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# A NEW METHOD TO SEARCH FOR $D^0$-$\overline{D}^0$ MIXING[a]

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Several experimental works and theoretical calculations for $D^0$-$\overline{D}^0$ mixing have been done, since opposite sign dimuons event was reported in 1974-1975.[1] Over the past 20 years, persistent signal for same sign dimuons has been observed by backgrounds. But there is still a big gap between the upper bound of mass differences [$\Delta m(D^0$-$\overline{D}^0)$] and theoretical calcuations. We introduce a future experiment (especially FNAL E-803; COSMOS) using same sign dileptons with small hadronic energy. It will reduce the background and the gap between the upper bound of mass difference [$\Delta m(D^0$-$\overline{D}^0)$] and the theoretical calculations and give us unambiguous evidence for $D^0$-$\overline{D}^0$ mixing down to $10^{-3}$.

## 1 Introduction

All of the neutral flavored mesons have been observed to mix (e.g., $K^0$-$\overline{K}^0$, $B_d^0$-$\overline{B}_d^0$, $B_s^0$-$\overline{B}_s^0$) except the charm system.[2-4] However, since charm was observed in HPWF[1] and opposite sign dimuons are observed at SPEAR, [5] $D^0$-$\overline{D}^0$ mixing has been studied. For SPEAR, a crude limit on charm flavor-changing weak neutral currents was reported.[6] Figure 1 shows us the progress of the experimental $D^0$-$\overline{D}^0$ mixing with time. But, results from E653-FNAL (1983) to an experiment (E791-FNAL, 1995) in Fig. 1 are in the flat line, which ranges from 0.4 to $1.2 \times 10^{-2}$. The most recent significant observation, which was done by CLEO II with the process $D^0 - K^+\pi^-$, allows the $D^0$-$\overline{D}^0$ mixing to be in the same range.[7,8]

## 2 $D^0$-$\overline{D}^0$ Mixing and Same Sign Dimuons

We can search for $D^0$ using neutrino-induced single-$D^0$ production through the process $\nu_\mu + d \to \mu^- + c \to (c + \bar{u})D^0 \to \mu^+ + \nu_\mu + s$, which produces opposite-sign dimuons.[1] Now we propose a method to find $D^0$-$\overline{D}^0$ mixing using the process

$$\begin{aligned} \nu_\mu + d &\to \mu^- + c \to (c + \bar{u})D^0 \\ &\hookrightarrow (\bar{c} + u)\overline{D}^0 \to \mu^- + \bar{\nu}_\mu + \bar{s}, \end{aligned}$$

which will produce (1) same sign dimuons and (2) a $D^0$ at the neutrino interaction vertex. The first observation of same sign dimuons was done by the HPWF group with two very high energy muons.[6,9] It now appears that the most likely signal above background will occur when the hadronic energy of an event is relatively low compared to the $\mu^-$ momentum $P_\mu/E_H \geq 10^{-1}$. We point out that near the threshold for charm production, the kinematics favor considerable energy transfer to the charmed particles

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in the neutrino interaction, giving energetic muons. We therefore, choose mainly a sample of data that has $P_\mu \geq 9$ to 10 GeV and $E_H > 100$ GeV from published reports.[9-14] Figure 2 shows us the ratio of $[(\mu^-\mu^-)/\mu^-]$ from experiments with this approximate cut,[9-14] and the level of same sign dimuons is the same as the current limits on $D^0$-$\overline{D}^0$ mixing from other methods like $D^0 \rightarrow K^+\pi^-$,[7,8] with an expected decay ratio of $\sim 3 \times 10^{-3}$ for forbidden decay.

## 3 Unique Search for $D^0$-$\overline{D}^0$ Mixing

We have shown some positive evidence for $D^0$-$\overline{D}^0$ mixing using a same-sign dimuon signal at the mixing level of $\sim 5 \times 10^{-3}$. Using an emulsion or other suitable tracing detector, we can test whether $D^0 \rightarrow \overline{D}^0 \rightarrow \mu^- + \overline{\nu}_\mu + \overline{s}$ has occurred and measure the mixing ratio. Certainly, FNAL E-803 (COSMOS) will carry out this search, and we expect that mixing occurs at the level of $\sim 5 \times 10^{-3}$ with a powerful magnetic spectrometer, a muon detector and an approximate 1-ton emulsion target.[15] COSMOS will produce charm particles of about 200,000 events. Of these, about 80,000 events are expected as $D^0$'s. We expect 400 $\overline{D}^0$ events with an effective mixing level of $\sim 5 \times 10^{-3}$ for $D^0$-$\overline{D}^0$ mixing.

Figure 3 and Table 1 show us the theoretical calculations for mass difference $\Delta m(D^0$-$\overline{D}^0)$, the upper bound for the first as well as for the recent experiment reports. Even though the upper bounds of experimental mass difference $\Delta m(D^0$-$\overline{D}^0)$ still cover most of the theoretical calculations for $\Delta m(D^0$-$\overline{D}^0)$, these values do not match each other. For previous experiments, the ratio of $(D^0$-$\overline{D}^0)/D^0$ was calculated from the ratio of $[(\mu^-\mu^-)/\mu^-]$ without verifying whether the $\mu^-$'s come from $D^0$ or $\overline{D}^0$. With identification of $D^0$ and $\overline{D}^0$ particles, we can measure the $D^0$-$\overline{D}^0$ mixing more sensitively than before. The maximum flight length of a $D^0$ particle is around $1.5 \times 10^{-4}$ m, because the mean lifetime of $D^0$ is $(5\pm1) \times 10^{-13}$ s.[16] Therefore, emulsion can make the direct evidence of $D^0$-$\overline{D}^0$ mixing visible with good resolution. Even though there was no report for measuring $D^0$-$\overline{D}^0$ mixing using emulsion, the method to identify $D$ mesons inside of emulsion was already reported.[17-19] Figures 4 and 5 show another $D$ meson's trace, and the $D^0$-$\overline{D}^0$ event, generated by GEANT simulation, in the emulsion.

## 4 Conclusions

The future experiment (COSMOS; FNAL E-803) for searching for $D^0$-$\overline{D}^0$ mixing with the emulsion target will make the effective mixing level be $\sim 5 \times 10^{-3}$ or below, and the experimental value will be much closer to the theoretical value.

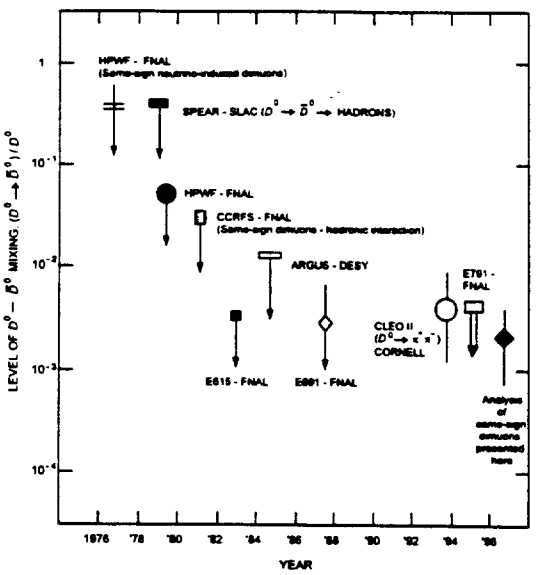


Figure 1: A set of results on the search for $D^0$-$\overline{D}^0$ mixing.[15]

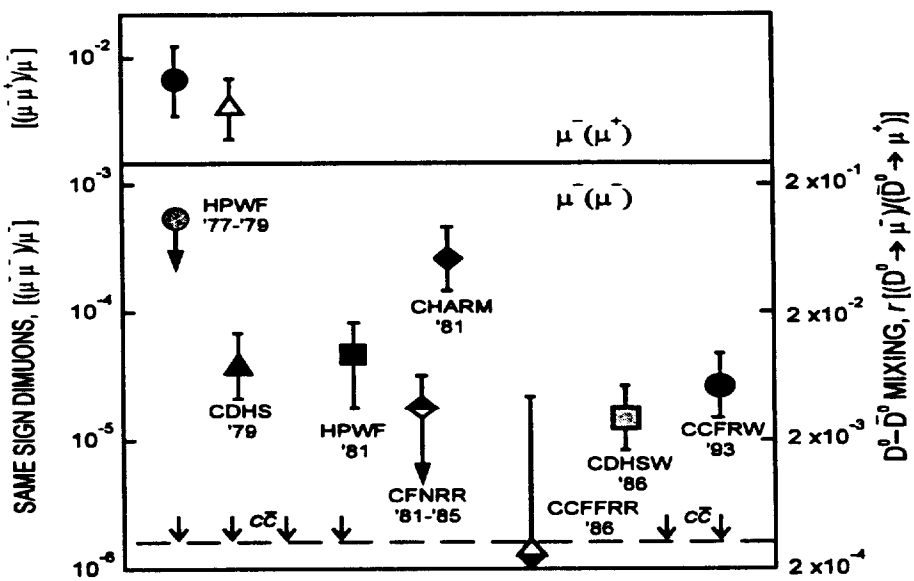


Figure 2: Progress in the study of selected same-sign dimuon events from Refs. 6,9,15, and 26.

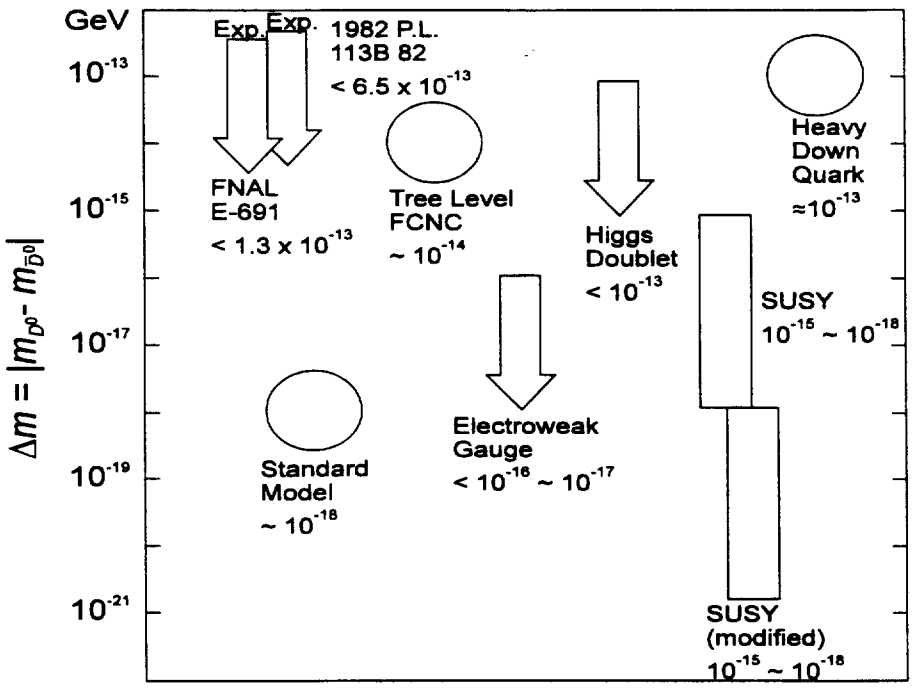


Figure 3: Mass difference of $D^0$-$\overline{D}^0$ from theoretical and experimental value for $D^0$-$\overline{D}^0$ mixing.

Table 1: Theoretical and experimental value for $D^0$-$\overline{D}^0$ mixing [$\Delta m(D^0$-$\overline{D}^0)$].

| Theory | $\Delta m(D^0$-$\overline{D}^0)$ | Ref. |
|---|---|---|
| Tree level FCNC | $\approx 8 \times 10^{-14}$ GeV | 20 |
| Higgs doublet | $<0.8 \times 10^{-13}$ $(\sin\theta_D/\sin\theta_k)$ GeV | 21 |
| Heavy down quark | $\approx 10^{-13}$ GeV | 22 |
| SUSY | $\sim 10^{-18}$ - $\sim 10^{-21}$ GeV | 23 |
| SUSY (change parameter) | $\sim 10^{-15}$ - $\sim 10^{-18}$ GeV | 23 |
| Electroweak gauge | $<10^{-16}$ - $\sim 10^{-17}$ GeV | 24 |
| Standard model | $\sim 10^{-18}$ GeV | 24 |
| Experiment (1982) | $<6.5 \times 10^{-13}$ GeV | 25 |
| Experiment (1995) | $<1.3 \times 10^{-13}$ GeV | 20 |

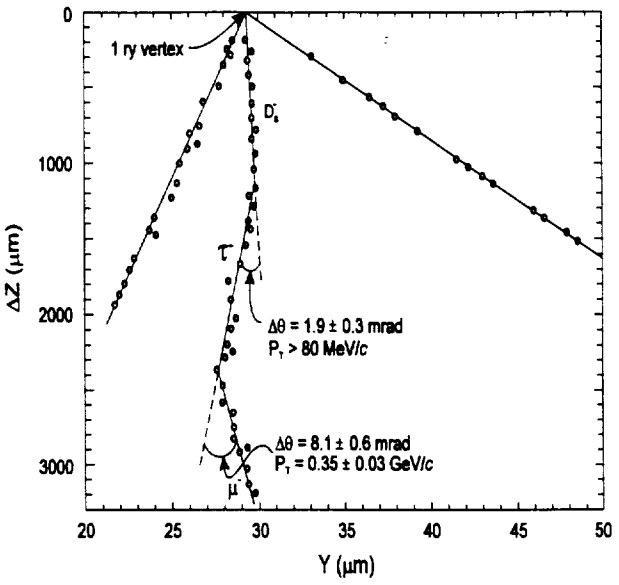


Figure 4: Candidate of a tauonic decay of $D_s$ found by the grain by grain measurement.[18]

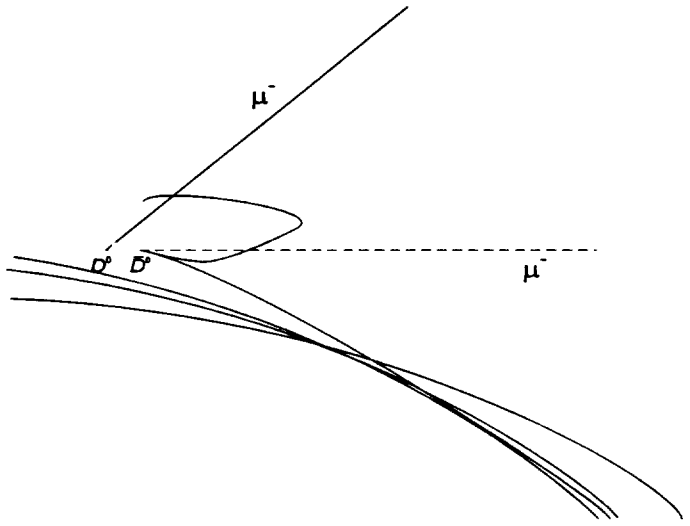


Figure 5: Candidate of a simulated $D^0$-$\overline{D}^0$ event in the emulsion generated by GEANT.

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