Title

PION MASS MEASUREMENTS USING NEUTRON TIME-OF-FLIGHT TECHNIQUES

Permalink

Authors

Haddock, Roy P.
Abashian, Alexander
Crowe, M.
et al.

Publication Date

1959-10-22

UCRL-8953

UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence Radiation Laboratory

BERKELEY, CALIFORNIA

PION MASS MEASUREMENTS USING NEUTRON TIME-OF-FLIGHT TECHNIQUES*

Roy P. Haddock, Alexander Abashian, Kenneth M. Crowe, and John B. Czirr

Lawrence Radiation Laboratory
University of California
Berkeley, California

October 22, 1959

Measurements of the speeds of neutrons emitted in the capture at rest of π^- mesons in hydrogen provide an excellent method for the determination of mass values for the π^- and π^0 mesons. Using energy balance of the reactions

$$\begin{array}{lr} \pi^- + p \rightarrow \gamma + n \text{ (8.8 Mev)} & (1) \\ \qquad\quad \searrow \pi^0 + n \text{ (400 kev)}\,, & (2) \end{array}$$

we can deduce the mass of the π^- through Reaction (1) and the π^-, π^0 mass difference through Reaction (2). Results obtained by using time-of-flight techniques to measure the neutrons' speeds have already been reported by Gettner et al.[1] and Hillman et al.[2] for flight paths of 2 to 5 ft. This letter reports preliminary results of our measurements for flight paths of 12.44 ft and 17.50 ft with similar techniques.

Figure 1 is a simplified schematic diagram of the experimental setup and electronics. The 110-Mev pions produced by an internal target of the 184-in. cyclotron were collimated into a 2-in.-high by 8-in.-wide beam; slowed down in carbon; counted by a 1-in.-thick plastic scintillator

---

*Work performed under the auspices of the U. S. Atomic Energy Commission.

(π counter); 1.5-in. high by 8-in. long; and stopped in a liquid hydrogen target. The hydrogen flask was a horizontal cylinder 1-in. high and 12-in. in diameter. Neutrons, which travel downward, were detected in a plastic scintillator 18-in. in diameter, 1-in. thick, viewed by seven RCA 7046 photomultipliers, through a 1-in. Lucite light pipe. Photons, from Reaction (1) and π^0 decay, which go upward, convert in a 1/4-in.-thick Pb sheet, 20-in. in diameter, 10-in. from the center of the target, and are detected by a coincidence between two plastic scintillators, each 3/8-in. thick (γ counters).

The electronics (see Fig. 1) is composed of two fast coincidences followed by a slow coincidence. One coincidence is between the π and γ counters and another is between the dynode signals of two sets of tubes of the neutron counter — the latter coincidence mode to reduce noise accidentals. Finally a $\pi - \gamma - n$ slow coincidence is made with 200-mμsec resolving time which triggers a 517A Tektronix scope with a 20-mμsec/cm sweep speed. The anode signals of the neutron counter tubes are combined in a distributed adding circuit and, together with a $\pi - \gamma$ coincidence signal, are displayed on the scope sweep, of which photographs are taken. Alternate runs were made with the variable delay set for $\pi - \gamma - \gamma$ and $\pi - \gamma - n$ coincidences.

We used styrofoam delay lines for most of the inserted delay. RG-63/U delay lines were used for fine adjustment. For such long cables one must know not only the transit time of the cable but the effect of dispersion as well. A cable measuring system is used which minimizes systematic errors due to dispersion. The output of a signal generator drives a pulse shaper which puts out two pulses with the same rise time as the phototubes. The shaped pulses are fed into the vertical plates of a 5-mμsec/cm two-beam scope, one signal coming in direct and the other via the unknown cable. A third pulse derived from the pulse shaper goes to the scope trigger. The frequency of the oscillator is adjusted so that the half heights of the succeeding pulses coincide. When this happens the period of the oscillator is the same as the length of the cables, i.e., $L/v = 1/f$. The frequency is measured by a Hewlett-Packard 524B frequency meter. In practice we measure the length of the unknown plus a fixed cable, then remove the unknown and measure the fixed cable. The difference between the oscillator period for the two measurements is the delay through the unknown. Dispersion effects are eliminated if the output pulse of the fixed cable is identical to a phototube pulse.

To analyze the time-of-flight data, we measured the distance between half heights of the two photographed pulses along with the amplitude of the signal from the neutron counter. We plotted the pulse-height spectrum of the background and compared it with that in the region of the neutron peak. We chose a pulse-height interval with the best signal-to-noise ratio, and measured the time distribution of the pulse in this interval for both the neutrons and the γ rays. The mean of the γ-ray distribution was used as our time reference point, and corresponds to the calculated photon flight time. The neutron flight time was taken to be: the photon flight time + the inserted delay + the difference between the mean of the neutron and γ-ray peaks. A composite plot of our measurements is shown in Fig. 2.

Table I lists the results of this experiment. The errors shown are over-all errors and are largely statistical.

Table I

Mass determinations from time of flight

Run	Flight path (ft)	Time (mμsec)	$\pi^- - \pi^0$ Mass (m_e)	π^- mass (m_e)
1	17.50±0.01	130.79±0.45		272.4±1.1
2	12.44±0.01	434.34±0.79	8.984±0.026	
3	17.50±0.01	596.0±1.1	8.998±0.024	
2-3	5.055±0.01	171.7±1.4	9.05±0.09	

The values quoted here agree favorably with recent accurate determinations by other means and by other groups. The currently recommended value of the π^- mass is $273.27 \pm 0.11\ m_e$.[3] Values for the π^-, π^0 mass difference have recently been reported as $8.8^{+0.4}_{-0.3}\ m_e$,[4] 8.90 ± 0.14,[5] and 9.01 ± 0.08.[2]

The method of computing the neutron's speed from measurement at two distances is inherently more accurate in that some systematic errors are eliminated. Scattering of the neutrons may shift the mean of the neutron distribution to longer times and also widen it. If the scattering is in the counter and not in the target, it will have little effect upon the value for the mass difference obtained from the difference measurement at two lengths. We have computed the scattering in the hydrogen target and found it to be negligible at these distances.

The standard deviation of the γ-ray peak is 3.5 mμsec; it is 4 to 6 mμsec for the fast neutron and 7 mμsec for the slow neutron. The size of the neutron widths is not completely understood at present and this uncertainty does not allow us to infer a meaningful limit for the π^0 lifetime.

The background in our neutron counter is currently limiting us in our ability to obtain more accurate measurements with longer flight paths. It appears to be due to three causes: radiation from the target, which decreases with solid angle and beam level; tube noise, which is constant but relatively small; and an effect that is of about constant value with depth. We are in the process of reducing the latter to allow us to increase the flight path by an appreciable factor.

We gratefully acknowledge the efforts of the many individuals who have assisted us in this experiment.

REFERENCES

1. Gettner, Holloway, Kraus, Lande, Leboy, and Selove, Phys. Rev. Letters 2, 471 (1959).
2. P. Hillman, W. C. Middlekoop, T. Yamagata, and E. Zavattini, submitted for publication in Nuovo cimento. We wish to thank the authors for permission to quote their result.
3. Cohen, Crowe, and Dumond, Fundamental Constants of Physics (Interscience Publishers, New York, 1957), p. 58.
4. Kuehner, Merrison, and Tornabene, Proc. Phys. Soc. (London) (to be published).
5. Cassels, Jones, Murphy, and O'Neill, Proc. Phys. Soc. (London) 74, 92 (1959).

FIGURE LEGENDS

I. Experimental arrangement.

II. Histograms of combined data. (a) γ ray at 17.50 ft; (b) 8.8-Mev neutrons at 17.50 ft; (c) 400-kev neutrons at 12.44 ft; (d) 400-kev neutrons at 17.50 ft.

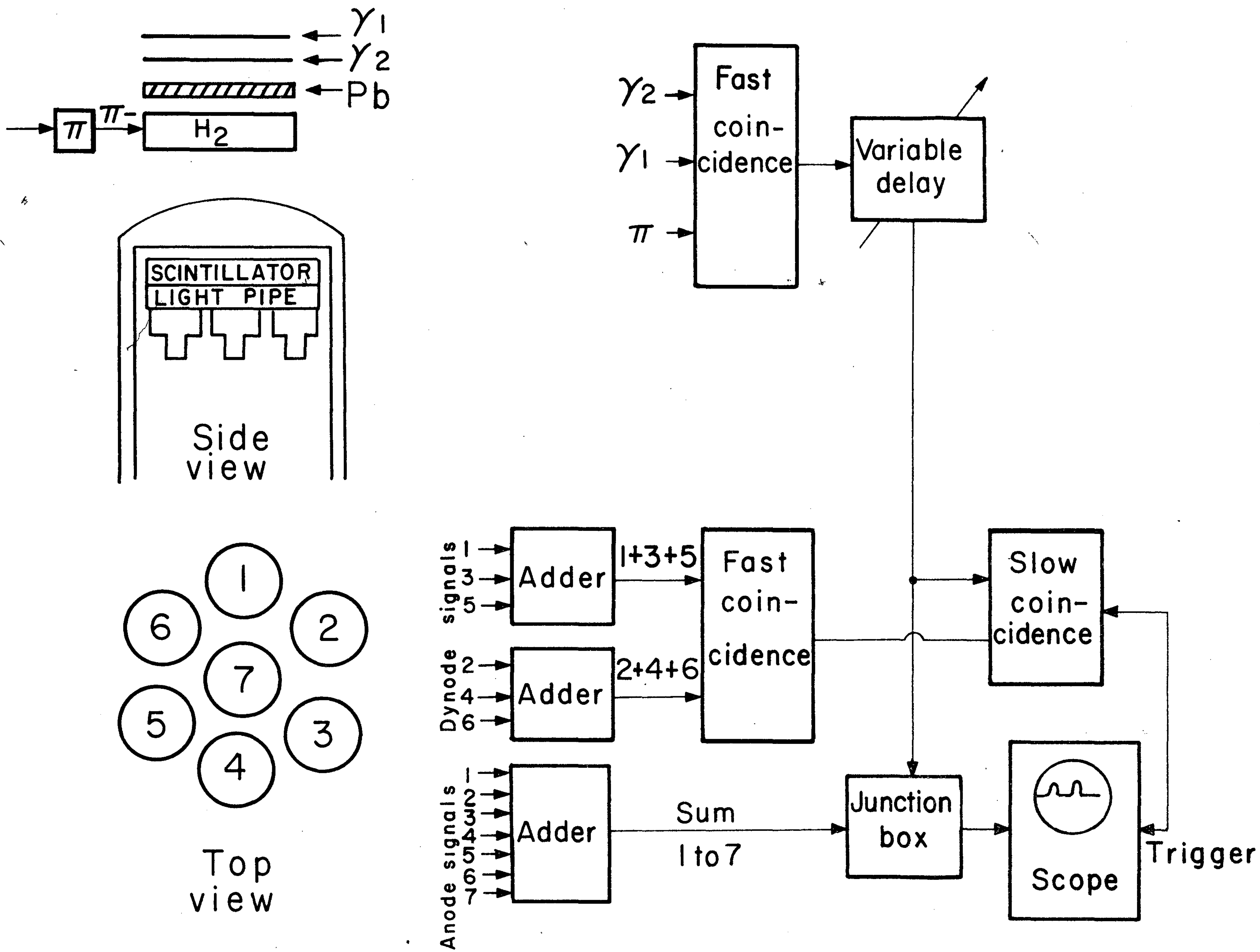
γ1
γ2
Pb
π
π-
H2
SCINTILLATOR
LIGHT PIPE
Side view
1
2
3
4
5
6
7
Top view
γ2
γ1
π
Fast coin-cidence
Variable delay
Dynode signals
1
3
5
2
4
6
Adder
Adder
1+3+5
2+4+6
Fast coin-cidence
Slow coin-cidence
Anode signals
1
2
3
4
5
6
7
Adder
Sum 1 to 7
Junction box
Scope
Trigger

Fig 1

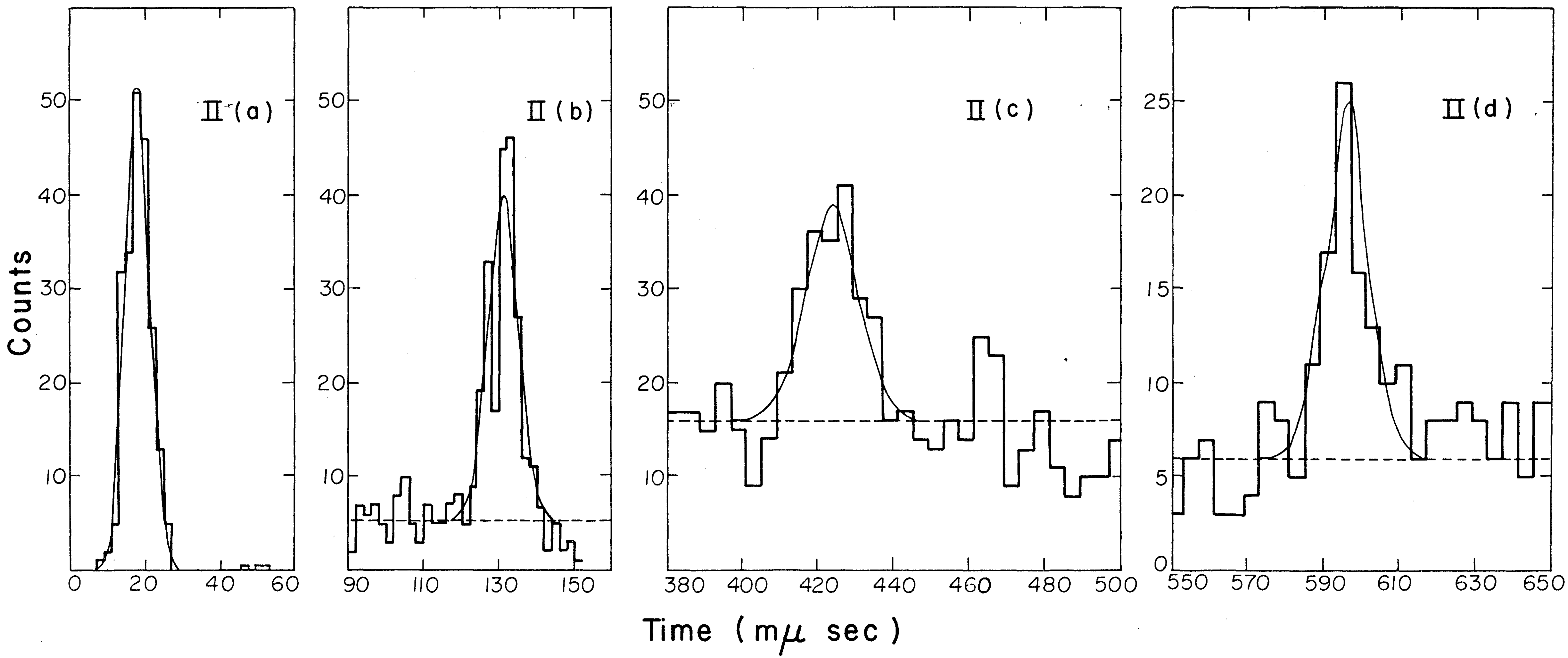
Counts
II (a)
II (b)
II (c)
II (d)
50
40
30
20
10
25
15
5
0
0 20 40 60
90 110 130 150
380 400 420 440 460 480 500
550 570 590 610 630 650
Time (mμ sec)

Fig 2