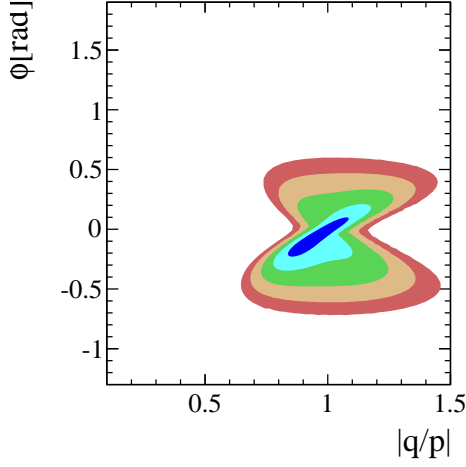


(c) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle, BaBar and CDF  $K\pi$  results. Does not include latest  $A_\Gamma$  result of LHCb.

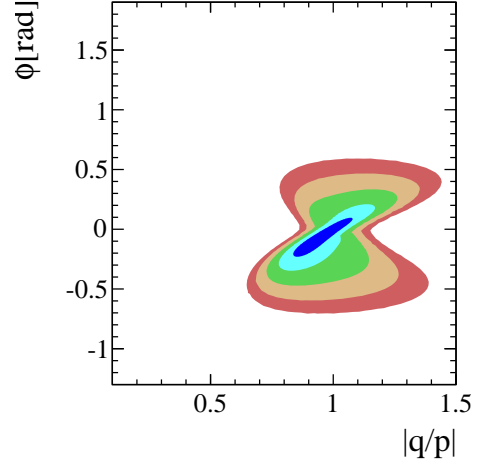


(d) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle, BaBar and CDF  $K\pi$  results. Include latest  $A_\Gamma$  result of LHCb.

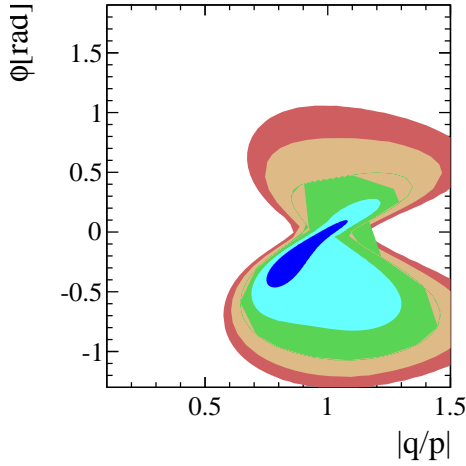
Figure 2: Two dimensional error ellipses of fit for All CPV including differing sets of data for  $x$  vs  $y$ . The biggest differences come from including the CDF result, which elongates the error ellipses. The differing colors represent the 1-5 $\sigma$  contours.



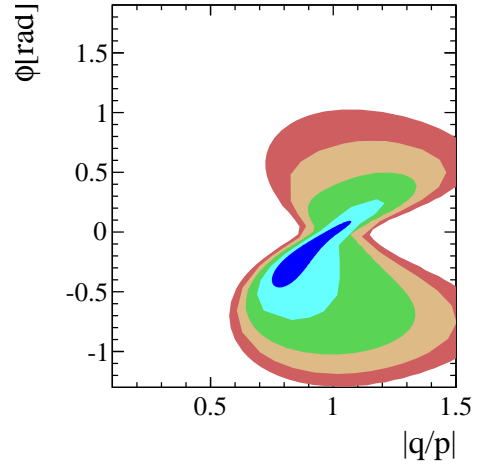
(a) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle and BaBar  $K\pi$  results. Does not include latest  $A_\Gamma$  result of LHCb.



(b) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle and BaBar  $K\pi$  results. Include latest  $A_\Gamma$  result of LHCb.



(c) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle, BaBar and CDF  $K\pi$  results. Does not include latest  $A_\Gamma$  result of LHCb.



(d) Two dimensional error ellipses for  $x$  and  $y$  from fit excluding Belle, BaBar and CDF  $K\pi$  results. Include latest  $A_\Gamma$  result of LHCb.

Figure 3: Two dimensional error ellipses of fit for All CPV including differing sets of data for  $\phi$  vs  $q/p$ . The biggest differences come from including the CDF result, which elongates the error ellipses. The differing colors represent the 1-5 $\sigma$  contours.