D^0-$\bar{D}^0$ Mixing and CPV: HFAG averaging of parameters

See also: http://www.slac.stanford.edu/xorg/hfag/charm/index.html

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University of Cincinnati

CHARM 2009 Workshop
Leimen, Germany
May 21st, 2009

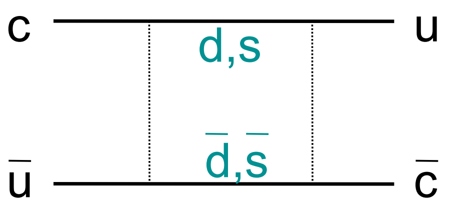
- *Introduction, notation*
- *observables and parameters*
- *fit results*
- *new developments*
- *summary*

Overview of charm group:

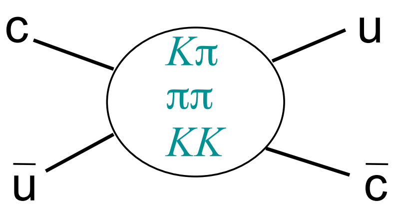
Charm subgroup:	***Activity:***
David Asner (Carleton, CLEOc) *David Cassel (Cornell, CLEOc)* *Jonathon Coleman (SLAC,BABAR)*	● *D_s decay constant*
Bostjan Golob (Ljubljana, BELLE) *Alan Schwartz (Cincinnati, BELLE)*	● *Excited $D_{(s)}^{**}$'s* ● *Mixing, indirect CPV*
Ruslan Chistov (ITEP, BELLE)	● *charm baryons*
Daniele Pedrini (Milan, FOCUS)	● *Direct CPV searches*
Lawrence Gibbons (Cornell, CLEOc) *Milind Purohit (South Carolina, BABAR)*	● *Hadronic branching fractions* ● *Semilept. decays (form factors)*
Brian Meadows (Cincinnati, BABAR)	

Brendan Casey (FNAL, D0)
Mark Mattson (Wayne State, CDF)
Changzheng Yuan (IHEP, BESIII)

Formalism I:



- *doubly-Cabibbo-suppressed w/r/t Γ_D*
- *GIM mechanism cancellation*
- *long-distance contributions*



Flavor eigenstates are not mass eigenstates:

$$i\frac{\partial}{\partial t}\begin{pmatrix}|D^0\rangle\\ |\overline{D}{}^0\rangle\end{pmatrix} = \left(\mathrm{M}-\frac{i}{2}\Gamma\right)\begin{pmatrix}|D^0\rangle\\ |\overline{D}{}^0\rangle\end{pmatrix}$$

$$\begin{aligned}|D_1\rangle &= p|D^0\rangle + q|\overline{D}{}^0\rangle \\ |D_2\rangle &= p|D^0\rangle - q|\overline{D}{}^0\rangle\end{aligned} \qquad \begin{aligned}|D_1(t)\rangle &= |D_1\rangle\, e^{-(\Gamma_1/2+im_1)t} \\ |D_2(t)\rangle &= |D_2\rangle\, e^{-(\Gamma_2/2+im_2)t}\end{aligned}$$

$$\begin{aligned}\Rightarrow\quad |D^0\rangle &= \frac{1}{2p}\left(|D_1\rangle + |D_2\rangle\right) \\ |\overline{D}{}^0\rangle &= \frac{1}{2q}\left(|D_1\rangle - |D_2\rangle\right)\end{aligned}$$

$$\begin{aligned}|D^0(t)\rangle &= e^{-(\overline{\Gamma}/2+i\overline{m})\,t}\left\{\cosh\left[(\Delta\gamma/4+i\Delta m/2)t\right]|D^0\rangle + \left(\frac{q}{p}\right)\sinh\left[(\Delta\gamma/4+i\Delta m/2)t\right]|\overline{D}{}^0\rangle\right. \\ |\overline{D}{}^0(t)\rangle &= e^{-(\overline{\Gamma}/2+i\overline{m})\,t}\left\{\left(\frac{p}{q}\right)\sinh\left[(\Delta\gamma/4+i\Delta m/2)t\right]|D^0\rangle + \cosh\left[(\Delta\gamma/4+i\Delta m/2)t\right]|\overline{D}{}^0\rangle\right.\end{aligned}$$

$$\overline{m} \equiv \frac{1}{2}\left(m_1+m_2\right) \qquad \overline{\Gamma} \equiv \frac{1}{2}\left(\Gamma_1+\Gamma_2\right) \qquad \Delta m \equiv m_2 - m_1 \qquad \Delta\gamma \equiv \Gamma_2 - \Gamma_1$$

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Formalism II:

$$\begin{aligned}
\langle f|H|D^0(t)\rangle &= e^{-(\overline{\Gamma}/2+i\overline{m})\,t}\left\{\cosh\left[(\Delta\gamma/4+i\Delta m/2)t\right]\mathcal{A}_f+\left(\frac{q}{p}\right)\sinh\left[(\Delta\gamma/4+i\Delta m/2)t\right]\bar{\mathcal{A}}\right. \\
\langle \bar{f}|H|\overline{D}{}^0(t)\rangle &= e^{-(\overline{\Gamma}/2+i\overline{m})\,t}\left\{\left(\frac{p}{q}\right)\sinh\left[(\Delta\gamma/4+i\Delta m/2)t\right]\mathcal{A}_{\bar{f}}+\cosh\left[(\Delta\gamma/4+i\Delta m/2)t\right]\bar{\mathcal{A}}\right.
\end{aligned}$$

$$\begin{aligned}
\mathcal{A}_f &\equiv \langle f|H|D^0\rangle & \bar{\mathcal{A}}_f &\equiv \langle f|H|\overline{D}{}^0\rangle \\
\mathcal{A}_{\bar{f}} &\equiv \langle \bar{f}|H|D^0\rangle & \bar{\mathcal{A}}_{\bar{f}} &\equiv \langle \bar{f}|H|\overline{D}{}^0\rangle
\end{aligned}$$

Since $\Delta m\,t \ll 1$ and $\Delta\gamma t \ll 1$, expand $\cos(\Delta m\,t)$, $\cosh(\Delta\gamma/2)t$, $\sin(\Delta m\,t)$, $\sinh(\Delta\gamma/2)t$:

$$\boxed{\begin{aligned}
R(D^0(t)\to f) &= |\mathcal{A}_f|^2\,e^{-\overline{\Gamma}t}\left\{1 + \left[\,y\,\mathrm{Re}(\lambda) - x\,\mathrm{Im}(\lambda)\,\right](\overline{\Gamma}t) + |\lambda|^2\frac{(x^2+y^2)}{4}(\overline{\Gamma}\,t)^2\right\} \\
R(\overline{D}{}^0(t)\to \bar{f}) &= |\bar{\mathcal{A}}_{\bar{f}}|^2\,e^{-\overline{\Gamma}t}\left\{1 + \left[\,y\,\mathrm{Re}(\bar{\lambda}) - x\,\mathrm{Im}(\bar{\lambda})\,\right](\overline{\Gamma}t) + |\bar{\lambda}|^2\frac{(x^2+y^2)}{4}(\overline{\Gamma}\,t)^2\right\}
\end{aligned}}$$

$$x \equiv \frac{\Delta m}{\overline{\Gamma}} \qquad y \equiv \frac{\Delta\Gamma}{2\overline{\Gamma}} \qquad \lambda \equiv \frac{q}{p}\,\frac{\bar{\mathcal{A}}_f}{\mathcal{A}_f} \qquad \bar{\lambda} \equiv \frac{p}{q}\,\frac{\mathcal{A}_{\bar{f}}}{\bar{\mathcal{A}}_{\bar{f}}}$$

Formalism III:

$$\lambda \;=\; \frac{q}{p}\,\frac{\bar{\mathcal{A}}_f}{\mathcal{A}_f} \;\equiv\; \left|\frac{q}{p}\right|\,\sqrt{R_D}\,e^{i(\phi+\delta)}$$

$$\bar{\lambda} \;=\; \frac{p}{q}\,\frac{\mathcal{A}_{\bar{f}}}{\bar{\mathcal{A}}_{\bar{f}}} \;\equiv\; \left|\frac{p}{q}\right|\,\sqrt{\overline{R}_D}\,e^{i(-\phi+\delta)}$$

$$\begin{aligned}
\frac{N(D^0\!\to f)}{dt} &\propto e^{-\overline{\Gamma}\,t}\left\{R_D + \left|\frac{q}{p}\right|\sqrt{R_D}\,[\,y\ \cos(\phi+\delta) - x\ \sin(\phi+\delta)\,]\,(\overline{\Gamma}t) + \left|\frac{q}{p}\right|^2\frac{(x^2+y^2)}{4}(\overline{\Gamma}\,t)^2\right.\\
&= e^{-\overline{\Gamma}\,t}\left\{R_D + \left|\frac{q}{p}\right|\sqrt{R_D}(y'\cos\phi - x'\sin\phi)(\overline{\Gamma}t) + \left|\frac{q}{p}\right|^2\frac{(x'^2+y'^2)}{4}(\overline{\Gamma}\,t)^2\right\}\\
\frac{N(\overline{D}{}^0\!\to \bar{f})}{dt} &\propto e^{-\overline{\Gamma}\,t}\left\{\overline{R}_D + \left|\frac{p}{q}\right|\sqrt{\overline{R}_D}y'\cos\phi + x'\sin\phi)(\overline{\Gamma}t) + \left|\frac{p}{q}\right|^2\frac{(x'^2+y'^2)}{4}(\overline{\Gamma}\,t)^2\right\}
\end{aligned}$$

$x' \equiv\; x\cos\delta + y\sin\delta$ $y' \equiv\; y\cos\delta - x\sin\delta$

$\lvert q/p\rvert$	CPV in mixing
$A_D \equiv (R_D - \overline{R}_D)/(R_D + \overline{R}_D)$	CPV in the decay amplitude (direct CPV)
ϕ	CPV in mixed/direct interference

No CPV ($R_D = \overline{R}_D$, $|q/p| = 1$, and $\phi = 0$):

$$\frac{dN(D^0\!\to f)}{dt} \;\propto\; e^{-\overline{\Gamma}\,t}\left\{R_D \;+\; \sqrt{R_D}\,y'(\overline{\Gamma}t) \;+\; \frac{(x'^2+y'^2)}{4}(\overline{\Gamma}\,t)^2\right\}$$

Formalism III:

$$\lambda \;=\; \frac{q}{p}\,\frac{\bar{\mathcal{A}}_f}{\mathcal{A}_f} \;\equiv\; \left|\frac{q}{p}\right| \sqrt{R_D}\; e^{i(\phi+\delta)}$$

$$\bar{\lambda} \;=\; \frac{p}{q}\,\frac{\mathcal{A}_{\bar{f}}}{\bar{\mathcal{A}}_{\bar{f}}} \;\equiv\; \left|\frac{p}{q}\right| \sqrt{R_D}\; e^{i(-\phi+\delta)}$$

$$\frac{N(D^0\to f)}{dt} \propto e^{-\bar{\Gamma}t}\left\{R_D + \left|\frac{q}{p}\right|\sqrt{R_D}\,[\,y\cos(\phi+\delta) - x\sin(\phi+\delta)\,]\,(\bar{\Gamma}t) + \left|\frac{q}{p}\right|^2 \frac{(x^2+y^2)}{4}(\bar{\Gamma}\,t)^2\right.$$

$$= e^{-\bar{\Gamma}t}\left\{R_D + \left|\frac{q}{p}\right|\sqrt{R_D}(y'\cos\phi - x'\sin\phi)(\bar{\Gamma}t) + \left|\frac{q}{p}\right|^2 \frac{(x'^2+y'^2)}{4}(\bar{\Gamma}\,t)^2\right\}$$

$$\frac{N(\overline{D}^0\to \bar{f})}{dt} \propto e^{-\bar{\Gamma}t}\left\{\overline{R}_D + \left|\frac{p}{q}\right|\sqrt{\overline{R}_D}y'\cos\phi + x'\sin\phi)(\bar{\Gamma}t) + \left|\frac{p}{q}\right|^2 \frac{(x'^2+y'^2)}{4}(\bar{\Gamma}\,t)^2\right\}$$

$x' \equiv\; x\cos\delta + y\sin\delta$ $\qquad$ $y' \equiv\; y\cos\delta - x\sin\delta$

$\lvert q/p\rvert$	CPV in mixing
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No CPV ($R_D = \overline{R}_D$, $\lvert q/p\rvert = 1$, and $\phi = 0$):

$$\frac{dN(D^0\to f)}{dt} \;\propto\; e^{-\bar{\Gamma}t}\left\{R_D \;+\; \sqrt{R_D}\,y'(\bar{\Gamma}t) \;+\; \frac{(x'^2+y'^2)}{4}(\bar{\Gamma}\,t)^2\right\}$$

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Observables:

FNAL E791	FOCUS	CDF		BELLE	CLEO(c)	
√			√	√	√	**Wrong-sign semileptonic $D^0(t) \rightarrow K^+ l^- \nu$ decays** measures x^2+y^2, no DCS contamination
√	√	√	√	√	√	**Wrong-sign hadronic $D^0(t) \rightarrow K^+\pi^-$ decays** measures $x' = x \cos\delta + y \sin\delta$, $y' = y \cos\delta - x \sin\delta$
√	√		√	√	√	**Decays to CP eigenstates: $D^0(t) \rightarrow K^+K^-, \pi^+\pi^-$** measures y_{CP}
			√	√	√	**Dalitz plot analysis of $D^0(t) \rightarrow K^0 \pi^+\pi^-$ decays** measures x, y
			√		√	**Dalitz plot analysis of $D^0 \rightarrow K^+\pi^-\pi^0$ decays** measures x'', y''
			√	√		**Dalitz plot analysis of $D^0 \rightarrow K^0 K^+ K^-$ decays** measures y_{CP} (CLEO, Belle)
					√	**Quantum correlations in $e^+e^- \rightarrow \psi(3770) \rightarrow D^0\overline{D}^0(n\pi^0)$** measures x^2+y^2, y, R_D, $\sqrt{R_D}\cos\delta$

Parameters:

purple = parameters
blue = observables
black = intermediate

$$R_M = \frac{1}{2}(x^2 + y^2)$$

$$\begin{aligned} 2y_{CP} &= \big(|q/p| + |p/q|\big)y\cos\phi - \big(|q/p| - |p/q|\big)x\sin\phi \\ 2A_\Gamma &= \big(|q/p| - |p/q|\big)y\cos\phi - \big(|q/p| + |p/q|\big)x\sin\phi \end{aligned}$$

$$\begin{aligned} x_{K^0\pi\pi} &= x \\ y_{K^0\pi\pi} &= y \\ |q/p|_{K^0\pi\pi} &= |q/p| \\ \mathrm{Arg}\,(q/p)_{K^0\pi\pi} &= \phi \end{aligned}$$

$$\begin{pmatrix} x'' \\ y'' \end{pmatrix}_{K^+\pi^-\pi^0} = \begin{pmatrix} \cos\delta_{K\pi\pi} & \sin\delta_{K\pi\pi} \\ -\sin\delta_{K\pi\pi} & \cos\delta_{K\pi\pi} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

$$A_M = \frac{|q/p|^2 - |p/q|^2}{|q/p|^2 + |p/q|^2}$$

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

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

$$\frac{1}{2}\left[R(D^0 \to K^+\pi^-) + \overline{R}(\overline{D}{}^0 \to K^-\pi^+)\right] = R_D$$

$$\frac{R(D^0 \to K^+\pi^-) - \overline{R}(\overline{D}{}^0 \to K^-\pi^+)}{R(D^0 \to K^+\pi^-) + \overline{R}(\overline{D}{}^0 \to K^-\pi^+)} = A_D$$

Observables II:

Dalitz analysis of $D^0(t) \to K^0 \pi^+ \pi^-$

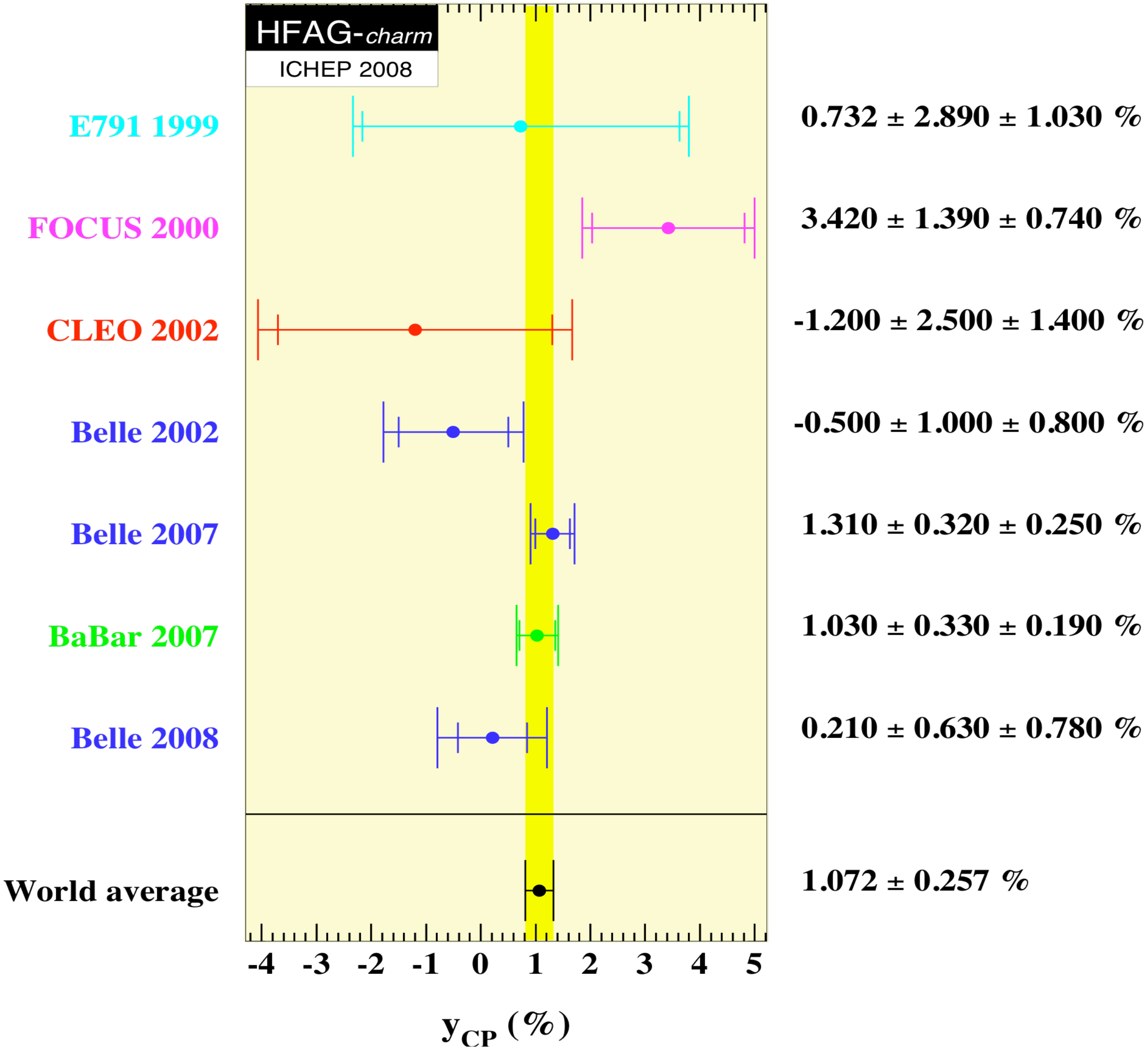
“wrong-sign” $D^0(t) \to K^+ l^- \nu$

Dalitz analysis of wrong-sign $D^0 \to K^+ \pi^- \pi^0$

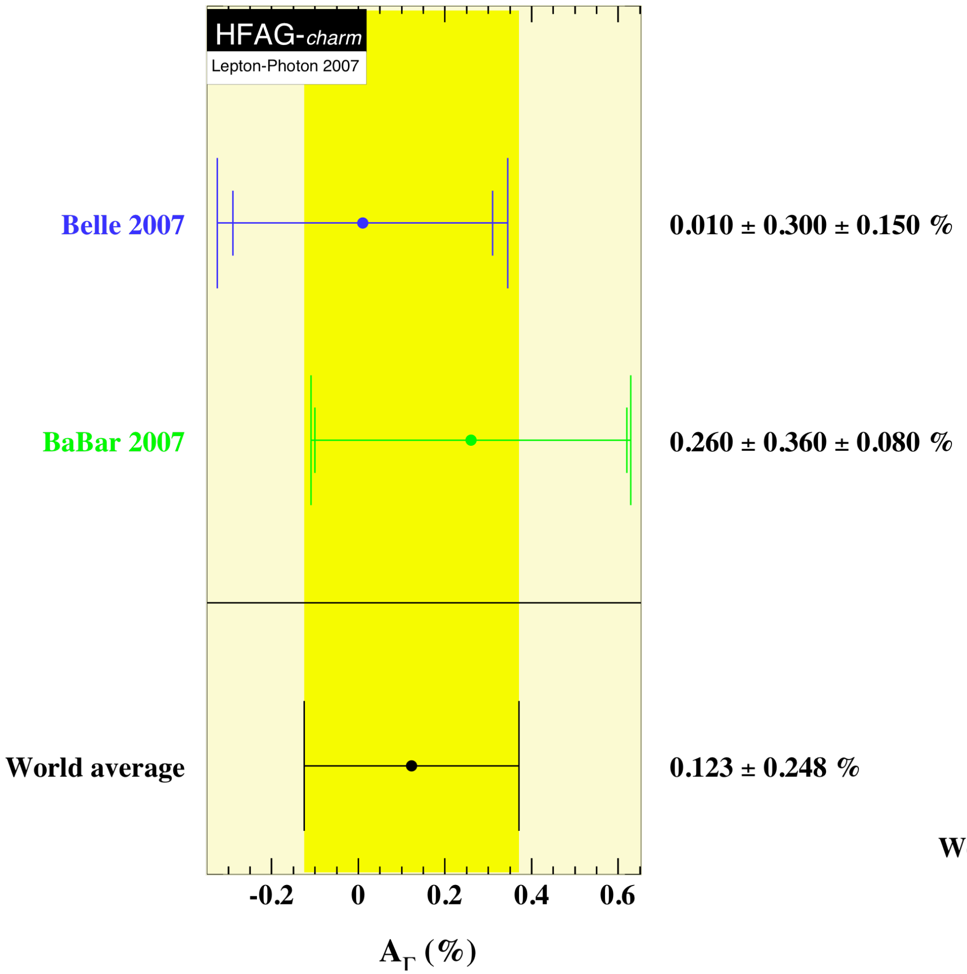
$e^+e^- \to \psi(3770) \to D^0 \bar{D}^0 (n\pi^0)$

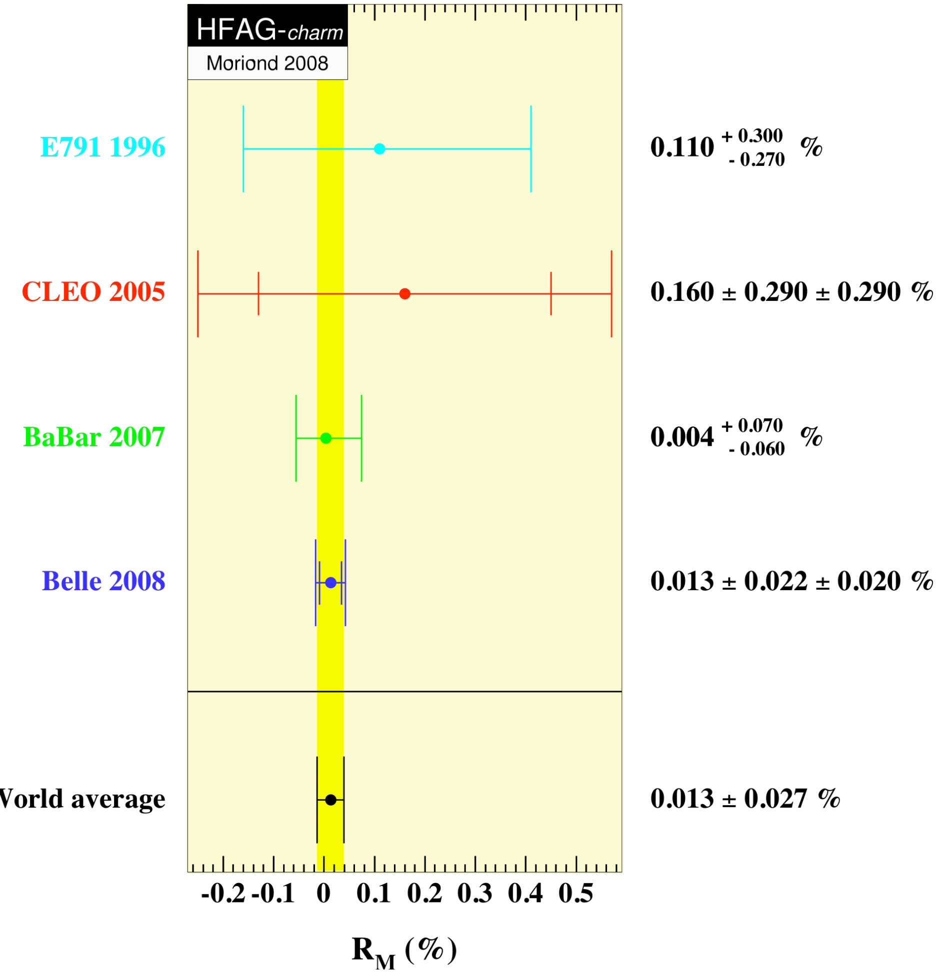
Index	Observable	Value	Source
1	y_{CP}	(1.072 ± 0.257)%	World average (COMBOS combination) of $D^0 \to K^+ K^- / \pi^+ \pi^- / K^+ K^- K^0$
2	A_Γ	(0.123 ± 0.248)%	World average (COMBOS combination) of $D^0 \to K^+ K^- / \pi^+ \pi^-$ results
(3-5) 6	x (no CPV) y (no CPV) |q/p| (no dCPV) Arg(q/p)=φ (no dCPV) x y |q/p| φ	(0.811 ± 0.334)% (0.309 ± 0.281)% $0.95 \pm 0.22^{+0.10}_{-0.09}$ (−0.035 ± 0.19 ± 0.09) radians $(0.81 \pm 0.30^{+0.13}_{-0.17})\%$ $(0.37 \pm 0.25^{+0.10}_{-0.15})\%$ $0.86 \pm 0.30^{+0.10}_{-0.09}$ (−0.244 ± 0.31 ± 0.09) radians	No CPV: World average (COMBOS combination) of $D^0 \to K^0 \pi^+ \pi^-$ results CPV-allowed: Belle $D^0 \to K^0_S \pi^+ \pi^-$ results; correlation coefficients: $\begin{matrix} 1 & -0.007 & -0.255\alpha & +0.216 \\ -0.007 & 1 & -0.019\alpha & -0.280 \\ -0.255\alpha & -0.019\alpha & 1 & -0.128\alpha \\ +0.216 & -0.280 & -0.128\alpha & 1 \end{matrix}$ (Note: $\alpha = (\|q/p\|+1)^2/2$ is a variable transformation factor)
7	R_M	(0.0130 ± 0.0269)%	World average (COMBOS combination) of $D^0 \to K^+ l^- \nu$ results
8	x" y"	$(2.61^{+0.57}_{-0.68} \pm 0.39)\%$ $(-0.06^{+0.55}_{-0.64} \pm 0.34)\%$	BaBar $K^+ \pi^- \pi^0$ result; correlation coefficient = −0.75. Note: $x'' = x \cos\delta_{K\pi\pi} + y \sin\delta_{K\pi\pi}$, $y'' = y \cos\delta_{K\pi\pi} - x \sin\delta_{K\pi\pi}$.
9	R_M y R_D $\sqrt{R_D} \cos\delta$	(0.199 ± 0.173 ± 0)% (−5.207 ± 5.571 ± 2.737)% (−2.395 ± 1.739 ± 0.938)% (8.878 ± 3.369 ± 1.579)%	CLEOc Ψ(3770) results; correlation coefficients: $\begin{matrix} 1 & -0.0644 & 0.0072 & 0.0607 \\ -0.0644 & 1 & -0.3172 & -0.8331 \\ 0.0072 & -0.3172 & 1 & +0.3893 \\ 0.0607 & -0.8331 & +0.3893 & 1 \end{matrix}$

Observables III:



Observables IV:





Observables IV:

"wrong-sign"
$D^0(t) \to K^+\pi^-$

10	R_D x'^{2+} y'^{+}	(0.303 ± 0.0189)% (−0.024 ± 0.052)% (0.98 ± 0.78)%	BaBar $K^+\pi^-$ results; correlation coefficients: 1 +0.77 −0.87 +0.77 1 −0.94 −0.87 −0.94 1
11	A_D x'^{2-} y'^{-}	(−2.1 ± 5.4)% (−0.020 ± 0.050)% (0.96 ± 0.75)%	BaBar $K^+\pi^-$ results; correlation coefficients same as above.
12	R_D x'^{2+} y'^{+}	(0.364 ± 0.018)% (0.032 ± 0.037)% (−0.12 ± 0.58)%	Belle $K^+\pi^-$ results; correlation coefficients: 1 +0.655 −0.834 +0.655 1 −0.909 −0.834 −0.909 1
13	A_D x'^{2-} y'^{-}	(2.3 ± 4.7)% (0.006 ± 0.034)% (0.20 ± 0.54)%	Belle $K^+\pi^-$ results; correlation coefficients same as above.
14	R_D x'^{2} y'	(0.304 ± 0.055)% (−0.012 ± 0.035)% (0.85 ± 0.76)%	CDF $K^+\pi^-$ results; correlation coefficients: 1 0.923 −0.971 0.923 1 −0.984 −0.971 −0.984 1

HFAG charm

Fit results:

no CPV

```
FCN=   25.62907   FROM MINOS     STATUS=SUCCESSFUL    550 CALLS    816 TOTAL
EDM=  0.83E-12          STRATEGY=1     ERROR MATRIX UNCERTAINTY=  0.0%

EXT PARAMETER                     PARABOLIC          MINOS ERRORS
NO.      NAME      VALUE          ERROR          NEGATIVE            POSITIVE
1        x         1.0115         0.23969        -0.24714            0.23359
2        y         0.73704        0.17756        -0.17970            0.17486
3        delta     0.37026        0.18556        -0.19271            0.18313
4        rd        0.33559        0.0083691      -0.0083777          0.0083641
5        ad        0.0000         fixed
6        qovp      1.0000         fixed
7        phi       0.0000         fixed
8        delta2    0.17121        0.37425        -0.39251            0.35996
```

all CPV

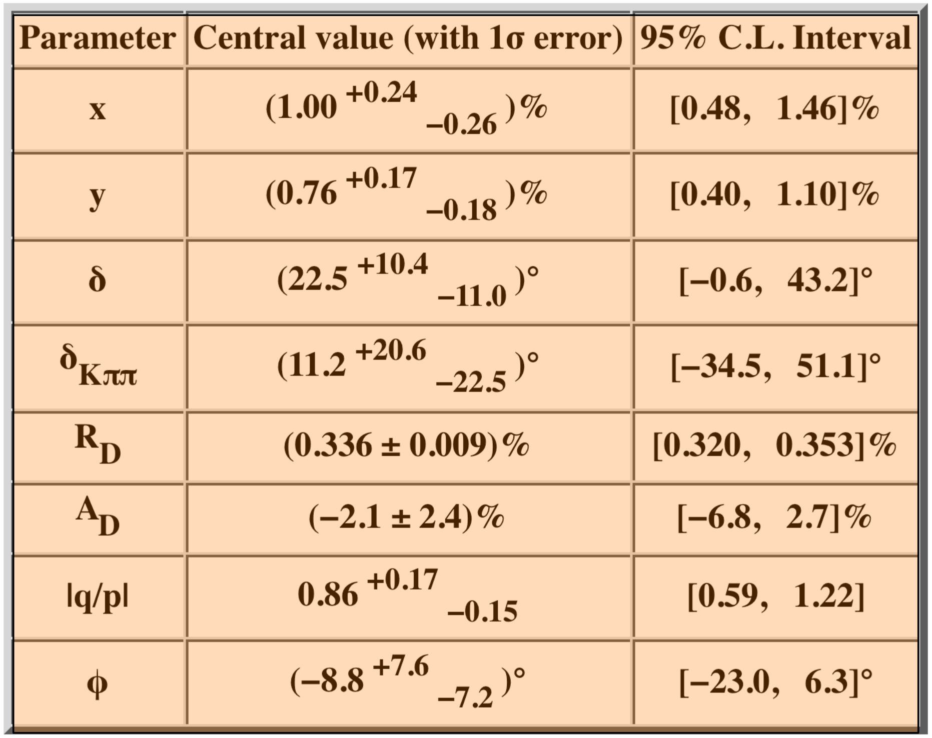
```
FCN=   25.26738    FROM MINOS    STATUS=SUCCESSFUL  1613 CALLS    4085 TOTAL
EDM=  0.33E-09          STRATEGY=1         ERROR MATRIX UNCERTAINTY=  2.0%

EXT PARAMETER                     PARABOLIC          MINOS ERRORS
NO.      NAME      VALUE          ERROR          NEGATIVE            POSITIVE
1        x         0.99965        0.24661        -0.25641            0.24007
2        y         0.76262        0.17669        -0.17991            0.17350
3        delta     0.39294        0.18362        -0.19126            0.18117
4        rd        0.33636        0.0085859      -0.0085469          0.0085815
5        ad        -2.1324        2.4412         -2.4119             2.4365
6        qovp      0.85727        0.16198        -0.14867            0.17447
7        phi       -0.15392       0.12928        -0.12608            0.13222
8        delta2    0.19508        0.37460        -0.39263            0.36039
```

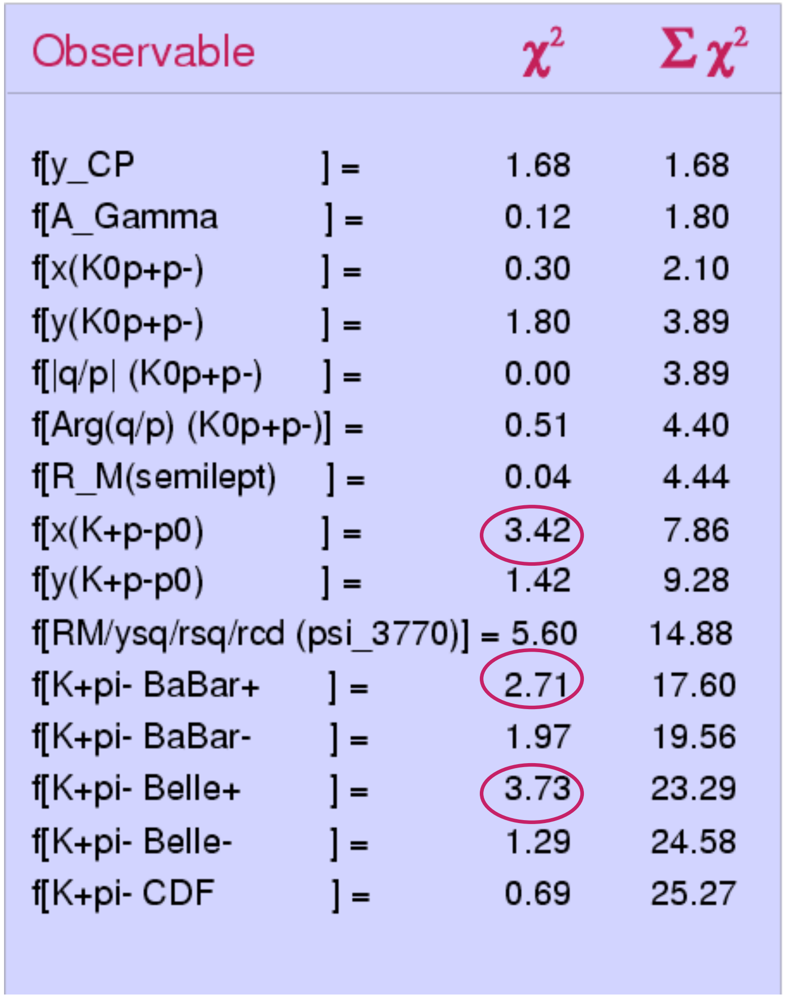
HFAG charm

Fit results II:

all CPV

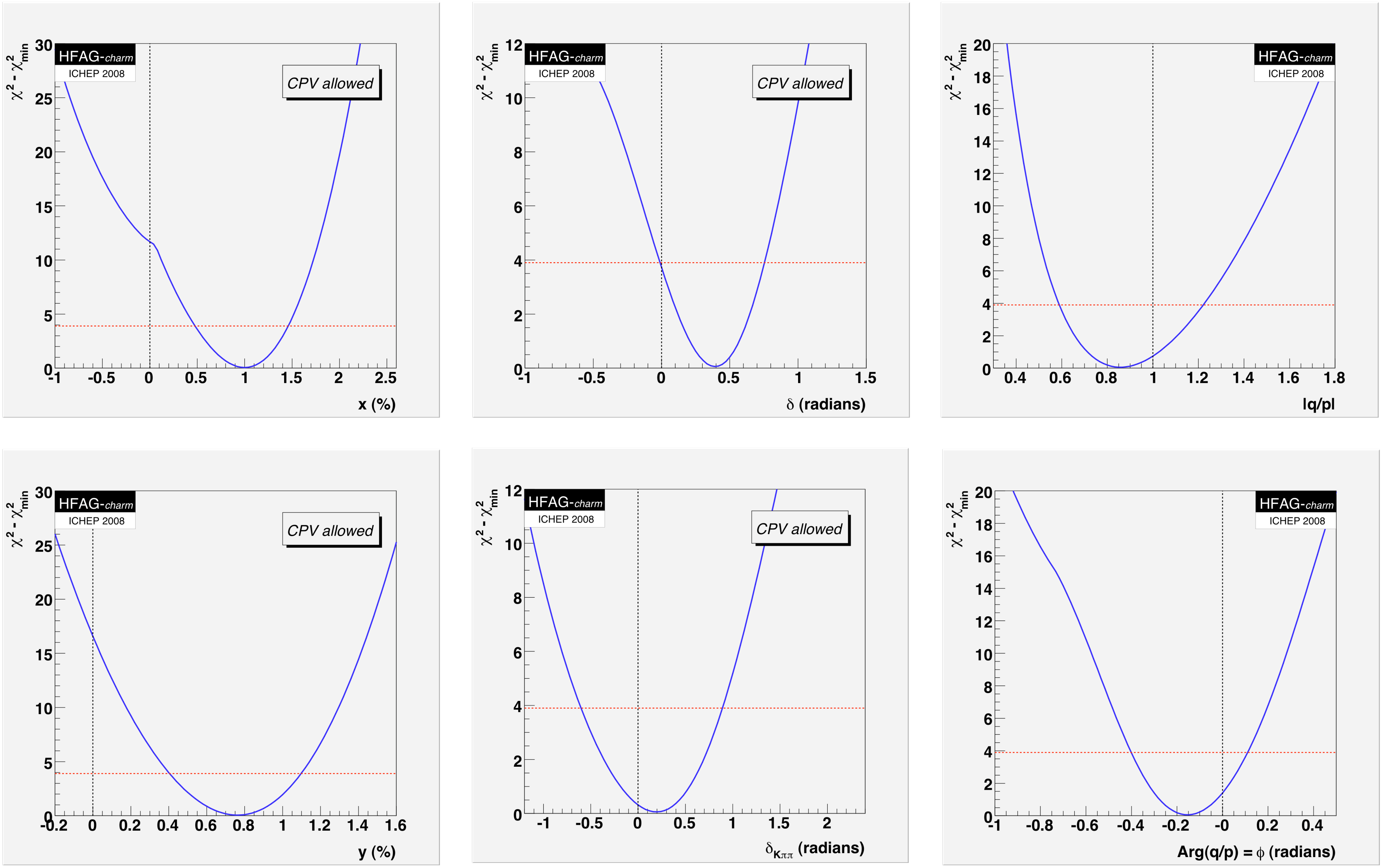


Parameter	Central value (with 1σ error)	95% C.L. Interval
x	$(1.00^{+0.24}_{-0.26})\%$	[0.48, 1.46]%
y	$(0.76^{+0.17}_{-0.18})\%$	[0.40, 1.10]%
δ	$(22.5^{+10.4}_{-11.0})°$	[−0.6, 43.2]°
$\delta_{K\pi\pi}$	$(11.2^{+20.6}_{-22.5})°$	[−34.5, 51.1]°
R_D	(0.336 ± 0.009)%	[0.320, 0.353]%
A_D	(−2.1 ± 2.4)%	[−6.8, 2.7]%
|q/p|	$0.86^{+0.17}_{-0.15}$	[0.59, 1.22]
φ	$(-8.8^{+7.6}_{-7.2})°$	[−23.0, 6.3]°

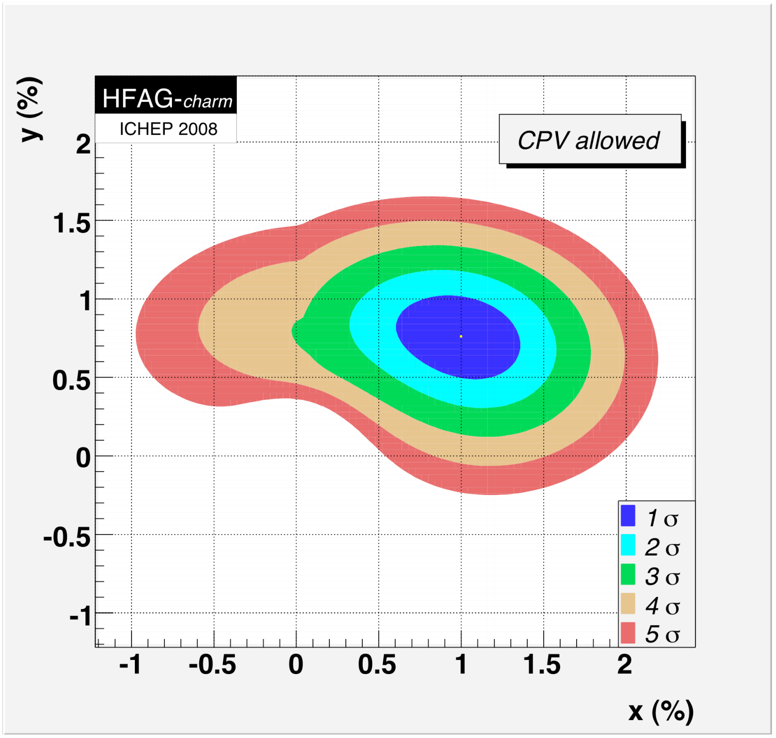


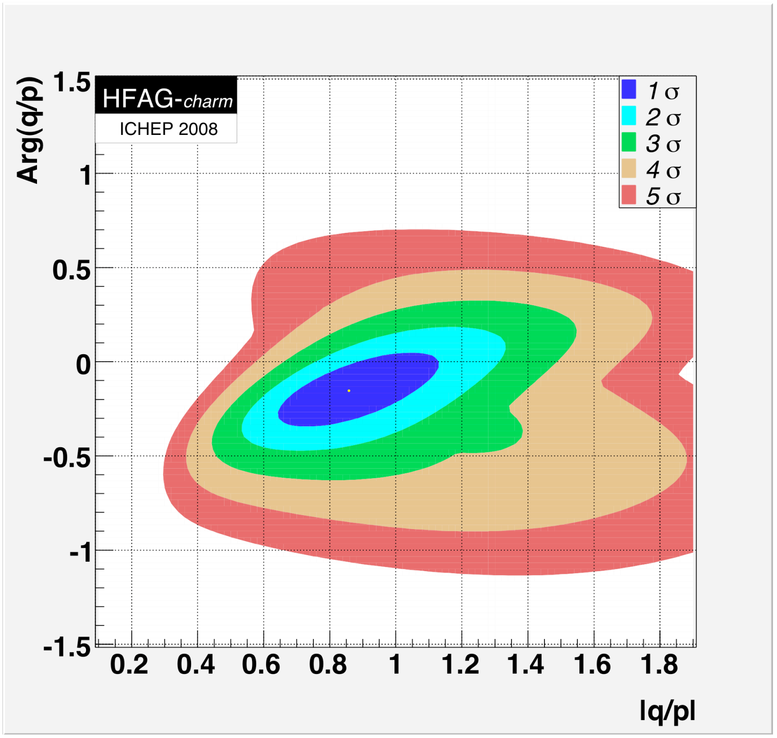
Observable	χ^2	$\Sigma\chi^2$
f[y_CP] =	1.68	1.68
f[A_Gamma] =	0.12	1.80
f[x(K0p+p-)] =	0.30	2.10
f[y(K0p+p-)] =	1.80	3.89
f[|q/p| (K0p+p-)] =	0.00	3.89
f[Arg(q/p) (K0p+p-)] =	0.51	4.40
f[R_M(semilept)] =	0.04	4.44
f[x(K+p-p0)] =	3.42	7.86
f[y(K+p-p0)] =	1.42	9.28
f[RM/ysq/rsq/rcd (psi_3770)] =	5.60	14.88
f[K+pi- BaBar+] =	2.71	17.60
f[K+pi- BaBar-] =	1.97	19.56
f[K+pi- Belle+] =	3.73	23.29
f[K+pi- Belle-] =	1.29	24.58
f[K+pi- CDF] =	0.69	25.27

1-d likelihood plots:



2-d likelihood plots:

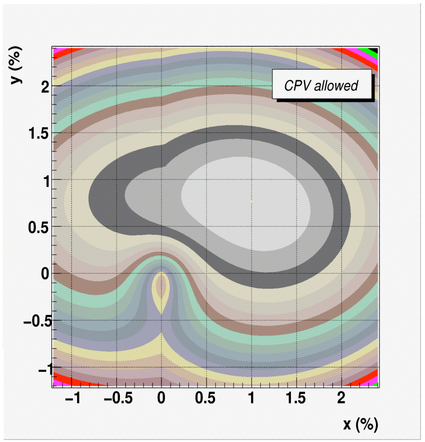




CPV-allowed, no mixing (x,y) = (0,0) point:

$\Delta\chi^2$ = *102.6,* *CL = 5.3 x* 10^{-23}

no mixing excluded at 9.8σ



ROOT default color palette

No CPV (|q/p|, φ) = (1,0) point:

$\Delta\chi^2$ = *1.33,* *CL = 0.486*

consistent with CP conservation

HFAG
charm

No direct CPV (new results):

Based on:

Y. Grossman, Y. Nir, G. Perez, arXiv:0904.0305 (19 Apr 2009)
A. Kagan, paper to be submitted.

Define 3 new parameters:

$$\boxed{\begin{aligned} x_{12} &\equiv \frac{2|M_{12}|}{\Gamma} \\ y_{12} &\equiv \frac{|\Gamma_{12}|}{\Gamma} \\ \phi_{12} &\equiv \mathrm{Arg}\left(\frac{M_{12}}{\Gamma_{12}}\right) \end{aligned}}$$

If no direct CPV:

$$\mathrm{Im}\left(\Gamma^{*}_{12}\frac{\overline{A}_f}{A_f}\right) \;=\; 0$$

So one can derive:

$$\left.\begin{aligned} xy &= x_{12}y_{12}\cos\phi_{12} \\ x^2-y^2 &= x^2_{12}-y^2_{12} \\ (x^2+y^2)|q/p|^2 &= x^2_{12}+y^2_{12}+2x_{12}y_{12}\sin\phi_{12} \\ \tan(2\phi) &= \frac{-\sin(2\phi_{12})}{\cos(2\phi_{12})+y^2_{12}/x^2_{12}} \end{aligned}\right\}$$

4 parameters (x,y,|q/p|,ϕ) now expressed in terms of 3 parameters (x_{12},y_{12},ϕ_{12}).
$\Rightarrow$
Additional constraint in fit

No direct CPV II:

Y. Grossman, Y. Nir, G. Perez, arXiv:0904.0305 (19 Apr 2009)
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Additional constraint in fit:

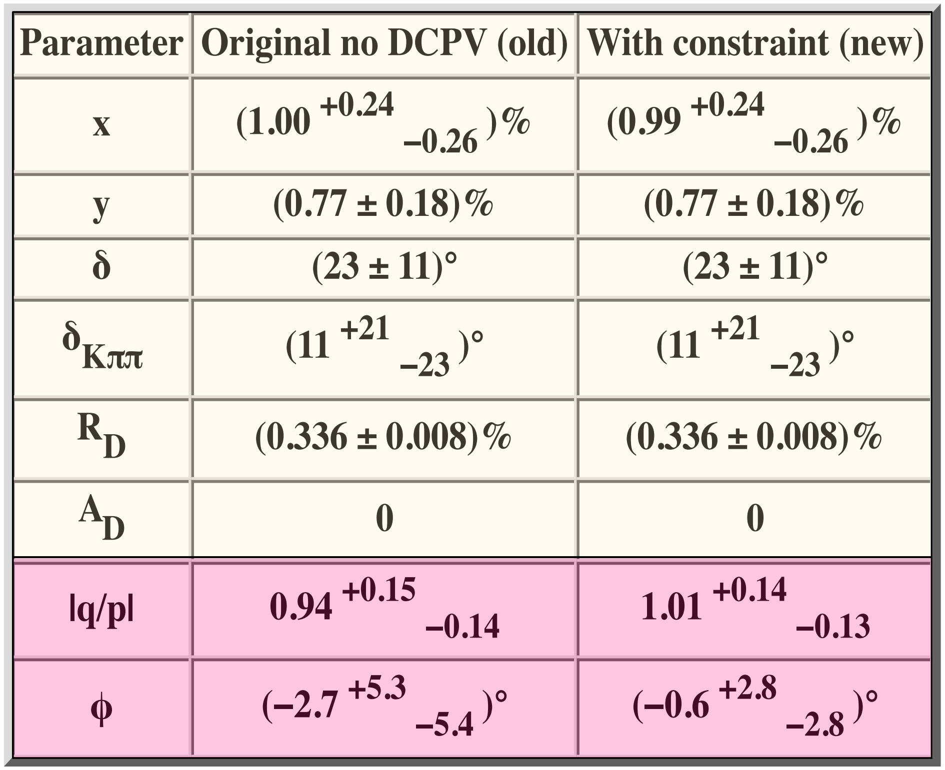
$$x_{12}^2 = \frac{x^4\cos^2\phi + y^4\sin^2\phi}{x^2\cos^2\phi - y^2\sin^2\phi}$$

$$y_{12}^2 = x_{12}^2 - x^2 + y^2$$

$$\sin\phi_{12} = -\frac{(x^2+y^2)\sin(2\phi)}{2xy}\left(\frac{y_{12}}{x_{12}}\right)$$

$$\Rightarrow \left|\frac{q}{p}\right|^2 = \frac{x_{12}^2 + y_{12}^2 + 2x_{12}y_{12}\sin\phi_{12}}{x^2+y^2}$$

preliminary



Parameter	Original no DCPV (old)	With constraint (new)
x	$(1.00\,^{+0.24}_{-0.26})\%$	$(0.99\,^{+0.24}_{-0.26})\%$
y	$(0.77 \pm 0.18)\%$	$(0.77 \pm 0.18)\%$
δ	$(23 \pm 11)°$	$(23 \pm 11)°$
$\delta_{K\pi\pi}$	$(11\,^{+21}_{-23})°$	$(11\,^{+21}_{-23})°$
R_D	$(0.336 \pm 0.008)\%$	$(0.336 \pm 0.008)\%$
A_D	0	0
$\lvert q/p\rvert$	$0.94\,^{+0.15}_{-0.14}$	$1.01\,^{+0.14}_{-0.13}$
ϕ	$(-2.7\,^{+5.3}_{-5.4})°$	$(-0.6\,^{+2.8}_{-2.8})°$

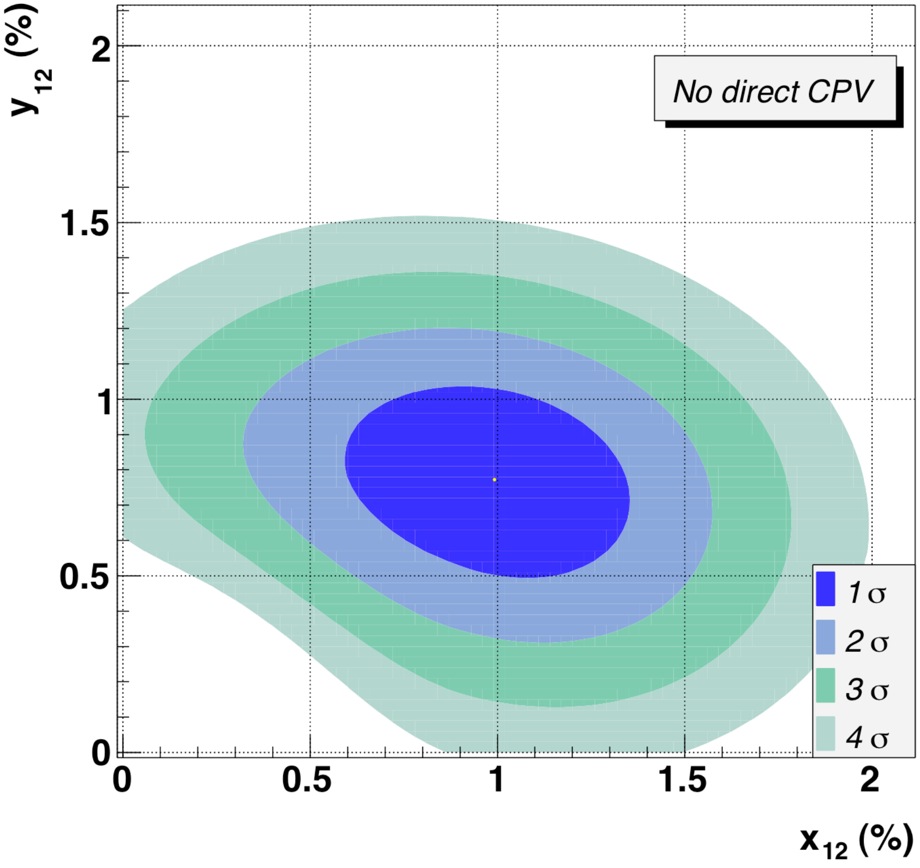
$\Rightarrow$ *Improvement in ϕ*

No direct CPV III:

Y. Grossman, Y. Nir, G. Perez, arXiv:0904.0305 (19 Apr 2009)
A. Kagan, paper to be submitted.

Can fit for x_{12}, y_{12}, ϕ_{12} directly:

preliminary



preliminary

Parameter	Fit result	95% C.L. Interval
x_{12}	$(0.99^{+0.24}_{-0.26})\%$	[0.46, 1.46]%
y_{12}	$(0.77 \pm 0.18)\%$	[0.41, 1.11]%
ϕ_{12}	$(0.91^{+4.7}_{-6.2})°$	[−17.2, 17.2]°

Summary

- The past two years have seen a renaissance in charm mixing/CPV measurements.

- Belle, Babar, and CDF have all observed mixing; combining all results gives a significance of mixing of 9.8σ

- The question now becomes: is there CPV in the charm system? This would be an unambiguous sign of new physics.

- thus far, no sign of CPV, although errors on |q/p| and ϕ are large

- Next "significant" advances:
  - Babar $D^0(t) \to K^0 \pi^+\pi^-$ (Dalitz plot) analysis for x, y, |q/p|, ϕ (480 fb^{-1})
  - Belle and Babar $D^0(t) \to K^0 K^+K^-$ Dalitz plot analysis for x, y
  - Belle analysis of $D^0(t) \to K^+ \pi^-$ for x, y, |q/p|, ϕ with all data (800 fb^{-1})
  - CDF analysis of $D^0(t) \to K^+ \pi^-$ for x, y, |q/p|, ϕ with all data (7-8 fb^{-1})
  - on the horizon: BESIII quantum correlation analysis for x, y, R_D, δ
  - over the horizon: Belle-II or SuperB