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ELECTRONIC MEASUREMENT OF THE LIFETIME OF D± MESONS

E. ALBINI [b], S.R. AMENDOLIA [c], R. BALDINI CELIO [a], G. BATIGNANI [f], F. BEDESCHI [c], G. BELLINI [b], E. BERTOLUCCI [c], D. BETTONI [c], G. BOLOGNA [e], L. BOSISIO [c], C. BRADASCHIA [c], M. BUDINICH [c], F. CELANI [a], A. CODINO [a], M. DELL'ORSO [c], B. D'ETTORRE PIAZZOLI [e], M. De VINCENZI [d], F.L. FABBRI [a], F. FIDECARO [c], L. FOÀ [c], E. FOCARDI [c], A. GIAZOTTO [c], M.A. GIORGI [c], P. LAURELLI [a,1], M. LEOPOLD [b], F. LIELLO [f], P.F. MANFREDI [b], G. MANNOCCHI [e], P.S. MARROCCHESI [c], A. MENZIONE [c], E. MERONI [b], L. MORONI [b], C. PALAZZI CERRINA [b], L. PETRILLO [d], M.L. PIAZZI [f], P. PICCHI [e], M. QUAGLIA [c], F. RAGUSA [b], P.G. RANCOITA [b], L. RISTORI [c], G. RIVELLINI [a], L. ROLANDI [f], S. SALA [b], L. SATTA [a], A. SCRIBANO [c], M. SEVERI [d], P. SPILLANTINI [a], A. STEFANINI [c], R. STANGA [c], M.L. VINCELLI [c], A. ZALLO [a] and I.P. ZIELINSKI [g]

[a] *INFN-Laboratori Nazionali di Frascati, Frascati, Italy*
[b] *Istituto di Fisica and Sezione INFN Milan, Italy*
[c] *Istituto di Fisica, Sezione INFN and Scuola Normale Superiore, Pisa, Italy*
[d] *Istituto di Fisica and Sezione INFN, Rome, Italy*
[e] *Istituto di Fisica Generale and Istituto di Cosmogeofisica del CNR, Turin, Italy*
[f] *Istituto di Fisica and Sezione INFN, Trieste, Italy*
[g] *Institute of Physics, Warsaw, Poland*

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Charmed meson pairs have been photoproduced coherently on an active silicon target. Ninety-eight decays have been analyzed and the lifetime of charged D's has been measured.

We describe the first results obtained in an experiment (NA1) performed at CERN to measure the lifetime of D-mesons in a purely electronic way.

D-meson pairs are coherently produced on an active silicon target by a bremsstrahlung photon beam of energy ranging between 40 and 150 GeV. A multiparticle spectrometer (fig. 1) measures the momenta of neutral and charged particles produced in a forward cone and selects candidates for $D-\bar{D}$ production. The path travelled by a D-meson is measured in the production target itself which is structured as a telescope of thin silicon detectors, each one producing a signal proportional to the multiplicity of crossing charged particles.

The North Area E4/H4 beam gives 3×10^6 electron/pulse at 150 GeV on a lead converter, 0.1 radiation length thick. The resulting photon beam crosses a set of collimators and reaches the experimental target, as shown in fig. 1. The electrons, after the converter, are swept into a tagging hodoscope which selects photons of energy larger than 40 GeV and provides their individual energy with an accuracy of ±5%.

The target is surrounded by a set of veto counters for charged particles and photons in order to eliminate the majority of incoherent events and all events in which particles are produced at angles larger than 30°.

The forward spectrometer covers a solid angle of 0.8×10^{-3} sr for charged particles and of 0.25 sr for photons. Four magnets, positioned on the beam axis, bend all charged particles into successive stacks of drift chambers in such a way that more and more energetic particles cross more and more magnetic field. This system provides a roughly uniform momentum resolution between 1 and 150 GeV/c ($0.5\% < \Delta p/p < 1.5\%$). Drift chambers are equipped with delay lines parallel to sense wires in order to solve quickly the

[1] Now at CERN, Geneva, Switzerland.

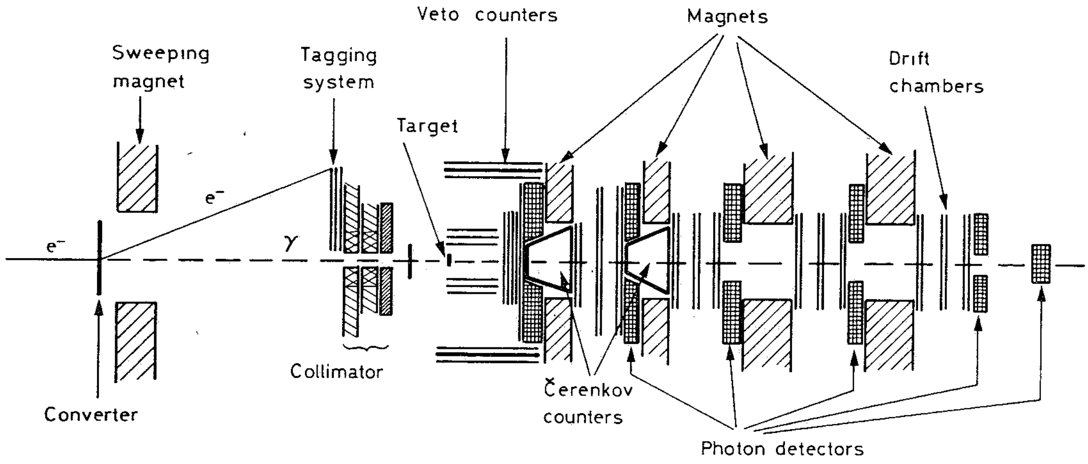

Fig. 1. Lay-out of the experimental apparatus.

pattern recognition problems arising in many-body events [1]. A set of MWPC and drift chambers, in front of the first magnet, measures also tracks outside the solid angle of the magnetic spectrometer [2].

In front of each magnet a shower detector collects photons which fall outside the magnet aperture. The first two are sandwiches of lead and scintillation hodoscopes with fingers 3.2 cm wide, while the last three are matrices of lead-glass counters with cells of 3.5 $\times$ 3.5 cm^2. All detectors are split longitudinally into two parts, the first one being 4 radiation lengths thick. Each detector provides a space resolution of ± 2 mm, while the energy resolution is $\sigma \cdot \sqrt{E_\gamma} = 17\%$ and $\sigma \cdot \sqrt{E_\gamma} = 5.8\%$, respectively, for sandwiches and lead-glass matrices.

Inside magnets 1 and 2, two multicell Čerenkov counters at atmospheric pressure separate pions from kaons in the momentum range $5 < p < 21$ GeV/c. The first one consists of 22 cells and is filled with CO_2, while the second is split into 10 cells and is filled with air. The efficiency of each individual cell has been measured to be of the of the order of 99%.

The active target (15% of a radiation length) consists of 40 silicon detectors, 300 μm thick, separated by gaps of about 100 μm. The energy deposited by a minimum ionizing particle in a layer is 90 keV, to be compared with an electronic noise of about 30 keV. Details of the construction and performances of these detectors, and of the associated electronics have been reported in previous papers [3–5].

The trigger logic is specifically designed to be extremely selective against electron pair background and provides a rejection power of better than 10^{-5} without any geometrical cut. Its efficiency is close to one for multibody hadronic events dropping to 25% for two-body final states (ρ^0 photoproduction). The mass scale and the resolution of the spectrometer are checked by reconstructing the ω and φ peaks in the $\pi^+\pi^-\pi^0$ channel. The resolution of ± 30 MeV obtained in the data agrees with what expected on the basis of a Monte Carlo simulation.

In a 40 day run taken before the 1980 SPS shut-down we have collected 1.8 million triggers containing $\sim 10^6$ hadronic events. These events have been reconstructed, searching for charmed pair production.

As a first step in the selection, events with energy smaller than 70 GeV and with maximum invariant mass smaller than 3.5 GeV have been rejected. Since this letter refers to the measurement of $D^\pm$ lifetime, we have further restricted the sample by selecting events with 6 or more charged particles. Also events with odd multiplicity (7 or 9 charged tracks) have been accepted in order to allow for the loss of the pion from the D^* decay outside the acceptance of the spectrometer.

The target does not provide geometrical information on the association of the particles produced in the decay of the two D's (D^*'s) and detected in the spectrometer. Therefore they are separated into two groups and all combinations are examined in turn, calculating for each of them the values of the masses M_1 and M_2. A combination is accepted only if each group contains at least one charged kaon candidate, defined as a particle not seen by the Čerenkov counters in the range 5–21 GeV/c or any charged particle with momentum outside this range. Charged groups are accepted only if their charge is ±1, and if they correspond to a $D^{\pm}$ decay channel allowed by the Cabibbo selection rule.

Finally, only events which have at least M_1 or M_2 in the mass range 1.75–2.1 GeV are retained. Since the final states we search for contain a pair of D-mesons, the analysis selects a narrow interval of M_1 and examines the mass spectrum of M_2. When M_1 is in the D or D^* mass region, peaks are expected to show up in the M_2 plots corresponding to the associated D or D^*. This is shown in fig. 2a and 2b, where the M_2 distributions are plotted for $1.85 < M_1 < 1.90$ and $2.00 < M_1 < 2.05$ GeV. These histograms are compared with the background measured by averaging the M_2 distributions obtained when M_1 falls in the nearby mass intervals (1.80–1.85 and 1.90–1.95 GeV for D's; 1.95–2.00 and 2.05–2.10 GeV for D^*'s). Clear peaks stand up over the background in the regions of the D and D^* masses.

This identification can be made much more selective if specific decay channels are chosen. Examples of these are given in fig. 3a and 3b where we show inclusive spectra of M_2 in $K^-\pi^+\pi^+$ (+$n\pi^0$'s) for two choices of the M_1 decay channel, $D^- \to K^+\pi^-\pi^-\pi^0$ and $\bar{D}^0 \to K^+\pi^-\pi^0$.

These plots show that the spectrometer is able to reconstruct charmed meson pairs with the expected mass resolution and that the chosen production mechanism provides powerful selection criteria to identify them. For instance, nineteen events contain a D^0 and a $\bar{D}^0$ in the final state. Once examined in the target

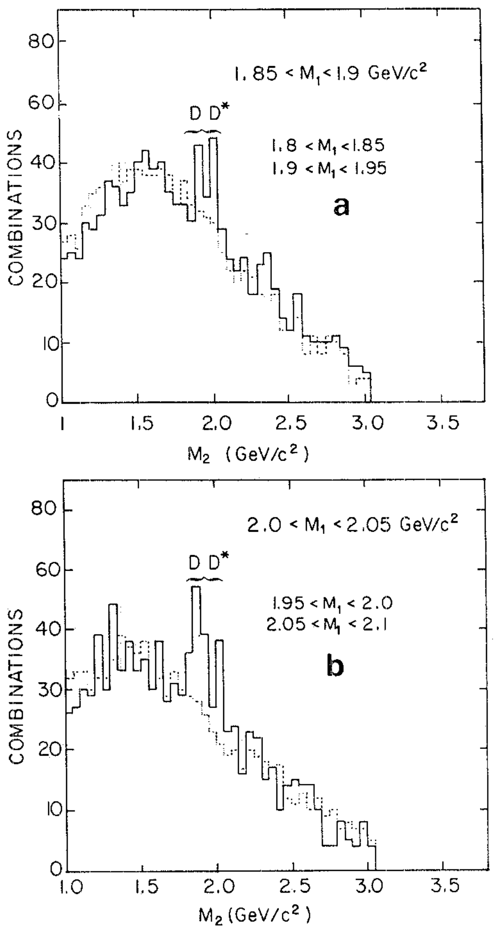

Fig. 2. (a) The full-line histogram is the inclusive mass distribution of M_2 when $1.85 < M_1 < 1.90$ GeV. The dotted line is the background, i.e. combinations with M_1 falling in the nearby ±50 MeV mass regions. (b) Same as in (a) but for $2.0 < M_1 < 2.05$ GeV.

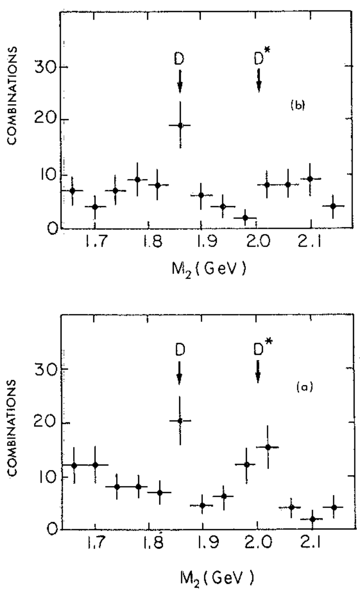

Fig. 3. (a) Exclusive mass spectrum in the $K^-\pi^+\pi^+(n\pi^0)$ decay channels for M_1 identified as $D^- \to K^+\pi^-\pi^-\pi^0$ in the mass range $1.80 < M_1 < 1.90$ GeV. (b) Same as (a) but for M_1 identified as $\bar{D}^0 \to K^+\pi^-\pi^0$.

four of these events show steps corresponding to short decays, while the others have flat patterns compatible with very fast decays. The visible steps and the percentage of flat events are consistent with $1 \times 10^{-13} < \tau_{D^0} < 4 \times 10^{-13}$ s. In the same way 6 fully reconstructed D^+D^- final states (5 with steps in the target and one flat) are consistent with $\tau_{D^+} > 4 \times 10^{-13}$. These samples are, however, too small to allow a precise measurement of the lifetime of different charmed particles. We have then chosen a more global approach, requiring that an event contains at least one reconstructed $D^\pm$-meson, relying on the additional selection provided by the analysis of the target pattern. The criteria used in this analysis, searching for configurations typical of $D^\pm$ decay, are the following:

(i) At least the first two bins must be empty to guarantee that the interaction has taken place inside the target.

(ii) The first level after the production point must extend at least over four layers and must correspond to at least two minimum ionizing particles in order to avoid $D^0(D^{*0})$–$\bar{D}^0(\bar{D}^{*0})$ final states. The request of at least four layers is a safe condition to firmly establish the presence of a level.

(iii) A step of $\Delta n = 2$, 4 or 6, extending again over at least four layers, must follow the first level to suggest the decay of a long lived particle.

A group of 86 events show the requested pattern and constitute the final sample used for the determination of $D^\pm$ lifetime. It contains 98 decays since 12 events show two steps. For each of them we measure the path length between the production and the decay points. The first one is identified by the spike corresponding to the recoil of the silicon nucleus, or, if this spike is not visible, by the first step of the event, while the decay is indicated by the subsequent step. Two examples of this topology are shown in fig. 4.

For the determination of the decay time the knowledge of the meson energy is needed but, since the in association of the D's measured in the spectrometer and the paths in the target is ambiguous, an average γ Lorentz factor $E_{tot}/M_{D^+} M_{D^-}$ has been attributed to both charmed particles. The error on the measured lifetime is practically unaffected by this approximation because the distribution of the meson energy clusters strongly around one half of the event energy, as a consequence of the coherence requirement which imposes the final state to be mainly pure $D(D^*)$–$\bar{D}(\bar{D}^*)$ system with small Q value.

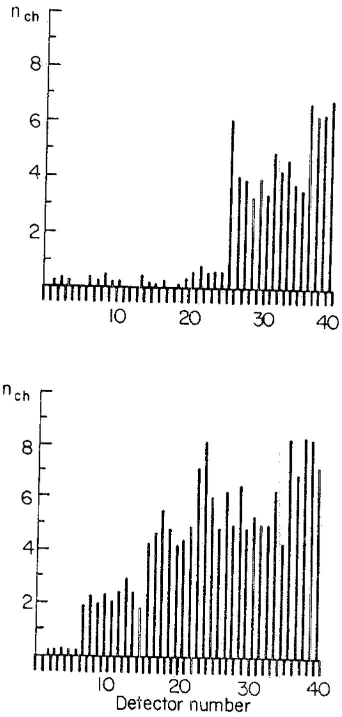

Fig. 4. Coherent production and pattern in the silicon target for two charmed events.

The time distribution of the 98 decays is shown in fig. 5a. Data have been corrected taking into account the limited length of the target and the minimum length of a detectable decay. A maximum likelihood fit with a single slope, gives $\tau = (8.9^{+2.9}_{-1.7}) \times 10^{-13}$ s. Two sources of background must be taken into account before quoting a value for the lifetime: the presence of fake steps due to hadron interactions or to γ-ray conversions and the contamination of D^0's to the $D^\pm$ sample.

The first background is largely suppressed in the analysis by rejecting events with identified electrons and by neglecting those steps which begin with a multiplicity overshoot, typical of incoherent hadron interactions. To evaluate the remaining contamination, a sample of events with the same structure of the D-candidates but falling outside the selected mass range have been examined in the target with the same criteria used to search for decays. The time distribution of these steps, obtained by using the average γ-factors of the D-decays, is completely flat as shown in fig. 5b,

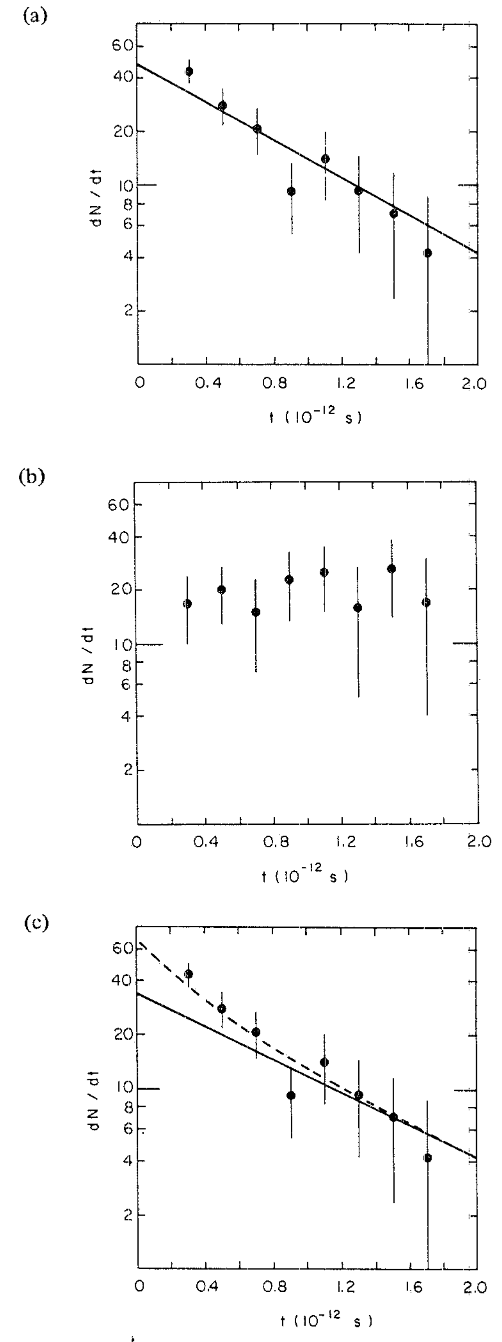

Fig. 5. (a) Time distribution of identified charmed particle decays fitted with a single slope after corrections. (b) Time distribution of background events. (c) Fit to the data taking into account a 20% D^0 contamination with $\tau_{D^0} = 2.5 \times 10^{-13}$ s. The full line gives the $D^{\pm}$ contribution.

which guarantees that the measured slope is not artificially built up by interaction processes. The relative amount of steps in the two samples of data show that 10% of the steps of the D-meson sample can be due to background. The correction for this flat noise under the exponential decrease of the time distribution reduces the value of the lifetime to 8.2×10^{-13} s whilst leaving almost unaffected the quoted error.

The second source of background in the time distribution is due to the presence of a D^0 contamination. Since truly neutral final states $D^0(D^{*0})$–$\bar{D}^0(\bar{D}^{*0})$ are largely suppressed by the request of at least 6 prongs and by the selection criteria used in the analysis of the target pattern, this contamination is mostly due to $D^{*\pm} \to D^0\pi^{\pm}$ decay. Using the known branching ratios, the mass spectrum defined by the coherent production mechanism and spin and isospin conservation, we have evaluated this contamination as a function of τ_{D^0}, shorter lifetimes corresponding to smaller effects. For $\tau_{D^0} = 2.5 \times 10^{-13}$ s, the average value of the data presented at the Bonn Conference [6], the contamination amounts to ~20%.

An overall fit to the data which takes into account this contamination gives (see fig. 5c):

$$\tau_{D^{\pm}} = (9.5^{+3.1}_{-1.9}) \times 10^{-13} \text{ s}$$

a figure which constitutes our estimate at the present stage of the analysis. We feel confident that this technique, with a finer target granularity, can be usefully applied to the measurement of D^0, F and Λ_c lifetimes.

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