Oscillazioni del mesone D^0

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About 30 years ago…

D^0 $I(J^P) = \frac{1}{2}(0^-)$

D^0 MASS

The fit includes $D^\pm$, D^0, $D_s^\pm$, $D^{*\pm}$, D^{*0}, and $D_s^{*\pm}$ mass and mass difference measurements.

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1864.5±0.4 OUR FIT	Error includes scale factor of 1.1.				
1864.1±1.0 OUR AVERAGE					
1864.6±0.3±1.0	641	BARLAG	90C	ACCM	π^- Cu 230 GeV
1852 ±7	16	ADAMOVICH	87	EMUL	Photoproduction
1861 ±4		DERRICK	84	HRS	e^+e^- 29 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1856 ±36	22	ADAMOVICH	84B	EMUL	Photoproduction
1847 ±7	1	FIORINO	81	EMUL	$\gamma N \to \overline{D}^0 +$
1863.8±0.5		[1] SCHINDLER	81	MRK2	e^+e^- 3.77 GeV
1864.7±0.6		[1] TRILLING	81	RVUE	e^+e^- 3.77 GeV
1863.0±2.5	238	ASTON	80E	OMEG	$\gamma p \to \overline{D}^0$
1860 ±2	143	[2] AVERY	80	SPEC	$\gamma N \to D^{*+}$
1869 ±4	35	[2] AVERY	80	SPEC	$\gamma N \to D^{*+}$
1854 ±6	94	[2] ATIYA	79	SPEC	$\gamma N \to D^0 \overline{D}^0$
1850 ±15	64	BALTAY	78C	HBC	$\nu N \to K^0 \pi\pi$
1863 ±3		GOLDHABER	77	MRK1	D^0, D^+ recoil spectra
1863.3±0.9		[1] PERUZZI	77	MRK1	e^+e^- 3.77 GeV
1868 ±11		PICCOLO	77	MRK1	e^+e^- 4.03, 4.41 GeV
1865 ±15	234	GOLDHABER	76	MRK1	$K\pi$ and $K3\pi$

[1] PERUZZI 77 and SCHINDLER 81 errors do not include the 0.13% uncertainty in the absolute SPEAR energy calibration. TRILLING 81 uses the high precision $J/\psi(1S)$ and $\psi(2S)$ measurements of ZHOLENTZ 80 to determine this uncertainty and combines the PERUZZI 77 and SCHINDLER 81 results to obtain the value quoted. TRILLING 81 enters the fit in the $D^\pm$ mass, and PERUZZI 77 and SCHINDLER 81 enter in the $m_{D^\pm} - m_{D^0}$, below.

[2] Error does not include possible systematic mass scale shift, estimated to be less than 5 MeV.

1977- SLAC

Outline

- Neutral mesons flavor oscillation
- Charm meson mixing (x,y)
- Evidence from B-factories
  - $D^0 \rightarrow K^- \pi^+$ (x',y')
  - $D^0 \rightarrow K^+ K^- / \pi^+ \pi^-$ (y_{CP})
  - $D^0 \rightarrow K_S \pi^+ \pi^-$ (x,y)
  - $D^0 \rightarrow K^- l^+ \nu_l$ and others
  - Outlook

Credits to Gianluca Cavoto and Brian Petersen

Neutral Mesons System

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

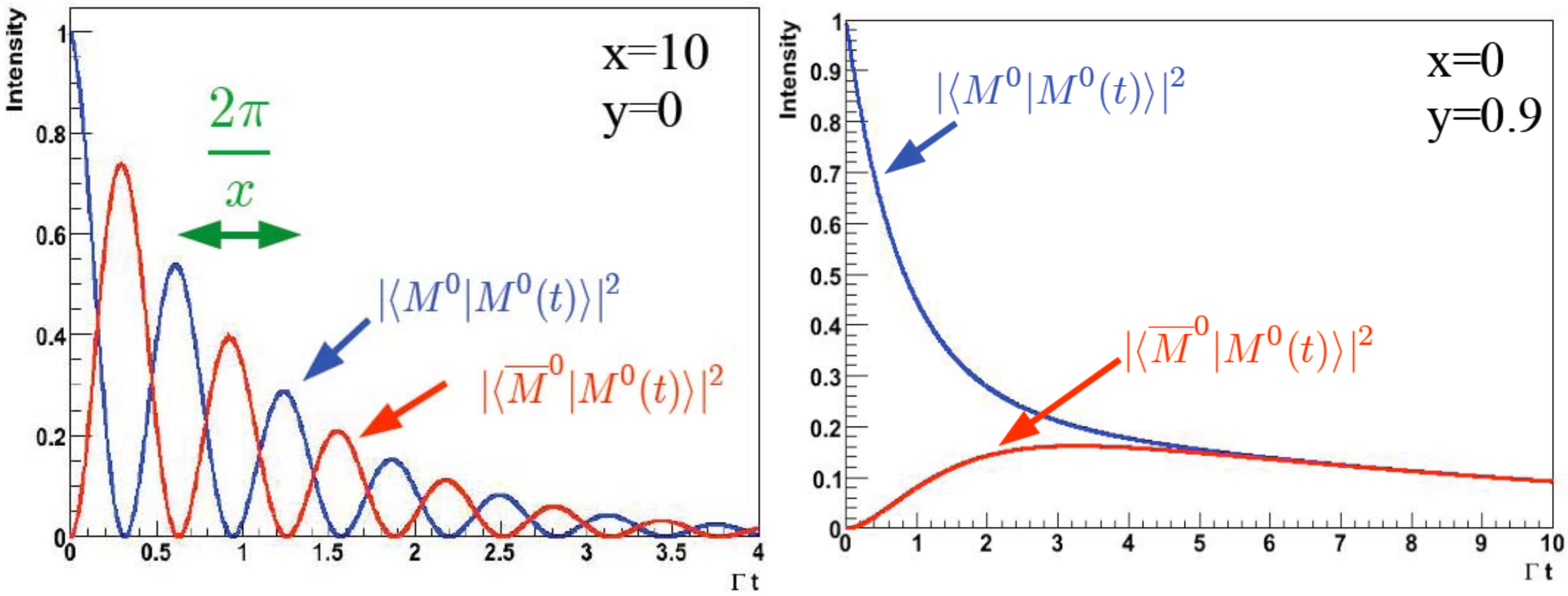
M^0 "oscillates" into $\overline{M}^0$!

(also dubbed "mixing")

An opposite flavor component appears after a while!

Some visual examples

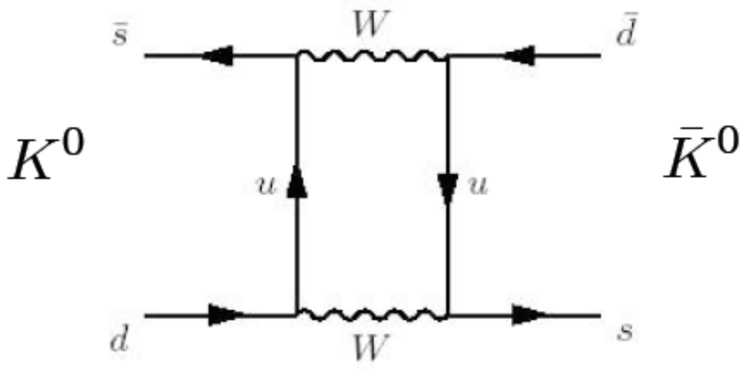
Probability to find a $M^0(\overline{M}^0)$ after a given time



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

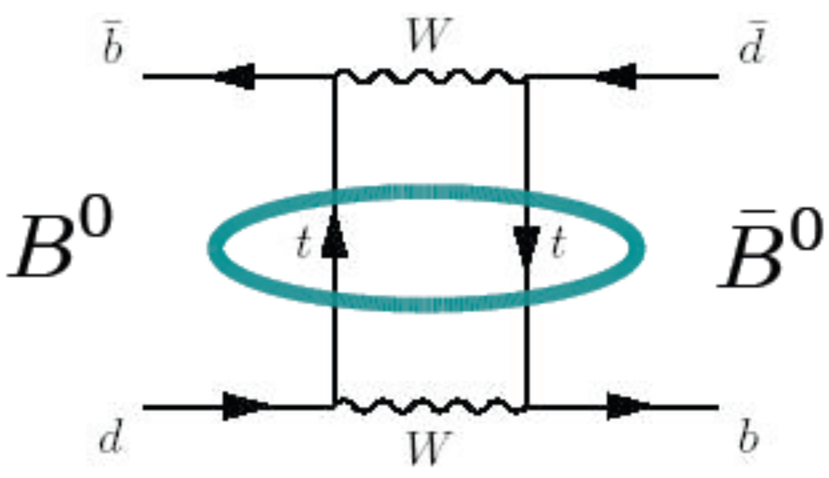
Introduce additional loop with new c quark

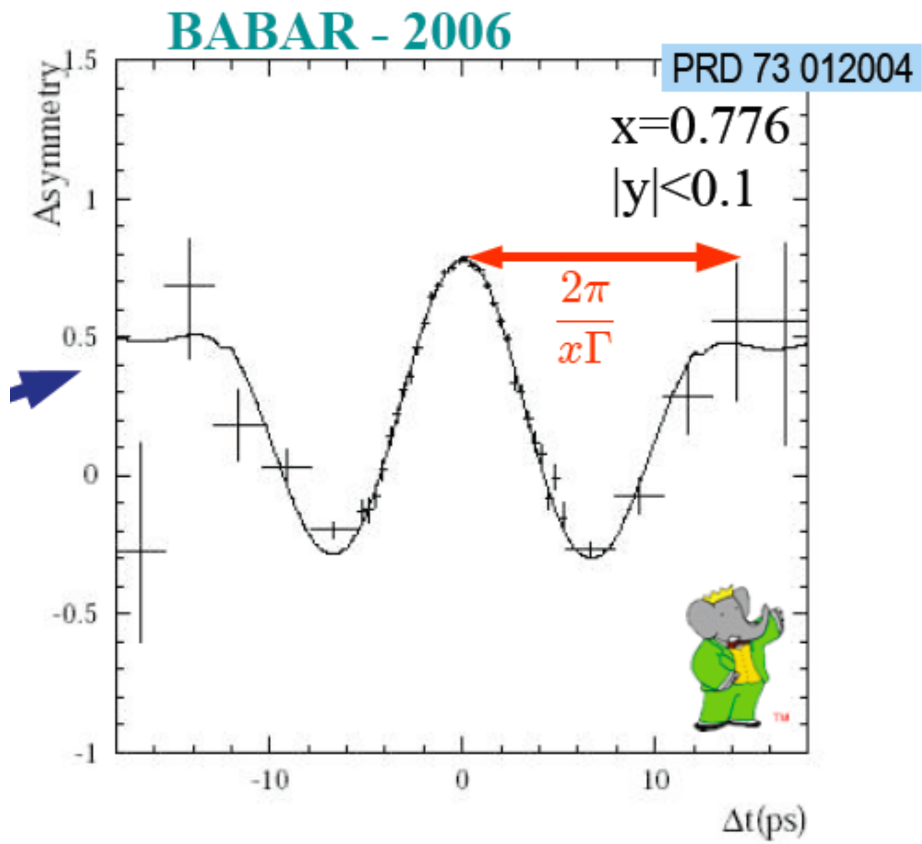
GIM predicted charm quark 4 years before observation

Also a powerful tool for NP

B0 mixing first (directly) observed by Argus (1987)

Large mix frequency implied t quark was heavy (>50 GeV)

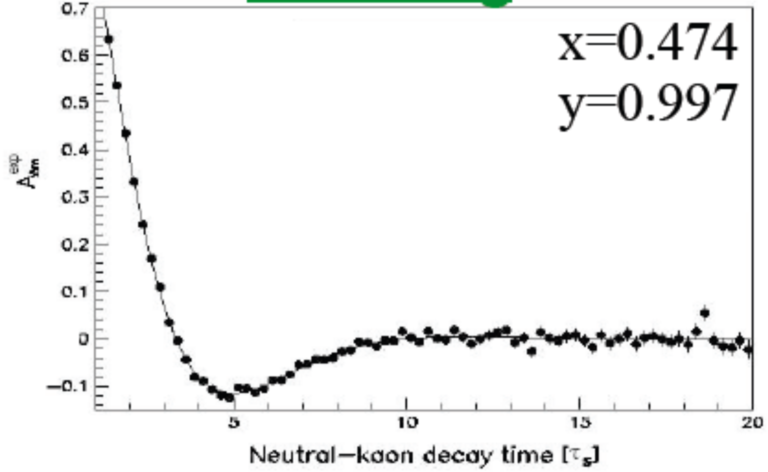




And the top was discovered 8 years afterwards!

The missing tile

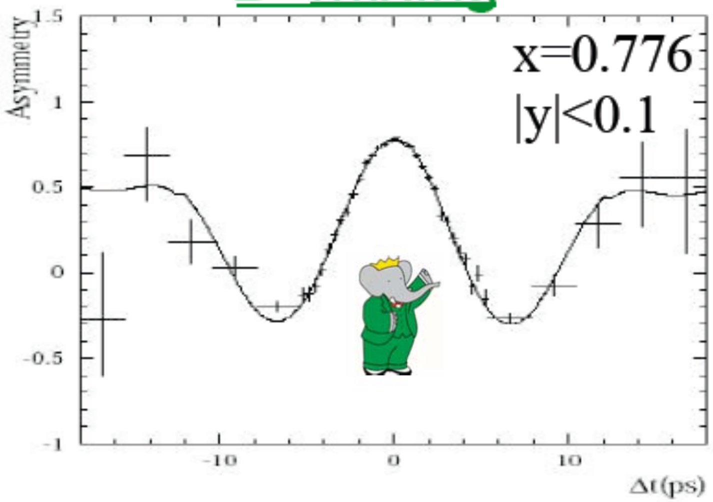
K^0 mixing



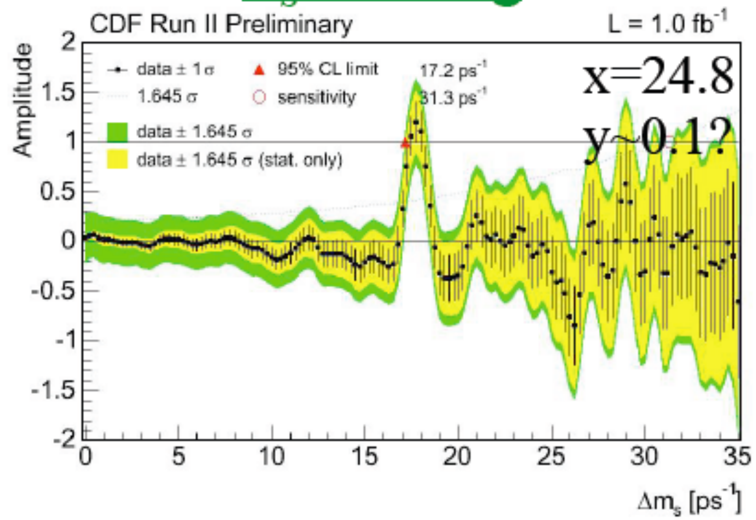
D^0 mixing

?

B^0 mixing



B_s^0 mixing



Charm Meson Mixing

Short and **Long** distance

- Prediction x and y

$$\left(\mathrm{M}-\frac{i}{2}\Gamma\right)_{ij} = \frac{\langle D_i|H_{\mathrm{eff}}|D_j\rangle}{2m_D} = m_D^{(0)}\delta_{ij}$$

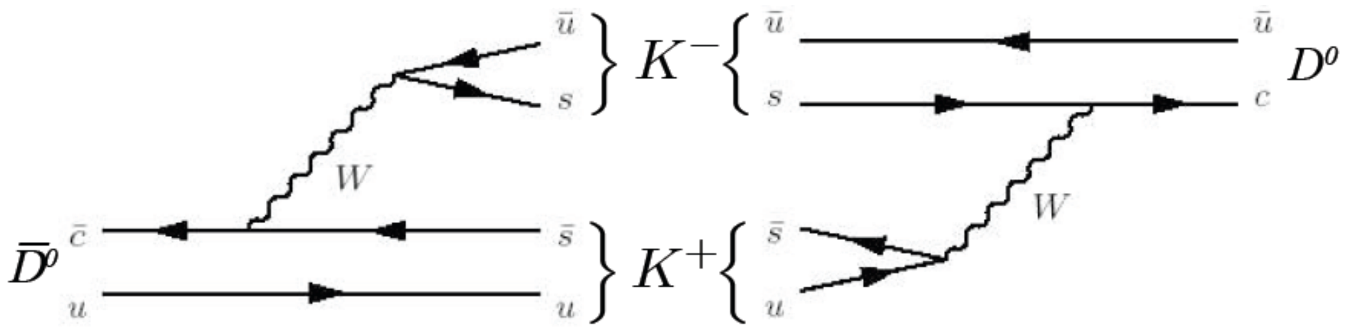
$$+ \frac{\langle D_i|H_w|D_j\rangle}{2m_D} + \frac{1}{2m_D}\sum_n \frac{\langle D_i|H_w|n\rangle\langle n|H_w|D_j\rangle}{m_D^{(0)}-E_n+i\epsilon}.$$

x *VIRTUAL* states

NP here??

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

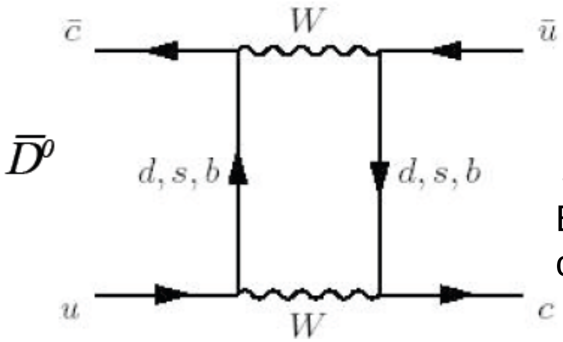
Sum of intermediate **REAL states**



Makes it difficult to predict SM expectation

SM Prediction for Charm Mixing

SM charm mixing box has down-type quarks in loop



Box diagram contribution

Effective GIM suppression:

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

bottom quark ruled out by V_{CKM}

$$x \sim 10^{-5}$$ Tiny!

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

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 !!!

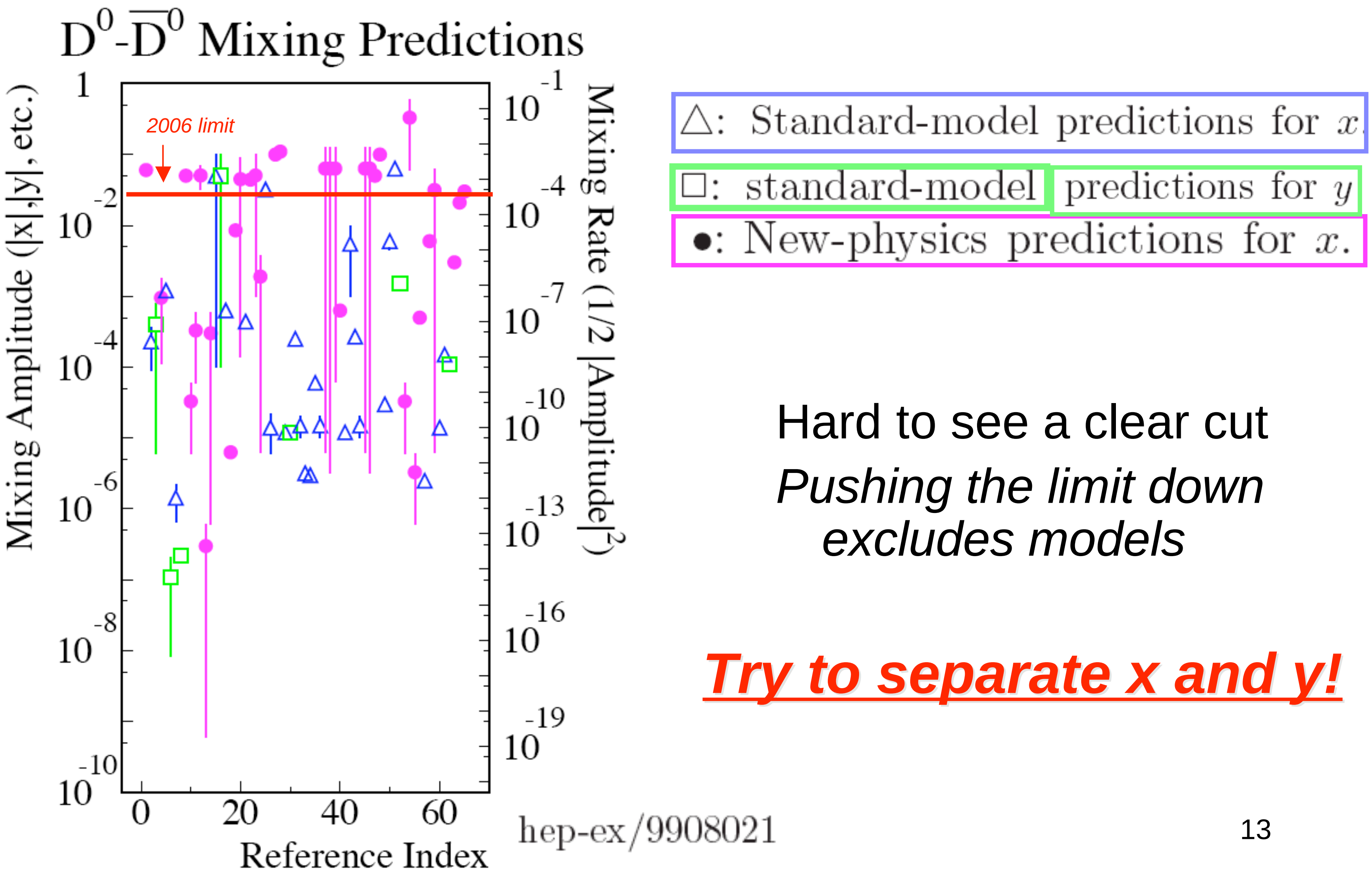
(HQET, propagation of common hadronic states,…)

SU(3) breaking effect more important for y

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

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

New Physics in Charm Mixing ?



hep-ex/9908021

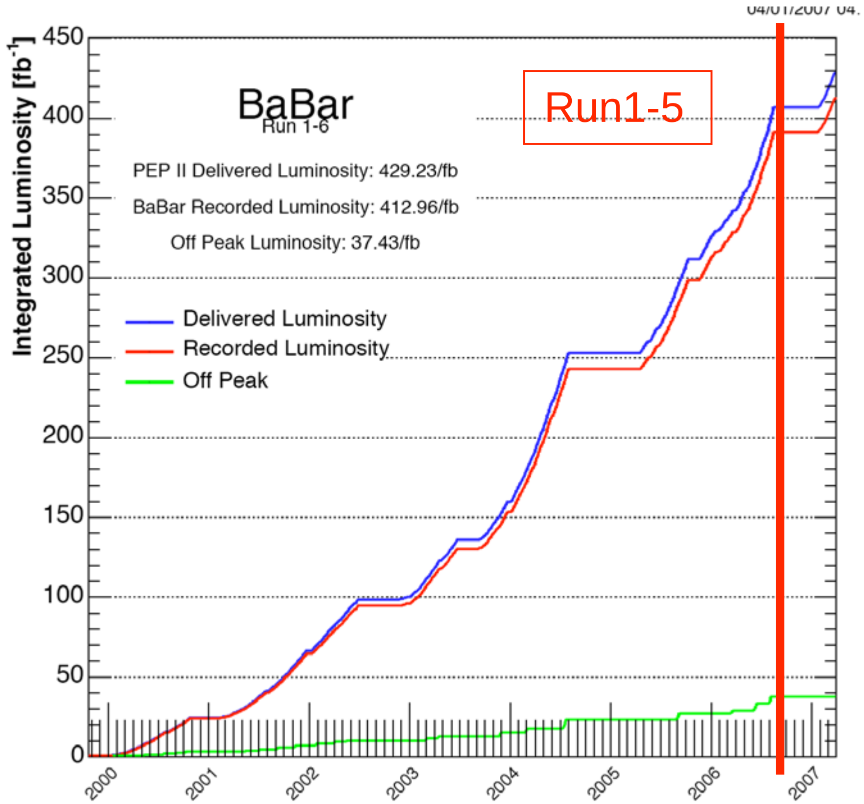
Hard to see a clear cut

Pushing the limit down excludes models

Try to separate x and y!

Experimental Searches

Charm physics with B-factory



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

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

$\sigma(c\bar{c})$ =1.3 nb ➡

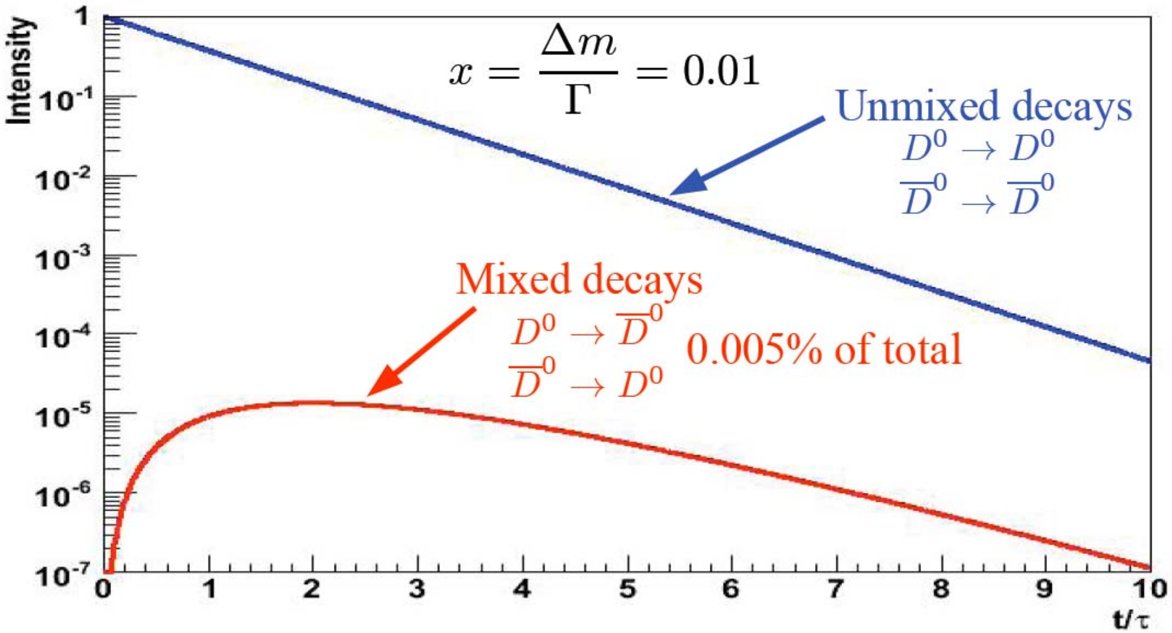
Millions of reconstructed charm hadrons

BaBar is also a charm factory

- Run1-5 (1999-2006), more than 500M $c\bar{c}$ events

The Technique

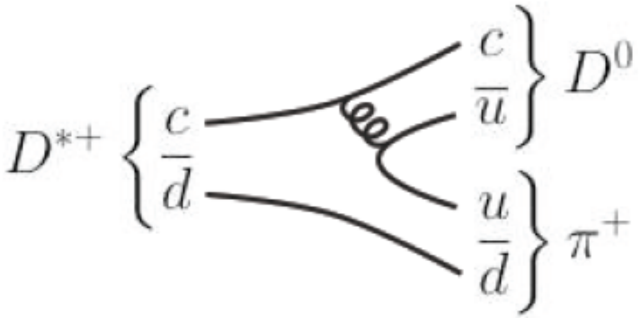
- Produce clean sample of D^0 and $\overline{D}^0$
- Identify flavor (D^0 or $\overline{D}^0$?) at decay time
- Measure rate of mixed decays as function of time



In principle it should be easy…

$D^0 \to K^-\pi^+$: Flavor tagging

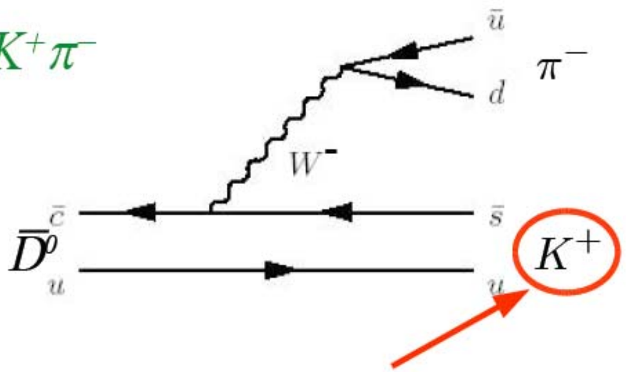
Use D^0 from $D^{*+} \to D^0\pi^+$ decays:



Flavor at production

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

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



Charge of K identifies decay flavor

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

Flavor at decay

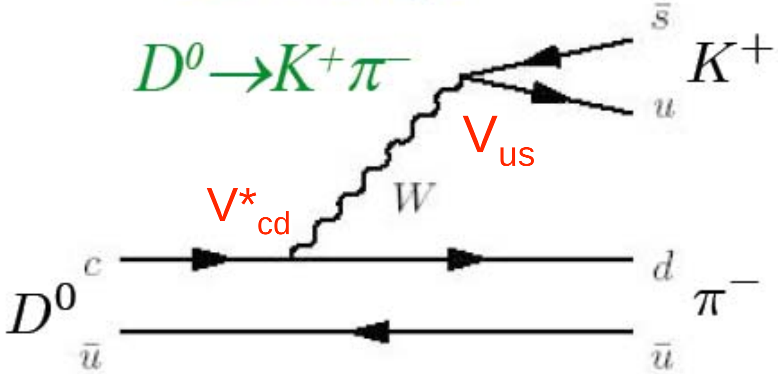
- Same flavour: Wrong-Sign (WS) mixing *may* have occured
- Opposite flavour: Right-Sign (RS) unmixed events

Double-Cabibbo Suppressed Decays

Hadronic decays do not uniquely identify decay flavor

Get unmixed wrong-sign decays from DCS decays

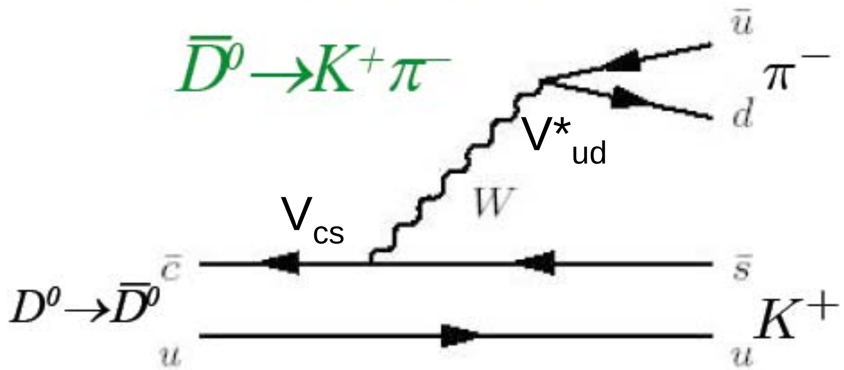
DCS decay:



Relative rate ~0.3%

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

Mixed decay:



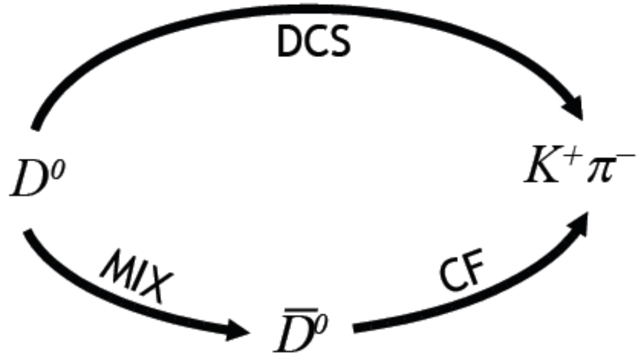
Relative rate: 0.005% (for x=0.01)

…Not so easy !

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)

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

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

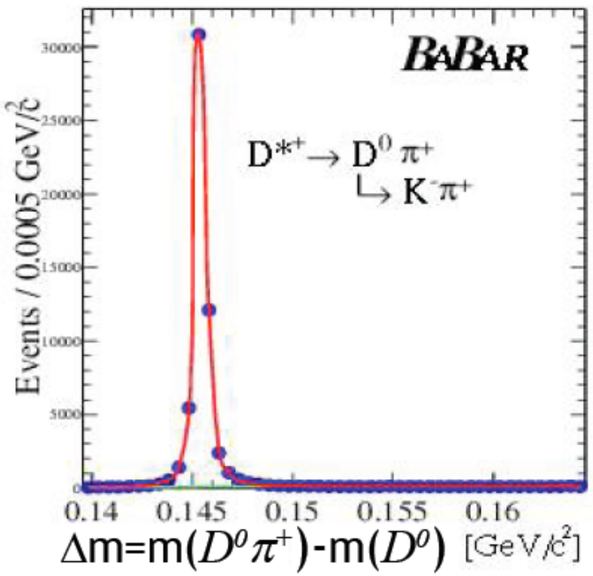
$$R_M \approx \frac{1}{2}(x^2 + y^2)$$

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

<u>D^0 selection:</u>

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

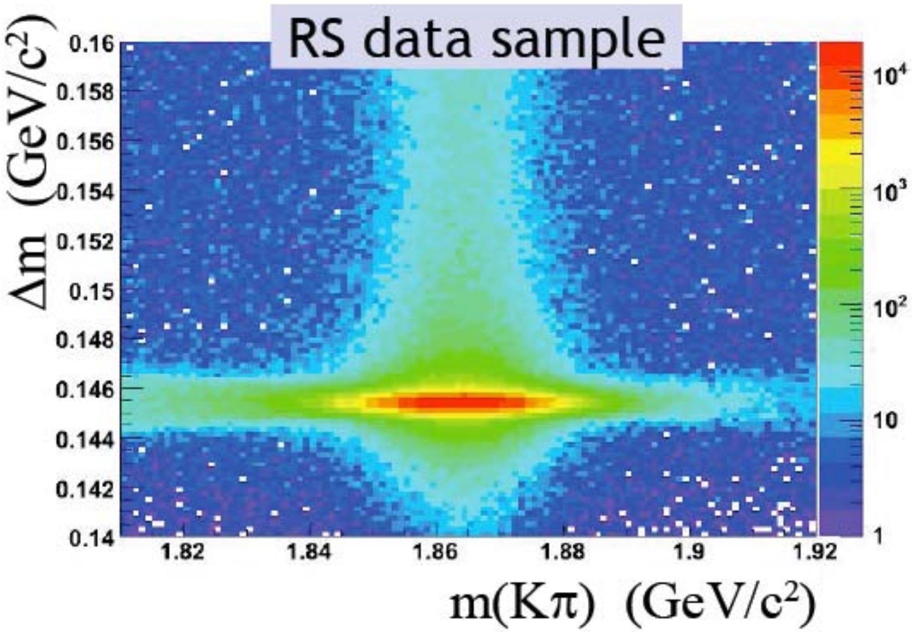
<u>Slow π selection:</u>

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

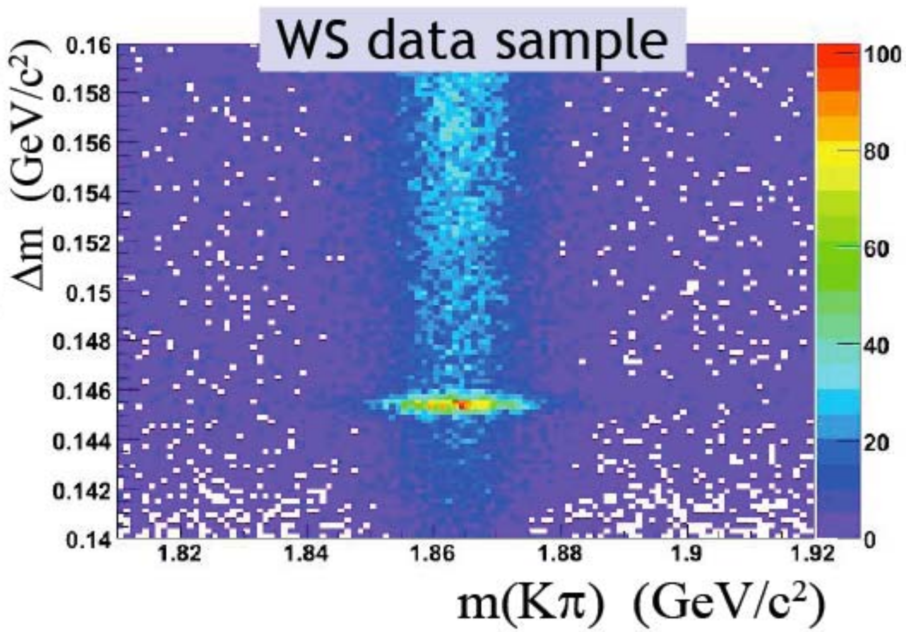
$\Delta m = m(K\pi\pi_s) - m(K\pi)$

RS and WS data set

1,229,000 RS events



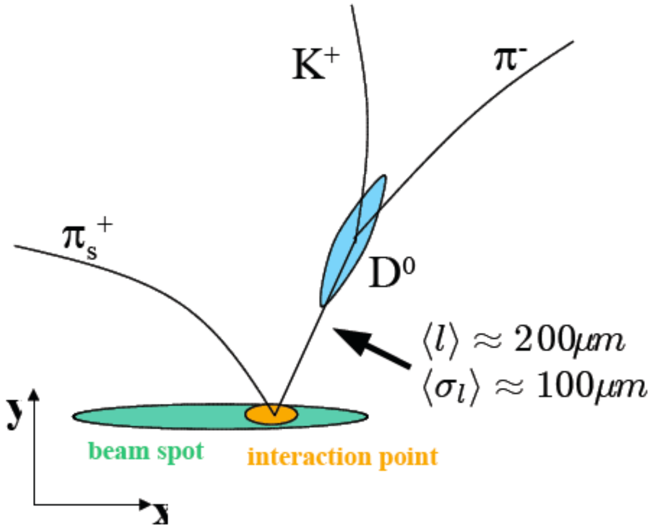
64,000 WS events



<u>Fit to m(Kπ) and Δm distribution:</u>

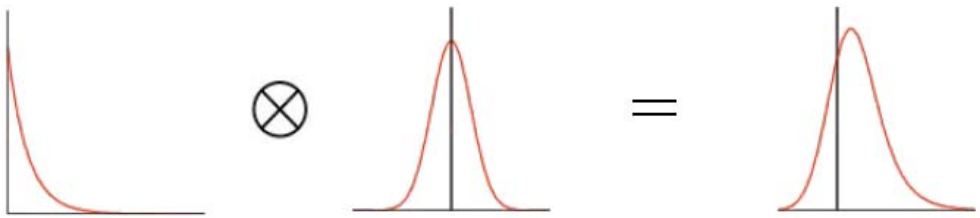
- RS and WS samples fit simultaneously
- Signal and some background parameters shared
- All parameters determined in fit to data, not MC

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



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

- Resolution function from RS sample

Background components

Random π_s:

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

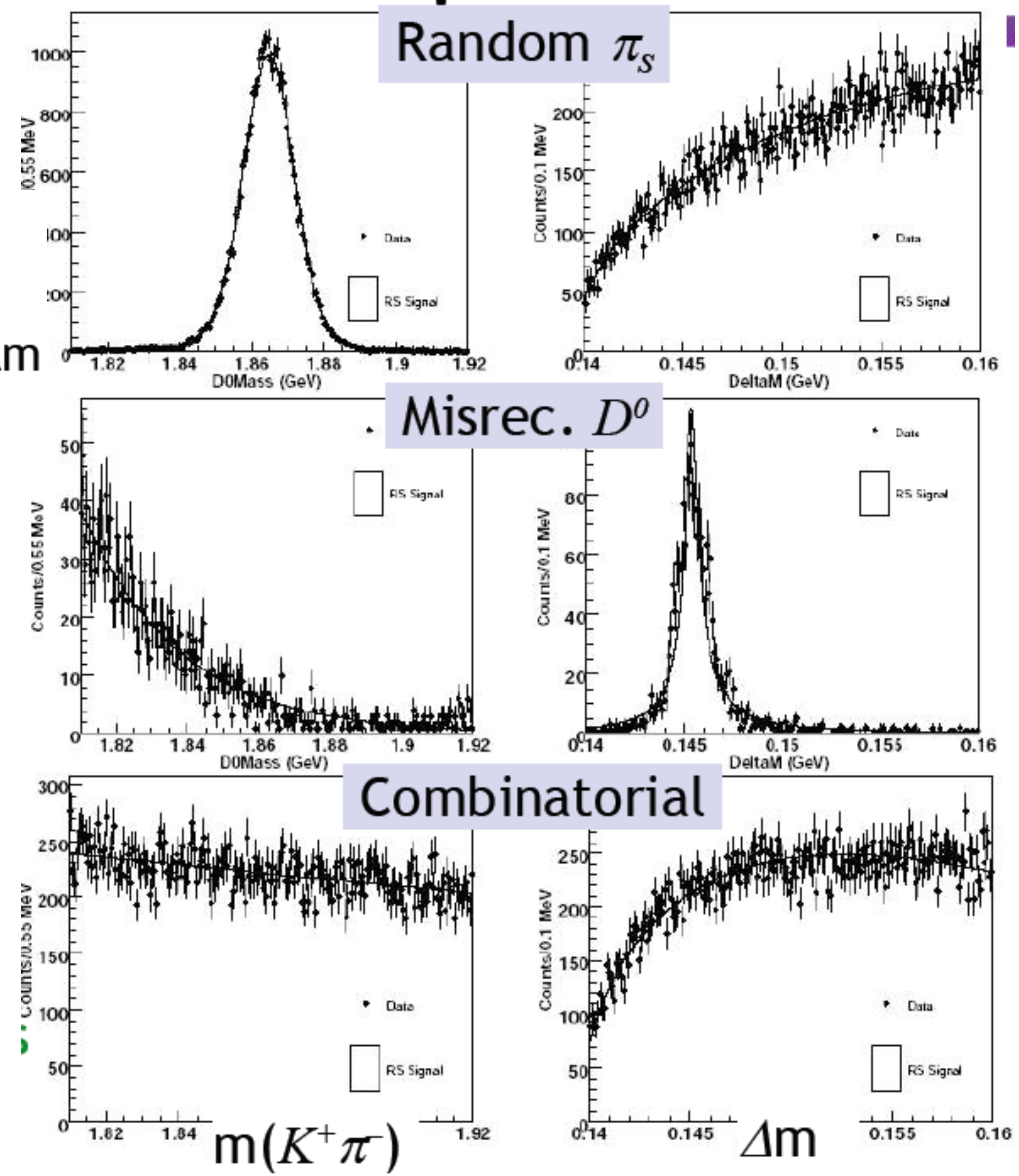
Misreconstructed D^0:

- 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:

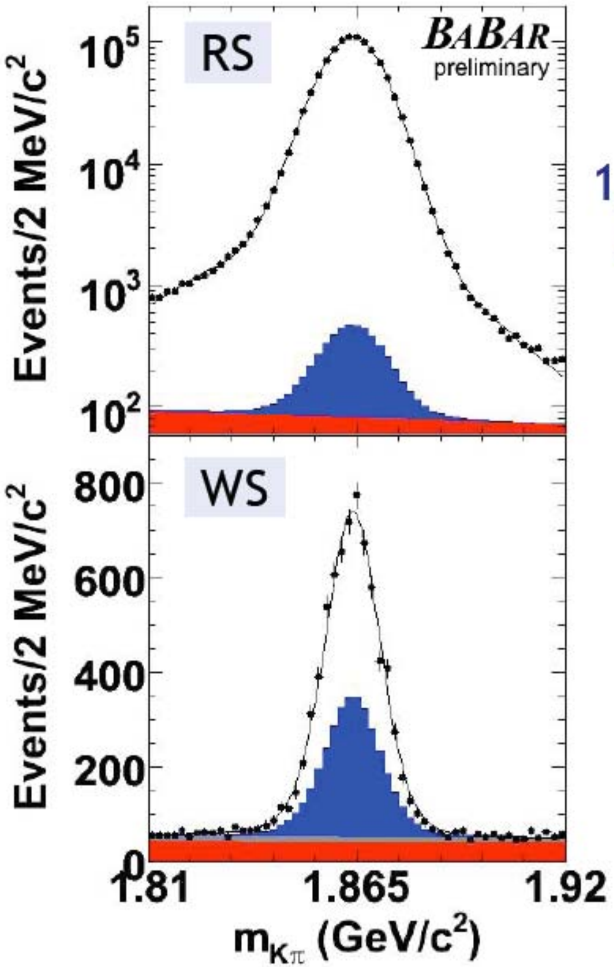
- Random tracks

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



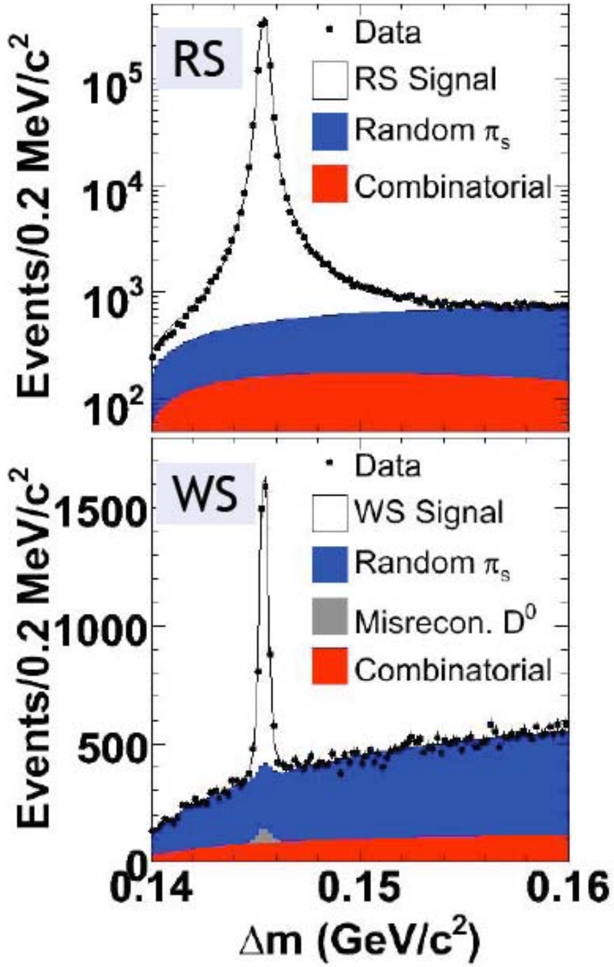
Signal Extraction

384 fb^{-1}



RS signal:
1,141,500±1200
combinations

WS signal:
4,030±90
combinations



RS decay time analysis

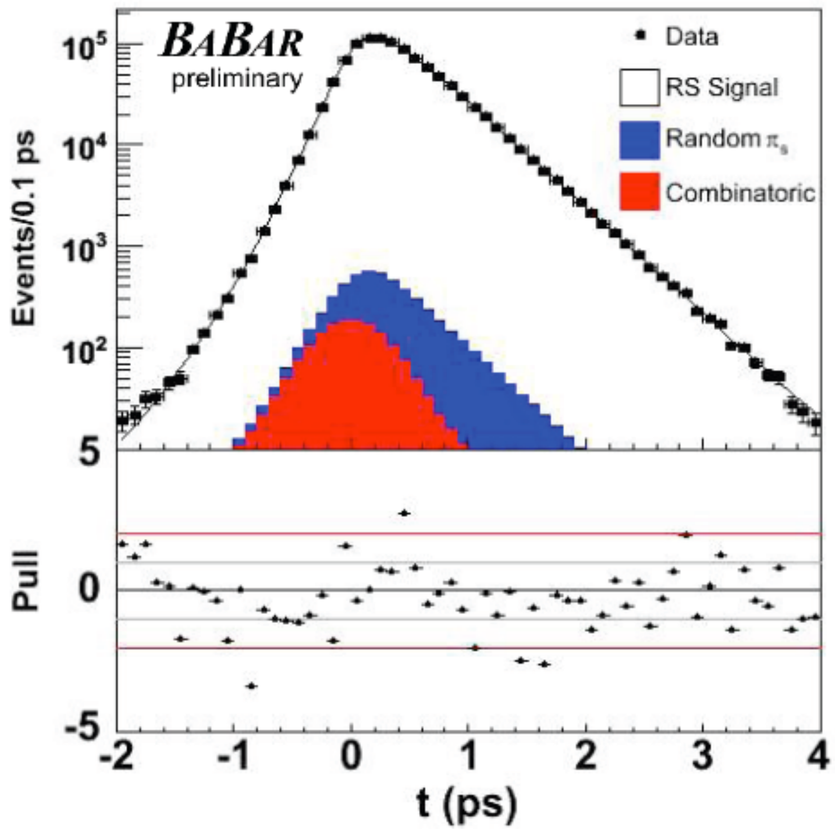
D^0 lifetime and
time resolution function
from RS sample

τ=(410.3±0.6(stat.)) fs

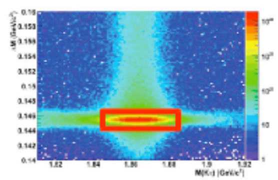
Consistent with PDG
(410.1±1.5 fs)

Systematics dominated
by resolution function

RS decay time, signal region



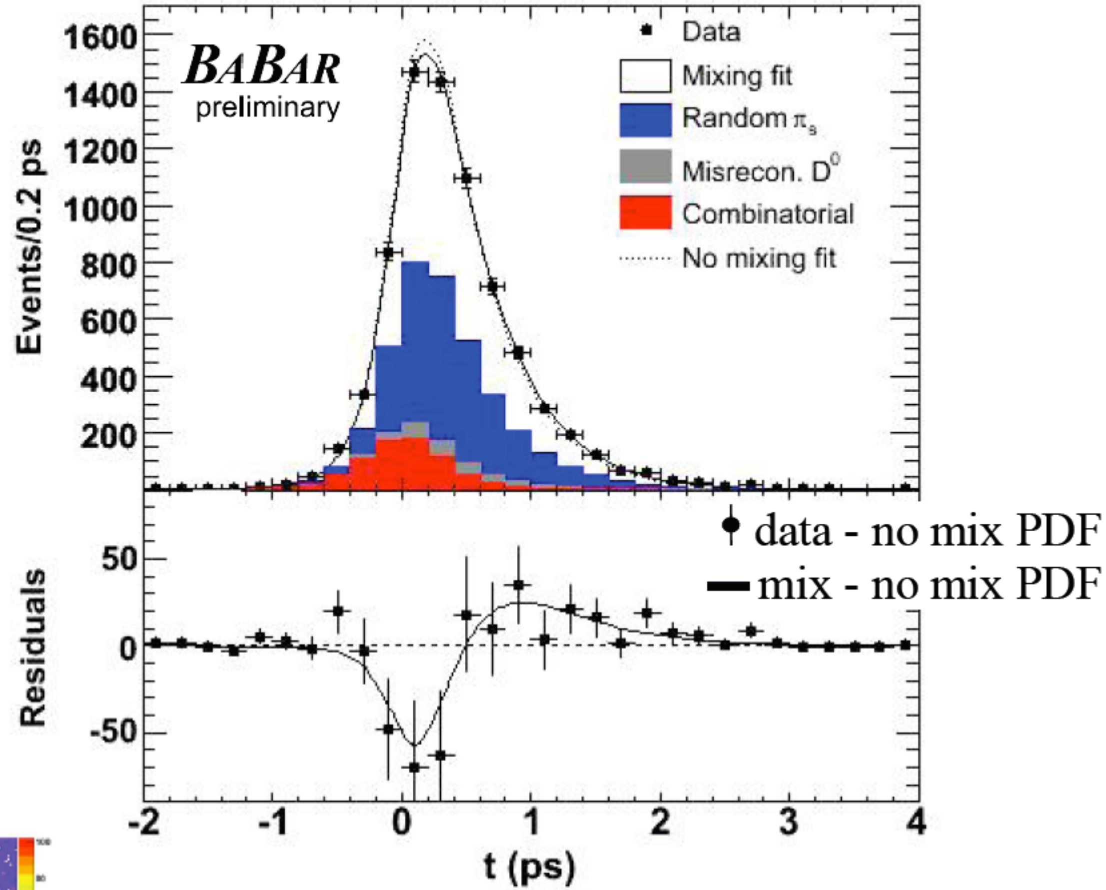
plot selection:
1.843<m<1.883 GeV/c²
0.1445<Δm< 0.1465 GeV/c²



WS decay time with mixing

384 fb^{-1}

WS decay time, signal region



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

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

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

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

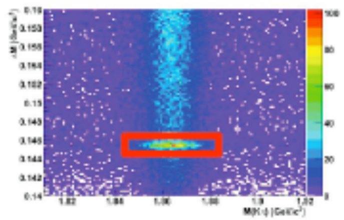
x'^2, y' correlation: -0.94

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

signal region:

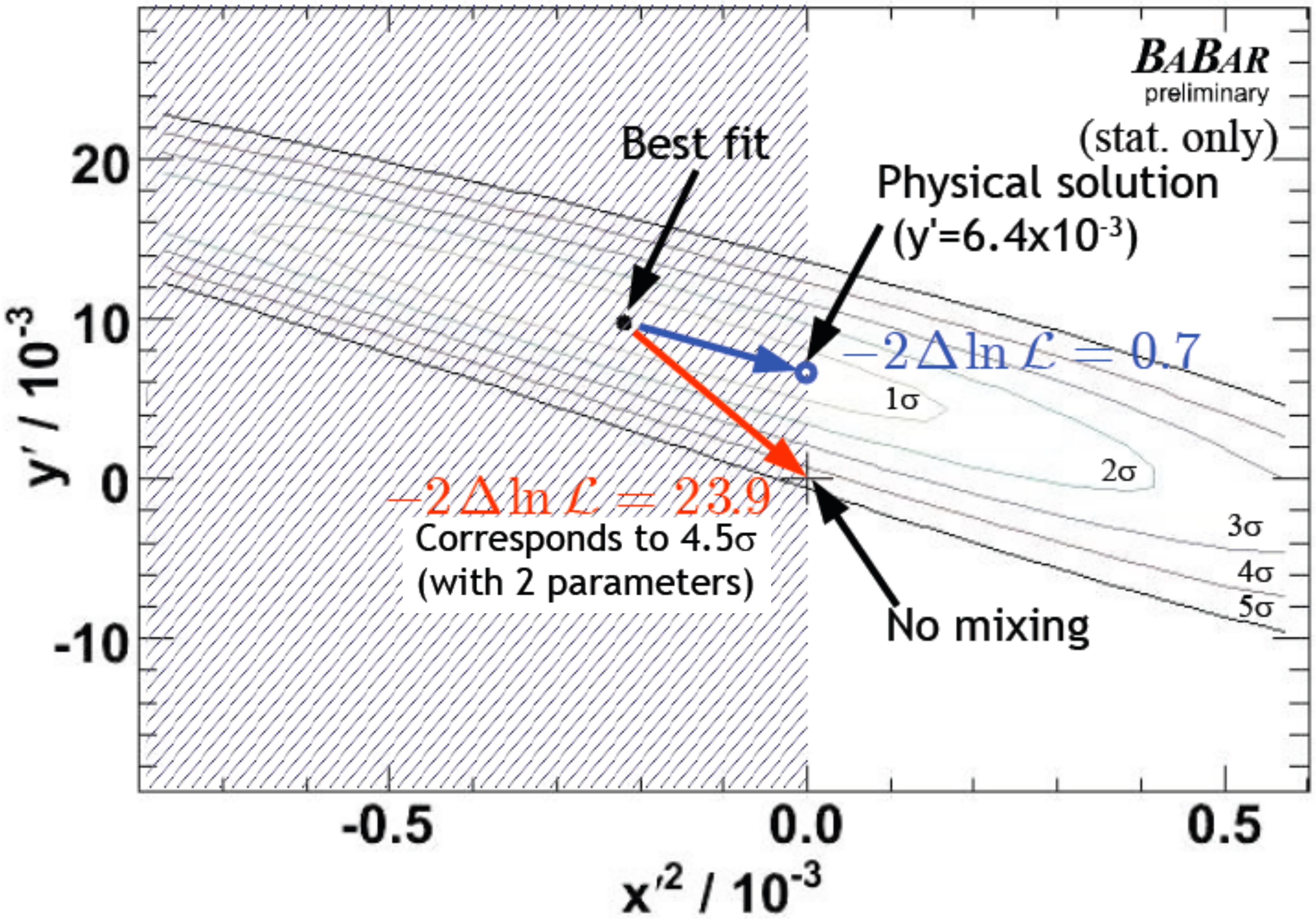
$1.843<m<1.883$ GeV/c^2

$0.1445<\Delta m<0.1465$ GeV/c^2



Evidence for D^0 mixing!

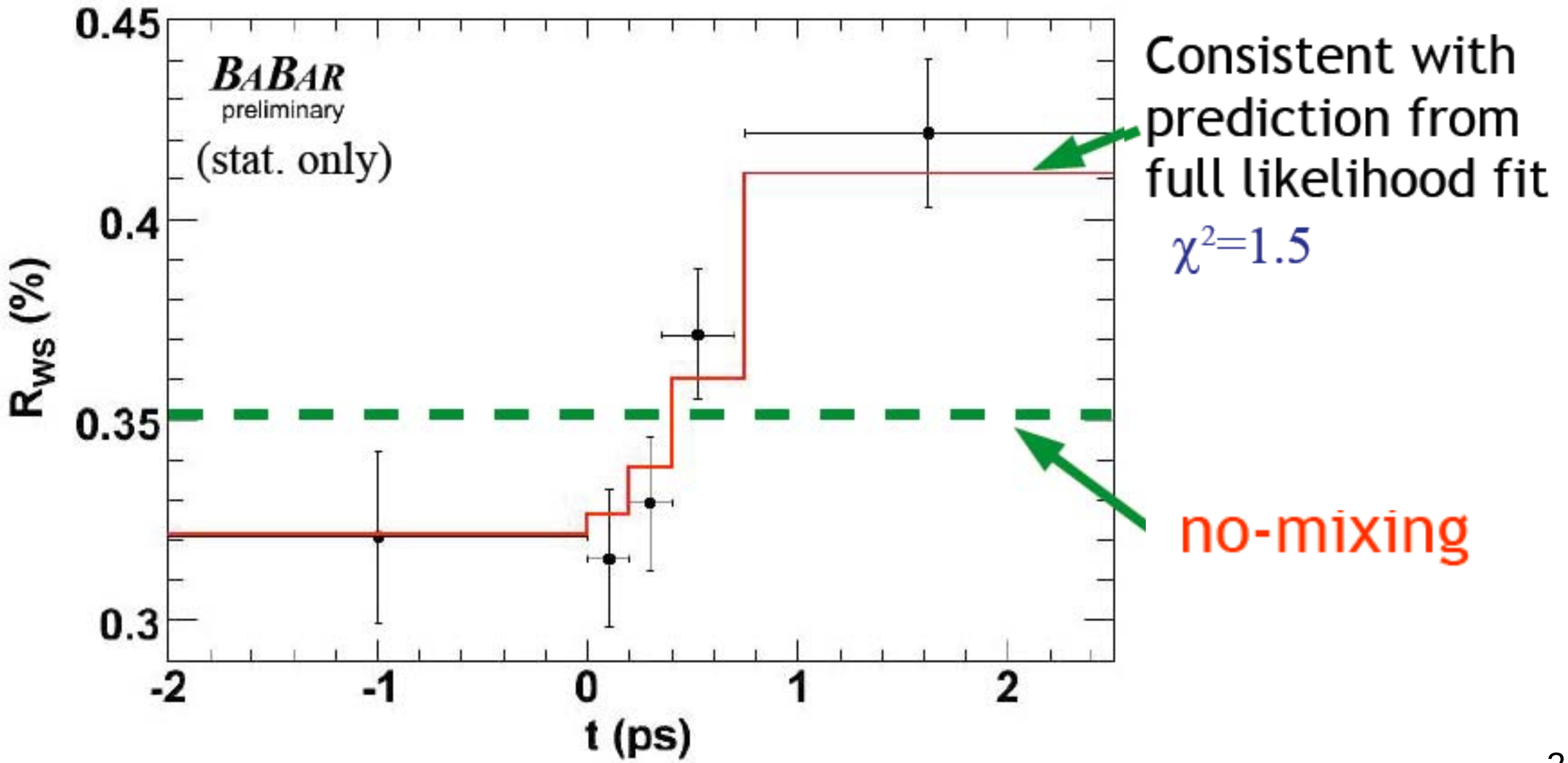
Best fit solution in unphysical region ($x'^2<0$)



Including systematics decreases signal significance 3.9 σ

Validation: $m(K\pi)$ 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

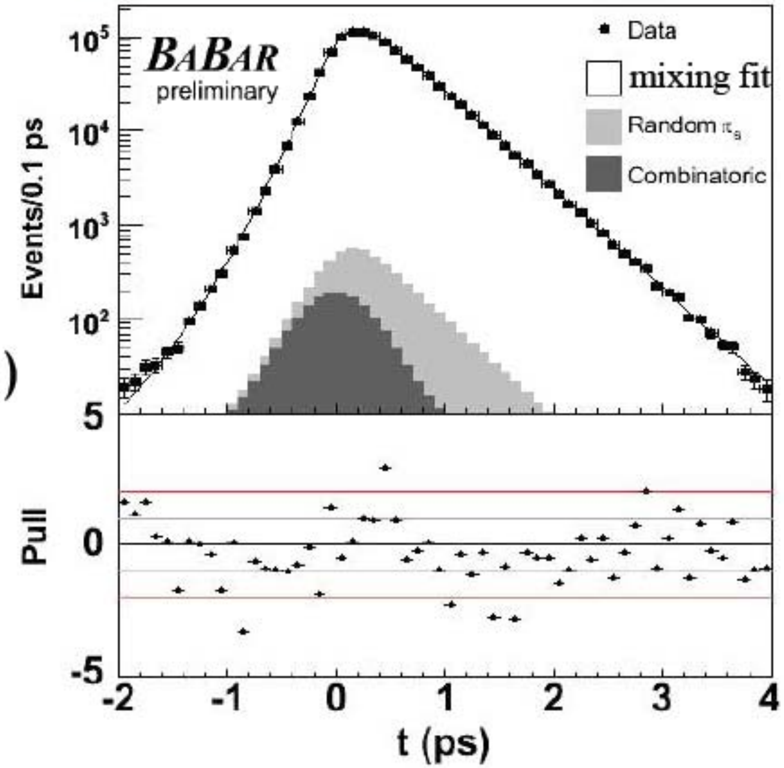
x'^2: $(-0.01\pm0.01)\times10^{-3}$

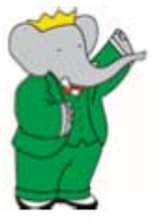
y': $(0.26\pm0.24)\times10^{-3}$

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

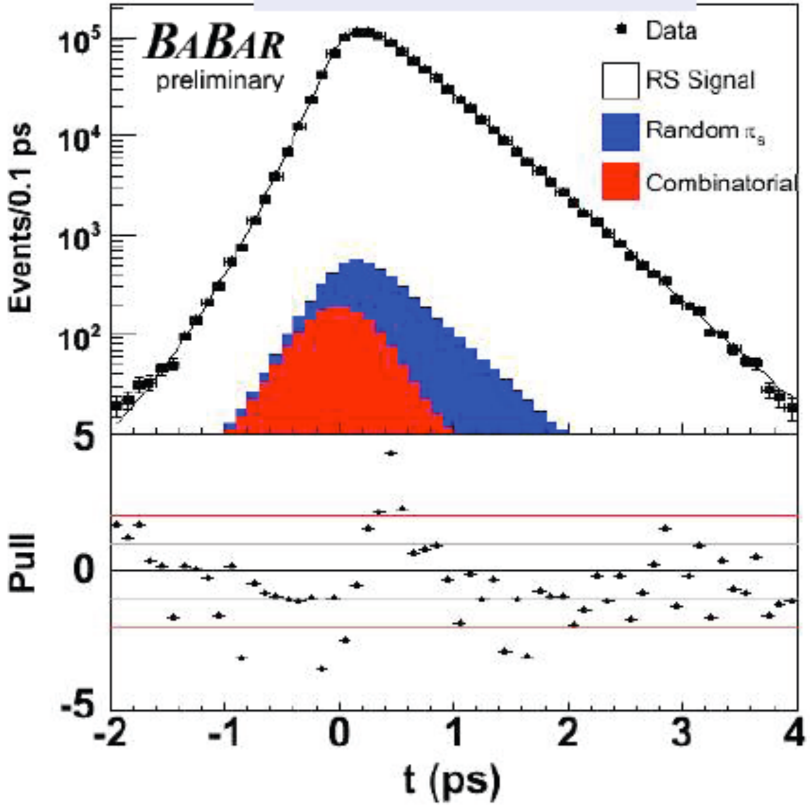
Effect is not seen in MC
- probably due to misalignment

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



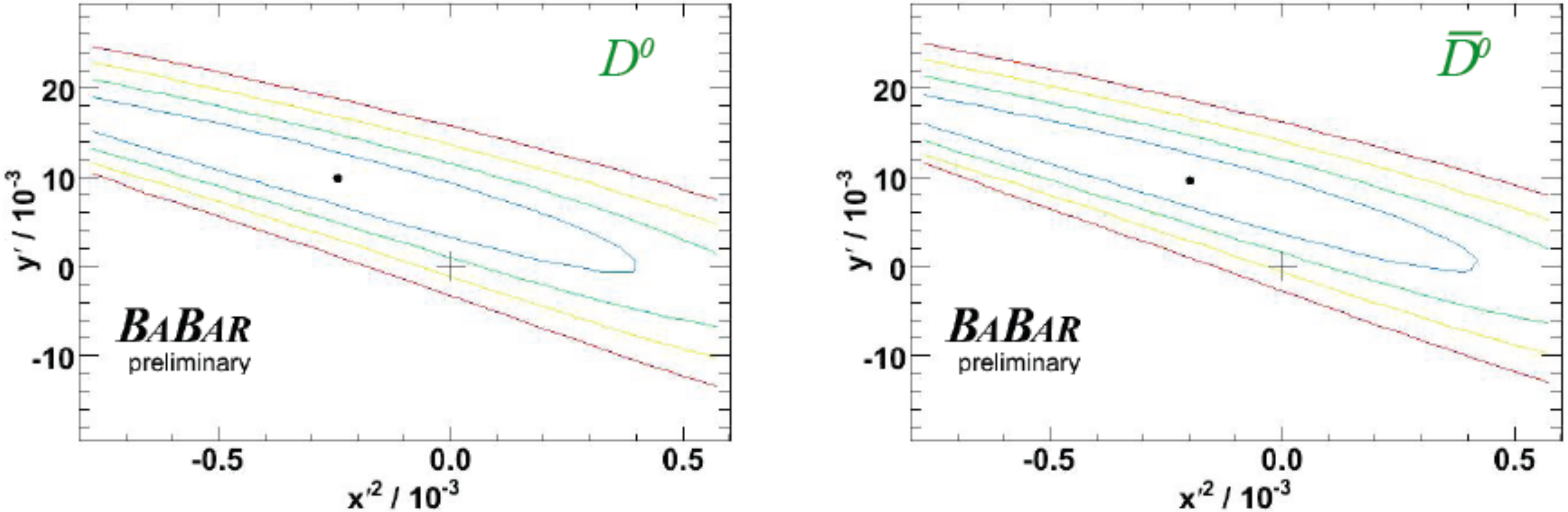
Allowing for CP violation

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 !

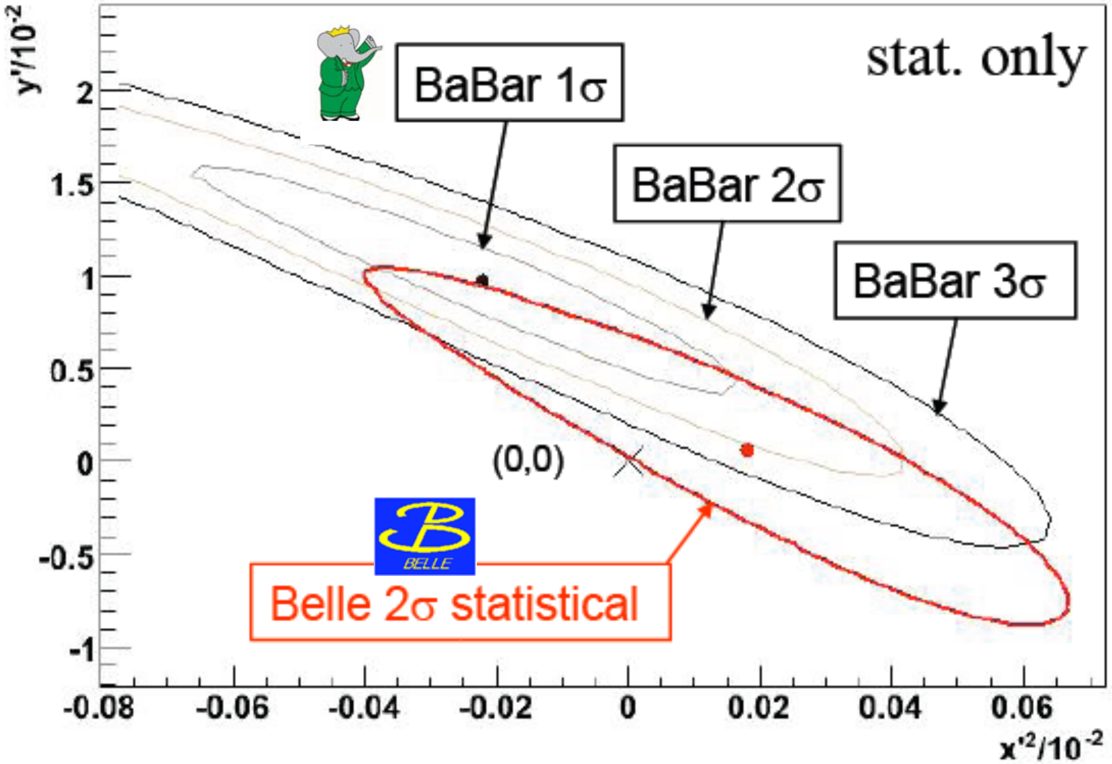


No evidence for CP violation found

Kπ analysis from Belle

hep-ex/0601029

Results consistent within 2σ:



More Results…!

Belle y_{CP} Measurement

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

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

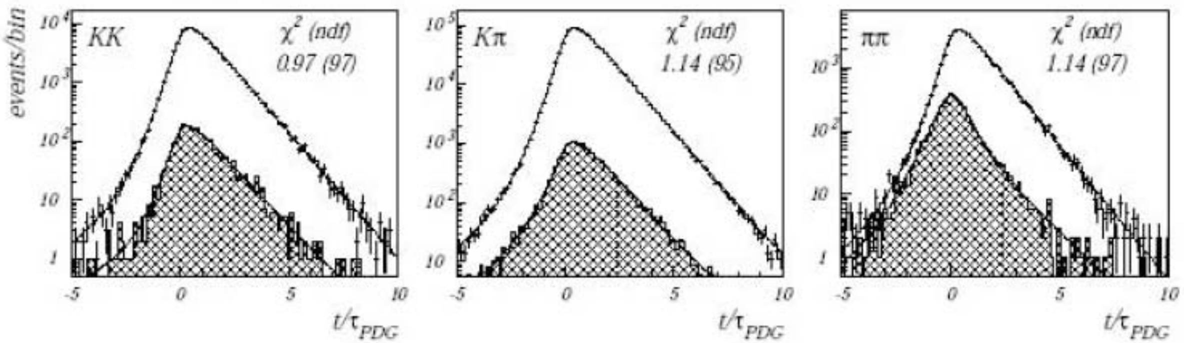
$$A_m = 1 - |q/p|$$

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

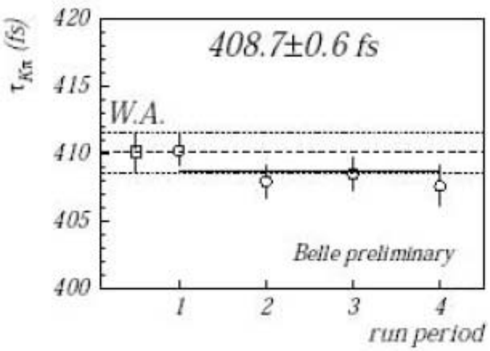
ϕ_D= mixing phase

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	$1.25\pm0.39\pm0.28$	$0.15\pm0.34\pm0.16$
$\pi\pi$	$1.44\pm0.57\pm0.42$	$-0.28\pm0.52\pm0.30$
$KK+\pi\pi$	$1.31\pm0.32\pm0.25$	$0.01\pm0.30\pm0.15$

Belle hep-ex/0703036

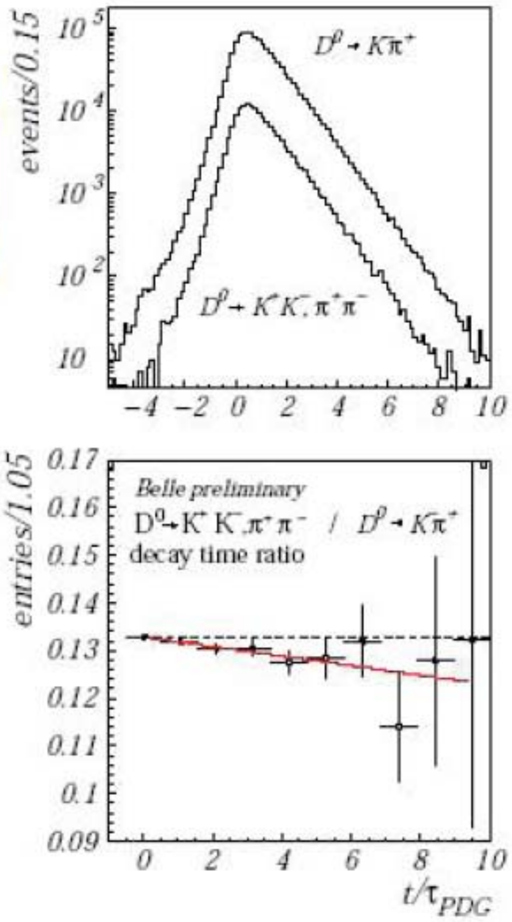
Belle preliminary (540 fb^{-1})

$$y_{CP} = 1.31\pm0.32\pm0.25\ \%$$

$> 3\sigma$ above zero
(4.1σ stat. only)
first evidence for $D^0-\bar{D}^0$ mixing

$$A_\Gamma = 0.01\pm0.30\pm0.15\ \%$$

no evidence for CP violation



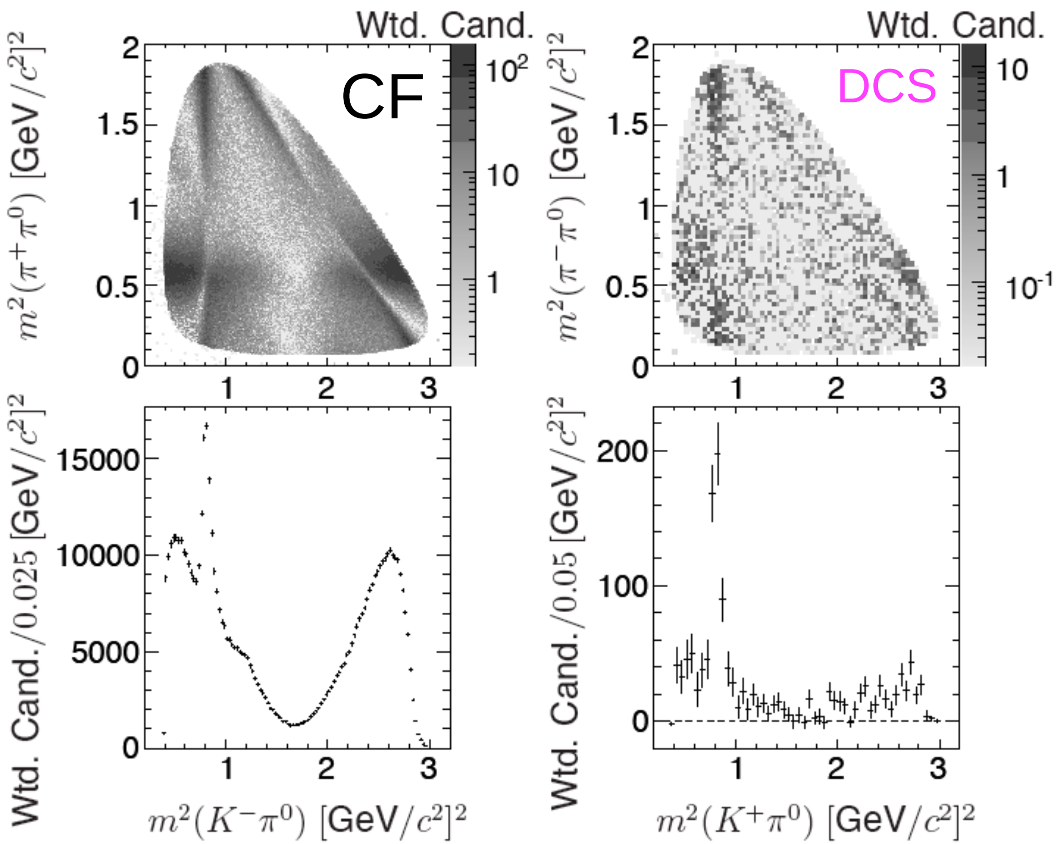
Separating x and y

- $K\pi$ 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 $K^-\rho^+$

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

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

Select special region of Dalitz plot

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

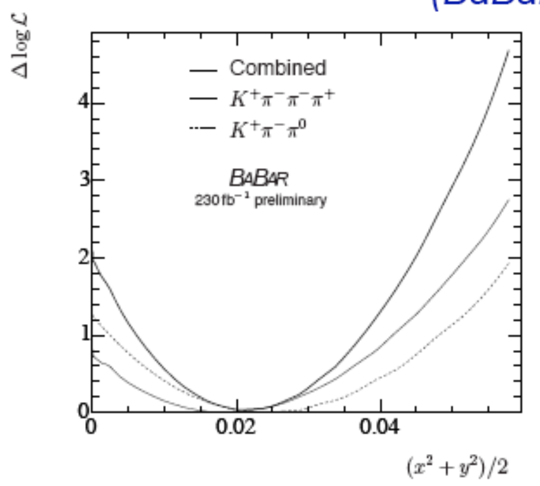
$$\widetilde{x}' = x\cos\widetilde{\delta} + y\sin\widetilde{\delta}$$
$$\widetilde{y}' = y\cos\widetilde{\delta} - x\sin\widetilde{\delta}$$

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.)

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

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

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

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

Time dependent Dalitz plot distribution

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

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

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 and y

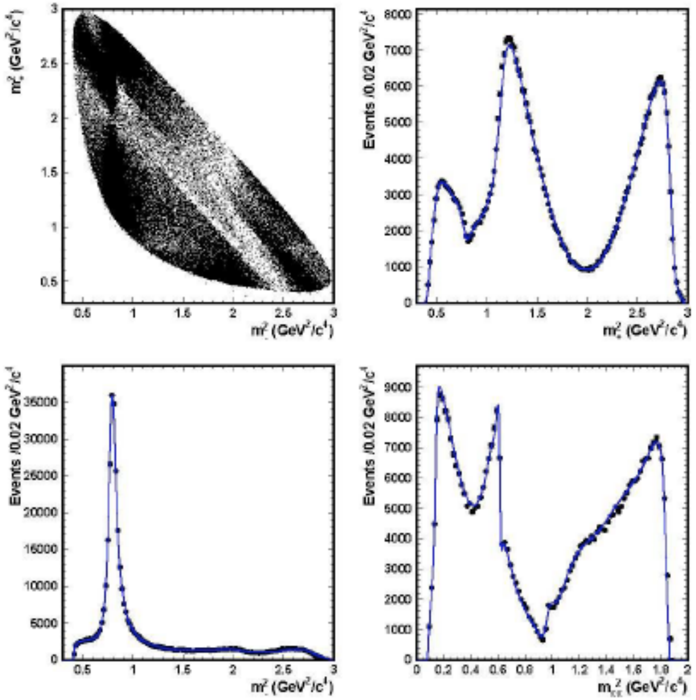
Both flavor ($K^{*-}\pi^+/K^{*+}\pi^-$) final states in the same Dalitz plot!

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

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

Belle, 540 fb^{-1}

Dalitz fit

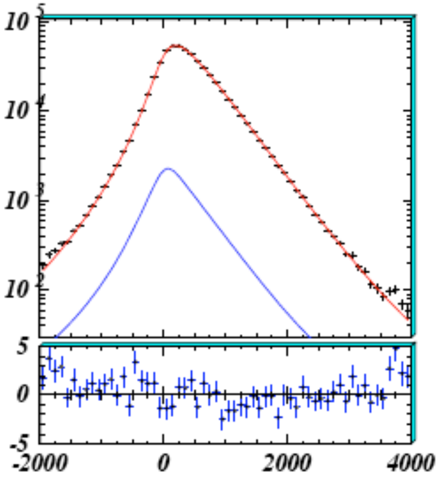


Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.629 ± 0.005	134.3 ± 0.3	0.6227
$K_0^*(1430)^-$	2.12 ± 0.02	-0.9 ± 0.5	0.0724
$K_2^*(1430)^-$	0.87 ± 0.01	-47.3 ± 0.7	0.0133
$K^*(1410)^-$	0.65 ± 0.02	111 ± 2	0.0048
$K^*(1680)^-$	0.60 ± 0.05	147 ± 5	0.0002
$K^*(892)^+$	0.152 ± 0.003	-37.5 ±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

Belle $D^0 \to K_S\pi^+\pi^-$ 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):

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

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

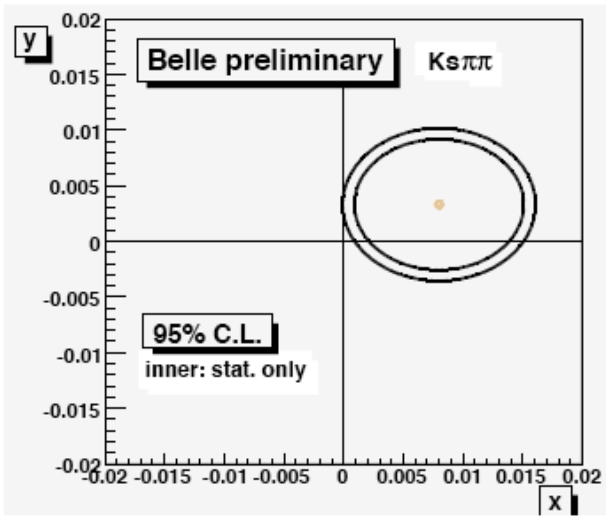
Systematics

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



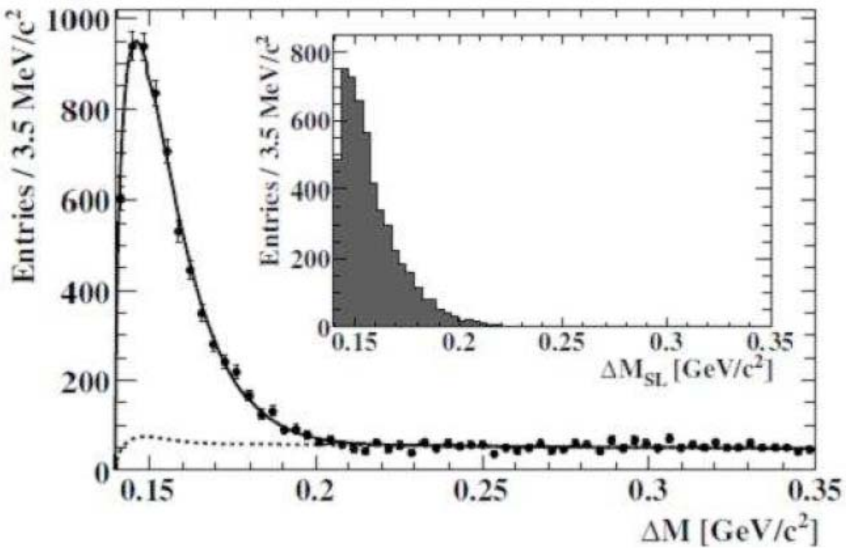
D-mixing with Semileptonic decay

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

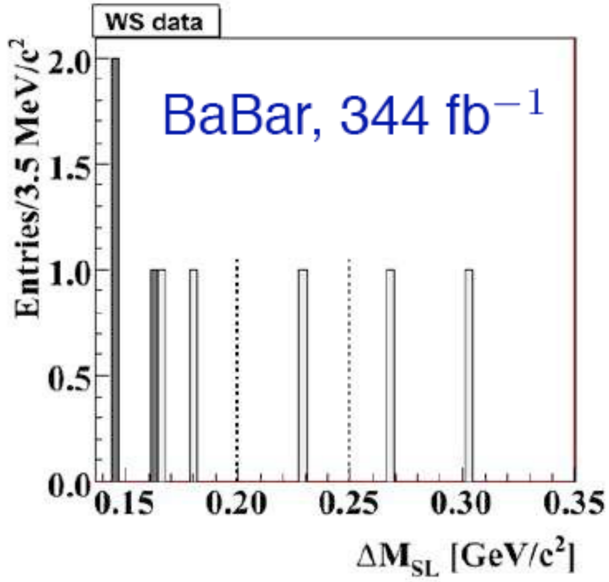
No DCS sl. ! $A_f = \bar{A}_{\bar{f}} = 0 \quad r(t) = \frac{e^{-t}}{4}(x^2 + y^2)\, t^2 \left|\frac{q}{p}\right|^2$

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

ΔM RS events



ΔM WS events



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

Measuring δ at ψ(3770) [CLEO-c]

by exploting the coherent production

$D_{CP\pm}$

neutral D CP eigenstate

ψ(3770) decay conserves CP

Need to run On threshold

- 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%,

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

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

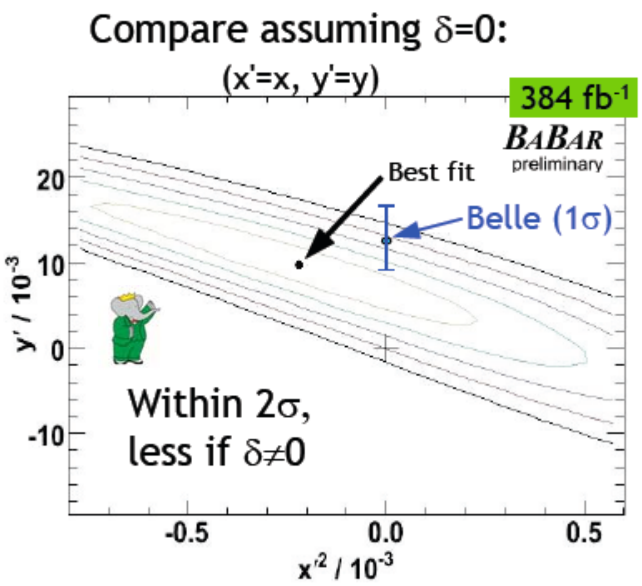
New results from Belle

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

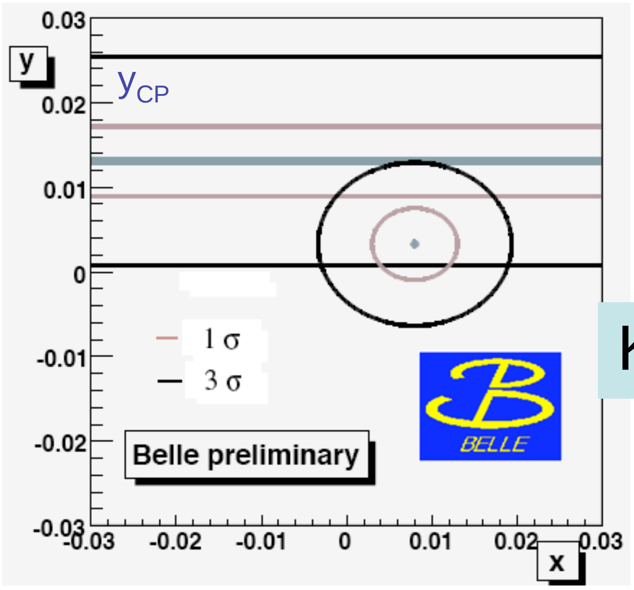
$$x = 0.80 \pm 0.29 \pm 0.17\ \% \ (2.4\sigma)$$

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

» BaBar $K_S\pi\pi$ on-going



y_{CP}



$K_S\pi\pi$

Interpreting the Results

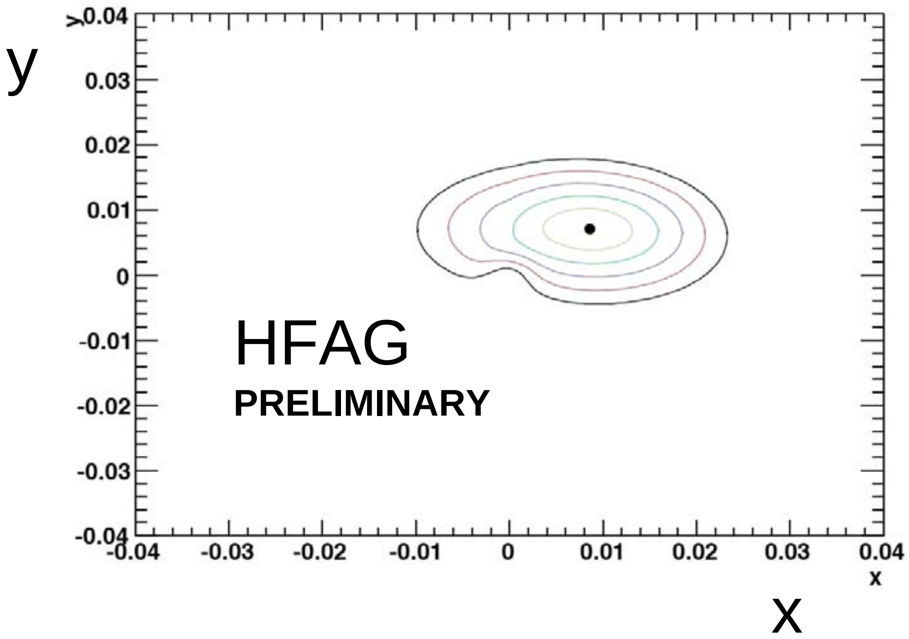
D^0 and $\bar{D}^0$

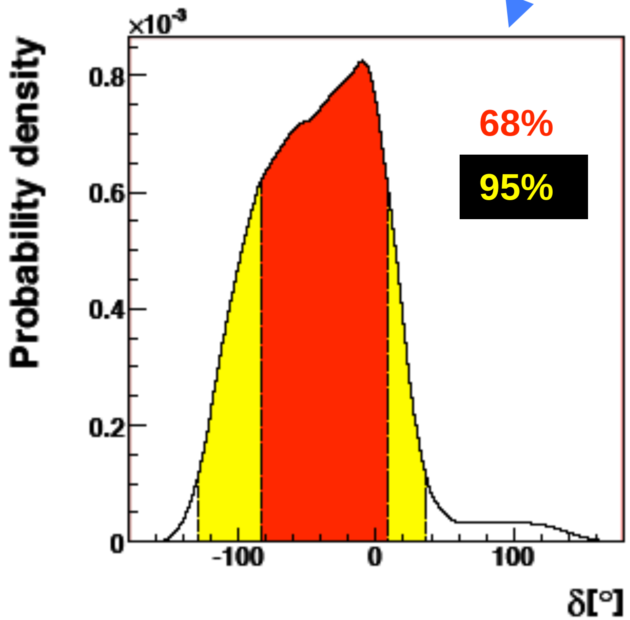
weak phase $2\phi_D$ of the mixing amplitude

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

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

Ciuchini et al.
hep-ph/0703294

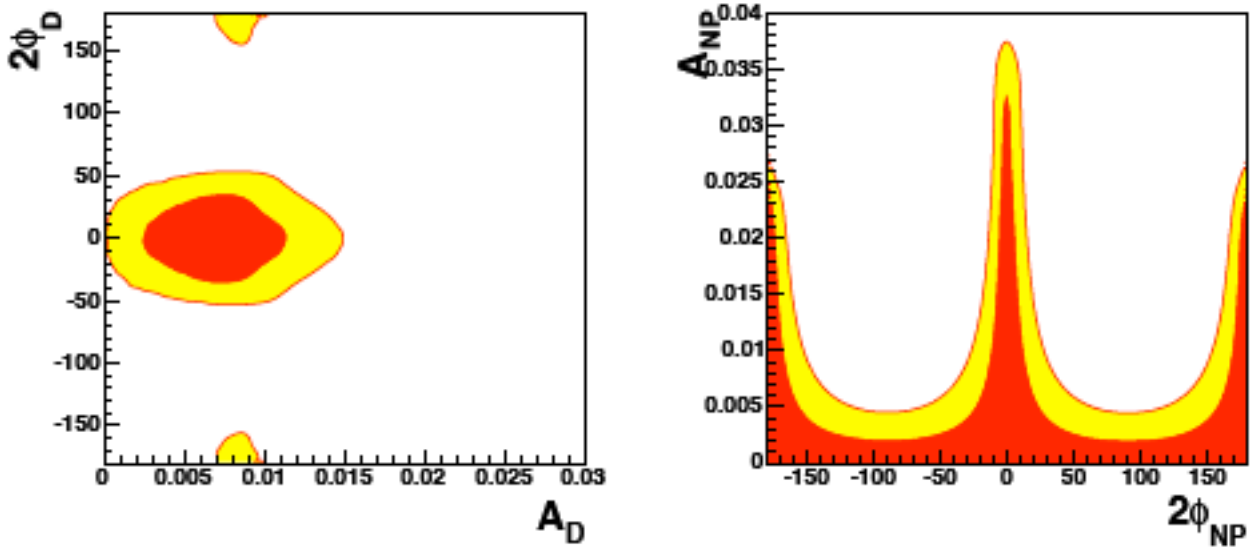




New Physics?

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

CP violation basically only in NP



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!