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OBSERVATION OF A FULLY RECONSTRUCTED $D^0\bar{D}^0$ PAIR WITH LONG LIFETIMES IN A HIGH RESOLUTION HYDROGEN BUBBLE CHAMBER AND THE EUROPEAN HYBRID SPECTROMETER

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ABSTRACT

In an experiment with a 360 GeV/c π^- beam at the CERN SPS using the high resolution hydrogen bubble chamber LEBC and the European Hybrid Spectrometer, an event has been observed of the type $\pi^- p \to \bar{D}^0 D^0 + 8$ prongs. The fully reconstructed decay modes are $D^0 \to K^-\pi^+\pi^0\pi^0$ and $\bar{D}^0 \to K^+\pi^+\pi^-\pi^-$, with all six charged tracks being detected in the spectrometer and all four photons from the π^0 decays detected in the lead glass gamma detection system. The D^0 has momentum 119.0 ± 0.6 GeV/c, $x_F = 0.31$, length 4.1 ± 0.1 mm and proper lifetime $2.1 \pm 0.1 \times 10^{-13}$s. The $\bar{D}^0$ has momentum 78.5 ± 0.3 GeV/c, $x_F = 0.19$, length 7.5 ± 0.1 mm and proper lifetime $5.9 \pm 0.1 \times 10^{-13}$s.

Direct measurements of the D^0 lifetime using the emulsion technique with ν beam [1,2] or γ beam [3] indicate a value $\lesssim 1 \times 10^{-13}$ s. We report here the observation of an exceptionally clean, fully reconstructed, unambiguous hadronic event containing a $D^0\bar{D}^0$ pair. If one accepts the value of the D^0 lifetime quoted above, then both D^0 and $\bar{D}^0$ in this event are rather long-lived.

The small rapid cycling liquid hydrogen LExan Bubble Chamber LEBC was specially designed and built for the study of short-lifetime particle properties [4]. In a prototype experiment at the CERN SPS, the hadronic production of charm was detected via a topological signal [5]. In order to more fully investigate the production and decay properties of charm particles, LEBC was coupled with the European Hybrid Spectrometer (EHS) [6,7,8] and during several SPS periods immediately prior to the SPS shutdown of June 1980, LEBC was exposed to beams of 360 GeV/c π^- and 360 GeV/c protons. Approximately 1.3 million pictures were taken (equally divided into pion and proton data) with the bubble chamber flash tubes fired by the interaction trigger described elsewhere [5]. This consists of scintillators upstream and downstream of LEBC which detect the incoming beam particle, veto upstream interactions and identify interactions in LEBC by detecting an outgoing multiplicity $\gtrsim 2$.

LEBC was equipped with two stereo views, both giving spatial resolution $\sim 40\mu$m. The beam included a kicker magnet to avoid background in the pictures coming from early tracks. The spectrometer, a preliminary version of EHS, consists of a charged particle momentum analysis stage [6], γ detection using the lead glass walls [8] and a single module of the pictorial drift chamber ISIS (referred to as ISIS1) giving ionization data for charged particle identification [7].

The triggered pictures are being double scanned and all multi-vertex events checked by a physicist. Fig. 1(a) shows a typical picture (containing an atypical event - the event described below).

In order to set up and test the analysis program chain [9] and to provide data for checking and calibration purposes, a small sample of multi-vertex events has been measured using the CERN ERASME system [10]. From this sample, 71 V^0 decays have been identified as either K^0, Λ

or $\bar{\Lambda}$. The percentage of V^0 decays with one or more tracks hybridized(*) is in agreement with that predicted by a Monte-Carlo calculation assuming 100% hybridization efficiency. The $\pi\pi$ mass distribution for the identified K^0 events is shown in fig. 2(a) and the $p\pi^+$ (and $\bar{p}\pi^+$) mass distribution for the identified Λ (and $\bar{\Lambda}$) in fig. 2(b). The K^0 and Λ ($\bar{\Lambda}$) masses are found to be 498.0 ± 1.0 MeV/c^2 and 1116.5 ± 1.5 MeV/c^2, respectively. For K^0 and $\Lambda(\bar{\Lambda})$ decays having both tracks hybridized the full widths at half maximum (FWHM) are 6 MeV/c^2 and 4 MeV/c^2, respectively. For decays in which only one track is accepted by the spectrometer for hybridization (the shaded events in fig. 2), the momentum of the second track is found by balancing the transverse momentum about the direction of the V^0. In this case the resolution deteriorates to 10 MeV/c^2 and 8 MeV/c^2. These values of the measured resolution are consistent with the EHS design measurement precision of $\Delta p/p \sim 1\%$ [6]. The γ detection system resolution is also in good agreement with design values [8]. The two photon mass distribution accumulated throughout the experiment shows a clear π^0 signal with FWHM $\sim$ 20 MeV [11].

The event of interest is shown in fig. 1(a). It was selected for the detailed analysis described here because the topological information alone makes it a highly probable charm candidate. It has been measured on three independent measuring devices and all measurements give compatible results. Fig. 1(b) shows a diagram of the event based on the ERASME digitizations. The event is a 360 GeV/c π^-p interaction giving 8 charged tracks and two neutral particles which materialise as 2-prong decay (V2) and 4-prong decay (V4), respectively. Of the six decay tracks, 5 are successfully matched between bubble chamber and spectrometer, the sixth being connected to a spectrometer track with the assumption of a small angle scatter (7.2 ± 0.6 mr) in the bubble chamber exit window which leaves the momentum of the track unchanged, within the error. There are no ambiguities in associating the tracks reconstructed in the spectrometer with those observed in the bubble chamber. Three of the tracks from the

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(*) When a track is successfully reconstructed using information from the bubble chamber and from the spectrometer it is said to be hybridized.

production vertex are also successfully hybridized. The momenta and space angles of all these tracks are summarized in table 1.

Four of the six charged decay particles (those labelled A,C,D and E in table 1) reach one of the γ detectors. Their energy release is significantly smaller than the momentum measured in the spectrometer, indicating that none of them are electrons. In addition, the γ detectors identify six showers which are also given in table 1. These can be associated to give three clear π^0's with reconstructed masses of 130 ± 9 MeV/c^2, 134 ± 11 MeV/c^2 and 140 ± 20 MeV/c^2(*). The momenta and angles of these are also given in table 1. No other $\gamma\gamma$ combination has a recognizable meson mass.

The ISIS1 particle identification information for this event is indicated in Table 1. For each track a maximum likelihood fit was performed to the ionisation distribution [12]. The results were then compared with the expected ionisations and computed as a number of standard deviations for each mass hypothesis. Fig. 1(c) shows the pictorial information from ISIS1 for this event. The labels correspond to those given in table 1. The track information is excellent. All tracks seen in this figure are clearly identified in the spectrometer, without ambiguity. The module used in this experiment is a prototype version of the full ISIS [7]. It has $\lesssim$ 60 active sense wires as compared with the 320 wires of the final chamber. The ionisation resolution is thus limited by sampling statistics and should be taken as corroborating evidence for mass assignments derived from kinematic hypotheses rather than definitive identification. This is reflected in the data of table 1.

If the 92.5 GeV/c negative particle from the V2 is a K^-, the 18.0 GeV/c positive particle is a π^+ and the 5.3 GeV/c π^0 and 3.2 GeV π^0 are associated with the decay, then the combination $K^-\pi^+\pi^0\pi^0$ gives a mass of 1.857 ± 0.022 GeV/c^2 in good agreement with the D^0 mass. Furthermore,

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(*) This π^0 is composed of 75 and 50 GeV photons. The position of the 75 GeV shower is uncertain because of the late development of the electromagnetic cascade in the lead glass converter. This uncertainty is then reflected in the large error.

the vector sum of outgoing momenta points, well within errors, at the production vertex. The ISIS1 data is consistent with this solution. The decay length and momentum of the D^0 are 4.1 ± 0.1 mm and 119.0 ± 0.6 GeV/c, respectively.

If the 16.1 GeV/c positive particle from the V4 is a K^+ and the other three particles are pions, the combination $K^+\pi^+\pi^-\pi^-$ gives a mass of 1.862 ± 0.009 GeV/c^2, also in excellent agreement with the D^0 mass. Again the vector sum of the four charged particles points at the production vertex and the ISIS1 data is consistent with their assigned mass. The decay length and momentum of the $\bar{D}^0$ are 7.5 ± 0.1 mm and 78.5 ± 0.3 GeV/c, respectively.

No other combinations (i.e. assuming different mass assignments and with and without associated π^0's) give any recognizable strange or charm masses. Table 1 gives the momenta and angles of all measured particles in the event.

The production characteristics are as follows: for the D^0, $x_F = 0.31$ and $p_T = 0.64$ GeV/c; for the $\bar{D}^0$, $x_F = 0.19$ and $p_T = 0.63$ GeV/c. Neither D^0 nor $\bar{D}^0$ can be associated with any reconstructed production π to make a D^* mass. It is noteworthy that 90% of the available energy of the event is contained in the three particles $D^0, \bar{D}^0, \pi^0$. The effective mass of this $D^0\bar{D}^0\pi^0$ system is 5.11 GeV/c^2 and the 3 two-body masses are $M(\bar{D}^0D^0) = 3.96$ GeV/c^2, $M(D^0\pi^0) = 2.86$ GeV/c^2, $M(\bar{D}^0\pi^0) = 3.04$ GeV/c^2.

We conclude that the event contains the decays $D^0 \rightarrow K^-\pi^+\pi^0\pi^0$ and $\bar{D}^0 \rightarrow K^+\pi^+\pi^-\pi^-$ with lifetimes of $(2.1 \pm 0.1) \times 10^{-13}$s and $(5.9 \pm 0.1) \times 10^{-13}$s, respectively. Previous direct measurements of the D^0 mean lifetime give $0.53 ^{+0.57}_{-0.25} \times 10^{-13}$s [1], $1.01 ^{+0.43}_{-0.27} \times 10^{-13}$s [2] and $0.58 ^{+0.8}_{-0.2} \times 10^{-13}$s [3]. The emulsion technique used in [1,2,3] is quite different from the present technique and scanning biasses and event losses are not the same. In particular, our detection efficiency for particle lifetimes $\lesssim 10^{-13}$ s is small [5]. Nevertheless, the present event is hardly consistent with the previous lifetime measurements and suggests that a longer mean lifetime applies for the D^0.

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TABLE 1

Summary of all reconstructed particle parameters, ISIS1 ionization data exposed as a number of standard deviations (σ) for each mass hypothesis and D^0, $\bar{D}^0$ parameters (see text). All angles are given with respect to the incident beam direction and transverse momenta, p_T, with respect to the appropriate incident particle. The π^0 quantities are the result of kinematic fits.

Track Label	Particle	p (GeV/c)	p_T (GeV/c)	λ (mr)	φ (mr)	ISIS1 particle identification < 2σ	2-3σ	3-4σ	> 4σ	Comment
A	K^-	92.5 ± 0.5	0.297 ± 0.015	- 3.1 ± 0.1	7.0 ± 0.1	e,π,K,p	-	-	-	
B	π^+	18.0 ± 0.2	0.113 ± 0.006	- 9.2 ± 0.3	0.6 ± 0.1	e,π	-	-	K,p	$D^0 \to K^-\pi^+\pi^0\pi^0$ $m = 1.857 \pm 0.022$ GeV/c² $p = 119.0 \pm 0.6$ GeV/c $p_T = 0.643 \pm 0.017$ $x_F = 0.31$ $\ell = 4.1 \pm 0.1$ mm $\tau = (2.1 \pm 0.1) \times 10^{-13}$ s
	γ	4.75 ± 0.12	0.040 ± 0.002	6.9 ± 0.3	- 7.5 ± 0.2	-	-	-	-	
	γ	0.48 ± 0.06	0.037 ± 0.005	73.7 ± 1.5	47.3 ± 2.0	-	-	-	-	
	π^0	5.28 ± 0.11	0.096 ± 0.004	13.4 ± 0.4	- 2.2 ± 0.3	-	-	-	-	
	γ	2.89 ± 0.15	0.042 ± 0.004	- 19.5 ± 1.0	- 71.2 ± 1.0	-	-	-		
	γ	0.34 ± 0.05	0.041 ± 0.006	- 25.3 ± 2.0	63.7 ± 1.5	-	-	-	-	
	π^0	3.23 ± 0.13	0.203 ± 0.010	- 20.1 ± 0.3	- 56.8 ± 1.6	-	-	-	-	
C	K^+	16.1 ± 0.2	0.387 ± 0.007	22.5 ± 0.3	- 15.6 ± 0.1	e,π,K	p	-	-	$\bar{D}^0 \to K^+\pi^+\pi^+\pi^-\pi^-$ $m = 1.862 \pm 0.009$ GeV/c² $p = 78.5 \pm 0.3$ GeV/c $p_T = 0.633 \pm 0.009$ $x_F = 0.19$ $\ell = 7.5 \pm 0.1$ mm $\tau = (5.9 \pm 0.1) \times 10^{-13}$ s
D	π^+	7.6 ± 0.1	0.206 ± 0.004	23.2 ± 0.4	- 18.9 ± 0.2	π	e,K	p	-	
E	π^-	35.7 ± 0.1	0.193 ± 0.008	5.6 ± 0.2	8.2 ± 0.1	π	K	p	-	
F	π^-	19.2 ± 0.3	0.412 ± 0.010	- 8.1 ± 0.5	18.1 ± 0.1	e,π,K	p	-	-	
G	$\pi^+/K^+/p$	12.9 ± 0.1	0.400 ± 0.004	2.9 ± 0.3	- 31.7 ± 0.2	π,K,p	-	e	-	Hybridized tracks from production vertex
H	π^-	6.4 ± 0.1	0.256 ± 0.004	- 24.5 ± 0.5	31.4 ± 0.3	π	e	K	p	
I	π^-	6.4 ± 0.1	0.333 ± 0.004	47.6 ± 0.5	- 21.4 ± 0.3	π	e	K	p	
	γ	75.0 ± 3.0	0.070 ± 0.041	4.2 ± 0.5	5.0 ± 0.2	-	-	-	-	
	γ	50.5 ± 3.0	0.068 ± 0.015	4.1 ± 0.2	7.3 ± 0.2	-	-	-	-	
	π^0	125.2 ± 4.1	0.907 ± 0.049	4.2 ± 0.3	5.9 ± 0.1	-	-	-	-	

FIGURE CAPTIONS

Fig. 1 The event discussed in the text. The track labels are common to fig. 1(a), (b) and (c) and to table 1.

(a) LEBC photograph of the event.

(b) Sketch of the event based on the measuring machine digitizations. It should be noted that the transverse scale is greatly magnified relative to that of fig. 1(a).

(c) The ISIS1 pictorial information for the event. The vertical axis is drift time and the horizontal axis gives the sense wire number.

Fig. 2 (a) $\pi\pi$ effective mass distribution for the V^0 sample described in the text. The shaded region shows events for which only one of the two decay tracks has been successfully reconstructed (see text).

(b) $p\pi^-$ and $\bar{p}\,\pi^+$ effective mass distribution for the V^0 sample described in the text. The shaded region shows events for which only one of the two decay tracks has been successfully reconstructed (see text).

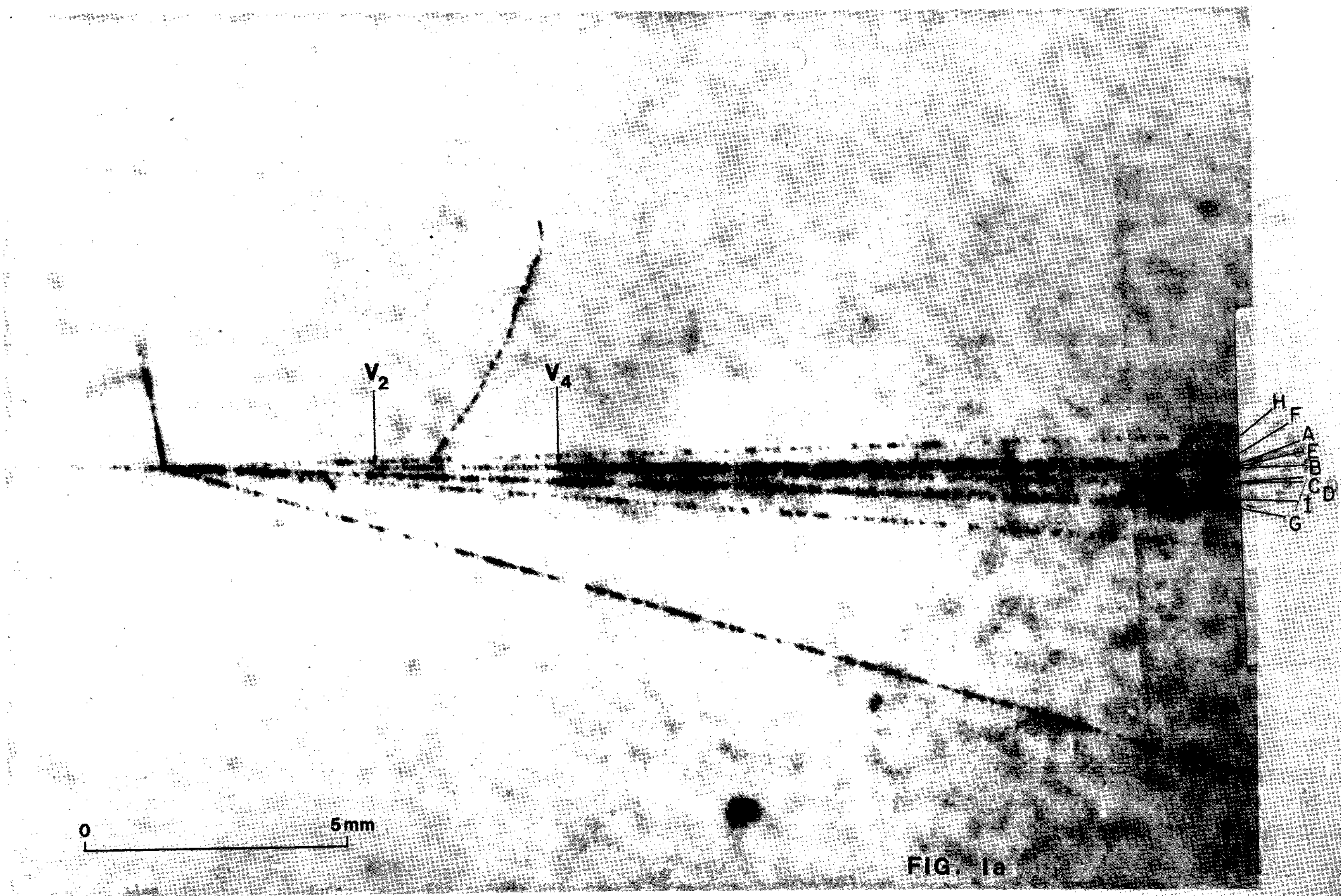


FIG. 1a

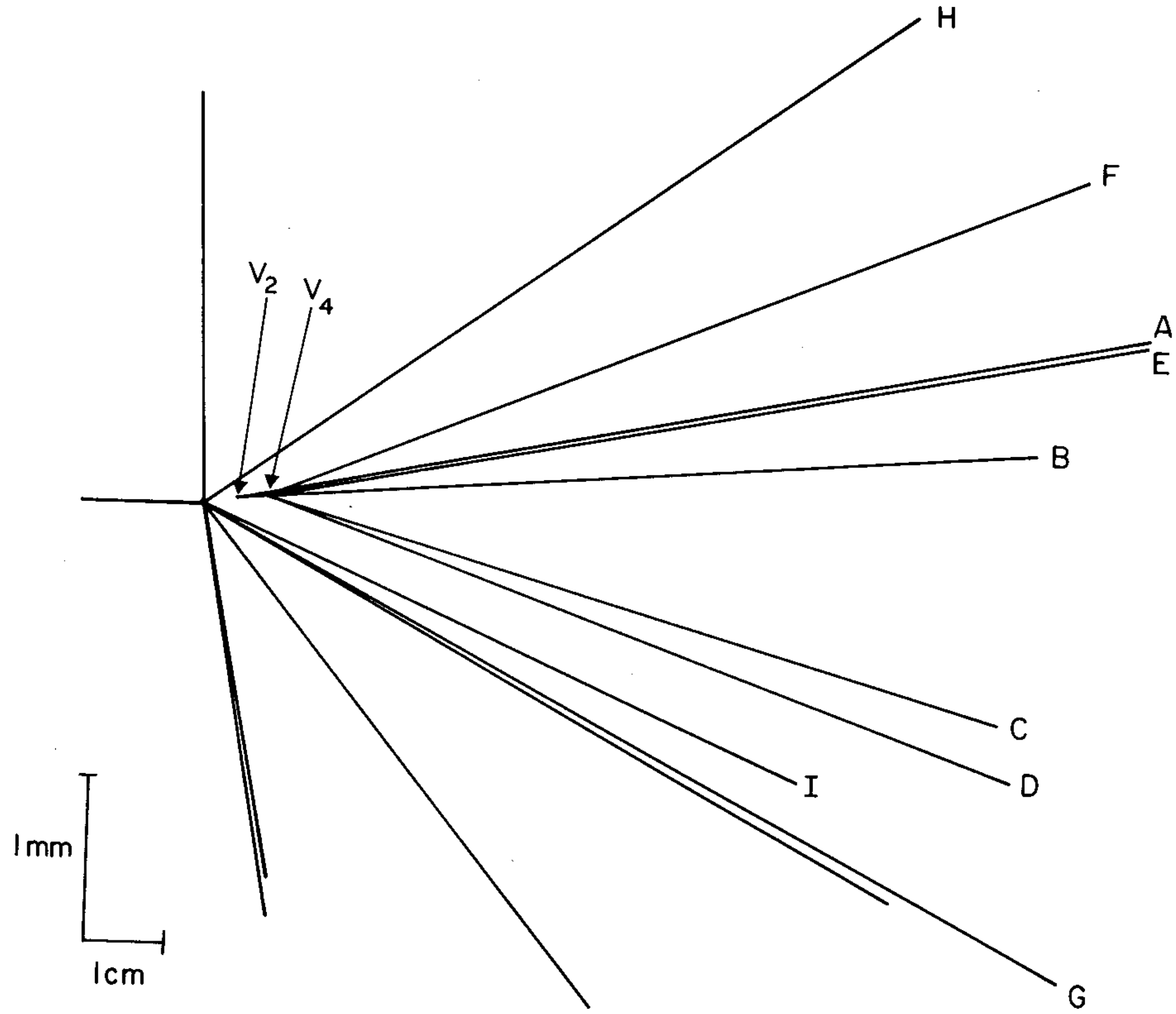


FIG. 1b

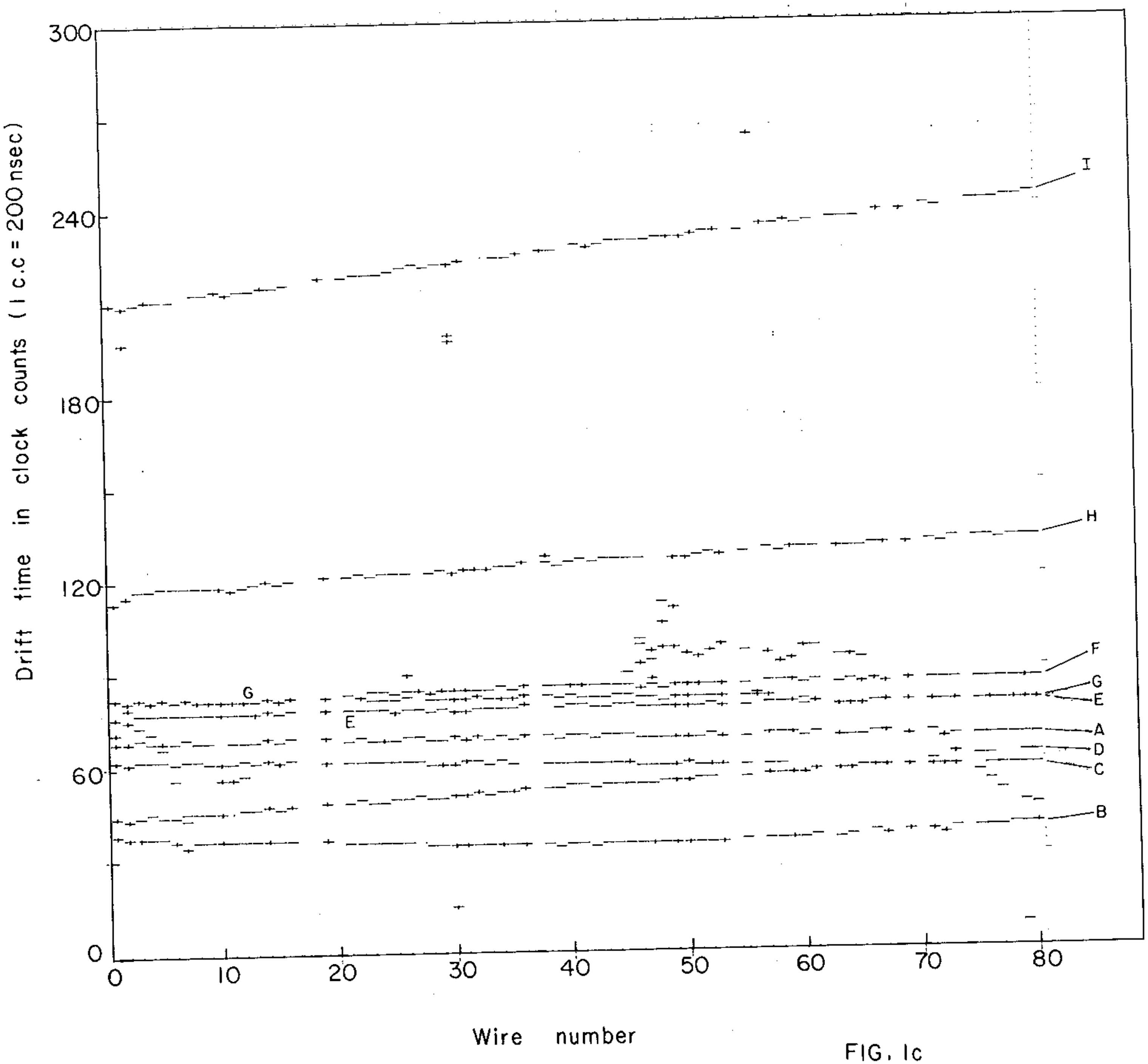
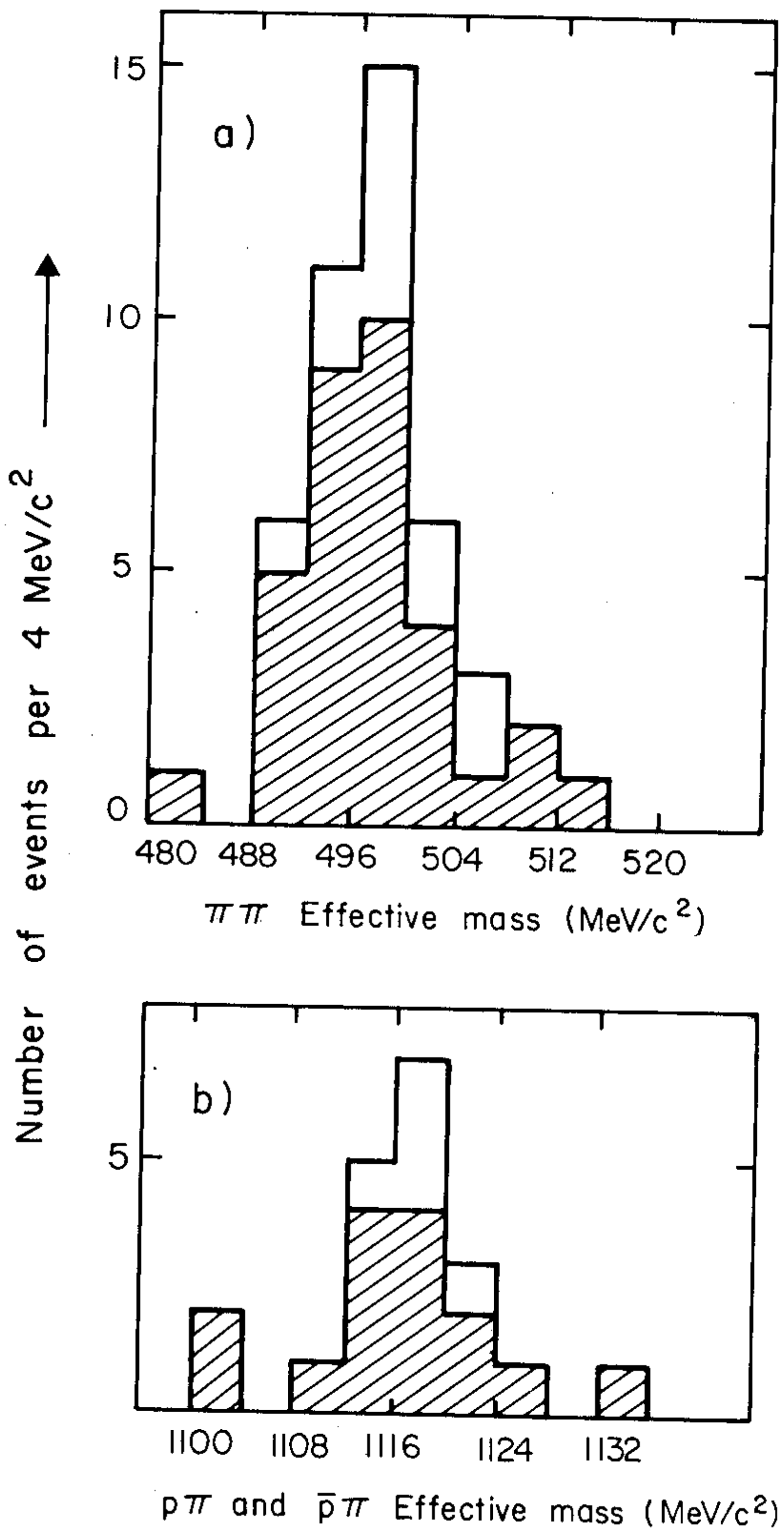

Drift time in clock counts (1 c.c = 200 nsec)
Wire number
0
60
120
180
240
300
0
10
20
30
40
50
60
70
80
I
H
F
G
E
A
D
C
B
G
E

FIG. 1c



Number of events per 4 MeV/c²
a)
15
10
5
0
480 488 496 504 512 520
ππ Effective mass (MeV/c²)
b)
5
1100 1108 1116 1124 1132
pπ and p̄π Effective mass (MeV/c²)

FIG. 2