Physics in Collision 2008, Perugia

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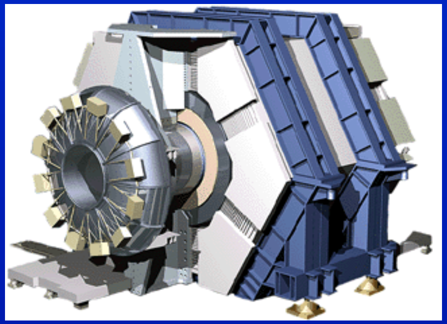
$D^0 - \overline{D}^0$ Mixing
an
Overview

Jörg Marks

University of Heidelberg

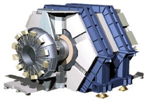
for the



BABAR Collaboration

Introduction

- Most unexpected physics result of last years spring conferences:
  Evidence for D^0 - $\bar{D}^0$ Mixing from the Belle and BaBar Collaborations
  CDF II was able to present evidence end of the year 2007
- Neutral meson mixing has been already observed in the *K* (1956), *B* (1987) and B_s (2006) systems
- Why is D^0 Mixing interesting ?
  - Processes with down type quarks are involved in the mixing loop
  - Within the Standard Model mixing and CP violation in the charm sector are expected to be small
  - Depending on the measured values of the parameters it could indicate new physics
- Present an overview of the mixing measurements of D^0 mesons



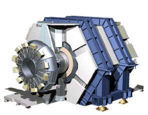
Outline

- Charm mixing phenomenology
  - Mixing
  - Time evolution
  - Processes
- Survey of recent results of D^0 mixing
  - Mixing parameters (and CP violation as related to mixing)
  - Experiments

    BABAR, Belle, CLEO, CDF
  - Techniques

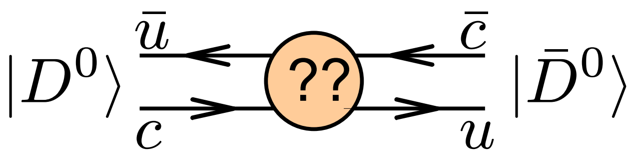
    Time-dependence, lifetime differences, Dalitz plot analyses
  - Hadronic decays

    Twobody and multibody decays, quantum correlated decays
- Summary



Mixing Formalism

Neutral D^0 mesons are created as flavor eigenstates of the strong interaction. They can mix through weak interactions.



- The time evolution is obtained by

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

- The physical eigenstates are D_1 and D_2:

$$|D_{1,2}\rangle = p|D^0\rangle \mp q|\bar{D}^0\rangle$$

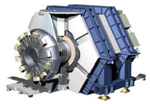
$$|D_{1,2}(t)\rangle = e^{-i(M_{1,2}-i\Gamma_{1,2}/2)t}|D_{1,2}(t=0)\rangle$$

D_1 : CP even
D_2 : CP odd

- Define mass and lifetime differences of D_1 and D_2:

$$x = \frac{\Delta M}{\Gamma} = \frac{M_1 - M_2}{\Gamma} \qquad y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

$$\Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

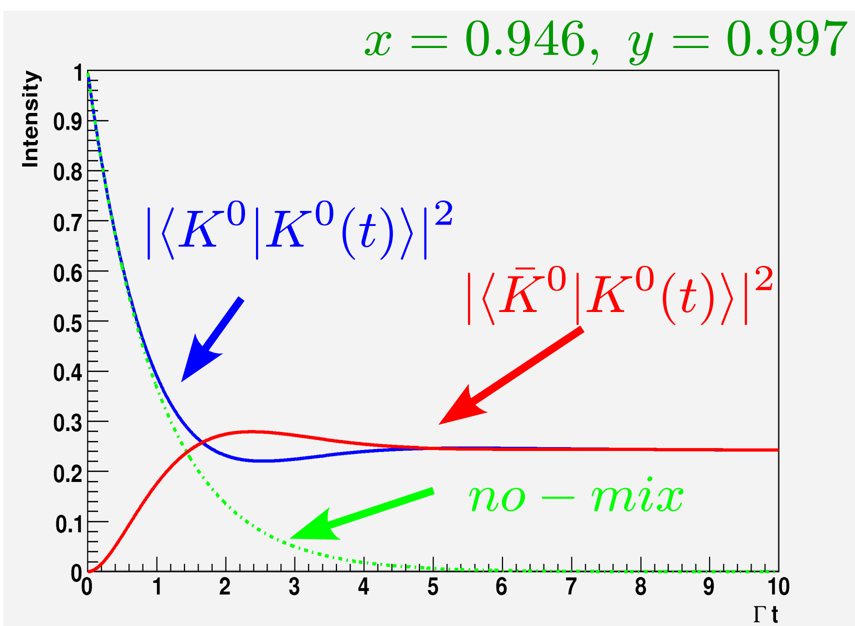


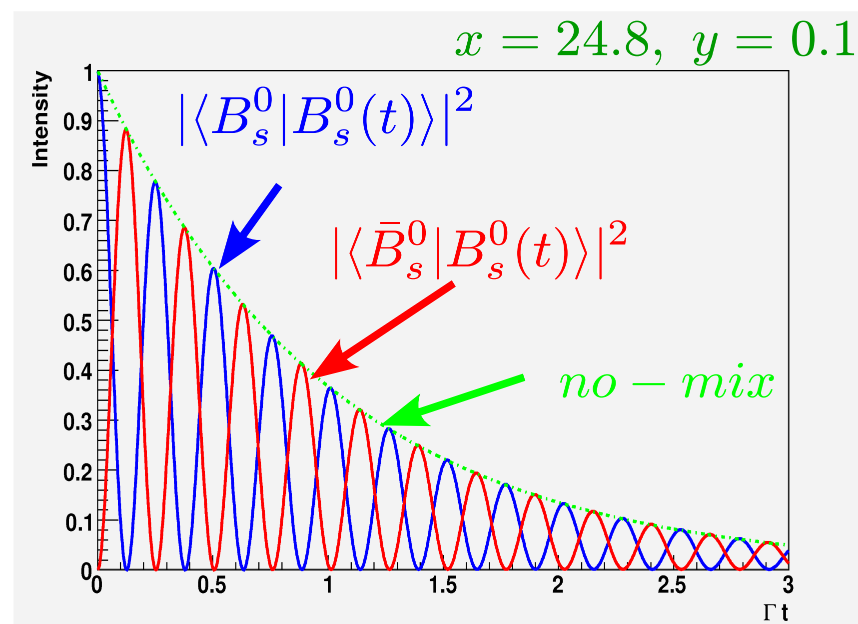
Time Evolution and Mixing

Mixing will occur if either x or y is non – zero. The time evolution of the probability to find a D^0($\bar{D}^0$) after a time t is:

$$I(D^0 \rightarrow D^0; t) \; : \; |\langle D^0 | D^0(t) \rangle|^2 = \frac{e^{-\Gamma t}}{2} [cosh(y\Gamma t) + cos(x\Gamma t)]$$

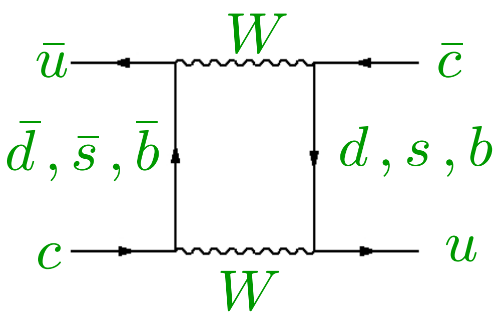
$$I(D^0 \rightarrow \bar{D}^0; t) \; : \; |\langle \bar{D}^0 | D^0(t) \rangle|^2 = \frac{e^{-\Gamma t}}{2} [cosh(y\Gamma t) - cos(x\Gamma t)] |\frac{p}{q}|^2$$

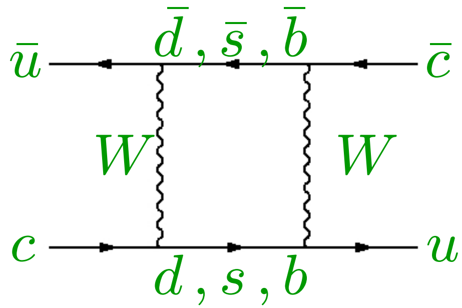




Charm Mixing Processes

- The box diagram contributions to charm mixing in the Standard Model are expected to be very small
  - d-type quarks enter the mixing loop



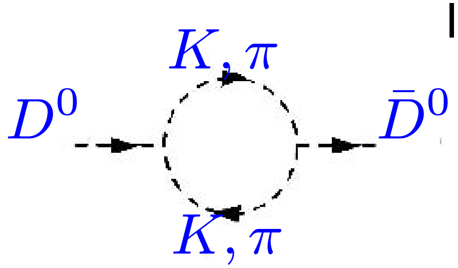


  - Suppression by
    - GIM mechanism (d,s)

$$x \sim \frac{m_s^2 - m_d^2}{m_c^2}$$

    - CKM matrix (b)
  - Lowest order short distance calculation: $x_{box} \approxeq O(10^{-5})$ $y_{box} \approxeq O(10^{-7})$
  - x and y enhancement due to higher orders in OPE: $x \sim y \approxeq O(10^{-3})$

- Long distance contributions dominate



Numerical predictions lack in precision

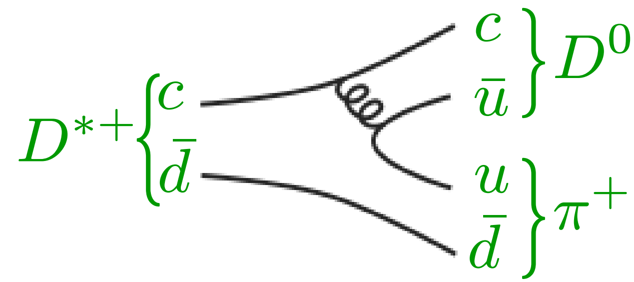
$$x \approxeq O(10^{-2})$$

$$y \approxeq O(10^{-2})$$

- New Physics
  - E.Golowich et al.: arXiv:0705.3650
    Which new physics model can yield sizeable values for x and y
  - CP violation in charm is small in SM
    Measurement of CPV: New Physics

Mixing in $D^0 \rightarrow K\pi$ - Flavor Tagging

- Flavor tagging at production time
  - Standard technique in charm physics: use

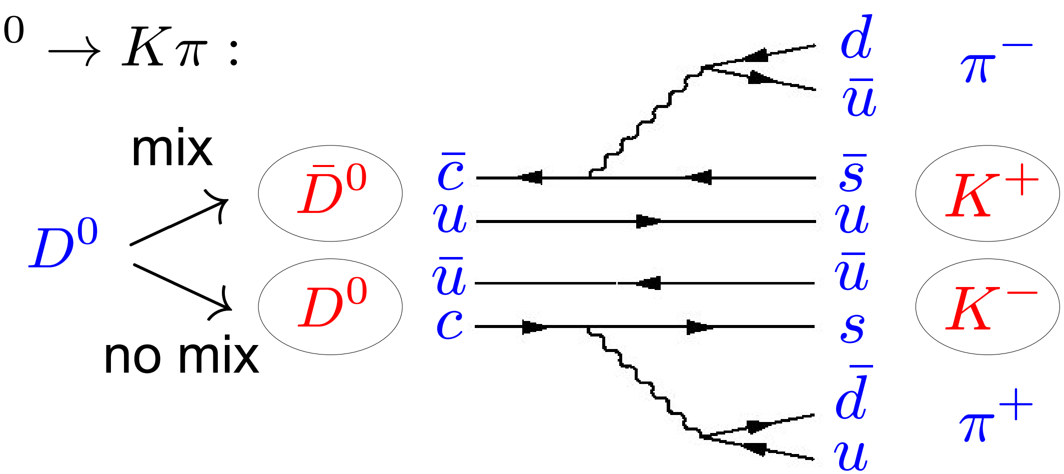


$$Q = m(D^0\pi^+) - m(D^0) - m(\pi^+) \approx 6MeV$$

- ❖ Narrow peak in $\Delta m = m(D^0\pi^+) - m(D^0)$ due to a small Q
- ❖ Select events around the expected Δm with good background suppression
- ❖ The charge of the low energy π determines the flavor of the D^0

- Flavor at decay time
  - Use final state particle properties to tag the D^0 flavor at the decay time

$D^0 \rightarrow K\pi$:



Wrong Sign Decay (WS)

D^0 Mixing

Right Sign Decay (RS)

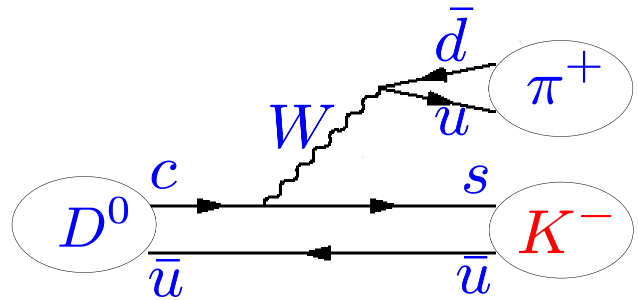
no D^0 Mixing

Doubly Cabbibo Suppressed Decays

The flavor tagging at decay time does not uniquely identify Mixing in hadronic D^0 decays

Cabibbo favored (CF) decay

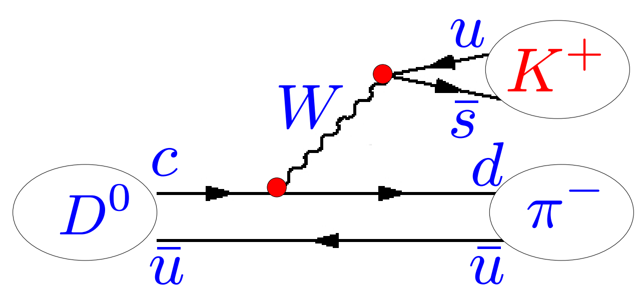
$R \approx 1$



RS decays

Doubly Cabibbo suppressed (DCS) decay

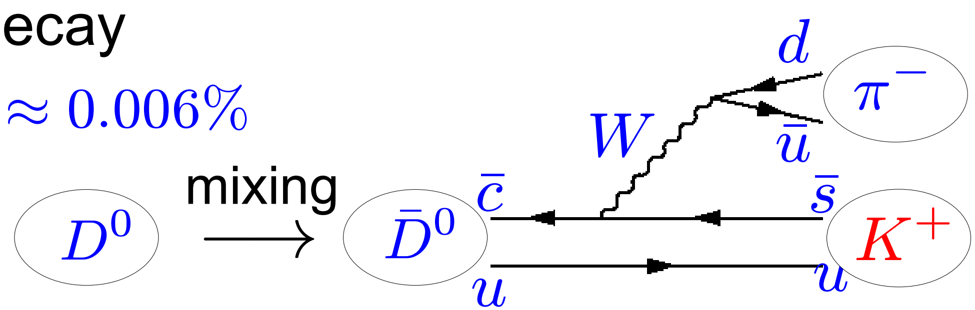
$R_D \approx 0.3\%$



WS decays

Mixed CF decay

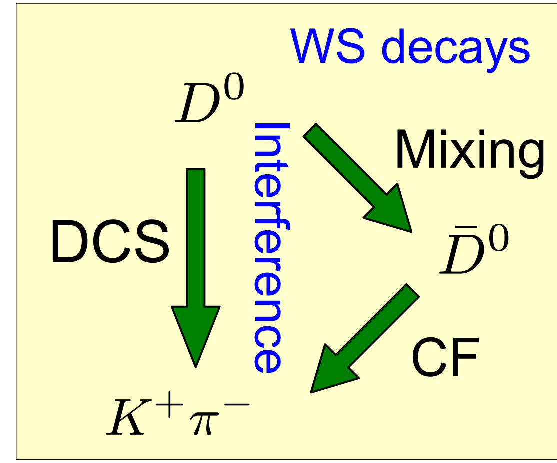
$R_M \approx 0.006\%$



Interference between DCS and mixed CF decay

Time Evolution in $D^0 \to K\pi$ Decays

- Discriminate DCS and mixing by their proper time evolution
  - DCS: exponential time distribution
  - mixed decays occur with a time structure



- Time evolution of the WS decay rate

  assume CP conservation and $|x| \ll 1$; $|y| \ll 1$

$$T_{WS}(t) \propto e^{-\Gamma t}\left(\underbrace{R_D}_{\text{DCS}} + \underbrace{\sqrt{R_D}\, y'\, \Gamma t}_{\text{Interference}} + \underbrace{\frac{x'^2 + y'^2}{4}(\Gamma t)^2}_{\text{Mixing}}\right)$$

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

- Strong phase $\delta_{K\pi}$

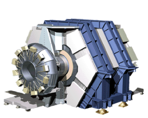
$$x' = \quad x \cos\delta_{K\pi} + y \sin\delta_{K\pi}$$
$$y' = -x \sin\delta_{K\pi} + y \cos\delta_{K\pi}$$

$$y'^2 + x'^2 = x^2 + y^2$$

$\delta_{K\pi}$ is the strong phase between CF and DCS amplitudes ($D^0 \to K\pi$)

phase may differ between decay modes

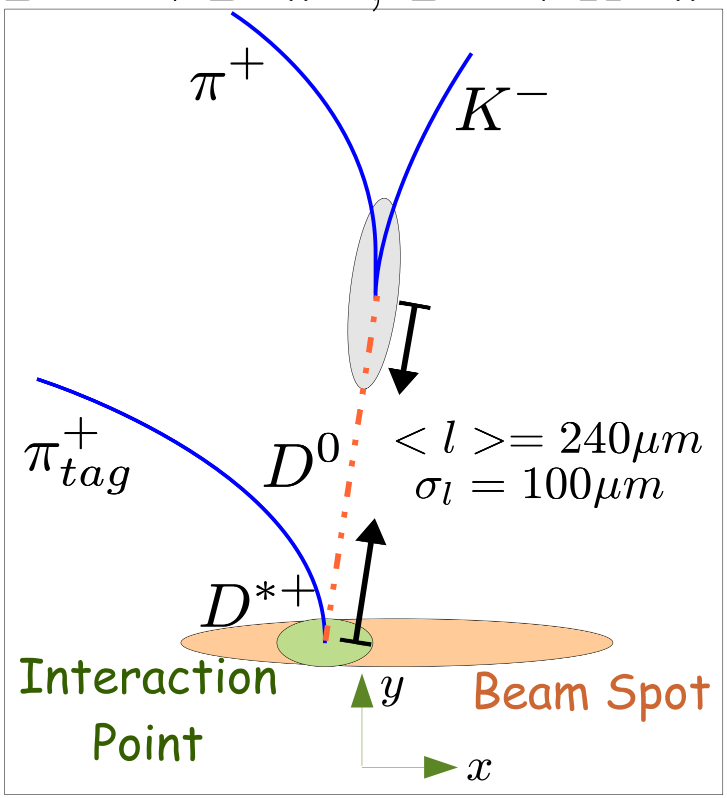
phase may vary over phase space for multibody decays



BABAR – $D^0 \to K\pi$ Event Selection

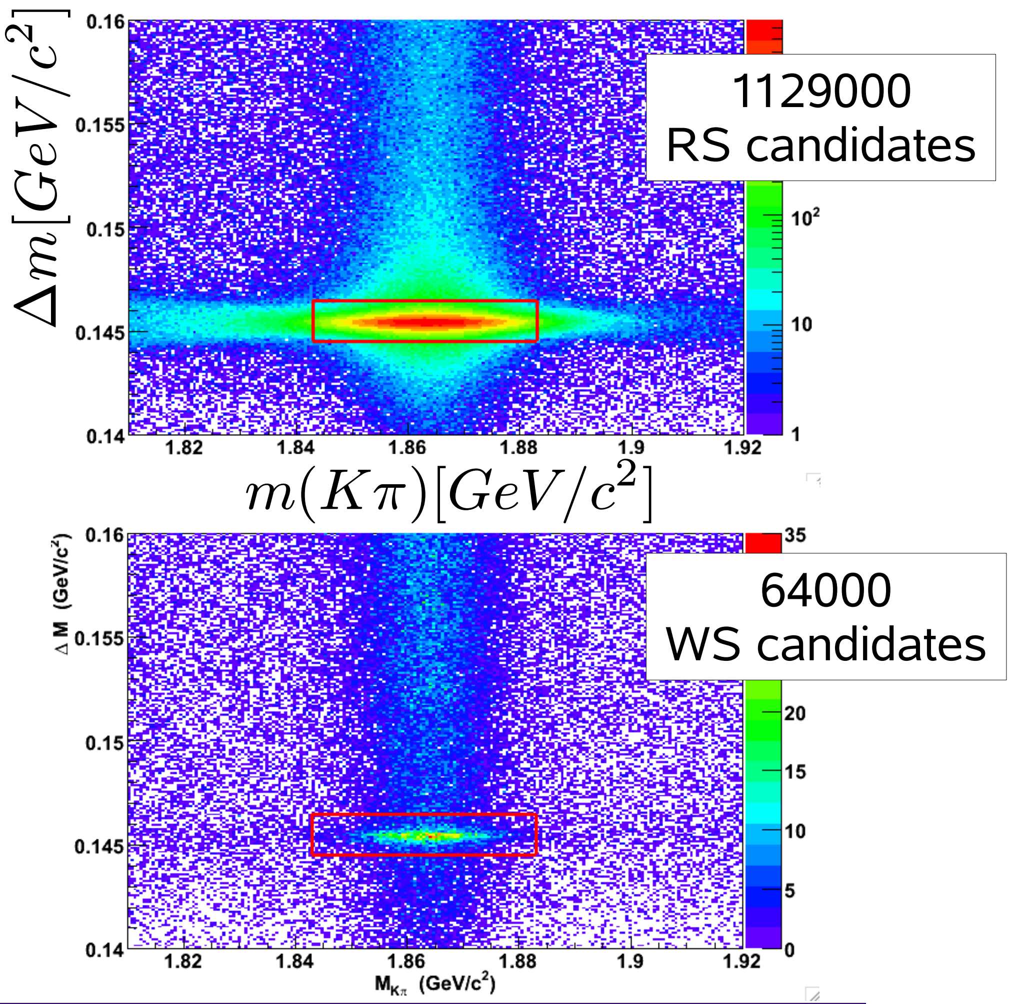
- Event topology

$D^{*+} \to D^0\pi^+ ,\ D^0 \to K^-\pi^+$



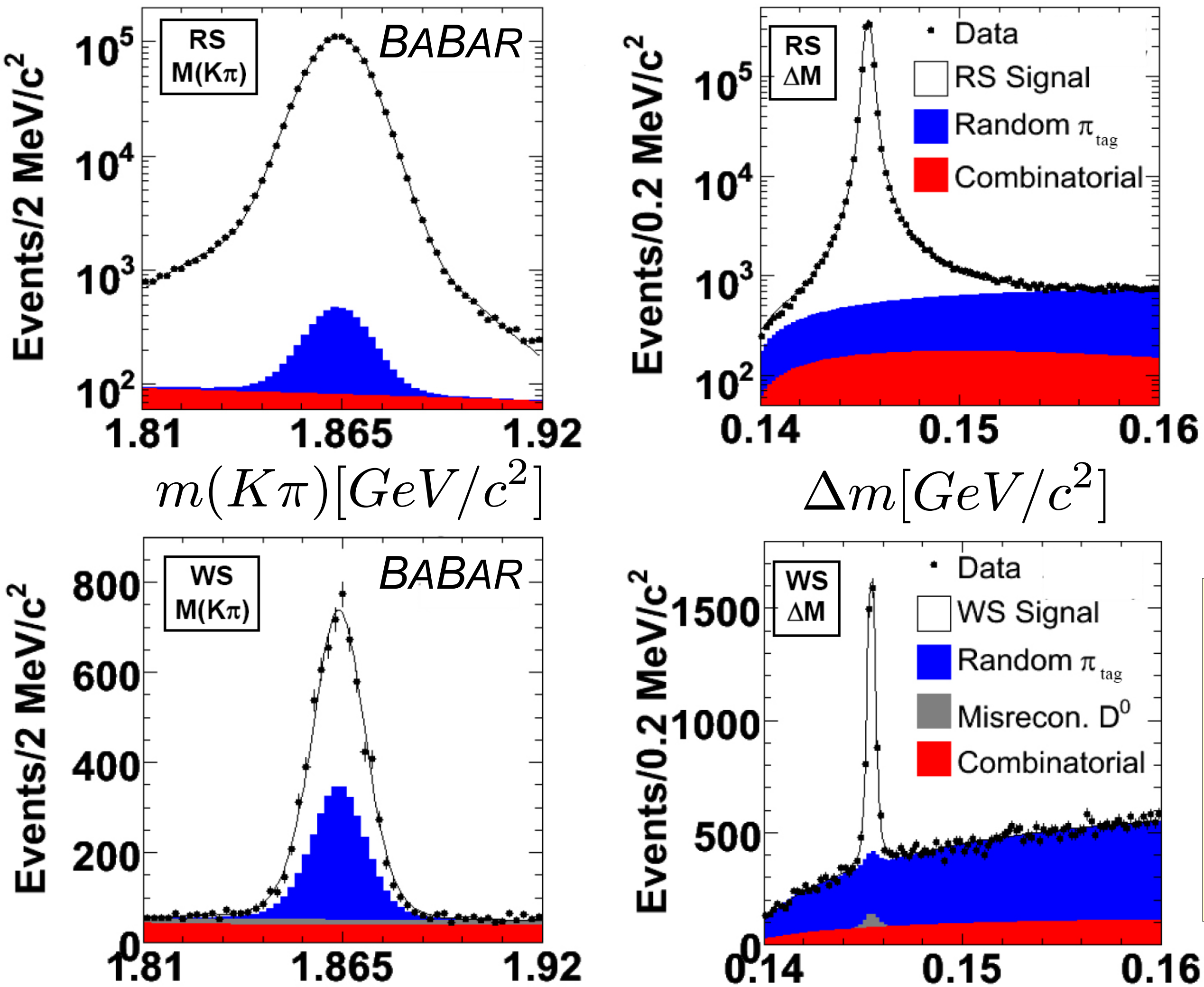
- Beam spot constraint vertex fit to π_{tag}, D^0 provides $t(D^0)$ and $\sigma_t(D^0)$

- D^0 selection (PID, m(Kπ), large $P^*(D^0)$)
- π^+_{tag} selection (Δm, small $P^*(\pi_{tag})$)



$D^0 \to K\pi$ – WS Branching Fraction

Determine Signal and background PDF's by unbinned maximum likelihood fit



RS Signal:

1141500 ± 1200 events

WS Signal:

4030 ± 90 events

WS branching fraction

BABAR (384 fb^{-1}):
PRL 98, 211802 (2007)
$R_{WS} = (0.353 \pm 0.008 \pm 0.004)\%$

Belle (400 fb^{-1}):
PRL 96, 151801 (2006)
$R_{WS} = (0.377 \pm 0.008 \pm 0.005)\%$

$D^0 \to K\pi$ – WS Decay Time Fit

BABAR (384 fb^{-1})
PRL 98, 211802 (2007)

- Fit the wrong sign D^0 decay time distribution

  Use the fit results of RS decay time and the resolution function

no mixing fit

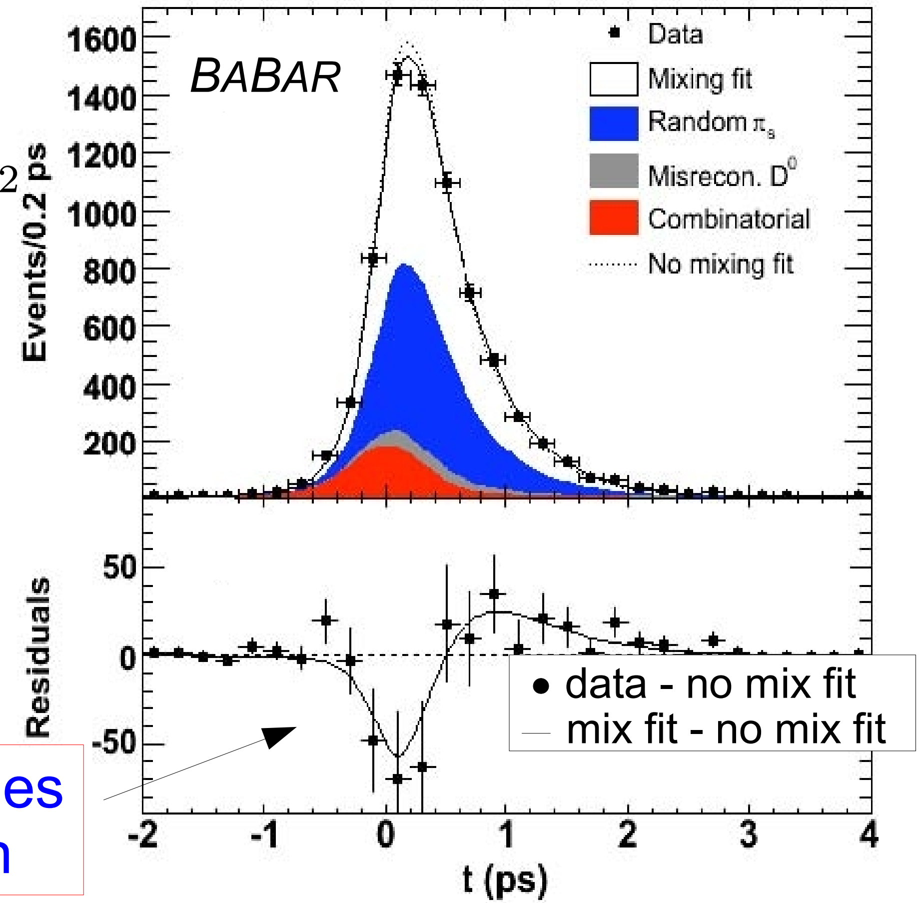
$$\frac{\Gamma_{WS}(t)}{e^{-\Gamma t}} = R_D + y'\sqrt{R_D}\Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2$$

mixing fit

- Mixing fit results

$$R_D = (0.303 \pm 0.016 \pm 0.01)\%$$
$$y' = (0.97 \pm 0.44 \pm 0.31)\%$$
$$x'^2 = (-0.022 \pm 0.03 \pm 0.021)\%$$

WS decay time, signal region



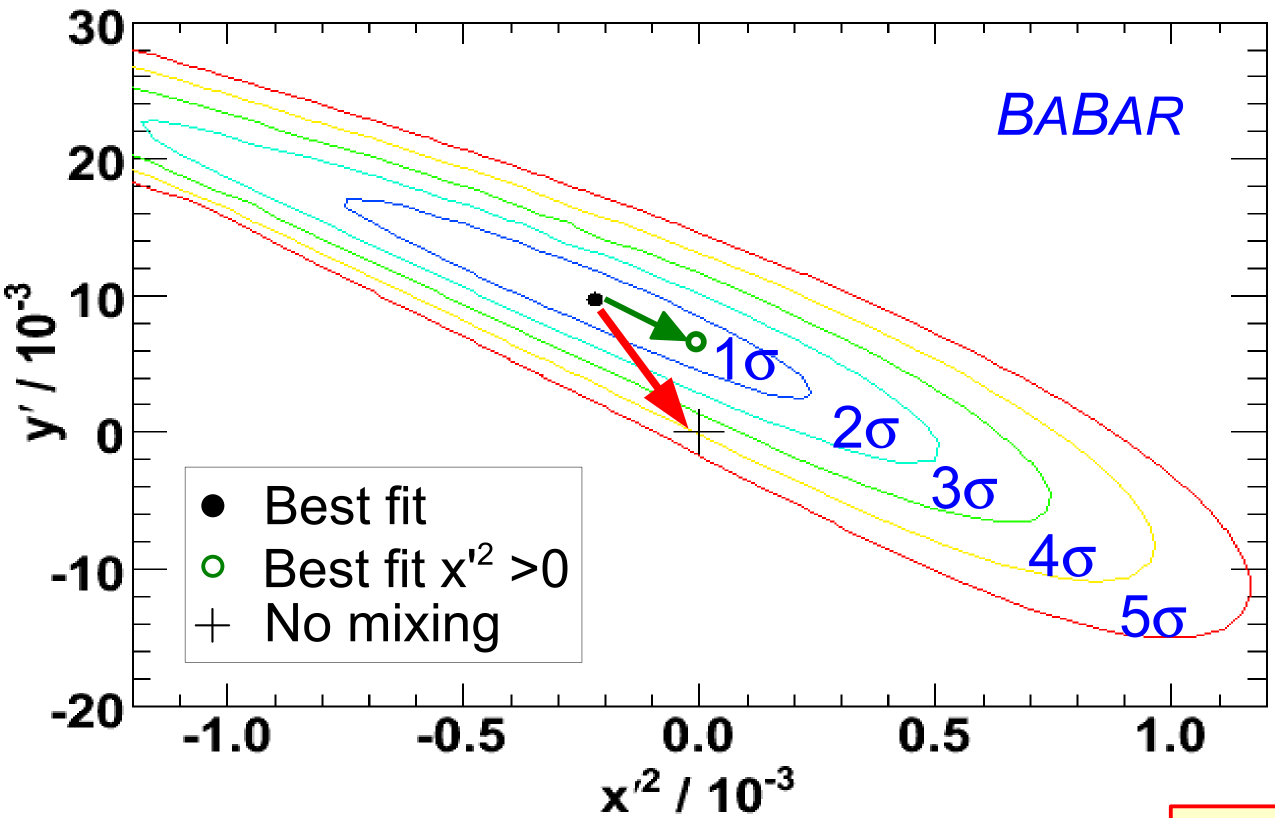
The mixing fit provides a better description

D^0 Mixing Fit - Likelihood Contours

- Significance is computed from change in log likelihood

  The contours include systematic errors

BABAR (384 fb^{-1})
PRL 98, 211802 (2007)



Best fit is in non physical region

Best fit with $x'^2 > 0$ has

$$-2\Delta\, ln\mathcal{L} = 0.7$$

Statistical errors only

Best fit to no mixing has

$$-2\Delta\, ln\mathcal{L} = 23.9\,(4.5\sigma)$$

Fit is inconsistent with no mixing at 3.9 σ

Evidence for $D^0 - \bar{D}^0$ Mixing

$D^0 \to K\pi$ – Fit Results CP Violation

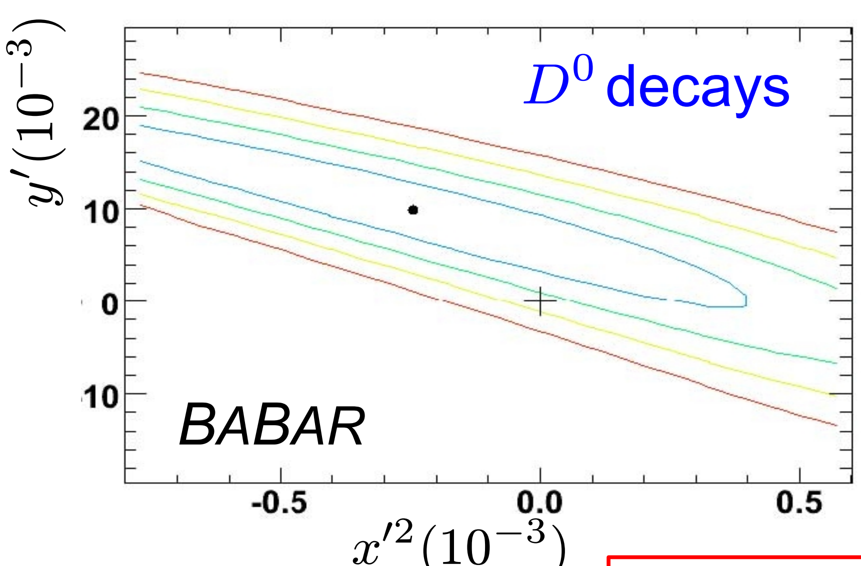
- Separate decay time fits to D^0(+) and $\bar{D}^0$(-) data

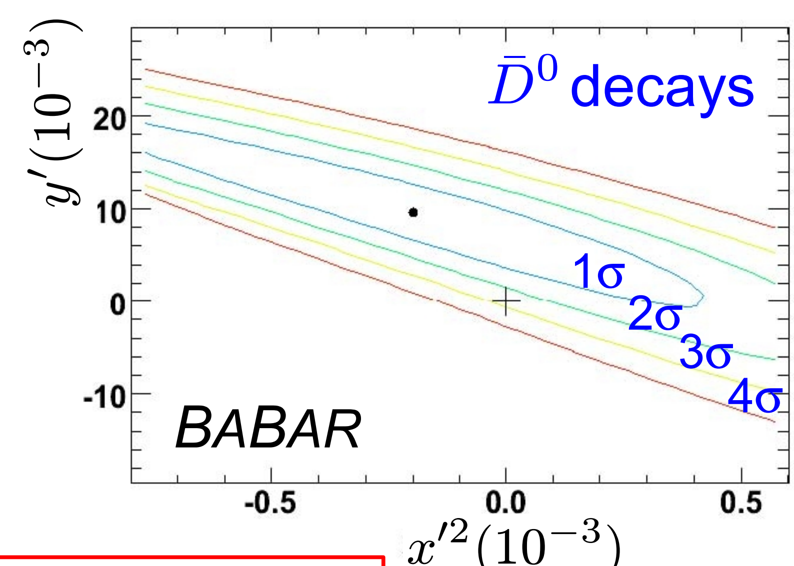
$$\frac{\Gamma^{\pm}_{WS}(t)}{e^{-\Gamma t}} = R_D^{\pm} + y'^{\pm}\sqrt{R_D^{\pm}}\Gamma t + \frac{(x'^{\pm})^2 + (y'^{\pm})^2}{4}(\Gamma t)^2$$

$$y'_{+} = (0.98 \pm 0.64 \pm 0.45)\%$$
$$x'^2_{+} = (-0.024 \pm 0.043 \pm 0.030)\%$$

$$y'_{-} = (0.96 \pm 0.61 \pm 0.43)\%$$
$$x'^2_{-} = (-0.02 \pm 0.041 \pm 0.029)\%$$

$$A_D = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-} = (-2.1 \pm 5.2 \pm 1.5)\%$$





No evidence for CP violation found

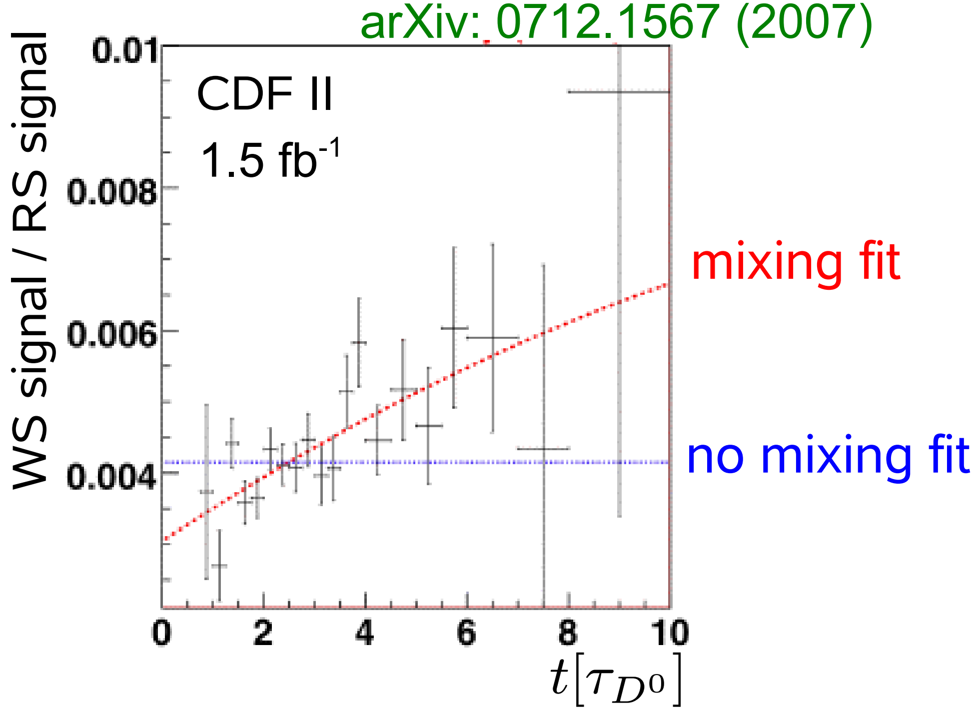
CDF II – D^0 Mixing in $D^0 \to K\pi$

- Measure the Number of WS and RS D^0 decays in bins of the decay time

$$N_{RS}^{tot} = (3.044 \pm 0.0023) \cdot 10^6$$
$$N_{WS}^{tot} = (12.7 \pm 0.3) \cdot 10^3$$

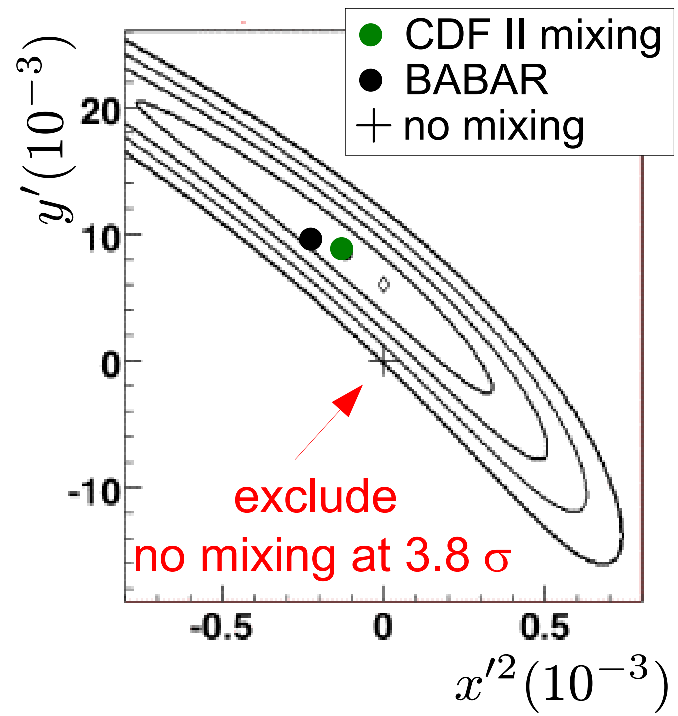
- Fit the $N_{WS}^{tot}/N_{RS}^{tot}$ vs the D^0 decay time

arXiv: 0712.1567 (2007)



- Mixing Parameter

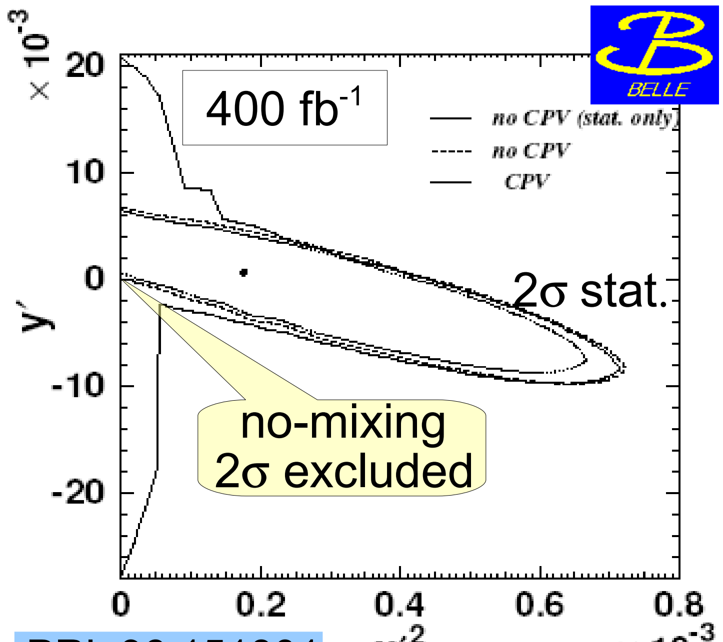
$$R_D = (0.304 \pm 0.055)\%$$
$$y' = (0.85 \pm 0.76)\%$$
$$x'^2 = (-0.012 \pm 0.035)\%$$



Very good agreement with *BABAR*

$D^0 \to K\pi$ Results: *BABAR* Belle CDF

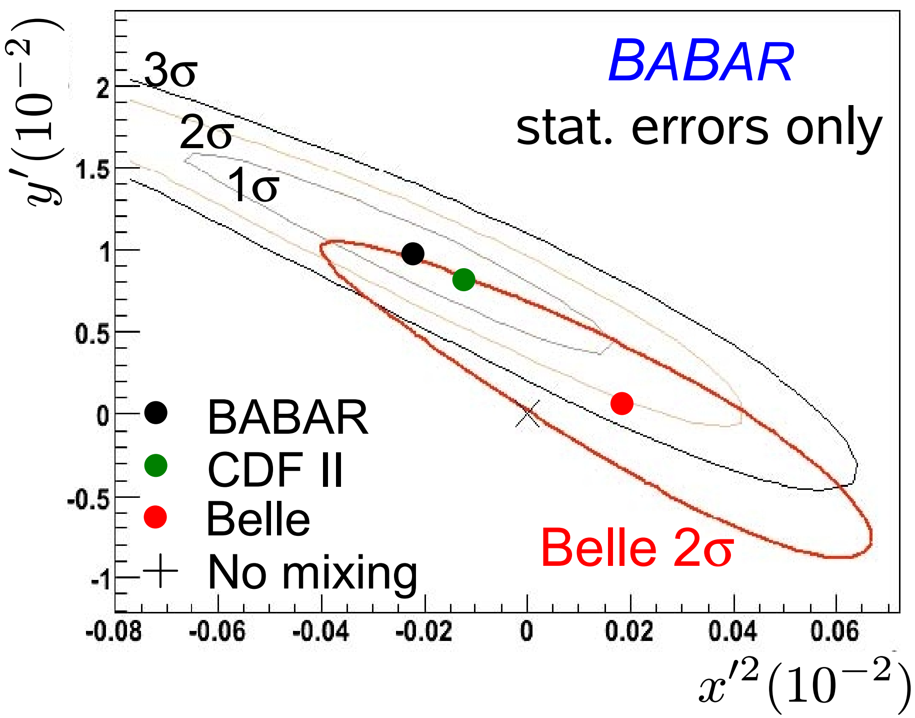
- Results of the $K\pi$ analysis by Belle in 2006



PRL 96,151801

$$R_D = (0.364 \pm 0.017)\%$$
$$y' = (0.06^{+0.40}_{-0.39})\%$$
$$x'^2 = (0.018^{+0.021}_{-0.23})\%$$

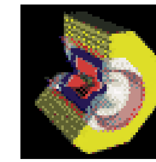
- Compare $D^0 \to K\pi$ results



All 3 mixing parameter measurements agree at the 2σ level

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

CLEO-c



arXiv: 0802.2264
(sub. to PRL)

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

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

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

  - 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

- 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

$$cos\,(\delta_{K\pi}) : \quad 1.10 \pm 0.35 \pm 0.07$$

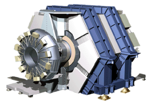
$$\mathrm{x}\;sin\,(\delta_{K\pi}) : \quad (4.4^{+2.7}_{-1.8} \pm 0.29) \cdot 10^{-3}$$

$$\delta_{K\pi} : \quad (22\;^{+11}_{-12}{}^{+\;9}_{-11})^{\circ}$$

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.



Measurement of y_{CP} - Introduction

- Decay time of D^0's is exponential with modifications due to mixing

$$\tau^{\pm} = \frac{\tau^0}{1 + |q/p|(y\,cos\phi_f \mp x\,sin\phi_f)}$$

$\tau^{\pm}$: lifetime of D^0 ($\bar{D}^0$) $\rightarrow$ CP+ eigenstates

τ^0: lifetime of D^0 $\rightarrow$ CP mixed (CF)

- A lifetime difference between CP+ and CP mixed states gives access to mixing

$$y_{CP} = \frac{\tau^0}{\tau} - 1 \quad \text{or} \quad y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^-K^+)} - 1 = \frac{\tau(K^-\pi^+)}{\tau(\pi^-\pi^+)} - 1$$

$y_{CP} \neq 0 \Rightarrow$ D^0-$\bar{D}^0$ mixing

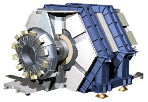
- Test of CP violation

$$\Delta Y = \frac{\tau^0 A_\tau}{\tau} \quad \text{with} \quad A_\tau = \frac{\tau^+ - \tau^-}{\tau^+ + \tau^-} = -A_\Gamma$$

$\Delta Y \neq 0 \Rightarrow$ CP violation in D^0-$\bar{D}^0$ mixing

CP violation in interf. between mixing and decay

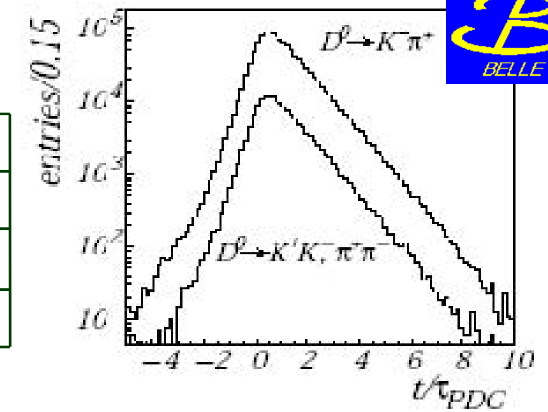
$y_{CP} = y$ in the limit of CP conservation



Belle - Results for y_{CP}

- Lifetime ratio measurements of CP+ and CP mixed D^0 decays by BELLE provide evidence for D^0-$\bar{D}^0$ mixing

Channel	Signal	Purity
K^+K^-	110K	98%
$\pi^+\pi^-$	50K	92%
$K\pi$	1.2M	99%

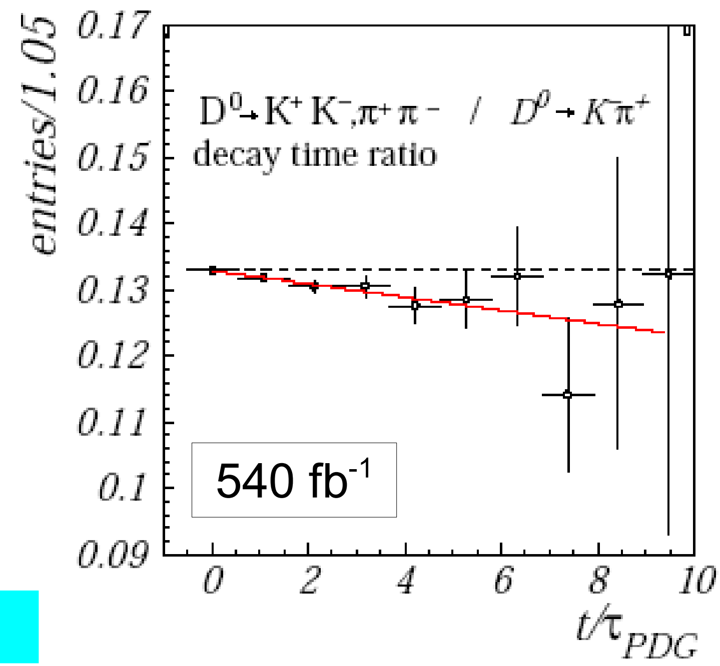


$$y_{CP} = (13.1 \pm 3.2 \pm 2.5) \cdot 10^{-3}$$

- Evidence for $D^0 - \bar{D}^0$ Mixing
  - exclude no-mixing at 3.2 σ (4.1 σ stat. only)

- No Evidence for CP violation

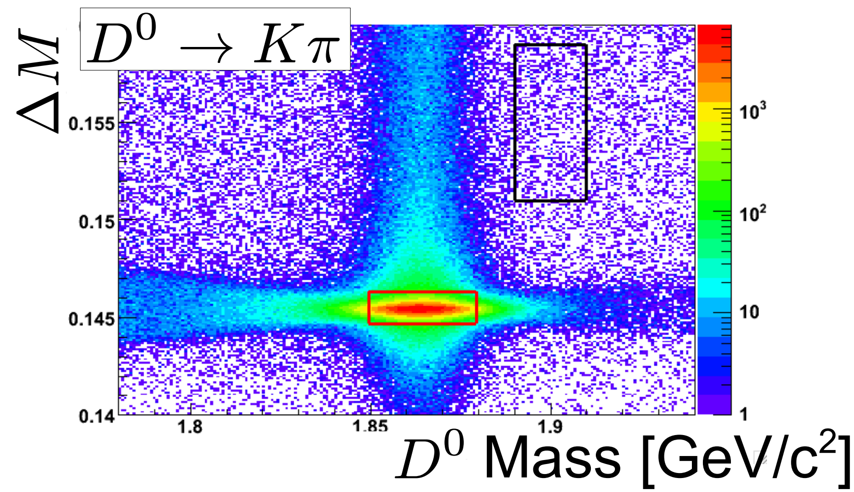
$$A_\Gamma = (0.01 \pm 0.3 \pm 0.15) \cdot 10^{-3}$$

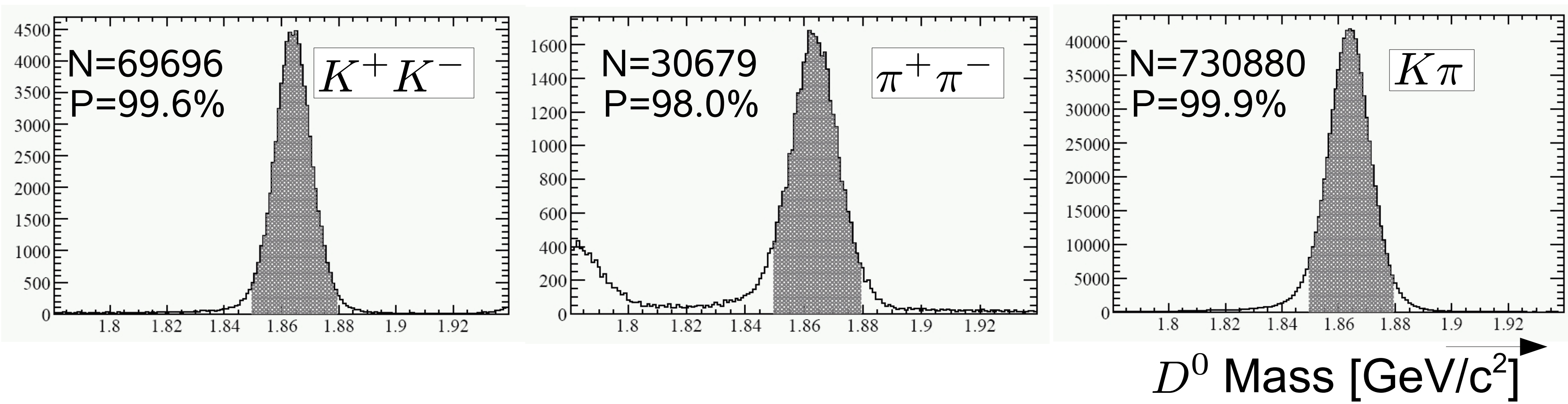


PRL 98, 211803 (2007)

BABAR - Lifetime Measurements (1)

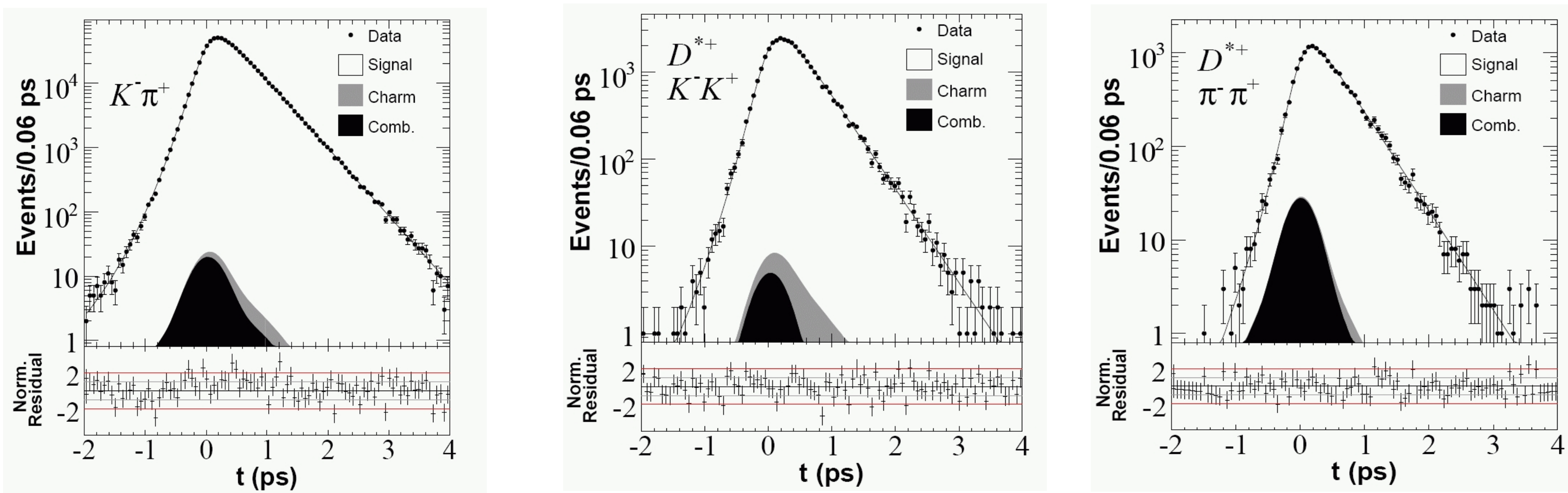
- Event selection from 384 fb^{-1}
  - Require $D^{*+} \to D^0 \pi_s^+$ tag identify D^0 flavour by π_s charge
  - Clean signal samples with high purity P



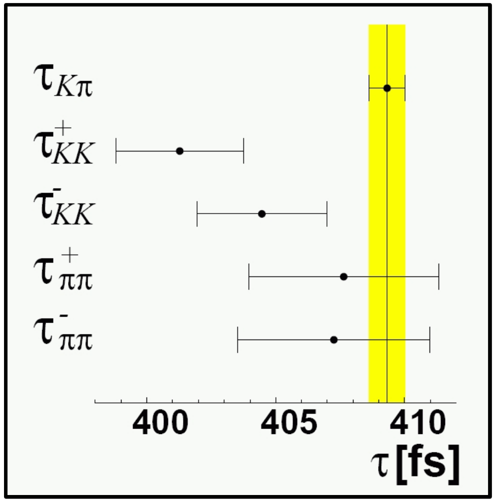


BABAR - Lifetime Measurements (2)

- Determine D^0 lifetimes from unbinned max. likelihood fit to all 5 samples



$\tau_{K\pi} = 409.33 \pm 0.7(stat.)\ fs$



- Summary of the lifetime measurements
  - Most of the measurement systematics of the signal cancel in the ratio
  - Systematics of the backgrounds to the different modes do not cancel

BABAR - Results for y_{CP}

- Determine y_{CP} and ΔY from $\tau_{K\pi}, \tau^{\pm}_{K^+K^-}, \tau^{\pm}_{\pi^+\pi^-}$ measurements

Tagged D^0 event sample (384 fb^{-1}):

arXiv: 0712.2249
(sub. to PRD-RC)

	y_{CP}	ΔY
K^-K^+	$(1.60 \pm 0.46 \pm 0.17)\%$	$(-0.40 \pm 0.44 \pm 0.14)\%$
$\pi^-\pi^+$	$(0.46 \pm 0.65 \pm 0.25)\%$	$(\ \ 0.05 \pm 0.64 \pm 0.32)\%$
combined	$(1.24 \pm 0.39 \pm 0.13)\%$	$(-0.26 \pm 0.36 \pm 0.08)\%$

- Evidence for $D^0 - \overline{D}^0$ Mixing at the 3 σ level
- No CP violation found

- Combined results with an untagged D^0 sample (91 fb^{-1})

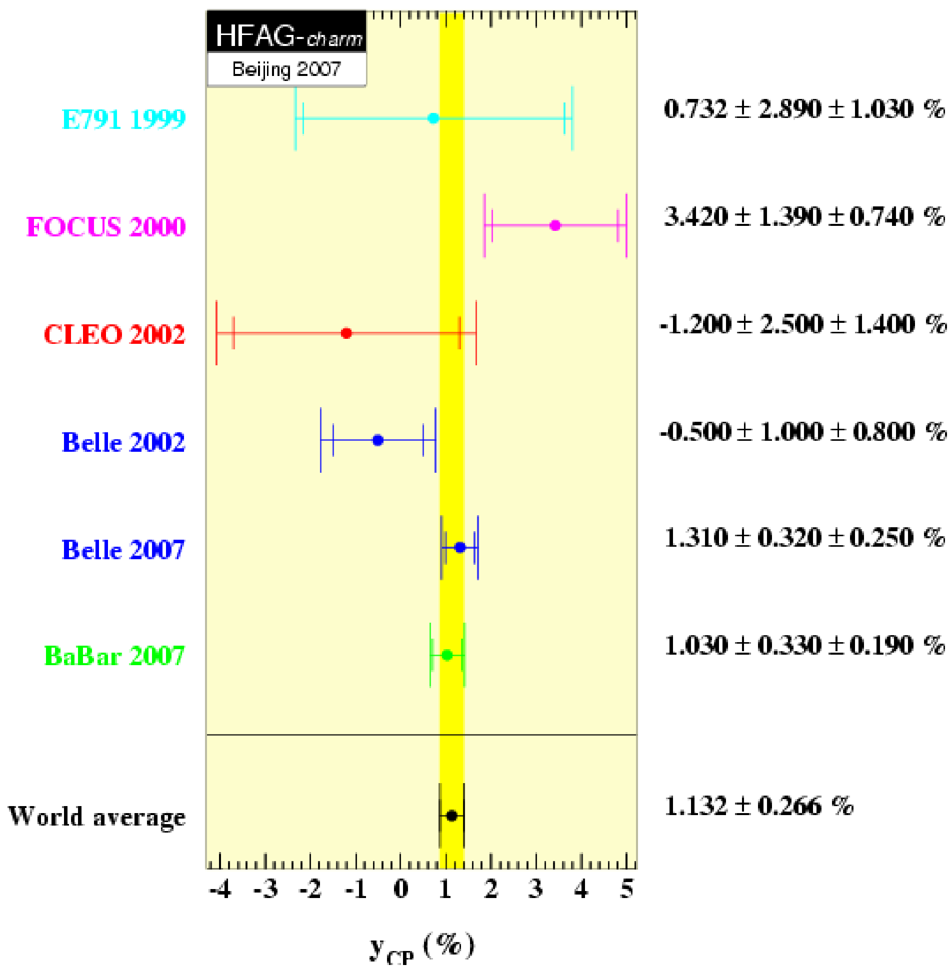
PRL 91, 221801
(2003)

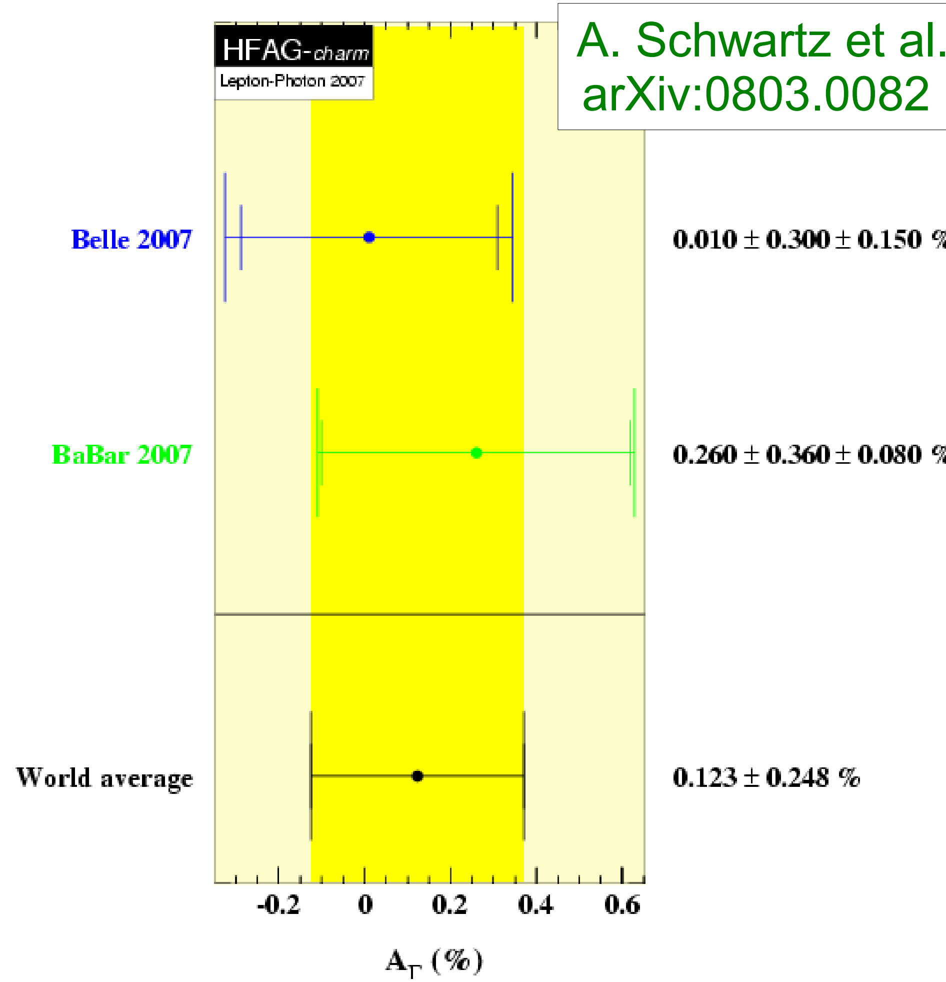
$$y_{CP} = (1.03 \pm 0.33 \pm 0.19)\%$$

Experimental Results - y_{CP}

- Combined y_{CP} and A_Γ as averaged by the charm subgroup of HFAG

A. Schwartz et al.
arXiv:0803.0082





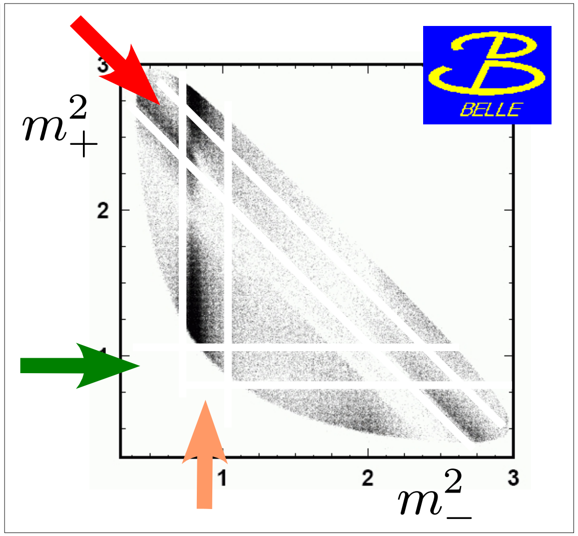
$$y_{CP} = (1.132 \pm 0.266)\%$$

$$A_\Gamma = (0.123 \pm 0.248)\%$$

Belle – t Dependent Dalitz Analysis (1)

- Dalitz plot of $D^0 \to K_s^0 \pi^+ \pi^-$
  - Different quasi 2 body amplitudes contribute and interfere
  - Dalitz analysis allows to determine amplitude and relative phases of 18 modes

CF: $D^0 \to K^{*-}\pi^+$
DCS: $D^0 \to K^{*+}\pi^-$
CP: $D^0 \to K_s^0 \rho^0$



$D^0 : m_+^2(K_s^0\pi^+)$
$\bar{D}^0 : m_+^2(K_s^0\pi^-)$

- Time dependence

$$\langle K_s^0\pi^+\pi^-|D^0(t)\rangle = \frac{1}{2}\overbrace{A(m_-^2, m_+^2)}^{\langle f|D^0\rangle}[e^{-i\lambda_1 t} + e^{-i\lambda_2 t}] + \frac{1}{2}\frac{q}{p}\overbrace{\bar{A}(m_-^2, m_+^2)}^{\langle f|\bar{D}^0\rangle}[e^{-i\lambda_1 t} + e^{-i\lambda_2 t}]$$

decay amplitude

$$\lambda_{1,2} = f(x, y)$$

  - The decay rates contain functions of x and y

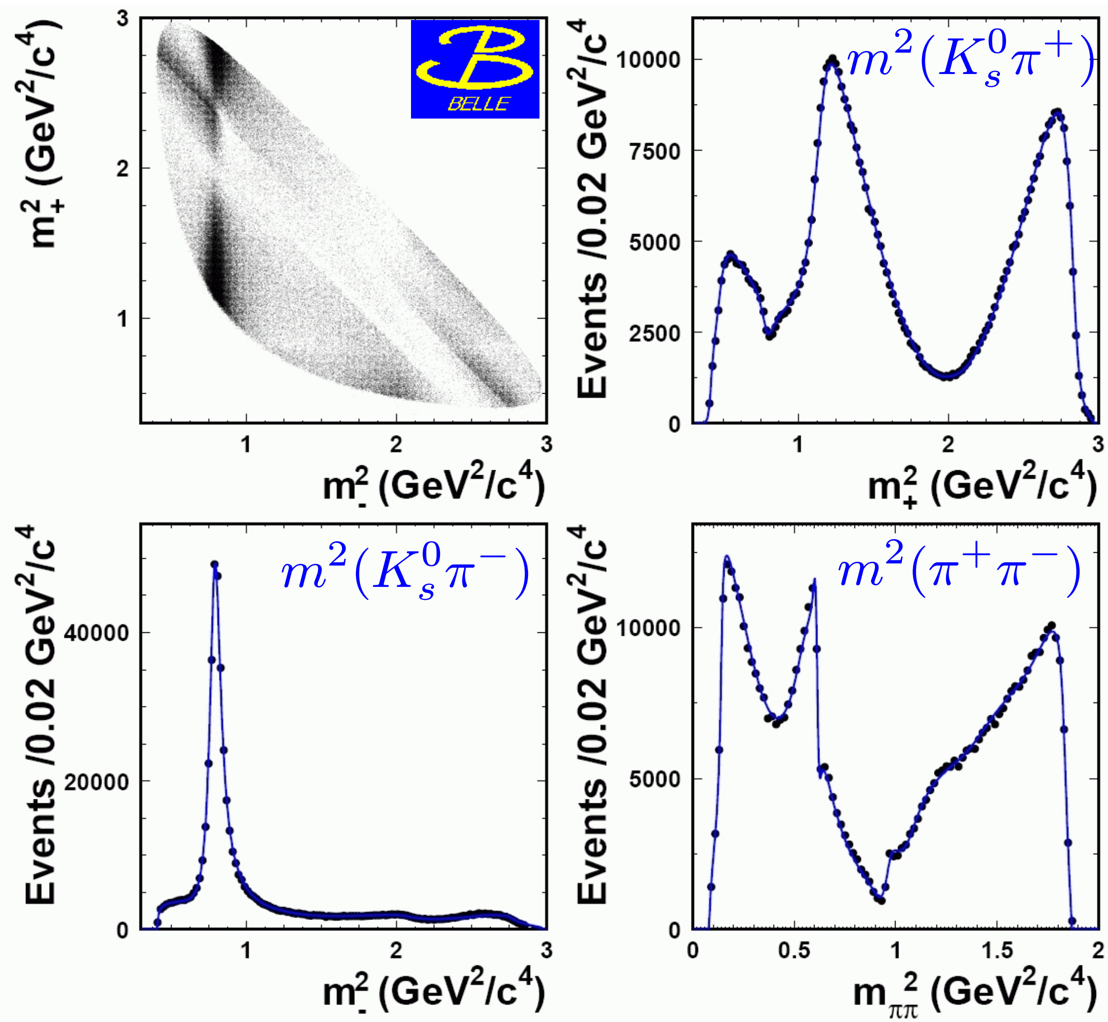
- Perform unbinned max. likelihood fit in the signal region to (m_+^2, m_-^2, t)

$\Rightarrow$ extract relative amplitudes and relative phases

$\Rightarrow$ x, y and τ_{D^0}

Belle – t Dependent Dalitz Analysis (2)

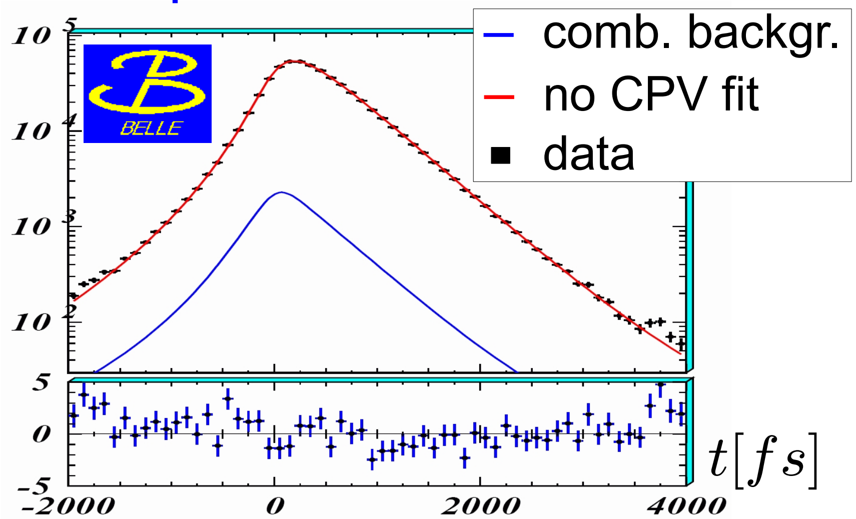
- Select 534410 ± 830 events in the signal region with 95 % purity in 540 fb^{-1}



Resonance	Amplitude	Phase (°)	Fit fraction
$K^*(892)^-$	1.629 ± 0.006	134.3 ± 0.3	0.6227
$K_0^*(1430)^-$	2.12 ± 0.02	-0.9 ± 0.8	0.0724
$K_2^*(1430)^-$	0.87 ± 0.02	-47.3 ± 1.2	0.0133
$K^*(1410)^-$	0.65 ± 0.03	111 ± 4	0.0048
$K^*(1680)^-$	0.60 ± 0.25	147 ± 29	0.0002
$K^*(892)^+$	0.152 ± 0.003	-37.5 ± 1.3	0.0054
$K_0^*(1430)^+$	0.541 ± 0.019	91.8 ± 2.1	0.0047
$K_2^*(1430)^+$	0.276 ± 0.013	-106 ± 3	0.0013
$K^*(1410)^+$	0.33 ± 0.02	-102 ± 4	0.0013
$K^*(1680)^+$	0.73 ± 0.16	103 ± 11	0.0004
$\rho(770)$	1 (fixed)	0 (fixed)	0.2111
$\omega(782)$	0.0380 ± 0.0007	115.1 ± 1.1	0.0063
$f_0(980)$	0.380 ± 0.004	-147.1 ± 1.1	0.0452
$f_0(1370)$	1.46 ± 0.05	98.6 ± 1.8	0.0162
$f_2(1270)$	1.43 ± 0.02	-13.6 ± 1.2	0.0180
$\rho(1450)$	0.72 ± 0.04	41 ± 7	0.0024
σ_1	1.39 ± 0.02	-146.6 ± 0.9	0.0914
σ_2	0.267 ± 0.013	-157 ± 3	0.0088
NR	2.36 ± 0.07	155 ± 2	0.0615

Belle – t Dep. Dalitz Analysis Results

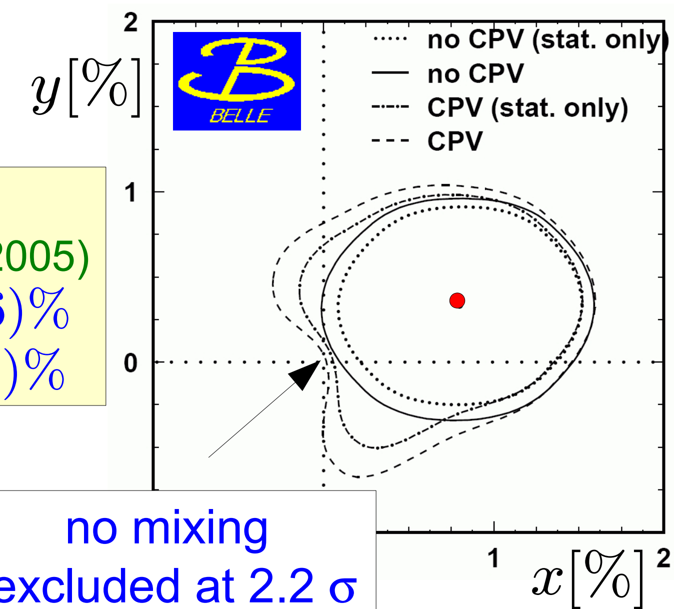
- Proper time fit results



$\tau_{K_s^0\pi^+\pi^-} = 409.9 \pm 0.9\ fs$

- Mixing parameter fit results

CLEO 9 fb^{-1} :
PRD 72, 012001 (2005)
$(-4.7 < x < 8.6)\%$
$(-6.1 < y < 3.5)\%$



no mixing
excluded at 2.2 σ

Belle 540 fb^{-1} : PRL 99, 131803 (2007)

$x = (0.80 \pm 0.29^{+0.09+0.10}_{-0.07-0.14})\%$

$y = (0.33 \pm 0.24^{+0.08+0.06}_{-0.12-0.08})\%$

- Allow for CP violation
  - Dalitz plot parameters from fit are similar for D^0 and $\bar{D}^0$ no direct CP violation
  - CP violation results :

$$|q/p| = 0.86^{+0.30+0.06}_{-0.29-0.03} \pm 0.08$$

$$arg\,(q/p)[^\circ] = -14^{+16+5+2}_{-18-3-4}$$

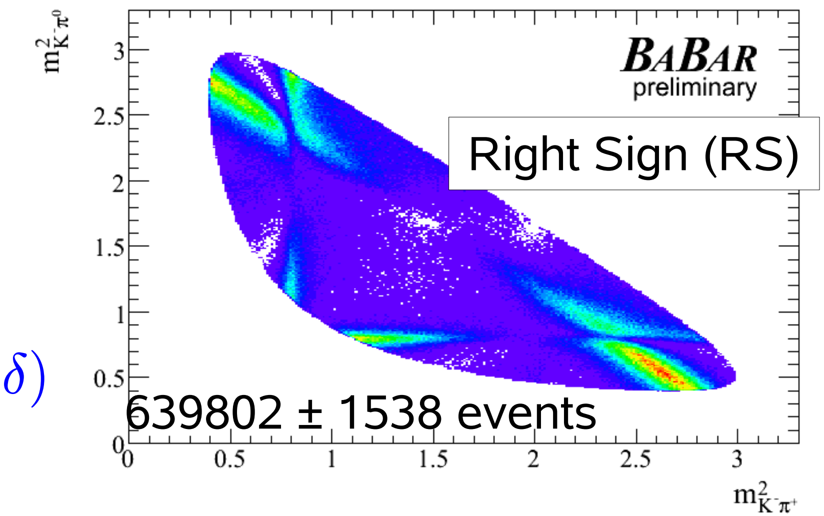
no CP violation

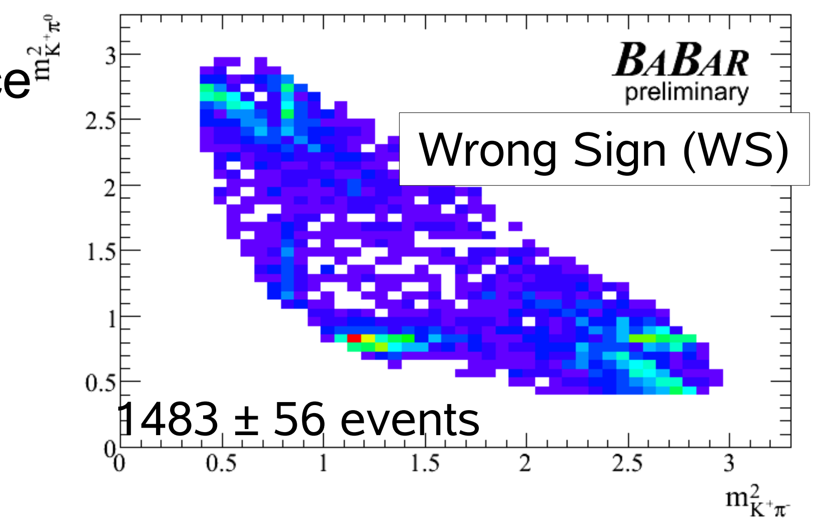
BABAR – $D^0 \to K^+\pi^-\pi^0$ Dalitz Analysis

- Analyse time dependence of Wrong Sign events in quasi 2 body decays
  - 2 types of WS decays (as in $D^0 \to K\pi$)
    - DCS: $D^0 \to K^+\pi^-\pi^0$
    - Mixing followed by CF decay: $D^0 \xrightarrow{\text{mixing}} \bar{D}^0 \to K^+\pi^-\pi^0$
    - Interference: $\Gamma_{K\pi\pi^0} = f(m^2_{K\pi}, m^2_{K\pi^0}, t, x, y, \delta)$
  - Determine DCS and CF Dalitz amplitudes and phases in a fit
  - Extract x and y from a fit to the time dependence of the relative WS decay rate:

$$y'' = y\,cos(\delta_{K\pi\pi^0}) - x\,sin(\delta_{K\pi\pi^0})$$
$$x'' = x\,cos(\delta_{K\pi\pi^0}) + y\,sin(\delta_{K\pi\pi^0})$$

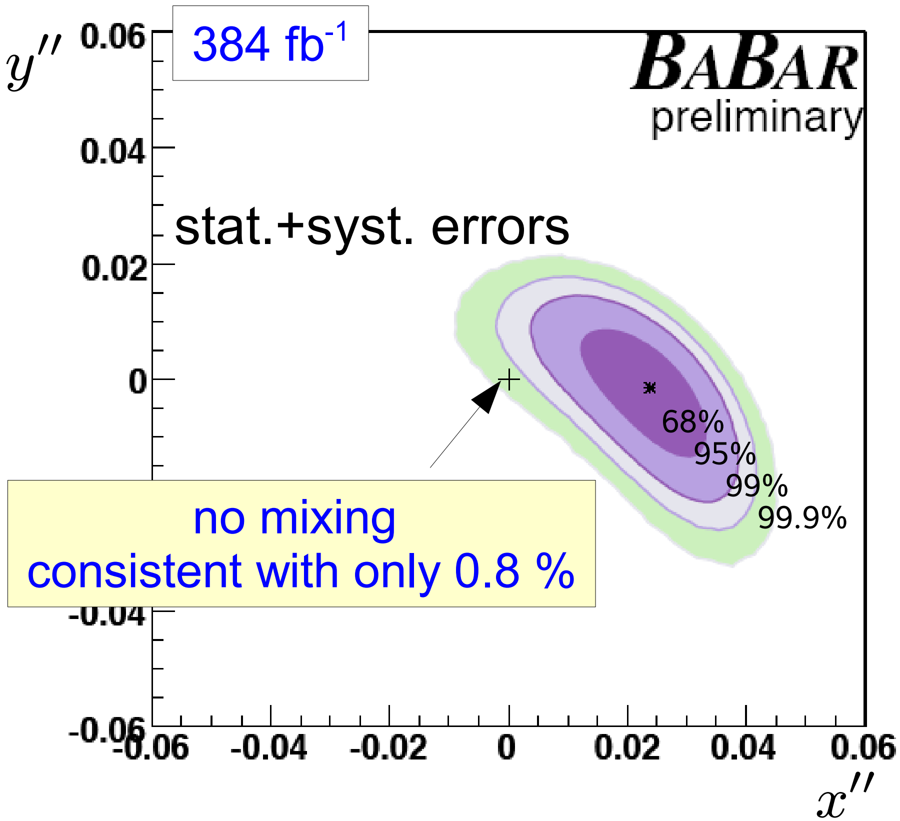
$\delta_{K\pi\pi^0}$: strong phase difference $(\neq \delta_{K\pi})$





BABAR – $D^0 \to K^+\pi^-\pi^0$ Results

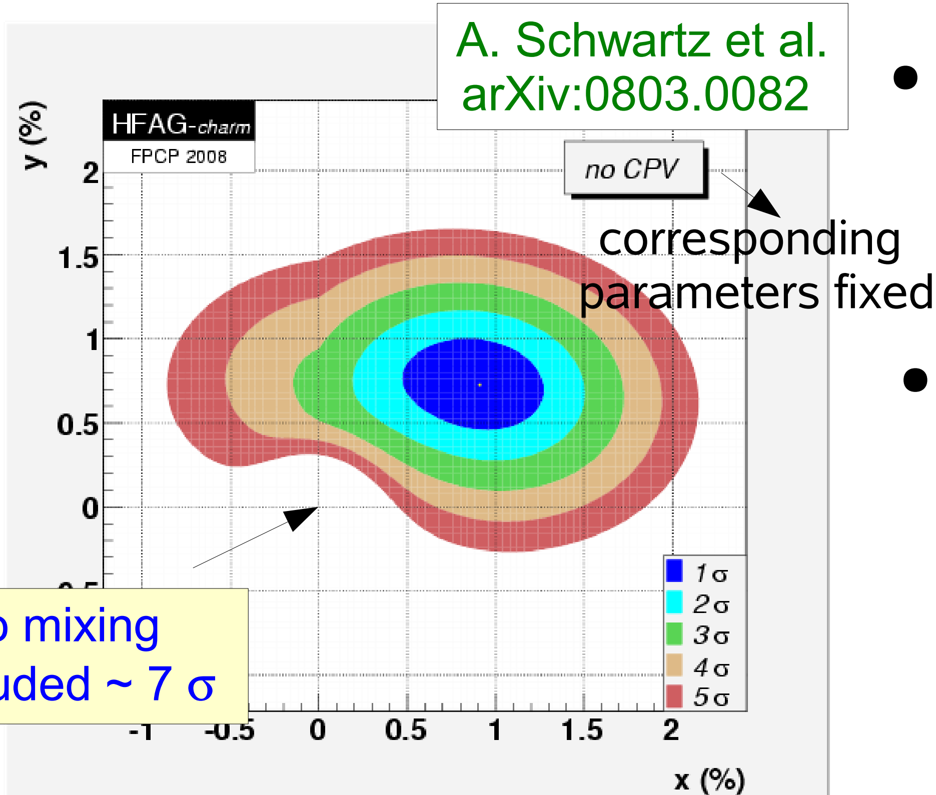
- Mixing parameter fit results



$$y'' = (-0.14 \pm 0.60 \pm 0.40)\%$$
$$x'' = (2.39 \pm 0.61 \pm 0.32)\%$$

D^0 Mixing - Combined Results

➢ World average mixing parameters are provided by the HFAG charm group



R_D : $(0.3342 \pm 0.0083)\%$

δ : $0.36 \pm 0.20\ rad$

$\delta_{K\pi\pi^0}$: $0.55 \pm 0.45\ rad$

- Experimental data indicates $D^0 \underset{\text{mixing}}{\rightarrow} \bar{D}^0$

$$y = (0.73 \pm 0.18)\%$$
$$x = (0.91 \pm 0.26)\%$$

- y measured from D^0 lifetime differences

$$y_{CP} = (1.132 \pm 0.266)\% \ > 0$$

$$\tau(\,|D_1\rangle\,) \ < \ \tau(\,|D_2\rangle\,)$$

CP even state CP odd state

- x determined from $D^0 \rightarrow K_s^0 \pi^+ \pi^-$

$$x > 0$$

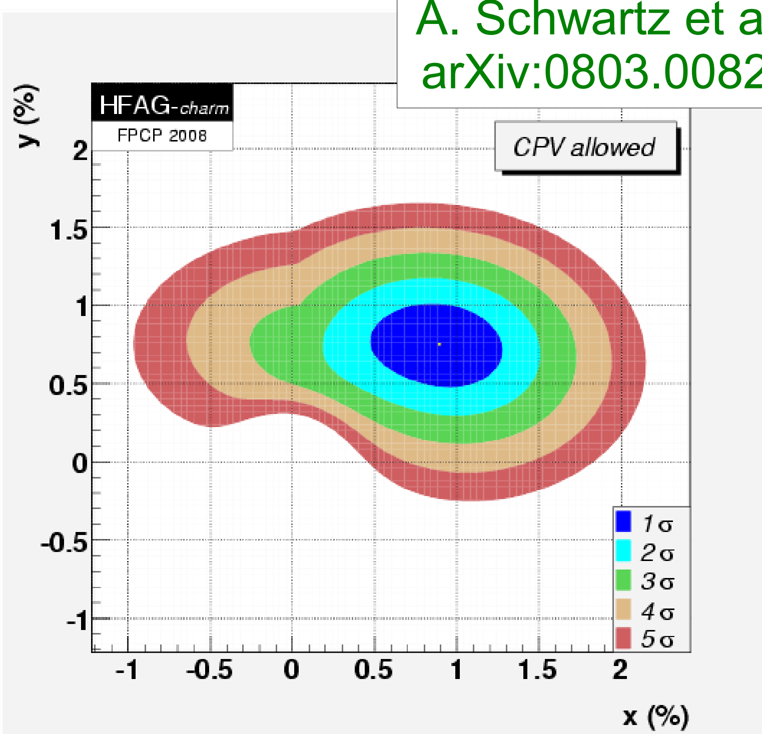
$$M_1(\,|D_1\rangle\,) \ > \ M_2(\,|D_2\rangle\,)$$

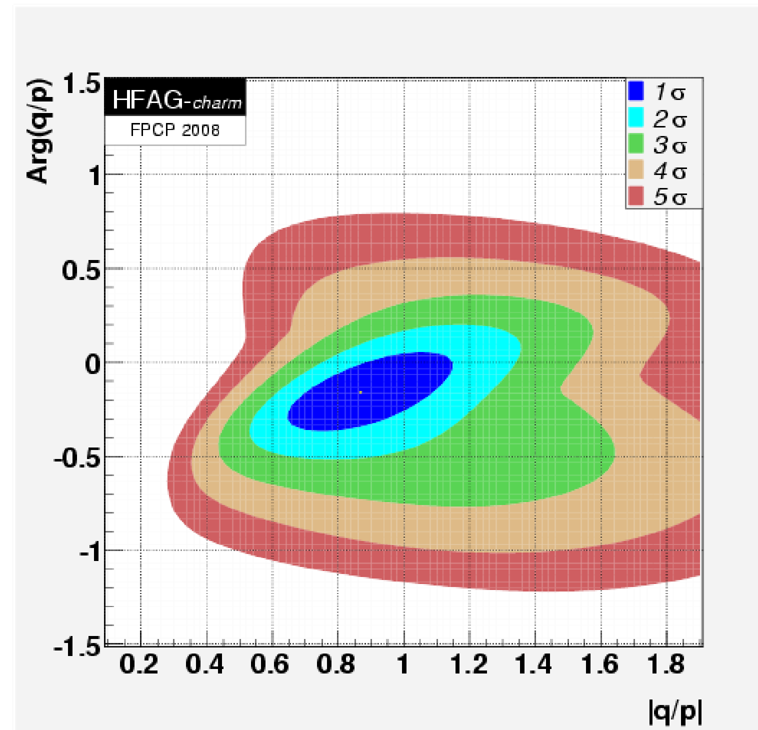
D^0 Mixing & CPV - Combined Results

➢ Global fit of mixing parameters allowing for CP violation

Parameters are almost identical to the CP conserving case

A. Schwartz et al.
arXiv:0803.0082



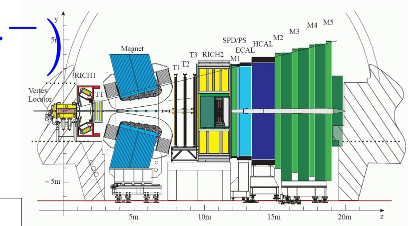


$$A_D = (-2.0 \pm 2.5)\,\%$$
$$|q/p| = 0.87 \pm 0.17$$
$$\phi = (-0.16 \pm 0.14)\,rad$$

Consistent with no CP violation

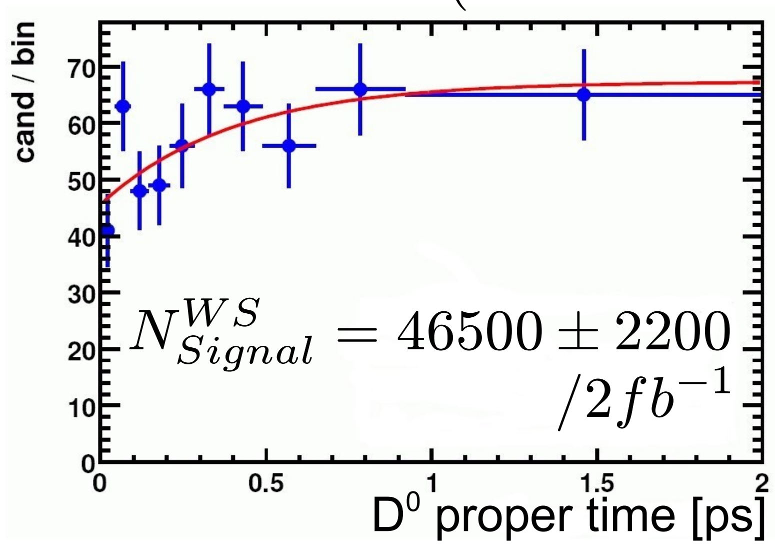
Towards D^0 Mixing at LHCb

- MC study of D^0 Mixing in $D^{*+} \to \pi_s^+ D^0(K^+\pi^-, K^+K^-, \pi^+\pi^-)$
  - Full detector simulation including trigger of minimum bias $b\bar{b}$ and signal events
  - Special higher level trigger stream for D*



LHCb-2007-049

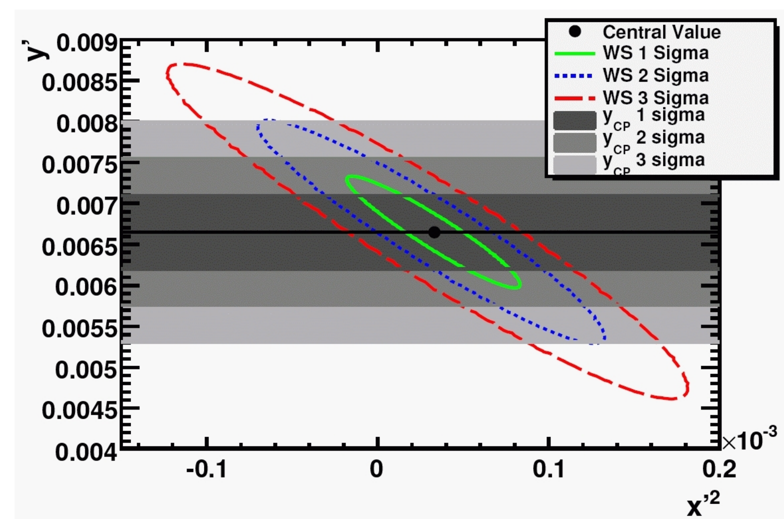
- Event yields after a cut based selection of $D^{*+}(D^0 \to K^+\pi^-)$



$$\epsilon^{RS/WS}_{Signal} = (1.39 \pm 0.17) \cdot 10^{-3}$$

$$Bckgr/Signal = 2.56$$

- Extract y_{CP} and (x'^2, y') from toy MC
  Statistical error by a factor 5 smaller compared to *BABAR*



Signal extraction, systematic errors and .... a lot more to be done

Summary

- Experimental Evidence of D^0 Mixing from 3 Experiments
- Measured values of the mixing parameters $x \approx y \approx 1\%$ are compatible with Standard Model
- World averages of the mixing parameters exclude No D^0 Mixing at $\sim 7\sigma$
- No Evidence for CP Violation in D^0 Mixing

Looking forward seeing new and updated results on D^0 Mixing at the summer conferences