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TIME-OF-FLIGHT SYSTEM FOR USE WITH THE SLAC 1.6 GeV/c SPECTROMETER FACILITY*

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ABSTRACT

A time-of-flight system has been built for a particle identification with the SLAC 1.6 GeV/c Spectrometer Facility. The system makes use of a nanosecond modulation of the SLAC primary electron beam. The flight time of the particle is determined by comparing the phase of the arrival of a pulse from a counter at the counting electronics to an rf waveform extracted from the deflection plates which modulate the accelerated beam. The system is relatively simple and has been used successfully in several experiments at SLAC.

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I. INTRODUCTION

We describe a time-of-flight system designed for use with the SLAC 1.6 GeV/c spectrometer. Although the system was designed specifically for use with this spectrometer, it could be used in any experimental area at SLAC.

A method often used to determine the time-of-flight through an experimental arrangement is to place two counters some distance apart and to measure the flight time between them utilizing a time-to-height converter. The first counter, being nearer the primary beam, can have an objectionable high counting rate. This becomes a severe problem with a linac with its short duty cycle and high intensity. The system we employ circumvents this problem entirely by removing the need for the first counter.

The primary beam is modulated into nanosecond bursts with separations that can be varied from 25 to 50 nsec.[1] Particles produced by the primary beam in a target will arrive at the time-of-flight counter with a definite phase relation to the primary beam modulation depending on their velocity. An essential part of the system is to provide a convenient reference signal related to the modulation of the primary beam. Once this signal has been obtained the time-of-flight system in its simplest form is composed of one counter and a standard coincidence circuit. In fact this is the way we have used the system a good part of the time. The time-of-flight counter can be put in any experimental area at SLAC at the convenience of the experimenter or conversely any counter of an experimental arrangement can be used. Usually the counter with the best resolution and lowest counting rate is preferred.

An important feature, unique to this system, is the capability of overcoming the problems associated with the high counting rates encountered with a linac.

For example, consider the problem of a counter system trying to identify a non-relativistic particle in an overwhelming flux of relativistic particles. Using the modulated beam, the relativistic particles will arrive at a different time than the particle of interest. Indeed the two types of particles will never arrive at the counter system at the same time. Thus, not only is a clean time-of-flight separation obtained but all accidental coincidences are also eliminated between the particle of interest and the background. We have been faced with a problem of this sort[2] and have used the time-of-flight to eliminate accidentals in an experiment very similar to that described above.

We can even go one step further. Consider a situation where the counting rates due to the background are so high that pile up or even blocking occurs in the phototubes. We could modulate the response of the phototube so that the relativistic particles do not even cause a pulse to appear at the output of the phototube. This can be accomplished by applying the time reference signal to the first dynode or a grid of a phototube (the 56AVP has a special grid for this purpose).[3,4]

The time-of-flight system is a useful device for particle identification and diagnostic work. It can be used as a sorting process rather than a device that discriminates against one particle in favor of another. It can accept the whole particle spectrum categorizing particles by their time-of-flight without the large statistical fluctuation experienced in counters due to the interactions of the particles in the counter. The effectiveness in discrimination of added requirements such as pulse height or Cerenkov radiation can easily be determined by observing the change in the time-of-flight spectrum before and after the new requirements are added.

II. CONSIDERATIONS OF TIME-OF-FLIGHT MEASUREMENTS WITH THE 1.6 GeV/c SPECTROMETER

Figure 1 shows the variation of flight times through the 1.6 GeV/c spectrometer as a function of momentum for relativistic particles, K's, protons and deuterons. Particles have a variation in flight time of several nanoseconds due to unequal path lengths through the spectrometer. This variation can be reduced by limiting the vertical aperture $\Delta\phi$ of the spectrometer. The solid lines in the figure indicate this variation for $\Delta\phi = 120$ mrad, the fullest possible aperture of the spectrometer. The spectrometer is normally run with $\Delta\phi = 60$ mrad. The dotted lines indicate the increased variation in flight time due to a 10% momentum acceptance of the spectrometer. Electrons and π's which are relativistic over the useful range of the spectrometer have no appreciable variation in velocity due to the 10% momentum acceptance. The two variations should be added in quadrature; however, on the graph they are added linearily to give the extreme variation.

By splitting the focal plane into regions of different momentum with the counters, the resolution between two different particles could be improved by considering the time-of-flight separately in the counters. The variation due to different length flight paths associated with $\Delta\phi$ acceptance of the spectrometer could be reduced in two ways:

1. Reduce the $\Delta\phi$ of the spectrometer. This can be done simply by reducing the spectrometer aperture.
2. Measure ϕ angle with two hodoscope counter arrays and measure the flight time separately for different ϕ angles. This requires running at a reduced counting rate in order to allow clear coincidences between the two arrays.

Since both possibilities entail running at reduced counting rates the first of the two is the better choice due to its simplicity. For most applications we do not need high resolution so we can accept a simple convenient system without having to require the highest resolution possible. However, it is useful to keep in mind where improvements in resolution can be made.

The whole set of curves in Fig. 1 is periodic with the period of the chopped beam. In order to make all particles separable at all momenta, it is necessary to be able to vary the frequency of the modulation of the beam. This problem becomes more severe at lower momenta with the correspondingly lower velocities.

III. GENERAL DESCRIPTION OF SYSTEM

Figure 2 shows a block diagram of the complete system. A set of electrostatic deflection plates has been installed just after the prebuncher of the accelerator. A high voltage pulse-modulated sine wave is applied to these plates. This scans the electrons across a small diameter aperture causing the beam injected into the accelerator to be modulated into narrow bursts separated by half the period of the applied rf. The chopped beam is monitored by a fast toroid mounted just after the electrostatic plates. The modulation of the beam is retained throughout the 2 miles of accelerator and the 2000 feet through the beam switchyard (BSY) into the experimental area. In the BSY we have installed a fast toroid for use of the experimenter to monitor the modulation of the beam. The toroid is mounted in the BSY rather than in the experimental area so that when the electron beam is converted to a neutral beam before reaching the end station, the toroid can still be used. It is mounted before the energy slits of the BSY to take advantage of the increased intensity before the slits. A circuit has been built which can sense electronically any unequal spacing between the narrow beam pulses.

When the beam passes through a target in the experimental area, particles of different velocity are produced and detected by the experimental apparatus. Particles of different velocity will arrive at the time-of-flight counter with different phases relative to the modulation of the beam. What is now needed is a reliable time reference to give the phase of the modulation of the beam. We have found the most convenient to be an rf signal derived from the electrostatic deflecting plates at the gun of the accelerator. This signal is necessarily in synchronism with the modulation of the beam. The signal is transported through a 50Ω cable the full length of the accelerator to the counting electronics area, utilizing the high quality drive line of the accelerator, which also feeds the 476 MHz to the klystrons of the accelerator. Thus, the signal is transported from the gun to the experimental area through a terminated cable without any active elements that could produce a drift in phase. At the counting electronics the zero-crossing of the rf signal is sensed and put into coincidence with the pulse from the time-of-flight counter. A time-of-flight spectrum can also be obtained utilizing a time-to-height converter with the counter and zero-crossing pulses serving as the start and stop pulses.

IV. MODULATION OF THE ACCELERATOR BEAM

The width of the pulses produced at the beam chopper should be consistent with the time resolution required in an experiment. The separation of the electron bunches due to the acceleration process in the SLAC machine is 350 psec permitting, in principle, a resolution that is a small fraction of this time. To achieve this high resolution the chopper plates must be driven synchronously with the accelerator rf power. In an experiment requiring a resolution on the order 1 nsec such a synchronization is unnecessary, since one can accept several rf bunches in one (chopped) pulse. This simplifies the operation and allows the possibility of increased beam intensity and reduced power to drive the chopper plates.

Figure 3 shows the electrostatic deflecting plates that are mounted at the gun of the SLAC accelerator. At each zero-crossing of the sine wave applied to the plates, electrons are allowed to pass through the aperture undeflected. The chopping power required depends on the energy of the beam, length and separation of the plates, distance to aperture, frequency of the sine wave, loading due to the beam striking the chopper plates, and the desired width of chopped pulses. The chopper plates originally built for Group C's 39 MHz had to be replaced due to the fact we had to chop at a low frequency and therefore required more power to drive the chopper plates.

Space requirements limited the length of the plates to 11.5 cm. The cutout portion of the plates reduces the interception of the deflected electrons by the plates and subsequent beam loading (see Fig. 3b). The surfaces surrounding the plates as well as the end surface in the plane of the aperture are coated with a carbon suspension to minimize secondary emission.

The signal voltage required is inversely proportional to the chopping frequency. Beam loading imposes severe requirements on the power. Two power sources have been constructed:

1. A fixed-frequency power amplifier at 39.667 MHz driven synchronously with the accelerator rf power.[1]
2. A power amplifier with a continuously variable frequency from 6 to 20 MHz. In addition eleven, fixed, crystal-controlled frequencies in the range 10 to 20 MHz are selectable via a switch. This unit could also be driven synchronously provided an appropriate subharmonic of

the accelerator rf is supplied. The output of the amplifier is 60 kW peak which corresponds at 360 cps to several hundred watts average power.

Figure 4 shows the wave form appearing on the chopper plates. The electrons are injected for 1.6 μsec in the center of the pulse where phase shifts due to transients are reduced. A 50Ω cable transmits the signal from the amplifier to a step up transformer which, together with the capacity of the deflection plates, resonates at the chopping frequency. At the present, it is required to change the transformer whenever the chopping frequency is altered.

A second set of chopper plates is being installed at the end of the first accelerator section which in conjunction with the first pair of plates can produce a chopped beam with separations up to 75 nsec. The first set of plates can be powered by the 39.667 MHz, while the second set can be driven off a subharmonic of the 39.667 MHz down to 6.611 MHz. This allows one to take advantage of both the sharp time definition of the 39.667 MHz chopping and the larger spacing of the lower chopping frequency. The second set of plates is also useful in removing dark current.

A single turn pick-up coil is placed downstream of the electrostatic deflection plates, to facilitate monitoring of the chopped beam. The single turn is wound on a ferrite torus (Ferroxcube type 528T-500, material 3C5), O. D. = 3.8 cm I. D. = 1.9 cm, H = 1.25 cm. The observed wave form obtained from the chopped beam is shown in Fig. 5. Most of the width of the signal is due to the limited frequency response of the toroid. A one-turn transformer has advantages over one with several turns since it yields higher current outputs with better rise times.

V. TIME MARKER

Once the beam is chopped the central problem becomes one of obtaining a reliable and convenient time marker to be placed in coincidence with the pulse of the time-of-flight counter. The voltage on the chopper plates is necessarily phase locked with the modulation of the beam. Since there is 60 kW of rf power available, it is easy to pick off a few volts to be used as a time marker in the experimental area. However, this signal must be transmitted over two miles to the experimental area without drift in phase or large attenuation. In order to accomplish this we made use of the drive line of the SLAC accelerator. The drive line distributes the 476 MHz rf power to feed the klystrons of the accelerator. At each klystron there is a high-pass filter which allows the low frequency chopper rf to pass unaffected down the drive line with only 4dB attenuation at 10 MHz for the entire two miles. Experimentally we have found the presence of the low frequency signal on the drive line to have no noticeable effect on the operation of the accelerator. The 50 volts derived at the chopping plates is inserted on the drive line at the gun end of the accelerator with a diplexer and removed the same way in Counting House A. The signal is transmitted through 400 m of 7/8" Heliax cable from the end of the accelerator to the experimental area (2dB loss at 10 MHz). This completely passive network is effected only by temperature which, for the extreme variations expected ($\pm 1^{\circ}$F for drive line and $\pm 20^{\circ}$F for the Heliax), gives only a variation in time of 0.15 nsec. The rf structure of the time marker allows one to make use of the chronotron method of Cottini and Gatti in a natural way.[5,6]

VI. BSY TOROID

A fast toroid was mounted in the BSY as a beam monitor and for possible use as a time marker in case the drive line scheme did not work out in practice. This was necessary since the design and planning of the system was done before the accelerator was in operation and there was no way of checking the feasibility of the drive line scheme.

The toroid is mounted just after collimator C-10. The toroid is placed outside of the vacuum around 5.2 cm diameter stainless tube (see Fig. 6). The tube is 28 cm long with two vacuum flanges welded on either end. One flange is insulated from the stainless steel tube with a ceramic insulator. This allows the toroid to magnetically sense the beam although it is external to the vacuum system. The toroid is made of two U-shaped ferrites, Ferroxcube type 1F/3C5-B6B. A copper strip 5 cm wide provides a single turn of a 1:1 transformer. This one turn rather than several not only gives us a bigger signal but has a faster rise time. Its performance is illustrated in Fig. 7. There is room for a second toroid around the tube for another purpose, if necessary. The signal is transported through 190 m of 7/8" Heliax cable to Counting House A.

Due to beam steering effects at the gun of the accelerator, it is possible for the spacing between the chopped beam pulses to be aperiodic by several nanoseconds. The toroid gives the experimenter a convenient monitor to check the modulation of the beam. We have also built a circuit that will take the signal from the toroid and electronically check the periodicity of the chopped beam.

VII. ELECTRONICS

Figure 2 shows a block diagram of the electronics. Below we describe the circuitry used in the Counting House.

1. Frequency doubling and zero-crossing circuit: The voltage of the rf signal, picked off at the chopper plates, is of the order of 10 volts by the time it reaches the Counting House. It is easy to sense the zero-crossing of this signal in a reliable way. However, for every period of the rf there are two chopped beam pulses. Since we would like to vary the frequency of the chopper rf, it would be inconvenient to generate the two signals with fixed delay lines. We have chosen to do it electronically.

Figure 8 shows the diagram for this circuit. Frequency doubling is effected via an unbalanced-to-balanced coaxial transformer, producing two signals 180° apart. Any asymmetries due to transformer construction or stray capacities can be removed by adjusting the "phase adjust" capacitor. The two sine waves are applied to two identical circuits. Q1 and Q2 are emitter coupled switches with a tunnel diode in the collector circuit of Q2 sensing one zero-crossing of the sine wave. A tunnel diode at Q4 senses the second zero-crossing π radian away. The duration of the pulse produced is determined by the inductor. Q5 and Q6 form an OR circuit while Q7 and Q8 provide an output stage. The CAL/RUN switch disables the upper channel thus allowing calibration of the time interval checking circuit. The circuit works over an input range from 1 to 1.5 volts. Once the "phase adjust" pot is set the output pulses are very closely equally spaced over the frequency range 10 to 20 MHz. Figure 9 shows the output waveform of the circuit with 10 and 20 MHz signals.

2. Time interval checker: In setting up the time-of-flight system we have to check that the beam chopping is periodic and that the zero-crossing and doubling circuit produces an equally spaced train of output pulses. Aperiodic spacing of the chopped beam pulses result from mis-steering of the beam through the chopper plates. An aperiodic output of the zero-crossing circuit is corrected by adjusting the "phase adjust" potentiometer. The circuit of Fig. 10 can check the presence of such asymmetries with a resolution of 1/3 nsec, the spacing due to the microwave rf structure in the beam. The input pulse is split into two components. One is applied to one side of a differential amplifier, the other is delayed through a fixed delay in series with a 50Ω trombone, and applied to the other side of the amplifier. The output transistor is capable of driving a 50Ω cable.

3. Time-to-height converter (THC): A time-to-height circuit was designed that could be driven off standard Chronetics logic pulses (300mV, 5 nsec). The circuit converts to a voltage the time separation between the leading edges of two pulses: In our case, an event pulse and the first zero-crossing reference pulse following the event. The coincidence logic shown in Fig. 2 ensures that a STOP signal arrives at the THC only after the receipt of a START pulse. The logic retains the leading edge of the STOP pulse even in the ambiguous cases where the STOP and START pulses overlap. The circuitry is made to block after receipt of the START and STOP pulses so that it is inoperative for the remaining part of the beam pulse (SLAC beam pulse = 1.6 μsec). The output of the circuit was made to drive the pulse height analyzers available at the time of construction.

The specifications of the circuit are:

Input sensitivity:	150mV for 5 nsec pulses.
Range:	56 nsec, max. (can be increased).
Linearity:	Better than 0.5 nsec in the range of 4 to 56 nsec.

Outputs:	1. -2 volts into 93 ohms. Rise Time: 250 nsec; decay time constant: 22 μsec.
	2. + 0.8 volts into 50 ohms.
	3. Two outputs of 0.4 volts into 50 ohms.
Busy Signal:	Inhibits incoming signals (START and STOP) whenever an event has been accepted. Duration of inhibit pulse is 3.5 μsec (can be varied).

Figure 11 shows the block diagram of the THC; the transistor numbering corresponds to that of the detailed circuit diagram, Fig. 12. The block diagram and its waveforms help to make the operation of the circuit clear.

A START pulse via the input stage, Q1 - Q2, triggers the blocking oscillator Q3 producing a signal whose duration is longer than the maximum time separation between the START and STOP pulse. The current switch, Q7 - Q9, is set and charges linearly the capacitor C. A circuit similar to Q1 - Q3 produces the pulse required to switch the current source off after receipt of a STOP signal. The time definition of the START pulse can be improved by the use of a zero-crossing discriminator. We used an EGG zero-crossing discriminator type T 140/N.

The voltage developed across the capacitor C decays with a time constant of 22 μsec to match the requirements of the Nuclear Data pulse height analyzers. Additional outputs are derived to drive the A/D converter of the SDS 9300 and to develop logic gating. The "busy" monostable applies negative pulses of 3.5 μsec duration to the right side of the input transistor pair in both, the START and STOP channel, to inhibit any signal arriving after the time-to-height conversion process has commenced.

VIII. PERFORMANCE

The time-of-flight system has been used in several experiments performed with the SLAC 1.6 GeV/c spectrometer. We have run the system for several days at a time and have not experienced any drifts or changes. The circuitry worked from the start and has not experienced any failures. The chopping operation at the gun has been very stable. The spacing between the chopped pulses has been found to be closely equal. Thus, the circuit that was built to electronically monitor the spacing was not very essential to the operation.

The best we have done with respect to loss of beam due to the chopping operation has been a loss of a factor of 3.5 from that possible without the modulation. However, not much effort has been made to understand and improve this situation.

We have found the time-of-flight system extremely useful for diagonostic work. At times we have relied on the time-of-flight only as a coincidence requirement. At other times we have just displayed the time-of-flight spectra as a monitor of the experiment. Sometimes we have used both. Although the system was designed specifically for use with the 1.6 GeV/c spectrometer, it can be used in any experimental area of SLAC.

Figures 13, 14, and 15 show time-of-flight spectra taken under varying experimental conditions with the 1.6 GeV/c spectrometer. The first two spectra are taken with no requirements made in the counting system other than a coincidence. Figure 15 shows the spectrum of range and Cerenkov radiation from a K-meson as required by the counters. For the particles of Fig. 13 and 14 the pulse heights in the counters are very similar in size but are clearly separable in the time-of-flight spectra.

IX. ACKNOWLEDGEMENTS

We are indebted to Roger Miller and Roland Koontz for the design of the rf deflection plates and for making them work; for the construction and installation of the toroid at the gun and for the step-up transformer at the chopper plates. We would like to thank Carl Olson and Bill Tomlin for constructing the high power rf amplifiers to drive the chopper plates. Thanks are due to Roger Coombes for the construction and installation of the BSY toroid assembly and to Dave Farkas for the construction of the diplexers used with the drive line.

REFERENCES

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5. C. Cottini and E. Gatti, Nuovo Cimento 4, 1550, (1956).

6. R. L. Anderson and B. D. McDaniel, Nucl. Instr. and Methods 21, 235, (1963).

FIGURE CAPTIONS

1. Time-of-flight of various particles through the 1.6 GeV/c spectrometer. Indicated are the extreme variations in flight path due to momentum acceptance and flight path differences of the spectrometer. The two variations are added linearly to show the extreme variations.
2. Block diagram of the complete system.
3. Deflection plates at the gun of the accelerator used to chop the beam. The design of the plates maximizes the deflection of the beam for a given rf voltage in the restricted space. The cutout portion of the plates is to minimize loading of the plates by the beam. The capacitive pickup serves as a monitor and a time marker.
4. The waveform observed on the chopper plates with 10 MHz rf.

   Vertical = 1025 V/div.

   Horizontal = (a) 2 μsec/div.

   (b) 40 nsec/div.

   The electron beam is injected for 1.6 μsec in the center portion of the pulse.
5. Waveform observed on the one-turn toroid mounted downstream of the gun using the chopped beam. τ_r (10 to 90%) $\cong$ 0.3 nsec.

   Vertical = 0.1 V/cm

   Horizontal = 0.5 nsec/cm
6. Beam switchyard one-turn toroid. Toroid used by the experimenter to monitor the chopping of the beam. The toroid is mounted outside the vacuum so changes can be made without breaking the vacuum of the accelerator.

7. BSY toroid using pulser as primary signal. Lower trace-input signal. Upper trace-output into 50Ω.

   Vertical = 0.1 V/cm

   Horizontal = 1 nsec/cm

   Sensitivity of toroid = 5 volts/amp

8. Frequency doubling and zero crossing circuit. This circuit takes the rf signal from the chopper capacitive pickup and converts it to a train of pulses equally spaced at a frequency twice that of the rf.

9. Output waveforms from zero-crossing circuit.

   Vertical = 0.1 V/cm

   Horizontal = 10 nsec/cm

10. Time interval checker. This circuit accepts the train of pulses from the BSY toroid or the frequency doubling circuit and produces a null output when they are equally spaced.

11. Block diagram of the time-to-height converter. The THC compares the leading edge of two pulses and converts this time separation to a voltage suitable for pulse height analysis. The circuit has a dead-time of 3.5 μsec so only one event is accepted for the duration of the 1.6 μsec SLAC beam pulse.

12. Detailed circuit diagram for the time-to-height converter.

13. Time-of-flight spectra obtained with the 1.6 GeV/c spectrometer at 1.33 GeV/c. No requirement is made on the events other than a coincidence between two scintillation counters. At this momentum it is hard to distinguish between these particles by pulse height. They are clearly separable by time-of-flight.

14. Time-of-flight spectra obtained with the 1.6 GeV/c spectrometer at 562 MeV/c. Here deuterons and alpha particles have insufficient range to make it through the counter system.

15. Time-of-flight spectra taken with the requirement of a focussing Cerenkov counter tuned for K-mesons.

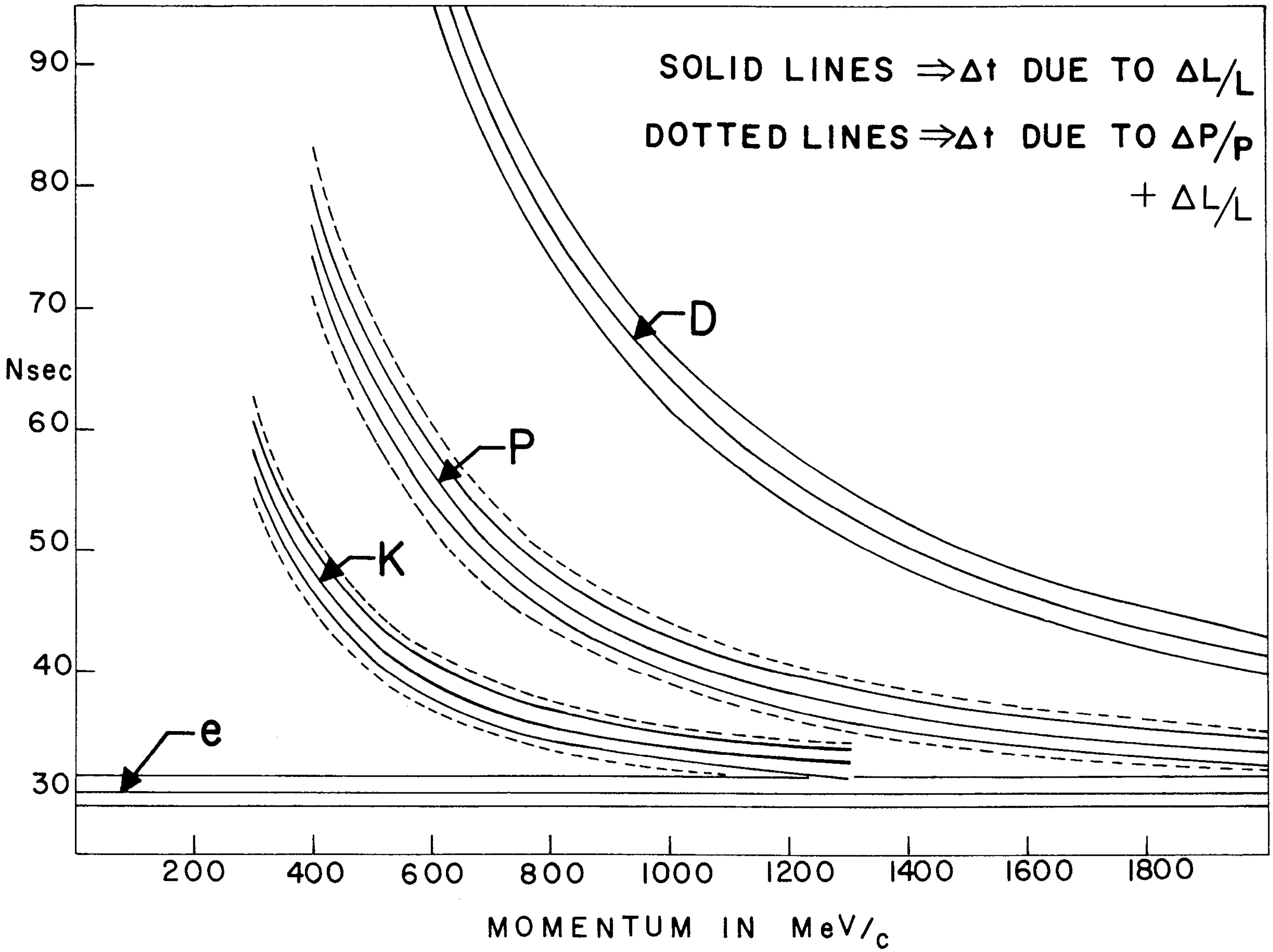

SOLID LINES ⇒Δt DUE TO ΔL/L
DOTTED LINES ⇒Δt DUE TO ΔP/P + ΔL/L
D
P
K
e
Nsec
90
80
70
60
50
40
30
200
400
600
800
1000
1200
1400
1600
1800
MOMENTUM IN MeV/c

Fig. 1

1148A1

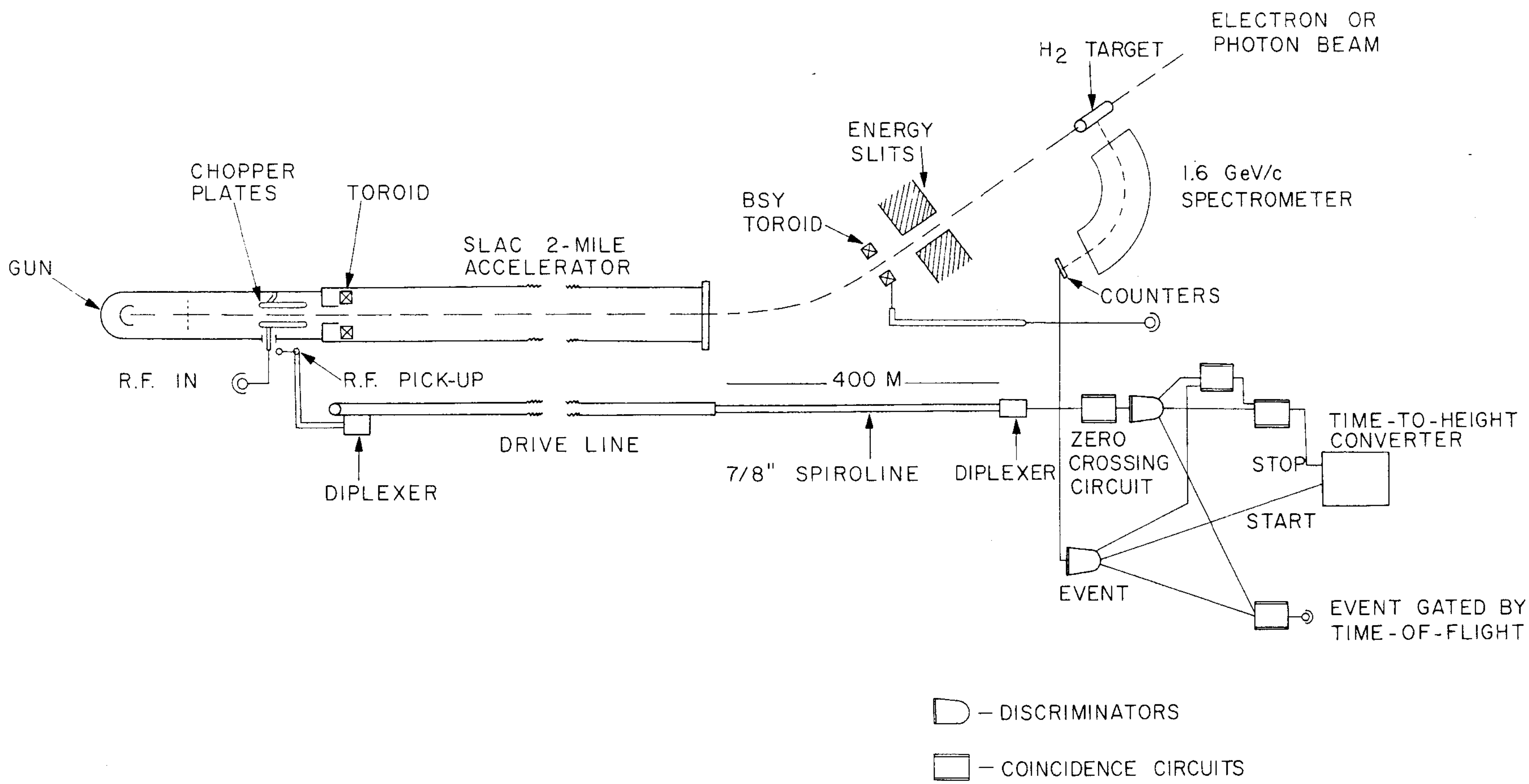

ELECTRON OR
PHOTON BEAM
H_2 TARGET
ENERGY
SLITS
1.6 GeV/c
SPECTROMETER
CHOPPER
PLATES
TOROID
BSY
TOROID
SLAC 2-MILE
ACCELERATOR
GUN
COUNTERS
R.F. IN
R.F. PICK-UP
400 M
TIME-TO-HEIGHT
CONVERTER
DRIVE LINE
ZERO
CROSSING
CIRCUIT
STOP
DIPLEXER
7/8" SPIROLINE
DIPLEXER
START
EVENT
EVENT GATED BY
TIME-OF-FLIGHT
— DISCRIMINATORS
— COINCIDENCE CIRCUITS

Fig. 2

1148A2

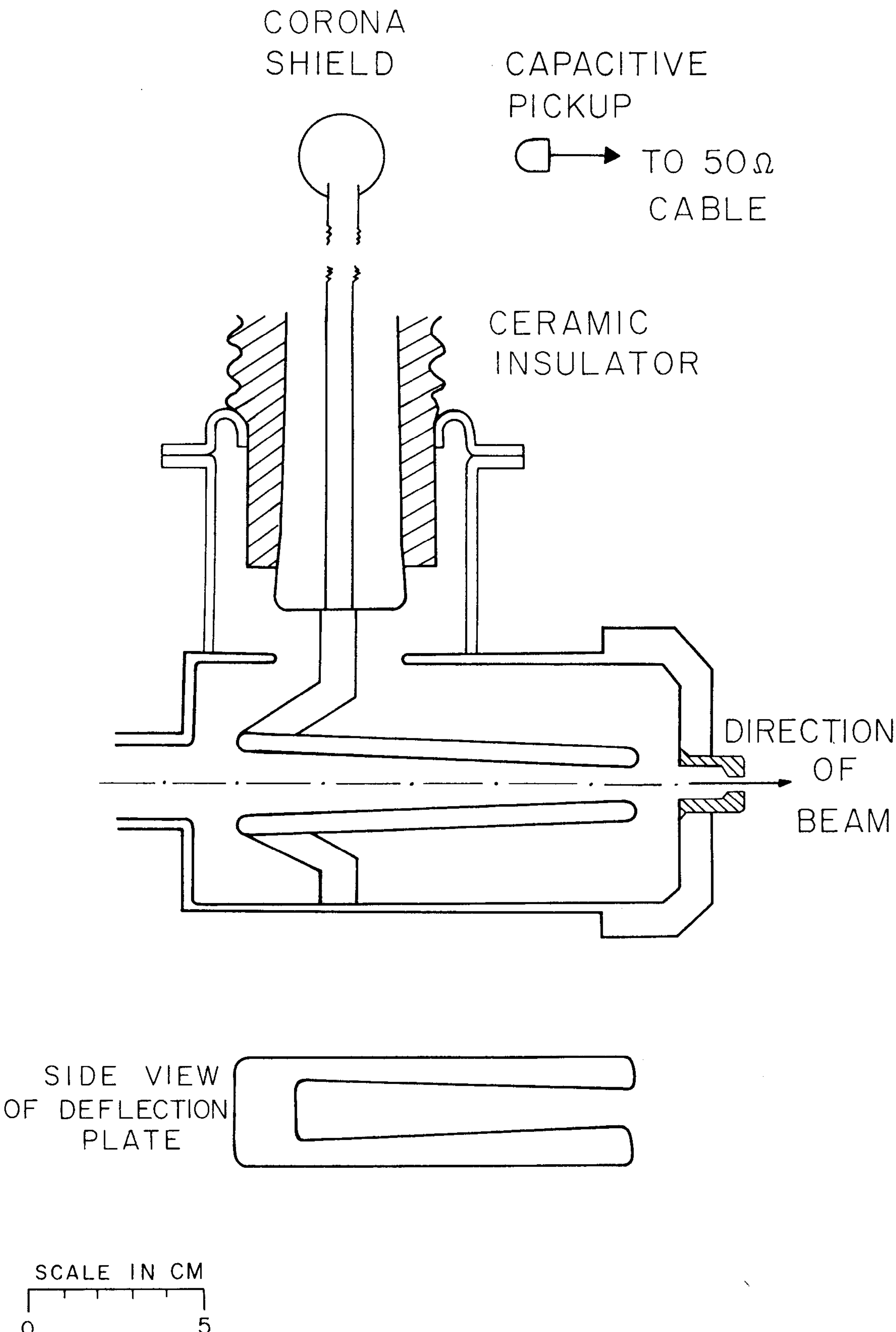
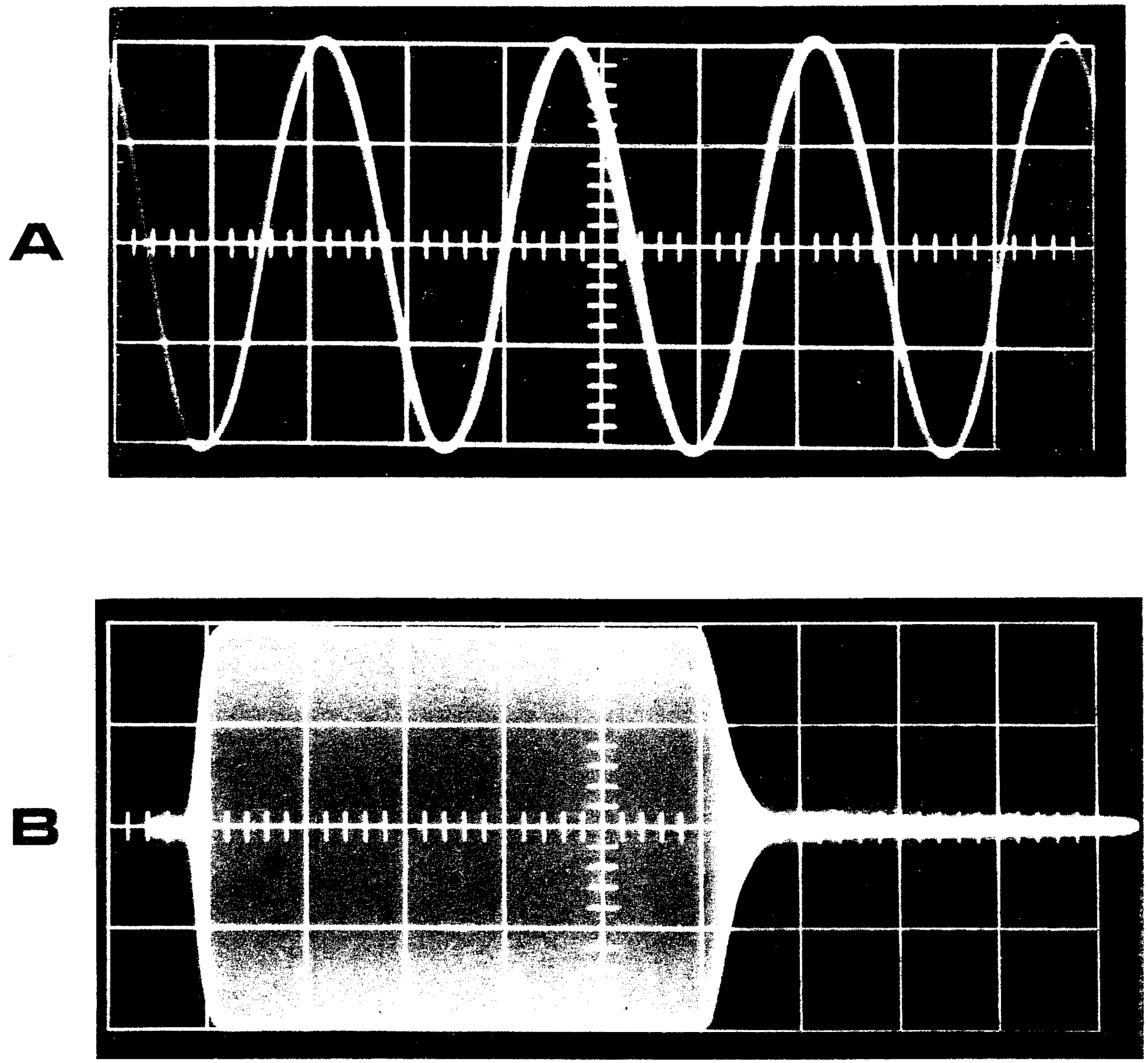

CORONA
SHIELD
CAPACITIVE
PICKUP
TO 50Ω
CABLE
CERAMIC
INSULATOR
DIRECTION
OF
BEAM
SIDE VIEW
OF DEFLECTION
PLATE
SCALE IN CM
0
5

FIG. 3

1148A3



1148A4

Fig. 4

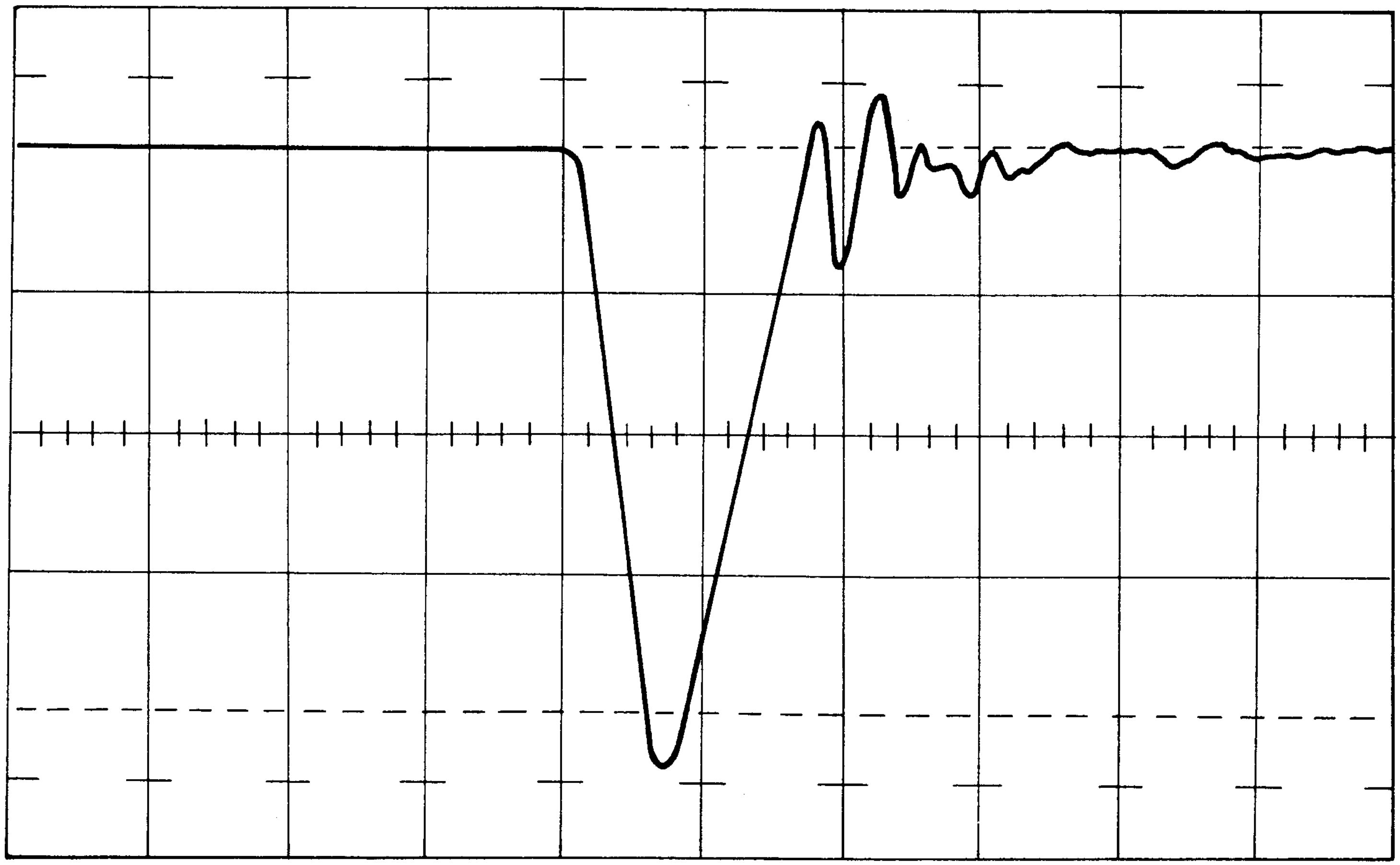


Fig. 5

1148A5

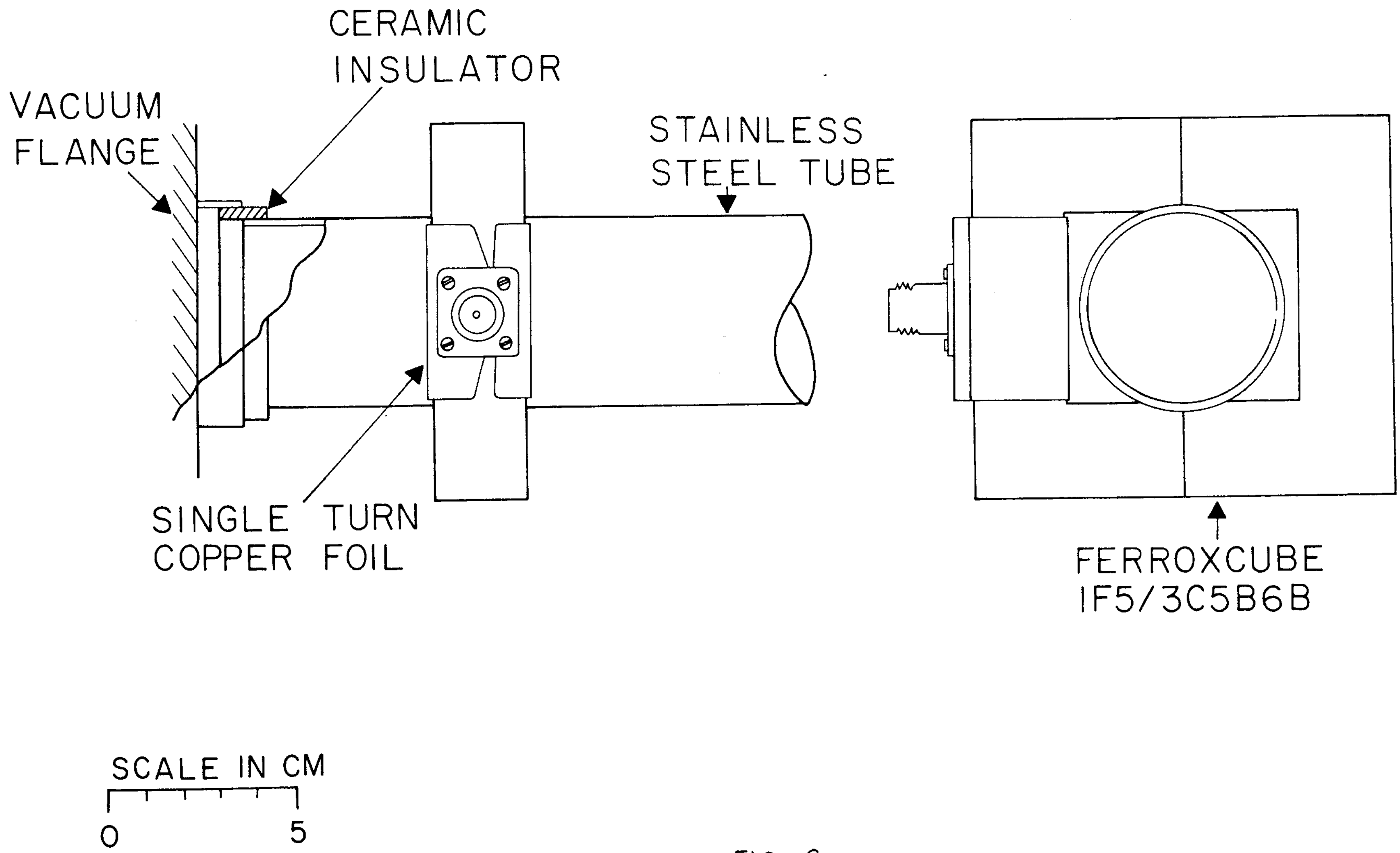
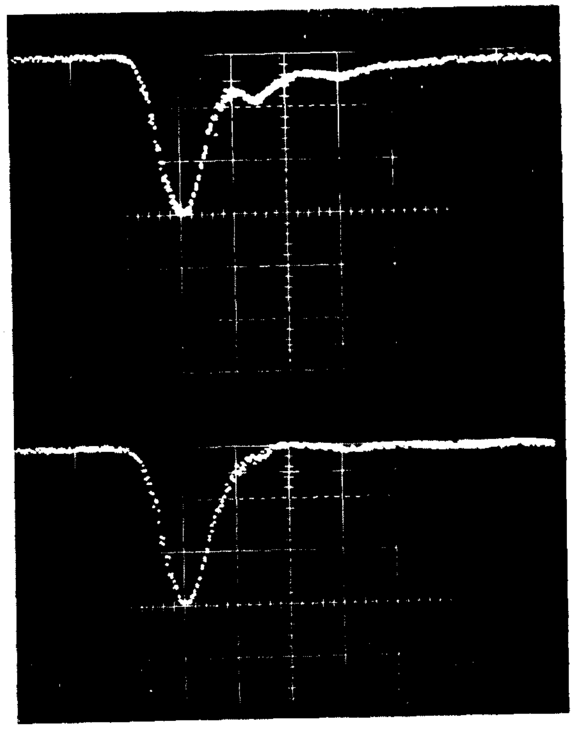

CERAMIC
INSULATOR
VACUUM
FLANGE
STAINLESS
STEEL TUBE
SINGLE TURN
COPPER FOIL
FERROXCUBE
IF5/3C5B6B
SCALE IN CM
0
5

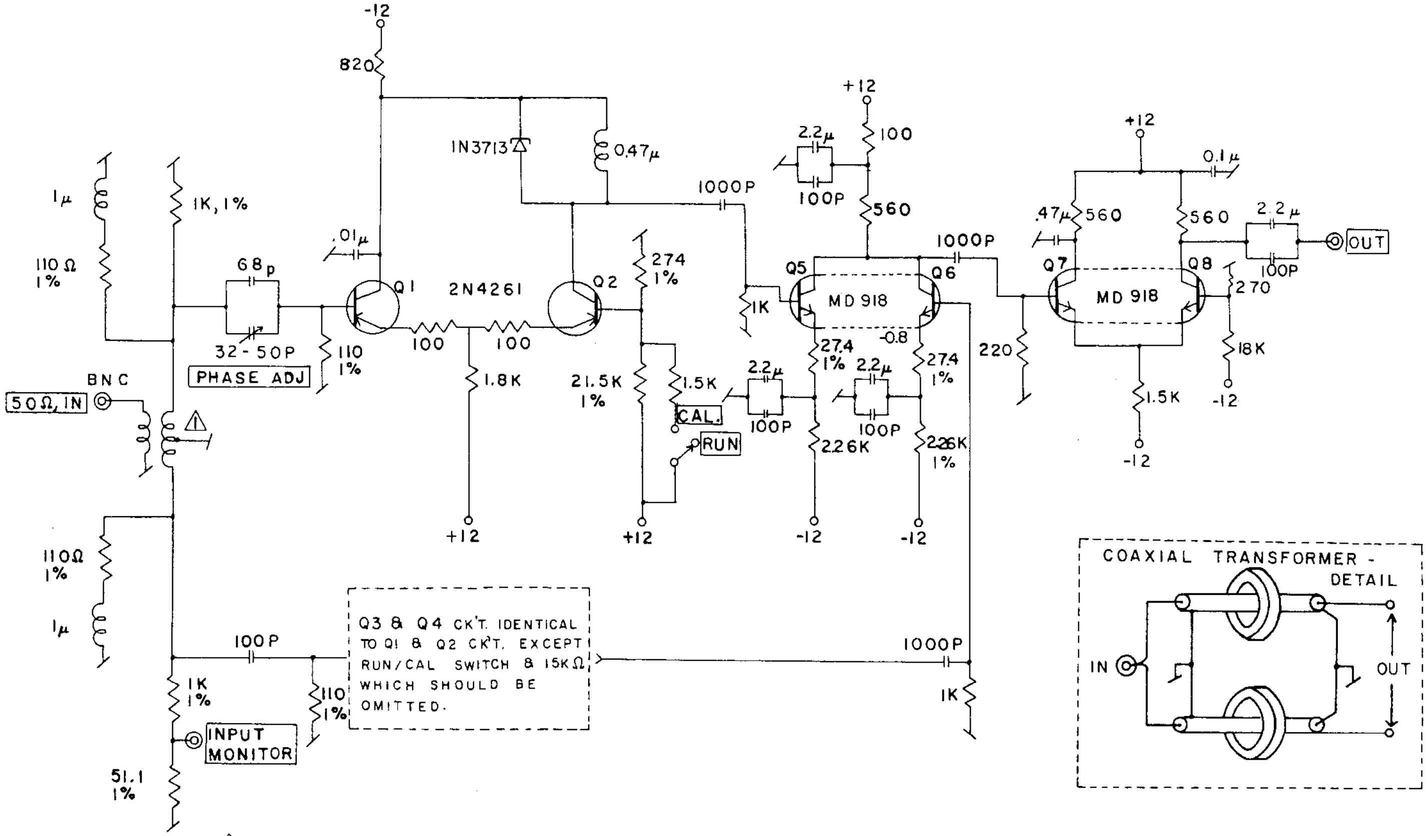
FIG. 6

1148A6



1148A7

Fig. 7



⚠1 COAXIAL TRANSFORMER, UNBALANCED TO BALANCED, FERROXCUBE 846T250/3E2A TWO CORES, CABLE MICRODOT # 260-3919, 100 Ω, 9 TURNS - SEE DETAIL.

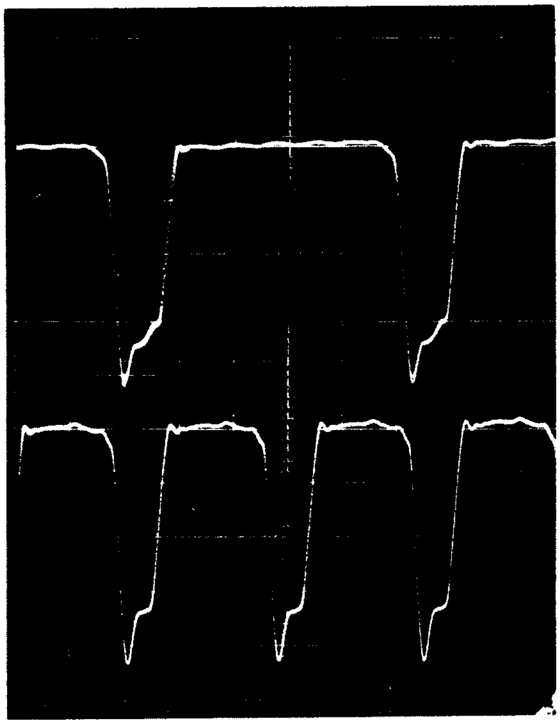
⚠2 RESISTORS 5%, 1/4W UNLESS SPECIFIED OTHERWISE.

⚠3 TRANSISTORS Q1 THRU Q4 MATCHED IN dc BETA (± 10%).

FREQUENCY DOUBLING & ZERO CROSSING CIRCUIT 10 to 20 MHz

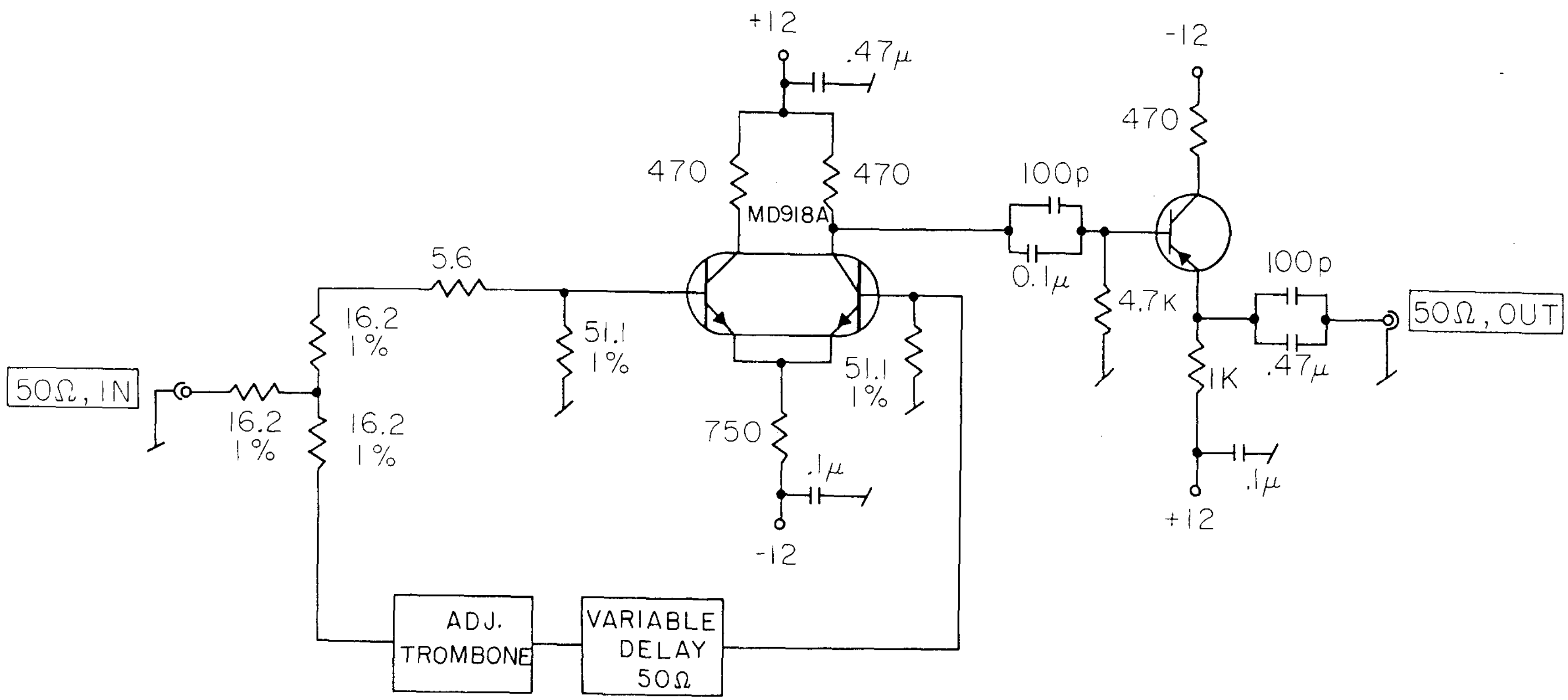
1148A8

Fig. 8



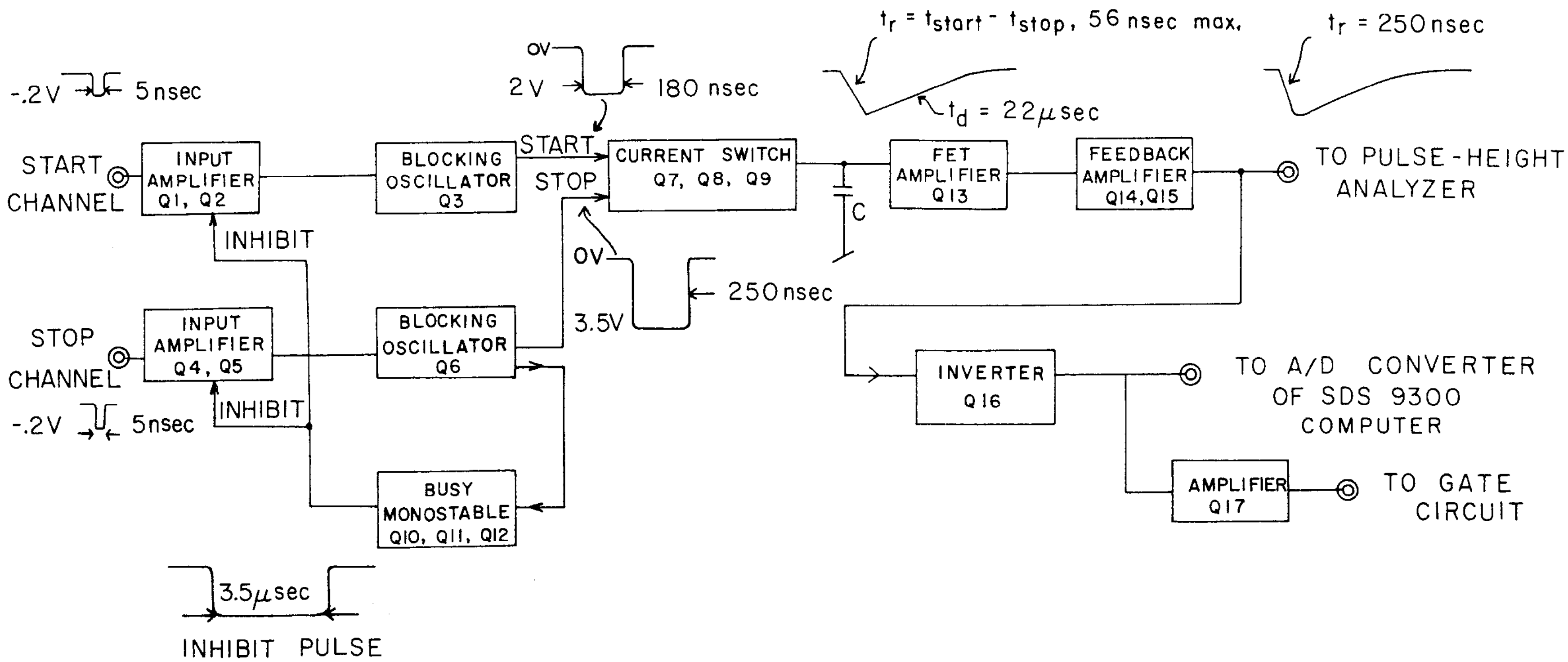
1148A9

Fig. 9



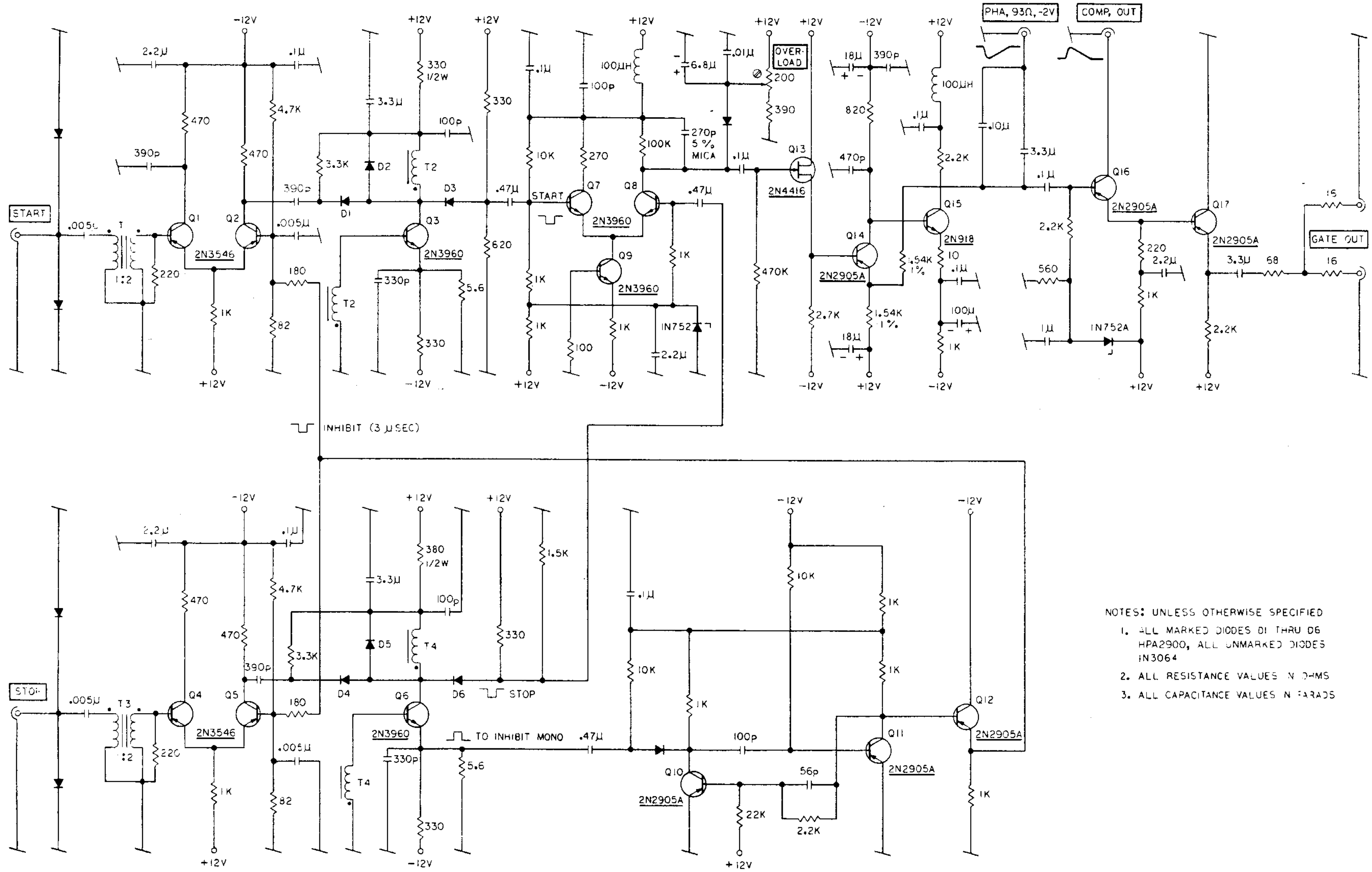
1148A10

FIG. 10



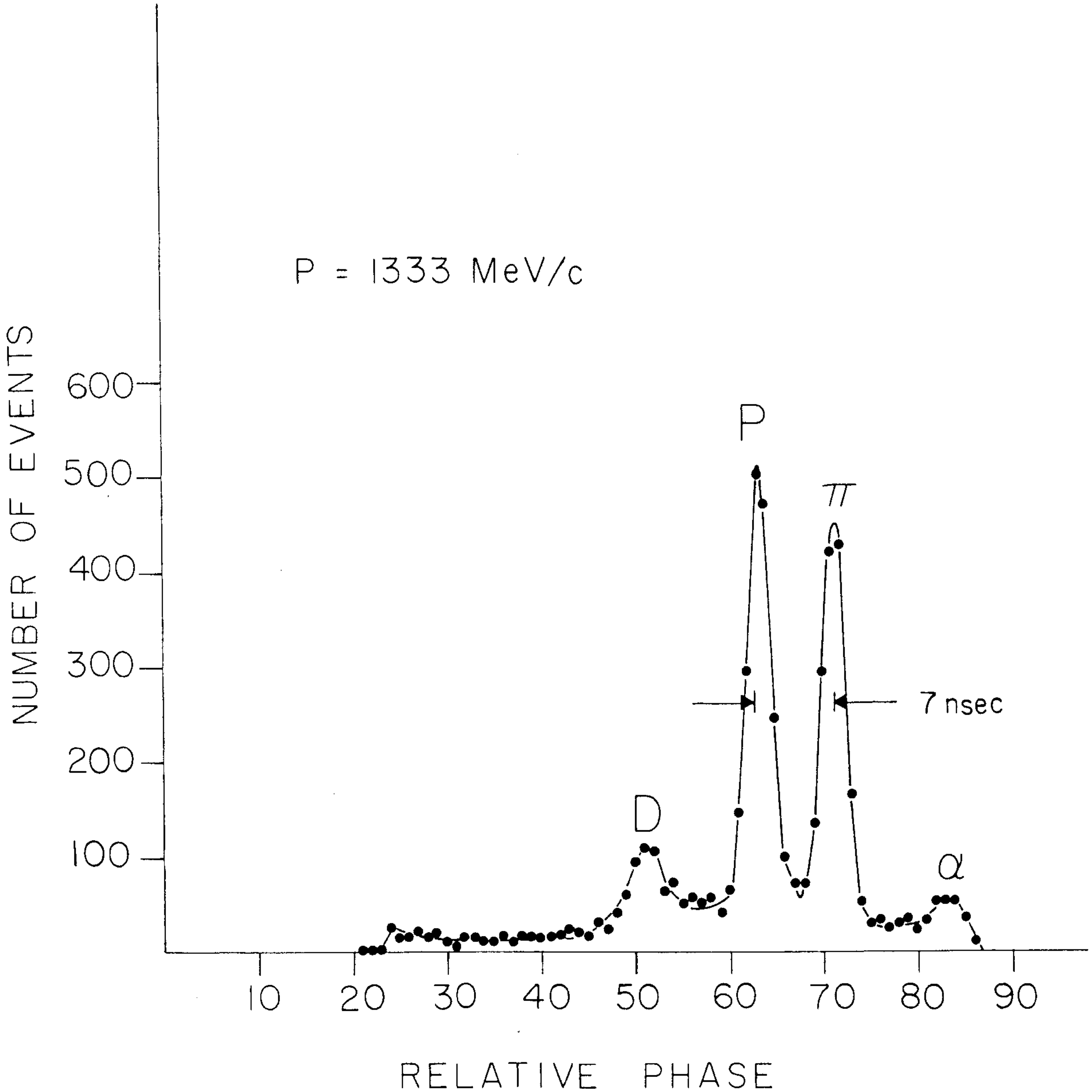
1148A11

FIG. 11



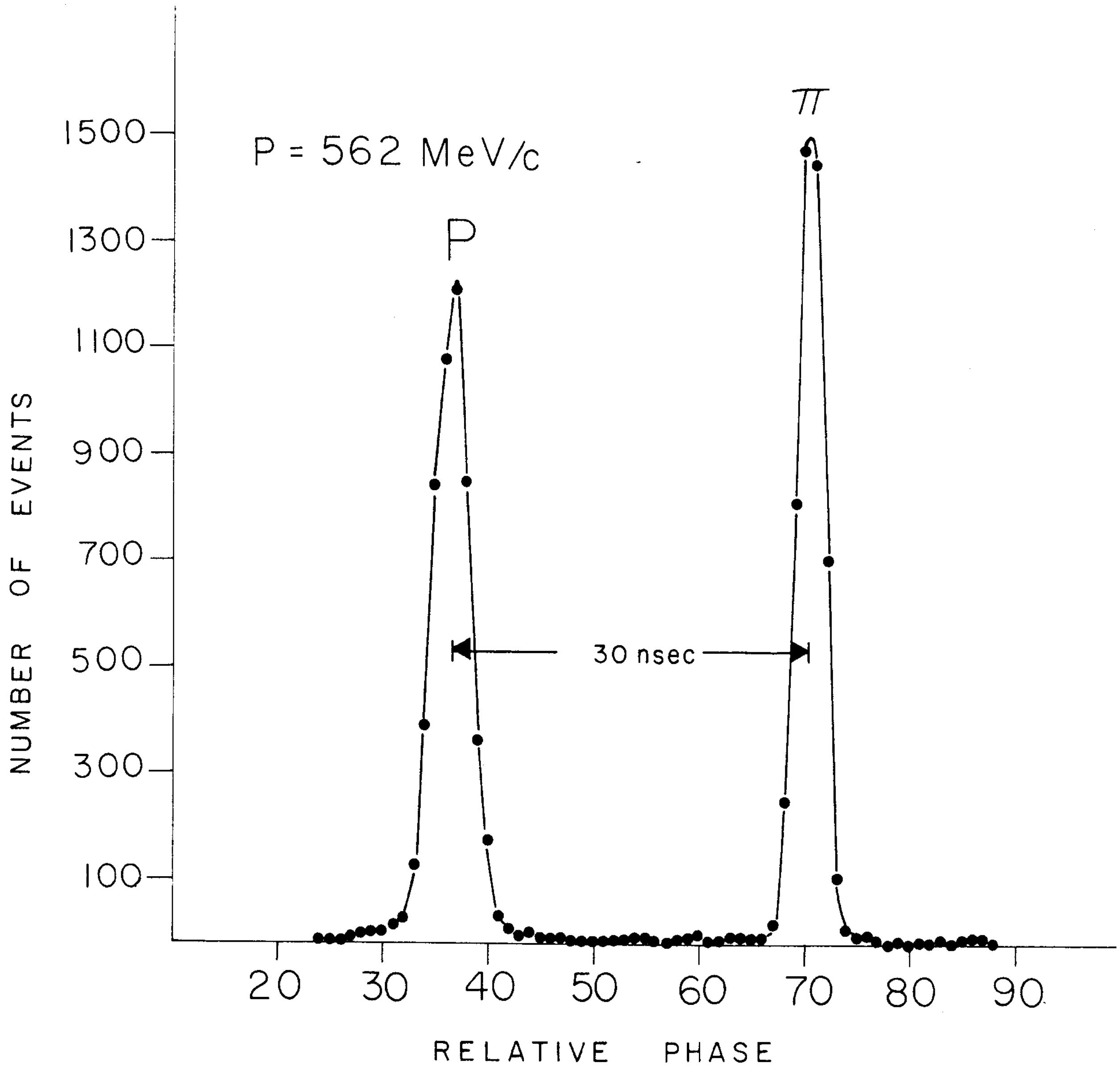
1148A12

Fig. 12



1148A13

Fig. 13



1148A14

Fig. 14

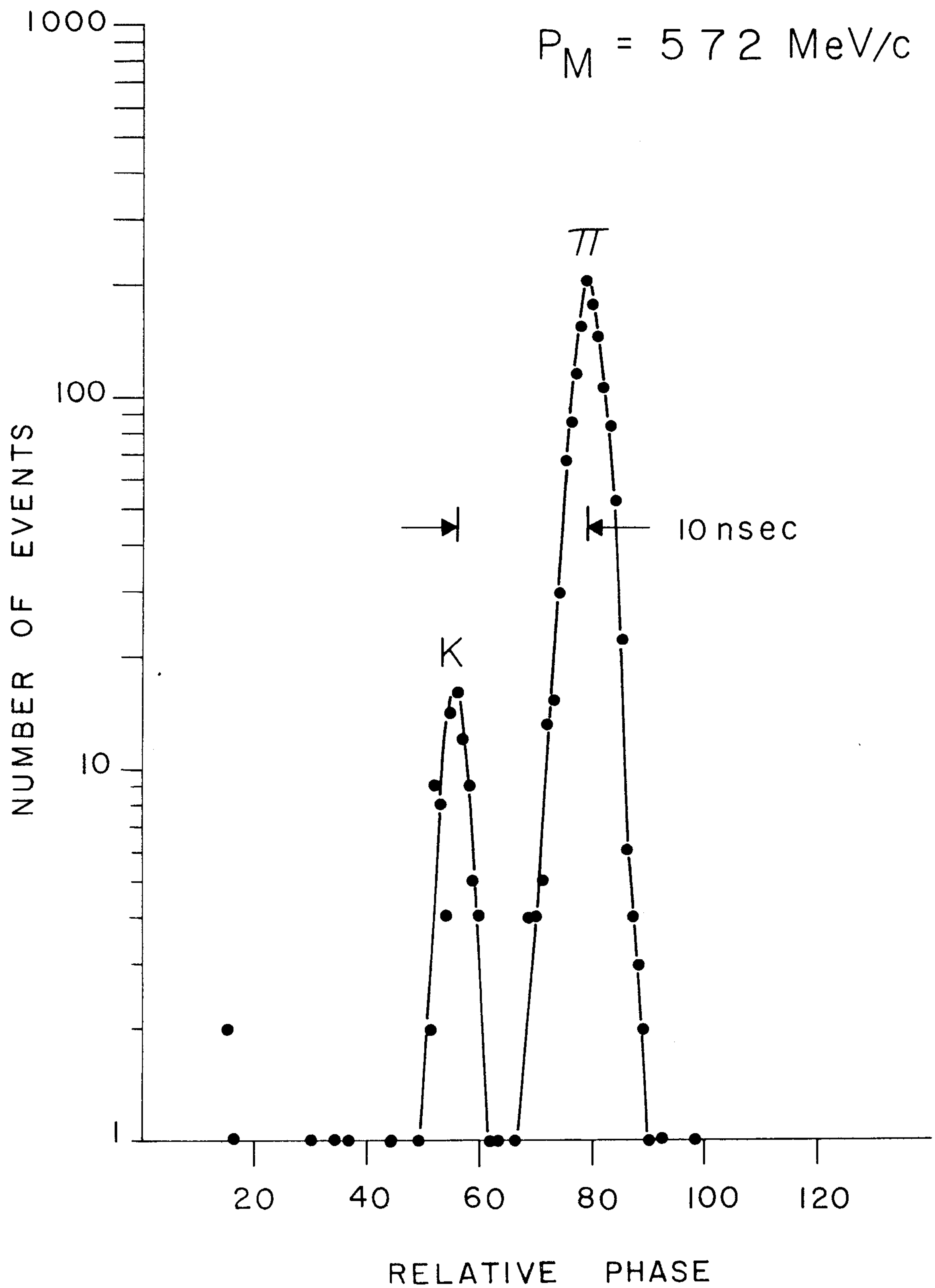


Fig. 15

1148A15