Title

TIME RESOLUTION OF A SCINTILLATION COUNTER SYSTEM

Authors

Bjerke, Arthur E.
Kerns, Quentin A.
Nunamaker, Thomas A.

Publication Date

1962-02-23

UCRL-9976

University of California

Ernest O. Lawrence Radiation Laboratory

Berkeley, California

Proceedings of 8th Scintillation Conductor Counter
Symposium (IRE) Wash. D. C. March 1962

UCRL-9976
Limited Distribution

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

TIME RESOLUTION OF A SCINTILLATION COUNTER SYSTEM

Arthur E. Bjerke, Quentin A. Kerns, and Thomas A. Nunamaker

February 23, 1962

TIME RESOLUTION OF A SCINTILLATION COUNTER SYSTEM*

Arthur E. Bjerke, Quentin A. Kerns, and Thomas A. Nunamaker

Lawrence Radiation Laboratory
University of California
Berkeley, California

Summary

Time resolution of a scintillation counter system composed of scintillator, light pipe, multiplier phototube, discriminator, and coincidence circuit is discussed. The discriminator and coincidence circuits can produce coincidence curves with edges as steep as 10 psec per decade. Multiplier phototubes are capable of similar resolution, providing they view sufficiently bright, well-defined light flashes.

In a time-of-flight measurement at the Berkeley 184-inch Cyclotron, the coincidence curve slope, measured from a counting rate of 50% to 5%, is 400 psec per decade. The light level corresponds to 2000 electrons reaching the first dynode of the multiplier phototube. A slope of 200 psec per decade would be expected if only the multiplier phototube and electronics were considered. Geometry and rate of light output of the scintillator are believed to limit system resolution at present.

Introduction

The problem of extracting the best possible timing information from nuclear scintillations becomes more acute as better time resolution in nuclear experiments is sought. A previous paper by the authors dealt with the use of tunnel diodes in standardizing multiplier phototube signals for optimum timing information. [1] The present work is concerned with a scintillation counter system used in a time-of-flight measurement. The approach was to make the time resolution of the electronics better than that expected of the scintillator, light pipe, and multiplier phototube. As these latter components of the system were added, the degradation of time resolution owing to the added statistics of each component could be measured. These statistics known, one can then predict the best possible time resolution of other similar systems.

Electronics Description

A straightforward discriminator is used, in which a zero-crossing multiplier phototube pulse fires a tunnel diode that produces a sharp, standardized output at the point of zero crossing; this is all done in the base of the multiplier phototube. The coincidence circuit takes these standardized pulses after transmission through a cable from the multiplier phototube, and restandardizes them. The restandardized pulses are then summed in a tunnel diode regenerator to produce the coincidence output.

Referring to Fig. 1, multiplier phototube signal current flows through the two series windings of a transformer. Two windings are used here to allow a favorable placement of AC ground between anode and D_{10}, as determined by capacity measurements on the tube. The shunt inductance of the transformer, plus the capacity between anode and D_{10}, form an 80-Mc tuned circuit which is overdamped to produce a "zero-crossing" pulse. A portion of the inverted "zero-crossing" signal is tapped off from the transformer output winding to provide a monitor signal proportional to multiplier phototube signal current. Signal current flows through the 27 Ω resistor that provides additional damping in this winding, and into the 1N3130 (50-ma peak current) tunnel diode. As the signal reaches a point slightly past zero the tunnel diode regenerates. The regenerator pulse rises in 150 psecs and is about 3 nsecs wide. The pulse leading edge is differentiated with a 200-psec time constant into a 50 Ω coaxial line. The tunnel diode and differentiating capacitor are built into a coaxial housing (Fig. 2) to preserve the pulse shape. The fast differentiation serves two purposes; (a) it minimizes feed-through of the original, relatively slow zero-crossing signal, and (b) since the pulse has a half width of 300 psec it is well suited for producing narrow coincidence curves.

The circuits described above are built into the multiplier phototube base housing (see Fig. 3). The fast signal is carried to a remote counting area by a high-quality coaxial line.

The signal now enters a restandardizing circuit (Fig. 4) comprising a grounded-base transistor, another coaxially-mounted tunnel diode regenerator and a grounded-emitter monitor.stage. Some distortion of the fast pulse is caused by the grounded-base transistor stage, which has a rise time of about 0.4 nsec. However, isolation between the tunnel diode regenerator stages is essential for stable operation of the system. The output of this circuit is identical to that of the first. A short length of 50 Ω coaxial cable carries the signal to the coincidence circuit, which is composed of another transistor isolation stage and tunnel diode regenerator. Bias on this regenerator adjusts the width of the coincidence curves.

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

Performance of the Electronics

Figure 5 shows two two-channel coincidence curves made by feeding artificial pulses into the "zero-crossing" signal monitor cable. The difference in width of the curves illustrates the effect of the coincidence tunnel diode bias adjustment.

If wider curves are desired, one may increase the pulse width by using a larger differentiating capacitor. In practice, when one is separating particles, this width is made sufficient to give a fairly high efficiency for the particles of interest. However, in studying the statistics, the width is observed to be only of secondary importance because the slope of the coincidence curve fully determines the statistics and is independent of the width, while the full width at half max is a measure of both the statistics and the width of the coincidence system.

The measured slope of the curves is essentially constant once the "shoulder" is passed and is about 10 psec per decade for both curves. Time shift with temperature is less than 3 psec per °C over a range of -10 to +50 °C. Time shift with power supply changes is less than 50 psec per 1% supply-voltage change. Power supplies regulated to 0.01% are used. Figure 6 shows timing shifts of tunnel diode output pulse as a function of multiplier phototube amplitude changes.

Effects of Multiplier Phototube Statistics

The effect of multiplier phototube statistics on time resolution is shown in Fig. 7. An edge of a two-channel coincidence curve is shown for each of four different light levels corresponding respectively to 10^2, 10^3, 10^4, and 10^5 electrons reaching the first dynode of the multiplier phototube. These curves were made using the previously described electronics with the addition in one channel of a 6342A 10-stage multiplier phototube illuminated by a UCLRL Mercury light-pulse generator.[2] The signal for the second coincidence channel was derived from the light pulser trigger. The light pulse and trigger pulse are generated simultaneously in the light-pulse generator, the light pulse having a full width at half maximum of less than 1.5 nsec.

The slopes (Fig. 7), after the initial shoulder, are 340, 120, 52 and 24 psecs per decade respectively for 10^2, 10^3, 10^4, and 10^5 photoelectrons reaching D_1. Previous work on the measurement of time spread of photomultiplier pulses for single electrons arriving at D_1 light levels has been done at this laboratory.[3] This work indicates the pulses have a distribution in time which if approximated by a Gaussian gives a standard deviation in the range 0.4 to 1.0 nsec for the faster tubes.

Our data for a single multiplier phototube plus coincidence system fits roughly a standard deviation σ of 1.65 nsec for singles with the system standard deviation, σ_{system} being

$$\sigma_{system} = \frac{\sigma_{singles}}{[\text{No. of } D_1 \text{ electrons}]^{1/n}} . \qquad (1)$$

The n is not constant; for low light levels it is about 2.23 and increases as the light level is increased to 2.75 for 10^3 to 10^4 electrons. We believe this effect arises because the actual phototube timespread does not fit a Gaussian distribution. At high light levels, system noise other than phototube statistics contributes to the total standard deviation. This contribution is:

$\sigma_{noise} \approx 7$ psec.

Effects of the Light Pipe and Scintillator

In order to evaluate the role of the light pipe and scintillator in determining time resolution of a counter system, arrangements were made to place two counters in an experiment being run at the Berkeley 184-inch Cyclotron. The beam intensity is about 3×10^5 particles per sec and consists of electrons, muons, and pions. Beam particles at the first counter have momentum 200 Mev/c but must pass through a combination of counters and absorber equivalent to about 31 g of carbon before reaching the second counter. At the second counter, 57 inches from the first, momentum of the muons is about 117 Mev/c and the pions are normally absent unless some absorber is removed.

Plastic scintillators in the shape of a 2 in. cube were used. The plastic is 97% polystyrene, 3% terphenyl, and 0.03% tetraphenyl butadiene. The light pipes are lucite, 5-1/2 in. long, and tapered to make a smooth transition from the square scintillator to the 2 in.-diam round multiplier phototube. Joints are made with epon and the assembly is wrapped in aluminum foil. Beam particles lose about 10 Mev of energy in each scintillator, producing 2000 electrons at the multiplier phototube first dynode. Figure 8 shows one of the counters with a UCLRL corona lamp attached.[4]

Figure 9 shows the experimental coincidence curve. The electrons travel at essentially the velocity of light c, while the muons' velocity varies from 0.88 c to 0.74 c over various sections of the beam path. A curve was made (Fig. 10) with some absorber removed from the beam path. Higher muon average velocity and less muon velocity-spread are evident in this curve. Also pions are now able to reach the second counter.

The slope measured between the 50% and 5% points on the leading edge of the electron curve is 400 psec per decade (this corresponds to a standard deviation of about 200 psec). At the 2000-electron light level this slope should be 200 psec per decade, if the light pipe and scintillator did not degrade system resolution.

The scintillator geometry is believed to be limiting resolution in this case. The obvious next step is to improve light pipe and scintillator statistics.

References

1. A. E. Bjerke, Q. A. Kerns, and T. A. Nunamaker, "Pulse Shaping and Standardizing of Photomultiplier Signals for Optimum Timing Information Using Tunnel Diodes," Lawrence Radiation Laboratory Report UCRL-9838, August 30, 1961 (unpublished).
2. Q. A. Kerns, F. A. Kirsten, and G. C. Cox, "Generator of Nanosecond Light Pulses for Phototube Testing," Rev. Sci. Instr. **30**, No. 1, 31 (1959).
3. Yahia El Hakim, "A Preliminary Investigation of the System Time Spread for Some Types of Multiplier Phototubes," Lawrence Radiation Laboratory Report UCRL-9200, May 11, 1960 (unpublished).
4. T. G. Innes and Q. A. Kerns, " A Triggered Nanosecond Pulsed Light Source," IRE Paper 23/2, Technical Sessions Program (WESCON), San Francisco, August 1961.

Figure Legends

Fig. 1. Simplified schematic of the electronics.

Fig. 2. Exploded view of the coaxial tunnel diode housing.

Fig. 3. Counter base assembly.

Fig. 4. Restandardizer plug-in box.

Fig. 5. Coincidence curves displaying the capabilities of the electronics.

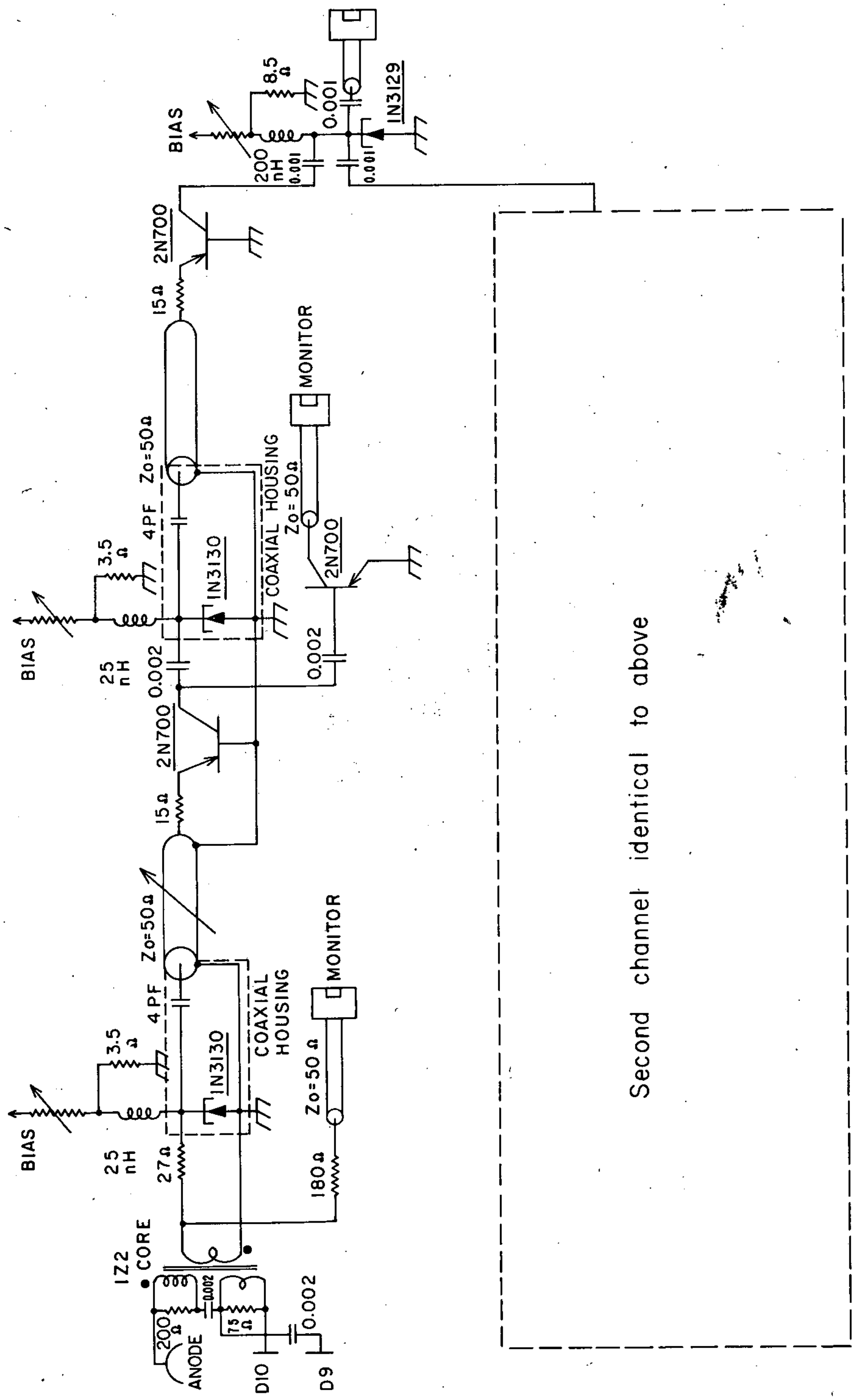
Fig. 6. Time shift of the tunnel diode output as a function of multiplier phototube signal amplitude.

Fig. 7. Coincidence curve edges, showing the effect of multiplier phototube statistics on the slope.

Fig. 8. Scintillation counter used in time-of-flight measurement.

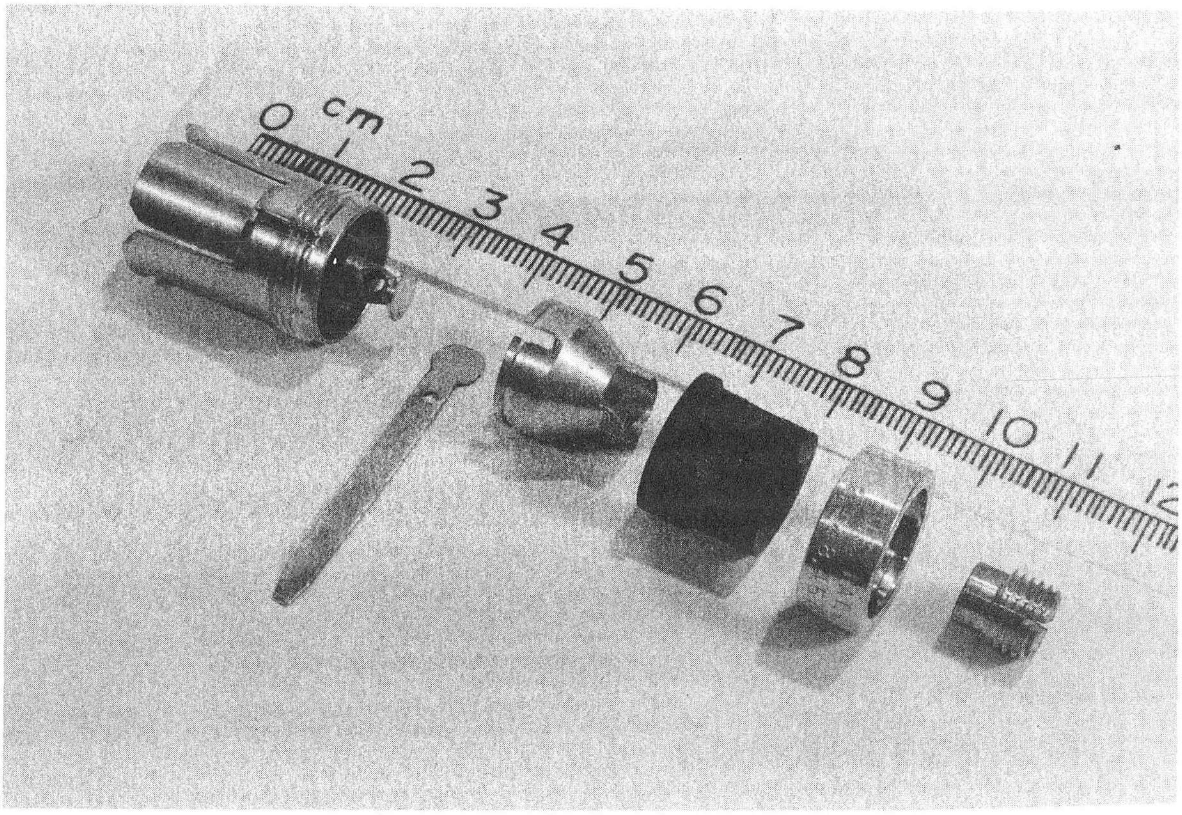
Fig. 9. Time-of-flight coincidence curve with absorber in place.

Fig. 10. Time-of-flight coincidence curve with absorber removed.


BIAS
8.5 Ω
0.001
IN3129
200 nH
0.001
0.001
2N700
15Ω
Zo=50Ω
MONITOR
Zo=50Ω
COAXIAL HOUSING
2N700
4PF
3.5 Ω
IN3130
BIAS
25 nH
0.002
0.002
2N700
15Ω
Zo=50Ω
4PF
3.5 Ω
IN3130
COAXIAL HOUSING
MONITOR
Zo=50 Ω
BIAS
25 nH
27Ω
180Ω
IZ2 CORE
0.002
200 Ω
75 Ω
0.002
ANODE
DIO
D9
Second channel identical to above

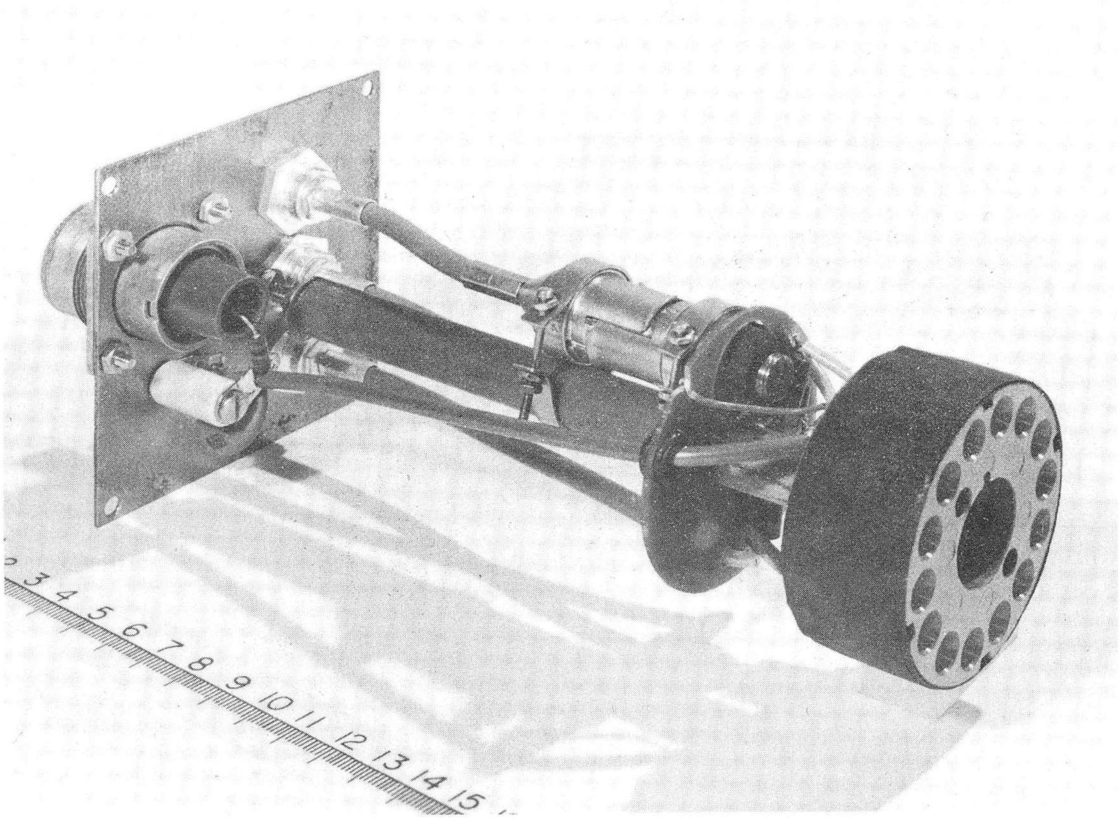
MUB-939

Fig. 1.



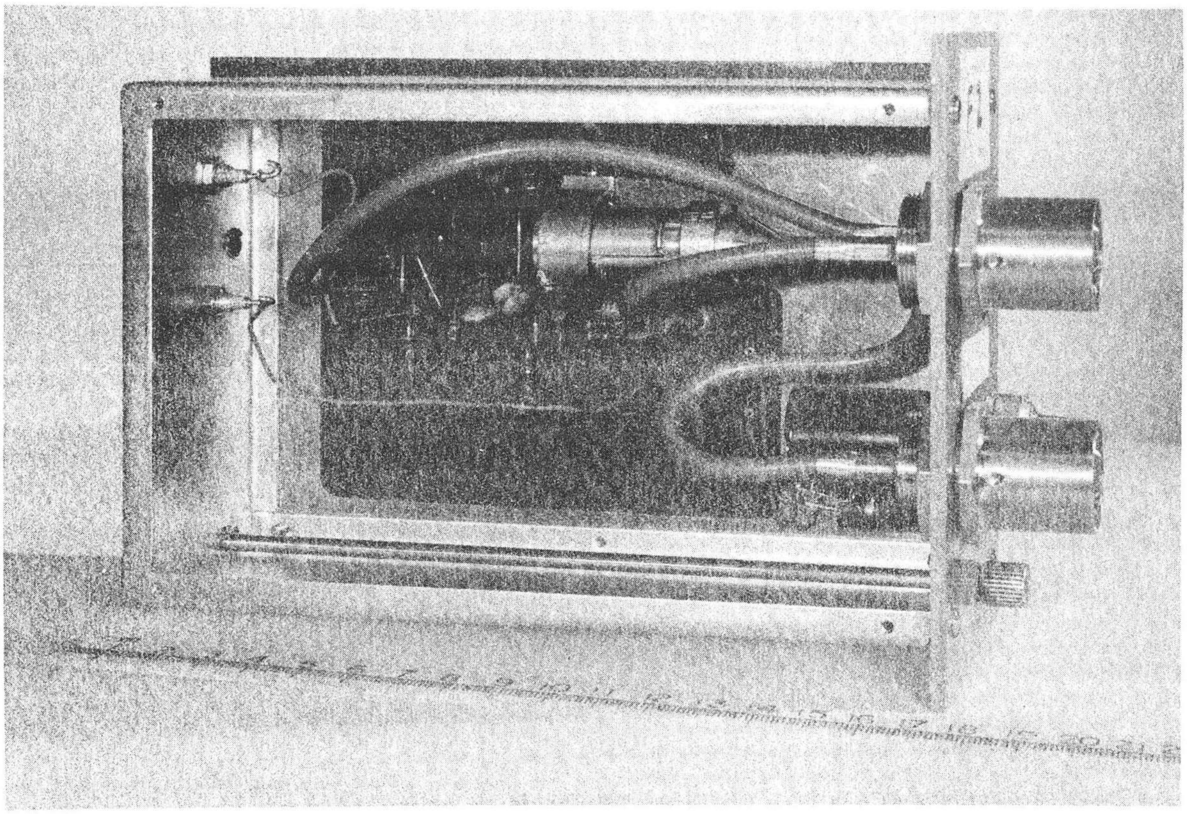
ZN-3020

Fig. 2.



ZN-3019

Fig. 3.



ZN-3018

Fig. 4.

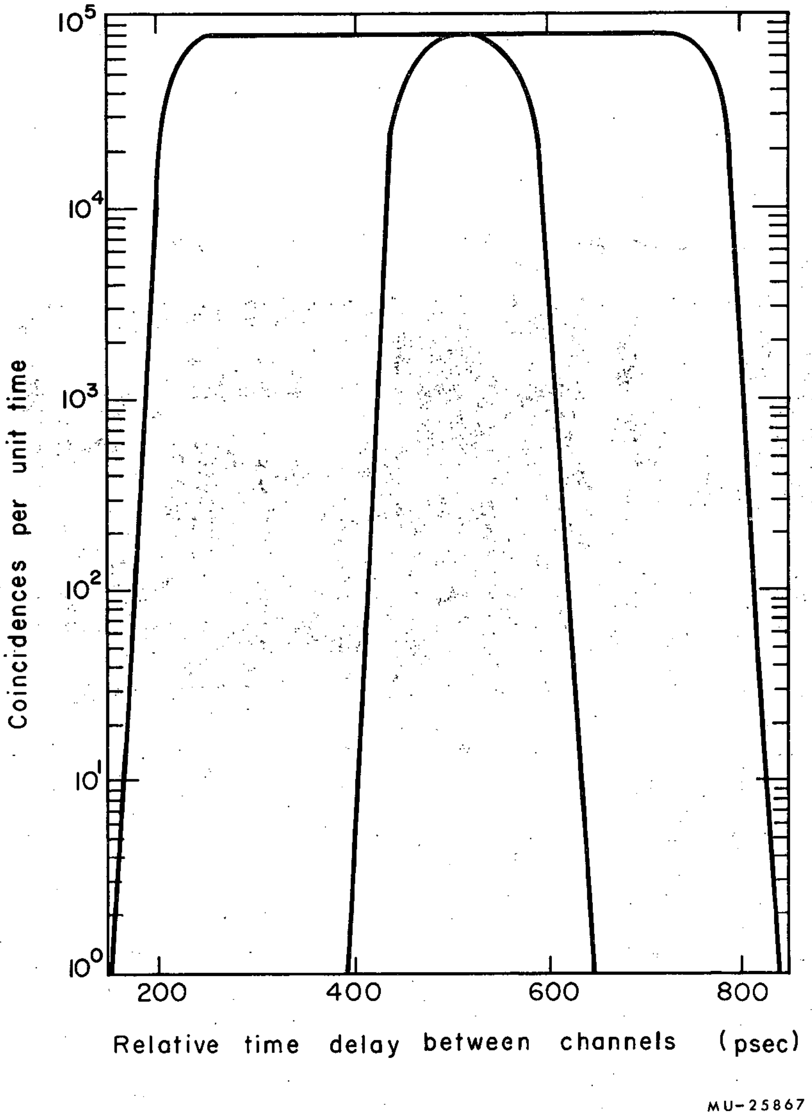

10^5
10^4
10^3
10^2
10^1
10^0
Coincidences per unit time
200
400
600
800
Relative time delay between channels (psec)
MU-25867

Fig. 5.

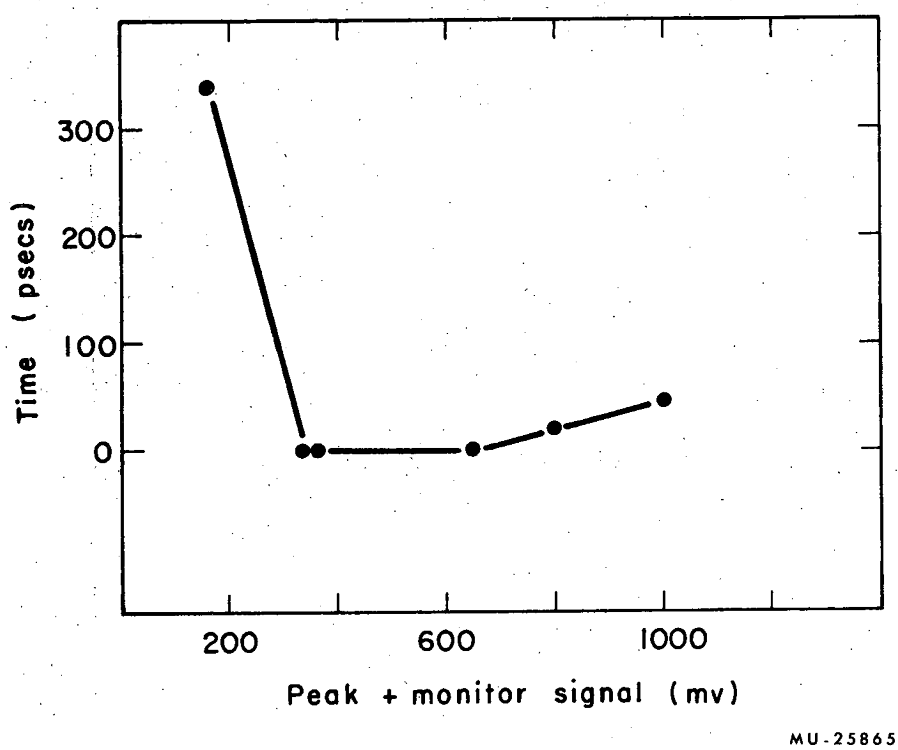
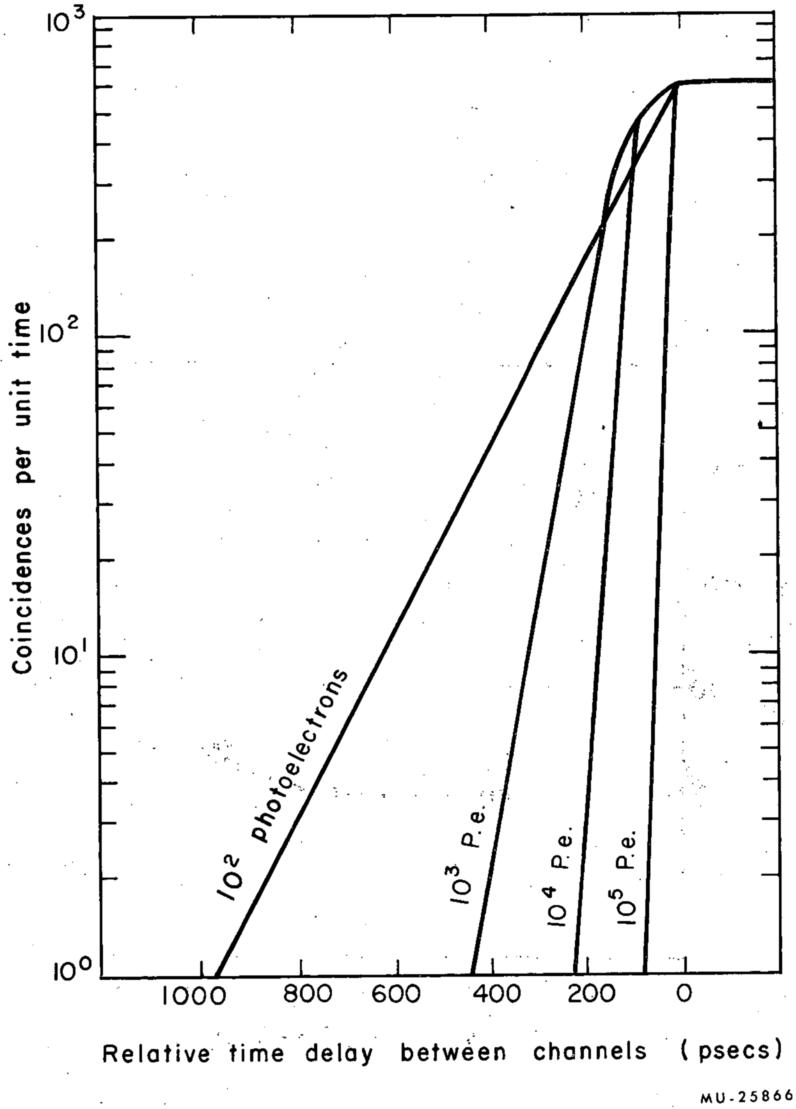
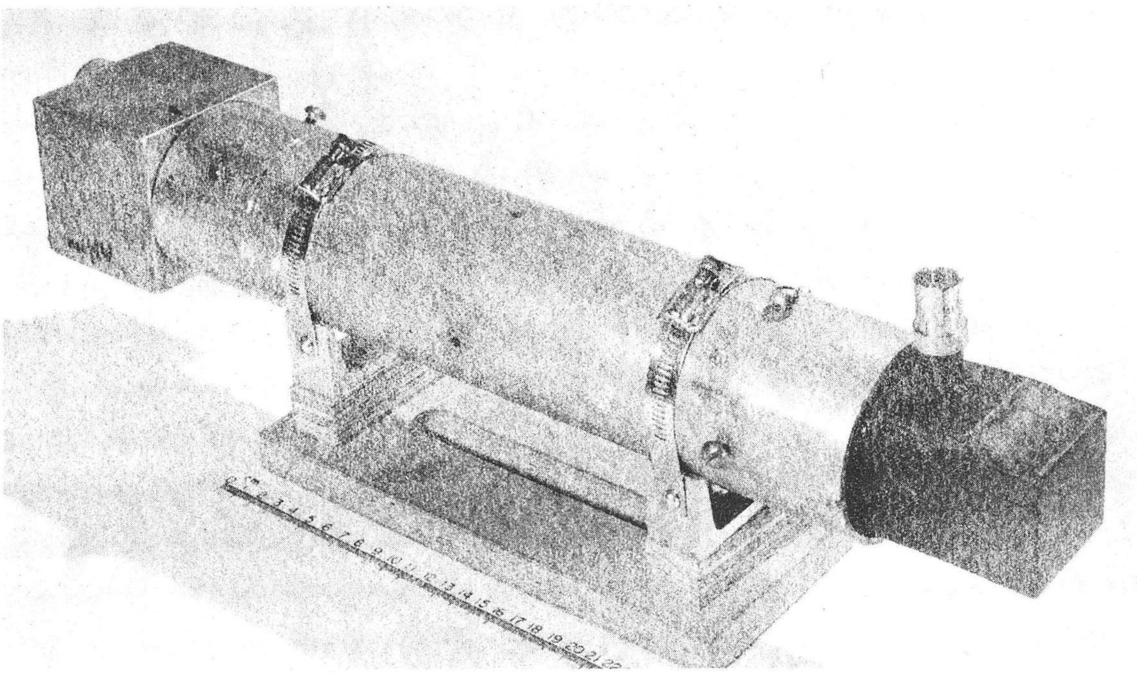

300
200
100
0
Time (psecs)
200
600
1000
Peak + monitor signal (mv)
MU-25865

Fig. 6.



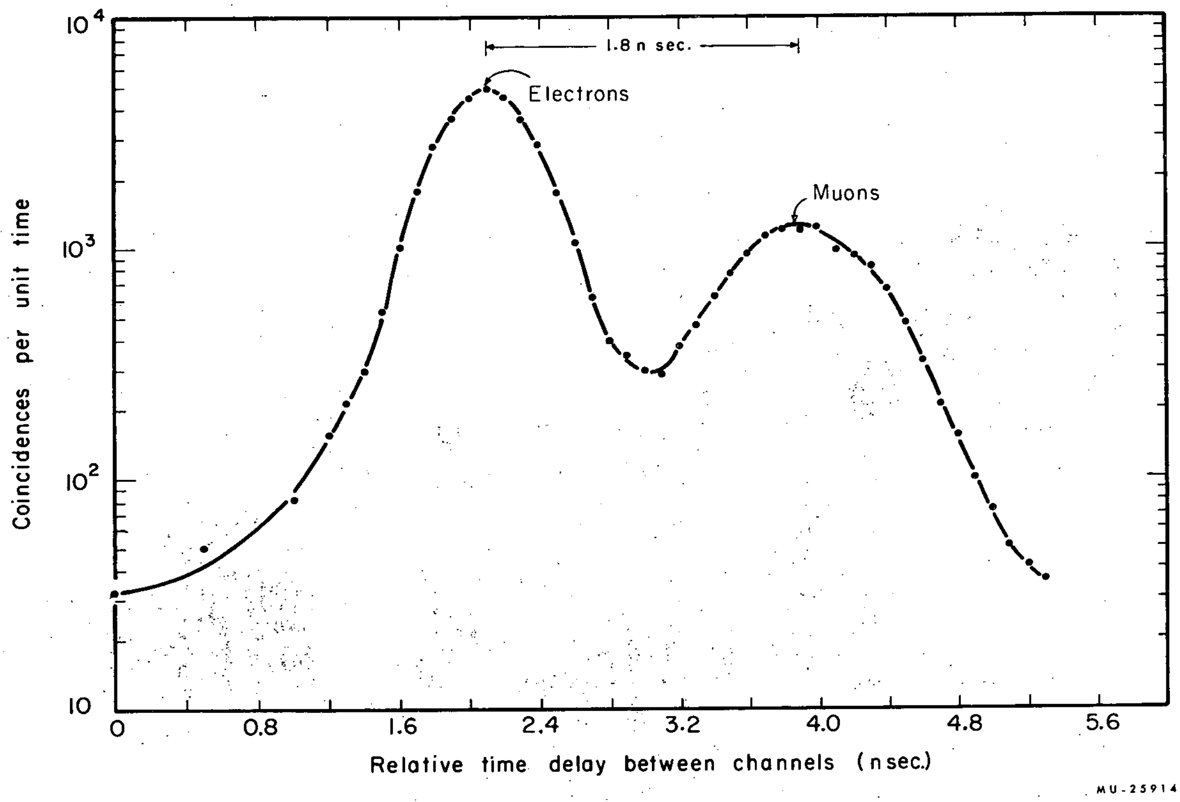
10^3
10^2
10^1
10^0
Coincidences per unit time
10^2 photoelectrons
10^3 P.e.
10^4 P.e.
10^5 P.e.
1000
800
600
400
200
0
Relative time delay between channels (psecs)
MU-25866

Fig. 7.



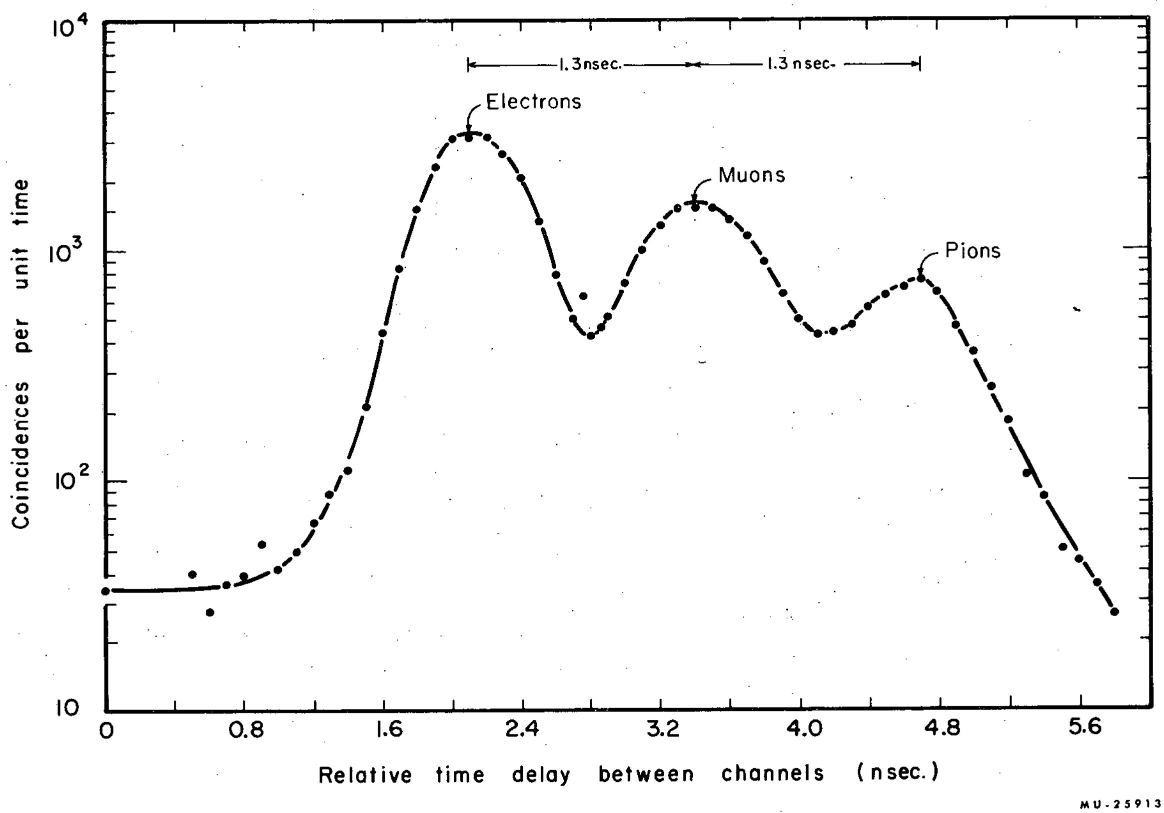
ZN-3017

Fig. 8.



1.8 n sec.
Electrons
Muons
Coincidences per unit time
10^4
10^3
10^2
10
0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
Relative time delay between channels (nsec.)
MU-25914

Fig. 9.



10^4
10^3
10^2
10
Coincidences per unit time
1.3nsec.
1.3 nsec.
Electrons
Muons
Pions
0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
Relative time delay between channels (nsec.)
MU-25913

Fig. 10.