Oscillazioni del mesone D^0

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Outline

- Neutral mesons flavor oscillation
- Charm meson mixing
- Evidence from B-factories
  - $D^0 \to K^- \pi^+$
  - $D^0 \to K^- l^+ \nu_l$, $D^0 \to K_s \pi^+ \pi^-$, $D^0 \to K^+ K^- / \pi^+ \pi^-$
- 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 flavor at t=0***

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

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

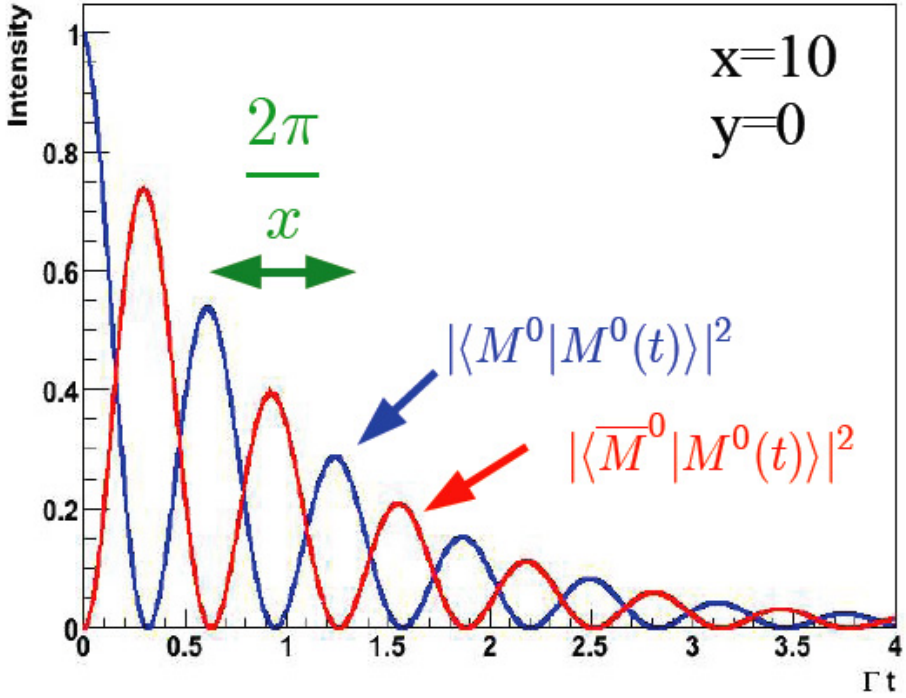
Where $\Delta\gamma = (y + ix)\Gamma \qquad \bar{\gamma} = (\Gamma_1 + \Gamma_2)/2 - i(m_1 + m_2)$

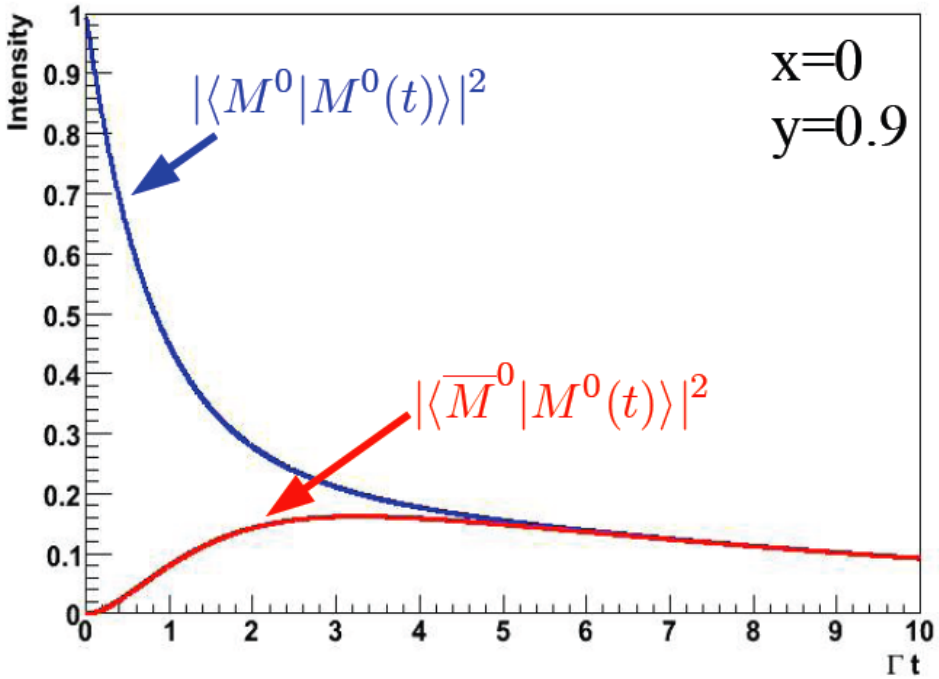
M^0 "oscillates" into $\overline{M}^0$!
(also dubbed "mixing")

An opposite flavor component appears after a while!

Some visual examples

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

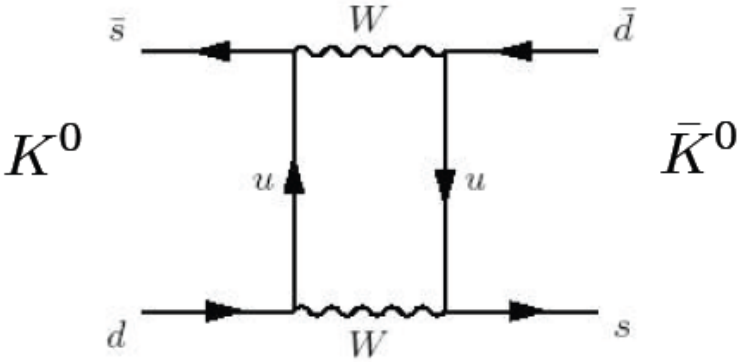




Lifetime units

How to generate this ??

Mixing through box diagram:



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

Glashow, Iliopoulus and Maiani (1970):

FCNC calculated from single quark loop still too large

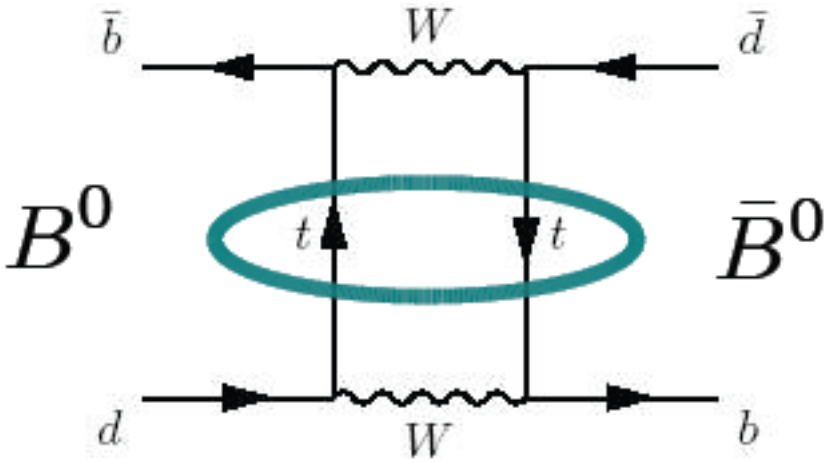
Introduce additional loop with new c quark

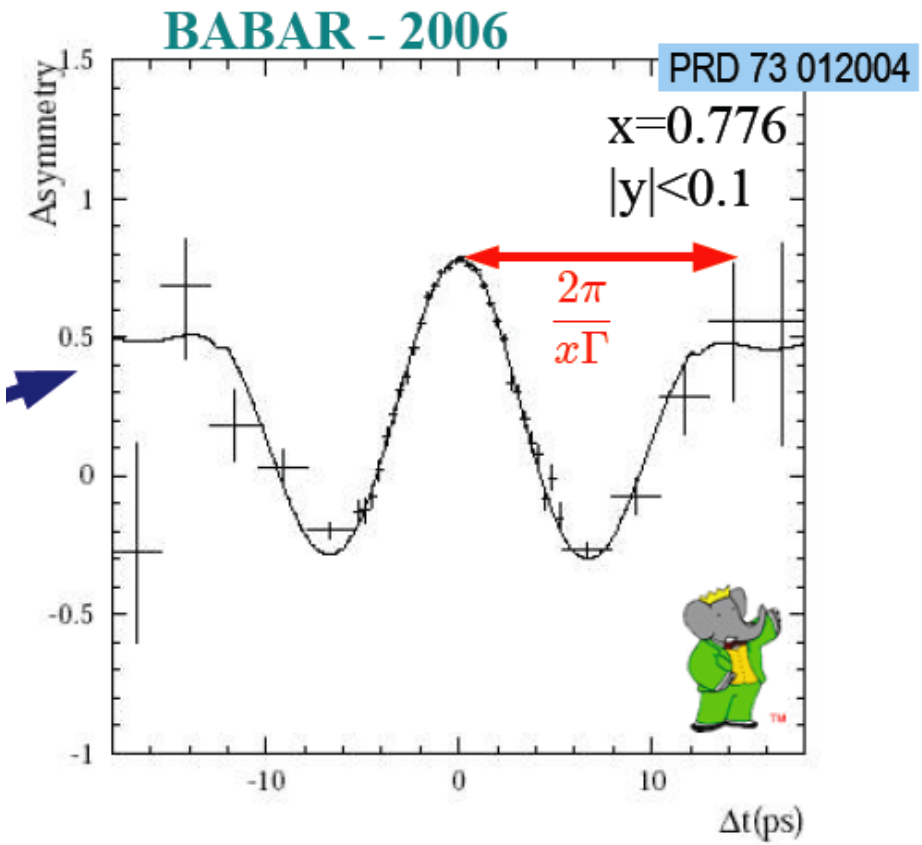
GIM predicted charm quark 4 years before observation

Can you see New Physics ?

B^0 mixing was argued by UA1 and directly observed by ARGUS in 1987

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





And the top was discovered 8 years after!

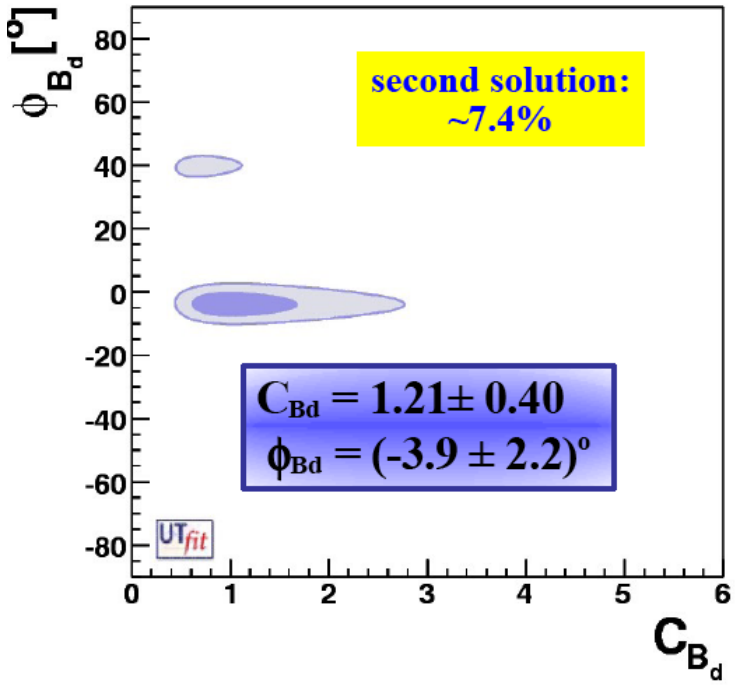
Even more ambitious today!

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

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

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

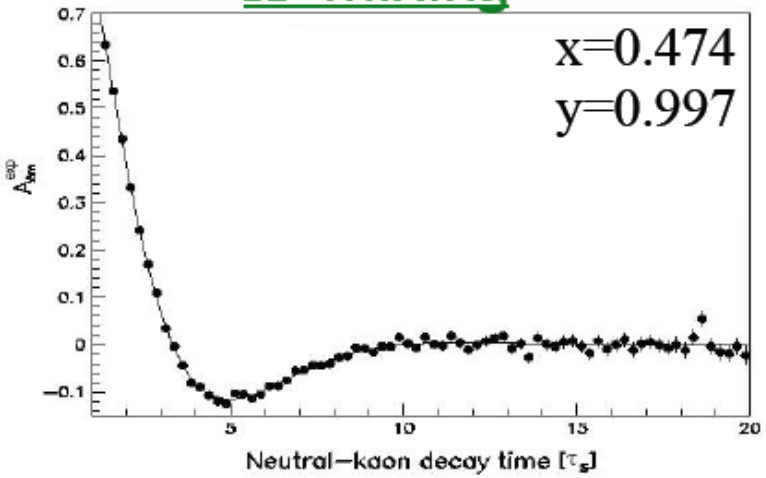
$$C_{\epsilon_K} = \frac{\Im[\langle K^0 | H_{eff}^{full} | \overline{K}^0 \rangle]}{\Im[\langle K^0 | H_{eff}^{SM} | \overline{K}^0 \rangle]}$$



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

The missing tile

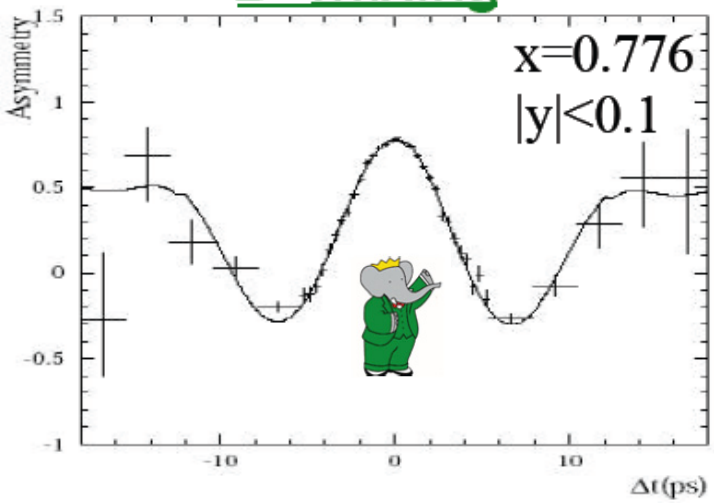
K^0 mixing



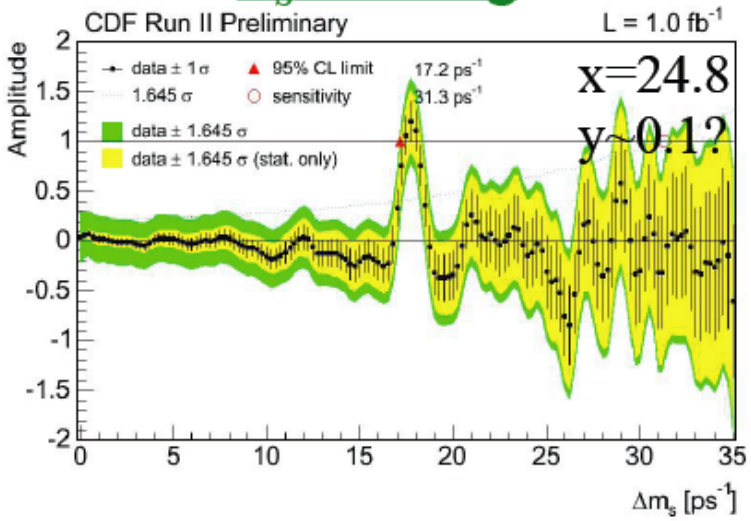
D^0 mixing

?

B^0 mixing



B_s^0 mixing



Charm Meson Mixing

Short and **Long** distance

- Prediction x and y

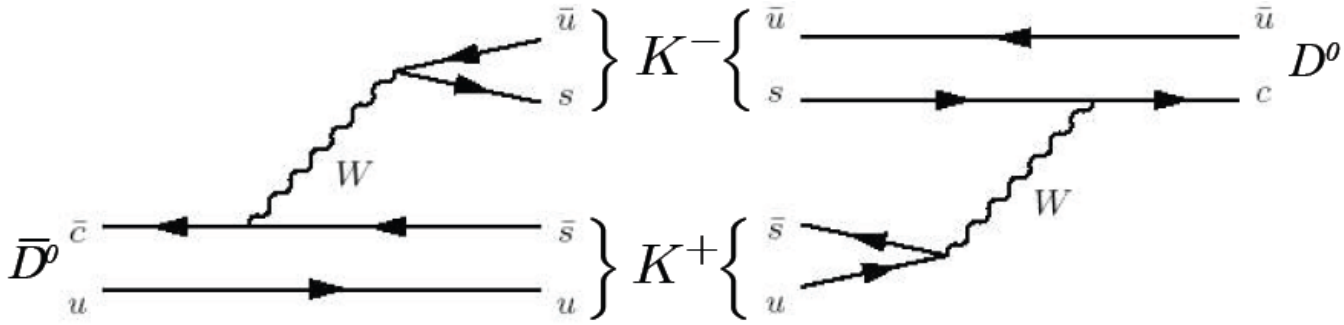
x *VIRTUAL* states

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

y

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

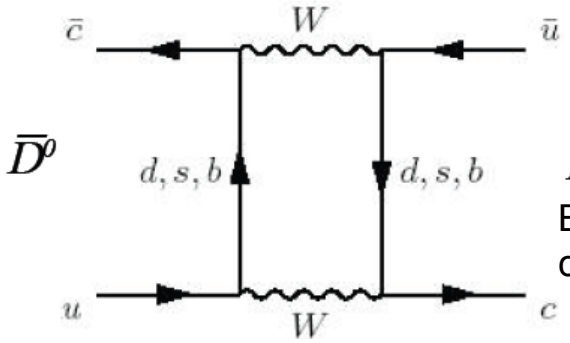
Sum of intermediate **REAL states**



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!

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

Naively

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

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

(HQET, propagation of common hadronic states,…)

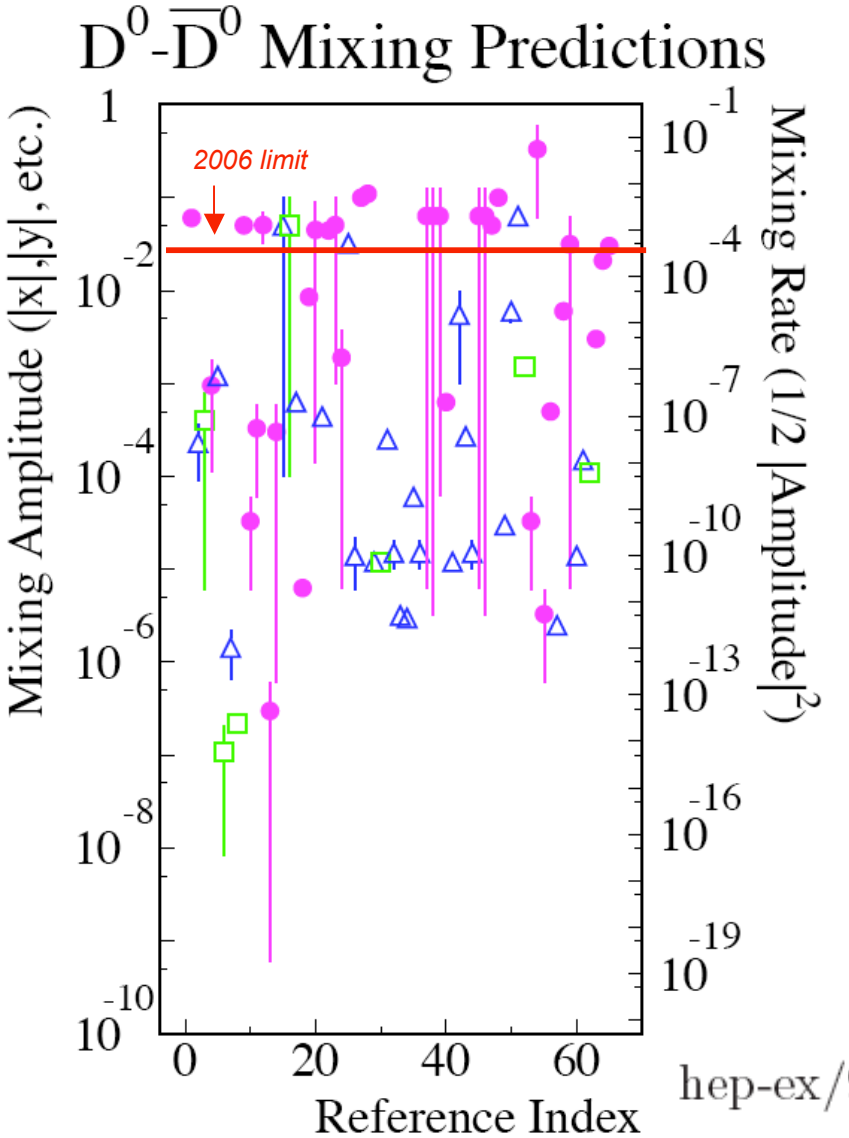
SU(3) breaking effect more important for y

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

S. Bianco *et al*, Riv. Nuovo Cim. **26N7**, 1 (2003)

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

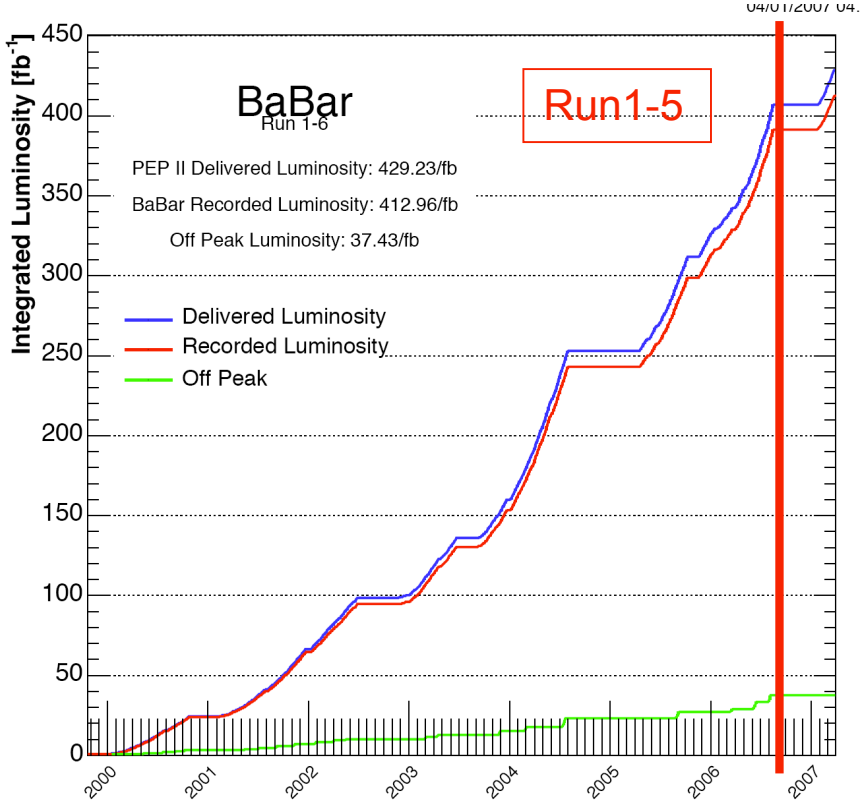
BaBar is a B-factory: $e^+e^- \to \Upsilon(4S) \to b\bar{b}$

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

$\sigma(c\bar{c})$ =1.3 nb

Millions of reconstructed charm hadrons

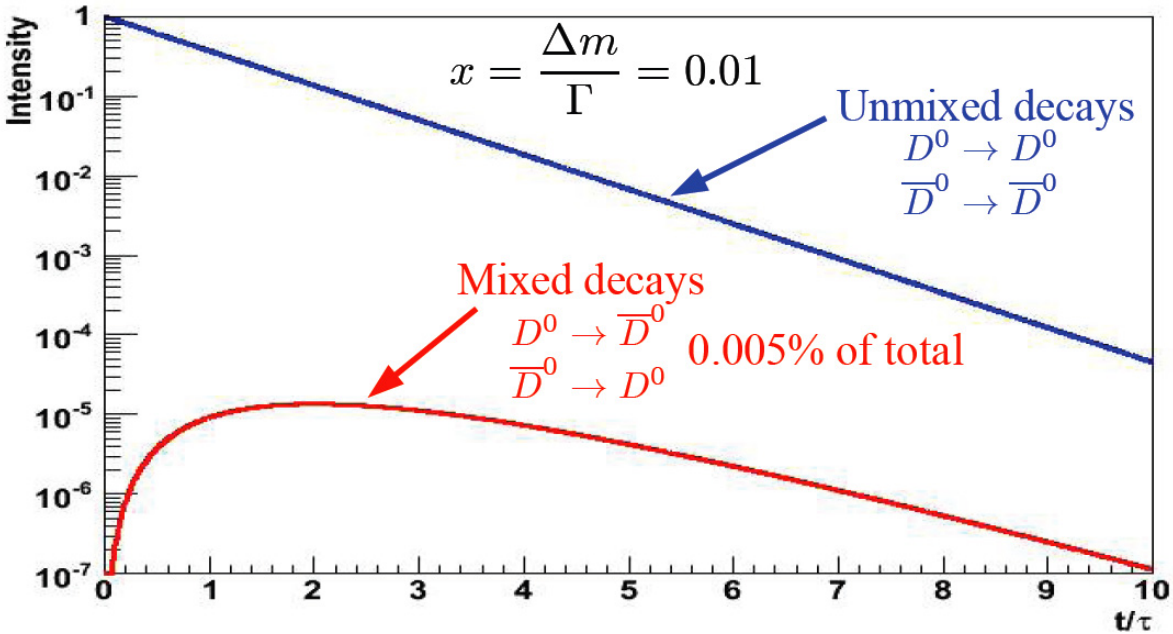
BaBar is also a charm factory



- Run1-5, more than 500M $c\bar{c}$ events

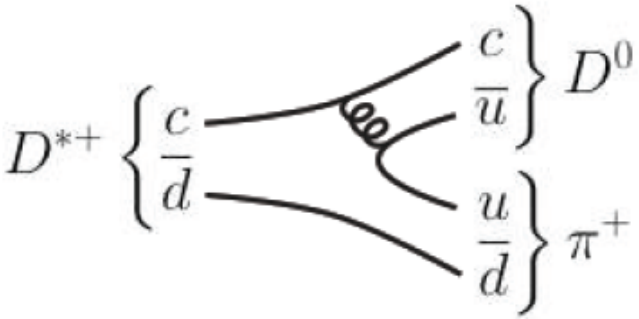
The technique

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



Flavor tagging

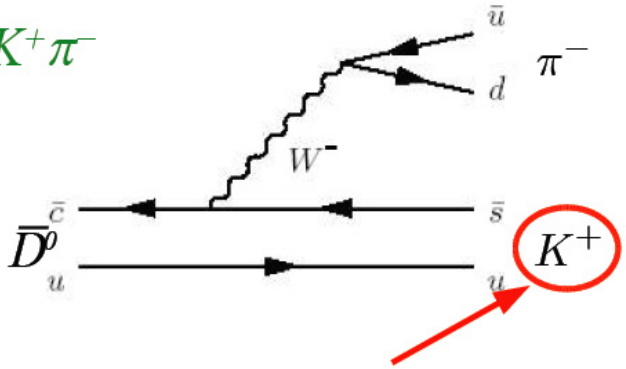
Use D^0 from $D^{*+} \to D^0 \pi^+$ decays:



Flavor 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

Flavor at decay

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

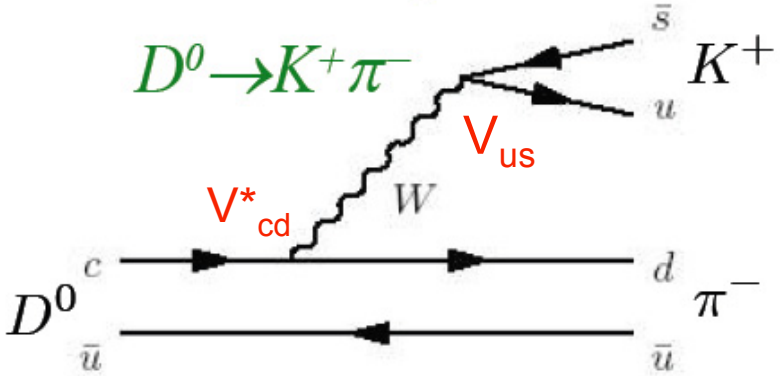
$$\overline{A}_f \equiv \langle f | H | \overline{D}^0 \rangle$$

Double-Cabibbo Suppressed Decays

Hadronic decays do not uniquely identify decay flavor

Get unmixed wrong-sign decays from DCS decays

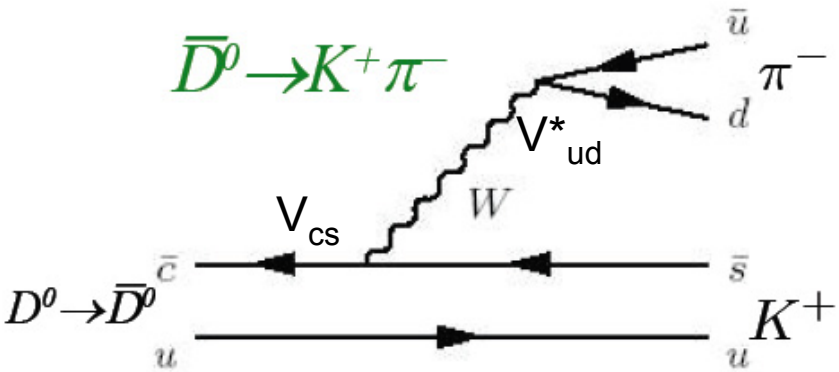
DCS decay:



Relative rate ~0.3%

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

Mixed decay:

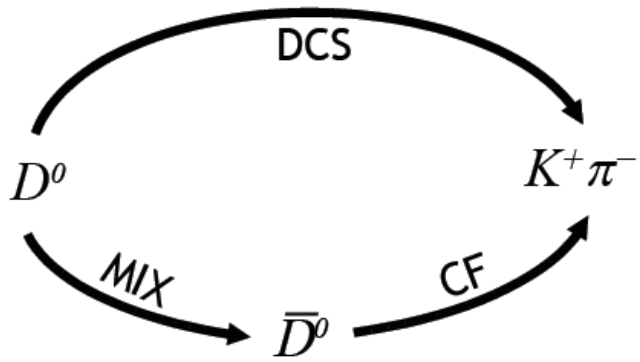


Relative rate: 0.005% (for x=0.01)

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)

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

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

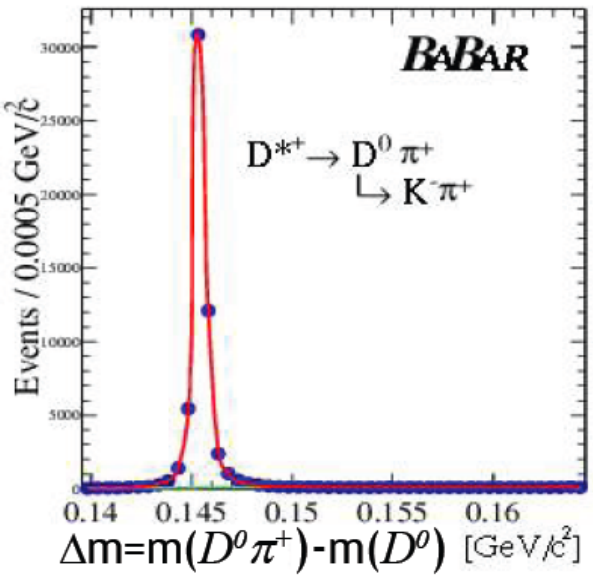
$$R_M \approx \frac{1}{2}(x^2 + y^2)$$

δ is the (relative) 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/c^2

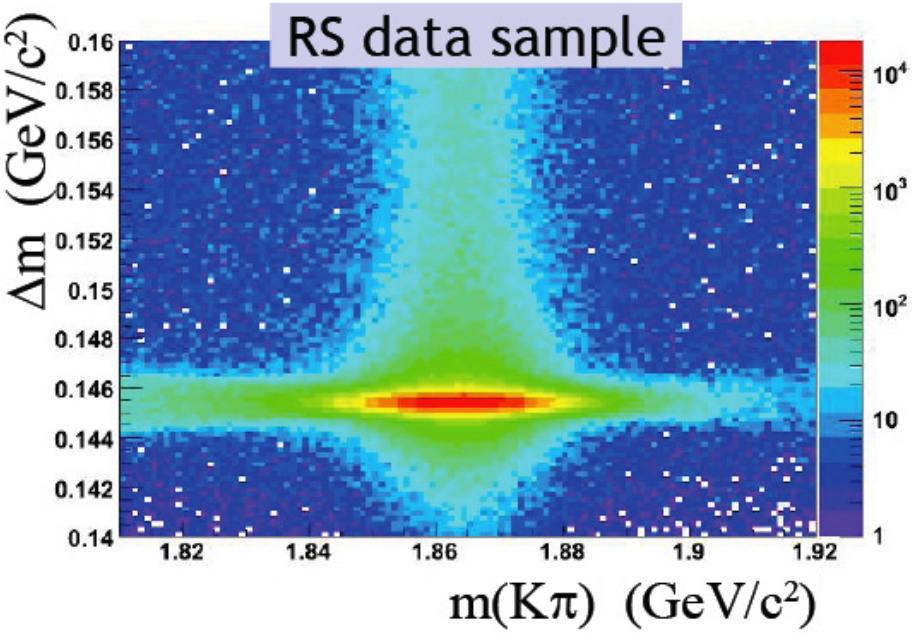
Slow π selection:

- $p^*(\pi_s) < 0.45$ GeV/c
- $p_{lab}(\pi_s) > 0.1$ GeV/c
- $0.14 < \Delta m < 0.16$ GeV/c^2

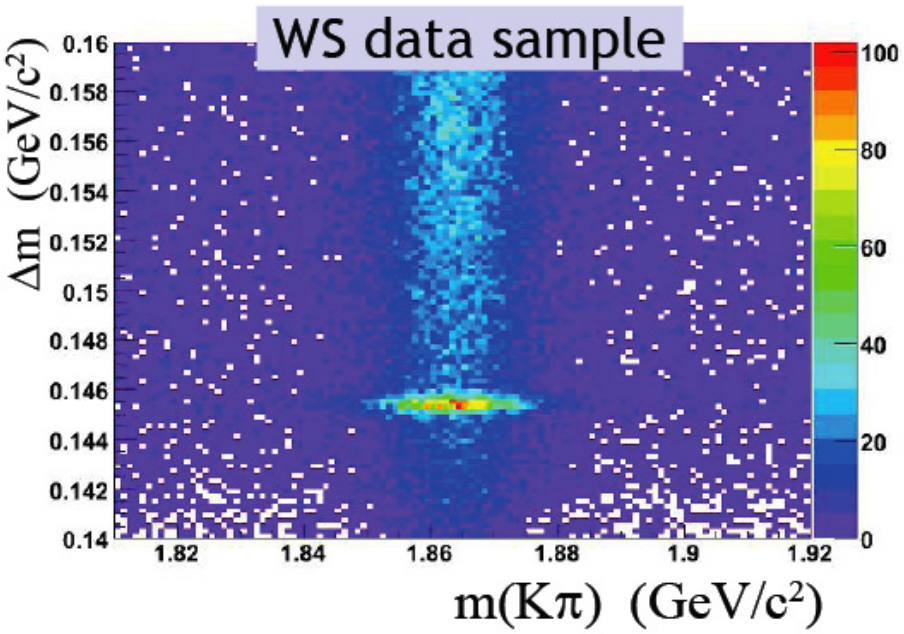
$\Delta m = m(K\pi\pi_s) - m(K\pi)$

RS and WS data set

1,229,000 RS events



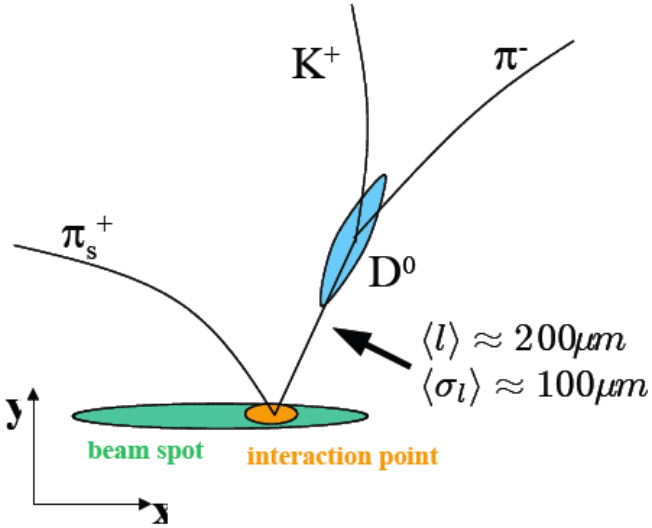
64,000 WS events



Fit to m(Kπ) and Δm distribution:

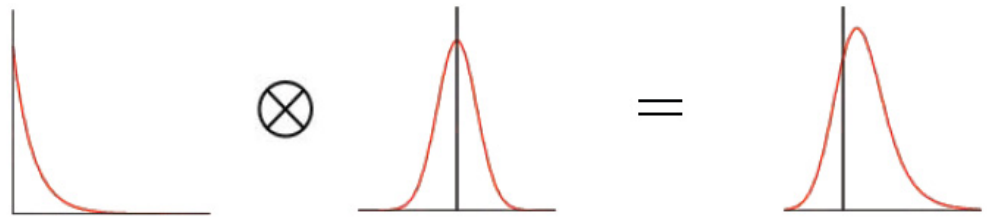
- RS and WS samples fit simultaneously
- Signal and some background parameters shared
- All parameters determined in fit to data, not MC

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

Selection criteria



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

- Resolution function from RS sample

Background components

Random π_s:

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

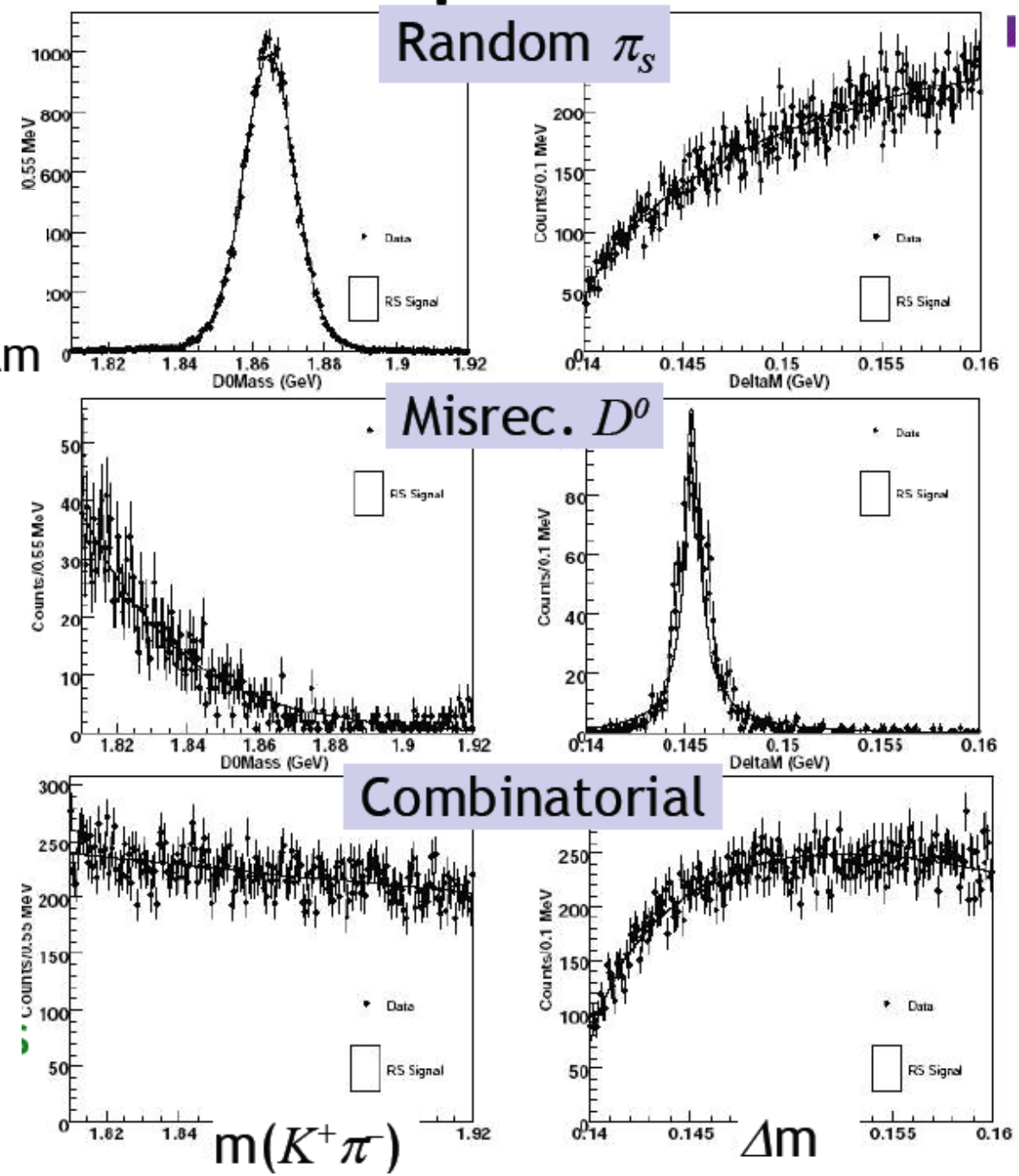
Misreconstructed D^0:

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

Combinatoric:

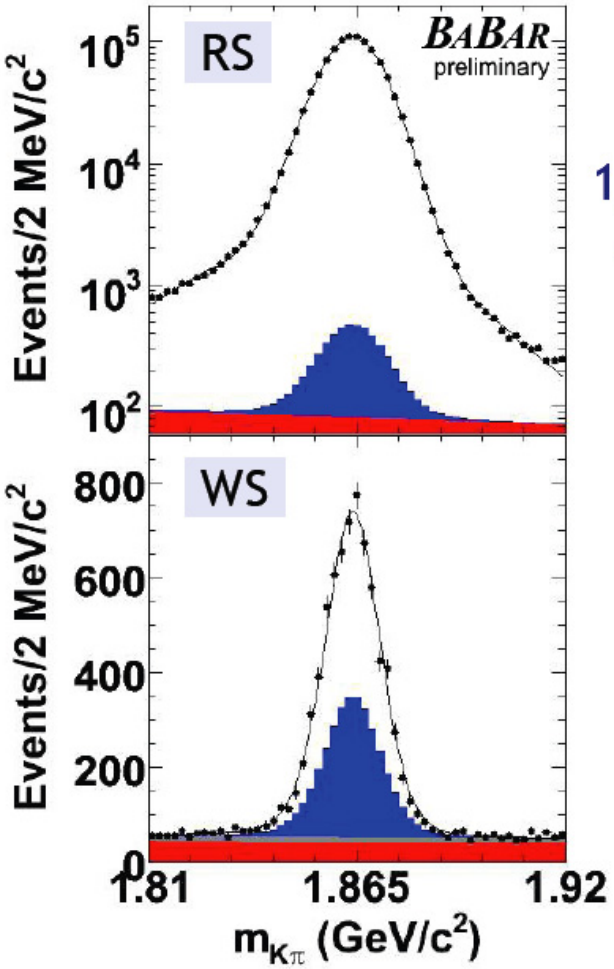
- Random tracks

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



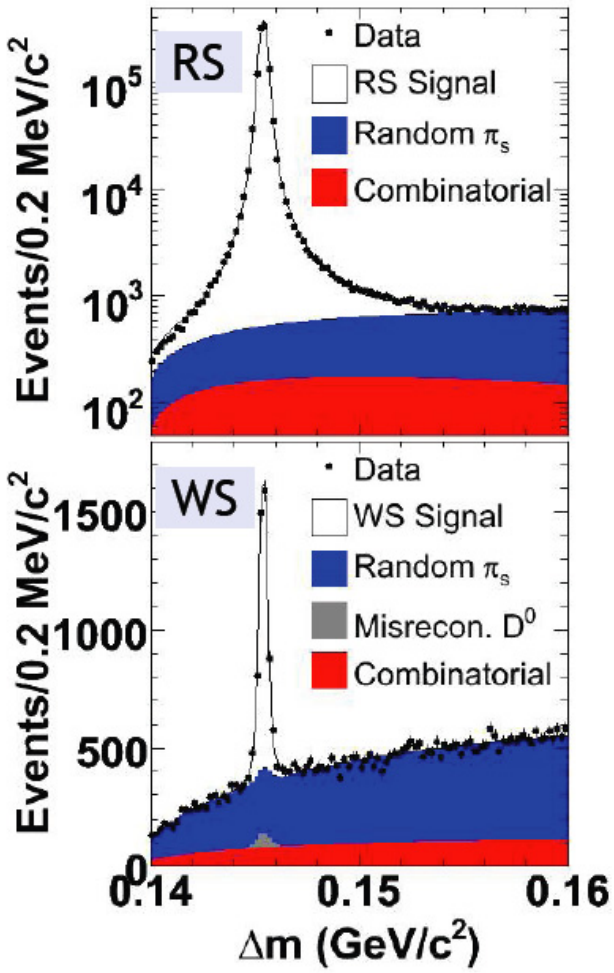
Signal extraction

384 fb^{-1}



RS signal:
1,141,500±1200
combinations

WS signal:
4,030±90
combinations



RS decay time analysis

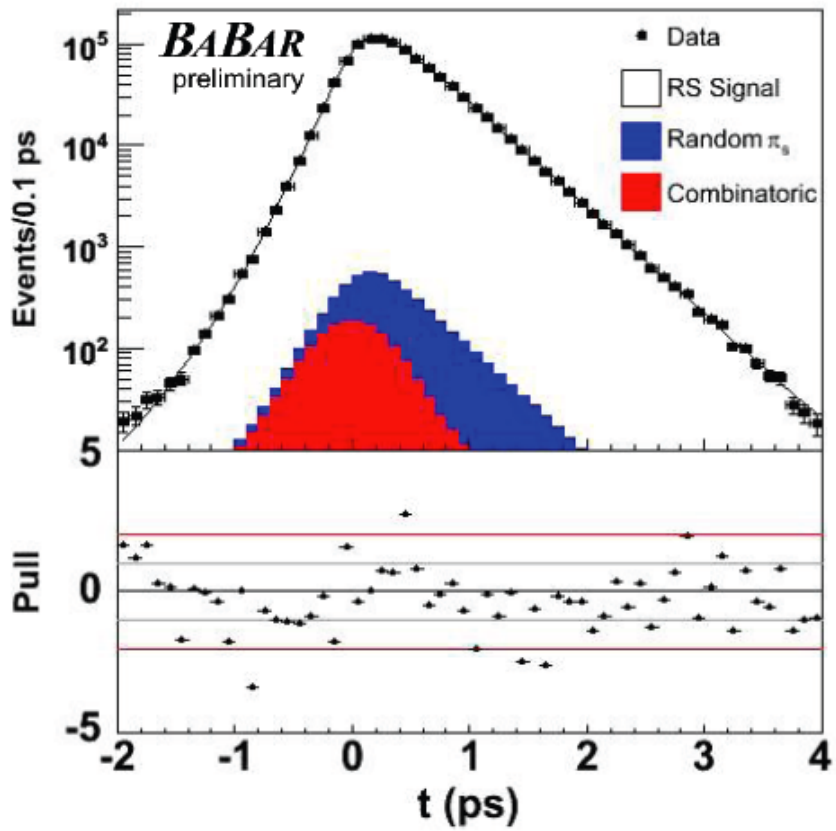
D^0 lifetime and
time resolution function
from RS sample

τ=(410.3±0.6(stat.)) fs

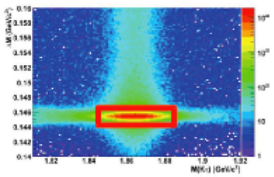
Consistent with PDG
(410.1±1.5 fs)

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

384 fb^{-1}

<u>Fit results allowing mixing:</u>

R_D: $(3.03 \pm 0.16 \pm 0.10) \times 10^{-3}$

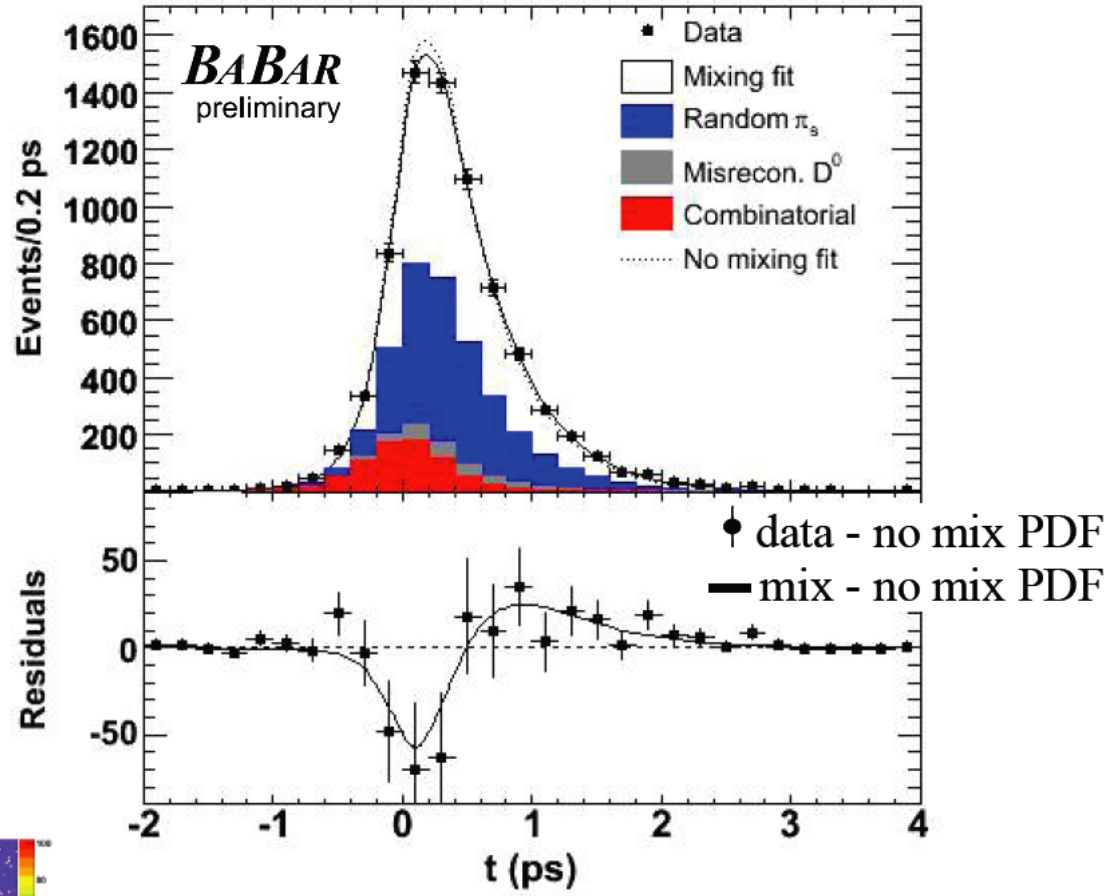
x'^2: $(-0.22 \pm 0.30 \pm 0.21) \times 10^{-3}$

y': $(9.7 \pm 4.4 \pm 3.1) \times 10^{-3}$

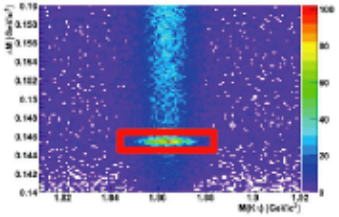
x'^2, y' correlation: -0.94

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

WS decay time, signal region

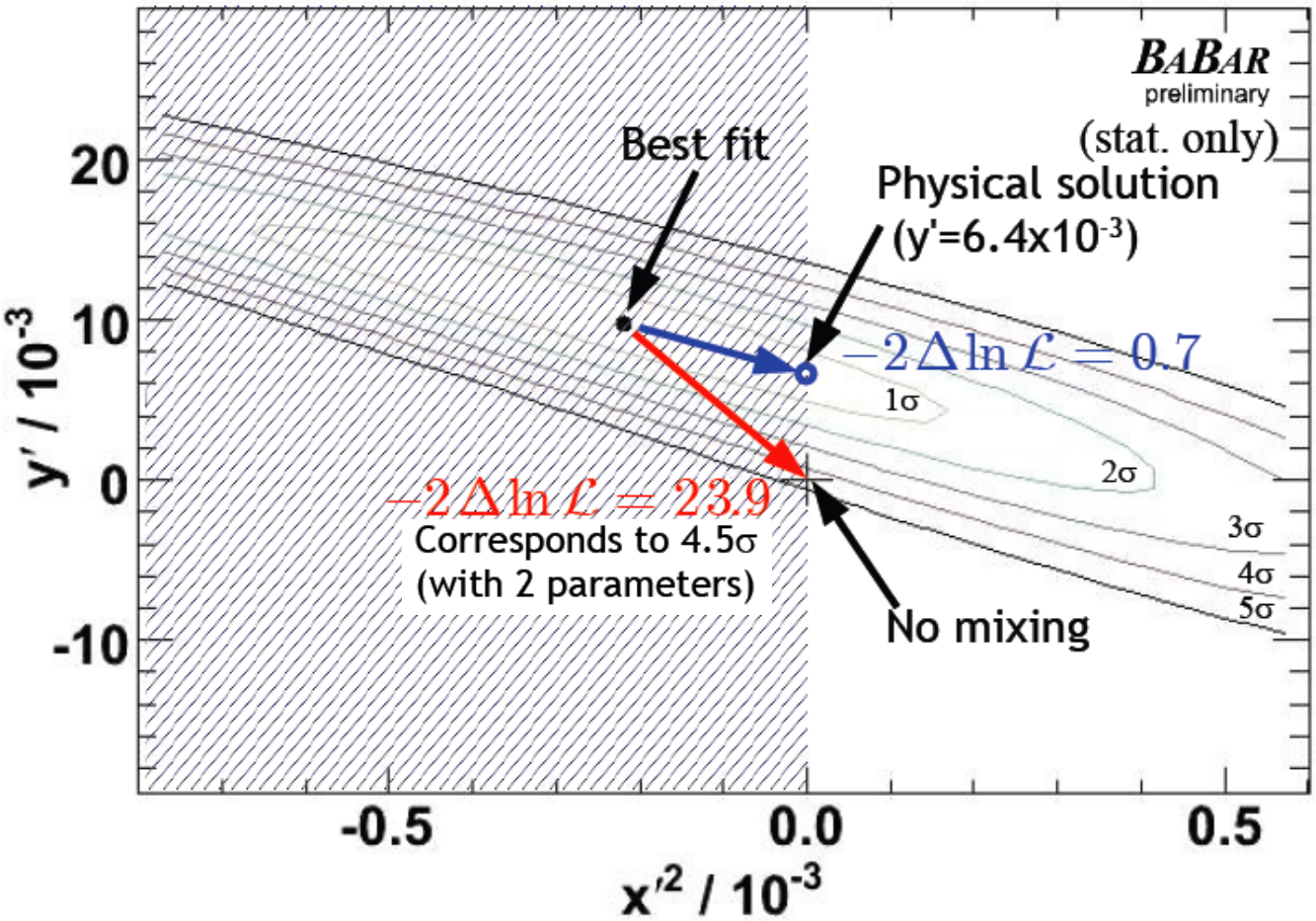


signal region:
1.843<m<1.883 GeV/c^2
0.1445<Δm< 0.1465 GeV/c^2



Evidence for D^0 mixing!

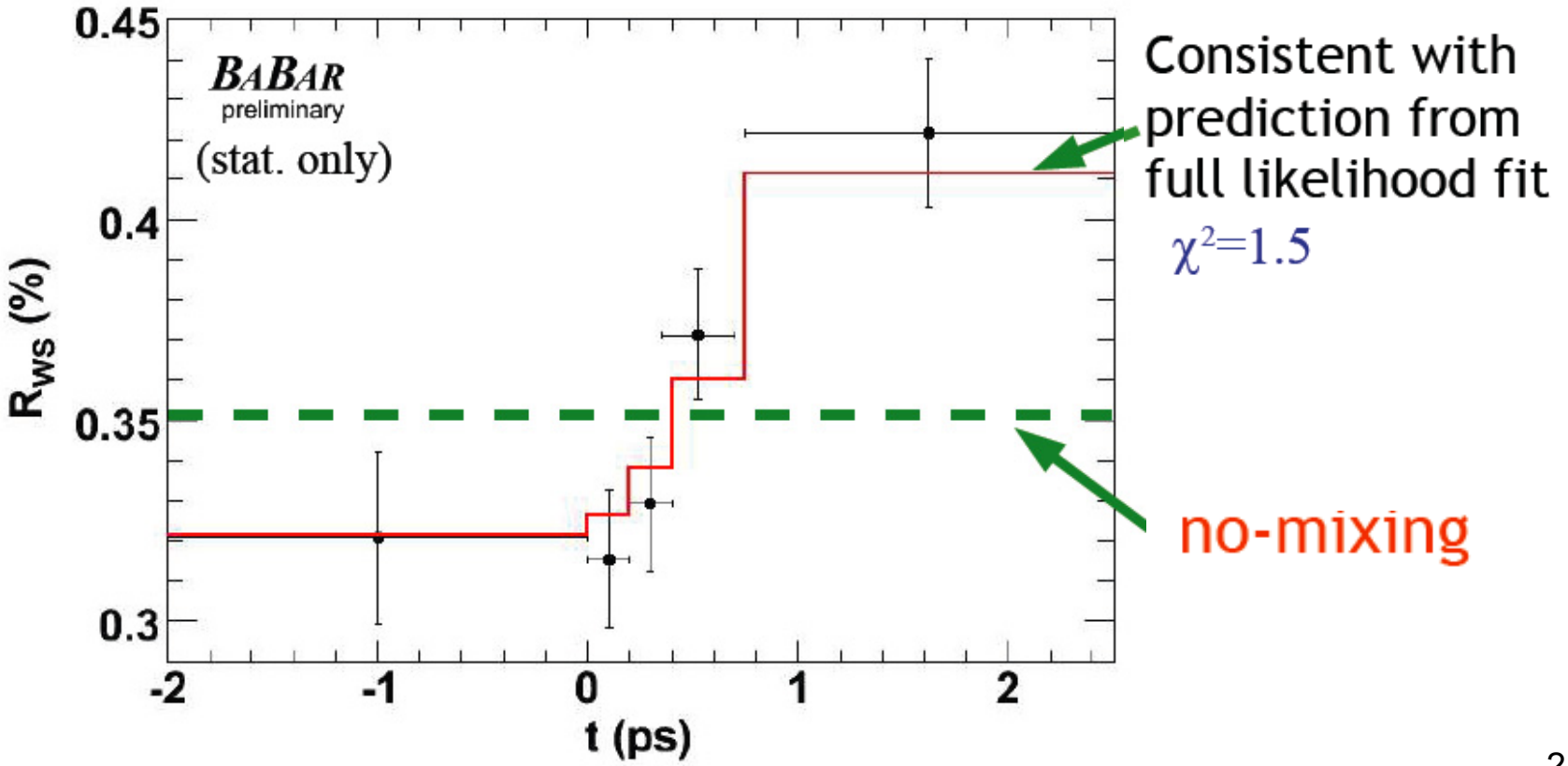
Best fit solution in unphysical region ($x'^2<0$)



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



Relative rate of WS events clearly increases with time

Validation: fit RS for mixing

Fit RS data with PDF allowing mixing

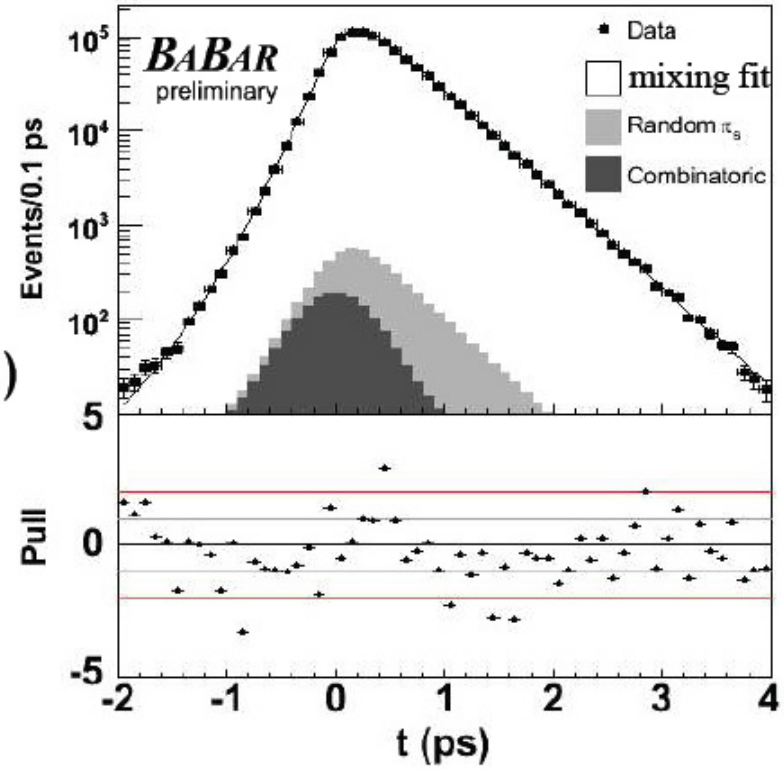
x'^2: $(-0.01 \pm 0.01) \times 10^{-3}$

y': $(0.26 \pm 0.24) \times 10^{-3}$

$-2\Delta \ln \mathcal{L} = 1.4$ (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

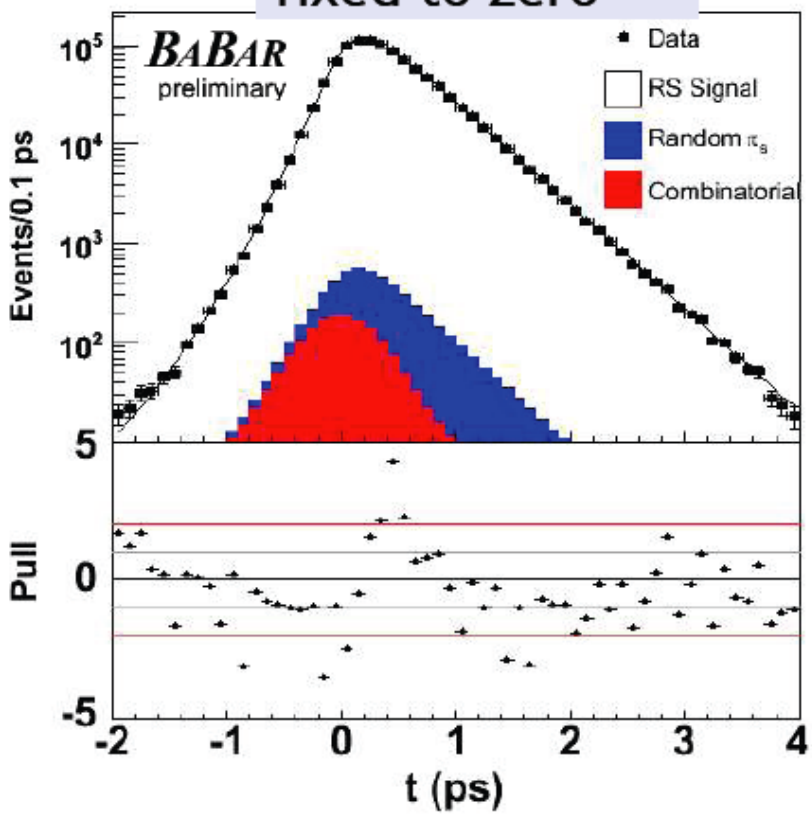
Effect is not seen in MC
- probably due to misalignment

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



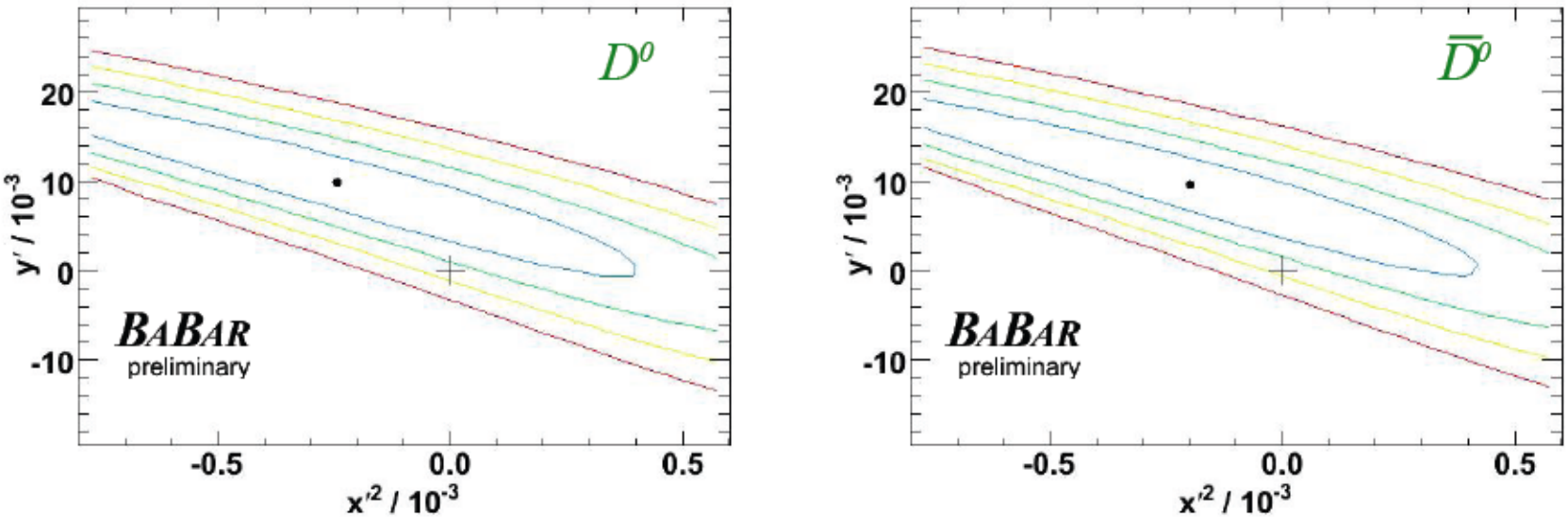
Allowing for CP violation

Results of fitting D^0 and $\bar{D}^0$ separately:

x'^{+2}: $(-0.24 \pm 0.43 \pm 0.30) \times 10^{-3}$ x'^{-2}: $(-0.20 \pm 0.41 \pm 0.29) \times 10^{-3}$

y'^{+}: $(9.8 \pm 6.4 \pm 4.5) \times 10^{-3}$ y'^{-}: $(9.6 \pm 6.1 \pm 4.3) \times 10^{-3}$

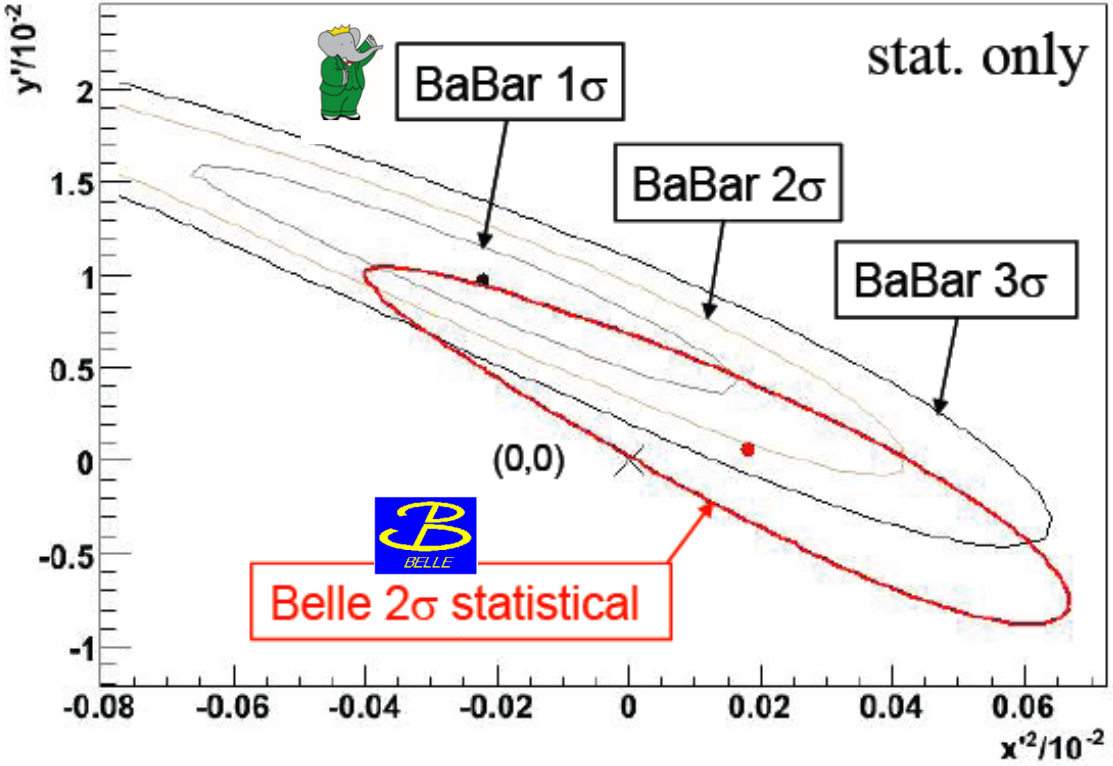
$A_D = (-2.1 \pm 5.2 \pm 1.5)\%$ CP asymmetry in DCSD !



No evidence for CP violation found

Kπ analysis from Belle

Results consistent within 2σ:



More evidence…!

Belle evidence on y_{CP}

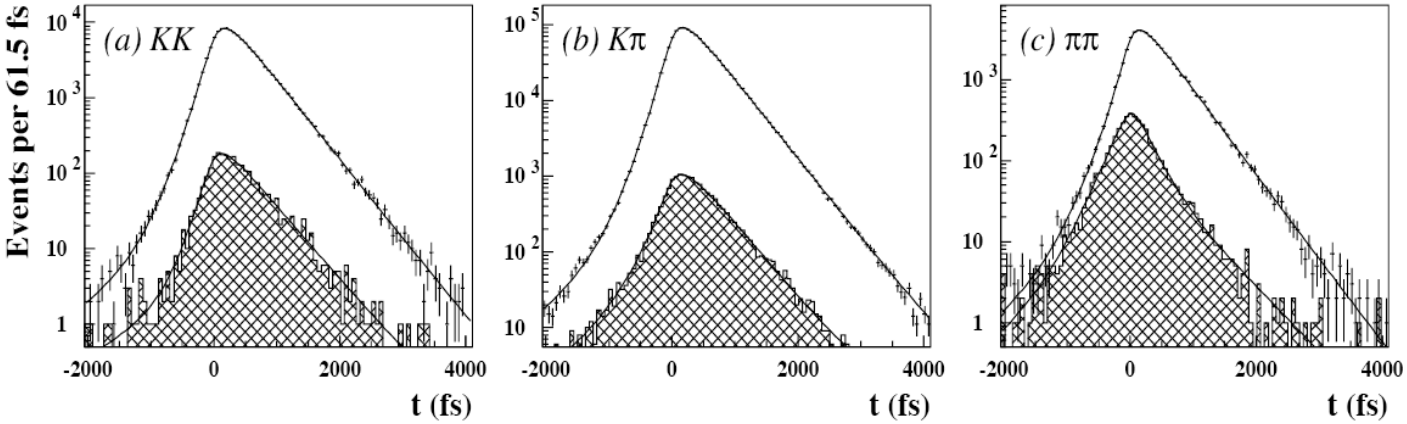
"Apparent" lifetime difference between $D^0 \to K^-\pi^+$ and K^+K^-, $\pi^+\pi^-$

$$y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1 \longrightarrow y_{CP} = y\cos 2\phi_D - A_m x \sin 2\phi_D$$

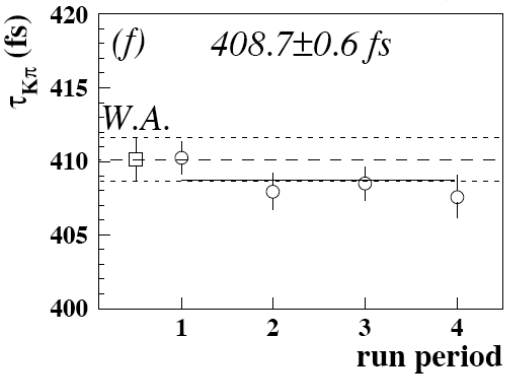
$$A_m = 1 - |q/p|$$

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)} \longrightarrow A_\Gamma = A_m y \cos 2\phi_D - x \sin 2\phi_D$$

ϕ_D= mixing phase



Stable $\tau_{K\pi}$ over different run periods



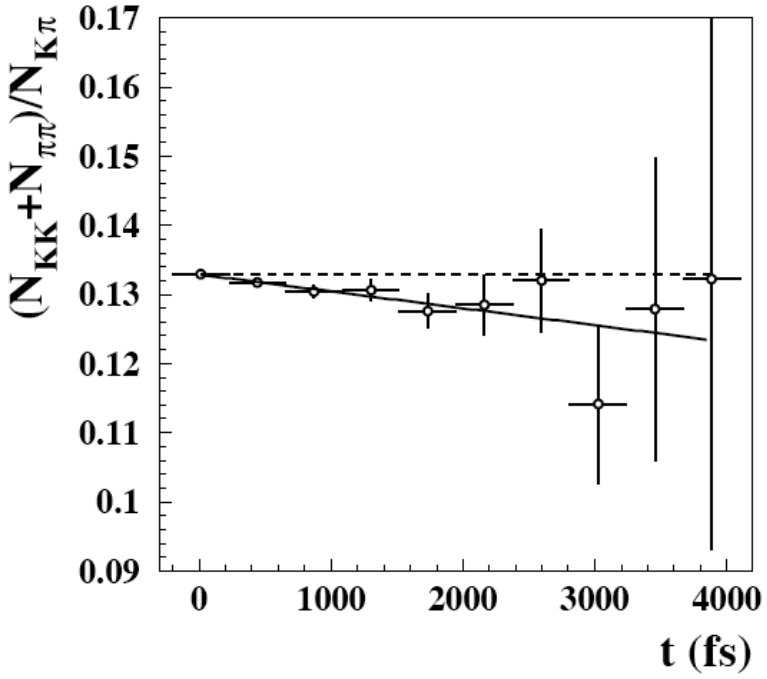
Results on y_{CP}

Belle hep-ex/0703036

540 fb^{-1}

$$y_{CP} = (1.31 \pm 0.32(\text{stat.}) \pm 0.25(\text{syst.}))\%$$

- >3σ effect
  (4.1 stat only)



$$A_\Gamma = (0.01 \pm 0.30(\text{stat.}) \pm 0.15(\text{syst.}))\%$$

No evidence of CP violation

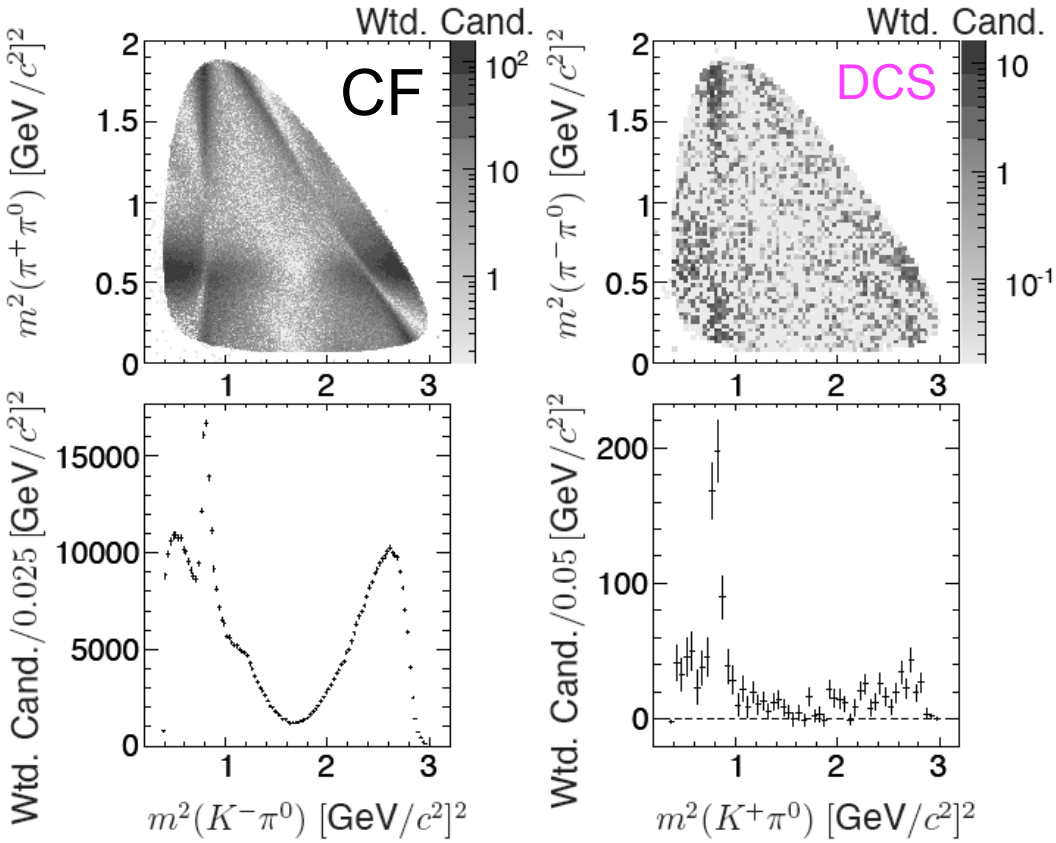
Separating x and y

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

Need info on **strong phases**

– Multibody decays:Dalitz models

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



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

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

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

Select special region of Dalitz plot

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

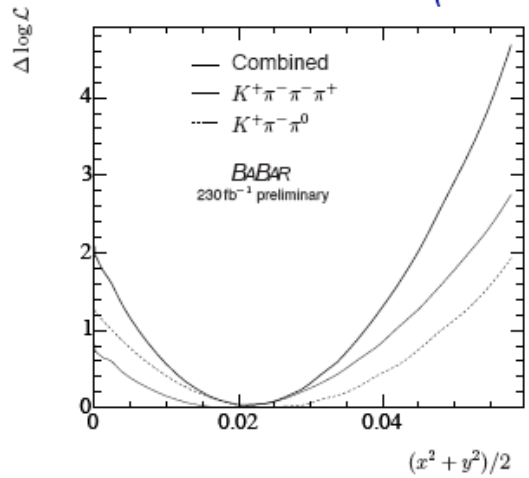
$$\widetilde{x}' = x\cos\widetilde{\delta} + y\sin\widetilde{\delta}$$
$$\widetilde{y}' = y\cos\widetilde{\delta} - x\sin\widetilde{\delta}$$

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.)

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

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

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

$$\langle K_S^0 \pi^+\pi^- | H | D^0(t) \rangle = \frac{1}{2p} \left(\langle K_S^0 \pi^+\pi^- | H | D_1(t) \rangle + \langle K_S^0 \pi^+\pi^- | H | D_2(t) \rangle \right)$$
$$\equiv A_1 \, e^{-(\Gamma_1/2 + i m_1)\, t} + A_2 \, e^{-(\Gamma_2/2 + i m_2)\, t}$$

$$R(D^0(t) \to K_S^0 \pi^+\pi^-) = |A_1|^2 \, e^{-\overline{\Gamma}(1+y)t} + |A_2|^2 \, e^{-\overline{\Gamma}(1-y)t} + 2e^{-\overline{\Gamma}t} \left[\mathrm{Re}(A_1 A_2^*) \cos xt - \mathrm{Im}(A_1 A_2^*) \sin xt \right]$$

The amplitudes A^j are functions of $m^2(K_S \pi^+)$ and $m^2(K_S \pi^-)$ and account for various intermediate states:

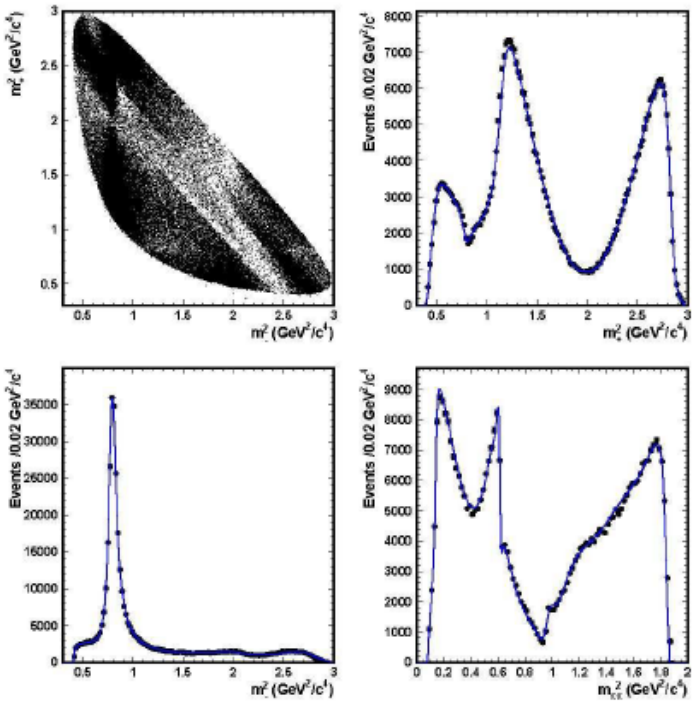
Both flavor ($K^{*-}\pi^+/K^{*+}\pi^-$) final states in the same Dalitz plot!
CP-eigenstate (ρK_S) and flavor states ($K^{*-}\pi^+$) in the same Dalitz plot!

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

Dalitz fit

Belle, 540 fb^{-1}

Very pure sample (95%)

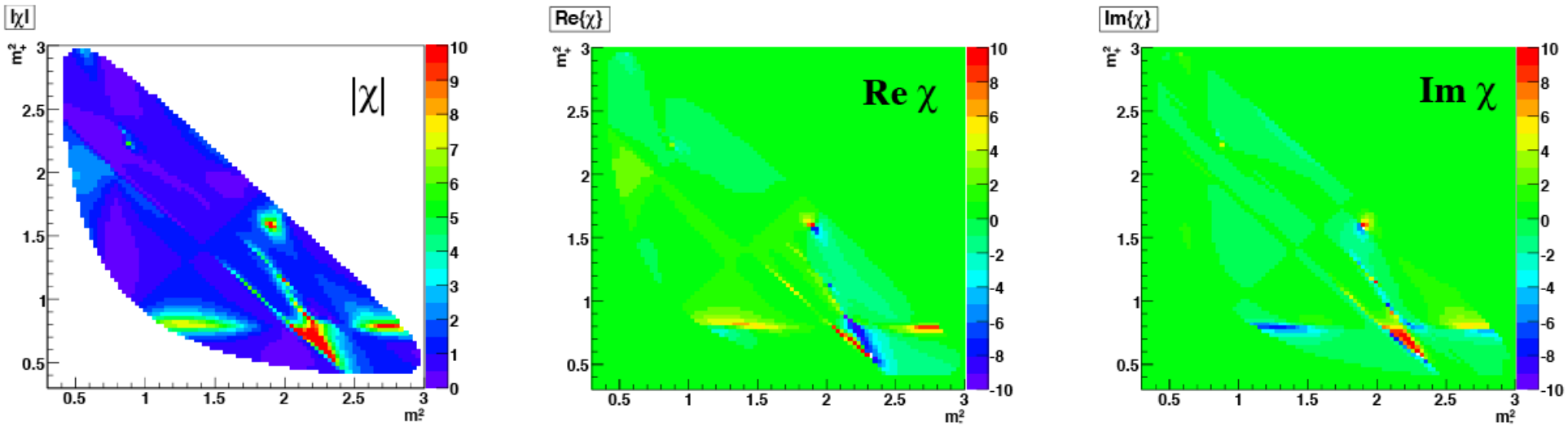


Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.629 ± 0.005	134.3 ± 0.3	0.6227
$K_0^*(1430)^-$	2.12 ± 0.02	-0.9 ± 0.5	0.0724
$K_2^*(1430)^-$	0.87 ± 0.01	-47.3 ± 0.7	0.0133
$K^*(1410)^-$	0.65 ± 0.02	111 ± 2	0.0048
$K^*(1680)^-$	0.60 ± 0.05	147 ± 5	0.0002
$K^*(892)^+$	0.152 ± 0.003	-37.5 ± 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

Sensitivity regions

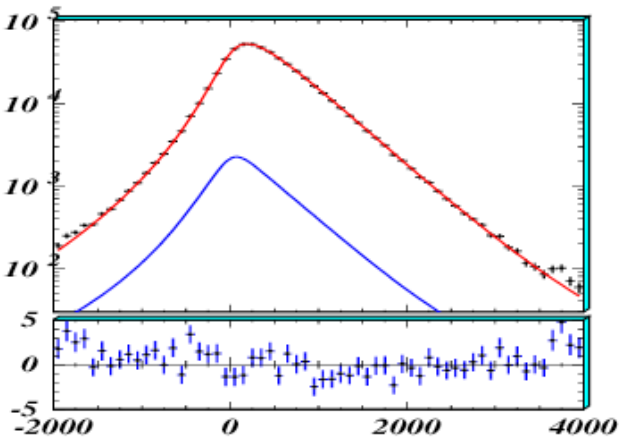
$$|\mathcal{M}|^2 \approx |\mathcal{A}(m_-^2, m_+^2)|^2 \left\{1 + [\mathrm{Im}(\chi)\, x - \mathrm{Re}(\chi)\, y]\, t + |\chi|^2 \left(\frac{x^2+y^2}{4}\right) t^2\right\} e^{-\Gamma t}$$



⇒ *much of sensitivity comes from the K*(890)⁺ region and interference region between ρ(770) and ω*

Belle $D^0 \to K_S\pi^+\pi^-$ results

Time fit (in projection):



$x = (0.80 \pm 0.29)\%$ *positive*

$y = (0.33 \pm 0.24)\%$

$t_D = (409.9 \pm 0.9)$ fs

consistent with PDG
(in fact better precision)

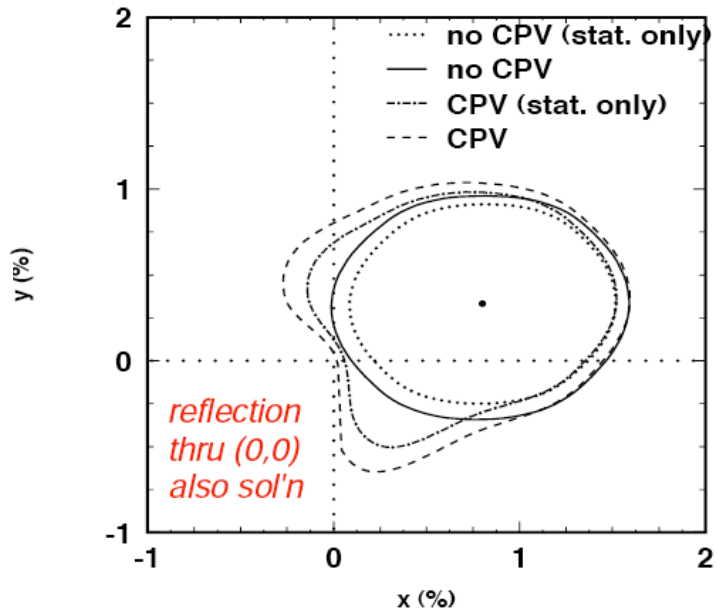
Largest systematic errors:	Δx (x 10^{-2})	Δy (x 10^{-2})
$p(D^*)$ cut	+0.076	−0.078
t dependence of Dalitz background	−0.056	−0.057
background timing parameters	±0.037	±0.063
decay model (form factors, variation of fixed masses & widths, K-matrix, no non-resonant comp., others)	+0.13 −0.11	+0.051 −0.066
TOTAL	**(+0.17, −0.15)**	**(+0.10, −0.15)**

Allowing for CP violation

hep-ex/0704.1000

$x = (0.80 \pm 0.29 \pm 0.17)\%$
$y = (0.33 \pm 0.24 \pm 0.15)\%$

$-2\Delta \ln \mathcal{L} = 7.33 \Rightarrow$ CL= only 2.6%



Allow for CPV: $e_{(1,2)} \equiv e^{-i(m_{(1,2)} - i\Gamma_{(1,2)}/2)t}$

$$\mathcal{M}(m_-^2, m_+^2, t) = \mathcal{A}(m_-^2, m_+^2)\frac{e_1(t)+e_2(t)}{2} + \left(\frac{q}{p}\right)\overline{\mathcal{A}}(m_-^2, m_+^2)\frac{e_1(t)-e_2(t)}{2}$$

$$\overline{\mathcal{M}}(m_-^2, m_+^2, t) = \overline{\mathcal{A}}(m_-^2, m_+^2)\frac{e_1(t)+e_2(t)}{2} + \left(\frac{p}{q}\right)\mathcal{A}(m_-^2, m_+^2)\frac{e_1(t)-e_2(t)}{2}$$

CPV result:
(preliminary)

$x = (0.81 \pm 0.30 \pm 0.17)\%$ $\quad |q/p| = 0.86\,^{+0.30}_{-0.29}$

$y = (0.37 \pm 0.25 \pm 0.15)\%$ $\quad \arg(q/p) = -14\,^{+16}_{-18}$

no dcpv →

$|q/p| = 0.95\,^{+0.22}_{-0.20}$

$\arg(q/p) = -2\,^{+10}_{-11}$

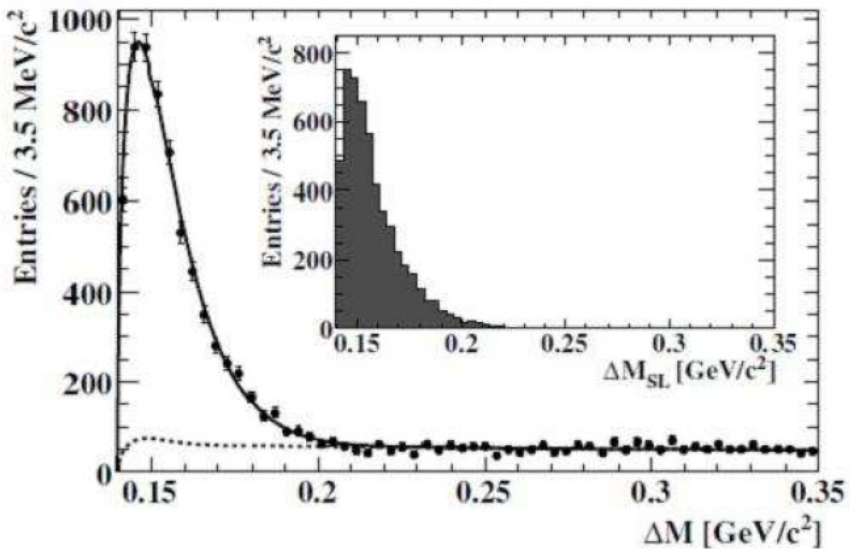
D-mixing with Semileptonic decay

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

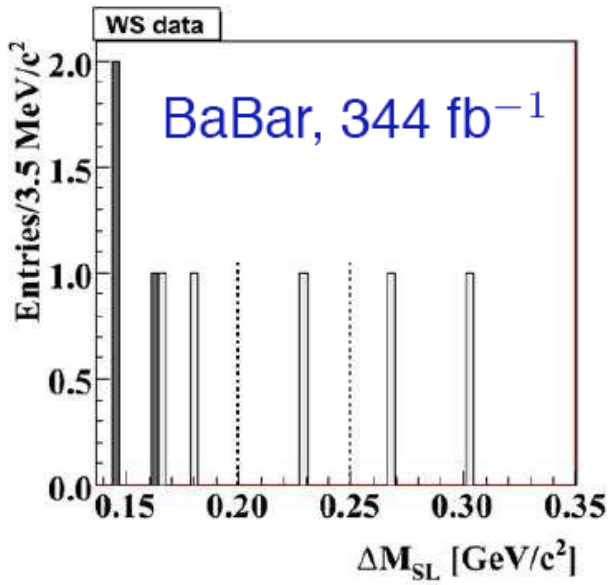
No DCS sl. ! $A_f = \bar{A}_{\bar{f}} = 0$ $\quad r(t) = \frac{e^{-t}}{4}(x^2+y^2)\,t^2 \left|\frac{q}{p}\right|^2$

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

ΔM RS events



ΔM WS events



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

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

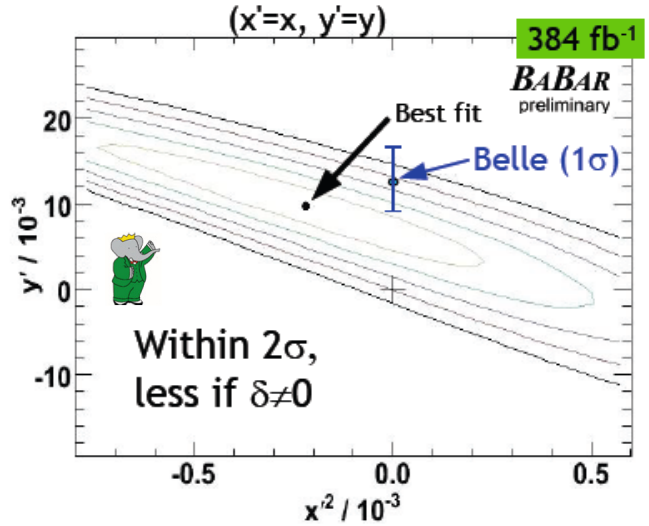
$$x = 0.80 \pm 0.29 \pm 0.17\ \%\ (2.4\sigma)$$

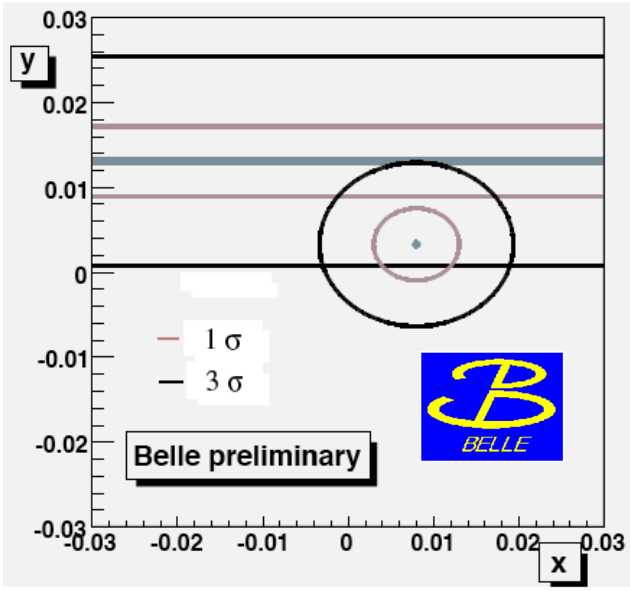
y_{CP}(WA) = 1.12 ±0.32 %

» BaBar updating multibody decays analysis, y_{CP} measurements

» BaBar $K_S\pi\pi$ on-going

Compare assuming δ=0:





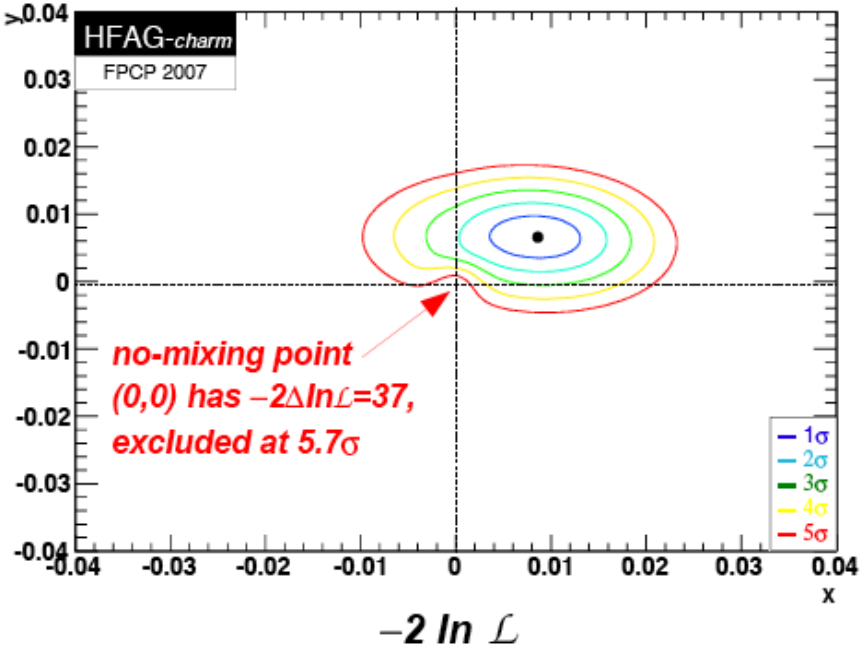
Gianluca Cavoto

Interpreting the results

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

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

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



$x = (0.87^{+0.30}_{-0.34})\%$
(2.6σ above zero)

$y = (0.66 \pm 0.21)\%$
(3.2σ above zero)

$\delta = (19^{+15}_{-17})^\circ$
(consistent w/zero)

Measuring δ

To beat down the model systematics measure phases directly

- Correlated D production - DD → $f_1 f_2$

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

- 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 $K^-l^+\nu$ double tags

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

- 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

- 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

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

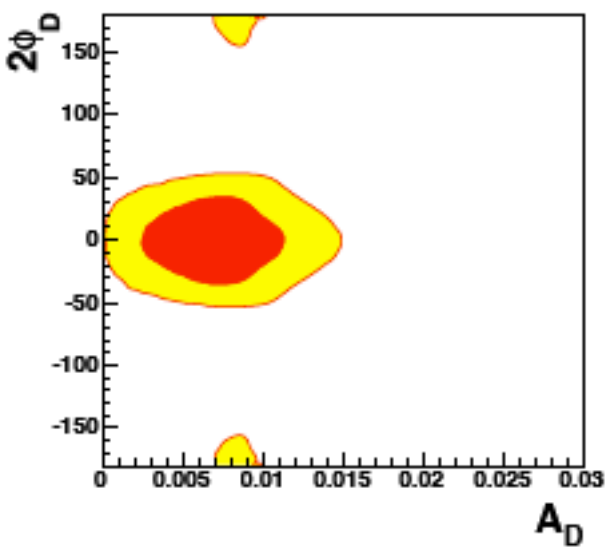
- Input R_D =(3.60±0.08)‰ from PDG2006+CDF ~±2%,

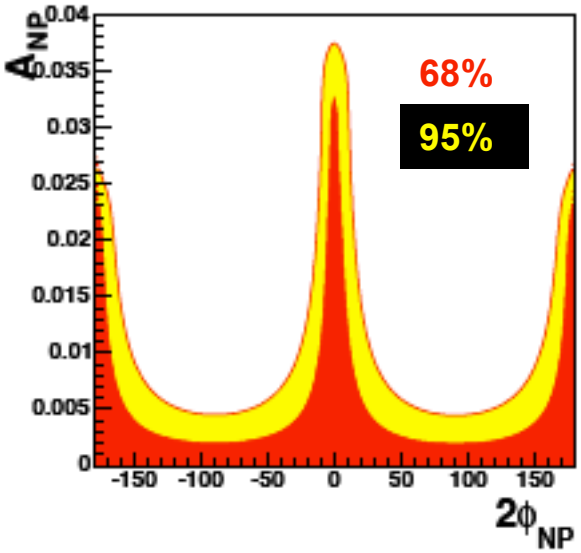
Need to run On threshold

- 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**!

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

Back up slides

Fit signal MC events

Performed extensive checks of mixing signal:

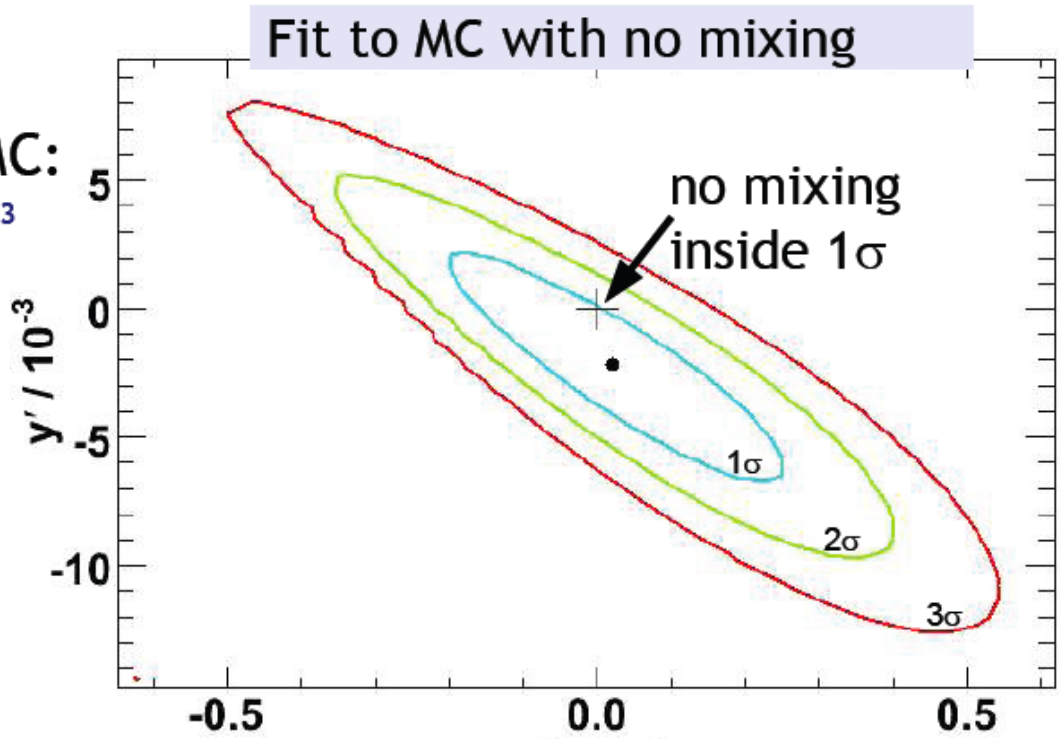
- Could something fake signal?
- Is significance estimated correctly?
- Are mixing parameters unbiased?

No signal found in MC:

x'^2: $(-0.02\pm0.18)\times10^{-3}$

y': $(-2.2\pm3.0)\times10^{-3}$

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