SEARCH FOR $D^0 - \overline{D^0}$ MIXING IN THE DECAY $D^0 \to K^* e\nu$

S. McGEE

Department of Physics and Astronomy, Wayne State University, Detroit, MI, 48202, USA

E-mail: mcgee@physics.wayne.edu

The CLEO collaboration reports on the first search for evidence of $D^0 - \overline{D^0}$ mixing in the semileptonic decay of $D^0 \to K^* e\nu$. Using $9fb^{-1}$ of integrated luminosity from the CLEOII.V dataset, a fit for wrong-sign events, $D^0 \to K^{*+}e^-\overline{\nu}$, gives an upper limit on $R_{mix} = \frac{N(D^0 \to \overline{D^0} \to K^{*+}e^-\overline{\nu})}{N(D^0 \to K^{*-}e^+\nu)}$ at a 95% C.L. of $< 0.86\%$.

1 Introduction

The transformation of the neutral mesons to their own anti-particles, such as $K^0 - \overline{K^0}$ or $B^0 - \overline{B^0}$, has at once revealed many mysteries and provided many solutions to questions of the nature of the fundamental particles and their interactions. Measurements from these systems have provided not only the foundation of what is known as the Standard Model, but have given us an indication as to why we exist to make the measurements in the first place. An explanation of the predominance of matter in the universe first came directly from the investigation of CP violation in the K^0 system.

Most of the studies on spontaneous mixing have been carried out on neutral mesons of the lighter down-type quarks; K^0,B^0_s, and B^0_d. The Standard Model reveals that the coupling of the *strange* and *bottom* quarks to the heavier *top* quark makes the transition through virtual intermediate states relatively common for these systems. Since the rate is dependent on the masses of the quarks in the loop, the rate of these transitions in the D^0 system, with it's coupling to the lighter *bottom* quark, is expected to be significantly lower. Therefore, it is possible that evidence of $D^0 - \overline{D^0}$ mixing is an indication of physics beyond the Standard Model[1].

To date, most of the D^0 mixing searches have been conducted with the hadronic decay channels. Unlike the semileptonic decays, these channels have the advantage of being completely reconstructable but their final states may be reached through either mixing or a highly suppressed direct decay refered to as a doubly-Cabbibo[a] suppressed decay (DCSD). This introduces an interference term into the mixing amplitude calculation[2]. The semileptonic decay channels

[a]This derives its name from the Cabbibo-Kobayashi-Maskawa (CKM) matrix which summarizes the strength of couplings that allow for cross-generational quark transitions[3].

of the D^0 are free from this interference thus allowing for an unambiguous indication of mixing.

However, the absence of an interference term in semileptonic decays means that these channels can not be used to probe the underlying mechanism through which mixing proceeded. Since the surviving term in the equation that describes the rate of 'wrong sign' (WS) or *mixed* decays, $D^0 \to K^{*+}e^-\overline{\nu}$, is symmetric in x and y,

$$D^0_{mix}(t) = \frac{1}{4}(x^2+y^2)t^2 \cdot e^{-t} \qquad R_{mix} = \frac{1}{2}(x^2+y^2) \tag{1}$$

where x and y represent mixing through virtual and real intermediates, respectively[2].

This does, however, simplify the computation of R_{mix}. Since a decay to the WS can have occured only through mixing, it is necessary only to divide the number of WS events by the number of 'right sign' (RS) events, $D^0 \to K^{*+}e^-\overline{\nu}$.

$$R_{mix} = \frac{N(D^0 \to \overline{D^0} \to K^{*+}e^-\overline{\nu})}{N(D^0 \to K^{*-}e^+\nu)} \tag{2}$$

In addition, because the decay rate of the mixed state is dependent on $t^2 \cdot e^{-t}$, lifetime information may also be used to identify mixed decays.

A search for mixing in the $K^*e\nu$ channel takes advantage of a mass cut on the K^* resonance and is eventually to be combined with the result from the search for mixing via the decay $D^0 \to Ke\nu$ also being done at CLEO.

2 Method

The benefits of a search for mixing in the semileptonic decay modes comes at the price of the missing neutrino. After the initial state of the D^0 is tagged with the soft pion π_s from the decay $D^* \to D^0\pi_s$, it is necessary to find some means to reconstruct the D^0 knowing that one of its daughters is unobservable. This reconstruction can be broken down into two steps. First, find the direction of the D^0, then its total momentum.

Traditionally at CLEO, the direction of the D^0 is approximated with the *thrust axis* $(\vec{TA})$[4]. This approximates the 'jet' or the massive-quark direction in the event. In this case, the *charm* quark.

At least two other vectors exist that can give us an indication of the D^0 direction. One is the reconstruction of the K^* and the e known as the pseudo-$D^0(\tilde{D^0})$. Lacking only the neutrino to be a complete reconstruction of the D^0,

$$\lim_{p_\nu \to 0} \vec{P}_{\tilde{D^0}} = \vec{P}_{D^0}. \tag{3}$$

Due to the relatively low energy release in the D^* decay, $M_{D^*} - M_{D^0} - M_{\pi_s}(Q)$, the $\vec{P}_{\pi_s}$ provides another indication to the direction of the D^0.

Correlations between these three indicators allow for calculation of a 'best guess' of the D^0 direction with better resolution than the $\vec{TA}$ alone. Assuming the 'best guess' can be written

$$\vec{D^0_{b.g.}} = \mathcal{A}\vec{TA} + \mathcal{B}\vec{P}_{\tilde{D}^0} + \mathcal{C}\vec{P}_{\pi_s} \tag{4}$$

we use monte carlo (MC) data to find the optimum set $(\mathcal{A}, \mathcal{B}, \mathcal{C})$ by maximizing $signal^2/background$ in the region $0 < Q < 20MeV$.

Once we have the direction of the D^0, it is necessary to calculate the total momentum. This is achieved by constraining the 4-vector to the mass of the D^0, $E^2 - \vec{P}^2 = M^2_{D^0}$, but leaves us with a quadratic ambiguity. We use a combination of two kinematics variables to calculate which solution has the higher probability of being correct; the decay angle distribution of the electron in the rest frame of the W and the momentum distribution of the D^0. Each plot is used as a probability density function with each solution falling into its respective region. By multiplying the resulting probabilities, the most-likely solution is taken to be that with the largest result.

Combining the resulting D^0 with a π_s candidate allows for calculation of Q, one of two variables used in a 2-dimensional fit. The other variable is the lifetime of the D^0 candidate. We know the decay point of the D^0 from the vertex of the electron and the charged π from the decay of the K^*. Also, the D^* decays instantaneously within the beam ribbon. The resolution of the beam ribbon is 1.1cm in the z-direction and 350μm in the x-direction, but only 7μm in the y-direction[2,8]. Using $\Delta y = y_{decay} - y_{beamspot}$ and p_y we can calculate the lifetime.

3 2-Dimensional Binned Fit

A 2-D binned maximum likelihood fitting technique is used. Shapes and function parameters are determined with a $20fb^{-1}$ MC data sample.

A fit to the RS data sample yeilds 638 ± 51 candidates. A fit to the WS data sampled yields -30.42 ± 8.17 candidates. This results is unphysical, so the WS signal piece is constrained to be ≥ 0 and refit. The confidence level drops, 29.2% $\rightarrow$ 15.8%, but the fit is still good. The results are shown in Figure 1.

We calculate our upper limit on R_{mix} using the more conservative result obtained from the constrained fit. This is equivalent to 1.99 WS signal events or $R_{mix} = 0.00 + 0.31$.

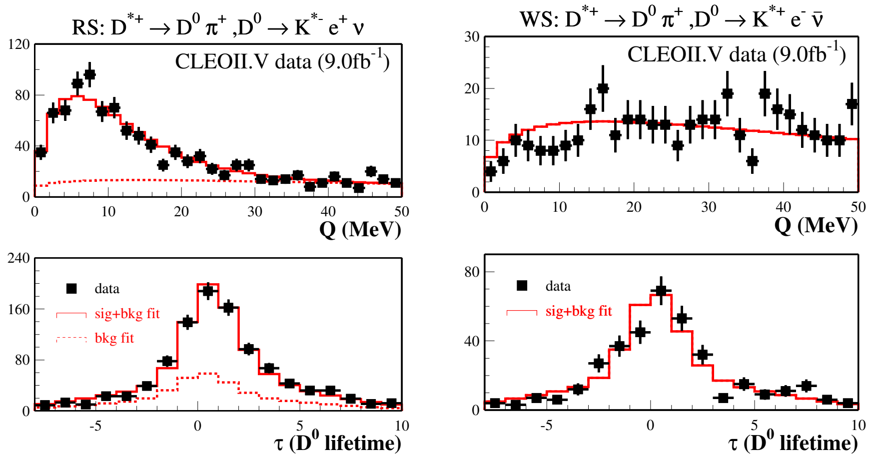

Figure 1. Projections from the 2-D fit of $9fb^{-1}$ of CLEOII.V data. The left-hand plots are the RS Q and τ with the appropriate signal and background levels. The right-hand plots show the WS results (no WS signal found).

4 Systematic error analysis

The systematic errors for this analysis come from two main sources; the efficiency with which we reconstruct both RS and WS events and how well we describe the functions we use to quantify the RS and WS signal and background.

The efficiencies are checked with a sample of roughly 20,000 RS events and 30,000 WS events. The efficiencies of the two are found to be consistent within MC statistics and therefore make a negligible contribution to the systematic error.

Each of the 2-dimensional functions used to describe the signal and background have at most 4 parameters that are determined with the MC sample. If we had an infinite amount of MC statistics, the errors ascribed to these parameters would be 0. Needless to say, we do not have the disk space for an infinite amount of statistics, so the variations in the parameters allowed by our finite sample add some systematic error. To determine this effect of finite statistics, each free parameter used to describe the data is varied up and down by 1σ. The resulting systematic error contribution is $\sigma = \pm 0.23\%$.

Using a MC sample to derive the parameters of the functions used to describe the signal and background Q and τ distributions assumes that the

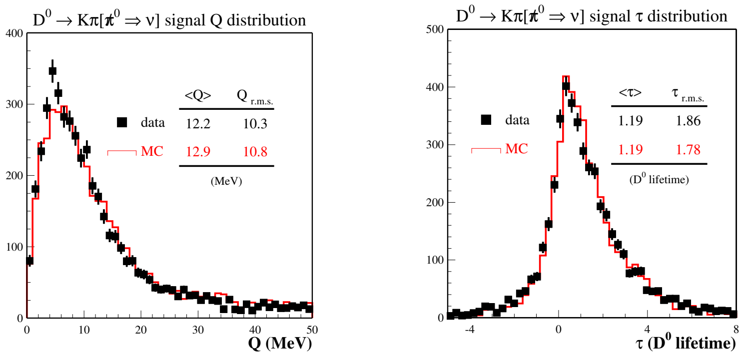

Figure 2. Q and τ distribution comparisons between data and MC signal samples after selecting for $D^0 \to K\pi\pi^0$ signal, excluding the π^0 and reconstructing as $D^0 \to K\pi\nu$. This shows excellent agreement between the reconstructions in MC and data.

MC correctly imitates data. To check this supposition, a fully reconstructable hadronic mode with similar kinematic characteristics to $D^0 \to K^*e\nu$ events is employed. The decay $D^0 \to K\pi\pi^0$ is chosen for these similarities and the existence of a large MC signal sample. By first reconstructing the D^0 candidates using a selection method similar to that done in the search for $D^0 - \overline{D^0}$ mixing in that channel[7], 2σ cuts can be made on the Q and M_{D^0} distributions to select signal candidates. The π^0 is then excluded and the D^0 is reconstructed as $D^0 \to K\pi\nu$ using the identical technique to reconstruct $D^0 \to K^*e\nu$. This technique is repeated for both a sample of MC and data events to qualitatively and quantitatively check the neutrino reconstruction method and determine the systematic errors on the parameters used to describe signal and background shapes.

For the signal shapes, after a background subtraction, the distributions for Q and τ are fit using identical functions to those describing the Q and τ distributions in the $D^0 \to K^*e\nu$ analysis. The relative variations of these parameters between the MC and data samples are subsequently used for a systematic error determination. The resulting systematic error contribution is $\sigma = \pm 0.07\%$.

A similar procedure is repeated to check the parameters used in a fit to the background. However, in this case M_{D^0} sidebands between $4 - 16\sigma$ above and below the nominal D^0 mass were selected. The resulting systematic error contribution is $\sigma = \pm 0.16\%$.

An independent method for determining the limits on variations in the background Q distributions is considered since the background Q distributions for the mode $D^0 \to K\pi\pi^0$ are markedly different than those for $D^0 \to K^*e\nu$. A simple flat function is substituted for the threshold functions used to described the RS and WS backgrounds. The resulting systematic error contribution is $\sigma = \pm 0.09\%$.

5 Conclusion

Including these systematic errors in the final result, our limit on $R_{mix} = 0.00 + 0.31 \pm 0.31$. This gives a 95% C.L. of $< 0.86\%$. This is the first time this particular mode has been used to set a limit on $D^0 - \overline{D^0}$ mixing. The existing limit on R_{mix} using a semileptonic channel was set by E791 with the decay $D^0 \to Kl\nu$[9]. That limit is a 95% C.L. of $R_{mix} < 0.6\%$. We hope to combine this result with the result from the search for $D^0 - \overline{D^0}$ mixing using the decay $D^0 \to Kl\nu$.

Acknowledgments

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation, the U.S. Department of Energy, the Research Corporation, the Natural Sciences and Engineering Research Council of Canada, and the Texas Advanced Research Program.

References

1. H. Nelson, *Compilation of $D^0 - \overline{D^0}$ Mixing Predictions*, **hep-ex/9908021**.
2. CLEO Collaboration, R. Godang, *et al.*, Phys. Rev. Lett. **84**, 22 (2000).
3. Griffiths, D., *Inroduction to Elementary Particles*, John Wiley & Sons, Inc., (1987)
4. S-J. Lee, CBX01-57, (2001). CLEO internal document.
5. F.Morrow, CSN-91/316, (1991). CLEO internal document.
6. CLEO Collaboration, S. Ahmed, *et al.*, Phys. Rev. Lett. **87**, 25 (2001).
7. CLEO Collaboration, G. Brandenburg, *et al.*, Phys. Rev. Lett. **87**, 071802 (2001).
8. CLEO Collaboration, D. Cinabro *et al.*, Phys. Rev. E **57**, 1193 (1998).
9. E791 Collaboration, E.M. Aitala *et al.*, Phys. Rev. Lett. **77**, 2384 (1996).