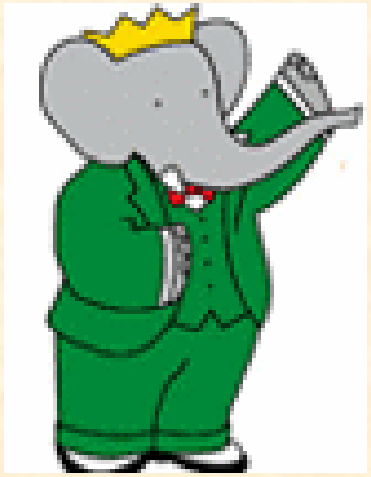
Evidence for D^0-$\overline{D}^0$ Mixing at the B Factories

James D. Olsen
Princeton University
(BaBar Physics Analysis Coordinator)

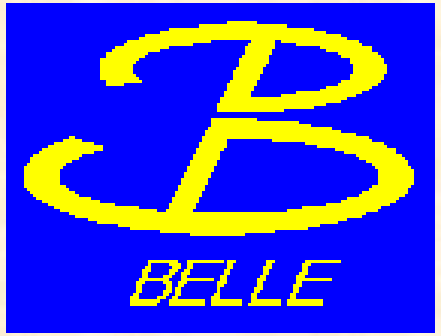
LHC Workshop
March 22, 2007

BaBar



Results presented at Moriond EW
March 13, 2007

First theory preprint, March 19:
Ciuchini et al, hep-ex/0703204



Neutral-Meson Mixing

Mass eigenstates:

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

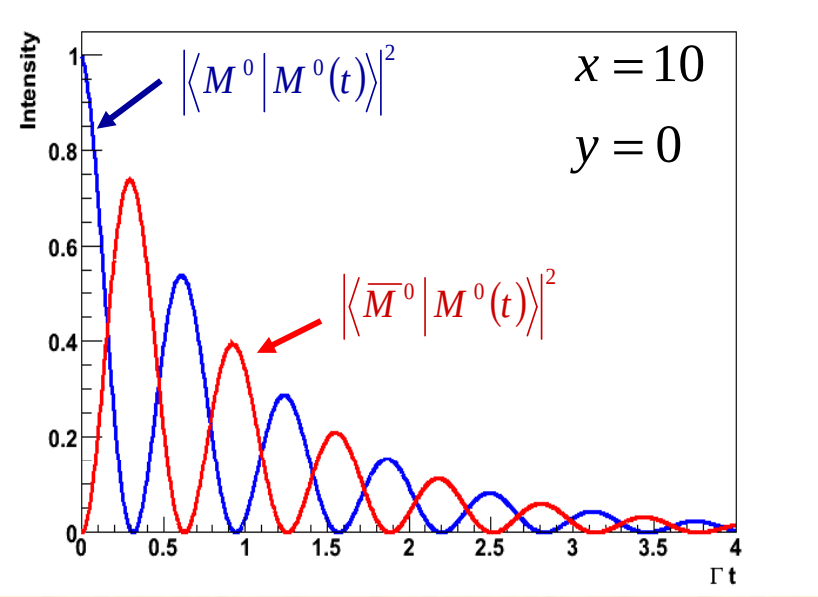
(p ≠ q → CP violation)

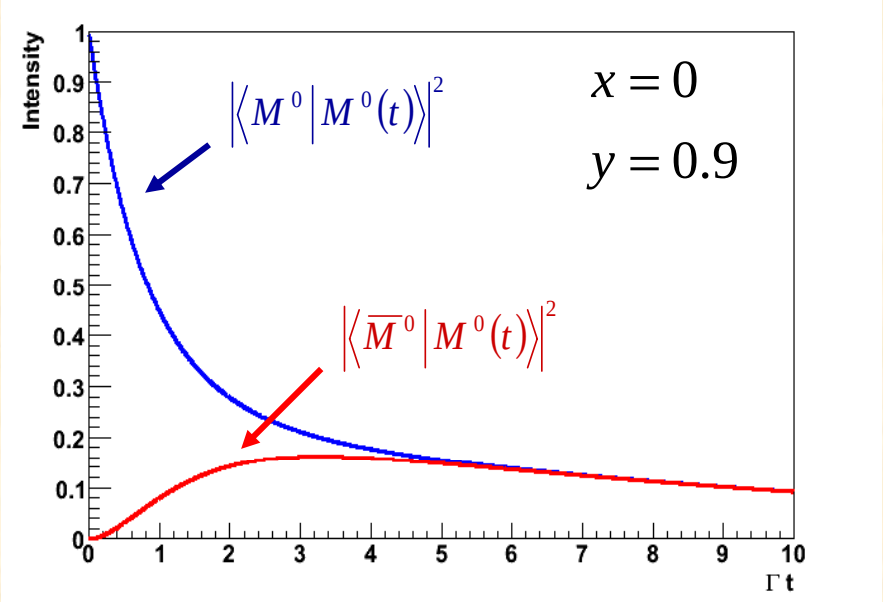
Time evolution:

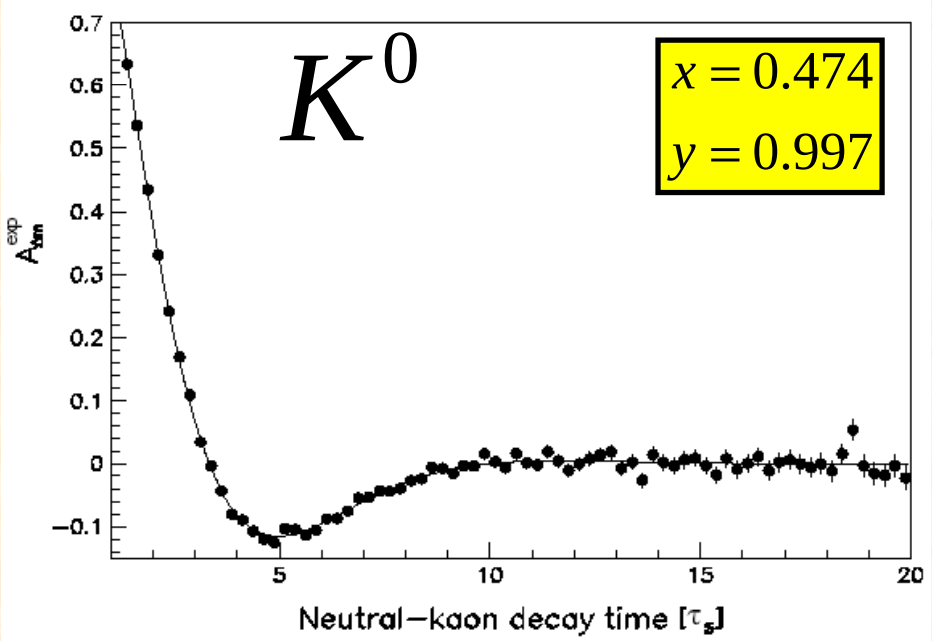
$$\left|M_{1,2}(t)\right\rangle = e^{-iM_{1,2}t}e^{-\frac{\Gamma_{1,2}}{2}t}\left|M_{1,2}(0)\right\rangle$$

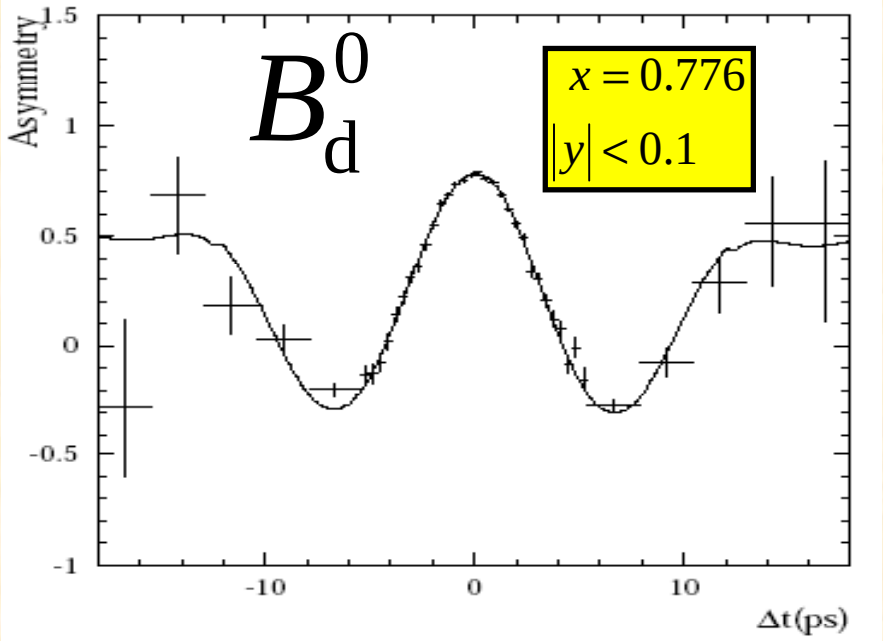
Mass difference: $x \equiv \frac{m_1 - m_2}{\overline{\Gamma}}$

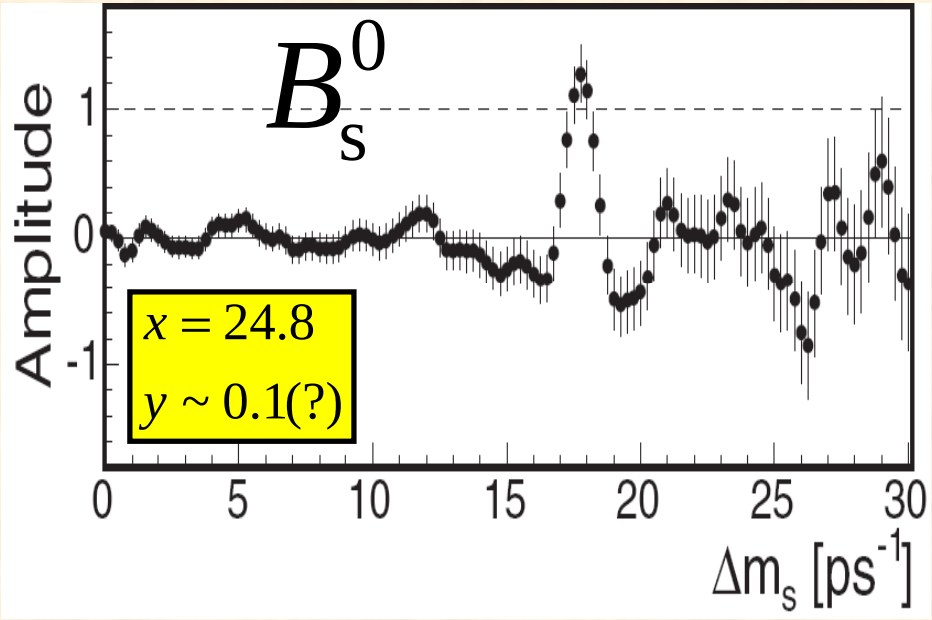
Lifetime difference: $y \equiv \frac{\Gamma_1 - \Gamma_2}{2\overline{\Gamma}}$











1958 – mixing in neutral kaons

1987 – mixing in B_d

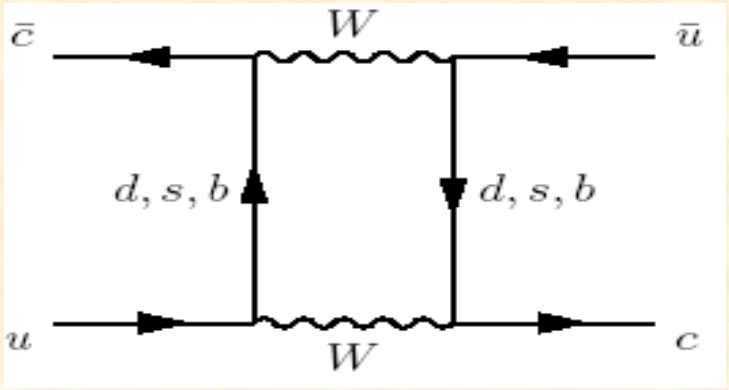
2006 – mixing in B_s

2007 – mixing in the D system?

Mixing expected to be extremely "slow" in the charm sector: x << 1

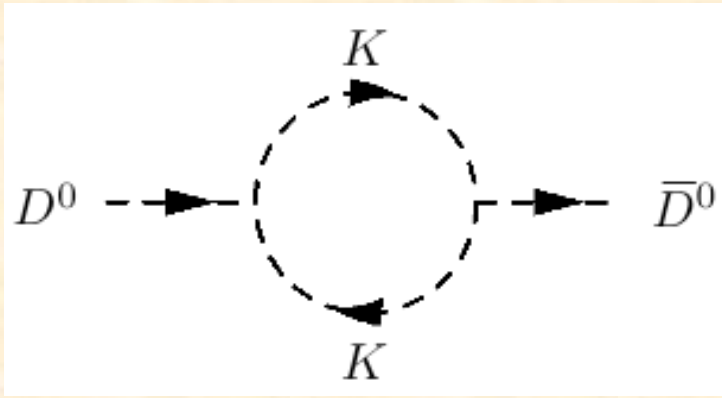
Charm-Meson Mixing (SM)

short distance ~ x



$O(10^{-5})$

long distance ~ y



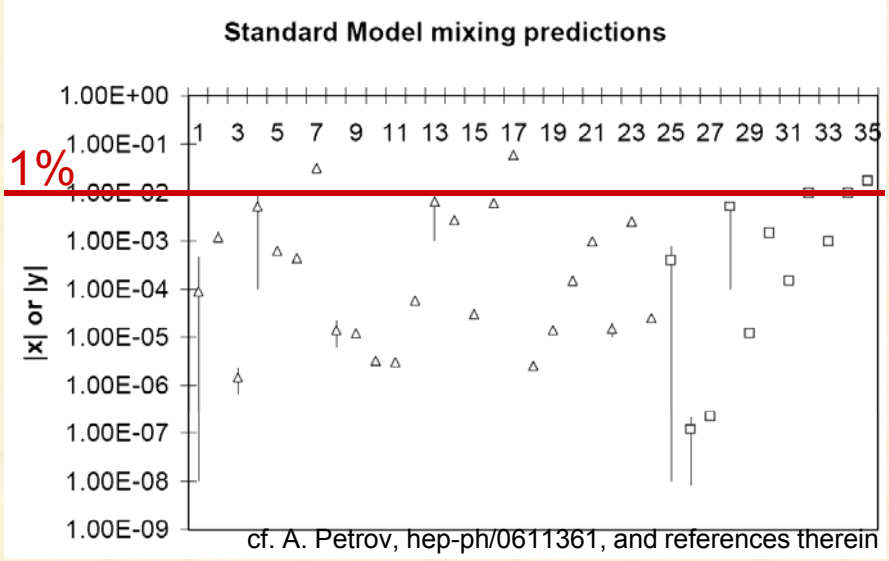
$O(10^{-3} - 10^{-2})$

Most calculations give:

x,y < 1%

"D^0-$\bar{D}^0$ is expected to be too small to measure with BaBar if the Standard Model is a complete description of physics."

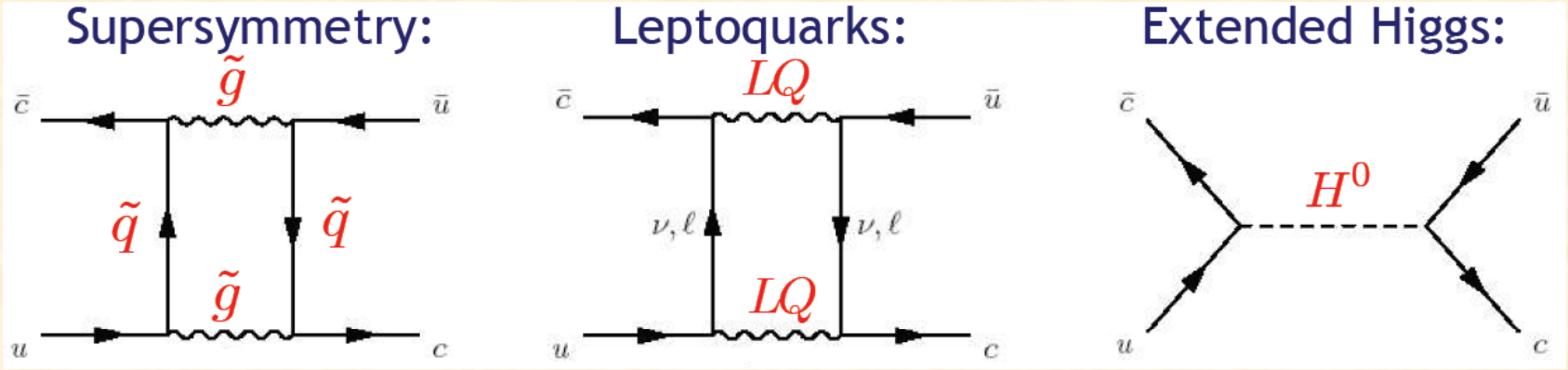
- BaBar Physics Book (1998)



cf. A. Petrov, hep-ph/0611361, and references therein

Charm-Meson Mixing (NP)

New particles enter primarily in the short distance contribution (x):



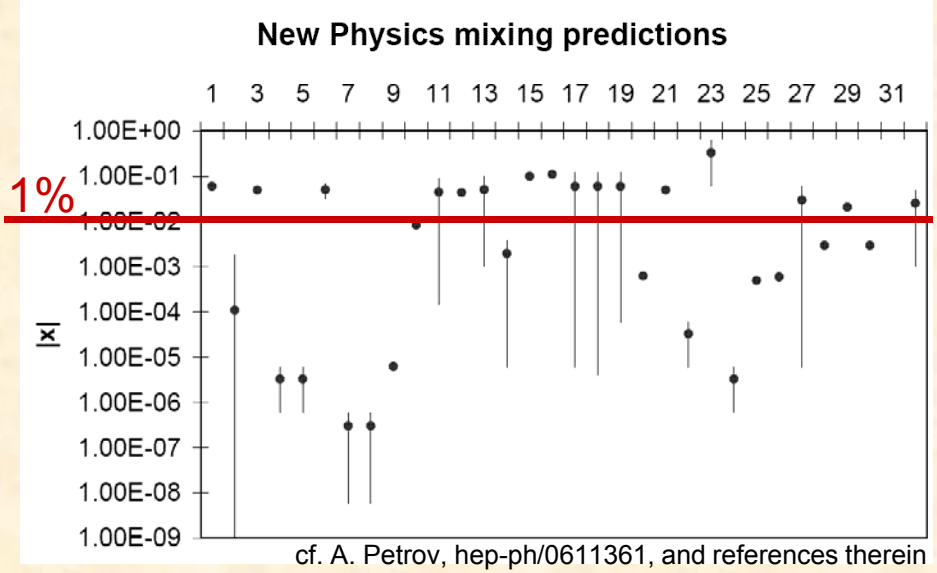
Signs of New Physics:

|x| >> |y|

CP violation

Suppression of new FCNCs via quark-squark alignment predicts "large" effects in D-$\bar{D}$ mixing:

Y. Nir and N. Seiberg, hep-ph/9304307 (1993)
Y. Nir, hep-ph/0206064 (2002)

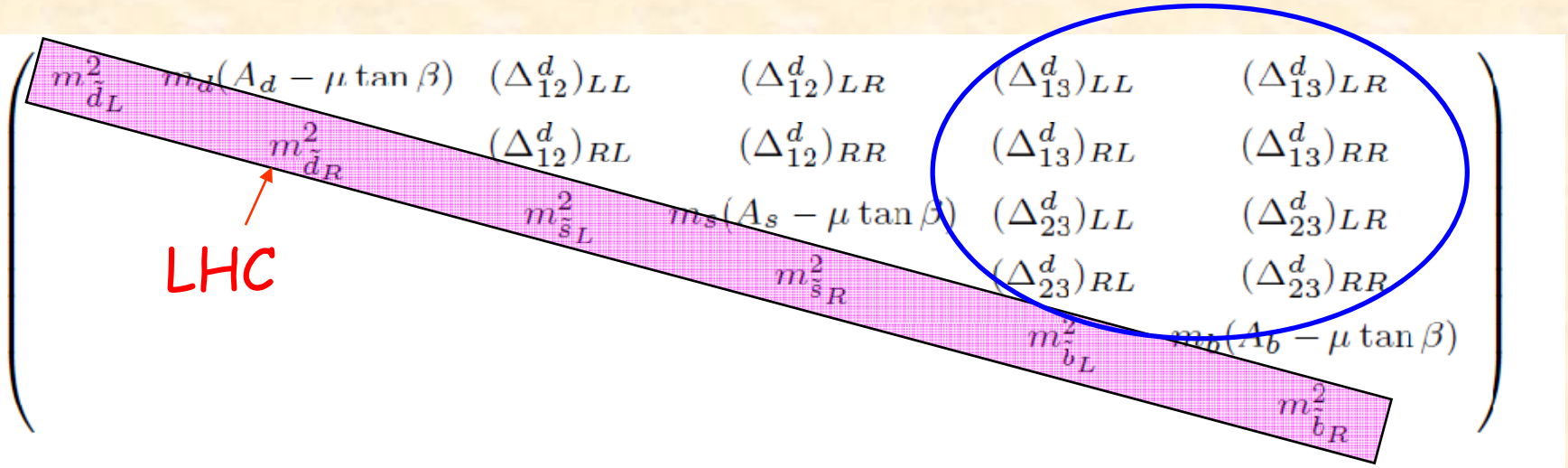


cf. A. Petrov, hep-ph/0611361, and references therein

Constraining the Squark Mass Matrix

Squark mass matrix (d sector)

B Factory, Tevatron



Assuming all Δ's small and squarks nearly degenerate, we can use mass insertion approximation (MIA):

$$(\delta^d_{ij})_{AB} = \frac{(\Delta^d_{ij})_{AB}}{\tilde{m}^2}$$

Observation of D-$\overline{\text{D}}$ mixing opens a new window on the off-diagonal elements of the squark matrix in the up-quark sector

~~B~~ D Factories

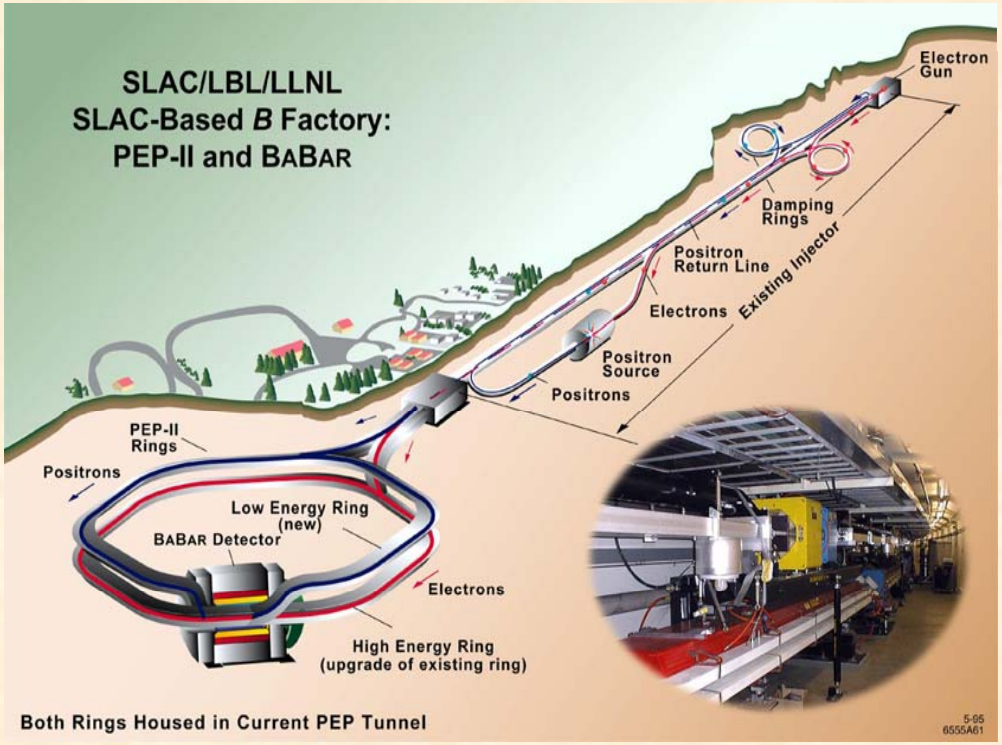
$e^+e^- \to \Upsilon(4S) \to B\bar{B}$ ~~$\to \Upsilon(4S) \to D\bar{D}$~~

PEP-II @ SLAC

beams: 8.9 x 3.1 GeV

$\mathcal{L}_{\text{peak}} = 1.2 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$, $\mathcal{L}_{\text{int}} \sim 400\,\text{fb}^{-1}$

10 countries, 77 institutions, ~550 physicists

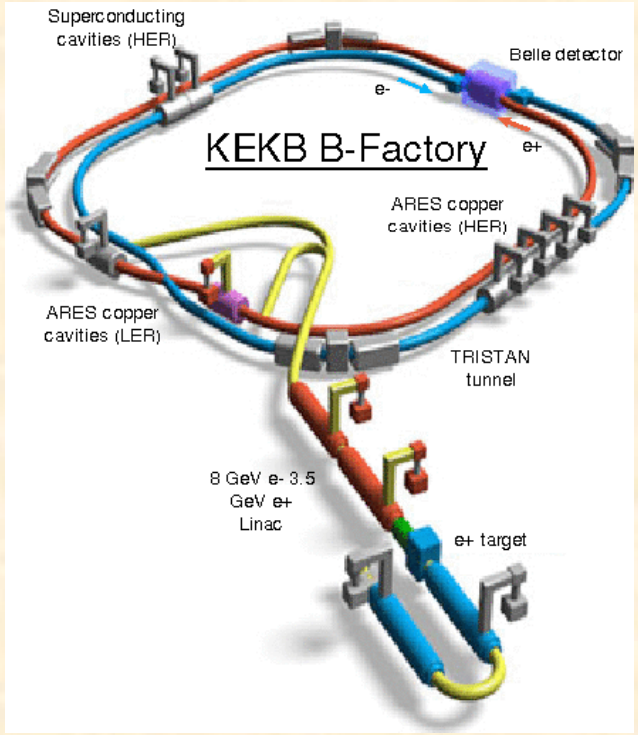


Belle @ KEK

beams: 8.0 x 3.0 GeV

$\mathcal{L}_{\text{peak}} = 1.7 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$, $\mathcal{L}_{\text{int}} \sim 700\,\text{fb}^{-1}$

13 countries, 57 institutions, ~400 physicists

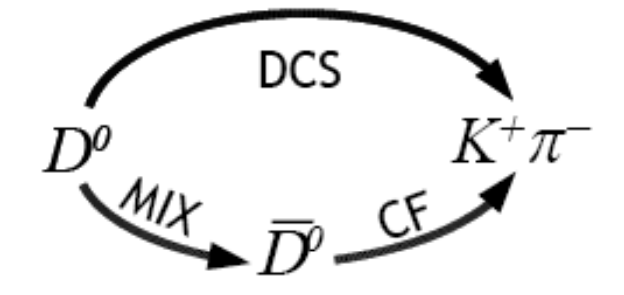


BaBar Analysis: $D^0 \to K\pi$

Two paths to the "wrong-sign" state:

$$D^0 \to K^+\pi^- \qquad \text{(DCS decays)}$$

$$D^0 \to \overline{D}^0 \to K^+\pi^- \qquad \text{(Mixing)}$$



Mixing modifies the exponential decay-time distribution:

$$\frac{dN}{dt} \propto e^{-\overline{\Gamma}t}\left[\underbrace{R_D}_{\text{DCS}} + \underbrace{\sqrt{R_D}\,y'\left(\overline{\Gamma}t\right)}_{\text{interference}} + \underbrace{\frac{x'^2 + y'^2}{4}\left(\overline{\Gamma}t\right)^2}_{\text{mixing}}\right]$$

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

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

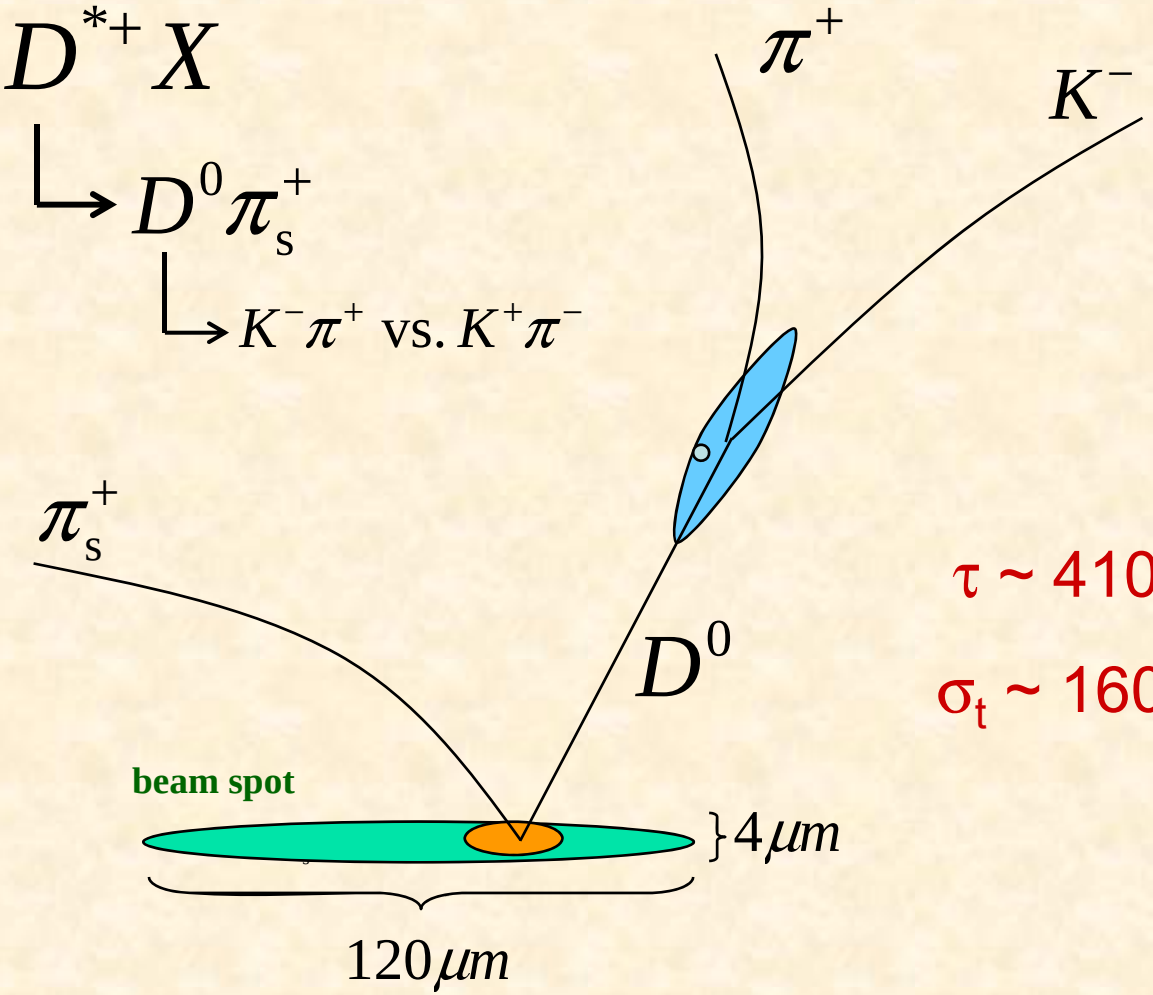
Strong phase $\delta \to 0$ in SU(3) limit

Experimental Technique

$e^+e^- \rightarrow D^{*+}X$

$\hookrightarrow D^0\pi_s^+$

$\hookrightarrow K^-\pi^+$ vs. $K^+\pi^-$



$\tau \sim 410\text{fs} \sim 120\mu\text{m}$

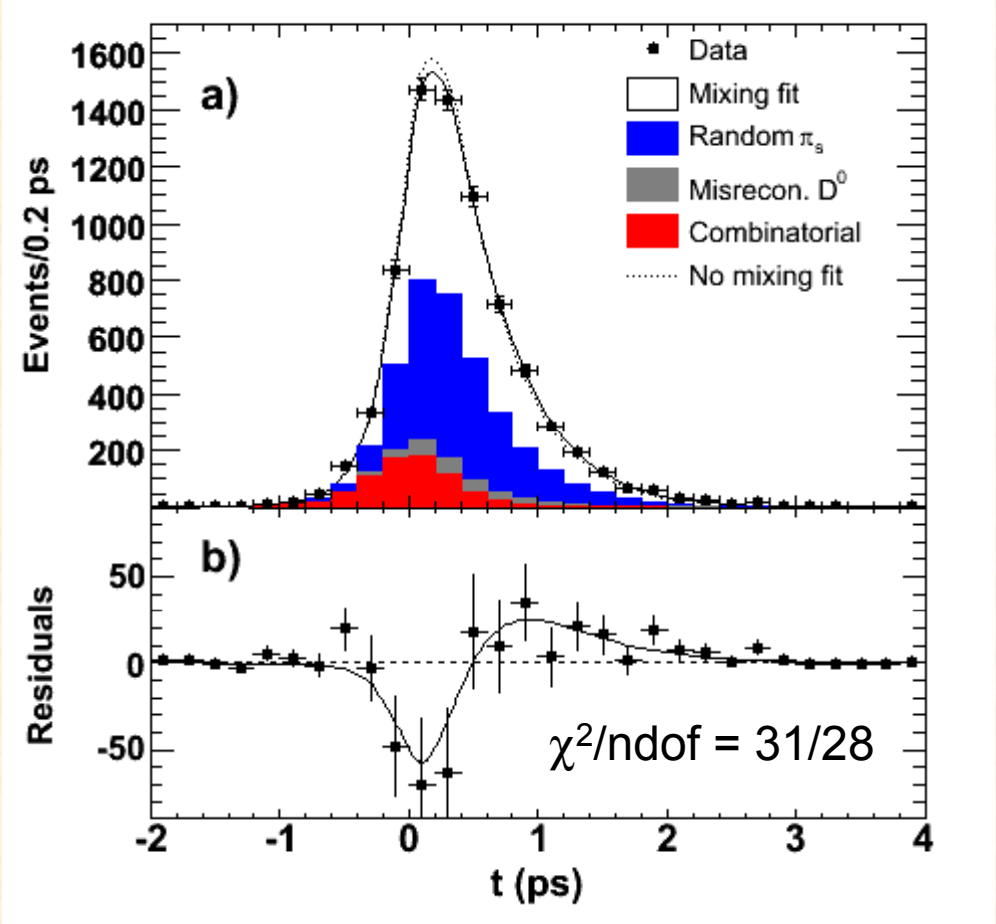
$\sigma_t \sim 160\text{fs} \sim 50\mu\text{m}$

BaBar Evidence for Mixing

Wrong-sign decay-time distribution

First assume no mixing:

$$\frac{dN}{dt} \propto e^{-\bar{\Gamma}t}\left[R_D + \sqrt{R_D}\, y'(\bar{\Gamma}t) + \frac{x'^2 + y'^2}{4}(\bar{\Gamma}t)^2 \right]$$



Mixing gives a better description of the data

$$x'^2 = (-0.022 \pm 0.030 \pm 0.021)\%$$

$$y' = (0.97 \pm 0.44 \pm 0.31)\%$$

3.9σ

No evidence for CP violation

hep-ex/0703020

Submitted to PRL on March 9

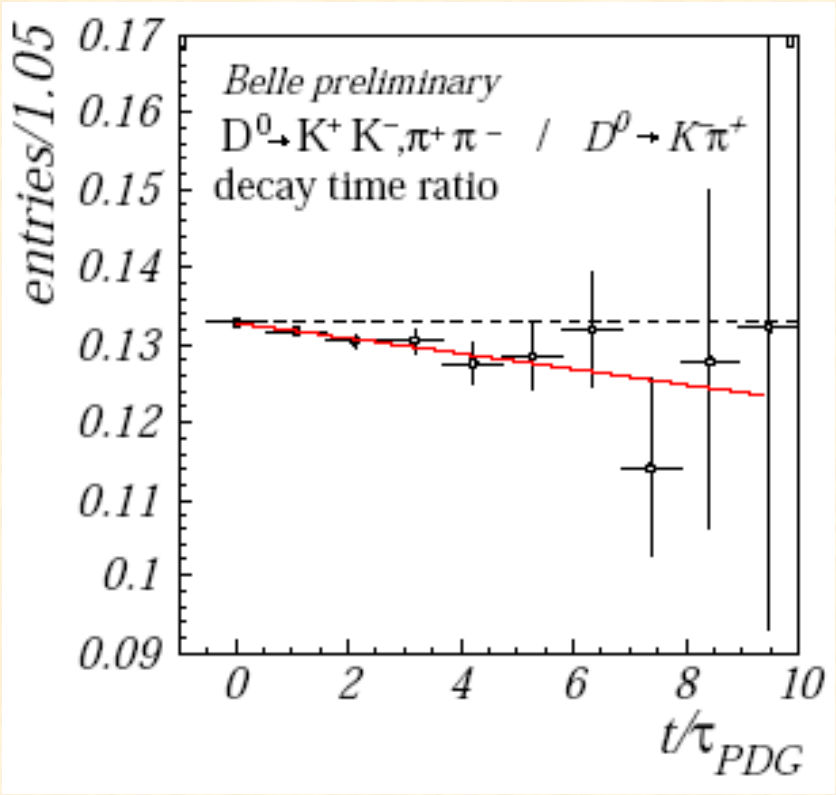
Belle Evidence in $D^0 \to K^+K^-, \pi^+\pi^-$

- Measure the lifetime for KK and ππ relative to Kπ
  - Kπ gives $(\Gamma_1 + \Gamma_2)/2$
  - KK and ππ give Γ_1

If no CP violation, direct access to the CP-even state (D_1)

$$y_{CP} = (1.31 \pm 0.32 \pm 25)\%$$
$$= y \text{ (if no CP violation)}$$

3.2σ



http://belle.kek.jp/belle/talks/moriondQCD07/Staric.pdf

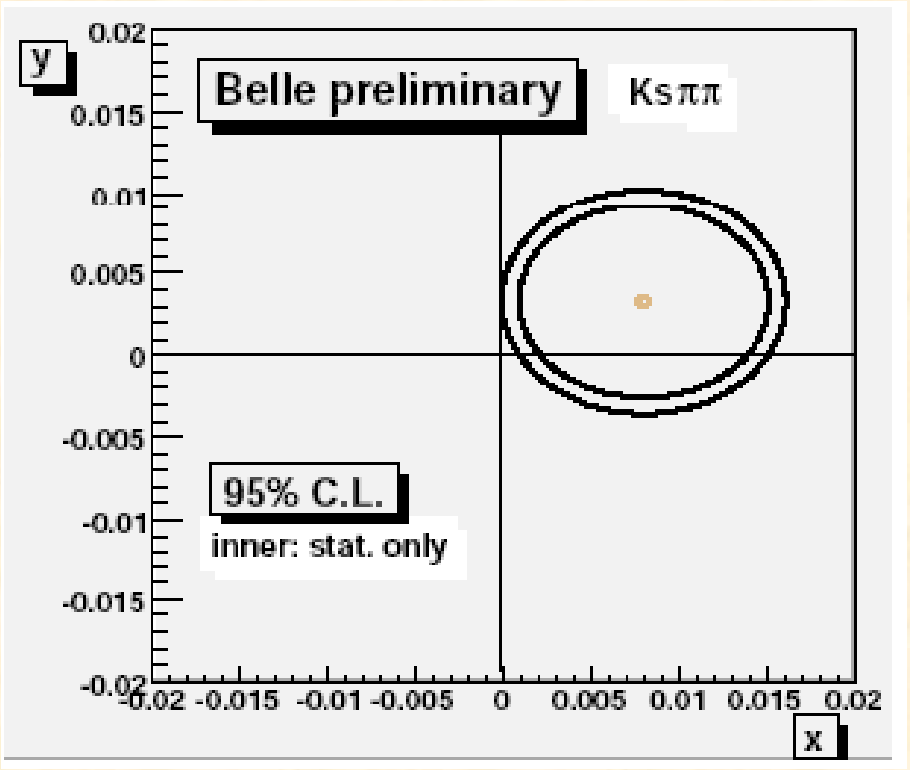
Belle Evidence in $D^0 \to K_S\pi^+\pi^-$

Similar technique as $D^0 \to K\pi$;
Dalitz analysis gives x and y

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

2.4σ

x > y, new physics?

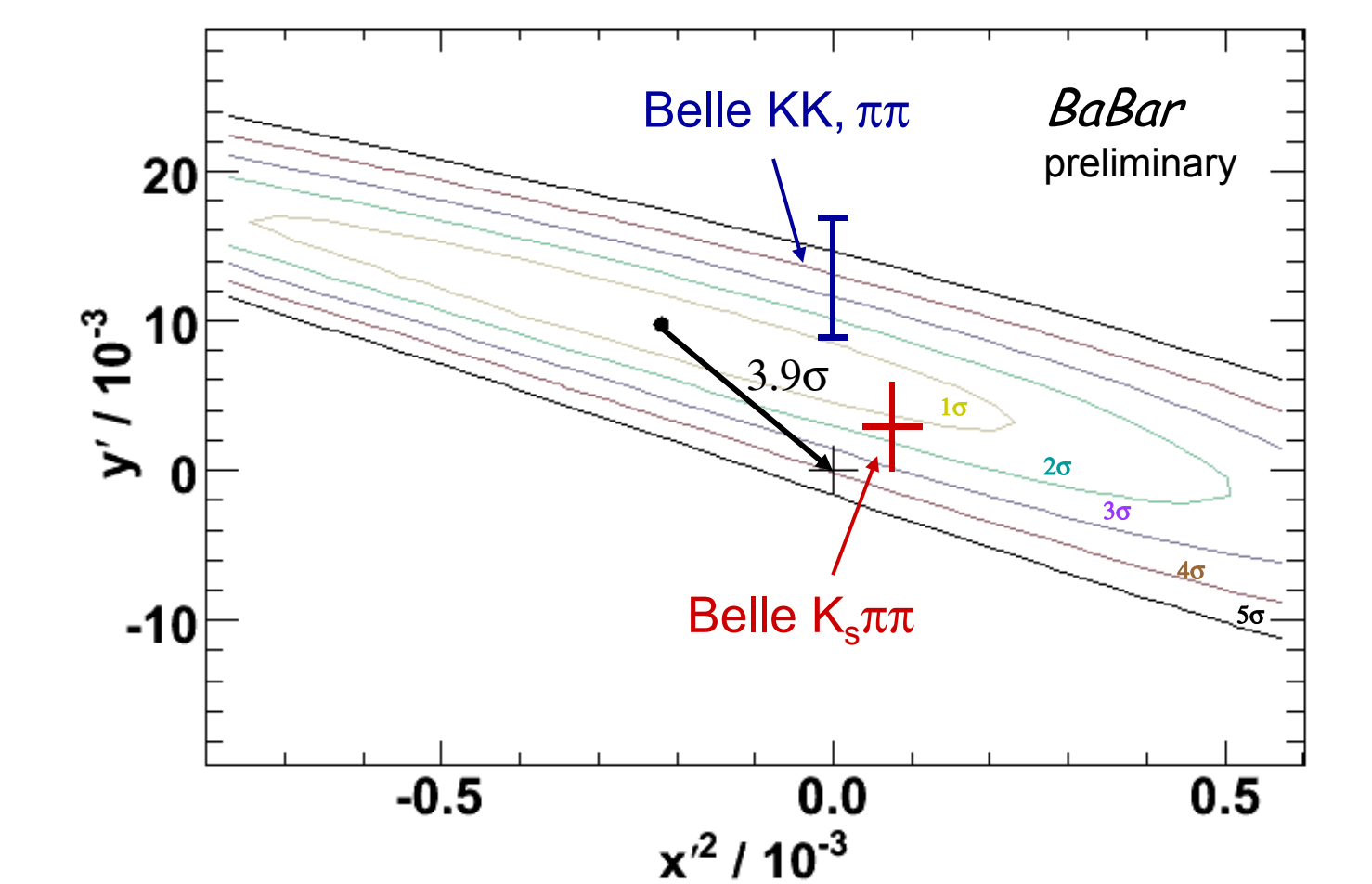


No evidence for CP violation

http://belle.kek.jp/belle/talks/moriondQCD07/Staric.pdf

Comparison of Results

Assuming SU(3) limit ($\delta = 0$) and no CP violation



BaBar and Belle are consistent and complementary

Summary and Outlook

- BaBar and Belle have presented independent and complementary evidence for D-$\overline{D}$ mixing
  - Assuming SU(3), both experiments see evidence for a ~1% lifetime difference ($\Gamma_1 > \Gamma_2$)
  - Belle also sees some evidence for |x| > |y|, but…
  - No sign of CP violation in either experiment
- Room for New Physics, but more data is needed to clarify the situation
  - B Factory datasets will double by ICHEP 2008
  - Many more decay modes to investigate
  - Look for more results at Lepton-Photon 2007, and…

See you in Philadelphia in 2008 with 2/ab !!