LIFETIME MEASUREMENT OF D_s -MESONS

The ACCMOR Collaboration

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ABSTRACT

We have observed a sample of 21 unambiguous decays of D_s mesons into $KK\pi$ hadronically produced in the NA11 and NA32 experiments at the CERN SPS using high resolution silicon microstrip detectors. We measure the mean lifetime and the mass of the D_s -meson to be $(3.3 \pm_{0.6}^{1.0}) \cdot 10^{-13}$ s and $1972.7 \pm 1.5 \pm 1.0$ MeV/c², respectively.

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1. INTRODUCTION

Over the last few years, weak decays of charmed particles have been actively studied by several experiments. However, while many measurements on the lifetime of neutral and charged D-mesons have been published, results on the direct observation of the D_s -meson (formerly called charmed F-meson) are still rather scarce [1]. So far, only three lifetime measurements for the D_s -meson have been published [2,3,4]. Using high resolution silicon strip detectors, the NA11 experiment by the ACCMOR collaboration was the first experiment to directly observe hadroproduced D_s events and to measure their lifetime. In this paper, we report results from the NA32 experiment, which has been carried out by the same collaboration, and give final results from the full data sample taken by the NA11 experiment.

In the NA32 experiment, a silicon active target was used, together with a telescope of silicon microstrip detectors. Interaction trigger data were collected with a 200 GeV/c incident beam of pions, kaons and protons. The NA11 results are extracted from data taken at different beam energies with a single electron trigger [5] and an inclusive ϕ trigger [6].

2. THE NA32 EXPERIMENT

The experiment was performed at the CERN SPS using the ACCMOR spectrometer in an unseparated hadron beam of 200 GeV/c. Two differential Cerenkov counters were used for tagging the incident beam particles. The large acceptance forward spectrometer [5] consisted of two magnets and 48 planes of drift chambers arranged in four groups. Four multicellular threshold Cerenkov counters were used to identify π , K, p in the momentum range 4-80 GeV/c.

An enlarged view of the target area is shown in figure 1. The beam was focussed on a silicon active target with a full width of 0.5 mm vertically and 8 mm horizontally. The target consisted of fourteen planes of identical silicon microstrip detectors. Each plane was 280 μm thick with 48 horizontal strips of 32 mm in length and 20 μm pitch mounted at distances of 500 μm along the beam. Two more silicon detectors (multiplicity counters) with 24 horizontal strips of 400 μm pitch were mounted 35 mm downstream of the target to detect any change in charge multiplicity. Each of the strips was connected via charge sensitive pre- and shaping-amplifiers to fast ADCs [7].

The beam telescope placed in front of the active target consisted of 2 planes of silicon microstrip detectors with capacitive charge division readout (60 μm pitch) and two planes of active target type detectors. The primary vertex was determined by the intersection of the extrapolated beam track with the interaction plane with a precision of 3 μm vertically, 25 μm horizontally and 80 μm along the beam direction independent of the topology of the event.

The trigger required a single beam particle to go through one of the 16 middle strips of both the last plane of the beam telescope and the first active target plane. An interaction, defined by having at least one strip with a pulse height of 3 minimum ionizing particles (m.i.p.) or more, had to occur in the central 16 strips of planes 2 to 7. In addition, a charged particle multiplicity of three or more was demanded in the two downstream multiplicity counters.

The reconstruction of charm decays is done by using information from a telescope of seven silicon microstrip detectors (VMsDs) [8] with capacitive charge division readout placed downstream of the target, and from the spectrometer. Six VMsDs were arranged in three pairs with strips at an angle of $\pm 14^\circ$ to the horizontal plane. A seventh counter had horizontal strips, matching the orientation of the active target strips. The measurement precision for tracks reconstructed in one of the $\pm 14^\circ$ views at the position of the primary vertex was 10 μm plus a multiple scattering contribution of 90 $\mu\text{m}/p$ (GeV/c).

3. DATA ANALYSIS

During 1984, we collected a total of 38 million interaction triggers. About 5 million of these triggers were taken with incoming K^- , 22 million with π^- and 11 million with p . The results presented here are based on the analysis of the K^- data.

To limit the computer time needed for data processing, we preselected events on the basis of the information from the active target and the VMsDs only. Events were selected which contained at least two track projections in one of the $\pm 14^\circ$ views displaced from the primary vertex. The impact parameter cut applied was on average 40 μm . This has to be compared with impact parameters between 30 and 300 μm for particles with a lifetime of $\sim 10^{-13}$ – 10^{-12} s. To avoid any loss of events with short decay length, events exhibiting a jump in the charged particle multiplicity of at least 2 m.i.p. in the active target were also retained. Secondary interactions in the active target identified by a pulse height of more than 10 m.i.p. in a strip were rejected. The preselection reduced the data by a factor 4.5.

For the remaining events, the drift chamber tracks were then used to guide the pattern recognition in the VMsDs. The secondary vertex search was restricted to those track combinations in the $KK\pi$ channel with an invariant mass between 1.7 and 2.2 GeV/c, where both kaons were identified in the Cerenkov counters.

The following selection criteria were applied:

- 1) The event had to be incompatible with a single vertex hypothesis and the three decay tracks had to form a vertex with a probability greater than 5%,
- 2) the $KK\pi$ vertex had to be downstream of the primary vertex with a minimum separation of 2 mm,
- 3) the $KK\pi$ momentum sum vector had to point to the primary vertex with a probability greater than 10%,
- 4) The decay tracks had to miss the primary vertex: the distance of the tracks to the primary vertex, in one of the $\pm 14^\circ$ views, had to be greater than 3σ for at least 2 tracks and 1σ for the third, where σ was the estimated error.

Finally, the reconstructed pattern of the event was checked for compatibility with the pulse heights measured in the active target.

Figure 2a shows a display of an event as seen in the active target. The numbers give the measured ionization loss of the charged particles traversing the detectors. The average pulse height of one m.i.p. correspond to ten counts which can be spread over two adjacent strips. The readout saturates at 250 counts. The beam particle enters from the left. The interaction point is marked by a large energy deposit from nuclear breakup and three charged minimum ionizing particles are produced forward. Figure 2b shows the same event with tracks reconstructed from the hit pattern in the drift chambers and the VMsDs. A total of seven tracks are reconstructed. A close study of the event reveals a $D_s^- \rightarrow K^+ K^- \pi^-$ decay (tracks 2,7,8 respectively) and a neutral particle decay (tracks 3,4). The D_s decays in air 9.5 mm downstream from the interaction point. The decay tracks are an identified K^- of 26.6 GeV/c, an identified K^+ of 47.7 GeV/c, and an identified π^- of 78.0 GeV/c. The invariant mass of the $KK\pi$ system is $(1975 \pm 6) \text{ MeV}/c^2$. The neutral decay is neither a γ nor a K^0 or a Λ^0 ; it is consistent with a charmed particle decay with a missing π^0 . Thus the particles observed in the active target are the D_s^- meson candidate together with tracks 5 and 6.

4. RESULTS

The $KK\pi$ invariant mass distribution of the decays satisfying the selection criteria is shown in Fig. 3a. A clear signal of 15 events appears at the D_s mass. Due to particle identification ambiguities, some events (hatched in Fig. 3a) are compatible with a $D \rightarrow K\pi\pi$ or $\Lambda_c \rightarrow Kp\pi$ interpretation. Those events are excluded from the lifetime measurement. The distribution of decay lengths for the D_s candidates, i.e. the events in the mass range $1.95\text{--}2.00 \text{ GeV}/c^2$, is shown in Fig. 3b.

To determine the lifetime, we performed a combined maximum likelihood fit to both the mass distribution and the lifetimes of the signal and the background, assuming a gaussian signal on a flat background. The mass of the gaussian was fitted and the width was determined by the mass resolution calculated for each event. The maximum and minimum detectable lifetimes and the precision of the lifetime measurement for each event were taken into account in the fit [9]. The mass range considered in the fit is $1.9\text{--}2.2 \text{ GeV}/c^2$ to avoid contribution to the background from $D^\pm \rightarrow K^\pm K^\mp \pi^\pm$ decays or charm decays with missing π^0 's. The maximum likelihood fit gives 11.7 D_s events on top of a background of 0.3 event per bin of $10 \text{ MeV}/c^2$. The lifetime obtained is :

$$\tau_{D_s} = (3.4^{+1.3}_{-0.9}) \cdot 10^{-13} \text{ s}$$

and the mass is $1972.6 \pm 2.1 \text{ MeV}/c^2$. For the background, a lifetime of $(2.1^{+1.0}_{-0.6}) \cdot 10^{-13} \text{ s}$ is found. All errors quoted are statistical only. The distribution of the lifetime of the D_s -candidates, corrected for the minimum detectable lifetime, is given in figure 3c.

We have checked for possible systematic errors in the lifetime determination by studying a sample of 1000 K_s^0 decaying to $\pi^+\pi^-$ before the first VMSD plane and about 100 D mesons decaying to $K^\pm \pi^\mp$, $K^\pm \pi^\mp \pi^\mp$, $K^\pm \pi^\mp \pi^\pm \pi^\mp$. We could not find any systematic errors not covered by the statistical errors.

5. THE NA11 EXPERIMENT

In a previous publication, we reported a measurement of the lifetime of the D_s -meson based on 3 events observed in the NA11 experiment [2]. Those events were selected in the analysis of a subsample of the data recorded in that experiment. In this section, we present a brief description of the NA11 experiment and the final result based on the analysis of the full data sample.

Many components of the apparatus, namely the spectrometer and the vertex telescope of silicon microstrip detectors, were the same as used in the NA32 experiment. However NA11 differed from NA32 experiment in two aspects. A 20 mm long Be target was used instead of the Si active target and two different trigger schemes were applied: a single electron trigger [5] to select events with a prompt electron from semileptonic charm decays and an inclusive ϕ trigger [6] to select events with a ϕ meson in the final state. An unseparated hadron beam was used. The negative beam contained about 96% π^- , 3.5% K^- , 0.5% $\bar{p}$ and the positive beam 20-50% π^+ , 3% K^+ and 40-70% p depending on the energy. Table 1 summarizes the recorded data.

The selection criteria used to extract clean charm decays were similar to those of the NA32 experiment, although no preselection was applied. The search for decay vertices was applied to the events with a $KK\pi$ combination in the mass range 1.7-2.1 GeV/c^2 . The $KK\pi$ invariant mass distribution of the selected decays is shown in Fig. 4a. Again a clear signal appears at the D_s mass. There is also a peak at the D^+ mass, which can be interpreted as $D^\pm \rightarrow K^\pm K^\mp \pi^\pm$ Cabibbo suppressed decays. The fact that a D^+ is not seen in Fig. 3a indicates different production mechanisms of D_s and D^+ for different incident particles.

The same likelihood fit as described for the NA32 experiment is applied to the events in the mass range 1.9-2.1 GeV/c^2 . The events compatible with a $D \rightarrow K\pi\pi$ or a $\Lambda_c \rightarrow Kp\pi$ interpretation are indicated in Fig. 4a and are excluded from the lifetime measurement. The fit gives a signal of 8.9 events upon a background of 0.3 events per bin of 10 MeV/c^2 . The lifetime obtained is:

$$\tau_{D_s} = 3.2 \pm_{1.0}^{1.5} \cdot 10^{-13} \text{ s}$$

and the mass $1972.8 \pm 2.1 \text{ MeV}/c^2$, in good agreement with the NA32 result. The distribution of decay lengths for the D_s candidates is shown in Fig. 4b. Their lifetime distribution, corrected for the minimum detectable lifetime, is given in Fig. 4c. The average lifetime for the decays with an invariant mass in the range 1.85-1.89 GeV/c^2 is $8.8 \pm_{2.0}^{3.6} \cdot 10^{-13} \text{ s}$, a value consistent with the D^+ lifetime [1].

6. CONCLUSION

We have observed $D_s^\pm \rightarrow K^+ K^- \pi^\pm$ decays both in the NA32 and the NA11 experiments using similar techniques. The D_s lifetime is measured to be $3.4 \pm_{0.9}^{1.3} \cdot 10^{-13} \text{s}$ using 12 events from the NA32 experiment and $3.2 \pm_{1.0}^{1.5} \cdot 10^{-13} \text{s}$ using 9 events from the NA11 experiment. The weighted average is:

$$\tau_{D_s} = 3.3 \pm_{0.6}^{1.0} \cdot 10^{-13} \text{s}$$

We could not find any systematic error not covered by the statistical errors. This value of the D_s lifetime agrees, within statistics, with other published values [2,3,4] and indicates that the D_s lifetime is close to the D^0 lifetime and significantly smaller than the D^+ lifetime [1].

The D_s mass is measured to be $1972.6 \pm 2.1 \text{ MeV}/c^2$ in the NA32 experiment and $1972.8 \pm 2.1 \text{ MeV}/c^2$ in the NA11 experiment. We have studied possible sources of systematic errors and carefully checked our calibration with K^0 , Λ^0 , D^0 and D^+ . We estimate the systematic error of the mass scale to be less than 0.5% . So we quote the averaged value for the D_s mass :

$$m_{D_s} = 1972.7 \pm 1.5 \pm 1.0 \text{ MeV}/c^2$$

The first error is statistical and the second systematic.

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Table 1

	single e-trigger	inclusive ϕ trigger	
beam momentum	-200 GeV*	± 200 GeV*	-100/+120 GeV
range π -K separation	6-5-44 GeV	6.5-44 GeV	3.5-22 GeV
# triggers	$4.4 \cdot 10^6$	$1.2 \cdot 10^6$	$6.0 \cdot 10^6$
# events after VMSSD analysis	5	8	21

* Events from this data sample were used in [2].

Figure captions

- Fig. 1 Side view of the target region showing the silicon active target and the silicon microstrip detectors. The different strip orientations are indicated.
- Fig. 2 a) Display of a D_s -event as seen in the active target. The numbers are measured pulseheights in units of 1/10 M.I.P.
b) Display of the event as seen in the VMSD. The coordinates in the VMSDs reconstructed from the analogue information are indicated with a cross. The full lines are tracks reconstructed in the VMSDs and in the drift chambers.
- Fig. 3 a) $K^+K^-\pi^\pm$ mass spectrum for the selected events of the NA32 experiment. There is only one event with a mass in the range $2.1-2.2 \text{ GeV}/c^2$ which is not shown in this figure. The hatched squares are events compatible with a $D \rightarrow K\pi\pi$ or with a $\Lambda_c \rightarrow Kp\pi$ interpretation.
b) Distribution of decay lengths for the D_s candidates, i.e. the events in the mass range $1.95-2.00 \text{ GeV}/c^2$ in a).
c) Distribution of the corrected lifetime for the D-candidates. The line shows the fitted exponential to the distribution normalized to the number of events. The small contribution of background is also included.
- Fig. 4 As Fig. 3, for the events from the NA11 experiment.

Fig. 1

a)

b)

Fig. 2

Fig. 3

Fig. 4