POSITION AND TRACK MEASUREMENT

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ABSTRACT

This paper gives a summary of six seminars held concerning the measurement of particle trajectories during the first month of the 1969 NAL Summer Study. It also summarizes the authors' recommendations for the role of NAL in the future development of these techniques.

INTRODUCTION

During the first part of the 1969 NAL Summer Study a series of seminars was held concerning techniques for measuring particle trajectories. The purpose of these seminars was to exchange information concerning the state of the art and to arrive at a recommendation as to what role NAL should play in the future development of these techniques. Six seminars and numerous corridor discussions were held. This article gives a summary of the information presented at these seminars; it has been prepared by the authors from notes taken at the seminars. In each case we have tried to summarize both the information presented by the person in charge of the seminar and the new insights revealed in the discussions.

The general subjects of the seminars and the person in charge of each were as follows:

1. Fast-Cycling Bubble Chambers--W. D. Walker
2. Vidicons as a means of Digitizing Optical Spark Chambers--A. Roberts
3. Proportional Chambers--J. Sculli
4. New Techniques for Position Measurement--R. Hofstadter
5. On-Line Computers at NAL--A. Brenner
6. Liquid Argon Chambers - L. Alvarez

At the seminar on new techniques for position measurement, A. Roberts gave a short talk on low-temperature chambers and D. Dorfan a short talk on semiconductor spark chambers.

I. FAST-CYCLING BUBBLE CHAMBERS

The present state of the art in fast-cycling bubble chambers is represented by the chamber built by Blumenfeld and his coworkers at Princeton and the research now being done at SLAC. The Princeton chamber has a diameter of 15 in., uses a gas driven expansion system, and is advertised as working at 15 cycles per second. It works reliably and has done experiments at 6 cycles per second. This chamber was designed some time ago and does not incorporate the more recent developments in the technology. It could be greatly improved if it were redesigned using modern techniques.

At SLAC they have built and tested 2-in. and 4-in. diameter fast-cycling chambers. Most of the work has been done with the 2-in. chamber and we shall deal chiefly with it in this report. The chamber was built using a stainless steel expansion system that was completely immersed in liquid hydrogen. The chamber was driven like a loud speaker using a form of shake table for the driving source. The resonance frequency of the mechanical system was roughly 100 cps. The chamber has been run with tracks at 90 cps. However, with the present system it cannot be kept running with good tracks for a long period at this rate. The chamber worked best with a short expansion cycle and a longer recovery cycle. The 4-in. chamber has been run successfully at 50 cycles/second.

W. D. Walker is now planning to build a 15-in. fast-cycling chamber at Wisconsin in order to further develop the technique. Calculations indicate that the system can be built with a mechanical resonance frequency of 1000 cps and a potential operating frequency of 500 cps. It is difficult to drive the chamber mechanically at this rate, but it does appear that a 100 cps rate can be attained.

It was also pointed out that the performance of conventional bubble chambers was continually being improved and that for example the Berkeley - SLAC 82-in. chamber now operates very well at 2 pictures/sec. The MURA-Argonne chamber has been made to work with a cycle that consists of a 20 msec expansion pulse, a short 20 msec over-pressure pulse and a 60 msec quiescent period prior to the next expansion cycle. This gives a cycle time of 100 msec. The chamber is now being run with an overall cycle that consists of 3 pulses, a one-second off time, and then three more pulses. This means the chamber has run for short times at a 3 cps rate and that it could run at 10 cps. The present limit is due to the capacity of the refrigerator.

In addition to the development of fast-cycling chambers, some work has also been done at CERN on the development of ultrasonic chambers. The ultrasonic chamber uses a large amplitude sonic standing wave to sensitize the chamber. The CERN chambers use a 10^5 cps sound wave in liquid helium at $4° \rightarrow 5°$ K. The bubbles absorb energy and have a 600 μs growth time. The tracks appear as a series of globules rather than as in a conventional chamber. The build-up time for the ultrasonic sound wave is long, and it may be difficult to pulse the chamber. This is an interesting technique which is only in its infancy.

Some work has also been started at SLAC on a form of ultrasonic chamber. They intend to use a small cylindrical cavity which is driven by piezoelectric crystals.

Some discussion also took place concerning the attainable precision in a fast-cycling chamber. If one is not careful the liquid begins to rotate at the rate of 1 to 5 cm/sec. The effects of thermal turbulence are not well understood and further work will be required to determine the precision of measurement with a fast-cycling chamber.

II. PROPORTIONAL CHAMBERS

At the time of the 1968 Summer Study the most promising new technique for the measurement of particle position was the wire proportional chamber. These chambers are constructed in a fashion similar to the wire chambers but operate in a proportional mode rather than in a spark mode. The general construction of such a chamber is shown in Fig. 1. When a charged particle passes through the chamber, it creates ion pairs. The electrons and ions are accelerated in the electric field around the wires and through inelastic collisions create other ion pairs. This multiplies the charge and results in a charge pulse appearing on the wire. This pulse can then be used to indicate that an ionizing particle has passed near the wire. The proportional chambers give promise of detectors with the following properties:

1. Good time resolution
2. No intrinsic recovery time
3. No spurious sparks
4. Low multiple scattering
5. Information on the density of ionization.

Thus the wire chambers have properties intermediate between those of scintillation counters and wire chambers. They could conceivably be used to replace both. It has also been suggested that one could place a scintillation counter next to the wire chamber plane and use fast timing techniques to measure the time required for the electrons in the gas to reach the wires. This would allow one to interpolate between the wires and thus improve the spatial resolution by an order of magnitude.

In the period since the 1968 Summer Study a considerable amount of work has been done on the proportional chambers and it is now clearer what can and cannot be done. Table I summarizes some representative data on the performance of proportional wire chambers. Column A comes from data reported by Bemporad, Beusch, Melissinos, Schuller, Astbury, and Lee.[1] Column B comes from data presented by Fischer and Shibata.[2] Bemporad et al., used their chambers in an experiment at the CERN PS for measuring the momentum of (9-16) GeV/c pions. When fitting straight line trajectories they found that the rms deviation of the coordinate measured by a given chamber from the trajectory obtained using the coordinates measured by the remaining chambers was one quarter of the 3 mm wire spacing.

Table I. Characteristics of Proportional Wire Chambers.

	A Bemporad et al.	B Fischer & Shibata
Wire Diameter	30μ	50μ
Wire Material	Gold-Plated Molybdenum	Stainless Steel
Wire Spacing	3 mm	0.27 mm
Gas	Argon & Propane	Ne + n-heptane
Spatial Resolution	0.76 mm	0.1 mm
Time Jitter FWHM	(60-80 nsec)[a]	10-15 nsec
Single Track Efficiency	>99%	?
Recovery Time	300 nsec	?
Signal Delay	75 nsec	?
Two Adjacent Wire Signals	10%	?
Three Adjacent Wire Signals	3%	?
Output Rise Time	20-50 nsec	?
Gate Width	150 nsec	

[a] Later results with isobutane-argon gas mixtures suggest that this can be reduced to 20 nsec.

It is clear from Table I that one that one can operate proportional chambers with a rate of 10^6 /wire, a spatial resolution of ± 0.25 mm and 100% efficiency. It also appears that with the proper amplifier, voltage, gas combination, one can obtain a fast output pulse with a jitter less than 20 nsec. It is not clear whether or not the jitter observed by Bemporad et al., is related to the 3 mm wiring spacing. So far no one has succeeded in using timing to increase the precision with which the position is measured. At present the recovery time of the chambers seems to be limited by the recovery time of the amplifiers.

The most disadvantageous feature of the chambers is that an amplifier is required for each wire. At present the chambers can achieve a gas gain of $\sim 10^4$ giving 1-10 mV into the amplifier. Typical integrated circuit amplifiers give additional gains of ~ 500. The amplifiers usually saturate at roughly 1.0 volt; to obtain greater speed it is usually advantageous to saturate the amplifier. The speed of the chamber also requires some intermediate storage device for holding the readout pulse while a decision is being made as to whether or not the event is interesting.

It is clear that the proportional chambers are a significant new device for measuring particle position. At present, however, they are not as fast as well-designed scintillator counter hodoscopes and require a comparable amount of circuitry. They have the advantage that they have less mass and that they can be constructed so that one can see through them.

III. CONVENTIONAL SPARK CHAMBERS

A. Optical Spark Chambers

Spark location accuracies of the order of ± 0.2 mm are easily attainable in conventional optical spark chambers, with gap efficiencies approaching 100%. Fast cameras have been developed to allow photographing rates up to 100 frames per second. The next major improvements in optical chamber techniques will likely come from refinements in the vidicon readout systems and the development of low-temperature gas chambers.

Vidicon Readout[3]

With a relatively inexpensive vidicon (e.g., $\sim$ \$100) a spatial resolution of $\sim \pm 0.3$ mm can be obtained for scans limited to < 30 cm in space. A typical unit has a resolution of ~ 1000 lines with a sensitive area of approximately 5/8 in. $\times$ 3/4 in. Typical scan times are of the order of 15-30 msec, although this number can be considerably reduced by restricting the scan to only those parts of the vidicon that might contain useful information on the particular event being studied. A limitation on the recovery speed of a vidicon system is the time required to "blank-out" the tube in preparation for the next event. In some newer tubes this is not necessary.

Recently vidicons of 2500-3600 lines resolution and greatly improved sensitivity have been made available. They will have the advantage of allowing a finer spatial resolution for the same area scanned, or of allowing a larger region in space to be scanned with the previous resolution.

Various readout configurations are possible with a vidicon system. For example, each chamber view may have its own dedicated vidicon. Then, the images of a combination of chamber views can be scanned serially or in parallel with other vidicons in the system. One of the principal advantages of the vidicon readout system over the usual film methods is the option of excluding all mirros from the system, which can result in a significant gain in the simplicity of an experimental setup and in the reconstruction accuracy.

The vidicon readout scheme suffers, along with some other electronic readout schemes, in its inability to operate inside strong magnetic fields without substantial shielding. For large experiments, with the detectors in low-field regions, the vidicon readout scheme promises to be the most economical of the electronic readout systems. A small computer can be efficiently used to control the vidicon scanning (to minimize scan time) and to analyze on-line some fraction of the data for monitoring purposes.

Low Temperature Chambers

The possibility of operating conventional optical chambers at low temperatures (e.g., liquid nitrogen temperature) to improve their spatial resolution has been considered by Roberts. The increase in the density of the chamber gas at low temperatures would result in the formation of a larger number of ion pairs, and a smaller diffusion of the ions and delta rays before the application of the high voltage pusle. Previous workers have demonstrated that chambers can indeed function at liquid nitrogen temperature, and have observed an increase in gap efficiency and spark brightness; however, no quantitative measurements have been made to determine the improvement in spatial resolution. Roberts estimates that a resolution of the order of ± 0.10 mm or better should be attainable.

B. Wire Spark Chambers

Wire spark chambers are rapidly becoming the most widely used type of spark chamber. Spatial resolutions of the order of ± 0.3 mm have been routinely obtained with magnetostrictive readout and ± 0.5 mm with core acoustic delay (sparkostrictive), and capacitor readout. Of the various types of readout, the magnetostrictive scheme appears to be generally the most attractive. The hardware for magnetostrictive readout systems is available commercially and has proven satisfactory in a wide class of experiments. The magnetostrictive and core readout schemes have the drawback that operation in a magnetic field of more than a few hundred or few gauss, respectively, is difficult. This very problem led to the development of the sparkostrictive and capacitor readout systems, which are not affected by magnetic fields. The sparkostrictive method, however, has met with only limited success; the problems have been principally associated with decreased accuracy and low readout efficiency.

Many groups at universities and national laboratories are actively engaged in research to improve wire chamber techniques. There is no evidence at present to indicate that a massive effort on the part of NAL could result in an order of magnitude improvement in the spatial resolution, sensitive time, or recovery time.

IV. NEW TECHNIQUES FOR POSITION MEASUREMENT

R. Hofstadter reviewed the Alvarez criticism that the diffusion of the ion pairs in a gas chamber would limit the precision with which one could locate the position of a particle, and he outlined the Alvarez suggestion that one could use liquid chambers to overcome this difficulty. Some work has been done in the past on multiplication in liquid argon but no one has succeeded in using it as a successful counter. Alvarez is now working on a liquid argon chamber, and he was scheduled to report on this project some time during the 1969 Summer Study.[4]

Hofstadter then proceeded to outline a new suggestion for precision position measurement which used a combination of NaI(Tl), fiber optics, an image intensifier, and a vidicon. He proposed to deposit a thin (10μ) layer of NaI(Tl) on a thin polished reflecting surface and then to connect this optically through short (1/16 in.) small-diameter fiber optics to an image intensifier tube. The output of the image intensifier would then be viewed with a vidicon tube. Calculations indicated that the thin NaI(Tl) would give out 300 photons when a minimum ionizing particle passed through. Thus there would be an adequate signal. In addition one can now obtain 6 to 15 μ diameter fiber optics so that there would be no loss in resolution in the coupling between the NaI(Tl) layer and the image intensifier. With such a system one could hopefully locate the point at which the particle passed through the NaI(Tl) to a precision of 10 μ. The principal disadvantage of this device is its thickness. It is estimated that it would be equivalent to 3/4 in. of glass. This would cause complications due to multiple scattering. One can visualize geometries in which the detector is not this thick.

At the same meeting A. Roberts spoke concerning low-temperature spark chambers. They are particularly attractive since one can visualize a chamber in which the plates are filled with liquid hydrogen. Since this suggestion has been mentioned elsewhere in this report, we shall not consider it further here.

Dorfan reported on some work being done at SLAC to develop a semiconductor spark chamber. This chamber uses two perpendicular wire grids which are plated one on each side of a glassy semiconductor. The voltage between the two grids is such that when a particle passes through the chamber, it produces ionization and causes a current to flow from a wire on one side to a wire on the other side at the point where the the particle passed. After the particle has passed through the chamber, the voltage across the chamber is decreased so as to make the chamber insensitive to the ionization produced by a subsequent particle but high enough to maintain the current between the wires at the point of passage of the first particle. This would give a latching spark chamber with a memory. So far SLAC has not been successful in making one of these chambers work. It is, however, a very interesting development and should be pursued with vigor.

R. R. Wilson[5] suggested a second form of wire proportional chamber in which the wires pass from a region of high pressure to a region of vacuum. After a particle passes through the chamber the wires become charged. An electron beam is then used to read out the charge on each wire. This should give an economical readout for a high-pressure proportional counter.

V. ON-LINE COMPUTERS

The effective operation of complex particle detection devices with electronic readout can be greatly enhanced if the devices are monitored with an on-line computer. Indeed, few wire-chamber experiments are attempted today without the benefit of an on-line computer. A separate subgroup has addressed itself to the problem of on-line computing at NAL and will present its full report elsewhere in the proceedings.[6] Here, however, we will summarize their recommendations and briefly discuss the interaction between on-line computers and detection systems.

The subgroup on on-line computers recommends that NAL make available, to those groups without a small computer, a dedicated local computer (including a generalized interface to experimental equipment) from a PREP pool. This computer would have magnetic tape-writing capabilities but no powerful arithmetic capability. The problem of providing the capability of carrying out extensive computational analysis on-line should be partially solved, for both the users who bring their own small computer and those who must borrow a NAL computer, by providing links from the large NAL computing complex to the individual small computers. For very large experiments in which the combination of a small computer linked to a large computer is substantially inferior to a single dedicated medium size computer ($200-$800K), the experimental group should justify the need for a medium-size computer facility in their proposal.

It is our feeling that the recommendations allow a very efficient match between the available computing power and the specific requirements of various particle detection systems. The advantages of individual groups having their own computers cannot be overemphasized. The programming and debugging can obviously be most efficiently done back at the university. Also, small computers are very useful in the initial development and testing of detection systems either at the university or at some nearby cyclotron or national laboratory test beam facility.

The general interface between the experiment and the computer should be capable of handling standard quad-scaler outputs, bit-latching gates for counter hodoscopes, fixed data information and analog to digital outputs, and should be sufficiently flexible so that computers other than the make chosen by NAL as its "standard" small computer can also be accommodated.

One of the minimal functions of an on-line computer in a typical wire spark-chamber experiment is to maintain and display histograms of spark distributions in each readout channel. This allows, for example, the quick discovery of a bad core, a demagnetized wand, a broken chamber wire, etc. In addition, current data on the efficiency of each chamber should be maintained. This, for example, could lead to an early discovery of a chamber gas leak. Depending on the nature of the experiment, of course, many other checks would be routinely made, even for those experiments using a minimal stand-alone small computer configuration. In addition the computer would serve the function of buffering data and transferring it to magnetic tape in a desirable format.

VI. LIQUID ARGON CHAMBERS

In a conventional neon-helium gas spark chamber there are thirty ion pairs per centimeter of gas and in order to obtain high efficiency it is necessary to use a gap of at least 3 mm. As a result for inclined tracks there is an uncertainty equal to the gap spacing multiplied by the tangent of the angle between the direction of the incident particle and the normal to the plane of the spark chamber. One way to reduce this error is to decrease the gap spacing by using a material that is more dense than a gas at STP. A group at Berkeley under L. Alvarez is trying to develop liquid argon chambers.[6]

If one assumes the liquid argon is just a dense gas and one extrapolates the electric field required to give gas multiplication up to these pressures, one obtains 5 million volts/cm. In order to achieve such fields the Berkeley group constructed a liquid argon chamber using a 4 μm diameter tungsten wire for the anode; Fig. 2 shows a schematic diagram of the counter. Using a cobalt-60 source they were able to obtain large ionization pulses with 3 kV on the argon chamber. This corresponds to an electric field at the wire of 1.5 million volts/cm. In the region of 1.5 MV/cm to 2.0 MV/cm the pulses were independent of the voltage.

Subsequent to this initial success they have constructed chambers with 13 μm (1/2 mil) gold-plated tungsten anodes. The general construction is shown in Fig. 3. These chambers have a plateau running from 5600 to 6400 volts. With the circuit shown in this figure they obtain a pulse with a risetime of 20 μs and a 1/e fall time of roughly 150 μs. In almost all circumstances the signal is a 50 picocoulomb charge. They are unable to see the proportional region. It is presumably very narrow and inhomogenities in the wire result in a large variation of the field along the wire. If the voltage is sufficiently high that the chamber actually sparks, it usually destroys the anode wire. They do not understand the mechanism for quenching the discharge.

They are now constructing counters with two wires separated by 3 mm and they hope to investigate the independence of the discharge. After that they intend to construct chambers with several wires which are plated or evaporated onto a glass substrata; Fig. 4 shows two possible patterns. The cathode will be a smooth flat plate. They will then use these chambers to see how well one can localize a particle and to investigate the precision with which one can localize the particle trajectory.

They already have ideas as to how they can construct very large chambers which measure trajectories to micron accuracies. They visualize a large piece of mylar 1 meter square on which are deposited wires 20 μm apart and 4 μm wide. This would give 50,000 wires per meter. The x wires might be on one side of the sheet and the y wires on the other side of the sheet. For the readout they propose to use a Fairchild chip which is 1/3 in. long and which has deposited on it 128 phototransistors. The cost of each chip is $40. These phototransistors have the property that the conductivity increases by a factor of 10^6 when a light is incident upon them. They propose to connect each chamber wire to a common line through these photo transistors. They will then read out the chamber by sweeping a properly focused laser beam across the line of phototransistors. They propose to make one sweep in 100 μs so that one would have a chamber with a potential speed of 10 kHz. This would give a relatively fast device with a resolution of a few microns.

VII. RECOMMENDATIONS FOR NAL

It is clear that there are many new and encouraging ideas for position and track measurement which could in time revolutionize the way we do high-energy physics. Some of these are:

1. Proportional wire chambers
2. Vidicon readouts for optical chambers
3. Low temperature gas chambers
4. NaI vidicon detectors
5. Liquid argon chambers
6. Fast-cycling bubble chambers
7. Semiconductor chambers

We feel that development of all these techniques should be encouraged but that NAL should not take an active role in developing all of them. We feel that the time at which one will do the first experiments at NAL is sufficiently close that one will be forced to use techniques which represent only a modest extrapolation from the techniques being used now. We recommend that NAL undertake the following role in the

the development of techniques for measuring particle trajectories.

1. Continue and strengthen the present development program in proportional wire chambers. Effort should be made to increase the speed, increase the resolution, and simplify the readout system.

2. Investigate and, if it looks promising, develop the vidicon techniques for reading out optical spark chambers.

3. Start a program on low-temperature spark chambers to see if one can use them to increase the precision of measurement and if one can build assemblies which combine the liquid hydrogen target and the spark-chamber detector assembly. This technique has great potential in that it might enable one to use very large hydrogen targets and still observe short proton recoil tracks.

4. Support and encourage but not necessarily engage in the development of fast-cycling bubble chambers. This is clearly an important technique which should be developed. It is assumed that development will take place at laboratories other than NAL.

5. Try as much as possible to develop a computer-counter spark-chamber interface system which is both standardized and flexible.

We have no recommendation at this time as to whether NAL should build or furnish spark-chamber systems. This is an issue which should be raised at a later date when the value of standard modules is clearer.

We also recommend that

1. The Hofstadter group should pursue the development of the NaI vidicon detector

2. The Alvarez group should pursue its development of the liquid argon counter

3. The SLAC group should continue the development of the semiconductor counter.

These are all exciting techniques which show promise of a new dimension in detector resolution.

REFERENCES

[1] Bemporad, Beusch, Melissinos, Schuller, Astbury, and Lee, Nucl. Instr. and Methods (to be published).

[2] J. Fischer and S. Shibata, Brookhaven National Laboratory BNL-12804

[3] See, for example, A. Roberts, Wire Arrays vs Vidicons: A Comparison of Large Wire Arrays with Optical Spark Chambers Using Vidicon Readout, National Accelerator Laboratory 1969 Summer Study Report SS-56, Vol. III.

[4] S. E. Derenzo, R. A. Muller, and L. W. Alvarez, The Prospect of High Spatial Resolution for Counter Experiments at NAL: A New Particle Detector Using Electron Multiplication in Liquid Argon, National Accelerator Laboratory 1969 Summer Study Report SS-154, Vol. III.

[5] R. R. Wilson, Position Indicating Proportional Counter, National Accelerator Laboratory 1969 Summer Study Report SS-149, Vol. III.

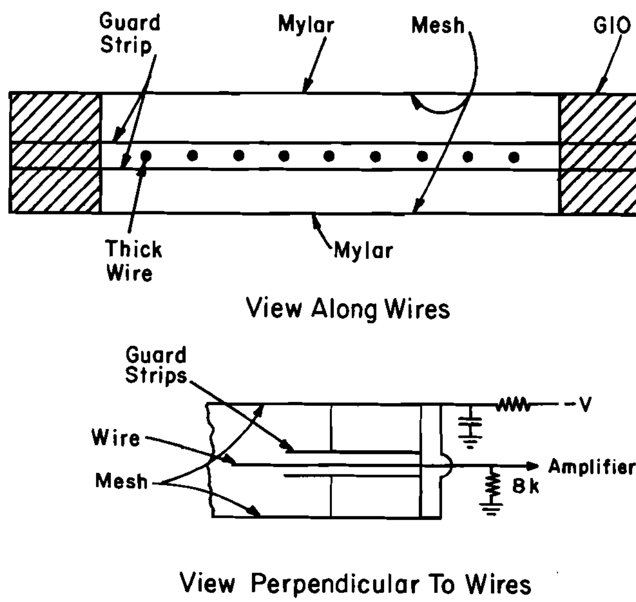


Fig. 1. Construction of a wire proportional chamber.

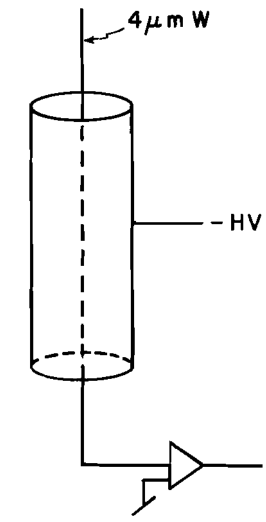


Fig. 2. The first successful liquid argon counter.

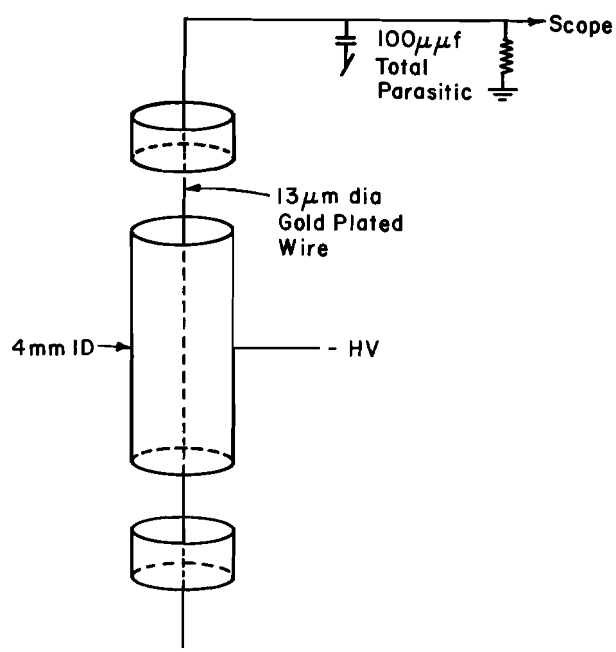
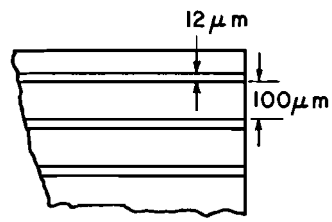
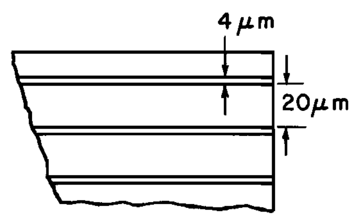


Fig. 3. Improved liquid argon counter.



(a)



(b)

Fig. 4. Two proposed construction procedures for obtaining higher resolution.