ISSN 0029 - 3865

CBPF-NF-032/86

MEASUREMENT OF THE D^+ AND D^0 LIFETIMES*+

by

J.C.Anjos, J.A.Appel[d], S.B.Bracker[g], T.E.Browder[a], L.M.Cremaldi[c]
J.R.Elliott[c,‡], C.O.Escobar[f], P.Estabrooks[b], M.C.Gibney[c], G.F.Hartner[g],
P.E.Karchin[a,†], B.R.Kumar[g], M.J.Losty[e], G.J.Luste[g],P.M.Mantsch[d],
J.F.Martin[g], S.McHugh[a], S.R. Menary[g], R.J. Morrison[a], T.Nash[d],
U.Nauenberg[c], P.Ong[g], J.Pinfold[c], G.Punkar[a],M.V.Purohit[d]
J.R.Raab[a], A.F.S.Santoro, J.S.Sidhu[b], K.Sliwa[d], M.D.Sokoloff[d], M.H.G.Souza,
W.J.Spalding[d], M.E.Streetman[d], A.B.Stundzia[g], M.S.Witherell[a]

Centro Brasileiro de Pesquisas Físicas - CBPF/CNPq
Rua Dr. Xavier Sigaud, 150
22290 - Rio de Janeiro - RJ - Brasil

a.University of California, Santa Barbara, California, USA

b.Carlenton University, Ottawa, Ontario, Canada

c.University of Colorado, Boulder, Colorado, USA

d.Fermi National Accelerator Laboratory, Batavia, Illinois, USA

e.National Research Council, Ottawa, Ontario, Canada

f.Universidade de São Paulo, São Paulo, Brasil

g.University of Toronto, Toronto, Ontario, Canada

*The Tagged Photon Spectrometer Collaboration
+Submitted to Phys. Rev. Lett.

CBPF-NF-032/86

ABSTRACT

We have used a silicon microstrip vertex detector with the Tagged Photon Spectrometer to measure the lifetimes of charmed mesons produced by a high energy photon beam at Fermilab. The D^+ lifetime, based on 969 $D^+ \to K^-\pi^+\pi^+$ decays, is measured to be $(1.06 \pm .05 \pm .03) \times 10^{-12}$ s. Using 1360 D^o decays into the modes $K^-\pi^+$ and $K^-\pi^+\pi^-\pi^+$, we determine the lifetime to be $(.435 \pm .015 \pm .010) \times 10^{-12}$ s. The ratio $\tau(D^+)/\tau(D^o)$ obtained from these two measurements is $(2.44 \pm .14 \pm .08)$.

The area of charmed particle lifetimes has recently received much attention from both experimental and theoretical physicists. The large difference between the D^o and D^+ lifetimes contradicts the simple spectator-quark model. Explanations for this difference include enhancement of the D^o decay rate due to the W-exchange diagram, and suppression of the D^+ decay due to destructive interference, among others.[1] Accurate measurements of the lifetimes of all the charmed particles are a necessary part of understanding the charm decay. This paper presents results from the analysis of D^+ and D^o lifetimes in a high energy photoproduction experiment, E691, using the Fermilab Tagged Photon Spectrometer (TPS). The characteristics of the experiment which are important for the lifetime measurement are high statistics with low background, proper time resolution much smaller than the lifetime, and good control of systematic errors.

The TPS is a two-magnet spectrometer of large acceptance, with drift chambers, Cerenkov counters, and electromagnetic and hadronic calorimetry. The original configuration of the spectrometer has been described elsewhere.[2] For the present experiment, more drift chamber planes were added and the Cerenkov counters were improved. In addition, nine silicon microstrip detectors[3] (SMD's) were installed downstream of a 5 cm beryllium target. These detectors, with 50 μm strip spacing, provided measurement of charged tracks with enough precision to resolve the charm vertex for approximately half of the decays. The trigger required a total transverse energy (E_T) in the calorimetry of at least 2.2 GeV. This requirement was about 80% efficient for events with charm, and suppressed the total hadronic interaction rate by a factor of about 2.5. The incident photon energy spectrum had approximately a bremsstrahlung form from 100–260 GeV. We recorded about 100 million events, of which 10% were taken without the E_T requirement; the present results are based on analysis of about 30 million events.

The events were reconstructed in the SMD-drift chamber tracking system and the Cerenkov counter information was used to identify particles. For each channel, there was a minimum requirement on the joint probability for the appropriate particle identification assignment. The charm decay tracks were required to form a good vertex, and all other tracks in the event were used to form possible primary vertices. A search was made for all primary vertex candidates within a transverse distance of 80 μm from the line of flight of the reconstructed charm candidate. To reduce the non-charm background, only charm candidates were chosen which decayed at least a distance L downstream of the primary vertex. The distance L was chosen to be 5–10 σ, depending on decay mode, where σ is the error on the distance between primary and secondary vertices. In the 20% of the events with multiple primary vertex candidates, L was calculated from the most downstream candidate, to be sure that it was downstream of any possible production point. The proper time was calculated from the point a distance L downstream of the primary vertex to the observed decay vertex. The fiducial region for decays was defined to end at the first SMD plane. In the D^o analysis we used only events for which the proper time corresponding to the end of this region, $t_{\max}$, was beyond the maximum time used in the fit (1.8 ps). For the D^+, the fit to the time spectrum extended to a maximum decay time of 4.0 ps. There was some loss of events at long decay times due to decay beyond the end of the fiducial region, which was taken into account when fitting the spectrum. D^+ events with $t_{\max} < 2.0$ ps were not used, in order to reduce the sensitivity of the lifetime to this correction.

The function

$$N \times f(t) \times \frac{1}{\tau} \exp(-t/\tau) + B(t)$$

was used to fit the proper time distribution. In this expression, $B(t)$ is the normalized time distribution for the background, as determined from the regions of the mass plot just outside the signal. The two parameters allowed to vary in the fit were N, the number of events in the charm signal, and τ, the charm lifetime. The function $f(t)$, which was obtained from the Monte Carlo, corrects for effects of absorption, acceptance, resolution, and efficiency. The effect of f(t) on the lifetime is small; using f(t)=1 rather than the function obtained from the Monte Carlo would change the lifetime by less than 10%.

For the D^o lifetime study, three independent samples were used: (Throughout the paper, the charge conjugate states are implicitly included.)

(A) $D^{*+} \to \pi^+ D^o, D^o \to K^- \pi^+$
(B) $D^{*+} \to \pi^+ D^o, D^o \to K^- \pi^+ \pi^- \pi^+$
(C) $D^o \to K^- \pi^+$, (no D^{*+}).

Events which satisfied the requirements for sample (A) were excluded from sample (C) so the samples are indeed independent. For sample (A) and (B) the mass difference $m(D^{*+})$-$m(D^o)$ was required to be between .1435 and .1475 GeV/c^2. The minimum decay length L used for each mode is shown in Table I. The mass distributions for the events which satisfy the vertex cuts are shown in Fig. 1; there is a clear D^o peak in each of the three modes. Table I gives the number of events in the signal and background for the mass range 1.839–1.889 GeV/c^2. The time distributions for the three D^o channels, shown in Fig. 2, all follow an exponential form. The maximum likelihood fits to the three distributions give the lifetimes shown in Table I. The three samples are statistically independent, and have different corrections and backgrounds. The fact that the three measurements agree within statistical errors provides some check of the corrections used. A global fit to all three samples gives our best number for the D^o lifetime, $\tau(D^o) = .435 \pm .015$ ps. The correction f(t) was determined from the Monte Carlo program, and the resulting shift in the D^o lifetime is -.03 ps, with an associated systematic error ±.007 ps. The background subtraction is negligible for the two D^* modes, and for channel (C) causes a correction of +.05 ps. The corresponding change in the average D^o lifetime is +.02 ps, with an error of ±.005 ps. The total systematic error is thus ±.010 ps.

The decay mode $D^+ \rightarrow K^-\pi^+\pi^+$ was used for the D^+ lifetime study. The mass spectrum for the accepted events, using a minimum decay length $L = 10\sigma$, is shown in Fig. 3. There are 969 D^+ events in the selected mass region $1.848 - 1.890$ GeV. The expected number of background events, as determined from the number of events outside the D^+ region, is 383 ± 9. This represents a reduction of the background by a factor of 300 due to the cuts on vertex separation.

The D^+ time distribution is shown in Fig. 4. The maximum likelihood fit, including the correction at long times described above, gives a lifetime of $1.06 \pm .05$ ps. The contributions to the systematic error for the D^+ are somewhat different from those for the D^o because of the longer lifetime. The correction to the D^+ lifetime for the effects of resolution, efficiency, acceptance, and false primary vertices is -.05 ps, with a systematic error of ±.015 ps. The absorption of the decay products in the beryllium target leads to an additional correction of -.03 ps, with an error of ±.005 ps. The background subtraction produces a correction to the D^+ mean lifetime of +.25 ps, which is relatively large because the effective lifetime of the background is much shorter than that of the signal. For the same reason, we were able to test the background subtraction by choosing samples with more or less background. The systematic error due to this subtraction is ±.025 ps. Adding these systematic errors in quadrature, the total systematic error is ±.03 ps.

The D^o lifetime of $(.435 \pm .015 \pm .010)$ ps that we measure is consistent with the world average of $(.43^{+.05}_{-.04})$ ps.[4] The D^+ lifetime of $(1.06 \pm .05 \pm .03)$ ps is somewhat higher than the world average of $(.92^{+.13}_{-.08})$ ps.[4] The ratio of lifetimes can be inferred from the ratio of semileptonic branching ratios $B(D^+ \rightarrow e^+ + X)/B(D^o \rightarrow e^+ + X)$, which Mark III has measured to be $2.3^{+0.5}_{-0.4} \pm 0.1$.[5] This is equal to the ratio of lifetimes if one ignores the Cabibbo- suppressed non-spectator process which only contributes to the

D^+ semileptonic decay. Our measurement of the ratio of lifetimes is $(2.44 \pm .14 \pm .08)$.

We gratefully acknowledge the assistance of the staff of Fermilab and of all the participating institutions. This research was supported by the U.S. Department of Energy, by the Natural Science and Engineering Research Council of Canada through the Institute of Particle Physics, by the National Research Council of Canada, and by the Brazilian Conselho Nacional de Desenvolvimento Cientifica e Tecnologico.

Table I. Characteristics of the samples used for the D^o Lifetime. L is the minimum decay length accepted and σ is the error in measuring the decay length. The error quoted on the expected background is the statistical error in determining the background from the mass region near the D^o.

Mode	L/σ	# Signal	# Background	Lifetime (ps)
$D^{*+} \rightarrow \pi^+ D^o, D^o \rightarrow K^- \pi^+$	5	385	16±2	.46±.03
$D^{*+} \rightarrow \pi^+ D^o, D^o \rightarrow K^- \pi^+ \pi^- \pi^+$	7	228	37±3	.40±.03
$D^o \rightarrow K^- \pi^+$	8	746	450±10	.43±.02

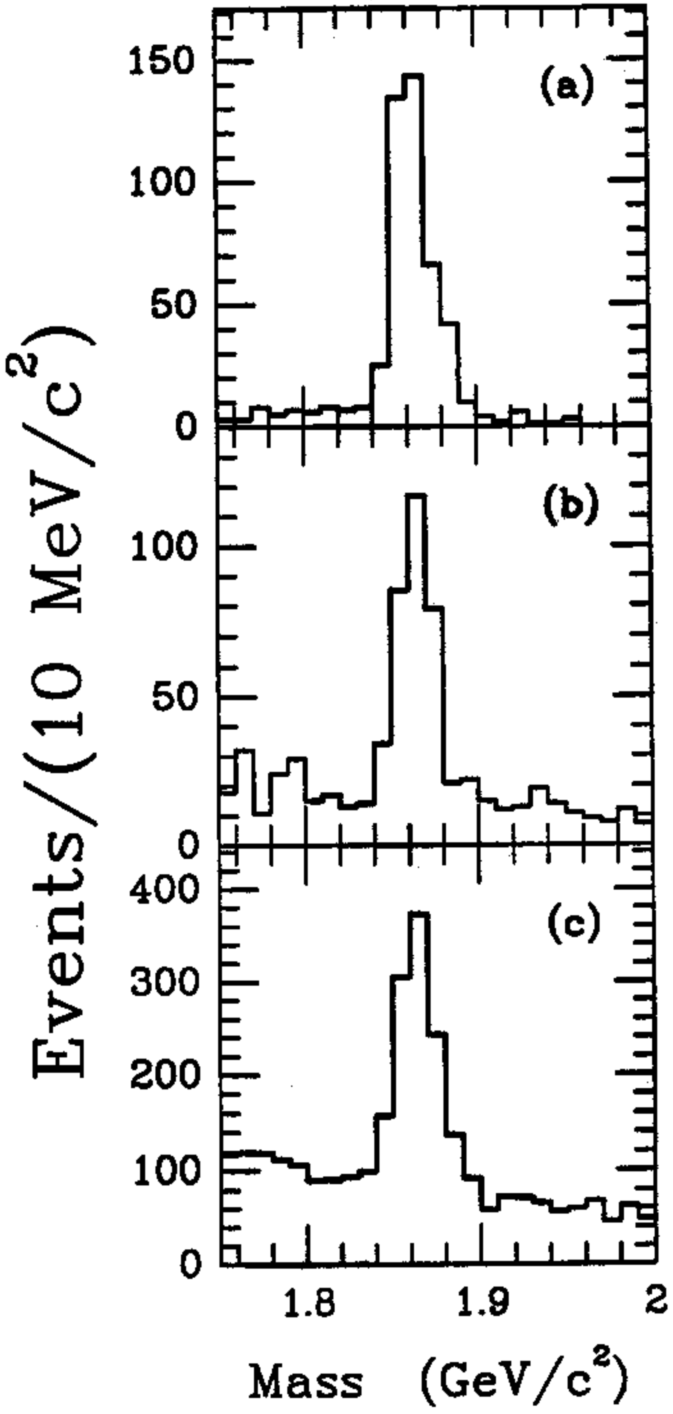
FIGURE CAPTIONS

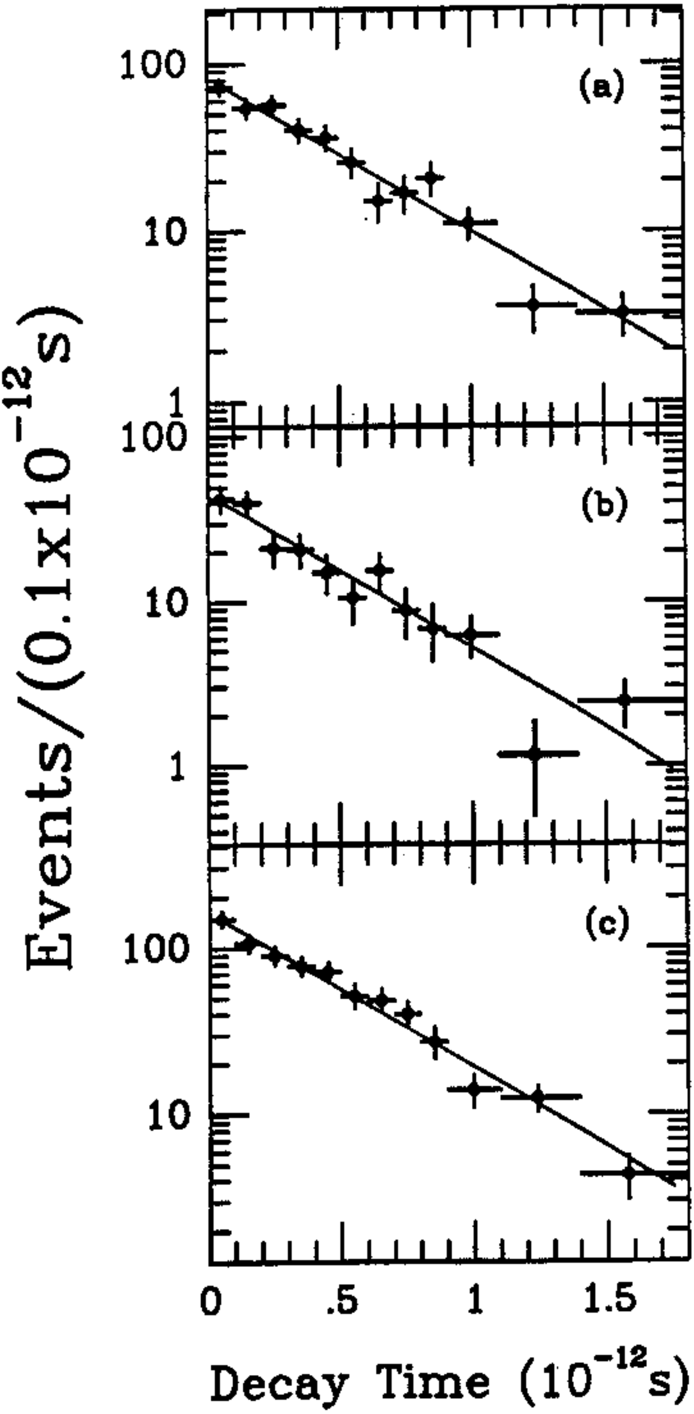
Fig. 1 Invariant mass spectra for three D^o channels with vertex cuts as described in the text. (a) $D^{*+} \rightarrow \pi^+ D^o$, $D^o \rightarrow K^- \pi^+$, (b) $D^{*+} \rightarrow \pi^+ D^o$, $D^o \rightarrow K^- \pi^+ \pi^- \pi^+$, and (c) $D^o \rightarrow K^- \pi^+$, no D^{*+}.

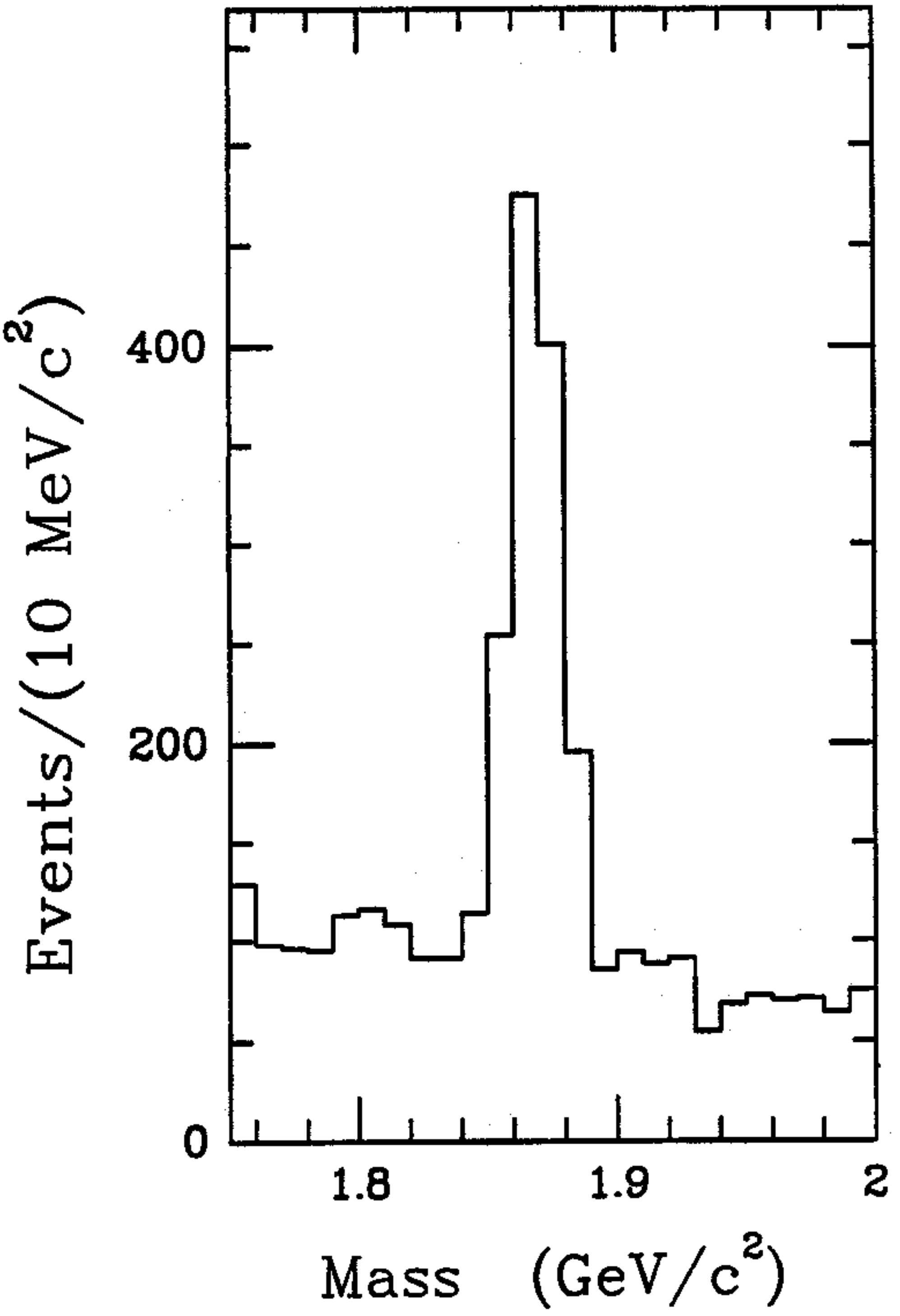
Fig. 2 Proper time spectra for the three D^o channels, in the same order as Fig. 1. The data points are shown with background subtracted. The smooth curve represents the best fit as described in the text.

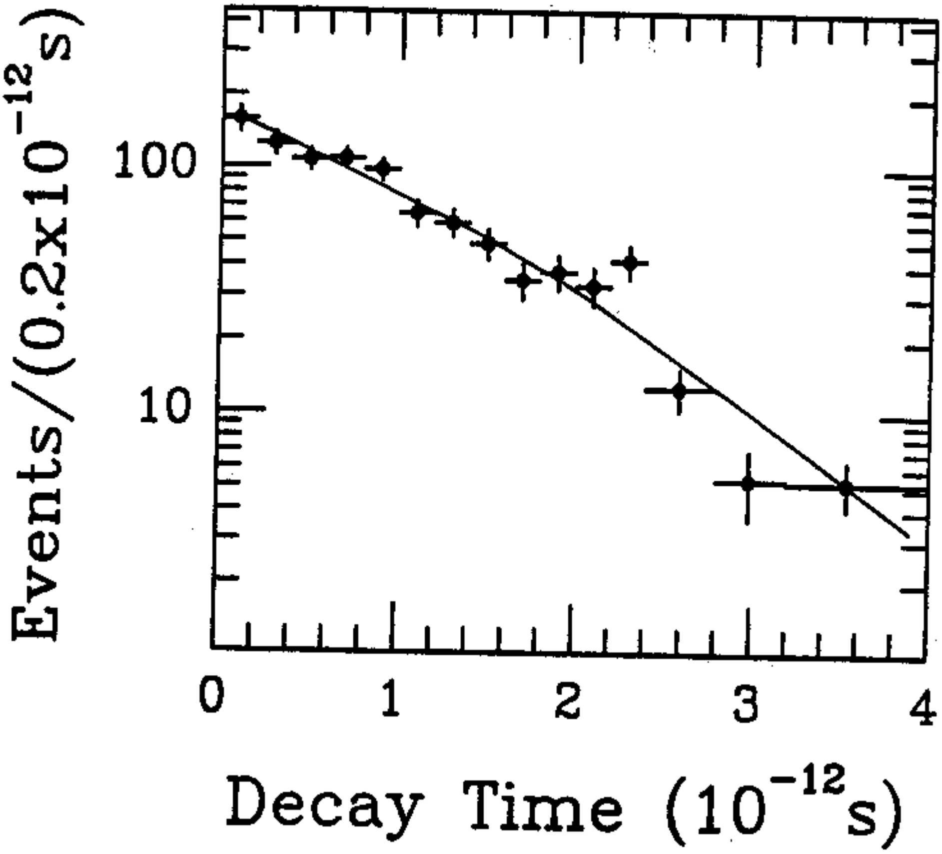
Fig. 3 Invariant mass spectrum for $K^- \pi^+ \pi^+$.

Fig. 4 Proper time spectrum for D^+ events. The data points are shown with background subtracted. The smooth curve represents the best fit as described in the text.


Events/(10 MeV/c^2)
150
100
50
0
(a)
100
50
0
(b)
400
300
200
100
0
(c)
1.8
1.9
2
Mass (GeV/c^2)


Events/(0.1x10^{-12}s)
100
10
1
100
10
1
100
10
(a)
(b)
(c)
0
.5
1
1.5
Decay Time (10^{-12}s)


Events/(10 MeV/c^2)
400
200
0
1.8
1.9
2
Mass (GeV/c^2)


Events/(0.2x10^{-12}s)
100
10
0
1
2
3
4
Decay Time (10^{-12}s)

REFERENCES

† Now at Electromagnetic Applications, Inc., Denver, Colorado.

‡ Now at Yale University, New Haven, Connecticut.

1. I.I. Bigi and M. Fukugita, Phys. Lett. *91B*, 121 (1980); S.P. Rosen, Phys. Rev. Lett. *44*, 4 (1980); M. Bander, D. Silverman, and A. Soni, Phys. Rev. Lett. *44*, 7 (1980); H. Fritzsch and P. Minkowski, Phys. Lett. *90B*, 455 (1980); M. Bauer and B. Stech, Phys. Lett. *152B*, 380 (1985); A.N. Kamal, SLAC-PUB-3443 (unpublished); L.L. Chau, Phys. Rep. *95*, 1 (1983); J.F. Donoghue, Phys. Rev. *D33*, 1516 (1986); and M.A. Shifman and M.B. Voloshin, Institute of Theoretical and Experimental Physics report ITEP-86-83 (unpublished). For early work see M.K. Gaillard, B.W. Lee, and J. Rosner, Rev. Mod. Phys. *47*, 277 (1975); M.B. Einhorn and C. Quigg, Phys. Rev. *D12*, 2015 (1975); R.L. Kingsley, S.B. Treiman, F. Wilczek and A. Zee, Phys. Rev. *D11*, 1919 (1975); and G. Altarelli, N. Cabibbo, and L. Maiani, Nucl. Phys. *B88*, 285 (1975).
2. See, for example, K. Sliwa, *et al.*, Phys. Rev. *D32*, 1053 (1985) and references therein.
3. P. Karchin, *et al.*, IEEE Trans. on Nucl. Sci. *NS-32*, 612 (1985).
4. Review of Particle Properties, Particle Data Group, Phys. Lett. *170B*, 1 (1986), and references therein.
5. R.M. Baltrusaitis, *et al.*, Phys. Rev. Lett. *54*, 1976 (1985).