MASTER THESIS

THE CATHODE READ OUT METHOD

FOR

THE LIMITED STREAMER TUBE

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CONTENTS

ABSTRACT

Limited streamer tubes are being constructed to determine incident positions of charged particles into lead glass calorimeter in TRISTAN VENUS detector. As a part of R and D work on TRISTAN VENUS detector, a test limited streamer tube was made and its performances were examined. The measured performances are output pulse amplitude, spatial resolution, separation of two tracks, dead space and recovery time. The spatial resolution is 2 mm, and for double tracks we obtained the same resolution if the separation of two tracks is longer than 6 cm. The measured recovery time is about 400 μsec and the dead space is less than 6 mm. It was concluded that the streamer tube has good enough performances to be used in the VENUS detector.

1.0 INTRODUCTION

1.1 TRISTAN VENUS detector

At National Laboratory for High Energy Physics (KEK), TRISTAN project is scheduled operating to start in fall of 1986. In this project, electrons and positrons are accelerated to about 30 GeV in the main ring, and collide at four interaction points, producing a center of mass energy of about 60 GeV. VENUS is one of experimental groups who work at the four interaction areas. In FIG-1, the outline of the VENUS detector is shown. The main purposes of VENUS are following.

1. Test of the standard electroweak theory (Glashow Weimberg Salam theory)

2. Search for top quark

3. Toponium physics (including search for Higgs boson)

4. Search for sequential heavy leptons

5. Test of QED and QCD

6. Neutrino counting

Seeing FIG-1, a central drift chamber and a super conducting magnet, which determine the momentum of charged particles, are surrounded by a cylindrical electromagnetic lead glass calorimeter. This calorimeter measures the energy of electrons (positrons) and photons. There are 5160 lead glass modules. Each module is of about 18 radiation length, with cross sectional area of 12 cm x 12 cm. It is a total absorption type shower calorimeter. The structure is of semi-tower geometry (see FIG-1) in order for particles not to pass through the gap of the lead glass blocks. The energy resolution is expected to be $7/\sqrt{E} + 2$ %. (2 % is a systematic error.)

In FIG-2, a result of the calibration experiment for the sum of the pulse height of two lead glass blocks with respect to the entrance position of electron beam is indicated. From this figure, we know that the sum of the pulse height drops by a few % if the entrance point of the beam is at the edge of the block. This pulse height variation has to be corrected in order to calibrate the energies of electrons (positrons) to the level of 1 % . For this purpose, two layers of limited streamer tubes (Barrel Streamer Tube or BST in short) are installed between the cryostat and the calorimeter (FIG-1). BST can also be used to determine the positions of photons. Some of the photons convert to the electron-positron pairs in the super conducting magnet or materials of other counters in the region between the interaction point and BST. If they convert, the accuracy of the production angle obtained by BST is much better than lead glass calorimeter. [1]

BST consists of 1200 streamer tubes and have a two layer structure staggered by half a cell. (see FIG-3) Each tube is 4.5 m long and has a rectanglar cross section of 19 mm x 13.5 mm. Tubes are made of resistive plastic. BST surrounds the cryostat cylindrically. As shown in FIG-2, the width of low pulse height region is about 1 cm, so the spatial resolution of BST must be better than 1 cm. For ϕ-direction, which is defined as an azimuthial direction of VENUS detector around the beam axis, spatial resolution of half a cell is good enough. Therefore a discriminator is used for each streamer tube to detect only whether a signal appears or not on the anode wire. On the other hand for z-direction, which is defined as a direction along the beam axis, cathode read out method described in section 1.3.2 is used because this method has good spatial resolution. The width of cathode strip is 25.4 mm and the width of the gap between strips is 12.7 mm. This paper is described about the R and D work of BST.

1.2 Limited Streamer Tube

The basic structure of a common single wire chamber is illustrated in upper picture of FIG-4. The shape of the chamber's cross section is either circle or square. The chamber is sealed hermetically with endcaps, and Argon gas mixed with quenching gas like methane, ethane, iso-butane and so on flows through holes in the endcaps. A thin wire is stretched as an anode between the center of each side of endcaps. A high voltage is applied to this anode wire.

In FIG-5, different modes are depicted as the function of the applied voltage. The first mode is the ionization mode. In this mode, the charge collected at the anode wire is just the number of electrons liberated by the incident charged particle. Ionization chambers are operated in this mode. [2],[3]

The second mode is the proportional mode. The electric field near the anode wire is stronger than that in ionization mode, so electrons are accelerated so far as to ionize gas molecules. As a result of a multi-process of this secondary ionizations and emission of photons which are converted to electrons, the avalanche occurs near the anode wire. The size of the output signal depends on the number of primary electrons. [2],[3] The chambers operated in this mode are M.W.P.C., drift chamber, and so on.

The third mode is the limited streamer mode in which we operate. Geiger-Muller mode takes the place of this mode in the case of small concentration of organic gas. [4] In other words, we must mix quenching gas at rather large concentration with argon gas to operate chambers in the limited streamer mode. For example, Ar : ethane = 1 : 1, Ar : isobtane = 1 : 2 and so on. General properties of this mode are as follows; a large signal amplitude, a leap structure in pulse height vs high voltage relation, a good localization of a discharge on the anode wire, and a resultant small dead zone in comparison with GM mode,and independence of amplitude signals on the magnitude of primary ionization. [4],[5],[6],[7],[8]

When we operate wire chambers in the limitted streamer mode, we can get the large signals, but on that account we cannot avoid the rather large dead time. [4],[7]

The mechanism of this mode is following. If the number of electron-ion pairs of the avalanche is much greater than that in proportional mode, the space-charge field is large enough to partially cancel the applied field. So electrons are cooled and radiative recombinations of electrons and positive ions occur. As a result, photons are emitted from the avalanche. Some of these photons produce electron-ion pairs outside of the space charge cloud. These electrons drift back to the avalanche. A few of these electrons can multiply at the tip of the positive ion cone where the field is the highest. So streamer grows. If an electron is created far enough away along the wire, another avalanche could occur. But such a chance is small. [4],[6]

In GM mode the localization of discharge is lost and the discharge spreads along the anode wire. Pulse amplitude and dead time are much larger than those in limited streamer mode. All output pulses are of the same size, regardless of the number of primary electrons. The mechanism of the GM mode is following. The initial avalanche emits a number of photons which ionize gas atoms apart from the avalanche. So new avalanches are created in the space to either side of the initial avalanche. These in turn produce further contiguous avalanches, and the process continues until avalanches have been created all the way down the wire in both directions from the original site. [4]

The last discharge mode is the spark mode. The spark corresponds to a current flowing in a gas from the anode wire to the cathode. There are two classes of breakdown. The first, and slower of the two, relies on the feeding of normal avalanches with secondary electrons ejected from the cathode. The second invokes the streamer mechanism. It is rapid, as it only requires the growth of one avalanche to critical proportions and the two ends of the streamer advance quickly towards the electrodes. On arrival, the conducting plasma then connects the anode and the cathode.

BST is operated in the limited streamer mode because of its advantages, good localization of discharge and large output amplitude. As is described in section 1.1, BST is 4.5 m long and consist of a great number of tubes. For that reason it has to operate stably. And as they have large output signals, we need not use a pre-amplifier or even if need, it is enough to use a simple one.

1.3 Methods of Position Determination

In this section we describe how to determine the incident position of a chrged particle in the limited streamer tube. The method to determine the position perpendicular and along an anode wire, is accounted for in section 1.3.1 and section 1.3.2 respectively.

1.3.1 Measurement of Drift Time -

Electron-ion pairs are created by an incident charged particle. The electrons drift at an approximetely unique velocity in the region from the production point to the neighbourhood of the anode wire, because the electric field in this region is approximately uniform. If we know the drift velocity of an electron, the incidence position perpendicular to an anode is easily determined with this time interval. Ordinarily the drift velocity is about 1 mm per 20 nsec. The spatial resolution using this method is usually expected to be several hundred microns. [2],[3]

1.3.2 Charge Division Method and Cathode Read Out Method -

A resistive metal wire is used as an anode wire in the charge division method. We get two signals from each end of the anode wire. The wire has a large resistance, so the ratio of pulse heights from each side is a function of the avalanche position. If we know this relation, it is possible to determine the incidence position of a charged particle along the anode wire. [5],[9],[10] Weak points of this method are that a spatial resolution is worse at either end of the wire, and that we cannot determine the position when two or more charged particles pass through the tube simultaneously.

In the cathode read out method a resistive plastic tube is used for the chamber body. Strips of conductors are attached outside the tube to be used as read out cathodes as shown in lower picture of FIG-4. Moving charges, electrons and positive ions in the tube, induce charges on the strips. From the pattern of induced charges on each strips we can determine the incidence position of a charged particle along the anode wire. The relation between the position and the corresponding pattern has to be investigated. [11],[12]

Using this method, we can expect a good spatial resolution independent of a detection position, and we have a possibility of determining the incidence positions for two or more charged particles if they are wide apart from each other. For this advantage, we study this method.

2.0 R and D TEST TUBE

Several kinds of performances of the limited streamer tube are measured. It has the same shape as illustrated in FIG-4. The tube's length is about 70 cm, and its cross section is 20 mm x 15 mm. The anode wire is made of Be Cu, W and of 50 m diameter. The tension of the wire is about 210 gramme. The width of the cathode strip is 25.4 mm and its spacing is 12.7 mm. The gas mixture is Ar : ethene = 1 : 1 and ethyl alchohol is added to this gas at the atomospheric pressure. In FIG-6, the single rate of this tube with ^{90}Sr source is indicated with respect to the applied high voltage. To operate the streamer tube stably, the high voltage in the platau region in this figure has to be supplied to the anode wire. The high voltage about 3.1 kV was selected. An oscilloscope picture of output pulses from the anode wire is shown in FIG-7. Ordinate is a time sweep and 50 nsec/div. Abscissa is a voltage and 20 mV/div.

3.0 MEASUREMENT

3.1 Output Amplitude

First, the quantity of charge from the anode wire was investigated. The set-up used for this investigation is shown in FIG-8. The anode wire is connected to a charge sensitive pre-amplifier, CANBERRA 2005, and the output sent to Le-Croy 3001 qVt (multi channel analyzer). For a charge calibration, the streamer tube is replaced by a capacitor and a signal whose decay time is long is applied to this capacitor. Because charge in the capacitor is the product of known capacitance and the voltage, we can calibrate this system.

In FIG-9 the quantity of charge induced on the anode wire is indicated as a function of the high voltage. Measurements were done using a β-source ^{90}Sr and a γ-souce ^{55}Fe. FIG-9 shows that there are two leaps in quantity of charge. The lowest mode is the proportional mode, where the primary ionization is proportional to the amount of pulse height. The other two modes are limited streamer modes.

In this figure there are two leaps. The first leap is from the proportional mode to the lower mode of the limited streamer mode. In the proportional mode, the avalanche is localized in a small part of the anode wire and only near the wire. As is described in section 1.2, the limited streamer appears suddenly when the space charge field of the avalanche becomes stronger. The stramers develop from the primary avalanche propagating from the anode wire along the field lines. The second leap is from the lower mode to the higher mode of the limited streamer mode. In the higher mode the streamer becomes more widely spread and involves a greater part of the anode wire than that in the lower mode. [4]

3.2 Position Determination

3.2.1 Charge Ratio Method -

In section 1.3.2, the method to determine the position along the anode wire and advantages of the cathode read out method has been mentioned.

There are two ways to determine the position using cathode read out method. One is to use a charge weighted average, and the other is to use the ratio of charges induced on one strip and the next. The former is called the charge centroid method and the latter method is called the charge ratio method. [11],[12]

The concept of the charge ratio method is illustrated in FIG-10. An avalanche occurs near the anode wire. The charge distribution induced on the cathode plane is indicated conceptually in FIG-10. The charge Q1 on the strip-1 is largest because the strip-1 is nearest to the avalanche. The charge Q2 is induced on the strip-2 which is next to the strip-1. This ratio Q2/Q1 has a relation to the position of the avalanche. Therefore if we know this relation, we can determine the position. The spatial resolution using this method is better than that using the charge centroid method when the spacing of the strips is wide. [11] If the charge ratio method is used, the spatial resolution does not become so bad with the rather wide spacing of the strips. For that reason we decided to use the charge ratio method to decrease the number of the read out channels.

3.2.2 Calibration Curve -

In the previous section, the need to know the relationship between the ratio Q2/Q1 and the corresponding position was mentioned. Theoretical calculation [12],[13] is difficult because strips are on the cathode plane and this plane is a conductor with high resistance. So the calibration curve was made by a mesurement. The set-up of this measurement is shown in FIG-11. A N pulse LASER, MOPA-600S, was used for this measurement. The total output energy a pulse of this LASER is 0.35 mJ, the pulse width is 500 psec (FWHM), the beam demension is 2.5 mm x 1.2 mm and the maximum frequency of the shots is 3 pps. The pulses of the LASER which pass through the pinhole of 1.5 mm diameter enters the limited streamer tube through a small hole picked on the tube and goes out from the tube through the same hole. The diameter of the hole is about 1.6 mm.

Trigger signals are generated from the photo-detector, SCIENTECH, INC. MODEL 301-020 HIGH SPEED PHOTODETECTOR whose resolution is 1 nsec. Ionization mechanism in the tube is following. Energy of photons is 3.7 eV (λ = 337.1 nm). Ar, ethane and ethanol gas flow in the tube. Their ionization energies are 15.8 eV, 11.8 eV and 10.6 eV respectively and these energies and their first exciting levels are above the energy of photons. Atoms in these gas cannot be ionized by a photon of LASER. But it is reported that the small concentration of impurity in the gas absorbs one or two photons and is ionized. [14],[15],[16],[17]

The LASER beam enters in the streamer tube at various points, and we obtained the ratios Q2/Q1 as a function of the entrance positions. The result of this measurement is shown in FIG-12. A fourth degree polynomial with least squares fit is used for the calibration curve. The polynomial is

$$Y = A_4 * X^4 + A_3 * X^3 + A_2 * X^2 + A_1 * X + A_0$$

$$A_4 = 97.9$$

$$A_3 = -271.2$$

$$A_2 = 282.2$$

$$A_1 = -144.0$$

$$A_0 = 35.1$$

where X is the charge ratio and Y is the corresponding position. In FIG-12 the calibration curve is also drawn. FIG-12 shows that small value of the ratio can't be used. From now on, this polynomial will be used to determine the position.

3.3 Cosmic Ray Test

In order to test the charge ratio method with the calibration curve mentioned in the previous section, position resolution of single tracks was measured using cosmic rays. The set-up is illustrated in FIG-13. The position where the charged particle enters the streamer tube is decided with two M.W.P.C.s placed above and below the streamer tube. The trigger signals are generated by the coincidence of two scintillation counter signals.

In FIG-14, the difference between the

position decided with M.W.P.C.s and that determined using the charge ratio method is shown. From the figure, we obtained the spatial resolution of about 2 mm (root mean square). The efficiency of this tube in this measurement is about 99 % . We show a pulse height spectrum of the cosmic rays in FIG-15, and that of LASER in FIG-16. The spectrum in FIG-15 is almost the same as that in FIG-16. This property that the pulse height is independent of the primary ionization is one of the characteristics of the limited streamer mode. (section 1.2)

3.4 Separation of Two Tracks

The limited streamer tubes in VENUS are 4.5 m long, and there are many chances that two or more particles hit the same tube simultaneously. Therefore the ability to separate multi-tracks is very important. If we use the charge ratio method, we may be able to determine the entrance positions of two or more charged particles. In this section we mention the separation of two tracks in the tube, but we can consider similarly the case of three or more tracks. BST is 4.5 m long, and this posibility is very important.

In FIG-17 the set-up to measure two particle separation is illustrated. The LASER beam is separated in two beams using a half mirror, KOYO SU-25 BEAM SPLITTER made from UV Silica. These beams are parallel to each other, and enter the tube simultaneously. Trigger signal is generated with a photo-detector at the down stream of the tube. The ionization mechanism is mentioned in section 3.2.2. The separation of two beams is changed in various length from 1 cm to 19 cm. If the separation is short, induced charges from one avalanche and other pile up on a single cathode plane. In FIG-18 the outline of the piled up charge distribution is shown conceptionally. When two tracks enter the streamer tube at a rather wide distance, the charge distribution on the cathode plane has two isolated peaks (FIG-18,(A)). When the distance becomes narrower, the two peaks overlap (FIG-18,(B),(C)). When the charge distribution is (A) or (B) of the figure, we can calculate the two incident positions by the charge ratio method. But in the case of (C), we can't determine the two positions. The critical distance beyond which we can separate the two positions is about 6 cm. In FIG-19 the relation between the incident beam separation and the measured distance of two pulses is shown. The spatial resolution is about 2 mm (root mean square), and is the same as that of the cosmic ray data. The pulse height spectrum when two beams are incident is shown in FIG-20. In comparison with the spectrum in FIG-15 or FIG-16, the pulse height of two beams is about twice as large. From this we can judge whether one or two particles hit the same strip. But according to FIG-16 the sigle particle spectrum has a long tail and about 10 % overlaps with that of two beams on FIG-20. So even when the separation is less than 6 cm, at least we know that two particles are incident with 90 % probability.

3.5 Dead Space and Recovery Time

We can get large signals in the limited

streamer mode, but for that reason we can't avoid rather large dead space and recovery time in this mode. [4],[7] After a streamer develops, some space of the streamer tube is partially charged up and the field becomes partially weak. So this space is insensitive for the charged particles. The dead zone is interpreted as the product of the effective length of a small part of the anode wire that becomes insensitive after the pulse formation, and the recovery time of that part. The set-up for the measurement of dead zone is illustrated in FIG-21. We used the same method as Alekseev [4]. A delayed self-coincidence method was used for this measurement. The method is following. The anode signal is separated in two signals with a discriminator. And one signal passes through the variable delay and make coincidence with the other one. The collimated source ^{90}Sr was used for this measurement. If a delay time is t and the second signal appears after t from the first signal, the second signal is coincident with the delayed first signal.

The dead space d(t) at time t is described as

$$\frac{N_\infty - N(t)}{N_\infty} = \frac{d(t)}{L} - \left(\frac{d(t)}{2L}\right)^2$$

where N_∞ is the count of the coincidence when the delay is large and there is no dead zone, N(t) is the count when the delay time is t and L is the width of a collimator. The right hand side is the probability that a particle enters the dead space at time t. And the left hand side is the probability that the streamer tube is dead at time t. The width of the collimeter is 1.5 cm. The result is shown in FIG-22. The recovery time is about 400 μsec, and the dead space d(t) is shown in FIG-23 as a function of time. The dead space is less than 6 mm after 20 μsec from the streamer formation.

4.0 CONCLUSION

We measured the output amplitude of the limited streamer tube as will be used in the VENUS barrel detector, and obtained the charge of 60 pC. The amplitude is independent of the primary ionization. The spatial resulution along the anode wire is about 2 mm (root mean square). For double tracks we obtained the same resolution if the separation of two tracks is longer than 6 cm. If it is shorter, we can't determine the entrance positions. But it is possible to know the number of tracks using the pulse height information with better than 90 % probability. The measured recovery time is about 400 μsec and the dead space is less than 6 mm after 20 μsec from the streamer formation. The measured performances are good enough that it can be used as the VENUS Barrel Streamer Tube. However, we measured them when the LASER beam enters the streamer tube perpendicularly. At TRISTAN experiment, particles enter BST diagonally, so it is necessary to measure the spatial resolution and the separation of two tracks when particles enter the tube diagonally.

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FIGURES

FIG- 1;A quadrant of cross section of VENUS detector. Ordinate is the distance in meter along the beam axis from the interaction point. Abscissa is the radius in meter.

FIG- 2;The entrance position dependence of the pulse height of lead glass counters for the 4 GeV electrons. X=0 cm denotes the center of A1. Two blocks are 1 mm apart from each other and slided by 12 cm and tilted by 4 degree with respect to the beam direction.

FIG- 3;Barrel Streamer Tubes. The upper picture shows a cross section of an octant of BST. The lower curve is an enlarged view. Tube length is about 4.5 meter. BST consists of 1200 tubes and two layer structure staggered by half a cell. A boundary surface of the two layers is Al foil connected to the ground. The tubes are made from polystyrene added carbon. The resistance of the tube is about 100 kΩ/sqr.
Anode wire is made from Re, W and its diameter is 60 μm.

FIG- 4;Upper; Basic structure of the limited streamer tube. Lower; Cathode strips attached on the limited streamer tube which are used for the read out.

FIG- 5;Various discharge modes as the applied high voltage is increased.

FIG- 6;Single rates of the streamer tube using ^{90}Sr as a function of applied high voltage. The platau starts at about 3.1 kV.

FIG- 7;An oscilloscope picture of pulse outputs from the anode wire.

FIG- 8;The setup of the output charge measurement. Used sources are ^{90}Sr and ^{55}Fe. The charge calibration is done by connecting the switch to the reseach pulser.

FIG- 9;The quantity of output charge with respect to the applied high voltage. The lower line denotes the proportional mode. Upper two lines are the limited streamer mode.

FIG-10;A concept of the charge ratio method. The upper picture is the charge distribution induced on the cathode plane. The shaded area is the charge induced on the strips. In this picture the avalanche occurs near STRIP-1,so the charge Q1 induced on STRIP-1 is the largest. Q2 is the charge induced on

STRIP-2 which is the next strip of STRIP-1. From the ratio Q2/Q1 the position is calculated.

FIG-11;The set-up to obtain the calibration curve using pulse LASER. The pulses of N_2 pulse LASER,MOPA-600S, through the pin-hole whose diameter is 1.5 mm enter the streamer tube through a small hole picked on the tube's wall, and go out from the tube through the same hole.And they enter the photo-detector ,SCIENTECH, INC. MODEL 301-020 HIGH SPEED PHOTODETECTOR. The pulse heights of the anode and the cathode signals are measured by CAMAC 2249W ADC. The gate signal is generated by the photo-detector. For the several entrance positions into the streamer tube the charge ratio is measured.

FIG-12;Calibration curve. Ordinate is the charge ratio Q2/Q1 or Q3/Q1, and abscissa is the relative position about the strip. The origin of the position is the center of the strip. The position is fitted to the curve. This curve is fourth degree polynomial.

FIG-13;The set-up of the cosmic ray measurement. The position where the cosmic ray passes through in the tube is determined by two M.W.P.C.s,and trigger signals are generated from the coincidence of two scintillation counters.

FIG-14;A distribution curve of the deviation between the position decided by M.W.P.C. and that from the charge ratio method. M.W.P.C. has 2 mm spacing between anode wires. The spatial resolution of the streamer tube is about 2 mm (root mean square).

FIG-15;A pulse height spectrum of the cosmic ray.

FIG-16;A pulse height spectrum of LASER beam.

FIG-17;The set-up to measure the simultaneous two tracks using LASER. The pulses of LASER is separated by a half mirror, KOYO SU-25 BEAM SPLITTER made from UV Slica, and enter the streamer tube.

FIG-18;A sketch of the induced charge on the cathode plane when two particles enter the tube simultaneously. (A) is the case that the separation of two beams is large and the distribution has two isolated peaks. (B) is the case that the separation is narrower than that of (A) and two peaks of the distribution overlap but the case that we can realize two peak structure. (C) is the case that the separation is narrower than that of (B). In this case, we can't realize two peak structure.

The charge ratio method can be used to determine two positions when the pattern is like (A) and (B).

It is impossible to distingush two tracks from one beam when the pattern is like (C).

FIG-19;The entrance positions as determined by the charge ratio method with respect to the incident beam separation. If the separation is longer than 6 cm, the spatial resolution is about 2 mm (root mean square).

FIG-20;A pulse height spectrum of two simultaneous LASER beams.

FIG-21;The set-up to measure the dead time. β-ray from ^{90}Sr source through a collimeter whose gap is 15 mm enters the streamer tube. Anode signals are separated in two signals with a discriminator. And one signal passes through the variable delay and make coincidence with other one.

The width of the input of the coincidence is 10 μsec. The single rate of the streamer tube is about 660 cps.

FIG-22;The recovery time. Ordinate is the counts of the coincidence for 300 sec. A broken line indicates the average counts after 400 μsec. Abscissa is the delay time t.

FIG-23;The dead space d(t) with respect to time t.

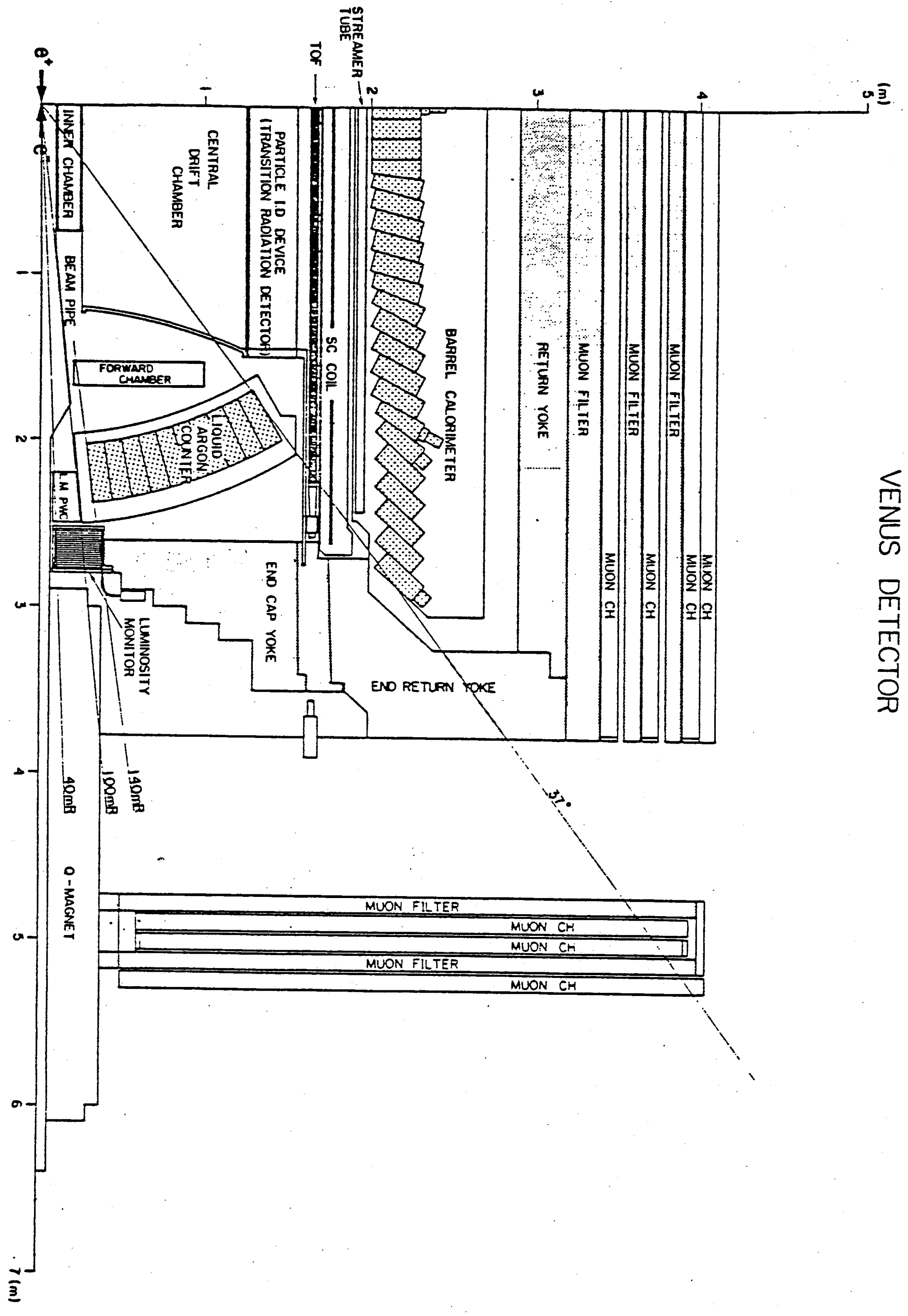

VENUS DETECTOR
e+
e-
INNER CHAMBER
CENTRAL DRIFT CHAMBER
PARTICLE I.D DEVICE (TRANSITION RADIATION DETECTOR)
TOF
STREAMER TUBE
SC COIL
BARREL CALORIMETER
RETURN YOKE
MUON FILTER
MUON FILTER
MUON FILTER
MUON CH
MUON CH
MUON CH
MUON CH
BEAM PIPE
FORWARD CHAMBER
LIQUID ARGON COUNTER
L.M PWC
LUMINOSITY MONITOR
END CAP YOKE
END RETURN YOKE
37°
140mR
100mR
40mR
Q-MAGNET
MUON FILTER
MUON CH
MUON CH
MUON FILTER
MUON CH
(m)
(m)

FIG-1

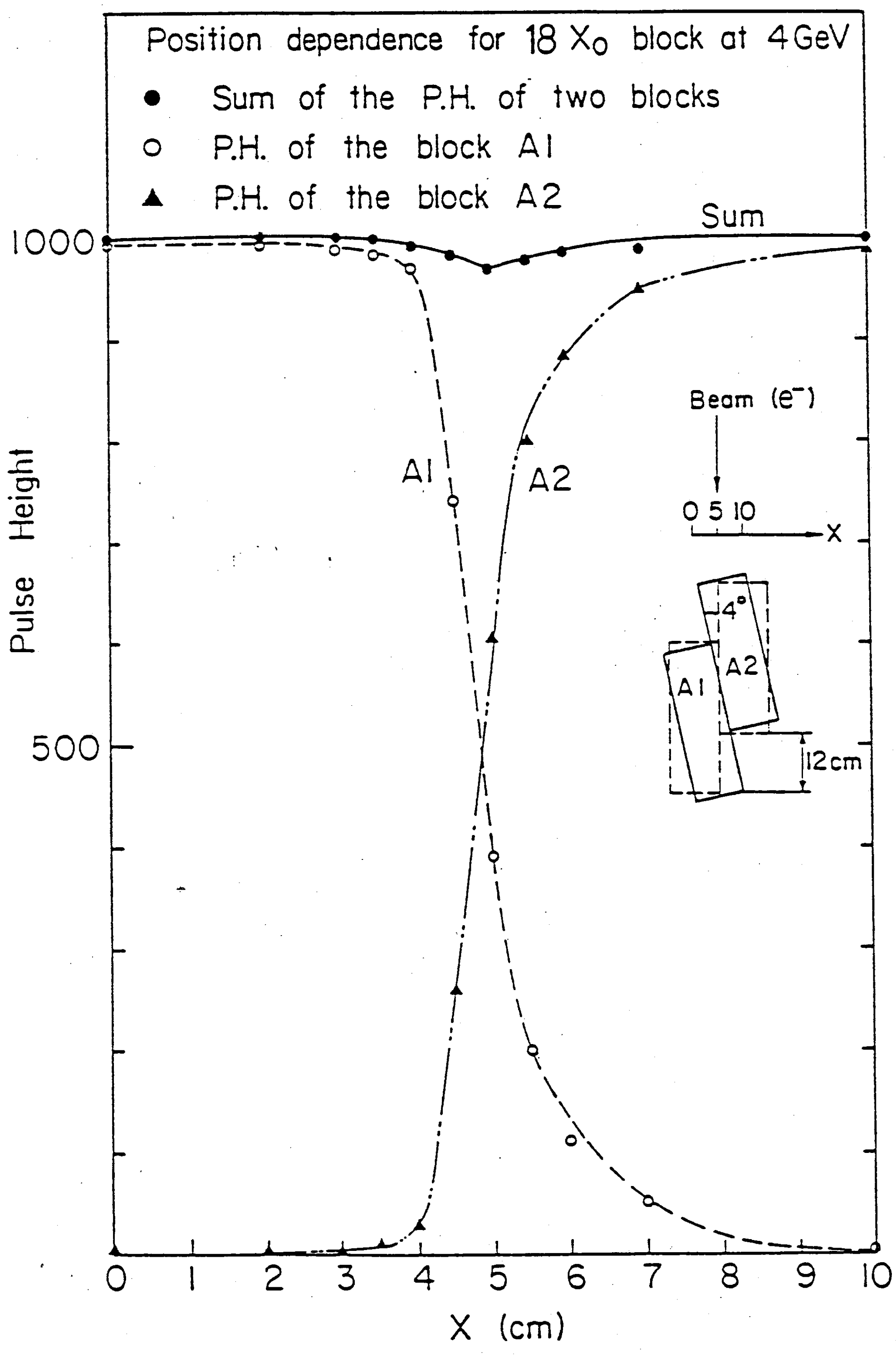

Position dependence for 18 X₀ block at 4GeV
Sum of the P.H. of two blocks
P.H. of the block A1
P.H. of the block A2
Sum
1000
500
A1
A2
Pulse Height
Beam (e⁻)
0 5 10
X
4°
A2
A1
12cm
0
1
2
3
4
5
6
7
8
9
10
X (cm)

FIG-2

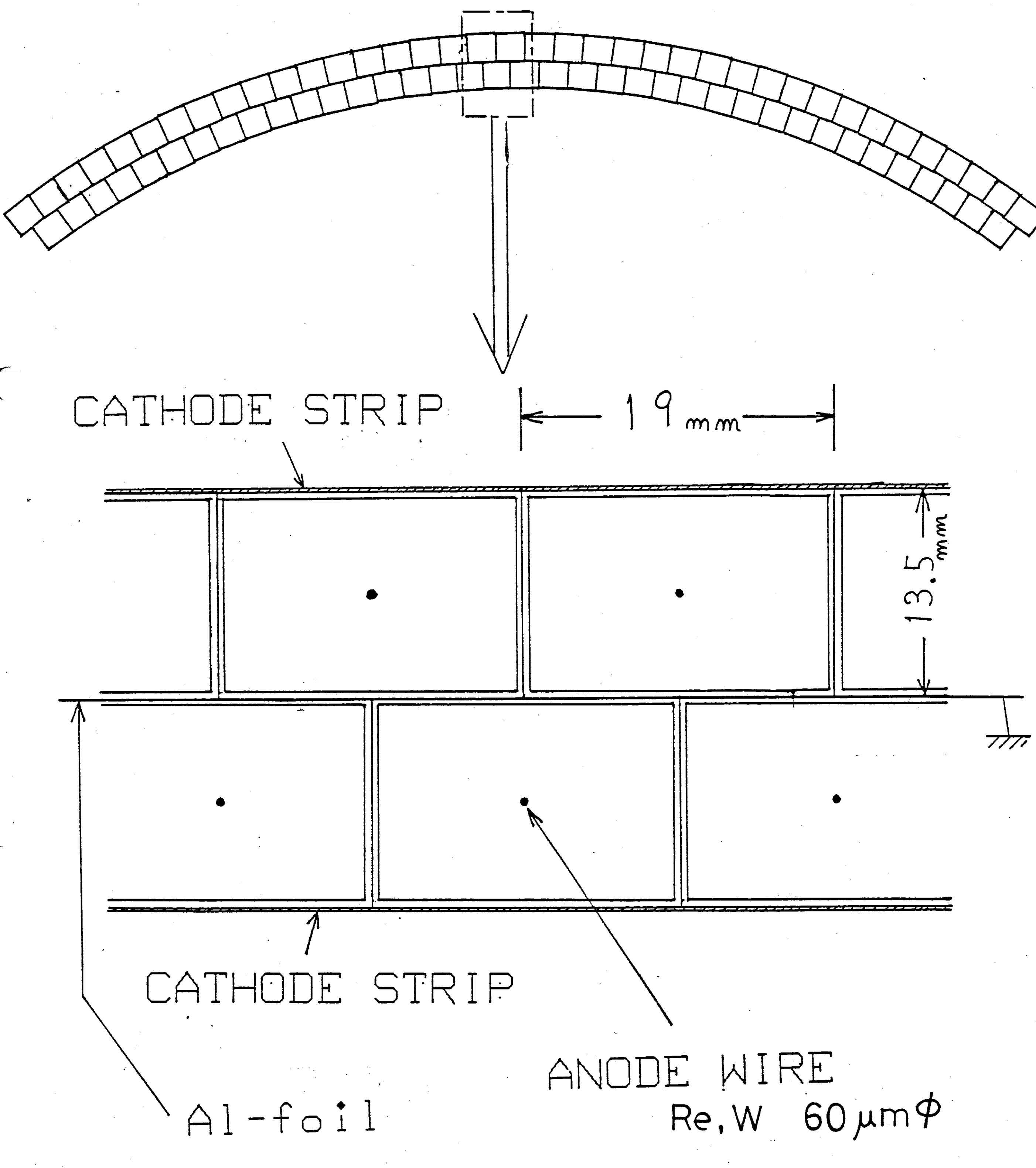

CATHODE STRIP
19 mm
13.5 mm
CATHODE STRIP
ANODE WIRE
Re, W 60μmΦ
Al-foil

FIG-3

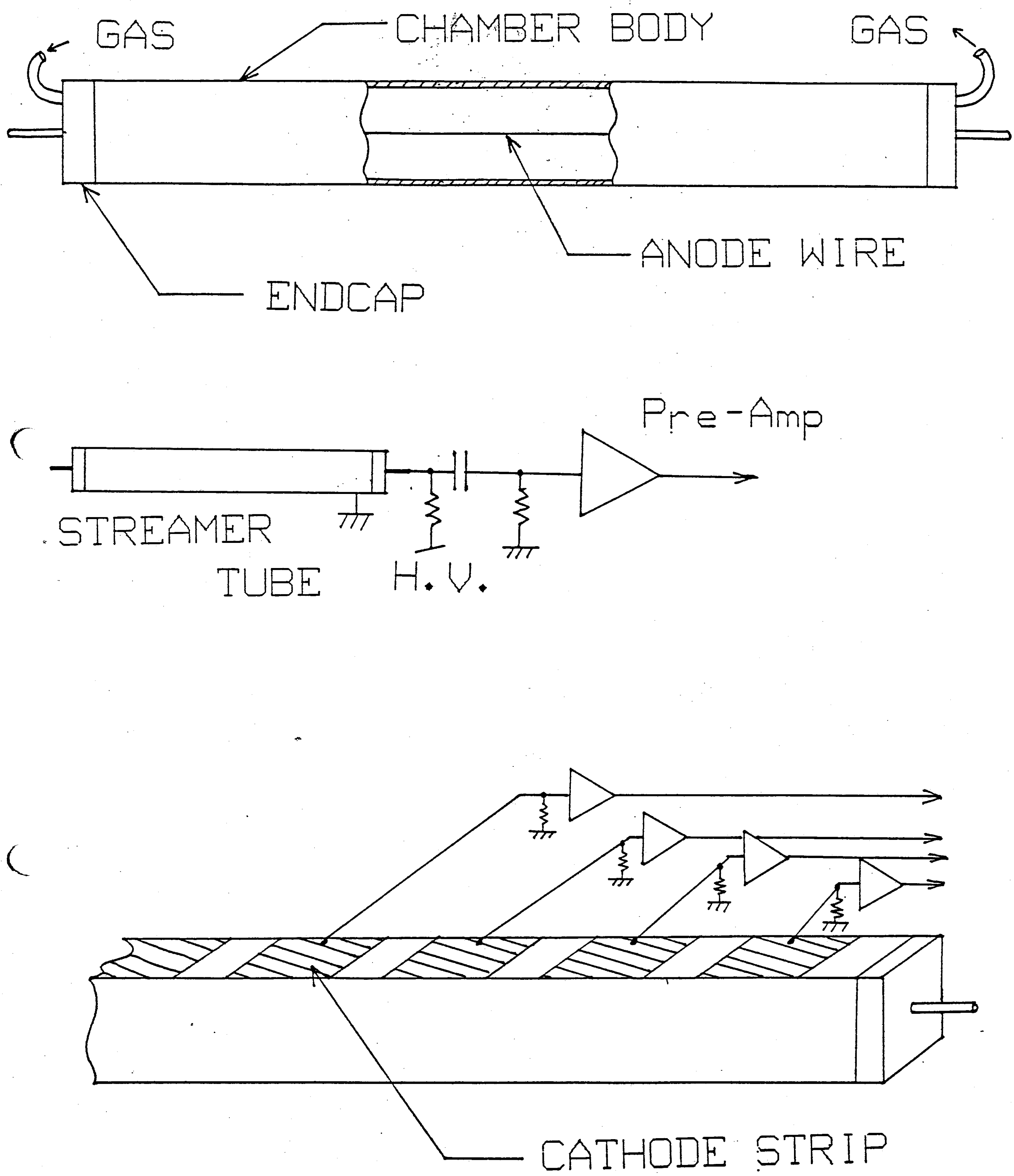

GAS
CHAMBER BODY
GAS
ANODE WIRE
ENDCAP
Pre-Amp
STREAMER
TUBE
H.V.
CATHODE STRIP

FIG-4

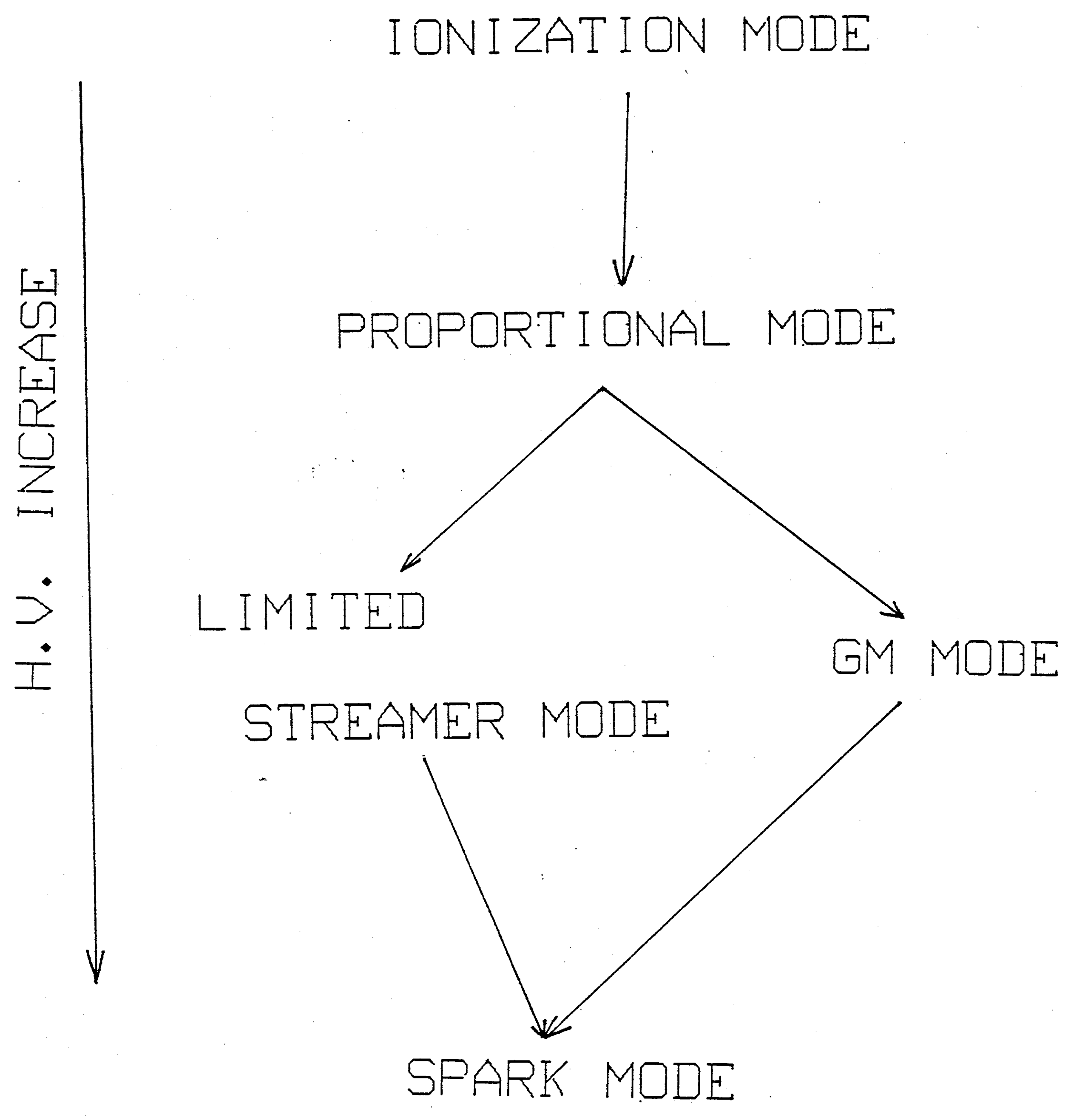
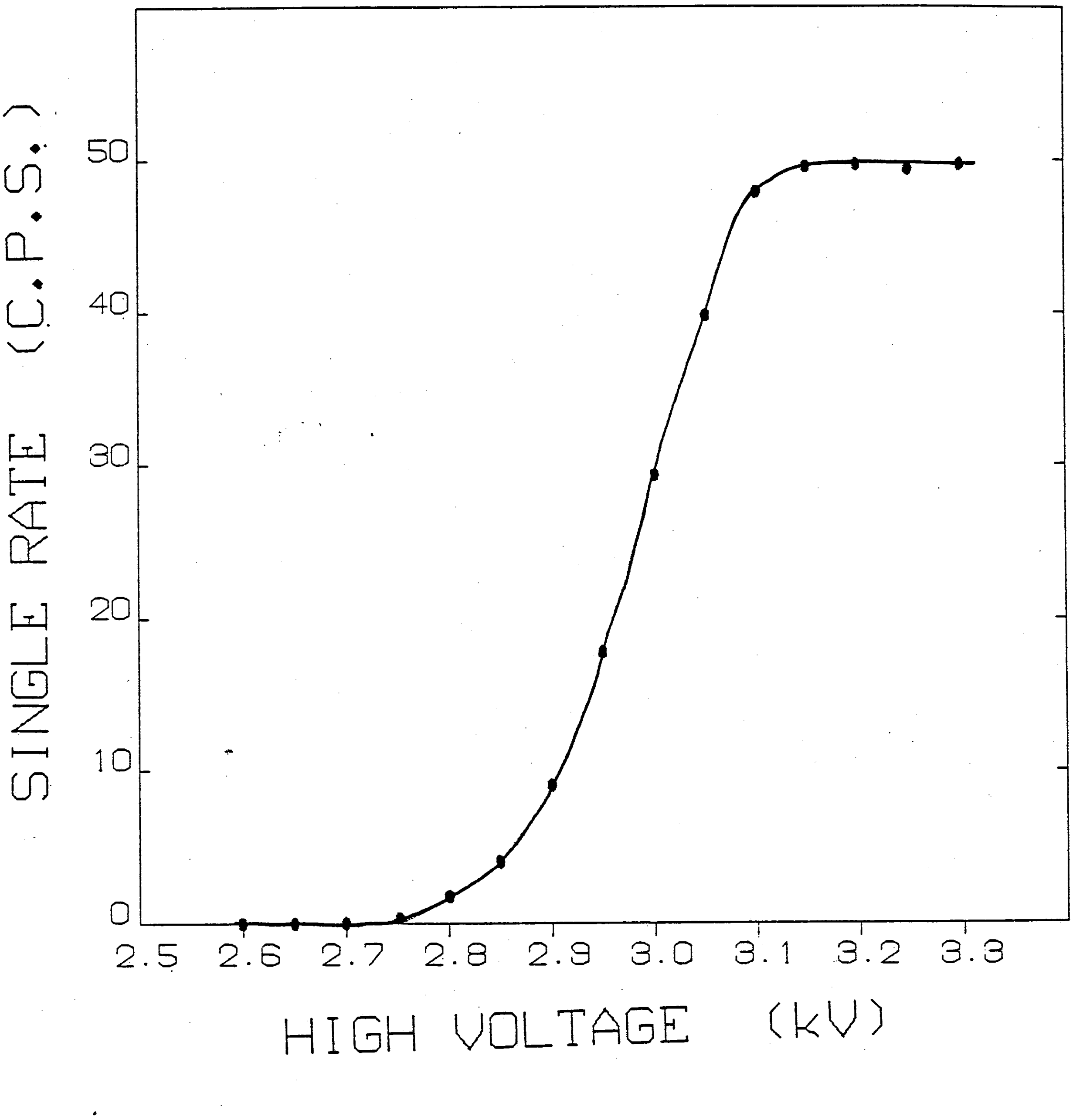
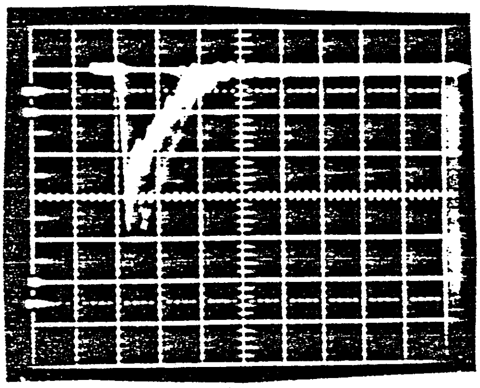

IONIZATION MODE
PROPORTIONAL MODE
LIMITED
STREAMER MODE
GM MODE
SPARK MODE
H.V. INCREASE

FIG-5



SINGLE RATE (C.P.S.)
50
40
30
20
10
0
2.5
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
HIGH VOLTAGE (kV)

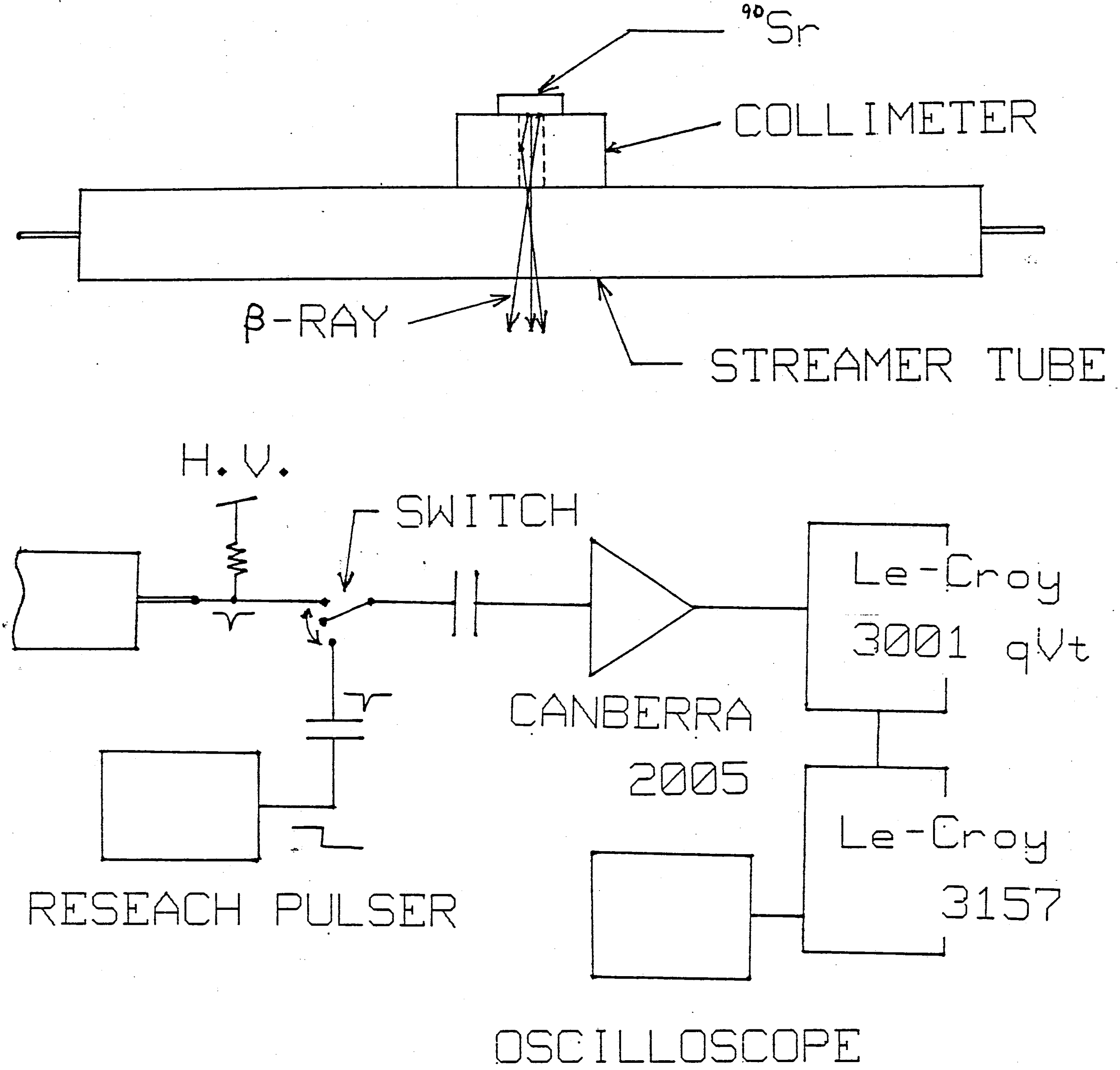
FIG-6



20 mV/DIV

50 μsec/DIV

FIG-7



90Sr
COLLIMETER
β-RAY
STREAMER TUBE
H.V.
SWITCH
Le-Croy
3001 qVt
CANBERRA
2005
Le-Croy
3157
RESEACH PULSER
OSCILLOSCOPE

FIG-8

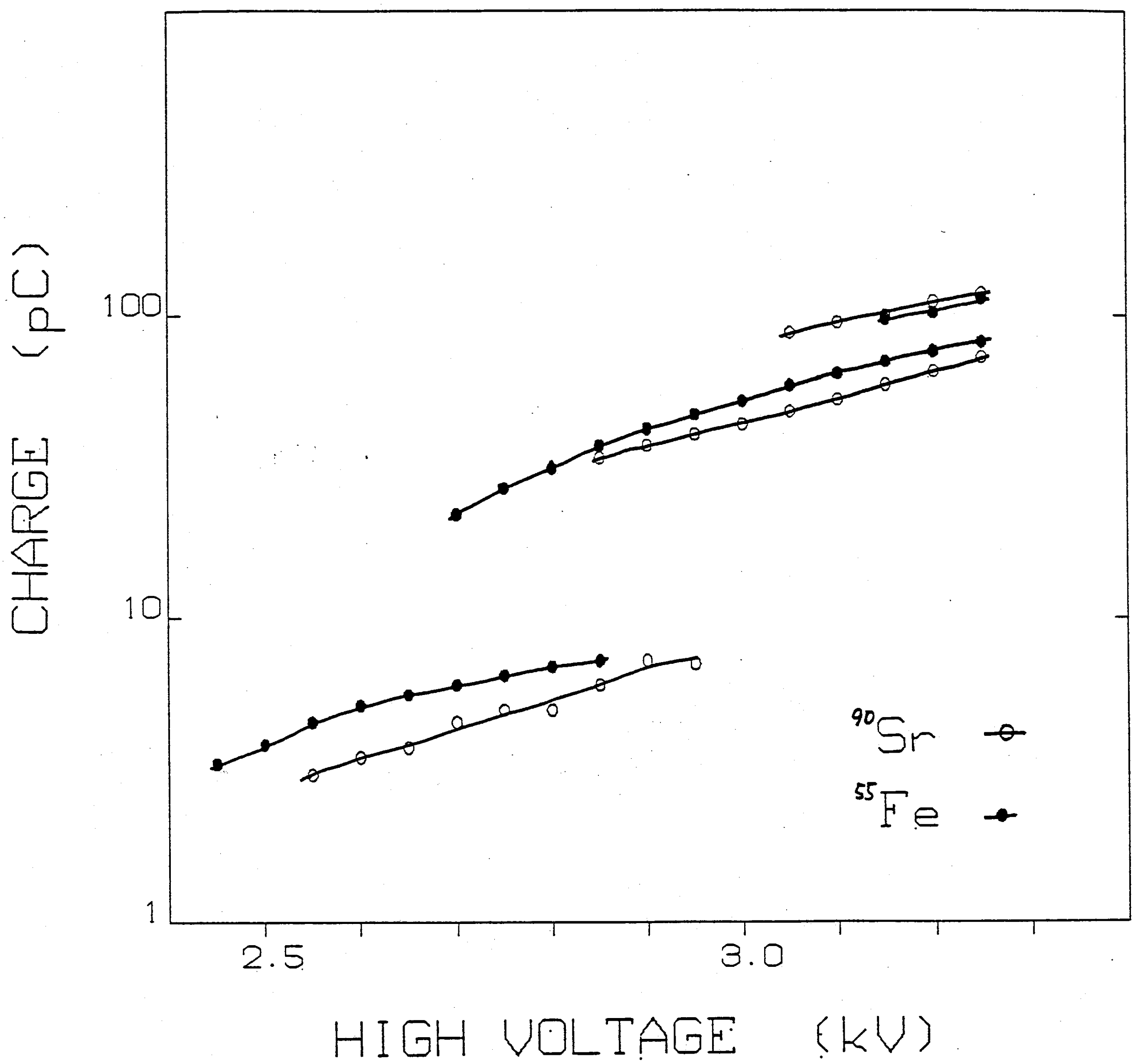


FIG-9

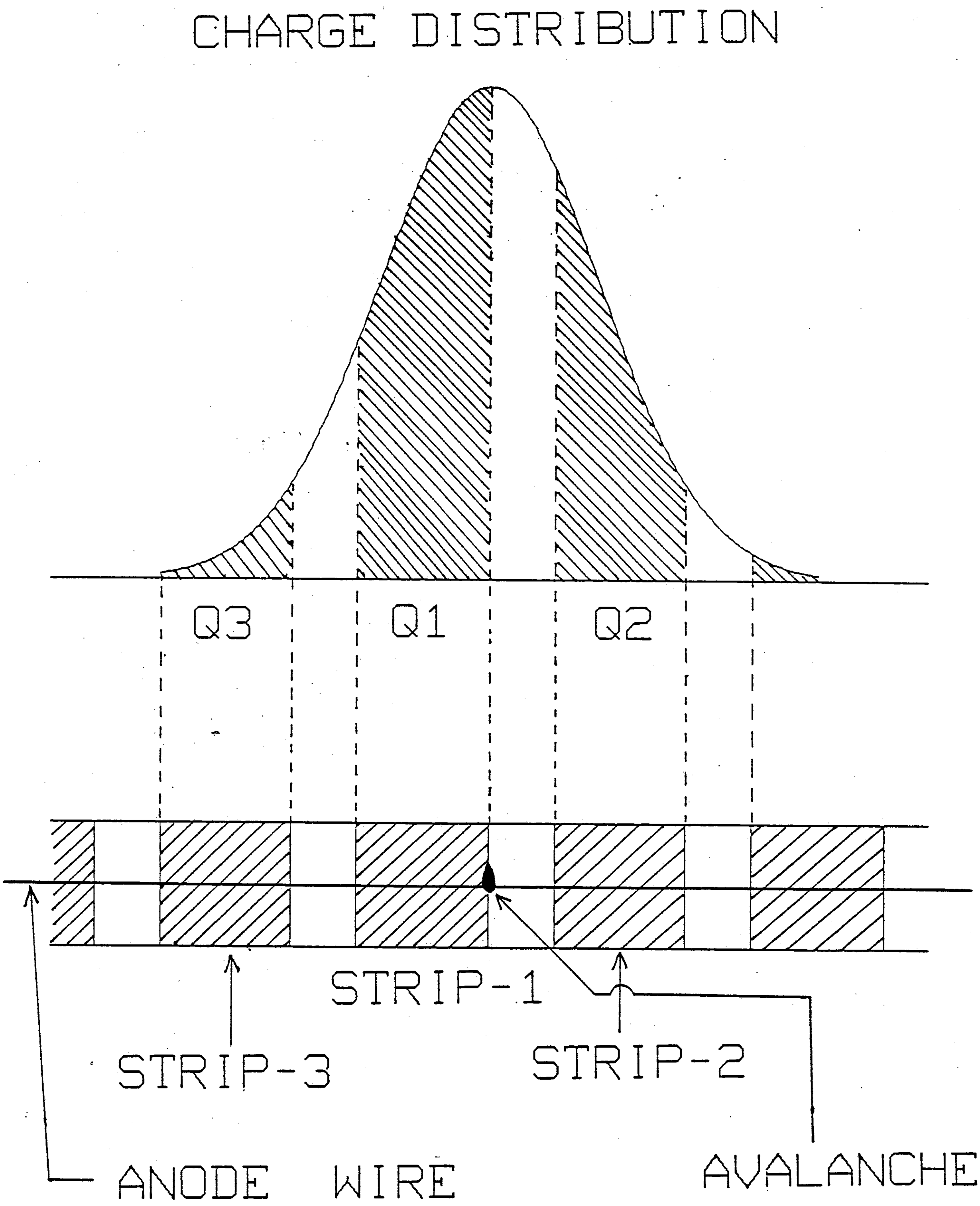
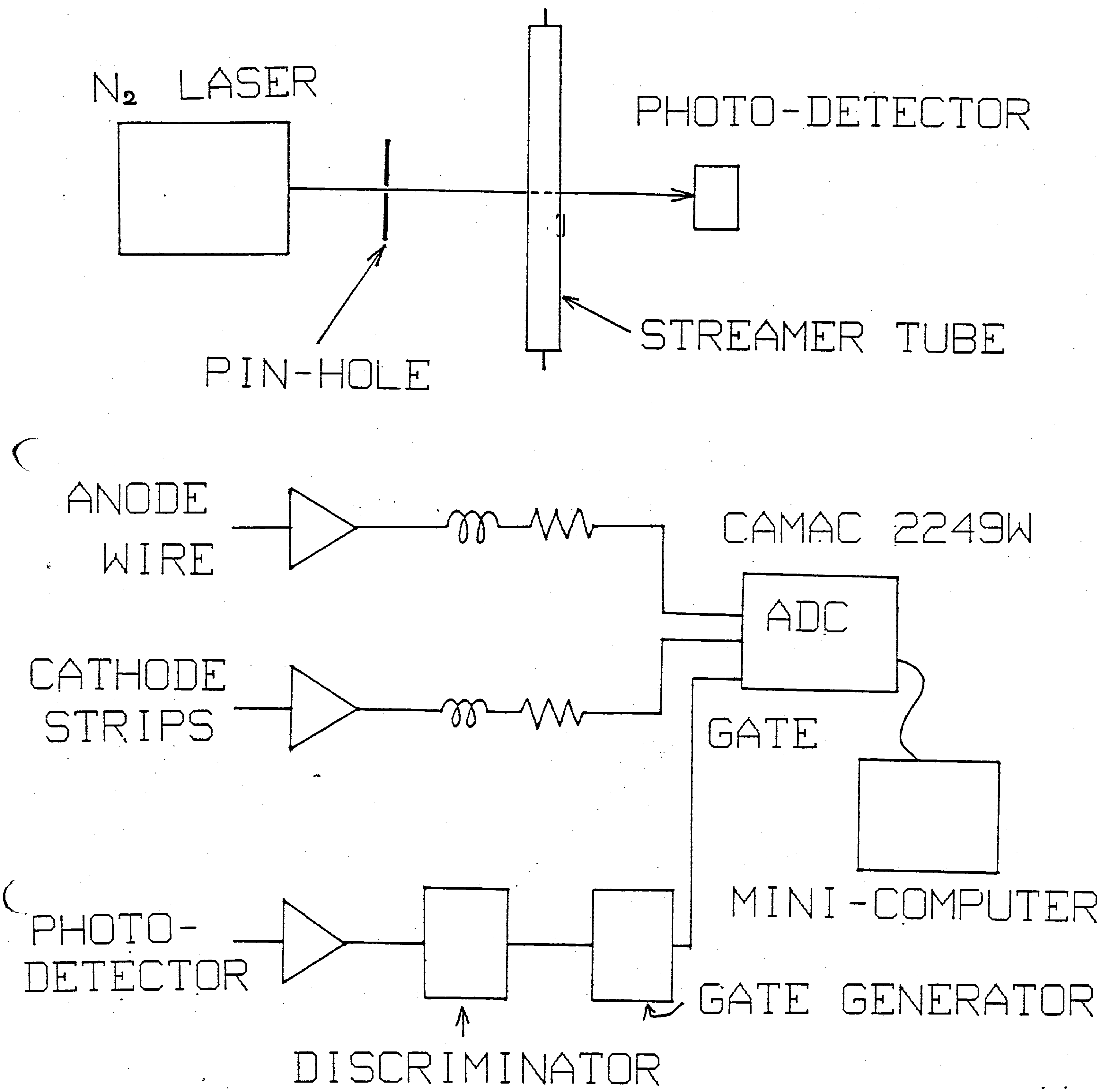

CHARGE DISTRIBUTION
Q3
Q1
Q2
STRIP-1
STRIP-3
STRIP-2
ANODE WIRE
AVALANCHE

FIG-10



N_2 LASER
PHOTO-DETECTOR
PIN-HOLE
STREAMER TUBE
ANODE WIRE
CAMAC 2249W
ADC
CATHODE STRIPS
GATE
PHOTO-DETECTOR
MINI-COMPUTER
GATE GENERATOR
DISCRIMINATOR

FIG-11

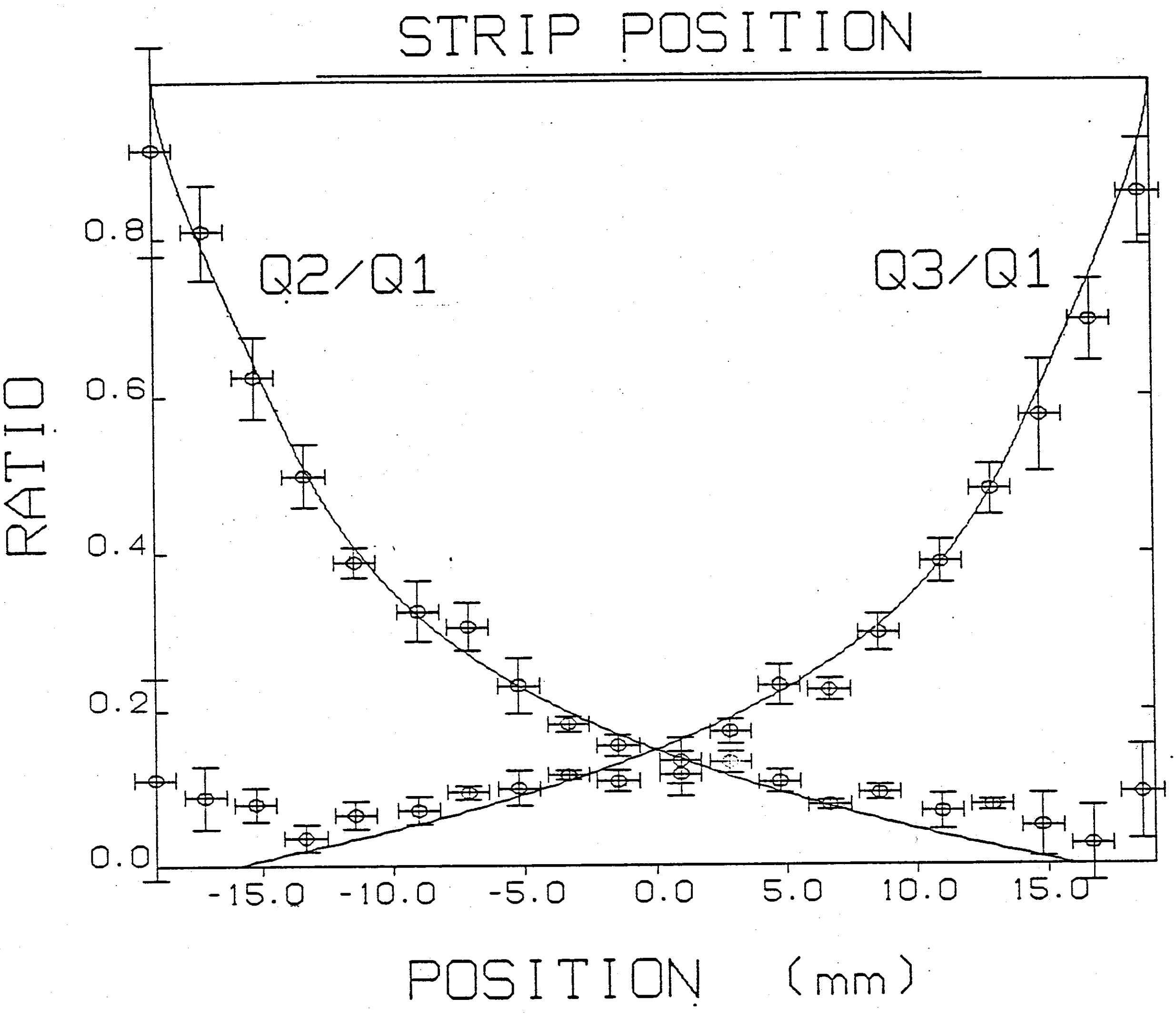
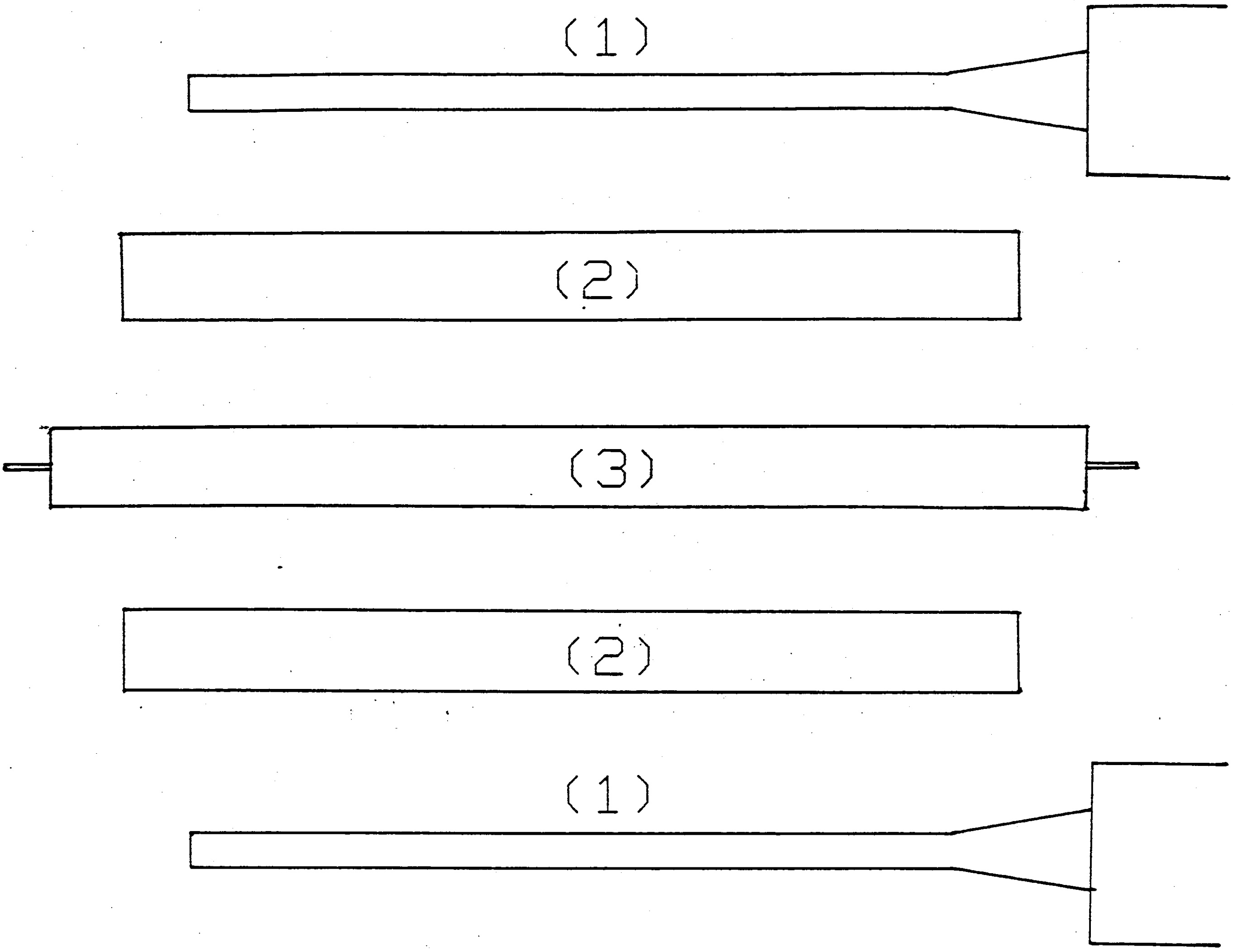

STRIP POSITION
Q2/Q1
Q3/Q1
RATIO
0.8
0.6
0.4
0.2
0.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
POSITION (mm)

FIG-12



(1) SCINTILLATION COUNTER
(2) M.W.P.C.
(3) STREAMER TUBE

FIG-13

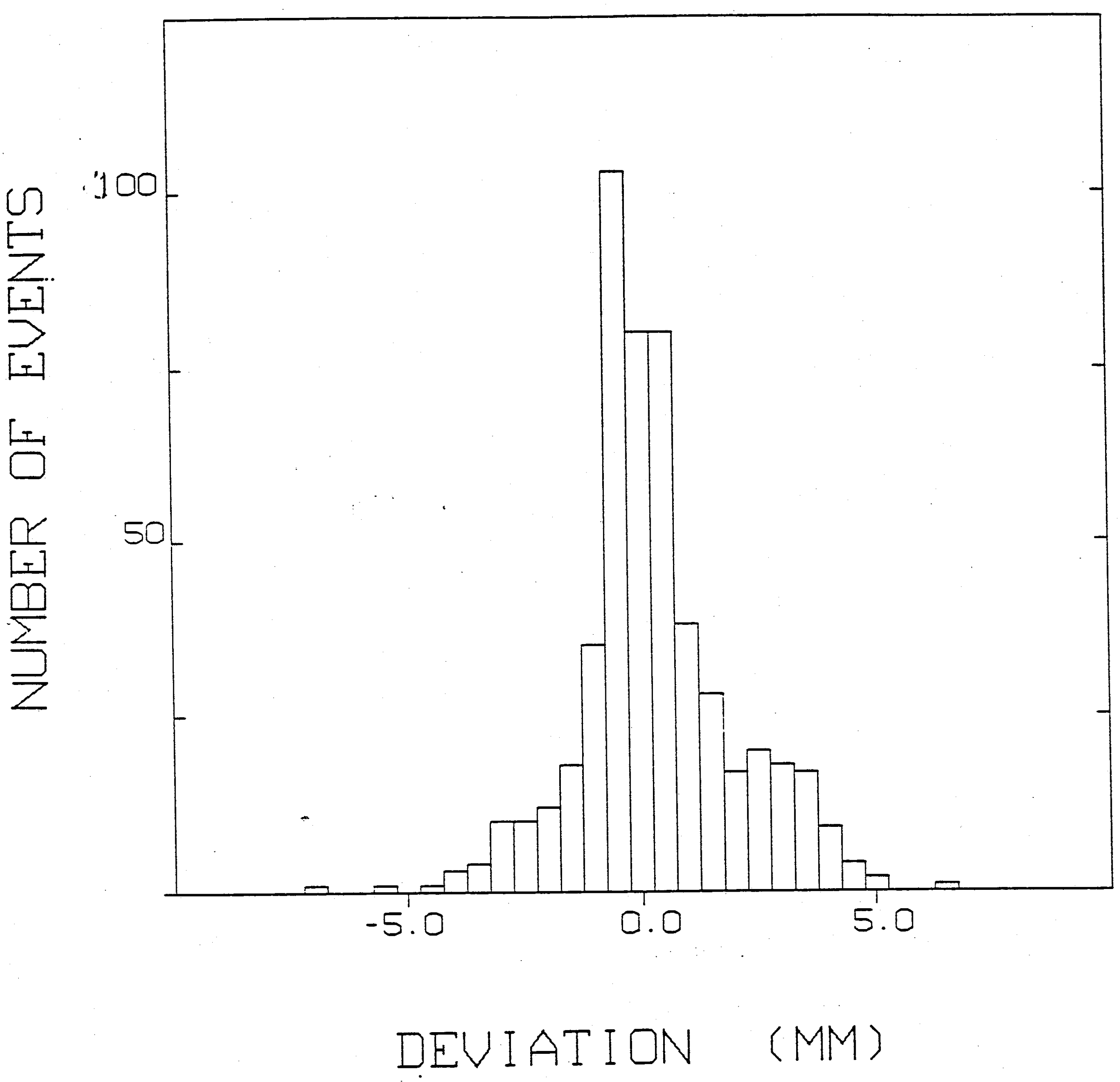


FIG-14

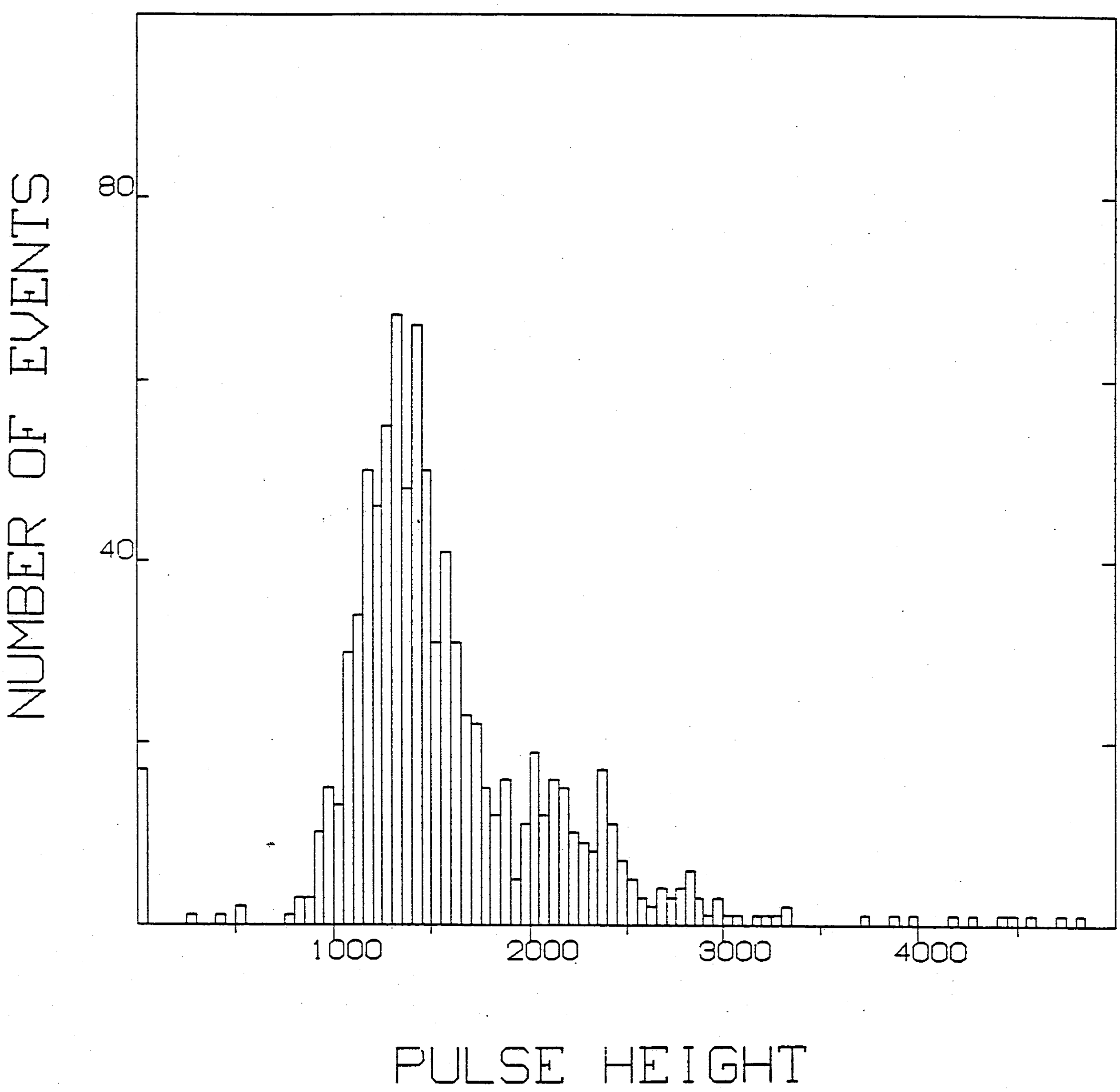


FIG-15

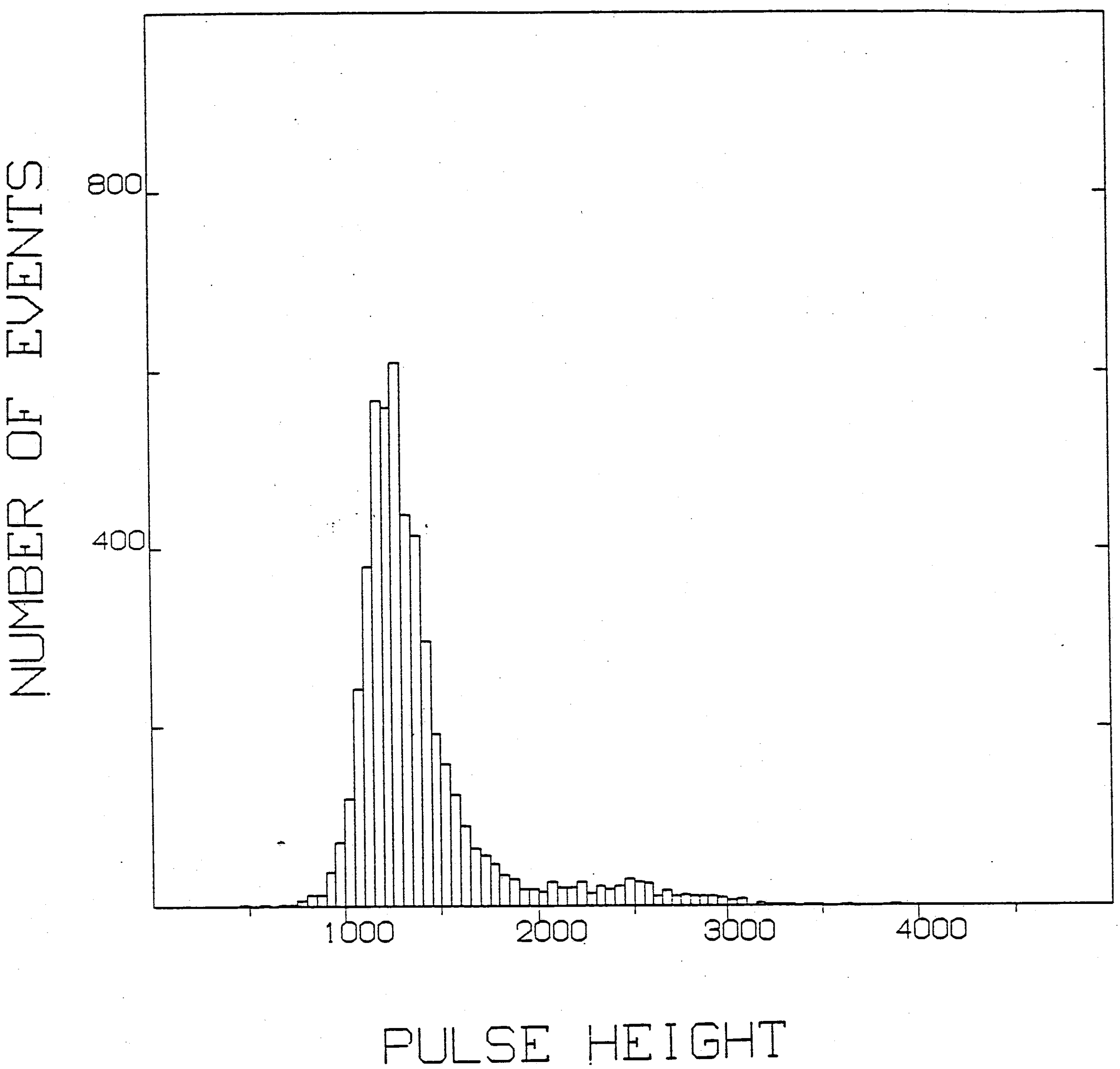


FIG-16

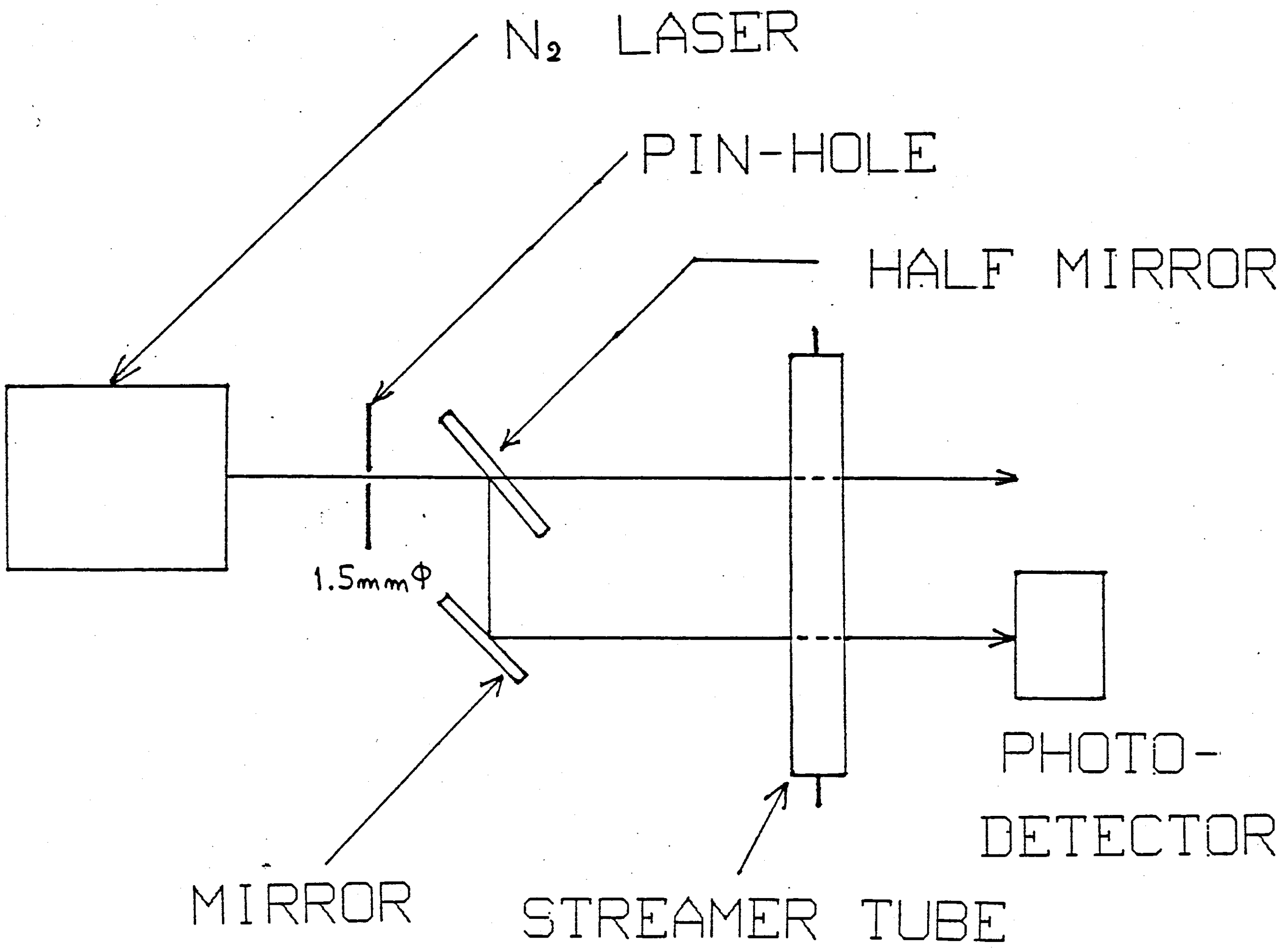

N₂ LASER
PIN-HOLE
HALF MIRROR
1.5mmΦ
MIRROR
STREAMER TUBE
PHOTO-
DETECTOR

FIG-17

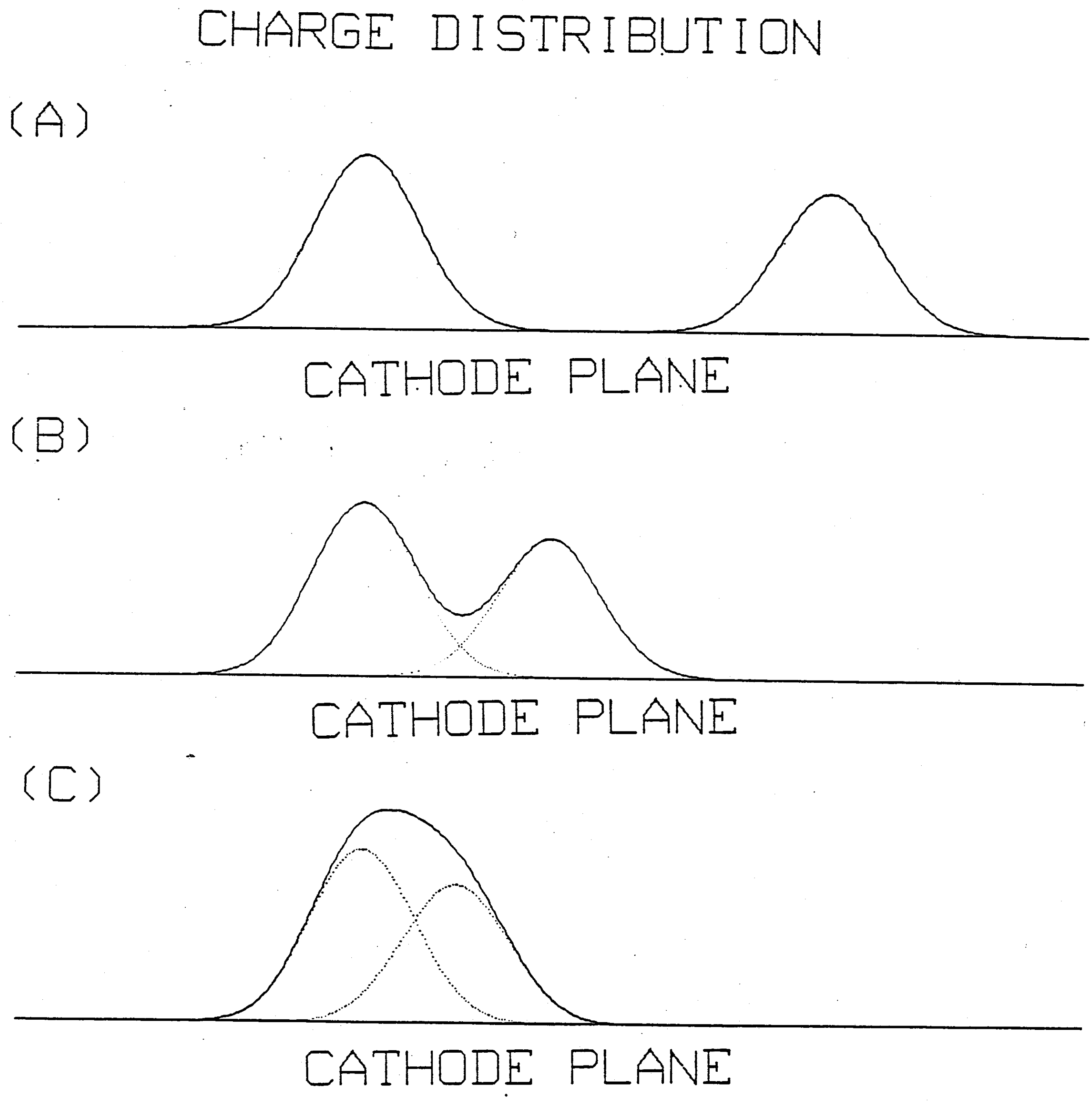

CHARGE DISTRIBUTION
(A)
CATHODE PLANE
(B)
CATHODE PLANE
(C)
CATHODE PLANE

FIG-18

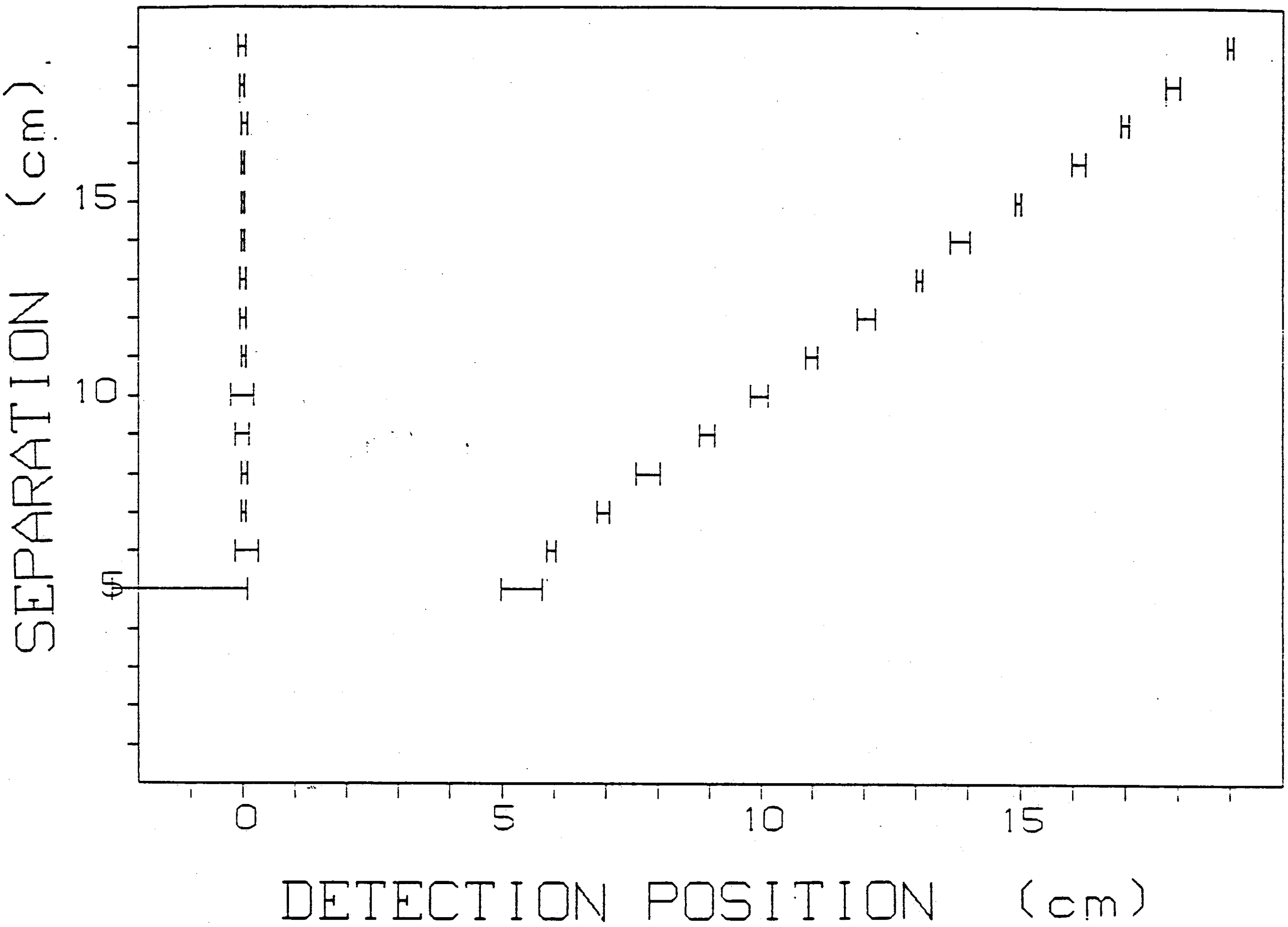


FIG-19

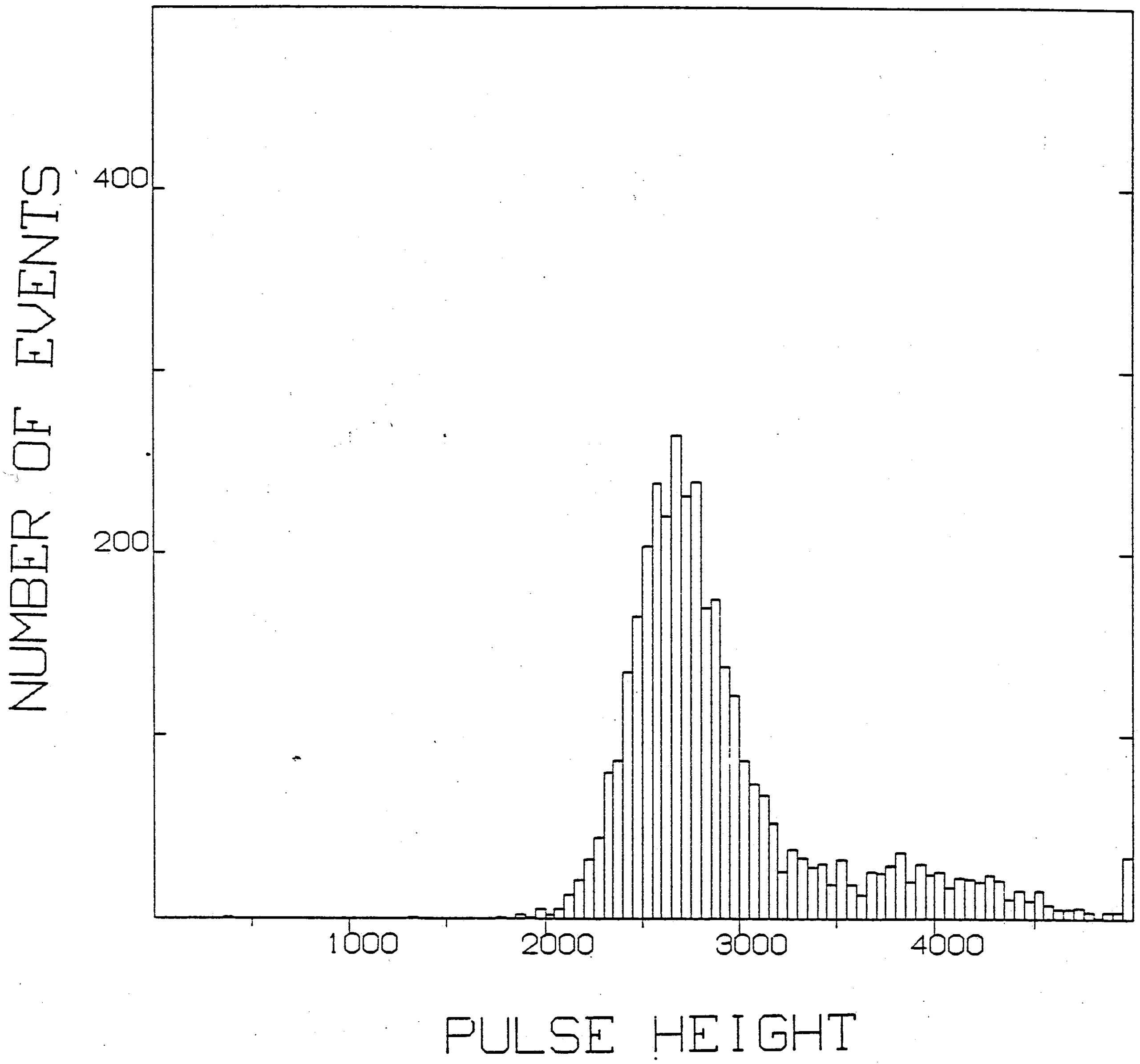


FIG-20

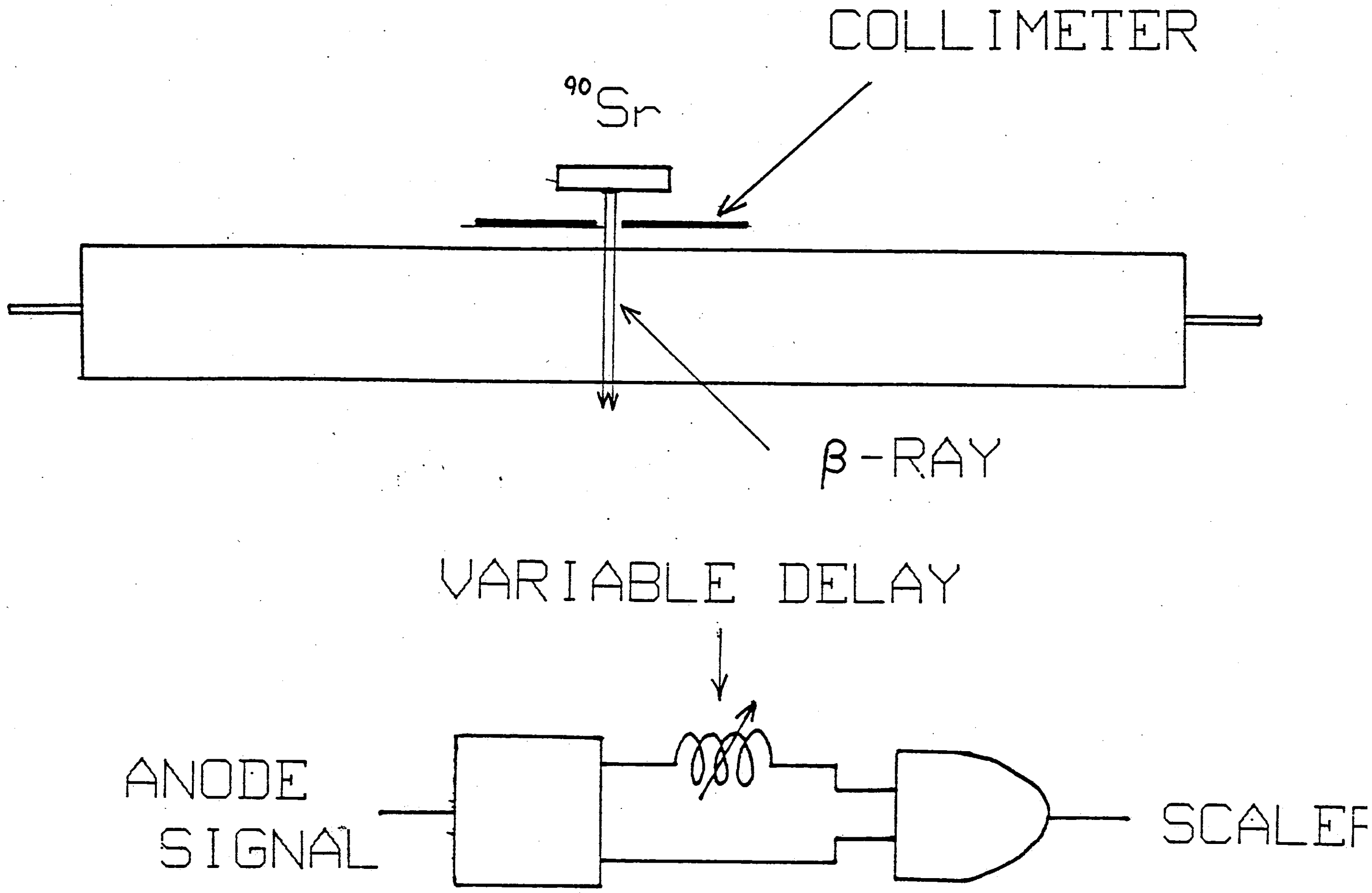
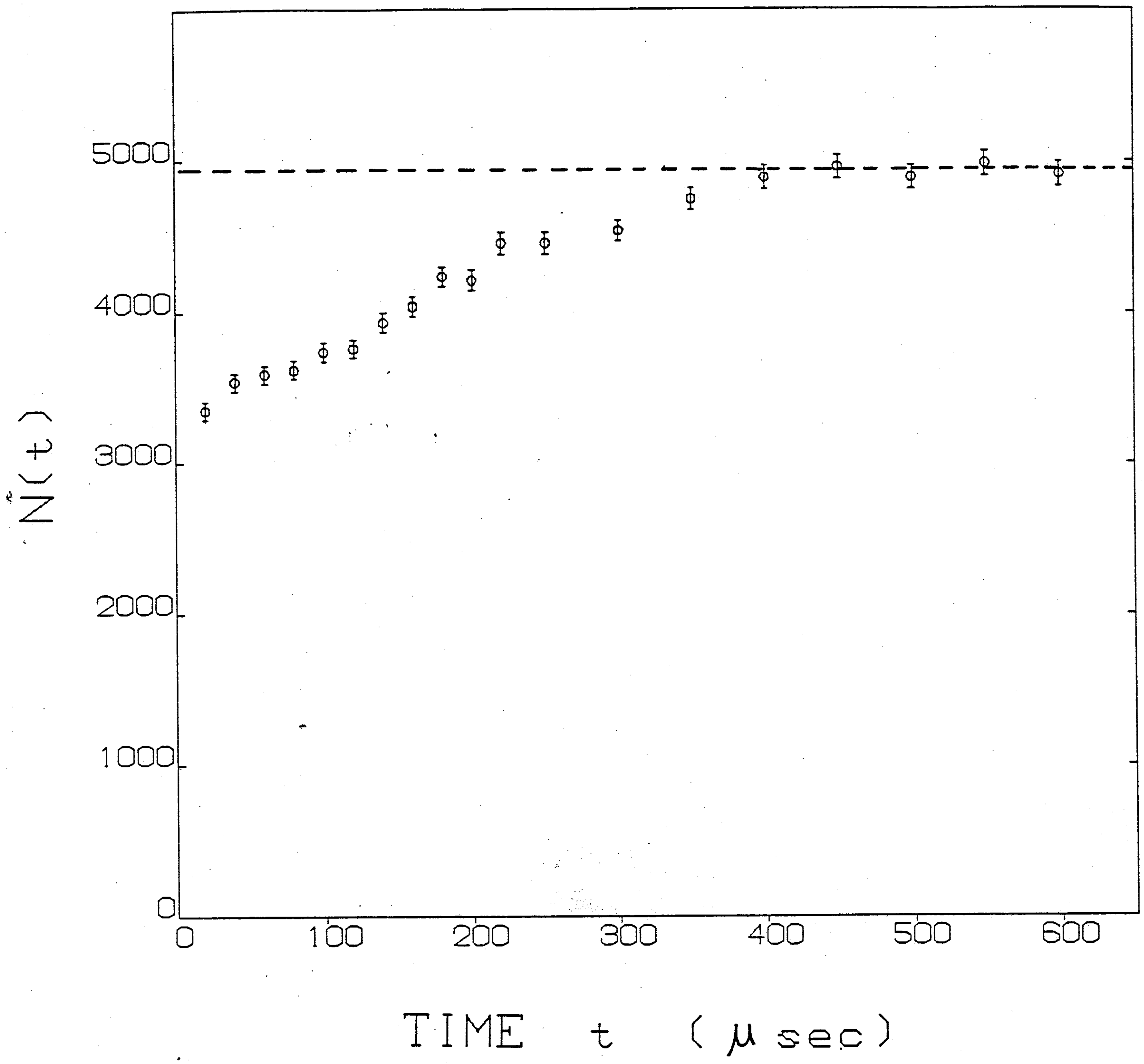


FIG-21



5000
4000
3000
2000
1000
0
N(t)
0
100
200
300
400
500
600
TIME t (μ sec)

FIG-22

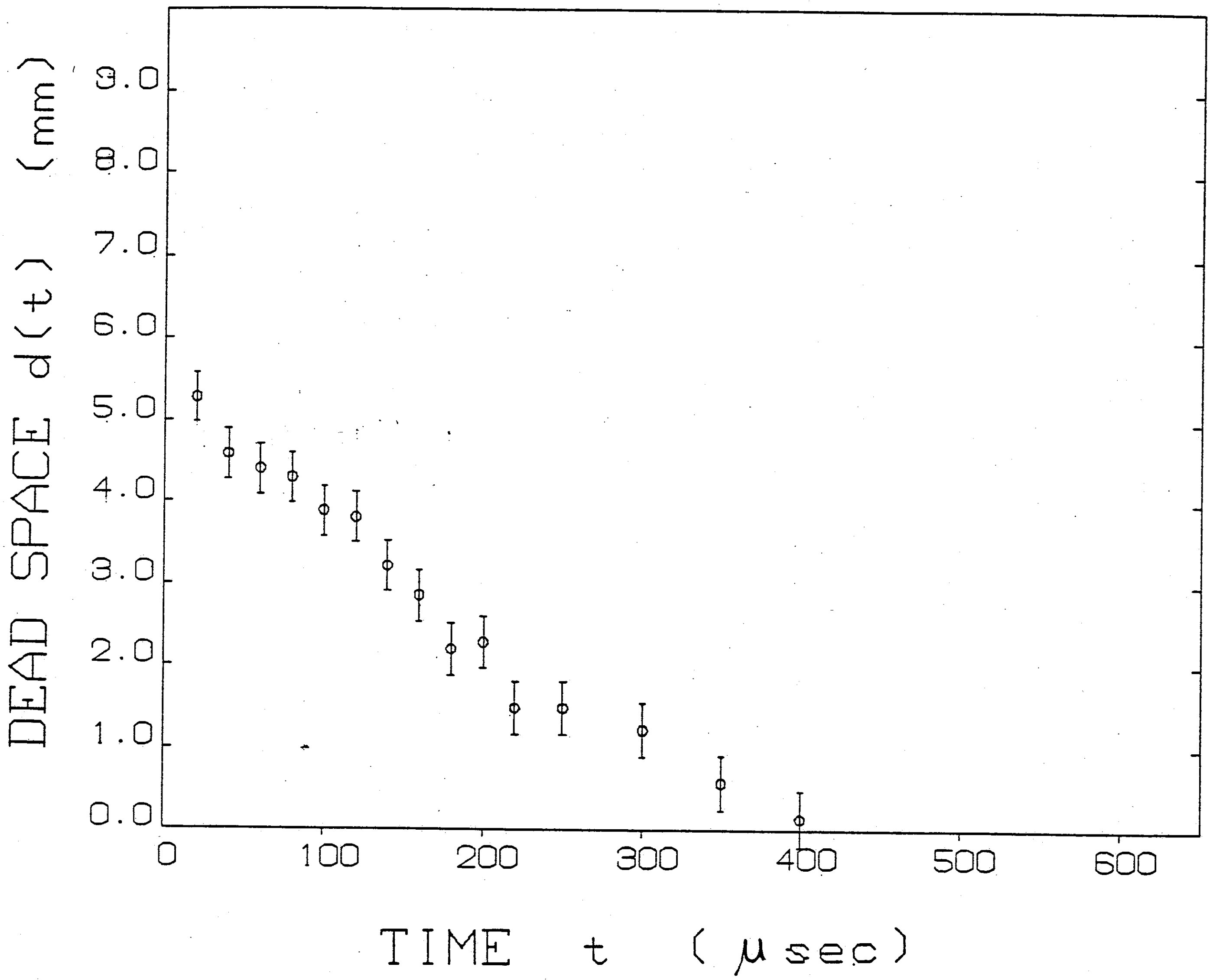

DEAD SPACE d(t) (mm)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
100
200
300
400
500
600
TIME t (μsec)

FIG-23