D-Mixing at CDF

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Introduction

The phenomenon of mixing has been conclusively observed in the K^0-$\overline{K}^0$ and B^0-$\overline{B}^0$ systems, but not yet in the D^0-$\overline{D}^0$ system. The parameters used to characterize mixing are $x = \Delta m/\Gamma$ and $y = \Delta\Gamma/(2\Gamma)$, where Δm and $\Delta\Gamma$ are the differences in mass and decay width between the two neutral D mass eigenstates, and Γ is the average width. The mixing rate within the Standard Model is expected to be small, the largest predicted values, including long-distance effects, are of order $|x|, |y| \lesssim 10^{-3} - 10^{-2}$, and are reachable with the current experimental sensitivity. Observation of $|x| \gg |y|$ would constitute unambiguous evidence for new physics. Similarly, as CP violation (CPV) in D-mixing is expected to be very small in the Standard Model, observing CP violating effects at current experimental sensitivity would be a clear signal of new physics [1].

D-Mixing in the $K^+\pi^-$ channel

To tag the flavour at production time is useful to study the decays where the D^0 meson comes from the decay of a $D^\star$ meson. The "wrong-sign" (WS) process, $D^\star \to D^0\pi^+ \to [K^+\pi^-]\pi^+$, can proceed either through direct doubly-Cabibbo-suppressed (DCS) decay or through mixing followed by the "right-sign" (RS) Cabibbo-favored (CF) decay $D^0 \to \overline{D}^0 \to K^+\pi^-$ [2]. For $|x|, |y| \ll 1$, and assuming negligible CPV, the ratio R of WS over RS decay rates can be approximated [3] as a quadratic function of the proper D^0 decay time t,

$$R(t) = R_D + \sqrt{R_D}\, y' \,(\Gamma t) + \frac{x'^2 + y'^2}{4}\,(\Gamma t)^2, \qquad (1)$$

where R_D is the ratio of DCS to CF branching fractions, $x' = x\cos\delta + y\sin\delta$, $y' = y\cos\delta - x\sin\delta$, and δ is the strong phase difference between the DCS and CF amplitudes.

The CDF II Detector

The CDF II detector is a multipurpose solenoidal magnetic spectrometer of 1.4 T surrounded by 4π calorimetry and muon filters that is axially and azimuthally simmetric around the interaction point. CDF II features very precise tracking and provides excellent mass and vertexing resolution and has good particle identification (PID) capabilities. Additional details of the detector can be found elsewhere [4]. The elements of the CDF II detector most relevant for heavy hadron physics analysis are the tracker that is composed of a silicon vertex detector and a drift chamber. The measurement of the specific ionization in the drift chamber, dE/dx, is used for PID (1.5σ K/π separation for $p_t > 2$ GeV/c. The achieved performance of the integrated tracker is a trasverse momentum resolution of $\sigma(p_t)/p_t^2 \sim 0.15\%$ (GeV/c)$^{-1}$ and an impact parameter resolution of $\sigma(d_0) \sim 35\ \mu$m for $p_t > 2$ GeV/c.

Measurement of the Mixing Parameters and Evidence for Charm Mixing

This measurement [5] uses data collected by the CDF II detector at the Tevatron collider, from February 2002 to January 2007, corresponding to an integrated luminosity of 1.5 fb^{-1} for $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

Signal extraction

The D^0 candidate reconstruction starts at trigger level with the selection of a pair of tracks from oppositely charged particles that are consistent with originating from a secondary decay vertex separated from the beamline A third low momentum track is then used, in the off-line reconstruction, to form a $D^\star$ candidate when considered as a pion and combined with the D^0 candidate. The tracks for the D^0 candidate are considered with both $K^-\pi^+$ and π^-K^+ mass assignments.

We exclude candidates with WS (RS) mass within 20 MeV/c^2 of the D^0 mass to reduce the background to the WS (RS) signal from RS (WS) decays where the D^0 decay tracks are misidentified because the kaon and pion assignments are mistakenly interchanged. This exploits the misassigned mass distribution having width 10 times while correct assignment width of about 8 MeV/c^2. We also compare the two-track PID probability (from the measured dE/dx) for both assignments and using the higher value further helps to reject mis-identified decays.

The proper decay time t is determined for each D^0 candidate by $t = m_{D^0}L_{xy}/p_t c$, where m_{D^0} is the world average value for the D^0 mass. To study $R(t)$, we divide the data into 20 bins of Γt ranging from 0.75 to 10; note that this long lever arm is a unique feature of the CDF experiment.

After RS and WS candidates are separately divided into time bins, they are further divided into bins of mass difference $\Delta m = m_{K\pi\pi} - m_{K\pi} - m_\pi$. For each Δm bin, we perform a fit of the corresponding $m_{K\pi}$ distribution to determine the D^0 signal yield. The distribution of D^0 signal yield versus Δm is fit using a least-squares method to get the $D^\star$ signal for each time bin.

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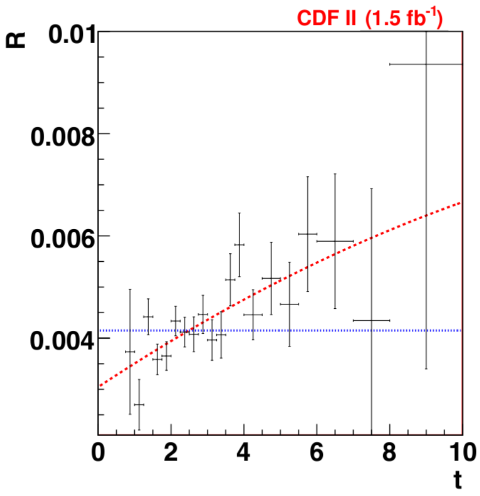

Figure 1: Ratio of prompt $D^\star$ WS to RS decays as a function of normalized proper decay time, the dashed curve is the best fit result and the dotted line is the fit assuming no mixing.

The signal shapes for the individual $m_{K\pi}$ and Δm distributions are fixed from the RS time-integrated fits. The background shapes for all the Δm WS (RS) distributions are fixed to the shape determined for the time-integrated WS (RS) distribution. The amplitudes of the signal and background shapes are determined independently for all $m_{K\pi}$ and Δm fits.

The $D^\star$ mesons that originate from B hadron decays must be treated as background to avoid the complication of measuring the D^0 decay length from the B decay point instead of the primary vertex. This background has a broad d_0 distribution than promptly produced $D^\star$ mesons, due to the decay length of the B hadrons. For each time bin, the prompt WS (RS) signal is determined from the number of WS (RS) $D^\star$ mesons and the shapes of the d_0 distributions.

The extracted time-integrated prompt $D^\star$ signals are $(12.7 \pm 0.3) \times 10^3$ WS events and $(3.044 \pm 0.002) \times 10^6$ RS events.

Results

The ratio of prompt WS to RS signal as a funtion of Γt is shown in Fig. 1. The uncertainties for each bin include statistical and systematic contributions. A least-squares parabolic fit of the data in Fig. 1 to Eq. (1) determines the the mixing parameters to be $R_D = (3.04 \pm 0.55) \times 10^{-3}$, $y' = (8.5 \pm 7.6) \times 10^{-3}$, and $x'^2 = (-0.12 \pm 0.35) \times 10^{-3}$, with a χ^2/n.d.f. of 19.2/17, while the no mixing fit has 36.8/19.

We compute Bayesian probability contours in the (x'^2, y') plane as shown in Fig. 2 and find that the data are inconsistent with the no-mixing hypothesis with a probability equivalent to 3.8 Gaussian standard deviations.

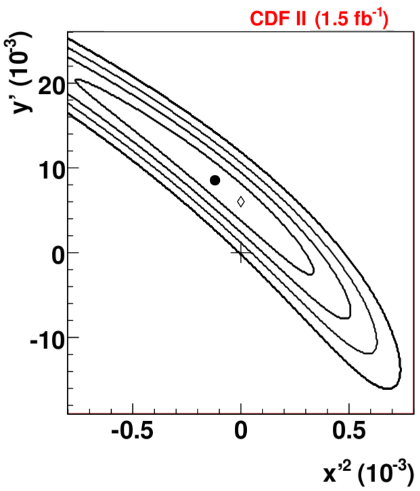

Figure 2: Probability contours in the (x'^2, y') plane corresponding to $1 - 4\ \sigma$, the closed circle shows the best fit result, the open diamond shows the values from the physically allowed fit ($x'^2 \geqslant 0$) and the cross shows the no-mixing point.

Future Prospects in the Charm Sector

CDF has today the world's largest charm samples. This provides the opportunity to pursue a rich analysis program that includes access to direct CP violating asymmetries, branching fractions, mixing and mixing-induced CP violation. All these¡are possible windows to physics beyond the Standard Model. As an example, in the first 2.9 fb^{-1} of collected data we reconstruct a huge sample of $D^\star \rightarrow D^0\pi$ candidates as shown in Tab. 1 (today we have more than 5 fb^{-1}).

D^0 decay mode	Number of events
$K^\mp\pi^\pm$	4×10^6
$\pi^+\pi^-$	170×10^3
K^+K^-	360×10^3

Table 1: Approximate number of reconstructed $D^\star \rightarrow D^0\pi$ events in about 2.9 fb^{-1} of collected data after backgrounds subtraction.

Charm Mixing

We are working on an improvement of the existing analysis, not only adding more data, but also studying improved techniques to gain in significance and to have an observation of the D-mixing in the $K^+\pi^-$ channel with at least 5σ, and be sensitive to CPV. In addition the lifetime analysis in $D^0 \rightarrow h^+h^-$ (where $h = K$ or π) with the measurement of

$$y_{\mathrm{CP}} = \frac{\tau(K^-\pi^+)}{\tau(h^-h^+)} - 1$$

is now accessible. Also in this measurement we are confident to get a result competitive with the current experimental values from B-factories [6].

CP Violation

Taking into account only the number of events we estimate we can make the most precise measurement to date of the CP violating asymmetries in Cabibbo-suppressed (CS) D^0 decays, $D^0 \rightarrow \pi^+\pi^-$ and $D^0 \rightarrow K^+K^-$. As an example, in Fig. 3 are shown the invariant $\pi^+\pi^-$ mass distributions for D^0 and $\overline{D}^0$ candidates in about 2.9 fb^{-1} of collected data after backgrounds subtraction, from that we can calculate the expected statistical resolution on the measurement of $A_{\mathrm{CP}}(\pi\pi)$ that is much better than the most recent results from B-factories as shown in Tab. 2, and similar results we estimate for the K^+K^- decay channel.

Experiment	$\sigma\,(A_{\mathrm{CP}}(\pi^+\pi^-))$ (%)	
	statistical	systematic
Our estimate	0.24	
CDF	1.20	0.60
BABAR	0.52	0.22
Belle	0.52	0.12

Table 2: Estimated statistical uncertainty on $D^0 \rightarrow \pi^+\pi^-$ CP asymmetry based on counting in comparison with current experimental results [7].

Summary

In summary, in 2007 CDF confirmed the *BABAR* evidence for charm mixing with time dependent $D^0 \rightarrow K^+\pi^-$ analysis [8] excluding the no mixing hypothesis at 3.8σ. Now, with the increasing datasets collected by the experiment, there is a lot of promising work in progress.

References

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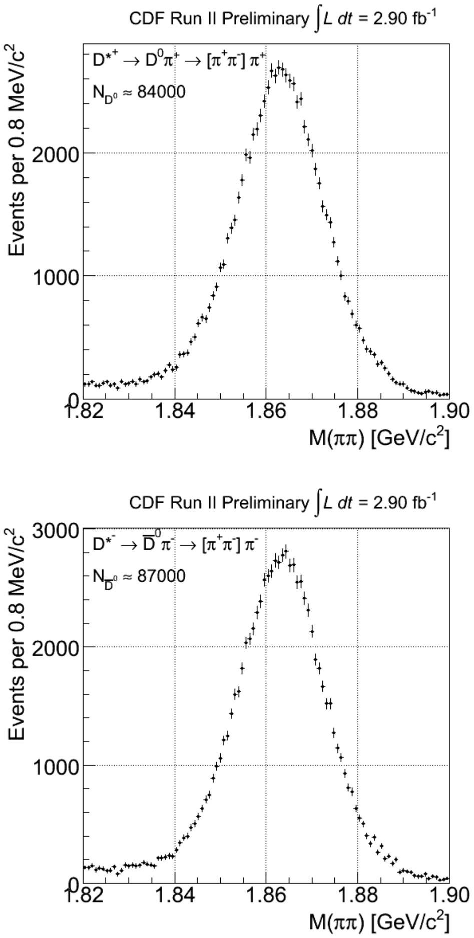

Figure 3: Invariant $\pi^+\pi^-$ mass distributions for D^0 (on the top) and $\overline{D}^0$ (on the bottom) candidates in about 2.9 fb^{-1} of collected data after background subtraction.