A Search for $D^0 - \overline{D^0}$ Mixing using Semileptonic Decay Modes

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Mixing:

$$D^0 \to \overline{D^0} \to K^+ l^- \bar{\nu}_l \quad \text{(e. g.)}$$

Experiments Measure:

$$r = \frac{\Gamma(D^0 \to \overline{D^0} \to \bar{f})}{\Gamma(D^0 \to f)}$$

Motivation:

- In the standard model, mixing in the charm sector is predicted to be much below the sensitivity of current experiments.
- Various extensions to the Standard Model allow for mixing rates measurable by existing experiments.
- Observation of a mixing signal could be an indication of new physics.
- Non-observation of mixing helps constrain theories that predict large mixing.

How do we look for Mixing in semileptonic decays?

Use the D^* Tag

'Right Sign (RS)' Decays:

$$D^{*+} \to \pi^+(D^0 \to K^- l^+ \nu_l)$$

'Mixed' Decays:

$$D^{*+} \to \pi^+(D^0 \to \overline{D^0} \to K^+ l^- \bar{\nu}_l)$$

Compared to hadronic decay modes:

- There is an unreconstructed neutrino.
- D^* mass peak is wider.
- There is more background.

Fully reconstructed decay modes of D^0 give rise to a much narrower and cleaner D^* signal.

So why study mixing the hard way?

In hadronic decays:

- Doubly Cabibbo Suppressed (DCS) decays can give rise to a wrong-sign signal, without any mixing.

For example:

$D^0 \to K^+\pi^-$ is possible.

Mixing process would look like:

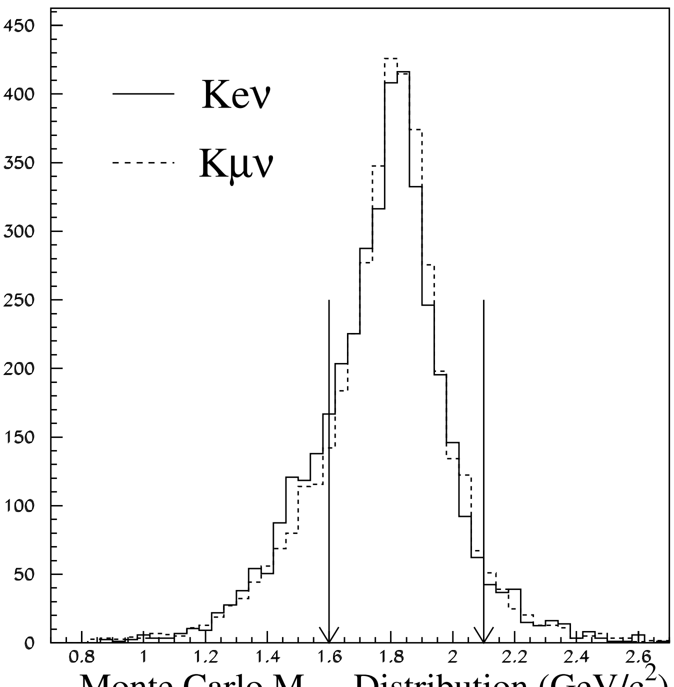
$D^0 \to \overline{D^0} \to K^+\pi^-$

- DCS and Mixing amplitudes can interfere, possibly hiding a mixing signal (*G. Blaylock, A. Seiden and Y. Nir, Phys. Lett.* **B355**, *555 (1995)*).
- Properly taking care of the interference term weakens the sensitivity of the fit considerably.

There is no DCS amplitude in semileptonic decays.

Event Selection

- Well seperated secondary vertex.
- Electrons identified in the EM calorimeter (hadron-electron misidentification rate $\sim 1\%$).
- Two walls of scintillation counters behind steel sheilding used for muon identification (hadron-muon misidentification rate $\sim 4\%$).
- Cerenkov identification for the K.
- Minimum parent mass, M_{min} in the range 1.6 to 2.1 GeV/c^2, where $M_{min} = P_T + \sqrt{P_T^2 + M_{Kl}^2}$.



Monte Carlo M_{min} Distribution (GeV/c^2)

Time evolution for RS and mixed decays
RS decays:

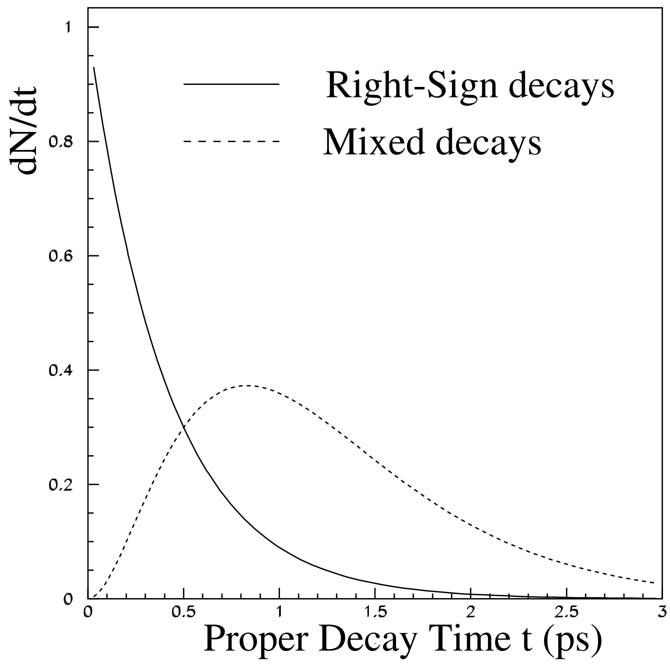
$$\frac{dN}{dt} \propto e^{-\Gamma t}$$

Mixed decays:

$$\frac{dN}{dt} \propto t^2 e^{-\Gamma t}$$

Mixed decays have a peculiar, hard-to-fake time evolution.

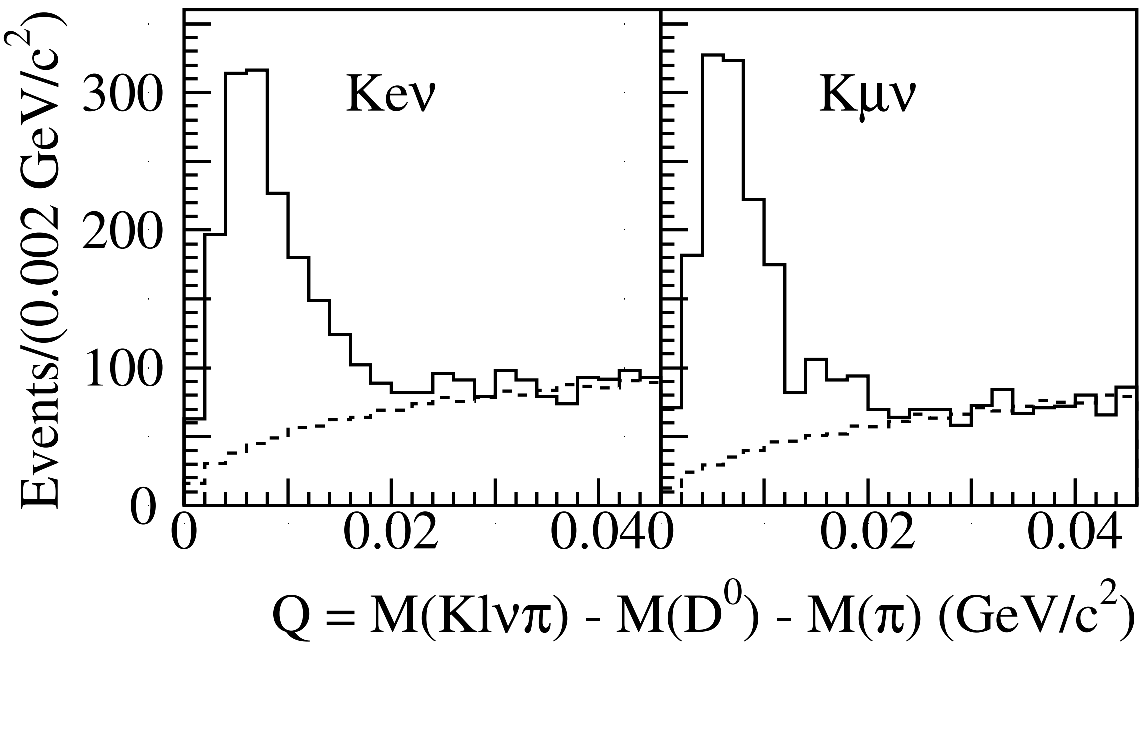
- Time evolution gives an additional handle to separate mixing signal from background



The Maximum Likelihood Fit

Two-dimensional unbinned maximum likelihood fit to the data performed using Q-value ($Q \equiv M(Kl\nu\pi) - M(D^0) - M(\pi)$) and proper decay-time t.

- Signal shape in Q-value – *obtained from the right-sign signal.*
- Signal shape in t –*obtained from right-sign signal.*
- Background shape in Q-value – *obtained from combining D^0 from one event with pions from another event.*
- Background shape in t –*obtained from right-sign side-band decay-time distribution.*



- One can solve for the D^0 momentum upto 2-fold ambiguity using the vertexing information.

- MC studies show that the 'higher' momentum solution gives a better estimate of the true momentum.

- Always pick the high momentum solution. (Fortunately the D^* mass width is not too sensitive to the magnitude of the D^0 momentum).

- Knowing the D^0 momentum, one can make the D^* mass peak and measure the proper decay time

Results of the fit

Parameter	Keν Mode	K$\mu\nu$ Mode
N_{mix}	$4.4^{+11.8}_{-10.5}$	$1.8^{+12.1}_{-11.0}$
N_{RS}	1237 ± 45	1267 ± 44

Mixing rate:

$$r = \frac{N_{mix}}{N_{RS}}\alpha$$

α: A factor to correct for the different detector acceptance for different decay-time behaviors of 'mixed' and 'right-sign' decays .

$$\alpha_{Ke\nu} = 0.44 \pm 0.02$$

$$\alpha_{K\mu\nu} = 0.46 \pm 0.02$$

This results in:

$$r_{Ke\nu} = (0.16^{+0.42}_{-0.37})\%$$

$$r_{K\mu\nu} = (0.06^{+0.44}_{-0.40})\%$$

The weighted average of the two results is:

$$r = (0.11^{+0.30}_{-0.27})\%$$

This gives an upper limit of:

$$r < 0.50\% \quad @\ 90\% \quad \text{Confidence Level.}$$

Systematic Uncertainties

- Smearing in proper decay time – effect on mixing rate is less than 10% of the statistical error and is ignored.
- Hadronic feedthrough into the RS semileptonic sample – only about 3% of the RS signal, and is ignored.
- Doubly mis-identified hadronic and semileptonic feedthrough in the wrong-sign sample – would give rise to a false mixing signal. None is seen and no correction made.
- The fitting procedure and the existence of any bias tested by doing the fit to a MC sample with a known amount of mixing. The fit always overestimates the mixing rate by about 10-15%, mainly due to an overestimate of α which arises from our choice of neutrino momentum. We choose not to correct for this overestimate.

A survey of other results:

Standard Model prediction:

$$r \sim 10^{-7} - 10^{-10}$$

E615 (looked for same-sign dimuon pairs):

$$r < 0.56\% \text{ @ } 90\%\text{C.L.}$$

E691 (D^* tag and $K\pi$ and $K\pi\pi\pi$ decay modes of D^0):

$r < 0.37\%$ @ 90% C.L., ignoring interference between mixing and DCS. If the interference is allowed, limits vary from (0.5-1.9)% in the $K\pi$ mode and (0.4-0.7)% in the $K\pi\pi\pi$ mode.

CLEO II:

$$\frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = (0.77 \pm 0.25 \pm 0.25)\%$$

Conclusion:

- A search for $D^0 - \overline{D^0}$ mixing has been performed using semi-leptonic modes in Fermilab E791 data.

- We set an upper limit on mixing of $r < 0.50\%$ @ 90% C.L.

- This limit does not suffer from DCS-mixing interference complications, nor does it depend on any model of charm production.

These transparencies will be available at the E791 web site:

http://fnphyx-www.fnal.gov/experiments/e791/welcome.html