New data on lifetimes of short-lived particles

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After publication of several recent exhaustive reviews on the technique and results of lifetime measurements of short-lived particles[1–4] (see also Refs. 5–7), new data appeared in the literature on experiments carried out in this area of high-energy physics. We present below a brief summary of the results and of modifications of the techniques of lifetime measurements of the τ lepton and of charmed and b hadrons which have appeared during 1982–1983.

First we shall describe experiments in colliding e^+e^- beams in which the lifetimes of the B mesons and the τ lepton have been measured. Then we shall list the results of measurements carried out by means of a hybrid emulsion technique, new data obtained in bubble chambers, and experiments on measurements of the lifetimes by purely electronic methods. In conclusion we shall enumerate the characteristics of the experiments planned at CERN on study of the physics of short-lived particles and shall give a table summarizing the present data on their lifetimes.

1. EXPERIMENTS IN COLLIDING e^+e^- BEAMS

a) Measurements of the lifetime of B mesons

At Stanford the lifetime of B mesons was measured almost simultaneously in two experiments in the PEP colliding e^+e^- beams.[8,9] One of these experiments used the MAC detector,[8] the central part of which consists of a cylindrical drift chamber for tracing charged particles. The chamber consists of nine cylindrical drift gaps placed in a solenoidal magnetic field of intensity 0.57 T. The radius of the smallest cylindrical drift gap is 12 cm, and the largest 45 cm. The accuracy in measurement of a point on the track is 200 μm. The drift chamber is surrounded by electromagnetic and hadronic calorimeters consisting of proportional wire chambers interlayered respectively with lead and iron. Two end calorimeters cover the range of angles beginning with 10° from the beam direction. The magnetized steel in the calorimeters produces a field of 1.7 T which together with the outer drift chambers serves for measurement of the momenta of the muons.

For measurement of the B-meson lifetime, events were selected which contained electrons and muons, i.e., semileptonic decays were investigated. A selection was made in the total and transverse energies and in the number of charged particles. It was required that the moun in the external detector join the track reproduced in the central drift chamber, and also that there be a correspondence of the height of the pulse to the energy dissipated in the calorimeter for one particle with minimum ionization. The candidate for the electron was identified as a track in the central drift chamber associated with a shower in the electromagnetic shower chamber and not accompanied by a large dissipation of energy in the hadronic calorimeter.

Separation of b-hadrons from charged particles was carried out statistically on the basis of the transverse momentum of the decay leptons p_T with respect to the direction of emission of the investigated decaying particle. A cutoff $p_T > 1$ GeV/c was used. An additional selection parameter was the impact parameter δ—the least distance from the projection of the lepton track on the plane perpendicular to the beam axis to the point of intersection of the beam with this plane. Analysis of samples of charmed and b particles showed that $\langle\delta\rangle_c \sim 20$–$30\mu$m and $\langle\delta\rangle_b \sim 160\mu$m. After cutoffs were made in the impact parameters, a kinematic analsysis was carried out.

In the experiment we measured the mean life of a sample of B mesons, which turned out to be

$$\tau_B = (1.8 \pm 0.6 \pm 0.4)\cdot 10^{-12}\ \text{sec},$$

where the first error is statistical and the second is systematic and corresponds to the systematic error in determination of $\langle\delta\rangle$. We note that the measured lifetime exceeds by at least an order of magnitude the value expected for b particles (see for example Ref. 4).

The second experiment at SLAC in PEP was carried out with the Mark II detector[7,9,10] and a vertex detector for the energy of the e^+e^- colliding beams of the center-of-mass system $E_{c.m.} = 29$ GeV. The vertex detector was a cylindrical multilayer drift chamber with high spatial resolution and was placed inside the main chamber which traced charged particles. The average spatial resolution of the vertex detector in hadron events was 100 μm per layer. Both chambers operated at a magnetic field of 0.23 T. The particle trajectories were extrapolated backward to the vertex of their origin with accuracy 100 μm in the plane perpendicular to the direction of motion of the particles. Electrons were identified by means of a calorimeter consisting of lead and liquid argon. Muons were identified by means of a system of four layers of hadronic absorber and wire proportional chambers.

Selection of events with semileptonic decays of B mesons was carried out by a procedure similar to that described above. The decay lengths were determined on the basis of the impact parameters of the decay leptons. For events with $|\delta| < 1$ mm a kinematic analysis was performed. The determination of the mean life of the b hadrons lead to the value

$$\tau_B = (12.0^{+4.5}_{-3.6} \pm 3.0)\cdot 10^{-13}\ \text{sec},$$

which is the average over the entire sample of b hadrons, weighted on the basis of the product of their production cross sections and the relative probabilities of the semileptonic decay channels. A parallel determination of the lifetime of charmed hadrons which agrees with the world data

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showed that the measurements contain no large systematic error.

b) Measurements of the lifetime of the τ lepton

The τ-lepton lifetime was also measured in e^+e^- colliding beams. One of the experiments was carried out at SLAC in the PEP by means of the vertex detector of the Mark II spectrometer.[7,10] The second experiment was set up at DESY in the PETRA Installation, and the detector CELLO was used for the measurements.[11]

In the SLAC experiment the lifetime of the τ lepton was determined from the distance between the vertex of its 3-prong decay and the region of collision of the e^+e^- beams. Since the energy at which the τ lepton is produced is known ($E_{c.m.} = 29$ GeV), the mean decay length is proportional to the lifetime.

A sample of 156 events was used for the analysis. The method of maximum likelihood was used to obtain an average value of the decay lengths $705 \pm 87\,\mu$m (the error is only statistical). Inclusion of possible sources of systematic errors led to a final result for the τ-lepton lifetime

$$\tau_\tau = (3.20 \pm 0.41 \pm 0.35)\cdot 10^{-13}\ \text{sec},$$

where the first error is statistical and the second is systematic. As the authors mention,[10] this value is in good agreement with that expected from the universality of weak interactions[1)]

$$\tau_\tau = \tau_\mu \left(\frac{m_\mu}{m_\tau}\right)^5 B_{\tau\to e} = (2.8 \pm 0.2)\cdot 10^{-13}\ \text{sec}.$$

In the experiment at DESY in the PETRA installation the collection of statistics was carried out for two colliding-beam energies: $E_{c.m.} = 17.1$ GeV and $E_{c.m.} = 11$ GeV. The measurements were made with the CELLO detector,[11] the central part of which consists of five proportional chambers and seven drift chambers located in a solenoidal magnetic field strength 1.3 T. The spatial resolution of the central part of CELLO is about 350 μm.

For measurement of the lifetime, events with four or more charged particles were selected. τ leptons, which decay into at least three charged π mesons, were used to establish the vertex. At an energy of 17 GeV about 200 such events were selected, and at 11 GeV about 70 events.

A χ^2 minimization procedure was used to determine the most probable vertex. Selection of candidates for τ-lepton decay was made on the basis of the value of the impact parameter: for at least three tracks the impact parameter must be less than 1 cm in the plane perpendicular to the beam direction, and less than 2.5 cm in the direction along the beam.

By means of the method of maximum likelihood the following value was obtained:

$$\tau_\tau = (4.7^{+3.9}_{-2.9})\cdot 10^{-13}\ \text{sec},$$

which is in good agreement with the results of the experiment described above and the theoretical predictions.

2. EXPERIMENTS IN NEUTRINO, PHOTON, AND HADRON BEAMS

a) Experiments with a hybrid emulsion technique

The new results have been obtained mainly in two emulsion experiments, one of which was carried out at Fermilab (E-531),[13] and the other at CERN in the SPS (Super Proton Synchrotron) (WA-58).[14]

In experiment E-531 emulsion stacks were exposed in a broad-band neutrino beam. The spectrometer consisted of drift chambers, which served for measurement of the secondary-particle momenta and for determination of the direction to the vertex of the interaction, as well as for determination of the coordinate of emission of the particles from the emulsion. The technique has been described in detail in the review by J. D. Prentice,[4] and therefore it will not be discussed here. We shall mention only that after observation of the point of emergence of the track from the main emulsion block the efficiency of following the track to the vertex of formation of the particle corresponding to it amounted to $89 \pm 2\%$ and was practically independent of the depth at which the vertex lay.

The search for charged-particle decays was carried out by following all tracks from the primary vertex to distances up to 6 mm. For decays of neutral particles a search was made inside a cylindrical region beyond the primary vertex of radius 300 μm and length 1000 μm. Another, more efficient method of searching for decays is to follow backward from the spectrometer those tracks which have no corresponding continuations in the emulsion coming out of the primary vertex. The following restrictions were placed on such tracks: they must pass within 2 mm of the primary vertex and the momenta of the particles corresponding to them must be at least 700 MeV/c. For these events the point of exit of the track from the removable layer of emulsion was determined from the spectrometer readings and then with efficiency $90 \pm 2\%$ the measurements were transferred to the main emulsion target.

On the basis of a statistics of 11 D^+ mesons, 19 D^0 mesons, 3 F^+ mesons and 8 Λ_c^+ baryons the following lifetimes were determined by the method of maximum likelihood:

$$\tau_{D^+} = (11.4^{+6.6}_{-4.4})\cdot 10^{-13}\ \text{sec},\quad \tau_{D^0} = (2.3^{+0.8}_{-0.5})\cdot 10^{-13}\ \text{sec},$$
$$\tau_{F^+} = (2.0^{+1.8}_{-0.8})\cdot 10^{-13}\ \text{sec},\quad \tau_{\Lambda_c^+} = (2.3^{+1.0}_{-0.6})\cdot 10^{-13}\ \text{sec}.$$

In experiment WA-58, which was carried out[14] at CERN in the PEP in a beam of tagged photons in the energy range 20 GeV $< E_\gamma <$ 70 GeV, 5000 emulsion layers of size $20\times 50\times 0.6$ mm were systematically bombarded. The emulsions were placed at an angle of 5° with respect to the beam direction, and the effective thickness of the layer in this case as 6.9 mm. About 10^6 photons were directed into each layer. Identification of the particles, measurement of the momenta, and detection of π^0 mesons were accomplished by the Omegá spectrometer.[4] The interaction vertices were established by means of the secondary tracks measured in the spectrometer. The search for the vertex in the emulsion was carried out in a region of target coordinates $11\times 3\times 0.6$ mm. After the interaction vertex was found, a search was carried out for secondary vertices (charged-particle decays by following along the track, and neutral-particle decays by scanning a cone behind the primary vertex with an opening angle 30° and a length either of 500 μm or of 200 μm). In the search for neutral-particle decays, tracks established in the spec-

1)The uncertainties in the value of $\tau_{i\tau}$ arise mainly as the result of error in measurement of $B_{\tau\to e}$.[12]

trometer but which were not matched with tracks coming out of the primary vertex were also followed into the interior of the emulsion. In evaluating the lifetime, allowance was made for the parameters l_{min} and l_{max} and the scanning efficiency. The length l_{min} is the smallest distance in which it is possible to detect a decay with a given topology (usually $l_{min} = 20\,\mu m$). The length l_{max} is the distance between the primary vertex and the boundary of the search volume, measured along the direction of emission of the investigated particle (for charged particles—up to the exit of the track from the emulsion). Measurement of the scanning efficiency showed that for charged-particle decays it does not depend on the decay length, while for neutral particles it falls off with distance.

For measurement of the lifetime 22 D^0 mesons and 18 charged charmed particles were selected, of which 7 were identified as Λ_c^+, four as $D^\pm$ with an admixture of F mesons and Λ_c^+.

Determinination of the lifetime by the method of maximum likelihood led to the following values:

$$\tau(D^0, \overline{D}^0) = (2{,}7^{+1{,}4}_{-0{,}7})\cdot 10^{-13}\ \text{sec},$$

$$\tau(D^\pm) = (3{,}44^{+2{,}0}_{-0{,}1})\cdot 10^{-13}\ \text{sec},$$

$$\tau(\Lambda_c^+) = (2.14^{+1{,}12}_{-0{,}66})\cdot 10^{-13}\ \text{sec}.$$

Among the emulsion experiments we would like to single out an attempt at direct observation of decays of b particles. In the experiment NA-19 performed at CERN[15] in a beam of 350-GeV π mesons a search was made for the cascade decay of b particles in emulsion leading to production of three or four muons in the final state.

The region of occurrence of the primary vertex was determined from the intersection of the trajectory of the beam particle with the tracks of the secondary particles which were recorded in the rear part of the spectrometer. A multiwire proportional chamber placed in front of the emulsion target determined the coordinates of the beam particle in the plane perpendicular to the beam with an accuracy of 70 μm. To reduce the search volume in the emulsion we placed directly beyond the stack a vertex detector consisting of four multiwire proportional chambers located behind each other with a gap of 0.5 mm.

Stacks of Ilford G5 emulsion of dimension $15\times 10\times 5$ were systematically bombarded in the beam. Fifty liters of emulsion were bombarded parallel to the beam, and 6 liters (17 stacks) perpendicular to the beam. During the exposure, the stacks were shifted by means of step translators in the plane perpendicular to the beam direction to obtain uniform bombardment of the entire surface. In the parallel bombardment the density of tracks was 900 particles/mm^2, and in the perpendicular bombardment it was up to 2000 particles/mm^2. Scanning of the perpendicularly bombarded emulsion layers was carried out automatically by the technique developed by the E-531 collaboration.[16]

From the $3.2\cdot 10^8$ interactions recorded, 171 events with three muons were selected, and for these events a search for decay vertices in the emulsion was made. Detection of charged-particle decays was accomplished by following along all secondary tracks with minimum ionization for a distance up to 2 mm for half of the sample and up to 1 mm for the remaining part. The search for neutral decays was carried out inside a cone behind the primary vertex of length 200 μm and opening angle 30°. No candidates for b-particle decay were found. It was assumed that the probability of observing decays of particles with lifetime $\tau \sim 10^{-13}$ sec is about 0.8. It is noted that this probability decreases by a factor of two for the regions of lifetimes $\tau \sim 2\cdot 10^{-14}$ sec and $\tau \sim 10^{-12}$ sec. The absence of candidates corresponds to an upper limit of the cross section for production of b particles of about 90 nb at the 90% confidence level for $\tau_b \sim 10^{-13}$ sec.

b) Experiments in bubble chambers

The lifetime of charmed particles produced in γp interactions at $E_\gamma = 20$ GeV was measured at SLAC in a hydrogen bubble chamber.[17] The beam of γ rays was produced by scattering of electron with energy 20 GeV by a laser beam. The dimensions of the chamber were about 1 m^3, and the repetition frequency was 10 Hz. The resolution of the optics was 55 μm, and depth of field viewed was ± 6 mm. The density of bubbles in the chamber was 70 cm^{-1}, and the diameter of the bubbles was 55 μm. Beyond the chamber were placed four sets of multiwire proportional chambers (MWPC), two Čerenkov counters, and a wall of lead glass. Triggering of the chamber required presence in three MWPC of signals from the charged particle produced in the working volume of the bubble chamber (processing of signals from the MWPC was carried out by a processor in a period of 200 msec), and dissipation of energy in the wall of lead glass.

For candidates for charmed particles, decays with two or more charged secondary tracks were selected. For one of the tracks the impact parameter had to exceed 110 μm (twice the track width), and for the others it had to be more than 40 μm. A cutoff of the minimum decay length was made at 500 μm. The lifetime was determined by the method of maximum likelihood with use of a set of parameters obtained from various evaluation procedures. From the decays of nine charged and eleven neutral charmed particles the following values were obtained:

$$\tau^\pm = (8.2^{+4{,}5}_{-2{,}5})\cdot 10^{-13}\,\text{sec and}\ \tau^0 = (6.7^{+3{,}5}_{-2{,}0})\cdot 10^{-13}\ \text{sec}.$$

In the CERN experiment[18] NA-18 in the SPS in a 340-GeV/c π^--meson beam the vertex detector was the heavy-liquid bubble chamber BIBC (Berne Infinitesimal Bubble Chamber).[3] The spectrometer in NA-18 was a streamer chamber. The BIBC bubble chamber filled with C_3F_8 had a high resolution of about 30 μm with photography by an ordinary optical system. The bubble density for particles with minimum ionization was 300 cm^{-1}. With holographic readout of information, which was not used in the present experiment, the resolution reaches 8 μm with a depth of field 9 cm.[9]

The events selected for analysis has tracks in the BIBC which were well matched with tracks in the streamer chamber and in which no clear unbalance of the transverse momenta was observed. Identification of the decaying particles was made on the basis of the established effective masses. The resolution in mass was ± 28 MeV/c^2 for D mesons, ± 31 MeV/c^2 for F mesons in decay by the channel

F→KK$n\pi$, and ± 43 MeV/c^2 for F mesons in decay by the channel F→$n\pi$.

After the selection 21 candidates for decay of D mesons remained, for which the following conditions had to be satisfied: in at least one of the projections the distance from the decay vertex to the closest secondary track had to exceed 25 μm; in at least one of the projections the maximum impact parameter had to exceed twice the diameter of a bubble.

An estimate of the mean life for D mesons, made by the method of maximum likelihood, leads to the following values:

$$\tau(D^0, \bar{D}^0) = (4.1^{+2.6}_{-1.3} \pm 0.5)\cdot 10^{-13}\,\text{sec},$$
$$\tau(D^{\pm}) = (6.3^{+4.8}_{-2.3} \pm 1.5)\cdot 10^{-13}\,\text{sec},$$

where the first error is statistical and the second is systematic.

In experiment NA-16 at CERN In the SPS in beams of π^- mesons and protons with momentum 360 GeV/c the LEBC-EHS collabration investigated the characteristics of charmed.[20] The vertex detector used was the LEBC high-repetition-rate hydrogen bubble chamber with high resolution.[3] The repetition frquency of the LEBC was about 30 Hz, and the resolvable bubble size was about 50 μm.

For momentum analysis of charged particles and detection of π^0's the EHS spectrometer was used.[3] Partial identification of the particles was accomplished in the ISIS drift chamber.[3] Decays which were masked were detected on the basis of secondary tracks which on extrapolation did not hit the interaction vertex, or on the basis of the rise of ionization.

To obtain a background-free sample of charmed particles, various kinematic cutoffs were used. To determine the lifetime by the method of maximum likelihood the minimum and maximum recorded decay lengths were taken into account; these lengths depend on the topology of the specific event, the size of the bubbles, the size of the LEBC, the depth focus, and the cutoff in the distance in the transverse direction with respect to the beam from the decay vertex to the beam axis (< 0.06 cm).

The following lifetime values were obtained:

$$\tau(D^0, \bar{D}^0) = (4.1^{+1.3}_{-0.9})\cdot 10^{-13}\ \text{sec—sample of 16 decays}$$
$$\tau(D^{\pm}) = (8.4^{+3.5}_{-2.2})\cdot 10^{-13}\ \text{sec—sample of 15 decays}$$
$$\tau(F^{\pm}) = (2.1^{+3.6}_{-0.8})\cdot 10^{-13}\ \text{sec—two decays.}$$

It should be mentioned that each sample agrees with a single exponential for decay of the corresponding meson.

By October 1983 the D-meson statistics processed was increased to 77 decays, and new data on the lifetimes[21] gives values

$$\tau(D^{\pm}) = (9.9^{+5.7}_{-3.0})\cdot 10^{-13}\,\text{sec and}$$
$$\tau(D^0, \bar{D}^0) = (3.7^{+2.0}_{-1.1})\cdot 10^{-13}\ \text{sec.}$$

c) Electronic measurements of the D-meson lifetime

The first purely electronic measurement of the lifetime of charmed particles was achieved in the experiment NA-1 performed at CERN in the photon beam of the SPS at energies 40–150 GeV.[22] The coherent photoproduction of charmed mesons in an active silicon target was studied. A multiparticle spectrometer served for measurement of the momenta of neutral charged particles and for selection of candidates for events with production of D$\bar{\text{D}}$ pairs. Separation into π and K particles was accomplished by Čerenkov counters in the momentum region 5–21 GeV/c. The length of the D-meson trajectory was measured in the target—a telescope of thin silicon detectors, in each of which was produced a signal proportional to the multiplicity of charged particles passing through the detector.

The active target (15% of a radiation length) consisted of 40 silicon detectors of thickness 300 μm with gaps between them of about 100 μm. A particle with minimum ionization dissipated in each layer an energy of 90 keV (with electronic noise of 30 keV).

The effective masses M_1 and M_2 of the two D mesons were established by sorting all particles of the final state. To choose a sample from 98 selected decays the ranges of the decaying particles were measured. The location of the production vertex was determined by means of the spike corresponding to recoil of the silicon nucleus or, if no spike was observed, by means of the first step in the sequence of signals from the active target. The decay vertex was determined on the basis of the next step.

The method of maximum likelihood with one exponential (decay of one particle) and with allowance of the limited thickness of the target, the minimum detectable decay length, and the calculated amount of impurities in the sample of D^0 measons leads to the value

$$\tau(D^{\pm}) = (9.5^{+3.1}_{-1.5})\cdot 10^{-13}\ \text{sec.}$$

The authors note that further refinement of the technqiue—construction of a target with a finer structure—should permit measurement of the lifetimes of the D^0 and F mesons and the Λ_c^+ baryon.

Probably the greatest achievement in the electronic measurement of the lifetimes of charmed particles can be considered to be the experiment NA-11 set up at CERN in the SPS.[23,24] Together with the ACCMOR spectrometer a silicon microstrip vertex detector with a resolution of 5 μm was used. Interactions of π^- mesons with energy 200 GeV with Be were studied and events with production of one electron were identified:

$$\pi^-\text{Be} \to \underset{\llcorner\!\!\longrightarrow\, eX}{D} \qquad + \underset{\llcorner\!\!\longrightarrow\, \text{hadrons}}{\bar{D}} \qquad + X' \quad \text{or cc},$$

where X and X' are any multiparticle states. Decrease of the background from hadrons, photons, and γ-ray conversion pairs was achieved by means of information from multiwire proportional chambers and a calorimeter.

For reproduction of events "off line" the following apparatus was used:

1) Six microstrip silicon detectors (MSD) which measured the position of the beam particles with an accuracy $\delta_{\text{horiz}} = 25\,\mu$m, $\sigma_{\text{vert}} = 6\,\mu$m;

2) six MSD which are described in detail below;

3) forty-eight drift planes of large size and two magnets for measurement of the momenta of charged particles;

4) three Čerenkov counters which permitted separation of π, K, and p in the momentum region 4–80 GeV/c.

The main characteristics of the microstrip silicon detectors were as follows: material—single crystal Si; thickness 280 μm ($3\cdot 10^{-3}$ radiation length); sensitive area 24×36 mm; number of strip diodes 1200; gap between strips 20 μm; strip length 36 mm; number of read-out strips 240; gap between read-out strips—in the central region 60 μm (every fourth strip is read out), and at the edges—120 μm; spatial accuracy—respectively 4.5 and 7.9 μm; two-particle resolution—60 and 120 μm. A more detailed description of the MSD can be found in Ref. 25.

To decrease the number of electronic channels and overcome problems of bringing out a signal from each strip to the external electronics, use was made of division of the charge in the interstrip capacitances. The analog electronics necessary for this purpose also provided a measurement of the energy loss of the passing particles.

The vertex telescope consisted of six planes of MSD and served for measurements of the coordinates of charged-particle tracks. The MSD detectors were divided into three groups, two crystals in each group. One of the MSD was located so that the angle between the strips and the horizontal plane as $+14°$, and for the other this angle was $-14°$. This configuration permitted reproduction of a track in space (two projections). The distance between the two MSD in each group (8 mm) was determined by the technical possibilities, and the distance between the groups (44 mm) was determined by considerations of accuracy in reproduction of the tracks and by the aperture of the telescope.

The position of a particle was determined from the center of gravity of the "clusters"—sequences of neighboring read-out strips with a total signal corresponding at least to the value expected for one particle.[25]

Reconstruction of events was carried out in three stages: decoding of the coordinates, establishment of the track, and reconstruction of the topology of the vertex. Here information on the energy loss was utilized, which permitted estimation of the multiplicity of charged particles. In the stage of decoding the coordinates a search for clusters and a determination of the coordinates of the tracks were carried out.

To reconstruct the track in space, information from all six MSD and the drift chamber was used. The vertex common for several tracks was determined by means of direct minimization of χ^2 with allowance for the complete correlation matrix of the errors of all tracks extrapolated to the vertex.

Selection of events at the trigger level was accomplished by a search for interactions with the cleanest signals from electrons. Final states with charged K mesons were also selected. For these events the data from the MSD were analyzed.

For candidates for decays of charmed particles the following conditions were required to be satisfied: a sufficiently large distance between the primary and secondary vertices, an excess of the impact parameters of the decay particles over two standard deviations, and conservation of momentum.

The results of the measurements led to the following values of the lifetimes[24]:

$\tau(D^0,\bar{D}^0) = (4.5 \pm 2.0)\cdot 10^{-13}$ sec for the $K\pi$ decay channel,

$= (4.1 \pm 1.2)\cdot 10^{-13}$ sec for the $K\pi\pi\pi$ decay channel,

$\tau(D^\pm) = (8.8 \pm 2.7)\cdot 10^{-13}$ sec for the $K\pi\pi$ decay channel.

The errors given here are only statistical, since the systematic errors have not been adequately studied.

To increase the rate of collection of statistics it is proposed in the future to use a trigger on change of the secondary-particle multiplicity. It is to be provided by an active target consisting of 15 MSD located one after the other with a small gap.

Very recently there have been published technical articles on use of charged-coupled devices (CCDs) for detection of high-energy particles. A CCD is a semiconductor integrated microcircuit consisting of a matrix of elementary cells (pixels). The typical useful area of the matrix is 0.5–1 cm^2, and the useful thickness is several tens of microns, with a substrate thickness of 1–2 mm. With use of a CCD as a detector of particles, each cell, with a size of several tens of microns, accumulates electrons (or holes) produced by the particle being detected in passing through the depleted zone of the semiconductor. Readout of information from a CCD is accomplished sequentially from each cell through the same exit device.

Detectors employing charged-coupled devices have high accuracy (of the order of one-tenth of the cell size) and good two-track resolution (usually the size of two cells).

The first results on operation of a telescope of charge-coupled devices in a beam of high energy particles were obtained in the control beam of π^- mesons with momentum 5 GeV/c in the CERN PS.[27] The efficiency for recording packs in one plane turned out to be $98 \pm 2\%$, the spatial resolution was 4.3 μm and 6.1 μm in two orthogonal directions, and the two-particle resolution was 40 μm. In the experiment a telescope of three CCD matrices with a sensitive area 8×13 mm and a cell size 22×22 μm as used. The indicated accuracy in determination of the coordinates was obtained by determination of the center of gravity of the distirbution of the charges over the cells. The experiment investigated P8600 detectors consisting of a two-dimensional CCD structure. The use of the detector involved first a mode of accumulation of charge in the detector as the result of passage of particles, and then a period of readout which was accomplished between beam spills. Readout from the detectors is accomplished by means of a charge-coupling mechanism.

For successful use of CCDs in the physics of short-lived particles it is necessary, the authors consider, to solve the following problems:

1) To decrease the thickness of the ceramic substrate (at present it amounts to 1.6 mm);

2) To decrease the readout time (it is possible to attain 0.1 msec);

TABLE I. Lifetimes of short-lived particles in units of 10^{-13} sec.

Experiment	Technique	τ_τ	τ_B	$\tau_{D^\pm}$	$\tau_{D^0, \bar{D}^0}$	$\tau_{F^\pm}$	$\tau_{\Lambda_c^+}$
PEP, e^+e^-	MAC	$4.1 \pm 1.1 \pm 1.2$	$18 \pm 6 \pm 4$	—	—	—	—
PEP, e^+e^-	«Mark II»	$3.2 \pm 0.4 \pm 0.35$	$12.0^{+4.5}_{-3.6} \pm 3.0$	—	—	—	—
PETRA, e^+e^-	CELLO	$4.7^{+3.9}_{-2.9}$	—	—	—	—	—
E-531	Emulsion + drift chambers	—	—	$11.4^{+6.6}_{-4.4}$	$2.3^{+0.8}_{-0.5}$	$2.0^{+1.8}_{-0.8}$	$2.3^{+1.0}_{-0.6}$
WA-58	Emulsion + Omega	—	—	$3.44^{+2.0}_{-0.1}$	$2.7^{+1.4}_{-0.7}$	—	$2.14^{+1.12}_{-0.66}$
NA-18	BIBC + streamer chamber	—	—	$6.3^{+4.8}_{-2.3} \pm 1.5$	$4.1^{+2.6}_{-1.3} \pm 0.5$	—	—
NA-16	LEBC + EHS	—	—	$9.9^{+5.7}_{-3.0}$	$3.7^{+2.0}_{-1.1}$	—	—
NA-1	Active silicon target	—	—	$9.5^{+3.1}_{-1.5}$	—	—	—
NA-11	MSD+ACCMOR	—	—	8.8 ± 2.7	4.5 ± 2.0, 4.1 ± 1.2 *)	—	—
Mean life[28]		—	—	$8.8^{+1.3}_{-1.0}$	$4.4^{+0.6}_{-0.5}$	$2.1^{+1.3}_{-0.6}$	$2.2^{+0.8}_{-0.5}$

The ratio of the lifetimes of charged and neutral B mesons according to the world statistcs data is at present $\tau_{D^+}/\tau_{D^0} = 2.0 \pm 0.48$ (Ref. 28). We note that in 1982 this ratio was 2.3 ± 0.8.[29]

*) The lifetimes of the D^0 meson were obtained respectively by the $K\pi$ and $K\pi\pi\pi$ decay channels.

3) to provide the possibility of operation at high beam intensities (triggered readout);

4) to increase the spatial accuracy (according to calculations this can be reduced to 2 μm or less).

The most obvious advantage of a CCD as a vertex detector of particles is the good two-track resolution, which exceeds, for example, the resolution of an MSD. This permits the CCD to be placed in the immediate vicinity of the interaction vertex at high energies, which is an important feature for study of short-lived particles. An increase of the efficiency for detection of small decay lengths occurs also as the result of the simultaneous measurement in one detector of the x and y coordinates of the track. Similar arguments can be used also for experiments in colliding beams.

d) Projected experiments at CERN on the physics of short-lived particles[27]

At CERN in the SPS in 1983–1986 it is planned to extend several experiments now going on and to carry out a number of new experiments on study of charmed and b particles.

1) Photon beam. In new runs of the experiment NA-1 it is proposed to replace the active silicon target by a single-crystal germanium target in combination with silicon telescope with a low density. This will lead to an increase of the resolution in the vicinity of the interaction vertex by a factor of three, which will permit study not only of $D^\pm$ mesons but also of shorter-lived particles (D^0, F, and so forth). The collection of statistics should be completed by the end of 1983.

In the proposal for experiment NA-14 it is proposed to use as vertex detector an active silicon target and a system of multistrip detectors. Selection of candidates for charmed particles will be made on the basis of a jump in multiplicity in the signals from the active target (as in NA-1) and the requirement of nonzero impact parameter determined by means of the MSD. It is proposed to collect a statistics of 10^4 reproduced decays of charmed particles (1984–1986).

In the EHS spectrometer it is proposed to replace the LEBC by a bubble chamber with high resolution, the HOLEBEC (proposal P–182). The illumination of the bubble chamber and the reading of the electronics are to be triggered by a hadron-production trigger. It is proposed to obtain about 10^3 reproduced decays of charmed particles (about 100 of them F mesons).

2) Hadron beams. In the continuation of experiment NA-11 to increase the rate of collection of statistics it is proposed to use a trigger on a jump in the secondary-particle multiplicity. By 1986 an increase of the statistics up to about 10^4 completely reproduced charmed-particle decays is expected.

Experiment NA-27 is a hadron analog of propsal P-182. The bubble chamber HOLEBC will be exposed in beams of π^- mesons and protons with momenta 360 GeV/c. The trigger for readout of the information from the electronic spectrometer EHS will be an interaction inside the HOLEBC.

Experiment WA-71 is intended to obtain a small but background-free sample of B mesons, and in this sample about 10^3 charmed-particle decyas should be recorded. The method involves use of an emulsion target and the Omega spectrometer. It is proposed to carry out the irradiation in a beam of π^- mesons with momentum 350 GeV/c. It is proposed to use semiconductor detectors for detection of the particle decays. Completion of the experiment is scheduled for the end of 1984.

Thus, by 1986 at CERN in the SPS a statistics of about 10^3–10^4 identified decays of charmed particles should be accumulated.

3) Plans for the Tevatron (Fermilab). At Fermilab the well-known E-531 collaboration has put forth a new proposal for irradiation of emulsion stacks in a high-energy proton beam (E-653). Of all the experiments planned at Fermilab, only in this one is it proposed to use a vertex detector with high resolution. In the remaining experiments emphasis will be given to a high rate of collection of statistics (for example, in experiment E-690 it is proposed to obtain about 10^4 charmed-particle decays per hour), and selection of candidates will be carried out off-line and probably will require a large amount of time.

In conclusion we present a table which summarizes the present data on charmed-particle lifetimes. In the table we have indicated the experiment, the technique, and the result. The experiments listed in the table have been described in the text.

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