A MEASUREMENT OF D^0 LIFETIME

NA1 COLLABORATION

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Abstract

A measurement of the lifetime of D^0 mesons photoproduced coherently off a Germanium target is presented. Signals have been observed for the production of $D^0\bar{D}$ into several channels and for $D^{*+} \rightarrow D^0\pi^+$. A sample of 58 D^0 decays gives a lifetime of $(3.4 \pm 0.5) \cdot 10^{-13}$ s.

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The lifetime of charmed particles is measured with the NA1 spectrometer selecting coherent photoproduction on an active target. Between the two most popular production mechanisms, hadro and photoproduction, the latter is favoured because of a larger signal to noise ratio since $\sigma(\gamma \rightarrow \text{charm}) = 10^{-2} \sigma_{\text{tot}}(\text{photoproduction})$ while $\sigma(\text{hadron} \rightarrow \text{charm}) = 10^{-3} \sigma_{\text{tot}}(\text{hadronic})$. In addition, coherent photoproduction selects processes with a limited number of secondaries associated with charmed particles, hence reducing the large combinatorial background which is the greatest problem in the identification of charm production. The experiment takes full advantage of the large Lorentz factor by measuring directly the decay paths, of the order of millimeters, of charmed particles by means of steps in multiplicity. In 1980 [1] the NA1 collaboration pioneered the technique of charm particle lifetime measurement using an active silicon [2] target in a photon beam and in a subsequent experiment has collected new data using an improved target to study the D^0 lifetime range with high efficiency.

The NA1 apparatus, sketched in Fig.1a, can be divided into 3 parts. The first consists of a tagging system, which is used to determine the energy of the incoming photon with a resolution of about 5% in the useful energy range. The second part consists of the active target (Fig.1b) [3] devoted to the measurement, event by event, of the decay path of the charmed particles. The target samples the ionization of crossing charged particles and identifies the locations of the primary and secondary vertices due to charmed particle production and decay by means of steps in ionization. It is structured into two detectors. First we have a Germanium block 5 mm thick, 5 mm high and 2 cm wide, read out on the upper face by means of 48 electrodes, 100 μm apart, orthogonal to the beam line (part of the data has been collected with a target with twice this granularity). This detector allows a very precise definition of decay lengths for lifetimes in the region of 10^{-13} s. It is followed by a telescope of 15 silicon layers, orthogonal to the beam, 200 μm thick, increasing the overall target length to 14 mm, hence enhancing the acceptance for lifetimes up to 10^{-12} s. An example of a D^0 event as seen in the target is shown in Fig.2. Following the target the FRAMM forward magnetic spectrometer [4] consists of bending magnets, drift and multi-wire proportional chambers. Charged particles are accepted between 0° and 30° and their momenta analyzed within $\pm 6^\circ$ around the beam line with a resolution $\Delta p/p \sim 10^{-2}$, roughly independent of momentum in the range 1 to 150 GeV/c. Two lead-scintillator electromagnetic shower detectors, positioned in front of the first two magnets detect electrons and photons in the angular

range 1.5° to 30° . Two lead glass shower arrays, positioned in front of the third magnet and at the end of the spectrometer, cover the region down to 0° . The good granularity of these detectors (typically of the order of 3.5 cm in the direction orthogonal to the beam) coupled to the magnetic analysis, makes a powerful tool to discriminate between hadrons and electrons. π/K discrimination is provided in the momentum range 4 to 21 GeV/c by 2 multicell gas Cerenkov counters.

Data were taken from November 83 to June 84 at the CERN SPS using 225 GeV electrons striking a 0.05 radiation length lead radiator. The following trigger conditions were used to reject the large electromagnetic background :

1. an incoming photon in the energy range 70 to 225 GeV;
2. at least a pair of charged tracks with more than 4 mr opening angle;
3. at least one charged particle or a photon seen by the shower detectors outside the horizontal plane.

The total sample amounts to $5 \cdot 10^6$ triggers. For charmed meson identification we have considered only events with at least 4 charged tracks, with no electrons within 5 mr of the forward direction and with at most one track not in the forward spectrometer acceptance. This selection reduces the data to about 150,000 purely hadronic events. In this sample we have so far investigated $D\bar{D}$ exclusive production and inclusive D^{*+} production.

A clean hadronic sample consisting of 23,000 events with an initial level of 0 in the target plus two or three subsequent multiplicity steps has been analysed to search for a D^0 signal and to evaluate the lifetime. This sample contains : i) events in which the $D\bar{D}$ pair is produced in association with extra charged particles, the first jump in multiplicity being due to the production and the second (second and third) to the decay of one (two) D mesons, ii) pure $D^0\bar{D}^0$ events with both meson decays visible in the target. For these events the difference in decay paths of the two D^0 's is used in the lifetime measurement¹.

¹ In principle the production point of a pure $D^0\bar{D}^0$ event can be identified by the ionization due to the recoil of the struck Germanium nucleus; however in our case the energy release (≤ 30 KeV) is comparable to the noise of the readout electronics ($\sigma \sim 27$ KeV).

The analysis of exclusive $D\bar{D}$ production has been performed by searching for charmed mesons decaying in the following channels in which a charged kaon is present :

$$D^0 \rightarrow K^- \pi^+$$

$$D^+ \rightarrow K^- \pi^+ \pi^+$$

$$D^0 \rightarrow K^- \pi^+ \pi^0$$

$$D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$$

$$D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$$

$$D^+ \rightarrow K^- \pi^+ \pi^+ \pi^- \pi^+$$

$$D^0 \rightarrow K^- \pi^+ \pi^0 \pi^0$$

$$D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0 \pi^0$$

$$D^0 \rightarrow K^- \pi^+ \pi^- \pi^+ \pi^0$$

Charged kaons are identified within the momentum acceptance of the Cerenkov counters. Outside this range the two possibilities ($\pi - K$) are taken into account in the combinatorial analysis. The invariant mass of all combinations of particles consistent with a $\bar{D}$ decay is computed and kept as a $\bar{D}$ candidate if it falls between 1.8 and 1.93 GeV/c^2 . For all events containing a $\bar{D}$ candidate all remaining particles are used to construct the possible D^0 combinations and their invariant mass is plotted in Fig.3a. A clear D^0 signal is seen and its width is as expected from the spectrometer resolution ($\pm 15 \text{ MeV}/c^2$). It is worth noting that 70% of the entries of this plot come from the signal or its combinatorial reflections, hence most of the apparent background is due to wrong combinations of good events. In the particular case of $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+ (\pi^0)$, the channel most affected by the combinatorial background, the $\bar{D}$ window has been reduced from 130 to 40 MeV/c^2 and only $\bar{D} \rightarrow K^+ \pi^- (\pi^0)$ combinations have been selected. The same procedure has been applied to events without $\bar{D}$ combinations in the selected window and the resulting mass histogram (dashed lines in Fig.3a) shows no signal. Events are finally selected if a $\bar{D}$ combination is contained in the interval 1.8 to 1.93 GeV/c^2 and a D^0 combination is found within $\pm 20 \text{ MeV}/c^2$ around the nominal D^0 mass. To match the configurations seen in the spectrometer with the pattern in the target we first sort the various combinations in each event ordering them according to the agreement of the $\bar{D}$ mass with the nominal mass. We then scan this list and accept the first configuration compatible with the pattern in the target; in 90% of the cases this is the first or the second combination of the list. The same procedure is repeated interchanging D with $\bar{D}$. In this way we find 46 D^0 and $\bar{D}^0$ decay candidates. In order to fix the energy and therefore the Lorentz factor for each decaying particle we rejected events with D^0 and $\bar{D}$ decaying into channels having the same change in multiplicity.

In a second analysis we have identified a different D^0 sample by studying the inclusive reaction :

$$\gamma + \text{Ge} \rightarrow D^{*+} + X, \text{ with } D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^- \pi^+$$

using the fact that the mass difference $\Delta M = M_{D^{*+}} - M_{D^0}$ is a very powerful signature of these events. The same kaon definition of the previous analysis has been used. D^0 candidates are defined in a window of 30 MeV/c² around the D mass, and the mass difference between D^{*+} and D^0 is plotted in Fig.3b and 3c before and after the request of one decay in the target. To make sure that the step observed in the target is associated with our D^0 we select $D(\bar{D})$ events without $\bar{D}(D)$ candidates decaying into channels with a multiplicity change of two. We find 12 extra D^0 decays with ΔM less than 156 MeV/c².

The final sample containing events from both analyses contains 58 decays. Corrections have been applied to the data for the inhomogeneity of the target (Germanium block + Silicon layers), and the range of detectable decay times ($t_{\min}$ and $t_{\max}$). A Monte Carlo simulation has shown that the time acceptance of the target is mostly affected by $t_{\min}$ and $t_{\max}$, while the correction due to the detailed target structure amounts to less than 3% in the range 1 to $20 \cdot 10^{-13}$ s. The efficiency for step finding is uniform over the same range. The distribution of the selected events versus $t - t_{\min}$ is shown in Fig.4. Corrected data have been fitted to an exponential decay function, by means of the maximum likelihood method, providing a lifetime of

$$\tau_{D^0} = (3.4 \pm 0.5) \cdot 10^{-13} \text{ s.}$$

The line superimposed on the data in Fig.4 shows the fitted exponential.

It is worth noting that in this measurement the final state is completely reconstructed, providing an unambiguous assignment of the energy to each individual D meson. The quoted errors are purely statistical. We believe that the complete separation of the event identification in the spectrometer from the decay length measurement in the target reduces the systematic errors to a negligible fraction of the statistical uncertainty.

References

- [1] E. Albini et al., Phys. Lett. 110B (1982) 339.
- [2] S.R.Amendolia et al., Nucl. Instrum. Methods 176 (1980) 449
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- [4] S.R.Amendolia et al., Nucl. Instrum. Methods 176 (1980) 461.

FIGURE CAPTIONS

1. a) Experimental apparatus b) A view of the active target
2. The pulse height for each Ge strip/Si layer in equivalent minimum ionizing particles for a typical D^0 decay taken from the D^{*+} sample (multiplicity 0 – 2 – 4).
3. a) D^0 invariant mass distribution for exclusive $D\bar{D}$ events as described in the text.

The solid line is for events with $M_{\bar{D}}$, the mass of the $\bar{D}$ candidate, in the selected interval (see text), while the dashed line is for events with $M_{\bar{D}}$ outside this interval. b,c) ΔM distribution for inclusive D^{*+} production, without (b) and with (c) the request of 2 steps in the target.
4. Decay time distribution for the corrected final sample. A straight line with the best slope (as computed with the maximum likelihood method) is superimposed .

FIG. 1a

FIG. 1b

Distance from start of GE in MM

FIG. 2

FIG. 3a

FIG. 3b

DECAY TIME

FIG. 4