Results on D mixing and CP violation at B factories

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for
The BaBar collaboration

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Outline

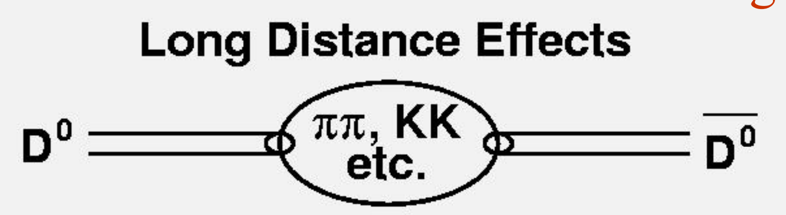
- D^0-$\overline{D^0}$ mixing
- CP violation in charm decays
- Experimental results using various final states:

	BaBar	Belle	CLEO	E791	Focus	CDF
$K^+\pi^-$	X	X	X	X	X	X
KK, $\pi\pi$	X	X X	X	X	X	
$K\pi\pi^0$	X	X				
$K^0_S\pi\pi$, $K^0_S KK$		X X	X			
Semi-leptonic	X	X	X	X		

- Summary

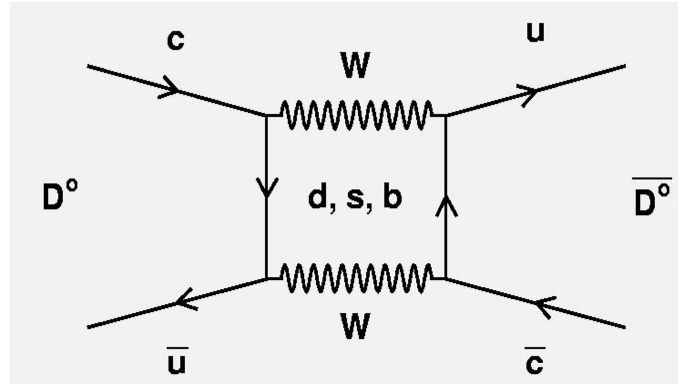
Physics of $D^0\bar{D}^0$ – mixing

- Common final states lead to mixing:



- Naively estimate of the mixing rate: BF ~ few x 10^{-3}, thus rate $r_{mix} \sim 10^{-5}$.

- Mixing at the quark level:



- Predicted rate for mixing: $r_{mix} \sim 10^{-7}$.

$$r_{mix} \equiv \Gamma(D^0 \to \bar{D}^0 \to l^- \nu X) \,/\, \Gamma(D^0 \to l^+ \nu X)$$

- If the Standard Model mixing rate were small we would have a large window for discovery of new physics.
- However, it appears that long distance contributions are large and the mixing rate ~ 10^{-4}.

- Possibililty of CP violation first noted by Pais and Treiman, who also established parameters for mixing (x, y, r). [Phys. Rev. D12, 2744 (1975)].
- It is possible that $\Gamma(D^0 \to \bar{D}^0) \neq \Gamma(\bar{D}^0 \to D^0)$

Experimental Technique

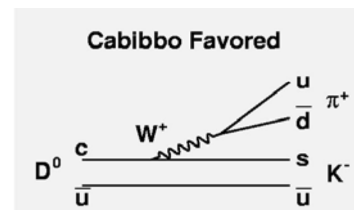
Flavor at Production:

- Charm flavor at production can be tagged by either
  - the slow pion in D^{*+} decays or
  - by double tagging

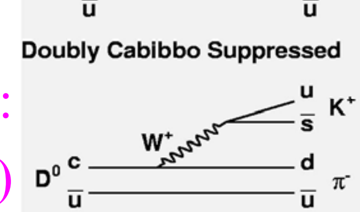
Flavor at Decay:

- Most decays of the D^0 are "Cabibbo-favored", e.g., $D^0 \rightarrow K^-\pi^+$.
- Hadronic "wrong-sign" decays ($D^0 \rightarrow K^+\pi^-$ in this case) can occur either via double Cabibbo-suppression (DCS) or due to mixing.
- Semileptonic "wrong-sign" decays only occur due to mixing.

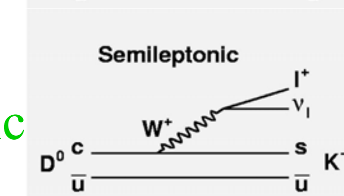
Right Sign:
(RS decays)



Wrong Sign:
(WS decays)



Semileptonic



Mixing Parameters

- Mixing in the neutral *D* system arises from the existence of two mass eigenstates D_1 and D_2 that are not flavor eigenstates

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix} = \left(\mathbf{M} - \frac{i}{2}\mathbf{\Gamma}\right)\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix}$$

$$|D_1> \;=\; p|D^0> + q|\bar{D}^0> \qquad |D_1(t)> \;=\; |D_1>\, e^{-i(\Gamma_1/2 - im_1)t}$$

$$|D_2> \;=\; p|D^0> - q|\bar{D}^0> \qquad |D_2(t)> \;=\; |D_2>\, e^{-i(\Gamma_2/2 - im_2)t}$$

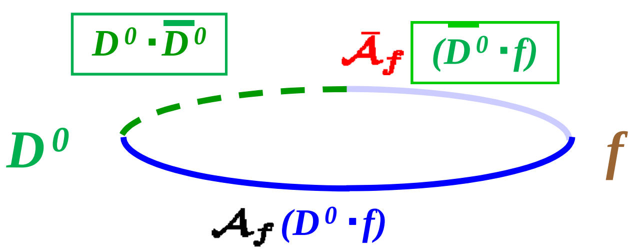
Eigenvalues are
$m_{1,2} + i\Gamma_{1,2}/2$

with means:
$M = (m_1 + m_2)/2$
$\Gamma = (\Gamma_1 + \Gamma_2)/2$

- It is usual to define mixing parameters as follows:

$$x = \frac{M_1 - M_2}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} \qquad \lambda_f \equiv (q/p)[\bar{\mathcal{A}}_f / \mathcal{A}_f]$$

CP violation when
$|\bar{\mathcal{A}}_f| \neq |\mathcal{A}_f|$: Decays
$|p| \neq |q|$: Mixing
$\mathrm{Im}(\lambda_f) \neq 0$: Interference



Time-dependent WS decay rate

Two types of WS Decays:

– Doubly Cabibbo-suppressed (DCS) $D^0 \to K^+\pi^-$

– Mixing followed by Cabibbo-Favored (CF) decay $D^0 \underset{\text{mix}}{\to} \overline{D}^0 \to K^+\pi^-$

Two ways to reach same final state ⇒ interference possible!

(assuming *CP*-conservation and |x|«1, |y|«1) :

$$\Rightarrow \frac{d\Gamma}{dt}[|D^0(t)\rangle \to f] \propto e^{-\Gamma t}\left(R_{\mathrm{D}} + \sqrt{R_{\mathrm{D}}}y'\,\Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2\right)$$

DCS decay **Interference between DCS and mixing** **Mixing**

$$x' = x\cos\delta_{K\pi} + y\sin\delta_{K\pi}, \qquad y' = -x\sin\delta_{K\pi} + y\cos\delta_{K\pi}$$

$\delta_{K\pi}$: strong phase difference between CF and DCS decay amplitudes

$\sqrt{R_D}$: magnitude of $\lambda^{-1}(K^+\pi^-)$

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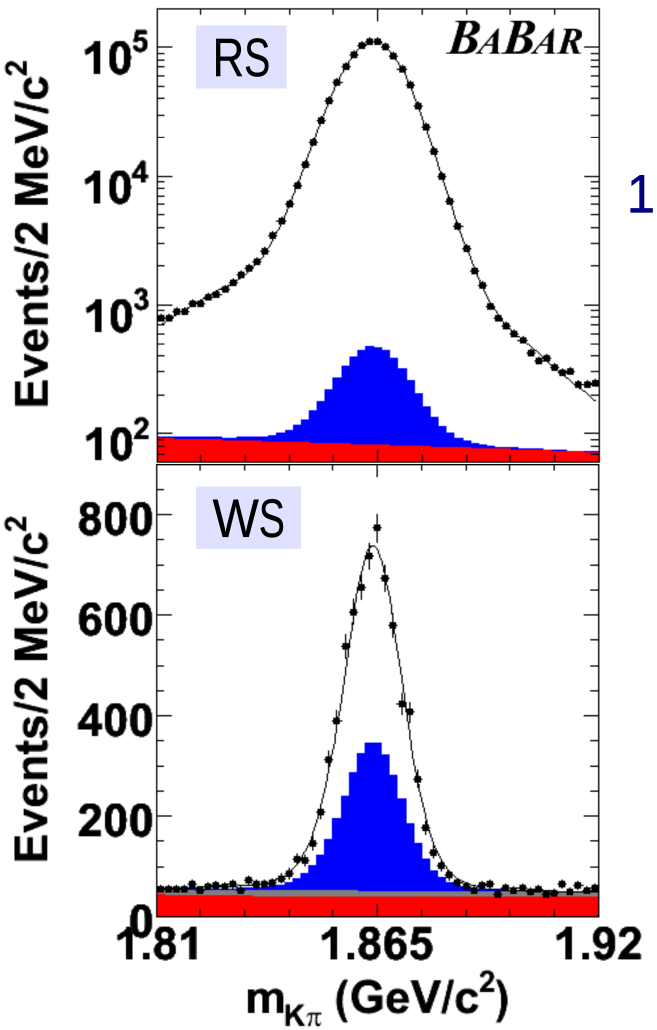
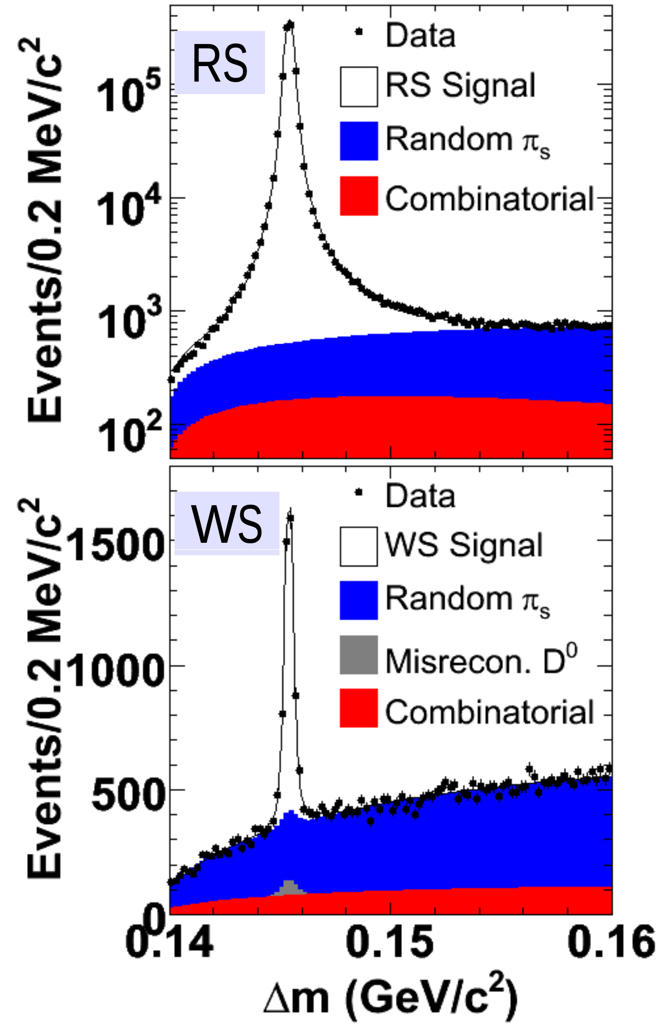
$m_{K\pi}$ & Δm Fit Results

PRL 98, 211802 (2007)



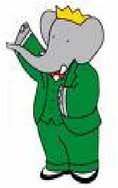
RS signal:
1,141,500±1200
combinations

WS signal:
4,030±90
combinations



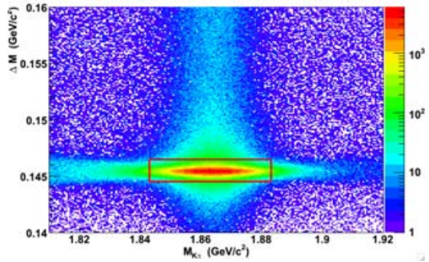
π_s is the pion from the D^{*+}

$\Delta m \equiv m_{K\pi\pi_s} - m_{K\pi}$



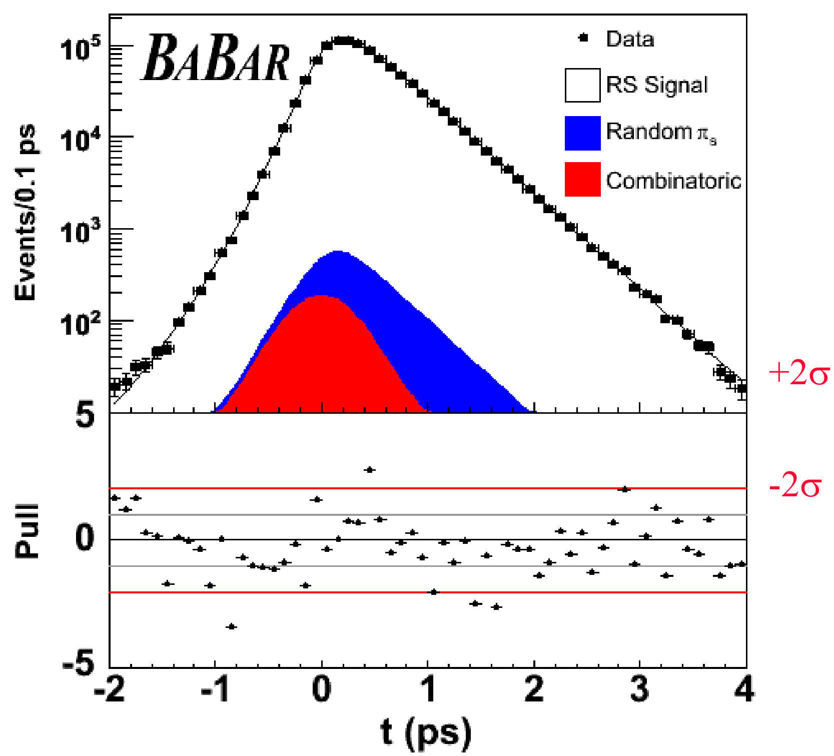
RS Proper Time Fit

plot selection:
1.843 < m < 1.883 GeV/c^2
0.1445 < Δm < 0.1465 GeV/c^2



PRL 98, 211802 (2007)

RS decay time, signal region



D^0 lifetime and
resolution function
fitted in RS sample

τ=410.3±0.6 (*stat*) fs

Consistent with PDG

τ_{PDG}=410.1±1.5 fs

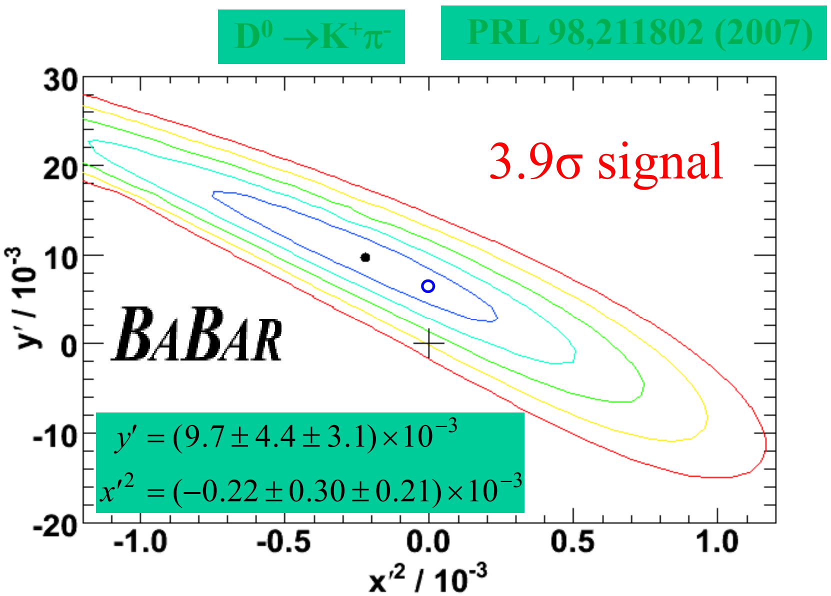
Systematics dominated by
signal resolution function

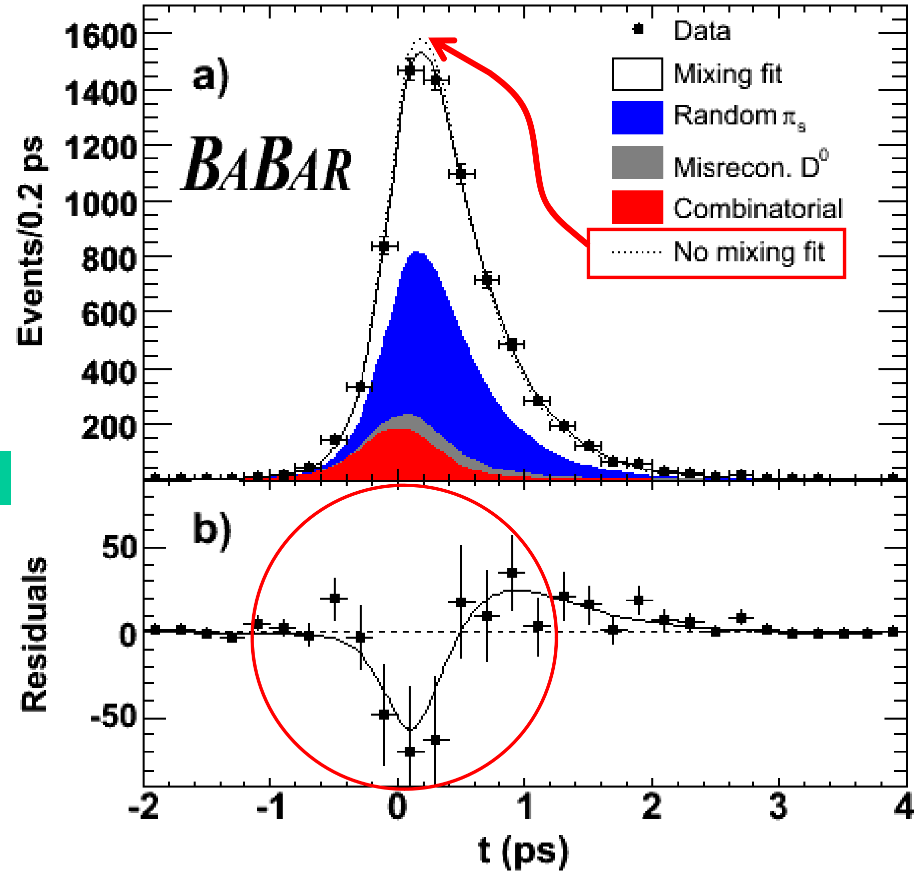
WS Decay Time Fit: Mixing Allowed

PRL 98, 211802 (2007)

Data: 384 fb^{-1}

* The dotted line is the no-mixing expectation.
* The solid line is the mixing fit.
* The difference between no-mixing hypothesis and the fit with mixing is shown in the residuals plot.





R_D: (3.03 ± 0.16 ± 0.10) x 10^{-3}

x'^2: (-0.22 ± 0.30 ± 0.21) x 10^{-3}

y': (9.7 ± 4.4 ± 3.1) x 10^{-3}

No evidence for CPV: the results for D^0 and $\overline{D^0}$ are consistent with each other

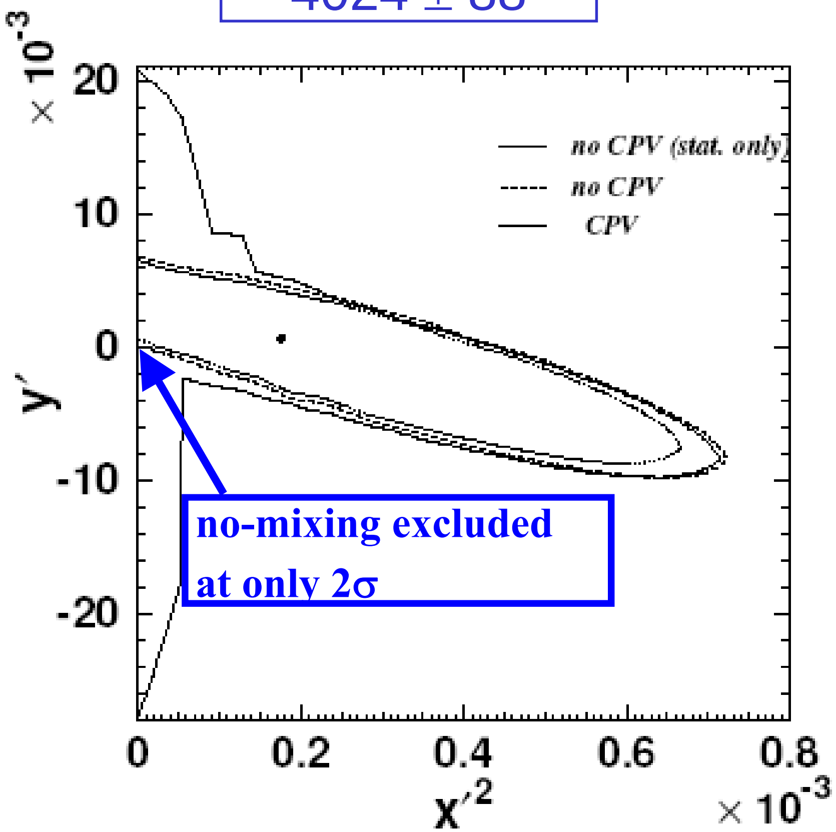
$D^0 \to K\pi$ Belle Measurement

PRL 96, 151801 (2006)

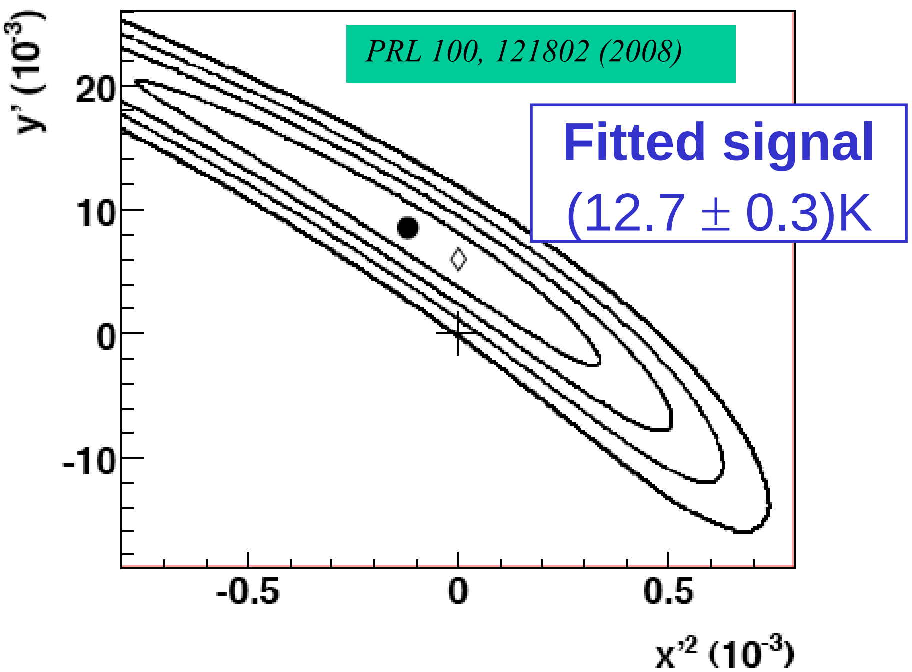
Data sample 400 fb^{-1}

Fit case	Parameter	Fit result ($\times 10^{-3}$)	95% C.L. interval ($\times 10^{-3}$)
No CPV	R_D	3.64 ± 0.17	$(3.3,\ 4.0)$
	x'^2	$0.18^{+0.21}_{-0.23}$	< 0.72
	y'	$0.6^{+4.0}_{-3.9}$	$(-9.9,\ 6.8)$
	R_M	-	$(0.63 \times 10^{-5},\ 0.40)$
CPV	A_D	23 ± 47	$(-76,\ 107)$
	A_M	670 ± 1200	$(-995,\ 1000)$
	x'^2	-	< 0.72
	y'	-	$(-28,\ 21)$
	R_M	-	< 0.40
No mixing	R_D	$3.77 \pm 0.08(\text{stat.}) \pm 0.05(\text{syst.})$	

Fitted signal
4024 ± 88



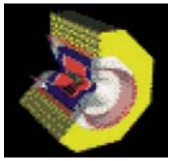
$D^0 \rightarrow K\pi$ CDF Measurement



Evidence for mixing at 3.8σ

- * Different Analysis
- * Different Production Environment
- * Confirmation of *BaBar* mixing result
  - ***Nearly identical results!***

Experiment	$R_D(10^{-3})$	$y'(10^{-3})$	$x'^2(10^{-3})$	Mixing Signif.
CDF	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	3.8
BABAR	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37	3.9
Belle	3.64 ± 0.17	$0.6 + 4.0 - 3.9$	$0.18 + 0.21 - 0.23$	2.0



Measurement of $\delta_{K\pi}$ by CLEO-c

PRD 78, 012001 (2008)
PRL 100, 221801 (2008)

- **Motivation**
  - Need $\delta_{K\pi}$ to compare the measurements of y and y'
  - $\delta = -\delta_{K\pi}$ is defined as the phase of the $K\pi$ DCS to CF amplitude ratio

$$\frac{\langle K^+\pi^-|D^0\rangle}{\langle K^+\pi^-|\bar{D}^0\rangle} = re^{-i\delta} \quad \text{with} \quad r \approx 0.06$$

- **Determination of the strong phase in quantum correlated $D^0\bar{D}^0$ pairs**

$$e^+e^- \to \psi(3770) \to D^0\bar{D}^0 \qquad \Rightarrow C = -1$$

  - Measure time integrated yields of correlated and uncorrelated D^0 decays
  - The ratio of correlated and uncorrelated D^0 decay rates depends on the mixing parameters and $\delta_{K\pi}$

    $\rightarrow$ Extract x^2, y, r^2 and cos($\delta_{K\pi}$) from time integrated yields
  - External branching fraction are used and including external mixing parameter measurements improves the $\delta_{K\pi}$ extraction

Results of the $\delta_{K\pi}$ measurement

PRD 78, 012001 (2008)
PRL 100, 221801 (2008)

- Extract the strong phase $\delta_{K\pi}$ in a fit to 281pb^{-1} of CLEO-c data
  (external branching fraction measurements are used)
  $x\,sin\,(\delta_{K\pi})$ can not be determined in this fit, therefore set $x\,sin\,(\delta_{K\pi}) = 0$

$$cos\,(\delta_{K\pi}):\quad 1.03^{+0.31}_{-0.17} \pm 0.06$$

- Including in addition external measurements of mixing parameters improves the fit.
  $x\,sin\,(\delta_{K\pi})$ can now be determined

$$cos\,(\delta_{K\pi}):\quad 1.10 \pm 0.35 \pm 0.07$$
$$x\,sin\,(\delta_{K\pi}):\quad (4.4^{+2.7}_{-1.8} \pm 0.29)\cdot 10^{-3}$$
$$\delta_{K\pi}:\quad (22\,^{+11}_{-12}{}^{+\ 9}_{-11})^{\circ}$$

external input parameters

Parameter	Average
y	0.00662 ± 0.00211
x	0.00811 ± 0.00334
r^2	0.00339 ± 0.00012
y'	0.0034 ± 0.0030
x'^2	0.00006 ± 0.00018

- Established a new technique using time independent measurements of mixing parameters and the strong phase.

Lifetime-Difference Measurements

- In the absence of *CPV*, D_1 is *CP*-even and D_2 is *CP*-odd
  - Measurement of lifetimes τ for D^0 decays to *CP*-even and *CP*-odd final states lead to a measurement for *y*.

$$y = \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to h^+h^-)} - 1$$

Mixed *CP*. Assume τ is mean of *CP* -even and *CP* -odd

K^+K^- or $\pi^+\pi^-$ *CP* -even

$$A_\tau = \frac{\tau(\bar{D}^0 \to h^+h^-) - \tau(D^0 \to h^+h^-)}{\tau(\bar{D}^0 \to h^+h^-) + \tau(D^0 \to h^+h^-)} = \frac{1}{2} A_M y \cos\phi_M - x \sin\phi_M$$

A_M: $|q/p|^2 - 1$

- Allowing for *CPV*, measure the D^0 and $\bar{D}^0$ asymmetry

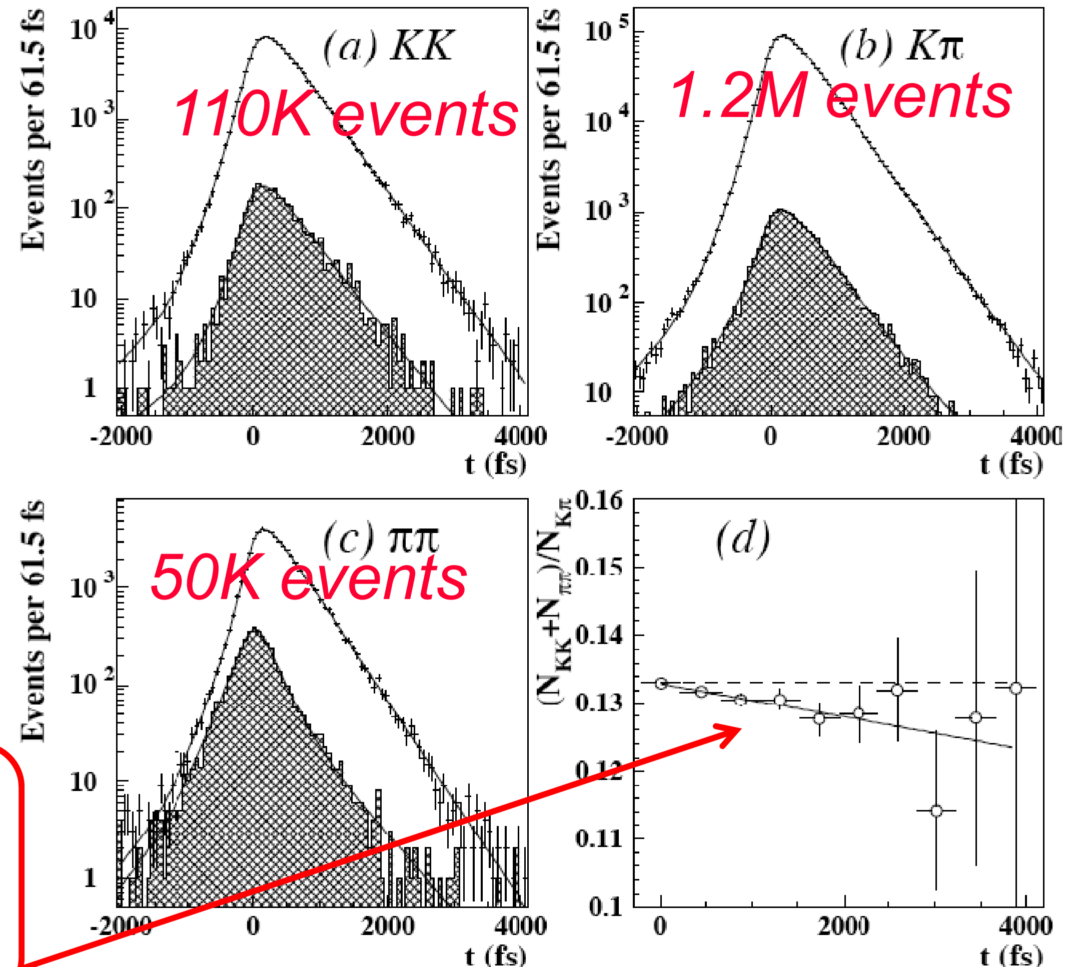
PRD 69,114021 (Falk, Grossman, Ligeti, Nir & Petrov)

Lifetime Ratio (y, A_Γ): Evidence Of Mixing At 3.2σ

PRL 98, 211803 (2007)

Data: 540 fb^{-1}

- Most of the systematic error cancels in the lifetime ratio.
- Bkgd related systematics do not.
- Require: p* > 2.5 GeV/c, $\sigma_t < 0.37$ ps
- Purity of selection 98%, 98%, 92% for KK, Kπ, ππ, respectively

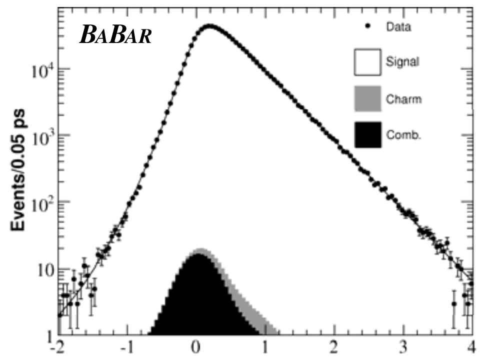


Ratio of D^0_{CP}/D^0 events varies as a function of time due to lifetime difference ($y \neq 0$)

Decay time fits to determine *y, ΔY*

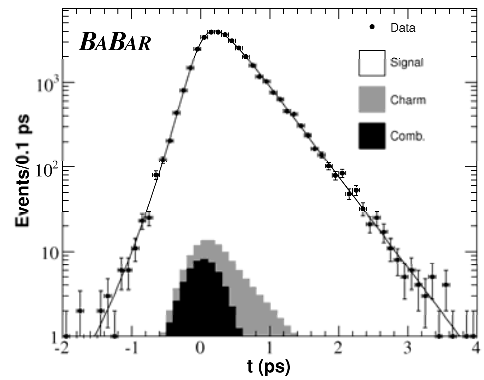
PRD 78, 011105(R) (2008) **[384 fb^{-1}]**

$D^0 \to K^-\pi^+ + \text{c.c.}$



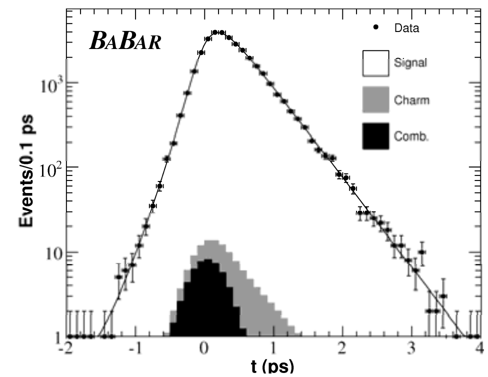
τ=409.3±0.7 fs

$D^0 \to K^+K^-$

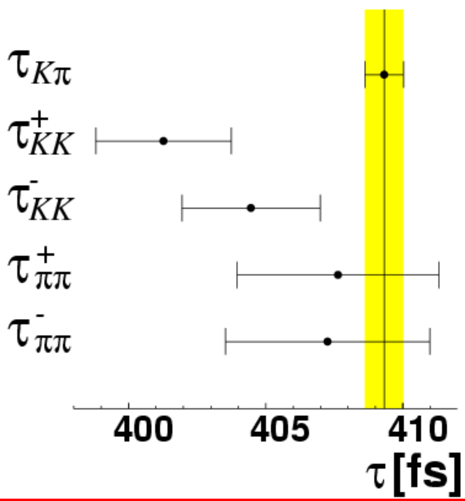


τ=401.3±2.5 fs

$\overline{D}^0 \to K^+K^-$

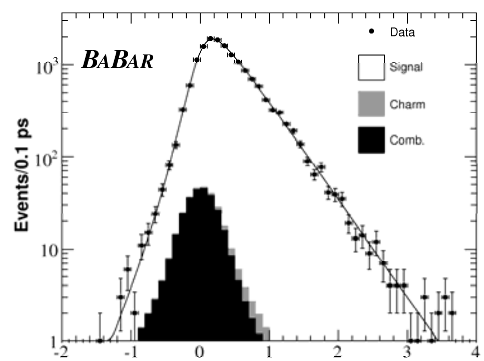


τ=404.5±2.5 fs



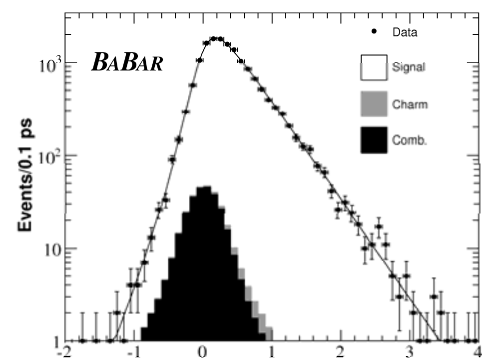
***Kπ* and *KK* lifetimes differ**

$D^0 \to \pi^+\pi^-$



τ=407.6±3.7 fs

$\overline{D}^0 \to \pi^+\pi^-$

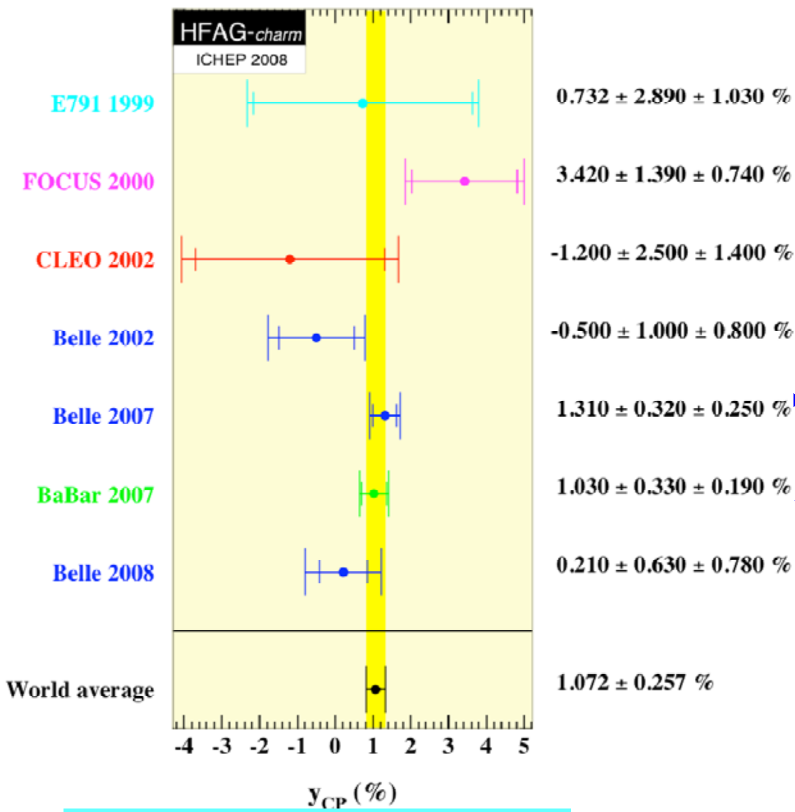


τ=407.3±3.8 fs

Lifetime-Difference Results

y_{CP} world average from HFAG

arXiv:0808.1297



$y = (1.132 \pm 0.266)\%$

Mode	y_{CP} (%)	A_τ (%)
K^+K^-	$1.25 \pm 0.39 \pm 0.28$	$0.15 \pm 0.34 \pm 0.16$
$\pi^+\pi^-$	$1.44 \pm 0.57 \pm 0.42$	$-0.28 \pm 0.52 \pm 0.30$
Combined	$1.31 \pm 0.32 \pm 0.25$	$0.01 \pm 0.30 \pm 0.15$

3.2 σ evidence - no CPV

PRL 98, 211803 (2007) 540 fb-1

Mode	y_{CP} (%)	$\Delta Y = (1 - y_{CP})A_\tau$ (%)
K^+K^-	$1.60 \pm 0.46 \pm 0.17$	$-0.40 \pm 0.44 \pm 0.12$
$\pi^+\pi^-$	$0.46 \pm 0.65 \pm 0.25$	$0.05 \pm 0.64 \pm 0.32$
Combined	$1.24 \pm 0.39 \pm 0.13$	$-0.26 \pm 0.36 \pm 0.08$

3.0 σ evidence - no CPV

PRD 78, 011105(R) (2008) 384 fb^{-1}

384 fb^{-1} tagged and 91 fb^{-1} untagged (*BaBar*)

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Time-Dependent Amplitude Analysis of $D^0 \rightarrow K^+\pi^-\pi^0$

- Similar to $D^0 \rightarrow K^+\pi^-$ but now $\bar{f}$ is an amplitude at a point in the Dalitz plot *(DP)* for the $K^+\pi^-\pi^0$ final state

- *CF* ($\bar{\mathcal{A}}_{\bar{f}}$) and *DCS* ($\mathcal{A}_{\bar{f}}$) amplitudes contribute to decay and describe density of points in the *DP* at time *t:*

$$\underbrace{|\mathcal{A}_{\bar{f}}|^2}_{\text{CSD}} + \underbrace{|\mathcal{A}_{\bar{f}}||\bar{\mathcal{A}}_{\bar{f}}|\,[y''\cos\delta_f - x''\sin\delta_f]\,(\Gamma t)}_{\text{DCS-Mixing interference}} + \underbrace{\frac{x^2+y^2}{4}|\bar{\mathcal{A}}_{\bar{f}}|^2(\Gamma t)^2}_{\text{Mixing}}$$

assumes $(|x|, |y| \ll 1)$

δ_f $= \mathrm{Arg}\{\bar{\mathcal{A}}_{\bar{f}}/\mathcal{A}_{\bar{f}}\}$ Depends on DP position

- The interference term permits measurement of

$$x'' = x\cos\delta_{K\pi\pi} + y\sin\delta_{K\pi\pi} \quad \text{and}$$
$$y'' = y\cos\delta_{K\pi\pi} - x\sin\delta_{K\pi\pi}$$

NOTE: $\delta_{K\pi\pi} \neq \delta$ is also unknown

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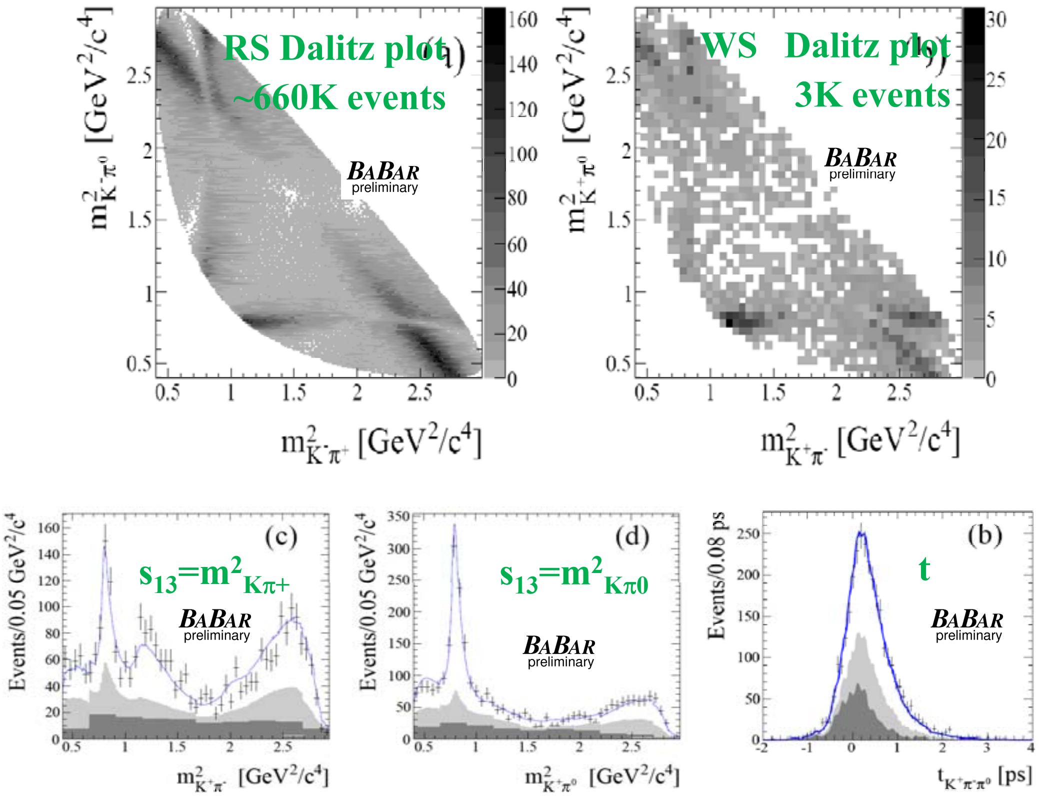
Evidence for Mixing in (*WS*) $D^0 \rightarrow K^+\pi^-\pi^0$

384 fb^{-1}

arXiv:0807.4544 [hep-ex]
Submitted to PRL



- Use **D*** tagged sample
- Find **CF** amplitude $\bar{\mathcal{A}}_{\bar{f}}$ from time-integrated fit to **RS** Dalitz plot
- Use isobar model description in time-dependent fit to **WS** plot to determine $\bar{\mathcal{A}}_{\bar{f}}$ and mixing parameters.

$$x'' = [\,2.61^{+0.57}_{-0.68}(\text{stat.}) \pm 0.39(\text{syst.})]\%$$

$$y'' = [-0.06^{+0.55}_{-0.64}(\text{stat.}) \pm 0.34(\text{syst.})]\%$$

Probability for no mixing = 0.1% (3.2σ)

No evidence for CPV

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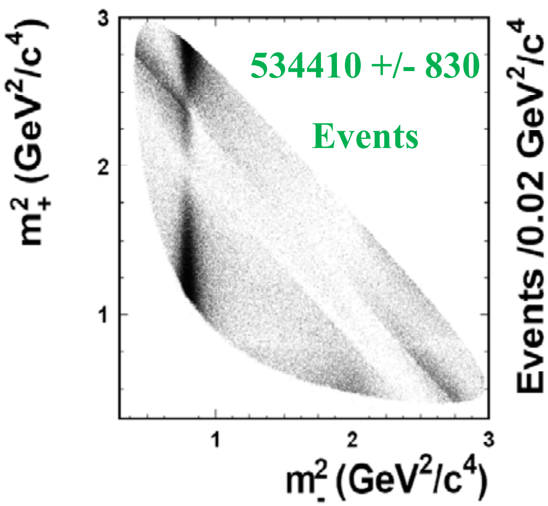
Time-Dependent Amplitude Analysis of $D^0 \rightarrow K_s\pi^+\pi^-$

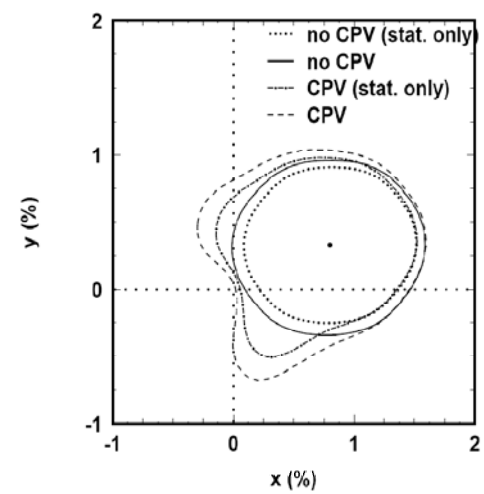
PRL 98, 211803 (2007) 540 fb^{-1}

PRD 72, 012001 (2005) 9 fb^{-1}

- Here, it is possible to measure *x, y,* |p/q| and *arg* $\{\lambda_{K_s\pi+\pi-}\}$; the $\bar{D}0$-$D0$ strong phase δ *is fixed* by presence of *CP eigenstates* in *f*
  - Strong phases of all points relative to *CP* eigenstates measured by time-dependent amplitude analysis of the *DP*.



Fit case	Parameter	Fit result	95% C.L. interval
No	$x(\%)$	$0.80 \pm 0.29^{+0.09}_{-0.07}{}^{+0.10}_{-0.14}$	$(0.0, 1.6)$
CPV	$y(\%)$	$0.33 \pm 0.24^{+0.08}_{-0.12}{}^{+0.06}_{-0.08}$	$(-0.34, 0.96)$
CPV	$x(\%)$	$0.81 \pm 0.30^{+0.10}_{-0.07}{}^{+0.09}_{-0.16}$	$\lvert x\rvert < 1.6$
	$y(\%)$	$0.37 \pm 0.25^{+0.07}_{-0.13}{}^{+0.07}_{-0.08}$	$\lvert y\rvert < 1.04$
	$\lvert q/p\rvert$	$0.86^{+0.30}_{-0.29}{}^{+0.06}_{-0.03} \pm 0.08$	-
	$\arg(q/p)(^\circ)$	$-14^{+16}_{-18}{}^{+5}_{-3}{}^{+2}_{-4}$	-



Mixing only at 2.4 σ level.
Hint that x > y ??

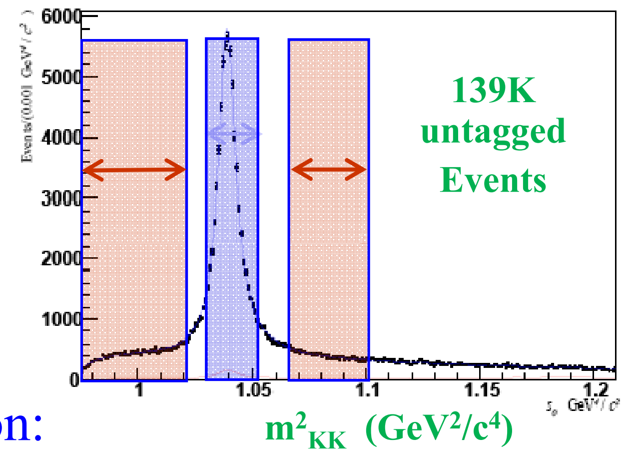
Previous result from CLEO (9 fb-1)
$(-4.7 < x < 8.6)\%$
$(-6.1 < y < 3.5)\%$ at 95% CL.

Measurement of y_{CP} in $D^0 \to K_S K^+ K^-$ decays

Arxiv:0807.0148v1 (2008) 673 fb^{-1}

- In effect, this is a measurement of lifetime τ in $CP=+1$ and $CP=-1$ parts of the $K_s K^+ K^-$ Dalitz plot.
- Choose ϕK_S *region* and its sidebands

$$\frac{\tau - \tau}{\tau + \tau} = y_{CP} \frac{f - f}{1 + y_{CP}(1 - f - f)}$$



- Fractions f of CP-even final state in each region:

$$f = \frac{\int |A_+|^2 dm^2_{K^+K^-} dm^2_{K^+K^0_S}}{\int [|A_+|^2 + |A_-|^2]\, dm^2_{K^+K^-} dm^2_{K^+K^0_S}}$$

over appropriate m(K^+K^-) range

A_+ and A_- are CP-even and odd amplitudes describing Dalitz plot population.

$$y_{CP} = (0.21 \pm 0.63(\text{stat.}) \pm 0.78(\text{syst.}) \pm 0.01(\text{model}))\%$$

Belle preliminary!

Results from semileptonic modes

	BaBar	Belle	CLEO	E791
r_M	< 0.12 % (90% CL) [2007]	< 0.06 % (90% CL) [2008]	< 0.78 % (90% CL) [2005]	< 0.50 % (90% CL) [1996]
Data set	344 fb^{-1}	492 fb^{-1}	9 fb^{-1}	2 x 10^{10} hadronic π^- interactions
Mode	e only	e+μ	e only	e+μ

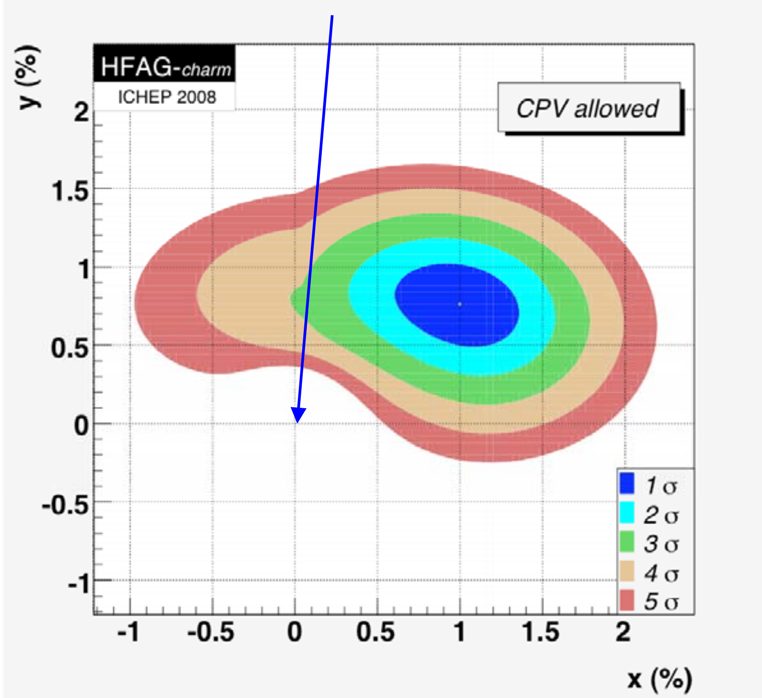
Final Step: Combine various mixing results (HFAG)

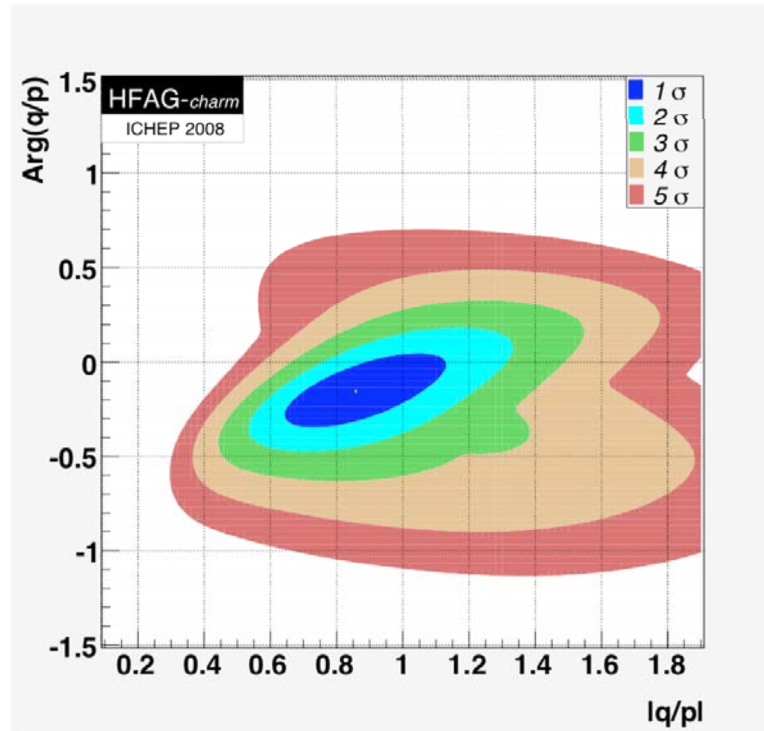
arXiv:0808.1297

New HFAG Average for ICHEP08

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

No-mixing point excluded at 9.8σ





$x = 1.00\pm^{0.24}_{0.25}$ % 3.4σ

$y = 0.76\pm^{0.17}_{0.18}$ % 4.1σ

$|q/p| = 0.86\pm^{0.17}_{0.15}$

$\mathrm{Arg}(\lambda_{K_S\pi^+\pi^-}) = (8.8\pm^{7.6}_{7.2})^{\circ}$

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Summary

- After 30 years, evidence for D^0 mixing is now compelling.
  - World averages of the mixing parameters exclude “No D^0 mixing” at $\sim 10\sigma$.
  - However, currently no single measurement exceeds 5σ!
- Evidence of D^0 mixing from several independent experiments.
- Measured values of the mixing parameters $x \approx y \approx 1\%$ are compatible with Standard Model expectations.
- No evidence for CP Violation in D^0 mixing.

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Signal and Background Components

$\Delta m \equiv m(K\pi\pi) - m(K\pi)$

$Q \equiv m(K\pi\pi) - m(K\pi) - m(\pi)$

Signal: (MC)

- Correct $D^{*+} \to D^0 \pi^+$
- Peaks in $m(K\pi)$ and Δm

Random π_s: (MC)

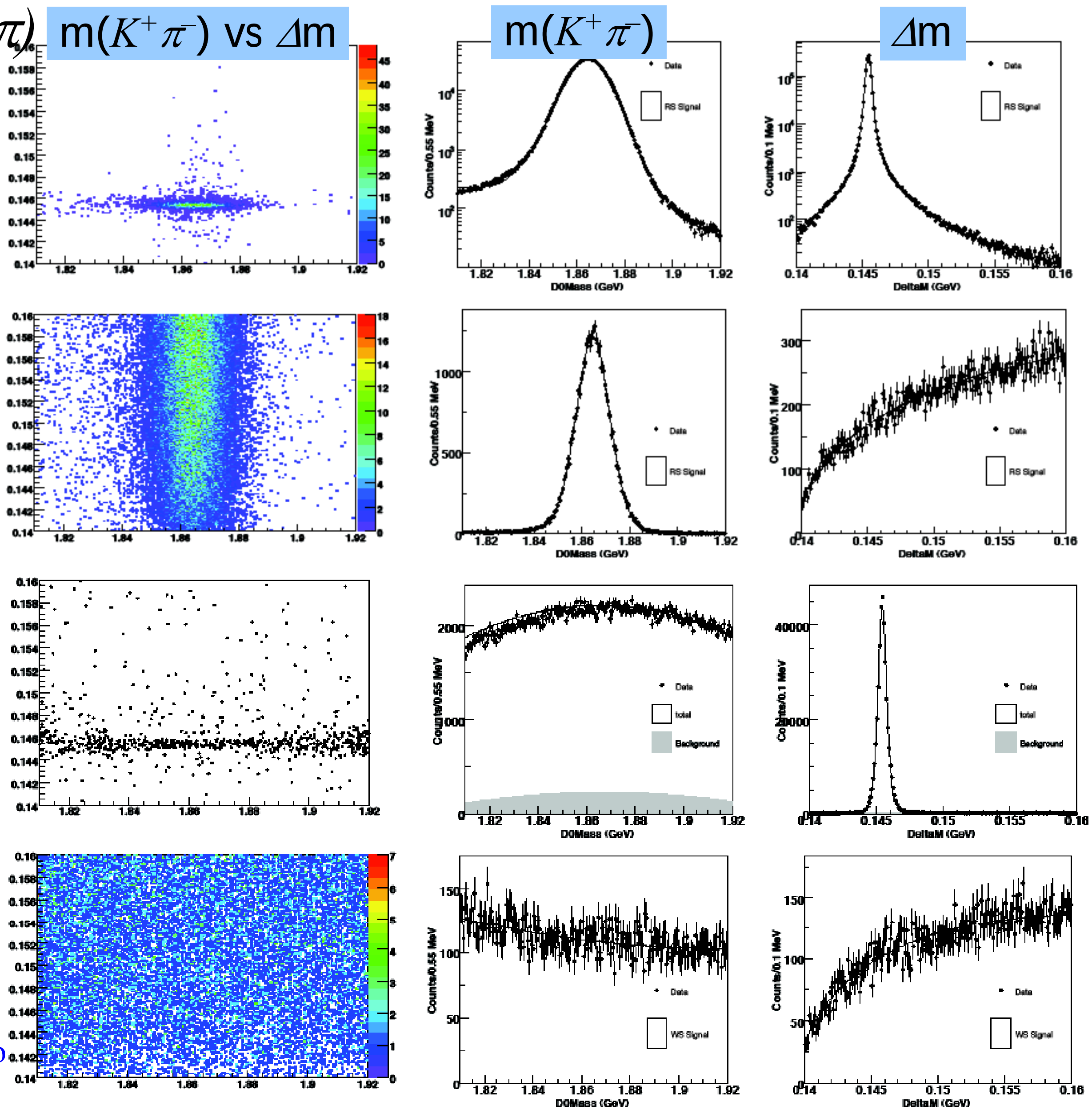
- Correct $\bar{D}^0$, wrong π_s
- Peaks in $m(K\pi)$, not Δm

Mis-reco D^0: (Data)

- Real $D^{*+} \to D^0 \pi^+$
- $D^0 \to K^- \mu^+ \nu$
- Double misid $D^0 \to K^- \pi^+$ (WS events only)

Combinatoric: (MC)

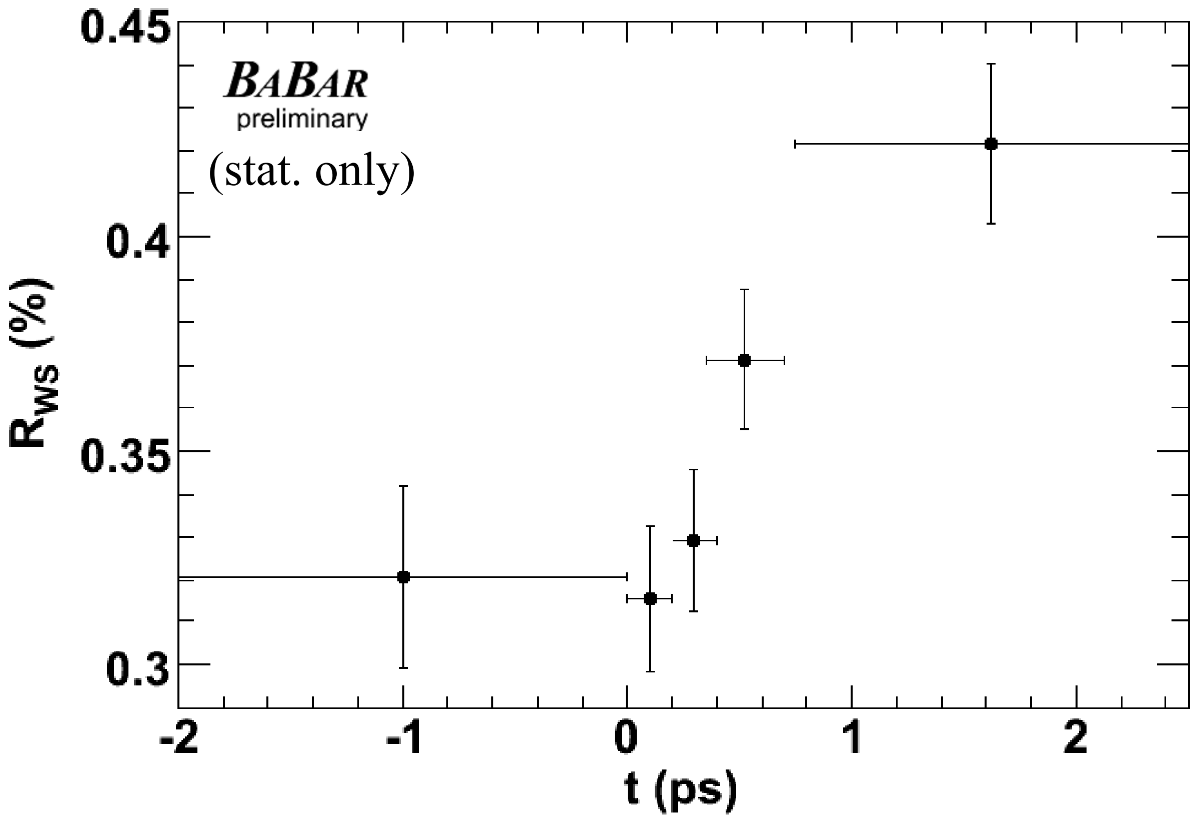
- Random tracks



M. V. Puro

Validation: Alternative Fit Strategy

Rate of WS events clearly increases with time:



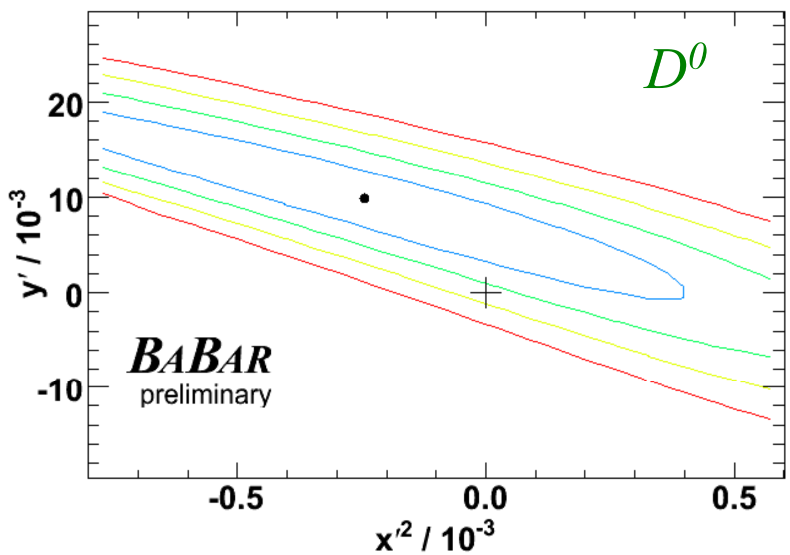
CPV Allowed Contours

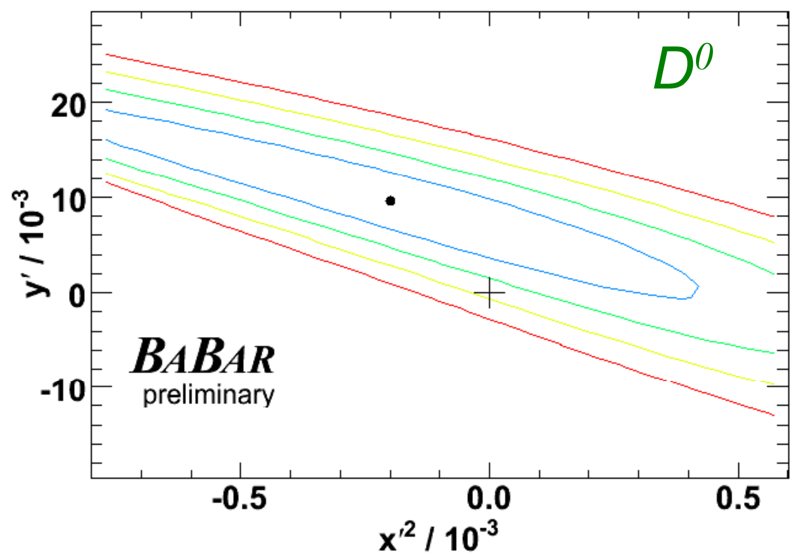
<u>Results of fitting D^0 and $\bar{D}^0$ separately:</u>

x'^{+2}: $(-0.24\pm0.43\pm0.30)\times10^{-3}$ x'^{-2}: $(-0.20\pm0.41\pm0.29)\times10^{-3}$

y'^{+}: $(9.8\pm6.4\pm4.5)\times10^{-3}$ y'^{-}: $(9.6\pm6.1\pm4.3)\times10^{-3}$

$A_D=(-2.1\pm5.2\pm1.5)\%$





No evidence for CP violation found

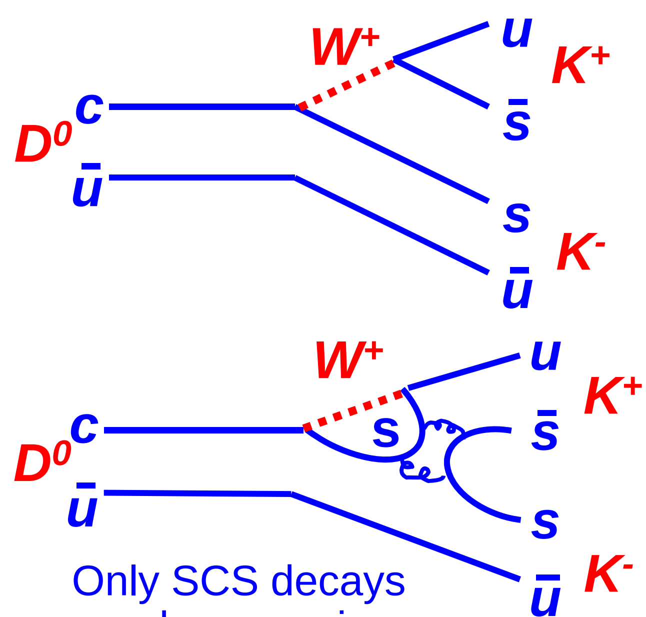
Search for direct CPV in time-integrated $D^0 \to K^+K^-, \pi^+\pi^-$ rates

$$A_{CP} = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} = \frac{2\,\mathrm{Im}\,A_1 A_2^* \sin(\delta_1 - \delta_2)}{|A_1|^2 + |A_2|^2 + 2\,\mathrm{Re}\,A_1 A_2^* \cos(\delta_1 - \delta_2)}$$

2 weak amplitudes with phase difference

strong phase difference

e.g., $D^0 \to K^+K^-$:



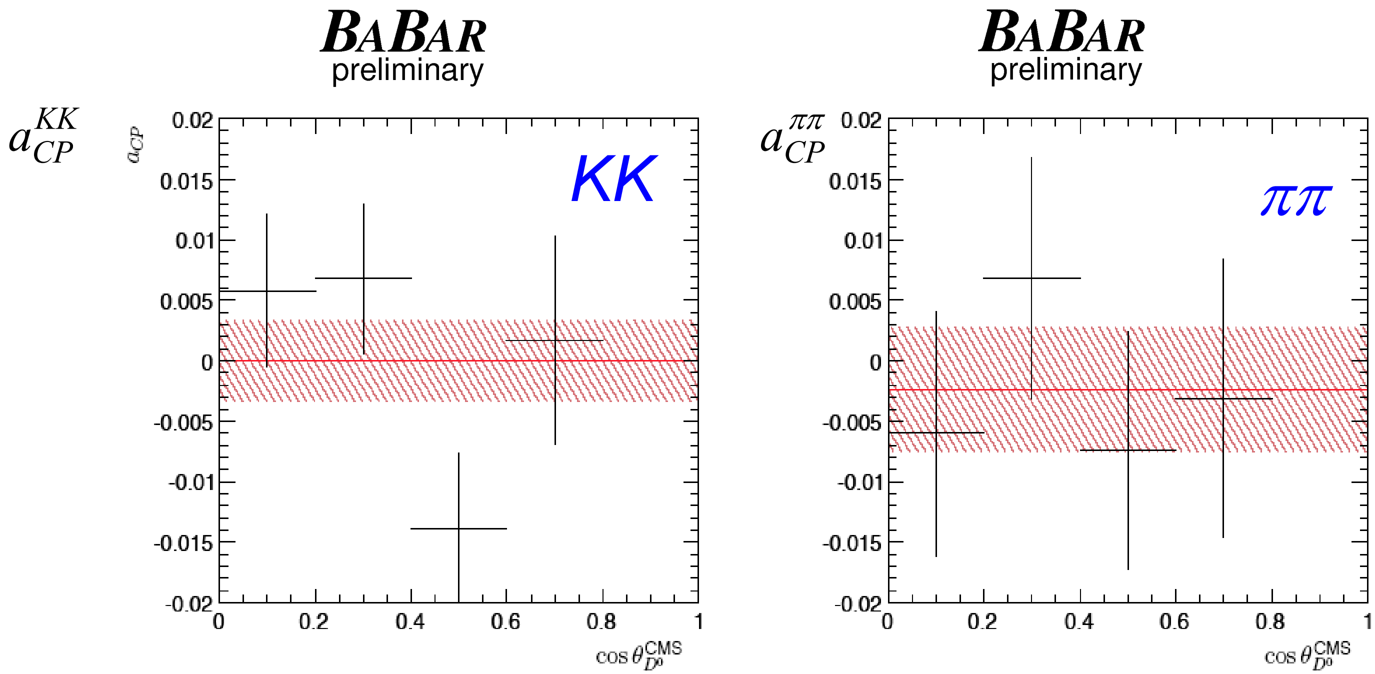
Only SCS decays probe penguins

Two amplitudes with different strong & weak phases needed to observe CPV (in SM from tree and penguins)

Standard model predictions for direct CPV asymmetries in these modes: O(0.001% - 0.01%)

F. Bucella et al., Phys. Rev. **D51**, 3478 (1995).
S. Bianco et al., Riv. Nuovo Cim. 26N7, 1(2003).

Search for CPV in $D^0 \rightarrow K^+K^-,\ \pi^+\pi^-$



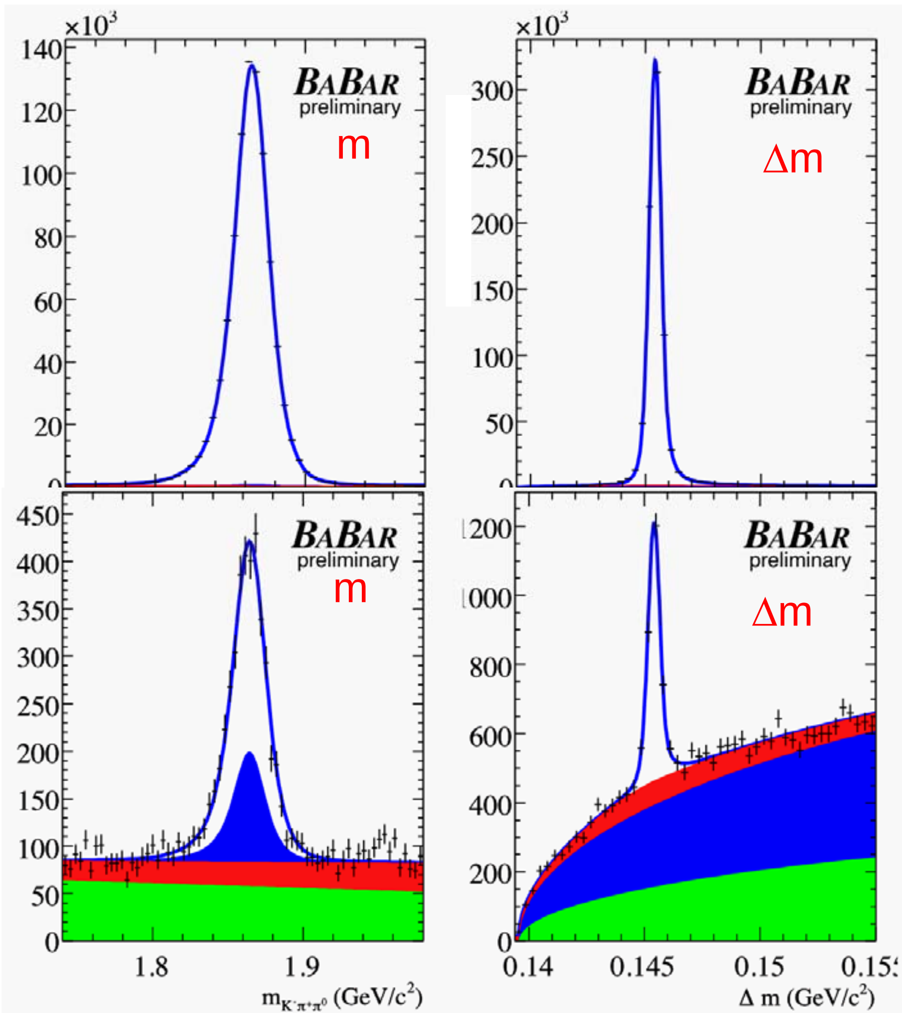
$$a_{CP}^{KK} = (\ \ 0.00 \pm 0.34\ (\text{stat.}) \pm 0.13\ (\text{syst.}))\%$$
$$a_{CP}^{\pi\pi} = (-0.24 \pm 0.52\ (\text{stat.}) \pm 0.22\ (\text{syst.}))\%$$

No evidence for CPV in either mode

RS and WS ($m_{K\pi\pi}$, Δm) fits

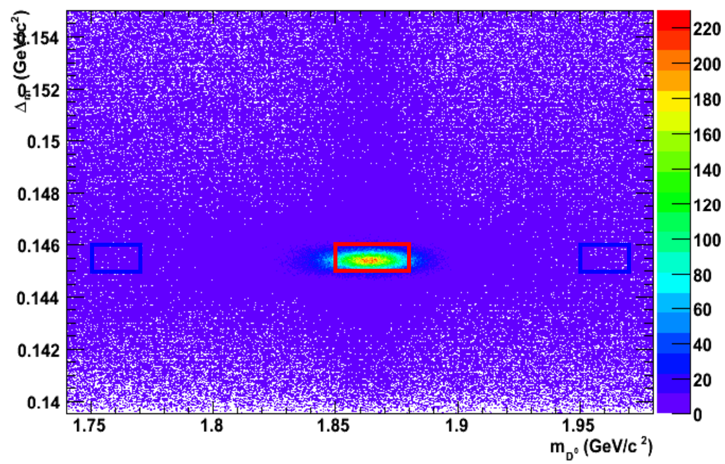
Determine signal and background yields in subsequent Dalitz analyses.

$0.145 < \Delta m < 0.146\,\mathrm{GeV}/c^2$ $\quad 1.85 < m_{K\pi\pi^0} < 1.88\,\mathrm{GeV}/c^2$



- signal
- mis-tagged D^0
- mis-reconstructed D^0
- combinatoric

signal and sideband regions

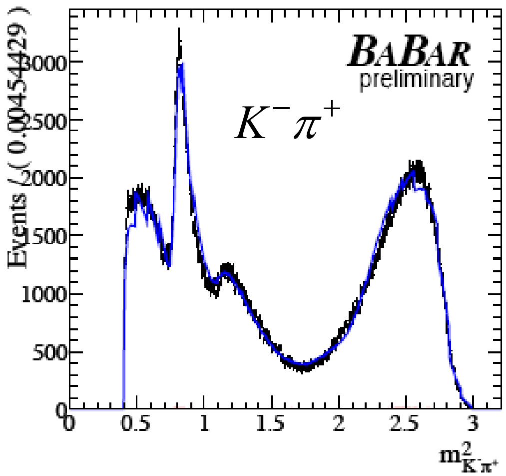


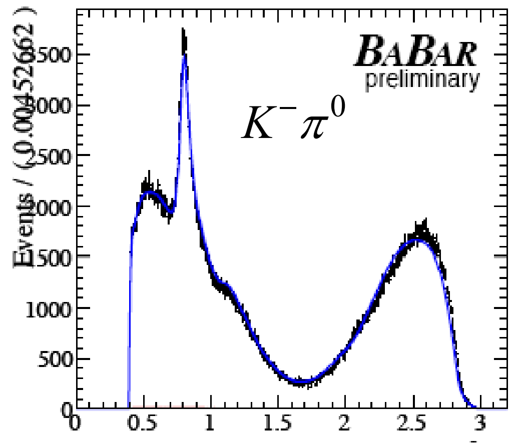
signal box yields:

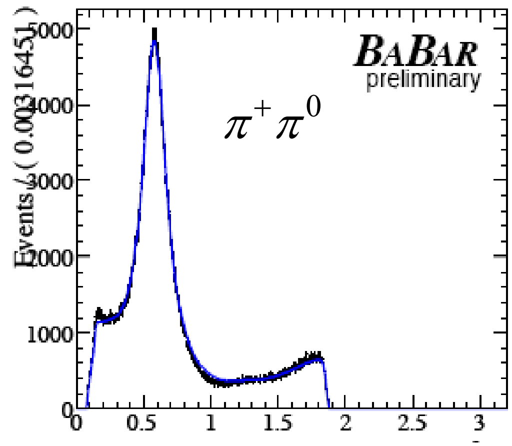
Category	N events (RS)	N events (WS)
Signal	639802 ± 1538	1483 ± 56
Combinatoric	1537 ± 57	499 ± 57
Mistag	2384 ± 57	765 ± 29
Misreconstructed D^0	3117 ± 93	227 ± 75

$D^0 \to K^-\pi^+\pi^0$ RS Dalitz fit

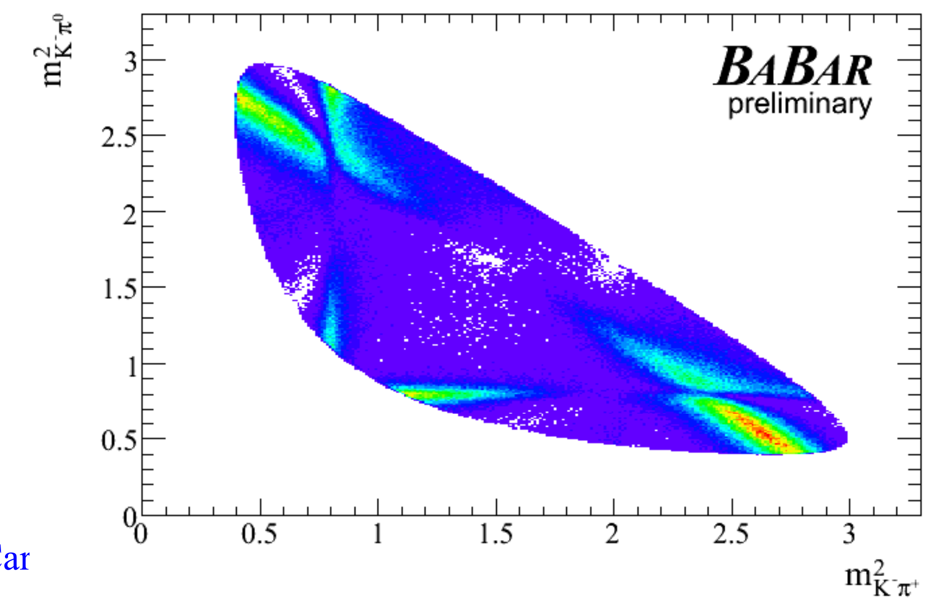
Time-integrated analysis to determine CF amplitudes, $\bar{A}_{\bar{f}}$





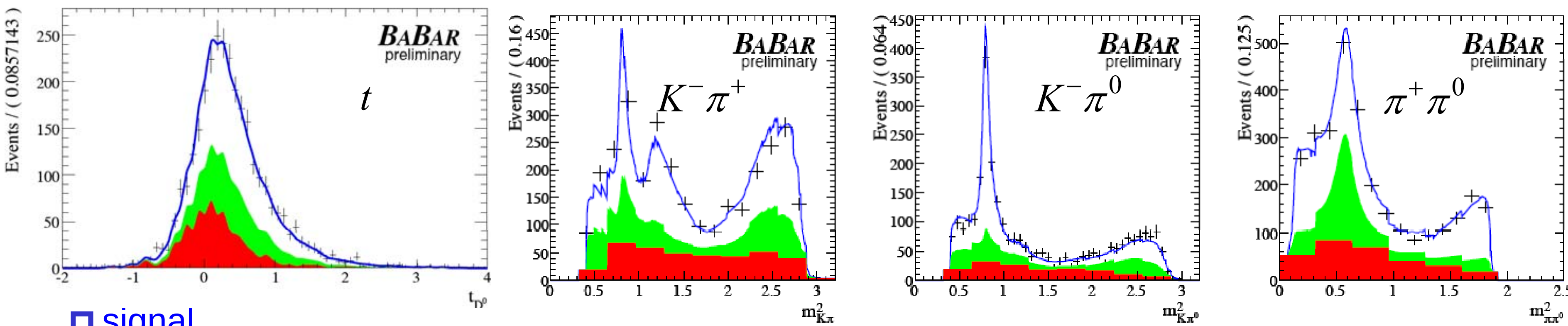


Resonance	Amplitude	Phase (degrees)	Fit Fraction (%)
$\rho(770)$	1 (fixed)	0 (fixed)	65.2 ± 4.5
$K^{*-}(1680)$	1.52 ± 0.06	144.3 ± 3.2	0.39 ± 0.04
$K_2^{*-}(1430)$	0.030 ± 0.001	-167.5 ± 2.5	0.31 ± 0.03
$K_2^{*0}(1430)$	0.0431 ± 0.0007	13.4 ± 0.9	0.73 ± 0.06
$K^{*-}(1410)$	0.24 ± 0.01	39.1 ± 4.1	0.17 ± 0.02
$K_0^{*-}(1430)$	2.95 ± 0.05	183.7 ± 0.9	3.6 ± 0.3
$K^{*-}(892)$	0.382 ± 0.001	163.3 ± 0.2	10.3 ± 0.7
$K^{*0}(1410)$	0.17 ± 0.01	-221.0 ± 3.5	0.009 ± 0.0001
$K_0^{*0}(1430)$	2.53 ± 0.01	91.6 ± 0.3	8.3 ± 0.6
$K^{*0}(1680)$	2.74 ± 0.07	-17.0 ± 1.5	1.4 ± 0.1
$K^{*0}(892)$	0.400 ± 0.001	3.4 ± 0.3	11.1 ± 0.7
$\rho(1700)$	6.06 ± 0.09	136.3 ± 0.7	4.1 ± 0.3
Total fit fraction = 106%			

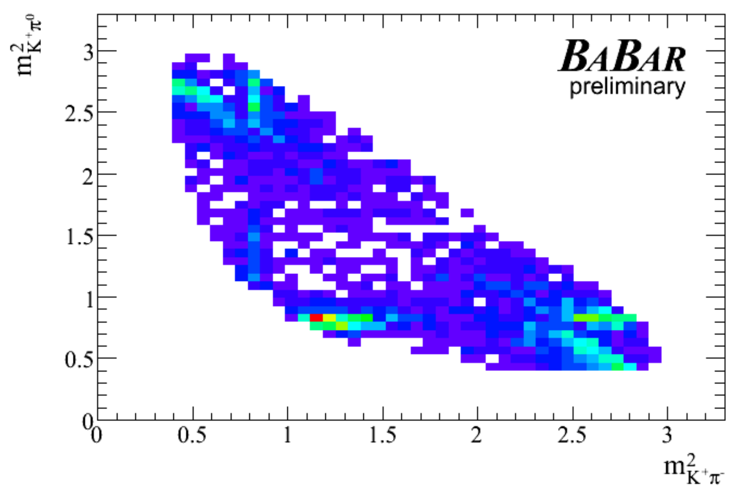


$D^0(t) \rightarrow K^+\pi^-\pi^0$ WS Dalitz fit results

Through t-dependence, distinguish DCS amplitudes from the CF amplitudes arising from mixing.



- signal
- mis-tagged D^0
- mis-reconstructed D^0 +combinatoric



Resonance	Amplitude	Phase (degrees)	Fit Fraction (%)
$\rho(770)$	1 (fixed)	0 (fixed)	39.8 ± 6.5
$K_2^{*0}(1430)$	0.088 ± 0.017	-17.2 ± 12.9	2.0 ± 0.7
$K_0^{*+}(1430)$	6.78 ± 1.00	69.1 ± 10.9	13.1 ± 3.3
$K^{*+}(892)$	0.899 ± 0.005	-171.0 ± 5.9	35.6 ± 5.5
$K_0^{*0}(1430)$	1.65 ± 0.59	-44.4 ± 18.5	2.8 ± 1.5
$K^{*0}(892)$	0.398 ± 0.038	24.1 ± 9.8	6.5 ± 1.4
$\rho(1700)$	5.4 ± 1.6	157.4 ± 20.3	2.0 ± 1.1
$\chi^2/ndof = 188/215 = 0.876$			
Total fit fraction = 102%			

Implications of Charm Mixing

BaBar and Belle mixing results first presented at Moriond electroweak conference on March 17

Several new hep-ph preprints on charm mixing since then, e.g.,

Five use D^0 mixing results to evaluate limits on:

- ❖Certain SUSY models (flavor suppresion by "alignment") hep-ph/0703204 hep-ph/0703235
- ❖Several little Higgs models hep-ph/0703254, arXiv:0704.0601
- ❖Non-universal Z' model hep-ph/0703270

"Models are further constrained, but constraints are limited by lack of precise SM value" → "Light non-degenerate squarks unlikely to be observed at LHC"

Currently, only an observation of CP violation in mixing would be a clear sign of New Physics

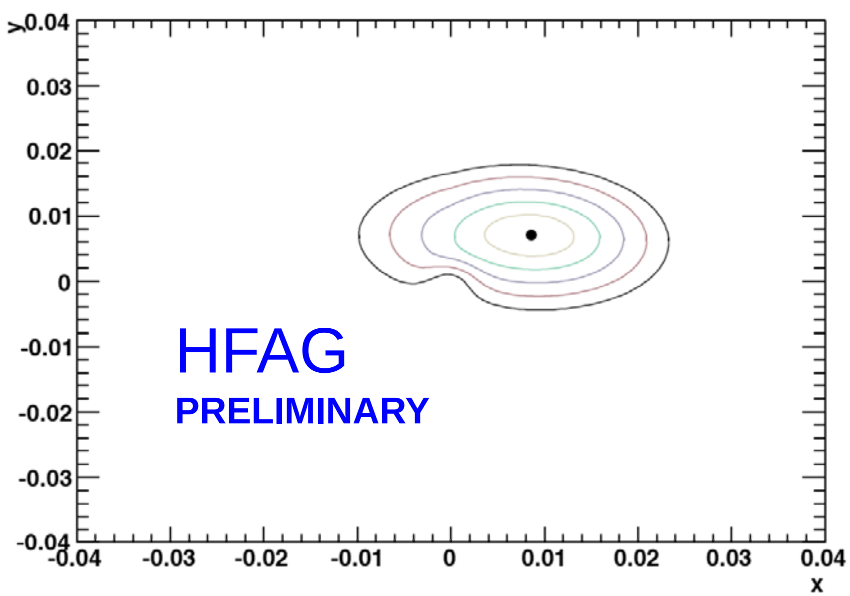
Interpreting the results

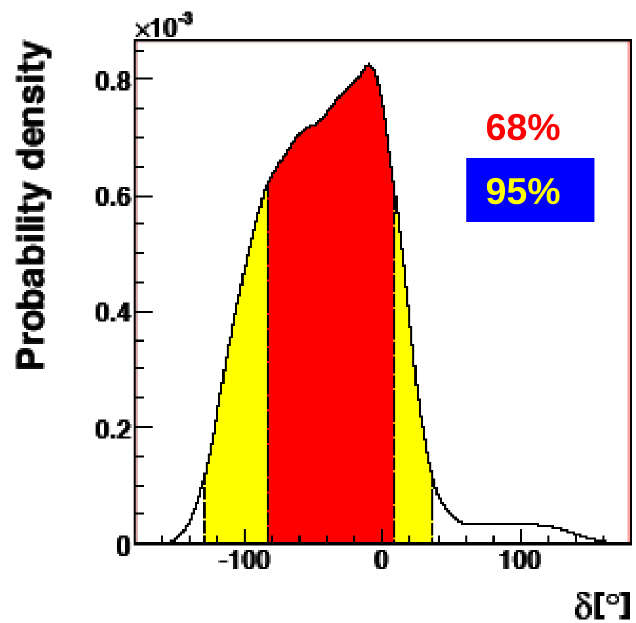
D^0 and $\bar{D}^0$ weak phase $2\phi_D$ of the mixing amplitude

Ciuchini et al. hep-ph/0703294

$$y'_{\pm} = (1 \pm A_m)(y' \cos 2\phi_D \mp x' \sin 2\phi_D)\,,$$
$$x'^2_{\pm} = (1 \pm 2A_m)(x' \cos 2\phi_D \pm y' \sin 2\phi_D)^2\,,$$
$$y_{\rm CP} = y \cos 2\phi_D - A_m x \sin 2\phi_D\,,$$
$$A_\Gamma = A_m y \cos 2\phi_D - x \sin 2\phi_D\,,$$

$$A_m = 1 - |q/p|$$





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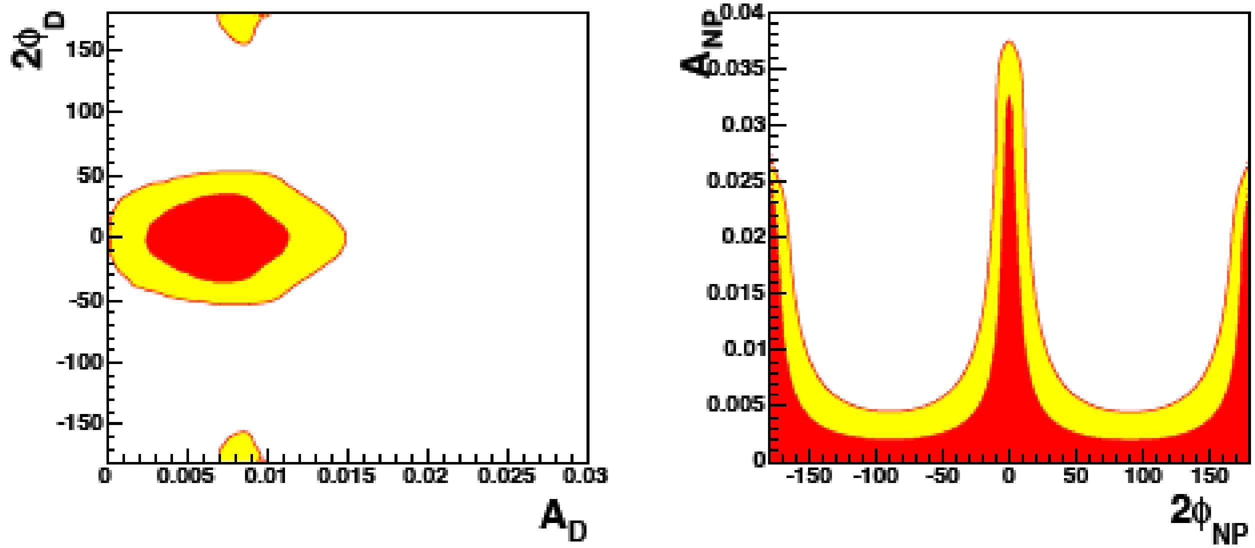
And CP violation?

In the standard model, $\phi \sim 2\,A^2\lambda^4\eta \lesssim 10^{-3}$



Ciuchini et al. hep-ph/0703294

In general NP weakly constrained if SM not known

Nevertheless SUSY coupling can be constrained hints on **squark and gluino masses**!

Neutral meson mixing always a window into unknown (virtual) states!

Model	Approximate Constraint
Fourth Generation (Fig. 2)	$\|V_{ub'}V_{cb'}\| \cdot m_{b'} < 0.5$ (GeV)
$Q = -1/3$ Singlet Quark (Fig. 4)	$s_2 \cdot m_S < 0.27$ (GeV)
$Q = +2/3$ Singlet Quark (Fig. 6)	$\|\lambda_{uc}\| < 2.4 \cdot 10^{-4}$
Little Higgs	Tree: See entry for $Q = -1/3$ Singlet Quark
	Box: Region of parameter space can reach observed x_D
Generic Z' (Fig. 7)	$M_{Z'}/C > 2.2 \cdot 10^3$ TeV
Family Symmetries (Fig. 8)	$m_1/f > 1.2 \cdot 10^3$ TeV
	(with $m_1/m_2 = 0.5$)
Left-Right Symmetric (Fig. 9)	No constraint
Alternate Left-Right Symmetric (Fig. 10)	$M_R > 1.2$ TeV ($m_{D_1} = 0.5$ TeV)
	$(\Delta m/m_{D_1})/M_R > 0.4$ TeV^{-1}
Vector Leptoquark Bosons (Fig. 11)	$M_{VLQ} > 55(\lambda_{PP}/0.1)$ TeV
Flavor Conserving Two-Higgs-Doublet (Fig. 13)	No constraint
Flavor Changing Neutral Higgs (Fig. 15)	$m_H/C > 2.4 \cdot 10^3$ TeV
FC Neutral Higgs (Cheng-Sher ansatz) (Fig. 16)	$m_H/\|\Delta_{uc}\| > 600$ GeV
Scalar Leptoquark Bosons	See entry for RPV SUSY
Higgsless (Fig. 17)	$M > 100$ TeV
Universal Extra Dimensions	No constraint
Split Fermion (Fig. 19)	$M/\|\Delta y\| > (6 \cdot 10^2$ GeV)
Warped Geometries (Fig. 21)	$M_1 > 3.5$ TeV
Minimal Supersymmetric Standard (Fig. 23)	$\|(\delta^u_{12})_{\rm LR,RL}\| < 3.5 \cdot 10^{-2}$ for $\tilde{m} \sim 1$ TeV
	$\|(\delta^u_{12})_{\rm LL,RR}\| < .25$ for $\tilde{m} \sim 1$ TeV
Supersymmetric Alignment	$\tilde{m} > 2$ TeV
Supersymmetry with RPV (Fig. 27)	$\lambda'_{12k}\lambda'_{11k}/m_{\tilde{d}_{R,k}} < 1.8 \cdot 10^{-3}/100$ GeV
Split Supersymmetry	No constraint

75

Table from

Golowich, Hewett, Pakvasa and Petrov:

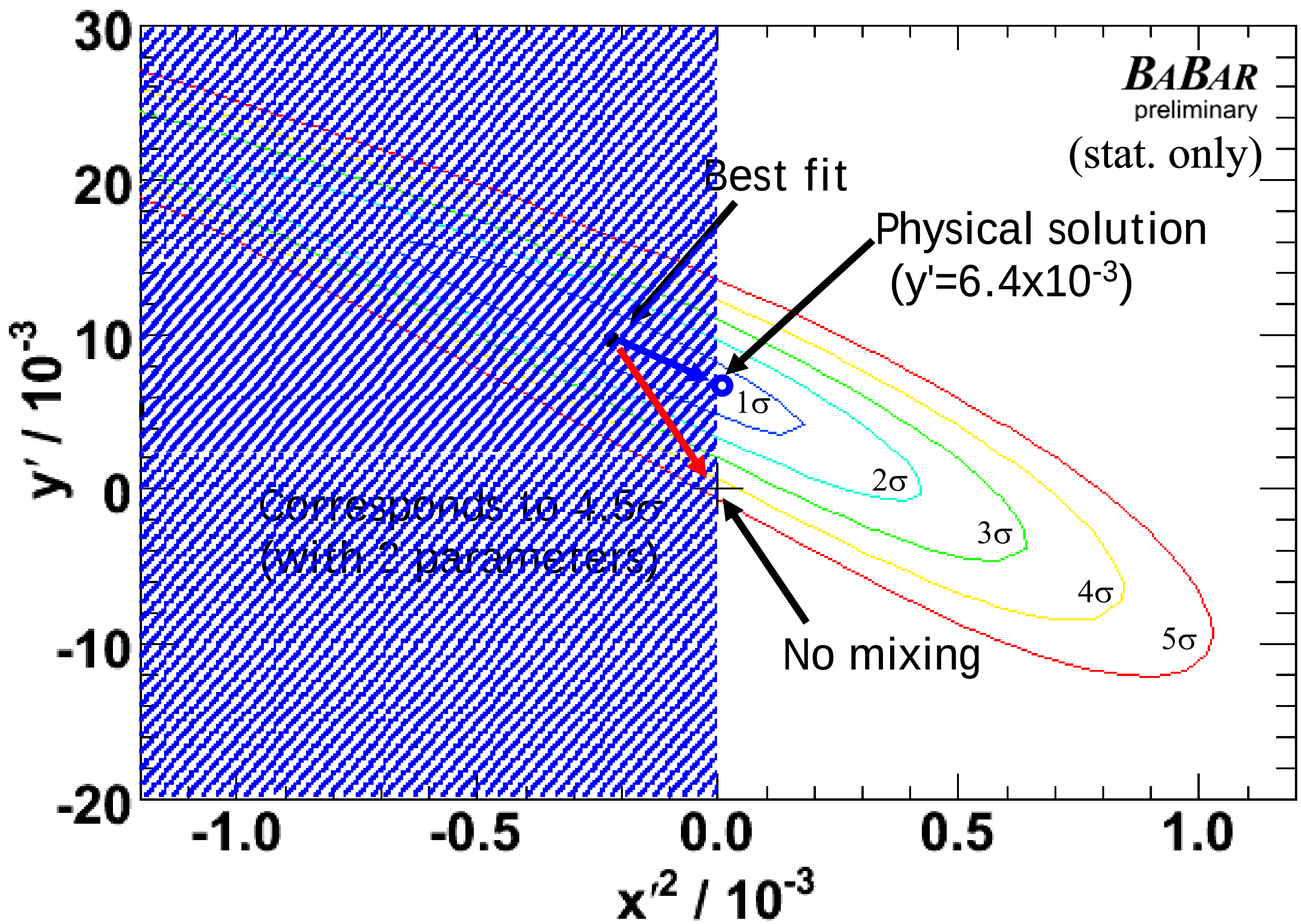
arXiv:0705.3650 [hep-ph]

"... for some models (Split Fermions, Flavor Changing Neutral Higgs) the constraints can be strong."

"Such a list is by nature approximate, and we refer the reader to the body of the paper for a more precise presentation of our results."

Signal Significance

Best fit is in unphysical region ($x'^2<0$)



Systematic Uncertainties

Two types of systematic uncertainties considered:

Fit model variations:

❖Change signal and background models used in fit, to test assumptions made

Selection criteria:

❖Mainly decay time (error) ranges used in fit

Systematic:	R_D	x'^2	y'
Fit Model	0.59σ	0.40σ	0.45σ
Selection Criteria	0.24σ	0.57σ	0.55σ
Total	0.63σ	0.70σ	0.71σ

Fraction of statistical uncertainty

x'^2-y' correlation also present in systematics

Effectively the (x'^2,y') contours increase by ~15%

Double tag at ψ(3770) [CLEO-c]

$D_{CP\pm}$

neutral D CP eigenstate

ψ(3770) decay conserves CP

- Reconstruct Double Tags: CP vs Kπ
- Asymmetry in CP+ vs CP- related to cosδ

$$A \equiv \frac{B(D_{CP+} \to K^-\pi^+) - B(D_{CP-} \to K^-\pi^+)}{B(D_{CP+} \to K^-\pi^+) + B(D_{CP-} \to K^-\pi^+)}$$

- R_D is ratio of DCS to Cabibbo favored rates

$$\cos\delta = \frac{A}{2\sqrt{R_D}}$$

- Input R_D =(3.60±0.08)‰ from PDG2006+CDF ~±2%,

Need to run

On threshold

- Updated results with 281 pb^{-1} at Winter Conferences
  - Expect σ(y)~ ±1.5% and $\sigma(\cos\delta_{K\pi})$ ~ ±0.3
  - Including systematic uncertainties
- Full CLEO-c dataset ~750 pb^{-1}
  - Expect σ(y)~ ±1.0% and $\sigma(\cos\delta_{K\pi})$ ~ ±0.1-0.2