Oscillazioni del mesone D^0

Gianluca Cavoto
INFN Roma La Sapienza

Seminario di fisica dei campi e particelle
Roma, 22 marzo 2007

Outline

- Neutral mesons flavour oscillation
- Charm meson mixing
- Evidence from B-factories
  - $D^0 \rightarrow K^- \pi^+$
  - $D^0 \rightarrow K_s \pi^+ \pi^-$, $D^0 \rightarrow K^+ K^- / \pi^+ \pi^-$
- Outlook

Neutral Mesons systems

– Two-level system $(M^0, \overline{M}^0)$
  - Weak interactions remove degeneracy, make them unstable

Time evolution by Schrödinger eq.:

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

2x2 hermitian matrices

Mesons decay!

Mass eigenstates:

$$|M_{1,2}\rangle = p|M^0\rangle \pm q|\overline{M}^0\rangle$$

Propagate with separate mass $m_{1,2}$ and width $\Gamma_{1,2}$:

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

Neutral mesons oscillations

Time evolution for meson of ***known flavour at t=0***

$$x = \frac{m_2 - m_1}{\Gamma} \qquad \Gamma = \frac{\Gamma_2 + \Gamma_1}{2}$$

$$y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$$

$$|M^0(t)\rangle = e^{-\bar{\gamma}t/2}\left(\cosh(\Delta\gamma t/2)|M^0\rangle - \frac{q}{p}\sinh(\Delta\gamma t/2)|\overline{M}^0\rangle\right)$$

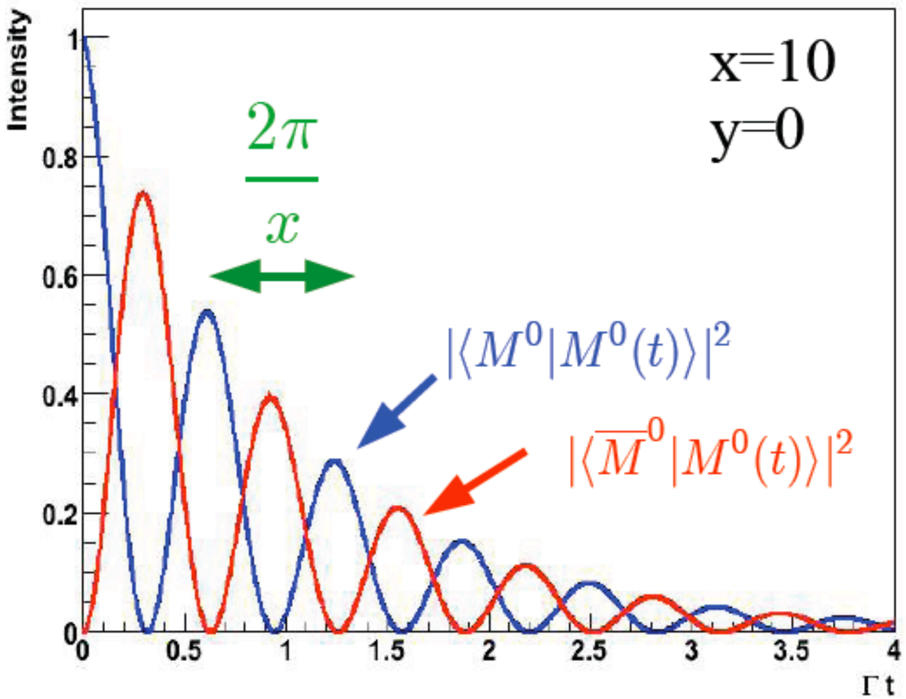
Where $\Delta\gamma = (y + ix)\Gamma \qquad \bar{\gamma} = (\Gamma_1 + \Gamma_2)/2 - i(m_1 + m_2)$

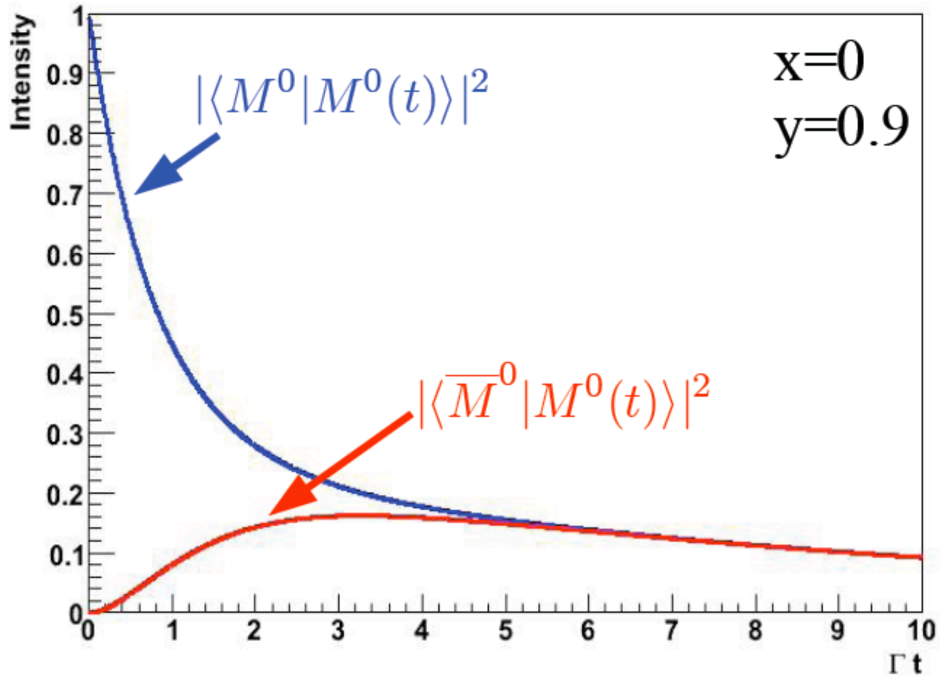
An opposite flavour component appears after a while!

M^0 "oscillates" into $\overline{M}^0$!
(also dubbed "mixing")

Some visual examples

Probability to find a $M^0(\overline{M}^0)$ after a given time

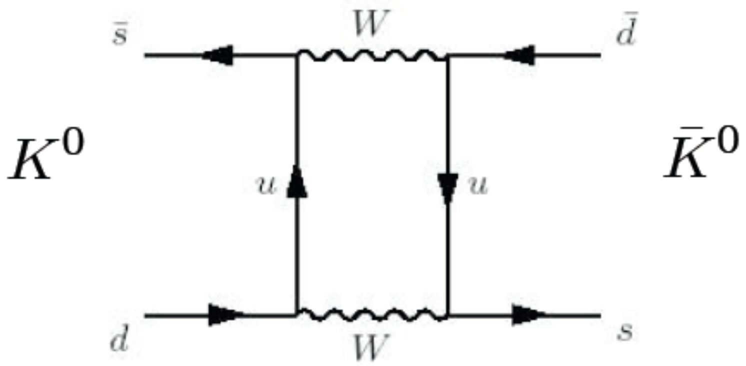




Lifetime units

How to generate this ??

Mixing through box diagram:



No tree level Flavour Changing Neutral Currents (FCNC) in SM

Glashow, Iliopoulus and Maiani (1970):

FCNC calculated from single quark loop still too large

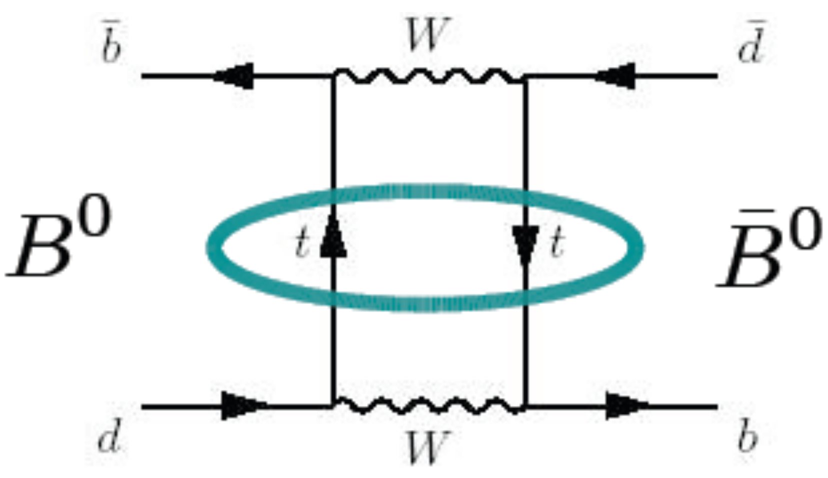
Introduce additional loop with new c quark

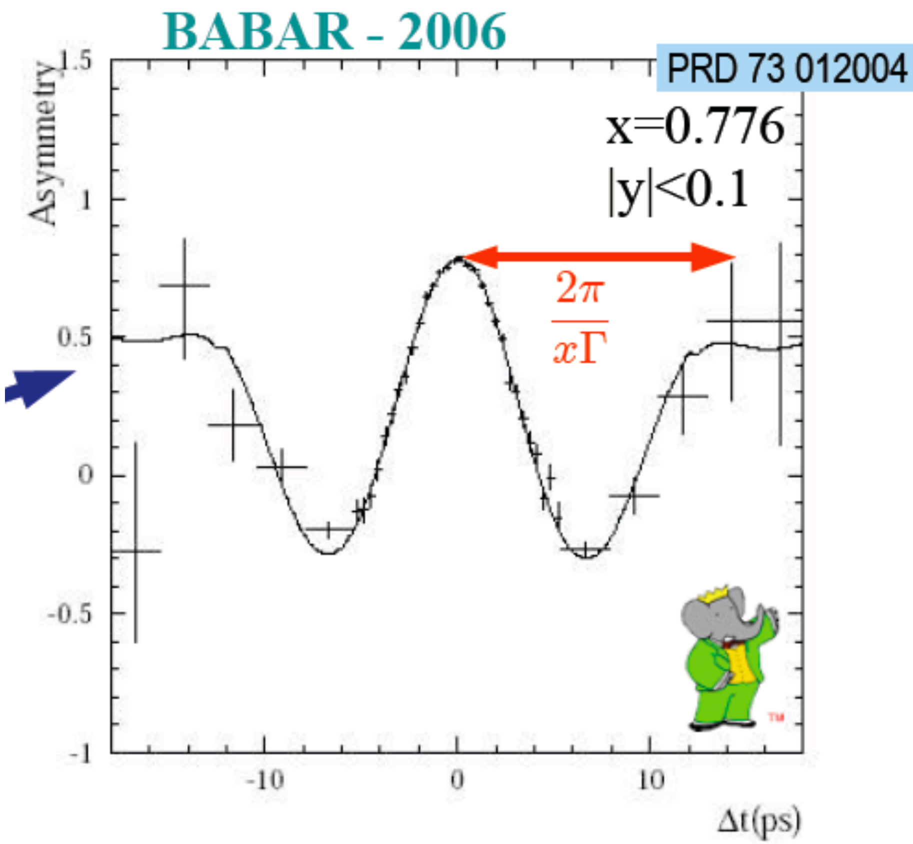
GIM predicted charm quark 4 years before observation

Can you see New Physics ?

B^0 mixing first observed by ARGUS experiment in 1987

Large mixing frequency implied t quark was heavy (m_t >50 GeV/c^2)





And the top was discovered 8 years after!

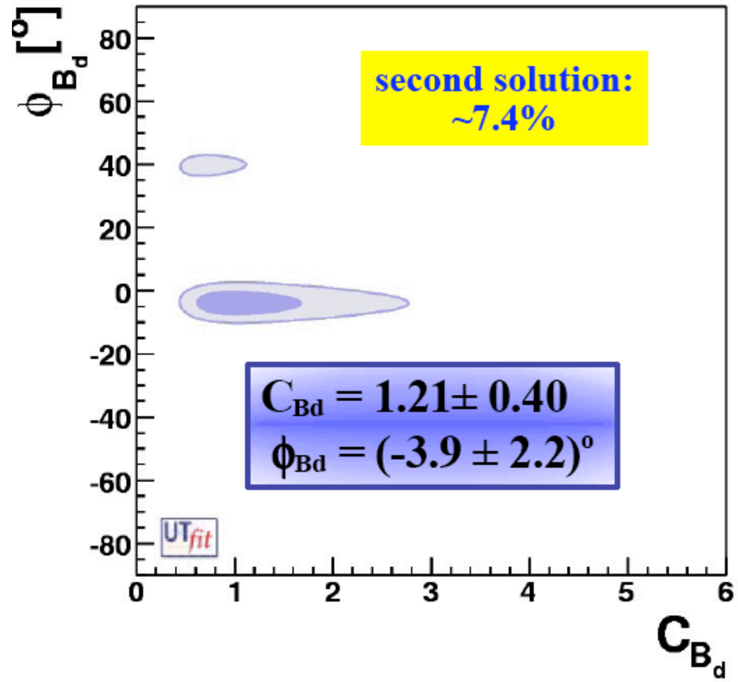
Even more ambitious today!

$B_{d,s}$ (K) mixing on the punch line for virtual effects from NP

Not only x and y but also ***phases*** in the mixing

$$C_{B_q} e^{2i\phi_{B_q}} = \frac{\langle B_q^0 | H_{eff}^{full} | \overline{B}_q^0 \rangle}{\langle B_q^0 | H_{eff}^{SM} | \overline{B}_q^0 \rangle}, \quad (q = d, s)$$

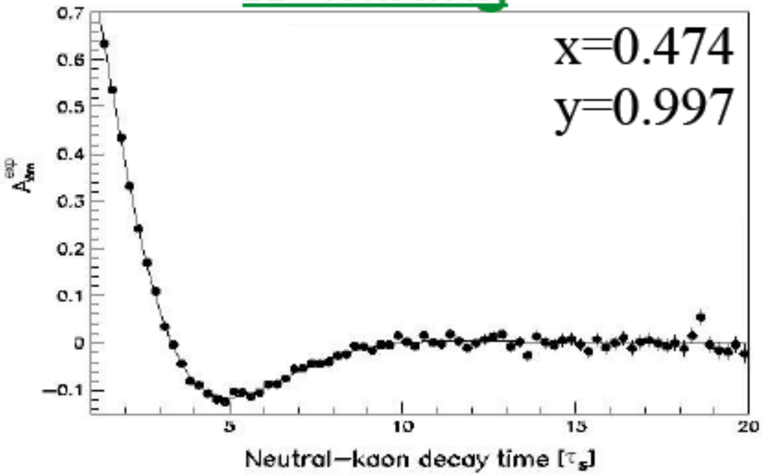
$$C_{\epsilon_K} = \frac{\Im[\langle K^0 | H_{eff}^{full} | \overline{K}^0 \rangle]}{\Im[\langle K^0 | H_{eff}^{SM} | \overline{K}^0 \rangle]}$$



M. Bona *et al.* (UTfit Collaboration)
Phys.Rev.Lett.97:151803,2006 hep-ph/0605213

The missing tile

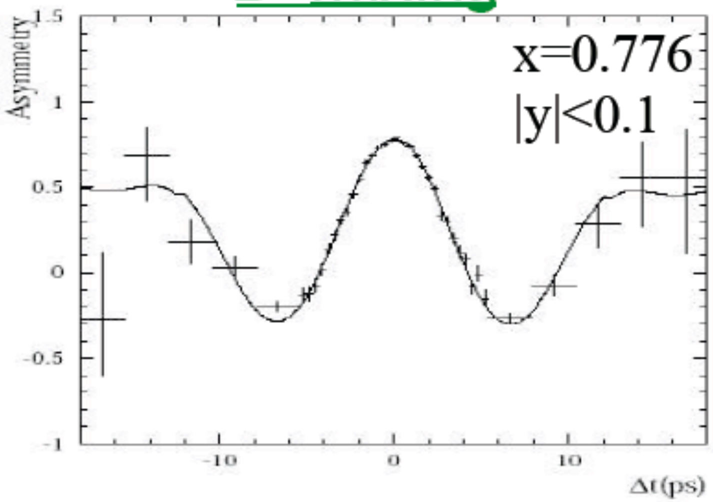
K^0 mixing



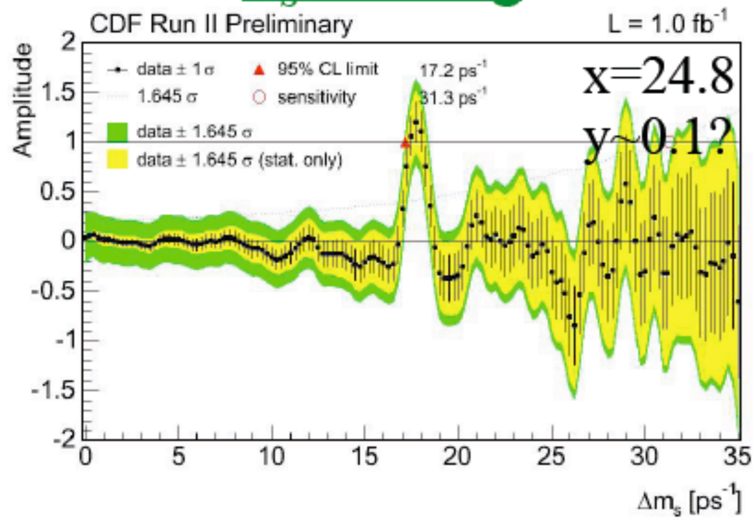
D^0 mixing

?

B^0 mixing



B_s^0 mixing



Charm Meson Mixing

Short and **Long** distance

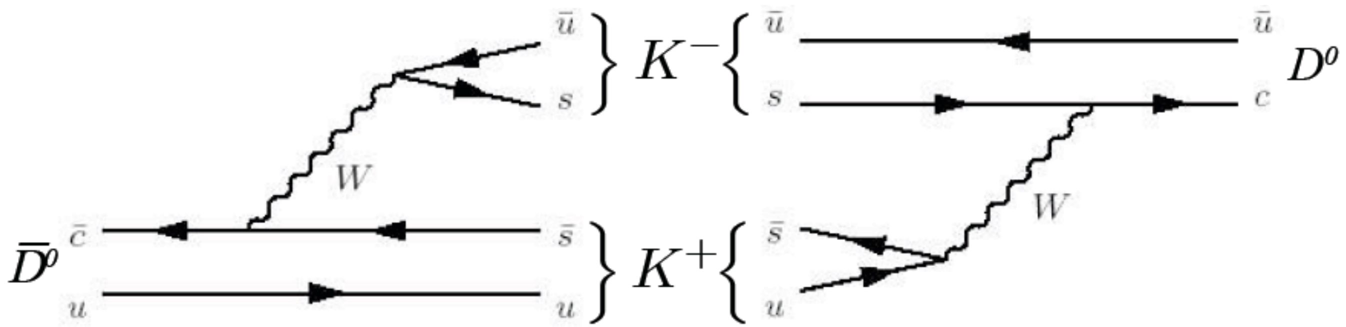
- Prediction x and y

x *VIRTUAL* states

$$\left(\mathrm{M} - \frac{i}{2}\Gamma\right)_{ij} = \frac{\langle D_i | H_{\mathrm{eff}} | D_j \rangle}{2m_D} = m_D^{(0)}\delta_{ij} + \frac{\langle D_i | H_w | D_j \rangle}{2m_D} + \frac{1}{2m_D}\sum_n \frac{\langle D_i | H_w | n \rangle \langle n | H_w | D_j \rangle}{m_D^{(0)} - E_n + i\epsilon}.$$

y $$\Gamma_{ij} = \frac{1}{2m_D}\sum_n \langle D_i | H_w | n \rangle \langle n | H_w | D_j \rangle \, \delta(E_n - m_D).$$

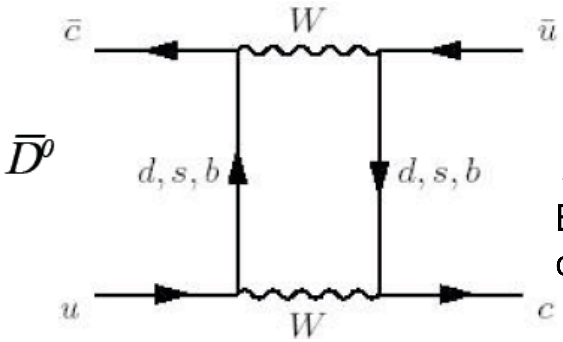
Sum of intermediate **REAL states**



Makes it difficult to predict SM expectation

SM prediction for charm mixing

SM charm mixing box has down-type quarks in loop



Effective GIM suppression:

$$x \propto \frac{(m_s^2 - m_d^2)^2}{m_c^2}$$

bottom quark

ruled out by V_{CKM}

Box diagram contribution → $x \sim 10^{-5}$ Tiny!

$$x,\ y \sim \sin\theta_c^2 \times [\mathrm{SU}(3)\ \text{breaking}].$$ →

Naively

$$x,\ y \sim \sin\theta_c^2 \times \left(\frac{m_s}{\Lambda_{\text{hadr.}}}\right)^2 \lesssim O(10^{-3})$$

Always hard to evaluate SU(3) breaking !!!

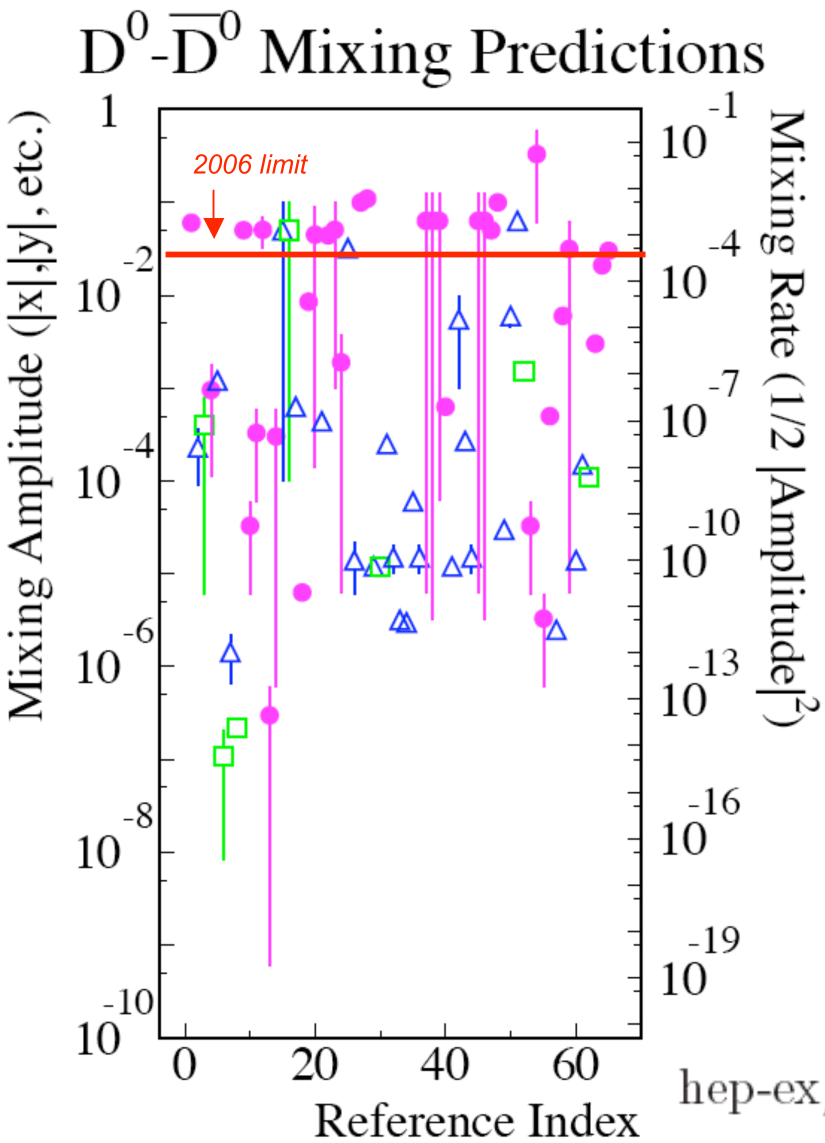
(HQET, propagation of common hadronic states,…)

SU(3) breaking effect more important for y

$$x \lesssim 10^{-3}, \qquad y \lesssim 10^{-2}.$$

G. Burdman and I. Shipsey, Ann. Rev. Nucl. and Part. Sci. **53**, 431 (2003).

New Physics in Charm ?



hep-ex/9908021

△: Standard-model predictions for x.

□: standard-model predictions for y

●: New-physics predictions for x.

Hard to see a clear cut

Pushing the limit down excludes models

Try to separate x and y!

Experimental Searches

Charm physics with B-factory

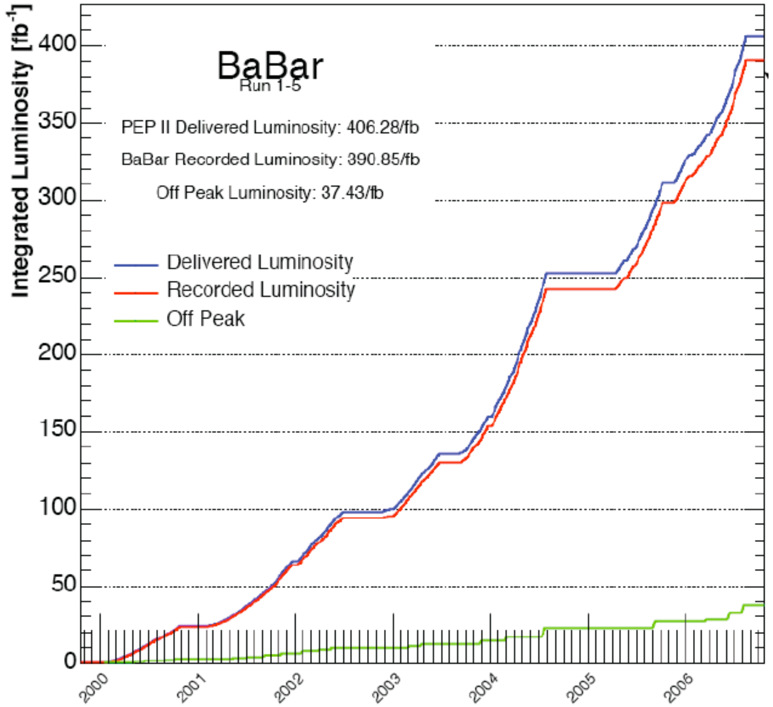
BaBar is a B-factory: $e^+e^- \to \Upsilon(4S) \to b\bar{b}$

$\sigma_{eff}(b\bar{b})$=1.1 nb, but

$\sigma(c\bar{c})$ =1.3 nb ➡

Millions of reconstructed charm hadrons

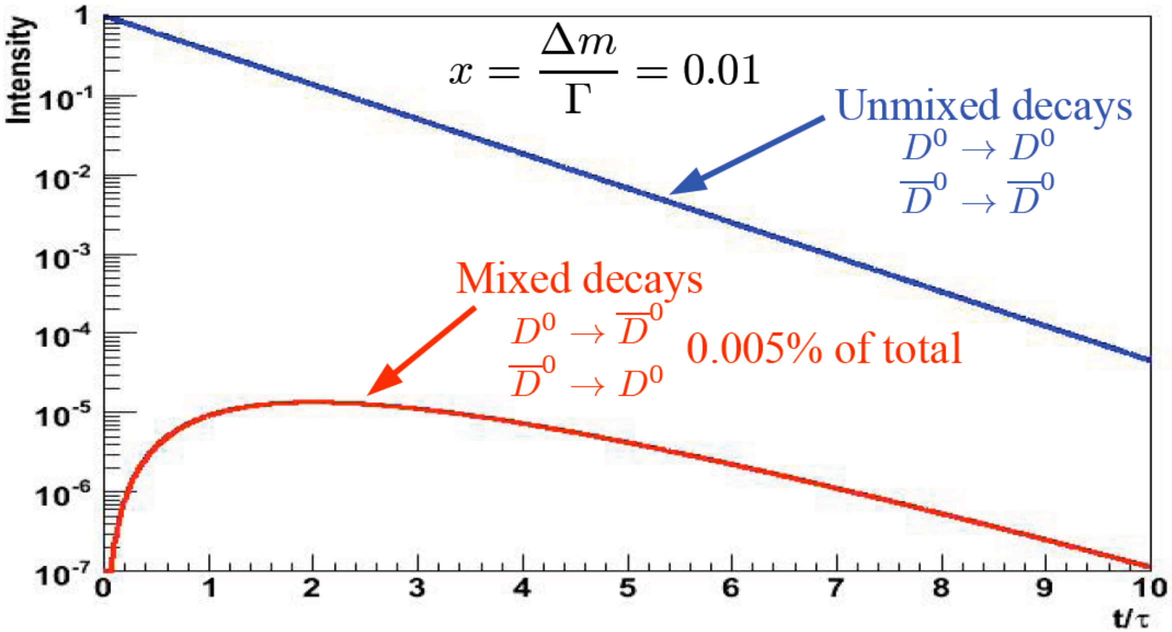
BaBar is also a charm factory



- Run1-5, more than 500M ccbar events

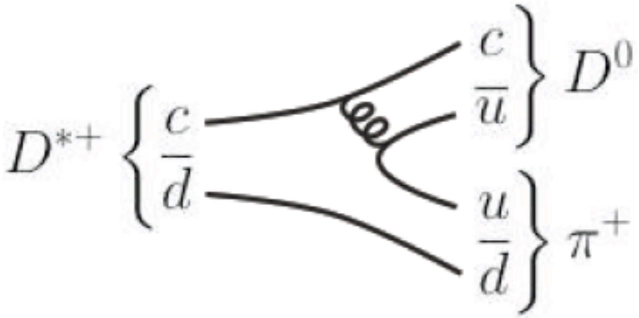
The technique

- Produce clean sample of D^0 and $\bar{D}^0$
- Identify flavor (D^0 or $\bar{D}^0$?) at decay time
- Measure rate of mixed decays as function of time



Flavour tagging

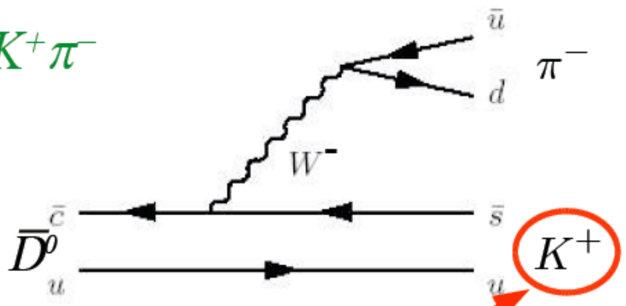
Use D^0 from $D^{*+} \to D^0 \pi^+$ decays:



Flavour at production

Charge of pion "tags" initial flavor as D^0 or $\bar{D}^0$

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



Charge of K identifies decay flavor

Flavour at decay

- Same flavour: Wrong-Sign (WS) mixing *may* have occured
- Opposite flavour: Right-Sign (RS) unmixed events

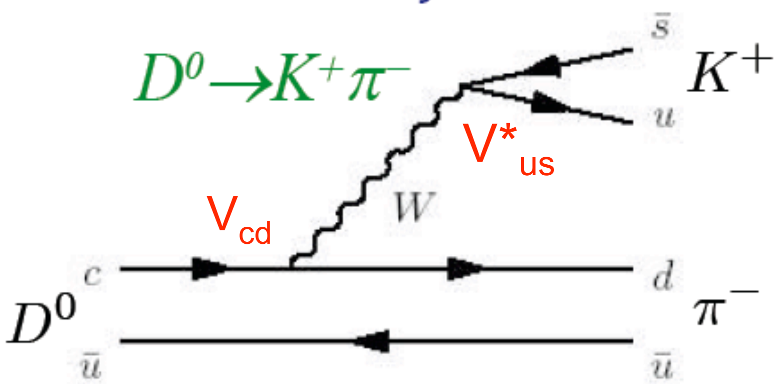
$$\overline{A}_f \equiv \langle f | H | \overline{D}^0 \rangle$$

Double-Cabibbo Suppressed Decays

Hadronic decays do not uniquely identify decay flavor

Get unmixed wrong-sign decays from DCS decays

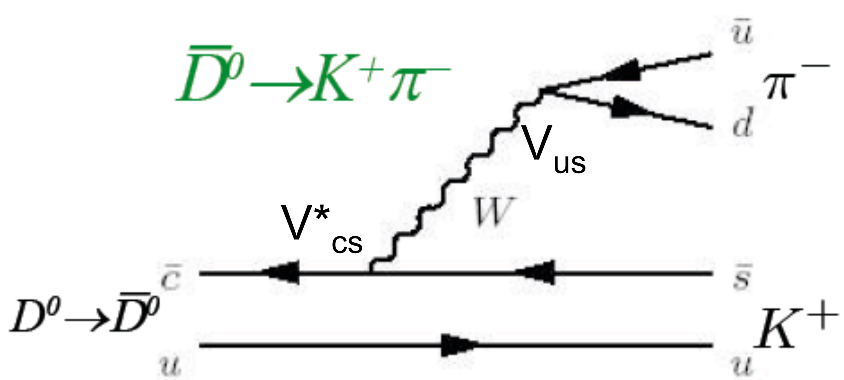
DCS decay:



Relative rate ~0.3%

$$A_f \equiv \langle f|H|D^0\rangle$$

Mixed decay:

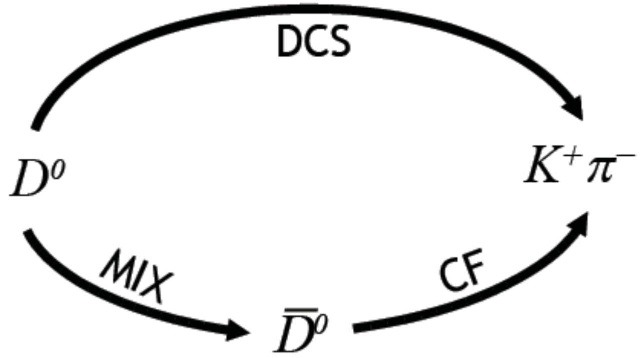


Relative rate: 0.005% (for x=0.01)

Time evolution

Discriminate DCS and mixing by their different time evolution

Also have interference effect:



WS (relative to RS) time-dep. rate (small x and small y limit)

$$r(t) = \overline{r}(t) = e^{-t}\left(\underbrace{R_D}_{\text{DCS}} + \underbrace{\sqrt{R_D}\, y' t}_{\text{Interference}} + \underbrace{\frac{1}{2} R_M\, t^2}_{\text{Mixing}}\right)$$

$$\frac{A_f}{\overline{A}_f} = -\sqrt{R_D}\, e^{-i\delta}$$

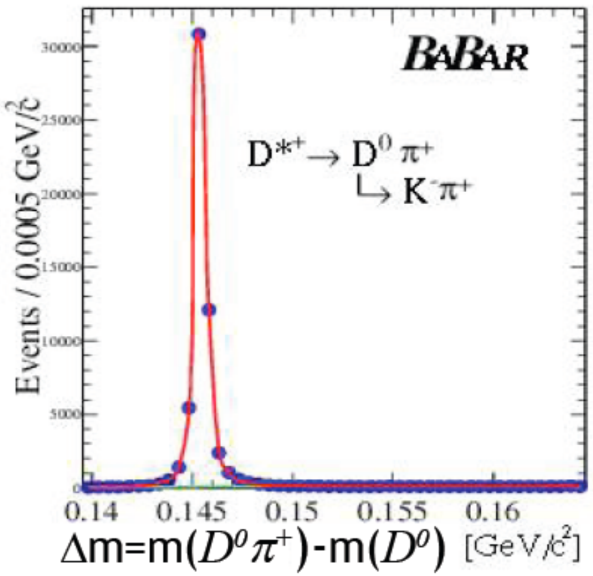
$$R_M \approx \frac{1}{2}(x^2 + y^2)$$

δ is the strong phase

$$y' = y\cos\delta - x\sin\delta$$
$$x' = y\cos\delta + x\sin\delta$$

Event Selection

$$Q = m(D^{*+}) - m(D^0) - m(\pi^+) \approx 6\,\mathrm{MeV}/c^2$$



Excellent background suppression

D^0 selection:

- Identified K and π
- $p^*(D^0)$> 2.5 GeV/c
- $1.81 < m(K\pi) < 1.92$ GeV/c²

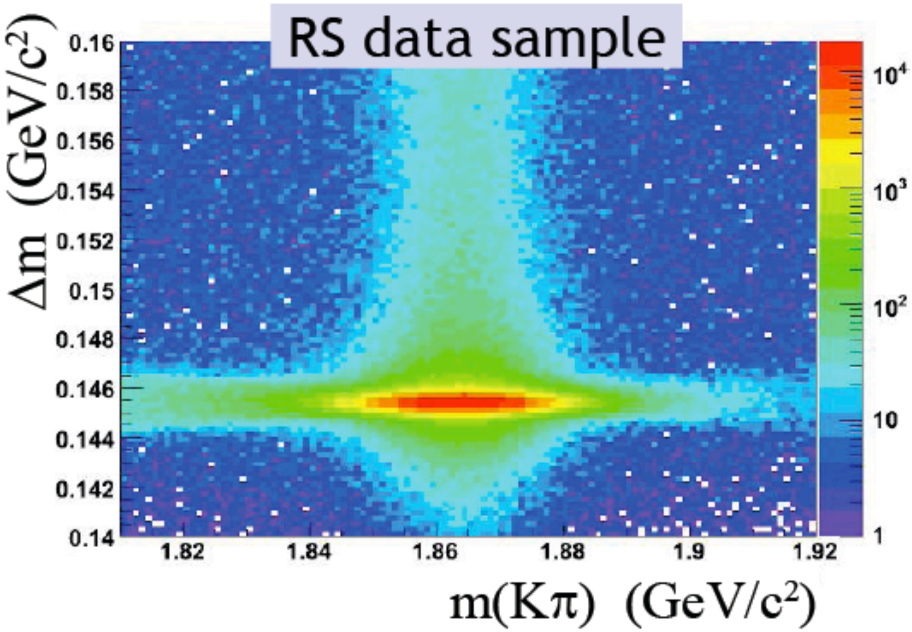
Slow π selection:

- $p^*(\pi_s)$< 0.45 GeV/c
- $p_{lab}(\pi_s)$> 0.1 GeV/c
- $0.14 < \Delta m < 0.16$ GeV/c²

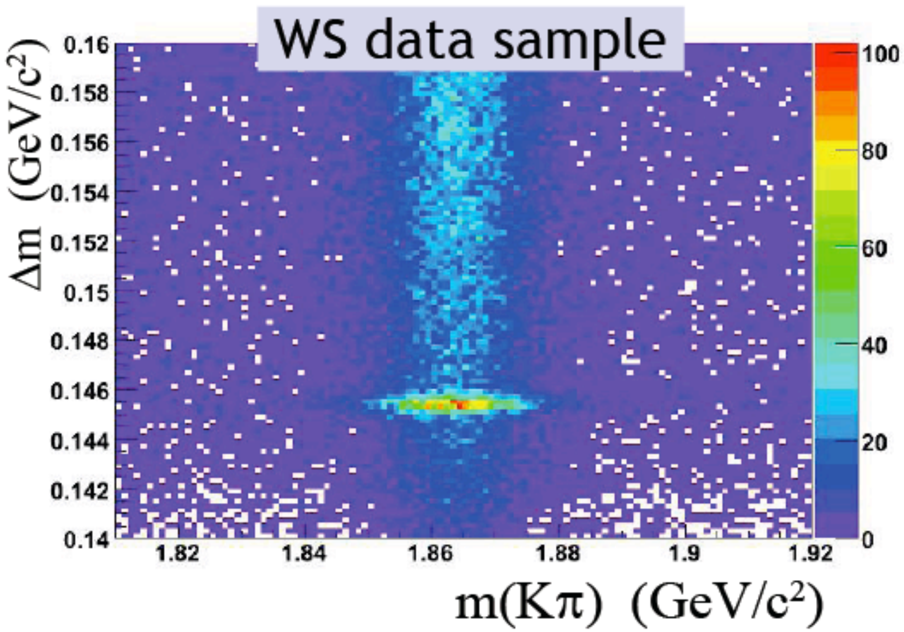
  $\Delta m = m(K\pi\pi_s) - m(K\pi)$

RS and WS data set

1,229,000 RS events



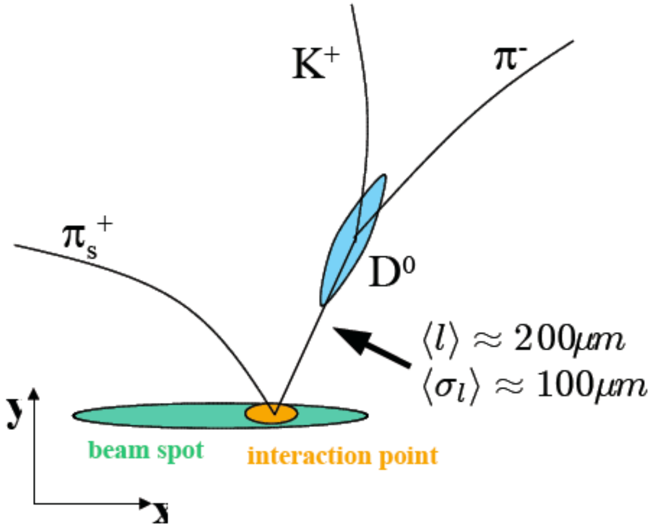
64,000 WS events



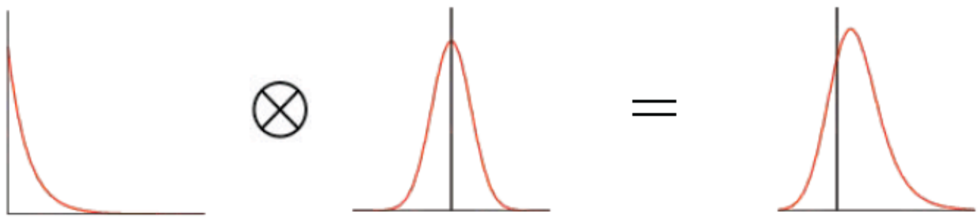
Fit to m(Kπ) and Δm distribution:

- RS and WS samples fit simultaneously
- Signal and some background parameters shared
- All parameters determined in fit to data, not MC

Decay time analysis



- D^0 and π_s constrained to luminous region
- Fit probability > 0.1%
- Reconstructed decay time, t: $-2<t<4$ ps
- Estimated decay time error, $\delta t<0.5$ ps



$$e^{-t/\tau} \otimes \frac{1}{\sqrt{2\pi}\sigma} e^{-t^2/2\sigma^2} = \frac{1}{\sqrt{2\pi}\sigma} \int_0^{\infty} e^{-t'/\tau} e^{-(t-t')^2/2\sigma^2} \, dt'$$

- Resolution function from RS sample

Background components

Random π_s:

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

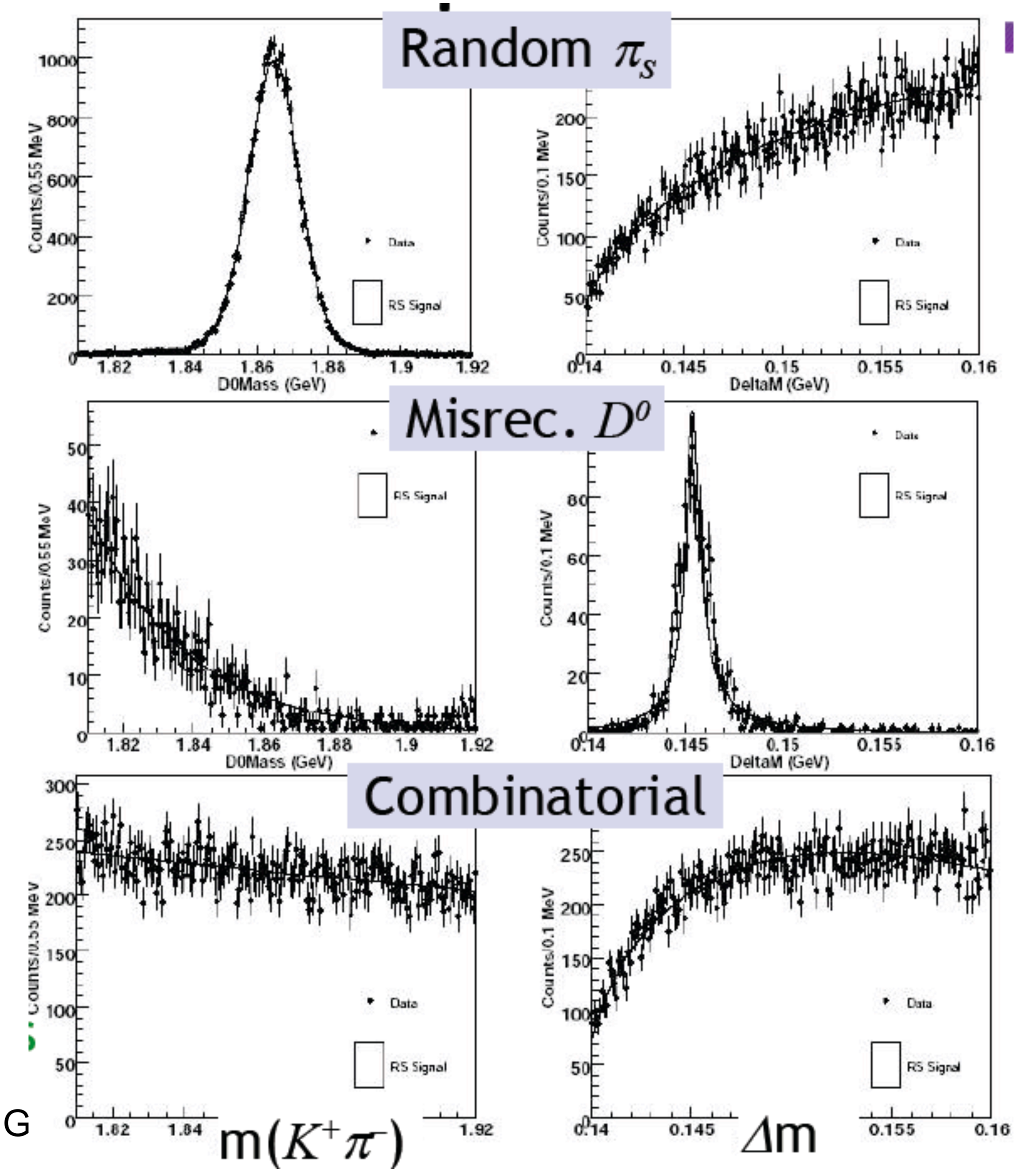
Misreconstructed D^0:

- Partially reco. D^0, $D^0 \rightarrow K^- \mu^+ \nu$
- Double misid $D^0 \rightarrow K^- \pi^+$ (WS events only)
- Peaks in Δm, not $m(K\pi)$

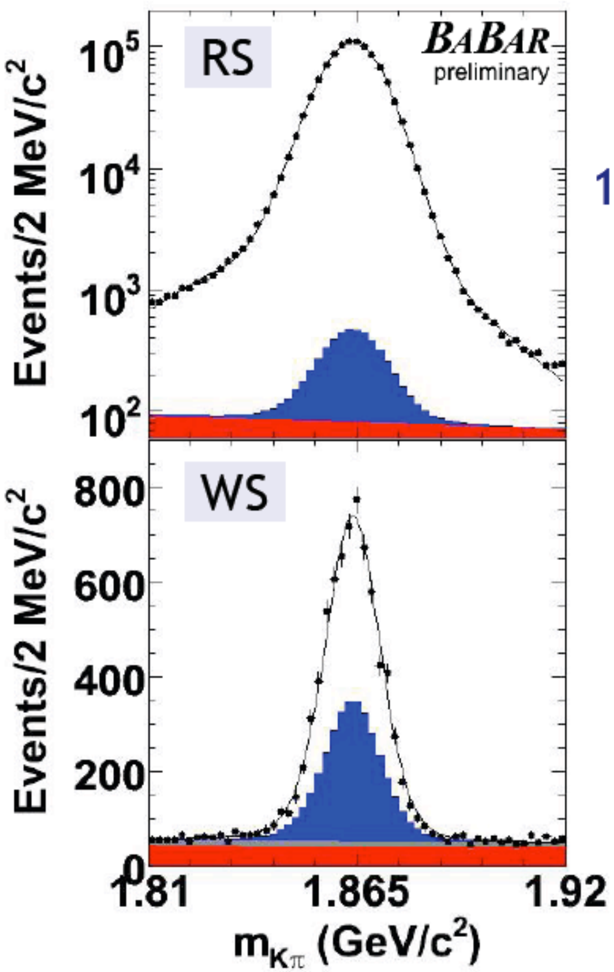
Combinatoric:

- Random tracks

Discrimination power from $m(K\pi)$ and Δm

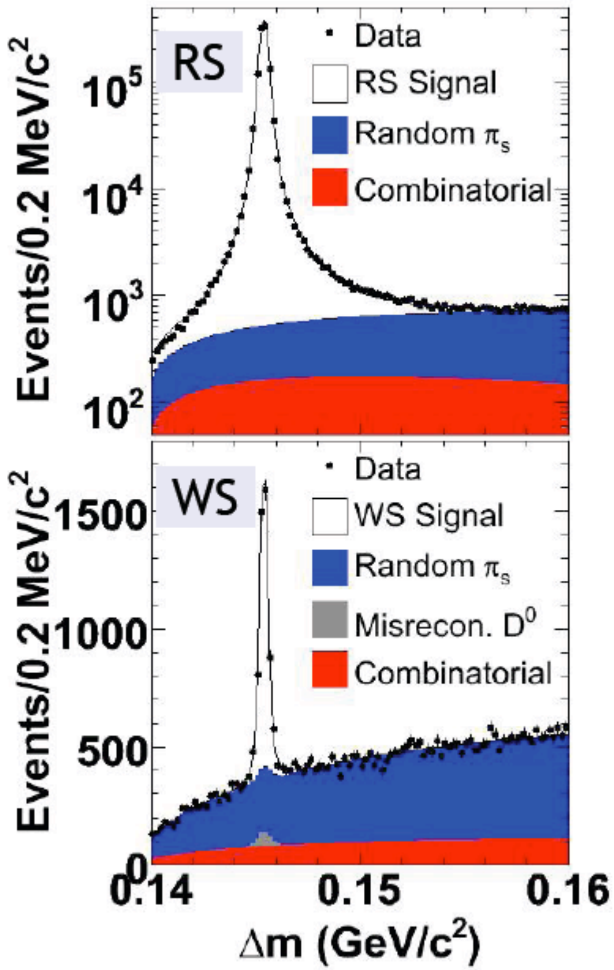


Signal extraction



RS signal:
1,141,500±1200 combinations

WS signal:
4,030±90 combinations



RS decay time analysis

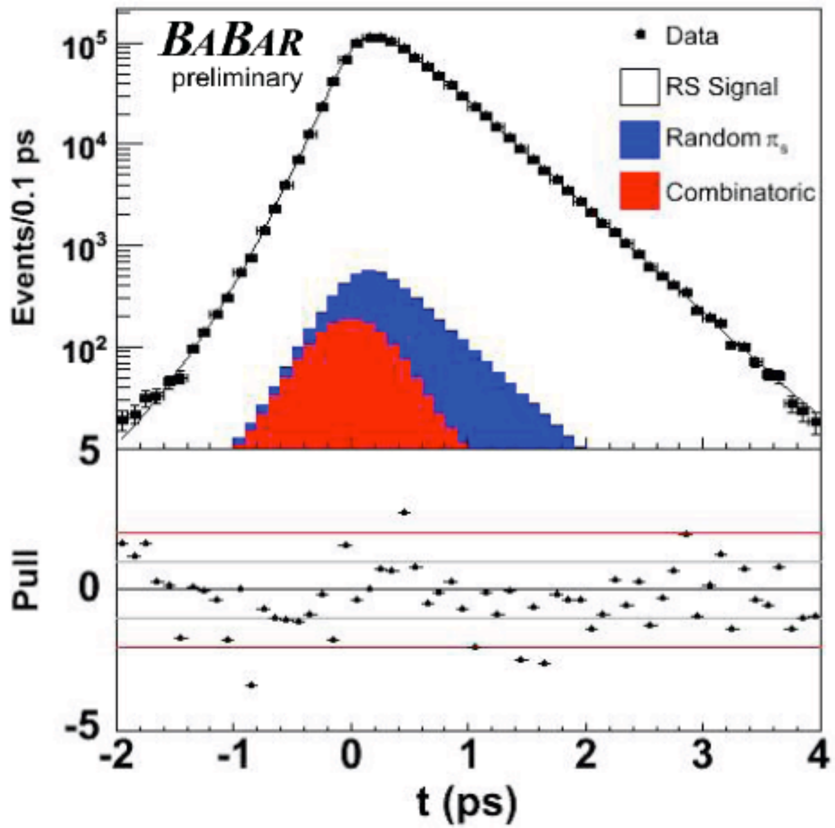
D^0 lifetime and
time resolution function
from RS sample

τ=(410.3±0.6(stat.)) fs

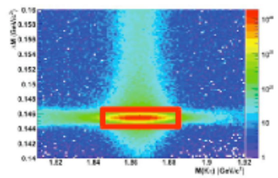
Consistent with PDG
(410.1±1.5 fs)

Systematics dominated
by resolution function

RS decay time, signal region

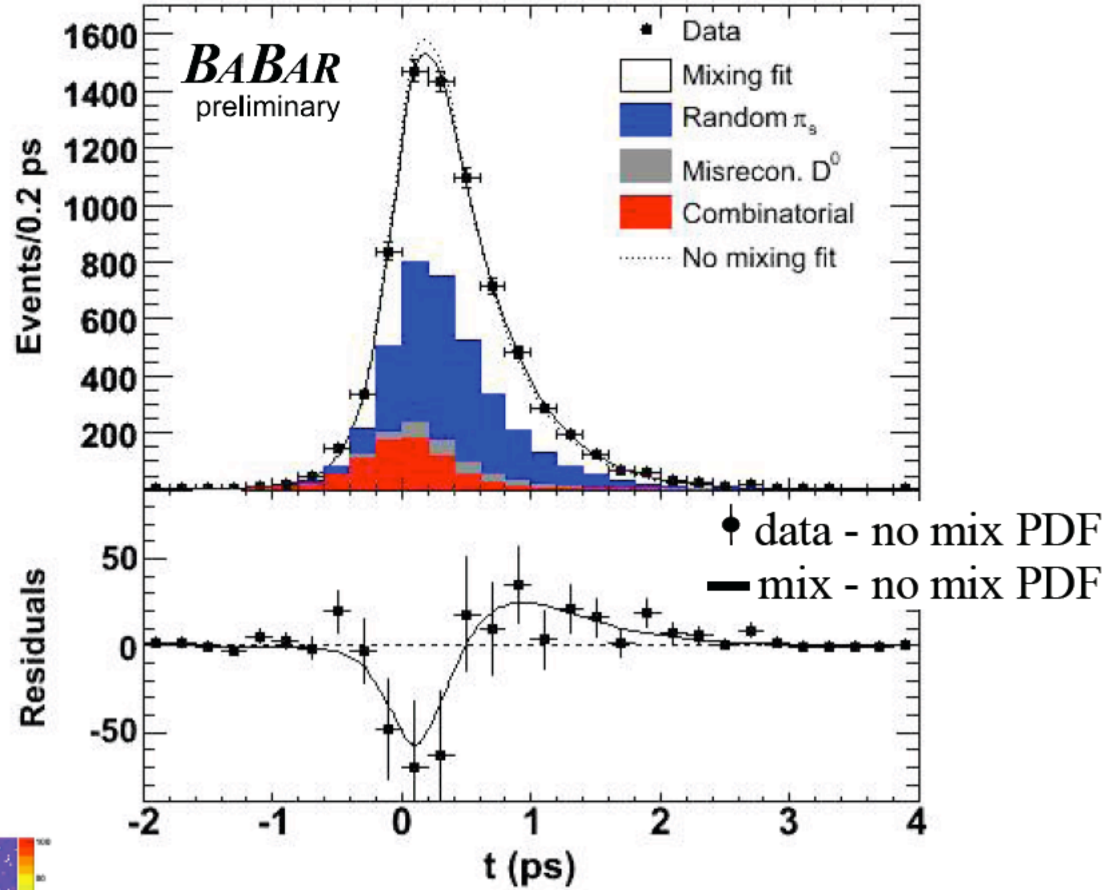


plot selection:
1.843<m<1.883 GeV/c^2
0.1445<Δm< 0.1465 GeV/c^2



WS decay time with mixing

WS decay time, signal region



Fit results allowing mixing:

R_D: $(3.03\pm0.16\pm0.10)\times10^{-3}$

x'^2: $(-0.22\pm0.30\pm0.21)\times10^{-3}$

y': $(9.7\pm4.4\pm3.1)\times10^{-3}$

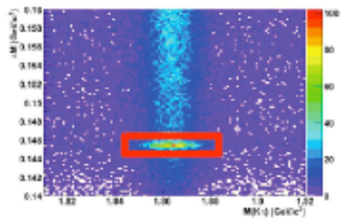
x'^2, y' correlation: -0.94

$$\chi^2/bin = 31/28$$

signal region:

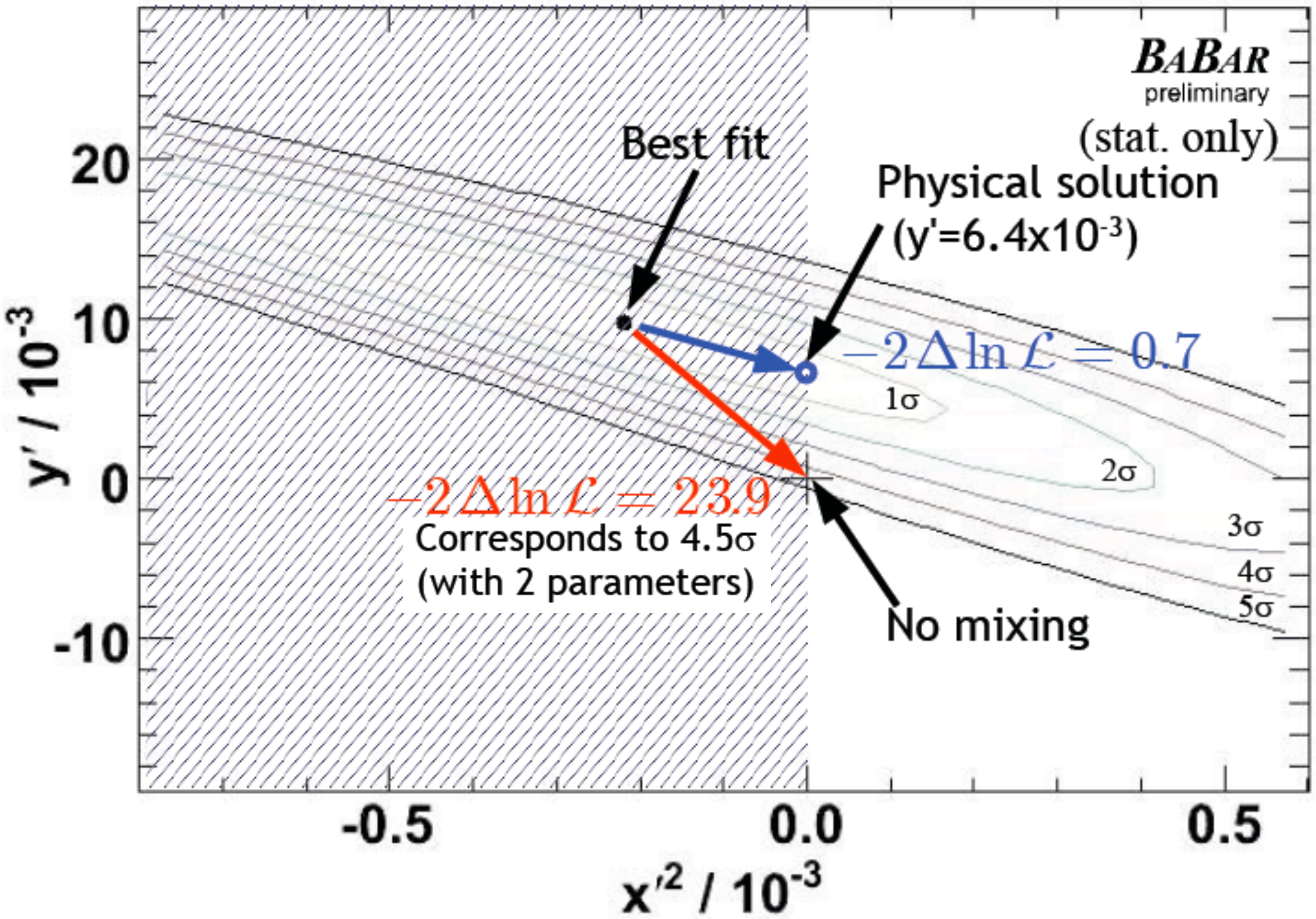
$1.843<m<1.883$ GeV/c²

$0.1445<\Delta m< 0.1465$ GeV/c²



Evidence for D^0 mixing!

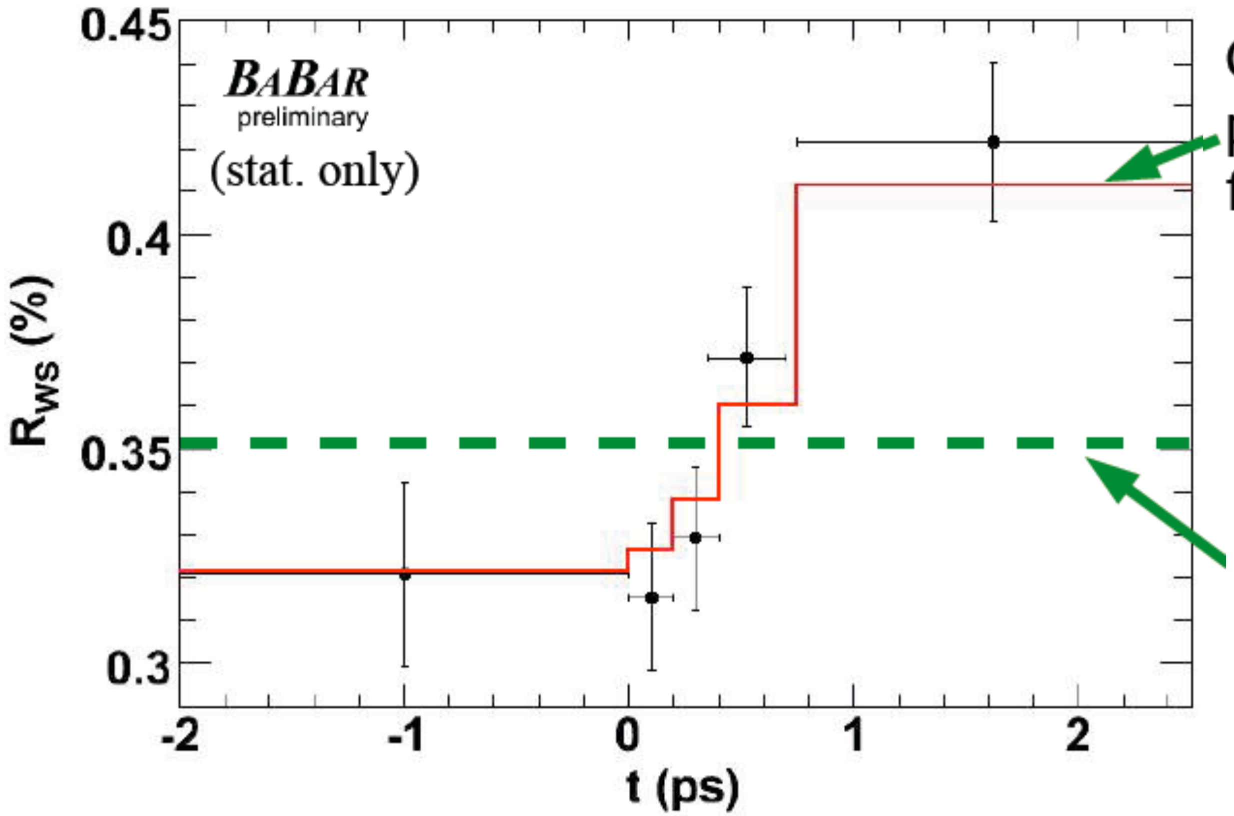
Best fit solution in unphysical region ($x'^2<0$)



Including systematics decreases signal significance 3.9 σ

Validation: *m(Kπ) and Δm* fit in t bins

- No assumptions made on time-evolution of background
- Each time bin is fit independently



Consistent with prediction from full likelihood fit

χ^2=1.5

no-mixing

Relative rate of WS events clearly increases with time

Validation: fit RS for mixing

Fit RS data with PDF allowing mixing

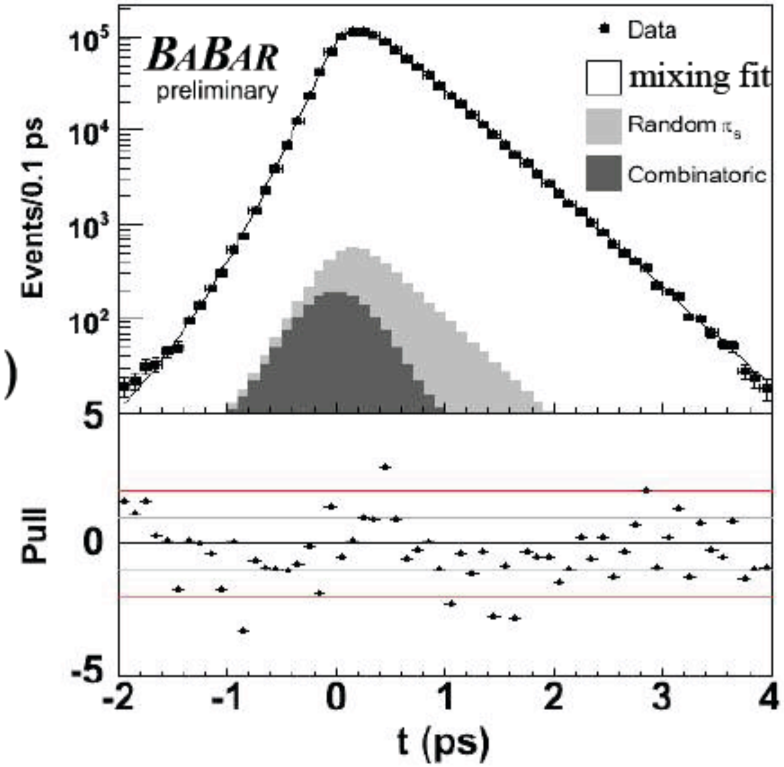
x'^2: $(-0.01\pm0.01)\times10^{-3}$

y': $(0.26\pm0.24)\times10^{-3}$

$-2\Delta\ln\mathcal{L} = 1.4$ (w.r.t. no mixing)

D^0 decay time distribution is described properly

RS decay time, signal region



Systematics uncertainty

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

Systematics on Decay time

Decay time resolution function in data has non-zero mean

Core Gaussian shifted 3.6±0.6fs

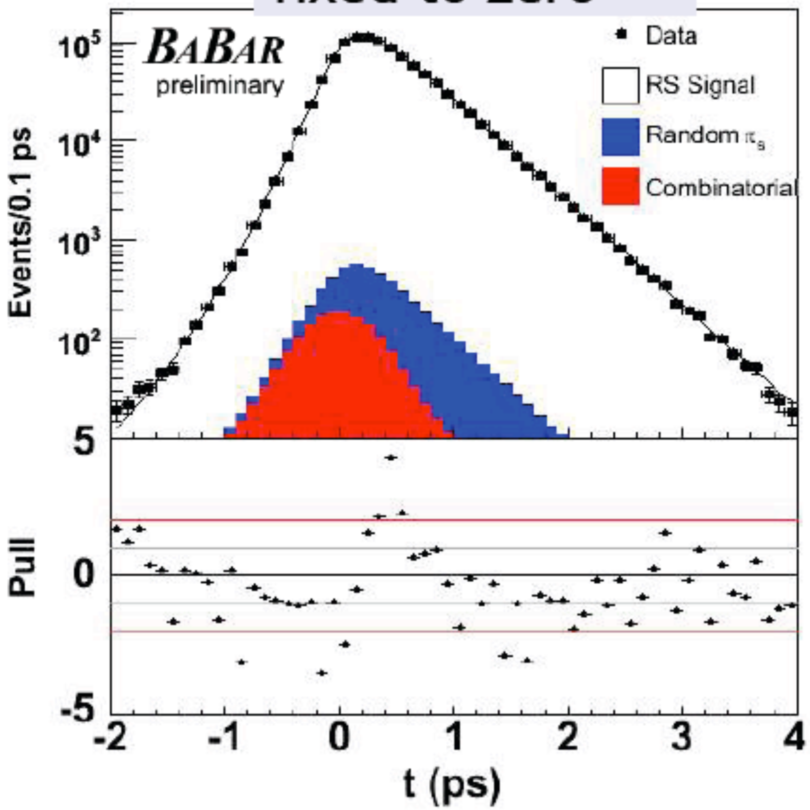
Effect is not seen in MC
- probably due to misalignment

For systematics set mean to 0:

Variation: y' 0.3σ ; x'^2 -0.3σ

No reason why resolution should be different for RS and WS decays

RS decay time, resolution mean fixed to zero



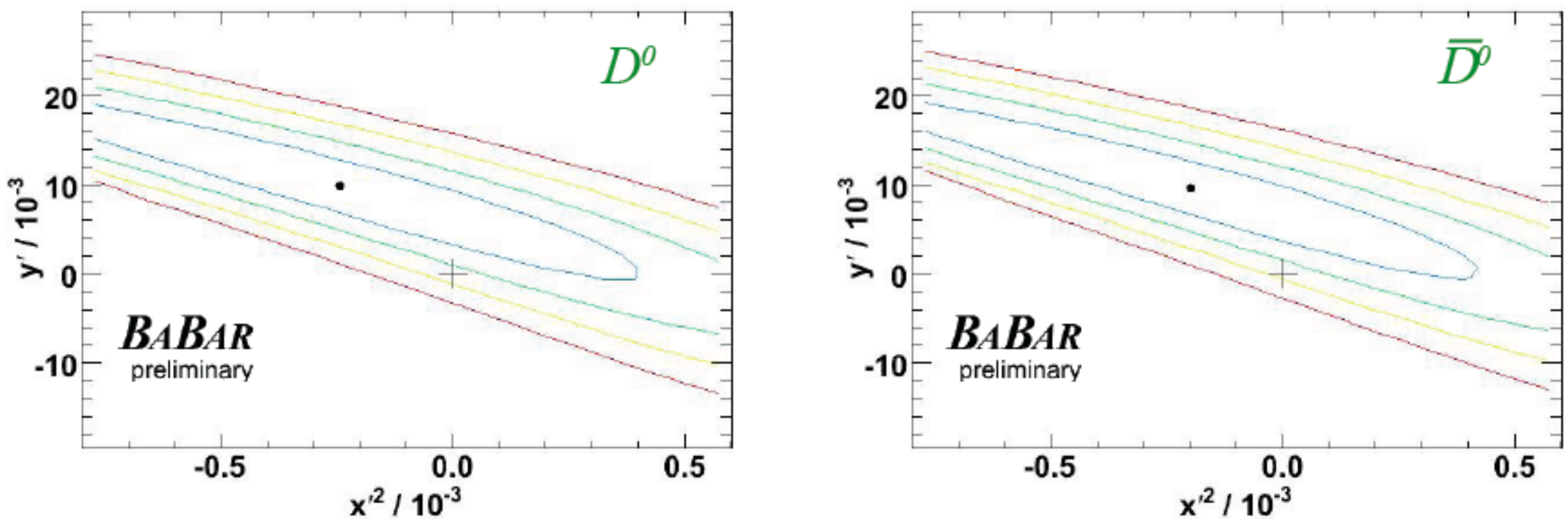
Allowing for CP violation

<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'^{-}: $(9.6\pm6.1\pm4.3)\times10^{-3}$

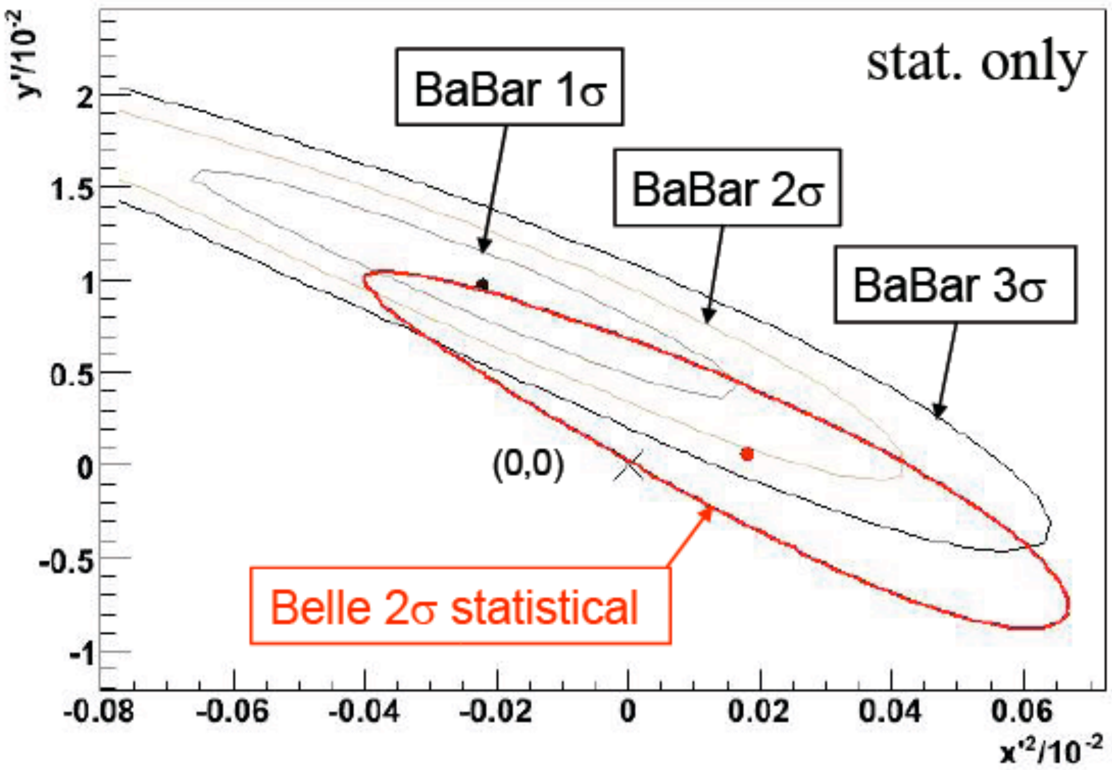
$A_D=(-2.1\pm5.2\pm1.5)\%$ CP violation in DCSD !



No evidence for CP violation found

Kπ analysis from Belle

Results consistent within 2σ:



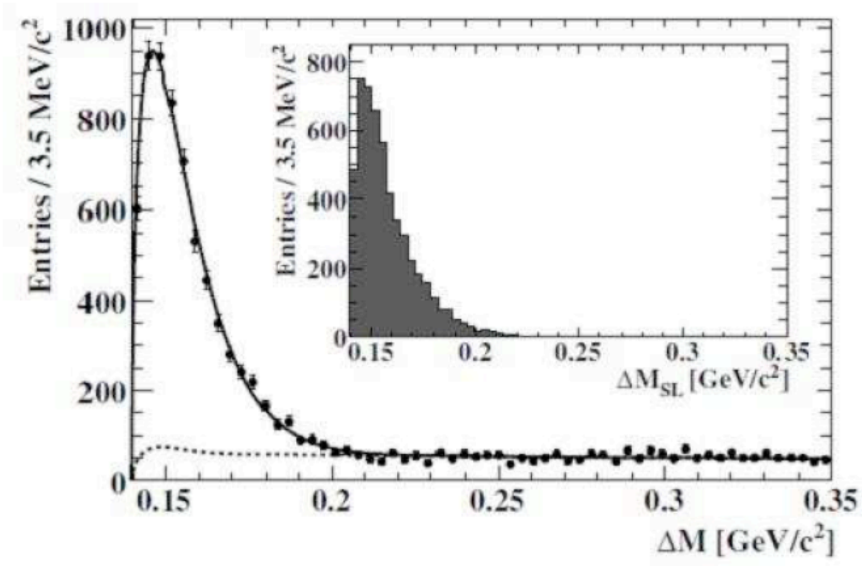
More evidence…!

D-mixing with Semileptonic decay

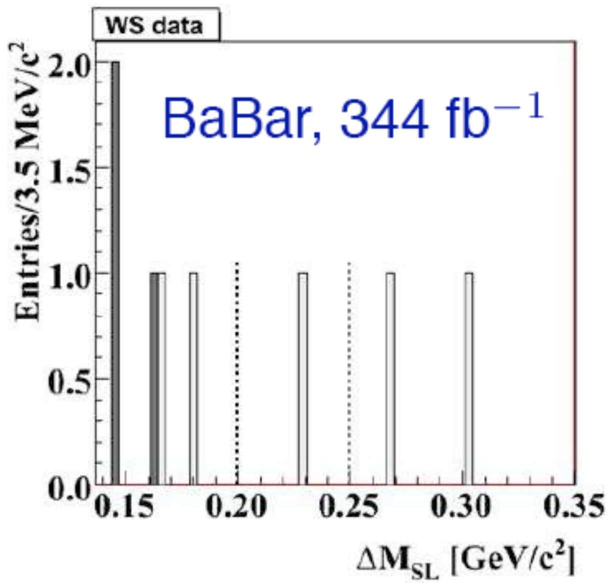
- No DCS sl. ! $A_f = \bar{A}_{\bar{f}} = 0$ $r(t) = \frac{e^{-t}}{4}(x^2+y^2)\,t^2\left|\frac{q}{p}\right|^2$

Double tag
$D^{*+} \to D^0\pi^+$, semil. and hadronic (fully rec.)
Several hadronic tagging modes

ΔM RS events



ΔM WS events



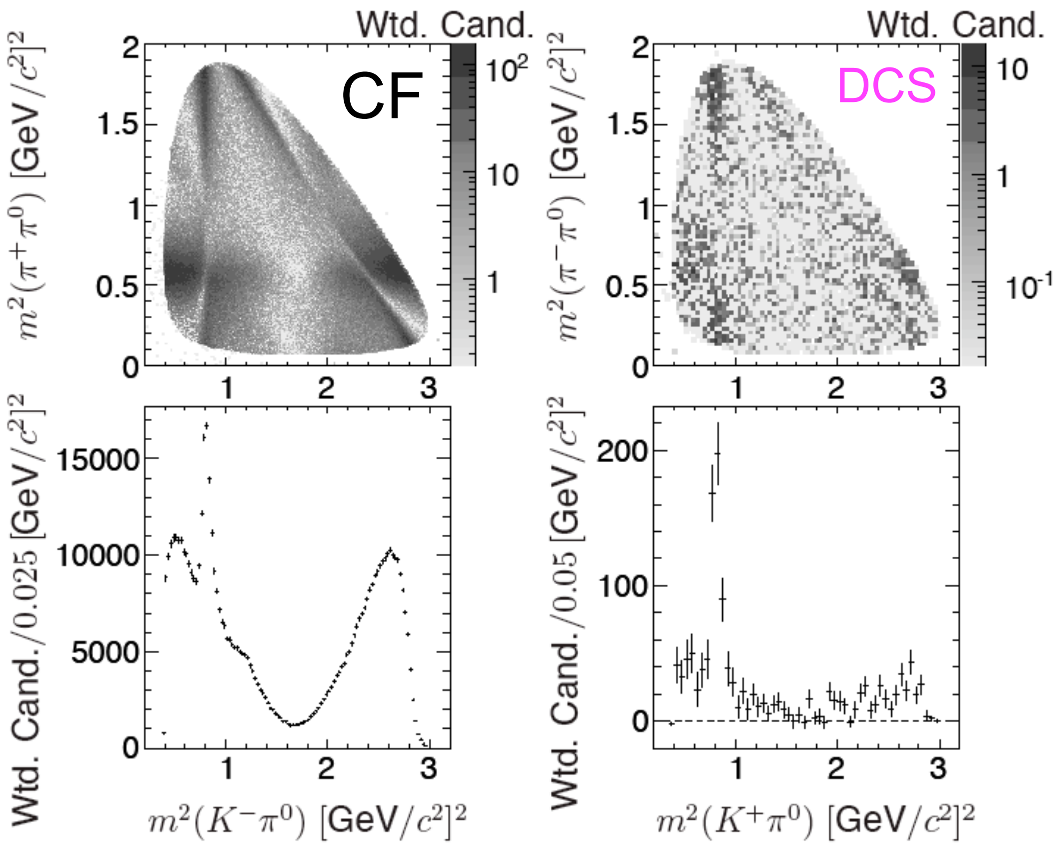
$$-1.3 \times 10^{-3} < R_M < 1.2 \times 10^{-3} \quad @\ 90\%\ C.L.$$

Separating x and y

- $K\pi$ only cannot separate x and y

Need info on **strong phases**

  - Multibody decays:Dalitz models



DCS decays proceed primarily through $K^{*+}\pi^-$ while CF through $K^-\rho^+$

$K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$

PRL 97, 221803 (2006)
hep-ex/0607090

Select special region of Dalitz plot

$$\frac{dN}{dt} \propto [\widetilde{R}_D + \alpha \widetilde{y}' \sqrt{\widetilde{R}_D}(\Gamma t) + \frac{\widetilde{x}'^2 + \widetilde{y}'^2}{4}(\Gamma t)^2] e^{-\Gamma t}, \quad 0 \le \alpha \le 1$$

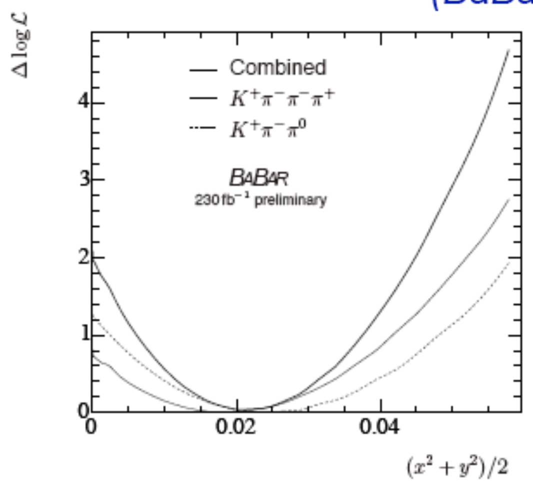
$$\widetilde{x}' = x \cos\widetilde{\delta} + y \sin\widetilde{\delta}$$
$$\widetilde{y}' = y \cos\widetilde{\delta} - x \sin\widetilde{\delta}$$

Effective phase

Mixing rate

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

(BaBar, 230 fb^{-1})



Results

- Assuming CP conservation
- Upper limits (95% C.L.)

$K\pi\pi^0$	$R_M < 0.054\%$
$K3\pi$	$R_M < 0.048\%$

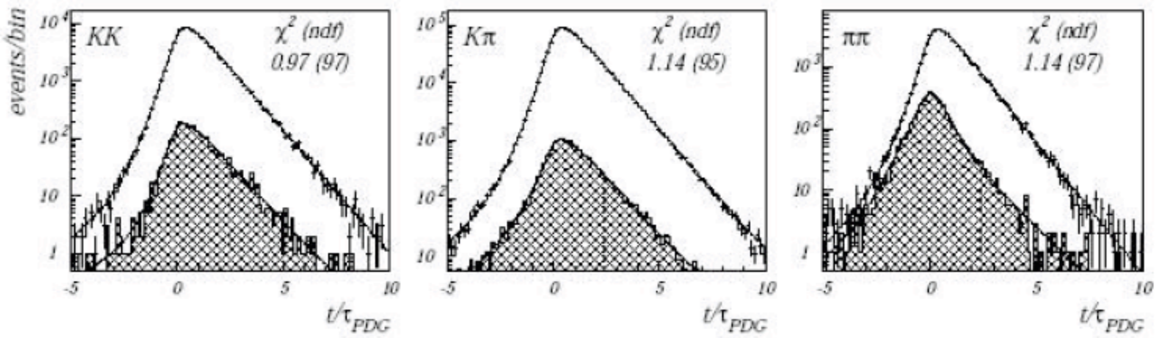
Combined result $R_M < 0.42 \times 10^{-3}$ @ 95% $C.L.$

y_{CP}

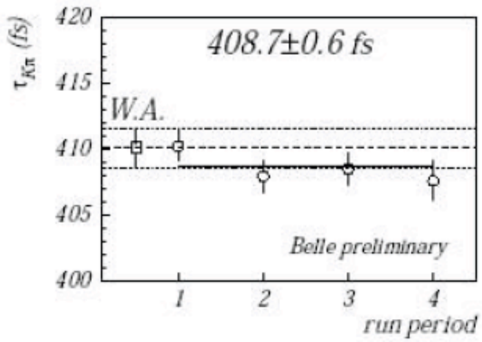
- Measurement of lifetime difference between $D^0 \to K^-\pi^+$ and $K^+K^-, \pi^+\pi^-$
  - ▹ mixing parameter: $y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1$
  - ▹ in CP conservation limit: $y_{CP} = y = \Delta\Gamma/\Gamma$
- If CP not conserved, difference in lifetimes of $D^0/\bar{D}^0 \to K^+K^-, \pi^+\pi^-$
  - ▹ CP violating parameter: $A_\Gamma = \frac{\hat{\Gamma}(D^0 \to KK) - \hat{\Gamma}(\bar{D}^0 \to KK)}{\hat{\Gamma}(D^0 \to KK) + \hat{\Gamma}(\bar{D}^0 \to KK)}$

Simultaneous $KK/\pi\pi/K\pi$ binned likelihood fit

quality of fit: $\tilde{\chi}^2 = 1.084$ (289)



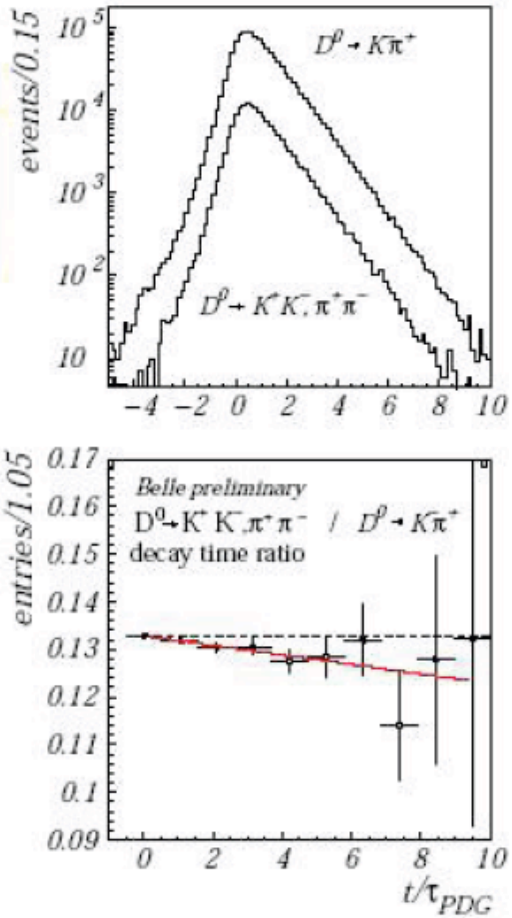
$D^0 \to K\pi$ lifetime very stable in slightly different running periods



Results on y_{CP}

Results (preliminary)

	y_{CP} (%)	A_Γ (%)
KK	1.25±0.39±0.28	0.15±0.34±0.16
$\pi\pi$	1.44±0.57±0.42	-0.28±0.52±0.30
$KK+\pi\pi$	1.31±0.32±0.25	0.01±0.30±0.15



Belle preliminary (540 fb^{-1})

$$y_{CP} = 1.31 \pm 0.32 \pm 0.25\ \%$$

$> 3\sigma$ above zero

(4.1σ stat. only)

first evidence for $D^0 - \bar{D}^0$ mixing

$$A_\Gamma = 0.01 \pm 0.30 \pm 0.15\ \%$$

no evidence for CP violation

$D^0 \rightarrow K_S \pi^+ \pi^-$

$$M(m_-^2, m_+^2, t) = A(m_-^2, m_+^2)\frac{e_1(t)+e_2(t)}{2} + A(m_+^2, m_-^2)\frac{e_1(t)-e_2(t)}{2}$$

where $m_\pm$ is defined with the D^* tag

$$m_\pm = \begin{cases} m(K_s, \pi^\pm) & D^{*+} \rightarrow D^0\pi^+ \\ m(K_s, \pi^\mp) & D^{*-} \rightarrow \bar{D}^0\pi^- \end{cases}$$

and time dependent functions with

$$e_{1,2}(t) = e^{-i(m_{1,2} - i\Gamma_{1,2}/2)t}$$

$|M(m_-^2, m_+^2, t)|^2$ thus includes x and y

The only measurement sensitive directly to x

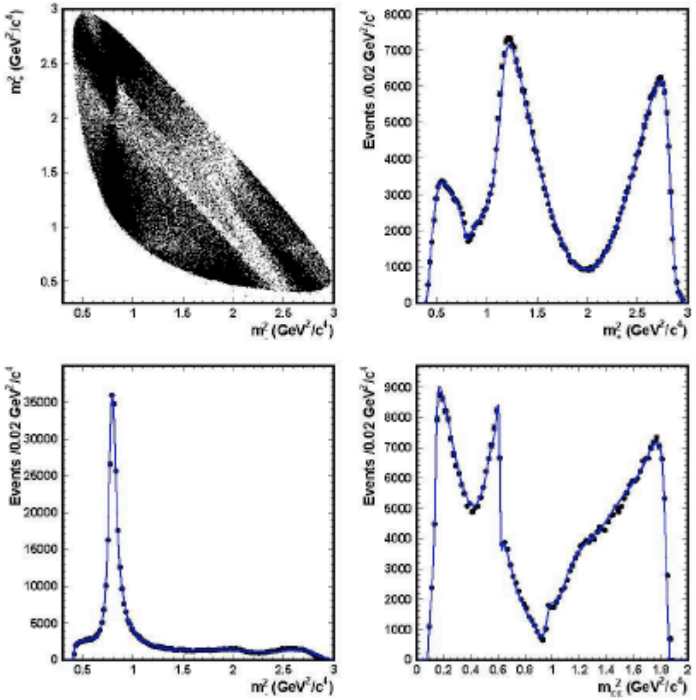
Both flavour ($K^{*-}\pi^+/K^{*+}\pi^-$) final states in the same Dalitz plot!

CP-eigenstate (ρK_S) and flavour states ($K^{*-}\pi^+$) in the same Dalitz plot!

$D^0 \to K_S\pi^+\pi^-$ Dalitz model

Belle, 540 fb^{-1}

Dalitz fit

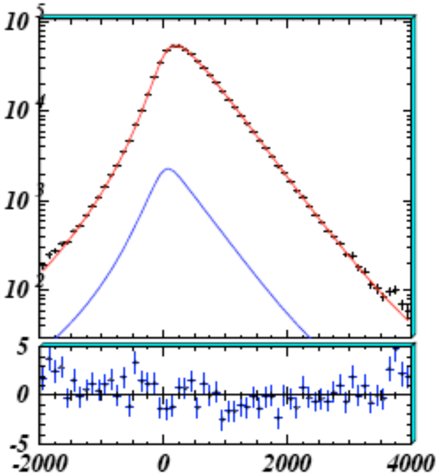


Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.629 ± 0.005	134.3 ± 0.3	0.6227
$K_0^*(1430)^-$	2.12 ± 0.02	-0.9 ± 0.5	0.0724
$K_2^*(1430)^-$	0.87 ± 0.01	-47.3 ± 0.7	0.0133
$K^*(1410)^-$	0.65 ± 0.02	111 ± 2	0.0048
$K^*(1680)^-$	0.60 ± 0.05	147 ± 5	0.0002
$K^*(892)^+$	0.152 ± 0.003	-37.5 ± 1.1	0.0054
$K_0^*(1430)^+$	0.541 ± 0.013	91.8 ± 1.5	0.0047
$K_2^*(1430)^+$	0.276 ± 0.010	-106 ± 3	0.0013
$K^*(1410)^+$	0.333 ± 0.016	-102 ± 2	0.0013
$K^*(1680)^+$	0.73 ± 0.10	103 ± 6	0.0004
$\rho(770)$	1 (fixed)	0 (fixed)	0.2111
$\omega(782)$	0.0380 ± 0.0006	115.1 ± 0.9	0.0063
$f_0(980)$	0.380 ± 0.002	-147.1 ± 0.9	0.0452
$f_0(1370)$	1.46 ± 0.04	98.6 ± 1.4	0.0162
$f_2(1270)$	1.43 ± 0.02	-13.6 ± 1.1	0.0180
$\rho(1450)$	0.72 ± 0.02	40.9 ± 1.9	0.0024
σ_1	1.387 ± 0.018	-147 ± 1	0.0914
σ_2	0.267 ± 0.009	-157 ± 3	0.0088
NR	2.36 ± 0.05	155 ± 2	0.0615

- Dalitz model: 13 different (BW) resonances and a non-resonant contribution
- Results with this refined model consistent with the analysis performed for the Belle ϕ_3 measurement, PRD73, 112009 (2006)
- To test the scalar $\pi\pi$ contributions, K-matrix formalism is also used

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

Time fit (in projection)



Results (preliminary)

$$x = 0.80 \pm 0.29 \pm 0.17\ \%$$

$$y = 0.33 \pm 0.24 \pm 0.15\ \%$$

most stringent limits on x up to now

Cleo, PRD 72, 012001 (2005):

$$x = 1.8 \pm 3.4 \pm 0.6\%$$

$$y = -1.4 \pm 2.5 \pm 0.9\%$$

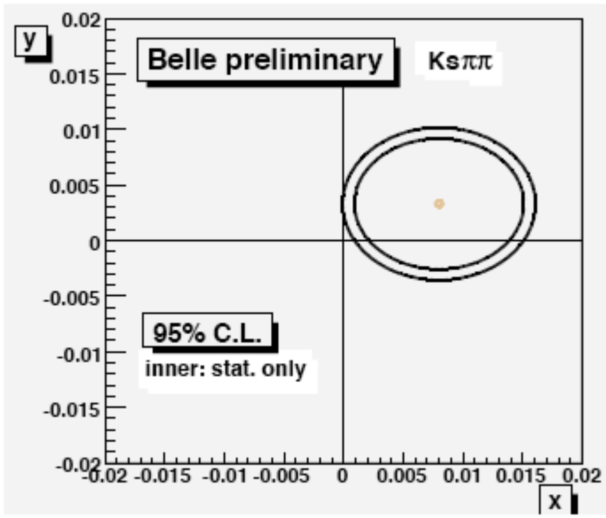
Systematics

Largest contributions ($\times 10^{-4}$)

x	y	
$^{+14.6}_{-13.6}$	$^{+7.8}_{-8.8}$	Model dependence
$^{+8.5}_{-6.8}$	$^{+6.6}_{-11.6}$	Time fit

Total ($\times 10^{-4}$)

x	y
$^{+16.9}_{-15.2}$	$^{+10.2}_{-14.6}$



Summary and Outlook

Summary

BaBar studied $D^0 \to K\pi$ decay

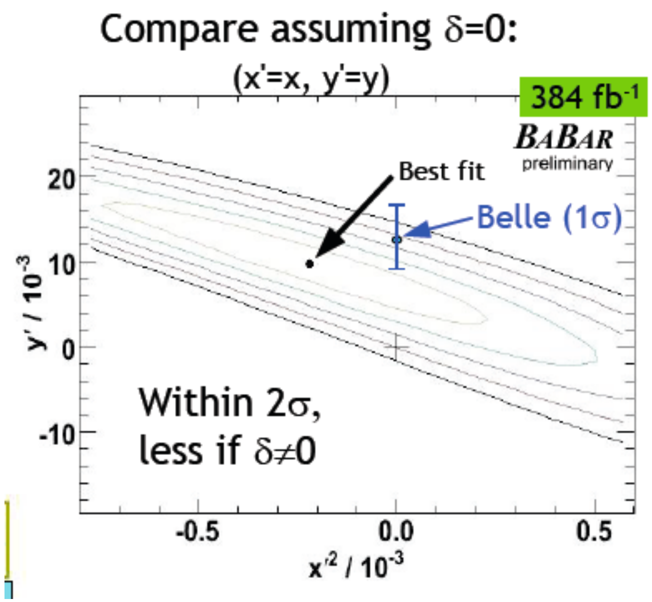
- Evidence for mixing (3.9σ)
- No sign of CP violation
- Consistent with other measurements and SM

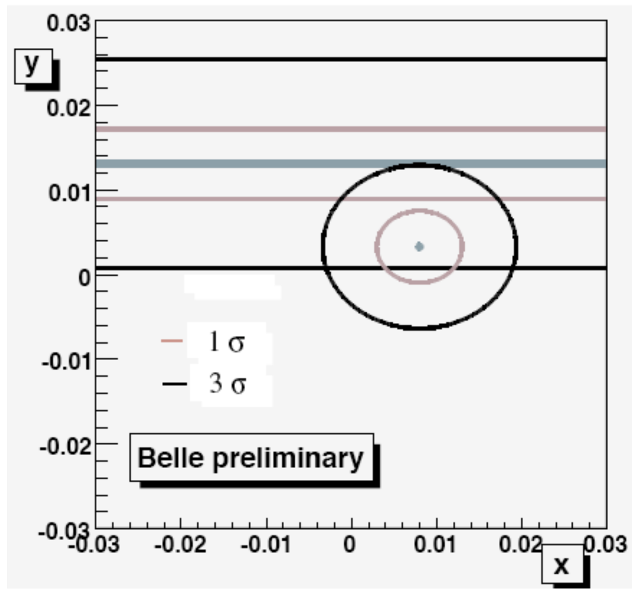
New results from Belle

- Evidence for mixing (3.2σ)
- Measures x and y directly
- No sign of CP violation

$$x = 0.80 \pm 0.29 \pm 0.17\ \%\ (2.4\sigma)$$

- More statistics needed





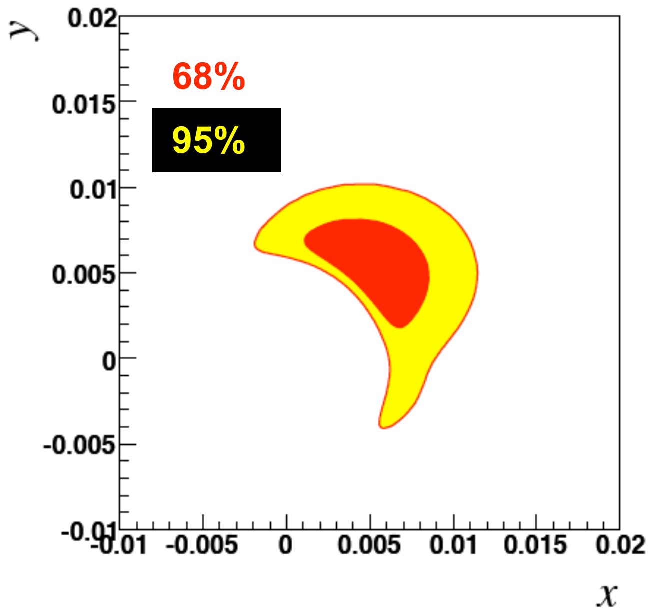
Interpreting the results

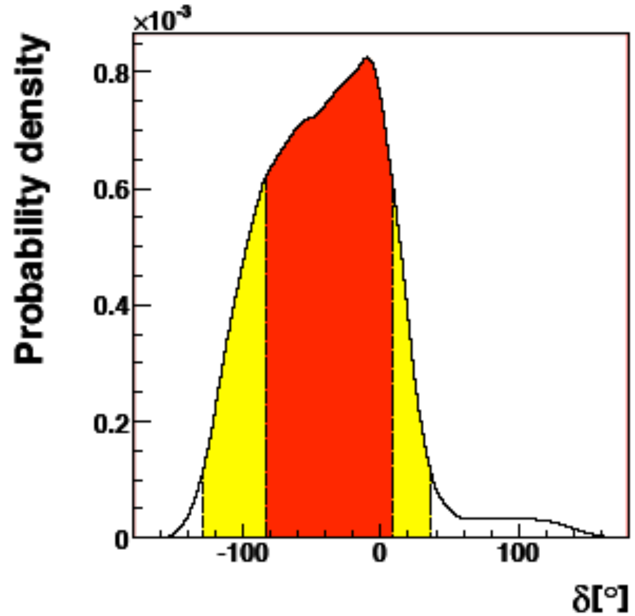
D⁰ and D̄⁰ ↓ — weak phase $2\phi_D$ of the mixing amplitude

Ciuchini et al.
hep-ph/0703294

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

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





Measuring δ

To beat down the model systematics measure phases directly

- Correlated D production - DD → $f_1 f_2$

$$|\psi(3770)\rangle \rightarrow |D\overline{D}\rangle_L = \frac{1}{\sqrt{2}}\left[|D^0(k_1)\overline{D^0}(k_2)\rangle + (-1)^L |D(k_2)\overline{D^o}(k_1)\rangle\right]$$

- For L=1 DCS contribution to $f_1=f_2=K^-\pi^+$ cancels
- Of course no DCS semileptonic amplitude

$$R_M \approx \frac{(K^-\pi^+)^2}{(K^-\pi^+)(K^+\pi^-)} \qquad R_M = \frac{(K^-\ell^+\nu)^2}{(K^-\ell^+\nu)(K^+\ell^-\overline{\nu})}$$

- 0.75 fb^{-1} ~1.6K $K^-\pi^+$, ~6.5K K^-l^+v double tags

$$\Rightarrow \quad \sqrt{2R_M} < 4\% @ 95\% C.L.$$

- Note CF vs CF indistinguishable from DCS vs DCS
  - Amplitudes interfere
  - correction factor $\left(1+2\sqrt{R_D}\cos\delta + R_D\right) \sim 1+0.12+0.0036$

Double tag at $\psi(3770)$ [CLEO-c]

$D_{CP\pm}$

neutral D CP eigenstate

$\psi(3770)$ decay conserves CP

Need to run On threshold

- Reconstruct Double Tags: CP vs $K\pi$
- Asymmetry in CP+ vs CP- related to $\cos\delta$

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

- R_D is ratio of DCS to Cabibbo favored rates

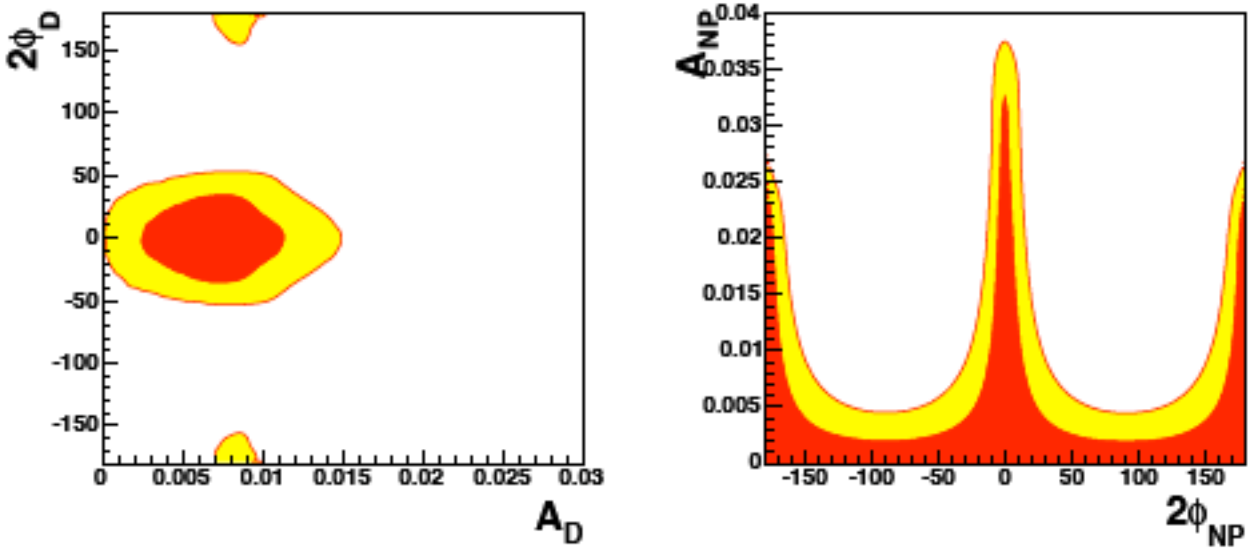
$$\cos\delta = \frac{A}{2\sqrt{R_D}}$$

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

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

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**!

Back up slides

Fit signal MC events

Performed extensive checks of mixing signal:

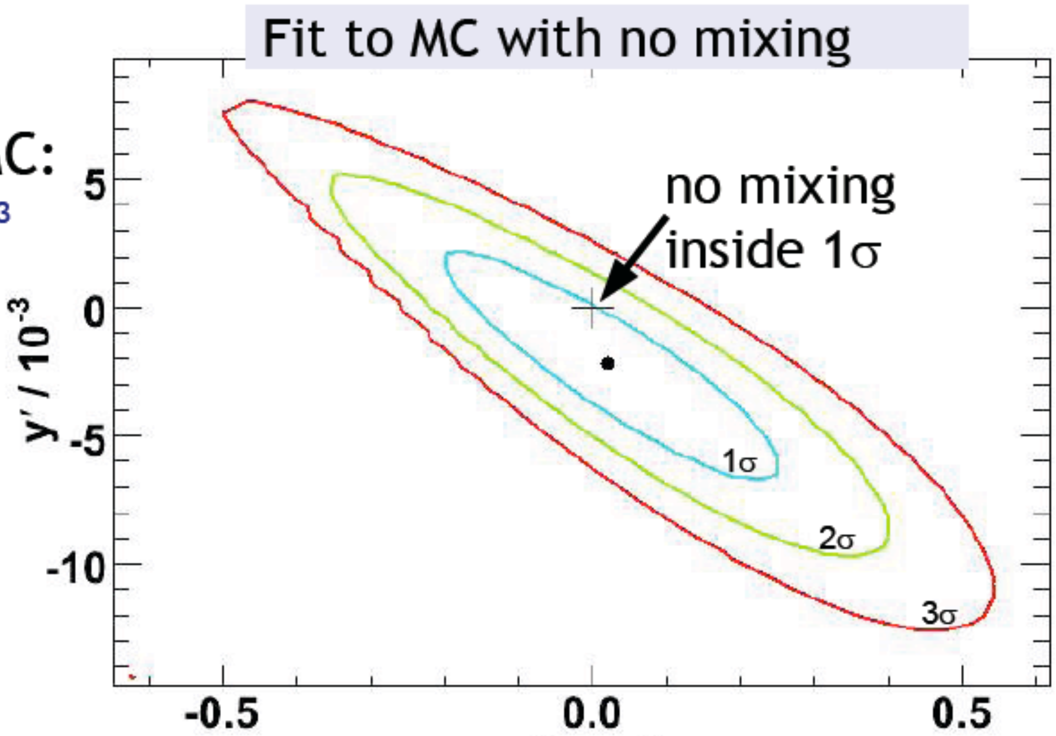
- Could something fake signal?
- Is significance estimated correctly?
- Are mixing parameters unbiased?

No signal found in MC:

x'^2: $(-0.02 \pm 0.18) \times 10^{-3}$

y': $(-2.2 \pm 3.0) \times 10^{-3}$

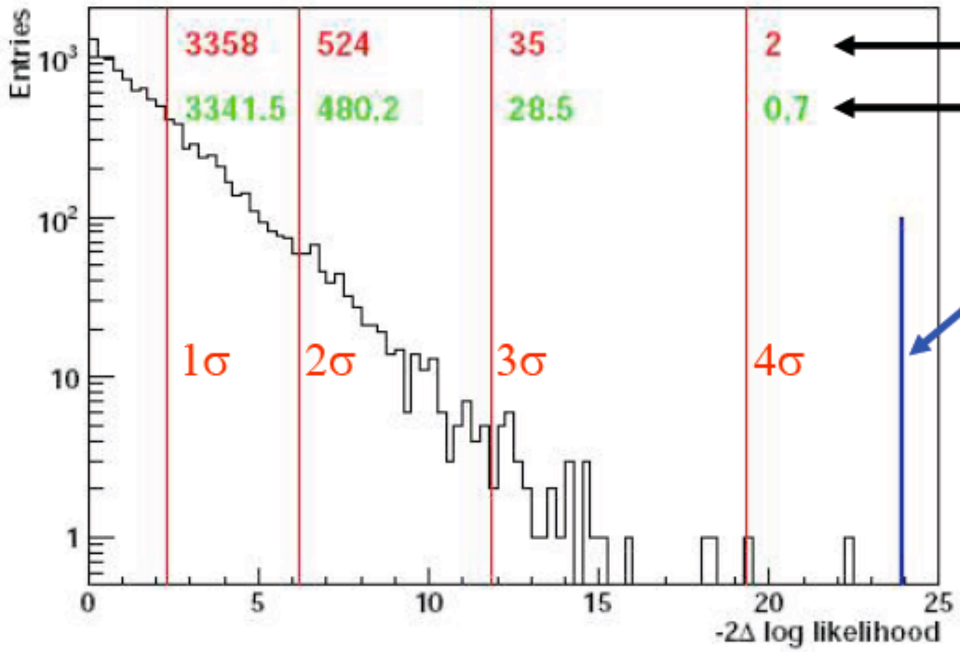
In MC with signal,
fit reproduces signal
- no intrinsic bias



Coverage test

Significance of signal is calculated as change in log likelihood with respect to no-mixing hypothesis

Generated >10000 toys without mixing to test $-2\Delta\ln\mathcal{L}$ gives correct frequentist coverage



#toys to the right of line

#toys expected

$-2\Delta\ln\mathcal{L} = 23.9$ observed in data