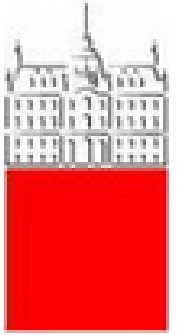


Searches for D^0 - \bar{D}^0 Mixing at Belle



B. Golob

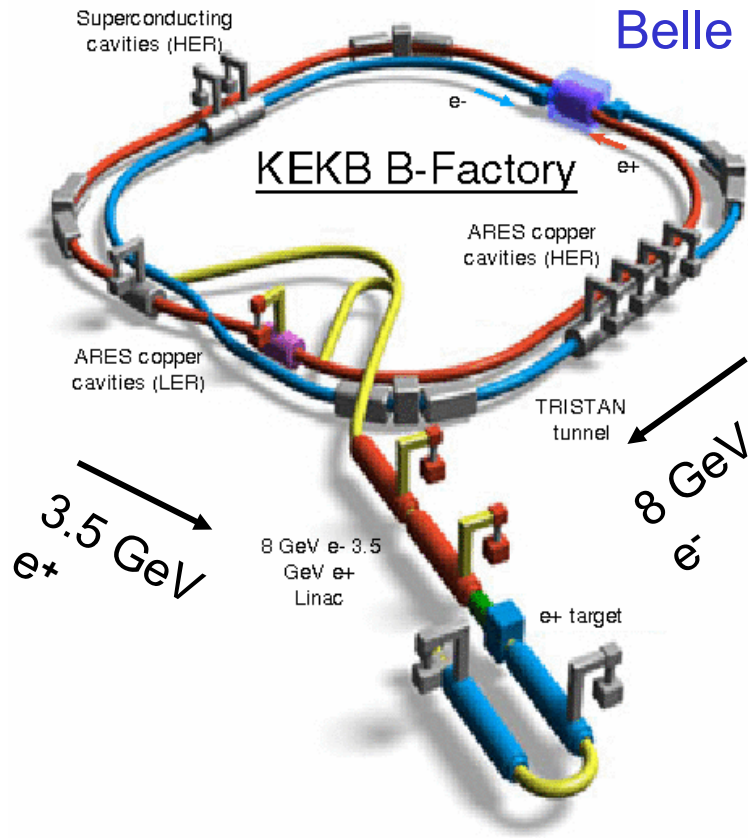
University of Ljubljana

Belle Collaboration

Outline

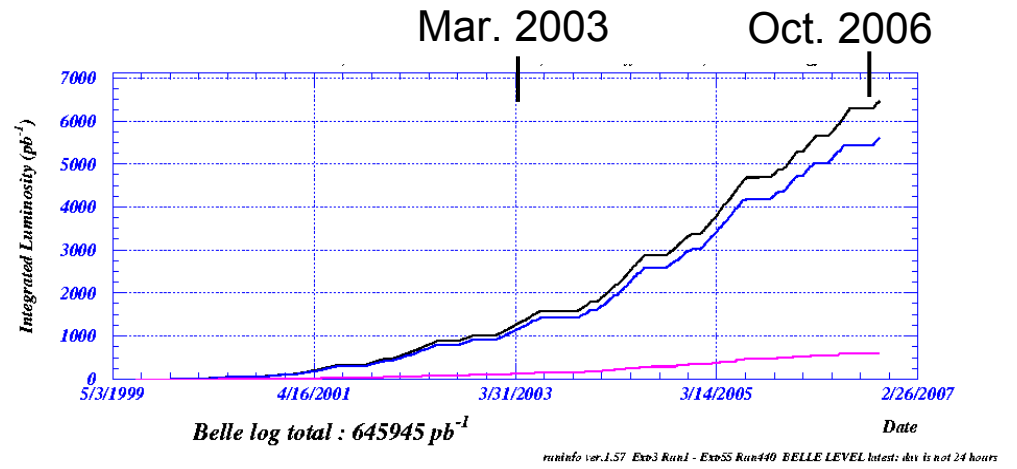
1. Introduction
2. Semileptonic decays
3. Hadronic decays
 $K^+\pi^-$
 $K^+\pi^-\pi^+$, $K^+\pi^-\pi^+\pi^0$
4. Outlook

Introduction

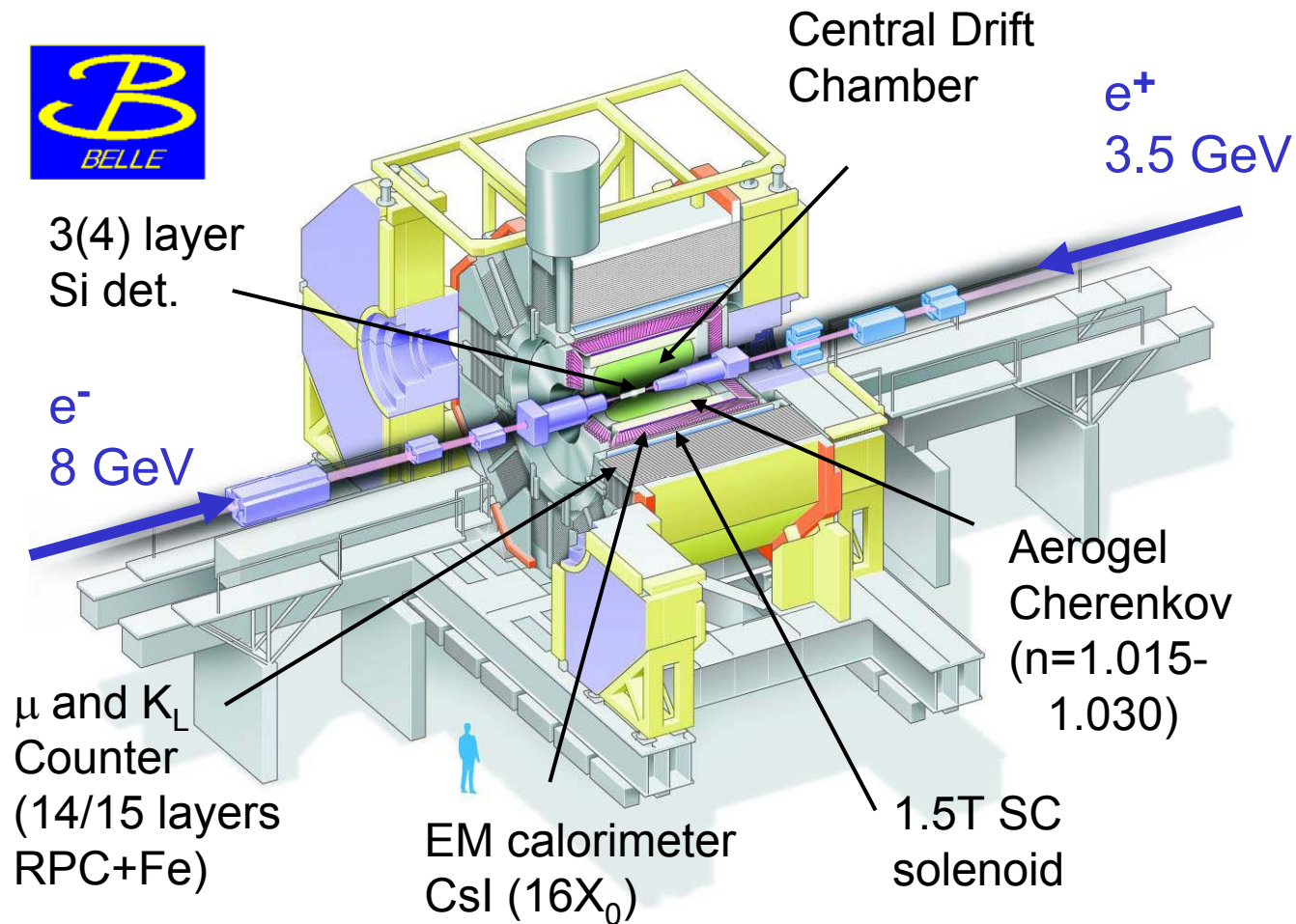


Continuous injection,
peak luminosity: $L = 16.5 \text{ nb}^{-1} \text{ s}^{-1}$

Integrated luminosity: $\int L dt \approx 650 \text{ fb}^{-1}$



Introduction cont^{ed}



tracking $\sigma(p_t)/p_t = 0.2\% \sqrt{(p_t^2 + 2.5)}$

PID $\epsilon(K^\pm) \sim 85\%$ $\epsilon(\pi^\pm \rightarrow K^\pm) \leq 10\%$ for $p < 3.5 \text{ GeV}/c$

Introduction cont^{ed}

D^0 - \bar{D}^0 mixing phenomenology

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle; \quad x \equiv \frac{m_2 - m_1}{\Gamma}; \quad y \equiv \frac{\Gamma_2 - \Gamma_1}{2\Gamma};$$

$$\langle f | D^0(t) \rangle = e^{-\left(\frac{1}{2} + i\frac{m}{\Gamma}\right)t} \left[A_f \cosh\left(\frac{ix + y}{2}t\right) + \frac{q}{p} \bar{A}_f \sinh\left(\frac{ix + y}{2}t\right) \right]$$

$$t \equiv \frac{t_{dec}}{\tau(D^0)}; \quad A_f \equiv \langle f | D^0 \rangle; \quad \bar{A}_f \equiv \langle f | \bar{D}^0 \rangle;$$

$$|xt|, |yt| \ll 1$$

Flavor tag at production

$$D^{*+} \rightarrow D^0 \pi_{slow}^+$$

$$D^{*-} \rightarrow \bar{D}^0 \pi_{slow}^-$$

$$p_{CMS}(D^*) \geq 2.5 \text{ GeV}$$

no D^{*} 's from B decays

also bkg. rejection, good resol. in $\Delta M = M(D^0 \pi_{slow}) - M(D^0)$

Semileptonic decays

Wrong charge combinations (WS):



no “DCS” decays $\Rightarrow N_{\text{WS}}/N_{\text{RS}} = R_M \approx (x^2+y^2)/2$

$$\langle K^+ \ell^- \nu | D^0(t) \rangle \propto \frac{x^2 + y^2}{4} t^2 e^{-t}$$

Observable:

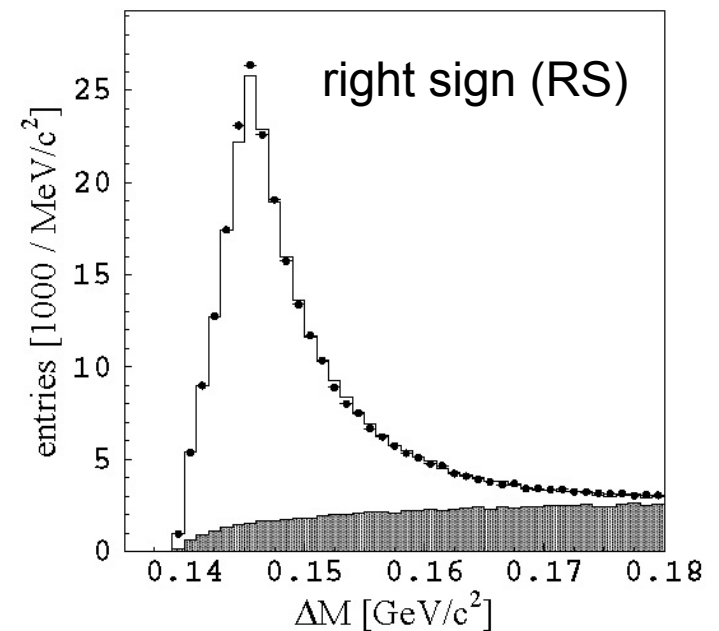
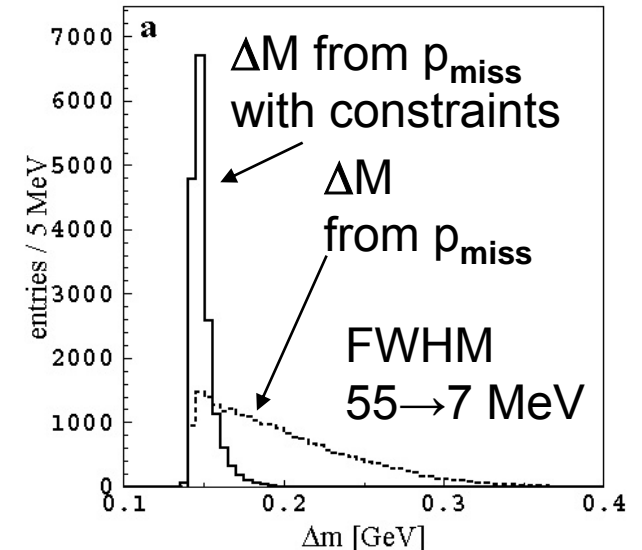
$$\Delta M = M(K e \nu \pi_{\text{slow}}) - M(K e \nu)$$

Reconstruct ν :

$$p_{\text{miss}} = p_{\text{CMS}} - p_{K e \pi} - p_{\text{rest}}$$

$$M(K e \nu \pi_{\text{slow}}) \equiv M(D^{*+}), \quad M^2(\nu) \equiv 0$$

$$N_{\text{RS}} = (229.45 \pm 0.69) \cdot 10^3$$



Semileptonic decays cont^{ed}

Reduce bkg., increase sensitivity:

$$t = \frac{M(D^0)}{c\tau(D^0)} \cdot \frac{L(D^0)}{p(D^0)}$$

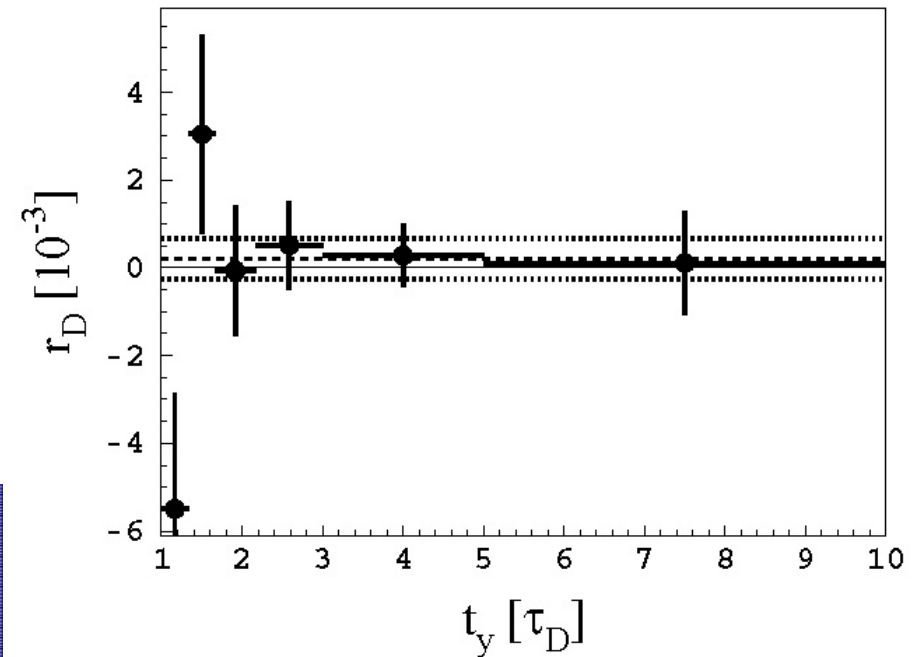
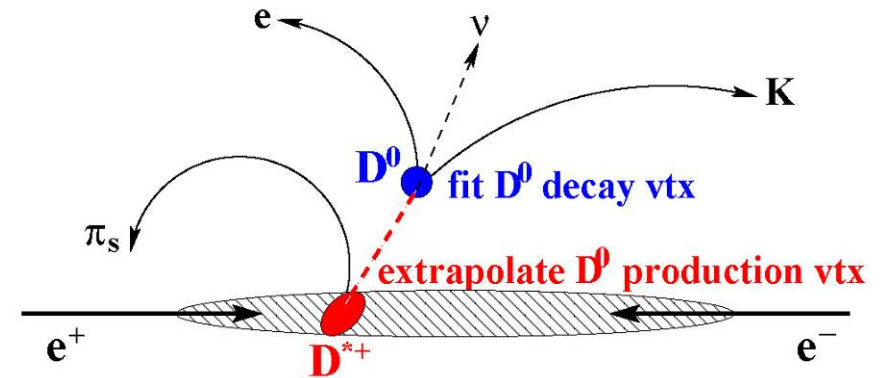
$\langle t \rangle(\text{bkg.}, \text{RS}) < \langle t \rangle(\text{mix. signal})$

6 bins in $1 < t < 10$

$$R_{M,i} = \frac{N_{WS,i}}{N_{RS,i}} \cdot \frac{\mathcal{E}_{RS,i}}{\mathcal{E}_{WS,i}}$$

$$R_M = (0.20 \pm 0.47 \pm 0.14) \cdot 10^{-3}$$

$$R_M < 1.2 \cdot 10^{-3} \quad 95\% \text{ C.L.}$$



dominating systematics from limited bkg. statistics (embedded π_{slow})

Hadronic decays $K^+\pi^-$

Wrong charge combinations (WS):

$$D^{*+} \rightarrow D^0 \pi_{\text{slow}}^+ \quad D^0 \rightarrow \bar{D}^0 \rightarrow K^+ \pi^-$$

DCS decays \Rightarrow interference

$$\langle K^+ \pi^- | D^0(t) \rangle \propto \left[R_D + \sqrt{R_D} y' t + \frac{x'^2 + y'^2}{4} t^2 \right] e^{-t}$$

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

Observables:

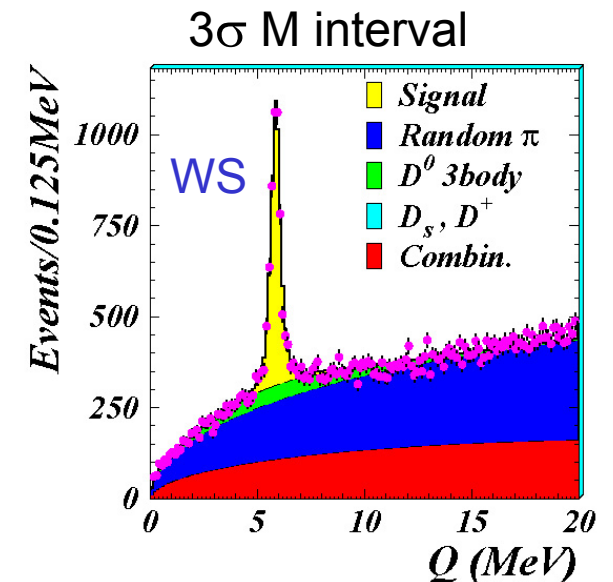
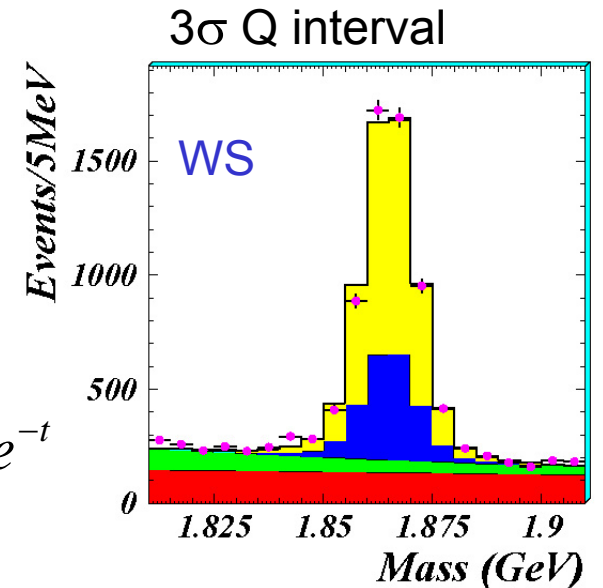
$$M = M(K\pi)$$

$$Q = M(K \pi \pi_{\text{slow}}) - M(K\pi) - M(\pi)$$

2D M-Q fit:

$$N_{\text{WS}} = 4024 \pm 88$$

$$R_D = \frac{\text{DCS rate}}{\text{CF rate}}$$



Hadronic decays $K^+\pi^-$ cont^{ed}

M, Q, σ_t dep^{ent} signal fractions used
in decay time fit (WS):

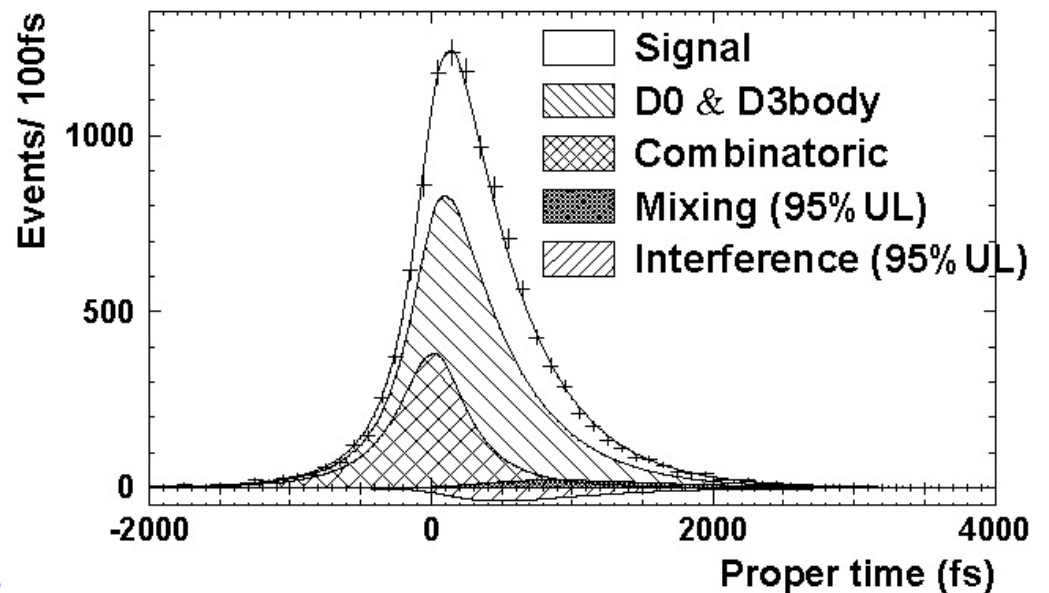
$$f_{sig}(M, Q, \sigma_t) \cdot \left[R_D + \sqrt{R_D} y' t + \frac{x'^2 + y'^2}{4} t^2 \right] e^{-t} \otimes R_{resol}(t) \quad (\text{RS decay time})$$

largest back. random π_{slow}
same resol. f. as signal

$$\tau(D^0) = 409.9 \pm 0.7 \text{ fs}$$

toy MC: no bias

x'^2, y', R_D free parameters



Hadronic decays $K^+\pi^-$ cont^{ed}

Results:

no CPV

$$R_D = (3.64 \pm 0.17) \cdot 10^{-3}$$

$$x'^2 = (0.18 \pm \begin{matrix} 0.21 \\ 0.23 \end{matrix}) \cdot 10^{-3}$$

$$y' = (0.6 \pm \begin{matrix} 4.0 \\ 3.9 \end{matrix}) \cdot 10^{-3}$$

CPV

$$A_D = (23 \pm 47) \cdot 10^{-3}$$

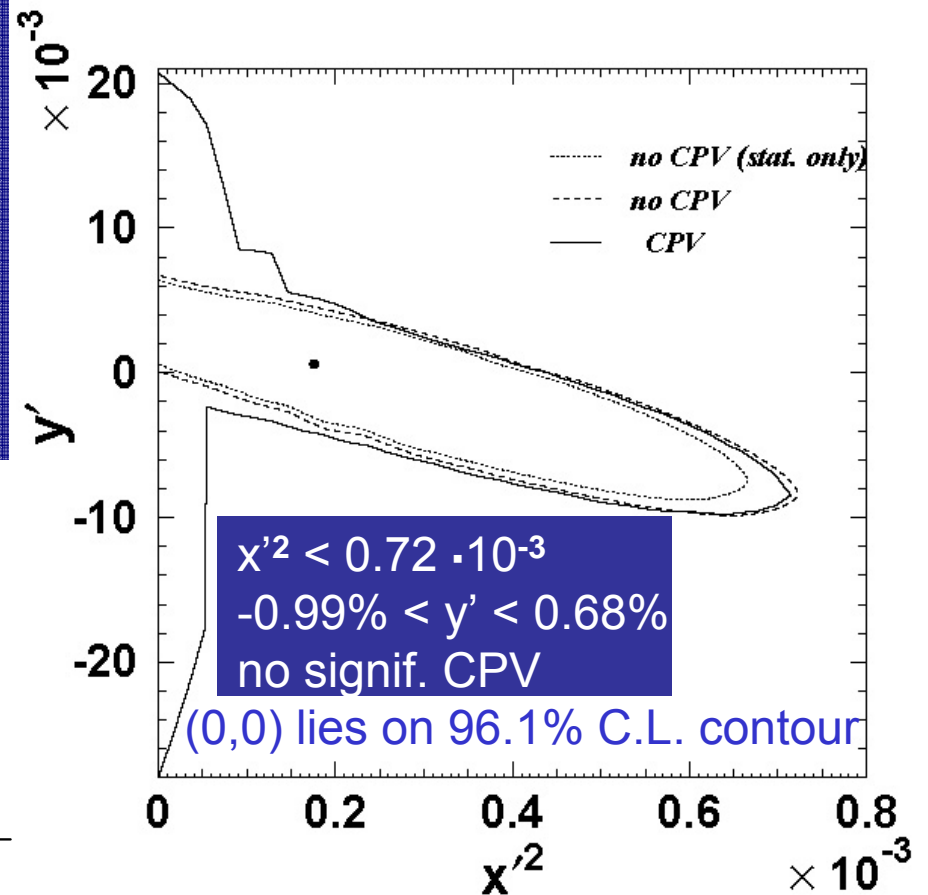
$$A_M = (670 \pm 1200) \cdot 10^{-3}$$

CPV allowed:

separate D^0 and \bar{D}^0 tags
 $(x'^2, y', R_D) \rightarrow (x'^{\pm 2}, y'^{\pm}, R_{D^{\pm}})$

$$A_D = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-} \quad A_M = \frac{R_M^+ - R_M^-}{R_M^+ + R_M^-}$$

95% C.L. (x'^2, y') contour
 frequentist, FC ordering



largest syst. due to $p^*(D^*)$ selection

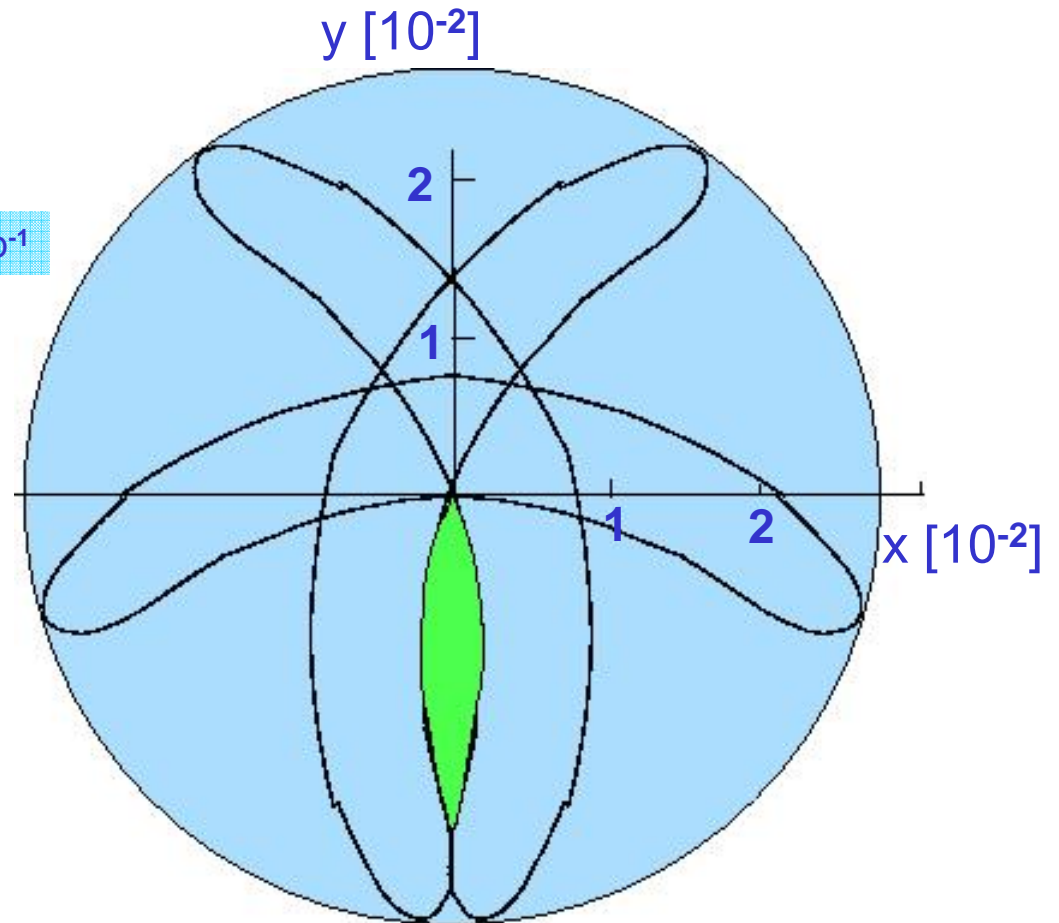
Hadronic decays $K^+\pi^-$ cont^{ed}

(x, y) plane:

$$\delta \approx 0^\circ \pm 70^\circ$$

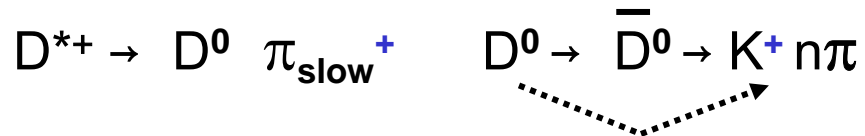
Cleo-c, hep-ex/0607078, 281pfb⁻¹

$$R_M \leq 0.4 \cdot 10^{-3} \\ @ 95\% \text{ C.L.}$$



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

Wrong charge combinations (WS):



DCS decays \Rightarrow interference

Time integrated rate WS/RS:

$$R_{WS} \equiv \frac{N_{WS}}{N_{RS}} = R_D + \sqrt{R_D} y' + \frac{x'^2 + y'^2}{2}$$

Observables:

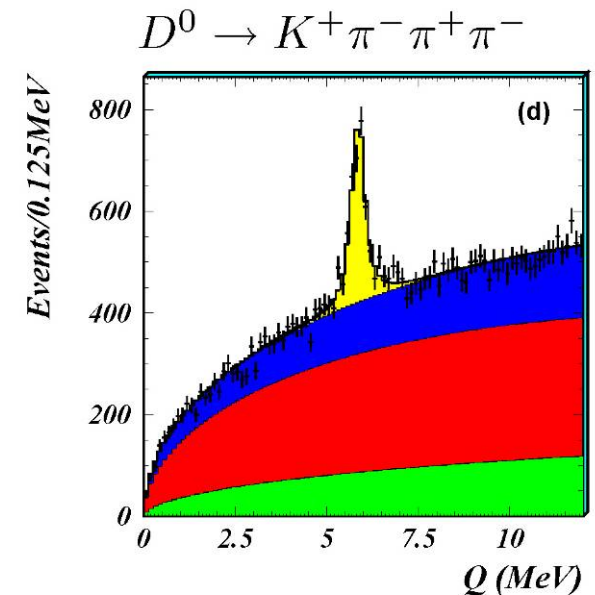
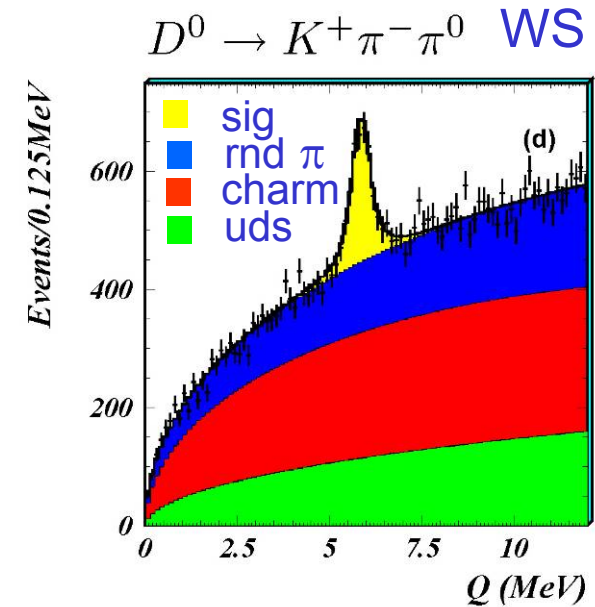
$$M = M(K n\pi)$$

$$Q = M(K n\pi \pi_{\text{slow}}) - M(K n\pi) - M(\pi)$$

2D M-Q fit:

$$N_{WS}(K\pi\pi^0) = 1978 \pm 104$$

$$N_{WS}(K3\pi) = 1721 \pm 75$$



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

cont^{ed}

PRL95, 231801 (2005), 280 fb⁻¹

Eff. correction:

K n π dominated by interm. states, diff. for WS/RS
 ε (Dalitz space $K\pi\pi^0$); ε (5D space $K3\pi$);

$$\bar{\varepsilon}_{RS} / \bar{\varepsilon}_{WS} = 1.01 \pm 0.05; \quad 0.98 \pm 0.04$$

$$N_{sig}^i = (N_{tot}^i - f_{bkg}^i (Q_{side\ band}) N_{bkg}) / \varepsilon^i$$

δ different for different channels

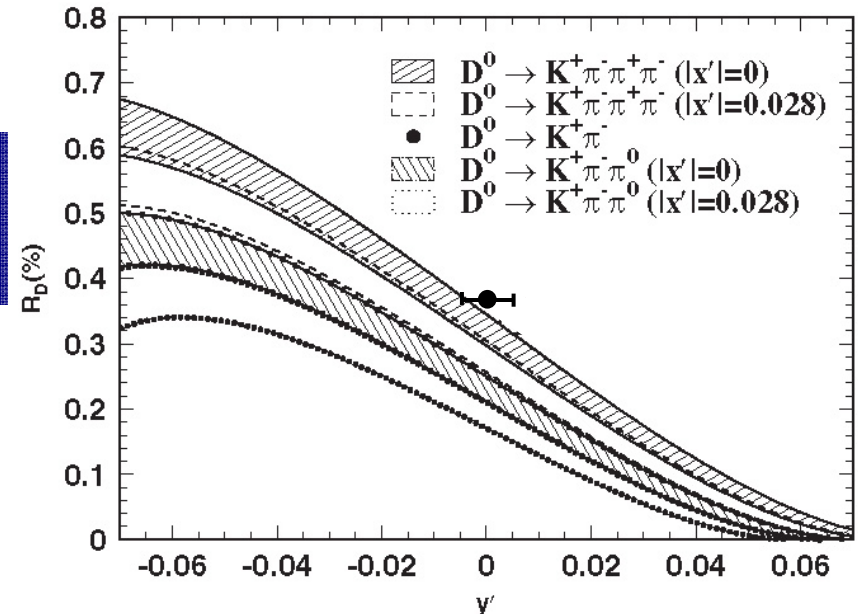
Results:

$$R_{WS} (K\pi\pi^0) = (2.29 \pm 0.15 \pm_{0.09}^{0.13}) \cdot 10^{-3}$$

$$R_{WS} (K3\pi) = (3.20 \pm 0.18 \pm_{0.13}^{0.18}) \cdot 10^{-3}$$

measured R_{WS} determines $R_D(y')$ for fixed x'^2 :

$$R_{WS} - R_D + \sqrt{R_D} y' + \frac{x'^2 + y'^2}{2} = 0$$



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

cont^{ed}

PRL95, 231801 (2005), 280 fb⁻¹

CPV:

$$A_{CP} = \frac{R_{WS}(D^0) - R_{WS}(\bar{D}^0)}{R_{WS}(D^0) + R_{WS}(\bar{D}^0)}$$

$$A_{CP}(K\pi\pi^0) = -0.006 \pm 0.053$$

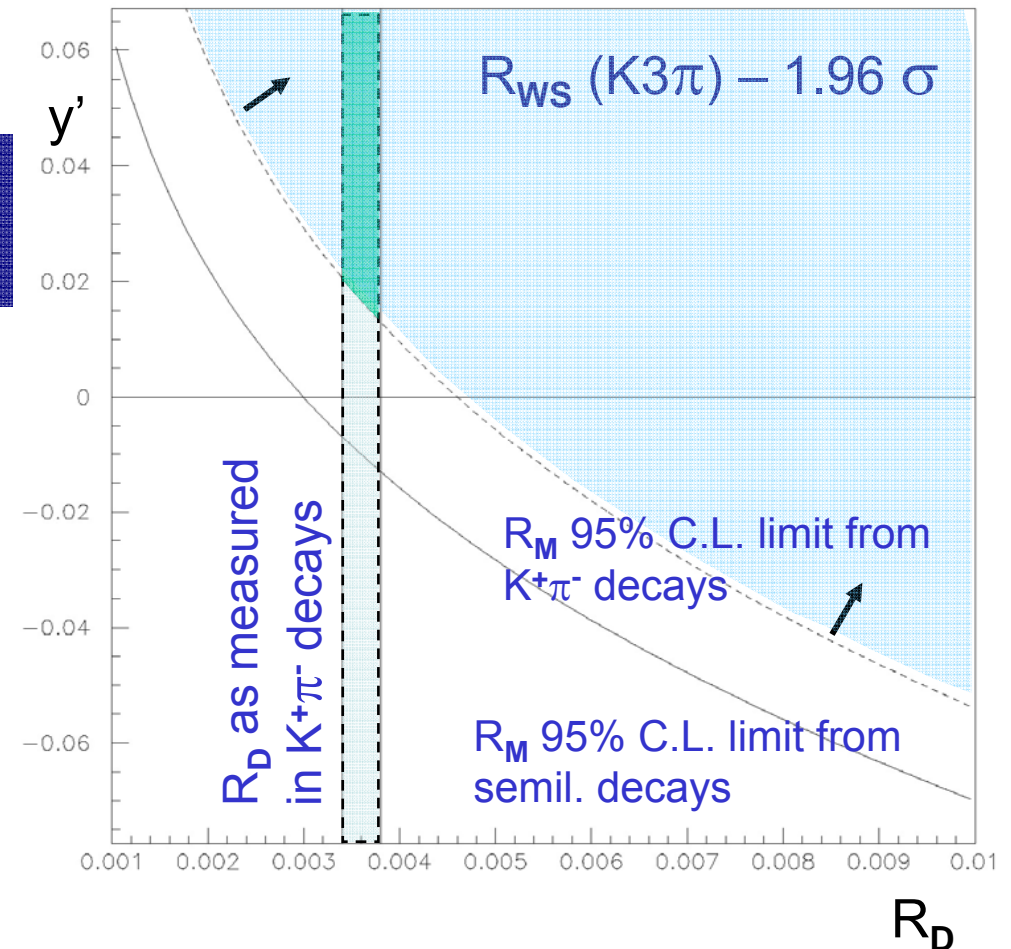
$$A_{CP}(K3\pi) = -0.018 \pm 0.044$$

(y', R_D) limits:

$$R_{WS} = R_D + \sqrt{R_D} y' + \frac{x'^2 + y'^2}{2}$$

$$\frac{x'^2 + y'^2}{2} = R_M \leq R_M^{\text{lim}} \quad \text{channel indep.}$$

$$y' \geq \frac{2R_{WS} - R_M^{\text{lim}}}{\sqrt{R_D}} - \sqrt{R_D}$$



Outlook

Mixing and CPV searches:

no evidence so far

semil. decays: $R_M < 1.2 \cdot 10^{-3}$ 95% C.L.

decays to $K^+\pi^-$: $R_M < 0.4 \cdot 10^{-3}$ 95% C.L.

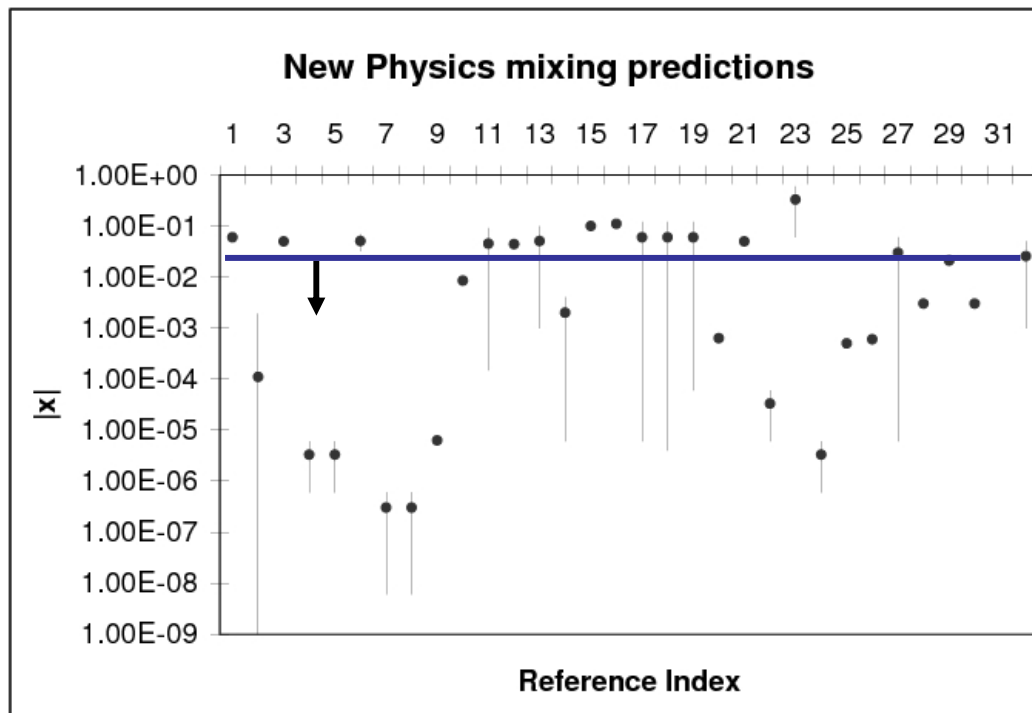
most stringent limits on mixing param^{ers} to date

decays to $K^+ n\pi$: precise WS rate meas^{ent}

PRD72, 071101 (2005), 253 fb⁻¹

PRL96, 151801 (2006), 400 fb⁻¹

PRL95, 231801 (2005), 280 fb⁻¹



A. Petrov, hep-ph/0311371

Outlook

New measurements under way:

BaBar+Belle 2 ab^{-1} , charm fact. 20 fb^{-1}

■ allowed ■ excluded $\sim 95\%$ C.L.

$\delta \approx 0^\circ \pm 25^\circ$

$K_S \pi \pi$ t-dependent
Dalitz & $K^+ K^- / \pi^+ \pi^-$

