HFAG Mixing Averages

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For Charm subgroup of HFAG

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

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HFAG Charm Group

Formed summer 2006 to provide averages of charm results

Members from most recent charm experiments:

- Milind Purohit (chair) (BaBar+E791)
- Brian Petersen (BaBar)
- Bostjan Golob (Belle)
- Alan Schwartz (Belle)
- Changzhen Yuan (BES)
- Mark Mattson (CDF)
- David Asner (CLEO-c)
- Lawrence Gibbos (CLEO-c)
- Brendan Casey (D0)
- Daniele Pedrini (Focus)

Ongoing efforts:

- Average mixing results
- Average CP violation in decay results
- Average absolute charm branching fractions
- ...

Averaging Charm Mixing Results

Have measurements of many different mixing related parameters: $y_{CP}, x'^2, y', R_M, \ldots$

Combine results to extract best possible constraints on fundamental mixing parameters: $x, y, q/p, \ldots$

Combination approach:

- Obtain likelihood distributions for measurements
  - Allows for non-Gaussian uncertainties
  - Combine results by adding likelihood distributions
- First combine measurements of same parameters
- Convert combined likelihoods into functions of the fundamental mixing parameters and add together

For CP violating case, we currently do not have all likelihoods

– Instead use a simple χ^2 combination
– Ignores the non-Gaussian errors

KK/ππ Lifetime Ratio Measurements

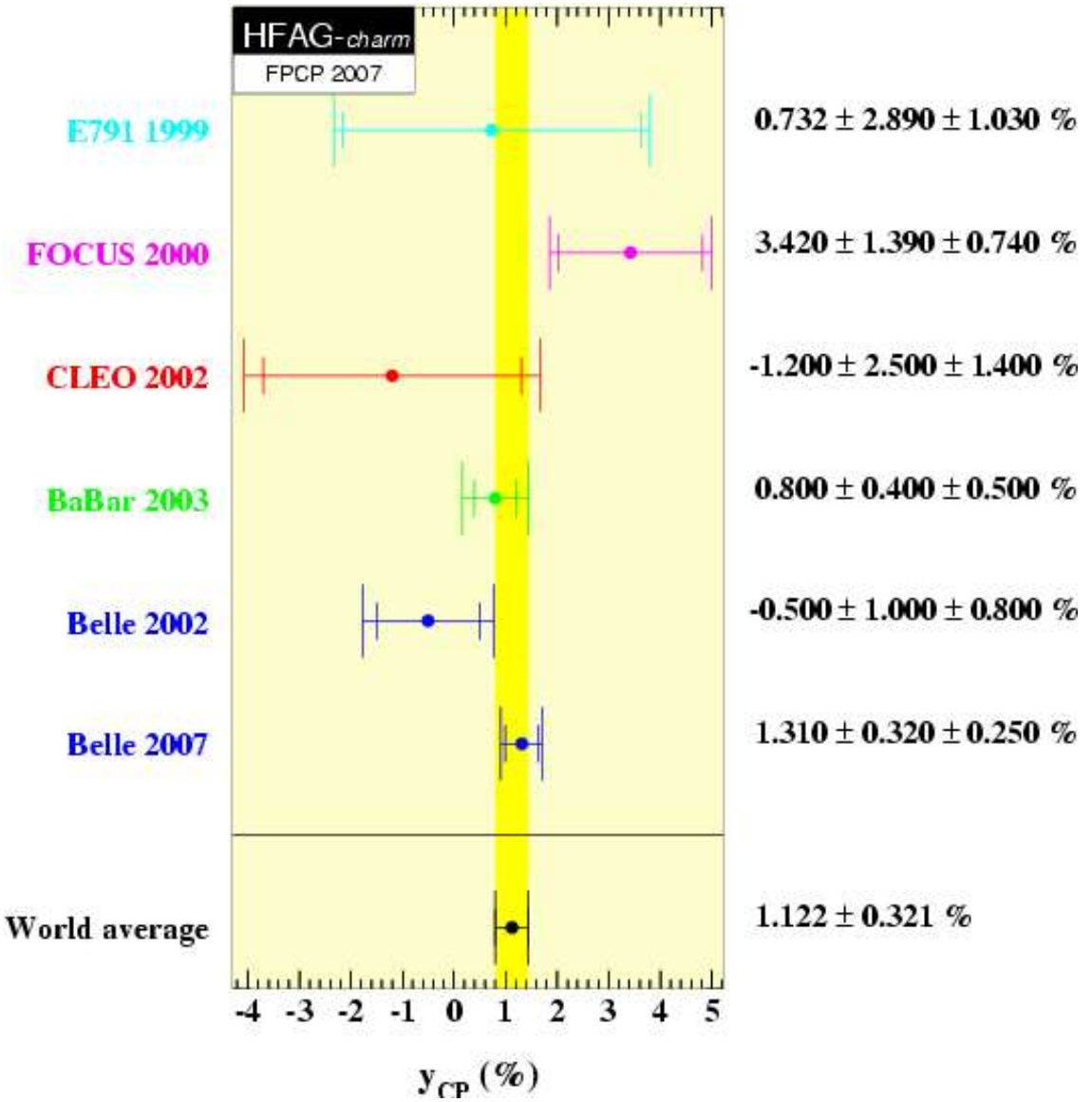
Many measurements of y_{CP}

Assume Gaussian uncertainties and no correlation between experiments, e.g. we do not normalize to the same the $\tau_{K\pi}$

<u>Combined Result:</u>

$y_{CP} = (1.12 \pm 0.32)\%$

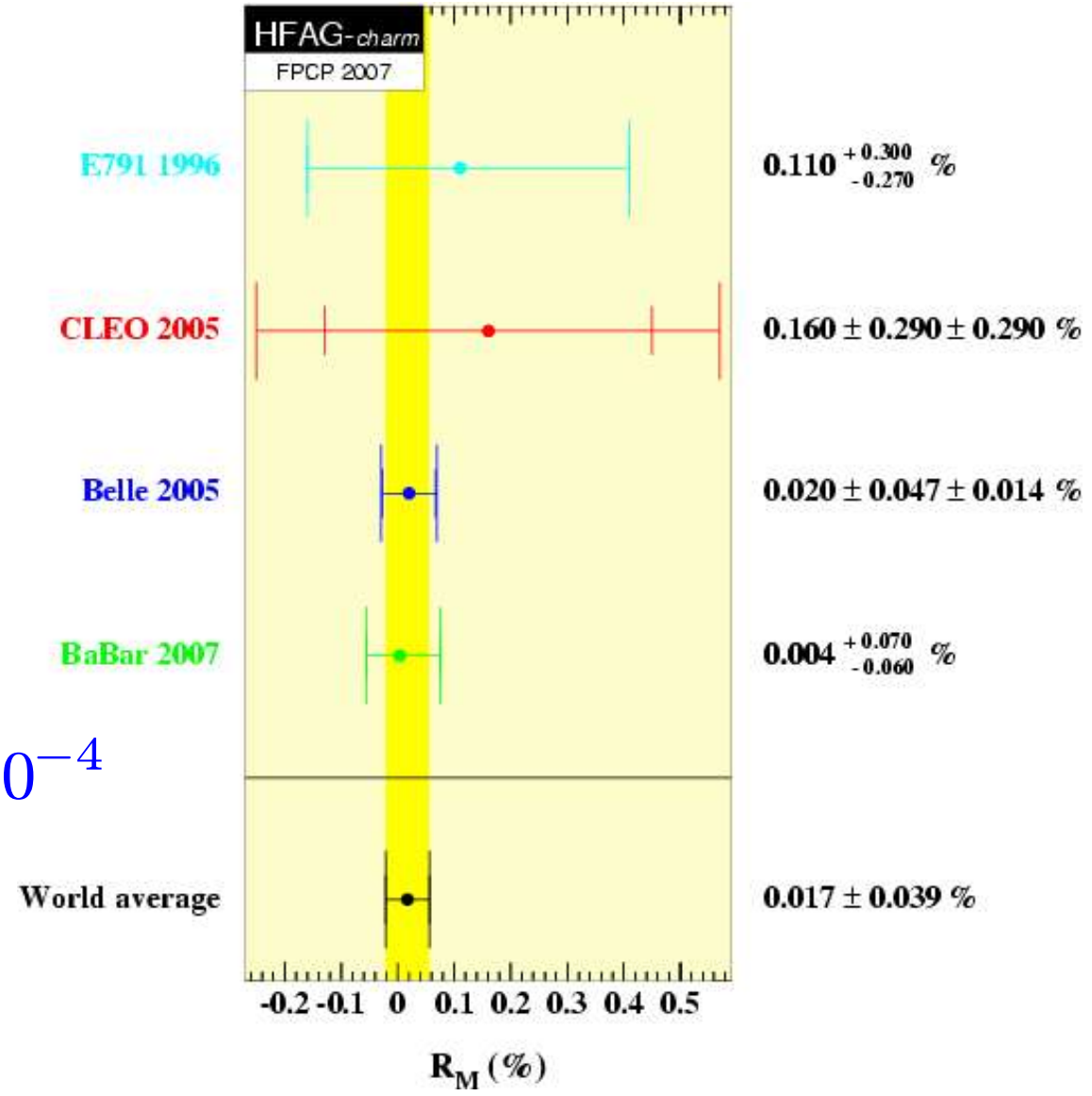
If no CPV: y_{CP}=y



Semileptonic Charm Decays

Semileptonic decays measures

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



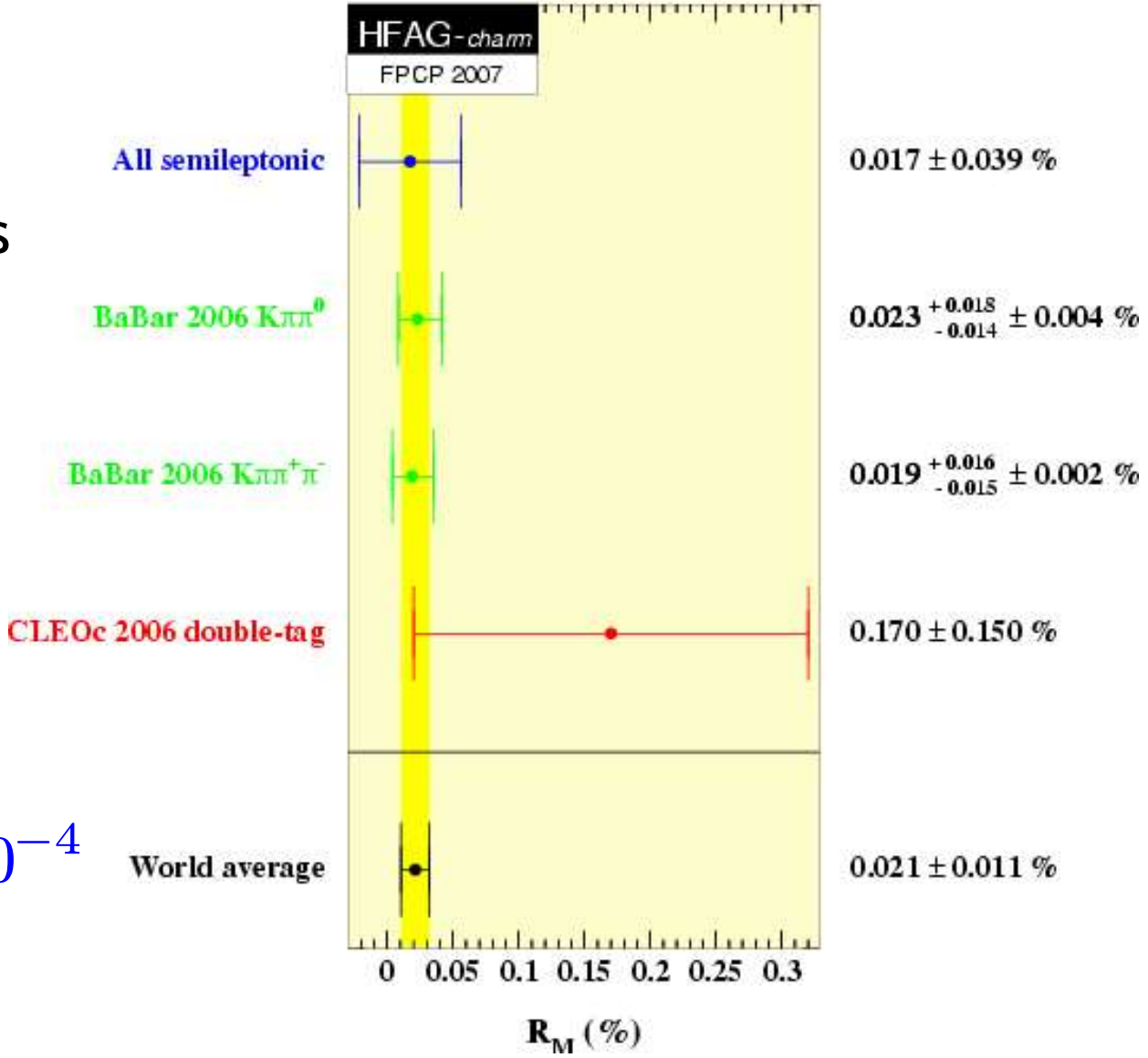
Combined Result:

$$R_M = (1.7 \pm 3.9) \times 10^{-4}$$

More Measurements of R_M

Have more precise measurements of R_M from hadronic D^0 decays
Combine these with semileptonic result

Use full likelihood for $K\pi\pi^0$ to account for asymmetric errors



Combined Result:

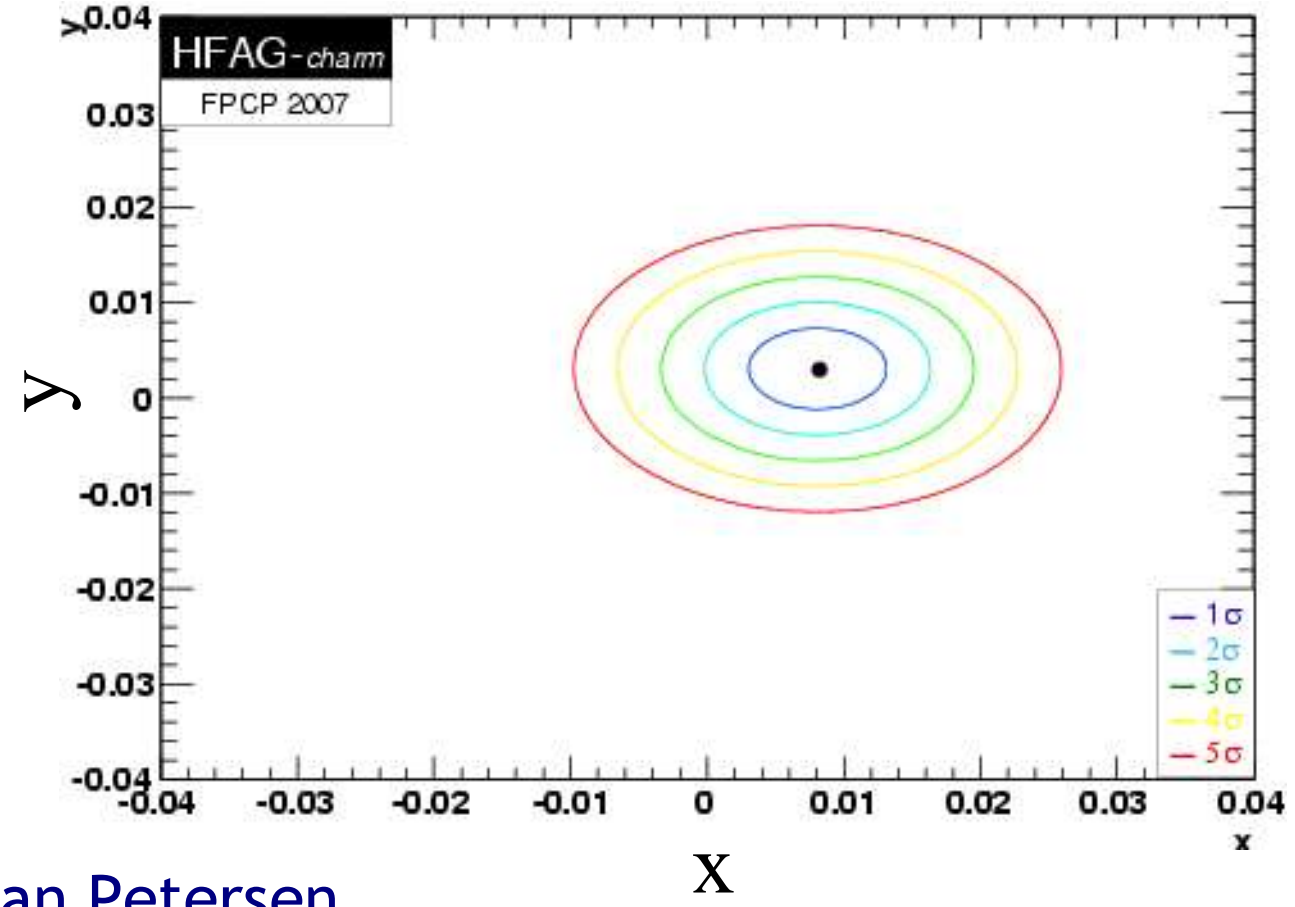
$$R_M = (2.1 \pm 1.1) \times 10^{-4}$$

$K_S\pi\pi$ Dalitz Plot Analysis

Combine 2005 CLEO and 2007 Belle results for $D^0 \to K_S\pi\pi$ decays (using Gaussian errors)

Combined Result:

$$x = (0.81 \pm 0.33)\% \qquad y = (0.31 \pm 0.28)\%$$



Note:

Contours correspond

1-CL=0.317 (1σ)

1-CL=4.55×10^{-2} (2σ)

1-CL=2.70×10^{-2} (3σ)

1-CL=6.33×10^{-5} (4σ)

1-CL=5.73×10^{-5} (5σ)

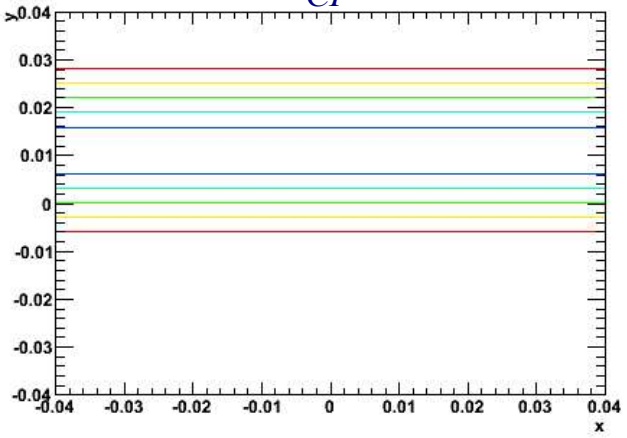
They are not

$-2\Delta\log(\mathcal{L})=1,4,9,\ldots$

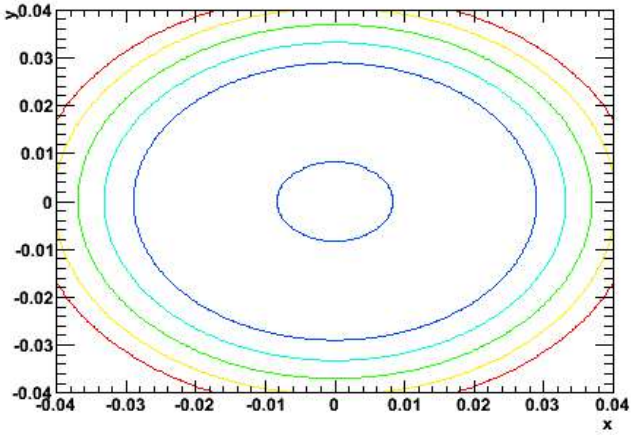
Combining y_{CP}, R_M and $K_S\pi\pi$

Combine likelihood contours assuming CP conservation:

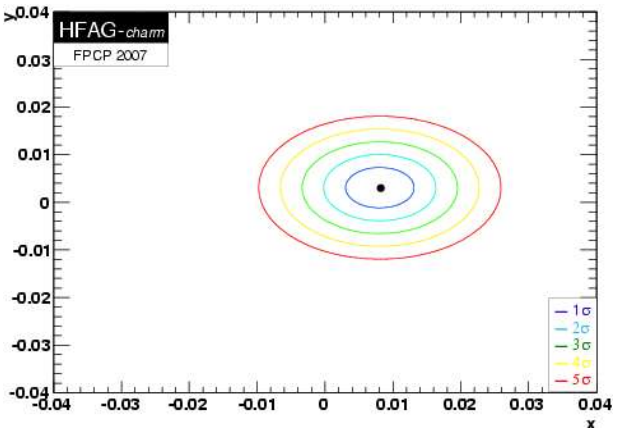
y_{CP}



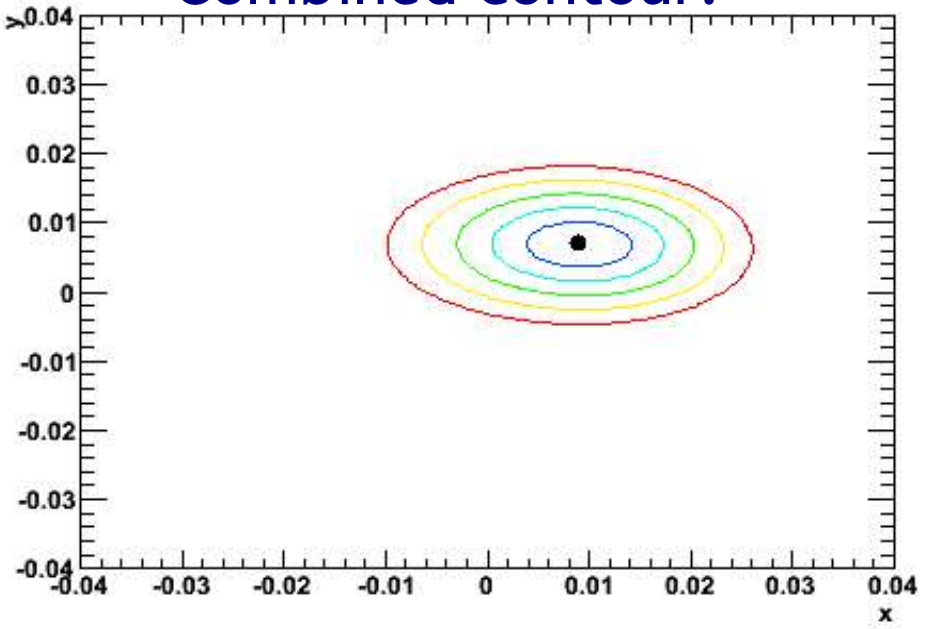
R_M



$K_S\pi\pi$



Combined contour:



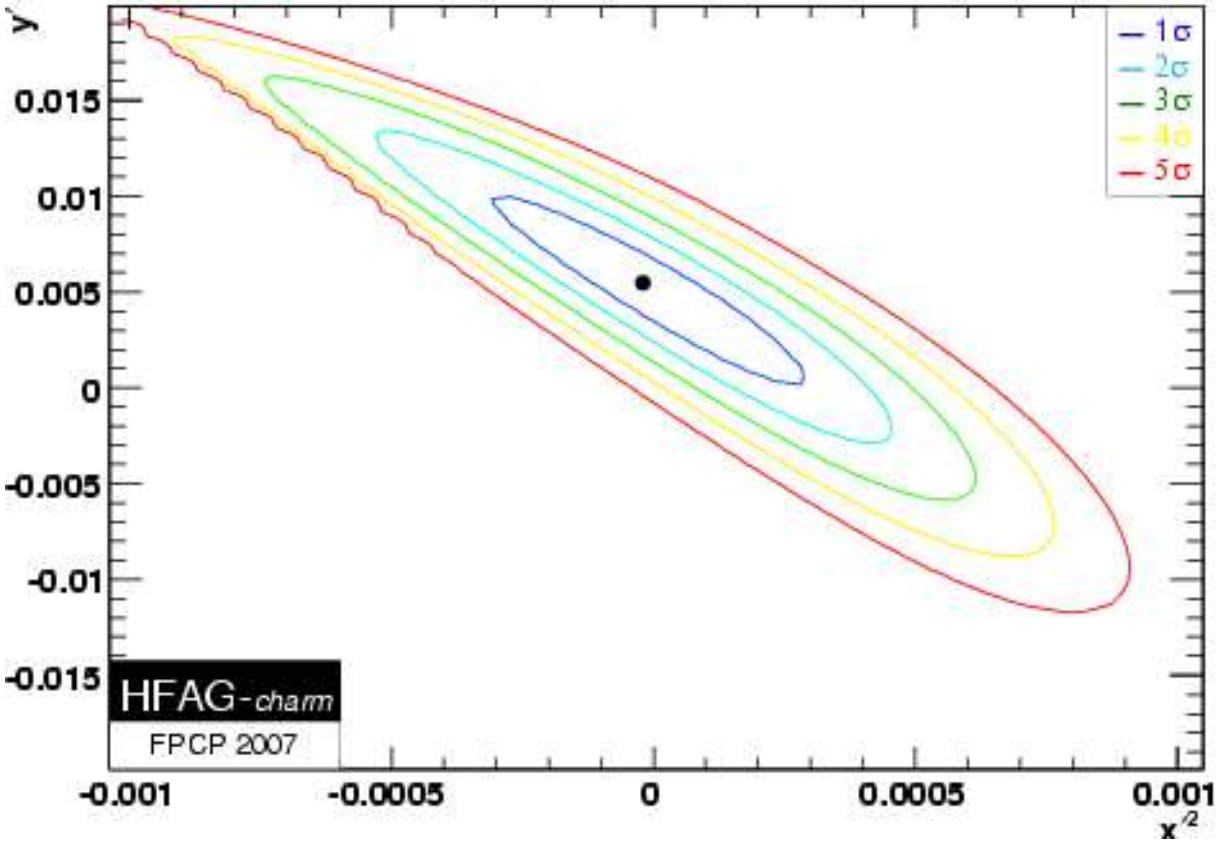
Combined Result:

$$x = (0.92 \pm 0.34)\%$$
$$y = (0.70 \pm 0.22)\%$$

Averaging WS $K\pi$ Mixing Results

In WS $K\pi$ mixing analyses, fitted parameters are highly correlated
We combine 3-dimensional likelihoods in (x'^2, y', R_D)

Combined contour in (x'^2, y'):



Combined Result:

$$x'^2 = (-0.1 \pm 2.0) \times 10^{-4}$$

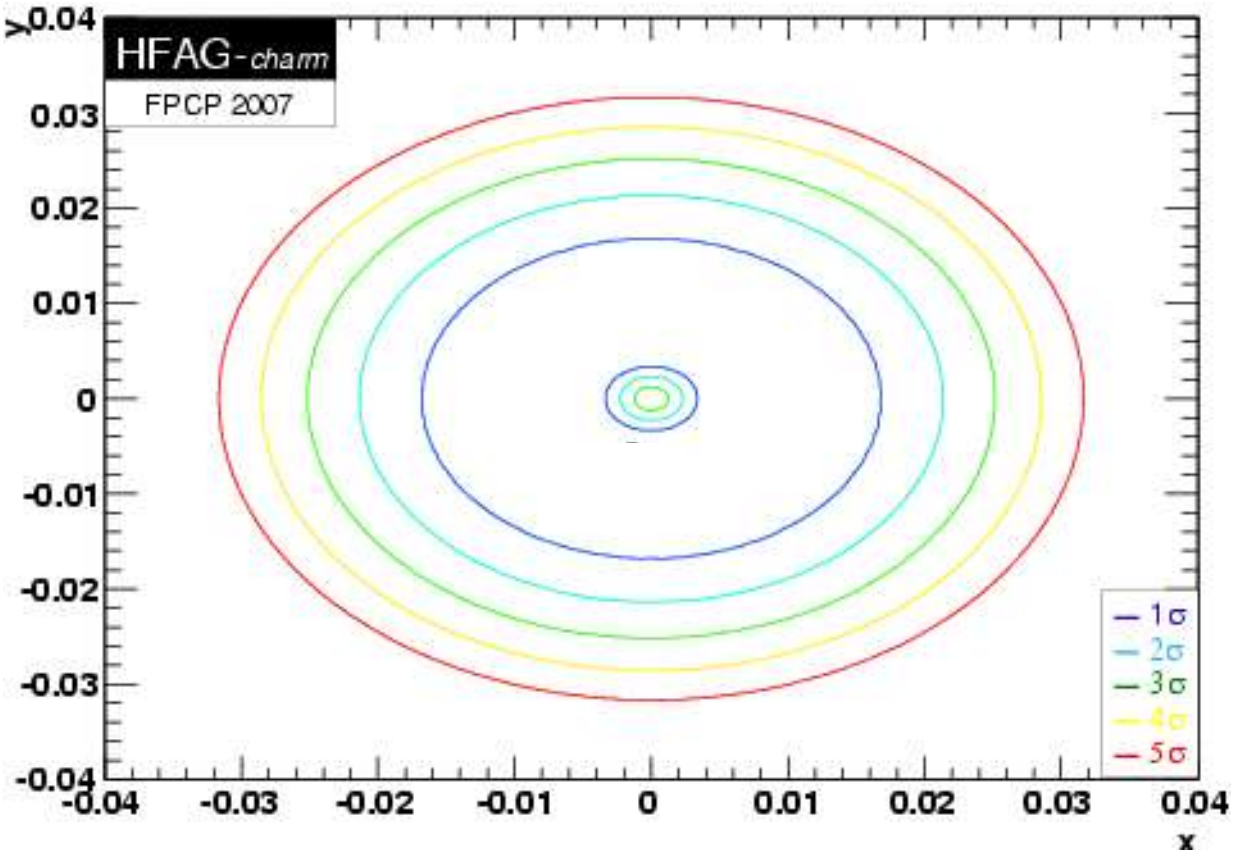
$$y' = (0.55^{+0.28}_{-0.37})\%$$

$$R_D = (0.330^{+0.014}_{-0.012})\%$$

(x,y) from WS Kπ Mixing

Transform likelihood from (x'^2, y') into $(x, y, \delta_{K\pi})$

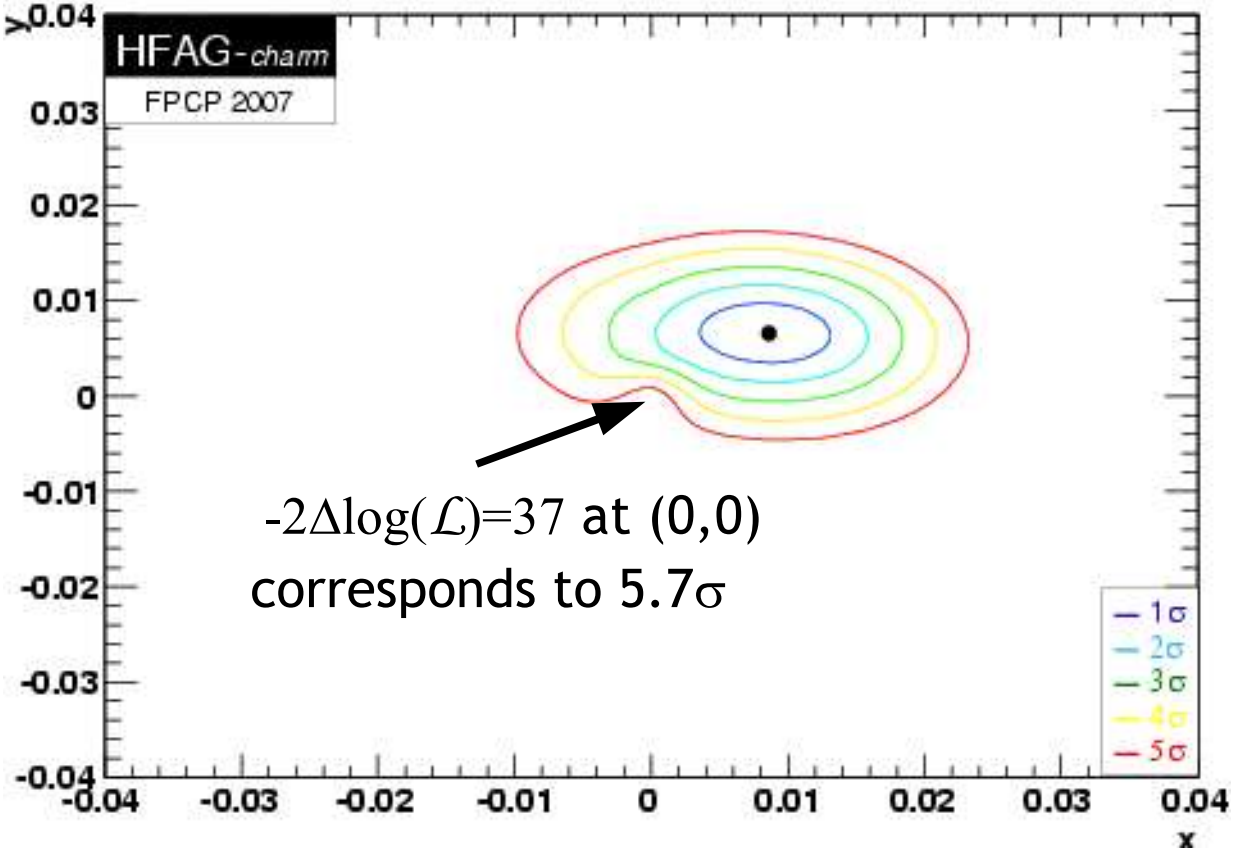
Without further input, this maps out circles when projected over $\delta_{K\pi}$:



Note that in this procedure we ignore the $x'^2<0$ part of the likelihood

Combining all CP Conserving Results

Adding $K\pi$ result does not change central values much, but it further excludes solutions around (x,y)=(0,0)



Combined Result:

$$x = (0.87^{+0.30}_{-0.34})\%$$

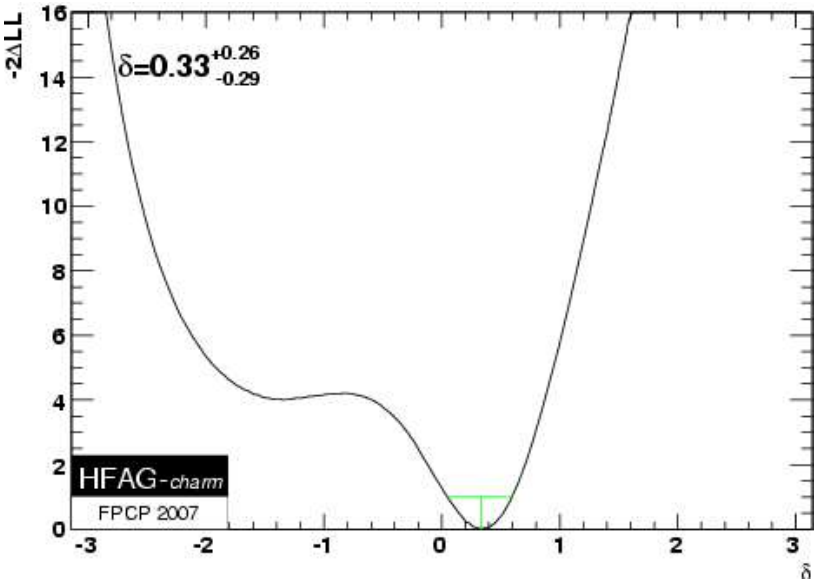
$$y = (0.66 \pm 0.21)\%$$

This average include preliminary CLEO-c measurement of

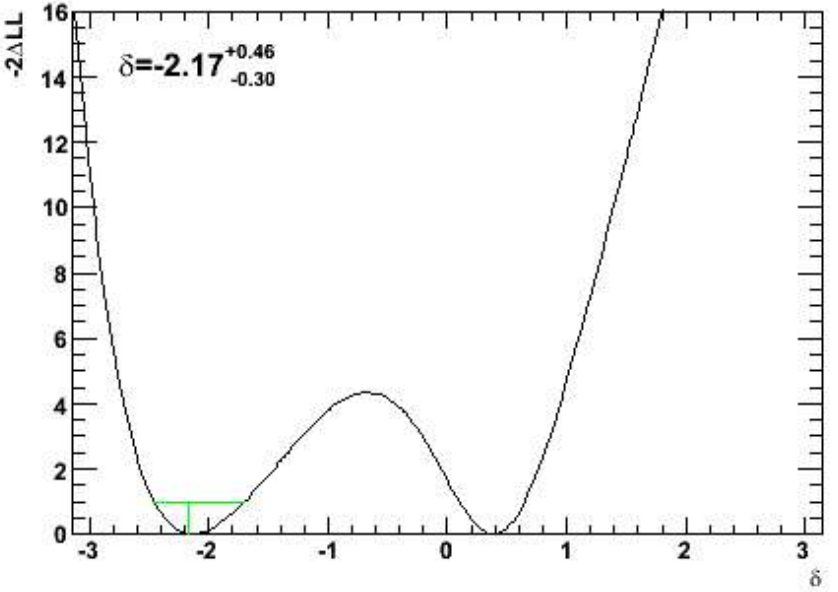
$$\cos\,\delta_{K\pi} = 1.09 \pm 0.66$$

$\delta_{K\pi}$ Measurement

Combination of measurements also gives value for $\delta_{K\pi}$



Without CLEO-c constraint on $\delta_{K\pi}$



Combined Result:

$$\delta_{K\pi} = (0.33^{+0.26}_{-0.29})\text{rad}$$

This is driven mainly by the "matching" of y' and y

Measurement of $\delta_{K\pi}$ from CLEO-c lifts a degeneracy in solutions for $\delta_{K\pi}$

Allowing for CP Violation

Currently combined using χ^2 minimization with
7 free parameters for
22 measurements
(we use the combined y_{CP} and semileptonic R_M)

Covariance matrices from the measurements are used, but non-Gaussian uncertainties are not taken into account
(Mainly affects $K_S\pi\pi$ and $K\pi$)

Relations used:

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

$$2y_{CP} = \left(|q/p|+|p/q|\right)y\cos\phi - \left(|q/p|-|p/q|\right)x\sin\phi$$
$$2A_\Gamma = \left(|q/p|-|p/q|\right)y\cos\phi - \left(|q/p|+|p/q|\right)x\sin\phi$$

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

$$x'^{\pm} = \left(\frac{1\pm A_M}{1\mp A_M}\right)^{1/4}(x'\cos\phi \pm y'\sin\phi) \qquad A_M = \frac{|q/p|^2-|p/q|^2}{|q/p|^2+|p/q|^2}$$
$$y'^{\pm} = \left(\frac{1\pm A_M}{1\mp A_M}\right)^{1/4}(y'\cos\phi \mp x'\sin\phi) \qquad \begin{pmatrix}x'\\y'\end{pmatrix} = \begin{pmatrix}\cos\delta & \sin\delta\\ -\sin\delta & \cos\delta\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}$$

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

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

Combined Fit Results

Allowing for CP violation:

(χ^2 fit)

$$x = (0.84^{+0.32}_{-0.34})\%$$

$$y = (0.69 \pm 0.21)\%$$

$$\left|\frac{q}{p}\right| = (0.88^{+0.23}_{-0.20})$$

$$\varphi = (-0.09^{+0.17}_{-0.19})\text{rad}$$

$$R_D = (0.335 \pm 0.011)\%$$

$$\delta_{K\pi} = (0.38^{+0.27}_{-0.29})\text{rad}$$

$$A_D = (-0.8 \pm 3.1)\%$$

No CP violation:

(Likelihood fit)

$$x = (0.87^{+0.30}_{-0.34})\%$$

$$y = (0.66 \pm 0.21)\%$$

$$R_D = (0.330^{+0.014}_{-0.012})\%$$

$$\delta_{K\pi} = (0.33^{+0.26}_{-0.29})\text{rad}$$

Little difference in non-CP parameters and no hints of CP violation

Contributions to χ^2

χ^2=14.4 for 7 d.o.f.
P(χ^2)=4.4%

Slight disagreement between y_{CP} and y

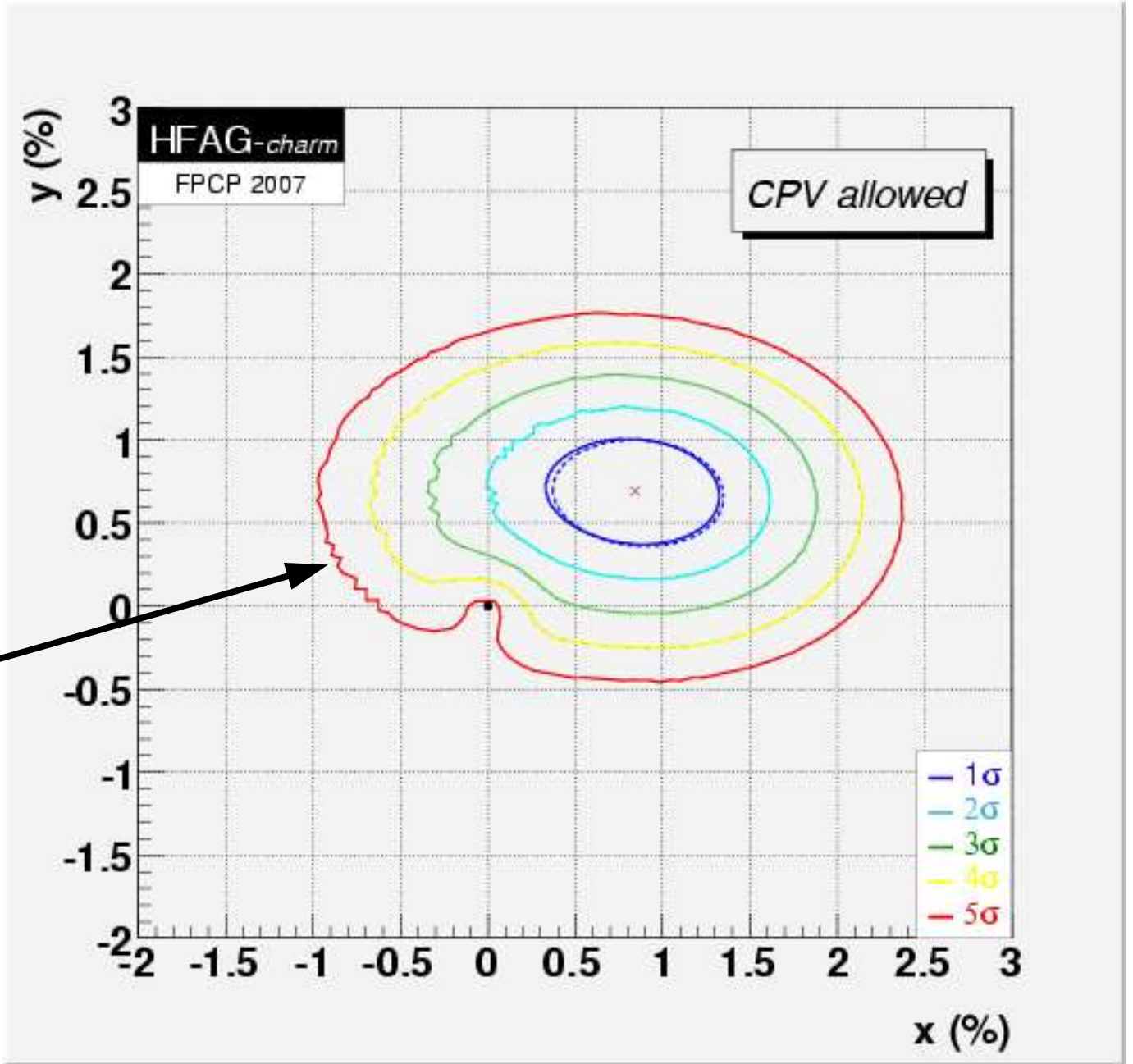
Slight disagreement between BaBar and Belle $K\pi$ results

Observable	χ^2	$\Sigma\chi^2$
f[y_CP]	= 1.83	1.83
f[A_Gamma]	= 0.27	2.10
f[x]	= 0.01	2.11
f[y]	= 1.87	3.98
f[|q/p|]	= 0.00	3.98
f[Arg(q/p)]	= 0.22	4.20
f[R_M(semilept)]	= 0.09	4.29
f[R_M(K+p-p0)]	= 0.85	5.14
f[R_M(K+p-p+p-)]	= 0.66	5.80
f[R_M(psi_3770)]	= 1.20	6.99
f[K+pi- BaBar+]	= 2.21	9.20
f[K+pi- BaBar-]	= 1.47	10.67
f[K+pi- Belle+]	= 2.52	13.19
f[K+pi- Belle-]	= 1.25	14.44

(x,y) Confidence Level Contours

Almost identical to contours from CP conserving procedure

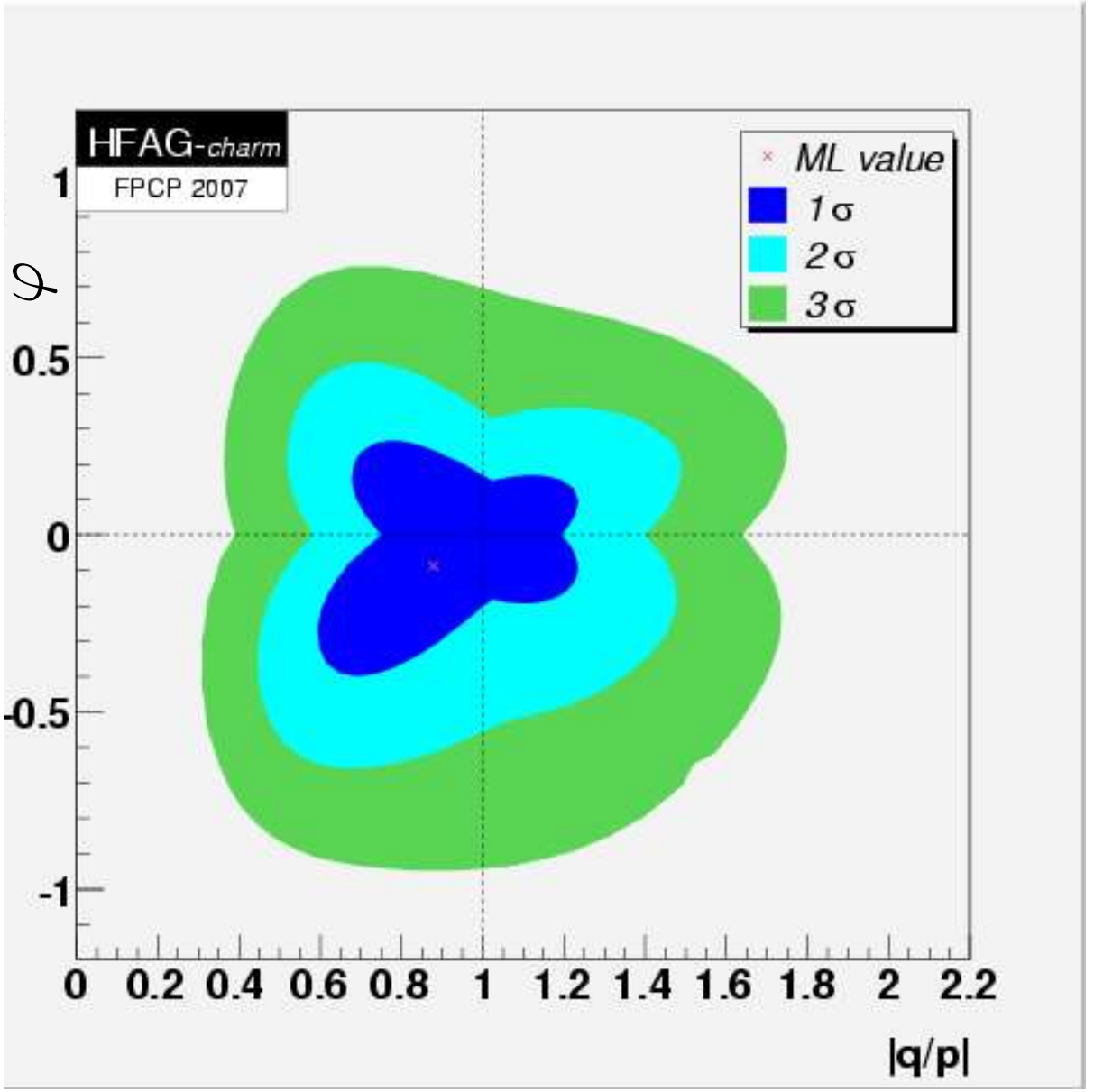
Small wiggles are an artifact of the contour calculation



CP Violation Parameters

Confidence levels for the CP violating parameters show evidence of two solutions

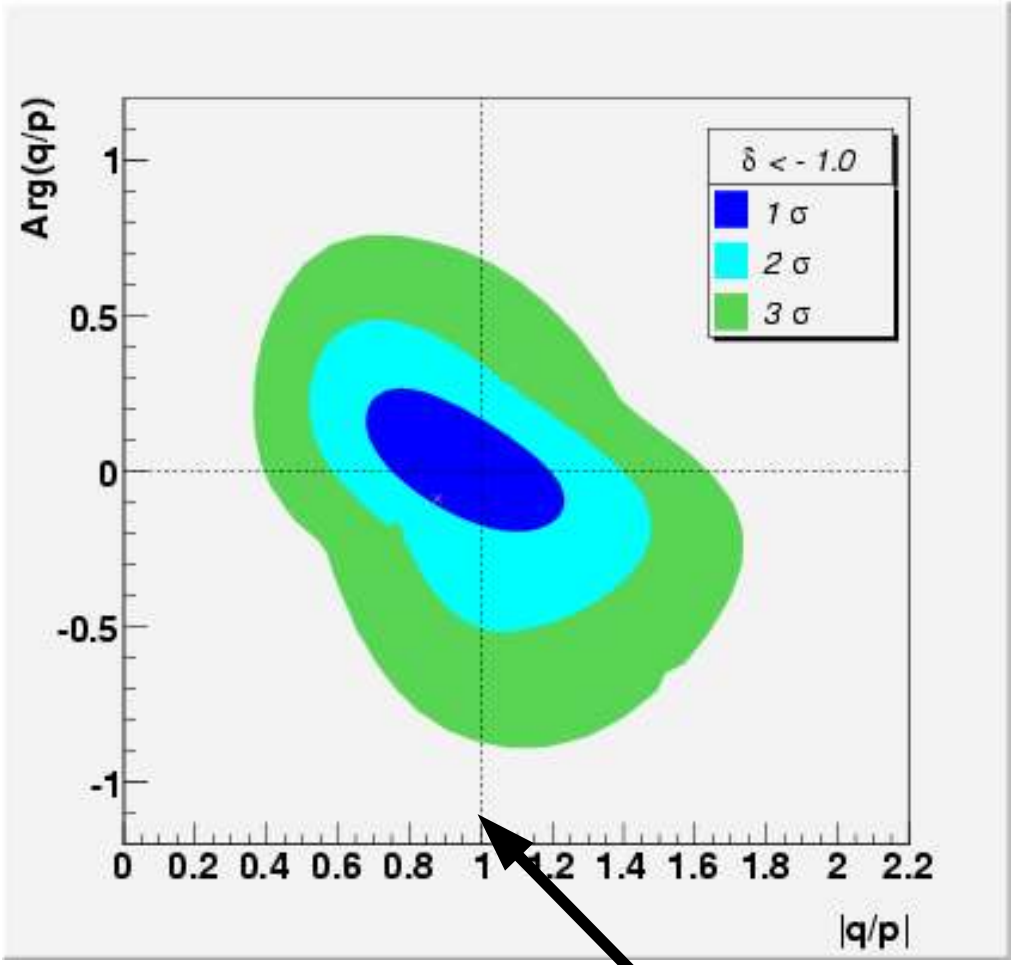
This is found to be due to degeneracy in $\delta_{K\pi}$ as CLEO-c results currently is not used in this average

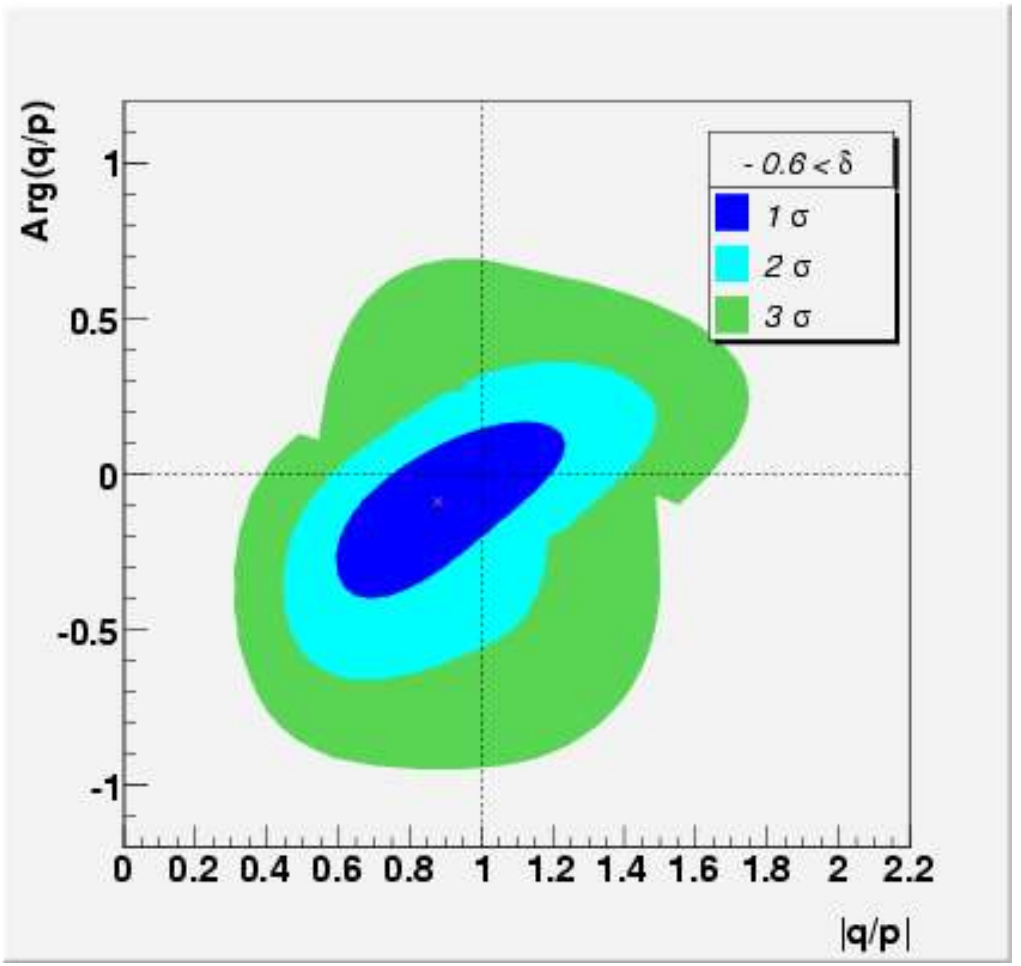


Degenerate Solutions

$\delta_{K\pi}$<–1 rad

$\delta_{K\pi}$>–0.6 rad





Disfavored by CLEO-c

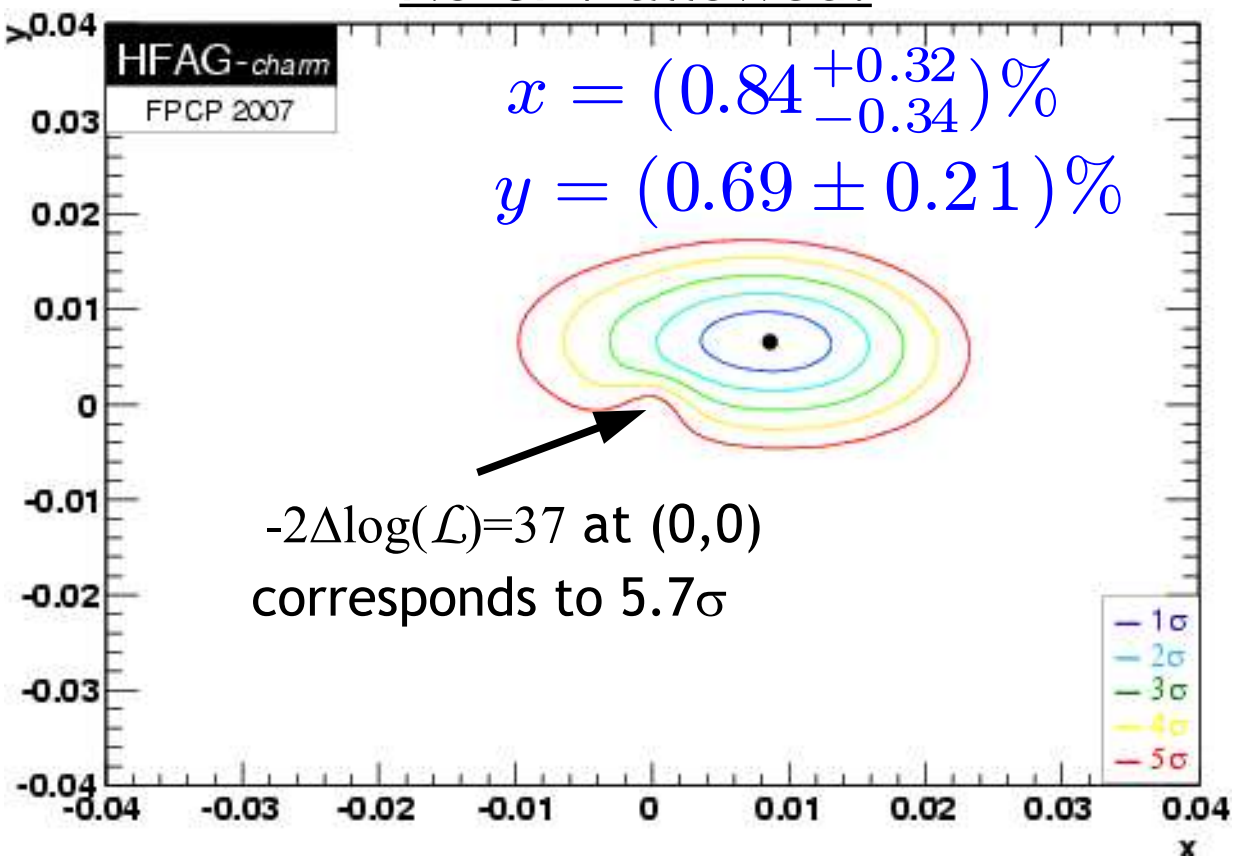
Summary

We have combined most measurements in D^0-$\bar{D}^0$ mixing
x and y appear to be 0.5-1.0% while there is no CP violation

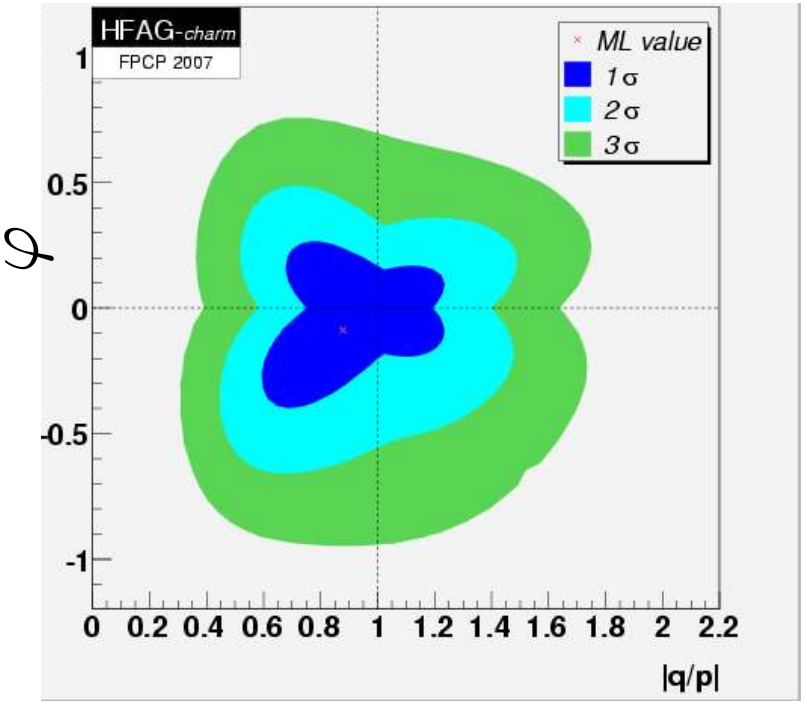
No CPV allowed:

$$x = (0.84^{+0.32}_{-0.34})\%$$
$$y = (0.69 \pm 0.21)\%$$

$$\left|\frac{q}{p}\right| = (0.88^{+0.23}_{-0.20})$$
$$\varphi = (-0.09^{+0.17}_{-0.19})\text{rad}$$



-2Δlog($\mathcal{L}$)=37 at (0,0)
corresponds to 5.7σ



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