Charm and Tau Decays at B-Factories

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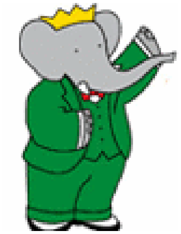
on behalf of the BaBar Collaboration

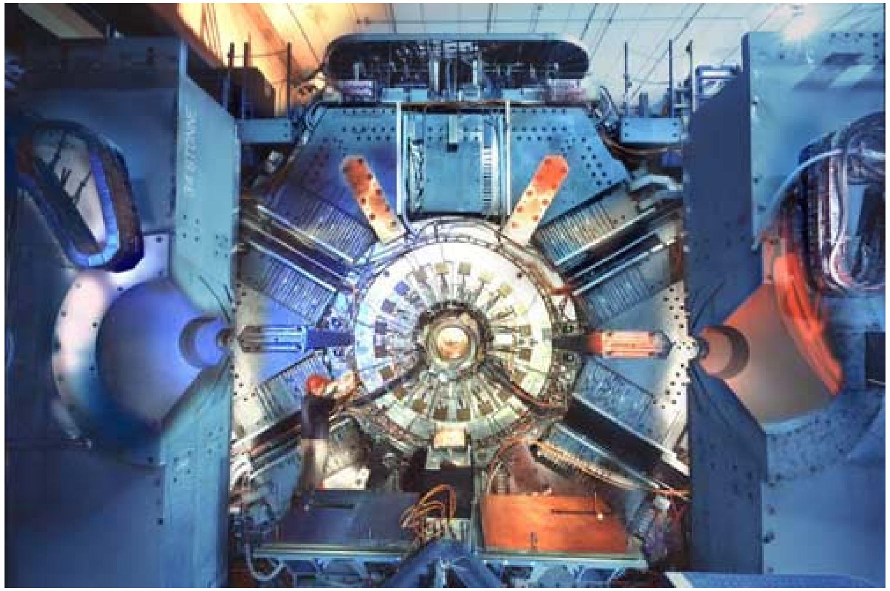
Les Rencontres de Physique de la Vallée d'Aoste

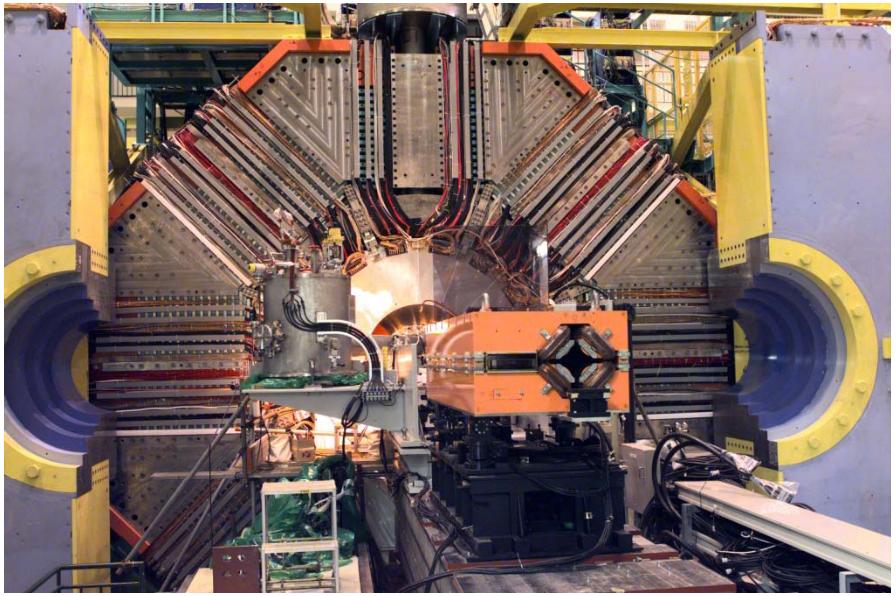
La Thuile, March 04, 2009



1. *B-Factories as Tau and Charm Factories*
2. *Tau Physics Results*
3. *Charm Physics Results*

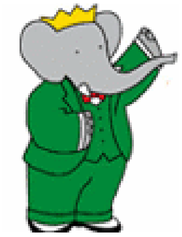
BELLE





B-Factories as Tau and Charm Factories

Production Cross section	Tau	Charm
	σ_{tt} ~ 0.92 nb	σ_{cc} ~ 1.30 nb

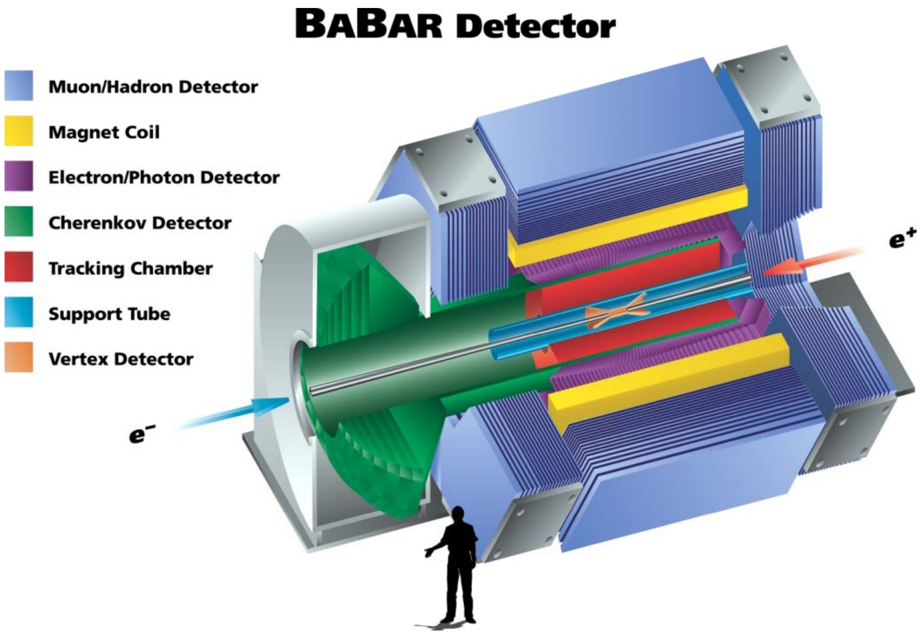


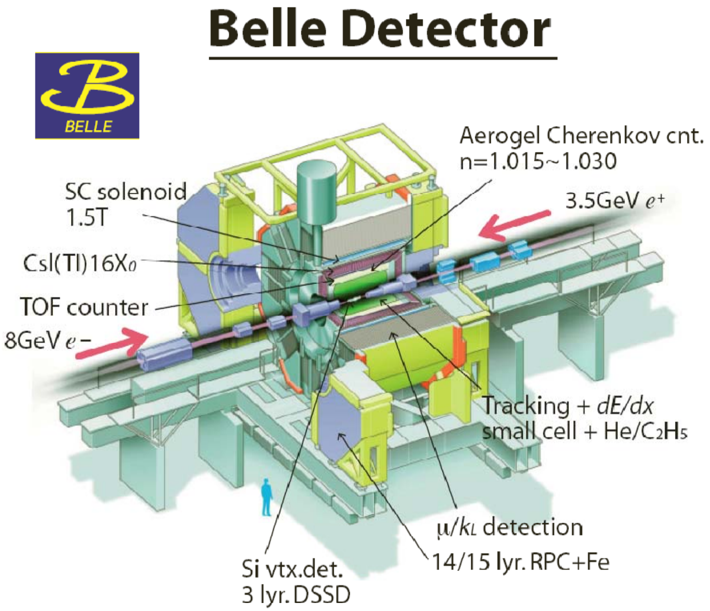
Rec. Luminosity
~530 fb^{-1}

Data collected
630M cc events,
440M τ pairs, etc.

Rec. Luminosity
~890 fb^{-1}

Data collected
1080M cc events,
740M τ pairs,





Tau Physics Results

Lepton universality

$|V_{us}|$ measurements

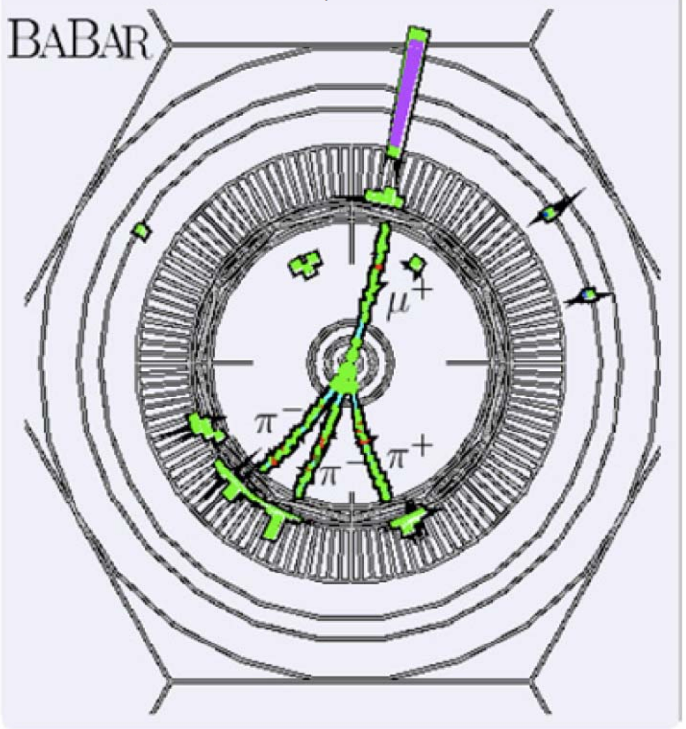
Lepton Flavor Violation decays

Tau Mass and and CPT test

Typical Tau Decay at B-Factories

- Tau pairs are produced back to back in the CM frame
- Taus decay into an odd number of charged tracks (1,3,5) and into any number of neutral pions (0,1,2,3)
- Makes for an easy topological identification and good background rejection
- One tau decays to the signal channel (signal side) while the other tau decays to a lepton or mesons and is used for tagging
- Typical selection criteria include
  - Energy and momentum of the signal side and tag particles
  - Topology of the event

$e^+e^- \to \tau^+(\to \mu^+\bar{\nu}_\tau\nu_\mu)\tau^-(\to \pi^-\pi^-\pi^+\nu_\tau)$



Lepton Universality

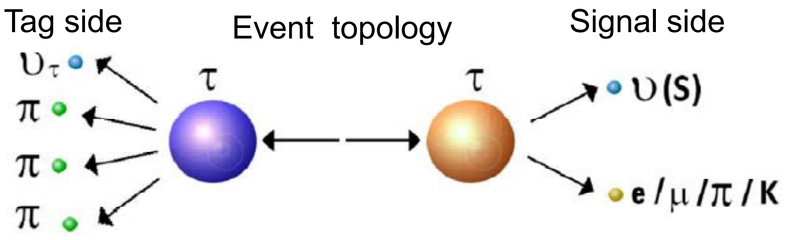
- Lepton Universality assumes that all weak couplings of leptons to the W are the same in the SM: **$g_e = g_\mu = g_\tau = g$** where $G_F = \frac{g^2}{4\sqrt{2}M_W^2}$
- Need to measure ratios of branching fractions in order to test Lepton Universality

$$\left(\frac{g_\mu}{g_e}\right)^2 = \frac{B(\tau \to \mu \nu_\mu \bar{\nu}_\tau)}{B(\tau \to e \nu_e \bar{\nu}_\tau)} \frac{f(m_e^2 / m_\tau^2)}{f(m_\mu^2 / m_\tau^2)}$$

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{B(\tau \to X \nu_\tau)}{B(X \to \mu \nu_\mu)} \frac{2 m_X m_\mu^2 \tau_X}{\delta_X m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2 / m_X^2}{1 - m_X^2 / m_\tau^2}\right)^2$$

$X = K, \pi$

δ_X = radiative correction

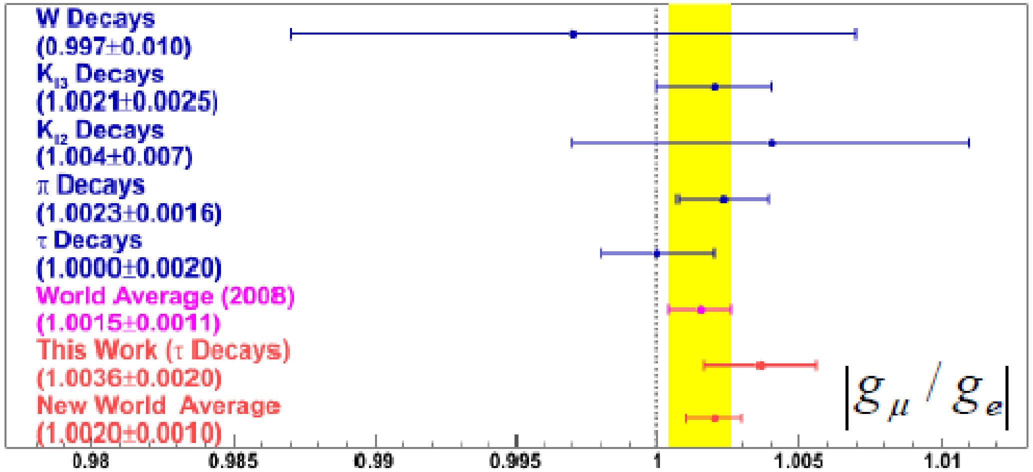


Lepton Universality Results

Babar Preliminary (467 fb^{-1})

From $B(\tau^- \to \mu^- \nu_\tau \overline{\nu_\mu})$

$|g_\mu / g_e| = 1.0036 \pm 0.0020$



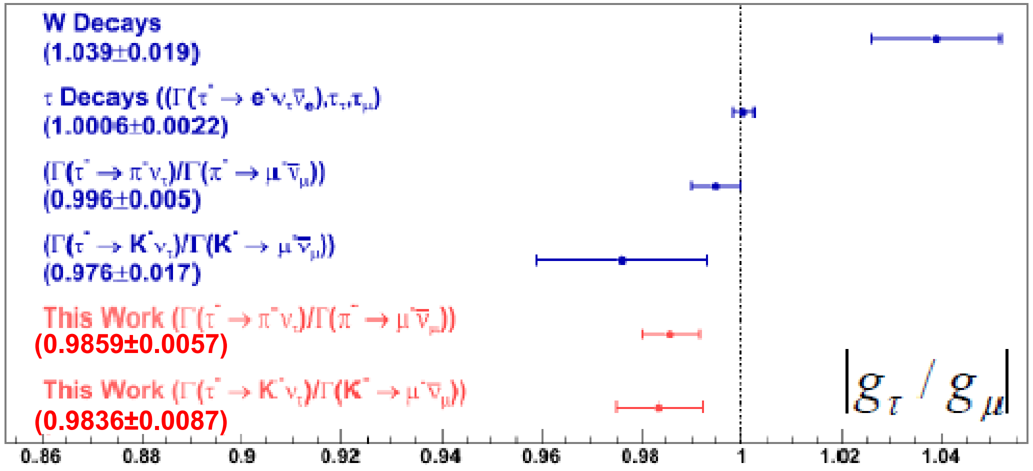
Babar Preliminary (467 fb^{-1})

From $B(\tau^- \to \pi^- \nu_\tau)$

$|g_\tau / g_\mu| = 0.9859 \pm 0.0057$

From $B(\tau^- \to K^- \nu_\tau)$

$|g_\tau / g_\mu| = 0.9836 \pm 0.0087$



Determination of $|V_{us}|$

- V_{us} From CKM unitarity $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$

From superallowed β decays $|V_{ud}| = 0.97408 \pm 0.00026$ T. Eronen et. al. PRL 100, 132502 (2008)

From e.g. inclusive $X_u l\nu$ decays $|V_{ub}| = (3.93 \pm 0.36) \times 10^{-3}$ PDG, Phys. Lett. B. 667, 1 (2008)

$$|V_{us}| = \sqrt{1 - |V_{ud}|^2} = 0.2262 \pm 0.0011$$

- V_{us} From Tau decays
  - Measure ratio of branching ratios
  - $|V_{ud}|$ from superallowed β decays
  - $f_K / f_\pi = 1.189 \pm 0.007$ from Lattice QCD
    - E. Follana et. al. PRL 100, 062002 (2008)
  - Electro weak corrections cancel

$$\frac{B(\tau \to K\nu_\tau)}{B(\tau \to \pi\nu_\tau)} = \frac{f_K^{\,2}\, |V_{us}|^2 \left(1 - \frac{m_K^{\,2}}{m_\tau^{\,2}}\right)}{f_\pi^{\,2}\, |V_{ud}|^2 \left(1 - \frac{m_\pi^{\,2}}{m_\tau^{\,2}}\right)} \times \frac{\delta_{\tau \to K\nu_\tau}}{\delta_{\tau \to \pi\nu_\tau}}$$

$$\frac{\delta_{\tau \to K\nu_\tau}}{\delta_{\tau \to \pi\nu_\tau}} = 1.0003 \pm 0.0044$$

W.J. Marciano et. al.	R. Decker et. al.
PRL 93, 231803 (2004)	Nuc. Phys. B 438, 17 (1995)
PRL 71, 3629 (1993)	Phys. Lett. B 334, 199 (1994)

Babar Preliminary (467 fb^{-1})

$$\boxed{\frac{B(\tau \to K\nu_\tau)}{B(\tau \to \pi\nu_\tau)} = 0.0653 \pm 0.0011}$$

$$\boxed{|V_{us}| = 0.2254 \pm 0.0023}$$

agrees with Unitarity

$|V_{us}|$ From Tau Decays

- V_{us} can be determined by measuring the ratio of the strange:non-strange content branching fractions of the τ lepton

$$R_{\tau,had} = \frac{\Gamma[\tau^- \rightarrow \nu_\tau hadrons(\gamma)]}{\Gamma[\tau^- \rightarrow e^- \nu_\tau \overline{\nu}_e]}$$

$$|V_{us}|^2 = \frac{R_{\tau,strange}}{(R_{\tau,non-strange} / |V_{ud}|^2) - \delta R_{\tau,theory}}$$

$$R_{\tau,non-strange} = R_{\tau,had} - R_{\tau,strange}$$

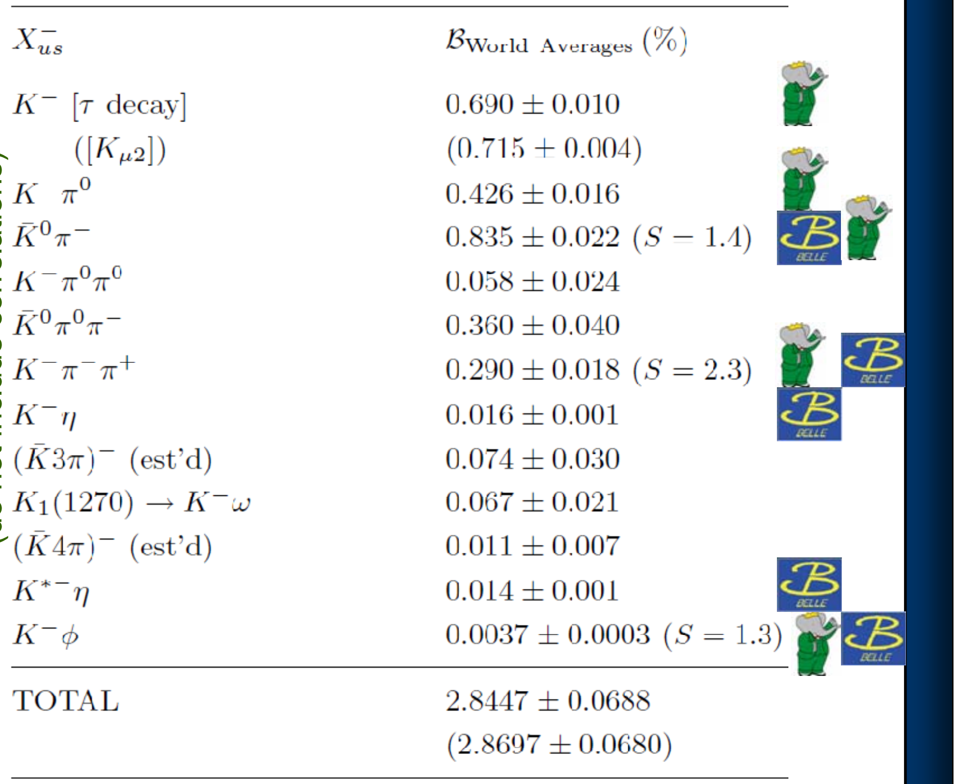
- Measurements of $R_{\tau,\mathrm{strange}}$
  - include Babar preliminary [ICHEP08]
    - $B(\tau \rightarrow \underline{K} \nu)$
    - $B(\tau \rightarrow \overline{K}^0 \pi^- \nu)$
  - include Belle [ICHEP08]
    - $B(\tau \rightarrow K^- \pi^- \pi^+ \nu)$

World average (preliminary)

$$\boxed{|V_{us}| = 0.2159 \pm 0.0030}$$

ICHEP08 Proc: arXiv:0811.1429 $B(\tau^- \rightarrow X_{us}^- \nu_\tau)$

(do not include correlations)



X_{us}^-	$\mathcal{B}_{\text{World Averages}}$ (%)
K^- [τ decay]	0.690 ± 0.010
$([K_{\mu 2}])$	$(0.715 + 0.004)$
$K\ \ \pi^0$	0.426 ± 0.016
$\bar{K}^0 \pi^-$	0.835 ± 0.022 $(S - 1.4)$
$K^- \pi^0 \pi^0$	0.058 ± 0.024
$\bar{K}^0 \pi^0 \pi^-$	0.360 ± 0.040
$K^- \pi^- \pi^+$	0.290 ± 0.018 $(S = 2.3)$
$K^- \eta$	0.016 ± 0.001
$(\bar{K} 3\pi)^-$ (est'd)	0.074 ± 0.030
$K_1(1270) \rightarrow K^- \omega$	0.067 ± 0.021
$(\bar{K} 4\pi)^-$ (est'd)	0.011 ± 0.007
$K^{*-} \eta$	0.014 ± 0.001
$K^- \phi$	0.0037 ± 0.0003 $(S = 1.3)$
TOTAL	2.8447 ± 0.0688 (2.8697 ± 0.0680)

3σ deviation from Unitarity result

$|V_{us}| = 0.2262 \pm 0.0011$

Lepton Flavor Violation (LFV)

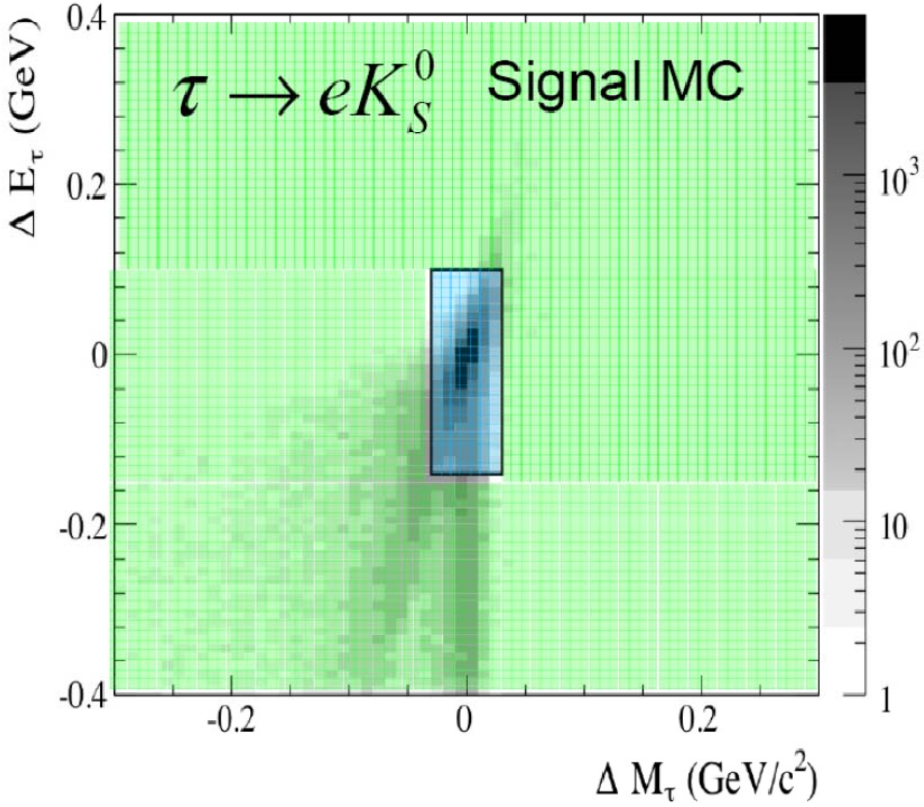
- Many new physics models predict LFV decay rates within reach at the B-Factories

- Searching for LFV events is done by looking at a signal box defined by

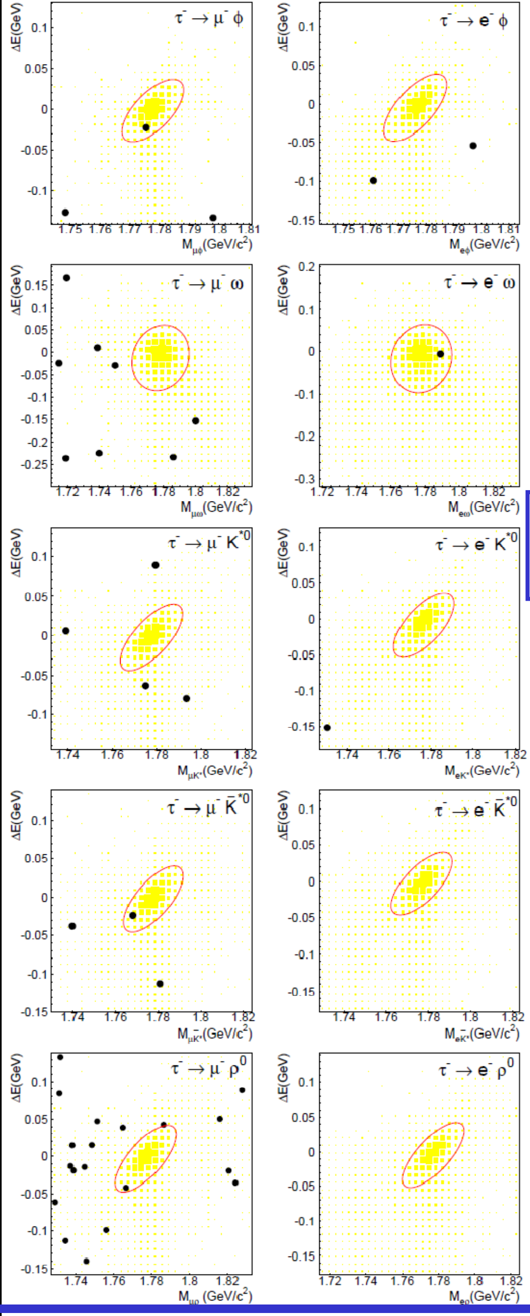
$$\Delta m = m_{rec} - m_{\tau}$$

$$\Delta E = E_{rec} - E_{CM}$$

  - No neutrino on signal side (fully reconstructed τ)
  - Tag side is 1-prong identified as electron or muon



LFV Results



Mode $\tau^- \to$	$N_{\rm obs}$	$N_{\rm exp}$	ϵ (%)	$\Delta\epsilon/\epsilon$ (%)	s_{90}	UL on $\mathcal{B}$ (90% CL)
$\mu^-\phi$	1	0.17 ± 0.12	3.14	5.2	4.17	1.3×10^{-7}
$e^-\phi$	0	0.18 ± 0.12	3.10	5.3	2.27	7.3×10^{-8}
$\mu^-\omega$	0	0.19 ± 0.20	2.51	6.3	2.22	8.9×10^{-8}
$e^-\omega$	1	< 0.24	2.46	6.3	4.34	1.8×10^{-7}
μ^-K^{*0}	0	0.26 ± 0.15	3.71	4.8	2.20	5.9×10^{-8}
e^-K^{*0}	0	0.08 ± 0.08	3.04	4.9	2.35	7.8×10^{-8}
$\mu^-\bar{K}^{*0}$	1	0.17 ± 0.12	4.02	4.8	4.14	1.0×10^{-7}
$e^-\bar{K}^{*0}$	0	< 0.17	3.21	4.9	2.45	7.7×10^{-8}
$\mu^-\rho^0$	1	1.04 ± 0.28	4.89	4.9	3.34	6.8×10^{-8}
$e^-\rho^0$	0	< 0.17	3.94	5.1	2.46	6.3×10^{-8}

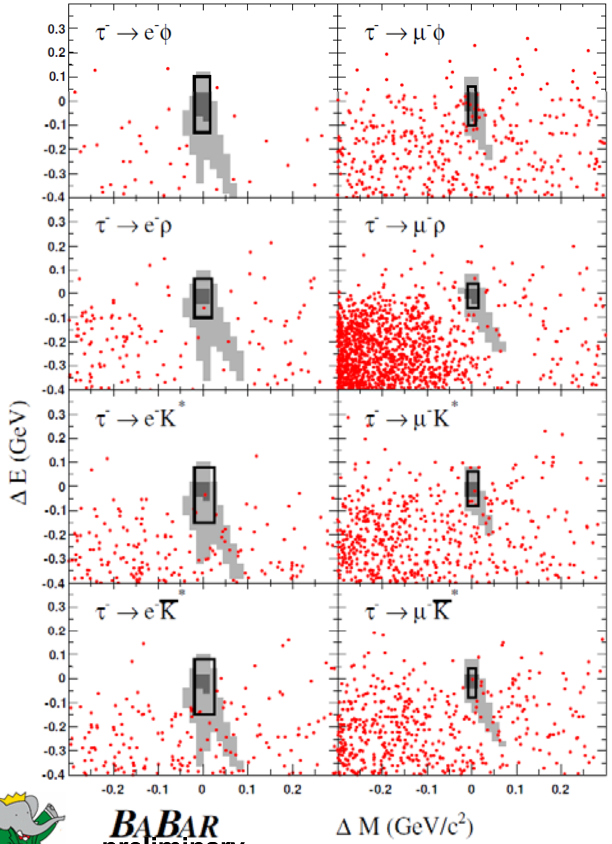
arXiv:0708.3276,
submitted to PRD(RC)

90% CL

$$B(\tau^\pm \to e^\pm f_0(980)) \times B(f_0(980) \to \pi^+\pi^-) < 3.4\times10^{-8}$$

$$B(\tau^\pm \to \mu^\pm f_0(980)) \times B(f_0(980) \to \pi^+\pi^-) < 3.2\times10^{-8}$$

arXiv:0810.3519,
submitted to Phys. Lett. B



Babar preliminary

$$B(\tau^\pm \to \mu^\pm K_s^0) < 4.0\times10^{-8} \quad 90\%CL$$

$$B(\tau^\pm \to e^\pm K_s^0) < 3.3\times10^{-8} \quad 90\%CL$$

PRL 100,071802 (2008)

$$B(\tau^\pm \to \mu^\pm \omega) < 1.1\times10^{-8} \quad 90\%CL$$

$$B(\tau^\pm \to e^\pm \omega) < 1.0\times10^{-8} \quad 90\%CL$$

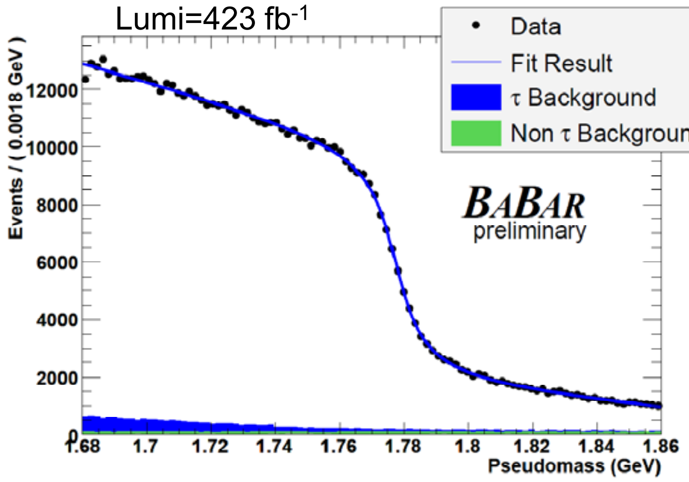
BABAR
preliminary

Lumi=451 fb^{-1}

90% CL

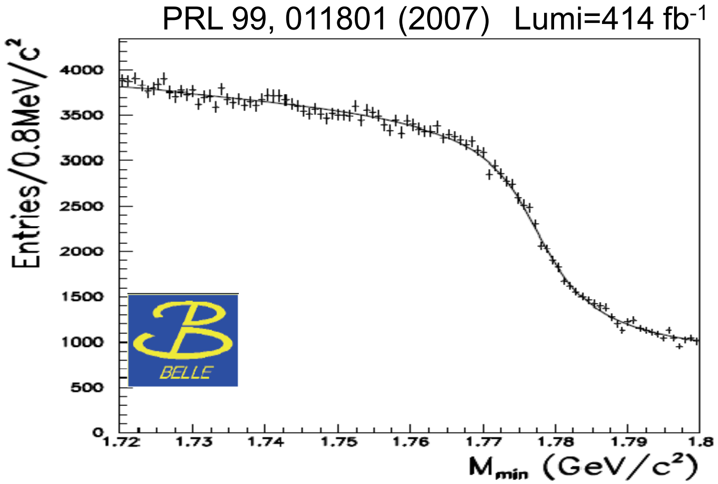
Mode	$\varepsilon[\%]$	$N_{\rm bgd}$	$\mathcal{B}^{90}_{\rm exp}$	$N_{\rm obs}$	$\mathcal{B}^{90}_{\rm UL}$
$e\phi$	6.43 ± 0.18	0.68 ± 0.14	5.0×10^{-8}	0	3.4×10^{-8}
$\mu\phi$	5.18 ± 0.26	2.76 ± 0.21	8.2×10^{-8}	6	20×10^{-8}
$e\rho$	7.31 ± 0.18	1.32 ± 0.19	4.9×10^{-8}	1	5.1×10^{-8}
$\mu\rho$	4.52 ± 0.41	2.04 ± 0.21	8.9×10^{-8}	0	2.8×10^{-8}
eK^*	8.00 ± 0.18	1.65 ± 0.29	4.8×10^{-8}	2	6.4×10^{-8}
μK^*	4.57 ± 0.36	1.79 ± 0.25	8.5×10^{-8}	4	19×10^{-8}
$e\overline{K}^*$	7.76 ± 0.17	2.76 ± 0.30	5.4×10^{-8}	2	5.0×10^{-8}
$\mu\overline{K}^*$	4.11 ± 0.31	1.72 ± 0.18	9.3×10^{-8}	1	8.0×10^{-8}

Tau Mass and CPT Test

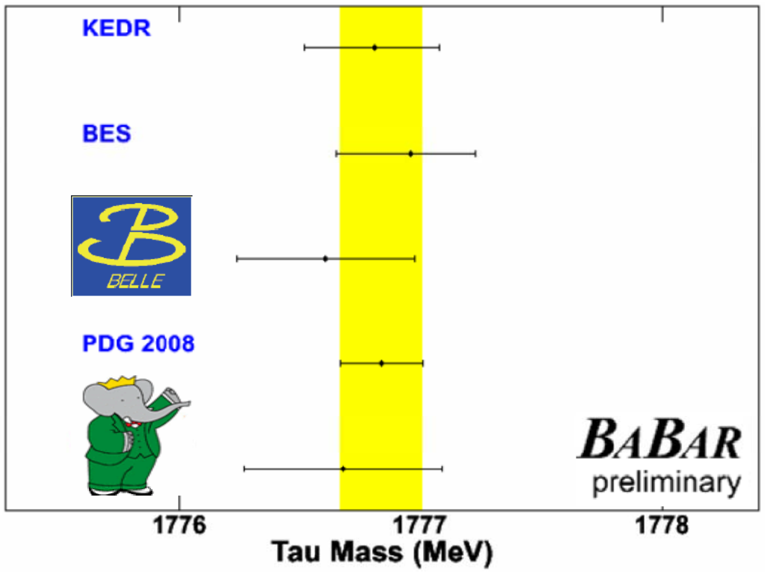


$$M_\tau = 1776.68 \pm 0.12(\text{stat}) \pm 0.41(\text{syst})\text{MeV/c}^2$$

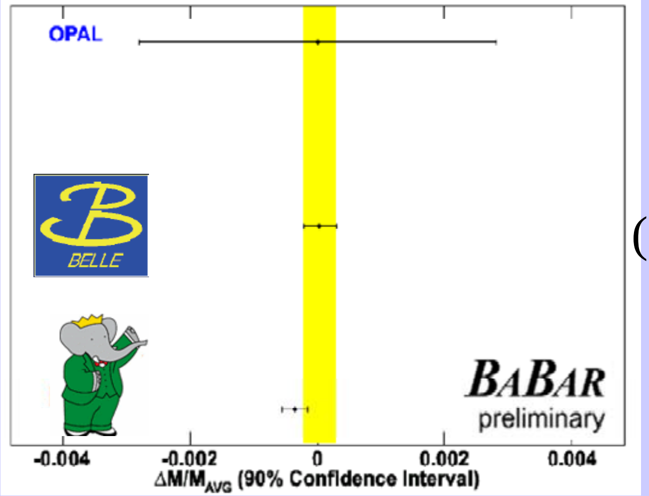
PRL 99, 011801 (2007) Lumi=414 fb^{-1}



$$M_\tau = 1776.61 \pm 0.13(\text{stat}) \pm 0.35(\text{syst})\text{MeV/c}^2$$



CPT test : $\frac{M(\tau^+) - M(\tau^-)}{M_{\text{average}}}$



$(0.28 \pm 1.5) \times 10^{-4}$

$(-3.5 \pm 1.3) \times 10^{-4}$

Charm Physics Results

D^0 Mixing Measurements

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

CP Violation in D Decays

D^0 Mixing Formalism

Neutral D mesons are produced as *flavor eigenstates* D^0 and $\overline{D^0}$ and decay via :

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

as *mass eigenstates* D_1, D_2

$$\begin{aligned} |D_1\rangle &= p|D^0\rangle + q|\overline{D}^0\rangle \\ |D_2\rangle &= p|D^0\rangle - q|\overline{D}^0\rangle \end{aligned}$$

where $|q|^2 + |p|^2 = 1$ and

$$\left(\frac{q}{p}\right)^2 = \frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}$$

D_1, D_2 have masses M_1, M_2 and widths Γ_1, Γ_2

Mixing occurs when there is a *non-zero* mass difference

$$\Delta M = M_1 - M_2$$

or lifetime difference

$$\Delta\Gamma = \Gamma_1 - \Gamma_2$$

For convenience define quantities ***x*** and ***y***

$$x = \frac{\Delta M}{\Gamma}, \quad y = \frac{\Delta\Gamma}{2\Gamma}$$

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

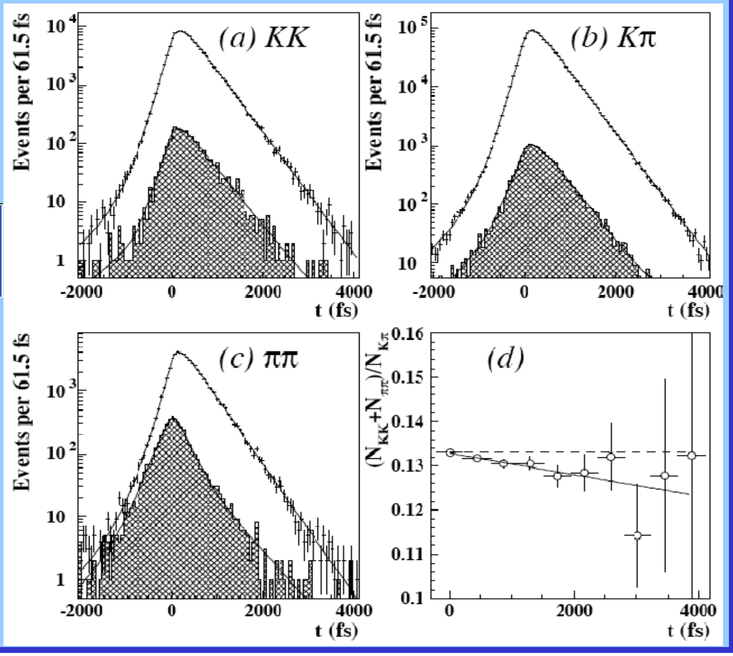
Lifetime Ratio Measurements

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

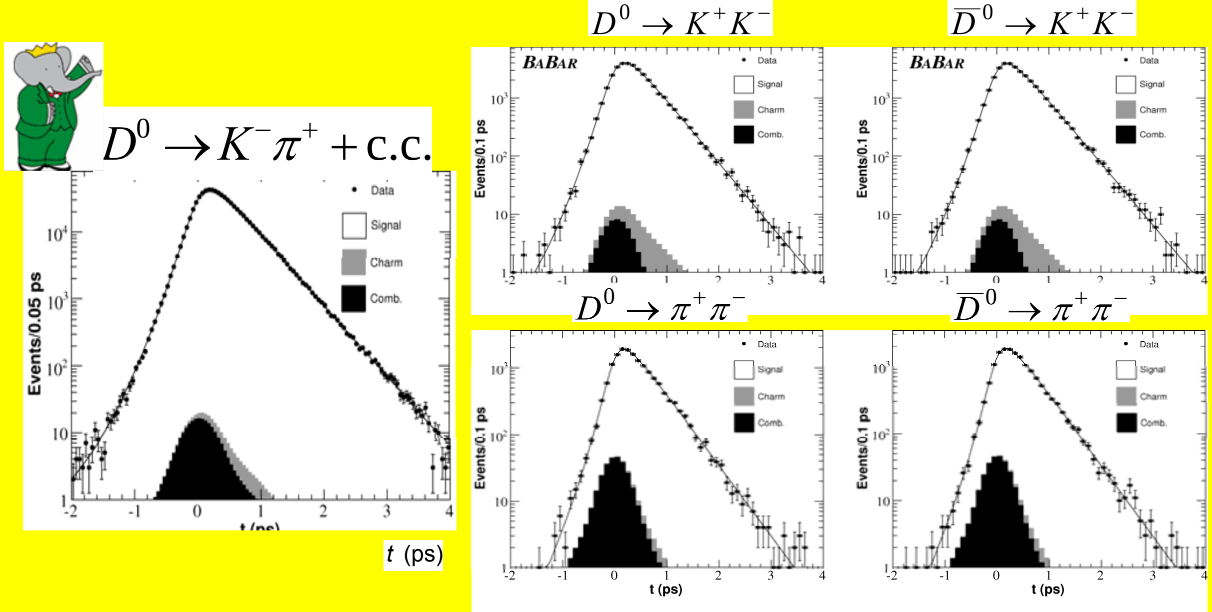
$$y_{CP} \equiv \frac{\tau_{K\pi}}{\langle \tau_{hh} \rangle} - 1, \quad h = K \text{ or } \pi$$

- Allowing for *CPV*, measure the D^0 and D^0 asymmetry

$$\Delta Y = \frac{\tau_{K\pi}}{\langle \tau_{hh} \rangle} \frac{\tau_{hh}^{+} - \tau_{hh}^{-}}{\tau_{hh}^{+} + \tau_{hh}^{-}} = -(1 + y_{cp}) A_{\Gamma}$$



- Tagged events (from D^{*+}! $D^0\pi^+$, decays)
- Most of systematic error cancels in the lifetime ratio.
- Bkg related systematics don't.
- Require:p*>2.5GeV/c, σ_t<0.37ps
- Purity of selection 98%, 98%, 92% for KK, Kπ, ππ, respec.


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

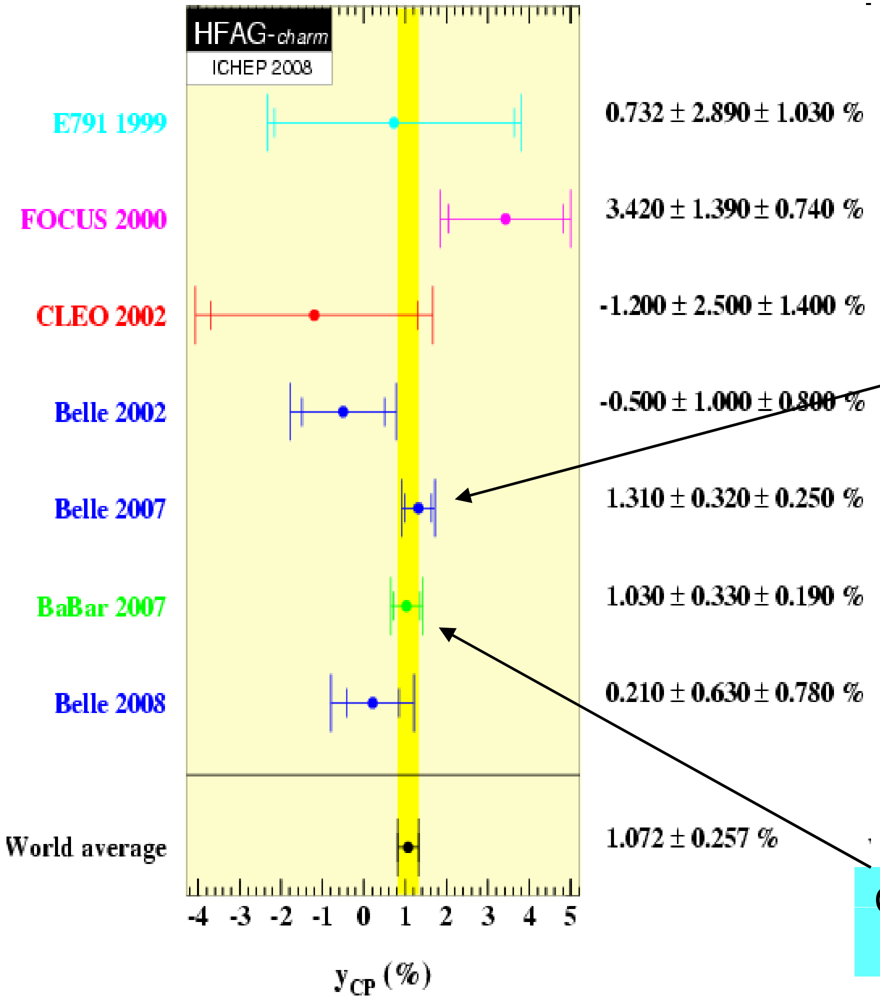
$D^0 \to K^+K^-$

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

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

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

Lifetime Difference Results



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

3.2 σ evidence - no *CPV*

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

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

3.0 σ evidence - no *CPV*

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

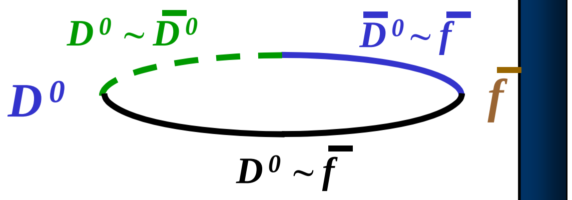
Combining 384 /fb tagged and 91 /fb untagged (*BaBar*):
y_{CP} = (1.03 ± 0.33(stat.) ± 0.19(syst.))%

HFAG World Average:
y_{CP} = (1.072 ± 0.257)%
arXiv 0808:1297 (2008)

Mixing in “Wrong Sign” Decays ($D^0 \to K^+\pi^-$)

Two types of WS Decays:

- Doubly Cabibbo-supressed (DCS)
- Mixing followed by Cabibbo-Favored (CF) decay



Two ways to reach same final state ⇒ interference!

Discriminate between DCS and Mixing decays by their proper time evolution

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

$$\frac{d\Gamma}{dt}[|D^0(t)\rangle \to f] \propto e^{-\Gamma t}\left(\underbrace{R_\mathrm{D}}_{\text{DCS decay}} + \underbrace{\sqrt{R_\mathrm{D}}y'\;\Gamma t}_{\text{Interference between DCS and mixing}} + \underbrace{\frac{x'^2+y'^2}{4}(\Gamma t)^2}_{\text{Mixing}}\right)$$

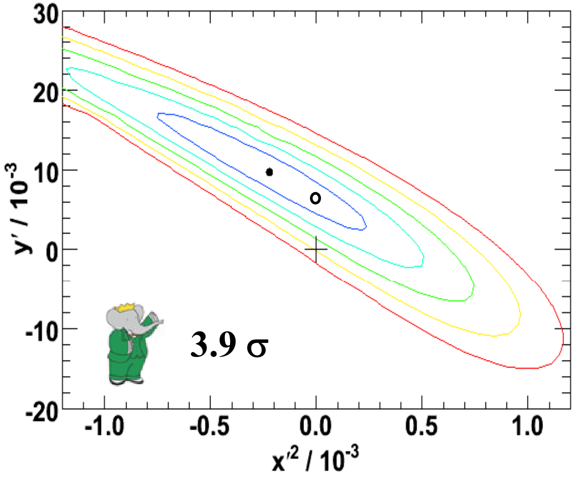
$\delta_{K\pi}$ strong phase difference between CF and DCS decay amplitudes

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

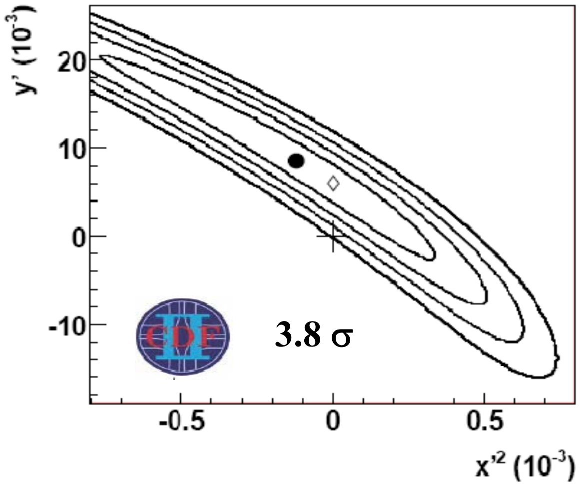
Observations of Mixing in $D^0 \to K^+\pi^-$

Evidence for mixing from *BaBar* (3.9σ) and confirmation by *CDF* (3.8σ)

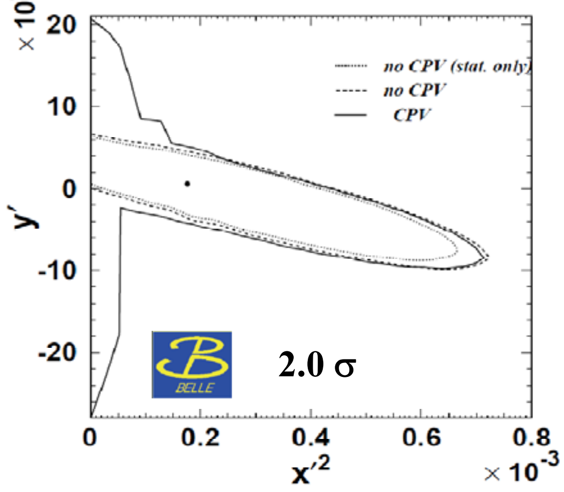
384 fb^{-1} PRL 98,211802 (2007)



1.5 fb^{-1} PRL 100,121802 (2008)



400 fb^{-1} PRL 96:151801 (2006)



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

CLEOc has measured $\delta_{K\pi}$, used to translate x'~x and y'~y, Phys. Rev. D 78, 012001 (2008)

Mixing in $D^0 \to K_s\pi\pi$ Decays

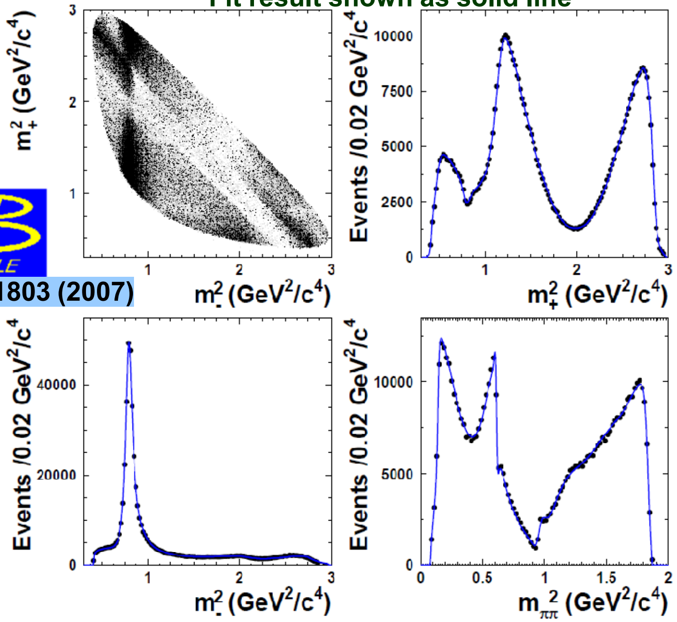
Time-dependent, Dalitz-plot mixing analysis

Uses D^{*+}! $D^0\pi^+$, $D^0 \to K_s\pi\pi$ + c.c. decays

Observe time dependence of D^0 decays

complexity due to Dalitz plot structure

Analysis assumes *CP* conservation



Dalitz plot distribution and projections. Fit result shown as solid line

PRL **99, 131803 (2007)**

D^0 decay amplitude is given by

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

where $\mathcal{A}$ and $\overline{\mathcal{A}}$ are amplitudes for decay to D^0 or $\overline{D}^0$ as functions of phase-space variables, and

$$m_\pm = \begin{cases} m(K_s, \pi^\pm) & D^{*+} \to D^0\pi^+ \\ m(K_s, \pi^\mp) & D^{*-} \to \overline{D}^0\pi^- \end{cases} \qquad e_{1,2}(t) = \exp\left(-i(m_{1,2} - i\Gamma_{1,2}/2)t\right)$$

Measures *x* and *y* : no strong phase, *sensitive to x directly*

$D^0 \rightarrow K_s\pi\pi$ Results

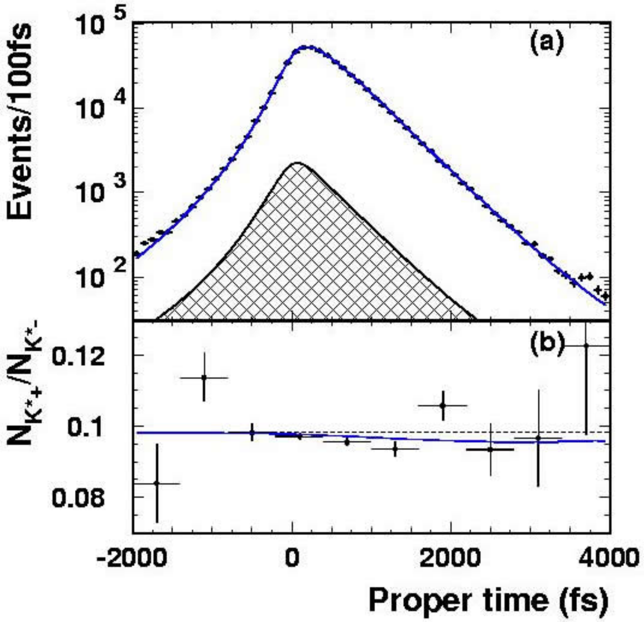
PRL **99, 131803 (2007)**

Lumi=540 fb^{-1}

Proper-time fit results

$$x_{K_s\pi\pi} = [0.80 \pm 0.29(stat.) \pm 0.17(syst.)]\%$$

$$y_{K_s\pi\pi} = [0.33 \pm 0.24(stat.) \pm 0.12(syst.)]\%$$

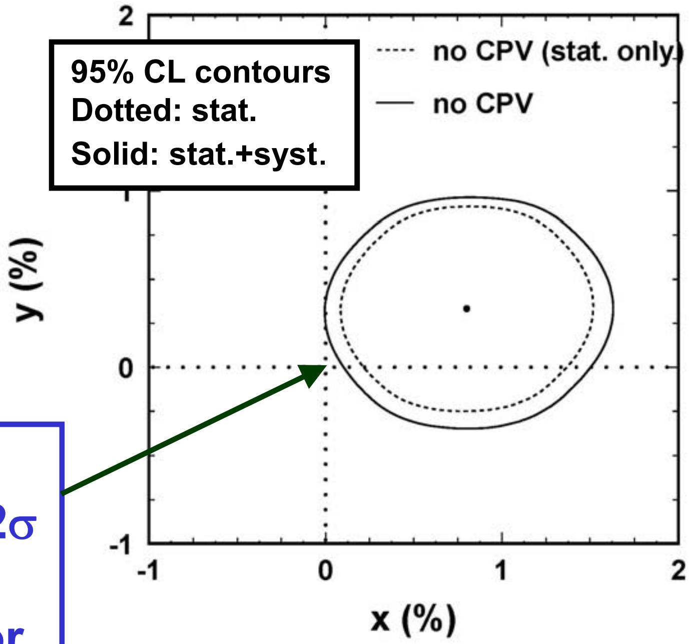


(a) Decay-time distribution for total Dalitz-plot region.

(b) Ratio of decay-time distributions for $K^*(892)^+$ and $K^*(892)^-$ regions.

No-mixing excluded at 2.2σ

No evidence for CP violation



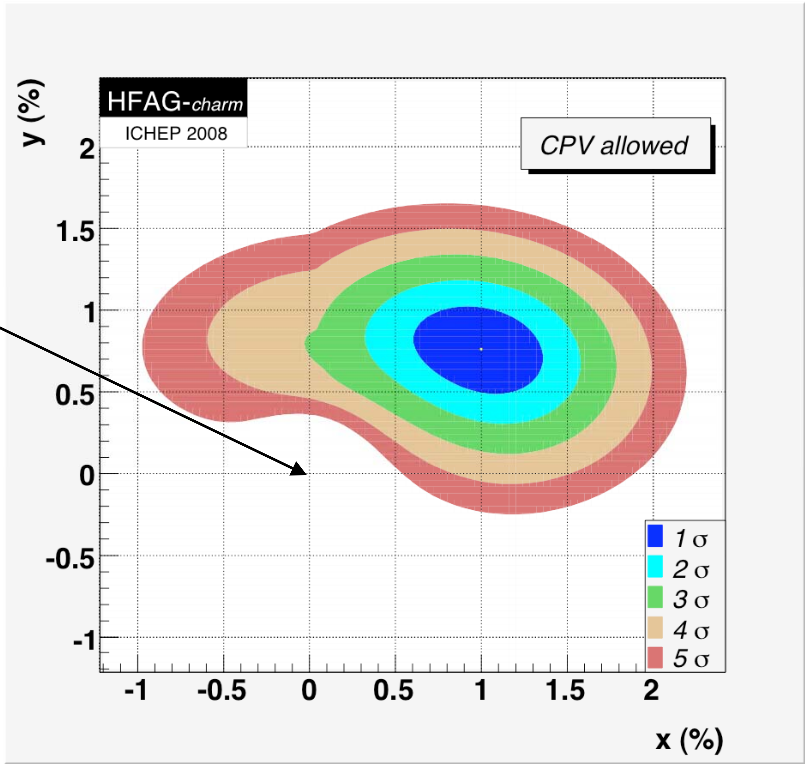
95% CL contours
Dotted: stat.
Solid: stat.+syst.

Largest systematics:
- **In *x*: from Dalitz fit model**
- **In *y*: from event selection**

Collective Evidence for D^0 Mixing

*BABAR: PRL **98**, 211802 (2007)*	$D^0\to K^+\pi^-$ *decay time analysis*	3.9σ
*BELLE: PRL **98**, 211803 (2007)*	$D^0\to K^+K^-, \pi^+\pi^-$ *vs* $K^+\pi^-$ *lifetime difference analysis*	3.2σ
*BELLE: PRL **99**,131803 (2007)*	$D^0\to K_s\pi^+\pi^-$ *time dependent amplitude analysis*	2.2σ
*CDF: PRL **100**, 121802 (2008)*	$D^0\to K^+\pi^-$ *decay time analysis*	3.8σ
*BABAR: PRD **78**, 011105 R (2008)*	$D^0\to K^+K^-, \pi^+\pi^-$ *vs* $K^+\pi^-$ *lifetime difference analysis*	3σ
BABAR: arXiv:0807, 4544 *(2008)*	$D^0\to K^+\pi^-\pi^0$ *time dependent amplitude analysis*	3.1σ
	all mixing results combined by HFAG:	**~10σ**

No-mixing point excluded at 9.8σ



Strong phase from CLEOc measurement
Phys Rev. D 78, 012001 (2008)

Time Integrated CP Violation

$$a_{CP}^{KK} = \frac{\Gamma(D^0 \to K^- K^+) - \Gamma(\overline{D}^0 \to K^- K^+)}{\Gamma(D^0 \to K^- K^+) + \Gamma(\overline{D}^0 \to K^- K^+)}$$

$$a_{CP}^{\pi\pi} = \frac{\Gamma(D^0 \to \pi^- \pi^+) - \Gamma(\overline{D}^0 \to \pi^- \pi^+)}{\Gamma(D^0 \to \pi^- \pi^+) + \Gamma(\overline{D}^0 \to \pi^- \pi^+)}$$

- Measure the time integrated CP asymmetries
- SM predictions for A_{CP} are tiny: O(0.001% - 0.01%)

⇒ observation of A_{CP} at ~0.1% level would indicate NP

- Relative π_s^+ and π_s^- tracking efficiencies not equal
  - Use $D^0 \to K^- \pi^+$ tagged and untagged data to determine this
- Due to Z/γ interference and radiative corrections D^0 and $\overline{D}^0$ are produced with a forward backward asymmetry in C.M. polar angle θ*
  - compute the D^0-D^0 flavor asymmetry vs $\cos\theta$ in the center of mass
  - extract A_{cp} and A_{fb} by constructing even and odd functions of $\cos\theta$

$$a^{\pm}(\cos\theta) = \frac{N^{D^0}(\pm\cos\theta) - N^{\overline{D}^0}(\pm\cos\theta)}{N^{D^0}(\pm\cos\theta) + N^{\overline{D}^0}(\pm\cos\theta)}$$

+ : forward hemisphere

- : backward hemisphere

$$\frac{a^+(\cos\,\theta) + a^-(\cos\,\theta)}{2} \approx a_{CP}(\cos\,\theta)$$

$$\frac{a^+(\cos\,\theta) - a^-(\cos\,\theta)}{2} \approx a_{FB}(\cos\,\theta)$$

$0 \le \cos\,\theta \le 1$

Time integrated CP asymmetries:

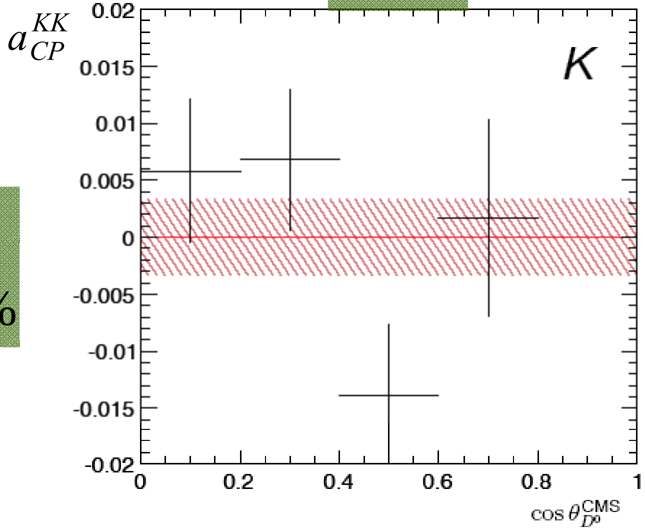
PRL 100, 061803 (2008)
luminosity: 384 fb^{-1}

$$a_{CP}^{KK} = (0.00 \pm 0.34 \pm 0.13)\%$$

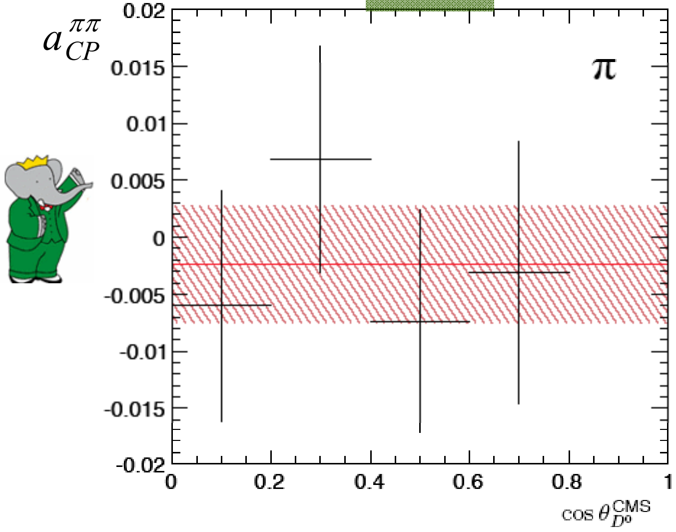
$$a_{CP}^{\pi\pi} = (-0.24 \pm 0.54 \pm 0.22)\%$$

No evidence for CPV

a_{CP}^{KK}



$a_{CP}^{\pi\pi}$



Time integrated CP asymmetries:

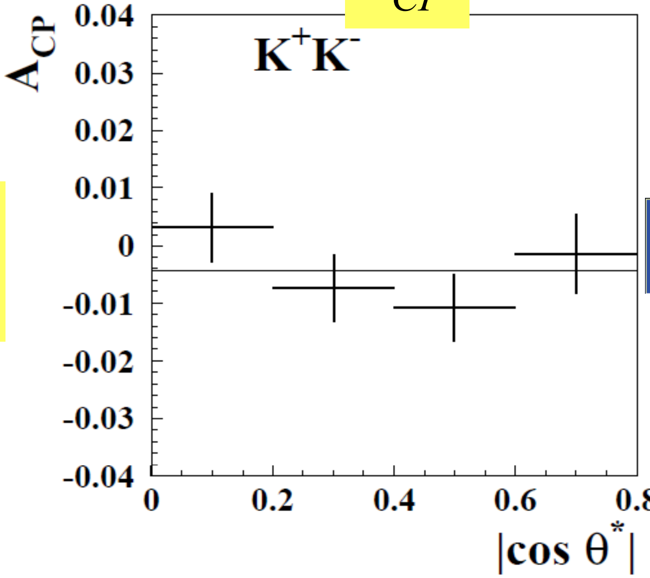
Phys. Rev B 670, 190 (2008)
luminosity: 540 fb^{-1}

$$a_{CP}^{KK} = (-0.43 \pm 0.30 \pm 0.11)\%$$

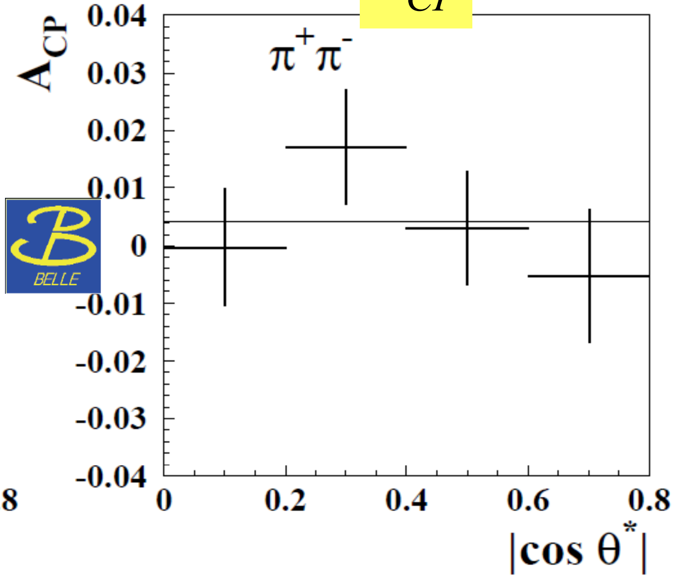
$$a_{CP}^{\pi\pi} = (-0.43 \pm 0.52 \pm 0.12)\%$$

No evidence for CPV

a_{CP}^{KK}



$a_{CP}^{\pi\pi}$

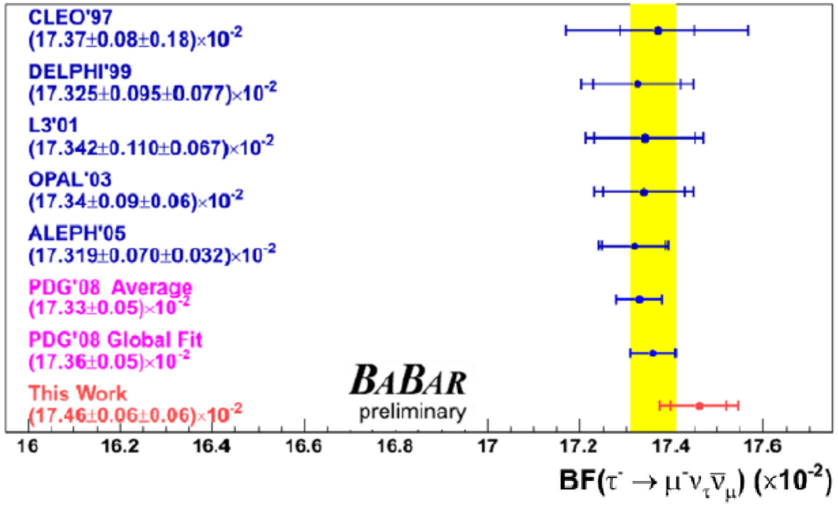


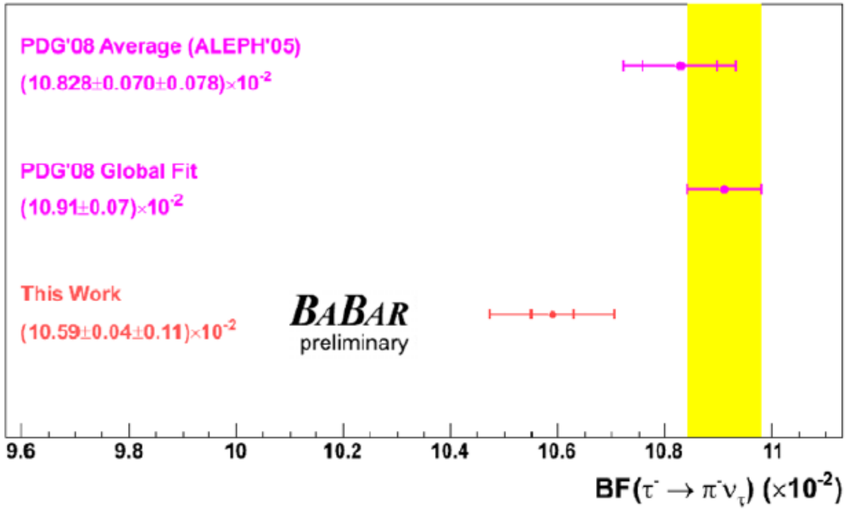
Summary

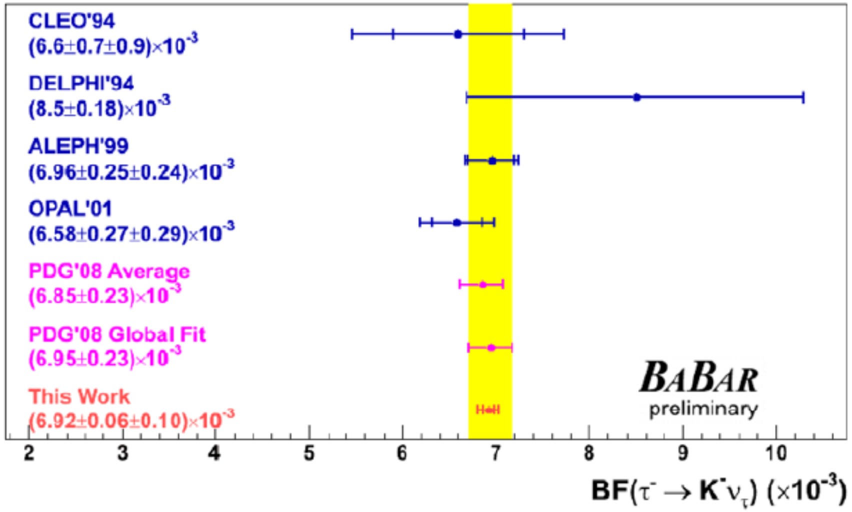
- Lepton Universality holds as measured by BaBar
- $|V_{us}|$ in good agreement with CKM Unitarity
  - but there is a ~3σ discrepancy from hadronic τ decays
- Limits on LFV in the 10^{-7} to 10^{-8} range
  - Need Super B-Factory to reach 10^{-9}
- Measurements on mass difference between τ^+ and τ^- provide new limits on CPT invariance
- Collective evidence for D^0 mixing is compelling
  - The no-mixing point is excluded at ~10σ, including systematic uncertainties
  - However, no single measurement exceeds 4σ
- Average values of the mixing parameters are x~*1 %*, y~*0.8 %*
  - compatible with the upper range of standard model predictions
- No evidence of CP violation in D^0 decays

Backup Slides

Lepton Universality Branching Ratios







Mixing in D mesons

- Neutral meson mixing has been already observed in the K (1956), B_d (1987) and B_s (2006) systems

- Why is D^0 mixing interesting ?
  - It completes the picture of quark mixing already observed in other systems
  - Provides new information about processes with down-type quarks in the mixing loop diagram
  - It is an important step towards the observation of CP violation in the Charm sector
  - New physics may be present depending on the measured values of the mixing parameters

Generic Mixing Analysis

Select a clean sample of *D*^{0} and $\overline{D}^0$ by tagging the *flavor at production time* using the decays of $D^{*\pm} \longrightarrow \pi_s^{\pm} D^0$

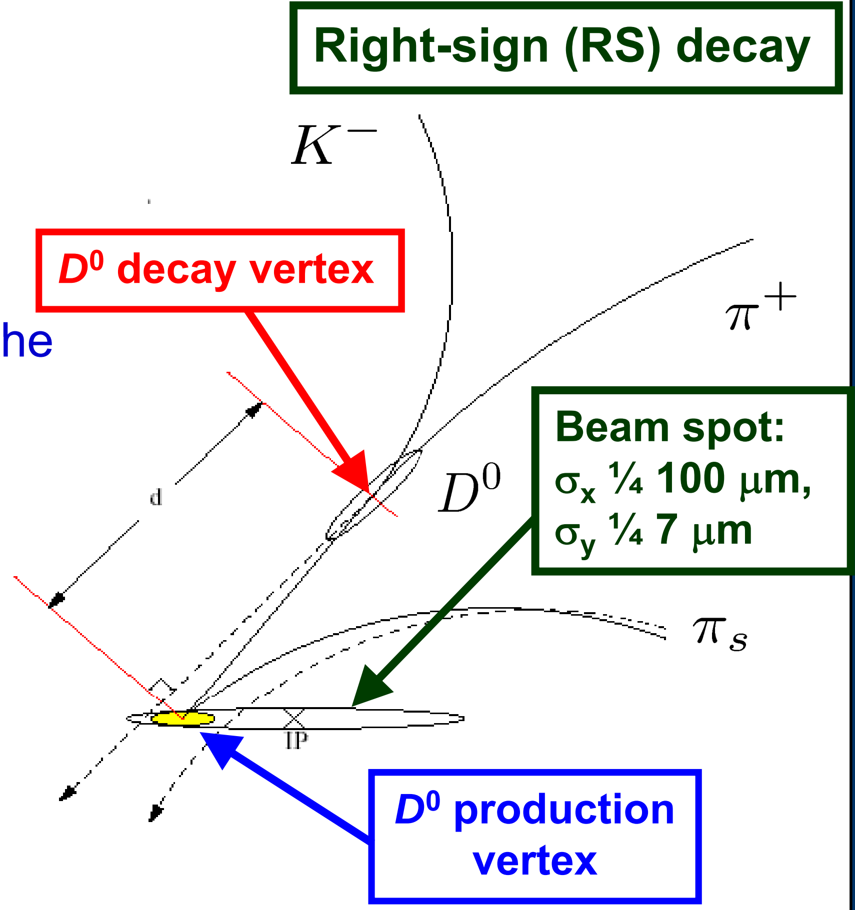
- We select events around the expected $$\Delta m = m(D^{*+}_{\rm rec.}) - m(D^0_{\rm rec.})$$
- The charge of the slow pion determines the flavor of the *D*^{0}

Identify the *D*^{0} *flavor at decay time* using the charge of the Kaon

$D^0 \rightarrow K^-\pi^+$ right-sign (RS)

$D^0 \rightarrow K^+\pi^-$ wrong-sign (WS)

Vertices fit with beamspot constraint determines **m$_{K\pi}$, Δ*m*, proper-time *t*** and **error δ_t**



Right-sign (RS) decay

***D*^{0} decay vertex**

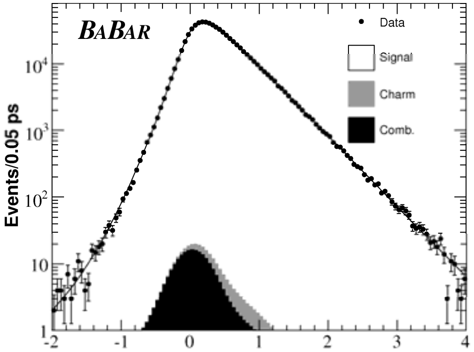
Beam spot:
σ_x ¼ 100 μm,
σ_y ¼ 7 μm

***D*^{0} production vertex**

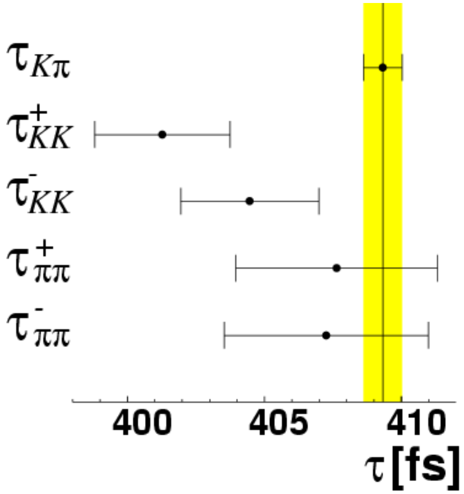
Typical D^0 flight length $d \sim 240$ μm
Average resolution $\sigma_d \sim 95$ μm

BaBar Lifetime Ratio Analysis

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

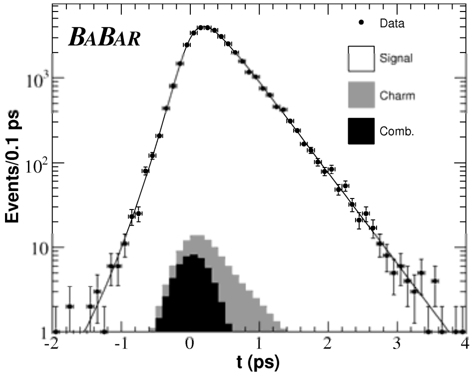


τ=409.3±0.7 fs



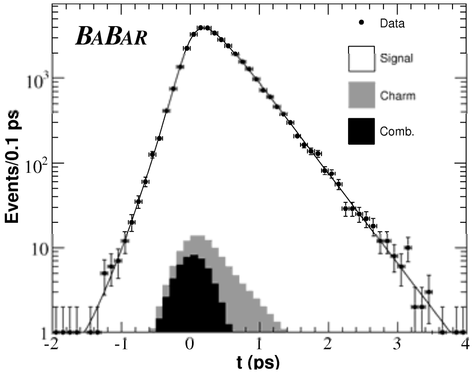
***Kπ* and *KK* lifetimes differ**

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



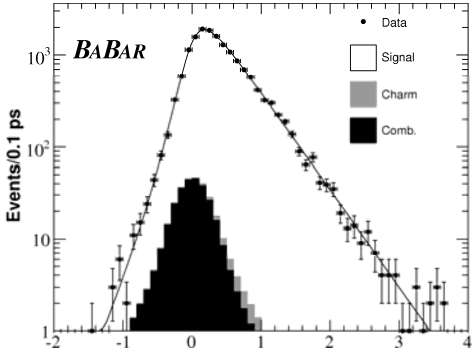
τ=401.3±2.5 fs

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



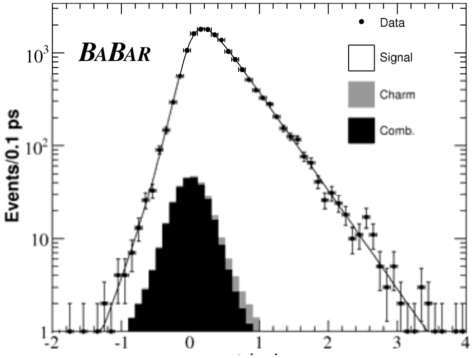
τ=404.5±2.5 fs

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



τ=407.6±3.7 fs

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



τ=407.3±3.8 fs

WS Fit with Mixing

Fit results allowing mixing:

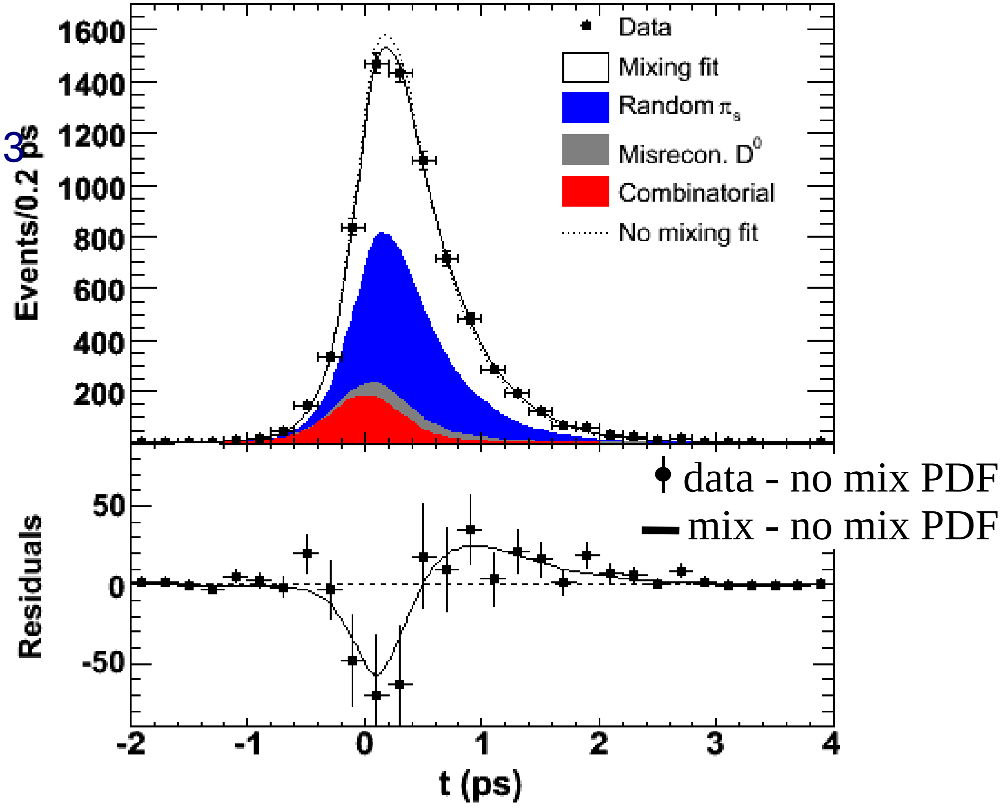
R_D: $(3.03 \pm 0.16 \pm 0.10) \text{x} 10^{-3}$

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

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

x'^2, y' correlation: -0.94

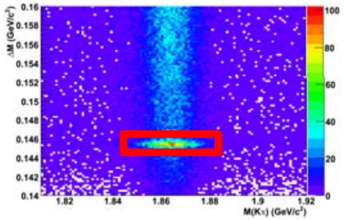
WS decay time, signal region



Fit with gives better description of data

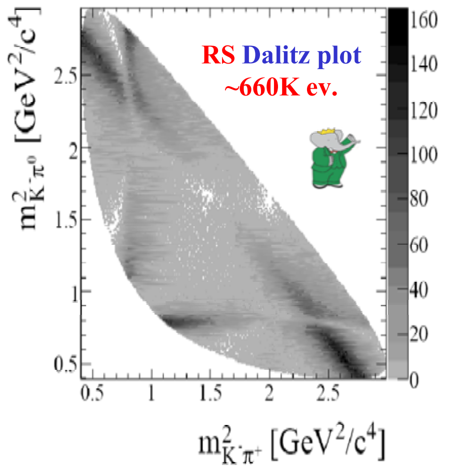
How significant?

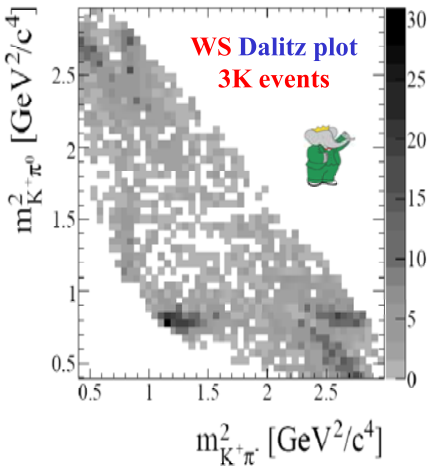
plot signal region:
$1.843 < m < 1.883$ GeV/c^2
$0.1445 < \Delta m < 0.1465$ GeV/c^2



Mixing in WS $D^0 \rightarrow K^+\pi^-\pi^0$ Decays

- Find *CF* amplitude $\overline{A}_{\bar{f}}$ from time-integrated fit to RS Dalitz plot
    - isobar model expansion
- Use this in time-dependent fit to WS plot to determine $A_{\bar{f}}$ and mixing parameters.





signal box:
0.1449<Δm<0.1459 GeV/c^2
1.8495<$m_{K\pi\pi}$*<1.8795* GeV/c^2

RS signal purity: 99%
WS signal purity: 50%

- Results:

$$x'_{K\pi\pi^0} = \left[\ 2.61^{+0.57}_{-0.68}(stat.) \pm 0.39(syst.)\right]\%$$
$$y'_{K\pi\pi^0} = \left[-0.06^{+0.55}_{-0.64}(stat.) \pm 0.34(syst.)\right]\%$$

- Main systematics:
    - Dalitz plot model
    - Event selection criteria
    - Signal and background yields

- No evidence for *CPV*

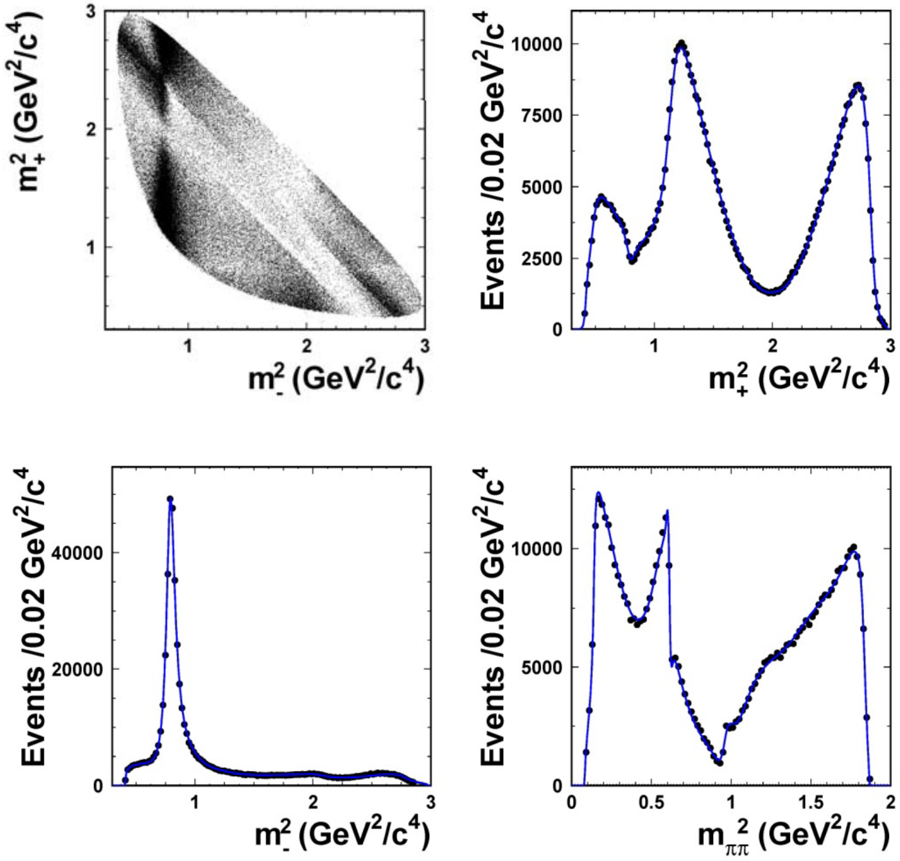
Belle $D^0 \to K_s \pi\pi$ analysis

Dalitz fit model

- Refinement of Belle φ_3 measurement
- 13 BW resonances + non-resonant contribution

TABLE I: Fit results for Dalitz plot parameters.

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 plot distribution and projections.
Fit result shown as solid line.

Mixing in *WS* $D^0 \to K^+\pi^-\pi^0$ Decays

- Analysis formally similar to the wrong sign $D^0 \to K^+\pi^-$ analysis but now mixing depends on position in Dalitz plot.

$$\frac{dN_{\bar{f}}(s_{12},s_{13},t)}{ds_{12}ds_{13}dt} = e^{-\Gamma t}\{|A_{\bar{f}}|^2 + \longleftarrow \boxed{\text{DCS}}$$

$$\boxed{\text{Interference}} \longrightarrow |A_{\bar{f}}||\bar{A}_{\bar{f}}|\left[y\cos\delta_{\bar{f}} - x\sin\delta_{\bar{f}}\right](\Gamma t) +$$

$$\boxed{\text{Mixing}} \longrightarrow \frac{x^2+y^2}{4}|\bar{A}_{\bar{f}}|^2(\Gamma t)^2\} \qquad (1)$$

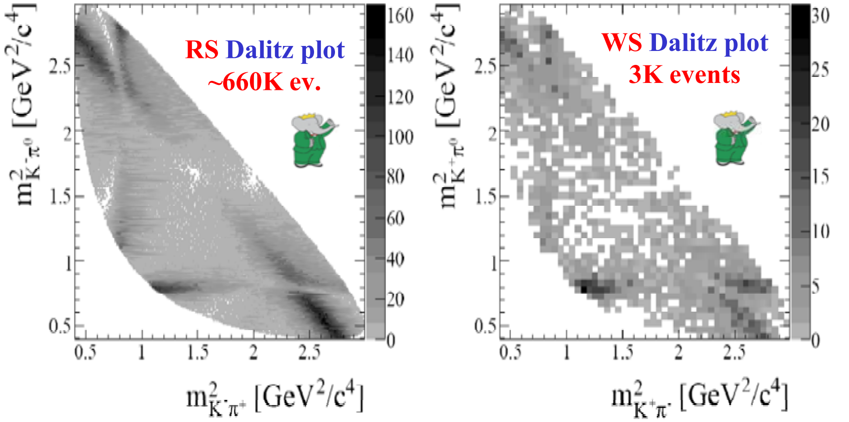
$$\bar{A}_{\bar{f}} = \bar{A}_{\bar{f}}(s_{12},s_{13}) = \left\langle K^+\pi^-\pi^0 \middle| H \middle| \bar{D}^0 \right\rangle$$
$$A_{\bar{f}} = A_{\bar{f}}(s_{12},s_{13}) = \left\langle K^+\pi^-\pi^0 \middle| H \middle| D^0 \right\rangle$$
$$s_{12} = m_{K^+\pi^-}$$
$$s_{13} = m_{K^+\pi^0}$$

- The measured mixing parameters are:

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

where $\delta_{K\pi\pi^0}$= phase difference between DCS $D^0\to\rho K^+$ and CF $\bar{D}^0\to\rho K^+$ reference amplitudes (and cannot be determined in this analysis)

384 fb-1 : arXiv:0807, 4544 [hep-ex], submitted to PRL



Results : No evidence of CPV

$$x'_{K\pi\pi^0} = \left[\;\; 2.61^{+0.57}_{-0.68}(stat.) \pm 0.39(syst.)\right]\%$$
$$y'_{K\pi\pi^0} = \left[-0.06^{+0.55}_{-0.64}(stat.) \pm 0.34(syst.)\right]\%$$

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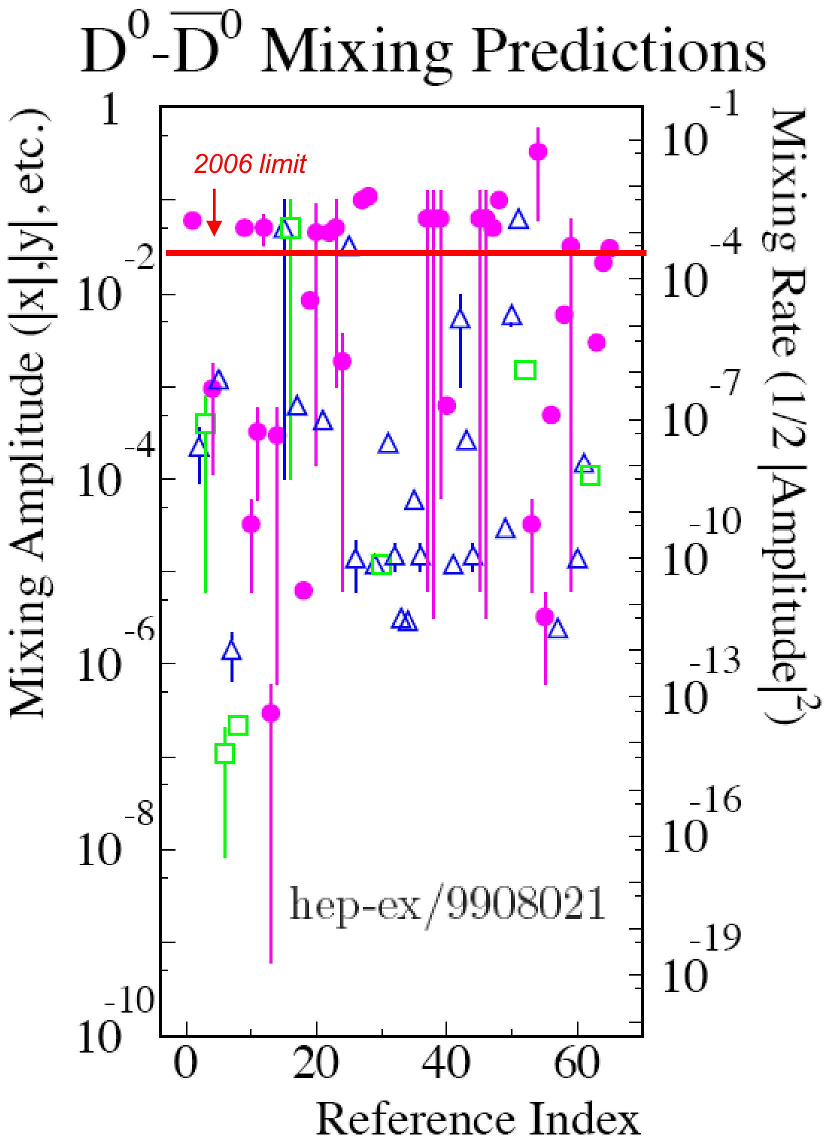
New Physics in Charm ?



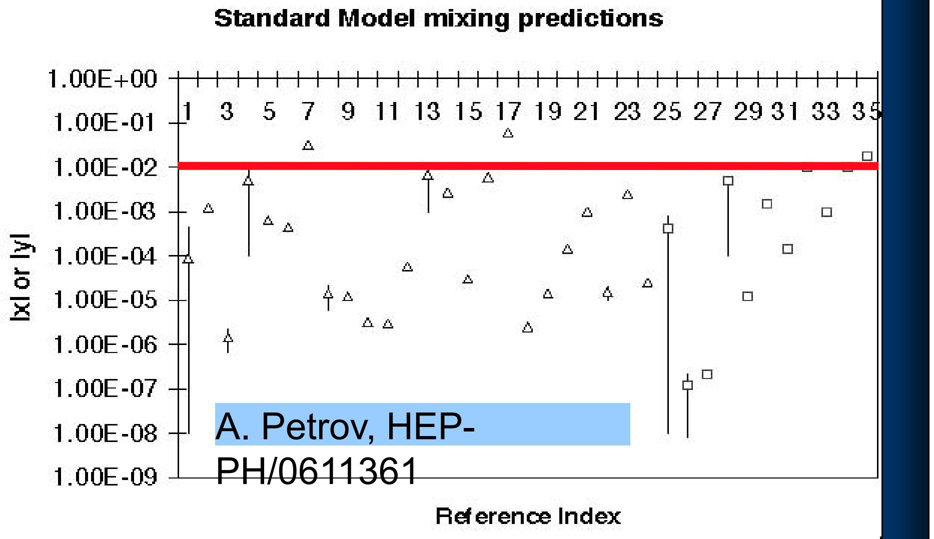
Δ: Standard model predictions for x

□: Standard model predictions for y

●: New physics predictions for x

- Hard to see a clear prediction
- *Pushing the limit down excludes models*

Try to separate x and y!

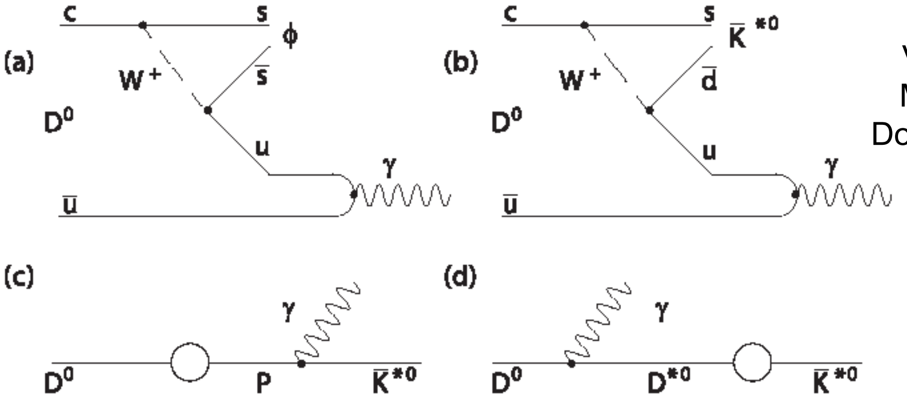


A. Petrov, HEP-PH/0611361

Radiative $D^0\to\phi\gamma$ and $K^*\gamma$ Decays

Phys. Rev. D78, 071101 (2008)

$D^0\to\phi\gamma$ Cabibbo suppressed, $D^0\to\overline{K}^{*0}\gamma$ Cabibbo favored radiative D^0 decays dominated by long range processes



Vector
Meson
Dominance

pole diagrams:
o = weak transition
P = pseudoscalar
meson

Mode:	Theoretical BF (×10^{-5}):
$D^0\to\phi\gamma$	0.1-3.4
$D^0\to\overline{K}^{*0}\gamma$	7-80

Results:

$$\frac{\mathcal{B}(D^0\to\phi\gamma)}{\mathcal{B}(D^0\to K^-\pi^+)}=(7.15\pm0.78\pm0.69)\times10^{-4},$$

$$\frac{\mathcal{B}(D^0\to\bar{K}^{*0}\gamma)}{\mathcal{B}(D^0\to K^-\pi^+)}=(8.43\pm0.51\pm0.70)\times10^{-3}$$

$$\mathcal{B}(D^0\to\phi\gamma)=(2.78\pm0.30\pm0.27)\times10^{-5},$$

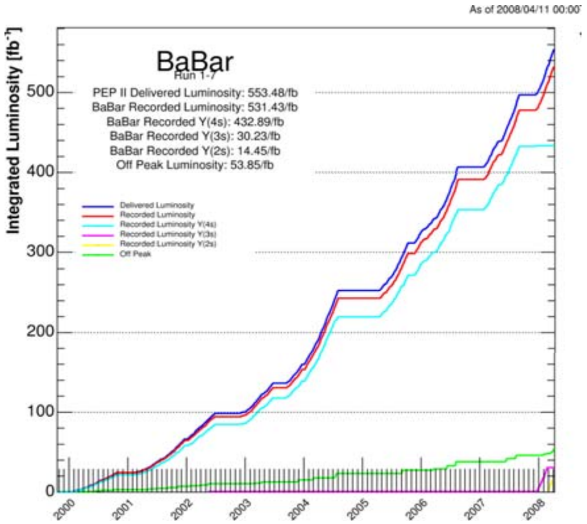
$$\mathcal{B}(D^0\to\bar{K}^{*0}\gamma)=(3.28\pm0.20\pm0.27)\times10^{-4}.$$

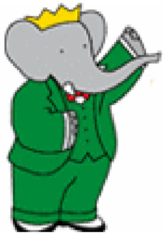
Using world average
$B(D^0\to K^-\pi^+)=(3.89\pm0.05)\%$:

new

Tau

$\sigma_{tt} \sim 0.92$ nb





Rec. Luminosity

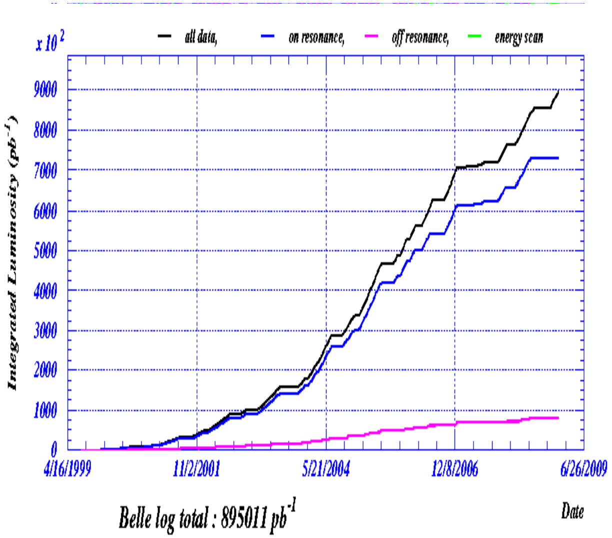
~530 fb^{-1}

Data collected

484M *BB* pairs,
630M cc events,
880M τ's, etc.

Charm

$\sigma_{cc} \sim 1.30$ nb



Rec. Luminosity

~710 fb^{-1}

Data collected

660M *BB* pairs,
860M cc events,
1200M τ's,
2.6M B_s , etc.

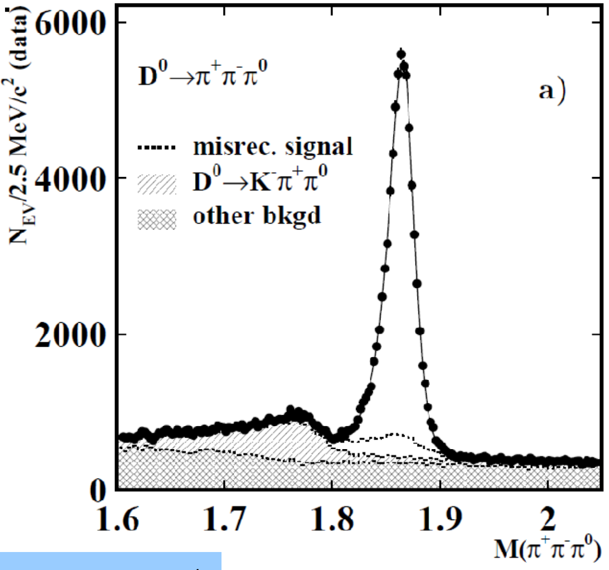
Time integrated CP asymmetries:

Phys Rev. B 662, 102(2008)

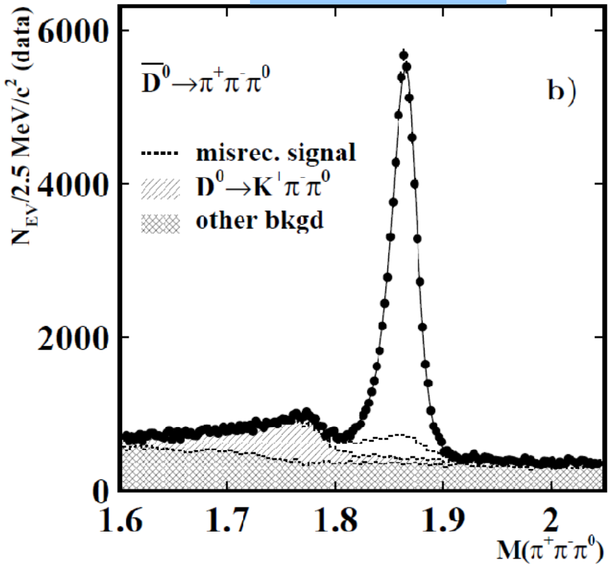
$$a_{CP}^{\pi\pi\pi} = (0.43 \pm 1.30)\%$$

No evidence for CPV

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



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



BaBar data used in these measurements: 384 fb^{-1}

Phase space integrated CP asymmetries:

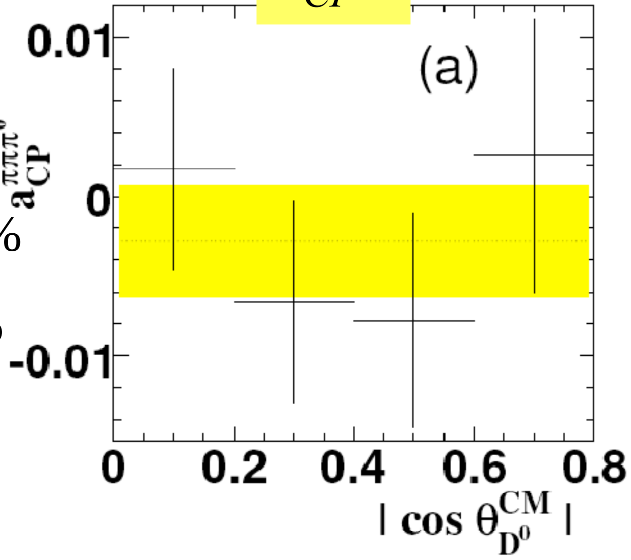
Phys. Rev. D 78, 051102 (2008)

$$a_{CP}^{\pi\pi\pi^0} = (-0.31 \pm 0.41 \pm 0.17)\%$$

$$a_{CP}^{KK\pi^0} = (1.00 \pm 1.67 \pm 0.25)\%$$

No evidence for CPV

$a_{CP}^{\pi\pi\pi^0}$



$a_{CP}^{KK\pi^0}$